NuSTAR Observations of Non-thermal Emission from Young Supernova Remnants

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TeVPA 2017
INTEGRAL, Swift BAT

Focal spot

Grazing incidence optics

NuSTAR
X-Ray Telescopes & the Electromagnetic Spectrum

Energy

Wavelength

100 meV  1 eV  10 eV  100 eV  1 keV  10 keV  100 keV  1 MeV

10 μm  1 μm  100 nm  10 nm  1 nm  100 pm  10 pm  1 pm

Infrared  Visible  Ultraviolet  X-Ray  Gamma Ray

Chandra & XMM-Newton
0.1 – 10 keV

NuSTAR
3 – 79 keV
Satellite (instrument)  

<table>
<thead>
<tr>
<th>Satellite (instrument)</th>
<th>Sensitivity</th>
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<tbody>
<tr>
<td>INTEGRAL (ISGRI)</td>
<td>~0.5 mCrab (20-100 keV) with &gt;Ms exposures</td>
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<tr>
<td>Swift (BAT)</td>
<td>~0.8 mCrab (15-150 keV) with &gt;Ms exposures</td>
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<tr>
<td>NuSTAR</td>
<td>1 μCrab (10-40 keV) in 1 Ms</td>
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**Sensitivity comparison**

*NuSTAR two-telescope total collecting area*
Previous high-energy X-ray view of the heart of the Milky Way

Did NASA's NuSTAR Capture 'Screams' of Zombie Stars?

New images captured by NASA of a mysterious glow at the center of our galaxy may have been produced by the "howls" of dead stars feeding off their live companions.
Evolved star/Fe core

Chandrasekhar mass
-> collapse

Inner part compressed to neutrons

Bounce, outward shock

Shock stalls

Shock reinvigorated [how?]
Neutrino Heating
Cassiopeia A

Iron

Silicon/Magnesium
Radioactive $^{44}\text{Ti}$
Cas A in Radioactivity

Grefenstette, FH et al, Nature 2014
Green – Si/Mg
Red – Fe
Blue – \(^{44}\)Ti
Locating the Most Energetic Electrons

6 cm radio  |  Chandra 5-6 keV  |  NuSTAR 10-20 keV
Zoom In on Interior Knots
GeV and TeV Emission
Another Famous Young Remnant– SN 1987A

Boggs, FH et al Science, 2015

Asymmetric cloud of supernova debris mostly thrown away from us

Neutron star (not seen) kicked toward us

Most of the X-ray glow from titanium is redshifted to lower energies as it moves away from us.
NuSTAR Legacy Surveys

NuSTAR GO Program: A0-3

25% NuSTAR time dedicated to Legacy Surveys
Program to observe HAWC, HESS, VERITAS sources
NuSTAR Observations of HESS J1640-465
Powered by a young pulsar

- Hard X-ray source discovered in Norma Survey
- Highly obscured – very faint in Chandra/XMM

*PSR J1640-4631 confirmed with a significant frequency shift due to spin-down of pulsar*

Young, energetic pulsar - 206 ms spin-down age, $\tau \sim 3$ kyr and energy, $\dot{E} \sim 5 \times 10^{36}$

Overlaid Periodogram

Sep 29 2013 Pulse Profile

*Two cycles show for clarity*

PSR J1640-4631: pulsar powering HESS J1640-465, (Gotthelf et al. 2014)
HESS J1640-465

“HESS Source of the Month” twice - different interpretations!


• Luminous, extended HESS TeV src., origin highly uncertain
• Coincident with radio SNR G338.3-0.0,
• Neighboring HII region due north - hadronic?
• Funk 2007: Extended XMM source - leptonic?
• Lumiere 2009: Chandra pt. src. + diff. emission.
• Slane 2010: Associated Fermi GeV source?

“Given the now available multi-wavelength data, it turns out that the hypothesis of a pulsar-wind origin of the gamma-ray emission is difficult to maintain; size and spectra (Fig. 2) of the source favor emission caused by interaction of supernova-accelerated cosmic rays with the dense ambient gas, in particular in the northern section of the remnant.”

HESS J1640-465

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