Spectral Evolution of NGC 300 ULX-1

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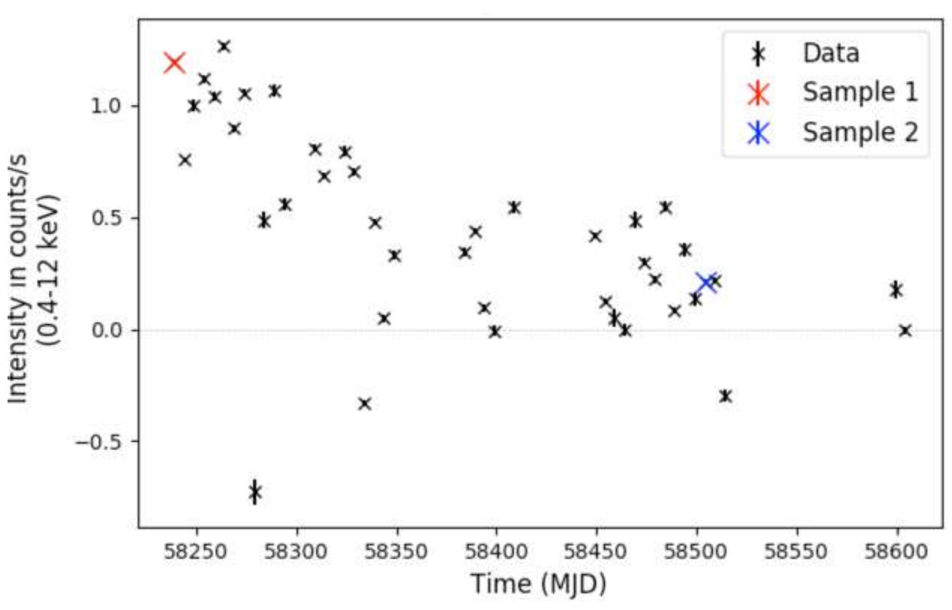
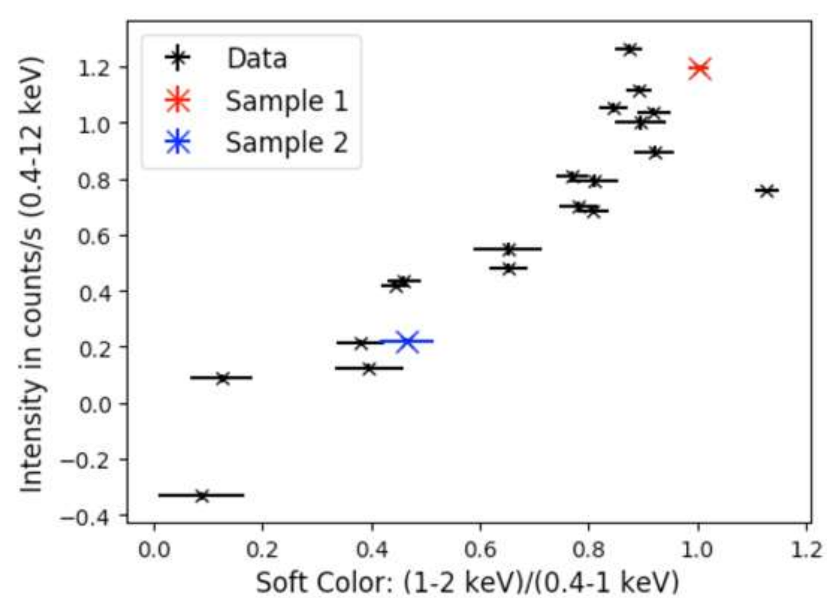
Introduction

- NGC300 ULX-1 is a **ULX (ultraluminous X-ray source) pulsar** originally associated with supernova impostor SN 2010da (Carpano+18a, Vasilopoulos+18a)
- ~31s pulsations were discovered during XMM-Newton/NuSTAR observations in December 2016 (Maitra+ 18)
- Monitoring with Chandra, NICER, XMM-Newton, and Swift showed that the spin period (exponentially) evolved from ~126s to ~18s over 4 years (Vasilopoulos+ 18b, Ray+ 19)
- Carpano+ 18 performed spectral fits (0.3-30 keV) with XMM-Newton and NuSTAR data from December 2016, adopting a two-component model comprising of a power law (Γ ~ 1.6) and a soft disk thermal blackbody with kT ~ 0.18 keV. They also note that the average pulsed fraction in the 0.2-10 keV band of XMM-Newton data was ~55%
- Walton+ 18 analyzed the **pulsed emission** with the same XMM-Newton and NuSTAR data (fitting over 0.3-40 keV) and identified a potential cyclotron resonant scattering feature at ~13 keV
- Spectral analysis of the **pulsed emission** by Ray+ 19 with NICER data (over two glitch epochs spanning 40 days total; 0.4-10 keV) suggests that the spectra are initially flatter (Fig. 11), and slowly evolve to softer spectra characterized by an average photon index of Γ ~ 1.5

Data Overview

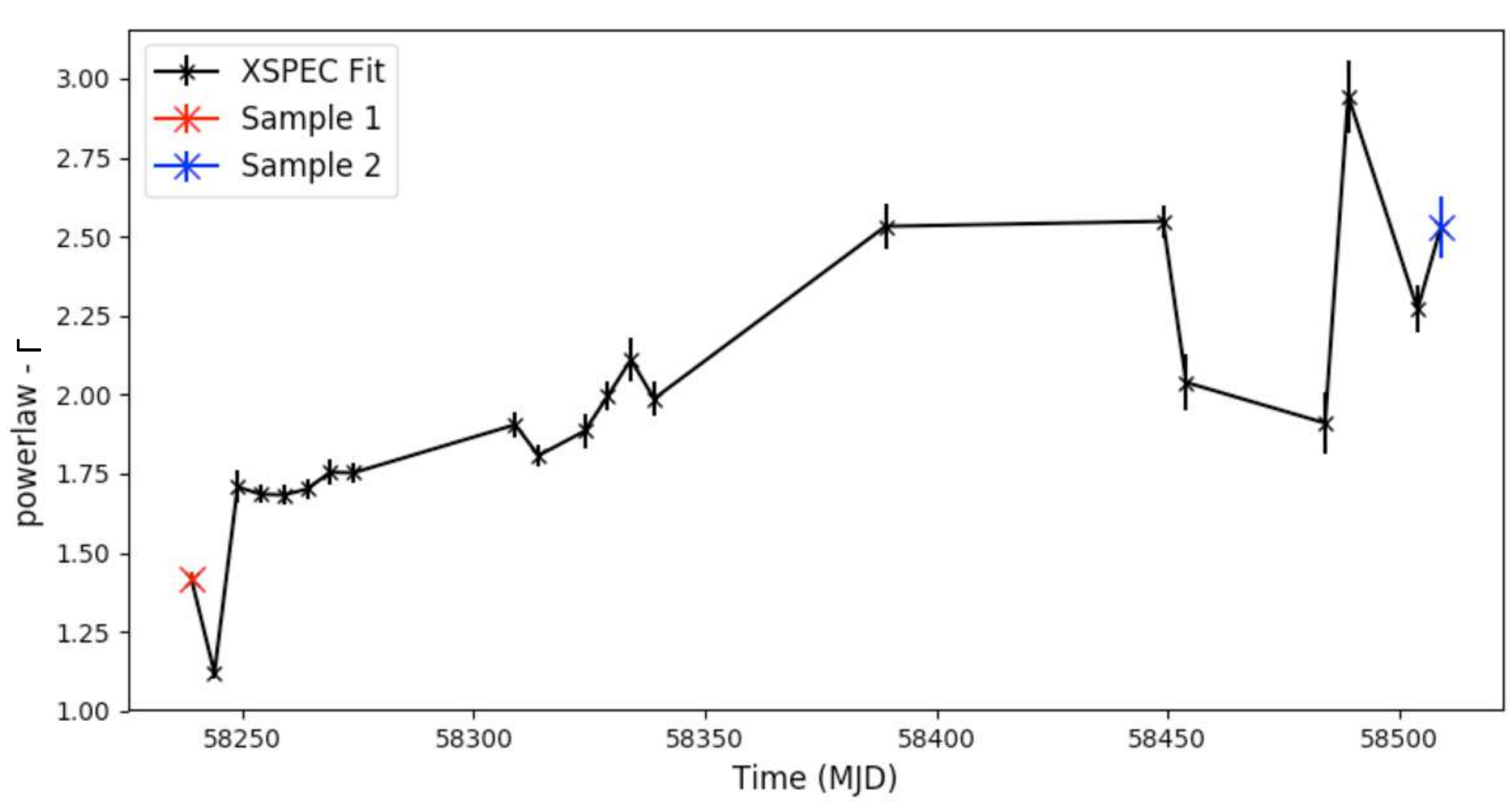


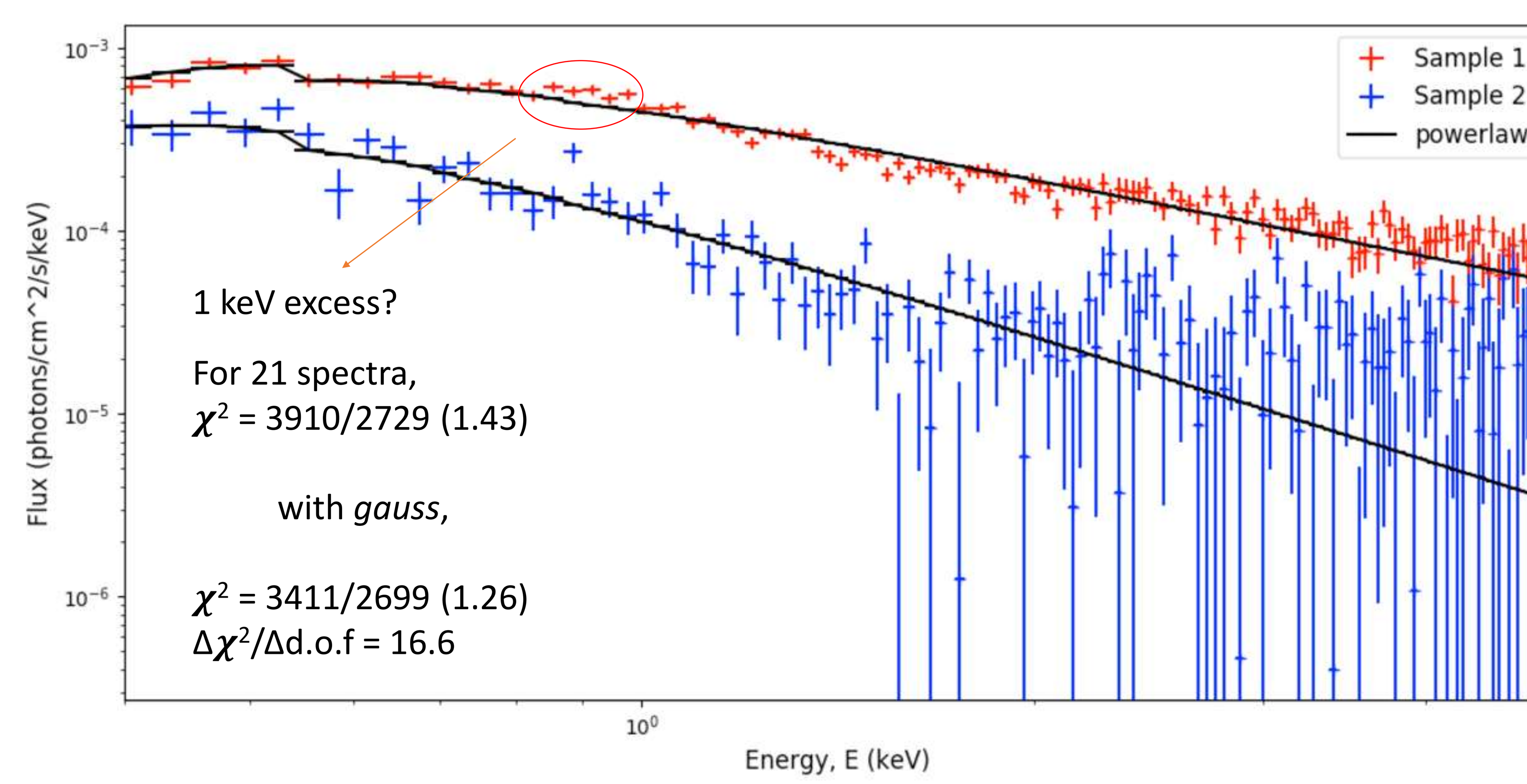


- Analyzed NICER observations spanning 05/2018 to 05/2019, totaling 236ks, with default NICER pipeline processing and 2018 gain calibration without restrictive overshoot/undershoot rate cuts
- Very short GTIs were discarded; average GTI length was ~600s
- Background subtraction was done with the 3C50 models (Remillard et al., in prep.), which makes use of three measured parameters that selects and re-normalizes the background spectrum, per GTI, from a library of blank-sky pointings binned in a grid of the 3C50 model parameters
- Data was put into **5-day bins** as the trend in the hardness intensity diagram was most evident
- Discarded 16/41 spectra due to background dominating
- 2% systematic error was assumed
- 4 more spectra were removed from the spectral analysis due to anomalous photon indices (Γ ≲ 1)
- **21 rebinned spectra** were used for spectral fitting; with **combined 180ks exposure** (76% of total)

The hardness intensity diagram shows that the source brightening is accompanied by an increase in the soft color, until the soft color reaches a value of 1, at which point there is a brightening at constant soft color. This initial result motivated us to move forward with spectral fitting in XSPEC.

Spectral Fitting





Simultaneously fitted 21 spectra with several models:

- **Energy range: 0.4 – 5 keV** (determined from comparing data spectra and background spectra)
- Two absorption components modeled with *tbnew* (Wilms+ 00):
  - Galactic absorption was frozen at 4.2×10^{20} cm^{-2} (Kalberla+ 05)
  - Intrinsic absorption was kept as a free parameter for the fit but was kept (assumed) fixed across all 21 spectra; inclusion of intrinsic absorption was motivated by modeling done in Walton+ 18
- **Model parameters** (e.g., *PhoIndex* and *norm* from *powerlaw*) were **free parameters** in the fit across all 21 spectra
- Tried single emission component fits, and obtained: [*powerlaw* – χ_{red}^2 = 3910/2729 (1.43), *bbodyrad – 11161/2729 (4.09), ezdiskbb – 5330/2729 (1.95) , diskbb – 5583/2729 (2.05)]*
- In the two figures above, we report the photon index Γ as a function of time, as well as two sample spectra and the corresponding power law fits
  - **Sample 1** (**red** in above figures) covers first 5 days of data, while **Sample 2** (**blue**) covers last 5 days of data; succinctly representing evolution of spectra over time
    - **Sample 1** represents the higher intensity and harder spectrum, along with the broad excess emission around 1 keV
    - **Sample 2** represents the lower intensity and softer spectrum, and no broad excess emission around 1 keV
  - Combined with the light curve, the analysis tells us that the **spectra are softer over time**, as suggested by the rise in the photon index, and this is **accompanied by decreasing intensity**
- Gauss (+powerl) was added for the first 10/21 spectra, and normalization was frozen at 0 for the latter 11, based on inspection of the ratios [Note: *laor* gives slightly poorer fit - 3501/2697 (1.30)]

Conclusions + Outlook

- Our analysis looks at **averaged spectra** across 9 months of observations (after discarding spectra due to dominating background), while Ray+ 19 only analyzed the **pulsed emission**
  - When comparing our **5-day averaged** light curve with Fig. 3 in Ray+ 19, the pulsed fraction is inferred to be ~60% over months of observations
  - We see similar spectral behavior with 5-day averaged spectra in the overlapping epoch (~40 days) with Ray+ 19, where the **spectra are initially flatter** (though our Γ is higher), **then Γ stays roughly constant at Γ ~ 1.75**
  - However, beyond the epoch covered by Ray+ 19, our spectral analysis with 5-day averaged spectra shows that **Γ continues to rise substantially as the intensity decreases**
  - Their work also supports our approach of increasing the bin size (to 5 days) as things are changing sufficiently slowly
- In agreement with other works, an **absorbed power law** provides the best fit to the data among simple single emission component models
  - We see that the averaged spectra become softer as intensity decays, because the photon index steepens. This tracks the result for the pulsed component, as shown by Ray+ 19 for MJD < 58280
- New calibration and gain for NICER will be released in 2020, so the data selection and spectral analysis will be redone
- Comparing the work done on pulsed emission by Ray+ 19 and our work, **pulsed flux dominates the source emission**, so we will next analyze separately how the pulsed and non-pulsed spectra evolve

References

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