CSIRO Astronomy and Space Science

Document History
This document version 1.1 is the second public release of the ASKAP early science program outline.
This is a living document, which will be updated and/or amended as technical assessments are made and ASKAP commissioning process continues.
Comments are welcome and should be addressed to the ASKAP Project Scientist (lisa.harvey-smith@csiro.au).

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<td>1.1</td>
<td>7th September 2015</td>
<td>Lisa Harvey-Smith, Matthew Whiting</td>
<td>Added sections on the early science software pipeline, a new baseline description of the program, FAQs and an estimate of likely observing time available for early science observations.</td>
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1 Introduction

ASKAP Early Science is an observing program aimed at producing scientifically useful data. It will commence when an array of twelve ASKAP antennas fitted with CSIRO’s Mk II phased array feeds (the instrument known as ASKAP-12) has been commissioned and scientifically verified. Early science observations will be carried out in parallel with the deployment of the Mk II phased array feeds on further ASKAP antennas.

The priorities for ASKAP early science are:

- Demonstrating the unique capabilities of ASKAP
- Providing data sets to the astronomy community to facilitate the development of analysis and interpretation techniques
- Providing a mechanism for feedback to CASS on the performance and characteristics of the system and opportunities for improvement
- Achieving high scientific impact

Early science observations should address at least one, but preferably all of these aims.

Although early science is a high priority for CASS, the installation of the remaining phased array feeds and commissioning of ASKAP to full specification will remain the overarching goal.

CASS staff will design and implement the ASKAP early science observing program, taking account of input from ASKAP users and from its science advisory committees. CASS staff and the ASKAP user community will develop and optimise calibration, imaging and processing techniques for ASKAP-12 on a shared-risk collaborative basis. In all matters relating to ASKAP early science, the responsibility for arbitration will lie with the CASS Director.

ASKAP early science data are non-proprietary and will be publicly released when they are deemed to be of appropriate quality by the ASKAP Project Scientist.

This document is related to the Announcement of ASKAP Early Science (issued May 2013) and the ASKAP Early Science Workshop announcement, which includes detailed information on the configuration of ASKAP’s early science array. Version 1.1 (this document) has been updated significantly from “ASKAP Early Science Program v1.0”, which was issued in 2013.

The latest versions of these ASKAP project documents are available here: http://www.atnf.csiro.au/projects/mira/science.html.

This set of documents supersedes the BETA Science and User Commissioning Plan by Feain (2011).
2 Commissioning

During commissioning, the ASKAP system commissioning team will carry out a series of functionality tests of ASKAP hardware, firmware and science processing software that will seek to ensure that the data quality is appropriate for the early science program.

CASS staff will conduct the commissioning program, but contributions from ASKAP science teams are welcome.
3 Science demonstration data from BETA, ASKAP-6 and ASKAP-12

Prior to and during the ASKAP Early Science program, CASS will carry out science demonstrations with BETA, ASKAP-6 and ASKAP-12 in order to demonstrate capabilities and inform users.

Demonstration data may fulfil a number of purposes. They may be used for scientific or technical research, to demonstrate ASKAP’s capabilities or to test algorithms or pipelines. Demonstration data will be publicly released when they are deemed to be of appropriate quality by the ASKAP Project Scientist. The order of release will necessarily reflect the somewhat unpredictable nature of the commissioning process.

CASS has already pursued relevant demonstrations with BETA including:

1. Continuum observations of several test fields and larger mosaicked regions at a range of frequencies between 700-1800 MHz. BETA data from these fields have provided a preliminary test of many facets of system performance and are leading to the publication of peer-reviewed papers (Heywood et al. 2015, submitted to MNRAS).

2. Spectral line observations of neutral hydrogen in nearby galaxies and galaxy groups, leading to the discovery of significant mass fractions outside of galaxies (Serra et al. 2015).

3. Targeted observations of bright radio continuum sources for HI absorption. These observations have resulted in several new discoveries and demonstrate the unique capabilities of BETA in the 700-1000 MHz frequency range (Allison et al. 2015).

4. A targeted observation of an OH megamaser at z=0.129, which demonstrates the spectral line capability of BETA in the region of 1.4 GHz (Harvey-Smith et al. in prep.).

All aspects of BETA performance relevant to science planning will be documented in McConnell et al. in prep.

CASS is also developing plans for demonstration data from ASKAP-6 and ASKAP-12, which will use Mk II phased array feeds. Suggestions for demonstration observations should be addressed to the ASKAP Project Scientist.
4 Development of the ASKAP Early Science Program

4.1 Baseline design

As input to the development of the early science program, CASS invited presentations from the ASKAP user community at an open community workshop held on August 5th 2013. As a result, a coordinated observing program with two major streams was proposed in The ASKAP Early Science Program v1.0. Based on advice from the ASKAP early science user community via the Early Science forum, informed by measurements of the ASKAP (Mk II) on-dish phased array feed performance and early science demonstrations with BETA, these observing programs have been refined.

The working baseline design comprises two primary observing streams:

1. A 1 MHz and 18.5 kHz survey in full Stokes, from 700-1800 MHz over a wide area of sky with 4-12 hours integration time per field and
2. An 18.5 kHz spectral line survey, over 1150-1450 MHz and targeted toward a small number of fields, with 120 hours integration time per field.

The first will provide a unique broadband data set, significantly increasing the number of radio sources known and constraining the evolution of radio-loud active galactic nuclei. It will also allow the study of magnetic fields, density and turbulence at a range of redshifts. The high spectral resolution component could be used to probe the environments of HI absorbing systems at a range of intermediate redshifts that has never yet been studied. This dataset will serve the EMU, FLASH and POSSUM science teams.

The second data set will enable the study of galaxy evolution as a function of environment as well as the morphology of (and interactions between) HI clouds and filaments between nearby galaxies. It could potentially incorporate a search for variable or transient sources. This dataset will serve the WALLABY and VAST survey teams and may also be useful to the FLASH team.

As part of the early science observations, CASS aims to support a search for variables and slow transient radio sources, the focus of the VAST survey team. Such a search could potentially probe unexplored parameter space, although the international capability in this field of research is developing rapidly. This aim may be achievable through repeated observations a single ASKAP field of view as proposed for the spectral line programs. The observing strategies for the primary surveys will be designed with searches for variable and transient sources in mind.

Additional observations are also under consideration.

Several additional observing modes/techniques will be tested during the early science program. These modes have not yet been demonstrated at the time of writing and therefore the sequencing of these observations is still to be determined.

The first observation under consideration is a deep integration on a small region of sky to investigate the possibility of a galaxy evolution study using HI stacking. This would require approximately 120 hours integration on a single ASKAP field, recorded in 18.5 kHz mode between 1000-1300 MHz. The data set would be useful for the DINGO and VAST survey teams. Members of the ASKAP commissioning and early science team are currently investigating the viability of such a survey using repeated observation of a single ASKAP field of view. The results of this investigation will inform whether it is viable to include a deep field in the early science program.
For the wide-field continuum survey, determining the polarisation of cosmic radio sources is an integral part of the science justification. However, at the time of writing a method of reliably calibrating the polarisation of an ASKAP field-of-view has not yet been demonstrated. This injects an implicit risk to the readiness of the polarisation aspect of the continuum-wide survey, and the situation will be carefully monitored and assessed throughout the commissioning process.

The remaining early science projects will require so-called ‘advanced observing modes’.

**Advanced observing modes**

The current ASKAP project plan has the fast transient and zoom modes being integrated and commissioned after the first ASKAP Early Science observations begin. These advanced observing modes are therefore considered likely to enter into the early science program at a later stage than the standard continuum and spectral line observing modes. CASS is working with interested parties, through the ASKAP early science forum and other community meetings, to develop a plan for integrating these observing modes into the early science program.

**4.2 Accommodating new ideas**

CASS will welcome new ideas for early science observations throughout the period of ASKAP Early Science. Suggestions should be addressed to the ASKAP Project Scientist.

**4.3 Pilot observations**

Once the basic commissioning of ASKAP-6 (and later ASKAP-12) has been completed, CASS will begin early science pilot observations. For each of the major observing streams and for the HI deep field, two waves of pilot observations will be carried out. The first will take place with an early ASKAP sub-array (probably ASKAP-6) and the second will be carried out with ASKAP-12.

The first round of pilot observations will be a short (a few hours) proof-of-concept using ASKAP-6 to test the data quality and to allow the science teams time to interact with the data and test their post-processing tools.

Data from the pilot observations will be publicly released. Science teams will have the opportunity to study the data and present results at the ASKAP early science forum and/or in written reports to CASS.

These initial pilot observations will be repeated with ASKAP-12 once the basic commissioning of this array is complete. Science teams will report their results to CASS and with this information in-hand, CASS will decide whether the science data quality is likely to warrant gathering larger amounts of data in that mode. If shortcomings are identified in the data quality, this information will inform how the commissioning and early science process should proceed.

Once CASS has deemed an ASKAP-12 pilot observation to be successful, the early science observing in that mode will proceed as soon as possible.

The zoom and fast transient capture modes may not yet be available when ASKAP-6 is functioning. When each mode becomes available, a pilot observation will be carried out with the best available sub-array at the time.

During mid-late 2015, CASS will work with early science teams to define the pilot observations that will be carried out with ASKAP-6 and ASKAP-12.

We currently anticipate the first early science pilot observations to start around August 2016.
4.4 A strawman model for ASKAP early science observing

The current ASKAP schedule identifies a period of 12-14 months between the start of ASKAP early science and the completion of commissioning of the full ASKAP array. This places a practical limit on ASKAP early science observing of approximately 12-14 months.

For the 14 months following the commencement of early science, CASS estimates that up to 25% of available telescope time could be made available for early science. Up to 20% of this time may need to be used for calibration and beamforming.

After taking account of maintenance time and shutdown periods, the available telescope time could therefore be up to 1800 hours.

Given the implicit priority of the basic continuum and HI modes, a logical estimate of integration times during the early science program is:

- For each of the two major observing streams, a total integration time of approximately 800 hours;
- For the HI deep field and for a zoom mode observing program, approximately 100 hours each.

This strawman model is not intended to represent an observing time commitment from CASS, but rather an estimate to guide ASKAP early science planning.

CASS looks forward to refining this model through discussions at the ASKAP Early Science Workshop on October 8th 2015.

5 ASKAP Processing Pipelines for Early Science

5.1 Expected pipeline processing capabilities

Early science observations and demonstration observations will not be processed automatically through the ASKAP real-time data processing pipeline. It is expected that Early Science observations will be processed in offline mode on the Pawsey Centre galaxy supercomputer. Here, offline mode means that the data from the telescope is stored on disk¹, from where it will be accessed and processed within a short period.

While the ASKAP Early Science program is being carried out, the ASKAP commissioning and early science team in Marsfield will develop expertise to process ASKAP-12 data in the supercomputing environment. The Early Science data processing will be run by members of either ATNF Operations or the ASKAP Commissioning & Early Science (ACES) team, using a well-defined pipeline built out of ASKAP Computing’s ASKAPsoft package. A prototype of this pipeline is already being used to process BETA observations.

Data, once verified, will be publicly released. Busy weeks, aimed at bringing together the CASS team and members of the relevant science survey teams and facilitating the rapid processing of data and sharing of results will be organised when the need arises.

In addition to training a group of expert users, CASS will interact regularly with ASKAP science teams via the monthly ASKAP Early Science Forum videoconference meetings.

The following table indicates the intended capabilities of the ASKAP pipelines at the time of Early Science:

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¹ This will be on the /scratch2 Lustre file system, where BETA measurement sets are currently kept prior to storage in the commissioning archive.
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<tr>
<th>Capability</th>
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<tr>
<td>Continuum MFS imaging</td>
<td>The workhorse continuum imager. Standard procedure is to run multi-scale, multi-frequency synthesis across the full 304MHz bandwidth. This will be capable of processing all 36 beams.</td>
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<tr>
<td>Full-Stokes continuum cubes at 1MHz resolution</td>
<td>The imager will also be able to produce continuum cubes in all Stokes parameters.</td>
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<tr>
<td>RM-Synthesis</td>
<td>This is the standard approach required for the POSSUM survey with full ASKAP, with RM synthesis performed on the extracted full-Stokes spectra at the location of identified Stokes-I sources.</td>
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<tr>
<td>Full spectral-resolution cubes</td>
<td>The imager will also be able to create full spectral-line cubes, imaging at 18.5kHz resolution. Continuum subtraction will be available in this processing mode.</td>
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<tr>
<td>Source-finding</td>
<td>The Selavy source-finder will be used to create source catalogues in all imaging modes (continuum, polarisation, spectral-line, absorption-line), and provide extracted spectra and moment-maps of detected sources as required.</td>
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<tr>
<td>Bandpass calibration</td>
<td>The bandpass calibration parameters will be determined from observations of B1934-638. The details of the calibration observations are still to be determined.</td>
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5.2 Likely restrictions on Early Science processing and capabilities

The Early Science program will not be the only activity involving the telescope and central processor at that time. There will be on-going commissioning activities, both with the telescope as additional PAFs are installed and enabled, and with the software pipelines as development and scaling work is done to prepare for the automated processing of full ASKAP datasets.

This will limit the amount of time available on galaxy for the processing of Early Science observations. It is currently anticipated that approximately 30%-50% of the galaxy system will be available for Early Science processing during this period, although this figure may be revised closer to the time as we better understand the actual performance of the software and other commissioning requirements.

It must also be recognised that the capabilities available in the ASKAPsoft pipelines for Early Science will be limited. The ASKAP computing team is not in a position to develop new functionality for the pipelines beyond that detailed above. Developing functionality that is not required for ASKAP Survey Science Projects is out of scope, however CASS will be submitting a proposal for a data post-processing and storage allocation to support early science teams to conduct their own advanced data processing at the Pawsey Centre.
6  Frequently Asked Questions

When will early science surveys start?
ASKAP early science surveys will begin as soon as the pilot observations with ASKAP-12 yield results deemed of acceptable scientific quality by the ASKAP Project Scientist, in consultation with the ASKAP user community. If one pilot survey fails for technical or operational reasons, CASS will make every effort to facilitate a second pilot observation to ensure that early science streams can begin as soon as possible.

How much time is each program allocated?
There are no formal time allocations for ASKAP early science. Each program will be adjusted and reviewed on an on-going basis through interactions such as ‘busy weeks’ and the ASKAP early science forum. Data quality and the progress of science research will be monitored. Early science observations will be reviewed regularly to maximise data quality and scientific impact.

When will ASKAP early science end?
The primary constraints on early science will be (i) the available time on the array not required by the commissioning team (ii) the available compute resources at the Pawsey centre (iii) availability of operations staff to carry out observations and run pipelines (iv) the end of ASKAP construction and commissioning, leading to availability of the full array.

The strawman presented in Section 4.4 should be viewed as a guide to assist science teams with planning their early science projects. CASS will review this model on an on-going basis as the early science and the commissioning programs progress.
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