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Probing the Origin of X-Ray Flares in the Low-hard State of GRS 1915+105 Using AstroSat and NuSTAR

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Abstract

We performed a detailed time-resolved spectral study of GRS 1915+105 during its low-flux rebrightening phase using the broadband capabilities of AstroSat and NuSTAR in 2019 May–June. The AstroSat light curves revealed erratic X-ray flares with count rates rising by a factor of ∼5. Flares with simultaneous LAXPC and SXT coverage were segmented and fitted using two degenerate but physically motivated spectral models: a reflection-dominated model (hereafter model A) and an absorption-dominated model (hereafter model B). In model A, the inner disk radius ($R_{\rm in}$) shows a broken power-law dependence on flux, indicating rapid inward motion of the disk at higher flux levels. In contrast, model B shows variable column density in the range of 10^{23}–10^{24} cm^{-2}, displaying a strong anticorrelation with flux. Both models exhibit significant variation in the ionization parameter between low- and high-flux segments. The total unabsorbed luminosity in the 0.7–30 keV energy range ranged from 6.64×10^{36} to 6.33×10^{38} erg s^{-1}. Across both models, several spectral parameters exhibited step-function-like behavior around flux thresholds of 5–10 $\times 10^{-9}$ erg cm^{-2} s^{-1}, indicating multiple spectral regimes. The disk flux contribution, more evident in model B, increased with total flux, supporting an intrinsic origin for the variability. These findings point to a complex interplay between intrinsic disk emission, structured winds, and variable local absorption in driving the flare activity.

Unified Astronomy Thesaurus concepts: Accretion (14); X-ray binary stars (1811); Stellar accretion disks (1579)

Materials only available in the online version of record: machine-readable tables

1. Introduction

X-ray binaries (XRBs) are astrophysical systems consisting of a compact object and a companion star emitting high-energy radiation. They are classified based on the mass of the companion star into low-mass XRBs (LMXBs) and high-mass XRBs (HMXBs; H. V. D. Bradt & J. E. McClintock 1983). LMXBs have companion stars with masses below 1 $M_\odot$, usually accreting matter via Roche lobe overflow, whereas HMXBs feature companions with masses exceeding 10 $M_\odot$, primarily accreting through stellar winds. Black hole XRBs (BHXRBs) exhibit distinct X-ray emission states, reflecting different accretion configurations. In the soft state, X-rays primarily originate from the thermal radiation of the accretion disk (N. I. Shakura & R. A. Sunyaev 1973), while in the hard state, they result from interactions between photons and high-energy electrons in the hot corona (N. I. Shakura & R. A. Sunyaev 1976; R. A. Sunyaev & L. G. Titarchuk 1980; A. P. Lightman & A. A. Zdziarski 1987). Observations suggest that the corona is significantly hotter than the accretion disk, with electron temperatures reaching around 100 keV, compared to the disk temperature of approximately 0.1 keV. The exact shape and position of the corona relative to the disk remain uncertain, and different geometries such as the lamppost corona, sandwich corona, etc. have been proposed (F. Haardt & L. Maraschi 1991; B. E. Stern et al. 1995; A. A. Zdziarski 1998). When X-rays from the corona are reflected off the accretion disk, they produce characteristic emission features, including the iron Kα fluorescence line at 6.4 keV (I. M. George & A. C. Fabian 1991; R. Ross & A. Fabian 2005). This reflection spectrum provides crucial insights into the velocity of the orbiting disk gas and reveals both special and general relativistic effects near the black hole.

GRS 1915+105, a superluminal XRB, was first observed in outburst by the WATCH all-sky monitor on board the GRANAT satellite in 1992 August (A. J. Castro-Tirado et al. 1992). GRS 1915+105 hosts a black hole with a mass of $12.5^{+2.0}_{-1.8}$ $M_\odot$ situated at a radio parallax distance of $8.6^{+2.0}_{-1.6}$ kpc, and the accretion disk is inclined at an angle of 60° (M. Reid et al. 2014). Unlike typical LMXBs, which spend long periods in quiescence before undergoing outbursts lasting from months to a few years, GRS 1915+105 exhibited persistent brightness from its discovery until mid-2018, after which its X-ray flux began an exponential decline, signaling a major shift in its long-term behavior. This decline marked the lowest soft X-ray flux recorded for the system in 22 yr of continuous monitoring by MAXI/GSC and RXTE/ASM (H. Negoro et al. 2018). The reduction in flux was interpreted as the system entering a quiescent phase, similar to transitions observed in other BHXRBs. However, in 2019 May (around MJD 58600), GRS 1915+105 exhibited a resurgence in activity, despite maintaining lower-than-average X-ray flux levels, with radio flares during this period suggesting high mass accretion rates (S. Motta et al. 2019; K. I. I. Koljonen & T. Hovatta 2021). M. Zhou et al. (2025) reported a significant reduction in ionization ($\log \xi$) of accretion disk winds during