Jets at all Scales
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GRS1915+105: a comparison of the plateau state to the canonical hard state

Pieter van Oers[1] and Sera Markoff[2]

[1]School of Physics & Astronomy, University of Southampton,
Highfield, Southampton SO17 1BJ, United Kingdom
email: `pvo1g09@soton.ac.uk`

[2]Astronomical institute "Anton Pannekoek", University of Amsterdam,
Science Park 904, 1098 XH, The Netherlands
email: `S.B.Markoff@uva.nl`

Abstract. GRS 1915+105 is a very peculiar black hole binary that exhibits accretion-related states that are not observed in any other stellar-mass black hole system. One of these states, however – referred to as the plateau state – may be related to the canonical hard state of black hole X-ray binaries. Both the plateau and hard state are associated with steady, relatively lower X-ray emission and flat/inverted radio emission, that is sometimes resolved into compact, self-absorbed jets. To investigate the relationship between the plateau and the hard state, we fit two multi-wavelength observations using a steady-state outflow-dominated model, developed for hard state black hole binaries. The data sets consist of quasi-simultaneous observations in radio, near-infrared and X-ray bands. Interestingly, we find both significant differences between the two plateau states, as well as between the best-fit model parameters and those representative of the hard state. We discuss our interpretation of these results, and the possible implications for GRS 1915+105's relationship to canonical black hole candidates.

Keywords. black hole physics, accretion, accretion disks, radiation mechanisms: general, X-rays: binaries, galaxies: active, galaxies: jets

1. Introduction

GRS 1915+105 is a hard X-ray transient located in the constellation of Aquila, at $l = 45.37°$, $b = -0.22°$. The obvious parallels to the jets in Active Galactic Nuclei (AGN) led to this source being classified as a "microquasar" (Mirabel & Rodríguez 1998). Observations with instruments onboard the *Rossi X-ray Timing Explorer* (*RXTE*) have revealed a richness in variability, distinguishing GRS 1915+105 from every other known BHB, over which astronomers are still puzzling to this day.

Belloni *et al.* (2000) were able to classify all variability patterns stretching over more than a year into only twelve classes, based on colour-colour diagrams and light curves. Most classes are understood as the interplay of two or three of three basic states (A, B and C). Class χ is reserved for state C exclusively and is usually called the *plateau* state. As both are associated with compact self-absorbed steady outflows (e.g. Homan & Belloni 2005, Remillard & McClintock 2006), it is tempting to compare the plateau state to the "canonical" hard state (HS). However, although the plateau state and the HS share many similarities, it does display some distinct properties that cannot be ignored. For instance, while the BHBs in the HS usually have a luminosity of $\lesssim 10\%\ L_{\rm Edd}$, the average luminosity observed in the plateau state is $\sim L_{\rm Edd}$. Moreover, the plateau X-ray photon index is never as hard (Fender & Belloni 2004).

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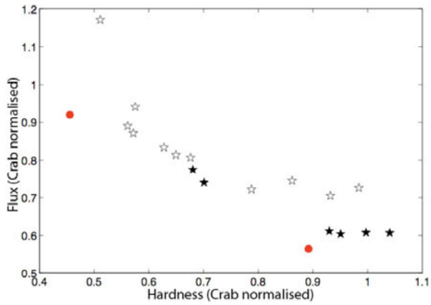

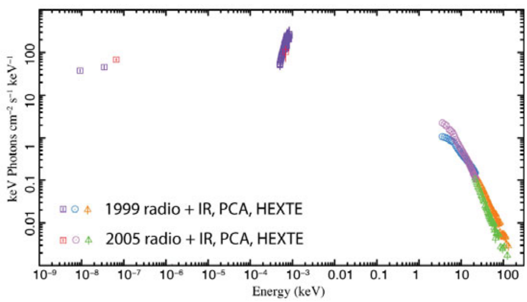

Figure 1. left: HID comparing our observations (filled circles) to the plateau states from Belloni *et al.* (2000) (data courtesy of T. Belloni). The 2005 observation is softer and of higher-luminosity. **right:** Comparison of the multi-wavelength SEDs for the 1999 and 2005 data set.

2. Observations

Based on the lightcurves and its position in the Hardness Intensity Diagram (HID) diagram (see Figure 1), GRS 1915+105 was in the plateau state on July 8th 1999 and April 13th 2005. To obtain multi-wavelength spectra for these episodes, quasi-simultaneous radio and infrared data were added to X-ray data, taken with *RXTE*: The 1999 data set comprises *RXTE* ObsID 40403-01-09-00, H and K bands from UKIRT and 2.25 & 8.3 GHz radio observations from GBI. The 2005 data set consists of *RXTE* ObsID 90105-07-02-00, K band from CTIO and 15 GHz radio from Ryle telescope.

3. Model and physical parameters

As we are dealing here with multi-wavelength spectra we will fit our datasets using the outflow dominated model from Markoff *et al.* (2005) (hereafter: MNW05), which was specifically designed for simultaneous radio through X-ray datasets. MNW05 has already been applied successfully to various Galactic sources in the HS: Cyg X-1, GX 339-4, XTE J1118+480, GRO J1655-40 and A0620-00 (MNW05, Maitra *et al.* (2009), Migliari *et al.* 2007, Gallo *et al.* 2007). In addition MNW05 has been successfully used to fit spectra from Supermassive Black Holes M81*, SGR A* and NGC4258 (Markoff *et al.* 2008, Markoff *et al.* 2007, Yuan *et al.* 2002). There exists, therefore, a solid framework for the modelling of a variety of BH systems, against which to test fits of data from the GRS 1915+105 plateau state.

In addition to the jet MNW05 includes a simple black body to account for the companion star and a "standard“ geometrically thin accretion disc Shakura & Sunyaev (1973). The main physical parameters in our jet are: The jet luminosity (N_j) that represents the power going into the jet and scales with the accretion power at the inner edge of the accretion disc. The power is equally divided to supply the internal and kinetic pressures. We assume that the kinetic energy is carried by cold protons, while the leptons do the radiating. The energy involved in the internal pressure goes into the particle and magnetic energy densities, with a ratio determined by $k = U_{\rm B}/U_{\rm e}$). The radius of the jet-base is also a free parameter, r_0. The particles start of in a quasi-thermal (relativistic) Maxwellian distribution, the peak energy of which is determined by the electron temperature (T_e). In a segment of the jet located at some variable distance ($z_{\rm acc}$) from the base, we assume 75 % of the leptons is accelerated into a power-law distribution with slope p.

All fits are done using the MNW05 model with an additive `Gaussian` line between 6 and 7 keV. These models are either convolved with `reflect` (Magdziarz & Zdziarski 1995) or multiplied with `smedge` (Ebisawa 1991), and consequently multiplied with a

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parameter	value	units	Reference
column density	4.7	10^{22} cm^{-2}	Chaty *et al.* (1996)
mass	14	$M_\odot$	Greiner *et al.* 2001
inclination	66	°	Fender *et al.* (1999)
distance	11	kpc	Chapuis & Corbel (2004)
donor temperature	4455	K	Alonso *et al.* (1999)

Table 1. Fixed physical parameters used in the fitting process, obtained from the literature. We omit the error bars, as they are not used in the fits.

similar				distinct			
parameter	units	HS range	GRS 1915+105	parameter	units	HS range	GRS 1915+105
r_0	r_g	3.5-20.2	20.4	$k(=U_B/U_e)$	r_g	1-7	692
T_e	10^9	20-52	9.2	z_{acc}	10^3 r_g	0.007-0.4	30
p		2.1-2.9	2.3	N_j	$10^{-2} L_{Edd}$	0.03-7	0.5

Table 2. 1999 parameters found to be similar (left) to and distinct (right) from canonical HS.

photo-electric absorption model (`phabs`) to account for the interstellar medium. Because including the `reflect` model was found to yield inferior statistics to including the `smedge` model and often yielded reflection component normalisation factors not deemed physical (MNW05) we did not pursue this line of investigation in great detail.

Table 1 shows the physical parameters we took from the literature.

4. Results

4.1. *1999*

From the 1999 data set fits (Figure 2) trends for the definitive plateau state are revealed. Qualitatively we see that, while in the HS we see a synchrotron domination below ~10 keV, the plateau state synchrotron is no longer dominant at these energies, but rather has a contribution of about 1% that of the inverse Compton up to ~50 keV. This result is qualitatively similar to the blazar sequence as found by e.g. Ghisellini *et al.* (1998) and Fossati *et al.* (1998), who find an anti-correlation between the frequency where the synchrotron power peaks and the power going in to the jet. A more quantitative comparison is made in Table 2. Indeed, while some parameters are quite similar to those found for the HS, other are quite distinct. The ratio k is more than 2 orders in magnitude larger in GRS 1915+105and $z_{\rm acc}$ increases an order in magnitude in our source. As may have been expected, the jet power approaches the Eddington luminosity in the plateau state. The relation between k and $z_{\rm acc}$ is further looked into in Polko *et al.* (in press). An correlation between k and the jet luminosity is also suggested by results from Markoff *et al.* (2008).

The bottom 2 plots in Figure 2 show the results of an attempt to find a statistically convincing fit with less extreme parameters. This fit is in fact a different local minimum with only slightly worse statistics ($\chi^2_{\rm red}$ ~1.44), representing a redistribution of the energy budget over the energy related parameters ($k \sim 29$, $N_{\rm j} \sim 1$ $L_{\rm Edd}$, $p \sim 1.8$). Indeed, the magnetic domination has dropped by a factor 15, almost comparable to values found in the HS. The reduction in k is mainly compensated by an increase in jet luminosity. In addition we see a decrease in p, which can perhaps be understood considering cooling break arguments and the fact that z_{acc} is so much further out in our source. Because of this increase in distance to the first acceleration zone, the magnetic fields involved in the acceleration are almost expected to have decreased further then usual. Hence electron cooling may be negigible in this case and we could be looking directly at an uncooled

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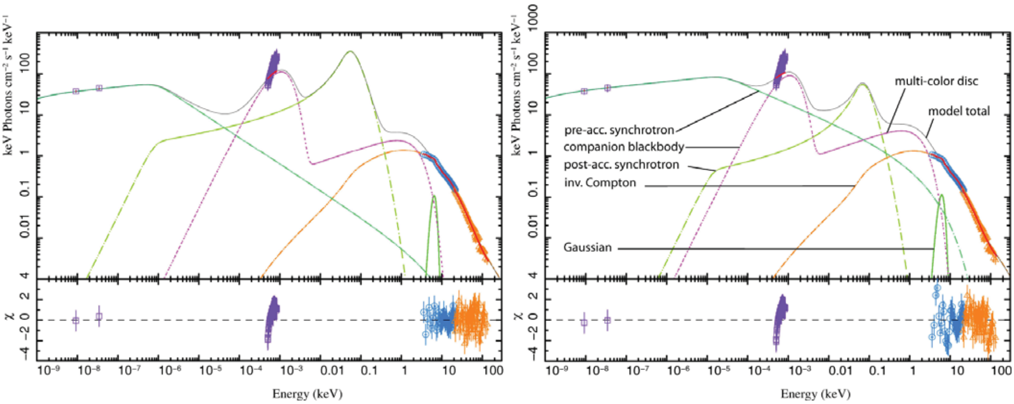

Figure 2. Multi-wavelength best fit (left; $\chi^2_{\rm red}$ ~1.16) and alternative (right: $\chi^2_{\rm red}$ ~1.44) fit model spectra for the 1999 data set. The alternative fit is still statistically convincing but reflects less extreme parameters (see text). Individual contributions from the MNW05 and Gaussian models are shown in the plot to the right. The "model total" curve is not forward-folded through the detector response matrices and does not include absorption due to the interstellar hydrogen column density or the `smedge` model.

particle distribution, which would decrease the spectral slope by ~ 0.5 (Heavens & Drury 1988).

4.2. *2005*

Because of the increased X-ray slope compared to the 1999 data set fitting this data set is increasingly difficult. Although two statistically convincing fits ($\chi^2_{\rm red}$ ~1) have been obtained for this data set, the results were found to have other physical uncertainties. One solution to getting an increased slope is to increase the decaying slope of the inverse Compton component. Reducing the electron temperature $T_{\rm e}$ is found to have exactly this effect. However the temperature has to be reduced to $\sim 4 \times 10^9$ K which will leave most particles at sub-relativistic speeds with Lorentz factor unity (consistent with thermal Comptonisation). As our model uses a relativistic Maxwellian this is not strictly justified.

Another solution to fitting the increased X-ray slope is to fit this regime with the exponential decay of the pre-acceleration synchrotron component. Although this theoretical shape is normally used, it may in reality be different. In addition this method of fitting requires an extremely hard synchrotron spectrum, normally only found in extremely relativistic sources.

Because of these issues we will not base any firm conclusions on the 2005 data set.

5. Conclusion

The MNW05 model seems to approximate rather well the 1999 data set, but clearly all the parameters need to be pushed into an extreme regime in order to fit to data well. The 2005 data set can be fit, but only marginally, suggesting already a difference between individual plateau states. Perhaps the plateau state would be better compared to the Hard Intermediate State (Belloni 2010), but in this case no reference framework is available yet. Recent evidence however suggests that in contrary to most canonical sources, GRS 1915+105may be moving on a radiatively efficient track (Corbel *et al.*, in prep.), perhaps explaining some of the extreme differences found between this source and other stellar mass black hole binaries.

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Discussion

MEIER: GRS 1915+105 shows a power spectrum with barndwidth limited noise +QPO when in the plateau state. GROJ 1655-40 also has such power spectrum when it produces a steady jet. Have you investigated whether GROJ 1655-40 was also in a plateau state at that time and if it has extreme parameters?

VAN OERS: GROJ1655-40 has been fitted by Migliari *et al.* (2007) but parameters are less extreme.

KALEMCI: GROJ 1655-40 will be extensively discussed in my talk tomorrow.

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