BETA commissioning plan for WALLABY

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1 Purpose of the BETA commissioning plan

The primary purpose of the BETA commissioning plan is to determine the tests that can be made on the system to ensure that the system is performing well for WALLABY.

In addition to potential new science that can be tested with the BETA instrument, it is imperative that the following be investigated:

- Pointing stability, slew rate and acceleration rate specifications which is vital for rapid FPA dithering.
- Single-dish evaluation of standing wave pattern using single dish maps.
- Interferometric evaluation of gain, phase and bandpass stability.
- The frequency dependence of the primary beam.
- RFI which will affect the observing bands within and around the WALLABY frequencies of interest. Any non-linear RFI behaviour and time dependence will need to be properly characterised.
- Far-sidelobe contamination from the Sun and possible mitigation strategies for day-time observations.
- Noise calibration techniques and the accuracy of the array calibration at various frequencies.

The BETA commisioning process also includes the testing and commissioning of the processing pipeline which will be operated on the HP cluster at iVEC@Murdoch.

2 BETA capabilities

BETA consists of the first 6 ASKAP dishes. The first phase array feed (PAF) will be mounted onto the first BETA antenna within the next month or so depending on weather conditions. The PAFs that will be mounted on BETA will be PAFs produced from the first generation design, while the eventual ASKAP PAFs will be made using the second generation design which will improve cost, weight and sensitivity ($T_{\rm sys}$) issues currently being experienced by the first generation PAFs.

Though cost and weight issues are very important, the main issue for HI users of the current generation PAFs is the fact that $T_{\rm sys}$ is approximately 100 K for frequency bands greater than 1.1 GHz. This halves the sensitivity of all

Table 1: Estimated BETA integration times for a galaxy with $M_{\rm HI} = 2 \times 10^9$ $M_\odot$.

Distance	3σ-detection	Replicating Westmeier+(2010)	New work$^+$
2 Mpc	3 minutes	37 days	146.5 days
20 Mpc	1.5 hours	1000 years *	—
200 Mpc	620 days	—	—

$^+$ Basically improve the surface brightness limit by a factor of two, so this is bringing it down from 0.14K to 0.07K.
* Assuming the $1/D^2$ rule for the flux, the brightness temperature dips from 0.14K to 0.0014K to go from 2 to 20 Mpc.

observations above 1.1 GHz as compared to those below 1.1 GHz which is at the proposed ASKAP $T_{\rm sys}$ of 50 K. As a comparison, current-day facilities such as the ATCA and the Westerbork Synthesis Radio Telescope have $T_{\rm sys} \sim 20$ K.

Modelling of the sensitivities and *uv*-coverage of this ASKAP precursor instrument can be found in the simulations developed by Emil Lenc at `http://www.atnf.csiro.au/people/Emil.Lenc/ASKAP/psf/sim/view.html`. It should be noted that Emil's calculator assumes a $T_{\rm sys} = 50$ K and hence, all the sensitivities calculations we made in this memo have been scaled to reflect the measured $T_{\rm sys} \sim 100$ K for observations above 1.1 GHz in frequency. Also, all the estimations of the BETA instrument is made with no tapering, whereby the BETA beam is assumed to be 79 by 58 arcseconds.

Using recent ATCA observations of the Sculptor galaxy group (Westmeier, Koribalski & Braun, 2010) as a benchmark example, we would require a 37-day integration with BETA to attain the same surface brightness limit. This long duration is due to to both the $T_{\rm sys}$ as well as the small collecting area of 6 12-metre dishes.

For example if we were to observe a given field to the surface brightness limit that Tobias did for NGC 300, we'd require 37 days. Table 1 provides the estimated BETA integration times for a galaxy with $M_{\rm HI} = 2 \times 10^9$ $M_\odot$ out at various distances. All the calculations assume a velocity width of 200 kms^{-1}.

A large HI galaxy ($5 \times 10^{10} M_\odot$) out at 350 Mpc (25,000 km/s) would be a 3-sigma detection by BETA after 9.3 days of integration. In fact, a 25-day integration will be sufficient for BETA to detect a $M_{\rm HI} = 1 \times 10^8$ $M_\odot$ galaxy out at 20 Mpc as well as a $M_{\rm HI} = 1 \times 10^{10} M_\odot$ galaxy out at 200 Mpc.

Even though the sensitvity of BETA is not super the survey speed for a 30-degree field is still very competitive with contemporary instruments. BETA will actually be at least 4.5 times faster than the ATCA (750 configuration, surface brightness: 0.14 K) for a 30-degree field because of the 400 pointings needed by the ATCA to cover 30-square degrees. In practise, the ATCA will require even more time to accommodate for slewing and other pointing overheads.

3 Work in collaboration with ASKAP commissioning team

ATCA 21-cm observations of two BETA test fields—centred at (i)the Fornax Cluster and (ii) the Circinus Galaxy have been obtained for the characterisation of the BETA instrument by the ASKAP commissioning team. The observations in the direction of Fornax will test the instruments response to a strong radio continuum source, while the Circinus field includes diffuse emission from the

Galaxy.

Several WALLABY team members helped with these ATCA observations. However, these observations were compromised by occasional instrument failures (e.g. the stability of the zoom blocks on the CABB instrument) as well as strong RFI in both the May and June observing runs. In addition, the June observations were cut short due to the ASKAP-VLBI testing program. Therefore it is likely that more ATCA observations will be required for a uniform sensitivity coverage of both 30 square degree BETA test fields.

4 Suggested WALLABY-driven observations with BETA

For the WALLABY BETA science observations, I propose that we consider observing a few "deep" fields in order to observe galaxies out beyond 12,500km/s. The idea is that since BETA would not be as effective for detecting the flocculent gas filaments between galaxies, it might be better to point BETA in the direction of a dense region of sky (such as the Great Attractor or some other cluster/group) to simply detect galaxies out to much greater depths than HIPASS. This way, we will be be producing some new science by exploiting BETA's wide bandwidth. We will probably double the number of sources that HIPASS found in any given field. A 12-hour integration with BETA is sufficient to detect every HIPASS source in a given field.

After much discussion with other HI-based SSTs (particularly DINGO and FLASH), we have decided that most of the WALLABY's technical and scientific needs from BETA are most similar to that of DINGO. As such, both our BETA commissioning programsd can be combined where our needs overlap and we propose to observe the following list of fields (in addition to the Fornax and Circinus fields that will be observed as a part of the ASKAP commissioning team's program):

1. Since the BETA field-of-view is approximately that of a HIPASS field, the HIPASS fields can provide a useful platform from which to select fields which are potentially interesting for WALLABY. Cube 313 from HIPASS has the highest density of sources of all the HIPASS cubes. This properties of this field includes:

   - A 12-hour integration would be able to detect HIPASSJ1317-13 with $M_{\rm HI} = 1.2 \times 10^{10} M_{\odot}$ out at 95 Mpc.
   - An integration time of 15 days or more, should also be able to detect HCG 62 within this field. This is a gas-poor galaxy group (4 galaxies—2 ellipticals & 2 S0s) with known shocks and cavities. There's also a faint FUV bridge between NGC 4761 and NGC 4778.
   - The centre of the BETA pointing need not coincide with the center of this HIPASS cube because there is an interesting cluster of sources (possibly a part of Virgo?) to one side of this cube which might benefit from such a BETA observation.

2. Shapley Supercluster (aka the Great Attractor, also cube 171 from HIPASS). Though this cube is not as dense in sources as cube 313, there are many galaxies which lie beyond 12000 km/s. Hence if we decide to do a detection experiment for galaxies between 200 to 350 Mpc, there are quite a

few galaxies (with prior optical redshifts) within this field of view. BETA would require a 9.3-day integration for a galaxy with $M_{\rm HI} = 5 \times 10^{10} M_{\odot}$ at 350 Mpc.

3. LGG-71 is a group of galaxies at 20Mpc which consist of a large variety of galaxy types. This field has also been observed by the GEMS galaxy group collaboration and therefore will have a large archive of ancillary data at other wavelengths.

4. GAMA equatorial field (RA: 09/15 hr) have a large archive of multi-wavelength ancillary observations (including optical redshifts) as well as previous observations from the Parkes radio telescope and the ATCA.

5. GAMA southern field is a field at declinations of -30 degrees and as with the equatorial field, multiwavelength ancillary data is available. Many optical redshifts are currently being determined for this field and they will be available in the near future.

6. 2dFGRS field near the Southern Galactic pole is a field which contains 4,295 galaxies with redshifts between 0.04 and 0.14. In addition to the proposed stacking experiment by the DINGO team, a BETA integration time of a few weeks of such a field will fulfill WALLABY's BETA science goals of detecting HI in galaxies at velocities higher than 12,500 km s^{-1}.

Our list of fields provides a variety of RA fields to enable 24-hour round-the-clock observations for our program. In addition, the observations of these fields will fulfill most of the BETA characterisation needs of both WALLABY and DINGO. Therefore by coordinating the BETA commissioning efforts between WALLABY and DINGO will provide a more efficient HI commissioning program for everyone involved.

In summary, a 12-hour integration is sufficient with BETA if we only want to detect all the sources found from HIPASS. On the other hand, if we wanted to replicate previous ATCA mosaic results such as the ones by Tobias on NGC300 (which is at a distance $\sim$2 Mpc), we'd require 37 days (without tapering). Therefore, given the constraints of the BETA instrument it is probably a better idea to set up an experiment to detect sources beyond what has been detected by HIPASS since this will be something new and will utilise the large bandwidth available with BETA.

5 Synergy with other ASKAP HI projects

The four HI ASKAP projects (WALLABY, DINGO, FLASH and GASKAP) will have similar commissioning concerns to the ones we've listed in Section 1 of this memo. However, due to the specific aims of each project, it is likely that the optimal BETA test fields will differ for each project.

Compared to the DINGO project, WALLABY is the shallower all-sky survey of HI emission and as such, WALLABY will be more interested in characterising the frequencies greater than 1.1 GHz and near-field observational considerations such as ASKAP's sensitivity to extended and diffuse emission. Therefore, it is less difficult to test the needs of a shallower project such as WALLABY with a pre-cursor instrument that is BETA, than those of a deep survey like DINGO. However since there will be frequency (and redshift) overlaps between DINGO and WALLABY, it is likely that some of the issues affecting DINGO will affect WALLABY as well.

The optimal test field for a deep HI survey such as DINGO would involve a field with many known optical redshifts and few strong radio continuum sources in order to optimise the detection of the faint high-redshift sources. In addition, DINGO's interest at frequencies below 1.1 GHz will result in a doubling of its sensitivity due to the uneven T_{sys} between the different frequency bands.

Although there is some overlap in terms of technical needs between an HI-absorption study such as FLASH with WALLABY (and DINGO), there are several technical issues affecting WALLABY and DINGO which will not apply to FLASH. For example, dithering is not a requirement for FLASH and the frequency range required by FLASH does not overlap with those of WALLABY or DINGO. It is likely that observation of strong radio continuum sources in order to maximise the chances of detecting the HI absorption line. There are also sources such as PKS1814-63 where both HI emission and HI absorption have been observed. However, sensitivity calculations may reveal that BETA is not the optimal instrument to do such absorption studies.

There is some overlap between GASKAP and FLASH with regards to the interests in both projects to detect HI absorption lines. The capabilities of BETA is insufficient to fully test the needs of GASKAP because GASKAP requires a higher velocity resolution (possibly with the future implementation of zoom modes) than is currently available with the BETA setup.