Multi-wavelength observations of 4U 1543−47 during outburst decay: state transitions and jet contribution

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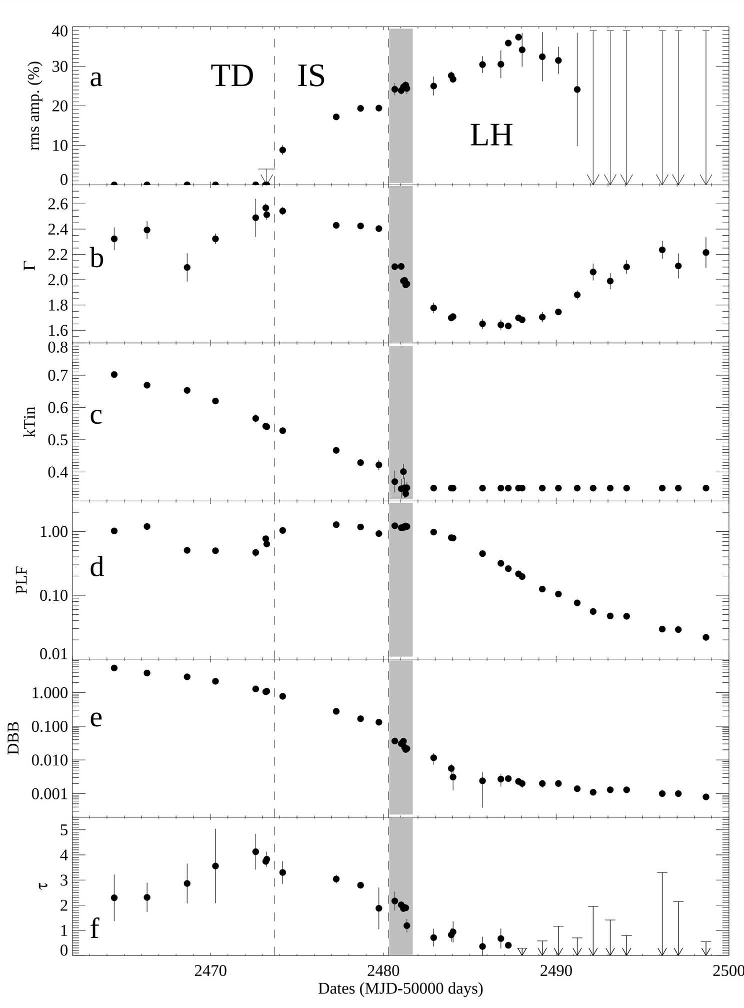
Abstract Multiwavelength observations of Galactic black hole (GBH) transients during the state transitions and in the low/hard state may provide detailed information on the accretion structure of these systems. 4U 1543−47 is a GBH transient that was covered exceptionally well in X-ray and infrared (daily observations) and reasonably well in optical and radio during its outburst decay in 2002. When all the available information is gathered in the intermediate and the low/hard state, 4U 1543−47 makes an important contribution to our understanding of state transitions and the role of outflows on the high energy emission properties of black hole binaries. The evolution of the X-ray spectral and temporal properties and the IR light curve place strong constraints on different models for explaining the overall emission from accreting black holes. The overall spectral energy distribution is consistent with synchrotron origin for the optical and infrared emission, however, the X-ray flux is above the power-law continuation of the optical and infrared flux. The infrared light curve, the HEXTE light curve and the evolution of the X-ray photon index indicate that the major source of hard X-rays cannot be direct synchrotron radiation from an acceleration region in a jet for most of the outburst decay.

Introduction

The 2002 outburst of 4U 1543−47 was first detected by the All Sky Monitor (ASM) on *RXTE* on MJD 52442 (Miller & Remillard, 2002). The source was observed in the optical and the infrared (OIR) with good coverage with the YALO consortium (Bailyn et al., 1999). These observations cover most of the outburst cycle and show a secondary maximum in the light curve peaking close to the MOST and ATCA radio detections on MJD 52487 and MJD 52490 respectively (Buxton & Bailyn, 2004). The 2002 outburst decay of 4U 1543−47 gives us a lot of observational data to work with: Short daily *RXTE* observations, and long *RXTE* observations during the transition and the LH state to characterize the spectral and temporal evolution in great detail, and radio, infrared and optical coverage to understand the relation between the jet and X-ray spectral states. In this work, we report on the *RXTE* observations during outburst decay, and combine the results with the optical, IR and radio information to understand the contribution of the jet on spectral and temporal properties of 4U 1543−47.

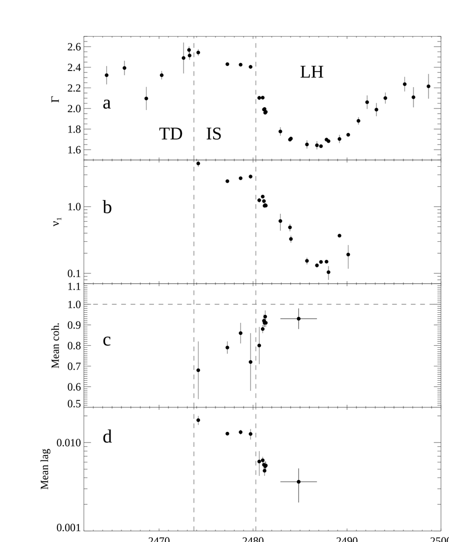
Spectral and temporal evolution



The evolution of (a) the total rms amplitude of variability in 3-30 keV band, (b) the photon index (Γ), (c) the inner disk temperature T_{in} (d) the power-law flux, (e) the disk-blackbody flux (both fluxes in 3–25 keV band, and in units of 10^{-9} $\mathrm{ergs\,cm^{-2}\,s^{-1}}$), (f) optical depth of the smedge component in the fit.

We marked the time of the first state transition from the thermal dominant (TD) state to intermediate state (IS) on ∼MJD 52474, when the source showed a sharp increase in the rms amplitude of variability, accompanied by a sharp increase in the power-law flux (Kalemci et al., 2004). Around MJD 52480, another set of sharp changes occurred; the rms amplitude of variability jumped to ∼24% level, accompanied by a sharp hardening of the photon index, and rapid cooling of the inner disk temperature. After all these changes (shown by the gray area), the source was in the low/hard (LH) state.

Coherence and lag

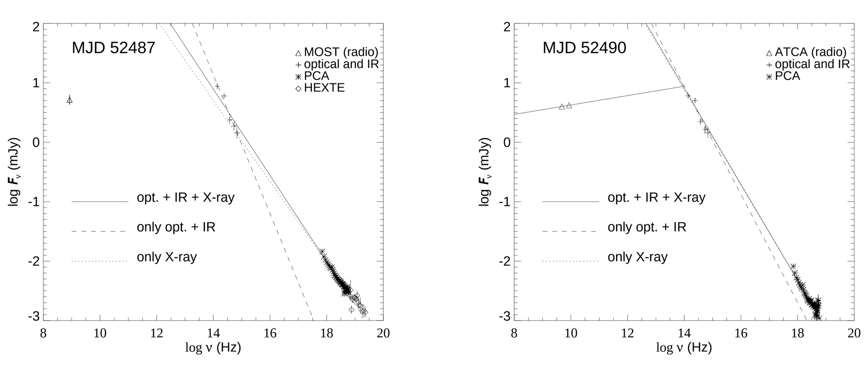


(a) Photon index, (b) Characteristic frequencies, (c) mean coherence, (d) mean lag in 1–10 Hz band, between 2–6 keV and 6–15 keV.

The characteristic frequencies decrease in time during the LH state. Notice the correlation between the photon index and the characteristic frequencies. The mean coherence increases during the transition to the LH state and approaches unity in the LH state. The mean lag decreases in the LH state.

SEDs

We have constructed two spectral energy distributions (SED) close to the peak of the IR maximum for the dates of the MOST (∼MJD 52487) and ATCA (∼MJD 52490) observations.



Spectral energy distribution of 4U 1543−47 at MJD 52487. The lines represent power law fits to different subsets of data

Spectral energy distribution of 4U 1543−47 at MJD 52490. The lines passing through the optical, IR and X-ray points represent power law fits to different subsets of data. Another line is drawn that passes through the radio points and intersects the power-law fits.

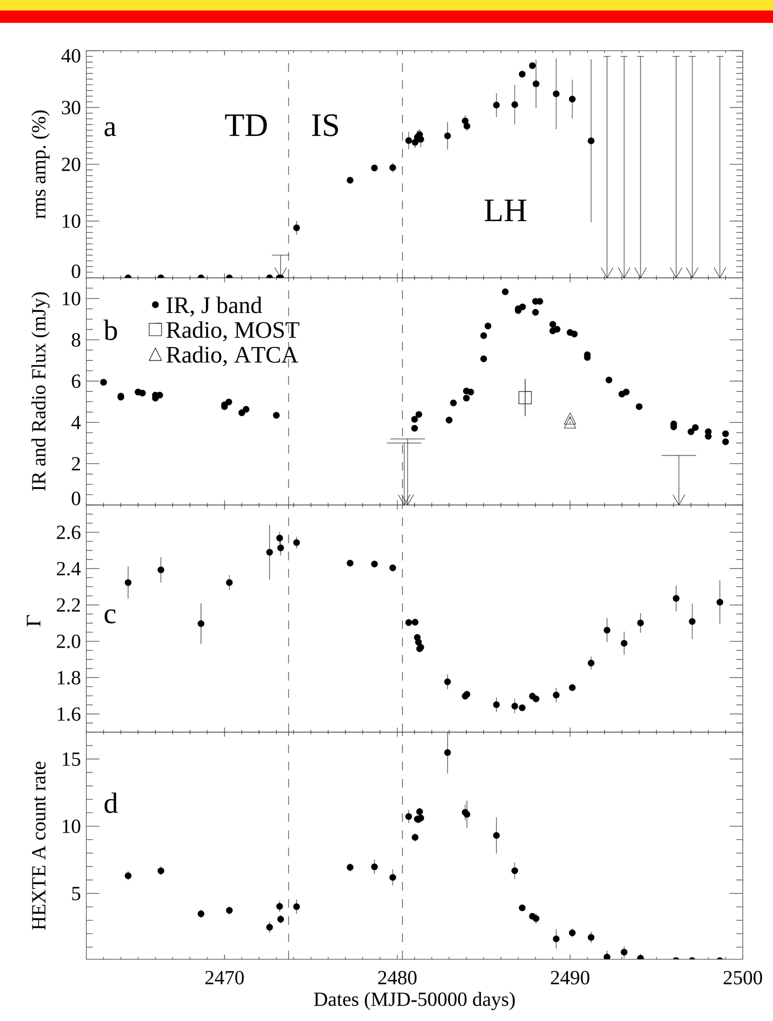
SED POWER-LAW FIT PARAMETERS

Data set	photon index	χ^2/DOF
MJD 52487		
Opt. and IR only	−2.16 ± 0.10	8.74 / 3
X-ray only[a]	−1.63 ± 0.01	39.78 / 62
Opt., IR, and X-ray	−1.73 ± 0.01	164.30 / 64
MJD 52490		
Opt. and IR only	−1.91 ± 0.10	14.66 / 3
X-ray only	−1.75 ± 0.02	47.68 / 43
Opt., IR, and X-ray	−1.80 ± 0.02	80.39 / 42

The fit parameters to the power-law fits are shown in the table. For MJD 52487, the OIR power-law index and the X-ray power-law index are different.

For MJD 52490, the discrepancy is much less, and the X-ray and OIR power-law indices are consistent within 2-σ uncertainty.

Infrared and Hard X-ray evolution



The evolution of a. the rms amplitude of variability, b. the J band infrared fluxes from Buxton & Bailyn 2004 (dots) along with radio fluxes from our observations (triangles) and Park et al. 2004 (upper limits and the square), c. the photon index, and d. HEXTE Cluster A count rate in 16-100 keV band. The gap in the IR light curve during the IS is due to lack of coverage.

The change in the hard X-rays with respect to the OIR is represented by the evolution of HEXTE cluster A count rate in 16–100 keV band. By the time the HEXTE count rate peaked, the power-law index dipped, and the J band flux started to rise. The lag between the time that hard X-rays peaked and the OIR peaked was about 2 days. Notice that the HEXTE flux decreases while the spectrum is still hardening and the IR flux was rising. This is hard to explain with X-rays coming from jet synchrotron.

Summary of all results

- 4U 1543−47 showed two state transitions during its decay in the 2002 outburst:

  -the first transition was from the TD state to the IS on ∼MJD 52474, and was marked by a jump in rms amplitude of variability and power-law flux.

  -the second transition was from the IS to the LH state, and was marked by a sharp hardening of the X-ray spectrum, and an increase in rms amplitude of variability.
- The spectrum softened at very low flux levels in the LH state.
- The characteristic frequencies decreased during the transition and in the LH state before they leveled off. The characteristic frequencies and the photon index showed a good correlation.
- The mean coherence was low during the IS, and then increased and approached unity as the source made the transition to the LH state. The mean lag, on the other hand, was high in the IS, and decreased during the transition.
- The HEXTE 16-100 keV light curve increased during the transition to the LH state while the photon index hardened. It did decay, however, while the IR flux was rising.
- The SEDs show that the OIR part of the spectrum can be represented by a power-law. For the SED on MJD 52487, the hard X-ray points are not a continuation of the OIR points and have a different index. For the SED on MJD 52490, the difference is less, and the X-ray and OIR power-law indices are consistent within 2-σ uncertainty.

Discussion

Using X-rays, OIR, and radio observations, we characterized the outburst decay of the GBHT 4U 1543−47, and placed constraints on several emission models. A large, non-thermal, and radiatively inefficient outflow could explain the spectral and temporal evolution in the IS. The presence of high energy cut-off in the X-ray spectra during the transition to the LH state is indicative of a thermal electron distribution. In general, our observations are consistent with a recessing accretion disk + hot corona + "compact" jet geometry with the main hard X-ray emission mechanism of Compton upscattering of soft accretion disk seed photons by energetic electrons in the corona. Here we used the word "compact" to also emphasize the size of the base of the jet, which most likely is small compared to the overall size of the corona. This interpretation can reasonably explain all aspects of our observations until deep in the LH state.

Our results do not strongly rule out the possibility of accretion disk being always close to the last stable orbit as in magnetic flares model (Merloni & Fabian, 2002, and references therein); however, the QPO frequency - photon index correlation, and the decrease of characteristic frequencies in time are two results from this and other sources that need to be understood for this model (Zdziarski et al., 2003; Tomsick, 2004).

Our observations disfavor synchrotron from a shock region in the jet as major source of hard X-rays until deep in the LH state. We cannot place constraints on different emission models after MJD 52490.

References

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