The Broadband Spectrum of Centaurus X-3

Amy M. Gottlieb[1,2,3], Katja Pottschmidt[1,2], Diana M. Marcu-Cheatham[1,2], Michael T. Wolff[4], Matthias Kühnel[5], Sebastian Falkner[5], Paul B. Hemphill[6], Slawomir Suchy[7], Peter A. Becker[8], Kent S. Wood[9], Jörn Wilms[5]

[1]CRESST/NASA-GSFC, Greenbelt, MD, USA, [2]UMBC, Baltimore, MD, USA, [3]University of Florida, Gainesville, FL, USA,
[4]Naval Research Laboratory, Washington, DC, USA, [5]ECAP & Remeis Observatory, Bamberg, Germany, [6]CASS/UCSD, La Jolla, CA, USA,
[7]Altensteig, Germany, [8]GMU, Fairfax, VA, USA, [9]Praxis Inc., Alexandria, VA, USA

E-mail: agottlieb7@ufl.edu

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Abstract

Cen X-3: This source is an eclipsing ~ 4.8 s X-ray pulsar consisting of a neutron star and an O6.5II mass donor in a ~ 2.1 d orbit (Ash et al., 1999, MNRAS 307, 357).

Suzaku: Cen X-3 was observed at average flux in 2008 for one binary orbit. We selected ~ 11 ks of constant hardness for spectral analysis, where $L_{avg,3-60keV,5.7kpc} = 2\times10^{37}$ ergs/s.

NuSTAR: Cen X-3 was observed during another phase of average flux in 2015 for ~ 22 ks. We present a preliminary spectral analysis where $L_{avg,3-60keV,5.7kpc} = 1.5\times10^{37}$ ergs/s.

Physical Continuum Model: The selected *Suzaku* data were successfully modeled with one of the first physical continuum models describing the emission from an accretion column, the "radiation dominated radiative shock" model of Becker & Wolff, 2007, ApJ 654, 435. Its main parameters are the radius, temperature, and pseudo cross-sections of the column.

Emission Geometry Model: The *Suzaku*-PIN pulse profile shows a phase shift at the cyclotron line energy as predicted by Schönherr et al., 2014, A&A 564, L8.

(A1) Lightcurves: *Suzaku* (BAT Context)

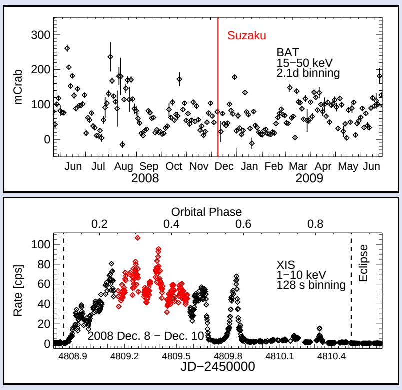


Figure 1: **Top:** Time of the *Suzaku* observation of Cen X-3 in the *Swift*-BAT longterm monitoring context. **Bottom:** *Suzaku*-XIS lightcurve of Cen X-3 covering one ~2.1 d binary orbit. The red part highlights ~11 ks selected for spectral analysis, see (B1) and (B2) below.

(A2) Hardness Selection: *Suzaku*

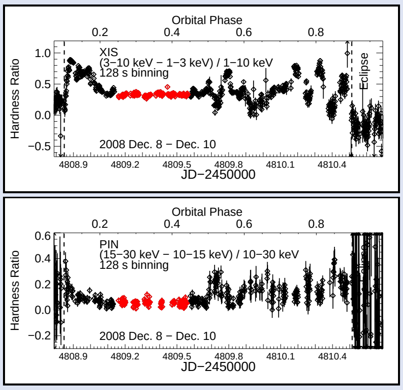


Figure 2: **Top:** Hardness ratio in the soft energy band as measured by *Suzaku*-XIS. **Bottom:** Hardness ratio in the hard energy band as measured by *Suzaku*-PIN. The red part shows near constant hardness in both energy bands and was therefore selected for spectral analysis, see (B1) and (B2) below.

(A3) Lightcurves: *NuSTAR* (BAT Context)

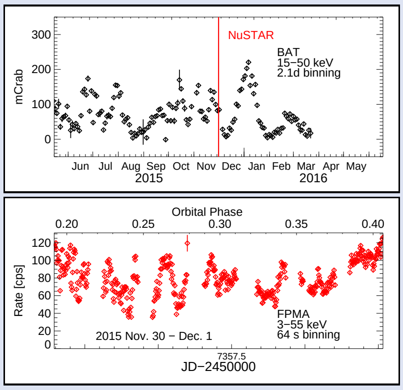


Figure 3: **Top:** Time of the *NuSTAR* observation of Cen X-3 in the *Swift*-BAT longterm monitoring context. **Bottom:** *NuSTAR*-FPMA lightcurve of Cen X-3 covering ~ 22 ks, see (B3) below for spectral analysis.

(B1) Spectrum: *Suzaku*, Empirical

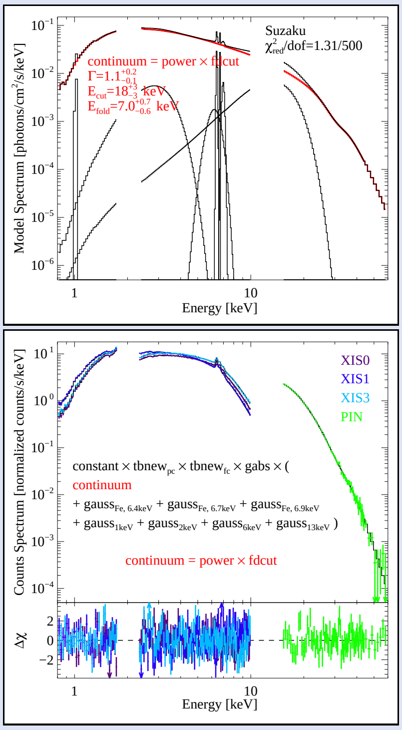


Figure 4: **Top:** Unfolded best fit model components with an empirical continuum (red) for the selected *Suzaku* data. **Bottom:** Counts spectra and total best fit model for the selected *Suzaku* data.

(B2) Spectrum: *Suzaku*, Physical

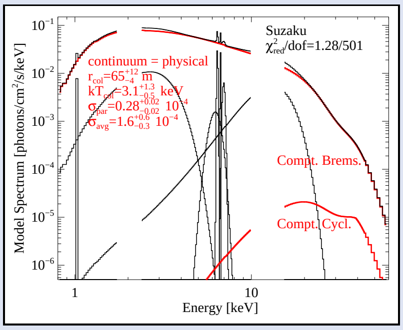


Figure 5: **Top:** Unfolded best fit model components with a physical continuum (red) originating in the accretion column for the selected *Suzaku* data.

Physical continuum, new for X-ray pulsar accretion:

`Xspec` implementation of analytical model by Becker and Wolff, 2007, ApJ 654, 435. See also session 201 (talks Wolff, Marcu-Cheatham), poster 120.24, and Wolff et al., 2016, ApJ, submitted.

Three components: Comptonized - (1) bremsstrahlung, - (2) cyclotron emission, - (3) blackbody radiation (negligible here).

See also alternative new `xspec` implementation of numerical model by Farinelli et al., 2016, A&A, in press.

Main result: Physical model fit is equivalent to best empirical fit.

Additional model input: Distance, standard neutron star mass and radius, $\sigma_{\perp} = \sigma_{\mathrm{T}}$, empirical fit: 0.1–75 keV unabsorbed flux $\rightarrow \dot{M}$, cyclotron line at ~30 keV $\rightarrow B$.

Other components, similar for empirical and physical fits:

Partial covering absorption, Kα lines from neutral, He-like, H-like iron, studied by Naik et al., 2011, ApJ 737, 79. We also see lines at ~ 1 and ~ 6 keV, possibly iron L and a Compton shoulder.

Cyclotron line: $E_{cyc} = 30.0^{+1.4}_{-0.7}$ keV, $\sigma_{cyc} = 6^{+1}_{-2}$ keV, $\tau_{cyc} = 0.7^{+0.3}_{-0.5}$

Broad components at ~ 2 and ~ 13 keV: The latter is often required for accr. pulsars. See also Cen X-3 *NuSTAR* fit (B3).

(B3) Spectrum: *NuSTAR*, Empirical

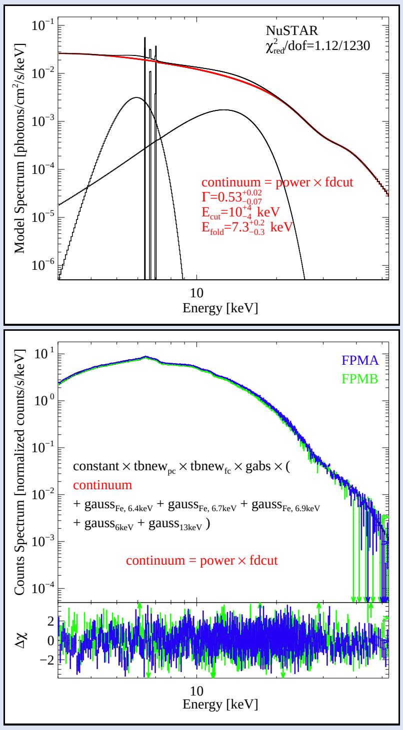
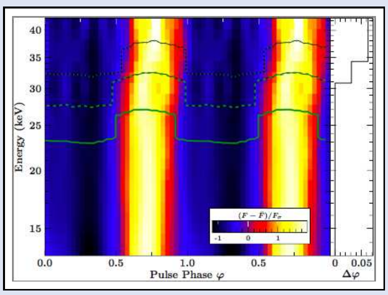


Figure 6: **Top:** Preliminary unfolded best fit model components with an empirical continuum (red) for the *NuSTAR* data. **Bottom:** Preliminary counts spectra and total best fit model for the *NuSTAR* data.

(C1) Phase Shift at Cyclotron Line

Figure 7: *Suzaku*-PIN pulse profile map for the data selcted in (A2): Normalized color-coded flux, F as a function of pulse phase, ϕ, and energy. Green contours represent S/N=10-30. The right panel shows the energy dependent phase shift, $\Delta\phi$, of each pulse profile with respect to the mean profile.



Using Monte Carlo simulations for cyclotron resonant scattering and a numerical ray-tracing routine accounting for general relativistic light-bending Schönherr et al., 2014, A&A 564, L8, showed that photons leaving the accretion column around the cyclotron resonance energy E_{cyc} have an altered emission geometry. Consistent with this picture we find that the main peak of Cen X-3's pulse profile shows a phase shift of ~ 0.06 above E_{cyc} ~ 30 keV with respect to the average 10–60 keV *Suzaku*-PIN pulse profile.

Acknowledgments

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