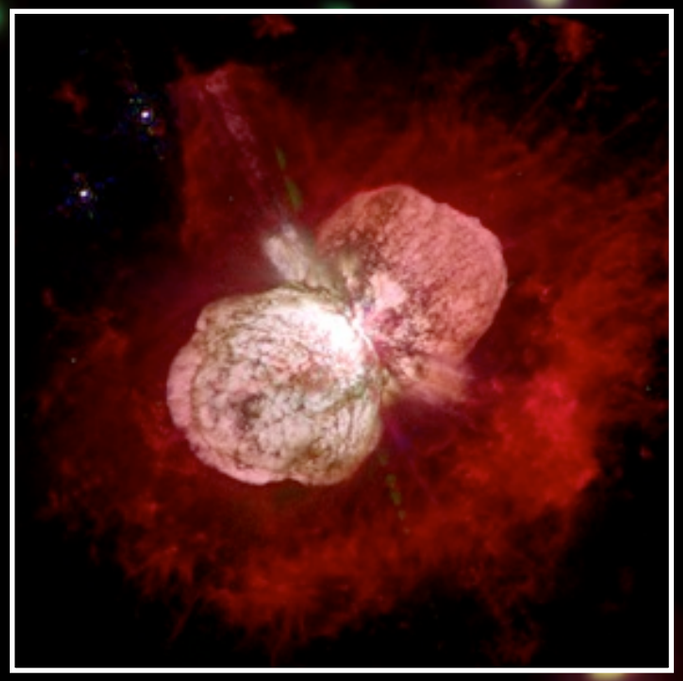
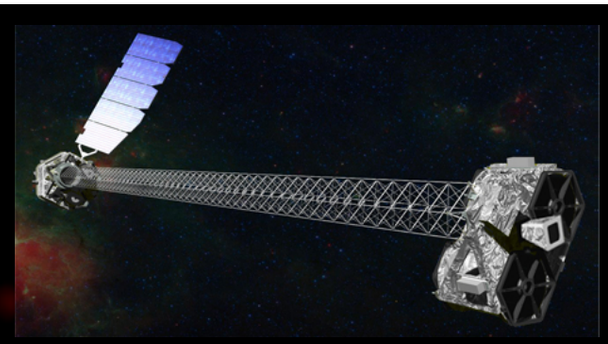
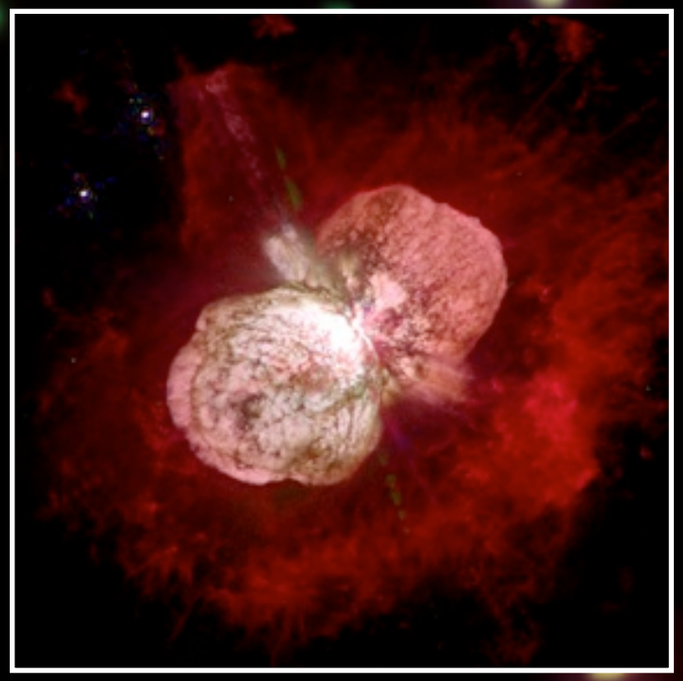




The Orbital Variation of Non-Thermal X-ray Emission from eta Carinae

Kenji Hamaguchi (NASA/GSFC & UMBC)
Michael F. Corcoran (NASA/GSFC & CUA)
Eta Carinae Team



Extended Emission

X-ray Homunculus Nebula

Outer Debris Field

Central Point Source

Wind-wind Colliding (WWC) Emission

Central Constant Emission

Chandra Observatory

X-ray True Color Image

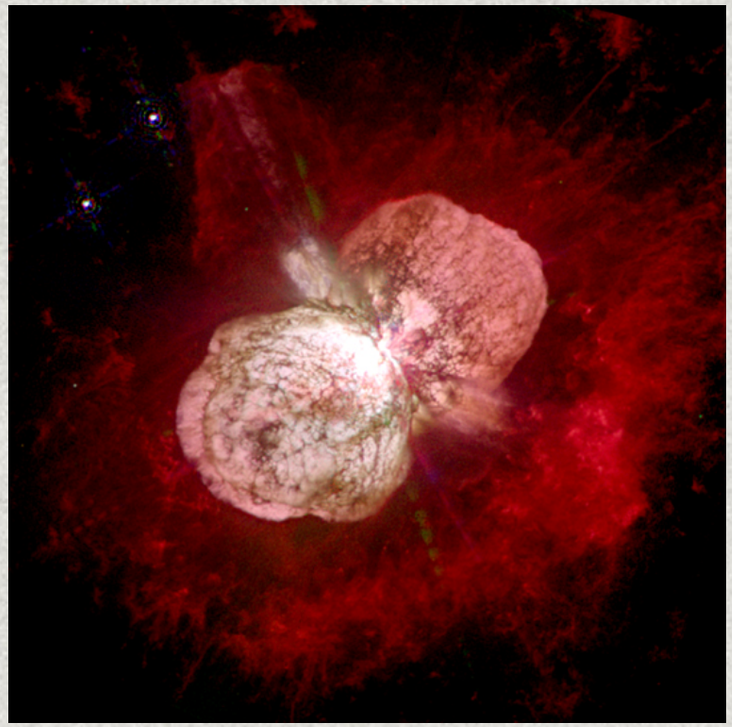
10”

23 kAU

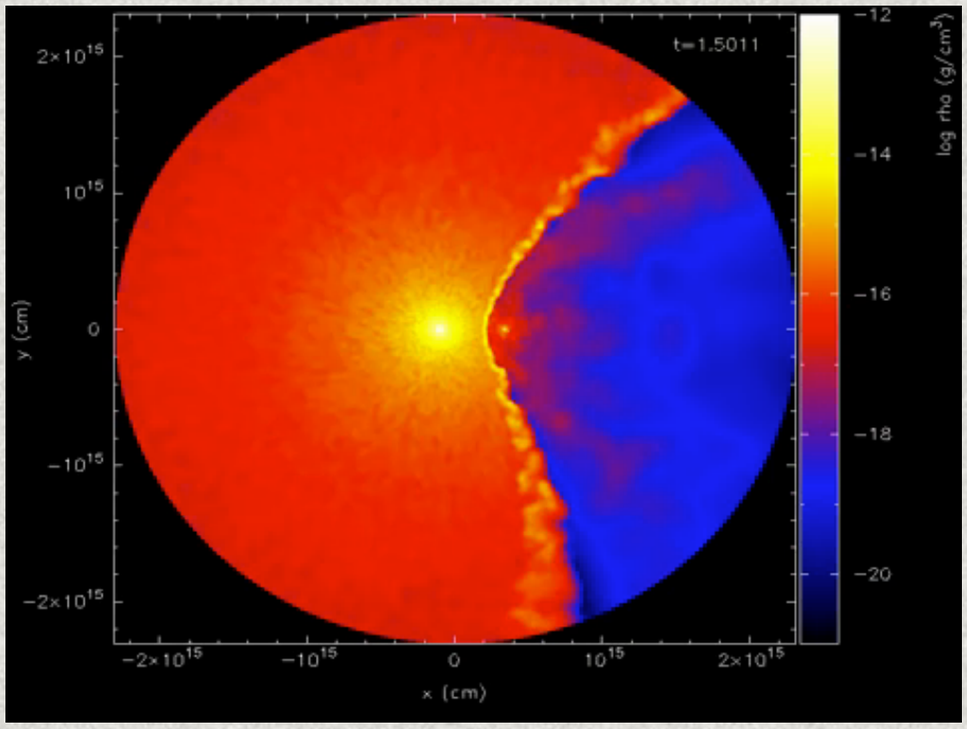
Eta Carinae

- Evolved supermassive star at 2.3 kpc
  - Hypernova progenitor?
  - Future γ-ray burst?
- Strong mass loss
  - Great eruption in ~1840
- Embedded binary system
  - *P* ~2023 days (~5.5 years)
  - *e* ~0.9
  - companion hasn't been seen directly.

	Type	Mass	*M*dot	v_{wind}
		$M_\odot$	$10^{-4} M_\odot$ yr^{-1}	km s^{-1}
A	LBV	90	8.5	420
B	O, WN?	30	0.1	3000



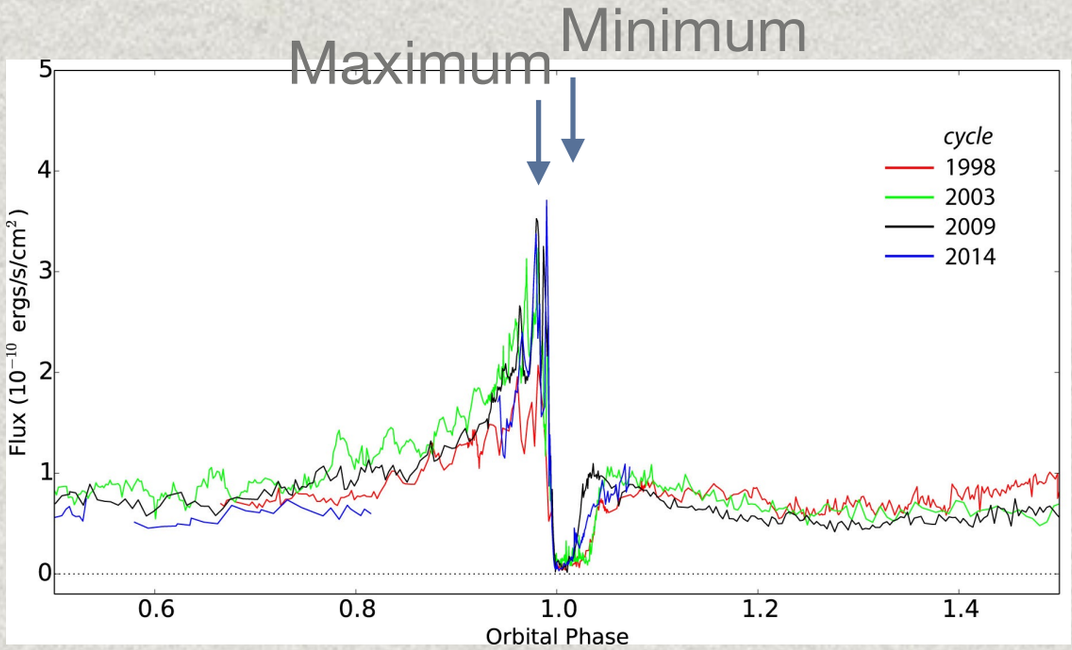
HST image of η Car



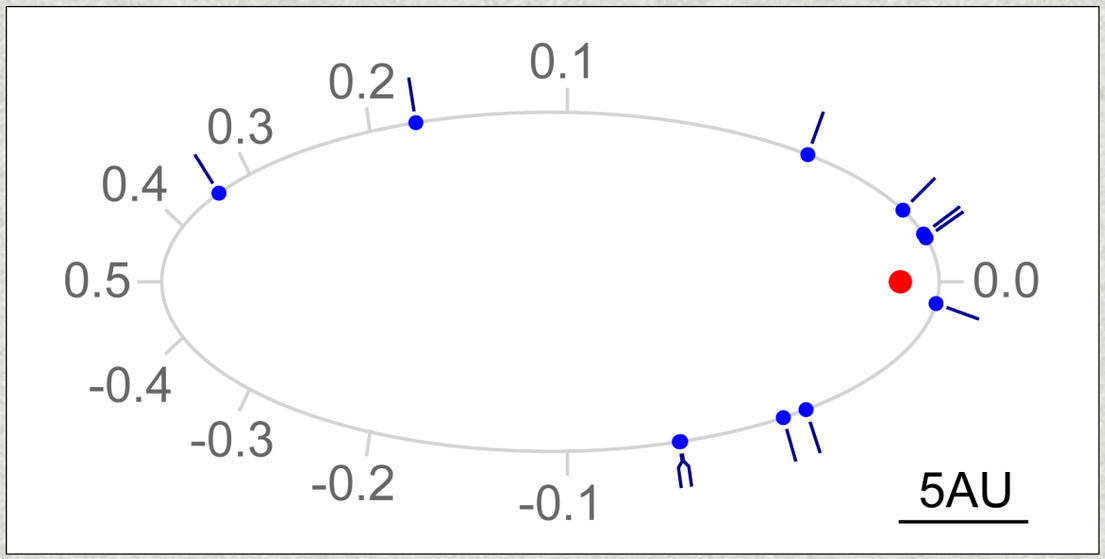
SPH simulation of the wind collision
Russell+2016

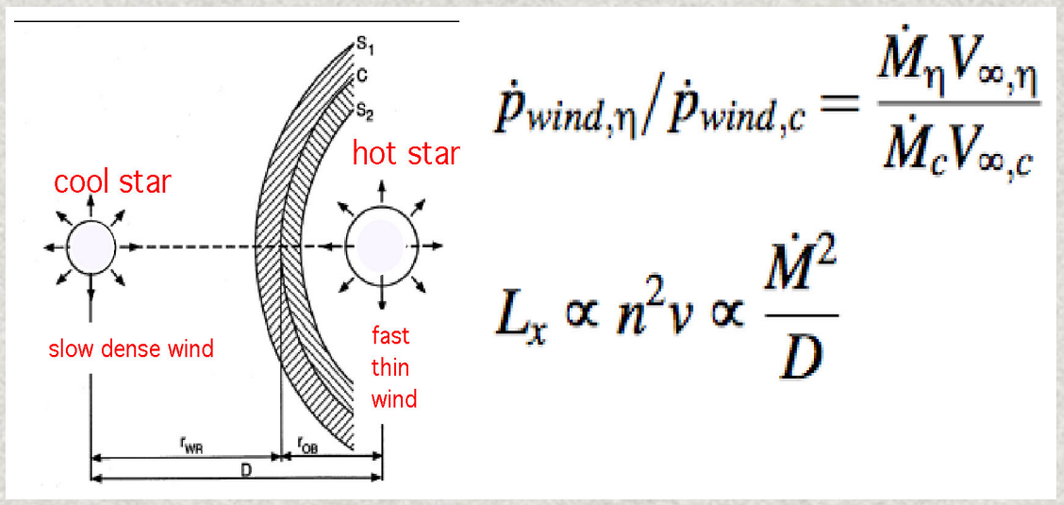
Wind-wind Colliding Activity

- Hot plasma emission
  - *kT* ~4-5 keV
  - *L*x increase toward periastron
- Plasma heating by wind-wind collision
- X-ray Minimum
  - Eclipse
  - Activity decay



RXTE/Swift phase folded light curves





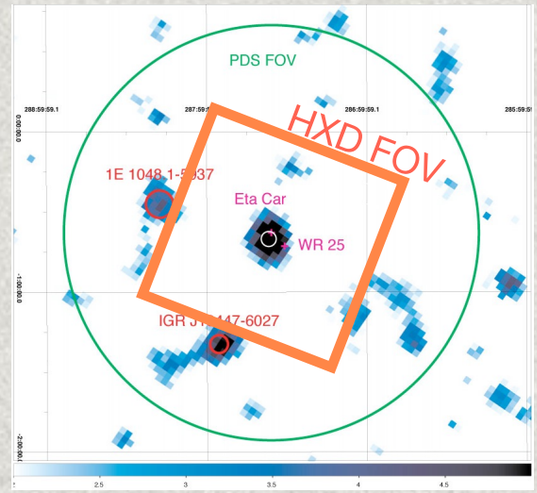
$$\dot{p}_{wind,\eta} / \dot{p}_{wind,c} = \frac{\dot{M}_\eta V_{\infty,\eta}}{\dot{M}_c V_{\infty,c}}$$

$$L_x \propto n^2 v \propto \frac{\dot{M}^2}{D}$$

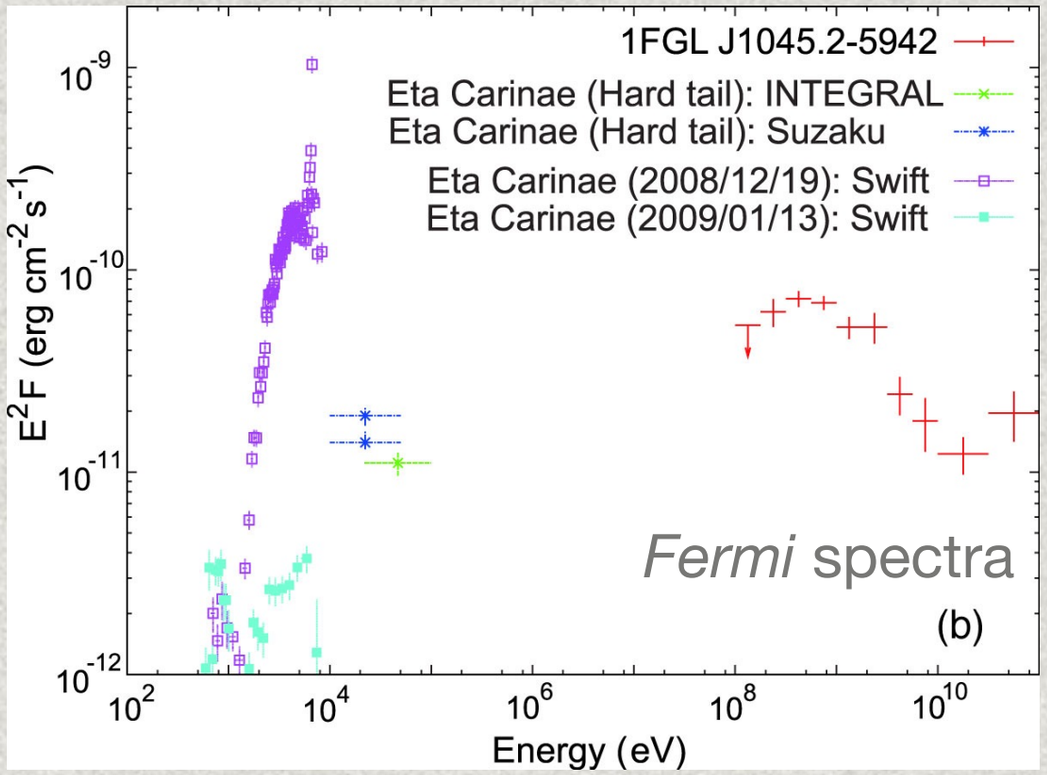
Extremely high-*E* Comp.?

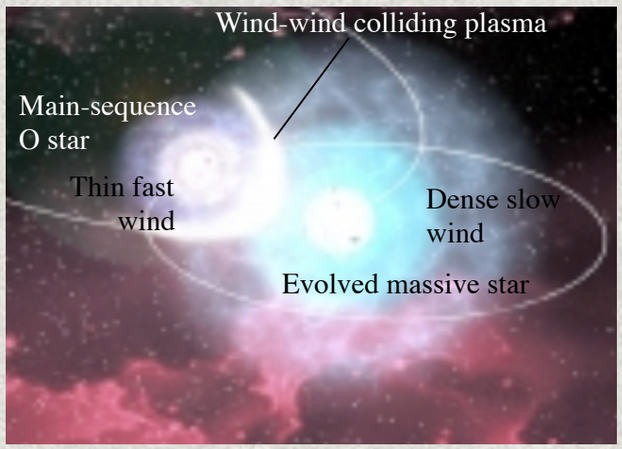
- X-rays (20-100 keV)
  - stable?
- γ-rays (GeV, TeV)
  - as powerful as a pulsar
  - orbital variation?
- Non-thermal?
  - Inverse-Compton?
  - Pion decay?

- Is it originated from *η* Car?
  - >~1’ position uncertainty
- How are the orbital variation?



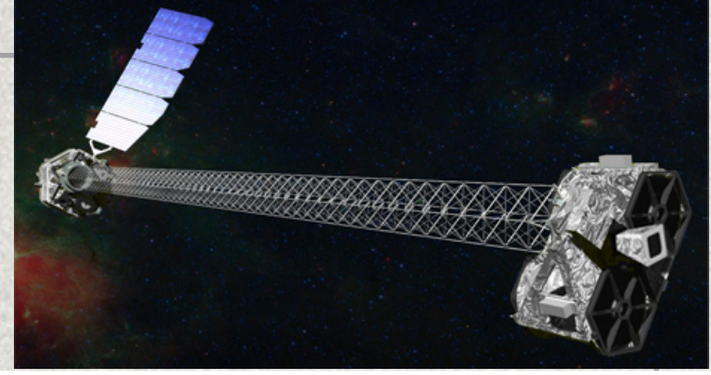
22-100 KEV W/INTEGRAL

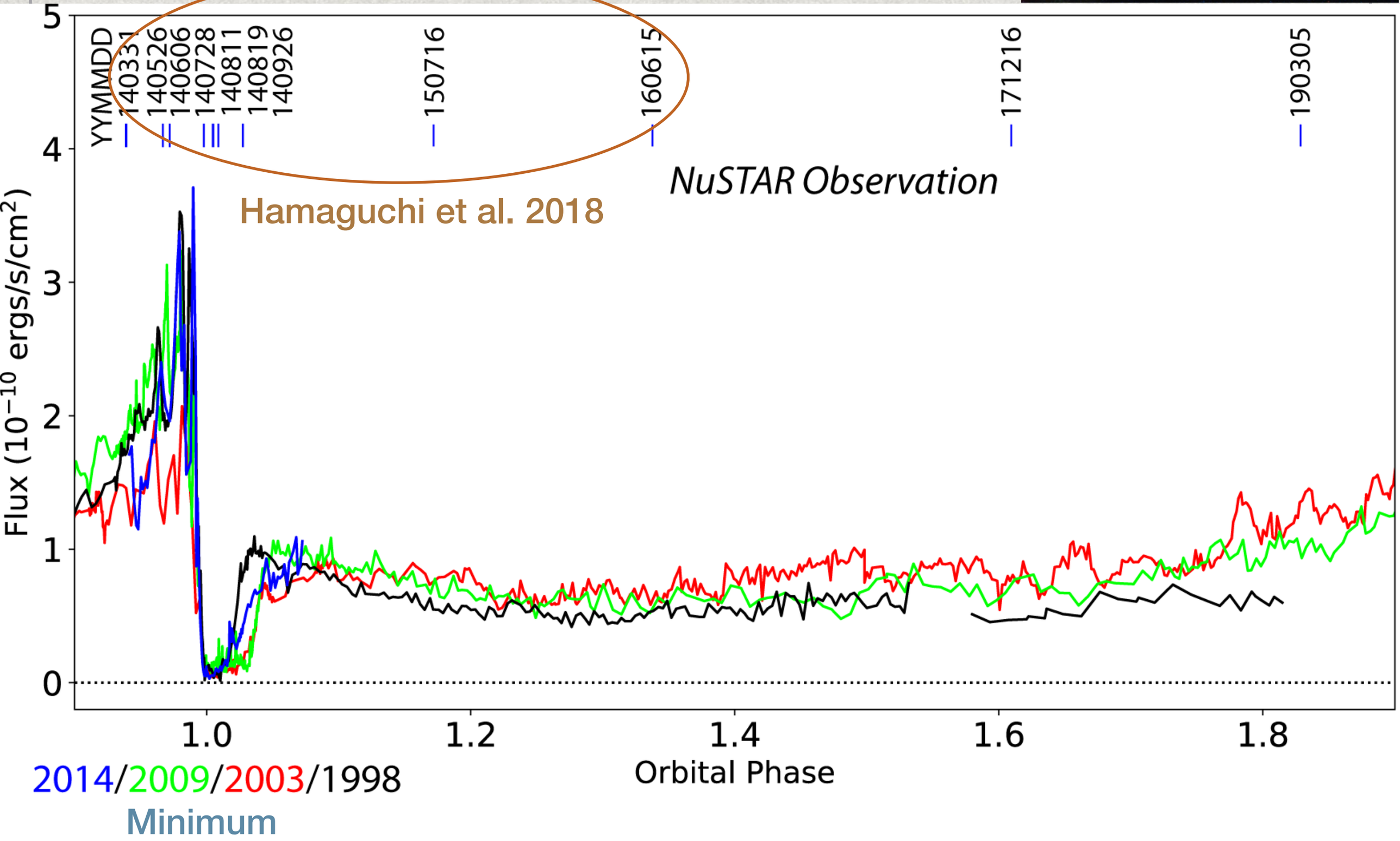




20-100 keV X-rays: Leyder+2008,2010, Sekiguchi+2009, Hamaguchi+2014, Hamaguchi+2016
GeV gamma-rays: Tavani+2009, Abdo+2010, Reitberger+2012,2015

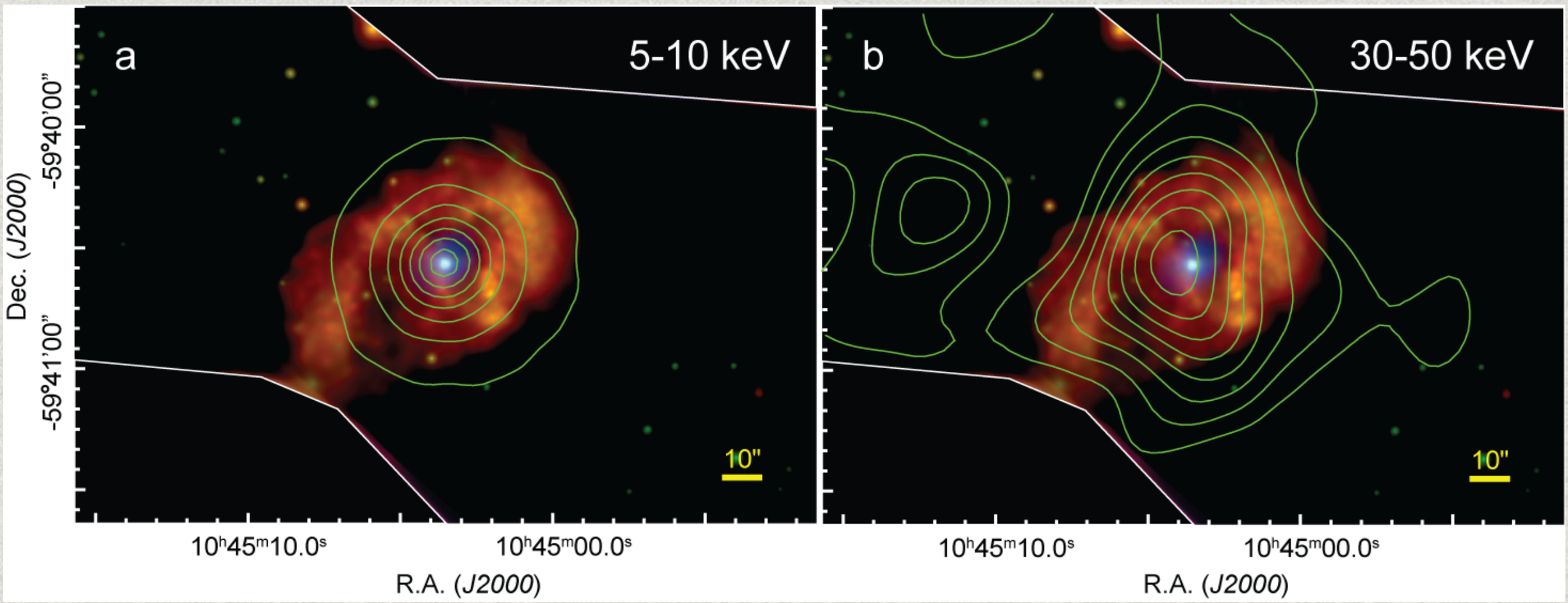
NuSTAR Observations





X-ray Images

- *NuSTAR* Image Contour on a *Chandra* true color image
  - Combination of two observing data after periastron (2015+2016)

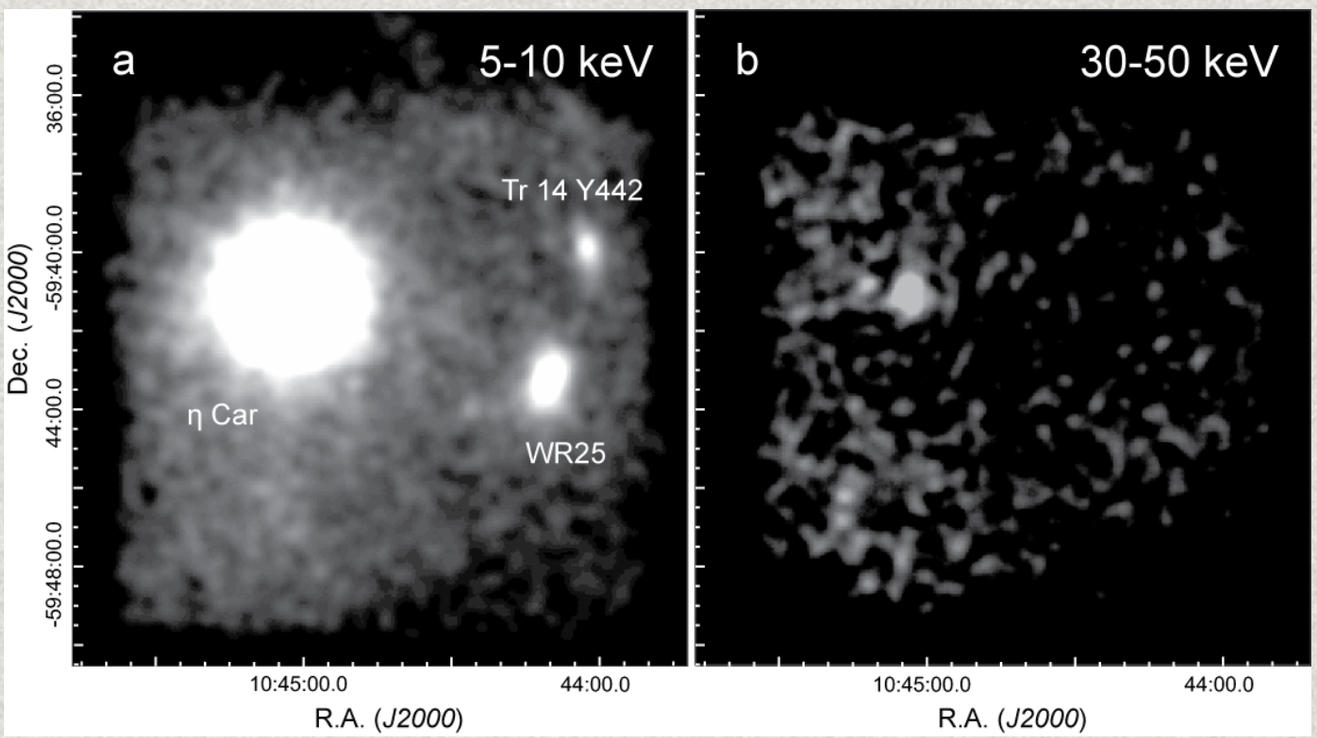


- The extremely hard X-ray source is located within $5''$ from the central binary system.

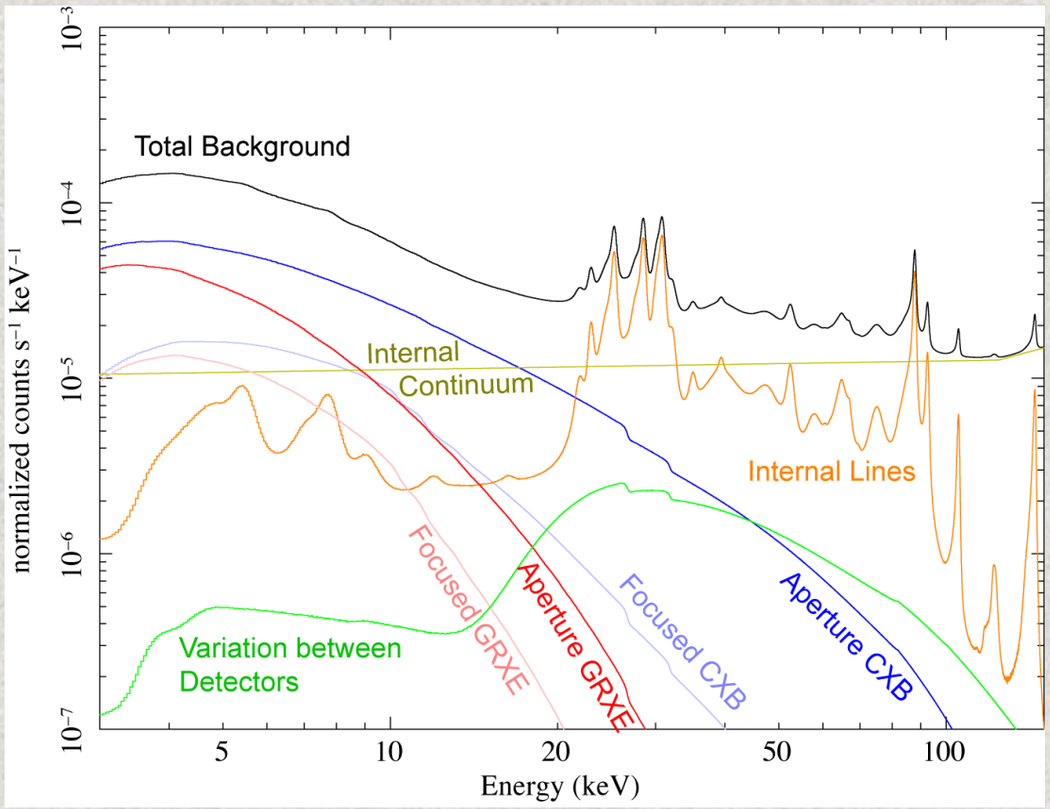
NuSTAR Background Reduction

- Remove the high background intervals
- Take a small ($r = 30'$) source region
- Estimate remaining background with Nuskybgd
  - Wik et al. 2014

NuSTAR image



Background components



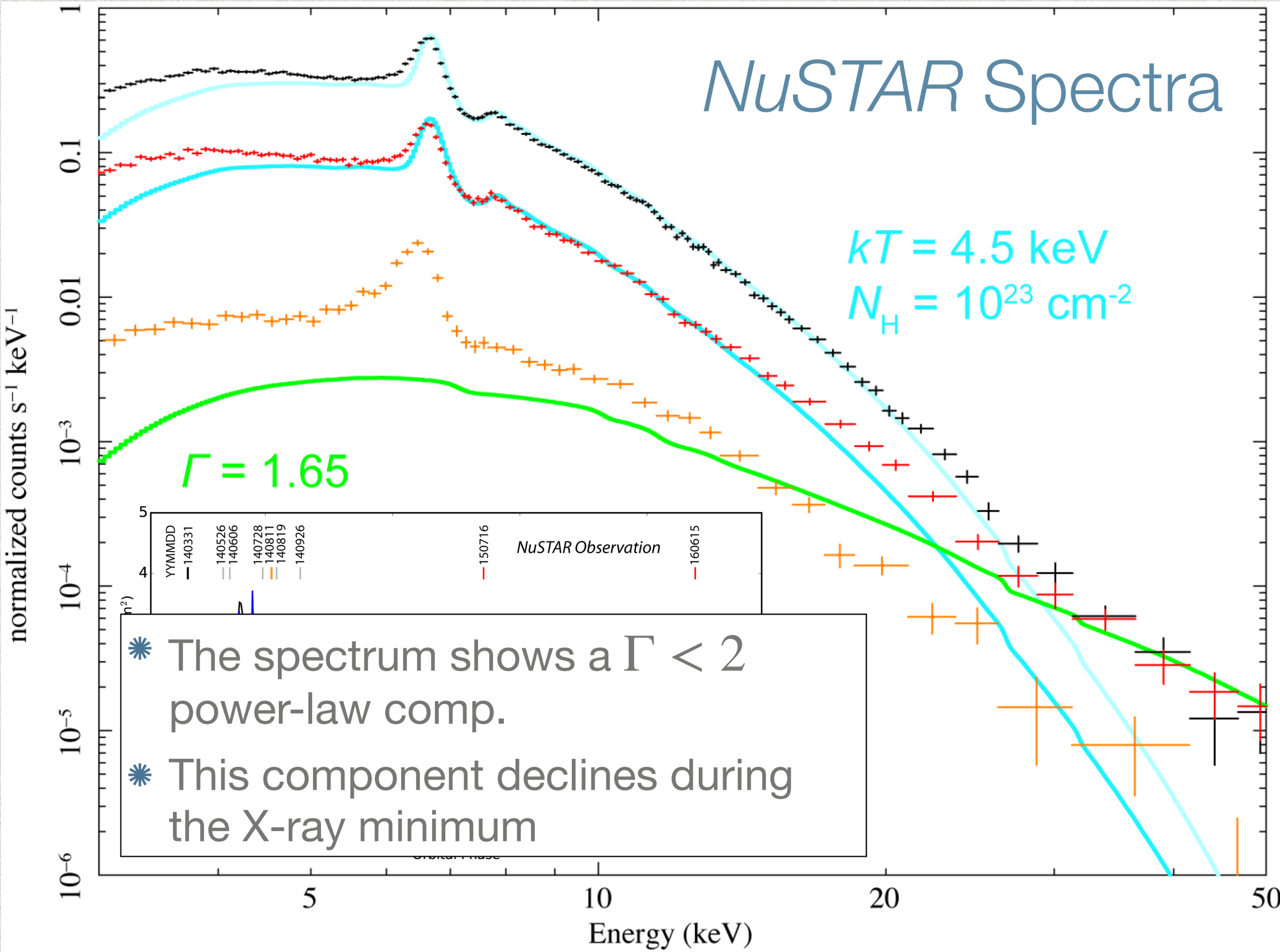
NuSTAR Spectra

kT = 4.5 keV

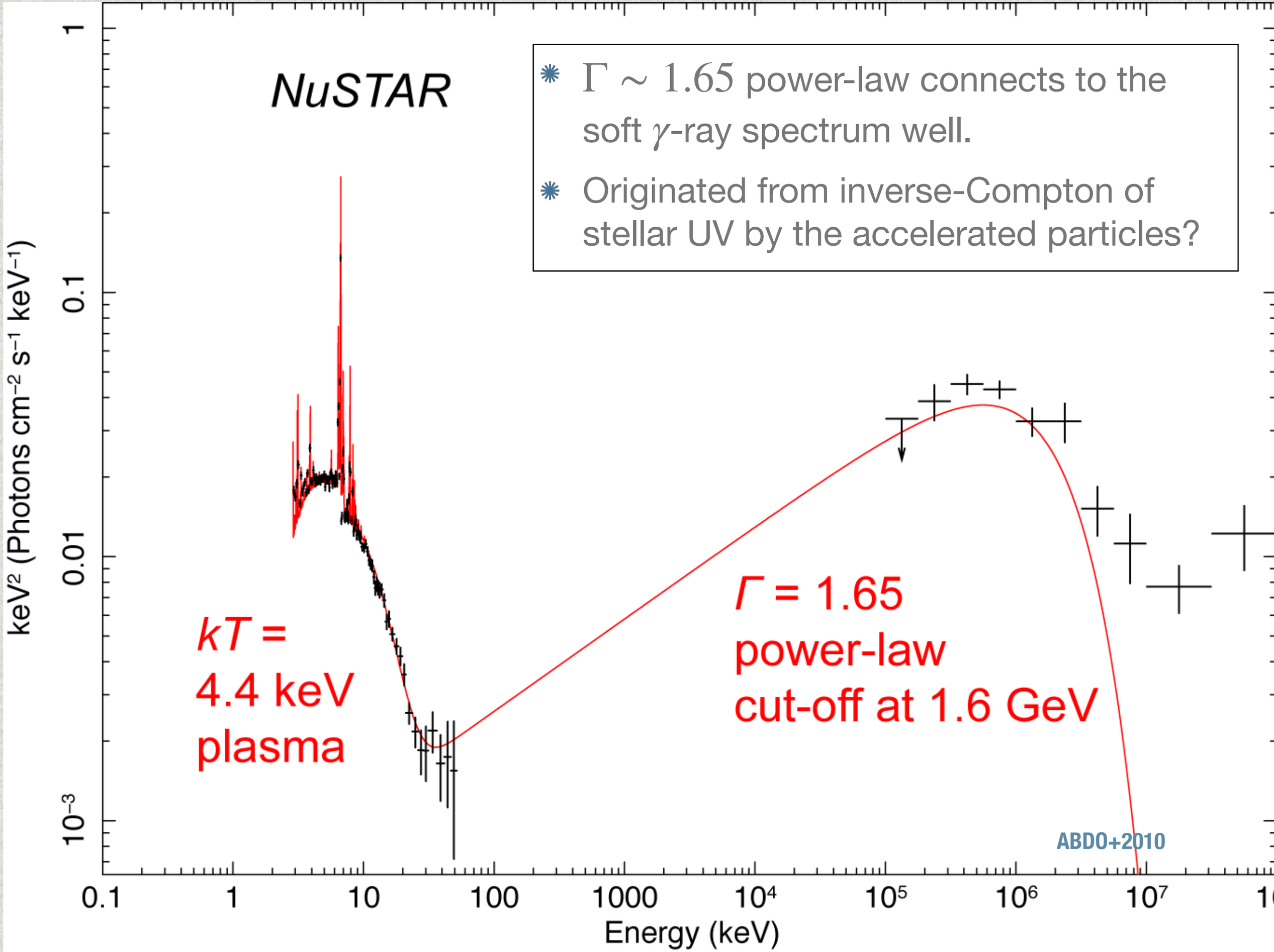
$N_H = 10^{23}$ cm^{-2}

Γ = 1.65

- The spectrum shows a $\Gamma < 2$ power-law comp.
- This component declines during the X-ray minimum



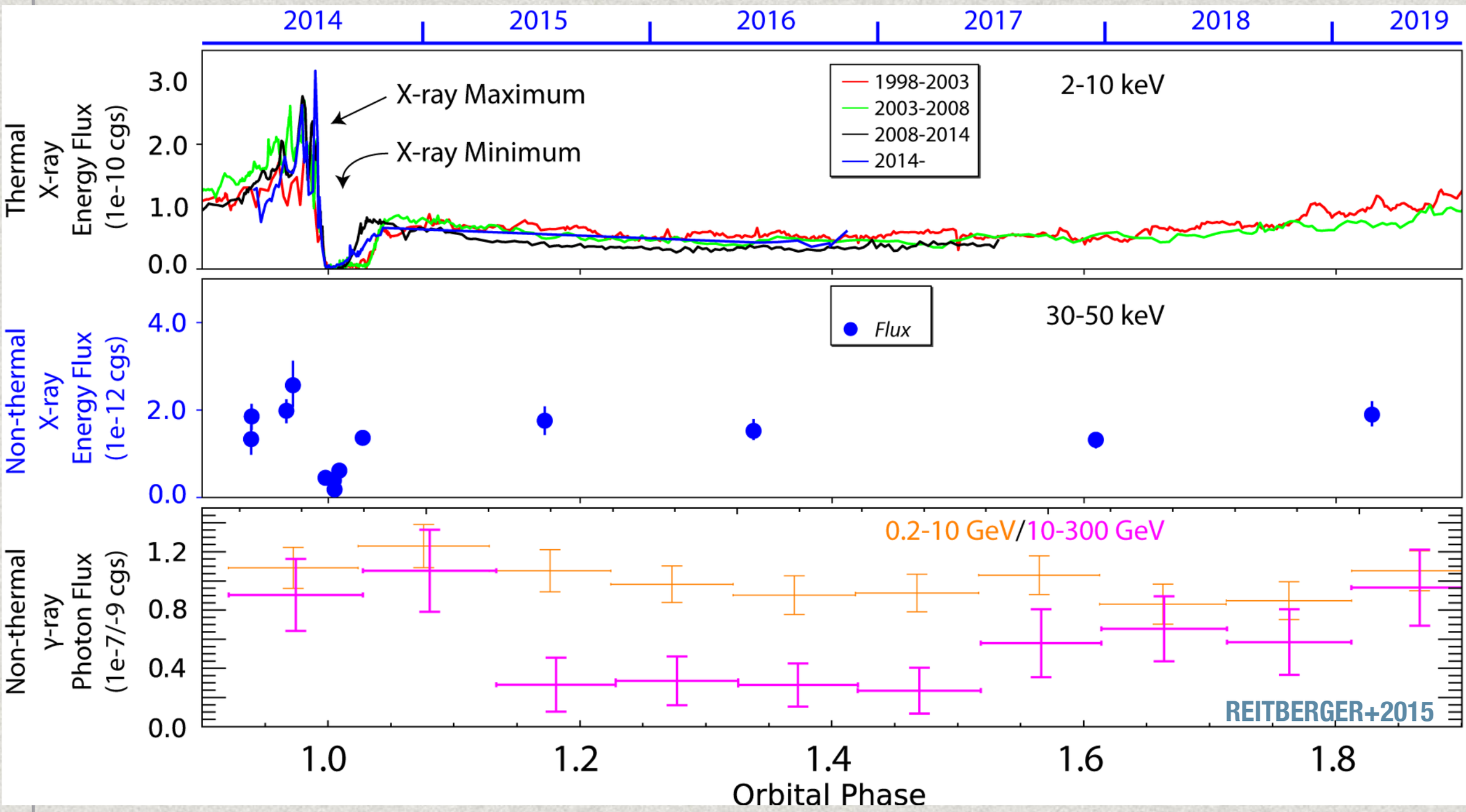
- $\Gamma \sim 1.65$ power-law connects to the soft γ-ray spectrum well.
- Originated from inverse-Compton of stellar UV by the accelerated particles?



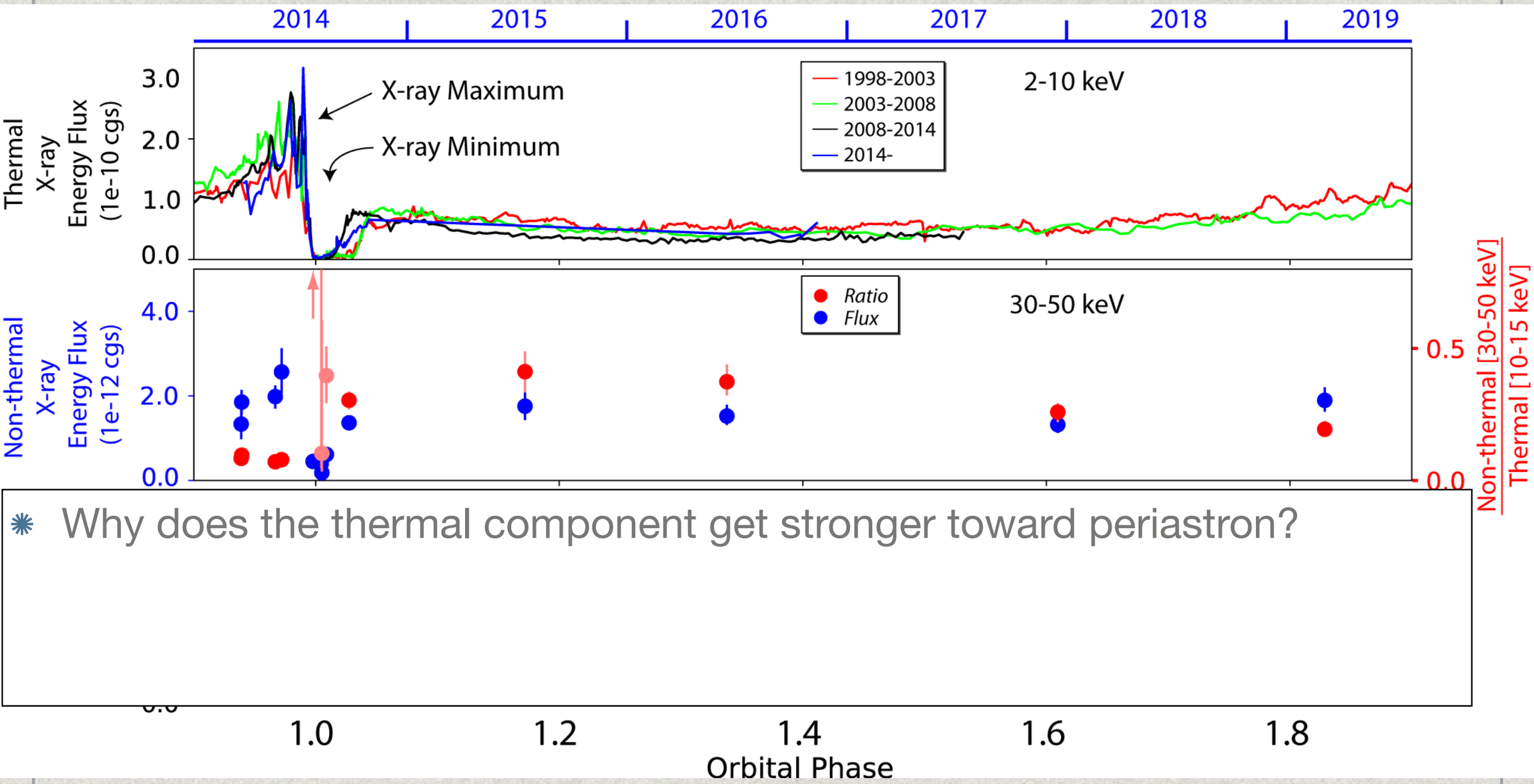
Flux Variation

Declines in both bands

- originates from the wind colliding region

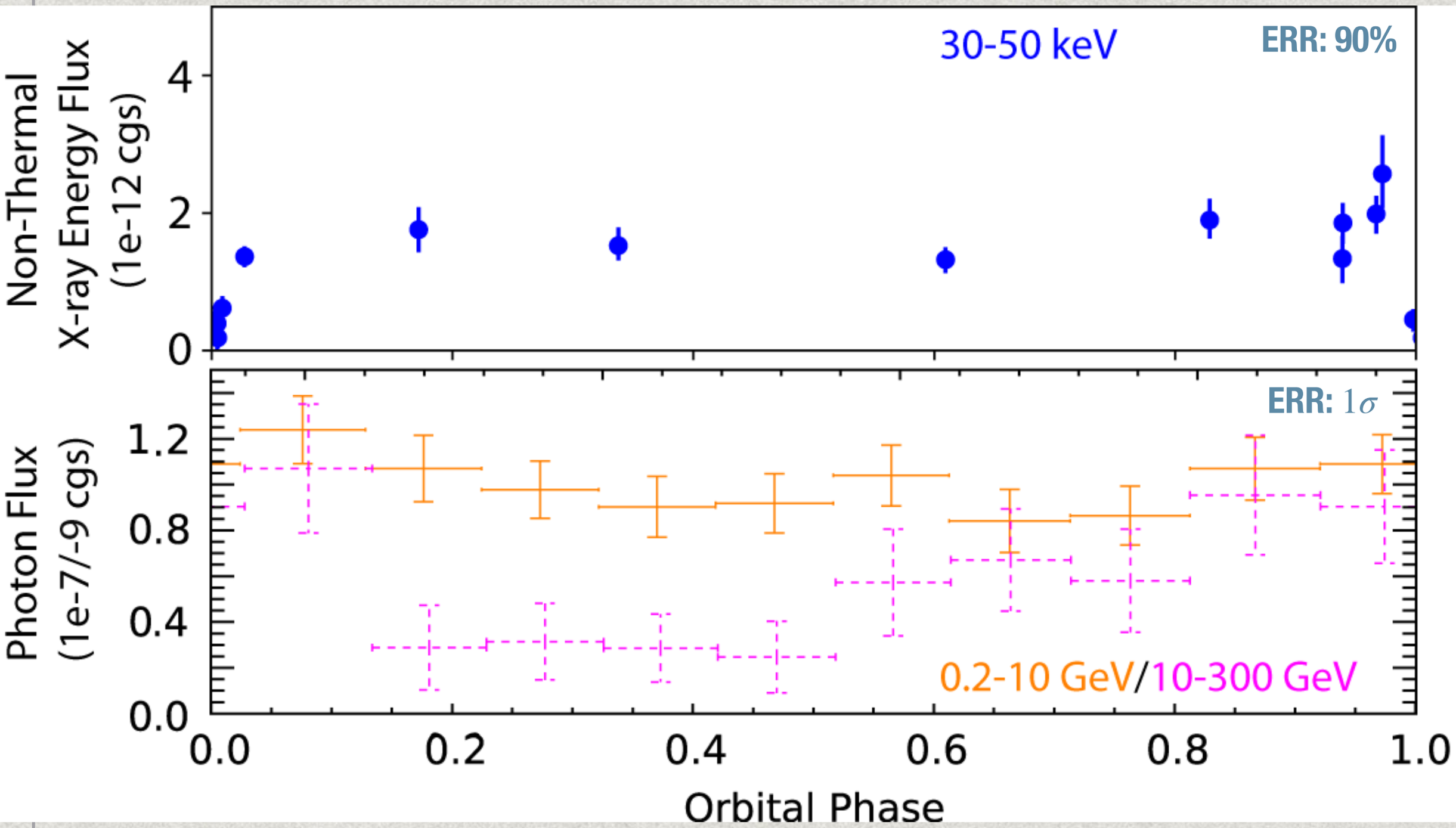


Flux Variation

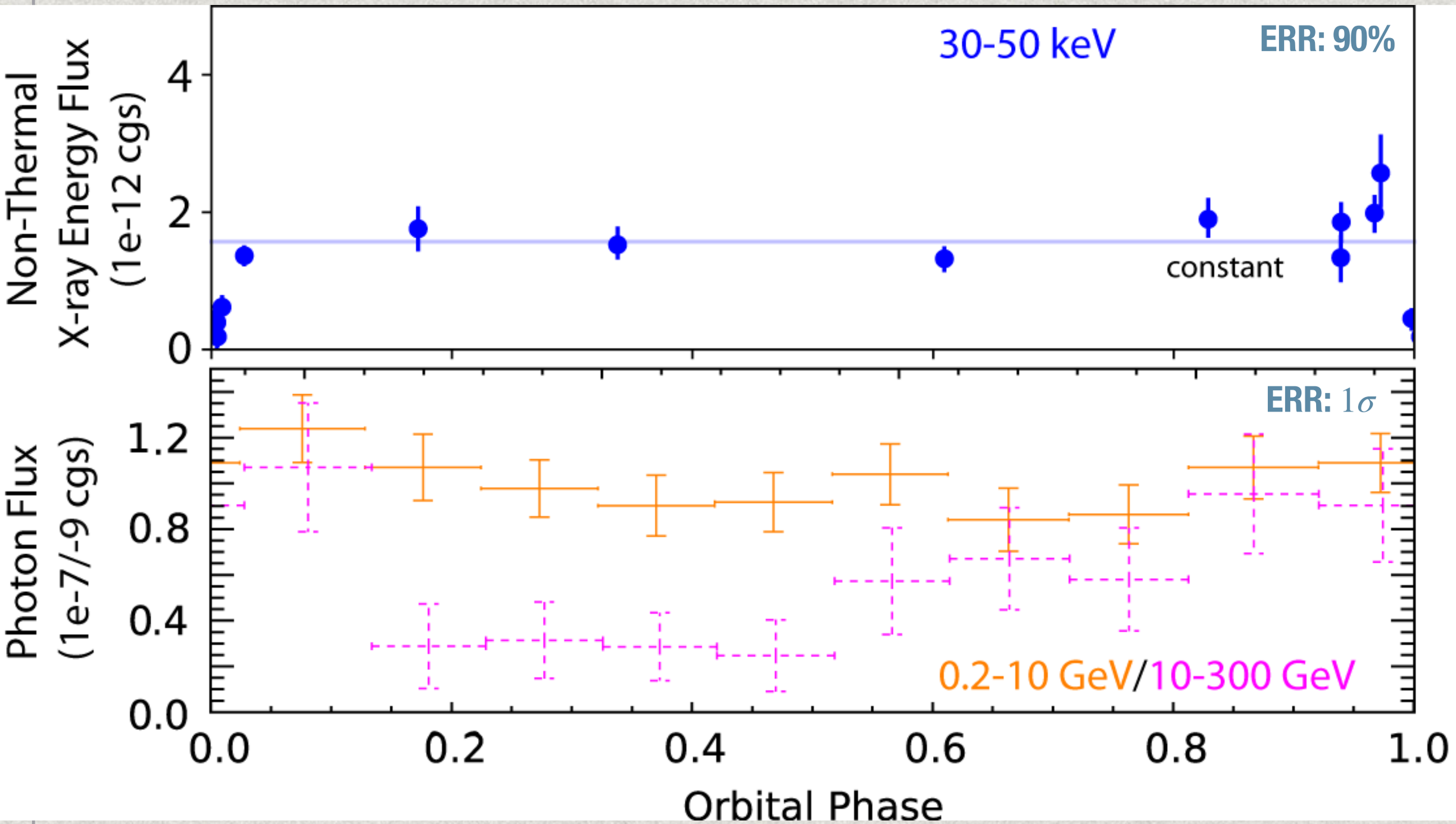


- Why does the thermal component get stronger toward periastron?

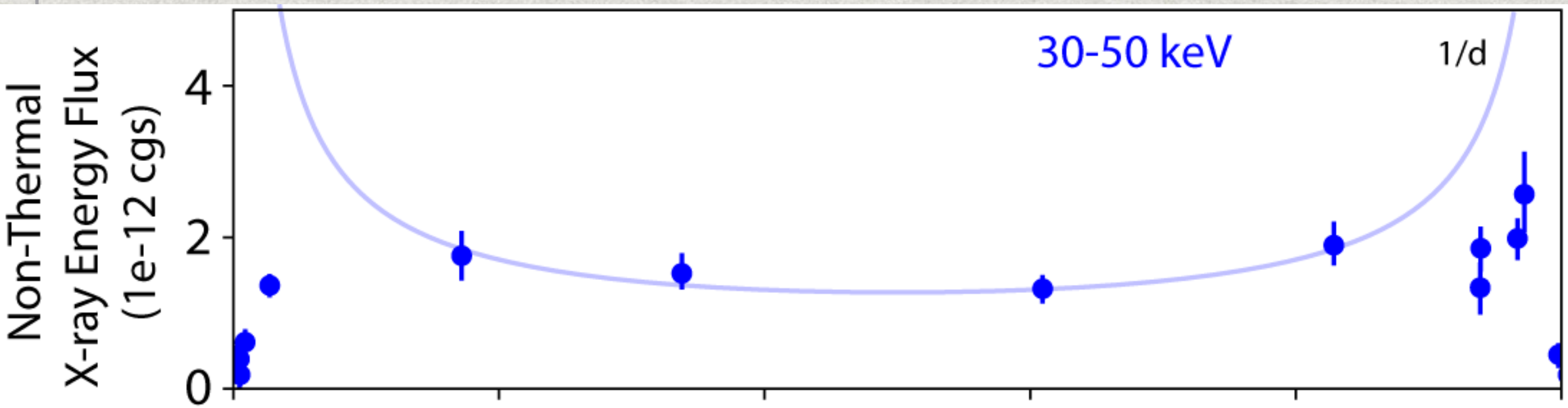
Non-thermal Flux Variation



Model


30-50 keV
ERR: 90%
constant
Non-Thermal
X-ray Energy Flux
(1e-12 cgs)
0
2
4
ERR: 1σ
0.2-10 GeV/10-300 GeV
Photon Flux
(1e-7/-9 cgs)
0.0
0.4
0.8
1.2
0.0
0.2
0.4
0.6
0.8
1.0
Orbital Phase

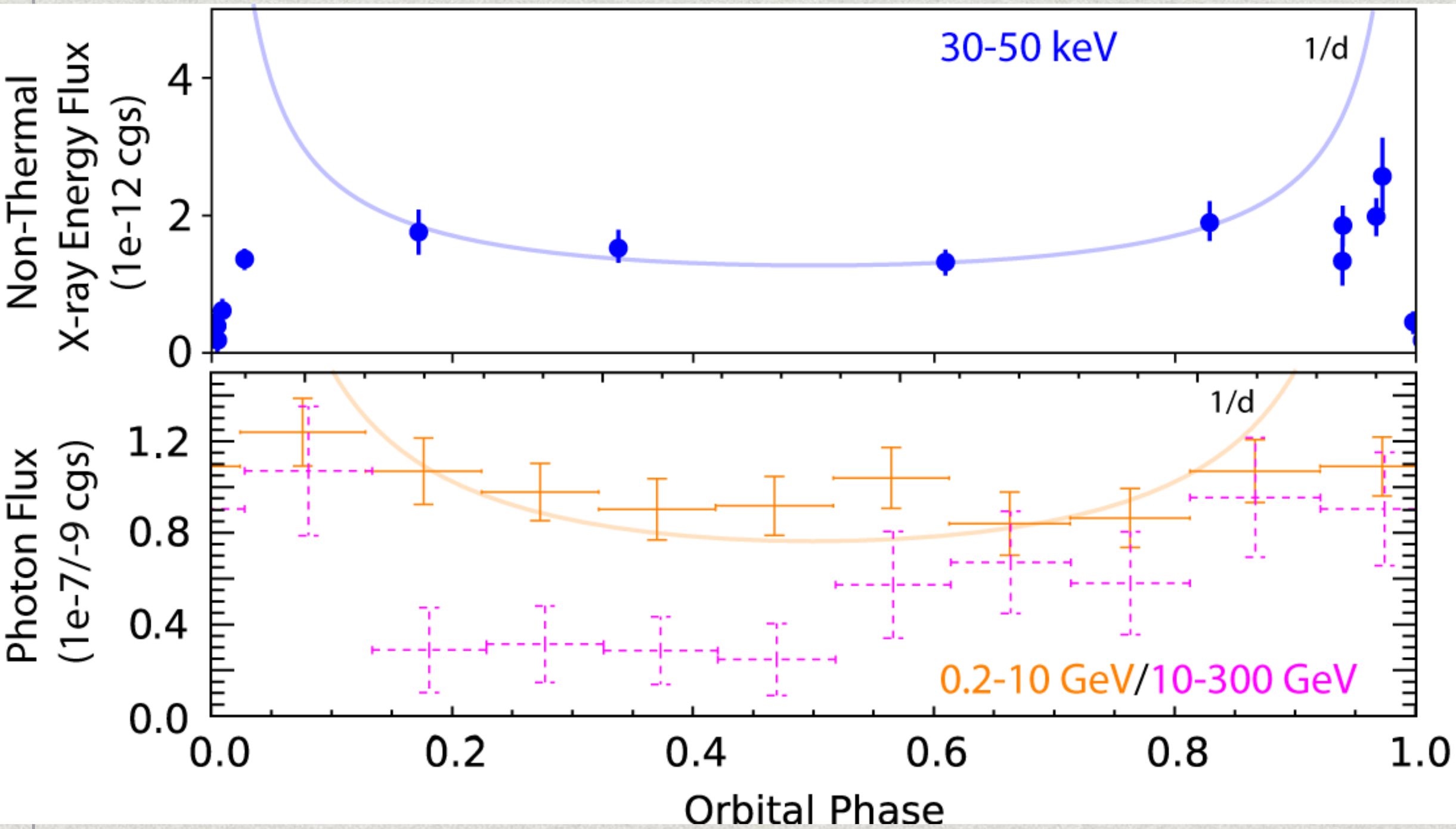
Model



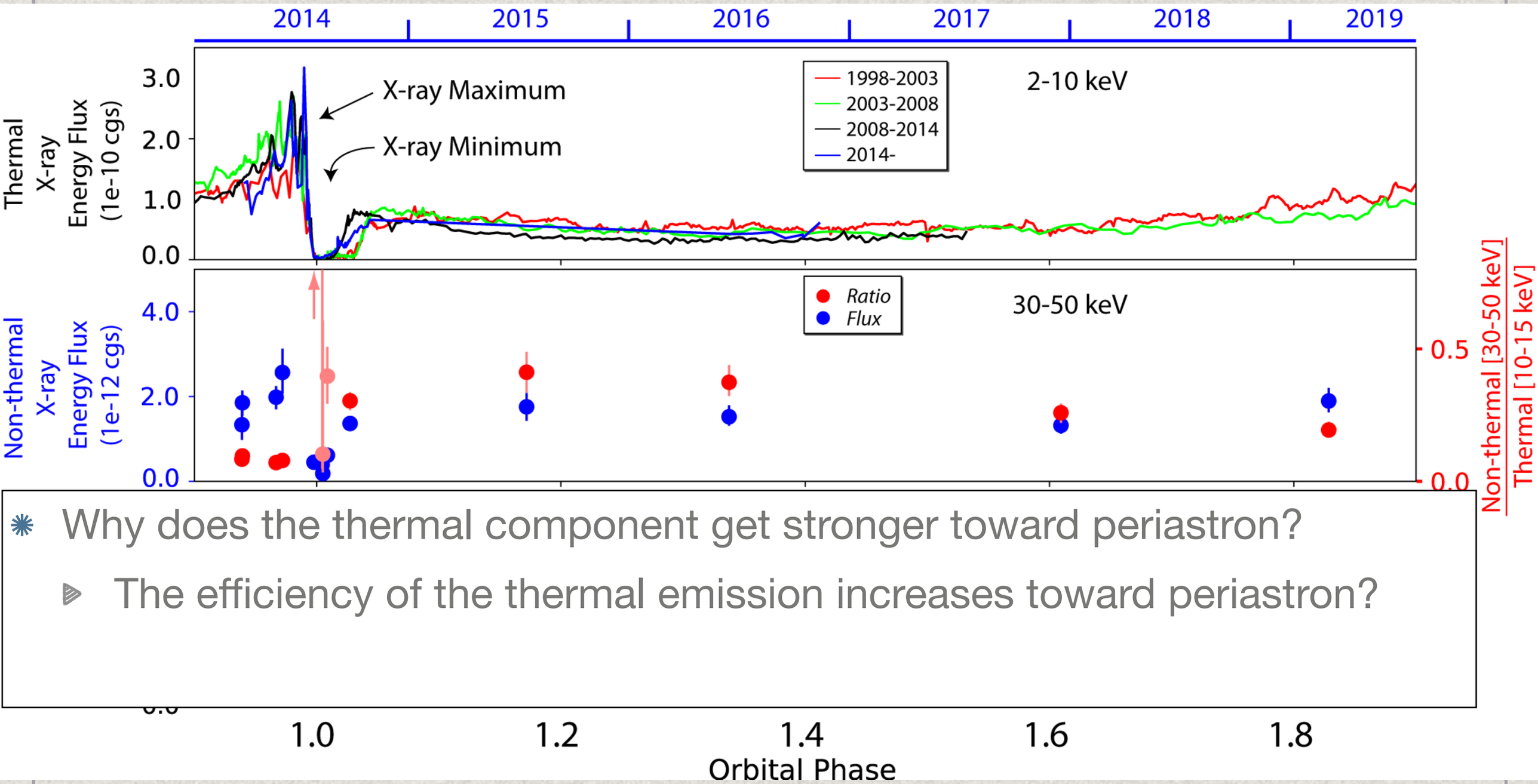
- If the non-thermal electrons fill the colliding wind region,
  - $N_{\rm acc} \propto nV$
  - $n \propto d^{-2}$
  - $V \propto d^{3}$
  - $U_{\rm UV} \propto d^{-2}$
- $L_{\rm IC} \propto N_{\rm acc} U_{\rm UV} \propto d^{-1}$

- n: plasma density
- $U_{\rm UV}$: stellar UV field
- d: distance between two stars

Model

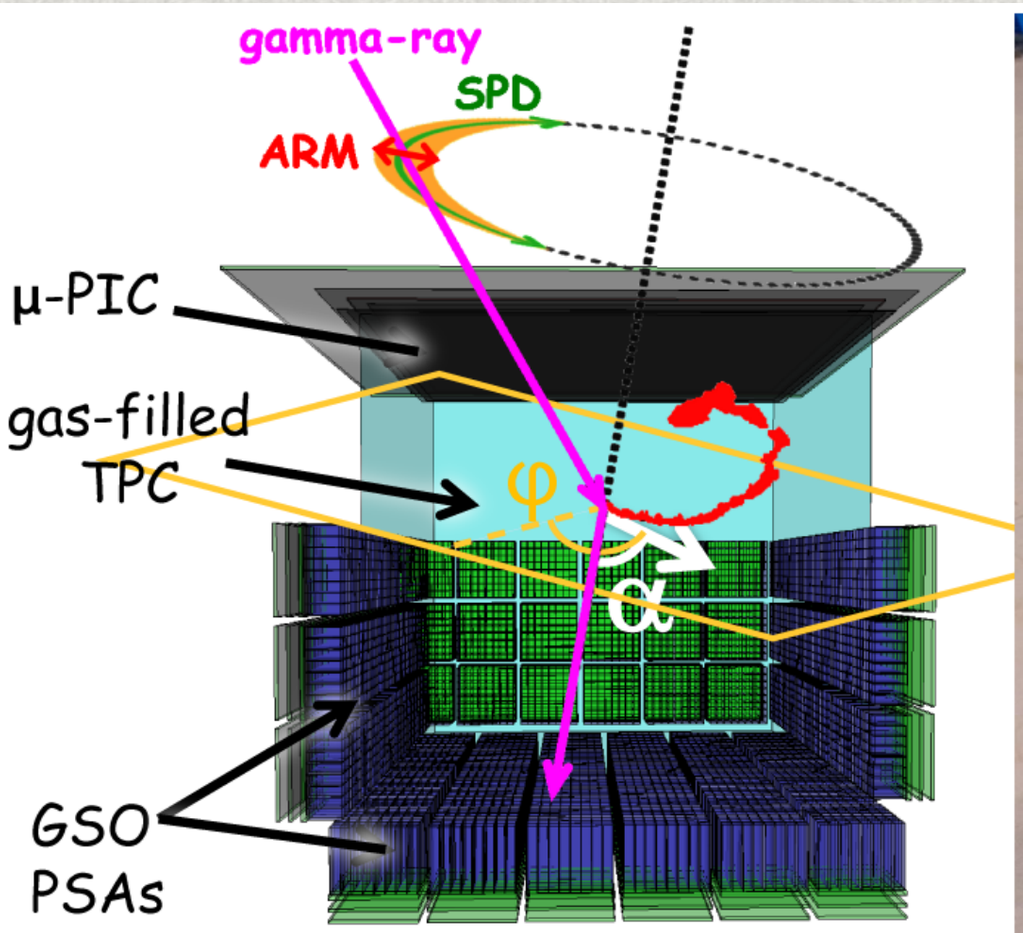

30-50 keV
1/d
Non-Thermal
X-ray Energy Flux
(1e-12 cgs)
0
2
4
1/d
Photon Flux
(1e-7/-9 cgs)
0.0
0.4
0.8
1.2
0.2-10 GeV/10-300 GeV
0.0
0.2
0.4
0.6
0.8
1.0
Orbital Phase

Flux Variation

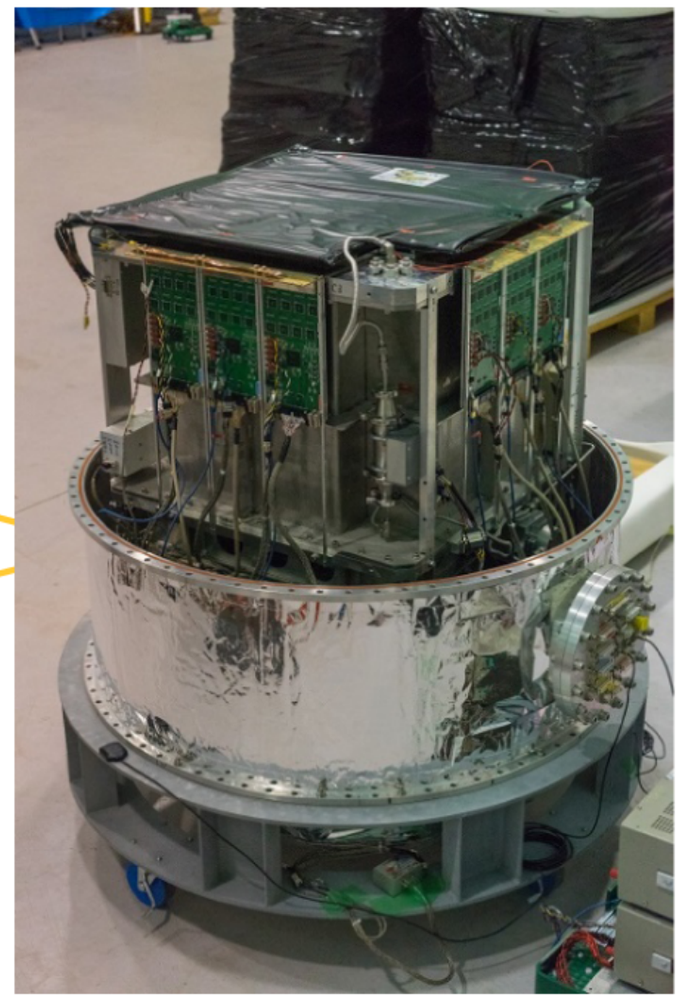


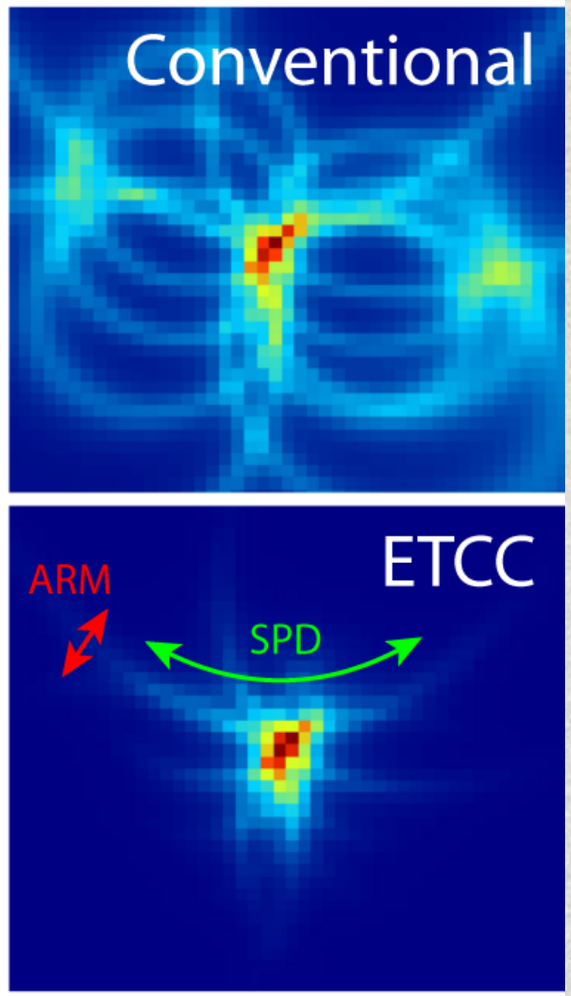
- Why does the thermal component get stronger toward periastron?
  - The efficiency of the thermal emission increases toward periastron?

A Space-Based All-Sky MeV Survey with the Electron Tracking Compton Camera (ETCC)



SMILE PROJECT: TANIMORI ET AL.





- Hamaguchi, Tanimori, Takada et al. Astro2020 APC white paper

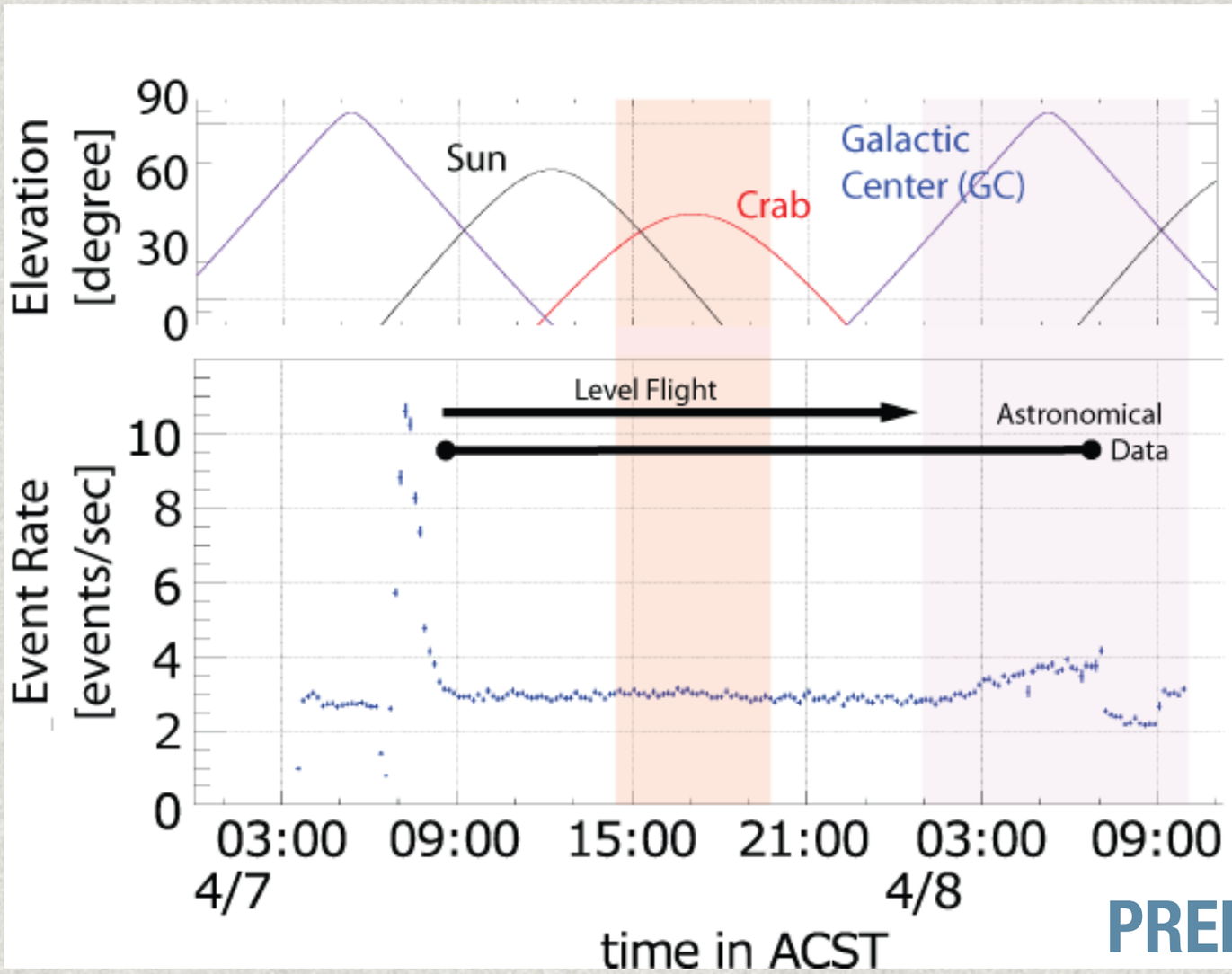
PROMOTOR

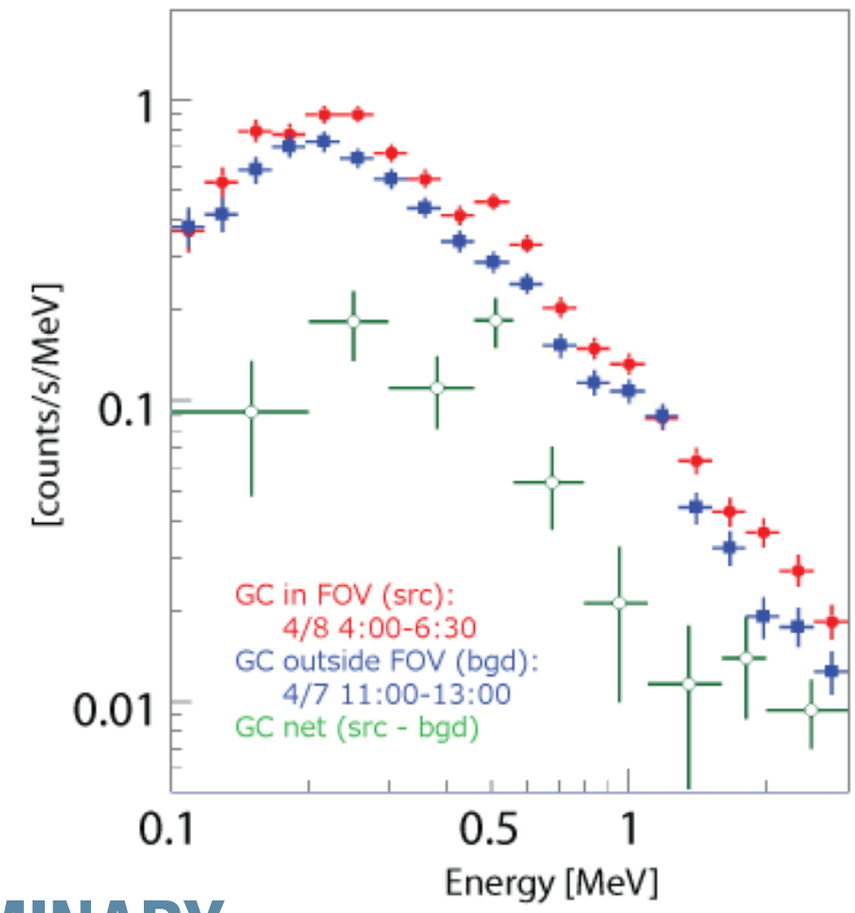
PI SMILE PROJECT

KEY DEVELOPER

REF: COMPTEL TALK BY PROF. COLLMAR

One day Balloon Flight in Australia in 2018

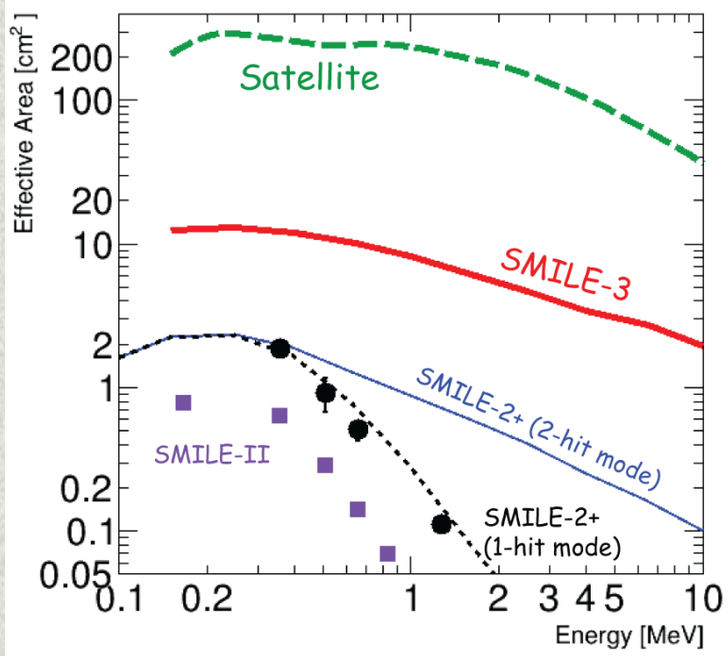


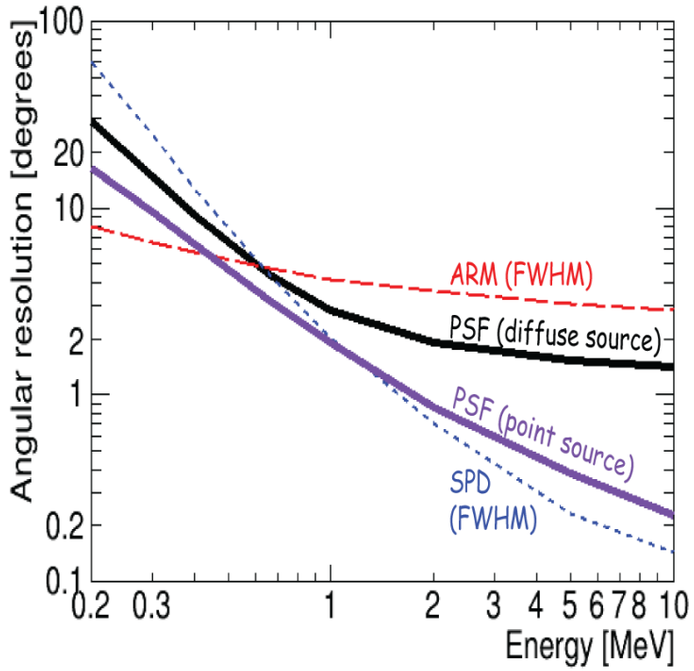


PRELIMINARY

- Background particle events are significantly reduced.
- Detection of 511 keV emission from the galactic center region at >5 σ in 2.5 hours.

Future Satellite Mission with ETCCs





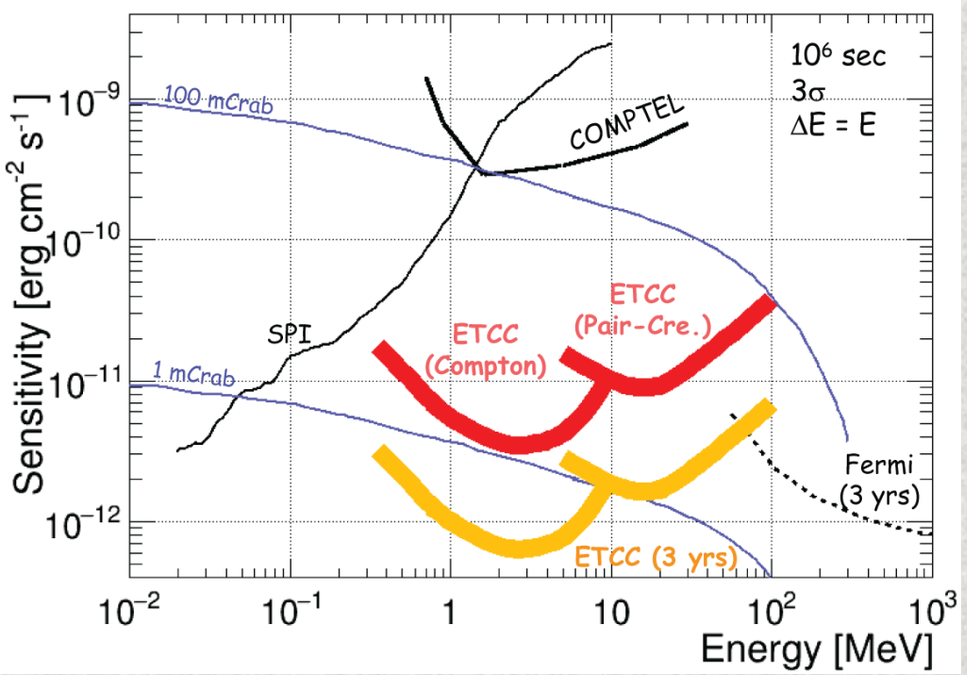


Table 1: Roadmap of the ETCC Development

Model	Eff (cm^{-2})	$\Delta E/E$* (%)	PSF (degree)	Band (MeV)	FoV (str)	Sensitivity (mCrab)	Year
SMILE-2+	1	12	10	0.2–2†	3‡	100 [1 day]	2018
SMILE-3	10–20	8–9	5	0.2–10	3‡	20 [14-50 day]	~2022
ETCC satellite	200	2	2	0.1–100	>4	1 [1 year]	~2030

Conclusion

- Non-thermal component is detected in the extremely hard X-ray band outside of periastron.
- NT originates from the wind-wind colliding region.
  - 30-50 keV peak is within 5″ from η Car
  - The flux declined during the X-ray minimum, when the thermal wind activity decays.
- The NT variation may be consistent with the variation expected with the wind colliding theory, while the thermal emission is not. Why?