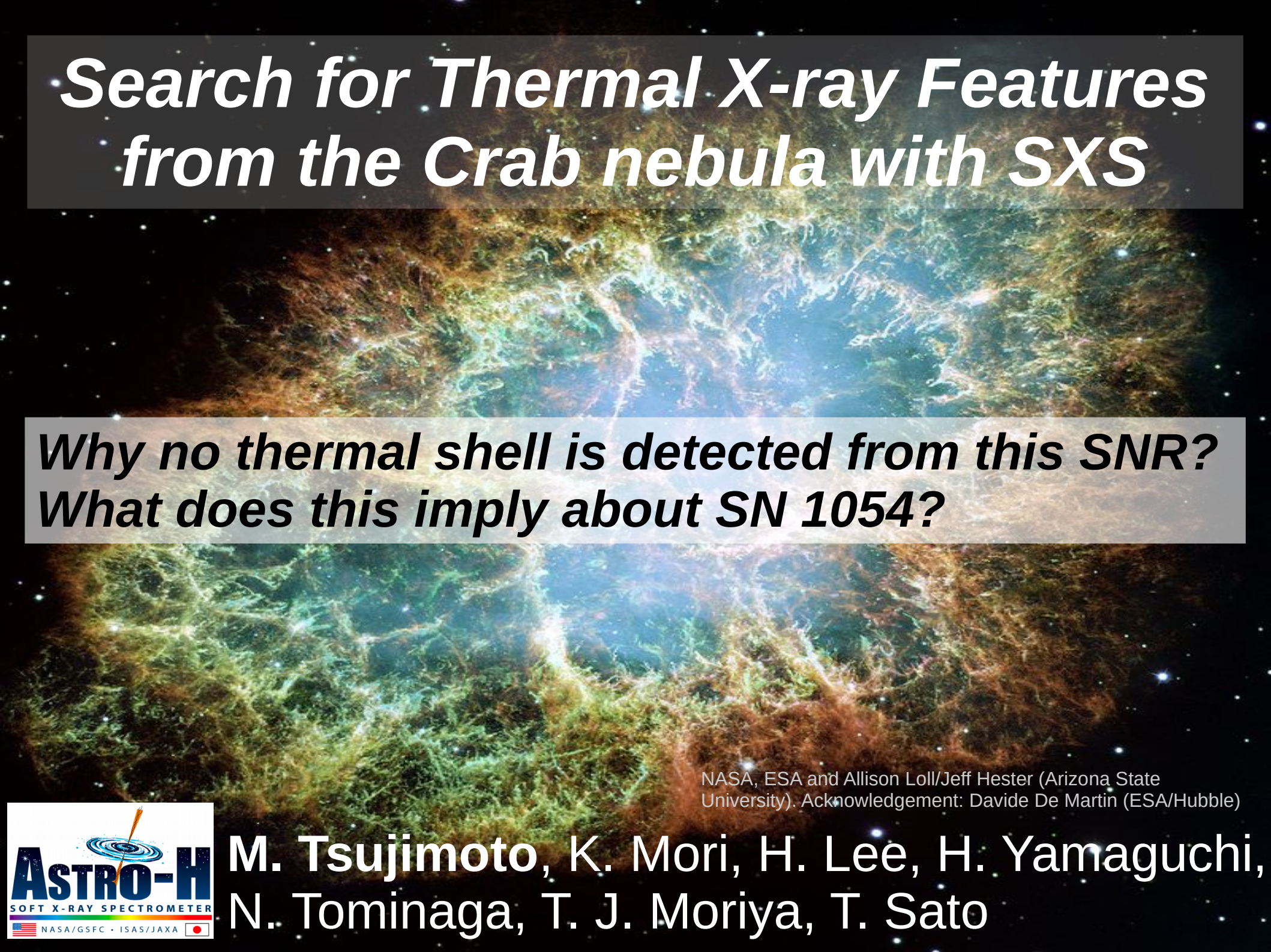
Search for Thermal X-ray Features from the Crab nebula with SXS

Why no thermal shell is detected from this SNR?
What does this imply about SN 1054?

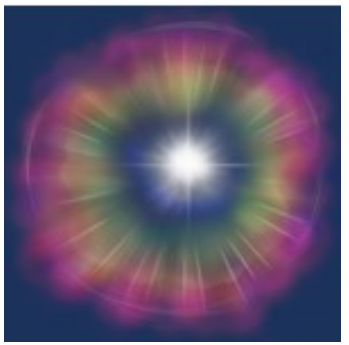
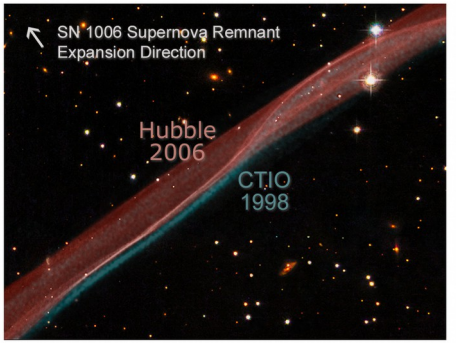


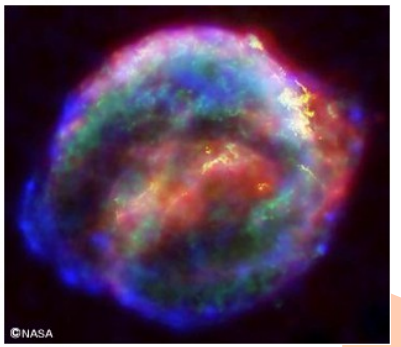
NASA, ESA and Allison Loll/Jeff Hester (Arizona State University). Acknowledgement: Davide De Martin (ESA/Hubble)

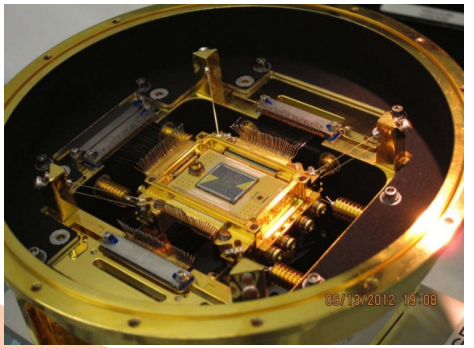
M. Tsujimoto, K. Mori, H. Lee, H. Yamaguchi, N. Tominaga, T. J. Moriya, T. Sato

Crab shell

- ~400 SNRs by X/γ-rays. (Ferrand & Safi-Harb 12)
- ~10% lack shells. ID'ed by PWN. Crab is one.
- Why no shells? A key to understand SNR variety.
- From SN explosion to SNRs.

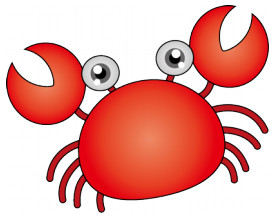








Progenitor **SN explosion** **SNR growth** **SNR emission** **Observation**

Tominaga, Moriya Lee Mori, Yamaguchi Tsujimoto, Sato



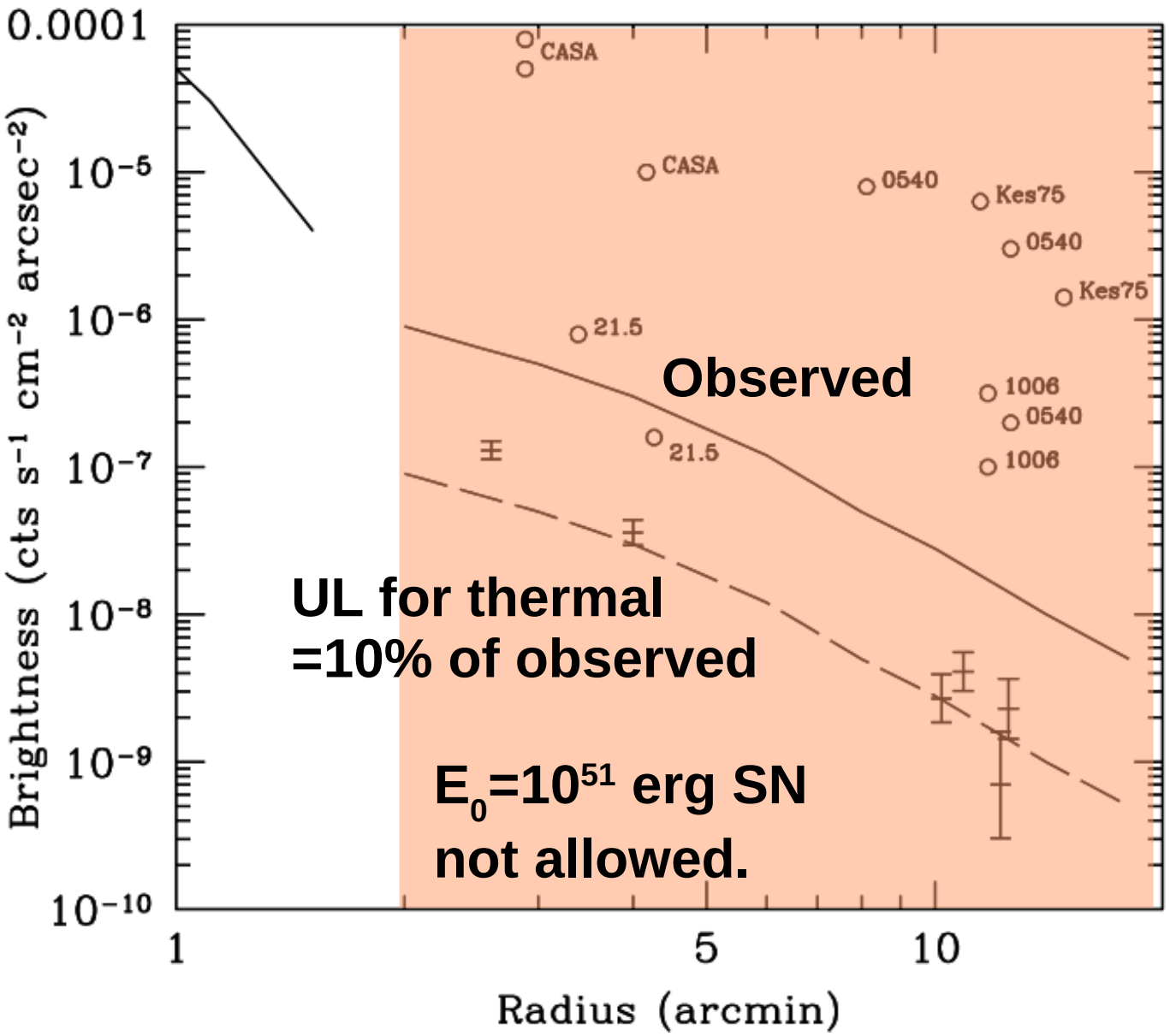
Crab is unusual as SNR

- Crab is a standard for X/γ-ray flux & time
  - Proved NS birth in SN (Baade & Zwicky 1934)
- When viewed as SNR, it has uncomfortably
  - Low visible mass: 4.6+/-1.8 Mo (Fesen+97)
  - Small kinetic energy $<10^{50}$ erg (Davidson+85)

    for a young Fe core-collapse SNR.
- Two ideas:
  - (1) Massive shell undetected (Chevalier77)
  - (2) Electron-capture SN w. $E_0 \sim 10^{50}$ erg (Nomoto+82)

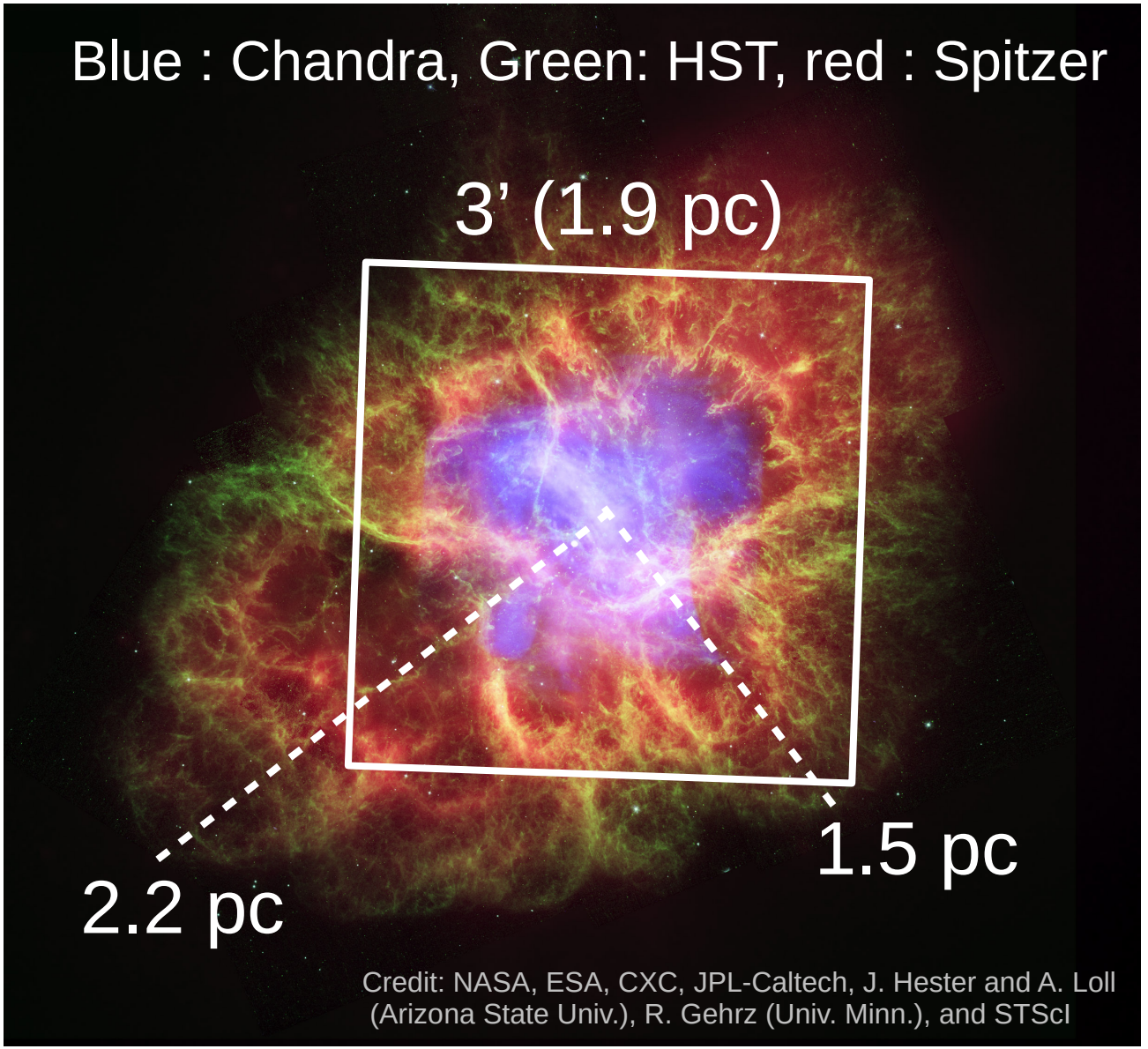
Search for undetected shell

- No shell in ou
  - Radio (Frail+
- Chandra give
- For EC possil
  - Use spectr
- Compare with



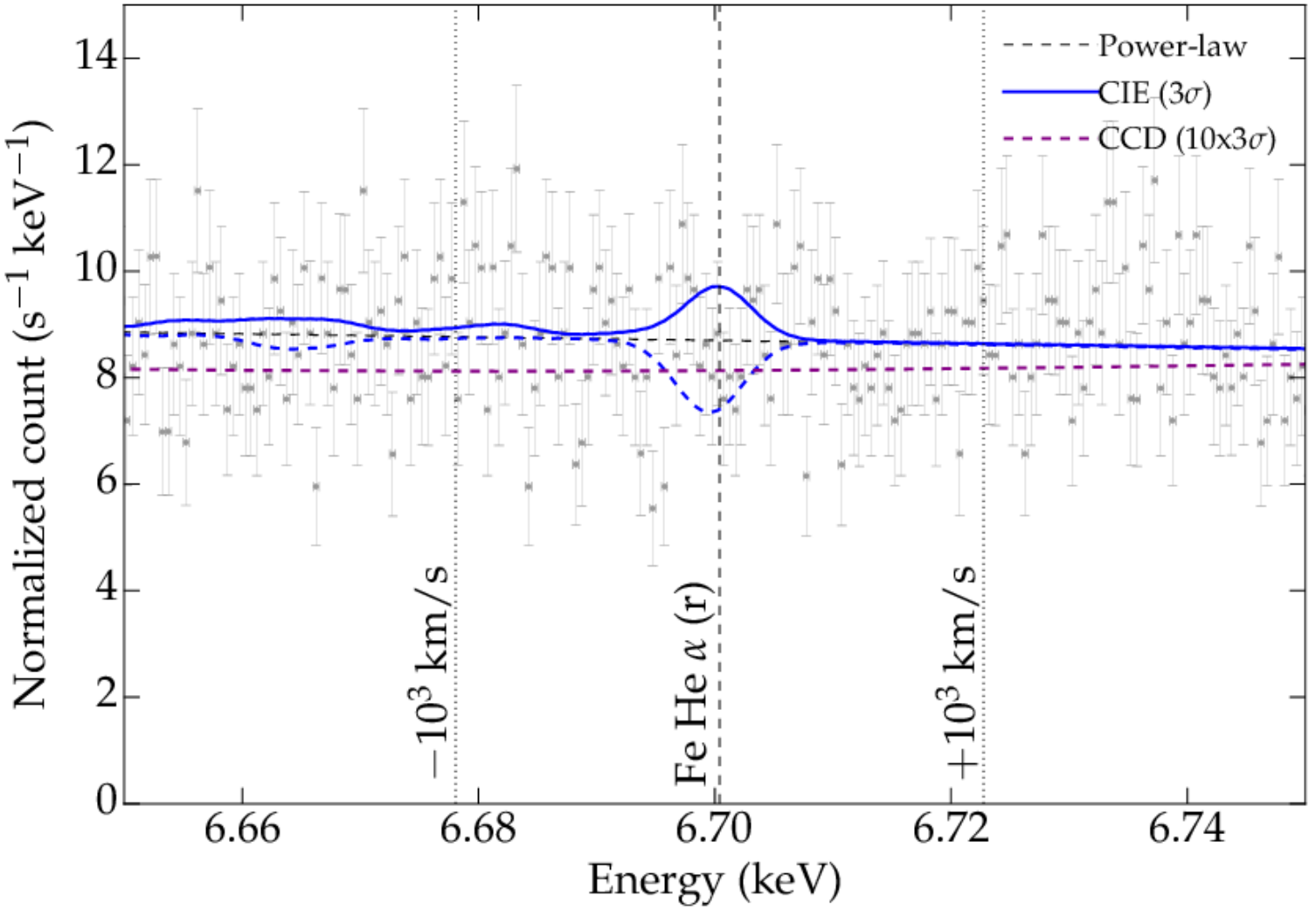
Observation

- Last data. Cal.
- t_{exp} = 9.7 ks
- *E* > 2 keV & *Fx*~0.3 “Crab” w. GV.
- ΔE=4.9 eV for extended src.
- High obs eff ~ 71% (c.f., 5% for XIS).



Plasma search (1) Method

- Upon local best-fit cont, thermal model added.

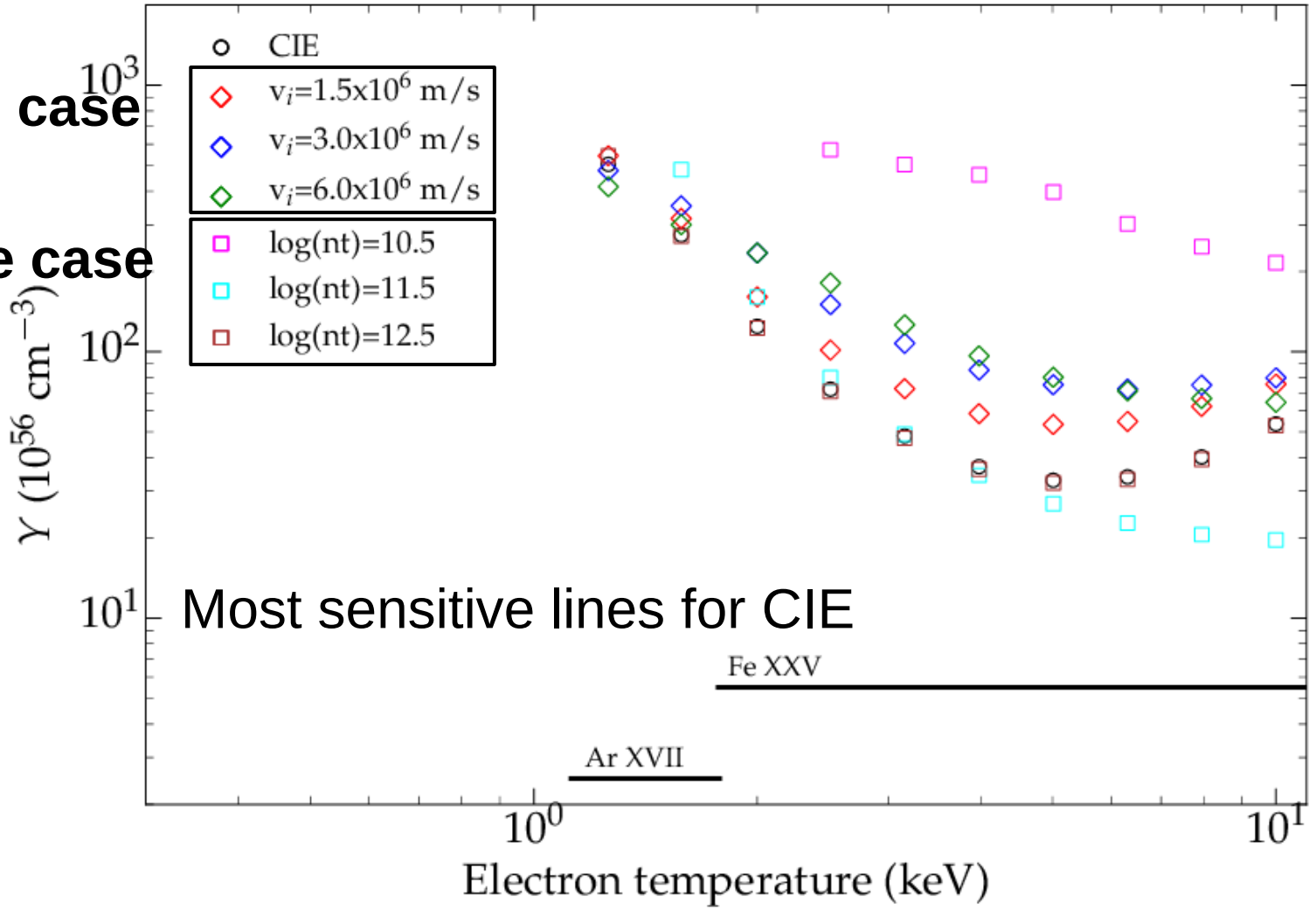


Plasma search (2) Result

- 3σ UL of $Y\ (=n_e^2 V)$ for CIE & non-CIE emission.

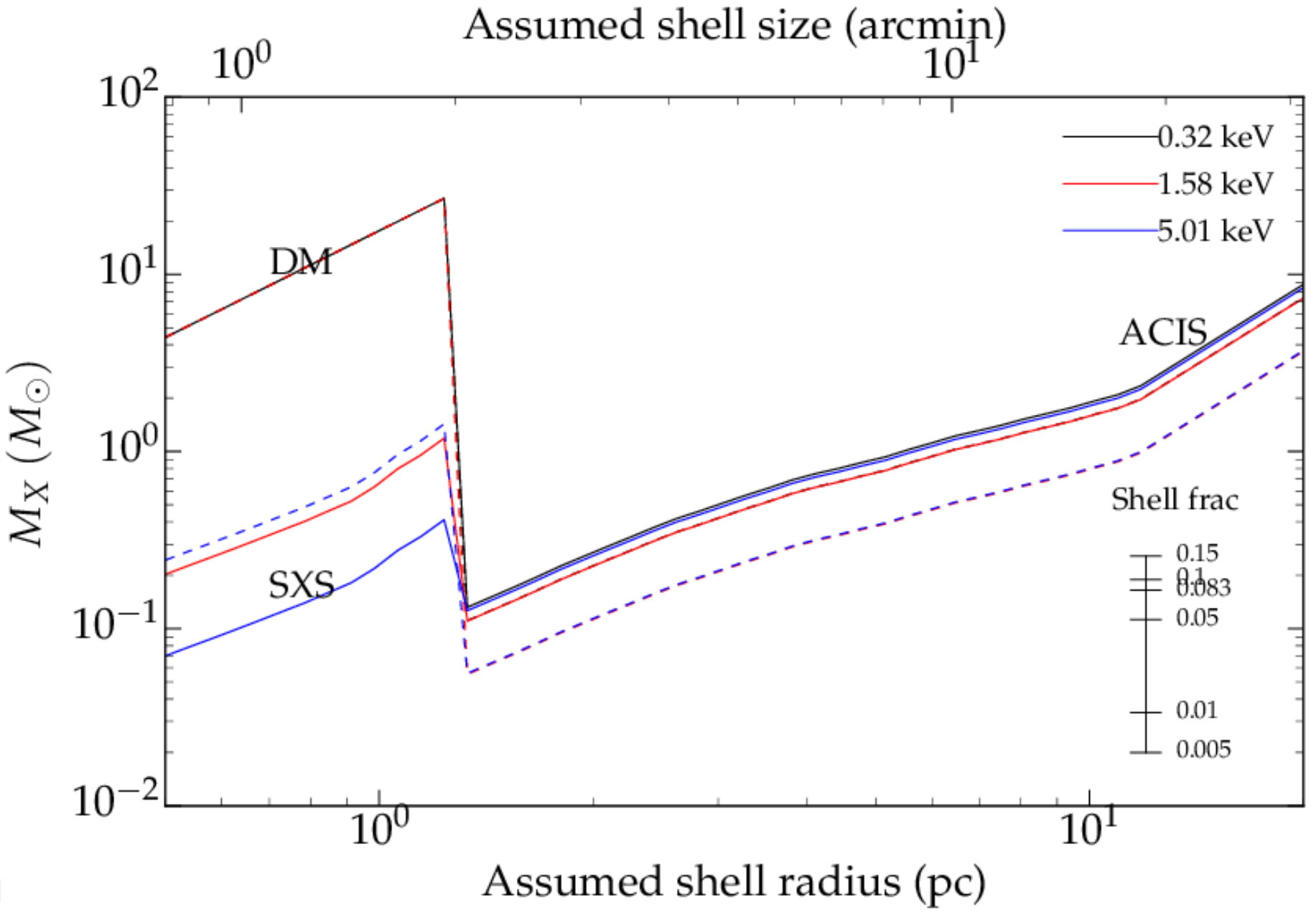
Ti!=Te case

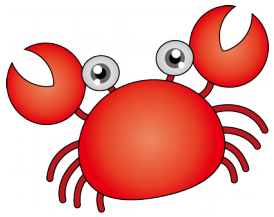
Tz!=Te case



Limit on plasma mass

-



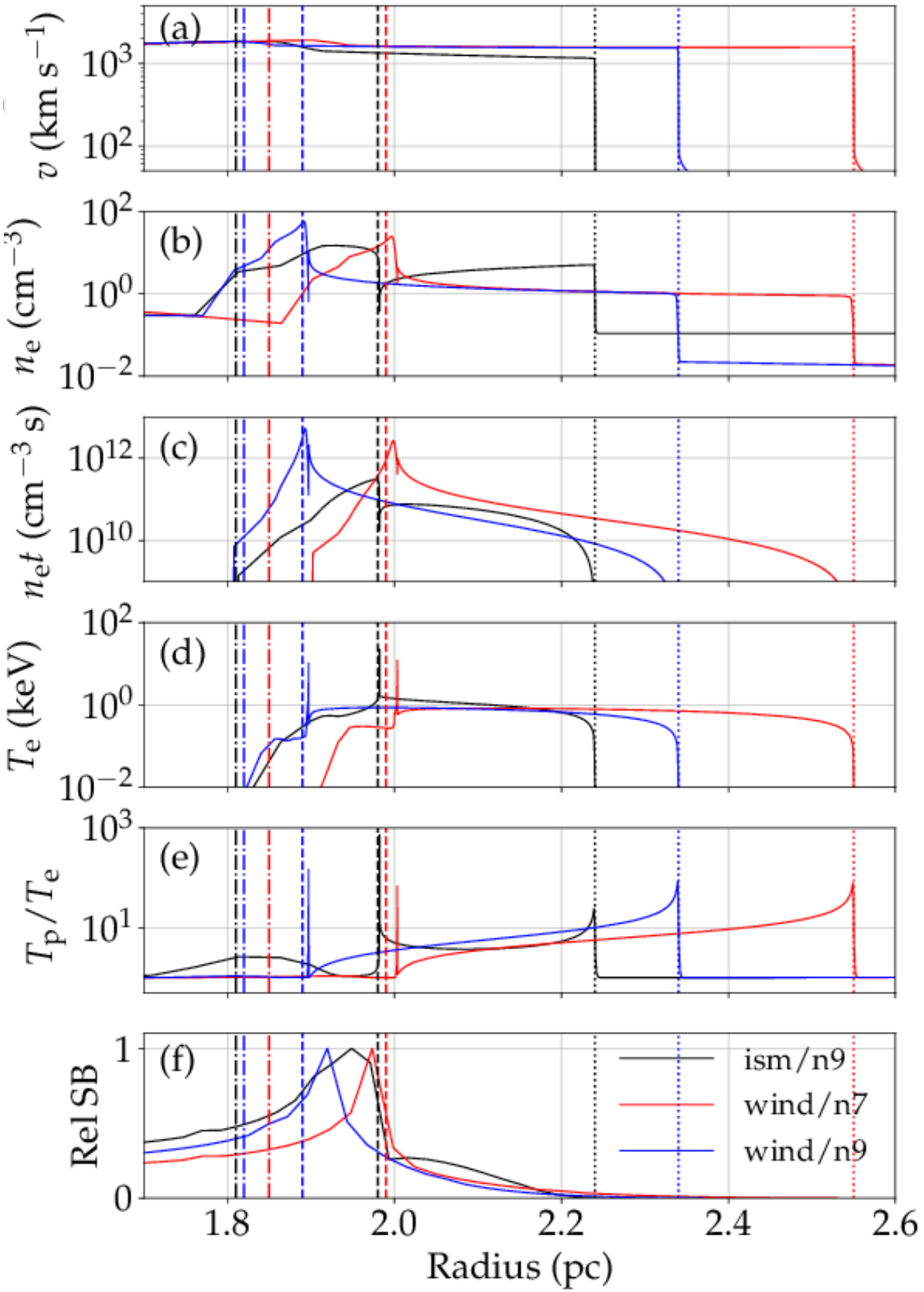


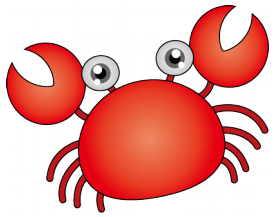
HD simulation (1) Setup

- CR-Hydro-NEI code (Ellison+07, Lee+14).
  - Time-dependent. NEI. 1D. Calculated to 10^3 yrs.

Parameters are from Patnaude+15, Moriya+14, Fransson+96, Crowther07.		SN explosion	
		(a) Fe core E_0=1.2x10^{51} erg M_{ej}=12.2 Mo	(b) EC E_0=0.15x10^{51} erg M_{ej}=4.4 Mo
SN env	(1) ISM n_0=0.1 cm^{-3}	**Fe-I**	**EC-I**
	(2) Wind $\dot{n}=M/4\pi r^2 v_{wind}$ (M=10^{-5} Mo/yr, v_{wind}=20 km/s)	**Fe-w**	**EC-w**

HD lt


(a)
v (km s^{-1})
10^3
10^2
(b)
n_e (cm^{-3})
10^2
10^0
10^{-2}
(c)
$n_e t$ (cm^{-3} s)
10^{12}
10^{10}
(d)
T_e (keV)
10^2
10^0
10^{-2}
(e)
T_p / T_e
10^3
10^1
(f)
Rel SB
1
0
ism/n9
wind/n7
wind/n9
1.8
2.0
2.2
2.4
2.6
Radius (pc)

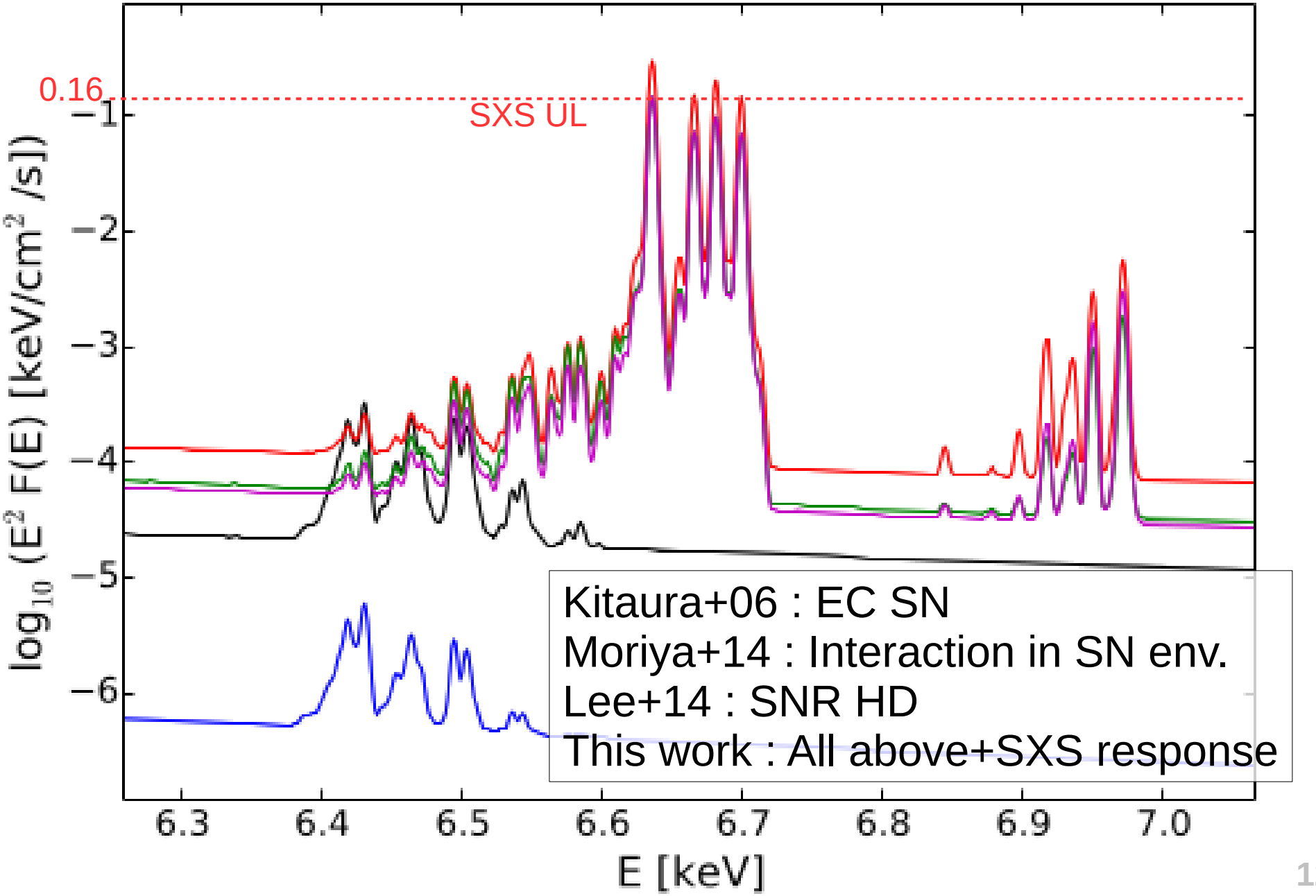


HD simulation (2) Result

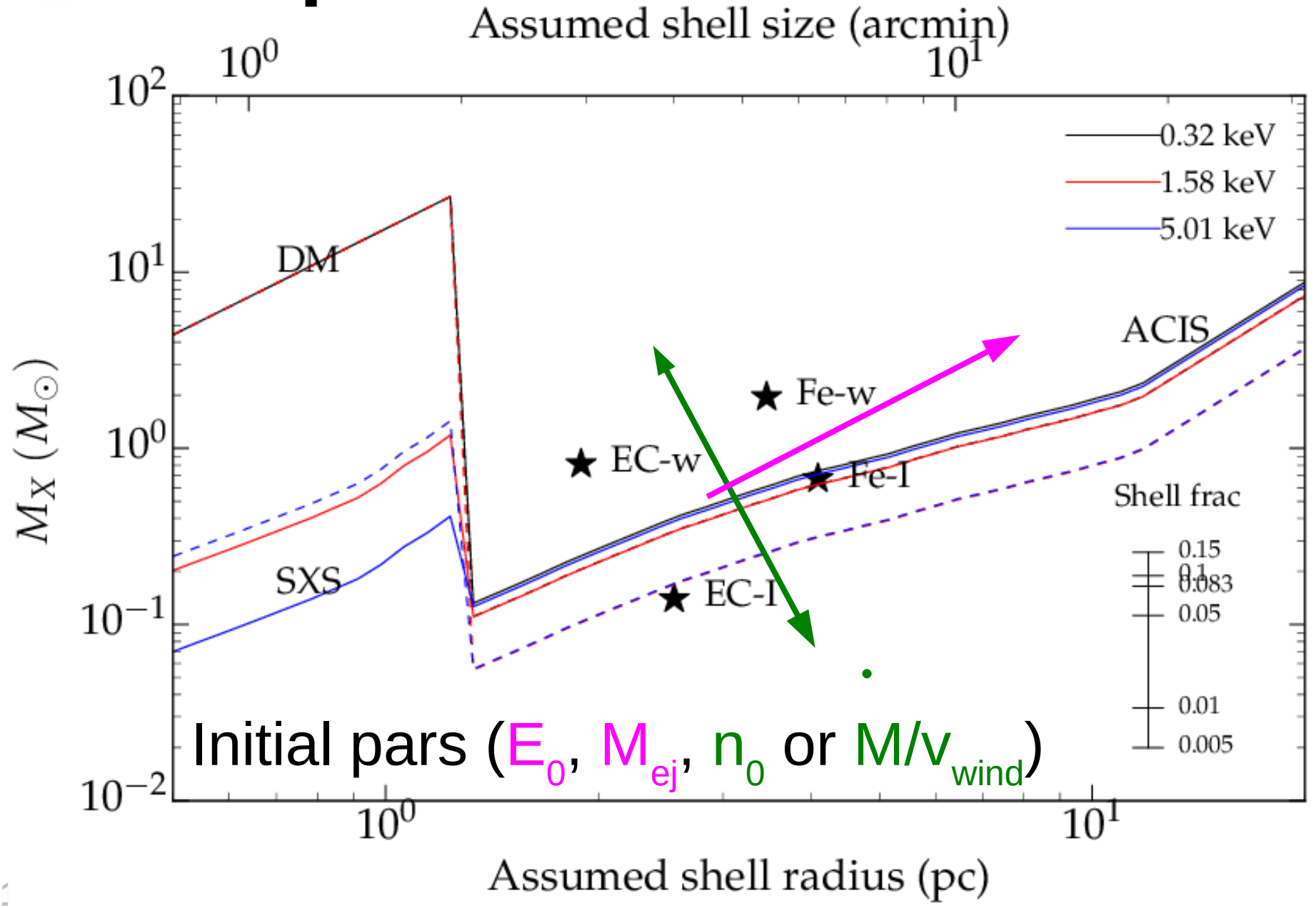
	Fe-l	Fe-w	EC-l	EC-w
R_{FS} (pc)	4.6	4.3	2.9	2.3
R_{CD} (pc)	4.1	3.5	2.6	1.9
R_{RS} (pc)	3.8	3.3	2.4	1.8
v_{FS} (km/s)	3.1e3	3.7e3	2.0e3	2.0e3
v_{RS} (km/s)	1.4e3	5.1e2	8.8e2	2.9e2
$\overline{T}_{\overline{Fe}}/\overline{T}_{\overline{e}}$ (keV)	130/1.0	50/0.51	57/0.71	62/0.74
$\overline{n}_{\overline{e}}\overline{t}$ (s cm^{-3})	0.21e11	9.9e11	0.22e11	11.8e11
$M_{unshocked}$ (Mo)	10	8.0	3.9	2.2

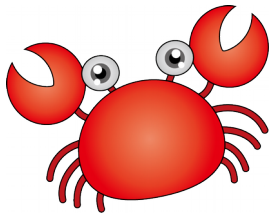
- Excellent agreement with analytical one (Truelove & McKee 99)
- Most ejecta unshocked for Fe models.

HD simulation (2) Result



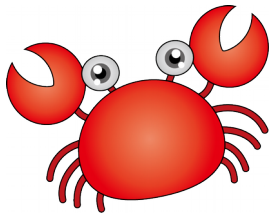
Comparison of obs & HD





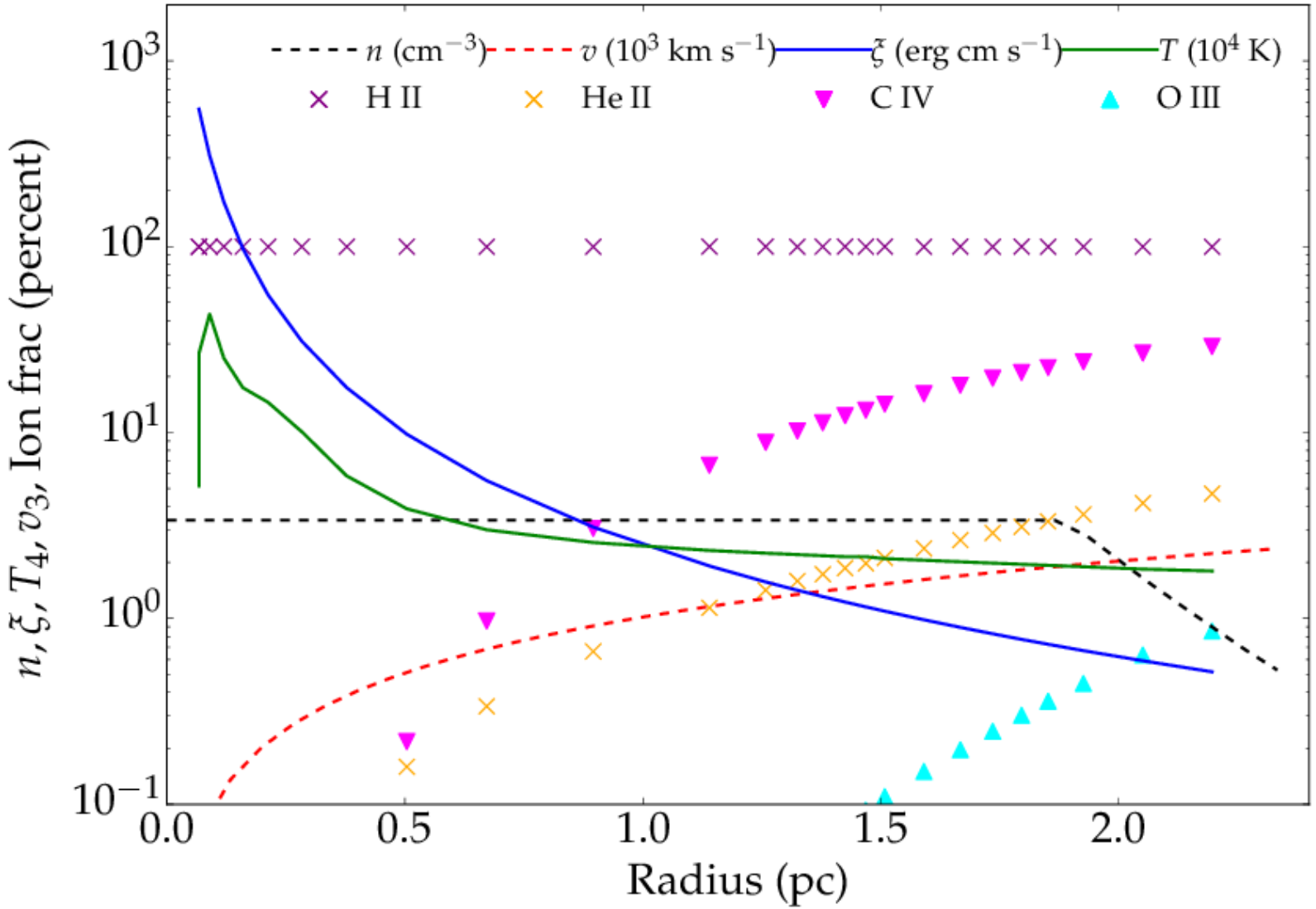
Constraints on SN1054

- Both Fe core and EC SN still allowed.
  - $M_{unshocked}$~8-10 M_o for Fe models.
  - R_{shell} by detection to distinguish Fe vs EC.
- Low density required.
  - [ISM] n_0<0.1 or 0.03 cm^{-3} (EC-I or Fe-I).
    - Consistent with Gal model & HI (Ferriere98, Wallace+94).
  - [wind] M/v_{wind}<10^{14} g cm^{-1} (EC- & Fe-w).
    - High val ($6x10^{18}$ g cm^{-1}; Smith 2013) disfavored.



How to see unshocked mass?

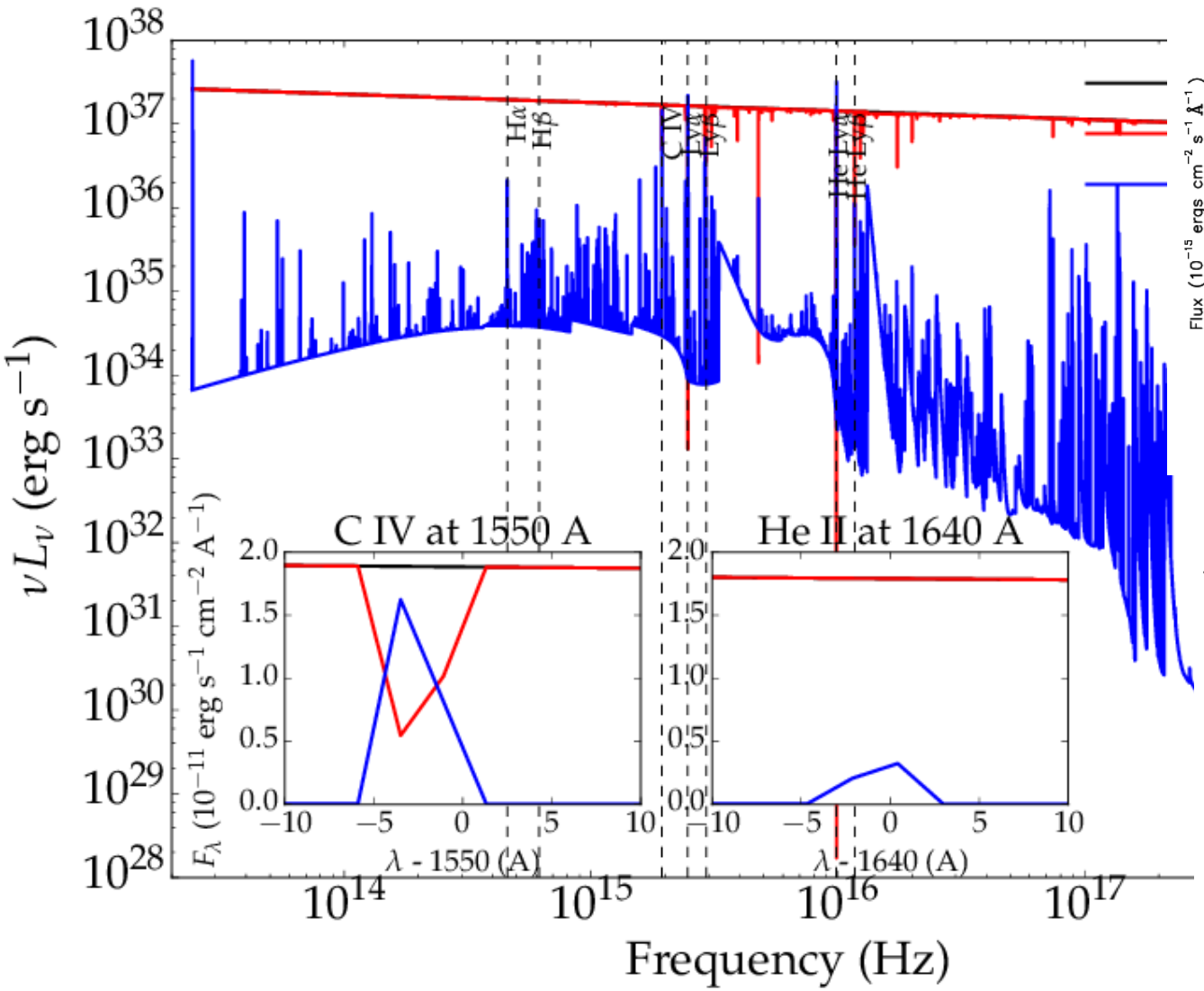
- Photo-ionization by synchrotron nebula.

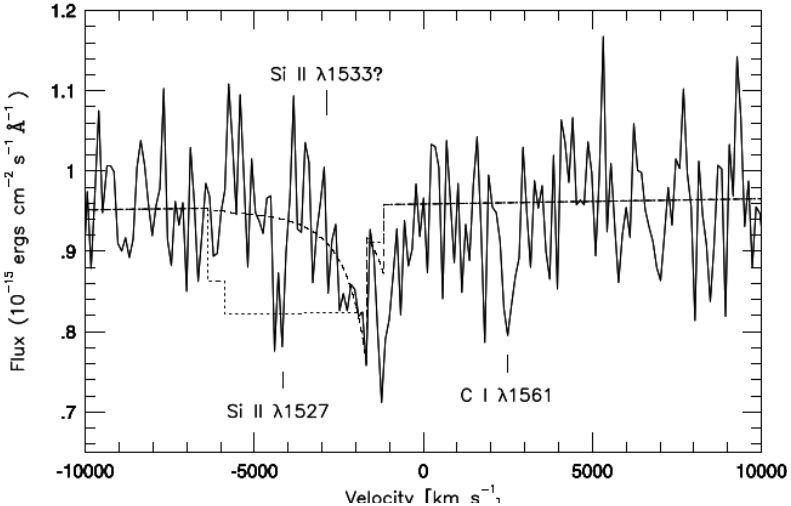


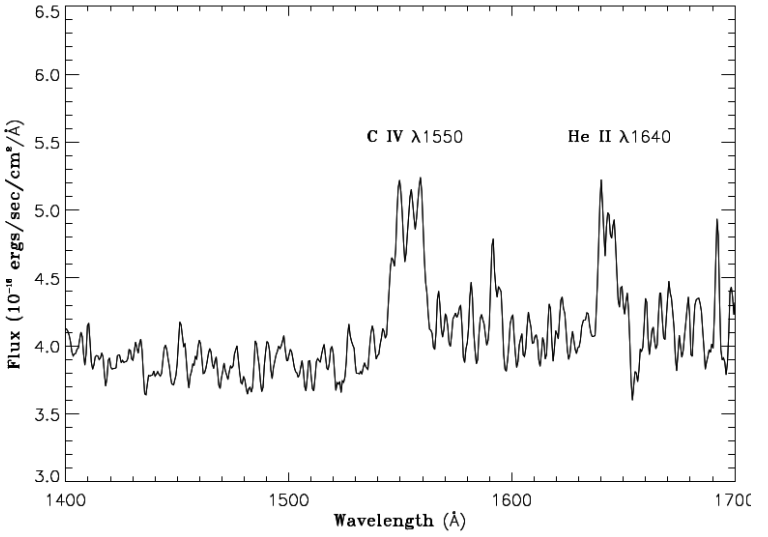
How to see unshocked mass?

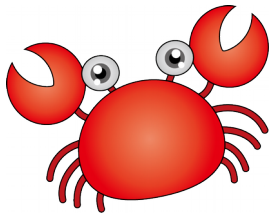
- Synthesis of photo-ionized plasma

Sollerman+ (2000)



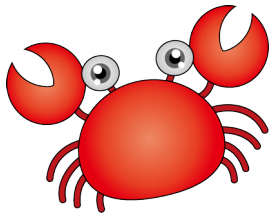






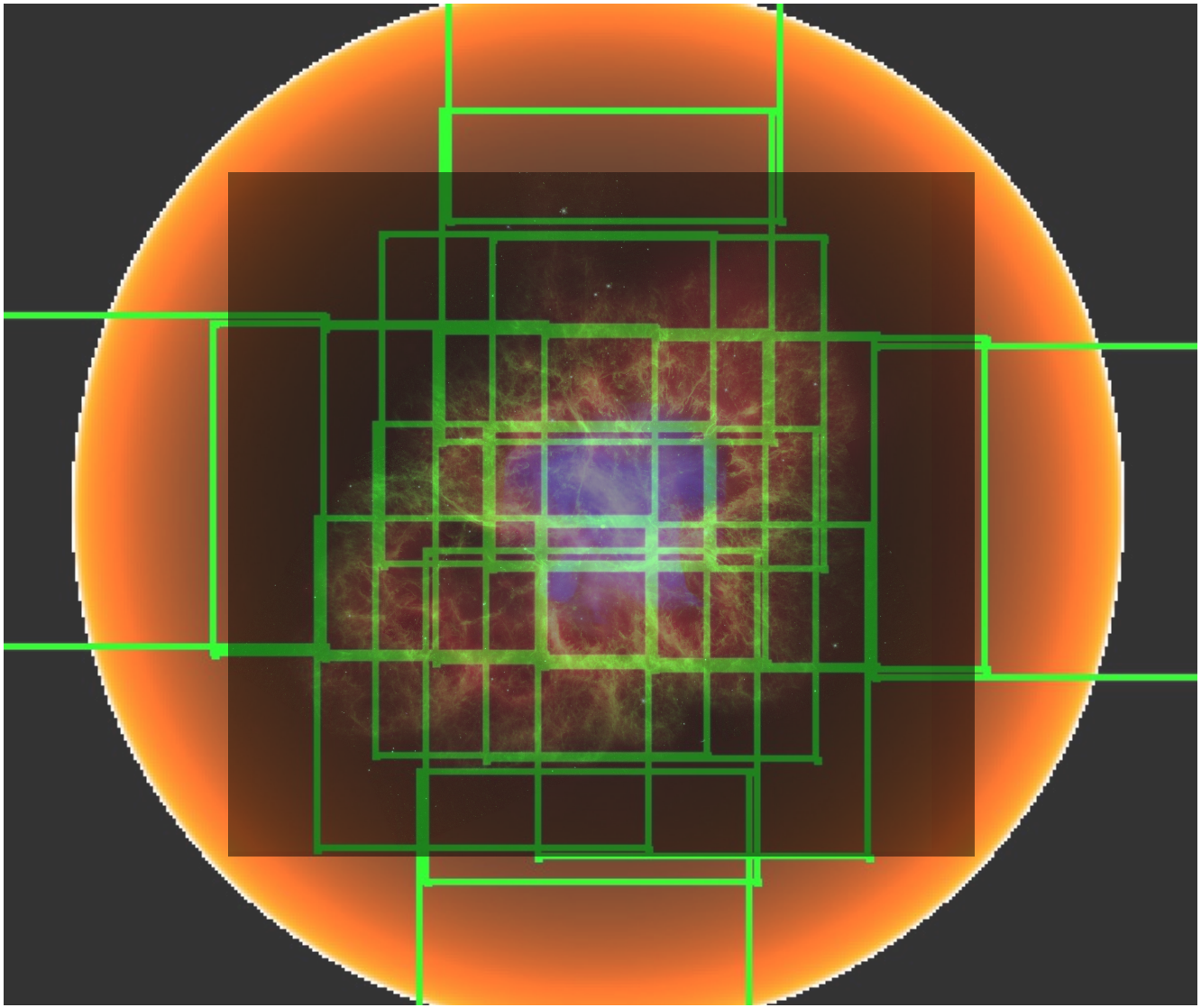
Conclusion

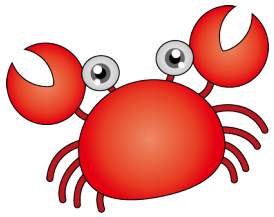
- Spectroscopic search of thermal plasma from Crab using SXS. No convincing features found.
- Other results re-evaluated for most stringent upper limit on Mx. SXS added new limits.
- Compared with HD simulation for
  - (a) Fe core, (b) electron capture SN
  - (1) ISM, (2) wind environment.
- Both Fe, EC SN models are still OK.
- The low density is strongly preferred.



What was next?

- Series of off-set pointing 8 hrs after the loss of S/C.
- GV open to allow access to low T.
- We should be back ASAP.





What are next?

- Goal: to understand the diversity of SNRs (including compact stars) in the context of SN.
- Tool: high-resolution X-ray spectroscopy. Rich information in dynamics and abundance.
- For Resolve, a path paved from ab-initio SN explosion calc to high-resolution spectra for EC channel.
- Advances expected in
  - SN exp calc in other channels (Fe core).
  - 3D NEI HD for SNR evolution.
  - Model generation & evolution of compact stars.