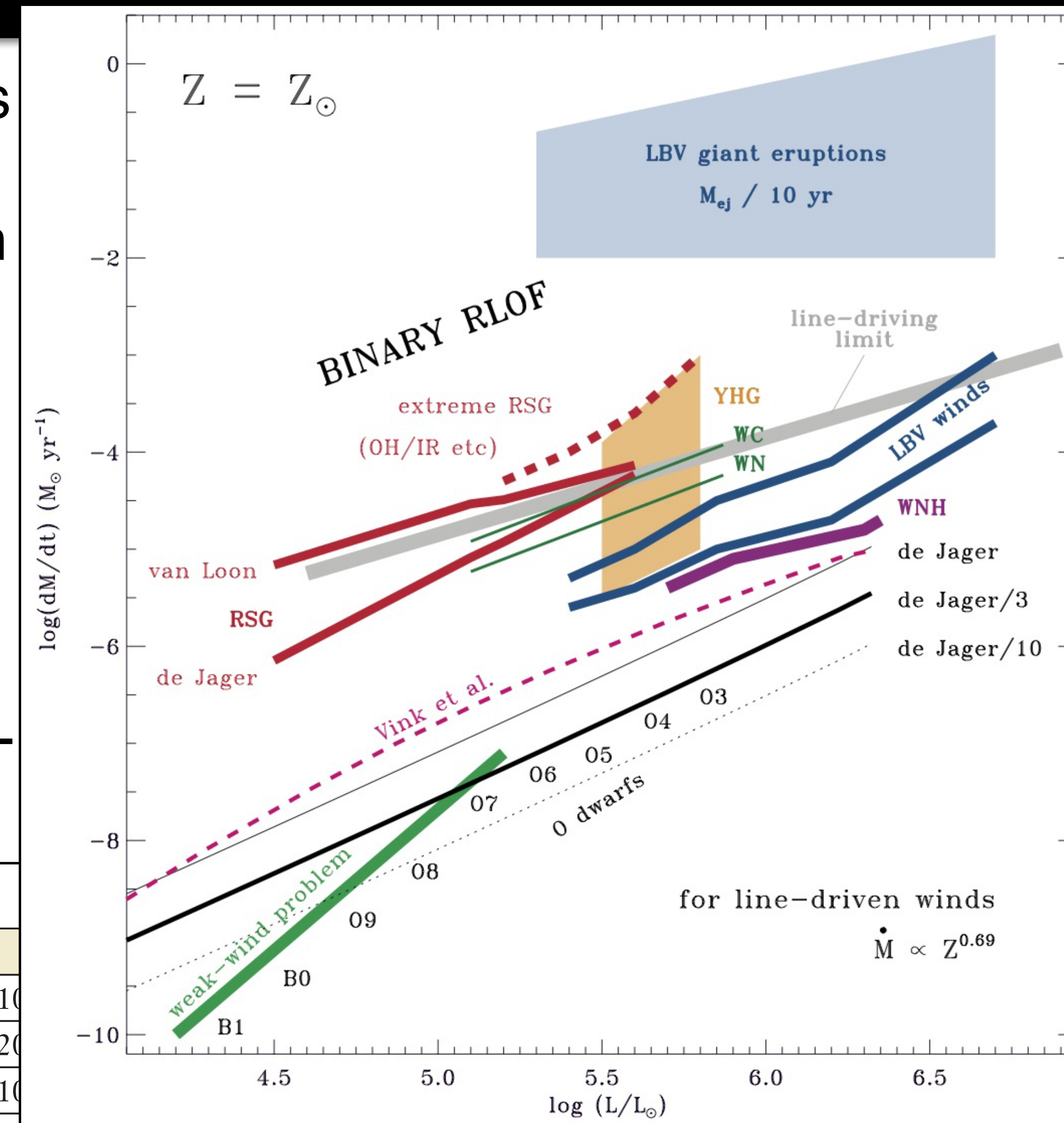
HARVARD-SMITHSONIAN
CENTER FOR ASTROPHYSICS

PROBING MASS LOSS IN SUPERNOVA PROGENITORS WITH LYNX

DAN PATNAUDE (SAO)

- when and how massive stars shed their envelopes remains an open question
- observed mass loss rates are generally lower than what is predicted
- many SNe progenitors now show evidence, direct or otherwise, for enhanced mass loss prior to core collapse:
  - shell burning leading to instabilities that eject mass (Smith and Arnett)
  - energy deposited in the envelope from a super-Eddington core (Quartaert and Shiode)



Smith (2014; ARA&A)

Table 1 Mapping of supernova (SN) types to their likely progenitor star properties

SN	Progenitor Star[a]	M_{ZAMS} ($M_\odot$)[b]	$\dot{M}$ ($M_\odot$ year^{-1})[c]	
II-P	RSG	8–20	10^{-6}–10^{-5}	[illegible]
II-L	RSG/YSG	20–30 (?)	10^{-5}–10^{-4}	[illegible]
II-pec	BSG (b)	15–25	10^{-6}–10^{-4}	[illegible]
IIb	YSG (b)	10–25	10^{-5}–10^{-4}	20–100
Ib	He star (b)	15–25 (?)	10^{-7}–10^{-4}	100–1,000
Ic	He star (b)/WR	25–?	10^{-7}–10^{-4}	1,000
Ic-BL	He star (b)/WR	25–?	10^{-6}–10^{-5}	1,000
IIn (SL)	LBV	30–?	(1–10)	50–600
IIn	LBV/B[e] (b)	25–?	(0.01–1)	50–600
IIn	RSG/YHG	25–40	10^{-4}–10^{-3}	30–100
IIn-P	Super-AGB	8–10	0.01–1	10–600
Ibn	WR/LBV	40–?	10^{-3}–0.1	1,000
Ia/IIn	WD (b)	5–8 (?)	0.01–1	50–100

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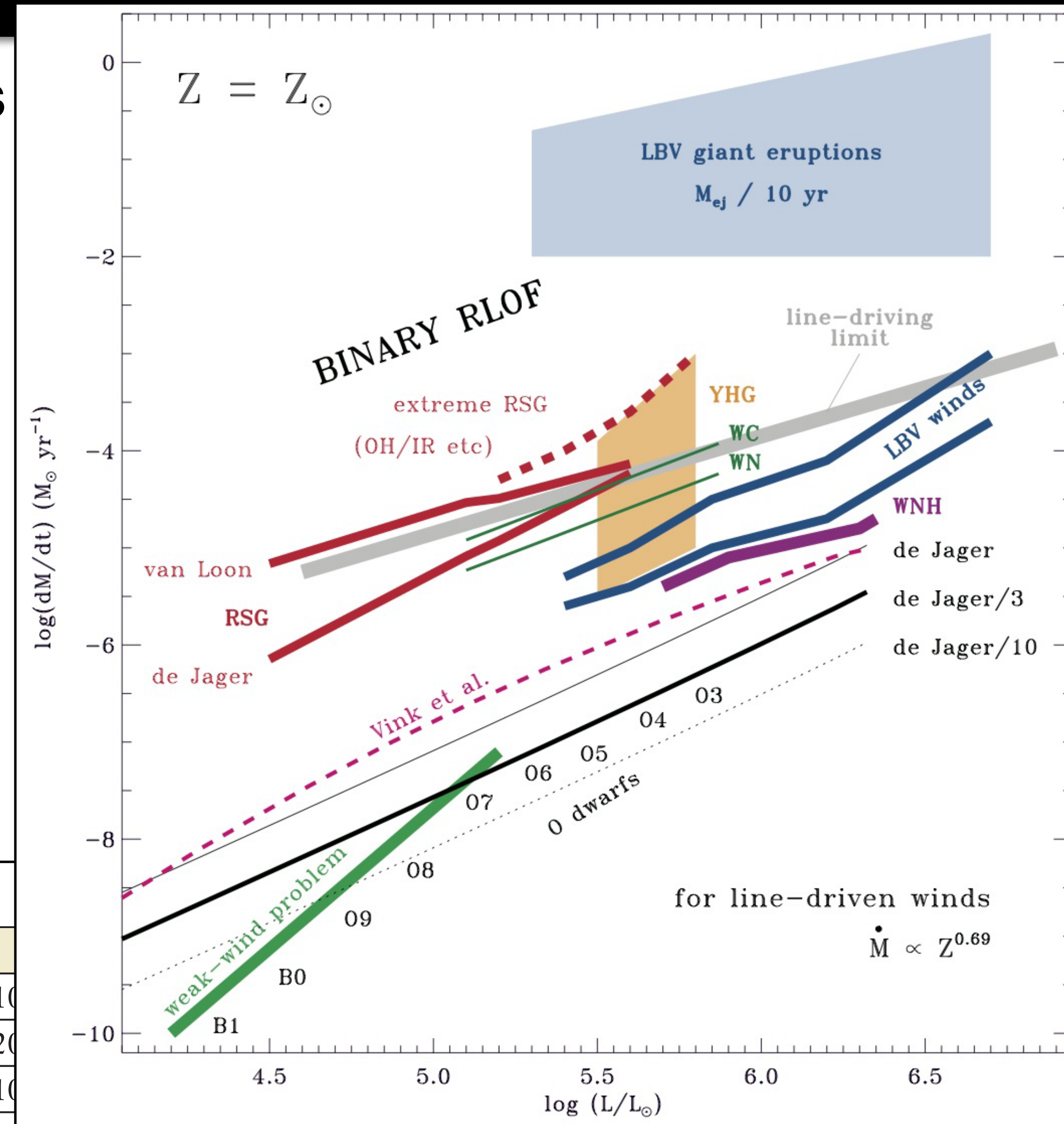
- observed mass loss rates are generally lower than what is predicted
- many SNe progenitors now show evidence, direct or otherwise, for enhanced mass loss prior to core collapse:
    - SN 2001em, SN 2014C, SN 1996cr ejected their shells ~ 100 - 10^4 years before core collapase
    - timing of ejection may be related to CC



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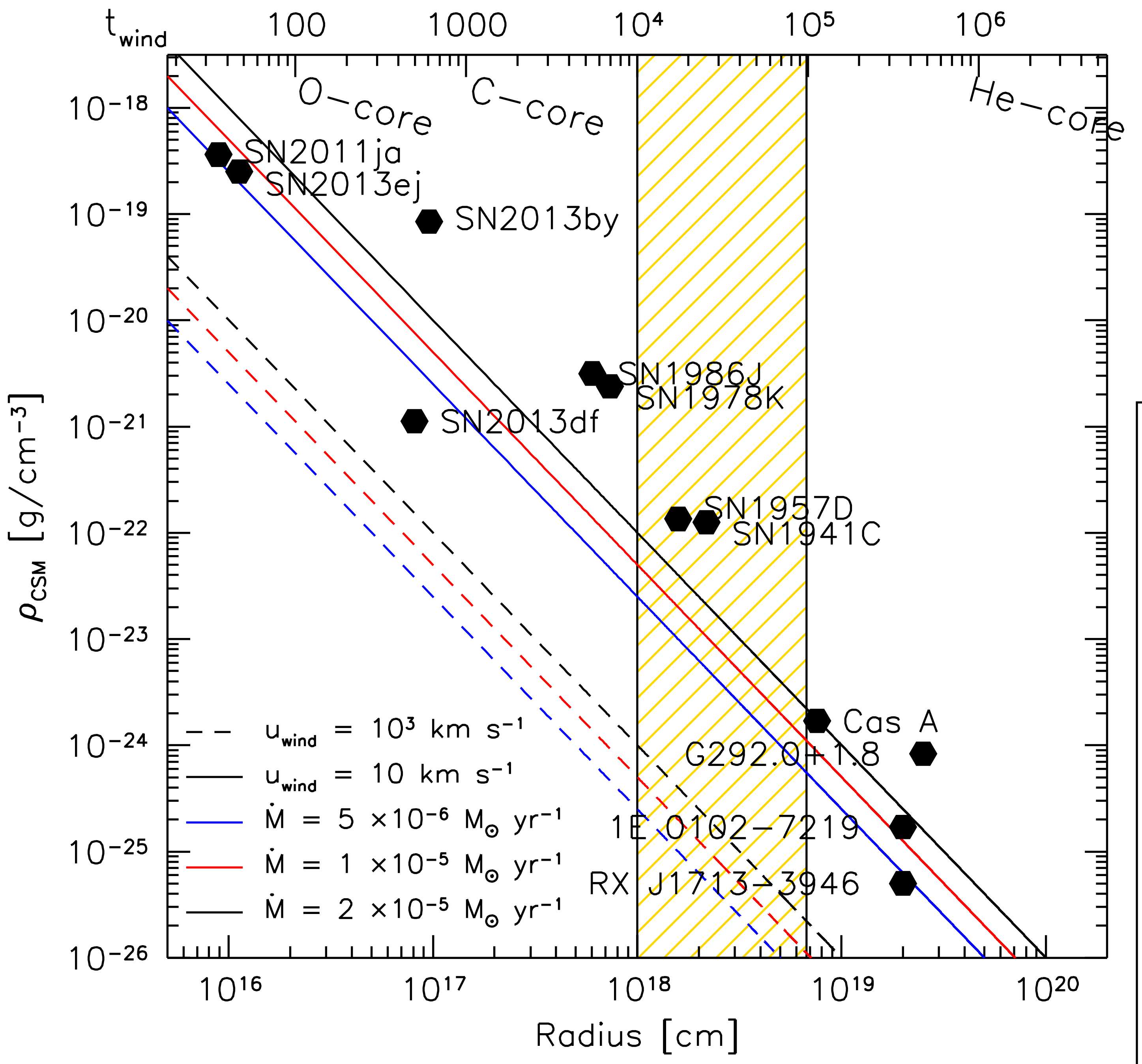
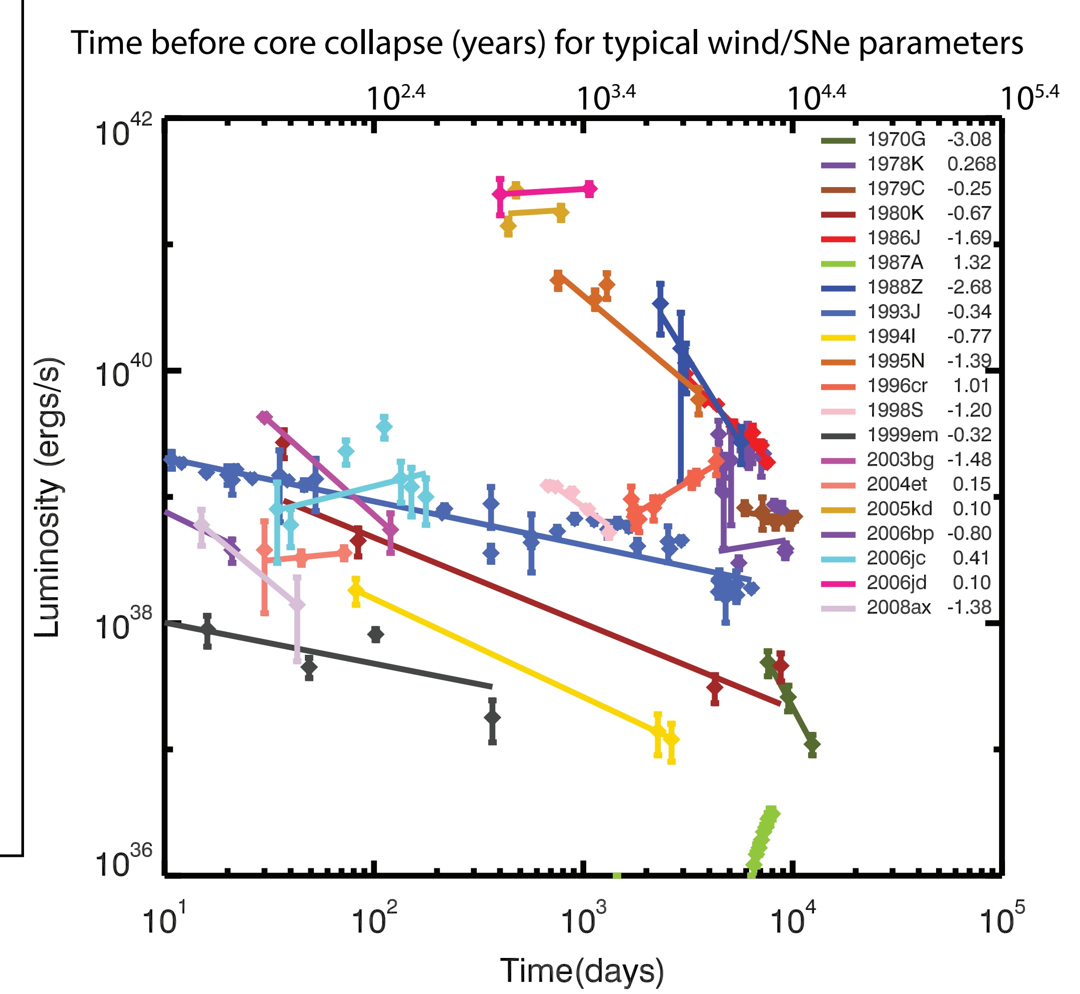
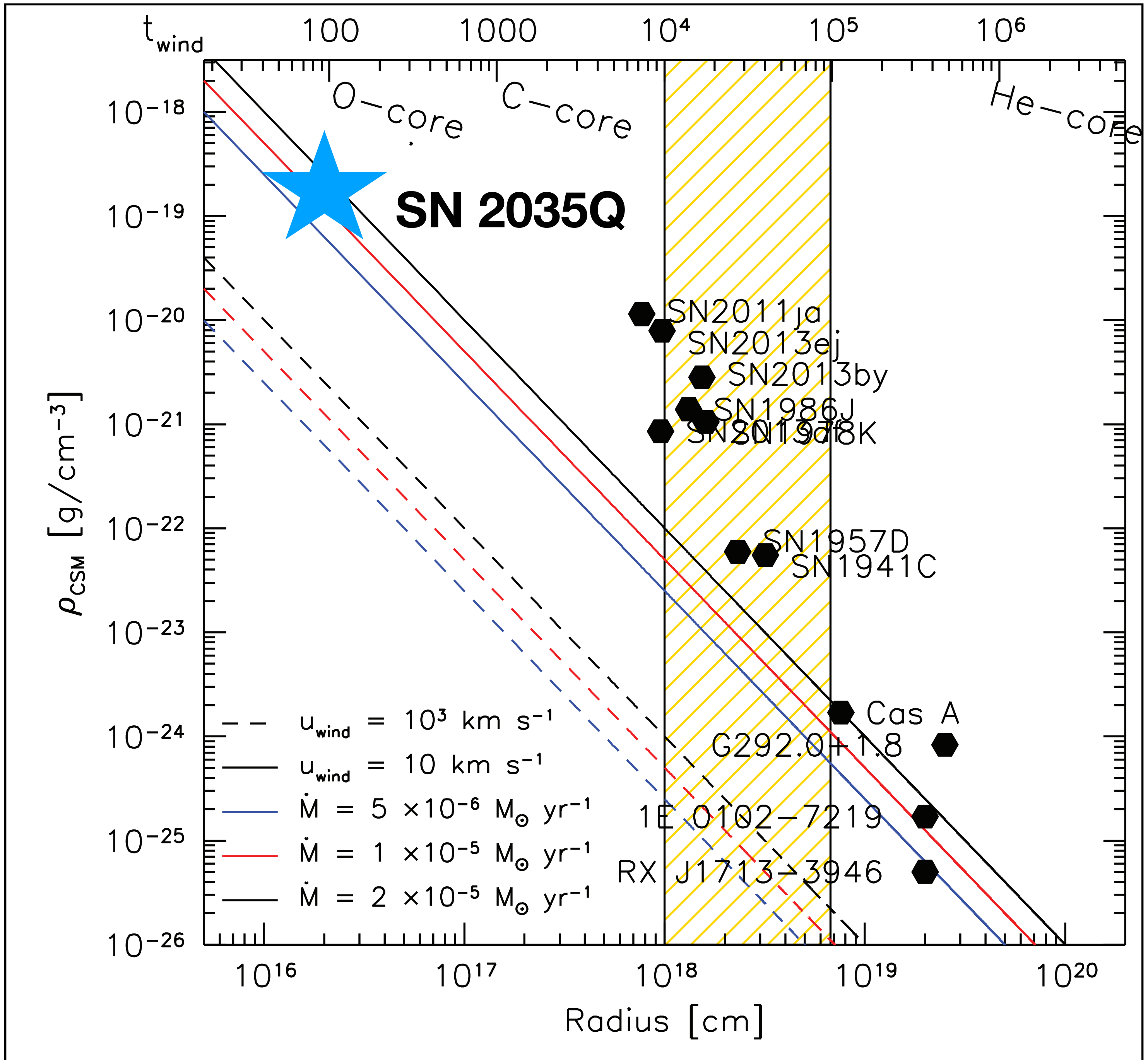


Current state of mass loss observations from SNR and SNe

$$L_X \sim \dot{M}^2$$
$$\rho_{\mathrm{CSM}} \sim \dot{M}$$

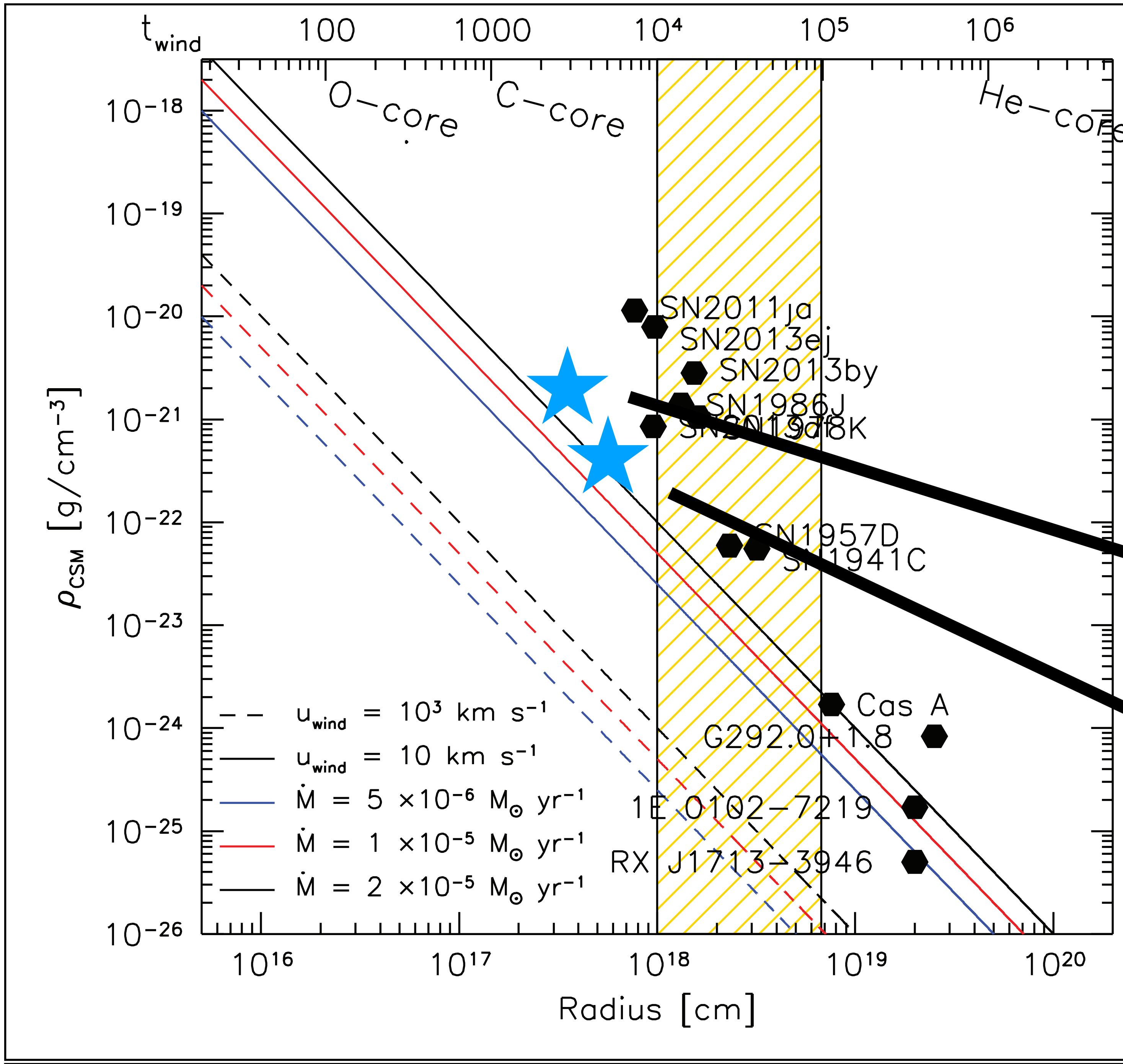


Dwarkadas and Gruszko (2012)



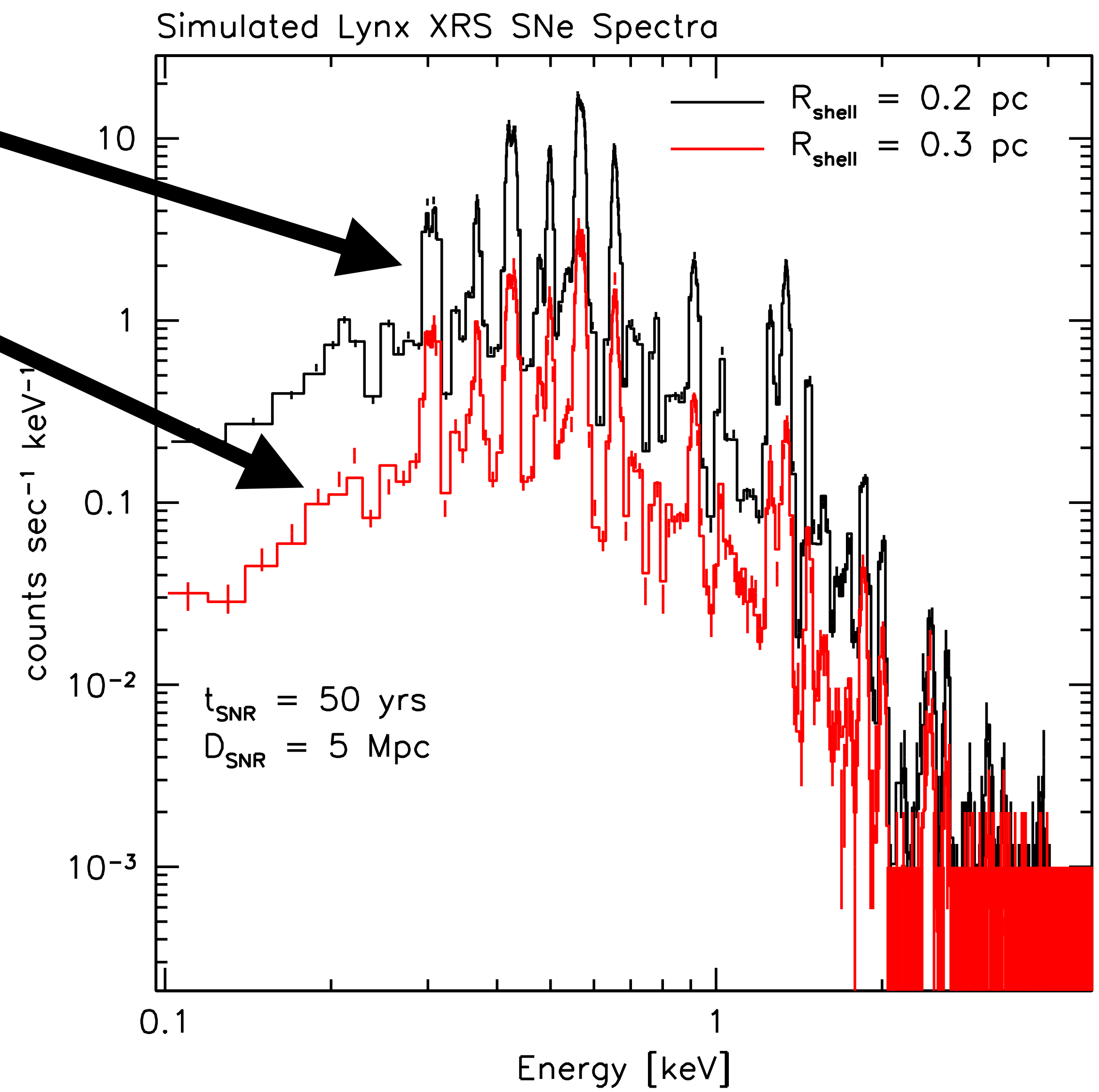
Future state of mass loss observations from SNR and SNe

- in 30-40 years, SNe we observe now with Chandra will probe CSM formed during latter stages of core helium burning
- shock will interact with CSM shells ejected during core carbon burning
- these shock—shell interactions will imprint themselves on the spectra and the effects will be observable for several *e-folding* times
- High throughput spatial and spectral resolution will allow us to probe the mass loss history of massive stars out to D ~ 10 Mpc

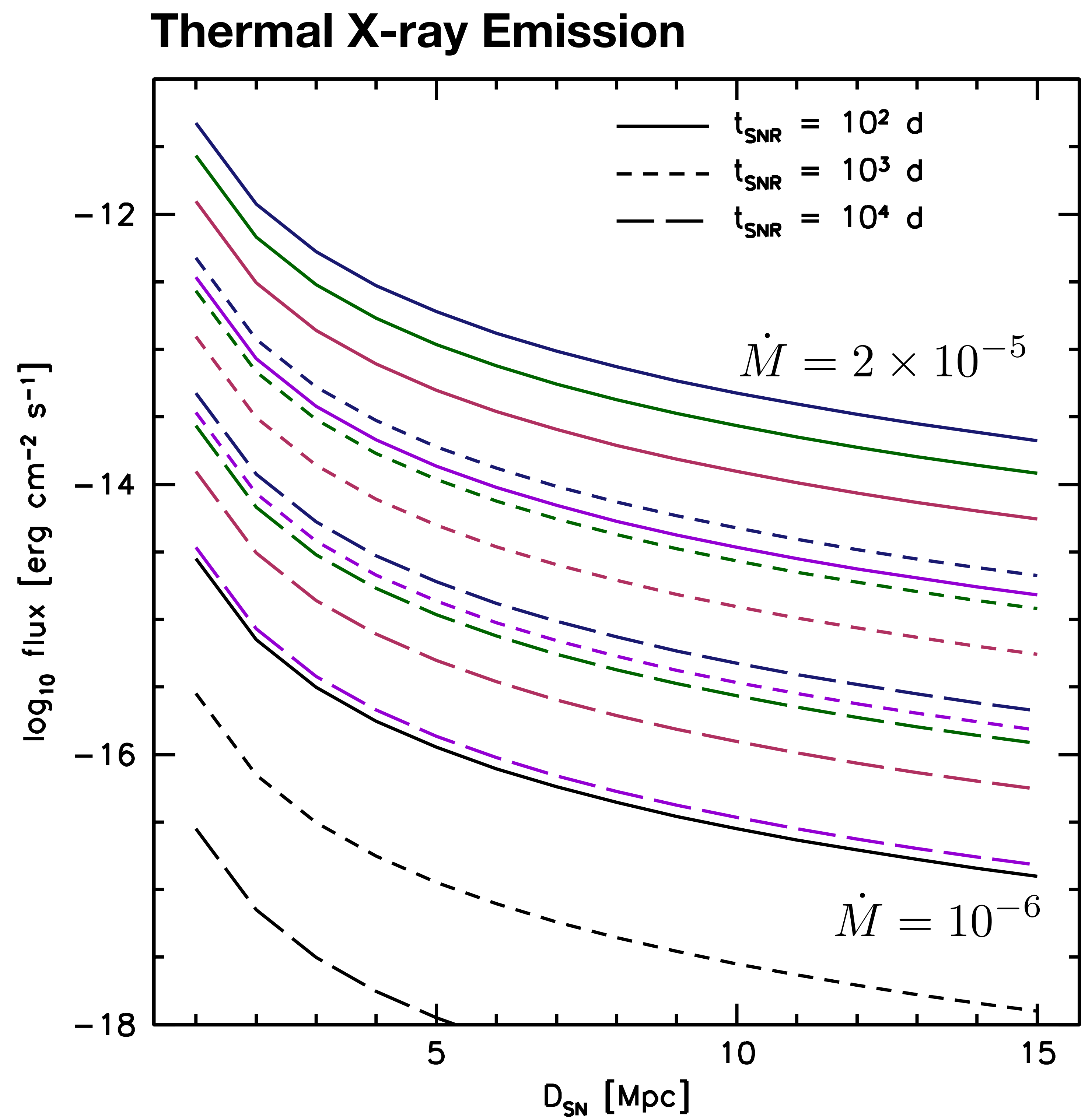


Future state of mass loss observations from SNR and SNe

SNe spectra at 50 years, highlighting the differences that result from mass loss events at different epochs



- Lynx will also probe the mass loss history of progenitors over time:



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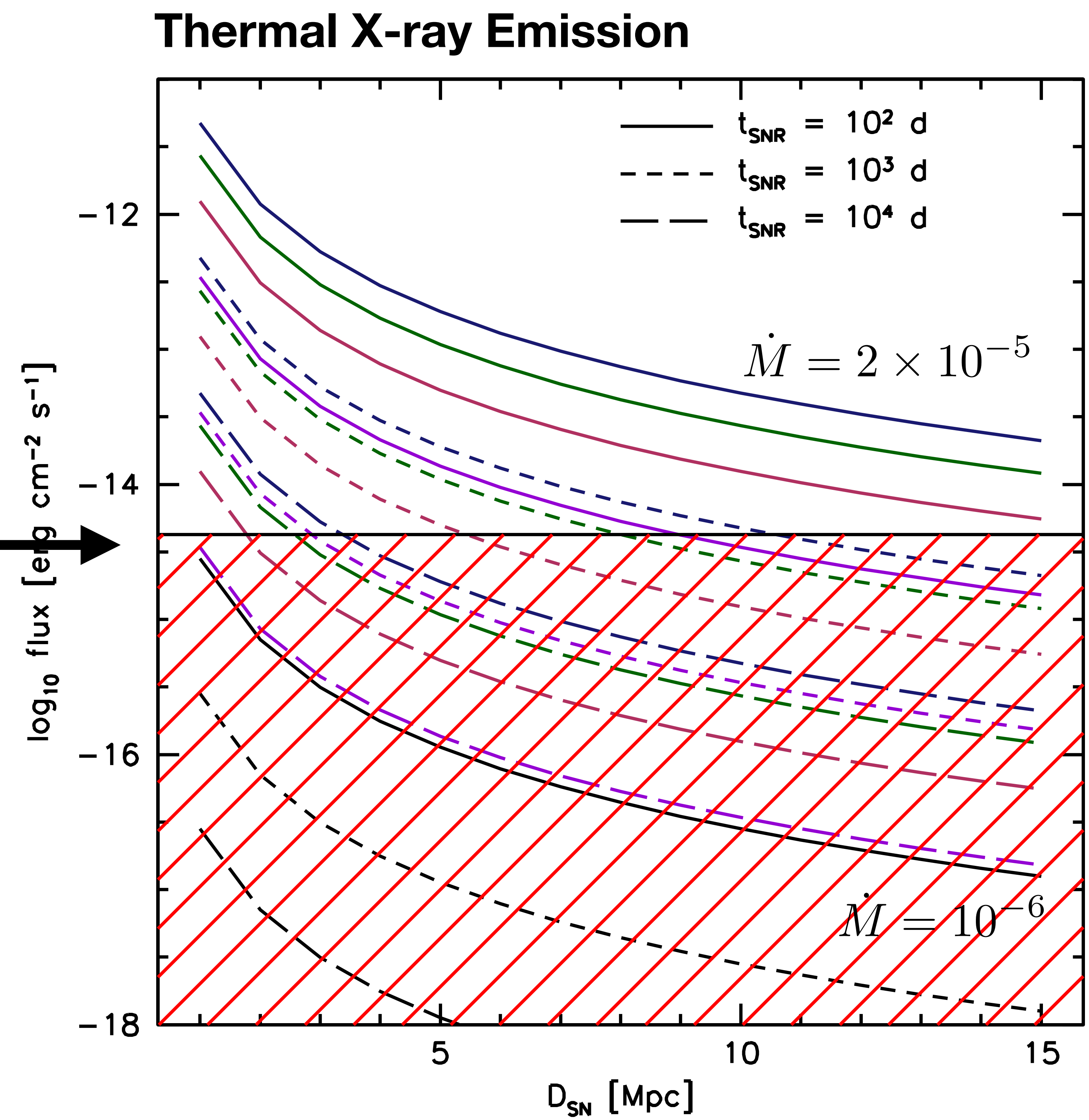
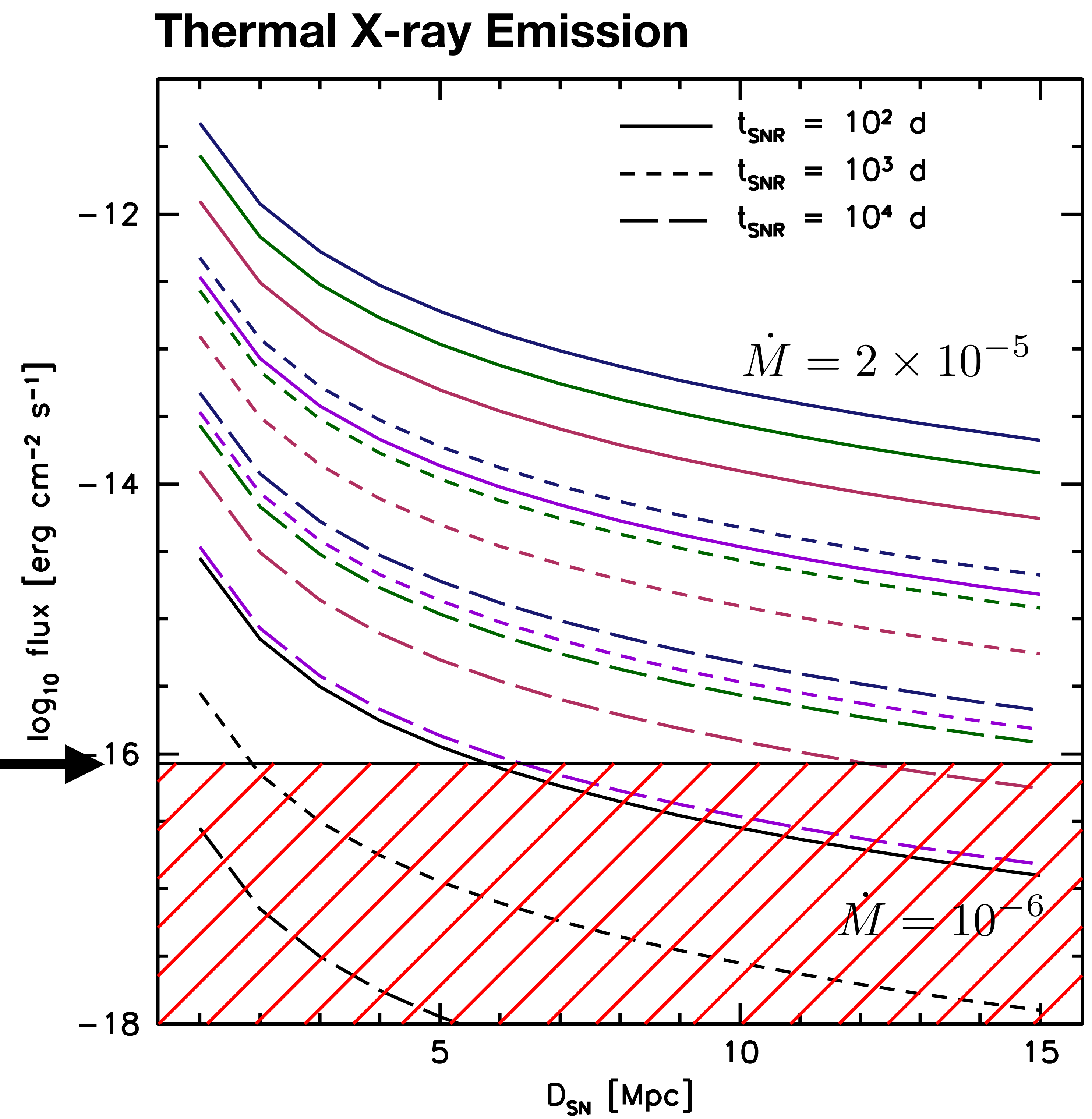
10^4 sec Chandra ACIS detection limit (Chandra POG)



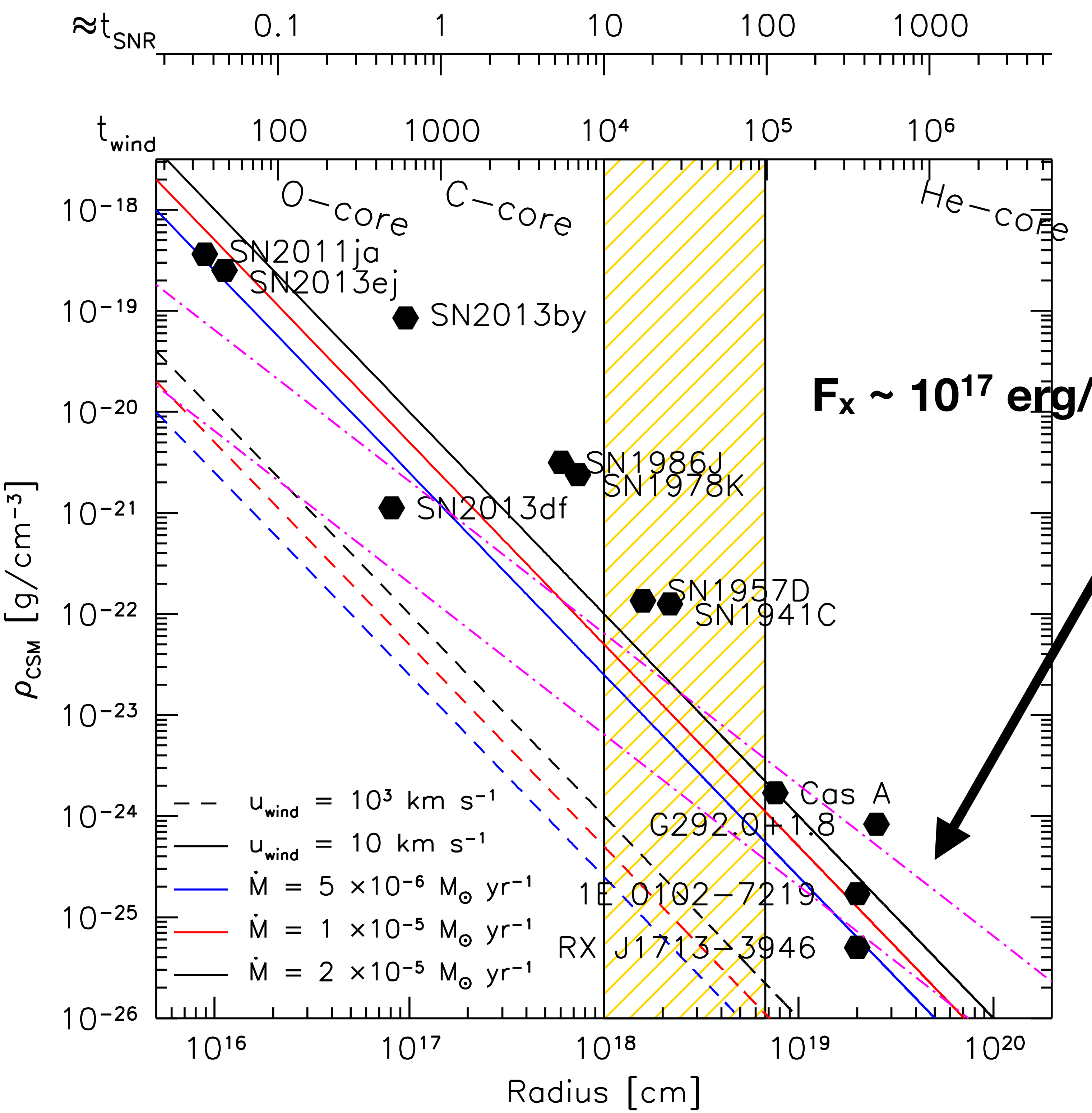
- Lynx will also probe the mass loss history of progenitors over time:

10^4 sec Lynx XRS detection limit (A. Vikhlinin)

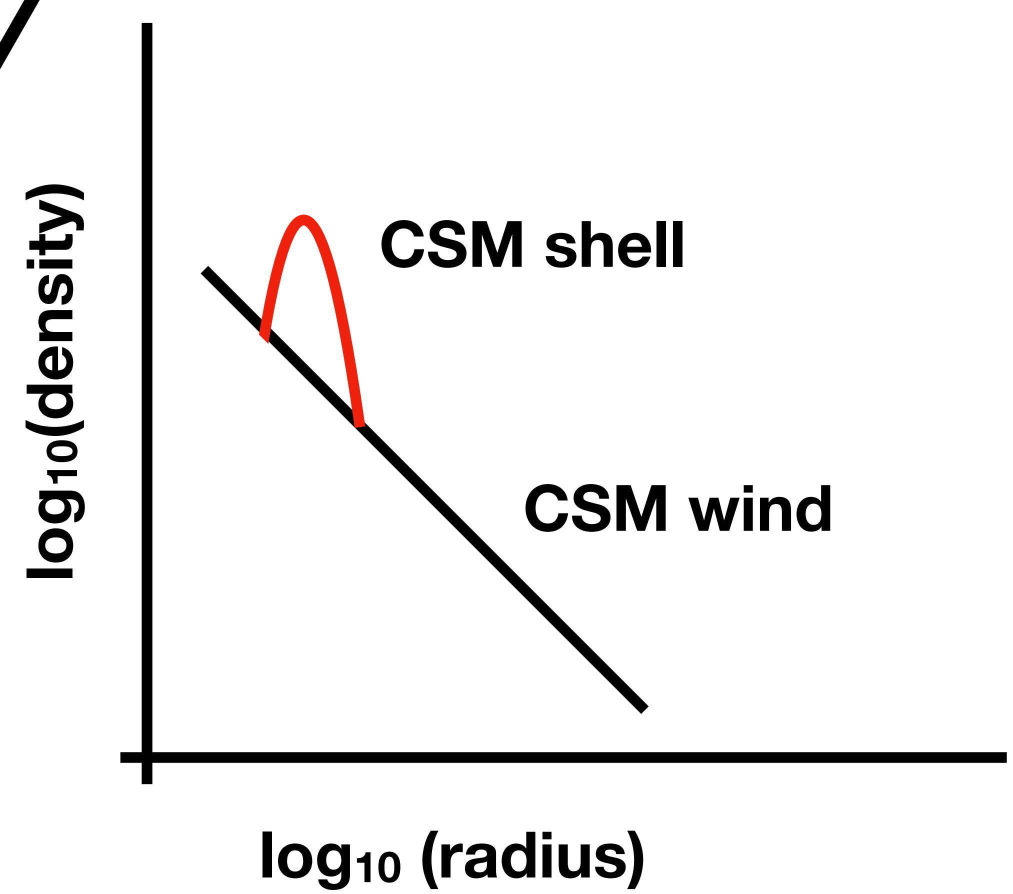


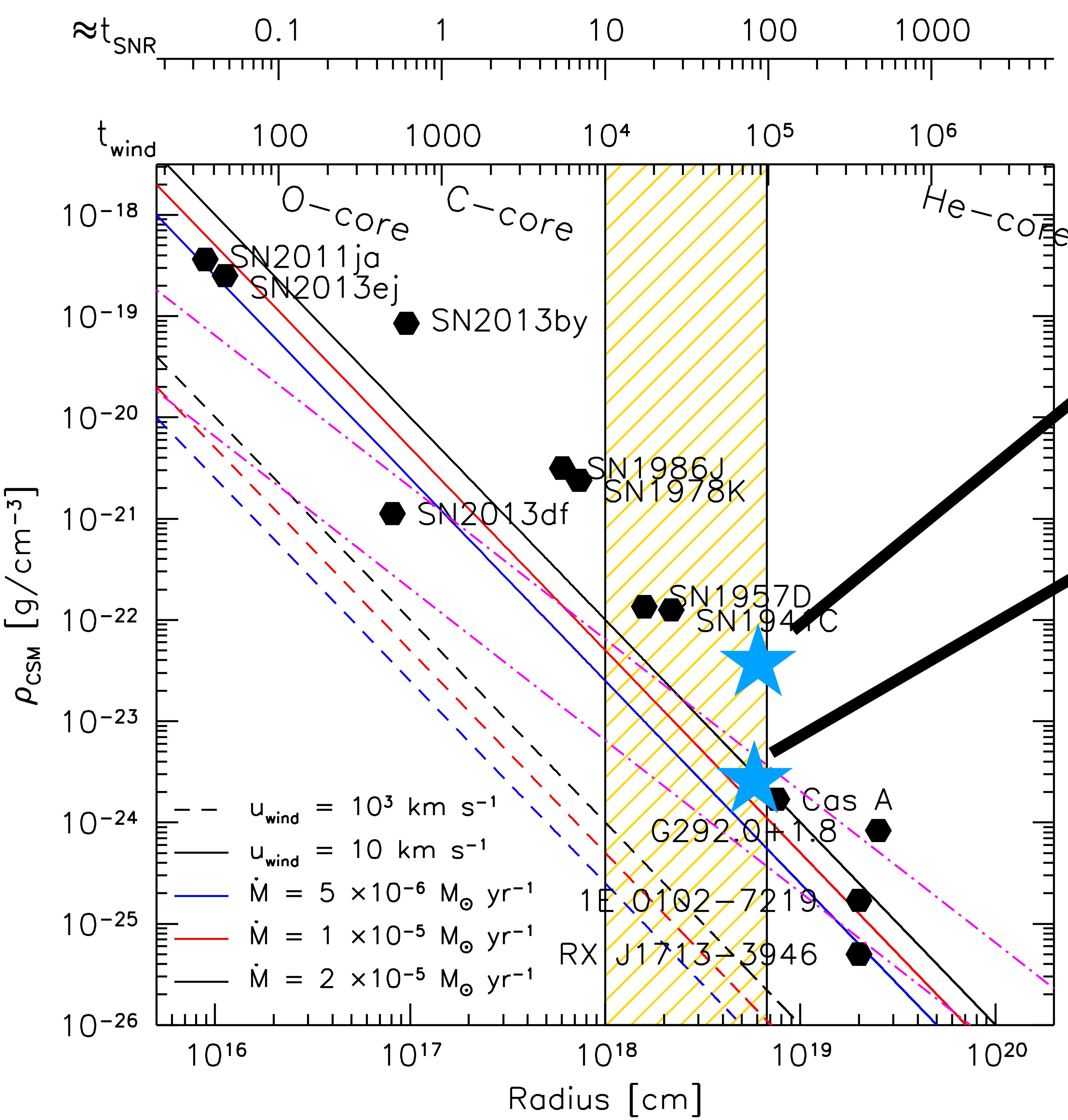
Pie in the Sky: Extragalactic SNR

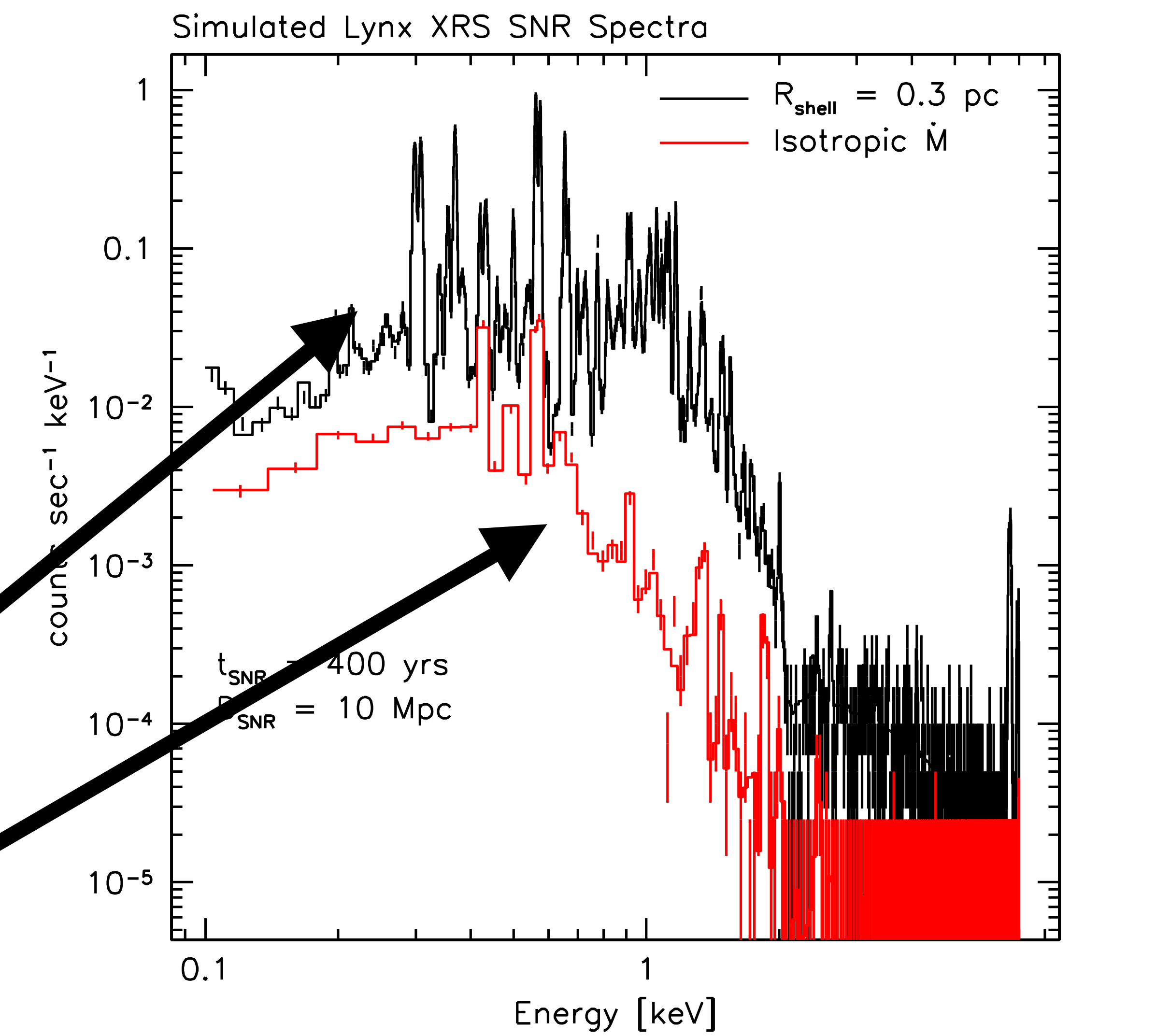
- SNR surveys out to D = 10 Mpc
- SN interaction with CSM affects SNR, centuries later
  - mass loss as a function of host galaxy metallicity can be studied



$F_x \sim 10^{17}$ erg/cm^2/s







Models derived from Patnaude et al. (2017). $15M_{sun}$ progenitor with two different mass loss scenarios

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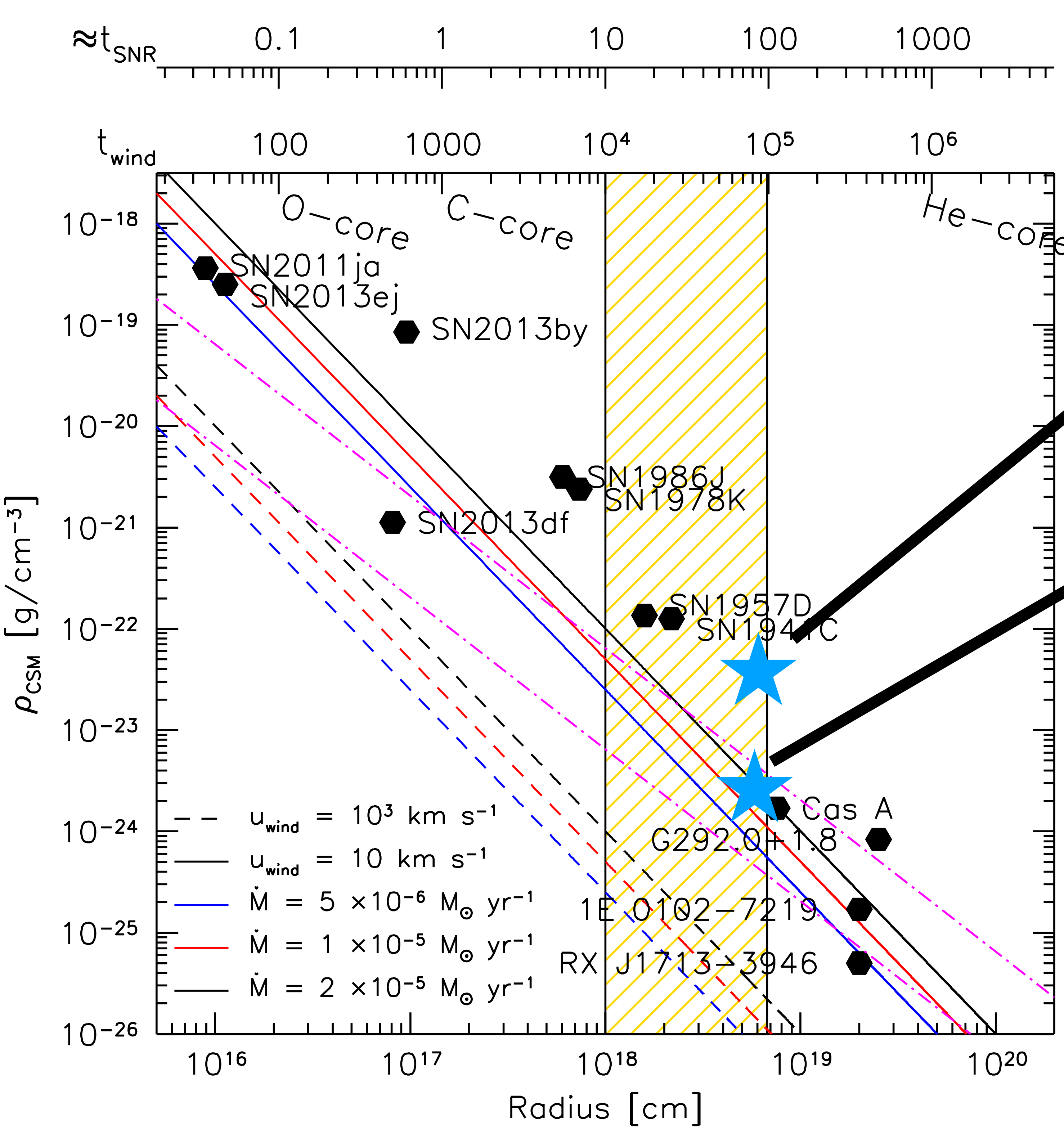

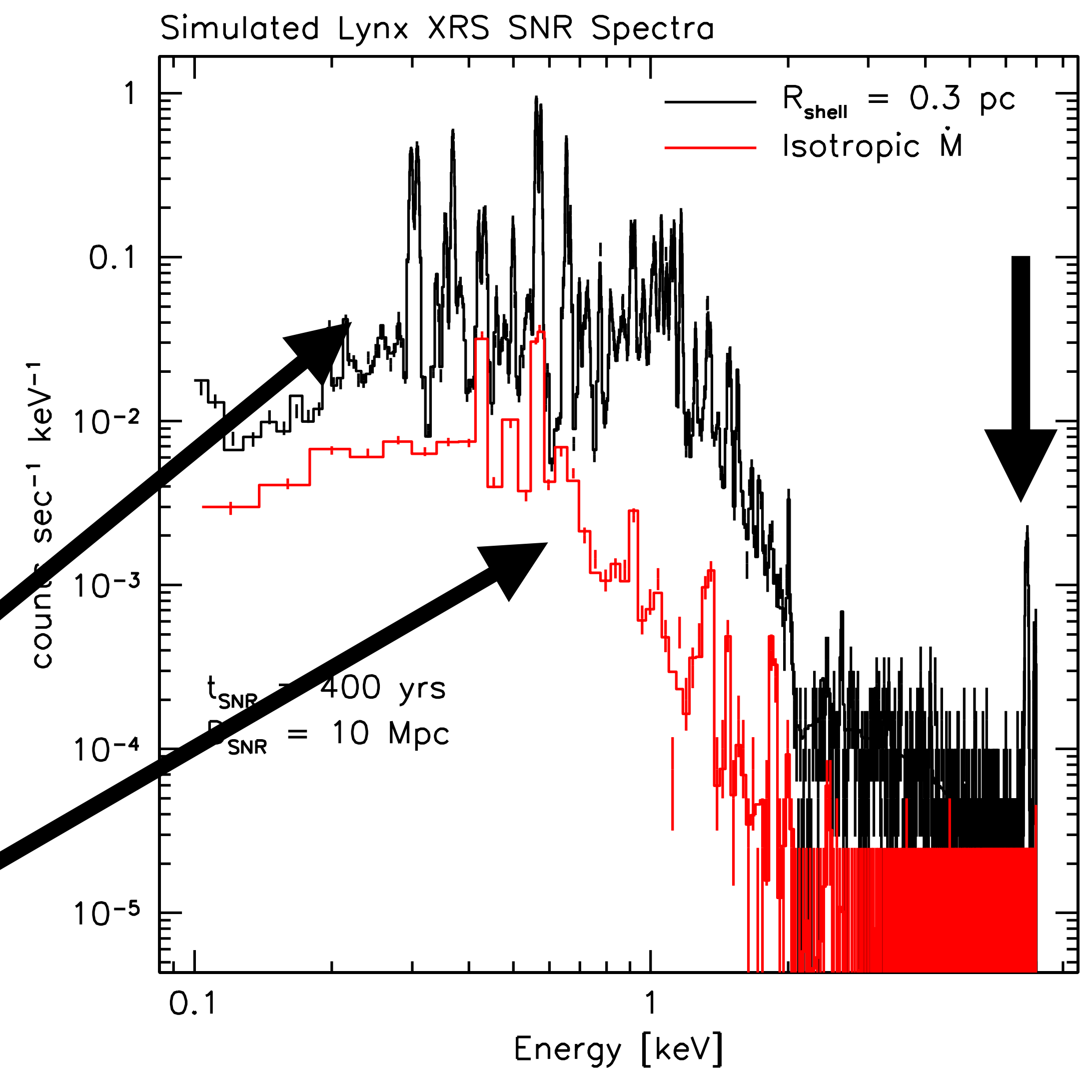

Differences in the X-ray spectrum can provide clues as to the mass loss history of the progenitor

Conclusions

- Lynx will probe the mass loss history of SNe:
    - observations performed now with Chandra will sample progenitor evolution ~ 100 - 1000 years before CC
    - followup Lynx observations of ~ 100s of SNe will paint a picture of mass loss at earlier times (currently not well sampled)
- High resolution X-ray spectroscopy can discern mass loss events ~ 10^3 - 10^4 years before core collapse
- Lynx will allow for surveys of young and middle-aged SNR out to distances of ~ 10 Mpc
    - probe influence of environment metallicity on SN and progenitor evolution