

Mass and Accretion Rate Determination of Black Holes through Radio Observations in Quiescent States

Sabyasachi Pal^{1,3}, Sandip K. Chakrabarti^{2,1}

¹ Centre for Space Physics, 43 Chalantika, Garia Station Road, Kolkata 700 084, India

² S.N. Bose National Centre for Basic Sciences, JD Block, Salt Lake, Kolkata 700098, India

³ Jadavpur University, Kolkata 700 032, India

In quiescent states of soft-X-ray transients, the accreting matter can be very hot. In presence of stochastic magnetic fields, the hot electrons will emit synchrotron radiation. Flaring may occur when there are reconnection events as on the surface of the sun. 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 $10 M_{\odot}$ residing at the center, we find the accretion rate to be at the most $(8.5 \pm 1.4) \times 10^{-11} M_{\odot} \text{yr}^{-1}$. This is consistent with the earlier estimate of the accretion rate based on optical and X-ray observations. Conversely, the mass of the black hole may be estimated if the accretion rate were known. We claim that this procedure is general enough to be used for any black hole candidate.

1 INTRODUCTION

Our understanding of the accretion process at low accretion rates suggests that magnetic field may be entangled with hot ions at virial temperatures and could be shared and multiplied by the local equipartition value (1). 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 QPOs, 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 blackhole transient A0620-00 [2].

A0620-00 is in a binary system and its mass is estimated to be around $10M_{\odot}$ [3]. It was discovered in 1975 through the Ariel V sky survey [4]. This object is located at a distance of $D = 1.05 \text{kpc}$ [5]. The galactic black hole transient 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 [6, 7]. More recent re-analysis of the 1975 data revealed that it underwent multiple jet ejection events [8]. There are no other reports of radio observations of this object. The outbursts and quiescence are thought to be due to some form of thermal instability in the accretion disk. In the quiescent state, the accretion rate becomes very low (e.g. [9]). Assuming there is a Keplerian disk, from optical and X-ray observations 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 [10,11]. Assuming a low-efficiency flow model, McClintock & Remillard [12], obtained the accretion rate to be, $10^{-10} M_{\odot} \text{ yr}^{-1}$ using X-ray observations. A0620-00 has been in a quiescent state for quite some time. 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 [1]. 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 present Paper, we report the observation of a micro-flare in radio wavelength (frequency 1.28MHz) coming from this object. In the next Section, we present the details of the observations and the results. In section 3, we analyze our observation and compute the accretion rate in the quiescent state.

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 45m diameter. During our observation, 28 out of 30 antennae were working and the observational conditions were stable. GMRT is capable of observing at six frequencies from 151MHz to 1420MHz. On the higher side, 608 - 614MHz and 1400-1420MHz are protected frequency bands by the International Telecommunication Union (ITU). The observed frequency $v_{\text{obs}} = 1280\text{MHz}$ was far away from the ITU bands. The bandwidth was 16MHz. There were 128 channels with a channel separation of 125kHz. The light-curve without the background subtraction is shown in Fig. 1. The data is integrated for 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 $8.6 \times 10^{-4} \text{ Jy}$. The background subtraction reveals that a micro-flare of average flux density of $F_v = 3.84\text{mJy}$ occurred and it lasted for about $t_f = 192 \pm 32$ seconds. We used the 3C147 as the flux calibrator and 0521+166 as the phase calibrator. No other source was found within the field of view. The confirmation of this micro-flare is shown by the fact that each of the antennae independently showed this event and the synthesized image of the field of view showed no significant signal.

3. Discussion

Close to a black hole, fast variability in time scales of the order of the light crossing time $t_l = r_g/c \sim 0.1M/10M_o \text{ ms}$, ($r_g = 2GM/c^2$ is the Schwarzschild radius) is possible. Shot noise in this time scale is observed during X-ray observations. The duration t_f of the micro-flare that we observe is much larger ($t_f \gg t_l$), and 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:

$$E_{\text{mag}} = B^2 V/8\pi = 4\pi D_{\text{obs}}^2 F_v t_{\mu f} \quad (1)$$

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, v_{obs} is the frequency at which the observation is

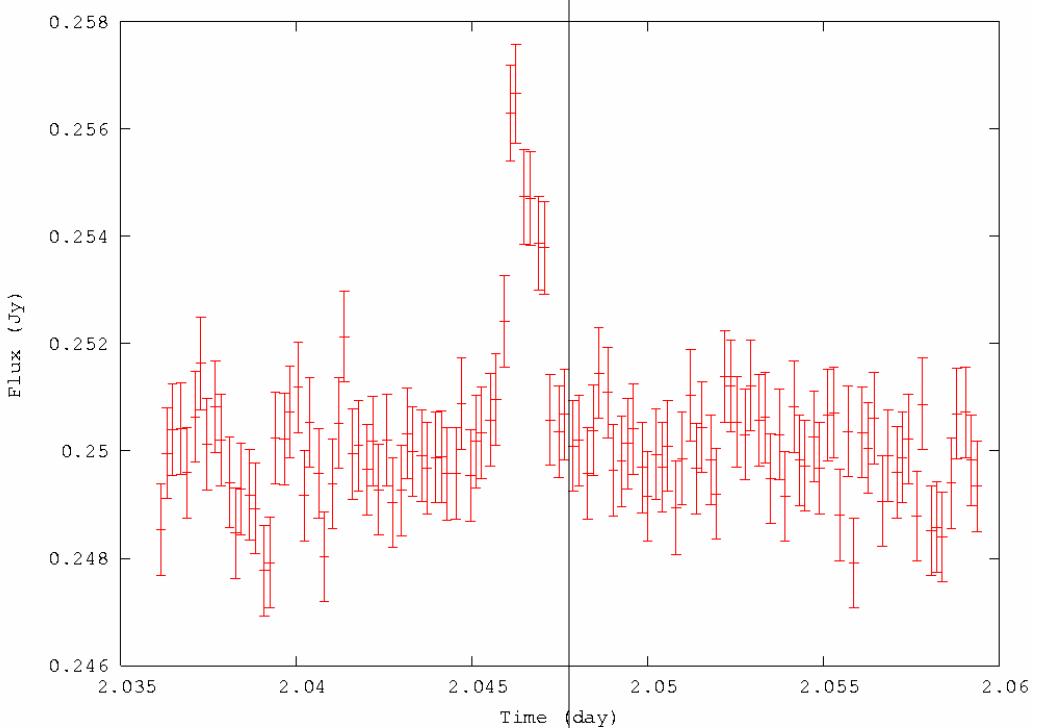


Fig.1. Light curve of A0620-00 without background subtraction on Sept. 29th, 2002 as obtained by GMRT radio observation at 1.28GHz. Subtracting the background reveals a micro-flare of mean flux 3.84mJy of duration $192 \pm 32\text{s}$.

made and F is the specific intensity of radiation. Here, B is the average magnetic field in the inflow where the flare forms. Re-writing Eq. (1) using the equipartition law,

$$B^2 / 8\pi \sim GM\rho/r = GM\Theta/4vr^3 \quad (2)$$

where ρ is the density of the flow in the accretion flow, $\Theta = dM/dt$ 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 Bondi flow [13], especially close to the black hole. Estimations of McClintock & Remillard [12] were carried out with a low-efficiency radial flow model. Thus we use the definition of the accretion rate to be $\Theta = 4\pi r^2 v$. 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, and since the Keplerian flow is absent, 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

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

Here $x = r/r_g$, is the dimensionless distance of the flaring region from the center. From transonic flow models [13], the flow is expected to be supersonic only around $x \sim 2 - 3$ before disappearing into the black hole. This gives the accretion rate of A0620-00 in the quiescent state to be

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

This is consistent with that reported by McClintock & Remillard [13] on the basis of X-ray observations.

The procedure we have suggested here is general and should be applicable to determine the mass of the black holes if the distance is reasonably well known. Only condition is that a hot, sub-Keplerian component should be present.

Acknowledgements.

We thank the staffs of the GMRT who have helped us to make this observation possible. GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research. SP thanks a CSIR Fellowship that supported his work at the Centre for Space Physics.

References

- [1] Rees, M, "Black Hole Models for Active Galactic Nuclei", ARAA, 22, p471, 1984
- [2] Sabyasachi Pal & Sandip K. Chakrabarti, "Mass accretion rate of the galactic black hole A0620-00 in its quiescent state", 421, p13P
- [3] Gelino, D.M., Harrison, T.E. and Orosz, J.A, "A Multiwavelength, Multiepoch Study of the Soft X-Ray Transient Prototype, V616 Monocerotis (A0620-00)", AJ, 122, p2668, 2001
- [4] Elvis, M., Page, C.G., Pounds, K.A., Ricketts, M.J. and Turner, M.J.L, "Discovery of powerful transient X-ray source A0620-00 with Ariel V Sky Survey Experiment", Nature 257, p656, 1975
- [5] Elvis, M., Page, C.G., Pounds, K.A., Ricketts, M.J. and Turner, M.J.L, "Discovery of powerful transient X-ray source A0620-00 with Ariel V Sky Survey Experiment", Nature 257, p656, 1975
- [6] Davis, R.J., Edwards, M.R., Morison, I., Spencer, R.E., "Observations of A0620-00 at 962 and 151 MHz", Nature, 257, p659, 1975
- [7] Owen, F.N., Balonek, T.J., Dickey, J., Terzian, Y., Gottesman, S.T., "Radio emission from the X-ray source A0620-00", ApJ 203, pL15, 1976
- [8] Kuulkers, E., Fender, R.P., Spencer, R.E., Davis, R.J. and Morison, I, "Multiple ejections during the 1975 outburst of A0620-00", MNRAS, 306, p919, 1999
- [9] Lasota, J.-P., "The disc instability model of dwarf novae and low-mass X-ray binary transients", New AR, 45, p449 , 2001
- [10] de Kool, M., "A model for the X-ray and optical emission from A0620-00", ApJ 334, p336, 1988
- [11] McClintock, J.E., Remillard, R.A, "The black hole binary A0620-00", ApJ 308, 110, 1986
- [12] McClintock, J.E., Remillard, R.A., "HST/STIS UV Spectroscopy of Two Quiescent X-Ray Novae: A0620-00 and Centaurus X-4", ApJ 531, p956, 2000
- [13] S. K. Chakrabarti, "Theory of Transonic Astrophysical Flows", (World Scientific: Singapore) , 2002
- [14] McClintock, J.E., Petro, L.D., Remillard, R.A., Ricker, G.R, "Periodic variability of the X-ray nova A0620-00 in quiescence", ApJL 266, p27, 1983