Harvard-Smithsonian Center for Astrophysics

Progenitor Mass Loss and Supernova Remnant Evolution

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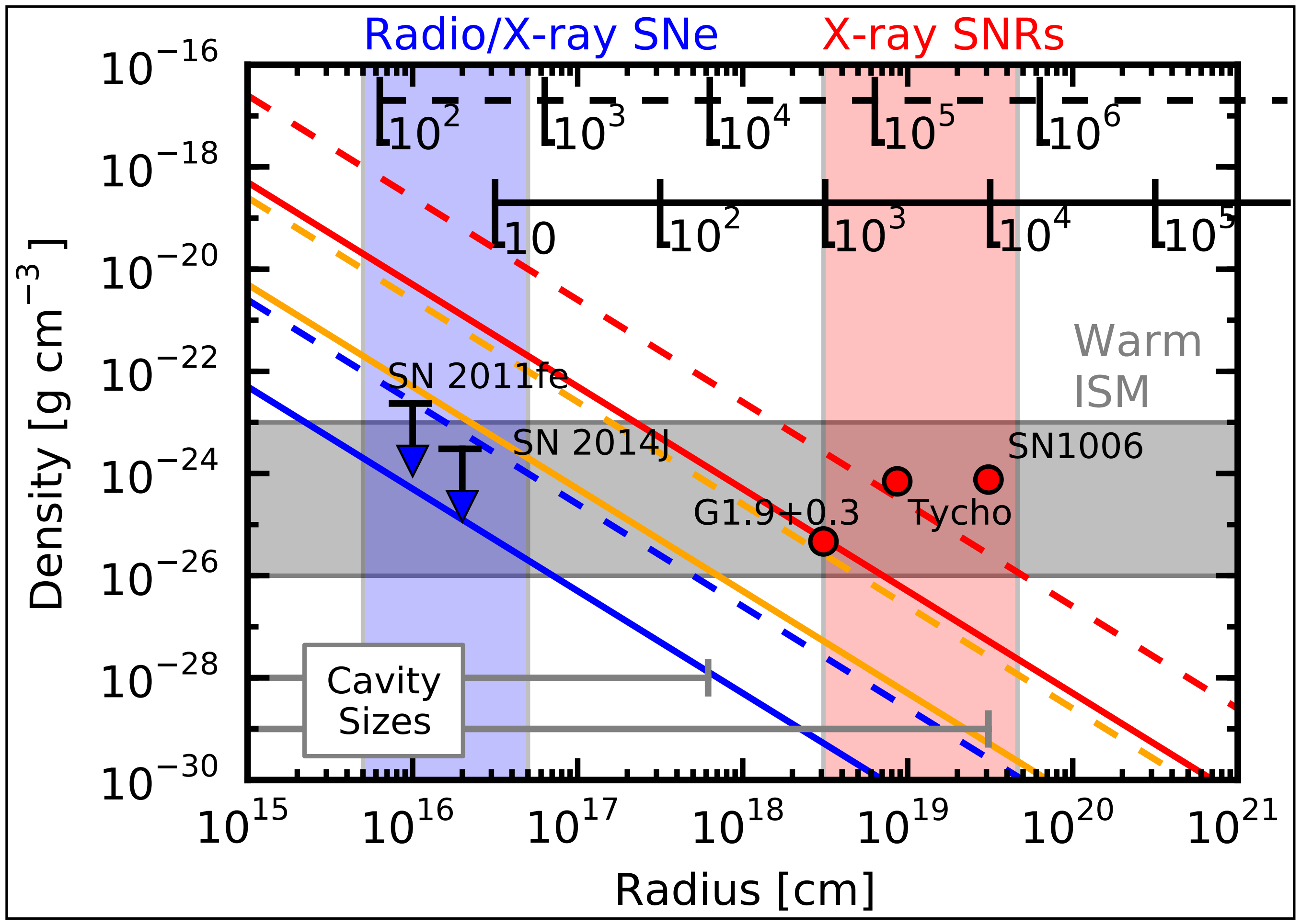
Chandra Theory: TM6-17003X
NASA ATP: 80NSSC18K0566

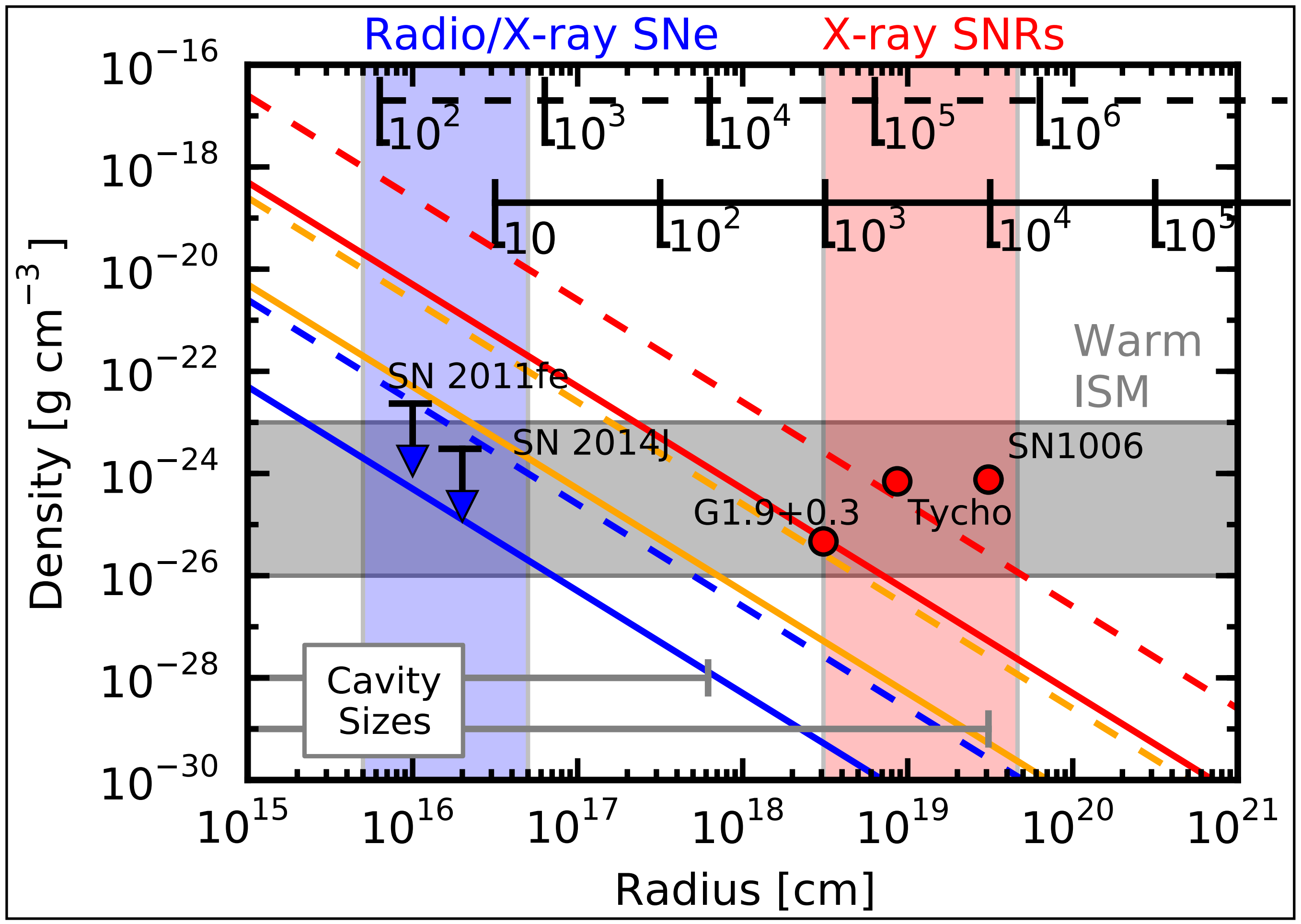
SNR as Probes of Progenitor Evolution



Patnaude & Badenes (2017; Handbook of SNe)

- SNe probe the last 50-100 years of progenitor evolution
- SNR sample a much earlier phase of evolution, but **late** evolution can definitely impact what we observe today, and how we interpret it
- Observations are biased by environmental and explosion properties

SNR as Probes of Progenitor Evolution



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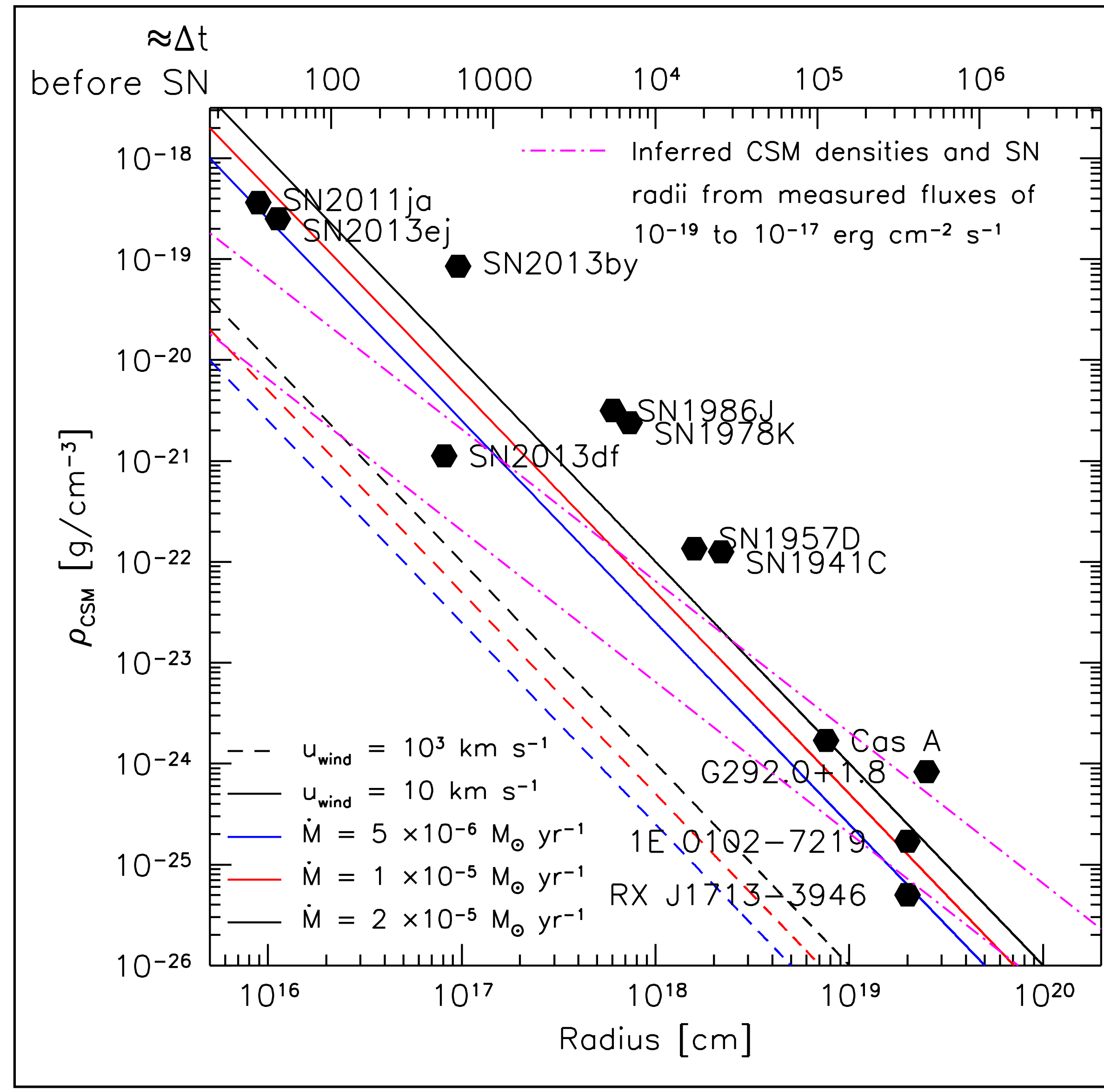
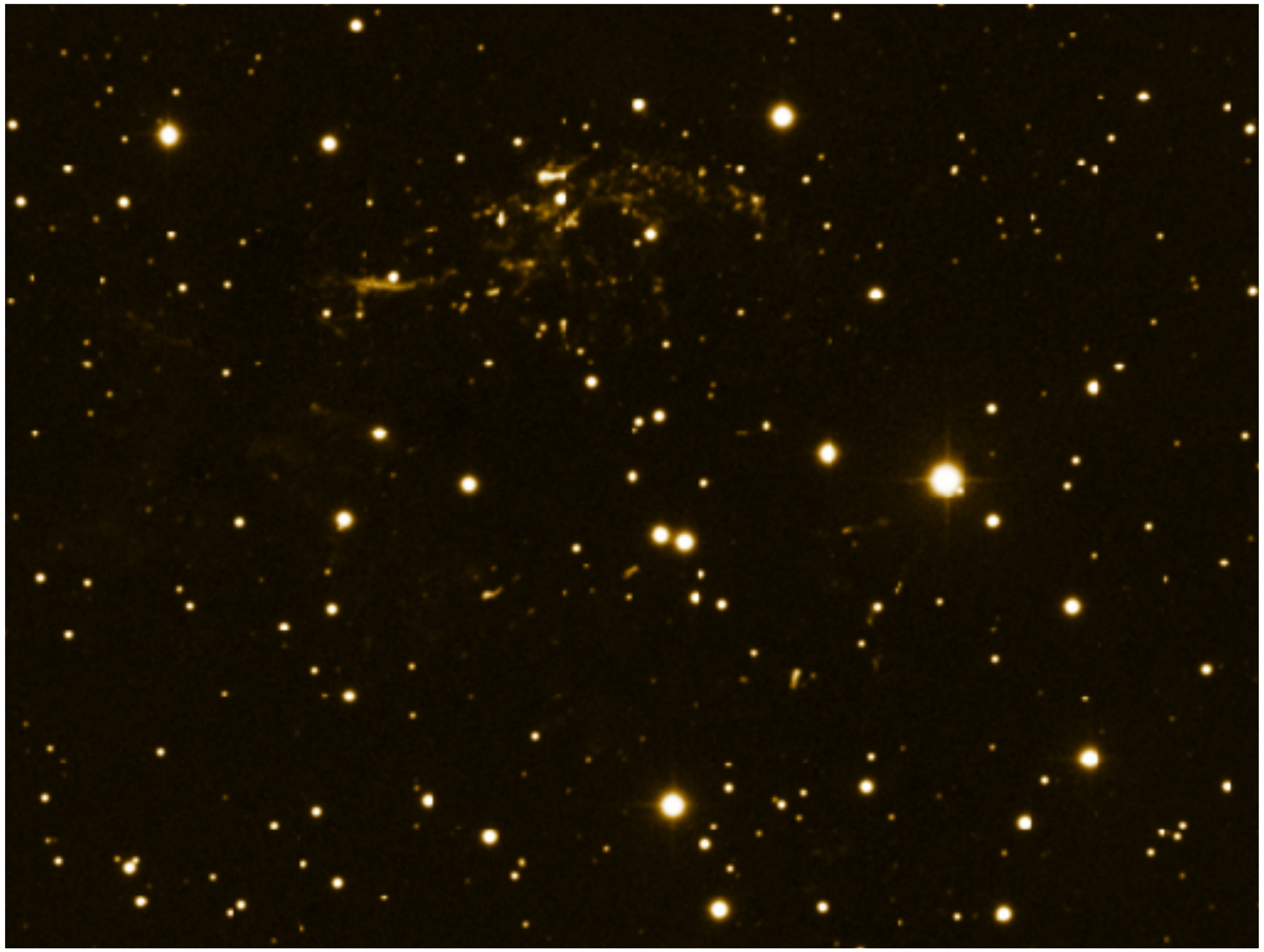


Patnaude et al. (2017)

Optical vs X-ray Emission

Optical emission arises from dense knots and is often times transient:

$$t_{\rm knot} \sim t_{\rm cool} \sim t_{\rm KH} \sim 30\,{\rm yr}$$



Cas A - 1951 - 2012 (Patnaude & Fesen, 2014)

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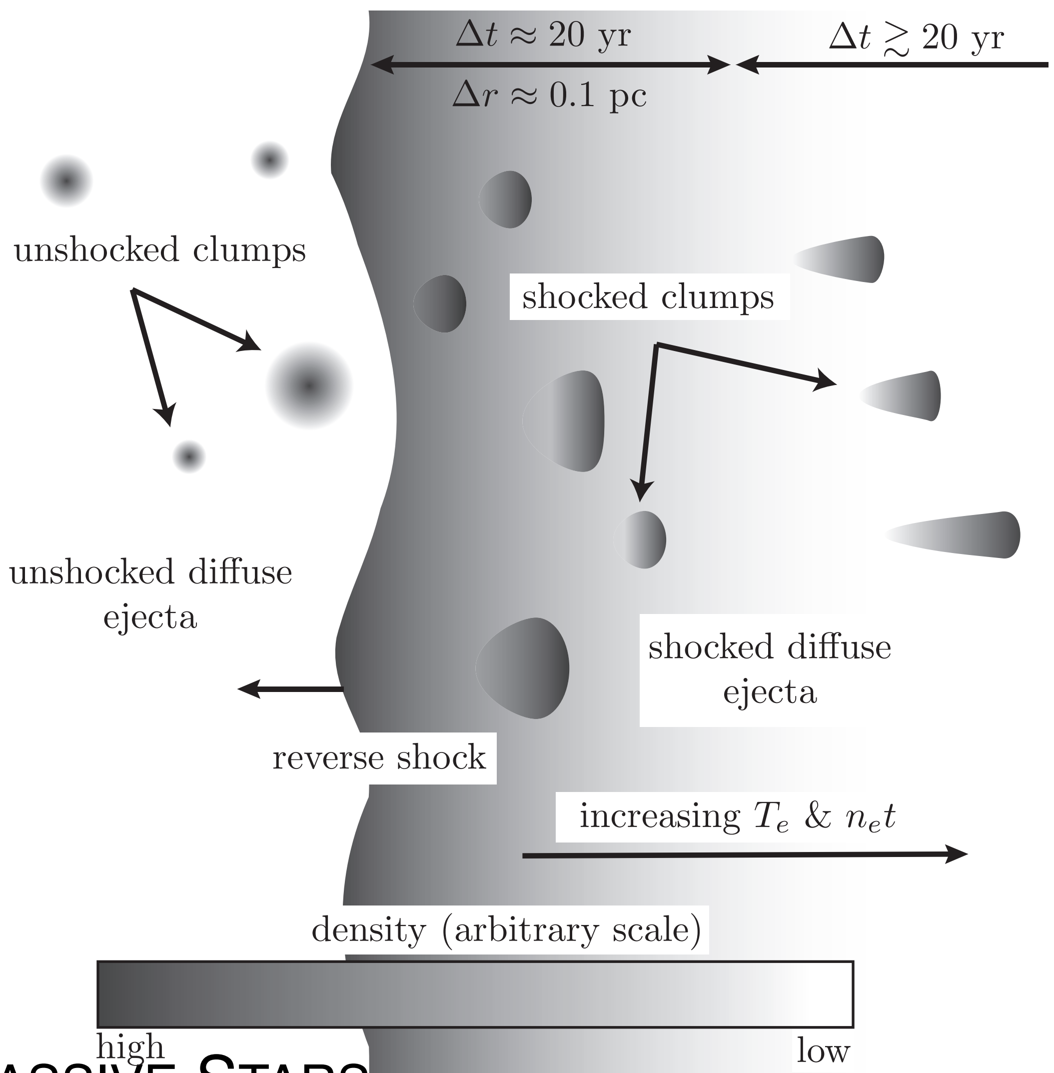

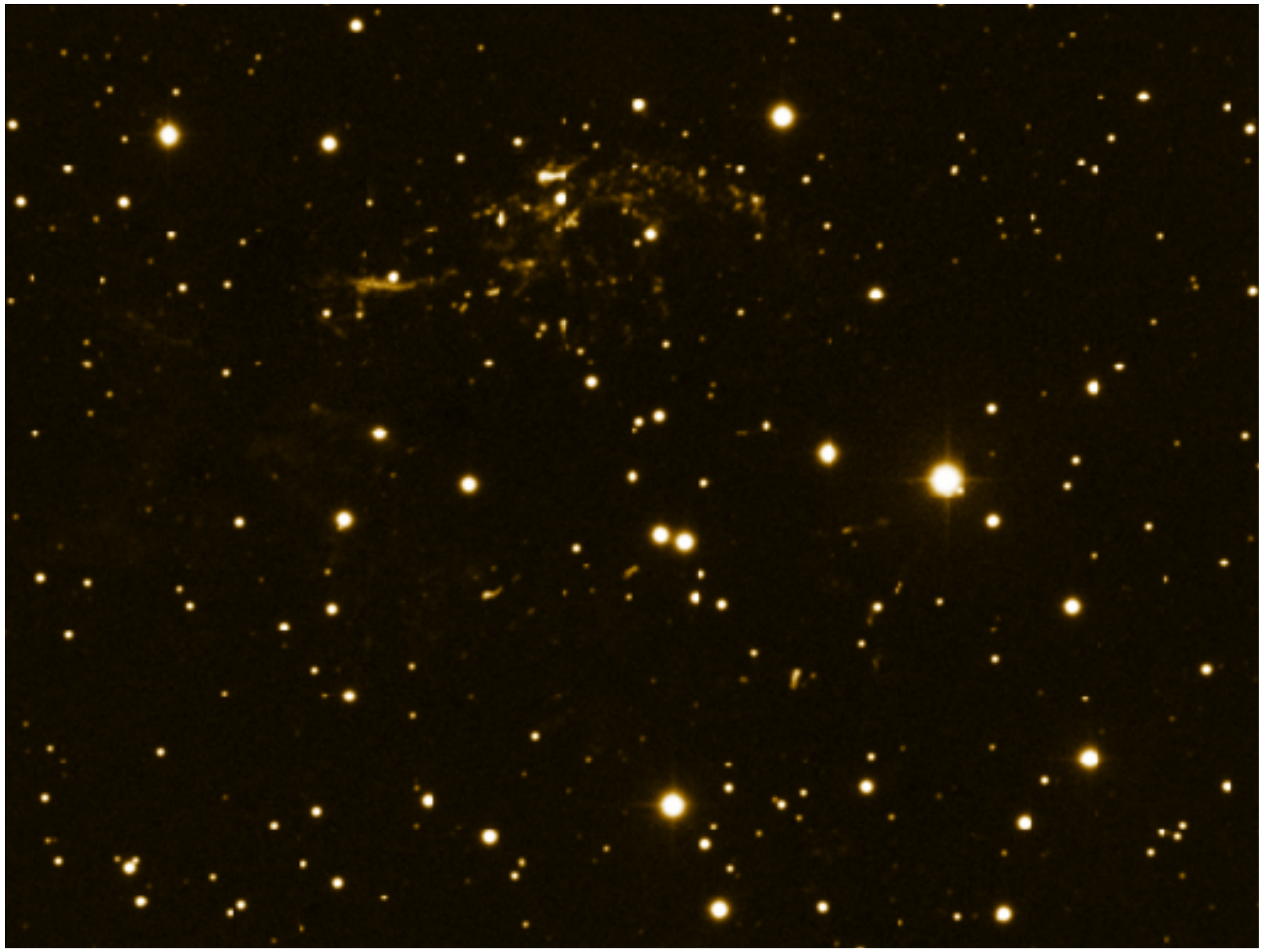

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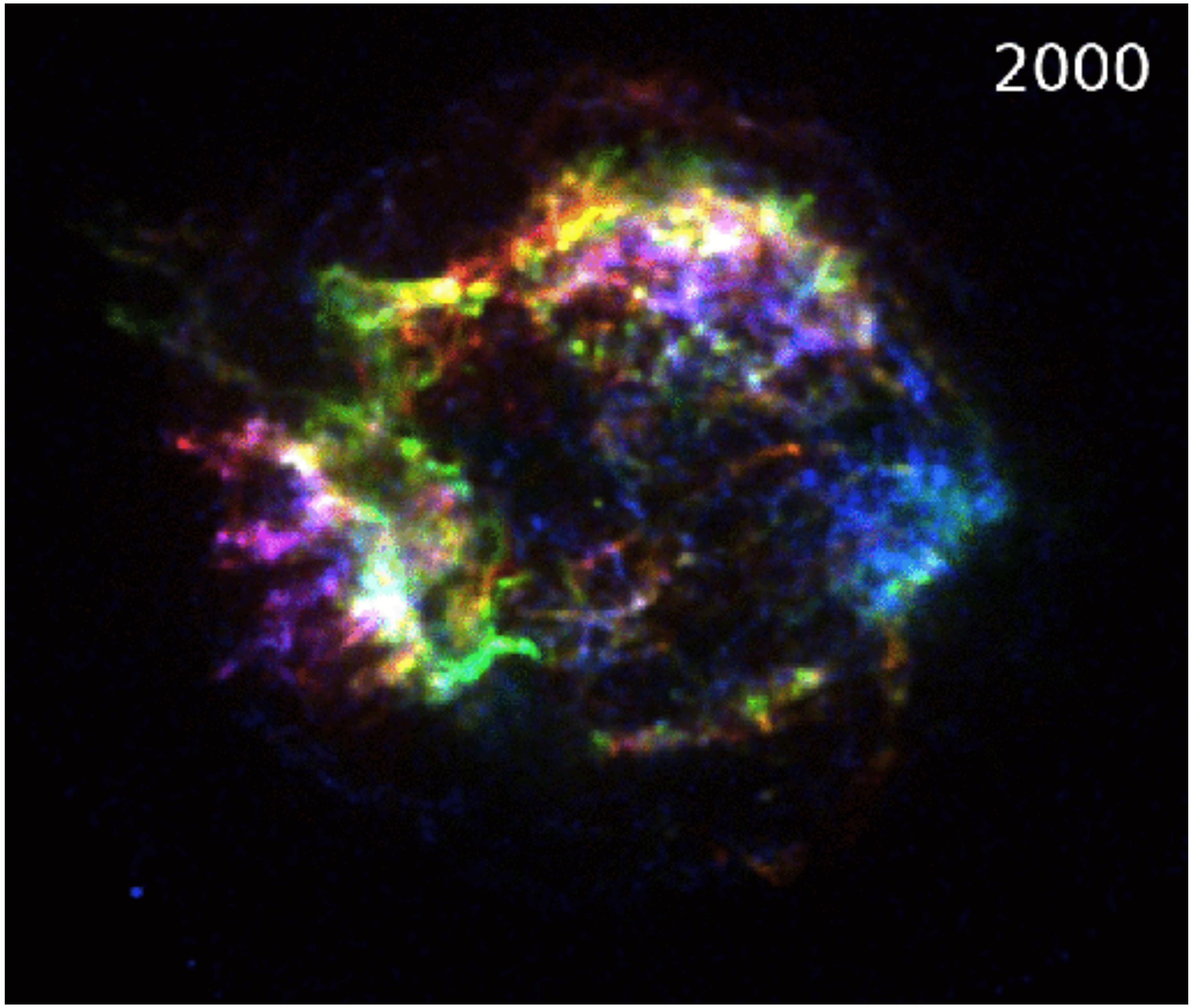
X-ray emission generally arises from more diffuse ejecta, and for typical SNR and CSM densities, is not an efficient coolant

$$t_{\rm rec} \sim 10^{12}/n_e \ {\rm s}$$

$$t_{\rm char} \sim 10^{11} \ {\rm s}$$



Cas A - 2000-2017

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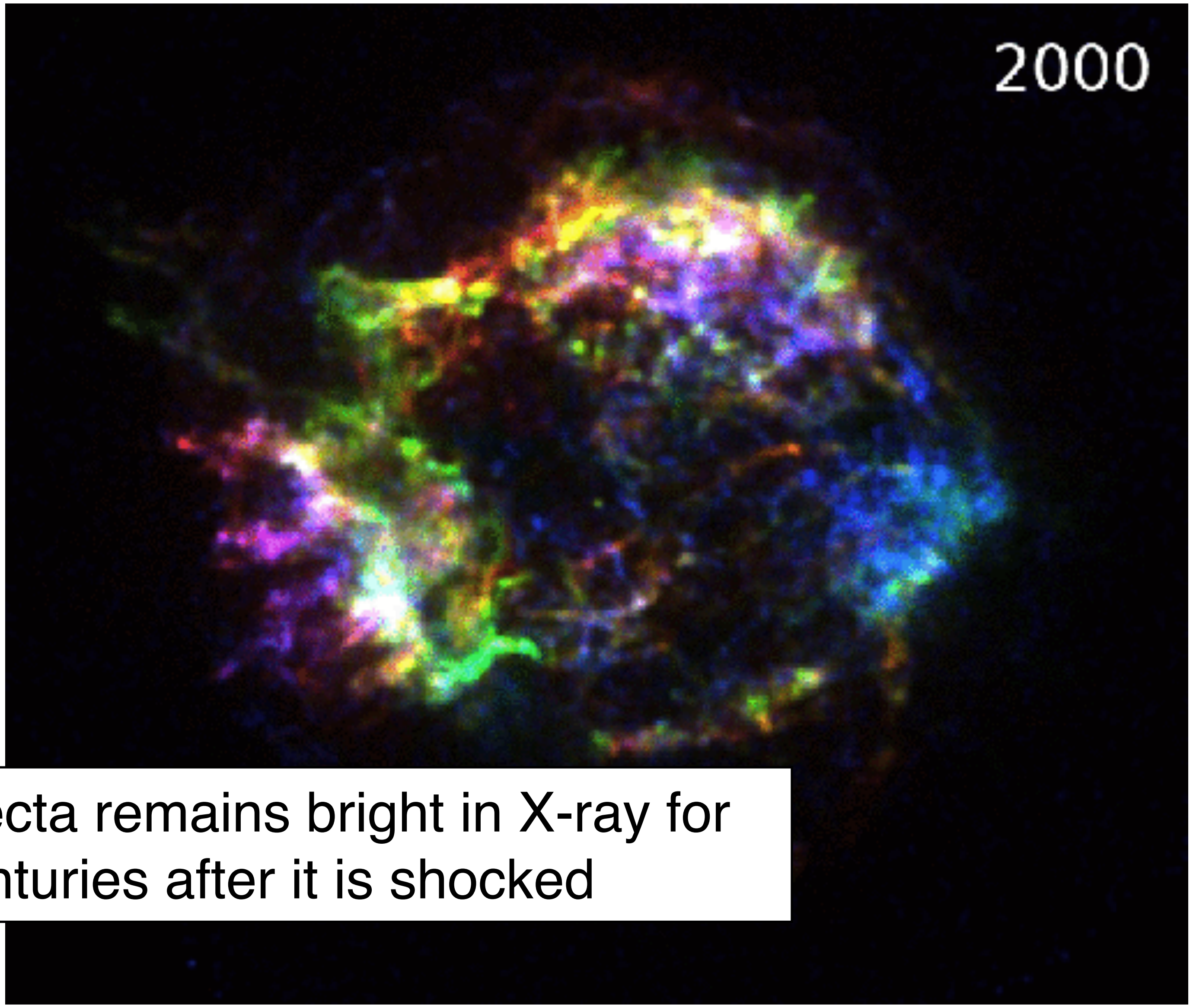
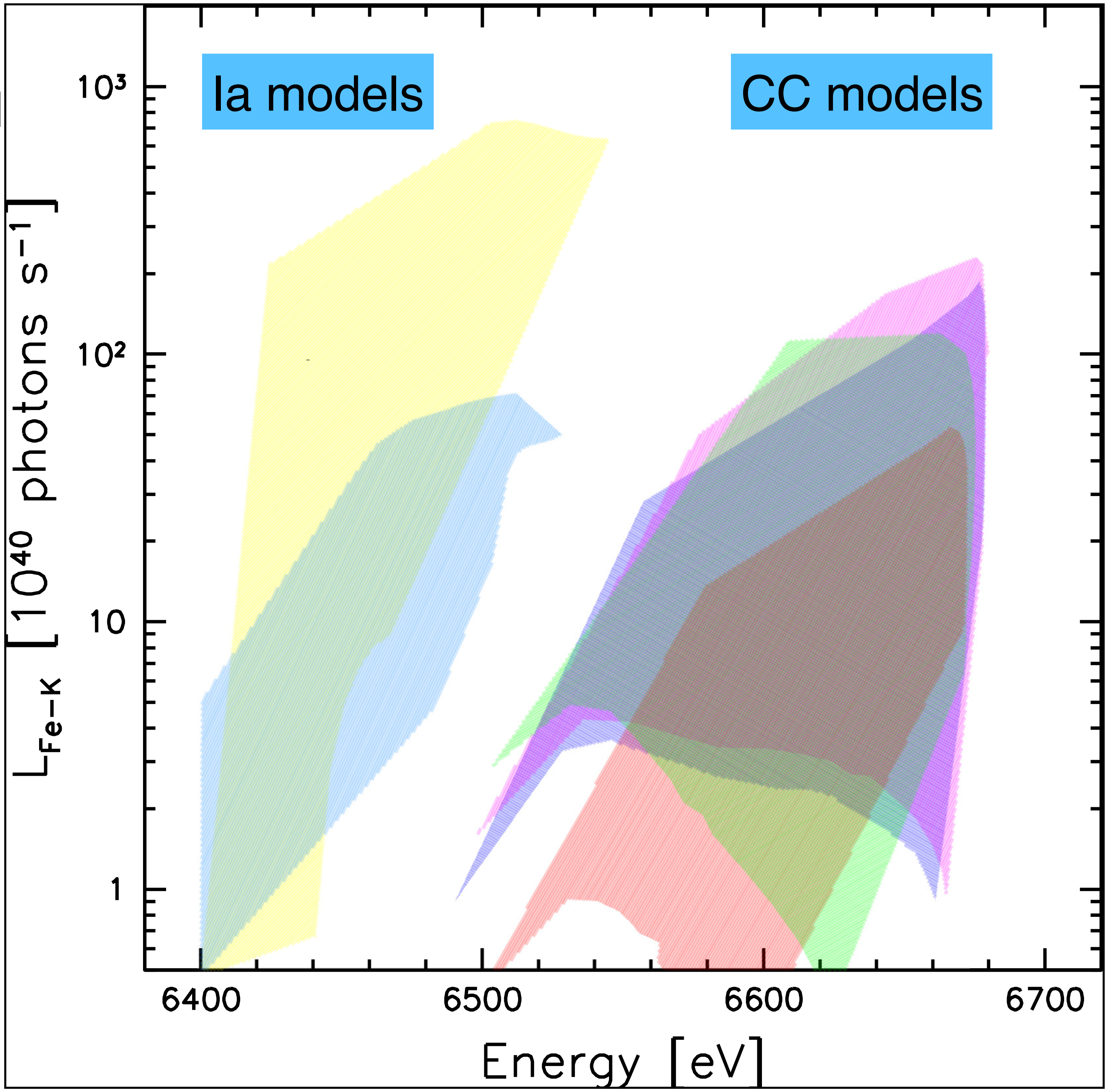


Ejecta remains bright in X-ray for centuries after it is shocked

Cas A - 2000-2017

Progenitor Models to SNRs

- Model SNe ejecta to ages of remnants
  - Compare bulk dynamical and spectral characteristics to observations
- The only assumption made is about the circumstellar environment
  - Ia models assume a constant density
  - CC models assume a power law in radius



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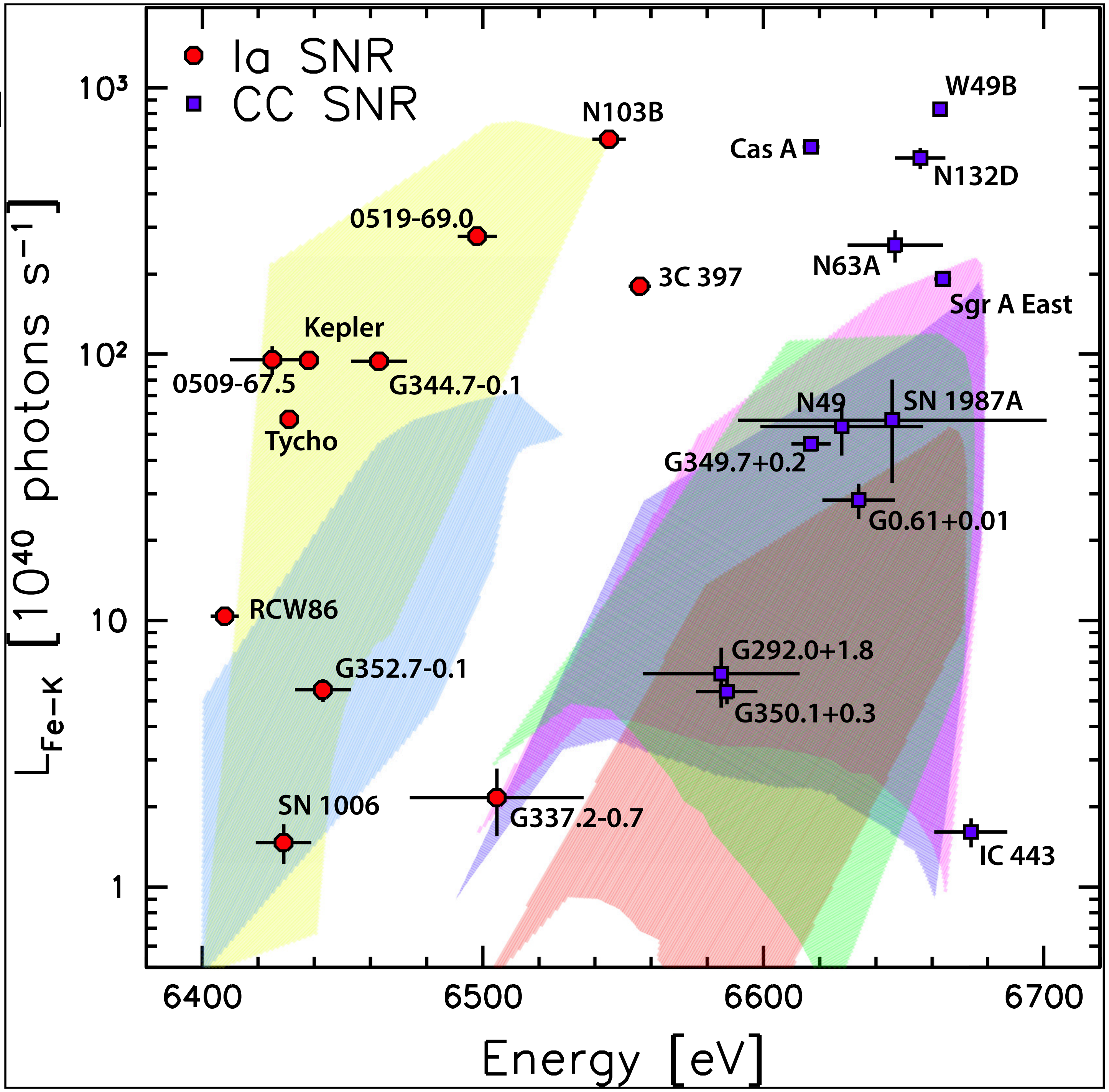
Models evolved to SNR ages show broad spectral agreement



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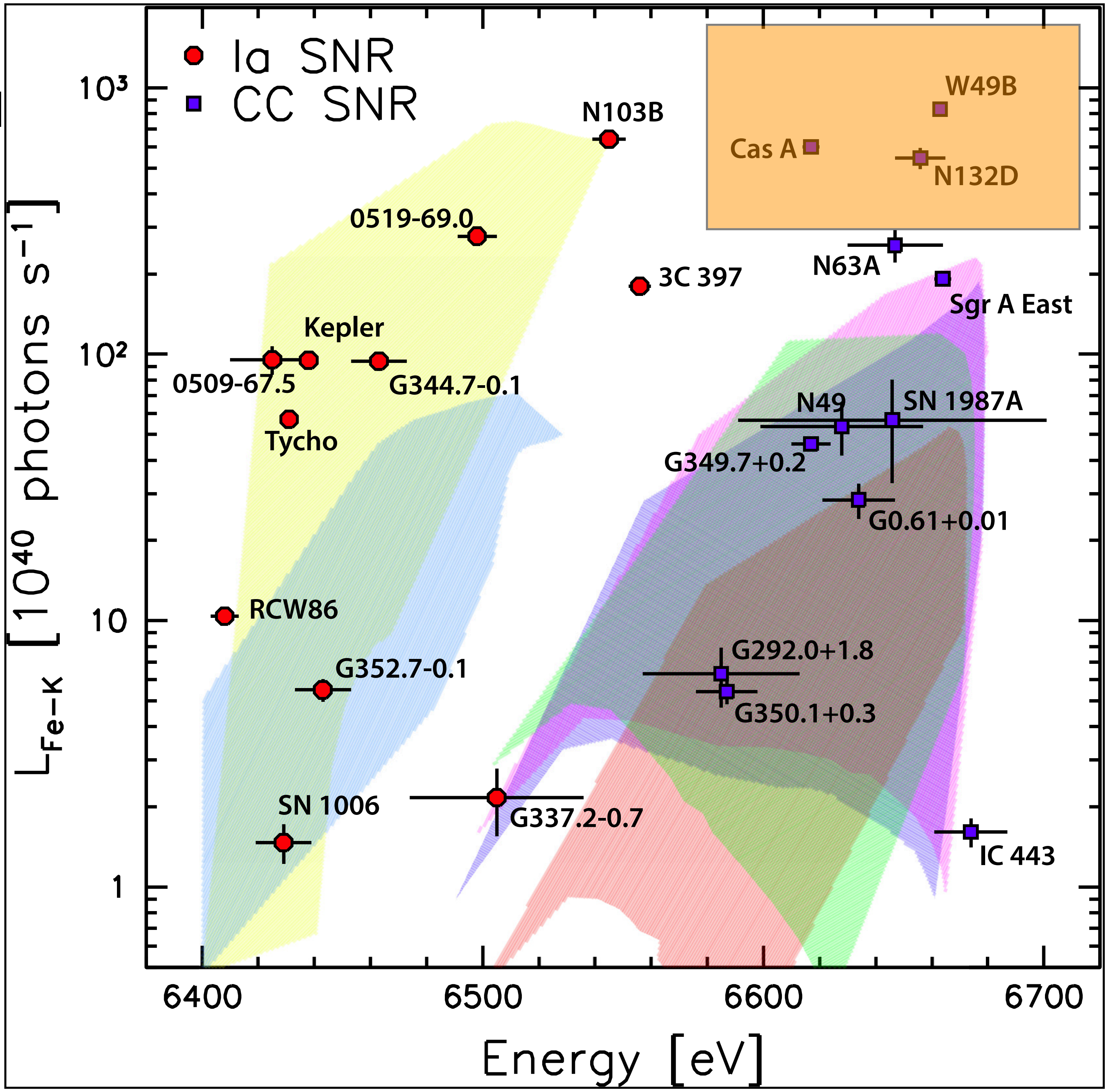
$$R_b \propto \left[\frac{Ag^n}{q}\right]^{1/(n-s)} t^{\frac{n-3}{n-s}}$$

$$L_X \propto q^2 \qquad q = \dot{M}/(4\pi v_w)$$



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Spectrum of SNR retains imprint of episodic mass-loss in progenitor for centuries after CC

$$R_b \propto \left[\frac{\cdots}{q}\right] \cdots t^{n-s}$$

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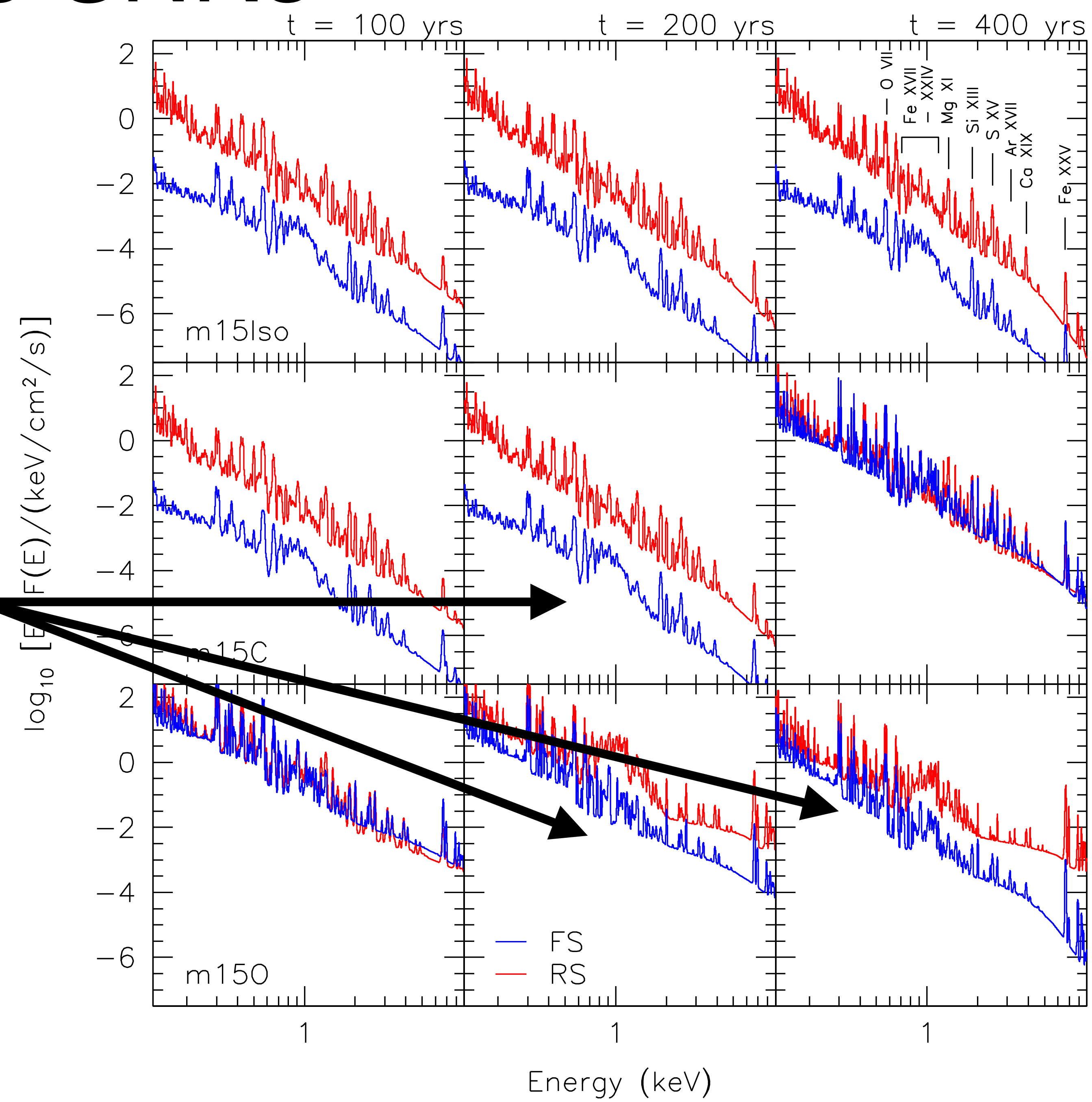
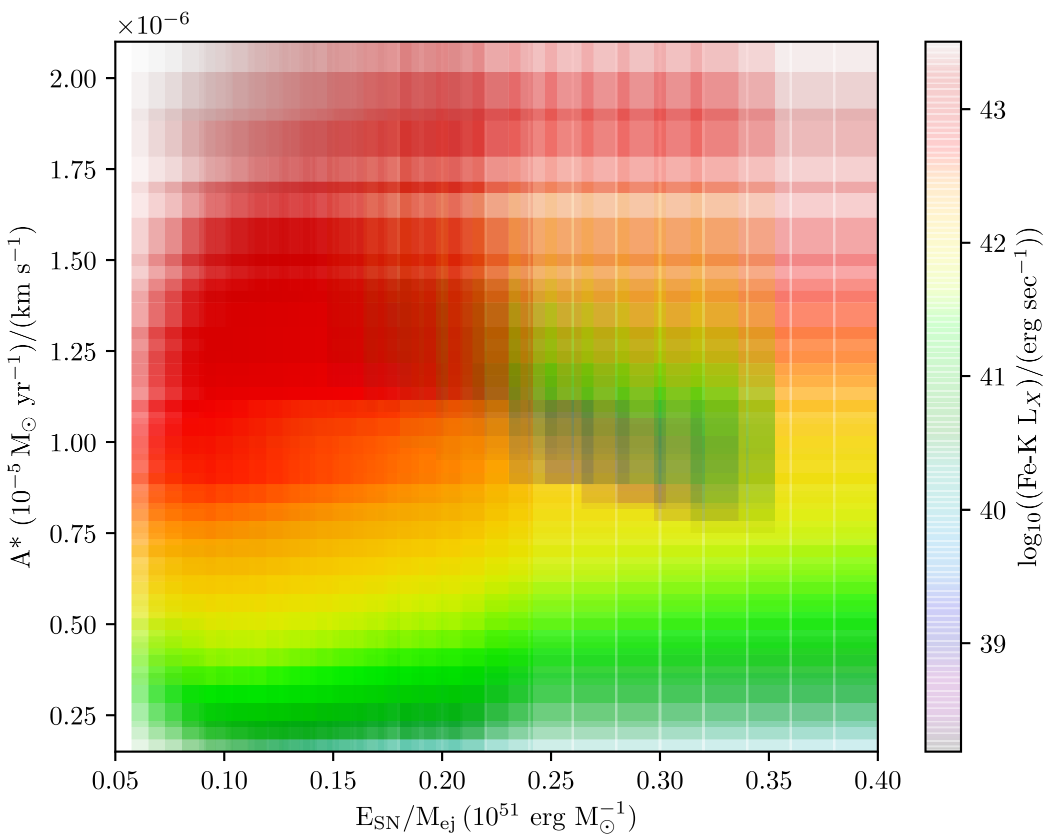


Patnaude et al. (2017)

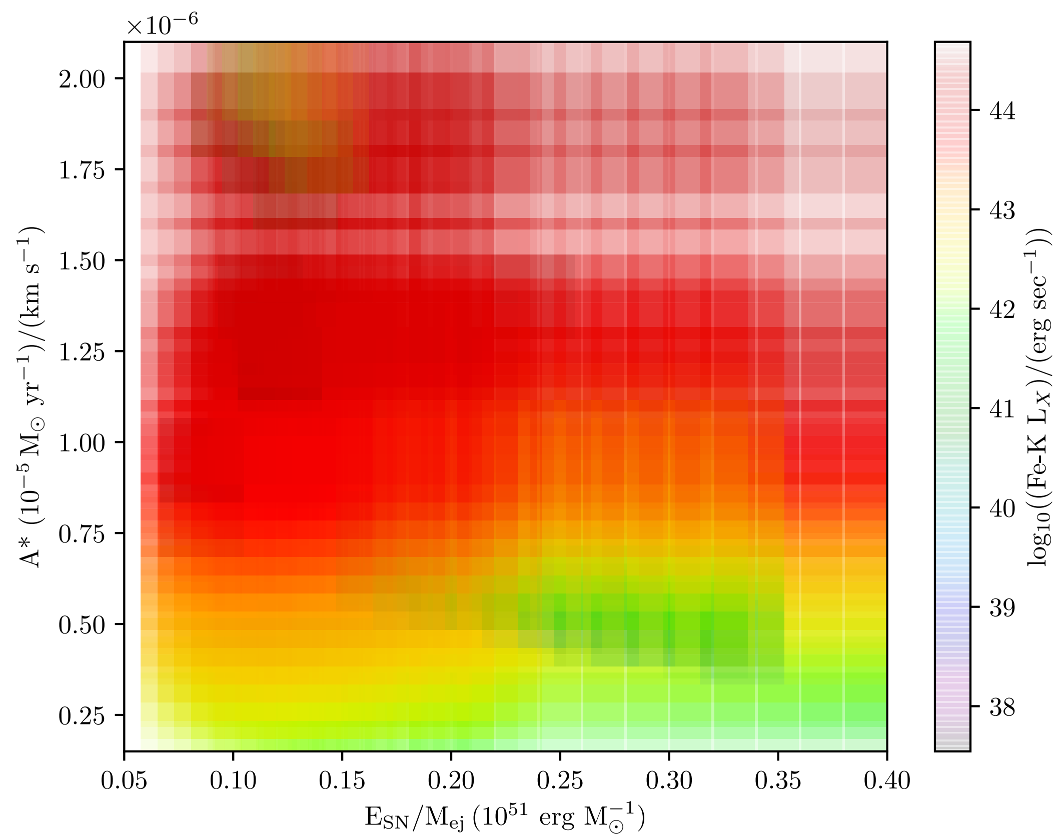
SNR vs Progenitor/Explosion Properties:

L_x (Fe-K) t_{SNR} ~ 80 yrs

Extended Progenitor



Compact Progenitor



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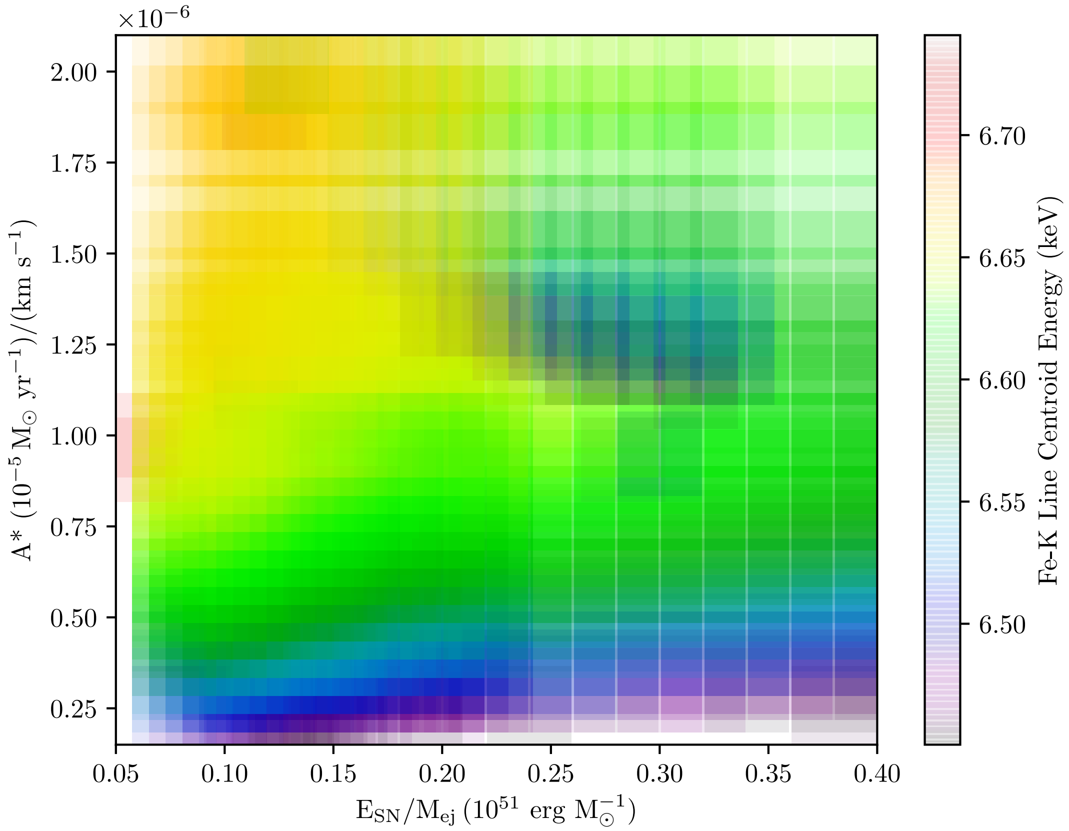

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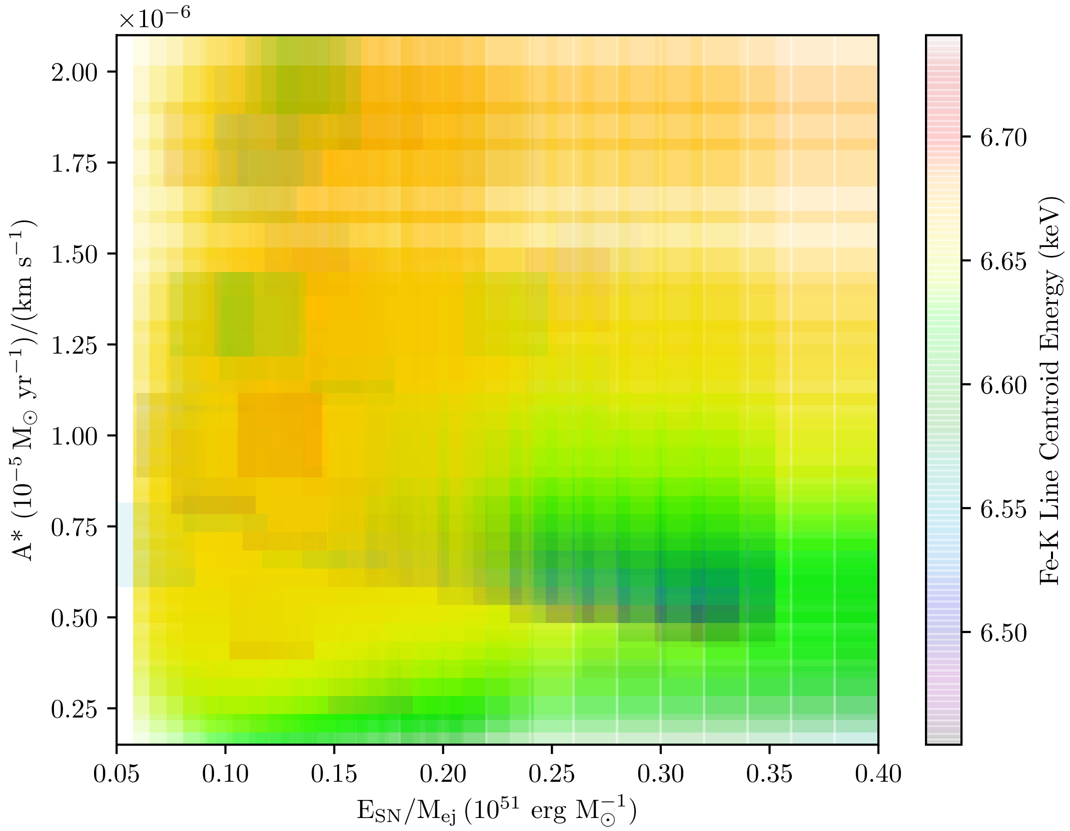

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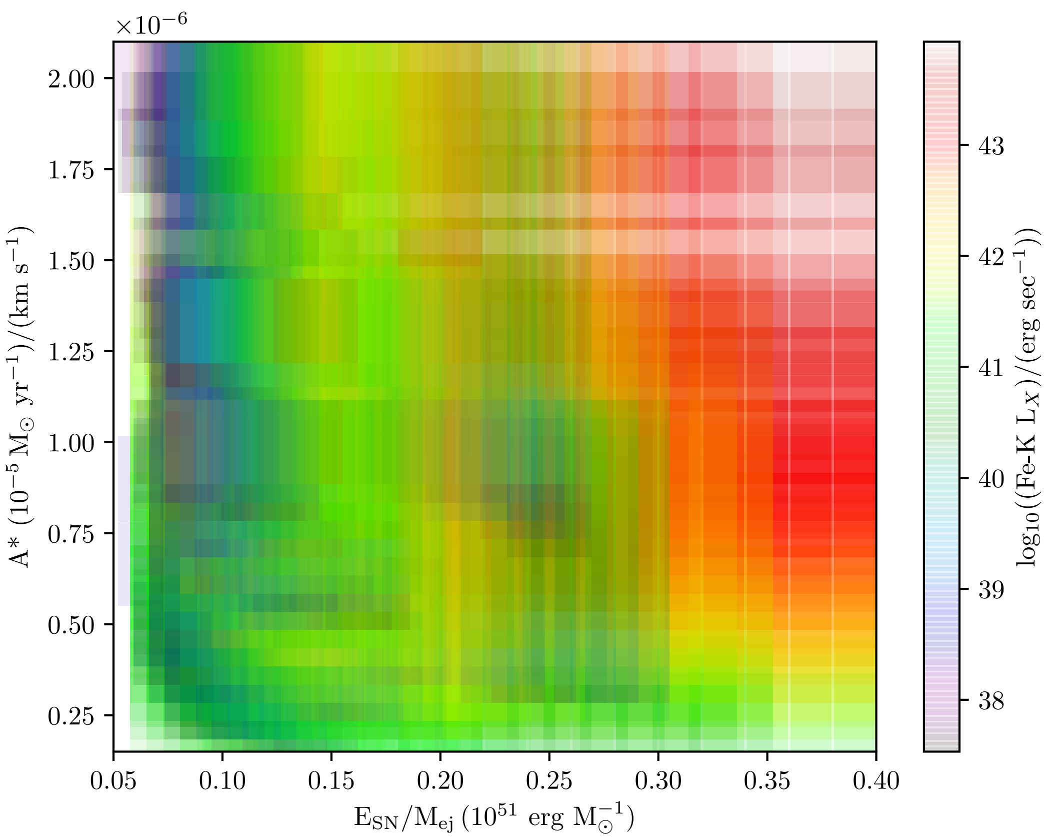

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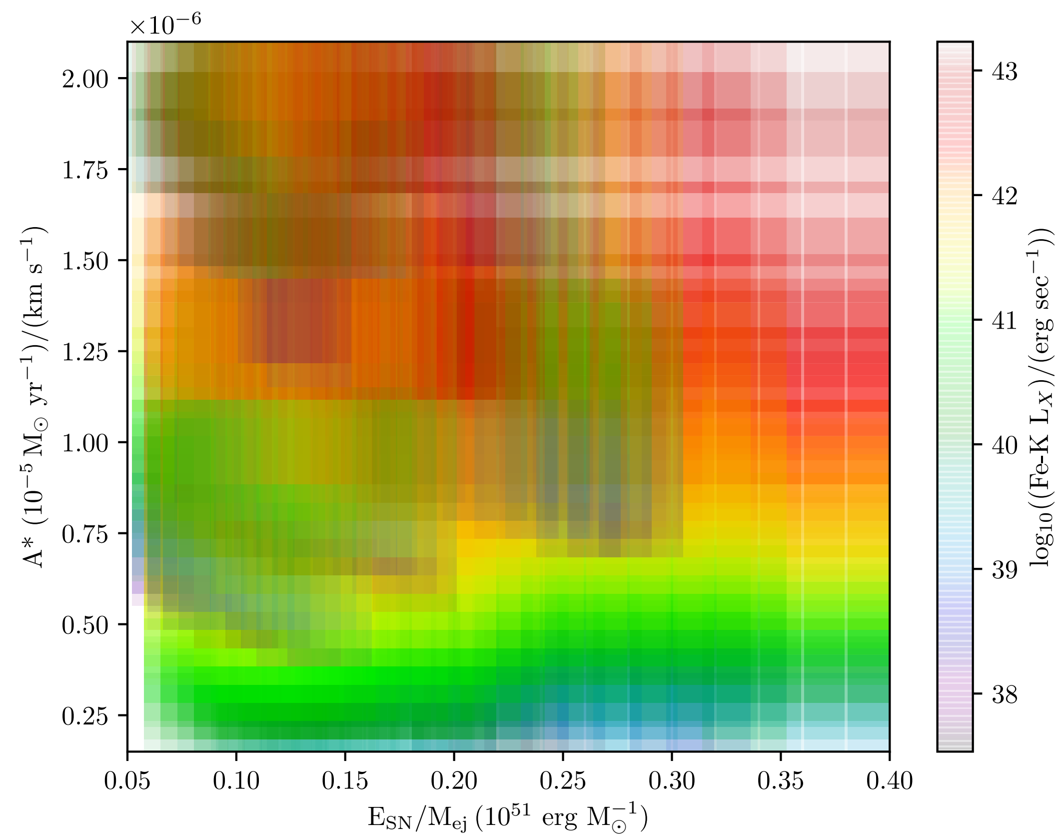

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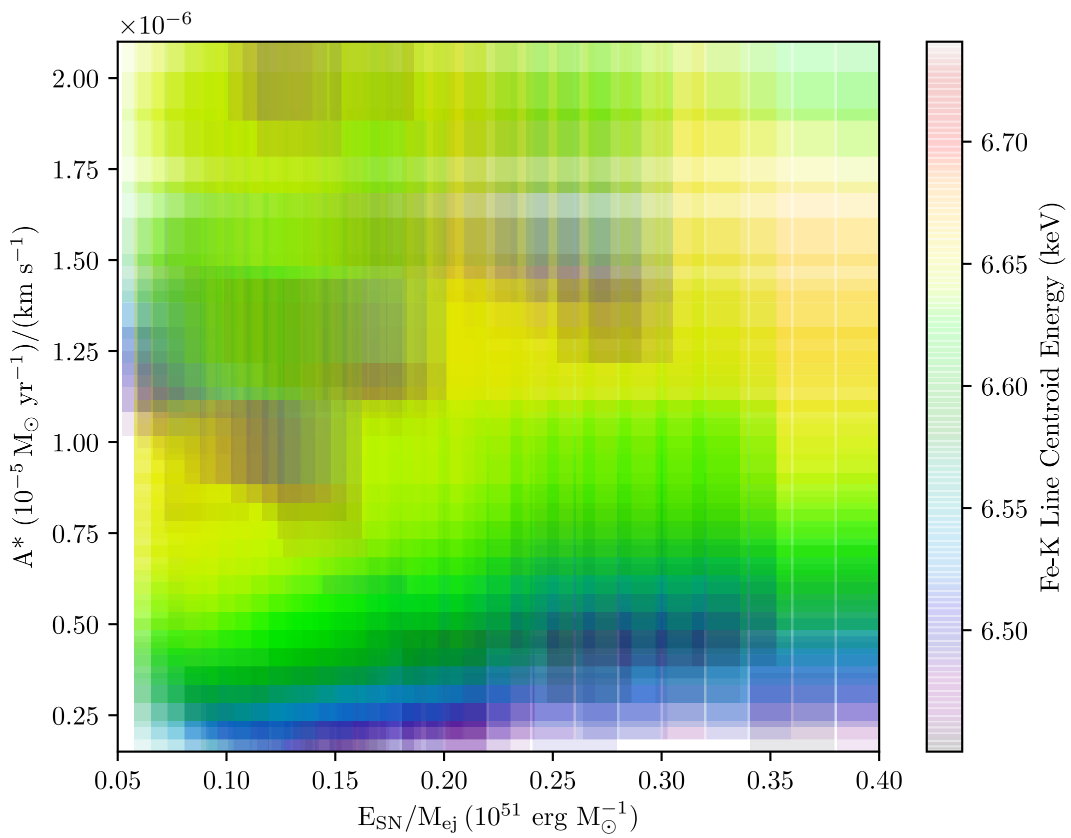

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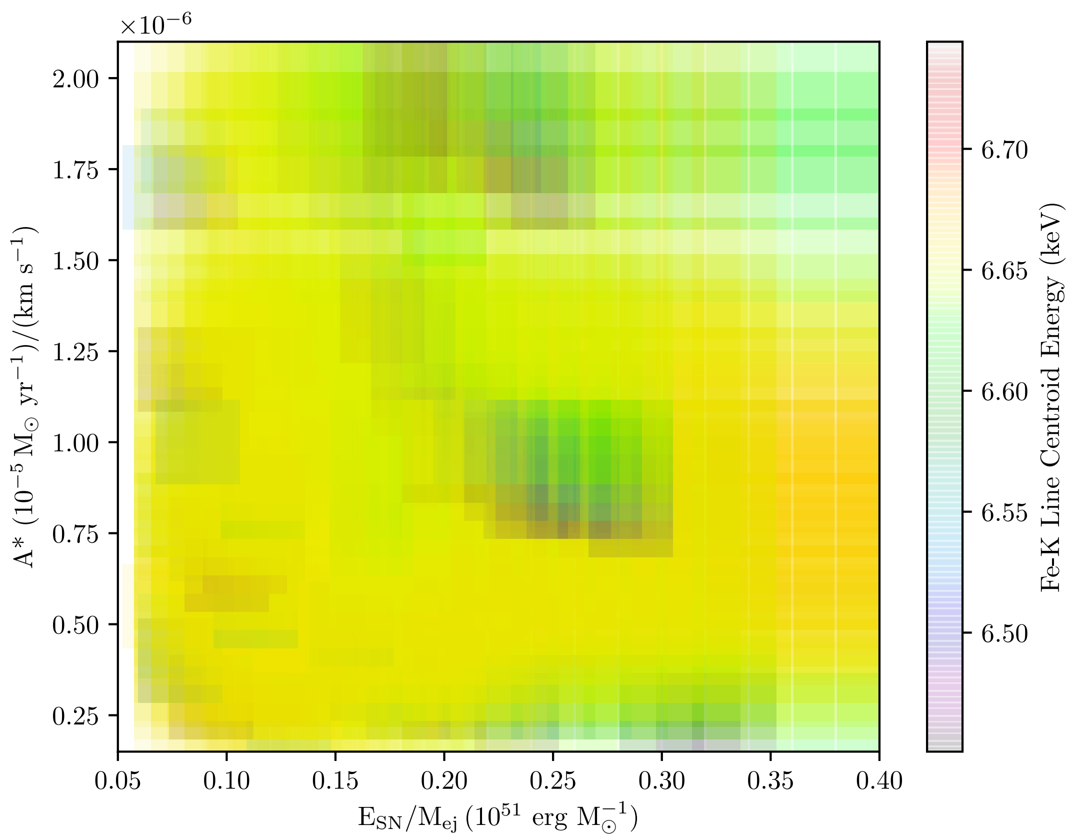

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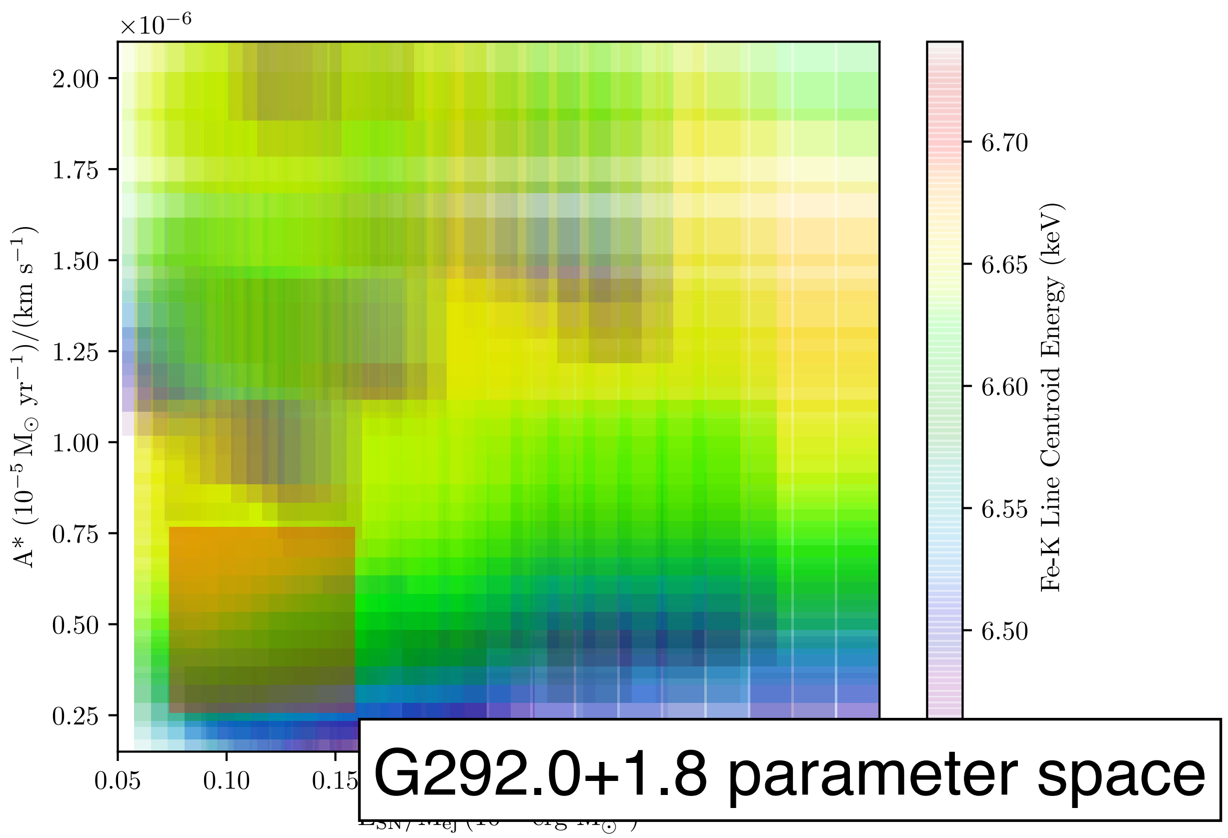

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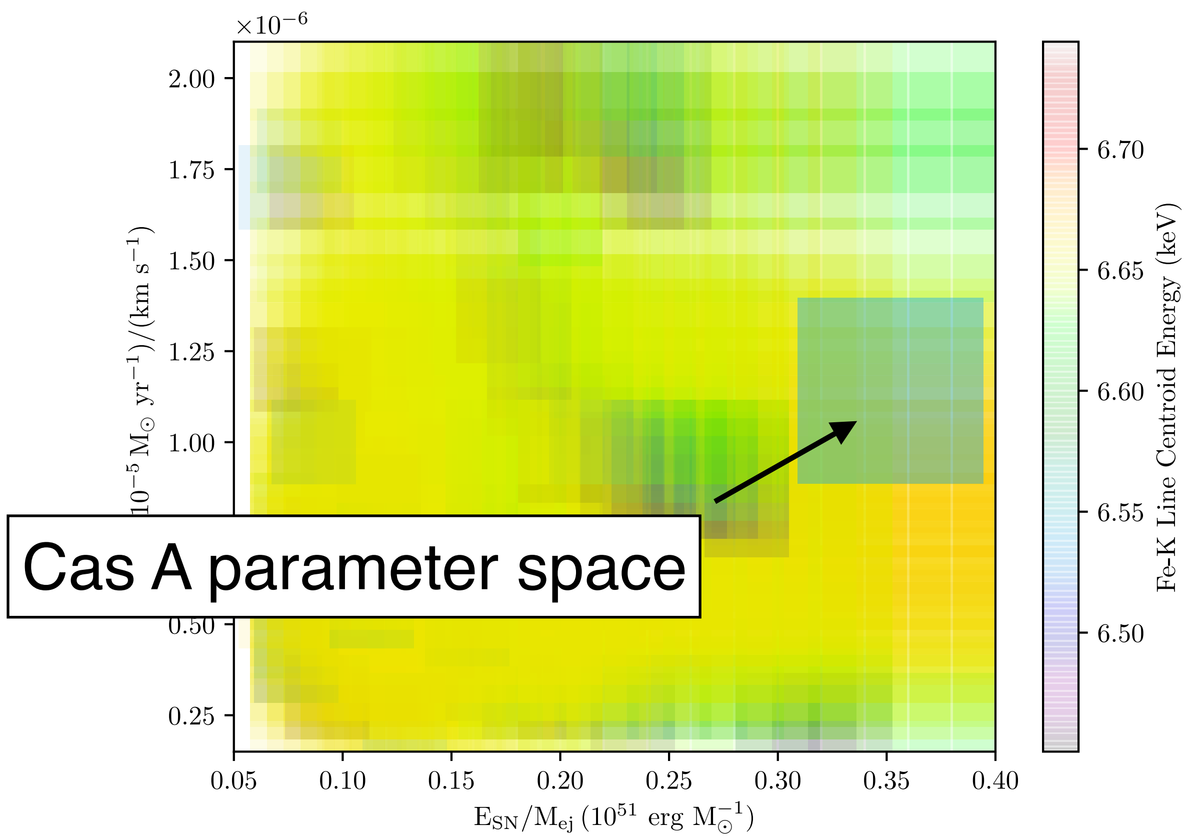


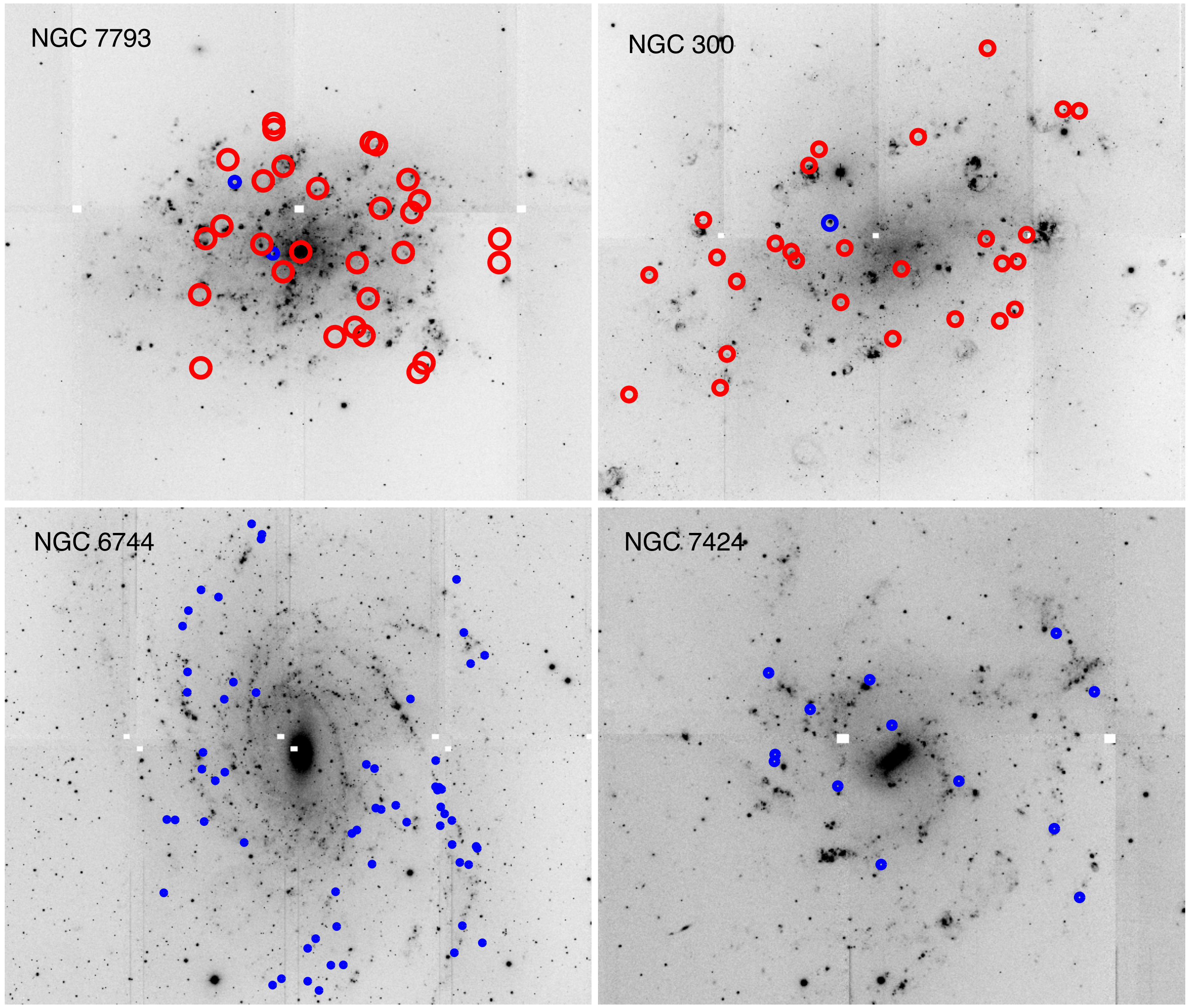
Environmental Metallicity Effects

Despite an inferred SN rate of ~ 1 per century, surveys of nearby galaxies fail to detect the population of young and middle-aged SNR

2 possible reasons for this:

1: SNR expand into a low density and relatively unmodified environment which is the result of weak progenitor winds
- the SNR are thus low surface brightness and dynamically young

2: SNR expand into a high pressure, metal-rich environment
- the SNR evolve quickly to the radiative phase



LCO Southern Hemisphere SNR Survey

Environmental Metallicity Effects

$$\dot{M} \propto Z^{\alpha}$$

$$L_w = \frac{1}{2}\dot{M}v_w^2$$

$$R(t) \propto L_w^{1/5} \propto Z^{\alpha/5}$$

$$\Lambda(T) \propto Z$$

$$t_{\rm cool} \sim t_{\rm kin} \propto Z^{-1+\alpha/2}$$

Phenomenologically, higher mass loss rates lead to higher wind luminosities and slightly larger wind blown bubbles

However, the wind-blown shell will cool on a shorter timescale, resulting in radiatively cooled shells of material closer to the progenitor

In the lower metallicity case, the opposite is true - winds are weaker, but the cooling time is longer, allowing the wind blown bubble to grow to a greater size before it cools

Metallicity, Progenitors, and SNR

$$R(t) \propto \dot{M}^{-1/(n-s)} \propto Z^{-\alpha/(n-s)}$$

$$R(t) \propto Z^{-\alpha/5}$$

$$t_{\rm cool} \propto \rho_{\rm amb}^{-9/17} \propto \dot{M}^{-9/17} \propto Z^{-9\alpha/17}$$

$$L_X \propto n^2\Lambda \propto Z^{2\alpha+1}$$

Stars with expanding into higher metallicity environments will result in smaller diameter SNR in both the ED and ST phases

The transition to the radiative phase will occur on a shorter timescale as it scales inversely with the metallicity

SNR will be brighter and more compact and appear older, while remaining dynamically young

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The lack of young, ejecta-dominated SNR in the local universe appears to be due to the host galaxy metallicity - higher Z environments encourage a rapid transition to the radiative phase, while lower Z environments result in SNR which remain in free expansion for longer times

Summary

- Properties of Galactic and Magellanic Cloud SNR are not always well described by progenitor models which include isotropic mass loss
- Models which include non-steady mass loss in last 10^4 years can explain bulk spectral features and dynamics
- Metallicity effects may explain lack of observed young SNR in nearby galaxies
- Continued observations of young SNe will probe earlier stages of progenitor evolution