ASKAP Pilot Surveys Phase II: Commensality and Efficiency

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1 Introduction

This document describes plans for a second phase of Pilot Surveys with ASKAP, to be conducted before commencement of routine observations for the full survey campaigns. The main focus will be to merge as many survey strategies as possible into a common set of observations so that multiple survey data products can be obtained from the same scheduling block. This will be essential to meet the goals of ASKAP's science teams in a reasonable number of years. We have seen that data storage is likely to remain the most significant practical limitation for ASKAP operations, providing additional motivation to minimise the amount of raw data required to meet survey science goals. Ultimately, data processing will need to keep pace with incoming data, and Pilot Surveys Phase II offers an opportunity to test procedures that bring us closer to that goal.

The observatory will attempt to improve data throughput and reduce the time between an observation and deposit of associated data products to CASDA. We will implement a more automated data management workflow that utilises a new ingest cluster and storage array at Pawsey, with the ultimate goal of fully isolating observing and processing activities.

2 Background

The first phase of ASKAP Pilot Surveys commenced in July 2019 and concluded in May 2020. Each team was granted 100 hours of telescope time, with the goal of testing proposed survey strategies and science data quality. Each team also developed their survey strategy independently. The strong focus on science readiness and data quality has helped prioritise development work required to meet quality standards in several key areas, including improved continuum subtraction and flux scale corrections across the field of view.

Developing independent survey strategies has been an extremely useful exercise, however it is not feasible to observe each team's full survey completely independently. Covering the entire visible sky, even with ASKAP's large field of view, requires over 1000 fields (depending on wavelength and footprint). With integration times of up to 16 hours required to reach sensitivity limits, a single all-sky survey could take 2 years of continuous observing. Conducting all survey projects independently could therefore take 10 to 15 years. Although there is currently no hard limit to the length of time ASKAP will remain operational, it was expected that the first group of surveys would be completed in about 5 years. This will clearly require the merger of as many observing strategies as possible into a combined survey strategy that is designed to meet several science goals with every scheduling block observed.

Some of the survey strategies cannot be made compatible with other observations due to configuration exclusivity (e.g. zoom observations with reduced continuum bandwidth or deep studies of less than the whole sky). This limits the efficiency that can be gained from commensal observing, but makes it important to consider all reasonable compromises. It is likely that some of the existing strategies could be combined with minimal impact on science outcomes. The purpose of the second phase of Pilot Surveys will be to implement a combined survey strategy and test whether we can achieve a significant improvement in total observing time while preserving the required data quality and improving throughput rates.

There are some technical capabilities that could significantly improve ASKAP's commensal efficiency, most notably split-band mode. However, since considerable development work is required to implement additional capabilities, building a combined survey strategy that relies on new features would lead to delays in starting Pilot Surveys Phase II.

For reference, we list in Table 2 the properties of the ASKAP Phase I Pilot Surveys.

Code	Survey	Mode	ν (MHz)	t_{int}	Footprint	Pitch	Rot.	Inter.	n_{field}
AS101	EMU	continuum	944	10 hr	closepack36	0.9	0	-	10
AS102	WALLABY	spectral	1296	16 hr	square_6x6	0.9	varied	2x	6
AS103	POSSUM	continuum	1296	10 hr	closepack36	0.9	0	-	10
AS104	DINGO (a)	spectral	1290	varied	square_6x6	0.9	varied	2x	3
AS104	DINGO (b)	spectral	1004	varied	square_6x6	0.9	varied	2x	1
AS106	CRAFT (a)	continuum	1296	100 hr	closepack36	0.9	170	-	1
AS106	CRAFT (b)	N/A	varied	varied	varied	varied	varied	varied	many
AS107	VAST	continuum	888	0.2 hr	square_6x6	1.05	0	-	113
AS108	GASKAP	16x/32x	varied	varied	closepack36	0.9	varied	3x	7
AS109	FLASH	spectral	856	2/6 hr	square_6x6	1.05	0	-	38
AS111	LIGO	continuum	944	10.5 hr	closepack36	0.9	0	-	-

3 Motivation

Our goal is to find a mode of operation that optimises access to survey data products for all ASKAP Survey Science Teams (SSTs) while improving data throughput and operational efficiency. Creating a combined strategy and providing science data to all teams promptly is challenging given the varying levels of technical complexity associated with each survey project. However, we feel that the effort in planning and the compromises that may be required will create a more inclusive, efficient and productive environment. ASKAP is a very different instrument to previous ATNF telescopes and we aim to explore new operational models to make the most of its capabilities.

Pilot Surveys Phase II will be an important opportunity to form commensal partnerships. The total time allocated will be similar to Pilot Surveys Phase I, i.e. 100 hours per survey team (with a few exceptions detailed later). We will allocate extra time to teams who have not received the expected amount of science-ready data from Pilot Surveys Phase I. Because we are planning to combine survey strategies where feasible, we hope that most teams will receive significantly more than 100 hours of useful data.

4 Survey Strategy

Feedback from the first phase of Pilot Surveys will determine whether the telescope is meeting science data quality requirements. However, even before all data are fully processed and assessed, it should be possible to revise survey strategies for Pilots Phase II.

Table 2 shows that there is potential for optimisations to have a significant impact on overall efficiency, especially for the all-sky survey projects. These could include, for example, agreement on standard observing frequencies, beam footprints, pitch and tiling schemes for each band. Pilot Surveys Phase I was observed over a period of roughly one year, with an intensive one-month block of time at the end. Phase II will be more structured, with an initial opportunity for technical test observations, followed by quality gates and finally, a high-throughput survey observing campaign with no opportunity for reprocessing.

4.1 Mode considerations

ASKAP cannot switch rapidly from one band to another due to overheads in the configuration process, update of beam weights, calibration and so on. This is likely to improve over time (and is already becoming more automated), but the most efficient and reliable mode of operation will likely involved minimising changes to the telescope's configuration (in particular, the filter band). Minimising the total number of modes required to complete surveys is therefore a key aspect of commensality and efficiency. Parameters that define an observing mode include:

- Filter band
- Centre frequency
- Beam footprint
- Frequency resolution
- Integration time
- Interleaving strategy

The finer points of footprint selection and the related topic of interleaving strategy have been discussed extensively, with the prime considerations being the level of variation in sensitivity across the field and obtaining the best spatial frequency sampling over the total integration time.

4.2 Beam footprints and interleaving

Because phased array feeds are a new technology, Pilot Surveys Phase I experimented with several different beam footprints. Unfortunately, overheads associated with footprint creation, maintenance and calibration are quite high from an operational perspective. It will be important to minimise the number of beam footprints required to maximise survey efficiency. For example, GASKAP uses closepack36 with rapid interleaving to ensure Nyquist spatial sampling, while WALLABY does not need the same amount of beam overlap and used square_6x6 with per-block interleaving. The closepack36 footprint requires 3 interleaving positions to achieve uniform sensitivity compared with two for square_6x6. The number of interleaves does not impact the total integration time, but it does influence how UV sampling is distributed. Using closepack36 with a slightly smaller beam spacing could meet noise uniformity requirements without interleaving at all, so this aspect of a survey strategy should be considered carefully.

Some individual fields will have total observing time constraints related to their time above the horizon, which is another factor to consider when planning interleaving. The total time required for a large survey depends on the number of fields it contains, which is directly related to the beam spacing. This means there is a trade-off between noise uniformity and survey speed. Small beam spacings have been preferred in the past due to poor models of the primary beam shape at large distances from the optical axis, but this may be less of a concern as we develop new methods of primary beam correction based on measured beam shapes.

4.3 Split band mode

One of the key features of ASKAP's digital system is its flexibility in selecting which channels from a given filter band to process. Digitisation covers roughly 600-700 MHz of bandwidth depending on the filter selected and only 288 MHz can be correlated. This allows the possibility of recording two or more disconnected sections of bandwidth. Given the contamination of the 1200-1300 MHz range with global navigation system satellite interference, the use of split bands in the middle filter (which covers the range 840-1440 MHz) would allow simultaneous observations at (say) 840-984 MHz and 1296-1440 MHz. Split bands would also be necessary to observe widely spaced spectral lines (e.g. for OH science) simultaneously.

The benefit that split band mode provides depends heavily on the science case. Careful analysis of efficiency with and without split band mode will be required to determine whether the additional development effort is justified. Internal discussion suggests that roughly 6 additional months would be needed to implement and commission split band mode and this estimate comes with significant risk of extended delays as it would be difficult to revert the system once work begins.

If split band mode can trim more time from the combined survey strategy than the delay required to implement it, then the feature is likely worthwhile. However, all science teams (even those not impacted by the feature) would need to be aware of the changed timeline. Initial discussions suggest that EMU and POSSUM would prefer to observe solely in the low band because source counts should be higher. In this case we would not implement split band mode for Pilots Phase II, though it may still be implemented at a later time. Split band mode may be the best way to merge EMU, POSSUM and WALLABY into one all-sky survey, in which case we would need dedicated support from CASS engineering teams that would likely impact the delivery timescale of other projects.

4.4 Processing considerations

One of the main goals for Pilots Phase II is to increase data throughput and avoid any reprocessing once survey observations begin. Quality gates will be used to ensure that the nominated processing strategy is producing output suitable for science. By default, the quality gate will be the first field of the observing plan developed for each SST. This will be observed in isolation and processed to completion before any additional fields are observed. Intermediate data products and pre-release data products from this quality gate will be made available to representatives of the SST for quality control prior to CASDA upload. Reprocessing of the quality gate will be allowed if any issues are detected. However, the quality gate field must be uploaded to CASDA and released before observations and processing will proceed in production mode for the rest of the team's Pilot Survey Phase II observing plan.

Outside of the quality gate field, data will only be available via CASDA. The first opportunity that a science team will have to view the survey data is when it appears on CASDA for validation. At this point, it is the responsibility of the SST to accept or reject the deposited data. This decision should be made within two weeks of deposit. Rejected scheduling blocks may be re-observed at the discretion of the operations team if time and resources allow. Rejected data cannot be used for research purposes.

In order to operate in continuous survey mode, we must complete all required processing in less than the time it took to observe each scheduling block (with an efficiency factor that becomes more stringent each year). We expect that the upgrade to Pawsey's computing platform in 2021 will help meet this goal, but we will still need to restrict the amount of reprocessing that takes place. The proposed strategy for Pilots Phase II takes us a step closer to a sustainable operations model and tests the assumption that we can meet science data quality requirements in a single pass, provided the parameters have been tuned on representative data beforehand.

4.5 Access to data from other survey projects

Several SSTs may benefit from, or have the intention to obtain, data products associated with observations outside their own time allocation. While this makes best use of available data, it does not constitute commensality in the sense that it increases processing load without reducing the total number of observing hours. Upon completion of the Pawsey hardware refresh we should have access to computing resources roughly 30 times more powerful than the current platform. At that time, we will re-assess the amount of auxiliary processing that can reasonably be attempted. However, for Pilot Surveys Phase II, we will prioritise key science outcomes for the SST who proposed the observation. Any additional processing will only be attempted if the total amount of processing required can be completed in less than the time it took to observe the scheduling block.

5 Case study

In this section we consider the SWAG-X observatory project as an example of developing a combined survey strategy.

5.1 SWAG-X: Survey With ASKAP of GAMA-09 + X-ray

SWAG-X is an ongoing Observatory Project which was designed to be as commensal as possible, combining the needs of various surveys into two different frequency passes of the GAMA-09 field. This was achieved at a reasonable level for all SSTs with the exception of GASKAP, which is the only survey to require both the 1800 MHz filter and zoom modes. Although the Milky Way will be covered as part of SWAG-X High, it will be at the standard spectral resolution which is largely too coarse for Galactic HI studies and the GAMA-09 region was specifically defined to be away from foreground Galactic emission.

To determine the ideal parameters for SWAG-X, we divided observations into two bands, a high and a low band which accommodate the majority of science cases for SSTs. SWAG-X Low is centred on the standard frequency of 888 MHz, and accommodates science cases for EMU, POSSUM, DINGO (high redshift), VAST, and FLASH, though at slightly different frequencies to what the science teams might otherwise prefer. Conversely, SWAG-X High is centred on 1296 MHz, and accommodates science cases for EMU, WALLABY, POSSUM, DINGO, FLASH (low redshift) and GASKAP (low spectral resolution). CRAFT will piggyback on all observations in commensal mode. The entire SWAG-X region (defined by its overlap with the eFEDS eROSITA performance verfication footprint) can be covered by ASKAP in 6 tiles for both frequencies, although with some extension beyond the eFEDS footprint particularly at lower frequencies.

For reference, we list in Table 5.1 the expected properties of SWAG-X.

Survey	Mode	Frequency	Integration	Footprint	Pitch	Rotation	Interleaved
AS112: SWAG-X Low	spectral	888 MHz	16 hr	closepack36	1.05	0	-
AS112: SWAG-X High	spectral	1296 MHz	16 hr	closepack36	0.9	0	3x

6 Timeline and planning

In April 2020, we began a concentrated campaign to complete observations for the first phase of Pilot Surveys. The observing duty cycle of the telescope, as presented at the April 2020 ATUC meeting, was 33% over the period of Pilot Surveys Phase I. This is expected to increase by 10% per year for the next few years. Given outstanding issues with data quality and the need to improve commensality, we strongly believe that at least one more Pilot Survey is required before full operations can commence.

6.1 Consolidation time: June-December 2020

While it is possible to process some observations in roughly the same amount of time required to gather the data, the same is not true of all modes. We have also found that many Pilot Surveys Phase I observations needed some amount of re-processing for parameter tuning, additional flagging or improvements to algorithms. With the disk configuration at the time, intensive processing could interfere with ingest of new data from the telescope. Processing activity was therefore kept to a minimum during the intensive observing campaign. Upon conclusion of Pilot Surveys Phase I observing we have a significant data backlog that will need to be cleared before observations can resume. This provides a natural buffer for consolidation and planning of Pilot Surveys Phase II.

For the reasons outlined above, the second half of 2020 has been used for data processing, consolidation of development, testing, and integration of changes to the telescope software and systems. There is no plan to conduct further survey observations during this time, though time-critical observations will be considered, along with test observations required to support and verify engineering changes. If time allows, we may conduct further observations for the SWAG-X and RACS observatory projects.

6.2 Survey Strategy Preparation: June 2020 onwards

The level of commensality we can achieve will be governed by science outcomes in conjunction with a reasonable timeline for completion. We will not enforce commensality decisions that greatly degrade science outcomes, but teams should be aware that the overall timescale for ASKAP surveys hinges on the level of commensality that can be achieved and we may insist on reasonable compromises to keep the surveys well bounded. The SSTs are expected to discuss opportunities for commensality between themselves and consult with the ASKAP operations team on technical capabilities or operational restrictions. The observatory will provide documentation such as a system description paper, this plan, and various memos as necessary.

Pilot Surveys Phase I strategies for all teams are documented on the SST Confluence page[1]. We refer teams to the report on Pilot Surveys Phase I ("ASKAP Pilot Surveys and the path beyond") which is also available through Confluence. Pilot Surveys Phase II observations should be designed to improve over Pilots Surveys Phase I in some way. We anticipate incremental improvements to data quality as a result of ongoing development, but each SST should also consider whether Pilot Surveys Phase II can provide additional information that will assist in preparing the the full surveys.

6.3 Initial workshop: August 2020

In August 2020, we held a community workshop to establish high-level survey merger possibilities as described above. During the workshop it became clear that there are significant barriers to achieving commensality. While EMU and POSSUM expect to be fully commensal, their joint science goals are optimised by observing in the low band at around 900 MHz, while WALLABY must observe in the mid band. Other projects tend to have mutually exclusive constraints such as the need for high cadence vs deep integration. As a result, we are investigating whether the timescale of ASKAP's first full-scale surveys can be extended by several years. This would avoid the need to make compromises that impact science outcomes. Even so, it is likely that technology and data processing capabilities will evolve significantly over the 5 to 10 year timescales required for full surveys. It is also likely that we will need to interrupt survey operations for extended maintenance and upgrades to the array. There may also be some impact in terms of RFI from SKA construction activities. We will therefore need to review the progress of full surveys on a regular basis to ensure that we continue to make the best use of the telescope.

[1] https://confluence.csiro.au/display/askapsst/Survey+Plans

6.4 Pawsey ingest cluster refresh

Pawsey delivered a new ASKAP data ingest cluster as part of the hardware refresh project in October 2020. This will need to be commissioned before commencing Pilot Surveys Phase II. Since the hardware is already in place and commissioning is underway, we do not anticipate major delays. We expect to transfer the MRO network link to the new ingest cluster in late November. The new cluster includes a small (500 TB) but isolated SSD storage array that should allow processing and observing to co-exist in all modes. This expectation will be thoroughly tested in advance of and throughout Pilot Surveys Phase II.

6.5 Specifying tests and Pilot Survey Observations

The ASKAP Operations team will create a detailed observing plan for Phase II based on technical feasibility and configuration constraints, in consultation with the survey teams. We initially expected this to follow quickly after the workshop, but the lack of clear opportunities for commensality and the need to complete Pilots Phase I processing has extended this timeline. In November 2020, we will provide information on how to specify observing requests. We will use the same specification approach for test observations and survey observations, though these do not have to be entered all at once.

We will be gathering requests for technical test observations and Pilot Surveys Phase II science fields using online spreadsheets. Each SST will have access to their own spreadsheet. These will be used to track the overall progress of observations, while the Observation Management Portal can be used to check the status of individual scheduling blocks. The spreadsheet approach is both human and machine readable, providing an effective prototype with which we can build experience for full operations. We outline the parameters needed from SSTs for this specification in the appendix of this document.

6.5.1 Technical Test Observations

Requests for technical test observations will be accepted prior to the start of Pilots Phase II, and with sufficient lead time to inform the requested survey strategy. These tests may be possible before Pilots Phase I processing is complete, but it would be preferable to wait until the closing stages. At this stage, we do not expect to begin test observations until early 2021.

Technical tests should address issues with the ASKAP system or trial the first use of a new telescope configuration, e.g. re-verification of zoom modes once issues related to loss of coherence are solved. Observations involving the use of an existing mode on a new part of the sky should be used as a quality gate (and included as part of the Pilot Survey specification) rather than a technical test.

6.5.2 Quality Gates

The first field observed as part of the Pilot Survey for a given team (or combination of teams) will act as a quality gate. This field should be representative of the remaining fields. If the pilot will cover several regions with very different properties, it may be appropriate to nominate more than one quality gate for each such region.

Quality gate observations will be reprocessed until the associated SST is willing to verify and release the data products on CASDA. They will have a high observing and processing priority. While a quality gate is being processed, no further observations for the associated Pilot Survey will be conducted. This is to ensure that we do not occupy disk space with data that may not be viable.

6.6 Pilot Surveys Phase II: First Quarter 2021

Quality gate observations for Pilot Surveys Phase II will begin when several prerequisites are met. These include:

- Processing of Phase I data is complete
- The new ingest cluster has been commissioned
- All required disks at Pawsey have been cleared
- Key consolidation development has been completed

Once the quality gate observation has been released, the associated survey observations will begin, though with a lower priority than other quality gates.

6.7 Time Allocation

The ASKAP Operations team will determine time allocation following the general principle of 100 hours per team (combined in commensal modes where possible, e.g. 200 hours for a combined EMU and POSSUM), with exceptions for GASKAP (100 hours each for OH and HI given problems with zoom mode coherence in Phase I), DINGO (150 hours to better test long integrations that form a key part of their science case and in the absence of split-band mode) and CRAFT (fully commensal with all non-zoom observations, therefore needing no dedicated time). Any disputes over the allocation of time, mode, etc. will be mediated by the ASKAP summit committee in the first instance or the CASS director if necessary.

7 Data access, release and publication policy

All Pilots Phase II data are covered by the standard ASKAP usage policy and remain property of the observatory (not the science teams). All data are expected to be released on CASDA if they are suitable for some form of science. One of the goals of Phase II will be to reduce the time taken for quality control. The target turn-around time of two weeks between upload (level 5) and release (level 6) established for Pilots Phase I was rarely realised in practice, but this goal will be enforced for Phase II and supported by an application programming interface for large scale validation tasks, which is currently under development.

The ASKAP publication policy applies to all data, which means that data released on CASDA can be freely used by anyone. Papers should not make use of unreleased data, but if this is unavoidable, they must follow the Early Science procedure and seek optional authorship as described in the publication policy.

8 Conclusions

ASKAP's unique survey capabilities have the potential for significant scientific impact, but also pose unique operational challenges. We feel that another phase of Pilot Surveys is justified due to the need for improved commensality and data throughput. As outlined above, Pilot Surveys Phase II will play a key role in continuing ASKAP on the path towards full survey operations.

A Phase II specification parameters

For Phase II test and survey observations, we will require the following parameters for each field to be provided by the SSTs. While we would prefer the information to be delivered using the machine-readable table format, we will also accept a parset as input which will be internally converted to the online table format. We welcome feedback on these input parameters and formatting and will work with SSTs to ensure the process of providing input is as straightforward as possible. Any unnecessary fields should be left blank.

The parameters are:

- **obstype [string, e.g. Observatory Project]:** the type of observation being specified, currently drawn from: Technical test, Quality gate, Phase II or Observatory Project
- **name [string, e.g. eFEDS_low_T0-0A]:** name of the field
- **ra [string, e.g. 08:38:49.742]:** right ascension of the field in sexagesimal J2000
- **dec [string, e.g. -01:39:31.93]:** declination of the field in sexagesimal J2000
- **rotation [float, e.g. -45.160]:** the rotation of the footprint in degrees (note: this value includes the -45° offset typical of ASKAP observations due to orientation of the PAF).
- **obstime [integer, e.g. 28800]:** the observation integration time in seconds
- **centrefreq [float, e.g. 864]:** the central frequency of the observation in MHz
- **filterband [string, e.g. FILTER_1200]:** the filter band of the observation, which can only be any of the following: FILTER_1200, FILTER_1450 or FILTER_1800
- **mode [string, e.g. standard_continuum]:** defines the zoom mode of the data (standard, or one of zoom2x, zoom4x, zoom8x, zoom16x or zoom32x) and its channel resolution (spectral or continuum)
- **footprint [string, e.g. closepack36_1.05_45]:** defines the footprint parameters of the observation in the condensed format: NAME_PITCH_ROTATION
- **haoffset [string, e.g. +]:** if there is a preference for the hour-angle offset of the observation, this can be specified as a + or - (note: this is generally only applicable to short observations, as most long observations are centred on transit)
- **interleaved [boolean, e.g. TRUE]:** defines whether the field will be interleaved during an observation (note: for daily interleaving, each interleave should be specified as a separate row in the spreadsheet due to the need to track observation success separately)
- **interval [integer, e.g. 900]:** defines the interleaving interval in seconds
- **name2/ra2/dec2/rotation2 [as above]:** same format as name/ra/dec/rotation, but for interleaving position #2 (only if interleaving and relevant)
- **name3/ra3/dec3/rotation3 [as above]:** same format as name/ra/dec/rotation, but for interleaving position #3 (only if interleaving and relevant)
- **priority [integer, e.g. 2]:** priority of a given field in the range 1-3, where 1 is the standard priority and 2 or 3 escalate the field in priority (note: this priority only applies relative to the pool of fields for a given SSP, not the overall observational priority)

An example of the spreadsheet format with filled-in data for RACS-MID can be found here:
https://docs.google.com/spreadsheets/d/1U4LUZL-e_4RWBToyecLESFdur8sXWAfKidOXyB9l8k0

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