A STUDY OF THE LOBES OF RADIO GALAXY HYDRA A USING MEERKAT OBSERVATIONS

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Image: Radio image of Hydra A
Credit: NASA/CXC/SAO

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ABOUT HYDRA A

Image: Optical image of Hydra A
Credit: Canada-France-Hawaii-Telescope/DSS

- Hydra A the brightest radio galaxy in Abell 780 located at its center
- High-luminosity FRI radio galaxy
- Has been observed in optical, radio, X-ray and gamma-rays

WHY STUDY HYDRA A?

- Strong radio emission originating from Hydra A
- Study radio lobes and probe high energy particles
- Search for scattered radiation

STRUCTURE OF RADIO SOURCES

STRUCTURE AND FORMATION OF HYDRA A

- Central supermassive black hole (experienced 3 generations of outbursts)
- Jets
- 2 inner radio lobes (generated by the more recent AGN activity)
- 2 giant outer radio lobes (generated by earlier AGN activity)
- X-ray cavities surrounding radio lobes

Credit: NSF/NRAO/VLA

RADIO IMAGE OF HYDRA A

Credit: NASA/CXC/U.Waterloo/C.Kirkpatrick et al.

X-RAY IMAGE OF HYDRA A

COMPOSITE RADIO AND X-RAY IMAGE OF HYDRA A

THE DATA

- Observations made using the MeerKAT telescope
- MeerKAT is an array consisting of 64 antennas 13.5 m in diameter each. It has a max baseline of 8 km
- Four observation epochs of 30 minutes each were accumulated with the full array
    - Frequency range: 856 MHz- 1712 MHz
- The CARACal (Jozsa et al. 2020) pipeline was used for the data reduction
- We derive fluxes from the radio maps obtained with CARACal.

Image: A single receptor that forms part of the MeerKAT telescope
Credit: South African Radio Astronomy Observatory (SARAO)

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SPATIAL ANALYSIS

*Bandwidth of all images is 80 MHz

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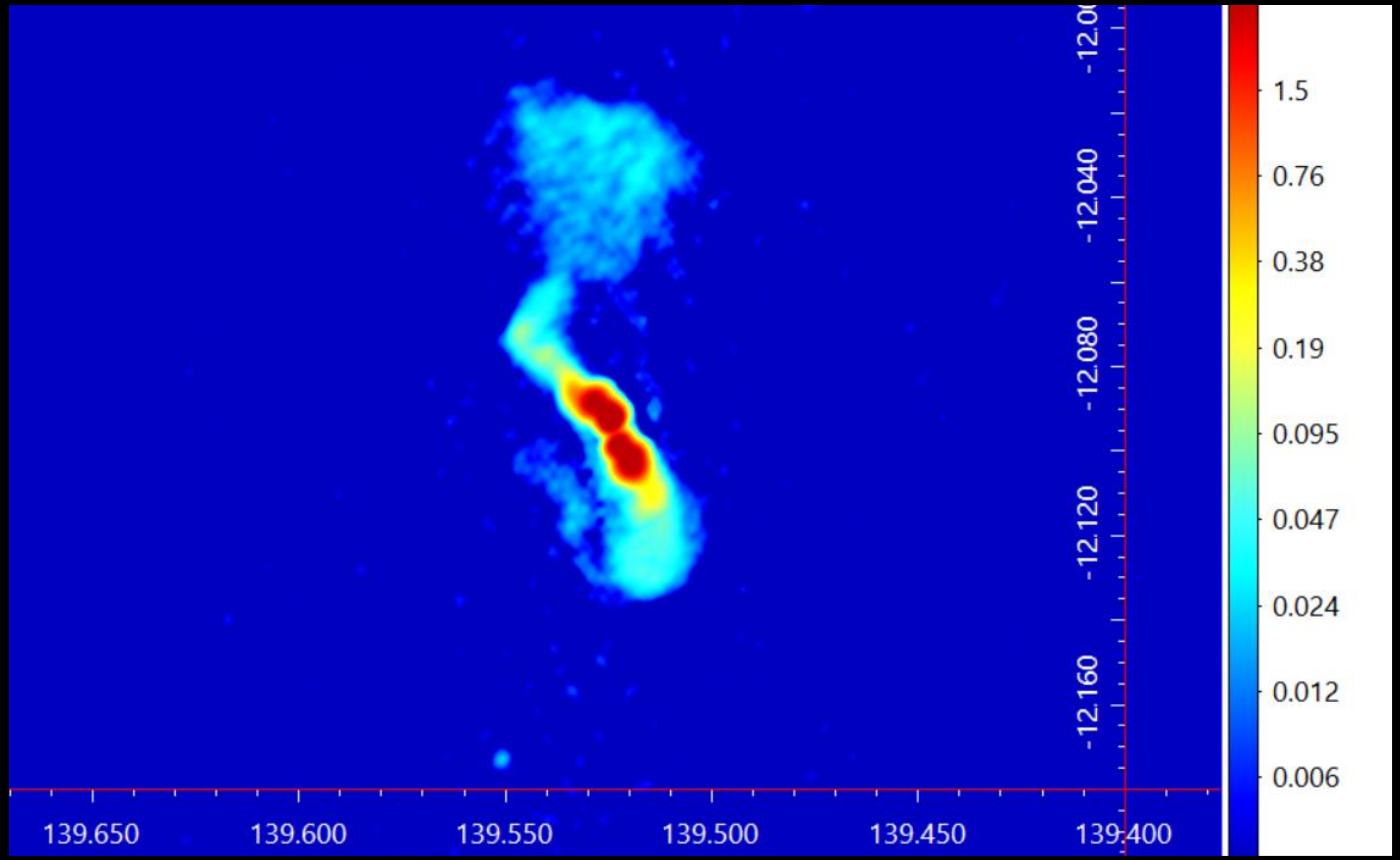
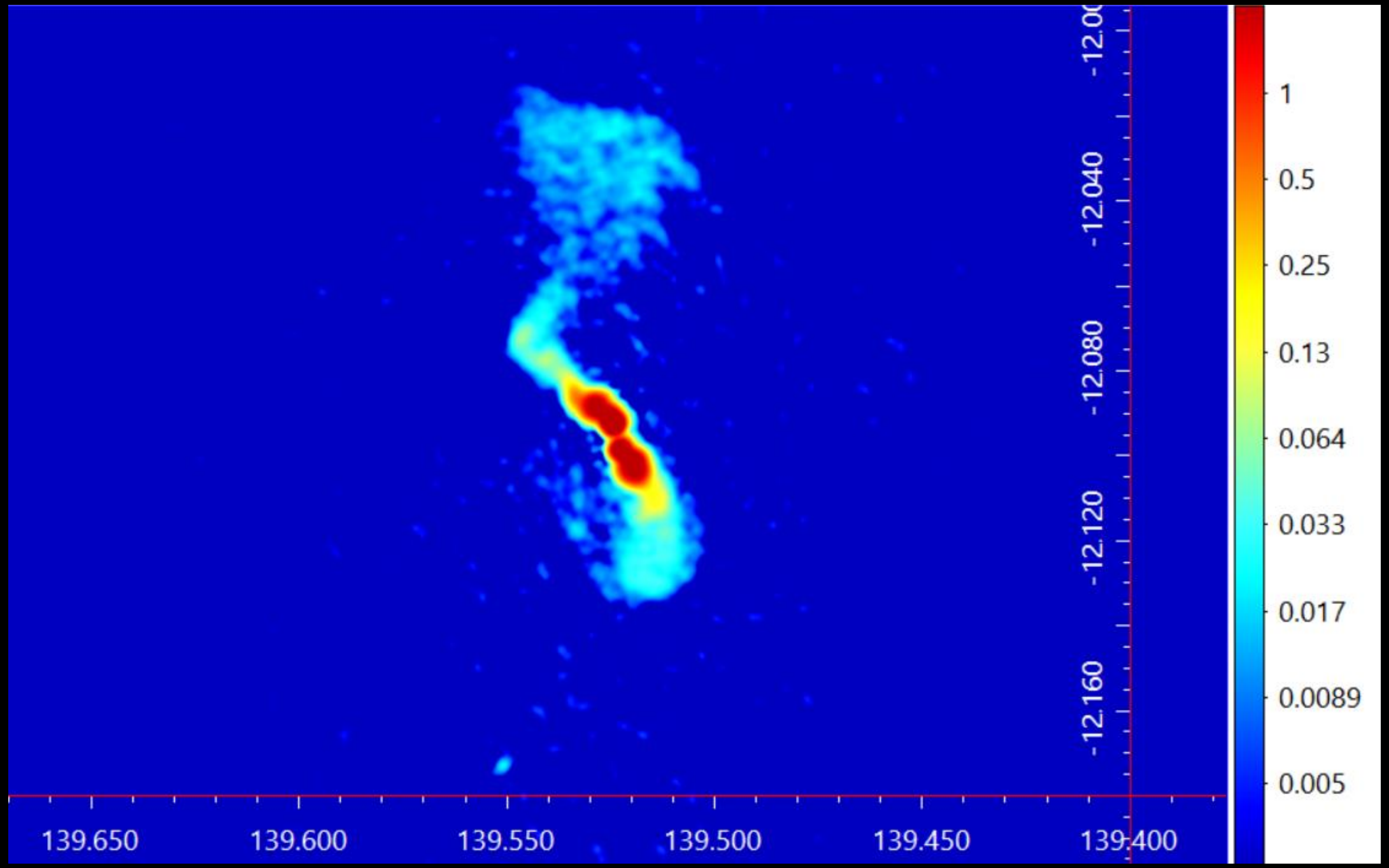
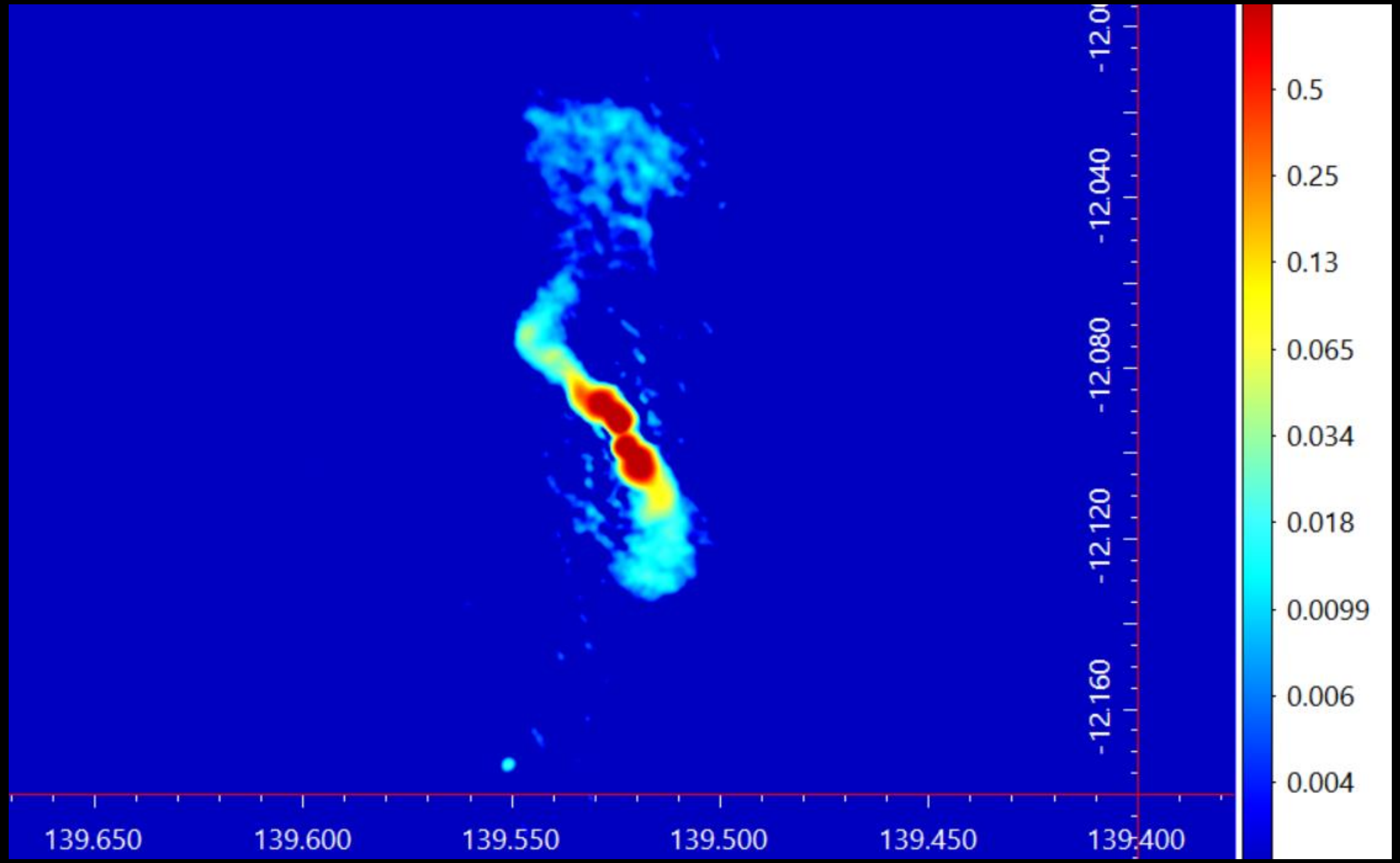


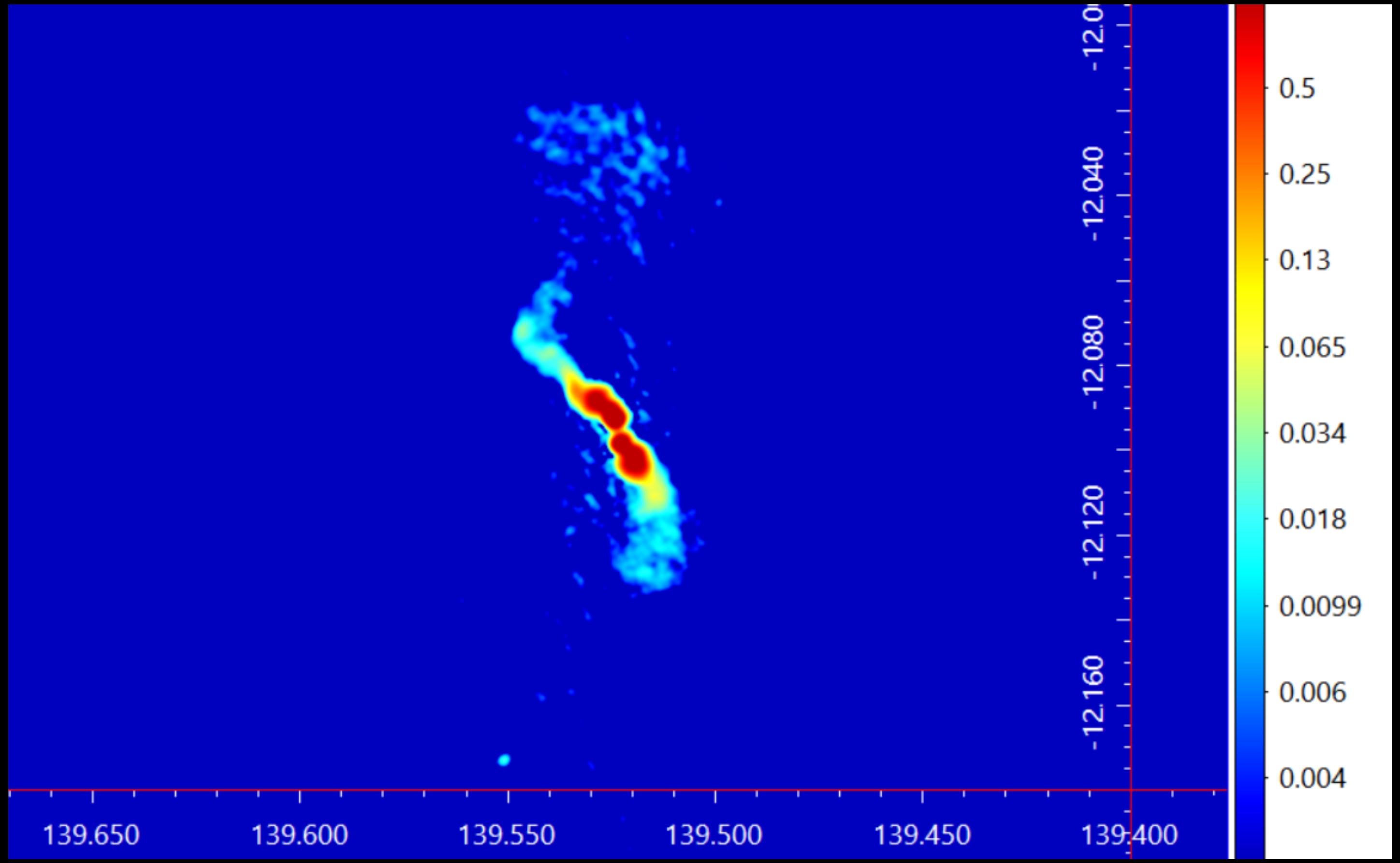
Preliminary image of Hydra A at 1000 MHz



Preliminary image of Hydra A at 1100 MHz

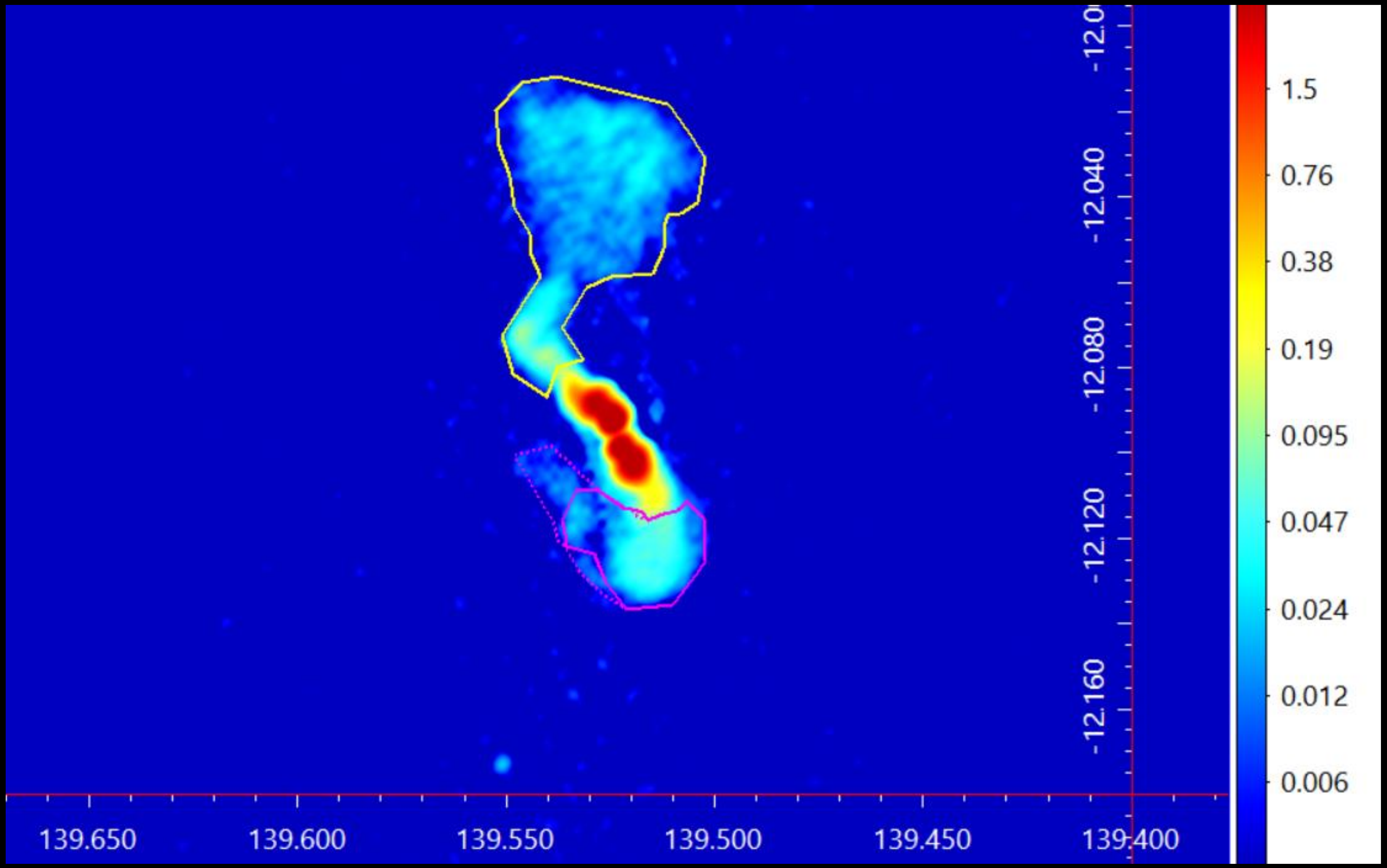


Preliminary image of Hydra A at 1330 MHz



Preliminary image of Hydra A at 1485 MHz

Morphology of radio emission



Preliminary image of Hydra A at 1000 MHz indicating the regions defined as the outer radio lobes

- 2 bright inner lobes
- 2 large diffuse radio lobes extending in the northern and southern directions
- S-shape symmetry

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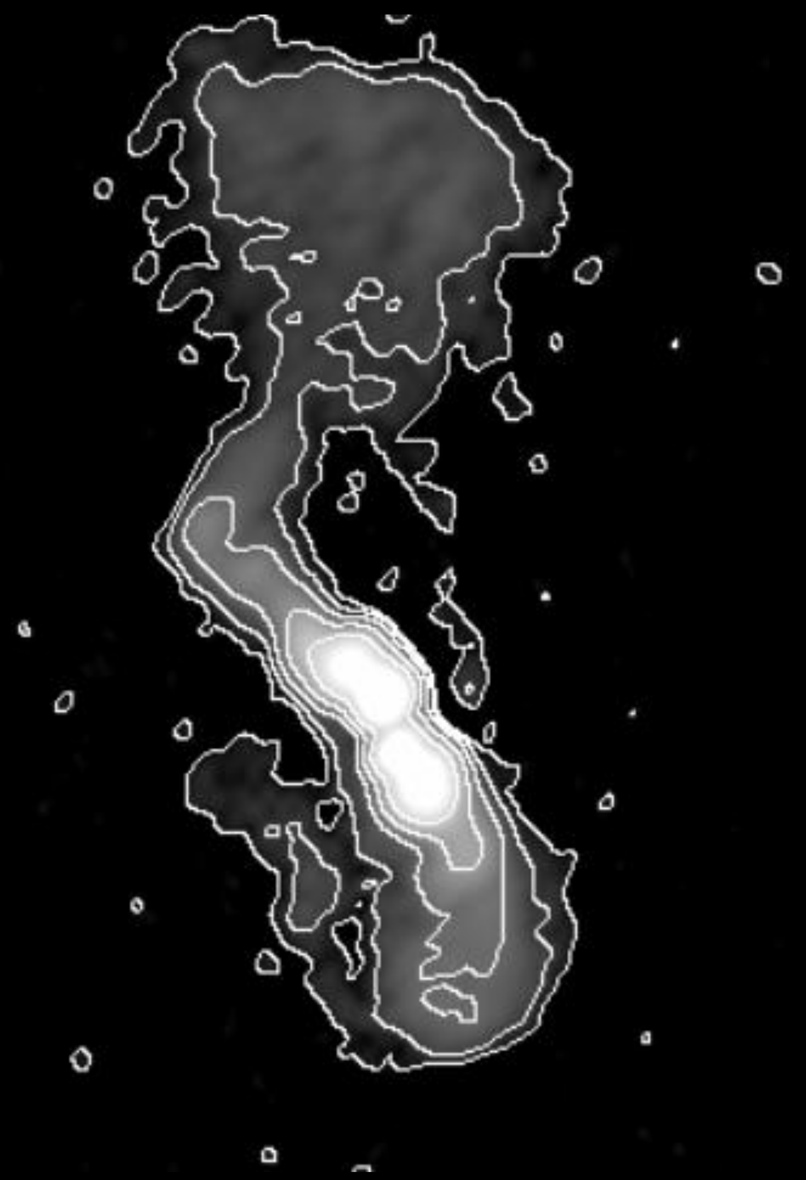
COMPARISON AT SIMILAR FREQUENCIES

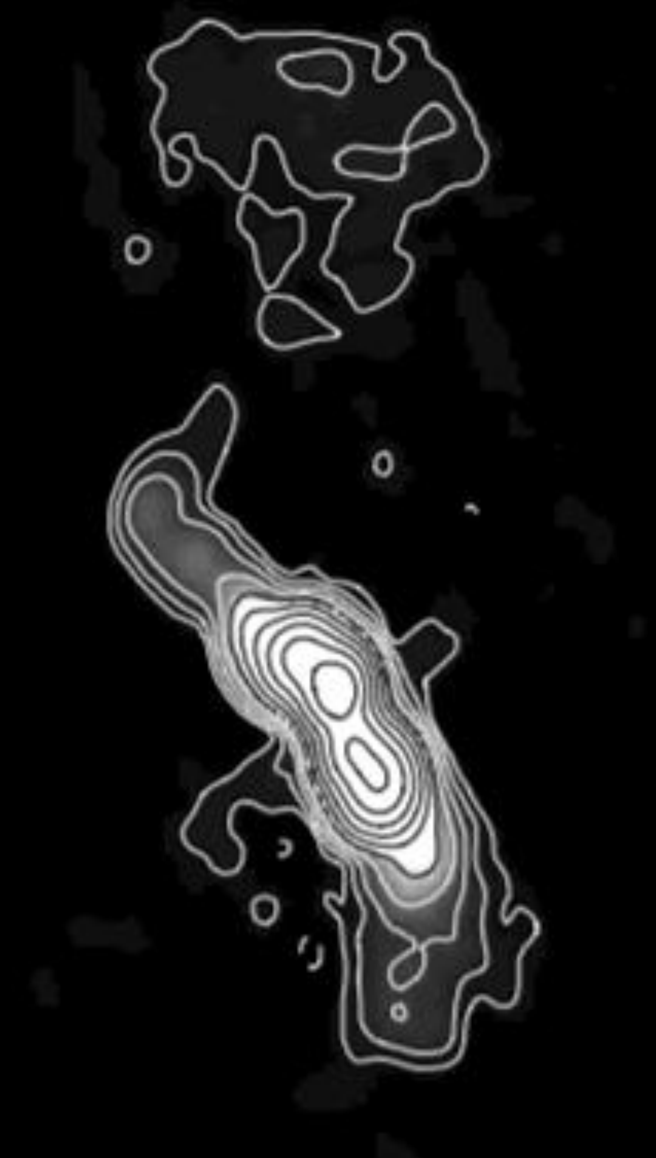
Image: Contour image of Hydra A at 1415 MHz, using VLA observations
Credit: Lane et al. 2004



Preliminary image of Hydra A at 1000 MHz using MeerKAT observations

MeerKAT allows us to:

- Study finer details such as a bridge to the northern lobe and a tail in the southern lobe
- Perform a spectral analysis in a broad frequency range



Hydra A at 1415 MHz using VLA observations

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MODELLING THE RADIO SPECTRUM IN HYDRA A

- Radio emission is produced by synchrotron radiation

- **Spectral Evolution of electrons in Radio galaxy lobes:**
  - Electrons are injected into the lobes
  - The electron population evolves according to the kinetic energy equation:

$$\frac{\partial N(E)}{\partial t} = \frac{\partial}{\partial E}[b(E)N(E)] + Q(E)$$

b(E) → Energy losses $\left(\frac{-dE}{dt}\right)$
N(E) → Electron spectrum
Q(E) → Source term

- Note:
  - Assume electrons are injected at an initial time with no subsequent injections(Q(E)=0)
  - High energy electrons can lose energy via a synchrotron mechanism and Inverse Compton Scattering with CMB photons
  - At the point of acceleration, the electron population is initially assumed to take the form :

$$N(E) = N_0 E^{-\gamma}$$

MODELLING THE RADIO SPECTRUM IN HYDRA A

- Solutions are given by*:

$$N(E,\theta,t) = N_0 E^{-\delta}(1 - E_T E)^{-\delta-2}$$

With the intensity at a given frequency

$$I_\nu(t) = 4\pi C_3 N_0 s B \int_0^{\pi/2} \mathrm{d}\theta \sin^2\theta \int_0^{E_T^{-1}} \mathrm{d}E\, F(x) E^{-\delta} \times (1 - E_T E)^{\delta-2}$$

E	⟶	Energy
θ	⟶	Pitch angle
t	⟶	Time since initial injection
$C_2, C_3, v_0, F(x)$	⟶	Constants defined by Pacholczyk

Kardashev-Pacholczyk (KP) model (1970):

- Electrons keep the same pitch angle (θ) during their lifetime

$$E_T \equiv C_2 B^2 (\sin^2\theta) t$$

- There is no cut-off but rather a spectral break

Jaffe-Perola (JP) model (1973):

- Electrons change their pitch angle (θ) on shorter times compared to their lifetimes

$$E_T \equiv C_2 B^2 \langle \sin^2\theta \rangle t$$

where $\langle \sin^2\theta \rangle$ represents the time averaged pitch angle.

- There is a cutoff moving at lower energies when the time increases- an exponential cutoff

*doi:10.1093/mnras/stt1526

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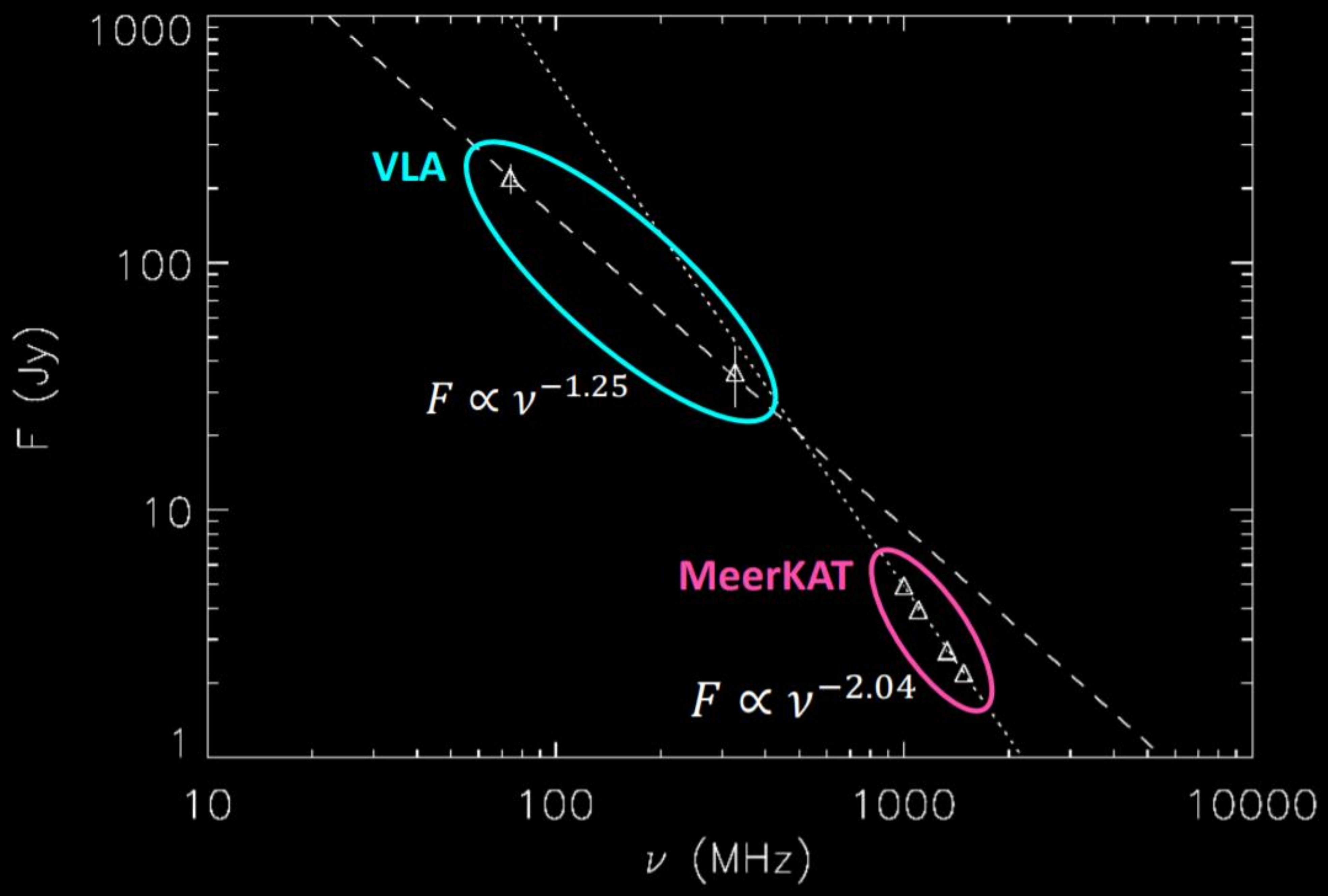
RADIO DATA FOR HYDRA A



Preliminary radio spectrum of Hydra A

- Flux density computed for the outer lobes at the 4 frequencies
- The spectrum in the MeerKAT frequency range is well described by a steep power law.
- Spectral index for MeerKAT data calculated to be

$$\alpha = 2.06 \pm 0.04^{*}$$

- We see a spectral break but not a single power law
- The change in the spectral index is clearly established

*statistical uncertainty

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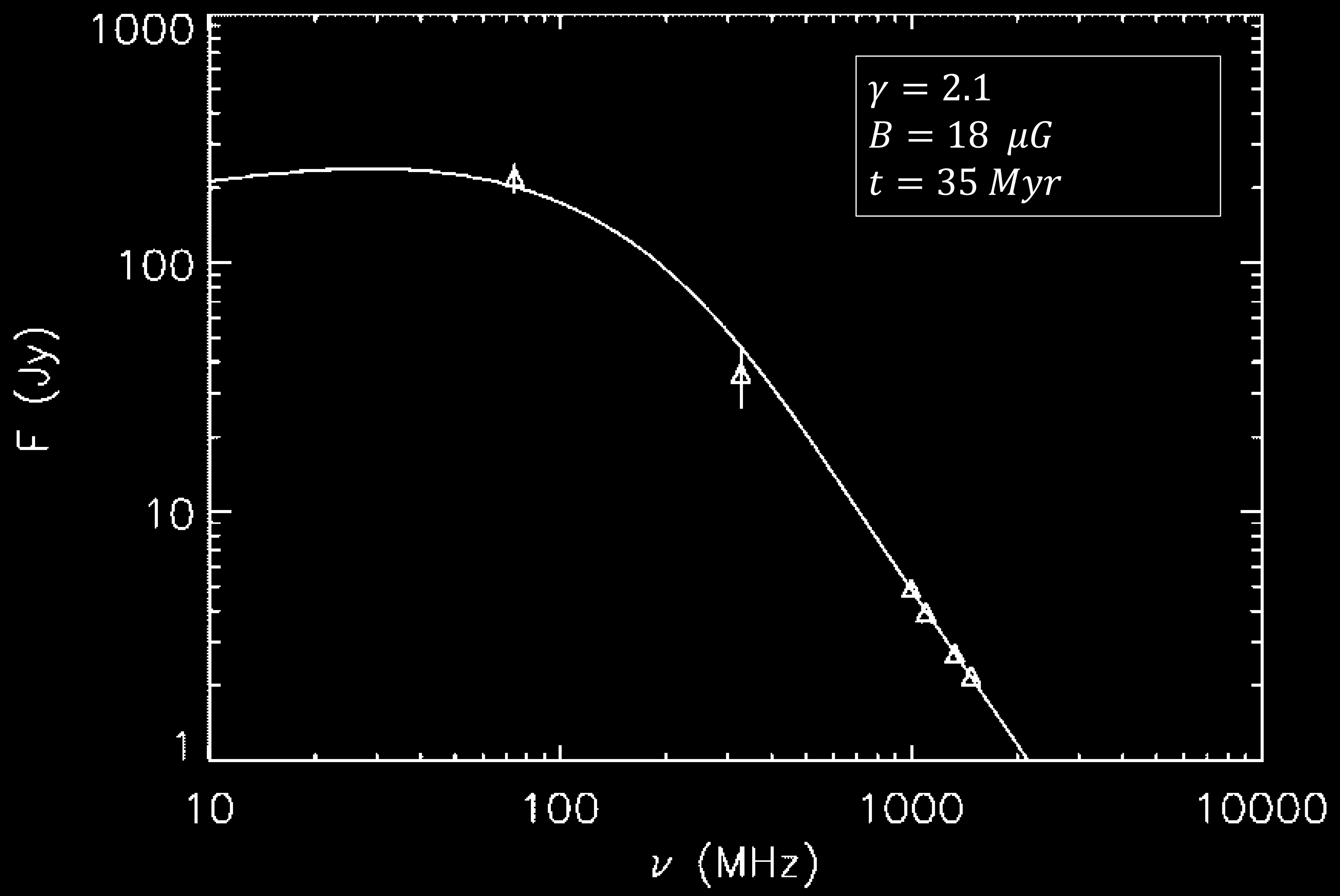
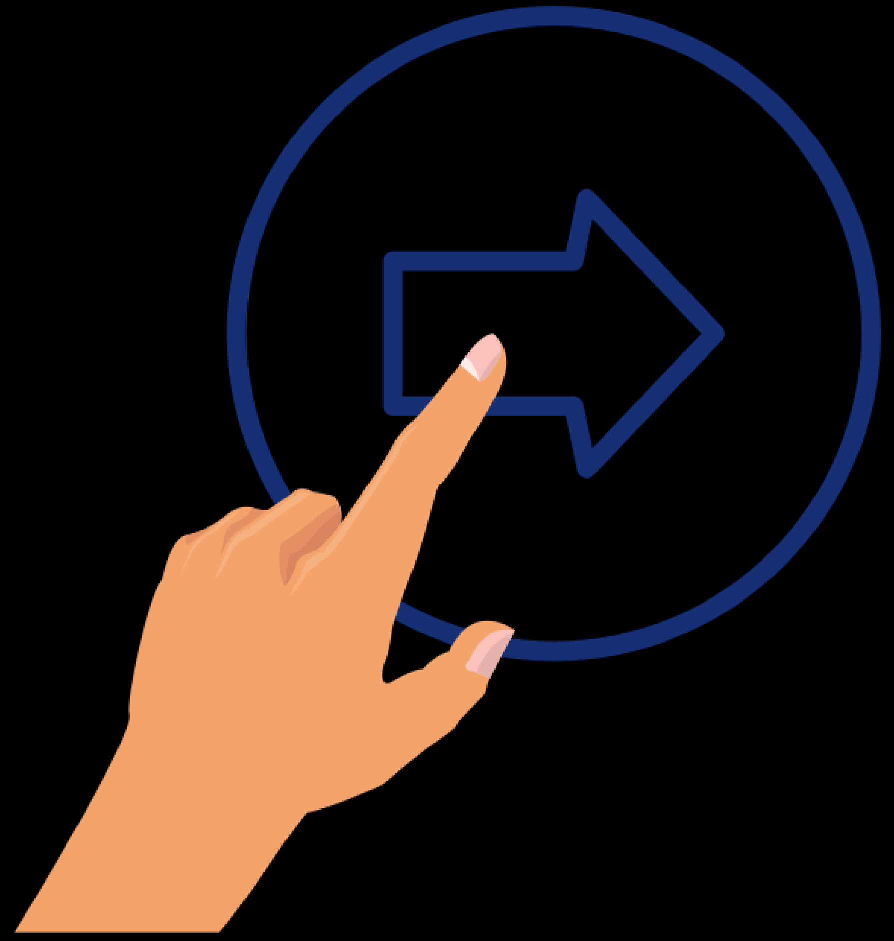
THE BEST-FIT VALUES OF THE AGE AND MAGNETIC FIELD



The values of the age and magnetic field found by minimizing the chi-squared statistic

WHAT COMES NEXT ?

- Constraining scattered emission
- Tracing the particle populations of radio lobes



ACKNOWLEDGMENTS

- Our study has made use of data obtained from the MeerKAT telescope that has been provided by the South African Radio Astronomy Observatory (SARAO)-which is a facility of the National Research Foundation, an agency of the Department of Science and Technology.