The Microquasar GRS 1915+105

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ABSTRACT

Microquasars are X-ray binaries that replicate quasars on smaller timescales. They are thus suitable "laboratories" for studying events that would take timescales of years in case of quasars.

Relativistic jets and powerful outflowsare an ubiquitous feature of accreting black holes, but the long dynamical timescales pose a constrainat on understanding them .Thus the key to the problem lies in studying binary systems in our own galaxy, which harbor stellar mass (5-15 Solar mass) black holes that mimic such events on smaller timescales.

GRS 1915+105 is a binary system in our galaxy containing an accreting black hole of stellar mass and could prove to be a key object for the study of the disc-jet interaction. Its peculiar X-ray properties allow us to study in detail the instabilities of the accreting matter.

The sections that follow put together the various observations of microquasar GRS 1915+105 that have led to a better understanding of such mechanisms.

Subject headings: Miroquasars, GRS 1915+105

1. Introduction

Microquasars are Radio Emitting X-ray Binaries that display relativistic radio jets. The importance of study of microquasars lies in the fact that they are stellar mass black holes or neutron stars that mimic those phenomenon observed in quasars(that contain super-massive black holes), but on smaller scales. Thus phenomena taking place in years in microquasars can be studied in much smaller timescales- from minutes to days, rather than years. The key parameter distinguishing microquasars and quasars is the mass of the central object. Also , for microquasars the temperature of inner parts of the accretion disk are of the order of 10^7 K while for quasars this temperature is 10^5 K (Marc Ribo, 2003). It was only after the devlopment of field of high energy astrophysics that we could discover microquasars. Currently 16 microquasars are known.

Among the microquasars known to date, the most fascinating one is GRS 1915+105.It is located in the Galactic plane. It was discovered as a transient hard X-ray source (Castro-Tirado et al, 1994) and is known to be the first Galactic source to display apparent superluminal motions of radio-emitting ejecta (Mirabel and Rodriguez,1994). GRS 1915+105 contains a 14 (+/- 4) solar mass black hole(Greiner et al, 2001). The black hole is fed by roche lobe overflow from a K-M giant companion of mass 1.2 (+/- 0.2) solar mass. Certain features of this microquasar make it really unique. It dispalys extreme variability in many different wavebands and its high accretion rate makes it regularly achieve luminosities not seen in other galactic x-ray souces (D. Rothstein et al, 2005). In the radio it can show superluminal ejections at arcsec scales(Mirabel et al, 1994) and a compact jet at milliarcsecond scales (Dhawan et al,2000).

2. Observations leading to the discovery of GRS1015+105

GRS 1915+105 was discovered on 15 August, 1992 by the watch all-sky X-ray monitor on GRANAT satellite. It consists of four identical units mounted in a tetrahedral configuration to cover the whole sky. Each instrument has a circular field of view of 4 steradians and an effective area of 30 cm^2. The toal energy range is approximately 6-150 KeV.

The data revealed a bright X-ray transient in the constellation Aquila with a flux of 0.3 crab (Castro-Tirado, 1992). The X-ray light curve is shown in Fig. 1.

The X-ray flux derived from WATCH observations was 3.0 x 10^{-9} ergs $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in August 1992. There are several molecular clouds in the direction of GRS 1915+105. Castro-Tirado (1994) have proposed that the star from which the compact object in GRS 1915+105 originated may have been born in one of theses molecular clouds. They also derived a lower limit fpr the distance of GRS 1915+105 as 1.5 kpc by taking into account the magnitude of the optical object and the possible extinction along the line of sight due to the molecular cloud at 1.5 kpc. The limiting magnitude for any optical emitting object was derived to be $>$ 21 (magnitude of optical counterpart taken to be as 1.0).

3. X-ray / IR correlation

In 1997, Eikenberry et al observed GRS 1915+105 on the nights of August 13 -15 UTC using the Palomar Observatory telescope and the cassegrain near-infrared array camera in the K band. GRS 1915+105 was observed for approximately 5 hours each night. Also X-ray observations were obtained on the same nights using Rossi X-Ray Timing Explorer.

The features that emerged through these obseravtions are shown in figure 2 . Large X-ray/IR flares were observed with quasi - periodicity of 30 minutes on August 14 and 15. The comparison of the X-ray and IR flares shows a one-to-one correspondence between the two. (Eikenberry et al, 1998) For every X-ray flare of seven there is a corresponding IR flare (and vice-versa). However in the later stages, the two decouple. The x-ray flares continue to exhibit large oscillations for thousands of seconds whereas the IR flares show a smoothly decaying phase. Also oscillations in the IR are of relatively smaller amplitude throughout. Smaller amplitude variatons were observed in some IR flares . Investigation of these subflares was extended in the July 1998 observations of the microquasar using the Palomar Observatory 5m telescope form July 8- 12. (Eikenberry et al, 2000) In these observations, shown in figure 3, six faint IR flares were observed having peak amplitudes of 0.3-0.6 mJy and having typical durations of 500 s. They repeat 30-60 minutes.

D. Rothstein et al in 2002 proposed that the 30 minute episode of jet formation could sometimes be a superposition of smaller, faster phenomena. Their conclusion was based on the July 2002 observations IR observations obtained using Plaomar observatory on 27- 29 July and X-ray observations obtained using the Proportional Counter Array on Rossi X-ray Timing Explorer.

The resulting light curves are shown in figure 4.

The resulting light curves show that X-ray oscillations undergo a series of wild oscillations and dips. The figures indicate that each IR flare is triggered by a X-ray spike. Further each IR flare seemed to return to the quiscent state only after the X-ray oscillations stopped.

Such a correlation between IR flare and X-ray oscillation did not seem obvious in 1997 observations by Eikenberry, since, as already mentioned above, the IR flares then decayed smoothly while the X-ray oscillations still continued. However, during these observations the IR sub flares did contribute an IR excess, but only on top of another larger flaring event (Eikenberry et al, 1998). In contrast to this, the 2002 observations seem to suggest that the 30 minute flares are entirely due to superposition of the subflares which are closely spaced so that it seems like a single continuous flare. (Rothstein et al, 2005).Thus each X-ray oscillation has an associated faint IR subflare.

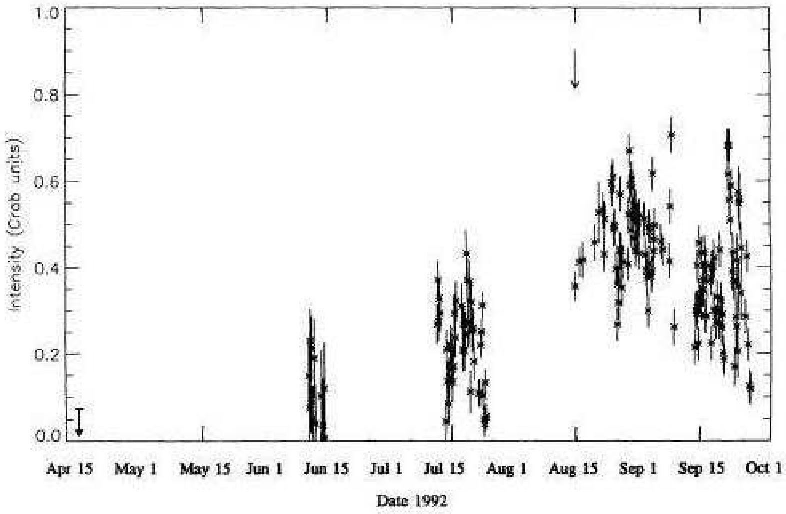


Fig. 1.— X-ray light curve for GRS 1915+105in the WATCh 6-15 KeV energy Band during April 15- September 30, 1992. The arrow indicates its discovery. (Castro- Tirado et al, 1994)

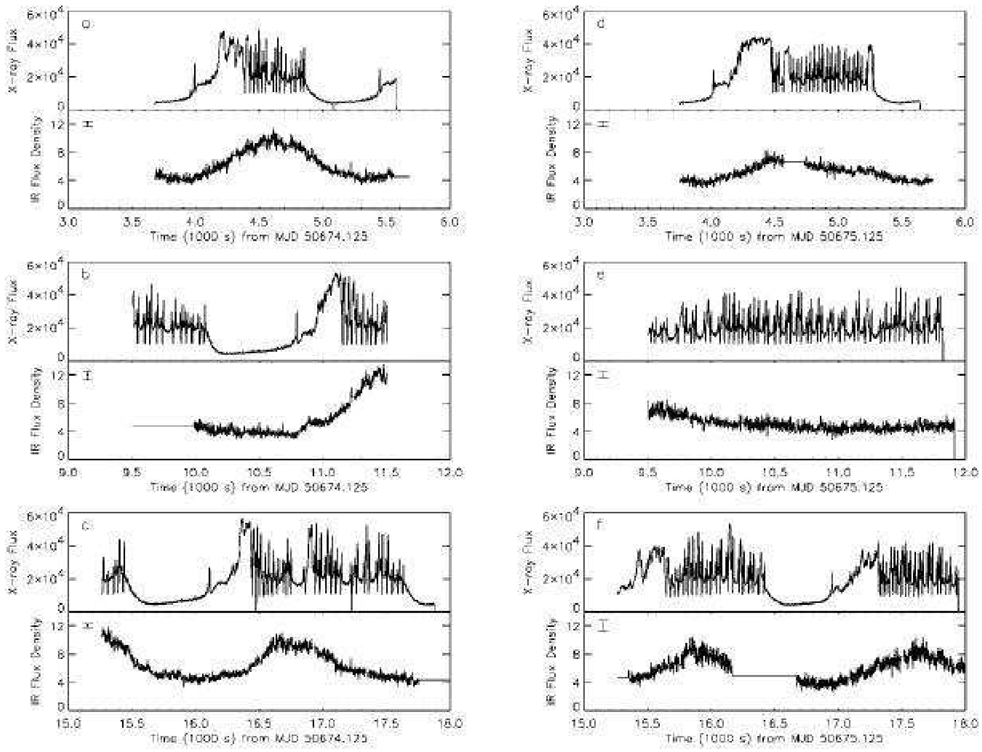


Fig. 2.— Simultaneous X-ray and IR observations of GRS 1915+105 at 1s time resolution (Eikenberry et al, 1998)

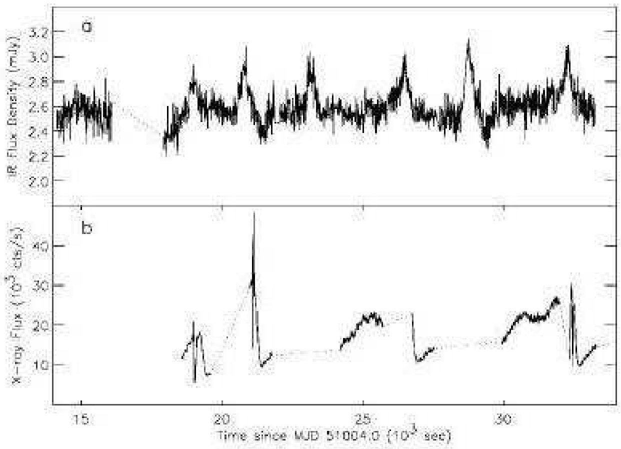


Fig. 3.— Light curves from July 1998 data(Eikenberry et al, 2000).

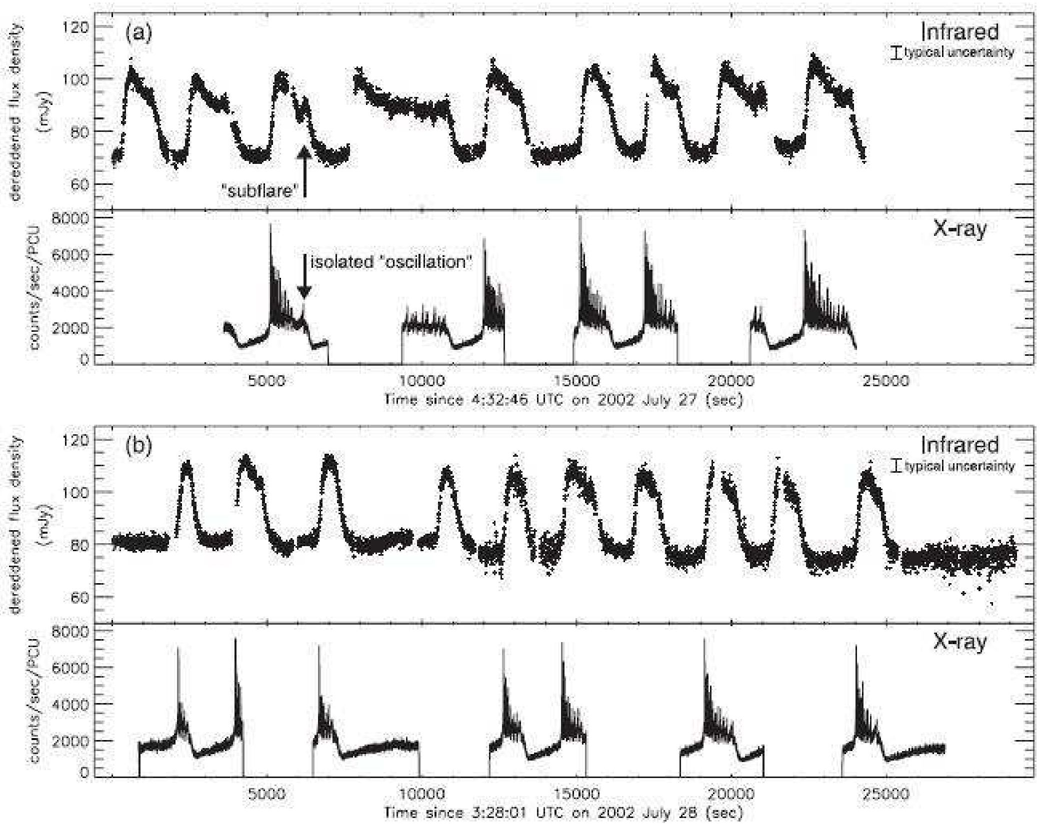


Fig. 4.— Light curves from July 2002 data (Rothstein et al, 2005)

3.1. Interpretations

Eikenberry et al(1998) have tried to explain this observed phenomenon which could be providing us with deeper knowledge of the central engine of a relativistic jet system. They interpret that the IR flux arises from the ejected synchrotron emitting plasma. Observing the relationship of IR and X-ray flares, they suggest that same events trigger both the flares, and that X-ray and IR emtting regions are initially close to each other, seperating, however, in later stages which explains the observed decoupling of the IR and X-ray flares. The IR flares decay smoothly in later stages, while X-ray flares still show wild oscillation suggesting the possibility of X-ray emitting region being in close vicinity of the inner disk. The IR emitting region is thought to be located far from the black hole by ¿10^{13} cm, while its size is estimated to be 10^{12} cm (Ueda et al, 2002).

As for the subflares observed in the IR region these are now referred to as "Class C " flares and these also may be coming from synchrotron emission from a plasma bubble (Eikenberry et al,2000 and Mirabel et al, 1998).

Combining two sets of data form 1997 and 2002 observations, an evident picture that arises is that the large-scale ejection may not always be present during the 30 minute transiton events discussed above; instead, the IR flares may sometimes be due to superpostion of smaller IR ejections ; arising only in the presence of a X-ray spike to trigger such an event (Eikenberry et al, 1998 and Rothstein et al, 2005).

4. Spectroscopy of the Infrared flares

Eikenberry et al in august 1998 obtained infrared spectra of GRS 1915+105 using the HNA long slit grating spectromoeter along with HgCdTe camera on Hale 5m telescope. Figure 5 shows the spectra for each spectrograph grating tilt on each night of observation from August 13th to 15th UTC.

Figur 6 shows the individual 5 minute spectra taken during first IR flare.

Figure 5 exhibits presence of HeI (2.058 um) , Br Gamma (2.1655 um), He II (2.189 um) emission lines. Figure 6 indicates that HeI and HeII are stronger in high-flux spectra and weaker in low-flux spectra.

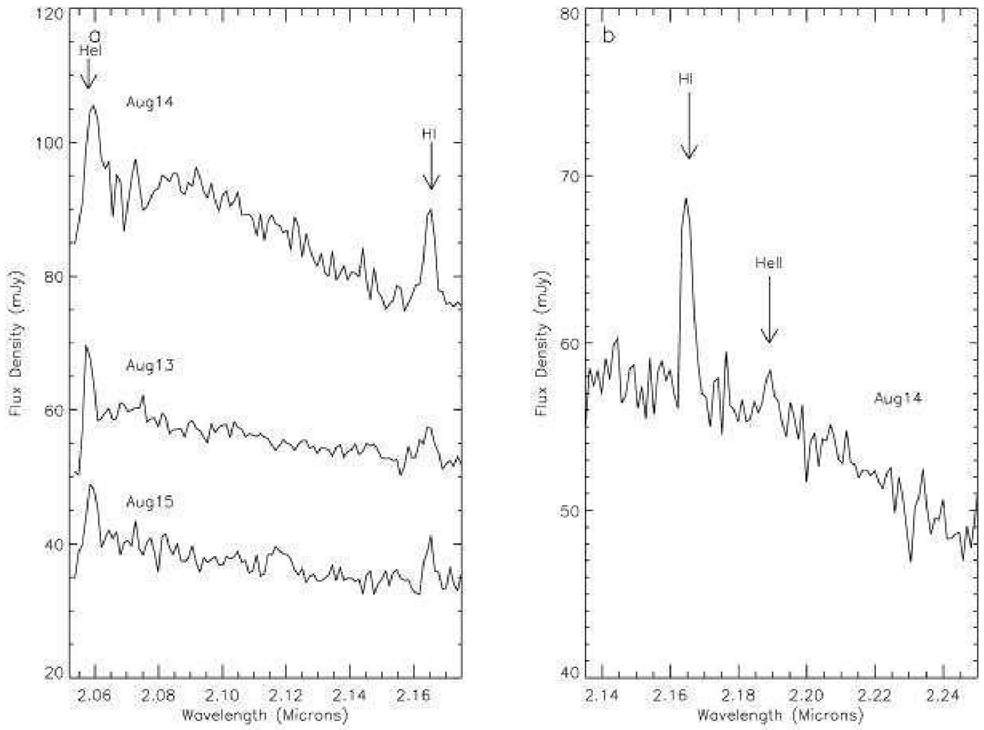


Fig. 5.— Summed IR spectra from GRS1915+105 (Eikenberry et al, 1999)

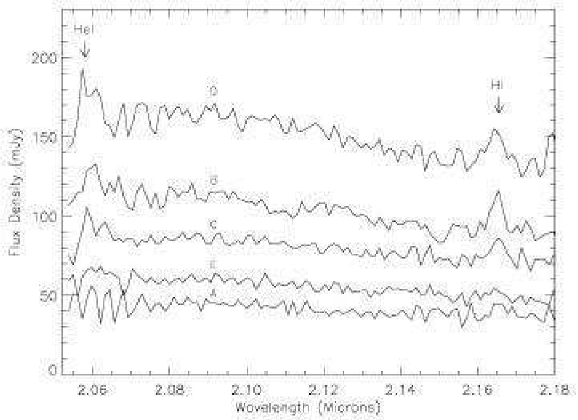


Fig. 6.— Individual 5 minute spectra taken during IR flare on 14 August 1997 (Eikenberry et al, 1999)

4.1. Interpretations

Based on this spectra Eikenberry et al could confirm the accretion disk scenario also proposed by Castro-Tirado et al, 1996. They based this conclusion on the fact that, for a high mass system, the lines originate in the circumstellar disk of an Oe/Be type companion; whereas for a low mass sytem, lines originate in an accretion disk around a compact object. However, O and B starts are not capable of producing photons that would doubly ionized He. Thus the appearence of this line leads to the conclusion that the accretion disk model is indeed true (Eikenberry et al 1999).

5. Radio Jets

The 1992 and 1993 VLA observations showed that the object changed both its radio "brightness" and its apparent position in the sky. In March of 1994, the object began an outburst of strong radio emission . On March and April of 1994, Mirabel and Rodriguez were able to track the movement of the two condensations in the jets of material moving away from the object's core. They found the ejected material to be moving at 92 percent of speed of light. They infered that these pair of blobs were ejected from the core on March 19, during a period when the object was emitting more X-rays than usual. (http://laserstars.org/news/GRS1915n105.html)

Extensive monitoring of GRS 1915+105 in the radio and X-ray band showed that the overall radio emission is correlated with its X-ray properties(Ishwara-Chandra et al)

Actually, the radio emission from the source could be broadly classified into three categories (Ishwar- Chandra et al) : the relativistic superluminal radio jets of flux density 1 Jy and above at cm wavelengths (Fender et al, 1999) ; the "baby" jets of 20 - 40 min durations with flux density of 20 - 200 mJy both in IR and radio (Eikenberry et al, 1998) and the plateau state with radio emission of 20 - 100 mJy for longer durations (Muno et al, 2001).

Ishwar Chandra et al presented the low frequency radio data taken simultaneously at 610 and 244 MHz and tried to come up with a geometric model for its source. The low frequency radio emission of microquasars can help us to understand compactness of the radio emitting plasma. The 610 and 244 MHz were carried out simultaneously with Giant Meterwave Radio Telescope (GMRT, Swarup et al, 1991)(June 21 and 22, 2003).

GMRT conists of 30 antennas, each of 45 metre diameter spread over about 25 km (www.ncra.tifr.res.in). The flux density scale is set by observing the primary calibrator 3C286 or 3C48. A phase calibrator was observed before and after a 30 min scan on GRS

1915+105 for phase calibration. The integration time was 16 s. (Ishwar- Chandra et al)

In Figure 8, the observed flux at different frequencies is plotted during the two observations These show that GRS 1915+105 exhibits strong radio emission at 610 and 244 MHz and there is no evidence for spectral turnover up to 244 MHz. (Ishwara Chandra et al).

In figure 8, the flux density increases at lower frequencies due to a large population of low energy electrons in an optically thin plasma. Since, no spectral turn over was found even at low radio frequencies of 244 MHz, Ishwar- Chandra et al suggest that the radio emission at high radio frequencies could be coming from compact jets, but the lower frequency emission comes from regions far from the accretion disk. They also suggest that the relativistic plasma which was ejected from the accretion disk will move outwards and in the process, will loose energy by radiating as well as by expanding ; forming a lobe. This reservoir of low energy electrons is likely to be the origin for optically thin low frequency radio emission. Figure 9 shows suggested model by them.

Once the bright, oppositely directed raio jets were detected , further study of the source structure with MERLIN revealed that the source is extended and hasa halo of low brightness emission around the source which is elongated nearly at right angles to the jet (Newell et al, 1996).

Newell et al observed GRS1915+105 using the MERLIN array of 8 telescopes at a frequency of 408 MHz on November 28, 1994.

The maps subsequently obtained by data analysis procedures are shown in figure 10.

The first map shows a bright jet-like extension approximately 1 arcsec in length; while the map on the right shows the presence of a halo around GRS 1915+105 with approximately 90 degrees to the jet direction.

Newell et al suggested that this could be due to precessio of the jet, but the exact cause seems unclear.

Multiwavelength observations by Fuchs et al in 2003 also lead to images showing a compact jet. The VLBA high resolution images on April 2, 2003 (figure 11) indicate the presence of a compact radio jet with 7 - 14 mas length, this jet being responsible for the high radio levels (Fuchs et al, 2004 a). The MERLIN image on April 18 (figure 12) showed a radio extension of approximately 0.3 arcsec which was interpreted as the trace of superluminal ejection which corresponds to the giant radio flare on April 4 seen in figure 13 (Fuchs et al, 2004 b).

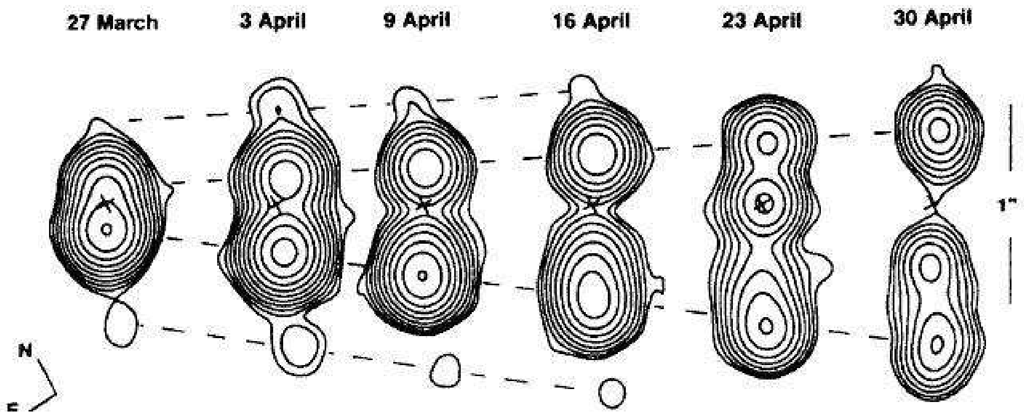


Fig. 7.— Movie made from of a series of VLA radio images of the 'microquasar' GRS 1915+105 taken at wavelength of 3.5 cm, showing the rapid ejection of jets over a month (March 27 to April 30, 1994) (http://laserstars.org/news/GRS1915n105.html)

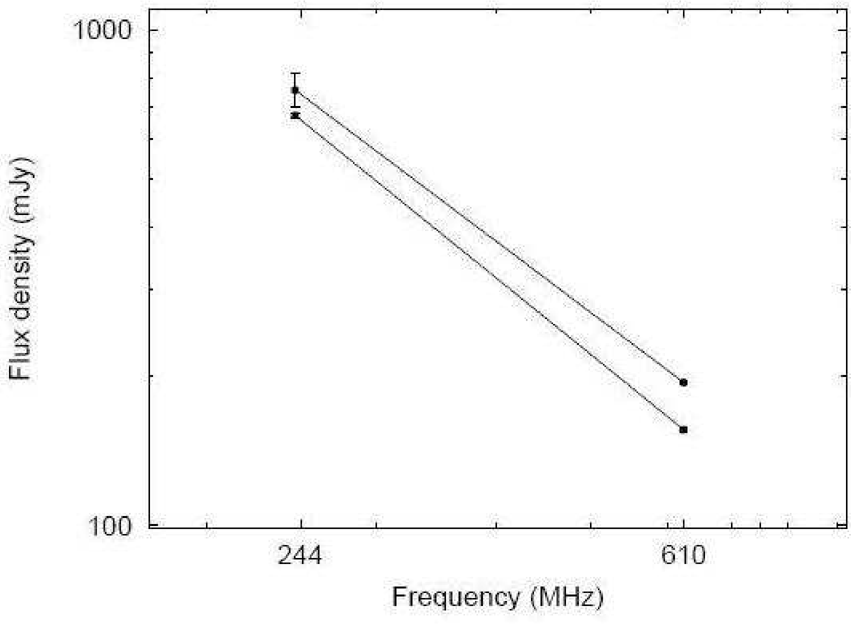


Fig. 8.— Plots for June 21 (upper) and June 22 (lower) between 610 and 244 MHz (Ishwar-Chandra et al)

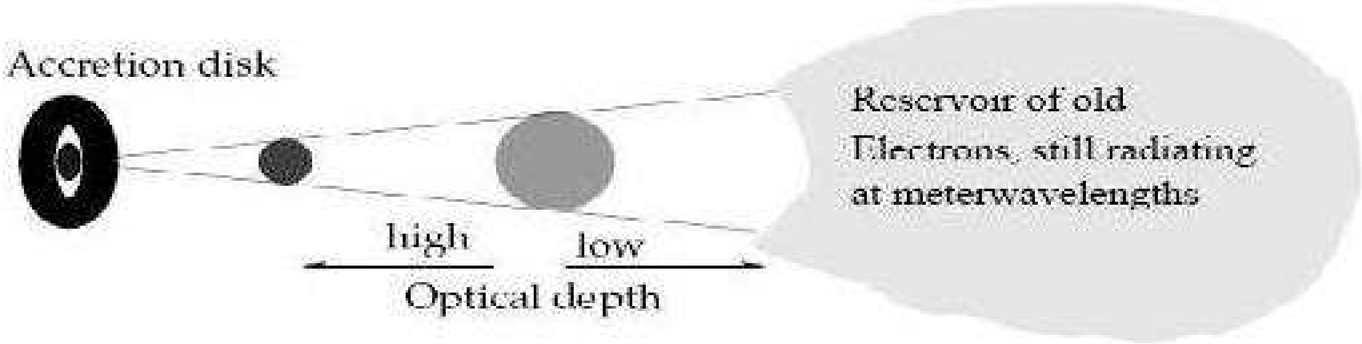


Fig. 9.— Model for possible location of low-frequency radio emitting region (Ishwar- Chandra et al)

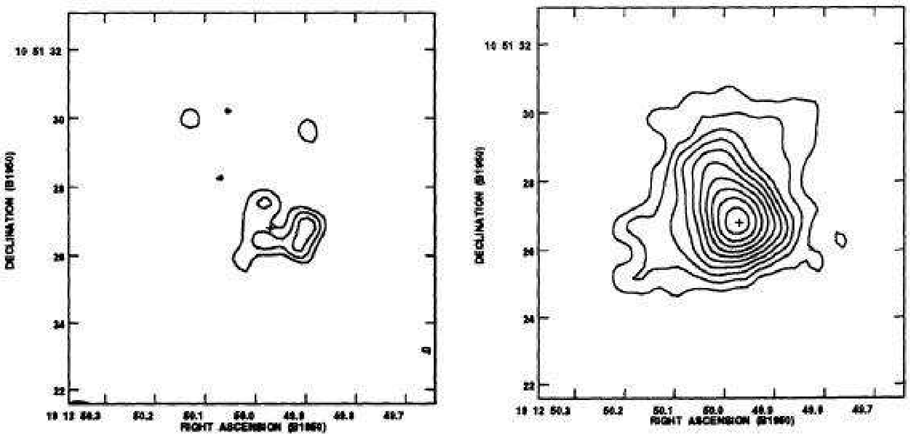


Fig. 10.— Maps of the MERLIN observations (Newell et al, 1996)

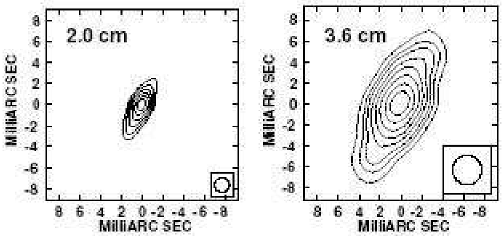


Fig. 11.— VLBA images on April 2, 2003 (Fuchs et al,2004 a)

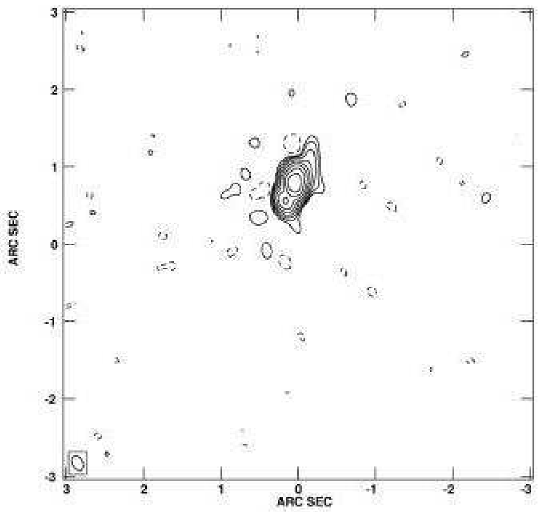


Fig. 12.— MERLIN image on April 17-18 (Fuchs et al 2004 b)

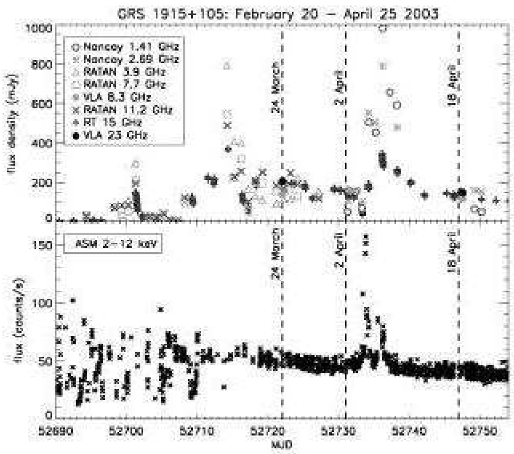


Fig. 13.— Radio and X-ray flux monitoring in March- April, 2003 (Fuchs et al 2004 b).

6. X-ray variability of GRS 1915+105

Paul et al in 1996 observed GRS 1915+105 on July 20-29 with the Indian X-ray Astronomy Experiment (IXAE) on the Indian satellite Indian Remote Sensing satellite-P3 (IRS-P3). The IXAE includes three collimated Pointed Proportional Counters (PPCs).

The X-ray light curve obtained with these observations did not show any large scale intensity variations on time scale of a minute or longer (Paul et al, 1997). However they could observe strong intensity variations on time scale of 0.1s - 10s. Similar bursts were seen in all the detectors (Figure 14).

The variations on timescales of fractions of a second seen in GRS 1915+105 indicate that the emission is from a compact region of size much smaller than a light second; also the total X-ray intensity greatly exceeds the Eddington luminosity from a neutron star with permitted mass limit (Paul et al, 1997). Thus the radiation could be coming from the accretion disk as suggested by Paul et al. Thus confirming the compact object to be a black hole.

In 1997 Yadav et al used IXAE PPC to make observations of GRS 1915+105 on June 12-29, 1997 and on August 7- 10, 1997 in energy range of 2- 18 KeV and with these observations they could observe four types of intense X-ray bursts (Yadav et al, 1999).

The figure 15 and 16 indicates a rise in intensity is by a factor of about 2 or more for regular bursts and by a factor of 3 or more for quasi-regular and irregular bursts. All the type of bursts show exponential rise and sharp linear decay. This separates them from neutron stars and assures that the observed phenomenon is due to accretion into a black hole; thus once again confirming that the compact object is a black hole. (Yadav et al 1999)

7. Conclusion

The observations of GRS1915+105 for X-ray / IR correlation, subflares, X-ray variabilty, radio observations ; all help in a deeper understanding of similar other sources. Detailed analysis of the data obtained for GRS 1915+105 can provide greater insights into the characteristics and workings of central engines of relativistic jet systems.

REFERENCES

Marc Ribo, ASP Conference Series, 2003

Castro-Tirado, Alberto J.; Brandt, Soren; Lund, Niels; Lapshov, Igor; Sunyaev, Rashid A.;

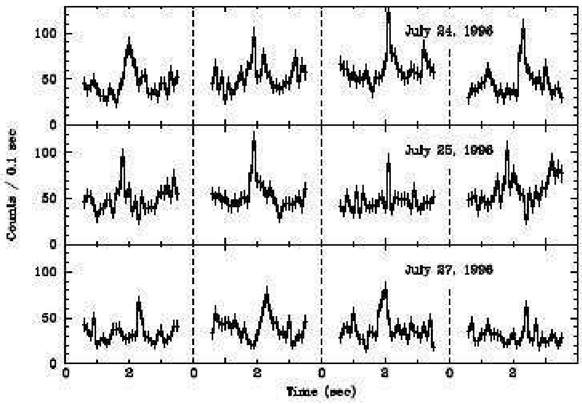


Fig. 14.— The flux variations on very small timescales seen in GRS 1915+105 with the IXAE (Paul et al, 1997).

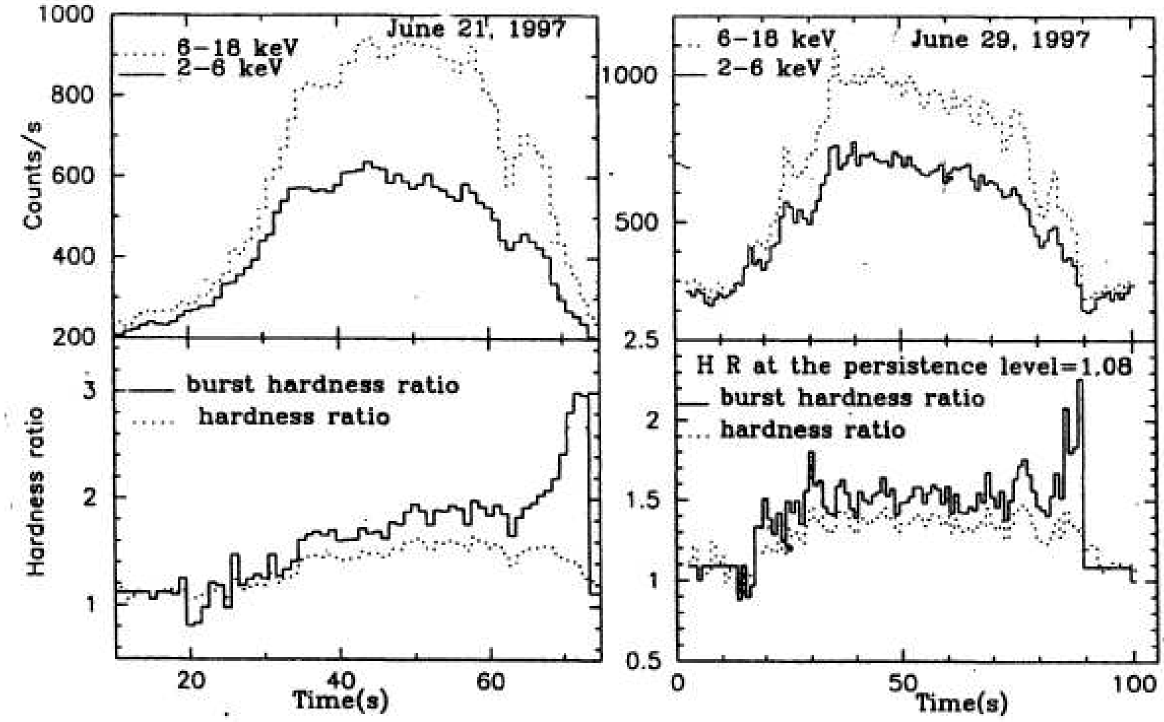


Fig. 15.— Fig. 15 Average burst profiles and hardness ratio for bursts observed on June 21 and 29, 1997 (Quasi-regular and irregular bursts)(Yadav et al, 1999).

Shlyapnikov, Aleksei A.; Guziy, Sergei; Pavlenko, Elena P (1994), The Astrophysical Journal Supplement Series, Vol 92

Mirabel and Rodriguez (1994), Nature,371

Greiner, J.; Cuby, J. G.; McCaughrean (2001), Nature,Vol 371

D.Rothstein, S.Eikenberry, and K.Matthews (2005), The Astrophysical Journal: 626

I.Mirabel L.Ridriguez and others, ASP Conference series, vol.144

V.Dhawan,I.Mirabel, L.Rodriguez,(2000), The Astrophysical Journal, vol.543

Eikenberry et al, 1998,1999,2000, The Astrophysical Journal

Ishwar - Chandra (Pune ,India)

Fender et al (1999, MNRAS) Vol 304

M.Muno, R.Ronald, E.Morgan,E.Waltman,V.Dhawan,R.Hjellming(2001), The Astrophysical Journal: 556

S.J.Newell, R.E. Spencer and F.H. Jowett, 1996, ASP(1996)

Y.Fuchs, J.Rodriguez, S.E. Shaw, P. Kretschmar, M. Ribo, S. Chaty, I.F. Mirabel, V. Dhawan,G.G. Pooley, I.Brown,R. Spencer,and D.C. Hannikainen 2004a, RevMexAP (Serie de conferenciod), 20

Y.Fuchs, J.Rodriguez, S.E. Shaw, P. Kretschmar, M. Ribo, S. Chaty, I.F. Mirabel, V. Dhawan,G.G. Pooley, I.Brown,R. Spencer,and D.C. Hannikainen, 2004b, Proceedings of 5th INTEGRAL workshop on INTEGRAL Universe (ESA SP-552)

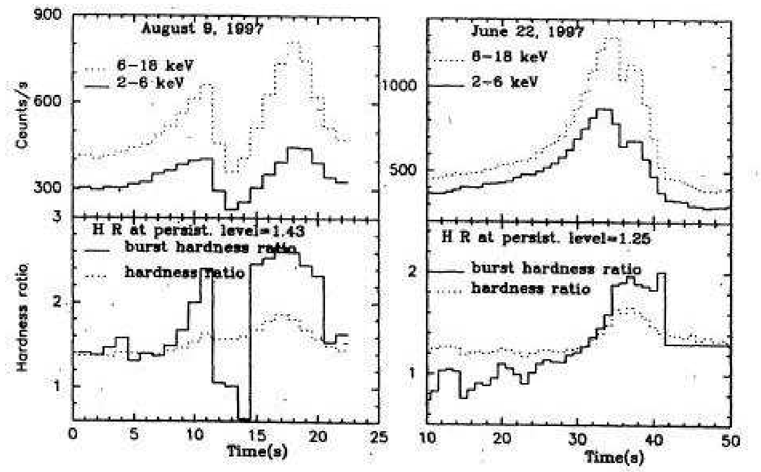
B.Paul,P. Agrawal, A.Rao,M.Vahia, J.Yadav, T.Marar, S.Seetha,K.Kasturirangan (1997), AA Vol 320

J.S.Yadav, P.C. Agrawal, B. Paul, A.R.Rao, M.N. Vahia, S. Seetha and K.Kasturirangan 1999 , Bull. Astr. Soc. India, 27

Y.Ueda, K.Yamaoka, C. Fernandez,V.Dhawan, S. Chaty, J.E. Grove and others,1999 , The Astrophysical Journal Vol.571

ww.ncra.tifr.res.in

ww.laserstars.org



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