MWA Observations of Cluster-Scale Non-Thermal Emission: the case of A3667

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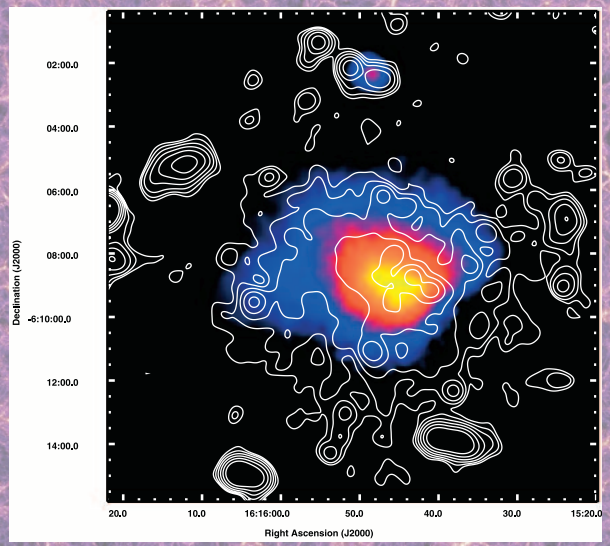
TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI VICTORIA UNIVERSITY OF WELLINGTON

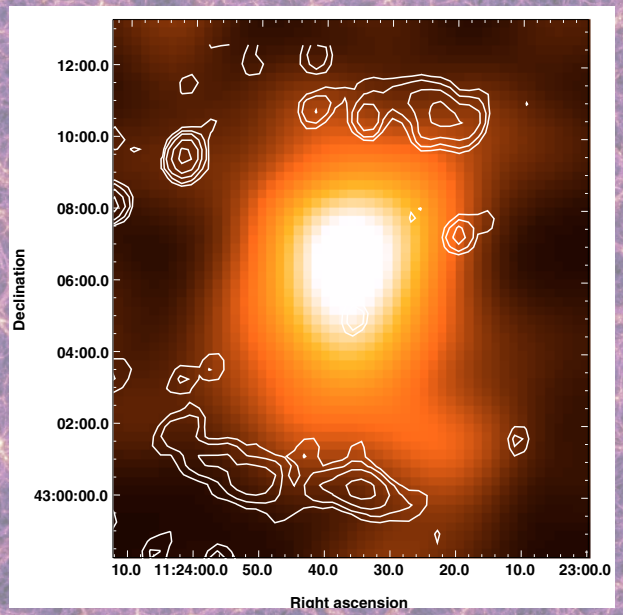
Diffuse Radio Emission in Galaxy Clusters on Mpc Scales

A2163, Govoni et al 2004



Synchrotron emission probes relativistic electrons in magnetic fields in the ICM. Extended over Mpc scales, low surface brightness ~ 1 μJy/arcsec^2 at 1.4 GHz, low number of sources detected

A1240, Bonafede et al 2009



Radio Halos are centrally located, regular structure similar to the X-ray morphology and unpolarised.
Origin:

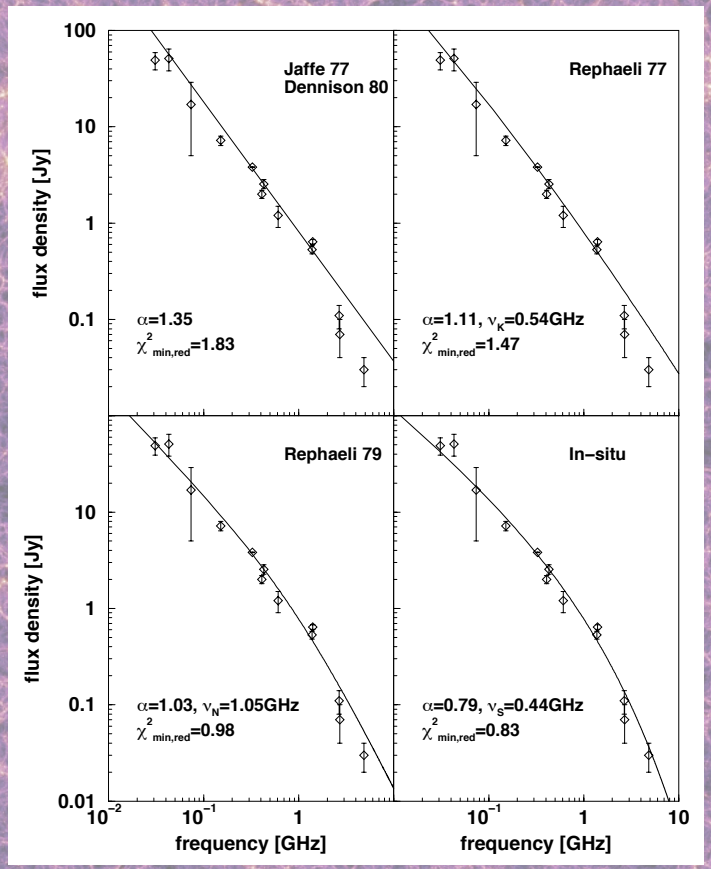
- The reacceleration of relativistic electrons
- Proton-proton collisions

Radio Relics are found on the cluster periphery, have an elongated morphology and are polarized up to 30%
Origin:

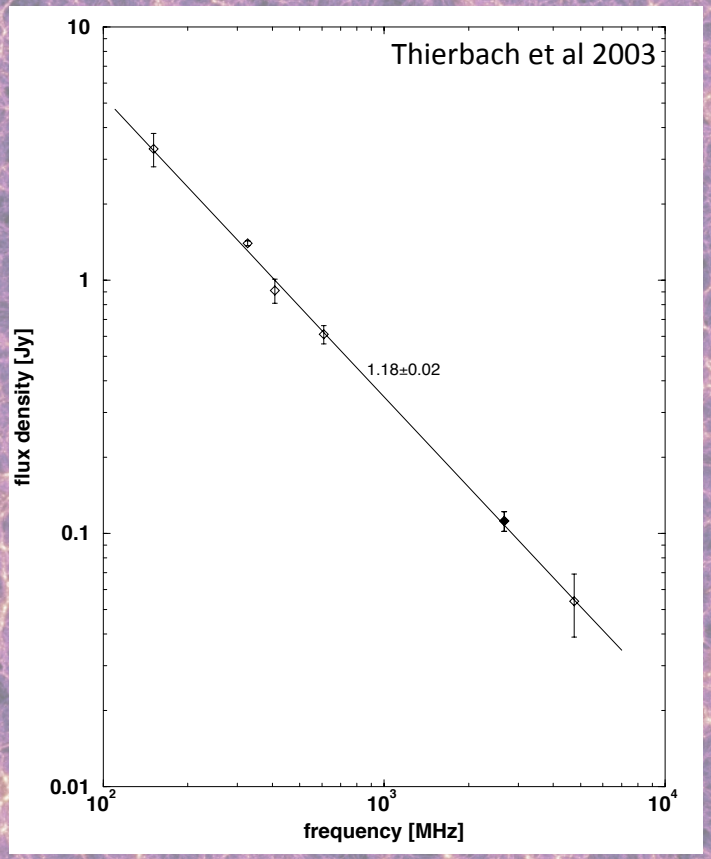
- Particles deposited by active radio galaxies
- Shock waves in cluster mergers

Spectral Index

Radio halos and relics exhibit a steep spectrum (α<-1). Easier to detect at low frequencies.

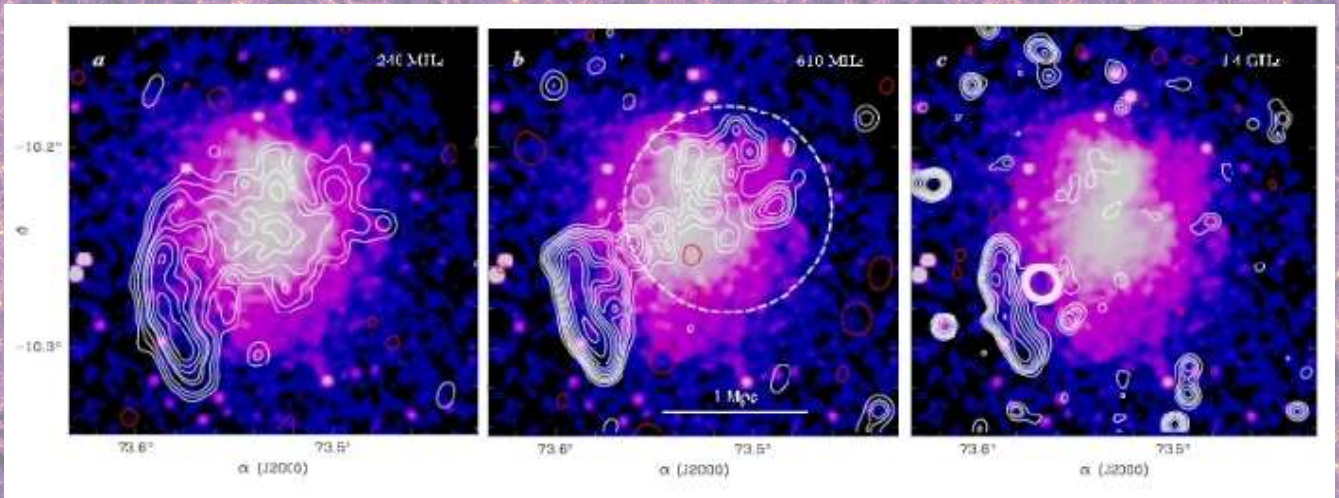


Coma Radio halo: curved

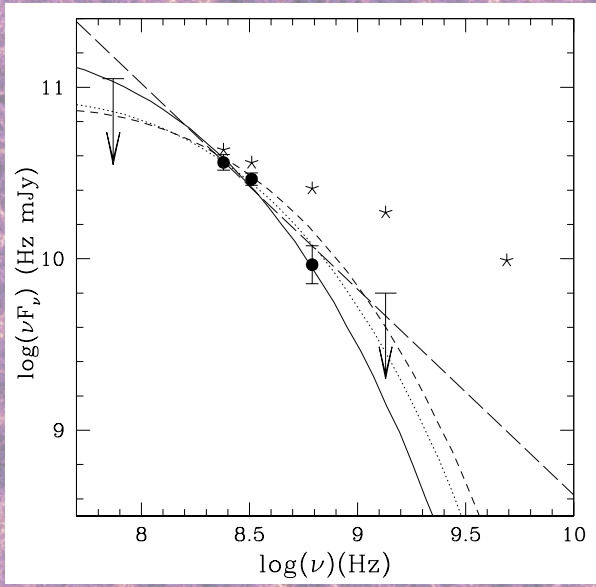


Coma radio relic: power law

Ultra Steep Spectrum Radio Sources



- Steep radio sources such as the halo in Abell 521 (α≈-2.1) can only be detected at low frequency
- Most observations to date carried out at 1.4 GHz are unable to detect such objects
- Evidence for turbulent reacceleration as the generation mechanism of radio halos



Brunetti et al 2008

Questions

- Short radiative lifetimes of electrons requires an acceleration or continuous injection mechanism
- Two proposed models for radio emission in halos
  - **Primary** electron scenario: particle acceleration due to turbulence or shocks
  - **Secondary** electron scenario: electrons injected by proton-proton collisions and emit within regions of enhanced magnetic fields
- Distinct testable predictions
  - Either all galaxy clusters host radio halos (**Secondary**) or only merging clusters (**Primary**)
- What is the connection between cluster mergers and dynamics with radio halos and relics?

Aims

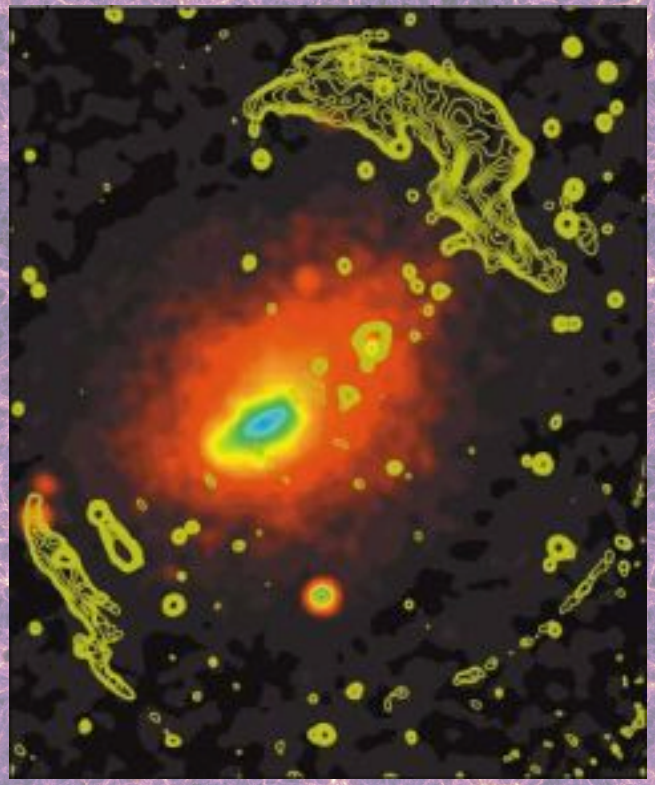
- Explore the capabilities of the MWA to detect radio halos and relics
  - Discover new radio halos and relics through the untargeted southern sky radio survey (GLEAM)
  - From this statistically significant sample answer questions regarding the formation of radio halos and relics and the connection with cluster mergers
  - Understand how radio emission is generated on large scales
    - Magnetic fields
    - Cluster dynamics
    - Primary or secondary model?

Challenges

- Low surface brightness and extended source detection is non trivial
- Point sources coincident with the extended emission must be subtracted to obtain accurate integrated fluxes
- Varying resolution with frequency

The case of A3667

- Chosen as a proof of concept
- Bright double relics
- Large angular extent
  - Z=0.055 (224 Mpc)
  - Spans ~3 Mpc (0.5 - 1.0 degrees)
- One of the most studied objects in the southern sky
- X-ray luminous



1.4 GHz contours over x-ray data Johnston-Hollitt et al.

MWA

- Array of 128 tiles of 4x4 dipoles
- Longest baseline of 3 km
- 1-3' resolution
- Low Frequency 75-300 MHz, 40 kHz channels
- Low RFI site at the MRO
- High surface brightness sensitivity
  ~1 K per 1 MHz band for 1 hour
- Confusion-limited sensitivity ~5-60 mJy
- Wide FOV 25-10 deg FWHM
- High survey efficiency

- MWA science goals
  - Epoch of reionisation
  - Solar heliospheric and ionospheric
  - Galactic and extragalactic
  - Transients

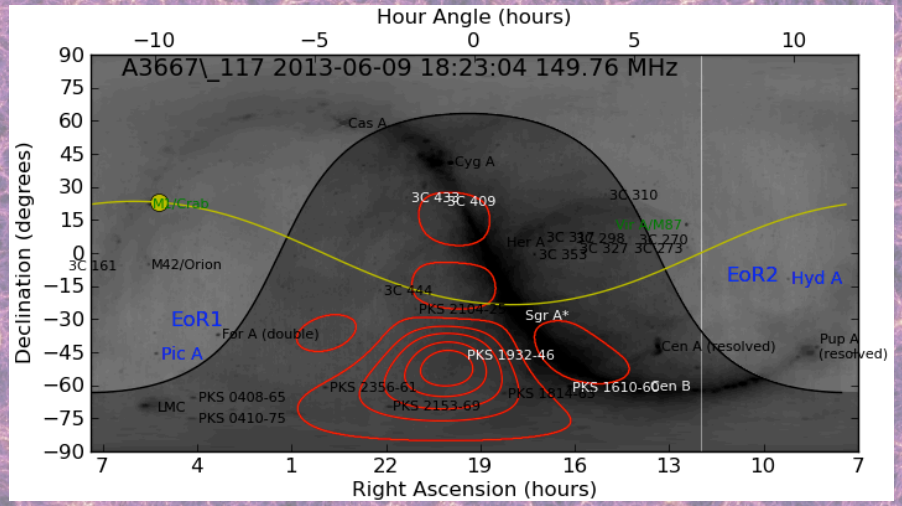
TESTING
BETA
TESTING

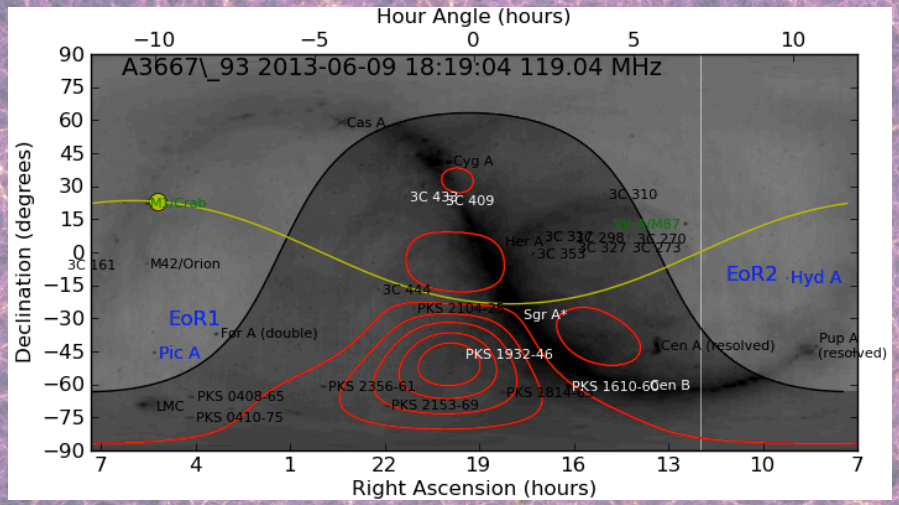
Observations of A3667

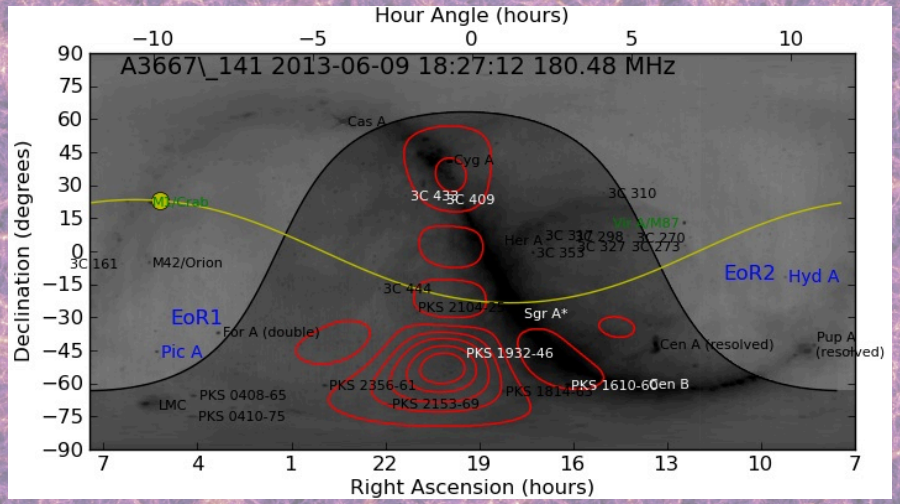
- 114 of the available 128 tiles
- 4 frequency bands:
  - 107.0 - 133.8 MHz (120 MHz)
  - 133.8 - 164.5 MHz (150 MHz)
  - 164.5 - 195.2 MHz (180 MHz)
  - 195.2 - 225.9 MHz (210 MHz)
- Bandwidth 30.7MHz = 768 x 40 KHz channels
- Resolution = 5.4’ x 3.7’
- Integration time = 3 x 120s, 10 mins per band
- Sensitivity = 40 mJy/beam at 120 MHz
  - No peeling and no self calibration
    - Cyg A is 97.6 degrees away and still ~ 19 Jy/beam

Wide FOV

- Primary beam has a FOV of more than 375-610 degrees^2
- Great for surveying the whole sky
- Not so great when side lobes are coincident with bright sources such as Cyg A
- Peeling is required but non trivial
- w-terms must be accounted for

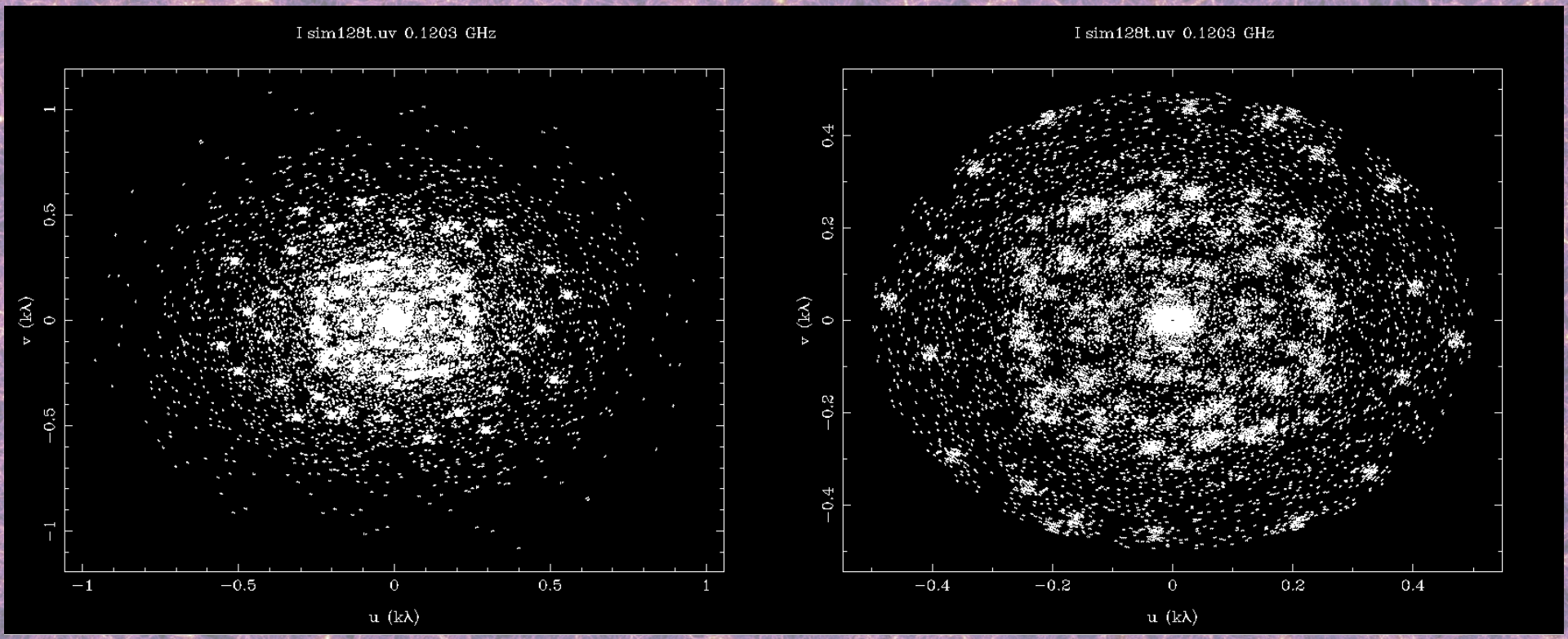






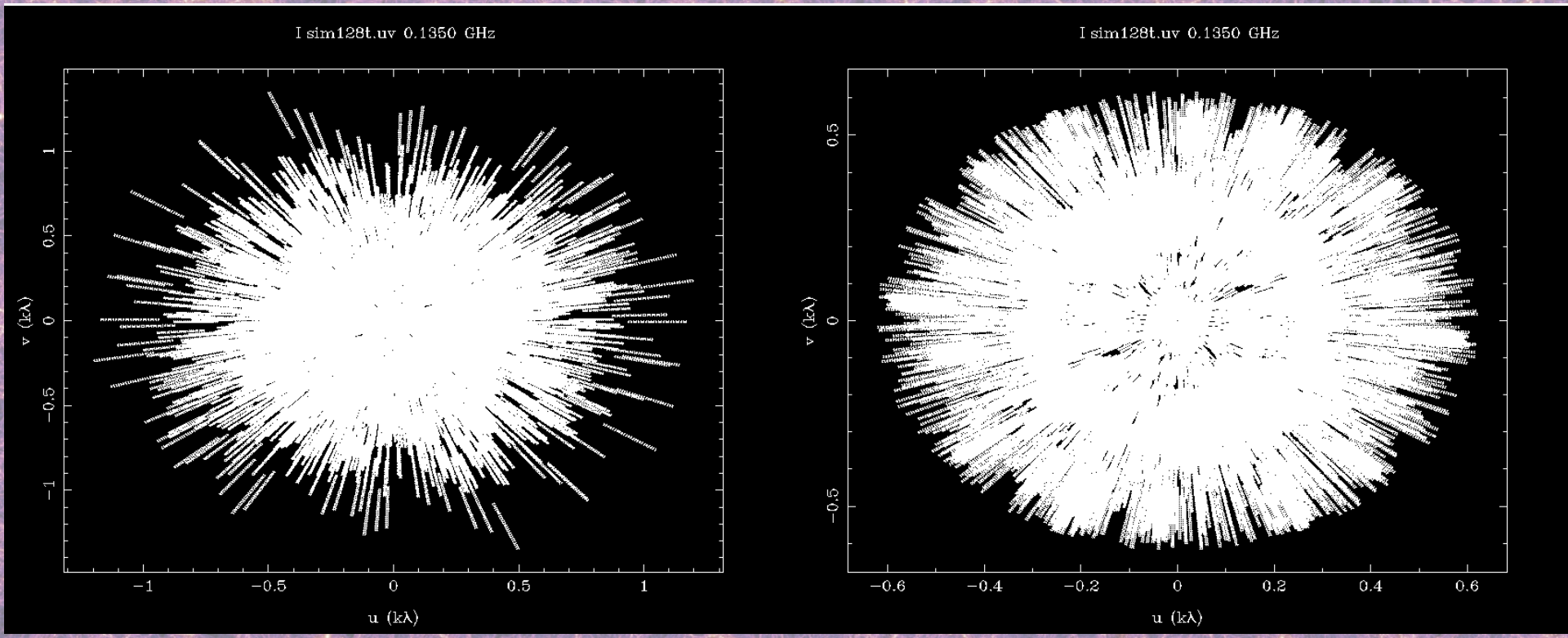
Simulated u-v coverage

Monochromatic snap shot u-v coverage



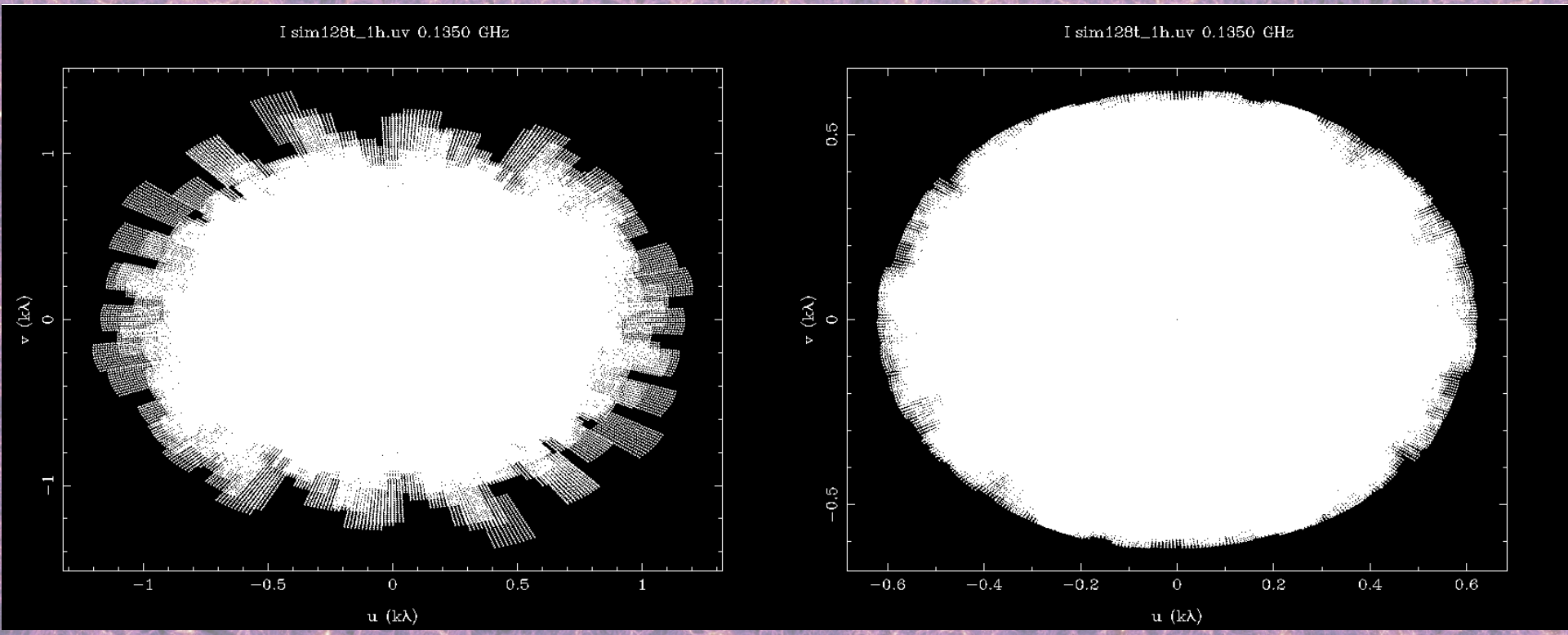
Simulated u-v coverage

Full bandwidth snap shot u-v coverage

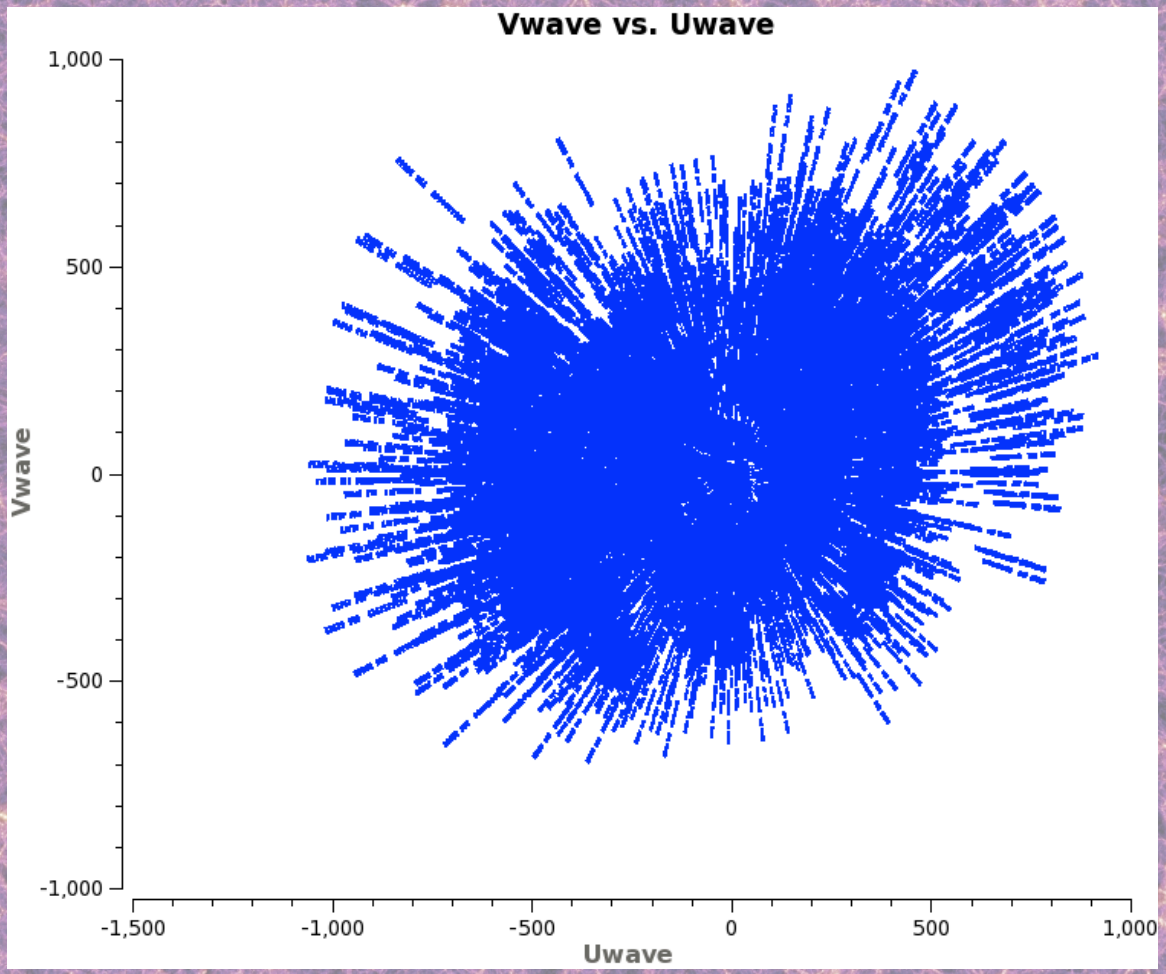


Simulated u-v coverage

Full bandwidth 1-hour u-v coverage

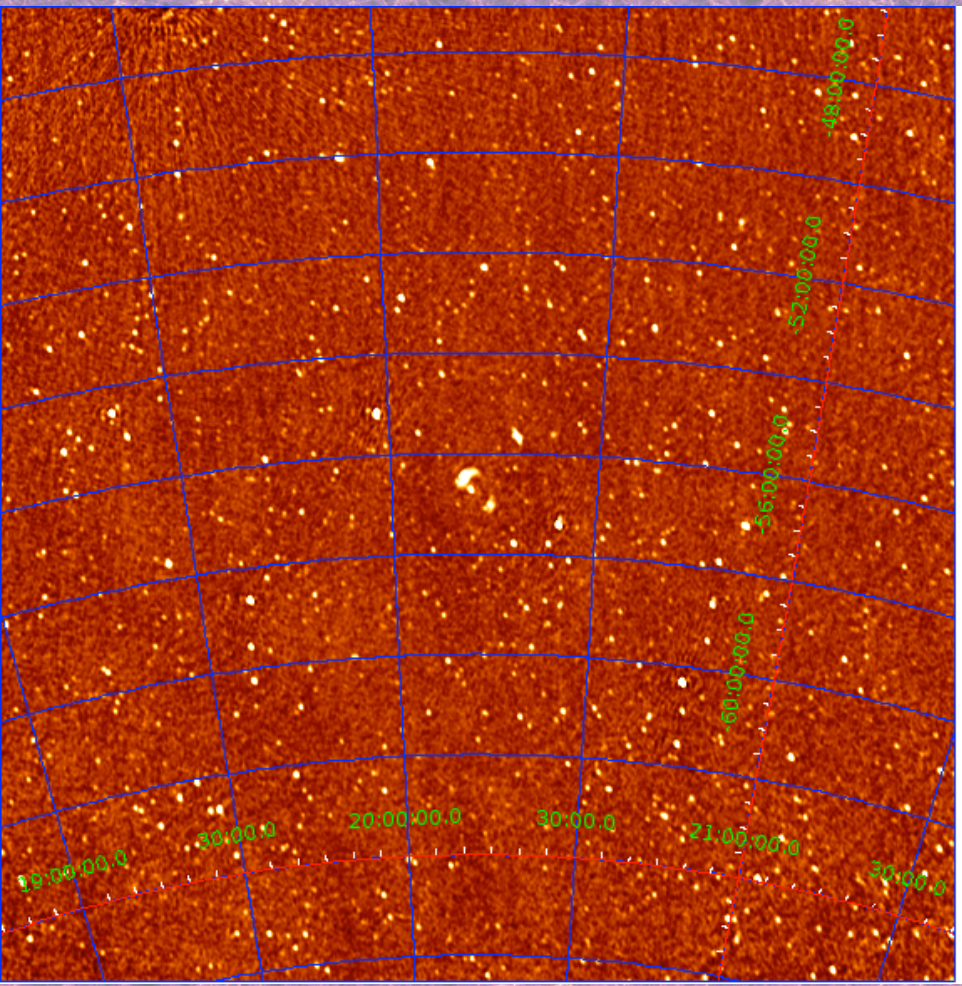


A3667 10 min u-v Coverage

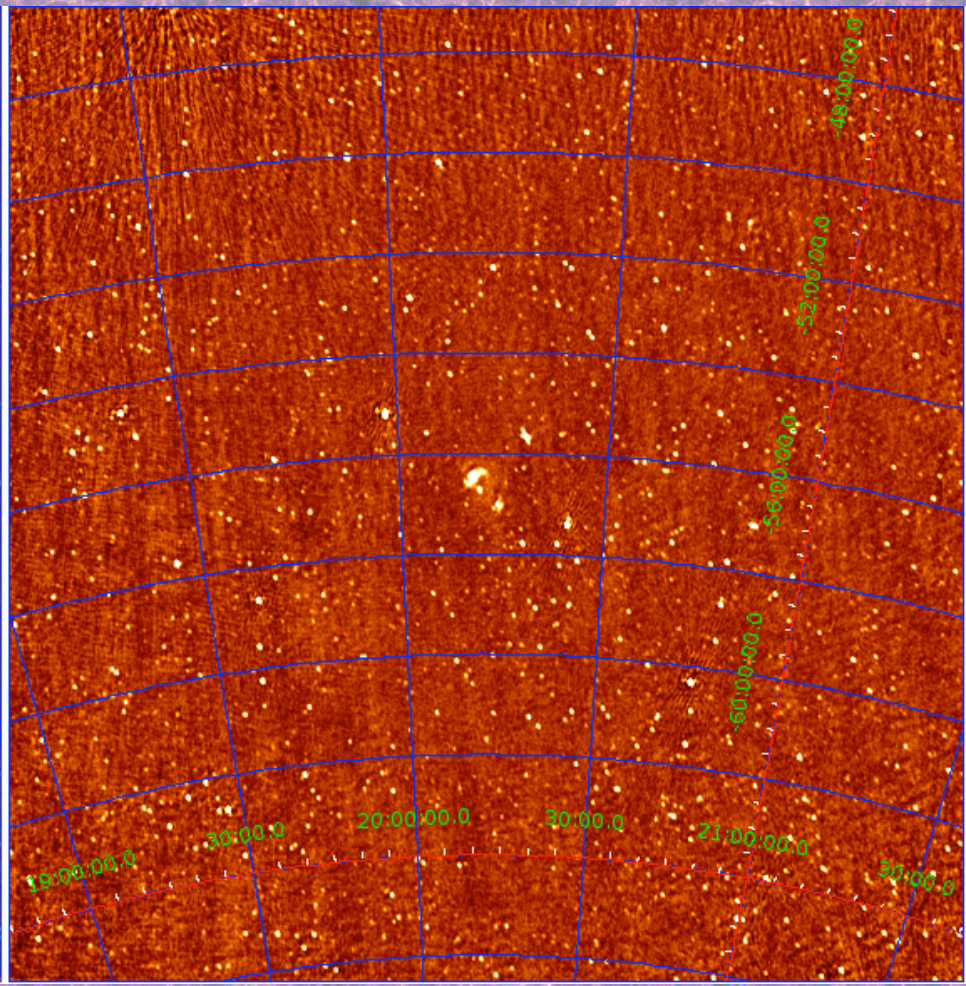


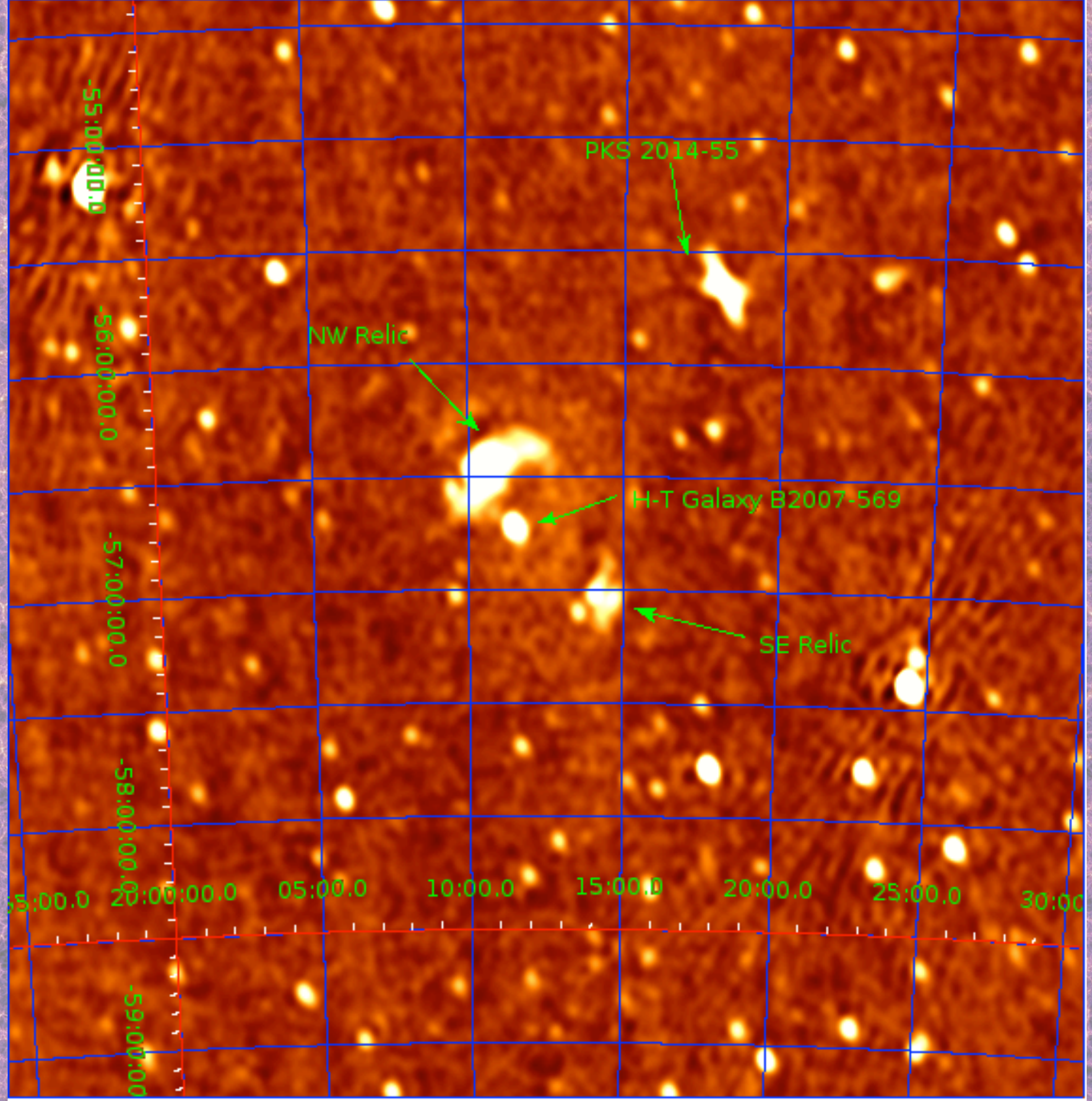
A3667 Results

120 MHz



150 MHz



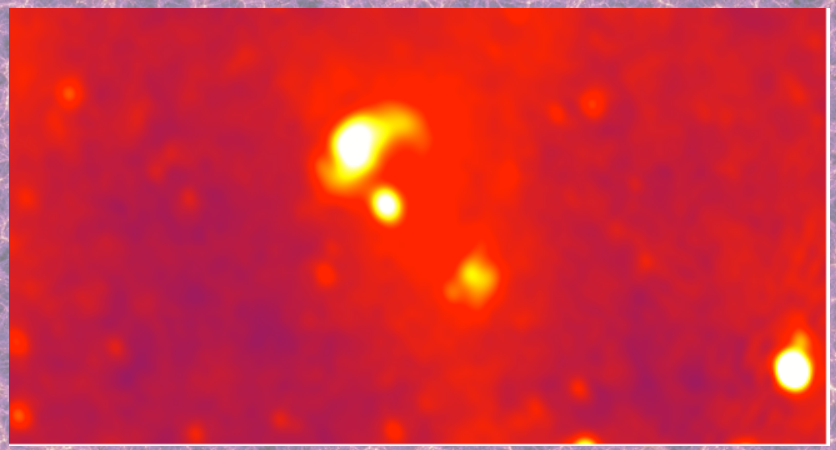

PKS 2014-55
NW Relic
H-T Galaxy B2007-569
SE Relic
-55:00:00.0
-56:00:00.0
-57:00:00.0
-58:00:00.0
-59:00:00
20:00:00.0
05:00.0
10:00.0
15:00.0
20:00.0
25:00.0
30:00

Weighting Schemes

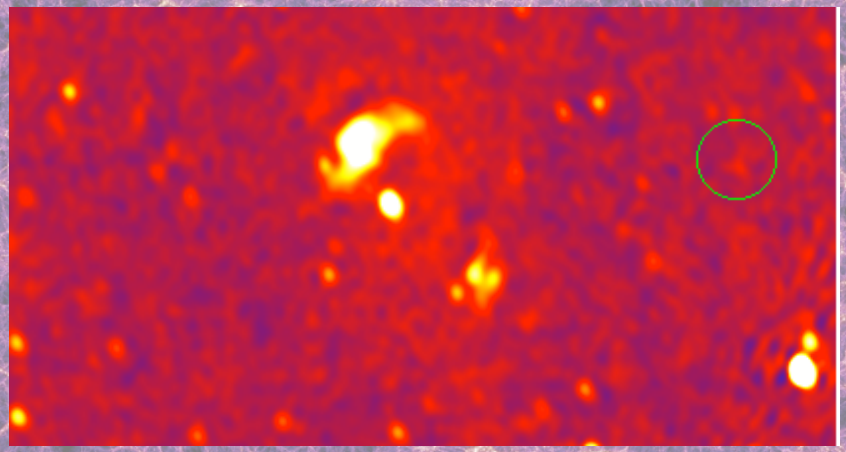
It is important to consider the choice of weighting scheme

- Natural - dominated by very extended emission
- Uniform - removes too many short baselines
- Robust - seems just right

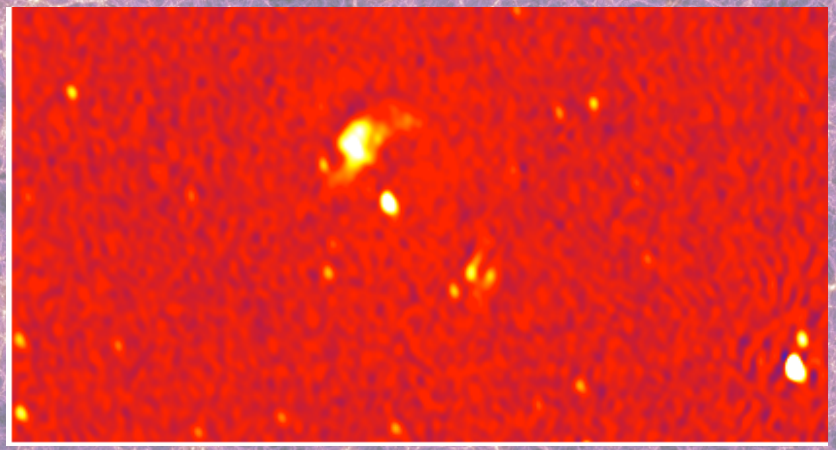
Natural



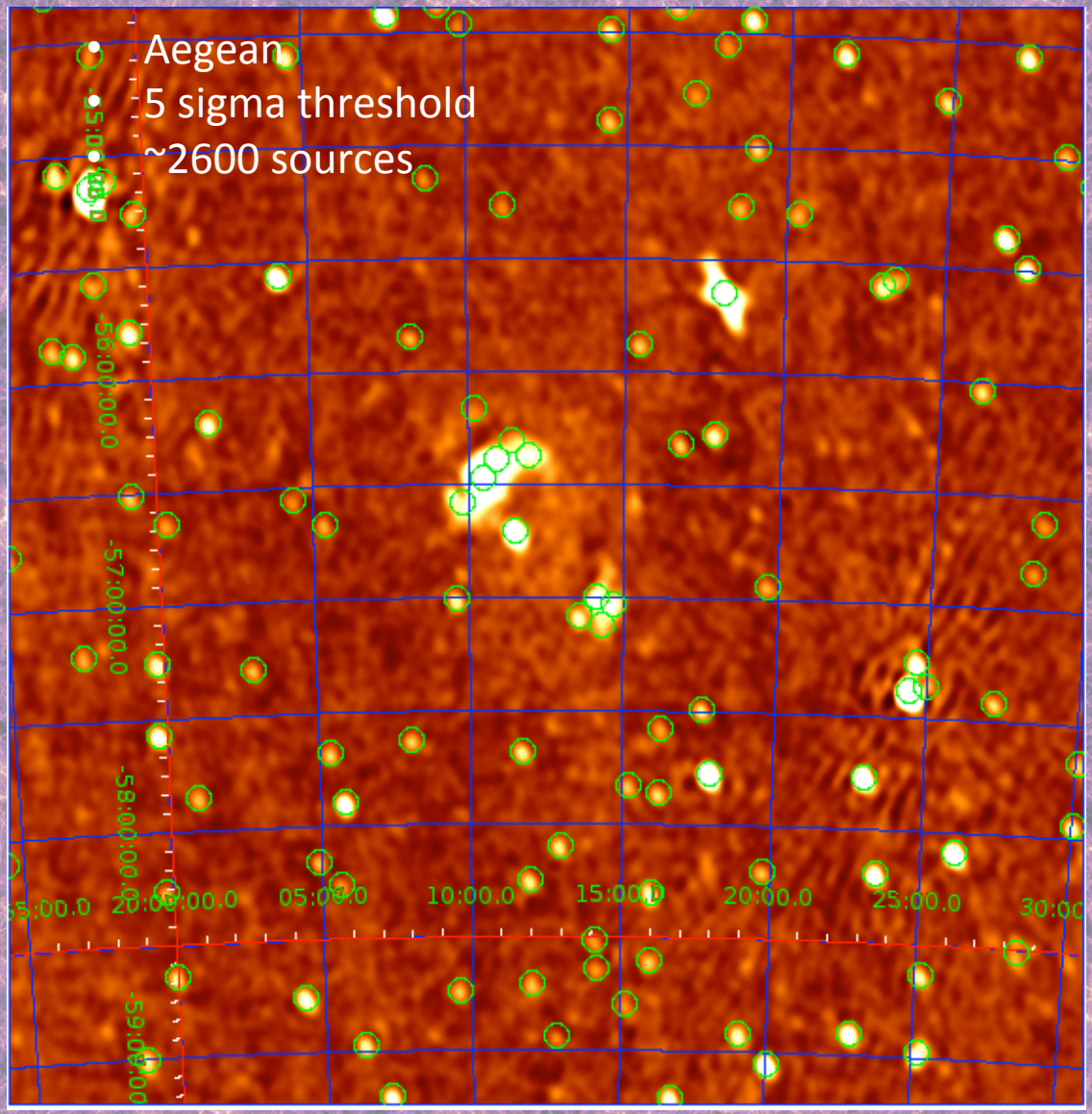
Robust (0)



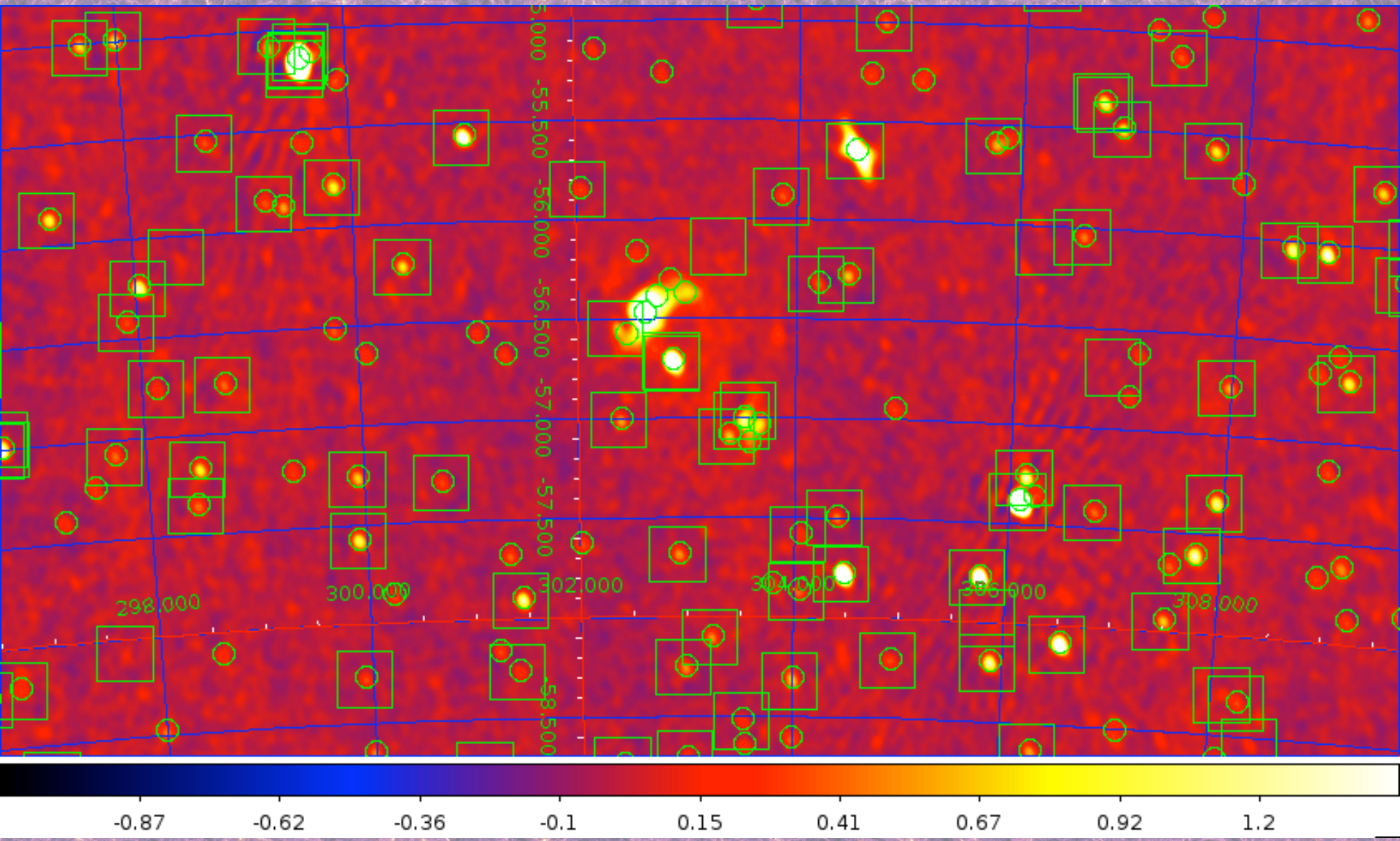
Uniform



Source Finding

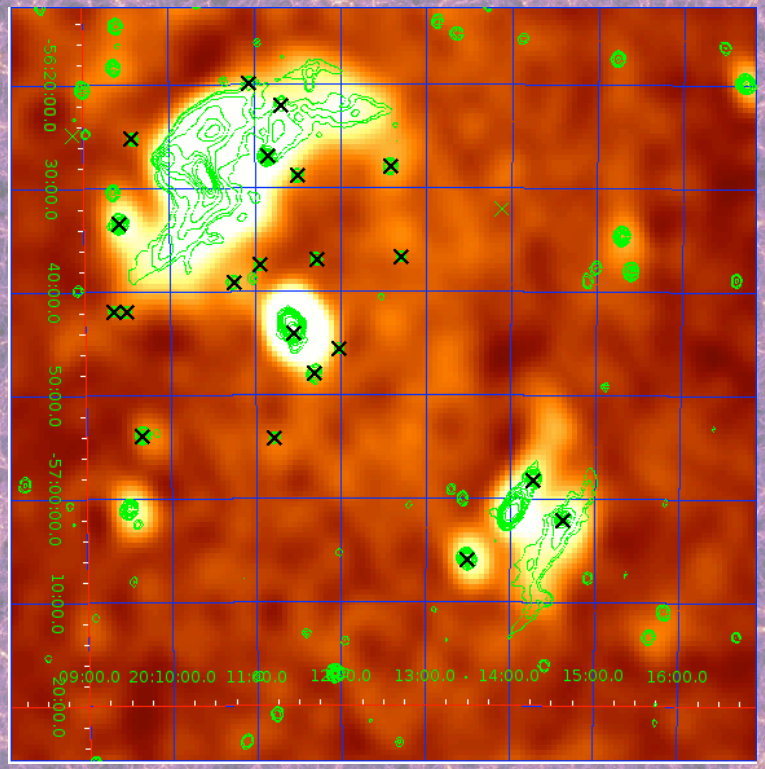


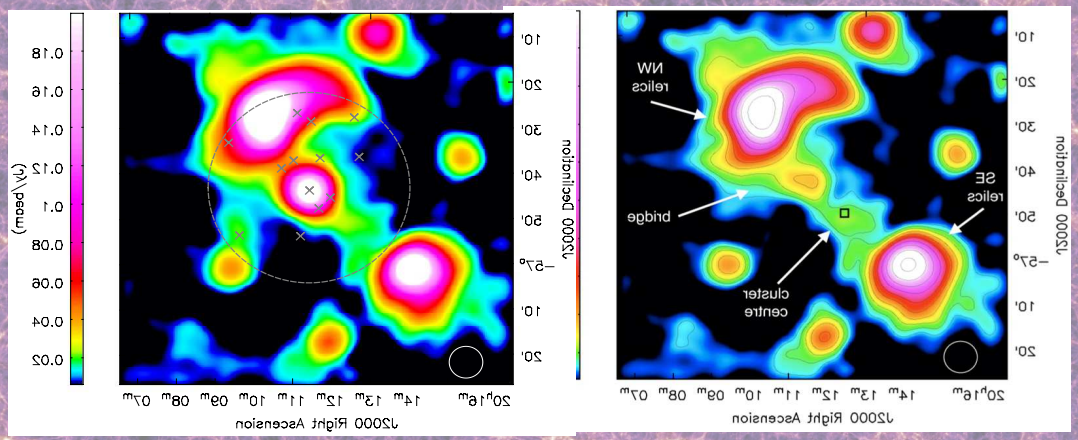
SUMSS Point Sources



A3667 Results - Point Source Subtraction

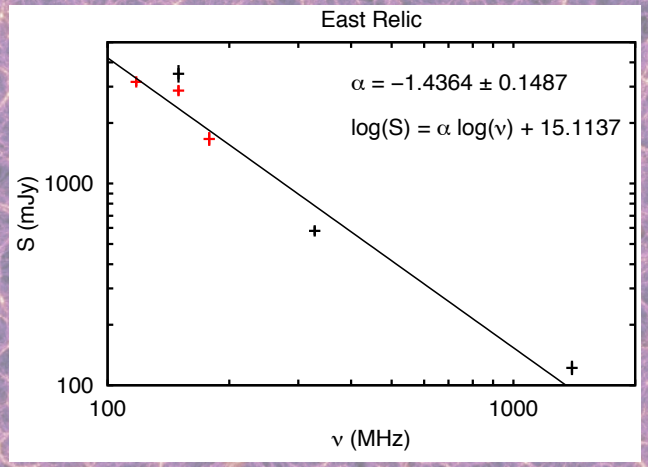
- Observations at higher frequency and resolution reveal numerous point sources projected against the relics of A3667
- Robust point source subtraction is required ideally at the same frequencies
  - The GMRT (TGSS) above -30 degrees
  - Alternatives must be used below
- Interesting to note that subtraction of the H-T galaxy B2007-569 reveals a radio halo and bridge in the center of the cluster (Carretti et al. 2013)

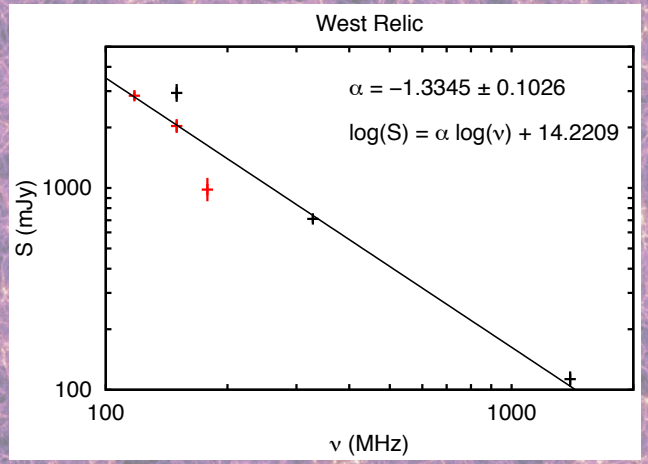


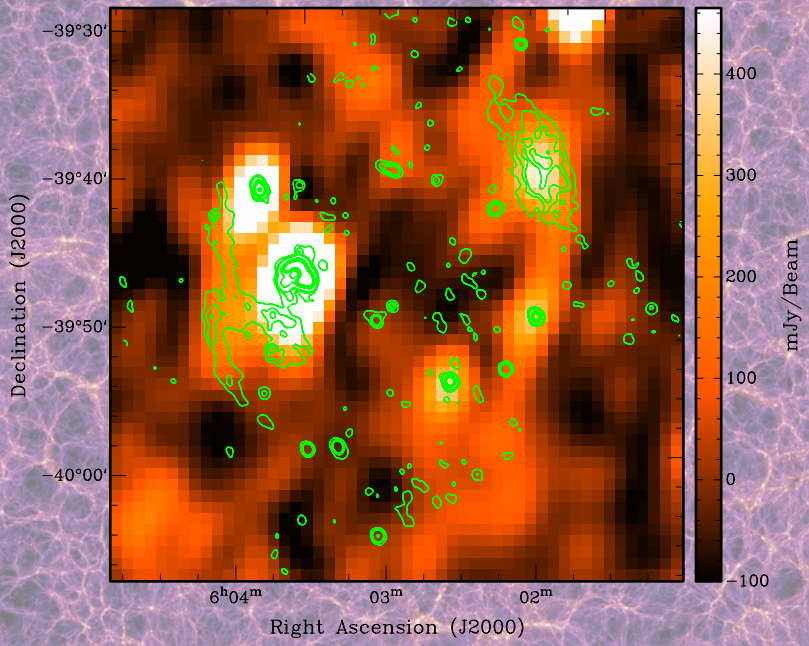


MWA and the GMRT

- Collaborators (Dwarakaneth et al) are already using the GMRT to study MWA data
- A3776 (George et al. in prep) comparison between MWA and GMRT at 150 and 325 MHz
  - Resolution = 39''
- The TIFR GMRT Sky Survey (TGSS) can be used for sources north of -30 degrees

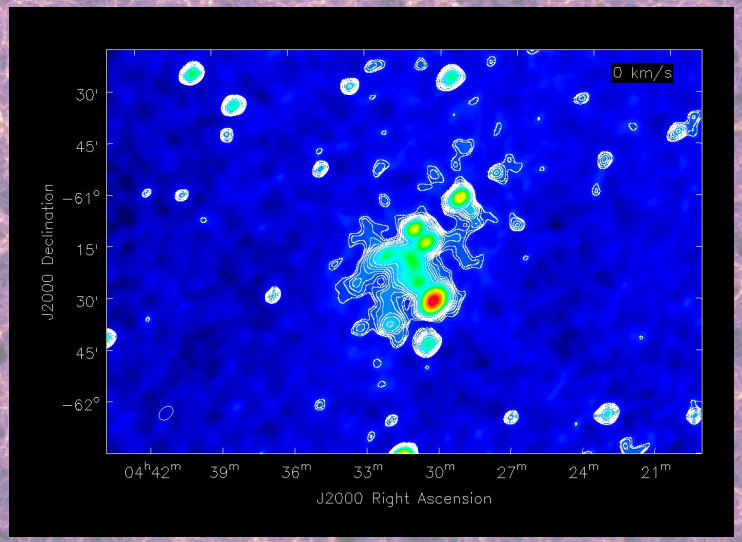


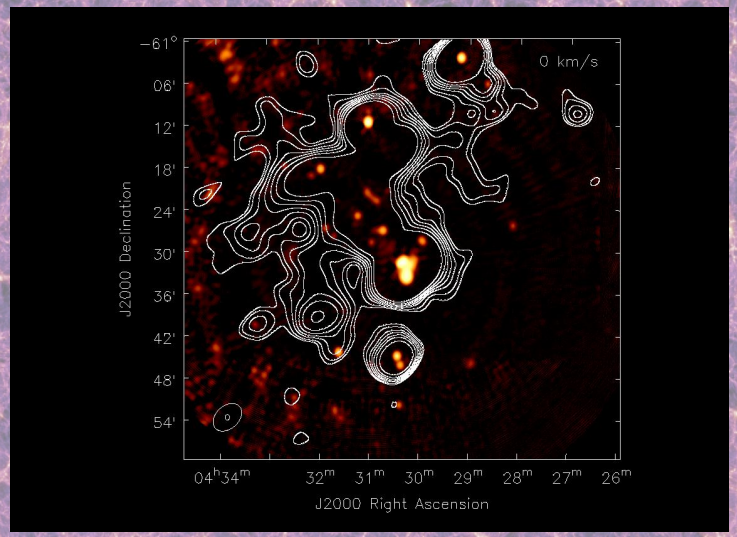




New Extended Radio Sources

- Diffuse radio emission detected in A3266
- MWA 120-185 MHz band
  - 185 MHz contours
- 1.4 GHz background smoothed to 50” resolution
- The MWA reveals that the entire clusters is permeated by diffuse, low surface brightness emission
- significant radio emission missed by the 1.4 GHz observations

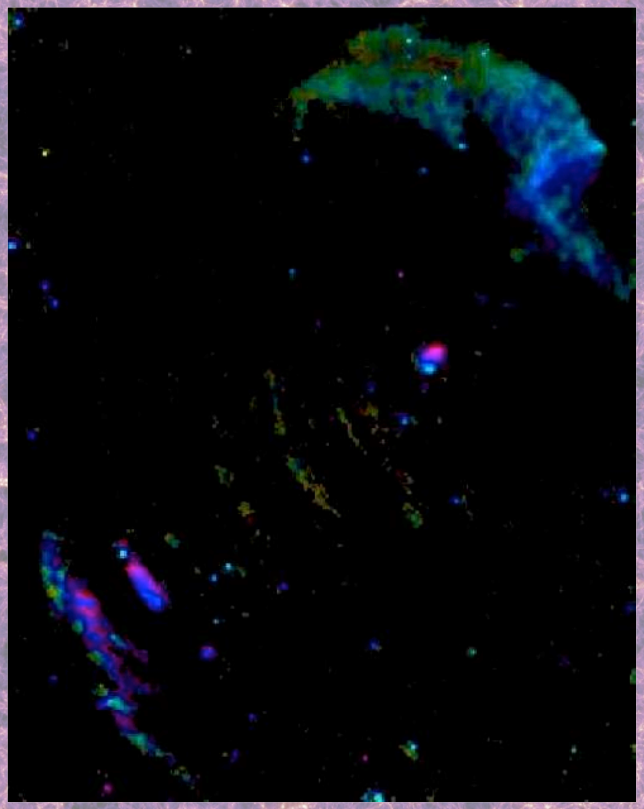




Johnston-Hollitt at al. (in prep)

Work in Progress

- Understanding the MWA data
  - Primary beam model & correction
  - Peeling bright sources
  - Flux calibration
  - Point source subtraction
  - Self-calibration
- Analysing A3667
  - Integrated fluxes
  - Spectral indices



Johnston-Hollitt PhD thesis

Conclusions

- The MWA works
- Still some work to do
  - Peeling sources
  - Removing point sources
  - Improving calibration
  - Flux calibration
- Lead to integrated fluxes and spectral indices
- Provide a test bed for advanced source detection algorithms to identify new extended low frequency objects