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The future is here! ORC's and other new wonders of radio surveys.

Mysterious Odd Radio Circle near the Large Magellanic Cloud -- An Intergalactic Supernova Remnant? Lord of the Rings, Recolimator #1, Dancing Ghosts & Potoroo

Miroslav Filipovic

THANKS: A lot of people … about 50+ BUT special THANKS to: my PhD students Rami, Velibor & Rami

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Obligatory ASKAP-EMU photo

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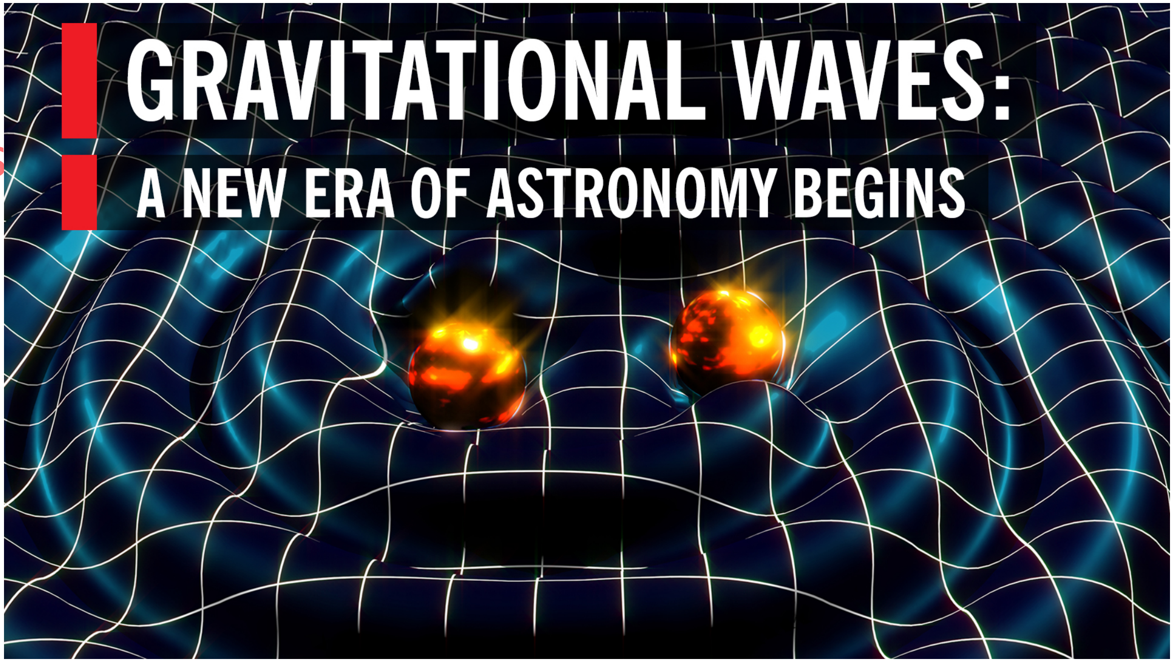
ERA of:

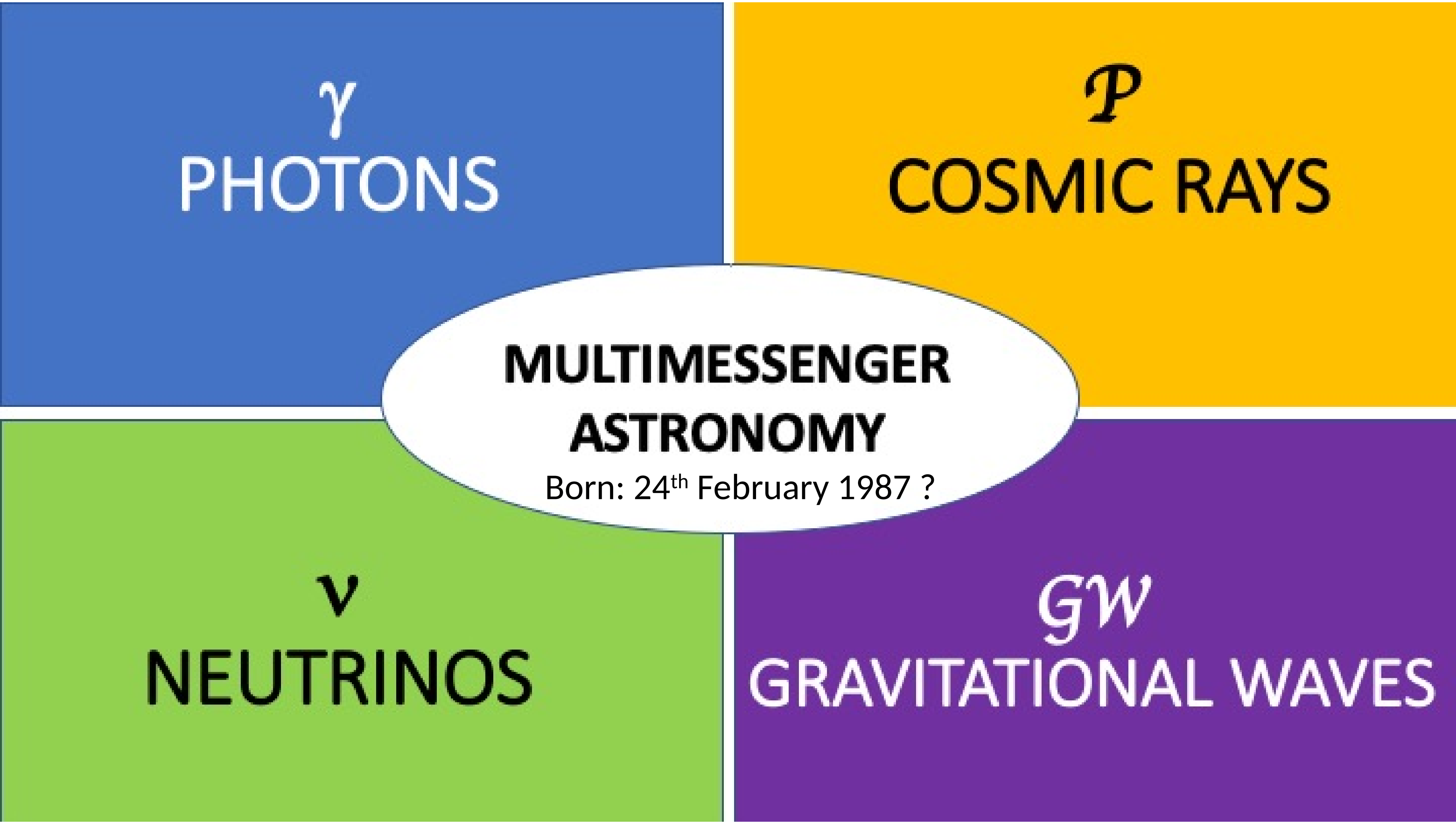
Bigger Telescopes?
Bigger ideas & questions
Bigger money!
~~Big disappointments?~~
Machine Learning

SURVEYS!!!!!!!!!!



...and (no) jobs in astronomy?

Multi-messenger Astrophysics



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Discovering the unknown-unknowns in big data & New telescopes

On 10th October 2022

HESS 2022

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ads

QUICK FIELD: Author First Author Abstract Year Fulltext All Search Terms

Back to results

author:"^Peebles" year:1967

VIEW

- Abstract
- Citations (97)
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- Co-Reads
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FEEDBACK

The Gravitational Instability of the Universe

Show affiliations

Peebles, P. J. E.

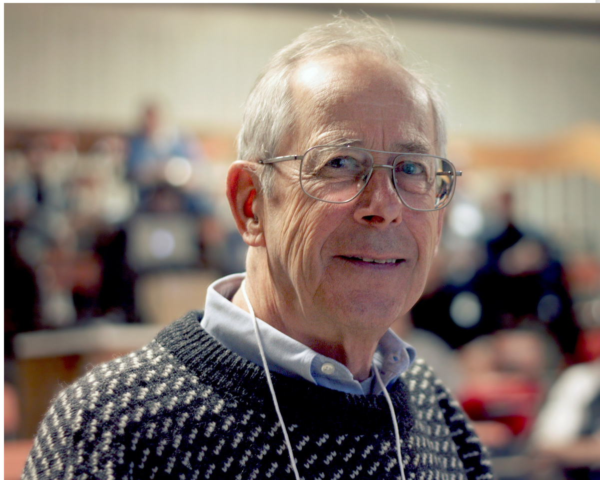
It is argued that the expanding universe is unstable against the growth of gravitational perturbations. The argument is directed toward two pyoblems, the physical conditions in the early, highly contracted phase of the expanding universe, and the formation of the galaxies.

Publication: Astrophysical Journal, vol. 147, p.859

Pub Date: March 1967

DOI: 10.1086/149077

Bibcode: 1967ApJ...147..859P



What does NEW TELESCOPES need to do to discover the unexpected?

- **Maximise the volume of new phase space**
- A good surrogate is to use # of known objects
- Maximised by an all-sky survey
- **Retain flexibility**
- Don’t optimise the telescope ONLY for your science goals
- **Develop data mining software to search for the unexpected**
  - This will be an important part of data-intensive research

SKA

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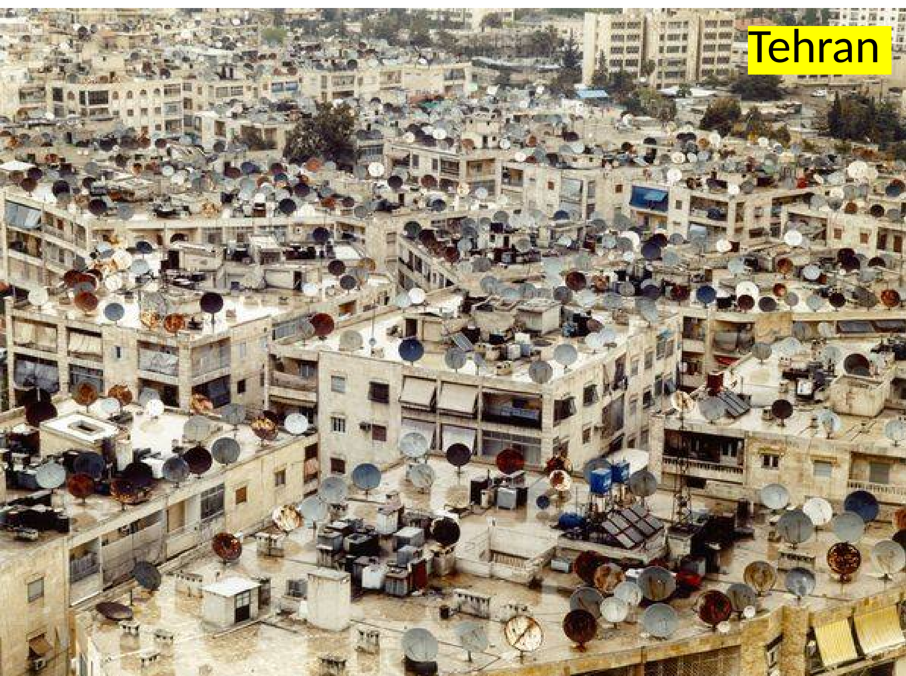
- SKA Low (MWA Mrk3)
- SKA High -- MeerKAT
- ASKAP/MWA
- Lofar/MeerKAT
- FAST
- eVLA+
- ATCA - BIGCAT
- ALMA, Parkes...



Australian Radio Telescopes and Facilities

Parkes
ATCA
Tidbinbilla
MOPRA
ASKAP
MWA

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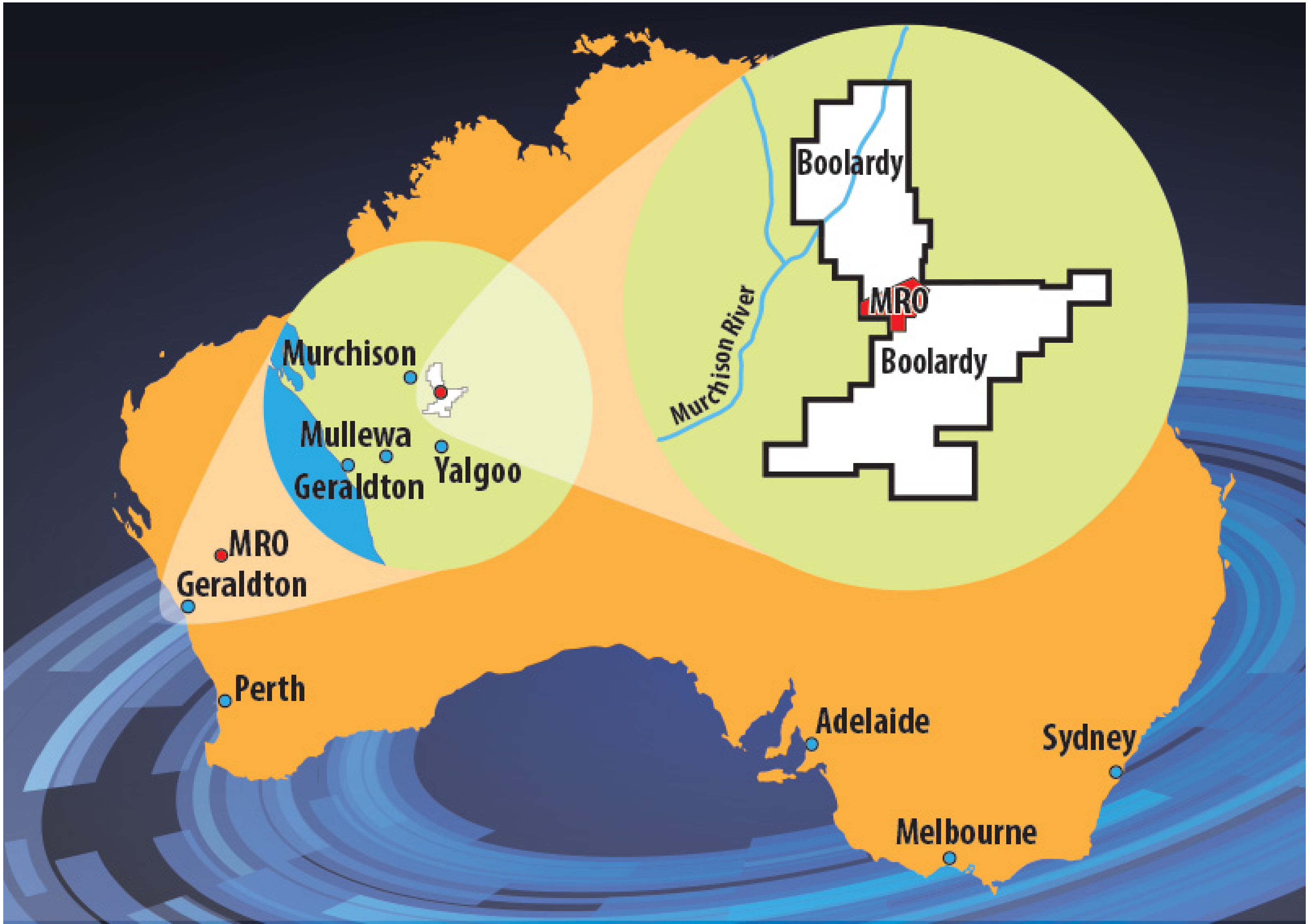
Murchison Radio Observatory



Slide courtesy of Antony Schinkel

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MWA Overview (Phase I)

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- SKA Precursor telescope in the low frequency regime
- Commissioned in 2013
- Large-N/Small-D concept

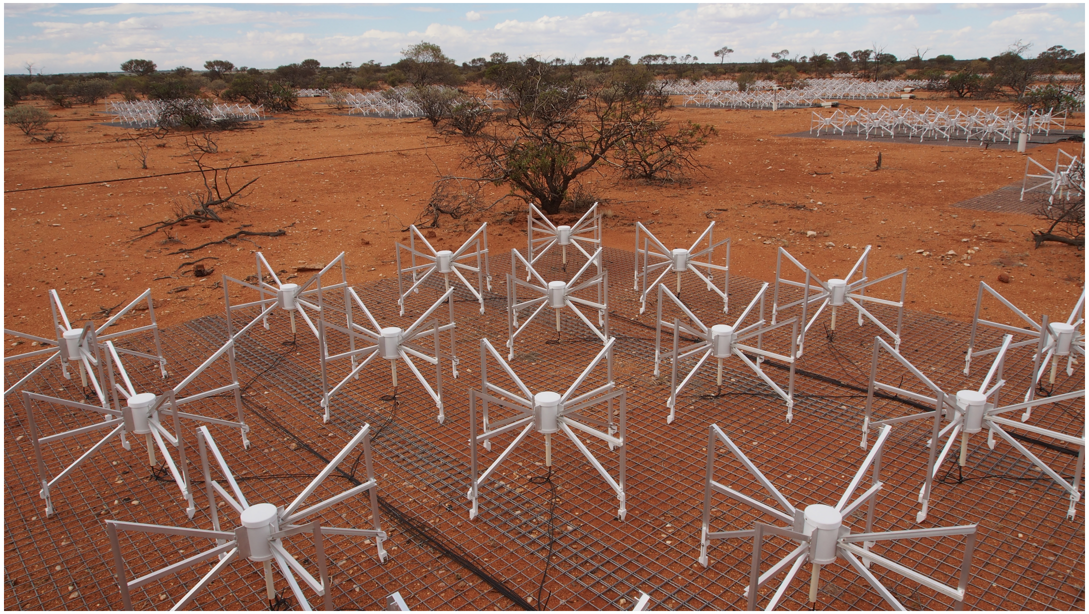


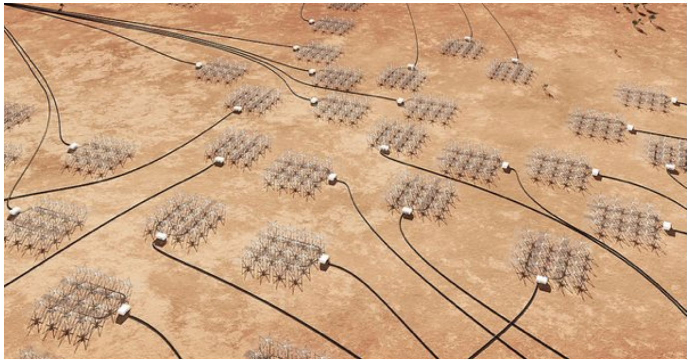
Image credit: SKA (https://www.skatelescope.org/)

Table 1 System parameters for the MWA.

Parameter	[a]Value
Number of tiles	128
Tile area (m^2)	21.5
Total collecting area (m^2)	2752
Receiver temperature (K)	50
Typical sky temperature (K)	350[b]
Field of view (deg^2)	610
Angular resolution (arcmin)	2
Frequency range (MHz)	80–300
Instantaneous bandwidth (MHz)	30.72
Spectral resolution (MHz)	0.04
Temporal resolution (s)	0.5
Minimum baseline (m)	7.7
Maximum baseline (m)	2 864
Estimated confusion limit (mJy)	10

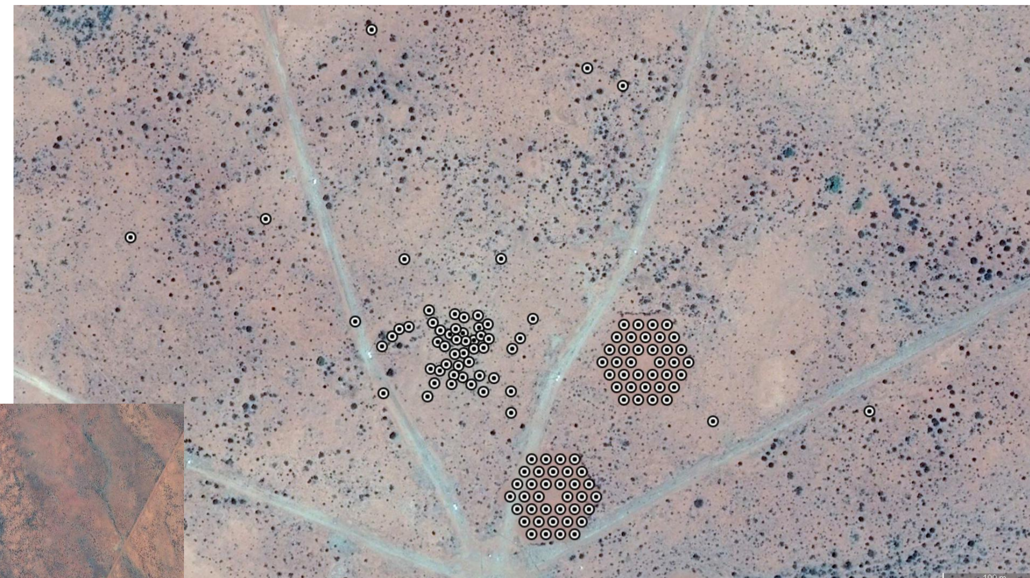
[a]For frequency-dependent parameters, listed values are given at 150 MHz.
[b]Sky temperature varies considerably with Galactic latitude. Here, we use typical values from Nijboer, Pandey-Pommier, & de Bruyn (2009) and Rogers & Bowman (2008).

Bowman et al. 2013



MWA Overview (Phase II)

- New 128 tiles:
  - 72 in 2 hexagonal grids
  - 56 in the extended configuration (expand max baseline to ~5km)
- However, still only 128 used at any time

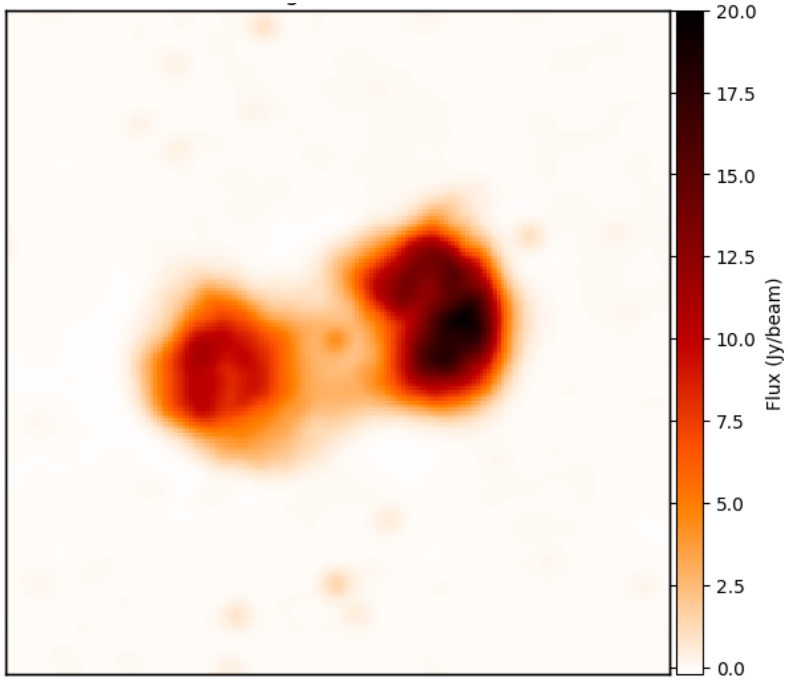


Images credit: MWA-LFD Project Wiki

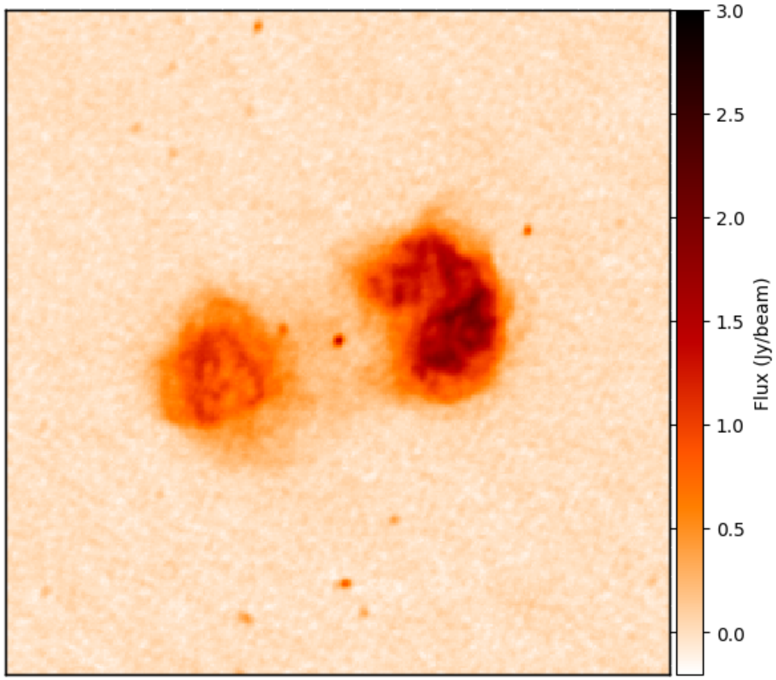
Wayth+ 18

Improved Resolution

Phase I



Phase II



Fornax A

The MWA

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A low frequency (80 - 300 MHz),

wide field of view,

high sensitivity,

versatile radio telescope.

- Detection of redshifted 21cm emission from EoR
- Solar, heliospheric and ionospheric astrophysics
- Time-domain astrophysics
  - large FoV
  - triggered by Swift GRBs
  - rapid response to transient events (~30s; Kaplan et al. 2015)
- Galactic and extragalactic science
  - wide frequency coverage (SNs, SNRs, PWN, GC, AGNs…)

Archival Analysis

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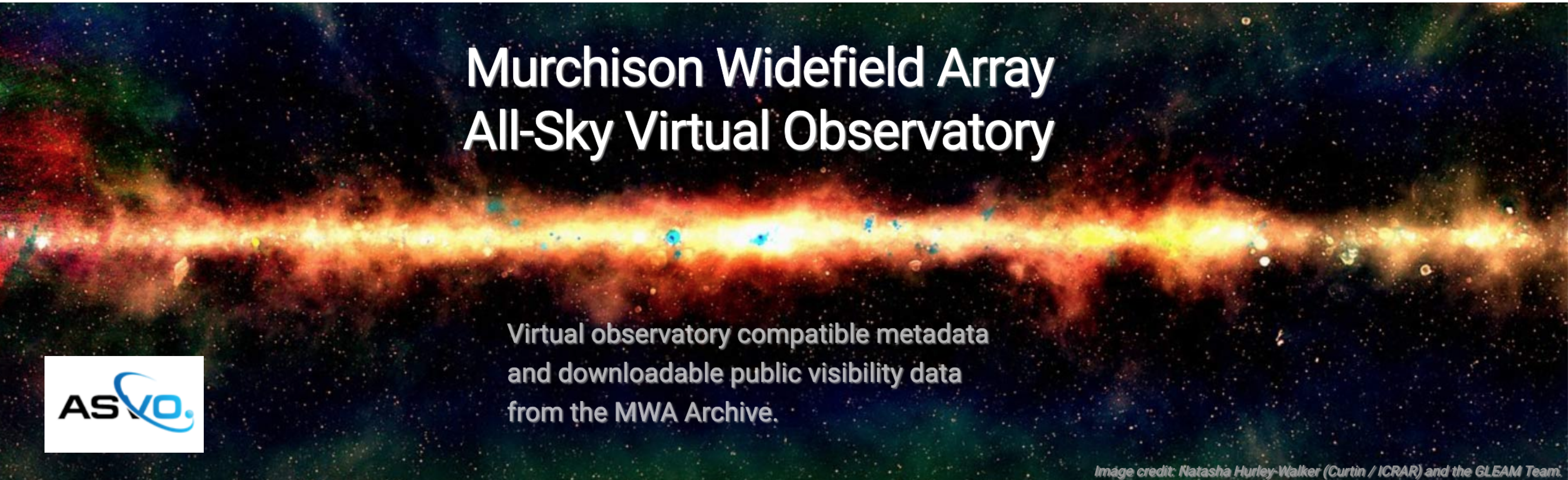
- http://asvo.mwatelescope.org/
- > 30 PB of data
- Data older than 18 months is public
- e.g. Tingay et al. (2018b) used archive to search for emitted signals from ‘Oumuamua



GLEAM

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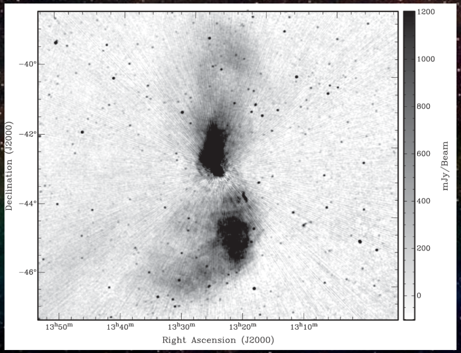
Survey overview:
- whole sky < Dec +30 deg
- meridian drift scans
- switching between 5 bands (30.7MHz bandwidth) every 2 min



McKinley et al. 2018

GLEAM I Catalogue (Hurley-Walker et al. 2017, 2019a,b)
- only the first year of observations
- > 300 000 sources in 20 x 7.68MHz bands
- 99% complete for > 0.5Jy and 50% for > 0.05Jy

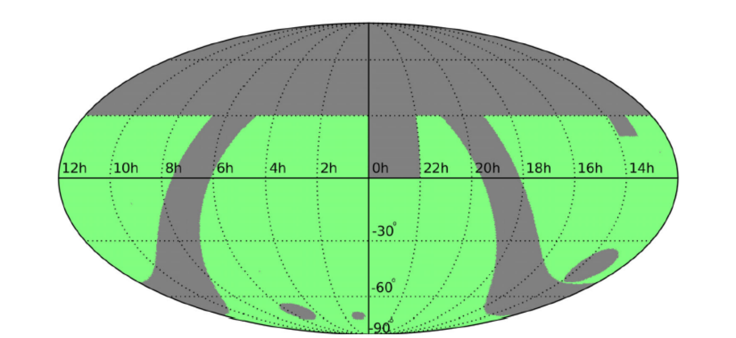
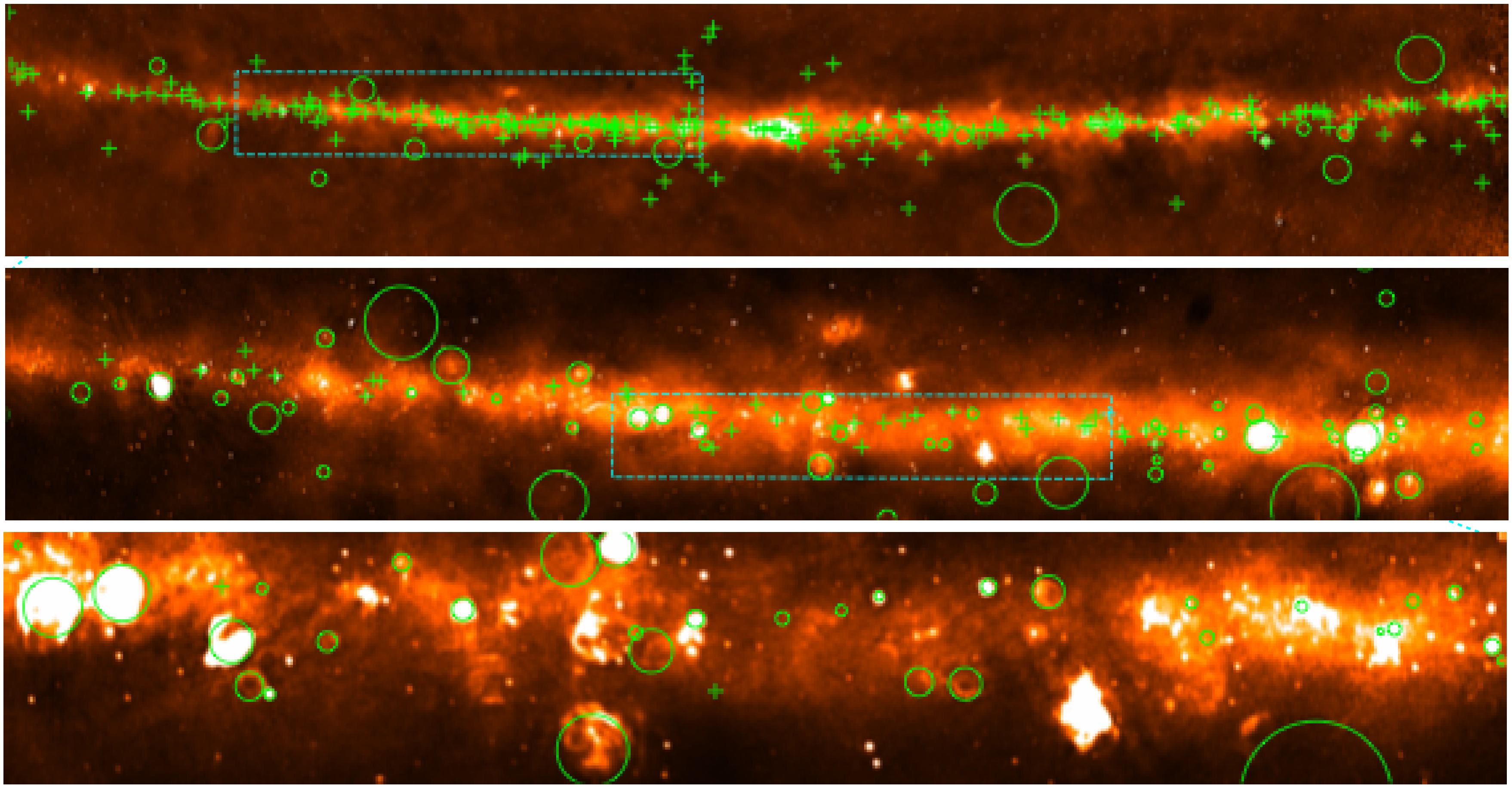


Figure 11. Detected sources that fall within the green shaded area, described in Table 3, are included in the catalogue.

GLEAM I Catalogue coverage (Hurley-Walker et al. 2017)

Image credit: Natasha Hurley-Walker (Curtin / ICRAR) and the GLEAM Team.

“My god, it’s full of SNRs”

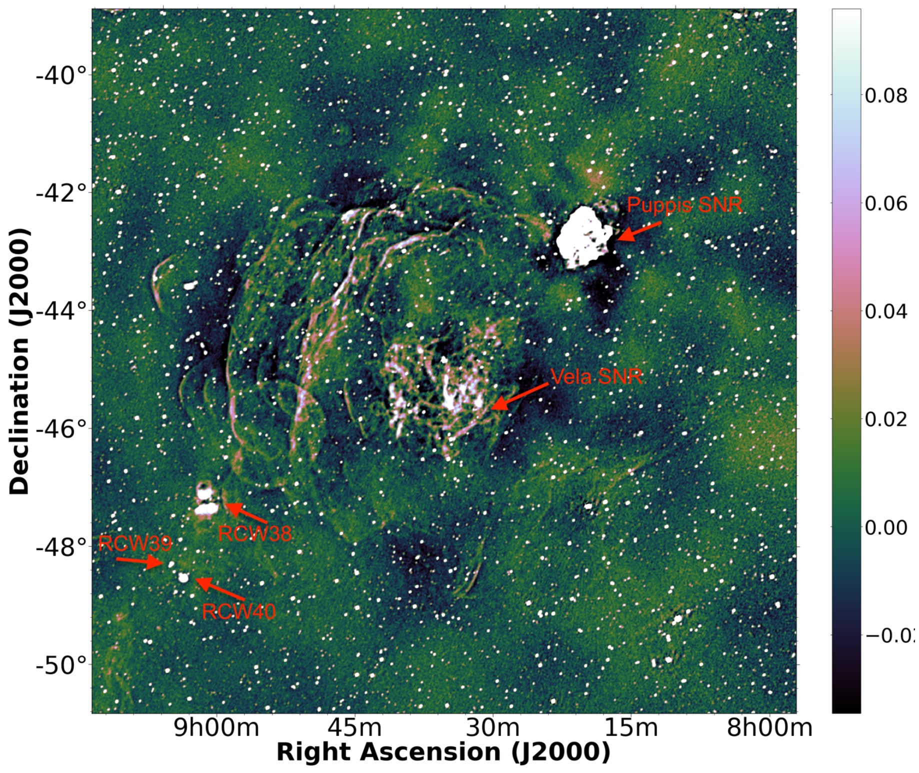


MWA 170-231MHz (wideband)

N. Hurley-Walker+ 2019a,b

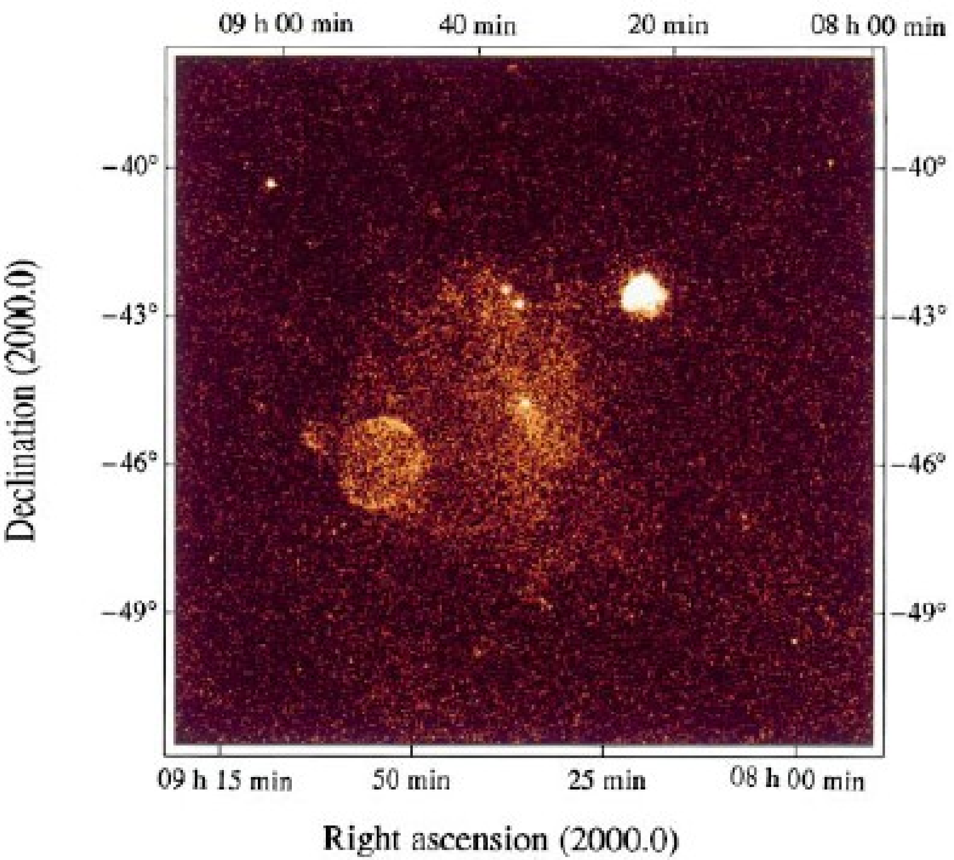
Vela Constellation – Large Field Study

Radio Continuum - MWA



Tremblay, Grey, et al. 2021

ROSAT >1.3keV



MWA-Mk2 -- VELA @ 100 MHz

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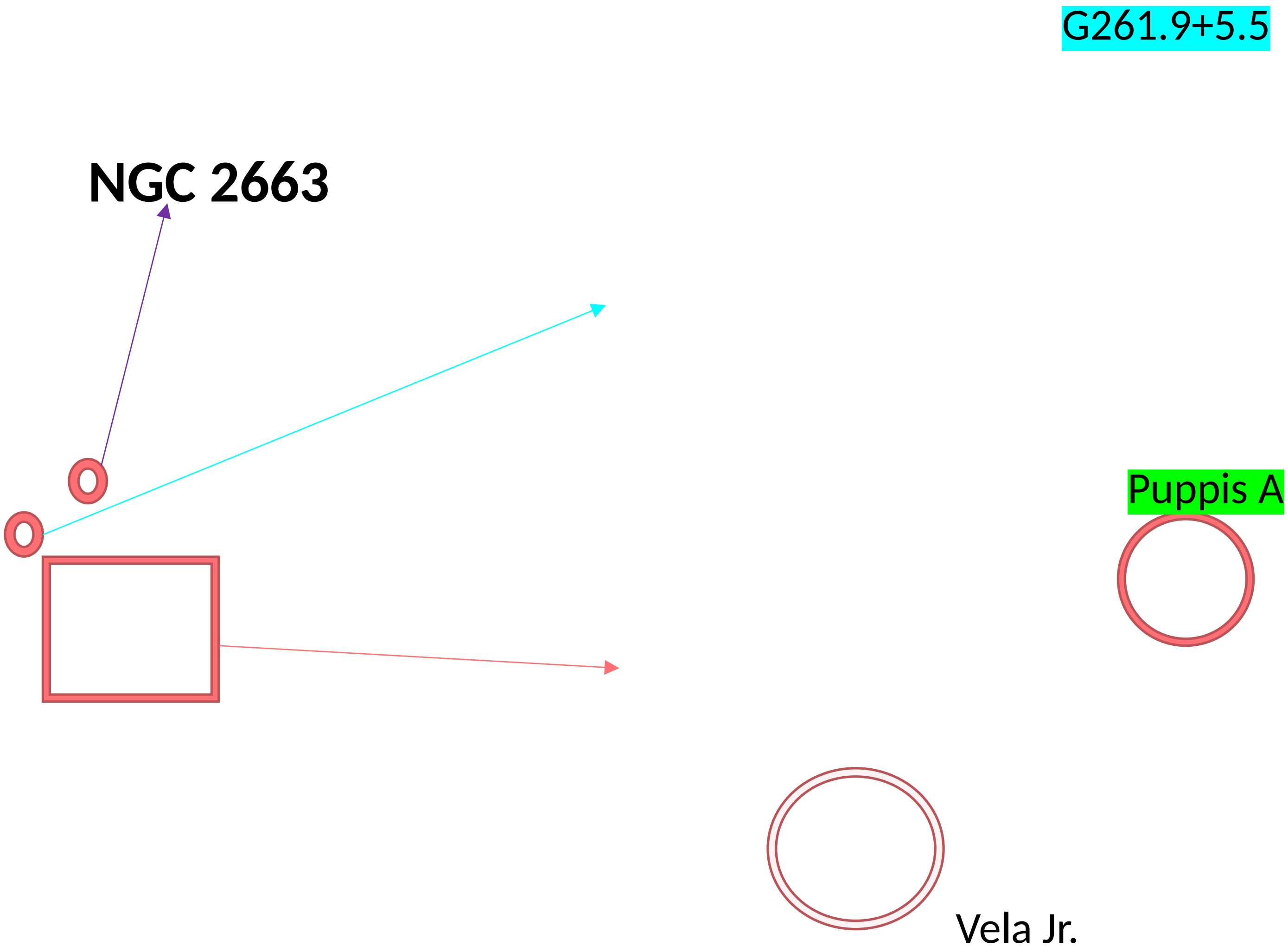
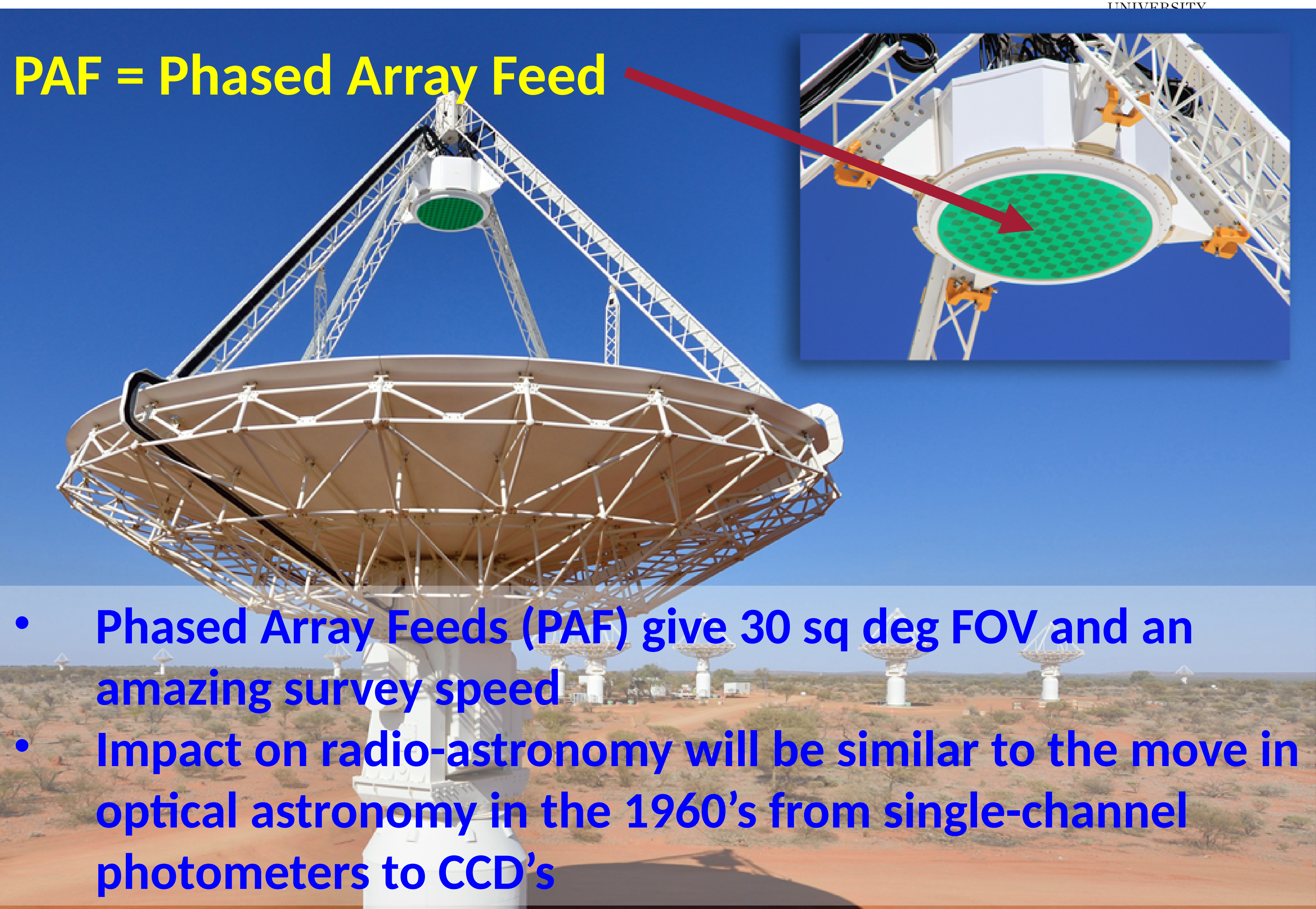


Credit: Natasha & Chenoa

Key ASKAP innovation



PAF = Phased Array Feed

- **Phased Array Feeds (PAF) give 30 sq deg FOV and an amazing survey speed**
- **Impact on radio-astronomy will be similar to the move in optical astronomy in the 1960’s from single-channel photometers to CCD’s**

The bad news:

Data Rate to correlator = 100 Tbit/s
= 3000 Blu-ray disks/second
= 62km tall stack of disks per day
= world internet bandwidth in June 2012
Processed data volume = 70 PB/year

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ASKAP Current Status

- **Now routinely observing with up to 36 antennas at 288 MHz BW**
- **Still some maintenance/upgrades – actual number of antennas may be less for some observations (but still >30)**
- **Still conducting tests to establish optimum observing techniques and processing parameters**
- **Max dynamic range of 830,000, with rms=17μJy, using 28 antennas, achieved on 1934-638. But dynamic range and rms still limited on routine observations pending development of the Sky Model**

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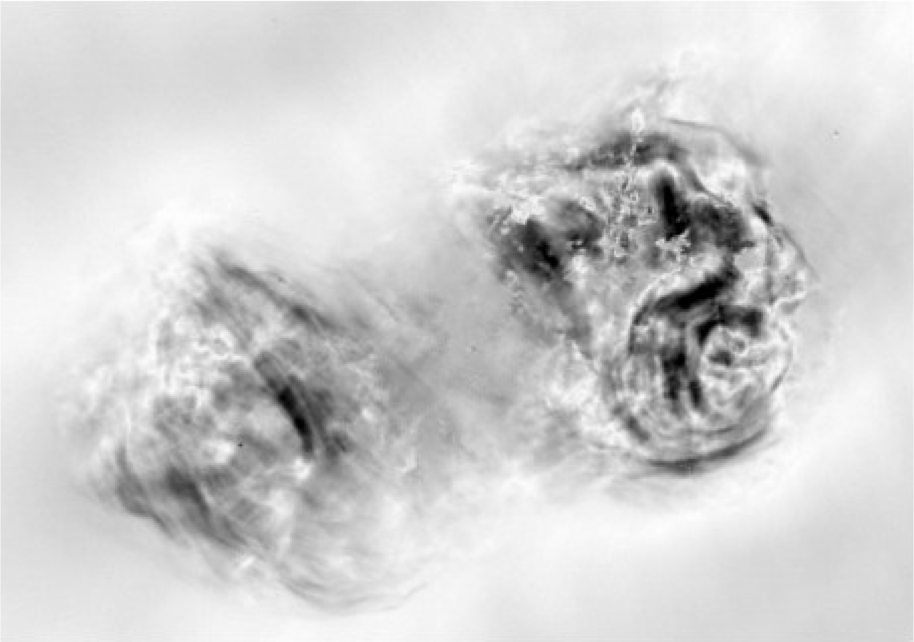
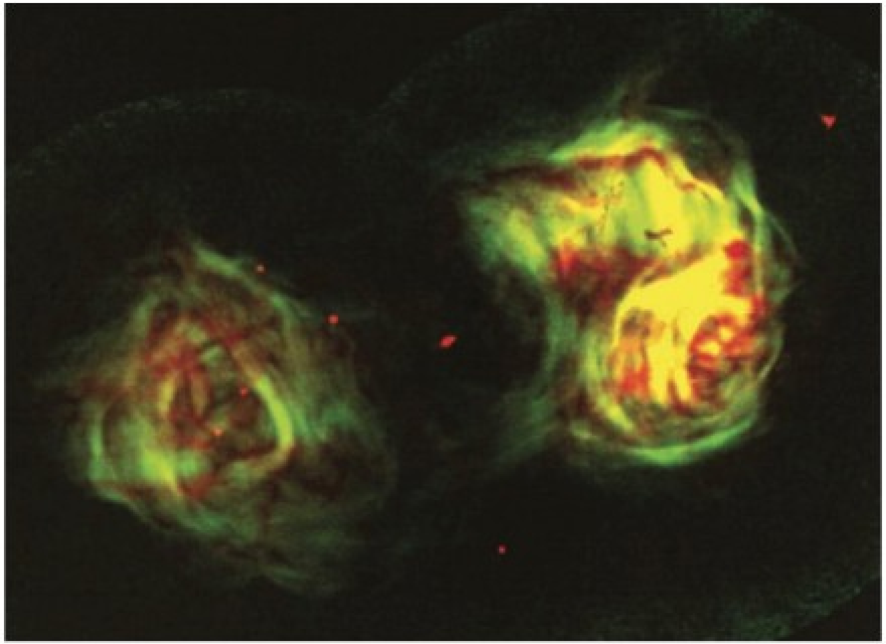
ASKAP Science projects

- **Evolutionary Map of the Universe (EMU)**
- **Widefield ASKAP L-Band Legacy All-Sky Blind Survey (WALLABY)**
- **The First Large Absorption Survey in HI (FLASH)**
- **An ASKAP Survey for Variables and Slow Transients (VAST)**
- **The Galactic ASKAP Spectral Line Survey (GASKAP)**
- **Polarization Sky Survey of the Universe's Magnetism (POSSUM)**
- **The Commensal Real-time ASKAP Fast Transients survey (CRAFT)**
- **Deep Investigations of Neutral Gas Origins (DINGO)**
- **The High-Resolution Components of ASKAP: Meeting the Long Baseline Specifications for the SKA (VLBI)**
- **Compact Objects with ASKAP: Surveys and Timing (COAST)**

Fornax A linearly polarised intensity



ASKAP image courtesy of Craig Anderson



VLA image courtesy of NRAO/AUI

Rapid ASKAP Continuum Survey (RACS)

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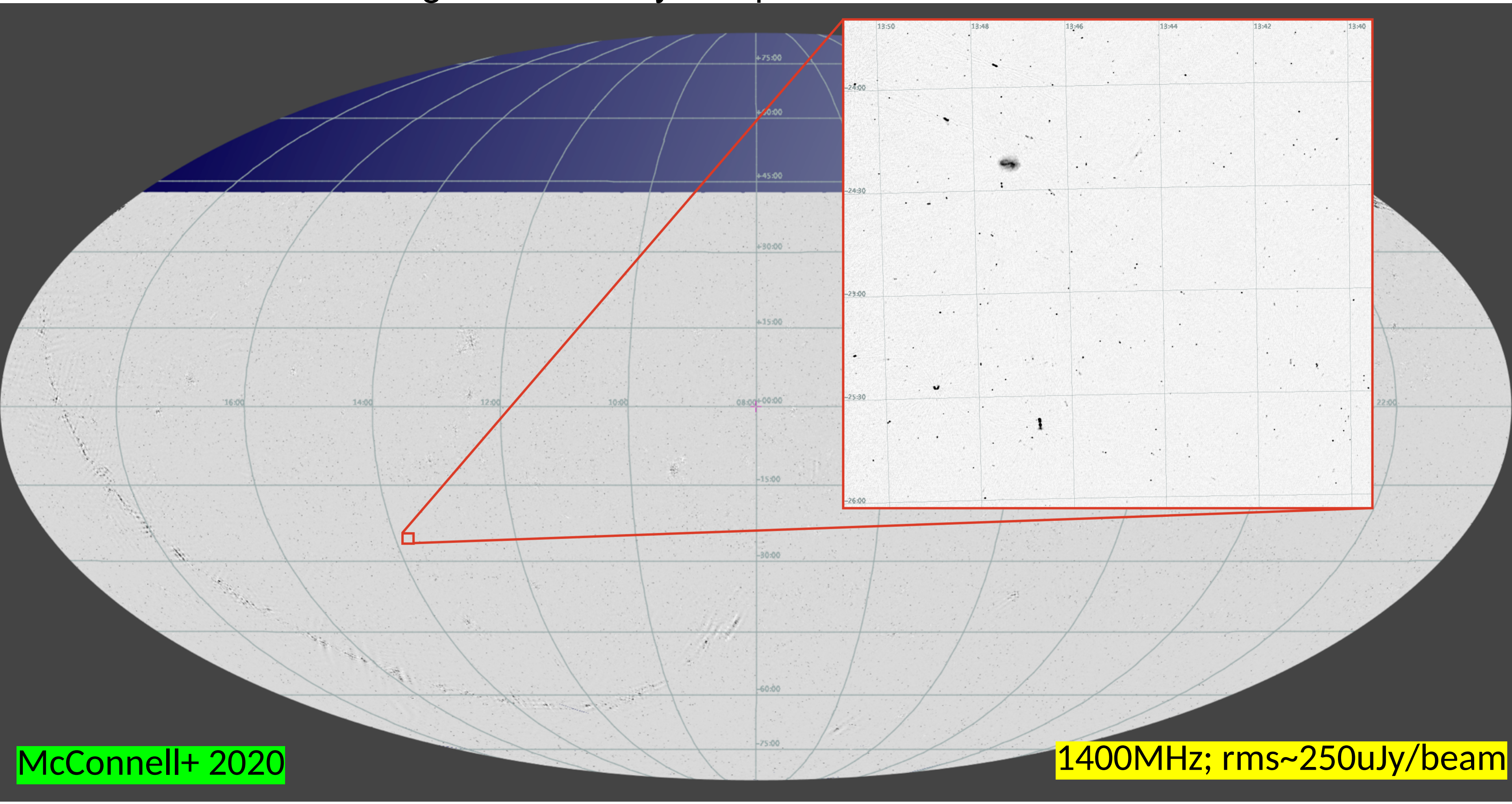
RACS will be the first large-area survey completed with the full 36-dish ASKAP



RACS will provide the first iteration of the Global Sky Model that will be needed to calibrate future deep ASKAP surveys and to provide the astronomical community with a powerful new radio imaging survey of the southern sky.

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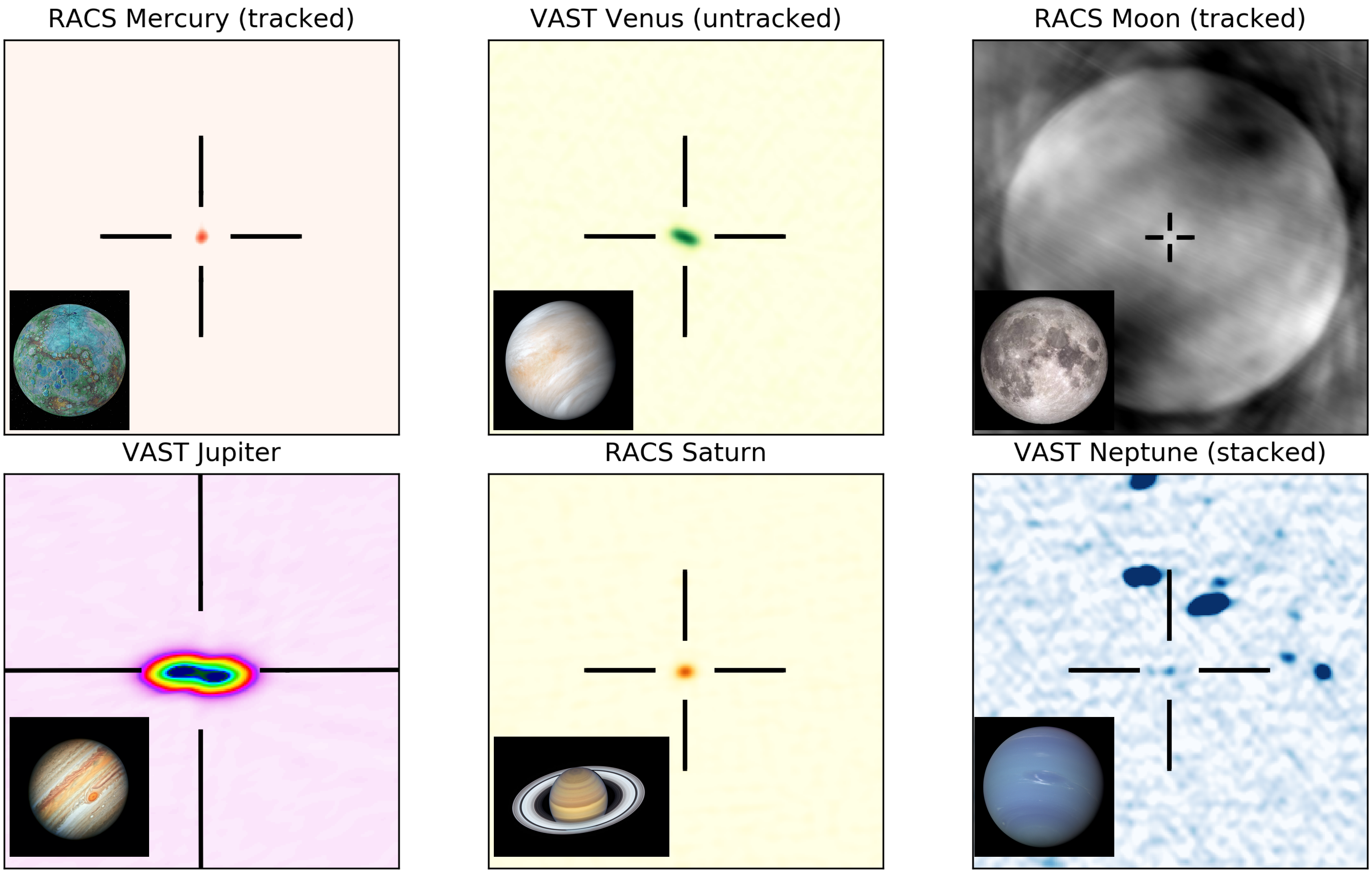
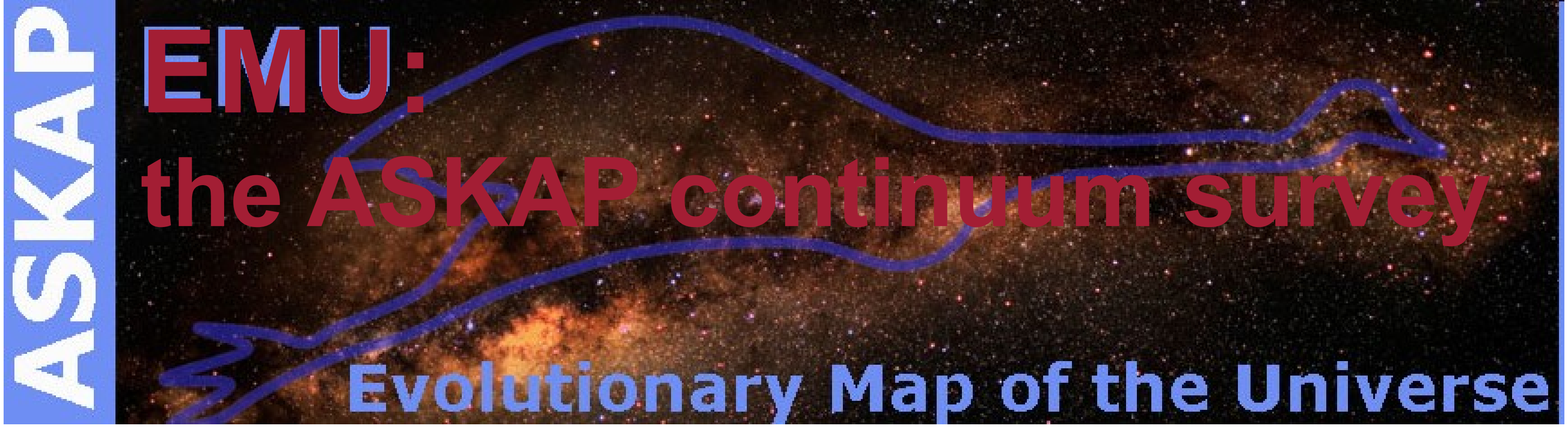
ASKAP (RACS) Planets





- Deep radio image of 75% of the sky to declination +30°
- Will detect and image ~70 million galaxies at 20 cm
  - **c.f. 2.5 million detected over the entire history of radio-astronomy so far**
- Science–driven international project
  - **300 scientists in 21 countries**
- Will deliver science-ready products, including:
  - **Cross-identification with optical/IR/X-ray data**
  - **Ancillary data (redshifts etc)**
  - **Algorithms to “discover the unexpected” (WTF?)**
  - **40x deeper and 5 x better resolution than NVSS (10 arcsec)**

Size of radio continuum surveys over time

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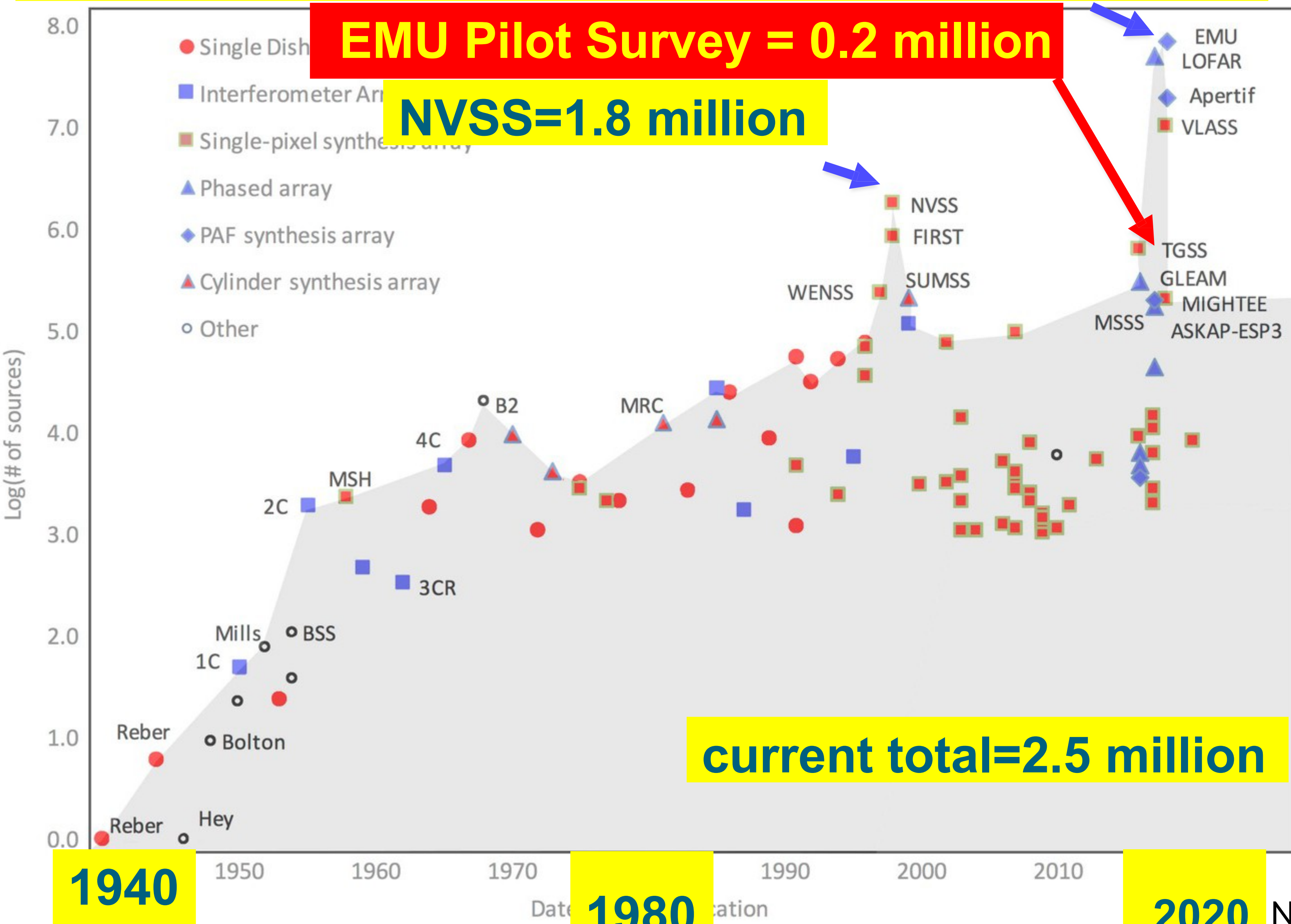
ASKAP Radio Continuum survey: EMU = 70 million



Norris 2019

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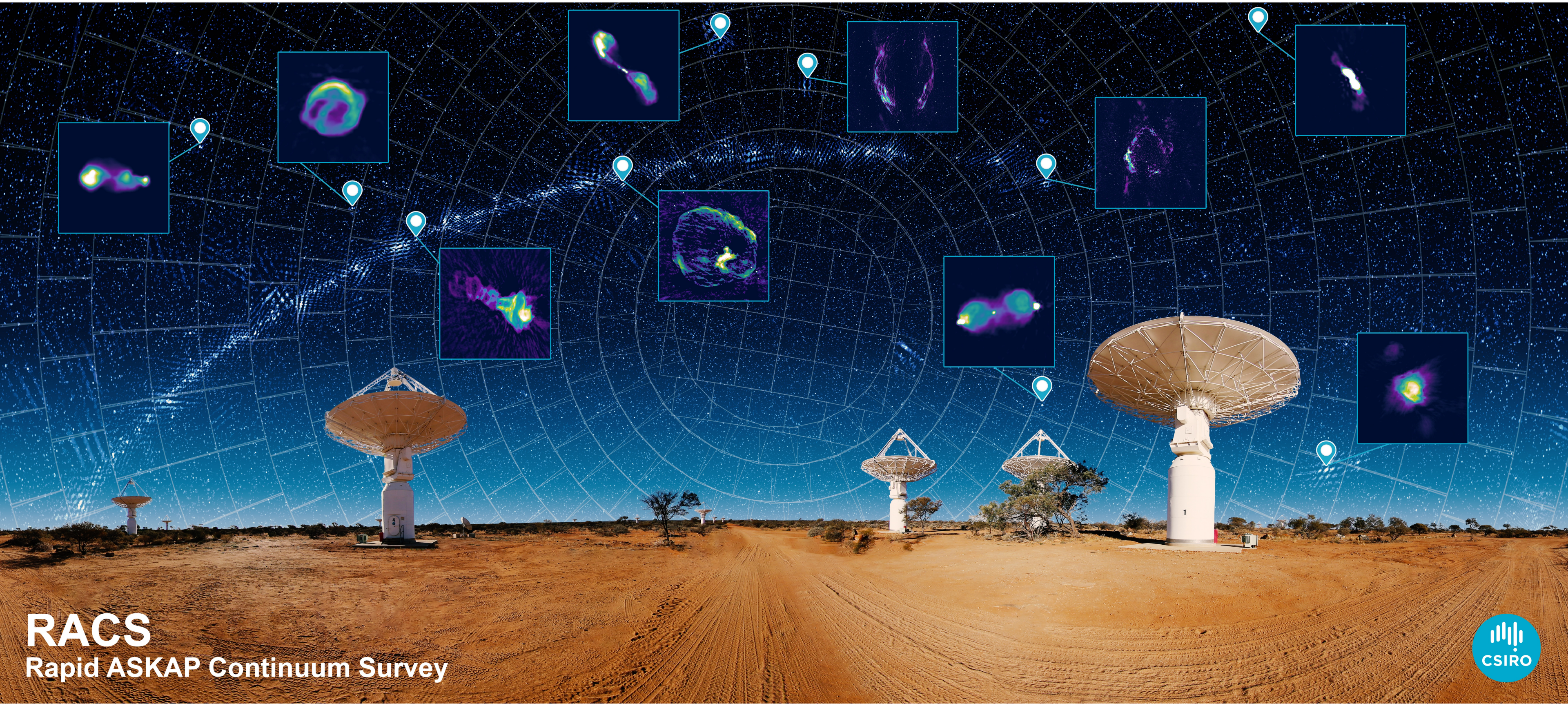
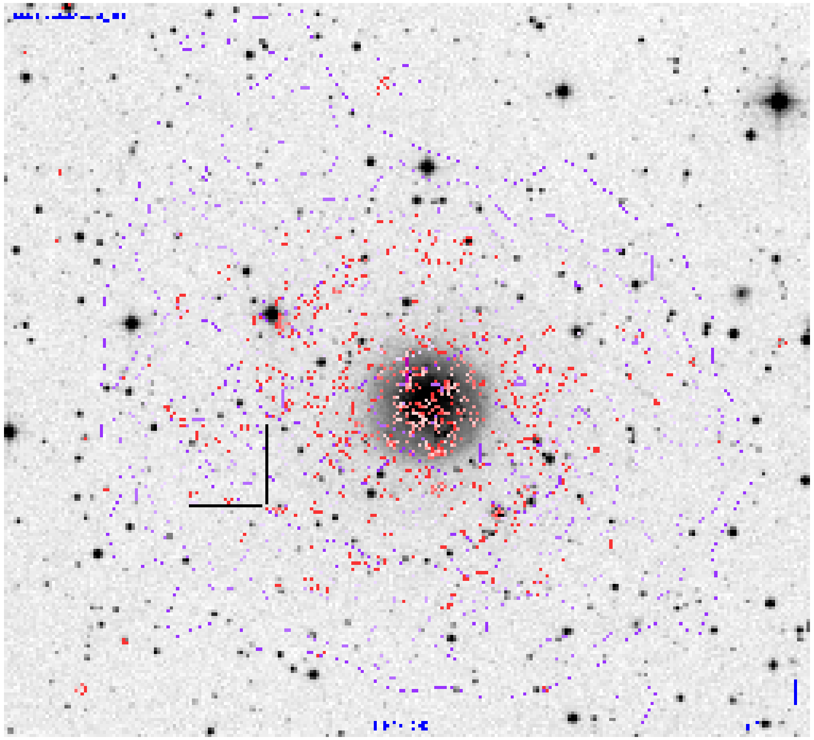
ASKAP



+ MeerKAT, eVLA, LOFAR, GMRT

Host-less intergalactic SNe

NGC 1058



Zinn+2011

Strange Case of the LMC Odd Radio Circle*?

Filipovic+22

GASS & HI4PI and J0624-6948

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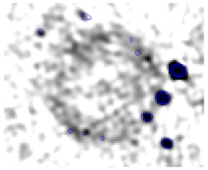

HESS 2022

Run-away LMC SNR or … ???

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30 Doradus

B.S.=12”

D=48.5pc

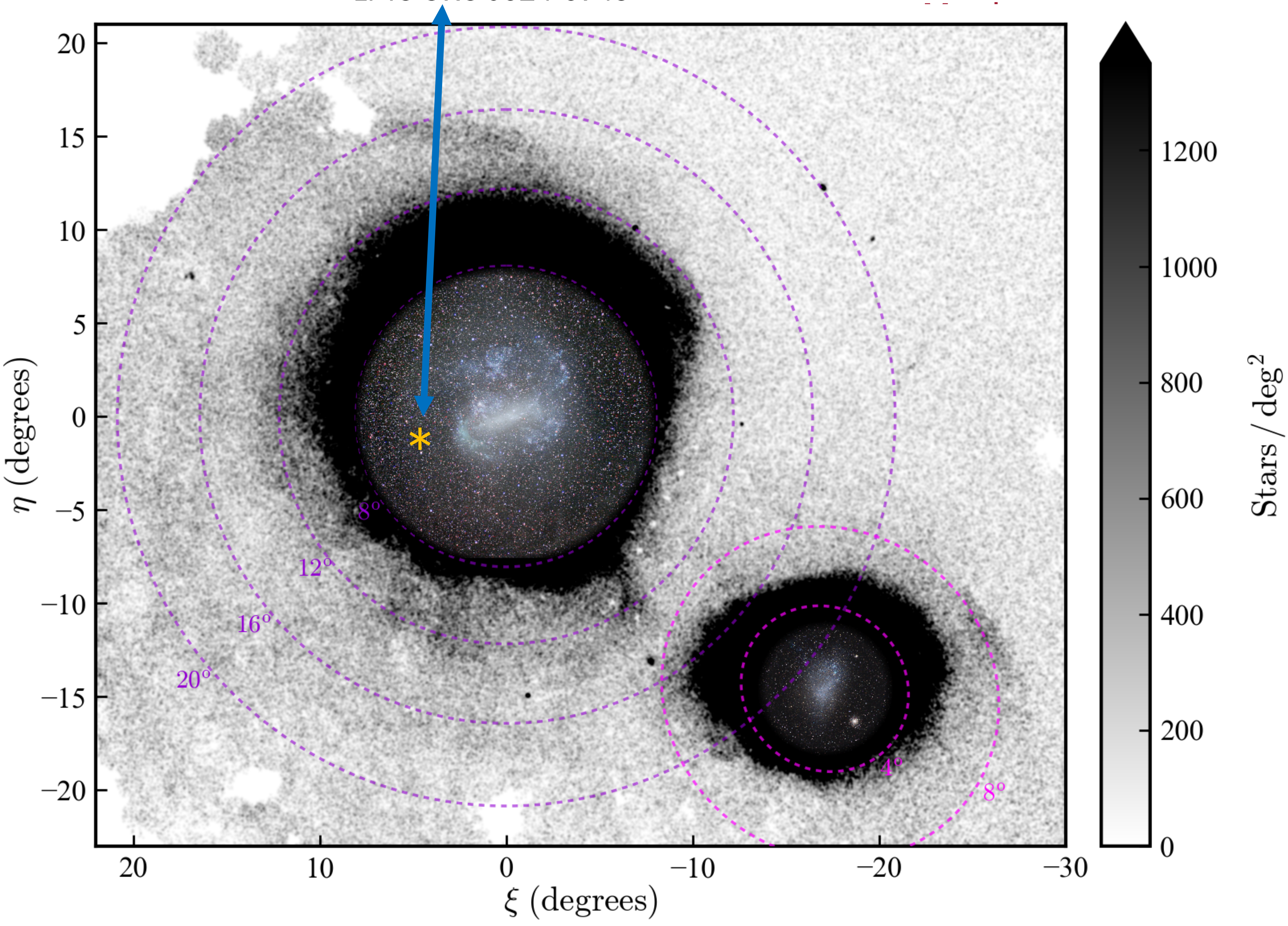
~2.5^{o} (~1.7kpc)

rms=>58μJy/beam

ASKAP 888MHz

LMC ORC 0624-6948

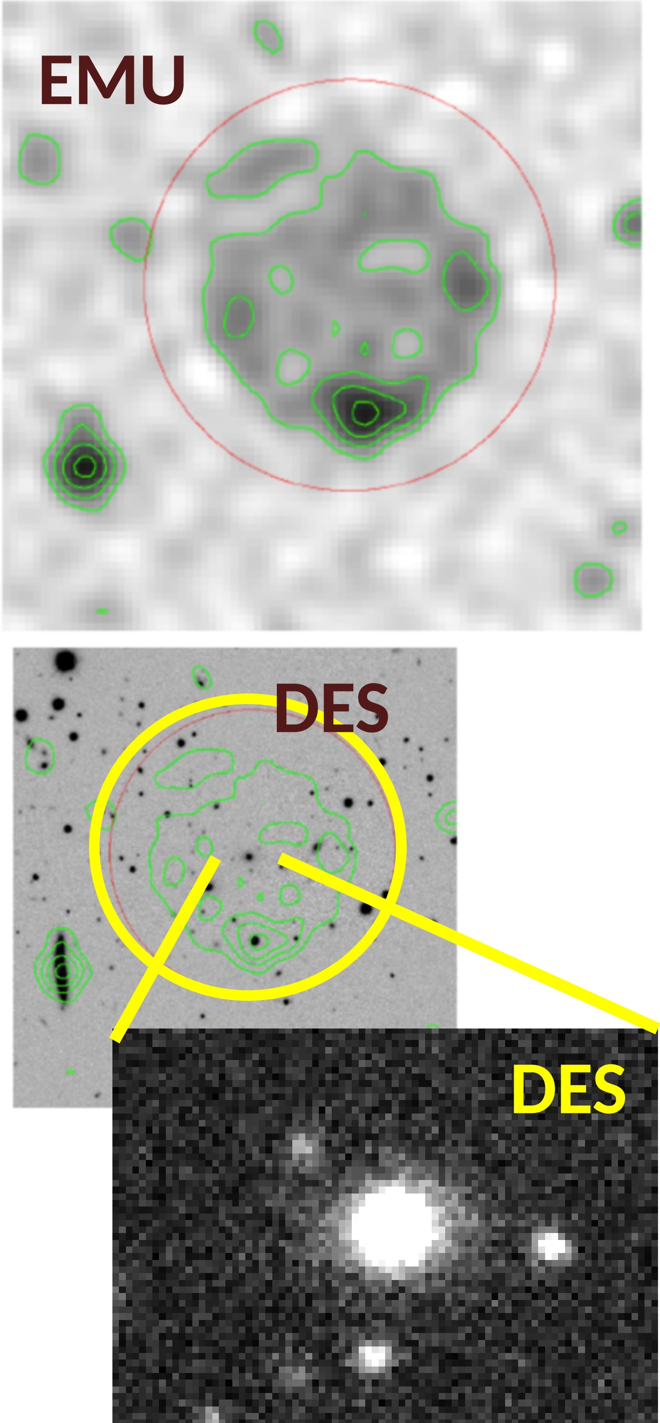
Courtesy of D.



Odd Radio Circles –ORC’s

- No corresponding optical diffuse emission. Faint red object at centre is probably a galaxy
- NOT an artefact!
- Is it… SNR, planetary nebula, starburst ring, gravitational lens, bent-tail galaxy, pulsar wind nebula, end-on BL Lac, Einstein ring, cluster halo, etc
- So WTF? Consistent with edge-brightened sphere. Spherical shock from something that went bang?
- Now finding other examples in the EMU pilot data
- Not seen before in radio surveys because (a) rare, (b) low-surface brightness
- Several other examples have now been found in the pilot survey
- A new phenomenon – shock from an explosion?

Norris+20, Koribalski+21



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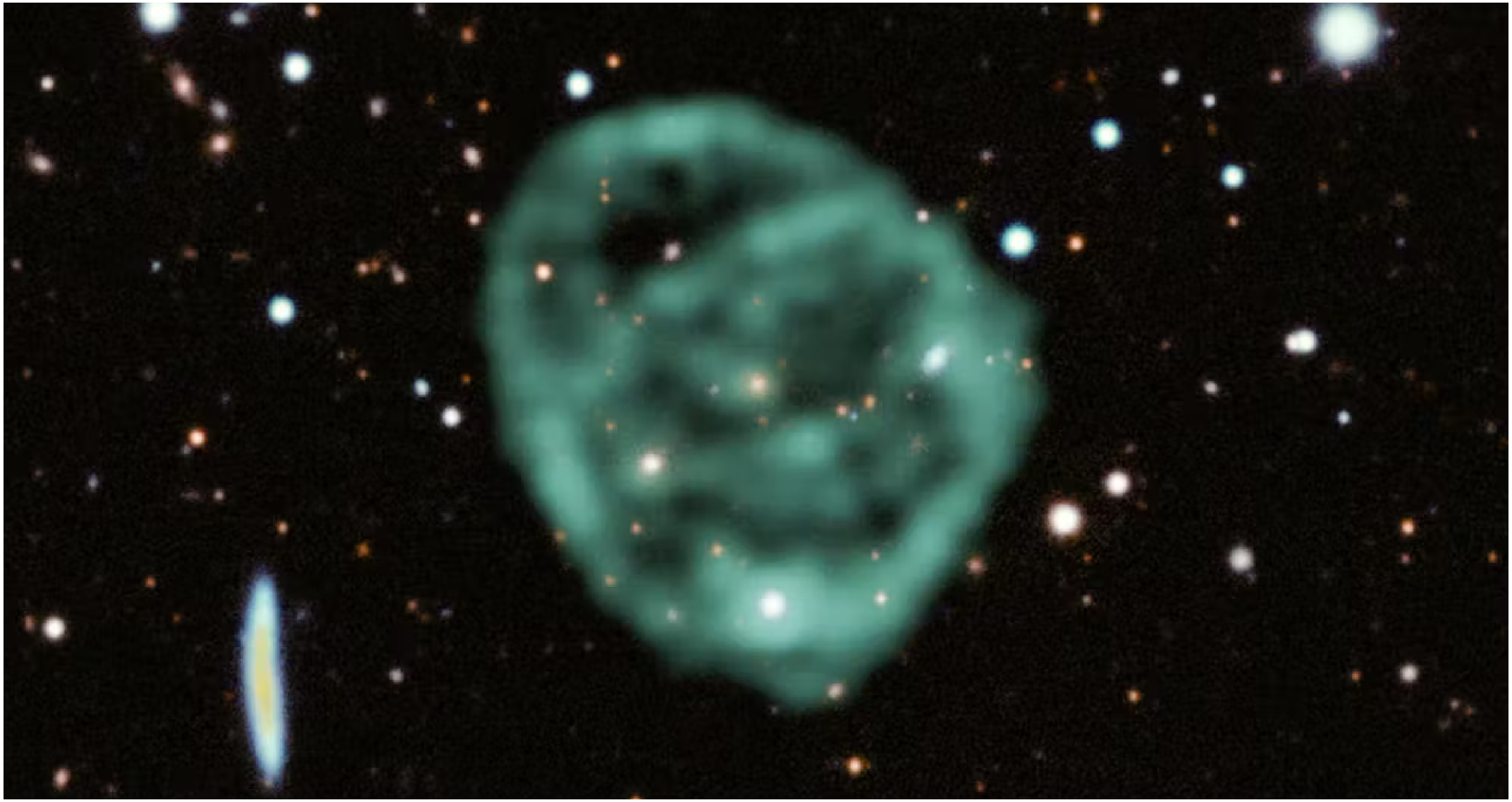
Odd Radio Circles (ORCs)



MeerKAT, Norris+22

ASKAP

888 MHz; B.S.=13”

2.1 GHz; B.S.=15”

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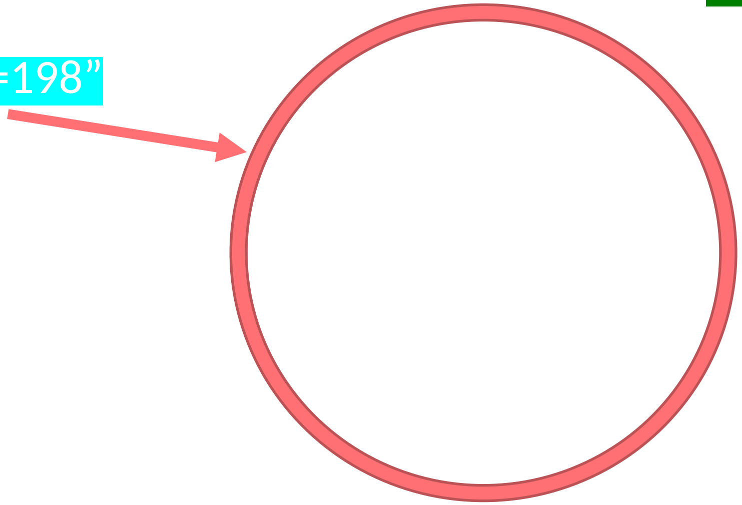
ATCA

Run-away LMC SNR or … ???

ATCA

ATCA

D=198”



5.5 GHz; B.S.=10”

9.0 GHz; B.S.=10”

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LMC_ORC_0 J0624-6948
Spectral index: -0.4 < α < -0.75 ✉ same spectral age

Contours are from ATCA 2.1 GHz

Total LMC ORC

S_{888}=11.7 mJy

S_{2100}=9.1 mJy

S_{5500}=4.5 mJy

S_{9000}=3.6 mJy

Radio point-like sources in the field have distinctively different α

Effective 10-cm map

Thickness of the ring ~30”

D~198”

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2100 MHz

2100 MHz

Polarisation

LMC_ORC

5500 MHz

5500 MHz

GPS

9000 MHz

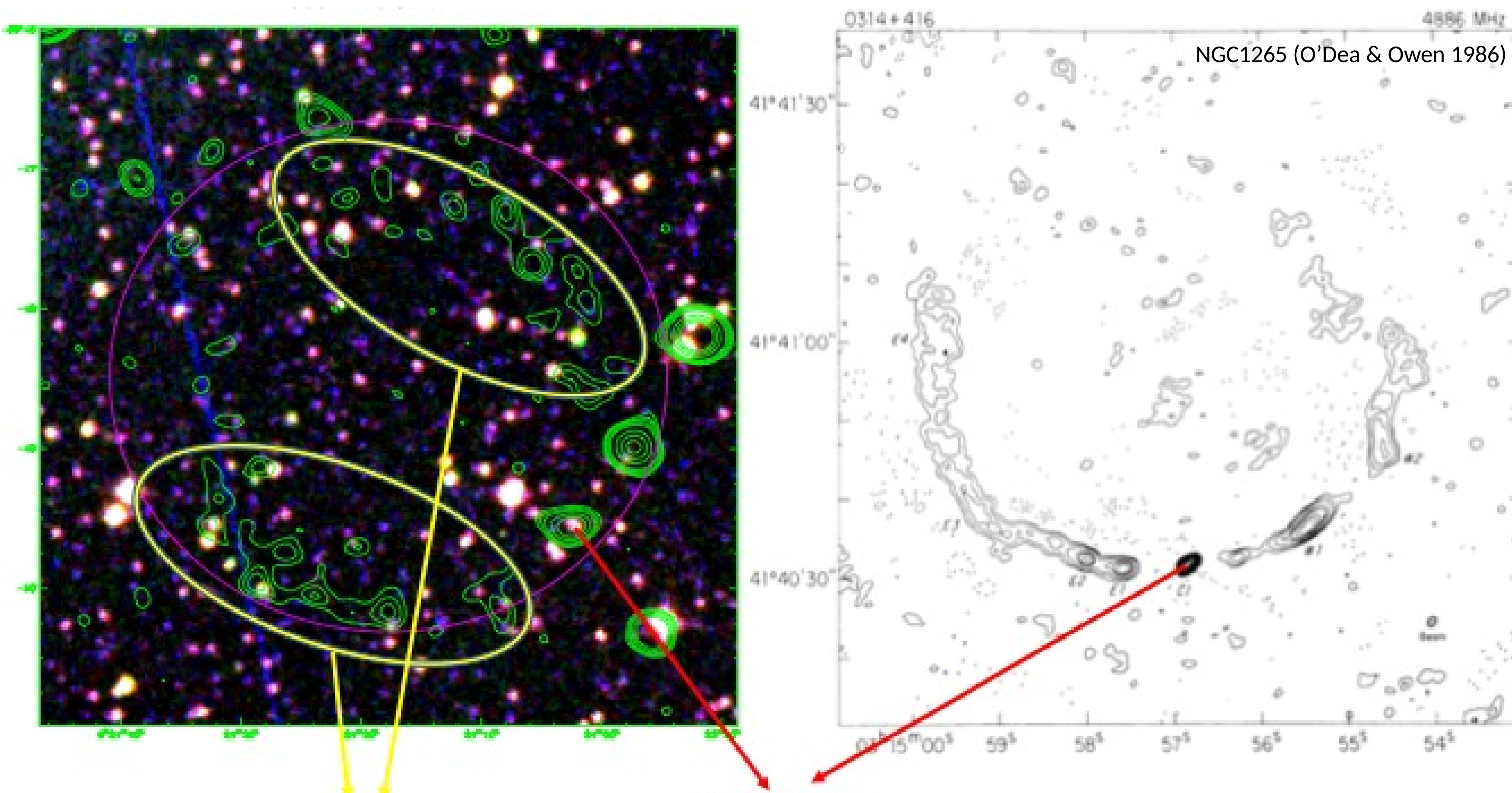
9000 MHz

No Pol >1% !

J0624-6948 as Uruk-Hai ?

To be or NOT to be… ORC?

Case for AGN (NAT) ???



JETS?

HOST GALAXY?

NO !!!

Radio JETS are synchrotron i.e. also steep radio spectra

To be or NOT to be… ORC?

1.4 GHz

To be or NOT to be... is J0624-6948 an ORC?

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It is circular/ring!

But…

Much bigger (3’ vs. 1’)

Different spectral index (-0.54 vs -1.0)

No central source (engine?)

No polarisation

To be or NOT to be… Run-away LMC SNR or ORC

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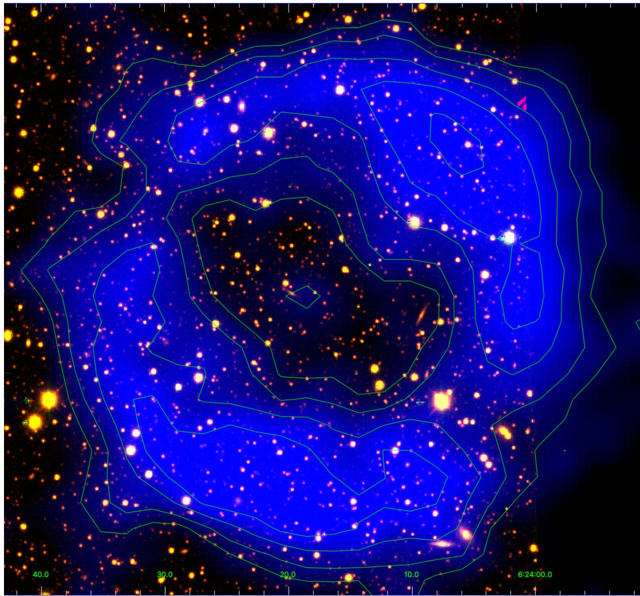
Case for ”run-away” LMC (or MW) SNR

- Located “between LMC and MW”. ~2.1^{o} from the LMC.
- NO OBVIOUS OPTICAL or X-ray counterpart (good reasons for that)!!!
- Typical LMC SNR size with diam*=47.5pc where $d_{lmc\ av}$=41pc
- Perfect(?) D=198"±2" ring with thickness of ~30”
- ”classical SNR” bi-lateral shape
- But NO polarisation!



* Using distance to LMC of 50kpc

To be or NOT to be… Run-away LMC SNR or ORC

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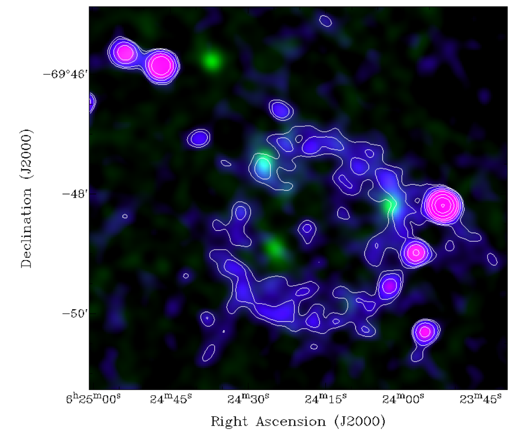
Case for "run-away" LMC (or MW) SNR

PART 2



- SN(R) progenitor
  - Likely Type Ia, but
  - CC shouldn't be ruled out either!!!
  - From LMC but also possible from MW

  From High Velocity Star(s) ?
- Evolving/Expanding in rarified environment – like MW Loops?
- S_{1GHz}=0.0119 Jy; Σ=1.54x10^{-22} W/(m^2 Hz SR); $L_{10MHz-100GHz}$=6.3x10^{25} W
- Evolving in very low ambient ISM ✉ n_H~0.008 cm^{-3} ✉ "ideal SNR"
- α=-0.54±0.06 ✉ typical for mid-age SNR with low Σ
- Age: 4000-9000 yrs (ejecta dominated to Sedov phase)
- Assuming above D, α, S_{888}, $dist_{lmc}$, and filling factor of 0.875

  Equipartition give us: B=7.5μGa and E_{min}=5.65 x 10^{48} ergs

* Using distance to LMC of 50kpc

To be or NOT to be...

remnant of stellar super-flare (RSSF) or ORC_0 ?

Baby ORC?

What if it is nearby Remnant of Stellar Super-Flare?

- Distance from Gaia -- 58.5pc (p=17.0781)
  - M-dwarf class star (Gaia EDR3 5278760380137682816)
  - Size of shell ~ 0.186 ly (0.0578pc)
  - Age of 55-550 yrs if we assume
    - V_{exp} ~ 50-500 km/s
  - Proper motion in Dec=46.087mas/yr !
- Flare stars are known X-ray objects!
- Modelling E:
  - E_{CME} = >2x10^{36} erg M/(1x10^{21} g) (v_{CME}/(450 km/s))^2
  - $M_{ejection}$ >2x10^{22}g = 1x10^{-11} M_{Sun} = 3x10^{-6} M_{Earth}

A CME on the Sun can travel Alfven speed (282.1 km/s) which would give an age of the ORC_0 of ONLY ~100yrs (t=s/v; s=d/2=0.0285pc=8.8^11km)

Fun fact:
M-dwarf A.K.A.:
Ultracool Dwarf (UCD) stars,
and
UV-Ceti type stars.

NOT PN or SN event!

"Maybe it's more like the ejection of a whole shell of stuff?"

Not just one side (flare) eruption!

Or maybe a multiple simultaneous eruptions?

Active Star HR 9024 (Argiroffi+19):
E_{CME} = 5.2×10^{34} erg
$M_{ejection}$ 1.2×10^{21} g

If RSSF then proper motion will be observable!

CME = Coronal Mass Ejection; non-thermal origin as mag field produce them.

To be or NOT to be…
WHAT is J0624-6948 ?

Mid-age run-away LMC SNR (TN vs CC) -- 45%

or

Old-ish run-away Galactic SNR (TN vs CC) – 40%

or

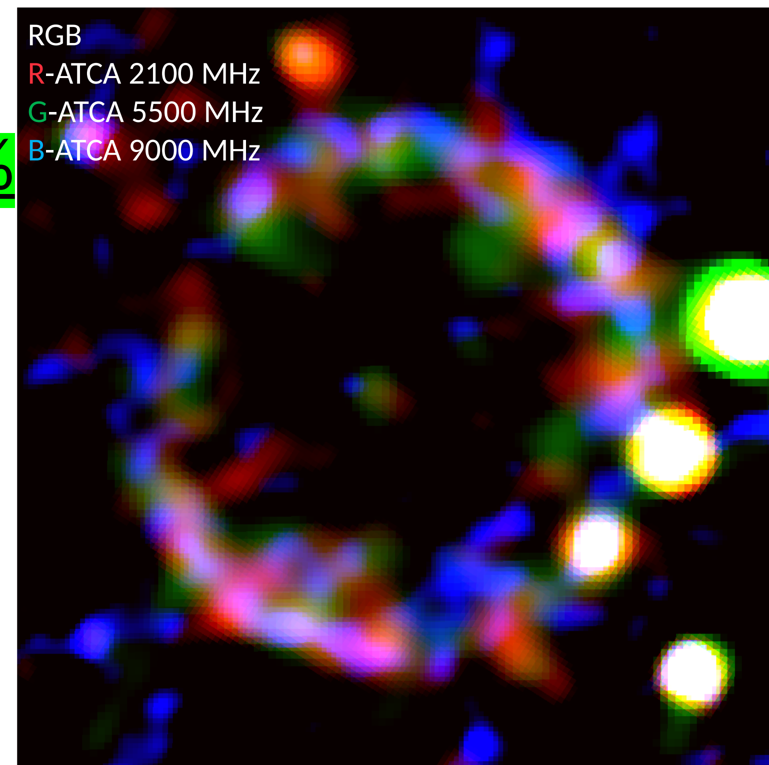
Nearby star super-flare???!! – 5%

or

…or precessing “BL-Lac” ??? –5%

or

something else ? -- 5%



To be or NOT to be…

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J0624-6948 as Unique SNR?

What is next?

- Parkes (search for PSR)
- Optical narrow-bands (Halpha, [SII] and [OIII])
- MeerKAT
- ?

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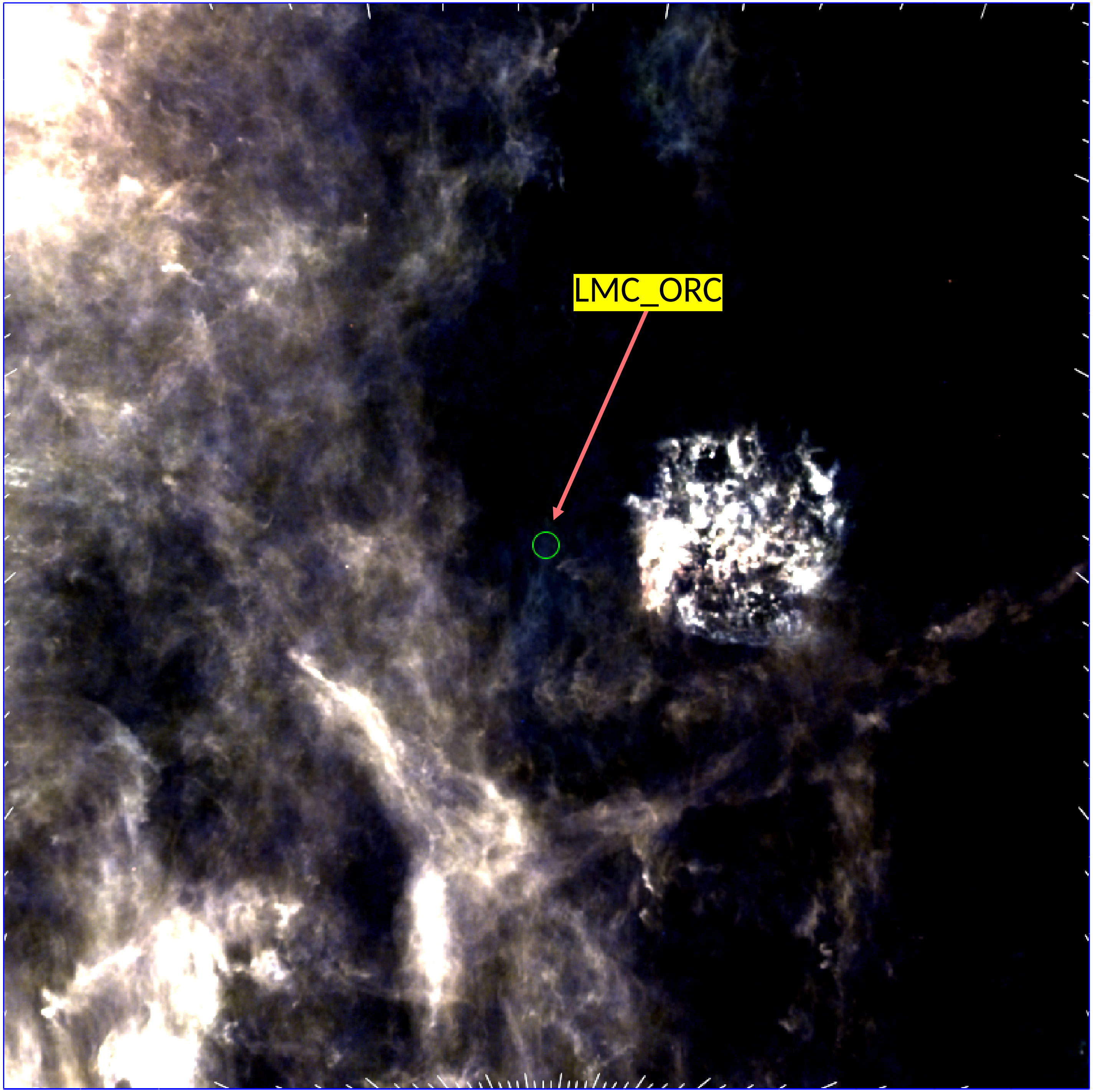

?

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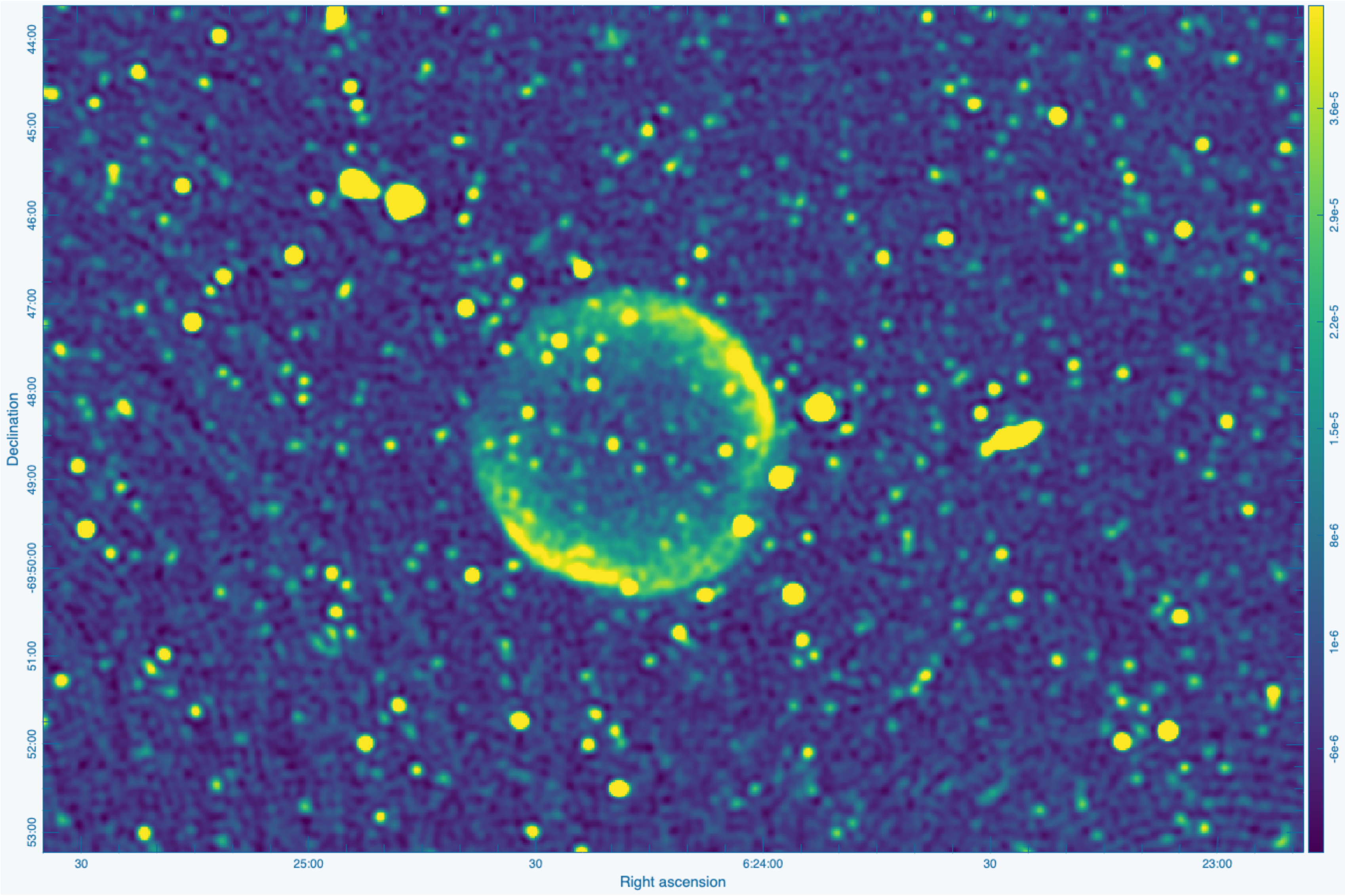
LMC ORC with MeerKAT



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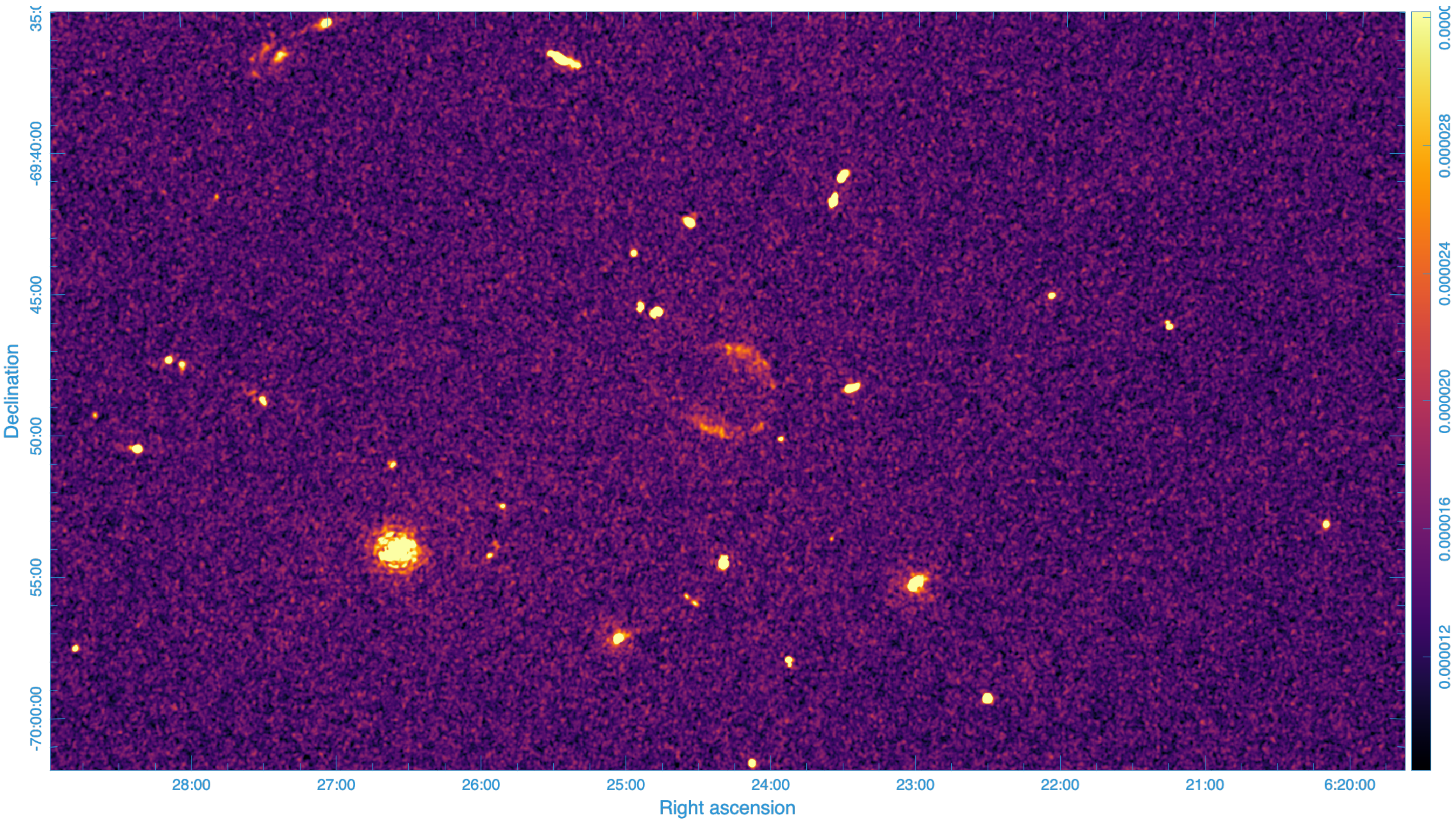
LMC ORC with MeerKAT



Not even a trace of Hα (CTIO 4m)

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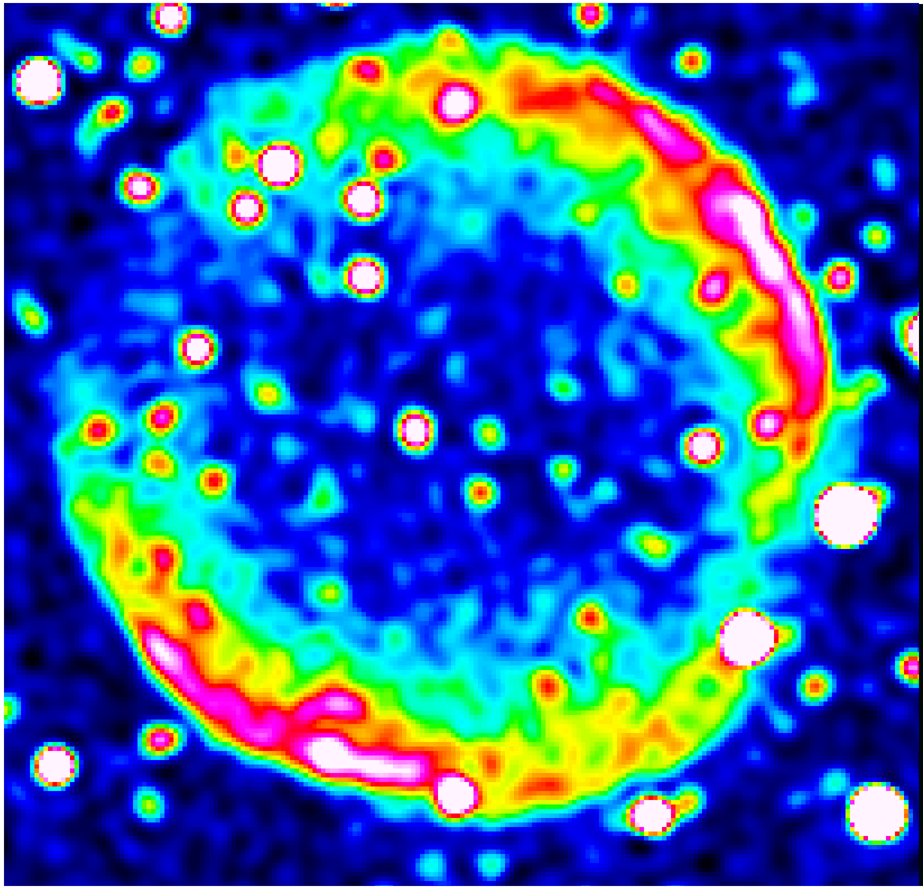
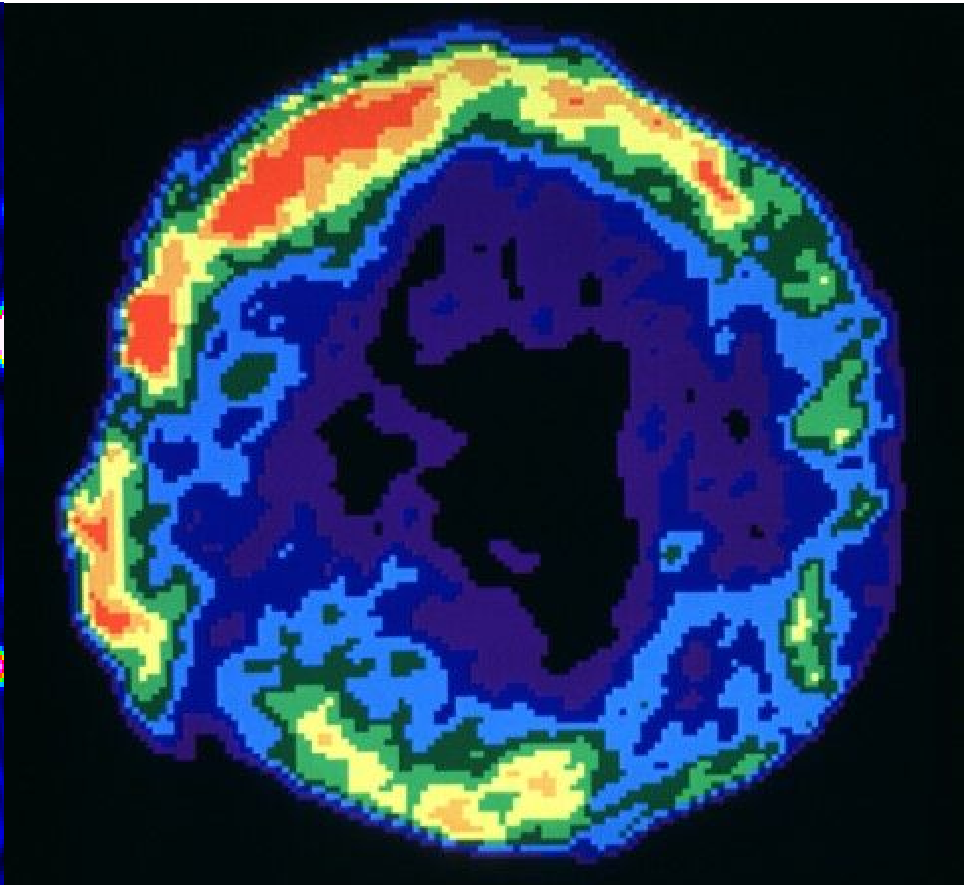
LMC_ORC

ycho





Reynoso+1997

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Curious case of NGC 2663

- Possible first case of observed recollimation phenomenon detected on kpc phenomenon on kpc scales?
- Positioned in extremely poor environment
- Very large galaxy in the nearby universe (< 200 Mpc) with jets about 350 kpc at 28.5 Mpc.
- Unusual fractional polarization
- SMBH might be offset
- First of many to come from EMU Survey?

Velovic+22

Recollimation shocks on kpc-scale

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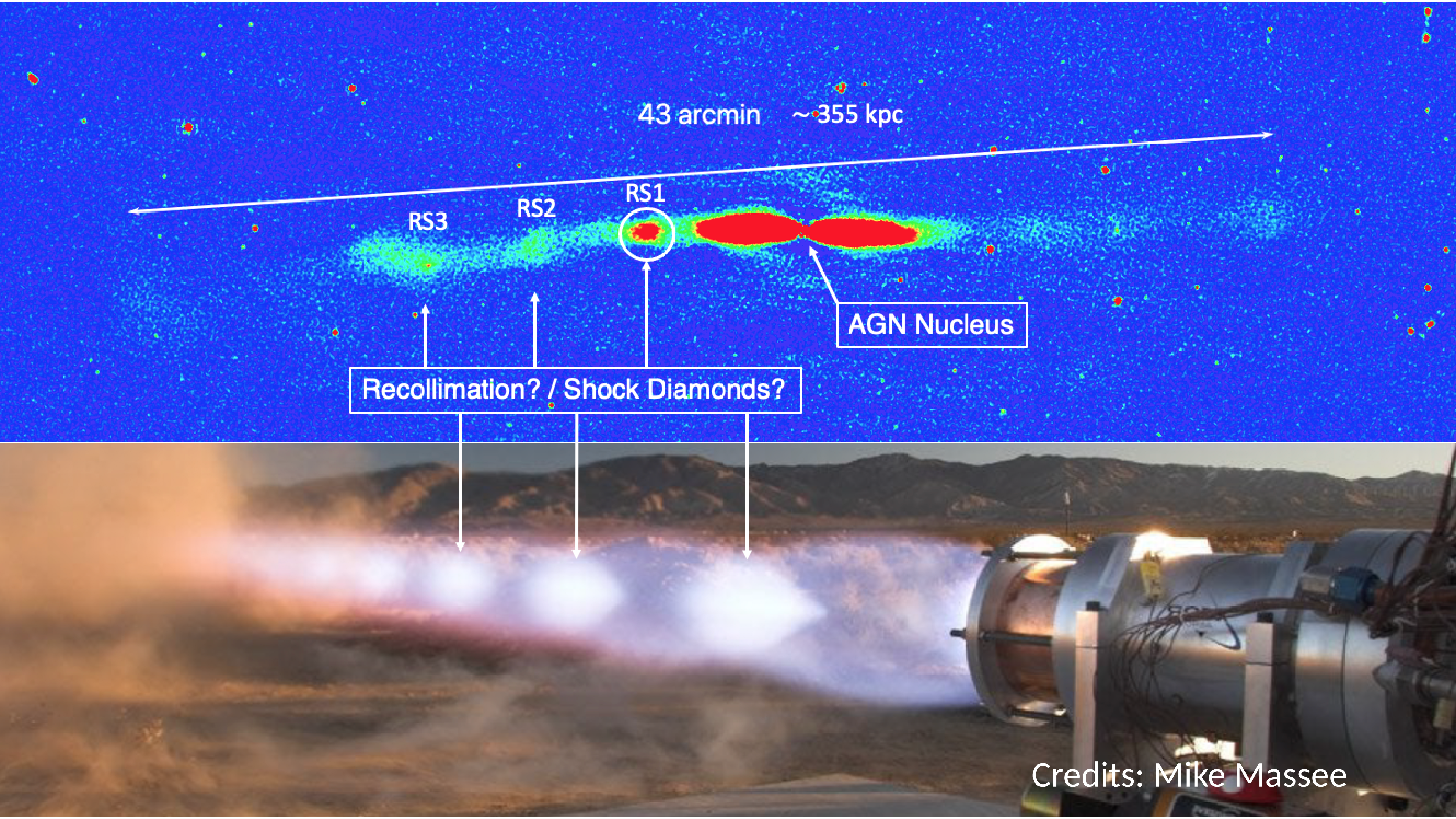

Pressure mismatch between the jet and the ambient medium.

Jet narrows and brightens up.

Multi frequency radio observations

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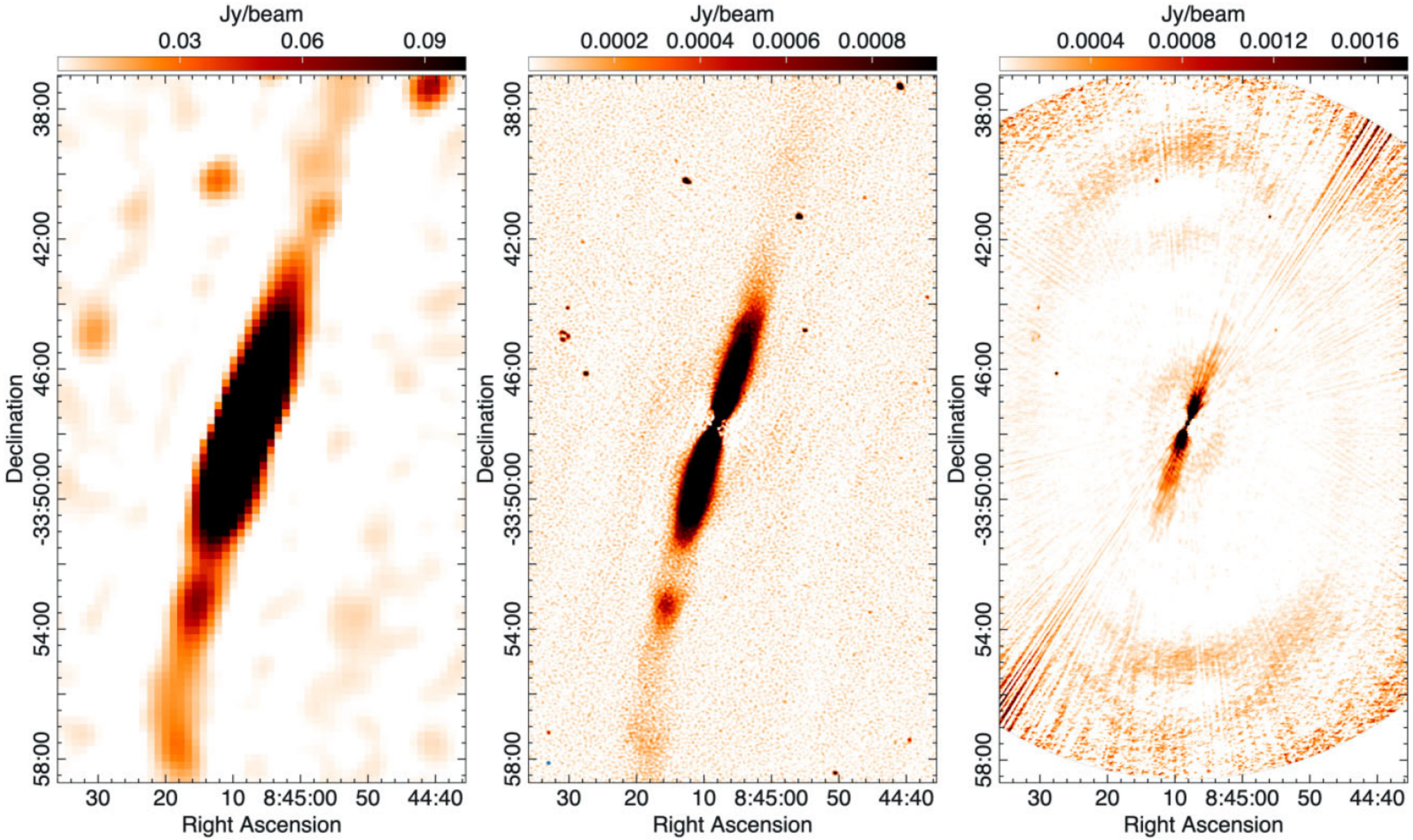

Frequency:	200 MHz	1520 MHz	2368 MHz
Resolution:	128´´x 105 ´´	6 ´´	9.6´´x 3.6´´
FOV:	25˚	25˚	16´

NGC 2663 polarization

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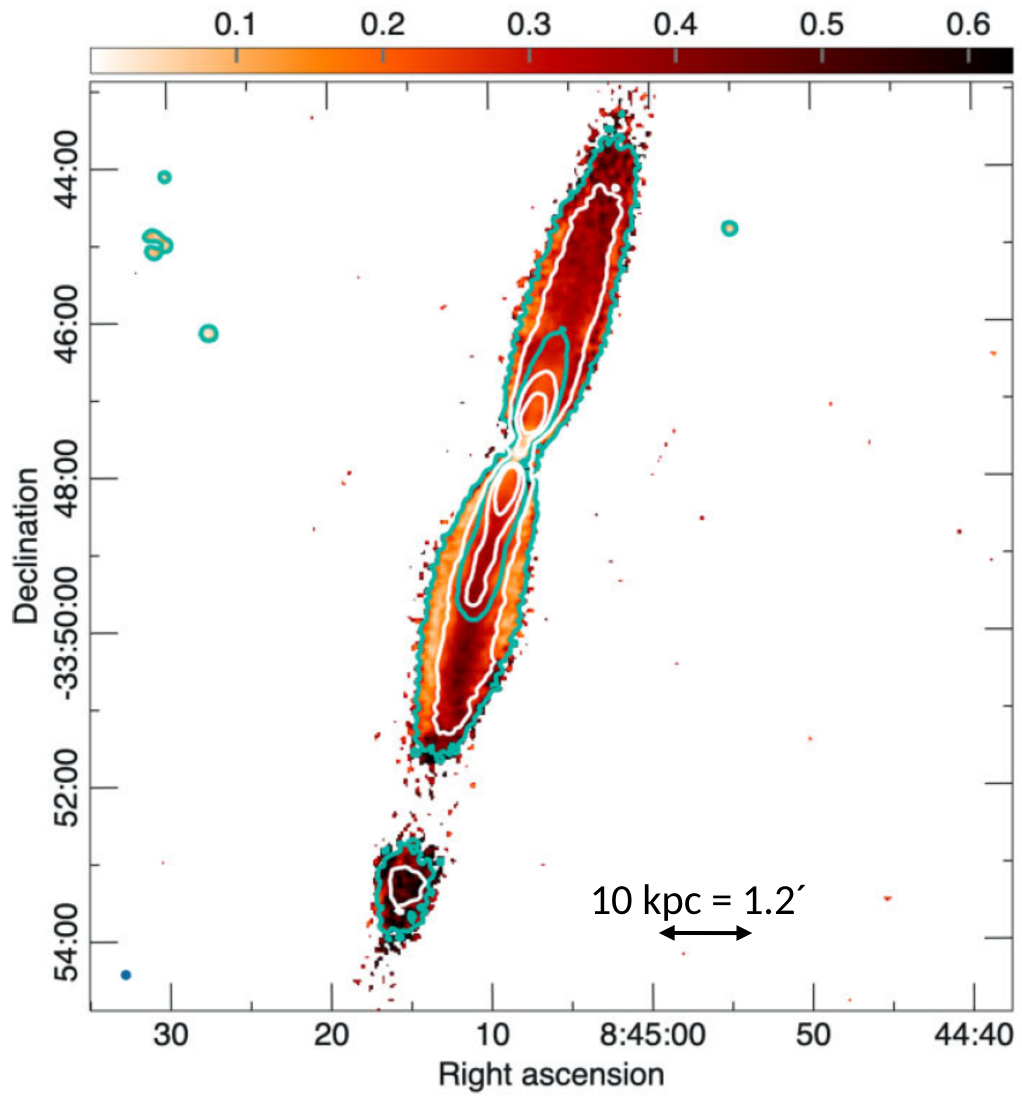
- Fractional polarization is strongest along the ridge line and dropping towards the edges.
- Non-uniform cross-section - Coaxial *spine/sheath* jet structure.
- The inner spine of the jet has linear polarization.
- Toroidal field dominance in the outer sheath.



ASKAP 1520 MHz

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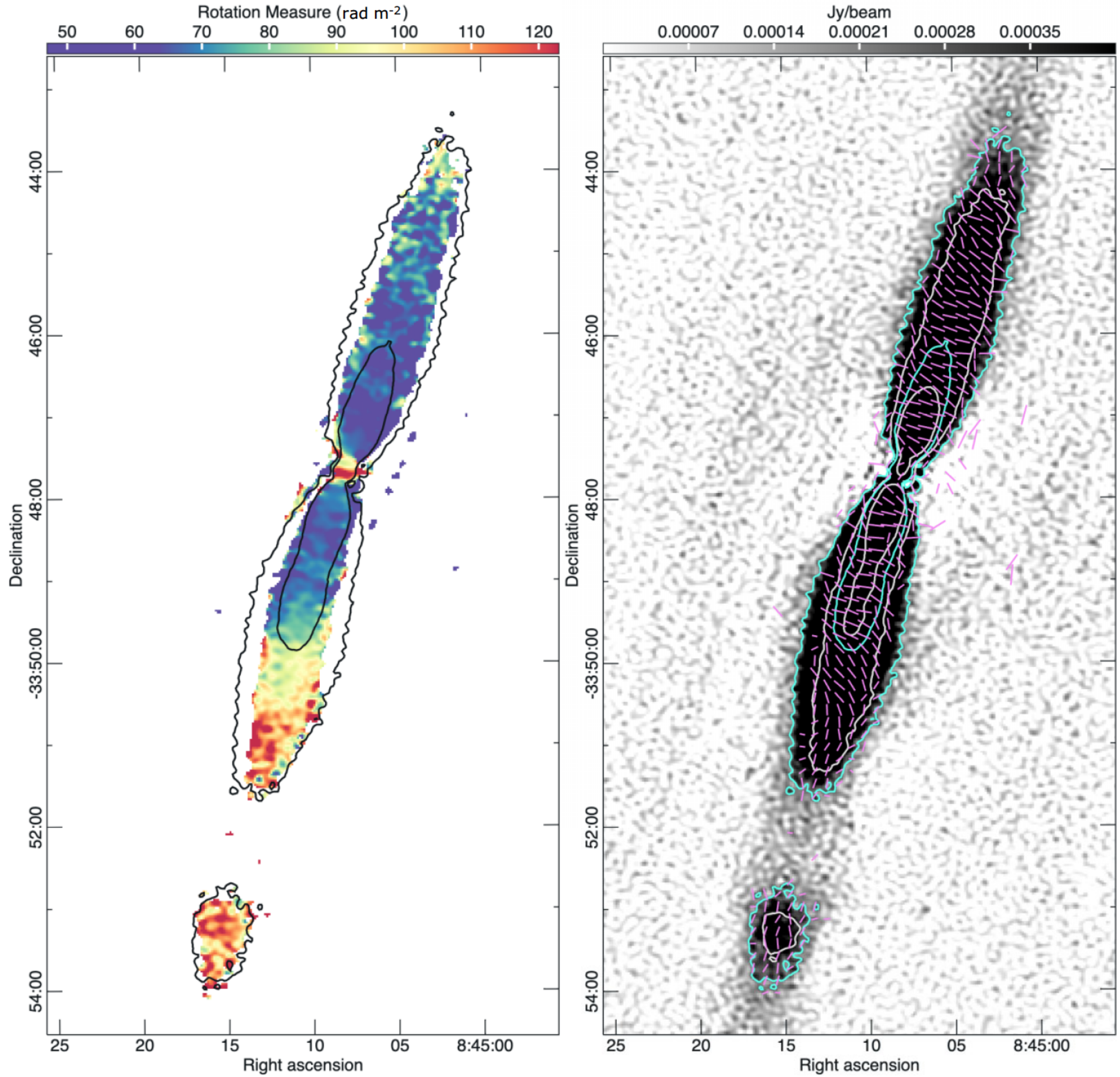

RM colour map - corresponding to peak polarization intensity after RM Synthesis.

Angled jets:
Northern jet is closer to the observer than the southern jet.

Magnetic field vectors change direction in the recollimation knot.

ASKAP 1520 MHz

Recollimation?

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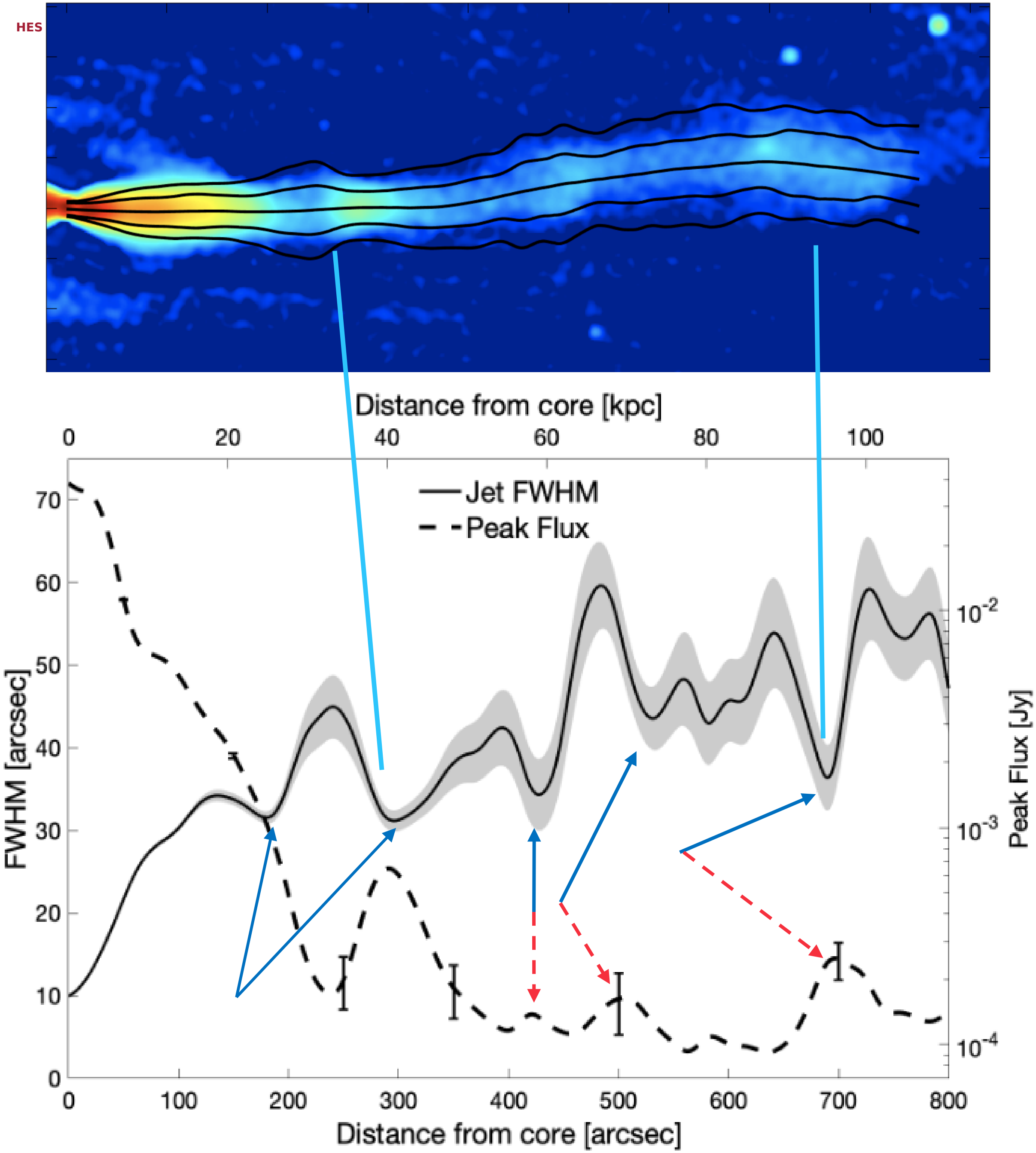

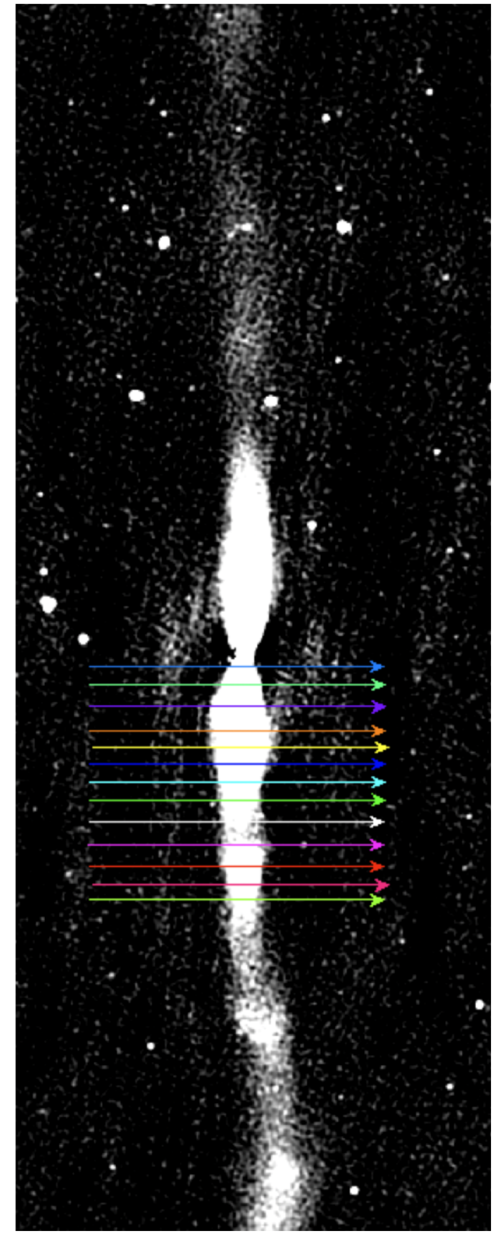

Recollimation?

Chandra x-ray

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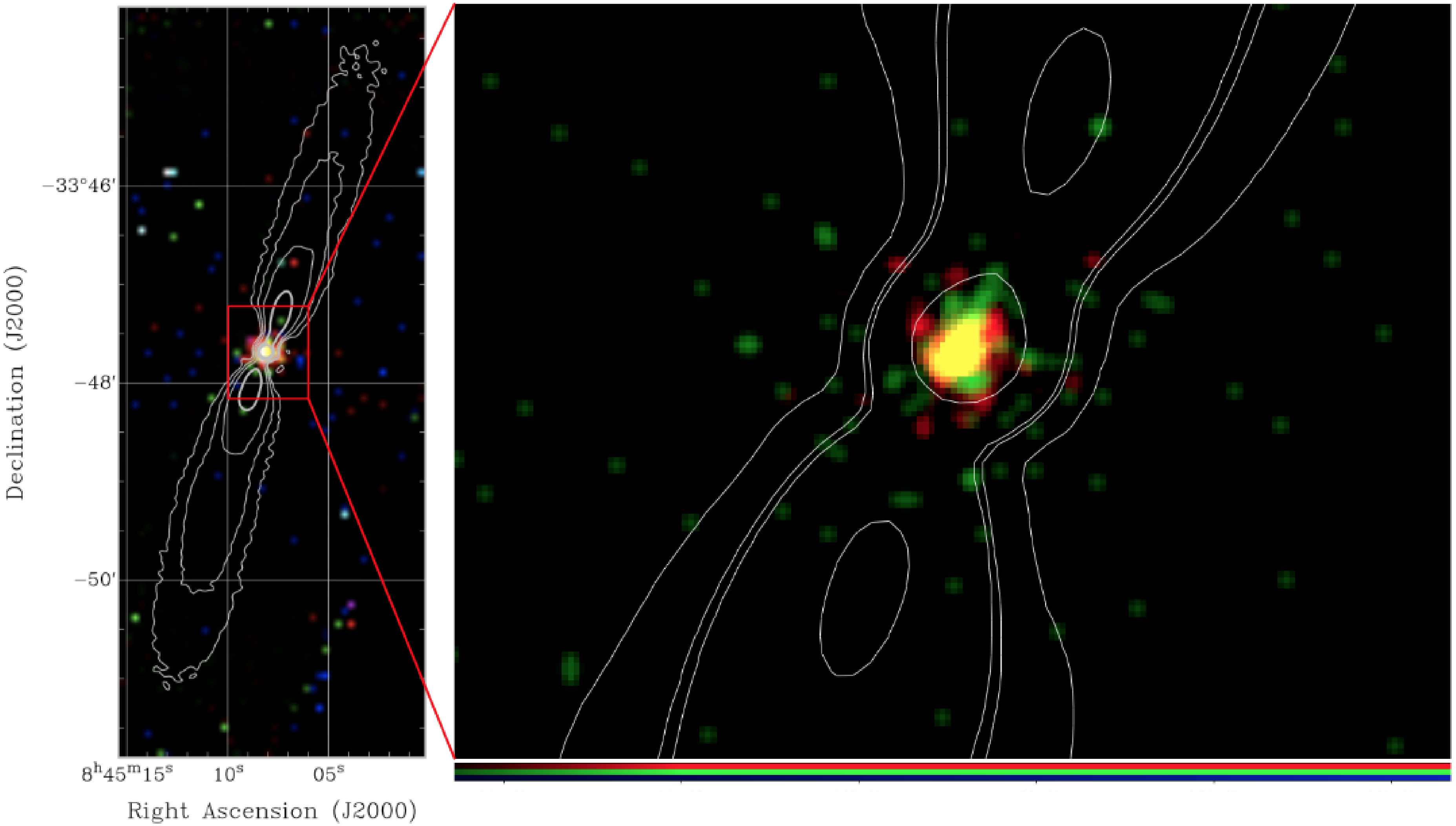
RGB image overlaid with ASKAP contours



R.G,B: soft (0.5 - 1.2 keV), medium (1.2 - 2.0 keV) and hard (2.0 - 7.0 keV) X-ray emission.

Other Candidates:

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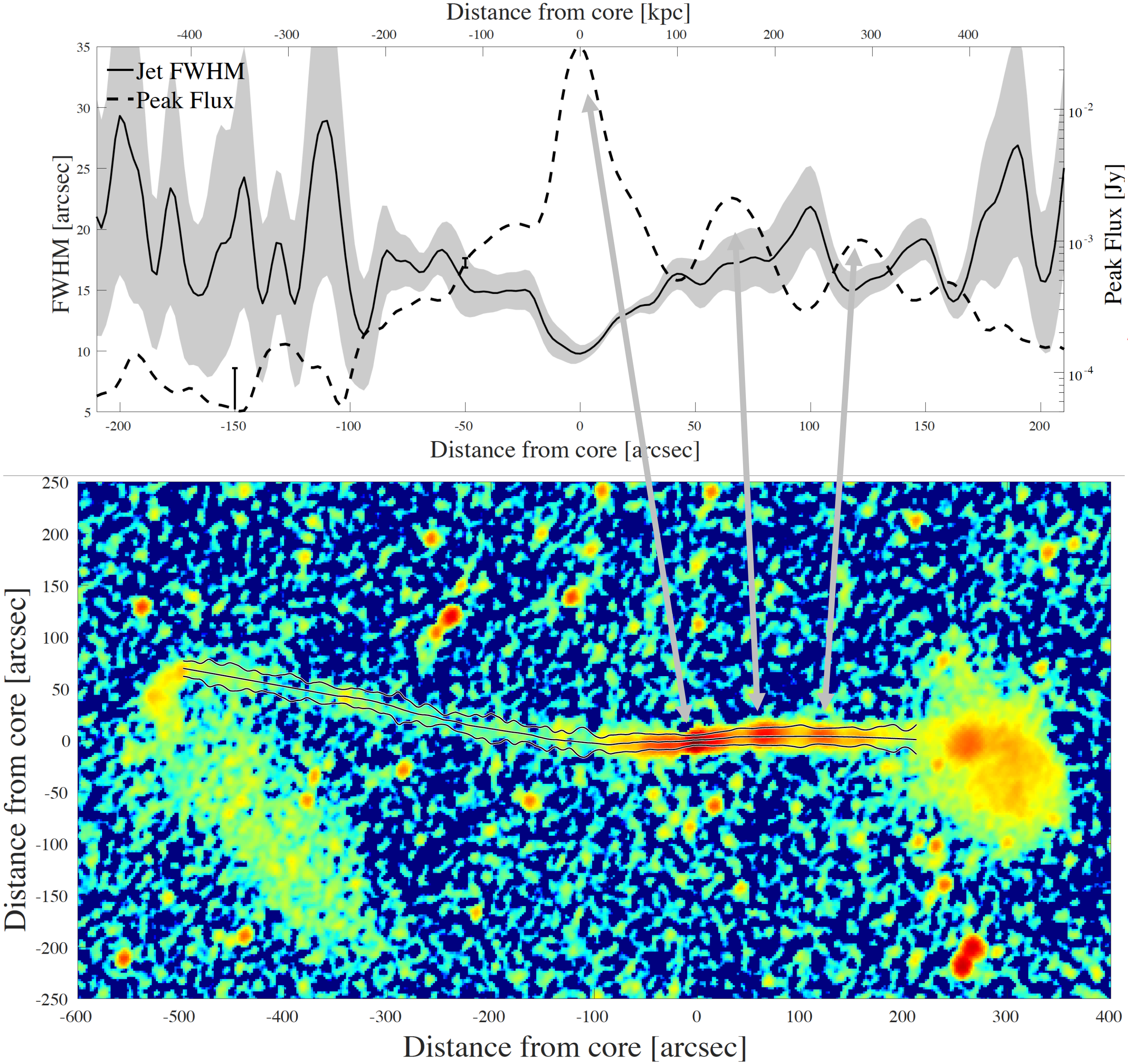

WISEA J052643.14-604210.5

D: ~490 Mpc

Angular size: ~ 22 arcmin

Size: ~ 2.6 Mpc

Summary

- Possible first detection of a kpc-scale recollimating jets.
- Recollimation region is distinctive at all wavelengths and has been detected with different instruments.
- Unusual polarization behavior of the jet.
- Extremely rarified environment
- More data with new instruments and surveys.

The Dancing Ghosts

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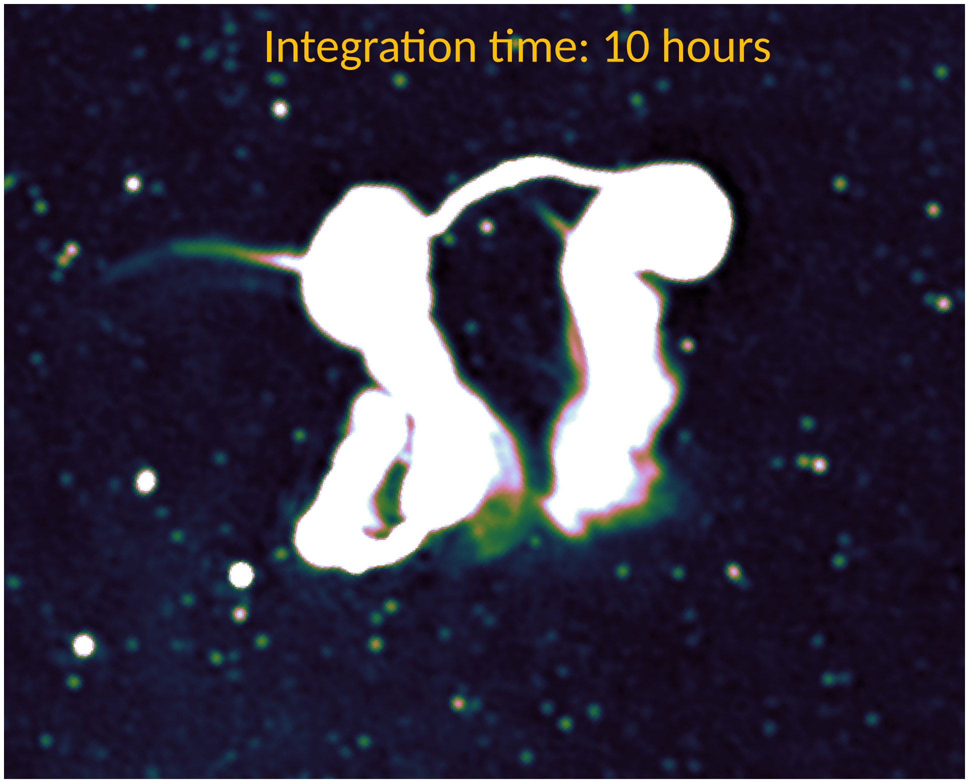
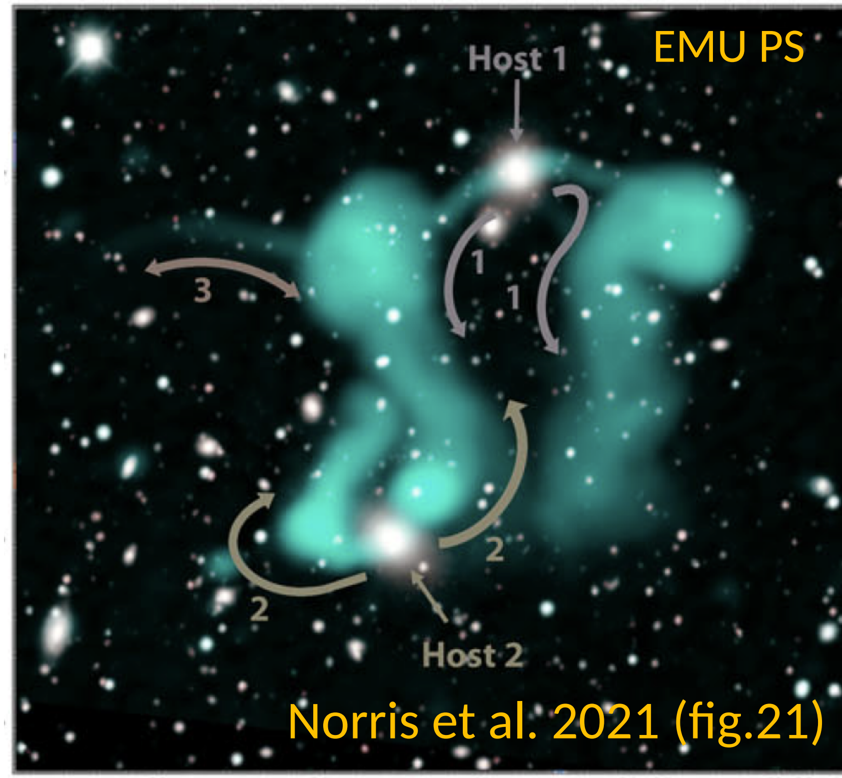
MeerKAT vs ASKAP observations

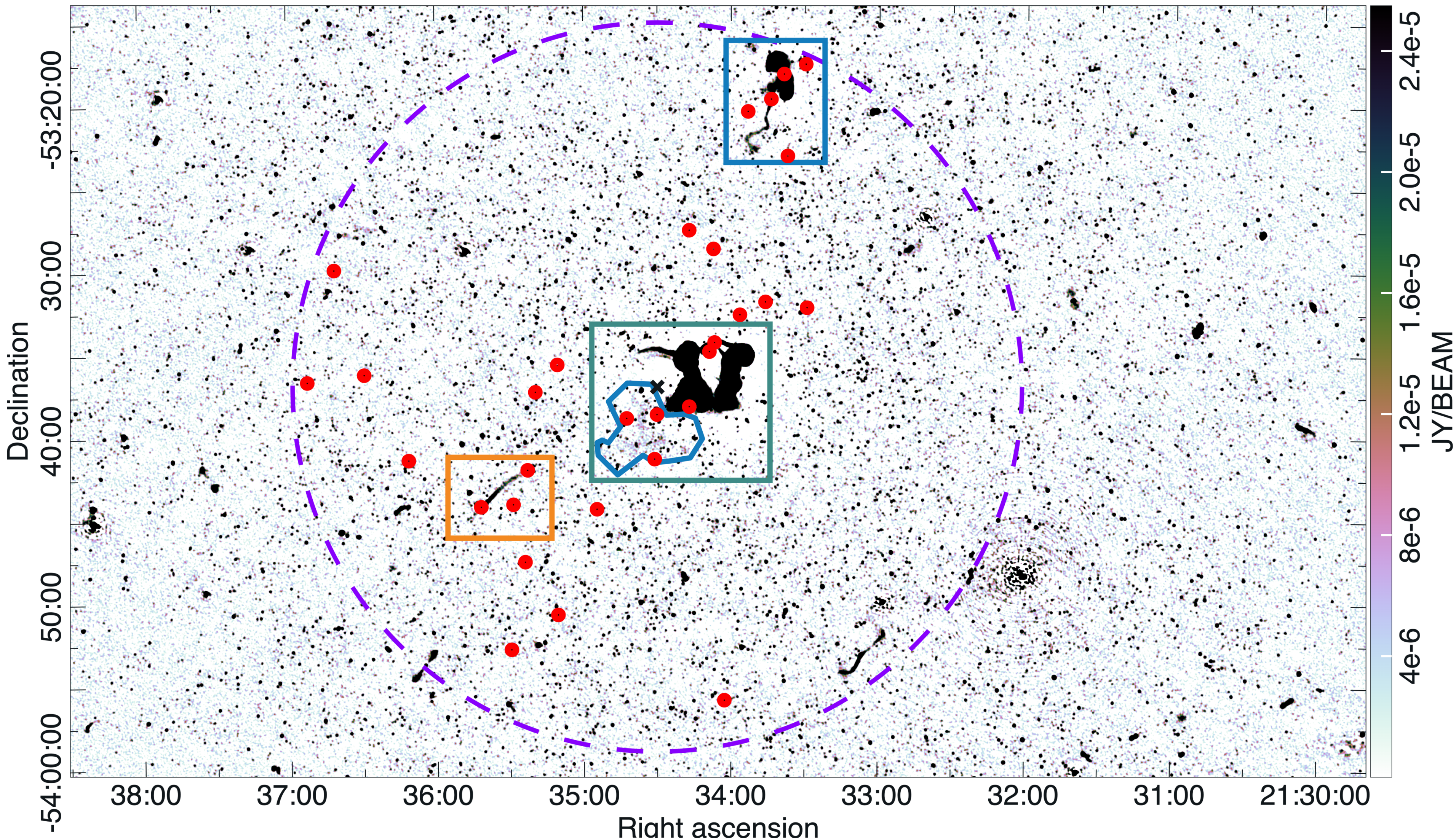




MeerKAT observations:
Frequency: 1284 MHz
Beam size: 7.5´´ x 7.1´´

ASKAP observations:
Frequency: 943 MHz
Beam size: 14.0´´ x 10.9´´

Cluster radius: ~22 arcmin
30 members, including PKS2130-538 complex



Abell 3785; z = 0.077 ~ 335 Mpc

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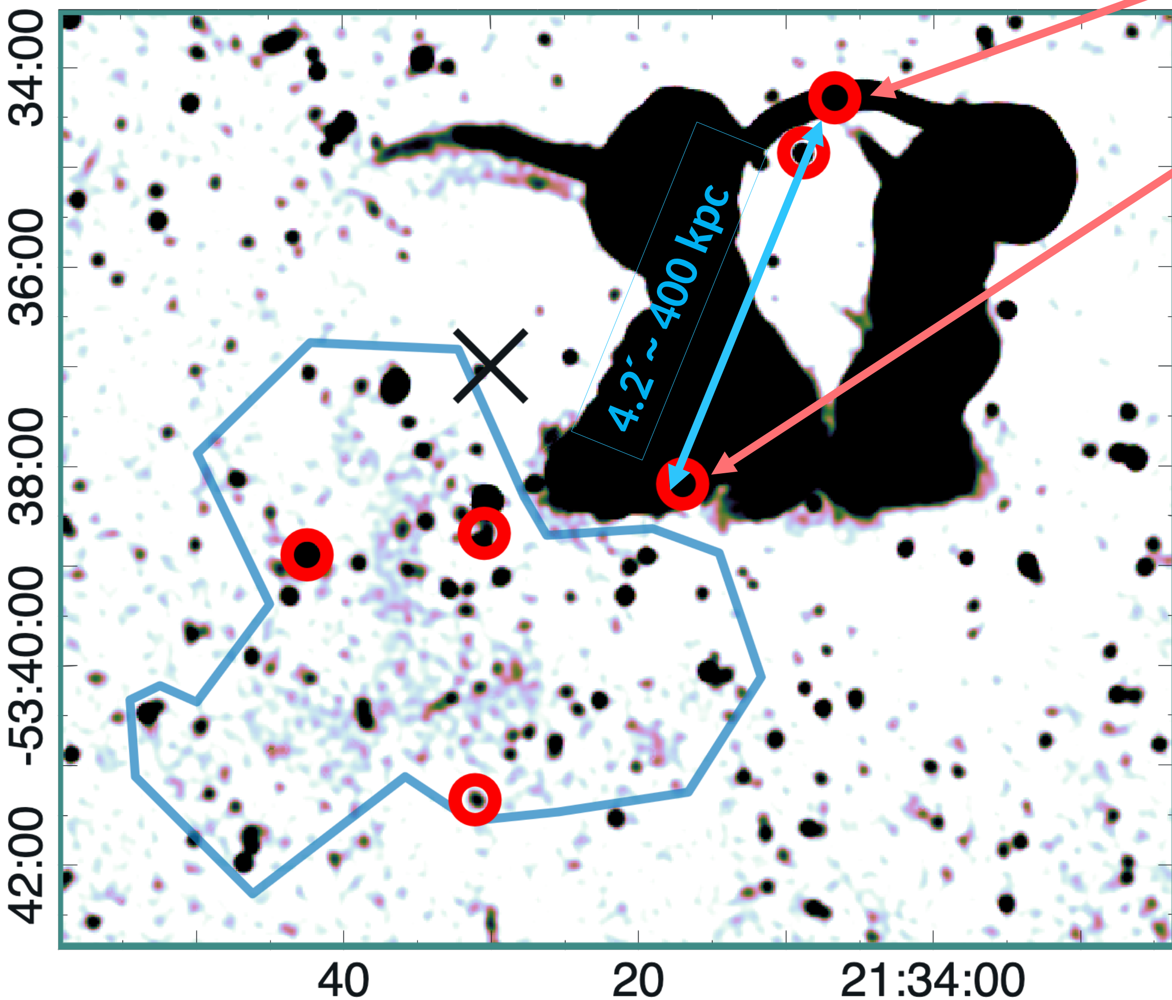

MeerKAT (1284 MHz)

J213406
z = 0.0785 ~ 346 Mpc

J213417
z = 0.0765 ~ 338 Mpc

Detected 30 members of Abell 3785 galaxy cluster (red circles).

Low diffuse emission ~ 5′

X marks the centre

Distance Between two hosts:
Angular: 4.2′~ 400 kpc
Radial: ~ 8 Mpc

Dissection of the ghosts

MeerKAT – ASKAP comparison

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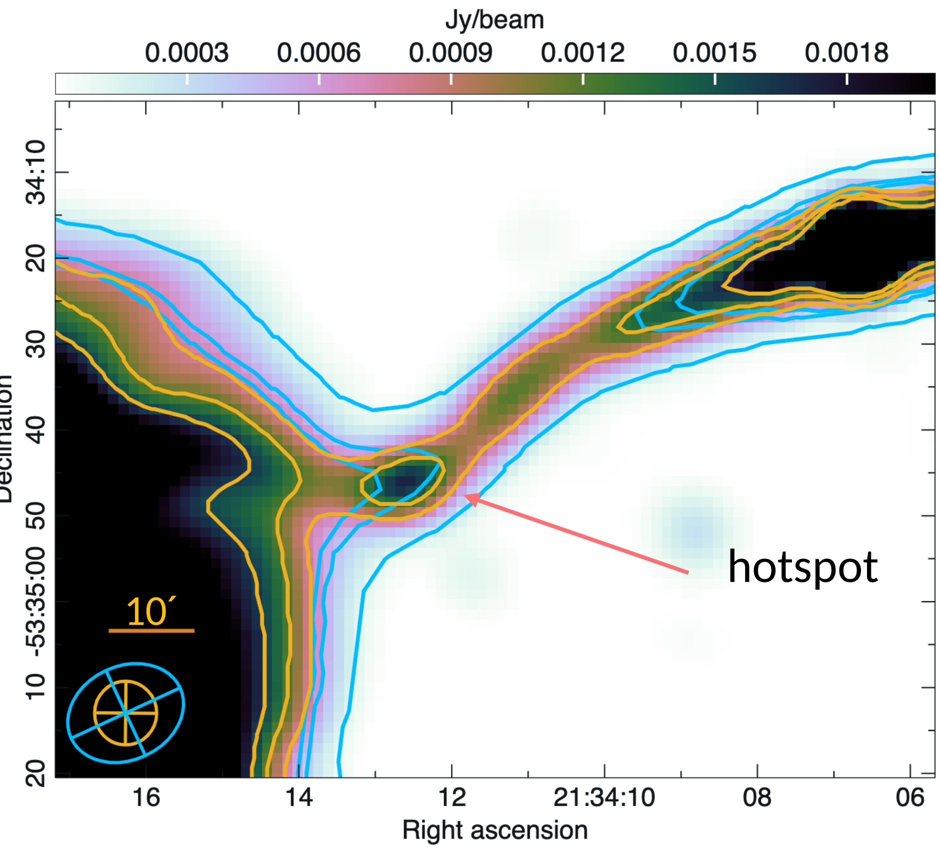
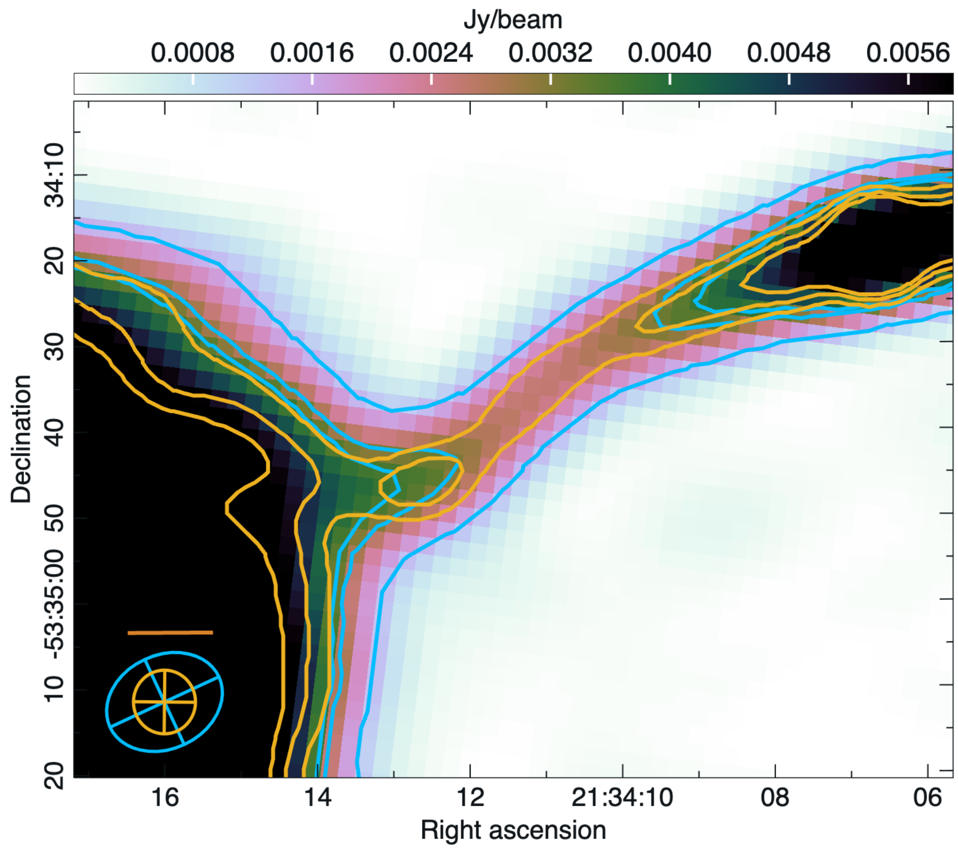
Region A



MeerKAT



ASKAP

Hotspot prior to lobe creation is revealed in MeerKAT

MeerKAT – ASKAP comparison

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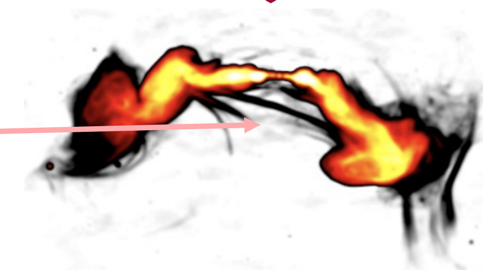
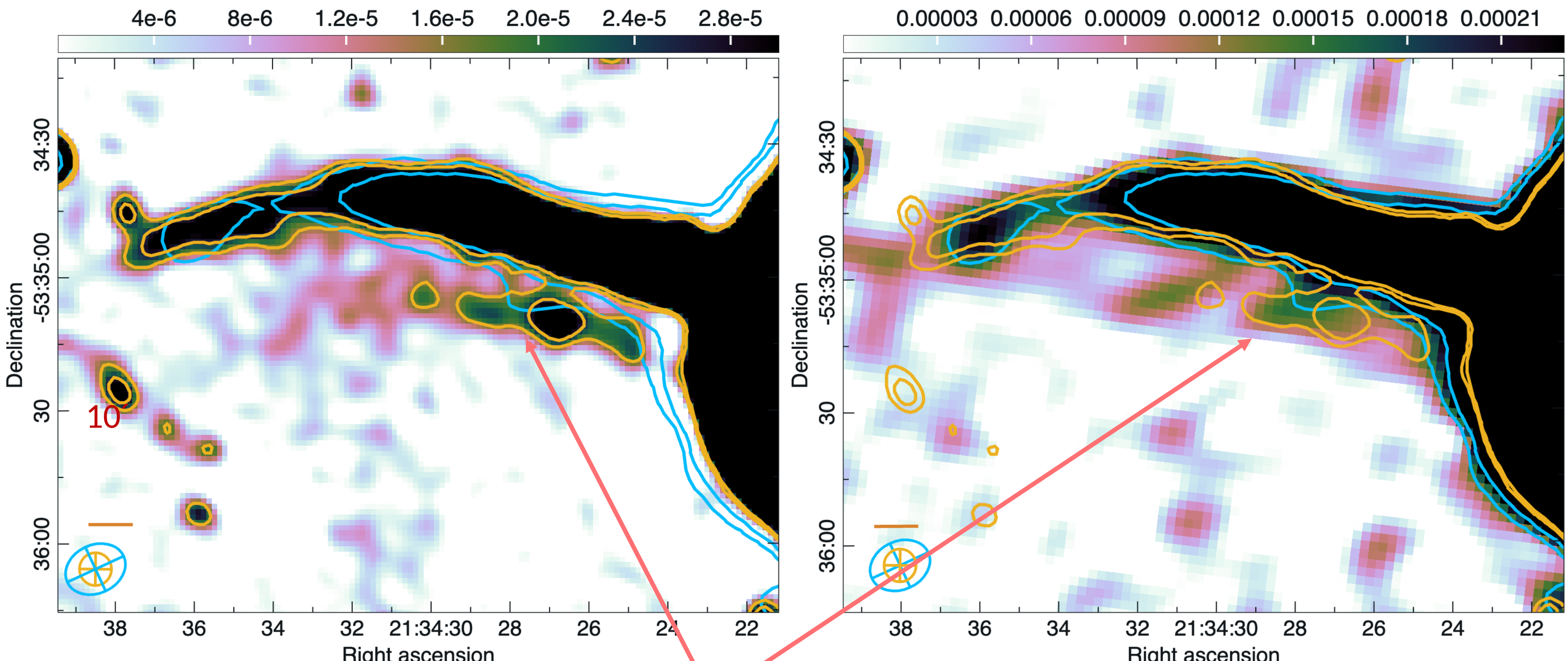
Thin stream of low surface brightness structures – Wisps

Collimated Synchrotron Threads (CST)?

Ramatsoku et al. 2020



Region **B**



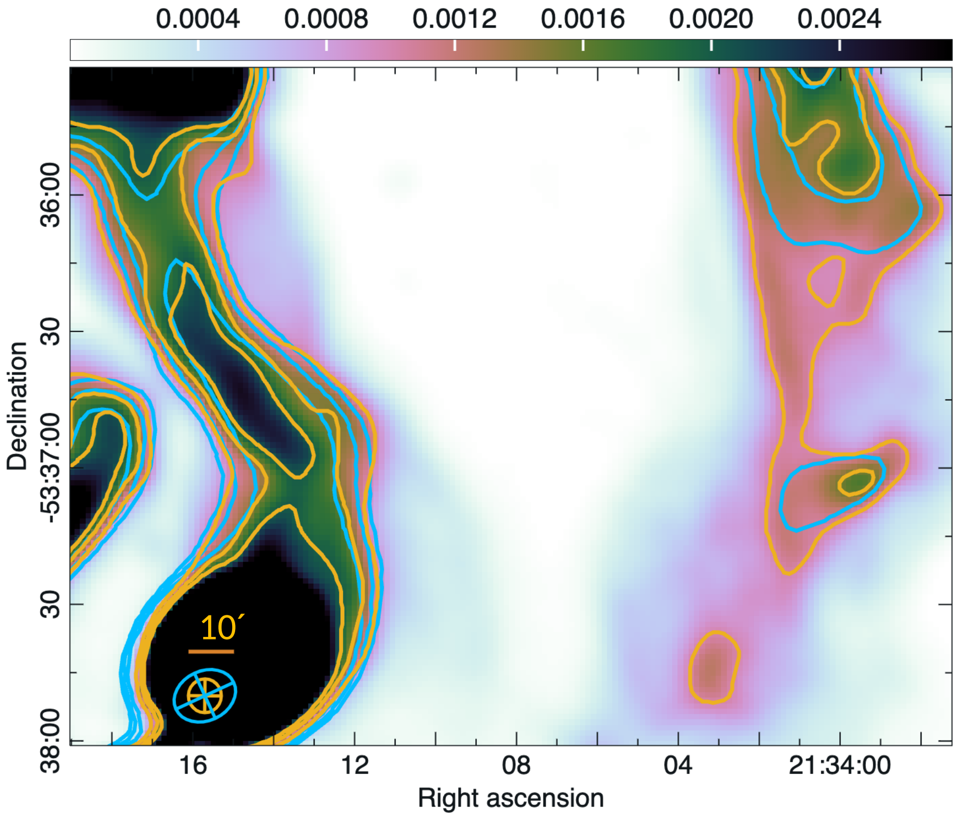
MeerKAT

ASKAP

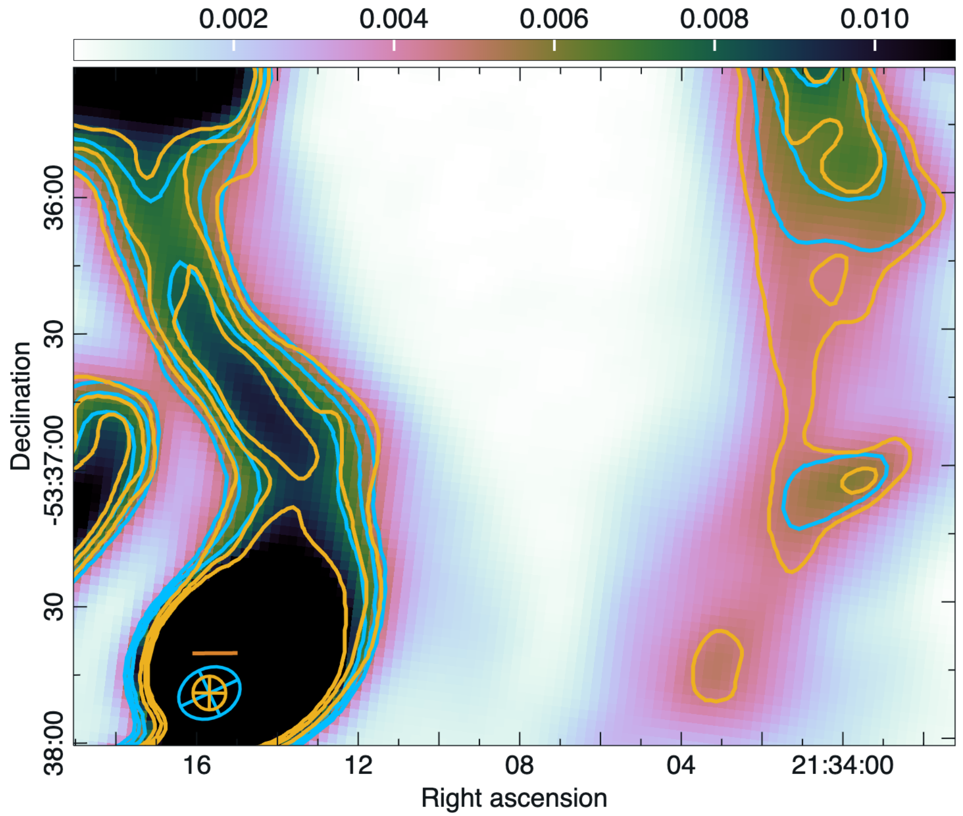
Additional wisp is revealed with MeerKAT observation.

MeerKAT – ASKAP comparison

Region C



MeerKAT



ASKAP

MeerKAT reveals more low surface brightness structure

MeerKAT (1284 MHz)

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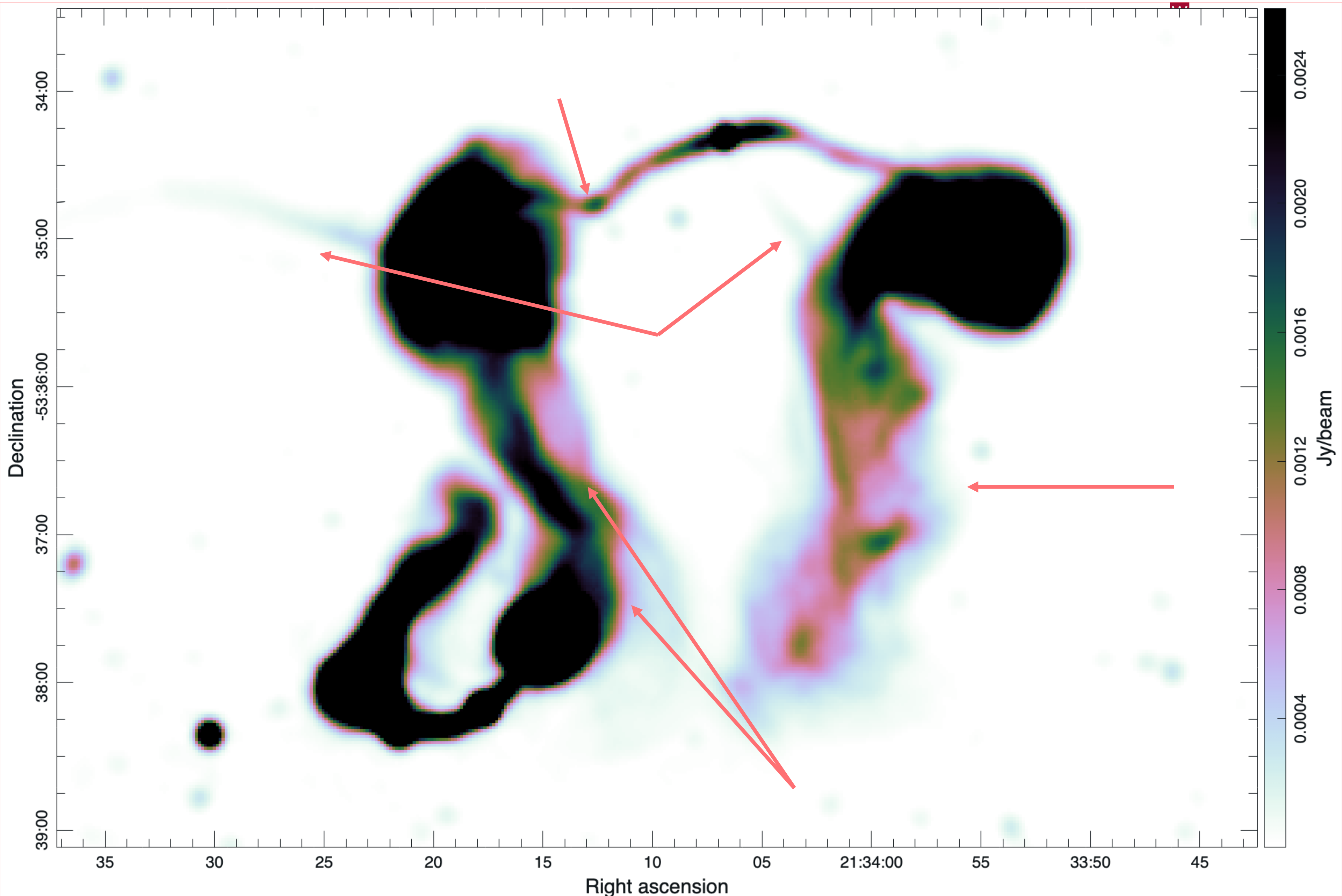

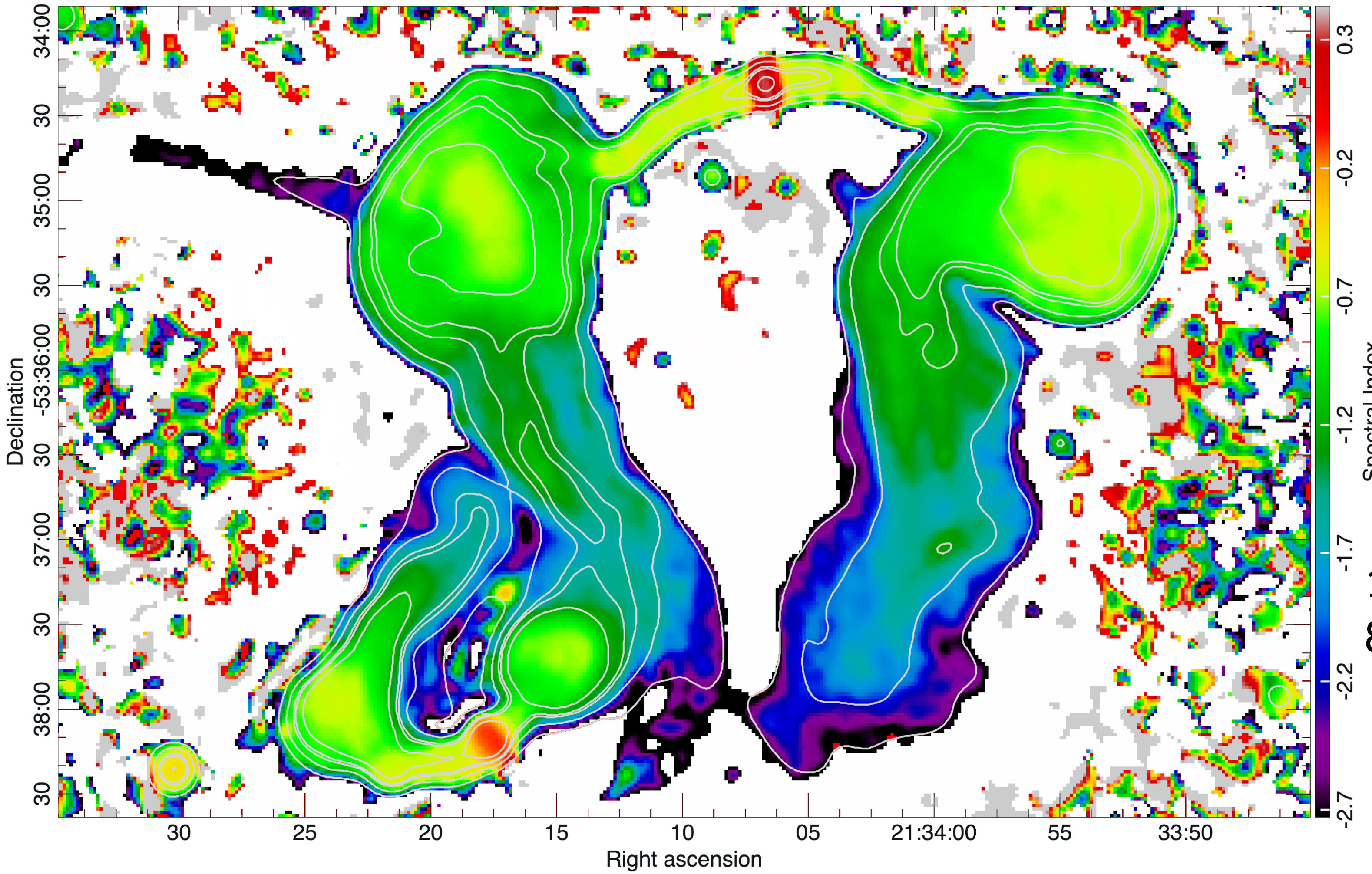

14 channels:
860-1860 MHz

MeerKAT 1284MHz Spectral index

Cores: N(0.25) / S (−0.2)
Jets: − 0.6 to −0.7.
Lobes: −0.7 to −1.1
Wide tails: −1.7 to −2.3
Wisps: <−2.4

ASKAP Spectral index (Norris et al. 2021)

Cores: ~ 0
Jets: −0.4 to −0.5
Lobes: −0.6 to −0.7
Wide tails: −1.5
Wisps: −2.1

MeerKAT - Fractional polarization intensity at 1284 MHz

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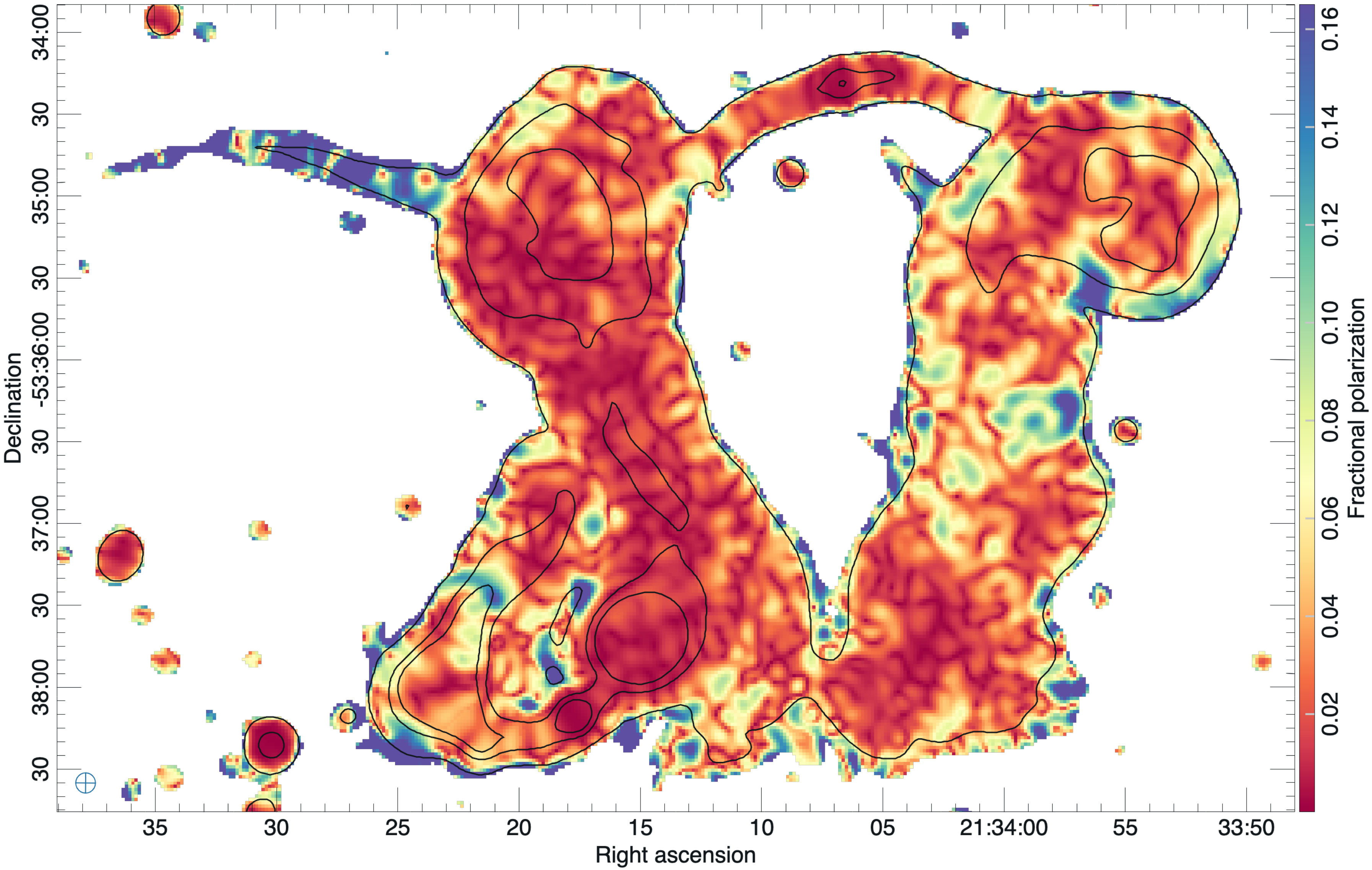
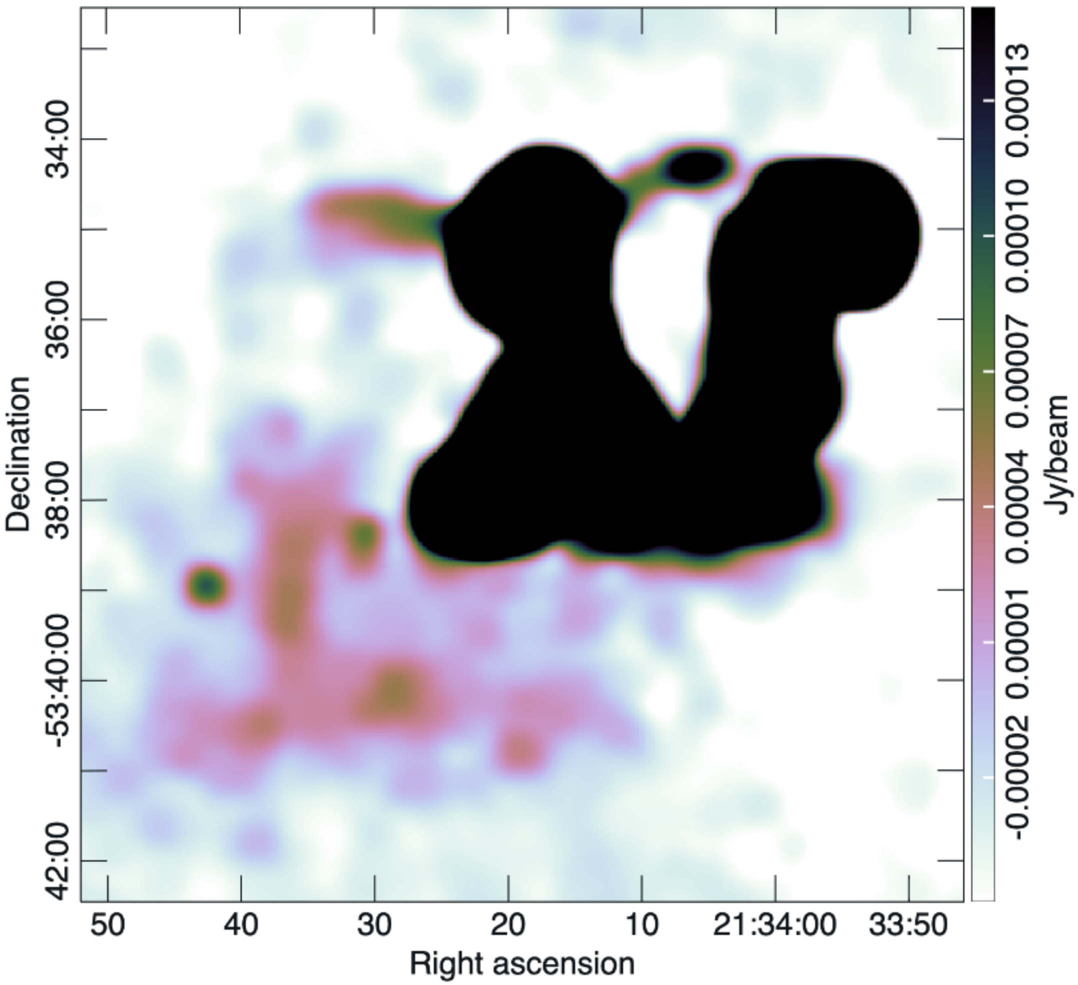
- Faint or no polarization in the hosts.
- Highest polarization in the wisp(s) and lobes



3 key questions to answer:

- Do we see signs of interaction in the Dancing Ghosts?
- What is the nature of the associated diffuse emission?
- What is the nature of wisps?

Diffuse emission



- Radio halo?

In the vicinity of the cluster centre; recent merger?

-Does not have halo-shape.

- Very steep SI ~ -2.4

indicates relic-type origin

- Close to the cluster centre.

- Ancient emission

originating from the hosts

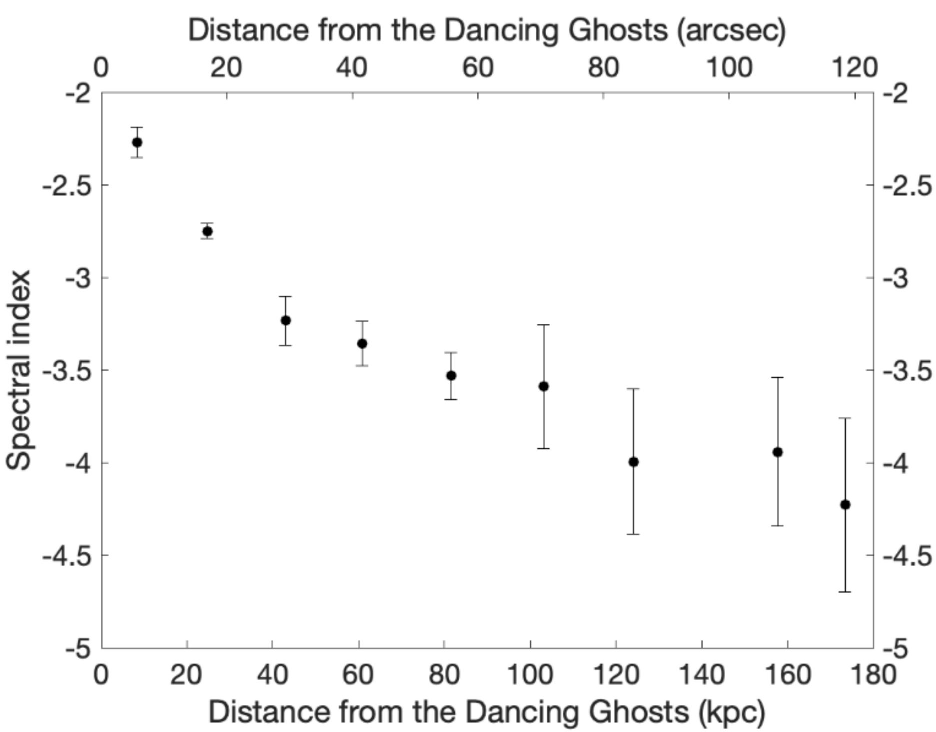
Wisps - Synchrotron Filaments

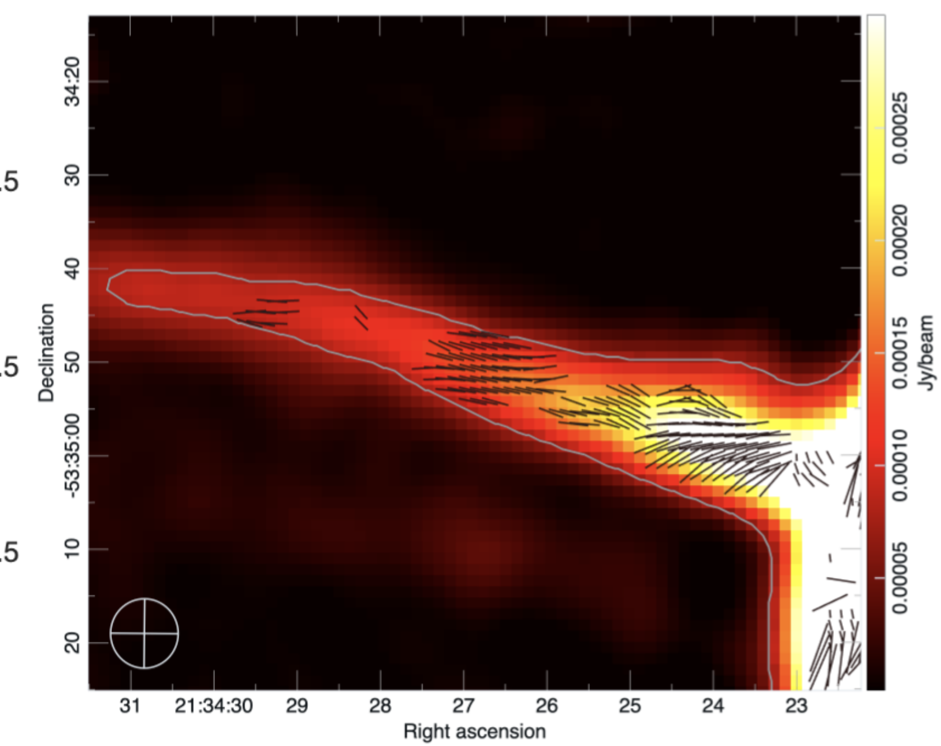
Magnetic filaments, being stretched during interaction with ICM (SI)

Interaction of Jet and a dense cloud (Jet bending)

Cosmic ray re-acceleration (External source of energy or reconnection)

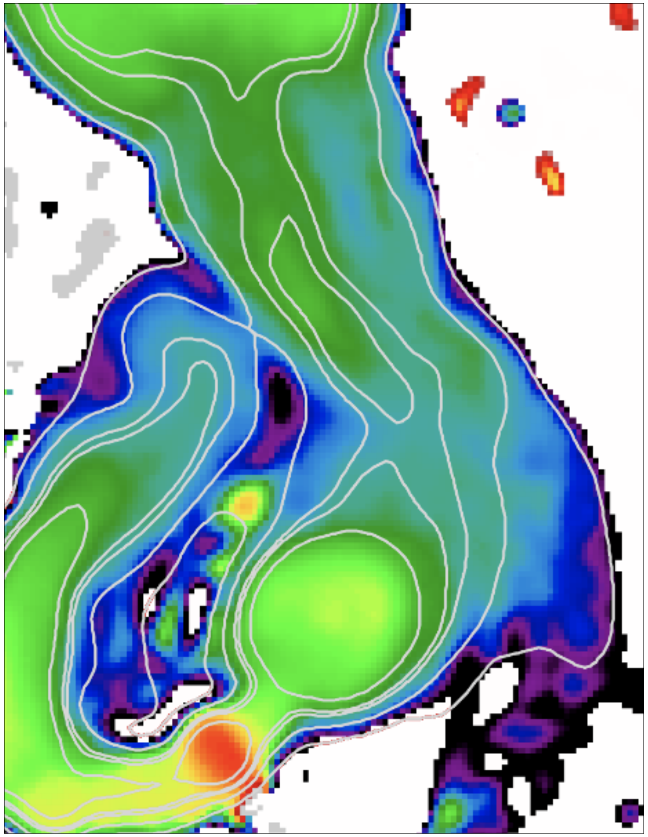
- The magnetic field vectors are oriented along the structure
- The spectral index steepens with the distance from the lobe of the Dancing Ghost.



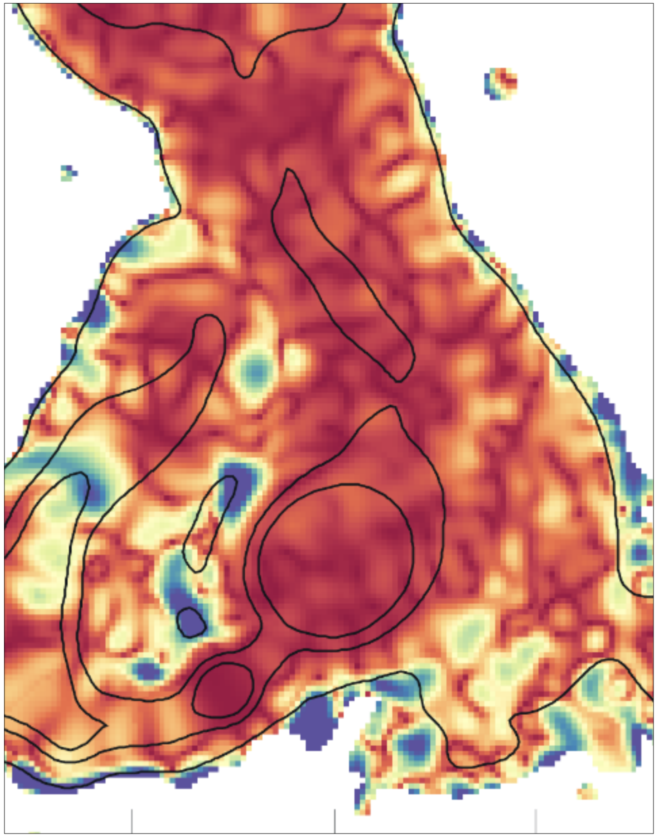


MeerKAT 1248MHz – Region of possible interaction

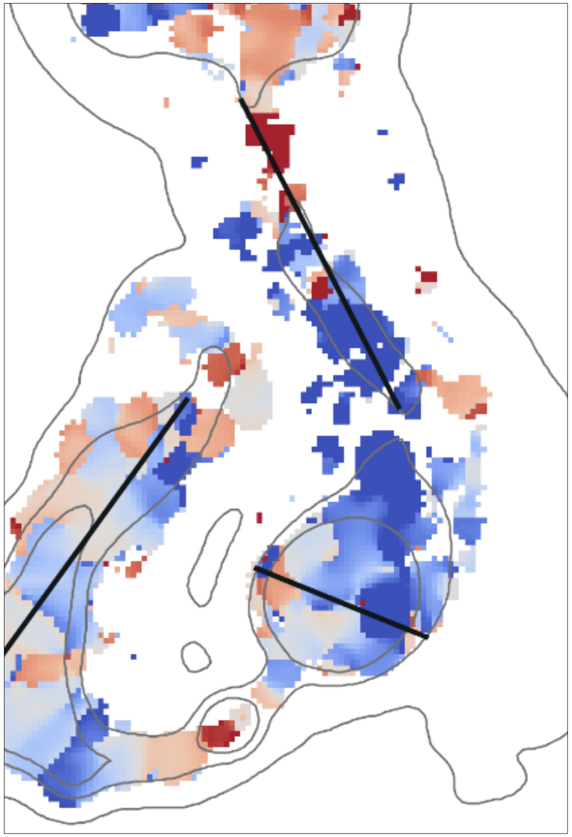
No discontinuity!



Spectral Index



Fractional Polarization



Rotation Measure

Summary

- New features showing in meerkat images (hotspots, wisps, low surface brightness structure)
- Diffuse emission near the dancing ghost may represent radio halo, radio relics or ancient emission originating from the dancing ghosts.
- Spectral Index – inverted core, flat jets and steep lobes, extremely steep wisps and diffuse emission.
- Complex polarization, dominant in lobes.
- 30 detected sources from Abell 3785

Fast as Potoroo: Radio-continuum detection of a bow-shock PWN CXOU J163802.6-471358 and its pulsar

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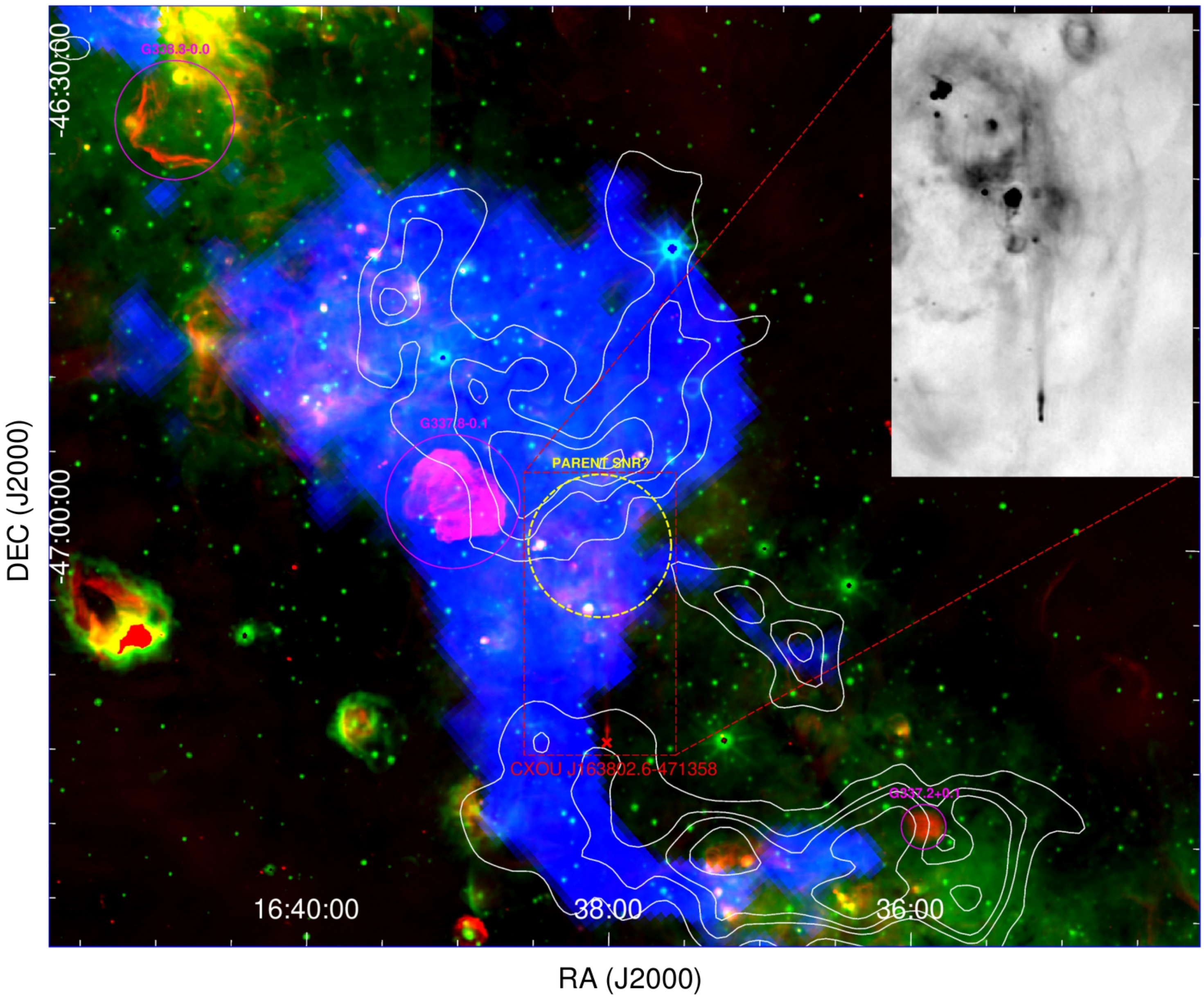
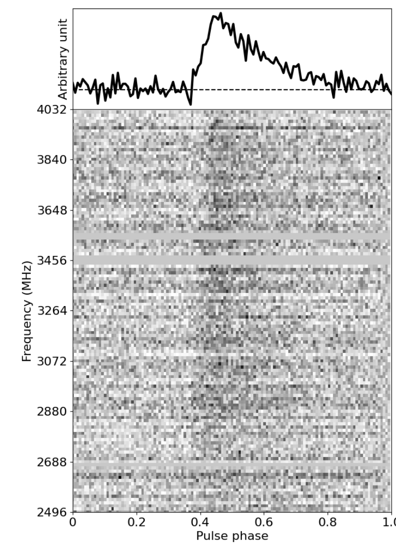
WORK IN PROGRESS






WORK
IN
PROGRESS

WORK IN PROGRESS

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