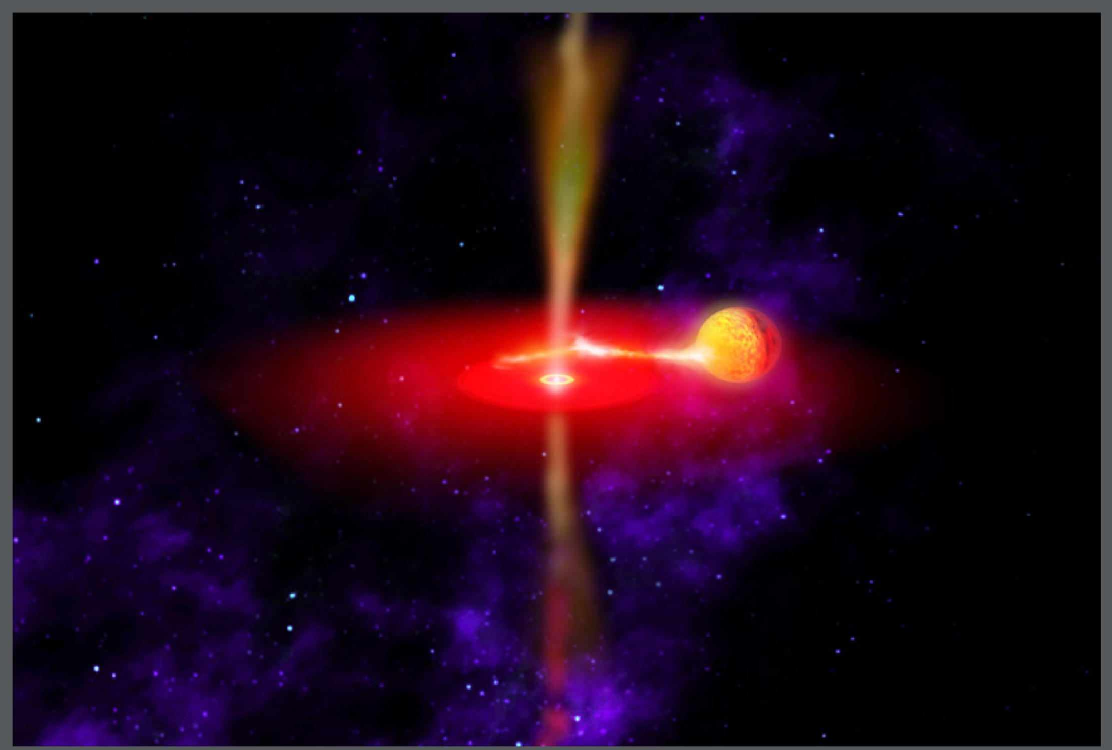
The GRS 1915+105 plateau state compared to the canonical hard state

Pieter van Oers[1,2], Sera Markoff[2], Dipankar Maitra[2], Michael Nowak[3], Jörn Wilms[4], Alberto Castro-Tirado[5], Farid Rahoui[6,7], Jerome Rodriguez[6], and Vivek Dhawan[8], Emilios Harlaftis[9]

[1]School of Physics & Astronomy, University of Southampton, United Kingdom, [2]Astronomical institute "Anton Pannekoek", University of Amsterdam, The Netherlands, [3]Kavli Institute for Astrophysics and Space Research, Massachusetts Institute of Technolgy, Cambridge, USA, [4]Dr. Karl Remeis-Sternwarte and ECAP, Universität Erlangen-Nuremberg, Germany, [5]Instituto de Astrofísica de Andalucía (IAA-CSIC), Spain, [6]Laboratoire AIM,CEA/IRFU, Université Paris Diderot, CNRS/INSU, CEA Saclay, DSM/IRFU/SAp, Gif sur Yvette, France, [7]AstroParticule & Cosmologie (APC) / Université Paris VII / CNRS / CEA / Observatoire de Paris, Paris Cedex 13, France, [8]National Radio Astronomy Observatory, 10003 Lopezville Road, Socorrow, USA, [9]In memoriam



Artist's impression of a black hole binary system. Credit: Dana Berry (CfA/NASA)

Abstract

The microquasar GRS 1915+105 is a very peculiar black hole binary in the constellation of Aquila, 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 (HS) of black hole X-ray binaries. Both the plateau and HS are associated with steady, relatively lower X-ray emission and flat/inverted radio emission, that is sometimes resolved into compact, self-absorbed jets. However, while generally black hole binaries quench their jets when the luminosity becomes too high, GRS 1915+105 seems to sustain them despite the fact that it accretes at near- or super-Eddington rates. In order to investigate the relationship between the plateau and the HS, we fit two multi-wavelength observations using a steady-state outflow-dominated model, developed for HS 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 HS. We discuss our interpretation of these results, and the possible implications for GRS 1915+105's relationship to canonical black hole candidates.

variable	units	range found in canonical BHs	GRS 1915+105 MJD 51367	GRS 1915+105 MJD 53473
N_j	10^{-1} L_{Edd}	$0.0034 - 0.71$	$4.88^{+0.00}_{-0.31}$	$16.86^{+0.45}_{-0.38}$
r_0	GM/c^2	$3.5 - 20.2$	$20.4^{+1.1}_{-0.1}$	$3.52^{+0.03}_{-0.05}$
T_e	10^{10} K	$2.0 - 5.23$	$0.94^{+0.02}_{-0.04}$	$0.388^{+0.001}_{-0.001}$
p		$2.1 - 2.9$	$2.27^{+0.07}_{-0.02}$	$2.11^{+0.01}_{-0.01}$
k		$1.1 - 7$	557^{+57}_{-90}	405^{+23}_{-12}
z_{acc}	GM/c^2	$7 - 400$	*6612*	*4000*
ϵ_{sc}	10^{-4}	$1.6 - 299$	$3.1^{+0.5}_{-1.4}$	$0.35^{+0.09}_{-0.16}$
r_{in}	GM/c^2	$0.1 - 486$	$2.55^{+0.39}_{-0.41}$	$4.28^{+0.01}_{-0.05}$
T_{disk}	keV	$0.06 - 1.53$	$0.85^{+0.05}_{-0.03}$	$0.81^{+0.02}_{-0.01}$

Table 1: *Parameter ranges found in canonical black holes and GRS 1915+105. N_j is the jet normalization, r_0 the jet-base radius, T_e the initial lepton temperature, p the power-law index of the lepton distribution, k the ratio between magnetic and particle energy densities, z_{acc} the location of the jet particle acceleration front, $\epsilon_{sc} \propto$ the acceleration efficiency.*

The plateau state and the hard state

Belloni et al. (2000) were able to classify data stretching over more then a year into twelve classes. Class χ is associated with jets and called the *plateau* state, from its appearance in radio (Fig. 2).

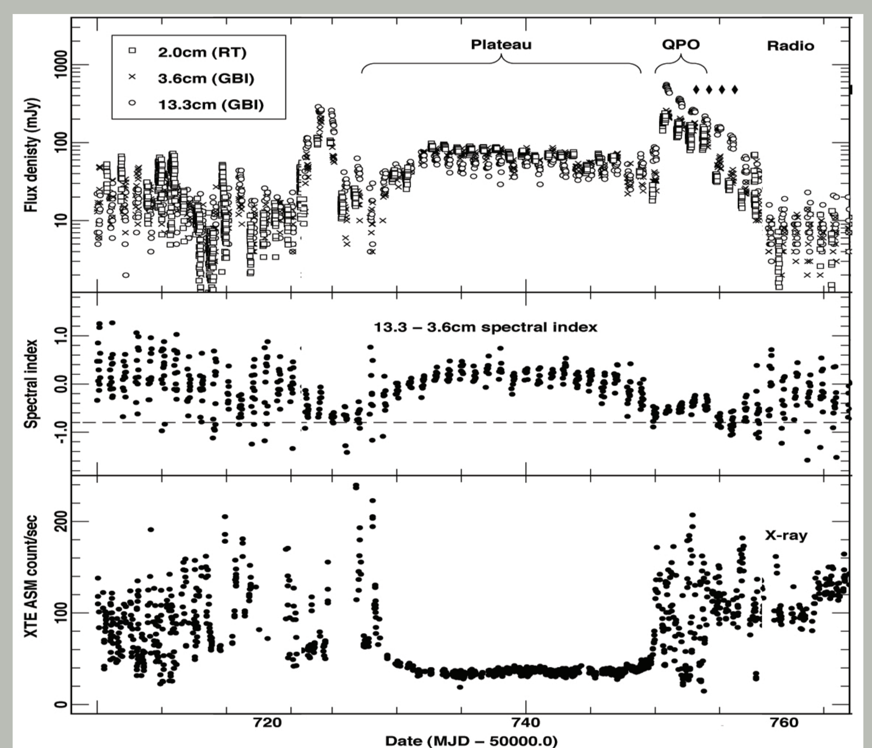


Figure 2: *The plateau state received its name from the characteristic light curve in radio, that can measure a flux density of up to ∼ 100 mJy. The state asserts itself rapidly, showing an optically thick radio spectrum, while the X-rays become quasi-stable and hard and decrease in intensity. (From Fender et al. 1999)*

In the literature we find some obvious differences. In the plateau state, compared to the HS:

- The average bolometric luminosity is a factor 100 higher.
- The X-ray photon index is usually steeper (McClintock & Remillard 2003).
- A power-law tail is always present (Reig et al. 2003) .

We will quantify the relationship of the above two states using an outflow-dominated model (Markoff et al. 2005).

References

* Belloni, T., Klein-Wolt, M., Méndez, M., et al, A&A, 355, 271, 2000
* Ebisawa, K., PhD thesis, 1991
* Fender R.P., Garrington, S.T., McKay, D.J., et al. MNRAS, 304, 865, 1999
* Ghisellini G., Celotti A., Fossati G., et al., MNRAS, 301, 451, 1998
* Mitsuda, K., Inoue, H., Koyama, K., et al., PASJ, 36, 741–759, 1984
* Markoff, S.B., Nowak, M.A., Wilms, J., ApJ 635, 1203M
* McClintock, J.E., Remillard, R.A., ArXiv e-prints, 0306213, 2003
* Reig, P., Belloni, T., van der Klis, M., A&A, 12, 229, 2003

Results

The main best fits obtained using our model are in Fig. 1 and the parameters are in Tab. 1.

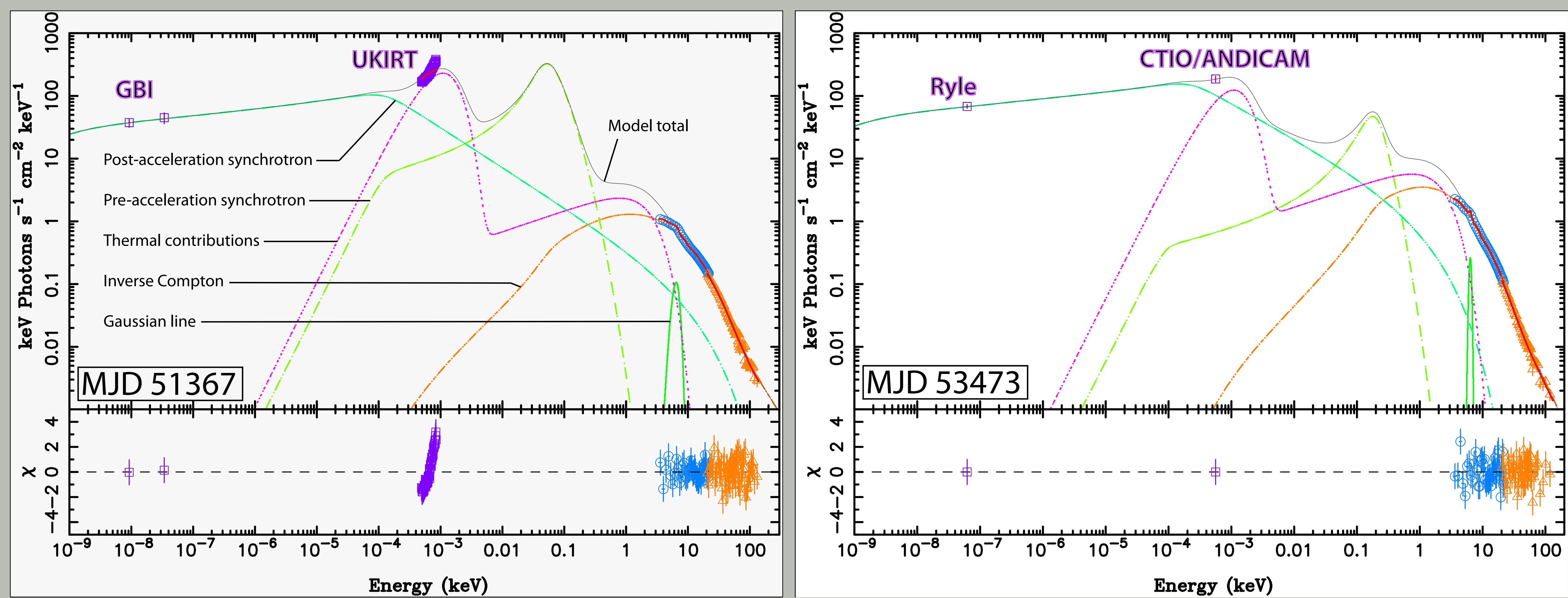


Figure 1: *Best-fit results using the Markoff et al. (2005) outflow-dominated, steady state model.*

Observations

Based on the X-ray lightcurves (Fig. 3) and hardness-intensity diagram (HID; Fig. 4) GRS 1915+105 was in the plateau state on MJD 51367 and 53473. We add quasi-simultaneous radio and infrared data to the *RXTE* X-ray data to create multi-wavelength spectra (Fig. 1).

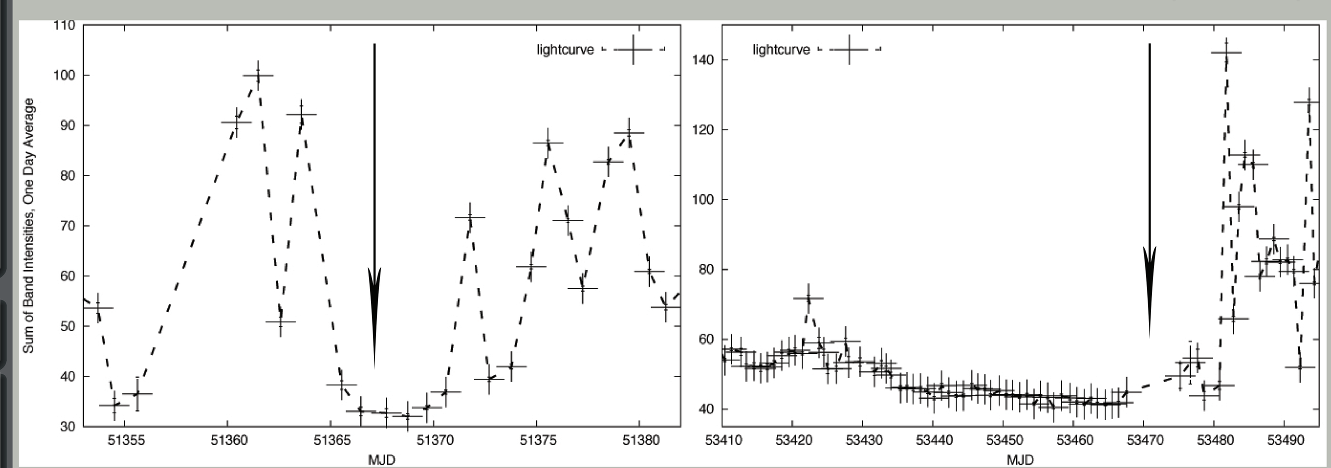


Figure 3: *All-Sky Monitor X-ray lightcurves.*

Observations

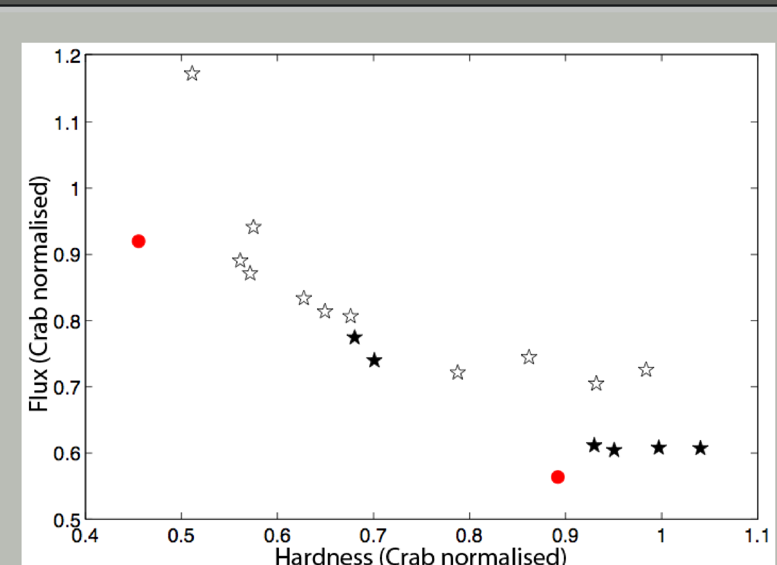


Figure 4: *HID comparing our observations (red dots) to the plateau states from Belloni et al. 2000 (stars). The soft, higher-luminosity red dot is MJD 53473, the other one is MJD 51367. (Courtesy of T. Belloni)*

Model and physical parameters

Fits were done using:

- a steady-state outflow-dominated model (Markoff et al. 2005), that includes disk emission (following Mitsuda et al. 1984) and a blackbody to model the companion star in the infrared
- a Gaussian at ∼ 6.4 keV to model the iron line complex
- a smeared edge model to account for relativistic smearing of the iron line (`smedge`; Ebisawa 1991)
- a photo-electric absorption model (`phabs`) to account for the interstellar medium

We fixed the hydrogen column density N_H, black hole mass, inclination, distance and donor temperature in accordance with other publications.

Discussion and Conclusions

The jet model that was successfully used to model HS also works at the high luminosity levels of the plateau state. Furthermore we see

Comparing both data sets with the HS:

- Extreme values, related to the jet power N_j, magnetic domination k and the location of the first acceleration zone z_{acc}, are obtained. The extreme magnetic domination may be required to sustain the jets at high power and is possibly also related to the high z_{acc}. Work investigating the links between z_{acc} and the physical parameters in the jet is underway (Polko et al. in prep.)
- The electron temperature T_e in the plateau state is a little lower, consistent with a higher cooling rate at GRS 1915+105's extreme luminosity.
- In the plateau state the synchrotron flux no longer dominates the soft X-ray band (below ∼ 10 keV), but contributes at about 10% of the inverse Compton flux to ∼ 50 keV. This result is qualitatively similar to the blazar sequence (Ghisellini et al. 1998).

Comparing our two plateaux to each other:

Larger differences in free parameter values are obtained for the two plateaux than when using the same model to fit the HS in entirely different sources. Also a different N_H is required. Both indicate that plateau state classification on the basis of colour and timing properties should be expanded to include broadband attributes.

Results have been submitted for publication to MNRAS