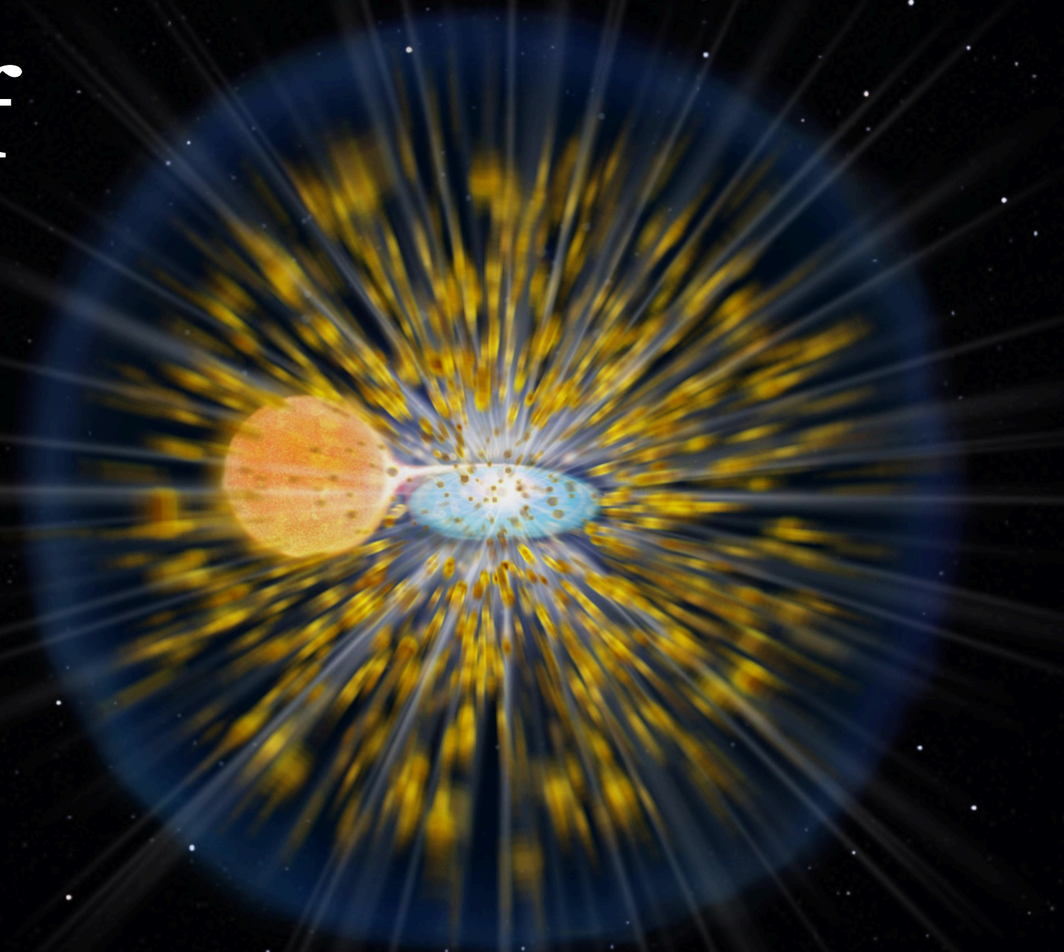
# X-Ray Characterization of the Post-Nova Stage: V2487 Ophiuchi



Elif Şafak

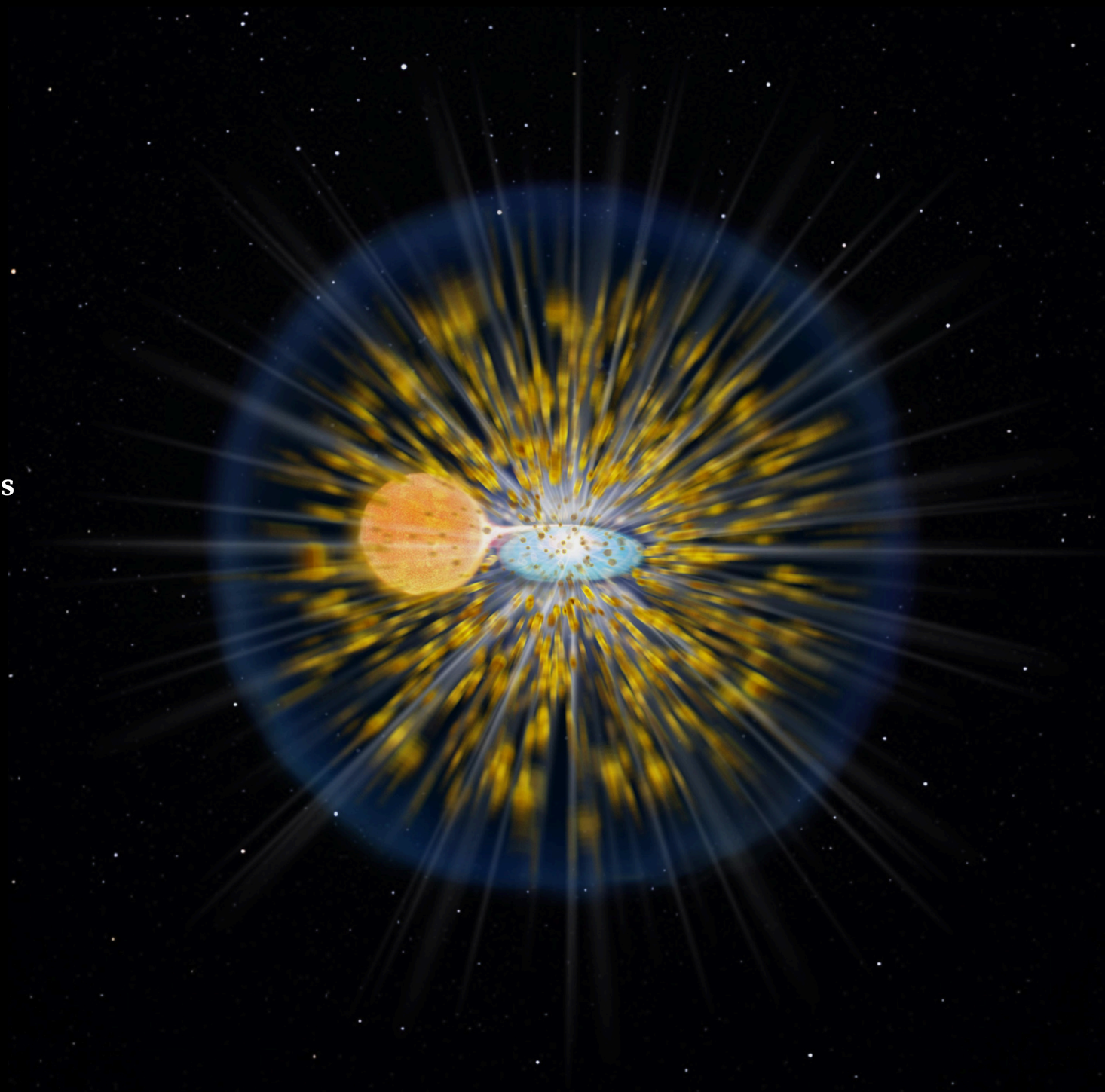
Gloria Sala, Marina Orio, Juan Luna, Margarita Hernanz, Domitilla de Martino

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

NewAthena Rising

# Index





# Intermediate Polar System

7% of CV population (Schreiber et al. 2021)

magnetized WD (0.1-10 MG)

$P_{spin} < P_{orb}$

$L_X \sim 10^{33}$ erg $s^{-1}$ (0.2-10.0 keV)

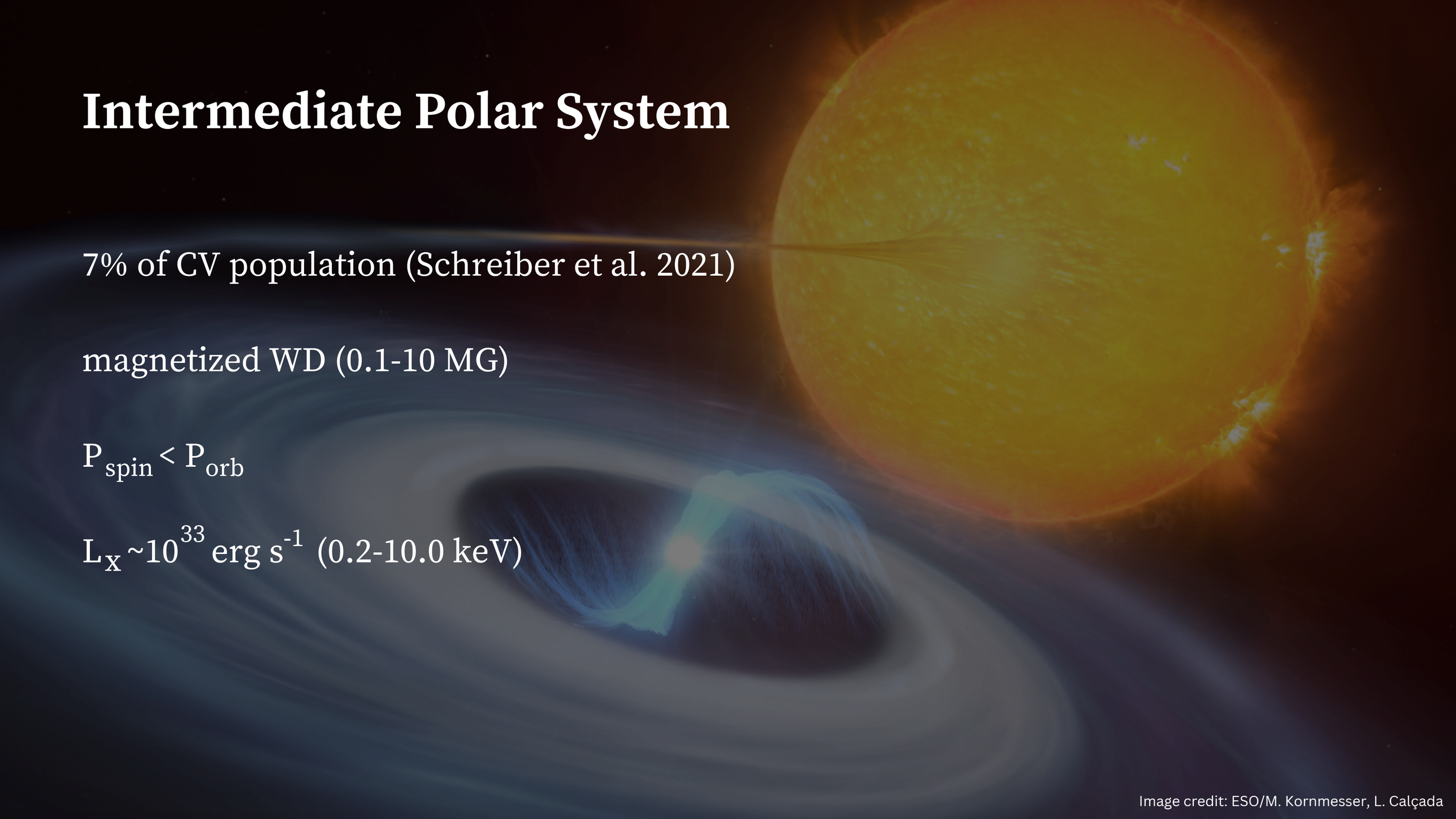


Image credit: ESO/M. Kornmesser, L. Calçada

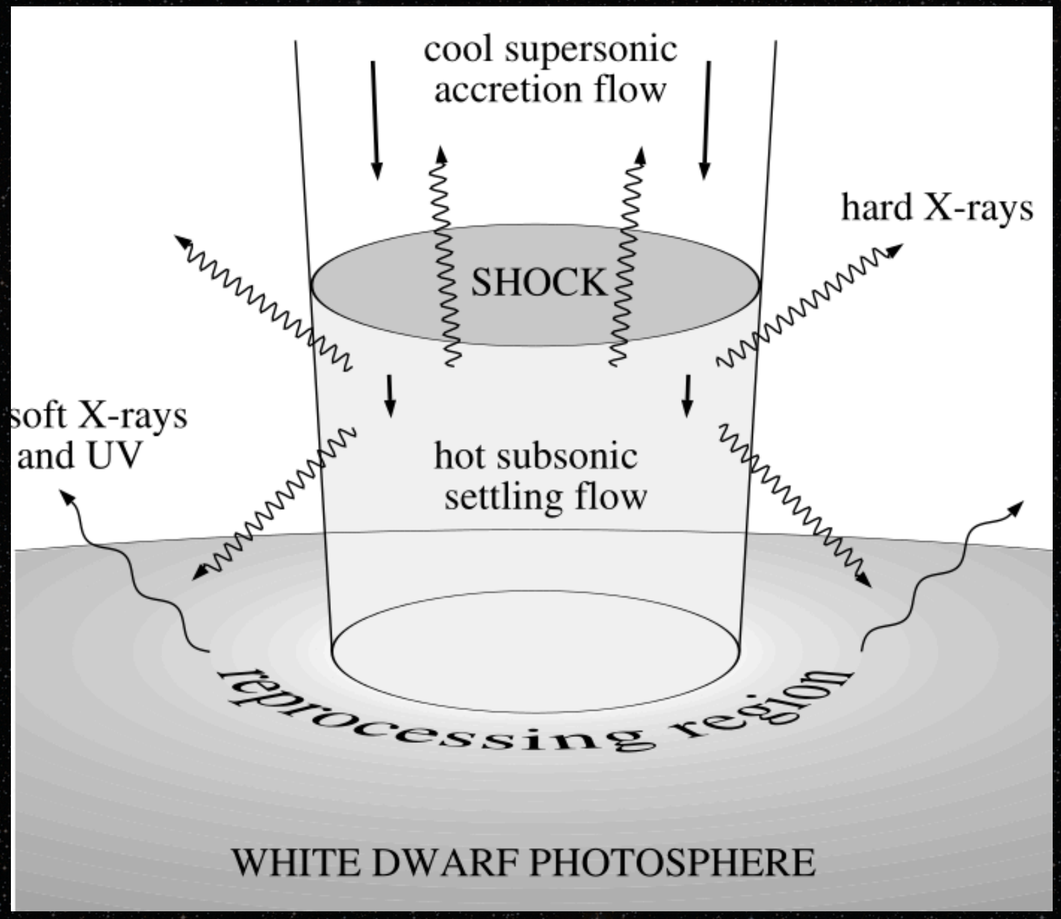
# Accretion Process

cool and supersonic infalling matter

standing shock

multi-temperature plasma

accretion-powered X-ray

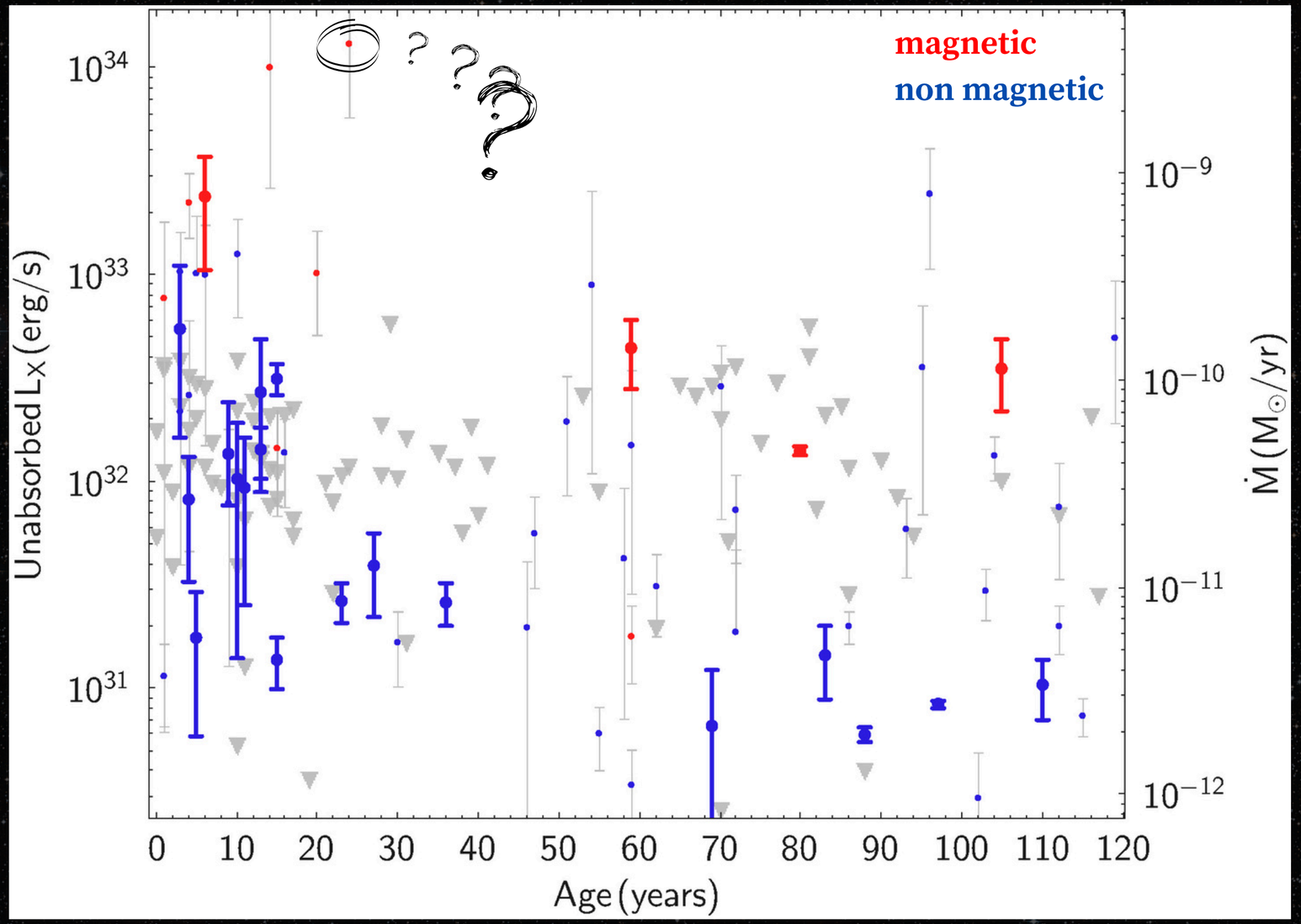



non-magnetic CVs: $L_x \sim 10^{30} - 10^{32}$ erg s$^{-1}$

magnetic CVs: $L_x \sim 10^{32} - 10^{34}$ erg s$^{-1}$

$$kT_{\rm sh} = \frac{3}{16}\mu m_{\rm H}\, v_{\rm ff}^2 \qquad v_{\rm ff}^2 = 2GM\left(\frac{1}{R+H_{\rm sh}} - \frac{1}{R_{\rm m}}\right)$$

# Motivation

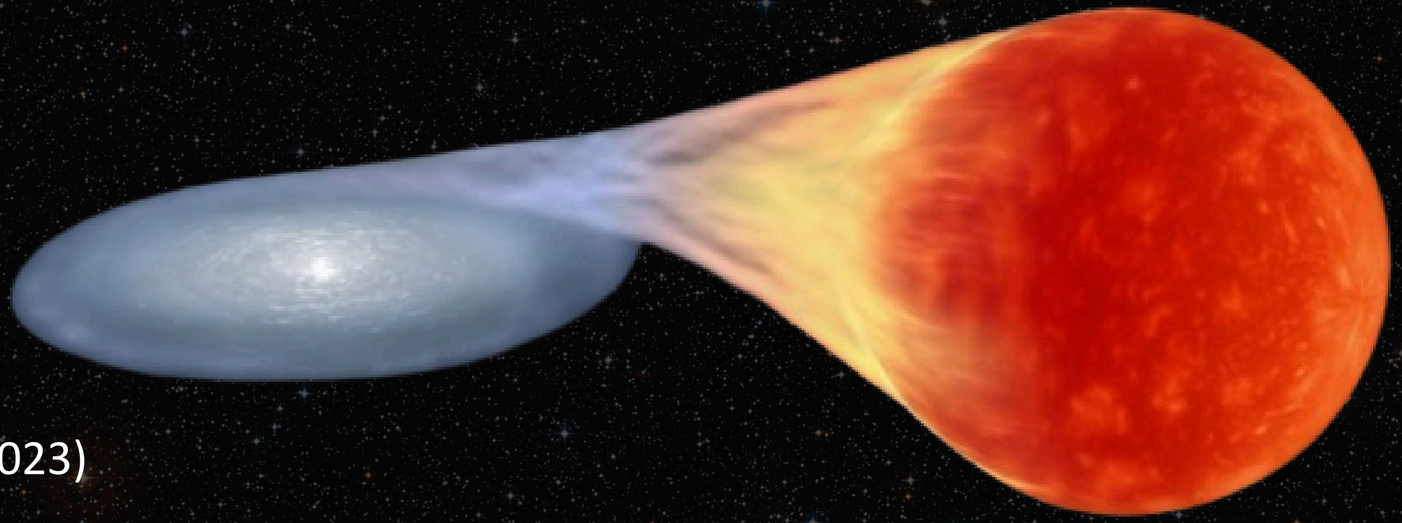



Sala et al. 2025 (A&A)

# V2487 Oph

*Nova: same star, different drama*

Nova in 1900 (Pagnotta et al. 2009) and 1998 (Nakano, S. 1998)



The cast:

a degenerate star (1.35 $M_\odot$)
a late-type star (0.27 $M_\odot$)
(Hachisu et al. 2002; Rodríguez-Gil et al., 2023)

Distance is 6.4 kpc (Gaia DR3)

$P_{orb}$ = 0.753 ± 0.016 d (18.1 ± 0.4 h) (Rodríguez-Gil et al., 2023)

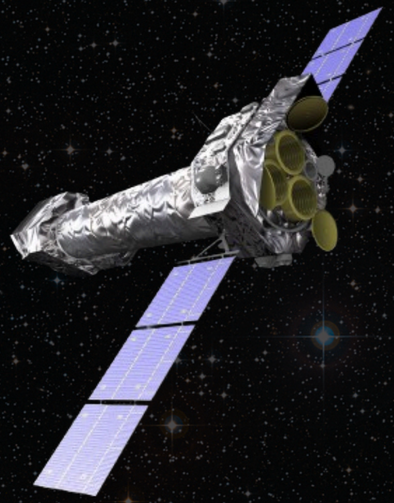
U Sco Class $t_3$ ~ 8 days

$P_{spin}$ ?

Image credit: NASA's Goddard Space Flight Center Conceptual Image Lab

# Observations in the X-rays

| Telescope | Observation Date | Exposure Time (s) |
|---|---|---|
| XMM-Newton | 2001-02-25 | 8312 |
| | 2001-09-05 | 8185 |
| | 2002-02-26 | 7619 |
| | 2002-09-24 | 8542 |
| | 2007-03-24 | 35589 |
| SuZAKU | 2010-10-09 | 56307.6 |
| NuSTAR | 2024-02-17 | 62921.0 |

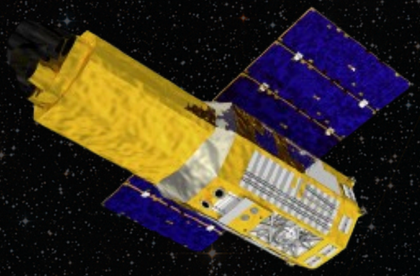


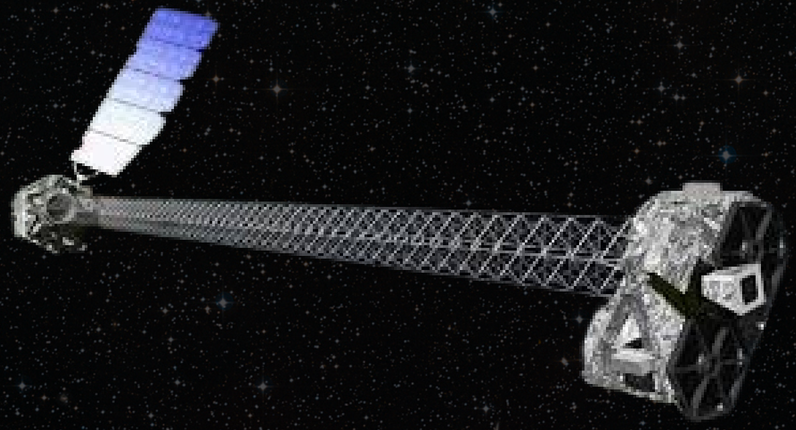
**XMM-Newton** (0.1 - 10 keV)

2001-02-25, 2001-09-05
2002-02-26, 2002-09-24
2007-03-24

**Suzaku** (0.1 - 10 keV)

2010-10-09

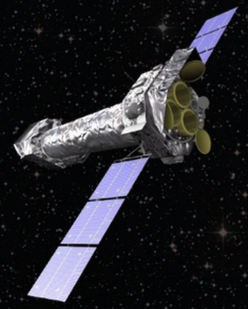




**NuSTAR** (3 - 79 keV)

2024-02-17

# XMM-Newton



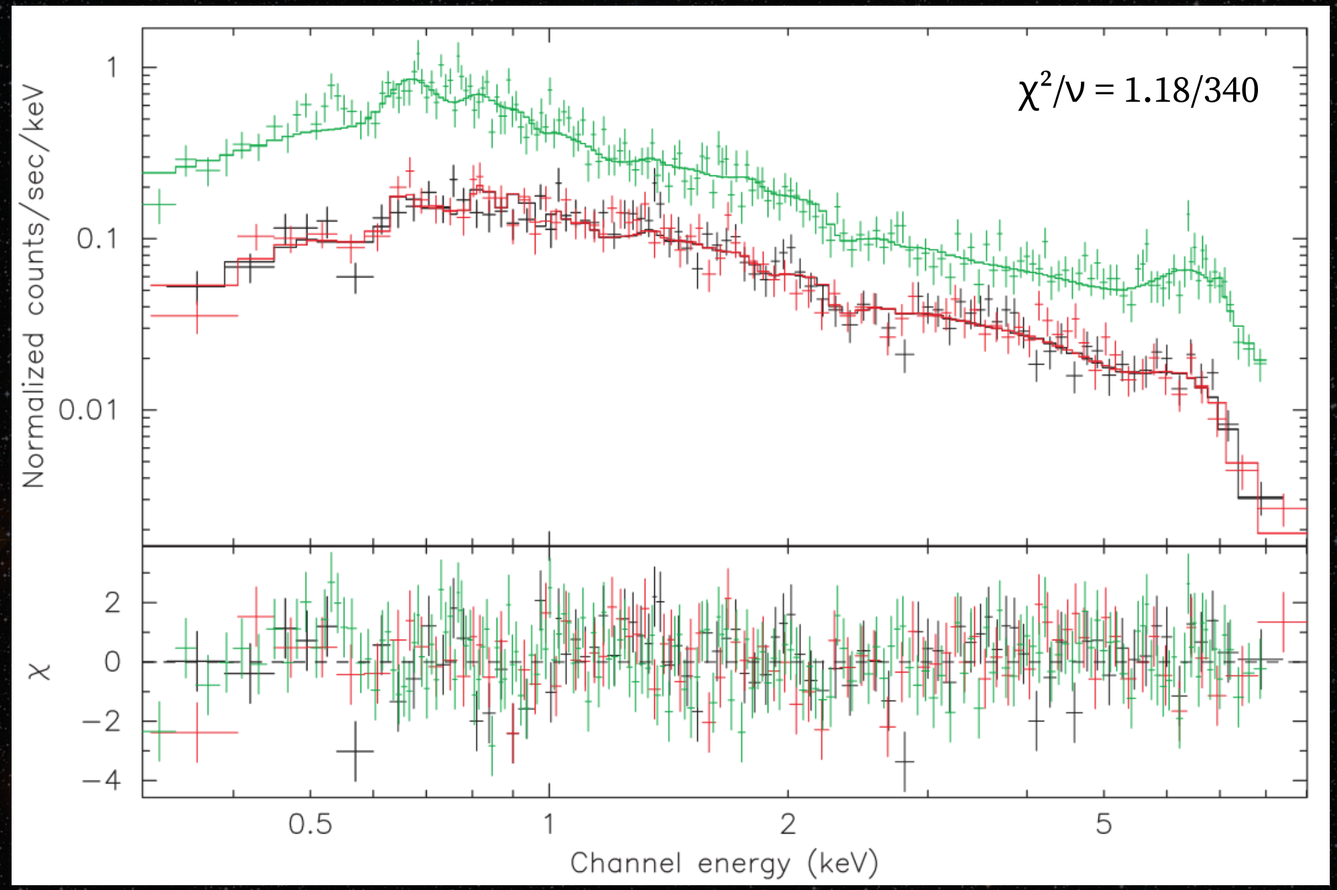
2001-02-25 (986 days after outburst)
2001-09-05 (1178 days after outburst)

Blackbody Temperature ~ 30 eV
$N_H = 4 \times 10^{22}$ cm$^{-2}$ (ISM)

$T_{low} = 0.2$ keV
$T_{high} \geq 48$ keV

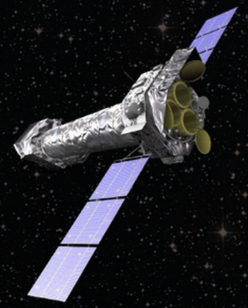
Fe $K_\alpha$ line emission at 6.4 keV

tbabs × pcfabs × (bbody + 2mekal + gauss)




Hernanz and Sala 2002 (Science)

# XMM-Newton



8.8 Years after outburst: 2007-03-24

Blackbody Temperature ~ 108 eV

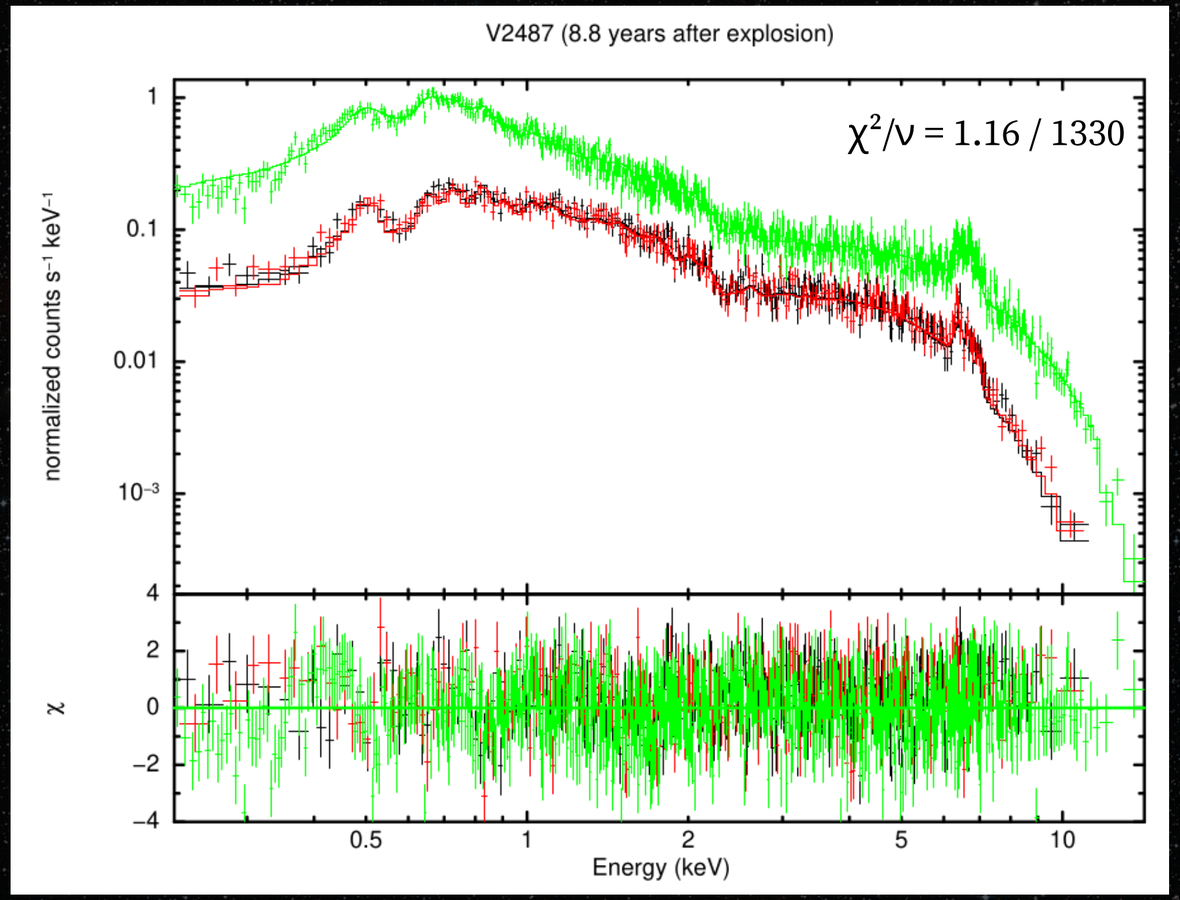
$N_H = 0.4 \pm 0.1 \times 10^{22}\ cm^{-2}$ (ISM)

$N_H = 29 \pm 6 \times 10^{22}\ cm^{-2}$ (intrinsic)

$T_{low} = 5 \pm 3$ keV

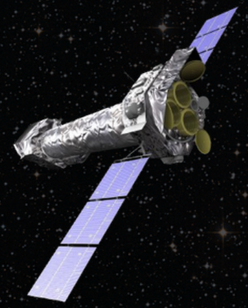
$T_{high} \geq 28$ keV

phabs × (bbody + n*mekal + gauss) × pcfabs




Carlo Ferri PhD Thesis, 2011

# XMM-Newton



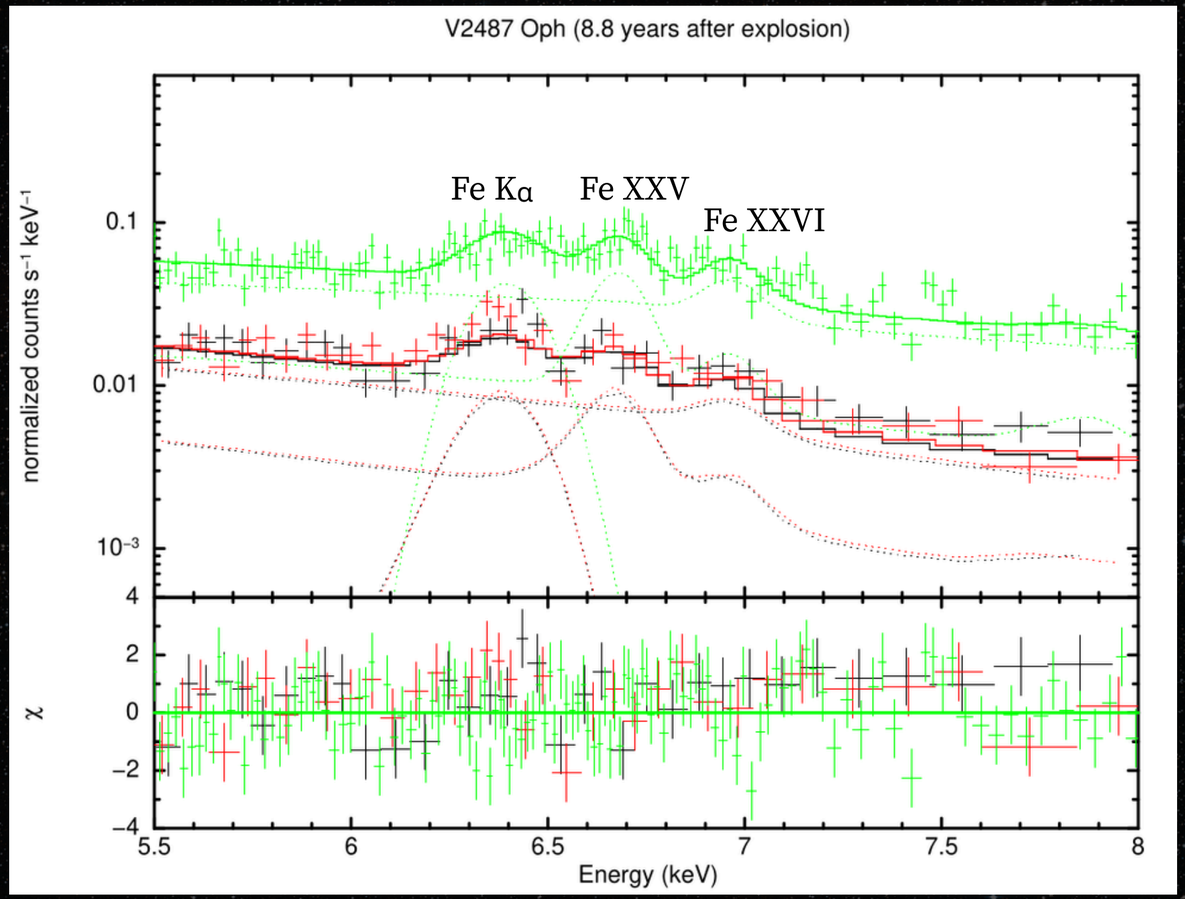
8.8 Years after outburst: 2007-03-24

Fe $K_\alpha$ emission line at 6.4 keV

Fe XXV emission line at  6.7 keV

Fe XXVI emission line at 6.97 keV

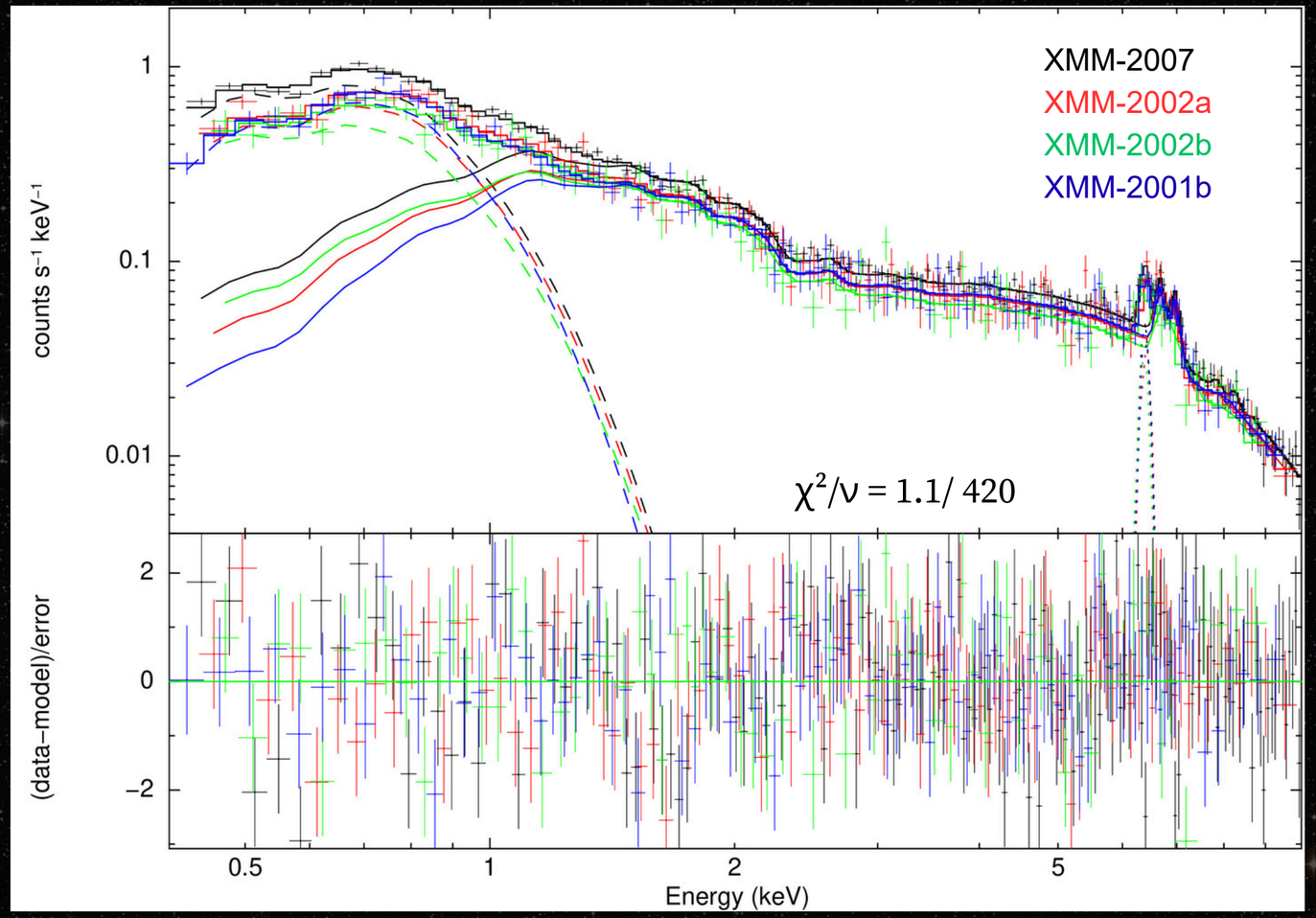
*Significant iron emission lines*




Carlo Ferri PhD Thesis, 2011

# X-ray Analysis over 23 years observations

## XMM-Newton (2001-2007)




tbabs × pcfabs × (bbody + **mkcflow** + gauss)

Blackbody Temperature ~ 108 eV

$N_H = 0.5 \pm 0.06 \times 10^{22}$ cm$^{-2}$ (ISM)

$N_H = 29 \pm 4 \times 10^{22}$ cm$^{-2}$ (intrinsic)

cvf (%) = 0.58 ± 0.04

$T_{low} \leq 2.6$ keV

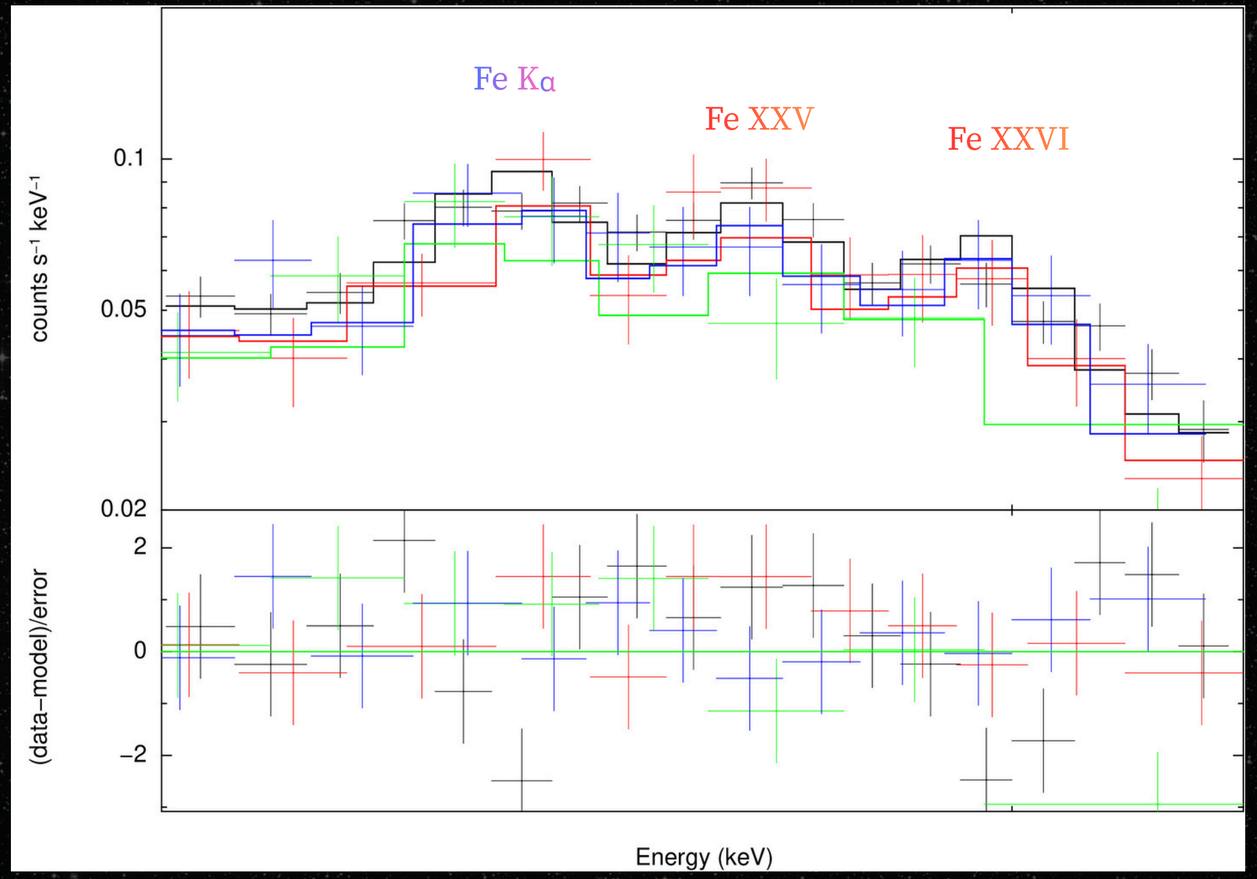
$T_{high} = 54 \pm 20$ keV

$Z = 1.8 \pm 0.6\ Z_{\odot}$

Fe $K_{\alpha} = 6.4 \pm 0.02$ keV

# X-ray Analysis over 23 years observations

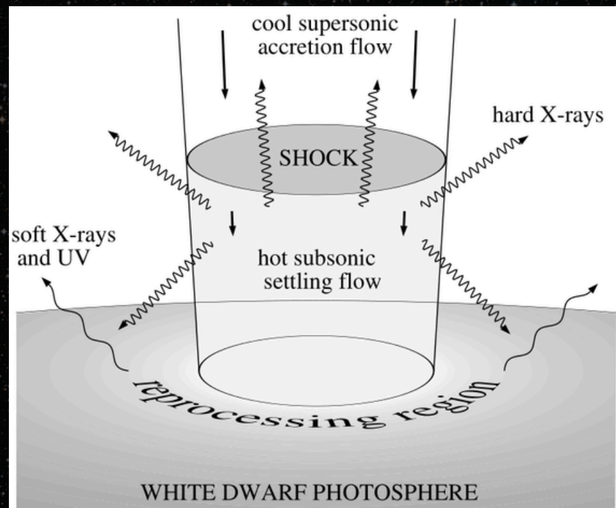
## XMM-Newton (2001-2007)




Fe Kα emission line at 6.4 keV

Fe XXV emission line at 6.7 keV

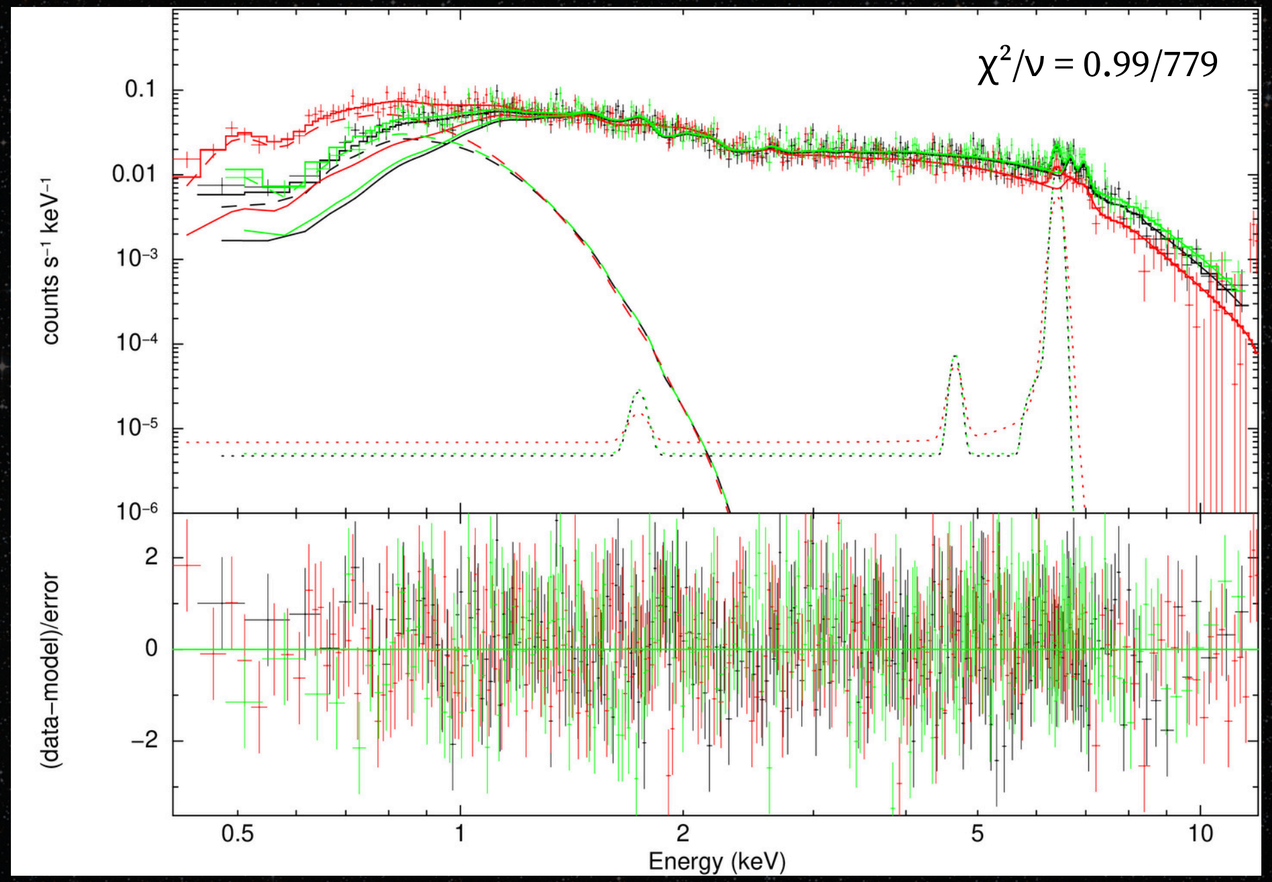
Fe XXVI emission line at 6.97 keV



# X-ray Analysis over 23 years observations

## Suzaku (2010)

12 years after the outburst




tbabs × pcfabs × (bbody + mkcflow + gauss)

Blackbody Temperature ~ 102 eV

$N_H = 0.4 \pm 0.04 \times 10^{22}$ cm$^{-2}$ (ISM)

$N_H = 26 \pm 5 \times 10^{22}$cm$^{-2}$ (intrinsic)

cvf (%) = 0.5 ± 0.05

$T_{low} \leq 2.4 \pm 1.5$ keV

$T_{high} = 34 \pm 15$ keV

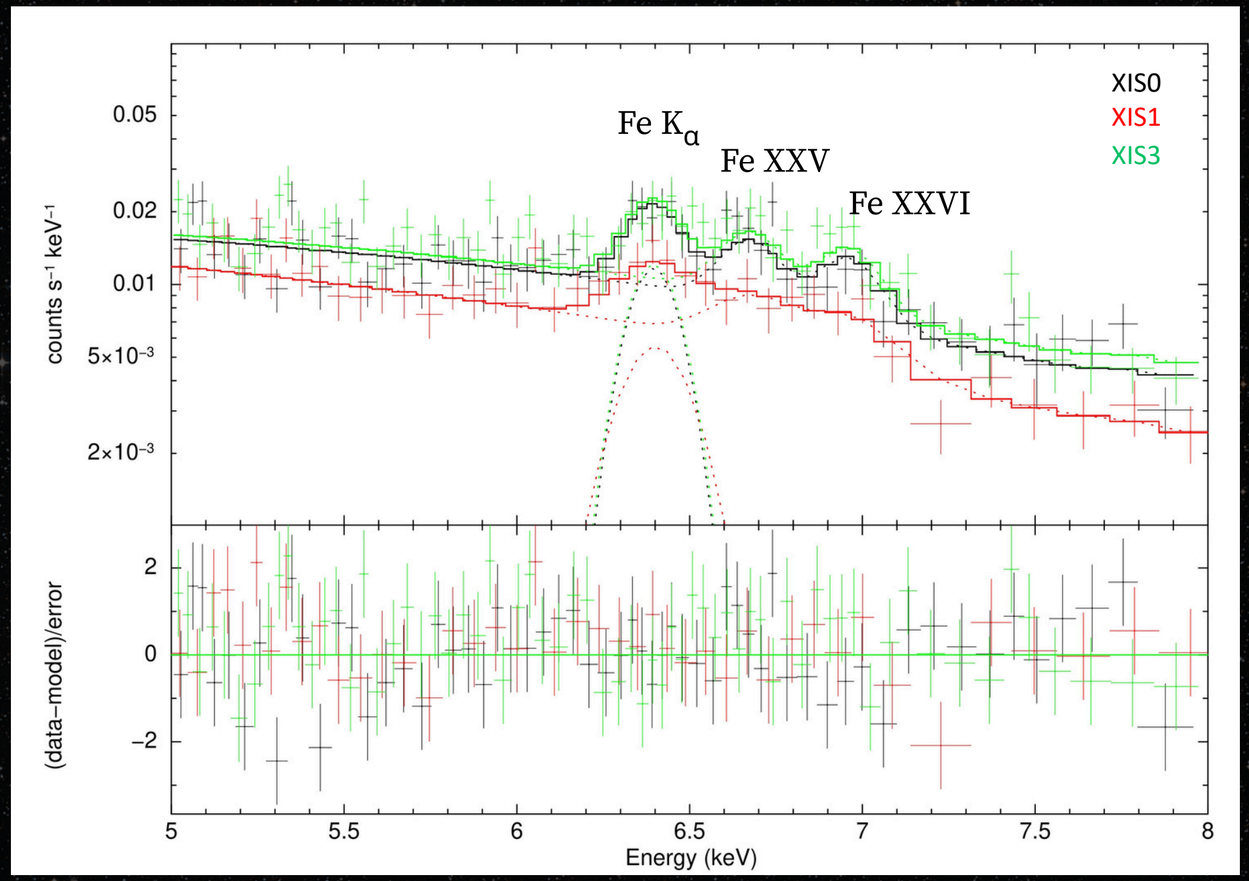
$Z = 1.1 \pm 0.4\ Z_{\odot}$

Fe $K_{\alpha} = 6.4 \pm 0.02$ keV

# X-ray Analysis over 23 years observations

## Suzaku (2010)

12 years after the outburst




Significant iron emission lines:

Fe Kα emission line at 6.4 keV

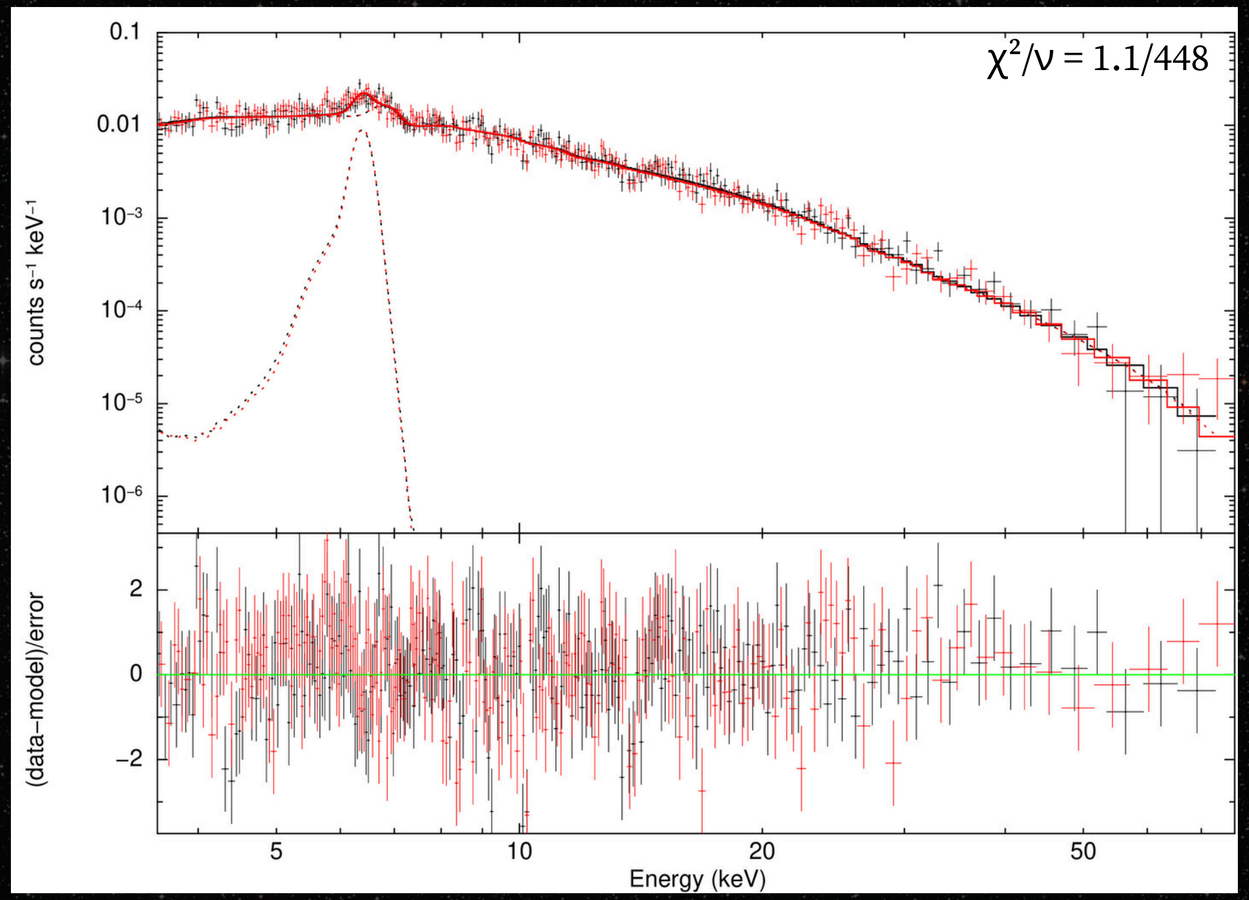
Fe XXV emission line at 6.67 keV

Fe XXVI emission line at 6.97 keV

# X-ray Analysis over 23 years observations

## NuSTAR (2024)

26 years after the outburst




tbabs × pcfabs × (**reflect** × mkcflow + gauss)

$N_H = 4 \times 10^{22}$ cm$^{-2}$ (intrinsic) *(fixed)*

cvf (%) = 0.52 *(fixed)*

$T_{low} \geq 0.74$ keV

$T_{high} \geq 74.8$ keV

$Z = 1.5 \pm 0.4\ Z_\odot$

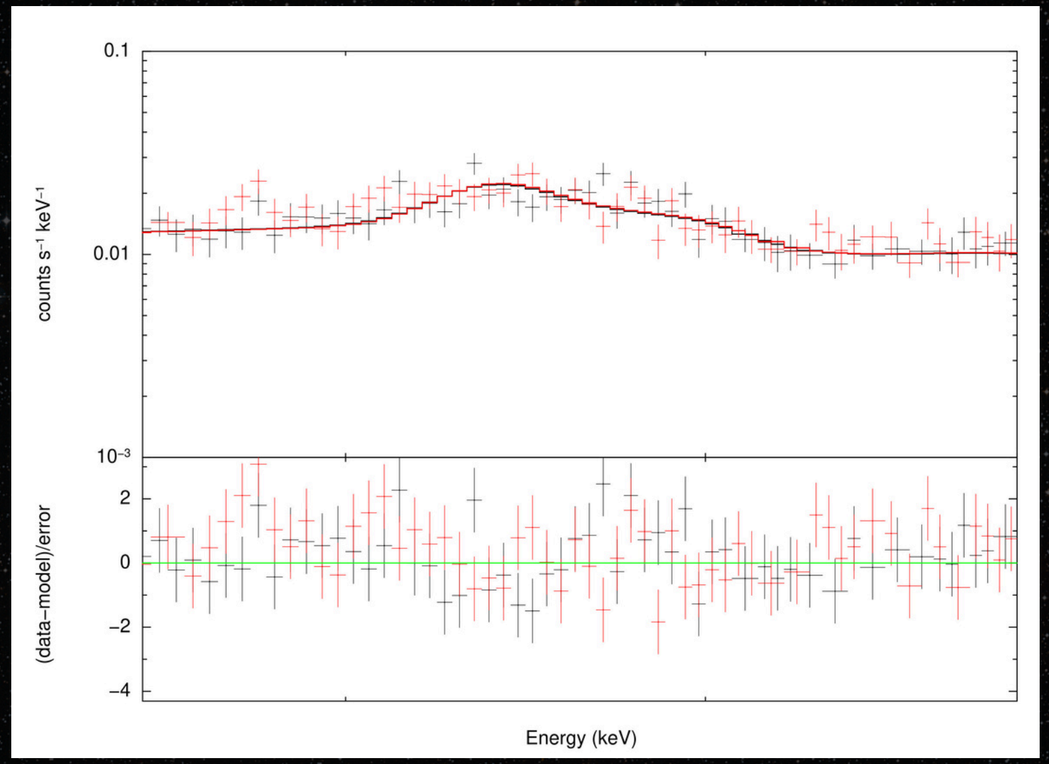
$\Omega = 1.08$ (-0.18, +0.82)

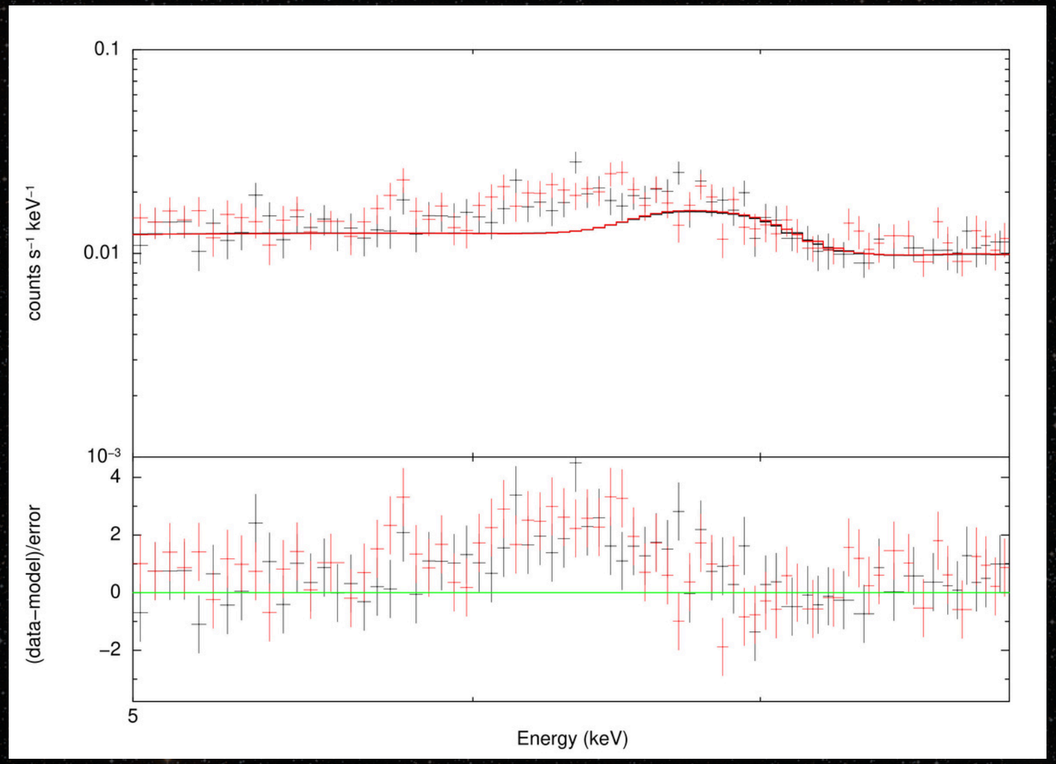
cosi ≥ 0.45

# X-ray Analysis over 23 years observations

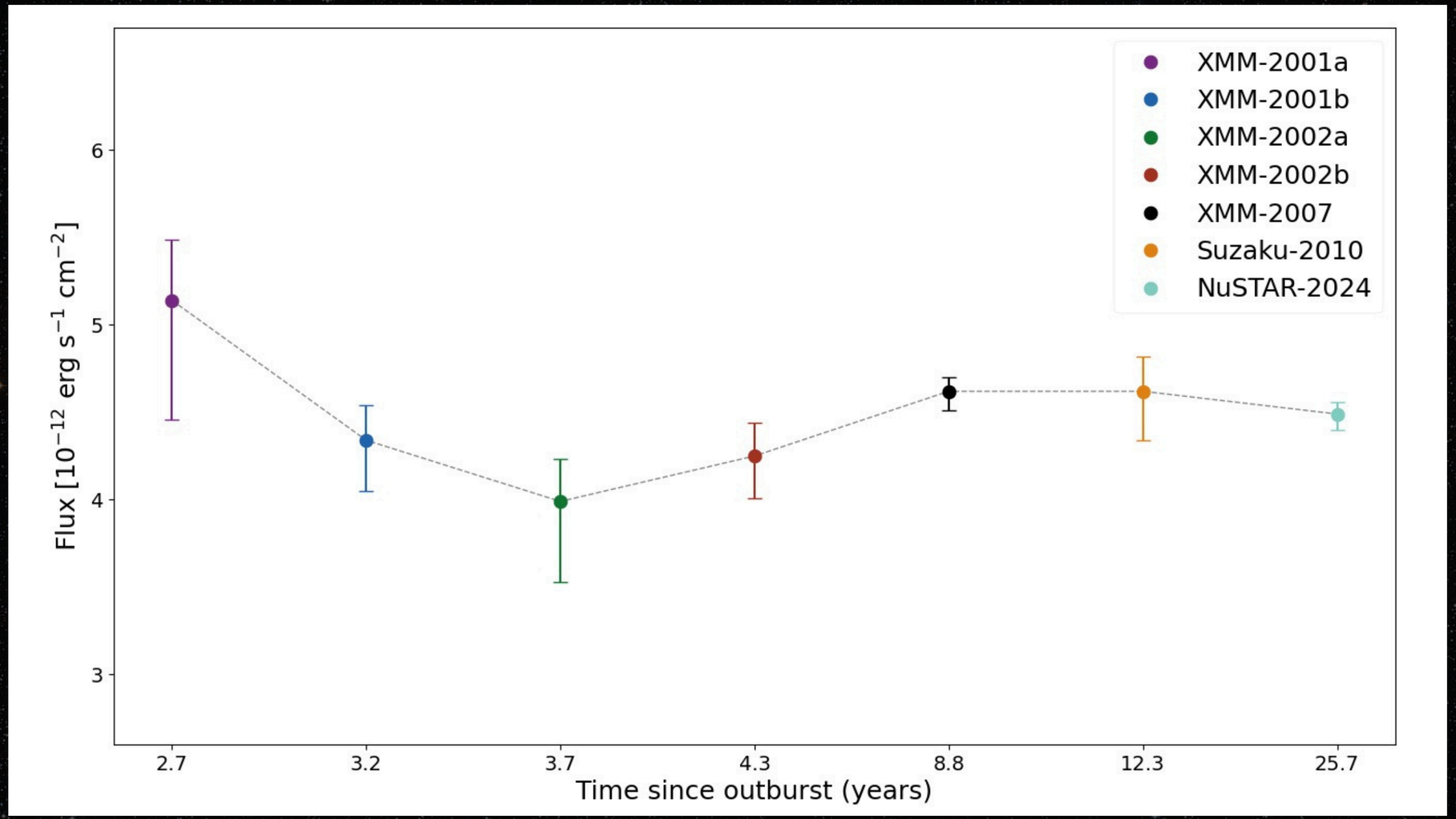
## NuSTAR (2024)

tbabs × pcfabs × (**reflect** × mkcflow + gauss)



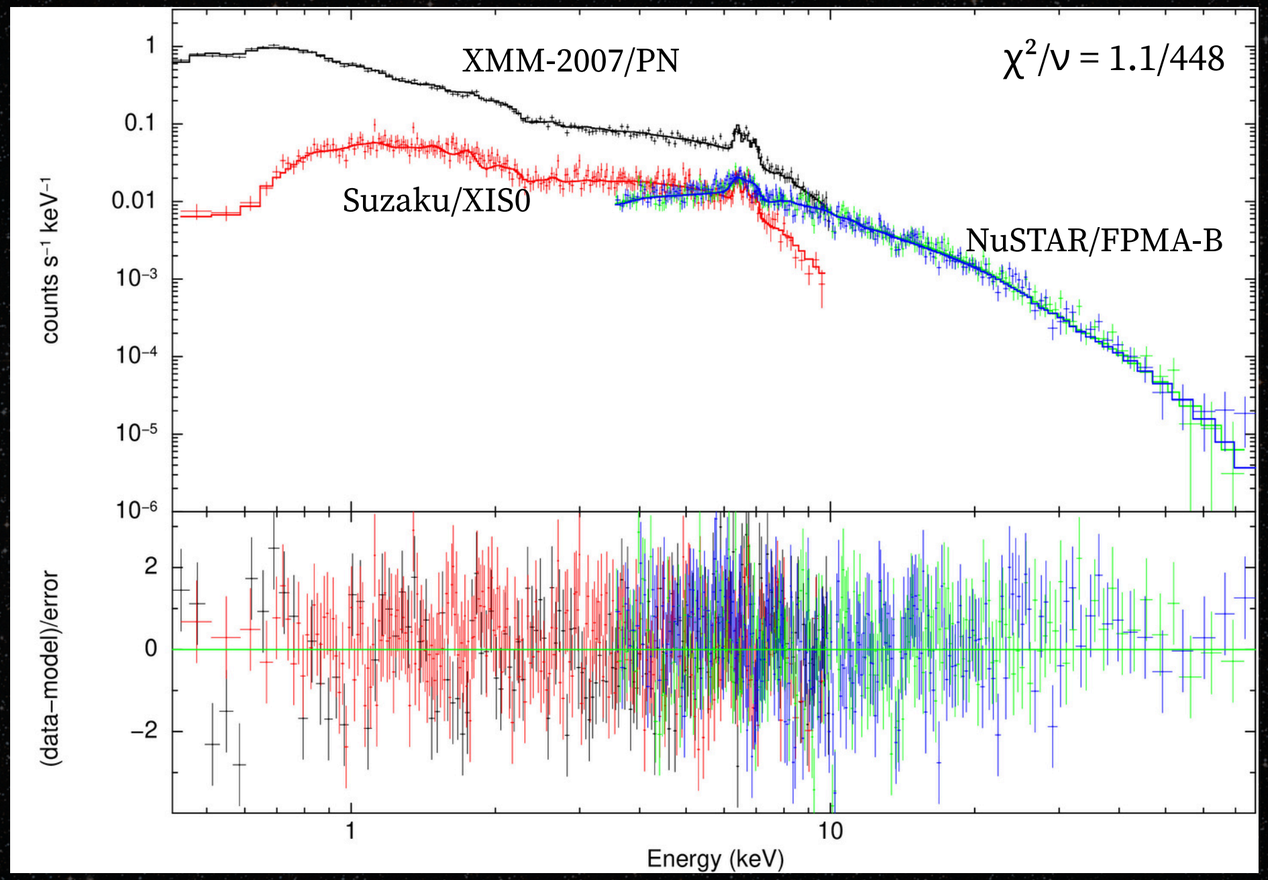



# Flux of X-ray Observations



# X-ray Analysis over 23 Years of Observations

## Broadband X-ray Analysis (0.4 - 78.0 keV)




tbabs × pcfabs × **bbody** (**reflect** × mkcflow + gauss)

Blackbody Temperature ~ 100 eV

$N_H = 0.4 \pm 0.02 \times 10^{22}$ cm$^{-2}$ (ISM)

$N_H = 17 \pm 3 \times 10^{22}$ cm$^{-2}$ (intrinsic)

cvf (%) = 0.5 ± 0.05

$T_{low} \leq 1.9$ keV

$T_{high} = 70 \pm 5$ keV

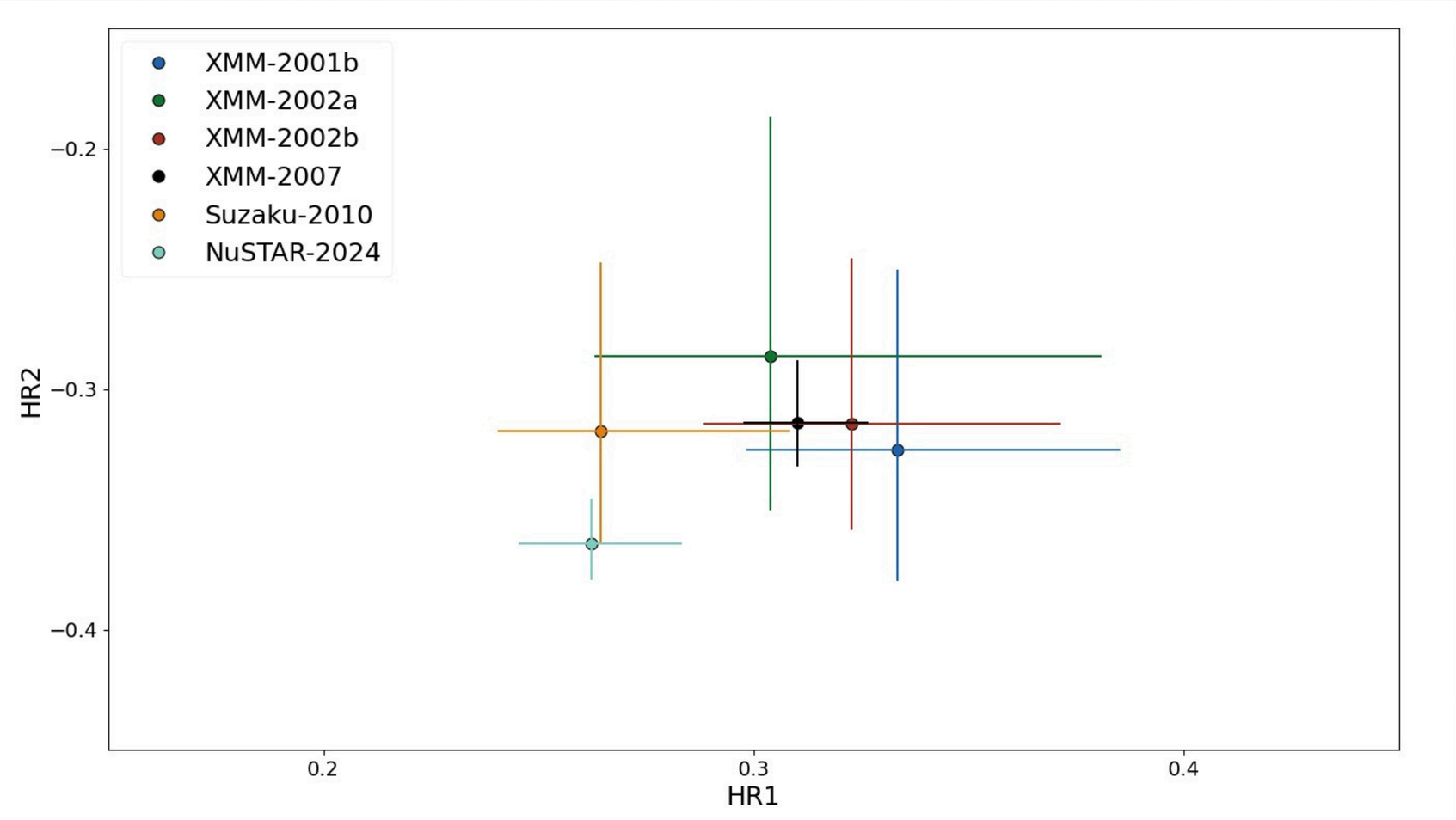
$Z = 1.8 \pm 0.6$ Z

Fe K$\alpha$ = 6.4 ± 0.02 keV

$\Omega = 1.0 \pm 0.3$

cosi ≥ 0.61

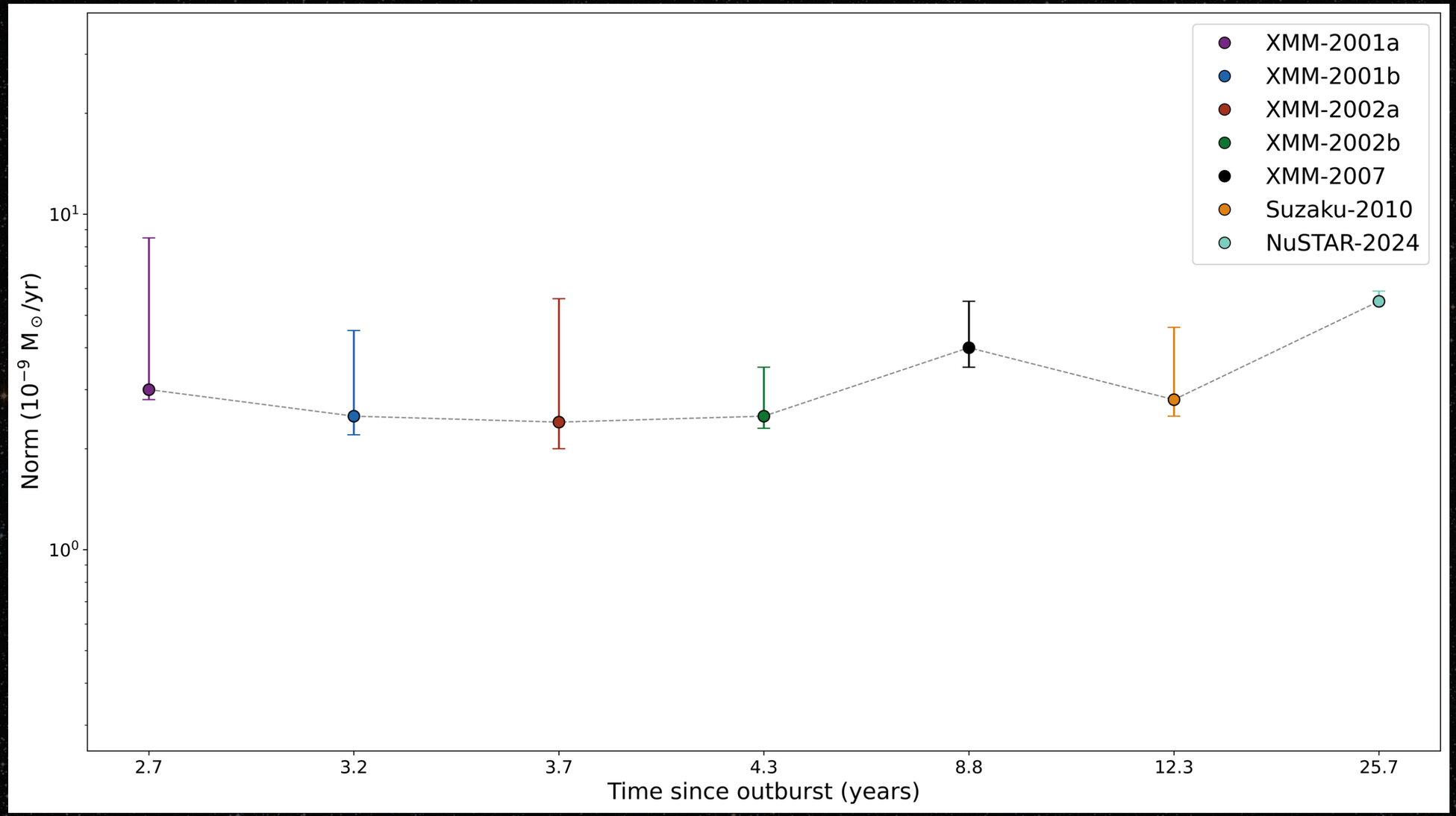
# Hardness Ratio of X-ray Observations



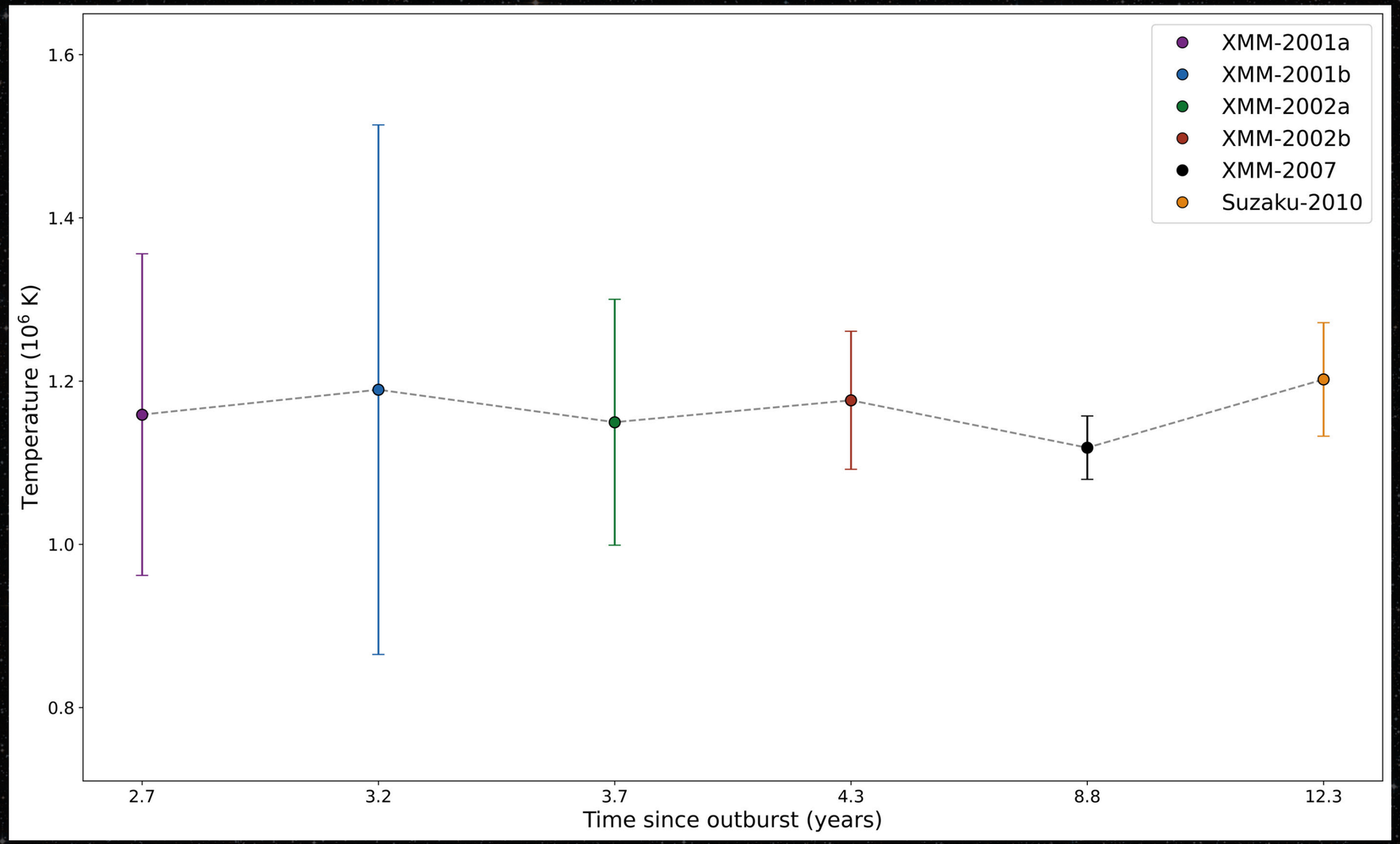

band 1 = 3.0 keV - 5.0 keV
band 2 = 5.0 keV - 8.0 keV
band 3 = 8.0 keV - 10.0 keV

**HR = (H-S)/(H+S)**

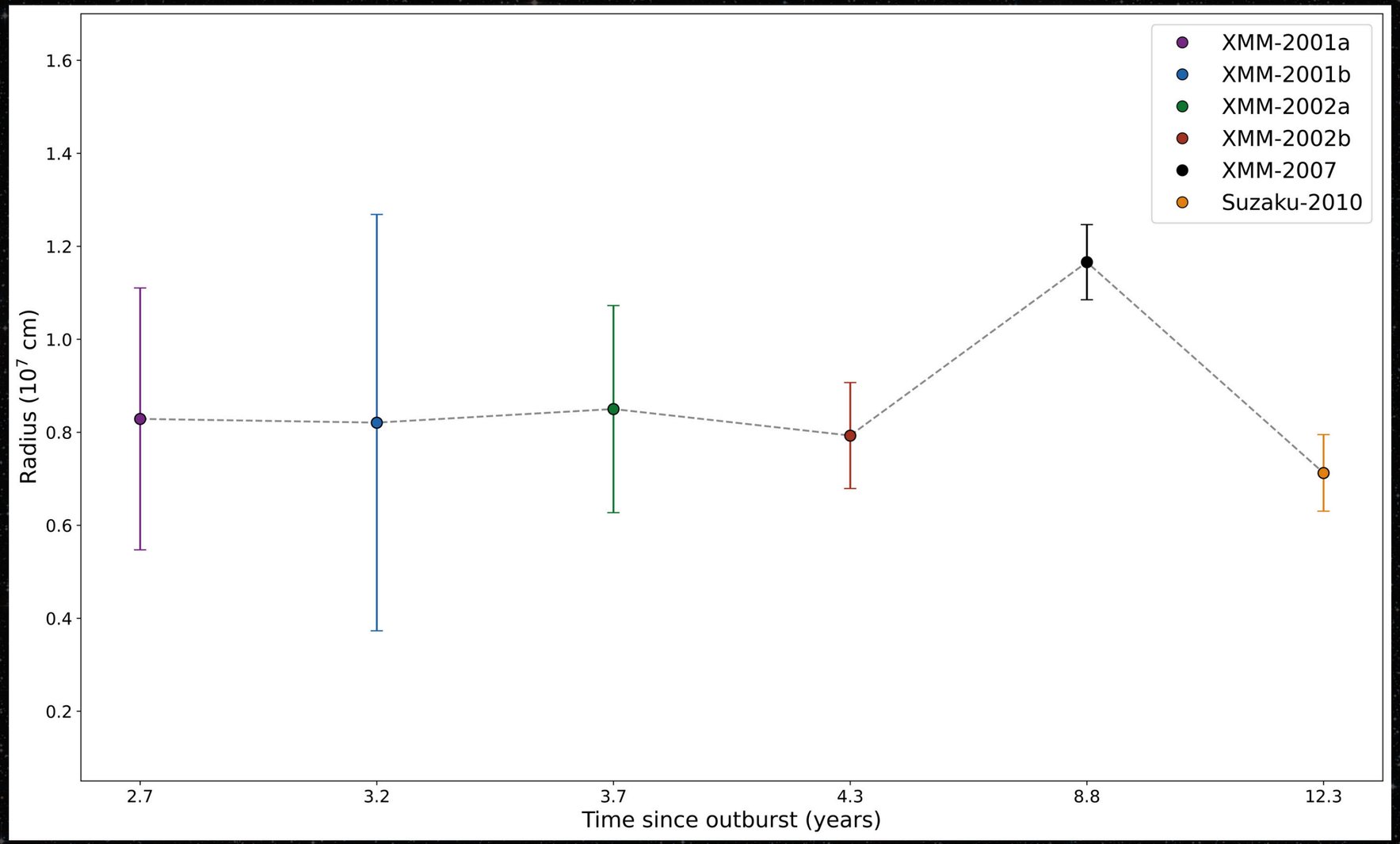
# Plasma Evolution (2001-2024)



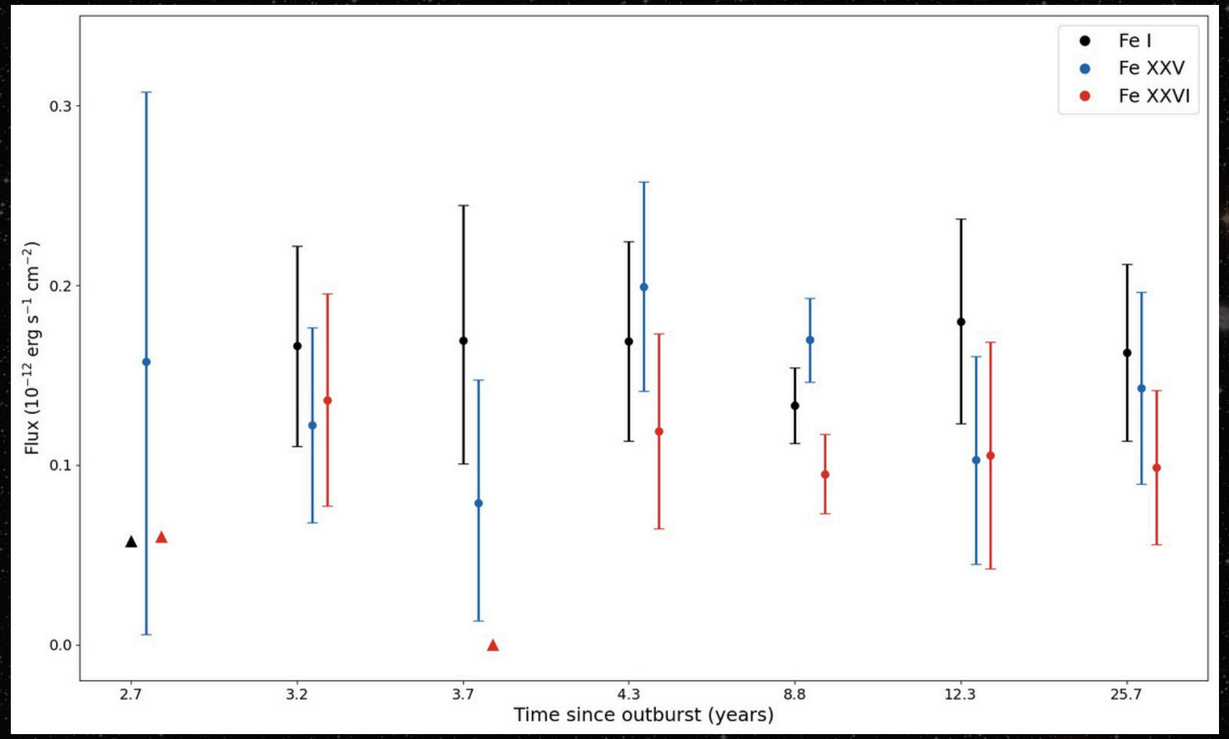
# Blackbody Evolution (2001-2010)

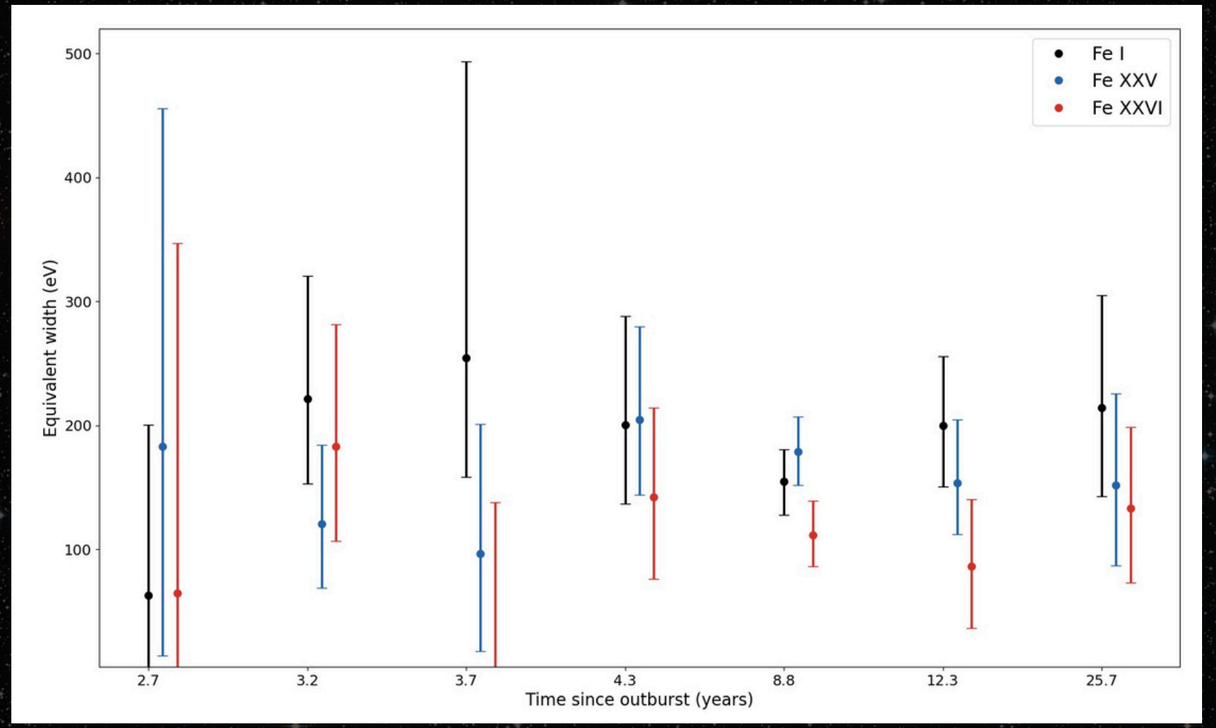


# Blackbody Evolution (2001-2010)



# Flux and EW of Iron Lines from 2001 to 2024



# Take home messages

- EW of the highly ionized iron lines (from shock-heated plasma)
- Plasma temperature evolution
- Hardness Ratio of the spectra

is the cooling flow ***cooling down****?*

- **reflection**

*Thank you!*