A NuSTAR view of SS433

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1. Abstract:

In this work we present a characterization of different outflows parameters of the X-ray binary SS433 throughout the precessional cycle of the system, by analyzing 10 NuSTAR (3–70 keV) observations of ∼30 ks that span ∼1.5 precessional cycles. We extract averaged spectra and model them using a combination of a double thermal jet model (bjet) and pure neutral and relativistic reflection (xillverCp and relxilllpCp) over an accretion disk.

2. Introduction:

SS433 is a galactic microquasar with powerful outflows, originated in jets, accretion disk and winds, with well known orbital, precessional and nutational periods. It is composed of an A-type supergiant star and either an accreting neutron star or a black hole (Robinson et al. 2017), with an orbital period of 13.1 days (Fabrika 2004), located at a distance of 5.5 ± 0.2 kpc (Lockman, Blundell, & Goss 2007). Jets in SS 433 are its more prominent feature, with luminosities of $L\_jet \gtrsim 10^{39}$ erg/s (Marshall et al. 2002). Although SS 433 has been extensively studied in the X-ray domain, data from NuSTAR satellite are not completely exploited yet. In this article we present a spectral analysis of a publicly available dataset consisting of ten NuSTAR observations of SS 433, performed between October 2014 and July 2015.

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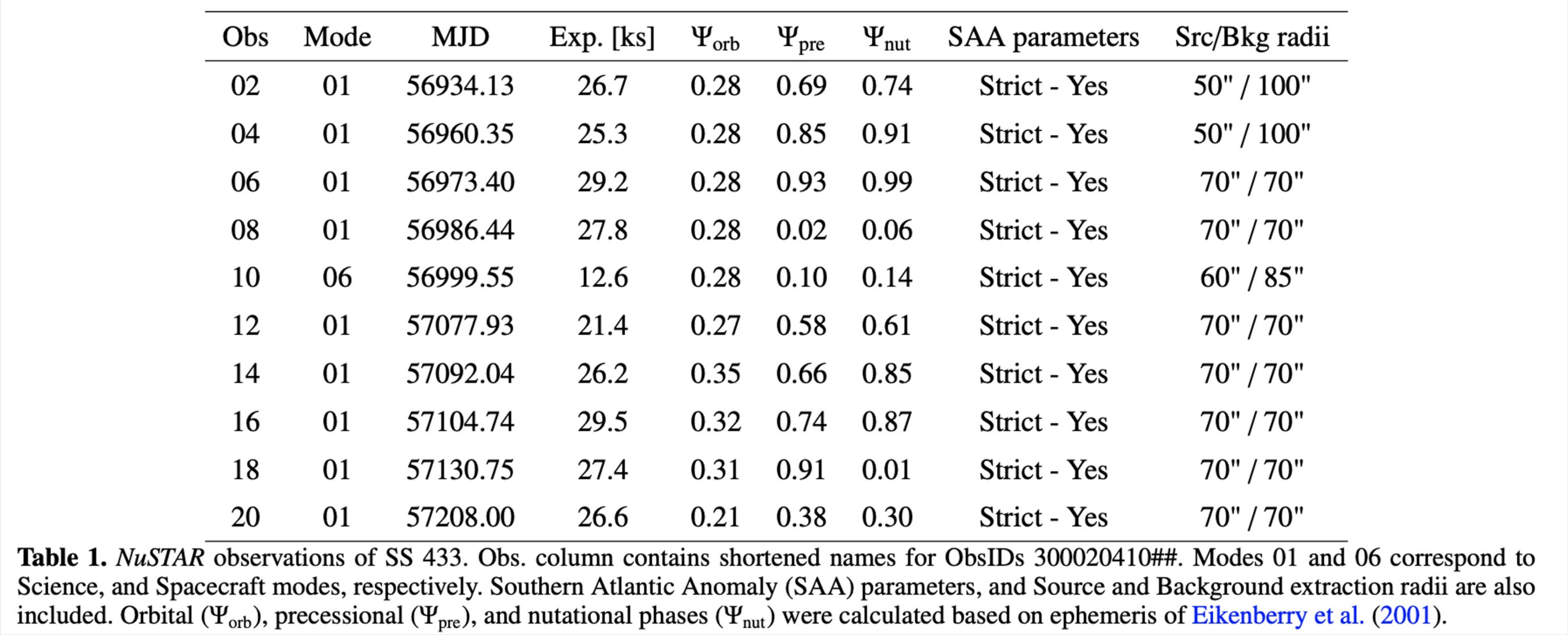
3. Nustar Data:

NuSTAR observed SS 433 for 10 times between modified Julian dates (MJD) 56934 and 57207 with typical exposures of 20–30 ks in the 0.2–0.3 orbital phase range, spanning over roughly one and a half precessional periods of the source. In Table 1 we show the ten observations and their characteristics.



Obs	Mode	MJD	Exp. [ks]	Ψ_{orb}	Ψ_{pre}	Ψ_{nut}	SAA parameters	Src/Bkg radii
02	01	56934.13	26.7	0.28	0.69	0.74	Strict - Yes	50" / 100"
04	01	56960.35	25.3	0.28	0.85	0.91	Strict - Yes	50" / 100"
06	01	56973.40	29.2	0.28	0.93	0.99	Strict - Yes	70" / 70"
08	01	56986.44	27.8	0.28	0.02	0.06	Strict - Yes	70" / 70"
10	06	56999.55	12.6	0.28	0.10	0.14	Strict - Yes	60" / 85"
12	01	57077.93	21.4	0.27	0.58	0.61	Strict - Yes	70" / 70"
14	01	57092.04	26.2	0.35	0.66	0.85	Strict - Yes	70" / 70"
16	01	57104.74	29.5	0.32	0.74	0.87	Strict - Yes	70" / 70"
18	01	57130.75	27.4	0.31	0.91	0.01	Strict - Yes	70" / 70"
20	01	57208.00	26.6	0.21	0.38	0.30	Strict - Yes	70" / 70"

Table 1. *NuSTAR* observations of SS 433. Obs. column contains shortened names for ObsIDs 300020410##. Modes 01 and 06 correspond to Science, and Spacecraft modes, respectively. Southern Atlantic Anomaly (SAA) parameters, and Source and Background extraction radii are also included. Orbital (Ψ_{orb}), precessional (Ψ_{pre}), and nutational phases (Ψ_{nut}) were calculated based on ephemeris of Eikenberry et al. (2001).

4. Results :

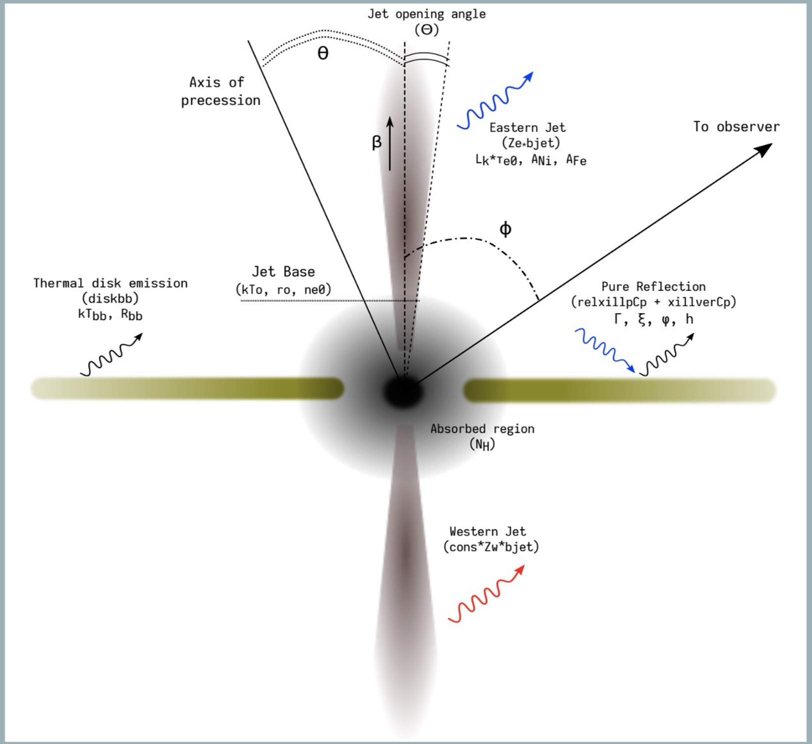
To investigate the spectral X-ray variability of SS 433 along the ten NuSTAR observations, we propose the same spectral model for the whole set of averaged spectra, with similar Galactic absorption, jet and accretion disk components.

To represent the X-ray emission from the jet in SS433, we considered a spectral model developed by Khabibullin et al. (2016) (bjet), where they adopted a jet opening angle and bulk velocity fixed at $\Theta = 0.024$ rad and $\beta = 0.2615$, respectively.

To account for the precessional motion of the jet (Doppler shifting and boosting, and broadening) we included a convolution model (zashift in XSPEC), a Gaussian smoothing component gsmooth (with index $\alpha = 1$) and a western jet attenuation factor (constant in XSPEC). Therefore, both jet X-ray spectra are modelled by zashift*bjet+cons*zashift*bjet, in XSPEC language.

For the accretion disk emission, we included a linear combination of direct thermal emission from a BB spectrum (diskbb), and pure-reflected neutral (xillver; García et al. 2013) and relativistic-emission spectra (relxill; Dauser et al. 2014). In both latter components, we chose to use the coronal flavours (Cp).

On this Figure we show a simplified picture of the SS433 jet-disk system, indicating each model contribution to the total X-ray spectra.



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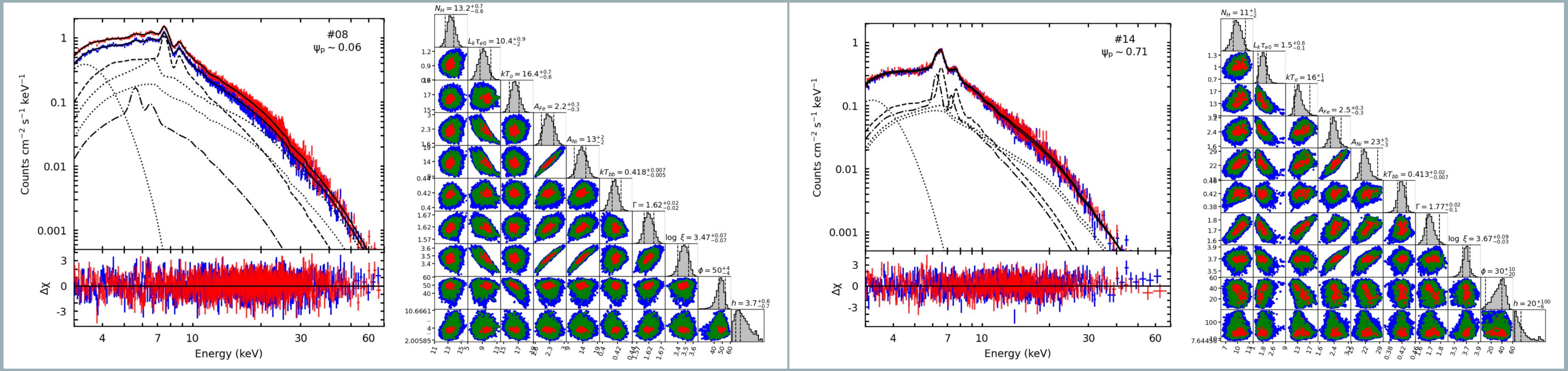
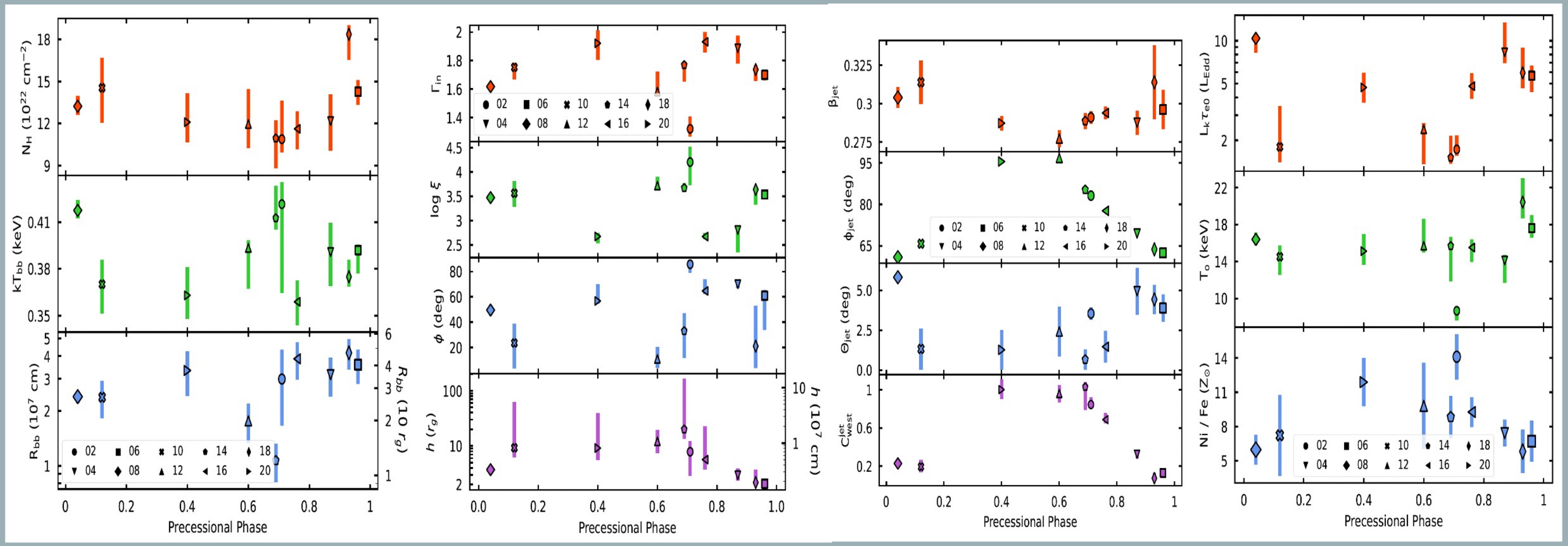
In this Figure, we show observations #08 (ψ_pre ~ 0.06) and #14 (ψ_pre ~ 0.71) spectra and their best fits along with their residuals. These two examples show two very different instances of the precessional motion.



Left column: Sample of NuSTAR FPM-A/B averaged spectra fitted with a combination of bjet , diskbb , xillverCp and relxilllpCp. Dashed line corresponds to the eastern jet model component. Dot-dashed line corresponds to the western jet model component. Dotted lines corresponds to the different disk model components. Right column: one and two dimensional distribution of some continuum model parameters derived from the MCMC simulations. Colours indicate confidence levels: red=90%; green= 99%, blue=99.9%.

5. Final comments:

We find an average jet bulk velocity of $\beta = v/c \sim 0.29$ with an opening angle of $\lesssim 6$ degrees. Eastern jet kinetic power ranges from 1 to 10×10^{38} erg/s, with base "coronal" temperatures To, ranging between 14 and 18 keV. Nickel/iron ~ 8.5. The western to eastern jet flux contribution becomes ~ 1 on intermediate phases, about 35% of the total precessional orbit. The 3–70 keV total unabsorbed luminosity of the jet and disk ranges from $2\text{–}20 \times 10^{37}$ erg/s, with the jet being completely soft X-ray dominated (3–10 keV) while the disk reflection component completely hard X-ray dominated (10–70 keV). At low opening angles Θ we find that the jet expands sideways following an adiabatic expansion of a gas with temperature To. Finally, the central source and lower parts of the jet could be hidden by an optically thick region of $\tau \sim N_H \sim 15 \times 10^{22}$ cm^{-2} and size $R \sim N_H/n_{e0} \sim 1.5 \times 10^{9}$ cm ($\lesssim 600\ r_g$ for $M_{BH} = 3\ M_\odot$).



The precessional evolution of the bjet and different disk components parameters derived from the 3–70 keV fit to NuSTAR spectra.

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