Jets at all scales
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GRS 1915+105 “celebrates its majority” (1992–2010)

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Abstract. Over the 18 years since its discovery, GRS 1915+105 has continuously brightened in the X/γ-ray sky. It is considered the prototypical microquasar. Most of these are LMXBs that show sporadic ejection of matter at apparently superluminal velocities. In these the three basic ingredients of quasars are found: a black hole, an accretion disc and collimated jets of high energy particles, but in microquasars the black hole is only a few $M_\odot$ instead of several $\times 10^6$ $M_\odot$; the accretion disc had mean thermal temperature of several $\times 10^6$ K instead of several $\times 10^3$ K, and the particles ejected at relativistic speeds travel distances of a few ly only, compared to few $\times 10^6$ ly as in radio galaxies. However many open issues remain to be addressed.

Keywords. X-rays: individual (GRS 1915+105), accretion disks, acceleration of particles, black hole physics

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1. The discovery

The *Granat* satellite was launched in Dec 1989, carrying the SIGMA gamma-ray telescope, the ART-P X-ray telescopes and the WATCH all-sky X-ray monitor. WATCH was scrutinizing the sky with the four units and on 15 Aug 1992, after returning from Crimean Astrophysical Observatory (where we managed to discover during the night the optical counterpart to X-ray Nova Per 1992), a very unusual, hard X-ray source outshone the rest of sources in the WATCH sky: the GRanat Source located at RA=19h15m, Dec=$+10^o.5$ (Castro-Tirado, Brandt & Lund 1992, Castro-Tirado *et al.* 1994). See Fig. 1.

At our request, SIGMA observed the field, improving the 1° WATCH error box, reporting a much more accurate position leading to the discovery of a variable radiosource months after (Mirabel *et al.* 1993a), whose position could be accurately placed on the sky with respect to field stars in the optical. At this precise location, an IR counterpart was reported (Mirabel *et al.* 1993b, Castro-Tirado *et al.* 1993), which was later confirmed by means of near-IR spectroscopy, showing variable, non Doppler-shifted emission lines, with the system suggested to be a low-mass X-ray binary (LMXB) (Castro-Tirado *et al.* 1996), which was finally confirmed in 2001. See also Fig. 2.

Although activity was already seen by BATSE/*CGRO* since Mar 1992 (Paciesas *et al.* 1995), GRS 1915+105 remained undetected in an archival *Einstein*/HRI pointed observation in the 1970s (Castro-Tirado 1994). The first two years of WATCH observations indeed revealed a highly variable object (Sazonov *et al.* 1994).

2. The superluminal source

GRS 1915+105 is the first superluminal source discovered in the Galaxy (Mirabel and Rodriguez 1994): in 1994, clouds of plasma were ejected in opposite directions from the central source at speeds close to (but less than) that of light (0.92c), and the relativistic effects led to the apparent superluminal motion. The energetics and bulk Lorentz factor were consistent with radiation pressure acceleration of pair plasmoids (Liang and Li 1995) at a distance D = 12.5 ± 1.5 kpc (Chaty *et al.* 1996). The jet power was estimated to be $\sim 10^{38}$ erg/s (Fender *et al.* 1999).

VLBI imaging resolved the nucleus as a compact jet of length ∼10 AU. Its properties were better fitted by a conically expanding synchrotron jet model rather than a thermal jet. The nuclear jet varied in ∼30 min during minor X-ray/radio outbursts and reestablished within ∼18 hr of a major outburst, indicating the robustness of the X-ray/radio (or disk/jet) system to disruption. A limit of < 100 km/s was placed on its proper motion with respect to its neighborhood (Dhawan *et al.* 1999).

3. The jet-disk connection

Multi-wavelength observations revealed the probable synchrotron origin of the IR emission (Fender & Pooley 1998, MNRAS 300, 576), and this was consistent with a scenario wherein the IR flux originates in a relativistic plasma that has been ejected from the inner accretion disk (Eikenberry *et al.* 1998, Mirabel *et al.* 1998). Analysis of 165 *RXTE* observations allowed the observations to be classified into 12 classes, which could be ascribed to 3 basic states: a hard state corresponding to the non-observability of the innermost parts of the accretion disk, and two softer states with a fully observable disk (Belloni *et al.* 2000).

4. A massive black hole

Evidence for GRS 1915+105 containing a Kerr rotating black hole ($a^* = 0.98$) leading to a frame dragging effect was proposed already in 1998 (Cui *et al.* 1998). The mass function was determined in 2001, thanks to ESO´s VLT mid-res near-IR spectroscopy (Greiner *et al.* 2001). The compact object´s mass ($M_x = 14.0 \pm 4.4\ M_\odot$) was derived assuming an inclination of $i = 66^\circ \pm 2^\circ$ from the orientation of the radio jets and a more accurate distance. The mass for the early K-type giant star is $M_d = 0.81 \pm 0.53\ M_\odot$, consistent with a more evolved stripped-giant donor star in GRS 1915+105 (Harlaftis and Greiner 2004). 7 years of K-band monitoring of the low-mass X-ray binary GRS 1915+105 allowed to detect orbital and superhump signatures. Positive correlations between the

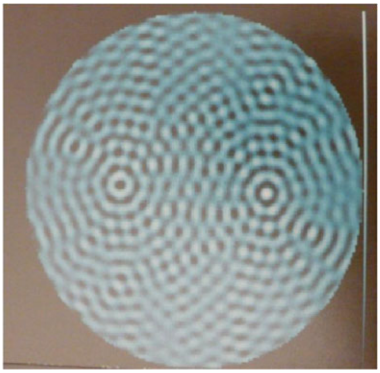

Figure 1. The WATCH/*Granat* cross-correlation map on 15 Aug 1992, showing GRS1915+105 disputing with Sco X-1 the supremacy in the X-ray sky.

infrared flux and the X-ray flux and X-ray hardness were demonstrated. Analysis of the frequency spectrum showed that the orbital period of the system is $P_{orb} = 30.8 \pm 0.2$ d (Neil *et al.* 2007).

5. Selected recent results

For an extensive review on the data gathered until 2003 (and the corresponding interpretation), we refer the reader to the review work published in 2004 (Fender and Belloni 2004). In this section some selected results obtained since then are briefly mentioned.

Based on radio and X-ray observations, the semi-quantitative model for the state transition proposed by Fender & Belloni (2004) could be extended to other microquasars (Fender *et al.* 2004). *RXTE* and *CGRO*/OSSE spectra were well fitted by Comptonization of disc blackbody photons, with very strong evidence for the presence of a non-thermal electron component in the Comptonizing plasma (Zdiarski *et al.* 2005). Based on a spectral analysis of the X-ray continuum it was confirmed that the compact primary in GRS 1915+105 is a rapidly rotating Kerr black hole (McClintock *et al.* 2006). X-ray spectral and temporal analysis of four observations showed strong radio to X-ray correlations (Rodriguez *et al.* 2008). However, GRS 1915+105 is considered an outlier on the L_X-L_R relation like H 1743-322 (Coriat *et al.* 2010).

In addition, phase-resolved *CXO* X-ray spectroscopy gives support to a highly variable disk wind (Neilsen *et al.* 2010) and *Suzaku* observations give evidence for "self-shielding"; i.e. the Comptonizing corona becomes geometrically thick in the flare phase (Ueda *et al.* 2010). The plateau states can be described by the same broadband model with a steady outflow and an accretion inflow (van Oers *et al.* 2010).

Accretion disk winds as the jet suppression mechanism in GRS 1915+105 have been proposed (Neilsen and Lee 2009) and HESS upper limits on fluxes > 410 GeV imply that the radiative efficiency of the compact jet at VHE is $< 0.01\%$ (Acero *et al.* 2009).

GRS 1915+105 has been in a state of constant outburst since its discovery in 1992, an eruption which has persisted ∼100 times longer than those of more typical LMXBs. It has been proposed that the outburst could last ∼100 yr (Deegan *et al.* 2009).

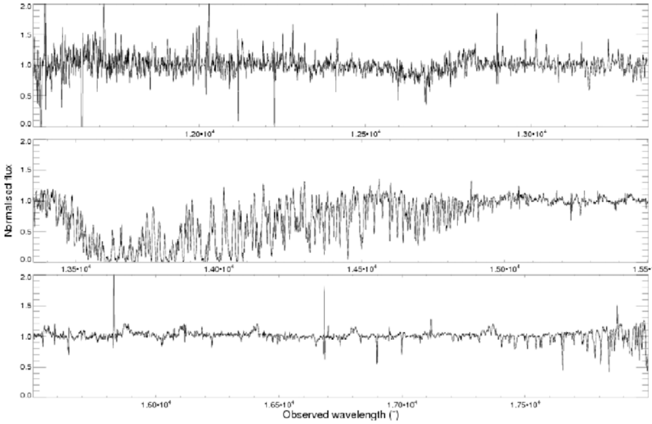

Figure 2. VLT/X-Shooter JH spectrum of GRS1915+105 obtained in June 2009 by A. de Ugarte Postigo. H I emission lines in the range 1.59-1.74 μm are noticeable. Based on data obtained from the ESO Science Archive Facility.

6. Summary and open questions

GRS1915+105 is the first highly relativistic ($\Gamma > 2$) jet source known in the Galaxy and can be considered as the "holy grail" for studying the jet-disk coupling in accreting black-hole (BH) systems (and also testing General Relativity effects) as it is located at an extreme range of parameter space for an outflow dominated model, requiring near- or super- Eddington accretion rates and maximal jet power (($\Gamma < 30$), and a high level of magnetic domination (at least in core $r < 100r_g$). Amongst the many open questions that remain to be addressed, here are few of them:

1. Magnetic fields and disk winds are ingredients finally being considered in the models. What about the MHD simulations?
2. Why are the near-IR emission lines not Doppler-shifted as in SS 433?
3. Is the slow and steady jet always present in hard state? If so, why we do not see its long-term action on the local ISM?
4. Is this the first hypernova we are aware of in the Milky Way? A WR-progenitor?
5. The outburst may last 100 yr. What is the duty cycle? In any case, have we just seen in 1992 the onset of a persistent LMXB?

References

Acero, F. *et al.* 2009, *A&A*, 508, 1135
Belloni T. *et al.* 2000, *A&A*, 355, 271
Castro-Tirado, A. J., Brandt, S., & Lund, N. 1992, *IAU Circ.*, 5590
Castro-Tirado, A. J. *et al.* 1993, *IAU Circ.*, 5830
Castro-Tirado, A. J. 1994, *Ph.D. Thesis*, Copenhagen Univ.
Castro-Tirado, A. J. *et al.* 1994, *ApJ* (Supplement Series), 92, 469
Castro-Tirado, A. J. *et al.* 1996, *ApJ* (Letters), 491, L99
Coriat, M. *et al.* 2010, *These Proceedings*
Chaty, S. *et al.* 1996 *A&A*, 318, 825
Cui, W. *et al.* 1998 *ApJ* (Letters), 492, L53
Deegan, P. *et al.* 2009 *MNRAS*, 400, 1337
Dhawan, V. *et al.* 2000 *ApJ*, 543, 373
Eikenberry, S. *et al.* 1998 *ApJ* (Letters), 494, L61
Fender, R. *et al.* 1999 *MNRAS*, 304, 865
Fender, R. & Belloni, T. 2004 *ARA&A*, 42, 317
Fender, R., Belloni, T., & Gallo, E. 2004 *A&A*, 355, 1105
Greiner, J., Cuby & McCaughrean 2001 *Nature*, 414, 522
Harlaftis, E. & Greiner, J. 2004 *A&A*, 414, L13
Liang, E. P. & Li, H. 1995, *A&A*, 248, L45
McClintock, J. *et al.* 2006, *ApJ*, 652, 518
Mirabel, I. F. *et al.* 1993a, *IAU Circ.*, 5773
Mirabel, I. F. *et al.* 1993b, *IAU Circ.*, 5830
Mirabel, I. F. & Rodríguez, L. F. 1994, *Nature*, 371, 46
Mirabel, I. F. *et al.* 1998, *A&A*, 330, L9
Neil, E. T. *et al.* 2007, *ApJ*, 657, 409
Neilsen, J. & Lee, J. C. 2009, *Nature*, 458, 481
Neilsen, J. *et al.* 2010, *These Proceedings*,
Paciesas, W. *et al.* 1995, *NYASA*, 759, 308
Rodriguez, J. *et al.* 2008, *ApJ*, 675, 1449
Sazonov, S. *et al.* 1994, *PAZh*, 20, 901
van Oers, P. *et al.* 2010, *MNRAS*, in press
Ueda, Y. *et al.* 2010, *ApJ*, 713, 257
Zdziarski, A. *et al.* 2005, *MNRAS*, 360, 825

Discussion

Neilsen: Regarding the infrared emission lines, I believe thath the interpretation is that when discrete ejection events occur, you have blobs of plasma above the disk that illuminate the outer disk and pump the infrared emission lines, so I think it's a good explanation.

Castro-Tirado: Yes, this is a plausible interpretation. When the near-infrared emission lines were first reported (Castro-Tirado *et al.* 1996), it was surprising not to find them Doppler-shifted and we also proposed at that time that the IR flux cloud arise from free-free emission in a wind flowing out o the accretion disk.

de Gouveia Dal Pino: Regarding your remark 7 on a potential connection between GRS 1915+105 and hypernova/WR late evolution, do you know any tentative modelling that tries to construct this link?

Castro-Tirado: Not in the particular case of GRS 1915+105, although for Wolf-Rayet progenitors to GRBs, has been suggested in several cases (e.g. Castro-Tirado *et al.* 2010 and references therein).