# X-Ray Spectroscopy of Young Supernovae

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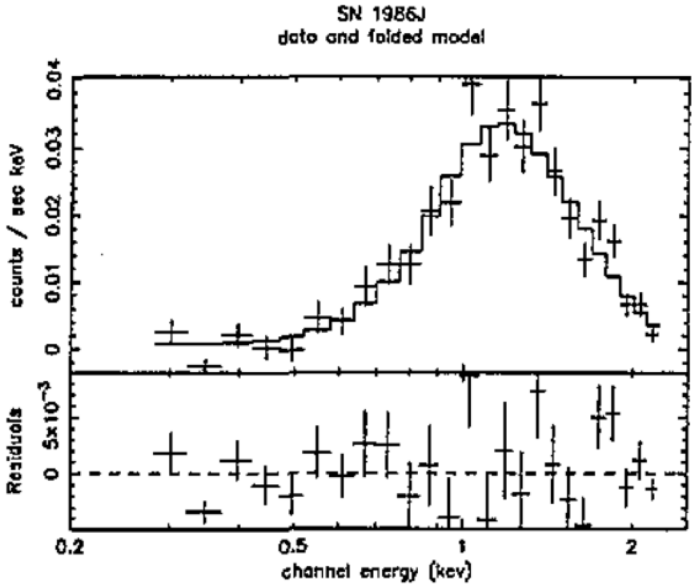
# X-Ray Supernovae (1995)

**Table 3.** Supernovae detected in the X-ray band.

| SN *name* | *Galaxy* | Date of optical max | B magnitude at max | SN type | Galaxy distance[a] | X-rays first observed | Satellite used |
|---|---|---|---|---|---|---|---|
| SN 1978K | NGC 1313 | ~1978 June 10[b] | ~13 | IIL | 4.5 Mpc | +~12.1 y | *ROSAT, Asuka* |
| | | ~1978 May 25[b] | ~14.5 | IIP | | | |
| SN 1980K | NGC 6946 | 1980 Nov 5 | 11.5 | IIL | 5.1 Mpc | +35 d | *Einstein* |
| SN 1986J | NGC 891 | 1983 Jan?[c] | ? | IIpec | 9.6 Mpc | ? | *ROSAT* |
| SN 1987A | LMC | 1987 May 9 | 3.5 | IIP | 50 ± 3 kpc | +154 d | *Ginga* |
| SN 1993J | NGC 3031 | 1993 Apr 18 | 11.4[d] | IIpec | 3.63 ± 0.34 Mpc | +5 d | *ROSAT, Asuka, GRO* |

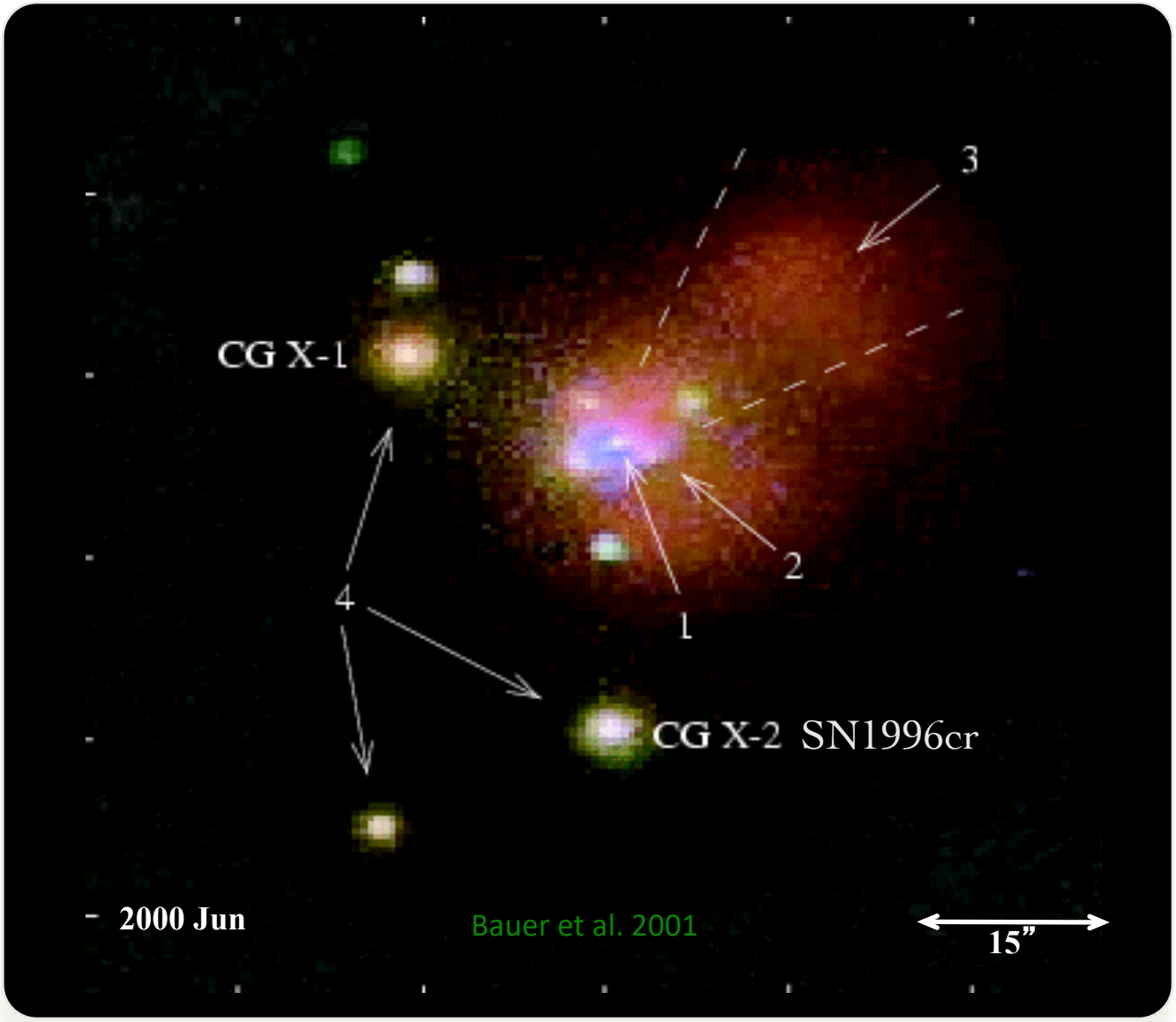
[a] Distances from: SN1978K, deVaucouleurs 1963; SN1980K, deVaucouleurs 1979; SN1986J, Tully 1988; SN1987A, numerous; SN1993J, Freedman *et al* (1993).
[b] Assume each type II subtype, matching optical light curve to average SN II optical behaviour to derive date of maximum (Ryder *et al* 1993a).
[c] Chevalier (1987).
[d] Richmond (1993).

X-Ray Emission from Supernovae (Schlegel 1995, Reports on Progress in Physics, 58, 1375)

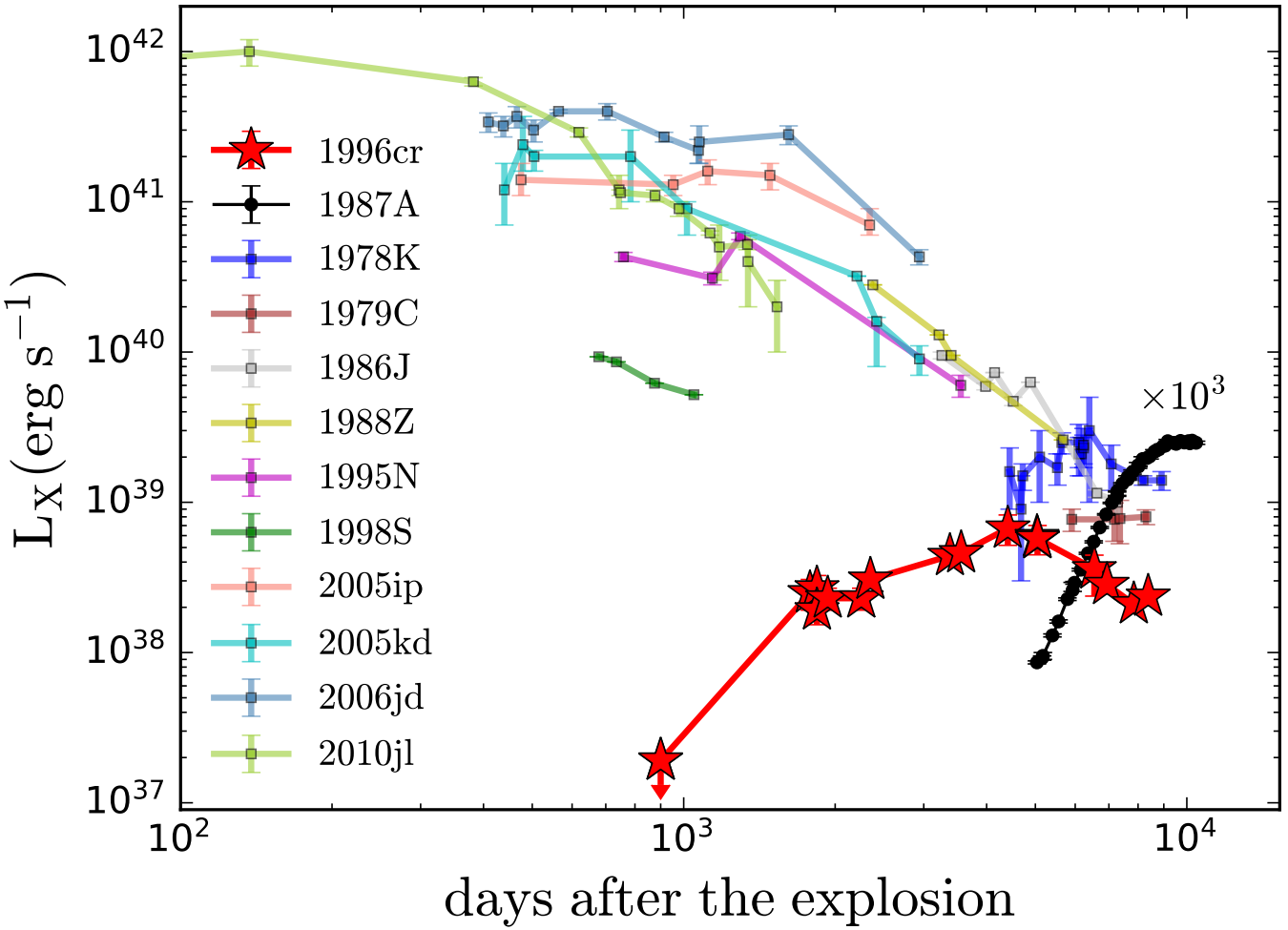



Rosat PSPSC Spectrum of SN 1986J

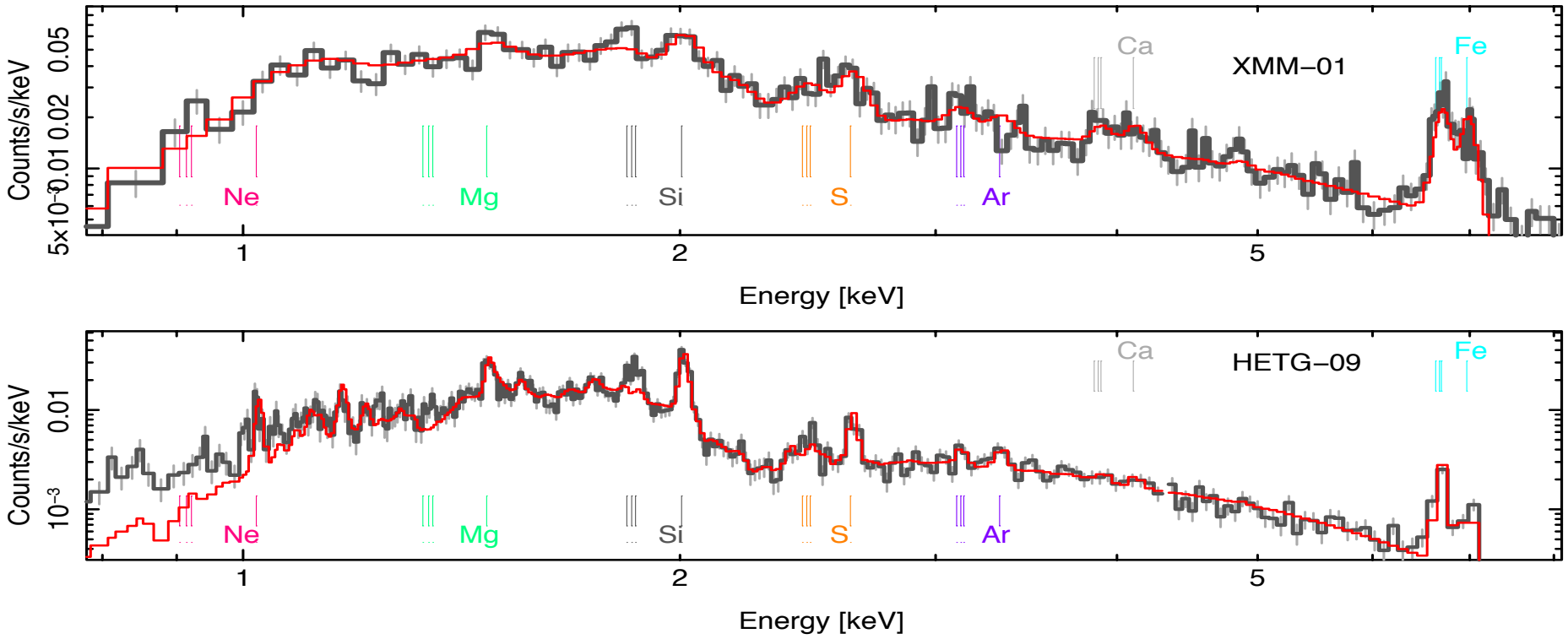
# SN1996cr



# SN 1996cr

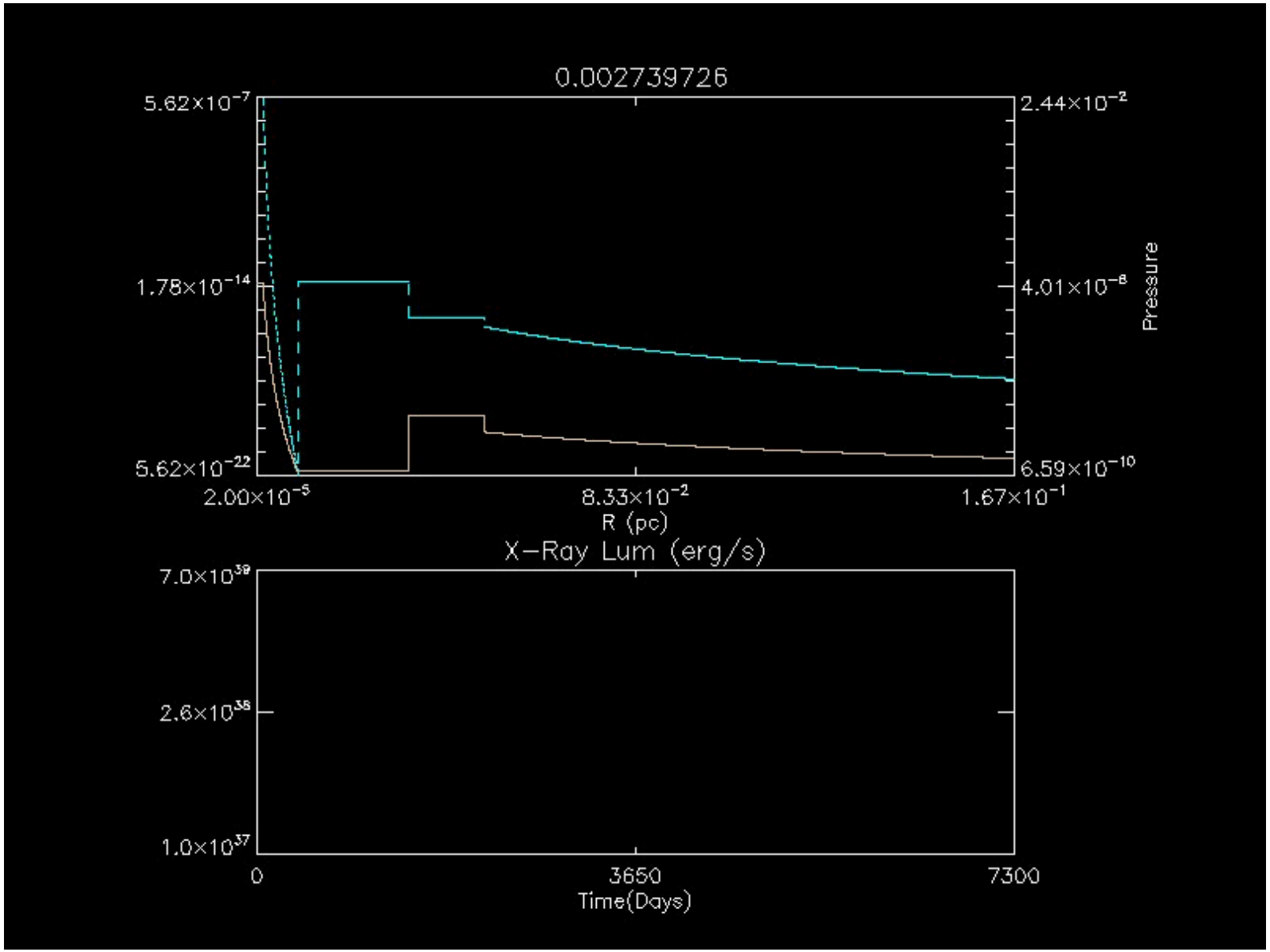

1996cr
1987A
1978K
1979C
1986J
1988Z
1995N
1998S
2005ip
2005kd
2006jd
2010jl
×10^3
L_X (erg s^-1)
10^42
10^41
10^40
10^39
10^38
10^37
10^2
10^3
10^4
days after the explosion

# 1996cr

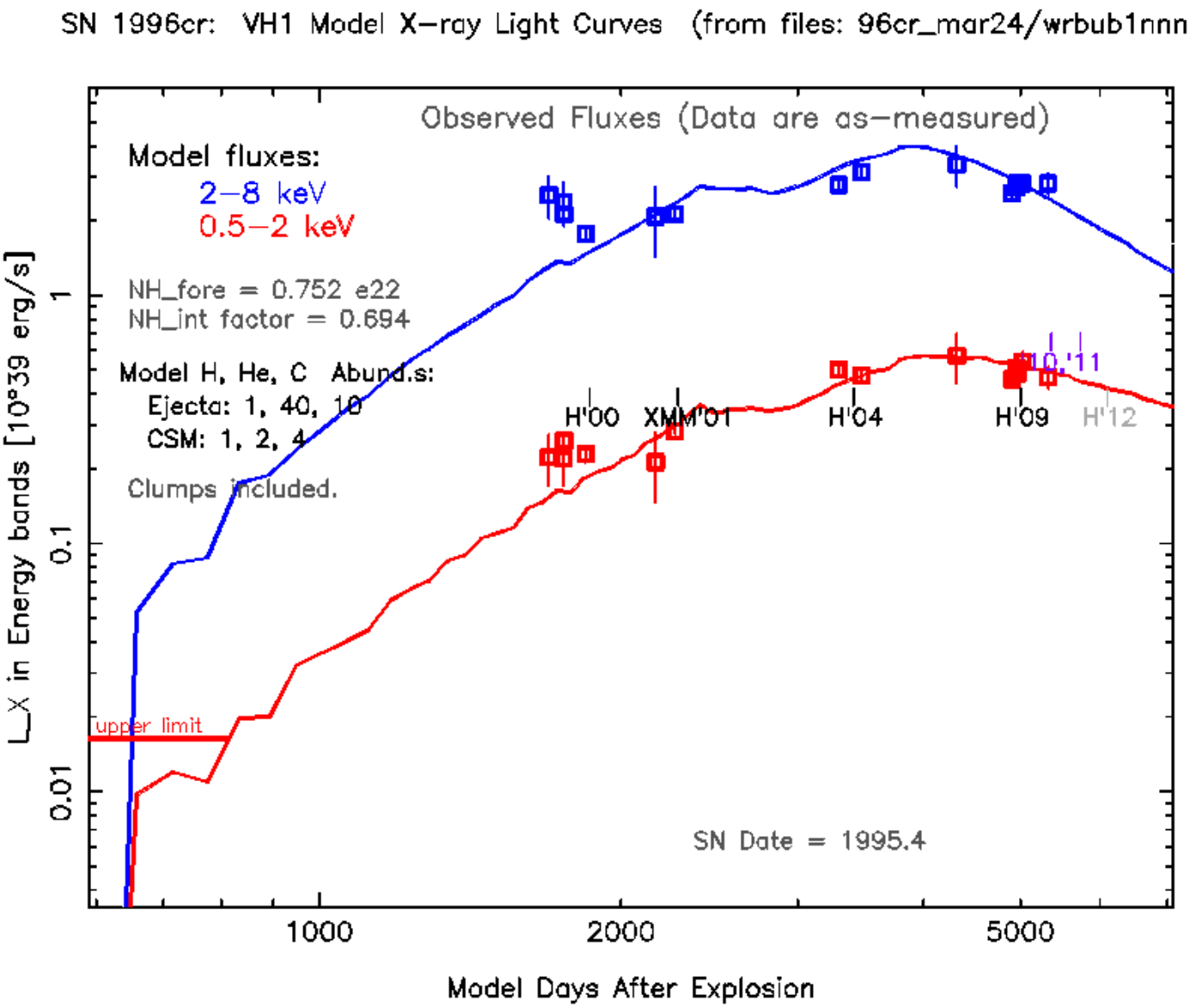



HETG 480 ks image

# SN 1996cr (Hydro and X-ray)



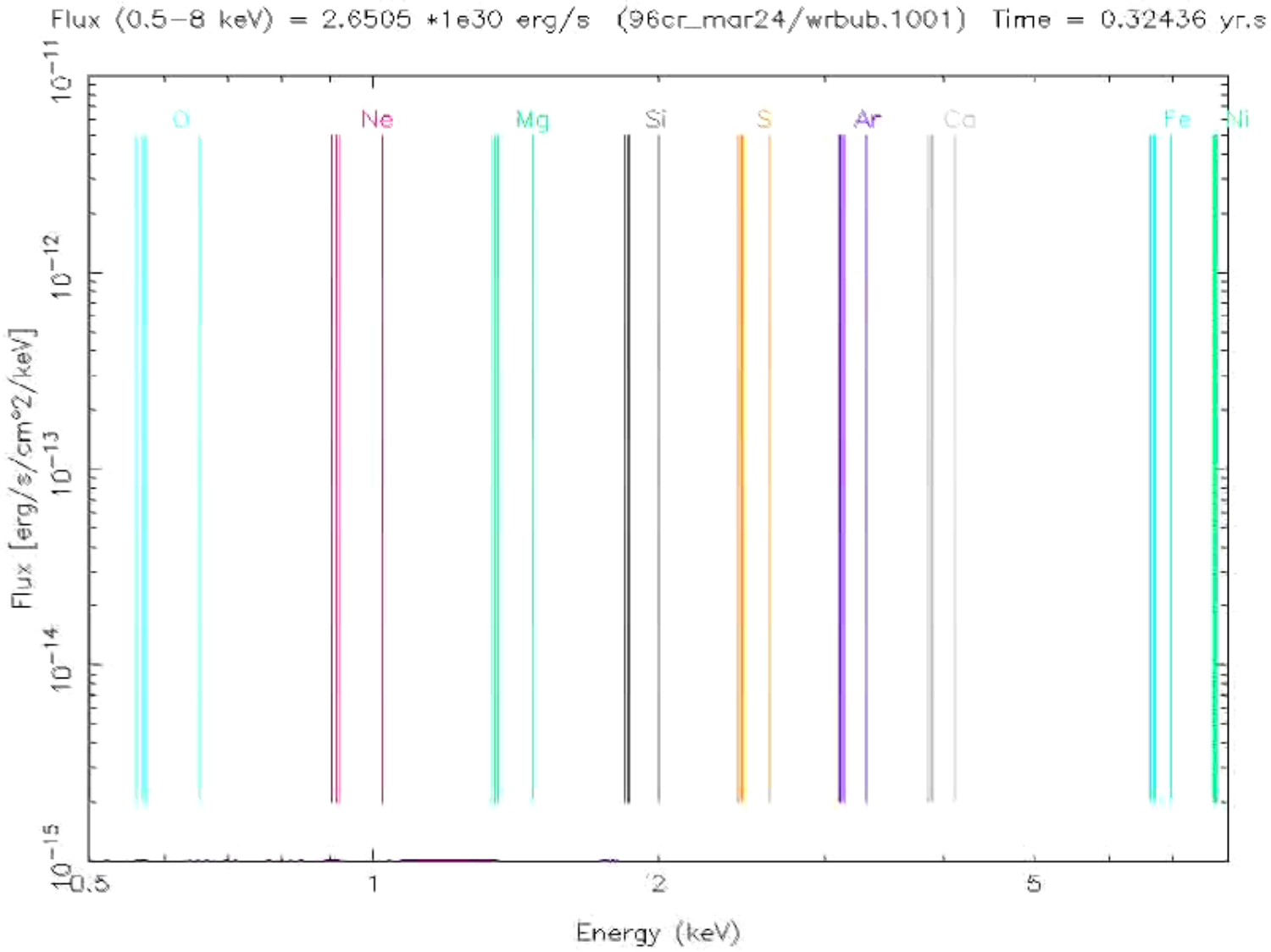
# 1996cr - Comparison with X-Ray data



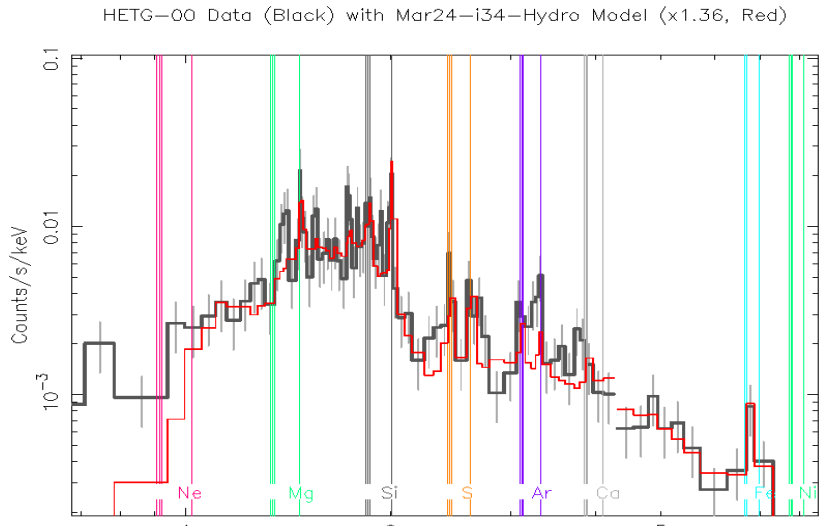

Dwarkadas, V. V.; Dewey, D.; Bauer, F, 2010, MNRAS, 407, 812

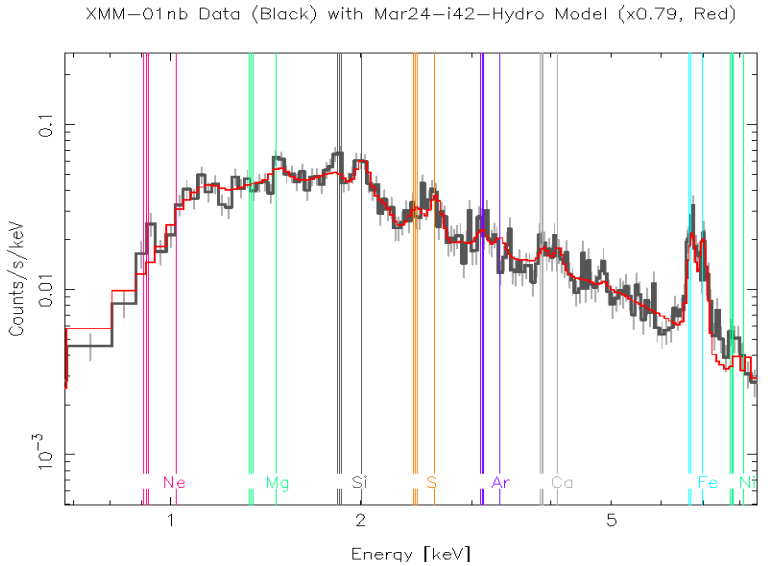
# 1996cr - Xray spectral evolution

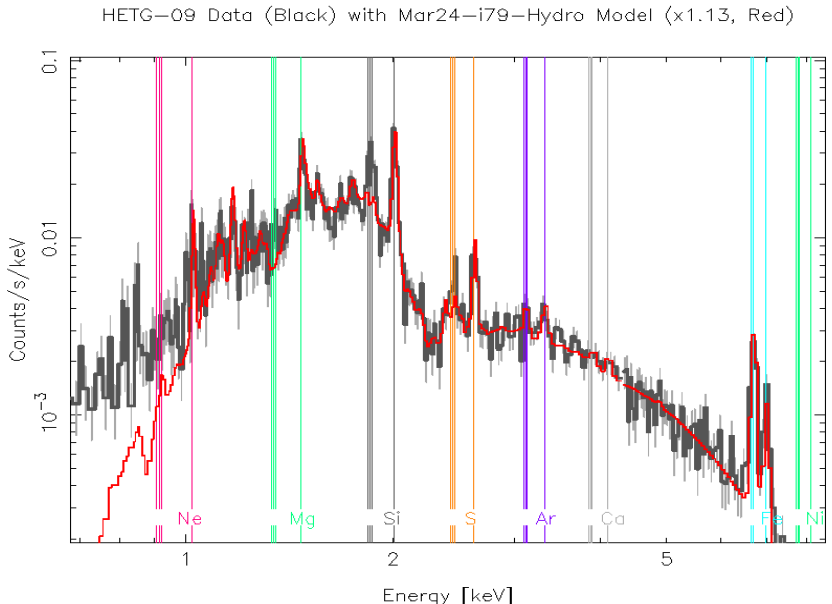
(Blue - CSM; Black - Ejecta; Red - Total)

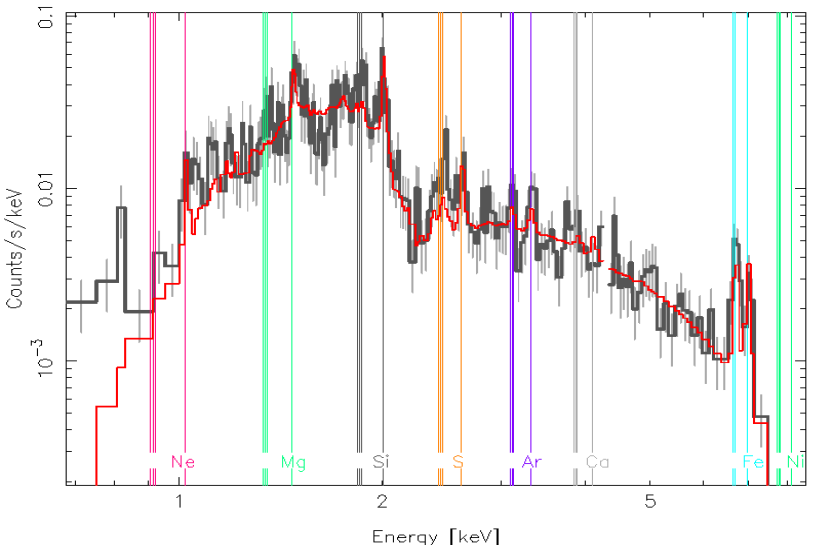


# SN 1996cr (Comparison between Observed and Simulated Spectra)

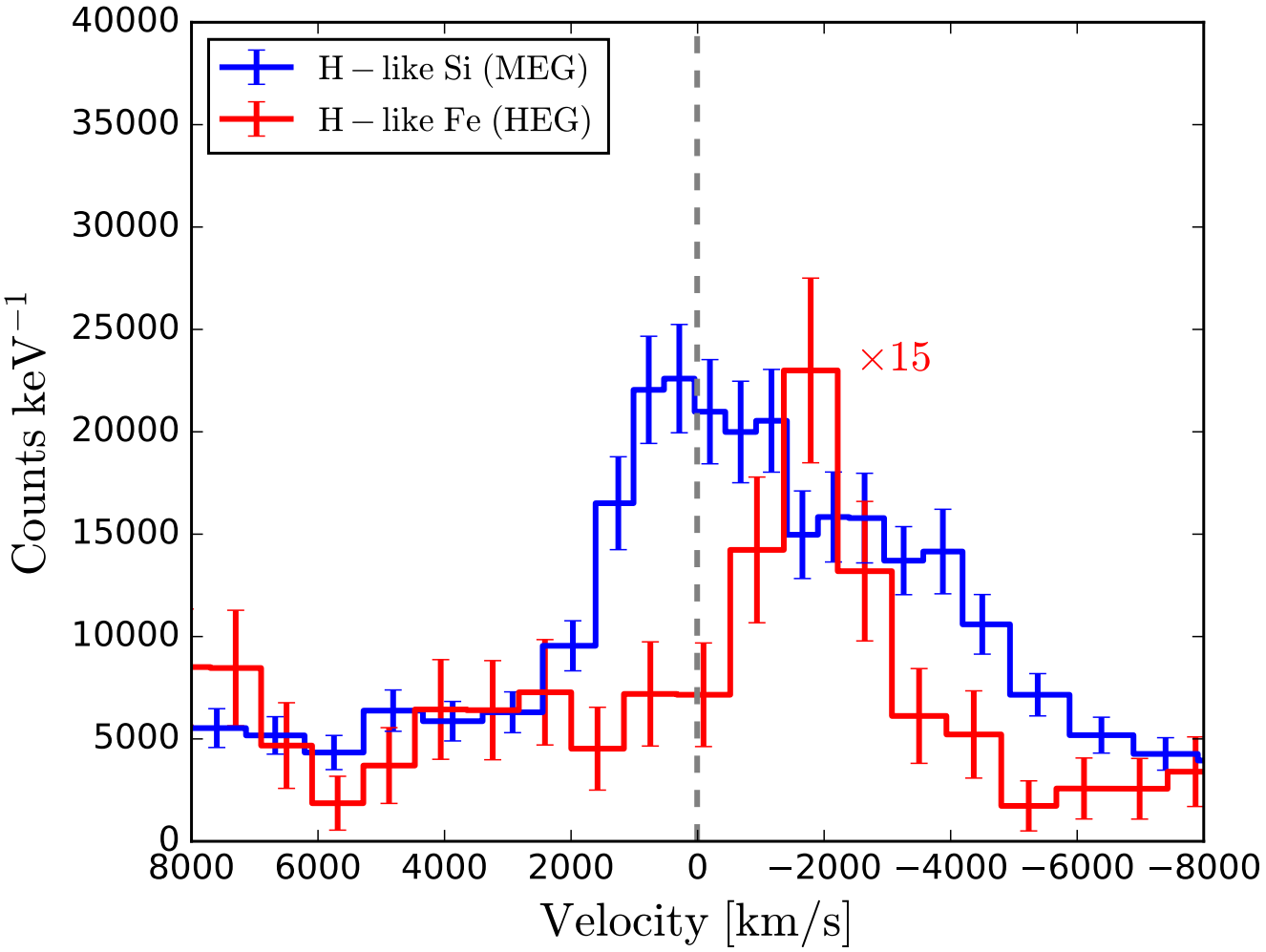


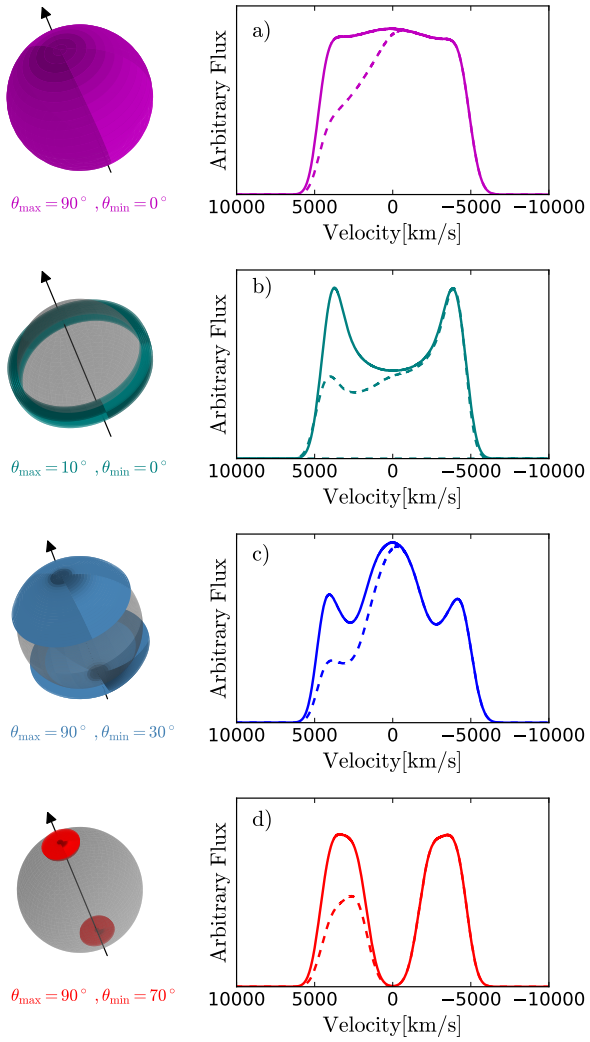
# Si and Fe Line Profiles



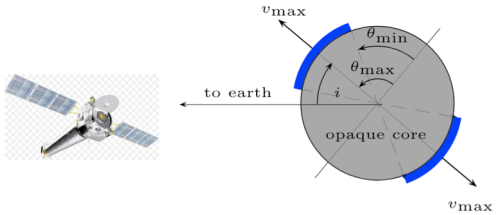

Asymmetric line profiles of H-like Si and H-like Fe profiles from 2009 HETG image.

1. Profiles are clearly asymmetric
2. Distinct profiles imply different physical/geometrical origins

# Shellblur Convolution Model




"shellblur" - spherical geometry parameterized by maximum velocity (vmax), inclination angle with respect to the line-of-sight (i), minimum and maximum aperture angles ($\theta_{min}$, $\theta_{max}$), and interior absorption term ($N_{ejecta}$).

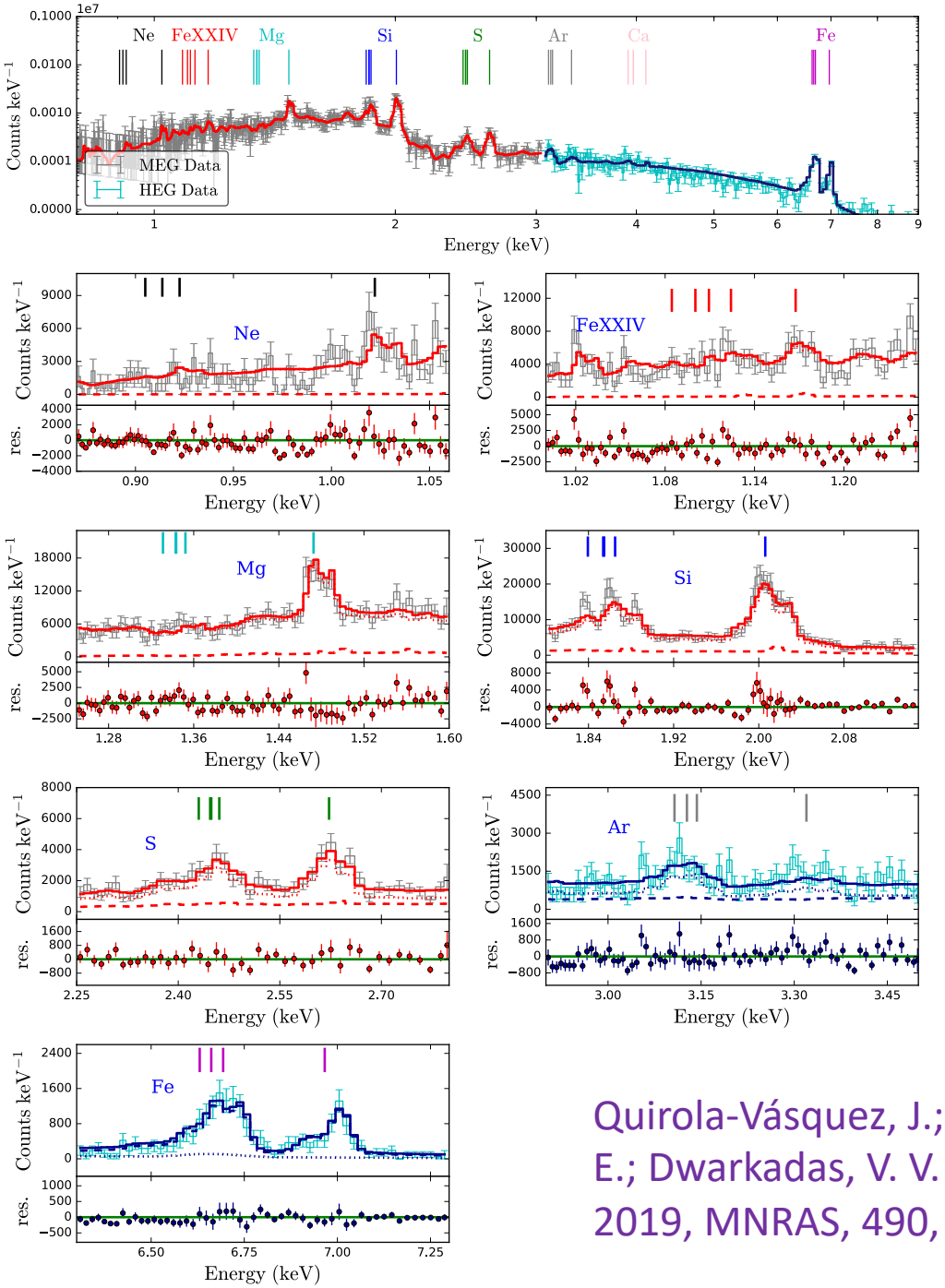



Examples of different expanding shock structure geometries,
(a) spherically symme
(b) a 10-wide equator
(c) a 60-wide polar ca
(d) a 20-wide polar ca
In all cases, maximum 5000 km $s^{-1}$, axis of symmetry i the line of sight, and a uniforr rovides a maximum obscuratio at the diameter) to the farsi nels show resulting velocity prof an input unresolved Gaussian keV. Two line-profiles are show 20 $cm^{-2}$ (i.e., unobscured $N_{ejecta}=2x10^{23}$ $cm^{-2}$ (i.e., obscured; dashed curves).

# Best-Fit Model M5

(two temperatures, two polar geometries, two absorptions) compared to the 2009 epoch spectra.

Close-up spectra of all detected H-like and He-like emission complexes and their residuals

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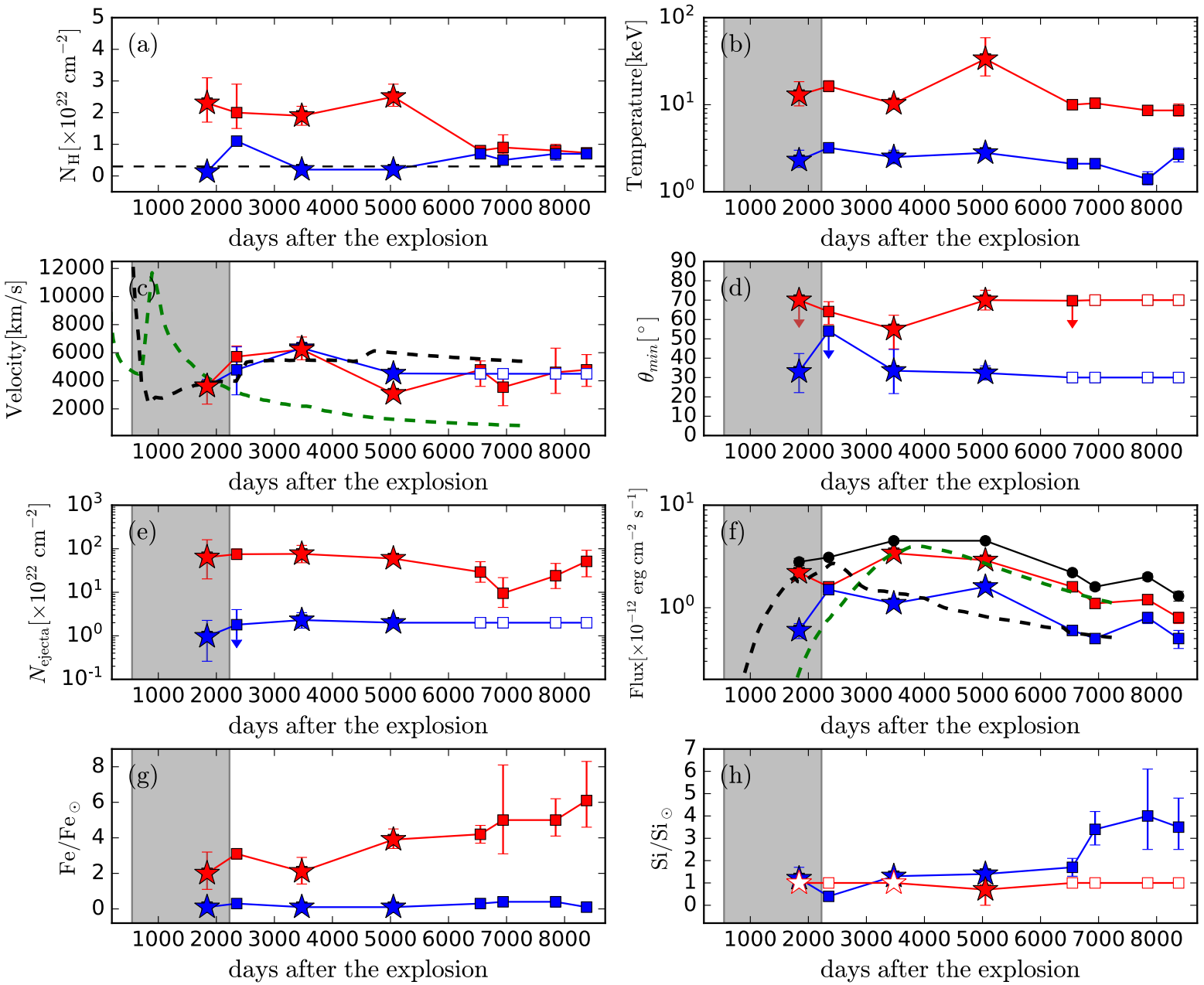
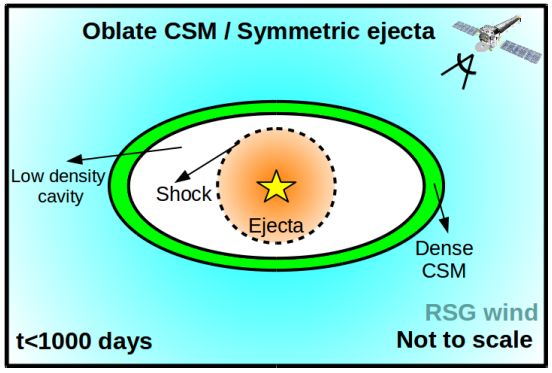
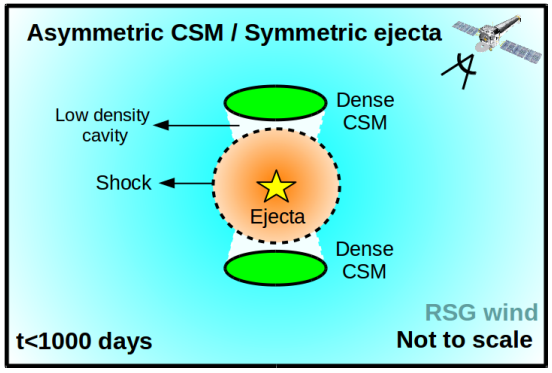
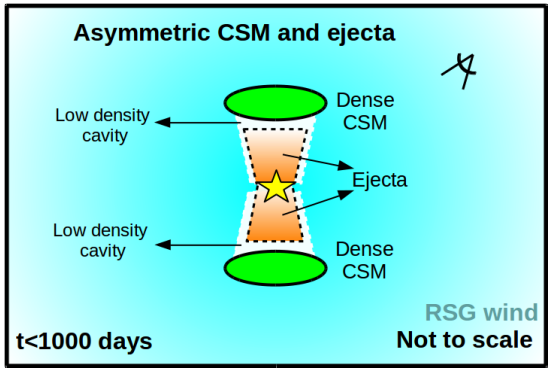
Evolution of parameters at different epochs. Red symbols and blue symbols denote parameters associated with the CR (high kT, high NH, narrow polar angle) and CF (low kT, low NH, wider polar angle) components, respectively.

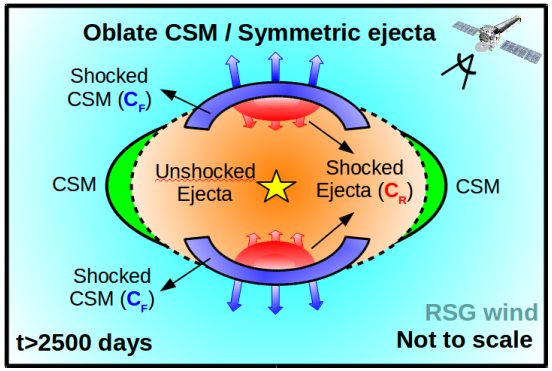


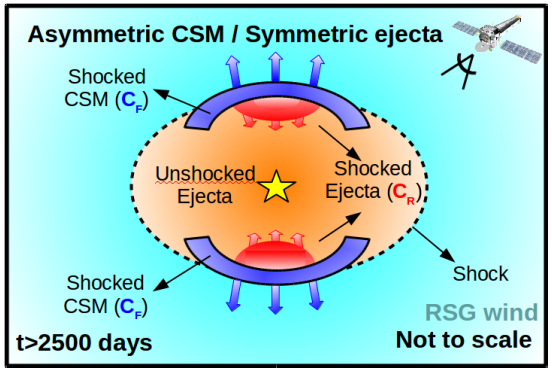
# Geometry

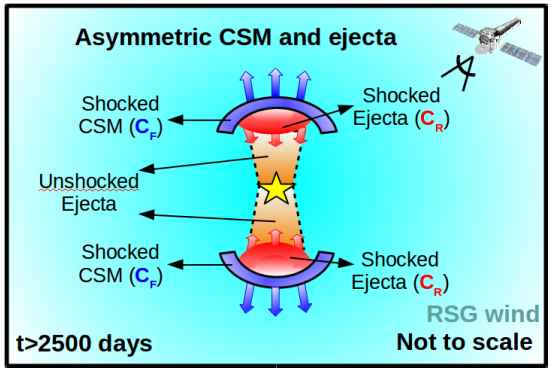

Oblate CSM / Symmetric ejecta
Low density cavity
Shock
Ejecta
Dense CSM
RSG wind
t<1000 days
Not to scale


Asymmetric CSM / Symmetric ejecta
Low density cavity
Dense CSM
Shock
Ejecta
Dense CSM
RSG wind
t<1000 days
Not to scale


Asymmetric CSM and ejecta
Low density cavity
Dense CSM
Ejecta
Low density cavity
Dense CSM
RSG wind
t<1000 days
Not to scale


Oblate CSM / Symmetric ejecta
Shocked CSM (C_F)
CSM
Unshocked Ejecta
Shocked Ejecta (C_R)
CSM
Shocked CSM (C_F)
RSG wind
t>2500 days
Not to scale


Asymmetric CSM / Symmetric ejecta
Shocked CSM (C_F)
Unshocked Ejecta
Shocked Ejecta (C_R)
Shock
Shocked CSM (C_F)
RSG wind
t>2500 days
Not to scale


Asymmetric CSM and ejecta
Shocked CSM (C_F)
Shocked Ejecta (C_R)
Unshocked Ejecta
Shocked CSM (C_F)
Shocked Ejecta (C_R)
RSG wind
t>2500 days
Not to scale

# Conclusions

- SN 1996cr is a clear example of a SN expanding within a wind-blown bubble, similar to SN 1987A.
- Numerical hydrodynamic simulations, combined with synthetic spectral calculations, enable us to excavate the SN environment, trace the evolution of the shock wave within the circumstellar medium (CSM), and hone in on the SN progenitor.
- The superb HETG 480 ks spectrum allows resolution of velocity profiles of Ne, Mg, Si, S and Fe lines.
- For once we can accomplish in X-rays what SN optical astronomers do regularly - explore possible geometrical models to describe the line profile, provide new insights into the SN morphology, and monitor the line evolution as a tracer of the ejecta-CSM interaction.
- We find that the data are best fit by two components – a hotter component with high NH and a narrow polar angle, and a lower kT component with lower NH and wider polar angle.
- We tentatively identify these as consistent with the reverse shocked ejecta and forward shocked CSM.

*Questions & Discussion*