# Science case for ATCA 7 mm receivers

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The CA's frequency coverage has a large gap between 26 GHz and 85 GHz. A lot of interesting science can be done at the intermediate frequencies, which has already been recognized by the EVLA and ALMA collaborations.

This document outlines the scientific opportunities and the technical feasibility of a 7 mm receiving system for the Compact Array. Here, the term "7 mm" refers to a receiver system which allows one to observe between the upper edge of the "12 mm" (16 GHz to 26 GHz) band and the forest of oxygen lines between 50 GHz and 70 GHz.

# 1 Scientific opportunities in the 7 mm band

## 1.1 Understanding star formation and its history in the Universe

One of the primary scientific goals of 7 mm receivers is the observation of redshifted CO, tracing the Universe's star formation history. With today's receivers, the CA can observe the CO $J(1-0)$ line at redshifts of $0.10 < z < 0.36$ (using the 3 mm band) and $3.43 < z < 6.20$ (using the 12 mm band). Continuous frequency coverage between 26 GHz and 50 GHz will narrow that gap considerably and will allow astronomers to observe CO $J(1-0)$ at redshifts as low as $z = 1.31$. Modelling of CO clouds requires multiple transitions to be observed, and the 7 mm-capable CA will be able to observe two CO transitions in galaxies with $1.31 < z < 1.71$ and $2.29 < z < 3.07$. At redshifts between 3.61 and 6.20, three transitions will be observable (Fig. 1). Furthermore, redshifted lines of $HCO^+$ and HCN as well as hydrogen recombination lines can be observed.

## 1.2 CMB foreground measurements

Upcoming high-precision CMB measurements suffer from considerable foreground emission which needs to be removed to filter out the CMB variations. The main foreground emission comes from vibrating dust and point sources, both of which can be significantly polarized. At 7 mm, the CA will be an excellent instrument to determine the contribution of point sources on an angular scale of $1'$, or multipoles of the order of $10^4$. Furthermore, the CA's polarization characteristics allow one to determine the contribution of these sources to the polarized signal, which contains information about reionization and gravity waves.

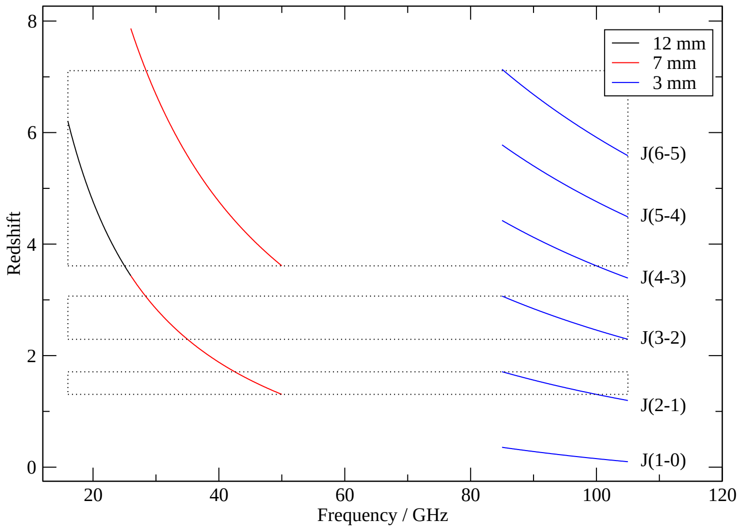


Figure 1: CO transitions at various redshifts and how they can be observed with the 7 mm-capable CA. Dotted boxed indicate redshifts at which the 7 mm system adds substantial information about the CO.

### 1.3 SZ effect measurements

The Sunyaev-Zeldovich effect, the scattering of CMB photons in hot galaxy cluster gas, provides insight into cluster mass and their physics independent of redshift throughout the Universe. Dedicated SZ-effect surveys will be carried out in the next few years, detecting hundreds of new clusters. The CA at 7 mm provides the resolution of tens of arcseconds to study these clusters in detail. Towards lower frequencies, CMB measurements are increasingly contaminated by synchrotron emission from radio galaxies and RFI, whereas higher frequencies lack the required sensitivity. The 7 mm band balances these effects nicely, and the CA's resolution of $1'$ at 30 GHz is of the same order as the expected average size of the fluctuations on the sky.

### 1.4 Observations of ”new” molecular lines

Kawaguchi et al. (1995) report on 188 lines in the 28 GHz to 50 GHz regime observed towards the late-type carbon star IRC +10216. 150 lines were assigned to 22 molecules and 38 lines remained unidentified. In general terms this band will offer the observer access to a number of transitions of molecules like SO, $SO_2$, SiS, $C_2S$, $SiC_4$, OCS, SiO, CS, $C_3H_2$, $H_2S$, methanol ($CH_3OH$) (and their isotopes) and a large number of carbonhydrates (like $CH_3OCH_3$, $CH_3CH_2OH$ etc). It should be pointed out that a large number of lines in this part of the spectrum have not even been identified and conversely the 7 mm transitions of many molecules have not yet been calculated. Most of these transitions trace different temperature and density regimes of the interstellar medium. Other transitions, like methanol ($CH_3OH$) and SiO give detailed information on the kinematics of the stellar disks, stellar jets and stellar envelopes.

| Molecule | MHz |
|---|---|
| SO | 30001.54 |
| $SO_2$ | 47661-48120 |
| SiS | 35780-36310 (36309.631) |
| $C_2S$ | ? |
| $SiC_4$ | ? |
| OCS | 36489-48652 |
| SiO | 42519-43424 (43423.847) |
| CS | 44005-48991 (48990.973) |
| $C_3H_2$ | 46755.620 |
| $H_2S$ | 35028.15 |

Table 1: Important molecular lines in the 7 mm band.

## 1.5 Very Long Baseline Interferometry (VLBI)

VLBI delivers images of AGN and their surroundings with a spatial resolution which is unachieved by any other instrument. VLBI observations are essential for studies of radio jets, nuclear absorption and emission lines, and masers. For compatibility with other VLBI arrays, a frequency of 43 GHz is desirable. 7 mm VLBI observations provide extremely high resolution whilst still having good sensitivity, and hence are superior to 3 mm VLBI observations when weak (sub-Jy) sources are targeted. In Sgr A*, 7 mm VLBI observations involving the CA may help to determine the scaling law of the scattering screen which are needed to determine the intrinsic size of the AGN. If Mopra and Parkes are outfitted with 7 mm systems as well, LBA-only observations would yield an angular resolution of 5 mas, and the future e-VLBI upgrade of the LBA will yield very sensitive images.

The CA may contribute long baselines to the Japanese VLBI network VERA in a survey of galactic $H_2O$ and SiO masers to map the 3D structure of the Milky Way.

The space-VLBI mission VSOP-2 is planned with 8 GHz, 22 GHz and 43 GHz receivers, and the CA could make a valuable contribution in this project, yielding an angular resolution of 40 $\mu$as at 43 GHz.

## 1.6 Blind survey to determine 7 mm source population

Only little is known about the source population at high frequencies, as most surveys have been undertaken at low frequencies and extrapolations are uncertain. But these population statistics are essential for observations of the CMB and the SZ effect. The broadband upgrade of the CA will allow to survey reasonably large areas of the sky at 7 mm with good sensitivity.

### 1.7 SN1987A

At 26 GHz, the CA's resolution is 0.4 arcsec, and SN1987A, having a current diameter of 1.6 arcsec, is only poorly resolved. With a system operating at frequencies as high as 45 GHz, the resolution would be almost doubled, matching that of the HST and Chandra, and resolving much finer detail in the supernova remnant. Given the importance of SN1987A and the CA's uniqueness in the southern hemisphere, this is a great opportunity.

### 1.8 Add 7 mm receiver in Mopra

As Mopra is essentially a copy of the CA antennas, it will be straight forward to add a 7 mm receiver.

## 2 Why 7 mm?

### 2.1 Fill gap between 12 mm and 3 mm

The factor-of-four leap in frequency between the 12 mm and the 3 mm band leaves an uncomfortably large gap in the CA's frequency coverage. It is unreasonable to entirely ignore such a wide portion of the spectrum, especially as the CA antennas were specified for 7 mm-wavelength operation.

### 2.2 Atmospheric window excellent

There is an atmospheric opacity trough between the 22 GHz water vapour line and the absorption by oxygen at frequencies higher than 50 GHz. Depending on the atmospheric water vapour content, the opacity in this window is a factor of two to five lower than in the 3 mm band. This window allows one to make high resolution images at the CA's relatively low altitude with much better sensitivity than at 3 mm, and hence should be explored.

### 2.3 Receivers and antennas excellent at 7 mm

The 7 mm band is the highest for which the AT antennas were originally designed to operate at the full 22 m aperture. Receiver performances decrease towards higher frequencies, and the antenna surface accuracies, measured in fractions of a wavelength, become worse. With the CA antennas designed for 7 mm-wavelength operation, this band is expected to deliver excellent results. The CA antennas have a surface rms of 160 $\mu$m to 180 $\mu$m, corresponding to a fraction of 1/38 of a wavelength at 46 GHz. The aperture efficiency at this wavelength is approximately 50 %. Also, the CA's pointing errors of typically 10 arcsec will correspond to 1/6 of the telescopes' main beams, compared to 1/3 and more at 3 mm. The CA will be much easier to use at 7 mm.

### 2.4 Complement 3 mm receivers

Because CA antenna 6 is not outfitted with a 3 mm receiver but will have a 7 mm system, the resolution of the two bands will match well. This will allow astronomers to make matching-resolution images without waiting for the array configuration to be changed.

### 2.5 Compete with other telescopes

Both ALMA and the EVLA will operate at 30 GHz to 45 GHz. ALMA is unlikely to have these receivers until 2012, and although the VLA is outfitted today with 7 mm receivers today, this band does not have a very high priority for the VLA upgrade. 7 mm receivers for the EVLA may take as long as 2012 to be installed. The estimated effective surface area of the CA at 7 mm, 1140 $m^2$, is one quarter of the VLA's effective surface area of 4640 $m^2$ at this frequency, and hence can compete in areas where sensitivity requirements are not extreme. As long as ALMA does not operate at 7 mm, ATCA will be the only instrument in the southern hemisphere.

## 3 Technical feasibility of frequency agility and wide bands

Commercially available components have 26 GHz to 40 GHz or 33 GHz to 50 GHz. Fractional bandwidths exceeding 1.5 are problematic, so one has to decide on one of these to keep costs low. Frequency agility is no problem. The built-in LOs are tunable between 11.2 GHz and 15.6 GHz with a 4-12 GHz bandwidth, and hence provide LO frequencies between 21.6 GHz and 58.8 GHz

## 4 Version history of this document

1. Version: 23 August 2004, presented at projects meeting (?)