

SNRs:
(& PWNE, SBs, ...)
FUTURE SCIENCE
OBJECTIVES AND
INSTRUMENT REQUIREMENTS

High-Energy Space Missions Workshop
GammaSIG Session
29 June 2015

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NASA / Goddard

Theme: SNRs, ...

To better understand the origins and evolution of the universe and everything in it through study of high energy particles,

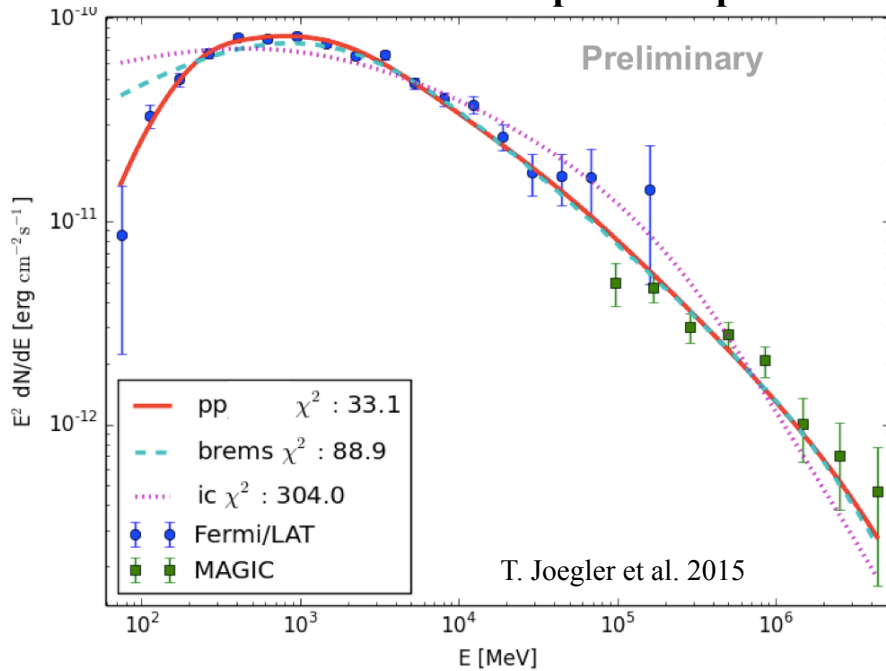
- › to understand the fundamental physics of acceleration in a variety of systems and
- › to understand particles' interaction with, propagation through, and impact on environments at all scales (local, galactic, and extragalactic)

Discrepancies with predictions will indicate the need for new particles and/or fundamental physics. (See Regina's talk at the end!)

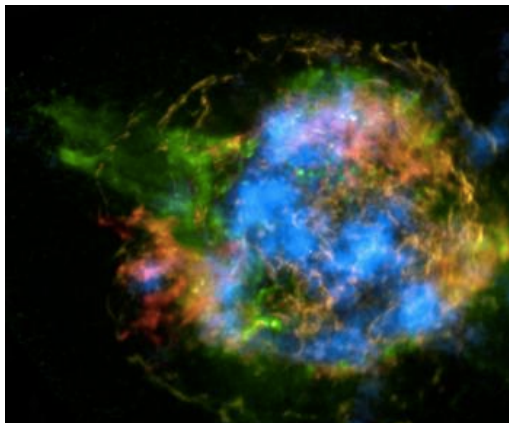
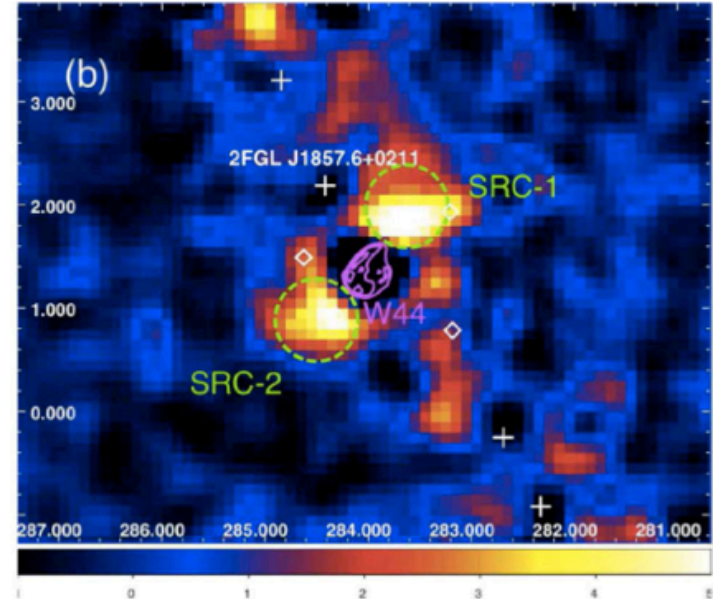
Science Topics: SNRs

Most likely largest contributors of energetic particles sculpting galaxies...

W51C: 3rd SNR w evidence of pion bump

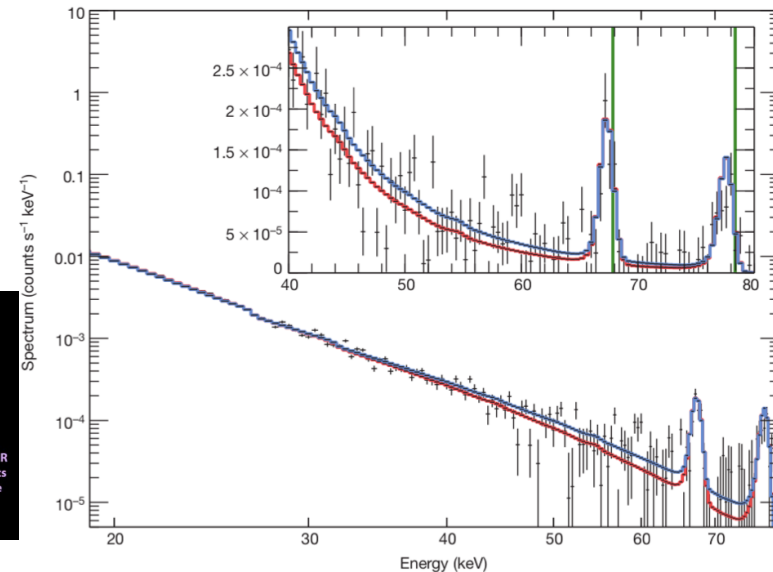
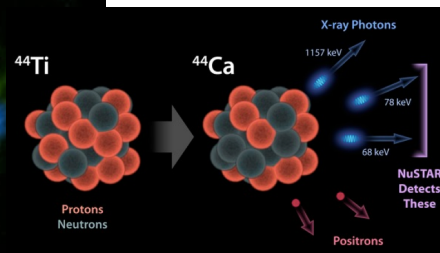


W44: Particle escape? Shocked cloud?



NuSTAR ^{44}Ti

Grefenstette et al. 2014



Science Topics: SNRs

Most likely largest contributors of energetic particles sculpting galaxies...

- Constrain hadronic and leptonic particle populations' number and energy distributions
 - via spectral decomposition of spatially well-resolved remnants (MeV, GeV-TeV)
 - connect to direct cosmic ray measurements!
 - constrain CR origins
 - link to their impact on galaxies' physical and chemical evolution
- Resolve shell structure to
 - observe acceleration processes and
 - connect w MW data more directly (filaments, B-fields, ...).
 - Connection to progenitor type through shape?
- Measure gradients in emission (given a known photo-particle background) to constrain escape processes.
- ^{44}Ti predictions for Type Ia progenitor possibilities (other than CO white dwarf?)

- Testing a variety of sources (eg progenitor) in a variety of environments will probe more physical processes and help minimize the impact of incomplete (MW) data sets.

Instrument Requirements: SNRs

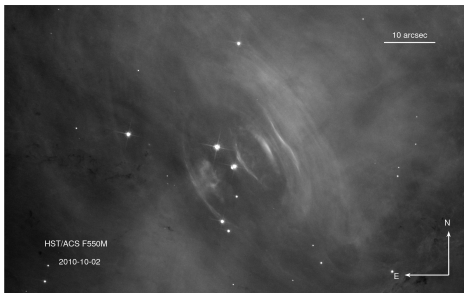
Most likely largest contributors of energetic particles sculpting galaxies...

Topic	Spatial coverage	Spatial resolution	Energy range	Spectral resolution	Line/continuum sensitivity	Timing?	Polarization	Real-time capability
Particle populations	5-10° / All sky	~<0.05°	MeV – TeV	<~15%	~10 ⁻¹³ erg cm ⁻² s ⁻¹	Poss. ~3ms (remove pulsar)		
Shell	~5° / All sky	<0.01°	MeV – GeV?	<~15%	~10 ⁻¹³ erg cm ⁻² s ⁻¹		<20%?	(X-ray scale: ~ years)
Escape	5-10° / All sky	<0.1°	MeV – TeV	<~15%	~10 ⁻¹⁴ erg cm ⁻² s ⁻¹			
⁴⁴ Ti lines	5-10° / All sky	~0.01°	keV – 1.157 MeV	<0.2%	~10 ⁻⁷ phot cm ⁻² s ⁻¹			
?								

Science Topics: PWNe

Particles accelerated by the wind from pulsars...

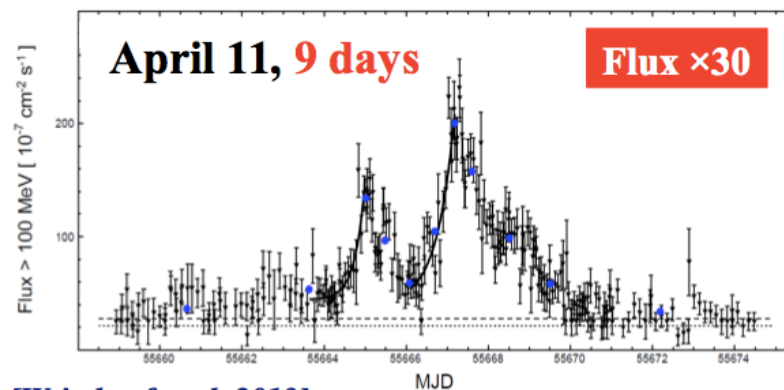
The variable Crab Nebula



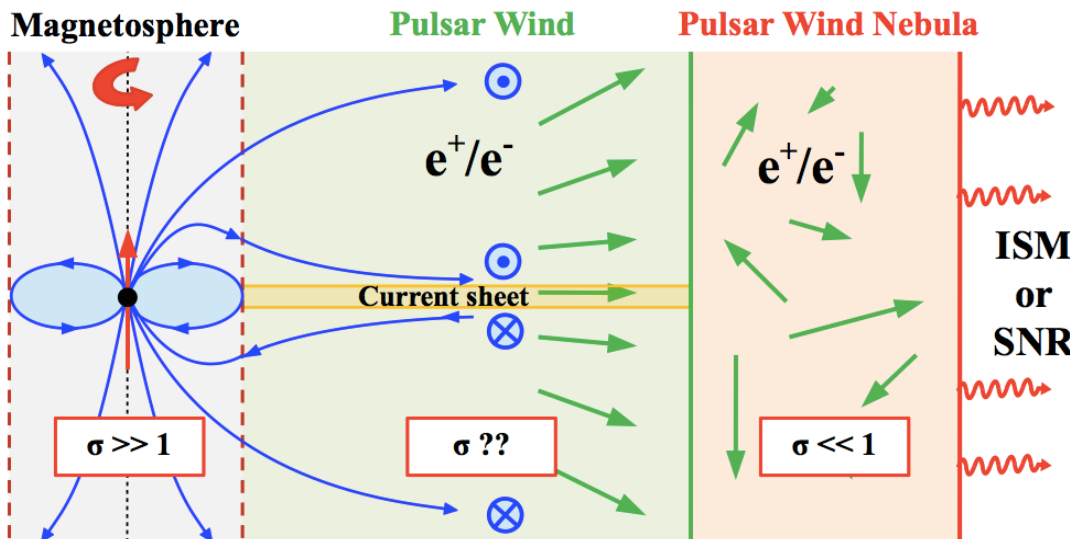
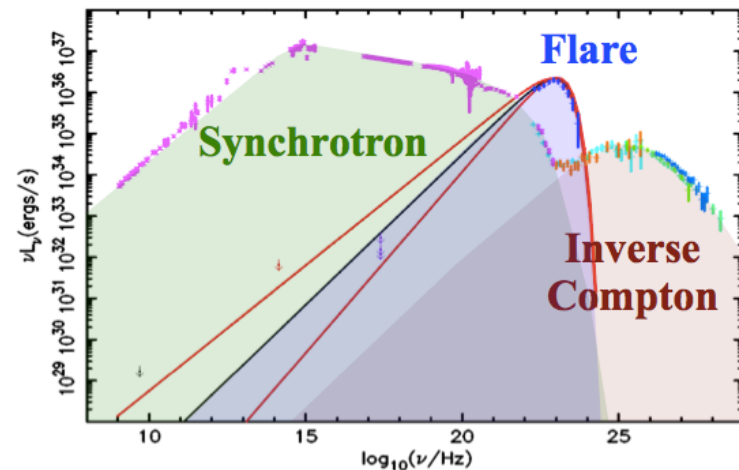
Discovery of MeV-GeV Flares from the Crab!

Striped wind simulations explain the “ σ problem”

[Buehler et al., 2012]



[Weisskopf et al. 2013]



$$\sigma = \frac{\text{Poynting flux}}{\text{Particle kinetic energy flux}}$$

Transition $\sigma \gg 1$ to $\sigma \ll 1$
unknown: “sigma” problem

Science Topics: PWNe

Particles accelerated by the wind from pulsars...

- Probe particle acceleration in relativistic shocks and associated magnetic field strengths through measurement of spectral cutoff(s) above 100keV (presently little to no data), probing in particular the inner regions where non-dissipative MHD models fail (“ σ problem”)
- Polarization measurements could constrain the magnetic field geometry in the acceleration region.
- Better understand the physics and origin of the Crab GeV flares by observing any MeV variability around the synchrotron cutoff energy

- Testing a variety of sources in a variety of environments will probe more physical processes and help minimize the impact of incomplete (MW) data sets;
- NB! This is limited due to the relative faintness of PWNe other than the Crab (next brightest are ~ 2 orders of magnitude lower in flux)

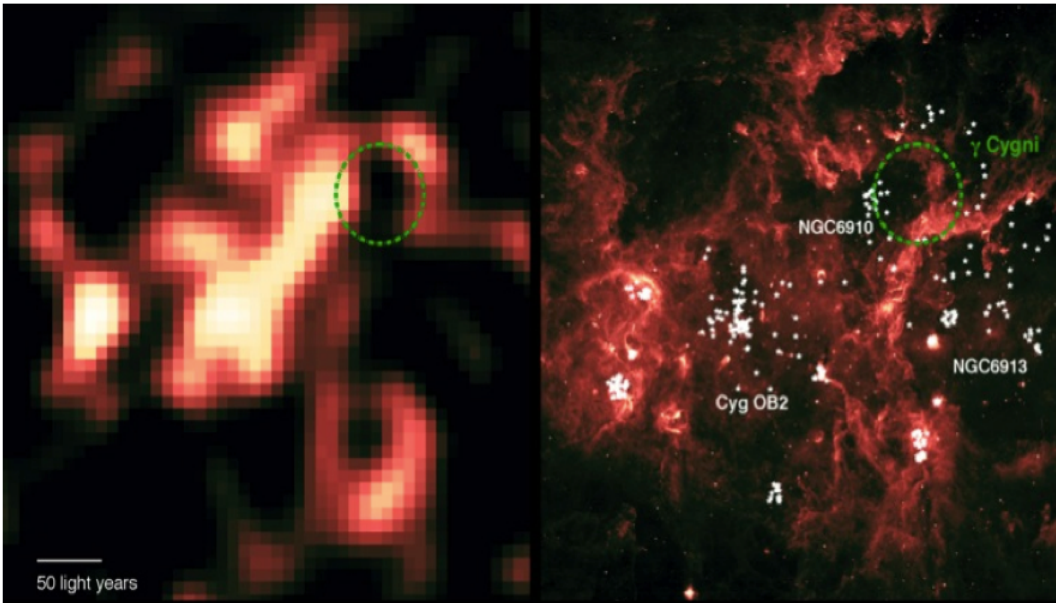
Science Topics: PWNe

Particles accelerated by the wind from pulsars...

Topic	Spatial coverage	Spatial resolution	Energy range	Spectral resolution	Line/continuum sensitivity	Timing?	Polarization	Real-time capability
Spectral Cutoffs	All sky	$\sim < 0.01^\circ$	keV – MeV	$< \sim 10\%$	$\sim 10^{-12}$ erg $\text{cm}^{-2}\text{s}^{-1}$	$< 3\text{ms}$ (remove pulsar)		
B-field geometry	Crab, (others)	$< 0.01^\circ?$	$\sim \text{MeV}$	$< \sim 15\%$	$\sim 10^{-13}$ erg $\text{cm}^{-2}\text{s}^{-1}?$		10% (0.2%)	
Crab flares	$\sim 3^\circ$	$< 0.1^\circ?$	$\sim 1 \text{ MeV} - 1 \text{ GeV}$ (contemporaneous)	$< \sim 15\%$	$\sim 10^{-12}$ erg $\text{cm}^{-2}\text{s}^{-1}$			Y + MW, Flare \sim few days
?								

Science Topics: Superbubbles

Groups of massive stars...



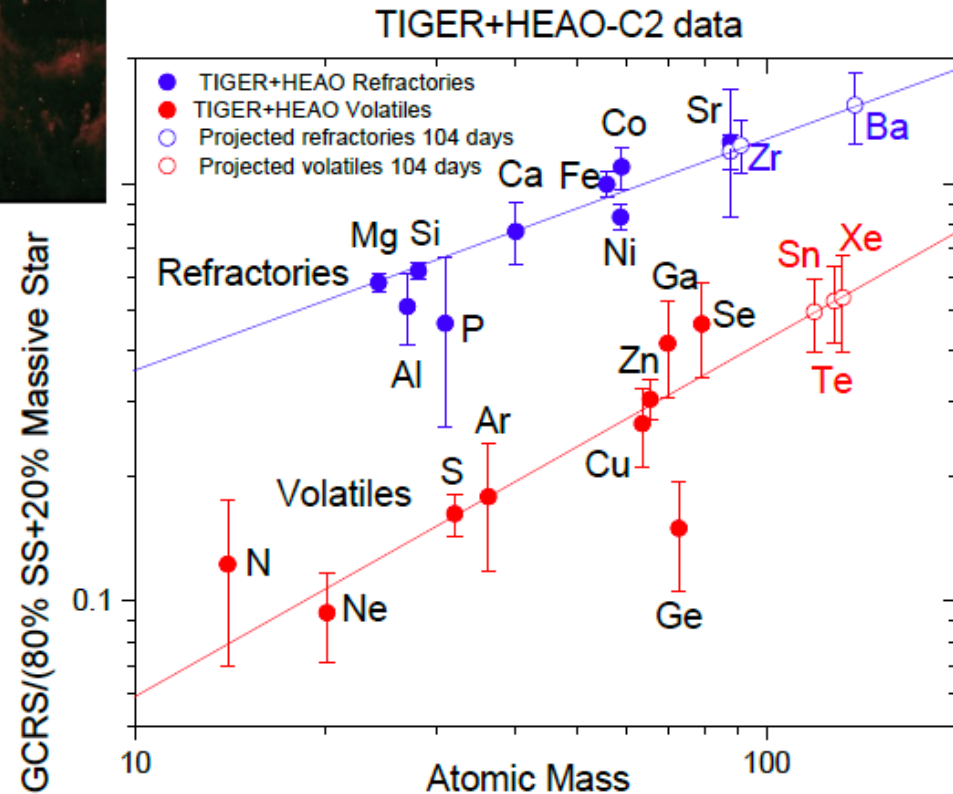
Cocoon of 10-100 GeV γ -ray emission

IR emission from the Cygnus Superbubble

Credit: I. A. Grenier (Fermi LAT/AIM/U. Paris Diderot/CEA) and L. Tibaldo (Fermi LAT/SLAC).

CRs from Massive Stars?

R. Binns et al. ICRC 2013



Science Topics: Superbubbles

Groups of massive stars...

- Trace massive star formation
 - ^{26}Al , ^{60}Fe lines: lifetime of order OB association('s evolution) and independent of local ionization state.
 - energetic particles can seed further star formation in nearby clouds.
- Map the Galaxy's distribution of
 - ^{26}Al , ^{60}Fe lines: trace large scale outflow of particles, energy, and momentum which can significantly affect galaxy evolution.
- Study of the spectral and spatial distribution of continuum emission can address the same particle acceleration and interaction topics as for SNRs in particularly energetic and structured environments (ex: Cygnus cocoon)

Science Topics: Superbubbles

Groups of massive stars...

Topic	Spatial coverage	Spatial resolution	Energy range	Spectral resolution	Line/continuum sensitivity	Timing?	Polarization	Real-time capability
^{26}Al , ^{60}Fe lines	$\sim 20^{\circ 2}$ regions, Galaxy	$< 0.05^{\circ}$	$\sim 1\text{-}6$ MeV	$< \sim 10\%$; $< 0.2\%^*$ *resolve Doppler broadening	$\sim 10^{-7}$ $\text{cm}^{-2}\text{s}^{-1}\text{MeV}^{-1}$			
Particle populations	$\sim 20^{\circ 2}$ regions, all sky	$< 0.1^{\circ}$	MeV – TeV	$< \sim 15\%$	$\sim 10^{-13}$ $\text{erg cm}^{-2}\text{s}^{-1}$	Poss. $\sim < 3\text{ms}$ (pulsars)		
?								

Connections to Other Science Topics

To better understand the origins and evolution of the universe and everything in it through study of high energy particles,

- Novae as scaled down SNe/R with more human-accessible time scales
- γ -ray binaries: particle acceleration and associated magnetic field from interaction between a pulsar's relativistic wind and the companion's wind
- Magnetars, rotation-powered pulsars: origin of MeV γ -rays from magnetic fields above Schwinger (QED) limit
- Galactic center as collection of pulsars / SNRs / massive stars / ...
- Low energy CR nuclear lines from interactions in ISM/clouds (eg ^{12}C , $^{16}\text{O} \Rightarrow 4.4, 6.1 \text{ MeV}$)
- ...
- Discrepancies indicate need for new particles and/or physics!

Testing a variety of sources (eg progenitor) in a variety of environments will probe more physical processes and help minimize the impact of incomplete (MW) data sets.

Theme and Topics

To better understand the origins and evolution of the universe and everything in it through study of high energy particles:

Fundamental physics of particle acceleration:

- › Shock acceleration in SNRs, PWNe, and superbubbles, including key observables such as $e^{+/-}$, p populations and particle escape
- › PWNe: “ σ problem”
- › Crab(like?) flares

Galaxy evolution and feedback:

- › Trace CR source distribution and propagation in our Galaxy
- › Distribution of star formation in the last ~ 1 Myr
- › Acceleration, escape, and propagation of low(er) energy CRs responsible for majority of galactic chemistry and heating

What other topics or themes should be included?

What other science topics are connected, at any energy?

Contact us!

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