Observational facts of extragalactic SNRs

Are there ANY surprises?

M. D. Filipović & Luke M. Bozzetto & Q. Roper
(Western Sydney University)

F. Haberl, R. Sturm
(Max-Planck-Institut für extraterrestrische Physik)
P. Kavanagh,
(Dublin Institute for Advanced Studies)
M. Sasaki
(Institüt fur Astronomie und Astrophysik, Tübingen)
D. Urosević & BaneBojanMarko)
(Uni of Belgrade)
P. Maggi
(Laboratoire AIM, IRFU/Service d'Astrophysique)

Crawford, E. J. De Horta, A. Y., Tothill, N. F. H., Stupar, Kothes, R., M., **Grive, K.,**
Parker, Q. A., Reid, W. A., Dickel, J., Williams, R., Ehle, M., Gruendl, R., Chu, Y.-H., Points, S., Brantseg, T.,
McEntaffer, R. L., Pietsch, W. Payne, J. L., Smith, R. C., Ballet, R., Buckley, D., Cajko, K., Lakicevic, M. , Warth, G.

Image background image taken from the MCELS (Smith et al. 2005)

The CRAB Nebula and the first "cover-up" in the history of science

24th June 1054 and the East-West Schism

For many days Venus and SN 1054 occupied symmetric positions with respect to the Sun

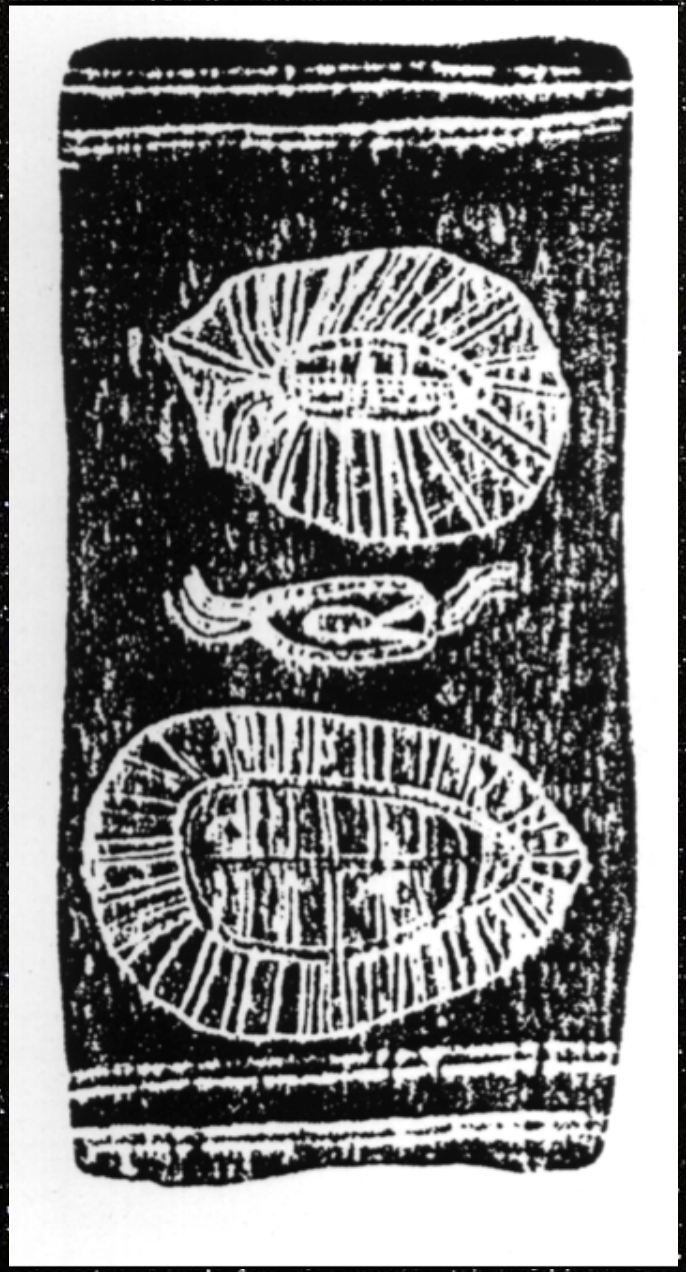
The coinage of Costantino Monomaco

(Solidus Aureus) Minted from 1042 to 1055 for 4596 days.

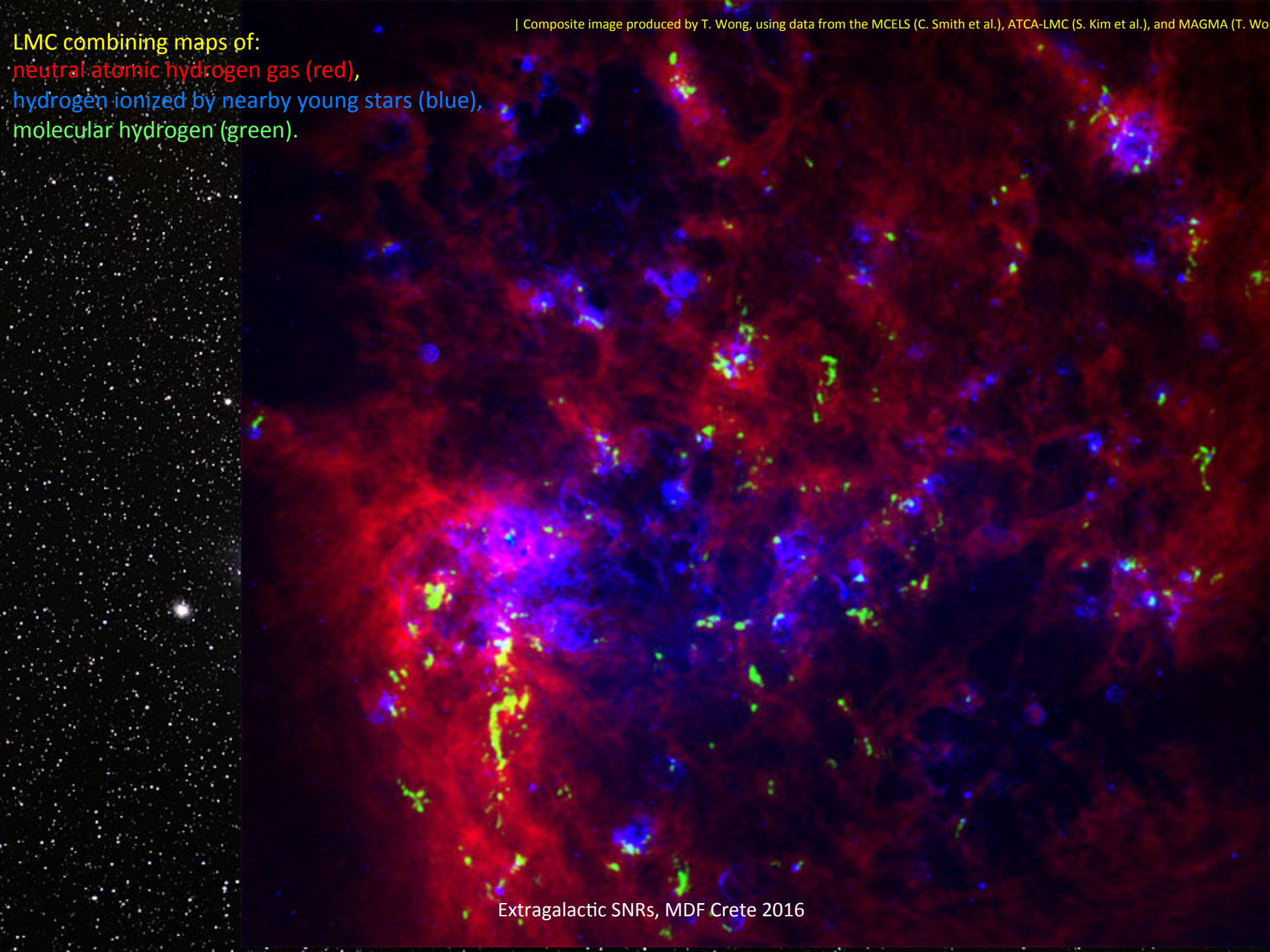
Two varieties:

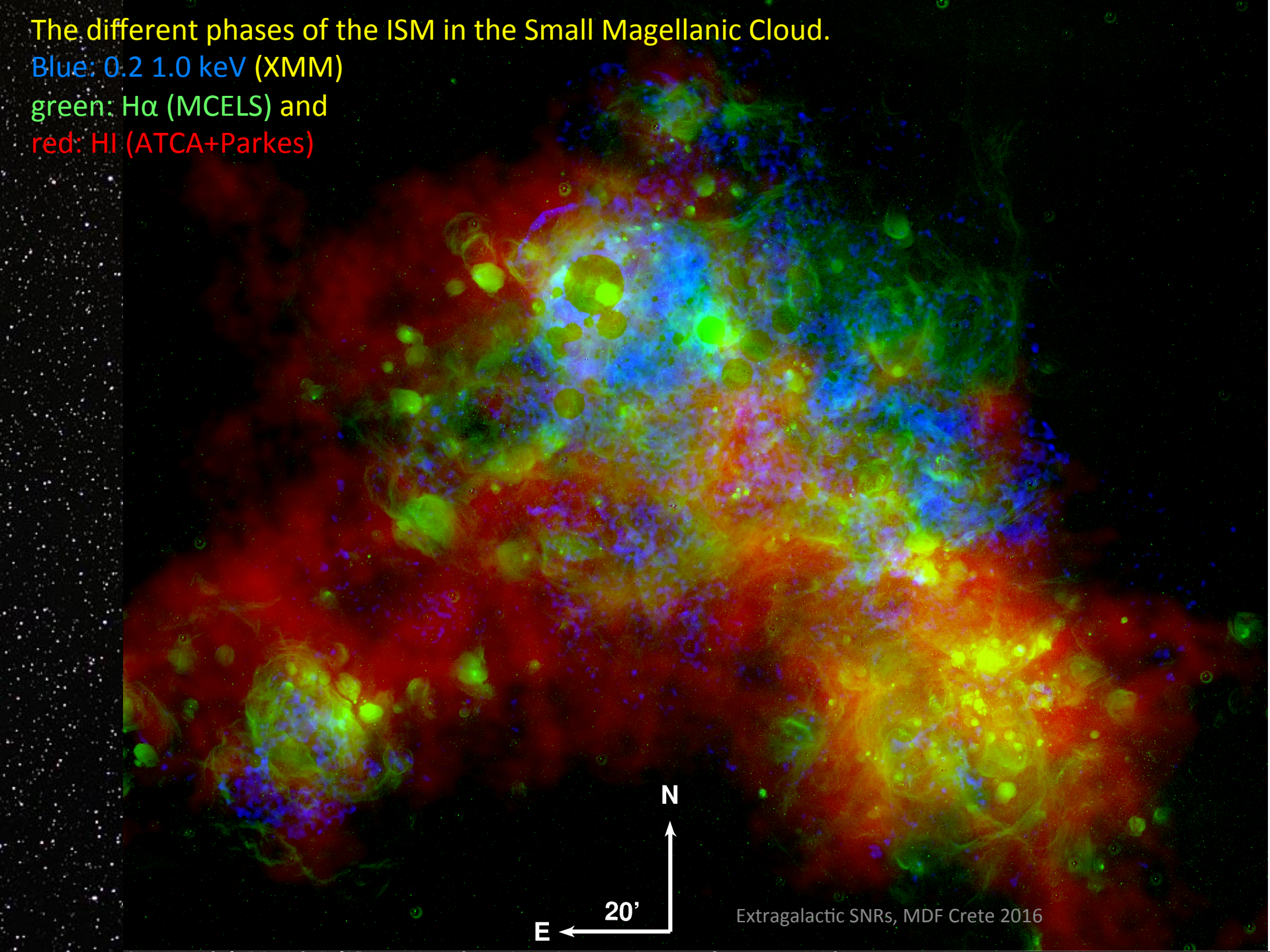
Out of the 4000 known coins, in 20 the emperor's face is sided by two symmetric stars

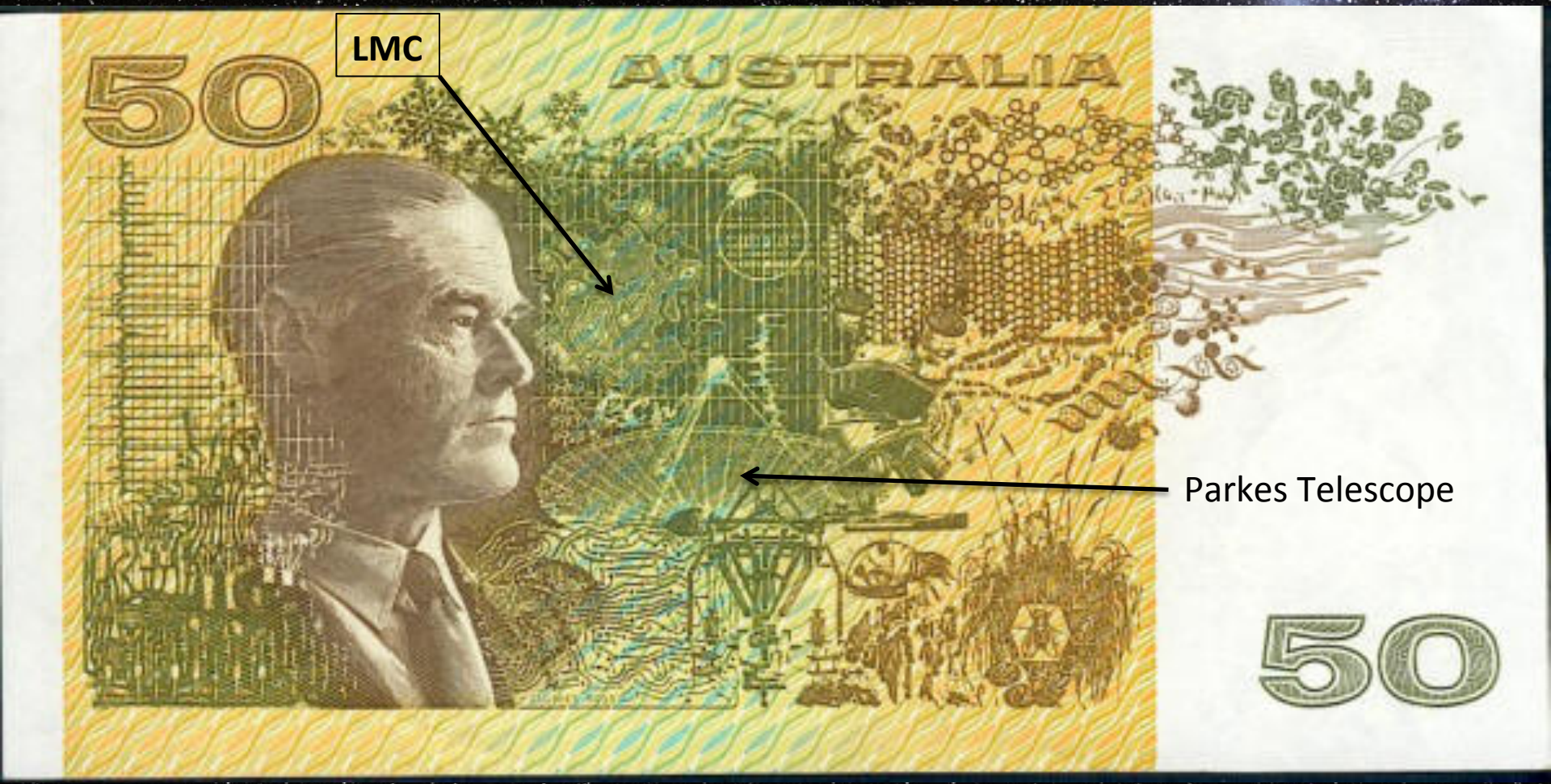
4000:4596 = 20:x -> x = 23 days!!!



Haynes+1991


LMC combining maps of:
neutral atomic hydrogen gas (red),
hydrogen ionized by nearby young stars (blue),
molecular hydrogen (green).
| Composite image produced by T. Wong, using data from the MCELS (C. Smith et al.), ATCA-LMC (S. Kim et al.), and MAGMA (T. Wo


The different phases of the ISM in the Small Magellanic Cloud.
Blue: 0.2 1.0 keV (XMM)
green: Hα (MCELS) and
red: HI (ATCA+Parkes)
N
E
20’
Extragalactic SNRs, MDF Crete 2016


LMC
50
AUSTRALIA
Parkes Telescope
50


AL 08519999
50
Australia
AL 08519999

Our business started in 1964

telescope at Mt. Stromlo. There is no central exciting star and it has a looped filamentary appearance characteristic of some remnants of galactic supernovae. It is therefore suggested that N49 is a supernova remnant and it is the first extragalactic "radio" supernova to be discovered. Cassiopeia A, the well-known galactic supernova, which has a similar spectral index to N49, would be five times more intense if placed at the same distance as N49 (55 kpc).

My Brief Extragalactic SNRs history

- 60-ties … Fesen+ Dopita+ optical work…
- M31 Dickel 1968 and 70-ties
- LHG 1981 (soft X-rays from the LMC)
- 1987A
- Chu&Kennicutt 1988 – MCs SNR environments
- Dickel+ 1993+ Mag Fields of MCs SNRs
- Prompt type Ia (Borkowski+ 2006)
- Chomiuk&Wilcots 2009 – 43 SNRs in "distant" galaxies
- Long+ 2010 on M33
- Other nearby Galaxies SNRs - Leonidaki+ 2013
- Expansion of MCSNR 0509-675 (Hovey+15, Roper+16)

TYPE CLASSIFICATION OF MAGELLANIC CLOUD SNRS

CORE COLLAPSE:

- PRESENCE OF A PULSAR OR OTHER COMPACT REMAINS IN A REGION OF YOUNG STARS
- OXYGEN RICH

TYPE Ia:

- XRAY SPECTRA SHOW LINES OF HIGHLY IONIZED INTERMEDIATE MASS ELEMENTS
- BALMER DOMINATED IN OPTICAL

SNR IDENTIFICATION

- EXTENDED GENERALLY SHELL -LIKE OBJECT - ~0.3 PC FOR 1987A TO 158 PC FOR DEM L203

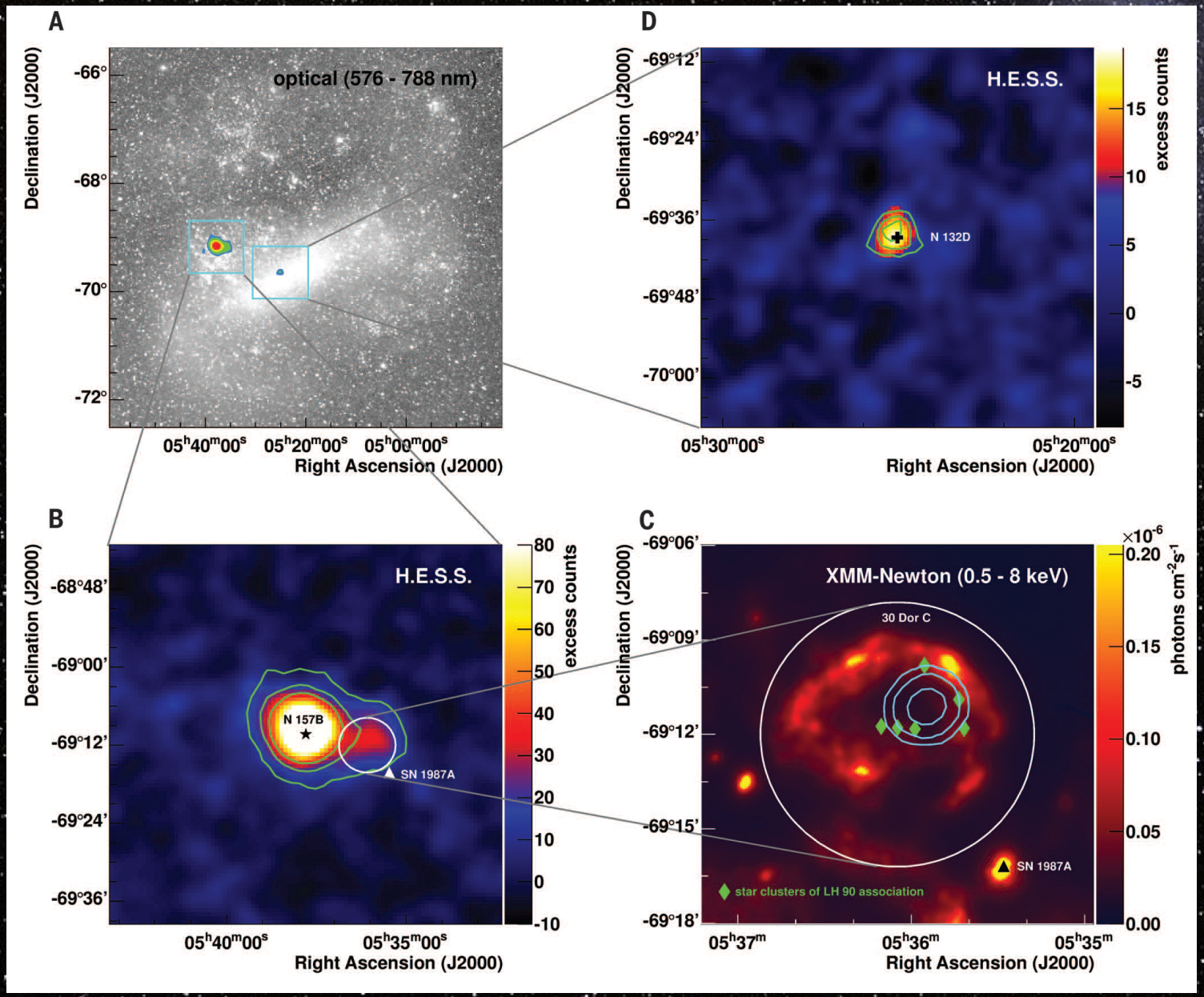
  (1 PC IS 4 ARCSEC AT THE LMC AND 3.4 ARCSEC AT THE SMC)
- NON THERMAL RADIO SPECTRA - TYPICAL SPECTRAL INDICES, $\alpha = -0.5$,

  WHERE $S_f = \text{const } f^{\alpha}$
- THERMAL X-RAYS - TYPICAL TEMP ~ 1 keV WITH A LARGE SPREAD
- CAVEAT - THE SNR WILD CHILD HAS

  FLATTER RADIO SPECTRA AND NON-THERMAL HIGH ENERGY X-RAY TAILS
- [S II]/ Hα > 0.4

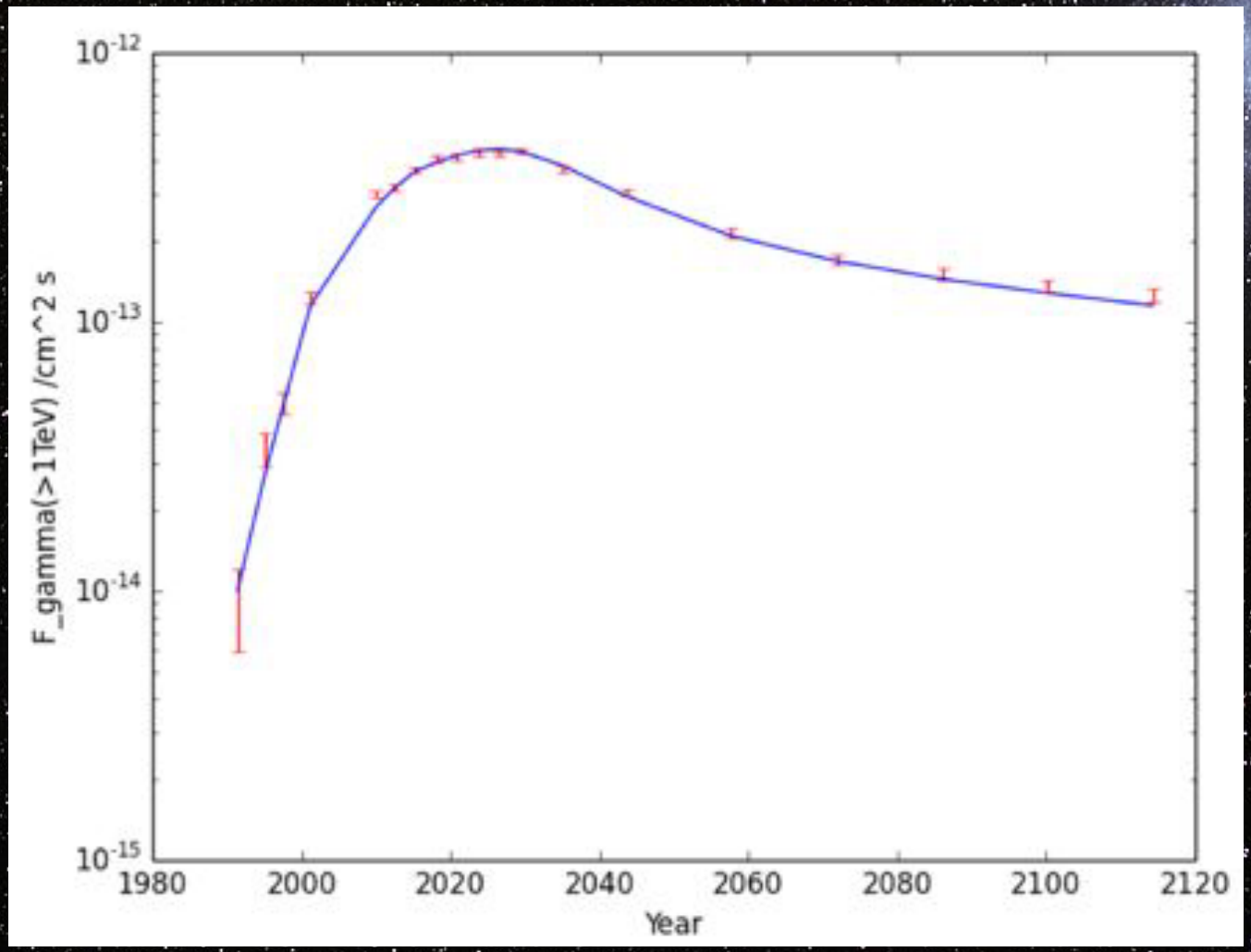
H.E.S.S. LMC

Abramowski et al 15



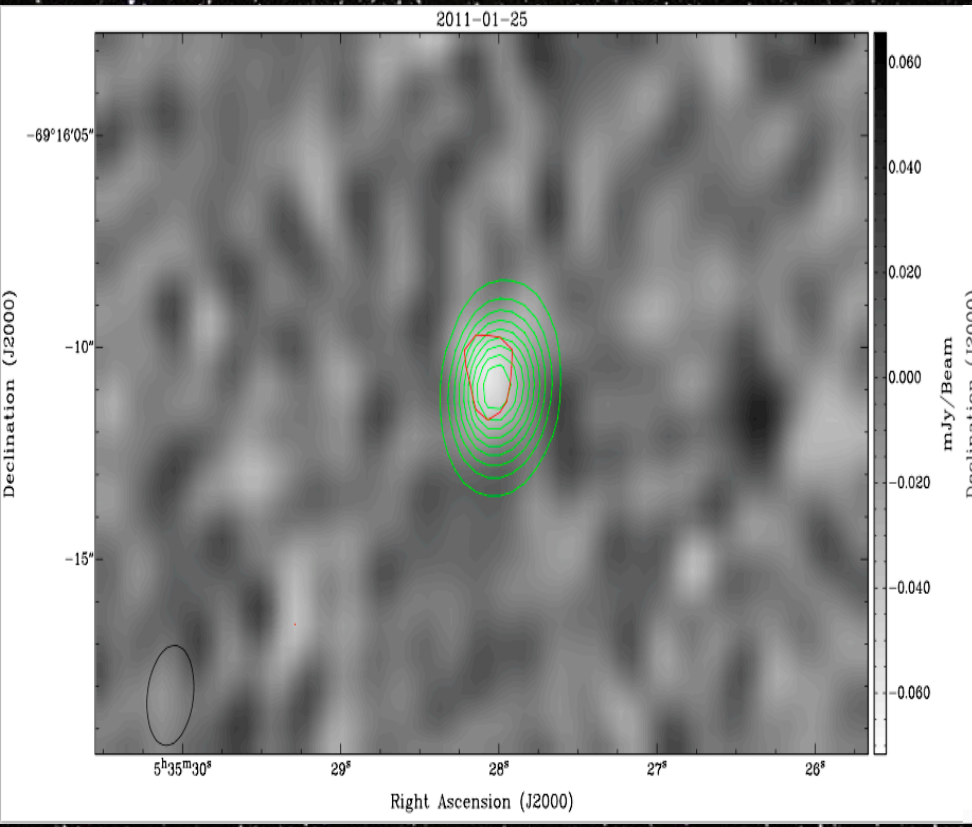
Kavanagh TALK!!!

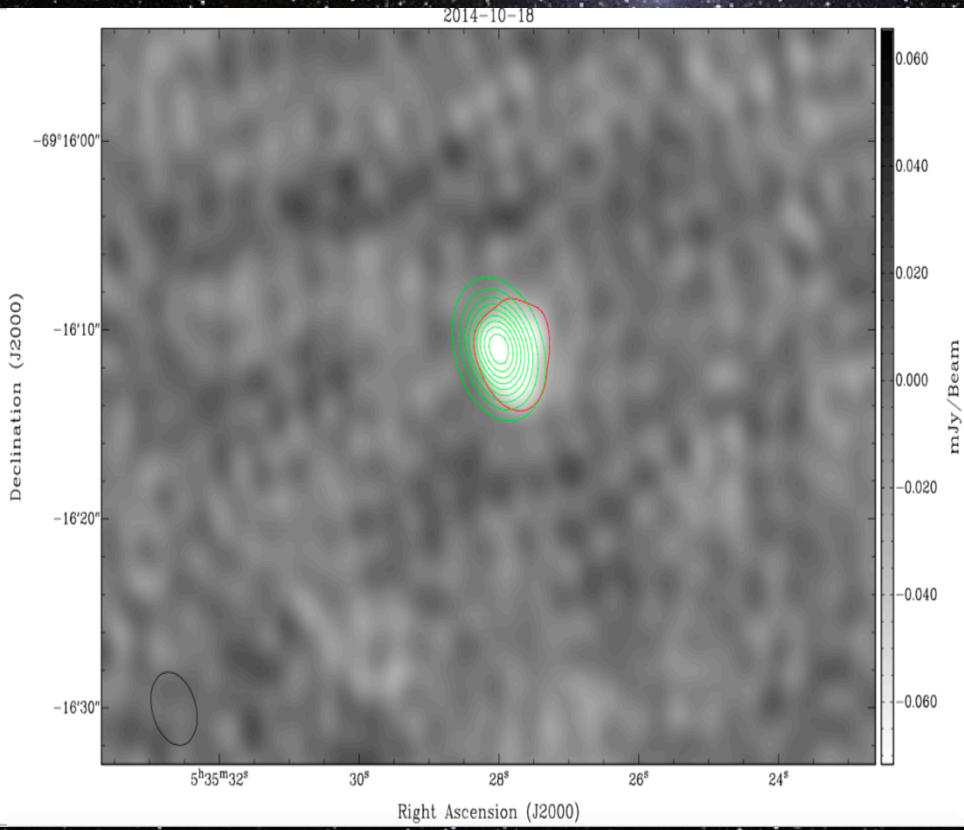
CTA LMC SN 1987A



Predicted gamma-ray light curve for SN1987A (blue, from E.G. Berezhko, priv. com.) and anticipated detections with CTA for several 50h observations distributed over decades (red points).

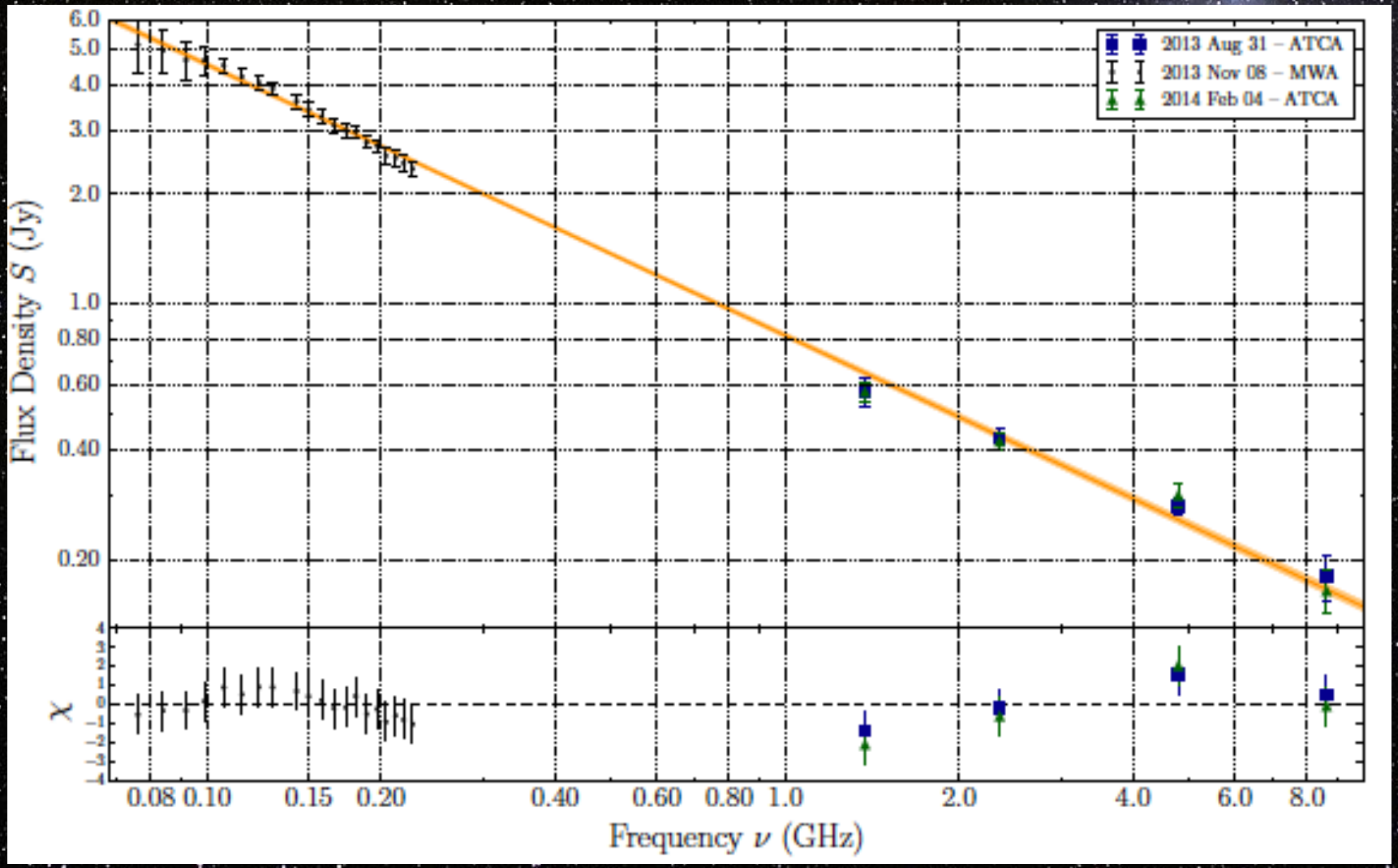
SN1987A Circular Polarisation Detection



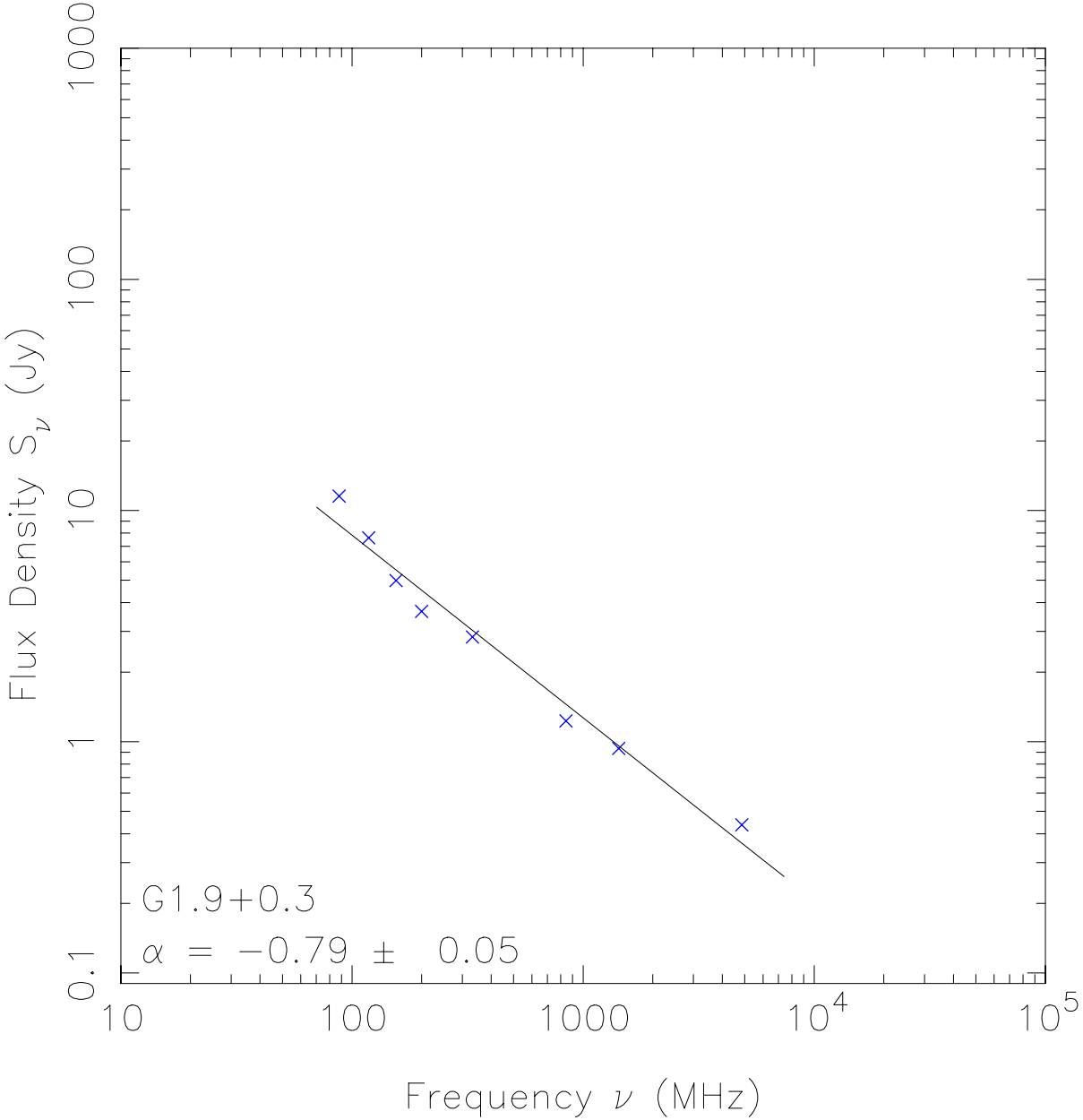


Two separate observations imaged (Stokes-V vs. Stokes-I).
Contours: Stokes-I SN1987A (*Green*), Stokes-V 3σ *r.m.s.* (*Red*)

1987A radio spectral index α=-0.74



Callingham+ 16


Flux Density S_ν (Jy)
1000
100
10
1
0.1
10
100
1000
10^4
10^5
Frequency ν (MHz)
G1.9+0.3
α = −0.79 ± 0.05

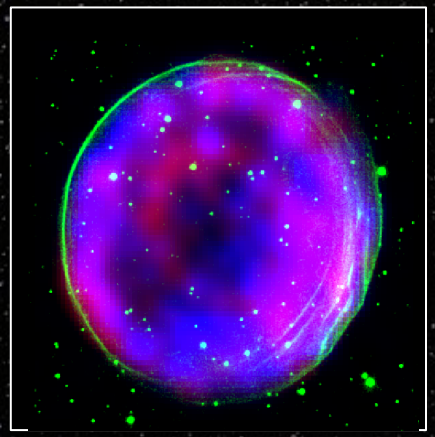
G1.9+0.3

LMC SNR 0509-67.5

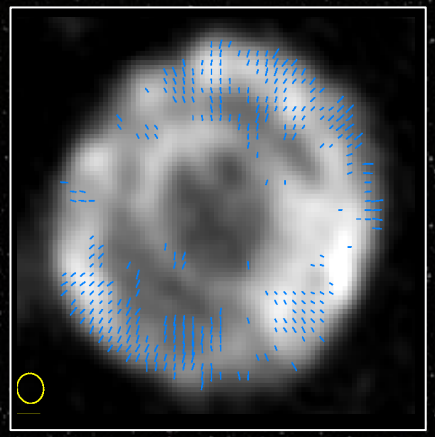
Bozzetto+ 2014, MNRAS

Type Ia, ~310 yr

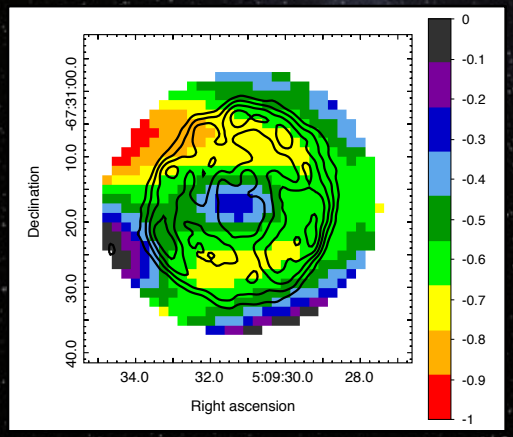
Morphology



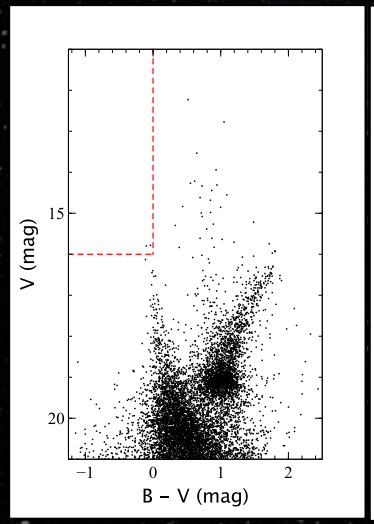
Polarisation

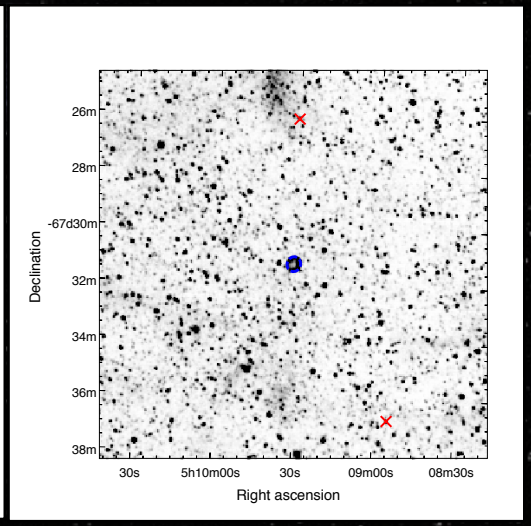


Spatial spectral variations

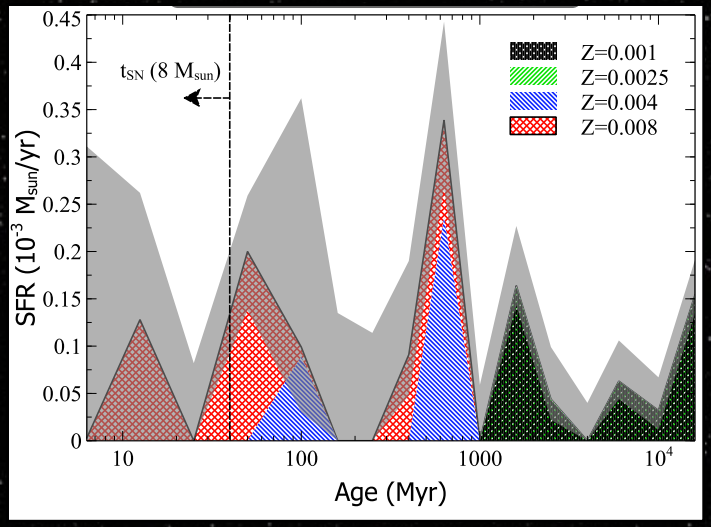


Stellar Environment





Star Formation History

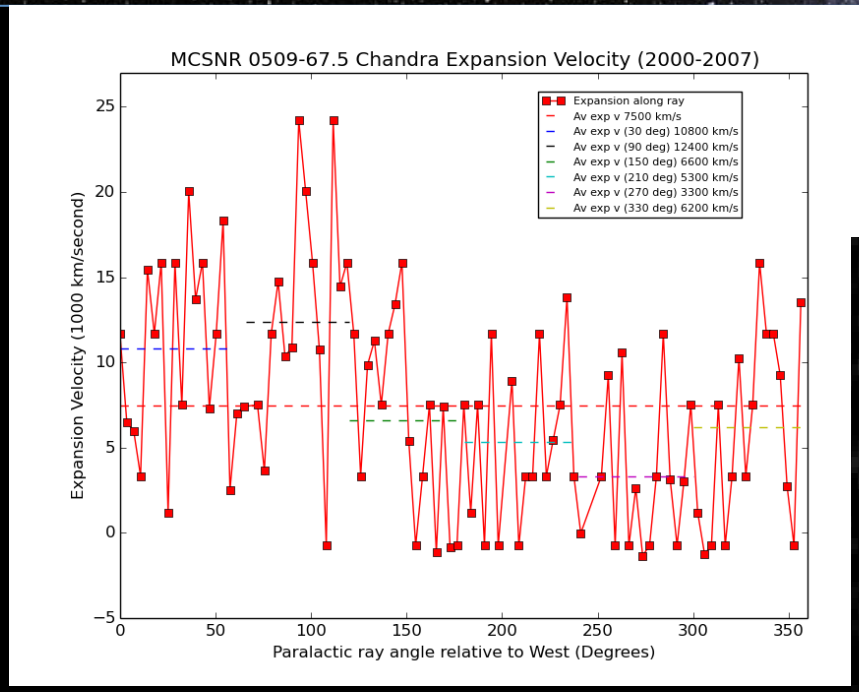


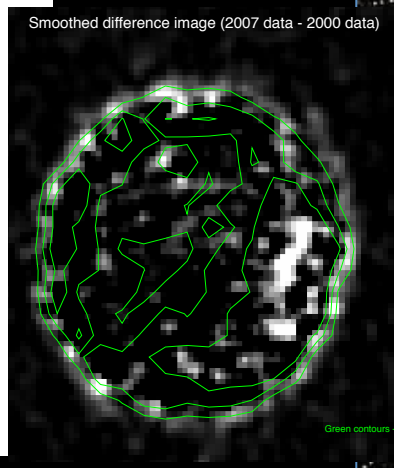
LMC SNR J0509−6731

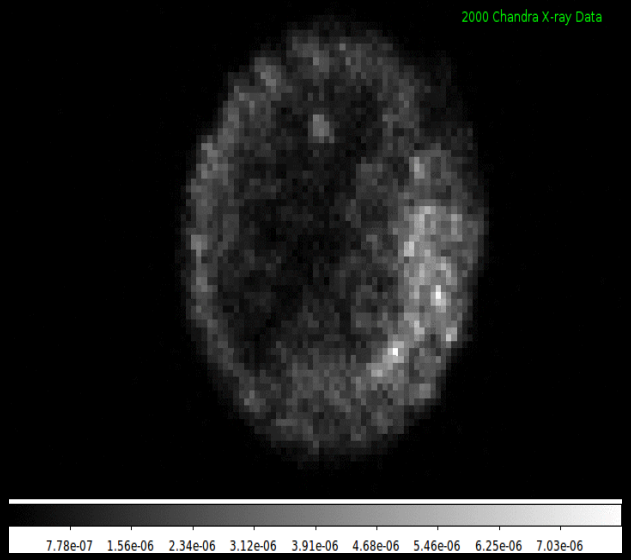
Hovey+ 15 → HST expansion ~6500km/s

D = 8 pc x 7 pc

Cassiopeia A	325 yr	−0.77
SNR J0509−6731	~310 yr	−0.73
Kepler's SNR	409 yr	−0.64
Tycho's SNR	441 yr	−0.61
SN 1006	1007 yr	−0.60

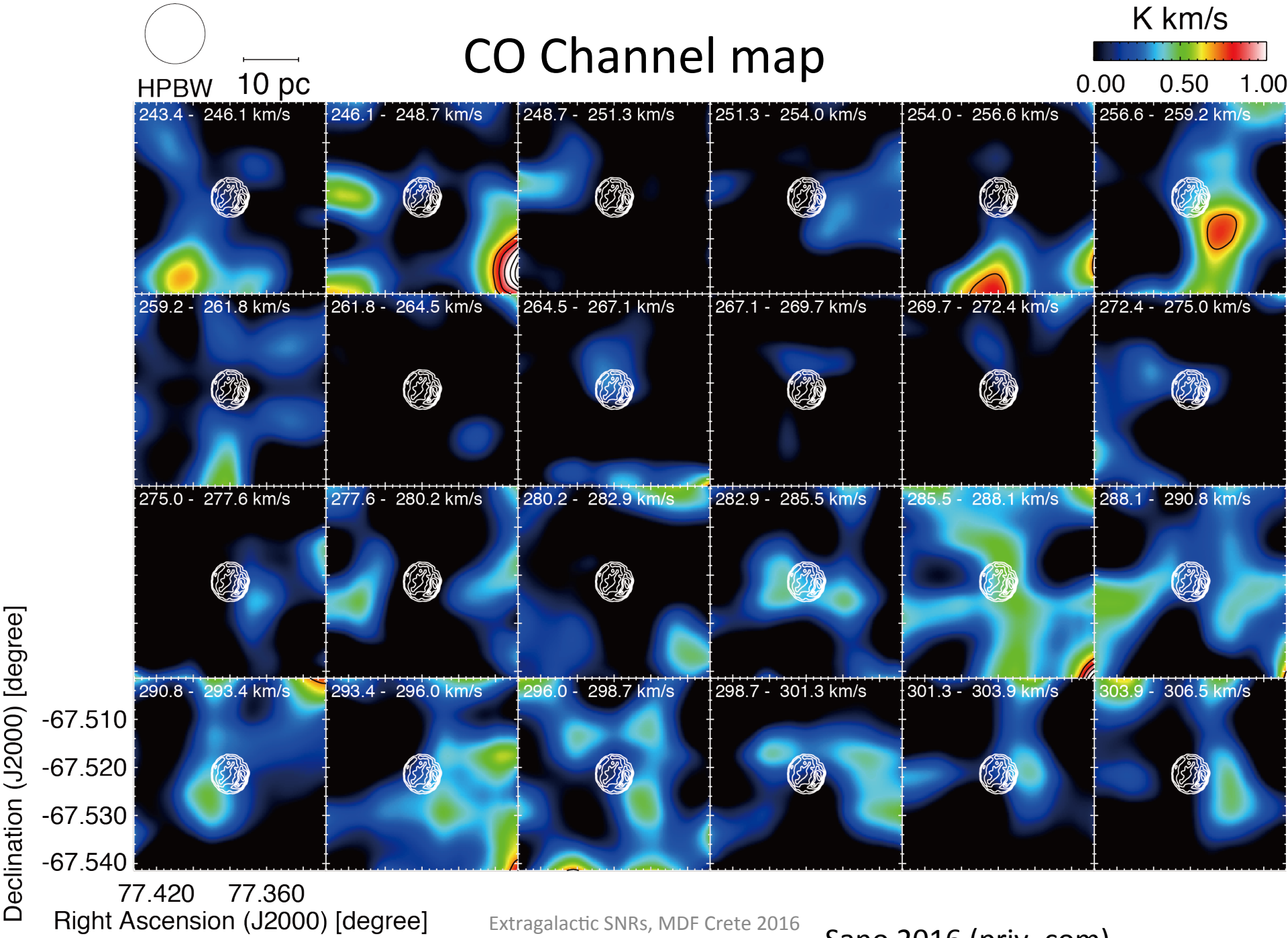






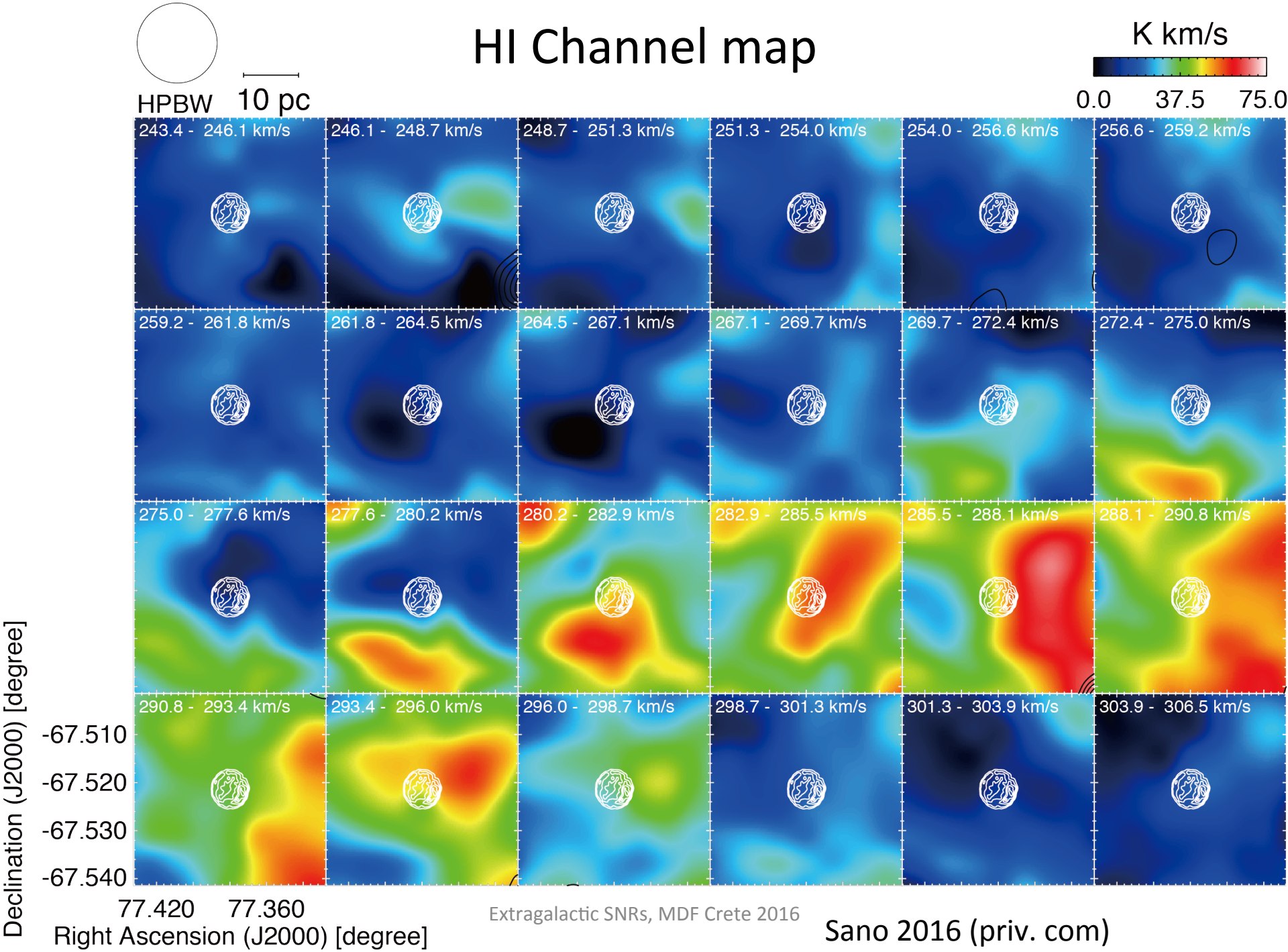
Up to 12,000±1,800 km/s Between 2000 and 2007!

CO Channel map



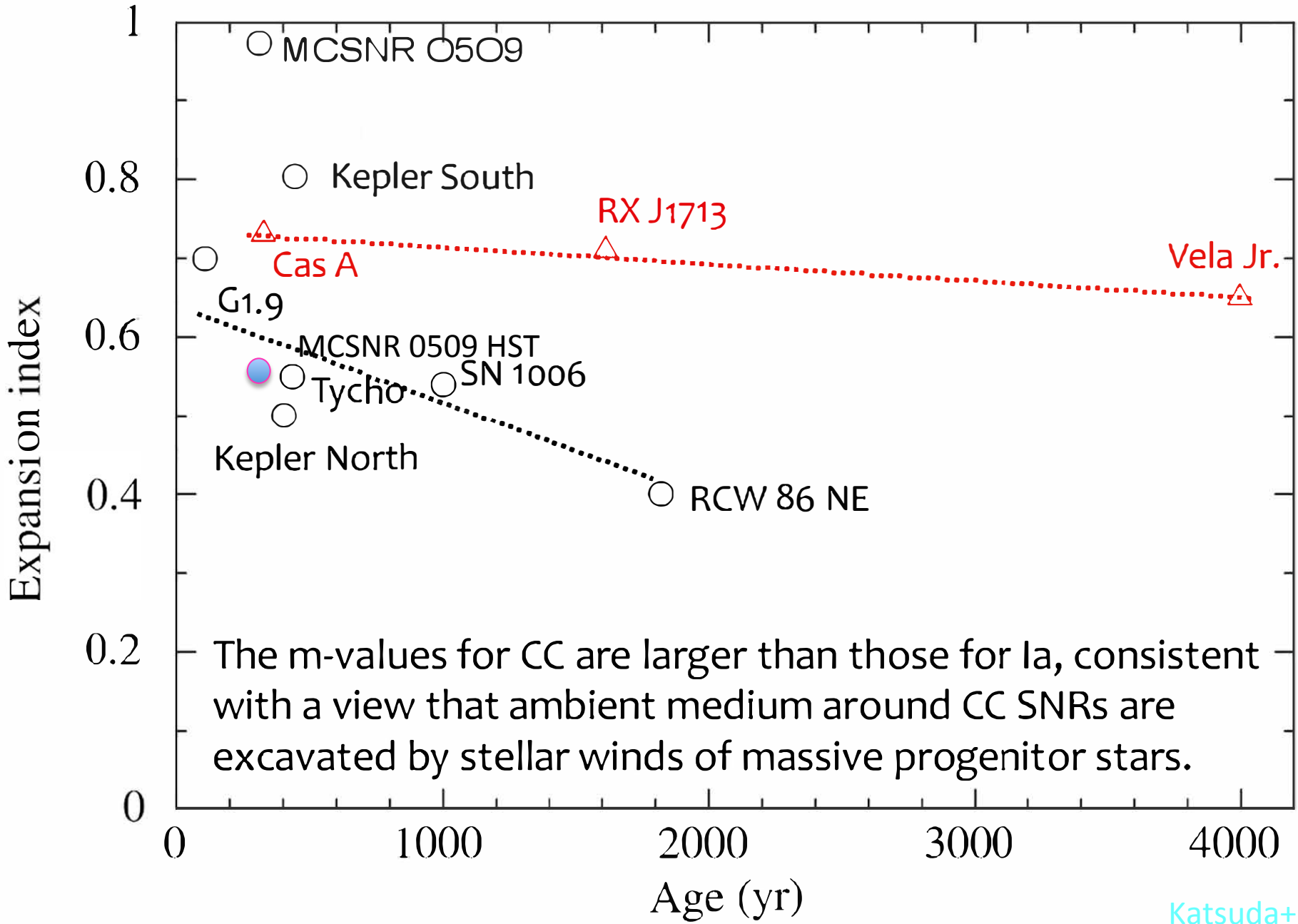
Sano 2016 (priv. com)

HI Channel map



Sano 2016 (priv. com)

What Can We Learn from Expansion Index?



The m-values for CC are larger than those for Ia, consistent with a view that ambient medium around CC SNRs are excavated by stellar winds of massive progenitor stars.

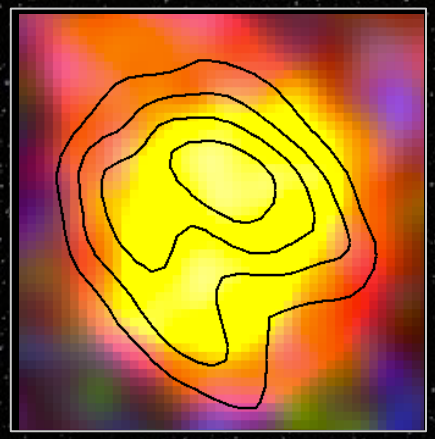
Katsuda+

LMC SNR 0536-7038

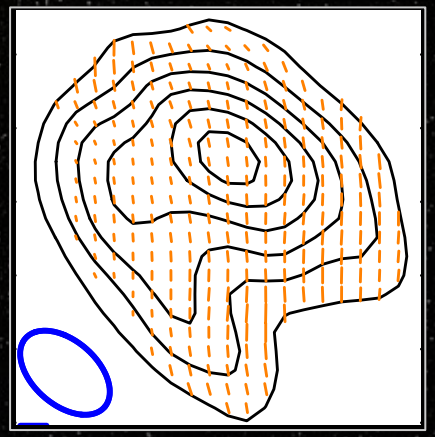
Bozzetto et al. 2014, ApSS

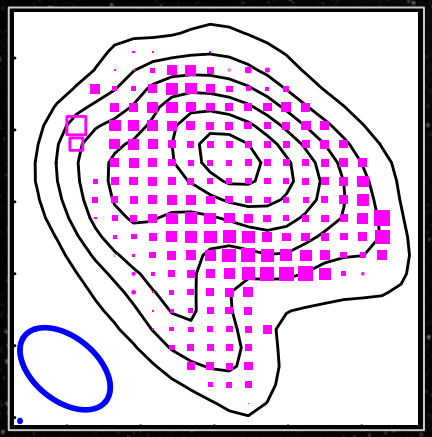
Type Ia, ~13,500yr

Morphology

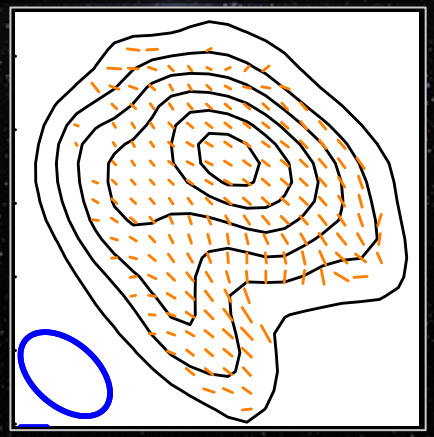


ATCA 6cm Magnetic Field





α = -0.52±0.07

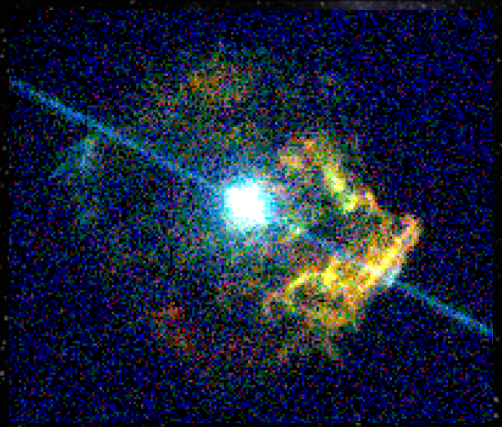


LMC SNR 0540-6919

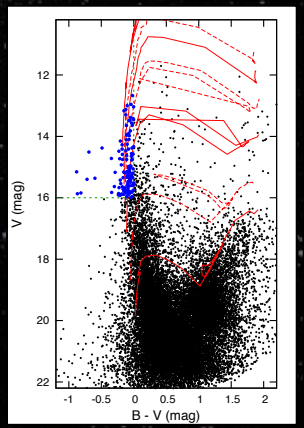
Brantseg et al. 2014, ApJ

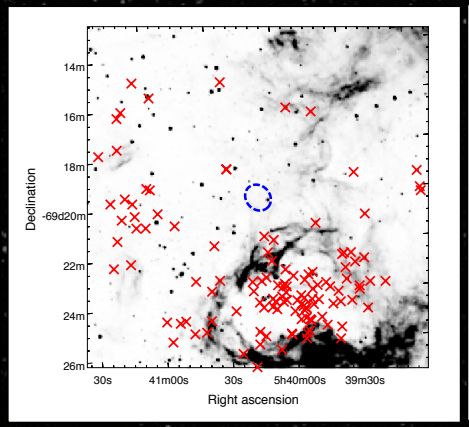
CC-PWN, ~760yr

Morphology

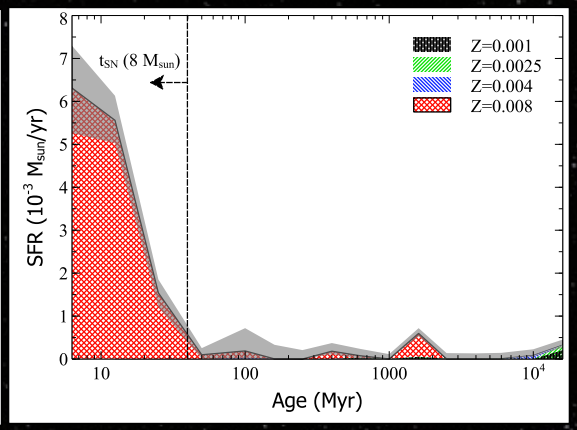


Stellar Environment





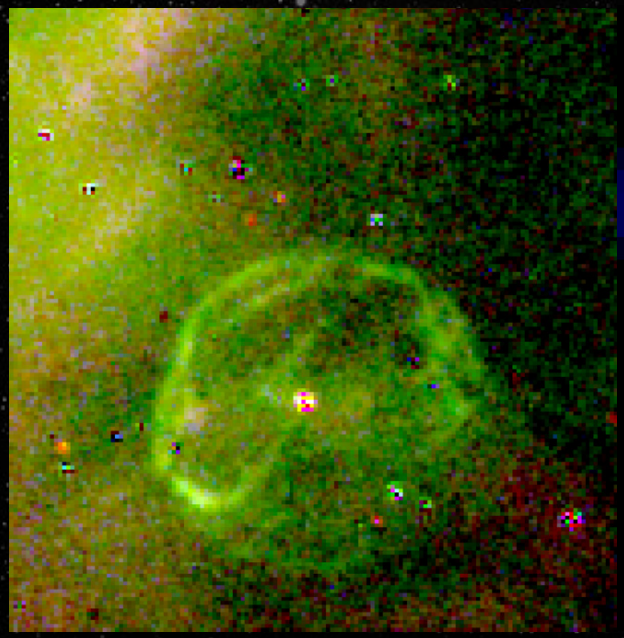
Star Formation History



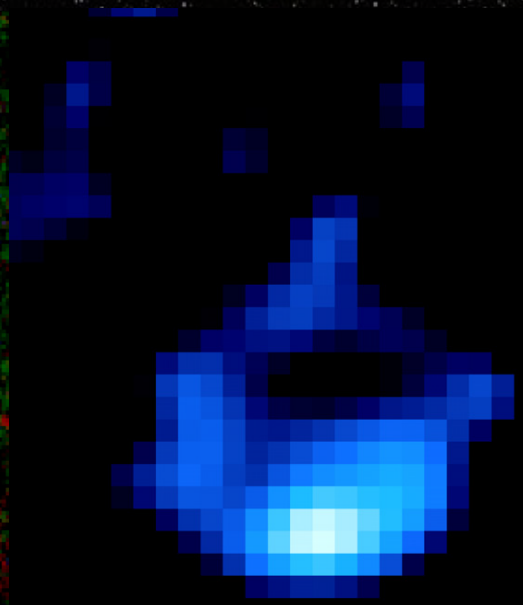
SMC SNR 0127-7332 (SXP 1062)

Haberl et al. 2012, A&A

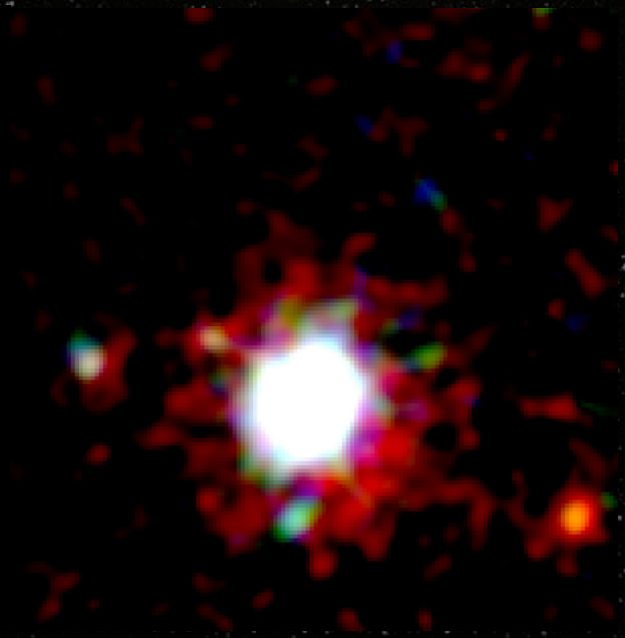
- SNR around Be/X-ray binary,
- Oxygen-rich -> Type Ib?
- Neutron start with a spin of 1062sec
- <25,000yr



MCELS



ATCA



XMM

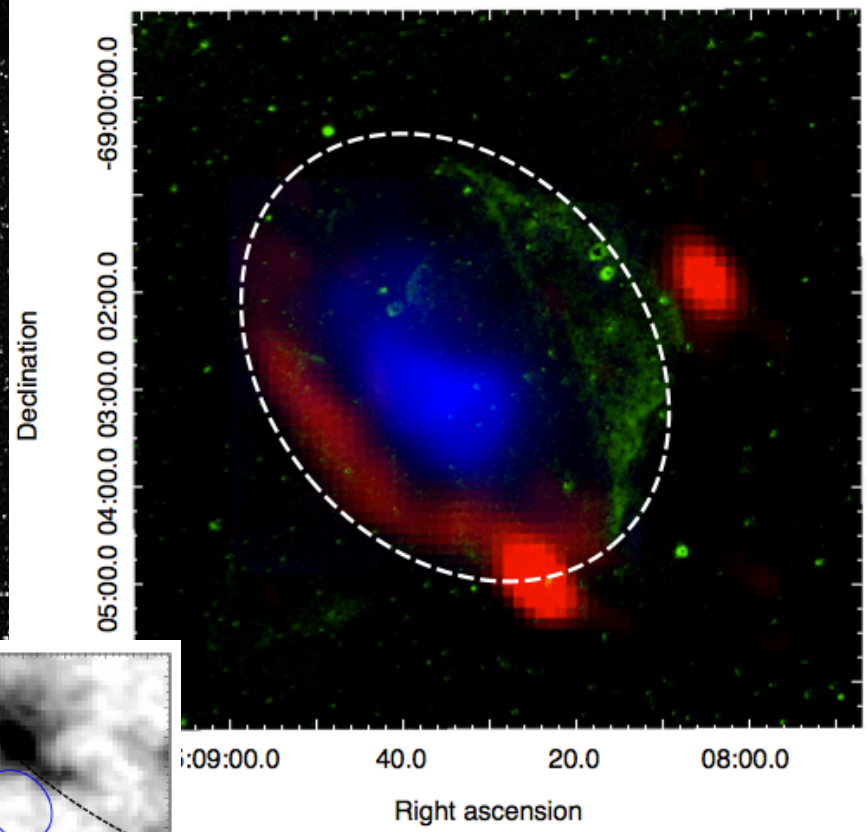
MC SNR 0508-6902

~74 pc **x** 57 pc

Fe mass of 0.5–1.8 Msol

TYPE Ia

B ~ 29 μGa



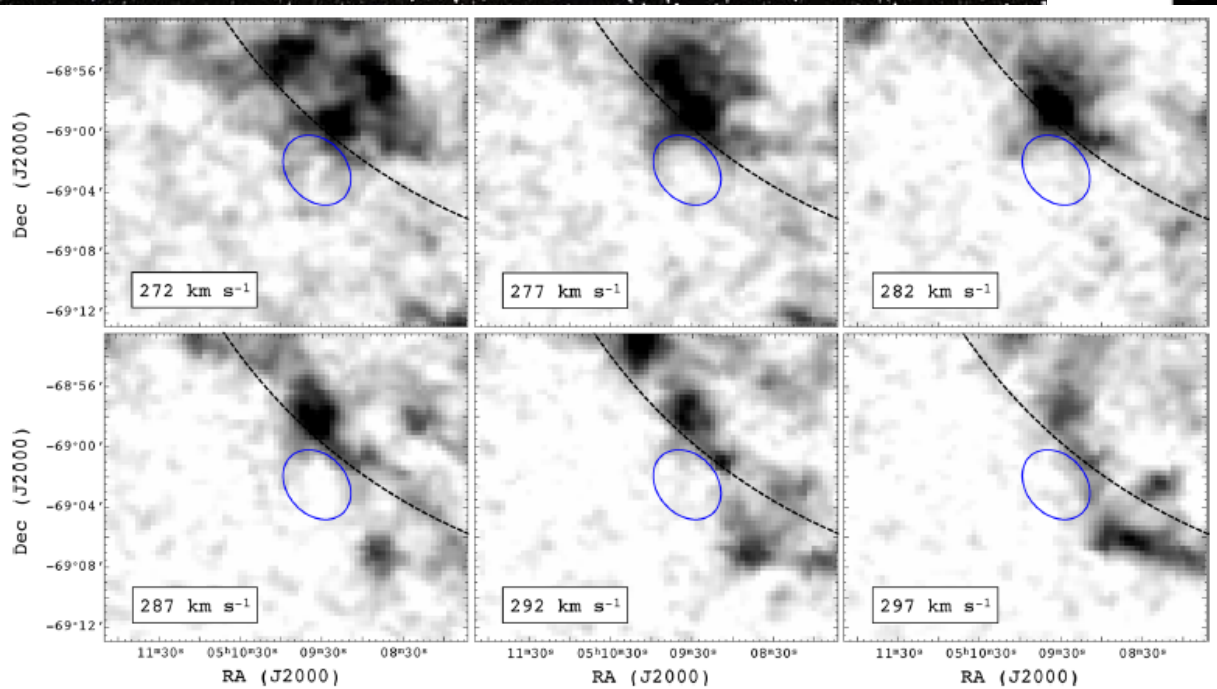


Figure 9. H I channel maps of SGS 5 in the region of MCSNR J0508−6902. The dimensions of the SNR are shown by the blue ellipses. The black dashed lines mark the approximate SGS 5 dimensions as determined by Kim et al. (1999). The heliocentric velocities are also indicated. A density gradient across MCSNR J0508−6902 due to SGS 5 is evident in each channel.

GREEN – MCELS

BLUE – XMM-Newton

RED -- ATCA

Bozzetto et al. 14

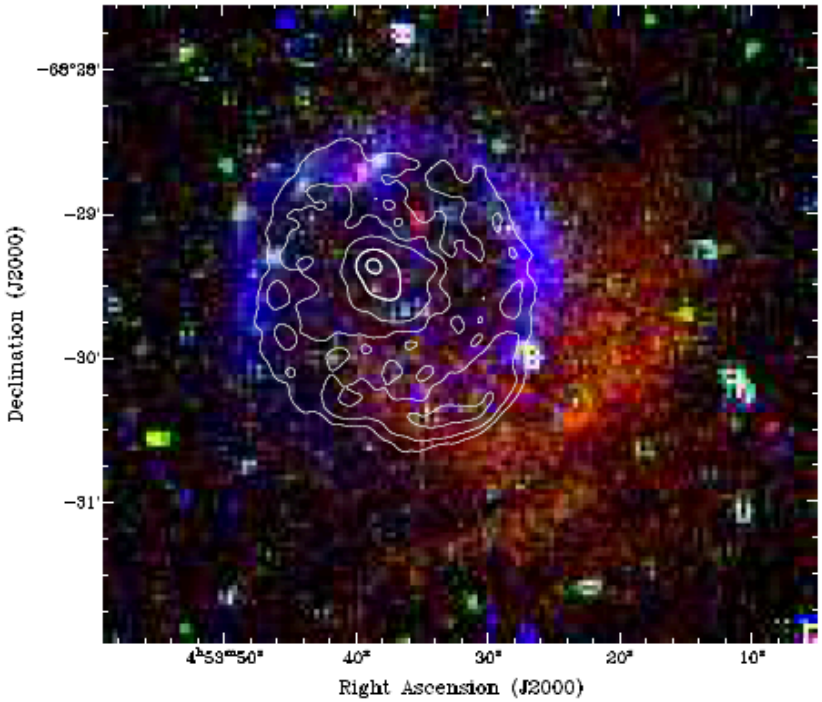
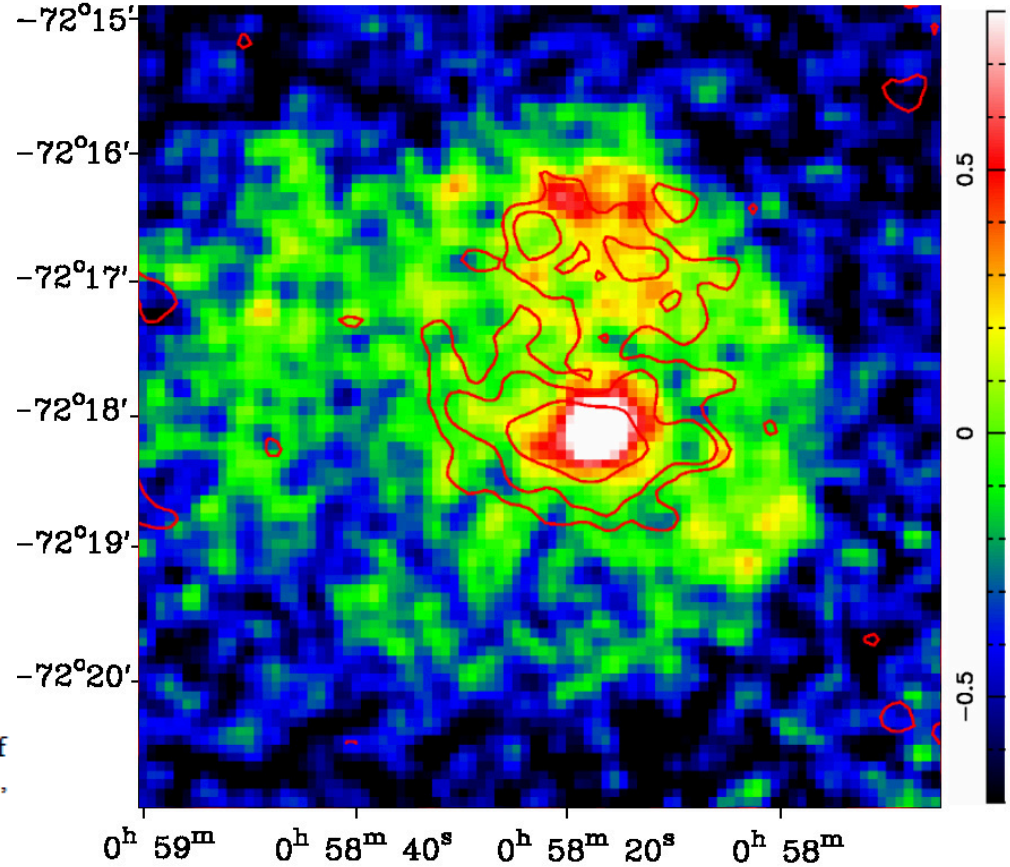
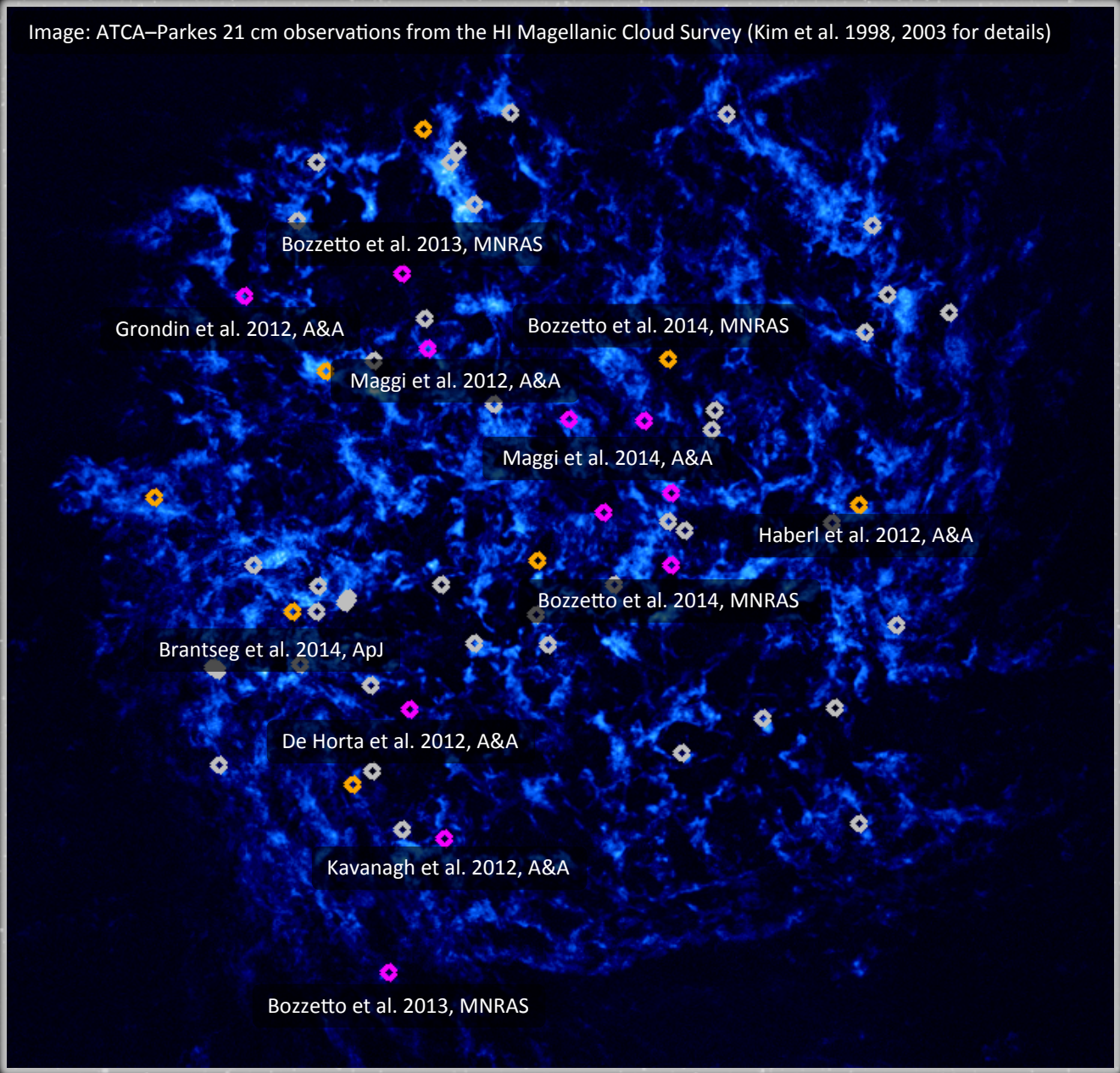


Fig. 7. MCELS composite optical image (RGB=H_α,[SII],[OIII]) of SNR J0453–6829 overlaid with 13 cm contours. The contours are 0.12, 0.4, 1, 4 and 8 mJy/beam.



Haberl et al. 2012

Owen+ 11 & Maitra+ 2015



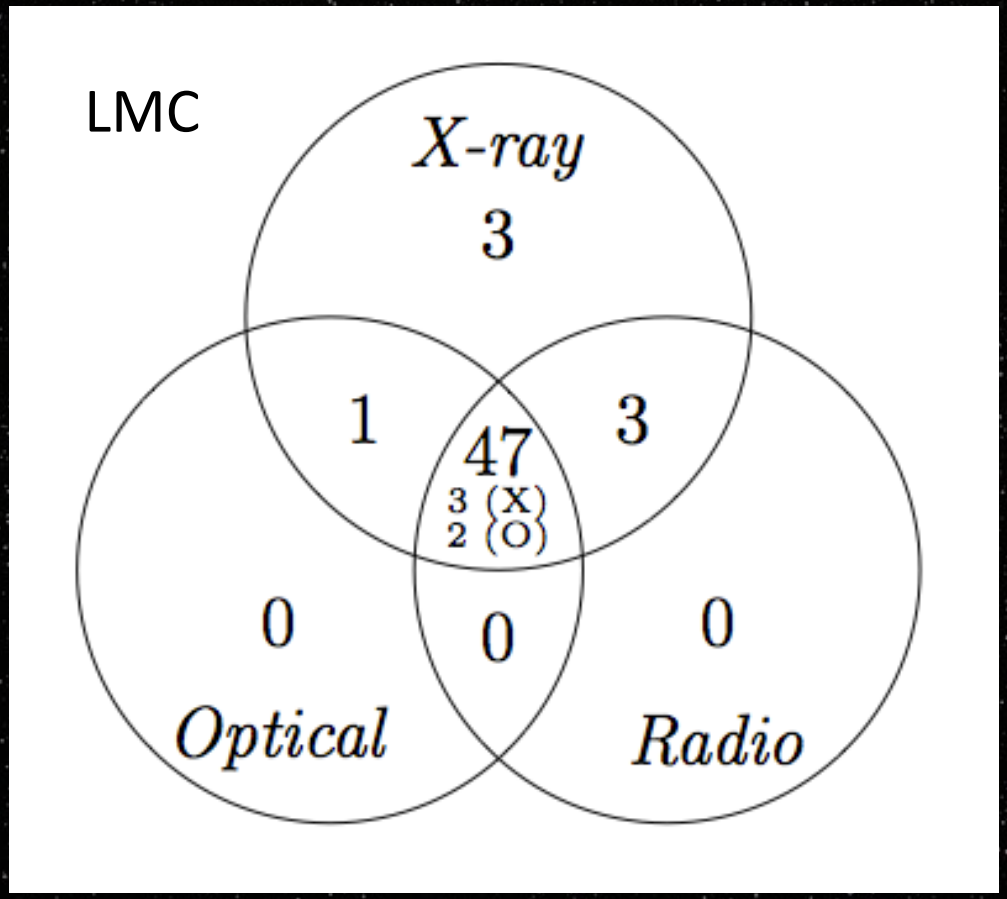
- 59 SNRs now classified
- 19 candidates
- 5 PWN (5-10%)
- 15 Type Ia (~20%)
- Detecting the very old and diffuse remnants

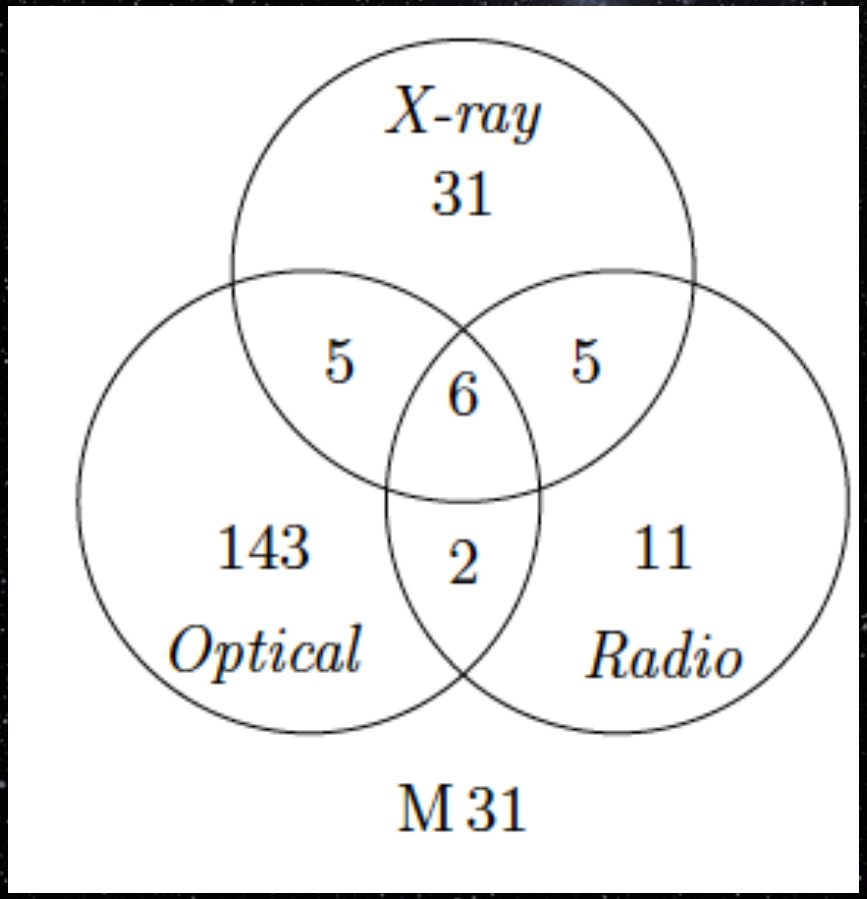
- Re-measure fluxes and extents

Published new SNR

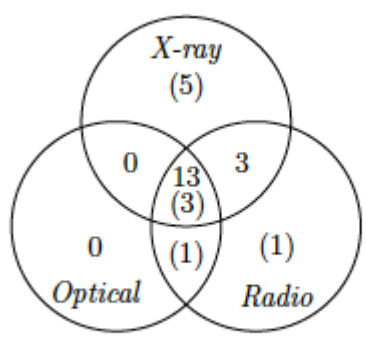
Published additional data

Unpublished

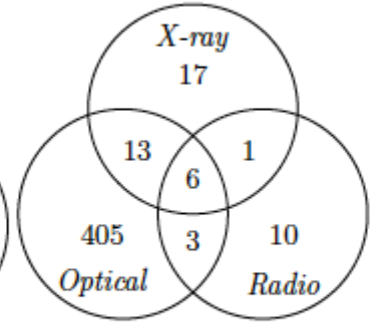

LMC
X-ray
3
1
47
3 (X)
2 (O)
3
0
0
0
Optical
Radio


X-ray
31
5
6
5
143
2
11
Optical
Radio
M 31

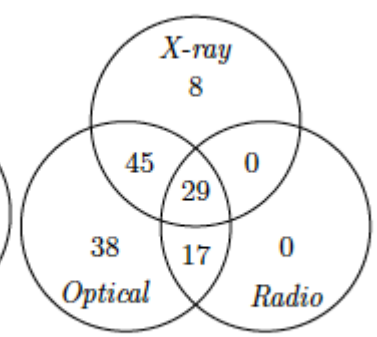
Multi-wavelength Detection



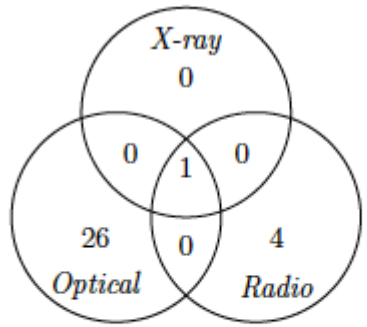
SMC



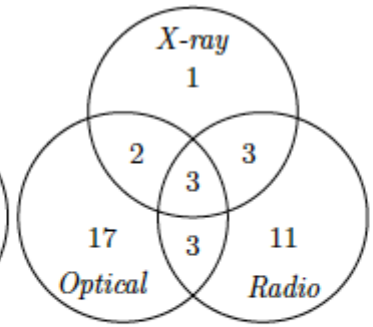
NGC 2403, 3077, 4214, 4395, 4449, 5204



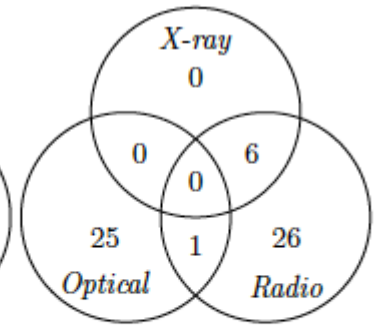
M33



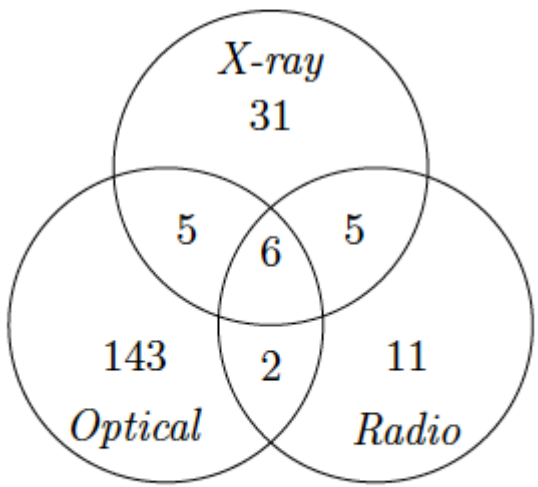
NGC 7793



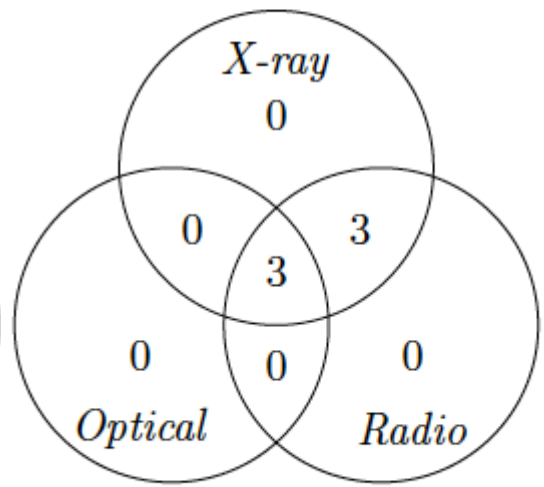
NGC 300



NGC 6946

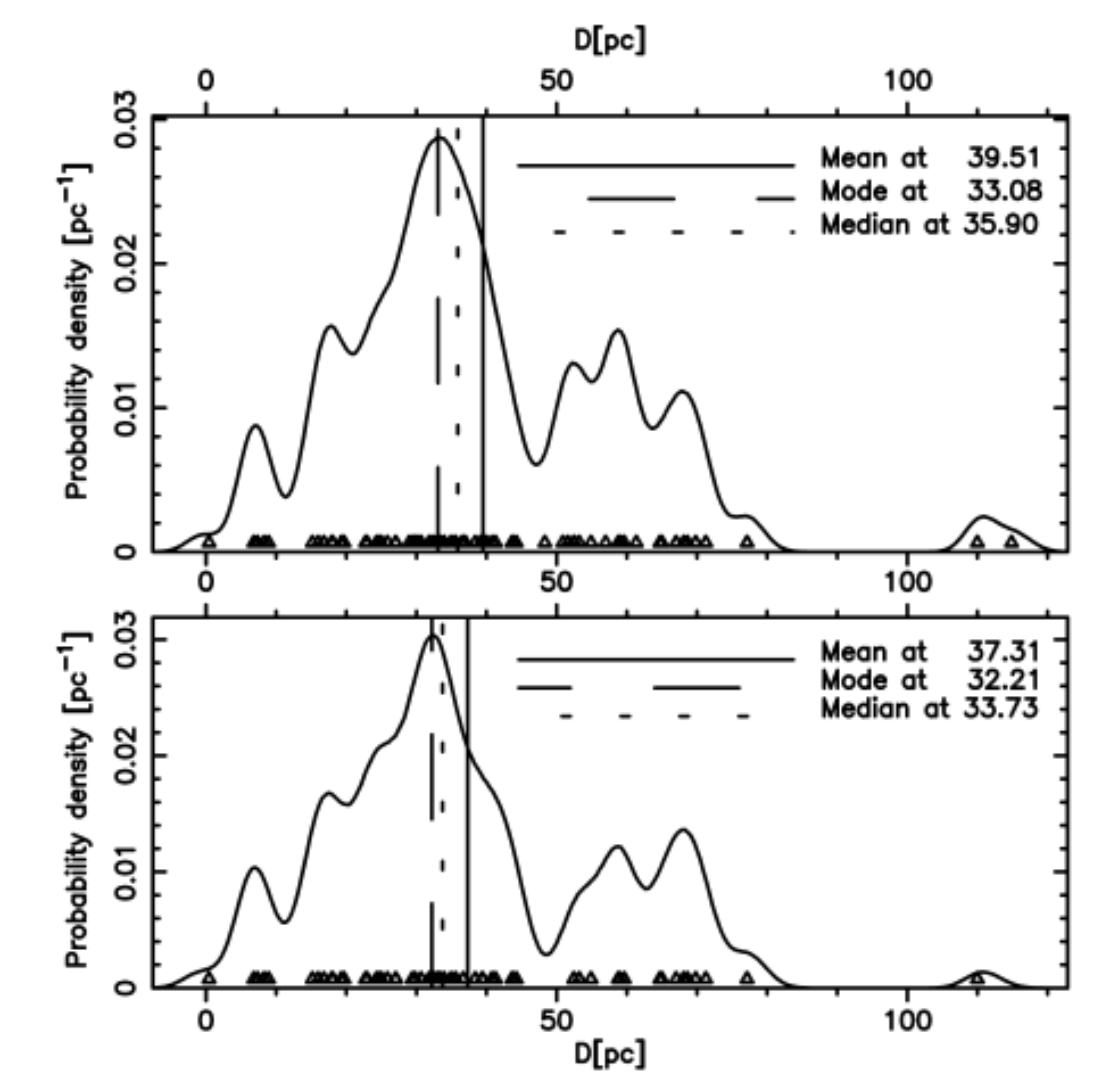


M 31



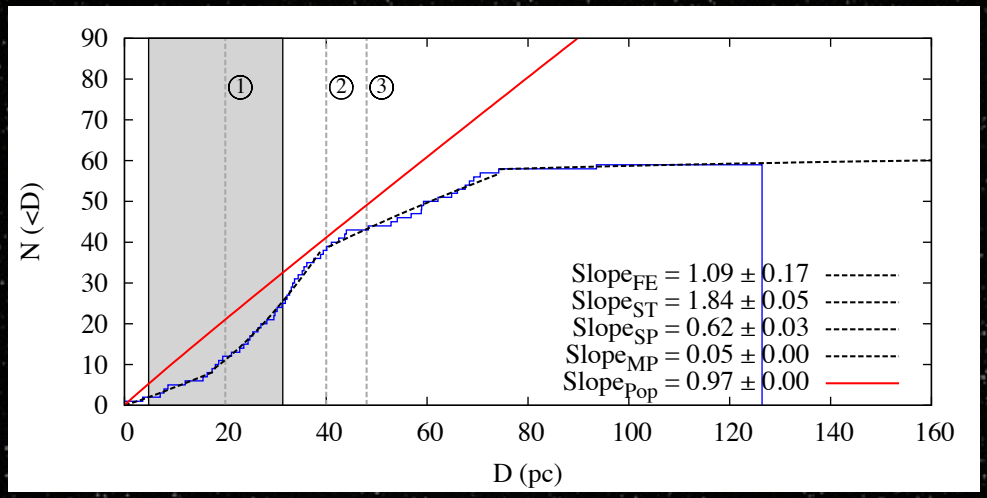
NGC 55

Diameter Distribution LMC SNRs

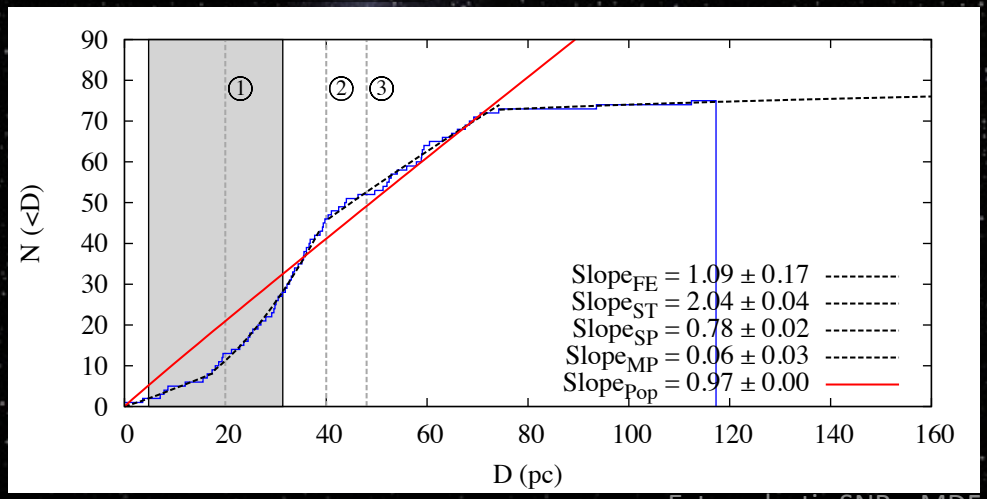


Cumulative number-diameter relationship (LMC sample only)

Confirmed



Candidate inclusive



FE = Free expansion

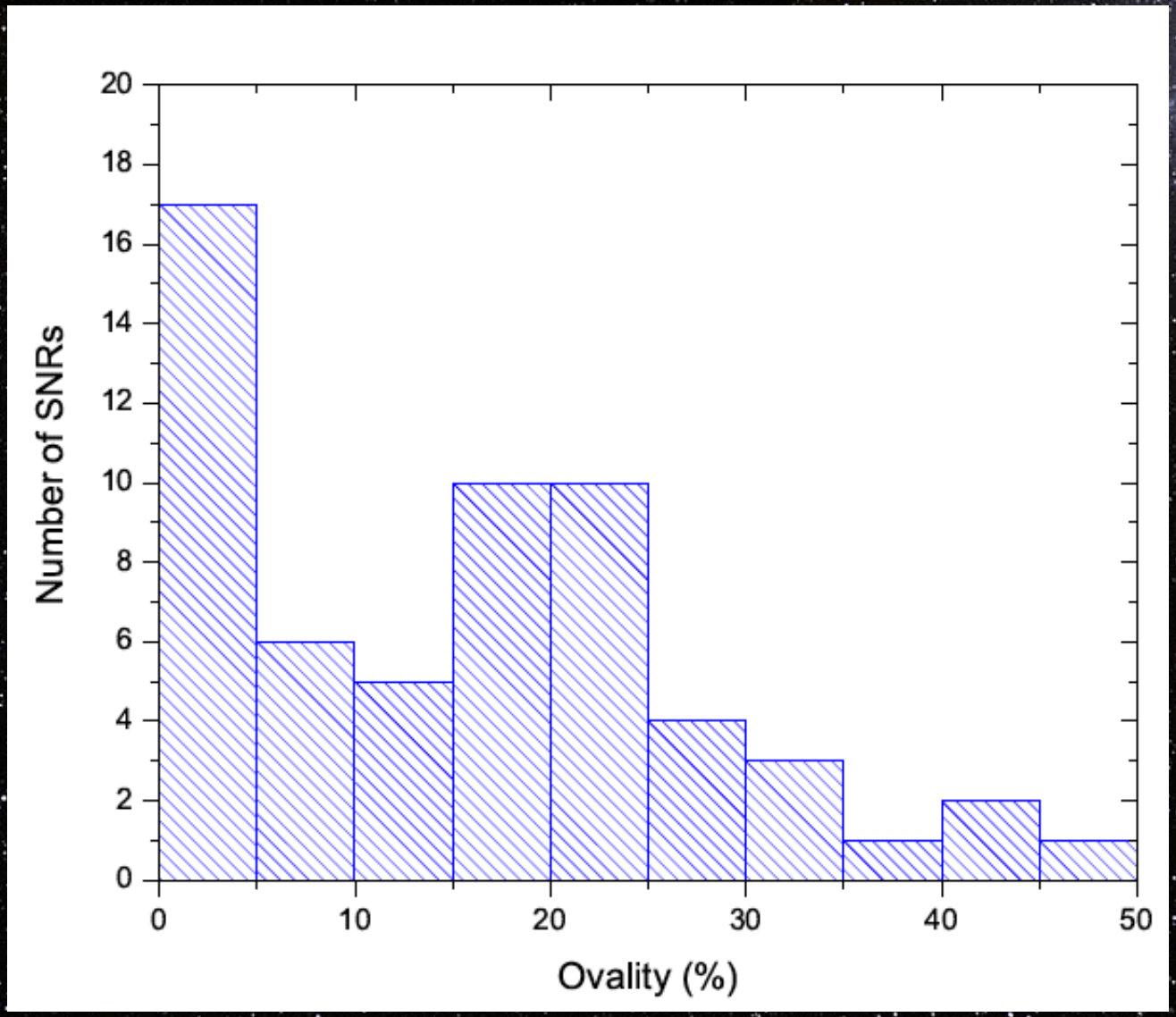
ST = Sedov-Taylor

SP = Snowplough

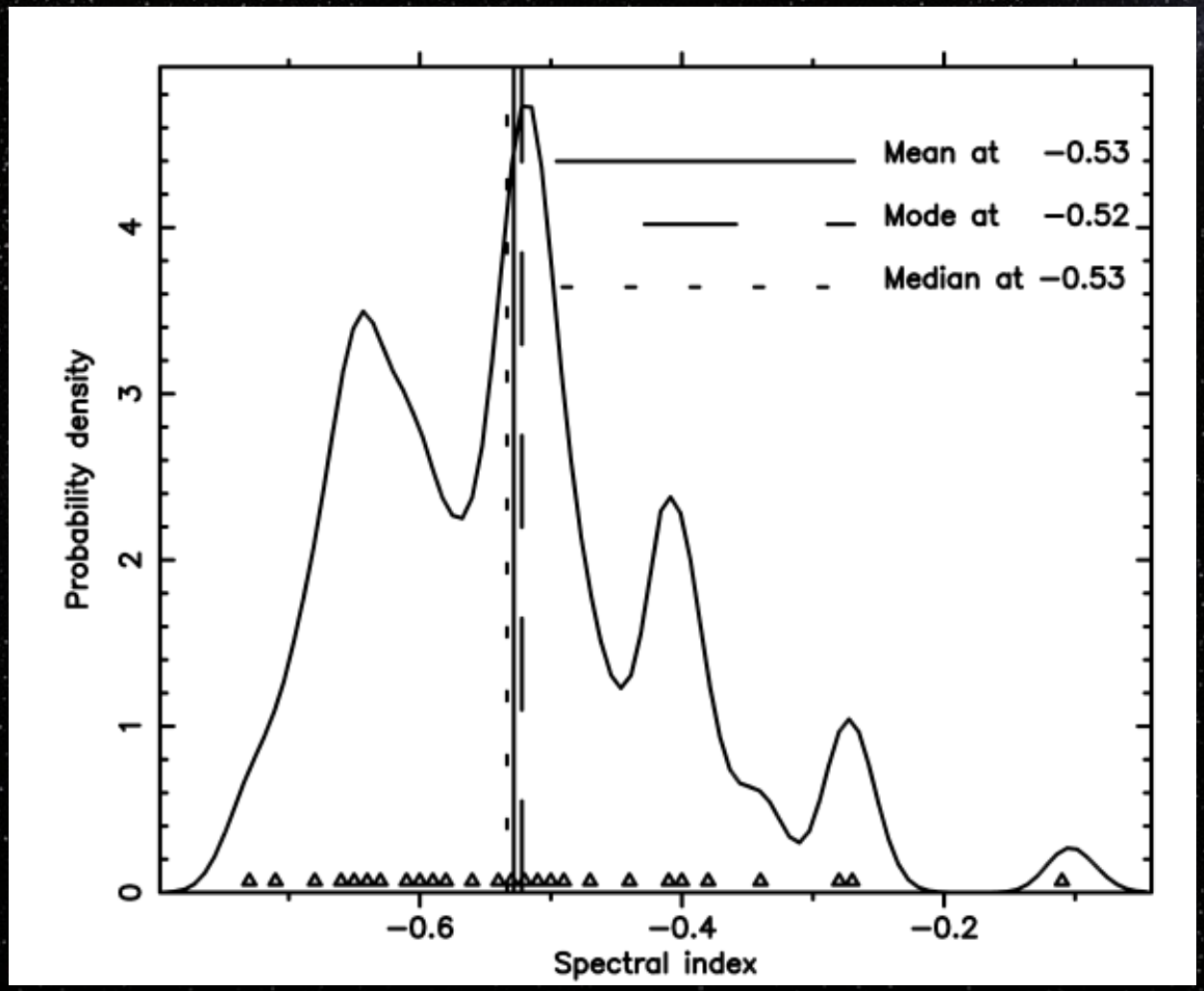
MP = Merger phase

Pop = Population

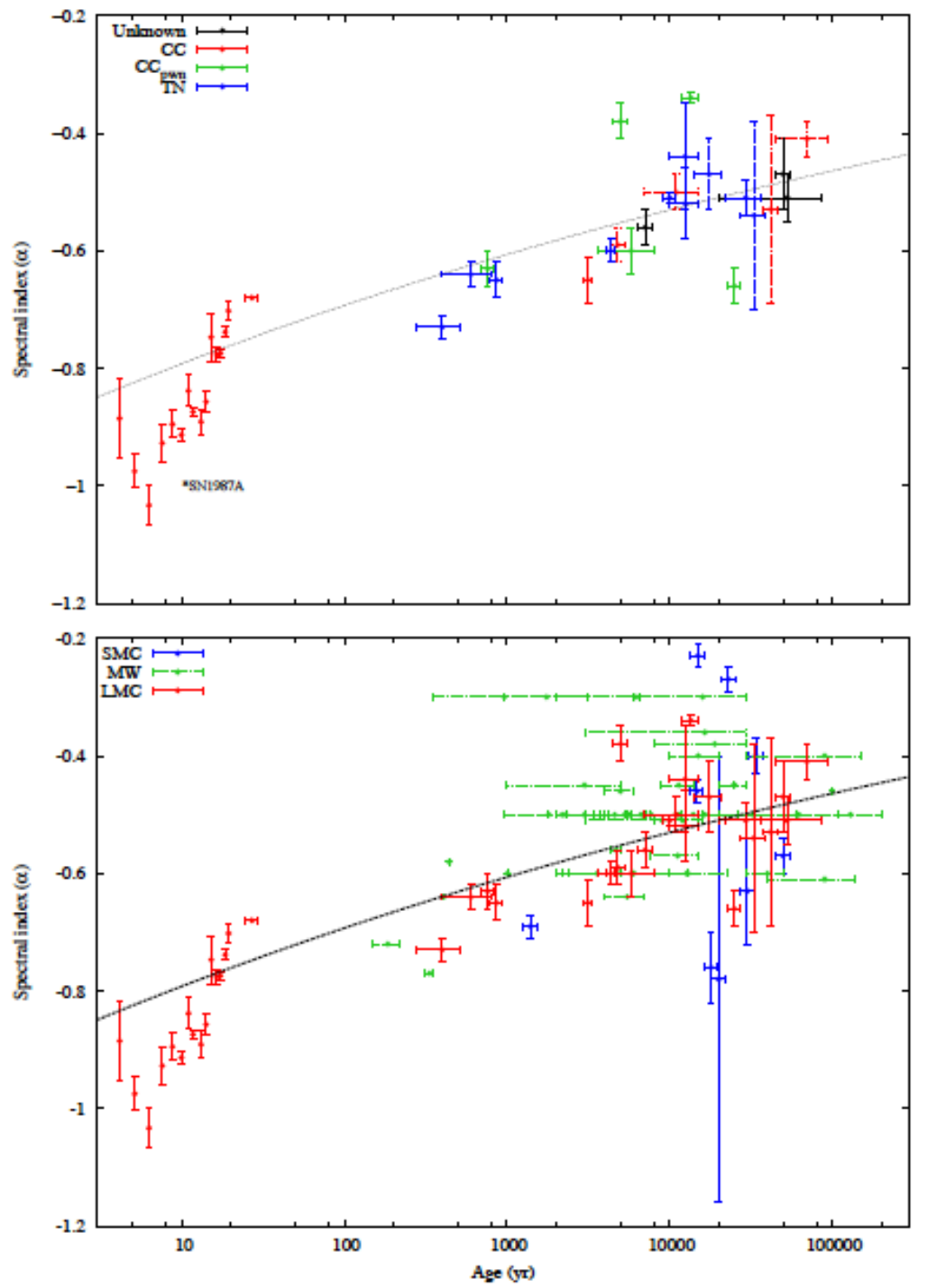
Ovality Distribution LMC SNRs



LMC (59 SNRs) **SMC (19 SNRs)**

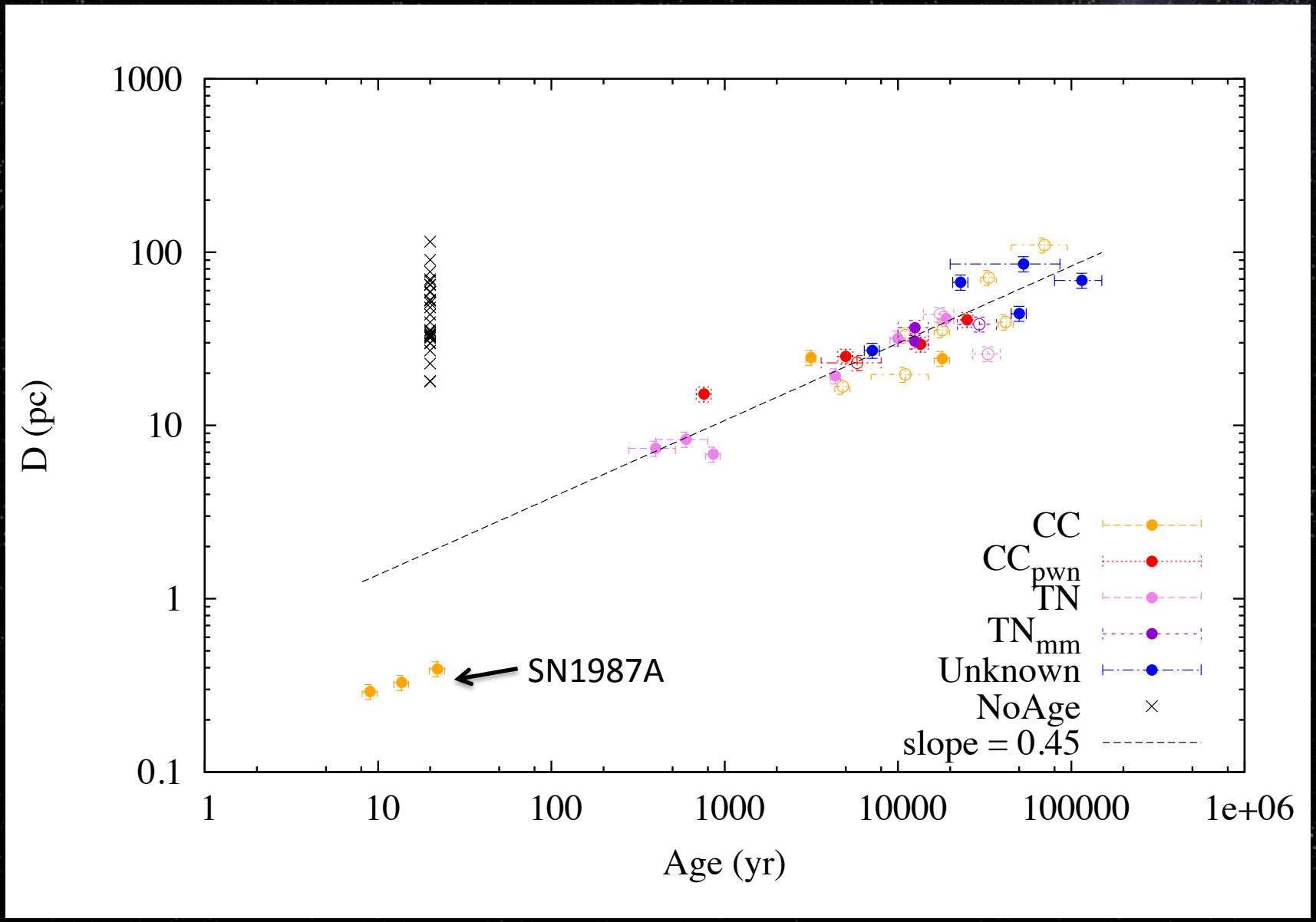


Spectral Index Distribution

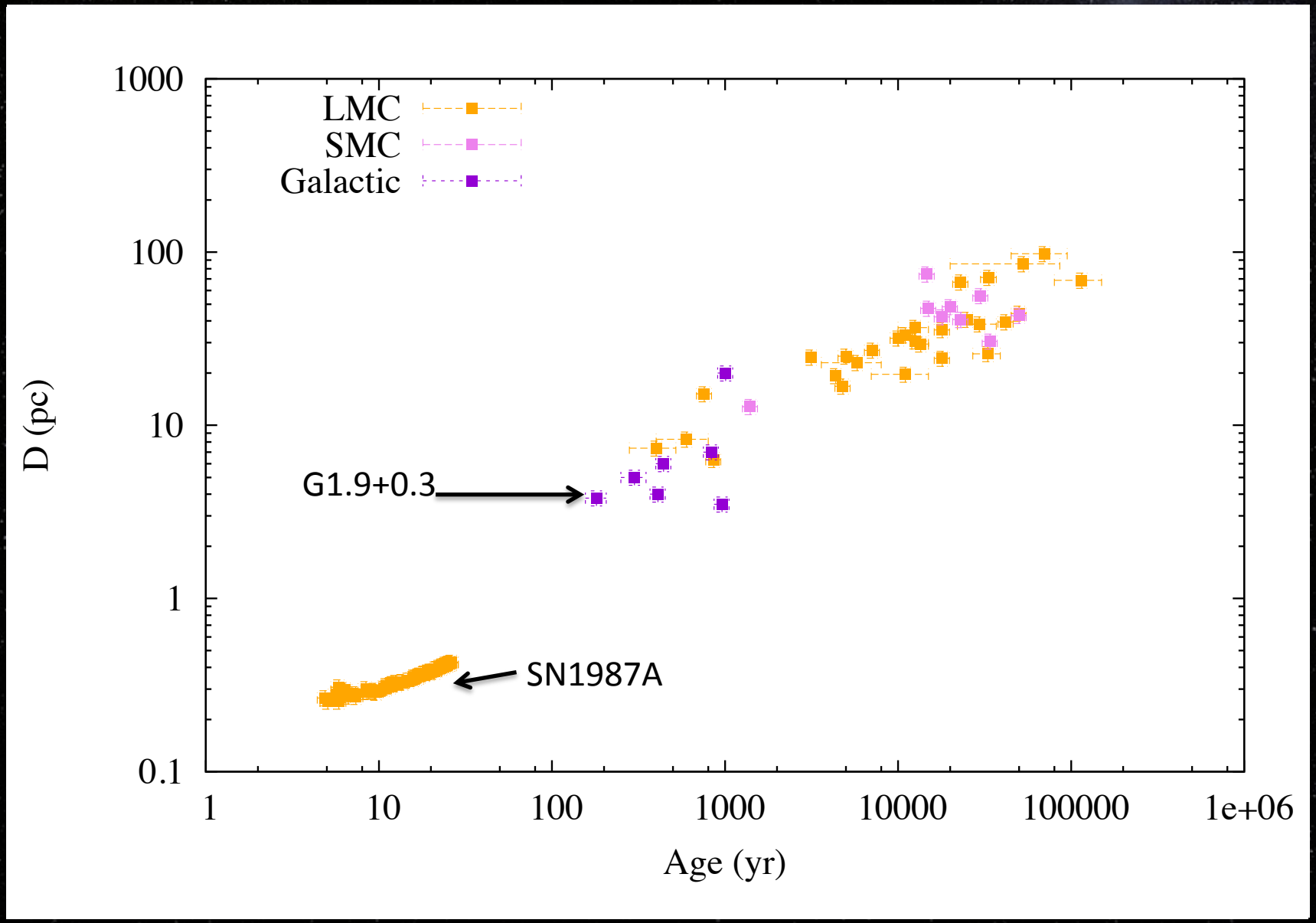


* SN1987A values from Gaensler et al. 1997

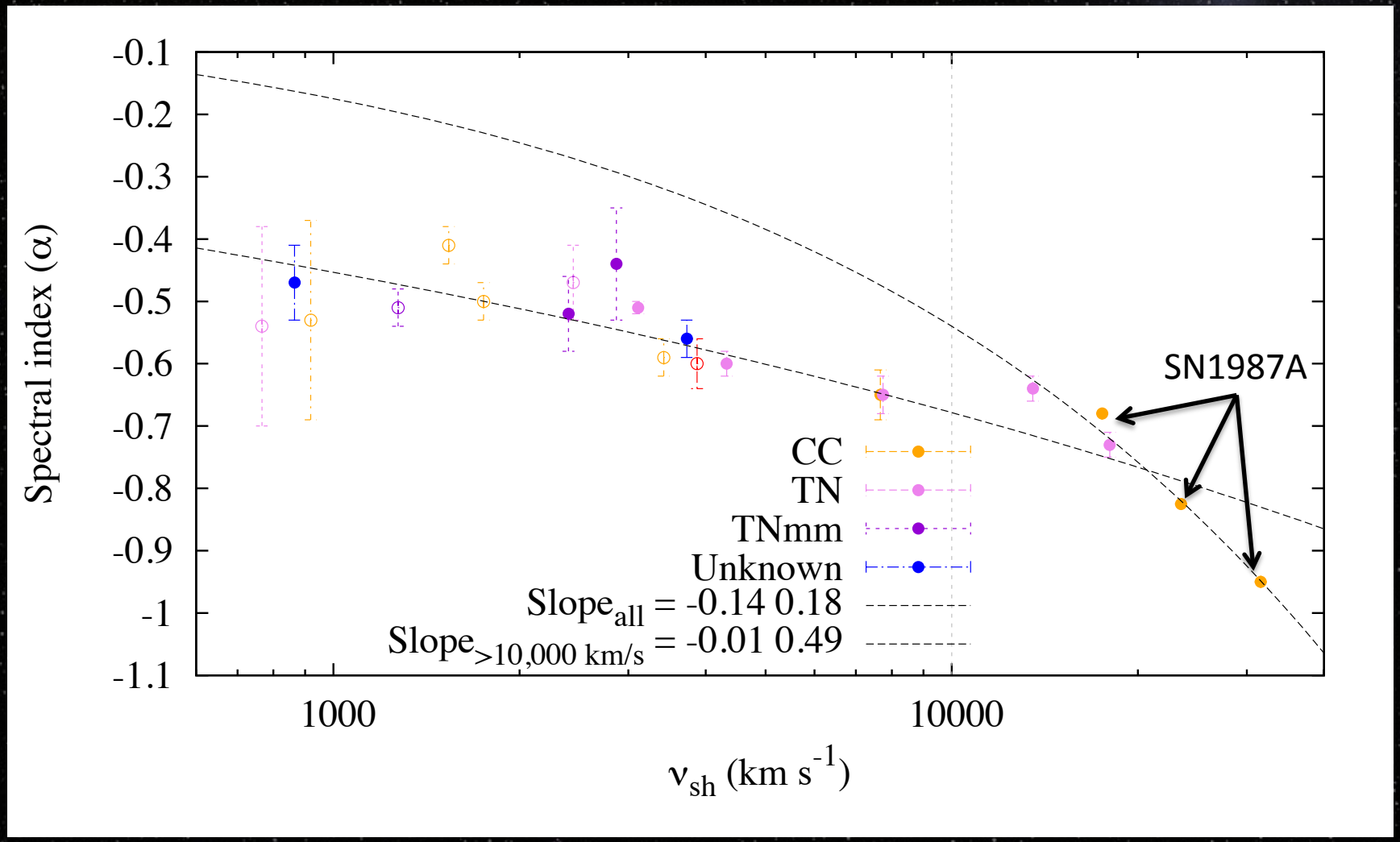
SNR Diameter Evolution -- LMC



SNR Diameter Evolution MCs+MW



Average Expansion Velocity vs. Radio Spectral Index (LMC)



LMC SNR RC Luminosity function

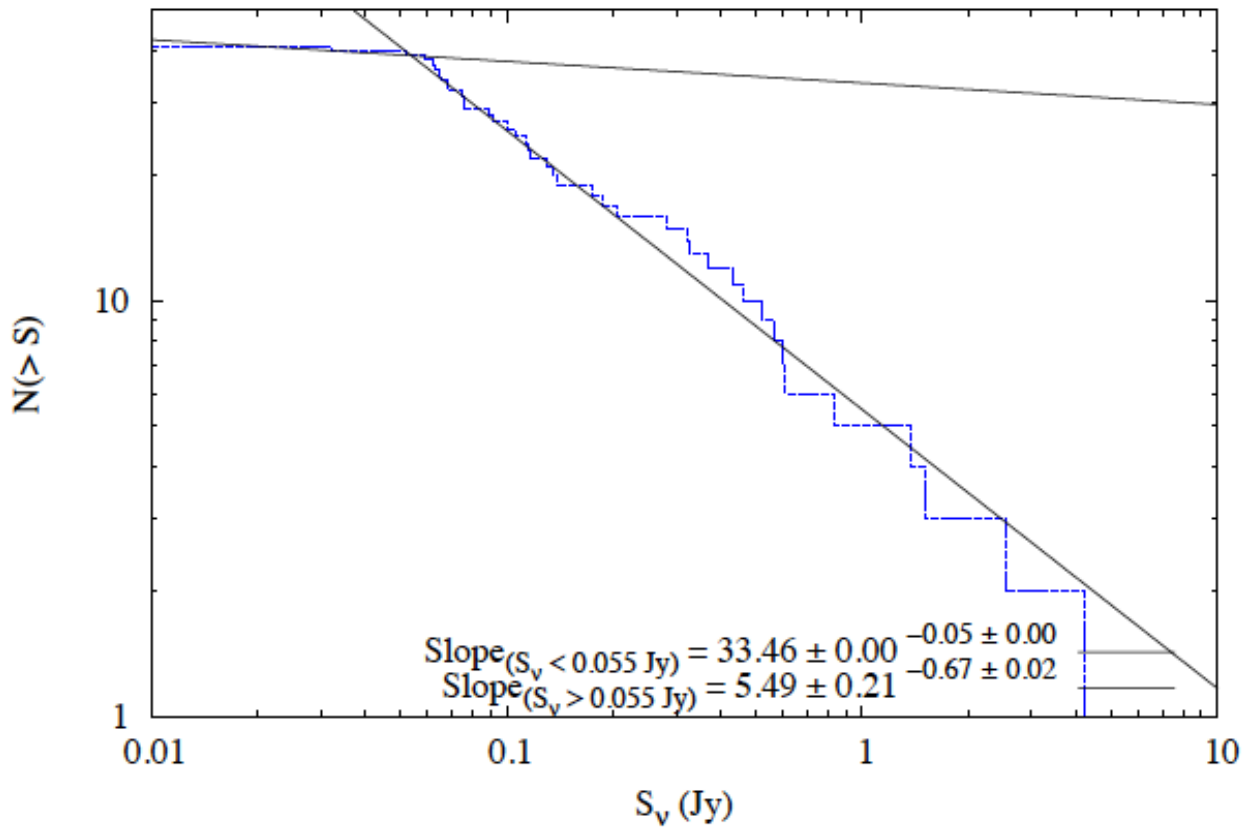
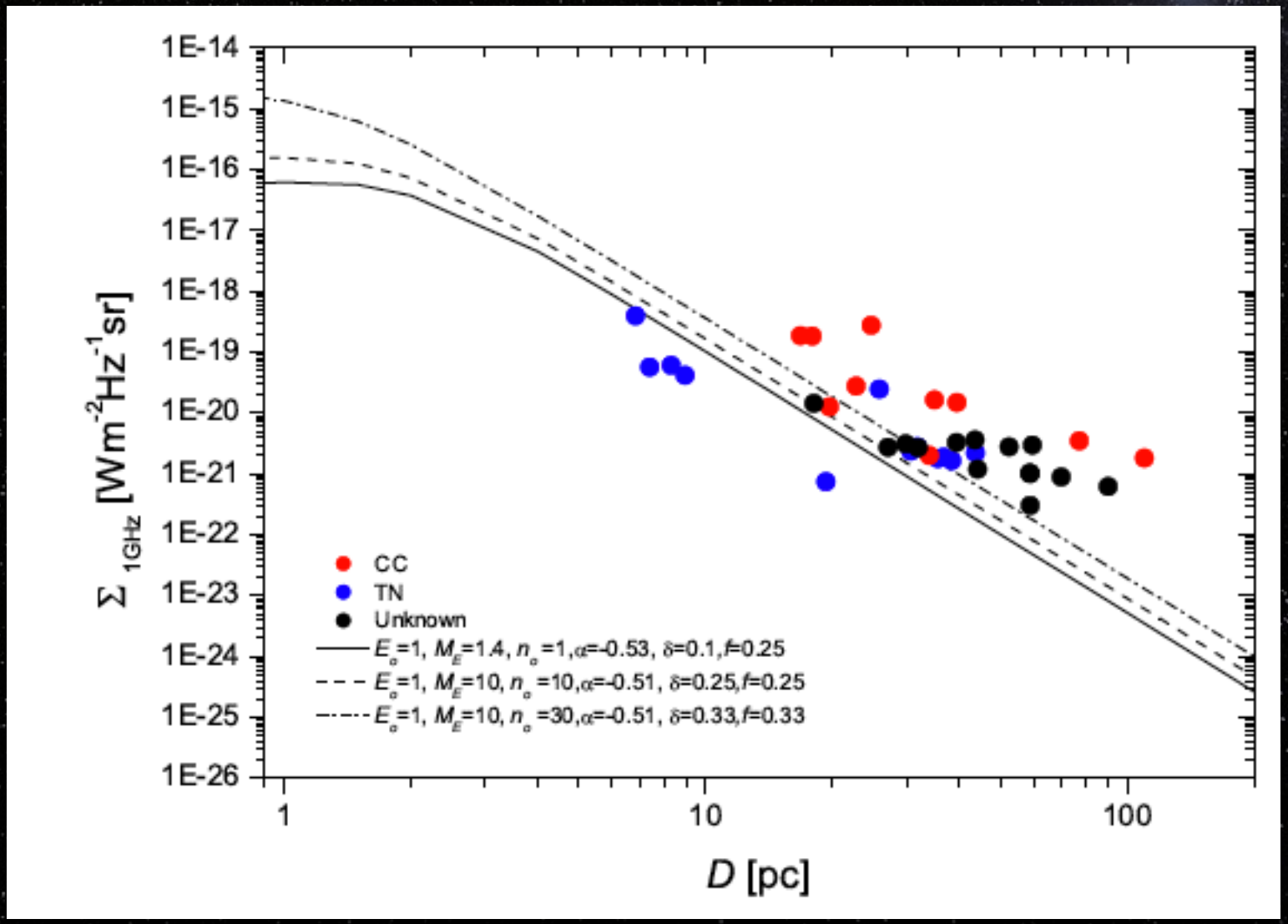
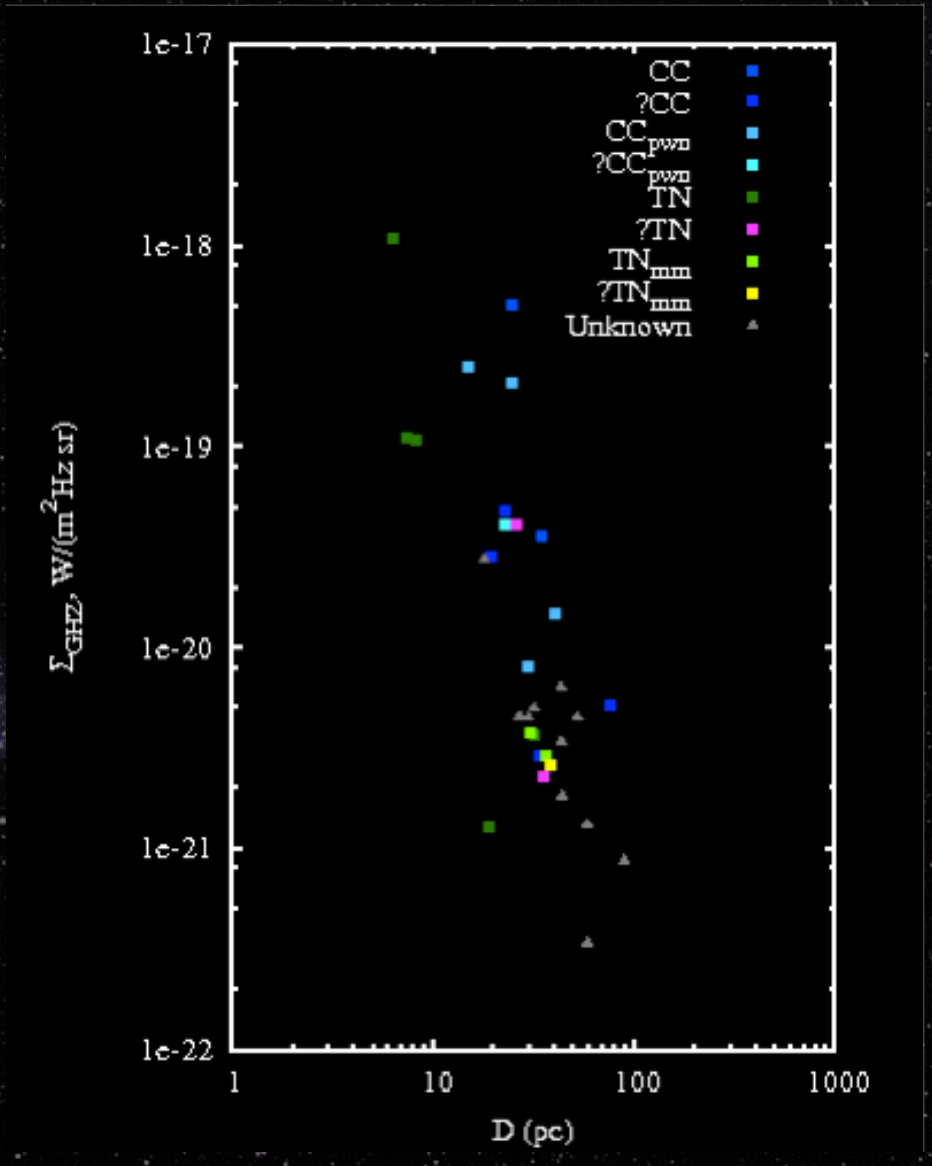


Fig. 18.— Luminosity function for a sample of 40 LMC SNRs at $\lambda = 20$ cm, represented by a blue dashed line. The two solid black lines represent the power law fits to the two components above and below the break at 55 mJy.

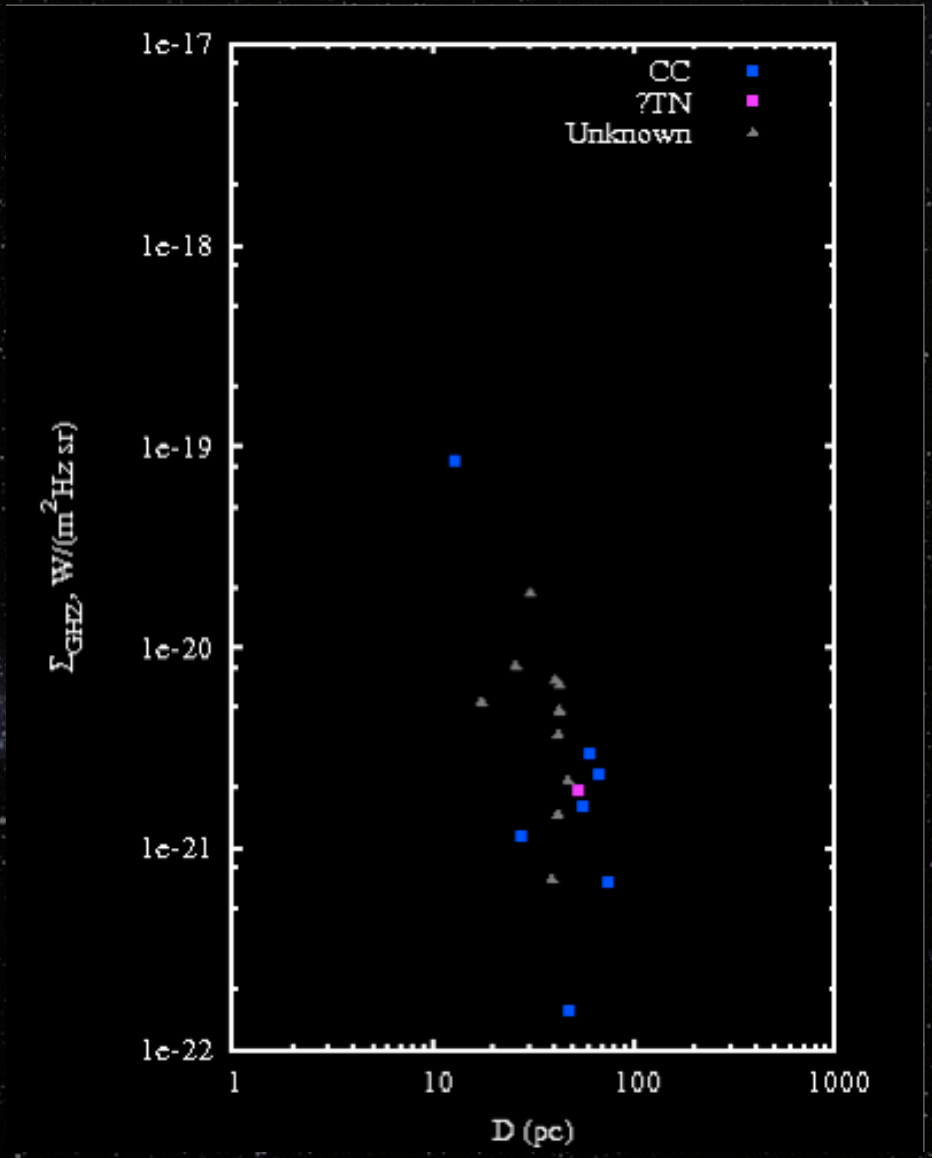
LMC SNR equipartition evolution models



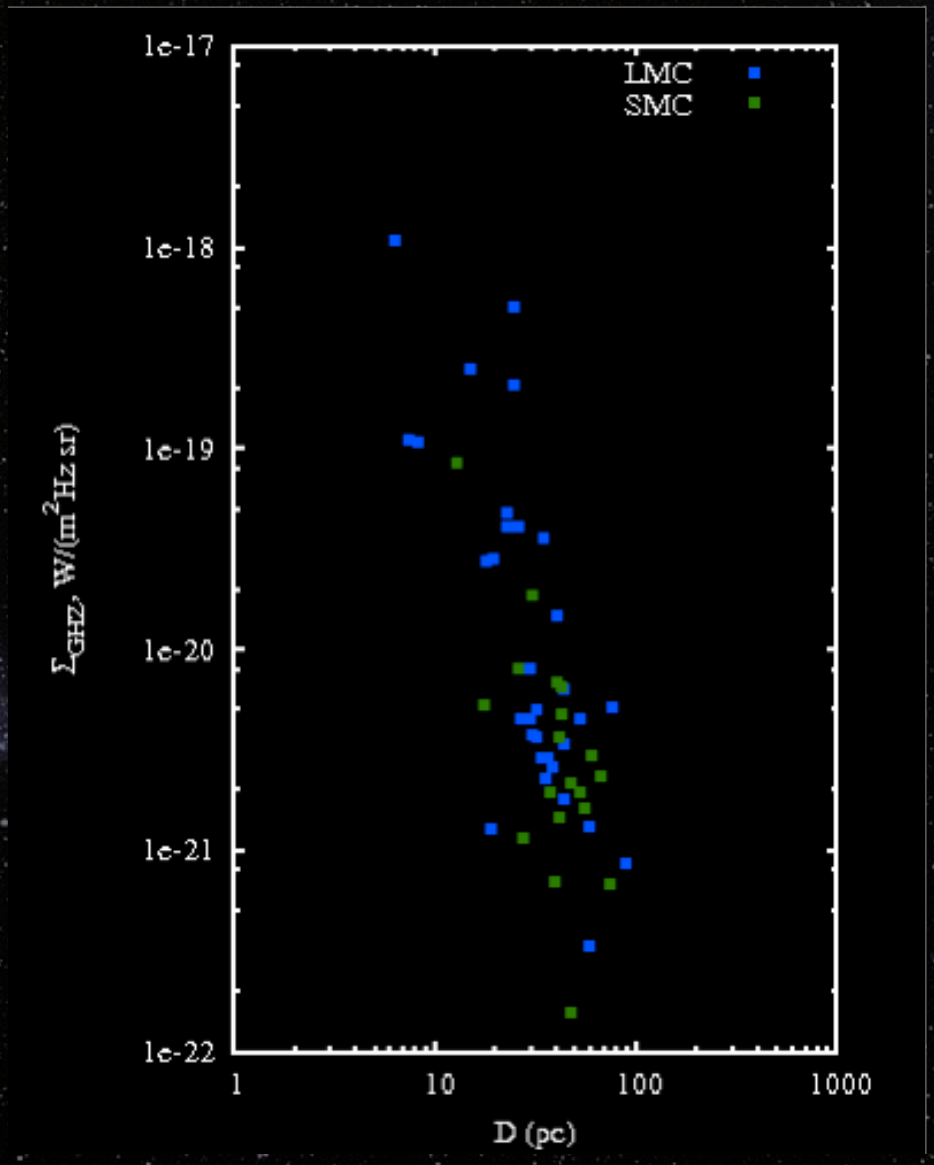
Σ – *D* Distribution LMC SNRs



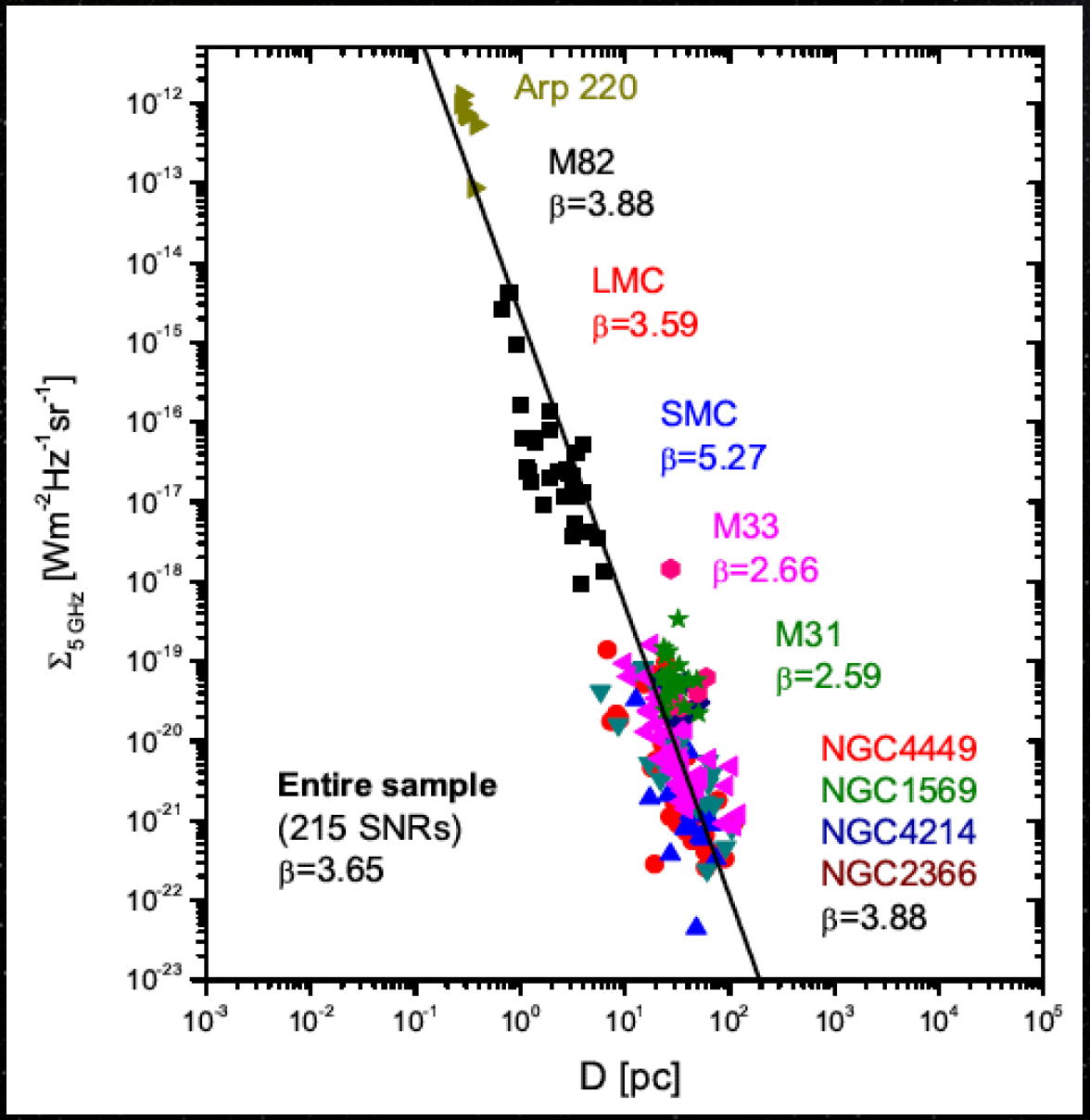
Σ – *D* Distribution SMC SNRs



Σ – *D* Distribution MCs SNRs



Σ – *D* Distribution ALL extraGal SNRs



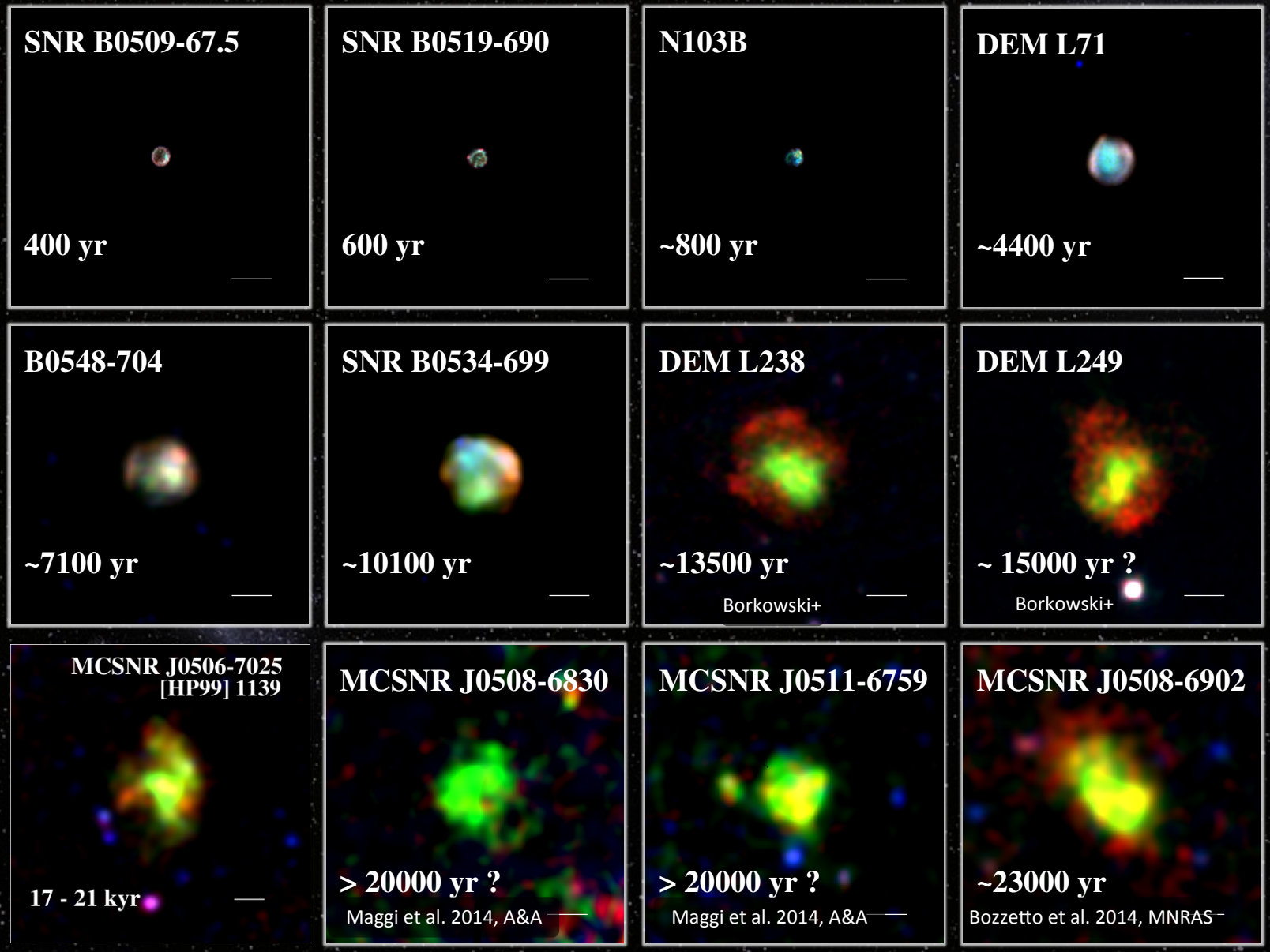
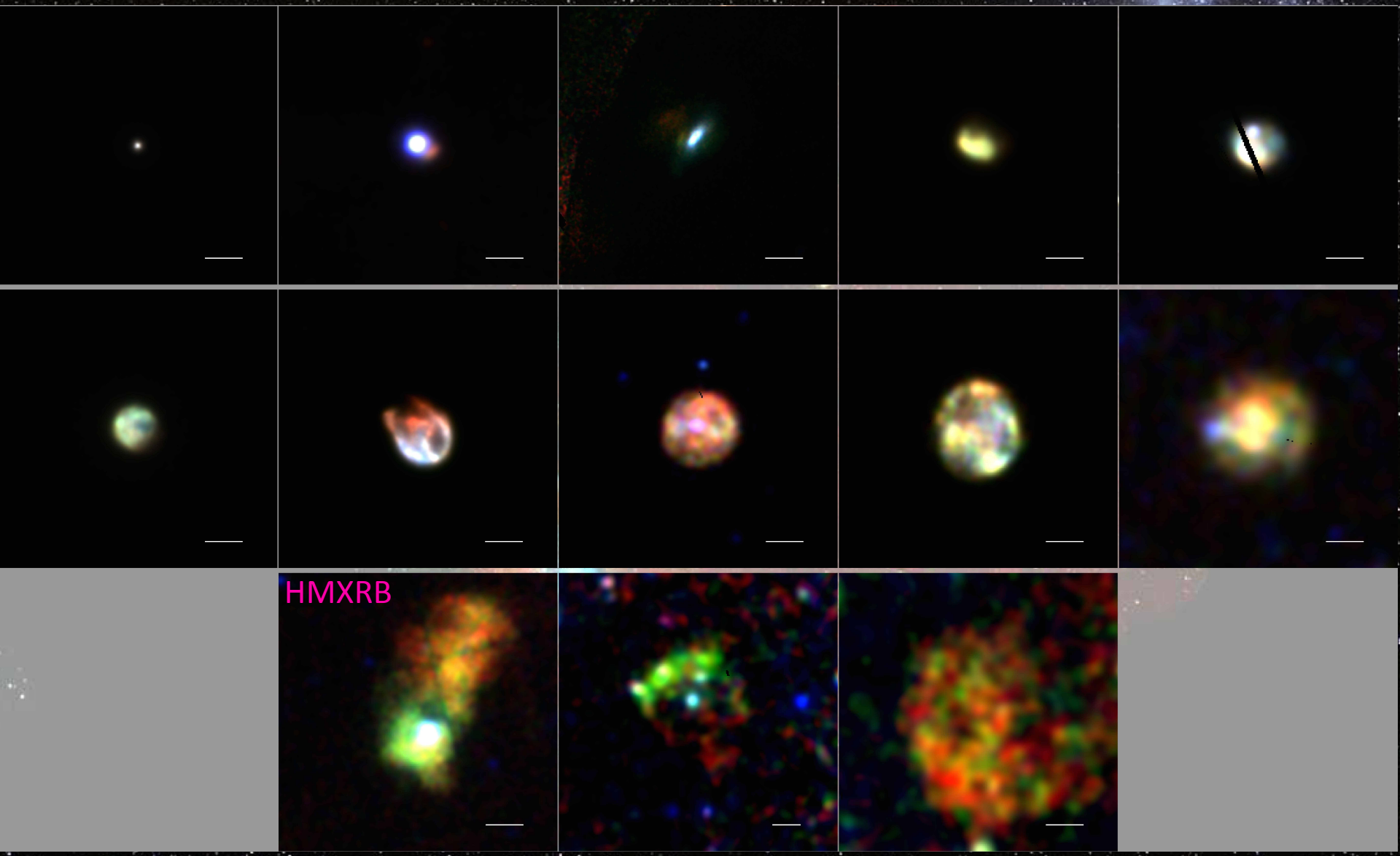


Image from Maggi et al. (2016)

Maggi TALK!!!

Credit: P. Maggi 2014

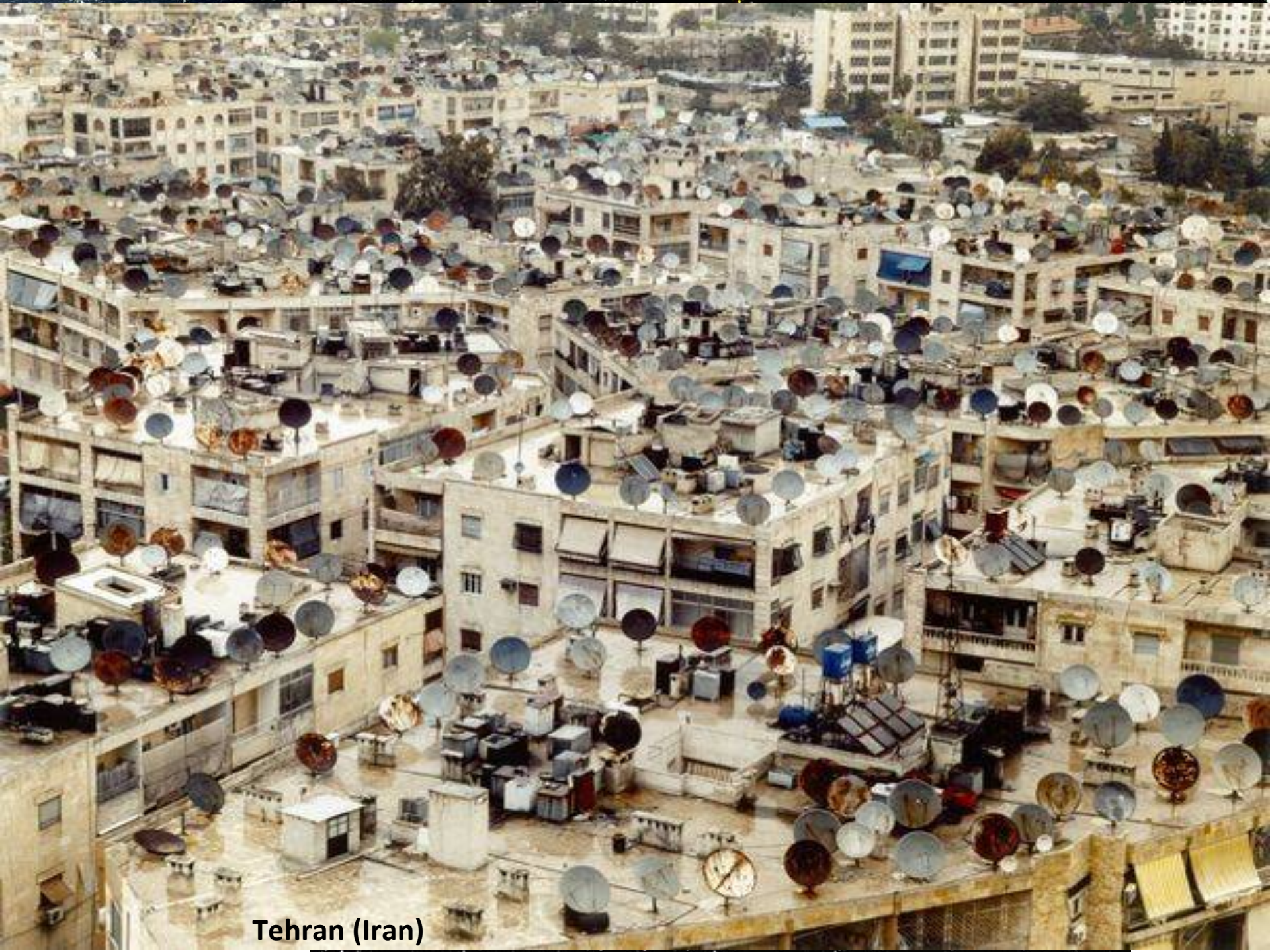


Future Work

- Have an in-depth look into this new class of Type Ia SNRs proposed by Borkowski+ and see if we find any deviations form normal Type Ia remnants in the radio-continuum
- A better study of magnetic fields of SNRs, tracking evolution and observing the difference (if any) between the SNR types.
- Try to better constrain statistics by taking into account the local ISM density
- CTA + ASKAP/ATCA/MOPRA/MWA + eRosita + …


We're All Different!
Just Accept It.

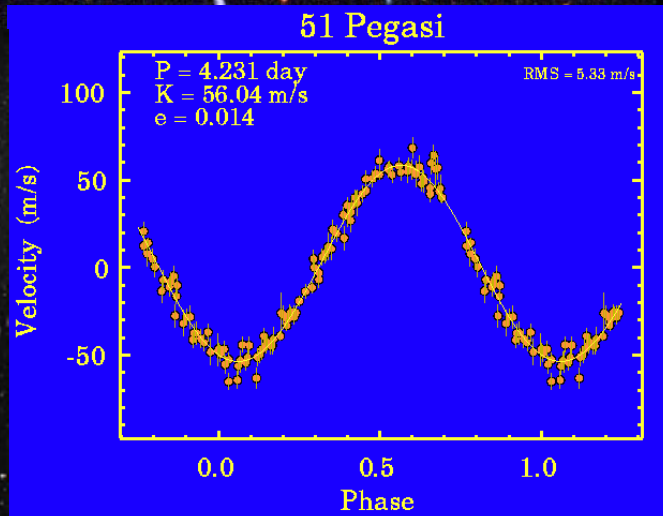

We are all different!
ROSAT PSPC
Vela & Puppis SNR's
2 degrees
Just accept it!



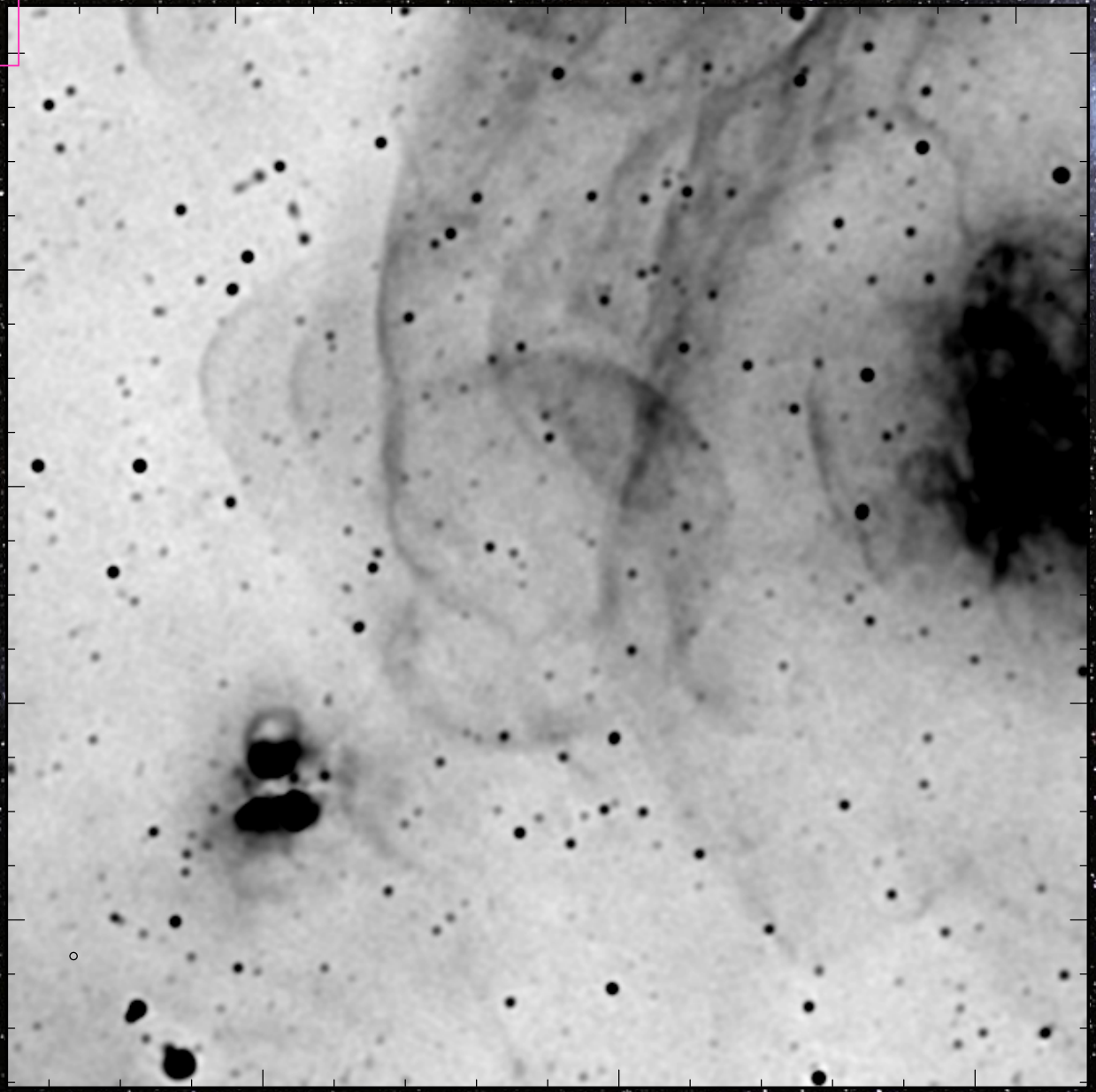
Tehran (Iran)

Thank You

A universe made for life?

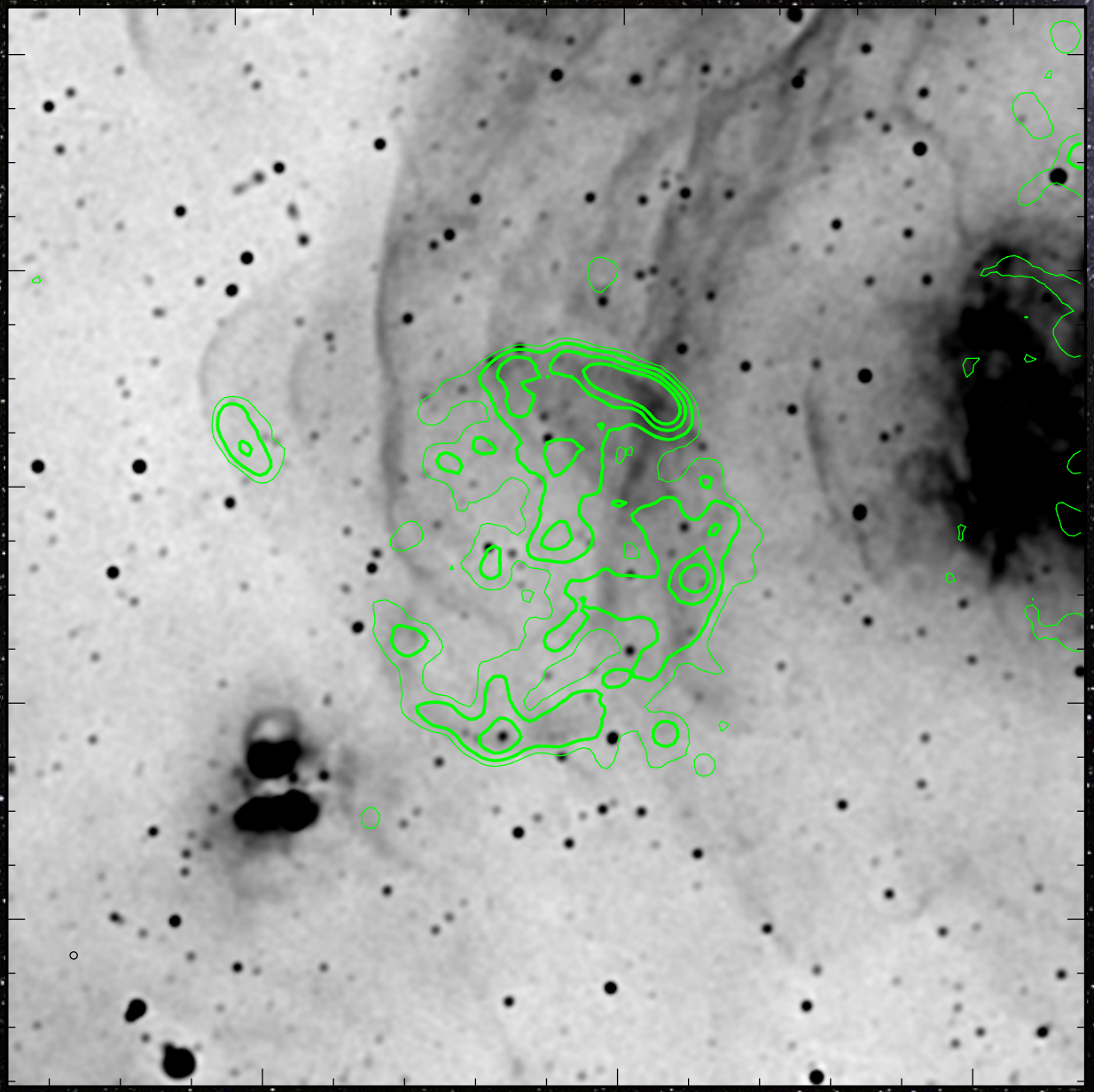


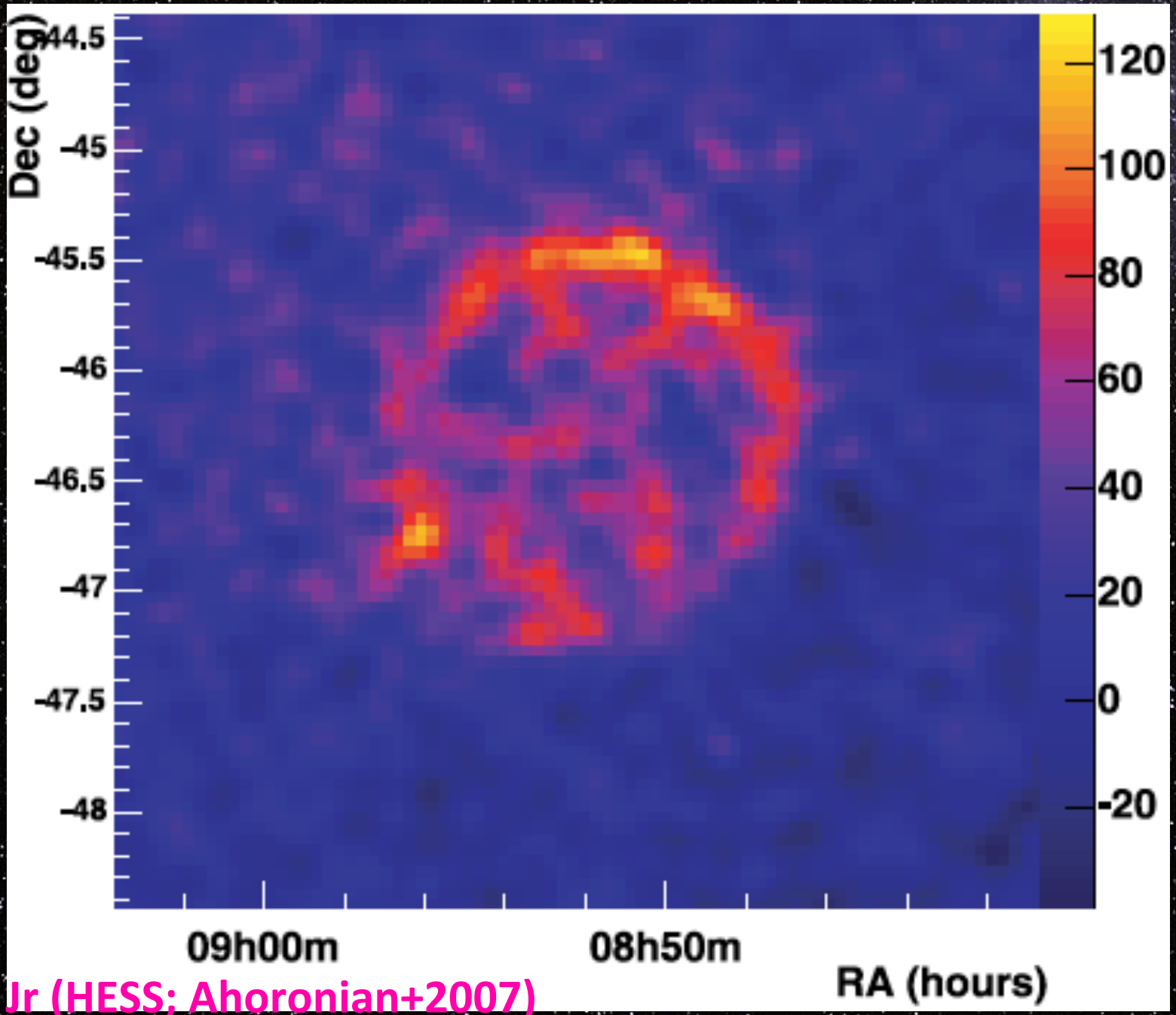
MWA at 200MHz



VELA Jr

VELA Jr





VELA Jr (HESS; Ahoronian+2007)