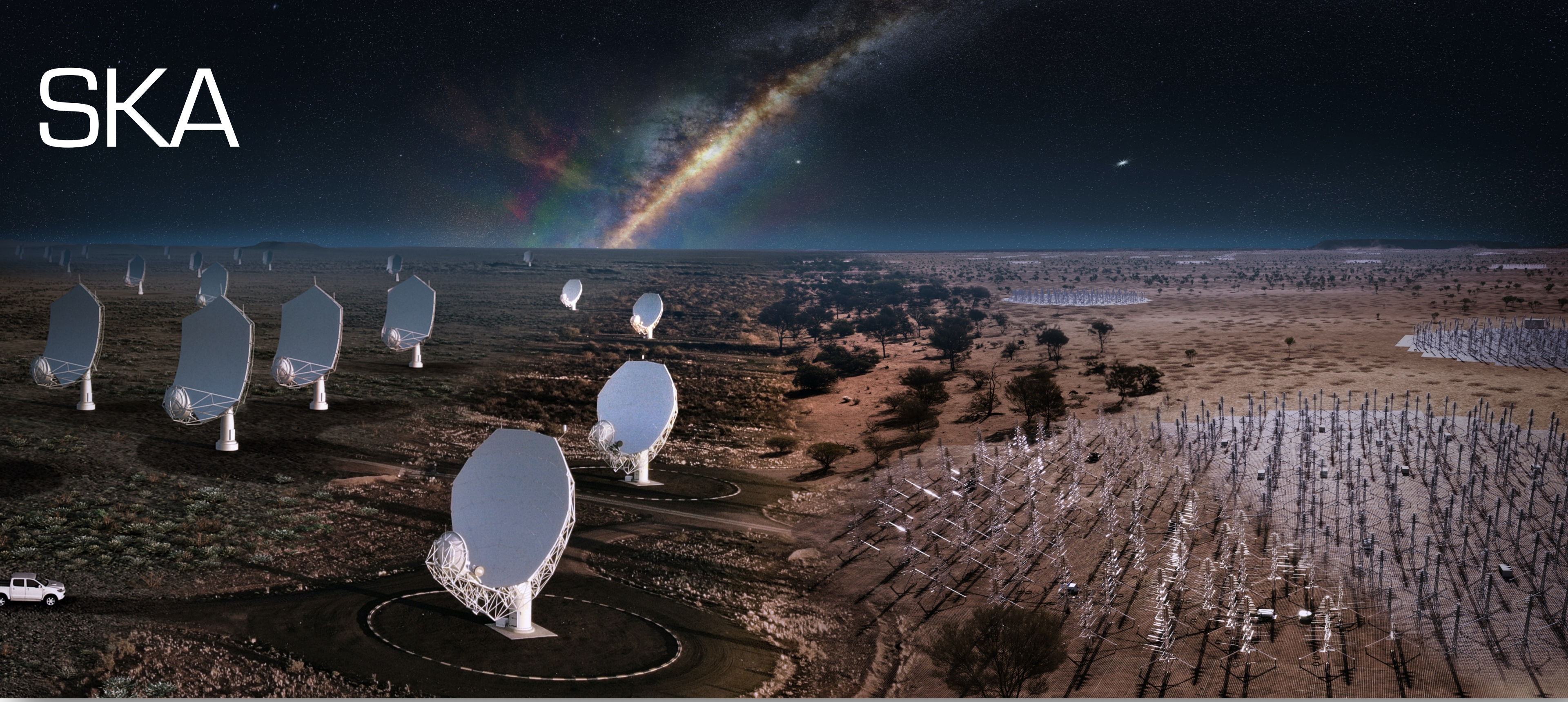


The impact of SKA on Galactic Science:
a glimpse at the Galactic Plane with SKA precursors

G. Umana, INAF, Italy

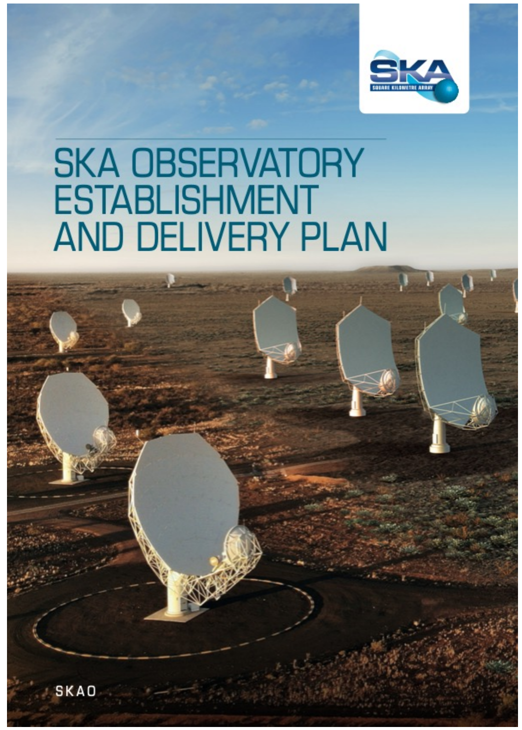
INAF
ISTITUTO NAZIONALE DI ASTROFISICA

SKA SQUARE KILOMETRE ARRAY Italy

Credits

SKA/Documentations

https://www.skatelescope.org/key-documents/



2021

Useful updates:

Minutes/Slides from Monthly SWG Chairs telecons

https://astronomers.skatelescope.org/swg-chairs-meeting-minutes/

MeerKAT www.ska.ac.za

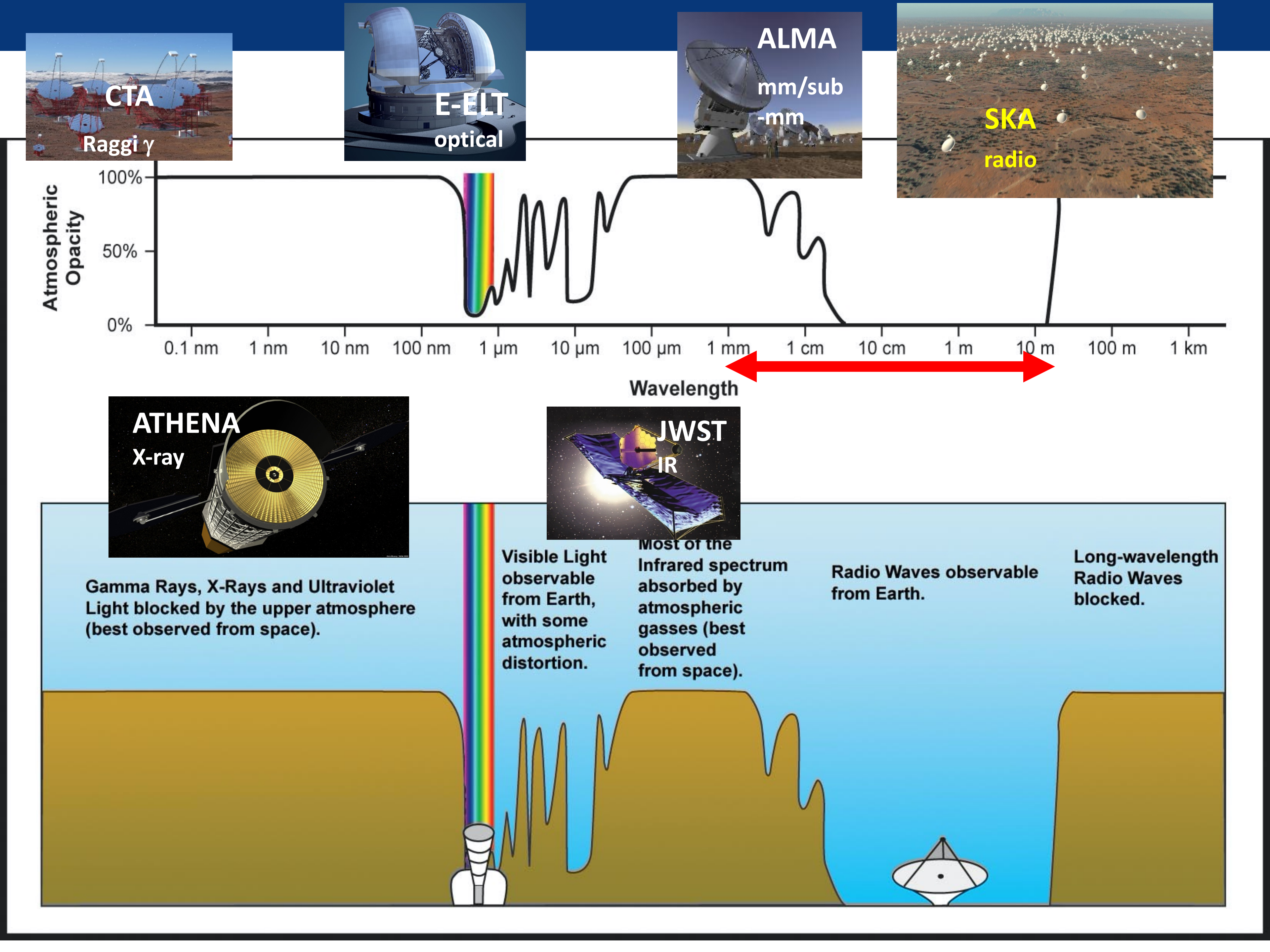
SKA SOUTH AFRICA
SQUARE KILOMETRE ARRAY

ASKAP www.atnf.csiro.au

CSIRO

Talk OUTLINE

- What is Radioastronomy?
- The Square Kilometre Array project
- The Status of the Project
- The impact of SKA on Galactic Science
- Results from SKA precursors


CTA
Raggi γ
E-ELT
optical
ALMA
mm/sub
-mm
SKA
radio
Atmospheric Opacity
100%
50%
0%
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
ATHENA
X-ray
JWST
IR
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).
Visible Light observable from Earth, with some atmospheric distortion.
Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio Waves observable from Earth.
Long-wavelength Radio Waves blocked.

Radioastronomy: Looking beyond the eyes

Reveals the unseen Universe

- Some cosmic objects can be observed only in the radio
- Very energetic events can be observed in the radio
- Raw material from which the stars form can be traced only in the radio
- Same astrophysical phenomena in stars can be probed only in the radio

Can penetrate Interstellar material (dust)

- Allowing to observe inside very dusty environments
- Allowing to observe very distant objects

In particular, we succeeded :

In studying very distant regions of our Galaxy;

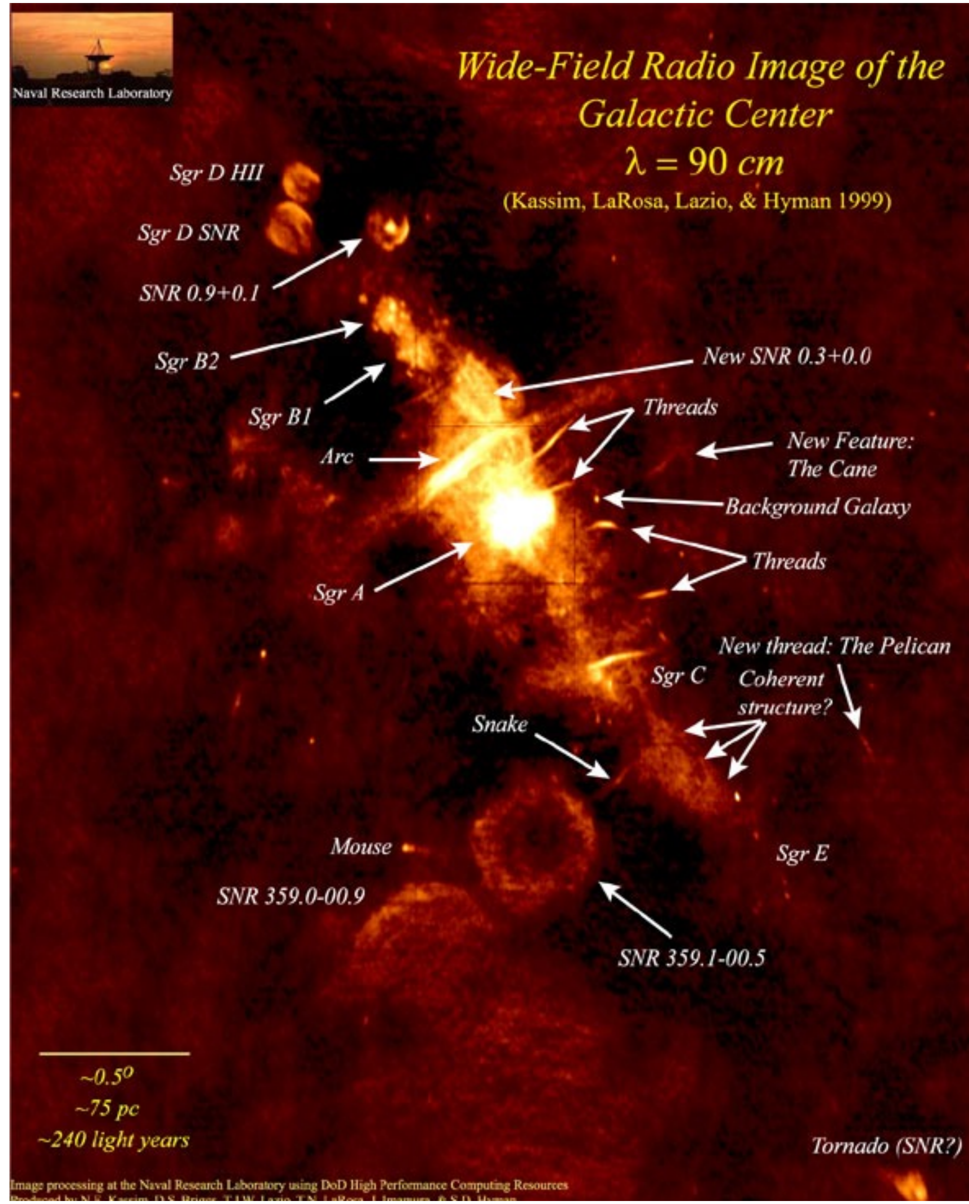
In revealing details in very obscured SFRs;

In studying the Galactic Centre

Different view of Galactic Centre

Optical

Radio



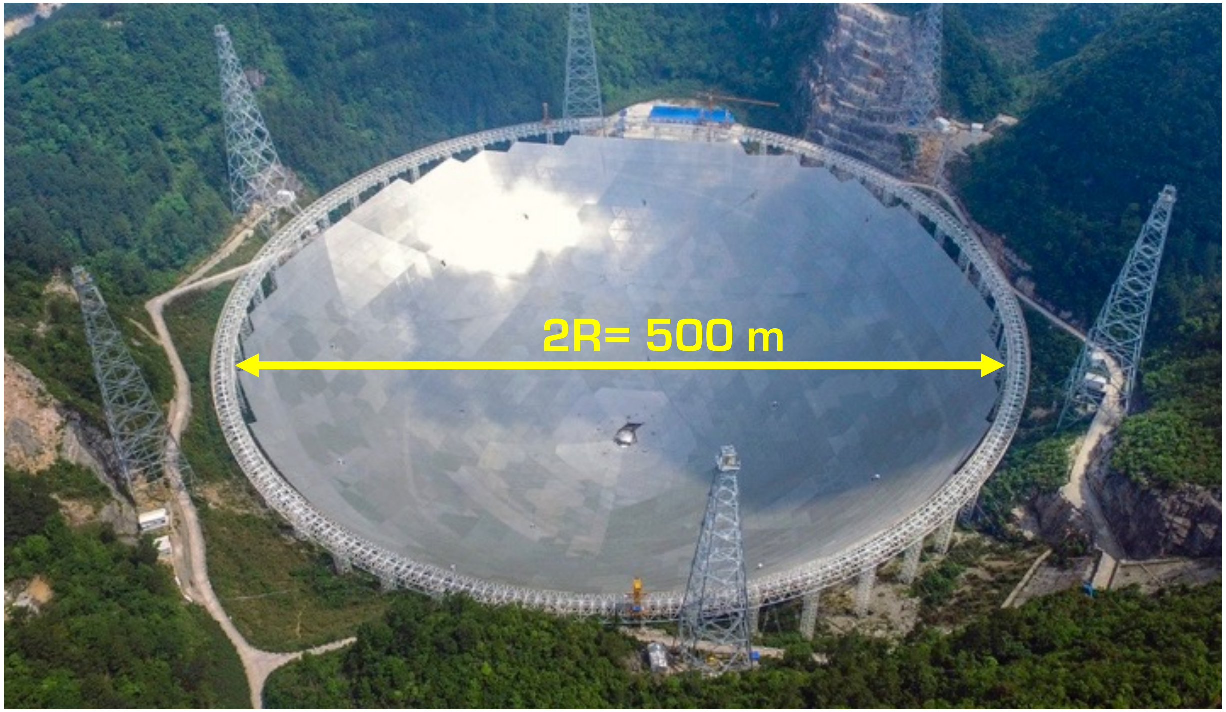
Need for large aperture

Radiotelescope performance is based on three parameters:

- Sensitivity [collecting area (R^2), receivers]
- Survey Speed [Sensitivity, FOV]
- Angular Resolution [2R] $\theta \propto \lambda / 2R$

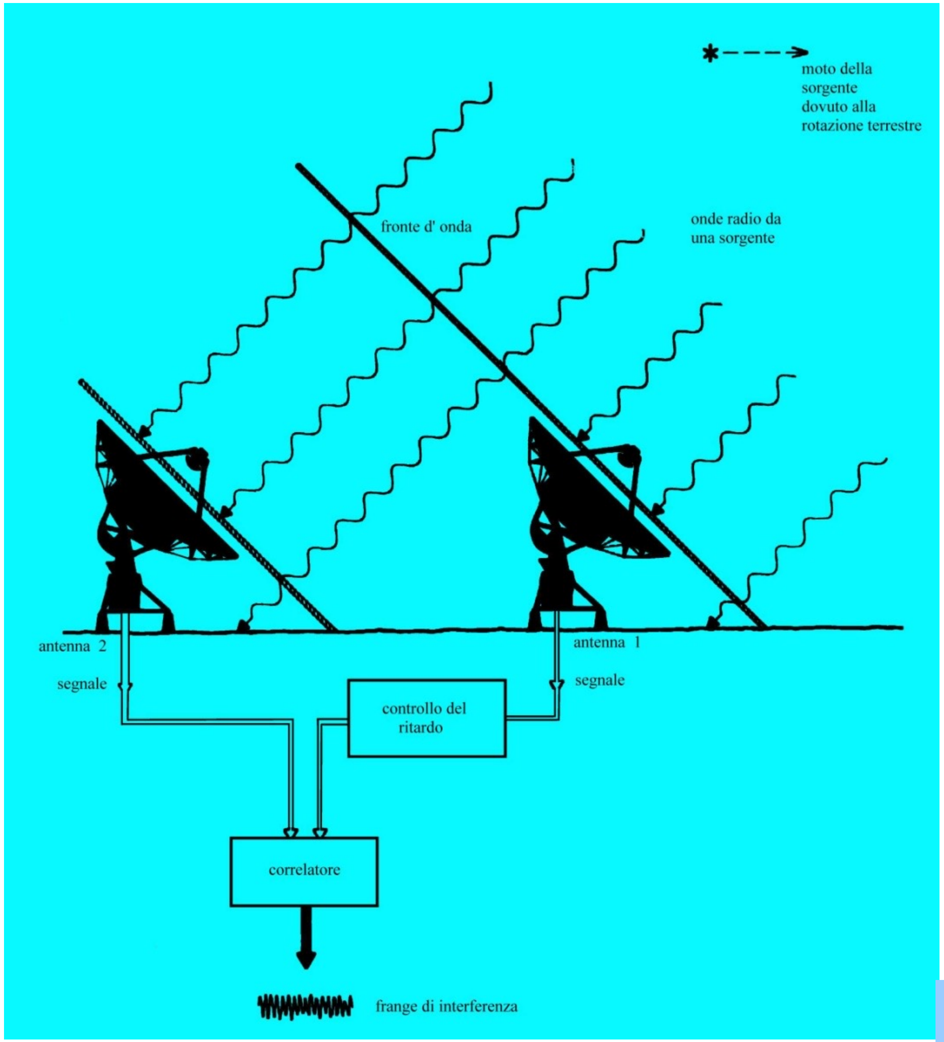
To optimize those parameters
➔ very large diameter

A "mission impossible"



Fast Radiotelescope, no-stereable
China

Interferometry



Signals from different single-dish telescope can be combined electronically

- Simulating a Radiotelescope whose diameter D is ugual to the space between antennas (baseline)
- Improving angular resolution without necessity to build "monster" antenna

Sir Martin Ryle (Cambridge)

First Radio Interferometer 1948

Nobel Prize 1974

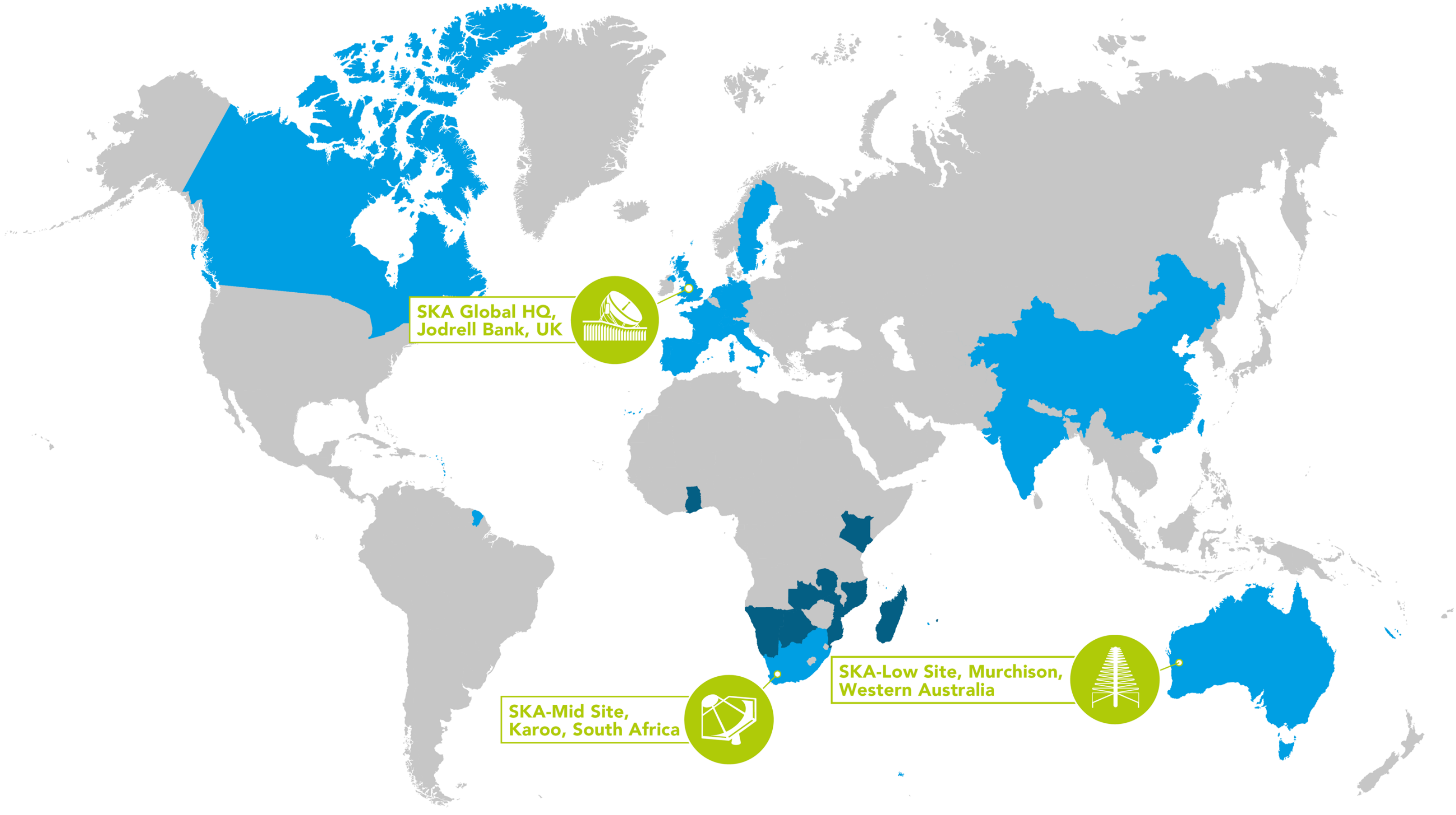
The SKA will be an aperture synthesis instrument:
signals from separated antennas digitally combined to produce
a telescope with diameter ugual to the largest antenna separation

The SKA is an international effort to build the world's largest radio telescope, *with eventually over a square kilometre of collecting area*

The SKA will be the world's premier imaging and surveying telescope, *with a combination of unprecedent versatility and sensitivity.*

Science observations already possible with SKA in 2028

The Project: a global Research Infrastructure



SKA Partners – includes Members of the SKA Organisation, precursor to the SKAO –, current SKAO Member States*, and SKAO Observers (as of January 2022)

African Partner Countries

The SKA Observatory

Major dates

- **October 2013** IGO model first proposed
- **October 2015** Start of negotiations to draft the SKA Convention
- **May 2018** SKA Convention text agreed after 4 rounds of negotiations
- **March 2019** SKA Convention signed in Rome
- **2019-20** Ratification process by parliaments
- **2020** SKA Observatory enters into force after 5 ratifications secured

The SKA Observatory launched on 4 February 2021

The SKA Observatory

The creation of the SKAO is result of 10 yrs of:

- **Engineering design**
- **Scientific prioritization**
- **Negotiations**

More than **500 engineers** from 100 Companies and Research Institutes

More than **1000 scientists**

And **dozens of politicians**

In more than 20 Countries around the world

Intergovernmental Organisation (IGO) as model for governance

IGO = ‘Convention’ agreed between governments

Best governance model for SKA

Government commitment: Long-term political stability, funding stability

A level of independence in structure

Availability of ‘supporting processes’ through Privileges and Immunities from members: functional support for project

‘Freedom to operate’, specifically through procurement process, employment rules and so on

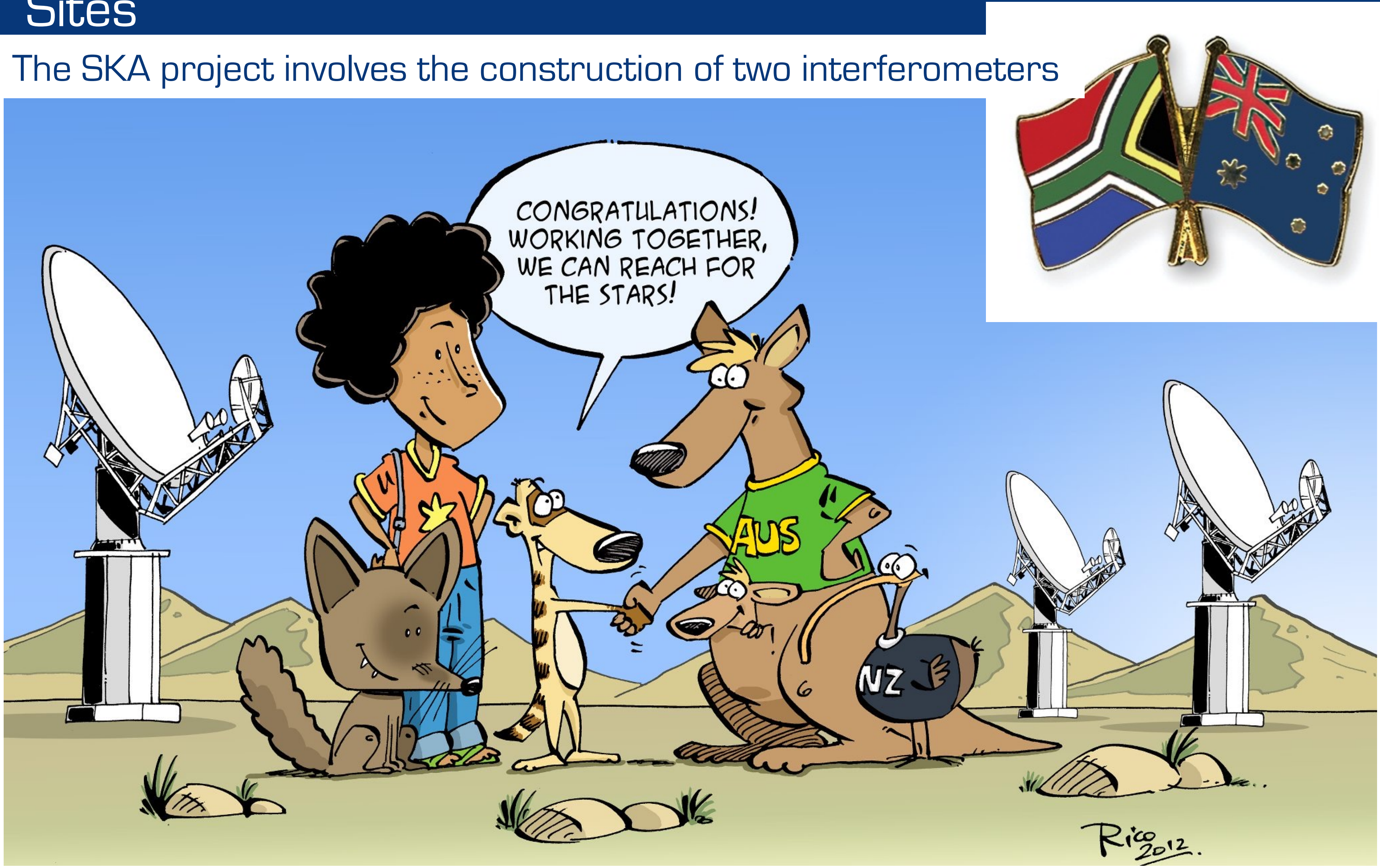
Status of the Project: the road to an IGO

Rome, 12th of March 2019- Italian Ministry of Education, Universities and Research

The initial signatories of the SKA Observatory Convention. From left to right: UK Ambassdor to Italy Jill Morris, China's Vice Minister of Science and Technology Jianguo Zhang, Portugal's Minister for Science, Technology and Higher Education Manuel Heitor, Italian Minister of Education, Universities and Research Marco Bussetti, South Africa's Minister of Science and Technology Mmamoloko Kubayi-Ngubane, the Netherlands Deputy Director of the Department for Science and Research Policy at the Ministry of Education, Culture and Science Oscar Delnooz, and Australia's Ambassdor to Italy Greg French (Credit: SKA Organisation)

Sites

The SKA project involves the construction of two interferometers



Australia-will host low frequency SKA element: **SKA_LOW**

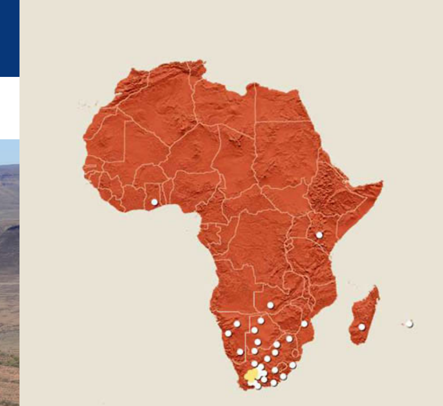
South-Africa -will host mid-frequency SKA element: **SKA_MID**

60 SKA dishes will be added to ASKAP Cancelled

2012

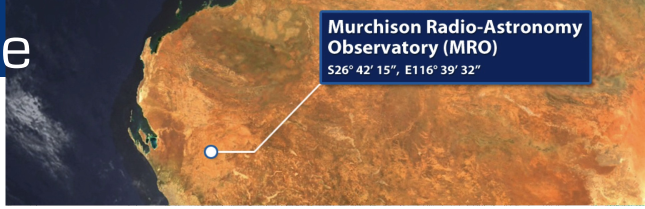
SKA AFRICA
SQUARE KILOMETRE ARRAY

South Africa's Karoo Region

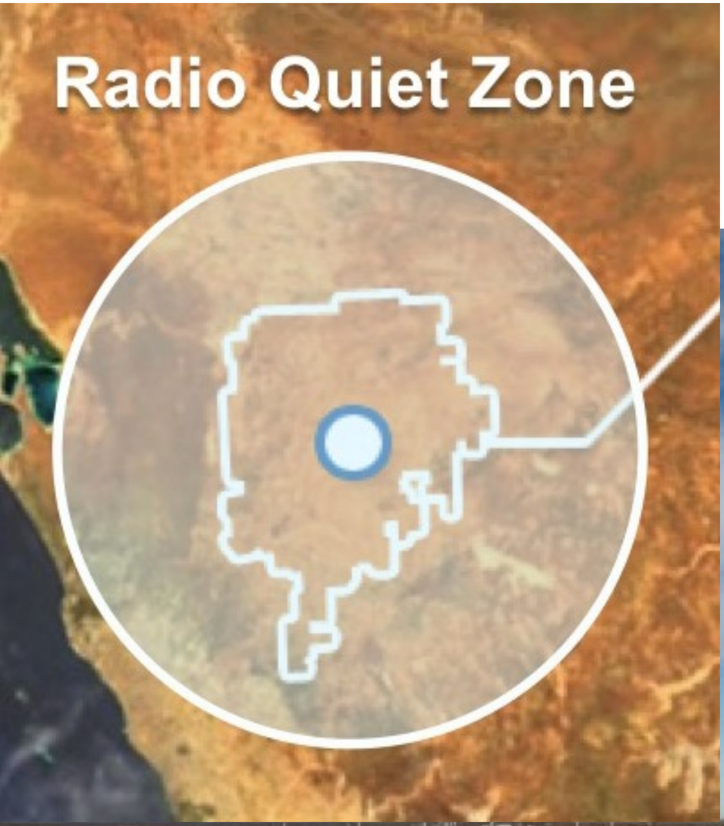


600 km north of Cape Town

Western Australia's Murchison Shire



800 km north of Perth

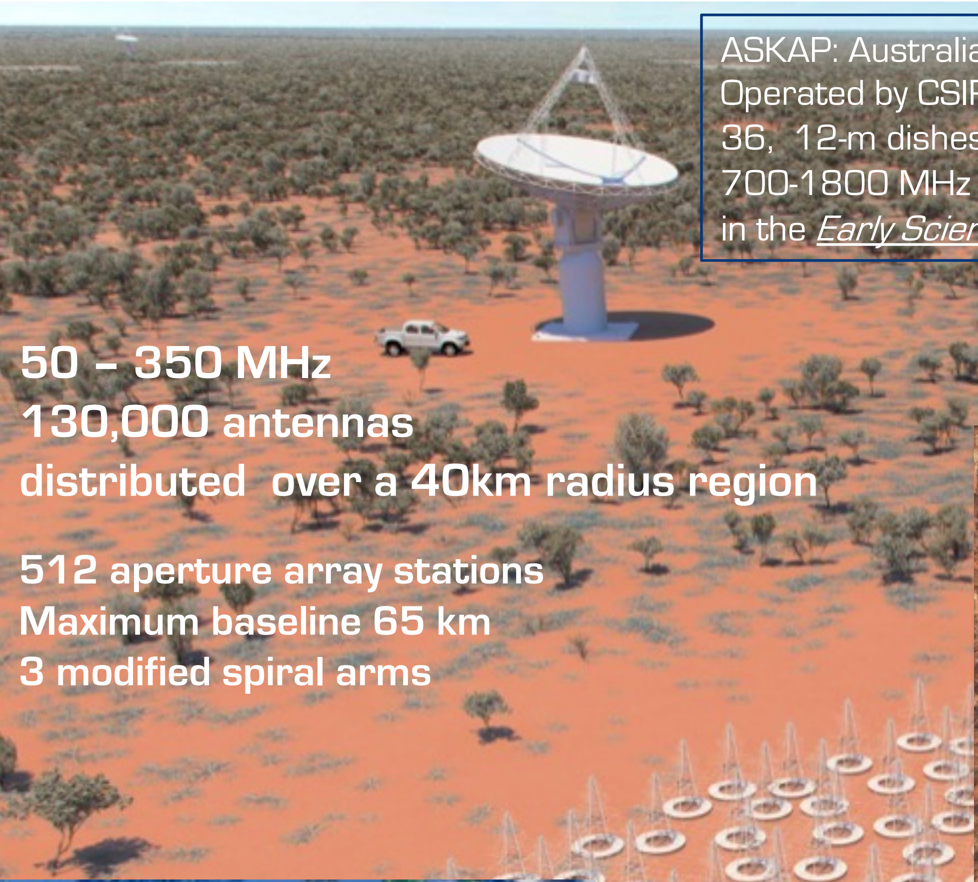


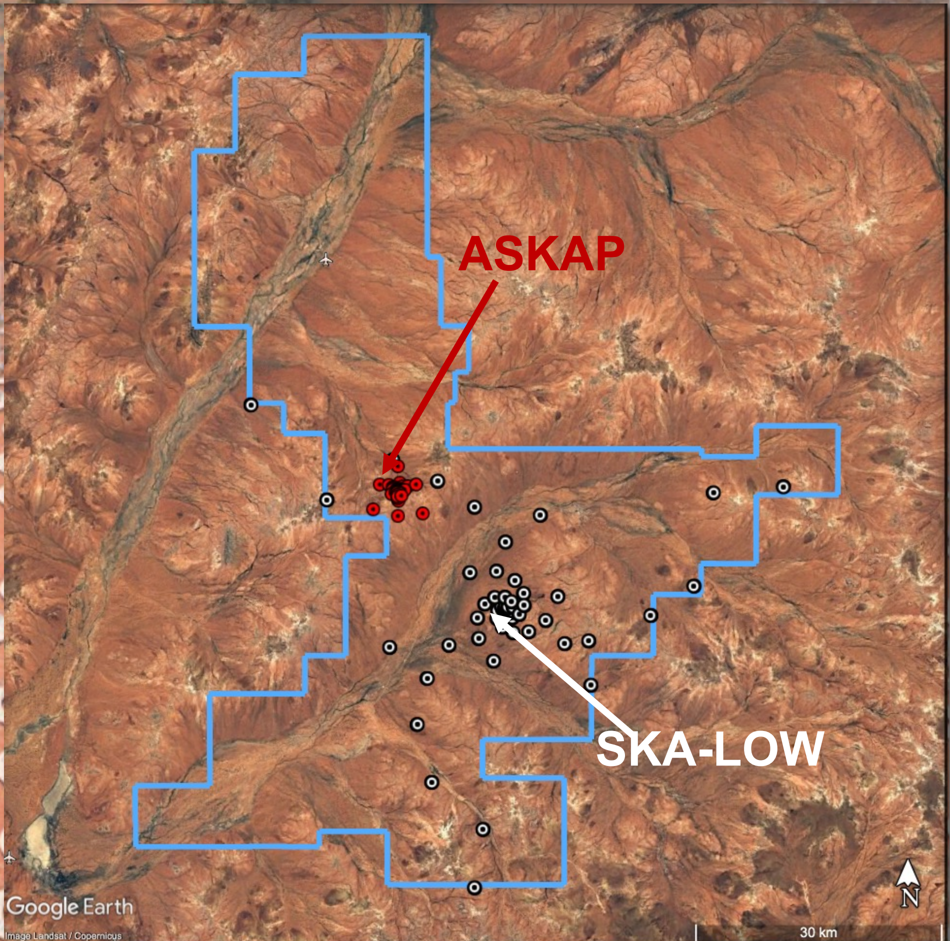
SKA-LOW

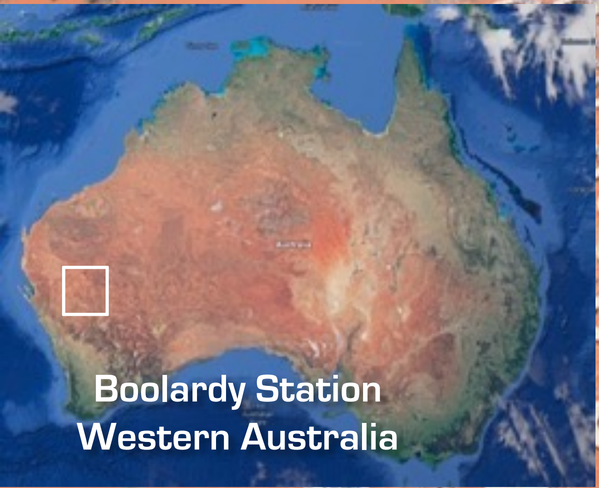
ASKAP: Australian SKA pathfinder
Operated by CSIRO
36, 12-m dishes over 6 km
700-1800 MHz
in the *Early Science* phase

50 – 350 MHz
130,000 antennas
distributed over a 40km radius region

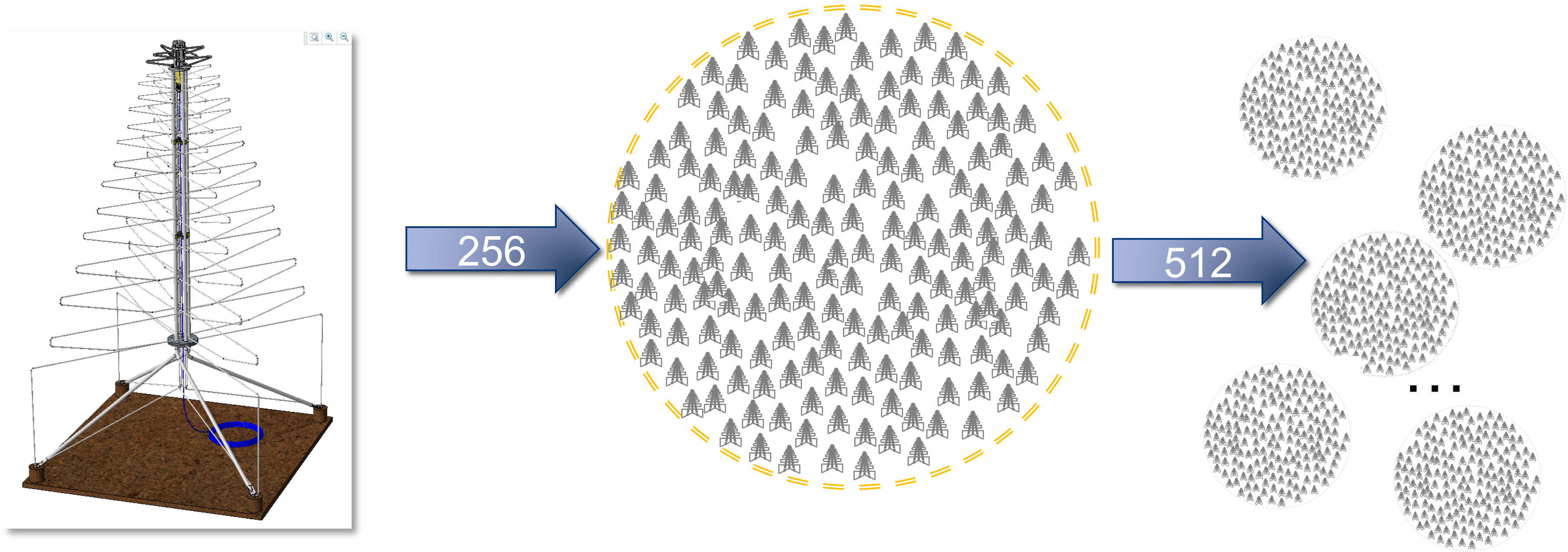
512 aperture array stations
Maximum baseline 65 km
3 modified spiral arms







SKA-LOW: Array of Arrays



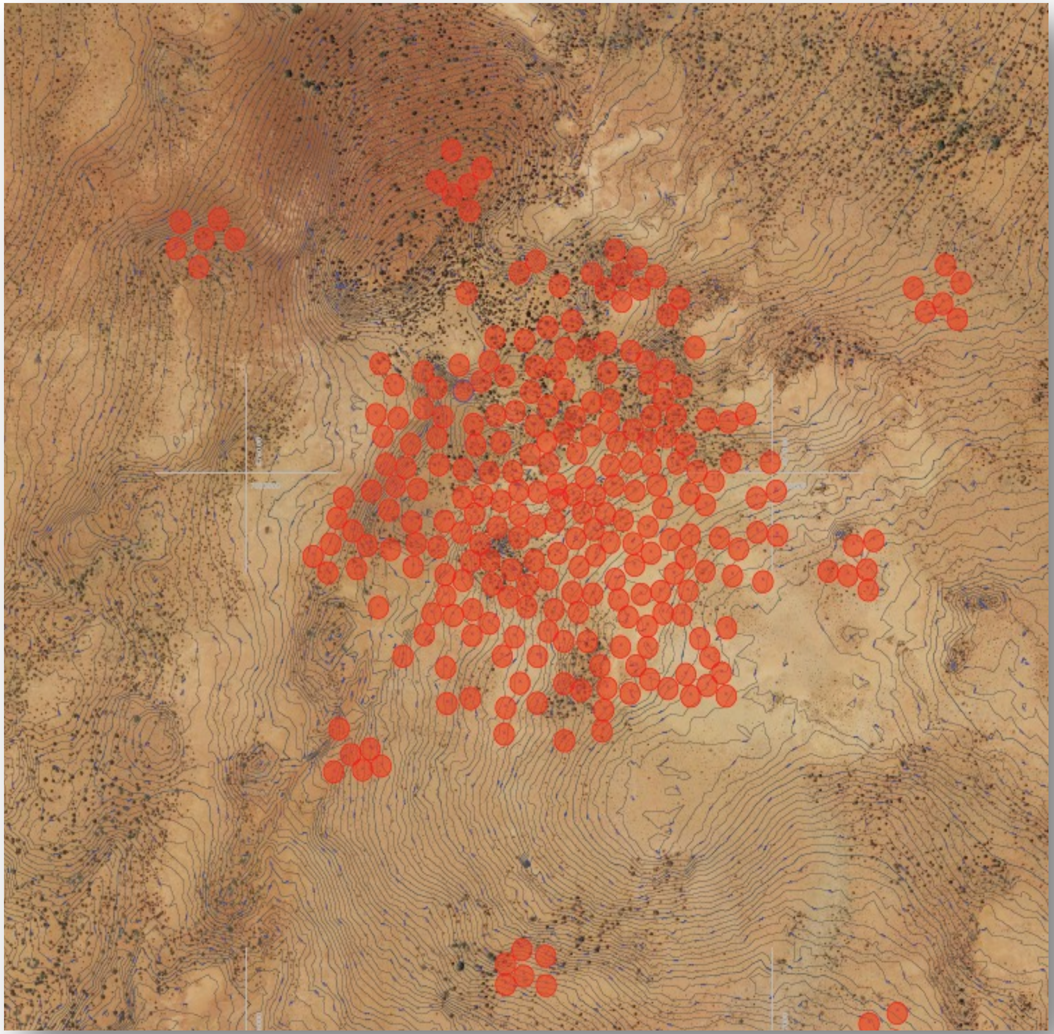
SKA-Low
Antenna/Receptor

SKA-Low
“Station”

SKA-Low
“Array”

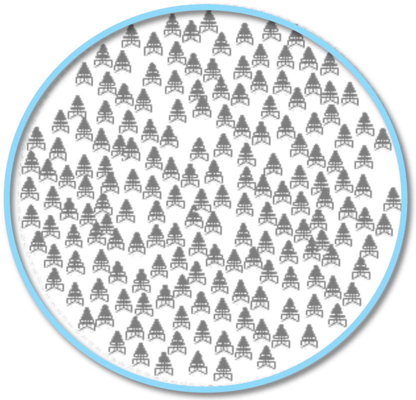
The antennas in an SKA-Low station work together to act in an analogous manner to a dish. FOV of about 20 deg^2

SKA1-LOW Layout



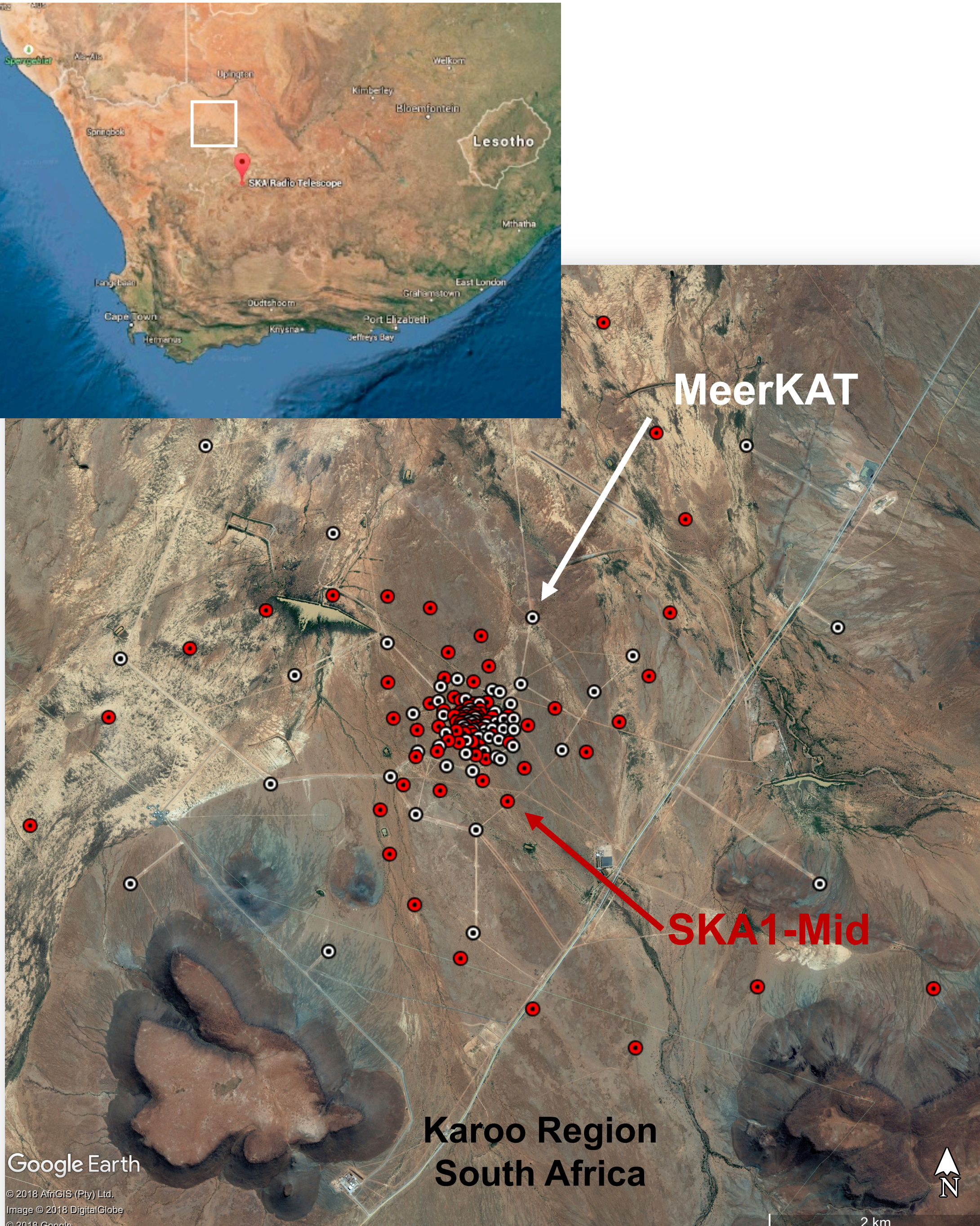
512 aperture array stations
Maximum baseline 65 km
(11" @110 MHz)
3 modified spiral arms

50% within 1 km randomly distributed
Others in clusters of 6 stations arranged randomly over an area of 100 to 150m in diameter



256 antennas per station
38m station diameter

SKA-MID Layout

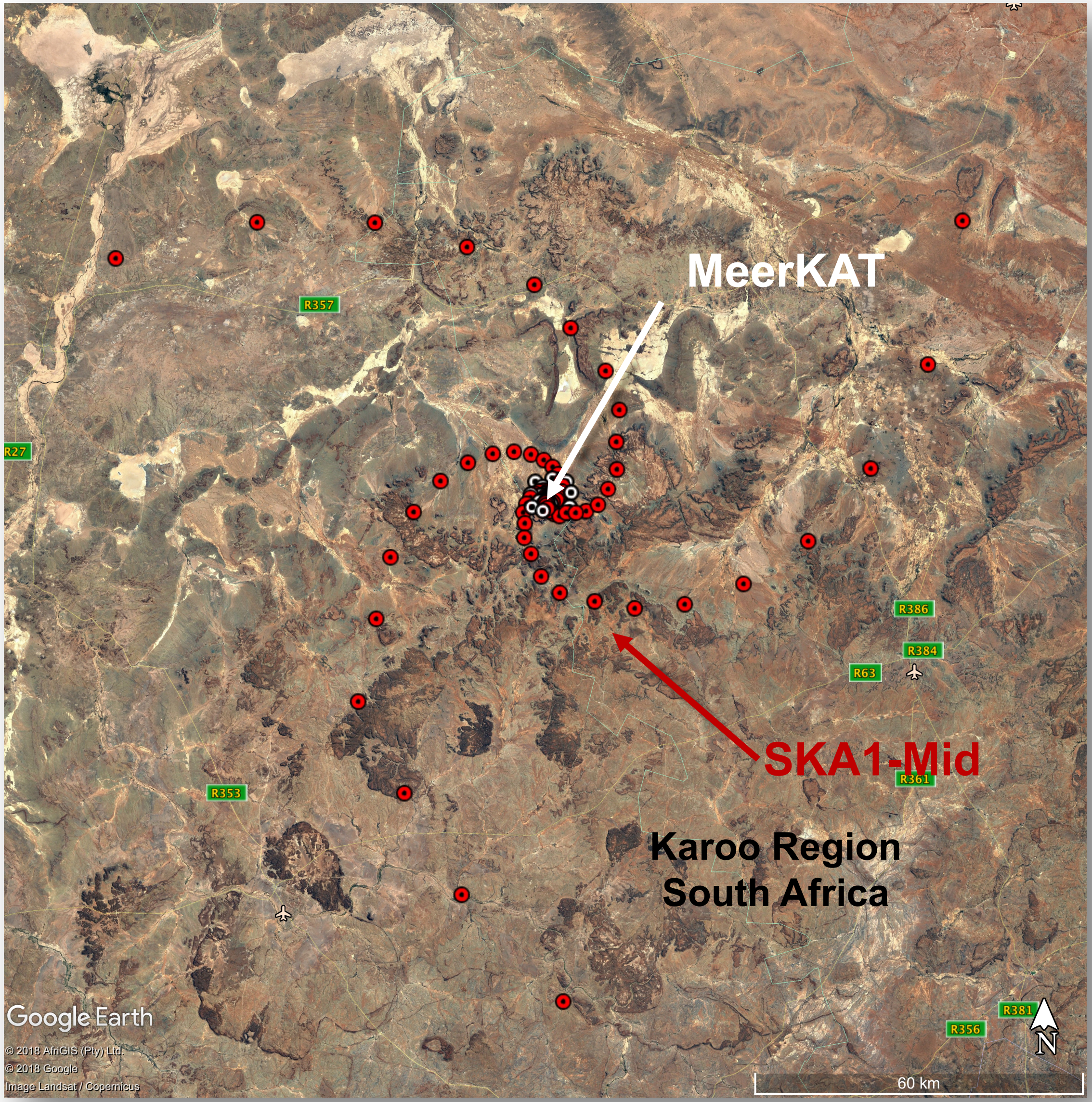


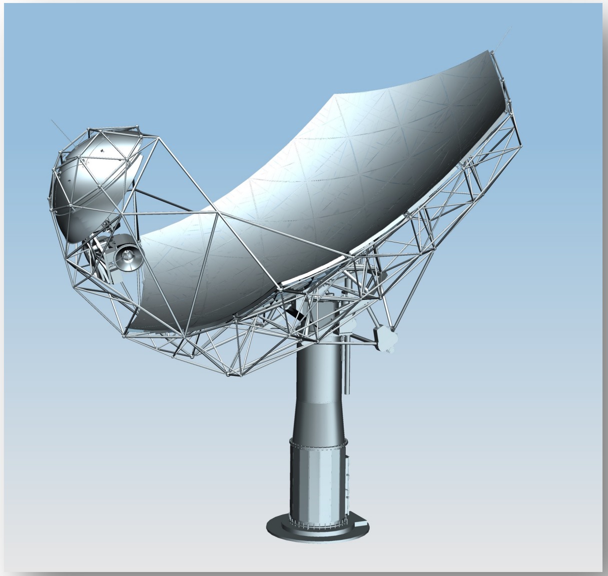
MeerKAT:
Operated by SARAO
64, 13.5-m dishes over 8 km
580-3500 MHz
L-band (900-1670) open-time proposals

133 SKA 15m dishes
64 MeerKAT 13.5m dishes

~ 50% within ~2 km randomly distributed

SKA-MID Layout





133 SKA 15m dishes
64 MeerKAT 13.5m dishes

Maximum baseline 150 km
(0.22" @1.7 GHz; 34 mas @15 GHz)
3 logarithmic spiral arms

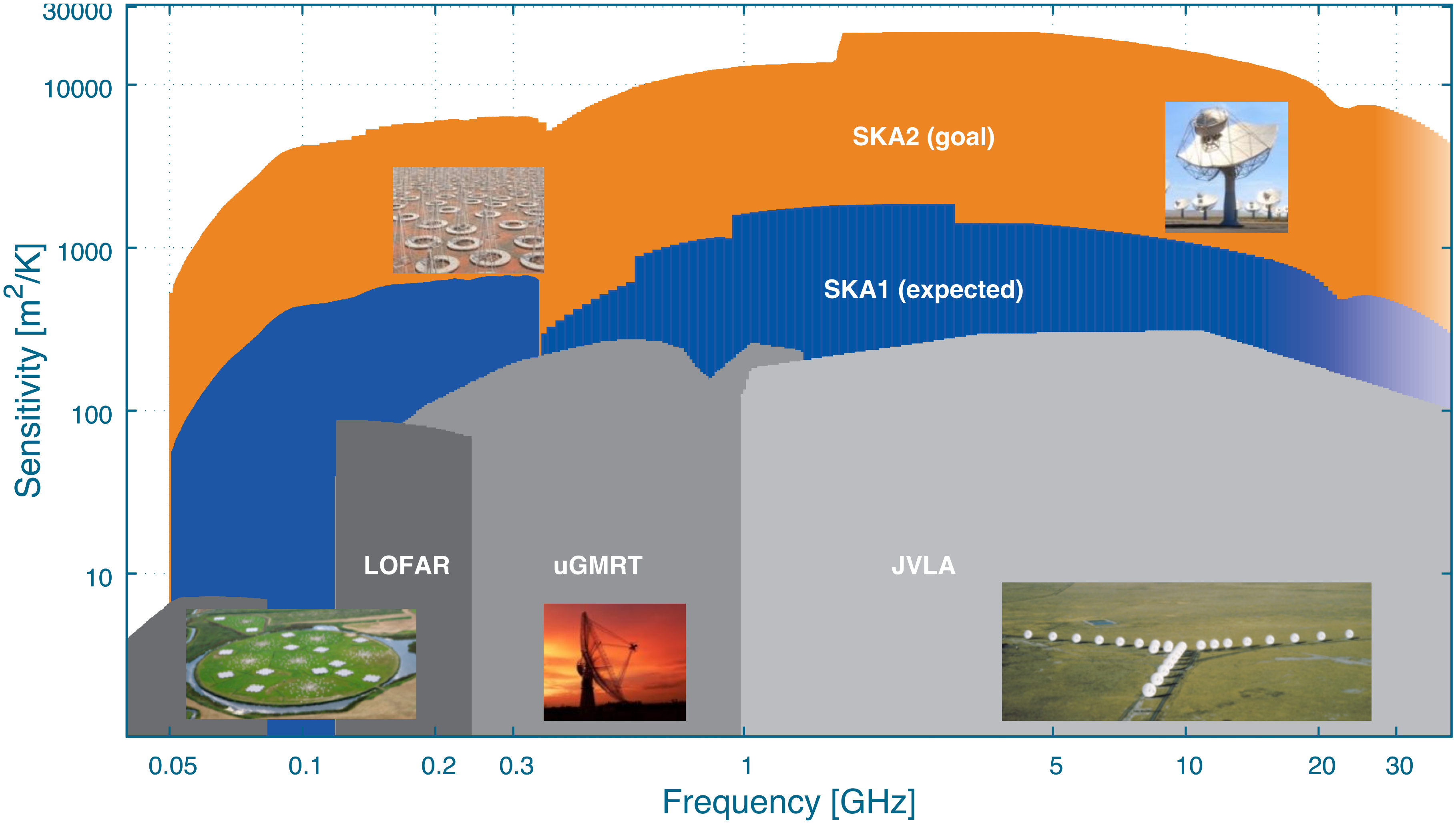
Nominal Frequency	110 MHz	300 MHz	770 MHz	1.4 GHz	6.7 GHz	12.5 GHz
Range [GHz]	0.05-0.35	0.05-0.35	0.35-1.05	0.95-1.76	4.6-8.5	8.3-15.3
Telescope	Low	Low	Mid	Mid	Mid	Mid
FoV [arcmin]	327	120	109	60	12.5	6.7
Max. Resolution (arcsec)	11	4	0.7	0.4	0.08	0.04
Max. Bandwdith [GHz]	0.3	0.3	1	1	4	5
Cont. rms, 1 hr (μJy/beam)[a]	26	14	4.4	2	1.3	1.2
Line rms, 1 hr [μJy/beam][b]	1850	800	300	140	90	85

a) Continuum sensitivity at nominal frequency, assuming fractional bandwidth of $\Delta\nu/\nu = 0.3$

b) Line sensitivity at nominal frequency, assuming fractional bandwidth per channel of $\Delta\nu/\nu = 10^{-4}$

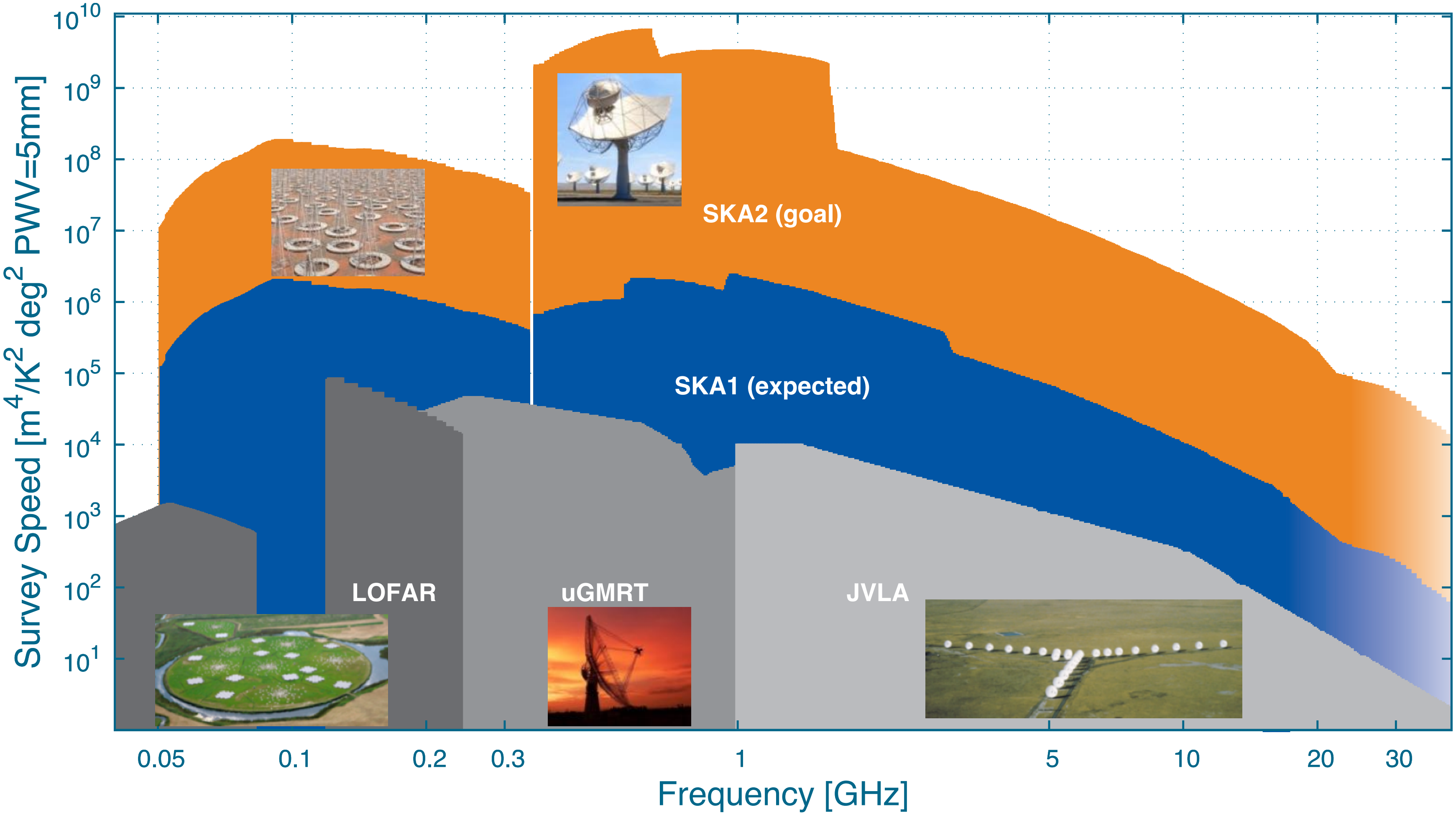
Anticipated SKA1 Science Performance: https://astronomers.skatelescope.org/documents/

SKA expected performance: SENSITIVITY



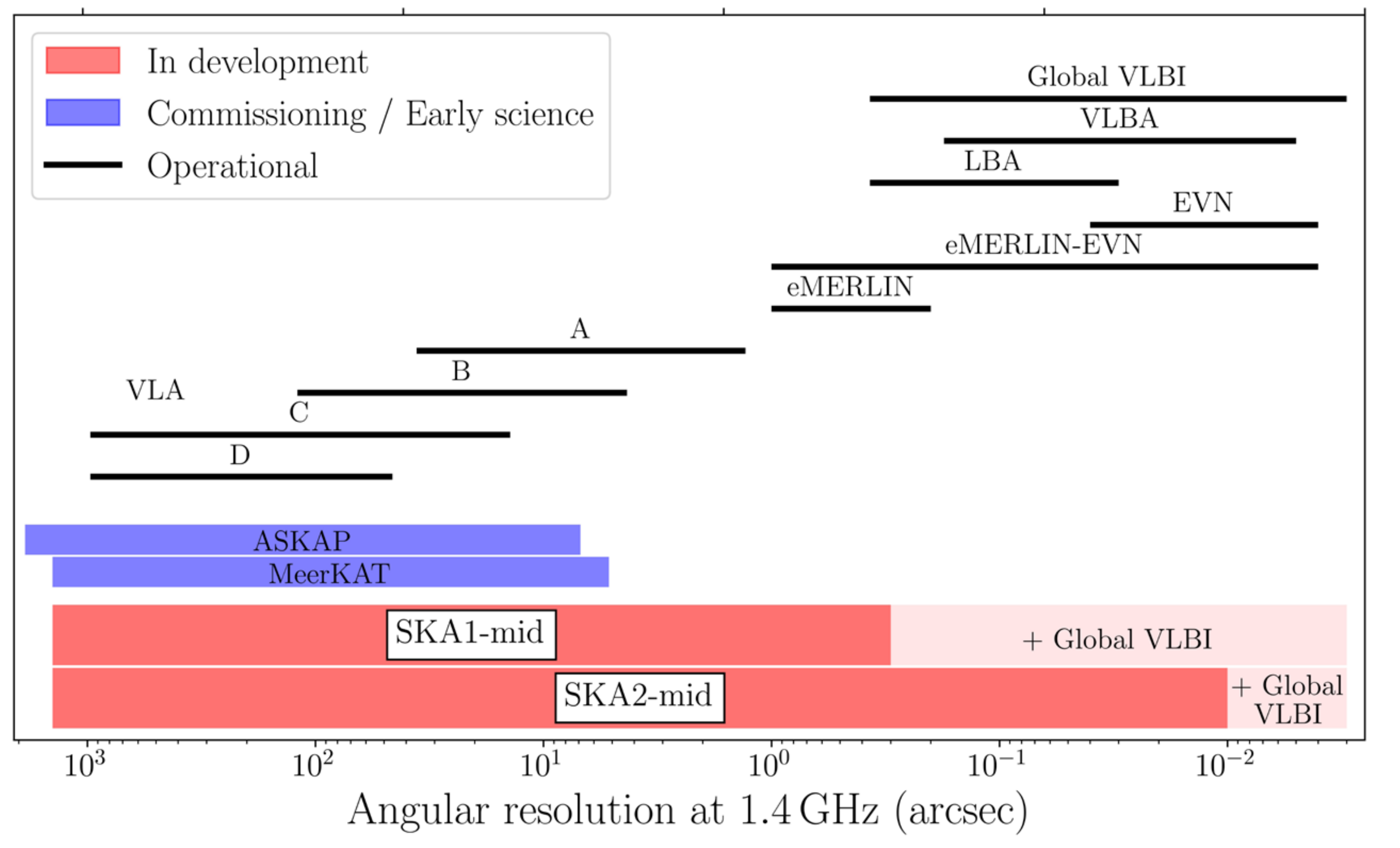
Adapted from T. Bourke et al., 2018

SKA expected performance: SURVEY SPEED



Adapted from T. Bourke et al., 2018

SKA expected performance: Angular resolution



Costs

3 sites: 2 telescopes (radio quiet locations) + HQ

One Observatory

Design Phase: > €170M; cash + kind (scientists + engineers)

Phase 1 (~10% of full SKA)

Construction: € 1.3 Billions

Operations (first 10 years): € 0.7 Billions

Phase 2.....

......????????

Key project milestone

	SKA-Low	SKA-Mid
Start of construction (T0)	1ST JULY **2021**	1ST JULY **2021**
Earliest start of major contracts (C0)	AUGUST **2021**	AUGUST **2021**
Array Assembly 0.5 finish (AA0.5) SKA-Low = 6-station array SKA-Mid = 4-dish array	FEBRUARY **2024**	MARCH **2024**
Array Assembly 1 finish (AA1) SKA-Low = 18-station array SKA-Mid = 8-dish array	FEBRUARY **2025**	FEBRUARY **2025**
Array Assembly 2 finish (AA2) SKA-Low = 64-station array SKA-Mid = 64-dish array, baselines mostly <20km	FEBRUARY **2026**	DECEMBER **2025**
Array Assembly 3 finish (AA3) SKA-Low = 256-station array, including long baselines SKA-Mid = 133-dish array, including long baselines	JANUARY **2027**	SEPTEMBER **2026**
Array Assembly 4 finish (AA4) SKA-Low = full Low array SKA-Mid = full Mid array, including MeerKAT dishes	NOVEMBER **2027**	JUNE **2027**
Operations Readiness Review (ORR)	JANUARY **2028**	DECEMBER **2027**
End of construction	JULY **2029**	JULY **2029**

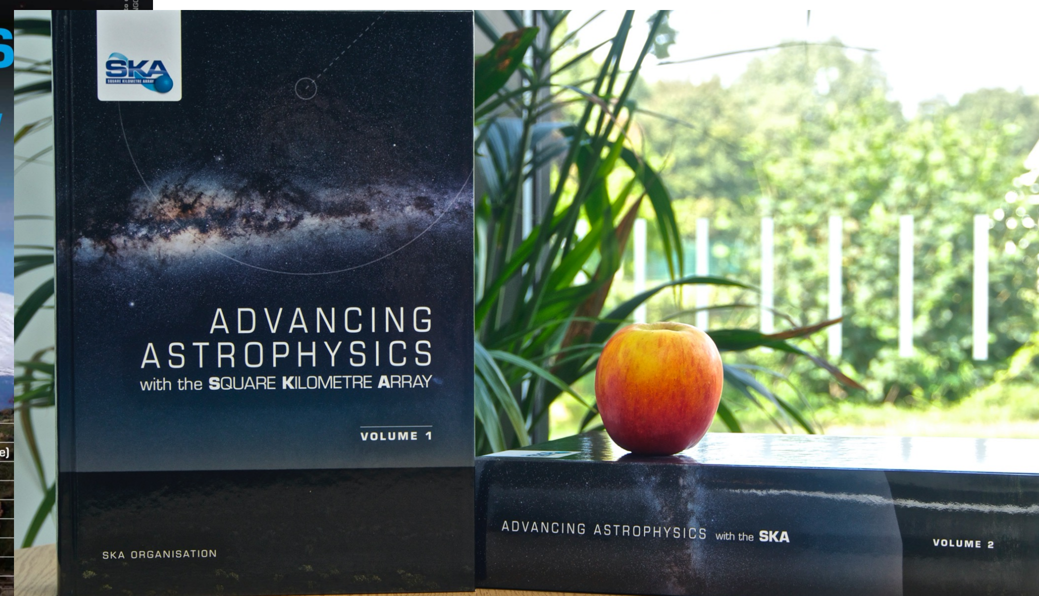
The schedule covers the construction phase of the project from T0, start of SKA1 construction, to the end of construction (T0 + 6.5 years + 18 months of schedule contingency).

Array assembly (AA):
A package of hardware and software, characterised by the number of dishes/stations included in the array and by its capability as an end-to-end telescope system with predefined functionality.

A very important Science Meeting organized by SKAO and INAF— June 2014

More than 250 scientists presenting:

- Results from SKA SWGs
- New opportunities with SKA capabilities



SKA Science BOOK 2015

135 Chapters, 2000 pages, 8.8 kg

Plus new science directions that continue to emerge!

SKA-Science Working Groups

12 science working groups (SWGs) established to provide a conduit for interaction with the astronomical community.

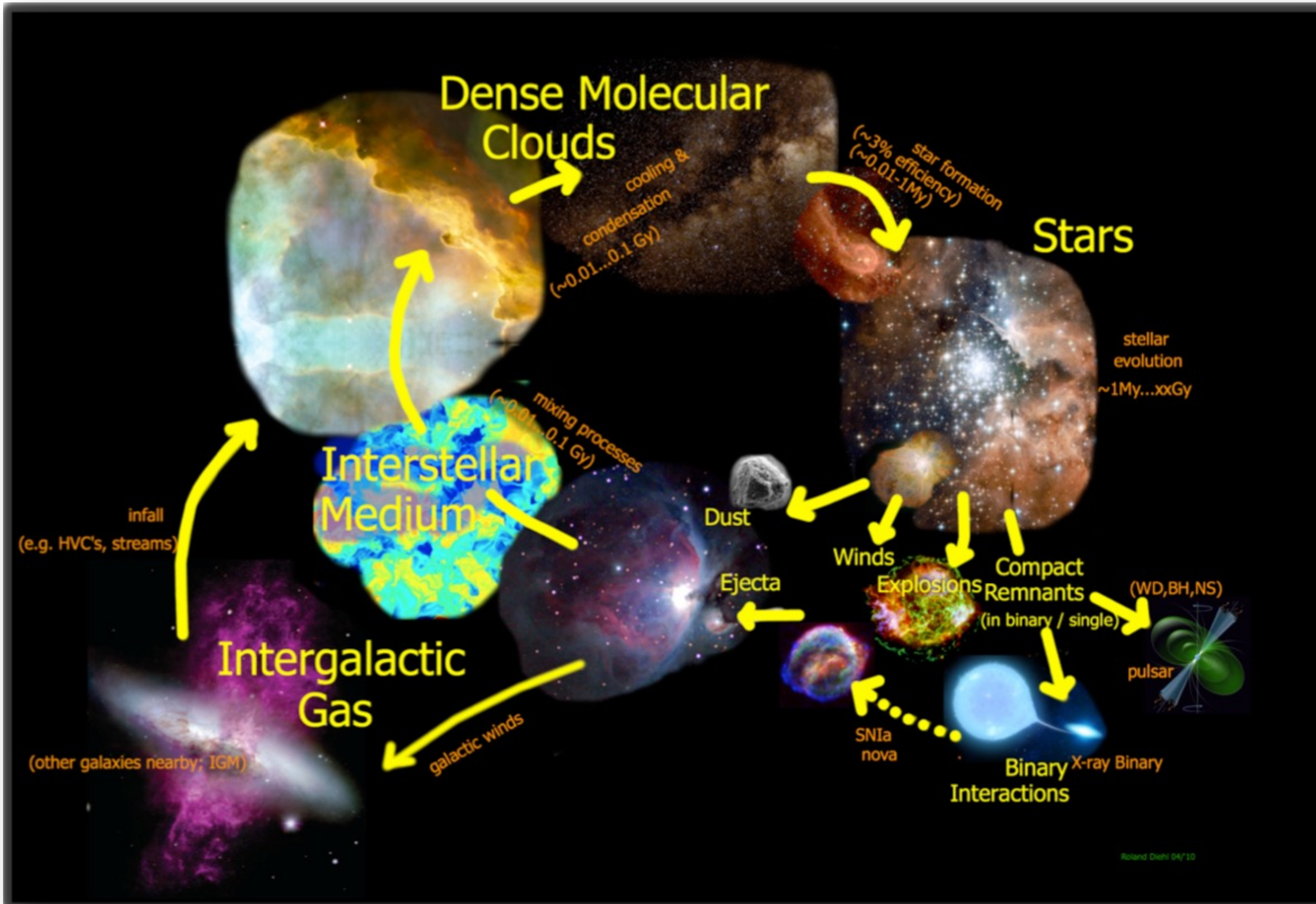
SWGs are scientific advisor committees for the SKAO

They are intended to cover all science areas that will be addressed with the SKA.

- A forum for the keys areas of interest
- Development of objectives and collaborations

https://astronomers.skatelescope.org/science-working-groups/

Our Galaxy : the cycle of the matter in the Galaxy



Using the Milky Way as a resolved template to understand how galaxies work

The impact of SKA on Galactic Science

The SKA will address several galactic science topics:

(list not exhaustive!)

Massive stars formation

- A census of the early stage of massive stars formation in the GP
- Giant HII and interaction with their environments: triggered star formation

Evolved stars

- Detection of SNRs
- Detection of PNs

To derive accurate space density and rate formation
Radio needed for robust identification

Radio Stars

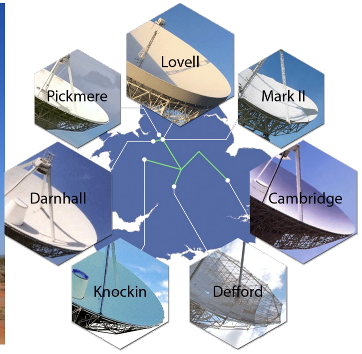
Serendipitous discoveries

Providing the most complete catalog of Galactic Sources to date

The SKA precursors and pathfinders

A series of demonstrator telescope and systems already operational or under development:

to test and develop new techonologies for SKA
to anticipate SKA's scientific achievements
to anticipate SKA's requirements in terms of data processing



https://www.skatelescope.org/precursors-pathfinders-design-studies/

SKA Precursors: **ASKAP**

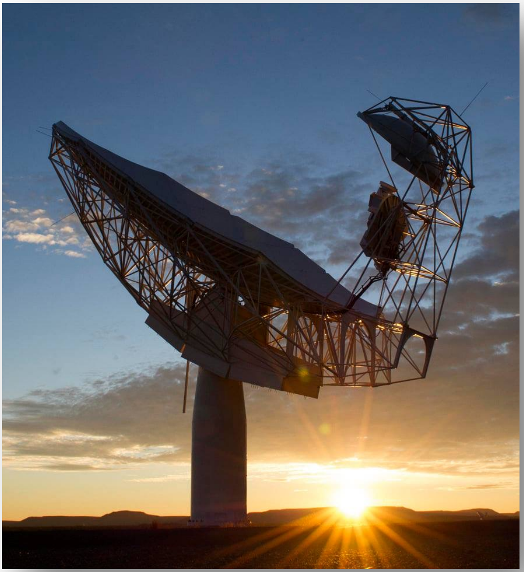
Specifications

36 antennas (12 m)
Max baseline: 6 km
Frequency coverage: 0.7- 1.8 GHz
Bandpass: 300 MHz
Sensitivity: 25 μJy/hr @ 1.4 GHz
Angular resolution= 10 arcs
FOV (PAF)= 30 deg^2
Survey Speed= 220 deg^2/hr (0.1 mJy)

Large surveys, ToO, DDT

Unique capability:
The **Ph**ased **A**rray **F**eed: Innovative technology, allows a FOV of 30 deg^2

SKA Precursors: MeerKAT



Specifications

64 Antennas (13.5m)

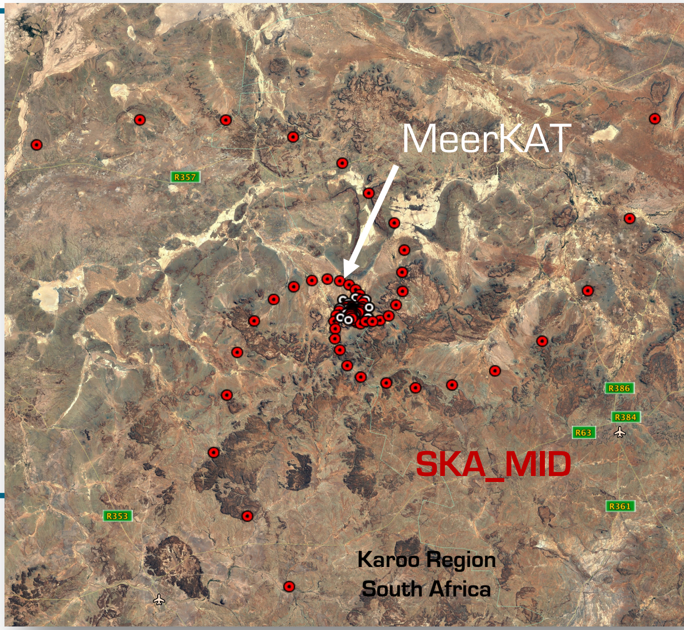
Max baseline: 8 km

Frequency coverage: 0.6- 1.75 GHz

Bandpass: 750 MHz

Sensitivity: 4-5 μJy/hr @ 1.4 GHz

Large surveys, open call, ToO, DDT



Array layout: 70% of the antennas in the 1km core

+ an extended component up to 7.7 km

Excellent surface brightness sensitivity on angular scales 1'

Two aims:

Scientific

Provide a good estimation of the scientific potential of deep radio surveys in the field of stellar/Galactic radio astronomy.

- *Catalogues of different population of Galactic radio sources*
- *Define detection rates for different classes of radio stars.*
- *Prove the importance (uniqueness) of radio observations in the field of Stellar Astrophysics*

Technical

Test bed for the SKA surveys: strategy for the GP section

- *Source complexity: issues due to complex structures in the GP*
- *Source variability: issues due to the variable sources in the GP*
- *Source finding: issues due to the diffuse emission in the GP*
- *Source identification: how to identify/discriminate different populations (e.g. Galactic vs Extragalactic, different type of stars)?*

Norris et al., 2011

EMU

Evolutionary Map of the Universe

Deep radio image of 75% of the sky

Will detect and image ~40 million galaxies
Primary science goal: **How did galaxies form and evolve?**

With its **foreseen sensitivity** and **angular resolution**
.....will provide a “good view” of the
Galactic Plane @ L-Band

Will bridge the gap in sensitivity and resolution between available GP surveys:

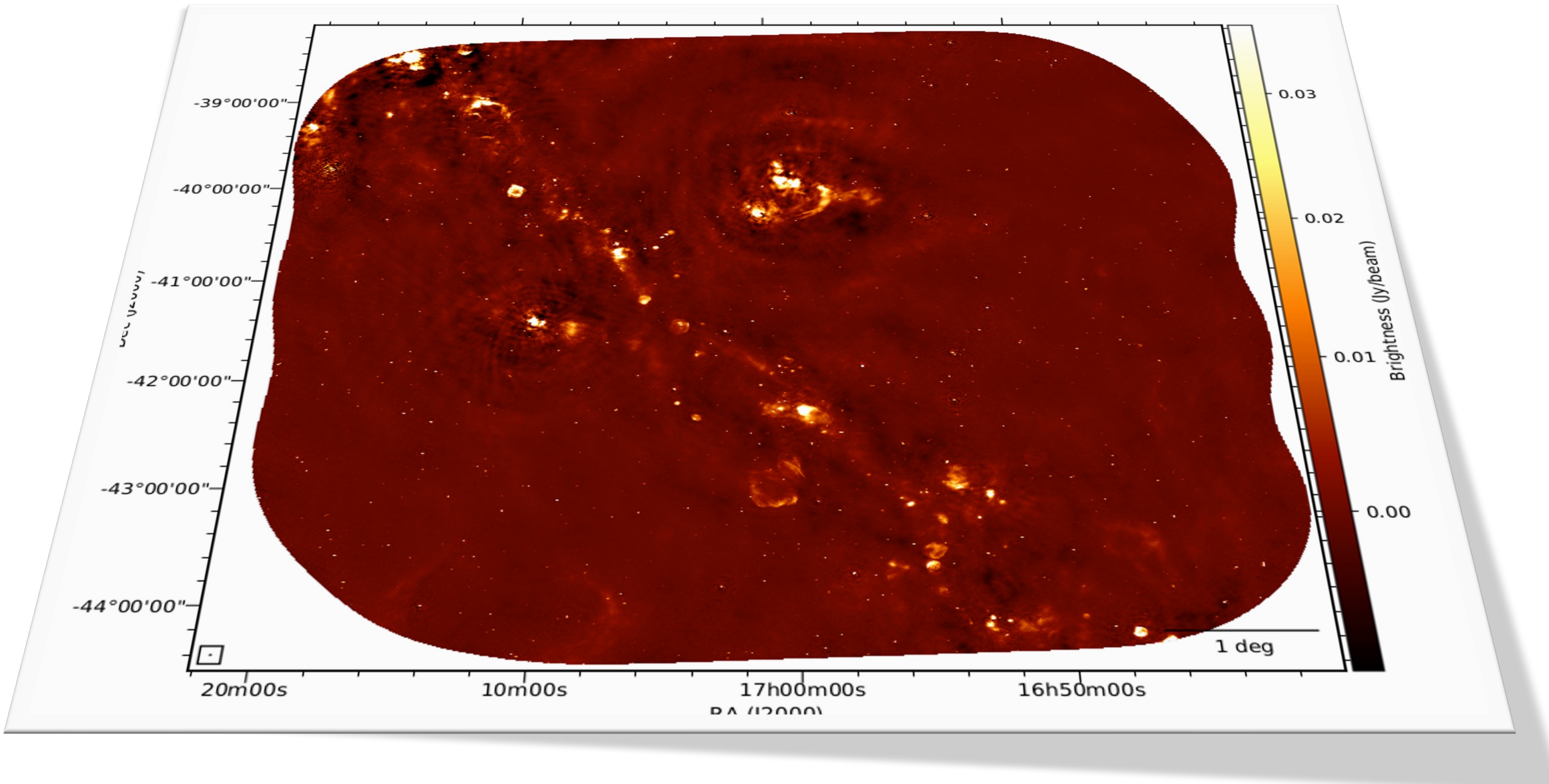
- **high angular resolution, limited areas or**
- **lower angular resolution, wide areas:**

Field center 343.5, 0.75

Dimensions 6x6 deg^2

Umana+, 2021

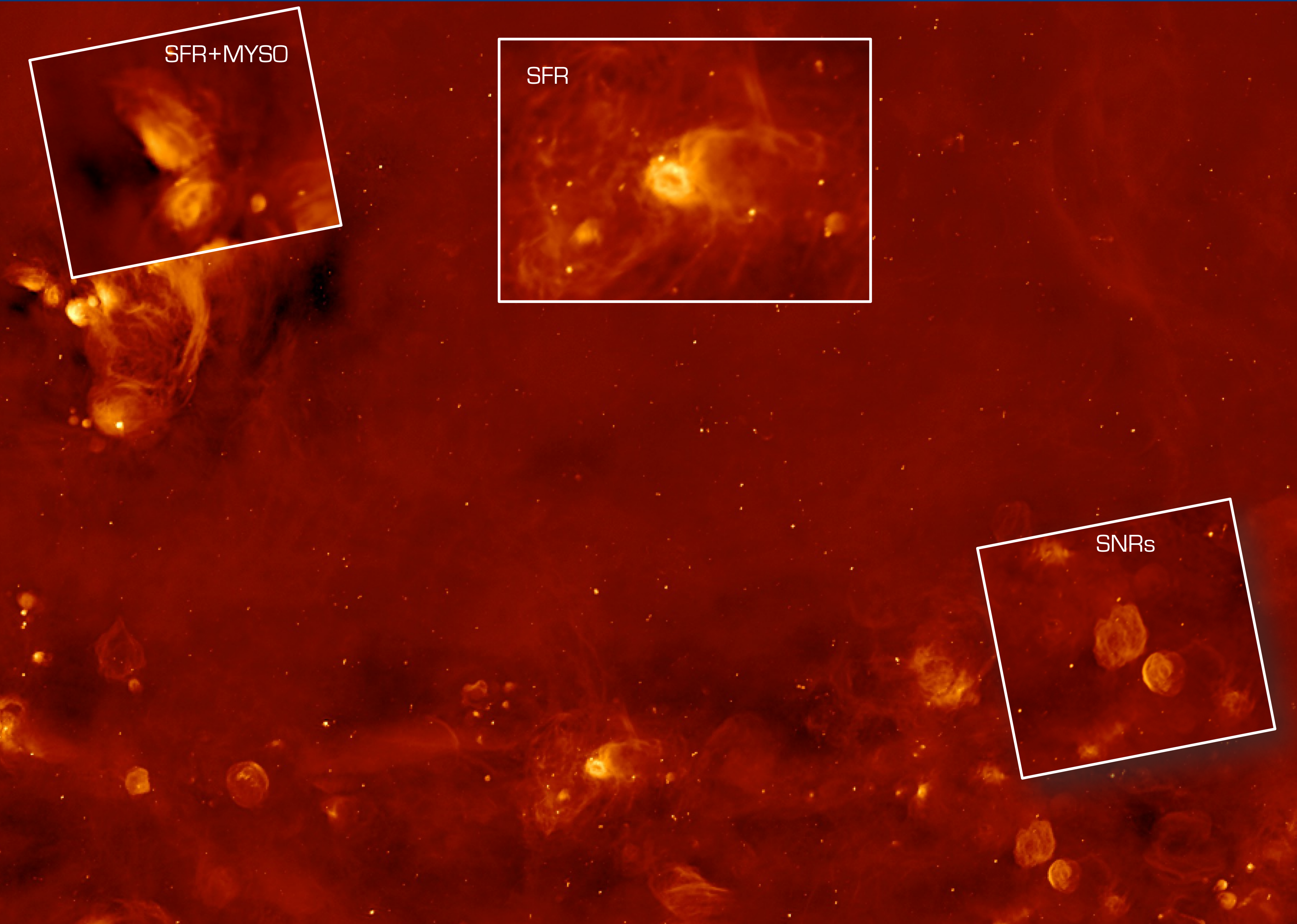
Band 1 (920 MHz, B=288 MHz)



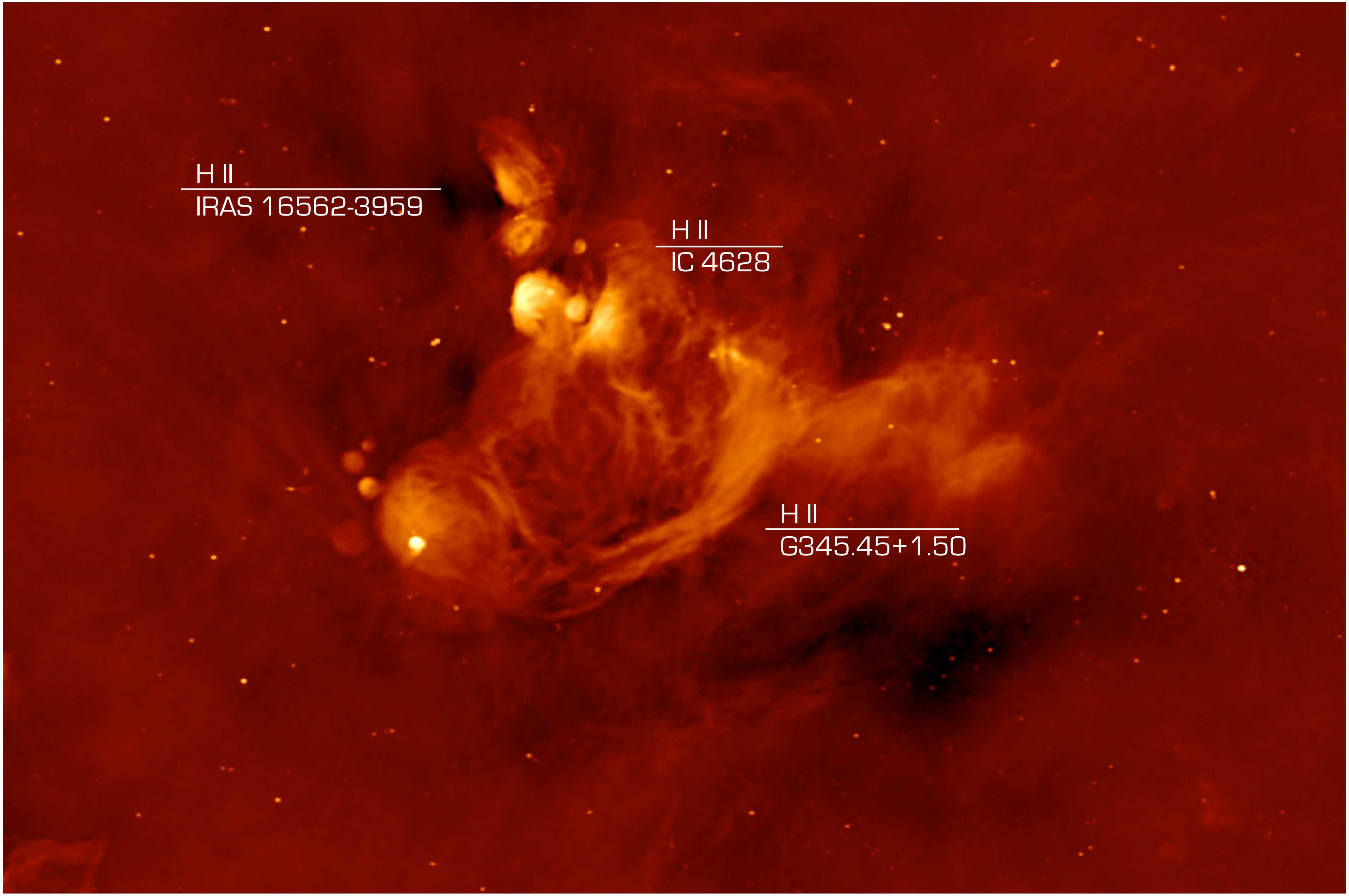
The catalogue of the compact radio sources in the SCORPIO field comprises is presented **4111 source components** (Riggi et al., 2021)

Highlighted the ASKAP capability to map complex sources at different angular scales

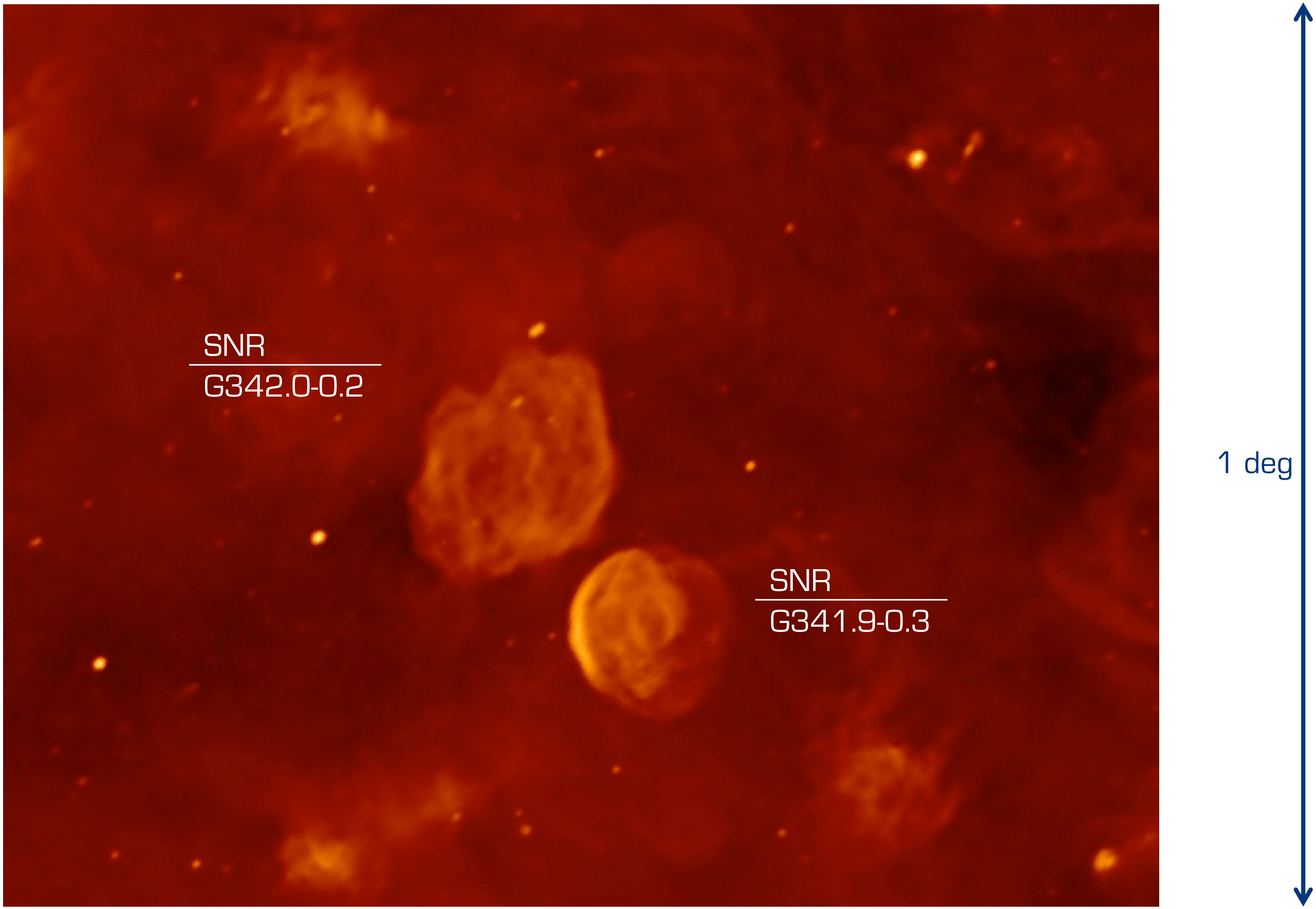
The SCORPIO field



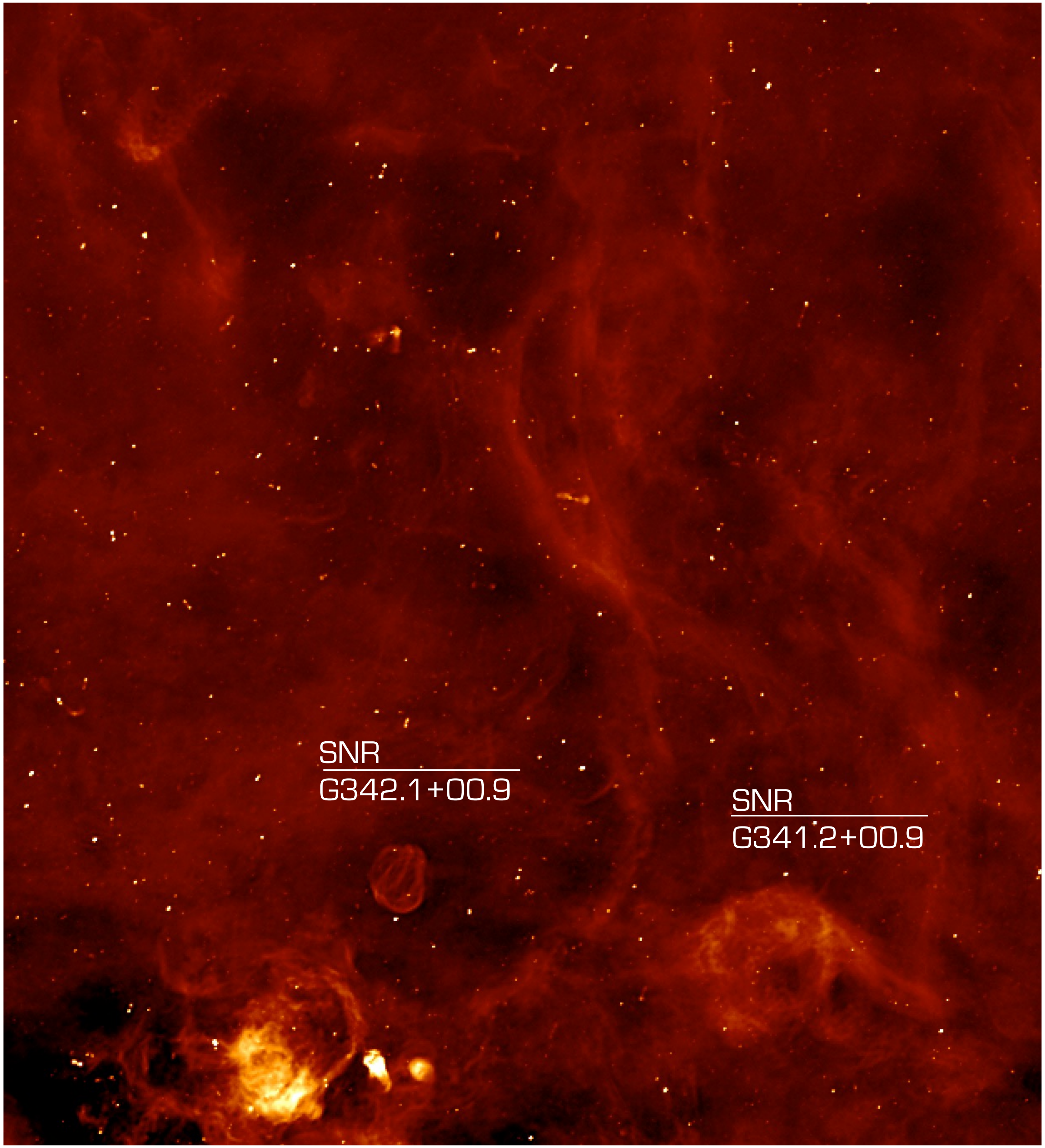
The SCORPIO field: Sco B1



SNR G342.0-0.2 and SNR G341.9-0.3



The SCORPIO field



2x 2.5 deg
342.02, 1.37

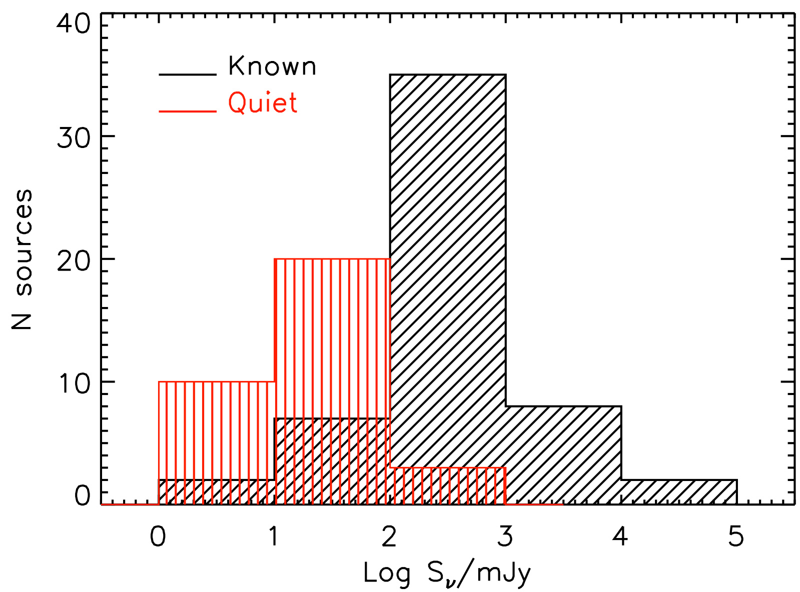
The SCORPIO field

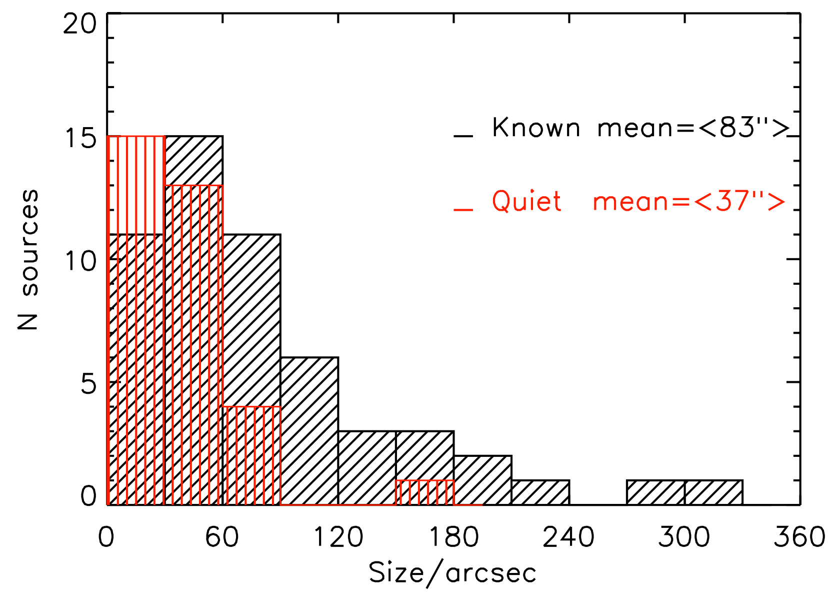
ASKAP map: HII

A total of **382 HII** in SCORPIO/ASKAP field

- All the known and candidate HII are detected
- 99/220 (**45%**) of the radio quiet are detected
- 5/5 reported without radio data, detected

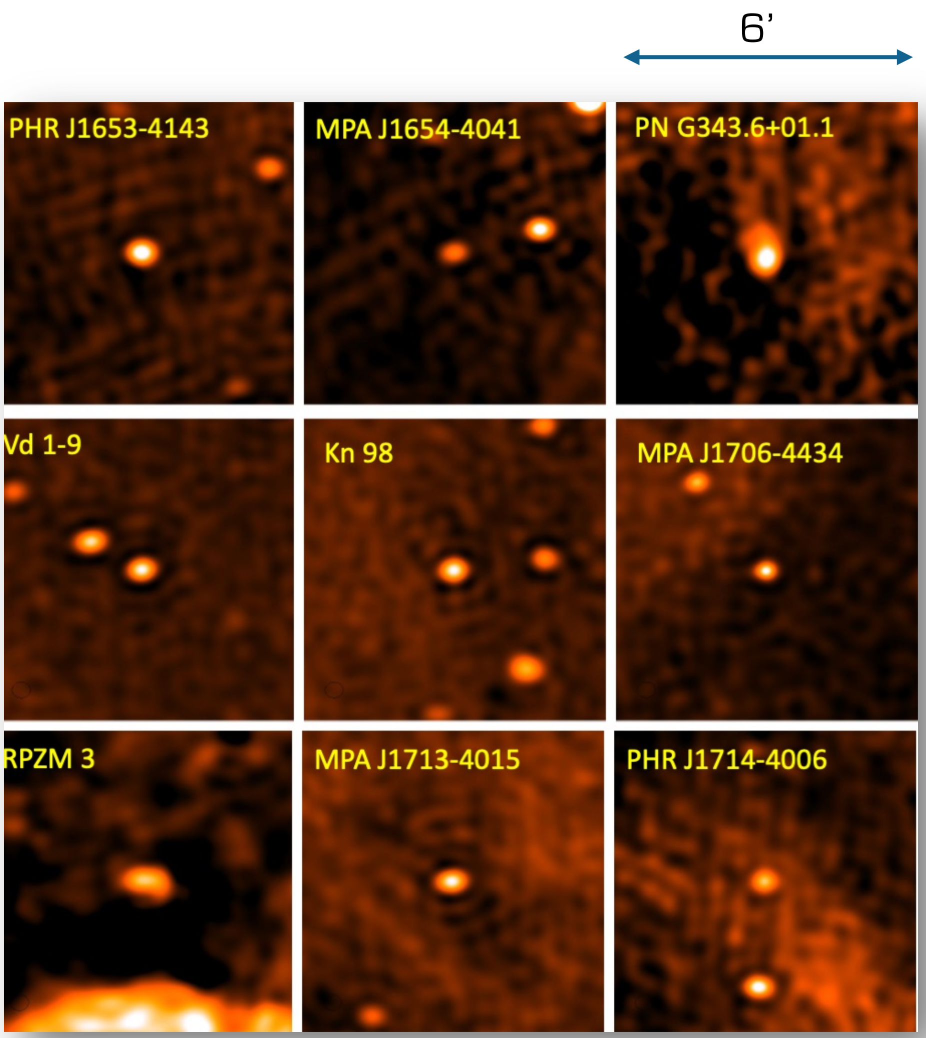
A total of **261** detections, **96** new detections





Radio quiet H II regions appear to be fainter and more compact than known H II s

Previous non detections related to sensitivity limits



A total of **48** HASH PNe in SCORPIO/ASKAP field

- 29/35 True/confirmed PNe are detected
- 3/6 Likely PNe, detected
- 2/7 Probably PNe, detected

A total of **34** detections, **20** new detections

According to HASH classification:

T, morphologies and spectral features of PN

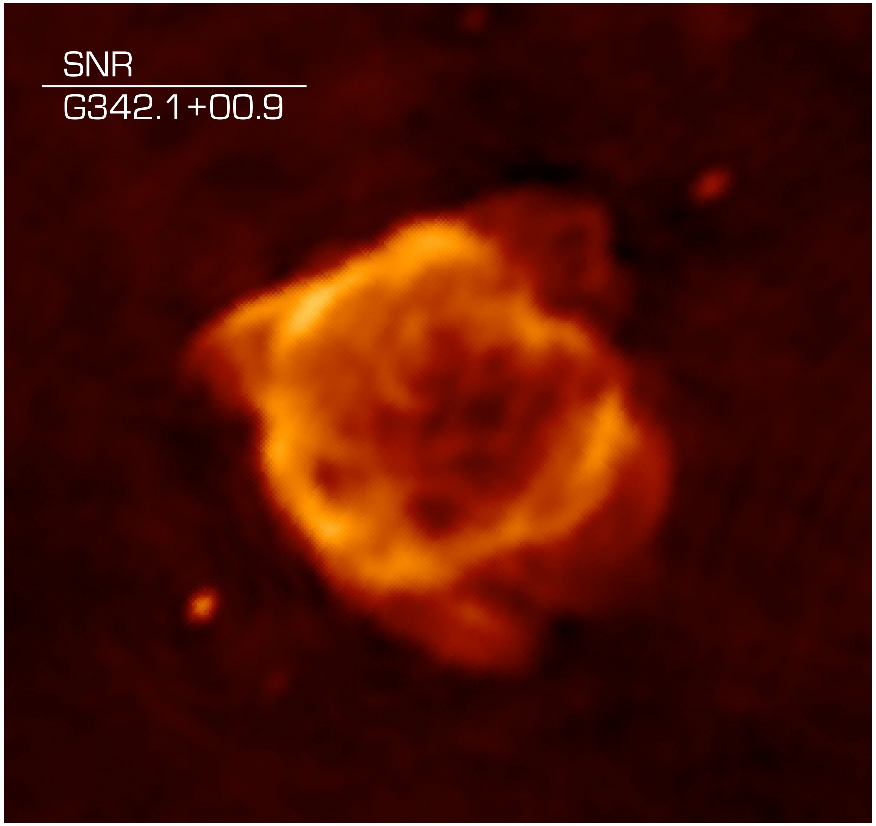
L, as above, but not conclusive

P, as above because poor data with poor S/N

ASKAP map: SNRs

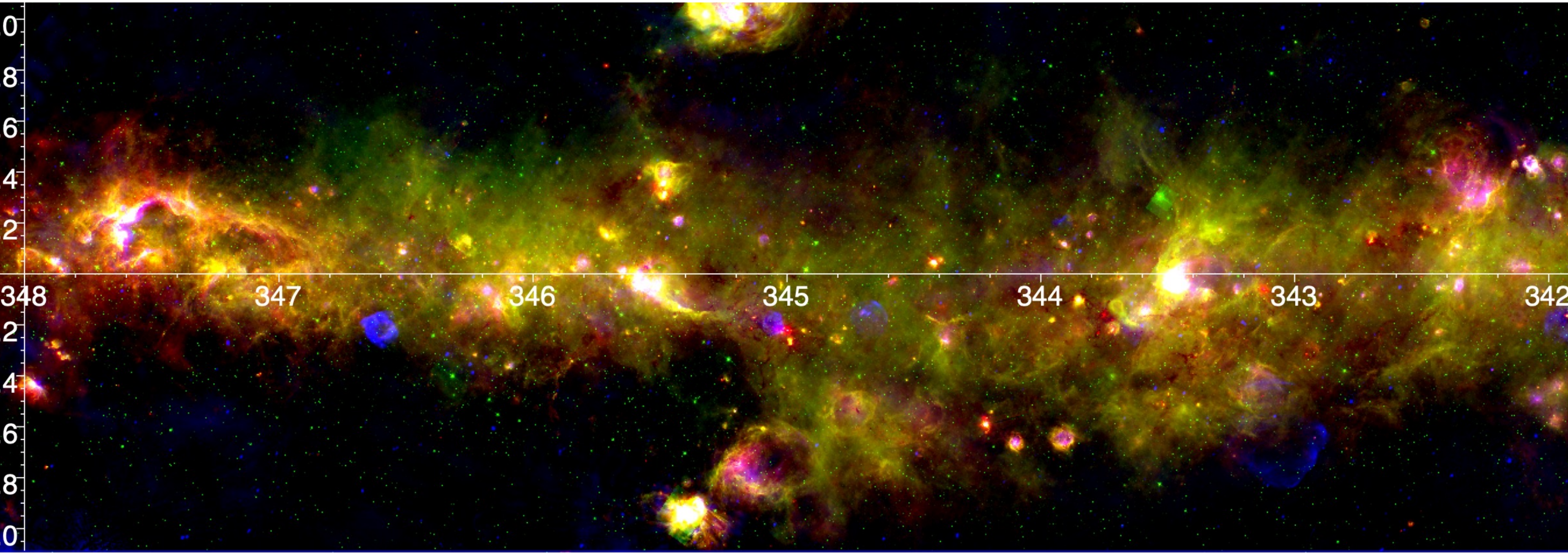
- ✓ 14 SNRs from Green 2019
- ✓ 2 SNR candidates from Whiteoak and Green (1996)
- ✓ 3 SNR candidates from Ingallinera et al., 2019

  in SCORPIO/ASKAP field , all detected



Source name	type	frequency range (GHz)	Source size (arcmin^2)
G340.4-0.4*	S	0.330−5	10×7
G340.6+0.3	S	0.330−5	6×6
G341.2+0.9	C	0.330−1.425	22×16
G341.9-0.3	S	0.408−5	7×7
G342.0-0.2	S	0.408−5	12×9
G342.1+0.9	S	0.843−1.384	22×16
G343.1-0.7	S	0.843−8.55	27×21
G343.1-2.3	C?	0.330−8.46	32×32
G344.7-0.1	C?	0.408−11.2	8×8
G345.1-0.2	S?	0.843−1.4	6×6
G345.1+0.2	S	0.843	10×10
G345.7-0.2	S	0.843−5	6×6
G346.6-0.2	S	0.408−5	8×8
G347.3-0.5	S?	1.36	65×55
G348.5+0.1	S	0.08−14.7	15×15
G348.5-0.0*	S?	0.333−5	10×10

* This SNR is only partially detected at the end of our ASKAP map.



A composite image of a portion of the SCORPIO field (341<l<348)
Green for Spitzer/GLIMPSE (IRAC, 8 **µ**m); Red from Herschel (PACS, 70 **µ**m), Blue for 20cm radio emission (ASKAP)
8 **µ**m and 70 **µ**m emissions are tracers of dust, radio emission traces ionized gas.

Dust and radio are largely spatially coincident in star-forming regions, while there is little correlation in SNRs , that stand out in blue.

Umana+, 2021

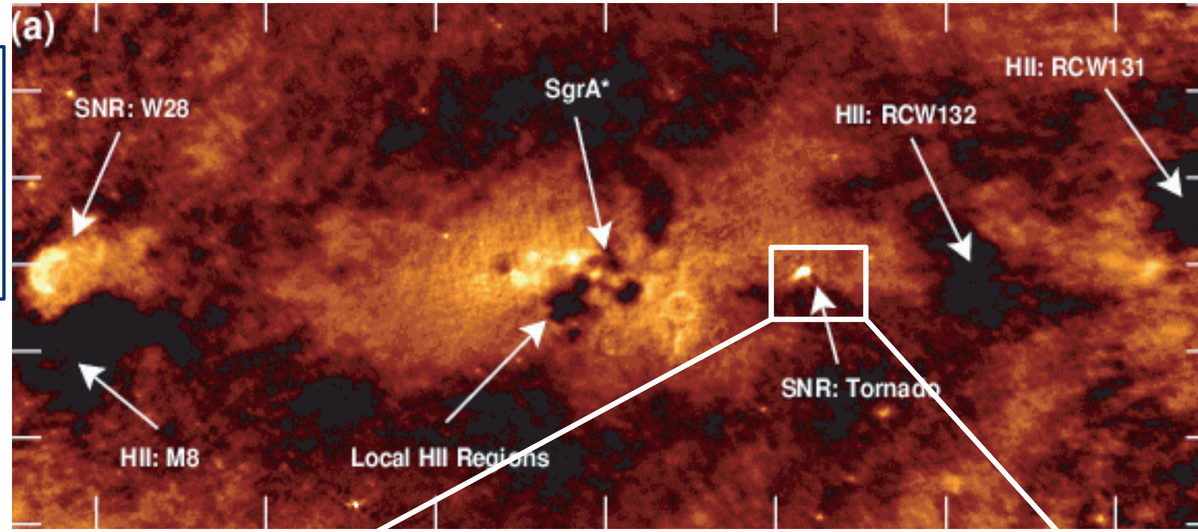
The 1.28 GHz MeerKAT Galactic Plane Survey

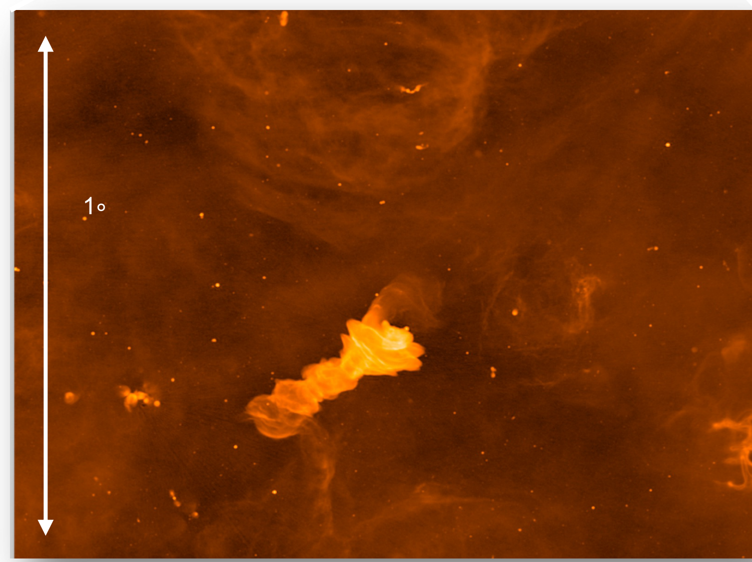
VLA, 74 MHz, 125”- LaRosa, 2005

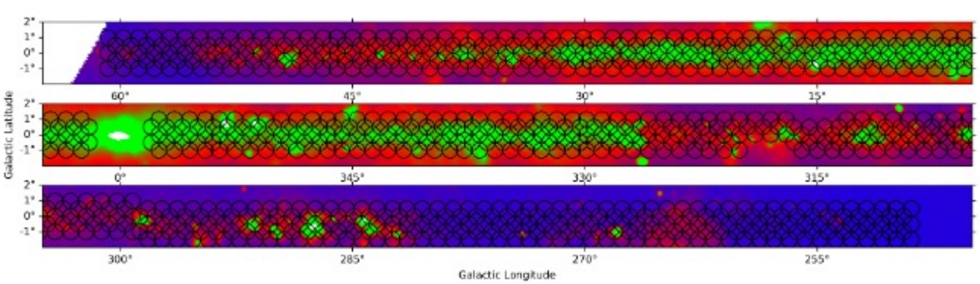
Observed in L band (856-1712 MHz)
l=2°-60°, 252°-358°, b=|1.5°|

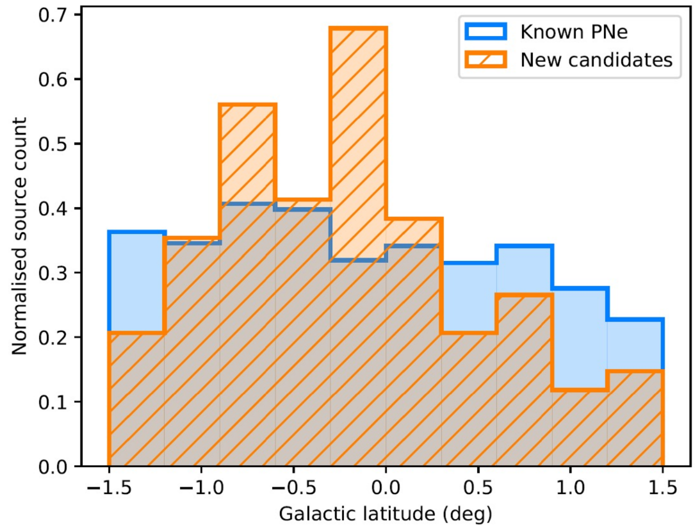
rms in non dinamic range limited
environment a10-15 μJy
rms close to the GP 100-200 μJy

Goedhart et al., in progress







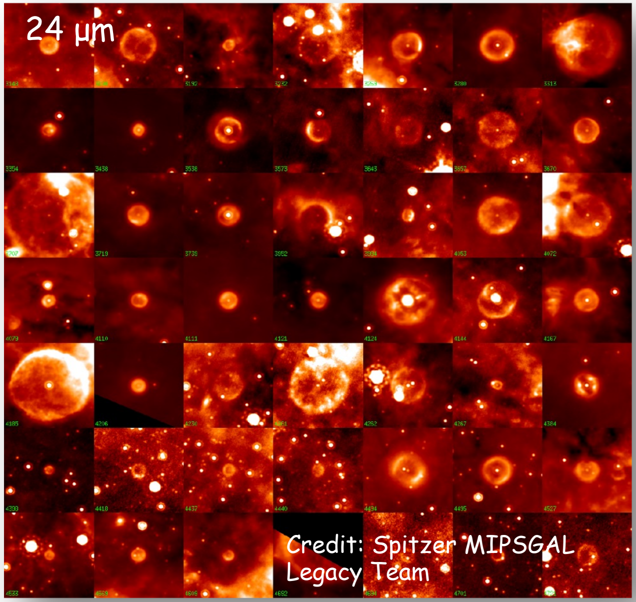


There are about 3000 known PNe but the models predict about 20000 of them

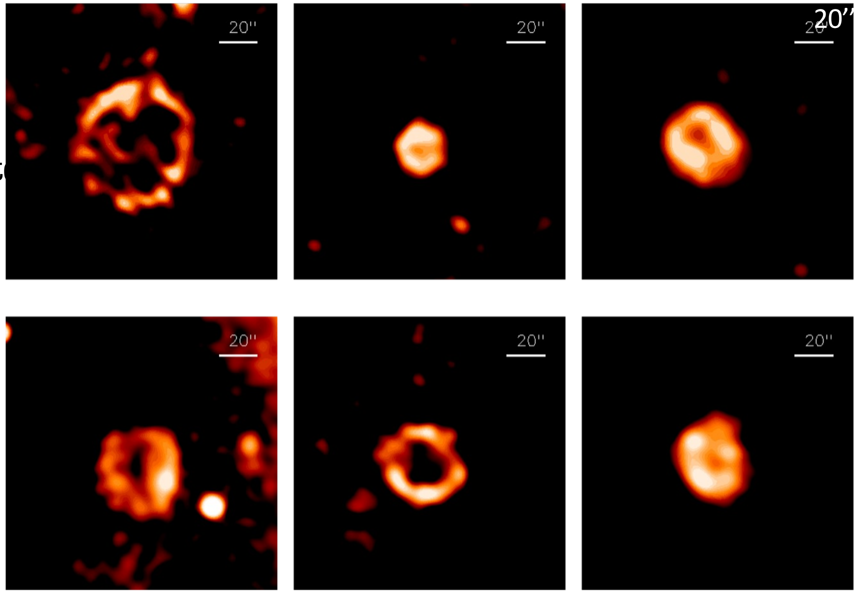
Radio and infrared can be the key to find the others

About **400** "bubbles" found in MIPSGAL (24 μm)- **MBs**
Carey et al., 2009, Mizuno et al 2010

Possibly related to late stages of stellar evolution
only 30% have been identified



Radio observations:
Morphological , Spectral index , Pol. to discriminate LBV, PN, WR (thermal) from SNR (non-thermal)



244 MBs falling in MeerKAT tiles
146/244 detected
(**137 new det.**)

Providing a very promising sample to look for evolved stars candidates

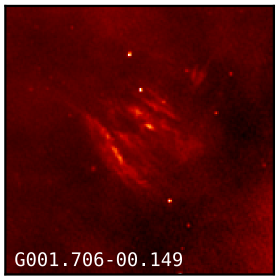
The 1.28 GHz MeerKAT Galactic Plane Survey

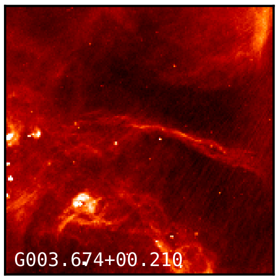
Catalog of extended and diffuse radio source (1st release)

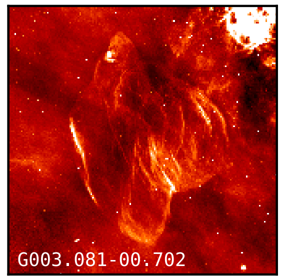
- 1st quadrant: 2º < l < 12º
- 3rd quadrant: 252º < l < 270º
- 4th quadrant: 342º < l < 358º

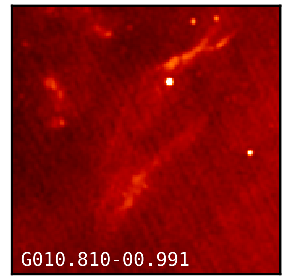
5527 sources:

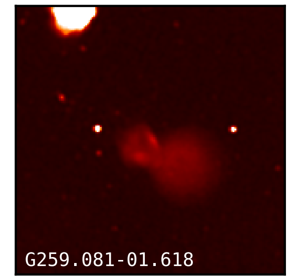
20% known Galactic objects
40% Radio Galaxies
40% unknown

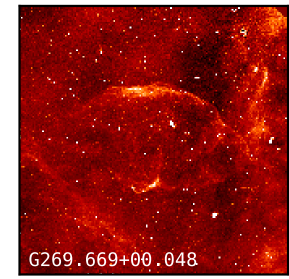


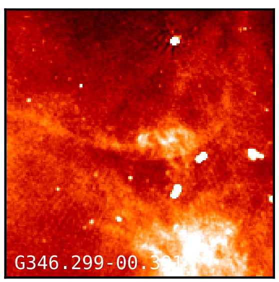


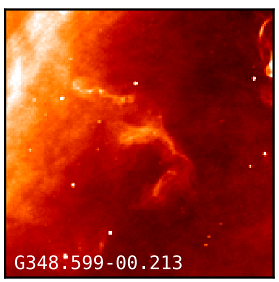


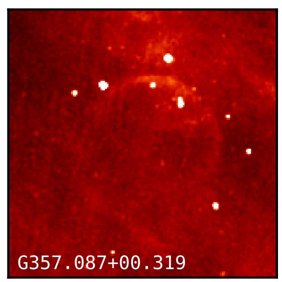


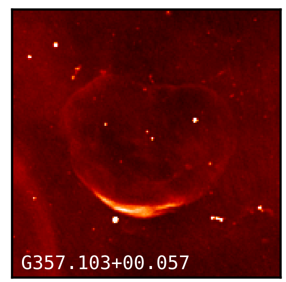


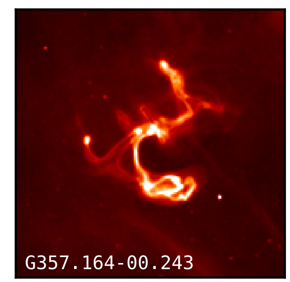


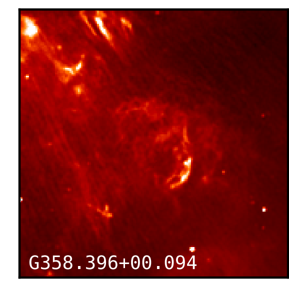












Bordiu +, 2022 in progress

Outlook & Conclusions

The SKA precursors observations demonstrates their unique capability of mapping complex sources, at different angular scales, with a trade-off between sensitivity to extended and diffuse emission and ability to reveal the finest details.
High potentiality for Galactic studies

We are able to detect and study a **very large number of galactic objects**, both extended (SNRs, HII, evolved stars) and point-like (mostly stars) with several scientific implications, including statistical study on populations and more detailed studies on smaller samples.

Precursors observations as test-bed:

- to identify, and possibly overcome, technical issues arising from the complex structure of the Galactic plane;
- to develop and test source finding and classification algorithm.

Only SKA with its **unparallel resolution and sensitivity** will allow to detect and studies *complete sample of galactic objects*