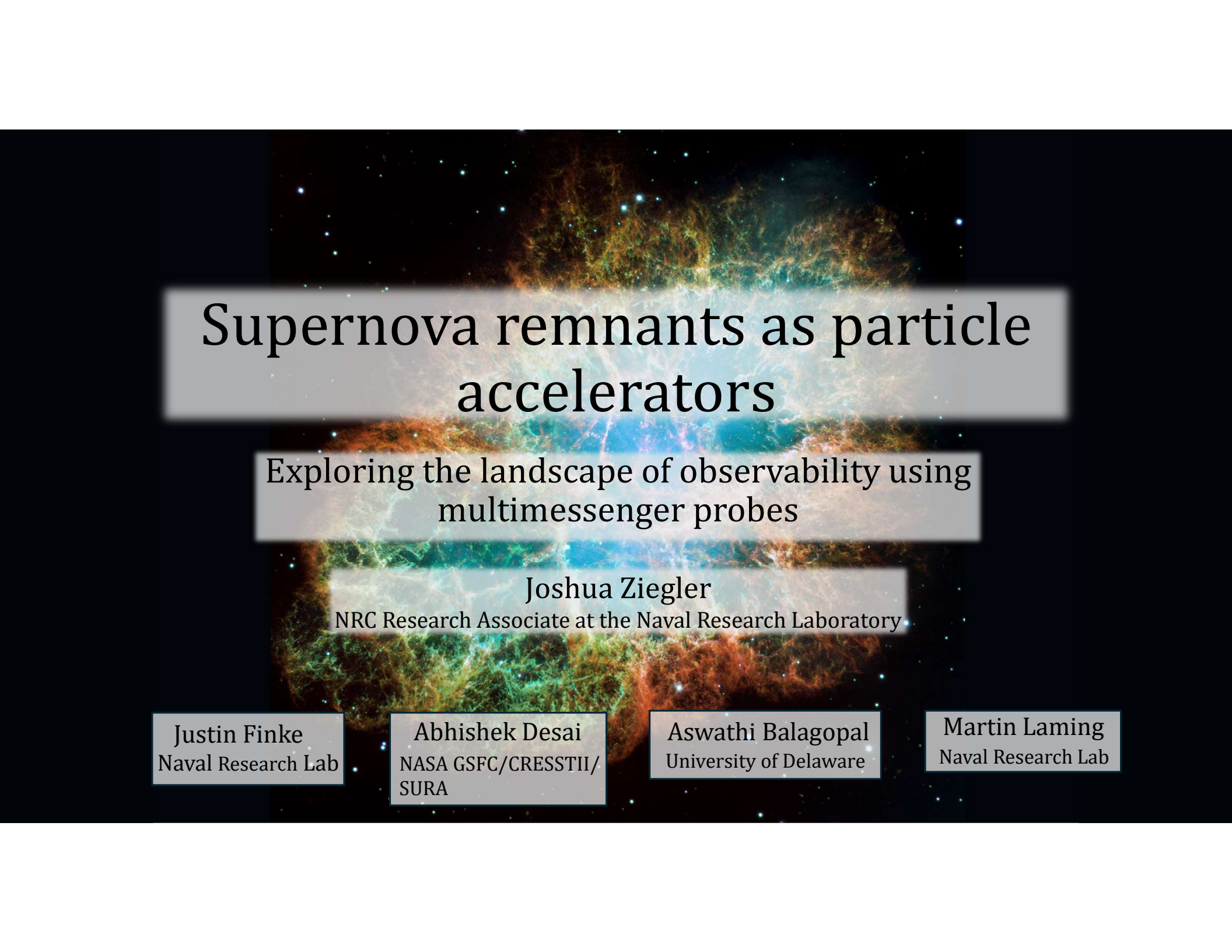




Supernova remnants as particle accelerators

Exploring the landscape of observability using multimessenger probes

Joshua Ziegler

NRC Research Associate at the Naval Research Laboratory

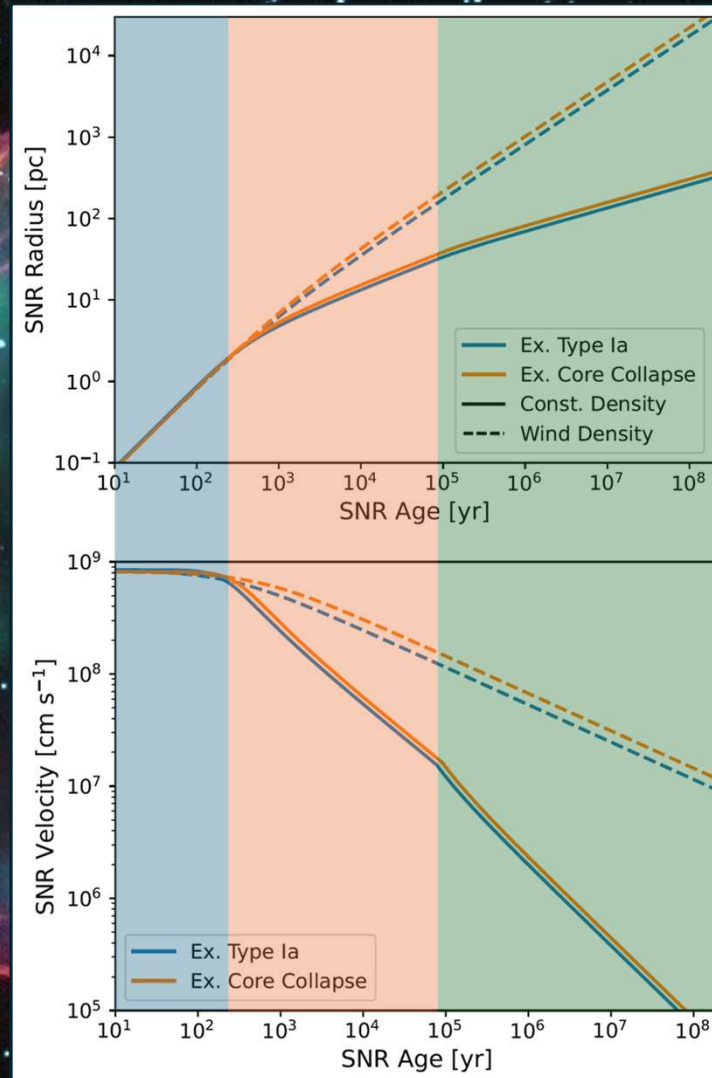
Justin Finke
Naval Research Lab

Abhishek Desai
NASA GSFC/CRESSTII/
SURA

Aswathi Balagopal
University of Delaware

Martin Laming
Naval Research Lab

- After supernova, ejecta expands into ISM
- SNR accumulates mass from ISM
- $M_{ej} v_0^2 \approx (M_{ej} + M_{ISM}) v^2$
- Sedov time t_s : when mass accumulated from ISM is comparable to ejected mass
- Radiation time t_r : energy lost by thermal radiation is comparable to initial (kinetic) energy from supernova
- Continued expansion due to pressure from interior of SNR



Free Expansion Phase:

$$v \approx v_0$$

Sedov Phase:

$$v \propto t^{-3/5}$$

Snowplow Phase:

$$v \propto t^{-5/7}$$

Sedov 1946
Taylor 1950
Blinnikov 1982
Cox 1972

- Magnetic instabilities form in front of and behind shock front
- Charged particles cross from upstream to downstream and back, reflecting off magnetic instabilities each time
- As long as particles have relativistic energies

$$\left\langle \frac{\Delta E}{E} \right\rangle \sim \text{const.}$$

- Energy increase factor depends on SNR expansion speed
- If $P = \text{const.}$:

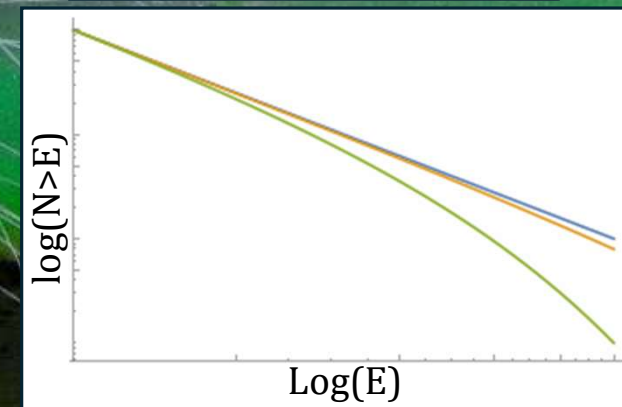
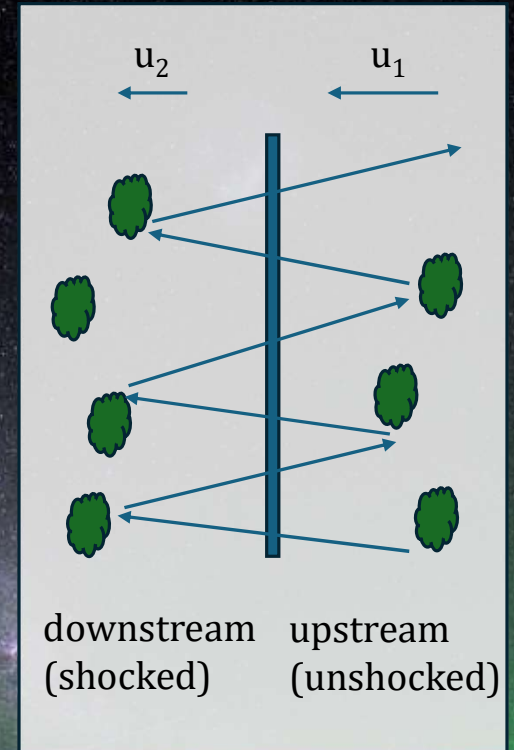
$$N(> E) = N_0 \left(\frac{E}{E_0} \right)^{-s}$$

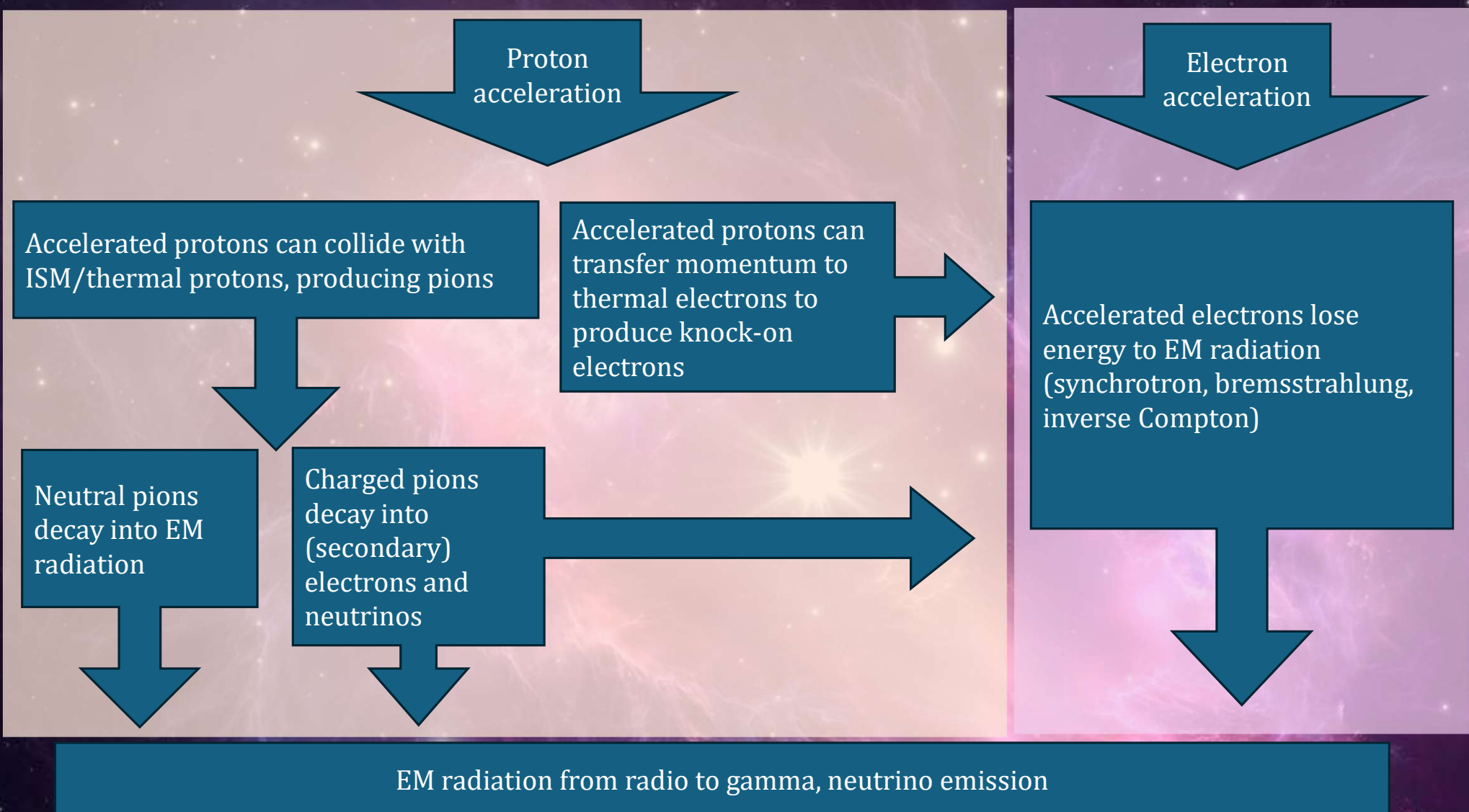
- If $P = gE^{-q}$:

$$N(> E) \sim \left(\frac{E}{E_0} \right)^{-\left(s+r \ln \frac{E}{E_0}\right)}$$

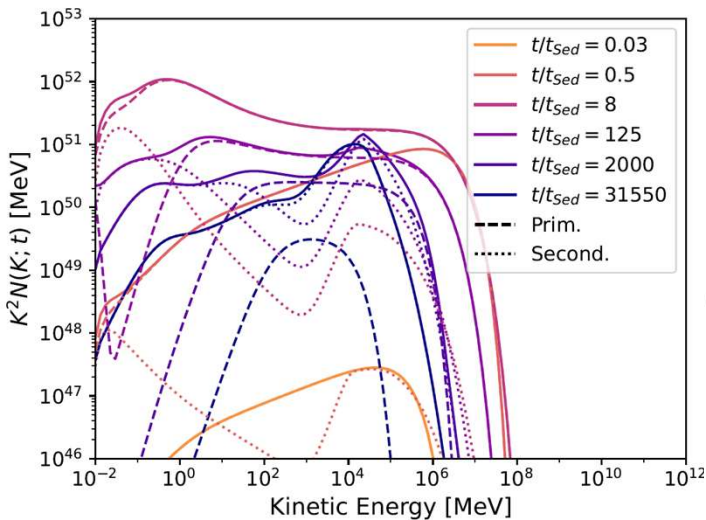
$$s = -\frac{q}{2} - \frac{\ln P_0}{\ln \frac{\Delta E}{E}}, \quad r = \frac{q}{2 \ln \frac{\Delta E}{E}}$$

[Bell 1978a](#)
[Bell 1978b](#)
[Fraschetti and Pohl 2017](#)
[Massaro et al. 2004](#)
[Ziegler et al. 2026](#)

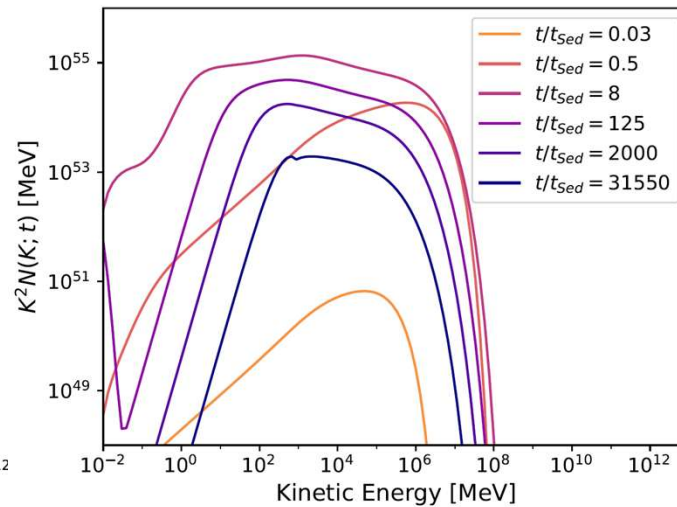




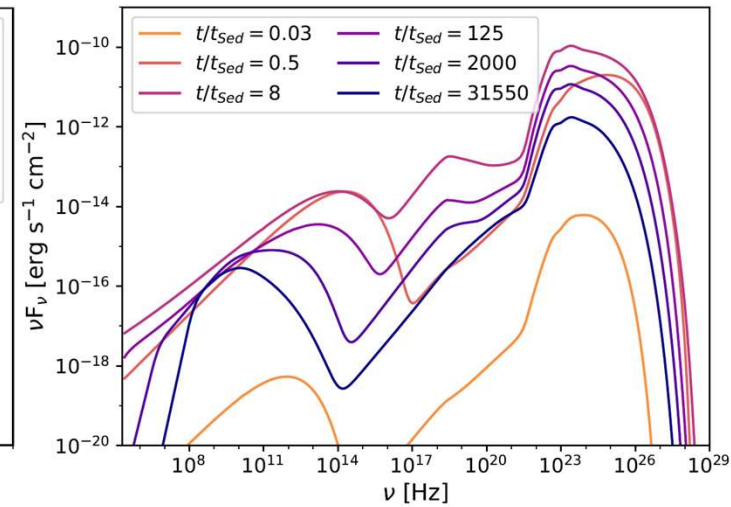
Electron



Proton



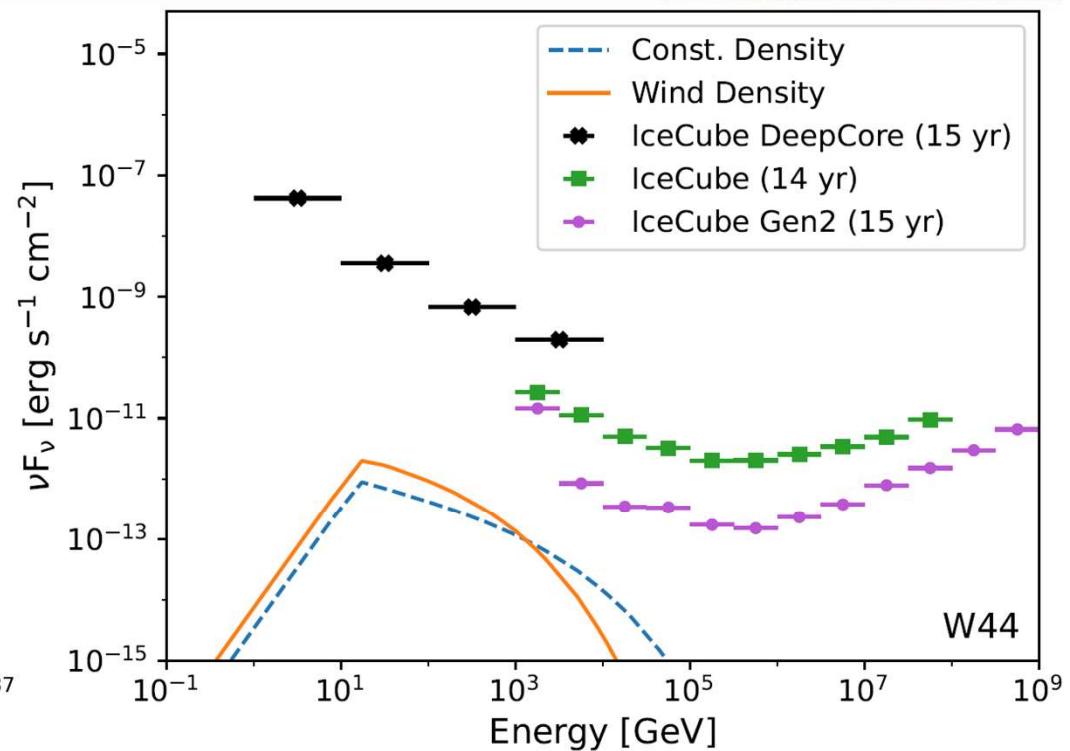
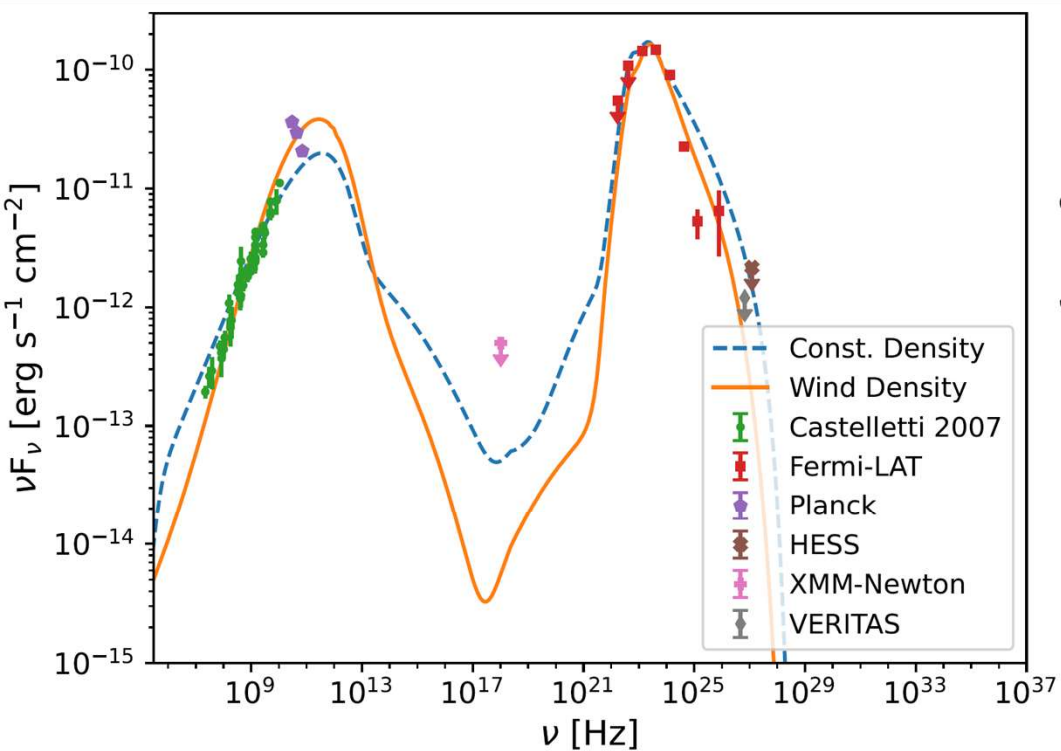
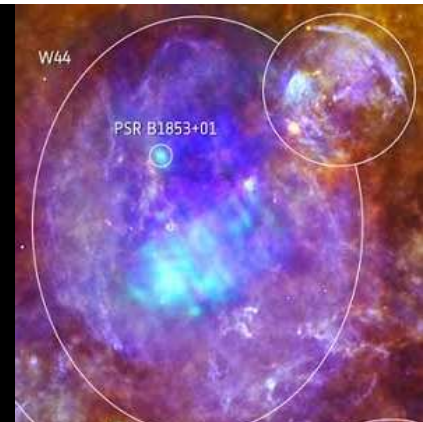
SED



- Proton and electron distributions initially increase until around Sedov time and then decrease
- Primary electrons dominate over secondary and knock-on electrons until around the radiation time, when shock has slowed enough to no longer allow Fermi acceleration
- SED depends on age of SNR, various properties of SNR and ISM environment
 - Observation of SED at sufficiently many frequencies can constrain model parameters

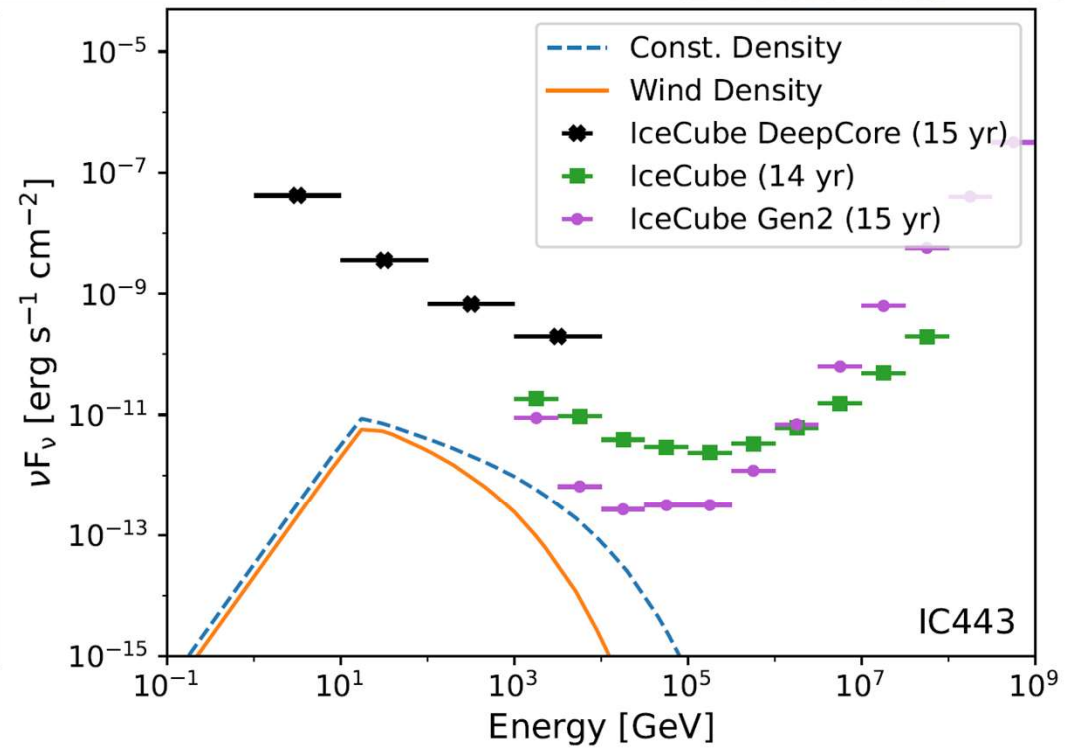
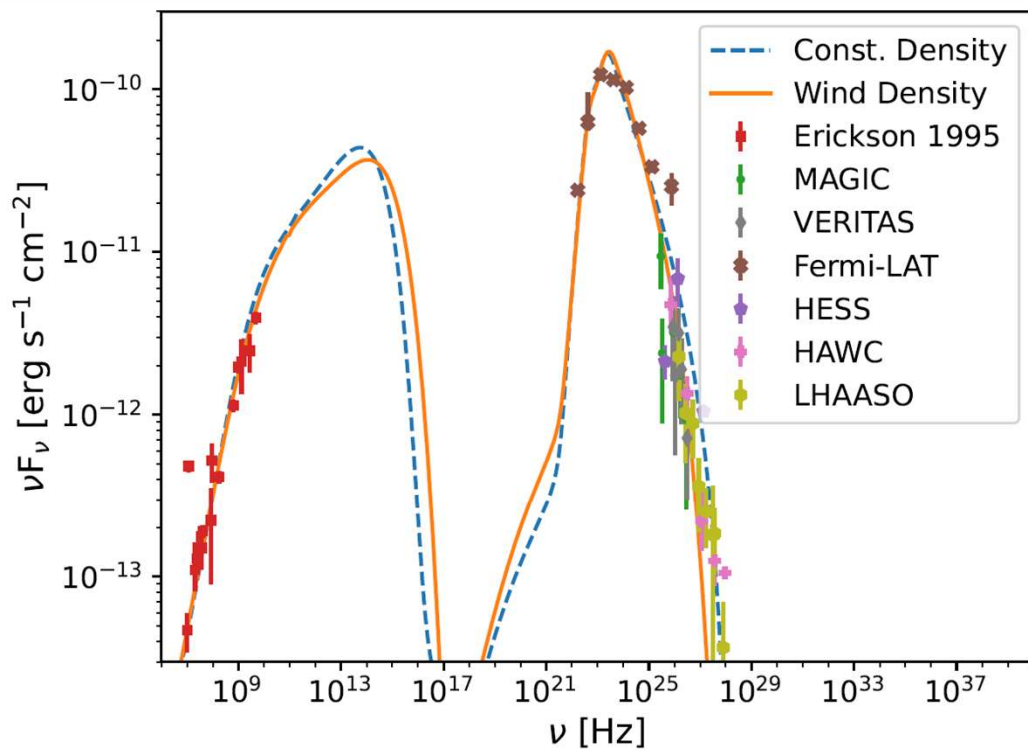
W44

$\sim 1.8 \times 10^4$ yrs
Dec: 1°



IC 443

~ 6000 yrs
Dec: 23°

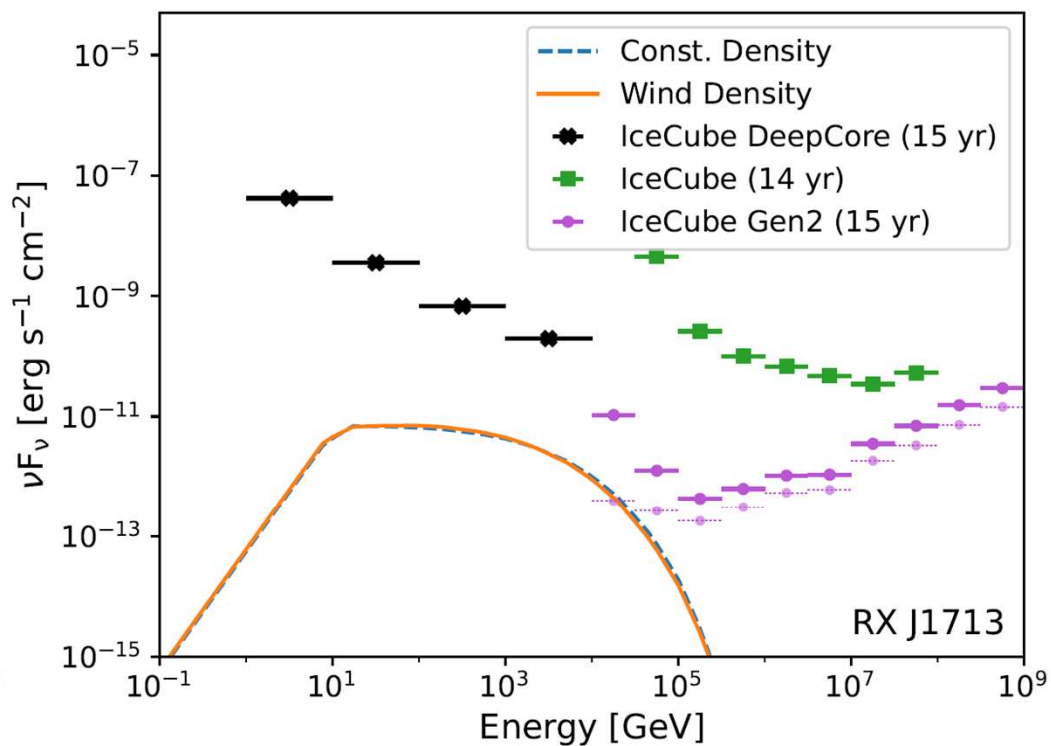
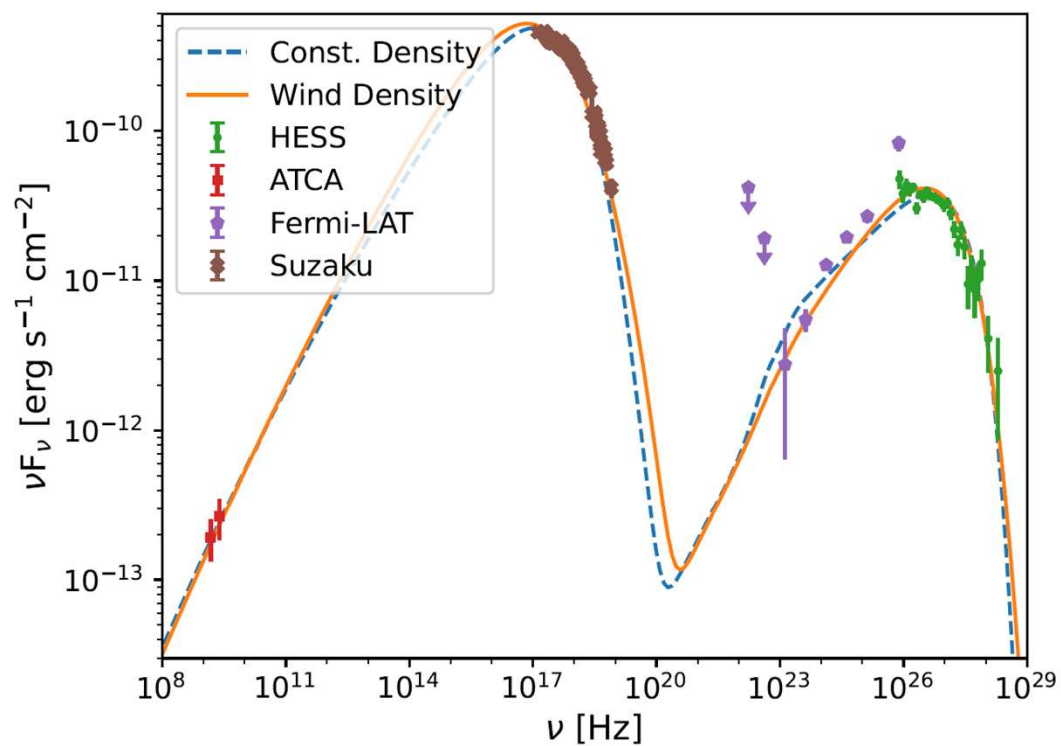


RX J1713

~ 1600 yrs
Dec: -40°

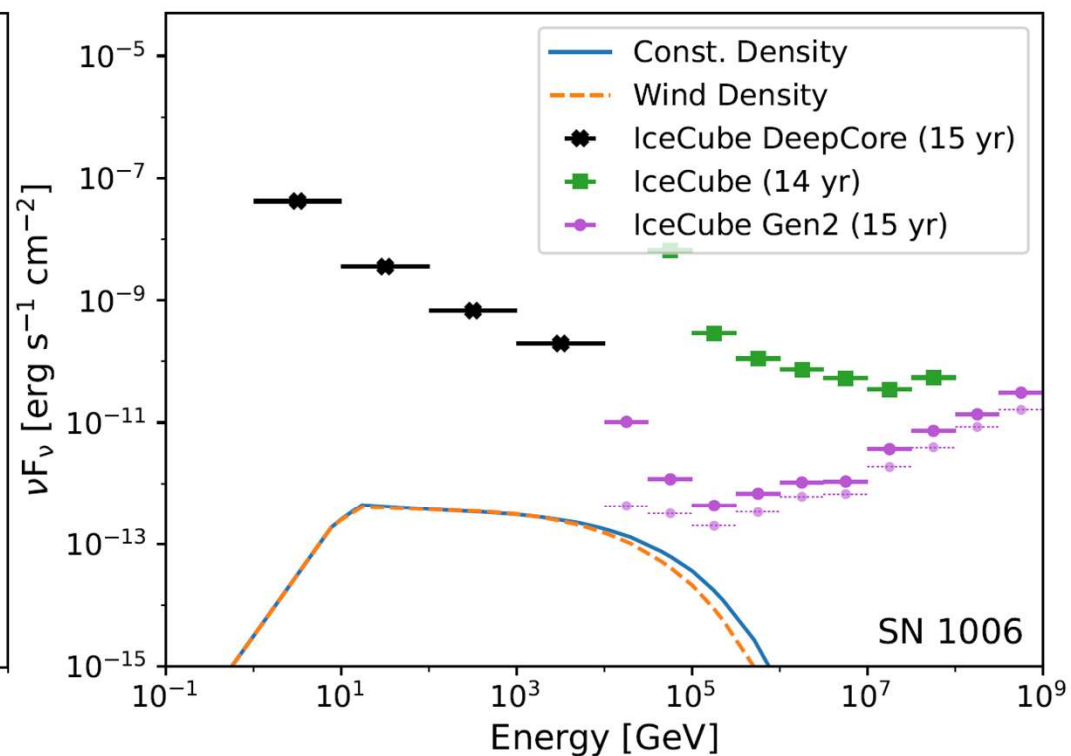
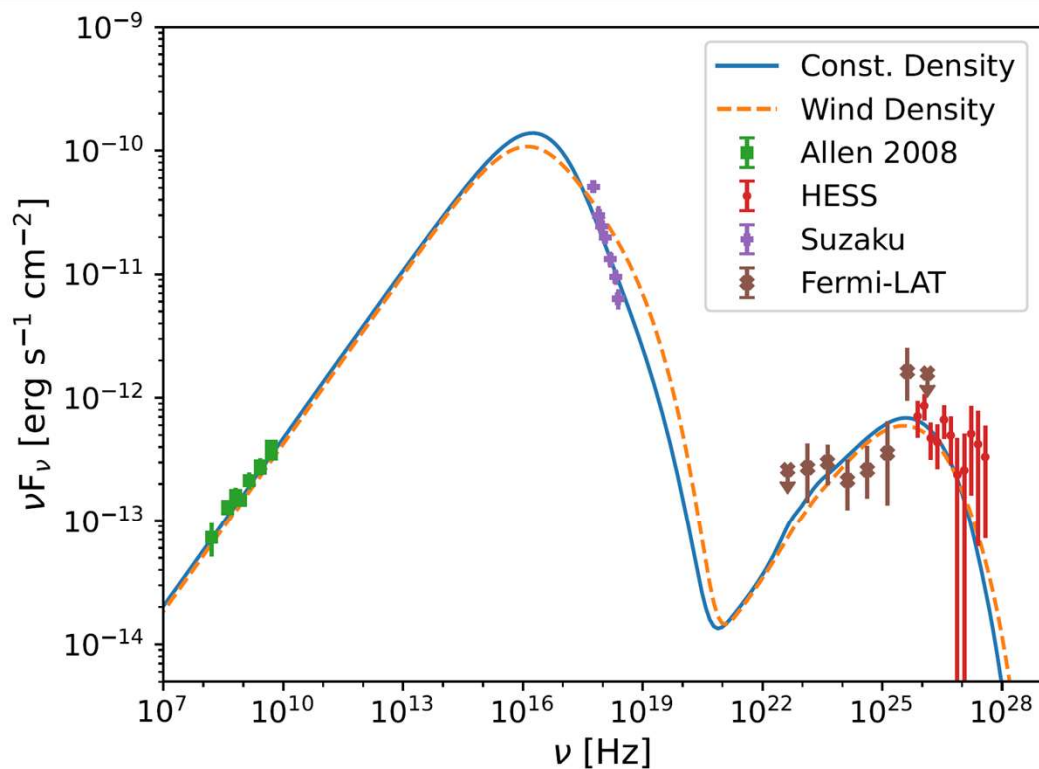
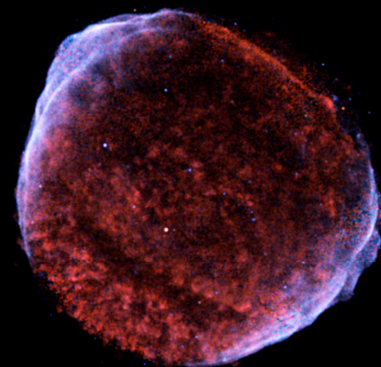
H.E.S.S. (2016) RX J1713.7-3946, $E > 2$ TeV

68% PSF



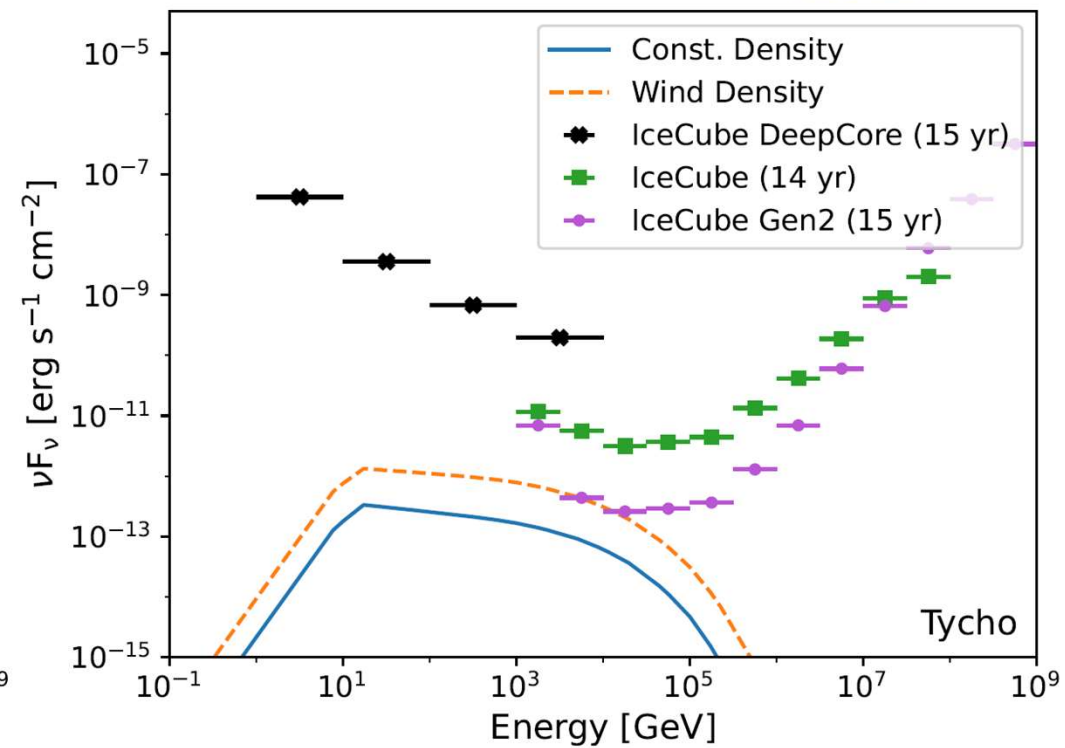
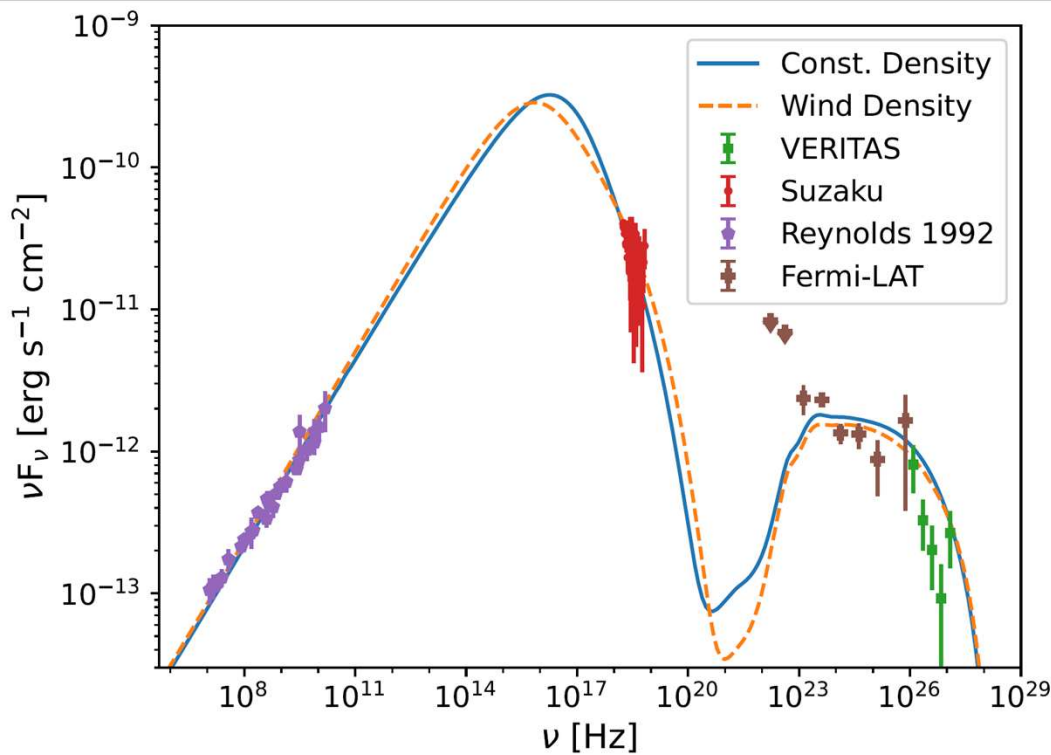
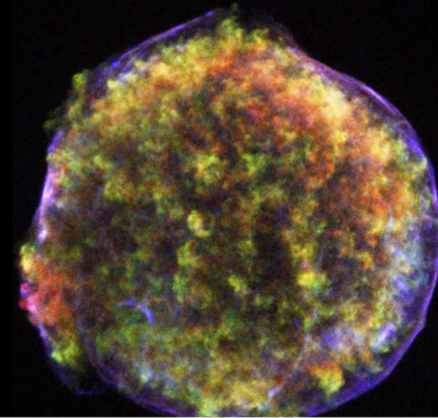
SN 1006

~ 1000 yrs
Dec: -42°



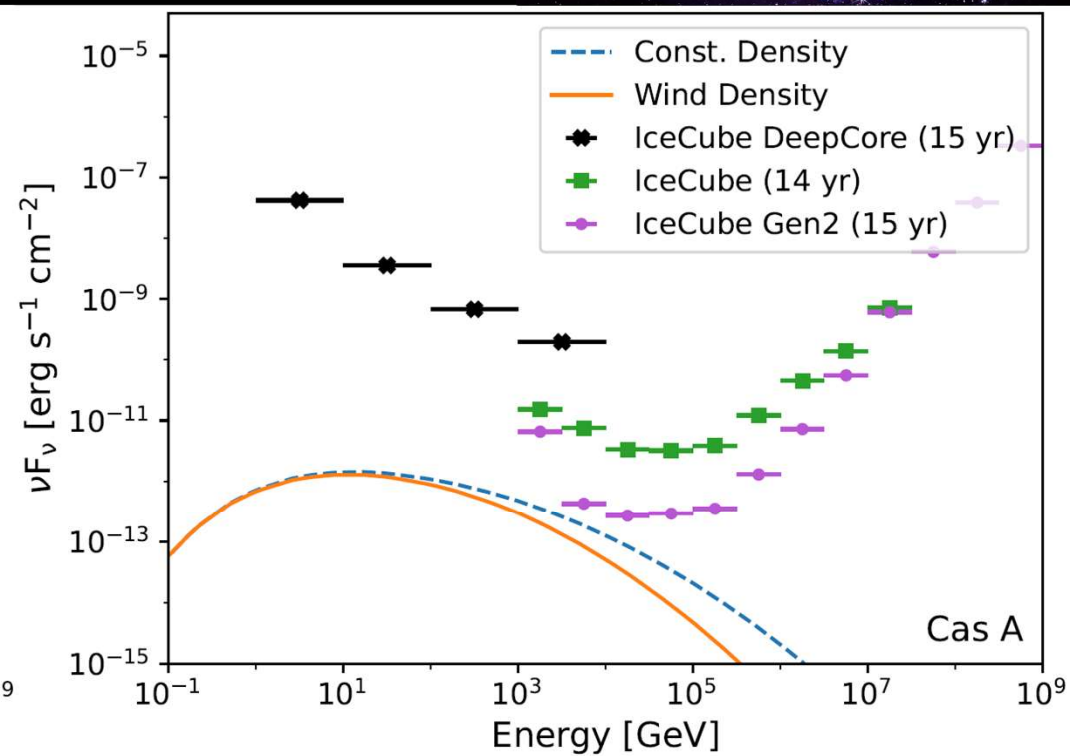
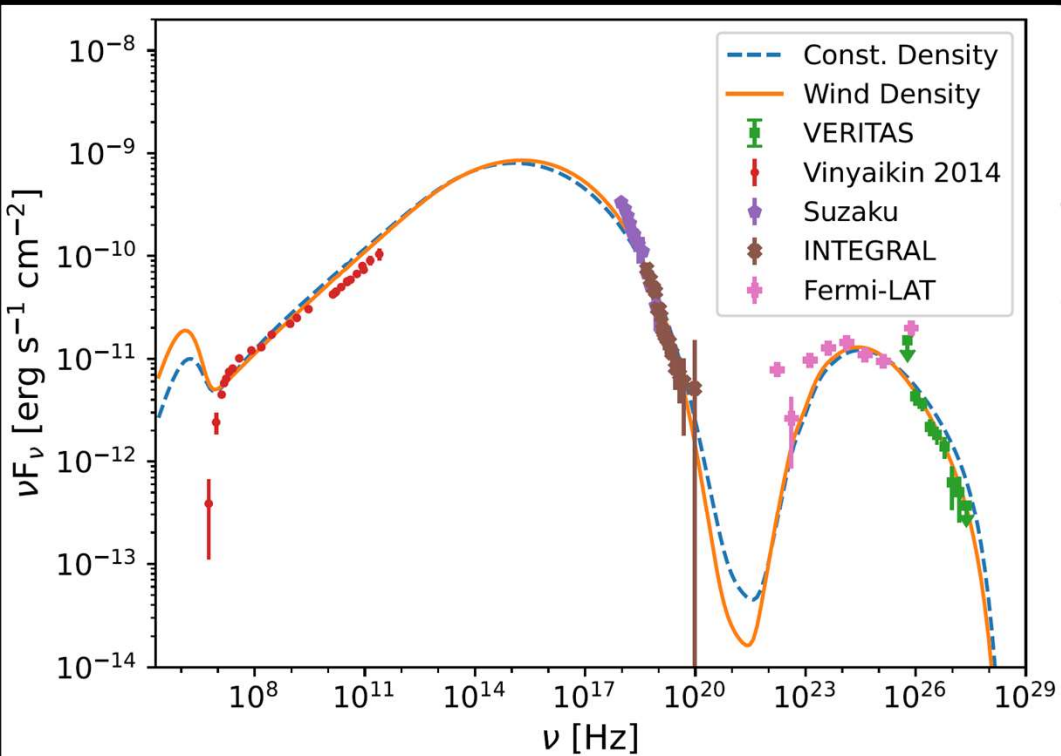
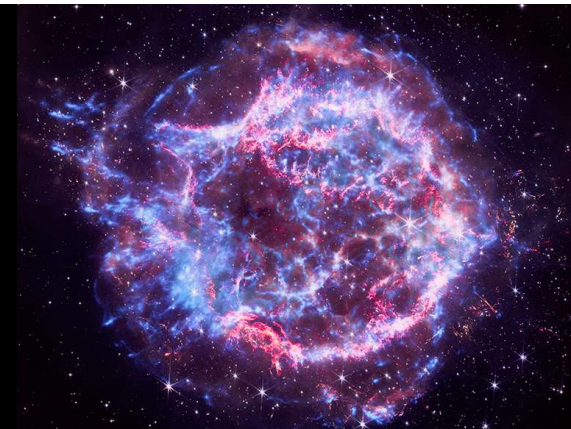
Tycho's SNR

~ 450 yrs
Dec: 64°

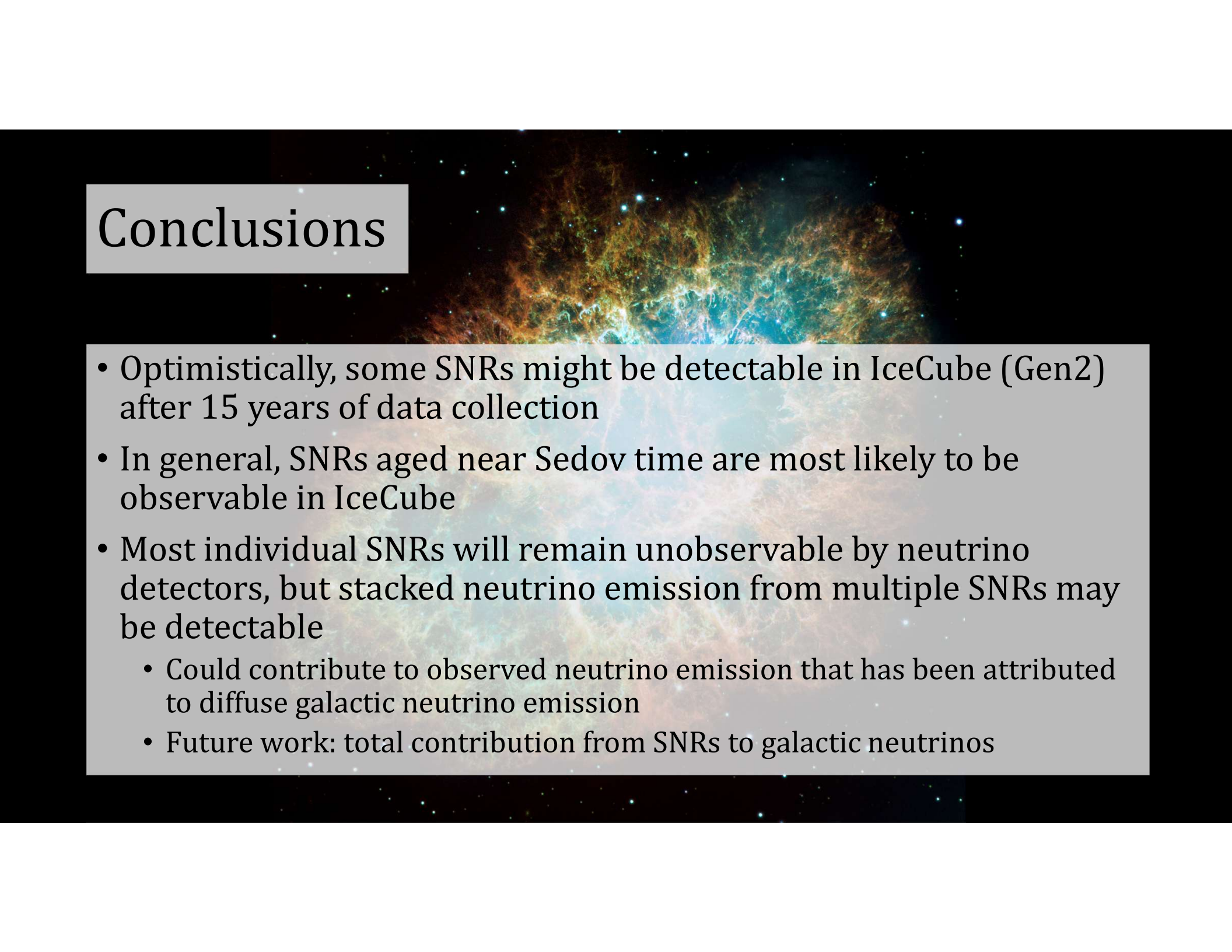


Cassiopeia A

~ 350 yrs
Dec: 59°



Conclusions



- Optimistically, some SNRs might be detectable in IceCube (Gen2) after 15 years of data collection
- In general, SNRs aged near Sedov time are most likely to be observable in IceCube
- Most individual SNRs will remain unobservable by neutrino detectors, but stacked neutrino emission from multiple SNRs may be detectable
 - Could contribute to observed neutrino emission that has been attributed to diffuse galactic neutrino emission
 - Future work: total contribution from SNRs to galactic neutrinos