

**SNRS:**  
**(& PWNE, SBS, ...)**  
**FUTURE SCIENCE**  
**OBJECTIVES AND**  
**INSTRUMENT REQUIREMENTS**

Fermi Symposium  
GammaSIG Session  
13 Nov 2015

Terri Brandt  
NASA / Goddard

# Theme: SNRs, ...

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

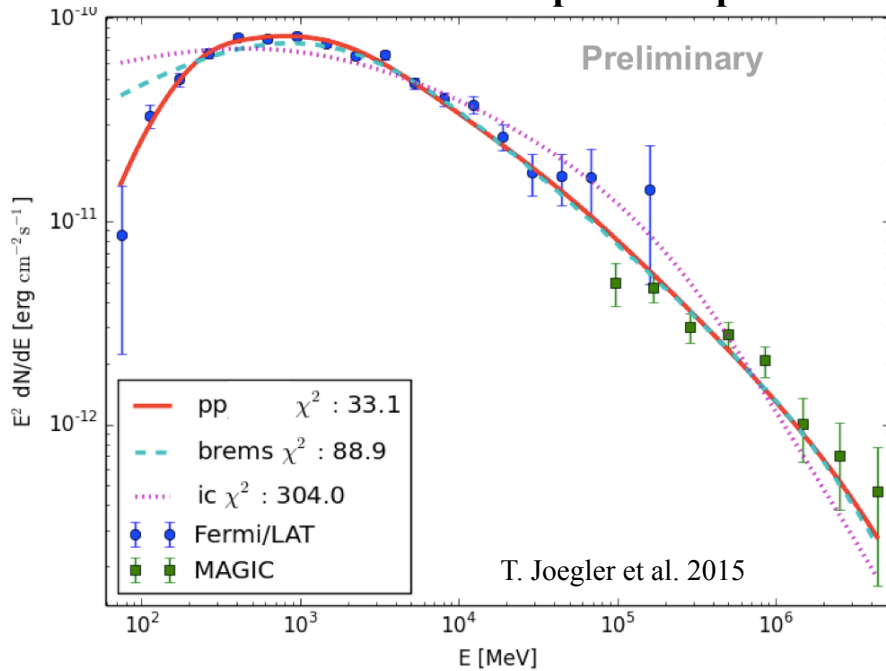
- › to understand the fundamental physics of acceleration in a variety of systems and
- › to understand particles' interaction with, propagation through, and impact on environments at all scales (local, galactic, and extragalactic)

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

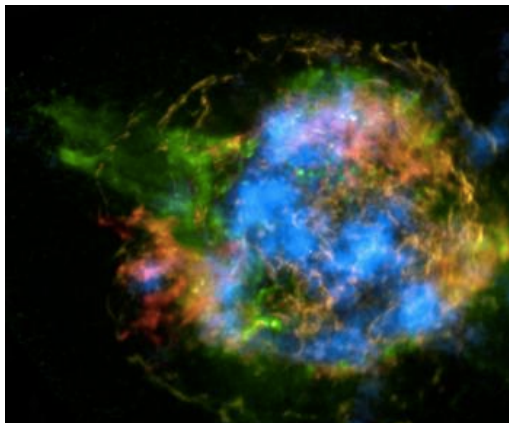
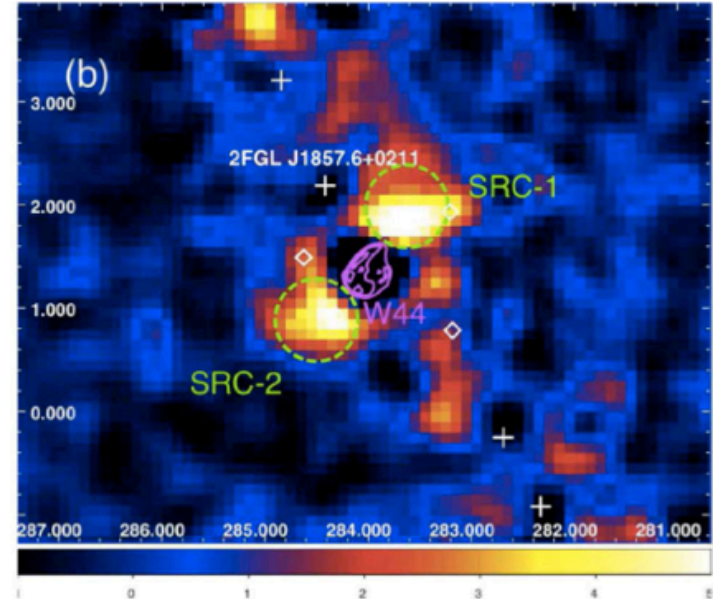
# Science Topics: SNRs

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

W51C: 3<sup>rd</sup> SNR w evidence of pion bump

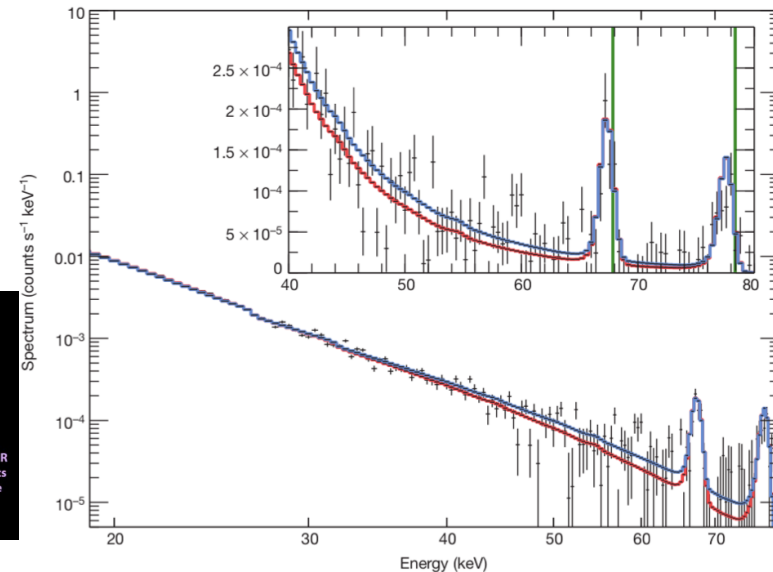
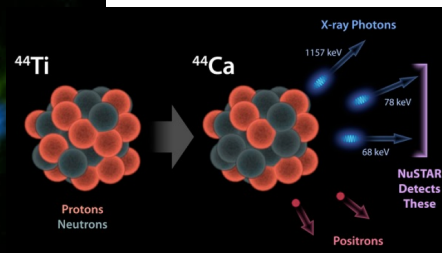


W44: Particle escape? Shocked cloud?



NuSTAR  $^{44}\text{Ti}$

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.
- $^{44}\text{Ti}$  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

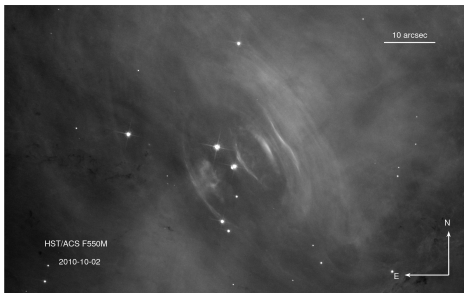
Most likely largest contributors of energetic particles sculpting galaxies...

| 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 <sup>-13</sup> erg cm <sup>-2</sup> s <sup>-1</sup> | ~0.1-3ms (remove pulsar) |              |                        |
| Shell                  | ~5° / All sky    | <0.01°             | MeV – GeV?      | <~15%               | ~10 <sup>-13</sup> erg cm <sup>-2</sup> s <sup>-1</sup> |                          | <20%?        | (X-ray scale: ~ years) |
| Escape                 | 5-10° / All sky  | <0.1°              | MeV – TeV       | <~15%               | ~10 <sup>-14</sup> erg cm <sup>-2</sup> s <sup>-1</sup> |                          |              |                        |
| <sup>44</sup> Ti lines | 5-10° / All sky  | ~0.01°             | keV – 1.157 MeV | <0.2%               | ~10 <sup>-7</sup> phot cm <sup>-2</sup> s <sup>-1</sup> |                          |              |                        |
| ?                      |                  |                    |                 |                     |   |                          |              |                        |

# Science Topics: PWNe

Particles accelerated by the wind from pulsars...

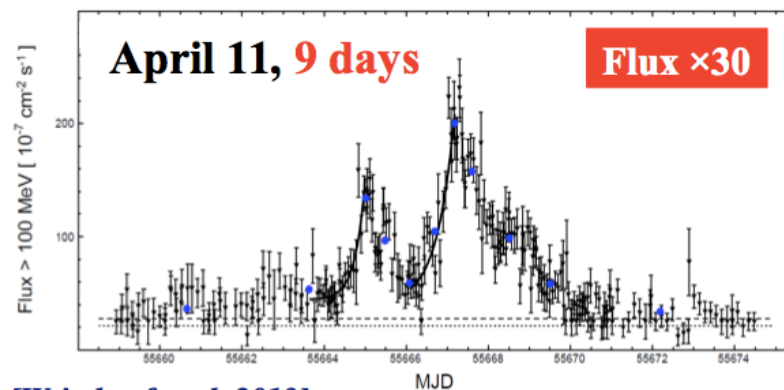
## The variable Crab Nebula



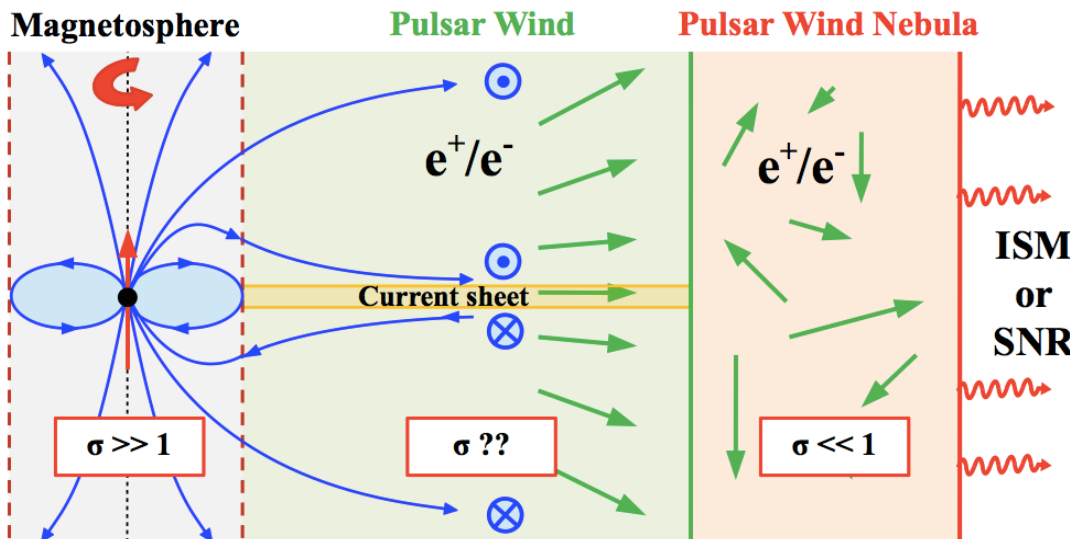
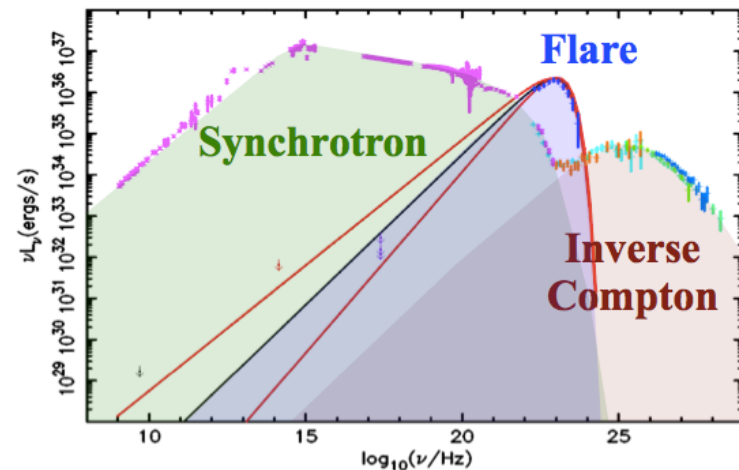
Discovery of MeV-GeV Flares from the Crab!

Striped wind simulations explain the “ $\sigma$  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 (“ $\sigma$  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  $\sim 2$  orders of magnitude lower in flux)

# Science Topics: PWNe

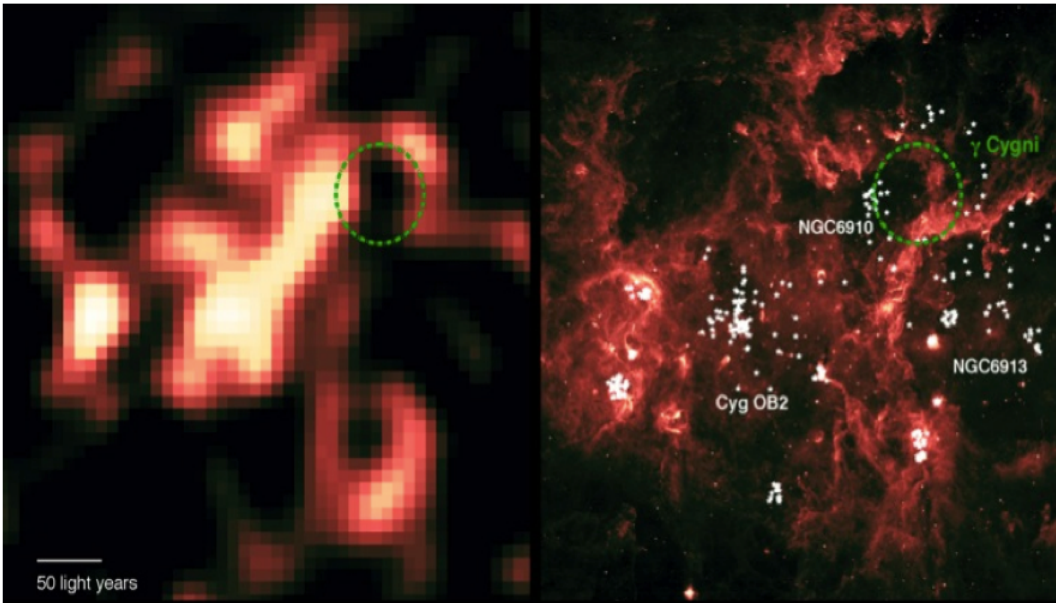
Particles accelerated by the wind from pulsars...

| 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   | $< \sim 10\%$       | $\sim 10^{-12} \text{ erg cm}^{-2}\text{s}^{-1}$  | $< 3\text{ms}$<br>(remove pulsar) |               |                                     |
| B-field geometry | Crab, (others)   | $< 0.01^\circ?$     | $\sim \text{MeV}$   | $< \sim 15\%$       | $\sim 10^{-13} \text{ erg cm}^{-2}\text{s}^{-1}?$ |                                   | 10%<br>(0.2%) |                                     |
| Crab flares      | $\sim 3^\circ$   | $< 0.1^\circ?$      | $\sim 1 \text{ MeV} - 1 \text{ GeV}$<br>(contemporaneous) | $< \sim 15\%$       | $\sim 10^{-12} \text{ erg cm}^{-2}\text{s}^{-1}$  |                                   |               | Y + MW,<br>Flare $\sim$<br>few days |
| ?                |                  |                     |   |                     |   |                                   |               |                                     |



# Science Topics: Superbubbles

Groups of massive stars...



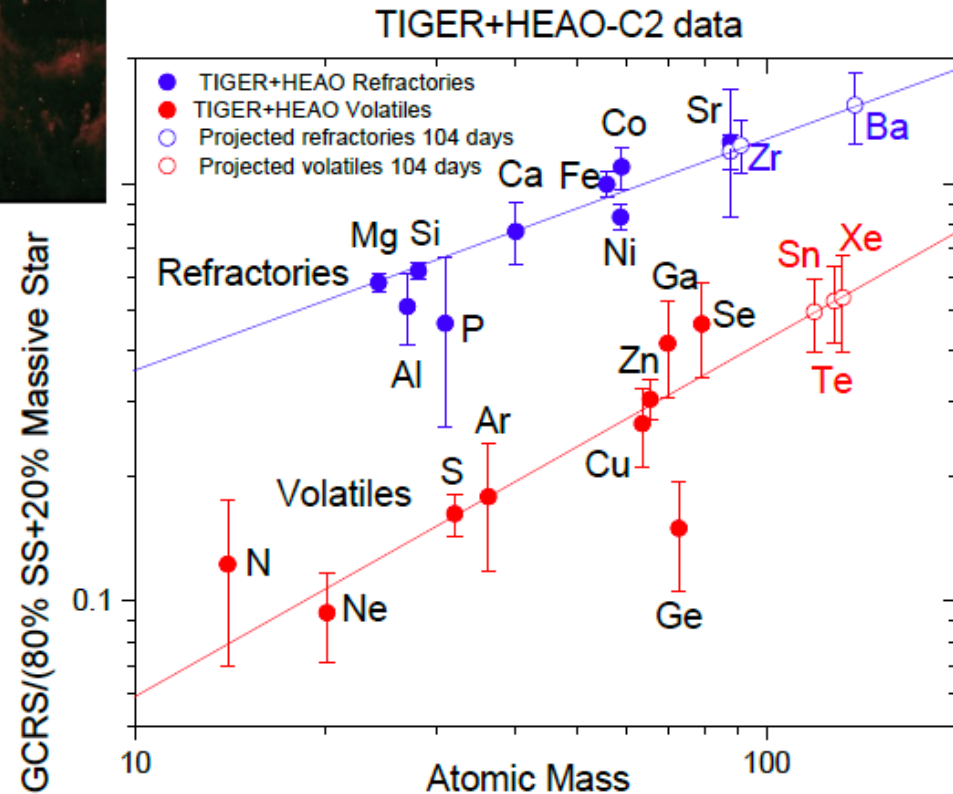
**Cocoon of 10-100 GeV  $\gamma$ -ray emission**

**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
  - $^{26}\text{Al}$ ,  $^{60}\text{Fe}$  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
  - $^{26}\text{Al}$ ,  $^{60}\text{Fe}$  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 |
|---|--------------------------------------|--------------------|-----------------------|--|---|-------------------------------------|--------------|----------------------|
| $^{26}\text{Al}$ , $^{60}\text{Fe}$ lines | $\sim 20^{\circ 2}$ regions, Galaxy  | $< 0.05^{\circ}$   | $\sim 1\text{-}6$ MeV | $< \sim 10\%$ ; $< 0.2\%^*$<br>*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
- $\gamma$ -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  $\gamma$ -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  $^{12}\text{C}$ ,  $^{16}\text{O} \Rightarrow 4.4, 6.1 \text{ MeV}$ )
- ...
- 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: “ $\sigma$  problem”
- › Crab(like?) flares

Galaxy evolution and feedback:

- › Trace CR source distribution and propagation in our Galaxy
- › Distribution of star formation in the last  $\sim 1$  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 me!**

[terri.j.brandt@gmail.com](mailto:terri.j.brandt@gmail.com)



Fermi-LAT shows hint of a “pion bump”  
in Cas A; Yuan+ 2013

