Observational facts of extragalactic SNRs

Are there ANY surprises?

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Extragalactic SNRs, MDF Crete 2016
The CRAB Nebula and the first “cover-up” in the history of science

24th June 1054 and the East-West Schism

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!!!
LMC combining maps of:
neutral atomic hydrogen gas (red),
hydrogen ionized by nearby young stars (blue),
molecular hydrogen (green).
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)
Extragalactic SNRs, MDF Crete 2016
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 $S_\nu = \text{const } \nu^\alpha$

• THERMAL X-RAYS - TYPICAL TEMP ~ 1 keV WITH A LARGE SPREAD FLATTER RADIO SPECTRA AND NON-THERMAL HIGH ENERGY X-RAY TAILS

• $[S\,\text{II}] / H\alpha > 0.4$

Extragalactic SNRs, MDF Crete 2016
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 $\alpha = -0.74$
Extragalactic SNRs, MDF Crete 2016

$G1.9+0.3$

$\alpha = -0.79 \pm 0.05$
**Results | Individual SNRs**

**LMC SNR 0509-67.5**

**Morphology**

**Polarisation**

**Spatial spectral variations**

**Stellar Environment**

**Star Formation History**

Extragalactic SNRs, MDF Crete 2016
**LMC SNR J0509–6731**

Hovey+ 15 → HST expansion ~6500 km/s

\[ D = 8 \text{ pc} \times 7 \text{ pc} \]

<table>
<thead>
<tr>
<th>SNR/Source</th>
<th>Age</th>
<th>Expansion Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassiopeia A</td>
<td>325 yr</td>
<td>-0.77</td>
</tr>
<tr>
<td>SNR J0509–6731</td>
<td>~310 yr</td>
<td>-0.73</td>
</tr>
<tr>
<td>Kepler’s SNR</td>
<td>409 yr</td>
<td>-0.64</td>
</tr>
<tr>
<td>Tycho’s SNR</td>
<td>441 yr</td>
<td>-0.61</td>
</tr>
<tr>
<td>SN 1006</td>
<td>1007 yr</td>
<td>-0.60</td>
</tr>
</tbody>
</table>

**Up to 12,000 ± 1,800 km/s**

Between 2000 and 2007!

Extragalactic SNRs, MDF Crete 2016
CO Channel map

Sano 2016 (priv. com)
Extragalactic SNRs, MDF Crete 2016

Sano 2016 (priv. com)
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.
**Results**

<table>
<thead>
<tr>
<th>Individual SNRs</th>
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<tbody>
<tr>
<td><strong>LMC SNR 0536-7038</strong></td>
</tr>
<tr>
<td>Morphology</td>
</tr>
<tr>
<td>ATCA 6cm Magnetic Field</td>
</tr>
<tr>
<td>$\alpha = -0.52 \pm 0.07$</td>
</tr>
<tr>
<td><strong>LMC SNR 0540-6919</strong></td>
</tr>
<tr>
<td>Morphology</td>
</tr>
<tr>
<td>Stellar Environment</td>
</tr>
<tr>
<td>Star Formation History</td>
</tr>
<tr>
<td><strong>Type Ia, ~13,500yr</strong></td>
</tr>
<tr>
<td><strong>CC-PWN, ~760yr</strong></td>
</tr>
</tbody>
</table>

Extragalactic SNRs, MDF Crete 2016
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
MC SNR 0508-6902
~74 pc x 57 pc
Fe mass of 0.5–1.8 Msol
TYPE Ia
B ~ 29 μGa

Bozzetto et al. 14
Fig. 7. MCELS composite optical image (RGB=$H\alpha$,[SII],[OIII]) of SNR J0453–6829 overlaid with 13 cm contours. The contours are 0.12, 0.4, 1, 4 and 8 mJy/beam.
Results | LMC Population

Image: ATCA–Parkes 21 cm observations from the HI Magellanic Cloud Survey (Kim et al. 1998, 2003 for details)

- 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

Extragalactic SNRs, MDF Crete 2016
Results | Multi-wavelength Detection

Extragalactic SNRs, MDF Crete 2016
Extent

Multi-wavelength Detection

Results
Results

Diameter Distribution LMC SNRs

Extragalactic SNRs, MDF Crete 2016
Cumulative number-diameter relationship (LMC sample only)

Confined

Candidate inclusive

FE = Free expansion
ST = Sedov-Taylor
SP = Snowplough
MP = Merger phase
Pop = Population

Extragalactic SNRs, MDF Crete 2016
Ovality Distribution LMC SNRs
Results | Spectral Index Distribution

LMC (59 SNRs) | SMC (19 SNRs)

Extragalactic SNRs, MDF Crete 2016
Results

Spectral Index Distribution

* SN1987A values from Gaensler et al. 1997

Extragalactic SNRs, MDF Crete 2016
Results

SNR Diameter Evolution -- LMC

Extragalactic SNRs, MDF Crete 2016
SNR Diameter Evolution MCs+MW

Results

Extragalactic SNRs, MDF Crete 2016
Results

Average Expansion Velocity vs. Radio Spectral Index (LMC)

-1.1
-1
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1

Slope all = -0.14 0.18
Slope >10,000 km/s = -0.01 0.49

SN1987A
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.
Results

Evolu(on and sta(s
cs

LMC SNR equipartition evolution models

Extragalactic SNRs, MDF Crete 2016
Results | Evolution and statistics

Σ – D Distribution LMC SNRs

Extragalactic SNRs, MDF Crete 2016
Results | Evolution and statistics

$\Sigma - D$ Distribution SMC SNRs

Extragalactic SNRs, MDF Crete 2016
Results | Evolution and statistics

Σ – D Distribution  MCs SNRs

Extragalactic SNRs, MDF Crete 2016
Results

\(\Sigma - D\) Distribution ALL extraGal SNRs

Extragalactic SNRs, MDF Crete 2016
<table>
<thead>
<tr>
<th>SNR B0509-67.5</th>
<th>SNR B0519-690</th>
<th>N103B</th>
<th>DEM L71</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 yr</td>
<td>600 yr</td>
<td>~800 yr</td>
<td>~4400 yr</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>B0548-704</th>
<th>SNR B0534-699</th>
<th>DEM L238</th>
<th>DEM L249</th>
</tr>
</thead>
<tbody>
<tr>
<td>~7100 yr</td>
<td>~10100 yr</td>
<td>~13500 yr</td>
<td>~ 15000 yr ?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MCSNR J0506-7025 [HP99] 1139</th>
<th>MCSNR J0508-6830</th>
<th>MCSNR J0511-6759</th>
<th>MCSNR J0508-6902</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 - 21 kyr</td>
<td>&gt; 20000 yr ?</td>
<td>&gt; 20000 yr ?</td>
<td>~23000 yr</td>
</tr>
</tbody>
</table>

Image from Maggi et al. (2016)
Extragalactic SNRs, MDF Crete 2016

Maggi TALK!!!
Evolu(on and sta(tics – LMC Type CC SNRs

Results

Credit: P. Maggi 2014

Extragalactic SNRs, MDF Crete 2016
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 from 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!

Just accept it!

Extragalactic SNRs, MDF Crete 2016
Tehran (Iran)
Thank You

A universe made for life?

Extragalactic SNRs, MDF Crete 2016
VELA Jr (HESS; Ahoronian+2007)