Type Ia Supernova Remnants, Circumstellar Interaction, and Supernova Progenitors

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University of Pittsburgh

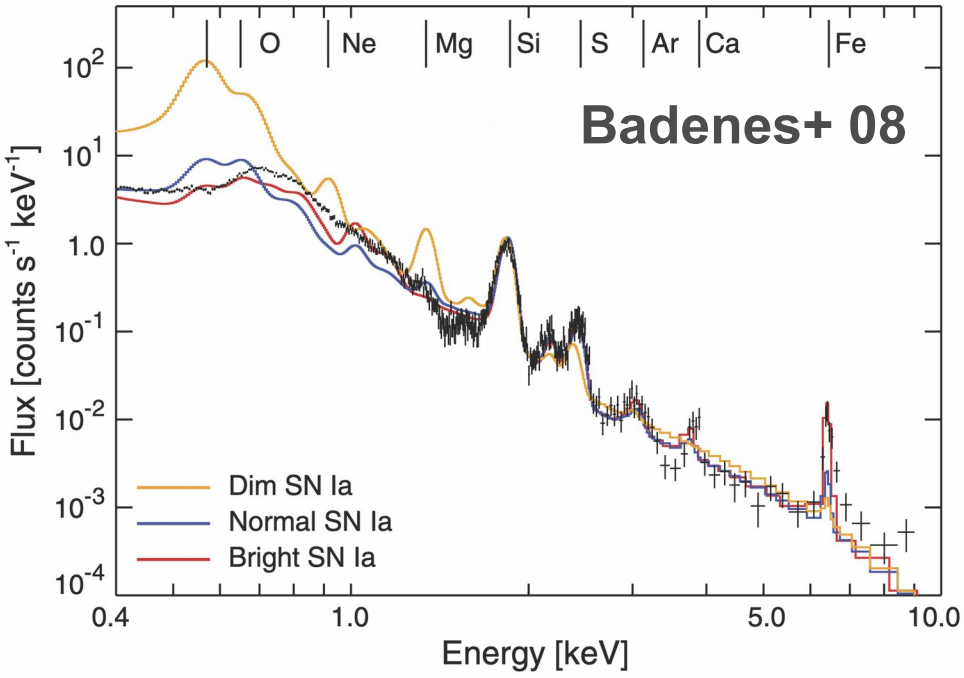
This Talk in a Nutshell

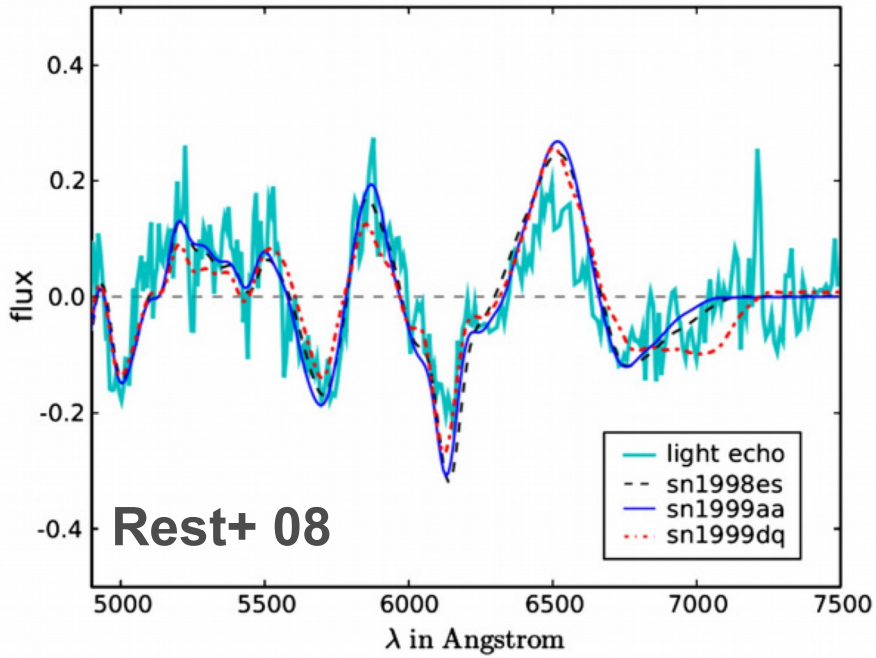
Carles Badenes
EAS 06/28/22

X-ray spectra of SNRs constrain SN Ia explosion physics & progenitor properties:

- ^{56}Ni mass ⇔ brightness [Badenes+ 06,08; Krause+ 08; Rest+ 08].
- WD mass ⇔ Ch/sub-Ch explosions [Yamaguchi+ 15].
- Pre-SN mass loss rate ⇔ WD accretion mode [Badenes+ 07, Williams+ 11, Yamaguchi+ 14].

We are working on a new model grid to map the parameter space for CSM interaction in Type Ia SNRs





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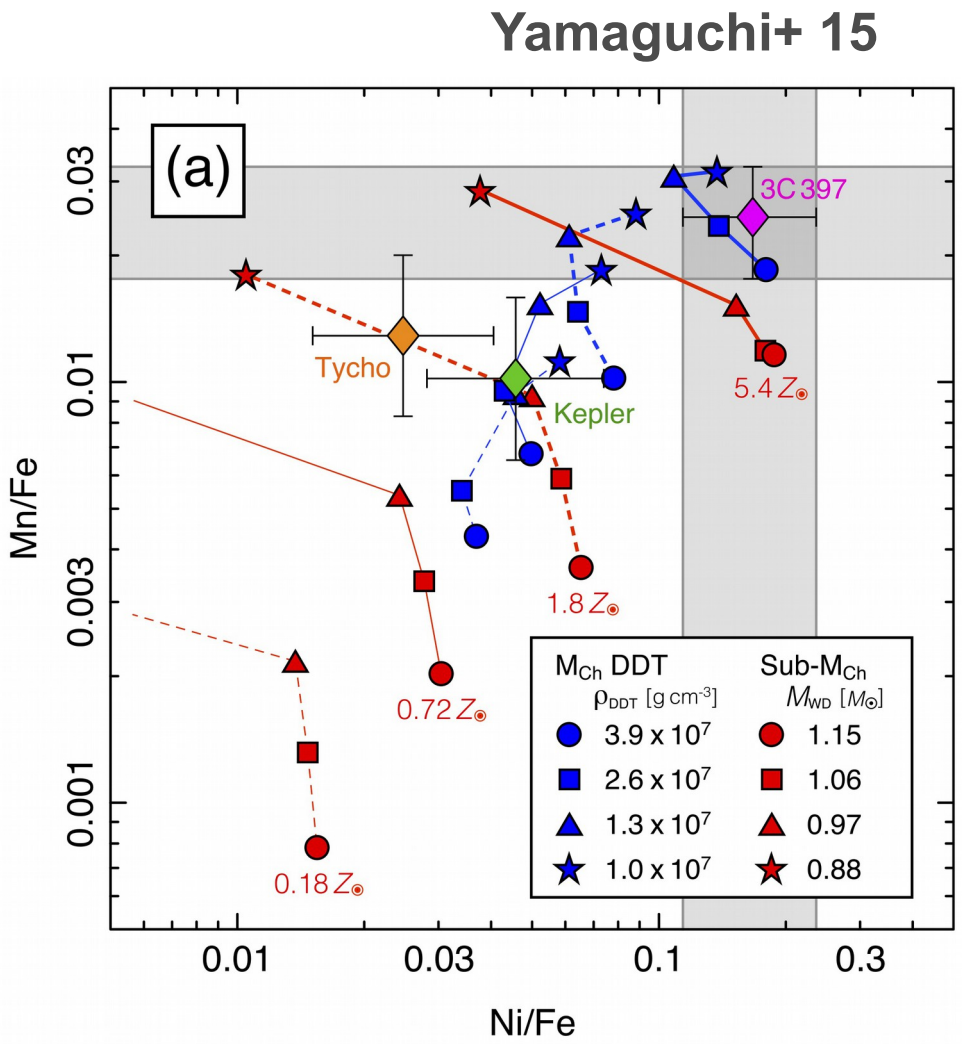

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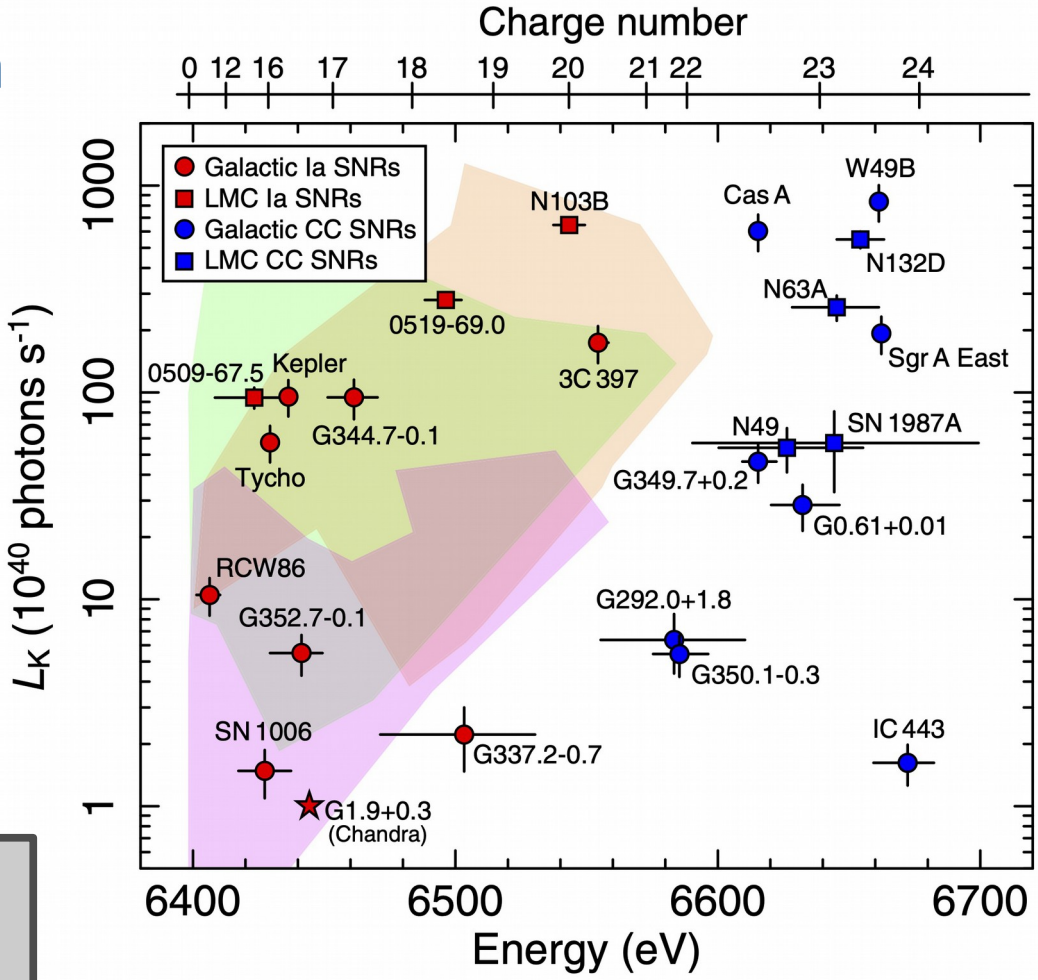

Yamaguchi+ 14

Circmustellar Interaction in SNRs

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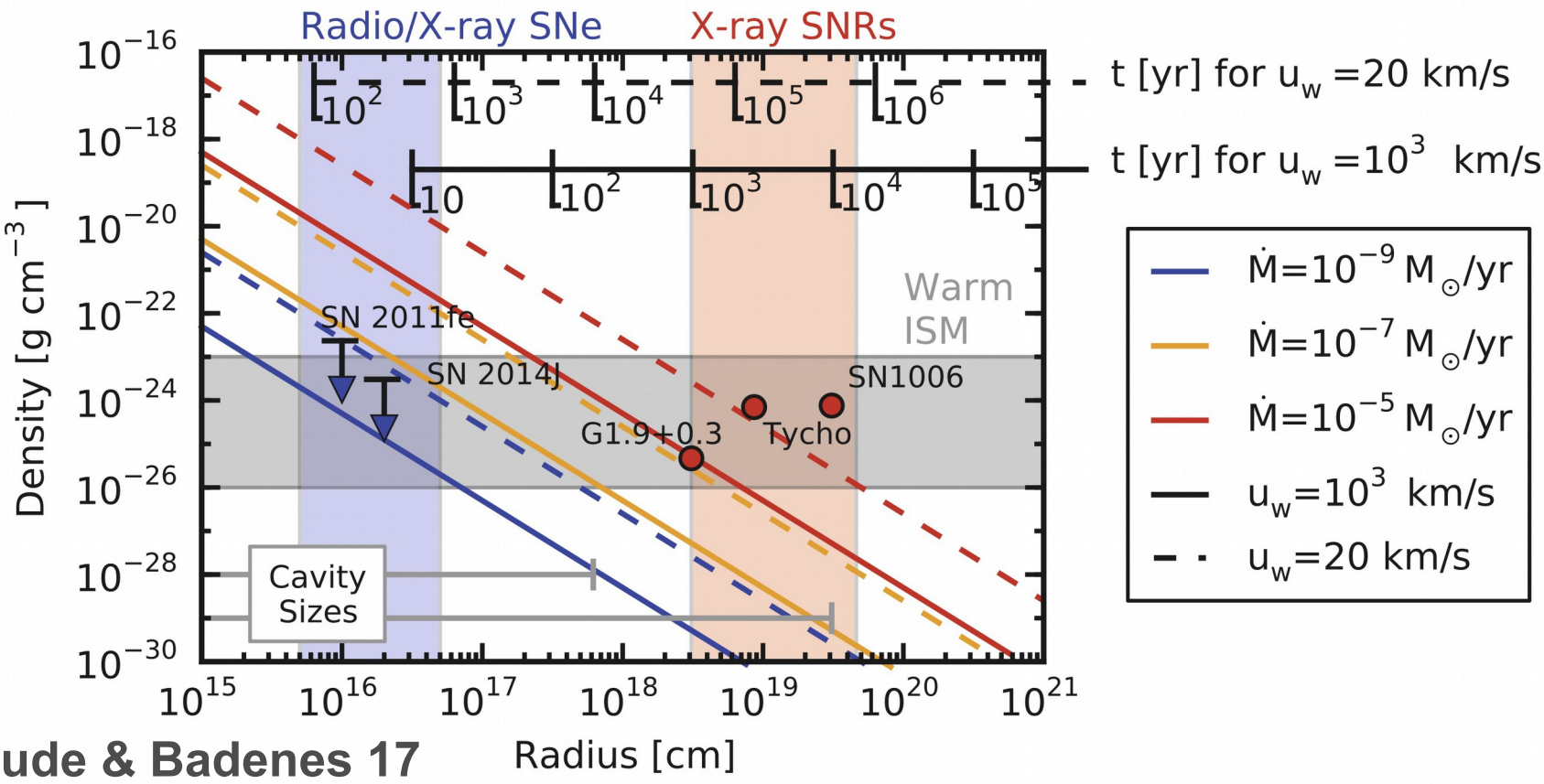
- **AM structure** ⇒ progenitor mass-loss. Modified circumstellar medium (CSM) vs. undisturbed interstellar medium (ISM)
- **SNe** ⇒ Follow-up (radio/X-ray) probes to ~ 100 AU.
- **SNRs ⇒ spatial (and temporal) scales relevant for stellar evolution** of SN progenitors ($t \lesssim \tau_{KH}$). **Probe dynamical interaction!**



Patnaude & Badenes 17

Circmustellar Interaction in SNRs

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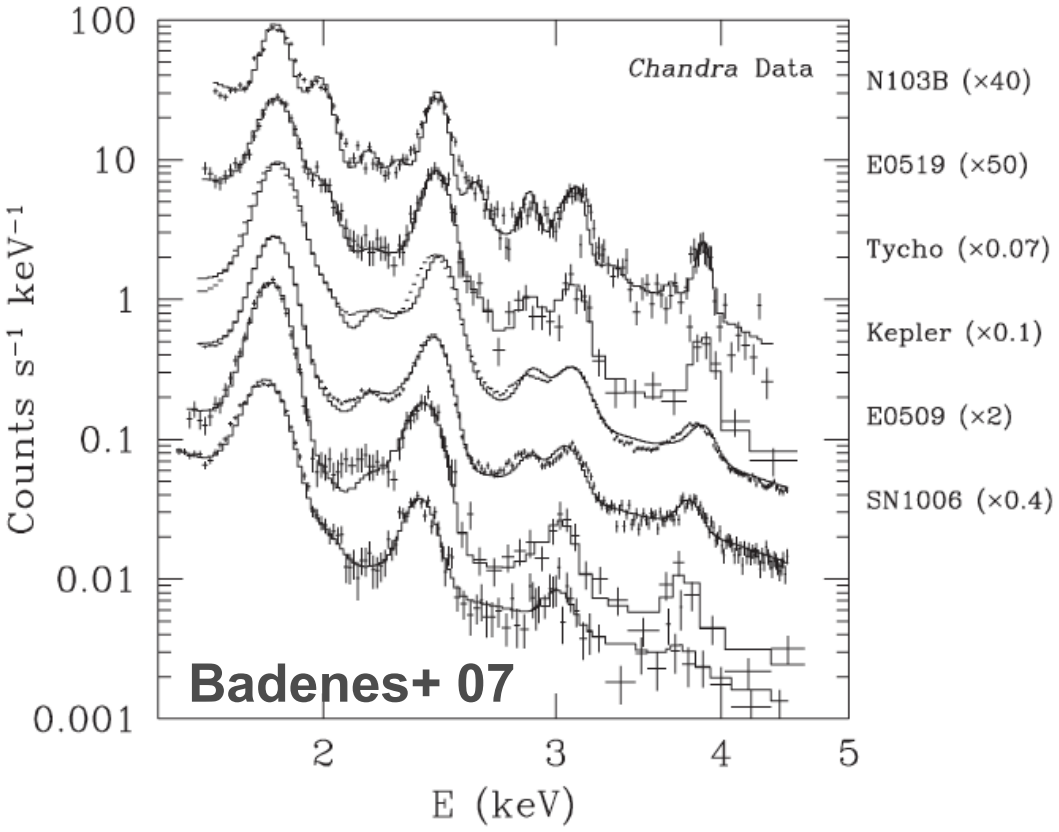
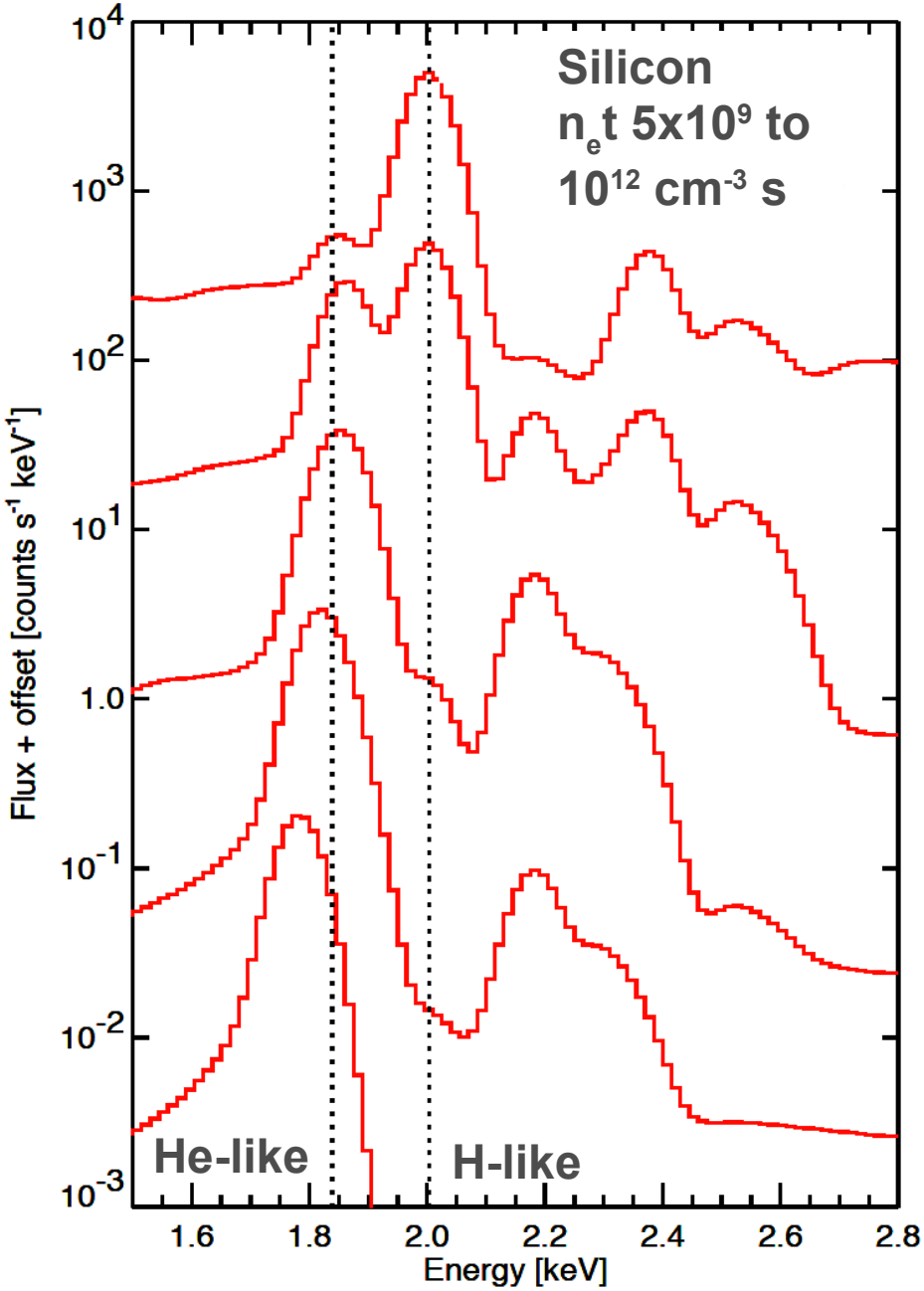
- **X-ray spectra ⇒ constrain AM structure.** NEI plasma: ionization timescale (**$n_e t$**) [Badenes+ 07].
- **High $n_e t$ ⇒ high centroid energy and line flux.**





CSM Interaction in SNRs: Fe K

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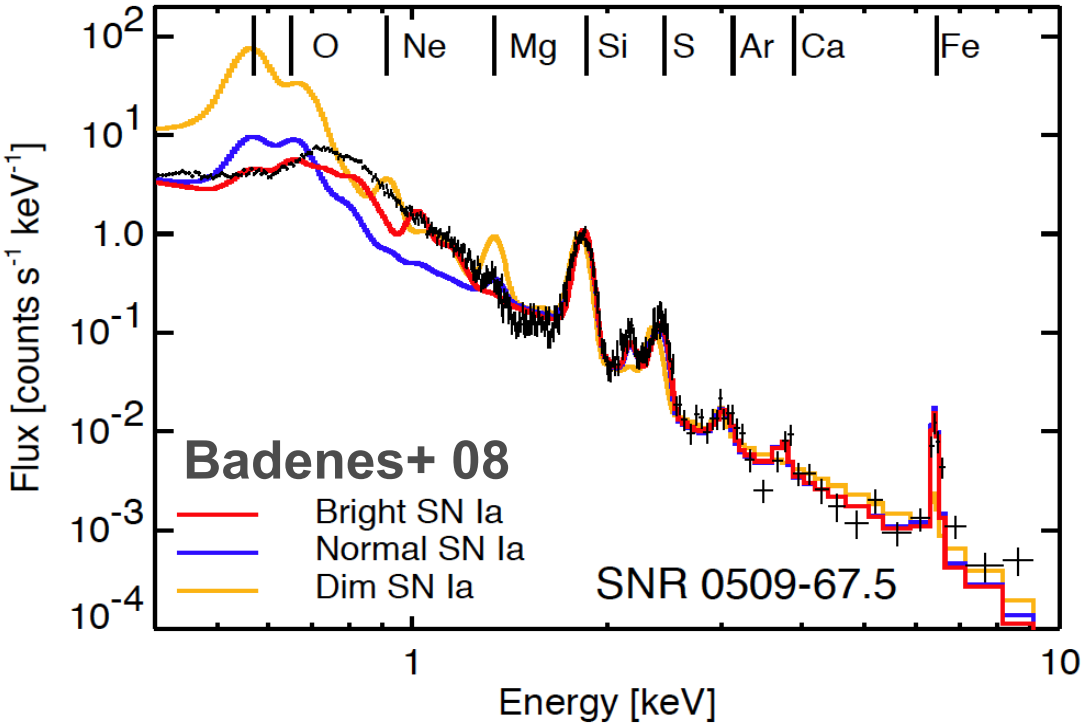
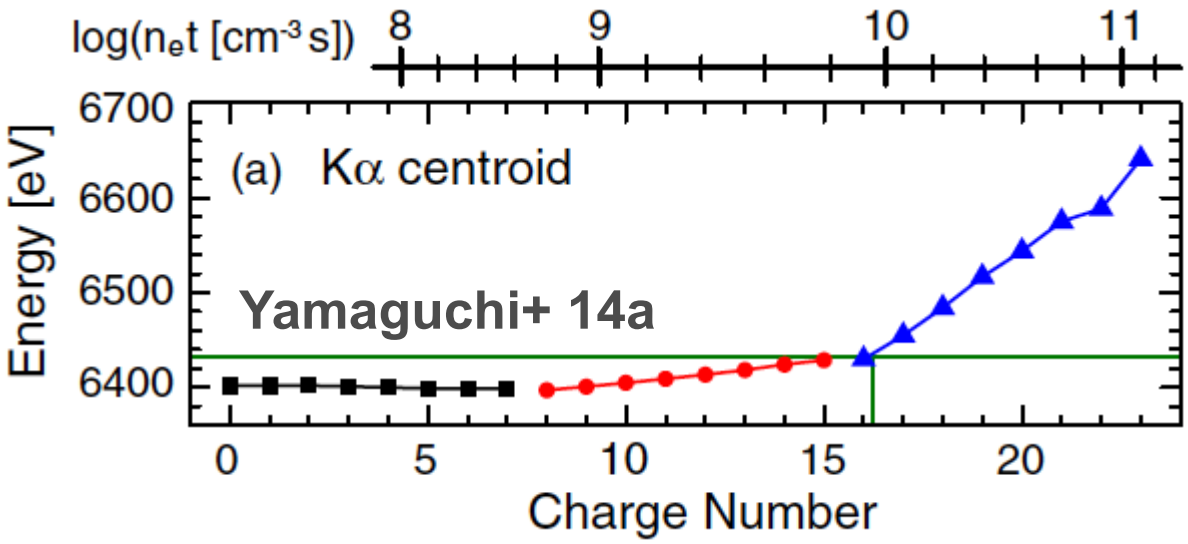
- Use **Fe Kα line blend** at ~6.5 keV as an AM density diagnostic.
- All SNe (Ia and CC) eject some Fe ⇒ innermost layers.
- Large $n_e t$ required to fully ionize Fe ⇒ **large dynamic range in ρ_{AM}**.
- **Bulk properties** ($n_e t$ ⇔ line centroids, ages, radii) ⇔ progenitor mass loss.





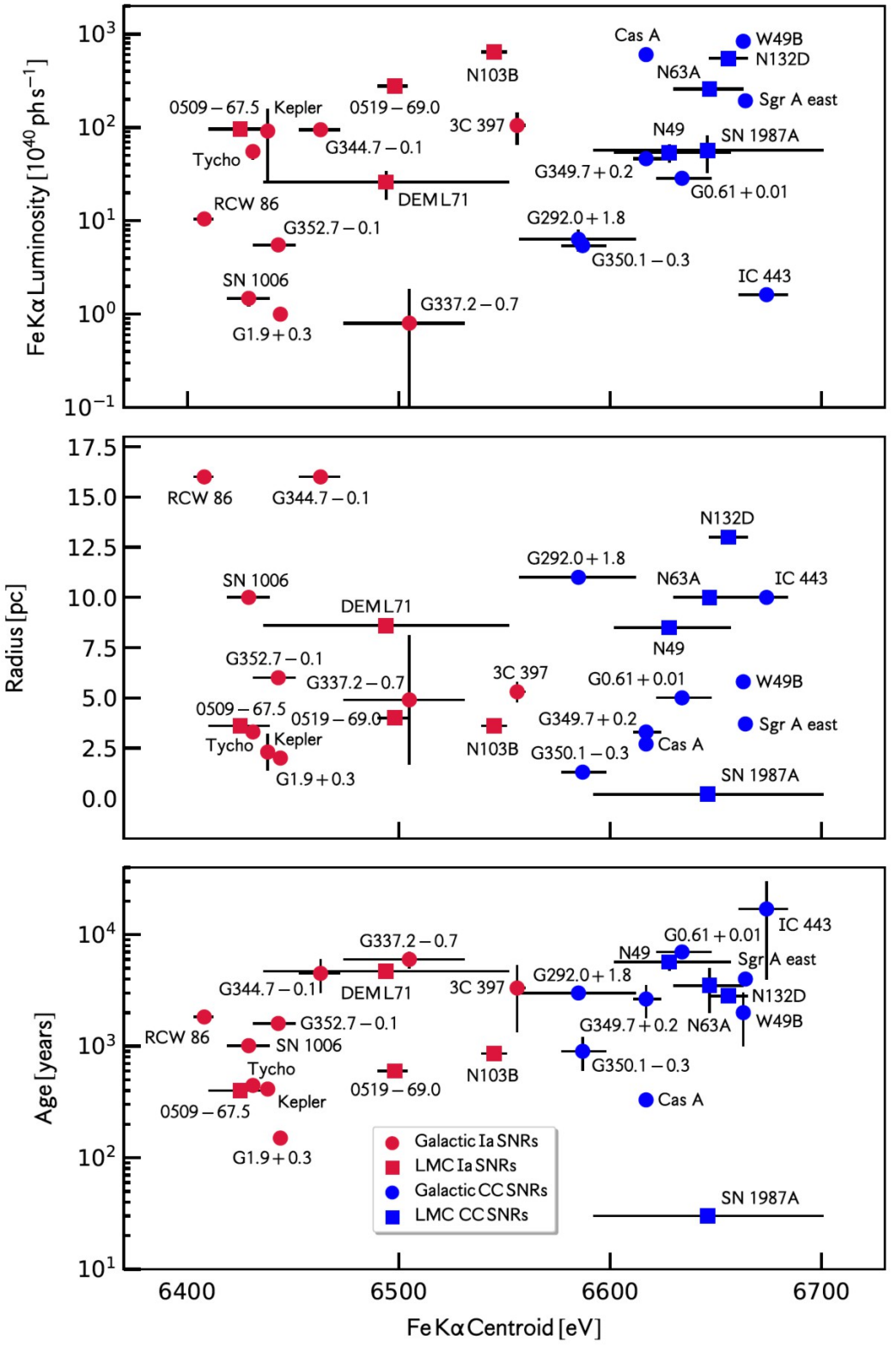
SNRs in Bulk

- Require Fe Kα centroid: **25 SNRs** (*Suzaku, Chandra, XMM*) [Yamaguchi+ 14, Borkowski+ 13, Maggi+ 16, M-R+ 18].

- **Bulk properties:** Fe Kα centroid, Fe Kα luminosity, radius, age.

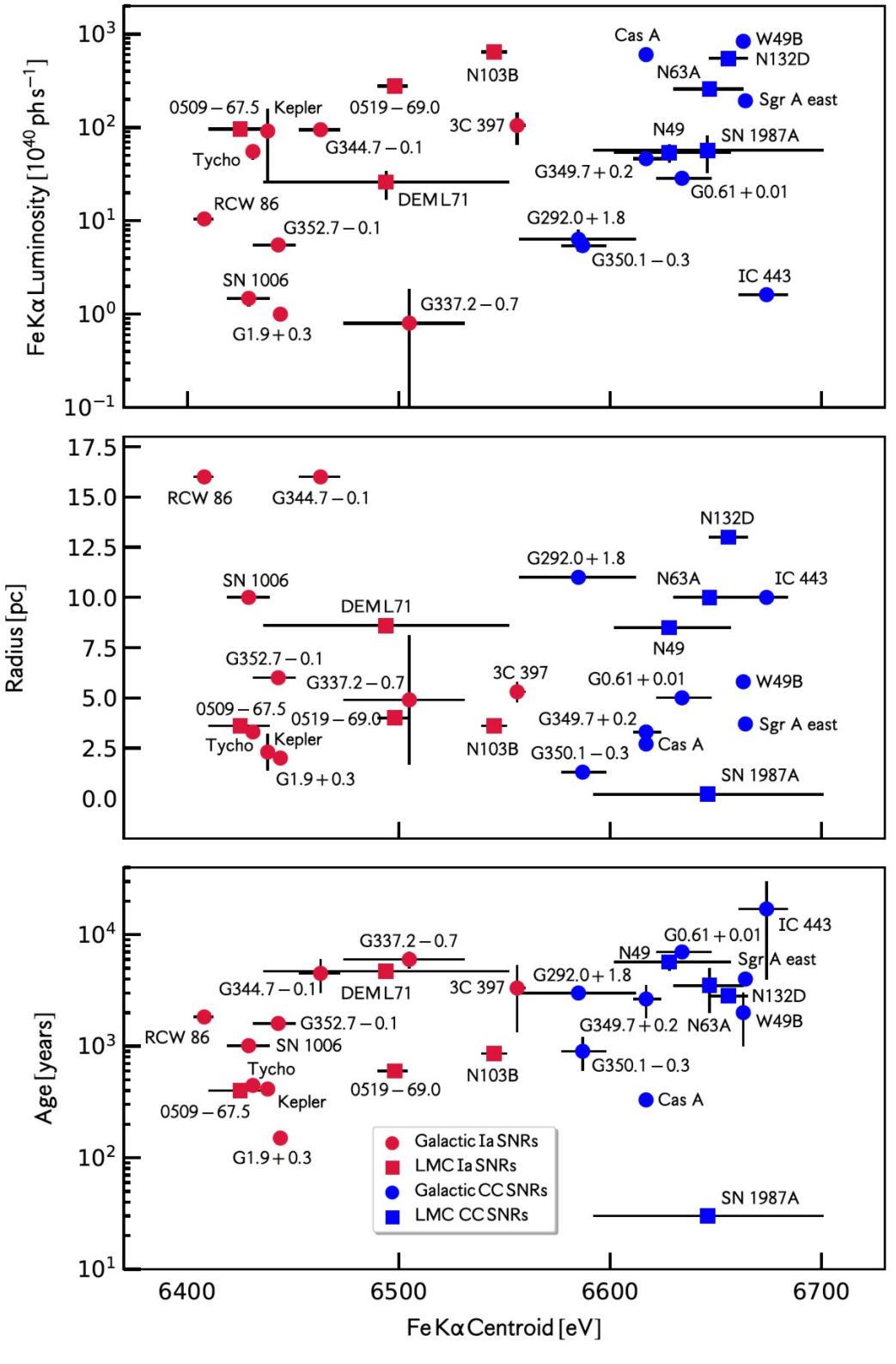
- A pattern emerges: **Ia SNRs below ~6.55 keV (Fe^{+21}), CC SNRs above** [Yamaguchi+ 14, but see Maggi & Acero 17].

- **CC/Ia SNRs have similar ages/radii, but very different $n_e t$ ⇔ different AM densities!**



Models

- **HD+NEI Models required** to draw quantitative conclusions on progenitor mass loss!



Models: Uniform AM

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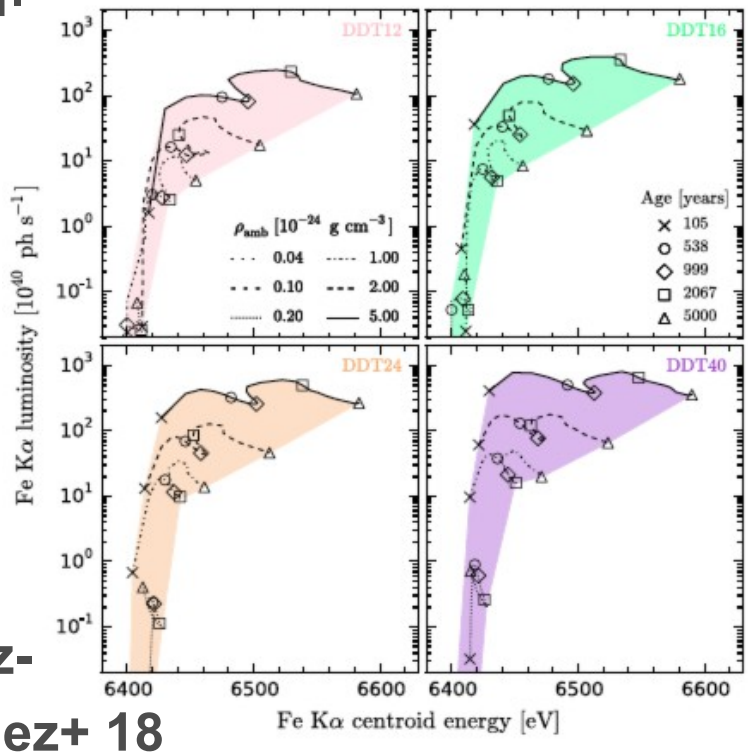
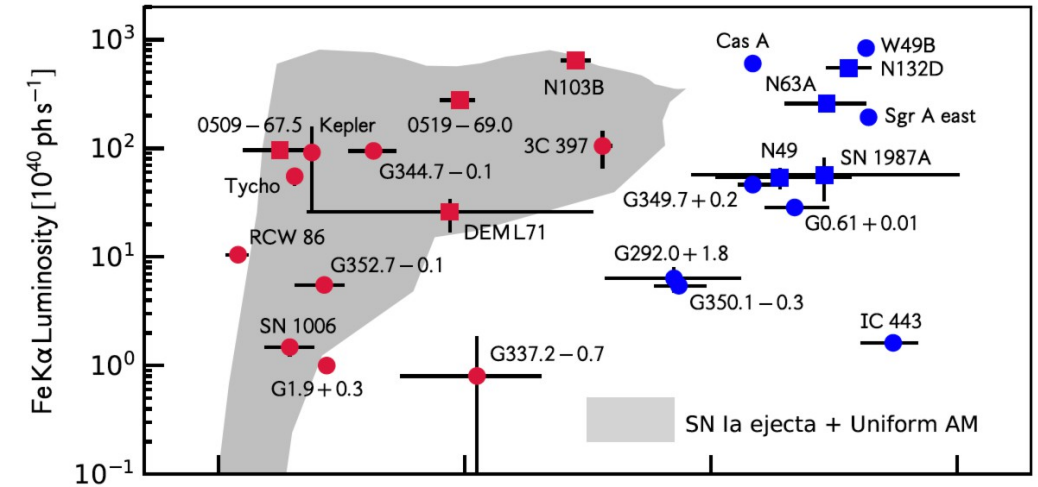
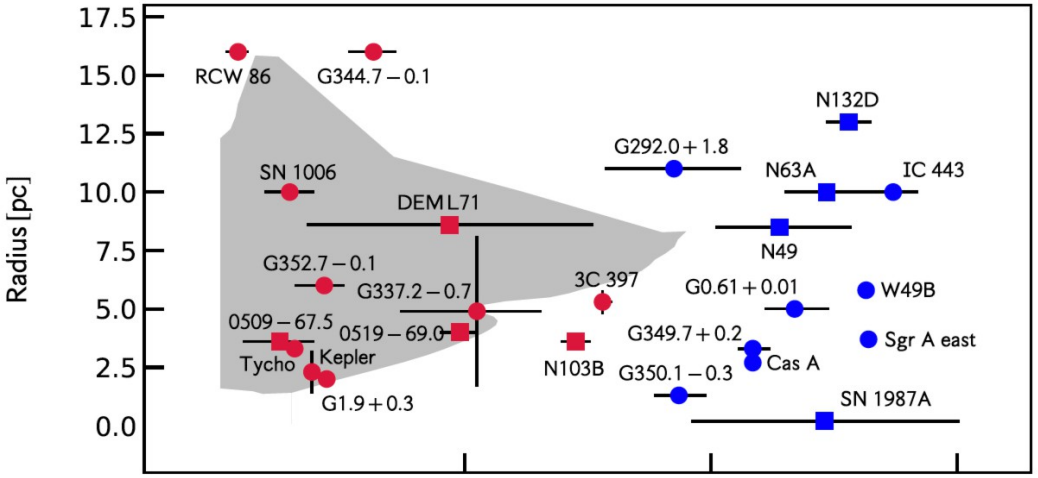
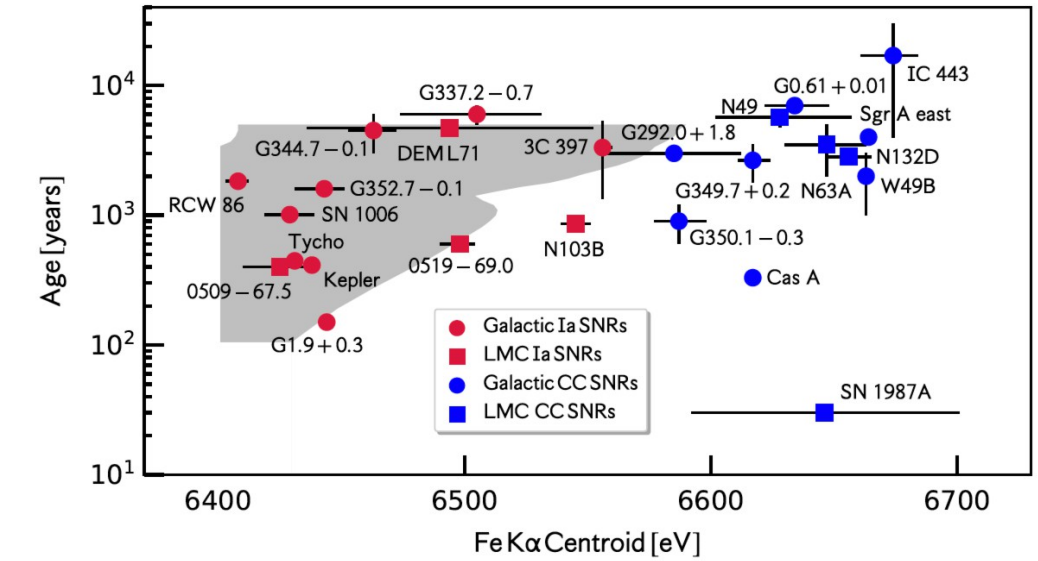
- **Uniform AM models work remarkably well for most SN Ia** [Badenes+07, Yamaguchi+ 14, M-R+ 18].



Martínez-Rodríguez+ 18



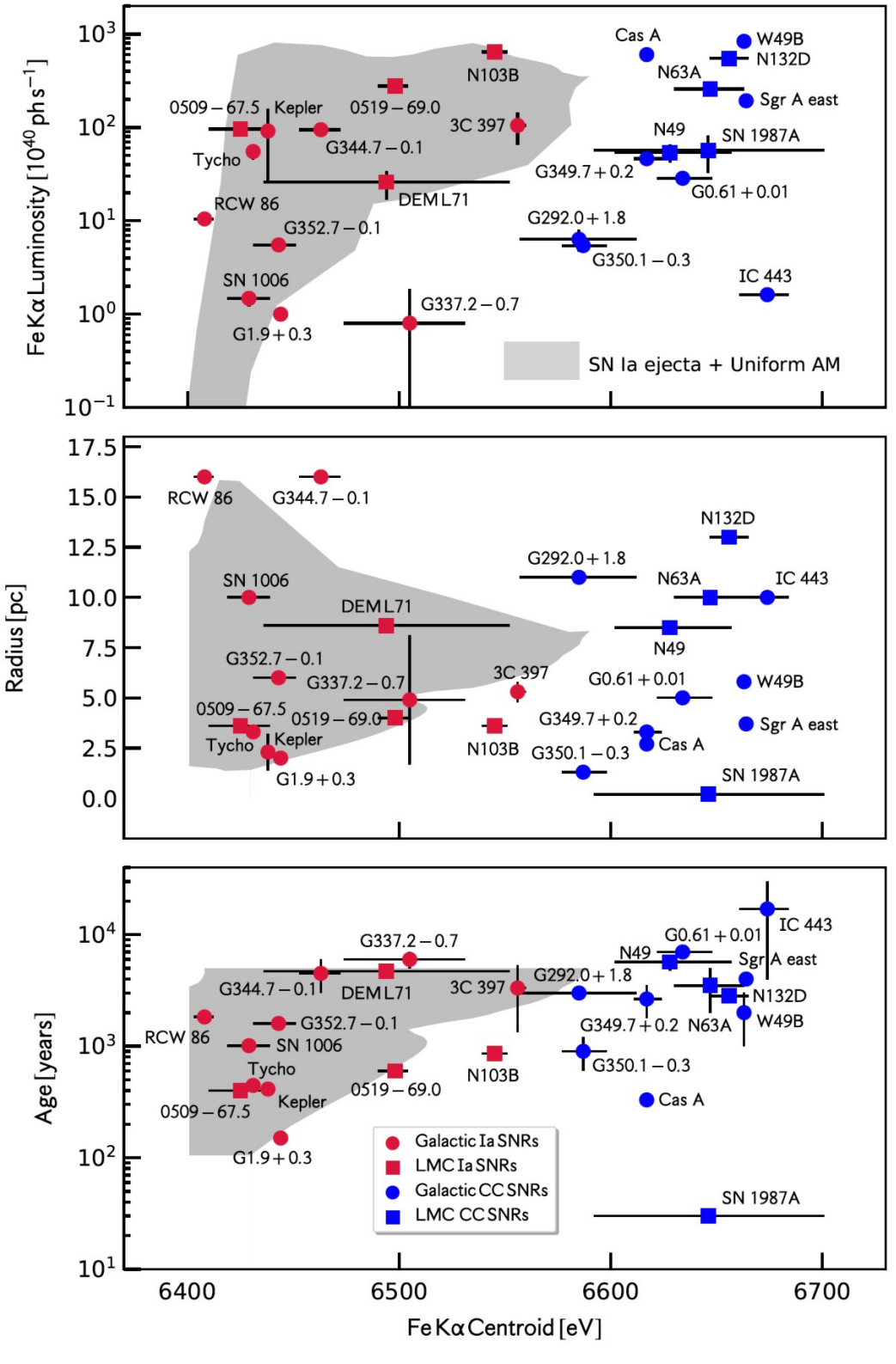




Models: Uniform AM

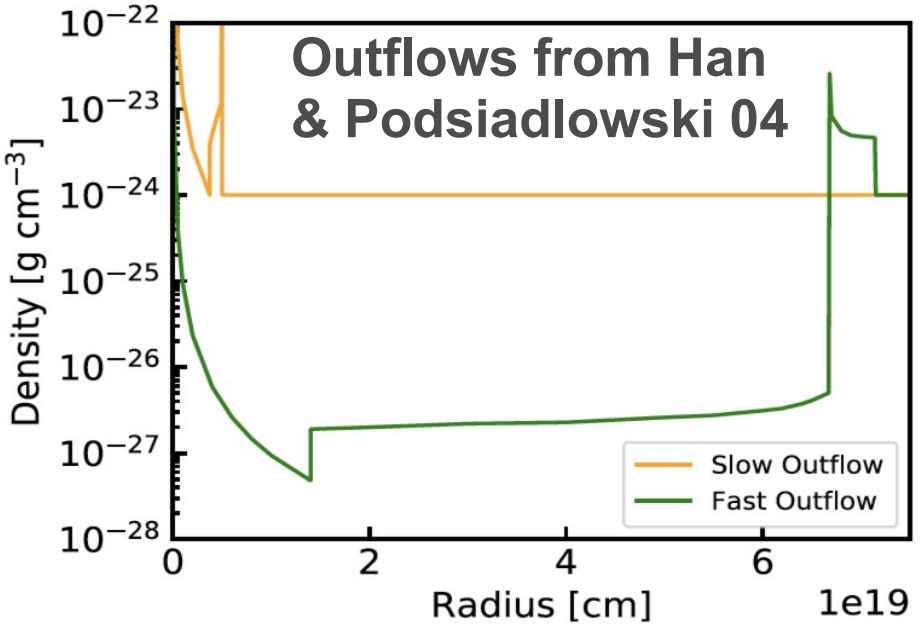
- **HD+NEI Models required** to draw quantitative conclusions on progenitor mass loss!
- **Uniform AM models work remarkably well for most SN Ia** [Badenes+07, Yamaguchi+ 14, M-R+ 18].
- Exceptions: N103B, RCW 86, Kepler, ... [Badenes+ 07, Patnaude+ 12, Williams+ 11,14, Broersen+ 14].

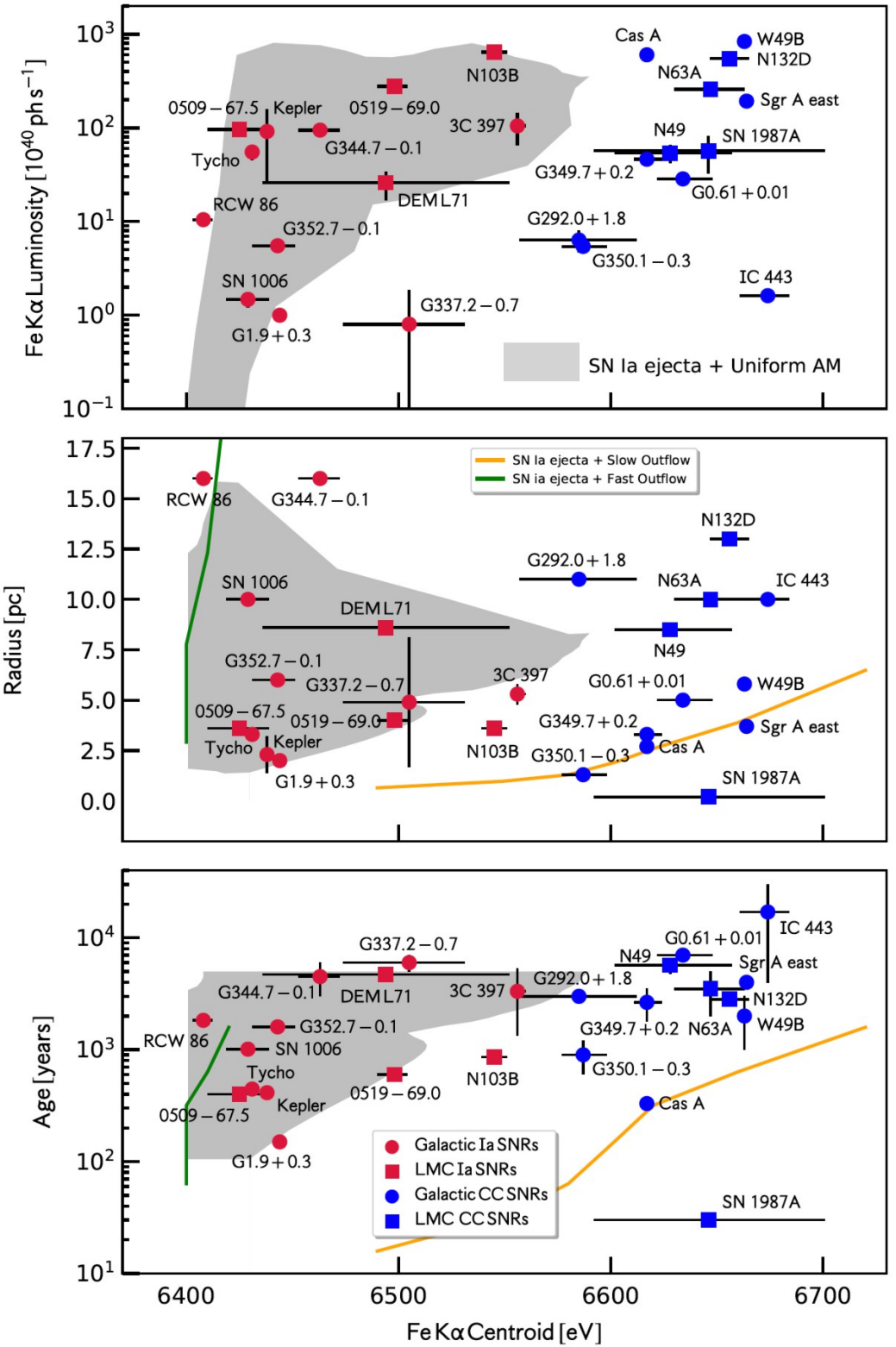
Most Type Ia SNRs show no evidence for strongly modified AM on ~pc scales



Models: Outflows

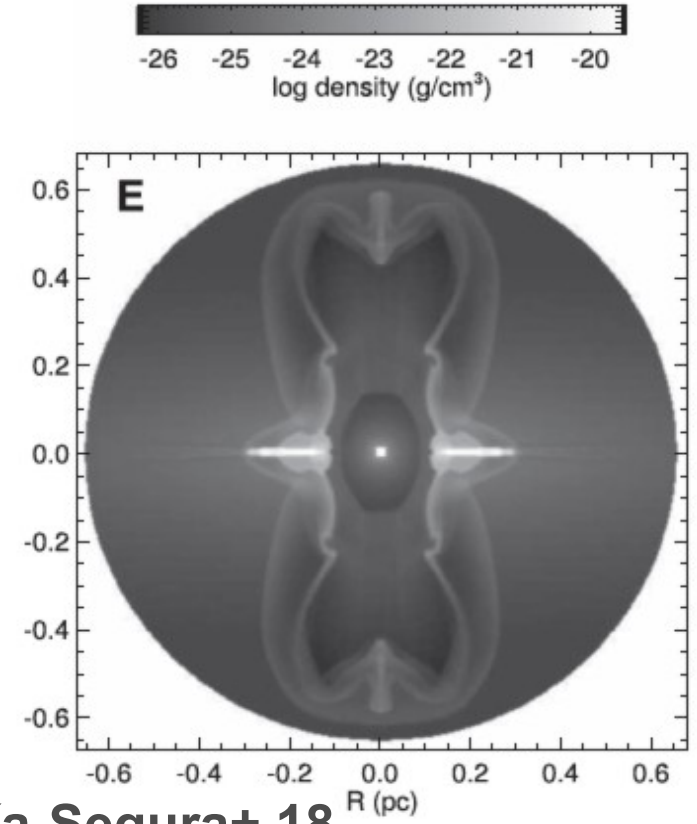
- **Fast outflows:** large cavities, consistent with RCW 86 [Badenes+ 07, Williams+ 11, Broersen+ 14].
- **Slow outflows:** dense CSM, ruled out [Badenes+ 07, Patnaude & Badenes 17].
- Intermediate cases?





Models: CE cocoons

- **Post-CE PN models** [García-Segura+ 18].
- Models with short delays (SN ≲1000 yr after CE) do not work. Longer delays might be OK.



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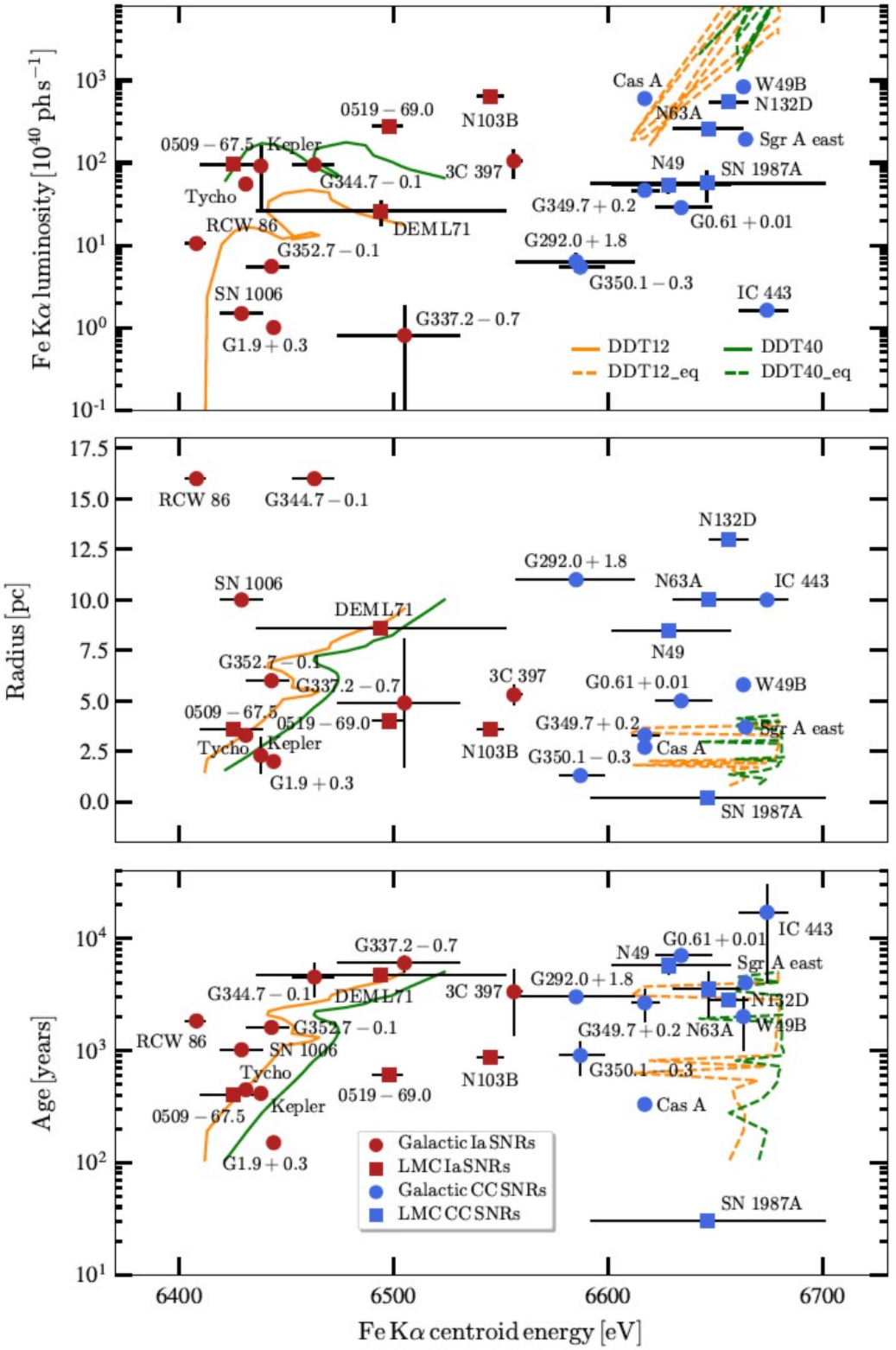

Looking Forward

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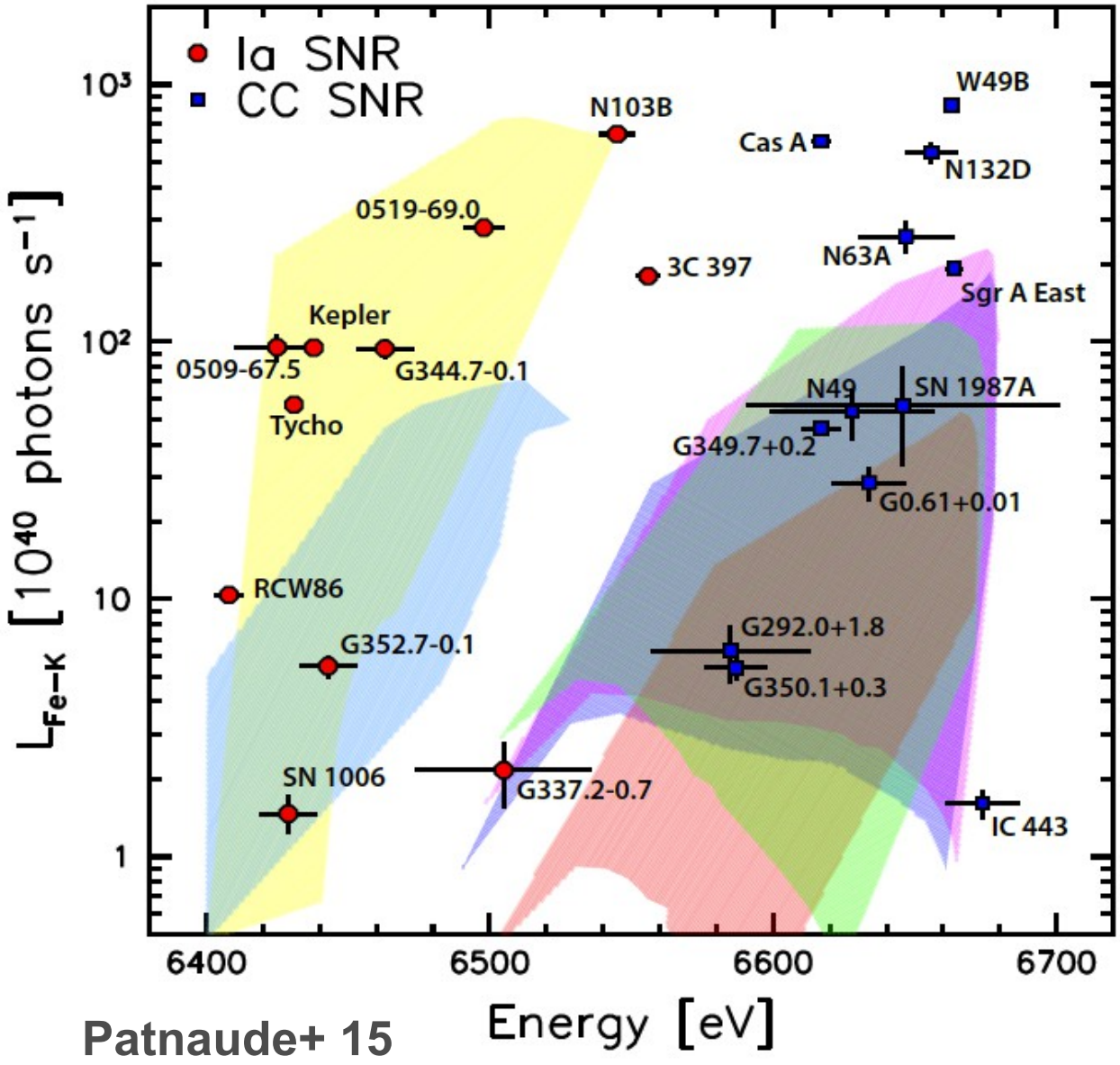
- **Explore parameter space for AM interaction in Type Ia SNRs** [Travis Court PhD, in progress].

- **Part of a large effort**: CR-modified dynamics [Lee+ 14], CC SNR models. [Patnaude+15,17, Jacovich+ 21].

- **XRISM**: velocity vs. $n_e t$ for Tycho and SN1006 ⇔ discriminate Ch and sub-Ch explosions.



Patnaude+ 15

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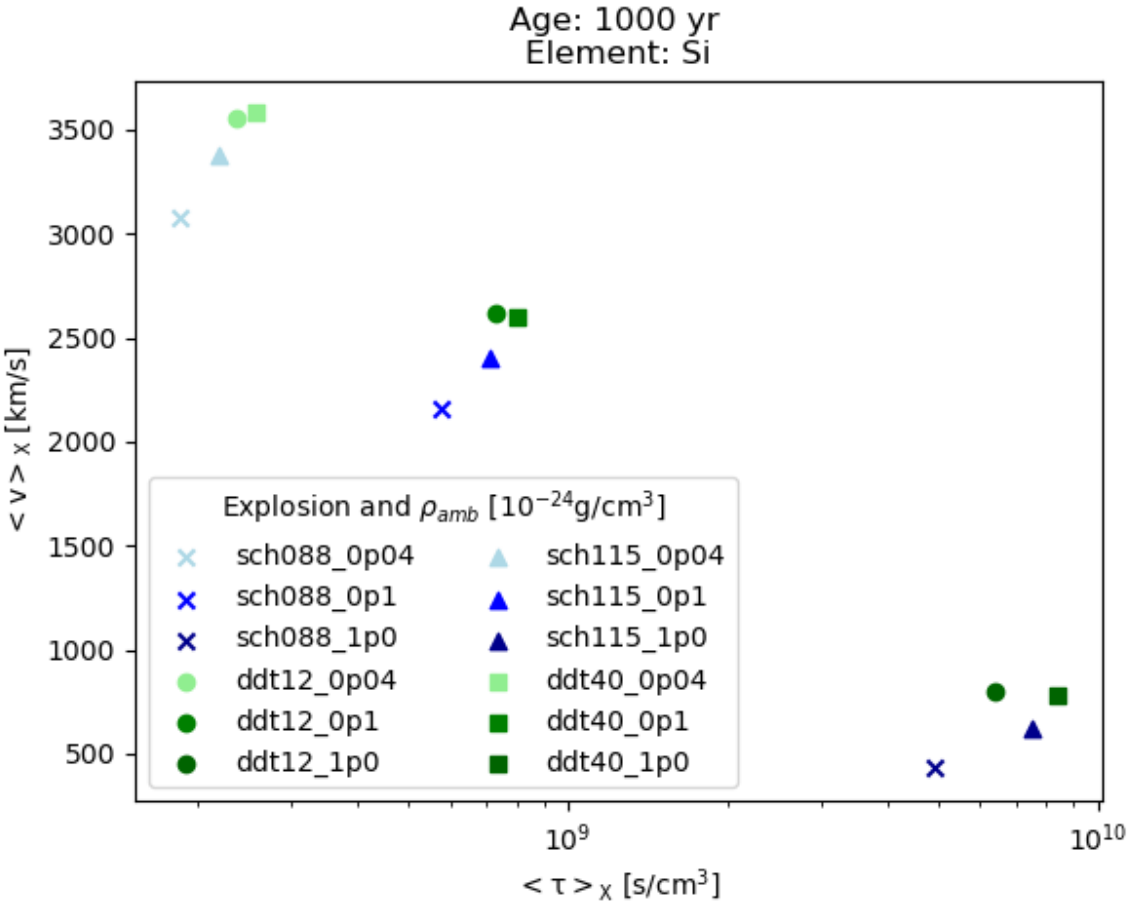

Extra Plots

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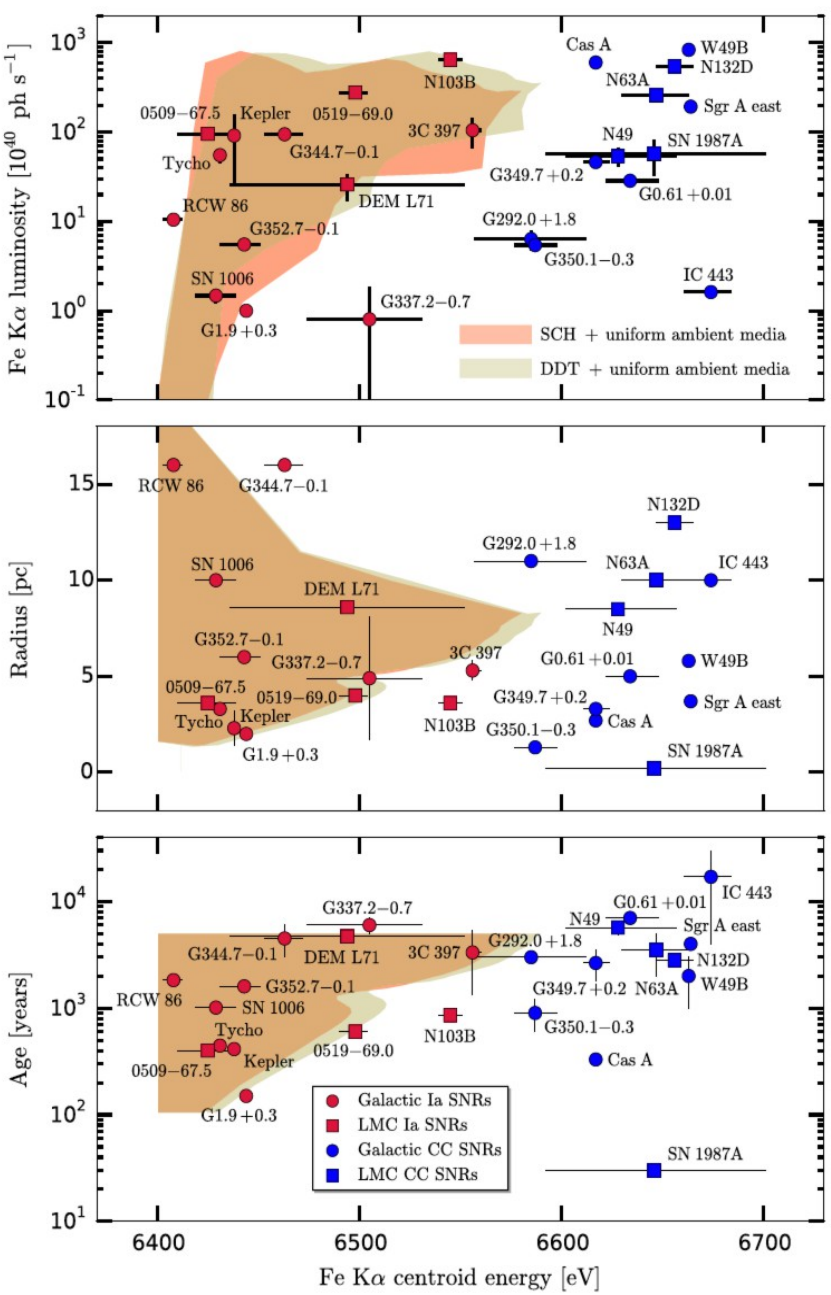

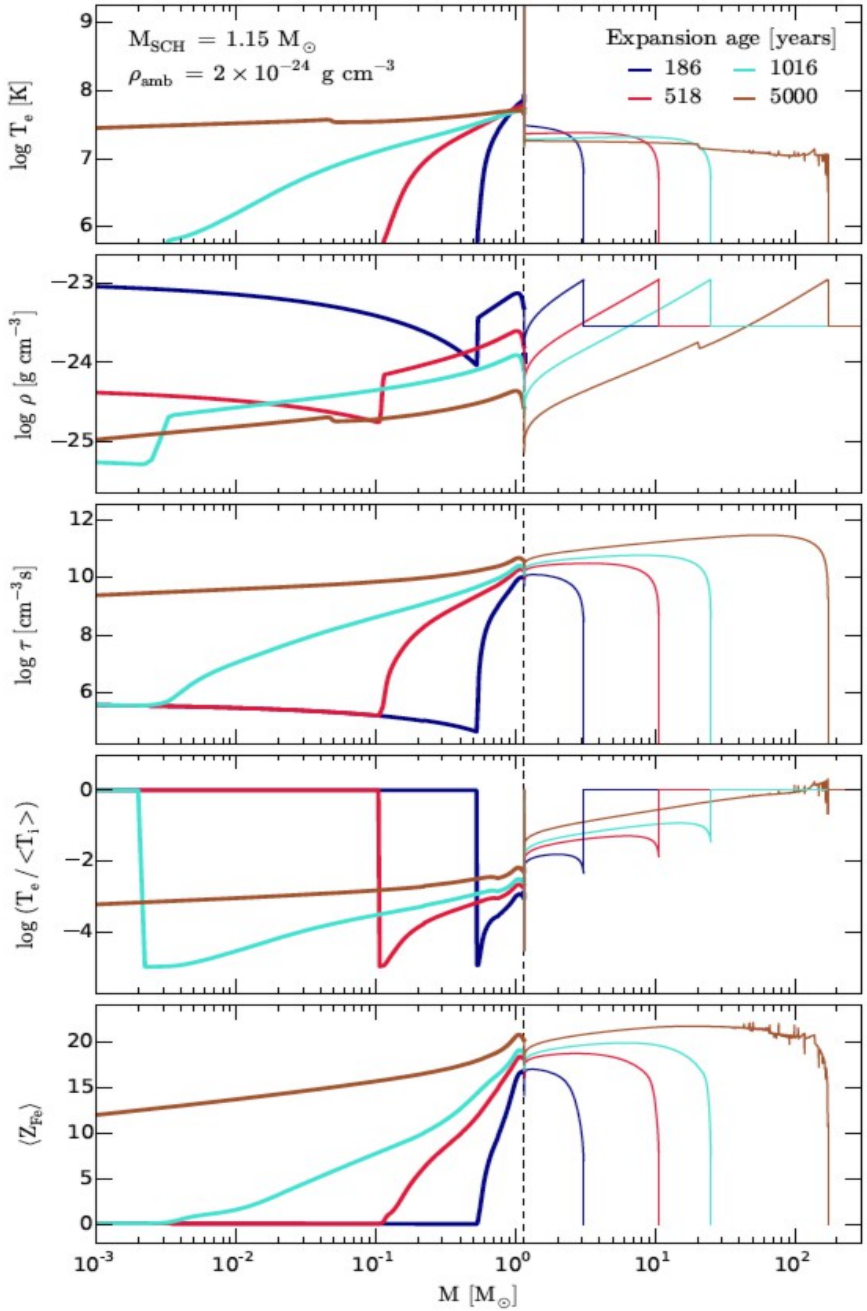

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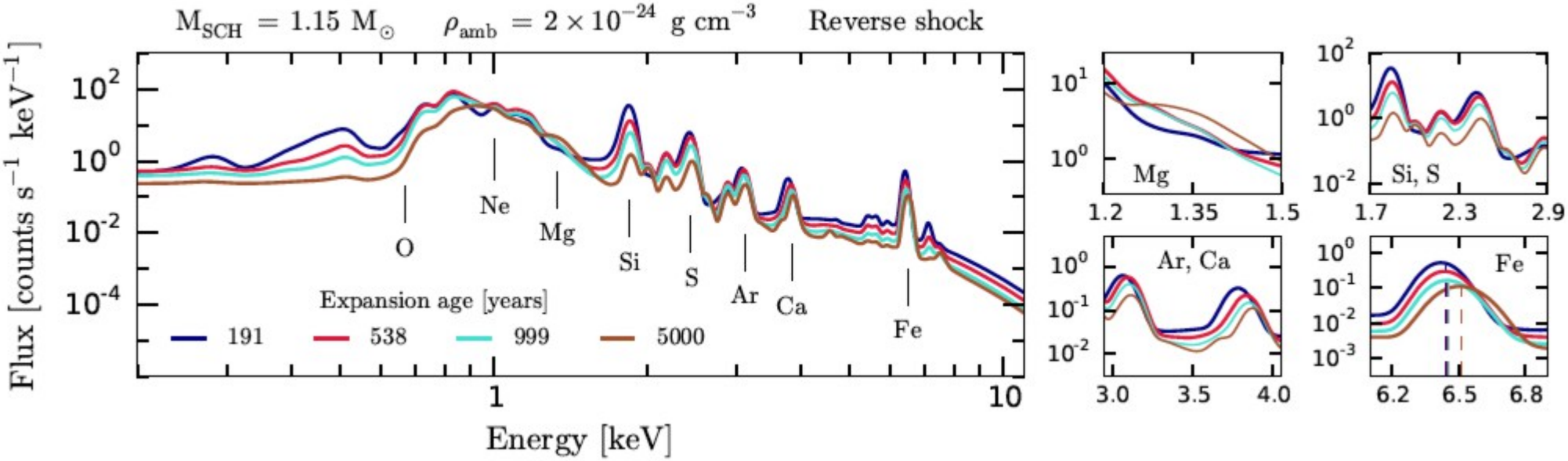

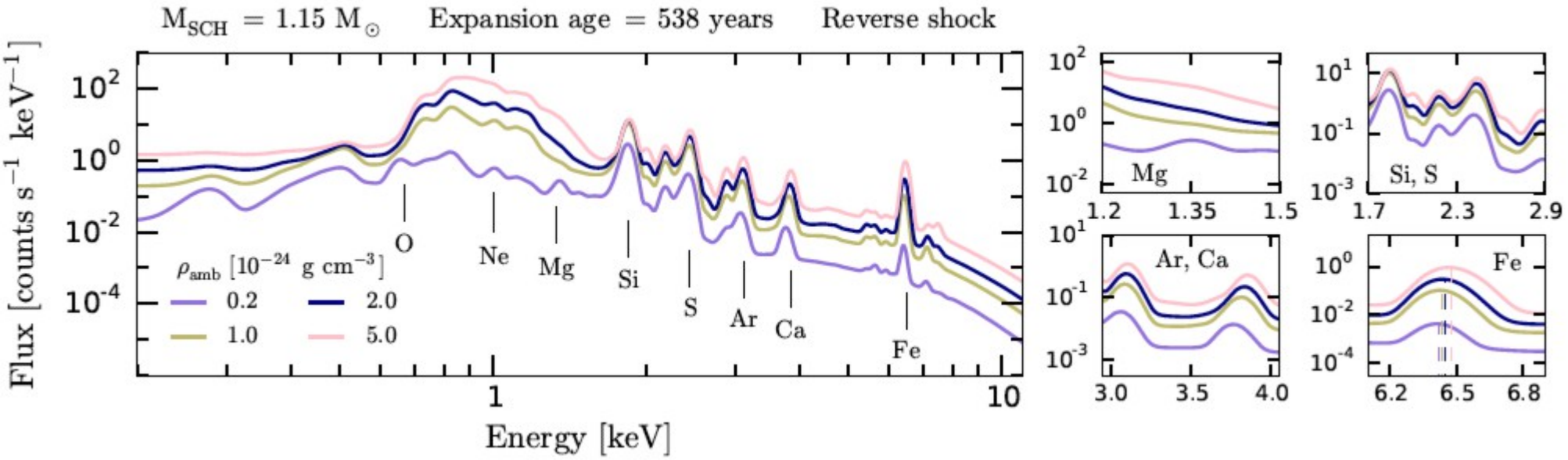

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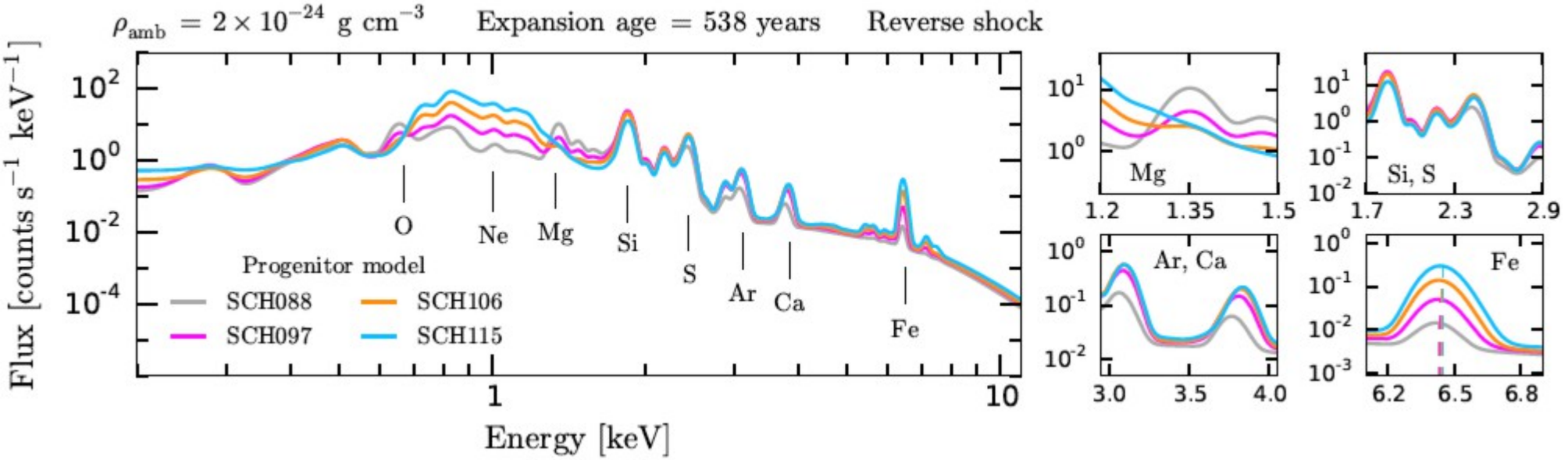

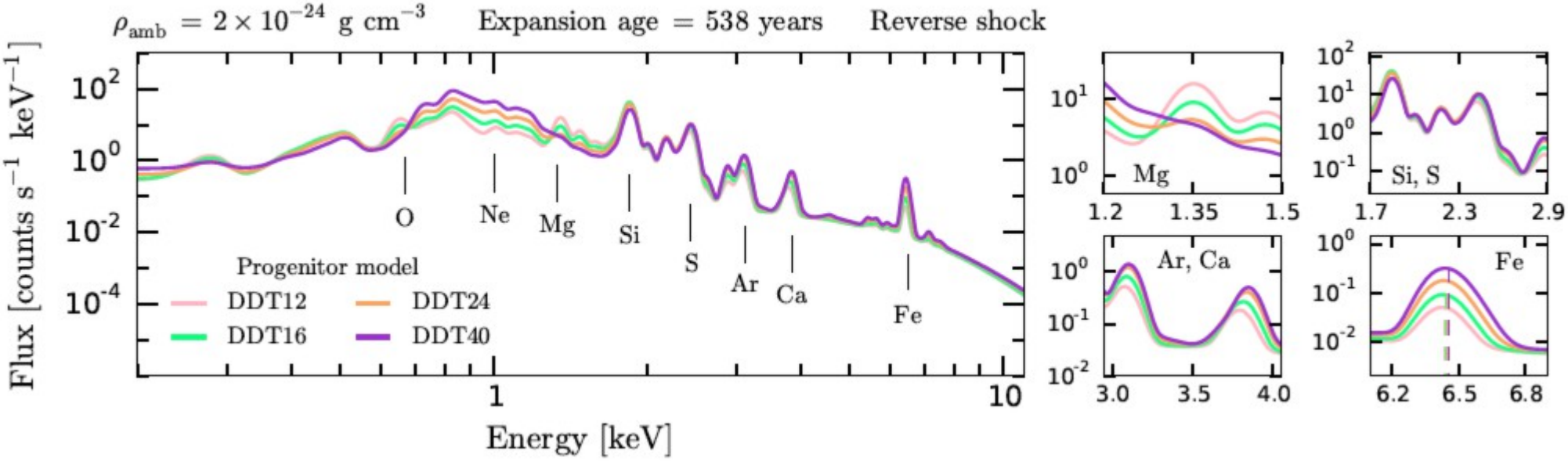

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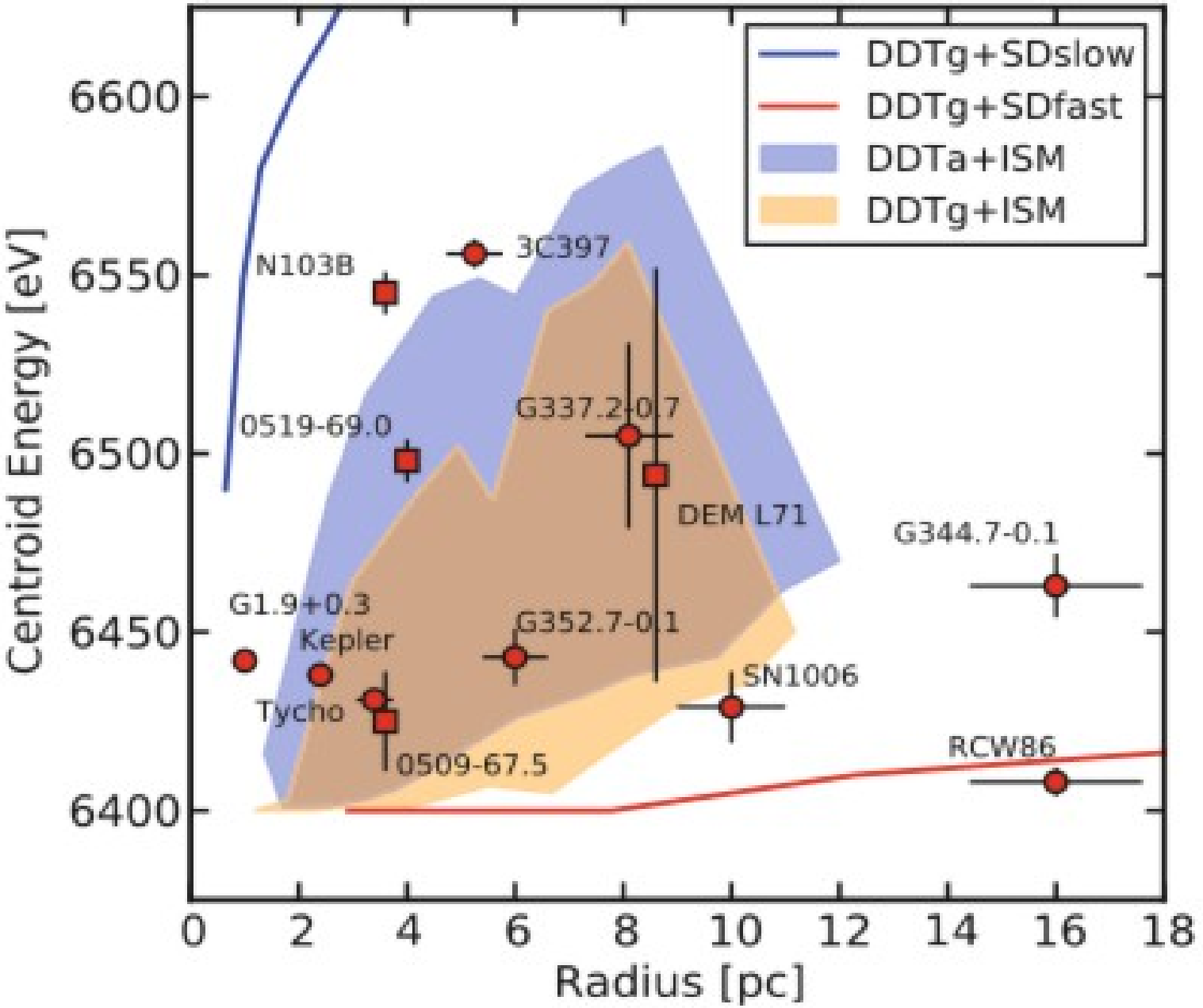

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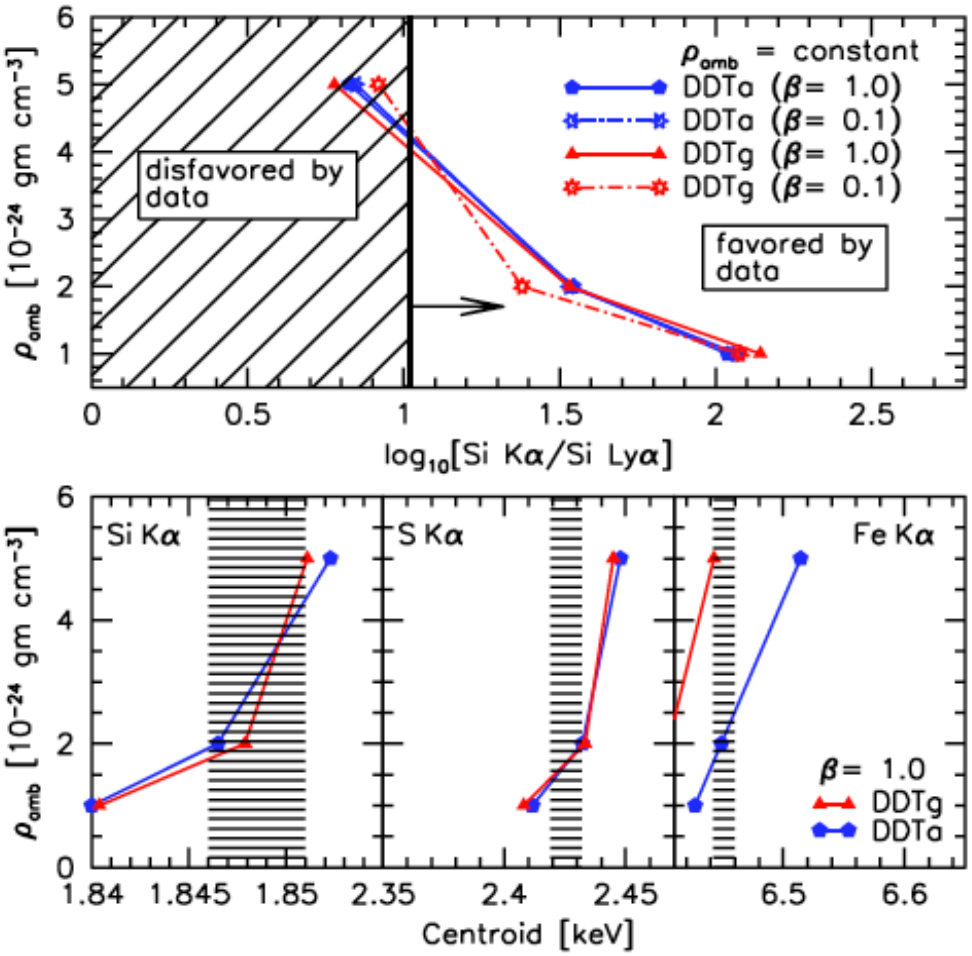

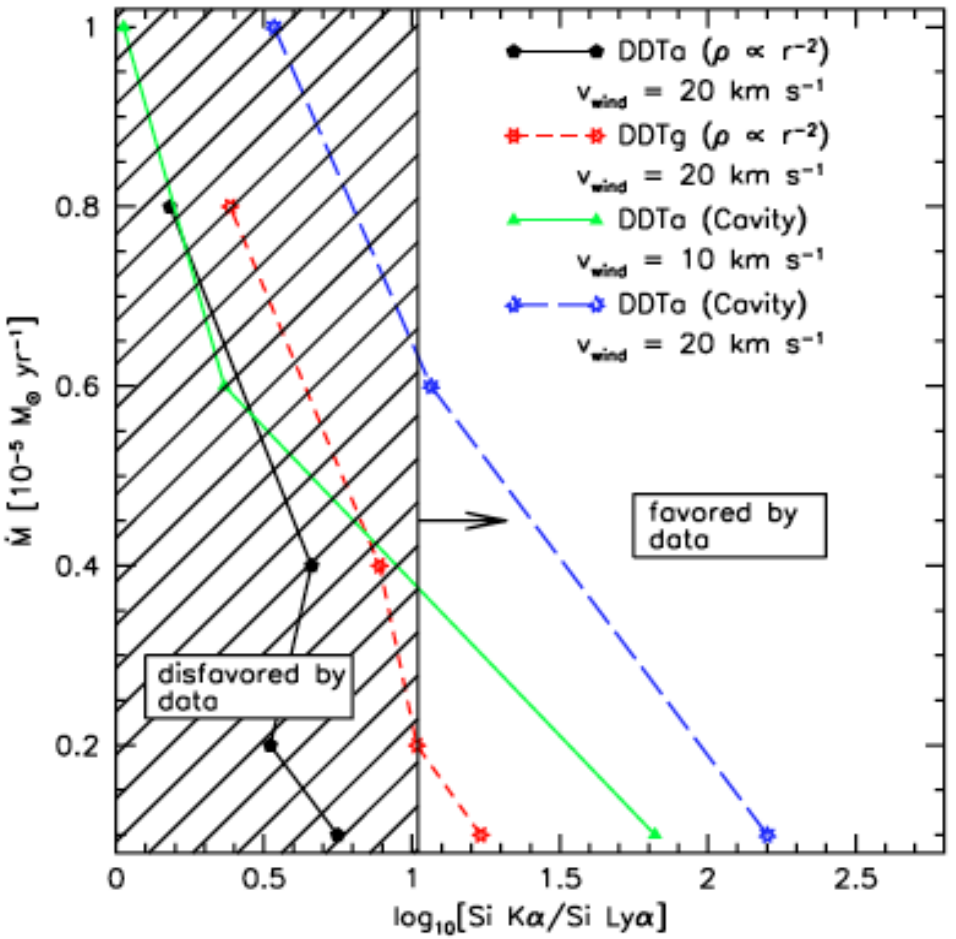

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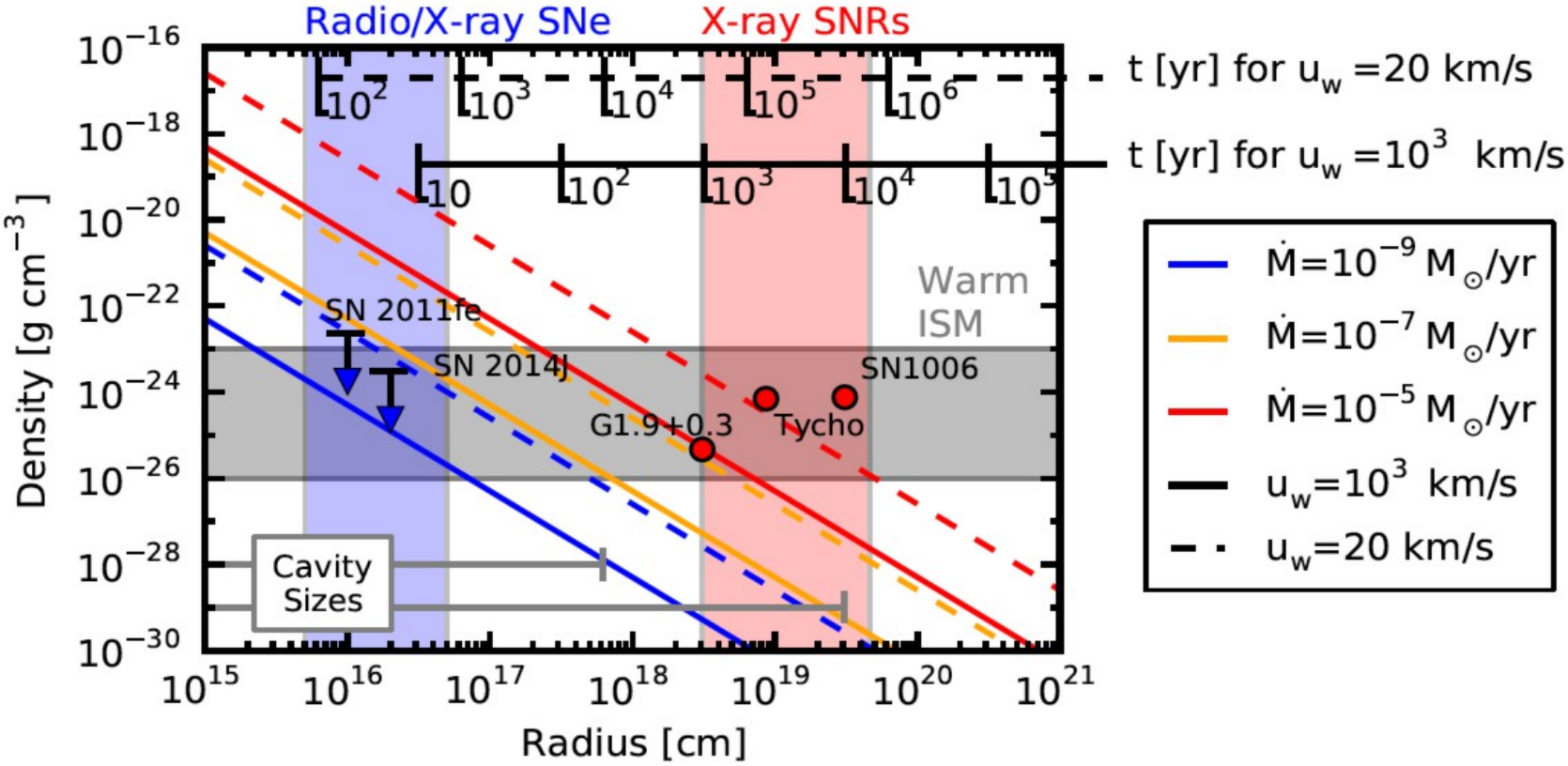

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