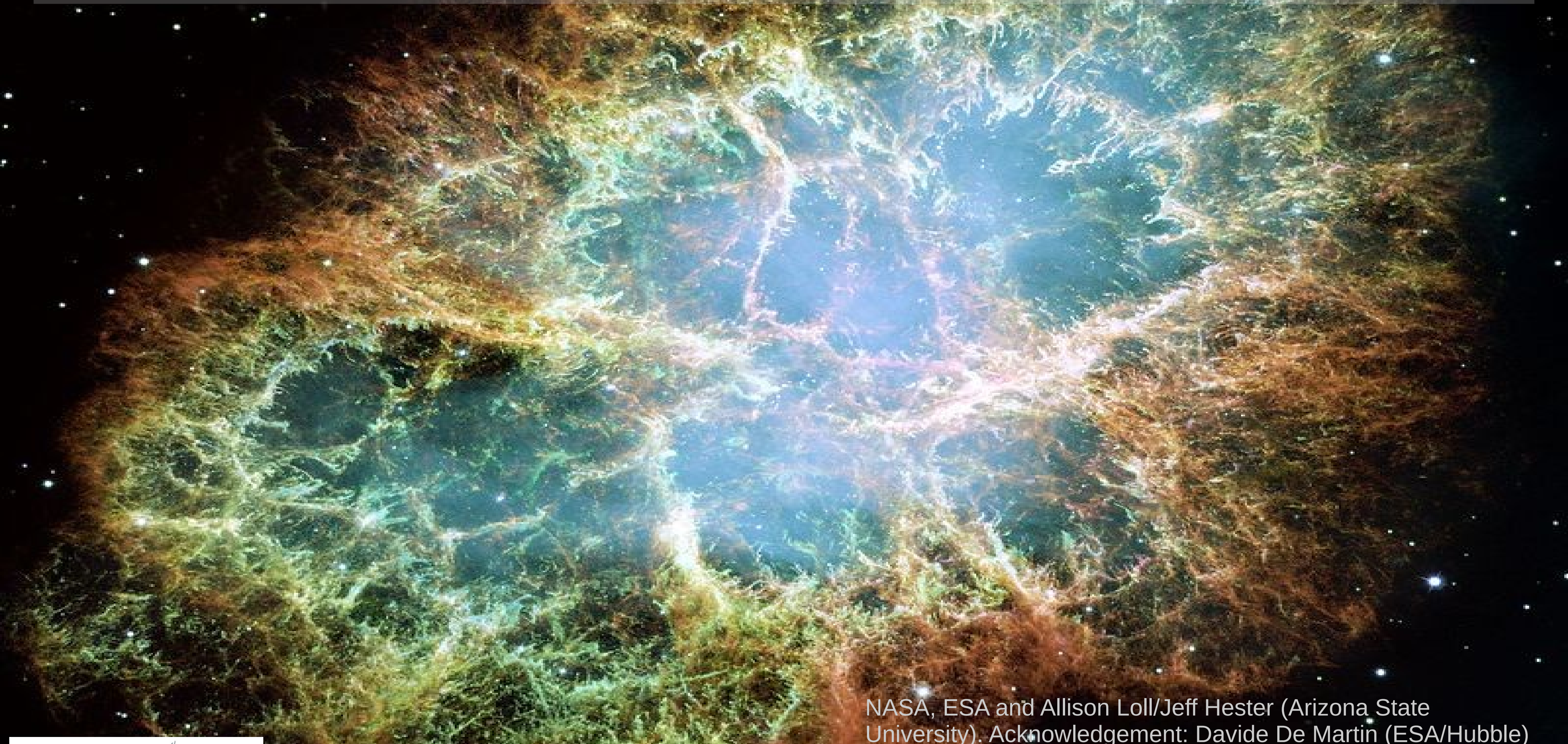
Search for Thermal X-ray Features from the Crab nebula with SXS



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

ASTRO-H
SOFT X-RAY SPECTROMETER
NASA/GSFC • ISAS/JAXA

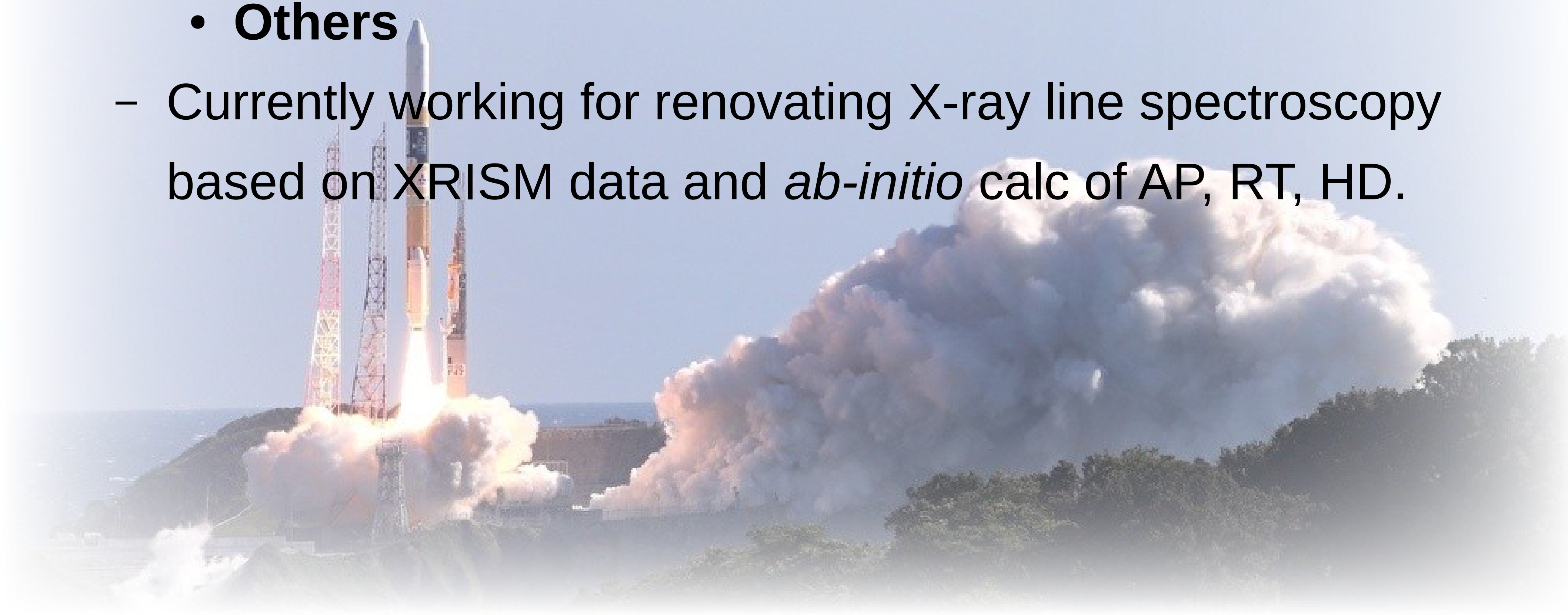
Self-introduction

- Space projects: committed to
    1. Suzaku/XIS for operation, calib (2008-2015)
    2. Astro-H/**SXS** for design, InT, operation, calib (2008-2017)
    3. XRISM/*Resolve* for InT, operation, calibration (2017-present)
    4. LiteBIRD for design, InT, calibration (2017-present)

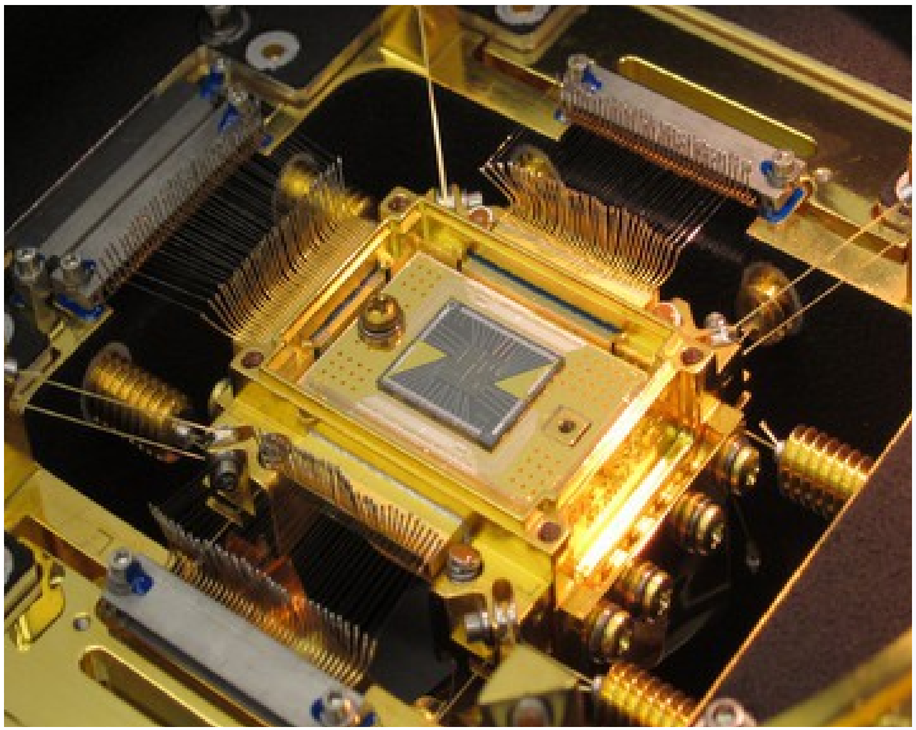
ASTRO-H SXS test, 2014-01-15 ©Tsukuba, JAXA/ISAS

Self-introduction

- Scientific interests:
  - Plasma phenomena in
    - Stellar flares
    - X-ray binaries (WD, NS, BH)
    - **Others**
  - Currently working for renovating X-ray line spectroscopy based on XRISM data and *ab-initio* calc of AP, RT, HD.

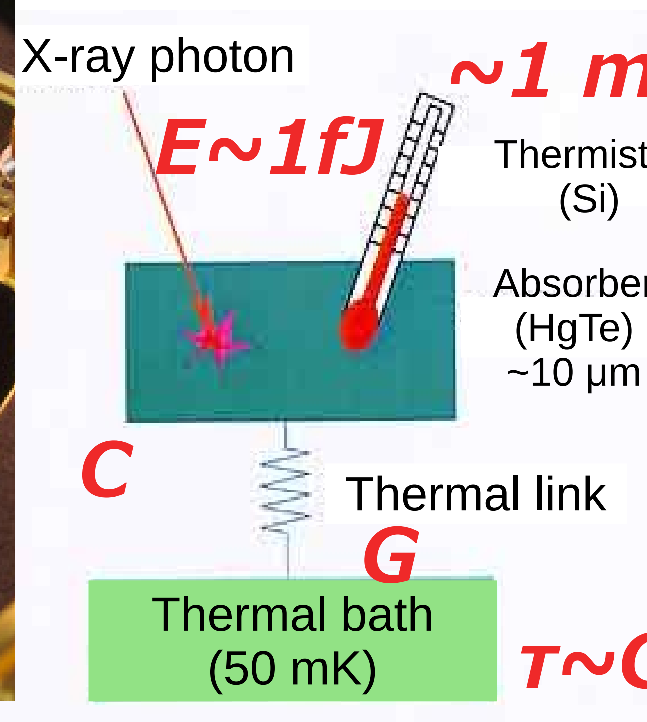


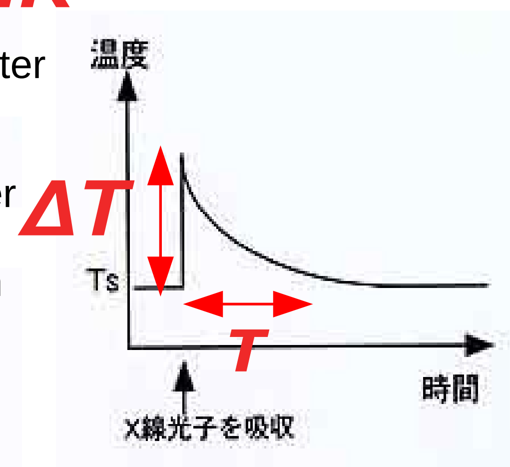
X-ray microcalorimetry



$\Delta T = E/C$

~ 1 mK

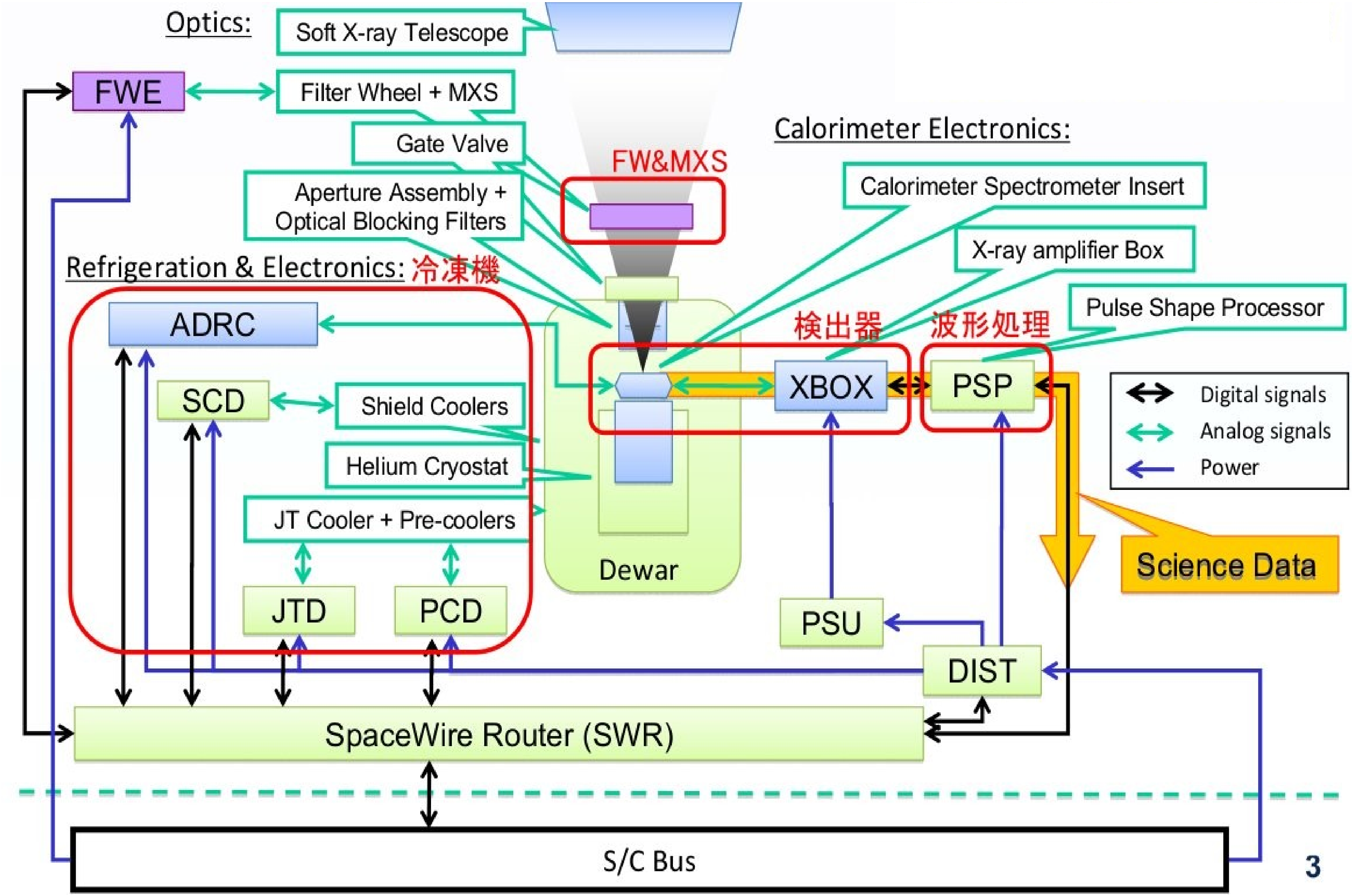


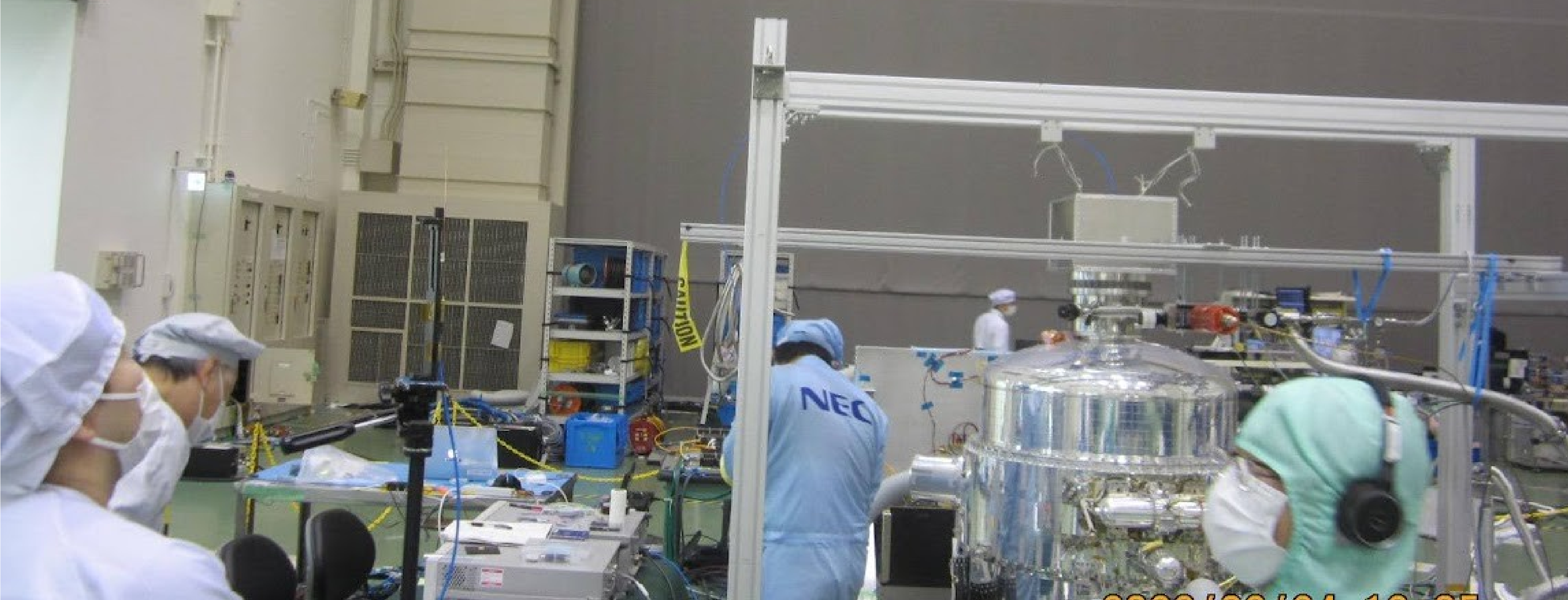


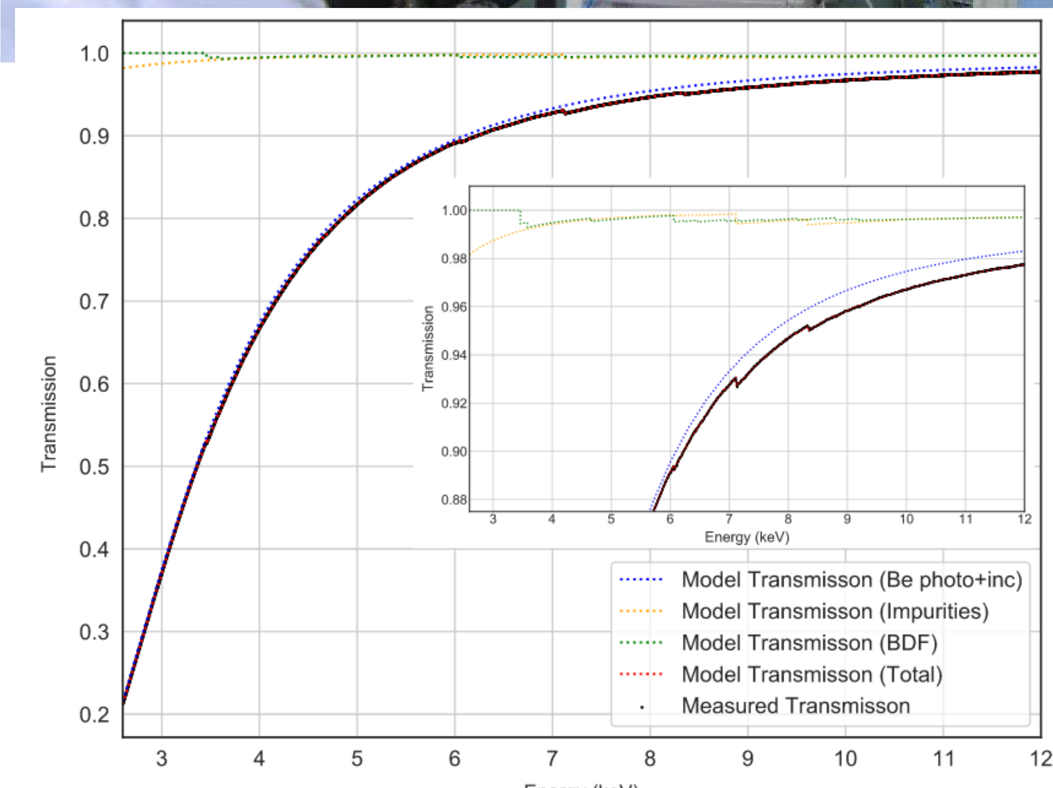
$\tau \sim G/C$

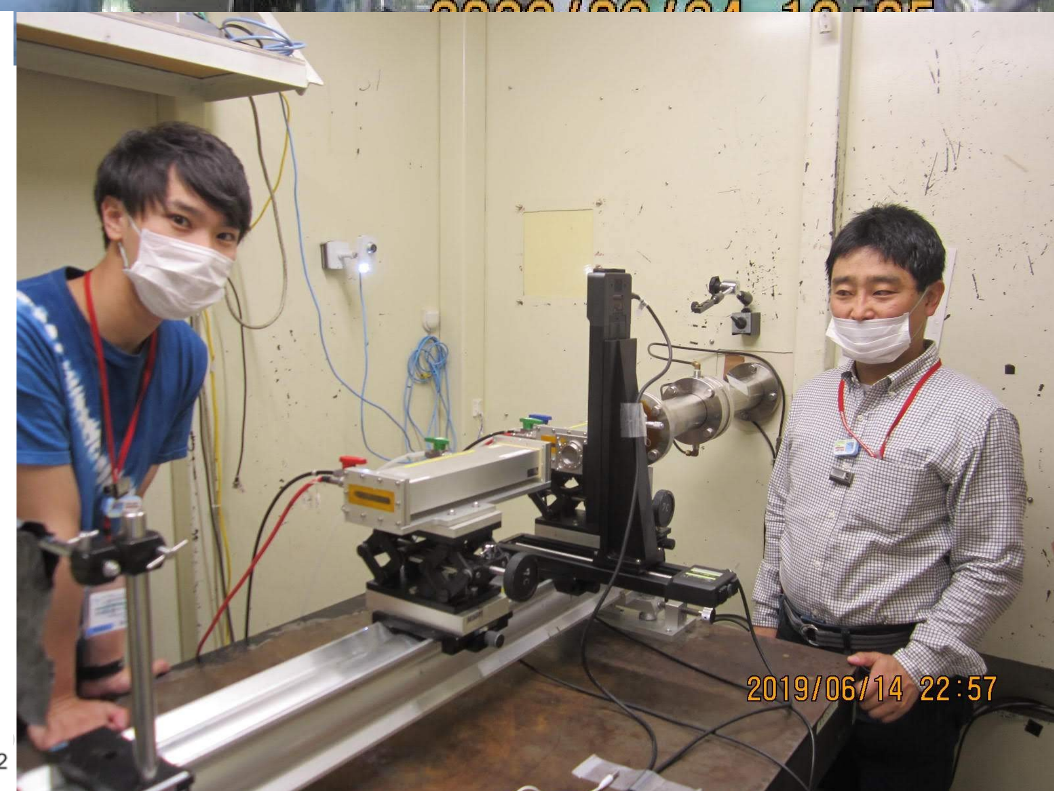
~ 3 ms

X-ray microcalorimetry

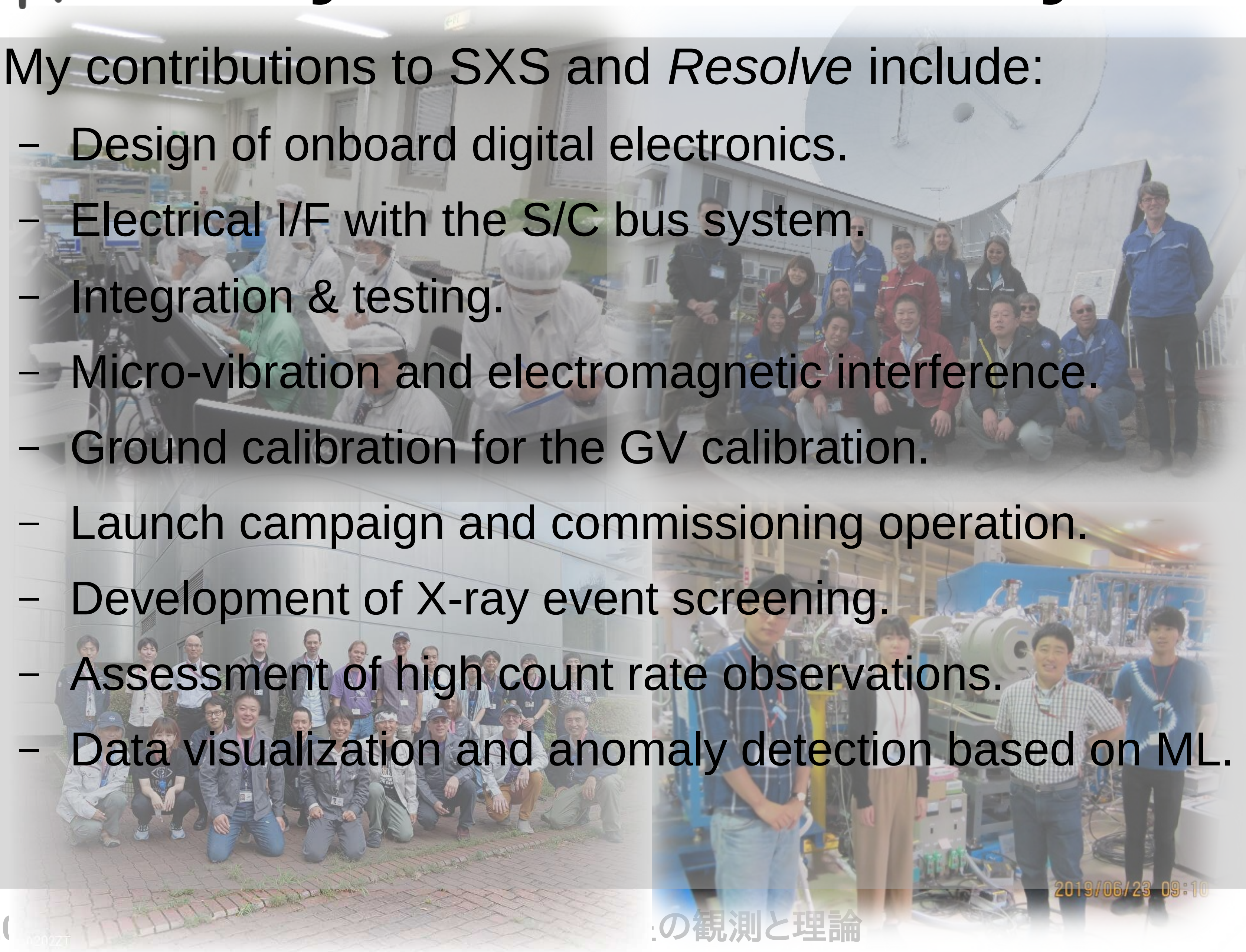



NEC


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Transmission
3
4
5
6
7
8
9
10
11
12
1.00
0.98
0.96
0.94
0.92
0.90
0.88
Transmission
Energy (keV)
Model Transmisson (Be photo+inc)
Model Transmisson (Impurities)
Model Transmisson (BDF)
Model Transmisson (Total)
Measured Transmisson


2019/06/14 22:57

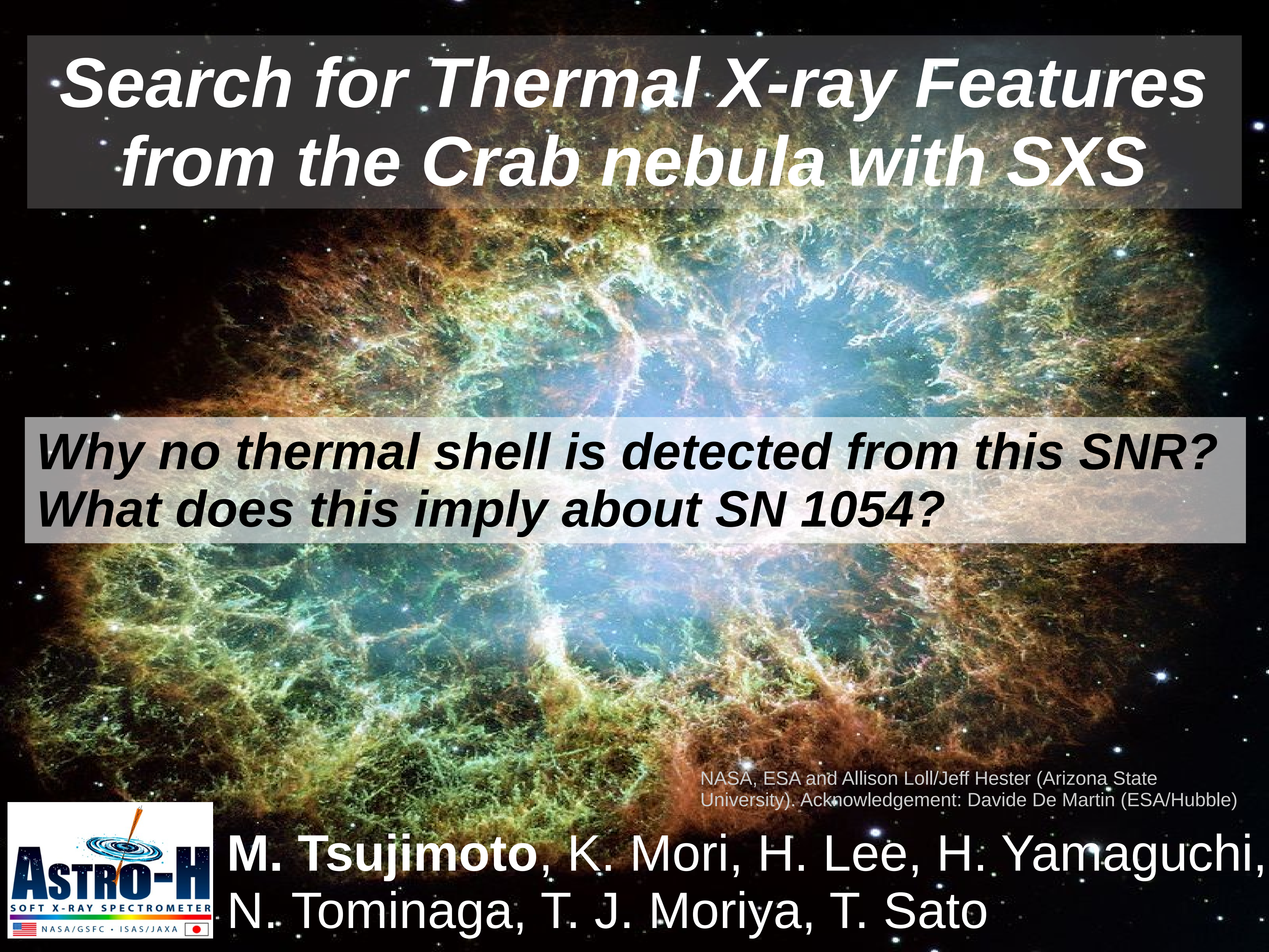
X-ray microcalorimetry



- My contributions to SXS and *Resolve* include:
  - Design of onboard digital electronics.
  - Electrical I/F with the S/C bus system.
  - Integration & testing.
  - Micro-vibration and electromagnetic interference.
  - Ground calibration for the GV calibration.
  - Launch campaign and commissioning operation.
  - Development of X-ray event screening.
  - Assessment of high count rate observations.
  - Data visualization and anomaly detection based on ML.

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?



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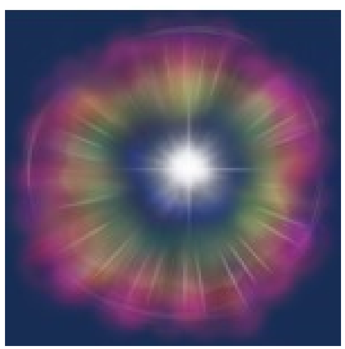
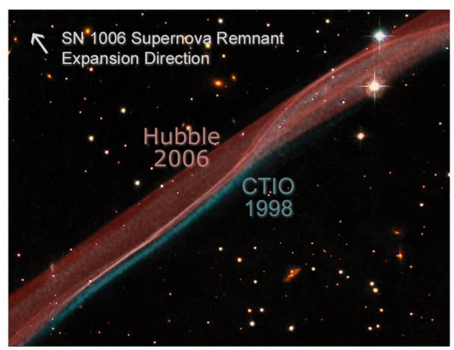
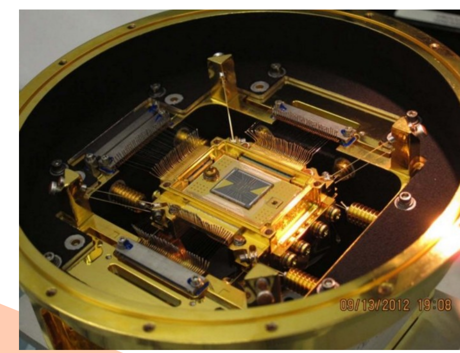
Crab shell

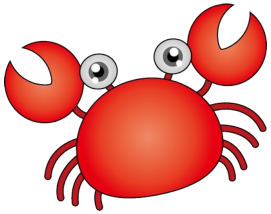
- ~400 SNRs by X/γ-rays. (Ferrand & Safi-Harb 12)
- ~10% lack shells. ID’ed by PWN. Crab is one.
- Why no shells? A key to understand SNR variety.
- From SN explosion to SNRs.



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

Tominaga, Moriya Lee Mori, Yamaguchi Tsujimoto, Sato

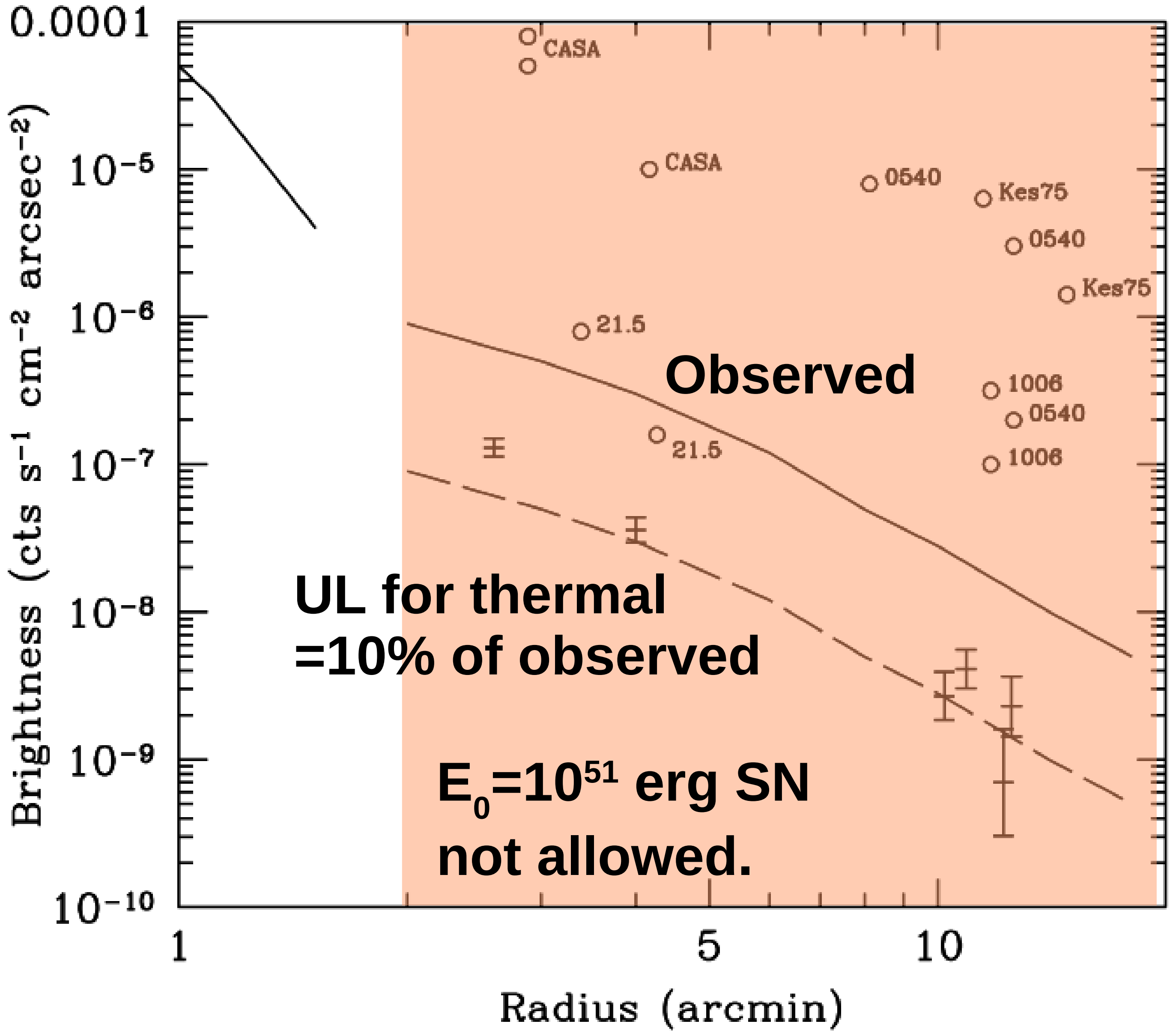


Crab is unusual as SNR

- 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_0~10^{50} erg (Nomoto+82)

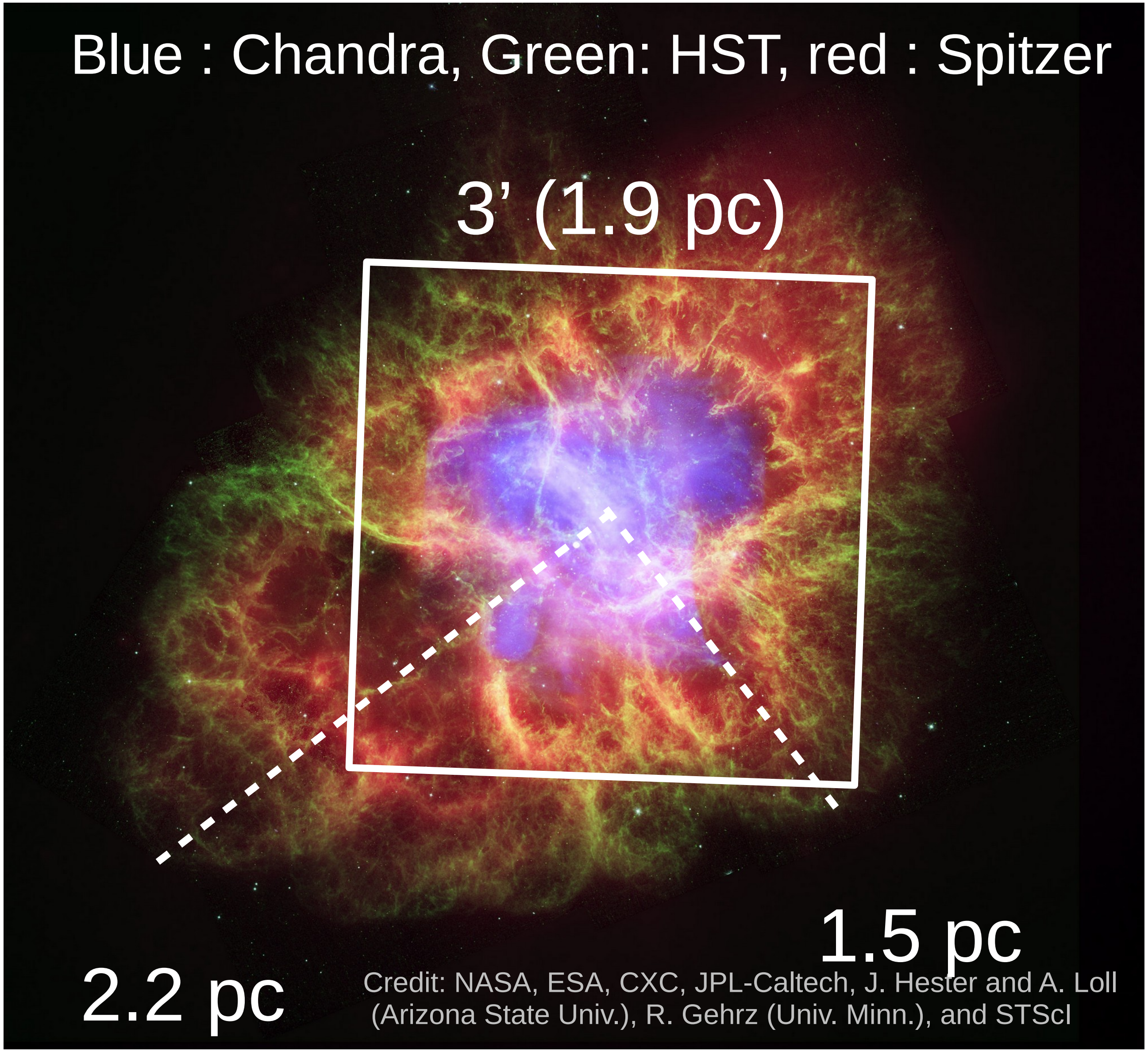
Search for undetected shell

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



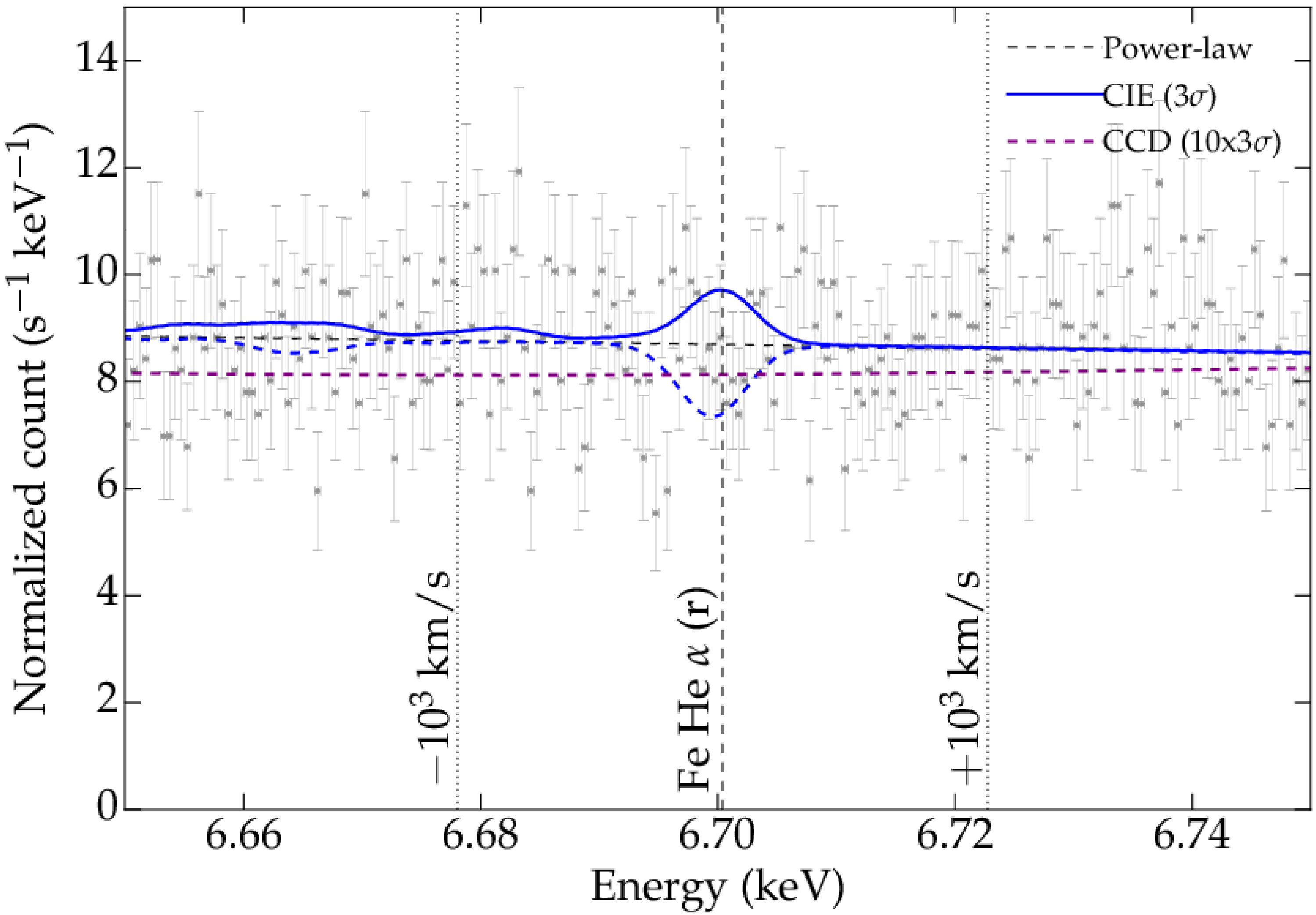
Observation

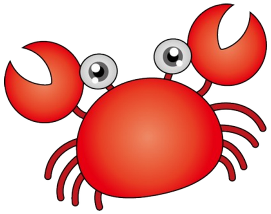
- Last data. Cal.
- t_{exp} = 9.7 ks
- *E* > 2 keV & *Fx*~0.3 “Crab” w. GV.
- ΔE=4.9 eV for extended src.
- High obs eff ~ 71% (c.f., 5% for XIS).



Plasma search (1) Method

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



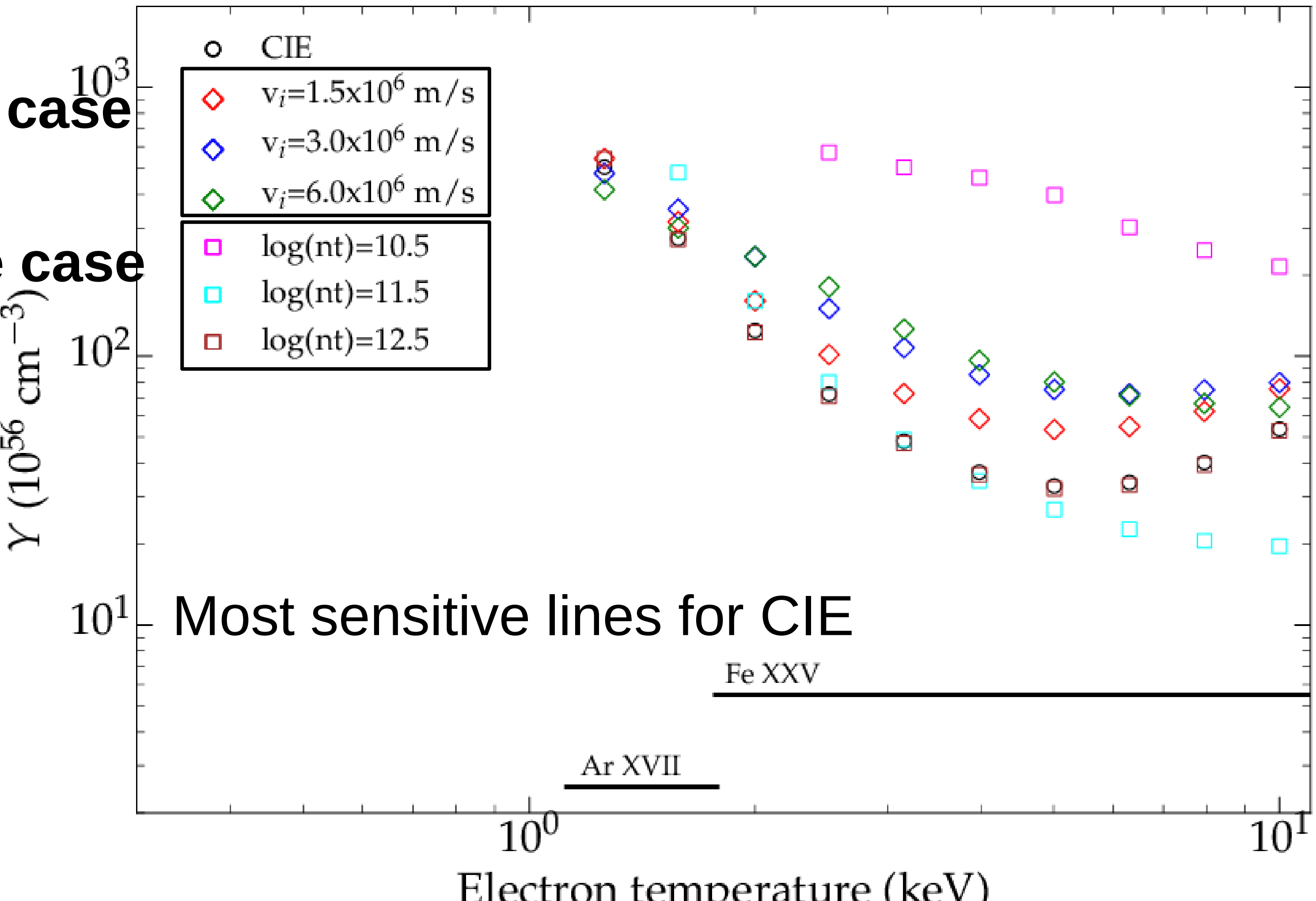


Plasma search (2) Result

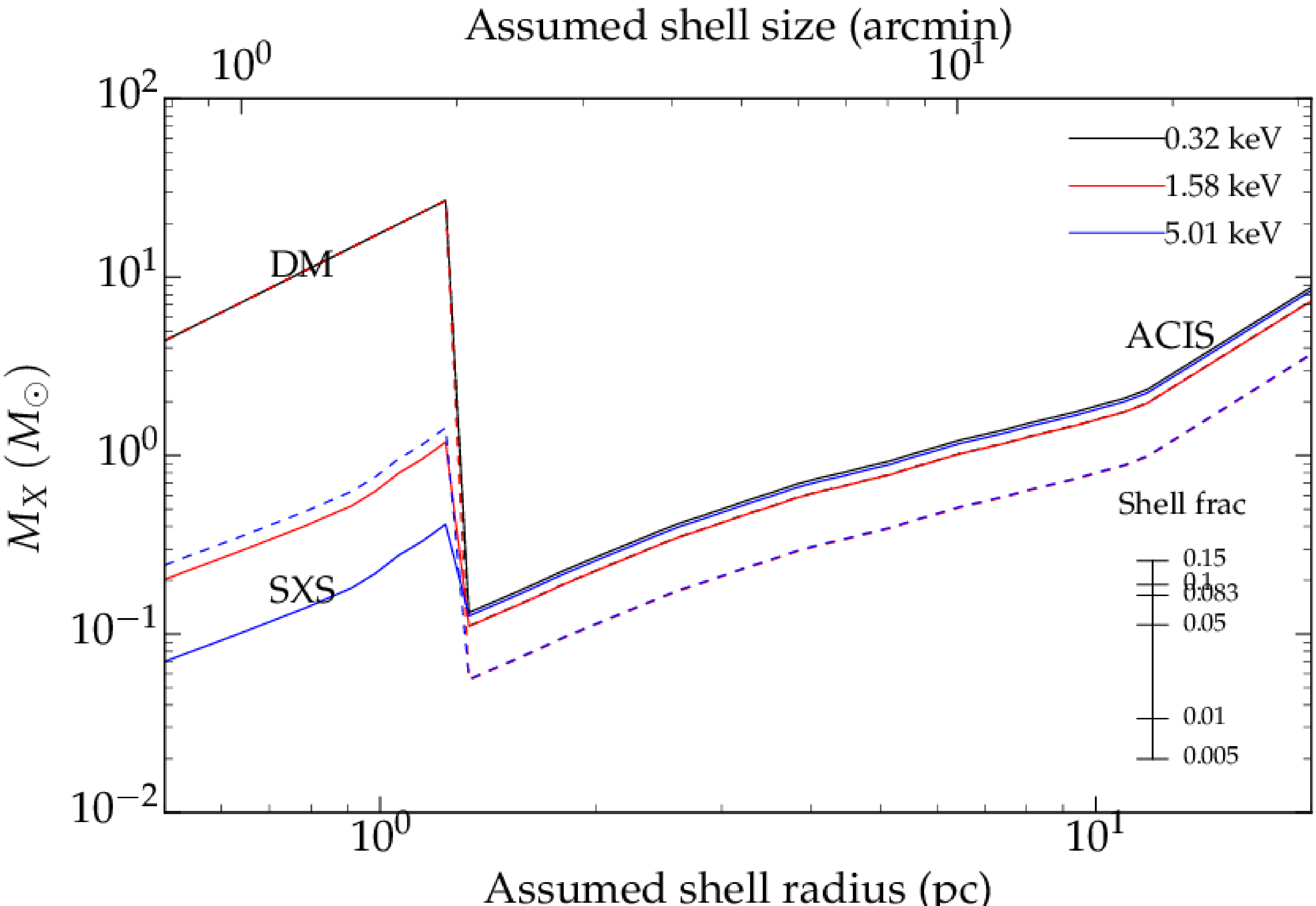
- 3σ UL of Y (=n_e^2V) for CIE & non-CIE emission.

Ti!=Te case

Tz!=Te case



Limit on plasma mass

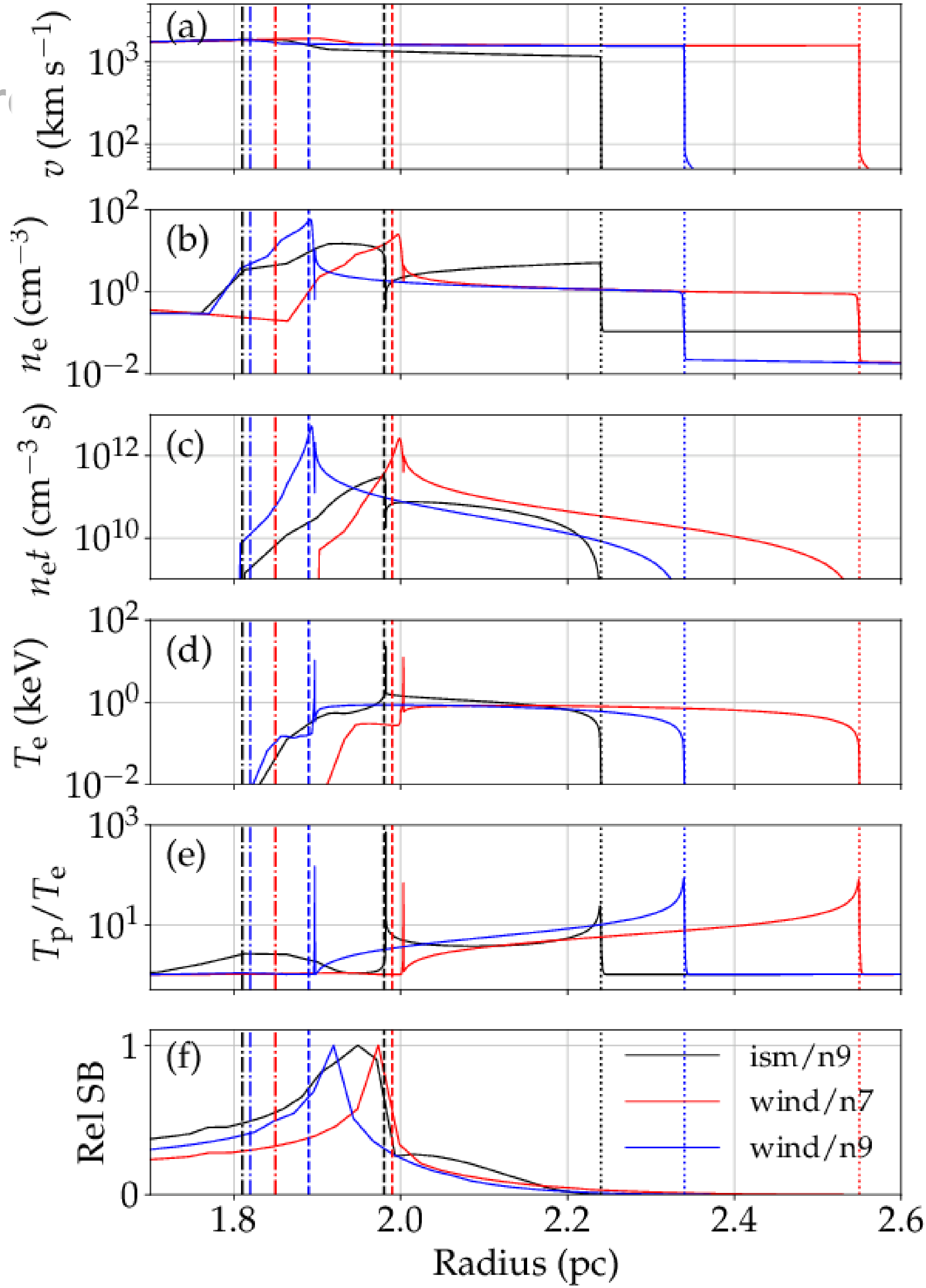
- 

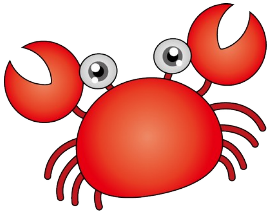
HD simulation (1) Setup

- 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 $n=\dot{M}/4\pi r^2 v_{wind}$ ($\dot{M}$=10^{-5} Mo/yr, v_{wind}=20 km/s)	**Fe-w**	**EC-w**

HD… lt


(a)
v (km s^{-1})
(b)
n_e (cm^{-3})
(c)
$n_e t$ (cm^{-3} s)
(d)
T_e (keV)
(e)
T_p/T_e
(f)
Rel SB
ism/n9
wind/n7
wind/n9
Radius (pc)

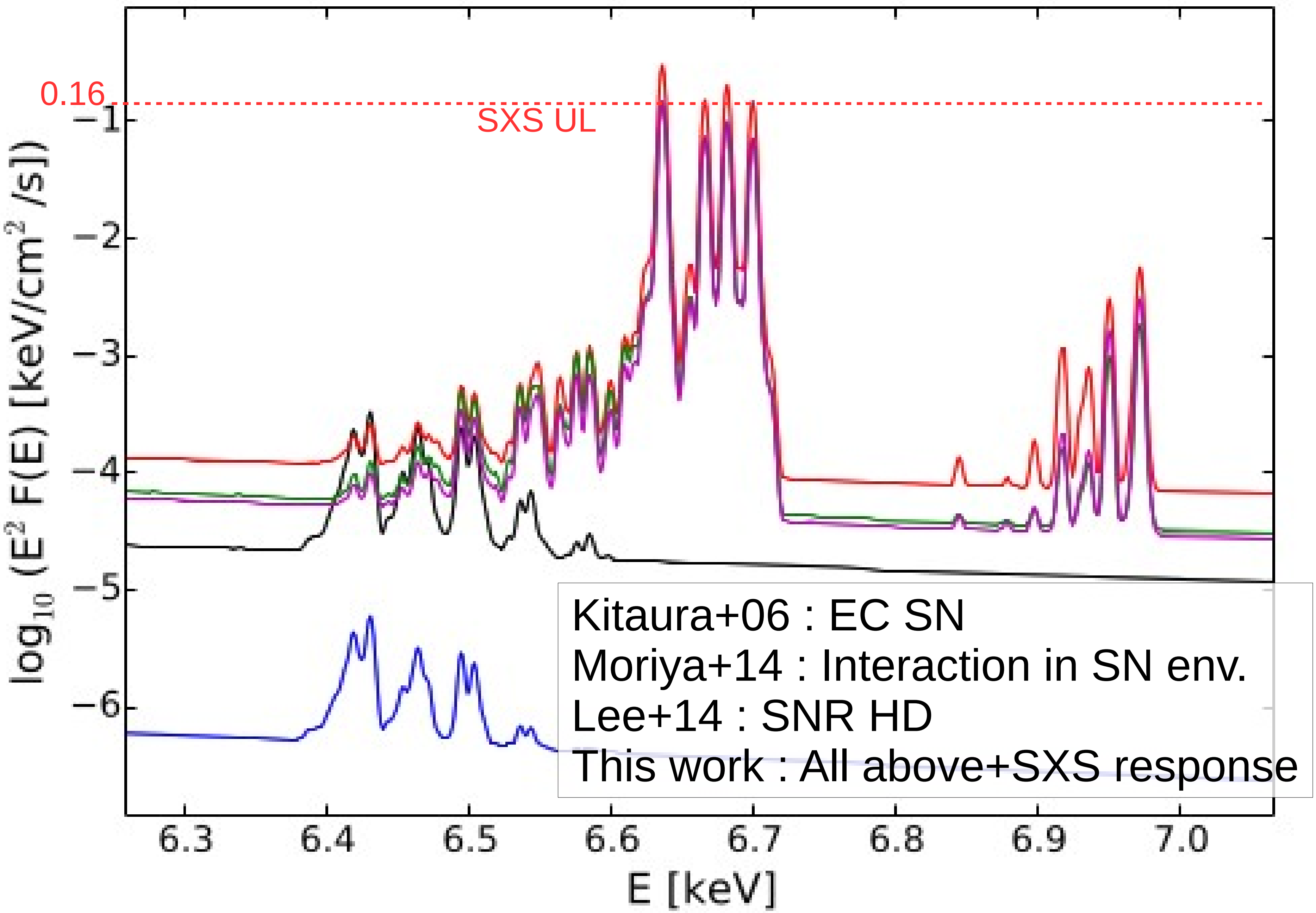


HD simulation (2) Result

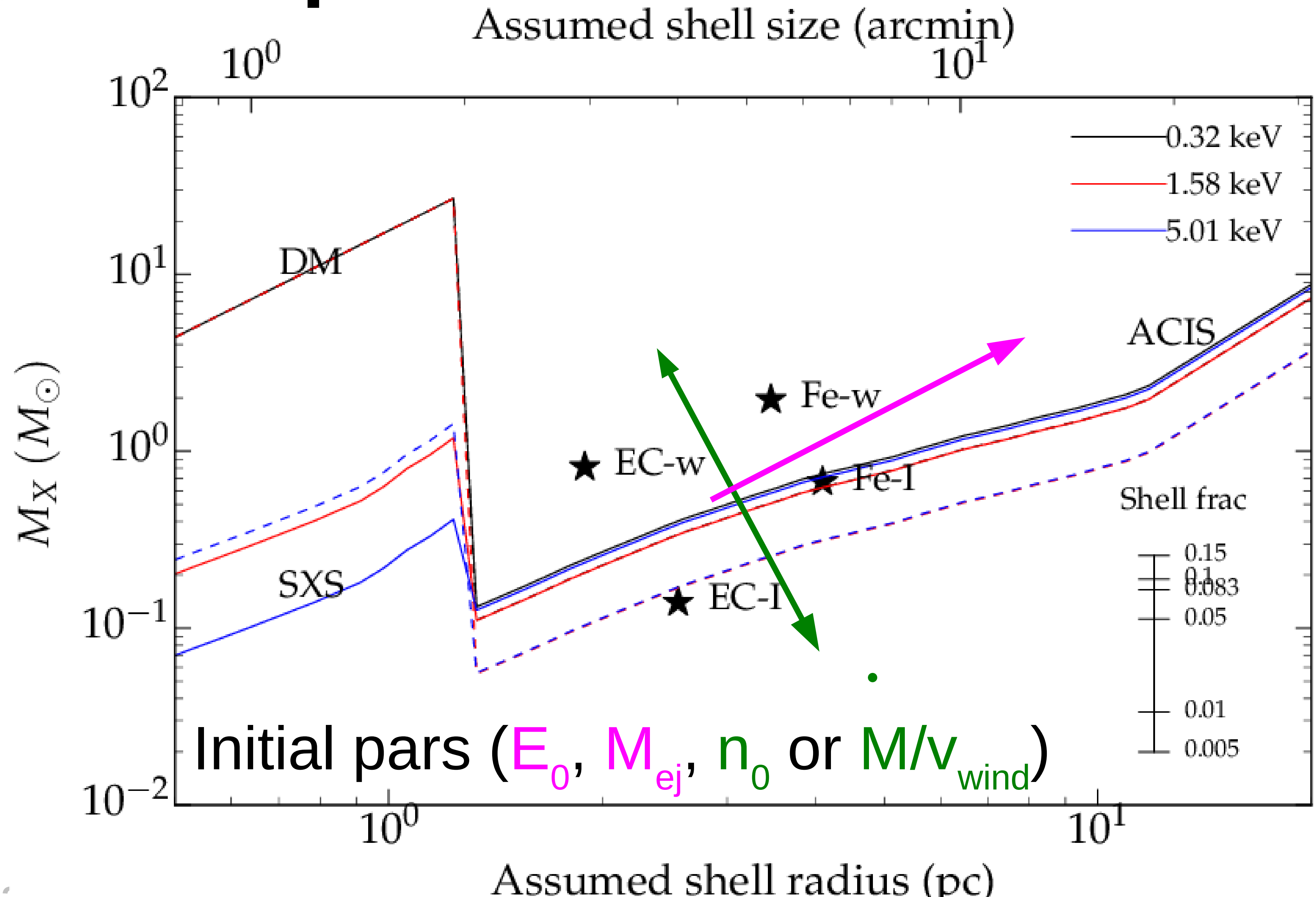
	Fe-I	Fe-w	EC-I	EC-w
R_{FS} (pc)	4.6	4.3	2.9	2.3
R_{CD} (pc)	4.1	3.5	2.6	1.9
R_{RS} (pc)	3.8	3.3	2.4	1.8
v_{FS} (km/s)	3.1e3	3.7e3	2.0e3	2.0e3
v_{RS} (km/s)	1.4e3	5.1e2	8.8e2	2.9e2
$\overline{T}_{\overline{Fe}}/\overline{T}_{\overline{e}}$ (keV)	130/1.0	50/0.51	57/0.71	62/0.74
$\overline{n}_{\overline{e}}\overline{t}$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

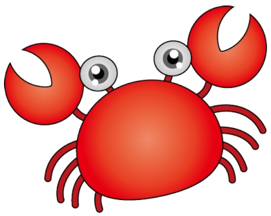
- Excellent agreement with analytical one (Truelove & McKee 99)
- Most ejecta unshocked for Fe models.

HD simulation (2) Result



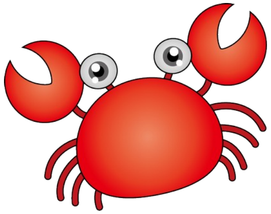
Comparison of obs & HD





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.



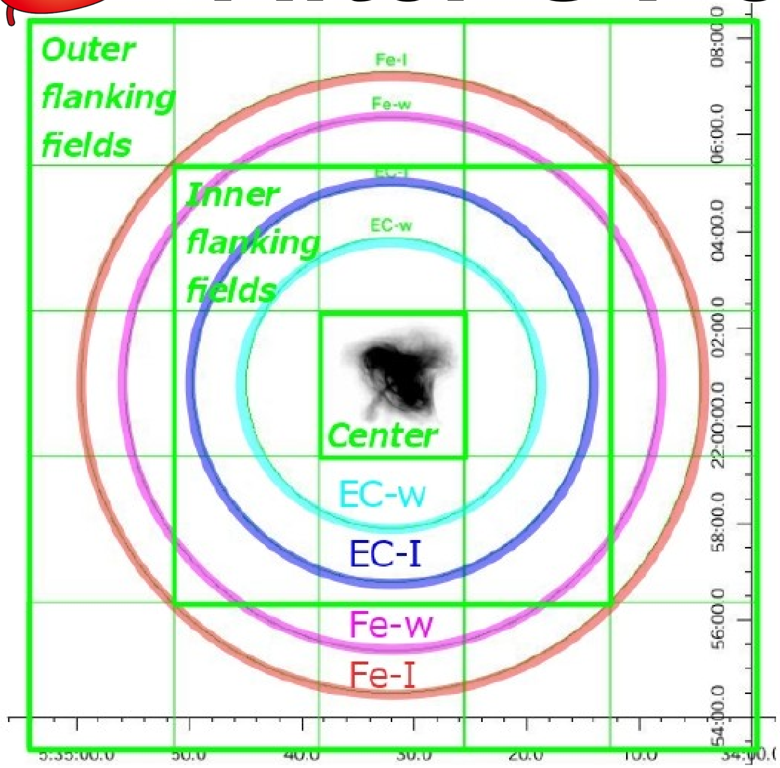
Conclusion

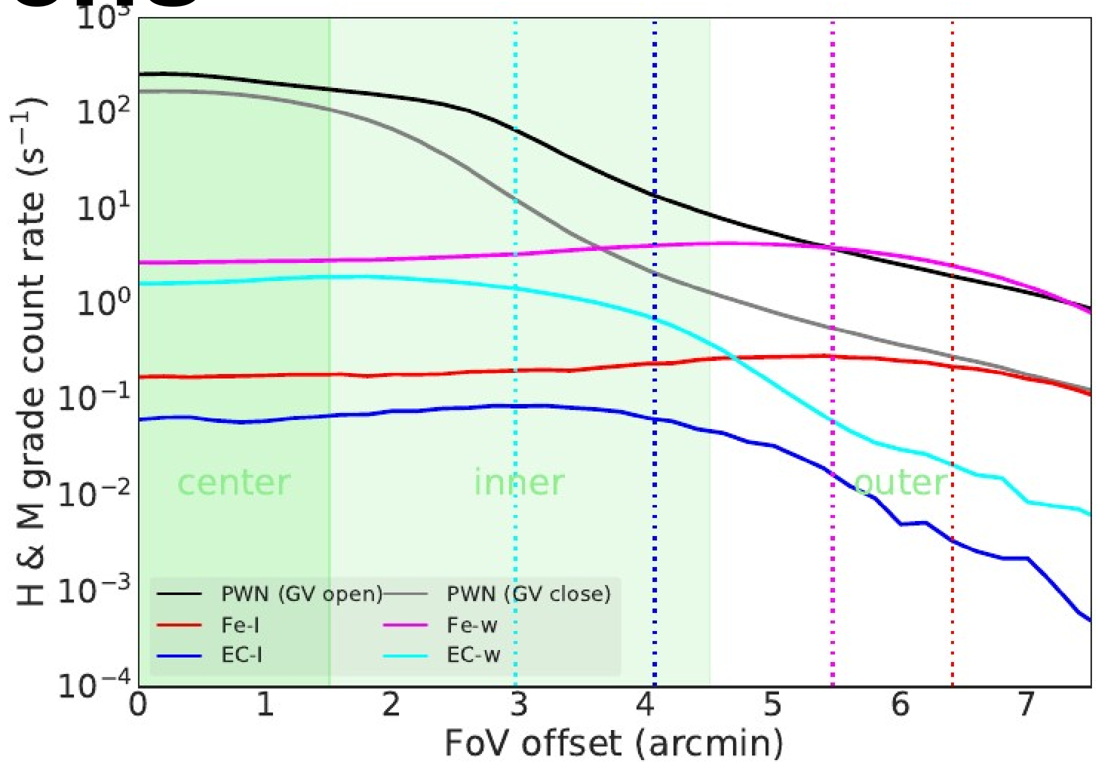
- Spectroscopic search of thermal plasma from Crab using SXS. No convincing features found.
- Other results re-evaluated for most stringent upper limit on Mx. SXS added new limits.
- Compared with HD simulation for
  - (a) Fe core, (b) electron capture SN
  - (1) ISM, (2) wind environment.
- Both Fe,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

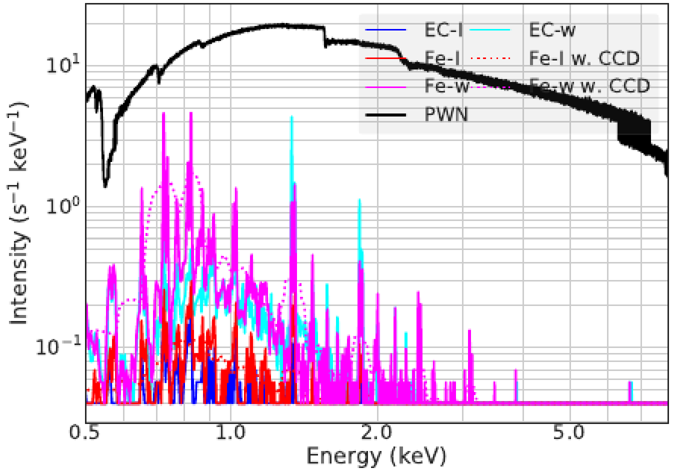
What are next?

- 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.

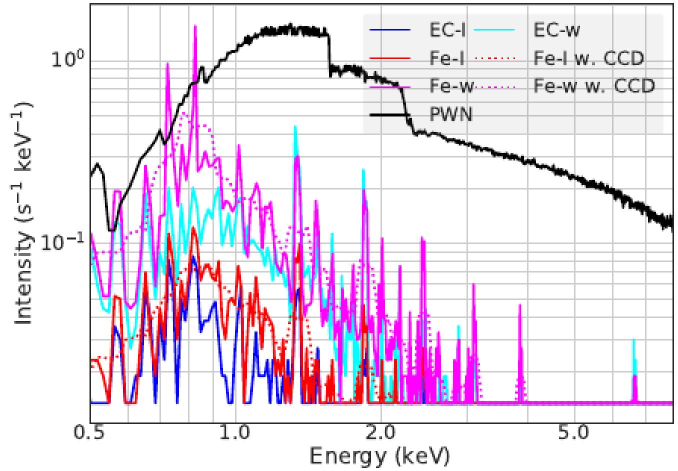
After GV opens



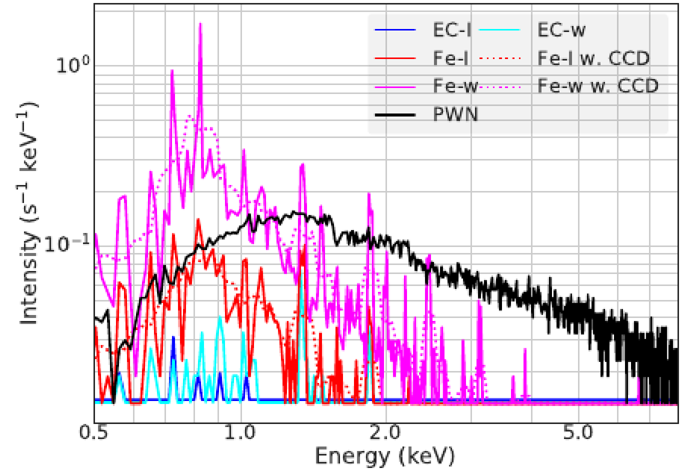




(a) Center at 0′ offset



(b) Inner flanking field at 3′ offset



(c) Outer flanking field at 6′ offset