Wide-Field Wide-Band Imaging with the EVLA

- Initial results with images and error estimates

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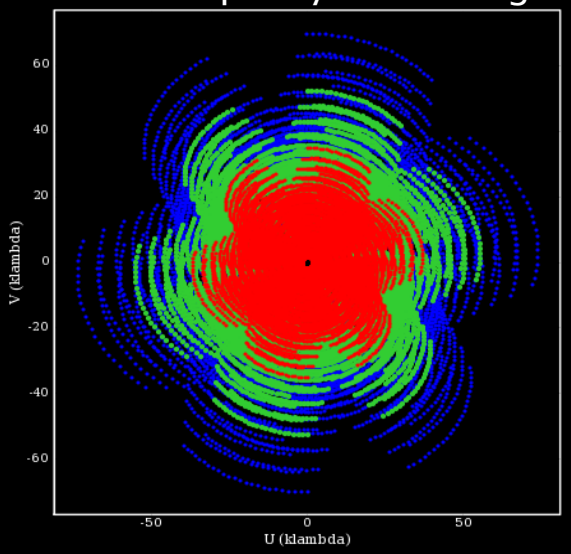
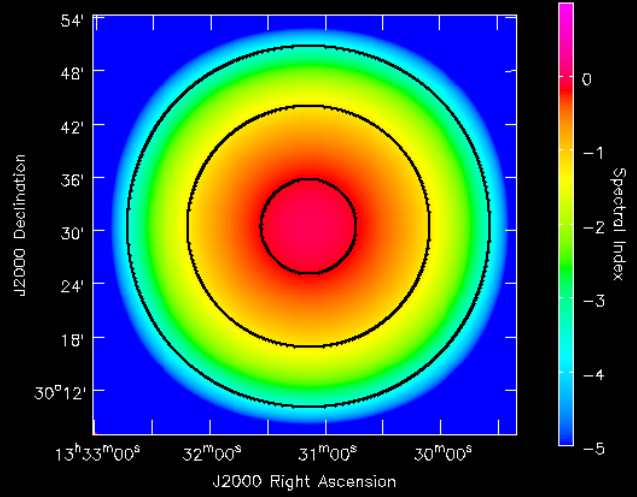
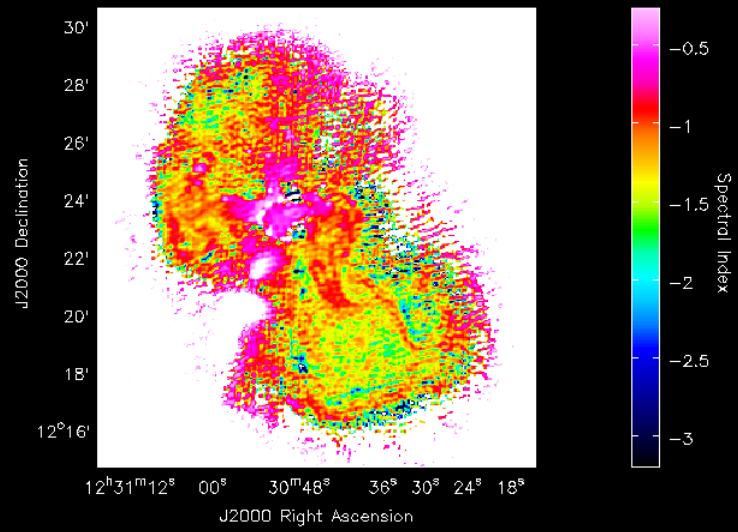
Multi-Frequency UV-coverage



Spectral Index of the Primary Beam



Spectral Index of the M87 halo



The EVLA as a survey instrument

Continuous frequency coverage between 1 and 50 GHz
Each receiver band has an instantaneous bandwidth ratio of 2:1 (upto 8GHz)

=> Increased imaging sensitivity at each band

" Continuum imaging at full broad-band sensitivity across wide fields of view "

(1) Effects of the frequency-dependence of the sky and instrument

- Varying angular resolution, varying antenna field-of-view, sky spectrum

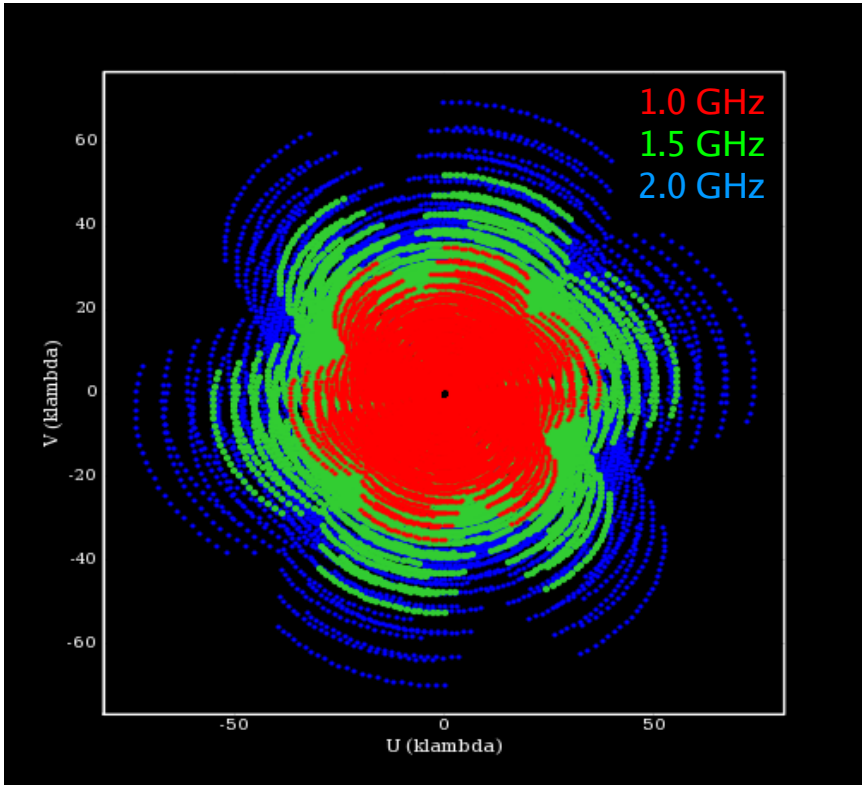
(2) Results with a new multi-scale wide-band imaging algorithm

- Wide-field images of continuum flux, spectral index and spectral curvature

Multi Frequency Synthesis Imaging

Combine measurements from multiple frequencies while imaging

EVLA L-Band UV-coverage



Higher Angular Resolution

Higher UV-filling factor

Higher Imaging Sensitivity

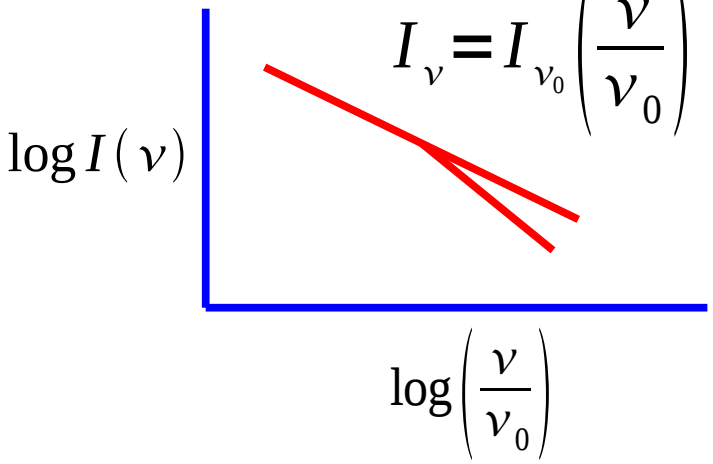
For flat-spectrum brightness distribution...
Standard imaging algorithms suffice

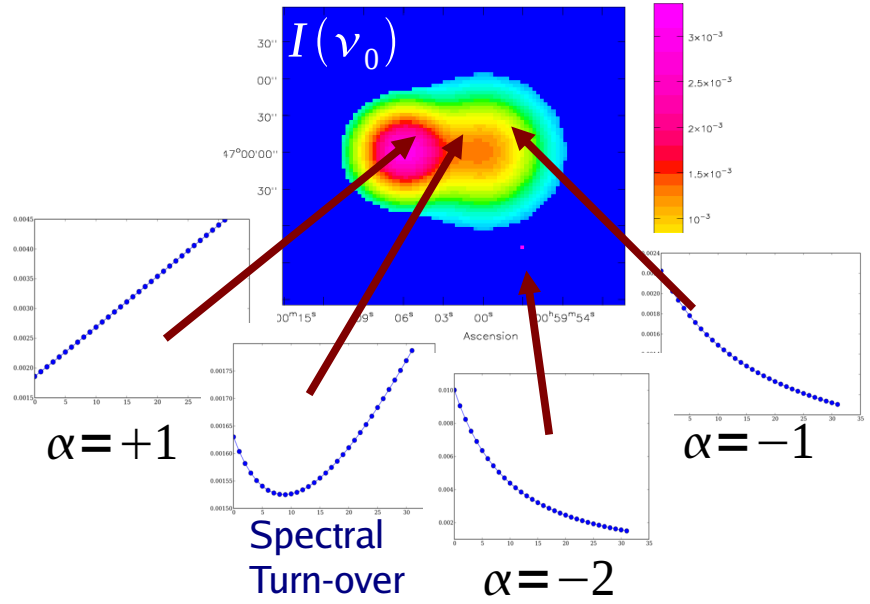
With spectral structure....
Standard imaging algorithms interpret spectral variation as spatial structure

Multi-Scale Image Model for Wide-Band Sky Brightness

Power Law with a Varying Spectral Index
(spectral breaks, steepening, turnovers..)

$$I_\nu = I_{\nu_0}\left(\frac{\nu}{\nu_0}\right)^{\alpha+\beta\log(\nu/\nu_0)}$$

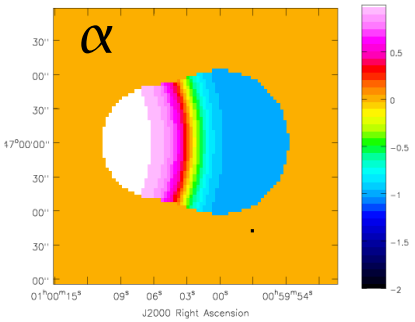




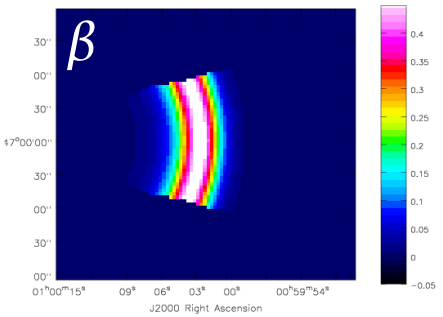
For EVLA L-Band (1-2 GHz)

Need SNR > 6 to measure $\alpha = -1.0$
Need SNR > 100 to measure $\Delta\alpha = -0.2$

Average Spectral Index

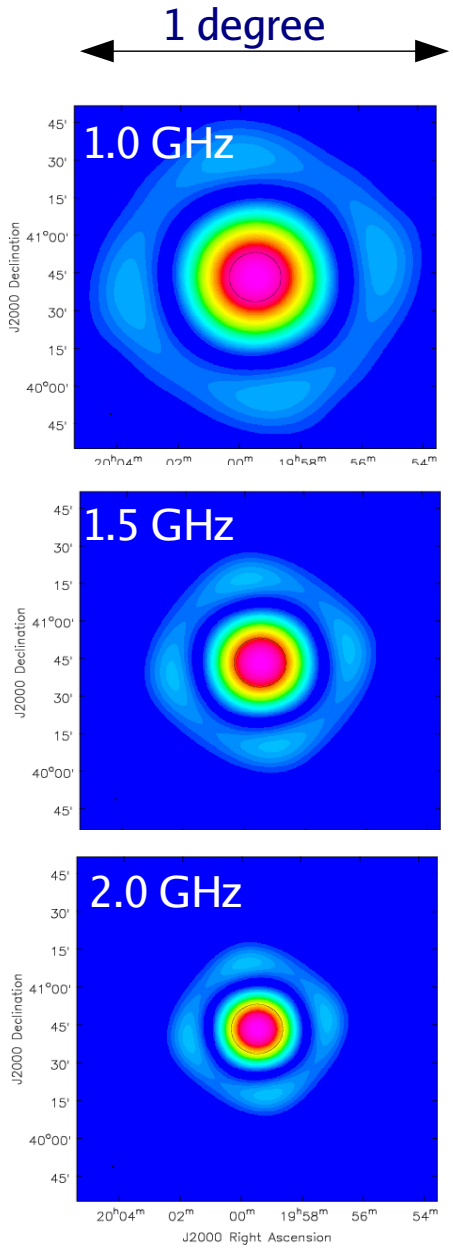


Gradient in Spectral Index

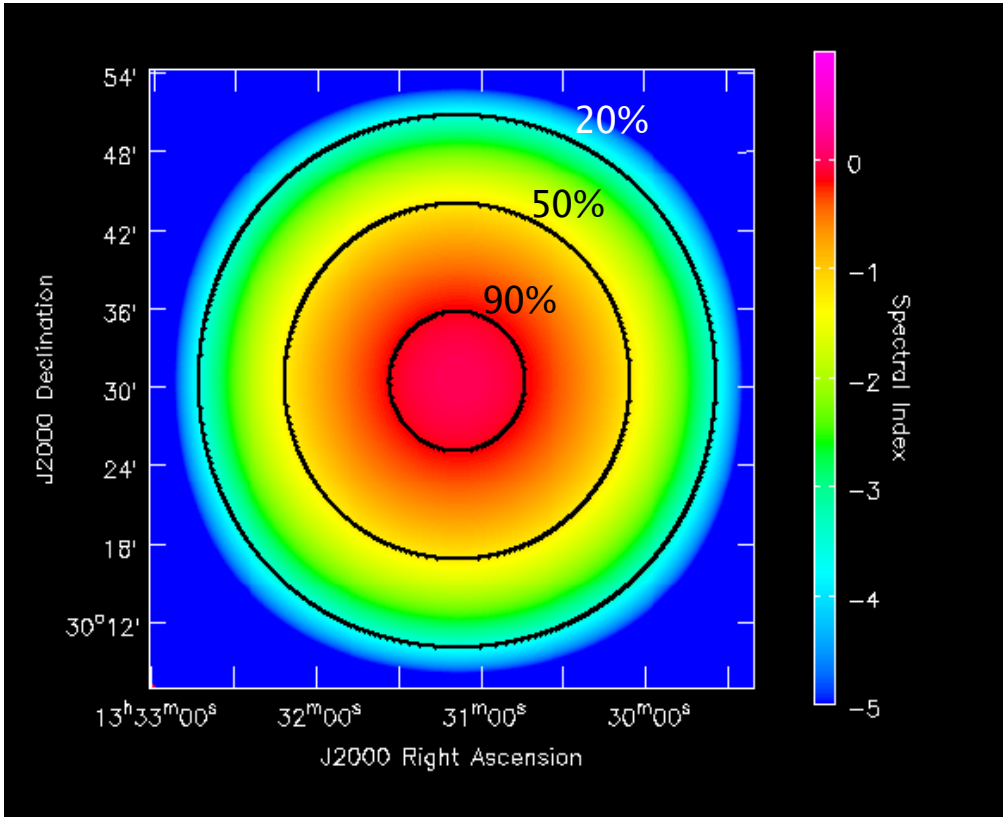


Error on reconstructed spectral structure : $\delta\alpha < 0.05$, $\delta\beta < 0.1$

Frequency-dependent Field of View



"Spectral Index"of the EVLA L-band Primary Beam



At the half-power point

$$\alpha_{PB} = -1.4$$

Apparent Spectral Index of a Source

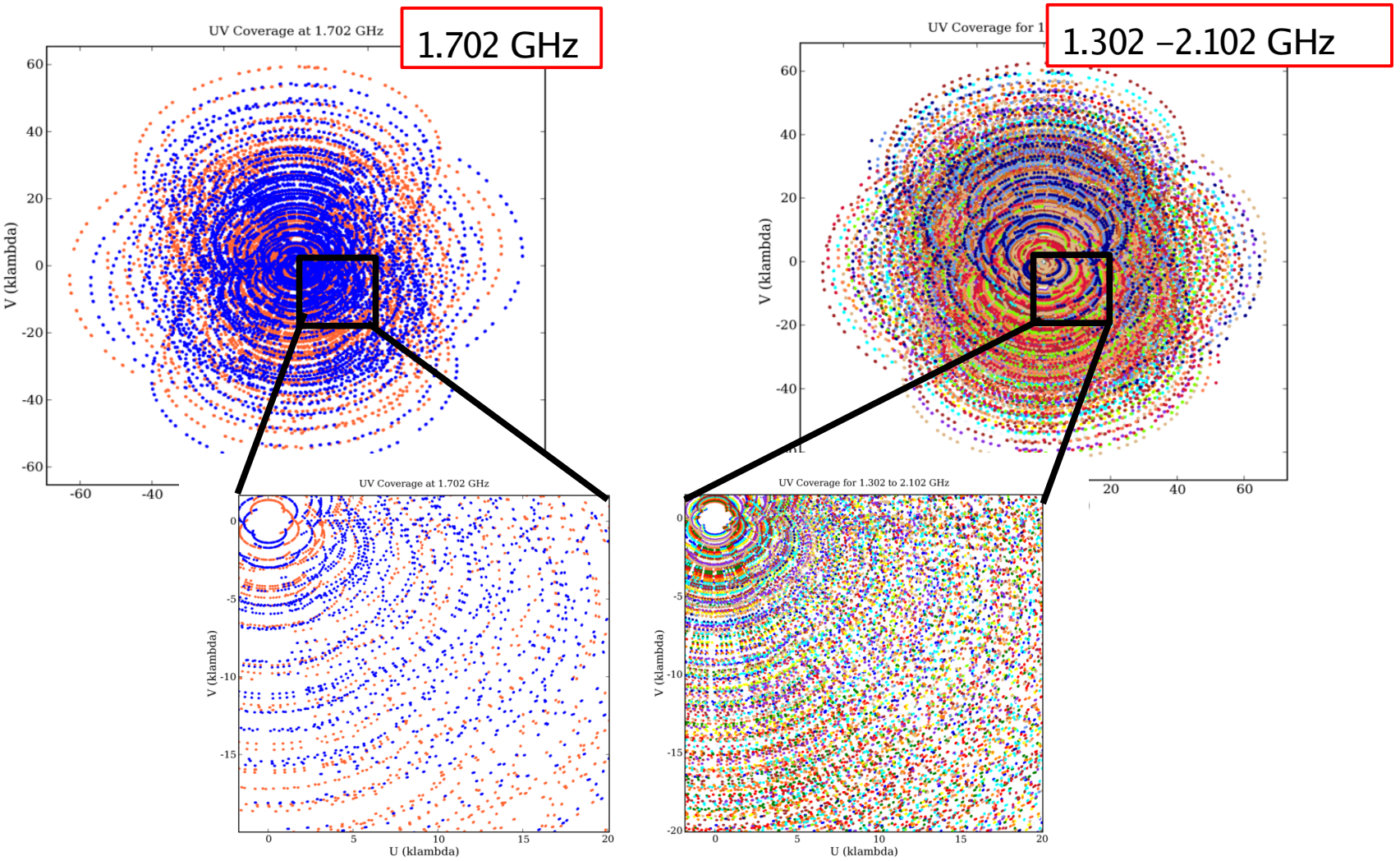
$$\alpha_{sky} + \alpha_{PB}$$

Error on best-corrected spectral index :

$$\delta\alpha < 0.1\,(pt), \quad \delta\alpha < 0.2\,(ext)$$

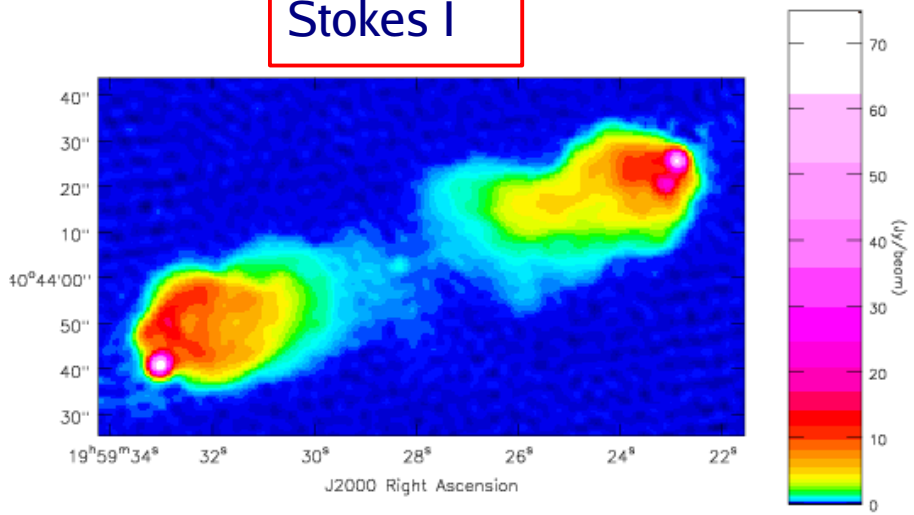
UV-Coverage - (E)VLA observation of CygnusA

(Cycle through 9 frequency bands, 20 one-minute snapshots per band, spread over 8 hours)

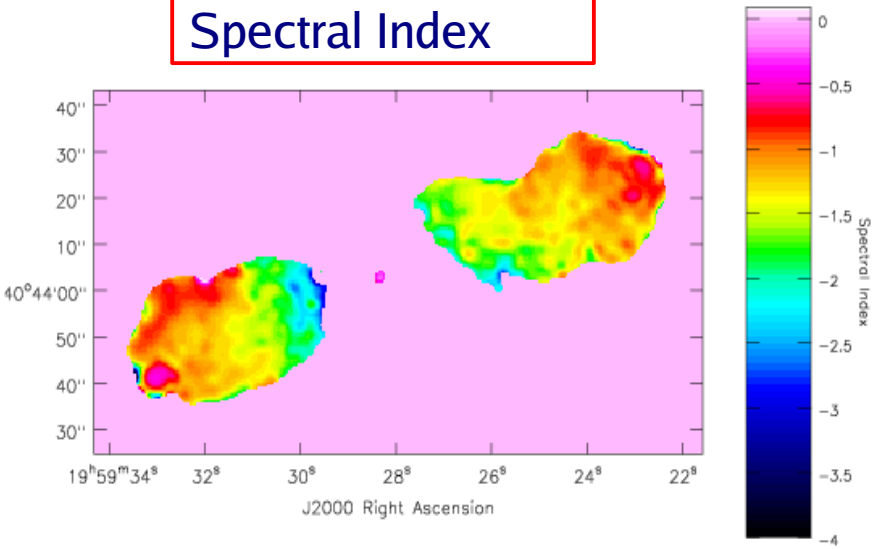


Cygnus-A : Stokes I, Spectral Index (1.3 –2.1 GHz)

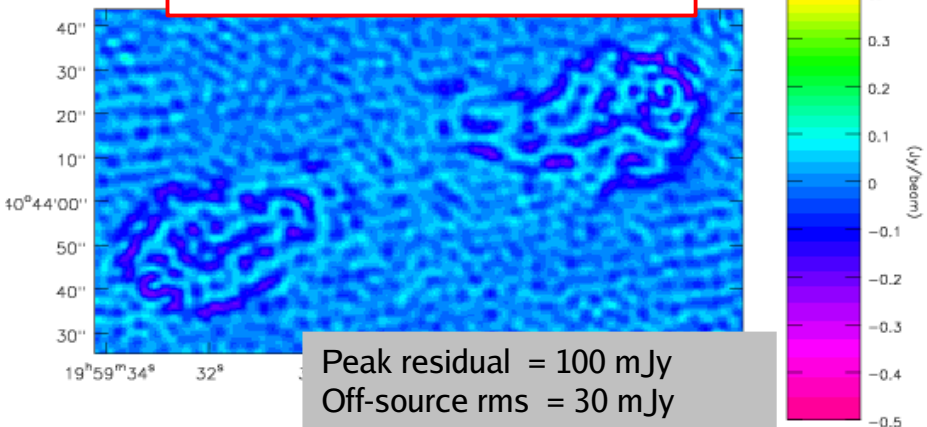
Stokes I



Spectral Index



Continuum Residuals



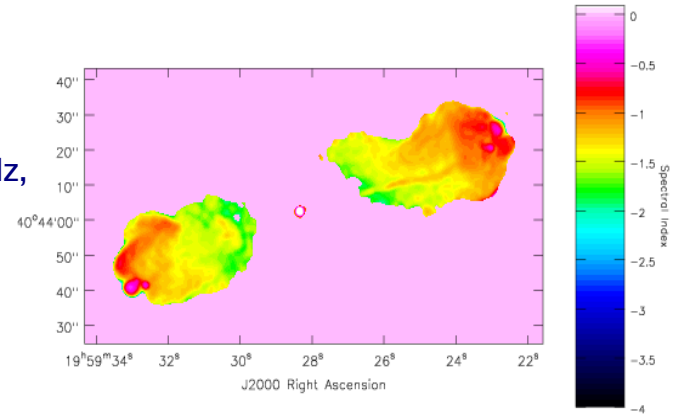
Peak residual = 100 mJy
Off-source rms = 30 mJy

- Has detail and fidelity of multi-scale deconvolution
- Error on estimated spectral index <= 0.2

For comparison :

Sp.Ndx. map constructed from 1.4GHz and 4.8GHz,

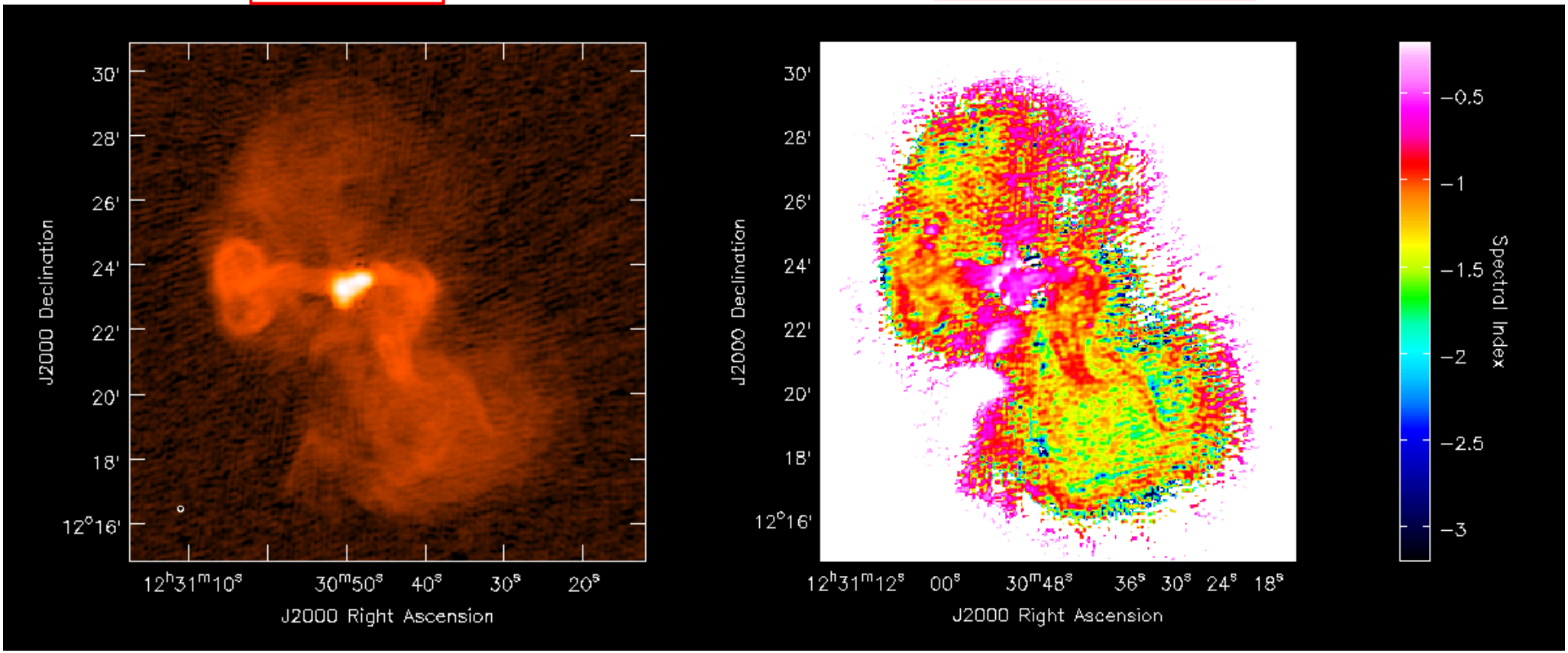
Images obtained from C.Carilli et al, Ap.J. 1991. (VLA A,B,C,D Array at L and C band)



M87 : Stokes I , Spectral Index (1.1 –1.8 GHz)

Stokes I

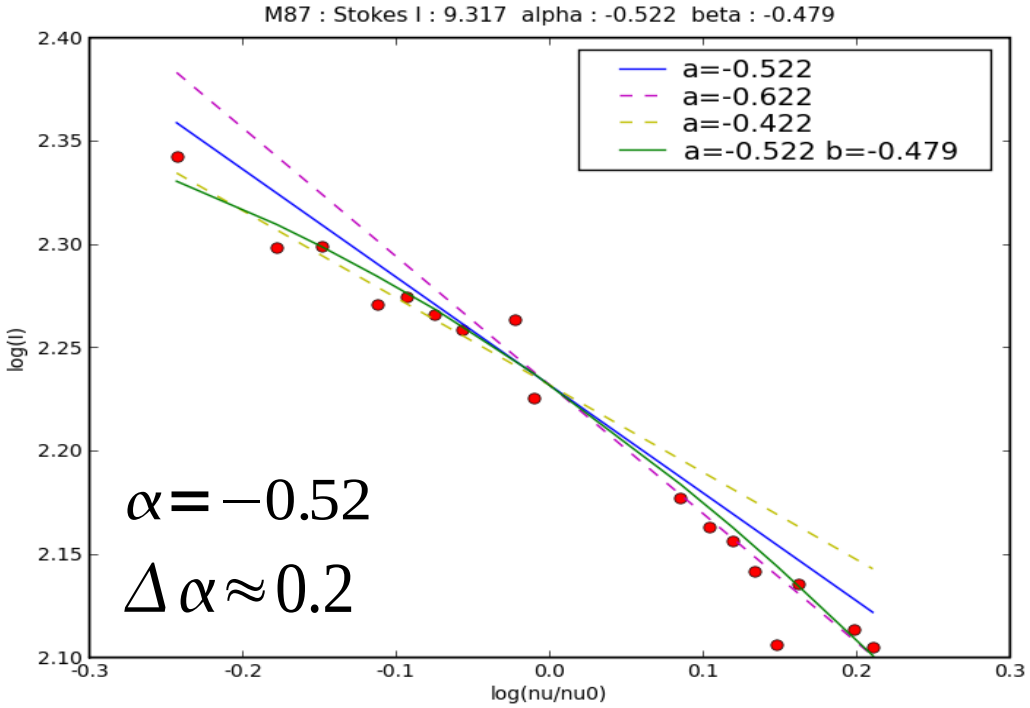
Spectral Index

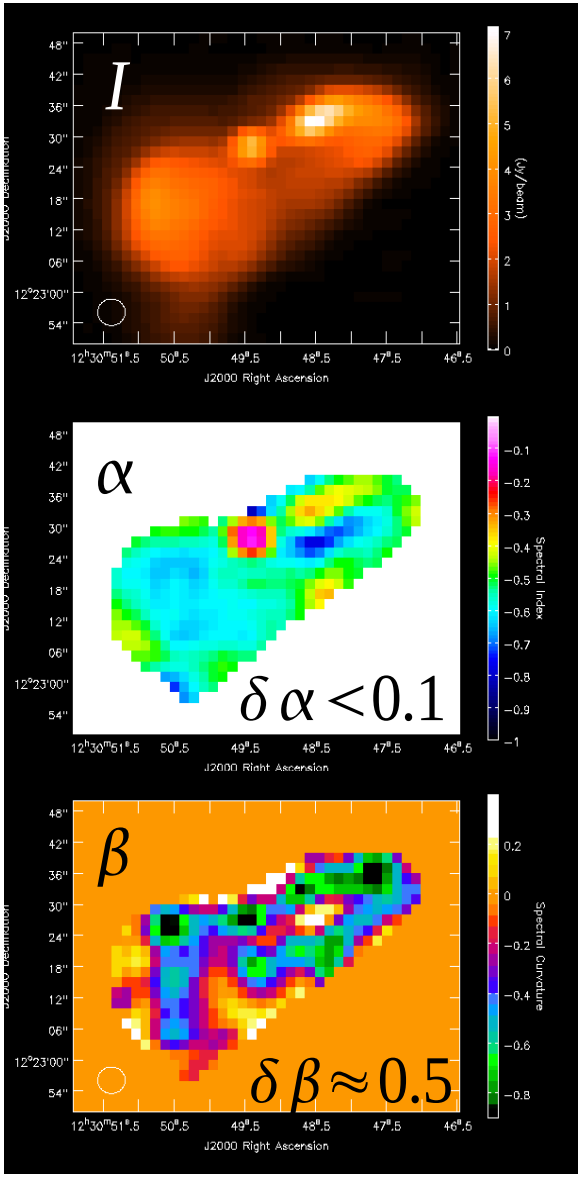


VLA C : Cycle through 16 frequencies between 1.18 –1.86 GHz, => 10 x 3min 'snapshots' per frequency

Error bar on measured spectral index < 0.2 in the halo and filaments (SNR < 10)
< 0.05 in the core/jet region (SNR > 1000)

M87 spectral curvature (1.1 –1.8 GHz)





From existing P-band (327 MHz), L-band (1.42 GHz) and C-band (5.0 GHz) images of the core+jet (from F.Owen)

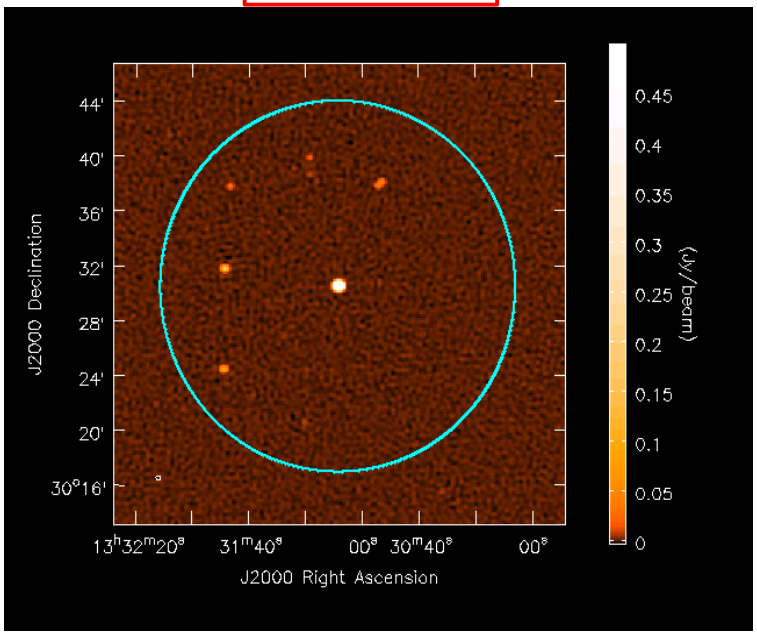
P-L spectral index : -0.36 ~ -0.45

L-C spectral index : -0.5 ~ -0.7

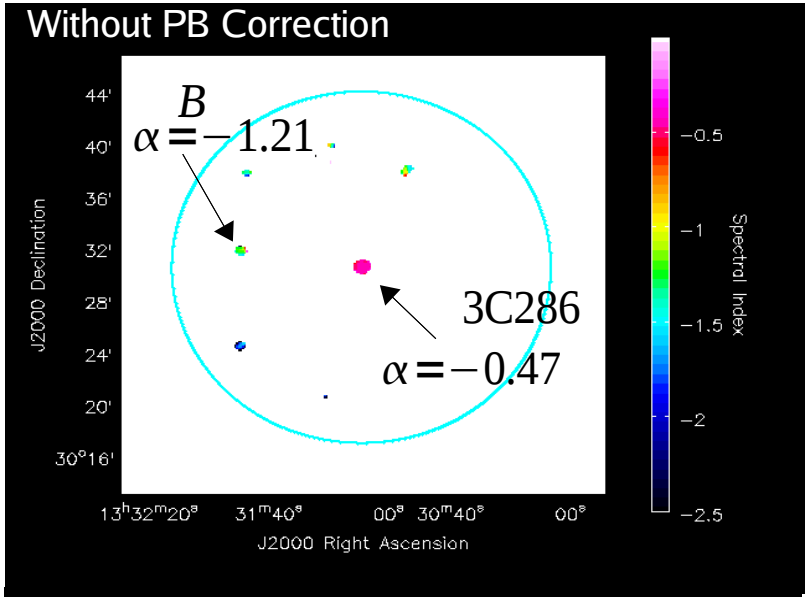
Spectral index variation ~ 0.2 is detectable with SNR > 100

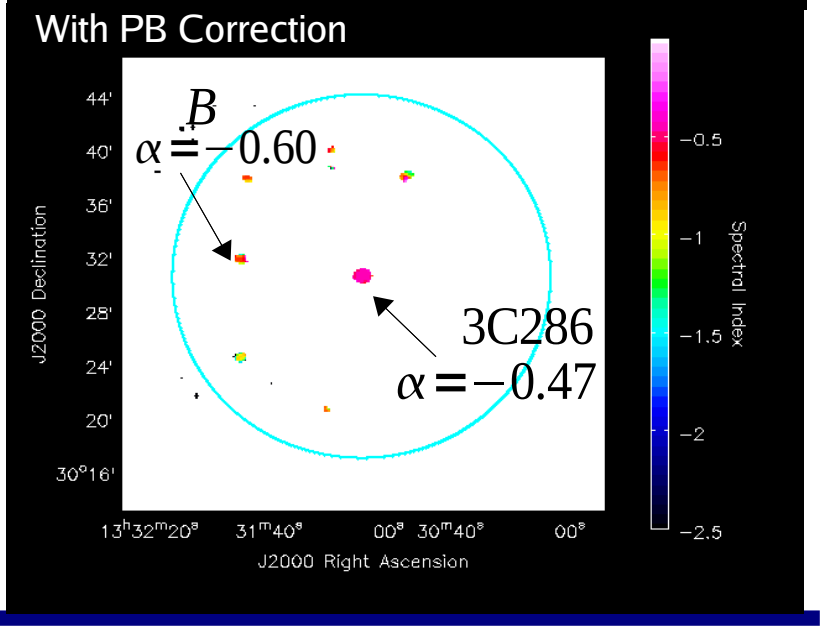
3C286 field : MFS + Freq/Time-varying PB correction

Stokes I



Spectral Index





Error on α : $\delta\alpha_{3C286} \approx 0.03$ $\delta\alpha_{B} \approx 0.1$

(SNR > 14000, 1400) (SNR : 100, 10)

Verified via holography and another observation with "B" at the pointing center and "3C286" at the 70% of the PB.

Summary of thesis project

Wide-Band Imaging :

- Evaluated existing imaging methods for the EVLA and identified areas of improvement.
- Extended the multi-scale and multi-frequency imaging algorithms.
- Derived a combined algorithm, implemented and tested it on simulated and real (E)VLA data.

Astrophysics :

- Used high angular-resolution 1-2 GHz spectral index maps of M87 along with existing maps at other bands (74 MHz, 300 MHz) to partially constrain evolution models (dynamical and synchrotron) for different features across the source.

Software : CASA

- Multi-Scale Multi-Frequency CLEAN : Available in current CASA release
- Wide-band Primary Beam correction : Implemented and being tested (will be released soon)

Data products :

Images of reference-frequency flux, spectral index and spectral curvature

(Also implemented in ASKAPsoft, tested within a parallel environment, being tested for mosaic imaging and wideband ATCA data)

Summary : What can you do with this imaging algorithm ?

- Images at full continuum sensitivity
  - minimize imaging artifacts due to frequency-dependent sky and instrument

- Spectral index and curvature at the angular resolution of the highest frequency
  - errors are a strong function of signal-to-noise and spatial scale
  - with multi-band observations, measure the flux and a slope at each band
  - works with moderately resolved sources and overlapping sources

- Correction of the frequency-dependent PB up to the 40% of the reference PB
  (about 10% of the highest frequency PB for a 2:1 bandwidth)
  - Pointing overlaps for mosaic imaging can be decided accordingly.

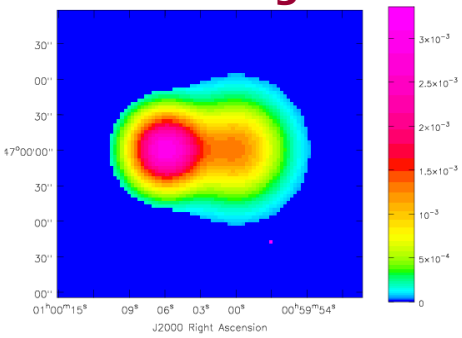
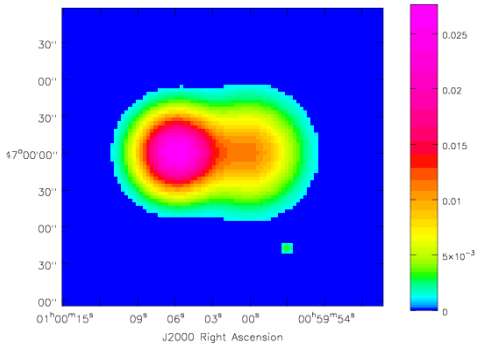
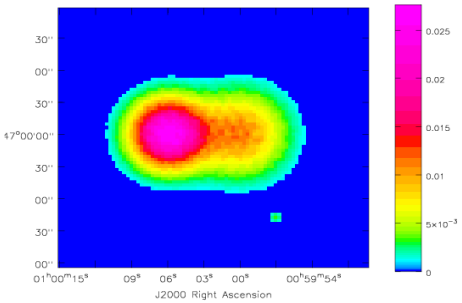
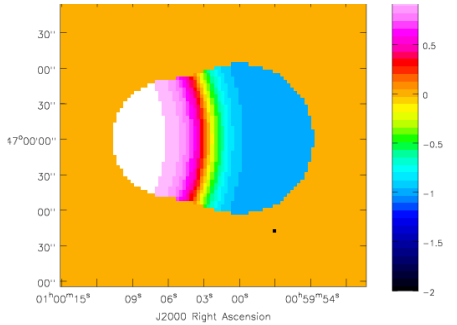
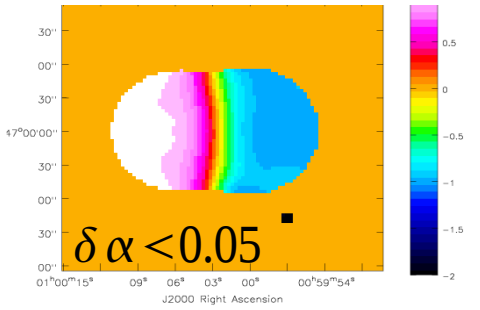
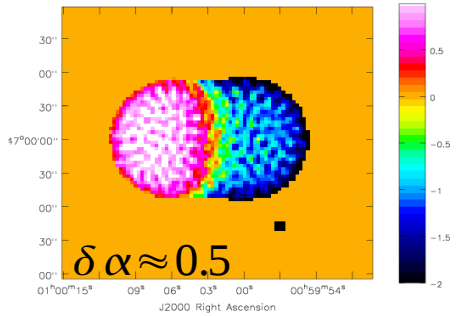
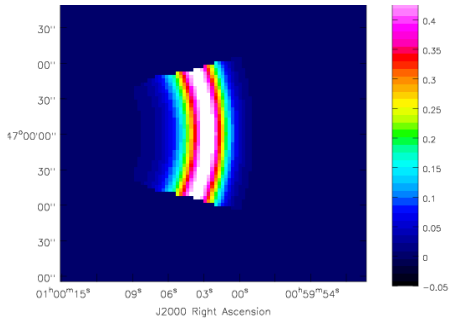
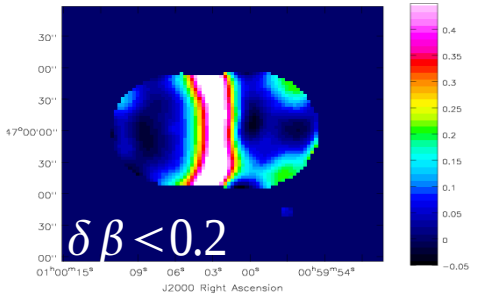
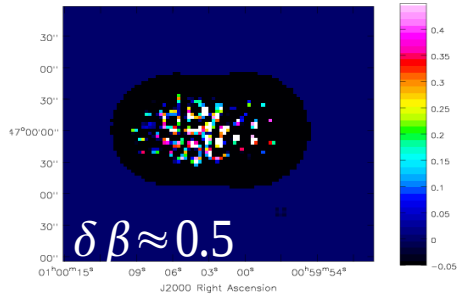
- Spectrum is not restricted to a power-law.
  - Uses a polynomial in frequency and can handle arbitrary smooth spectra.

- Increase the instantaneous spatial frequency coverage
  - imaging with sparse arrays
  - spatio-spectral imaging of time-variable sources from snapshots

Multi-Scale Multi-Frequency CLEAN

on simulated EVLA data (1-2 GHz)

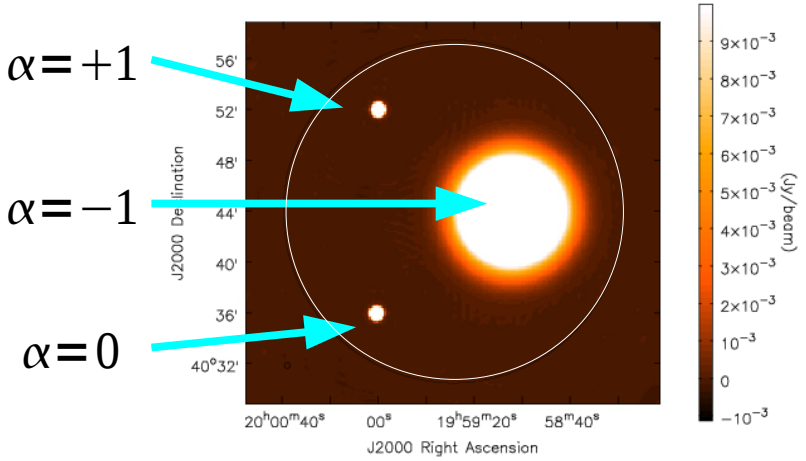
MFS

	True Images	multi-scale	point-source
Image at reference frequency $I(\nu_0)$			
Average Spectral Index α			
Gradient in Spectral Index β			

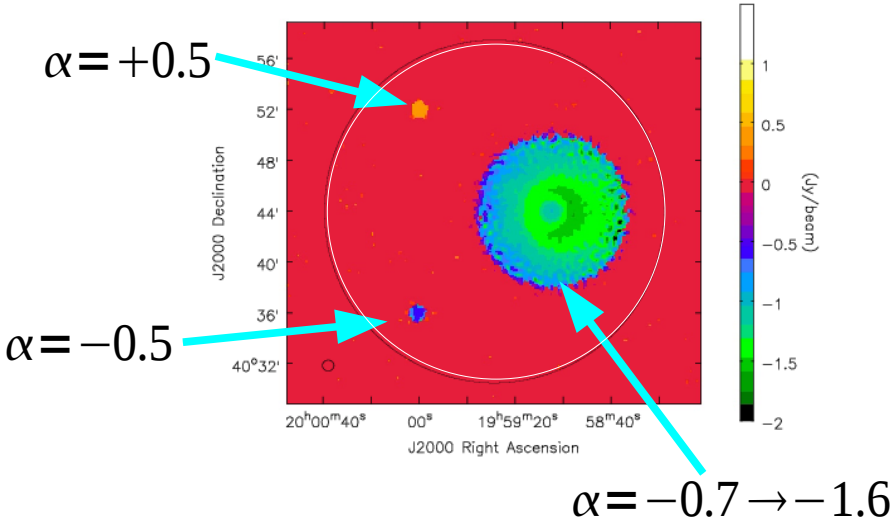
Wide-Band Primary-Beam correction

on simulated EVLA data (1-2 GHz)

Stokes I image at Reference Frequency

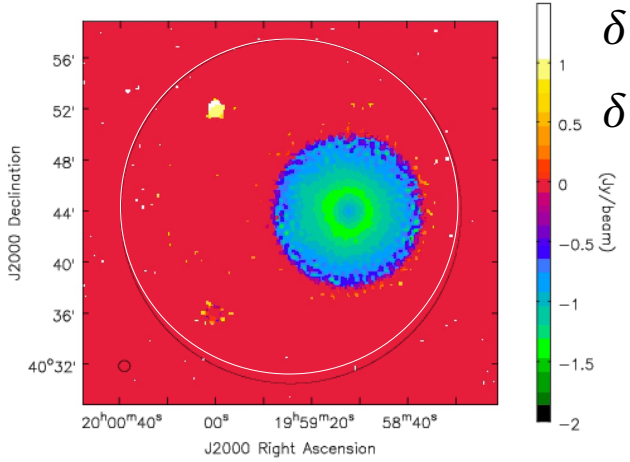


Spectral Index –WITHOUT PB-correction



Spectral Index - WITH PB-correction

Using an average primary beam



Using time varying (rotating) primary beams