The long outburst of the black hole transient GRS 1716-249

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The GRS 1716-249 outburst evolution:

The outburst of the black hole transient (BHT) GRS 1716-294 was monitored in radio and X-ray with ATCA, VLA, LBA and the Neil Gehrels Swift Observatory (Swift), respectively, from December 2016 to October 2017 (see Fig. 1). We present the the spectral and timing analysis of the observations performed with the XRT and BAT telescopes on-board of Swift during the whole outburst. The XRT light curve in Fig. 1 shows three flares in corrispondence to dips in the BAT light curve and in both the hardness ratio.

This indicates a softening in the X-ray spectra.

Then, we focus on Spectral Energy Distribution (SED) of GRS 1716-249. We computed it with multi-wavelength observations, including radio, infrared (REM), otical/UV (UVOT) and γ-ray (INEGRAL/SPI) observations, performed on 2017 February (orange line in Fig. 1), when GRS 1716-249 was in the hard intermediate state (HISM).

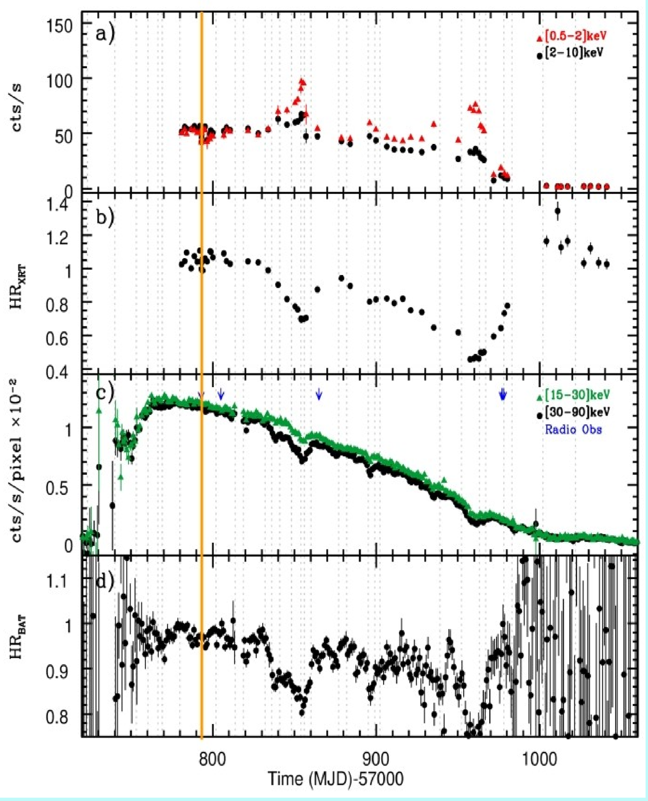


Fig. 1: Swift/XRT and BAT light curves and Hardness Ratio evolution. The radio observation are shown with blue arrows.

The failed transition to the soft state:

The XRT and BAT broad band spectra were modeled with a thermal Comptonization + multi-color disk blackbody. During the whole outburst, the spectral parameters of the fit are characteristic of the hard (HS) and HIMS (Fig. 2), in agreement with the evolution of the root mean square amplitude of the flux variability.

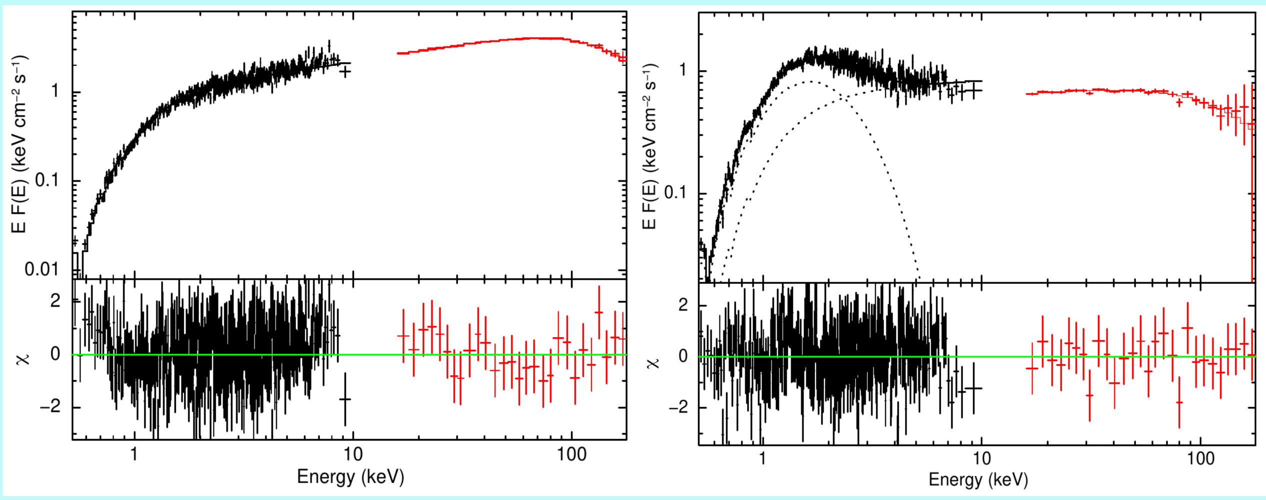


Fig. 2: A hard and the softer broad band energy spectra of GRS 1716-249.

- The photon index varies from 1.6 up to 1.9 while the electron temperature is well constrained when the source is bright in hard X-ray (kT_e ~[50÷70] keV).
- Softer episodes: significant weak soft thermal component (0.2 keV <kTin< 0.5 keV)

The disc luminosity never dominates the emission of the source (F_{disc}< 34% F_{bol}).

The source showed the transition HS-to-HIMS, but did not make the transitions to the soft states. The XRT Hardness-Intensity Diagram in the top panel of Fig. 3 shows that the source softens and hardens back two times along the Intermediate State branch (on the top – from right to left), until to the softer state observed (magenta square in Fig.3).

Then, the fractional rms variability amplitude decreases from values of 25-30%, typical of the HIMS (Fig 3 down panel) to a value of 17% (purple triangle) in correspondence of the first dip shown in the HR plots (Fig. 1). During the outburst the rms does not drop down to the typical values of the soft state (≤5%, Mũnoz-Darias+11). It reaches the lower values around 12% in correspondence of the third softening. Then it rises up to values of 40% (typical of HS) in the final part of the outburst (Bassi+19).

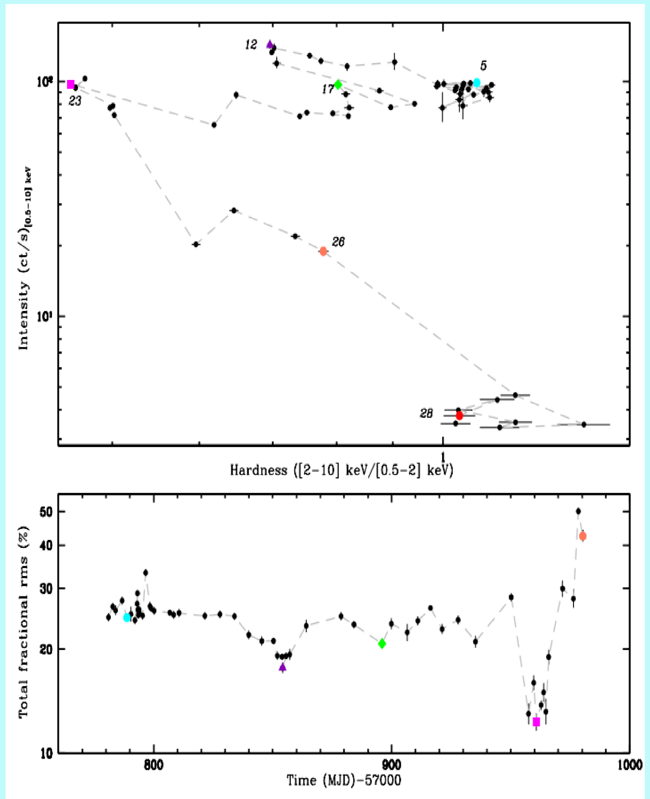
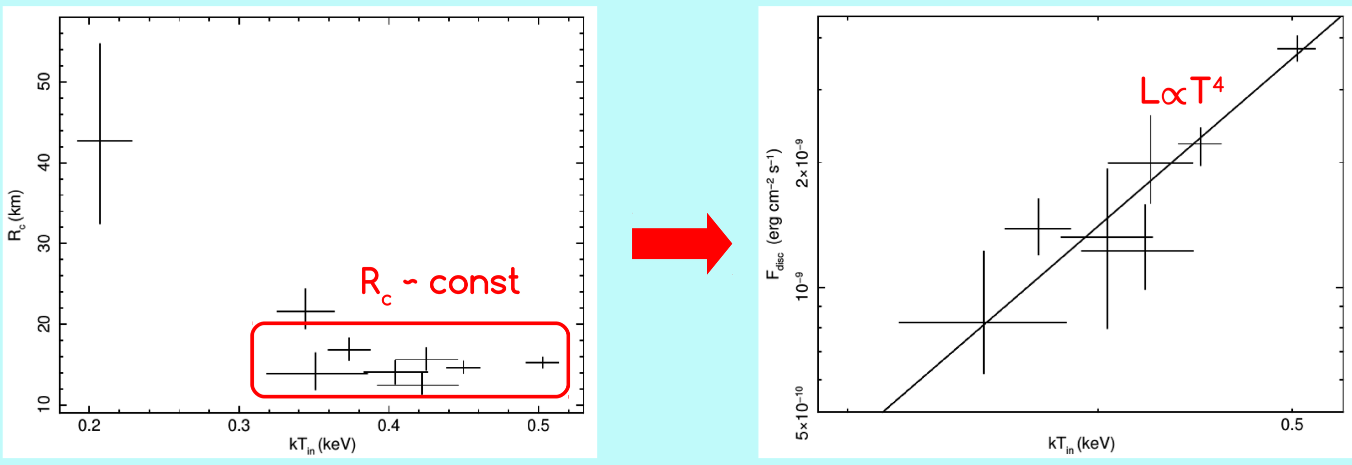


Fig. 3: Hardness-Intensity Diagram (Top panel) and XRT fractional rms evolution (Bottom panel).

The X-ray spectral analysis showed that the source never performed the transition to the soft state (SS) even though the accretion disc seemed to have reached the innermost stable circular orbit (ISCO) during the HIMS (Bassi+19).

The inner disc radius:

Fig. 4:



We estimated the inner disc as a function of the inclination angle (R_c) from the DISKBB model.

The plot R_c versus the inner disc temperature (kT_{in}, Fig. 4 left panel) shows that most of our estimations are consistent with a constant radius R_c ~15 km.

Plotting the observed flux versus kT_{in}, including only spectra with R_c almost constant, shows that the disc luminosity varies as a function of the inner disc temperature with a slope of about 4 (Fig. 4 right panel).

The inner disc temperature increases at constant inner disc radius

➡ Innermost stable circular orbit (ISCO)

The high enrgy tail:

The GRS 1716-249 X/γ-ray spectrum collected on February 2017, when it was in HIMS, shows a high energy excess (in addition to the thermal Comptonization) above 200 keV (INEGRAL/SPI):

- Power law photon index: Γ~1.22
- Flux: $F_{[150\text{-}400]\,keV}$= 3.8x10^{-9} erg cm^{-2} s^{-1}

This high energy excess above was observed also in other BHTs in HS-HIMS (Del Santo+08, Bouchet+09, Droulans+10) and it is usually explained in terms of Comptonization due to a non-thermal electron population in the corona (Poutanen & Coppi 1998, Zdziarski+01, Del Santo+13), possibly responsible also for the tail observed in SS.

An alternative scenario puts jets at the origin of this hard X-ray emission produced via synchrotron radiation.

The strong polarisation measurements of the hard X-ray emission above 200 keV reported in Cyg X-1 support this hypothesis (Laurent+11, Jourdain+12, Rodriguez+15).

The radio/X-ray correlation:

The accretion flow behaviour is strictly coupled to the outflows emission during the different spectral states.

Two branches in the radio/X-ray flux correlations (Fig. 5) were observed for several BHTs in the HS:

- Radio loud: $L_R \propto L_X^{0.7}$ (Corbel+03, Gallo+03)
- Radio quiet (or "outliers"): $L_R \propto L_X^{1.4}$ (Coriat+11, Corbel+13)

GRS 1716-249 is located on the radio-quiet branch during the whole outburst (red stars Fig. 5).

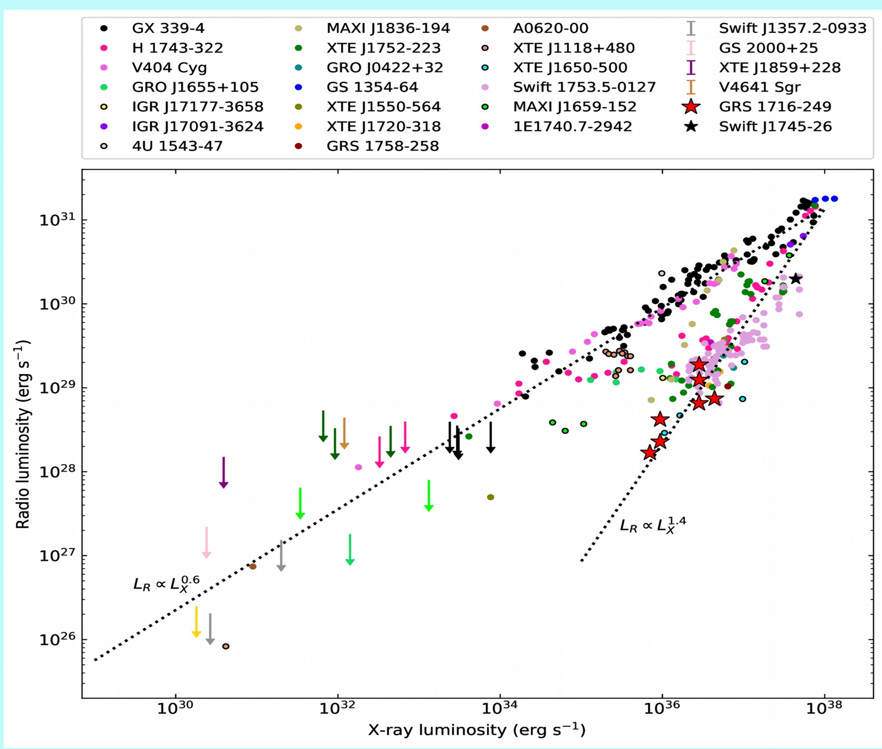


Fig. 5: Radio/X-ray luminosity correlation.

Hybrid thermal/non-thermal models:

The GRS 1716-249 spectrum was fitted with both EQPAIR (Coppi 1992) and BELM (Belmont+08) models.

In EQPAIR the emission of the disc/corona system is assumed to be produced by a spherical hot plasma cloud with continuous acceleration of electrons illuminated by soft photons emitted by the accretion disc. The electron distribution at low energies is Maxwellian, with an electron temperature kT_e. While, at high energies the electrons are characterised by a non-thermal distribution.

BELM, in addition to the processes considered in EQPAIR, takes also into account the magnetic field located in the corona and the self-absorbed synchrotron emission resulting by the interaction of the leptons with it.

Our fit showed that the high energy tail observed above 200 keV can be produced by the non-thermal Comptonizing electrons as was observed for other BHTs (Del Santo+08, +13, +16).

Fitting the broad band spectra with BELM, we estimated an upper limit on the magnetic field of the corona of about 1.5x10^6 G (Bassi et al. in prep.).

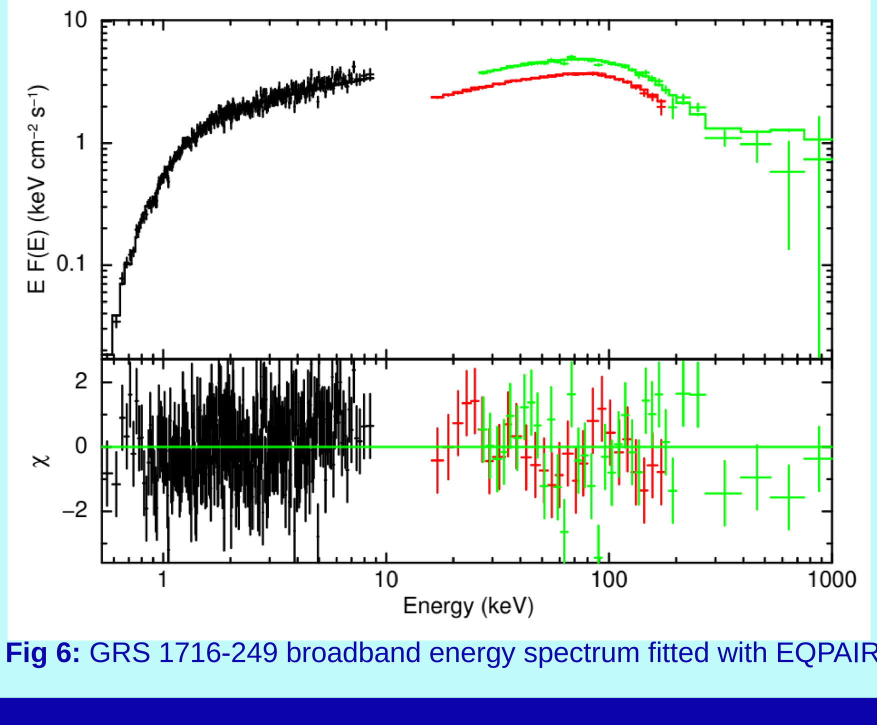


Fig 6: GRS 1716-249 broadband energy spectrum fitted with EQPAIR

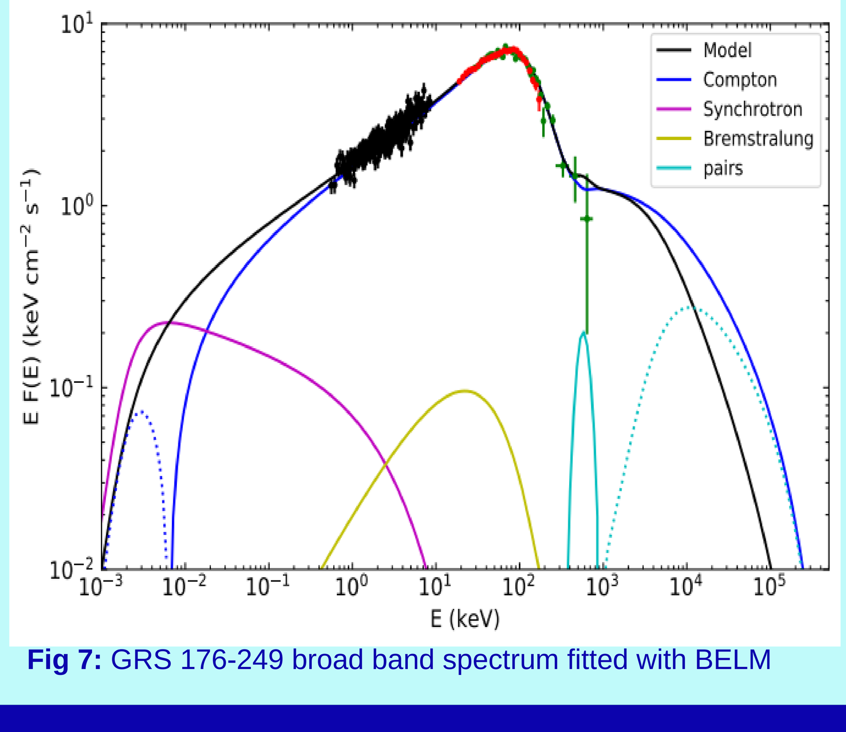


Fig 7: GRS 176-249 broad band spectrum fitted with BELM

The SED of GRS 1716-249 modelling:

- **Accretion flow emission**: disc+thermal Comptonization (DISKIR)
- **Jet emission**: internal shock emission model (ISHEM, Malzac 2013, 2014). The model simulates the hierarchical merging of shells ejected at the base of the jet. A fraction of the kinetic energy of the shells is converted into internal energy and radiation by the shocks produced by the merge of the shells. The fluctuation of the Lorentz factor of the shells in the jet is defined by the X-ray variability.

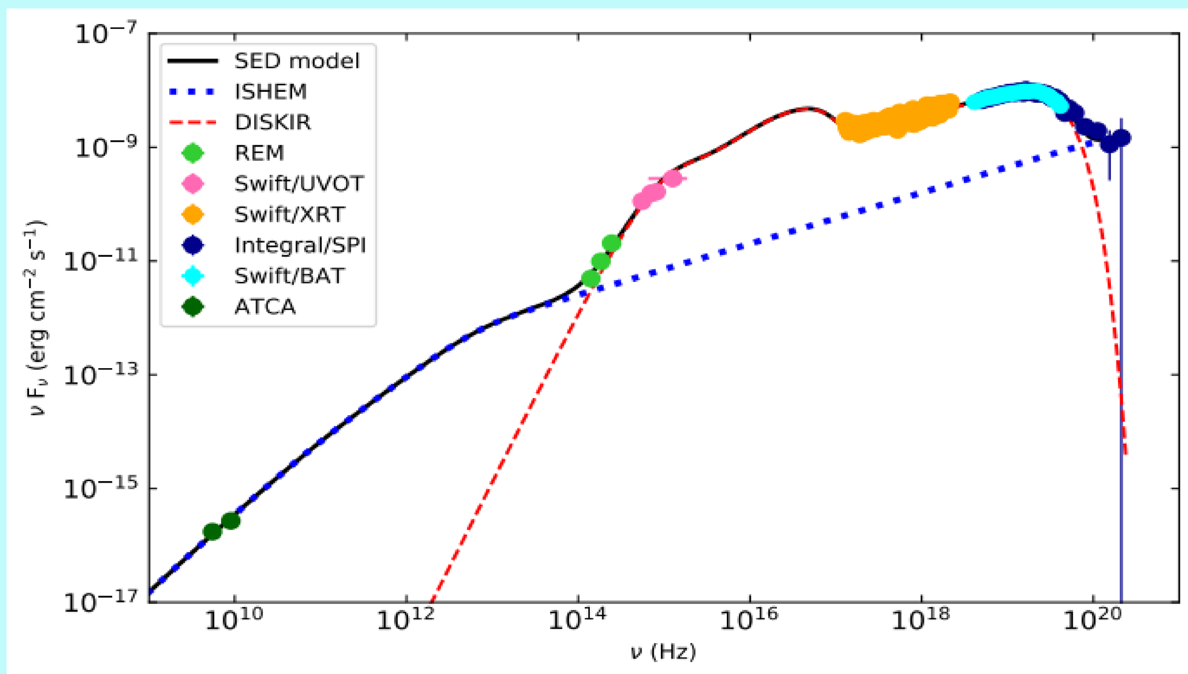


Fig. 8: Spectral energy distribution of GRS 1716-249 built with the data collected during the multi-wavelength campaign performed on February-March 2017. To reproduce the high energy excess observed we used the ISHEM model assuming an electron distribution p=2.1 (Bassi et al. in prep.).

Assuming an electrons distribution with a slope of 2.1, the jet emission can also reproduce the excess observed in hard X-ray.