Investigations of supernovae and supernovae remnants in the era of SKA

Authors: Lingzhi Wang, Xiaohong Cui, Hui Zhu, Pérez-Torres Miguel, Wenwu Tian, Xiaofeng Wang

Speaker : Lingzhi Wang

National Astronomical Observatories, Chinese Academy of Sciences, CHINA

2014/06/10

Advancing Astrophysics with the Square Kilometre Array
8-13 June 2014 Giardini Naxos, Italy
Outline

- Introduction
- SKA1 science aims
  - Radio detection from Type Ia supernovae
  - Unbias survey for core collapse supernovae. See Pérez-Torres Miguel' talk
  - From SNe to young SNRs to old SNRs
  - Multi-wavelength investigation of cosmic ray origin via SKA & CTA
- Summary
Radio emission

Type II SN1979C
Cross circles, solid line: 14.9GHz
Open squares, dash-dot line: 4.9GHz
Open stars, dotted line: 1.5GHz

\[
S(\text{mJy}) = K_1 \left( \frac{v}{5 \text{ GHz}} \right)^{a} \left( \frac{t - t_0}{1 \text{ day}} \right)^{\beta} e^{-\tau_{\text{external}}} \left( \frac{1 - e^{-\tau_{\text{CSM clumps}}}}{\tau_{\text{CSM clumps}}} \right) \left( \frac{1 - e^{-\tau_{\text{internal}}}}{\tau_{\text{internal}}} \right)
\]


Bremsstrahlung (free-free):
Electron is accelerated as it passes a charged particle thereby emitting a photon

Synchrotron:
A charged particle moving in a magnetic field experiences acceleration and emits a photon
SD model of Type Ia SNe

- EVLA 19uJy for SN 2011fe

\[
\frac{L}{10^{26} \text{ erg s}^{-1} \text{ Hz}^{-1}} = \Lambda \left( \frac{\dot{M}}{W_{\text{wind}}/10 \text{ km s}^{-1}} \right)^{1.65} \times \left( \frac{\nu}{5 \text{ GHz}} \right)^{-1.1} \left( \frac{t-t_0}{1 \text{ day}} \right)^{-1.5} e^{-7CSM_{\text{external}}}
\]
# SKA1 and CTA's parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fiducial frequency (GHz)</th>
<th>Resolution (&quot; at fiducial frequency)</th>
<th>FoV (deg², at 1.4 GHz)</th>
<th>Bandwidth (MHz)</th>
<th>Sensitivity (μJy hr⁻¹/²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKA1-low</td>
<td>0.11</td>
<td>~14</td>
<td>~30</td>
<td>250</td>
<td>~2</td>
</tr>
<tr>
<td>SKA1-mid</td>
<td>1.67</td>
<td>~0.3</td>
<td>~1</td>
<td>770</td>
<td>~1</td>
</tr>
<tr>
<td>SKA1-sur</td>
<td>1.67</td>
<td>~1</td>
<td>~20</td>
<td>500</td>
<td>~4</td>
</tr>
<tr>
<td>ASKAP</td>
<td>1.4</td>
<td>~9</td>
<td>30</td>
<td>300</td>
<td>~30</td>
</tr>
<tr>
<td>MeerKAT</td>
<td>1.4</td>
<td>~13</td>
<td>0.86</td>
<td>500</td>
<td>~3</td>
</tr>
<tr>
<td>CTA</td>
<td>1 TeV</td>
<td>0.04-0.05 deg</td>
<td>6-8 deg</td>
<td>10⁻¹³ erg cm⁻² s⁻¹</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1:** Parameters for SKA phase 1 telescopes (SKA1-low, SKA1-mid, & SKA1-sur) and their precursors (ASKAP & MeerKAT)
Radio detection of Type Ia SNe via SKA1
Radio detection of core collapse SNe
‘supernova rate problem’
2 factor larger at 2 sigma


SNR:SFR multiplies by efficiency of forming CC SNe
Assuming canonical parameters for optically luminous CC SNe: Mmin=8M_solar; Mmax=40M_solar

60% cc supernovae are missing at z=2.
Due to dust obscuration or to intrinsic faint
Fig. 2.— Estimated radio core-collapse supernova detection rate as a function of redshift at 1.4 GHz, assuming $f_{\text{radio}} = 10\%$. Predictions are shown for different survey sensitivities: $S_{\text{min}} = \{10 \ \mu\text{Jy (blue)}, 1 \ \mu\text{Jy (blue)}, 100 \ \text{nJy (blue)}, 50 \ \text{nJy (thick red), 10 nJy (blue), 1 nJy (blue)}\}$ from bottom to top solid curves, respectively. We adopt 50 nJy as our benchmark sensitivity hereafter. For comparison, the red-dashed curve shows the LSST optical supernova detection rate per year per deg$^2$ (Lien & Fields 2009). Also, the top solid curve (black) plots the ideal core-collapse RSN rate for comparison.
From SNe to young SNRs to old SNRs

B direction: radial

Young SNRs: eg. Tycho

B direction: tangential

Old SNRs: eg. CTB1: ~10,000yr


Fürst & Reich 2004
Cosmic particles
Dominated by proton, there are also electron...

2013, Science, 339, 807-811

Cosmic Particle Accelerators Identified

This year, astronomers traced high-energy particles called cosmic rays back to their birthplaces in the debris clouds of supernovae—a feat that Science’s editors chose as a runner-up for Breakthrough of the Year. Theorists had long suspected that most cosmic rays are accelerated in the shock waves from massive exploding stars called supernovae. But magnetic fields in space scramble the particles’ trajectories, making it impossible to trace them back to their sources. Instead, astronomers looked for the radiation signatures of reactions that cosmic rays trigger when they crash into thinly scattered atoms in interstellar space. This year, the Fermi Gamma-ray Space Telescope found them—right where they were supposed to be.

Breakthrough of the Year 2013
Why SKA?

Why we need high resolution and sensitivity?

1.4GHz continuum observation of SNR W49B
Left: resolution ~1 arcmin  Right: resolution ~6arcsec

Filamentary emissions are very important to study the particle acceleration!
Why combination of SKA+CTA?

γ-rays (its trajectories are unaffected by interstellar and Galactic magnetic fields) are an excellent tracer of CR accelerators. Accelerated CRs produce γ-rays after interaction with interstellar material.

The key issue in SNR case: identification of γ-ray emission mechanisms:

π0: hadronic origin of γ-ray
CRs + gas -> pp -> π0 -> 2γ

IC: leptonic origin of γ-rays
eγ -> eγ
SNRs: one of the main sources of CRs

Thick solid: total non-thermal flux

Hadronic emissions:
Thin solid: neutral pion decay $\gamma$ rays
Dot dash: synchrotron from secondary electrons produced by charged pion
Short and long dash: bremsstrahlung from secondary electrons

Leptonic emissions:
Long dash: synchrotron emission from primary electrons
Dotted: IC from primary electrons
Short dashed: bremsstrahlung from primary electrons

Yamazaki et al. 2006, MARAS, 371,1975
Discovery of SNR G353.6-0.7/HESS J1731-347

1. The radio and X-ray morphologies of G353.6-0.7 march the outline of HESS J1731-347.
2. Distance of ~3.2 kpc, age of ~27,000 yr, density $n_0 \sim 5 \text{ cm}^{-3}$;
3. Radio spectral index of ~0.4, favour a non-thermal feature.

Our observations suggest that cosmic rays may originate the SNR-cloud interaction.

Radio (grey)+X-ray (red, ROSAT)+gamma-ray (green) images of G353.6-0.7 (Tian et al. 2008 & 2010)
Summary

Radio emission from the interaction between explosion front shock and its surrounding circumstellar medium (CSM) or interstellar medium (ISM) provides an important probe to see their last evolution stage. While no radio emission was detected from Type Ia supernovae by current telescopes. **SKA will possibly first detect radio emissions of Type Ia supernovae due to its much better sensitivity and resolution.**

There is a 'supernovae rate problem' for the core collapse supernovae because the optically dim ones are missing due to intrinsically faint or due to dust obscuration. **A number of dust-enshrouded optically hidden supernovae will be discovered via SKA1-sur, especially for those located in the innermost regions of host galaxies.** Meanwhile, the detection of intrinsically dim ones will also benefit from SKA1. The observed rate will provide unique information about the current star formation rate and the initial mass function.

After supernova explosion, the shock wave expels and heats the surrounding CSM and ISM, forming supernova remnants. **More supernova remnants will also be discovered by SKA, which may decrease the great number discrepancy between the expected and observed.** Several Supernova remnants have been confirmed to accelerate protons, main component of cosmic rays, to very high energy by their shocks. The cosmic ray origin will hopefully be solved by combining the low frequency (SKA) and very high frequency (Cherenkov Telescope Array: CTA) bands' observations.