Tidbinbilla 12-mm Upgrade: Science Case

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1 Summary

This document highlights the science that will be possible with a wide-band dual-beam, dual-polarisation upgrade to the 12 mm system on the Tidbinbilla 70 m antenna. The upgrade would consist of three parts: receiver, IF down-conversion and back-end processor. The receiver would be upgraded by adding a second polarisation to the off-axis feed and a switching mechanism to allow beam switching. The IF would be upgraded to a 4 channel fully tunable system with a bandwidth of at least 1 GHz. JPL are currently working on the receiver and IF down-conversion upgrade with the first step being a dual-beam, dual-polarisation system with 600 MHz bandwidth by September 2007.

The current ATNF multibeam autocorrelator would eventually be replaced with a next-generation spectrometer which would be powerful enough to process four 2-GHz channels (two dual polarisation beams) simultaneously. The present proposal is requesting the purchase of a spectrometer to handle the existing two-IF on-axis system to assess its suitability for upgrade to a 4-IF, wide-band system and to provide a back-end capable of making the most of the available bandwidth for the winter 2007 season.

The final upgrade would more than double the sensitivity of 12 mm observing using the 70 m and vastly improve the flexibility of the system. It would make some new projects viable and greatly improve the efficiency of current observing programs.

2 Scientific Benefit

This upgrade will yield two main benefits for science using the 12-mm system at Tidbinbilla - sensitivity and flexibility. Enabling dual polarisation observations and the second beam would more than double the sensitivity of the system. As most of the scientific projects are sensitivity limited, this is of utmost importance.

A fully tunable wide bandwidth system will enable some projects to be done which are currently not possible. It will also allow multiple molecular transitions to be observed simultaneously, decreasing the observing time needed for some projects (such as observations of multiple NH_3 transitions).

Given the restricted availability of Tidbinbilla for ground based astronomy, any upgrades which better use the available time will yield significant scientific benefit.

3 Sample Science

3.1 Water Masers

In the low densities and temperatures of interstellar gas clouds it is possible to get conditions where masers (the radio equivalent of lasers) naturally occur. These masers arise from rotational transitions in molecules and are commonly found from OH, water and methanol molecules. One of the most common of these masers comes from a transition of water at 22.235 GHz. These water masers are found in a variety of astrophysical environments, including high-mass star forming regions, outflows from low-mass young stellar objects (YSO), the envelopes of cool evolved stars and disks and outflows from the super-massive black holes powering AGN (Active Galactic Nuclei). Although the water masers are very strong in some sources, in many cases they are both weak and highly variable, particularly towards YSOs and evolved stars. The Tidbinbilla 70 m provides an ideal instrument for targeted searches and monitoring of water masers, particularly those which are relatively weak and hence more difficult to observe with smaller and less efficient antennas.

Presently the Greenhill et al. water megamaser survey relies on a 400 MHz bandwidth single polarisation auto-correlator. The increased sensitivity of this system would allow similar surveys to find weaker sources and included a larger sample size of galaxies.

3.1.1 Current limitations

The current ATNF correlator does not have the bandwidth to cover the velocity range of known water megamasers and even higher bandwidths are needed for surveys.

3.1.2 Requirements

400 MHz bandwidth with 8192 spectral points (0.66 km/s)

3.2 Star Formation

Radio observations of molecular line transitions are one of the few ways of studying regions of current star formation, as these regions are typically highly embedded and obscured at optical wavelengths. In the 12 mm window, the most studied molecules are the many thermal ammonia transitions (which can be used to calculate properties such as the temperature, density and optical depth) as well as water and methanol masers (which can be used to trace the kinematics of the gas around the stars). There are however more than 300 molecular transitions observed astronomically in the 12 mm band. Many of these transitions are quite weak and need a long integration time for detection. Some of these are "biomolecules" which are the simplest building blocks of the complex organic molecules which surround us on Earth. Understanding the origin of these molecules is important for our understanding on how life evolves.

Improvements to the sensitivity of the system would make the detection of rarer lines more viable. A flexibly configurable backend which could be used to simultaneously observe multiple high spectral resolution windows within the full input bandwidth would significantly increase the efficiency of observing. Multiple NH_3 transitions could be observed simultaneously. Different species (for example NH_3 and water) could also be observed simultaneously. With a wide enough front end bandwidth, blind spectral line surveys of all molecules towards a number of star forming regions could be performed.

Molecular line observations such as these overlap the NASA origins program (particularly research area three: investigation six) and complement missions such as SIRTF and eventually ALMA. To understand the formation of stars and planets IR and sub-mm observations are needed to trace the dust, but molecular line observations are needed to trace the actual molecular clouds and can often penetrate much closer to the forming stars than IR observations due to obscuration.

3.2.1 Current limitations

The current correlator and IF bandwidth essentially limits the simultaneous observation of more than a single molecule / transition.

3.2.2 Requirements

To achieve these aims, a 2 GHz fully tunable bandwidth system which can be divided up into multiple windows of high (0.2 km/s) spectral resolution would be required. This would allow multiple molecules to be observed simultaneously. 4 GHz or more of bandwidth would be advantageous. Each window would typically be 16 or 32 MHz wide with 1024 to 2048 spectral points.

For spectral line surveys high spectral resolution and wide bandwidth is required. 512 MHz with 8192 is thought achievable - wider bandwidths with the same spectral resolution would be advantageous.

3.3 High redshift molecules

Understanding the star formation history of the universe requires probing the environments in high redshift galaxies. One way to do this is to observe giant molecular clouds which provide the fuel and the sites for star formation to occur. Observations of ^{12}CO (whose rotational transitions are caused primarily by collisions with the more abundant H_2) provide information on the temperature, density and kinematics of these massive gas reservoirs.

At present, little is known about the molecular gas conditions in the early universe. At high redshifts ($z > 3.5$), the well studied CO$(1-0)$ line falls outside most observing windows. Instead, higher transitions have been observed. On the whole it has been argued that at high redshifts, the line luminosity increases proportionally as J^2, where J is the upper transition level, and so higher J levels are better suited to observing high redshift star-forming galaxies. However, recently there has been some contradictory evidence suggesting that observing the higher transition lines may miss up to two magnitudes of extended cooler gas seen in the lower transitions.

Some recent cosmological theories predict temporal variation of fundamental constants. By comparing the ratio of the frequency of the 21-cm HI line to the absorption frequency of lines such as HCN and HCO+ in high redshift galaxies, variations in the fine structure constant can be measured. The front-end frequency range of the 12 mm receiver would detect these 3-mm lines at redshifts of 2.3 to 3.9.

3.3.1 Current limitations

Because of relatively large errors in optical redshifts towards target Galaxies, wide bandwidths are needed to search for CO and HCO^+ (hundreds of MHz). If the redshift is even more poorly determined (e.g. photometric redshifts), or not known at all, GHz of bandwidth is needed. The current 64 MHz maximum bandwidth is significantly too narrow for this application and a fully tunable system would be required. As these lines are very weak, any improvements to the sensitivity of the system increase the chance of detection.

3.3.2 Requirements

2 GHz bandwidth with 2048 spectral points. 4 GHz or more bandwidth would be advantageous for "blind" searches.

Absorption observation require much higher spectral resolution (<1 km/s). If achievable a 1 GHz bandwidth with 4096 spectral points would be just adequate, but 512 MHz with 8192 spectral points would provide better spectral resolution. Increasing the bandwidth while retaining the spectral resolution would be advantageous, but unrealistic with the current technology.

3.4 Zero spacings

Interferometers are insensitive to very extended structures because the antennas cannot be placed closer together than their dish diameter. To properly create maps of extended objects, data from a single dish should to be combined with the interferometric data. To ensure no gap in the u-v coverage the single dish diameter should be larger than the minimum interferometer spacing. For calibration purposes, the single dish diameter should be large enough for a significant overlap with the interferometer u-v spacings. For 12 mm observing, the 70 m Tidbinbilla telescope makes an ideal match to the ATCA which has a minimum spacing of 30 m. The only other 12 mm antennas in the Southern Hemisphere are Mopra and Parkes. Mopra is too small for this purpose. Tidbinbilla has an advantage over the effective 55 m size of Parkes due to its higher sensitivity and greater u-v overlap with the ATCA.

3.4.1 Current limitations

The current backend is significantly less powerful than the new correlator being designed for the ATCA.

3.4.2 Requirements

No specific back-end requirements. As this would be used to supplement ATCA observations, it would be most useful to have a backend with similar spectral resolution/bandwidth possibilities, making a system with 2 GHz and flexible configuration ideal.