Galactic plane observations with GMRT

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Introduction:

- Sources seen in the Galactic plane mimics to what we see in a Galaxy.
- So, research work towards the Galactic plane involves multiple types of science cases and objects.
- Some of these are: (i) studies of star forming regions (multiband studies typically involving UV, IR and Radio), (ii) study of special types of stars (e.g., magnetically dominated for cyclotron emission, or for finding hot Jupiters), (iii) studies of HII regions, (both continuum and through RRL emission),

Introduction...

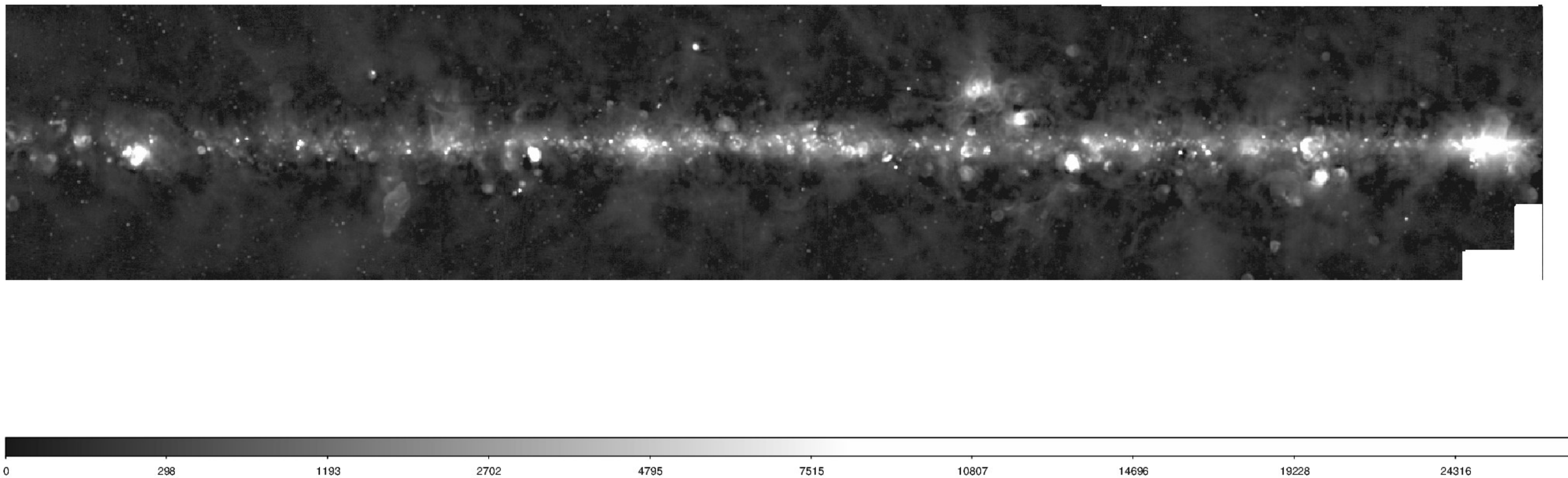
Stellar remnants, either as Neutron stars (pulsars), or supernova remnants.

- Pulsars dissipate their rotational energy surrounding through relativistic wind. In some cases, it generates pulsar wind nebula (PWN).
- Beyond stellar regions, studies done on the general ISM (e.g., WIM through scatter broadening or free-free absorption).
- Studies are also made of variable or transient compact objects (stellar mass black-holes could cause some of them).

Introduction: Spectral lines

- Spectral lines from the Galactic plane also provide important information in Radio.
- HI line observations help in determining distance; provide a measure of turbulence; studying the WNM and CNM.
- Radio Recombination Lines (RRL) [Bohr transition from high `n’ to `n-1’] from ionised gas provide information on the temperature and density of the emitting region.
- Radio emission could be combination of thermal and non-thermal emission. Multiband observations could separate them.

Various studies

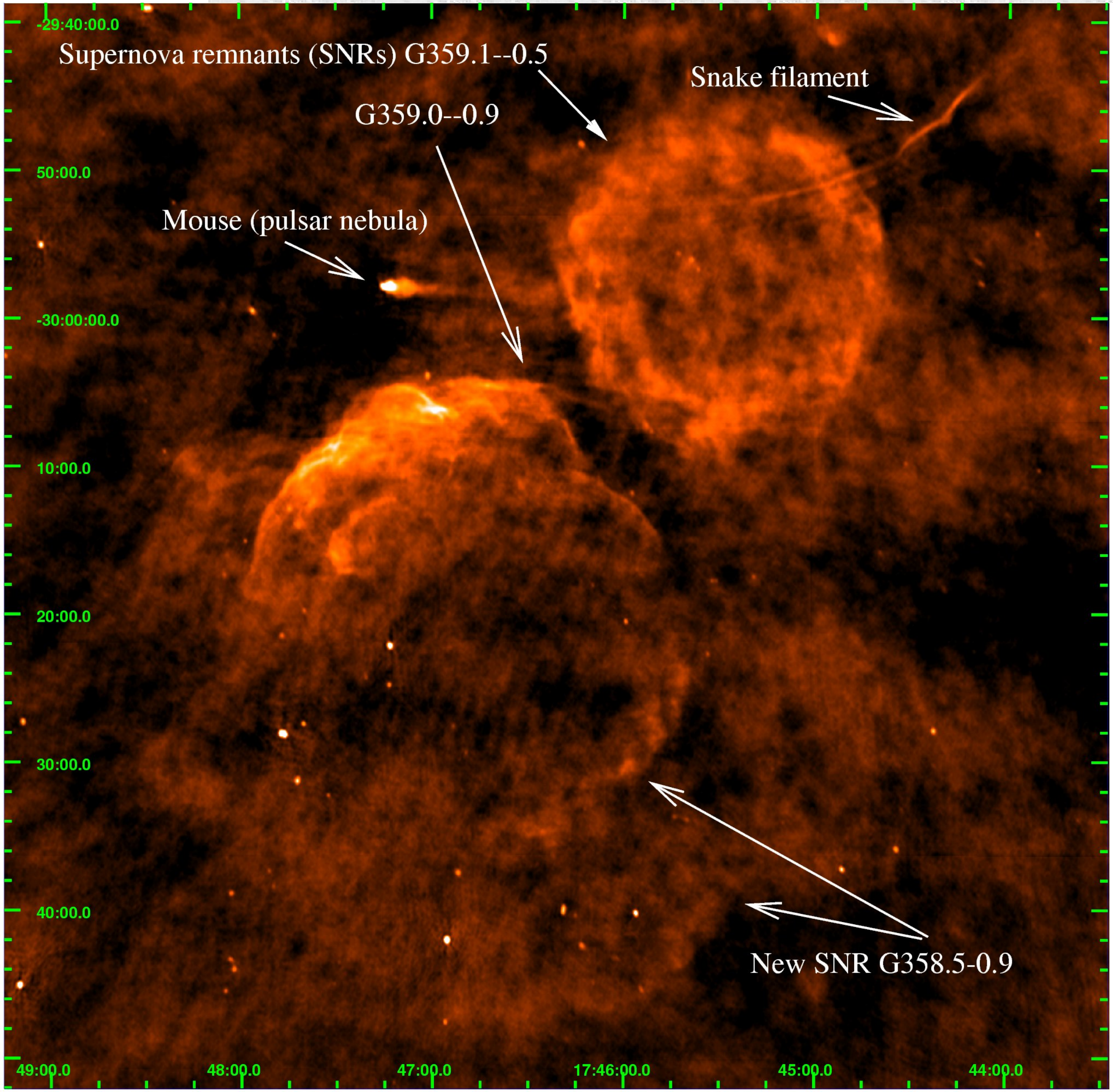


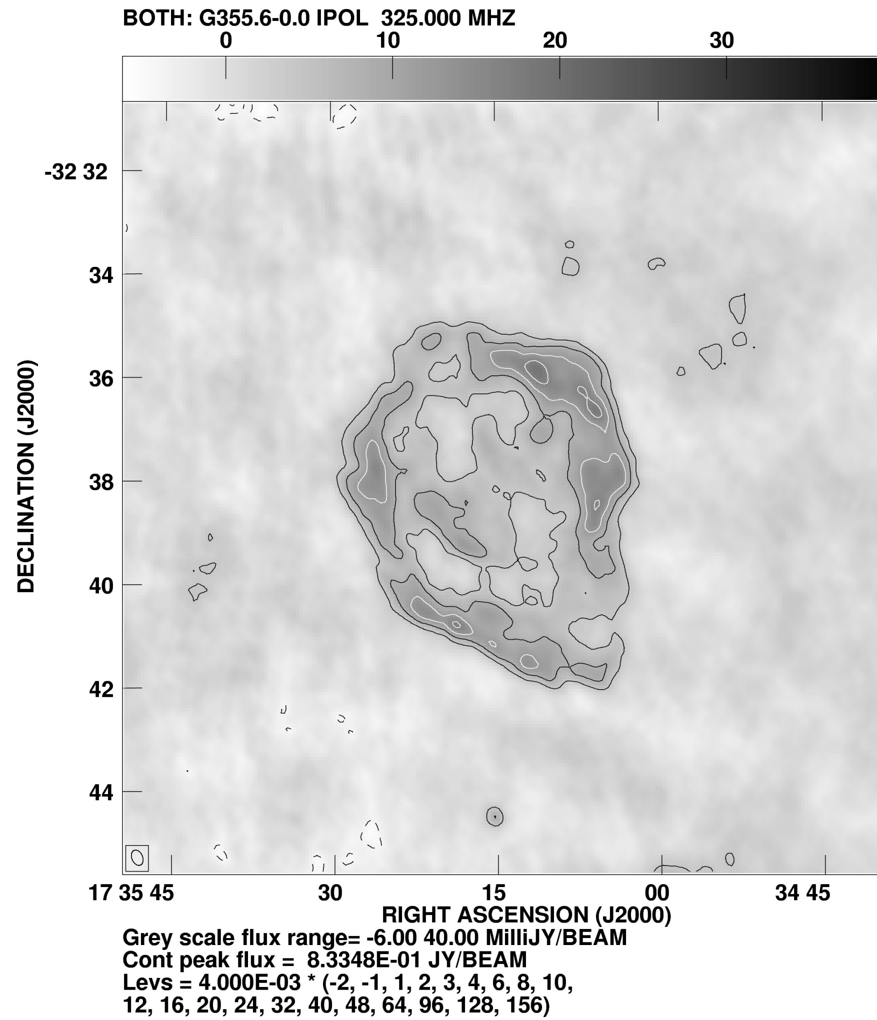
A view of the inner Galactic plane (l=0-25 deg) at 11 cm (Bonn single dish).

Introduction...:

- We donot know what fraction of pulsars have PWNs.
- A large fraction of pulsars and supernova remnants (SNRs) in our Galaxy are still unaccounted.
- SNRs discovered ~294 (Green 2014). Expected >1000 (Tammann et al. 1994).
- Surveys biased against small and large SNRs.
- Small SNRs are missed due to limited instrumental resolution. Large SNRs are missed due to confusion in Galactic plane.

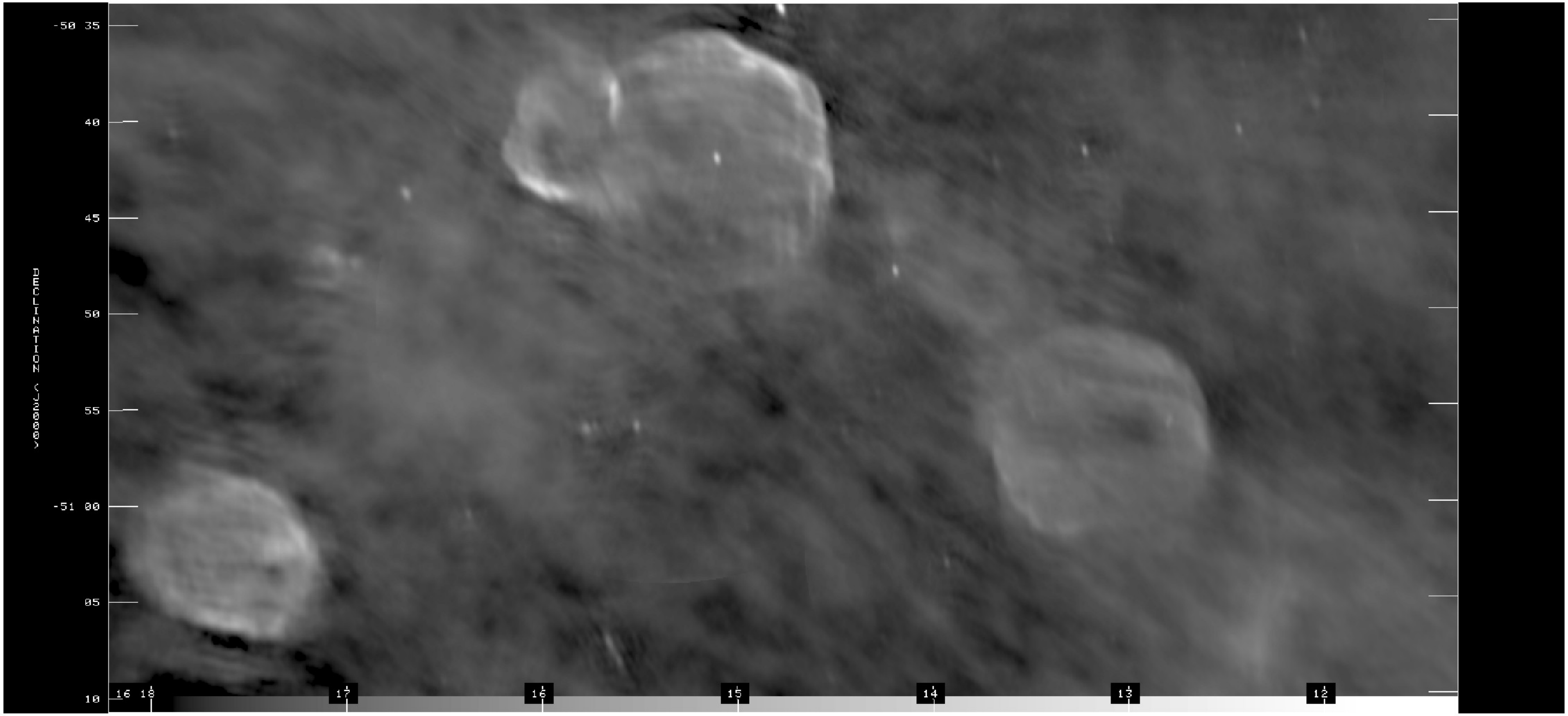
Study of supernova remnants in the Galaxy.





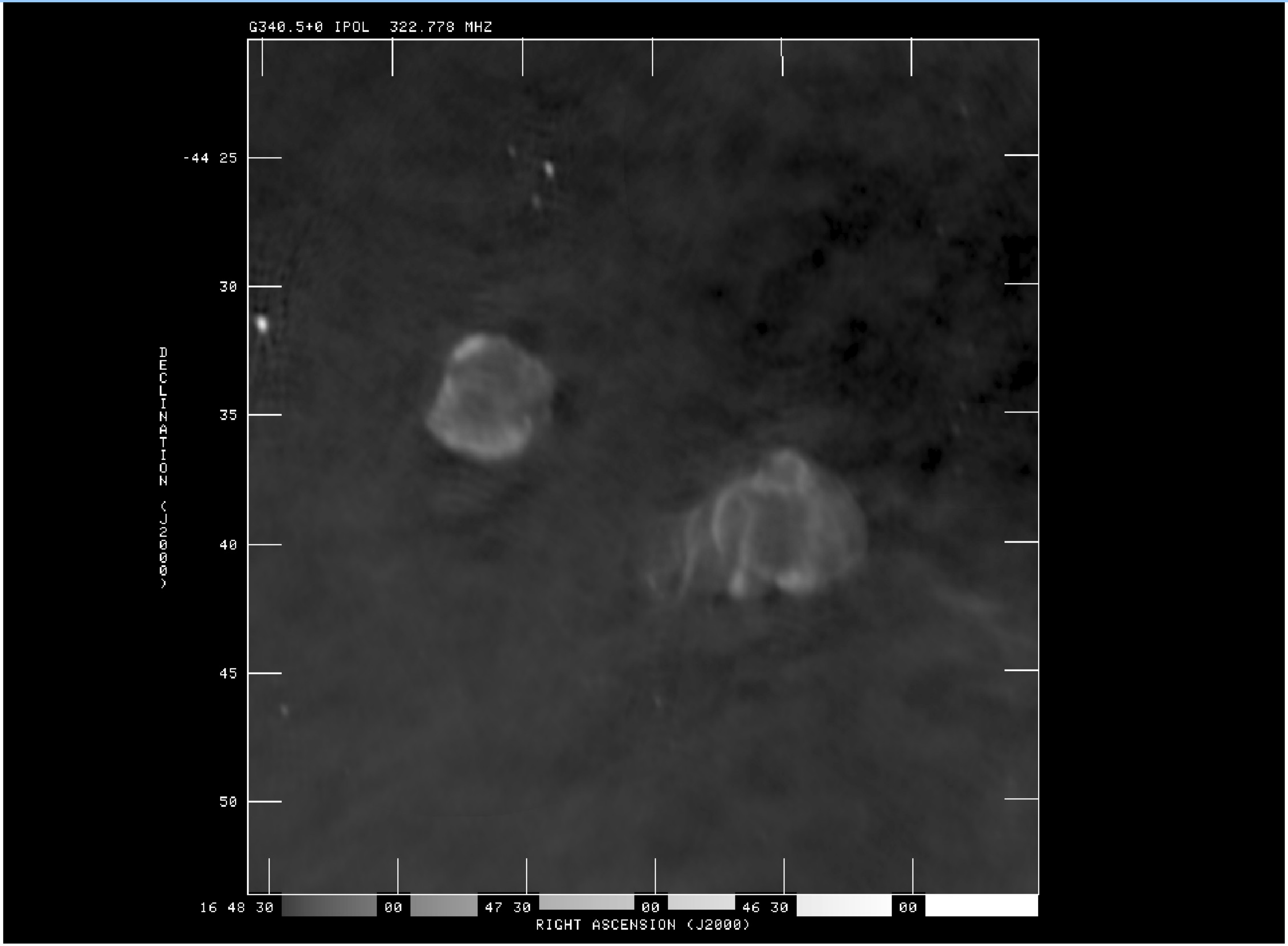
330 MHz image of the field G358.8--01 located about 1 degree south of the Galactic Centre. The resolution is ~14" and the rms noise ~1 mJy/beam. This is the highest sensitivity image of the region and is made from GMRT data. The map is used to confirm a faint barrel shaped SNR shown near the bottom.

Obs. of SNRs with GMRT: Results



The field G332.2+0.4 showing 3 known SNRs.

Obs. of SNRs: Results ...

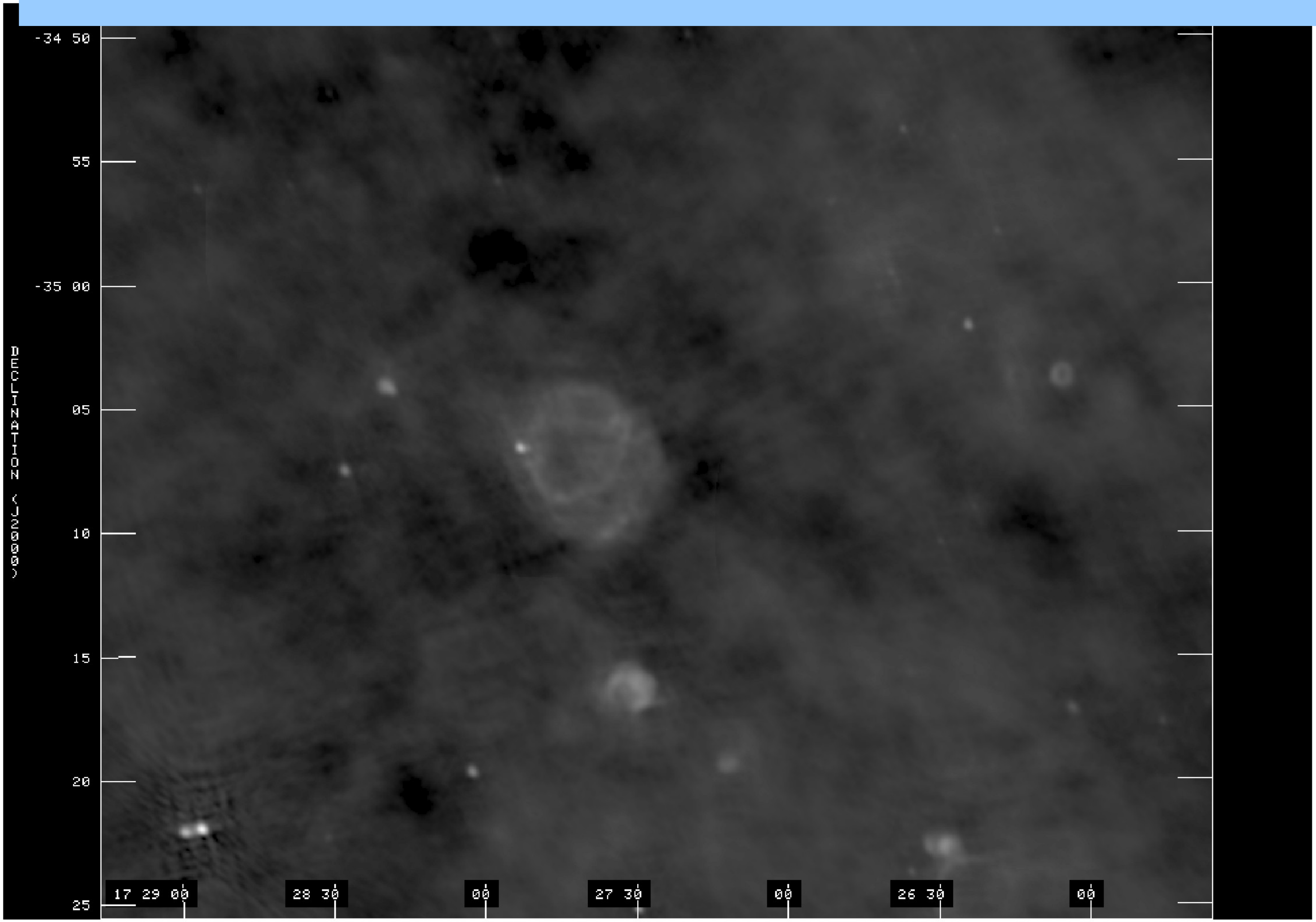


The field G340.5+0.7 showing 2 known SNRs.

Obs. of SNRs: Results ...

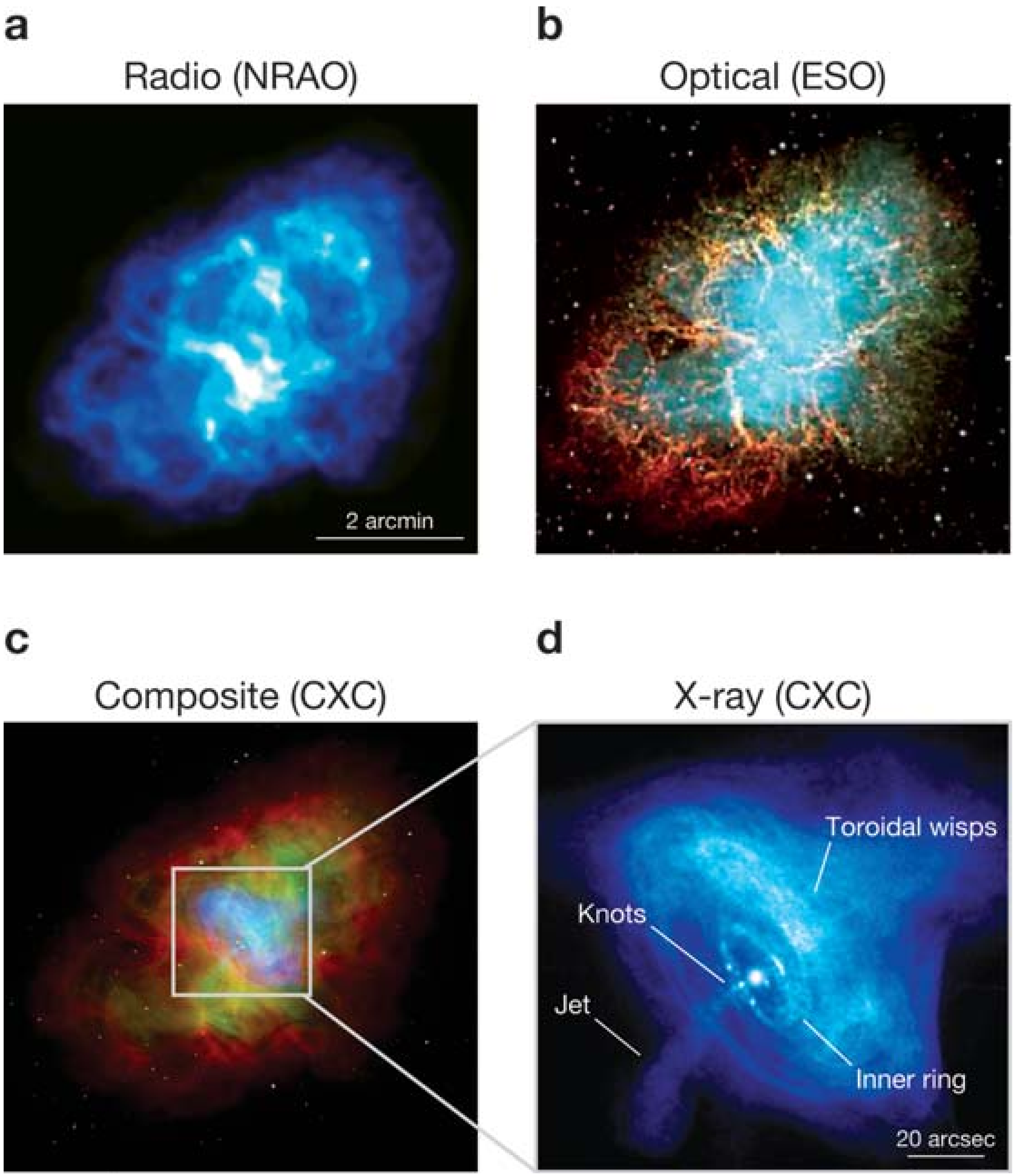
A known SNR G346.6--0.2.

Obs. of SNRs: Results ...



SNR G352.7—0.1 (Double ring).

Pulsar Wind nebula (PWN)



Images of the Crab nebula (one of the best studied PWN) at different wave bands (Gaensler & Slane 2006).

GMRT observation of X-ray source CXOU J163802-471358

Density of warm ionised medium near the Galactic centre:

- Interstellar medium (ISM) has several components.
- Warm & cold neutral medium + warm and hot ionised component.
- Galactic centre (GC) region has much higher luminosity, velocity dispersion and a dense ISM.
- Scattering size of GC masers and Sgr A*

  ~0.1" to 1" at 1 GHz.

Model of WIM (Cordes 2004)

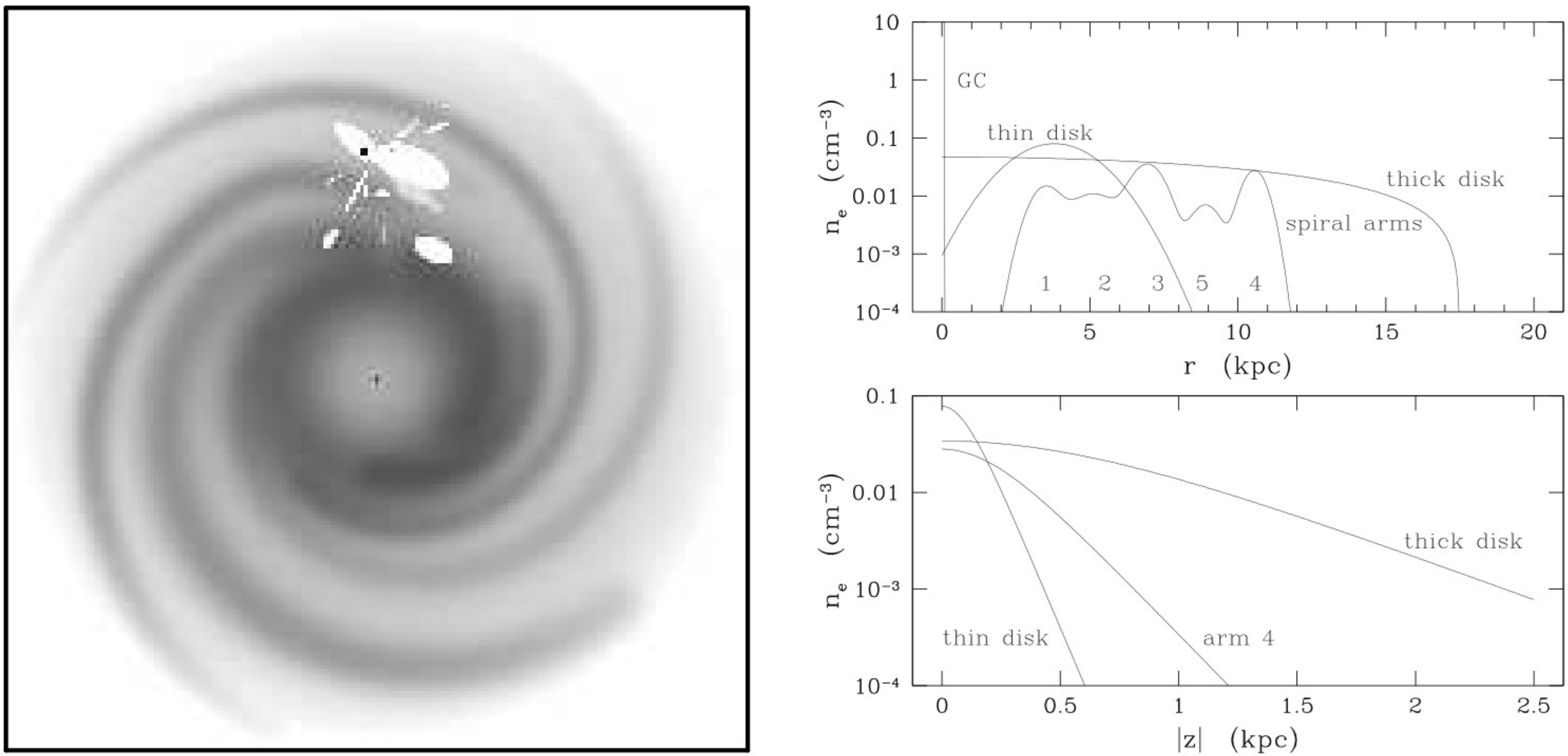


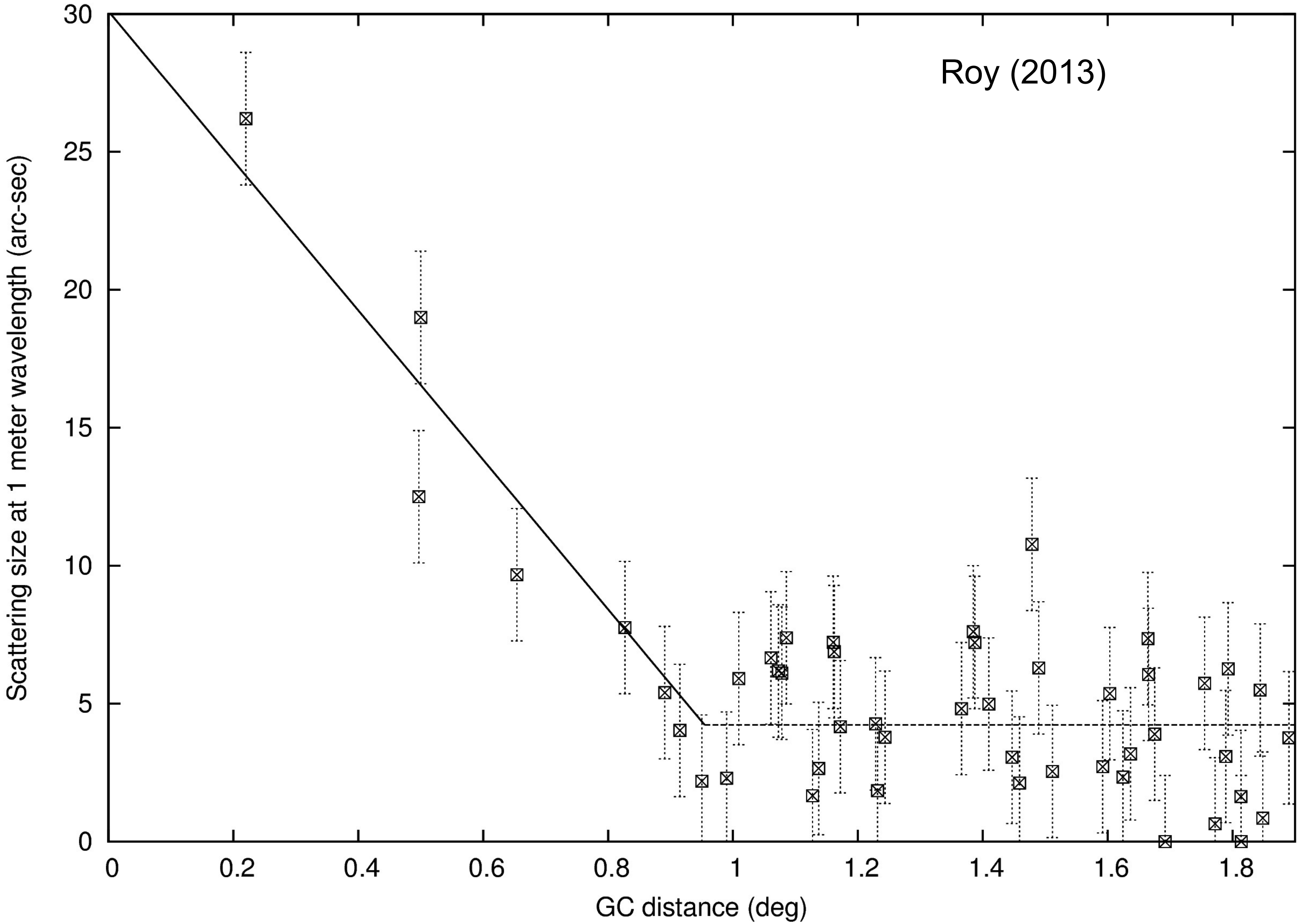
Figure 1. Left: Gray-scale plot of $\log n_\mathrm{e}$ in a frame that is 20 kpc x 20 kpc. The Sun is within the white patches that represent regions of low electron density in the local ISM. Right: cross sections through various components of the model showing characteristic Galactocentric and z scales.

Introduction...

- Lazio & Cordes (1998) constrain the Hyperstrong scattering regime within 0.5 deg from the GC.
- Predicts a screen distance of ~130 pc from GC.
- To explain scattering size of GC sources, electron density ~10 cm^{-3}.
- Scattering diameter of ~100" for extragalactic sources (EG) at 1 GHz.
- Apparent scattering diameter depends on GC to Screen distance.

$\Theta s_{(EG)} / \Theta s_{(GC)} = D/d$ (D— GC distance, d-- GC to screen distance).

Scattering size of EG sources at 1m



GC scattering and missing EG sources

- Sixty-two compact (likely EG) sources seen at 0.154 GHz (S>100 mJy) with GMRT. Consistent with EG source count (checked range of spec. index and if they could be Gal. nonthermal sources).

- Checked for missing sources in the hyperstrong scattering region (0.5 deg of GC) in LC2008 at 1.4 GHz w.r.t. GPSR catalog at 4.8 GHz.
- Expected 5 EG sources above the median flux density of sample at 1.4 GHz.
- Detected 7 likely EG sources out of 10 expected.

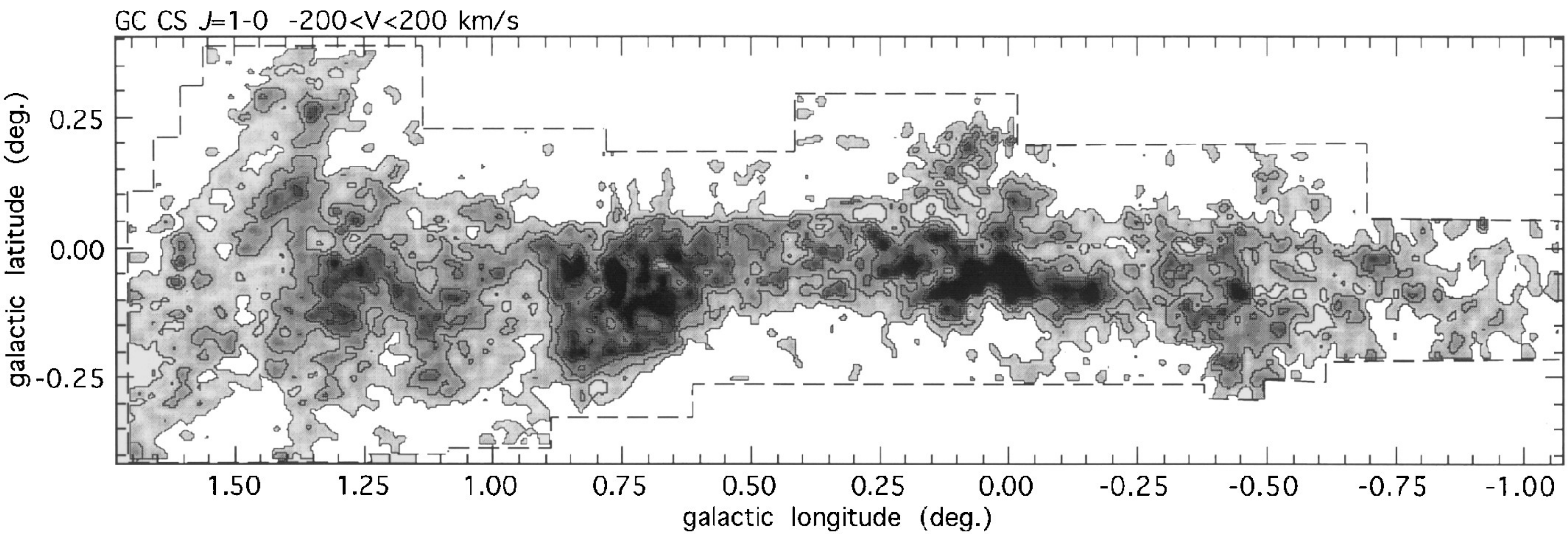
Free-free absorption of GC sources

- Higher values (>0.5) of τ seen only within 0.6 deg from GC (7 out of 8 extended sources).
- τ varies widely towards the inner GC sources.
- Angular size of absorption ~5-10' (~20 pc).
- WIM clumply with typical electron density ~10.cm^{-3}.

GC scattering and dense molecular clouds

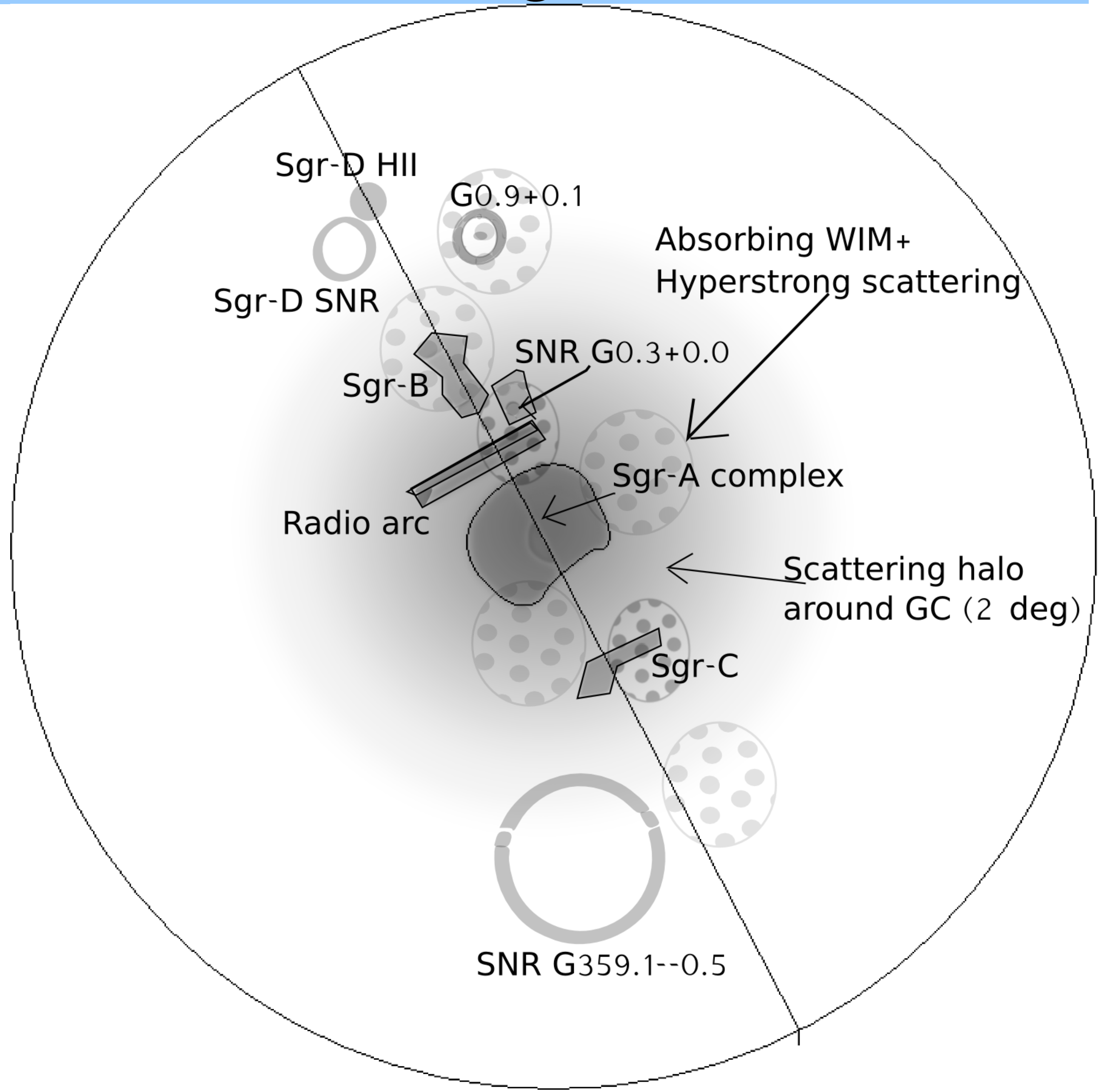
- Ionised interfaces of dense molecular clouds cause heavy scattering in GC (Lazio 1998).
- CS J=2-1 transition vel. int. map (Tsuboi 1999).
- Narrow distribution in –0°.2<b<0°.1 near GC.

No. 1, 1999 MOLECULAR CLOUDS IN GALACTIC CENTER REGION. I.



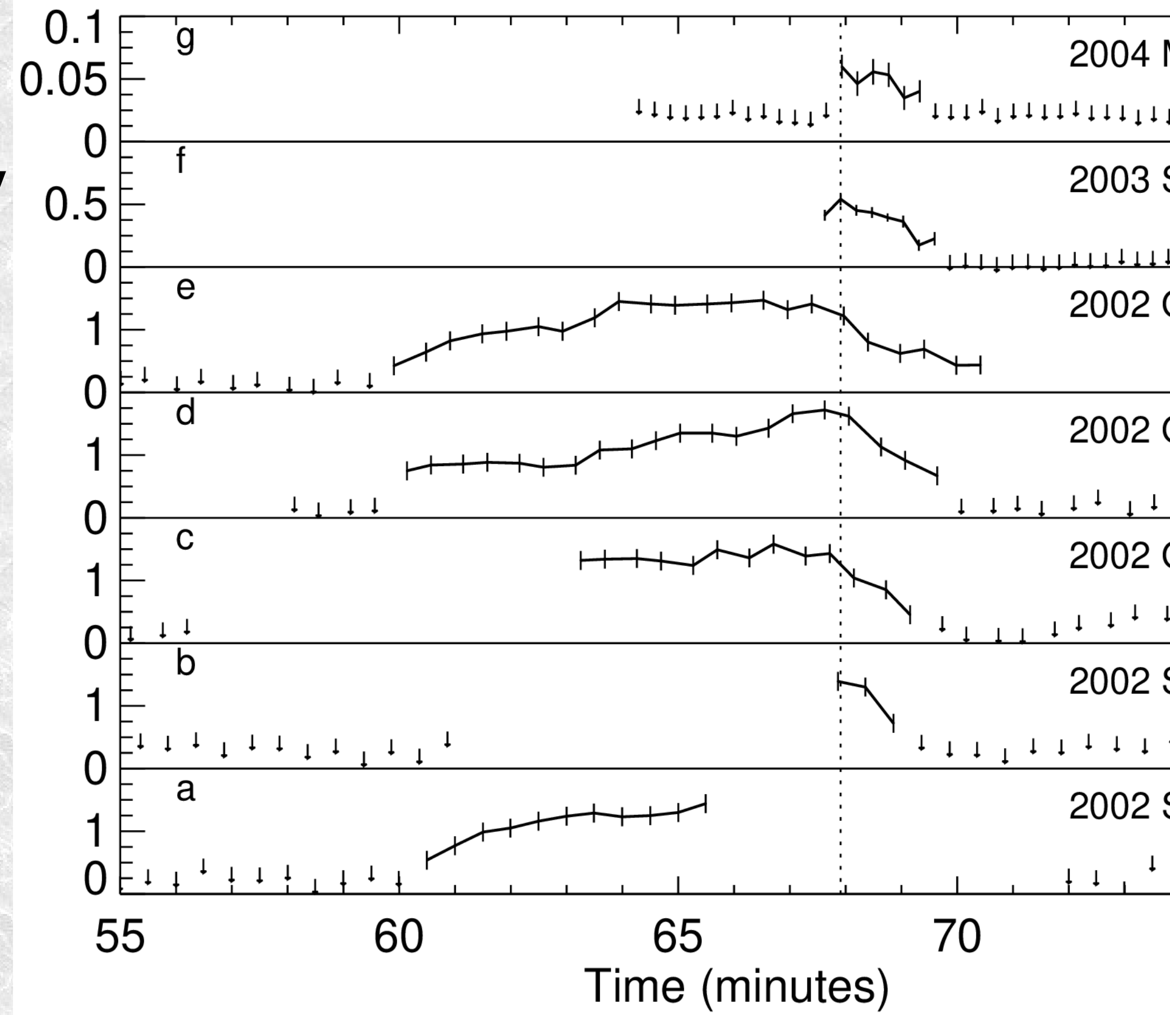
GC scattering

- Hyperstrong scattering region either asymmetric in l, b or located far away from GC (Bower 2013).
- New weak scattering region within 1 deg of GC (n_e ~1 cm^{-3}).



GMRT observations of GCRT J1745-3009

- GCRT bursting transient radio source discovered by Hyman et al. at 330 MHz.
- Brightness temp $>10^{15}$ K.
  - Likely to be coherent emission.
  - On 10 minutes, after each 77 minutes.



GCRT...

Cyclotron emission or pulsar emission known to be coherent.

77 min too high for a typical pulsar.

Nulling pulsar (e.g., B1931+24 off ~90% time, quasi-periodic bursts) remains possible.

GMRT observations in 2003 to detect transients resulting in its re-detection.

Serendipitous detection from 2004 SNR data.

GCRT...

Peak flux densities.

1→ 0.4→ 0.06 Jy.

2002→2003 →2004.

75 → 25 → 6 mJy.beam^{-1} rms.

Unresolved with beam size ~15''.

2004 → new state ?

Very steep spectral index of -13±3 (Hyman et al. 2007).

GCRT 2004...2003

Very steep spectrum→ probably near cutoff freq. of line emission.

Is it cyclotron maser ?

Reanalysed 2003 GMRT data.

~3 improvement in rms noise.

Detection of circular polarisation at ~tens of percent level.

(Roy et al. 2010)

GCRT...

Cyclotron or plasma emission produces high circular polarisation.

$$B = \frac{(2\pi\nu mc)}{e}$$

Required magnetic field ≤120 Gauss.

Neutron star based models ruled out.

Stars within only ~few tens of pcs have detectable cyclotron emission.

Lack of optical counterpart suggest brown dwarf or extrasolar planet.

Calibration issues:

- When observing part of the sky where sky temperature (T_ant) is a significant fraction of the total system temperature (T_sys), variation of T_ant between target source and calibrator cause a source dependent change in total power.
- It could change the correlation efficiency of the digital correlator and could cause saturation of the system when system power rises beyond the linear regime of operation.
- Users should get proper control on the total output power from the antennas.

Calibration Issues...

- For a radio telescope to work in the linear range of operation, the output power must lie within certain ranges.
- An automatic level control (ALC) is employed to provide negative feedback to the amplifier gains when output power increases.
- The new analogue backend system of the GMRT has no automatic level control. This is thought to improve dynamic range.

Introduction...

- Amplitude of unnormalised cross correlation measured by a correlator is related to visibility amplitude through a scaling factor called `gain'. In general, the gain is a function of antenna (could vary with temperature) and is independent of T_sys.

- If gains do not change during observations, the flux densities of sources can be established with observations of a single flux density calibrator along with phase calibrator and target sources. The above is often used at GMRT for interferometric observations.

Technical challenges

- However, it encounters serious problem for observations near the Galactic plane at lower frequency bands (below 600 MHz).
- The system could be non-linear if the gains have to remain unchanged while observing the target sources and the calibrators (often away from the Galactic plane).
- This problem has been `partially' addressed by keeping the ALC off which keeps the gain unchanged, and adjust the system gain at the start of the observations such that the source with maximum sky temperature produce the highest tolerable total power.

Technical challenges...

- However, this causes the input operating point of the correlator to change with change in source, which changes the correlation efficiency of the correlator resulting in amplitude calibration error that could be 10% for a reduction in total power by 5.
- However, the flux density scale at low radio frequencies is now believed to be accurate to 2% (e.g., consistency of primary calibrator flux densities among Scaife & Heald (2012) vs. Perley & Butler vs. Baars et al. 1977).

Technical challenges...

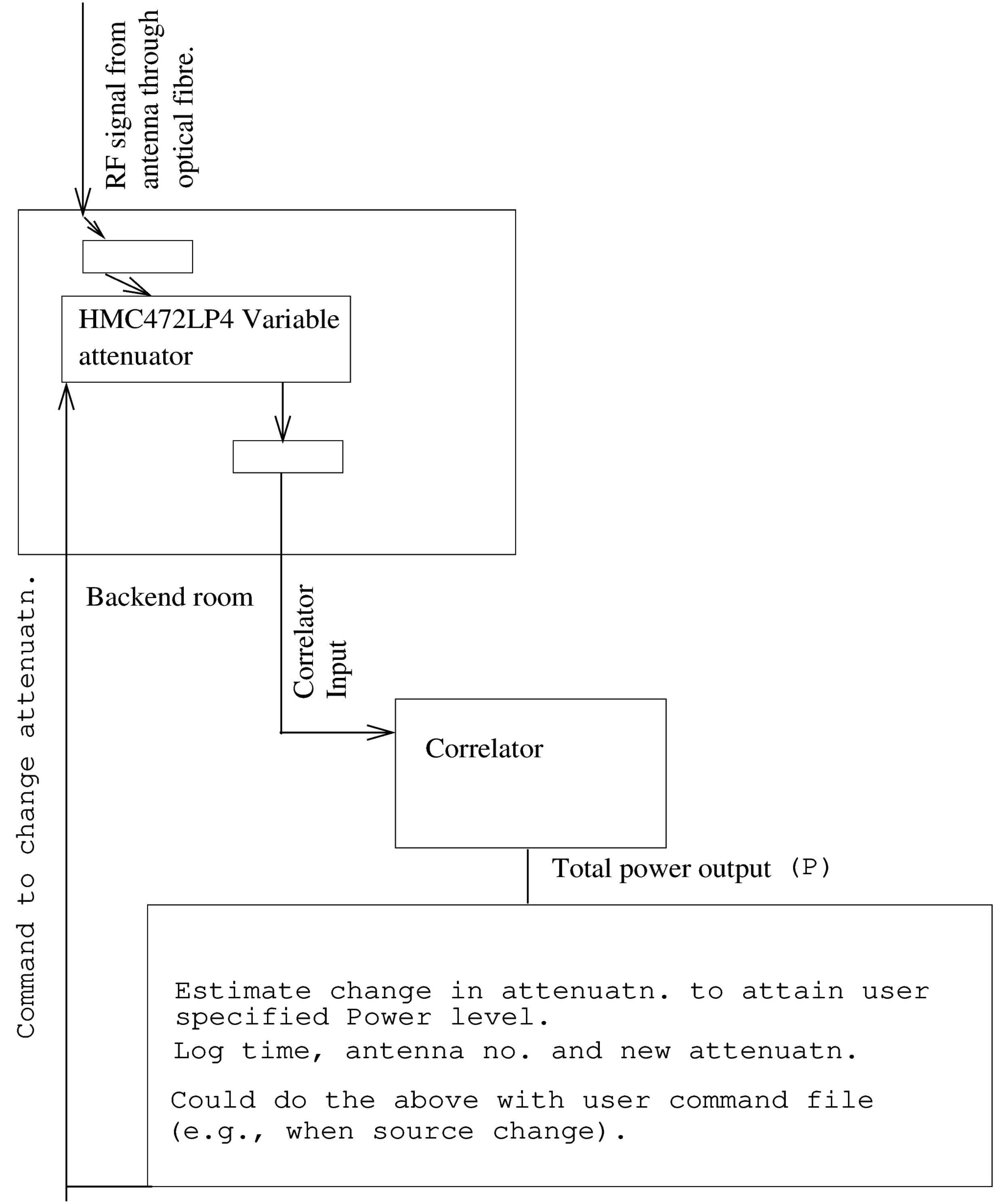
- One would like to have the same accuracy in GMRT flux density measurements, which would drastically reduce the error in spectral indices of sources measured from flux densities obtained from different frequency bands.

- The above could be achieved by suitably changing the attenuations of the attenuators connected in the antenna based broadband radio frequency (RF) signal chain while one observes different parts of the sky.

Procedure

- The upgraded electronic system of the GMRT features a variable attenuator (HMC472LP4) which supports 0-31.5 dB variable attenuation in steps of 0.5 dB (accuracy 0.25 dB, or 1.5%) in the RF chain of the antennas.
- We change the attenuation values of the above:
- The attenuator values will be changed (i) depending on **change of source**. The magnitudes of changes are determined initially by **Power equalising** to the same **power** level on each of the sources and the calibrators using the from the GMRT wide-band backend (GWB).

Procedure



Software ALC