

A GHz Flare in a Quiescent Black Hole and A Determination of the Mass Accretion Rate

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Abstract If the total energy of a radio flare is known, one can estimate the mass accretion rate of the disk by assuming equipartition of magnetic energy and the gravitational potential energy of accreting matter. We present here an example of how such an estimate could be done. Our recent radio observation using the Giant Meter Radio Telescope (GMRT) of the galactic black hole transient A0620–00 at 1.280 GHz revealed a micro-flare of a few milli-Jansky. Assuming a black hole mass of $10 M_{\odot}$ for the compact object, we find the accretion rate to be at the most $\dot{M} = (8.5 \pm 1.4) \times 10^{-11} (x/3)^{5/2} M_{\odot} \text{ yr}^{-1}$, where, x is the distance from the black hole in units of Schwarzschild radius. This is consistent with the earlier estimate of the accretion rate based on optical and X-ray observations. We claim that this procedure is general enough to be used for any black hole candidate.

Key words: Black hole physics – accretion: accretion disks – magnetic fields – radio continuum: stars – stars: individual (A0620–00)

1 INTRODUCTION

Our understanding of the accretion processes at low accretion rates suggests that magnetic field may be entangled with hot ions at virial temperatures and could be sheared and amplified to the local equipartition value (Rees 1984). If so, dissipation of this field, albeit small, should produce micro-flares from time to time, and they could be detectable especially if the object is located nearby. In the case of AGNs and QSOs, the flares are common and the energy release could carry information about the accretion rates in those systems. We present here an application of this understanding of the accretion process in the context of the galactic black hole transient A0620–00 (Pal & Chakrabarti, 2004).

A0620–00 was discovered in 1975 through the Ariel V sky survey (Elvis et al. 1975). It is located at a distance of $D = 1.05$ kpc (Shahbaz, Naylor & Charles 1994). A0620–00 is in a binary system and its mass is estimated to be around $10 M_{\odot}$ (Gelino, Harrison & Orosz 2001). A0620–00 is not particularly well known for its activity in radio wavelengths. It was last reported to have radio outbursts in 1975 at 962 and 151 MHz (Davis et al. 1975; Owen et al. 1976). A few years after these observations, Duldig et al. (1979) reported a low level activity at

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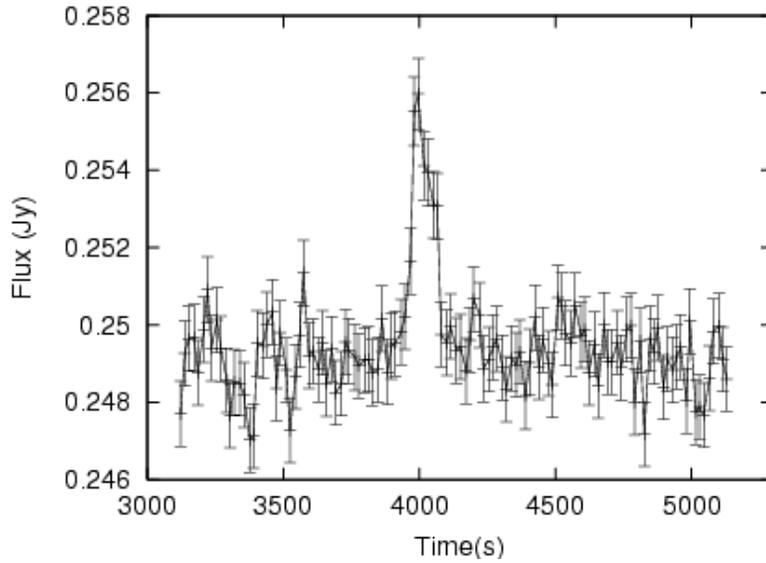


Fig. 1 Light curve of A0620-00 without background subtraction on Sep. 29th, 2002 as obtained by GMRT radio observation at 1.28 GHz. Subtracting the background reveals a micro-flare of mean flux 3.84 mJy of duration 192 ± 32 s.

2 cm (14.7 GHz). More recent re-analysis of the 1975 data revealed that it underwent multiple jet ejection events (Kuulkers et al. 1999). There are no other reports of radio observations of this object. The outbursts and quiescence states are thought to be due to some form of thermal-viscous-instability in the accretion disk. In the quiescent state, the accretion rate becomes very low (e.g. Lasota 2001). Assuming that there is a Keplerian disk, from the observations in the optical and the X-ray, the accretion rate was estimated to vary from a few times the Eddington rate in outbursts to less than $10^{-11} M_{\odot} \text{ yr}^{-1}$ in quiescence (de Kool 1988; McClintock & Remillard 1986). Assuming a low-efficiency flow model, McClintock & Remillard (2000), obtained the accretion rate to be $\sim 10^{-10} M_{\odot} \text{ yr}^{-1}$ using X-ray observations. A0620-00 has been in a quiescent state for quite some time. In the present Paper, we report the observation of a micro-flare in radio wavelength (frequency 1.28 GHz) coming from this object.

2 OBSERVATIONS AND RESULTS

On Sept. 29th, 2002, during UT 00:45-02:03 we observed A0620-00 with the Giant Meter Radio Telescope (GMRT) located in Pune, India. GMRT has 30 parabolic reflector antennae placed with altazimuth mounts each of which is of 45 meter diameter placed in nearly ‘Y’ shaped array. It has a tracking and pointing accuracy of $1'$ for wind speeds less than 20 km s^{-1} . GMRT is capable of observing at six frequencies from 151 MHz to 1420 MHz. On the higher side, 608 – 614 MHz and 1400 – 1420 MHz are protected frequency bands by the International Telecommunication Union (ITU). During our observation, 28 out of 30 antennae were working and the observational conditions were stable. The observed frequency is $\nu_{\text{obs}} \sim 1280 \text{ MHz}$ which is far away from the ITU bands. The band width is 16 MHz. There were 128 channels with a channel separation of 125 kHz. We used 3C147 as the flux calibrator and 0521+166 as the phase calibrator. No other source was found within the field of view. The primary beam width was 0.5 degree and the synthesized beam width was 3 arc second.

Data analysis were carried out using the AIPS package. The data for A0620–00 is band passed, channel averaged, and self calibrated. The light-curve without the background subtraction is shown in Fig. 1. The data is integrated in every 16 seconds. The background is due to two side lobes and is found to be constant in time. The UV coverage was very good and the background was found to be constant within the field of view with rms noise 8.6×10^{-4} Jy as tested by the task IMAGR in AIPS. The background subtraction reveals that a micro-flare of average flux density $F_\nu = 3.84$ mJy occurred and it lasted for about $t_{\mu f} = 192 \pm 32$ seconds. We found that each of the antennae independently showed this event and the synthesized image of the field of view showed no significant signal from any other source. This confirms the presence of this micro-flare very convincingly.

3 INTERPRETATION OF THE MICRO-FLARING EVENT

Fast variabilities occur in time scales of the order of the light crossing time $t_l = r_g/c \sim 0.1 \frac{M}{10 M_\odot}$ ms, ($r_g = 2GM/c^2$ is the Schwarzschild radius) in the vicinity of a black hole. Shot noise in this time scale is observed during X-ray observations. Since the duration $t_{\mu f}$ of the micro-flare that we observe is much larger ($t_{\mu f} \gg t_l$), hence we rule out the possibility that it is a shot noise type event.

Assuming that the flare is due to magnetic dissipation, with an energy density of $B^2/8\pi$, the expression for the total energy release (fluence) is:

$$E_{\text{mag}} = \frac{B^2}{8\pi} V = 4\pi D^2 \nu_{\text{obs}} F_\nu t_{\mu f}, \quad (1)$$

where $V \sim r_g^3$ is the lower limit of the volume in the accretion flow that released the energy, D is the distance of the source from us, ν_{obs} is the frequency at which the observation is made and F_ν is the specific intensity of radiation. Here, B is the average magnetic field in the inflow where the flare forms. Re-writing Eqn. (1) using the equipartition law,

$$\frac{B^2}{8\pi} \sim \frac{GM\rho}{r} = \frac{GM\dot{M}}{4\pi v r^3}, \quad (2)$$

where ρ is the density of matter in the accretion flow, \dot{M} is the accretion rate and v is the velocity of inflow. Since there is no signature of a Keplerian disk in the quiescent state, one may assume the inflow to be generally like a low-angular momentum flow (Chakrabarti, 1990), especially close to the black hole. Estimations of McClintock & Remillard (2000) was carried out with a low-efficiency radial flow model. Thus, we use the definition of the accretion rate to be $\dot{M} = 4\pi\rho r^2 v$. More specifically, we assume, the free-fall velocity, $v \sim (2GM/r)^{1/2}$. Introduction of pressure and rotation effects do not change the result since the gas is tenuous, i.e., hot, and since the Keplerian flow is absent, i.e., the angular momentum is very low. These simple but realistic assumptions allow us to obtain the upper limit of the accretion rate of the flow to be,

$$\dot{M} \sim (3.5 \pm 0.58) \times 10^{14} x^{5/2} \text{ gm s}^{-1} = (5.5 \pm 0.91) \times 10^{-12} x^{5/2} M_\odot \text{ yr}^{-1}. \quad (3)$$

Here $x = \frac{r}{r_g}$, is the dimensionless distance of the flaring region from the center. From the transonic flow models (Chakrabarti 1990), the flow is expected to be supersonic only around $x_c \sim 2 - 3$ before disappearing into the black hole. Ideally, in a subsonic flow ($x > x_c$), the chance of flaring is higher as the residence time of matter becomes larger, or comparable with the reconnection time scale. For $x < x_c$ there is little possibility of flaring. We thus estimate the the accretion rate of A0620–00 in the quiescent state to be

$$\dot{M} = (8.5 \pm 1.4) \times 10^{-11} \left(\frac{x}{3}\right)^{5/2} M_\odot \text{ yr}^{-1}. \quad (4)$$

In the case of a low angular momentum flow, there are possibilities of shock formation at around $x \sim 10$ (Chakrabarti, 1990). So it is likely that the flare forms in the immediate vicinity of the post-shock (subsonic) region where the density of matter as well as magnetic pressure are very high. In any case, the rate we get is consistent with that reported by McClintock & Remillard (2000) on the basis of X-ray observations. It is to be noted that Duldig et al. (1979) found a flux of 44 ± 14 mJy well after the outburst in 1975 and concluded that intermittent emissions are possible and that mass transfer continues even in quiescence states. Our result also verifies such an assertion.

The procedure we have suggested here is sufficiently general. For instance, it is generally believed that in the hard state of a black hole, the hot, sub-Keplerian matter plays an important role in producing the so-called Compton cloud and this would be ideal location for flaring activities if some entangled magnetic fields are present. In case the mass of the black hole and its distance are known, as in the present case, the mass accretion rate could be calculated. In case the accretion rate and the distance were known then the mass could be estimated by inverting the logical steps given above. One of our assumptions is to estimate the magnetic field by assuming it to be in equipartition with the gravitational energy density. In reality, the magnetic field could be less than the equipartition value. On the other hand, since we assumed flow to be freely falling, while in presence of angular momentum, the flow would slow down and both the density and the magnetic field energy would be higher. These two opposite effects should make our estimate to be still sufficiently realistic.

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