ABSTRACT BOOK

Scientific Organizing Committee:
P. Boumis (Greece, co-chair)
J. Raymond (USA, co-chair)
T. Bell (UK)
W. Blair (USA)
K. Borkowski (USA)
A. Decourchelle (France)
R. Fesen (USA)
D. Green (UK)
R. Kothes (Canada)
A. Rest (USA)
P. Slane (USA)

Local Organizing Committee:
P. Boumis (Greece, co-chair)
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D. Abartzi (Greece)
S. Akras (Brazil)
A. Chiotellis (Greece)
M. Kopsacheili (Greece)
M. Kourniotis (Greece)
I. Leonidaki (Greece)
A. Manousakis (Poland)
M. Pliatsika (Greece)
Z.T. Spetsieri (Greece)
S. Williams (Greece)

Venue: Minoa Palace Resort & Spa (Imperial Main Hall)

A conference organized by the National Observatory of Athens, Greece

CONFERENCE PROGRAM

Sunday June 05

16:00 – 18:30		Registration
20:30 – 00:00		**Welcome Reception** @ beach area of Minoa Palace Resort

Monday June 06

07:45 – 08:30		Registration

Session 1 [Radiation studies from gamma-rays to radio in Galactic and Extragalactic SNRs]

Morning Session (Chair: D. Green)

08:30 – 08:40		P. Boumis/J. Raymond - Welcome
08:40 – 09:20		R. Chevalier (Opening Plenary) [Trends in SNR research]
09:20 – 10:00	**[S1]**	B. Williams [Recent Progress on Young Galactic SNRs]
10:00 – 10:20	↓	R.C.G. Chaves [TeV Remnants in the H.E.S.S. Galactic Plane Survey]
10:20 – 10:40		M.-H. Grondin [New Extended GeV Sources in the Galactic Plane Found in a Search of the Pass 8 data from Fermi-LAT]
10:40 – 11:00		M. Arias de Saavedra Benítez [SNRs with LOFAR]
11:00 – 11:30		Coffee Break & Poster Viewing
11:30 – 12:10		I. Leonidaki [Probing the properties of extragalactic SNRs]
12:10 – 12:30		M. Filipovic [Observational facts of Extragalactic SNRs]
12:30 – 12:50		B.-C. Koo [Infrared SNRs and their Infrared to X-ray Flux Ratios]
12:50 – 13:10		F. Acero [Thermal X-rays and shock speed measurement in RX J1713.7−3946]
13:10 – 14:40		Lunch

Session 1 [Radiation studies from gamma-rays to radio in Galactic and Extragalactic SNRs] & Session 2 [The search for the binary companions of SN progenitors in SNRs]

Afternoon Session (Chair: W. Blair)

14:40 – 15:00		K. S. Long [Radio Properties of M33 SNRs: Results from a New Deep JVLA Survey]
15:00 – 15:20		X. Tang [Gamma ray emission from middle aged SNRs interacting with molecular clouds]
15:20 – 15:40		T. E. Woods [SN Ia Archaeology: Searching for the relics of progenitors past]
15:40 – 16:20	**[S2]** ↓	W. Kerzendorf [Surviving companions of SNe]
16:20 – 16:50		Coffee Break & Poster Viewing
16:50 – 17:30		S. Van Dyk [SN Progenitors and Their Binary Companions]
17:30 – 17:50		B. Dinçel [OB Runaway Stars inside the SNRs S147 and IC443]
17:50 – 18:10		C. -J. Li [Type Ia SNR N103B: structure of the remnant and properties of the progenitor]
18:10 – 18:30		L. Hovey [Reviving the Single Degenerate Scenario for the Ia SN Event that Formed Remnant 0509-67.5]

Tuesday June 07

Session 3 [Pulsar wind nebulae (including Crab flares)] & Session 4 [Magnetic fields in SNRs and PWNe]

Morning Session (Chairs: P. Slane / R. Kothes)

09:00 – 09:40	**[S3]**	S. Safi-Harb [High-energy observations of PWNe]
09:40 – 10:00	↓	R. Kothes [On Distance and Age of PWN 3C58]
10:00 – 10:40		T. Temim [Evolution of Pulsar Wind Nebulae inside SNRs]
10:40 – 11:00		M. F. Bietenholz [New Radio and Optical Expansion Rate Measurements of the Crab Nebula]
11:00 – 11:30		Coffee Break & Poster Viewing
11:30 – 11:50		L. Pavan [The Lighthouse nebula: a run-away pulsar, its PWN, jets and parent SNR]
11:50 – 12:10		D. A. Green [GMRT observations of the radio trail from the PWN CXOU J163802.6-471358]
12:10 – 12:30		B. Olmi [Newest insights from MHD numerical modeling of PWNe]
12:30 – 13:10	**[S4]** ↓	S. Reynolds [Magnetic fields in SNRs and PWNe: Deductions from X-ray observations]
13:10 – 14:40		Lunch

Session 4 [Magnetic fields in SNRs and PWNe] & Session 5 [Collisionless shock waves in SNRs]

Afternoon Session (Chairs: R. Kothes / J. Hughes)

14:40 – 15:20		W. Reich [Magnetic fields in SNRs and PWNe: radio polarization results]
15:20 – 15:40		D. Castro [The Northern Rims of SNR RCW 86 – Chandra's Recent Observations and their Implications for Particle Acceleration]
15:40 – 16:00		P. Kavanagh [Magnetic field estimates from the synchrotron X-ray shell of 30 Dor C, the first TeV superbubble]
16:00 – 16:20	**[S5]** ↓	S. Knezevic [Hα imaging spectroscopy of Balmer-dominated shocks in Tycho's SNR]
16:20 – 16:50		Coffee Break & Poster Viewing
16:50 – 17:30		E. Amato [Recent developments on the SNR-CR connection]
17:30 – 17:50		P. F. Winkler [Expansion Measurements of Young Type Ia SNRs and the Physics of Nonradiative Shocks]
17:50 – 18:30		P. Ghavamian [Electron-ion thermal equilibration in collisionless shocks]

Wednesday June 08

Session 6 [Jets and asymmetries in SNe and their remnants] & Session 7 [SNRs as probes and drivers of galaxy structure]

Morning Session (Chairs: R. Fesen / M. Filipovic)

09:00 – 09:40	**[S6]** ↓	N. Soker [The role of jets in exploding SNe and shaping their remnants]
09:40 – 10:00		J. P. Hughes [A Kinematic Study of Tycho's SNR]
10:00 – 10:20		A. Wongwathanarat [3D long-time CCSN simulations: from shock revival to shock break-out]
10:20 – 10:40		S. Park [A Chandra Study of G299.2-2.9: The Remnant of an Asymmetric Type Ia Explosion?]
10:40 – 11:00		S. Orlando [Modeling post-explosion anisotropies of ejecta in SNR Cassiopeia A]
11:00 – 11:30		Coffee Break & Poster Viewing
11:30 – 12:10		L. Lopez [Investigating the symmetry and progenitors of SNRs using x-ray observations]
12:10 – 12:30		G. Leloudas [What do the remnants of superluminous SNe look like?]

12:30 – 13:10	**[S7]**	G. Dubner [Radio emission from supernova remnants]
13:10 – 13:30	↓	J. West [Bilateral symmetry in SNRs and the connection to the Galactic magnetic field]
13:30 – 13:50		S. Sarbadhicary [Statistical modelling of supernova remnant populations in the Local Group]
13:50 – 14:00		**Conference Photo**
17:00 – 23:00		**Excursion #1: Chania City Tour**
17:00		Buses depart from Minoa Palace Resort to Chania
23:00		Buses depart from Chania to Minoa Palace Resort

Thursday June 09

Session 7 [SNRs as probes and drivers of galaxy structure] & Session 8 [SNe and SNRs cosmic ray acceleration]

Morning Session (Chairs: M. Filipovic / S. Reynolds)

09:00 – 09:40		H. Lee [Broadband Emission Models for Young to Middle-aged SNRs and What To Learn from Them]
09:40 – 10:00		W. P. Blair [X-ray, Optical, and Radio properties of the extensive SNR population in M83]
10:00 – 10:20		P. Maggi [X-raying SNRs in the Magellanic Clouds]
10:20 – 11:00	**[S8]** ↓	A. Spitkovsky [Particle acceleration in collisionless shocks: insights from kinetic simulations]
11:00 – 11:30		Coffee Break & Poster Viewing
11:30 – 11:50		K. Koyama [Iron K shell line, a probe of low energy cosmic rays in SNRs]
11:50 – 12:10		A. Weinstein [Studies of young and hard-spectrum SNRs with VERITAS]
12:10 – 12:30		G. Ferrand [3D simulations of young core-collapse SNRs undergoing efficient particle acceleration]
12:30 – 12:50		V. Dwarkadas [Gamma-rays and Neutrinos from Efficient Cosmic-Ray Acceleration in Young SNe]
12:50 – 13:10		K. Auchettl [G 346.6-0.2: Non-thermal X-ray emission from a Mixed-Morphology SNR]
13:10 – 14:40		Lunch

Session 8 [SNe and SNRs cosmic ray acceleration] & Session 9 [SN ejecta – abundances, clumpiness]

Afternoon Session (Chair: S. Reynolds / L. Lopez)

14:40 – 15:20		M. Lemoine-Goumard [Acceleration of cosmic rays at SNR shocks: constraints from gamma-ray observations]
15:20 – 15:40		M. Miceli [Modeling the shock-cloud interaction in SN 1006: particle acceleration and non-thermal emission]
15:40 – 16:00		A. Wilhelm [Stochastic acceleration and magnetic damping in Tycho's SNR]
16:00 – 16:20		M. Cardillo [The middle aged SNR W44: most likely reacceleration without any break]
16:20 – 16:50		Coffee Break & Poster Viewing
16:50 – 17:30	**[S9]** ↓	C. Badenes [The Riddle of Steel: Fe-peak Elements in Type Ia SNRs]
17:30 – 17:50		M. Matsuura [ALMA observations of SN 1987A – mixing, nucleosynthesis and dynamics of the ejecta]
17:50 – 18:10		K. A. Frank [A New Approach to X-ray Analysis of SNRs]
18:10 – 18:30		M. M. Schulreich [Assessing the link between recent SNe near Earth and the iron-60 anomaly in a deep-sea crust]
20:15		Buses depart from Minoa Palace Resort to Cabana Mare Beach Restaurant
20:30 – 00:30		**Conference Banquet** @ Cabana Mare Beach Restaurant
00:30		Buses depart from Cabana Mare Beach Restaurant to Minoa Palace Resort

Friday June 10

Session 9 [SN ejecta – abundances, clumpiness] & Session 10 [SNe and SNRs with circumstellar interactions]

Morning Session (Chair: L. Lopez / J. Raymond)

09:00 – 09:40		D. Milisavljevic [Deciphering the encoded debris of SNe]
09:40 – 10:00		M. Barlow [The dust masses in the remnants of Cas A, SN1993J and SN 1980K]
10:00 – 10:20		Y.-H. Lee [Near-Infrared Spectroscopic Study of SN Ejecta and SN Dust in Cassiopeia A]
10:20 – 10:40		J. Larsson [The ejecta of SN 1987A]
10:40 – 11:00		I. De Looze [The dust mass in Cassiopeia A]
11:00 – 11:30		Coffee Break & Poster Viewing
11:30 – 12:10	**[S10]**	R. McCray [Supernova 1987A at 29 years]
12:10 – 12:30	↓	D. N. Burrows [The X-ray evolution of SNR 1987A]

12:30 – 12:50	E. Dwek [Thirteen years of pummeling the circumstellar ring around SN1987A]
12:50 – 13:10	C. Kilpatrick [A Survey for Galactic SNR/Molecular Cloud Interactions Using Carbon Monoxide]
13:10 – 14:40	Lunch

Session 10 [SNe and SNRs with circumstellar interactions]

Afternoon Session (Chair: J. Raymond)

14:40 – 15:20	D. Patnaude [X-ray observations of SNRs as probes of progenitor evolution]
15:20 – 15:40	C. Black [A new distance determination to the Cygnus Loop]
15:40 – 16:00	A. Z. Bonanos [Probing the physics of bright SNe with high-cadence photometry]
16:00 – 16:20	S. Benetti [The spectacular evolution of SN 1996al over 15 years: a low energy explosion of a stripped massive star in a highly structured environment]
16:20 – 16:50	Coffee Break & Poster Viewing
16:50 – 17:10	P. Zhou [Discovery of an expanding molecular bubble surrounding Tycho's SNR (SN 1572): evidence for a single-degenerate progenitor]
17:10 – 17:30	A. Chiotellis [On the interaction of type Ia SNRs with planetary nebulae]
17:30 – 18:10	J. Vink (Closing Plenary) [SNR research: where do we stand today, and what will the future bring]
18:10 – 18:30	J. Raymond [Closing Remarks]

Saturday June 11

09:00 – 18:00	**Excursion#2: Full-day Boat trip to Gramvousa and Balos** Buses depart/arrive from/to Minoa Palace Resort

END OF CONFERENCE

CONFERENCE POSTERS

Session 1 [Radiation studies from gamma-rays to radio in Galactic and Extragalactic SNRs]

S1.1	B. Arbutina	Some statistics of optical supernova remnant candidates in nearby galaxies
S1.2	R. Bandiera	Synchrotron emission in the case of a partly random magnetic field, and the study of some general properties of radio shell-type supernova remnants.
S1.3	P. Boumis	A deep optical study of the supernova remnant G 166+4.3
S1.4	J. Devin	Disentangling the hadronic from the leptonic emission in the composite SNR G326.3-1.8
S1.5	V. Dwarkadas	The X-ray Emission From Young Supernovae as a Probe of their Progenitors
S1.6	E. Egron	Observations of Supernova Remnants with the Sardinia Radio Telescope
S1.7	B. Eichmann	The Radio-Gamma Correlation In Starburst Galaxies
S1.8	T. Ergin	Investigating the X-ray and Gamma-ray Properties of the Galactic Supernova Remnants Kes 69, 3C 396, 3C 400.2
S1.9	B. Humensky	The TeV Morphology of the Interacting Supernova Remnant IC 443
S1.10	Y. Kim	A New Supernova Remnant Candidate in the UWIFE [Fe II] Line Survey
S1.11	M. Kopsacheili	New candidate supernova remnants in nearby galaxies
S1.12	K. S. Long	The X-ray Properties of Supernova Remnants in Nearby Galaxies
S1.13	S. Loru	Modelling high-resolution spatially-resolved SNR spectra with the Sardinia Radio Telescope
S1.14	P. Maggi	Fe K and ejecta emission in SNR G15.9+0.2 with XMM-Newton
S1.15	D. Onić	On the shape of SNR IC443 radio to infrared continuum spectrum
S1.16	O. Petruk	Magnetohydrodynamic simulations of the polarized radio emission of the adiabatic SNRs in ISM with nonuniform distribution of density and magnetic field
S1.17	G. Puehlhofer	New constraints on the TeV SNR shells RX J1713.7-3946 and HESS J1731-347
S1.18	A. Sezer	Searching for the Time Variation in Supernova Remnant RX J1713.7-3946
S1.19	A. Sezer	Searching for evidence of non-thermal X-ray emission from supernova remnant W49B
S1.20	W. Sun	Chandra Observation of the Supernova Remnant N11L
S1.21	I. Sushch	Deep H.E.S.S. Observations of the Supernova Remnant RX J0852.0-4622
S1.22	M. Vučetić	Optical observation of supernova remnant in elliptical galaxy NGC 185
S1.23	J. West	Cygnus Loop: A double bubble?
S1.24	X. Zhang	The role of the diffusive protons in the gamma-ray emission of supernova remnant RX J1713.7-3946 - a two-zone model

Session 2 [The search for the binary companions of SN progenitors in SNRs]

S2.1	S. Gomes	A survey of symbiotic stars in the SMC
S2.2	A. Pannicke	Runaway Stars in Supernova Remnants

Session 3 [Pulsar wind nebulae (including Crab flares)]

S3.1	R. Bandiera	A (semi)-analytic view of the inner structure of Pulsar Wind Nebulae
S3.2	B. Guest	Peering deeper into the plerionic supernova remnant G21.5-0.9
S3.3	R. W.-Y. Leung	High Resolution Radio Imaging Study of the Pulsar Wind Nebula MSH 15-52
S3.4	C. Maitra	The intriguing double torus-jet PWN around PSR J0855-4644
S3.5	C.-Y. Ng	Discovery of a Radio Bubble Trailing PSR J1015-5719
S3.6	I. Sushch	Radio Observations of the Pulsar Wind Nebula HESS J1303−631 with ATCA
S3.7	S. Tanaka	A Stochastic Acceleration Model of Radio Emission from Pulsar Wind Nebulae

Session 4 [Magnetic fields in SNRs and PWNe]

S4.1	O. Kobzar	Nonlinear Evolution of the Nonresonant Instability Upstream of a Young Supernova Remnant Shock
S4.2	O. Petruk	Magnetohydrodynamic simulations of the post-adiabatic supernova remnants in the interstellar magnetic field
S4.3	P. Reich	A new high-latitude low-surface brightness SNR
S4.4	M.S.E. Roberts	What Can Redbacks and Black Widows Teach Us About Pulsar Winds?
S4.5	S. Safi-Harb	Insights into pulsars' magnetic field evolution and energy loss mechanisms from studying pulsar-SNR associations

Session 5 [Collisionless shock waves in SNRs]

S5.1	L. Hovey	A Direct Measurement of the Forward Shock Speed in Supernova Remnant 0519-69.0: Constraints on the Age, Ambient Density and Electron-ion Temperature Equilibration.

Session 6 [Jets and asymmetries in SNe and their remnants]

S6.1	M. Gabler	The first few month of a supernova remnant

Session 7 [SNRs as probes and drivers of galaxy structure]

S7.1	A. Asvarov	SNRs in the late stages of evolution
S7.2	D. Huizenga	A Radio Selected Supernova Remnant Catalog in the Magellanic Clouds
S7.3	D. Leahy	Supernova Remnant Explorer
S7.4	D. Leahy	HI absorption spectra for Supernova Remnants in the VGPS survey
S7.5	M. Sasaki	SNR-shock Impact on Star Formation
S7.6	B. Vukotić	An empirical study on distances and evolution of supernova remnants: insights from "Sigma D" data distribution

Session 8 [SNe and SNRs cosmic ray acceleration]

S8.1	R. Brose	Transport of magnetic turbulence in supernova remnants
S8.2	E. Giacani	The interstellar medium towards three Supernova Remnants
S8.3	J. Niemiec	Electron energization through spontaneous turbulent magnetic reconnection at nonrelativistic perpendicular shocks
S8.4	M. Pavlović	Radio evolution of supernova remnants including non-linear particle acceleration" and not "Importance of Richtmyer-Meshkov Instability on Measurements of Cosmic-Ray Acceleration Efficiency at Supernova Remnants
S8.5	J. Shimoda	Importance of Richtmyer-Meshkov Instability on Measurements of Cosmic-Ray Acceleration Efficiency at Supernova Remnants
S8.6	L. Supan	First GMRT radio observations of the SNR candidate G29.37+0.10

Session 9 [SN ejecta – abundances, clumpiness]

S9.1	P. Cigan	High-resolution observations of dust in SN1987A
S9.2	R. Fesen	Optical and UV Spectra of the Remnant of SN 1885 (S And) in M31
S9.3	S. Marassi	SN Dust Yields: Fallback, Metallicity and Rotation Impact
S9.4	H. Matsumura	Discovery of Recombining Plasma in G166.0+4.3: A Mixed-Morphology Supernova Remnant with an Unusual Structure
S9.5	F. Priestley	The origin of the argonium emission discovered in the Crab Nebula
S9.6	E. Tsiakaliari	Dust formation in Supernovae

Session 10 [SNe and SNRs with circumstellar interactions]

S10.1	A. Alarie	Multispectral analysis of Cygnus Loop and IC 443 with iFTS
S10.2	N. Bartel	Supernova research with VLBI
S10.3	M. Bocchio	Dust grains from the heart of supernovae
S10.4	Y.-H. Chu	Type Ia Supernova Remnants in the Large Magellanic Cloud

S10.5	J. E. Drew	Exploiting IPHAS H-alpha imagery of supernova remnants
S10.6	É. Harvey	The previous nebulous incarnations of type Ia supernovae
S10.7	D. Kantzas	Early time signatures of gamma-ray emission from Supernovae in dense Circumstellar Media
S10.8	D. Kantzas	The Effect of Circumstellar Medium on Cosmic Ray Acceleration in Type Ia Supernovae
S10.9	H.-G. Lee	Near-infrared IFU and MOS observations of supernova remnants
S10.10	Y.-H. Lee	Supernova Remnants in the UWIFE and UWISH2 Surveys
S10.11	M. Miceli	Investigating the Galactic Supernova Remnant Kes 78 with XMM-Newton
S10.12	E. R. Micelotta	Dance into the fire: dust survival inside supernova remnants
S10.13	C. Fransson	The circumstellar ring of SN 1987A
S10.14	S. Orlando	Three-dimensional hydrodynamic modeling of SN 1987A from the supernova explosion till the Athena era
S10.15	L. Pan	The impact of supernova remnants on interstellar turbulence and star formation
S10.16	S. P. Reynolds	Asymmetric Expansion of the Youngest Galactic Supernova Remnant G1.9+0.3
S10.17	A. Sarangi	Dust formation in dense CSM behind the shock: A study based on SN2010jl
S10.18	X. Tang	Kinematic evolution of non-radiative supernova remnants
S10.19	B. Yu	Determination of the extinction law of dust in SNRs

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Session I.

Radiation studies from gamma-rays to radio in Galactic and Extragalactic SNRs – Oral Talks

Thermal X-rays and shock speed measurement in RX J1713.73946

Oral Talk

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Abstract

Despite being one of the prototype of Galactic cosmic ray accelerator, important parameters such as age, shock speed, ambient medium density and progenitor properties are still poorly known for the SNR RX J1713.73946. In particular, determining the ambient density is crucial to understand the nature of the gamma-ray emission and constrain the fraction of kinetic energy transferred to hadrons accelerated at the shock front of the SNR. For over a decade, thermal X-ray emission, which could constrain the ambient density, has been searched for in this synchrotron dominated SNR. Deep XMM-Newton and Suzaku observations have finally revealed this emission and its nature will be discussed (ejecta or shocked ISM). Another possibility to constrain the ambient density medium is through X-ray proper motion measurements. The South-East region of the SNR present the best example of clear and sharp X-ray filaments and the shock in this region is probably expanding in the low density carved by the strong winds of the progenitor. Using follow-up XMM observations of the South-East region and 13 years of leverage, we will present the first clear measurement of proper motion in RX J1713.73946 and the implication in terms of ambient density, shock speed, and age of the SNR.

SNRs with LOFAR

Oral Talk

Maria Arias de Saavedra Benitez, Jacco Vink

University of Amsterdam, Netherlands

Abstract

The Low Frequency Array (LOFAR) is a new-generation radio interferometer in the Netherlands that covers the largely unexplored low-frequency ranges of 10-90 MHz (with the Low Band Antenna, LBA) and 110-240 MHz (with the High Band Antenna, HBA) with unprecedented sensitivity and angular resolution. The telescope offers very interesting possibilities for the study of supernova remnants (SNR), whose steep spectral indexes render them more dominant at low frequencies. LOFAR frequencies allow us to observe different absorption processes affecting SNRs at low frequencies: both internal and external free-free absorption, and perhaps even synchrotron self-absorption in certain exceptional cases. In this talk I intend to present my initial results from LOFAR imaging of two SNRs: Cassiopeia A and VRO42.05.01. From a technical point of view, Cas A is of importance to LOFAR because, as the brightest source in the radio sky, it can contaminate entire observations if it enters a beam side lobe. In order to properly subtract its contribution to the visibilities of any given target a high resolution model of Cas A is required. This data set was taken with the aim of making such a model, and here I will present an LBA image and discuss the absorption processes present. VRO42.05.01 is a mixed-morphology SNR, and as such has an overall flat (α=0.37) spectral index. Some MMSNRs are known to have spectral index segregation, with faint steep spectral regions and bright flat spectral regions. We took both LBA and HBA data of VRO.42.05.01, which allows us to explore local variations in the spectral index and their correlation with density. For both sources, I will show how the morphology at LOFAR frequencies compares to high frequencies, and what we can learn from that.

TeV Remnants in the H.E.S.S. Galactic Plane Survey

Oral Talk

Ryan C. G. Chaves

CNRS Montpellier, France

Abstract

The H.E.S.S. Galactic Plane Survey (HGPS), sensitive to very-high-energy gamma rays from ~0.2 to ~50 TeV, is now complete and shows supernova remnants to be one of the dominant TeV source populations in the Galaxy. The HGPS is the culmination of a decade-long, 2800-hour observation program that provides the first comprehensive view of the TeV Galaxy with high angular resolution (~5 arcmin) and sensitivity ($\sim 1-2\%$ Crab Nebula flux). In some composite SNRs, we are able to distentangle TeV emission originating in interior pulsar wind nebulae from that of the SNR shells. We also can resolve SNR shells themselves, and not only the most well-known high-energy SNRs, but some unexpected discoveries as well. We recently searched for new TeV shell morphologies in the HGPS dataset, revealing: HESS J1534-571, coincident with the cataloged SNR candidate G323.7-1.0; HESS J1912+101, intruigingly with noobvious MWL counterpart; and HESS J1614-518, with a possible GeV gamma-ray counterpart. The TeV properties of these and other shells can reveal the non-thermal particle acceleration processes at work in SNRs and shed light on the important questions concerning cosmic-ray acceleration up to PeV energies and young remnants in the Galaxy that are possibly missing from current surveys. A public release of the HGPS survey maps, as well as a standardized catalog of Galactic TeV sources and study of multi-wavelength associations (notably SNRcat), is in preparation and will also be presented.

Trends in supernova remnant research

Invited Talk

Roger Chevalier

University of Virginia, USA

Abstract

I will discuss some current research trends, including tying remnants and pulsar nebulae to particular progenitor star and supernova types, and the emission from supernova remnants in molecular clouds. Outstanding questions in the field will also be considered.

Observational facts of extragalactic SNRs

Oral Talk

Miroslav Filipovic[1], P. Kavanagh, F. Haberl, M. Sasaki, L. Bozzetto, D. Urosevic

[1]University of Western Sydney, Australia

Abstract

This is an exciting time for the discovery of supernova remnants (SNRs) in galaxies other than our Milky Way. SNRs reflect a major process in the elemental enrichment of the interstellar medium (ISM). The study of this interaction in different domains including radio, optical, IR and X-ray, allow a better understanding of these remnants and their environments. Nearby external galaxies offer an ideal laboratory, since they are near enough to be resolved, yet located at relatively known distances.I will review our most recent searches for SNRs in the Magellanic Clouds, M33, M31, NGC 300, NGC 45, NGC 6744 and NGC 7793. New high resolution ($\sim 1''$) and sensitive (< 0.3 mJy beam-1) radio (ASKAP, ATCA & MWA), X-ray (XMM & CHANDRA), IR (Herschel and Spitzer) and optical (WIFES) images of these galaxies have preliminarily revealed thousands of sources from which we found a total of over 300 extended sources that are SNRs or candidates. We investigate their intrinsic and overall properties and found some remarkable and unexpected differences. I will also present our breakthrough studies of first extragalactic SNRs expansion as well as our first detection of circular polarisation in extragalactic SNR. You will have a chance to see the most complete Sigma-D study of all KNOWN SNRs and how they interact with nearby molecular clouds. I will present the case for DD vs. SD in Type Ia for some 15 LMC SNRs based on our X-ray and radio observations. Finally, I will present our strategies for the next 10 years on how to observe SNRs with the next generation of instruments – from ASKAP/MWA2 to CTA via eRosita and whoever else.

New extended GeV sources in the Galactic plane found in a search of the Pass 8 data from Fermi-LAT

Oral Talk

Marie-Helene Grondin[1], Jamie Cohen[2], Elizabeth Hays[2], Marianne Lemoine-Goumard[2]

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Abstract

Spatially resolving pulsar wind nebulae (PWNe) and supernova remnants (SNRs) at GeV energies enables accurate representation of spectra, aids identification of multiwavelength counterparts, and probes possible substructure within the gamma-ray sources. Using 6 years of Fermi-LAT Pass 8 data above 10 GeV, we searched for spatially extended sources near the Galactic plane. The improved angular resolution and photon acceptance of the Pass 8 event reconstruction significantly aids in characterizing source extension and assessing spectral and morphological properties, a key consideration for studies of PWNe and SNRs in the gamma-ray band. Selecting photons above 10 GeV strikes a balance between keeping photon statistics high and diffuse gamma-ray emission low, and also carries the benefit of a near constancy with energy of the point spread function of the LAT. More than 30 significantly extended sources are detected, many of which are resolved at GeV energies for the first time.

Infrared supernova remnants and their infrared to X-ray flux ratios

Oral Talk

Bon-Chul Koo[1], **Ji Yeon Seok, Jae-Joon Lee, Il-Gyo Jeong, Hyun-Jeong Kim**

[1]Seoul National University, S. Korea

Abstract

Supernova remnants (SNRs) are one of prominent objects in infrared (IR) emission, and their Infrared-to-X-ray (IRX) flux ratios are generally thought to indicate the relative importance of dust cooling to gas cooling in hot dusty plasma. But recent high-resolution IR space missions show that SNRs have diverse morphology in IR dust emission often very different from their X-ray appearance, suggesting different origins for the IR dust emission. We explored how the natural and/or environmental properties of SNRs affect the IRX morphology of SNRs and their IRX flux ratios.We first investigated IR and X-ray properties of 20 Galactic SNRs that are relatively well defined in both bands. We found that the observed IRX flux ratios of some SNRs agree with theoretical ratios of SNR shocks in which dust grains are heated and destroyed by collisions with plasma particles. For the majority of SNRs, however, the IRX flux ratios are either significantly smaller or significantly larger than the theoretical ratios. The SNRs with the smallest IRX flux ratios are young SNRs with X-ray emission dominated by metal-rich SN ejecta. There are, however, also evolved SNRs with good IRX morphological correlation but have small IRX flux ratios. For these SNRs, low dust-to-gas ratio (DGR) of the ambient medium seems to be a plausible explanation. On the other hand, the SNRs with the largest IRX flux ratios have anticorrelated IRX morphology and relatively low dust temperatures. We have found that these SNRs are located in dense environment, and their IR emission is probably from dust heated by shock radiation rather than by collisions.We also derived IRX flux ratios of SNRs in the Large Magellanic Cloud (LMC) using *Spitzer* and *Chandra* SNR survey data and compared them with those of Galactic SNRs. We found that the IRX flux ratios of the LMC SNRs are systematically lower than those of the Galactic SNRs, which appears to be consistent with the low DGR of the LMC. We also confirmed the relation between IRX flux ratios and the IRX morphology. We will discuss the implications of our results for the study of SNRs in external galaxies.

Probing the properties of extragalactic SNRs

Invited Talk

Ioanna Leonidaki[1,2]

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[2]IESL/FORTH, Heraklion, Crete, Greece

Abstract

The investigation of extragalactic SNRs gives us the advantage of surmounting the challenges we are usually confronted with when observing Galactic SNRs, most notably Galactic extinction and distance uncertainties. At the same time, by obtaining larger samples of SNRs, we are allowed to cover a wider range of environments and ISM parameters than our Galaxy, providing us a more complete and representative picture of SNR populations. I will outline the recent progress on extragalactic surveys of SNR populations focusing on the optical, radio, and X-ray bands. Multi-wavelength surveys can provide several key aspects of the physical processes taking place during the evolution of SNRs while at the same time can overcome possible selection effects that are inherent from monochromatic surveys. I will discuss the properties derived in each band (e.g. line ratios, luminosities, densities, temperatures) and their connection in order to yield information on various aspects of their behaviour and evolution. For example their interplay with the surrounding medium, their correlation with star formation activity, their luminosity distributions and their dependence on galaxy types.

Radio properties of M33 supernova remnants: results from a new deep JVLA Survey

Oral Talk

Knox S. Long[1], Richard L. White[1], Robert H. Becker[2], David J. Helfand[3], William P. Blair[4], P. Frank Winkler[5]

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[5] Middlebury College, USA

Abstract

We have carried out new 6 and 20 cm observations of M33 with the Jansky Very Large Array, primarily to study the properties of supernova remnants in the galaxy. Our scaled array observations have a limiting sensitivity of about 25 μm Jy (5σ) and a resolution of $5''$ (FWHM), corresponding to a spatial resolution of 20 pc at the distance of M33. We detect about 85 of the SNRs contained in the list of 137 optically identified SNRs described by Long et al. (2010), and a few additional objects from the survey of Lee & Lee (2014). A substantial fraction of the optical SNRs not detected are in regions where emission from H II recombination makes identification of non-thermal emission from the SNR difficult. We also discuss a blind search for SNRs based on the radio emission alone. Of the SNRs we detect in this search at radio wavelengths, 53 have also been detected at X-ray wavelengths. Thus we are able make a direct comparison of the X-ray, optical, and radio properties of the SNRs in M33, the first time that has been possible to a significant extent in an external spiral galaxy.

Gamma ray emission from middle aged supernova remnants interacting with molecular clouds

Oral Talk

Xiaping Tang[1], Roger A. Chevalier[2]

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Abstract

Gamma ray emission from several middle aged supernova remnants (SNRs) has been detected in space-based GeV observations and ground-based TeV observations. The characteristic pion-decay signature identified in spectra of the remnants IC443 and W44 provides strong evidence for cosmic ray (CR) proton acceleration in SNRs. Multi-wavelength observations further reveal a spatial correlation between the molecular cloud (MC) interaction region and the gamma ray emitting region. Radio emission, however, was found not to be well-correlated with the high energy emission. Based on observed MC associations, two scenarios have been proposed to explain the observed gamma ray emission from these middle aged SNRs. In one, accelerated CR particles escape from the SNR and then illuminate nearby MCs, producing gamma ray emission, while the other involves direct interaction between the SNR and molecular clumps. Here I present a new model of the direct interaction type that involves the collision between MC clumps and a radiative SNR. The model can explain the discrepancy between radio and gamma ray emission morphology. The gamma ray spectra from these middle aged SNRs show steeping from GeV to TeV energies that is believed to be due to the limited acceleration time of CR particles. However, the spectral shape cannot be fitted by a simple exponential profile. We derive a time dependent solution for diffusive shock acceleration in the test particle limit and show that it is capable of explaining the observed spectral steepening at high energy.

Recent progress on young Galactic supernova remnants

Invited Talk

Brian J. Williams

NASA GSFC / USRA, USA

Abstract

I will review progress in the past few years on several young (less than a few thousand years old) supernova remnants within the Milky Way galaxy and the Magellanic Clouds. I will focus on objects like Tycho, Kepler, 3C 397, W49B, and Cas A. I will discuss not only what has been learned about particular remnants, but also what these remnants can tell us about their pre-supernova progenitor systems. I will also show areas in which newly launched and upcoming observatories, such as Hitomi (Astro-H) and JWST can contribute to the study of supernova remnants.

SN Ia archaeology: Searching for the relics of progenitors past

Oral Talk

Tyrone E. Woods[1], Marat Gilfanov[2], Alejandro Clocchiatti[3], Armin Rest[4]

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Abstract

Despite the critical role that SNe Ia play in the chemical enrichment of the Universe and their great importance in measuring cosmological distances, we still don't know for certain how they arise. In the canonical form of the "single-degenerate" scenario, a white dwarf grows through the nuclear burning of matter accreted at its surface from some companion star. This renders it a hot, luminous object (a supersoft X-ray source or SSS, 10^5-10^6K, 10^{38}erg/s) for up to a million years prior to explosion. Past efforts to directly detect the progenitors of very recent, nearby SNe Ia in archival soft X-ray images have produced only upper limits, and are only constraining assuming progenitors with much higher temperatures than known SSSs. In this talk, I will outline an alternative approach: given that such objects should be strong sources of ionizing radiation, one may instead search the environment surrounding nearby SN Ia remnants for interstellar matter ionized by the progenitor. Such "fossil nebulae" should extend out to tens of parsecs and linger for roughly the recombination timescale in the ISM, of order 10,000 100,000 years. Progress on this front has been hampered by the failure to detect nebulae surrounding most known SSSs using 1m class telescopes in the early 1990s. I will present new benchmark calculations for the emission-line nebulae expected to surround such objects, demonstrating that previous non-detections are entirely consistent with the low ISM densities expected in the vicinity of most SN Ia progenitors (Woods & Gilfanov, 2016). Modern large optical telescopes are now well able to reach the required limiting surface brightness needed to find such faint emission. With this in mind, I will introduce our new narrow-band survey for fossil nebulae surrounding young Magellanic SN Ia remnants and SSSs, already underway using the Magellan Baade telescope (PI: Alejandro Clocchiatti). In addition to opening a new era of "SN Ia archaeology", I will show how our deep observations can also serve as a new probe of the structure of the ISM in nearby galaxies.

Session I.

Radiation studies from gamma-rays to radio in Galactic and Extragalactic SNRs – Posters

Some statistics of optical supernova remnant candidates in nearby galaxies

Poster

Bojan Arbutina, Milica Vučetić

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Abstract

In this paper we analyse statistical properties of optical supernova remnant (SNR) candidates in nearby galaxies from a catalogue compiled by Vucetic et al. (2015). Although, there are more than 1000 optical SNRs detected, it seems that the number is still insufficient to draw firmer conclusions about their evolution. Some parameters (such as angular diameters and distances) are still poorly determined. We conclude that a combination of multiwavelength observations is necessary to improve the statistics of SNRs.

Synchrotron emission in the case of a partly random magnetic field, and the study of some general properties of radio shell-type supernova remnants.

Poster

Rino Bandiera[1], Oleh Petruk[2]

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Abstract

We present an extension of the classical synchrotron emission theory, for the combination of an ordered magnetic field plus a random component. Exact analytical formulae are obtained for a power-law distribution of radiating particles. We also discuss a treatment of the internal Faraday rotation. These results are then applied to discuss some general properties of the structure of the radio emission and polarization from shell-type supernova remnants. To this purpose we have used a thin-layer approximation to model the supernova remnant shell: this approximation does not guarantee the same level of accuracy of numerical simulations, but is adequate to show at least qualitatively how the observed maps are affected by the geometry of the source. Some further considerations are presented on the more general case in which the energy distribution of the emitting particles is not a pure power law.

A deep optical study of the supernova remnant G 166+4.3 (VRO)

Poster

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Abstract

We present the first CCD images of the VRO 42.05.01 (G 166.0+4.3) supernova remnant in Hα+[N II], [O III] 5007 and [S II] at a moderate angular resolution. Low and high-dispersion spectroscopy was also performed at selected areas around this extended remnant. Diagnostic diagrams of the line intensities from the present spectra and the new kinematical observations both confirm the supernova origin. Taking into account our results (i.e. shock velocities, morphological characteristics etc.) together with observations of other wavelengths (i.e. radio), we provide new significant information on the interaction between this SNR and the surrounding Interstellar medium (ISM).

Disentangling the hadronic from the leptonic emission in the composite SNR G326.3-1.8

Poster

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Abstract

Supernova remnants (SNRs), pulsar wind nebulae (PWNe) and pulsars are the usual suspects to accelerate the bulk of cosmic rays in our Galaxy.In those objects the gamma-ray emission allows us to probe the population of high-energy particles and in particular the population of accelerated hadrons radiating through the pion-decay mechanism. Those Galactic accelerators are most of the time studied as independent objects, even if, in the case of some core-collapse supernovae, the shell-like SNR, the PWN and the pulsar are in fact present in the same object.In the case of composite SNRs, both the SNR shell and the PWN are bright enough to be observed in the same source. Understanding the nature of the gamma-ray emission in such objects can be challenging for sources of small angular extension. Previous studies of the composite SNR G326.3-1.8 (radius=0.3°) revealed bright and extended gamma-ray emission but its origin remained uncertain.With the recent Pass8 Fermi-LAT data that provide an increased acceptance and angular resolution, we investigate the detailed morphology of this composite SNR in order to distinguish the SNR from the PWN contribution. In particular, we take advantage of the new possibility to filter events based on their angular reconstruction quality (PSF types). Disentangling the different components is crucial to clearly model the spectral properties of the source and to understand its nature.

The X-ray emission from young supernovae as a probe of their progenitors

Poster

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Abstract

Even after several decades of study, the progenitor stars of supernovae (SNe) have proven difficult to identify. The identification of progenitors has generally been the purview of optical astronomy, aided in part by stellar evolution models. But observations at otherwavelengths can also provide several hints about the progenitors.We have aggregated together data available in the literature, or analysed by us, to compute the lightcurves of almost all young SNe (days to years after explosion) that have been detected in X-rays. Currently we have about 60 SNe spanning all the various types, but the database is expanding rapidly. The lightcurves themselves span 12 orders of magnitude in luminosity. We use this library of lightcurves and spectra to explore the diversity of SNe, the characteristics of the environment into which they are expanding, and the implications for their progenitors. X-ray spectra can provide insight into the density structure, composition and metallicity of the surrounding medium, and the ionization level, through the spectra themselves as well as the X-ray absorption. Since core-collapse SNe expand mainly in environments created by the progenitor star mass-loss, this can provide crucial information about the nature of the progenitor star, and its mass-loss parameters in the decades or centuries before its death. We explore all SN types, with emphasis on Type IIP and Type IIn SNe. IIPs have the lowest X-ray luminosities, which is surprising given the high mass-loss rate, and low velocity, winds expected from their red supergiant (RSG) progenitors, and therefore the high density medium into which IIP SNe are expected to expand into. We show that the low X-ray luminosity sets a limit on the mass-loss rate, and thereby initial mass of a RSG star which can become a Type IIP progenitor. This initial mass limit, of about 19 $M_{\odot}$, is consistent with that obtained via direct optical progenitor identification. IIns are observed to have high X-ray luminosities in general, but their light curves are very diverse, with some of them tending to fall off very steeply. We explore the implications of this behaviour.

Observations of supernova remnants with the Sardinia Radio Telescope

Poster

Elise Egron[1], Alberto Pellizzoni[1], Sara Loru[1], Noemi Iacolina[1], Simona Righini[3], Matteo Bachetti[1], Raimondo Concu[1], Marco Marongiu[1], Andrea Melis[1], Sara Mulas[2], Giulia Murtas[2], Maura Pilia[1], Roberto Ricci[3], Alessio Trois[1]

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Abstract

In the frame of the Astronomical Validation and Early Science activities for the 64m Sardinia Radio Telescope (SRT, http://www.srt.inaf.it), we performed 6-22 GHz imaging observations of the complex-morphology SNRs W44 and IC443. We adopted innovative observing and mapping techniques providing unprecedented accuracy for single-dish imaging of SNRs at these frequencies, revealing morphological details typically available only at lower frequencies through interferometry observations. High-frequency studies of SNRs in the radio range are useful to better characterize the spatial-resolved spectra (and then physical parameters) of different regions of the SNRs interacting with the ISM. Furthermore, synchrotron-emitting electrons in the high-frequency radio band are also responsible for the observed high-energy phenomenology as -e.g.- Inverse Compton and bremsstrahlung emission components observed in gamma-rays, to be disentangled from hadrons emission contribution (providing constraints on the origin of cosmic rays).

The radio-gamma correlation in starburst galaxies

Poster

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Abstract

A systematic study of the non-thermal electron-proton plasma and its emission processes in starburst galaxies is presented in order to explain the correlation between the luminosity in the radio band and the recently observed gamma luminosity. In doing so, a steady state description of the cosmic ray electrons and protons within the spatially homogeneous starburst is considered where continuous momentum losses are included as well as catastrophic losses due to diffusion and advection. The primary source of the relativistic cosmic rays, most likely supernova remnants, provides a quasi-neutral plasma with a power law spectrum in momentum where we account for rigidity dependent differences between the electron and proton spectrum.We examine the resulting leptonic and hadronic radiation processes by synchrotron radiation, inverse Compton scattering, Bremsstrahlung and hadronic pion production. Finally, the observations of NGC 253, M 82, NGC 4945 and NGC 1068 in the radio and gamma-ray band as well as the observed supernova rate are used to constrain a best-fit model.In the case of NGC 253, M 82, NGC 4945 our model is able to accurately describe the data, showing that: (i) Supernovae are the dominant particle accelerators for NGC 253, M 82 and NGC 4945, but not in the case of NGC 1068. (ii) All considered starburst galaxies are poor proton calorimeters in which for NGC 253 the escape is predominantly driven by the galactic wind, whereas the diffusive escape dominates in NGC 4945 and M 82 (at energies > 1 TeV). (iii) Secondary electrons from hadronic pion production are important to model the radio flux, but the associated neutrino flux is below the current observation limit.

Investigating the X-ray and gamma-ray properties of the Galactic supernova remnants Kes 69, 3C 396, 3C 400.2

Poster

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Abstract

Kes 69, 3C 396, 3C 400.2 are mixed-morphology (MM) Galactic supernova remnants (SNRs), where Kes 69 and 3C 396 are interacting with molecular clouds (MCs). Previous X-ray studies showed that the emission from these SNRs is thermal. It has been suggested that MM SNRs interacting with MCs are potential candidates for overionized plasma in X-rays and hadronic gamma-ray emission. Recently, Chandra observations revealed signs of overionized plasma in 3C 400.2. In this presentation, we give preliminary results of our analysis of the archival Suzaku and Fermi-LAT data of these SNRs and we interpret the outcome.

The TeV morphology of the interacting supernova remnant IC 443

Poster

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Abstract

IC443 is a Galactic supernova remnant (SNR) in which there is clear evidence for the interaction of a dense molecular cloud with the supernova blast wave. This interaction makes the region an excellent laboratory in which to study the connection between particle acceleration and gamma ray emission in SNRs. Previous observations in the GeV to TeV band with MAGIC and VERITAS showed gamma-ray emission coincident with an extended region of interaction between the shock wave and the molecular cloud. At lower energies (MeV to GeV), Fermi-LAT observations have revealed the signature of hadronic emission with its characteristic pion bump. Furthermore, observations in other wavelengths such as radio, infrared, optical and X-rays indicate that the environment around the remnant is complex, with a range of different densities. In this new study, with the help of additional data, VERITAS observations have been used to resolve the TeV morphology of IC443 at the few arc-minute scale. We will present results on the gamma-ray morphology and discuss possible sources of the emission, including the shell of the remnant and other gaseous structures in the vicinity.

A new supernova remnant candidate in the UWIFE [Fe II] line survey

Poster

Yesol Kim, Bon-Chul Koo

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Abstract

We report the discovery of a new supernova remnant (SNR) candidate in the narrow-band [Fe II] 1.644 um line imaging survey UWIFE (UKIRT Widefield Infrared Survey for Fe). UWIFE covers the first quadrant of the Galactic plane ($7^\circ < l < 62^\circ$, $|b| < 1.5^\circ$), and, by visual inspection, we have found $\sim$200 extended Ionized Fe objects (IFOs) in the survey area. Most of IFOs are associated with SNRs, young stellar objects, HII regions, and planetary nebulae. But about 12% of IFOs are not associated with any known astronomical objects, and the SNR candidate, IFO J183749.829-061452.41 (hereafter IFO J183749) is one of those. IFO J183749 is a 6"-long, faint, arc-like filament with small-scale irregular structures. It appears to be a portion of a circular loop, but the rest of the loop is not seen in [Fe II] emission. It is found to coincide with a well-defined radio continuum arc. The radio arc has a complicated morphology, and IFO J183749 coincides with the bright inner part of the radio arc. Hydrogen recombination lines have been detected toward the radio arc from low-resolution surveys, so it has been known as an HII region (G25.8+0.2) at a kinematic distance of 6.5 kpc. But the inside of this radio arc is filled with soft X-rays, while, just outside the arc to the north, there is hard X-ray nebula harboring a young pulsar. Therefore, the nature of this arc-like structure seen in radio and [Fe II] emission is uncertain. In this presentation, we present the results of follow-up spectroscopic study of IFO J183749 using IGRINS (Immersion Grating Infrared Spectrograph) which is high spectral resolution (R$\sim$40,000) spectrograph covering H and K-bands, simultaneously. We have found that the [Fe II] filaments are both spatially and kinematically distinct from the HII filaments. The intensity ratios of [Fe II] to Br lines suggest that the HII filaments are photoionized while the [Fe II] filaments are shock-ionized, which supports the SNR origin for IFO J183749. We discuss the association of IFO J183749 with other sources in the region.

New candidate supernova remnants in nearby galaxies

Poster

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Abstract

Supernova remnants (SNRs) are objects of high importance since they provide major amounts of energy to the interstellar medium (ISM), while at the same time, they depict the end-point state of massive stars (M $>$ 8 $M_\odot$). In order to investigate the physical properties of these objects and their interplay with their environment, we have embarked in an extensive investigation of the SNR populations in nearby galaxies of different morphological types. This effort has been initiated with six galaxies, mostly irregulars,in the northern hemisphere (Leonidaki et al. 2010, 2013). Following this context, we present new candidate SNRs (down to fluxes of 10^{-16} erg sec^{-1} cm^{-2}) of five spiral galaxies in the southern hemisphere (NGC 45, NGC 55, NGC 1313, NGC 1672, NGC 7793), based on deep narrow-band Hα and [S II] images observed with the 4m Blanco telescope at CTIO, Chile. The new detections were achieved by calculating the [S II]/Hα flux ratio, where all sources with [S II]/ Hα $>$ 0.4 were considered as candidate SNRs. Furthermore, we use the derived properties of the newly detected candidate SNRs ([S II]/Hα ratios, Hα fluxes) to investigate how they are distributed according to their brightness and their behavior in different environments (irregulars vs. spirals).

The X-ray properties of supernova remnants in nearby galaxies

Poster

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Abstract

More extragalactic SNRs have been detected in X-rays in nearby galaxies than in the Milky Way. Most of the X-ray detected SNRs were first identified optically, and then detected as soft X-ray sources in deep imaging observations with Chandra and in some cases XMM. Here, we discuss the large X-ray samples of SNRs in M51, M83, and M101, with the goal of understanding which SNRs are detected in X-rays and which are not. Not surprisingly perhaps, most of the SNRs in these galaxies are middle-aged SNRs; very few analogs of Cas A or other young objects have been found. Trends of X-ray luminosity with diameter are absent, probably because the total amount of swept up material is the dominant factor in determining the X-ray luminosity of a SNR at a particular time. SNR expanding into high density media evolve rapidly and have X-ray luminosities that peak at small diameters, whereas those expanding into lower density media evolve more slowly and have luminosities that peak later.

Modelling high-resolution spatially-resolved SNR spectra with the Sardinia Radio Telescope

Poster

Sara Loru[1], Alberto Pellizzoni[1], Elise Egron[1], Noemi Iacolina[1], Simona Righini[3], Matteo Bachetti[1], Raimondo Concu[1], Marco Marongiu[1], Andrea Melis[1], Sara Mulas[2], Giulia Murtas[2], Maura Pilia[1], Roberto Ricci[3], Alessio Trois[1]

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Abstract

Supernova Remnants exhibit spectra typically featured by synchrotron emission mostly arising from the relativistic emitting electrons in the radio band and high-energy emission from both leptonic processes like Bremsstrahlung and Compton Inverse produced by the radio-electrons interacting with ambient photons, and hadronic process of pi0 mesons decay which is a direct signature of Cosmic Rays accelerated in Supernova Remnants. Single particle population models based on integrated radio fluxes are too simplistic in order to describe SNR phenomenology. On the other hand, spatially-resolved high-frequency radio data are often lacking. Thanks to radio imaging observations obtained in three frequency bands (1.4, 7, 22 GHz) with the Sardinia Radio Telescope (www.srt.inaf.it), we can model separately different SNR regions. Indeed, in order to disentangle interesting and peculiar hadron contributions in the high-energy spectra and better constrain SNRs as Cosmic Rays emitters, it is crucial to fully constrain lepton contributions first through radio-observed parameters.In particular, the Bremsstrahlung and Inverse Compton bumps observed in gamma-rays are typically bounded to synchrotron spectral slope and cut-off in the radio domain, associated with different SNR regions and electron populations.

Fe K and ejecta emission in SNR G15.9+0.2 with XMM-Newton

Poster

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Abstract

We present a study of the Galactic supernova remnant SNR G15.9+0.2 with archival XMM-Newton observations. Using EPIC's collective power, we report for the first time the detection of Fe K line emission from SNR G15.9+0.2. We measure the line properties (e.g. centroid energy and width) and find evidence for spatial variations. We discuss how SNR G15.9+0.2 fits within the current sample of SNRs with detected Fe K emission and found that it is the core-collapse SNR with the lowest Fe K centroid energy. We also present some caveats to the use of Fe K line centroid energies as typing tools for SNRs. We analyse the emission-line rich X-ray spectra extracted from various regions. The abundances of Mg, Si, S, Ar, and Ca are super-solar and their ratios strongly suggests that the progenitor of SNR G15.9+0.2 was a massive star, strengthening the physical association to a candidate Central Compact Object detected with Chandra. Using the absorption column density and ambient medium density constrained by the X-ray spectral analysis, we revise the measurements of the age and distance to the SNR.

On the shape of SNR IC443 radio to infrared continuum spectrum

Poster

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Abstract

Recently, the SNR IC443 was detected at all nine Planck satellite frequencies (Planck Collaboration Int.XXXI 2016). The characteristic dip in emissivity between around 50 to 250 GHz is observed. It is proposed to be due to a break in the synchrotron power law resulting from the injection mechanism of the energetic particles, or due to cooling losses by the energetic particles. In this work, different emission models that can be responsible for the particular shape of IC443 SED are tested and discussed. The possibility of spinning dust emission signatures are emphasized.

Magnetohydrodynamic simulations of the polarized radio emission of the adiabatic SNRs in ISM with nonuniform distribution of density and magnetic field

Poster

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Abstract

Polarized radio emission has been mapped with great details in several Galactic supernova remnants (SNRs). The polarization of synchrotron emission contains a wealth of information but has not yet been exploited to the extent it deserves. We have developed a numerical method to model the maps of the Stokes parameters for SNRs during their adiabatic phase of evolution, in either a uniform or a non-uniform environment. The method consists in the following steps.

1. A 3-dimensional magneto-hydrodynamical structure of the SNR is simulated, taking into account the interstellar magnetic field, and a possible gradient of the ISM density and/or of the ambient magnetic field.
2. The acceleration of particles at the forward shock and their evolution downstream are modelled.
3. The generation and dissipation of the turbulent component of magnetic field has been calculated everywhere in the SNR, taking into account its interaction with the accelerated particles.
4. Our generalization of the classical synchrotron theory, to include both the ordered and the disordered components of magnetic field, is used to model the emission.
5. The internal Faraday rotation of the polarization plane is considered.
6. Finally, 2-D maps are derived, for different orientations of the SNR with respect to the observer.

We present details of the model, as well as some results of the numerical simulations.

New constraints on the TeV SNR shells RX J1713.7-3946 and HESS J1731-347

Poster

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Abstract

Resolved TeV-emitting supernova remnants remain a small and precious class of sources to study cosmic ray acceleration in SNRs. We present new multi-wavelength results of the two prominent objects RX J1713.7-3946 and HESS J1731-347. For RX J1713.7-3946, extensive new H.E.S.S. data have permitted to study the nature of the TeV-emitting CR particles through improved broadband spectral studies, as well as through detailed investigations of morphological differences between TeV gamma-rays and X-rays. Concerning HESS J1731-347, the TeV morphology of the object and its surroundings has been studied using cosmic ray acceleration simulations of the object. The SNR also hosts a luminous X-ray emitting central compact object (CCO). Investigations of the CCO in X-rays and in the infrared have permitted to set interesting constraints on the SNR and its progenitor.

Searching for the time variation in supernova remnant RX J1713.7-3946

Poster

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Abstract

Supernova Remnant RX J1713.7-3946 emits synchrotron X-rays and very high energy gamma-rays. Recently, thermal X-ray line emission is detected from ejecta plasma. CO and HI observations indicate that a highly inhomogeneous medium surrounding the SNR. It is interacting with dense molecular clouds in the northwest and the southwest of the remnant. The origin of the gamma-ray emission from RX J1713.7-3946 is still uncertain. Detection of rapid variability in X-ray emission from RX J1713.7-3946 indicates the magnetic field B$\sim$ mG. In this work, we investigate the time variation in X-ray flux, luminosity and photon index of RX J1713.7-3946. For this investigation, we study the northwest part of the remnant using Suzaku data in 2006 and 2010. We present preliminary results based on our analysis and interpretations about these X-ray time variability.

Searching for evidence of non-thermal X-ray emission from supernova remnant W49B

Poster

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Abstract

Synchrotron X-ray emission, which arises from electrons being accelerated by the shock front of a supernova remnant (SNR), has been detected predominantly in young shell type remnants. The detection of synchrotron X-ray emission allows one to investigate the properties of the underlying particle population. Using a $\sim$470 ks Suzaku observation of SNR W49B, we search for evidence of non-thermal X-ray emission by extracting X-ray spectra from different regions across the remnant. We model each spectra using a combination of thermal emission and non-thermal models in an attempt to characterise the presence of X-ray synchrotron emission. Here we present our initial results and preliminary conclusions.

Chandra observation of the supernova remnant N11L

Poster

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Abstract

We performed a Chandra X-ray study of the supernova remnant (SNR) N11L in the Large Magellanic Cloud (LMC). The X-ray emission is predominantly distributed within the main shell and the northern loop-like filaments traced by the optical narrow band images, with an indistinct extension along the north area. The brightest emission comes from a northeast-southwest ridge, and peaks at two patches at center and southwest. Spectral analysis indicates that the blast wave is propagating in a inhomogenous environment, and the X-ray emission overall is dominated by thermal gas whose composition is consistent with the LMC average abundance. The ionization time of the hot plasma implied by the X-ray spectral analysis is consistent with the Sedov age of the SNR derived from the best-fit parameters and the apparent radius of the SNR based on the optical images, however, the consequent explosion energy is no only at least one order of magnitude less than the canonical value of 10^{51} ergs, but also takes a small portion of the thermal energy of the hot gas. That discrepancy supports the blown-out scenario.

Deep H.E.S.S. observations of the supernova remnant RX J0852.0-4622

Poster

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Abstract

The largest TeV source, RX J0852.0-4622 (Vela Jr.), is one of the few supernova remnants (SNRs) with well resolved shell-like morphology at very-high-energy (VHE; E>100 GeV) gamma-rays. Strong non-thermal emission across the electromagnetic spectrum from radio to VHE gamma-rays, young age and proximity of the remnant makes it one of the prime objects for the study of particle acceleration aiming to test the paradigm of SNRs being sources of Galactic cosmic rays. Here we present deep H.E.S.S. observations of RX J0852.0-4622 with roughly doubled exposure comparing to previously published results. Improved statistics together with new analysis techniques result in a firm determination of the cut-off in the gamma-ray spectrum and allow the spatially resolved spectroscopy studies. A smooth connection of the H.E.S.S. spectrum to the spectrum at GeV energies as reported by Fermi/LAT provides an exciting opportunity to recover the present-time parent particle population in both leptonic and hadronic scenarios directly from the gamma-ray data alone. These new observations provide us a deeper insight and better understanding of the physical processes in SNRs.

Optical observation of supernova remnant in elliptical galaxy NGC 185

Poster

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Abstract

In this paper we discuss the previously known optical supernova remnant (SNR) in NGC 185 galaxy, a dwarf elliptical companion of the Andromeda galaxy, in order to gain more information about its properties and evolutionary status. To this end, we observed a central portion of NGC 185, through the narrowband Hα and [SII] filters, on a 2m RCC-telescope at National astronomical observatory Rozhen, Bulgaria. Also, we performed MHD simulations using the Pluto code, for the case of low environmental density and high pressure, in order to discuss evolution of a SNR in a gas poor dwarf galaxy.

Cygnus Loop: A double bubble?

Poster

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Abstract

The Cygnus Loop is a well-studied, large, bright and nearby supernova remnant (SNR) that has been observed across the electromagnetic spectrum. It is believed to be an SNR shell with a blow-out region in the south. However, it has also been suggested that this object is in fact two SNRs. We consider this two-SNR scenario by using a multi-wavelength view, focusing on new multi-frequency radio polarization data from the GALFACTS survey, with the addition of microwave (Planck), infrared (WISE), ultraviolet (GALEX), X-ray (ROSAT), and gamma-ray (Fermi-LAT) data. In addition, we present modelling efforts that support the 2-SNR interpretation.

The role of the diffusive protons in the gamma-ray emission of supernova remnant RX J1713.7-3946 — a two-zone model

Poster

Xiao Zhang, Yang Chen

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Abstract

RX J1713.7−3946 is a prototype in the γ-ray-bright supernova remnants (SNRs) and is in continuing debates on its hadronic versus leptonic origin of the γ-ray emission. We explore the role played by the diffusive relativistic protons that escape from the SNR shock wave in the γ-ray emission, apart from the high energy particles' emission from the inside of the SNR. In the scenario that the SNR shock propagates in a clumpy molecular cavity, we consider that the γ-ray emission from the inside of the SNR may either arise from the IC scattering or from the interaction between the trapped energetic protons and the shocked clumps. The dominant origin between them depends on the electron-to-proton number ratio. The surrounding molecular cavity wall is considered to also produce γ-ray emission due to the "illumination" by the diffusive protons that escaped from the shock wave during the expansion history. We simplify the algorithm for Li & Chen's (2010) "accumulative diffusion" model for diffusive escaping protons. This two-zone model is fit to the broad-band spectrum of the SNR that incorporates the updated 5-yr Fermi data, with application of the MCMC method. The broad-band spectrum can be well explained by this two-zone model, in which the γ-ray emission from the inside governs the TeV band, while the outer emission component substantially contributes to the GeV γ-rays. The two-zone model can also explain the TeV γ-ray radial brightness profile that significantly stretches beyond the nonthermal X-ray emitting region.

Session II.

The search for the binary companions of SN progenitors in SNRs – Oral Talks

OB Runaway Stars inside the Supernova Remnants S147 and IC443

Oral Talk

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[2]Astrophysical Institute and University Observatory Jena - Germany

Abstract

We present first results of a long term study: Searching for OB–type runaway stars inside supernova remnants (SNRs). We identified spectral types and measured radial velocities (RV) by optical spectroscopic observations and we found OB runaway stars inside SNR S147 and IC443. HD 37424 is a B0.5V type star with a peculiar velocity of 74.0 ± 8 km s^{-1}. Tracing back the past trajectories via Monte Carlo simulations, we found that HD 37424 was located at the same position as the central source PSR J0538+2817 30±4 kyr ago. This position is only ∼4 arcmin away from the geometrical center of the SNR. So, we suggest that HD 37424 was the pre–supernova binary companion to the progenitor of the pulsar and the SNR. We found a distance of 1333^{+103}_{-112} pc to the SNR. The age is 30±4 kyr and the total visual extinction towards the center is 1.28±0.06 mag. The zero age main sequence progenitor mass should be greater than 13 $M_\odot$. We calculated the pre–supernova binary parameters for different progenitor masses. The values found for the Roche Lobe radii suggest that it was an interacting binary in the late stages of the progenitor. This is the first OB runaway star ever found which is directly linked to a neutron star (NS) and a SNR. Another OB runaway star we found is the B0II/III type star HD 254577 inside SNR IC443. The proper motion of the star is significantly larger than the average proper motion of the other members of GEM OB1 association. The peculiar velocity of the star is 35 ± 7 km^{-1}s at 1.5 kpc. The bow shock direction of the pulsar wind nebula shows that the NS and HD 254577 may have a common origin; binary supernova disruption. Unlike S147, the explosion center we found is far away from the geometrical center, close to the eastern edge of the remnant. But the relation to the SNR is still possible. This source provided us with important information of SNR expansion in the medium with inhomogeneous density distribution.

Reviving the Single Degenerate Scenario for the Ia Supernova Event that Formed Remnant 0509−67.5

Oral Talk

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Abstract

Utilizing our proper motion measurements in Hovey et al. (2015) of the supernova remnant 0509−67.5, we are able to determine a dynamical offset of the explosion site from the geometric center along an approximately east-west dynamical axis where the remnant displays asymmetries in brightness and morphology. We measure projected shock speeds of 5740 ± 380 km s^{-1} to the west and 6370 ± 160 km s^{-1} to the east along our dynamical axis, and a projected diameter of $26.350 \pm 0.034''$. This measurement is used in a Monte-Carlo simulation of various hydrodynamic models where we find a continuum of dynamical offsets of the explosion site relative to the geometric center based on initial assumptions. In our first scenario, the remnant expands into different ambient medium densities on each side for the entire lifetime of the remnants evolution, and we find the offset to be $0.790 \pm 0.350''$ to the west along the dynamical axis. If, however, we model the initial asymmetry to be a result of partitioning the initial explosion energy, we find an offset of $1.370 \pm 0.603''$ in the same direction as the first. Our third scenario is one in which the shock in the west has recently plowed into an over-dense region. This limiting case predicts no dynamical offset of the explosion site from the geometric center. This new determination, along with photometry with wide-band images obtained with the *Hubble Space Telescope*, reveals 21 stars with $I-$band magnitudes ranging from 26.90 to 20.51 (assuming an E(B-V) of 0.13) within the 3-σ error circle of these possible explosion sites. Our results are in contention with the previous claim in Schaefer & Pagnotta (2012), thereby reviving the single degenerate scenario for the progenitor system of the supernova remnant 0509−67.5.

Surviving companions of SNe

Invited Talk

Wolfgang Kerzendorf[1]

[1]ESO - Germany

Abstract

Most supernovae should occur in binaries. Massive stars, the progenitors of core collapse supernovae (SN II/Ib/c), have a very high binarity fraction of 80% (on average, they have 1.5 companions). Binary systems are also required to produce thermonuclear supernovae (SN Ia). Understanding the role that binarity plays in pre-supernova evolution is one of the great mysteries in supernova research. Finding and studying surviving companions of supernovae has the power to shed light on some of these mysteries. Searching Galactic and nearby supernova remnants for surviving companions is a particularly powerful technique. This might allow to study the surviving companion in great detail possibly enabling a relatively detailed reconstruction of the pre-supernova evolution. In this talk, I will summarize the multitude of theoretical studies that have simulated the impact of the shockwave on the companion star and the subsequent evolution of the survivor. I will then give an overview of the searches that used these theoretical findings to identify surviving companions in nearby supernova remnants as well as their results. Finally, I will give an outlook of new opportunities in the relatively young field.

Type Ia SNR N103B: structure of the remnant and properties of the progenitor

Oral Talk

Chuan-Jui Li[1], You-Hua Chu[2], Robert Gruendl, et al.

[1]Institute of Astronomy and Astrophysics, Taiwan
[2]Academia Sinica, Institute of Astronomy and Astrophysics, Taiwan

Abstract

N103B is a Type Ia supernova remnant (SNR) projected in the outskirt of the superbubble around the rich cluster NGC 1850 in the Large Magellanic Cloud (LMC). We have obtained *Hubble Space Telescope (HST)* images to study the physical structure of this SNR and its underlying stellar population. We have also obtained high- and medium-dispersion spectra of the SNR to identify the shocked gas components and to determine the excitation and abundances of the gas. The *HST* Hα image of N103B shows an incomplete filamentary elliptical shell and several groups of prominent knots. Our long-slit, high-dispersion spectra show that the filamentary shell is dominated by hydrogen Balmer lines; its lack of forbidden line emission indicates that the filamentary shell results from collisionless shocks into a mostly neutral medium. In contrast, the prominent knots show large velocity widths in both Hα line and [N II] $\lambda\lambda$6548, 6583 lines. Furthermore, the [S II] λ6716/λ6731 ratios in the knots imply electron densities $>$5000 cm^{-3}. These spectral properties suggest that these knots are most likely circumstellar material ejected by the progenitor before the SN explosion. Interestingly, using our high-dispersion spectra, we found that the N103B SNR is inside a slow expanding shell ($V_{\rm exp} \sim 10$ km s^{-1}). This kinematically identified shell is not visible morphologically. Considering the optical and X-ray properties of N103B and the discovery of the slow expanding shell encompassing the SNR, we suggest that the progenitor of N103B is a single-degenerate binary system; furthermore, the progenitor moved through the interstellar medium roughly along the minor axis of the filamentary elliptical shell. The supernova explosion center can be approximated by the center of the elliptical shell, and used to search for the surviving companion of the supernova. We suggest possible candidates for the surviving companion and implications on its mass and evolutionary stage.

Supernova Progenitors and Their Binary Companions

Invited Talk

Schuyler D. Van Dyk[1]

[1]IPAC/Caltech - USA

Abstract

It is absolutely essential to determine the stellar origins of supernovae, i.e., their progenitors or progenitor systems. I will briefly review what we know about the progenitors of supernovae beyond the Local Group from their direct identification in high spatial resolution pre-explosion images, primarily obtained with the Hubble Space Telescope. I will also touch on attempts to recover a surviving companion in core-collapse progenitor binary systems, particularly for the stripped-envelope supernovae, and the implications from these searches.

Session II.

The search for the binary companions of SN progenitors in SNRs – Posters

A survey of symbiotic stars in the SMC

Poster

Sidcley Gomes[1], S. Akras[1,2], R.D. Goncalves[1], H. Boffin[3], L. Guzman-Ramirez[3]

[1]Valongo Observatory, Federal University of Rio de Janeiro (OV-UFRJ), Brazil
[2]National Observatory (ON-MCTI), Brazil
[3]European Southern Observatory, Chile

Abstract

Symbiotic systems (SySt) are interacting binary systems with a cool giant star and a hot star, generally a white dwarf. These systems are considered as potential candidates for type Ia supernova (SN Ia) progenitors. For verifying this hypothesis the total number of these systems has to be compared with the SN Ia rate in a galaxy to probe the connection between SySt and SNe Ia. We have started a systematic survey of SySt in the Small Magellanic Cloud (SMC) via the detection of the O VI λ6825 Raman scattered line, commonly observed in SySt. From September to December 2015, eleven 6.8'x6.8' fields of the SMC were observed (one of them centered on a known SySt - SMC 3), by using FORS2 (FOcal Reducer and Spectrograph) at the Very Large Telescope (VLT). From the preliminary analysis of these data we were able to recover the known SySt as well as to identify 18 new O VI Raman scattered emitters. Seven out of the 18 candidates have 2MASS data, which allow us to plot them together with 19 IPHAS Galactic disk SySt and the 8 know SySt in the SMC in the $J - H$ vs. $H - Ks$ diagnostic diagram.

Runaway Stars in Supernova Remnants

Poster

Anna Pannicke[1], Baha Dincel[2], Ralph Neuhauser

[1]Astrophysical Institute and University Observatory Jena - Germany
[2]Institut fur Astronomie und Astrophysik Tubingen - Germany

Abstract

Half of all stars and in particular 70% of the massive stars are part of a multiple system. A possible development for the system after the core collapse supernova (SN) of the more massive component is as follows: The binary is disrupted by the SN. The formed neutron star is ejected by the SN kick whereas the companion star either remains within the system and is gravitationally bounded to the neutron star, or is ejected with a spatial velocity comparable to its former orbital velocity (up to 500 km/s). Such stars with a large peculiar space velocity are called runaway stars. We present our observational results of the supernova remnants (SNRs) G184.6-5.8, G74.0-8.5 and G119.5+10.2. The focus of this project lies on the detection of low mass runaway stars. We analyze the spectra of a number of candidates and discuss their possibility of being the former companions of the SN progenitor stars. The spectra were obtained with INT in Tenerife, Calar Alto Astronomical Observatory and the University Observatory Jena. Also, we investigate the field stars in the neighborhood of the SNRs G74.0-8.5 and G119.5+10.2 and calculate more precise distances for these SNRs.

Session III.

Pulsar winds nebulae (including Crab flares) – Oral Talks

New Radio and Optical Expansion Rate Measurements of the Crab Nebula

Oral Talk

Michael F. Bietenholz[1], Richard L. Nugent[2]

[1]Hartebeesthoek Radio Astronomy Observatory, South Africa
[2]IOTA, International Occultation Timing Association, Houston, TX 77219, USA

Abstract

We present new JVLA radio observations of the Crab nebula, which we use, along with older observations taken over a ∼30-yr period, to determined the expansion rate of the synchrotron nebula. We find a convergence date for the radio synchrotron nebula of AD 1255 ± 27. We also re-evaluated the expansion rate of the optical line emitting filaments, and we show that the traditional estimates of their convergence date are slightly biased. We find an un-biased convergence date of AD 1091 ± 34, ∼40 yr earlier than previous estimates. Our results show that both the synchrotron nebula and the optical line-emitting filaments have been accelerated since the explosion in AD 1054, but former more strongly than the latter. This finding supports the picture that the filaments are the result of the Rayleigh-Taylor instability at the interface between the pulsar-wind nebula and the surrounding freely-expanding supernova ejecta, and rules out models where the pulsar wind bubble is interacting directly with the pre-supernova wind of the Crab's progenitor. Our new observations were taken ∼2 months after the gamma-ray flare of 2012 July, and also allow us to put a sensitive limit on any radio emission associated with the flare of <0.0002 times the radio luminosity that of the nebula.

GMRT observations of the radio trail from the PWN CXOU J163802.6-471358

Oral Talk

D. A. Green[1], S. Roy[2]

[1]Cavendish Laboratory, UK
[2]National Centre for Radio Astrophysics (NCRA-TIFR), Pune, India

Abstract

CXOU J163802.6-471358 is compact X-ray source which has a 40 arcsec tail and is identified as a pulsar wind nebula (PWN). The Molonglo Galactic Plane Survey (MGPS) includes a nearby radio source, offset from the X-ray position in the same direction as the X-ray tail. However, the relatively low resolution of the MGPS data do not resolve the structure of this radio emission in any detail. We present GMRT observations of this radio trail from this PWN, at 325 and 1280 MHz, with resolutions down to 5 arcsec. The GMRT observations reveal the radio trail to be a well defined, linear feature about 90 arcsec in extent. Our Dual frequency observations do not reveal any evidence of significant spectral index variation along this radio trail.

On Distance and Age of Pulsar Wind Nebula 3C58

Oral Talk

Roland Kothes[1]

[1]Dominion Radio Astrophysical Observatory, Canada

Abstract

A growing number of astronomers present evidence that the pulsar wind nebula (PWN) 3C58 is much older than predicted by its proposed connection to the historical supernova of AD1181. There is also a great diversity of arguments. The strongest arguments rely heavily on the assumed distance of 3.2 kpc. I have re-visited the distance determination of 3C58 based on new HI data from the Canadian Galactic Plane Survey and our recent improvements of therotation curve of the outer Milky Way Galaxy. I also used newly determined distances to objects in the neighbourhood, which are based on trigonometric parallax. I have derived a new more reliable distance estimate of 2 kpc for 3C58. This makes the connection between the PWN and the SN1181 once again much more viable.

Newest insights from MHD numerical modeling of Pulsar Wind Nebulae

Oral Talk

Barbara Olmi[1], Luca Del Zanna, Elena Amato, Niccolo Bucciantini, Rino Bandiera

[1]Universita degli Studi di Firenze, Italy

Abstract

Numerical MHD models are considered very successful in accounting for many of the observed properties of Pulsar Wind Nebulae (PWNe), especially those concerning the high energy emission morphology and the inner nebula dynamics. Although PWNe are known to be among the most powerful accelerators in nature, producing particles up to PeV energies, the mechanisms responsible of such an efficient acceleration are still a deep mystery. Indeed, these processes take place in one of the most hostile environment for particle acceleration: the relativistic and highly magnetized termination shock of the pulsar wind.

The newest results from numerical simulations of the Crab Nebula, the PWN prototype, will be presented, with special attention to the problem of particle acceleration. In particular it will be shown how a multi-wavelengths analysis of the wisps properties can be used to constrain the particle acceleration mechanisms working at the Crab's termination shock, by identifying the particle acceleration site at the shock front.

The Lighthouse nebula: a run-away pulsar, its PWN, jets and parent SNR

Oral Talk

Lucia Pavan[1], Pol Bordas[2], Gerd Puhlhofer[3] et al.

[1]University of Geneva, Switzerland
[2]MPI Kernphysik, Heidelberg, Germany
[3]IAAT, Tubingen, Germany

Abstract

Some 10-20 kyr ago a pulsar was born from a core collapse event, receiving right away a strong kick. Nowadays this pulsar is powering the Lighthouse Nebula (IGR J11014-6103): a complex system of outflows comprising the bow-shock PWN, and two well collimated jets extending perpendicularly to the pulsar's direction of motion. Whereas sharing some clear commonalities with the well known Guitar Nebula, the Lighthouse nebula is the only such system where the parent supernova remnant is well visible and bright in X-rays. I will describe the results from our recent Chandra X-ray campaign, and follow-up optical and radio observations, analyse the properties of the PWN, and possible interpretations on the nature of the long helicoidal jets and of the other outflows that we identified. I will also discuss the link between this system and its parent supernova remnant MSH 11-61A, which could help shedding a light on the processes that give birth to such peculiar systems.

High-Energy Observations of Pulsar Wind Nebulae

Invited Talk

Samar Safi-Harb[1]

[1]University of Manitoba, Canada

Abstract

Pulsar Wind Nebulae (PWNe), the inflated bubbles of relativistic particles and magnetic fields injected by neutron stars, provide unique laboratories for probing Natures most powerful accelerators and the interaction of their winds with the surrounding SN ejecta or ISM. PWNe have become an important legacy of the Chandra X-ray Observatory and currently represent the largest population of identified Galactic very high-energy gamma-ray sources. I will review the growing X-ray and gamma-ray observations of these fascinating objects which, together with radio observations, allow us to infer the physical properties of these systems. I will focus on the PWN diversity among the SNR population, in connection with their debated SN progenitors and environment.

Evolution of Pulsar Wind Nebulae inside Supernova Remnants

Invited Talk

Tea Temim[1]

[1]NASA GSFC / UMD, USA

Abstract

Composite supernova remnants (SNRs) are those consisting of both a central pulsar that produces a wind of synchrotron-emitting relativistic particle and a supernova (SN) blast wave that expands into the surrounding interstellar medium (ISM). The evolution of the pulsar wind nebula (PWN) is coupled to the evolution of its host SNR and characterized by distinct stages, from the PWNs early expansion into the unshocked SN ejecta to its late-phase interaction with the SNR reverse shock. I will present an overview of the various evolutionary stages of composite SNRs and show how the signatures of the PWN/SNR interaction can reveal important information about the SNR and PWN dynamics, the SN progenitor and explosion asymmetry, the properties of the SN ejecta and newly-formed dust, particle injection and loss processes, and the eventual escape of energetic particles into the ISM. I will also discuss recent multi-wavelength observations and hydrodynamical modeling of evolved systems in which the PWN interacts with the SNR reverse shock and discuss their implications for our general understanding of the structure and evolution of composite SNRs.

Session III.

Pulsar winds nebulae (including Crab flares) – Posters

A (semi)-analytic view of the inner structure of Pulsar Wind Nebulae

Poster

Rino Bandiera[1], Barbara Olmi[1], Luca del Zanna[1], Niccol Bucciantini[1], Elena Amato[1]

[1]INAF- Arcetri Astrophysical Observatory, Florence, Italy

Abstract

When the wind of an active pulsar impacts on the surrounding medium, it forms a termination shock (TS) that feeds a relativistic and magnetized bubble, known as "Pulsar Wind Nebula". About thirty years ago, Kennel Coroniti investigated this scenario, but unfortunately their results failed to match the observed morphologies. That model was in principle correct, but its main drawback was the assumption of a spherical symmetry. More recently, numerical codes have been used to simulate in detail the dynamical structure of PWNe: they have shown complex morphologies, with a closer resemblance with observations. We show how Kennel Coroniti model can be generalized to two dimensions, by solving the jump equations for an oblique TS, and then the relativistic MHD equations in the downstream regions closest to the TS. In this way we can obtain two dimensional, steady state solutions, which in the inner regions agree quite well with the numerical ones. This method is semi-analytic and computationally rather light: given the shape of the TS (in an analytic form), the spatial behaviour of the physical quantities (like velocity, pressure, magnetic field) is derived. Maps of the synchrotron emission are also obtained. A final goal is to use semi-analytic modelling, together with numerical simulations, to improve inversion techniques, aimed at deriving the pulsar-wind parameters from observations.

Peering deeper into the plerionic supernova remnant G21.5-0.9

Poster

Benson Guest[1] and Samar Safi-Harb [1]

[1]University of Manitoba, Canada

Abstract

The supernova remnant G21.5-0.9 has been observed regularly with the Chandra X-ray observatory since its launch in 1999. The remnant hosts a bright pulsar wind nebula (PWN), powered by a 61.8 ms pulsar (PSR J1833-1034), and a faint limb-brightened shell revealed in X-rays with Chandra. The nature of the X-ray emission from the shell (thermal versus non-thermal) and knots within the nebula (ejecta?) remains a puzzle. To address this, we present a follow-up X-ray analysis of G21.5-0.9 utilizing the deepest ($>$ 1 Msec total) exposure to date, including $\sim$780 ks with the Advanced CCD Imaging Spectrometer (ACIS) and $\sim$310 ks with the High Resolution Camera (HRC). These observations spanning $\sim$15 years also allow for the study of variability and tracking the motion of small-scale structures within the PWN.

High resolution radio imaging study of the Pulsar Wind Nebula MSH 15-52

Poster

Ryan W.-Y. Leung, C.-Y. Ng

The University of Hong Kong, Hong Kong

Abstract

We present a new high-resolution radio imaging study of the pulsar wind nebula (PWN) MSH 15−52, also dubbed as "the hand of God", with the Australia Telescope Compact Array observations. The system is powered by a young and energetic radio pulsar B1509−58 with high spin down luminosity of $\dot{E} = 2 \times 10^{37}$ erg s^{-1}. Previous X-ray images have shown that the PWN has a complex hand-shape morphology extending over 10 pc with features like jets, arc, filaments and enhanced emission knots in the HII region RCW 89. The new 6cm and 3cm radio images show different morphology than the X-ray counterpart. No radio counterpart of the X-ray jet is detected, instead we found enhanced emission in a sheath surrounding the jet. Additional small-scale features including a polarized linear filament next to the pulsar have also been discovered. Our polarisation measurements show that the intrinsic orientation of magnetic field aligns with the sheath. Finally, spectral analysis results indicate a steep spectrum for the system, which is rather unusual among PWNe. Implications of these findings will be discussed. The Australia Telescope Compact Array is part of the Australia Telescope National Facility which is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO. This work is supported by an ECS grant under HKU 709713P.

The intriguing double torus-jet PWN around PSR J0855-4644

Poster

Chandreyee Maitra[1], Fabio Acero, Christo Venter

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Abstract

PSR J0855-4644 is a nearby, fast spinning, and energetic radio pulsar spatially coincident with the rim of the supernova remnant RX J0852.0-4622 (aka Vela Jr). XMM Newton observations of the pulsar region have shown an arcmin scale extended emission, the pulsar wind nebula (PWN), around the X-ray counterpart of the pulsar. Here, we present results from the small scale structure of the nebula provided by a Chandra observation of this source. This observation has revealed an arc second scale compact PWN around the pulsar showing a possible double torus+jet morphology. This makes it only the third source of its kind, and being an nearby object provides us with the golden opportunity to investigate the physics of equatorial and polar outflows in PWNe. Modeling the geometry of this source is also crucial to understand why no gamma-ray pulsations have been detected by the Fermi-LAT telescope for this high E_{dot}/d^2 pulsar. In order to constrain the pulsar spin inclination angle, we model the double torus morphology and then compare it with theoretical phase-plots to understand this radio loud, gamma-ray quiet system.

Discovery of a Radio Bubble Trailing PSR J1015-5719

Poster

C.-Y. Ng

The University of Hong Kong, Hong Kong

Abstract

PSR J1015-5719 is a young and energetic pulsar with a characteristic age of 39 kyr and a spin down luminosity of 8.3×10^{35} erg s^{-1}. We report on radio imaging observations of the field made with the Molonglo Observatory Synthesis Telescope and the Australia Telescope Compact Array at 36, 16, 6, and 3 cm. We discovered a highly linearly polarized radio nebula associated with the pulsar. It shows a faint triangular head region centered on the pulsar, followed by a bubble with 40" diameter and a faint tail of $\sim$1' further south. At the pulsar distance of 5 kpc, the physical size of the bubble seems too small for it to be the parent supernova remnant. We believe that it is more likely to be a pulsar wind nebula (PWN), based on the flat radio spectral index of $\sim$0.15 and high degree of polarization we found. Similar bubbles have been found in other PWNe such as the Guitar Nebula, and it was attributed to instability in the flow. We compare the PWN of J1015 with these cases and discuss the physical environment in the system. The Australia Telescope Compact Array is part of the Australia Telescope National Facility which is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO. MOST is operated by The University of Sydney with support from the Australian Research Council and the Science Foundation for Physics within the University of Sydney. This work is supported by an ECS grant under HKU 709713P.

Radio Observations of the Pulsar Wind Nebula HESS J1303-631 with ATCA

Poster

Iurii Sushch[1], Igor Oya, Ullrich Schwanke, Simon Johnston, Matthew Dalton

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Abstract

Based on its energy-dependent morphology the initially unidentified very high energy (VHE; E > 100 GeV) gamma-ray source HESS J1303-631 was recently associated with the pulsar PSR J1301-6305. Subsequent detection of X-ray and GeV counterparts further support the identification of the H.E.S.S. source as an evolved pulsar wind nebula (PWN). Recent radio observations of the PSR J1301-6305 region with ATCA dedicated to search for the radio counterpart of HESS J1303-631 are reported here. Observations at 5.5 GHz and 7.5 GHz do not reveal any extended emission associated with the pulsar. The analysis of the archival 1.384 GHz and 2.368 GHz data also does not show any significant emission. The 1.384 GHz data reveal a hint of an extended shell-like emission in the same region which might be a supernova remnant (SNR). The implications of the non-detection at radio wavelengths on the nature and evolution of the PWN, as well as the possibility of the SNR candidate being a birth-place of PSR J1301-6305 are discussed.

A Stochastic Acceleration Model of Radio Emission from Pulsar Wind Nebulae

Poster

Shuta Tanaka[1], **Katsuaki Asano**[2]

[1]Department of Physics, Konan University, Japan
[2]The University of Tokyo, Japan

Abstract

The broadband emission of Pulsar Wind Nebulae (PWNe) is well described by non-thermal emissions from accelerated electrons and positrons. However, the difference of spectral indices at radio and X-rays are not reproduced by the standard shock particle acceleration and cooling processes, and then, for example, the broken power-law spectrum for the particle energy distribution at the injection has been groundlessly adopted. Here, we propose a possible resolution for the particle distribution; the radio emitting particles are not accelerated at the pulsar wind termination shock but are stochastically accelerated by turbulence inside the PWNe. The turbulence may be induced by the interaction of the pulsar wind with the supernova ejecta. We upgrade our one-zone spectral evolution model including the stochastic acceleration and apply it to the Crab Nebula. We consider both continuous and impulsive injections of particles to the stochastic acceleration process. The radio emission in the Crab Nebula is reproduced by our stochastic acceleration model. The required forms of the momentum diffusion coefficient will be discussed.

Session IV.

Magnetic fields in SNRs and PWNe – Oral Talks

The Northern Rims of SNR RCW 86 - Chandra's Recent Observations and their Implications for Particle Acceleration

Oral Talk

Daniel Castro[1]

[1]NASA-GSFC, USA

Abstract

The Chandra observations towards the northwest (NW) and northeast (NE) rims of supernova remnant (SNR) RCW 86 reveal great detail about the characteristics of the shocks, particle acceleration and the local environments in these 2 distinct regions. Both the NW and NE of RCW 86 show clear evidence of non-thermal X-ray emission, identified as synchrotron radiation from shock-accelerated electrons with TeV energies, interacting with the compressed, and probably amplified, local magnetic field. Magnetic field amplification (MFA) is broadly believed to result from, and contribute to, cosmic ray acceleration at the shocks of SNRs. However, we still lack a detailed understanding of the particle acceleration mechanism, and with this study we address the connection between the shock properties and ambient medium with MFA. The Chandra observations of RCW 86 allowed us to constrain the magnitude of the post-shock magnetic field in the NE and NW rims by deriving synchrotron filament widths, and also the densities in these regions, using thermal emission co-located with the non-thermal rims. I will discuss our analysis in detail and comment on how MFA appears to be related to certain characteristics of the SNR shock.

Magnetic field estimates from the synchrotron X-ray shell of 30 Dor C, the first TeV superbubble

Oral Talk

Patrick Kavanagh[1], Jacco Vink[2], Manami Sasaki[3], Pierre Maggi[4], Frank Haberl[5], Miroslav Filipovic[6], Luke Bozzetto[6], Stefan Ohm[7]

[1] Dublin Institute for Advanced Studies, Ireland
[2] Anton Pannekoek Institute/GRAPPA, University of Amsterdam, Netherlands
[3] IAAT, University of Tuebingen, Germany
[4] CEA Saclay, France
[5] MPE, Germany
[6] Western Sydney University, Australia
[7] DESY Zeuthen, Germany

Abstract

Superbubbles are powered by the stellar winds and subsequent supernovae of a massive stellar population and are often argued as strong candidates for Galactic cosmic-ray acceleration sites. The recent detection of TeV γ-rays from 30 Dor C in the Large Magellanic Cloud by the *High Energy Stereoscopic System* (*H.E.S.S.*) has shown that superbubbles can and do accelerate particles up to very high cosmic-ray energies, and are a new and important source class in TeV astronomy. However, the dominant production mechanism (i.e., hadronic or leptonic) is still unclear. The answer to this question is locked in the unique synchrotron X-ray shell of 30 Dor C. The widths of the synchrotron emission regions are directly related to the magnetic field, which is a crucial parameter assessing dominant γ-ray emission mechanism. In this talk we will present a study of the synchrotron emission region widths in 30 Dor C using several hundred ks of archival X-ray data from *XMM-Newton*. We constructed radial emission profiles from various regions of the synchrotron shell, fitted emission models to determine the widths, and derived B-field values in the downstream regions using appropriate models. The resulting low B-field estimates, of the order of a few μG, favour a leptonic origin for the γ-ray emission. Hadronic cosmic rays are likely to be accelerated as well, but the low density inside the bubble suppresses their emissivity.

Magnetic fields in SNRs and PWNe: radio polarization results

Invited Talk

Wolfgang Reich[1]

[1]Max-Planck-Institut fur Radioastronomie, Bonn, Germany

Abstract

Polarized radio emission arises from ordered magnetic fields,where a variety of morphologies are observed. These are related to SNR evolution, a central object and/or an interaction with the ambient medium. The interpretation of SNR polarization data may depend on calibration issues and Faraday effects. Magnetic field strength estimates from radio data by equipartition or compression arguments, are mostly lower compared to estimates from high-energy data. Current SNR-catalogues are incomplete in particular for faint large objects. Follow-up work of recent Galactic plane surveys has revealed more objects with low surface-brightness and high polarization percentage. Their identification is difficult and progress is slow.

Magnetic fields in Supernova Remnants and Pulsar-Wind Nebulae: Deductions from X-ray Observations

Invited Talk

Stephen P. Reynolds[1]

[1]North Carolina State University, USA

Abstract

Magnetic field strengths B in synchrotron sources are notoriously difficult to measure. Simple arguments such as equipartition of energy can give values for which the total energy is a minimum, but there is no guarantee that Nature obeys it, or even if so, what particle population (just electrons? electrons plus ions?) should have an energy density comparable to that in magnetic field. However, the operation of synchrotron losses can provide additional information, if those losses are manifested in the synchrotron spectra as steepenings of the spectral-energy distribution above some characteristic frequency often called a "break" (though it is more typically a gradual curvature). A source of known age, if it has been accelerating particles continuously, will have such a break above the energy at which particle radiative lifetimes equal the source age, and this can give B. However, in spatially resolved sources such as supernova remnants (SNRs) and pulsar-wind nebulae (PWNe), systematic advection of particles, if at a known rate, gives a second measure of particle age to compare with radiative lifetimes. In most young SNRs, synchrotron X-rays make a contribution to the X-ray spectrum, and are usually found in thin rims at the remnant edges. If the rims are thin in the radial direction due to electron energy losses, a magnetic-field strength can be estimated. I present recent modeling of this process, along with models in which rims are thin due to decay of magnetic turbulence, and apply them to the remnants of SN 1006 and Tycho. In PWNe, outflows of relativistic plasma behind the pulsar wind termination shock are likely quite inhomogeneous, so magnetic-field estimates based on source lifetimes and assuming spatial uniformity can give misleading values for B. I shall discuss inhomogeneous PWN models and the effects they can have on B estimates.

Session IV.

Magnetic fields in SNRs and PWNe – Posters

Nonlinear Evolution of the Nonresonant Instability Upstream of a Young Supernova Remnant Shock

Poster

Oleh Kobzar[1], **Jacek Niemiec, Martin Pohl**

[1]Institute of Nuclear Physics, Polish Academy of Sciences, Poland

Abstract

Collisionless shocks of supernova remnants (SNR) are thought to be the acceleration sites of high-energy cosmic rays (CRs). Efficient particle production in the diffusive shock acceleration process requires turbulent amplified magnetic fields in the shocks precursor. Here we report results of new particle-in-cell (PIC) simulation studies of the nonresonant cosmic-ray-current-driven instability that operates upstream of young SNR shocks and may be responsible for magnetic-field amplification, plasma heating, and hydrodynamical turbulence. Earlier PIC simulations of this instability used computational boxes with periodic boundary conditions. Our current study for the first time applies a realistic setup with open boundaries in the CR drift direction, which accounts for mass conservation in decelerating flows. In this way both the temporal and the spatial development of the instability can be investigated. The results of our large-scale high-resolution PIC experiments demonstrate magnetic-field amplification as expected on the grounds of our earlier studies with periodic simulation boxes. The effects of backreaction on CRs that slow down the initial ambient plasma-CR relative drift velocity, limit further growth of the turbulence and lead to its saturation are also re-confirmed. We discuss a detailed spatio-temporal structure of the shock precursor, the evolution of CR distribution, and the microphysics of the saturation processes.

Magnetohydrodynamic simulations of the post-adiabatic supernova remnants in the interstellar magnetic field

Poster

Oleh Petruk[1], **Taras Kuzyo**[2], **Vasyl Beshley**[2]

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Abstract

The evolution of the adiabatic supernova remnants (SNRs) is typically described by the Sedov analytical solutions for the strong point explosion. The speed and the temperature of the shock wave decreases with time and the adiabatic condition is violated due to increase of the radiative losses of energy. As a result, the SNR shock enters the radiative stage. The duration of the transition phase from the adiabatic to the fully radiative stage is almost the same as the adiabatic stage. The period of time between the end of the adiabatic and the beginning of the radiative stage is called the post-adiabatic stage. Hydrodynamic properties of the post-adiabatic SNRs are well known. In contrast, the effect of the interstellar magnetic field on the evolution of such SNRs is not studied. We have used the code PLUTO (Mignone et al. 2007) in order to solve the system of magneto-hydrodynamic (MHD) equations with the radiative losses numerically. Influence of different values of the magnetic field strengths as well as its different orientation (perpendicular and parallel to the shock normal) on the evolution of SNRs are investigated. We have shown that the parallel magnetic field does not affect the distribution of the hydrodynamic parameters, while the presence of the perpendicular field leads to the significant decrease of the gas compression factor; this effect becomes more prominent for higher magnetic field strengths. The study is important in particular for the cases of the SNR-molecular cloud interaction where one may expect an increase of the hadronic component of the gamma-ray emission.

A new high-latitude low-surface brightness SNR

Poster

Patricia Reich[1], R. Kothes, T. Foster, W. Reich

[1]MPIfR Bonn, Germany

Abstract

We have discovered a new SNR in the Galactic Anticentre at a Galactic latitude of about 10° with the DRAO synthesis telescope at 21-cm. Here we report on follow-up Effelsberg observations at 6-cm. This shell-type SNR is almost circular with a diameter of about 1.5°. Its radio surface brightness is extremely low and it is highly linearly polarized. High-velocity HI-gas from the anti-centre shell seems associated, which places the SNR at a distance between 0.5 kpc and 2.5 kpc.

What Can Redbacks and Black Widows Teach Us About Pulsar Winds?

Poster

Mallory S. E. Roberts[1], Hind Al Noori, Maura McLaughlin, Jason Hessels, Rene Breton

[1]New York University Abu Dhabi, UAE

Abstract

Redbacks and Black Widows are close binary systems where the wind from a millisecond pulsar is forced to shock at $\sim 10^4$ light cylinder radii rather than the more typical 10^8 of pulsar wind nebulae. This means they can potentially probe σ in a region very different than a PWN termination shock. It is also the case that the primary shock is likely limited to a region very near the companion star, and hence only near the equatorial plane of the pulsar wind. X-ray observations of these systems show a variety of orbitally dependent behavior. Sometimes the emission is very inefficient, but in some cases it is extremely efficient. This suggests the shock must be taking place in a magnetic field of several Gauss and that most of the pulsar spin-down power comes out as an equatorially concentrated wind. However, the interpretation is complicated by a potentially significant role for the magnetic field of the companion. I will present an overview of the multiwavelength observations of these systems as well as new NuStar data on one particularly interesting system, PSR J2129-0429, and discuss the implications for pulsar winds.

Insights into pulsars' magnetic field evolution and energy loss mechanisms from studying pulsar-SNR associations

Poster

Samar Safi-Harb[1], Adam Rogers[1]

[1]University of Manitoba, Canada

Abstract

The characteristic ages of neutron stars are often inconsistent with their hosting supernova remnant (SNR) ages. We address this discrepancy by studying a sample of pulsars, including those with extreme magnetic fields (such as magnetars and the Central Compact Objects), securely associated with SNRs. We discuss the implications of our study to magnetic field evolution in neutron stars and their distinct energy loss mechanisms.

Session V.

Collisionless shock waves in SNRs – Oral Talks

Recent developments on the SNR-CR connection

Invited Talk

Elena Amato

INAF - Osservatorio Astrofisico di Arcetri, Italy

Abstract

The last few years have been rich of progress both for the science of Supernova Remnants and for Cosmic Rays. We have learnt from X-ray observations of SNRs that they host multi-TeV electrons and amplified magnetic fields, likely hints of efficient CR acceleration. We have seen gamma-ray emission from SNRs and gathered direct evidence of the presence of relativistic hadrons at least in a couple of these sources. Finally we have learnt how to properly use optical emission lines as a diagnostic of efficient CR acceleration in SNRs. On the CR side, direct experiments have shown the first clear evidence of structure in the spectra of protons and He nuclei below the knee, and in the meantime very recent measurements cast doubt about the position of the protons' knee. After briefly reviewing these recent developments, I will discuss whether and how they fit within the current theoretical framework of the SNR-CR connection.

Electron-ion thermal equilibration in collisionless shocks

Invited Talk

Parviz Ghavamian

Towson University, USA

Abstract

Collisionless shocks are loosely defined as shocks where the transition between pre- and post-shock states happens on a length scale much shorter than the collisional mean free path. In this talk I review our state of knowledge regarding electron heating in astrophysical shocks, mainly associated with supernova remnants (SNRs). Observations of non-radiative SNRs indicate that the ratio of electron temperature, (Te), to ion temperature (Tp), declines with increasing shock speed. Such behavior can be understood on the basis of cosmic-ray driven waves generated by cosmic rays in a shock precursor. The damping of these waves heats electrons to a nearly constant energy, resulting in the observed decline in Te/Tp with shock speed. Similar mechanisms may work in supernova ejecta shocks and solar wind shocks, though with different scaling between Te/Tp and and shock speed.

Hα imaging spectroscopy of Balmer-dominated shocks in Tycho's supernova remnant

Oral Talk

Sladjana Knezevic[1], Ronald Laesker[2], Glenn van de Ven[3], Joan Font-Serra[4], John C. Raymond[5], Parviz Ghavamian[6], John Beckman[4]

[1]Weizmann Institute of Science, Israel
[2]Turola Observatory, Finland
[3]MPIA, Germany
[4]IAC, Spain
[5]CfA, USA
[6]Towson University, USA

Abstract

We present Fabry-Perot interferometric observations of the narrow Hα component in the shock front of the historical supernova remnant Tycho (SN 1572). Using GHaFaS (Galaxy Hα Fabry-Perot Spectrometer) on the William Herschel Telescope, we observed a great portion of the shock front in the northeastern region of the remnant. The high spatial ($\sim$0.2$''$/pixel) and spectral resolution (FWHM of 19 km/s) together with the large field-of-view (3.4$'$x3.4$'$) of the instrument allow us to measure the narrow Hα-line width across individual parts of the shocks simultaneously and thereby study the indicators of several shock precursors in a large variety of shock front conditions. Covering one-fourth of the remnant's shell, we find a strong evidence for the broadening of the narrow Hα line beyond its intrinsic width of $\sim$20 km/s and a presence of an intermediate component with width of order $\sim$150 km/s. Suprathermal narrow-line widths point toward an additional heating mechanism in the form of a cosmic-ray precursor, while the intermediate component, previously only qualitatively reported as a small non-Gaussian contribution to the narrow component, reveals a broad-neutral precursor.

Expansion measurements of young type Ia supernova remnants and the physics of nonradiative shocks

Oral Talk

P. Frank Winkler[1], Joseph Putko[1,2], William P. Blair[3], Knox S. Long[4], John C. Raymond[5]

[1]Middlebury College, USA
[2]Universidad de La Laguna, Spain
[3]Johns Hopkins University, USA
[4]Space Telescope Science Institute, USA
[5]Harvard-Smithsonian CfA, USA

Abstract

We will report on optical proper motion measurements of the Tycho (SN1572) and SN1006 remnants, based on CCD images at multiple epochs with total baselines of over twenty years. Optical emission from both Tycho and SN1006 is almost entirely in the Balmer lines of hydrogen, and arises from pre-shock neutral atoms that pass unimpeded through the collisionless shock into the hot post-shock environment. The lifetime for these neutrals is short, so the Balmer radiation occurs only immediately behind the shock, making the Balmer filaments the best measure of the shock position over time. Measurement of proper motions in Tycho is complicated by the fact that some of the brightest filaments do not evolve coherently over time. From images at seven different epochs we have identified filaments that maintain their morphology coherently, and we measure proper motions from 0.19 to 0.26 arcsec/yr, equivalent to an expansion index from 0.35 to 0.52. (The expansion index is the ratio of the current proper motion to the historical average—with 0.4 indicating Sedov expansion) For SN1006, we will report for the first time optical proper motion measurements carried out around much of the shell rim, where the Balmer emission is mostly extremely faint. Expansion rates vary by more than a factor of 2, from 0.27 to 0.6 arcsec/yr, equivalent to expansion index values ranging from 0.34 to well above Sedov. For both Tycho and SN1006, we compare the optical measurements with those in radio and X-ray bands, where emission arises from somewhat farther behind the shock. Past proper expansion measurements for young SNRs have sometimes found quite different values, though usually this has been for measurements carried out in different regions for different bands. We find generally good agreement between measurements in different bands for filaments located at similar positions around the shell rims. Spectra of the Balmer filaments show both narrow and broad components: the former from cold neutrals that are collisionally excited after penetrating the shock, and the latter from hot neutrals that have undergone charge exchange with hot post-shock protons. From spectral profiles it is possible to extract information about the post-shock temperature, shock velocity, electron-proton temperature equilibration, and cosmic-ray acceleration. We will discuss progress we are making in these areas. This work has been supported by the NSF through grant AST-0908566, and by NASA through grants Chandra GO2-13066 and HST GO-13432.003.

Session V.

Collisionless shock waves in SNRs – Posters

A direct measurement of the forward shock speed in supernova remnant "0519−69.0": Constraints on the age, ambient density and electron-ion temperature equilibration

Poster

Luke Hovey[1], John P. Hughes[2], Kristoffer Eriksen[1], Viraj Pandya[3]

[1]Los Alamos National Laboratory, USA
[2]Rutgers University, USA
[3]Princeton University, USA

Abstract

The supernova remnant 0519-69.0 is the second youngest Ia remnant in the Large Magellanic Cloud. The typing of the remnant rests primarily on ejecta abundances inferred from X-ray spectra and the Balmer-dominated nature of its forward shock. Using two narrow-band Hα imaging with the *Hubble Space Telescope* separated by $\sim$1 year we are able to measure the global shock velocity of the remnant to be 2780 km s^{-1}. Using the global shock speed with the measured size of the remnant as constraints we employ one-dimensional hydrodynamic simulations to constrain the age and ambient medium density of the remnant. We also report on the degree of electron-to-ion temperature ratios for select portions of the rim for which we have spectroscopic measurements using the Robert Stobie Spectrograph on the *Southern African Large Telescope*.

Session VI.

Jets and asymmetries in SNe and their remnants – Oral

A kinematic study of Tycho's supernova remnant

Oral Talk

John P. Hughes[1], **Toshiki Sato**[2]

[1]Rutgers University, Dept. of Physics & Astronomy, USA
[2]Tokyo Metropolitan University and Institute of Space and Astronautical Science, Japan

Abstract

Thanks to its confirmed nature as the remnant of a standard Type Ia supernova from spectroscopy of its light echo, Tycho's supernova remnant is a unique object that can provide a new perspective into thermonuclear supernova explosions. More than 400 years after its discovery as a supernova in November 1572, the remnant is now spread out over an 8 arcminute diameter region in a fairly symmetric, but patchy, shell-like morphology. The remnant's thermal X-ray emission is dominated by a strong Si Kα line and also shows line emission from other species such as S, Ar, Ca, and Fe. Existing proper motion and X-ray line width measurements indicate that Tycho's Si-rich ejecta shell is expanding at $\sim$4700 km s^{-1}. We have taken advantage of the huge number of Si line photons in the 750-ks *Chandra* ACIS observation from 2009 to make the first direct velocity measurements of ejecta in Tycho. The patchy nature of the ejecta shell allows for identification of red- and blue-shifted clumps of emission from the receding and approaching hemispheres. We use nonequilibrium ionization thermal models to jointly fit both ACIS-S and ACIS-I observations to determine the radial expansion velocity of individual clumps and associated systematic uncertainty. Red-shifted clumps have speeds of 3500–7800 km s^{-1} and blue-shifted clumps 1600–5000 km s^{-1} with a systematic uncertainty of 500-2000 km s^{-1} determined by intercomparison of the ACIS-S and ACIS-I spectral results. From our *Chandra* radial analysis of surface brightness, centroid energy, and line width, we have confirmed previous line width measurements from *Suzaku*, but are able to utilize finer radial bins that reveal additional structure in the kinematics of Tycho. In particular the Si and S line widths reach a deep minimum at the position of the peak surface brightness near the remnant's edge and where Doppler broadening from the shell expansion is minimum. From the measured line widths and assuming that Doppler and turbulent broadening can be neglected, we estimate ion temperatures of $1.2^{+0.2}_{-0.1}$ MeV and $1.2^{+0.4}_{-0.6}$ MeV for Si and S, respectively. The electron temperature we measure in the Si-rich ejecta is $\sim$1 keV, so the electron-to-ion temperature ratio is $\beta = T_e/T_{\rm ion} \sim 0.001$, broadly consistent with spherically symmetric 1-D hydrodynamical models for Tycho. The research was partially supported by NASA grant NNX15AK71G, funds from Rutgers University, Tokyo Metropolitan University, and the Institute of Space and Astronautical Science, as well as a JSPS Graduate Fellowship.

What do the remnants of superluminous supernovae look like?

Oral Talk

Giorgos Leloudas

Weizmann Institute of Science, Israel

Abstract

The remnants of core-collapse supernovae often present significant asymmetries while those of thermonuclear supernovae are, more or less, spherically symmetric. As superluminous supernovae (SLSN) do not occur in Milky Way-type galaxies (they prefer metal-poor starburst dwarfs), our chances of studying directly a SLSN remnant are very limited, except perhaps in the Magellanic clouds. Therefore, the only way of probing the SLSN geometry, and thus identifying potential SLSN remnant candidates, is through polarimetry of the explosions themselves. I will present the first polarimetric observations of SLSNe obtained through a dedicated ToO program at the VLT. LSQ14mo is a SLSN-I that showed only a very limited degree of polarisation (P = 0.52%), which corresponds to an upper limit of 10% in the photosphere asphericity. In addition, this signal can be entirely due to interstellar polarisation in the host galaxy. This is perhaps surprising as the leading models for H-poor SLSNe involve a magnetar or CSM interaction, i.e. configurations that are not expected to be spherically symmetric. Observations of a SLSN-II yielded a more significant degree of polarisation, while preliminary analysis for a SLSN-R reveals similarly low levels of asphericity as for LSQ14mo.

Investigating the symmetry and progenitors of supernova remnants using X-ray observations

Invited Talk

Laura Lopez

Ohio State University, USA

Abstract

In this talk, I will review recent advances in the understanding of SNe based on studies of SNRs, particularly using *Chandra* and *NuSTAR* X-ray observations. I will highlight investigations of SN asymmetry, based on morphologies and heavy metal (like iron and titanium) kinematics and abundances. I will discuss the role of nature versus nurture in the shaping of SNRs, and I will present several recent investigations demonstrating that both explosion geometry and inhomogeneous environments can produce large-scale asymmetries in the SNRs.

Modeling post-explosion anisotropies of ejecta in SNR Cassiopeia A

Oral Talk

Salvatore Orlando[1], **Marco Miceli**[2], **Maria Letizia Pumo**[1], **Fabrizio Bocchino**[1]

[1]INAF, Osservatorio Astronomico di Palermo, Italy
[2]Dip. di Fisica e Chimica, Universita‘ di Palermo, Italy

Abstract

Supernova remnats (SNRs) show a complex morphology characterized by an inhomogeneous spatial distribution of ejecta, believed to reflect pristine structures and features of the progenitor supernova (SN) explosion. Here we investigate how the morphology of the SNR Cas A reflects the characteristics of the progenitor SN with the aim to derive the energies and masses of the post-explosion anisotropies responsible for the observed spatial distribution of Fe and Si/S. We model the evolution of Cas A from the immediate aftermath of the progenitor SN to the 3D interaction of the remnant with the surrounding medium, taking into account the distribution of element abundances of the ejecta, the back reaction of accelerated cosmic rays at the shock front, and the deviations from equilibrium of ionizazion. We derive the mass of ejecta and energy of explosion appropriate to match the observed average expansion rate and shock velocities. We find that the post-explosion anisotropies (pistons) reproduce the observed distributions of Fe and Si/S if they had a total mass of $\approx 0.25\,M_\odot$ and a total kinetic energy of $\approx 1.5 \times 10^{50}$ erg. The pistons produce a spatial inversion of ejecta layers at the epoch of Cas A, leading to the Si/S-rich ejecta physically interior to the Fe-rich ejecta. The pistons are also responsible for the development of bright rings of Si/S-rich material which form at the intersection between the reverse shock and the material accumulated around the pistons during their propagation.

A Chandra study of G299.2-2.9: the remnant of an asymmetric type Ia explosion?

Oral Talk

Sangwook Park[1], **Seth Post**[1]

[1]University of Texas at Arlington, USA

Abstract

Our deep 640 ks *Chandra* observation of the Galactic Type Ia supernova remnant (SNR) G299.2−2.9 show some peculiar characteristics. The central emission feature of the Si- and Fe-rich ejecta is generally-circular, but its western part is elongated all the way out to the westernmost outer boundary of the SNR. The central ejecta feature shows a higher Fe/Si abundance ratio in the northern half. Surrounding these ejecta features are multiple shells of the swept-up medium. The radial density profile of the bright inner shell suggests the shock interaction with a uniform medium, but the faint outer shell is likely emission from the shock propagating into a stellar wind. We place a conservative upper limit of ∼8 kpc for the distance to this SNR. At this distance we estimate low values for the explosion energy ($E_0 \sim 5 \times 10^{50}$ erg) and the Fe ejecta mass ($\sim 0.2\ M_\odot$).

The role of jets in exploding SNe and shaping their remnants

Invited Talk

Noam Soker

Technion, Israel

Abstract

I will present observational support for the role of jets in shaping SNRs. In the case of SNR of SN Ia, the jets are likely to be launched during the pre-SN evolution, such as during the formation of the planetary nebula into which the explosion might take place. In core collapse SNe the jets can be launched a long time before the explosion, such as in SN 1987A, or during the explosion itself, as might be the case in Cassiopeia A. I will connect the role of jets to other astrophysical objects where jets play a leading role in shaping.

3D long-time CCSN simulations: from shock revival to shock break-out

Oral Talk

Annop Wongwathanarat[1], Ewald Mueller[2], Thomas Janka[2]

[1]RIKEN, Japan
[2]MPIA, Germany

Abstract

I will report about recent progress on simulating long-time evolution of neutrino-driven core-collapse supernovae in three dimensions. These simulations cover the shock revival phase and the propagation of the SN shockwave through the envelope of the exploding star. The results demonstrate that large-scale asymmetries in the metal-rich ejecta after the shock break-out still carry information of the early-time asymmetries created during the explosion phase, despite being modified by fragmentation due to Rayleigh-Taylor instabilities. Our results also show that the stellar structure, which determine the growth rate of Rayleigh-Taylor instabilities at composition interfaces and thus the efficiency of outward mixing of metals and inward mixing of hydrogen after the passage of SN shock, play an important role in shaping the morphology of the ejecta at late times. Therefore, studies of global asymmetries of the ejecta and mixing might offer some insights on the structure of the progenitor star.

Session VI.

Jets and asymmetries in SNe and their remnants – Posters

The first few months of a supernova remnant

Poster

Michael Gabler[1], H.-T. Janka[1] and A. Wongwathanarat[2]

[1]MPIA, Germany
[2]RIKEN, Japan

Abstract

We perform long-term, hydrodynamical simulations of supernova remnants in 3 dimensions. Continuing the simulations of A.Wongwathanarat "3D long-time CCSN simulations: from shock revival to shock break-out" we follow the evolution of the shock and the ejecta during the first few months after the explosion. The explosion is simulated with a ray-by-ray gray neutrino transport approximation and the so called Yin-Yang grid (an axis-free spherical polar coordinates grid). For the late phases we investigate here, the neutrino transport is no longer needed. We study the rising bubbles of the ejecta and follow how their morphology changes due to acceleration at the stellar surface. We further include the energy input caused by the decay of nickel and can identify the first traces of the influence of this radioactive heating. The bubbles, which otherwise would expand homologously, start to inflate due to the additional energy source of the nickel decay.

Session VII.

SNRs as probes and drivers of galaxy structure – Oral Talks

X-ray, optical, and radio properties of the extensive SNR population in M83

Oral Talk

William Blair[1], Knox S. Long[2], Frank Winkler[3], Roberto Soria[4], Kip D. Kuntz[1], Paul P. Plucinsky[5], Michael A. Dopita[6]

[1]Johns Hopkins University, USA
[2]Space Telescope Science Institute, USA
[3]Middlebury College, USA
[4]International Centre for Radio Astronomy Research, Curtin University, Australia
[5]Harvard-Smithsonian Center for Astrophysics, USA
[6]Research School of Astronomy & Astrophysics, ANU - Australia

Abstract

The nearly face-on spiral galaxy M83 (d=4.6 Mpc) provides a significant opportunity for finding and studying a large and diverse sample of SNRs all at the same distance, given its active star formation, a starburst nuclear region, and at least six SNe since 1923. As the result of a concerted effort involving ground and spaced-based studies at radio (ATCA), optical and NIR (Magellan 6.5m and HST), and X-ray (Chandra) wavelengths, we have identified almost 300 SNRs in M83. Of these, at least 87 and 47 were detected in the X-ray and radio bands. Some 227 of the SNR candidates are within the regions observed in [Fe II] 1.64 microns with HST WFC3/IR, and we detect $\sim$100 of them, including $\sim$8 in dusty regions where the [Fe II] emission was the primary means of identification. Follow-up ground-based spectroscopy of 99 of the 300 SNRs with Gemini-S and the GMOS instrument shows that essentially all of the SNRs identified in ground-based imaging have the [S II]:Hα ratios expected of bona fide SNRs, and that most of the SNRs in the sample are normal ISM-dominated SNRs, in the sense that the line widths are narrow and the spectra look like radiative shocks. We have studied a number of interesting individual SNRs and historical SNe counterparts, as well as investigating the ensemble population of nearly 300 SNRs to better understand their properties as a group, their evolution, and their impact on their host galaxy. Of particular interest is a set of the smallest diameter (and hence presumably youngest) objects measured with HST, where the 0.04$''$ WFC3-UVIS pixels correspond to $\sim$1 pc. One SNR has very broad emission lines and given its small size, was most likely a SN that occurred during the last century but was missed. A number of the other objects are comparable to the Crab Nebula or Cas A in size, but very few show the high velocities and spectral signatures of ejecta. Rather, their spectra show low velocities and normal ISM-dominated emissions, albeit often with high densities. We attribute this surprising result to the high pressure ISM in M83 (implied by strong soft but diffuse X-ray emission seen with Chandra) in addition to the generally high chemical abundances in M83. We are also assessing the stellar populations and star formation histories near many of the young SNRs to constrain the local main sequence turnoff masses and thus the precursor star masses for the SNe that created the remnants we see. WPB acknowledges support from NASA grants HST GO-12513-01-A and HST-GO-13361.001-A, both to Johns Hopkins University.

Radio emision from supernova remnants

Invited Talk

Gloria Dubner

Institute for Astronomy and Space Physics, Argentina

Abstract

The vast majority of supernova remnants (SNRs) in our Galaxy and nearby galaxies have been discovered through radio observations, and only a very small number of the SNRs catalogued in the Milky Way have not been detected in the radio band, or are poorly defined by current radio observations. The study of the radio emission from SNRs is an excellent tool to investigate morphological characteristics, marking the location of shock fronts and contact discontinuities; the presence, orientation and intensity of the magnetic field; the energy spectrum of the emitting particles; and the dynamical consequences of the interaction with the circumstellar and interstellar medium. I will review the present knowledge of different important aspects of radio remnants and their impact on the interstellar gas. Also, new radio studies of the Crab Nebula carried out with the Karl Jansky Very Large Array (JVLA) at 3 GHz and with ALMA at 100 GHz, will be presented.

Broadband emission models for young to middle-aged supernova remnants and what to learn from them

Invited Talk

Shiu-Hang (Herman) Lee

ISAS/JAXA, Japan

Abstract

Confronted by the good quantity and quality of observational data across the electromagnetic spectrum as well as our gradually improving knowledge on the physics of collisionless shocks, any reasonable model of SNR emission nowadays has to satisfy a more and more stringent set of observational and physical constraints.

In this talk, I will review the current status of broadband emission models for young to middle-aged SNRs, including their applications on understanding SNR interactions with the surrounding interstellar environments. If time allows, I will sum up in a few words the future prospects brought about by the synergy of upcoming missions with sophisticated theoretical and numerical models.

X-raying supernova remnants in the Magellanic Clouds

Oral Talk

Pierre Maggi[1], R. Hirschi[1], F. Haberl[2], G. Vasilopoulos[2], W. Pietsch[2], J. Greiner[2], P. J. Kavanagh[3], M. Sasaki[3], L. M. Bozzetto[4], M. D. Filipović[4], S. D. Points[5], Y.-H. Chu[6], J. Dickel[7], M. Ehle[8], R. Williams[9]

[1]CEA Saclay, France
[2]MPE Garching, Germany
[3]IAAT Tuebingen, Germany
[4]University of Western Sydney, Australia
[5]Cerro Tololo Inter-American Observatory, Chile
[6]Institute of Astronomy and Astrophysics, Academia Sinica, Taiwan
[7]University of New Mexico, USA
[8]XMM-Newton SOC, ESAC, Spain
[9]Columbus State University Coca-Cola Space Science Center, USA

Abstract

The Magellanic Clouds (MCs) offer an ideal laboratory for the study of the SNR population in star-forming galaxies, since they are relatively nearby and free of large absorption. Both the LMC and SMC have been targeted by large XMM-Newton surveys, which, combined with archival observations, provide the best dataset to systematically study the X-ray emission of their numerous SNRs (~ 60 in the LMC, ~ 20 in the SMC). In this talk, I will highlight the results from this homogeneous analysis, which allows for the first time meaningful comparisons of temperature, chemical composition, and luminosity of SNRs in the MCs. The SNRs can be used as probes of their host galaxies: We measured chemical abundances in the hot phase of the LMC, and constrained the ratio of core-collapse to type Ia SN rates. The X-ray luminosity function of SNRs in the MCs are compared to those in other Local Group galaxies with different metallicities and star formation properties. Finally, we present a new population of evolved type Ia SNRs that was discovered recently in the MCs via their iron-rich X-ray emission.

Statistical modelling of supernova remnant populations in the Local Group

Oral Talk

Sumit Sarbadhicary[1], Carles Badenes[1], Laura Chomiuk[2], Damiano Caprioli[3], Daniel Huizenga[2]

[1]Univerity of Pittsburgh, USA
[2]Michigan State University, USA
[3]Princeton University, USA

Abstract

Supernova remnants (SNRs) in the Local Group offer unique insights into the origin of different types of supernovae. However, the intrinsic diversity and environment-driven evolution of SNRs require the use of statistical methods to model SNR populations in the context of their host galaxy. We introduce a semi-analytic model for SNR radio light curves that uses the physics of shock propagation through the ISM, the resultant particle acceleration and the range of kinetic energies observed in supernovae. We use this model to reproduce the fundamental properties of observed SNR populations, taking into account the detection limits of radio surveys and the wealth of observational constraints on the stellar distribution and ISM structure of the host galaxy from radio, optical, and IR images. We can reproduce the observed radio luminosity function of SNRs in M33 with a SN rate of $(3.5 - 4.3) \times 10^{-3}$ SN per year and an electron acceleration efficiency, $\epsilon_{\rm e} \sim 0.01$.This is the first measurement of $\epsilon_{\rm e}$ using a large sample of SNRs. We show that dim Galactic SNRs like SN1006 would have been missed by archival radio surveys at the distance of M33, and we predict that most SNRs in M33 have radio visibility times of 20-80 kyrs that are correlated with the measured ISM column densities N_H: $t_{\rm vis} \propto N_H^{\alpha}$ with $\alpha = -0.36 \pm 0.01$, whereas a small fraction of SNRs have visibility times 10 kyrs that appear uncorrelated with column density. This observationally-anchored approach to the visibility time of SNRs will allow us to use SNR catalogs as SN surveys; to calculate SN rates and delay time distributions in the Local Group.

Bilateral symmetry in supernova remnants and the connection to the Galactic magnetic field

Oral Talk

Jennifer West[1], Samar Safi-Harb[1], Tess Jaffe[2], Gilles Ferrand[1], Roland Kothes[3], Tom Landecker[4], Tyler Foster[5]

[1]University of Manitoba, Canada
[2]IRAP, France
[3]Dominion Radio Astrophysical Observatory, Canada
[4]NRC-Herzberg, Canada
[5]Brandon University, Canada

Abstract

We will present models of the radio synchrotron emission from Galactic Supernova Remnants (SNRs) that use current models of Galactic magnetic field to simulate SNR emission as a function of their position in the Galaxy. This work reveals a connection between SNRs and their environment and a relationship between the angle of the symmetry axis of bilateral SNRs and the Galactic magnetic field. Results from studying the impact of the so-called quasi-parallel and quasi-perpendicular cosmic ray electron acceleration scenarios will also be presented. This relationship has implications for understanding the magnetic field geometry and cosmic ray electron distribution in SNRs, and possibly even a new method for determining distances to features of the Galactic magnetic field as well as distances to some SNRs.

Session VII.

SNRs as probes and drivers of galaxy structure – Posters

SNRs in the late stages of evolution

Poster

Abdul Asvarov

Institute of Physics, Azerbaijan

Abstract

The study of evolved supernova remnants (SNRs) is important in many respects. Their properties are determined mainly by the energy of supernova explosion and by the conditions in the interstellar medium (ISM) where the evolution takes place. On the other hand SNRs themselves can determine the structure and energetics of ISM. Therefore, the study of these objects can significantly enhance our understanding of ISM. In contrast to many young SNRs, the evolved and old ones are weak sources of radio and X-ray emission which complicates the study of these objects. However, old SNRs mainly manifest themselves through optical line emission. Although it is difficult to use the optical data to obtain numerical estimates for the global physical paraticameters of SNR, with the help of statistical methods a very rich available statistics in optical wavelengths can be used for understanding the nature of these objects and their role in shaping of the interstellar medium. In this presentation we model the statistics of supernova remnants by considering the various possible paths of their evolution and then compare the results of modeling with the observational statistical data. In the modelling of SNR evolution we have considered the effect of the pressure in the ISM, the effect of particle acceleration at the shock wave in the earlier stages of evolution, etc.

A radio selected supernova remnant catalog in the Magellanic Clouds

Poster

Daniel Huizenga[1], Laura Chomiuk[1], Carles Badenes[2], Sumit Sarbadhicary[2]

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Abstract

Statistical studies of supernova remnants (SNRs) require an SNR population with a set of well understood selection criteria. Current catalogs of SNRs in the Magellanic Clouds (MCs) have been compiled from detections at various wavelengths (radio, optical, and X-ray) and therefore are not complete in any statistical sense. Here we present a catalog of SNRs in the MCs with a quantitative radio selection criteria. We will highlight previously undocumented SNRs and any significant non-detections of previously known remnants.

Supernova Remnant Explorer

Poster

Denis Leahy

University of Calgary, Canada

Abstract

A software tool has been created which includes all stages of evolution of a spherical supernova remnant, from ejecta-dominated stage to dissipation and merging with the interstellar medium. The principles of operation of the software, and the application of this tool to observations of supernova remnants is demonstrated.

HI absorption spectra for supernova remnants in the VGPS survey

Poster

Denis Leahy, Sujith Ranasinghe

University of Calgary, Canada

Abstract

The set of supernova remnants (SNR) from Green's SNR catalog which are found in the VLA Galactic Plane Survey are studied here. For this set of 34 SNR, we extract and analyze HI absorption spectra in a uniform way and construct a catalog of absorption spectra and distance determinations. The results of this work will be summarized.

SNR-shock impact on star formation

Poster

Manami Sasaki, Baha Dincel

Institut für Astronomie und Astrophysik, Tuebingen, Germany

Abstract

While stars form out of cores of molecular clouds due to gravitational collapse of the clouds, external pressure caused by shock waves of stellar winds or supernovae are believed to be responsible for triggering star formation. However, since massive stars evolve fast and their supernova remnants (SNRs) can only be observed up to an age of around 10^5 years, SNRs found near star-forming regions have most likely resulted from the same generation of stars as the young stellar objects (YSOs). Shock waves of these SNRs might show interaction with the existing YSOs and change their nature. We study YSO candidates in Galactic SNRs CTB 109, IC 443 and HB21, which are known to show interaction with molecular clouds and have associated infrared emission. By photometric and spectroscopic studies of YSOs in the optical and the near-infrared, we aim to find clear observational evidences for an interaction of SNR-shocks with YSOs.

An empirical study on distances and evolution of supernova remnants: insights from ΣD data distribution

Poster

Branislav Vukotić

Astronomical Observatory, Belgrade, Serbia

Abstract

For the selected sample of calibrators, with radio surface brightness (Σ) and linear diameter (D) data, we reconstruct the probability density function of the data in the ΣD plane, called ΣD pdf map. The ΣD pdf map is calculated with bootstrap approach by resampling the calibrating sample data. Unlike standard linear fit based calibrations our method gives more robust results. A probability density distribution for D is obtained for each particular Σ value. This also gives a probability distribution of the corresponding statistical distance. We calculate distances for extragalactic and Galactic SNR calibrating samples and compare the results with standard, fit based approaches. In addition, utilizing the ΣD pdf map we quantify the data grouping in the ΣD plane which can be very useful tool for the studies on ΣD evolution of supernova remnants.

Session VIII.

SNe and SNRs cosmic ray acceleration – Oral Talks

G346.6-0.2: Non-thermal X-ray emission from a Mixed-Morphology Supernova Remnant

Oral Talk

Katie Auchettl[1], B.T.T. Wong[2], C.-Y. Ng[2], P. Slane[3]

[1]Ohio State University/CCAPP, USA
[2]The University of Hong Kong, Hong Kong
[3]Harvard-Smithsonian Center for Astrophysics, USA

Abstract

The detection of non-thermal X-ray emission from supernova remnants (SNRs) provides us with a unique window into studying particle acceleration at the shock-front. All of the 14 or so SNRs in which non-thermal X-ray synchrotron emission has been detected are shell-like in nature, and show no direct evidence of interaction with large nearby molecular clouds. Here we present a new X-ray study of the molecular cloud interacting mixed-morphology (MM) SNR G346.6-0.2 using XMM-Newton. We found that the X-ray emission arises from a cool recombining plasma with sub-solar abundances, confirming previous Suzaku results. In addition, we identified an additional power-law component in the spectrum, with a photon index of ~ 2. We investigated its possible origin and conclude that it most likely arises from synchrotron emission produced by particles accelerated at the shock. This makes G346.6-0.2 an important new object in the class of synchrotron emitting SNRs, as unlike shell type X-ray synchrotron SNRs, MM SNRs are usually thought to have shock velocities that are effectively too slow to accelerate electrons. The dense environment and nature of the remnant, provide conditions unseen in shell type X-ray synchrotron SNRs, providing a unique opportunity to study the effect that these properties have on the production of X-ray synchrotron emission.

The middle aged SNRs W44: most likely reacceleration without any break

Oral Talk

Martina Cardillo[1], Elena Amato[1], Pasquale Blasi

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Abstract

Supernova remnants (SNRs) are thought to be the primary sources of Cosmic Rays (CRs) in the Galaxy. In the last few years, the wealth of γ-ray data from GeV and TeV instruments has provided important information about the high energy particles' content of these objects, allowing us to make progress in assessing their role as CR accelerators. In particular, the spectrum of the γ-ray emission below E=200 MeV, detected by AGILE and Fermi-LAT in the two middle aged Supernova Remnants (SNRs) W44 and IC443, has been taken as a proof of CR acceleration in these sources. In fact, the only firm conclusion that one can derive from the low energy spectrum of these sources is that CRs are present in the environment of these remnants. Assessing whether the emitting particles are freshly accelerated or rather reaccelerated from the galactic pool is not as straightforward. Making this discrimination in the case of SNR W44 is the purpose of this work. Using the latest Voyager 1 data to estimate the galactic electrons', protons' and Helium distributions, we compute the radio and γ-ray emission from pre-existing CRs after reacceleration and compression at the SNR blast wave. We show that this component can explain alone the radio and γ-ray data and that the source spectrum can be very well reproduced by the galactic CR distribution derived from Voyager 1, without any additional spectral feature, except for a high energy cut-off related to the finite time for particle reacceleration. Our study provides an upper limit on the efficiency of W44 as a source of fresh CRs. This upper limit turns out to be very low, as one would expect for a middle aged source with a slow blast wave.

Gamma-rays and Neutrinos from Efficient Cosmic-Ray Acceleration in Young SNe

Oral Talk

Vikram Dwarkadas[1], Matthieu Renaud[2], Alexandre Marcowith[2], Vincent Tatischeff[3]

[1]University of Chicago, USA
[2]LUPM Universite Montpellier, France
[3]University of Paris-Sud, France

Abstract

It is widely accepted that supernova (SN) shocks can accelerate particles to very high energies, although the maximum energies are still unclear. These accelerated particles can interact with other particles to produce gamma-ray emission. Details of the process are not well characterized, including the dynamics and kinematics of the SN shock wave, the nature and magnitude of the magnetic field, and the details of the particle acceleration process. The properties of the SN shock itself are regulated by the surrounding medium, which in a massive star is formed by mass-loss from the pre-SN progenitor during its lifetime. Thus the spectra of accelerated particles, and the resultant gamma-ray emission, depend on the evolution of the SN progenitor before it explodes.

Herein we explore detailed aspects of SN evolution, particle acceleration, and the non-thermal emission, for young SNe right after outburst. We use these calculations to predict and constrain the detectability of young SNe of various types, via their hadronic signatures, namely gamma-ray emission from pp interactions, and synchrotron emission from secondary leptons. Our calculations also allow us to constrain the resulting TeV neutrino flux. After outlining the general considerations, we will provide a quantitative example in the form of the well-studied radio SN 1993J, for which we will calculate the gamma-ray and neutrino flux. We will also comment on the horizon of detectability of 1993J-like SNe with the upcoming Cherenkov Telescope Array (CTA).

3D simulations of young core-collapse supernova remnants undergoing efficient particle acceleration

Oral Talk

Gilles Ferrand & Samar Safi-Harb

University of Manitoba, Canada

Abstract

Within our Galaxy, supernova remnants are believed to be the major sources of cosmic rays up to the 'knee'. However important questions remain regarding the share of the hadronic and leptonic components, and the fraction of the supernova energy channelled into these components. We address such question by the means of numerical simulations that combine a hydrodynamic treatment of the shock wave with a kinetic treatment of particle acceleration. Performing 3D simulations allows us to produce synthetic projected maps and spectra of the thermal and non-thermal emission, that can be compared with multi-wavelength observations (in radio, X-rays, and γ-rays). Supernovae come in different types, and although their energy budget is of the same order, their remnants have different properties, and so may contribute in different ways to the pool of Galactic cosmic-rays. Our first simulations were focused on thermonuclear supernovae, like Tycho's SNR, that usually occur in a mostly undisturbed medium. Here we present our 3D simulations of core-collapse supernovae, like the Cas A SNR, that occur in a more complex medium bearing the imprint of the wind of the progenitor star.

Iron K shell line, a probe of low energy cosmic rays in SNRs

Oral Talk

Katsuji Koyama[1] & Tamotsu Sato[2]

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Abstract

Since the discovery of non thermal power-law X-rays at the rim of SN1006 by Koyama et al. (1995), this feature has been established to be evidence of high energy cosmic rays (HECRs). The HECRs are created by a diffuse shock acceleration process. Accordingly low energy cosmic rays (LECRS) must be presented as the injector of this acceleration process. We found for the first time that the K-shell line from neutral iron at 6.4 keV is good tracer of LECRs in SNRs. This paper present the observational facts for LECRs from intermediate aged SNRs, 3C391, Kes79, Kes 78 and W44 in the Scutum Arm region (see figure, Sato et al. 2014, 2015). Two SNRs, 3C391 and W44, exhibit recombining plasma (RP), an unusual structure in the frame work of the standard SNR evolution scenario. Together with the RP, we discuss the origin of LECRs in the SNRs

Acceleration of cosmic rays at supernova remnant shocks: constraints from gamma-ray observations

Invited Talk

Marianne Lemoine-Goumard

CNRS-IN2P3, Université de Bordeaux, France

Abstract

Supernova remnants (SNRs) are thought to be the primary sources of the bulk of Galactic cosmic-ray (CR) protons observed at Earth, up to the knee energy at $\sim$3 PeV. Our understanding of CR acceleration in SNRs mainly relies on the Diffusive Shock Acceleration theory which is commonly invoked to explain several observational (though, indirect) lines of evidence for efficient particle acceleration at the SNR forward shocks up to very high energies. In particular, recent observations of young SNRs in the high-energy (HE; $0.1 < E < 100$ GeV) gamma-ray domains have raised several questions and triggered numerous theoretical investigations. However, these detections still do not constitute a conclusive proof that supernova remnants accelerate the bulk of Galactic cosmic-rays, mainly due to the difficulty of disentangling the hadronic and leptonic contributions to the observed gamma-ray emission. In my presentation, I will review the most relevant results of gamma ray astronomy on supernova remnants (shell-type and middle-age interacting with molecular clouds) and the constraints derived concerning their efficiency to accelerate cosmic-rays.

Modeling the shock-cloud interaction in SN 1006: particle acceleration and non-thermal emission

Oral Talk

Marco Miceli[1], S. Orlando[2], F. Acero[3], S. Katsuda[4], A. Decourchelle[5], V. Pereira[6], G. Dubner[7]

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[5]Service d'Astrophysique, CEA Saclay, France
[6]Universidad Complutense de Madrid, Spain
[7]IAFE, Argentina

Abstract

The supernova remnant SN 1006 is a source of high-energy particles and its southwestern non-thermal limb is interacting with a dense ambient cloud, thus being a promising region for gamma-ray hadronic emission. We performed 3-D magnetohydrodynamic simulations modeling the evolution of SN 1006 and its interaction with the ambient cloud. We synthesized from the model the synchrotron X-ray emission, that we compared against actual XMM-Newton and Chandra observations to derive the physical parameters of the cloud. Our model allowed us to explain the observed morphology, the azimuthal variations of the cutoff frequency, and the azimuthal modulation of the shock proper motion. We also synthesized the leptonic and hadronic gamma-ray emission and compared our results with HESS and Fermi-LAT data. The comparison between model and observations allowed us constrain the spectrum of the hadrons accelerated at the shock front. In particular, we found that the upper limit for the total hadronic energy in the southwestern limb of SN 1006 is about 2.5×10^{49} erg.

Particle acceleration in collisionless shocks: insights from kinetic simulations

Invited Talk

Anatoly Spitkovsky

Princeton University, USA

Abstract

I will describe recent progress in understanding the physics of collisionless shocks using ab-initio kinetic simulations. Particularly, I will concentrate on shock acceleration efficiency for electrons, protons and ions, and on new insights into the shock injection physics and magnetic field amplification mechanisms.

Studies of young and hard-spectrum supernova remnants with VERITAS

Oral Talk

Amanda Weinstein (for the VERITAS collaboration)

Iowa State University, USA

Abstract

The gamma-ray emission arising from charged particle interactions with ambient photons and interstellar material provides an essential probe of the nature and mechanism of charged particle (cosmic ray) acceleration taking place within supernova remnants (SNRs). The VERITAS observatory (sensitive to gamma rays with E > 85 GeV) has undertaken observations of a number of different supernova remnants. These studies have the twin goals of constraining particle acceleration models via measurements of the broadband energy spectrum and of mapping particle diffusion within SNRs. Of particular interest are SNRs that are expected to contain a more energetic particle population, either due to their youth or the fact that they evince an unusually hard spectrum. We discuss VERITAS observations of several young and/or hard-spectrum supernova remnants, including updated results from deep VERITAS observations of two young, gamma-ray bright SNRs, Tycho's SNR and Cassiopeia A (Cas A).

Stochastic acceleration and magnetic damping in Tycho's SNR

Oral Talk

Alina Wilhelm[1], Igor Telezhinsky[2], Vikram Dwarkadas[3], Martin Pohl[2,1]

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[2]Institute of Physics and Astronomy, University of Potsdam, Karl-Liebknecht-Strasse 24/25, 14476 Potsdam, Germany
[3]University of Chicago, USA

Abstract

Tycho's Supernova remnant (SNR) is also known as historical Supernova SN 1572 of Type Ia. Having exploded in a relatively clean environment and with a known age, it represents an ideal astrophysical testbed for the study of cosmic-ray acceleration and related phenomena. A number of studies suggest that shock acceleration with very efficient magnetic-field amplification is needed to explain the rather soft radio spectrum and the narrow rims observed in X-rays. We show that the wideband spectrum of Tycho's SNR can be alternatively well explained when accounting for stochastic acceleration as a secondary process. The re-acceleration of particles in the turbulent region immediately downstream of the shock provided by the fast-mode waves is efficient enough to impact particle spectra over several decades in energy. Our self-consistent model contains hydrodynamic simulations of the SNR plasma flow. The particle spectra are obtained from the time-dependent transport equation and the background magnetic field is computed either from the induction equation or it follows analytic profiles depending on the considered model. Although not as efficient as standard diffusive shock acceleration, stochastic acceleration leaves its imprint on the particle spectra. This is especially notable in the emission at radio wavelengths and soft γ-rays. Excessively strong magnetic fields and the so-called Alfvénic drift are not required in this scenario. The narrow X-ray and radio rims arise from damping of the turbulent magnetic field. We find a lower limit for the downstream magnetic field strength, $B_d = 173\,\mu$G and investigate the energy-dependence of the X-ray filament width. We conclude that stochastic re-acceleration is an important mechanism for modifying particle and emission spectra in SNR and that the magnetic-field damping should be taken into account to properly explain the synchrotron intensity profiles of Tycho.

Session VIII.

SNe and SNRs cosmic ray acceleration – Posters

Transport of magnetic turbulence in supernova remnants

Poster

Robert Brose[1], **I. Telezhinsky**[2], **M. Pohl**[2,1]

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[2]Institute of Physics and Astronomy, University of Potsdam, Karl-Liebknecht-Strasse 24/25, 14476 Potsdam, Germany

Abstract

Supernova remnants are known as sources of galactic cosmic rays for their non-thermal emission of radio waves, X-rays, and gamma-rays. However, the observed CR spectra are hard to reproduce within the standard acceleration theories based on the assumption of Bohm diffusion and steady-state calculations. We point out that a time-dependent treatment of the acceleration process together with a self-consistent treatment of the scattering turbulence is necessary. Therefore we numerically solve the coupled system of transport equations for cosmic rays and isotropic Alfvénic turbulence. The equations are coupled through the growth rate of the turbulence determined by the cosmic-ray gradient and the spatial diffusion coefficient of cosmic rays given by the spectral energy density of the turbulence. The system is solved on a co-moving expanding grid extending upstream for dozens of shock radii, allowing for self-consistent study of cosmic-ray diffusion in the vicinity of their acceleration site. The transport equation for cosmic rays is solved in a test-particle approach based on pre-calculated hydro models. We demonstrate that the system is typically not in a steady state. In fact, even after several thousand years of evolution, no equilibrium situation is reached. The resulting time-dependent particle spectra strongly differ from those derived assuming a steady state and Bohm diffusion. The turbulence spectra show that bohmlike diffusion is achieved only in a small energy band. Our results indicate that proper account for the evolution of scattering turbulence is crucial for the formation of the observed soft spectra.

The interstellar medium towards three Supernova Remnants

Poster

Elsa Giacani, Alberto Petriella

Institute of Astronomy and Space Physics, Buenos Aires, Argentina

Abstract

In the last years, with the increasing number of discovered γ-ray sources, important efforts have been dedicated to establish the origin of this high-energy emission using observations in other spectral bands. Supernova remnants (SNRs) have been proposed as possible generators of γ-rays in our Galaxy, among other astrophysical sources. SNR's shocks are expected to be sites of cosmic ray acceleration and clouds of dense material can provide an effective target for proton-proton collisions and subsequent production of γ-rays. We present a preliminary study of the molecular and atomic material towards G40.5$-$0.5 and G45.7$-$0.4 (two SNRs located in the vicinity of high-energy sources) and the TeV SNR candidate G44.5$-$0.2, to establish the origin of the γ-ray emission. In addition, the study of the interstellar medium also provides important clues on how SNRs interact with and modify their local environment.

Electron energization through spontaneous turbulent magnetic reconnection at nonrelativistic perpendicular shocks

Poster

Jacek Niemiec[1], Artem Bohdan[1], Oleh Kobzar[1], Martin Pohl[2,3]

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Abstract

Results of recent kinetic two-dimensional particle-in-cell studies of high Mach-number nonrelativistic perpendicular shocks with applications to young supernova remnants are reported. These new large-scale simulations sample a representative portion of the shock surface to fully account for time-dependent effects. They are performed for different orientations of the average large-scale magnetic field with respect to the 2D simulation plane to allow an insight into the 3D physics. We discuss the nonlinear shock structure and particle energization processes with emphasis on the dynamics on electron heating and pre-acceleration needed for their injection into diffusive shock acceleration. To this end we investigate the microphysics of electron acceleration during spontaneous turbulent magnetic reconnection at the shock ramp and compare the efficiency of these processes to electron energization resulting from their interactions with electrostatic Buneman modes in the shock foot. The influence of the global shock front nonstationarity effects such as the shock rippling and self-reformation is also discussed.

Radio evolution of supernova remnants including non-linear particle acceleration

Poster

Marko Pavlović

University of Belgrade, Serbia

Abstract

Supernova remnants (SNRs) are believed to accelerate particles up to high energies, at least reaching a few PeV, through the mechanism of diffusive shock acceleration (DSA). Detection of synchrotron radio emission from cosmic ray (CR) electrons supports this picture. We use two-dimensional hydrodynamic simulations of SNRs, evolving through a homogeneous ambient medium, coupled with particle acceleration and magnetic field amplification at non-relativistic shocks to derive the total radio emission. We assume that dynamical reaction of the accelerated particles on the plasmas involved in the shock formation may not be negligible as previously assumed in test particle methods and the CR spectrum is affected in a substantial way. We coupled a simple Blasi's semi-analytical model that deals with these non-linear effects in a quantitative way and changes hydrodynamics by means of an effective adiabatic index. Bell's cosmic-ray non-resonant streaming instability is considered to be responsible for the amplification of precursor magnetic field. We obtained the radio synchrotron surface brightness increasing with time in the free expansion phase, achieving its peak value at the beginning of the Sedov phase, and then decreasing during later phases. The dependence of the radio surface brightness on the diameter (time), has been calculated for different values of the interstellar medium density, supernova explosion energy, injection efficiency and different initial ejecta clumping, covering the region of the existing experimental points. Obtained evolutionary tracks will be of the utmost importance for the future observations carried out from a powerful radio telescopes like ALMA and SKA. This method can provide distances to SNRs but also important information and constraints on the evolutionary stage of SNRs, their CR production efficiency as well as the parameters of the surrounding medium.

Importance of Richtmyer-Meshkov Instability on Measurements of Cosmic-Ray Acceleration Efficiency at Supernova Remnants

Poster

Jiro Shimoda[1], Tsuyoshi Inoue,[2], Yutaka Ohira[1], Ryo Yamazaki[1], Aya Bamba[1], Jacco Vink[3]

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[2]National Astronomical Observatory of Japan, Japan
[3]Astronomical Institute Anton Pannekoek/Gravitation and AstroParticle Physics Amsterdam (GRAPA), University of Amsterdam, Netherlands

Abstract

Using three-dimensional (3D) magnetohydrodynamics (MHD) simulations, we show that the efficiency of cosmic-ray (CR) acceleration in supernova remnants (SNRs) is over-predicted if it could be estimated based on proper motion measurements of Hα filaments in combination with shock-jump conditions. The CR acceleration efficiency at the SNR has been widely discussed, which seems to be ubiquitously so high that back reaction of CRs onto background shock structure is significant, with assuming that SNRs shock is plane parallel. The role of the Richtmyer-Meshkov Instability (RMI) has recently been studied using MHD simulations that have shown that the forward shock of SNRs is rippled due to the interaction with interstellar medium, which has Kolmogorov-like density power spectrum. The kinetic energy of the shock wave is transferred into that of downstream turbulence as well as thermal energy that is related to the shock velocity component normal to the shock surface. Our synthetic observation shows that the CR acceleration efficiency is overestimated by 10-40% despite of no CR acceleration. Furthermore, our simple analytical argument gives upper and lower bounds of apparent CR production efficiency, which is roughly consistent with our numerical results.

First GMRT radio observations of the SNR candidate G29.37+0.10

Poster

Leonardo Supan, Gabriela Castelletti, Alberto Petriella, Elsa Giacani

Institute of Astronomy and Space Physics, Buenos Aires, Argentina

Abstract

G29.37+0.10 is a radio system comprising a point-like source and extended non-thermal emission, which has been proposed to be a new supernova remnant. The TeV source HESS J1843−033, whose origin is still uncertain, appears located in projection in coincidence with G29.37+0.10. We present a radio image of G29.37+0.10 with unprecedented resolution for this source, based on new observations at 610 MHz carried out with the Giant Metrewave Radio Telescope. A study combining these radio data with a spectral and morphological analysis of the X-ray emission and the interstellar medium was carried out to investigate whether G29.37+0.10 is a remnant of a stellar explosion and its possible connection with HESS J1843−033.

Session IX.

SN ejecta – abundances, clumpiness – Oral Talks

The Riddle of Steel: Fe-peak Elements in Type Ia Supernova Remnants

Invited Talk

Carles Badenes

University of Pittsburgh, USA

Abstract

Recent results in have added to the controversy about the nature of the binary companion of the exploding white dwarf in Type Ia Supernovae, which must be either another white dwarf (double degenerate systems, DD) or a non-degenerate star (single degenerate systems, SD). On the one hand, there are no clear signs of dynamical interaction between SN ejecta and circumstellar material, which seems to favor DD systems. On the other hand, there is mounting evidence that at least some exploding SN Ia have ejecta masses very close to the Chandrasekhar limit, which is more naturally explained by the SD scenario. I will describe recent X-ray observations of Type Ia Supernova Remnants that can shed light on the properties of SN Ia progenitors and the SD vs. DD debate.

The dust masses in the remnants of Cas A, SN1993J and SN 1980K

Oral Talk

Mike Barlow & Antonia Bevan

University College London, UK

Abstract

Using a recently developed 3D Monte Carlo dust line-scattering and absorption code, Bevan & Barlow (2016, MNRAS) have modeled the red-blue line asymmetries in the late-time Hα and [O I] spectra of SN 1987A caued by the preferential absorption by internal dust particles of redshifted photons from the far side of the ejecta. They found dust masses that grew from $\leq 10^{-3}$ M$_\odot$ on day 714 to ≥ 0.10 M$_\odot$ by day 3604, a trend that agrees with the day $615 - 9200$ SED modeling results of Wesson et al. (2015) for SN 1987A, for which Herschel and ALMA observations indicate a dust mass of $\sim$0.7 M$_\odot$ by day 9200. Similar red-blue emission line asymmetries are often observed in the late-time optical spectra of other supernova ejecta and remnants. With the aim of increasing the number of SNR dust mass determinations, we have modeled the red-blue emission line asymmetries in the late-time optical spectra of SN 1993J and SN 1980K published by Milisavljevic & Fesen (2013), as well as modeling similar red-blue line asymmetries seen in the integrated optical spectrum of Cas A published by Milisavljevic et al. (2013). Depending on grain composition, clumped dust masses of 0.1-0.4 M$_\odot$ are required to provide fits to the Year-31 Hα and [O I] line profiles of SN 1980K, while fits to the Year-16 [O II] and [O III] line profiles of SN 1993J require up to 0.18 M$_\odot$ of clumped ejecta dust. For Cas A, the fits to its [O I], [O II] and [O III] integrated line profiles require about 1 M$_\odot$ of internal dust to be present.

The dust mass in Cassiopeia A

Oral Talk

Ilse De Looze[1], Mike Barlow[1], and the SPIRE SAG6 team

[1]University College London, UK

Abstract

Theoretical models predict that core-collapse supernovae (CCSNe) can be efficient dust producers (0.1-1 M_{sun}) and potentially responsible for most of the dust production in the early Universe. Observational evidence for this dust production efficiency has remained limited. Herschel observations from 70-500 microns of the 335-year old Cassiopeia A have indicated the presence of $\sim$0.1 M_{sun} of cool (T$\sim$35 K) dust interior to the reverse shock (Barlow et al. 2010), while Dunne et al. (2009) have claimed a detection of $\sim$1 M_{sun} of cold ($\sim$20 K) dust, based on SCUBA 850-micron polarimetric data. At sub-millimeter wavelengths, the supernova dust emission is heavily contaminated by interstellar dust emission and by the synchrotron radiation from the SNR. We present the first spatially resolved analysis of the infrared and submillimeter emission of Cas, A at better than 1 parsec resolution, based on our Herschel PACS and SPIRE 70-500um images. We used our PACS IFU and SPIRE FTS spectra to remove the contaminating emission from bright lines (e.g. [OIII]88, [CII]158). We updated the spectral index of the synchrotron emission based on recent Planck data, and extrapolated this synchrotron spectrum from a 3.7 mm VLA image to infrared/submillimeter wavelengths. We modeled the interstellar dust emission using a Galactic dust emission template from Jones et al. (2013), while the ISM dust mass is scaled to reproduce the continuum emission in the SPIRE FTS spectra at wavelengths $>$ 650 micron (after subtraction of synchrotron emission). The UV radiation field that illuminates the ISM dust was constrained through PDR modelling of the [CI] 1-0, 2-1 and CO 4-3 lines observed in the SPIRE FTS spectra, and was found to range between 0.3 G_0 and 1.0 G_0 in units of the Draine IS radiation field. Within the uncertainties of the radiation field that illuminates the ISM material and the observational errors, we detect a dust mass of up to 0.8 M_{sun} in Cas, A, with an average temperature of 30 K, in the region interior to the reverse shock. Our SN dust mass map has a rather smooth appearance, which suggests that dust formed uniformly throughout the ejecta. A Cas A dust mass of up to 0.8 M_{sun} is in the same range as the $\sim$0.7 M_{sun} of dust found in SN 1987A (Matsuura et al. 2015) and the $\sim$0.2 M_{sun} of dust found in the Crab Nebula (Gomez et al. 2012; Owen & Barlow 2015). With these dust masses core-collapse supernovae can potentially account for the very large large masses of dust that have been observed in some high redshift galaxies.

A New Approach to X-ray Analysis of SNRs

Oral Talk

Kari A. Frank[1], David Burrows[1], Vikram Dwarkadas[2]

[1]Pennsylvania State University, USA
[2]University of Chicago, USA

Abstract

We present preliminary results of applying a novel analysis method, Smoothed Particle Inference (SPI), to XMM-Newton observations of SNR RCW 103 and Tycho. SPI is a Bayesian modeling process that fits a population of gas blobs ("smoothed particles") such that their superposed emission reproduces the observed spatial and spectral distribution of photons. Emission-weighted distributions of plasma properties, such as abundances and temperatures, are then extracted from the properties of the individual blobs. This technique has important advantages over analysis techniques which implicitly assume that remnants are two-dimensional objects in which each line of sight encompasses a single plasma. By contrast, SPI allows superposition of as many blobs of plasma as are needed to match the spectrum observed in each direction, without the need to bin the data spatially. The analyses of RCW 103 and Tycho are part of a pilot study for the larger SPIES (Smoothed Particle Inference Exploration of SNRs) project, in which SPI will be applied to a sample of 12 bright SNRs.

The ejecta of Supernova 1987A

Oral Talk

Josefin Larsson

KTH Royal Institute of Technology, Sweden

Abstract

Due to its proximity SN 1987A offers a unique opportunity to directly observe the geometry of a stellar explosion as it unfolds. In this talk I will present recent spectral and imaging observations of SN 1987A obtained with HST and VLT/SINFONI at optical and NIR wavelengths. These observations make it possible to determine the three-dimensional distribution of different emission lines from the ejecta, including Hα, [Ca II] $\lambda\lambda 7292, 7324$, [O I] $\lambda\lambda 6300, 6364$, [Si I]+[Fe II]1.644$\mu$m and He I 2.058 μm. The geometry is highly asymmetric, showing a "dipole structure" with a north/south asymmetry on large scales, as well as clumping on smaller scales. The observed asymmetries are much larger than seen in current 3D explosion models. The SINFONI observations also reveal the first detection of molecular hydrogen in the ejecta. The molecular hydrogen is concentrated to the core and is likely excited by UV radiation resulting from the ^{44}Ti decay.

Near-Infrared Spectroscopic Study of Supernova Ejecta and Supernova Dust in Cassiopeia A

Oral Talk

Yong-Hyun Lee[1], Bon-Chul Koo[1], Dae-Sik Moon[2], Jae-Joon Lee[3], Michael G. Burton[4]

[1]Seoul National University, S. Korea
[2]University of Toronto, Canada
[3]Korea Astronomy and Space Science Institute, S. Korea
[3]University of New South Wales, Australia

Abstract

We have carried out near-infrared (NIR) spectroscopic observations of the Cassiopeia A supernova (SN) remnant. We obtained medium-resolution, JHK (0.95 – 2.46 μm) spectra around the main ejecta shell. Using a clump-finding algorithm, we identified 63 'knots' in the two-dimensional dispersed images, and derived their spectroscopic properties. We first present the result of spectral classification of the knots using Principal Component (PC) Analysis. We found that the NIR spectral characteristics of the knots can be mostly (85%) represented by three PCs composed of different sets of emission lines: (1) recombination lines of H and He together with [N I] lines, (2) forbidden lines of Si, P, and S lines, and (3) forbidden Fe lines. The distribution of the knots in the PC planes matches well with the above spectral groups, and we classified the knots into the three corresponding groups, i.e., He-rich, S-rich, and Fe-rich knots. The kinematic and chemical properties of the former two groups match well with those of Quasi-Stationary Flocculi and Fast-Moving Knots known from optical studies. The Fe-rich knots show intermediate characteristics between the former two groups, and we suggest that they are the SN ejecta material from the innermost layer of the progenitor. We also present the results of extinction measurements using the flux ratios between the two NIR [Fe II] lines at 1.257 and 1.644 μm. We have found a clear correlation between the NIR extinction and the radial velocity of ejecta knots, indicating the presence of a large amount of SN dust inside and around the main ejecta shell. In a southern part of the ejecta shell, by analyzing the NIR extinction together with far-infrared thermal dust emission, we show that there are warm ($\sim$100 K) and cool ($\sim$40 K) SN dust components and that the former needs to be silicate grains while the latter, which is responsible for the observed NIR extinction, could be either small ($\lesssim$0.01 μm) Fe or large ($\gtrsim$0.1 μm) Si grains. We suggest that the warm and cool dust components represent grain species produced in diffuse SN ejecta and in dense ejecta clumps, respectively.

ALMA observations of supernova 1987A mixing, nucleosynthesis and dynamics of the ejecta

Oral Talk

Mikako Matsuura[1], R. Indebetouw, J. Kamenetzky, F. Abellan, M. J. Barlow, V. Bujarrabal, J. Marcaide, R. McCray, S. Woosley, et al.

[1]Cardiff University, UK

Abstract

ALMA observations of supernova 1987A mixing, nucleosynthesis and dynamics of the ejecta We present a molecular line survey for supernova 1987A, using the Atacama Large Millimetre / submillimetre Array (ALMA). We detected the CO, SiO, HCO+ and SO molecular lines from the ejecta. Those molecules can probe three different aspects of the SN 1987A ejecta: 1. Footprints of mixing and dynamics in the early days after the supernova explosion, 2. Molecular chemistry in the last twenty-five years 3. Explosive nuclear synthesis, using isotopologues, hence isotope ratios The extent of mixing after supernova explosions is still not well understood. Molecules can provide a new tool to probe this: microscopic mixing stirs the elements from different layers of nuclear-reaction zones in the stellar core, opening the possibility to form molecules with elements from different nuclear-burning zones. This process should have increased the abundance of HCO+, making it feasible now for ALMA to detect them. Our new ALMA observations have revealed several interesting features of the molecular gas. For instance, the SiO molecular lines clearly show dips in the line profile, while the CO lines do not. The different line profiles suggest that SiO and CO are spatially distributed at different locations. This could potentially be caused by different dynamics taking place immediately after the explosion, as SN hydrodynamical simulations suggest. ALMA spectra contain lines of isotopologues, which are molecules composed of atoms with different isotopes, and allow us to estimate the isotope ratios. Our upper limits of 28Si/29Si and 28Si/30Si are consistent with theoretically predicted values for SN 1987A. However, the ratios are at least a factor of two larger than isotopes measured in SN-associated pre-solar grains. Such thing could support the theory that neutron-rich isotopes are produced less efficiently in low metallicity environments, such as the Large Magellanic Cloud, where SN 1987A is located.

Deciphering the Encoded Debris of Supernovae

Invited Talk

Dan Milisavljevic

Harvard-Smithsonian CfA, MA, USA

Abstract

Theory and observation strongly favor the notion that asymmetric explosions drive core-collapse supernovae. Where and how this asymmetry is introduced is uncertain, in part because of limited constraints on various dynamical processes that may take place deep inside the star prior to and during core collapse. Fortunately, the debris fields of supernovae encode valuable information about these processes in their three-dimensional kinematics and chemical abundances. Accessing that information accurately, however, is not straightforward since observed properties may have multiple origins; e.g., asymmetries in both the explosion mechanism and/or turbulent stellar interior, and nonuniform circumstellar environments. I argue that the key to deciphering supernova debris fields is via end-to-end investigations that connect extragalactic events with young, nearby supernova remnants. This approach has the unique ability to trace the sources of mixing and clumping at large and small scales back to the time of explosion. I will emphasize how a holistic SN-SNR methodology is necessary for the next generation of three-dimensional core-collapse simulations seeking to robustly model and interpret the gravitational wave, neutrino, and EM signatures of supernovae.

Assessing the link between recent supernovae near Earth and the iron-60 anomaly in a deep-sea crust

Oral Talk

Michael M. Schulreich & Dieter Breitschwerdt

Department of Astronomy and Astrophysics, Berlin Institute of Technology, Germany

Abstract

Some time ago, an enhanced concentration of the radionuclide ^{60}Fe was discovered in a deep-sea ferromanganese crust, isolated in layers dating from about 2.2, Myr ago. Since ^{60}Fe (half-life of 2.6, Myr) is not naturally produced on Earth, such an excess can only be attributed to extraterrestrial sources, particularly one or several nearby supernovae in the recent past. It has been speculated that these supernovae might have been involved in the formation of the Local Superbubble, our Galactic habitat. The aim of this talk is to provide a quantitative evidence for this scenario. For that purpose, I will present results from high-resolution hydrodynamical simulations of the Local Superbubble and its neighbour Loop I in different environments, including a self-consistently evolved supernova-driven interstellar medium. For the superbubble modelling, the time sequence and locations of the generating core-collapse supernova explosions are taken into account, which are derived from the mass spectrum of the perished members of certain, carefully preselected stellar moving groups. The release and turbulent mixing of ^{60}Fe is followed via passive scalars, where the yields of the decaying radioisotope were adjusted according to recent stellar evolution calculations. The models are able to reproduce both the timing and the intensity of the ^{60}Fe excess observed with rather high precision.

Session IX.

SN ejecta – abundances, clumpiness – Posters

High-resolution observations of dust in SN1987A

Poster

Phil Cigan, Haley Gomez, Mikako Matsuura

Cardiff University, UK

Abstract

Interstellar dust is important for a variety of fundamental astrophysical processes and yet the origin of this dust is not particularly well-constrained. Dust can form in the envelopes of evolved stars, but not efficiently enough to overcome destruction rates and yield the abundances observed in our galaxy. Supernovae, which dominate the mechanical evolution of the ISM, can help balance the dust production budget. SN1987A, being relatively young as well as the brightest supernova observed in over 400 years, is a unique and exciting laboratory for studying supernova ejecta dust production. We have obtained new high-resolution observations of the continuum emission from the SN1987A system with ALMA, which we present here. We analyze the location and morphology of the dust, and compare with resolved emission at different wavelengths. In the future, we will use the relative distributions of dust and molecular species such as CO and SiO to help determine the dust composition and constrain the physics of supernova dust formation.

Optical and UV Spectra of the Remnant of SN 1885 (S And) in M31

Poster

Robert Fesen[1], Peter Hoeflich[2], Andrew Hamilton[3]

[1]Dartmouth College, USA
[2]Florida State University, USA
[3]University of Colorado, USA

Abstract

The remnant of Supernova 1885 (S And), a probable Type Ia supernova, can be seen in absorption against the bulge of the Andromeda galaxy, M31. Here we present *Hubble Space Telescope* optical and ultraviolet STIS spectra of S And taken in order to investigate the remnant's three dimensional structure. Optical spectra covering 2900 − 5700 Å, taken using six 0.2" wide slit positions in two orientations, show broad Ca II H&K absorption extending out to at least 11,500 km s^{-1} consistent with previous HST narrow passband Ca II images of S And. We find enhancement of Ca II absorption between expansion velocities of 2,000 and 5,000 km s^{-1} suggestive of a lumpy Ca-rich shell. These spectra, together with previous HST images, indicate a remnant with less than a 10 percent departure from purely spherical expansion, a layered abundance structure indicative of a detonation phase, and a clumpy and plume-like Fe distribution suggestive of Rayleigh-Taylor instabilities although significantly less than expected from hydrodynamic simulations.

Supernova Remnants in the UWIFE and UWISH2 Surveys

Poster

Yong-Hyun Lee[1], Bon-Chul Koo[1], Jae-Joon Lee[2]

[1]Seoul National University, S. Korea
[2]Korea Astronomy and Space Science Institute, S. Korea

Abstract

We have searched for near-infrared [Fe II] (1.644 μm) and H_2 1-0 S(1) (2.122 μm) emission features associated with Galactic supernova remnants (SNRs) using the narrow-band imaging surveys UWIFE/ UWISH2 (UKIRT Widefield Infrared Survey for [Fe II] / H_2). Both surveys cover about 180 square degrees of the first Galactic quadrant ($7° < l < 62°$; $-1.5° < b < +1.5°$), and a total of 79 SNRs are falling in the survey area among the currently known 294 Galactic SNRs. The images show diffuse structures as deep as the surface brightness limit of 10^{-19} W m^{-2} arcsec^{-2} which is comparable with a 5σ detection limit of point sources of 18 mag. In order to inspect the narrow-band features, we subtracted H and K-band continuum images obtained from the UKIDSS GPS (UKIRT Infrared Deep Sky Survey of the Galactic Plane) from the [Fe II] and H_2 narrow-band images, respectively. By this time, we have found 19 [Fe II]- and 18 H_2-emitting SNRs, and these are likely to increase in future as we inspect the images in more detail. Some of the SNRs show bright, complex, and interesting structures that have never been reported in previous studies. Since [Fe II] and H_2 lines trace dense atomic and molecular gases associated with SNR shocks, our results can help us understand the environment and evolution of individual SNRs. Among the SNRs showing both [Fe II] and H_2 emission lines, some SNRs show the "[Fe II]-H_2 reversal" phenomenon, i.e., the H_2 emission features are detected outside the [Fe II] emission boundary. This is opposite to the standard picture: If the shocks are driven by the same blast wave, we expect the H_2 filaments to be closer to the explosion center than the [Fe II] filaments. In this presentation, we show several examples of such SNRs detected in our study, and present high resolution ($R \sim 40{,}000$) H and K-band spectra of H_2 emission features obtained by using IGRINS (Immersion Grating Infrared Spectrograph).

SN Dust Yields: Fallback, Metallicity and Rotation Impact

Poster

Stefania Marassi, Raffaella Schneider, Marco Limongi, Alessandro Chieffi

INAF/Astronomical Observatory of Rome, Via Di Frascati 33 00078 Monteporzio, Italy

Abstract

Dust is an important ingredient in astrophysical environments as it regulates the physical and chemical conditions of the interstellar medium (ISM). Sites of dust formation are the expanding ejecta of core-collapse SNe. The amount of dust freshly condensed in SN explosions and surviving the subsequent passage of the reverse shock is a key quantity to assess the role of SNe as cosmic dust factories. Dust production in SNe depends on the SN type and on the physical properties of the stellar progenitor, such as its mass, ejecta temperature profile, metallicity and explosion energy. Using detailed pre-supernova and supernova explosion models for rotating and non-rotating progenitors with masses ranging between 13 to 120 $M_\odot$ and metallicities in the range $0 < Z/Z_\odot < 1$ (Limongi & Chieffi 2012, Limongi & Chieffi, in preparation), we investigate dust formation in SN ejecta. We follow nucleation and grain growth, taking into account the evolution of newly condensed grains and their partial destruction through the passage of the reverse shock in the supernova remnant. We assess the impact of stellar rotation and metallicity on the temperature and density profiles of the ejecta, and, as a consequence, on the resulting grain size distribution. Extending the models to the metal-free (Pop III) supernovae, we compute the mass-dependent dust and metal yields and we predict the chemical composition of star forming regions where second generation, low-mass stars form. We then compare the model predictions to the observed surface elemental abundances of carbon-normal and carbon-enhanced metal poor stars, and derive interesting constraints of the mass of Pop III stars and on the properties of the first SNe.

Discovery of Recombining Plasma in G166.0+4.3: A Mixed-Morphology Supernova Remnant with an Unusual Structure

Poster

Hideaki Matsumura[1], H. Uchida[1], T. G. Tsuru[1], T. Tanaka[1], M. Itou[1], M. Nobukawa[2], K .K. Nobukawa[3]

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[2]Nara University of Education, Japan
[3]Nara Women's University, Japan

Abstract

Mixed-morphology supernova remnants (MM-SNRs) have center-filled thermal X-ray emissions in a synchrotron radio shell. From the X-ray spectra of several MM-SNRs (e.g., W49B: Ozawa et al. 2009; IC 443: Yamaguchi et al. 2009), the Suzaku satellite has recently discovered recombining plasmas (RPs) characterized by a higher ionization temperature (kT_z) than an electron temperature (kT_e), while most of shell-like SNRs are explained as collisional ionization equilibrium (CIE: $kT_z = kT_e$) or ionizing plasma (IP: $kT_z < kT_e$). The formation process of the RPs have not been understood yet. G166.0+4.3 is a Galactic SNR whose synchrotron radio emission is extremely asymmetric: A large bipolar structure in southwest (Wing region) with a smaller semicircle shell in northeast (Shell region). From a previous X-ray observation with XMM-Newton, Bocchino et al. (2009) classified G166.0+4.3 as a MM-SNR and reported that the plasma is explained by a typical IP model. However, the origin of the unusual structure is still unclear. We have performed a long-time (totally 230 ks) observation of G166.0+4.3 with the Suzaku satellite in 2014. From the spectral analysis of the Wing region, we confirmed that the plasma is well represented by an IP model with kT_e of 0.85 keV. Applying a similar IP model to the Shell region, however, we found excesses at ∼2.0 keV and ∼2.6 keV corresponding to $\mathrm{Si_{XIII}}$ Lyα (2.0 keV) and the edge of a radiative recombining continuum of $\mathrm{Si_{XIII}}$ (2.67 keV) + $\mathrm{S_{XIV}}$ Lyα (2.63 keV), respectively. This fact indicates a sign of an RP in the Shell region of G166.0+4.3. We explained the spectrum as an RP model whose electron temperature is 0.46 keV which is smaller than that of the IP model in Wing region. We also found that the Fe-rich ejecta asymmetrically spread over the Wing region. These results suggest an inhomogeneous ambient medium in the vicinity of G166.0+4.3 which provides a clue to the cause of the unusual morphology. A supportive evidence is shown by a recent Fermi observation. Miguel (2013) discovered a GeV gamma-ray emission from the northeast part of this remnant, suggesting an existing of nearby molecular clouds. We also estimated the total ejecta mass to be larger than 8 solar masses. Although no candidate for progenitor has been detected around this remnant, a core-collapse SN is preferable as its origin. In this poster, we will present details of our analysis and discuss a relation between the unusual morphology and the cause of the RPs.

The origin of the argonium emission discovered in the Crab Nebula

Poster

Felix Priestley, Mike Barlow, Serena Viti

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Abstract

We present a study of the origin of the argonium (ArH^+) emission discovered by Herschel in the Crab Nebula (Barlow et al. 2013). The argonium molecule is believed to be formed principally by the reaction of singly ionised argon (Ar^+) with molecular hydrogen (H_2), and to be destroyed by reactions with H_2 and UV photons. For the case of the argonium ground state absorption lines seen by Herschel along several interstellar sightlines (Schilke et al. 2014), those authors argued that the presence of H_2 in both the formation and destruction mechanisms means that ArH^+ must form in largely atomic interstellar hydrogen clouds containing only trace amounts of H_2. However, In the case of the Crab Nebula the observed argonium emission might originate either from transition regions containing both Ar^+ and H_2, or alternatively from inside the Crab Nebula's H_2 knots into which X-ray photons or charged particles from the pulsar wind nebula have penetrated to produce Ar^+ and other ions. We report the results of our numerical studies that have used a combination of photoionisation and photodissociation region codes to investigate these alternative scenarios for producing ArH^+ in the Crab Nebula.

Dust formation in Supernovae

Poster

Eleni Tsiakaliari[1], Haley Gomez[1], Mikako Matsuura[1]

[1]Cardiff University, UK

Abstract

Supernovae were formerly thought to be major dust destroyers but recent studies suggest that dust formation occurs in the ejecta (Gall et al. 2014, Matsuura et al. 2015). Hence, supernovae could account for the dust enrichment of the Interstellar Medium (ISM). Multi-wavelength data (Herschel, Spitzer and XMM-Newton) of the galactic remnant W44 were used to study the dust mass enclosed within it along with its interaction with the surrounding ISM. Initial results and future plans are presented here.

Session X.

SNe and SNRs with circumstellar interactions – Oral Talks

The spectacular evolution of Supernova 1996al over 15 years: a low energy explosion of a stripped massive star in a highly structured environment

Oral Talk

Stefano Benetti

INAF-Osservatorio Astronomico di Padova, Italy

Abstract

The final fate of massive stars is not well explored and depending on the stellar mass may have very much different outputs, ranging from very energetic explosions (e.g. GRB-SNe) to direct collapse on black-holes with very weak or not explosion at all (Heger, Woosley, & Baraffe, 2005). Here I present the case of SN 1996al. I describe the physical properties of this luminous supernova in the framework of a very weak explosion (kinetic energy of $\sim 1.6 \times 10^{50}$ erg), where the bolometric luminosity is sustained by the conversion of the kinetic energy into radiation thanks to the interaction between a low mass (~ 1.15 $M_\odot$, 87% of which is Helium, the remaining is Hydrogen) symmetric ejecta with an highly asymmetric circumstellar material. The detection of Hα emission in pre-explosion archive images suggests that the progenitor of SN 1996al was most likely a massive star (~ 25 $M_\odot$ ZAMS) that had lost a large fraction of its hydrogen envelope before explosion, and was hence embedded in a H-rich cocoon. The low-mass ejecta and modest kinetic energy of the explosion are then explained with massive fallback of material into the compact remnant, a $7-8$ $M_\odot$ black hole. Finally, I will try to place this particularly interesting SN in the framework of the SNIIn zoo.

A new distance determination to the Cygnus Loop

Oral Talk

Christine Black[1], Robert A. Fesen[1], Jack M.M. Neustadt[1] and Dan Milisavljevic[2]

[1]Dartmouth College, USA
[2]Harvard-Smithsonian CfA, MA, USA

Abstract

We will present optical images and spectra of a few stars that are projected within the Cygnus Loop supernova remnant's boundaries that show evidence for aninteraction of recent stellar mass loss material with the remnant's forward shock. Shock interactions are visible in the spectra and morphology of these star's mass loss material, indicating these stars currently lie inside the remnant. Such stellar mass loss/shock interactions yield a new and robust distance method for estimating a distance to the Cygnus Loop based on stellar spectroscopic distances. We find the Cygnus Loop lies at a distance of 1.1 ± 0.2 kpc, significantly larger than previous estimates but more consistent with a supernova explosion energy of around 10^{51} erg.

Probing the physics of bright supernovae with high-cadence photometry

Oral Talk

Alceste Bonanos, Panos Boumis

IAASARS, National Observatory of Athens, Greece

Abstract

We propose high-cadence photometry as a tool to probe the physics of both thermonuclear and core-collapse supernova explosions. We demonstrate the idea by conducting high-cadence monitoring of theoptical light curve of the nearby, Type Ia SN 2014J in M82. B and V-band photometry on days 15−18 after t_{max}(B) was obtained with a cadence of 2 min per band, using the 2.3 m Aristarchos telescope, at Helmos Observatory, Greece. The data reveal evidence for rapid variability at the 0.02−0.05 mag level on timescales of 15−60 min on all four nights. The rapid variability could be due to one or a combination ofthe following scenarios: the clumpiness of the ejecta, their interaction with circumstellar material, the asymmetry of the explosion, or the mechanism causing the secondary maximum in the near-infrared lightcurve. We present our plans to use the new Prime Focus Instrument with its fast-frame sCMOS cameras on the Kryoneri 1.2 m telescope in Greece, constructed as part of ESA's lunar monitoring project NELIOTA, to systematically monitor bright supernovae for rapid variability.

The X-ray evolution of SNR 1987A

Oral Talk

David N. Burrows[1], Kari A. Frank[1], Sangwook Park[2], Dick McCray[3], Svetozar Zhekov[4]

[1]Penn State University, USA
[2]University of Texas at Arlington, USA
[3]Univ. of California Berkeley, USA
[4]Bulgarian Academy of Sciences, Bulgaria

Abstract

Due to its age and close proximity, the remnant of SN 1987A is the only supernova remnant in which we can study the early developmental stages in detail, providing insight into stellar evolution, the mechanisms of the supernova explosion, and the transition from supernova to supernova remnant as the debris begins to interact with the surrounding circumstellar medium (CSM). We present the latest results from 16 years of Chandra ACIS observations of SN 1987A, now covering 4600−10600 days after the supernova. At approximately day 7500, the east-west asymmetry of the ring began to reverse, while the soft X-ray light curve switched from an exponential increase to a linear brightening. Since day 9700 the soft X-ray light curve has flattened and remained approximately constant at about 8×10^{12} ergs cm^{-2} s^{-1}, evidence that the blast wave has now left the dense material of the known equatorial ring and is beginning to probe the unknown territory beyond.

On the interaction of type Ia supernova remnants with planetary nebulae

Oral Talk

Alexandros Chiotellis[1], Panos Boumis[1], Sander Walg[2], E. Lefa[3]

[1]IAASARS, National Observatory of Athens, Greece
[2]Radboud Universiteit Nijmegen, The Netherlands
[3]National and Kapodistrian University of Athens, Greece

Abstract

Type Ia supernovae (SNe Ia) are believed to result from the thermonuclear explosion of carbon oxygen white dwarfs. However, the exact nature of their progenitor systems remains illusive. One of the key tools to determine/eliminate the origin of SNe Ia is the study of their interaction of with circumstellar structures formed by the mass outflows of the progenitor system. In this work we present the case where a SN Ia occurs in the center of a planetary nebula (PN). We preform 2D hydrodynamic simulations and we study the results of a SN Ia-PN interaction on the morphological, kinematical and emission properties of the resulting supernova remnant (SNR). We compare the results of our simulations with the properties of historical SNRs-resulting from SNe Ia-which show evidence of interaction with circumstellar structures e.g. Kepler's SNR. Finally we discuss whether the scenario of a SNR Ia-PN interaction is aligned to the current properties/limitations of the circumstellar medium around SNe Ia imposed by observations.

Thirteen years of pummeling the circumstellar ring around SN 1987A

Oral Talk

Eli Dwek[1], Richard G. Arendt[1], 2, Patrice Bouchet[3], John Danziger[4]

[1]NASA GSFC, Observational Cosmology Lab, USA
[2]CRESST/UMBC, USA
[3]Laboratoire AIM Paris-Saclay, CEA-IRFU/SAp, CNRS, France
[4]INAF-Osservatorio Astronomico di Trieste, Italy

Abstract

Since 2003, about 6000 days after the explosion, the radiative energy output from SN 1987A has shifted from being dominated by the release of radioactive energy from the ejecta, to the release of mechanical energy caused by the interaction of the SN blast wave with the circumstellar ring. The energy from the interaction is released at X-ray, UV-optical, and infrared (IR) wavelengths. The 5-35 micron IR spectrum from the ring is dominated by the emission from collisionally-heated silicate dust. The circumstellar ring around SN 1987A therefore provides astronomers with a unique laboratory for studying the physical conditions and gas-dust interaction in dusty astrophysical plasmas. In particular, the X-ray and IR observations can be used to determine the erosion efficiency of dust grains in such hostile astrophysical environment. In this talk I will summarize what we have learned from 12 years of Gemini and Spitzer observations of the ring around SN 1987A.

A survey for Galactic supernova remnant/molecular cloud interactions ssing carbon monoxide

Oral Talk

Charles Kilpatrick, George Rieke, John Bieging

University of Arizona, USA

Abstract

Supernova remnants are one of the primary engines through which stars add energy to the interstellar medium. The efficiency of this transfer of energy is enhanced where supernova remnants encounter dense interstellar gas, such as in molecular clouds. Unique signatures have been observed toward these supernova remnant/molecular cloud interactions in the form of unusual molecular line profiles and bright non-thermal radiation. The sites of these interactions also provide some of the best examples for evidence of cosmic-ray acceleration and Galactic sources of very high-energy gamma-rays. Despite the large number of individual studies that examine supernova remnant/molecular cloud interactions, very little is known about their overall rates and characteristics. This lack of information limits the usefulness of individual supernova remnant/molecular cloud interactions to enhance our understanding of supernova feedback and cosmic-ray acceleration. I will discuss recent work studying large populations of supernova remnants in the ^{12}CO $J = 2 - 1$ and $J = 3 - 2$ lines and the observational signatures associated with molecular shocks from supernova ejecta. Broadened molecular lines and molecular line ratios indicative of warm gas can be used to identify and characterize populations of supernova remnant/molecular cloud interactions. From this large sample, I will discuss new constraints on the energetic processes to which supernova remnants contribute, especially the rate of GeV and TeV gamma-ray production associated with supernova remnant/molecular cloud interfaces.

Supernova 1987A at 29 years

Invited Talk

Richard McCray

Univ. of California Berkeley, USA

Abstract

In the 29 years since it was discovered, SN 1987A has evolved from supernova to supernova remnant, in the sense that its luminosity is now dominated by radiation from its shock interaction with circumstellar matter rather than radioactive decay of newly synthesized elements. The circumstellar matter has a complex structure and the impact of the supernova debris results in a complex distribution of shocks, with velocities ranging from a few hundred to several thousand km/s. The supernova blast wave is overtaking dense knots in the equatorial ring, resulting in rapidly brightening optical "hotspots", while the interaction with less dense matter gives rise to X-rays. The X-rays illuminate the outer supernova debris, causing it to glow at optical wavelengths. The ALMA telescope provides a new window at mm/sub-mm wavelengths, enabling us to probe the structure of the cold inner debris through molecular emission lines.

X-ray observations of SNRs as probes of progenitor evolution

Invited Talk

Daniel Patnaude

Harvard-Smithsonian CfA, MA, USA

Abstract

Supernovae and their remnants represent the violent endpoints in the evolution of some stars. In this talk, I will review results from observations of core-collapse and Ia supernova remnants, and discuss how these results allow us to infer the evolutionary properties of the progenitor system. I will then present recent results from a theoretical study which directly relates bulk observable properties of supernova remnants to progenitor models. I present a framework which allows for end-to-end simulations of massive stars, from the pre-main sequence to millennia after core-collapse.

Discovery of an expanding molecular bubble surrounding Tycho's supernova remnant (SN 1572): evidence for a single-degenerate progenitor

Oral Talk

Ping Zhou[1], Yang Chen[1], Zhi-Yu Zhang[2,3], Xiang-Dong Li[1], Samar Safi-Harb[4], Xin Zhou[1,5], Xiao Zhang[1]

[1]Nanjing University, China
[2]ROE, UK
[3]ESO, Germany
[4]University of Manitoba, Canada
[5]Purple Mountain Observatory, China

Abstract

Whether the progenitors of Type Ia Supernovae, single degenerate or double- degenerate white dwarf (WD) systems, is a highly debated topic. To address the origin of the Type Ia Tycho's supernova remnant (SNR), SN 1572, we have carried out a ^{12}CO J=2−1 mapping and a 3-mm line survey towards the remnant using the IRAM 30 m telescope. We show that Tycho is surrounded by a highly clumpy molecular bubble at the local standard of rest velocity $V_{LSR} \sim 62$ km s^{-1} which has an expanding velocity of ∼5 km s^{-1} and a mass of ∼220 $M_{\odot}$ (at the distance of 2.5 kpc). Enhanced ^{12}CO J=2−1 line emission relative to ^{12}CO J=10 emission and possible line broadenings (in velocity range −64 to −60 km s^{-1}) are found at the northeastern boundary of the SNR where the shell is deformed and decelerated. These features, combined with the morphological correspondence between the expanding molecular bubble and Tycho, suggest that the SNR is associated with the molecular bubble at the velocity range from −66 km s^{-1} to −57 km s^{-1}. The most plausible origin for the expanding bubble is the fast outflow (with velocity >100 km s^{-1}) driven from the vicinity of a massive WD as it accreted matter from a non-degenerate companion star. The SNR has been expanding in the low-density wind-blown bubble and the shock wave has just reached the molecular cavity wall. The expanding bubble presents new evidence for the progenitor of Tycho being a single-degenerate system.

SNR research: where do we stand today, and what will the future bring

Oral Talk

Jacco Vink

Anton Pannekoek Institute/GRAPPA, Netherlands

Abstract

I will summarise the highlights of the conference, and will deduce from that more general conclusions: what has been the overall progress over the last 10 years in supernova remnant research? and what important questions should we focus on the coming ten years? In this light it is also good to remind us of the observing facilities that will come online in the near future: SKA, CTA, XIPE/IXPE (?), and further ahead: Athena.

Session X.

SNe and SNRs with circumstellar interactions – Posters

Multispectral analysis of Cygnus Loop and IC 443 with iFTS

Poster

Alexandre Alarie

Laval University, Canada

Abstract

Cygnus Loop and IC 443 are supernova remnants (SNRs) recognized as excellent laboratories to study the interaction between the SNR and the surrounding interstellar medium. The overall complex morphologies and large dimensions of those SNRs have always represented an observational challenge. This is especially true for optical observations for which the data available are very scarce. In order to palliate this scarcity in the optical regime, we are using two wide field-imaging Fourier transform spectrometers (iFTS): SpIOMM, attached to the Mont Megantic 1.6-m telescope and SITELLE recently installed at the Canada-France-Hawaii Telescope. Both instruments are capable of obtaining the spatially resolved visible spectrum of every source of light in an 11 arc minute field of view, in selected bandpasses. Using those iFTS on extended object such as Cygnus Loop and IC 443, we have obtained millions of spectra covering all major emission lines. Due to the large projected surface of Cygnus Loop and IC 443, we started a survey and the latest dataset will be presented. The extended 2D mappings of several emission lines ([O II] 3727, [O III] 4363, Hb, [O III] 4959, 5007, Ha, [N II] 6548, 6583 and [S II] 6716, 6731) allowed the creation of numerous ratios maps useful for shock diagnostics: shock velocity, electronic and temperature densities, location of incomplete shocks and extinction maps. These maps are then used to determine key parameters needed to compare the observations with theoretical shock models. Using the shock modeling code MAPPINGS, we can create abundances maps of nitrogen, oxygen and sulfur for an appreciable fraction of the observed regions. Furthermore, using the radial velocity as well as the spectro-imagery capability of the iFTS, we can have a glimpse of the three-dimensional structure of the remnants. All those data allow us to forge a coherent analysis of the complex interaction between the SNRs and their surrounding environment.

Supernova research with VLBI

Poster

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Abstract

Core-collapse supernovae have been monitored with VLBI from shortly after the explosion to many years thereafter. Radio emission is produced as the ejecta hit the stellar wind left over from the dying star. Images show the details of the interaction as the shock front expands into the circumstellar medium. Measurements of the velocity and deceleration of the expansion provide information on both the ejecta and the circumstellar medium. VLBI observations can also search for the stellar remnant of the explosion, a neutron star or a black hole. Combining the transverse expansion rate with the radial expansion rate from optical spectra allows a geometric determination of the distance to the host galaxy. We will present results from recent VLBI observations, focus on their interpretations, and show updated movies of supernovae from soon after their explosion to the present.

Dust grains from the heart of supernovae

Poster

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Abstract

It is observationally and theoretically well established that a considerable amount of dust is efficiently formed in regions around asymptotic giant branch (AGB) stars. This process is classically considered as the primary source of dust grains in galaxies, and the typical formation timescale in the Milky Way is $\sim 3 \times 10^9$ yr. In contrast, supernova (SN) explosions in the interstellar medium (ISM) trigger shock waves that are able to quickly processdust grains and are considered the dominant mechanism of dust destruction in the ISM. A recent theoretical work on interstellar dust destruction in shock waves led to an estimated lifetime of $\sim 6 \times 10^7$ yr and $\sim 3 \times 10^8$ yr for carbonaceous and silicate grains in our Galaxy, respectively (Bocchio et al. 2014), which is much shorter thanthe assumed dust formation timescale from AGB stars. This leads to the conclusion that a large amount of dust must be reaccreted from the gas phase. Although SNe are believed to be efficient interstellar dust destroyers, there is increasing observational evidence today for the formation of non-negligible quantities of dust grains in the ejecta of SNe. Given the relatively short timescale between the explosion of two SNe, this would lead to an effectively shorter timescale for dust formation. However, all the available measurements of the mass of freshly-formed dust are associated with young SNe, where the passage of the reverse shock has invested only a fraction of the total dust in the ejecta. In order to estimate the dust mass that is released into the ISM after the passage of the reverse shock, we recently developed a new code (GRASH_Rev, Bocchio et al. 2016), which follows the newly-formed dust evolution throughout the supernova explosion until the merging of the forward shock with the circumstellar ISM. The properties of dust formed in the ejecta are estimated using a recent nucleation model (Marassi et al. 2015) and the processing of dust grains is treated following Bocchio et al. (2014). We have considered four well-studied SNe in the Milky Way and Large Magellanic Cloud: SN 1987A, Cas A, the Crab Nebula, and N49. For all the simulated models, we find good agreement with observations. However, the largest dust mass destruction is predicted to occur between 10^3 and 10^5 yr after the explosions. Since the oldest SN in the sample has an estimated age of 4800 yr, current observations can only provide an upper limit to the effective dust yields. We find that between 1 and 8% of the observed mass will survive, leading to a SN dust production rate of $(3.9 \pm 3.7) \times 10^{-4}$ $M_\odot$ yr^{-1} in the Milky Way. This value is almost an order of magnitude larger than the observed dust production rate by AGB stars. However, interstellar dust destruction by SNe is observed and modelled to be larger than the dust formation rate by SNe by a factor > 100, therefore requiring dust accretion in the gas phase.

Type Ia Supernova Remnants in the Large Magellanic Cloud

Poster

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Abstract

About 10 Type Ia SNRs have been identified in the Large Magellanic Cloud. We have obtained Hubble Space Telescope (HST) H-α images for 9 of these SNRs. These high-resolution images show detailed structure of the SNRs. Several of them show knots indicating circumstellar interactions. This poster will present HST images of 9 Type Ia SNRs and discuss their physical structures.

Exploiting IPHAS H-α imagery of supernova remnants

Poster

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Abstract

A new $\sim$1 arcsec resolution complete image of Shajn 147 is being prepared and will be presented. Plans to use IPHAS H-α imaging to obtain WEAVE R=5000 pan-optical spectroscopy of nebulae, including SNR, from 2018 on will be outlined.

The previous nebulous incarnations of type Ia supernovae

Poster

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Abstract

There have been extensive efforts employed in identifying the progenitors of supernovae (Wang & Han 2012). Here we explore a layout of a simplified binary evolution track following such a system from planetary nebula and then on through classical, recurrent and/or symbiotic nova systems up to their final explosive event. By investigating the supernova precursor stages, we can gain insight on the environment in which these energetic events unravel and whether their observed outburst magnitudes may be inclination dependent. Bipolar planetary nebulae, classical & recurrent/symbiotic novae and type Ia supernovae are all linked to binaries that contain at least one white dwarf. Binary evolution is still poorly understood, but it is probable that the evolutionary sequence of a certain mass range follows the stellar phases in the order laid out above. Trying to understand morphologies and shaping mechanisms of classical and recurrent novae could lead to important advances in planetary nebula, shaping and deepening the knowledge on the environment into which type Ia supernovae expand. Classical and recurrent nova events are due to a thermonuclear runaway in the accreted envelope of a white dwarf. The thermonuclear runaway results in the expulsion of the accreted shell of material from the white dwarfs surface. For the higher mass white dwarf systems, less mass is expelled than was accreted since the previous eruption, leading to a net gain in mass. This can occur until the Chandrasekhar limit is reached (Hillman et al. 2015). In the lead up to a type Ia supernova, a classical nova producing system will outburst on shorter recurrence timescales until its final event. This hints at the shear amount of debris surrounding a supernovae Ia at outburst. The material deposited by the previous phases of evolution has been, in general, subject to shaping mechanisms. Some of the surrounding material from the planetary nebula phase ($V_{exp} < 100$ km s^{-1}), will be more strongly shaped than material from a faster nova event ($V_{exp} = 300 - 3000$ km s^{-1}), because the orbital motion of the pair is thought to strongly influence the structure of the expanding shell during the common-envelope phase. There are about 35 nova episodes in the galaxy per year and they evolve on human timescales, making these old nova shells excellent probes for many unsolved astrophysical problems including clumping, dust formation, shock interactions with CSM/ISM and shaping. Through a variety of observational techniques from deep imaging to spectroscopy and polarimetry as well as chemical and morpho-kinematic modelling, an attempt at understanding the true nature of the late-lifetimes of these cosmologically important systems are explored.

The effect of circumstellar medium on cosmic ray acceleration in type Ia supernovae

Poster

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Abstract

We present our results on the range and time evolution of the maximum energy that charged particles can obtain while they are accelerated in the forward shock of Supernova Remnants resulting by Type Ia Supernovae (SNe Ia). In particular, based on semi-analytical and numerical descriptions, we investigate the dynamics of a Supernova Remnant evolving in a modified ambient medium formed by the mass outflows of the progenitor system. We associate the ambient medium properties to the suggested diversity of SNe Ia progenitors and we study the effects of such an evolution on the acceleration of cosmic rays. We find that the range and the time evolution of the cosmic rays' maximum energy are strongly dependent on the ambient medium properties. Thus, combining this result with the predictions of SNe Ia population synthesis, we conclude that the modification of the ambient medium by the SN Ia progenitors cannot be neglected in the study on the origin of galactic cosmic rays.

Early time signatures of gamma-ray emission from supernovae in dense circumstellar media

Poster

Dimitrios Kantzas[1], **Maria Petropoulou**[2], **Apostolos Mastichiadis**[1]

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Abstract

We will present our results on the gamma emission from interaction-powered supernovae (SNe), a recently discovered type of SN suggested to be surrounded by a very dense Circumstellar Medium ($10^5 - 10^{11}$ cm^{-3}). These high densities favor the production of gamma ray photons through neutral pion decay as well as the photon production due to relativistic bremsstrahlung. Using a numerical code that includes synchrotron radiation, adiabatic losses due to the expansion of the source, relativistic bremsstrahlung, proton-proton collisions and proton-photon interactions, i.e. photopair ($p\gamma \to pe^{\pm}$) and photopion ($p\gamma \to p\pi^0$, $p\gamma \to p\pi^{\pm}$) production, we calculate the gamma ray emission (> 100 MeV) soon after shock breakout and follow its temporal evolution until $100-1000$ days. We show that both pp collisions and relativistic bremsstrahlung contribute significantly to the gamma ray emission and discuss the potential of detecting such SNe with the Fermi telescope.

Near-infrared IFU and MOS observations of supernova remnants

Poster

Ho-Gyu Lee

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Abstract

We present near-infrared IFU and MOS observations of two bright [Fe II] line emitting supernova remnants (SNRs). The two SNRs, G11.2-0.3 and RCW103, are selected from our near-infrared [Fe II] 1.64 um narrow band imaging survey of SNRs such as UKIRT unbiased [Fe II] imaging survey of the the Galactic plane and AAT [Fe II] imaging of some core-collapse SNRs. We detect several near-infrared hyperfine lines of [Fe II] at the southeastern shell of G11.2-0.3. We estimate the line strength and extinction-corrected density, which gives a clue to the origin of the iron-rich southeastern shell of G11.2-0.3. We obtain the MOS spectra of [Fe II]-emitting clumps inside RCW103. The observed clumps move about hundreds kilometers in radial direction, suggesting that they are shocked dense materials lost by stellar wind at the final stage of the evolution of the progenitor star.

Supernova Remnants in the UWIFE and UWISH2 Surveys

Poster

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Abstract

We have searched for near-infrared [Fe II] (1.644 μm) and H_2 1-0 S(1) (2.122 μm) emission features associated with Galactic supernova remnants (SNRs) using the narrow-band imaging surveys UWIFE/ UWISH2 (UKIRT Widefield Infrared Survey for [Fe II] / H_2). Both surveys cover about 180 square degrees of the first Galactic quadrant ($7^\circ < l < 62^\circ$; $-1.5^\circ < b < +1.5^\circ$), and a total of 79 SNRs are falling in the survey area among the currently known 294 Galactic SNRs. The images show diffuse structures as deep as the surface brightness limit of 10^{-19} W m^{-2} arcsec^{-2} which is comparable with a 5σ detection limit of point sources of 18 mag. In order to inspect the narrow-band features, we subtracted *H* and *K*-band continuum images obtained from the UKIDSS GPS (UKIRT Infrared Deep Sky Survey of the Galactic Plane) from the [Fe II] and H_2 narrow-band images, respectively. By this time, we have found 19 [Fe II]- and 18 H_2-emitting SNRs, and these are likely to increase in future as we inspect the images in more detail. Some of the SNRs show bright, complex, and interesting structures that have never been reported in previous studies. Since [Fe II] and H_2 lines trace dense atomic and molecular gases associated with SNR shocks, our results can help us understand the environment and evolution of individual SNRs.Among the SNRs showing both [Fe II] and H_2 emission lines, some SNRs show the "[Fe II]-H_2 reversal" phenomenon, i.e., the H_2 emission features are detected outside the [Fe II] emission boundary. This is opposite to the standard picture: If the shocks are driven by the same blast wave, we expect the H_2 filaments to be closer to the explosion center than the [Fe II] filaments. In this presentation, we show several examples of such SNRs detected in our study, and present high resolution ($R \sim 40{,}000$) *H* and *K*-band spectra of H_2 emission features obtained by using IGRINS (Immersion Grating Infrared Spectrograph).

Investigating the Galactic supernova remnant Kes 78 with XMM-Newton

Poster

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Abstract

The galactic supernova remnant Kes 78 is associated with a HESS gamma-ray source and its X-ray emission has been recently revealed by Suzaku observations which have found indications for a hard X-ray component in the spectra.We analyzed an XMM-Newton EPIC observation of Kes 78 and studied the spatial distribution of the physical and chemical properties of the X-ray emitting plasma. The EPIC data unveiled a very complex morphology for the soft X-ray emission. We performed image analysis and spatially resolved spectral analysis finding indications for the interaction of the remnant with a local molecular cloud. Finally, we investigated the origin of the hard X-ray emitting component.

Dance into the fire: dust survival inside supernova remnants

Poster

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Abstract

Core collapse supernovae (CCSNe) are important sources of interstellar dust, potentially capable of producing 1 $M_\odot$ of dust in their explosively expelled ejecta. However, unlike other dust sources, the dust has to survive the passage of the reverse shock, generated by the interaction of the supernova blast wave with its surrounding medium. Knowledge of the net amount of dust produced by CCSNe is crucial for understanding the origin and evolution of dust in the local and high-redshift universe. Our goal is to identify the dust destruction mechanisms in the ejecta, and derive the net amount of dust that survives the passage of the reverse shock. To do so, we have developed analytical models for the evolution of a supernova blast wave and of the reverse shock, and the simultaneous processing of the dust inside the cavity of the supernova remnant. We have applied our models to the special case of the clumpy ejecta of the remnant of Cassiopeia A (Cas A), assuming that the dust (silicates and carbon grains) resides in cool oxygen-rich ejecta clumps which are uniformly distributed within the remnant and surrounded by a hot X-ray emitting plasma (smooth ejecta). The passage of the reverse shock through the clumps gives rise to a relative gas-grain motion and also destroys the clumps. While residing in the ejecta clouds, dust is processed via kinetic sputtering, which is terminated either when the grains escape the clumps, or when the clumps are destroyed by the reverse shock. In either case, grain destruction proceeds thereafter by thermal sputtering in the hot shocked smooth ejecta. We find that 12 and 16 percent of silicate and carbon dust, respectively, survive the passage of the reverse shock by the time the shock has reached the center of the remnant. These fractions depend on the morphology of the ejecta and the medium into which the remnant is expanding, as well as the composition and size distribution of the grains that formed in the ejecta. Results will therefore differ for different types of supernovae. I will discuss our models and results and briefly illustrate the impact of the capabilities of the Athena+ X-ray mission on the variety of astrophysical problems involving the processing of dust particles in extreme environments characterized by the presence of shocked X-ray emitting gas.

The circumstellar ring of SN 1987A

Poster

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Abstract

The circumstellar ring of supernova 1987A first became visible a few months after the explosion due to photoionisation by the supernova flash. From 1995 hotspots appeared in the ring and their brightness increased nearly exponentially as a result of interaction with the supernova blast wave. Imaging and spectroscopic observations with the *Hubble Space Telescope* and the *Very Large Telescope* now show that both the shocked and the unshocked emission components from the ring have been decreasing since $\sim$ 2009. In addition, the most recent images reveal the brightening of new spots outside the ring. These observations indicate that the hotspots are being dissolved by the shocks and that the blast wave is now expanding and interacting with dense clumps beyond the ring. Based on the currently observed decay we predict that the ring will be destroyed by $\sim$ 2025, while the blast wave will reveal the distribution of gas as it expands outside the ring, thus tracing the mass-loss history of the supernova progenitor.

Three-dimensional hydrodynamic modeling of SN 1987A from the supernova explosion till the Athena era

Poster

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Abstract

The proximity of SN 1987A and the wealth of observations collected at all wavelenght bands since its outburst allow us to study in details the evolution of a supernova remnant (SNR) from the immediate aftermath of the SN explosion till its expansion through the highly inhomogeneous circumstellar medium (CSM). We investigate the interaction between SN 1987A and the surrounding CSM through three-dimensional hydrodynamic modeling. The aim is to determine the contribution of shocked ejecta and shocked CSM to the detected X-ray flux and to derive the density structure of the inhomogeneous CSM and clues on the early structure of ejecta. We show that the physical model reproducing the main observables of SN 1987A reproduces also the X-ray emission of the subsequent expanding remnant, thus bridging the gap between supernovae and supernova remnants. By comparing model results with observations, we constrain the explosion energy in the range $1.2 - 1.4 \times 10^{51}$ erg and the envelope mass in the range $15 - 17$ $M_{\odot}$. We find that the shape of X-ray lightcurves and spectra at early epochs (< 15 years) reflect the structure of outer ejecta. At later epochs, the shape of X-ray lightcurves and spectra reflect the density structure of the nebula around SN 1987A. This enabled us to ascertain the origin of the multi-thermal X-ray emission, to disentangle the imprint of the supernova on the remnant emission from the effects of the remnant interaction with the environment, and to constrain the pre-supernova structure of the nebula. Finally the remnant evolution is followed for 40 years, providing predictions on the future of SN 1987A until the advent of Athena.

The impact of supernova remnants on interstellar turbulence and star formation

Poster

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Abstract

The explosion energy of supernovae is believed to be a major energy source to drive and maintain turbulent motions in the interstellar gas. The interaction of supernova remnants with the interstellar medium plays a crucial role in shaping the statistics of interstellar turbulence, and has important effects on physical properties of molecular clouds. To investigate supernova-driven turbulence in molecular clouds and the implications for star formation, we conducted a large-scale MHD simulation, keeping track of the evolution of supernova remnants and their interactions with the interstellar gas in a region of 250 pc. The simulation accounts for the effects of gas heating and cooling, the magnetic fields and self-gravity, and the explosion energy of supernovae is injected as thermal energy at randomly selected locations in the simulation box. We analyzed the dense molecular clouds formed in our simulation, and showed that their properties, including the mass-size, velocity-size relations, mass and size probability distributions, and magnetic field-density relation, are all consistent with observational results, suggesting that the dynamics and structure of molecular clouds are the natural result of supernova-driven turbulence. We also found that, at the scale of molecular clouds, turbulent motions contain more power in solenoidal modes than in compressive modes. This suggests that the effective driving force for interstellar turbulence is largely solenoidal, in contrast to the recent

hypothesis that supernova driving is purely compressive. The physical reason is that, as a supernova remnant impacts the ambient interstellar gas, the baroclinic effect arises immediately, which preferentially converts compressive motions to solenoidal modes throughout the evolution of the remnant in the interstellar medium. The implications of our results concerning the statistics of supernova-driven turbulence in molecular clouds on theoretical modeling of star formation will be discussed.

Asymmetric expansion of the youngest Galactic supernova remnant G1.9+0.3

Poster

Stephen P. Reynolds

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Abstract

The youngest Galactic supernova remnant (SNR) G1.9+0.3, produced by a (probable) Type Ia SN that exploded around CE 1900, is strongly asymmetric at radio wavelengths, with a single bright maximum in its shell, but exhibits a bilaterally symmetric morphology in X-rays. It has been difficult to understand the origin of these contrasting morphologies. We present the results of expansion measurements of G1.9+0.3 that illuminate the origin of the radio asymmetry. These measurements are based on a comparison of our 2015 400-ks Chandra observation with earlier Chandra observations, including a 1-Ms observation in 2011. The mean expansion rate from 2011 to 2015 is 0.58% per yr, in agreement with previous measurements. We also confirm that the expansion decreases radially away from the remnant's center along the major E-W axis, from 0.77% per yr to 0.53% per yr. Large variations in expansion are also present along the minor N-S axis, but expansion there is strongly asymmetric and varies on small spatial scales. We use the "Demons" method to study the complex motions within G1.9+0.3. This method provides a nonparametric way for measuring these motions globally. We find motions varying by a factor of 5, from $0.09''$ to $0.44''$ per year. The slowest shocks are in the north, at the outer boundary of the bright radio emission, with speeds there as low as 3,600 km s^{-1} (for an assumed distance of 8.5 kpc), much less than the average shock speed of 12,000 km s^{-1}. Such strong deceleration of the northern blast wave most likely arises from the collision of SN ejecta with a much denser than average ambient medium there. The presence of this asymmetric ambient medium naturally explains the radio asymmetry. The SN ejecta have also been strongly decelerated in the N, but they expand faster than the blast wave. In several locations, significant morphological changes and strongly nonradial motions are apparent. The spatially-integrated X-ray flux continues to increase with time. As with Kepler's SN, the most recent historical SN in the Galaxy, the SN ejecta are likely colliding with the asymmetric circumstellar medium (CSM) ejected by the SN progenitor prior to its explosion. G1.9+0.3 fills the gap between distant Type Ia-CSM SNe and older Type Ia-CSM SNRs such as Kepler's SNR, providing us with a unique opportunity to learn about SN Ia progenitors.

Dust formation in dense CSM behind the shock: A study based on SN2010jl

Poster

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Abstract

Dust is known to form in the quiescent outflows of AGB stars and in the explosively ejected matter of core collapse supernovae (CCSNe). Recent optical and near-infrared (IR) observations of the light curve of the ultraluminous CCSN SN2010jl has shown evidence for the rapid rise of a thermal IR emission component from newly forming dust in its spectrum. The UV-optical light curve from the SN cannot be powered by the radioactivities in the ejecta, and is powered by the interaction of the SN blast wave with the ambient dense circumstellar (CSM) shell. Observations of the evolution of the broad H and He lines in the spectra show that the dust could not have formed in the SN ejecta, but must have formed in the CSM instead. The supernova blast-wave traverses the CSM heating and ionizing the gas and destroying all pre-existing molecules and dust grains. The shocked CSM gas cools rapidly behind the shock to temperatures below the dust condensation temperatures. However, the radiation emanating from the shocked CSM plays a pivotal role in determining the earliest epoch after which seed nucleation centers can form and survive in the post-shock region. We use X-ray and UV-optical data from SN2010jl to follow the evolution of the shock through the CSM, and solve for the time-dependent temperature and density profile of the post-shock gas. Embedding a 10 Å seed nucleation center in the dense cooling shell, we calculate its temperature, and the earliest epoch beyond which such grain can survive evaporation and rapidly grow to large submicron grains. Thereafter, we study the formation of possible dust species through nucleation of condensable elements, and trace their evolution in time through accretion and coagulation. The final dust mass yield has been calculated and compared with other known dust sources in the galaxy. Detection of the IR excess as early as 67 days post-explosion poses new challenges to our understanding of the dust scenario behind shocks. Our model, first of this kind, provides a complete picture of the formation of dust in such extreme astrophysical environments and the role of Type IIn supernova as sources of dust in galaxies.

Kinematic evolution of non-radiative supernova remnants

Poster

Xiaping Tang

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Abstract

The kinematic evolution of a non-radiative supernova remnant (SNR) is characterized by the transition from an ejecta dominated phase to an ambient medium dominated phase. The asymptotic behaviors of the remnant in the early ejecta dominated phase, when swept up ambient medium mass is negligible, and the late ambient medium dominated phase, when ejecta mass becomes negligible, have already been extensively studied. It is well known that in early ejecta dominated phase, the evolution of the SNR simply follows the free expansion solution or the self similar driven wave solution depending on the density profile of the ejecta. In the late ambient medium dominated phase, the evolution of the SNR asymptotically approaches the Sedov-Taylor solution. But in reality observed young non-radiative SNRs are always in transition from one asymptotic solution to the other, so it is essential to understand the transition between phases. We present a new approach based on dimensional analysis to derive an analytical solution describing the kinematic evolution of a SNR during the transition. Since no assumption for the dynamical structure within the remnant is required, the solution is simplified compared to previous work (e.g., Truelove & McKee 1999, TM99). We compared our

solution with the TM99 solution and 1D numerical simulation results for both a uniform density medium and a wind density profile ambient medium. For all our cases, the age calculated from our analytical solution at a certain radius is consistent with the numerical simulation to an accuracy of a few percent and provides a better fit than the TM99 solution.

Determination of the extinction law of dust in SNRs

Poster

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Abstract

Dust plays an important role in astrophysics, and the demand to characterize and understand dust is increasingly appreciated. In addition to asymptotic giant branch stars evolved from low- and intermediate-mass star, supernovae (SNe) are an important contributor to interstellar dust. On the other hand, SNe destroy interstellar dust due to its violent shock waves. How much SNe contribute to and affect interstellar dust is very unclear. The estimation of amount of dust from per SN has an uncertainty of three orders. Rather than from the dust emission, we study the dust property of SNR through its extinction, which has the advantage of avoiding the very uncertain dust temperature. The SNR S147 is chosen as the first target. Based on the LAMOST spectroscopic survey and the UCAC4 photometric catalog, the intrinsic color index is derived with its relation to the effective temperature given the spectral luminosity and metallicity in a way similar to Wang & Jiang (2014). Based on the color excess in various bands, the extinction curve is derived. Finally, we present a dust model to fit the extinction curve, which explores the properties of the dust in S147 including the dust size distribution, dust composition and shape etc. The properties are compared with that of the normal interstellar dust.

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