The technological and scientific development of ASKAP

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Abstract

Science results from pilot surveys with the full 36-antenna Australian Square Kilometer Array Pathfinder (ASKAP) have increased strongly over the last few years. This trend is likely to continue with full surveys scheduled to commence later this year. Thanks to novel Phased Array Feeds each ASKAP pointing covers around 30 square deg, making it a fast survey machine delivering high-resolution radio images of the sky. Among recent science highlights are the studies of neutral hydrogen in the Magellanic Clouds as well as nearby galaxy groups and clusters, catalogs of millions of radio continuum sources, the discovery of odd radio circles, and the localization of fast radio bursts, to name just a few. To demonstrate the ASKAP survey speed we also conducted the Rapid ASKAP Continuum Survey (RACS) covering the whole sky south of declination +41 deg at 15 arcsec resolution.

1. ASKAP surveys

Pilot Phase II of the large ASKAP science surveys, which were initially approved in 2009, focused on project commensality and is nearly complete. It was preceded by the Early Science Phase (ASKAP-12) and the Pilot Survey Phase I (see Figures 1 & 2). The Pilot Survey Phase II is likely completed by the time this meeting takes place. This will be followed by a consolidation period designed to further improve the telescope systems in advance of full surveys and migration of ASKAP’s processing pipeline to the new Pawsey Setonix platform. Once this is done, the full surveys can get under way (pending the outcome of updated proposals submitted in late 2021). For a description of the ASKAP system design and capabilities see Hotan et al. (2021).

Figure 1. The Australian SKA Pathfinder (ASKAP) is a powerful radio interferometer which consists of 36 x 12-m dishes, forming a 6-km diameter array. Each ASKAP antenna is equipped with a wide-field Phased Array Feed (PAF) allowing to form 36 beams that together provide a typical field of view of 30 square degree. See Hotan et al. (2021) for more details.

Figure 2. The ASKAP count-down clock, created by the ASKAP communications team.

ASKAP data are processed with the ASKAPsoft pipeline (Guzman et al. 2019) at the Pawsey Supercomputing Centre.

(1) https://data.csiro.au/domain/casdaObservation
(2) https://data.csiro.au/domain/casdaSkymap/search
Centre. The pipeline development, which includes
the creation of some source catalogues, is carried out in close
 collaboration with the survey science teams (e.g., Serra et
al. 2015a, Heywood et al. 2016, Kleiner et al. 2019). The
resulting ASKAP data products are uploaded, validated
and made public in the CSIRO ASKAP Science Data
Archive (CASDA1). An interactive CASDA Skymap2
allows users to visualize surveys, overlay catalogues and
explore the source parameters.

The CASDA Skymap currently highlights the Rapid
ASKAP Continuum Survey (RACS), which was
conducted as an observatory project to demonstrate the fast
survey speed of ASKAP. RACS commenced in April 2019.
The RACS-low data (centred at 887.5 MHz) are publicly
available, while RACS-mid (1367.5 MHz) and RACS-high
(~1700 MHz) observations and processing are under way.
For details of the survey design and first results see
McConnell et al. (2020). RACS-low (903 fields, 15min
integration time per field) has a resolution of ~15 arcsec
and an rms median noise of 250 µJy/beam. RACS-mid and
RACS-high (1493 fields each, 15 min. integration time per
field) are nearing completion.

Another ASKAP observatory project is SWAG-X, which
covers the GAMA-09 field and the eROSITA Final
Equatorial-Depth Survey (eFEDS) at full spectral
resolution. It was observed at both 888 and 1296 MHz
(together 16h per field) and the first dual-band data (6 of
the 12 fields) were released on the 12th of Jan 2022.

There are eight ASKAP survey science projects awaiting
time allocations. WALLABY (Koribalski et al. 2020) aims
to map the 21-cm spectral line of hydrogen (HI) over the
southern sky, while also producing deep radio continuum
maps as a by-product. It is expected to detect ~0.5 million
galaxies, determine their distances, HI and total masses. To
search the huge ASKAP spectral data cubes for sources and
create reliable source catalogs, the WALLABY team
developed a flexible 3D Source Finding Application
(SoFiA; Serra et al. 2015b, Westmeier et al. 2021). EMU
will provide a deep radio continuum survey at slightly
lower frequencies (centred on 944 MHz) expecting to
detect ~70 million galaxies (Norris et al. 2021a). FLASH
searches for intervening and associated HI absorption lines
against distant bright continuum sources and expects to
detect several hundred in each (Allison et al. 2022), while
VAST aims to detect highly variable and transient radio
sources (Murphy et al. 2021). CRAFT uses a specially
designed mode to detect and localize fast transient radio
sources such as FRBs (Bannister et al. 2019). Polarisation
studies are conducted by POSSUM aiming to produce a
catalogue of Faraday rotation measures for around a
million extragalactic radio sources (Anderson et al. 2021).
DINGO is planning to go deep in a small number of
pointings, aiming to detect hydrogen in distant galaxies
with optical redshifts via HI stacking. GASKAP uses high
velocity resolution to focus on spectral line studies of the
Galaxy Plane and Magellanic Clouds (Pingel et al. 2022).

Among the multitude of new ASKAP results are some
spectacular radio sources. Figure 3 shows an ASKAP
continuum image of the giant radio galaxy ESO 422-G028,
re-discovered in ASKAP RACS data. The old radio lobes
are nearly 2 Mpc apart, and a new inner jet shows its central
black hole is active again. Giant radio galaxies stand out
because of their large angular sizes and range of
morphologies. Figure 4 depicts PKS 2014-55 from the
EMU Pilot Survey (Norris et al. 2021a) overlaid onto an optical image from the
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2. Some ASKAP results

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Figure 3. ASKAP radio image of the giant radio galaxy
ESO 422-G028, obtained from public RACS-low data.

Figure 4. ASKAP radio continuum image of the X-shaped
radio galaxy PKS 2014-55 from the EMU Pilot Survey
(Norris et al. 2021a) overlaid onto an optical image from
the Digitized Sky Survey (see also Koribalski 2020).
lobes make it appear like a giant butterfly. Much deeper MeerKAT data (Cotton et al. 2020) reveal that backflow is responsible for the radio wings; see also Koribalski (2020).

Figure 5 highlights the nearby galaxy NGC 1371, a member of the gas-rich Eridanus group. WALLABY has been targeting a number of nearby galaxy groups/clusters to investigate the HI content and shape of galaxies in different environments, studying the effects of tidal interactions and ram pressure stripping on their outer disks.

![NGC 1371](image)

**Figure 5.** ASKAP HI intensity distribution (contours) of the galaxy NGC 1371 from WALLABY, overlaid onto an RGB colour image consisting of GALEX FUV, NUV and DSS B-band images. For details see For et al. (2021).

Odd radio circles (ORCs) were first discovered by Norris et al. (2021b) in the EMU Pilot Survey. A recent ASKAP discovery, ORC J0102-2450 (see Figure 6), was the third such radio circle with a prominent central galaxy (Koribalski et al. 2021), suggesting typical diameters of 300 – 500 kpc. None of the radio rings have – as yet – counterparts at any other wavelength. While some ideas have been put forward, likely related to an energetic event in the associated central galaxy, the ORC formation mechanism currently remains unknown. Deep MeerKAT follow-up observations are in hand and analysis is ongoing. As numerical simulations are under way to explore possible ORC origins, the search for more single and double ORCs continues.

Double radio relics, like the pair shown in Figure 7, highlight shock fronts in galaxy clusters, which tend to be filled with hot gas detectable in X-ray. This makes for a very strong synergy between radio, X-ray and optical data to study galaxy cluster formation, dynamics and evolution (e.g., Brüggen et al. 2021).

![Odd Radio Circle](image)

**Figure 6.** Left: ASKAP radio continuum image (contours) of the recently discovered odd radio circle ORC J0102-2450 overlaid onto a 3-color optical image from the Dark Energy Survey (DES). The 13 arcsec ASKAP beam is shown in the bottom left. For details see Koribalski et al. (2021). Right: Visiting ASKAP and the Murchison Radio-Astronomy Observatory with one of the 36 ASKAP antennas in the background.

![RGB Colour Image](image)

**Figure 7.** RGB colour image of the RXC J2143.9-5637 galaxy cluster (redshift $z = 0.0824$), consisting of ASKAP radio continuum emission (red colours and yellow contours) from the EMU Pilot Survey (Norris et al. 2021a), XMM-Newton X-ray (blue colours and white contours), and DSS optical (green colours) data.

The upcoming full ASKAP surveys will provide a flood of data (spectral line, radio continuum, transients, …) publicly available through CASDA. As a Pathfinder to the Square Kilometer Array, ASKAP is providing us with many valuable technology, computing and science lessons. ASKAP has huge discovery potential, often realized by comparison of the source radio emission with a wide range of multi-wavelength surveys and close collaborations within the international community.
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