

## The RRI 10.4m millimeter-wave telescope

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**Abstract.** The 10.4m millimeter-wave telescope of the Raman Research Institute has been in operation since 1988. It can observe over the 3-mm atmospheric transmission window (80-115 GHz) where rotational transitions of many molecules including CO lie. Dual polarisation cryogenic receivers developed at RRI are in use with the telescope. Filter bands and acousto-optic spectrometers are employed as back-ends for carrying out molecular spectroscopy. Study of SiO masers in late type stars, CO line observations of molecular clouds near massive stars, in the Gould's belt and near supernova remnants and millimeter wave recombination lines are some of the research programs undertaken. Future plans include the development of a four beam receiver to speed up mapping observations.

*Key words* : millimeter-wave telescope—molecular spectroscopy

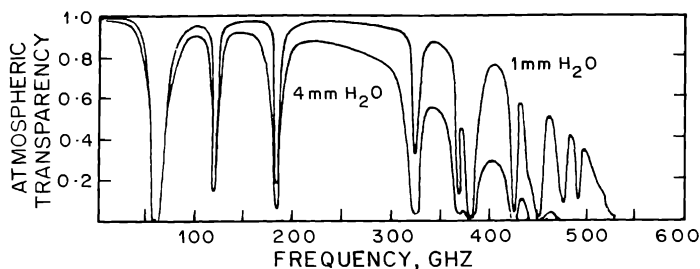
### 1. Millimeter-wave astronomy

Millimeter radio astronomy as an important branch of astronomy was born with the discovery of carbon monoxide in 1971 in the interstellar medium at 115 GHz by Wilson *et al.* (1971). In the two decades since this discovery, over 60 molecules have been detected in the ISM. Some of the organic molecules identified are quite complex containing as many as 13 atoms. Line radiation from molecules in the ISM has given us a wealth of new information. Molecular line studies are about the only way to probe the cold, dense regions where new stars are believed to be born. These studies have led to the discovery of the Giant Molecular Clouds, the most massive structures in the galaxy, the unexpected outflow phase of young stars, the circumstellar and interstellar masers, and a variety of chemical species.

Molecular clouds are mainly made up of H<sub>2</sub>. Being a homomorphic molecule H<sub>2</sub> has no permanent dipole moment and so does not radiate in its lower rotational transitions. Fortunately the next most abundant molecule CO has a permanent dipole moment leading to conveniently observable radio lines. The rotational levels of CO are excited by collisions with H<sub>2</sub>. Therefore CO is widely used as a tracer of H<sub>2</sub> in cold interstellar clouds.

Advances in millimeter-wave radio astronomy were limited by developments in antenna and receiver technology. During the eighties, many large telescopes some with surface accuracy high enough to go up to a few hundred GHz have been built and receiver technology has matured sufficiently to permit routine observations.

Fortunately for astronomers, the millimeter wave part of the electromagnetic spectrum is not used for radio communication and most transmitters have low power and narrow beams thus reducing drastically the problem of man made interference. But the millimeter wave astronomers have to contend with the problem of atmospheric absorption especially due to water vapour and oxygen. As seen in figure 1, the atmospheric transmission over the millimeter wave range shows some windows of high transparency which the ground based

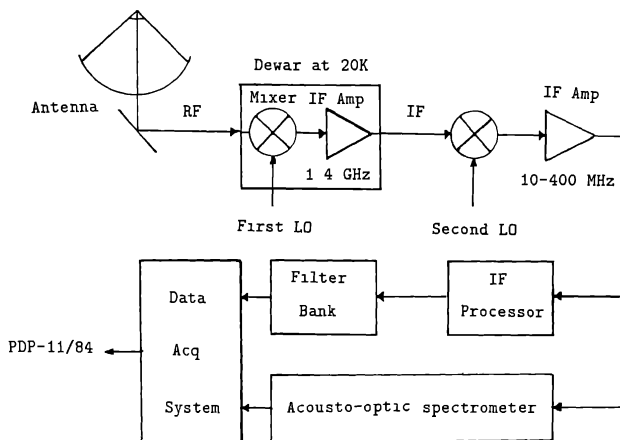


**Figure 1.** Atmospheric transparency over the millimeter-wave region of the electromagnetic spectrum for different amounts of water vapour content.

telescopes utilise. The amount of absorption being a function of the atmospheric water vapour content, strongly depends on the geographical location and season. Over the past two decades, better and better receivers have been developed for operation over these low attenuation bands. Rotational transitions of many astrophysically important molecules including CO fall in this range.

## 2. The RRI telescope

The Raman Research Institute has set up a millimeter wave radio telescope at Bangalore (longitude :  $77^{\circ} 35'$ ; latitude :  $13^{\circ} 01'N$ ; 930m above mean sea level.) which has been in operation since 1988. Figure 2(a) shows a schematic diagram of the telescope and the receiver system. The telescope is shown in figure 2(b). The telescope has an altitude-azimuth mount with the receiver at the Nasmyth focus. The primary is a 10.4m paraboloid made from



**Figure 2(a).** A simplified block diagram of the 10.4m telescope and the receiver system for one polarisation channel.

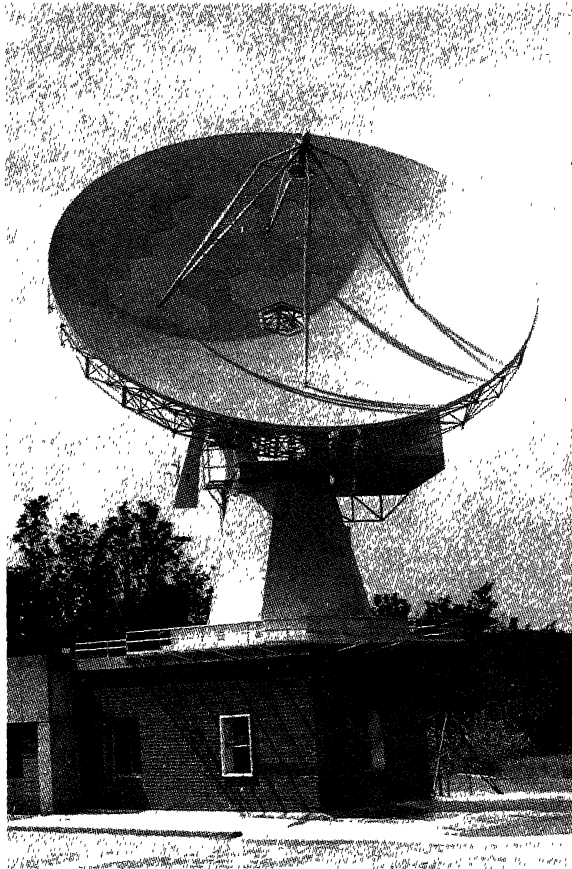


Figure 2(b). The 10.4m millimeter-wave radio telescope at the Raman Research Institute campus, Bangalore.

hexagonal honeycomb sandwiched aluminium panels, with a surface accuracy of  $\sim 100\mu$  rms. The antenna was fabricated at the National Aeronautical Laboratory. The secondary is a hyperboloid of diameter 60 cms and eccentricity 1.06. The tertiary mirror can be switched to throw the beam a few arcminutes in azimuth. The specifications of the antenna are listed in table 1.

Table 1. Telescope parameters

Primary Mirror (paraboloid) dia.	10.4m
Primary F/D	0.4
Secondary (hyperboloid) dia.	0.6 m
Mount	Elevation/Azimuth
Drive	Two DC motors per axis
Slew rate	40°/min
Encoders	21 bit (0.6")
Surface errors	120 $\mu$ rms
Control computer	PDP11/84
Frequency coverage	80-115 GHz

Millimeter wave receivers for radio astronomy are of heterodyne design in general. The first element is a mixer, either of a cryogenic Schottky or superconductor-insulator-superconductor junction design, because low-noise amplifiers at these frequencies have not yet become

available. Since the mixer is a lossy device, the IF amplifier should have very low noise temperature and is usually a cooled low-noise GaAs FET or HEMT amplifier. The IF signal is then fed to the spectrometers after further amplification and down conversion.

The RRI receiver system shown schematically in figure 2(a) employs mixers of Schottky type cooled to 20K, with the IF at 1.45 GHz. There are two such, one for each polarisation. The LO and RF are combined by a quasi-optical diplexer. The IF output from the mixers are further down converted to 150 MHz before being fed to the backends. The backends available are listed in table 2 and the overall performance is given in table 3.

**Table 2.** Back-ends

No.	Type <sup>1</sup>	Width (MHz)	Resolution (kHz)
1	FB	64	250
2	FB	128	1000
3	FB	6.4	50
4	AOS	120	230
5	AOS	29	80

<sup>1</sup>AOS: Acousto-Optic Spectrometer; FB: Filter Bank

**Table 3.** Telescope performance

Frequency (GHz)	87	97	114
$T_{R,DSB}$ (K)	240	270	280
$T_{SYS,DSB}$ (K)	350	—	530
Aperture efficiency	0.45	0.43	0.2
Beam size (")	75	65	60
Extended beam efficiency (on moon)	0.8	—	0.72

### 3. Observational programs

As examples of the kind of studies that can be carried out with this telescope, we give a brief summary of the observational work being done at RRI. Three projects which have been undertaken in the past are : (1) Circumstellar SiO masers; (2) Cometary globules in the Gum Nebula; (3) Gould's belt molecular clouds. We describe briefly these projects below.

#### 3.1. SiO masers

Maser emission from circumstellar matter around Mira variables which are pulsating red giants is a well known phenomenon but not yet completely understood. An observational study of about 170 Mira variables using the 10m telescope was undertaken during 1988-1991 (Patel 1990; Patel, Joseph & Ganesan 1992; Patel & Shukre 1993). The aim was to study the dependence of the maser phenomenon on the intrinsic properties of the Mira variables like spectral-type, luminosity, evolutionary stage, amplitude of pulsation and IR spectrum. Observations carried out at 86.2 GHz ( $\nu = 1, J = 2-1$  transition of the SiO molecule) resulted in seven new detections, including the carbon star T Cnc. The main results are summarised as : (1) Not all Mira variables show the SiO maser emission. The maser action is restricted to the mean spectral types M6-M10. (2) The maser luminosity is correlated with

bolometric magnitude. (3) There may be an anti-correlation between the SiO photon luminosity and the visual pulsational amplitude.

The following interpretations were given :

The cut-off in the maser luminosity at M6 may be due to a lack of SiO abundance in these stars. The decrease in maser luminosity with pulsational amplitude may be due to shorter coherence lengths as suggested by a correlation between expansion velocities and pulsational amplitudes. The correlation between bolometric magnitude and maser luminosity is consistent with radiative pumping.

### 3.2. Cometary globules

Radiation and stellar winds from massive stars can have significant effects on the nearby clouds. Acceleration of clouds and triggering of star formation in them are examples of such effects. The morphology of the clouds can also be much influenced in the process. Cometary globules (CGs) are thought to result from such effects. A significant population of such CGs are found in the Gum-Vela region. Their tails point away from a common center close to which massive stars are (and were) present. Some of the heads have embedded young stars. A CO study aimed at understanding the kinematics and origin of the system of CGs was undertaken at RRI (Sridharan 1992a, 1992b). A total of 35 CGs were observed leading to the following conclusions: The system of CGs is expanding at 12 km/s; The tails, the expansion and the star formation in CGs may be of common origin, namely due to the effects of the central stars. A  $^{13}\text{CO}$  column density map obtained from this study is shown in figure 3. This study is discussed separately elsewhere in this volume.

### 3.3. Gould's belt molecular clouds

Gould's belt is a local system of bright stars distributed roughly in a plane making an angle of  $18^\circ$  with the galactic plane. This system has been found to be expanding, with the sun located inside the region of expansion. Neutral hydrogen possibly associated with the Gould's belt has been found in the form of an expanding ring. An expanding molecular counterpart may also be present. Observations from the northern hemisphere suggest that many major molecular clouds may, indeed, be associated with the belt. The study undertaken at RRI is aimed at confirming the expansion in the southern part of the belt and constructing the three dimensional structure of the belt in molecular clouds (Ramesh 1993). Under this project  $^{12}\text{CO}$  and  $^{13}\text{CO}$  spectra were obtained towards 400 clouds. The data is being analysed.

Following is a list of ongoing projects :

1. SiO masers in semi-regular variables.
2. Time monitoring and polarisation studies of strong SiO masers.
3. ISM round SNRs.
4. ISM near massive young stars.
5. Recombination line studies of the galactic center, HII regions and circumstellar envelopes.

The first two projects are a continuation of the SiO maser studies undertaken in the past. Under the third project, regions around selected SNRs are being observed in CO. The fourth programme is to extend and generalise the conclusions of the previous study of CGs. The regions being studied are the surroundings of the Orion OB1 association and the Cep OB2 association. It is hoped to construct a general picture of evolution of molecular clouds near

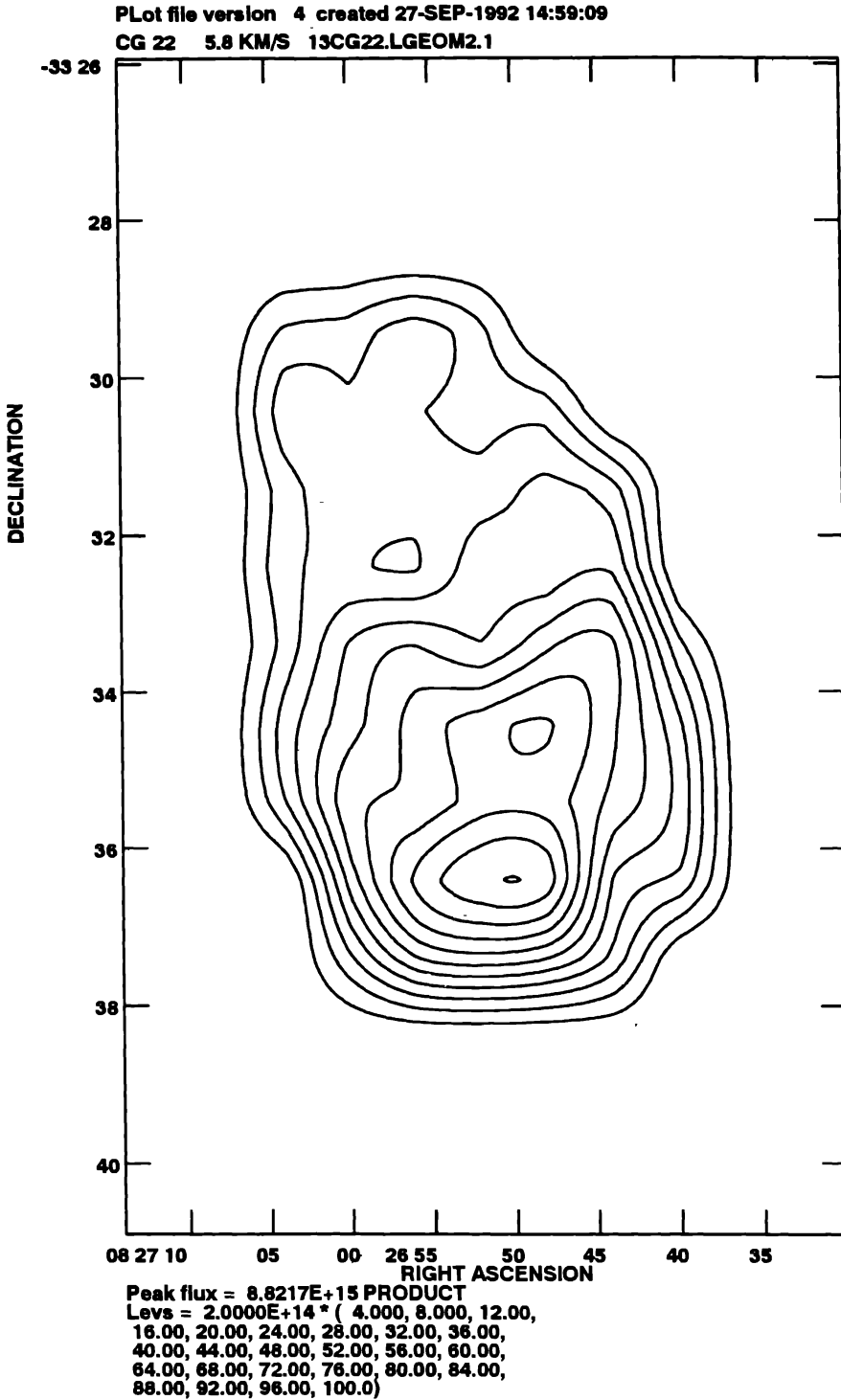


Figure 3. A contour plot of the  $^{13}\text{CO}$  column density distribution over CG22. The levels listed are in units of  $\text{cm}^{-2}$ .

massive stars. The last two projects are exploratory in nature. Very few HII regions have been studied in mm-wave recombination lines. The galactic center region has not been studied at all in recombination lines in the mm-wave range.

A significant amount of single dish mm-wave telescope time is devoted to mapping observations the world over. To produce a CO image of a molecular cloud at reasonable resolution will require hundreds of pointings. In order to reduce the time required to produce a map, it is planned to equip the RRI telescope with a four beam receiver. Each beam requires a complete receiver system with the feed horns positioned in the image plane suitably to offset the beams in the sky. This will reduce the mapping time by a factor of four. Preliminary studies indicate that the secondary reflector needs to be modified to achieve a sufficient field of view. To handle the back-end requirements of the four beam system, it is planned to build digital correlator spectrometers, which can be reconfigured to get large bandwidths at low resolution and small bandwidths at high resolution. The project is expected to be completed by the 1995-96 observing season.

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