Long-Term X-ray Activity of GRS 1915+105 studied with Swift and MAXI

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Abstract

GRS 1915+105 is one of the brightest black hole X-ray binaries (BHXBs) since it was first detected by GRANAT/WATCH in 1992 until it faded into a quiescent state in recent years. We studied its long-term activity using MAXI/GSC and Swift/BAT data for the duration of 2009 – 2019, the last ten years of its active state. We found that the 10 years' activity of GRS 1915+105 can be classified into four distinct spectral branches in the hardness-intensity diagram drawn with the MAXI/GSC and Swift/BAT bands. We named these branches the diagonal branch, the soft branch, the faint branch, and the quiescent branch based on their positions in the diagram. These branched can be also identified in the X-ray light curves, with each of them lasting for months to years. Although it is not straightforward to compare it with the "spectral states" found in the canonical "q-shaped" hardness intensity diagram often drawn for the outbursts of transient BHXBs, we find that the soft branch of GRS 1915+105 has similarities to the high/soft state of canonical BHXBs where the disk emission is dominant, while the faint branch is like the low/hard state where corona emission dominates. The diagonal branch, however, is difficult to interpret in the standard framework of BHXBs.

II. 10-Year X-ray Variabilities

❖ Instruments and data

- One-day average X-ray fluxes from August 2009 to August 2019
- 2 – 20 keV: MAXI Gas Slit Camera (GSC) on the International Space Station
- 15 – 50keV: Burst Alert Telescope (BAT) onboard Neil Gehrels Swift Observatory

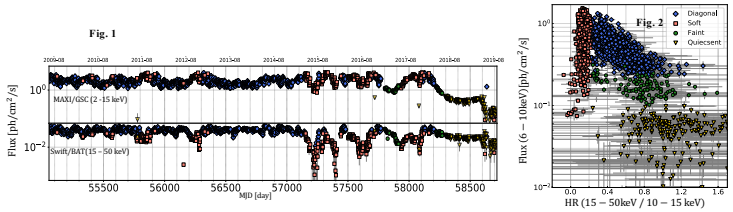
❖ Light Curve and Hardness-Intensity Diagram

X-ray timing activities of GRS 1915+105 is different from typical black hole X-ray binaries

- Persistently bright in X-ray; the characteristics of timing behaviors change on timescales of years (Fig. 1)
- Hardness-Intensity Diagram is NOT a "q" shape; there are multiple transition patterns. (Fig. 2)

❖ Classification of X-ray variations

Four distinct branches (**Diagonal**, **Soft**, **Faint**, **Quiescent**) are found in the light curve (Fig .1) and hardness-intensity diagram (Fig. 2) .

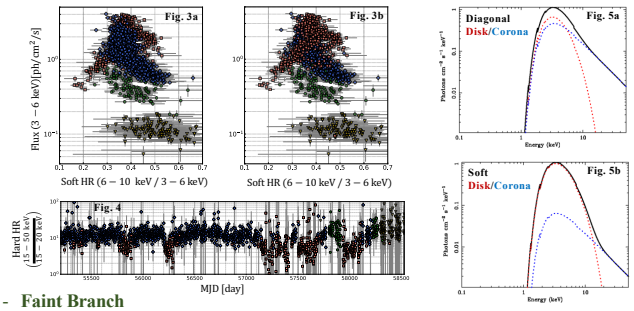


Diagonal : Anti-correlation between Med HR and flux (6 – 10 keV); low variability in soft and hard X-rays
Soft : Stable and low Med HR; highly variable soft X-ray flux, low and stable hard X-ray flux
Faint : Relatively rare. Hard-to-soft transition in Med HR; low soft X-ray flux, decreasing hard X-ray flux
Quiescent : Seen in 2018-2019. Hard color in Med HR, low variability both in soft and hard X-rays.

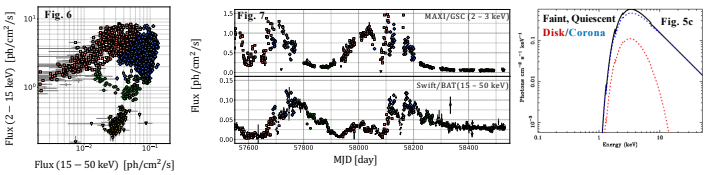
❖ X-ray Emission Processes in Each Branch

Assume a simple description of X-ray emission from a black hole X-ray binary: **tbabs*(diskbb + powerlaw)**
→ Soft X-rays from the accretion disk (diskbb)、 hard X-rays from hot corona (power-law)

- **Diagonal Branch**
  Trace in Soft HR vs. soft X-ray flux → Variation of Disk parameters (Tin, Norm) (Fig 3a)
  Stable hard X-ray emission (Fig. 1, Fig. 4) → stable power-law component
  → Variable contributions from the disk and corona (Fig. 5a)
  → Variation in disk inner radius Rin and optical depth of hot corona??
- **Soft Branch**
  Positive correlation in Soft HR (Fig. 3b) → Variable Tin (disk temperature)
  Low hard X-ray flux (Fig. 1, Fig. 4) → weak power-law component
  → Dominated by the thermal emission from the disk with variable Tin and Norm. (Fig. 5b)



- **Faint Branch**
  Stable and low soft X-ray flux and steadily decreasing hard X-rays (Fig. 6, Fig. 7)
  → Dominated by Power-law component with variable parameters (Fig. 5c)
  → Decreasing coronal emission with weak disk emission
- **Quiescent Branch**
  Even lower soft X-ray flux than Faint Branch, stable hard X-ray flux (Fig. 6, Fig. 7)
  → Dominated by Power-law component with slowly variable norm.(Fig. 5c)
  → Weak coronal emission with very weak (or no) disk emission



III. Key Results

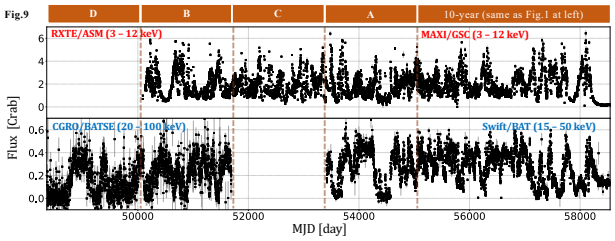
❑Long-term X-ray activities of GRS 1915+105 are classified to four Branches: **Diagonal**, **Soft**, **Faint**, and **Quiescent**
→ **Diagonal**: Variable contribution from the disk and the corona
→ **Soft** : Dominated by disk with variable inner temperature, small contribution from the corona
→ **Faint** : Weak disk emission with changing coronal emission
→ **Quiescent** : Very faint disk emission with weak coronal emission

❑GRS1915+105 stays in the **Diagonal Branch** for the largest fraction of time, and the X-ray behavior is most complex. Important for understanding the peculiar behavior of this source.

IV. 24-Year X-ray Variabilities

❖ Expanding the time coverage

- Rossi X-ray Timing Explorer (RXTE) All Sky Monitor (ASM): January 1996 – October 2011
- Compton Gamma-Ray Observatory (CGRO) Burst (BATSE): January 1991– June2000

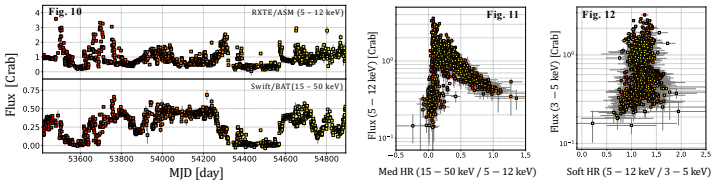


A) RXTE/ASM + Swift/BAT

One-day average fluxes from RXTE/ASM and Swift/BAT in 4.7 years (2004/11－2009/07; Fig. 10)

- Long dwell in **Soft Branch** at low luminosity (Fig. 11) — not seen in "10 year"
- Soft HR behavior in **Diagonal** and **Soft** branches (Fig. 12) — similar to "10 year"

→ Basically same X-ray emission process as discussed for "10 year"
→ low luminosity state in **Soft branch**: explained by a small disk contribution in Fig. 5b。

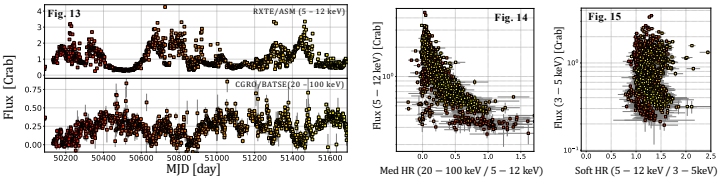


B) RXTE/ASM + CGRO/BATSE

One-day average fluxes from RXTE/ASM and CGRO/BATSE in 4.5 years (1996/01－2000/06; Fig. 13)

- Transition from **Faint Branch** to **Diagonal Branch** (Fig. 14)) — not seen in "10 year"
- Soft HR behavior in **Diagonal** and **Soft** branches (Fig. 14) — similar to "10 year"

→ **Faint** to **Diagonal** Transition caused by change of disk component, unlike **Faint** to **Soft**



C) RXTE/ASM only

One-day average fluxes from RXTE/ASM and in 4.4 years (2000/06－2004/11; Fig. 16)

- Soft HR-Intensity Diagram behavior similar to **Diagonal** and **Soft** branches in "10 year" (Fig. 17)
- Episodes of steady flux decay over several months (as in period A) are repeatedly seen (Fig. 16)