The radio survey of INTEGRAL sources

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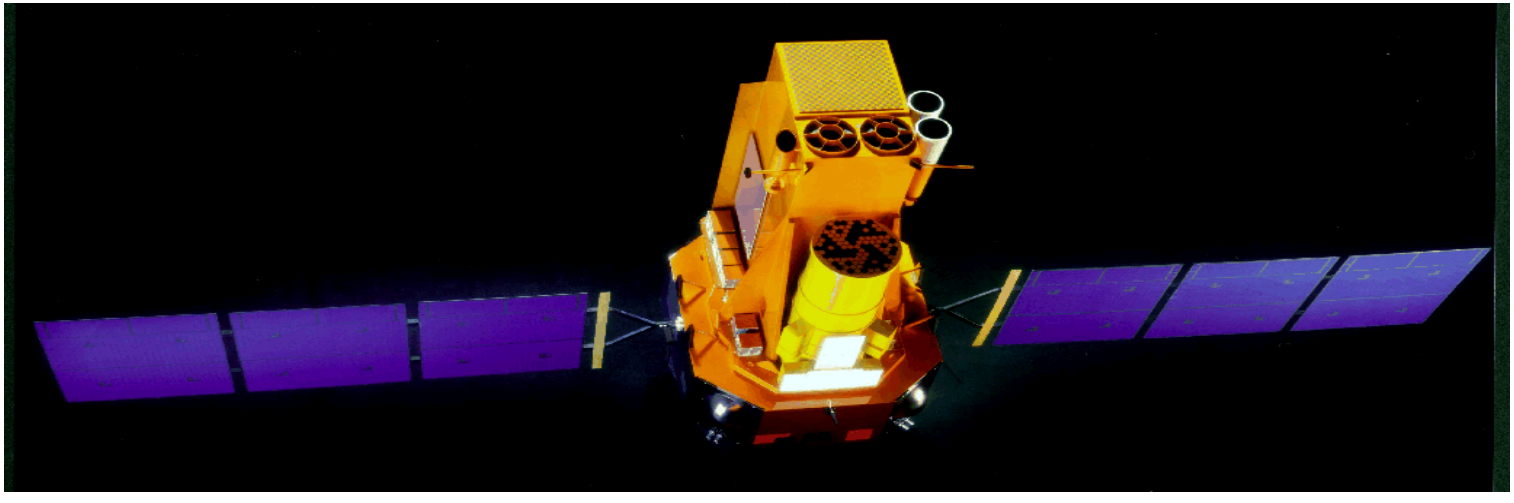
OUTLINE

1. The IBIS/ISGRI INTEGRAL sources
2. The GMRT radio survey
3. Discussions

International Gamma Ray Laboratory: INTEGRAL

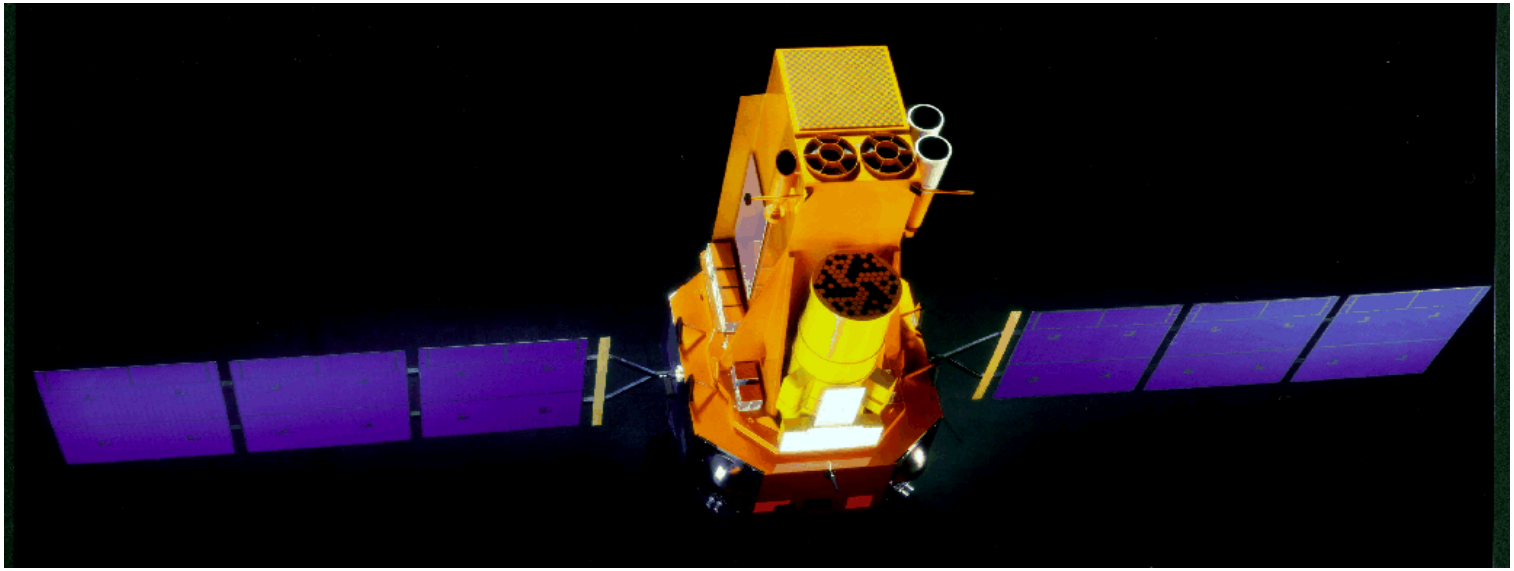


IMAGING AND SPECTROSCOPY AT 20 keV – 10 MeV
PLUS ON BOARD X-RAY AND OPTICAL IMAGING

The first IBIS/ISGRI hard X-ray galactic plane survey catalog
(Bird et al. 2004, ApJ 607, L33)

THE IBIS/ISGRI INTEGRAL SOURCES

The **INTEGRAL** satellite: International Gamma-ray Laboratory.
Launched in 17 October 2002.

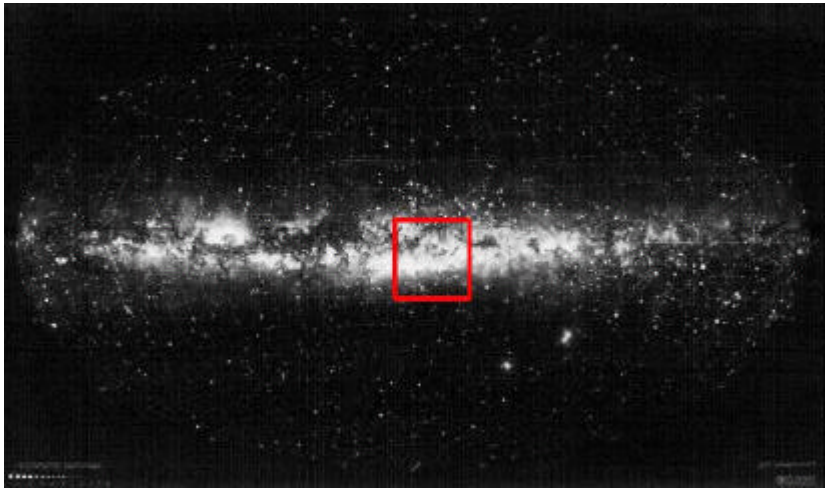


IBIS/ISGRI. From 20 keV to ~1 MeV. Astrometric accuracy of 2 arcminutes at 90% confidence level (1.6σ), that allows to **search for counterparts**.
INTEGRAL also carries the spectrometer SPI, the X-ray imager JEM-X and the Optical Monitoring Camera.

The **INTEGRAL imager IBIS/ISGRI** has detected 45 sources in cumulative observations within the mission Core Programme and pointed observations. **Bird et al. (2004)** .

Few of the known characteristics of the INTEGRAL sources are :

- Crowded in the galactic plane and mainly near the galactic center
- Hard X-ray emitters.
- Few are highly obscured sources
- Most are galactic
- Few are extragalactic



There is a **continuously updated web page** at:
http://isdc.unige.ch/~rodrigue/html/igrsources.html (J. Rodriguez)

Giant Meter-wave Radio Telescope: GMRT

GMRT consists of 30 antennas, each of 45 meter diameter, spread over 25 km, at Khodad, 90 km off Pune, India

It is the world's largest radio telescope at metre-waves.

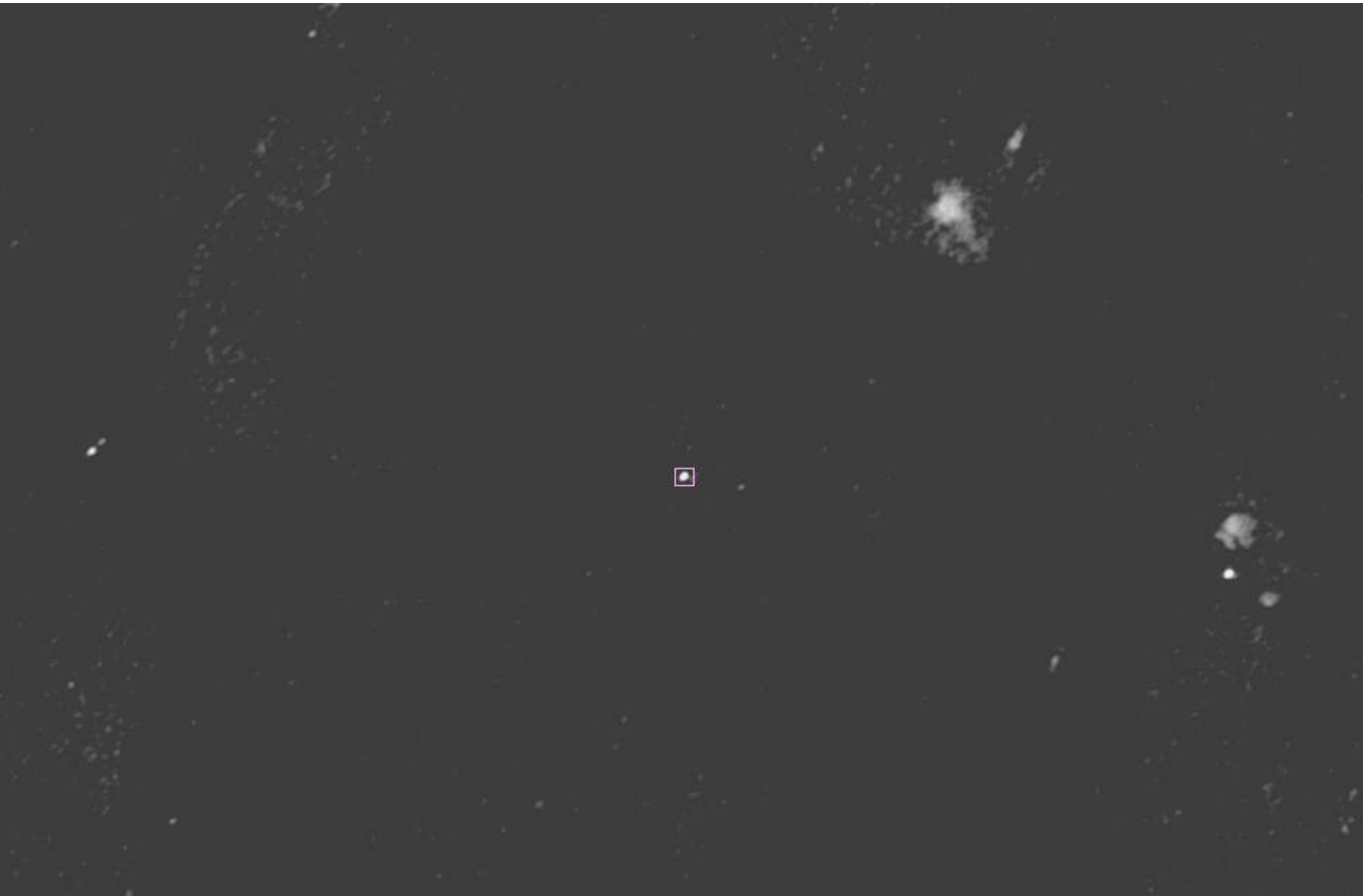
Novel antenna concept (SMART)

Frequency of operation 150 to 1450 MHz

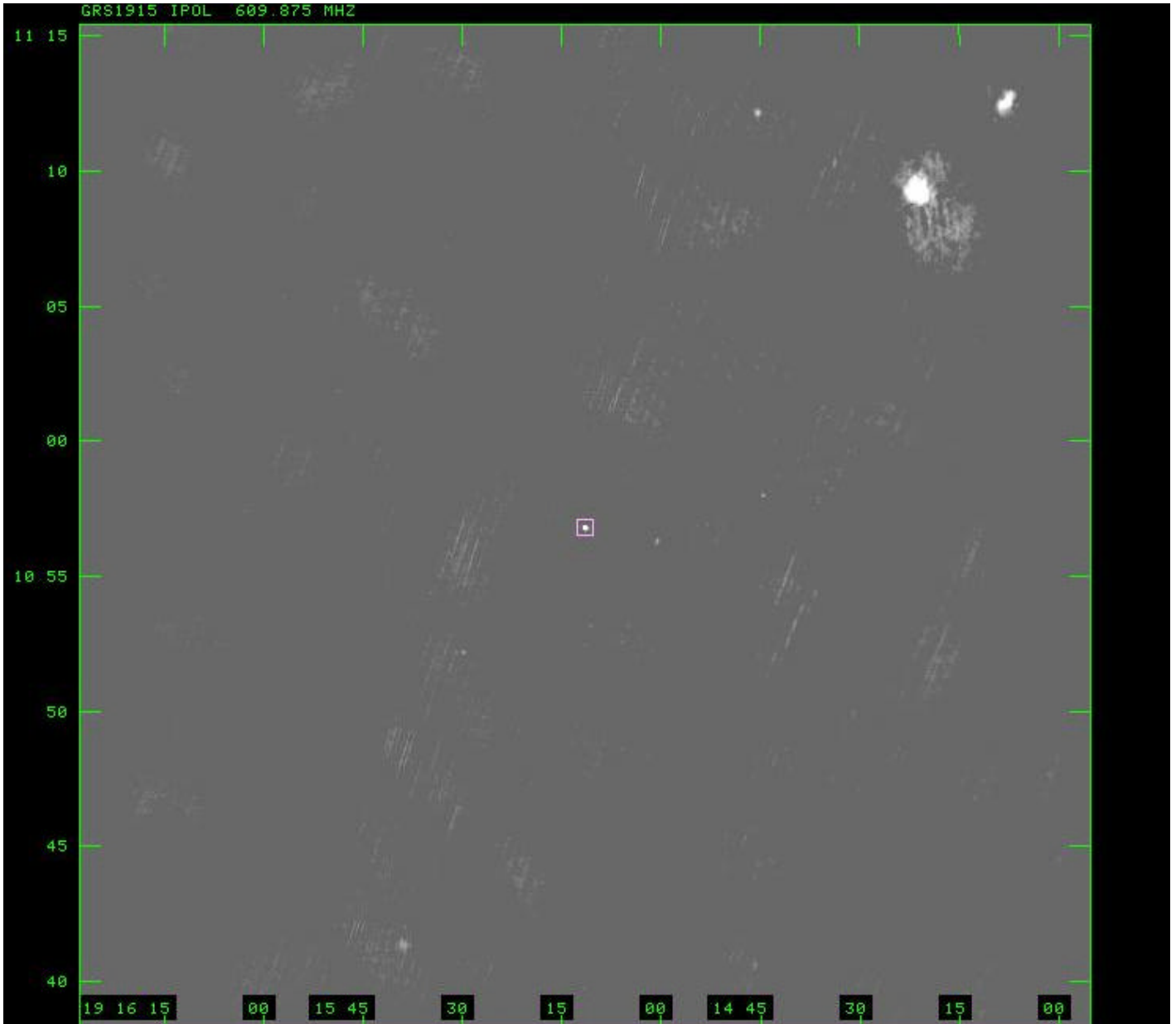
Tata Institute of Fundamental Research

URL: http://www.ncra.tifr.res.in

GRS1915+105 at 235 MHz – central part



GRS1915+105 at 610 MHz (June 22, 2003)

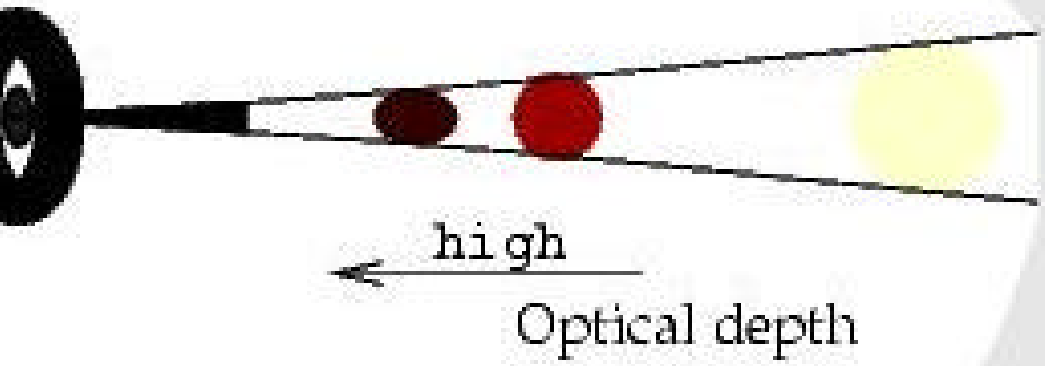


The microquasar GRS1915+105 shows more emission at low radio frequencies than expected from our understanding from high frequency observations

We suggest optically thin, diffuse lobes at the end of the jet which emits at meter-wavelengths.

Is this unique to GRS1915+105?

Jet ends as lobe?



Reservoir of old
Electrons, still radiating
at meterwavelengths

The Main Objectives of the Low frequency Radio survey of INTEGRAL sources

1. To explore the multi-wavelength nature
2. The look for the radio counterparts
3. To provide the best constraint on the position of the counterparts
4. To group the sources based on their radio morphology
5. To look for radio and X-ray correlation

Why Low Frequency?

Does the spectra turn over at low frequency?

Is there non-thermal extended emission?

What happens to the electrons which were emitting at high frequencies?

Advantages of Low Frequency studies:

1. *Synchrotron decay time scales are longer.*
2. *More electrons at lower energies*

GMRT Observations of the INTEGRAL sources

Low frequency (1280, 610 and 235 MHz) snapshot (30 mins) observations.

Our results suggests that :

- 25 out of 40 INTEGRAL sources observed have radio counterparts
- Mostly weak radio sources.
- Based on the radio morphology, X-ray variability and (tentative) multi-wavelength identification we categorize the INTEGRAL sources with radio counterparts into (a) point and (b) extended sources.
- The point sources are mostly galactic in origin.

- The extended sources can be further classified into:
  (a) diffused galactic regions and
  (b) extragalactic sources.

- Out of the 25 INTEGRAL sources with low frequency GMRT radio counterparts :
  (a) 10 are compact point sources and mostly galactic in origin
  (b) 4 are diffused galactic regions
  (c) 11 are extended sources and extragalactic in origin

The selection method for the radio counterparts:

We have searched the counterparts in the other energy band using the survey mentioned below:

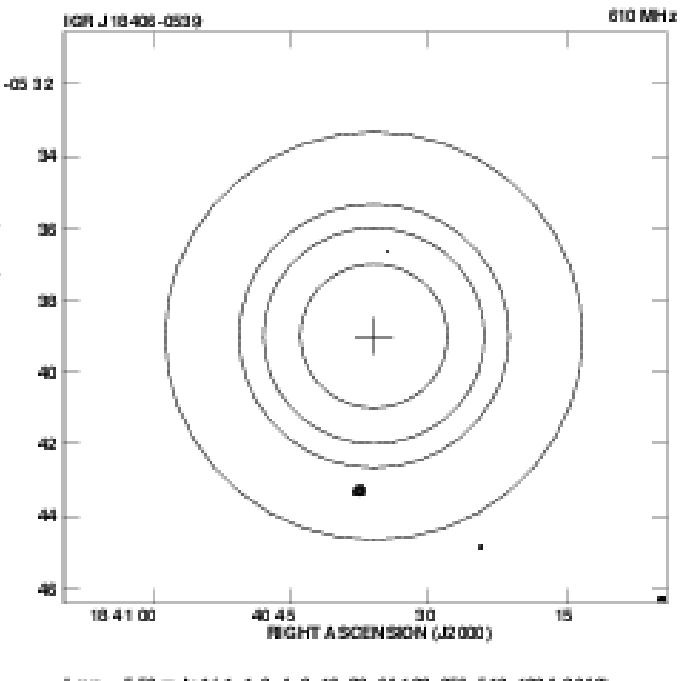
NED : archival data.
NVSS : radio catalog at 1.4 GHz.
2MASS :archival data
DSS : archival data

We assumed reasonable selection criteria for sources within the INTEGRAL position uncertainty circle of 3 sigma in the above surveys and ended up with a sample containing following no of sources corresponding to each survey:

- NVSS : ~ 2 sources within 10’ area at 1.4 GHz (Condon et al. 1998)
- DSS : ~1. 2 sources within 10’ area (the archival data) and consistent with radio position
- 2MASS : ~ 6 sources within 10’ area (the archival data) and consistent with radio position
- GMRT : ~ 2 sources within 10’ area at 1.28 GHz (GMRT survey)
  ~ 5 sources within 10’ area at 0.61 GHz (GMRT survey)

The result obtained from our radio observations and the information available at other wavebands is discussed further:

POINT SOURCE COUNTERPARTS:



gure 1. Radio image of IGRJ18406-0539 at 0.61 Hz

The cross sign and the circles indicates the INTEGRAL position and position uncertainity respectively (1 and 3 sigma).

The source IGR J06074+2205 is an extragalactic AGN.

The sources IGR J17091-3624, IGR J17303-0601, IGR J17464-3213, IGR J18027-1455 and IGR J18539+0727 qualify as MICRO QUASAR candidates

Table 1. Possible Radio counterparts of INTEGRAL sources observed with GMRT at 0.61 and 1.28 GHz.

Source	Freq. (GHz)	S(peak) (mJy)	σ $\frac{mJy}{b}$	Pos. off*
IGR J06074+2205	1.28	36.00±1.12	0.64	1.29
IGR J17091−3624	1.28	1.10±0.16	0.19	0.99
IGR J17303−0601	0.61	17.28±2.38	2.21	1.94
IGR J17456−2901	0.61	23.11±1.22	1.53	0.56
IGR J17460−3047	0.61	2.50±0.42	0.46	0.07
IGR J17464−3213	0.61	2.75±0.52	0.50	1.03
IGR J17475−2822	0.61	12.50±1.12	1.27	1.02
IGR J18027−1455	0.61	10.72±2.25	2.32	4.18
IGR J18406−0539	0.61	28.03±0.76	0.76	4.31
IGR J18539+0727	1.28	6.73±0.14	0.16	3.64

EXTENDED COUNTERPARTS (A):

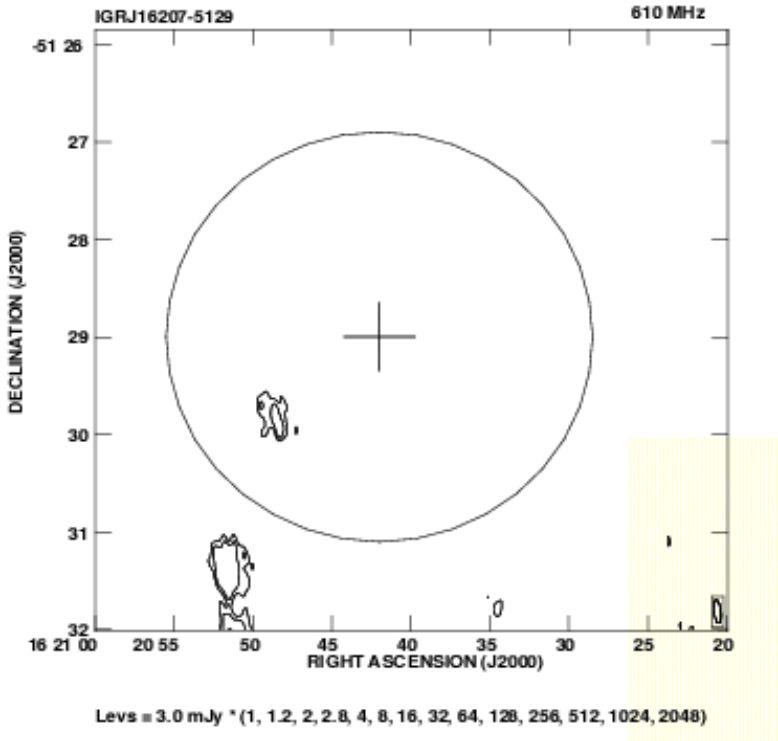


Figure 3. Radio image of IGRJ16207-5129 at 0.61 GHz

The cross sign and the circles indicates the INTEGRAL position and position uncertainity respectively (1 sigma).

The source IGR J16479-4514 is a HII region.

The source IGR J21247+5058 is an extragalactic radio galaxy

Rest other sources in the list qualify as extragalactic Radio sources

Table 3. Possible Radio counterparts of INTEGRAL sources observed with GMRT at 0.61 and 1.28 GHz

Source	Freq. (GHz)	S(Total) (mJy)	σ $\frac{mJy}{b}$	Pos. off*
IGR J15479−4529	1.28	22.2	0.50	3.98′
IGR J16207−5129	0.61	60.50	0.78	1.33′
IGR J16316−4028	1.28	11.60	0.19	2.09′
IGR J16479−4514	1.28	2445.45	1.24	3.30′
IGR J16558−5203	0.61	27.24	0.78	0.69′
IGR J17195−4100	0.61	33.44	0.56	0.98′
IGR J17200−3116	0.61	33.03	0.51	0.55′
IGR J17254−3257	0.61	359.65	0.43	3.12′
IGR J17285−2922	0.61	74.88	0.59	0.96′
IGR J18450−0435	0.61	207.94	0.76	5.90′
IGR J21247+5058 Radio Galaxy	0.61	180±1.59 core flux	1.61	0.57′

EXTENDED COUNTERPARTS (B):

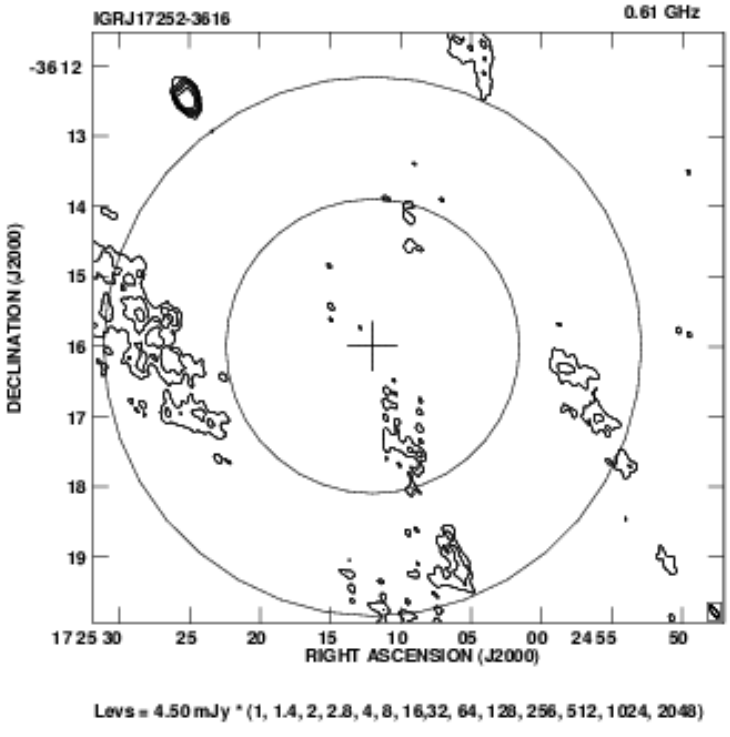


Figure 2. Radio image of IGR J17252-3616 at 0.61 GHz

The cross sign and the circles indicates the INTEGRAL position and position uncertainity respectively (1 and 3 sigma).

The source IGR J16167-4957 is a HII region (?).

Rest other sources in the list qualify as galactic diffused region

Table 2. Possible Radio counterparts of INTEGRAL sources observed with GMRT at 0.61 GHz

Source	Freq (GHz)	S(Total) (mJy)	σ $\frac{mJy}{b}$	Pos. off*
IGR J16167−4957	0.61	725	2.90	0.12′
IGR J16195−4945	0.61	256.4	0.84	0.84′
IGR J16393−4643	0.61	79.25	1.63	2.58′
IGR J17252−3616	0.61	36.74	1.88	0.82′

The INTEGRAL sources with no radio counterparts:

Table 4. No radio counterparts for the following INTEGRAL sources detected with GMRT at 0.61 and 1.28 GHz

Source	Freq. (GHz)	S(peak) (mJy)
IGR J00370+6122	0.61	<7.00
IGR J01363+6610	0.61	<7.00
IGR J16318−4848	0.61	<6.50
IGR J16320−4751	0.61	<4.00
IGR J16358−4726	0.61	<7.50
IGR J16418−4532	1.28	<1.00
IGR J17391−3021	1.28	<1.04
IGR J17488−3253	0.61	<2.10
IGR J17544−2619	0.61	<7.35
IGR J17579−2201	0.61	<7.90
IGR J18027−2016	0.61	<7.00
IGR J18325−0756	0.61	<3.00
IGR J18483−0311	0.61	<4.24
IGR J18490−0000	0.61	<3.50
IGR J19140+0951	0.61	<5.50

Work in progress:

- Analysis of recent **GMRT** observations at 610 and 235 MHz.
- Search for **radio variability** with the orbital period (observations done with the GMRT in Jan 2005).
- Search for **X-ray variability** with the orbital period (International collaboration).
- Dual frequency GMRT observations at 235 and 610 MHz , to search for **jets at arc second scales** for the newly discovered INTEGRAL sources.
- **Observations** of **V0332+53** are in progress (Jan 11, 1.29 GHz, Jan 18, 1.4 GHz, weekly observations are scheduled for the next month)
- Recent selections for NTT (SOFI, JHK) + VLA

CONCLUSION:

1. We have **discovered the low frequency radio counterparts** after careful examination of modern archive databases and follow-up interferometric radio observations. 5 new microquasars may have been identified. Similar studies may reveal a previously unnoticed population of ***silent* microquasars**. The microquasar phenomenon **may not be as rare as it seems**.

2. We have identified 2 HII regions also associated with the INTEGRAL sources.

3. We have proposed an association between 25 INTEGRAL sources and their radio counterparts. Rest 15 INTEGRAL sources have no low frequency radio counterpart (or were quiet at the time of the observations!)

4. We have much more (Cyg X-1, Cyg X-3, GRS1915, SS433, GX339-4,….)

5. Want to have your favorite source(s) observed with GMRT: let me know!


THANK YOU!