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).

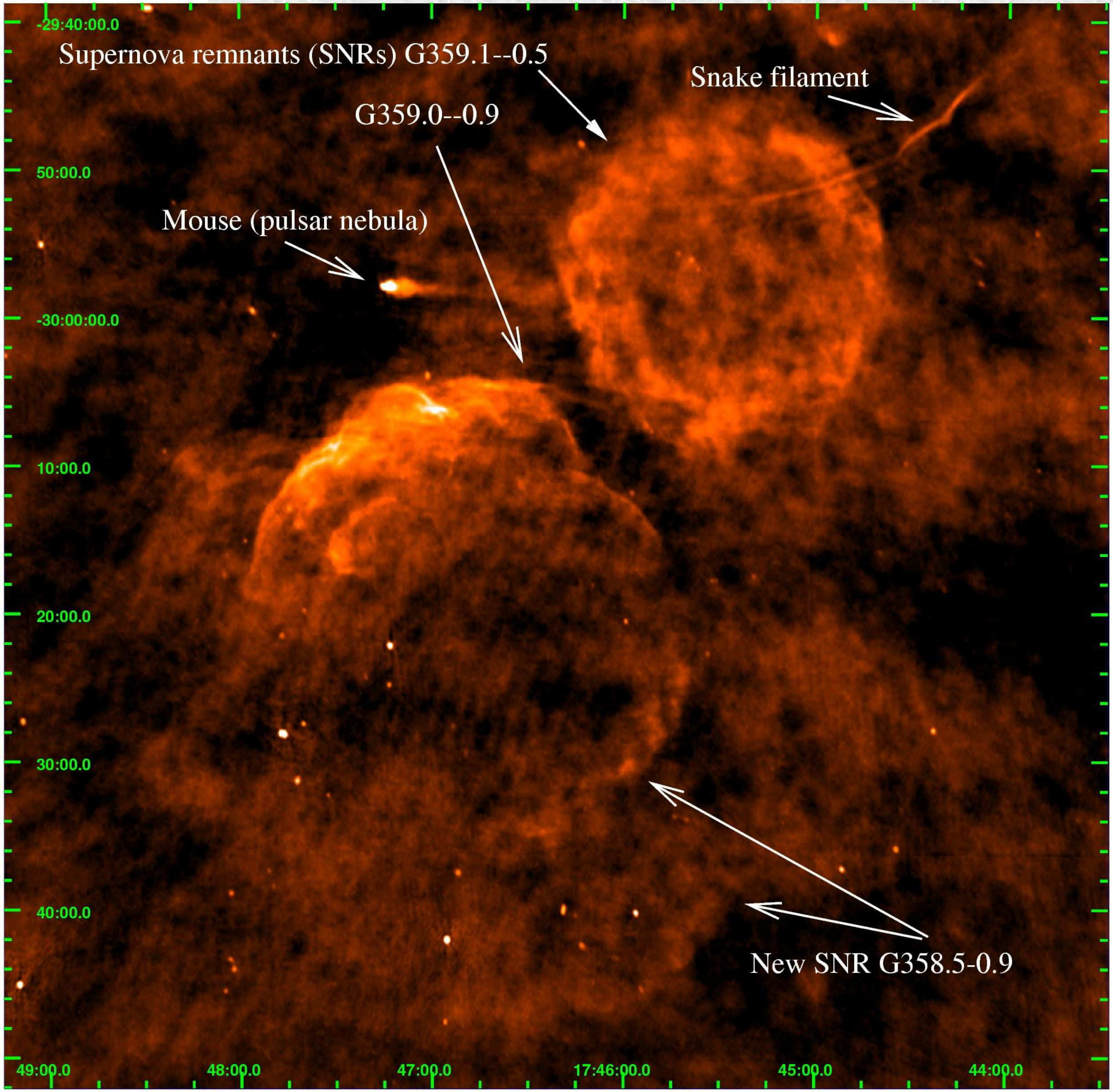
Introduction: Spectral lines

- 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.

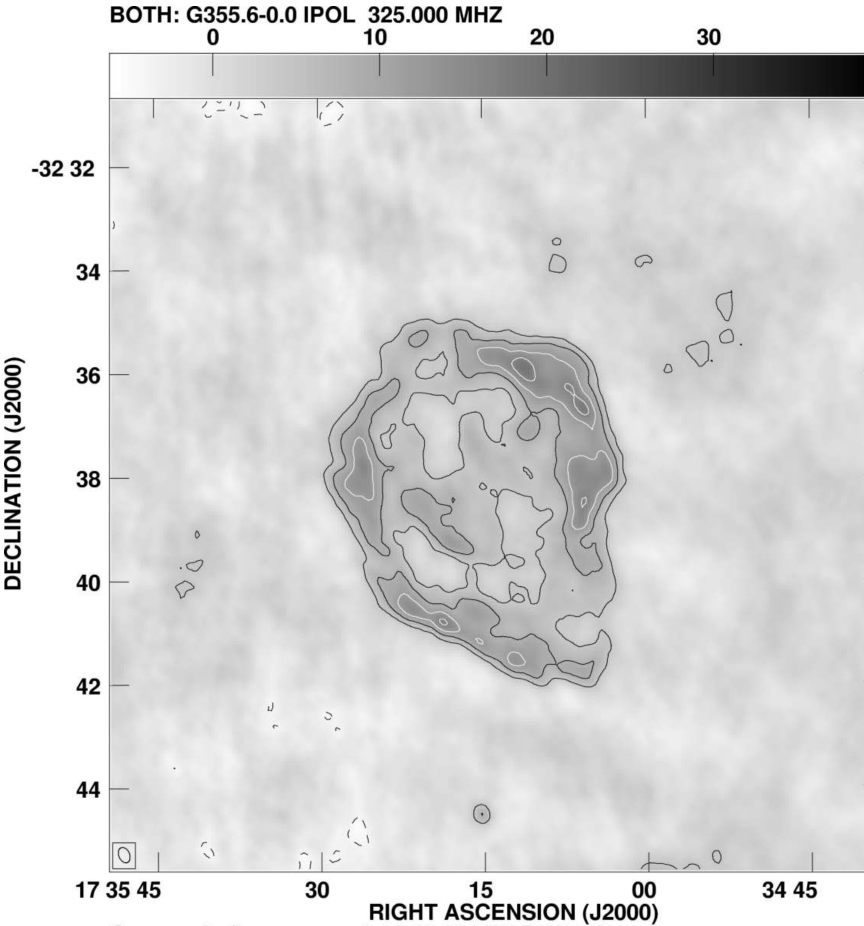
Introduction...:

- 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.

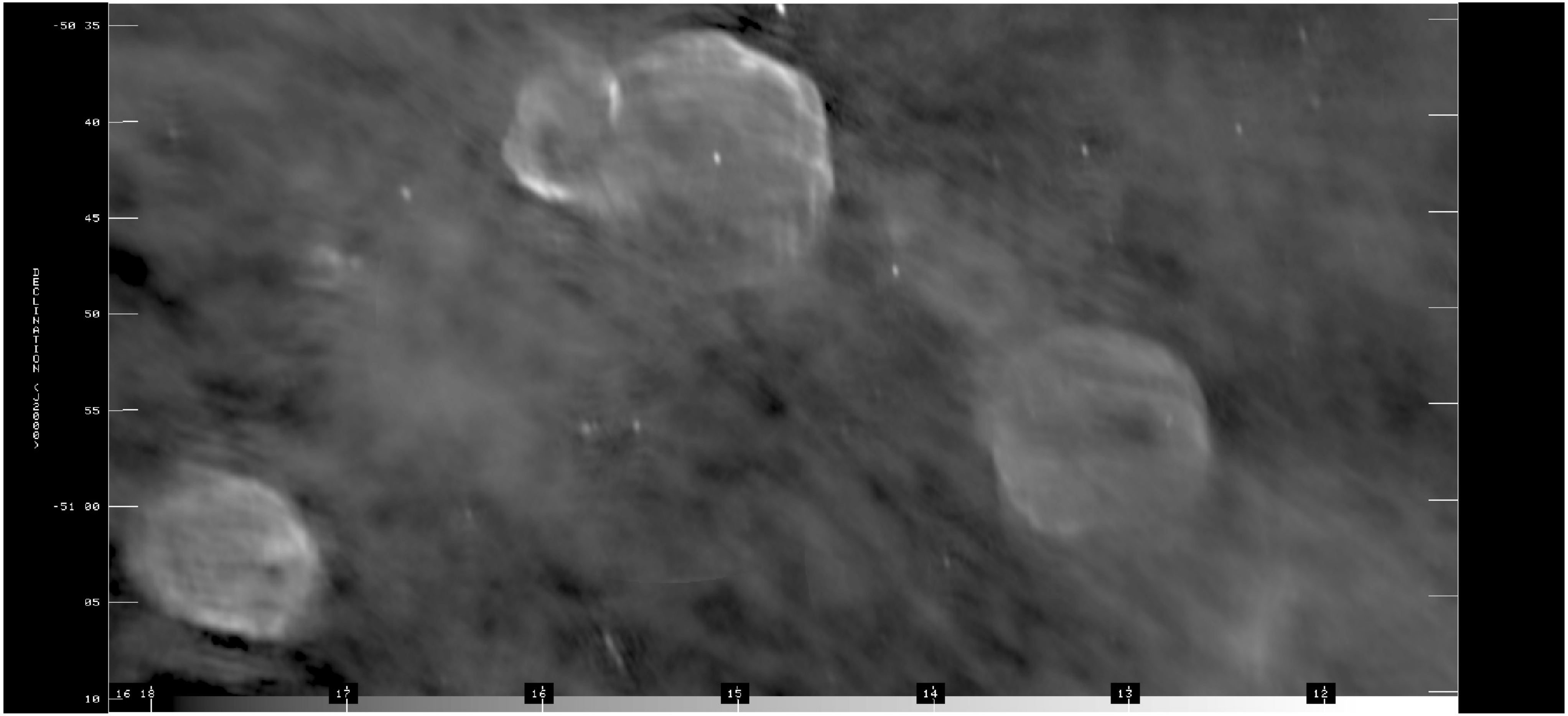


330 MHz image of the field G358.8--01 located about 1 degree south of the Galactic Centre. The resolution is ~14" and the rms noise ~1 mJy/beam. This is the highest sensitivity image of the region and is made from GMRT data. The map is used to confirm a faint barrel shaped SNR shown near the bottom.



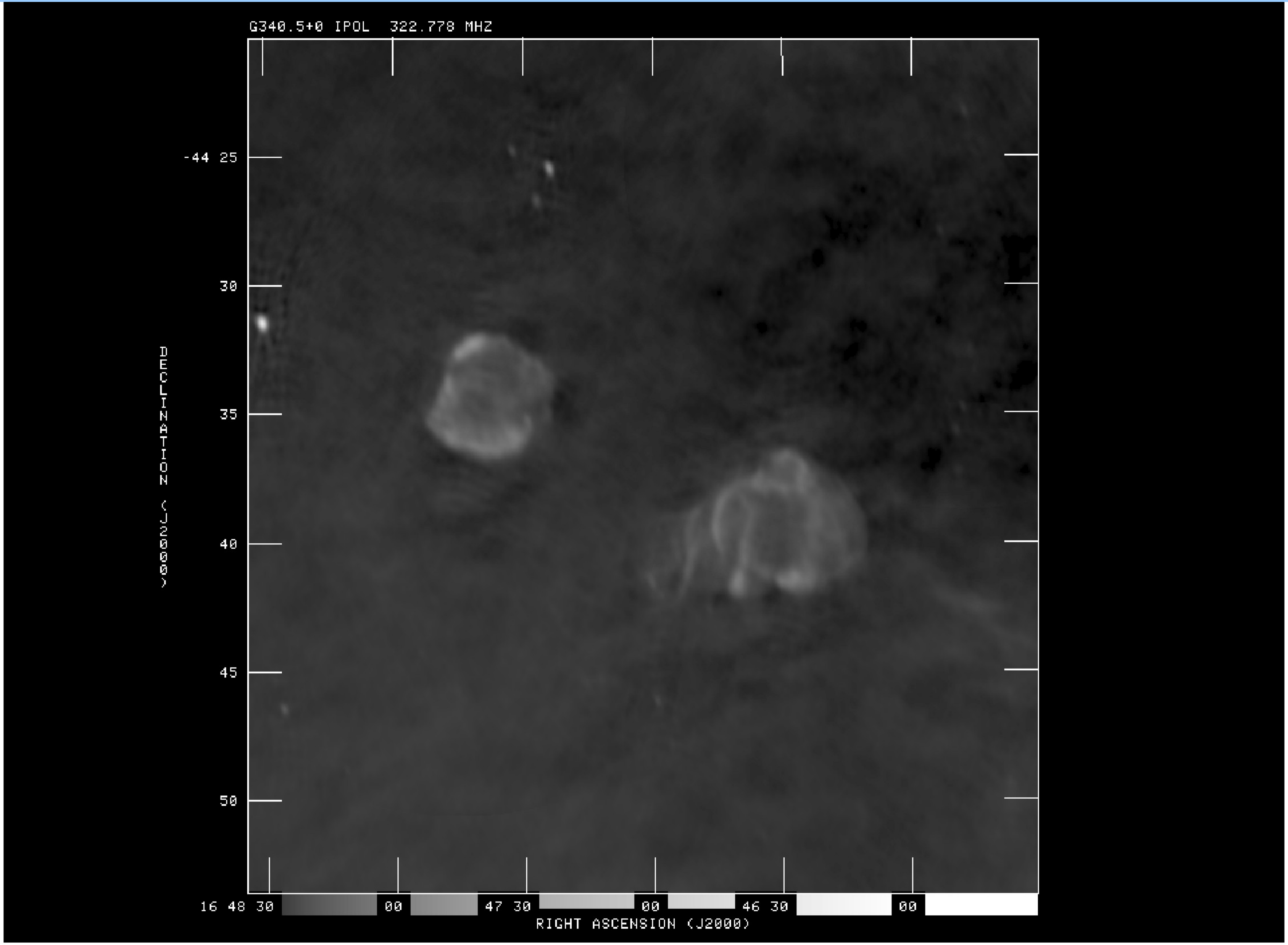
Grey scale flux range= -6.00 40.00 MilliJY/BEAM
Cont peak flux = 8.3348E-01 JY/BEAM
Levs = 4.000E-03 * (-2, -1, 1, 2, 3, 4, 6, 8, 10,
12, 16, 20, 24, 32, 40, 48, 64, 96, 128, 156)

Obs. of SNRs with GMRT: Results



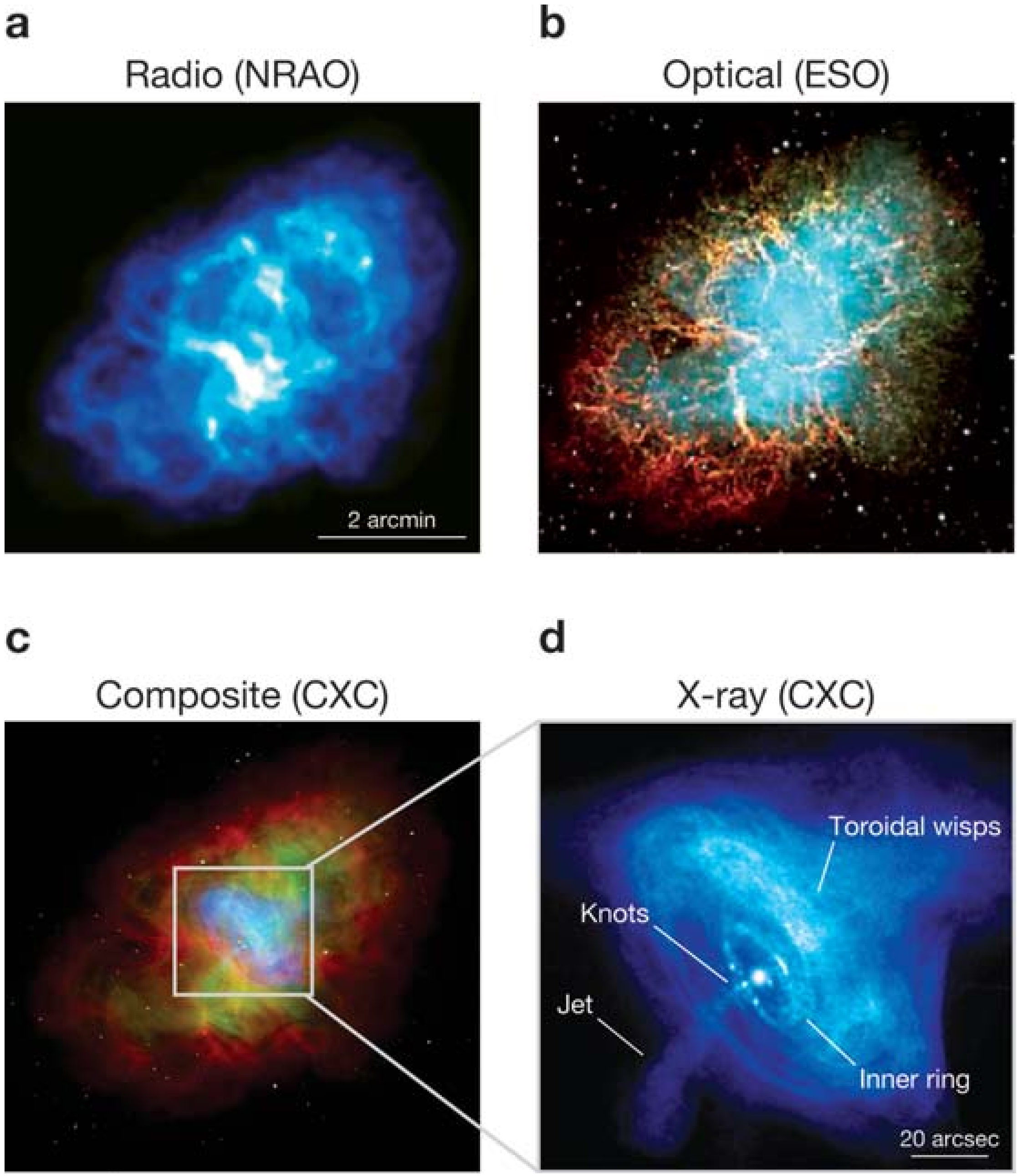
The field G332.2+0.4 showing 3 known SNRs.

Obs. of SNRs: Results ...



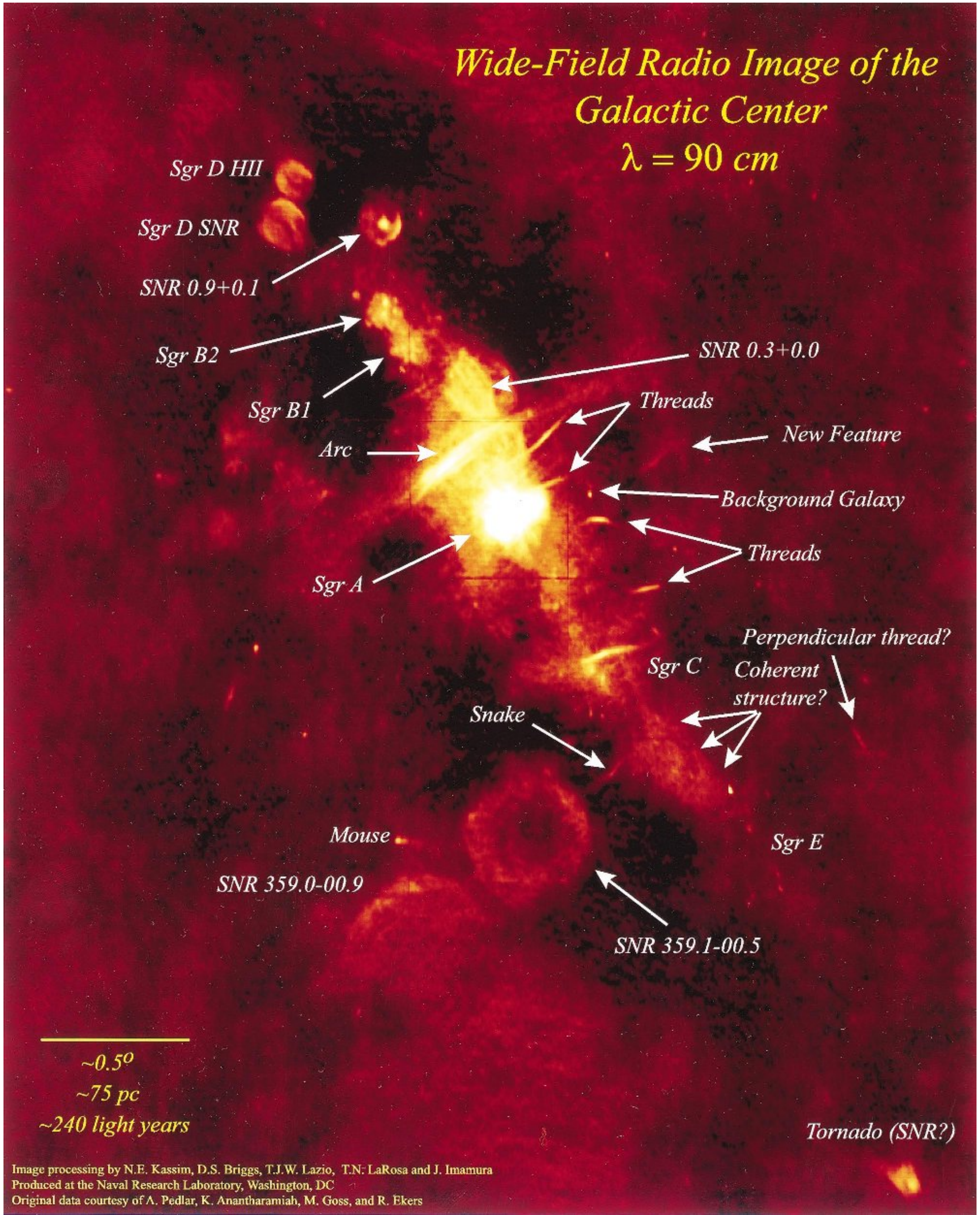
The field G340.5+0.7 showing 2 known SNRs.

Pulsar Wind nebula (PWN)



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

Complex region towards the GC



Wide-Field Radio Image of the Galactic Center
$\lambda = 90$ cm

Image processing by N.E. Kassim, D.S. Briggs, T.J.W. Lazio, T.N. LaRosa and J. Imamura
Produced at the Naval Research Laboratory, Washington, DC
Original data courtesy of A. Pedlar, K. Anantharamiah, M. Goss, and R. Ekers

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)

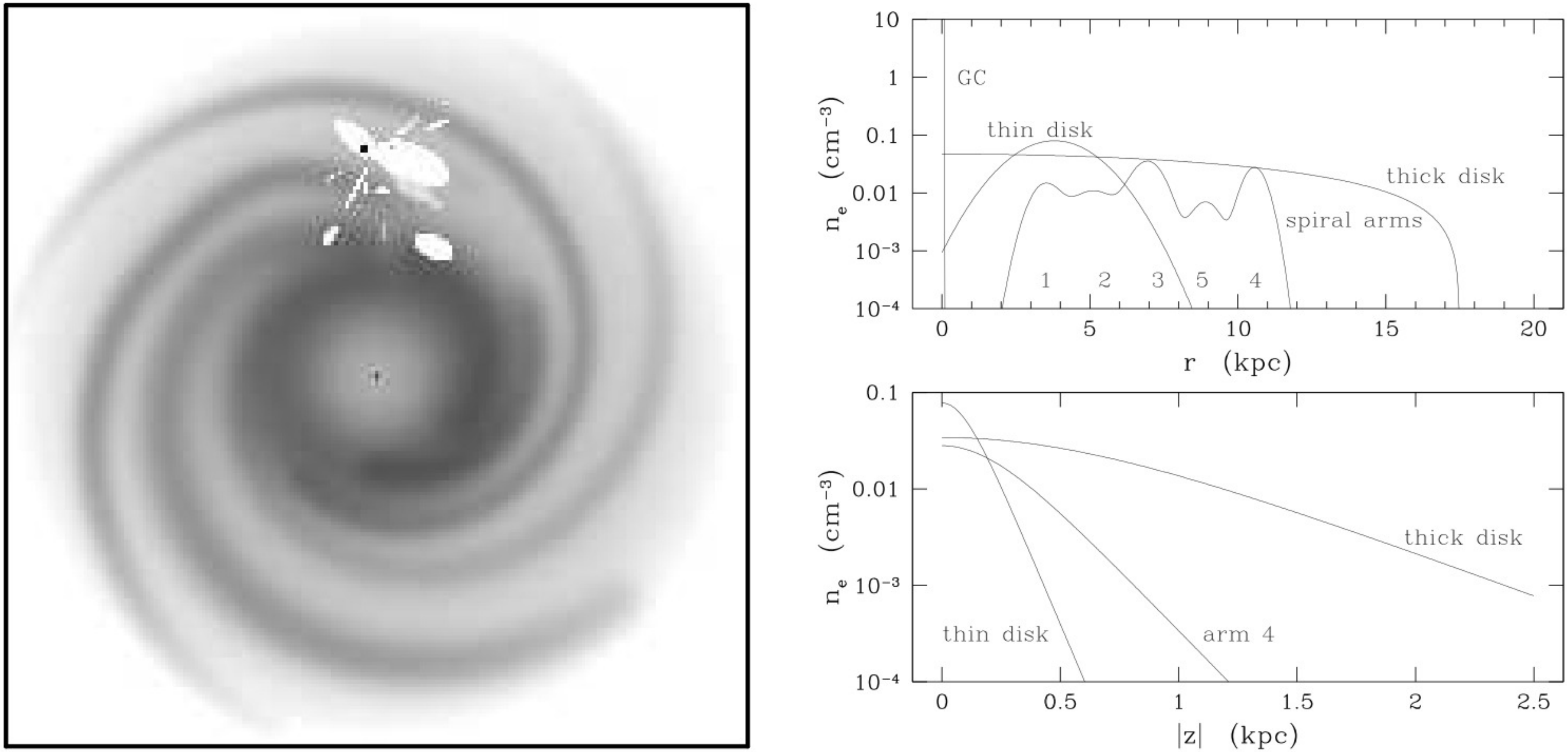


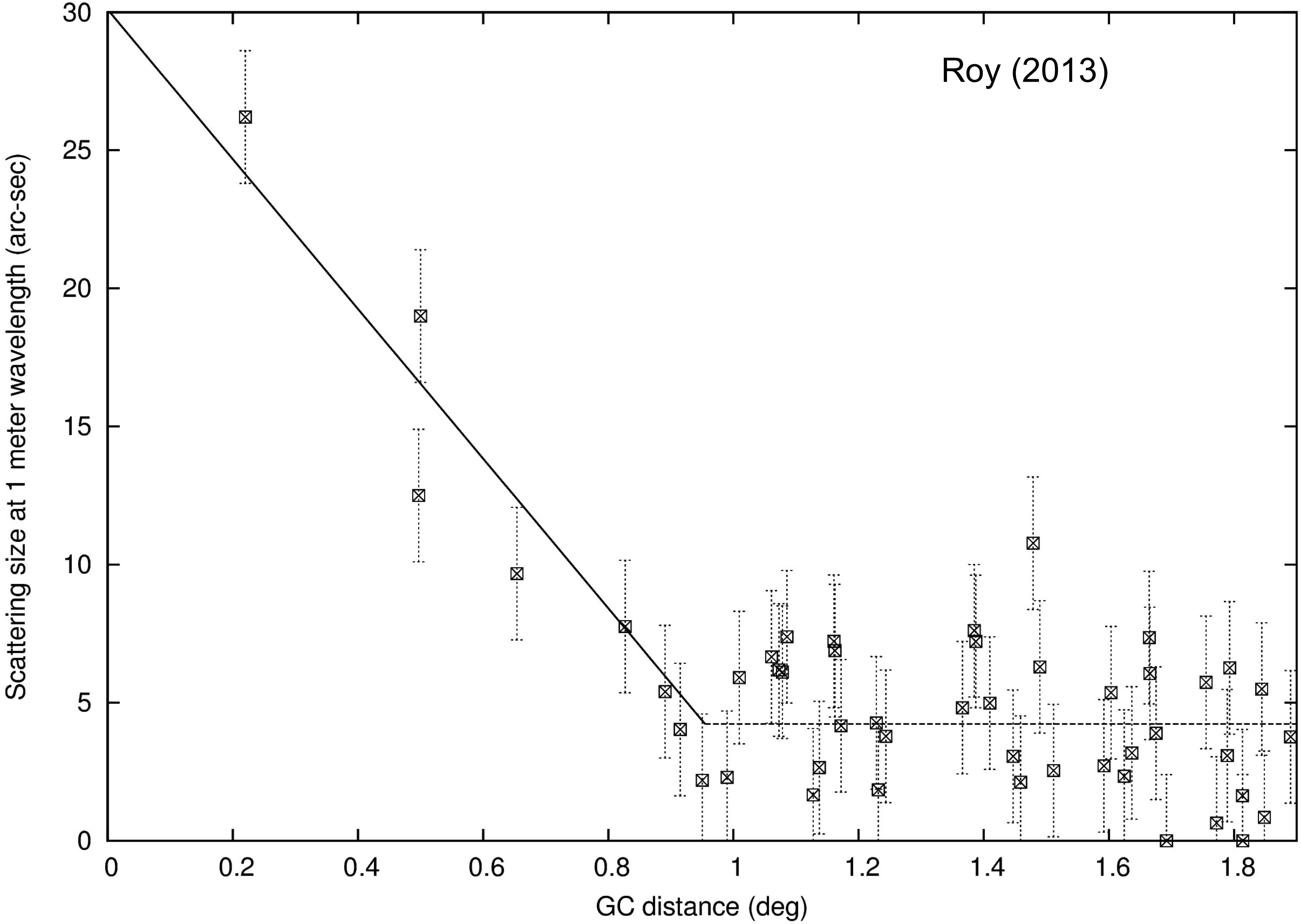
Figure 1. Left: Gray-scale plot of $\log n_{\rm e}$ in a frame that is 20 kpc x 20 kpc. The Sun is within the white patches that represent regions of low electron density in the local ISM. Right: cross sections through various components of the model showing characteristic Galactocentric and z scales.

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

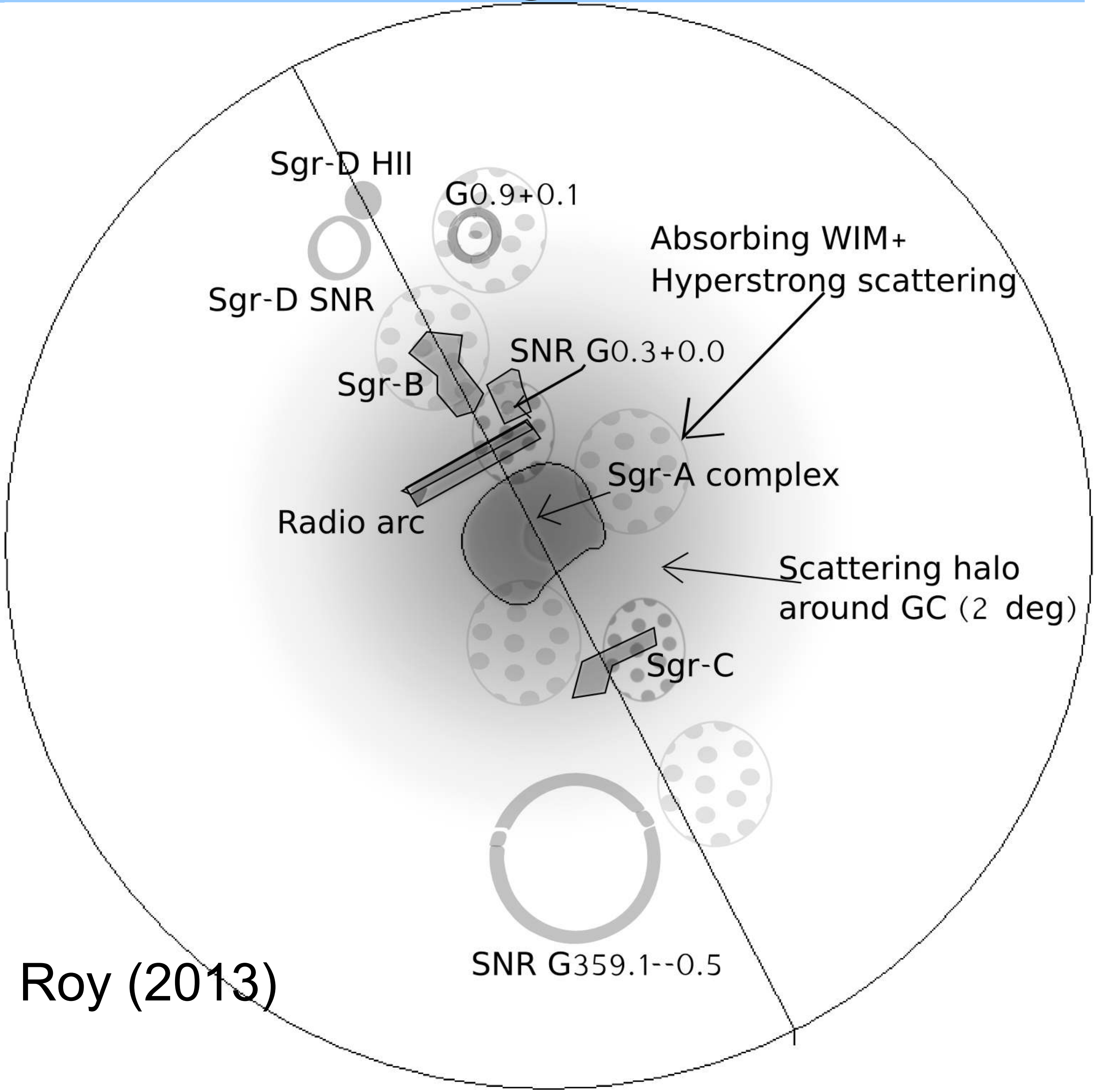


Free-free absorption of GC sources

- 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

- 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}).



Roy (2013)

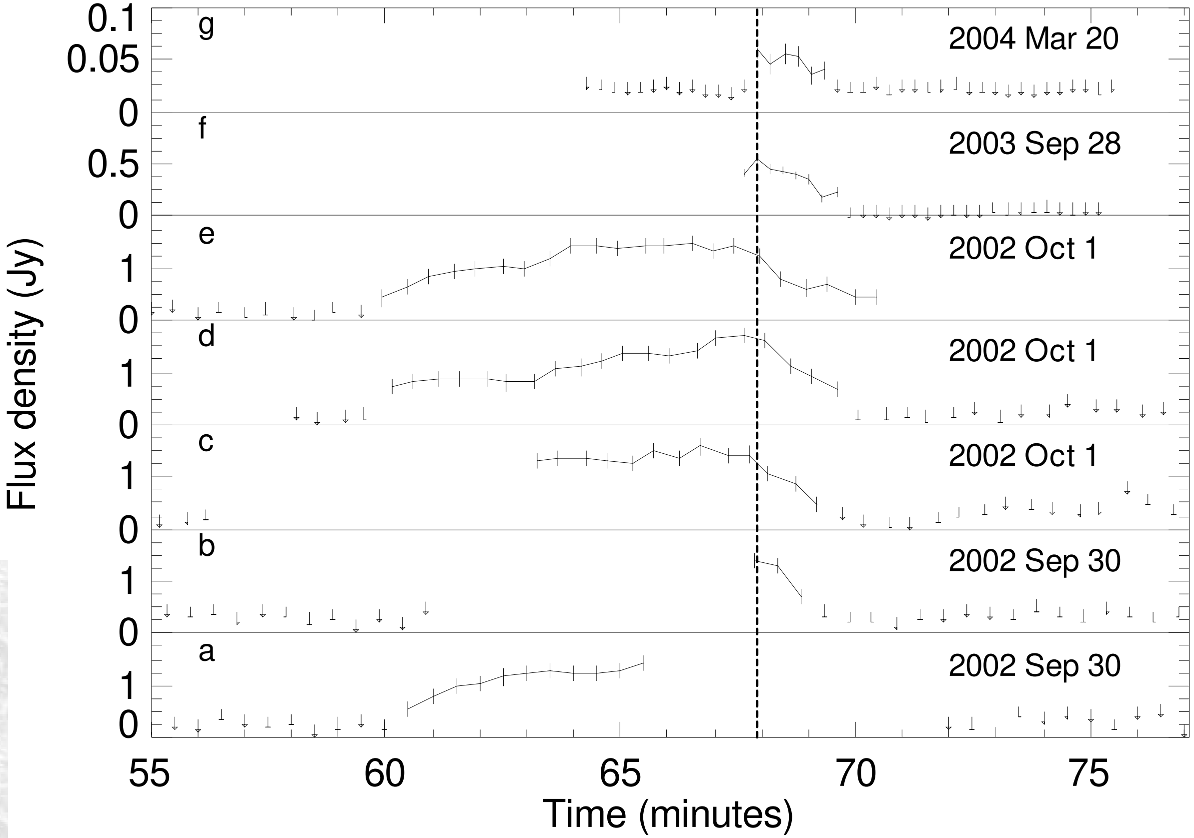
GMRT observations of Galactic Centre Radio Transient (GCRT) J1745-3009

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.

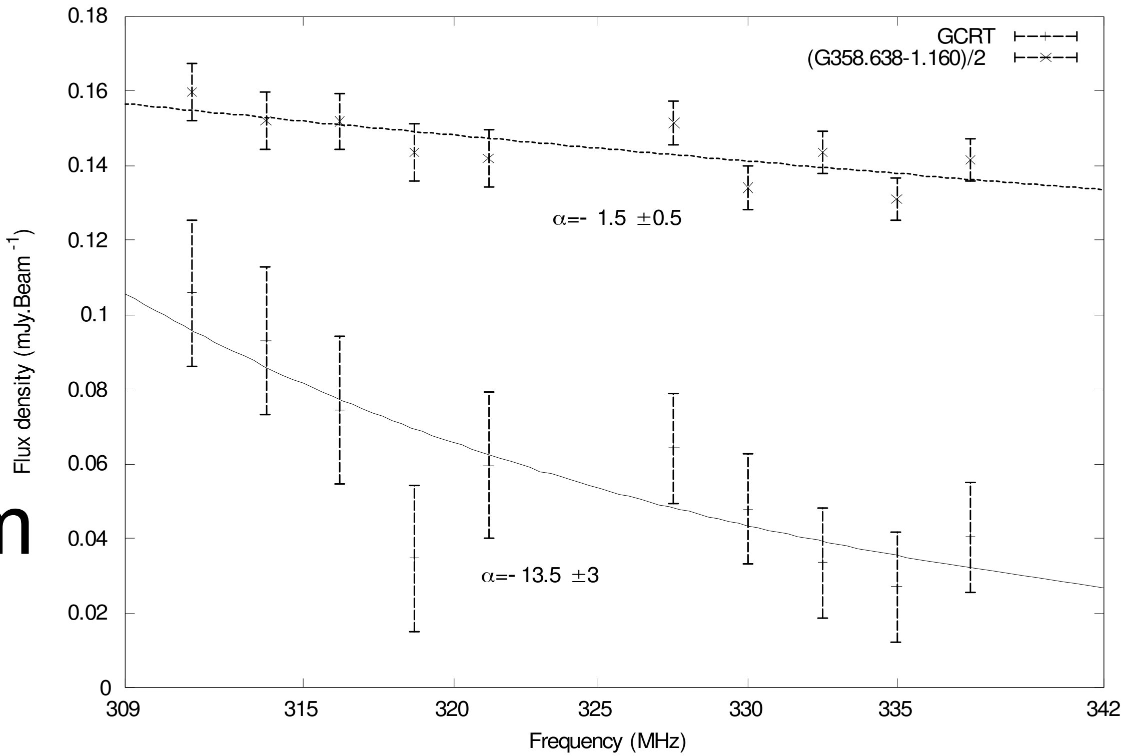
2002→2003 →2004.

75 → 25 → 6 mJy.beam^{-1} rms.

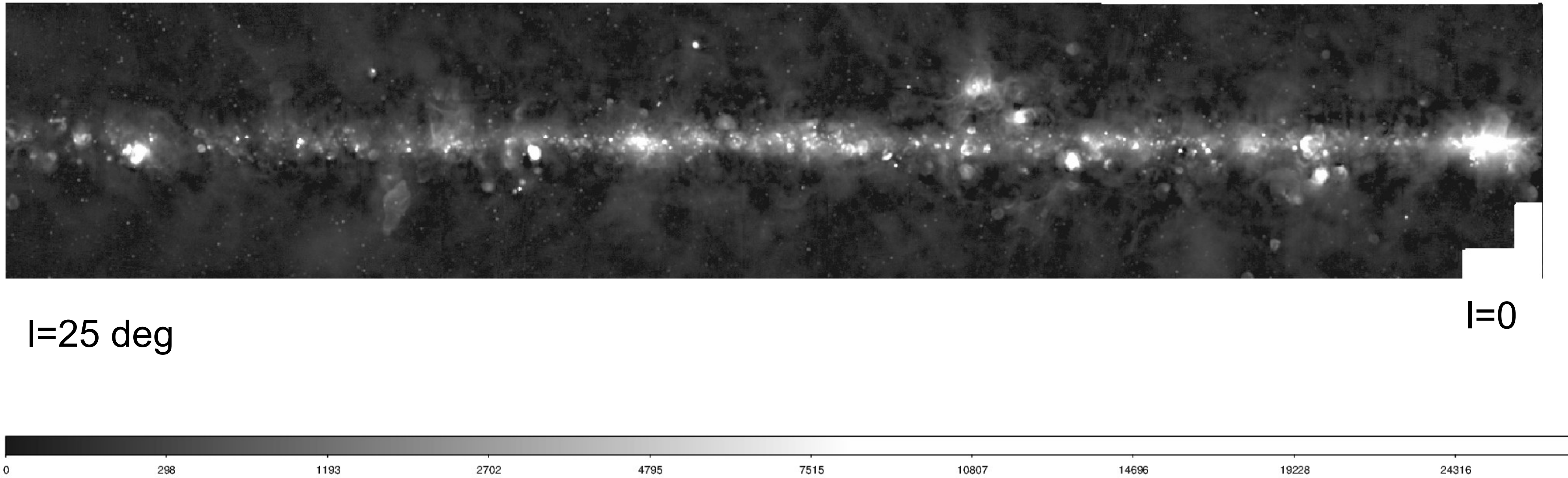
Unresolved with beam size ~15".

2004 → new state ?

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

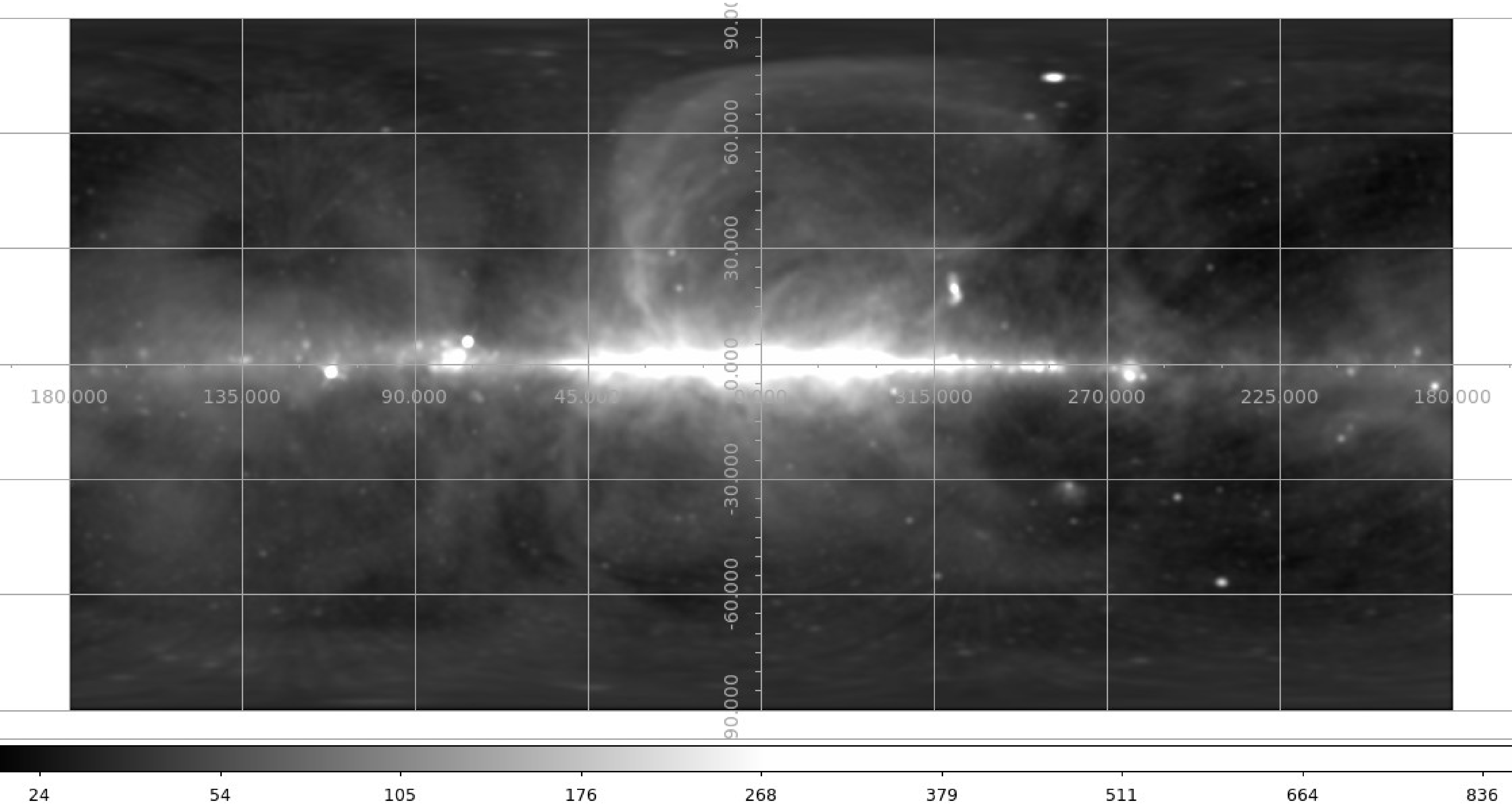


Single dish surveys



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

Sky temperature at ~1m



Sky temperature (bottom) at 330 MHz with GMRT primary beam. Deduced from Haslam et al. (1982) all sky survey at 408 MHz.

Calibration issues:

- As shown, when observing Galactic plane, **sky temperature** (T_ant) could be 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 uGMRT has **no** automatic level control (ALC). Removal of ALC is expected to improve dynamic range.

Calibration issue: Background

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

- If **G 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 principle is often valid for typical interferometric observations (out of Galactic plane).

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 reach ~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 **values** of the **attenuators** connected in the antenna based broadband radio frequency (RF) signal chain while one observes different **sources** of the sky.

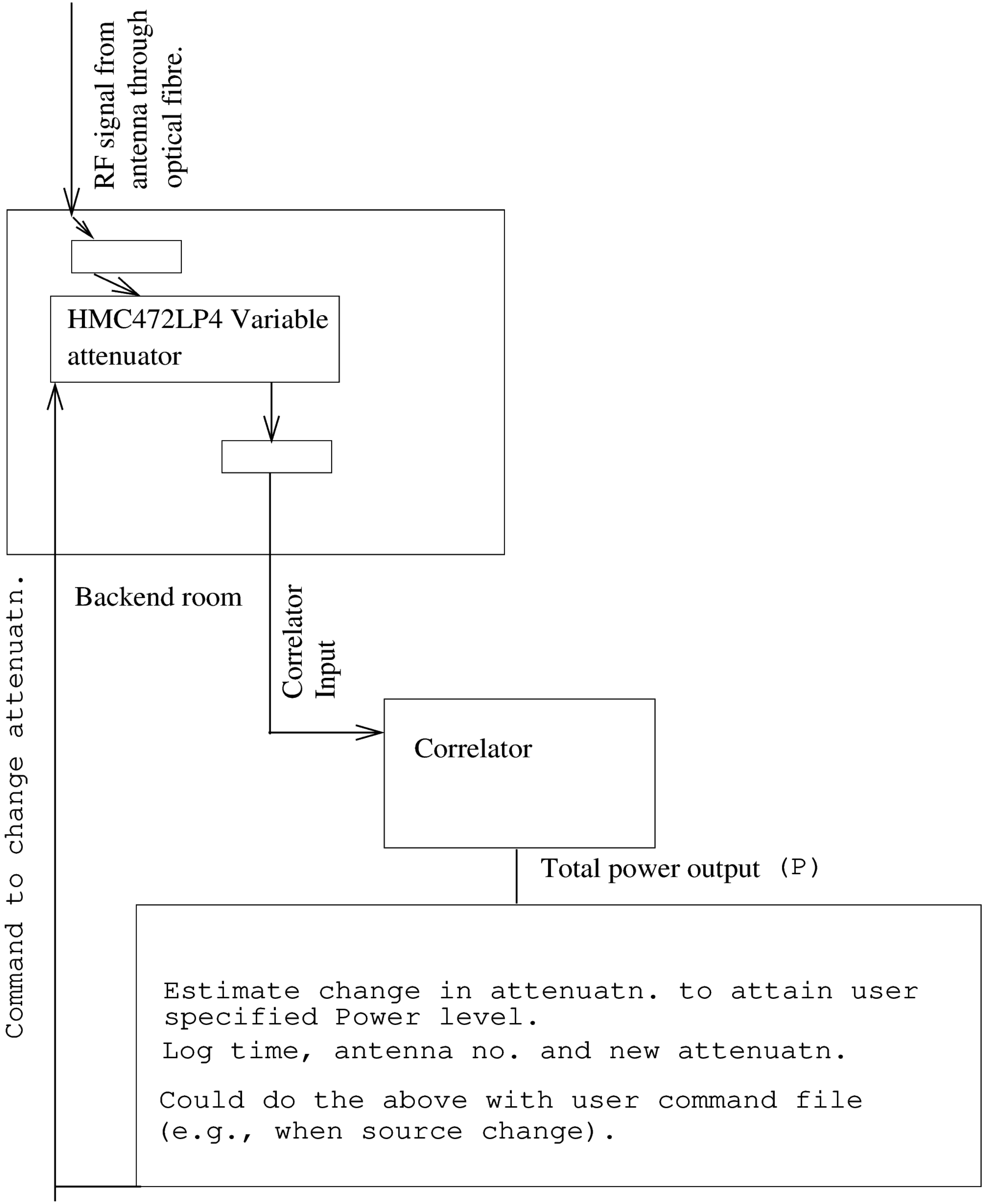
Procedure

- uGMRT 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 **equalising Total Power** to the same level on each of the sources and the calibrators using data the from the GMRT wide-band backend (GWB).

Procedure



Estimate change in attenuatn. to attain user specified Power level.

Log time, antenna no. and new attenuatn.

Could do the above with user command file (e.g., when source change).

Software ALC

Procedure...

- The **attenuation** values are recoreded for each **sources** and antennas in **different files**.
- When source changes, the corresponding attenuation file is activated for the source to keep the output power of the correlator **constant**.
- User later uses the above files offline while analysing data, and **changes** the Gains towards different sources using the differences of the attenuation values (in dB) w.r.t. the **primary flux calibrator**.

Implementation of software ALC

- Mode I: change attenuation with change in T_ant (source change) implemented by writing a set of scripts. (i) 'power_eq.run SRC' is used at start of an observing seesion from the Command file.

- During the 1st scan of each of the source, it calls power_eq' (Raskar et al. 2013) for the GWB which reads the total power from the antennas and computes the attenuation required to bring the total power to optimal value (P_opt).

Implementation of software ALC

- After the 1st scan on each of the sources, during source change, a command 'run ASRC' is used from the command file.

  In the above, SRC is source name (gain table is named as 'ASRC' in the Aips RUNFIL area).

- To analyse the data, one determines the change in attenuation from the Secondary cal. using a script 'attenuation.difference.gwb' in db.

- These are then converted to actual ratio, and are then applied on each target source in Aips task CLCAL (to modify the corresponding SN table). The same can be done in CASA.

Summary

- Galactic plane observations are crucial to study interesting Galactic objects.
- However, varying sky temperature causes a technical challenge during low radio frequency observations.
- One needs to be aware and check with observatory for a suitable observing plan to avoid saturating the receiver chain.