Pulsar observations with NuSTAR

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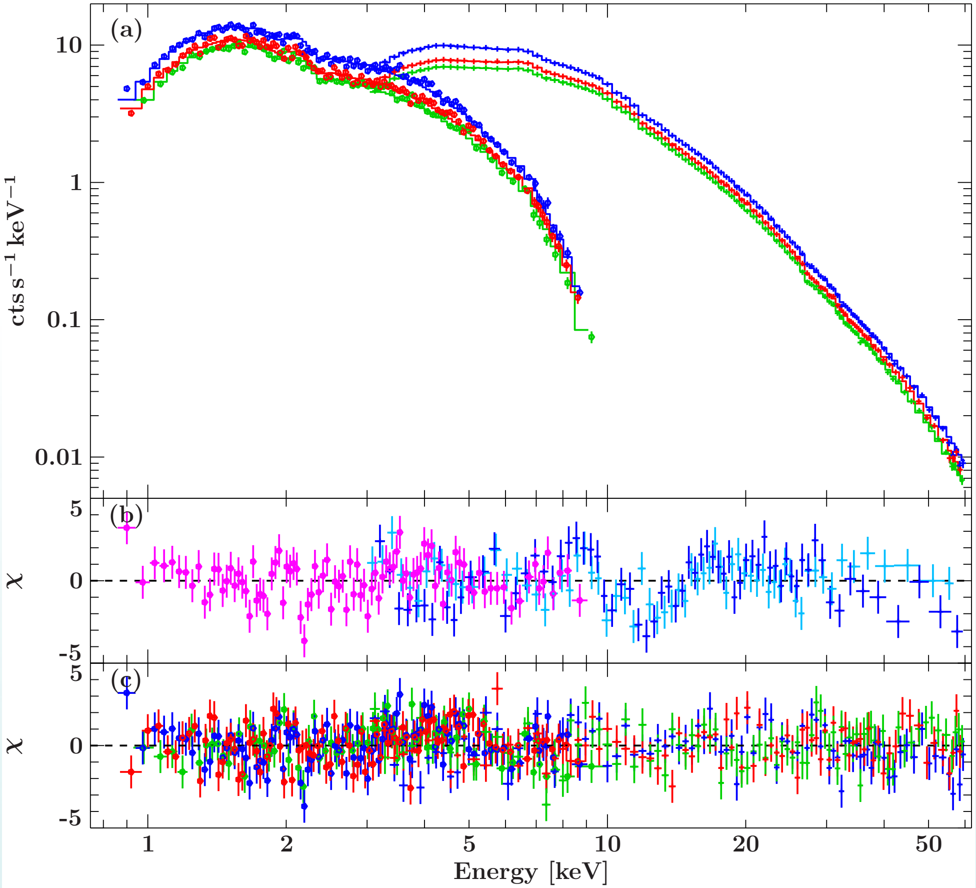
New lines

Name	Type	E_{cyc} [keV]	Reference
IGR J16393-4643	Obscured pulsar	29.3 ± 1.3	Bodaghee et al., 2016
2S 1553-542	Be companion	27.34 ± 0.38	Tsygankov et al., 2016
KS 1947+319	Be companion	12.2 ±0.7	Fürst et al., 2015
IGR J17544-2619	SFXT	16.9 ± 0.3	Bhalerao et al., 2015
RX J0520.5–6932	Be companion	31.3 ± 0.8	Tendulkar et al., 2014
GRO J1008-57	Be companion	78 ± 3	Bellm et al., 2014

KS 1947+319

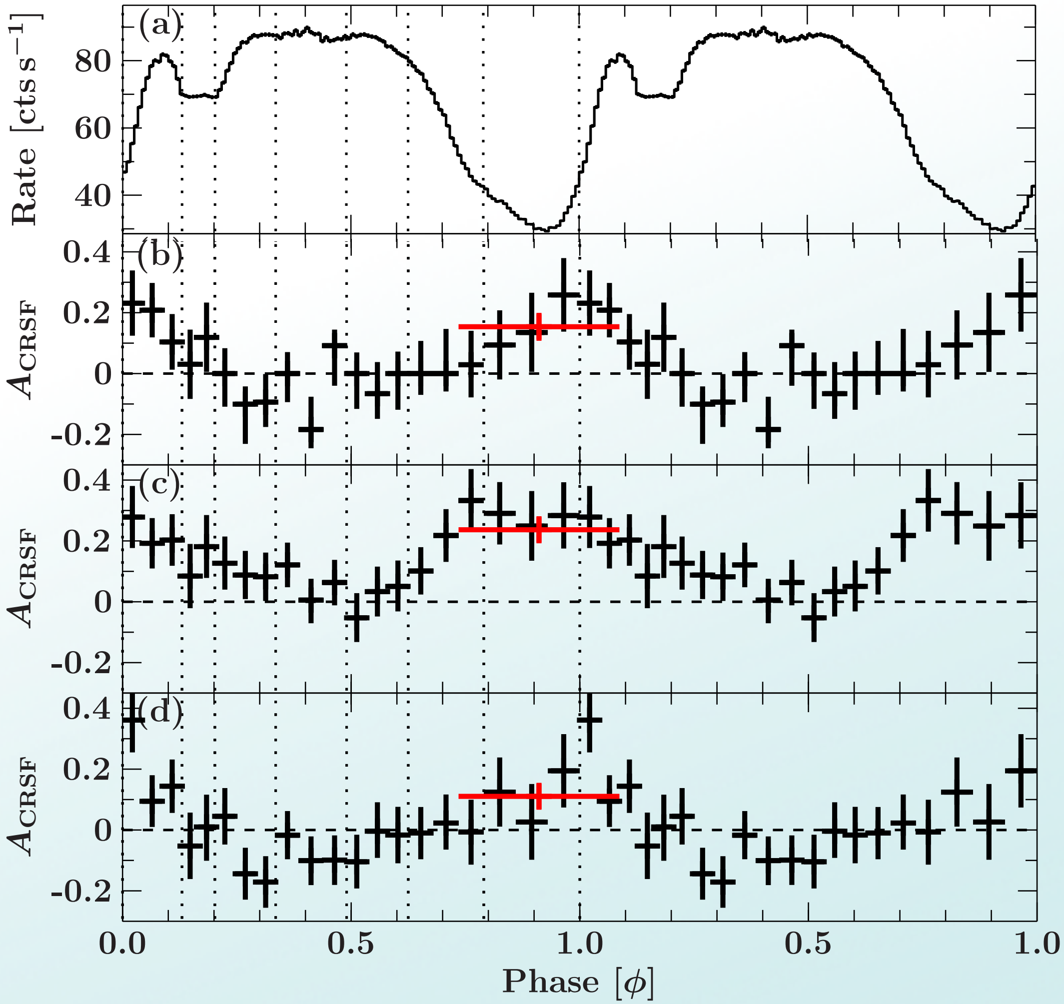


- Outburst in 2013 after 11 years of quiescence
- Triggered 3 *NuSTAR* observations

- Discovery of cyclotron line at 12.3keV in brightest observation

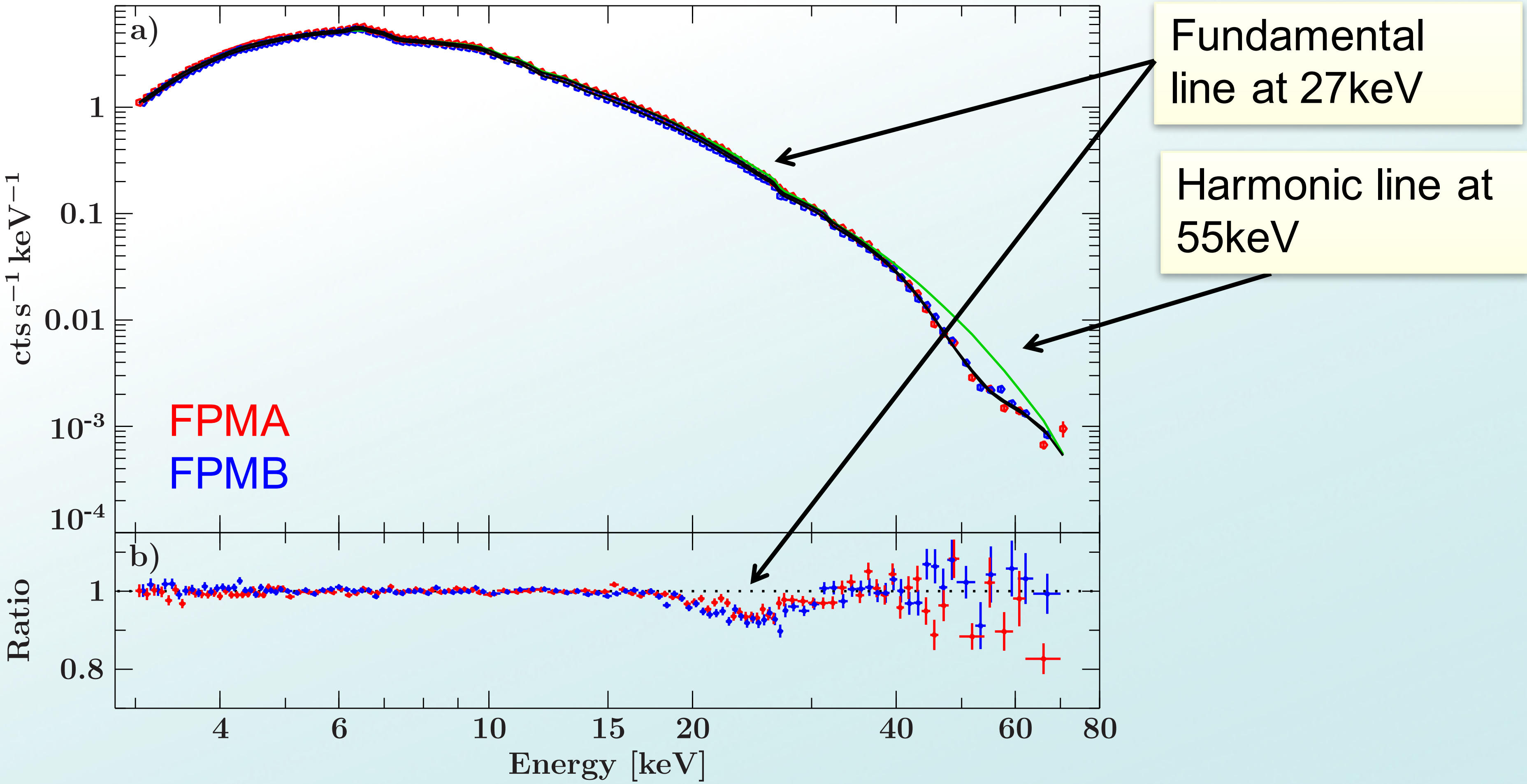
- Only possible due to continuous coverage of relevant energy band (~10-15 keV)

KS 1947+319



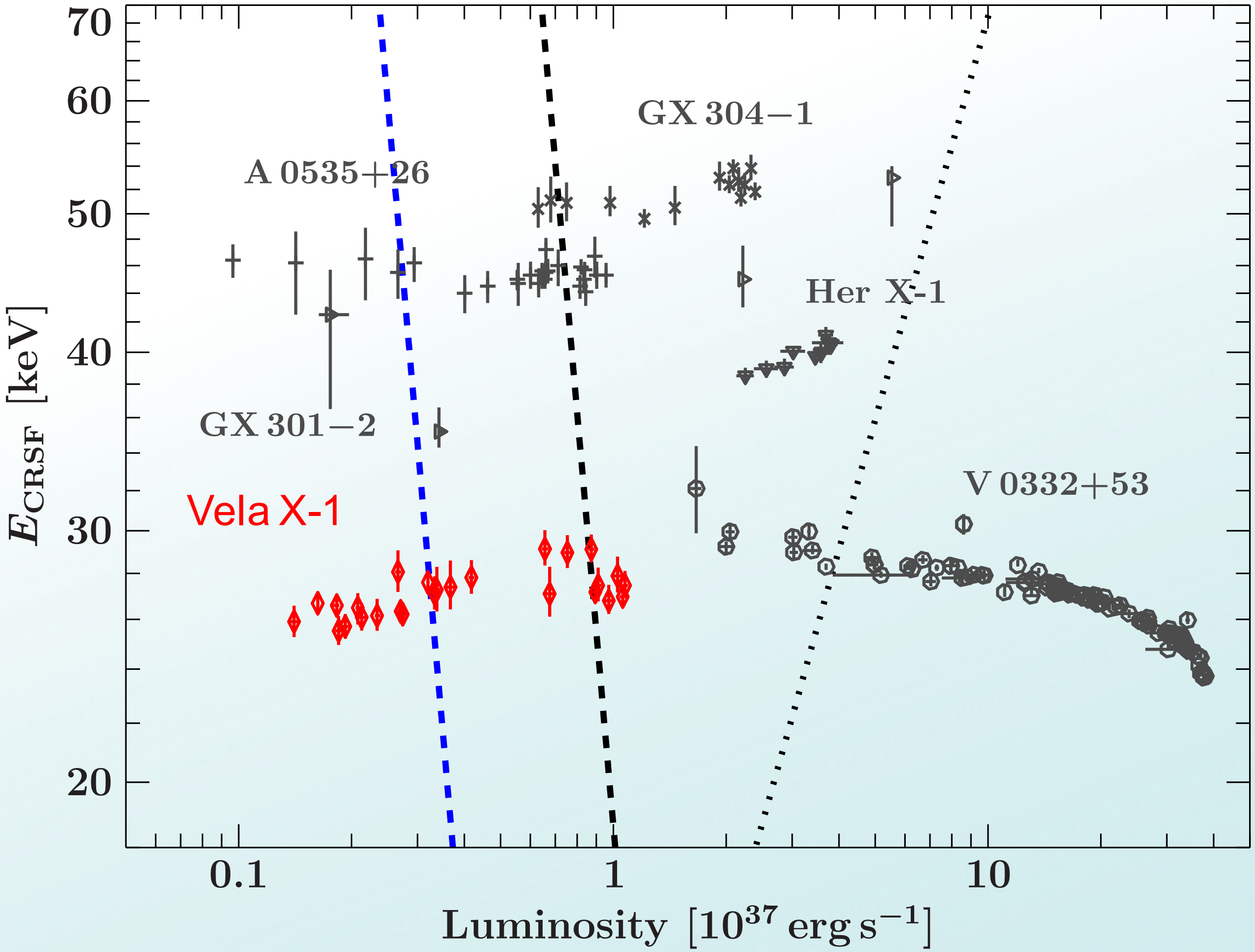
- Very strong phase dependence of CRSF strength in all observations
- Detected significantly only during minimum of pulse profile!
- Contains information about the emission geometry and location

Vela X-1 spectrum



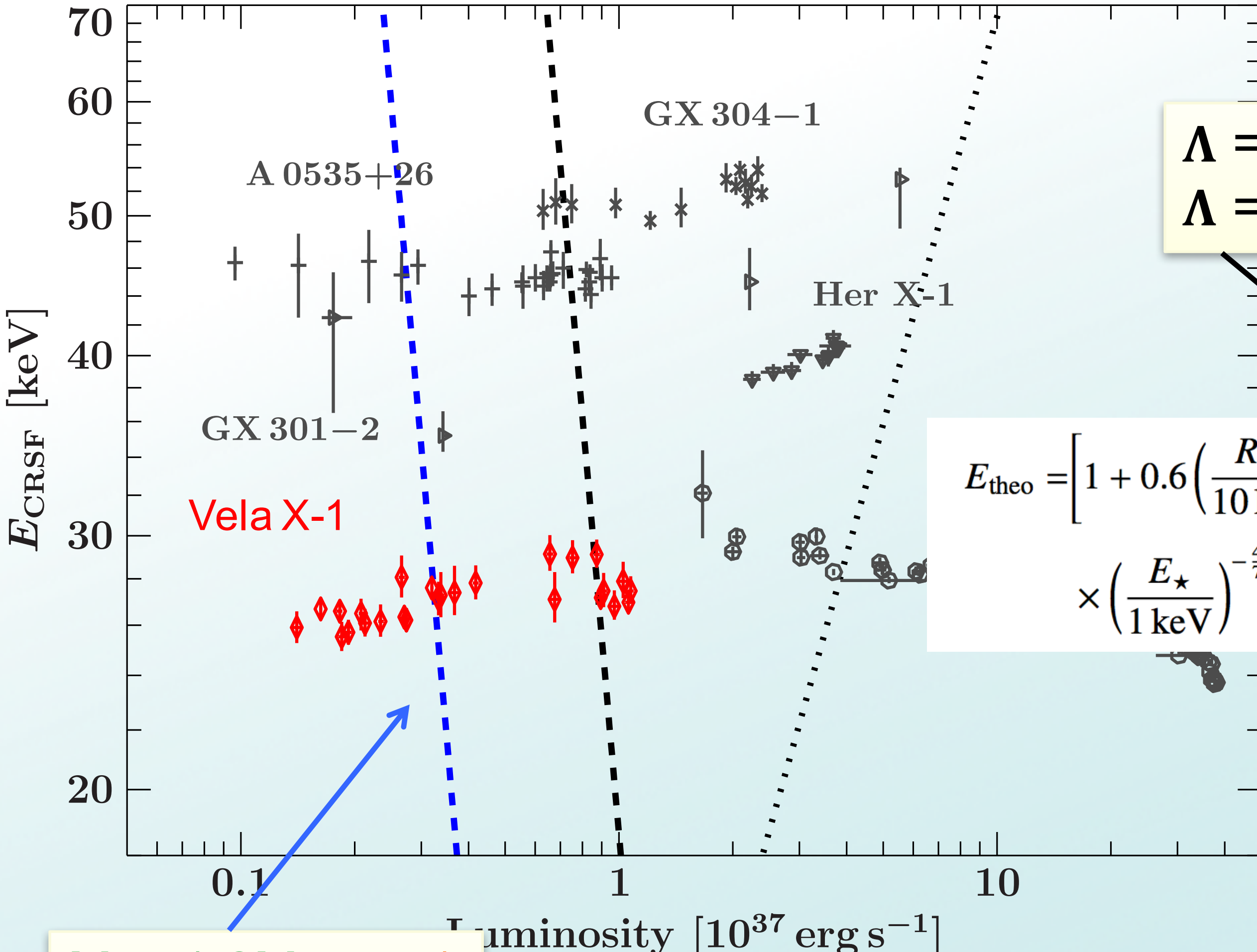
Fürst et al., 2014

Vela X-1 in context



Fürst et al., 2014

Vela X-1 in context



Λ = 0.1 for disk accretion
Λ = 1 for 'wind' accretion

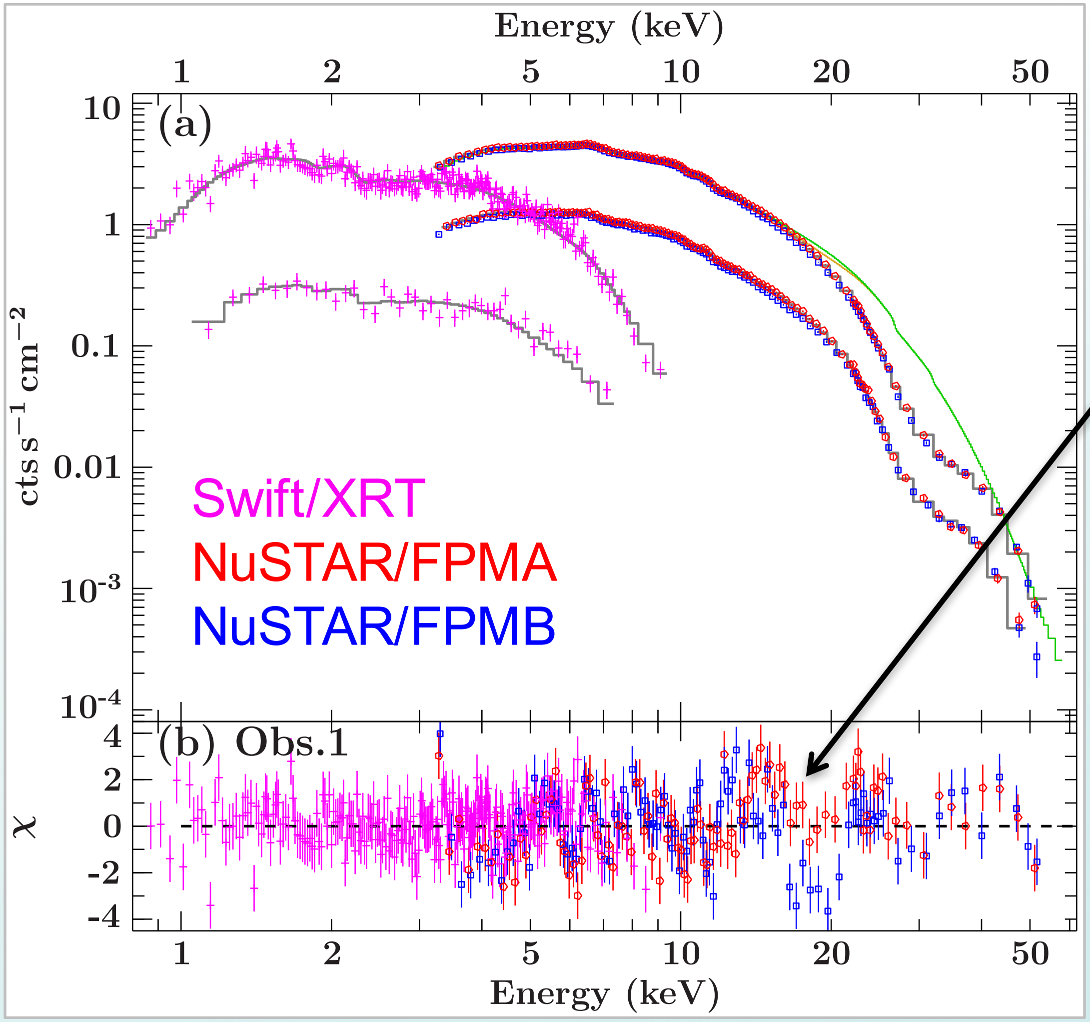
$$E_{\rm theo} = \left[1 + 0.6\left(\frac{R_\star}{10\,\rm km}\right)^{-\frac{13}{14}}\left(\frac{\Lambda}{0.1}\right)^{-1}\left(\frac{\tau_\star}{20}\right)\left(\frac{M_\star}{1.4\,\rm M_\odot}\right)^{\frac{19}{14}} \times \left(\frac{E_\star}{1\,\rm keV}\right)^{-\frac{4}{7}}\left(\frac{L_x}{10^{37}\,\rm erg\,s^{-1}}\right)^{-\frac{5}{7}}\right]^{-3} \times E_\star \quad .$$

Becker et al. (2012)

$M_\star = 1.8 M_\odot$, **Λ**=1

Fürst et al., 2014

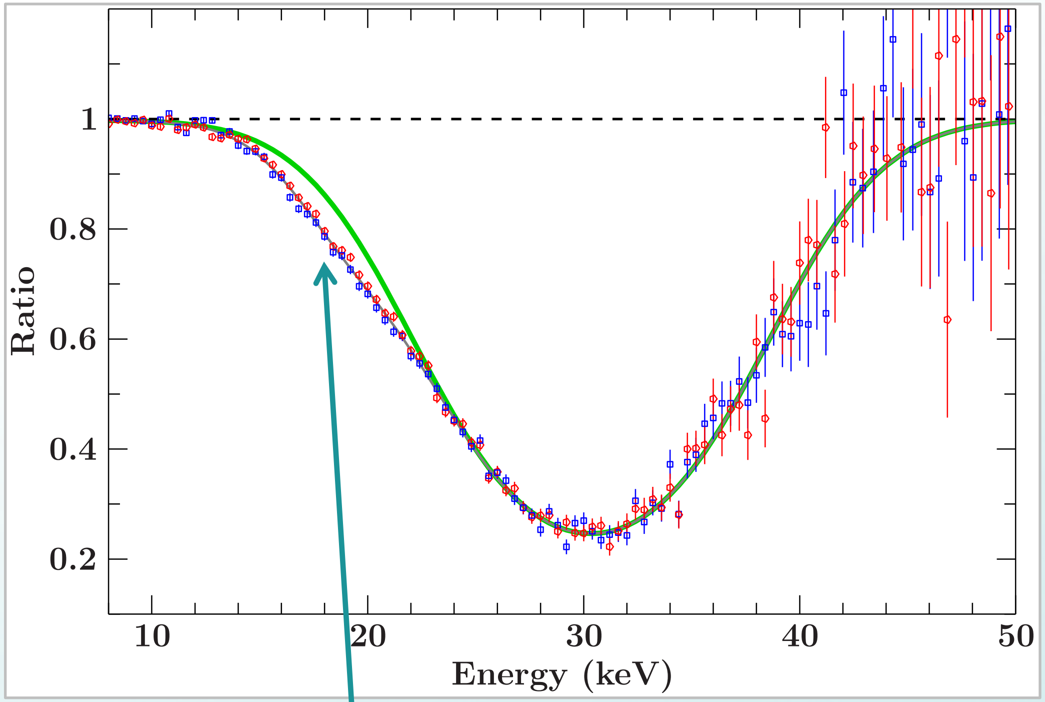
Cep X-4: CRSF profile



Significant residuals visible at the red end of the line

Fürst et al., 2015

Cep X-4: CRSF profile



Zoom on the CRSF region

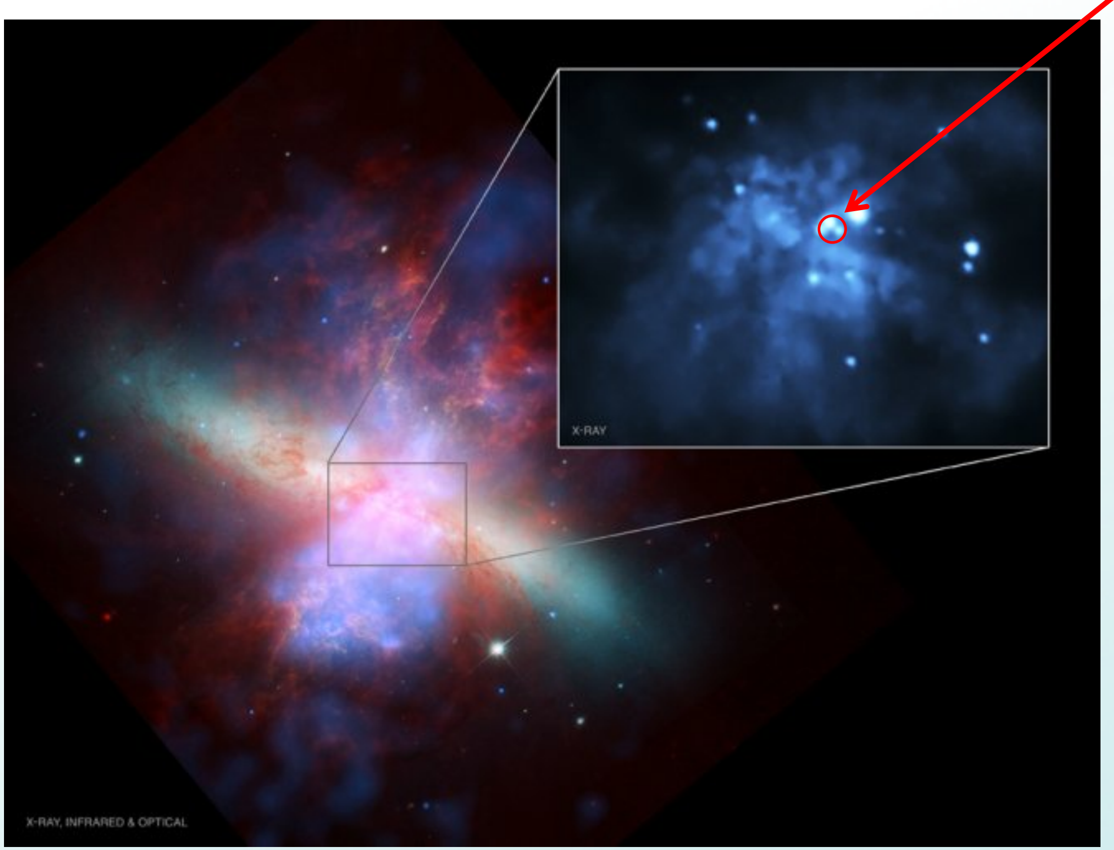
Asymmetric line profile required, modeled by a second Gaussian line.

Comparison with theory in preparation.

Green line assumes symmetric line shape

Fürst et al., 2015

Ultra-luminous X-ray sources (ULXs)



- First ultra-luminous neutron star ($L_X \sim 10^{40}$ erg/s)
- no CRSF, what is the B-field?
- How does it accrete?
- Use Galactic sources to extrapolate
- Are there more out there?

X-ray: NASA/CXC/Tsinghua Univ./H. Feng et al.; Full-field: X-ray: NASA/CXC/JHU/D.Strickland; Optical: NASA/ESA/STScI/AURA/The Hubble Heritage Team; IR: NASA/JPL-Caltech/Univ. of AZ/C. Engelbracht

Bachetti et al., 2014

Summary

- *NuSTAR* is a CRSF discovery machine
- High sensitivity at hard X-rays and spectral resolution key to uncover new features about CRSF behavior
- Pulse-to-pulse and phase-resolved analysis help us understand accretion regime and emission geometry
- Monitoring of sources in outburst is important to sample different physical conditions