INSTITUTE FOR
RADIO ASTRONOMY & SPACE RESEARCH
AN INSTITUTE OF AUT UNIVERSITY

Early Science with *SKA Precursors and Pathfinders*

Sergei Gulyaev

C4SKA, Auckland, New Zealand, 14 February 2020

SKA Precursors & Pathfinders

- The Observatory convention states: “The purpose of the SKAO shall be to facilitate and promote a global collaboration in radio astronomy with a view of the delivery of transformational science.”
- The SKA does not exist yet, but its role in promoting global research and collaboration in radio astronomy and astrophysics is already enormous!
- A great part of this role is directed and guided through SKA pathfinders and precursors.

SKA Precursors & Pathfinders

- In 2008, the SKA Science and Engineering Committee ("SSEC") recognised that there had been a proliferation of self-declared "SKA Pathfinders" and that a clear definition of what constitutes a Pathfinder facility was necessary to protect the SKA brand name. Therefore, the following designations were established:
- Precursor facility: A telescope on one of the two candidate sites
- Pathfinder: SKA-related technology, science and operations activity

Apply for designation

To apply for a designation, an “SKA Contribution” must satisfy one or more of the following criteria in the areas of technology, science and operations:

- it contains new technical elements that have not been tried before on the scale of a large telescope and which are part of the SKA Baseline Design – technology;
- it will carry out observational tests, both simulated and real, that explore new capabilities at flux density and dynamic range levels similar to or scalable to the full SKA – science;
- it tests methods of scheduling and allocating time similar, or scalable to, that needed for the SKA – operations.

Applications for an SKA designation should be sent to the Director-General of SKA Organisation and must include the following:

Home » Precursors and pathfinders
Print this page

Precursors And Pathfinders

Precursor facilities

Did you know?

- Australian SKA Pathfinder (ASKAP)
- MeerKAT
- Murchison Widefield Array (MWA)
- Hydrogen Epoch of Reionization (HERA)

Precursor telescopes like the South African MeerKAT and HERA, along with the Murchison Widefield Array (MWA) and CSIRO's Australian SKA Pathfinder (ASKAP) are providing SKA scientists with invaluable knowledge to assist in the design of the SKA's main telescopes over the coming decade.

Located at future SKA sites, these precursors are and will be in future carrying out scientific study related to future SKA activities, as well as helping the development and testing of new crucial SKA technologies.

Pathfinders

Pathfinder telescopes and systems, dotted around the globe are also engaged in SKA related technolog studies. These include the famous Arecibo radio telescope in Puerto Rico, which starred in the James B "Goldeneye", the LOFAR low-frequency array, which is based in Europe, and the EVLA, in North Americ famously seen in the hit movie "Contact". Here is a list of SKA Pathfinders;

- APERture Tile In Focus (APERTIF), The Netherlands
- Arecibo Observatory, Puerto Rico
- Allen Telescope Array (ATA), USA
- Canadian Hydrogen Intensity Mapping Experiment (CHIME), Canada
- electronic European VLBI Network (eEVN), Europe
- Electronic MultiBeam Radio Astronomy ConcEpt (EMBRACE), France & The Netherlands
- e-MERLIN, UK
- Expanded Very Large Array (EVLA), USA
- Effelsberg 100m Radio Telescope, Germany
- Five-hundred-meter Aperture Spherical Telescope (FAST), China
- Giant Metrewave Radio Telescope (GMRT), India
- Low Frequency Array (LOFAR), The Netherlands
- Long Wavelength Array (LWA), USA
- NenuFAR, France
- Parkes Telescope, Australia
- SKA Molonglo Prototype (SKAMP), Australia
- VLBI Exploration of Radio Astrometry (VERA), Japan

Canada's CHIME Telescope Joins SKA Pathfinder Family

CHIME's huge reflectors are 100m long and each one measures 20m across. (Credit: CHIME)

SKA Pathfinder Telescope CHIME Detects Second Repeating Fast Radio Burst

CHIME is an unusual telescope with no moving parts and a huge field of view, which stretches almost from the northern to the southern horizon. (Credit: CHIME)

Latest News

3rd February 2020
Italy ratifies SKA Observatory Convention

31st January 2020
Astronomers detect distant space-time 'dragging' for the fir time

29th January 2020
SKA signs cooperation agreement with Cherenkov Telescope Array

Japan's VERA Telescope Granted SKA Pathfinder Status

SKA Global Headquarters, 3 July 2018 – The VLBI Exploration of Radio Astrometry (VERA) telescope, operated by the National Astronomical Observatory of Japan, has been officially designated as an SKA pathfinder.

In operation since 2003, VERA uses Very Long Baseline Interferometry (VLBI) to explore the three-dimensional structure of the Milky Way based on high-precision astrometry of Galactic maser sources. It comprises four Cassegrain antennas each measuring 20 metres in diameter.

VERA joins more than a dozen pathfinder facilities around the globe which are contributing to SKA-related technology and science. Pathfinder telescopes provide valuable information to teams working on the design of the SKA, but unlike precursors they are not located at SKA sites.

"VERA mainly performs K (22 GHz) and Q (43 GHz) band VLBI observations. Therefore, science cases at such high

Mizusawa station is one of four across Japan that make

Latest News

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SKA Pathfinder Apertif Officially Opened In The Netherlands

The upgrade means that the Westerbork Synthesis Radio Telescope can now map a patch of the sky 37 times the area of the full Moon. (Credit: ASTRON)

Latest News

3rd February 2020
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Convention

31st January 2020
Astronomers detect dis
space-time 'dragging' fo
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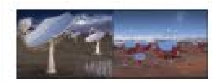
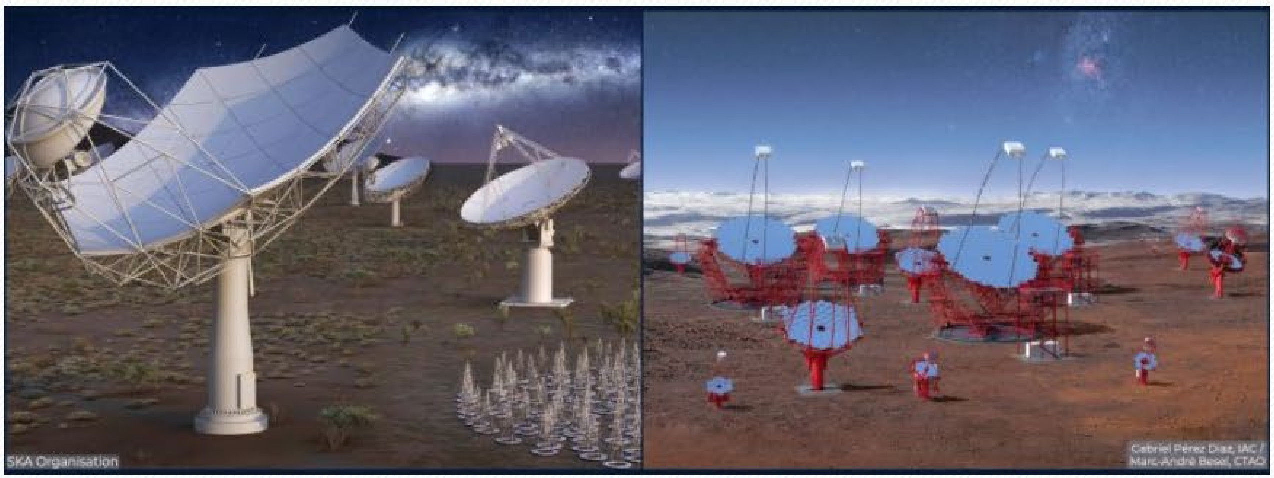


29th January 2020
SKA signs cooperation
agreement with Cheren
Telescope Array

SKA Signs Cooperation Agreement With Cherenkov Telescope Array

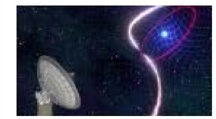


Artists' impressions of the SKA (left) and CTA (right) antennas which will operate in the radio and gamma-ray bands respectively.

SKA Global Headquarters, 29 January 2020 – The SKA Organisation (SKAO) will engage in closer collaboration with the Cherenkov Telescope Array Observatory (CTAO) under a new agreement signed by the two research infrastructures.

Latest News

3rd February 2020
Italy ratifies SKA Obse
Convention



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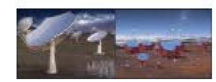


29th January 2020
SKA signs cooperation
agreement with Chere
Telescope Array

COMPUTING | NEWS

SKA and CERN co-operate on extreme computing

11 August 2017

SKA Organisation and NRAO team up to develop next-generation astronomy data reduction software

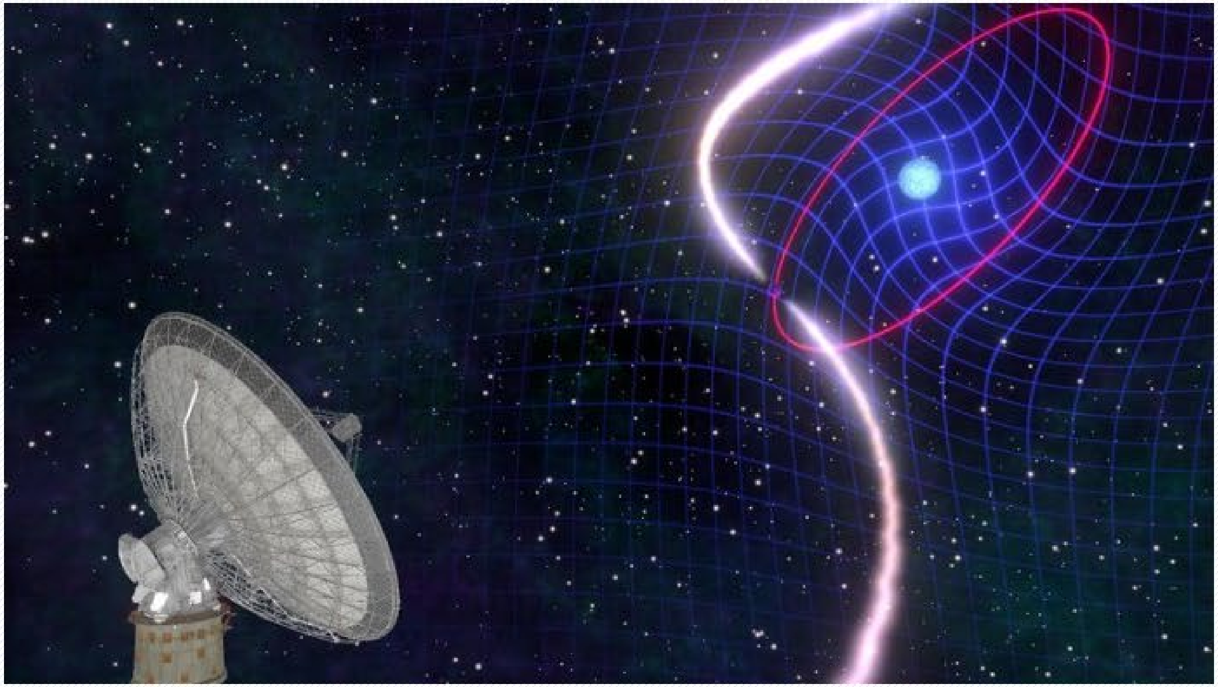
NRAO operates JVLA and ALMA. Home of the ngVLA gravitational effect of the white dwarf resulted in a change in the pulsar's path, known as Lens-Thirring precession (named after the two scientists who predicted this effect in 1918), of around 150km over 20 years. The observations were conducted using two SKA pathfinders: CSIRO's Parkes Telescope and the Molonglo Observatory Synthesis Telescope.

Using the two telescopes, the team were able to measure the arrival times of the pulsar signals. "We could track the pulsar in its orbit with an average ranging precision of 30 km per measurement, over a period of almost twenty years" explained Dr. Vivek Venkatraman Krishnan, the lead author.

New and upcoming radio telescopes such as MeerKAT and the SKA will play a central role in understanding how Einstein's theory is at play in such natural laboratories. "With the SKA expected to detect more exotic binary systems like this one, we'll be able to investigate many more effects predicted by general relativity" concluded Dr. Evan Keane, co-author and sci
Organisation in the UK.

commonly known a
dragging". Later in
and Hans Thirring
support from Alber
calculated this effe
System using gene
particular, they cal
dragging of space-
rotation of the Sun
movement of plane
concluded that the
impossibly small to
time – until now.

Astronomers Detect Distant Space-Time 'Dragging' For The First Time



The white dwarf-pulsar binary system PSR J1141-6545 discovered by CSIRO's Parkes radio telescope – an SKA pathfinder – which was used for the study. The pulsar orbits its white dwarf companion every 4.8 hours. The white dwarf's rapid rotation drags space-

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29th January 2020
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REPORT

Lense–Thirring frame dragging induced by a fast-rotating white dwarf in a binary pulsar system

V. Venkatraman Krishnan[1,2,*], M. Bailes[1,3], W. van Straten[4], N. Wex[2], P. C. C. Freire[2], E. F. Keane[1,5], T. M. Tauris[6,7,2], P. A. ...
+ See all authors and affiliations

Science 31 Jan 2020:
Vol. 367, Issue 6477, pp. 577-580
DOI: 10.1126/science.aax7007

RESEARCH

GRAVITATION

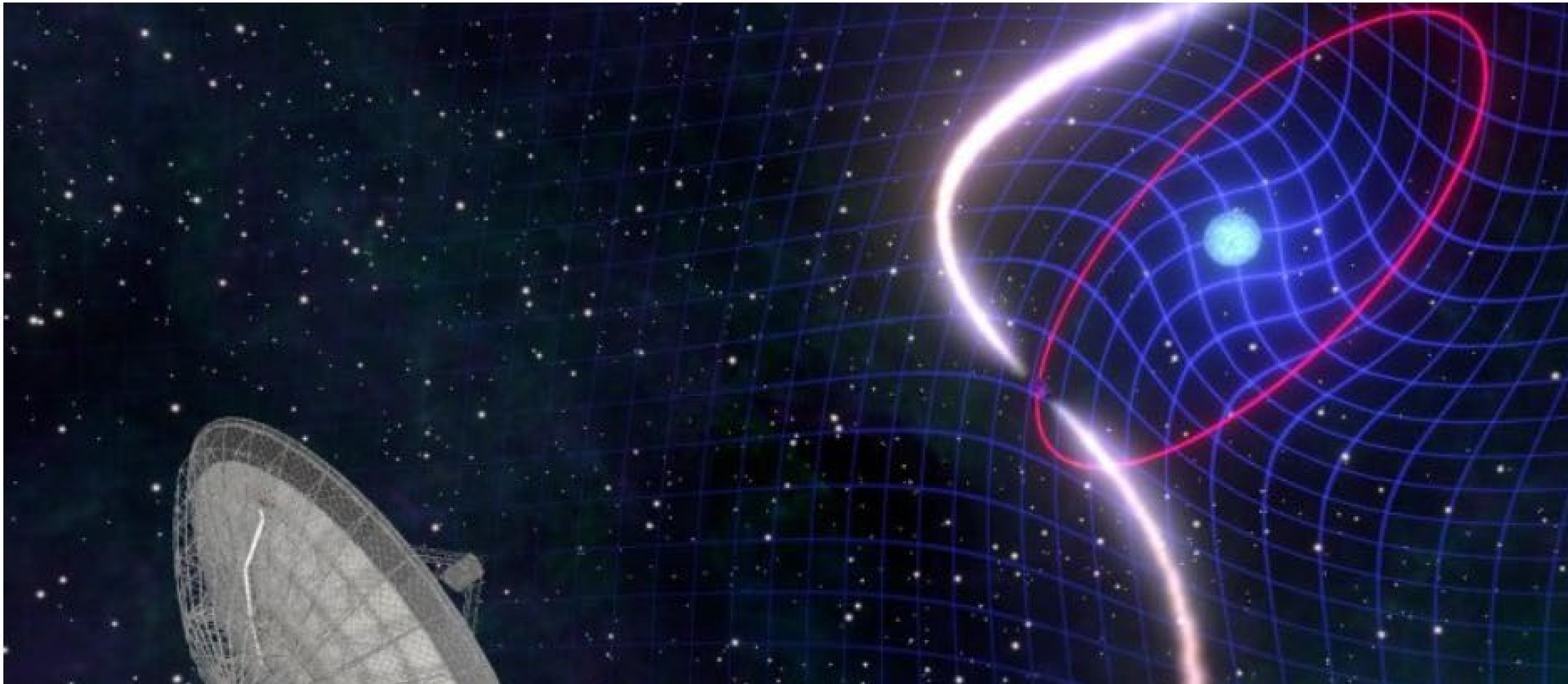
Lense–Thirring frame dragging induced by a fast-rotating white dwarf in a binary pulsar system

by the spin of either the pulsar or its companion is expected to contribute to spin–orbit coupling. These relativistic effects are seen in addition to Newtonian contributions from a mass-quadrupole moment (QPM) induced by the rotation of the body (*6*). Both contributions

Einstein's General Relativity Confirmed: Astronomers Witness the Dragging of Space-Time

TOPICS: Astronomy Astrophysics Popular

By ARC CENTRE OF EXCELLENCE OF GRAVITATIONAL WAVE DISCOVERY JANUARY 30, 2020



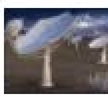
The SKA Link To The Event Horizon Telescope Black Hole Image

SKA Global Headquarters, Jodrell Bank, UK, 15 April 2019 – The first ever image of a black hole released by the Event Horizon Telescope (EHT) Collaboration was made possible thanks to VLBI, a technique the SKA will take full advantage of. One of SKA Organisation's astronomers was also involved in the results.

SKA System Scientist Dr. Robert Laing was part of a global team of more than 200 researchers involved in the result, and he co-authored two of the six papers published in *The Astrophysical Journal Letters* (the summary and instrumentation papers).

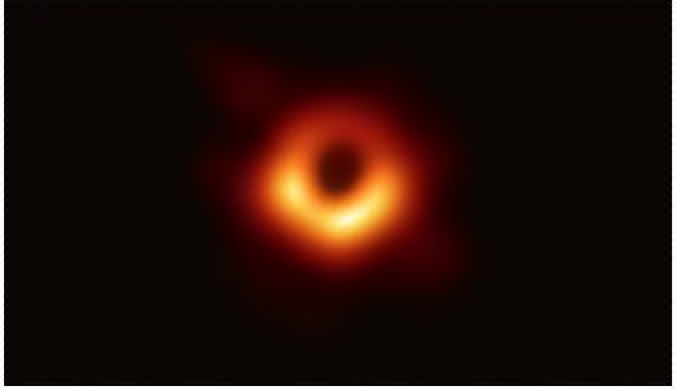
The announcement which was broadcast around the world was also shown at the SKA Science Conference taking place at the same time in Cheshire. 300 astronomers from 20 countries, including some who were involved in the EHT results, gathered to watch the live

Lates



telescopes spread around the globe, using a technique called Very Long Baseline Interferometry (VLBI). By combining the signals from telescopes observing the same object at the same time, but from different locations, the effect is like observing with a radio telescope the size of the Earth. VLBI is a technique that the SKA will contribute to in the future.

"The Event Horizon Telescope goes in very close to the nucleus of an active galaxy," Dr Laing explained. "SKA VLBI will go a little bit further out but in much more detail and sensitivity so they give you complementary pictures of the same objects."

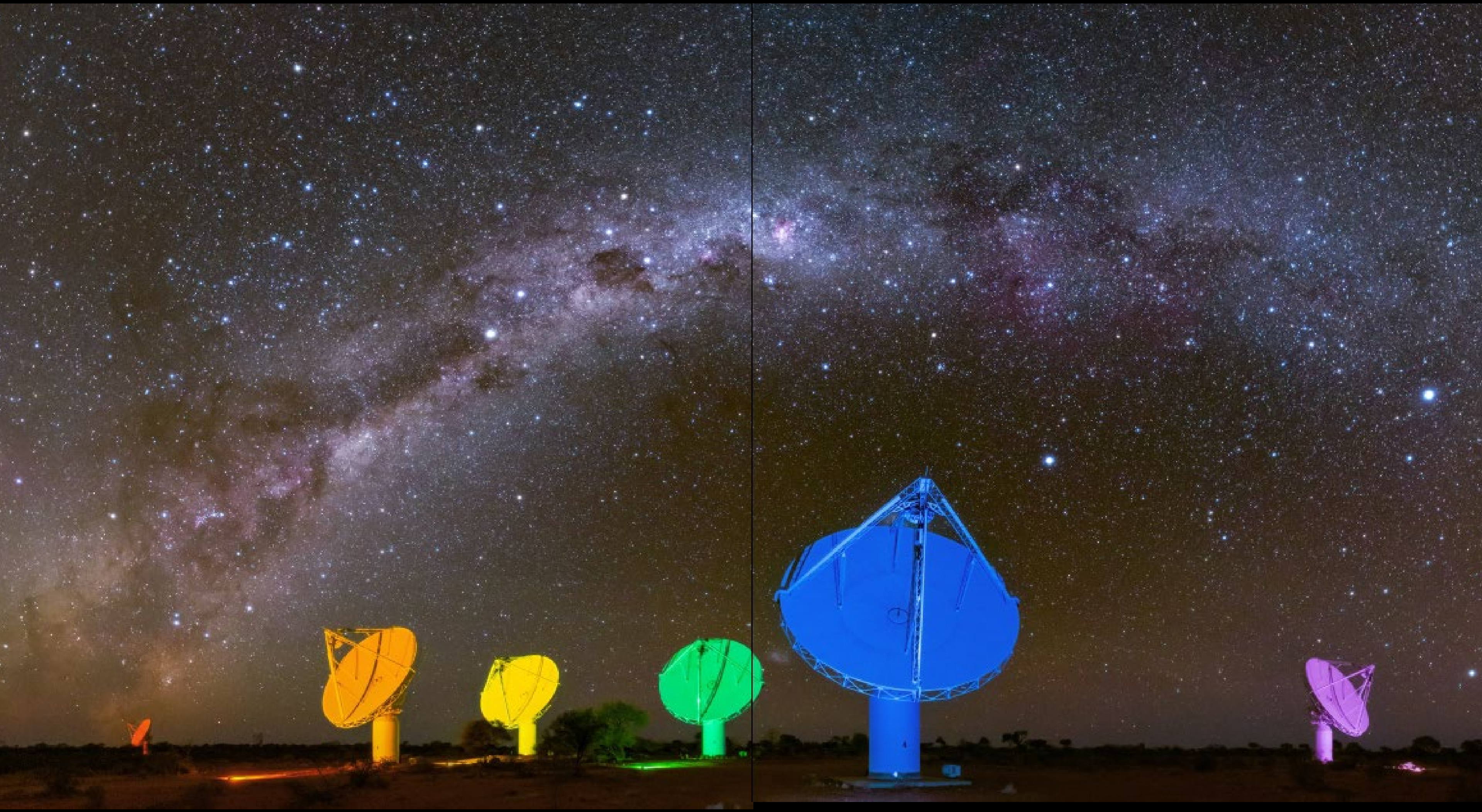


The first direct visual evidence of a supermassive black hole and its shadow (Credit: Event Horizon Telescope Collaboration)

Dr. Laing previously worked for the European Southern Observatory on the ALMA telescope project, which was one of the key facilities in the EHT observations. Read more on the Event Horizon Telescope website.

Listen to Dr. Laing and SKA Organisation VLBI expert Cristina Garcia Miro discuss the result, and the potential synergies between the SKA and EHT, in the video below.

ASKAP at night



ASKAP Survey Science Projects [edit]

In 2009, after an open call for proposals, CSIRO announced that ten major science projects had been selecte
projects' authors, 33% were from Australia and New Zealand, 30% from North America, 28% from Europe, an
world.

The ten ASKAP Survey Science Projects are:

Highest Priority [edit]

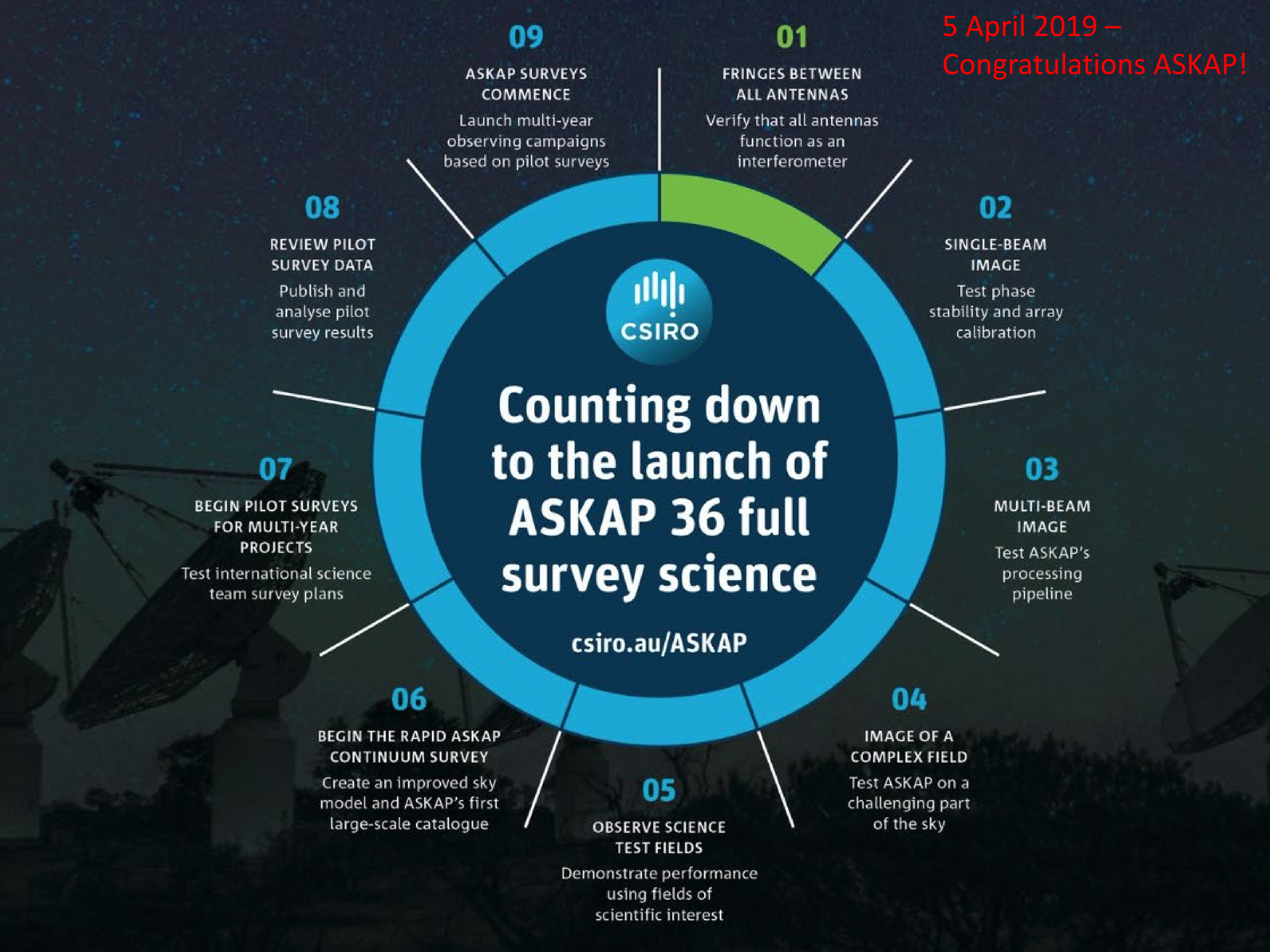
- EMU: Evolutionary Map of the Universe[17]
- WALLABY: Widefield ASKAP L-Band Legacy All-Sky Blind Survey[18]

Slightly Lower Priority [edit]

- COAST: Compact Objects with ASKAP: Surveys and Timing
- CRAFT: The Commensal Real-time ASKAP Fast Transients survey
- DINGO: Deep Investigations of Neutral Gas Origins[19]
- FLASH: The First Large Absorption Survey in HI[20]
- GASKAP: The Galactic ASKAP Spectral Line Survey[21]
- POSSUM: Polarization Sky Survey of the Universe's Magnetism[22]
- VAST: An ASKAP Survey for Variables and Slow Transients[23]
- VLBI: The High Resolution Components of ASKAP: Meeting the Long Baseline Specifications for the SKA

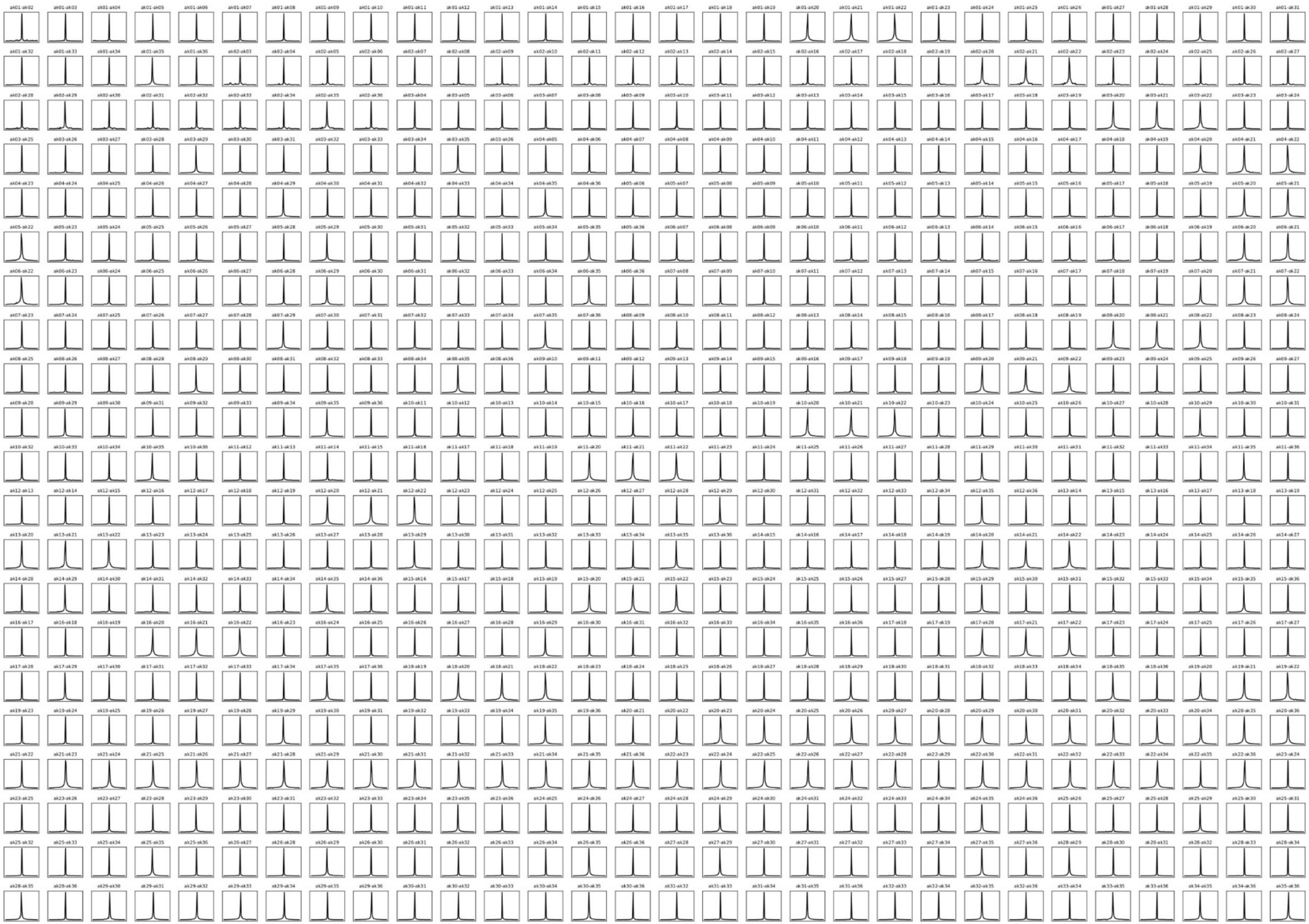

ASKAP Phased array Feed:
188 receivers, 94 for each
polarisation.

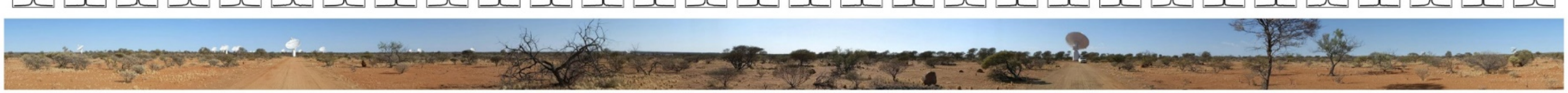
5 April 2019 – Congratulations ASKAP!



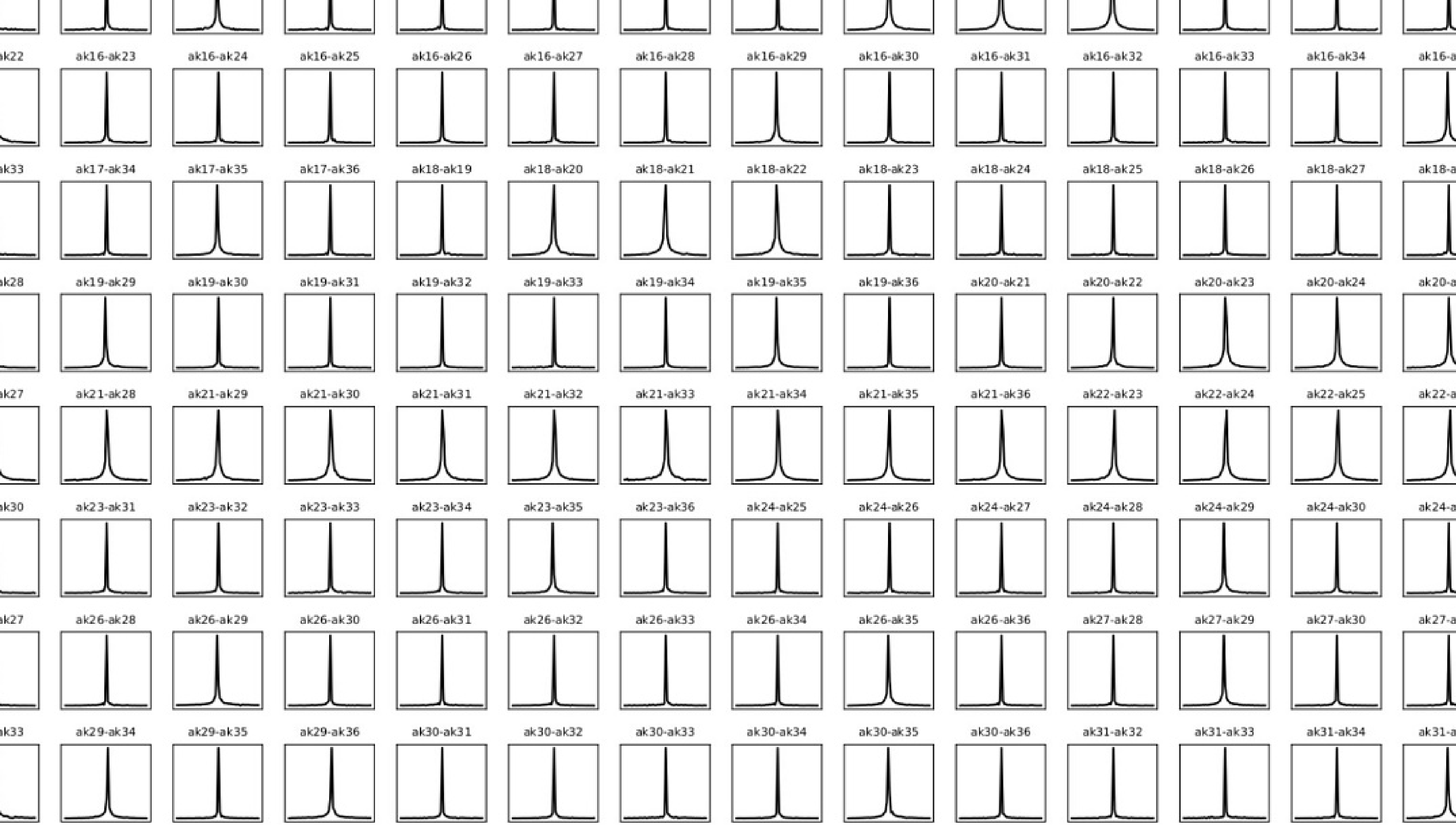
First fringes between all 36 ASKAP antennas

February 22nd, 2019: Correlated signal from PKS B1934-638 detected on 630 baselines





360-degree panoramic photograph showing all visible antennas tracking the radio galaxy PKS B1934-638 during the first calibration observations made with the full array



photograph showing all visible antennas tracking the radio galaxy PKS B1934-638 du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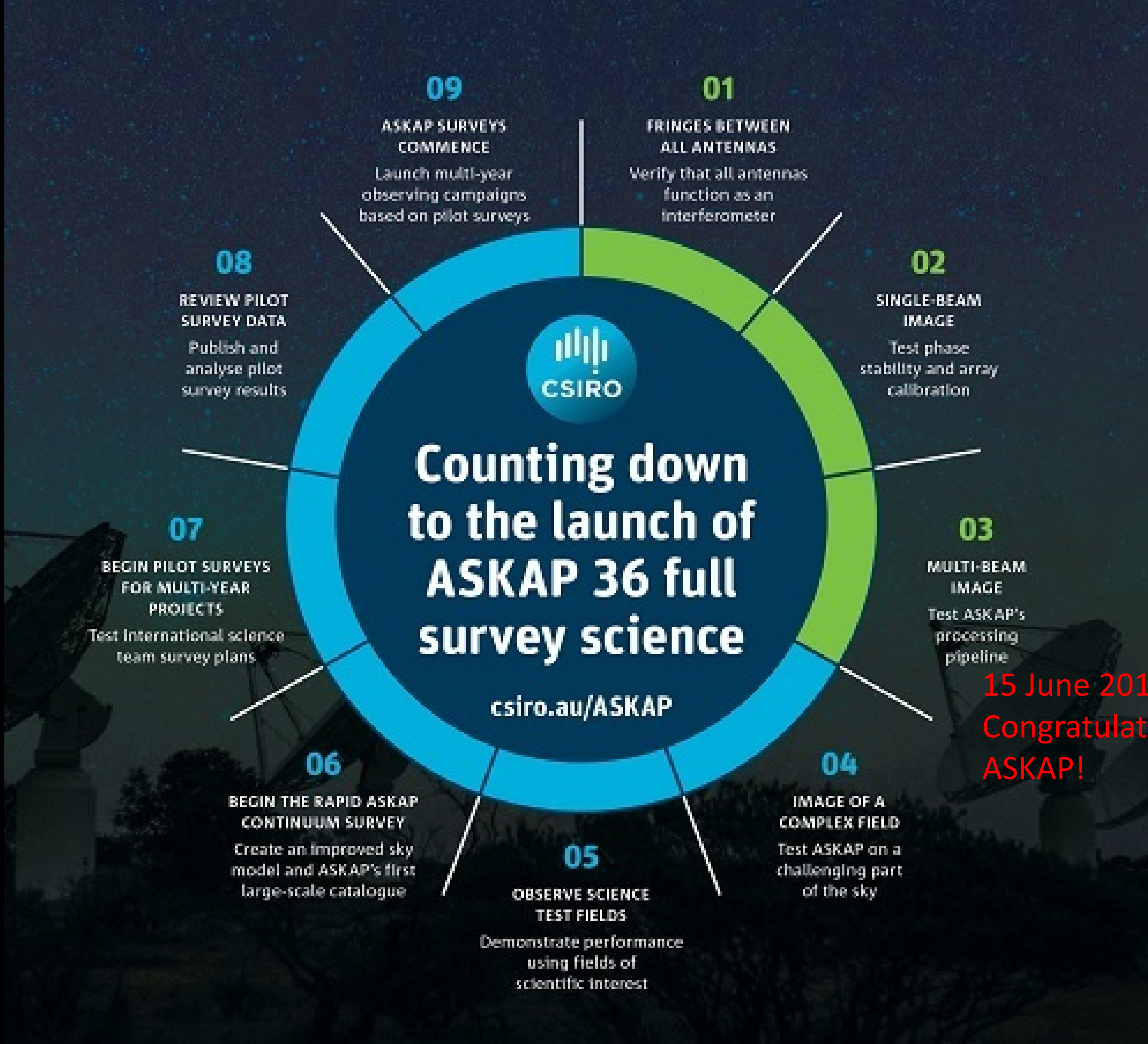
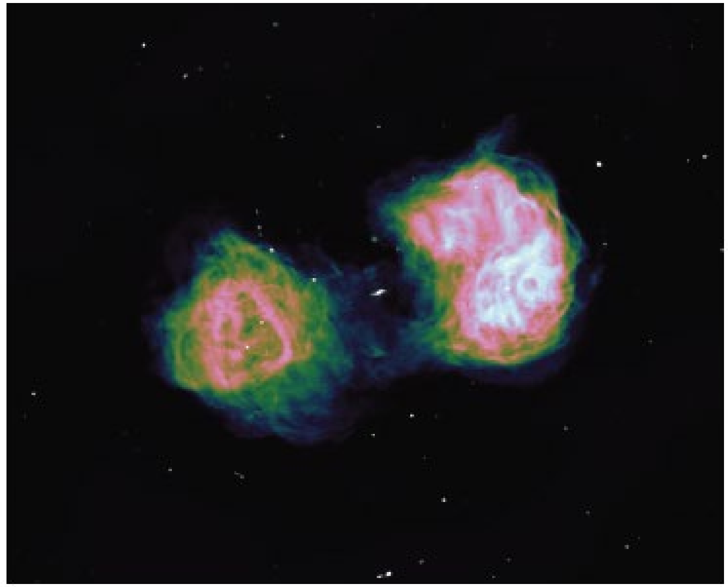
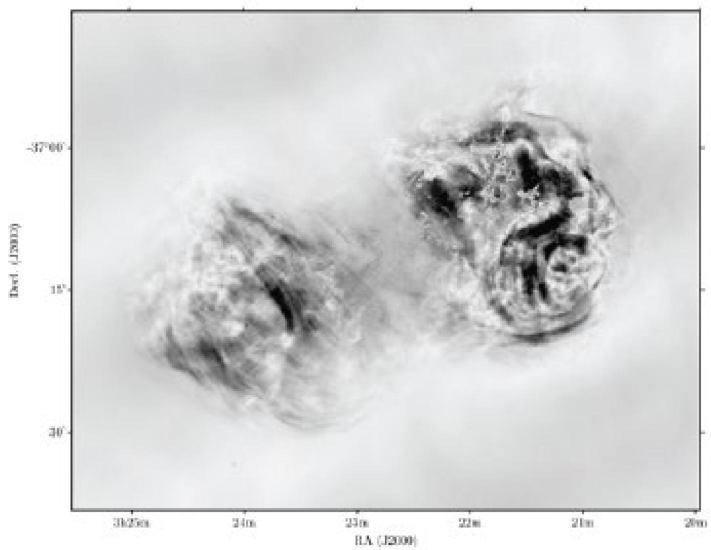


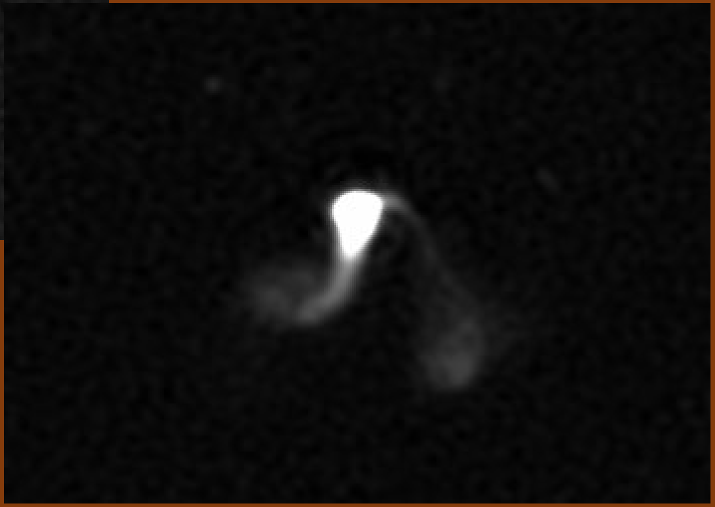
15 June 2019 – Congratulations ASKAP!





Top: this image of the radio galaxy Fornax A was the first to be made with all 36 ASKAP antennas and highlights ASKAP's ability to detect details in extended, diffuse emission. Below: all ASKAP data provides useful polarisation information as X-Y phase alignment is performed automatically at beam formation using the on-dish calibration system. The results shown here compare well with VLA data. Images: Emil Lenc and Craig Anderson.


Jet
Lobe
Galactic centre

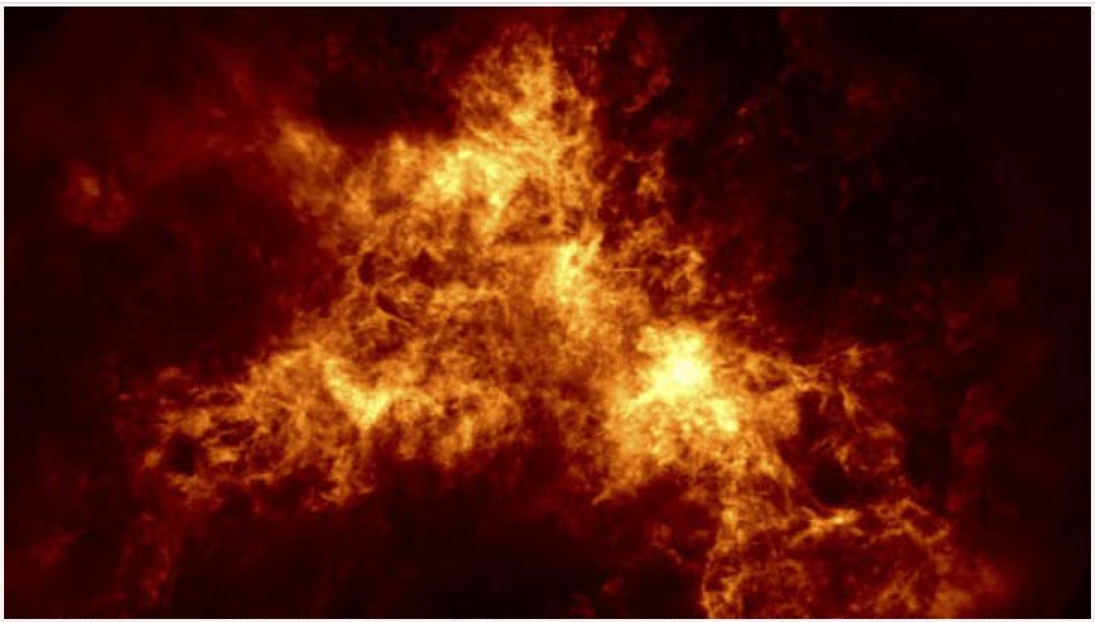


ASKAP Telescope Captures Most Detailed Radio Image of Small Magellanic Cloud

Nov 29, 2017 by News Staff / Source

« Previous | Next »

Astronomers using CSIRO's Australian Square Kilometre Array Pathfinder (ASKAP) at the Murchison Radio-Astronomy Observatory in Australia have created the most detailed radio image of a nearby dwarf galaxy called the Small Magellanic Cloud, revealing secrets of how it formed and how it is likely to evolve.

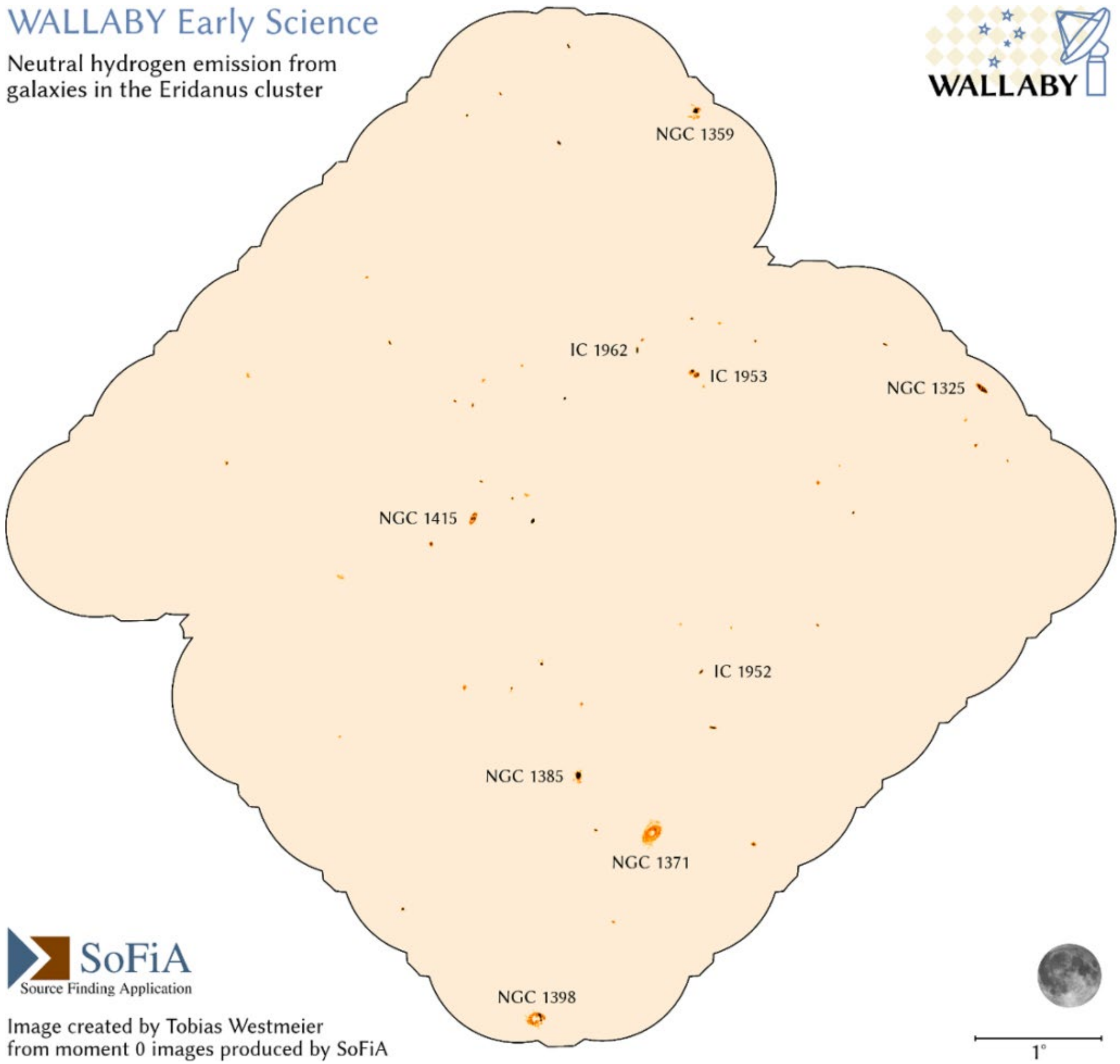


Atomic hydrogen gas in the Small Magellanic Cloud as imaged with CSIRO's Australian Square Kilometre Array Pathfinder. Image credit: Australian National University / CSIRO.

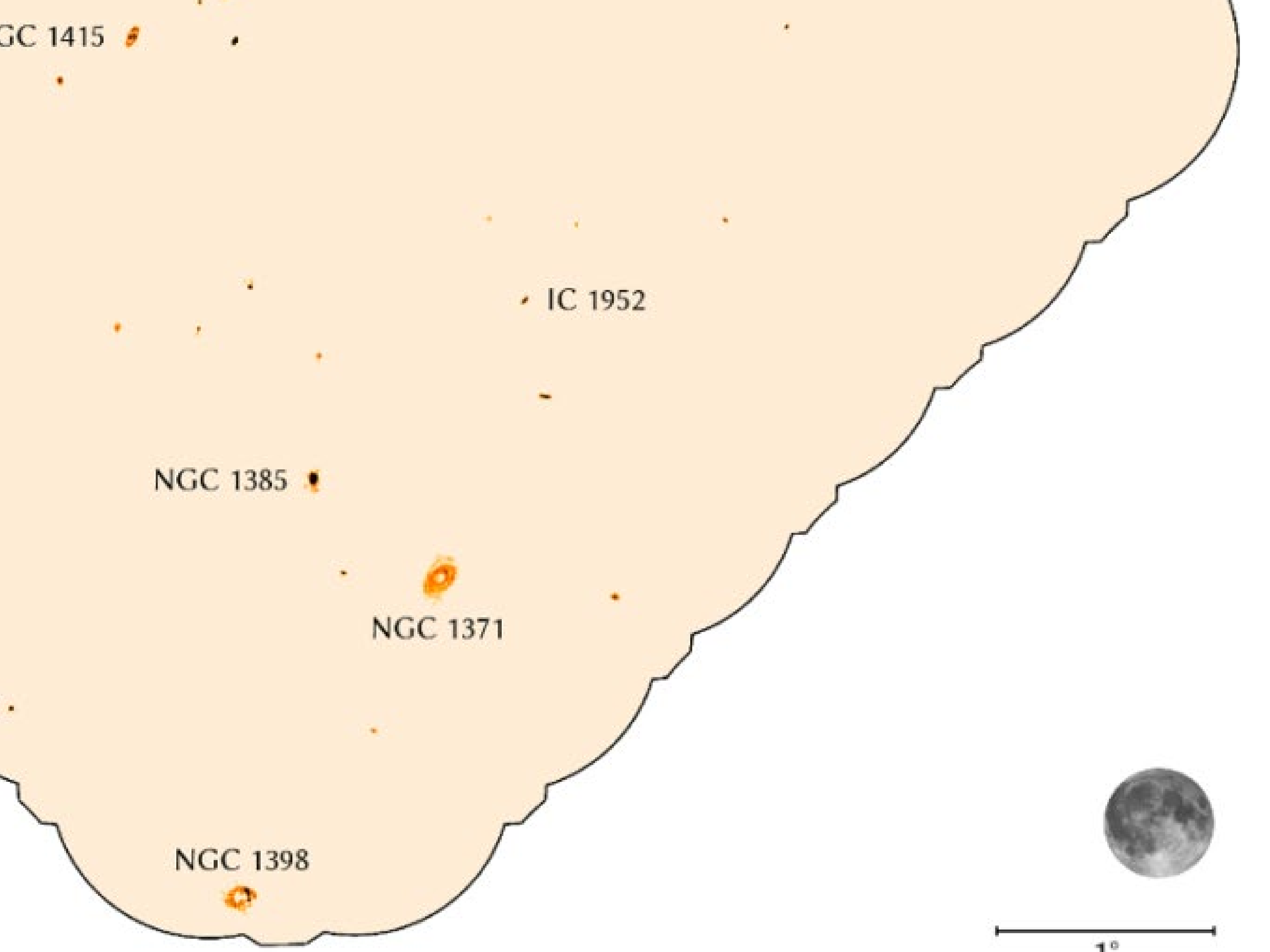
The Small Magellanic Cloud, a dwarf galaxy that is a satellite of our Milky Way Galaxy, is located about 210,000 light-years away in the southern constellation

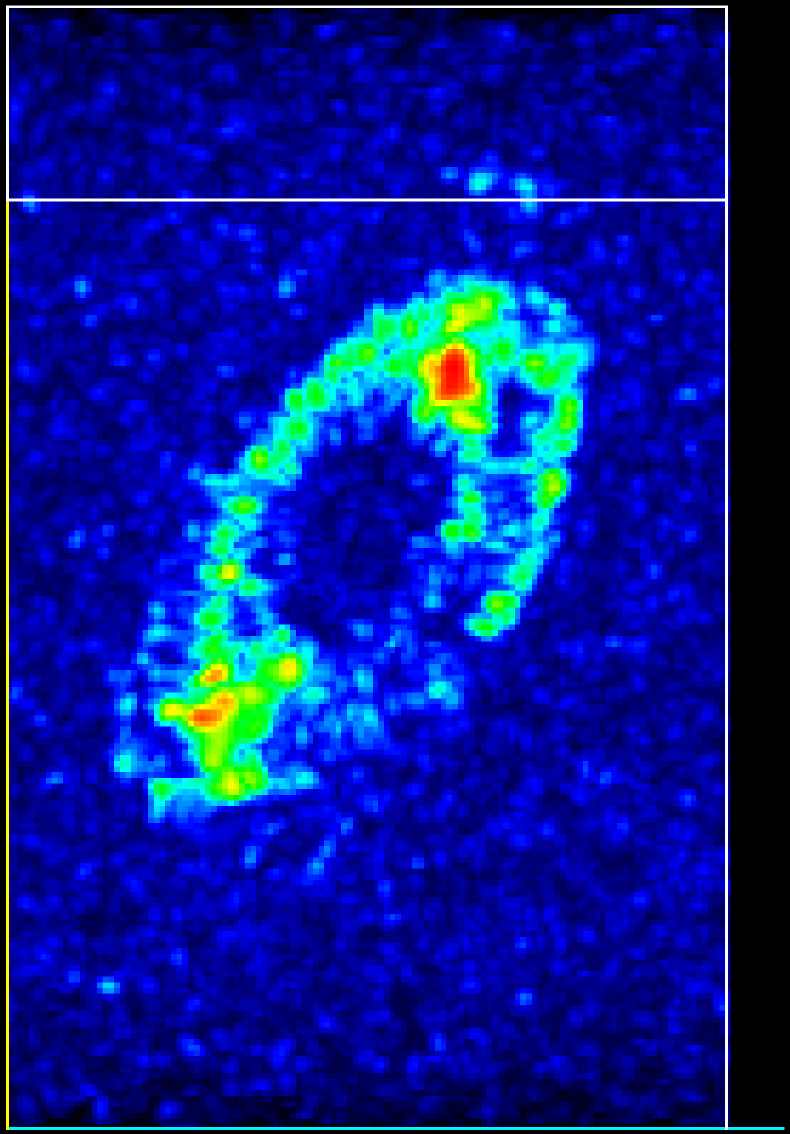
SoFiA 2 – Source Finding Application

- SoFiA 2 is a part of the ASKAP WALLABY project.
- In 2019 SoFiA 2 successfully passed its first full-scale test after running the pipeline on the Eridanus early science data cube.
- For this purpose, they ran eight instances of SoFiA 2 in parallel on the cluster at ICRAR, processing almost 200 GB of data covering the full 30 deg^2 field of view and the redshift range of $500 < cz < 8500$ km/s.
- Next slide presents the resulting image from SoFiA 2, showing more than 50 genuine H I detections across the entire region.

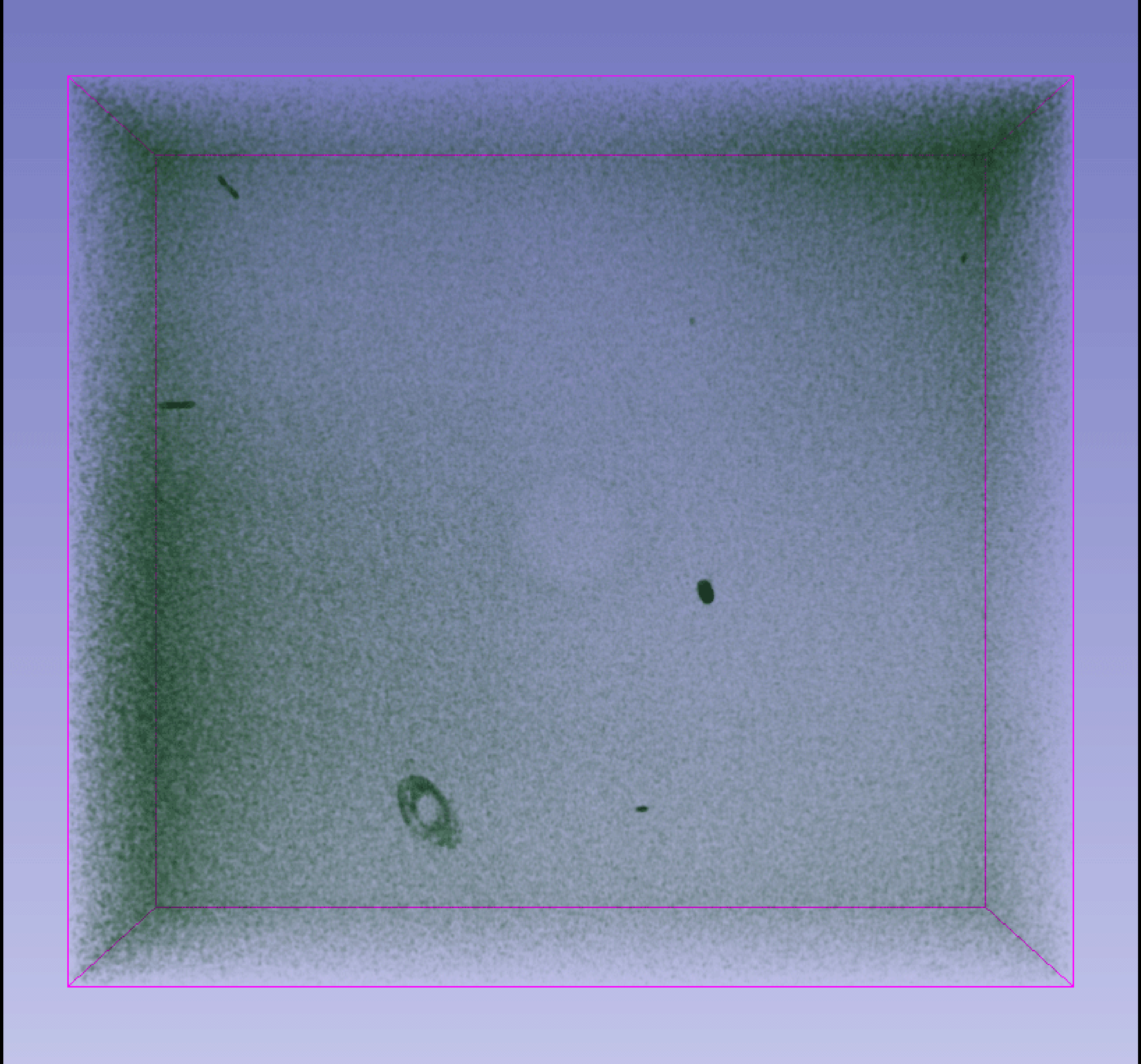


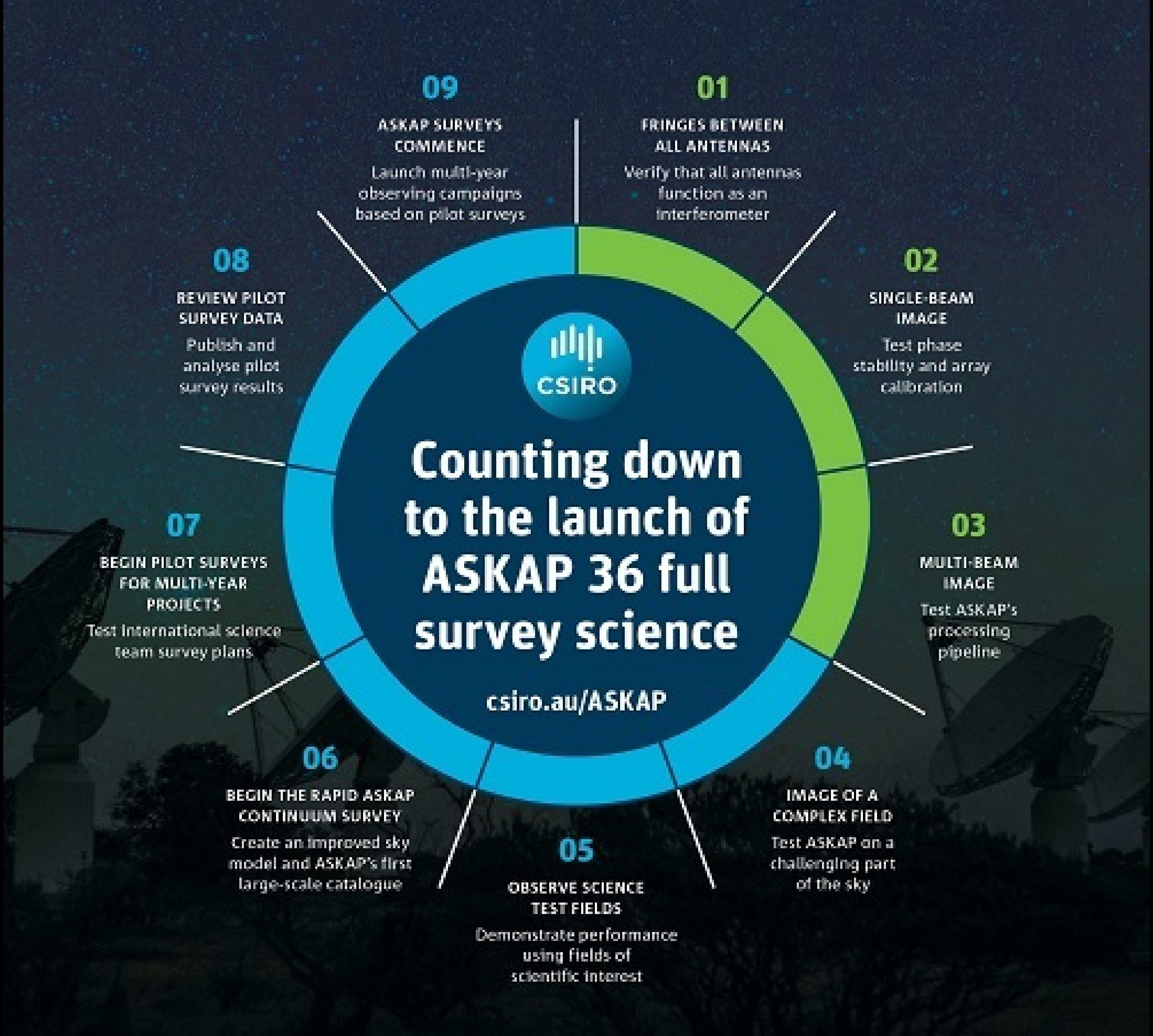
WALLABY Early Science
Neutral hydrogen emission from galaxies in the Eridanus cluster
WALLABY
NGC 1359
IC 1962
IC 1953
NGC 1325
NGC 1415
IC 1952
NGC 1385
NGC 1371
NGC 1398
SoFiA
Source Finding Application
Image created by Tobias Westmeier from moment 0 images produced by SoFiA
1°


GC 1415
IC 1952
NGC 1385
NGC 1371
NGC 1398



ASKAP 3D image of NGC 1371 in the Eridanus early science field




CSIRO
Counting down to the launch of ASKAP 36 full survey science
csiro.au/ASKAP
01
FRINGES BETWEEN ALL ANTENNAS
Verify that all antennas function as an interferometer
02
SINGLE-BEAM IMAGE
Test phase stability and array calibration
03
MULTI-BEAM IMAGE
Test ASKAP's processing pipeline
04
IMAGE OF A COMPLEX FIELD
Test ASKAP on a challenging part of the sky
05
OBSERVE SCIENCE TEST FIELDS
Demonstrate performance using fields of scientific interest
06
BEGIN THE RAPID ASKAP CONTINUUM SURVEY
Create an improved sky model and ASKAP's first large-scale catalogue
07
BEGIN PILOT SURVEYS FOR MULTI-YEAR PROJECTS
Test international science team survey plans
08
REVIEW PILOT SURVEY DATA
Publish and analyse pilot survey results
09
ASKAP SURVEYS COMMENCE
Launch multi-year observing campaigns based on pilot surveys

CSIRO

Counting down to the launch of ASKAP 36 full survey science

csiro.au/ASKAP

01

FRINGES BETWEEN ALL ANTENNAS

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IMAGE OF A COMPLEX FIELD

Test ASKAP on a challenging part of the sky

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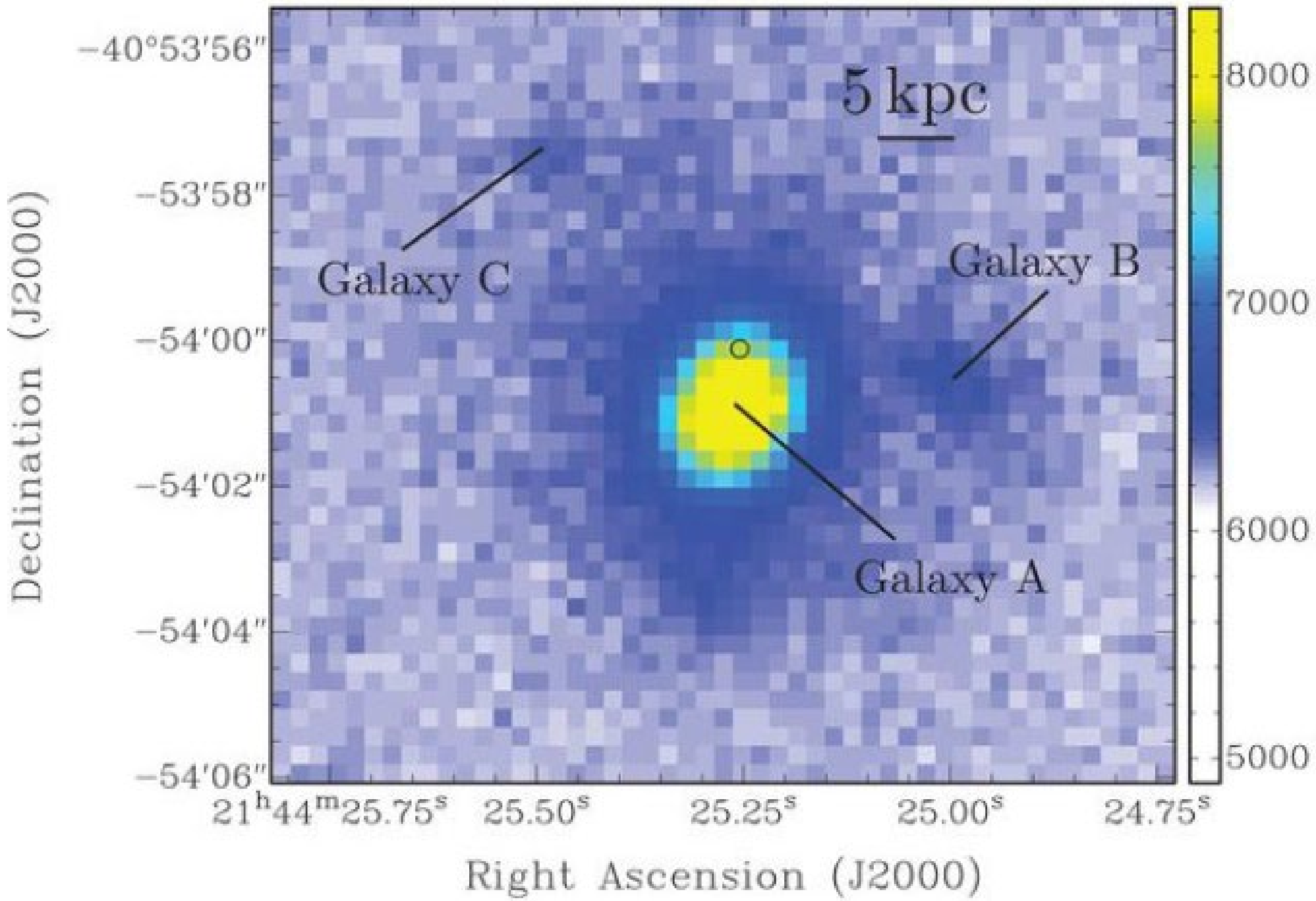
ASKAP SURVEYS COMMENCE

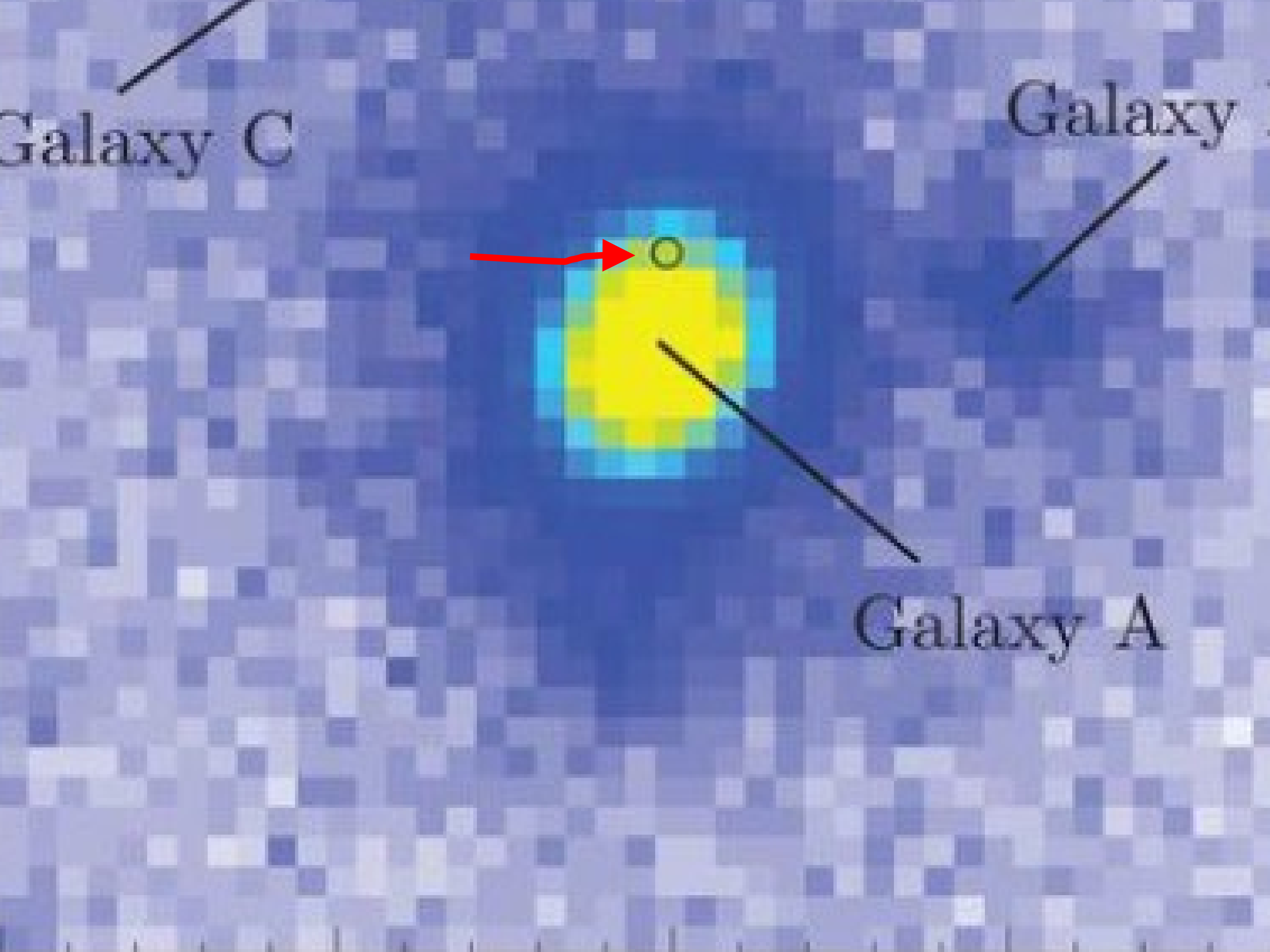
Launch multi-year observing campaigns based on pilot surveys

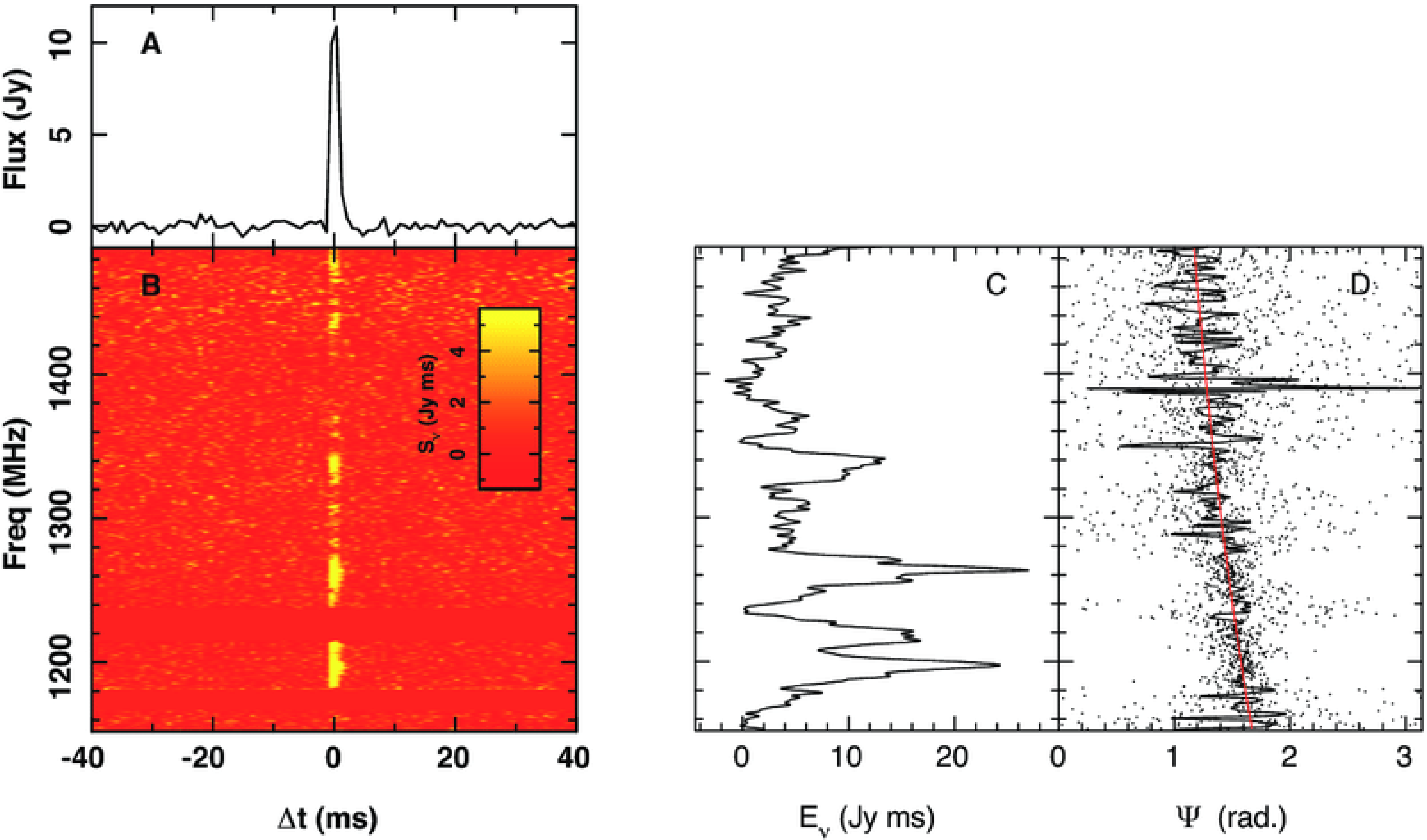
http://www.atnf.csiro.au/projects/askap/askap-G23.html

Bannister, K.W.; Deller, A.T.; Phillips, C. et al.
"A single fast radio burst localized to a massive galaxy at cosmological distance". Science, 365, 565–570 (2019). Published online in Science 27 June 2019, doi:10.1126/science.aaw5903.

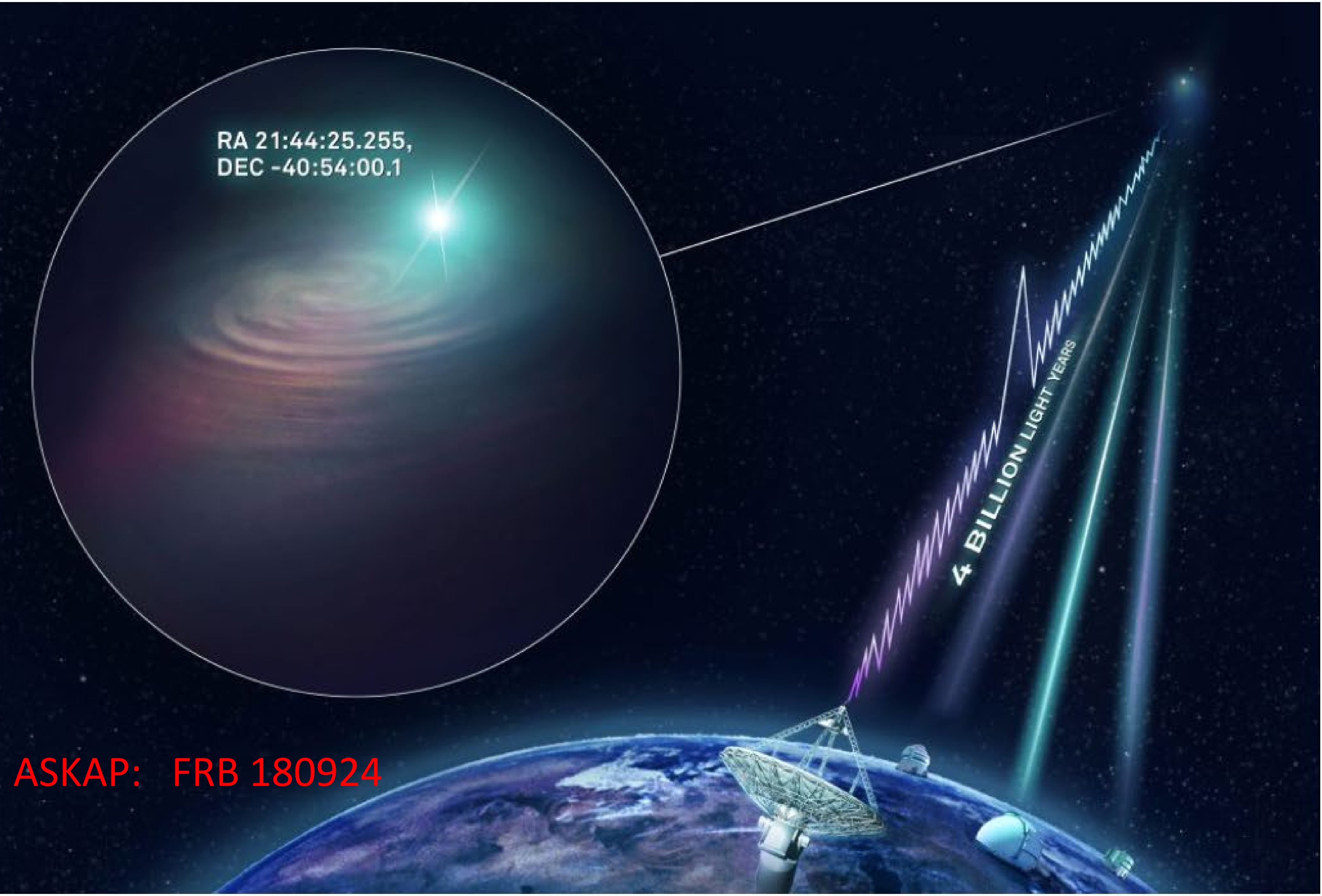


The host galaxy of FRB 180924, imaged with ESO's Very Large Telescope. The FRB came from within the small circle. (From Bannister et al. 2019)

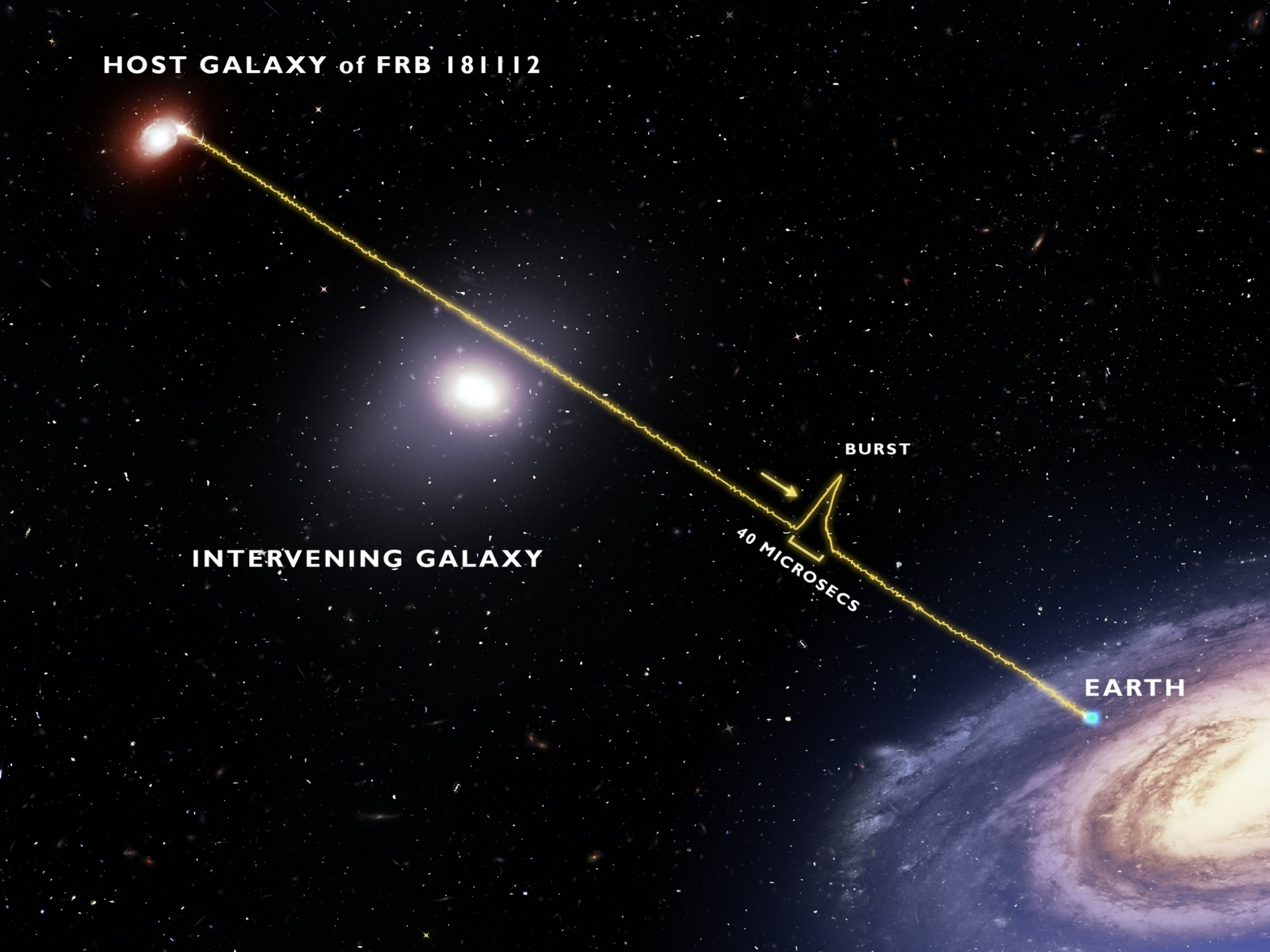

Galaxy C
Galaxy
Galaxy A



ASKAP: FRB 180924

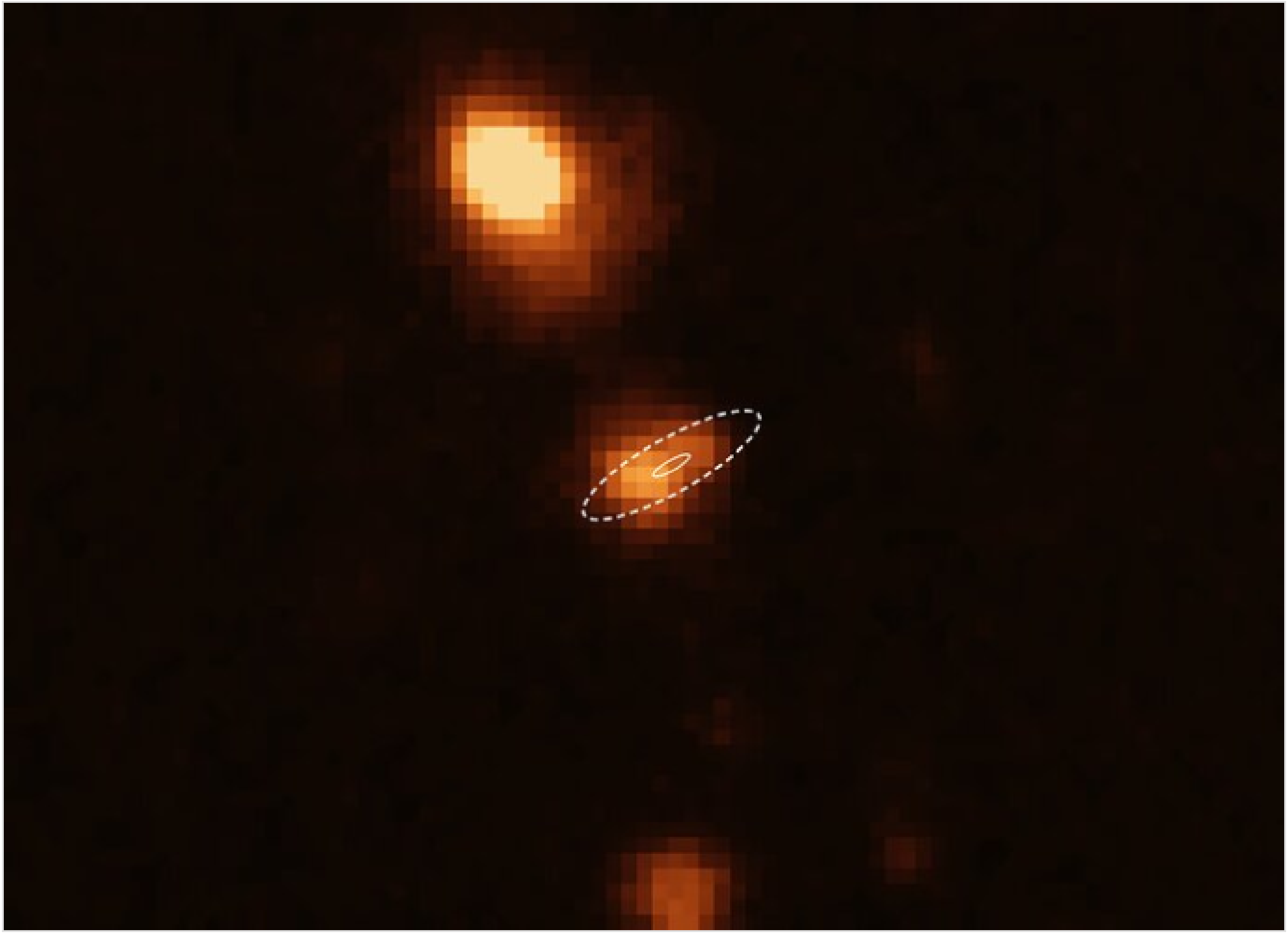


ASKAP: FRB 180924


HOST GALAXY of FRB 181112
INTERVENING GALAXY
BURST
40 MICROSECS
EARTH

European
Southern
Observatory

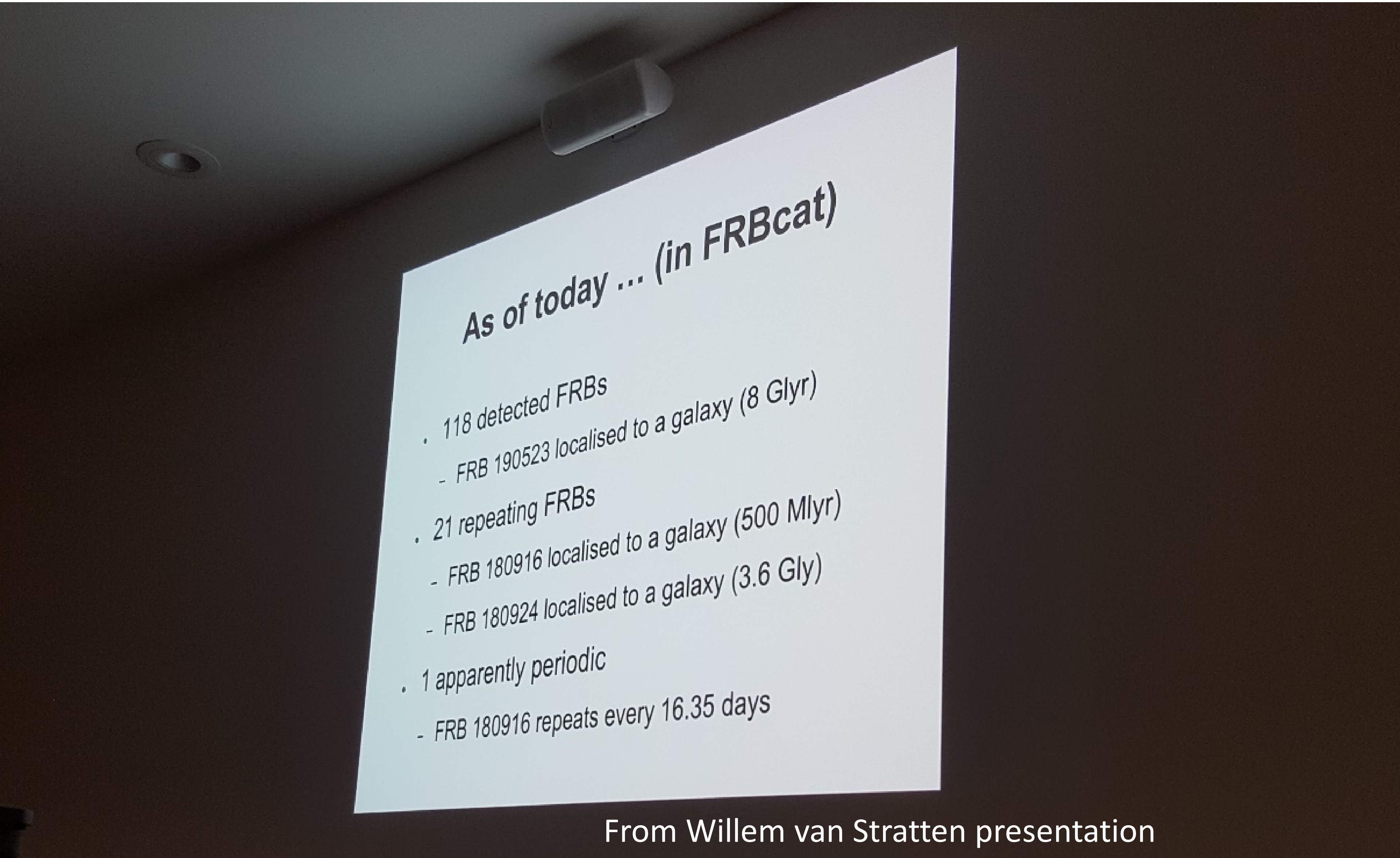
VLT image of the location of FRB 181112



Soon after the Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope pinpointed a fast radio burst, named FRB 181112, ESO's Very Large Telescope (VLT) took this image and other data to determine the distance to its host galaxy (FRB 181112 location indicated by the white ellipses). The analysis of these data revealed that the radio pulses have passed through the halo of a massive galaxy (at the top of the image) on their way toward Earth.

Credit: ESO/X. Prochaska et al.

FRBs and CHIME



From Willem van Stratten presentation

Canada's CHIME Telescope Joins SKA Pathfinder Family

CHIME's huge reflectors are 100m long and each one measures 20m across. (Credit: CHIME)

nature

Letter | Published: 02 July 2019

DSA-10 in OVRO (Caltech)

A fast radio burst localized to a massive galaxy

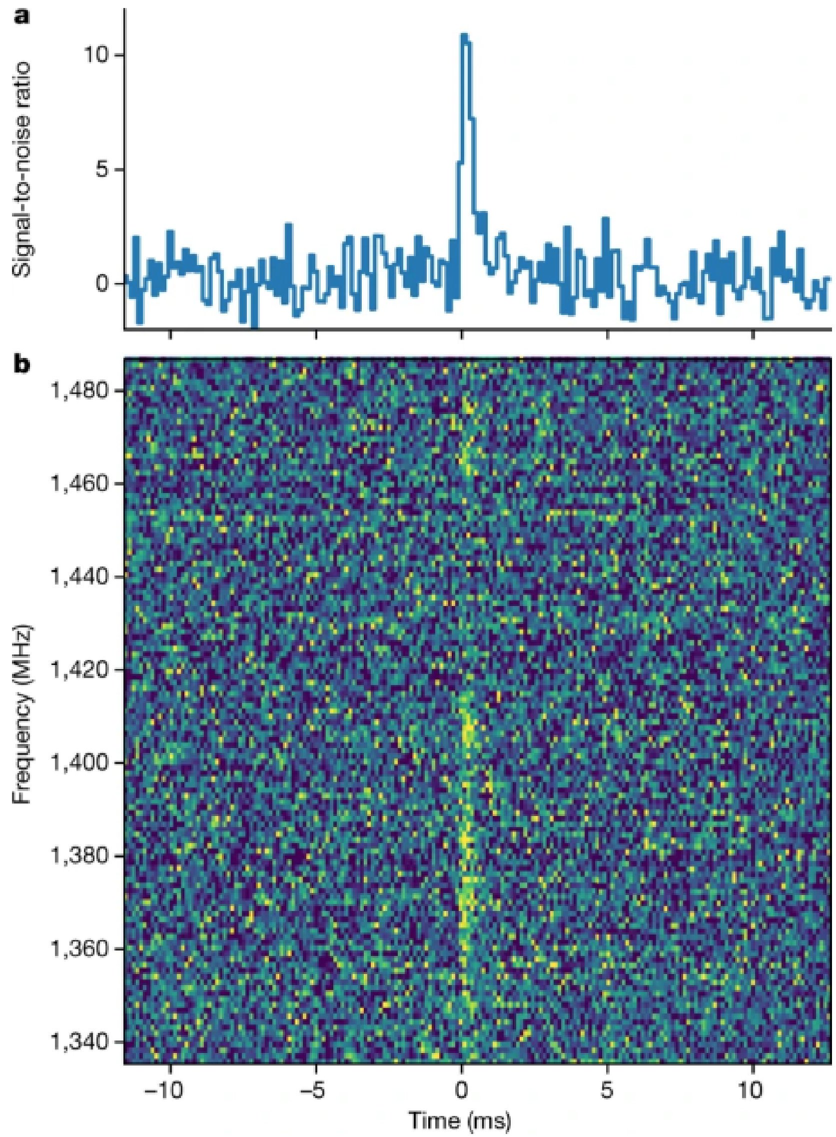
V. Ravi, M. Catha, L. D'Addario, S. G. Djorgovski, G. Hallinan, R. Hobbs, J. Kocz, S. R. Kulkarni, J. Shi, H. K. Vedantham, S. Weinreb & D. P. Woody

Nature **572**, 352–354(2019) | Cite this article

Abstract

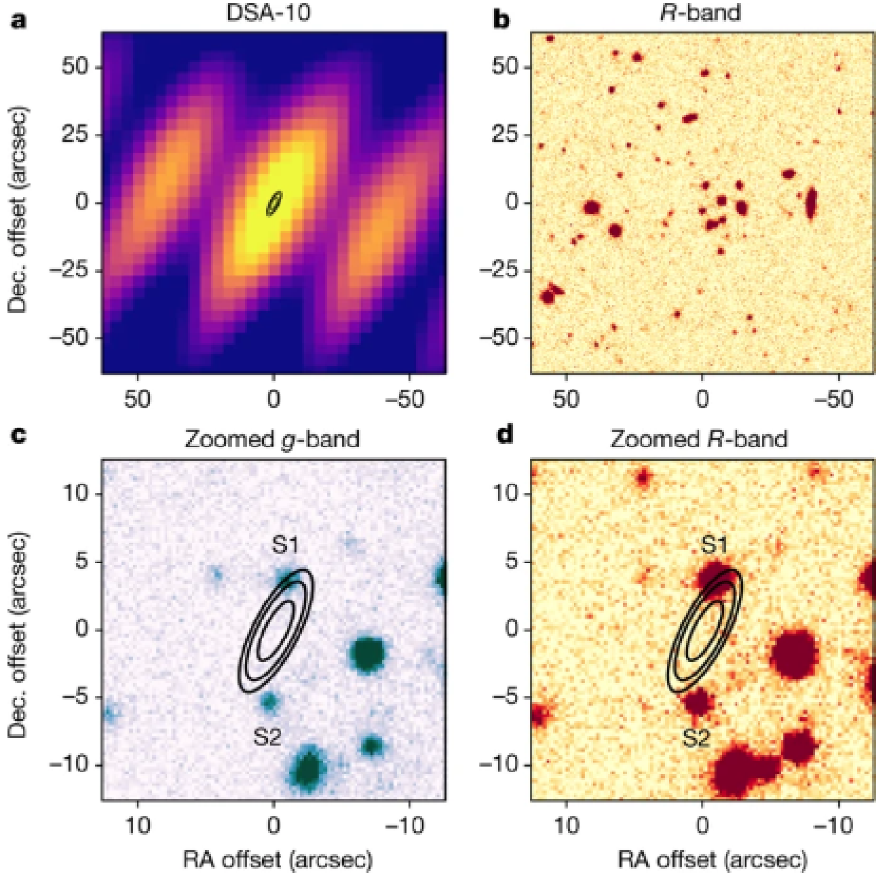
Intense, millisecond-duration bursts of radio waves (named fast radio

Fig. 1: Time-frequency data on FRB 190523.



a, Dedispersed temporal profile of the burst, averaged over the DSA-10 frequency band. The data are measures of the received power in 131.072-μs bins, in units of the root-mean-square (r.m.s.) off-burst signal-to-noise ratio. **b**, The dedispersed dynamic spectrum of the burst, again in units of the r.m.s. off-

Fig. 2: Images of the sky location of FRB 190523.



All images are centred on J2000 coordinates RA 13 h 48 min 15.6(2) s; dec. +72° 28′ 11(2)″. **a**, Dirty snapshot image of the burst, obtained with DSA-10 (see Methods). **b**, Optical image in the *R*-band filter, obtained with KeckI/LRIS. The position of FRB 190523 coincides with an apparent grouping of galaxies. **c**, **d**, Zoom-in on the burst localization region in the *g*- and *R*-filters of KeckI/LRIS. The position of FRB 190523 is indicated with 68%, 95% and 99% confidence containment ellipses in **a**, **c**, **d**. The only galaxy detected above the 26.1-magnitude *R*-band detection limit within the 99% confidence containment ellipse, indicated by S1, is PSO J207+72. A galaxy to the south of the 99% confidence ellipse is labelled S2.

A competition? No. Collaboration and complementarity

ersion March 8, 2019
using LaTeX **twocolumn** style in AASTeX62

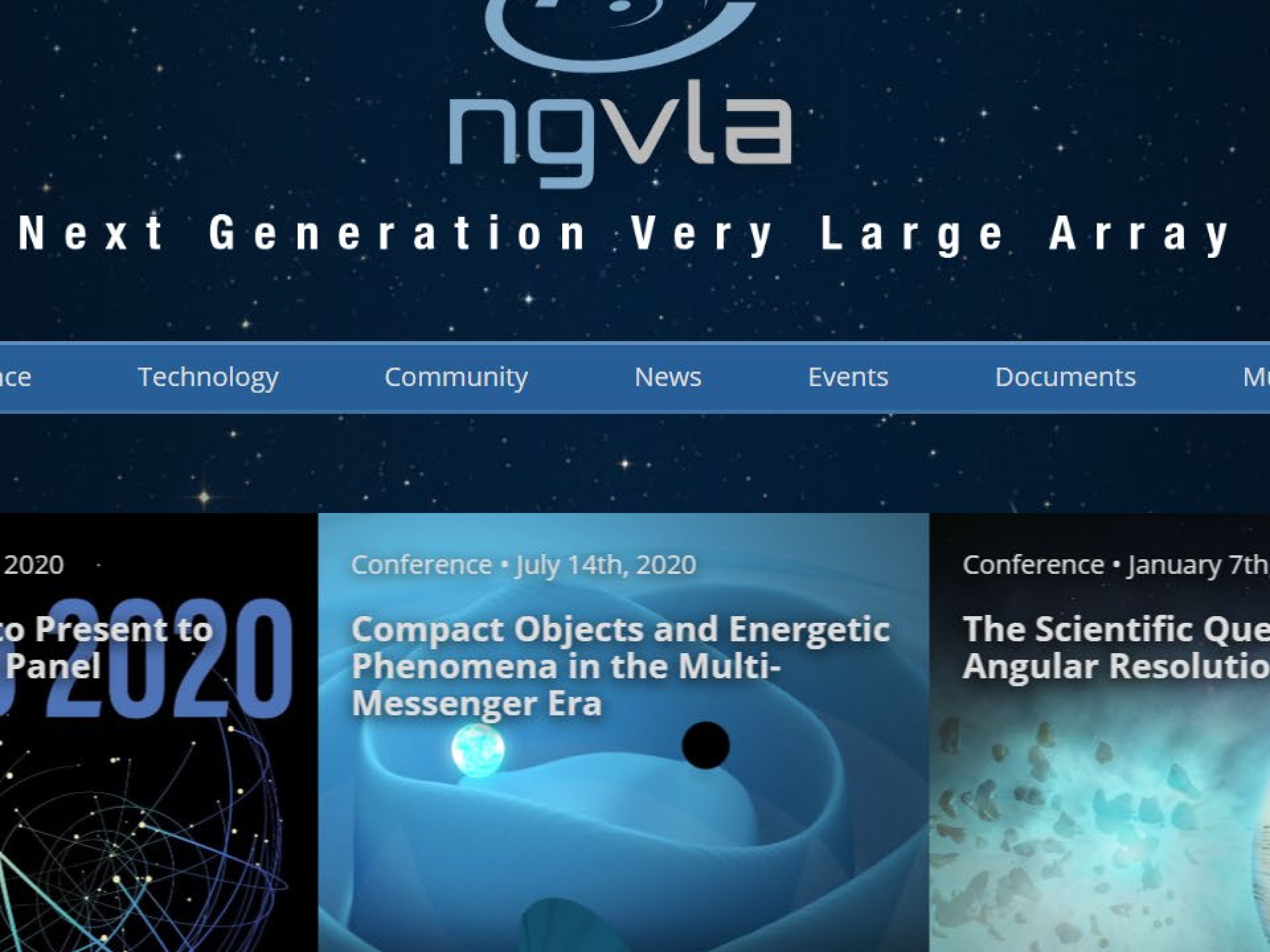
THE DSA-2000: A RADIO SURVEY CAMERA FOR THE NEXT DECADE

allinan,[1] Vikram Ravi,[1] Sandy Weinreb,[1] Jonathon Kocz,[1] David Woody,[1] James Lamb,[1] Michael Eastwood,[1] Larry D'Addario,[1]
Maura McLaughlin,[2] Scott Ransom,[2] and Xavier Siemens[2]

[1]*Department of Astronomy, California Institute of Technology, 1200 E. California Blvd, Pasadena CA, 91125, USA*
[2]*The NANOGrav Collaboration*

ABSTRACT

We present the Deep Synoptic Array 2000-antenna concept (DSA-2000): a world-leading radio survey tele-
scope and multi-messenger discovery engine for the US community. As an evolution of the 110-antenna DSA,
now under construction, the DSA-2000 is proposed to consist of 2000 × 5 m dishes instantaneously covering
he 0.7 – 2 GHz frequency band. The DSA-2000 will be the first true radio camera, outputting science-ready
mage data with a spatial resolution of ∼ 3.5″. Baseline specifications include an equivalent point-source sen-
sitivity to the SKA-mid array, but with 10× the survey speed. The DSA-2000 will be a survey instrument in
advance of the ngVLA, and as a counterpart survey instrument to the LSST. In a 5-yr prime phase, the entire sky
with declination > −30° will be imaged over sixteen epochs, detecting > 1 billion radio sources in a combined
full-Stokes sky map with 500 nJy/beam rms noise. A high-spectral resolution (24 kHz; ∼ 5 km s^{-1} at 1.4 GHz)
all-sky image cube will also be delivered for spectral-line studies. In addition, the array will be a cornerstone
for multimessenger science, serving as the principal instrument for the US pulsar timing array community, and


ngvla
Next Generation Very Large Array
nce
Technology
Community
News
Events
Documents
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2020
to Present to
Panel
2020
Conference • July 14th, 2020
Compact Objects and Energetic Phenomena in the Multi-Messenger Era
Conference • January 7th
The Scientific Que
Angular Resolutio

ngVLA Reference Design Released

August 6th, 2019

The ngVLA Reference Design is a low-technical-risk, costed concept that supports the key science goals for the facility, and forms the technical and cost basis of the ngVLA Astro2020 Decadal Survey proposal. The compendium includes a total of 56 technical documents and represents the work of more than 54 engineers and scientists contributing to the project.

ngVLA & SKA Projects Explore Scientific Alliance

June 26th, 2019

The ngVLA and SKA projects are currently investigating a process to establish a scientific alliance that may result in an exchange of observing time across an unprecedented suite of cutting-edge telescopes spanning more than 3 orders of magnitude in observing frequency (50MHz – 116 GHz).

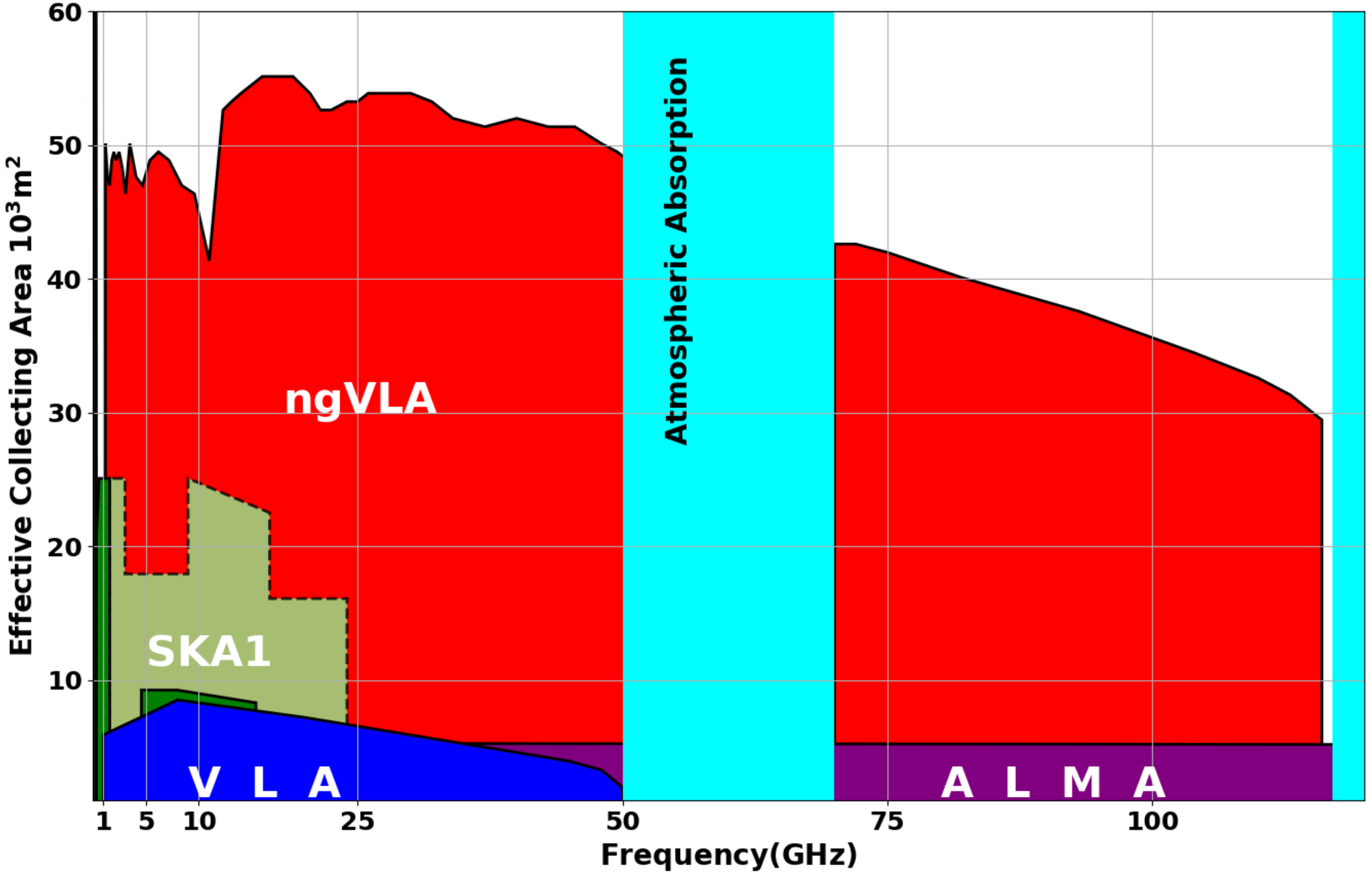
ngVLA

- Ten times the sensitivity of the VLA and ALMA,
- continental-scale baselines
- sub-milliarcsecond-resolution
- a dense core on km-scales for high surface brightness sensitivity.

“Such an array bridges the gap between ALMA, a superb sub-mm array, and the future SKA1 optimized for longer wavelengths.”

ngVLA Science Book, December 2018

ngVLA



60
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Effective Collecting Area $10^3 m^2$
Atmospheric Absorption
ngVLA
SKA1
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A L M A
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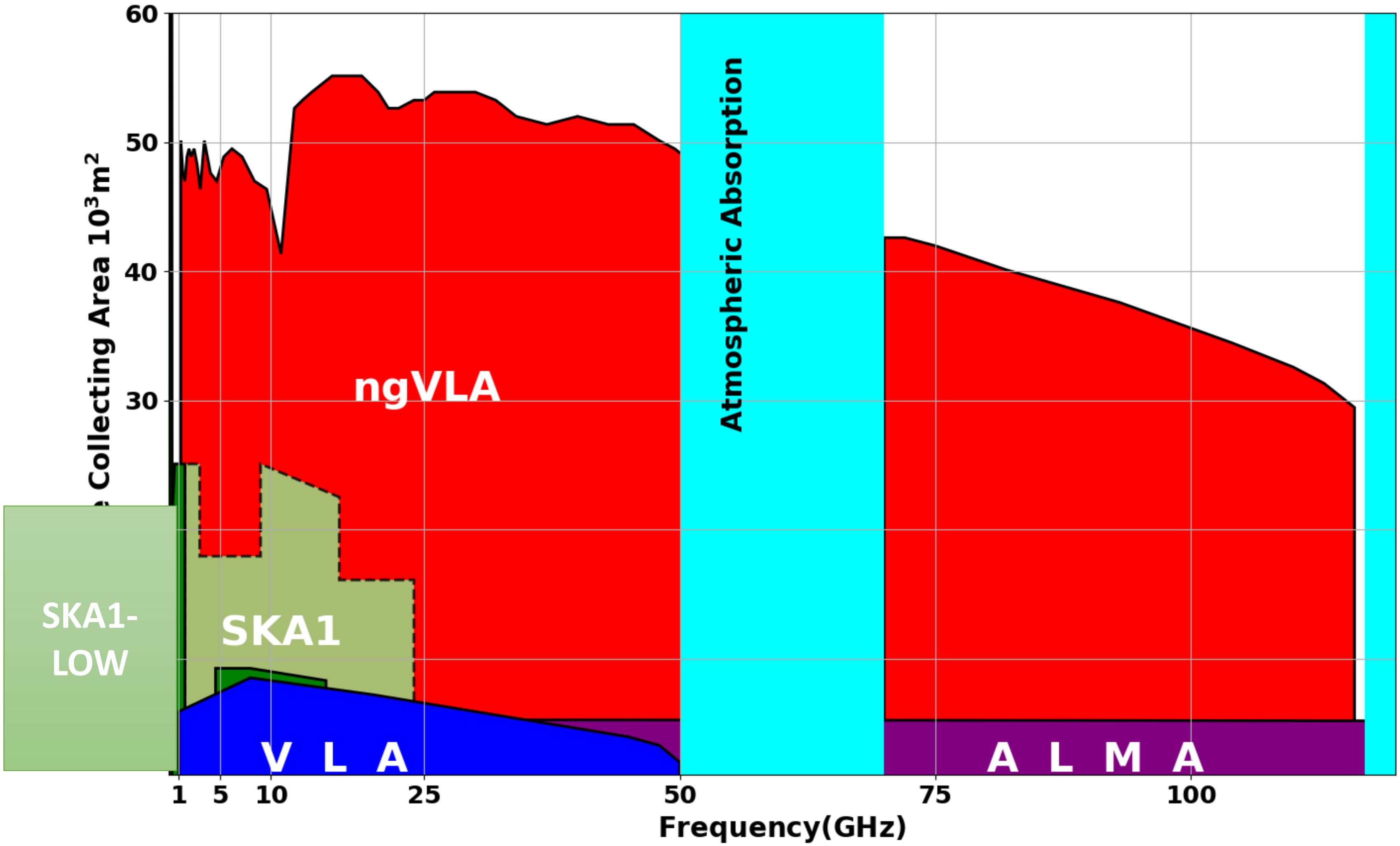
75
100
Frequency(GHz)

ngVLA



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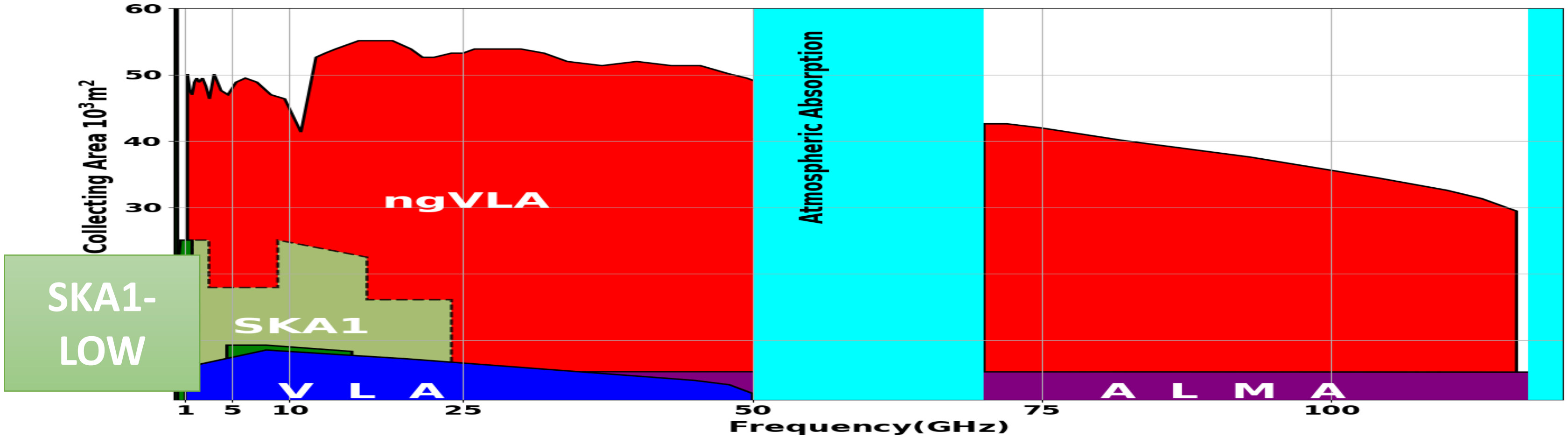
Frequency(GHz)

ngVLA



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Collecting Area 10^3m^2
ngVLA
Atmospheric Absorption
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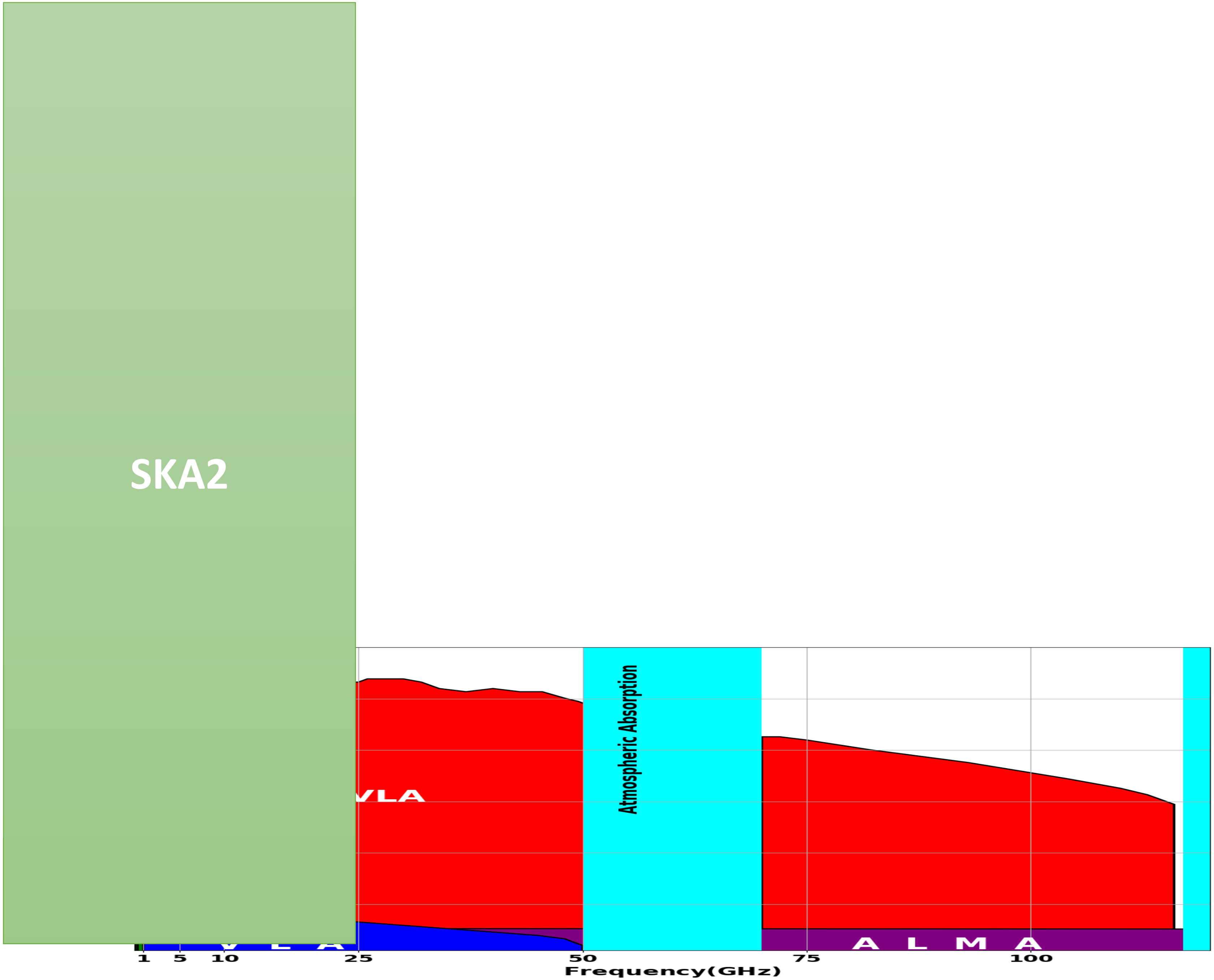
Frequency(GHz)
SKA1-LOW


SKA2
VLA
Atmospheric Absorption
A L M A
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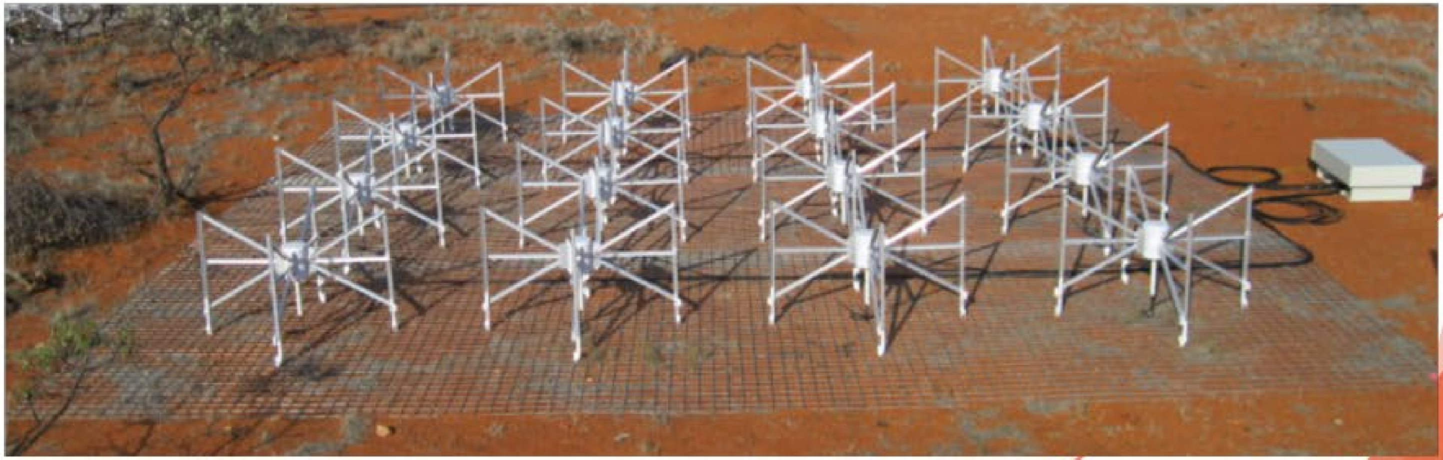
75
100
Frequency(GHz)

MWA
MURCHISON
WIDEFIELD
ARRAY

Gurlgamarnu

New Zealand's role in the Murchison Widefield Array

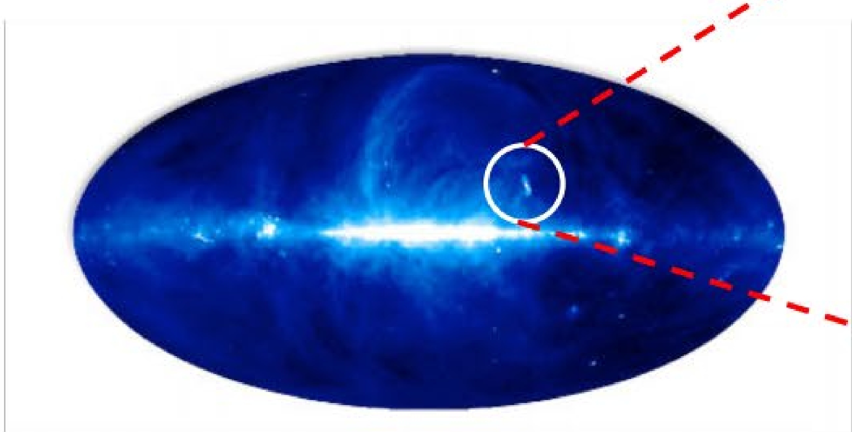
Prof. Melanie Johnston-Hollitt, MWA Director

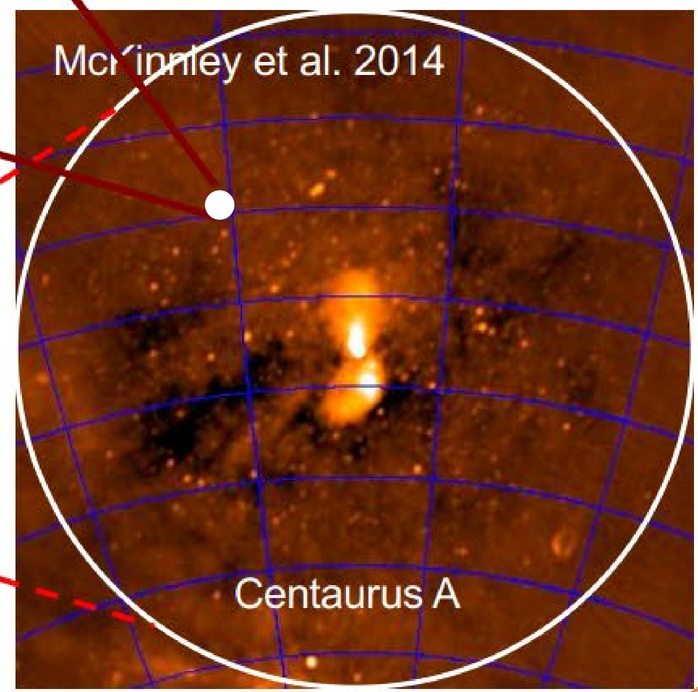


MWA FoV is huge!

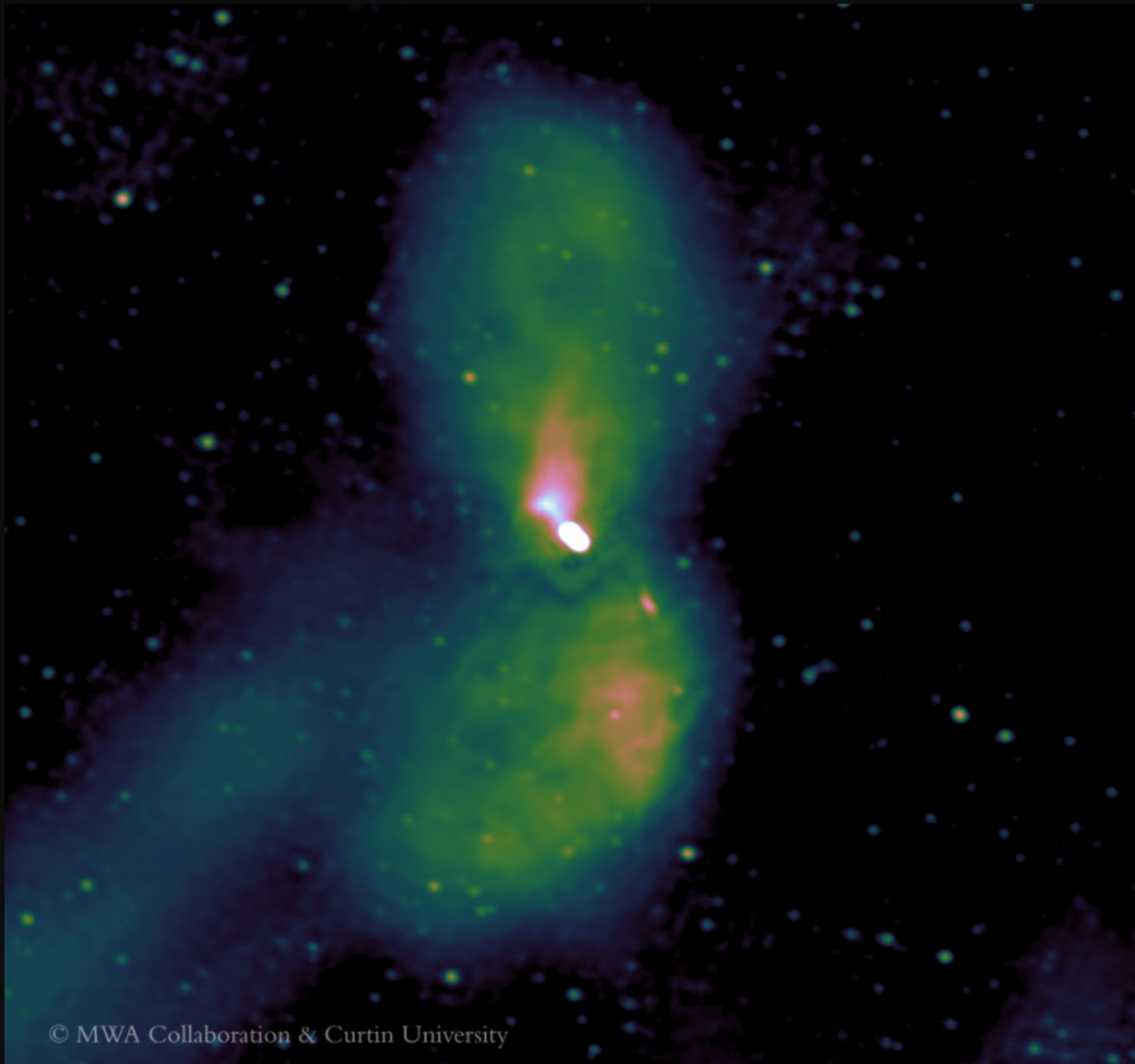
½
degree

MWA's field of view:
30 degrees!





From presentation by Melanie Johnston-Hollitt
at the NZ SKA Forum 2019


© MWA Collaboration & Curtin University

Current MWA Science

- First results from the Long Baseline Epoch of Reionisation Survey (**Lynch**)
- Towards a New MWA Limit on the Epoch of X-Ray Heating (**Pindor**)
- The Future of EoR Power Spectrum Analysis (**Barry**)
- Simulating MWA observations with OSKAR (**Line**)
- The POlarised GLEAM Survey (POGS) (**Riseley**)
- Galactic diffuse polarized emission at low frequencies (**Sun**)
- Searching for the First Black Holes with the MWA (**Seymour**)
- Physical properties of nearby galaxies using GLEAM Survey (**Yoshida**)
- Detecting and tracking space debris with the MWA (**Hancock**)
- Detection of Meteors and Space Debris with the MWA (**Zhang**)
- Searching for low-frequency emission from Star-exoplanet interactions (**Lynch**)
- Properties of Pulsars at Low Radio Frequencies (**Xue**)
- A preliminary pulsar blind search with MWA incoherent summed data (**Zhang**)
- No low-frequency emission from extremely bright Fast Radio Bursts (**Sokolowski**)
- Rapid follow-up of Gamma-ray Bursts using the upgraded MWA automatic triggering capability (**Anderson**)
- The imaging challenges of faint diffuse emission with MWA Phase II (**Hodgson**)
- A Murchison Widefield Array Phase II follow-up of diffuse, non-thermal cluster emission (**Duchesne**)
- Detecting New SNR with the MWA (**Hurley-Walker**)
- The SKA-Low Aperture Array Verification System (**Wayth**)

EoR

Polarimetry

Galaxies

SSA + NEO

Exoplanets

Plusars

Transients

Cosmic Web + Clusters

Galactic Science

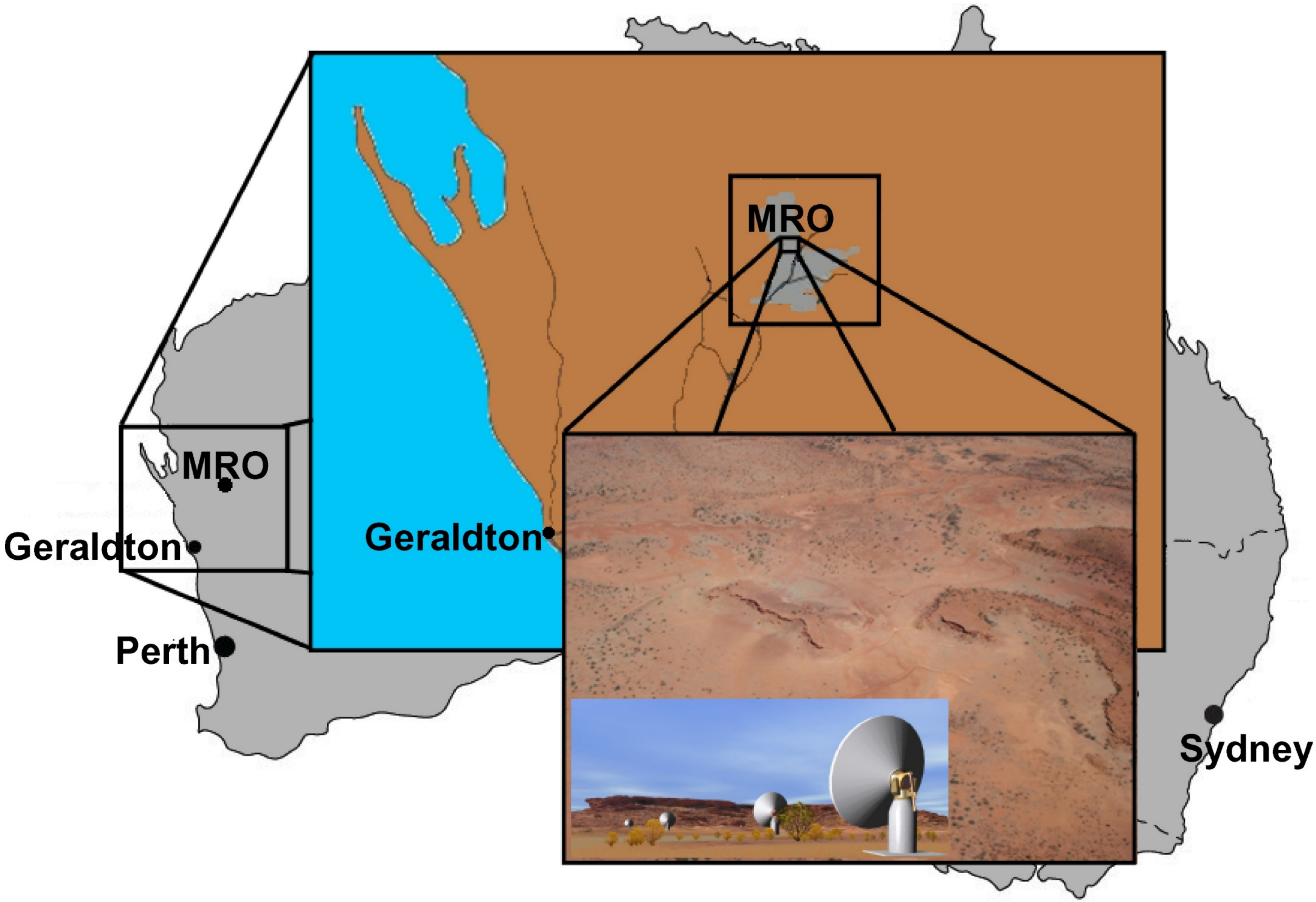
SKA Development

From presentation by Melanie Johnston-Hollitt at the NZ SKA Forum 2019

THE GALACTIC AND EXTRA-GALACTIC ALL-SKY MWA SU

The GLEAM survey covers the entire sky south of Dec +30. A description of the science motivations and survey meth
GLEAM Survey definition paper by Wayth et al. (2015). As has been previously demonstrated in Hurley-Walker (2014),
surveying technique for the MWA and we re-use the basic strategy for GLEAM. The sky is divided into seven strips in
summarised below. The Declinations are chosen such that the peak in the primary beam response for a given setting
power point of the neighbouring beam along the meridian at 150 MHz.

The instantaneous frequency coverage of the MWA is 30.72 MHz, so the frequency range between 72 and 231 MHz is
contiguous coverage, but avoid the band around 137 MHz that is contaminated by satellite interference. The observin


MRO
MRO
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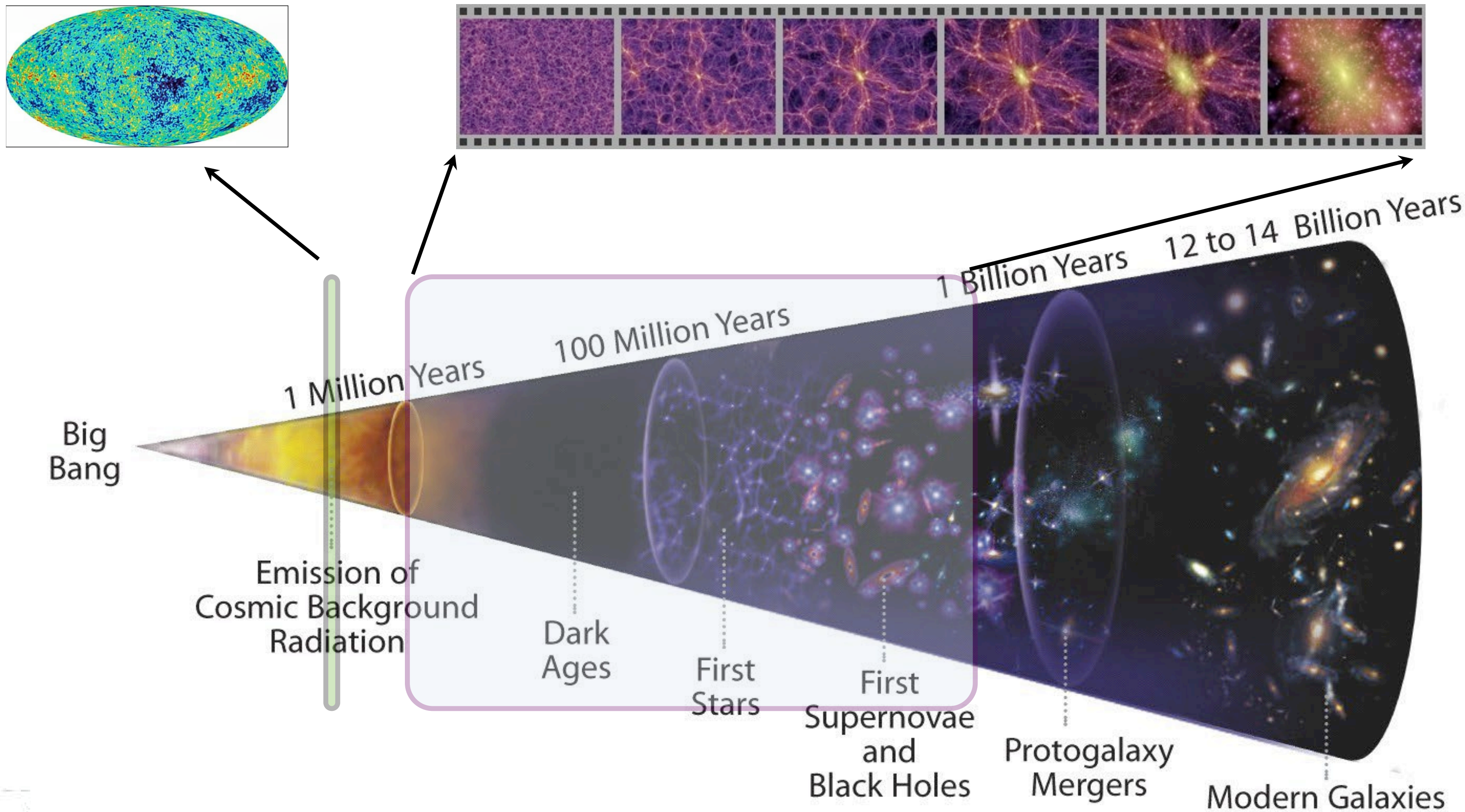
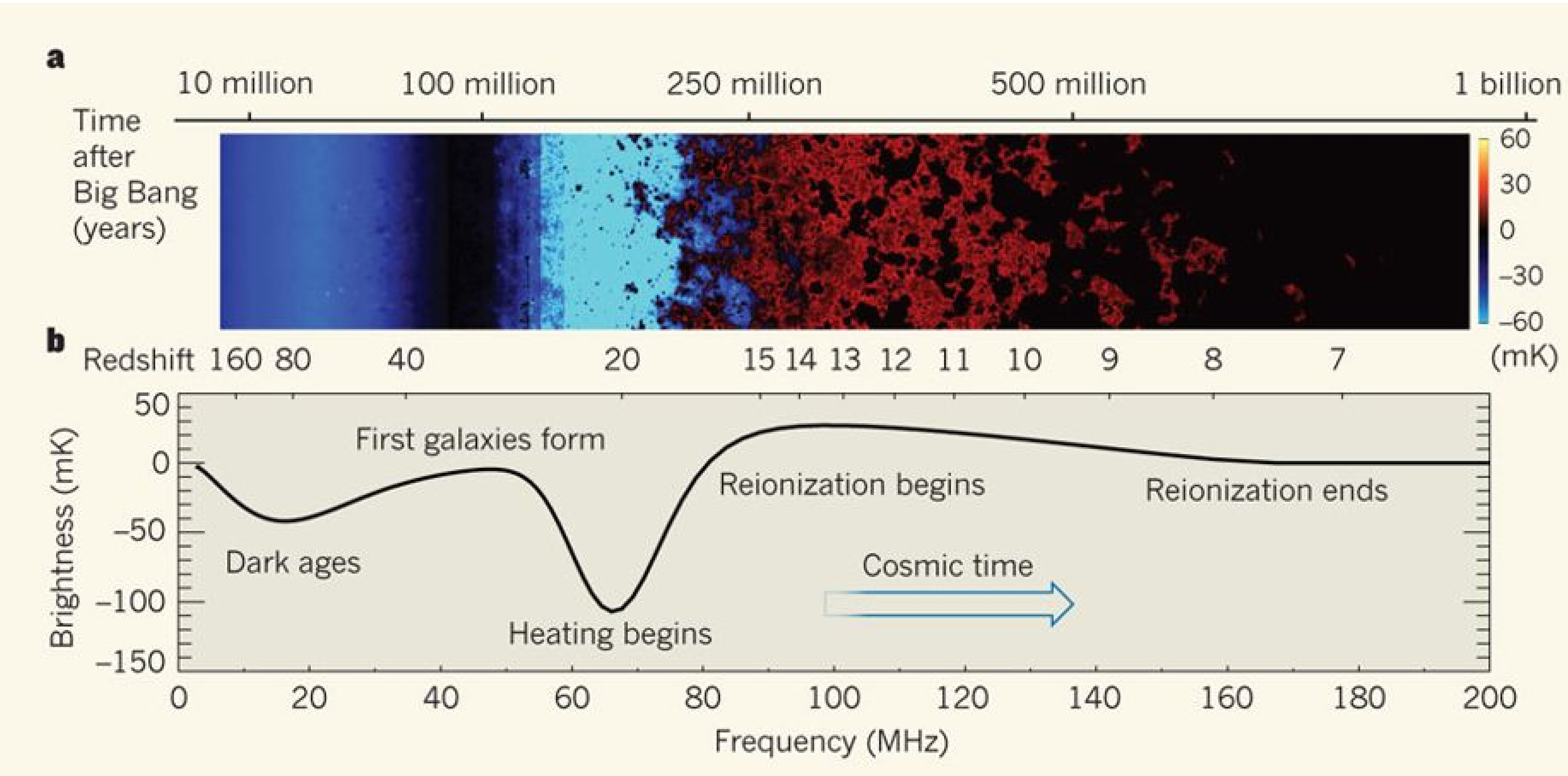
Geraldton
Perth
Sydney



Big Bang
1 Million Years
100 Million Years
1 Billion Years
12 to 14 Billion Years
Emission of Cosmic Background Radiation
Dark Ages
First Stars
First Supernovae and Black Holes
Protogalaxy Mergers
Modern Galaxies

Exploring t


a
Time after Big Bang (years)
10 million
100 million
250 million
500 million
1 billion
60
30
0
−30
−60
(mK)
b
Redshift 160 80 40 20 15 14 13 12 11 10 9 8 7
Brightness (mK)
50
0
−50
−100
−150
First galaxies form
Reionization begins
Reionization ends
Dark ages
Cosmic time
Heating begins
0 20 40 60 80 100 120 140 160 180 200
Frequency (MHz)

doi:10.1038/nature257

An absorption profile centred at 78 megahertz in the sky-averaged spectrum

Judd D. Bowman[1], Alan E. E. Rogers[2], Raul A. Monsalve[1,3,4], Thomas J. Mozdzen[1] & Nivedita Mahesh[1]

After stars formed in the early Universe, their ultraviolet light is expected, eventually, to have penetrated the primordial hydrogen gas and altered the excitation state of its 21-centimetre hyperfine line. This alteration would cause the gas to absorb photons from the cosmic microwave background, producing a spectral distortion that should be observable today at radio frequencies of less than 200 megahertz[1]. Here we report the detection of a flattened absorption profile in the sky-averaged radio spectrum, which is centred at a frequency of 78 megahertz and has a best-fitting full-width at half-maximum of 19 megahertz and an amplitude of 0.5 kelvin. The profile is largely consistent with expectations for the 21-centimetre signal induced by early stars; however, the best-fitting amplitude of the profile is more than a factor of two greater than the largest predictions[2]. This discrepancy suggests that either the

The absorption profile is found by fitting the integrated spectru with the foreground model and a model for the 21-cm sign simultaneously. The best-fitting 21-cm model yields a symmet U-shaped absorption profile that is centred at a frequency 78 ± 1 MHz and has a full-width at half-maximum of 19^{+4}_{-2} MHz, amplitude of $0.5^{+0.5}_{-0.2}$ K and a flattening factor of $\tau = 7^{+5}_{-3}$ (where t bounds provide 99% confidence intervals including estimates systematic uncertainties; see Methods for model definitio Uncertainties in the parameters of the fitted profile are estimat from statistical uncertainty in the model fits and from systema differences between the various validation trials that were perform using observations from both instruments and several different da cuts. The 99% confidence intervals that we report are calculated the outer bounds of (1) the marginalized statistical 99% confiden

Table 1 | Sensitivity to possible calibration errors

Error source	Estimated uncertainty	Modelled error level	Recovered amplitude (K)
LNA S11 magnitude	0.1 dB	1.0 dB	0.51
LNA S11 phase (delay)	20 ps	100 ps	0.48
Antenna S11 magnitude	0.02 dB	0.2 dB	0.50
Antenna S11 phase (delay)	20 ps	100 ps	0.48
No loss correction	N/A	N/A	0.51
No beam correction	N/A	N/A	0.48

The estimated uncertainty for each case is based on empirical values from laboratory measurements and repeatability tests. Modelled error levels were chosen conservatively to be five and ten times larger than the estimated uncertainties for the phases and magnitudes, respectively. LNA, low-noise amplifier; S11, input reflection coefficient; N/A, not applicable.

observations using restricted spectral bands yield nearly identical best-fitting absorption profiles, with the highest signal-to-noise ratio reaching 52. In Fig. 2 we show representative cases of these fits.

We performed numerous hardware and processing tests to validate the detection. The 21-cm absorption profile is observed in data that span nearly two years and can be extracted at all local solar times and at all local sidereal times. It is detected by two identically designed instruments operated at the same site and located 150 m apart, and even after several hardware modifications to the instruments, including orthogonal orientations of one of the antennas. Similar results for the absorption profile are obtained by using two independent processing pipelines, which we tested using simulated data. The profile is detected using data processed via two different calibration techniques: absolute calibration and an additional differencing-based post-calibration process that reduces some possible instrumental errors. It

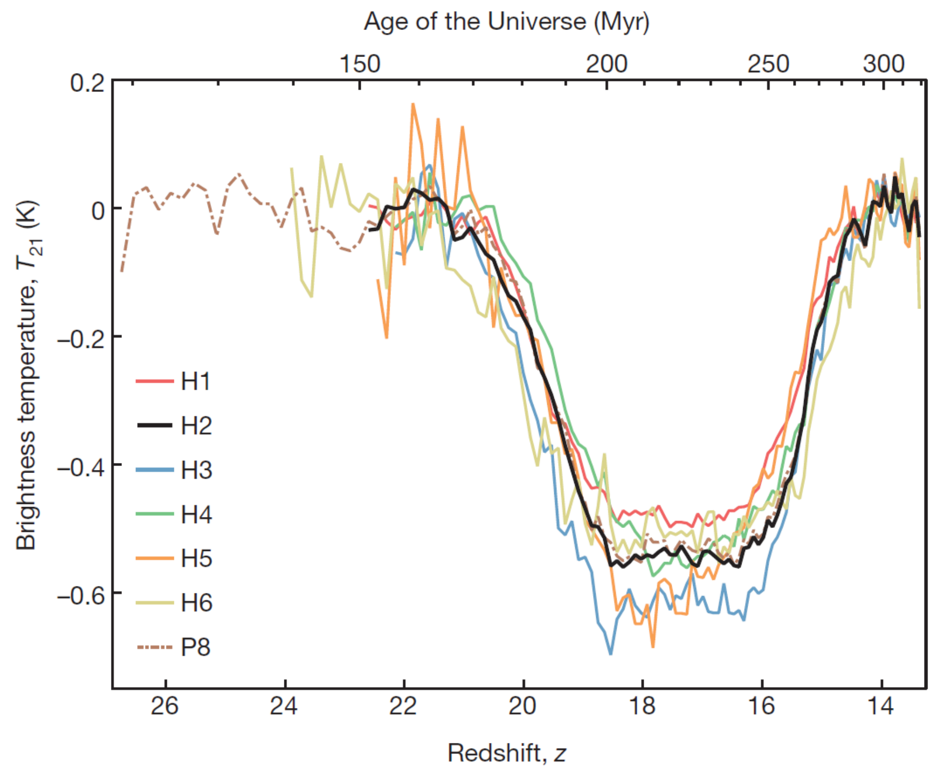


Figure 2 | Best-fitting 21-cm absorption profiles for each hardware case. Each profile for the brightness temperature T_{21} is added to its residuals and plotted against the redshift z and the corresponding age of the Universe. The thick black line is the model fit for the hardware and analysis configuration with the highest signal-to-noise ratio (equal to 52; H2; see Methods), processed using 60–99 MHz and a four-term polynomial (see equation (2) in Methods) for the foreground model. The thin solid lines are the best fits from each of the other hardware configurations

LETTER

doi:10.1038/nature25791

Possible interaction between baryons and dark-matter particles revealed by the first stars

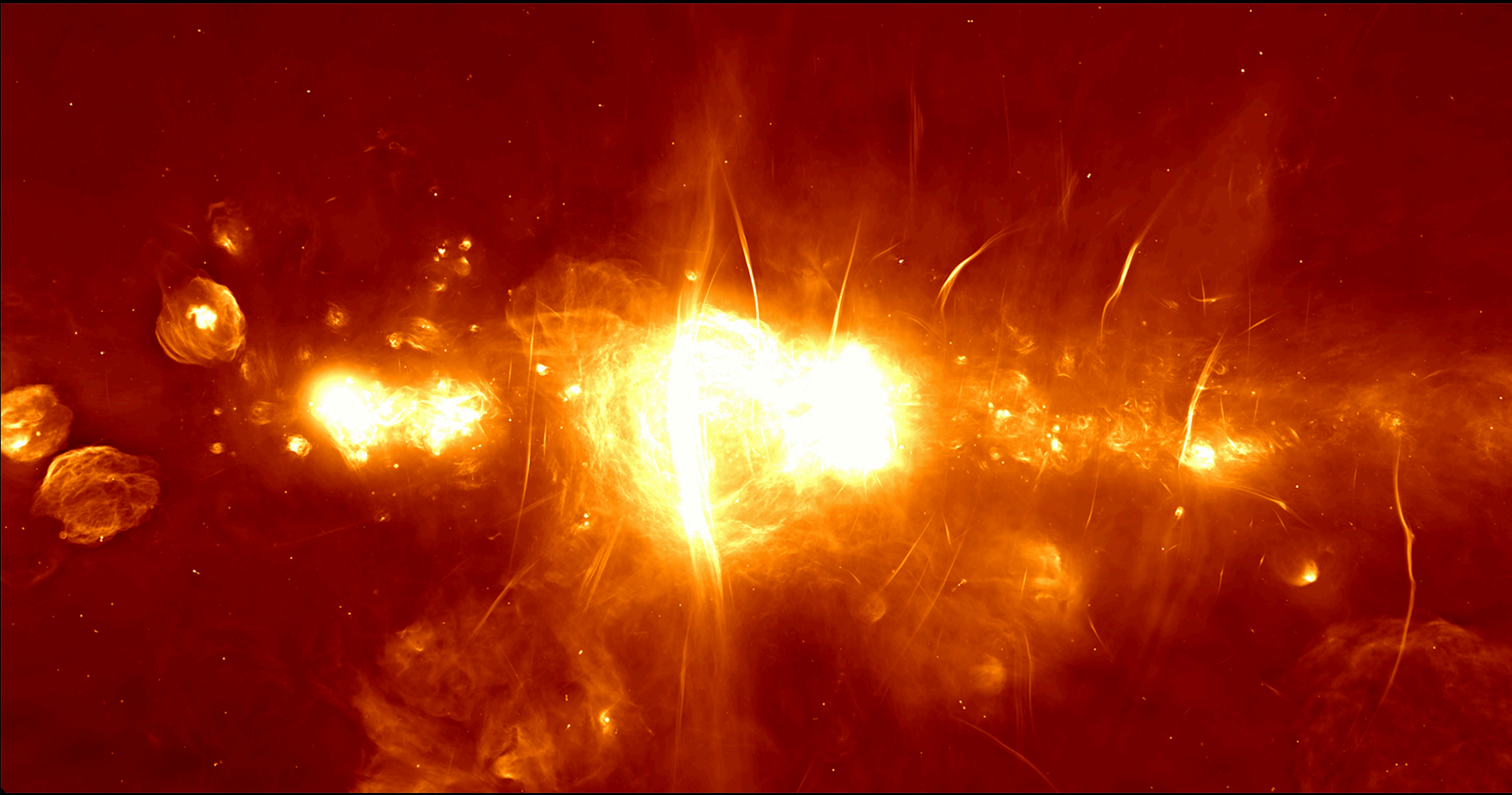
Rennan Barkana[1]

The cosmic radio-frequency spectrum is expected to show a strong absorption signal corresponding to the 21-centimetre-wavelength transition of atomic hydrogen around redshift 20, which arises from Lyman-α radiation from some of the earliest stars[1–4]. By observing this 21-centimetre signal—either its sky-averaged spectrum[5] or maps of its fluctuations, obtained using radio interferometers[6,7]—we can obtain information about cosmic dawn, the era when the first astrophysical sources of light were formed. The recent detection of the global 21-centimetre spectrum[5] reveals a stronger absorption than the maximum predicted by existing models, at a confidence level of 3.8 standard deviations. Here we report that this absorption can be explained by the combination of radiation from the first stars and excess cooling of the cosmic gas induced by its interaction with dark matter[8–10]. Our analysis indicates that the spatial fluctuations of the 21-centimetre signal at cosmic dawn could be an order of magnitude larger than previously expected and that the dark-matter particle is no heavier than several proton masses, well below the commonly predicted mass of weakly

Epoch of reionization Signature (EDGES)[5], which detected the signal's global spectrum from cosmic dawn and found an absorption peak at frequency $\nu = 78 \pm 1$ MHz ($z = 17.2$) with brightness temperature $T_{21} = -500^{+200}_{-500}$ mK; the uncertainties represent 99% confidence intervals and include both thermal and systematic noise. This absorption signal has passed robustness tests for variations in the hardware and processing configuration. If confirmed, this signal (which is 3.8σ below -209 mK, where σ is the standard deviation; the strongest possible absorption at this frequency under standard expectations) cannot be explained without a new dark-matter interaction, even if we take exotic astrophysics into account (see Methods). Indeed, $T_{21} = -300$ mK at $z = 17.2$ implies $T_{gas} < 5.1$ K, whereas the lowest possible value in the standard scenario is 7.0 K. Basic thermodynamics suggests that it is easy to heat the cosmic gas but difficult to cool it. The extra cooling indicated by the data is possible only through the interaction of the baryons with something even colder.

The only known cosmic constituent that can be colder than the early cosmic gas is dark matter. The reason for this is that dark matter is

MeerKAT inaugural image



Astronomy
Observatory
fanie@hartrao.ac.za
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Astronomers are riding the heatwave: tracing the energy from an accretion burst

15 January 2020

For the first time ever astronomers have detected the radiation stimulated by a “heat wave” of intense thermal energy from a massive new-born star, or so-called protostar.

The M2O collaboration studies the real-time growth of a new born star using “maser” emission caused by a “stellar outburst”. (Credit to Katharina Immer

South Africa's MeerKAT peers deep into the Universe

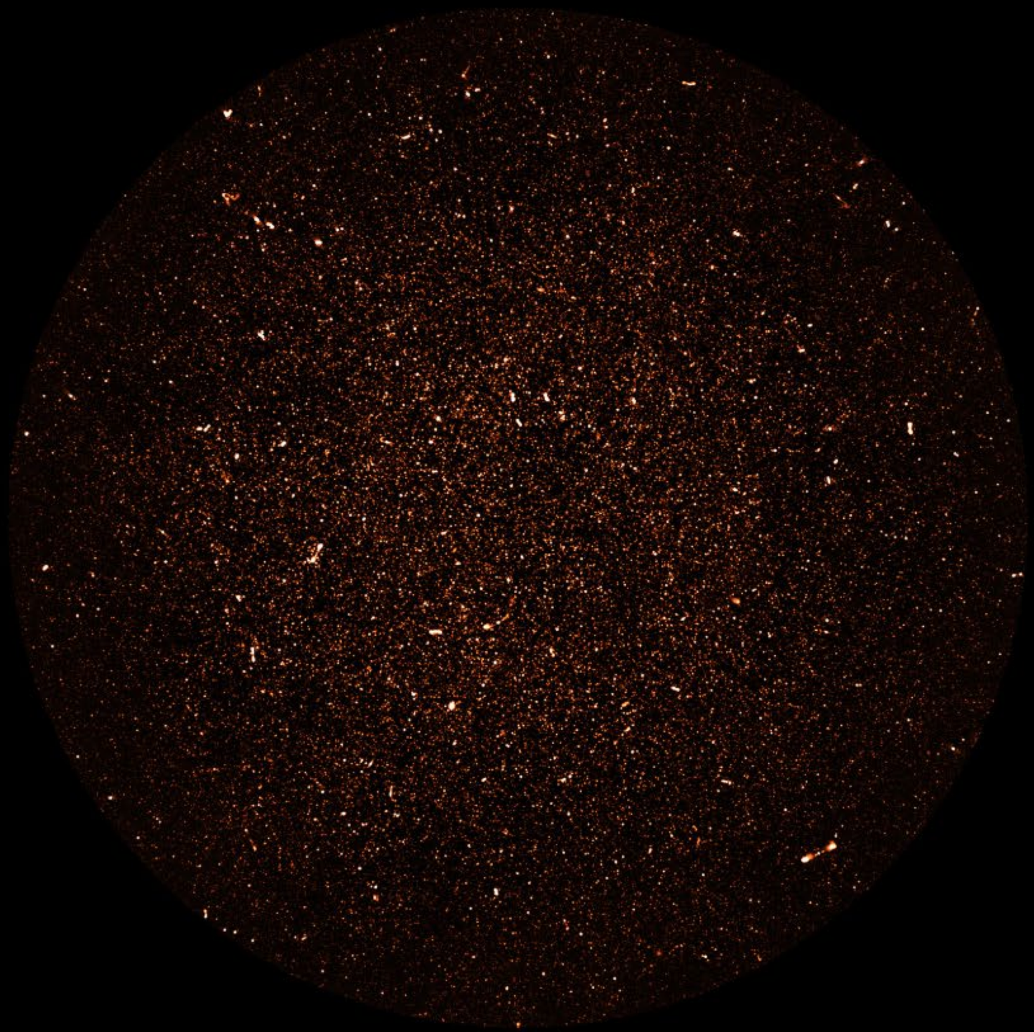
17 December 2019

First radio image of distant Milky Way-like galaxies reveals star forma
history of the Universe

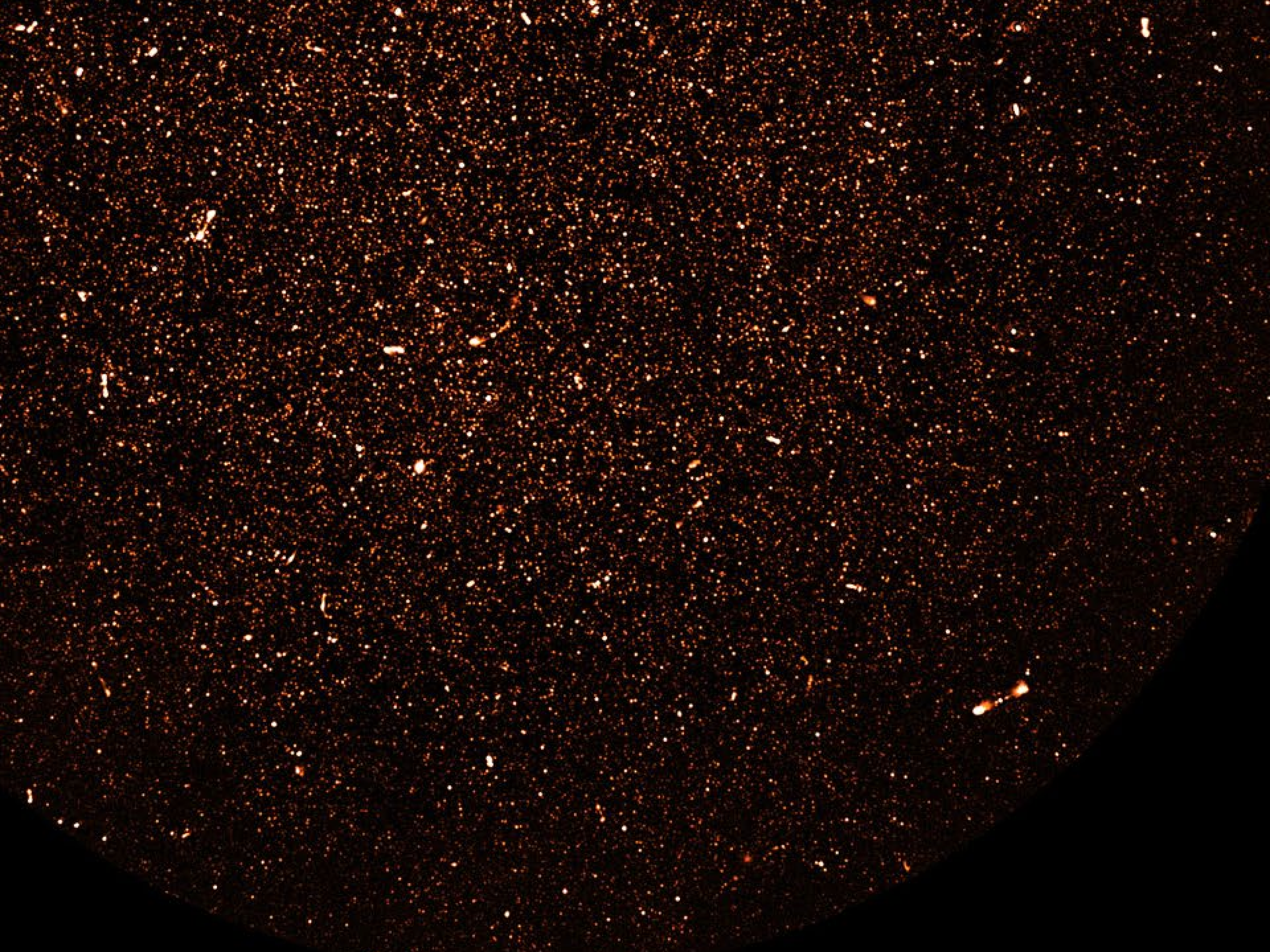
Look at this new radio image covered with dots, each of which is a distant galaxy! The brightest spots ar
that are powered by supermassive black holes and shine bright in radio light. But what makes this imag
are the numerous faint dots filling the sky. These are distant galaxies like our own that have never been
in radio light before.

To learn about the star-formation history of the universe, we need to look back in time. Galaxies throug
universe have been forming stars for the past 13 billion years. But most stars were born between 8 and
years ago, during an era called "cosmic noon".

It has been a challenge for astronomers to study the faint light coming from this era. Optical telescopes,
in Sutherland, can see very distant galaxies, but new stars are largely hidden inside dusty clouds of gas.
telescopes can see through the dust and observe the rare, bright "starburst" galaxies, but until now have

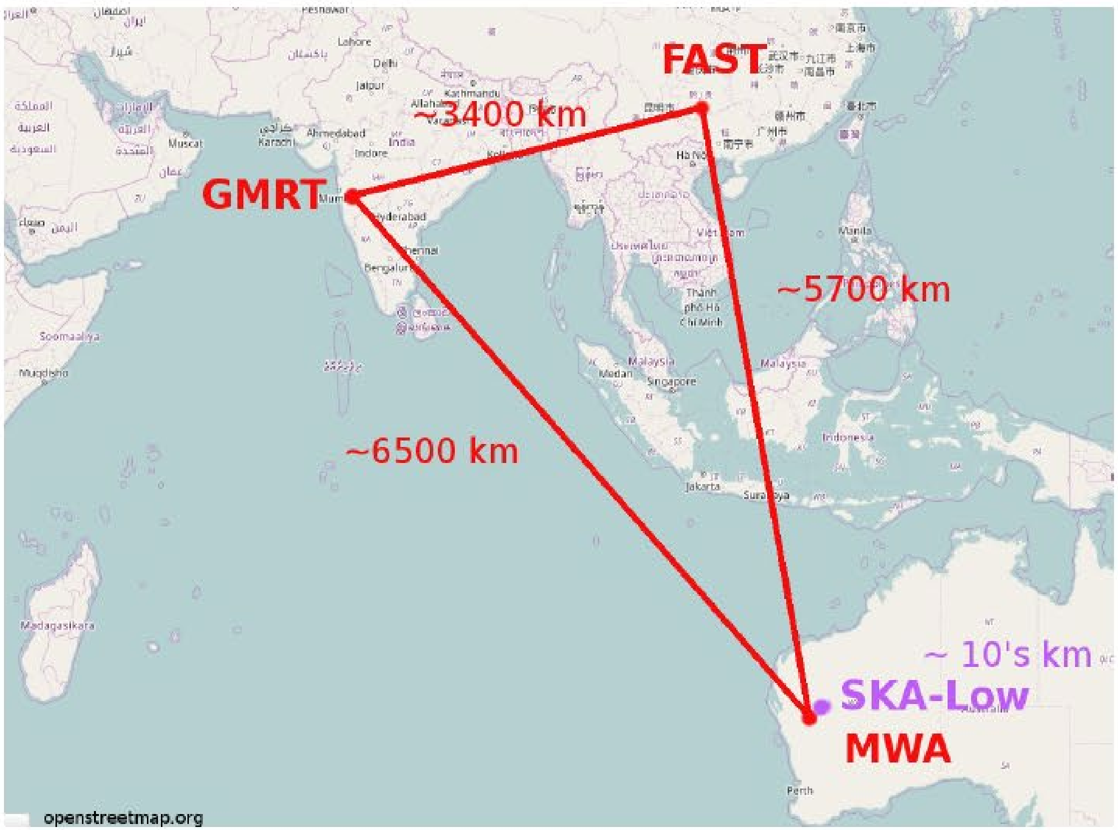


***MeerKAT image of radio galaxies:** Thousands of galaxies are visible in this radio image covering a square degree of sky near the south celestial pole, made by the MeerKAT radio telescope array in South Africa. The brightest spots are luminous radio galaxies powered by supermassive black holes. The myriad faint dots are distant galaxies like our own Milky Way, too faint to have been detected before now, which reveal the star-formation history of the universe.*



- Overview
- Registration
- Participant List
- Call for Abstracts
- Important Dates
- Conference Programme
  - Conference Presentations
  - Invited Speakers
  - Instructions for Speakers
  - SKA-VLBI documents
  - Video Conferencing/Streaming
- Conference Payment
- Invitation Letter and Visas
- Venue and Accommodation
  - Hotel Scam Warning
- Local Information and Activities
- Travel Information
- Organising Committees

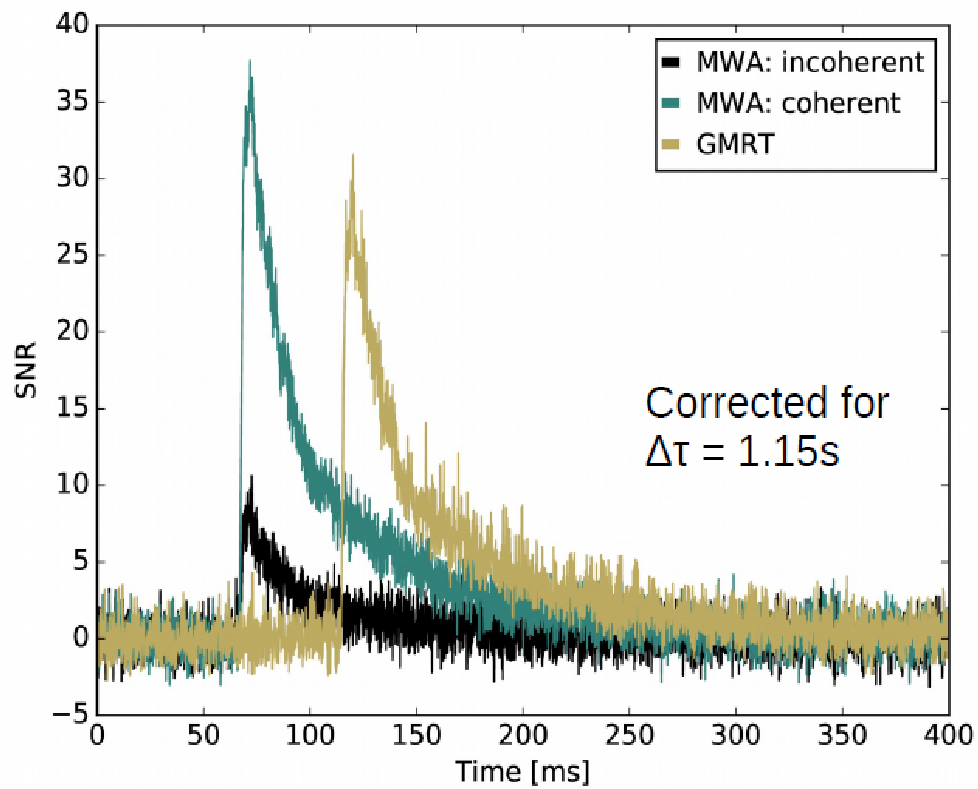
SKA-Low: Fringes GMRT-MWA: Just so you know...



From Franz Kirsten talk @ SKA-VLBI Workshop, October 2019

SKA-Low: Fringes GMRT-MWA: Just so you know...

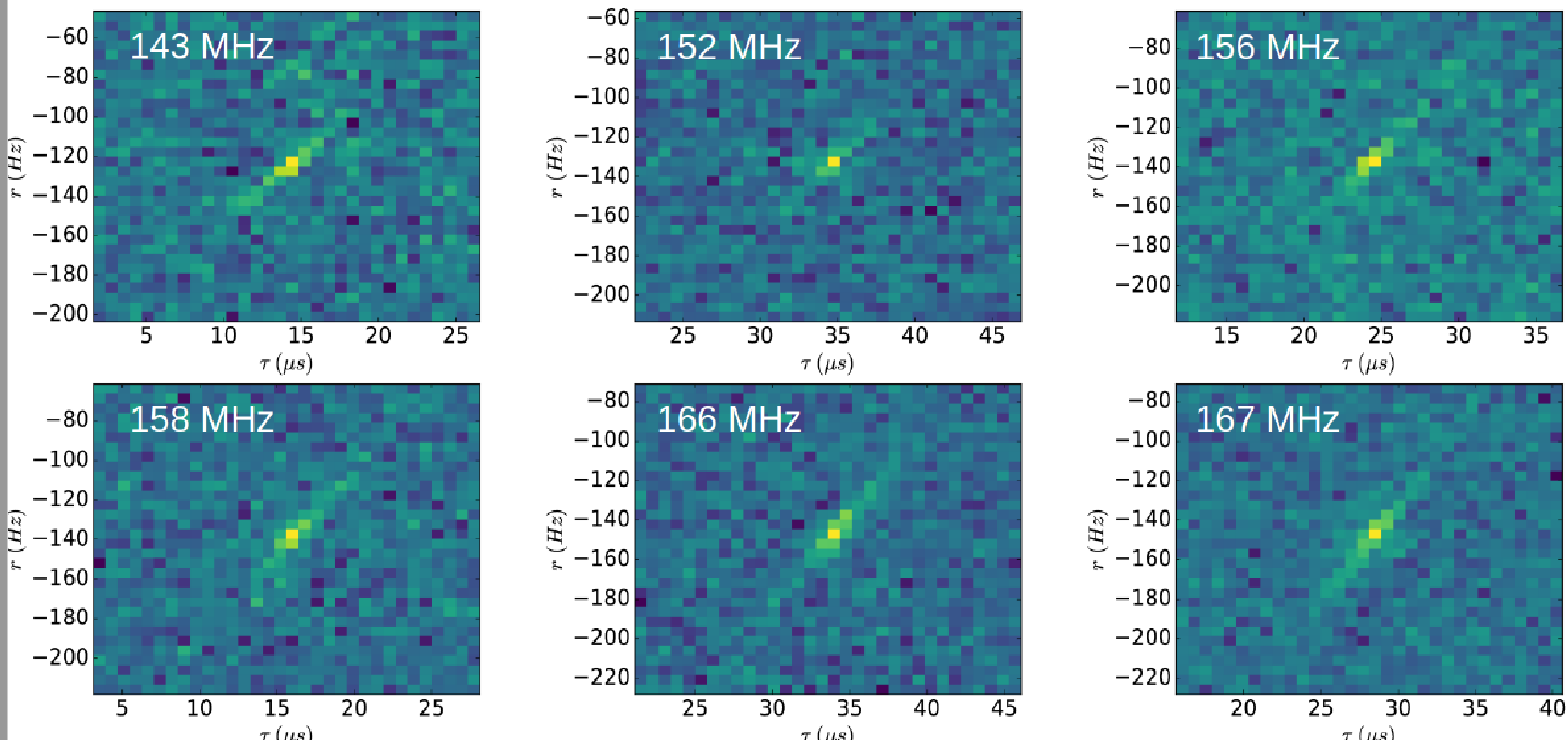
Done on Giant pulses of the Crab pulsar. In total on 12 pulses.



From Franz Kirsten talk @ SKA-VLBI Workshop, October 2019

SKA-Low: Fringes GMRT-MWA: Just so you know...

Custom code, highly non standard.



From Franz Kirsten talk

SKA + VLBI

SKA will greatly enhance modern VLBI

1. SKA (as well as FAST) will increase **sensitivity** of VLBI surveys significantly (geometric mean for SEFDs)
2. SKA+VLBI superior astrometric capabilities because it will allow very efficient phase-referencing
   - When an SKA antenna looks at a bright calibrator in the primary FoV, all other antennas at the target source
   - Cluster-Cluster technique of phase-referencing

3. Increase of baselines from 10^2 km (SKA1) and 10^3 km (SKA2) to 10^4 km (VLBI) and maybe even 10^5 km (SVLBI) – therefore greater angular resolution

SKA+VLBI Sensitivity

SKA Band	SKA-core SEFD [Jy]	Bandwidth [MHz]	Remote tel. SEFD [Jy]	Baseline sens. 60s [μJy]	Image noise 1hr [μJy/beam]
50% SKA1-MID	5.2	256	20	82	9
SKA1-MID	2.6	1024	20	29	3
Full SKA	0.26	2048	20	3	0.05

Table 1: Typical expected 1σ baseline and image sensitivities of various SKA-VLBI configurations at ∼3–8 GHz, with the inner 4 km of SKA core phased up. All the baseline sensitivities are given for a 100m-class remote telescope. 50% SKA1-MID (early operations): assuming an accompanying array of 5 25–30m dishes and a 100m-class antenna. SKA1-MID – same configuration. Note at ∼1–3 GHz and including SKA1-SUR as well will provide a similar sensitivity. Full SKA: 10x more sensitive than SKA1-MID.

Paragi et al. 2015

Astrometric accuracy

- Astrometric observations with current instruments are capable of reaching parallax precisions of 10 μas (e.g. Deller et al. 2013; Nagayama et al. 2011; Zhang et al. 2013; Reid et al. 2011).
- SKA-VLBI has the potential to reach parallax accuracies of 3 μas or better, sufficient for a precise distance to any Galactic object along a line of sight and masers in the Local Group galaxies.

SKA High Priority Science Objectives & VLBI

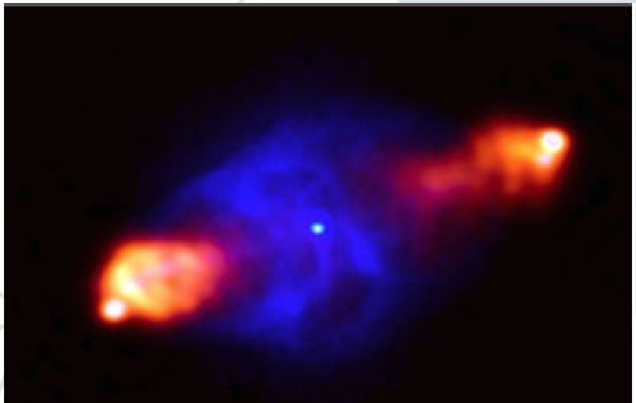
- **HI absorption systems at high redshift**
  - To resolve background source or absorber
  - **HPSO#13** for MID; complementary work on LOW

- **Pulsar scintillometry**
  - ISM as 10-50 AU scale interferometer (picoarcsec resolution)
  - Parallax distance (related to **HPSO#4** on pulsar timing)

- **AGN jet termination hot-spots with VLBI to reveal their physics**

- **Transient localization**
  - Localize FRB within the host galaxy with ~40 mas resolution (**HPSO#18**)

SKA1-LOW

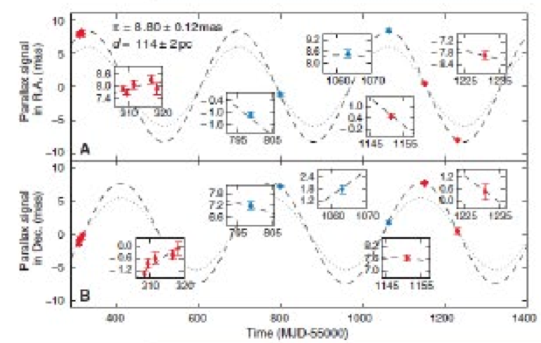


Cyg A (McKean et al. 2016)

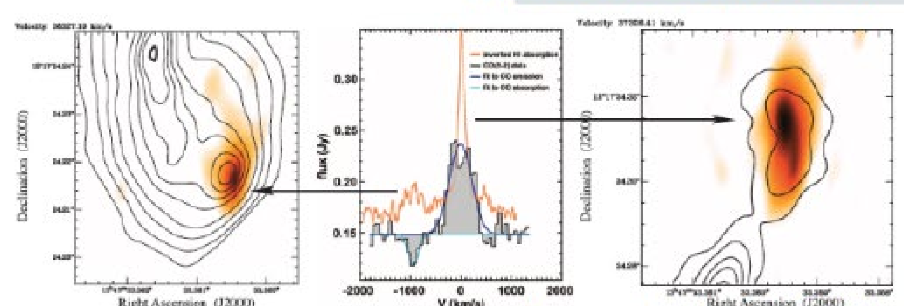
SKA High Priority Science Objectives & VLBI

- **Pulsar astrometry: HPSO#5**
  - Multi-beam calibration, precision ~10 μas and below!
  - Requires Band 5 for GC pulsars
- **Proper motion and parallax of stars/clusters: HPSO#26**
  - Methanol maser for high-mass, continuum for low-mass
  - 6D tomography of spiral arms
- **HI absorption: HPSO#16**
  - AGN feedback, Band 2, 1
- **Continuum surveys**
  - AGN vs. (nuclear) SF beyond $z > 0.1$
  - Cosmology with gravitational lensing
- **Transient localization and imaging, HPSOs#18-19**
  - Synchrotron (galactic/extragal), ToO, trigger
  - Localize FRB within their host on sub-pc scales

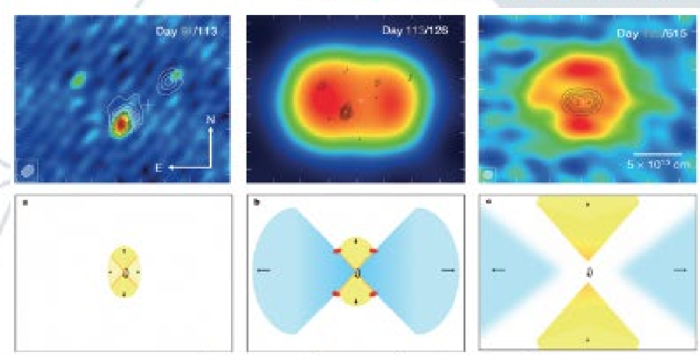
SKA1-MID



Miller-Jones et al. (2013)



Morganti et al. (2013)



Chomiuk et al. (2014)

from Paragi, 2019

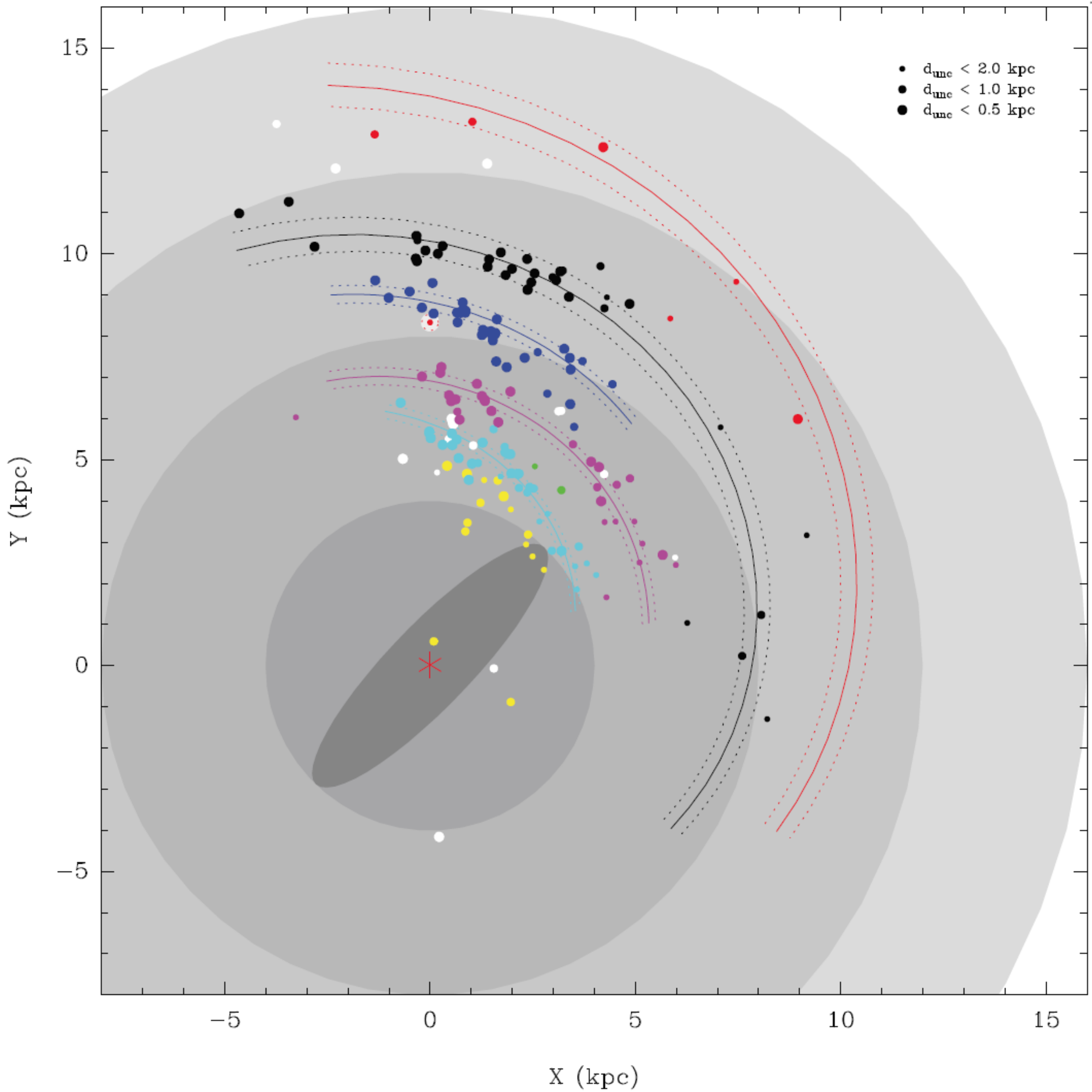


Figure 2. Parallax measurements for molecular masers associated with high-mass star formation across the Milky Way. These include published results from the VERA project and both published and unpublished results from the BeSSeL Survey. Starting from the outside, the Outer, Perseus, Local, Sagittarius, Scutum, and Norma spiral arms are indicated with lines. M. Reid et al. 2018

Galactic rotation curve

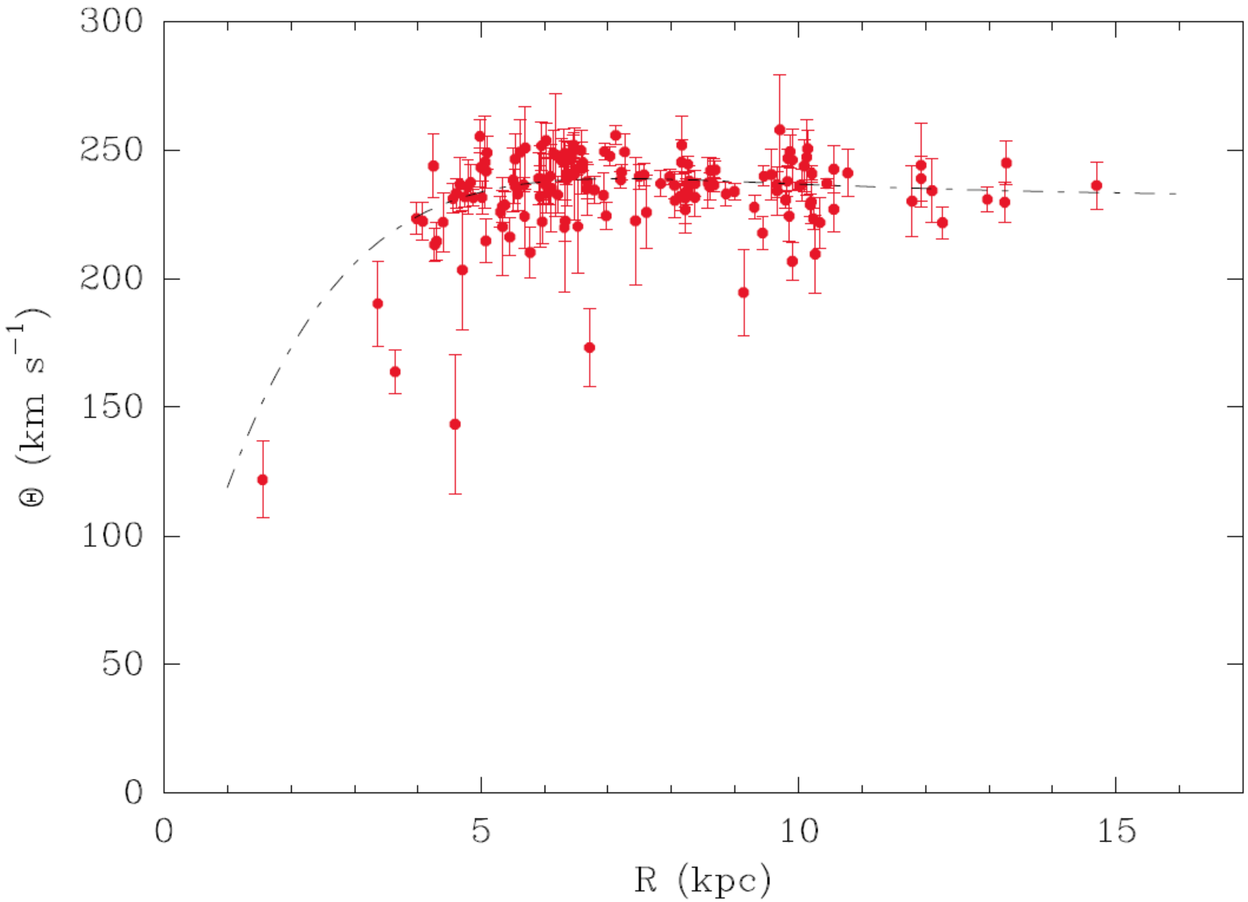


Figure 4. Rotation curve data from parallax measurements which supply full 6-dimensional phase-space information. The dashed line is a "universal" rotation curve (Persic, Salucci & Stel 1996) appropriate for spiral galaxies and fitted to the data.

Based on 200 maser parallax measurements from VLBA BESSEL Survey and VERA project (Reid, 2018)

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THANK YOU!

C4SKA, Auckland, New Zealand, 13-14 February 2020