# GRS 1758−258:
## RXTE monitoring of a rare persistent hard state Black Hole

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## Abstract

GRS 1758−258 is the least studied of the three persistent black hole X-ray binaries in our Galaxy. It is also one of only two known black hole candidates, including all black hole transients, which shows a decrease of its 3-10 keV flux when entering the thermally dominated soft state, rather than an increase.
We present the spectral evolution of GRS 1758−258 from *RXTE*-PCA observations spanning a time of about 11 years from 1996 to 2007. During this time, seven dim soft states are detected. We also consider *INTEGRAL* monitoring observations of the source and compare the long-term behavior to that of the bright persistent black hole X-ray binary Cygnus X-1. We discuss the observed state transitions in the light of physical scenarios for black hole transitions.

## GRS 1758-258

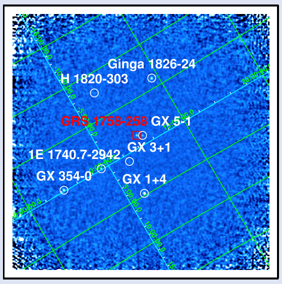


FIGURE 1: *INTEGRAL*-ISGRI count rate mosaic image in the 20–40 keV band obtained during Galactic Center Region Key Programme observations performed in spring 2007 (Lohfink et al., 2011).

GRS 1758−258 is an intermediate mass X-ray binary harboring a black hole and a companion consistent with an early A-type main sequence star, but with unusual colors (Muñoz-Arjonilla et al., 2010). Mass transfer is probably driven by Roche lobe overflow. Among such systems, usually transients, GRS 1758−258 is one of only few persistent sources. Generally it can be found in the hard state. However, in some respects it still displays a behavior typical for transient sources (hysteresis, rare decay-type soft states; Pottschmidt et al., 2006; Smith et al., 2001, 2002; Soria et al., 2011).

## Spectral Parameters

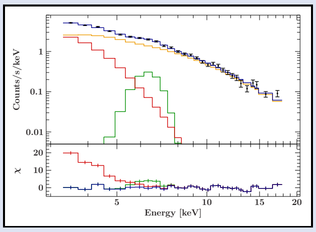


FIGURE 3: Example spectrum taken by *RXTE* on April 08, 2003, containing the absorbed powerlaw component (orange), the disk (red) and the iron line (green).

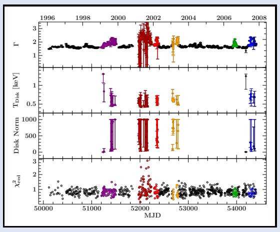


FIGURE 4: Spectral parameters from *RXTE* monitoring observations of GRS1758−258.

The *RXTE*-PCA spectra in the 3−20 keV band were fitted with an absorbed powerlaw, a weak neutral iron K$\alpha$ line, and a black body disk component where required, always including the Galactic ridge emission (see below). The column density due to interstellar absorption in the direction of GRS 1758−258 is fixed at $N_\mathrm{H} = 1.5\times10^{22}\,\mathrm{cm}^{-2}$ according to earlier results (Pottschmidt et al., 2008). The disk becomes visible in the dim soft states, the low source flux increasing the error bars.

## Background modeling: Galactic Ridge Emission

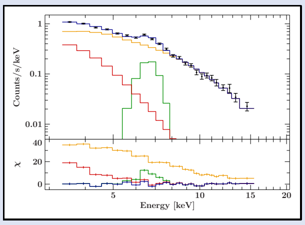


FIGURE 5: Spectrum of the Galactic Ridge emission as seen by *RXTE*. The data were fitted with two bremsstrahlung components (1: red, 2: orange) and an iron line complex as described in Ebisawa et al. (2007).

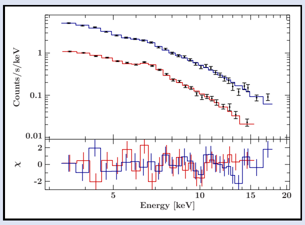


FIGURE 6: Spectrum for the April 2003 GRS 1758−258 observation, i.e. containing the source as well as the Galactic ridge contribution (blue), and spectrum for the Galactic ridge emission alone (red).

As GRS 1758−258 is a rather faint source located close to the Galactic Center, the *RXTE*-PCA spectra contain not only source counts but also a strong background component caused by the Galactic ridge emission (Fig. 6). In order to distinguish between these, a 13 ks background observation 1.5° offset from GRS 1758-258 was performed by *RXTE* in 1999. Fig. 5 contains the spectrum modeled with two bremsstrahlung components ($F_{1,3\text{–}8} = 0.015\,\mathrm{keV/s/cm^2}$, $kT_1 = 8\,\mathrm{keV}$, $F_{2,3\text{–}8} = 0.0027\,\mathrm{keV/s/cm^2}$, $kT_2 = 1.2\,\mathrm{keV}$). The iron line complex was modeled according to Galactic ridge observations performed with *Suzaku* (Ebisawa et al., 2007): Three lines at 6.4 keV, 6.67 keV and 7 keV, respectively, have equivalent widths that scale as 85:458:129.

## RXTE Monitoring

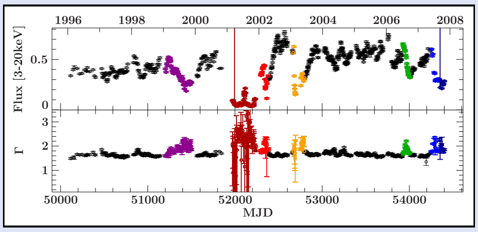


FIGURE 2: ***Top***: Flux in keV/s/cm² in the 3−20 keV band, fitted to the spectra taken by *RXTE*. ***Bottom***: Photon index obtained from modeling. Soft states are highlighted for episodes reaching a photon index above 2.

GRS 1758−258 was monitored by *RXTE* in 1−1.5 ks pointed snapshots monthly in 1996, weekly through 2000 and twice a week from March 2001 to October 2007. Every year there is a gap from November to January as the sun is too close to the Galactic center. The spectra were modeled taking into account the Galactic ridge background (see below for details). The flux has been corrected for the contribution of the Galactic ridge emission (Fig. 2 ***top***). Error calculation showed that typical uncertainties are in the range of 1−1.5%.
The photon index varies between 1.5 and 3. Most of the time, GRS 1758−258 is in the hard state. However, seven dim soft states, during which the flux decreases and the spectrum softens, appear clearly in the data (Fig. 2 ***bottom***). During the 2001 soft state (highlighted in dark red), the source almost turned off completely. This strong decline in flux makes GRS 1758−258 especially interesting as it is typical for transient, not for persistent sources (see also hardness intensity diagram below).

## Hardness Intensity Diagram

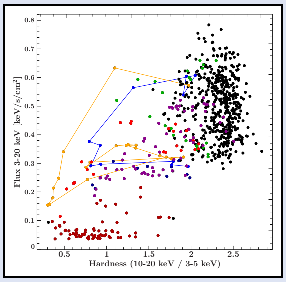


FIGURE 7: Hardness intensity diagram (HID) from *RXTE* monitoring observations of GRS 1758−258 from 1997 to 2007. The seven dim soft states are colored as above.

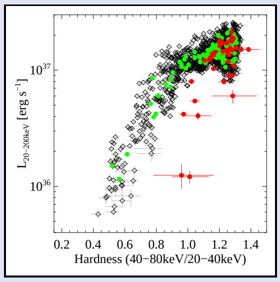


FIGURE 8: HID from *INTEGRAL* monitoring of GRS 1758−258 from 2003 to 2009 (red: monthly binning), compared to the HID from *RXTE* monitoring of Cyg X-1 from 1998 to 2010 (black: individual pointings, green: monthly binning).

For energies <20 keV the HID of GRS 1758−258 shows a clear hysteresis for hard and soft state fluxes (absorbed fluxes, see Fig. 7). This behavior is similar to that shown by black hole transients over their outbursts ("q"-shaped HID; Fender et al., 2004). Different from transients, there is no rise in the hard state from quiescence. During the most extreme soft state the 3−20 keV flux is clearly below the lowest hard state flux, with no full return to the hard branch observed down to near-quiescence. A comparison at these energies with our long-term *RXTE* monitoring observations of the persistent black hole X-ray binary Cyg X-1 is in preparation.
Results from spectral fits to 2003–2009 *INTEGRAL* monitoring data of GRS 1758−258 (Lohfink et al., 2011) allow us to extend the HID studies to higher energies (Fig. 8). For a luminosity-based comparison with the Cyg X-1 *RXTE* monitoring data, we assumed a distance of 2.5 and 8.5 kpc for Cyg X-1 and GRS 1758−258, respectively. As expected neither source shows hysteresis for energies >20 keV, i.e., in an energy range where only one, namely the hard, spectral component dominates. We confirm with the most extensive datasets to date that the hard states of both sources are remarkably similar in luminosity and hardness. While the decay towards softer, lower luminosity states is qualitatively similar in both sources as well, the luminosity of GRS 1758−258 has dropped more severely at a given hardness level than that of Cyg X-1.
Overall, the tracks of GRS 1758−258 in both HIDs are consistent with a persistent hard state source with occasional softening due to a temporary decrease in the mass accretion rate as suggested by Smith et al. (2002).

## Summary and Conclusions

The **main results** of our analysis of the 1996–2007 *RXTE* data of GRS 1758−258 are:

- Typical hard state fluxes after taking the galactic ridge emission into account: 0.2−0.4 keV/s/cm².
- Good description with absorbed power law with a photon index of 1.5−3.
- Possible detection of an additional weak Fe line.
- 7 occurences of soft states with photon indices above 2.
- Marginal disk detection during soft states with kT~500−800 eV.
- <20 keV HID shows hysteresis with no full return to the hard branch observed down to near−quiescence.
- >20 keV HID shows the same hard state luminosity and hardness as Cyg X-1 but a different decay.
- Soft states are most likely due to a decrease in mass accretion rate.

## References

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