Inflow-Outflow Properties of Accretion Disk around MAXI J1836-194 with TCAF Solution during its 2011 Outburst

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Abstract

Galactic black hole candidate (BHC) MAXI J1836-194 was discovered by MAXI/GSC on August 29, 2011 at sky location RA = 18^h 35^m 43.43^s, DEC = -19^o19'12.1". We study the BHC during its 2011 outburst using archival data of RXTE/PCA with the TCAF Solution. From spectral fits with the TCAF model fits file in XSPEC, we extracted physical accretion flow parameters, such as, Keplerian disk rate, sub-Keplerian halo rate, shock location and strength. Even probable mass of the black was also estimated from our study. Quasi-periodic oscillations (QPOs) are observed sporadically during the outburst. Based on the variation of flow parameters and nature of QPOs, the entire outburst was classified into two spectral states, hard and hard-intermediate. A deviation of the constancy of the TCAF model normalization was observed in five observations from hard-intermediate spectral states, where high radio-jets were present. We also estimated jet X-ray flux from our spectral study. Since, softer states were absent during the outburst, we termed this outburst of MAXI J1836-194 as 'failed-outburst'.

Key words: X-Rays:binaries – stars individual: (MAXI J1836-194) – stars:black holes – accretion, accretion disks – ISM: jets and outflows – radiation:dynamics

1. Introduction

Black hole candidate (BHC) MAXI J1836-194 was discovered simutaneously by MAXI/GSC and Swift/BAT on August 29, 2011 at sky location RA = 18^h 35^m 43^s.43, DEC = -19°19'12".1. The BHC has short orbital period ($\sim$ 4.7 hrs) and high spin parameters ($a = 0.88 \pm 0.03$) (Jana et al., 2016 and references therin). The companion is reported to be a high massive B[e] star (Cenko et al. 2011). After inclusion of two components advective flow (TCAF) model in HeaSARC's spectral analysis software package XSPEC as a local additive table model, accretion flow dynamics of several BHCs (for e.g., GX 339-4, H 1743-322, MAXI J1659-152, MAXI J1543-564, etc.) were studied and explained well (Debnath et al. 2014, 2015a,b; Mondal et al. 2014, 2015, 2016; Jana et al. 2016; Chatterjee et al. 2016; Molla et al. 2016, 2017; Bhattacharjee et al. 2017). We also estimated X-ray jet outflow rates and mass of unknown BHCs from spectral analysis using the TCAF solution.

2. Observation and Data Analysis

We use 2.5-25 keV RXTE/PCA archival data for 35 observation spread over the enire outburst. We carry out our data analysis with TCAF Solution in XSPEC to extract physical flow parameters, such as, Keplerian disk rate ($\dot{m}_d$), sub-Keplerian halo rate ($\dot{m}_d$), shock location (X_s), compression ratio (R) and mass of the BH. Low frequency quasi-periodic oscillations (QPOs) are observed sporadically in power-density spectra during the entire outburst.

TCAF normalization (N) is a function of mass, distance and inclination angle of the disk. Thus constant value of N should be required to fit all the data. However, higher values of N are required when jets are present, since in the present TCAF model, Jet calculations were not included. This gives us opportunity to calculate jet X-ray flux (F_{jet}) from the total X-ray flux (F_X). Then we freeze value of N at its lowest value (assuming there was no jet on that day) to calculate the disk X-ray flux (F_{dsk}). Then we take difference of F_{dsk} from F_X to calculate F_{jet} as, $F_{jet} = F_X - F_{dsk}$.

3. Result and Discussions

3.1. Timing Properties

Low frequency QPOs are observed sporadically on and off during entire 2011 outburst of MAXI J1836-194. Although a general trends of monotonically increasing frequencies in the rising phase and monotonically decreasing nature in the declining phase of the outburst are observed. Highest value of QPO frequency 5.17 Hz was observed on MJD=55820, when a transition between two (rising and declining) hard-intermediate spectral states are observed. Non-satisfaction of the resonance condition between cooling and infall time scales (Chakrabarti et al. 2015 and references therein) may be the reason behind the non-observation of QPOs on daily basis.

3.2. Spectral Properties

Based on the nature of low frequency QPOs, accretion rate ratio (ARR = $\dot{m}_h/\dot{m}_d$) and photon indices (Γ) we classified entire outburst into two harder spectral states: hard (HS) and hard-intermediate (HIMS), which are observed in the sequence of: *HS (Ris)* $\rightarrow$ *HIMS (Ris)* $\rightarrow$ *HIMS (Dec)* $\rightarrow$ *HS (Dec)*. In the HS (Ris), both $\dot{m}_h$ and $\dot{m}_d$ increases. ARR reaches on maximum value of MJD=55808 when it enters to HIMS (Ris). In this state, $\dot{m}_d$ increases and reaches maximum value on MJD=55820. ARR was minimum on this day. Highest value of QPO was also observed in the same day. We define this day as transition day between two HIMS. After that the BHC enters on HIMS (Dec). $\dot{m}_d$ is observed to be decreased but $\dot{m}_h$ is observed to be increased. On MJD = 55830, ARR was found to have local maxima as the BHC enters in HS (Dec). The shock becomes strong and moves away from the black hole during this state. Both $\dot{m}_h$ and $\dot{m}_d$ are found to be decreased but ARR increased. No sign of soft spectral state was found. This may be due to the BH is immersed in the excreation disk of the companion which is reported to be a B[e] star.

From the spectral study with TCAF solution, we predicted most probable range of the mass of the BHC as $\sim 7.5-11\ M_{\odot}$. We also find $\dot{m}_h$ attains value maximum ~ 10 days before $\dot{m}_d$ in both rising and declining phase. This allow us to estimate the viscous time scale for this outburst is ~ 10 days (see, Jana et al. 2016 for more details).

3.3. Estimation of X-ray Jet Flux

We find TCAF normalization (N) is varied over a small range of $\sim 0.25-0.35$ except five observations in hard-intermediate state (around $\sim$ MJD = 55820), when higher values are required. But, according to the TCAF solution, for a particular source, it should be constant, since N depends on intrinsic physical parameters (such as, mass, distance, disk inclination angle) of the source. The deviation could be due to non-inclusion of jet outflow processes in the current TCAF model *fits* file. This allows us to extract jet X-ray flux contributions from total X-rays as defined in §2. From the differences of F_X and F_{dsk}, we calculated the jet X-ray flux (F_{jet}). We require highest value of normalization ($N \sim 1.68$) on MJD = 55820. We find jet X-ray flux (F_{jet}) starts to increase from MJD = 55810 and was maximum on MJD = 55820. After that it decreases. The variation of N has similar trends as of X-ray jet fluxes. Observed radio fluxes (F_R) also showed roughly similar variations. We also see about $\sim 25\%$ X-ray is contributed by jet on average. When jet is strongest, the contribution is upto $\sim 44\%$.

We also find the correlation between F_R and F_X according to the relation $F_R \propto F_X^b$. Here, we obtain correlation index as $b = 1.85 \pm 0.17$. We also find another correlation between F_R and F_{jet}. In this case, the correlation index is found to be as $b = 0.97 \pm 0.11$. Our result is consistent with Russel et al. (2015).

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References

Cenko, S. B., Miller, A. A., & Bloom, J. S., et al., 2011, ATel, 3614, 1
Bhattacharjee, A., et al., 2017, MNRAS, 466, 1372
Chakrabarti, S. K., & Titarchuk, L. G., 1995, ApJ, 455, 623
Chakrabarti, S. K., Mondal, S., & Debnath, D., 2015, MNRAS, 452, 3451
Chatterjee, D., Debnath, D., & Chakrabarti, S. K., et al., 2016, ApJ, 827, 88
Debnath, D., Chakrabarti, S. K., Mondal, S., 2014, MNRAS, 440, L121
Debnath, D., Mondal, S., & Chakrabarti, S. K., 2015a, MNRAS, 447, 1984
Debnath, D., Molla, A. A., Chakrabarti, S. K., & Mondal, S., 2015b, ApJ, 803, 59
Jana, A., Debnath, D., & Chakrabarti, S. K., et al., 2016, ApJ, 819, 107
Jana, A., Chakrabarti, S. K., & Debnath, D., et al., 2017, ApJ (submitted)
Molla, A. A., Debnath, D., & Chakrabarti, S. K., et al., 2016, MNRAS, 460, 3163
Molla, A. A., Chakrabarti, S. K., Debnath, D., & Mondal, S., 2017, ApJ, 834, 88
Mondal, S., Debnath, D., & Chakrabarti, S. K., 2014, ApJ, 786, 4
Mondal, S., Chakrabarti, S.K., & Debnath, D., 2015, ApJ, 798, 57
Mondal, S., Chakrabarti, S.K., & Debnath, D., 2016, Ap&SS, 361, 309
Russel, T. D., Miller-Jones, J. C. A., & Curran, P. A., 2015, MNRAS, 450,1745