Wide Bandwidth Imaging

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Urvashi Rau

National Radio Astronomy Observatory.

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Outline

(1) What is wide-band imaging ?

- Bandwidth and sensitivity
- Frequency-dependent Instrument and Sky
- Bandwidth smearing
- Multi-frequency synthesis

(2) Imaging Algorithms

- Recap. of image-reconstruction methods
- Cube vs Continuum imaging (intensity and spectrum)

(3) Examples of various effects/corrections/errors

(4) Example of wide-band imaging trials on JVLA observations of a Galactic super-nova-remnant between 1-2 GHz.

Wide-band Imaging + Sensitivity

	L-Band (1 –2 GHz)	C-Band (4 –8 GHz)	X-Band (8 –12 GHz)
Bandwidth : $\nu_{max} - \nu_{min}$	1 GHz	4 GHz *	4 GHz *
Bandwidth Ratio : $\nu_{max} : \nu_{min}$	2 : 1	2 : 1	1.5 : 1
Fractional Bandwidth : $(\nu_{max} - \nu_{min}) / \nu_{mid}$	66%	66%	40%

* : Currently the max bandwidth is 2 GHz; it will increase with 3-bit samplers.

(1) Broad-band receivers increase 'instantaneous' sensitivity

Continuum sensitivity : (at field-center) $$\sigma_{cont} \propto \frac{SEFD}{\sqrt{N_{ant}(N_{ant}-1)\ \delta\tau\,\delta\nu}}$$

VLA → JVLA 50 MHz → 2 GHz Sensitivity improvement : $\sqrt{\frac{2\,GHz}{50\,MHz}} \approx 6$ times.

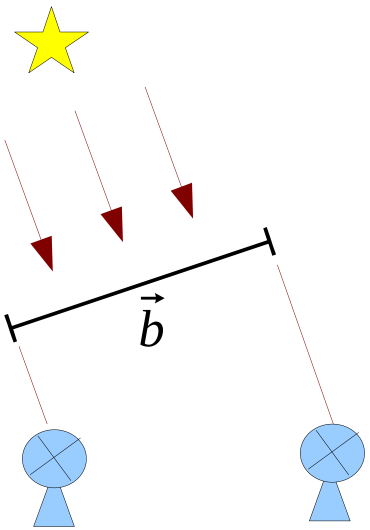
In practice, effective bandwidth for imaging depends on bandpass shape, data weights, and regions of the spectrum flagged due to RFI.

(2) Imaging must account for the frequency-dependence of the sky and instrument.

UV-coverage (imaging properties), sky-brightness (EM-spectrum), primary-beam (field-of-view)

Fractional bandwidth controls the magnitude of frequency-dependent effects within the band.

Frequency-dependent UV-coverage and PSFs



Spatial-frequency coverage changes with frequency

$$S(u,v)_\nu = \frac{\vec{b}}{\lambda} = \frac{\vec{b}\,\nu}{c}$$

The imaging properties of the interferometer change with frequency.

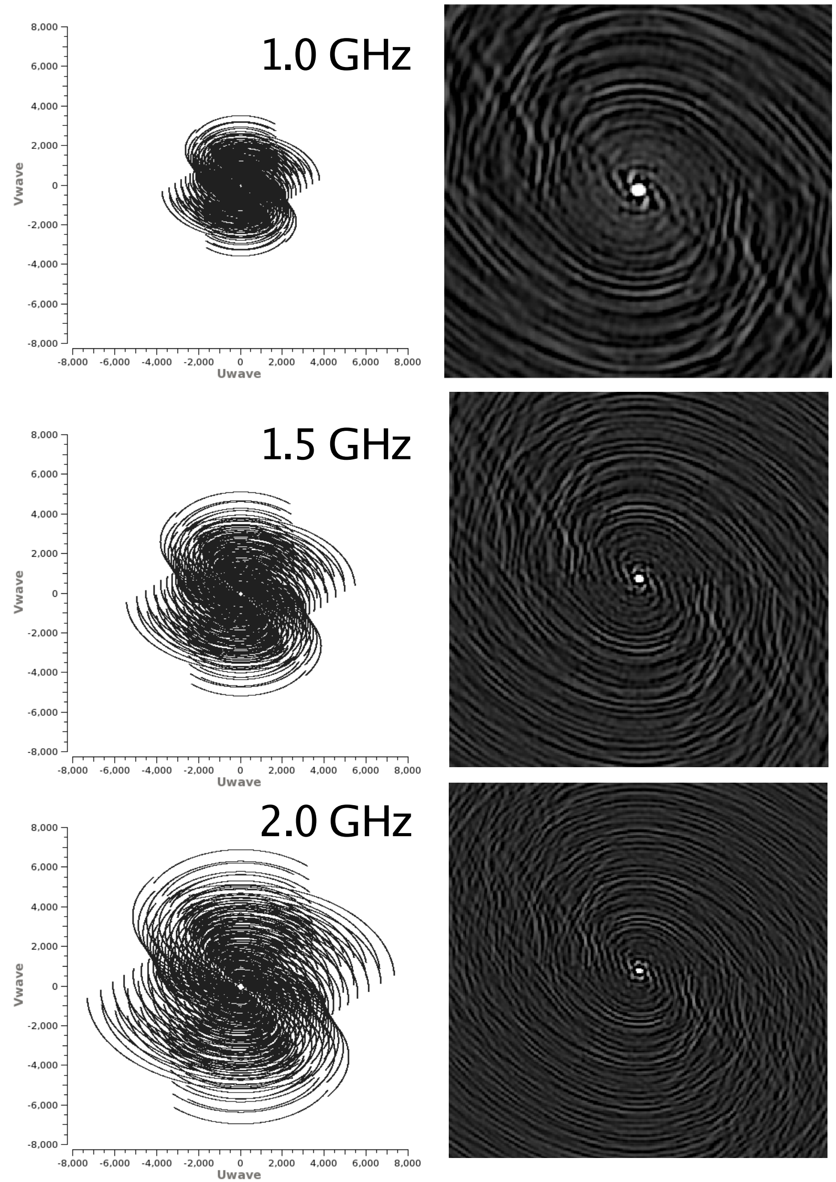
- Image angular-resolution (radians) : $\frac{\lambda}{b_{max}}$
- Largest spatial scale (radians) : $\frac{\lambda}{b_{min}}$

Broad-band signal → Channels :

Voltages measured by a broad-band receiver are split into several narrow-band channels (FX or XF), to measure visibilities at multiple frequencies, and to allow the correct uv-coverage to be used.

In the early days of wide-band receivers,
this was not the case......

$S(u,v)_\nu$ $\quad$ $I_\nu^{psf} = [F^{-1}] S_\nu$



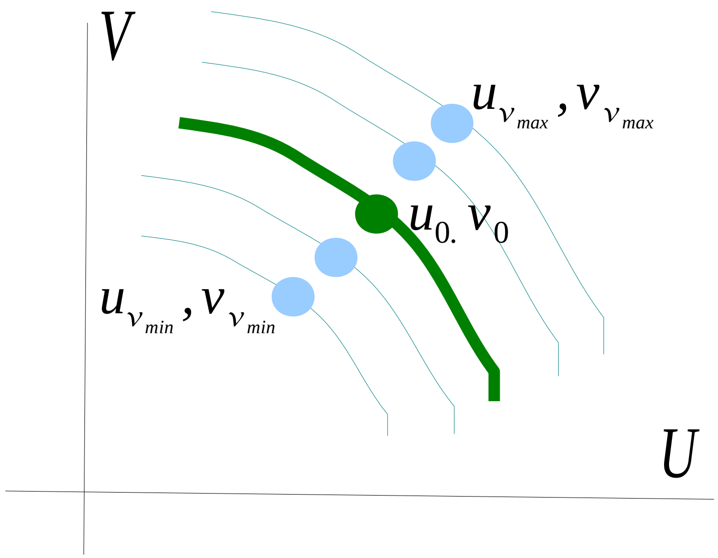
Bandwidth smearing (chromatic aberration)

In the early days of continuum-observing, only one visibility was computed across the entire bandwidth of the receiver, and attributed to the reference (or middle) frequency ν_0 . Delay-tracking was also done only at ν_0 .

The visibility $V(u_\nu)$ is mistakenly mapped to $u_0 = \frac{b\nu_0}{c} = \frac{\nu_0}{\nu} u_\nu$

Similarity theorem of Fourier-transforms :

$$V\left(\frac{\nu_0}{\nu} u_\nu, \frac{\nu_0}{\nu} v_\nu\right) \longrightarrow \left(\frac{\nu}{\nu_0}\right)^2 I\left(\frac{\nu}{\nu_0} l, \frac{\nu}{\nu_0} m\right)$$



A radial shift in the source position, with frequency.

=> Radial smearing of the brightness-distribution.

The shape of the smearing is controlled by the bandshape (See Chapter 18 by Bridle & Schwab)

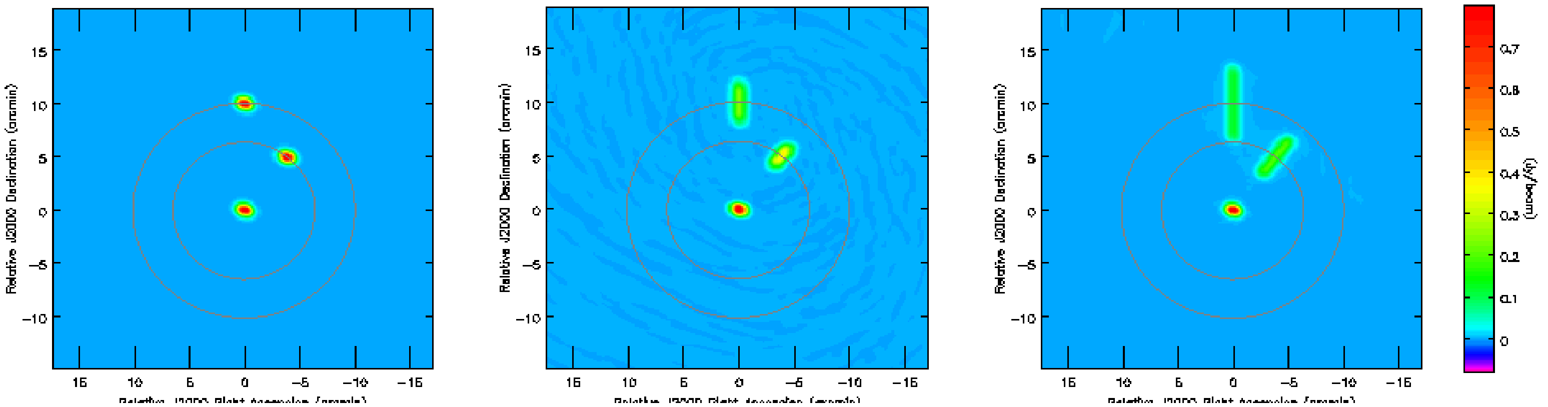
The measured visibility can be written as a weighted average along a radius in the UV-plane, where the "weight-spectrum" is given by the bandpass shape and delay-tracking error. This is further written as a product of the visibility function and a "delay function", which, in the image-domain becomes a position-dependent convolution with a radial 'distortion function'.

Note : Excessive channel-averaging during post-processing has a similar effect.

Bandwidth smearing (chromatic aberration)

An (exaggerated) example of bandwidth-smearing with a 1-2 GHz signal......

Bandwidth : 2 MHz 200 MHz 1.0 GHz



Contours represent 5 and 10 arcmin distances from the phase-center.

(1) If the bandpass shape is known, it is is possible to recover (partially) from bandwidth-smearing, but it is always best to avoid the problem altogether.

(2) Construct visibilities for multiple narrow-band channels, each with its own delay-tracking.

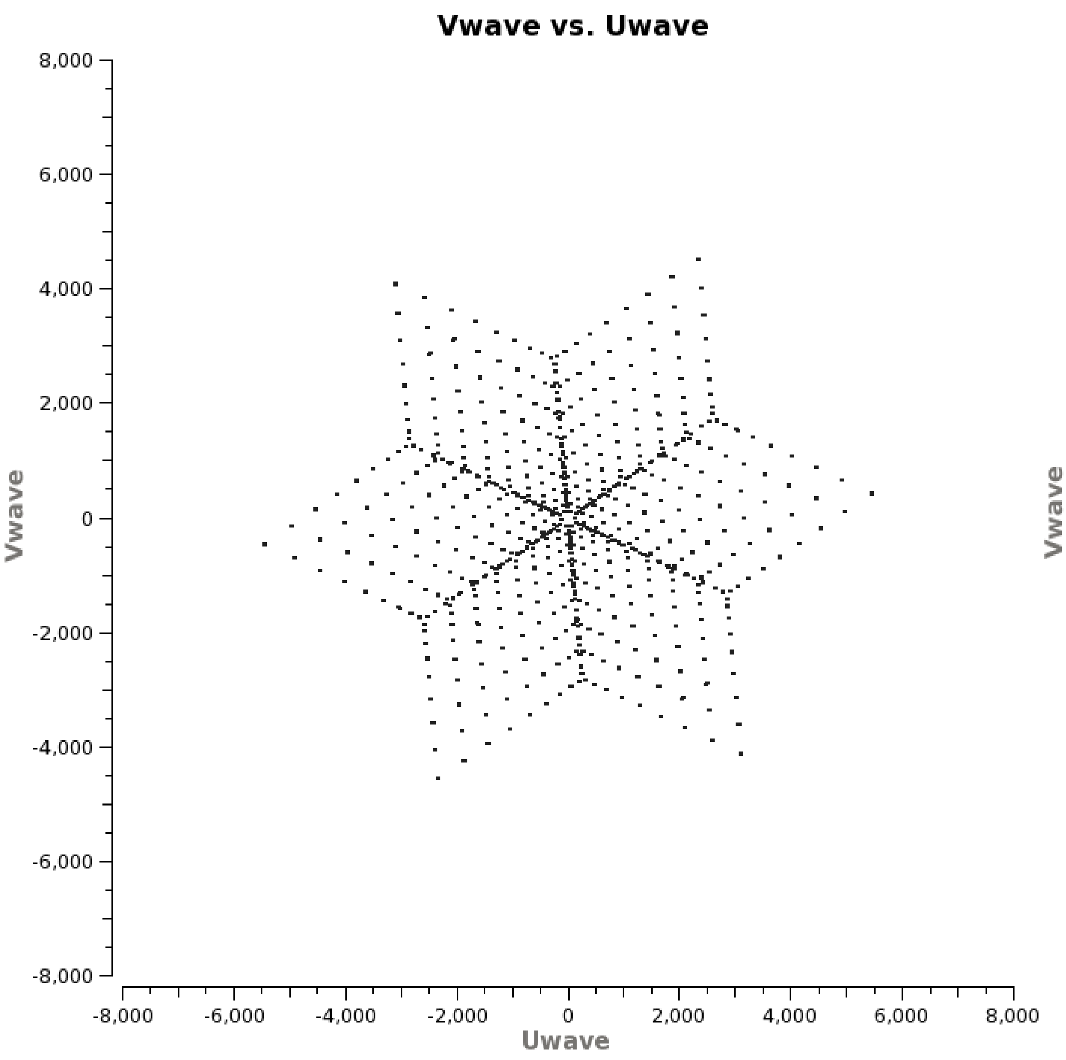
Bandwidth Smearing Limit (maximum channel-width) : $\delta\nu \; < \; \nu_0 \frac{D}{b_{max}}$

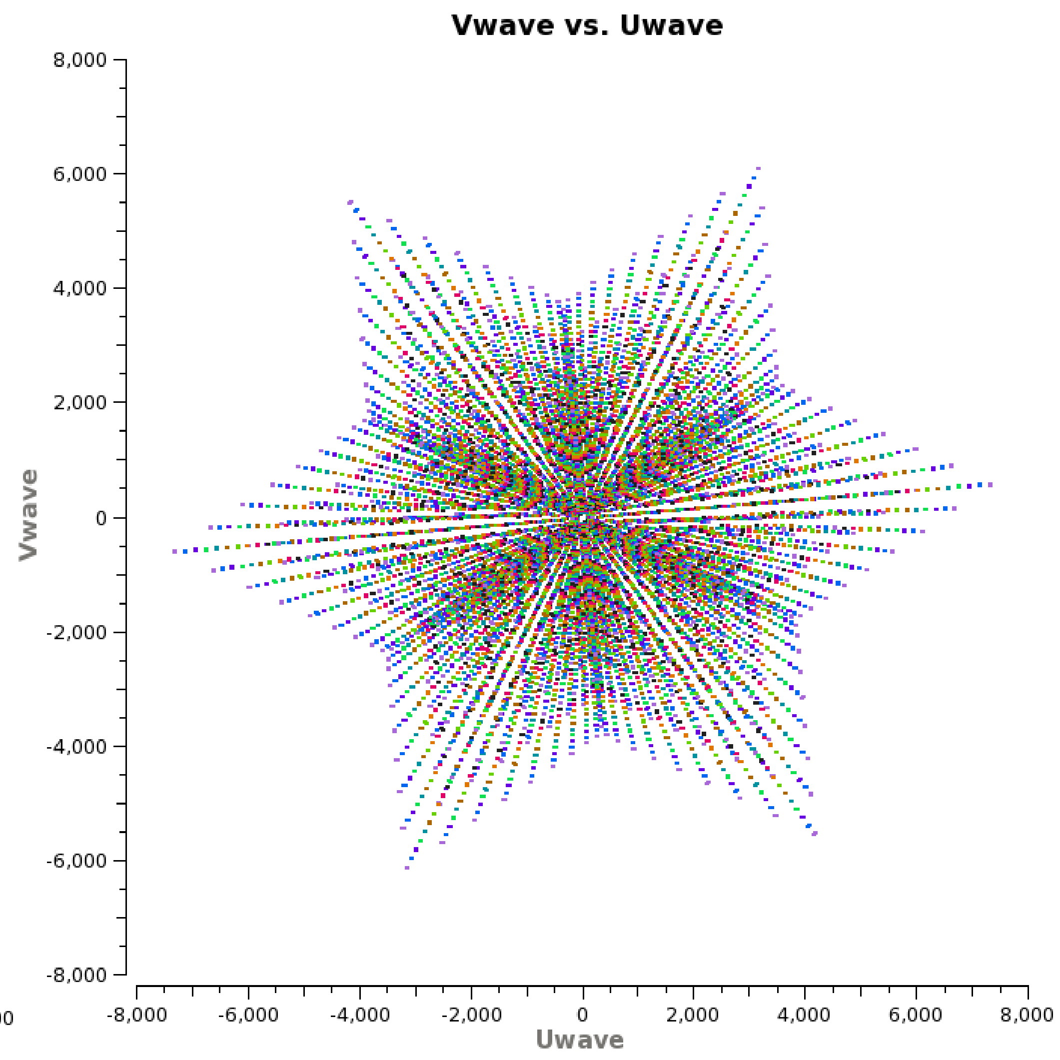
=> Place $V(u_\nu)$ at the correct location on the UV-plane.

=> UV-range spanned by $\delta\nu$ is smaller than a uv-grid cell (1 / f-o-v)

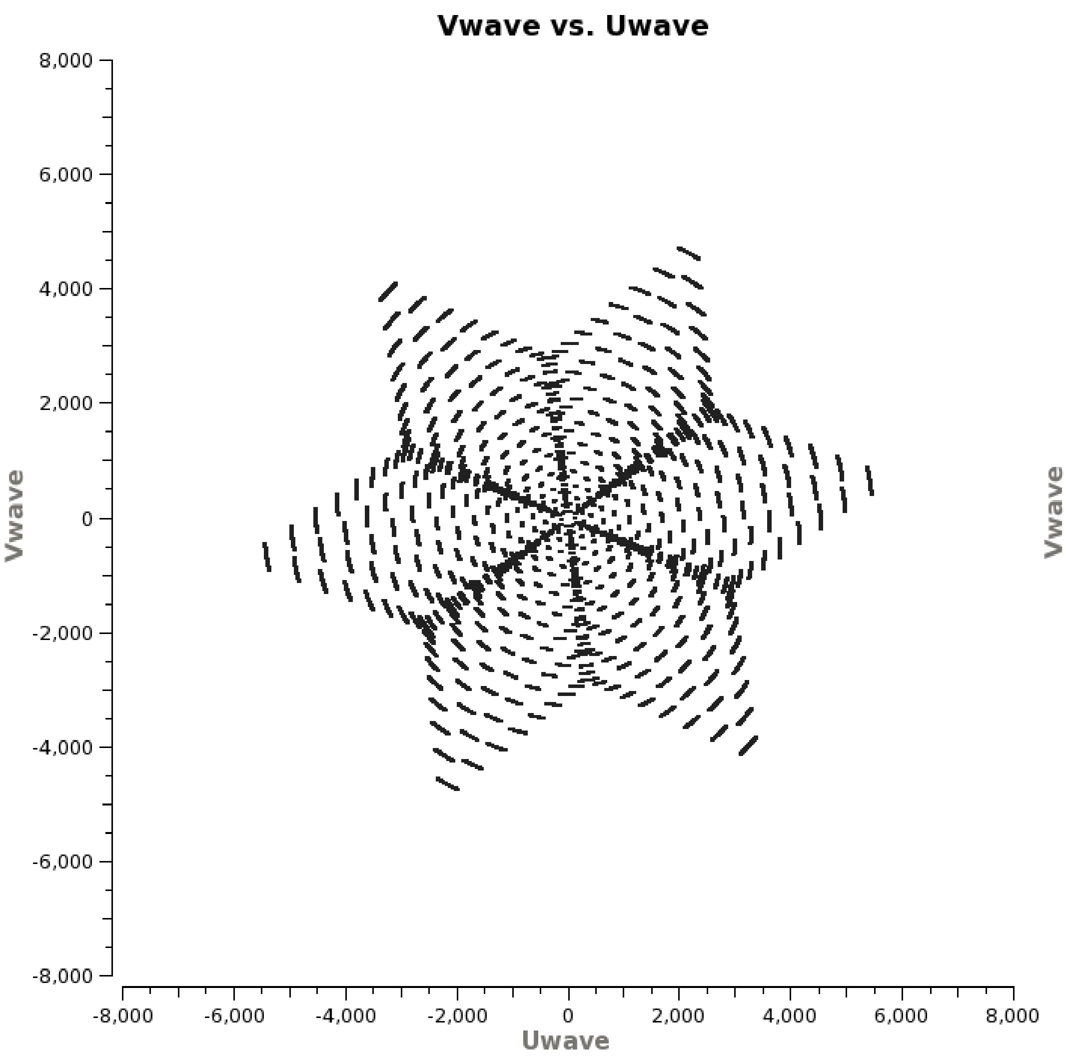
For example, at 1.4 GHz,
33 MHz (D-config),
10 MHz (C-config),
3 MHz (B-config),
1 MHz (A-config)

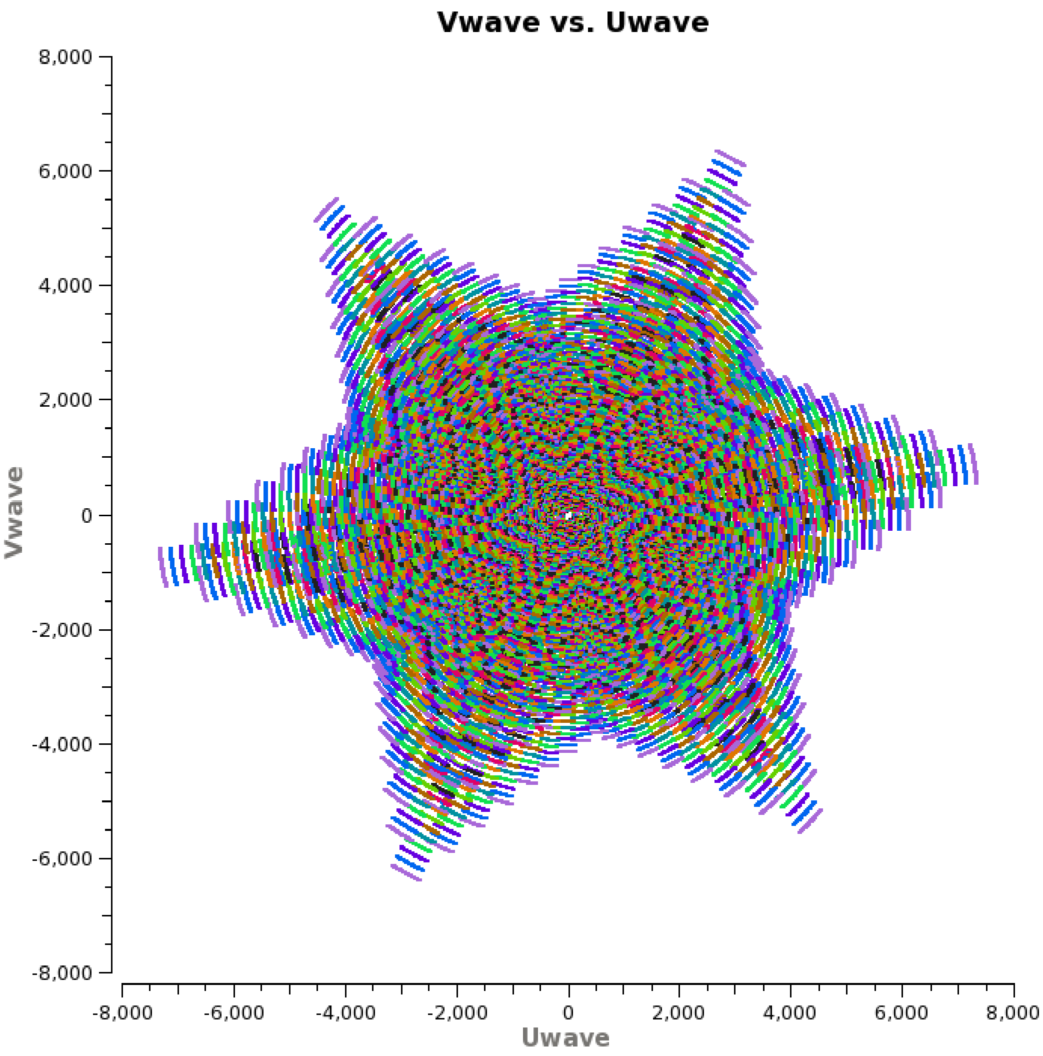
Multi-Frequency-Synthesis



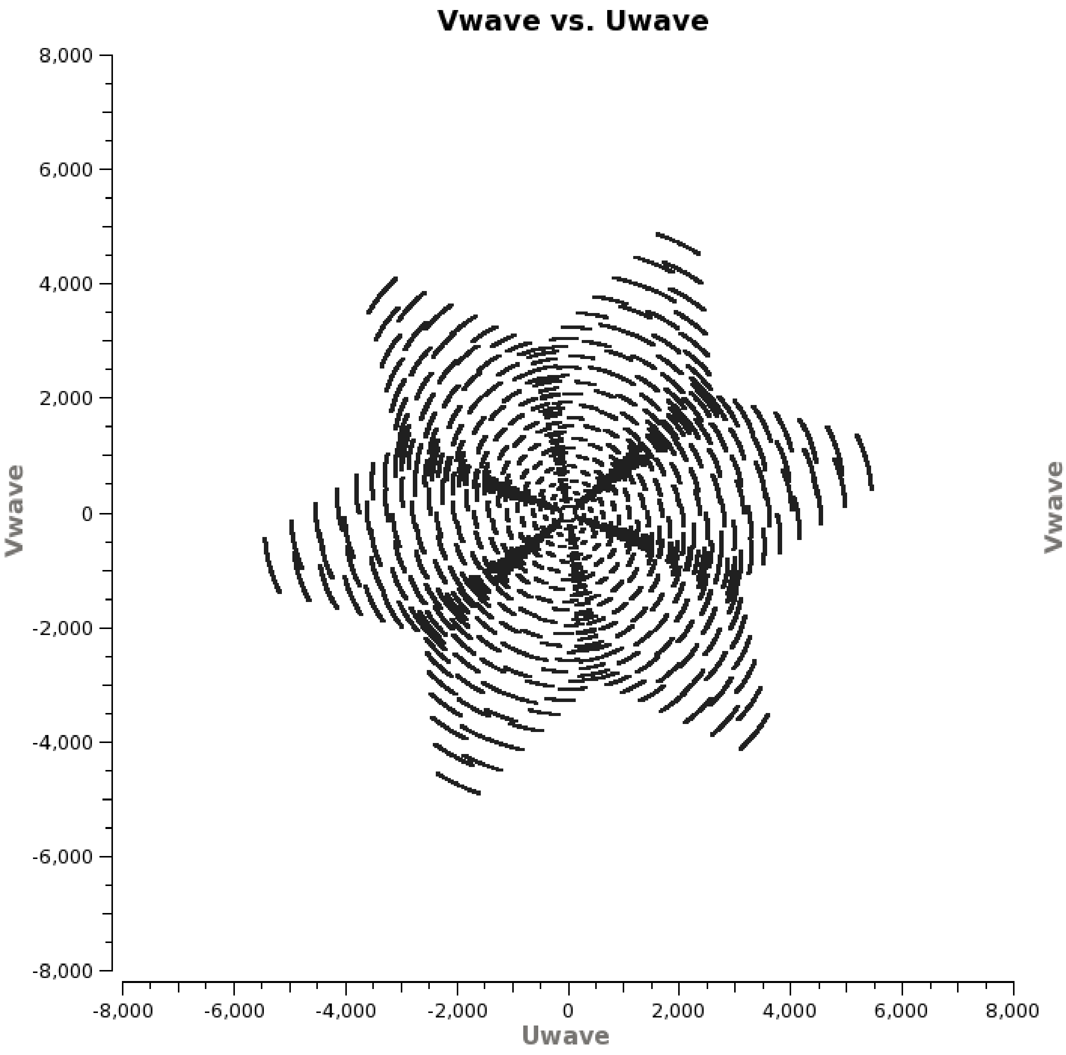


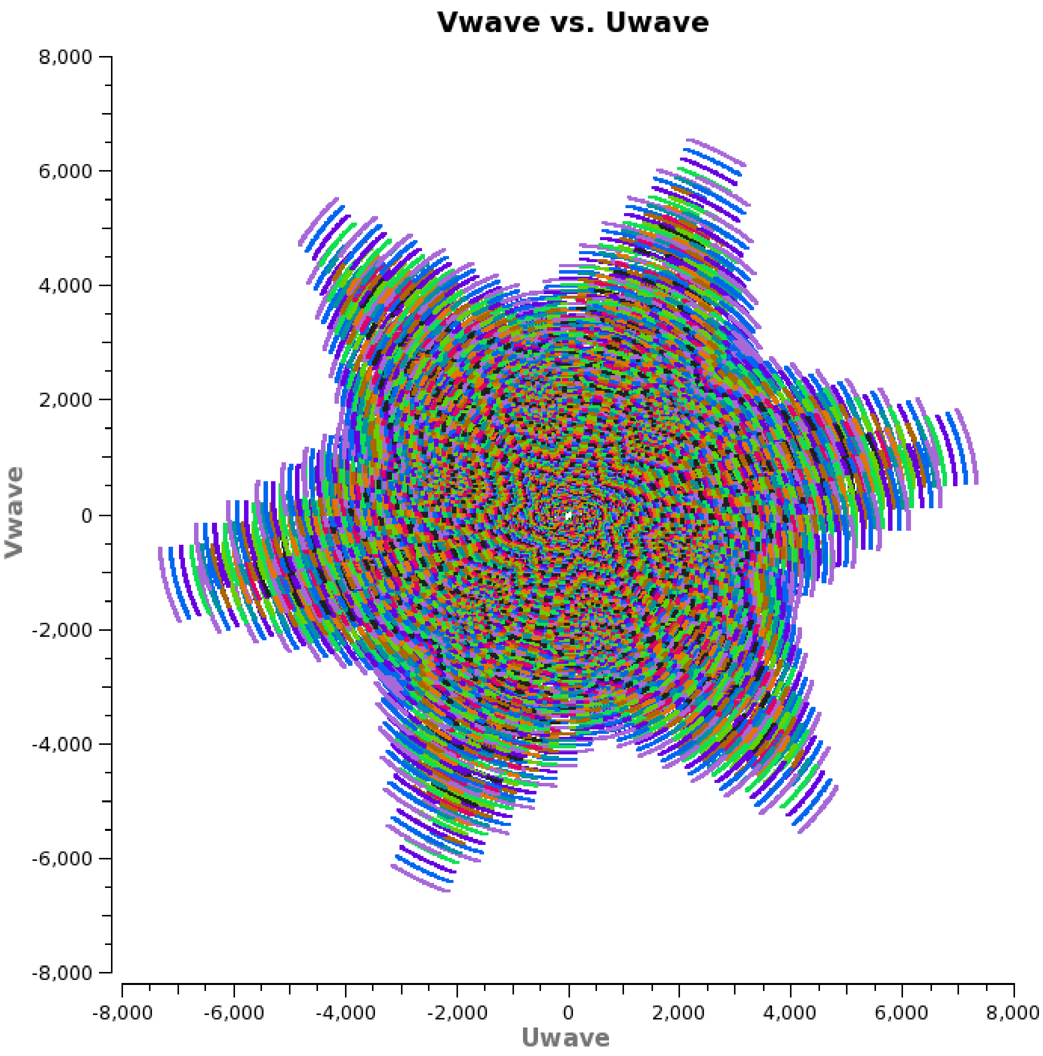
Multi-Frequency Synthesis



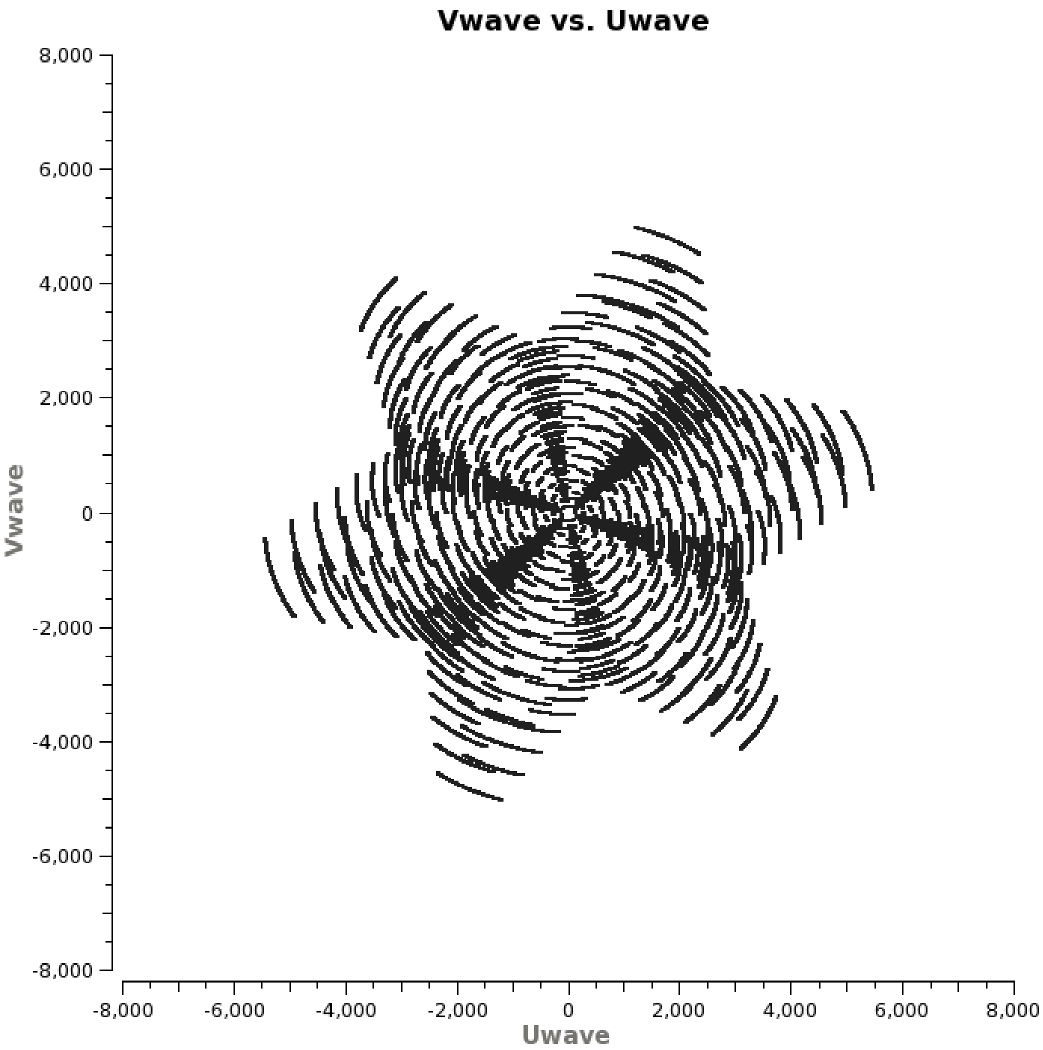


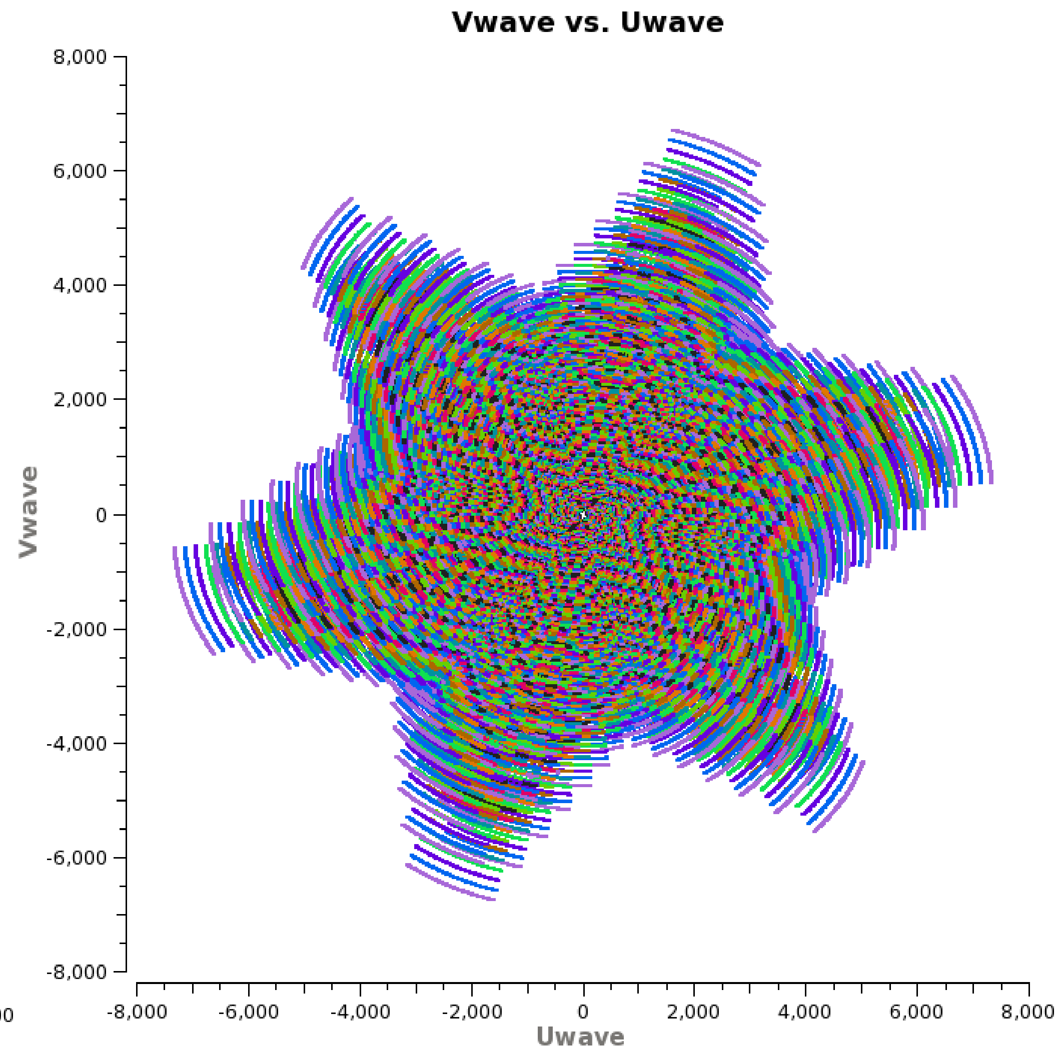
Multi-Frequency Synthesis



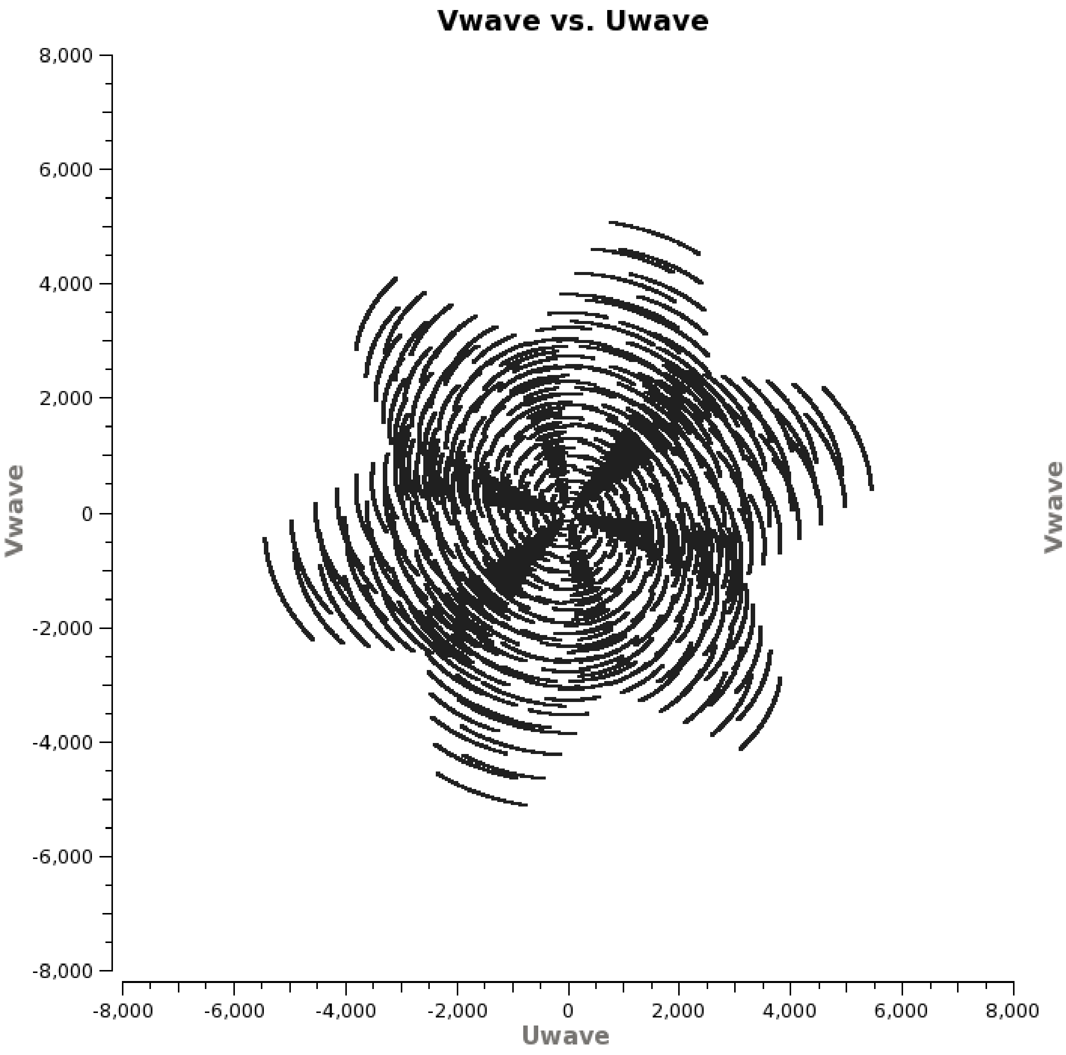


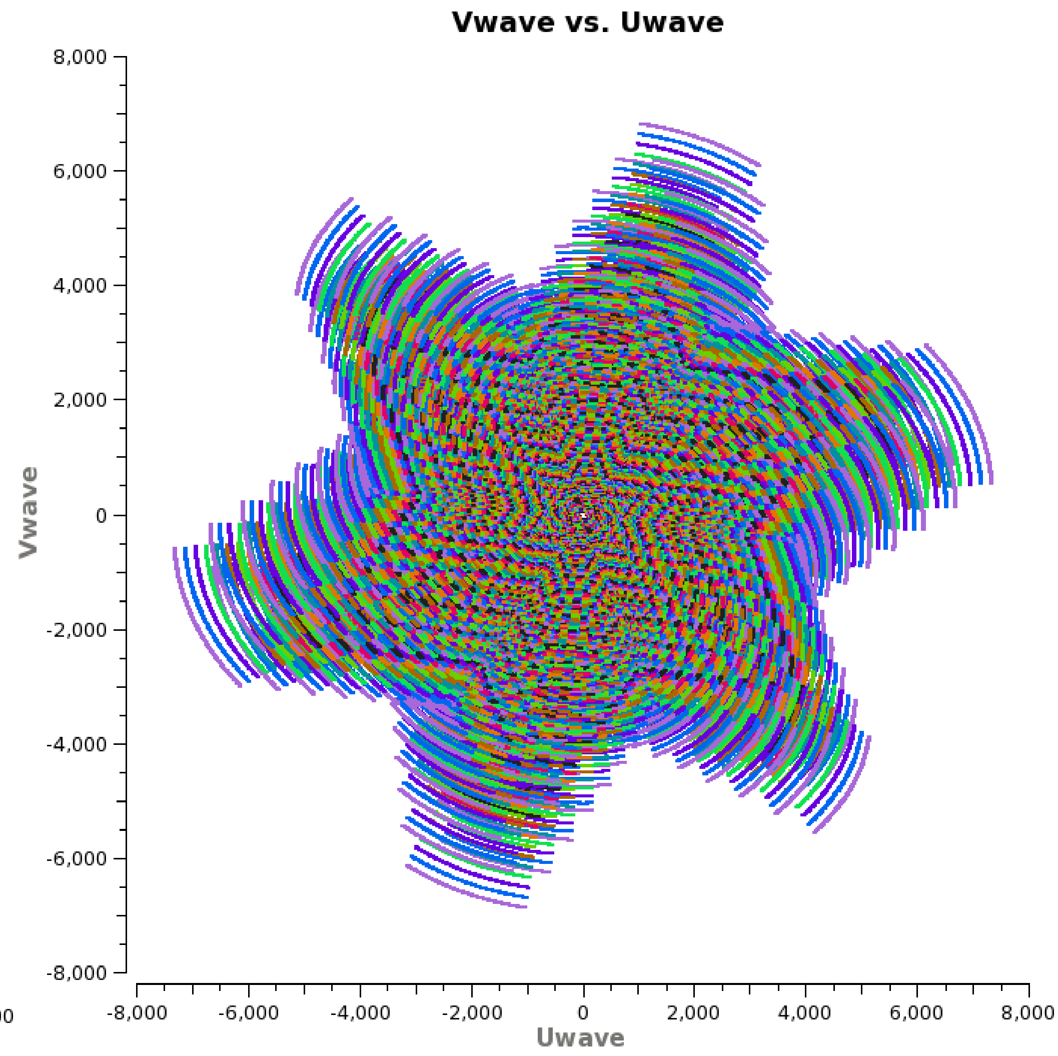
Multi-Frequency Synthesis



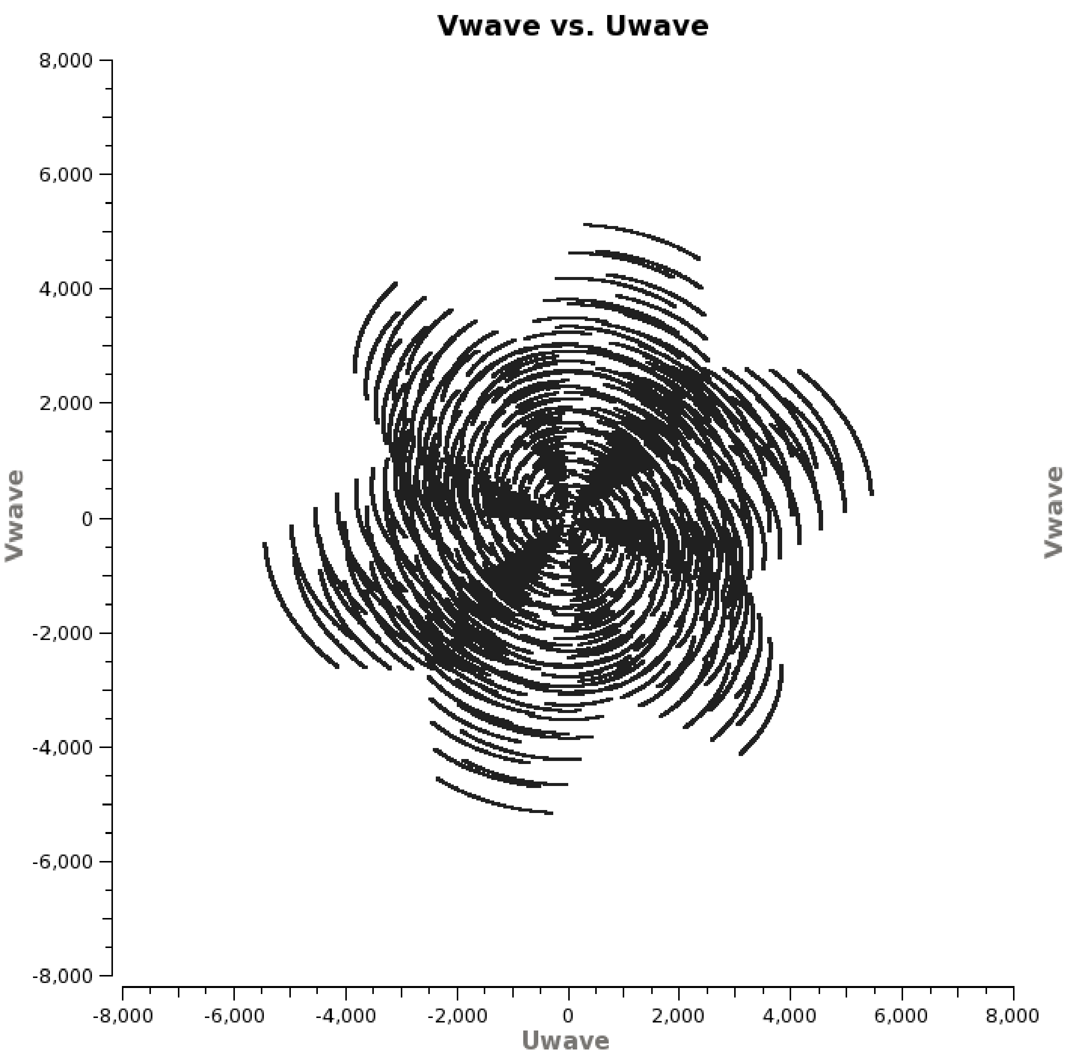


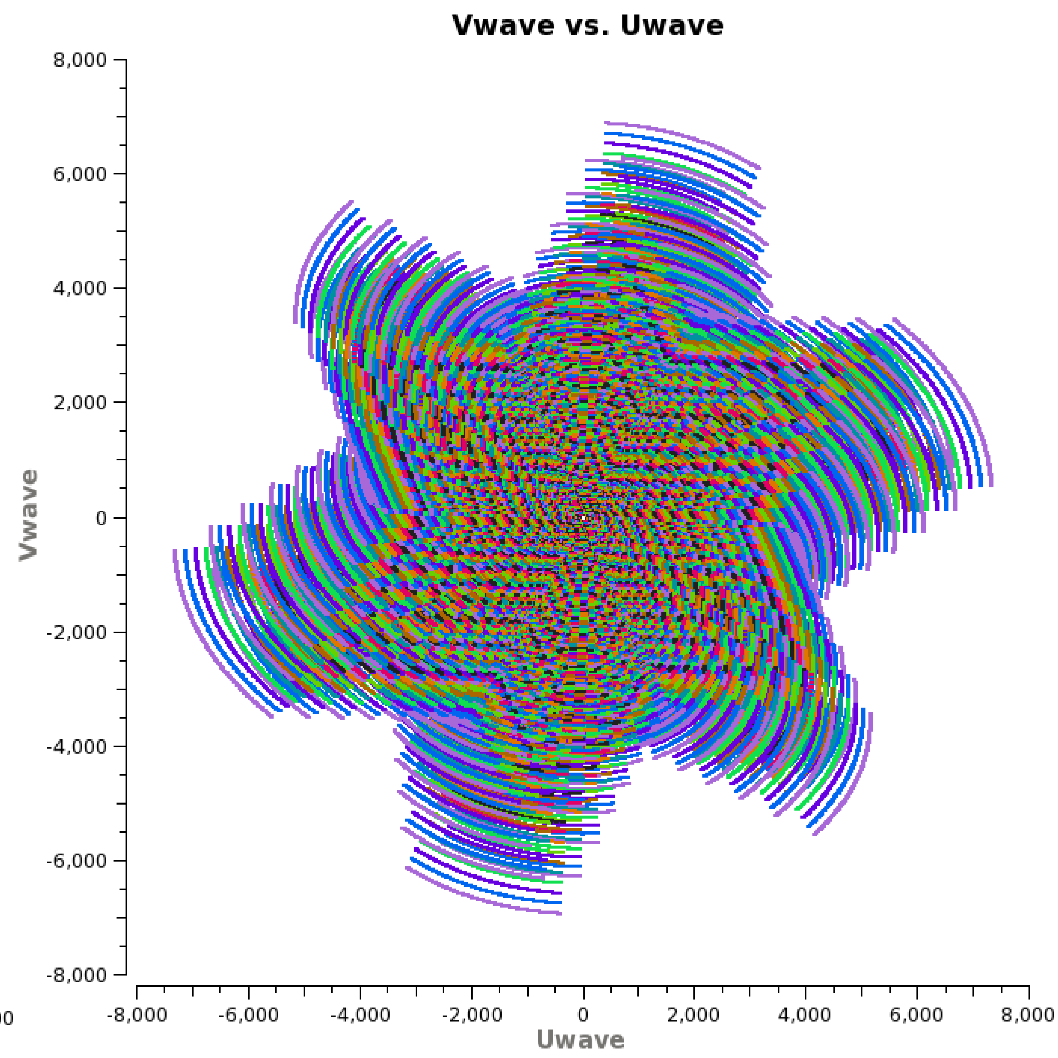
Multi-Frequency Synthesis



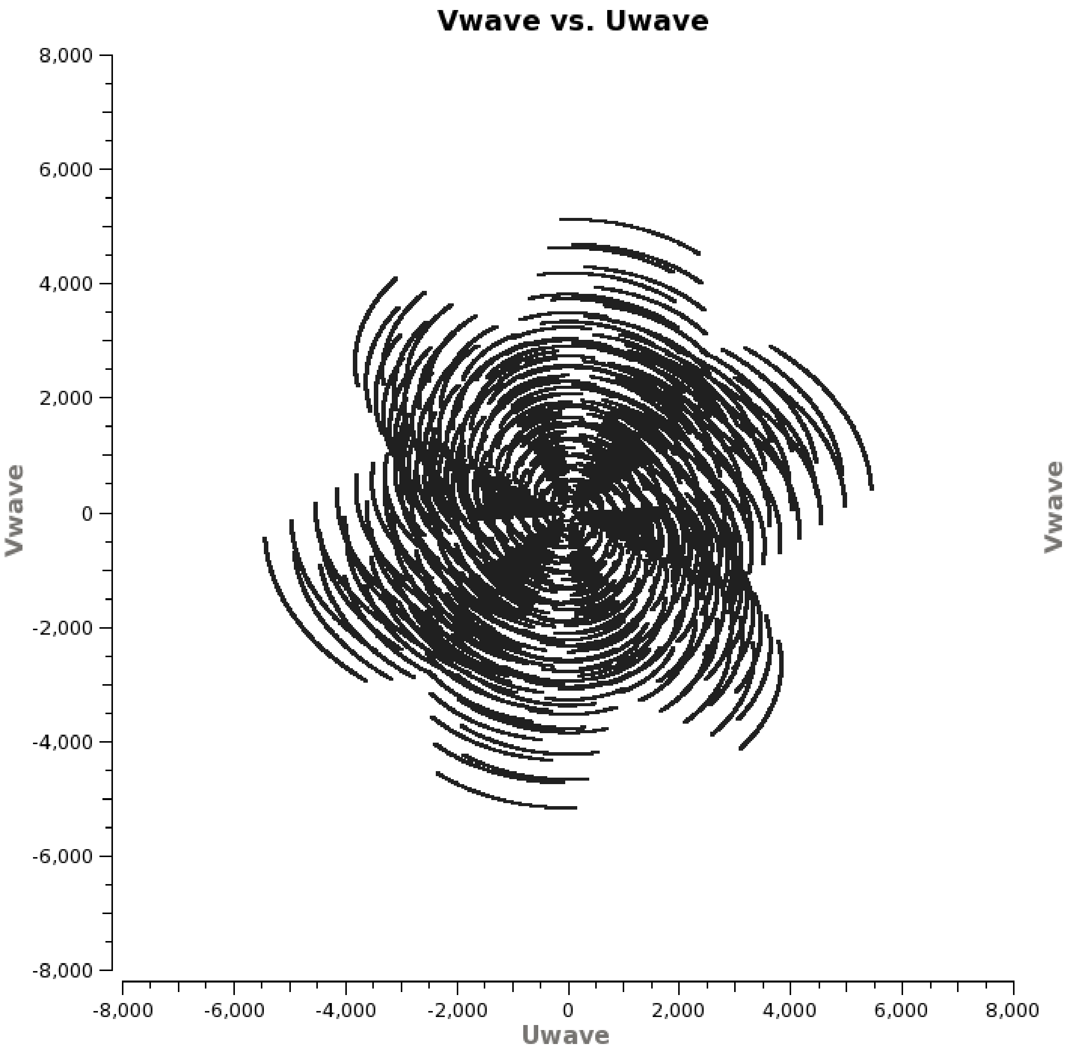


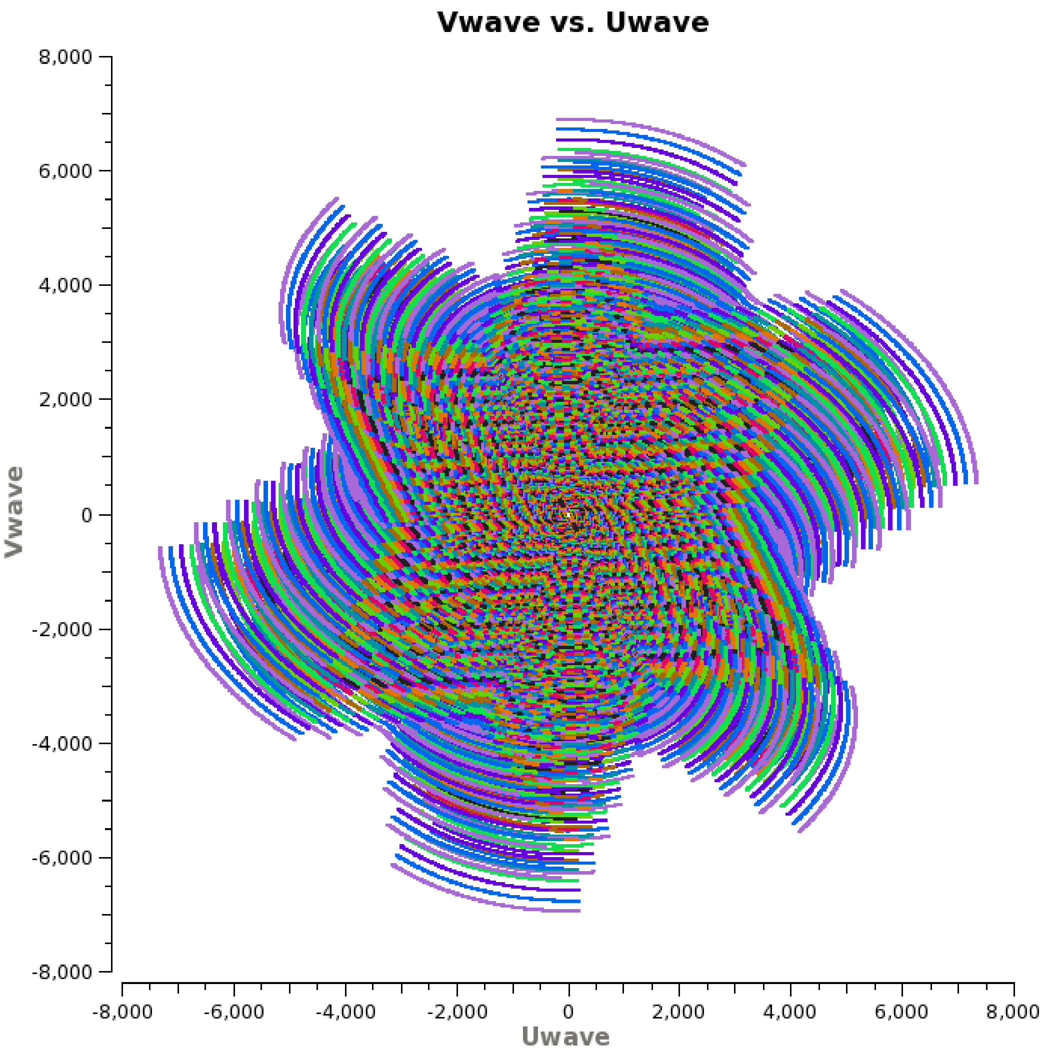
Multi-Frequency Synthesis



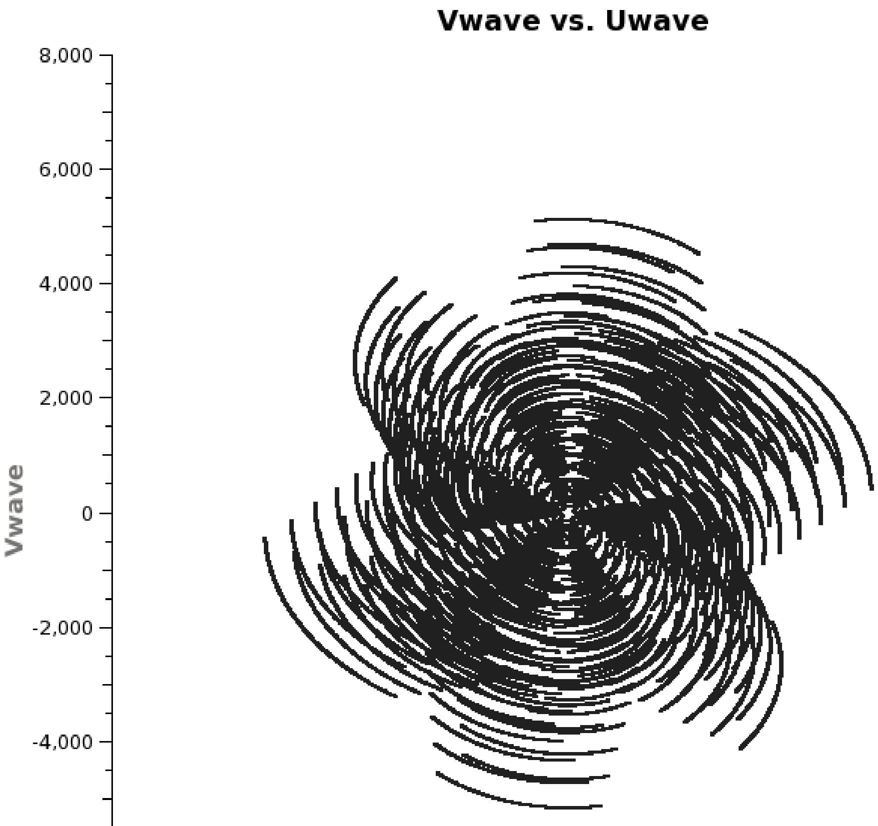


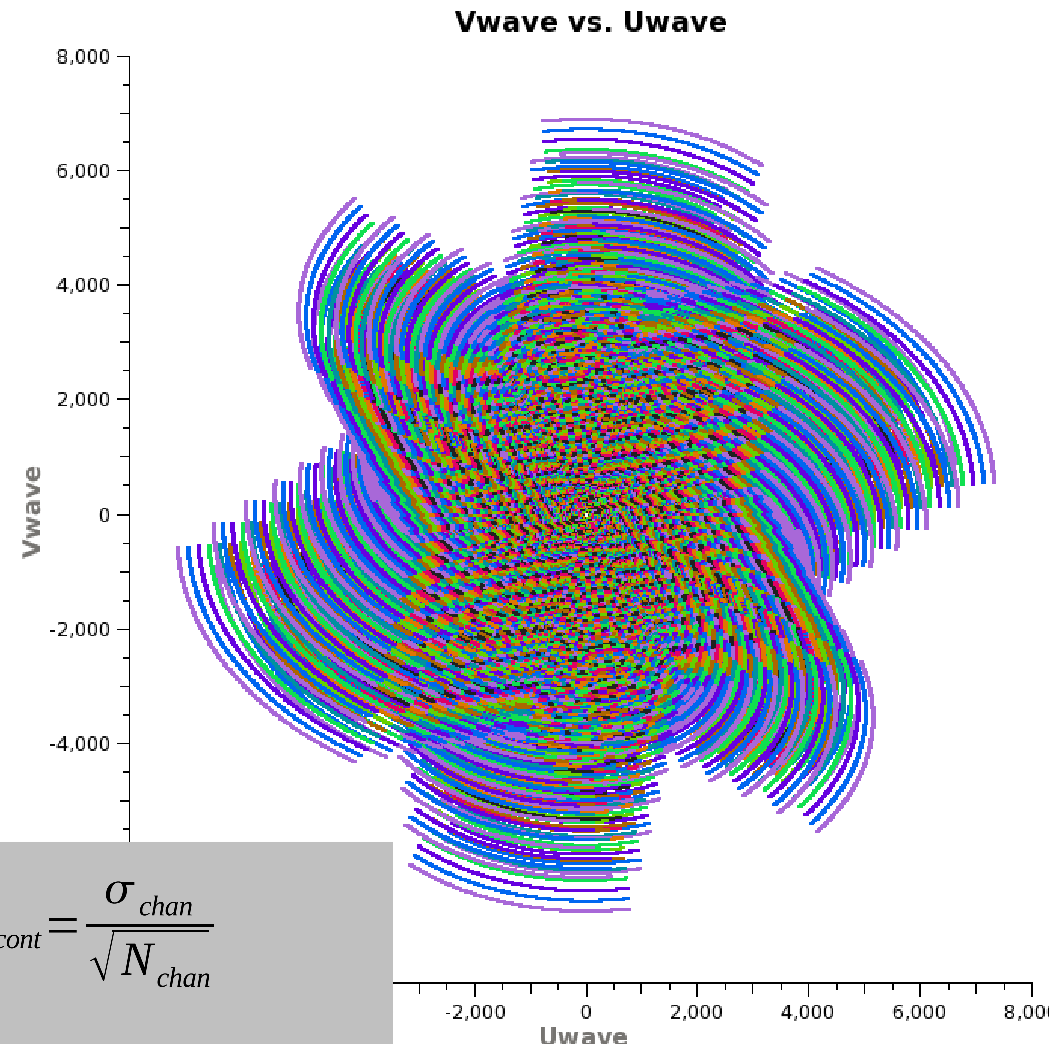
Multi-Frequency Synthesis





Multi-Frequency Synthesis



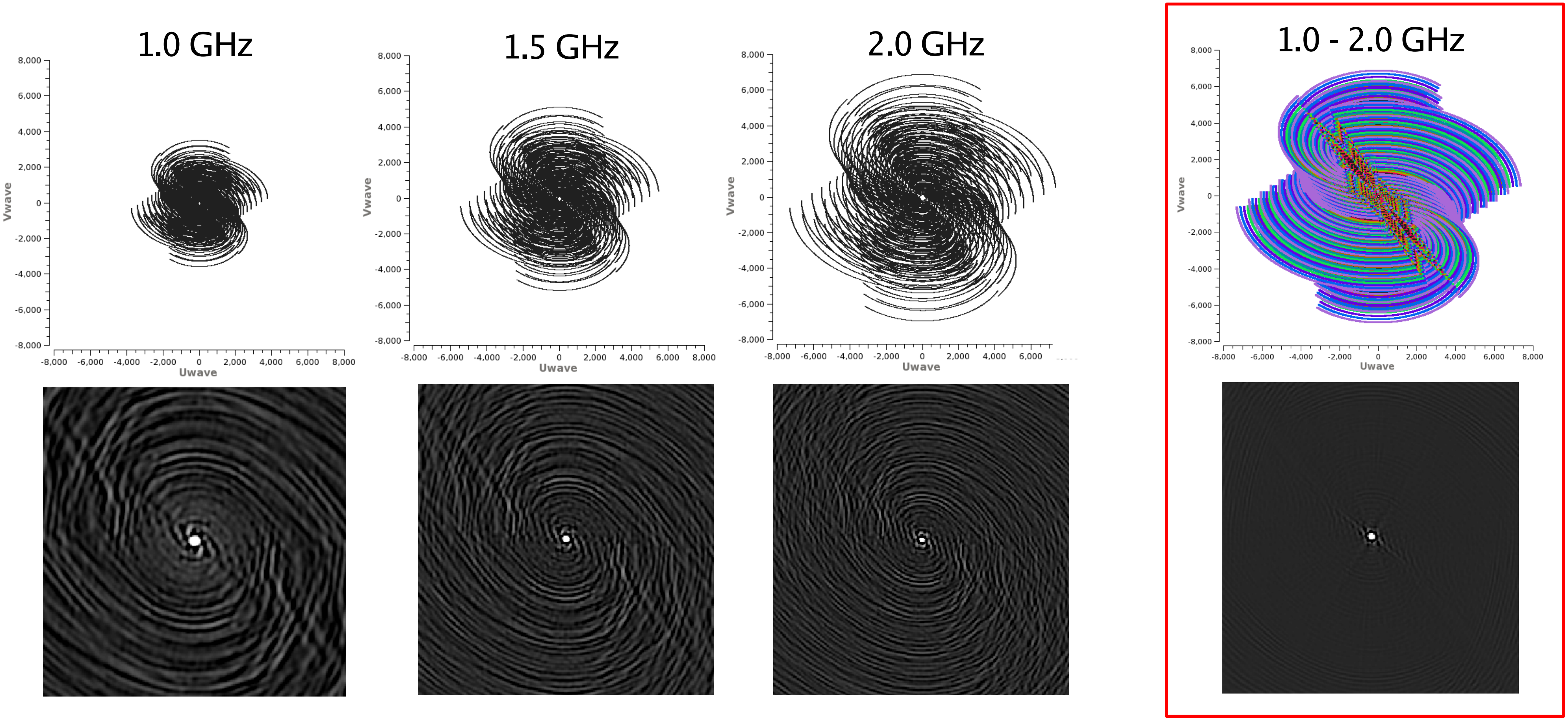


– Overlapping UV-coverage => better sensitivity $\sigma_{cont} = \frac{\sigma_{chan}}{\sqrt{N_{chan}}}$

– Increased UV-filling => better imaging-fidelity

– Larger spatial-frequency range => better angular-resolution $\frac{\lambda}{b_{max}}$

Point Spread Functions : Single vs Multi Frequency



JVLA D-config, 6 hour synthesis : Robust-weighted PSFs.

For a flat-spectrum sky-brightness, channels contain multiple measurements of the same visibility function

$$V(u_\nu, v_\nu) = \int\int I(l,m)\, e^{2\pi i (u_\nu l + v_\nu m)}\, dl\, dm$$

=> Standard Imaging and Deconvolution applies

Frequency-dependent Sky Brightness

When the source intensity varies with frequency, different channels measure the visibility function of different sky-brightness distributions

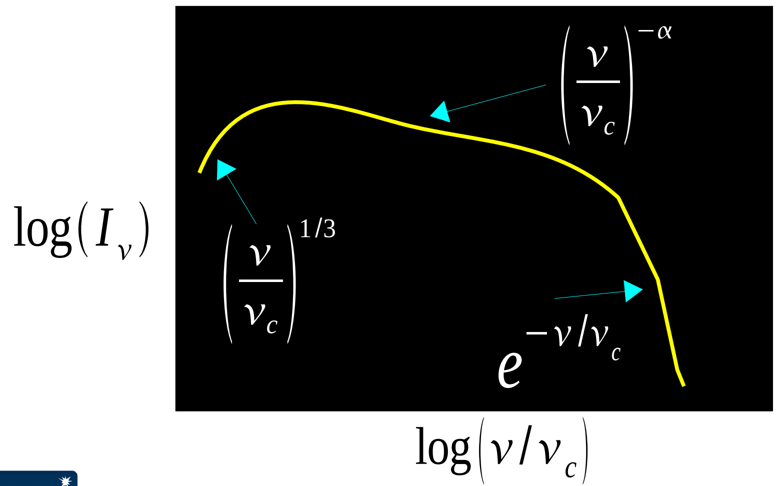
$$V(u_\nu, v_\nu) = \int\int I(l,m,\nu)\, e^{2\pi i (u_\nu l + v_\nu m)}\, dl\, dm$$

=> Cannot apply standard imaging techniques To the combined visibilities.

(1) Each point on the source has an intrinsic spectrum :

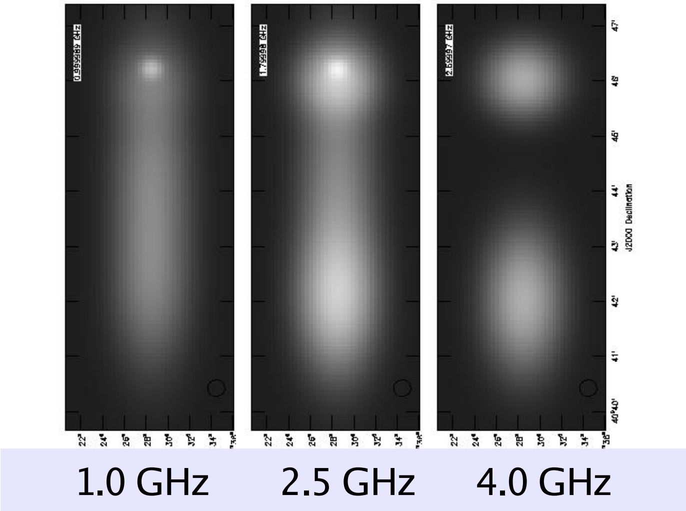
- The radio synchrotron spectrum is often a power law with varying spectral-index (spectral curvature)

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

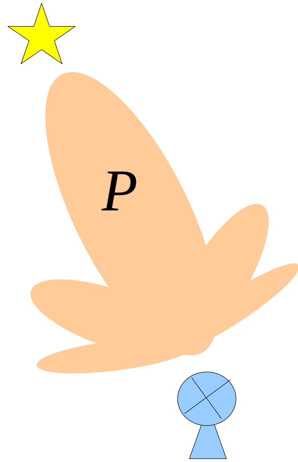


(2) Frequency probes source structure :

- Spectrum traces velocity structure (doppler-shifted line emission)
- Frequency probes depth in a 3D volume (solar flares/loops)



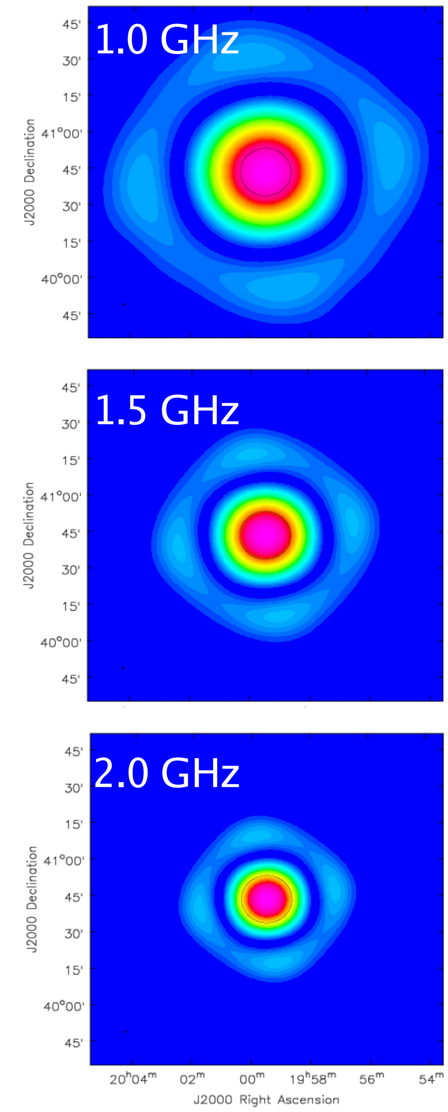
Frequency Dependent Antenna response (Primary-Beam)



Primary-beam scales with frequency

$$HPBW_{\nu} = \frac{\lambda}{D} = \frac{c}{\nu D}$$

EVLA Primary Beams



Bandpass calibration does **not** correct for off-axis gains or their frequency-dependence.

The average effect in the image-domain is a multiplication by an artificial PB-spectrum

=> Away from the pointing center, the Primary Beam introduces an artificial 'spectral index' on the measured sky : $\alpha_{observed} = \alpha_{sky} + \alpha_{PB}$

About -0.4 at the PB=0.8 (6 arcmin from the center at L-Band)
About -1.4 at the HPBW (15 arcmin from the center at L-Band)

Wide-field sensitivity depends on frequency.

Continuum sensitivity to a source with with a non-flat spectrum $\propto \frac{\sum_{\nu} w_{\nu} \cdot P_{\nu} \cdot I_{\nu}}{\sum_{\nu} I_{\nu}}$

What is wide-band Imaging ?

– Use broad-band receivers to increase instantaneous continuum sensitivity

-- Measure visibilities in many narrow-band channels to avoid bandwidth-smearing

-- Use multi-frequency-synthesis

--- to increase the uv-coverage used in deconvolution and image-fidelity
--- to make images at the angular-resolution allowed by the highest frequency

– Account for the sky spectrum

--- by modeling and reconstructing the spectrum as well as the intensity
--- by flattening it out (bandpass self-calibration)

– Account for the frequency-dependent off-axis gains of the antennas

--- by including the PB-spectrum in the sky-spectrum model
--- by applying wide-field imaging techniques to eliminate the effect during imaging.

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(2) Imaging Algorithms

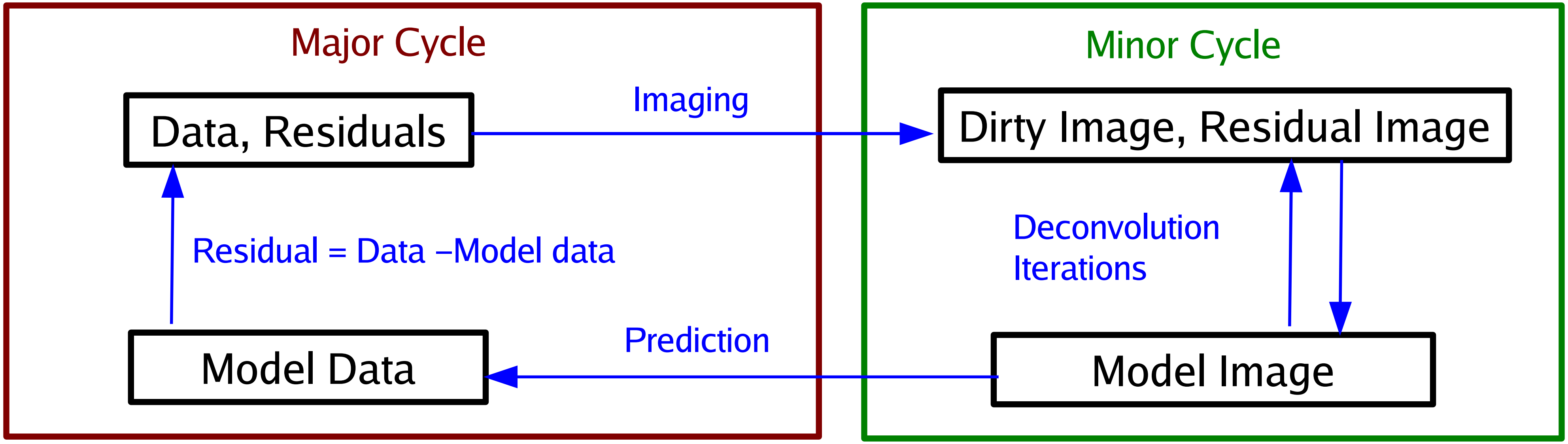
- Recap. of image-reconstruction methods
- Cube vs Continuum imaging (intensity and spectrum)

(3) Examples of various effects/corrections/errors

(4) Example of wide-band imaging trials on JVLA observations of a Galactic super-nova-remnant between 1-2 GHz.

Basic Imaging and Deconvolution (recap.)

Image Reconstruction : Iteratively fit a sky-model to the observed visibilities.



Measurement Equation : $[A] I^m = V^{obs}$

– The operator $[A]=[S][F]$ includes the UV-coverage, Instrumental-gains, data-weights.
– The vector I^m is the sky model (e.g. image-pixels, Gaussian set)

Fit the parameters of I^m via a weighted least-squares optimization :

– Minimize $\chi^2 = [V^{obs} - A I^m]^T W [V^{obs} - A I^m]$ ==> $\frac{\delta \chi^2}{\delta I^m} = 0$

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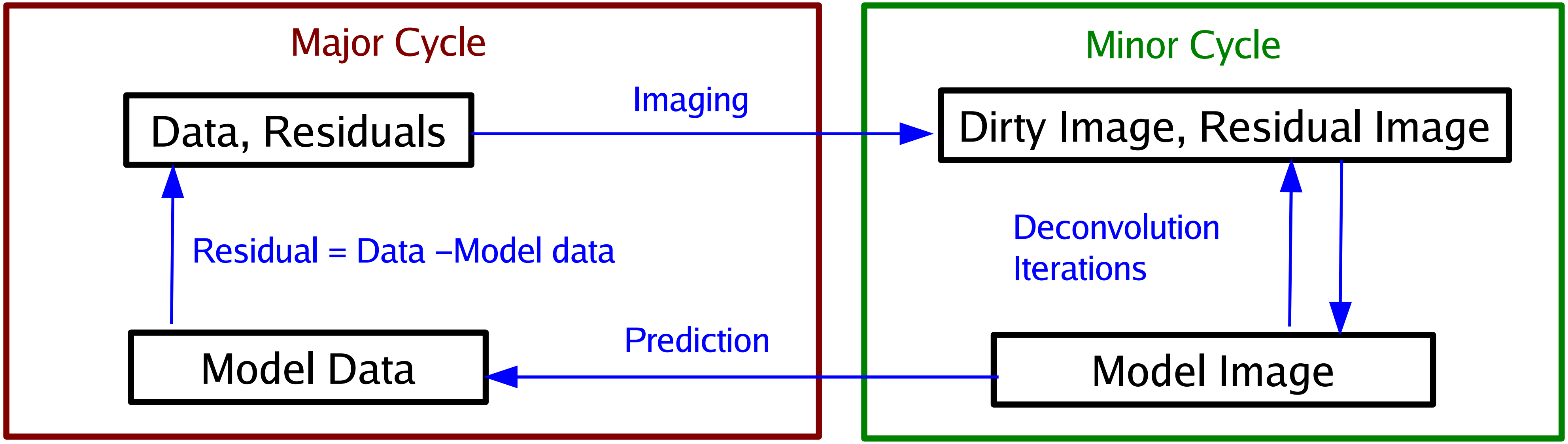

Normal Equations : $[A^T W A] I^m = [A^T W] V^{obs}$

– This describes an image-domain convolution $I^{psf} * I^m = I^{dirty}$

Iterative Solution : $I^m_{i+1} = I^m_i + g[A^T W A]^{+} \left(A^T W \left(V^{obs} - A I^m_i \right) \right)$

Deconvolution

Imaging
(Gridding + iFT)

Prediction
(FT + de-Gridding)

Deconvolution Algorithms (recap)

Clean (Hogbom, Clark, Cotton-Schwab) : $I^{sky} = \sum_x a_x \, \delta(x)$ — Chapters 7 and 8

Maximum Entropy : $I^{sky} = \sum_x a_x \, \delta(x)$ with a smoothness constraint

- Minimizing χ^2 is the same as maximizing likelihood $e^{-\frac{1}{2}\chi^2}$ (Bayesian idea)

Multi-Scale Clean : $I^{sky} = \sum_s [I_s^{shp} * I_s]$ — Solve for components of different sizes (similarly, multi-resolution clean) — Cornwell, 2008; Greisen, 2008

Adaptive-Scale-Pixel Clean : $I^{sky} = \sum_c a_x \, e^{-\frac{(x-x_c)^2}{\sigma^2}}$ — Solve for parameters of a Gaussian set — Bhatnagar, Cornwell 2004

Multi-Frequency Clean : — Conway et al 1991, Sault & Wieringa 1994

$$I_\nu^{sky} = \sum_t I_t \left(\frac{\nu - \nu_0}{\nu_0}\right)^t$$

Model the sky spectrum with polynomials,solve for Taylor-coefficient images.

Multi-Scale Multi-Frequency Clean : $I_\nu^{sky} = \sum_t I_t \left(\frac{\nu - \nu_0}{\nu_0}\right)^t$ where $I_t = \sum_s [I_s^{shp} * I_{s,t}]$

Rau, Cornwell, 2011

Cube (Spectral-Line) Imaging (See D.Meier's lecture)

(1) Image and deconvolve each channel separately (add them to form a continuum image).
– Pre-average channels up to the bandwidth-smearing limit to reduce data size.

(2) During image-restoration, convolve model images from all channels with a common 'restoring beam' derived from the angular-resolution allowed by the lowest-frequency. Smooth residual images to match the same target resolution.

(3) Source spectra can be derived from the smoothed restored images (at low angular resolution)

(4) Imaging-fidelity is limited to the single-frequency UV-coverage

– Reconstructions may not be consistent across frequency

(5) Imaging sensitivity is limited to the single-channel sensitivity $\sigma_{chan} = \sigma_{continuum} \sqrt{(N_{chan})}$

– Will not deconvolve sources that are below σ_{chan} but above $\sigma_{continuum}$

Cube (Spectral-Line) Imaging is the simplest form of wide-band imaging, and good for a quick-look to assess data-quality. It can handle arbitrary spectra and has no spectral-model dependence. For telescopes like JVLA and ALMA, it may suffice for many science-goals.

...... but you can often do better.

Continuum Imaging : multi-scale multi-frequency-synthesis

(2011A&A...532A..71R , arXiv:1106.2745)

Sky Model : Collection of multi-scale flux components whose amplitudes follow a polynomial in frequency

$$I_\nu^{sky} = \sum_t I_t \left(\frac{\nu - \nu_0}{\nu_0}\right)^t \quad \text{where} \quad I_t = \sum_s [I_s^{shp} * I_{s,t}]$$

Instrument Response to a Taylor-polynomial spectrum : $I_t^{psf} = \sum_\nu \left(\frac{\nu-\nu_0}{\nu_0}\right)^t I_\nu^{psf}$

Algorithm : Linear least squares + deconvolution

Data Products : Taylor-Coefficient images $I_{0,}^m I_{1,}^m I_{2,}^m \ldots$ that represent the sky spectrum

- Interpret in terms of a power-law (spectral index and curvature) $I_\nu = I_{\nu_0} \left(\frac{\nu}{\nu_0}\right)^{\alpha + \beta \log(\nu/\nu_0)}$

$$I_0^m = I_{\nu_0} \qquad I_1^m = I_{\nu_0}\alpha \qquad I_2^m = I_{\nu_0}\left(\frac{\alpha(\alpha-1)}{2} + \beta\right)$$

- PB-correction : Model the average PB-spectrum with a Tayor-polynomial, and do a post-deconvolution Polynomial-Division

$$\frac{(I_{0,}^m I_{1,}^m I_{2,}^m \ldots)}{(P_{0,} P_{1,} P_{2,} \ldots)} = (I_{0,}^{sky} I_{1,}^{sky} I_2^{sky} \ldots)$$

New algorithms.....
Still learning usage
patterns and errors

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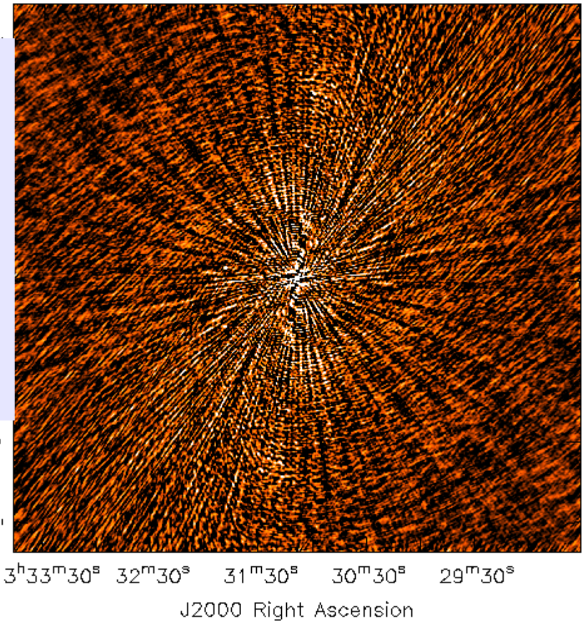
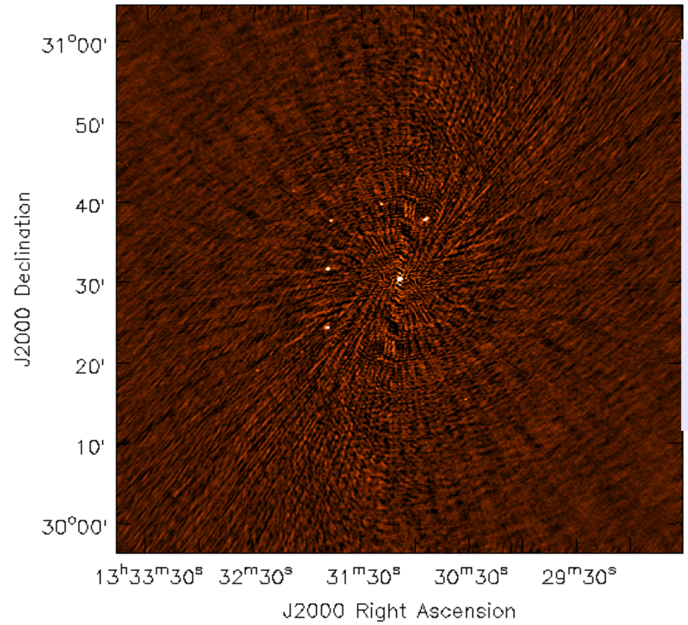
Dynamic-range with MS-MFS : 3C286 example : Nt=1,2,3,4



NTERMS = 1

Rms :
9 mJy -- 1 mJy

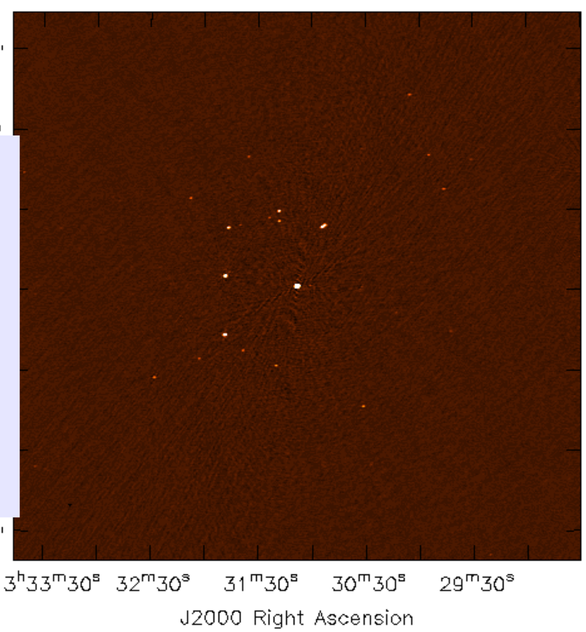
DR :
1600 -- 13000



NTERMS = 2

Rms :
1 mJy -- 0.2 mJy

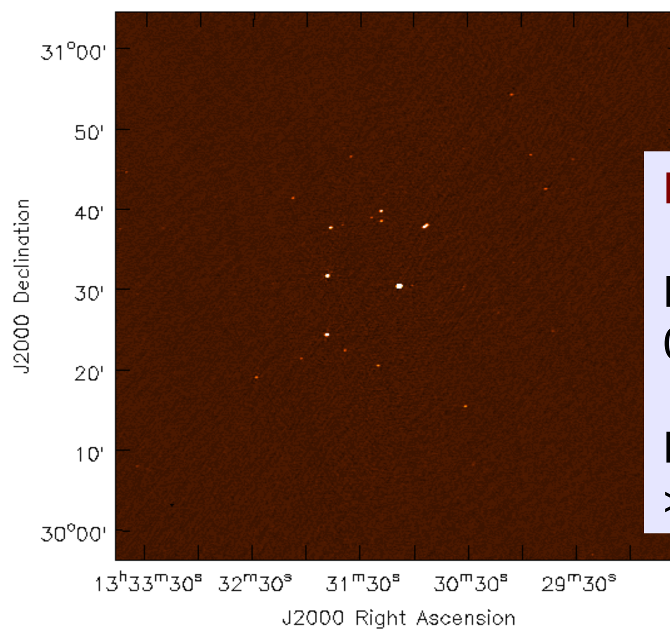
DR :
10,000 -- 17,000



NTERMS = 3

Rms :
0.2 mJy -- 85 uJy

DR :
65,000 -- 170,000

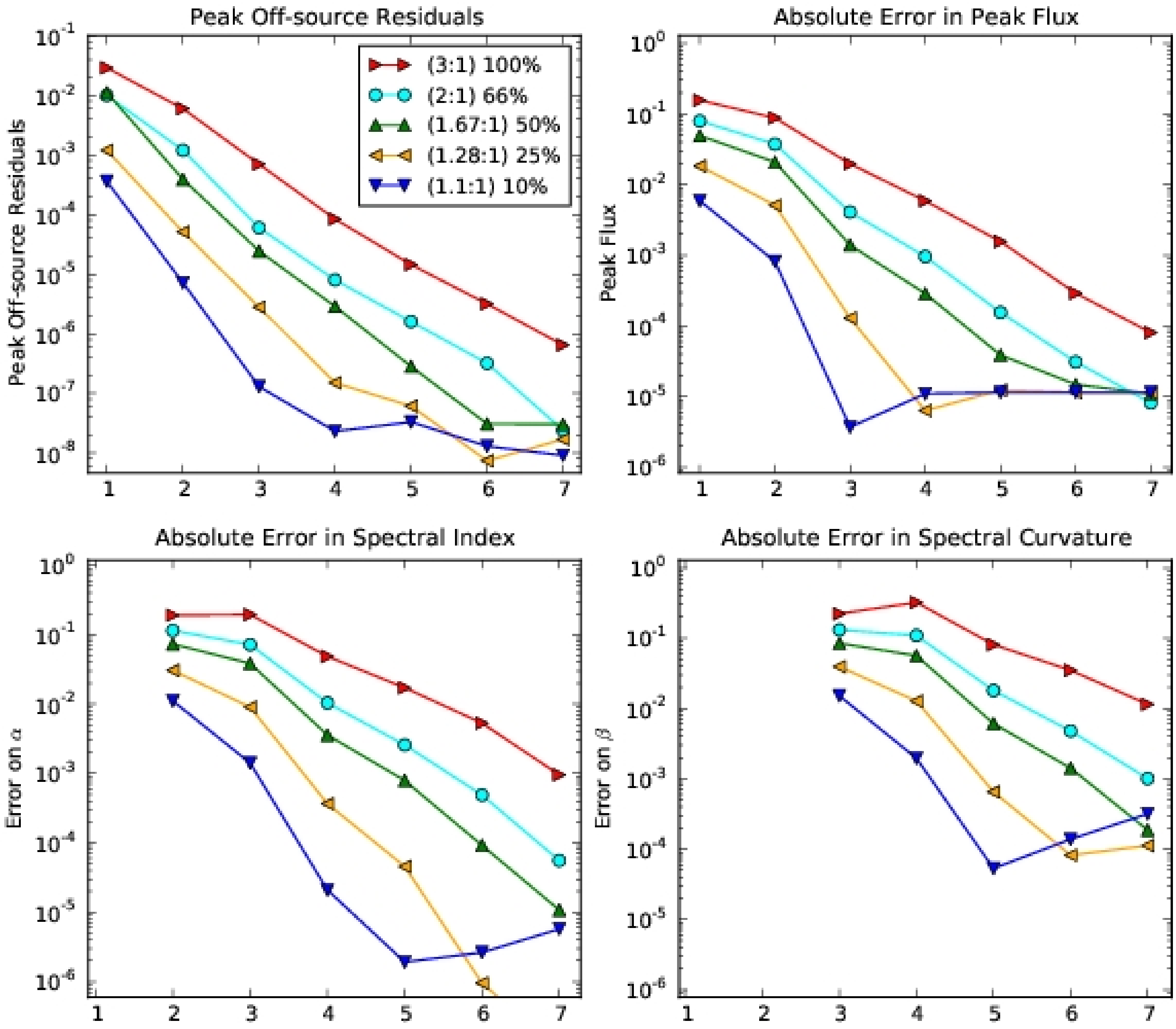


NTERMS = 4

Rms
0.14 mJy -- 80 uJy

DR :
>110,000 -- 180,000

Errors vs Nterms, BWR (for high signal-to-noise data)



If spectra are ignored

=> larger BWR gives larger errors

If there is high SNR,

=> more terms gives smaller errors

Note : These plots are for one point-source at the phase center, with very high signal-to-noise levels, I = 1.0 Jy, Spectral Index = -1.0

In practice, use nterms>2 for high SNR (>100), and only if you can see spectral artifacts in the image with nterms=2

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Spectral Index Accuracy (low signal-to-noise ratios)

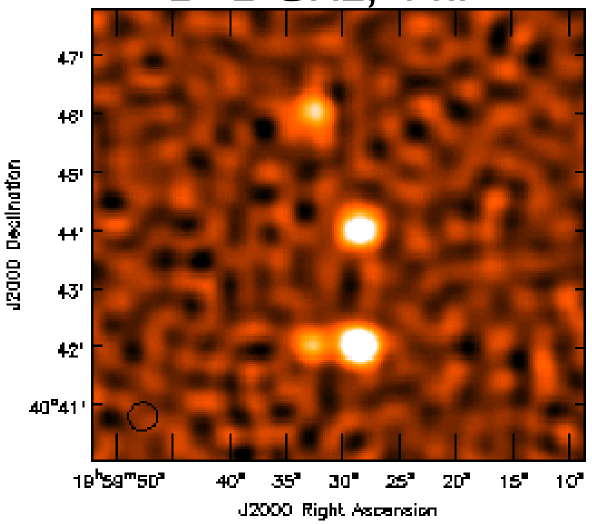
Accuracy of the spectral-fit increases with larger bandwidth-ratio   (basic polynomial fitting)

Source	Peak Flux	SNR	L alpha	C alpha	LC alpha	True
Bottom right	100 uJy	20	-0.89	-1.18	-0.75	-0.7
Bottom left	100 uJy	20	+0.11	+0.06	+0.34	+0.3
Mid	75 uJy	15	-0.86	-1.48	-0.75	-0.7
Top	50 uJy	10	-1.1	0	-0.82	-0.7

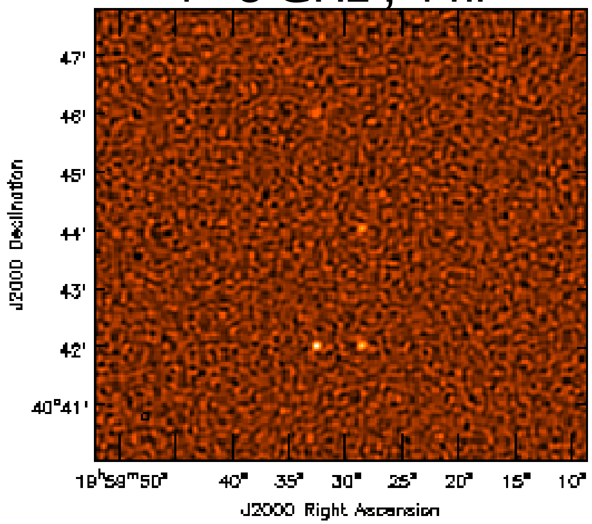
RMS

5 uJy

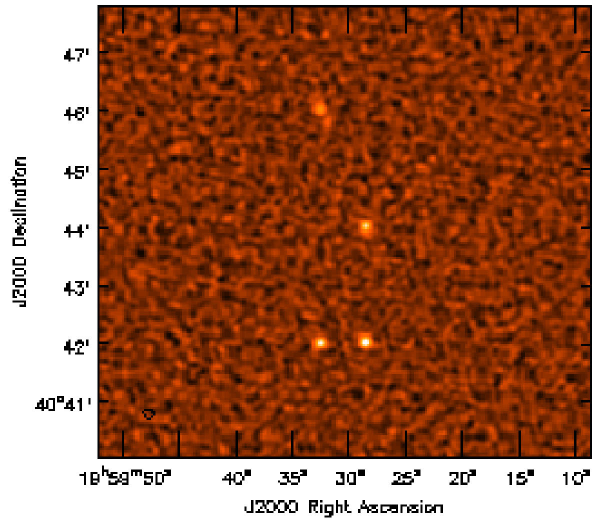
1 –2 GHz, 4 hr



4 - 8 GHz , 4 hr



1 –2 GHz, 4 - 8 GHz, 2 hrs each

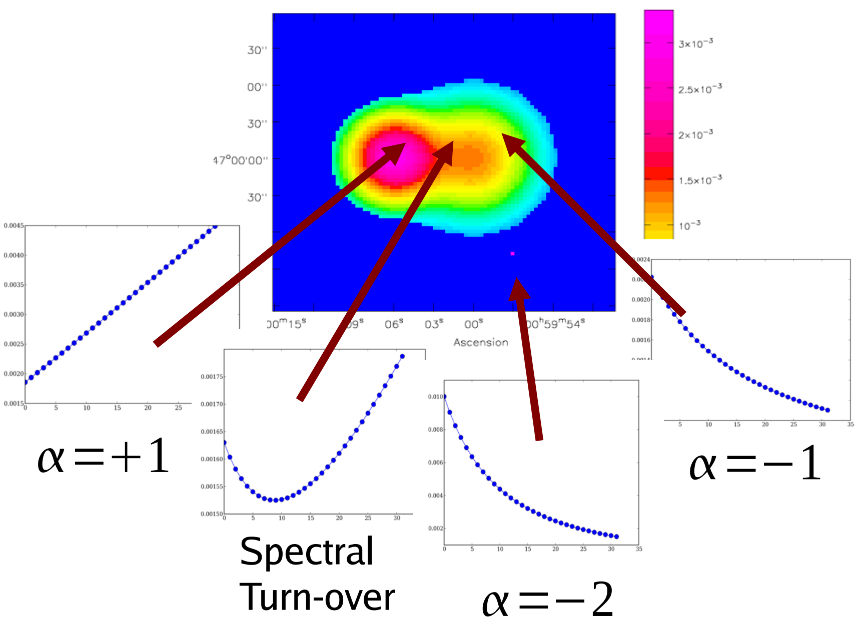


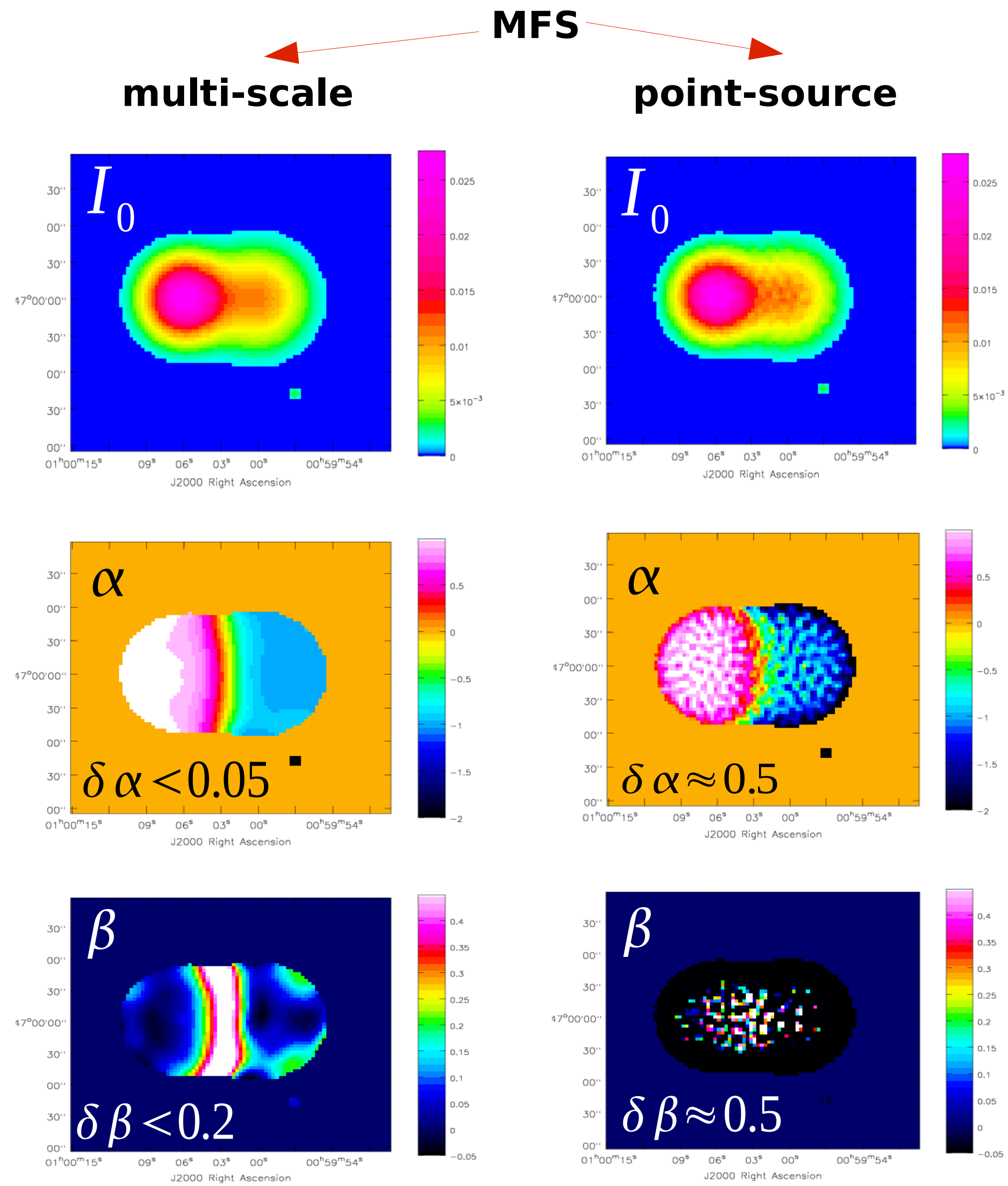
=> To trust spectral-index values, need SNR > 50 (within one band –2:1)
For SNR < 50 need larger bandwidth-ratio.

(Not tested !)

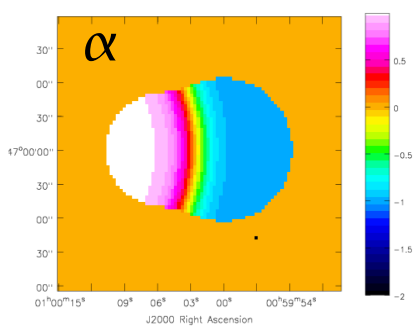
Example of wideband-imaging on extended-emission

Intensity Image

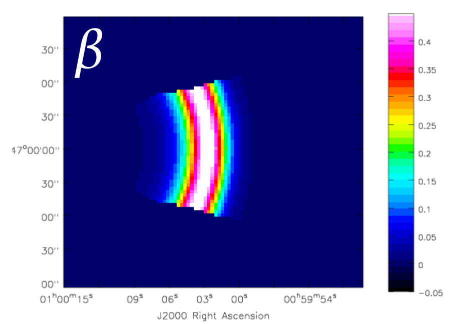




Average Spectral Index

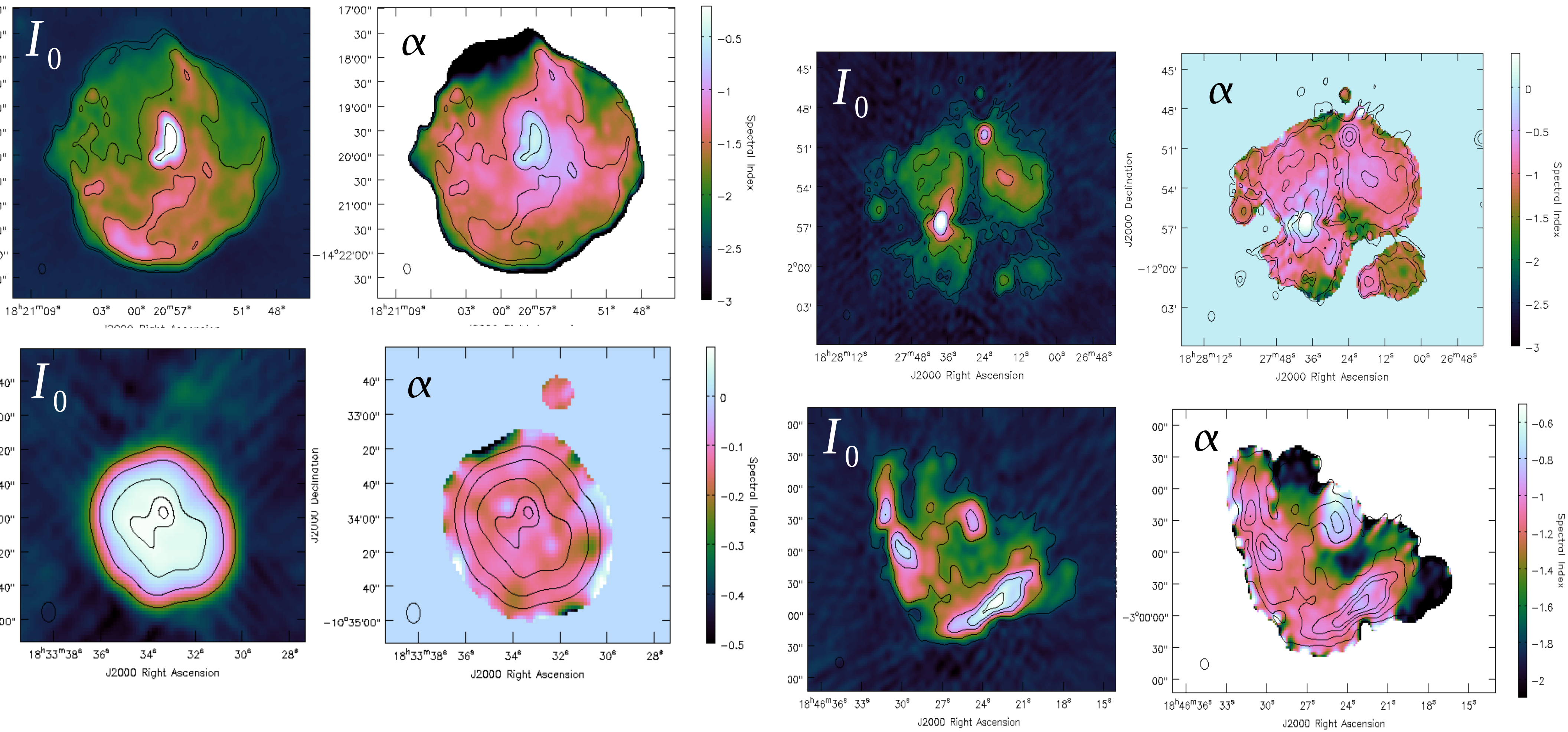


Gradient in Spectral Index



=> For extended emission - spectral-index error is dominated by 'division between noisy images'
– a multi-scale model gives better spectral index and curvature maps

Extended emission – SNR example (a realistic expectation)



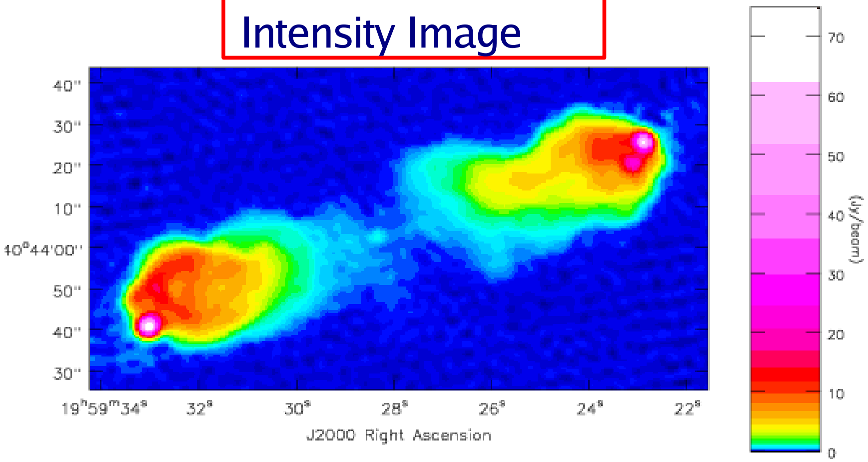
Results of a pilot survey (EVLA RSRO AB1345). These examples used nterms=2, and about 5 scales.

=> Within L-band and C-band, can tell-apart regions by their spectral-index (+/- 0.2) if SNR>100.
=> These images have a dynamic-range limit of few x 1000

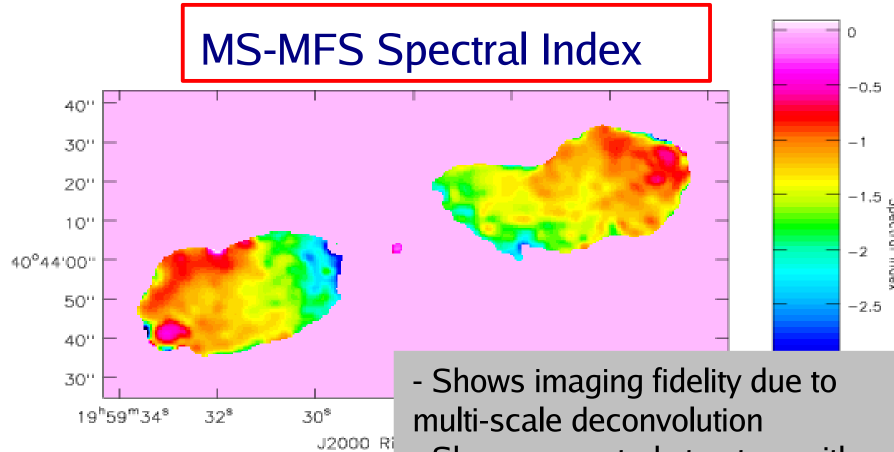
Reconstruction ambiguity : Single-SPW imaging (vs) MS-MFS

Data : 20 VLA snapshots at 9 frequencies across L-band + wide-band self-calibration

Intensity Image

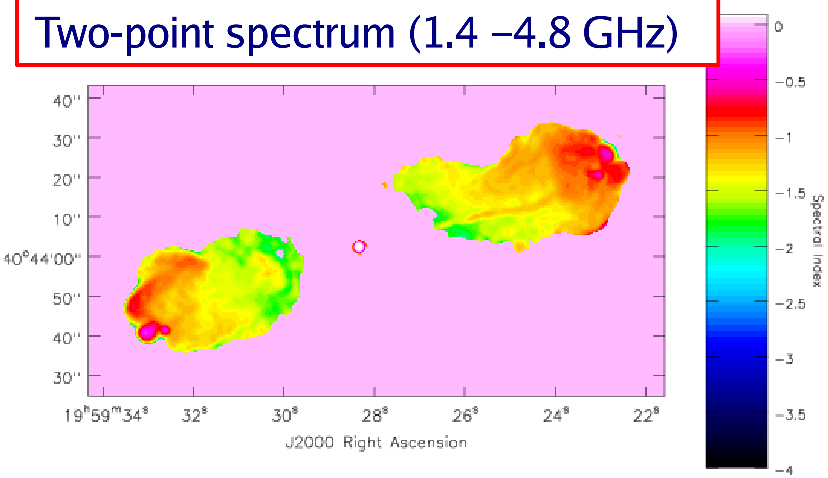


MS-MFS Spectral Index

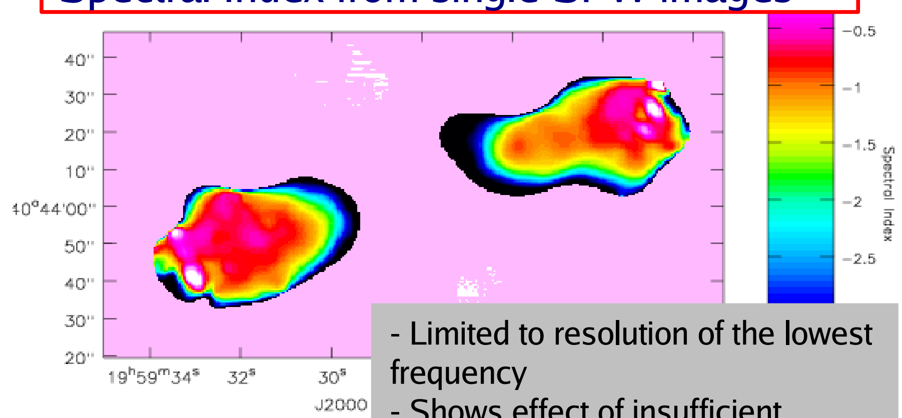


- Shows imaging fidelity due to multi-scale deconvolution
- Shows expected structure with errors < 0.2

Two-point spectrum (1.4 –4.8 GHz)



Spectral Index from single-SPW images



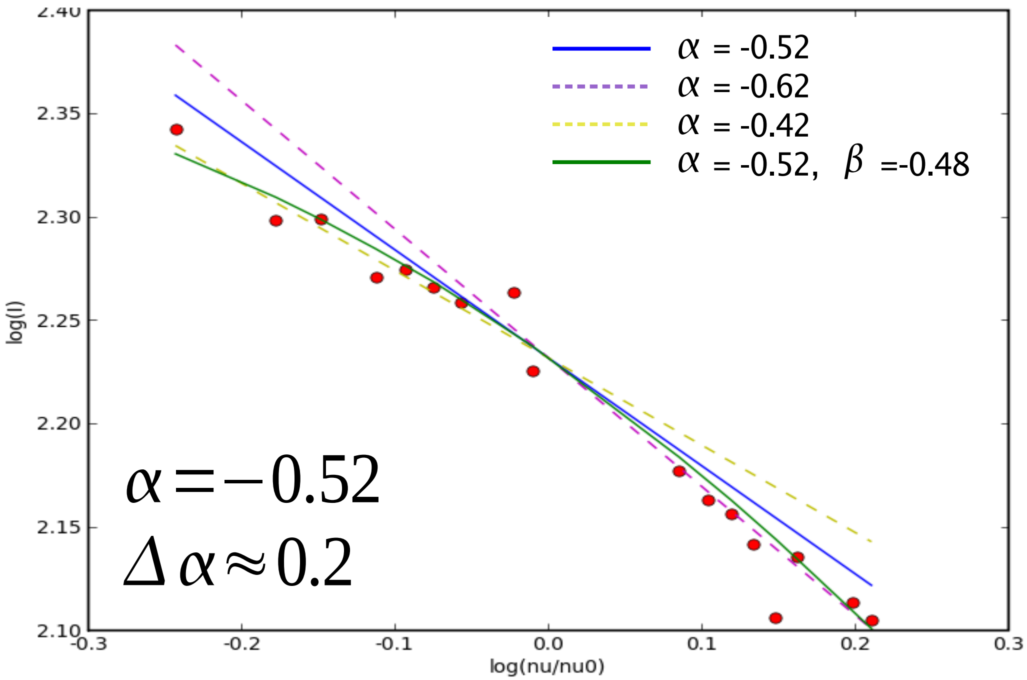
- Limited to resolution of the lowest frequency
- Shows effect of insufficient single-frequency uv-coverage

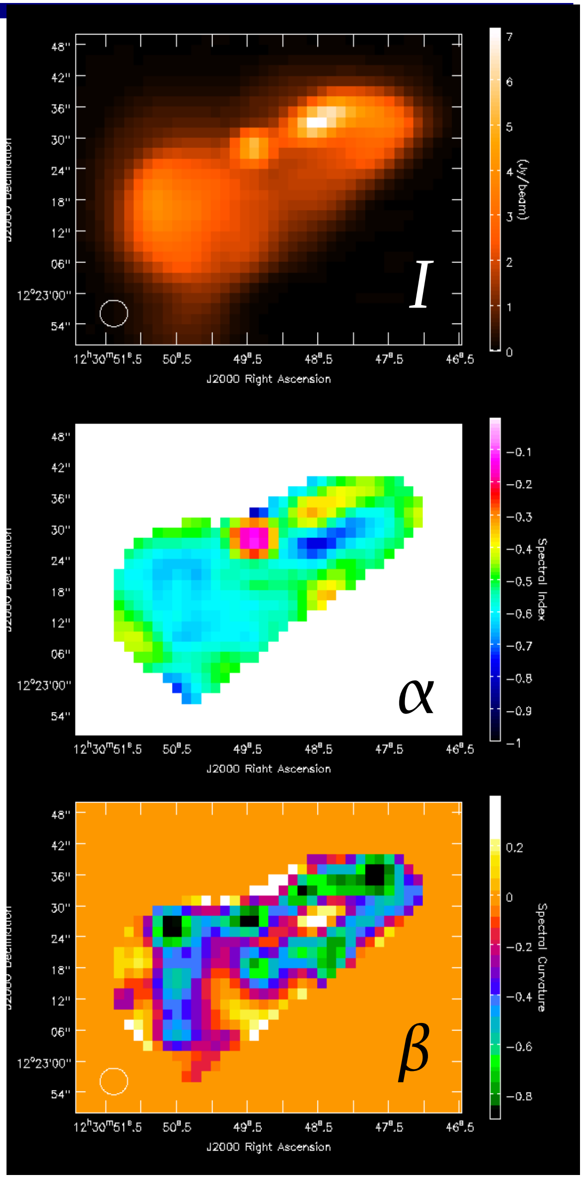
C.Carilli et al, Ap.J. 1991.
(VLA A,B,C,D Array at L and C band)

=> It helps to use the combined uv-coverage

Spectral Curvature

Data : 10 VLA snapshots at 16 frequencies across L-band





From existing P-band (327 MHz), L-band(1.42 GHz) and C-band (5.0 GHz) images of the core/jet

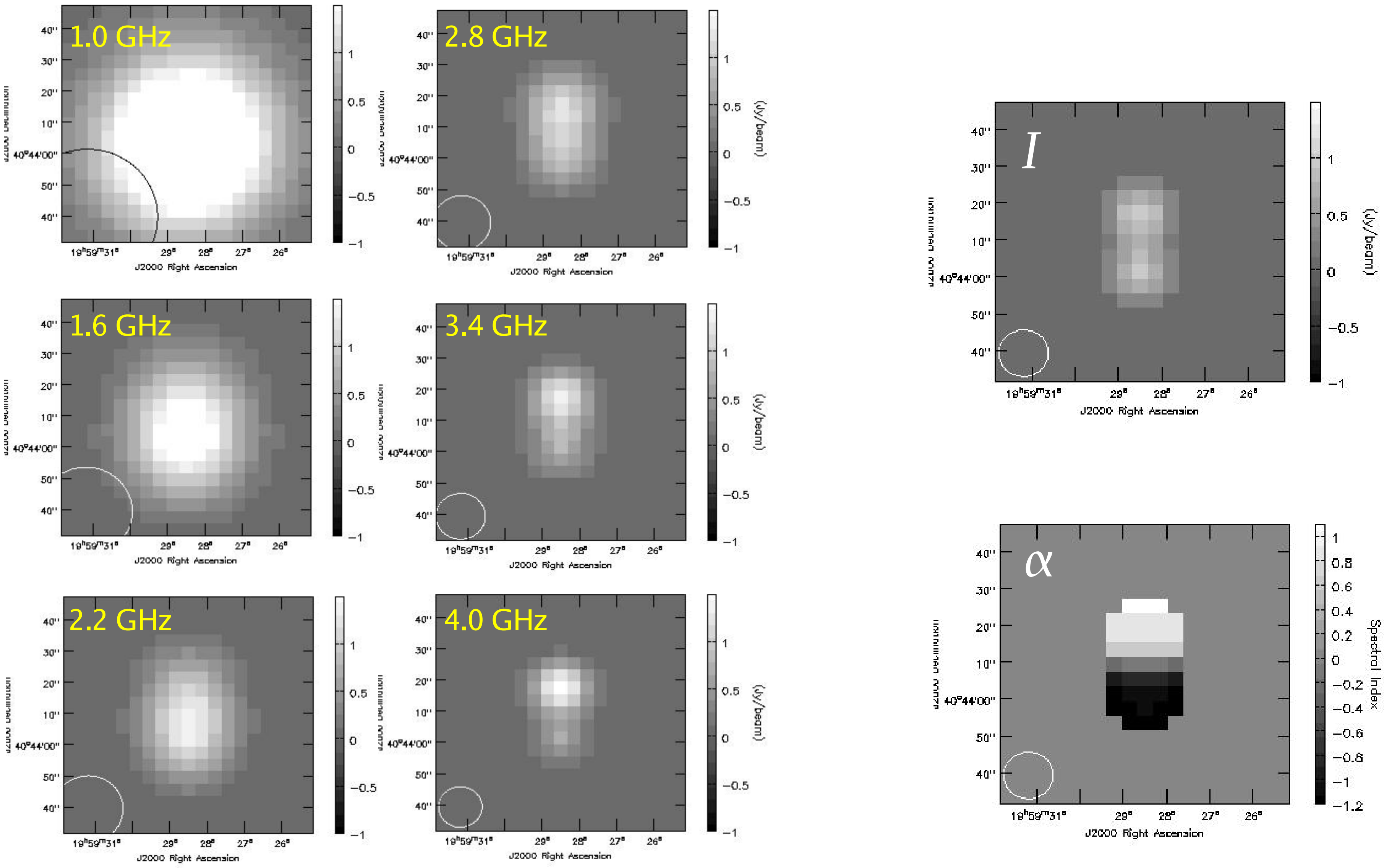
P-L spectral index : -0.36 ~ -0.45
L-C spectral index : -0.5 ~ -0.7

=> Need SNR > 100 to fit spectral index variation ~ 0.2 (at the 1-sigma level ...)

=> Be very careful about interpreting β

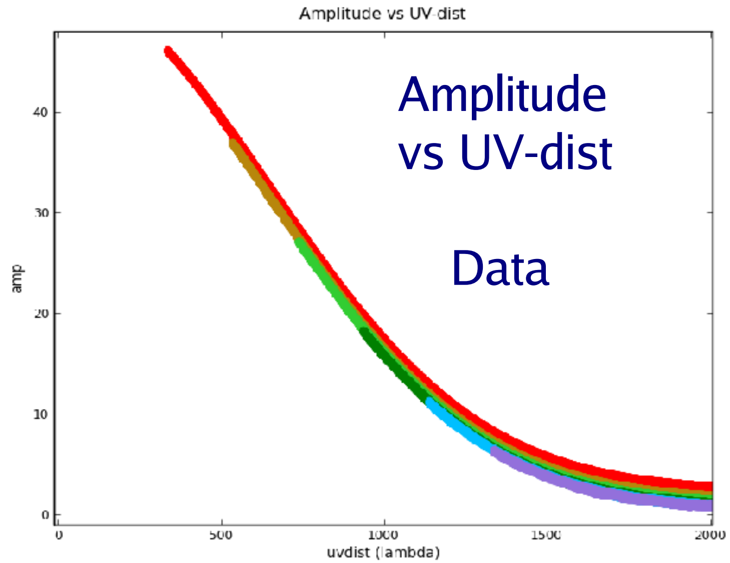
Moderately Resolved Sources + High SNR

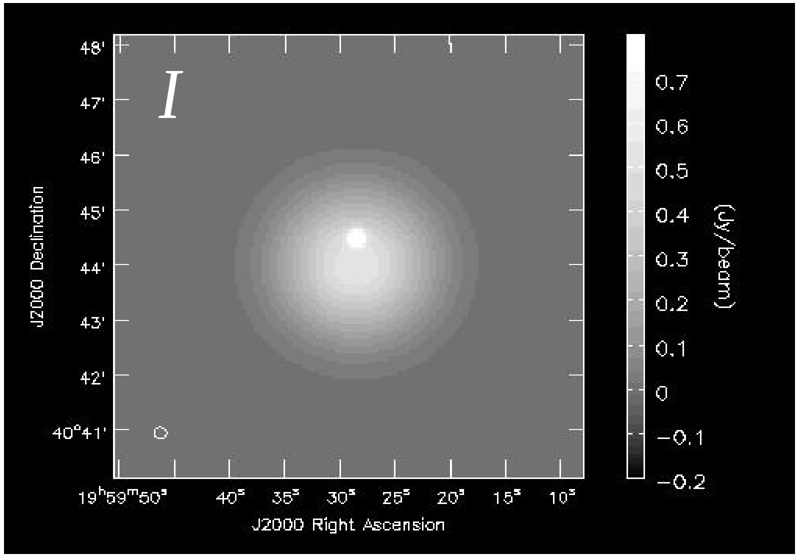
Can reconstruct the spectrum at the angular resolution of the highest frequency (only high SNR)

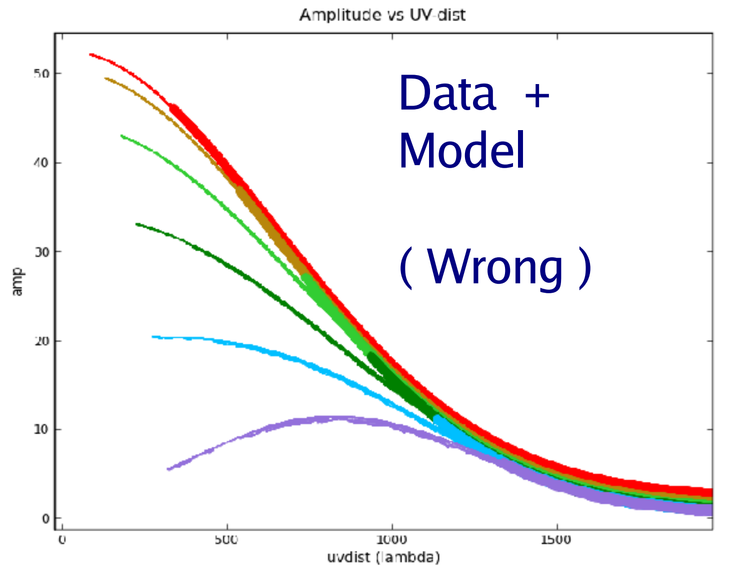


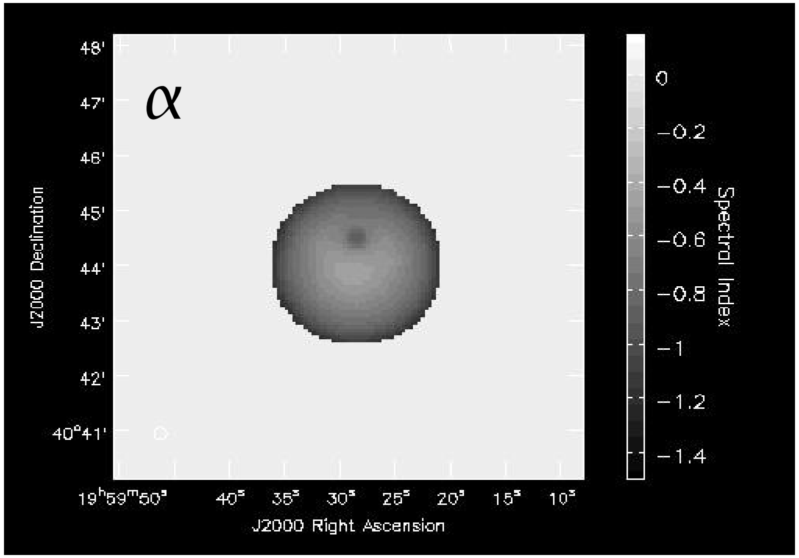
Very large spatial scales – Unconstrained spectrum

The spectrum at the largest spatial scales is NOT constrained by the data



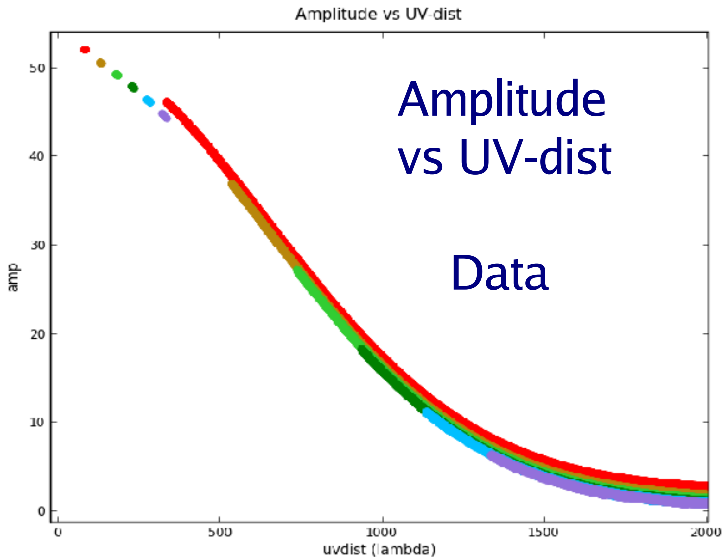


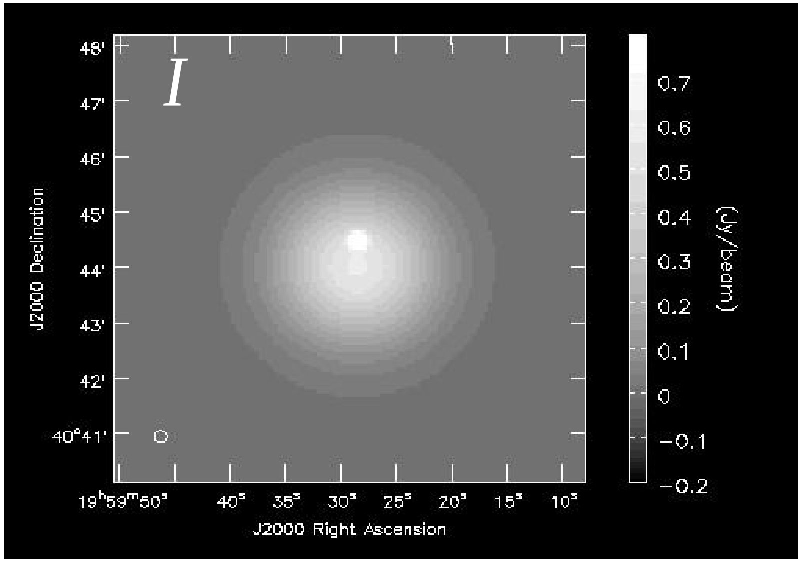


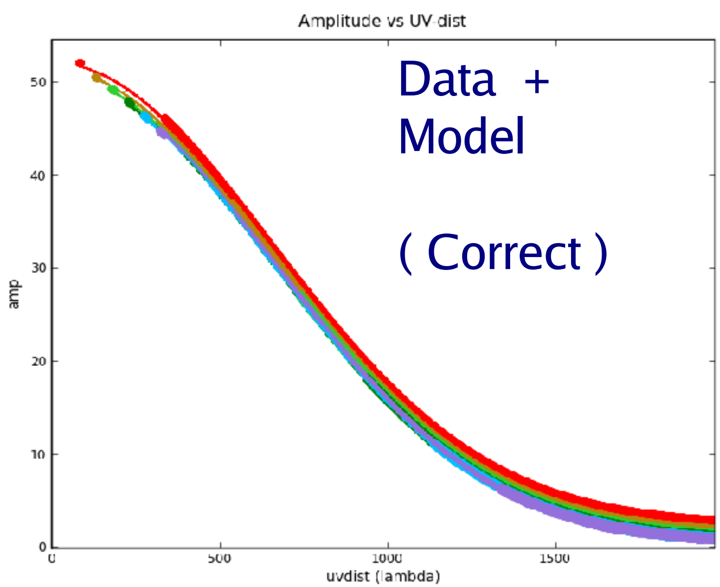


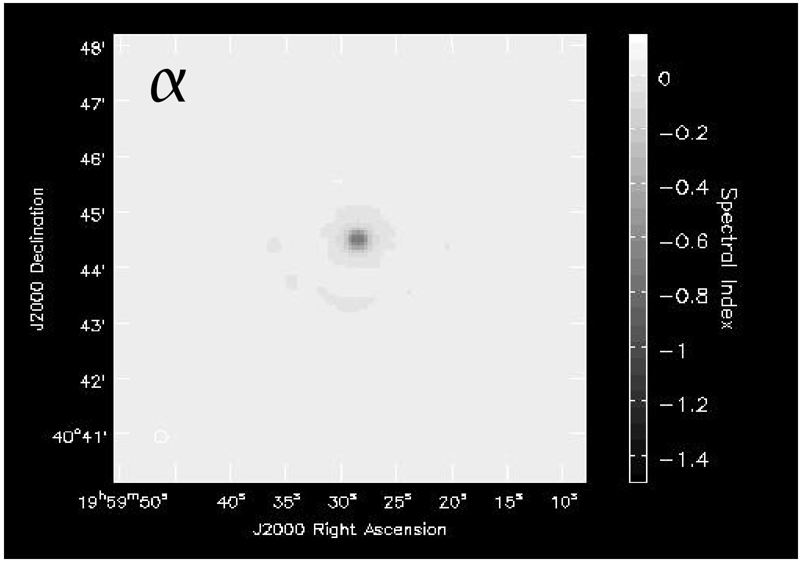
Very large spatial scales – Need additional information

External short-spacing constraints help (visibility data, or starting image model)

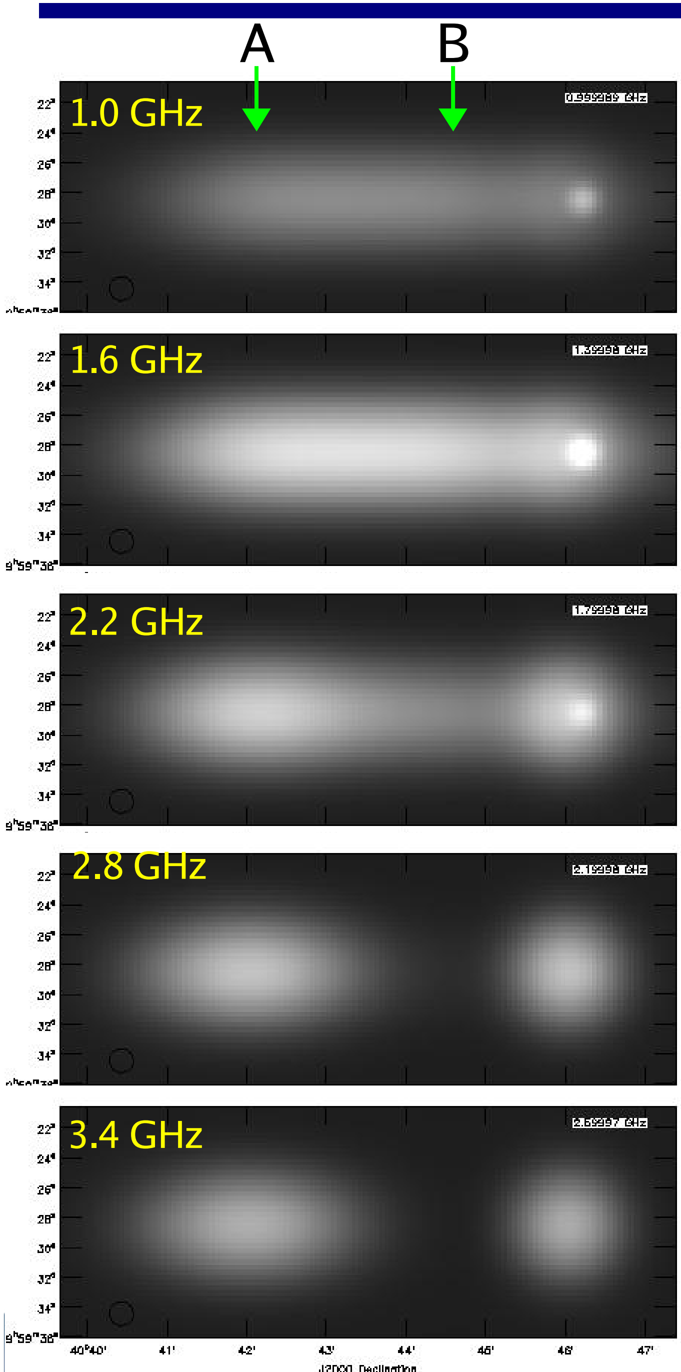


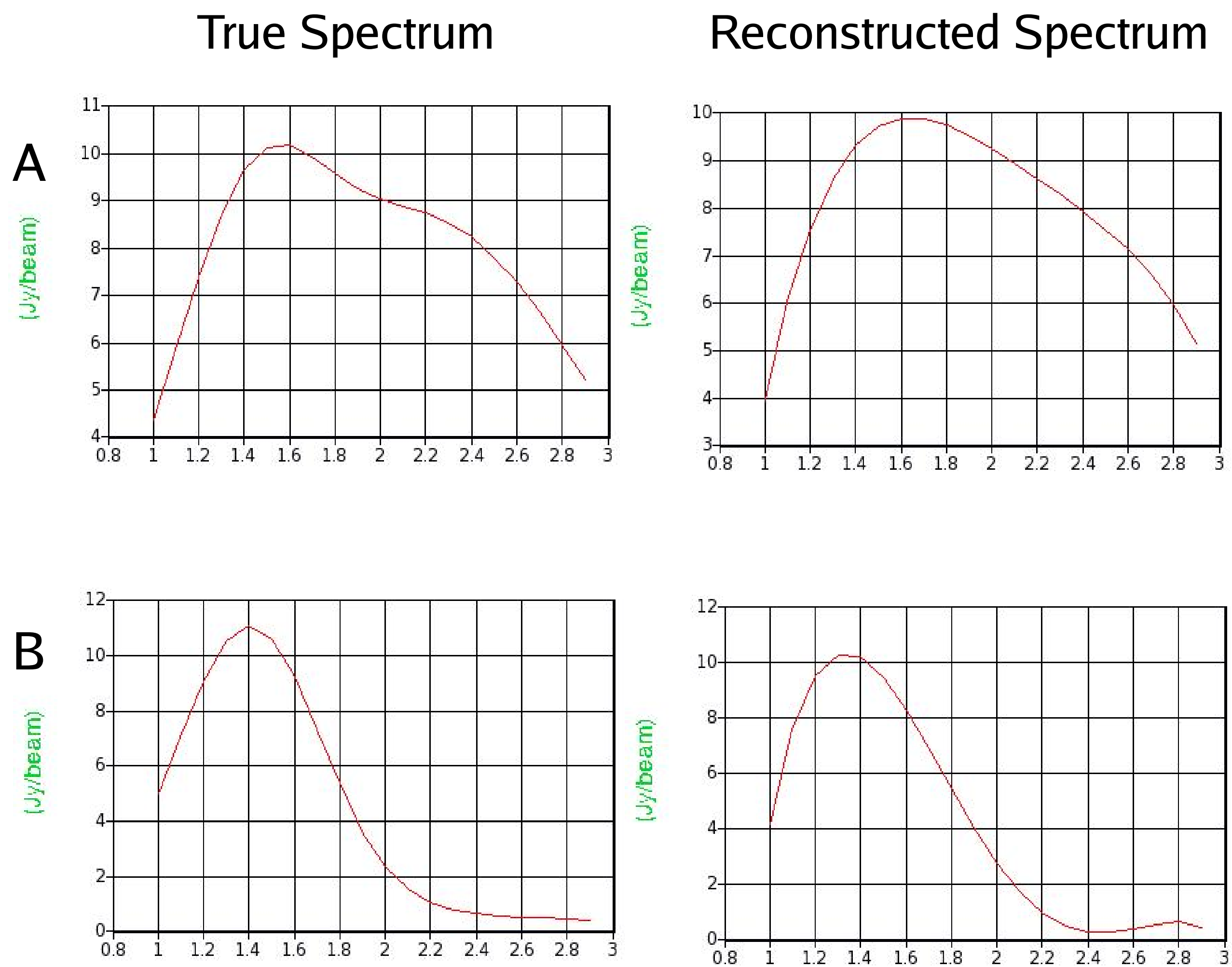






Non power-law spectra : Polynomial Spectral Fit

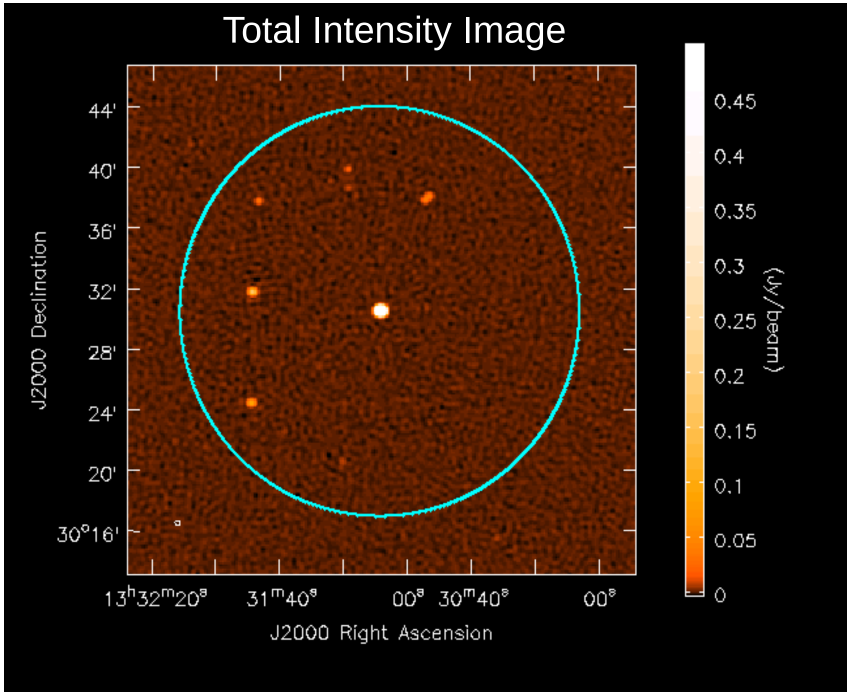


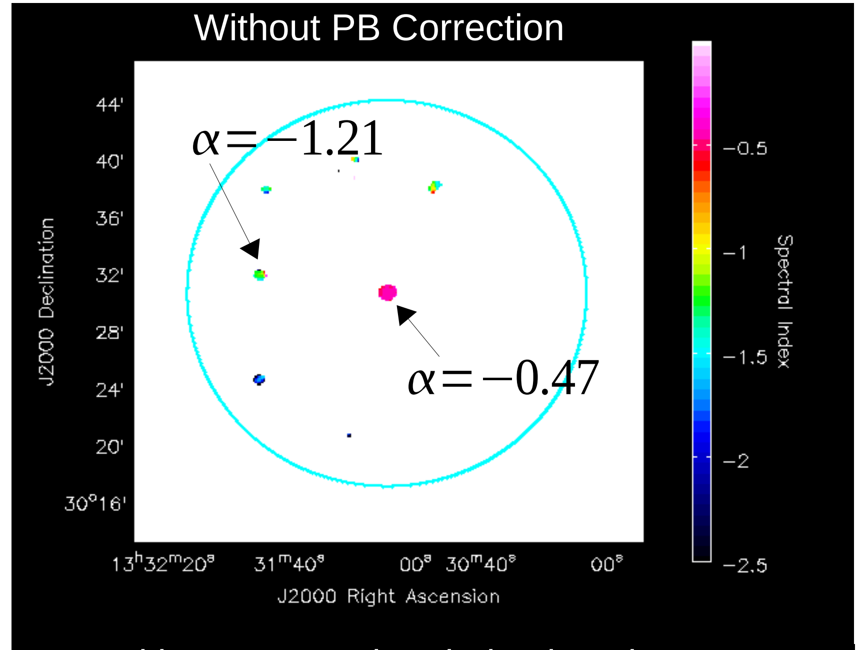


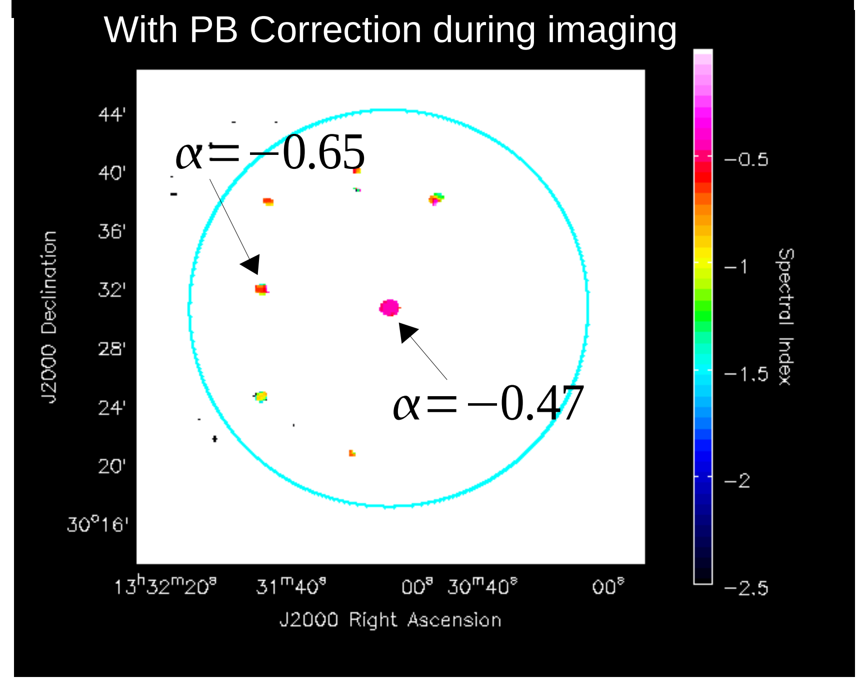
Angular resolution depends on the highest sampled frequency at which the emission exists.

Example of Imaging with wide-band PB (artificial spectrum)

3C286 field , C-config , L-band (30min)





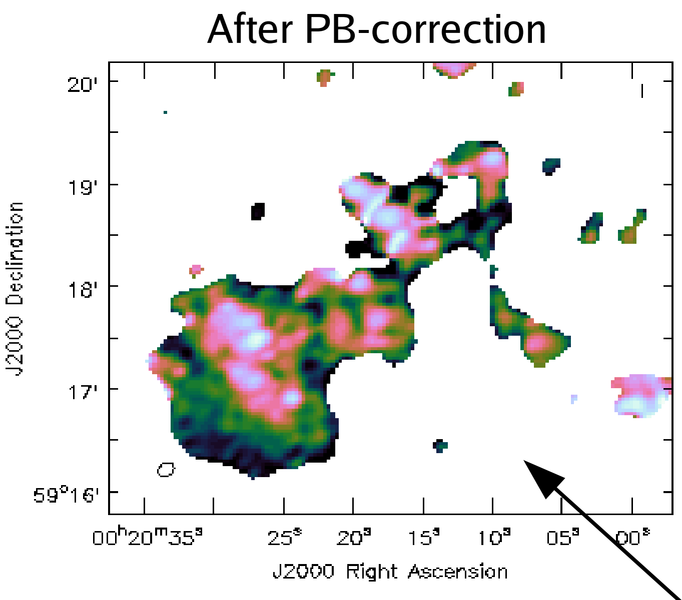


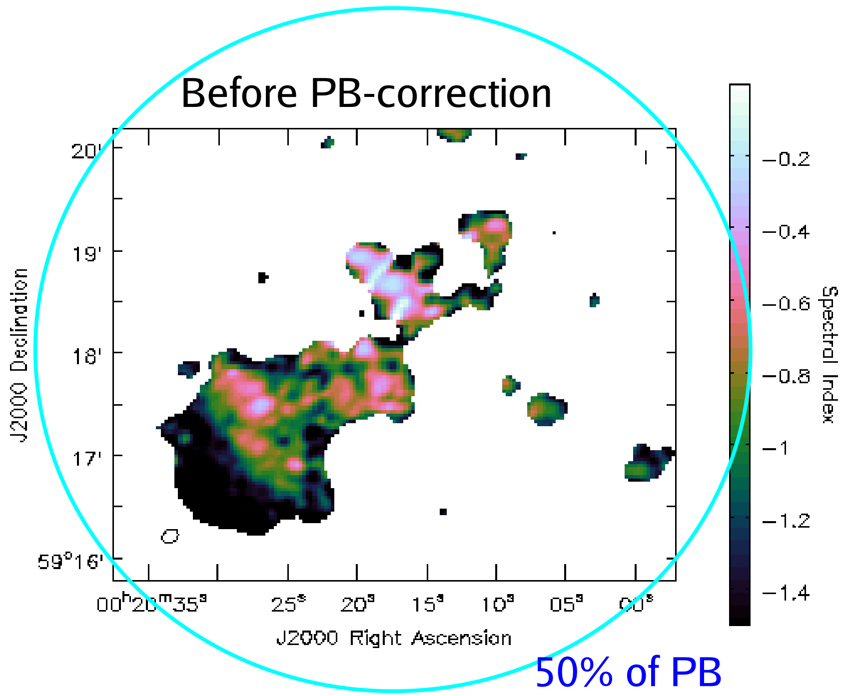
Post-deconvolution polynomial-division of the model spectrum by the PB-spectrum

Verified spectral-indices by pointing directly at one background source.

Obtained $\delta\alpha$ = 0.05 to 0.1 for SNR or 1000 to 20

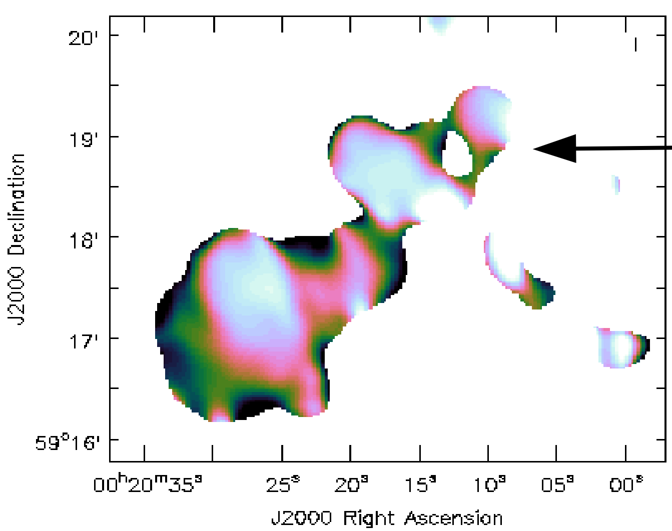
Continuum (MS-MFS) vs Cube Imaging (with PB-correction)





IC10 Dwarf Galaxy :

Spectral Index across C-Band.



MS-MFS : Result of wide-band PB-correction after MT-MS-MFS.

Cube : Spectral-index map made by PB-correcting single-SPW images smoothed to the lowest resolution.

Any post-deconvolution PB-correction assumes that the primary-beam does not vary / rotate during the observation.

=> Dynamic range limit of 10^4 ~ 10^5
=> Valid within ~HPBW (depends on dynamic-range)

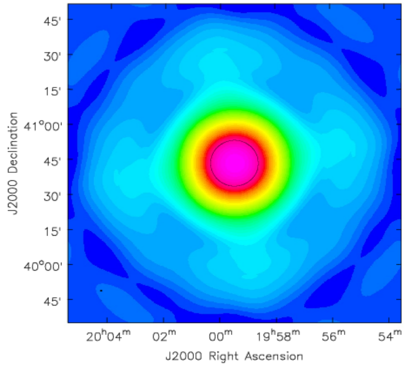
Other wide-field issues (primary-beam, w-term, mosaicing)

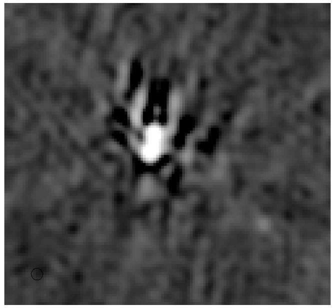
Wide-Band Imaging often requires Wide-field imaging techniques.

"Primary Beam" : The antenna-primary beam introduces a time-varying spectrum in the data.

Any algorithm that works only with "time-averaged" beams will not suffice for high dynamic-range imaging

(S.Bhatnagar's talk will describe techniques to deal with this)



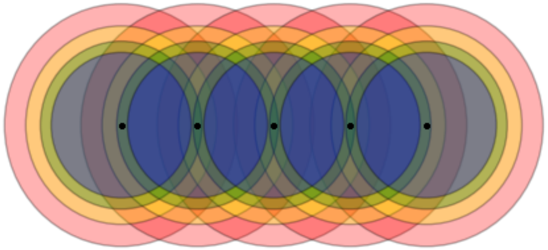


"W-term " : Also a frequency-dependent instrumental effect.

Narrow-band w-projection algorithm worka for wide-band.

(S.Bhatnagar's talk will explain what this is)

"Mosaicing" : Make observations with multiple pointing and delay-tracking centers. Combine the data during (or after) image-reconstruction.



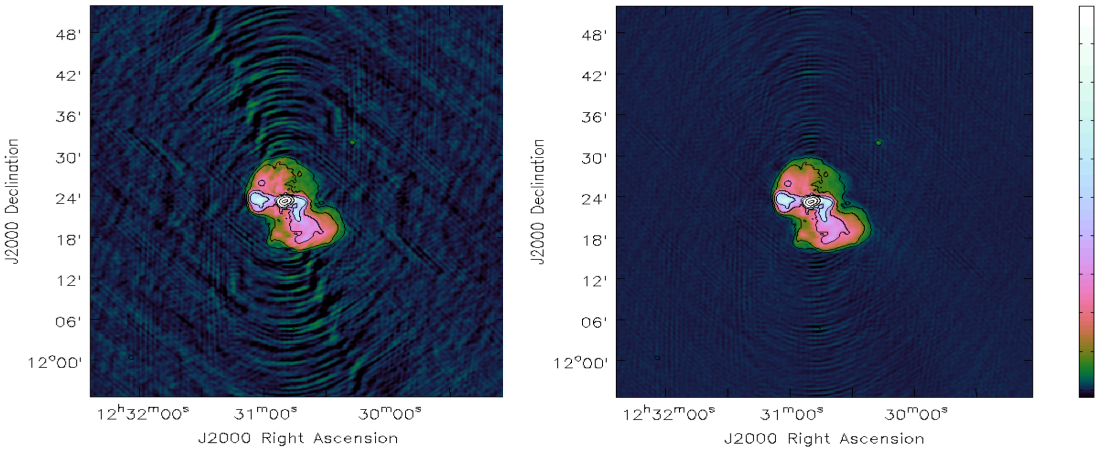
Single-pointing wide-band-imaging ideas will work for mosaics too.

(J.Ott's talk will describe mosaicing)

Using Wide-Band Models : Self-Calibration, Continuum-subtraction

WideBand Model : $I_{0,}^{m} I_{1,}^{m} I_{2,}^{m} \ldots$

Evaluate spectrum $I_{\nu}^{sky} = \sum_{t} I_{t} \left(\frac{\nu - \nu_0}{\nu_0} \right)^{t}$

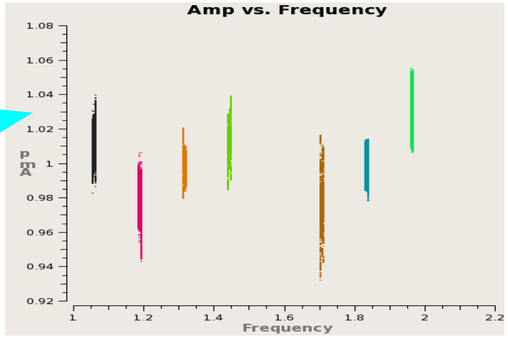


(1) Wide-Band Self-Calibration

– Can be used on target source, after initial calibration per spw.

- Can use it on the calibrator itself to bootstrap the model.

Amplitudes of bandpass gain solutions......



(2) Continuum Subtraction

-- De-select frequency channels in which your spectral-lines exist.

– Make a wide-band image model of the continuum intensity and spectra

– Predict model-visibilities over **all** channels

-- Subtract these model visibilities from the data

Wide-Bandwidths and Polarization / Faraday-Rotation

So far, we have focused on imaging the Stokes I = RR + LL and its frequency-dependence.
Stokes Q, U, V can also be imaged (cube or continuum).

Q = RR + I LL , U = RR −I LL , V = RR −LL

Q,U,V also change with frequency,
- Their spectra usually do not follow a power-law.
- Spectra may not even be smooth (i.e. cannot use a Taylor-polynomial) => Make a Cube

Faraday Rotation-Measure Synthesis

Brentjens, 2008

Make images of $F(\phi)$, the polarized surface-brightness at various Faraday-depths.

- P = Q + I U : Make spectral cubes for Q and U separately, and calculate P

- For each pixel in the P-cube, solve $P(\lambda^2) = \int F(\phi) e^{2\pi i \phi \lambda^2} d\phi$ for $F(\phi)$

This calculation is currently done post-deconvolution, but it could be folded into the major/minor cycle framework.

Outline

(1) What is wide-band imaging ?

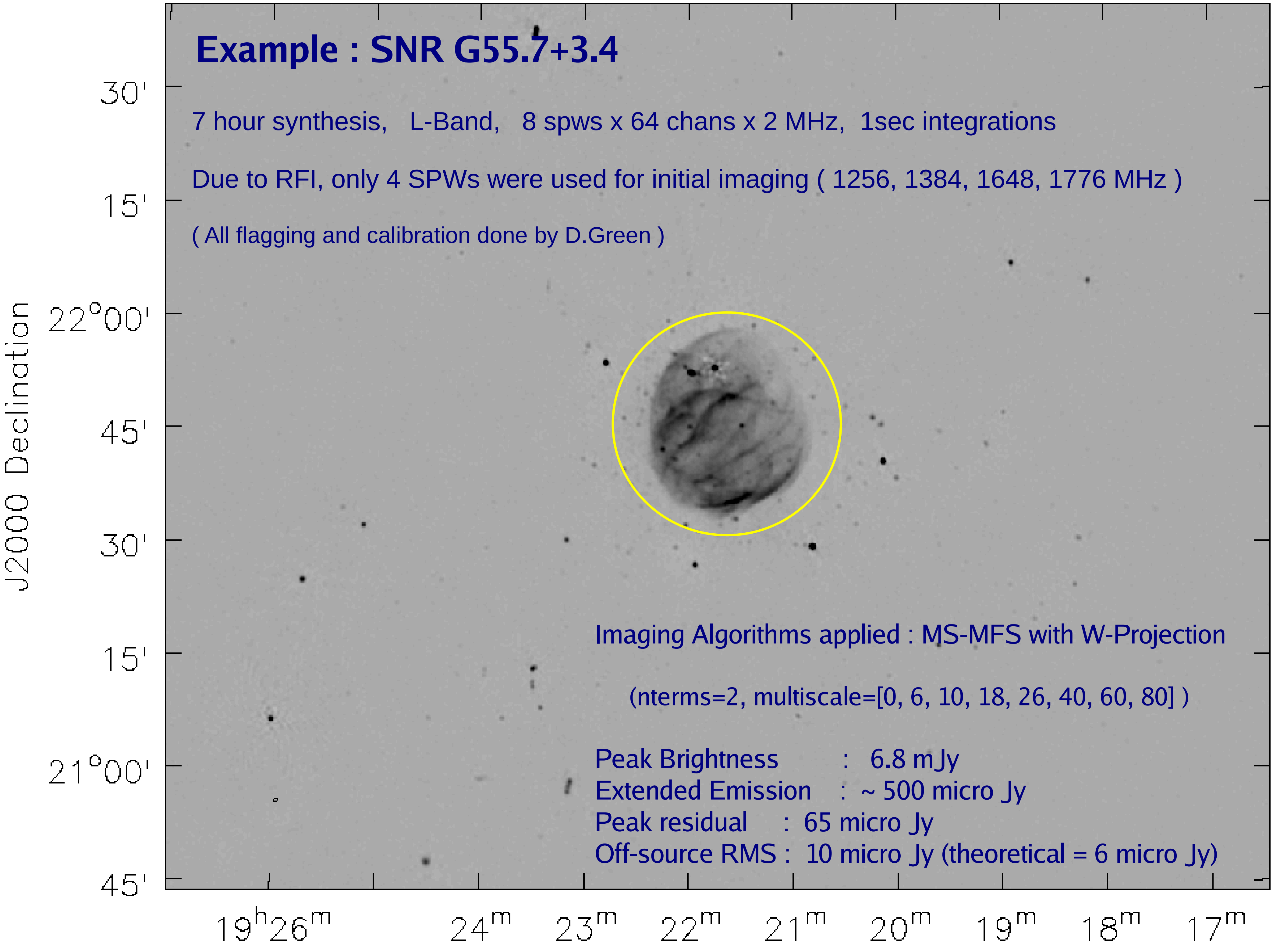
- Bandwidth and sensitivity
- Frequency-dependent Instrument and Sky
- Bandwidth smearing
- Multi-frequency synthesis

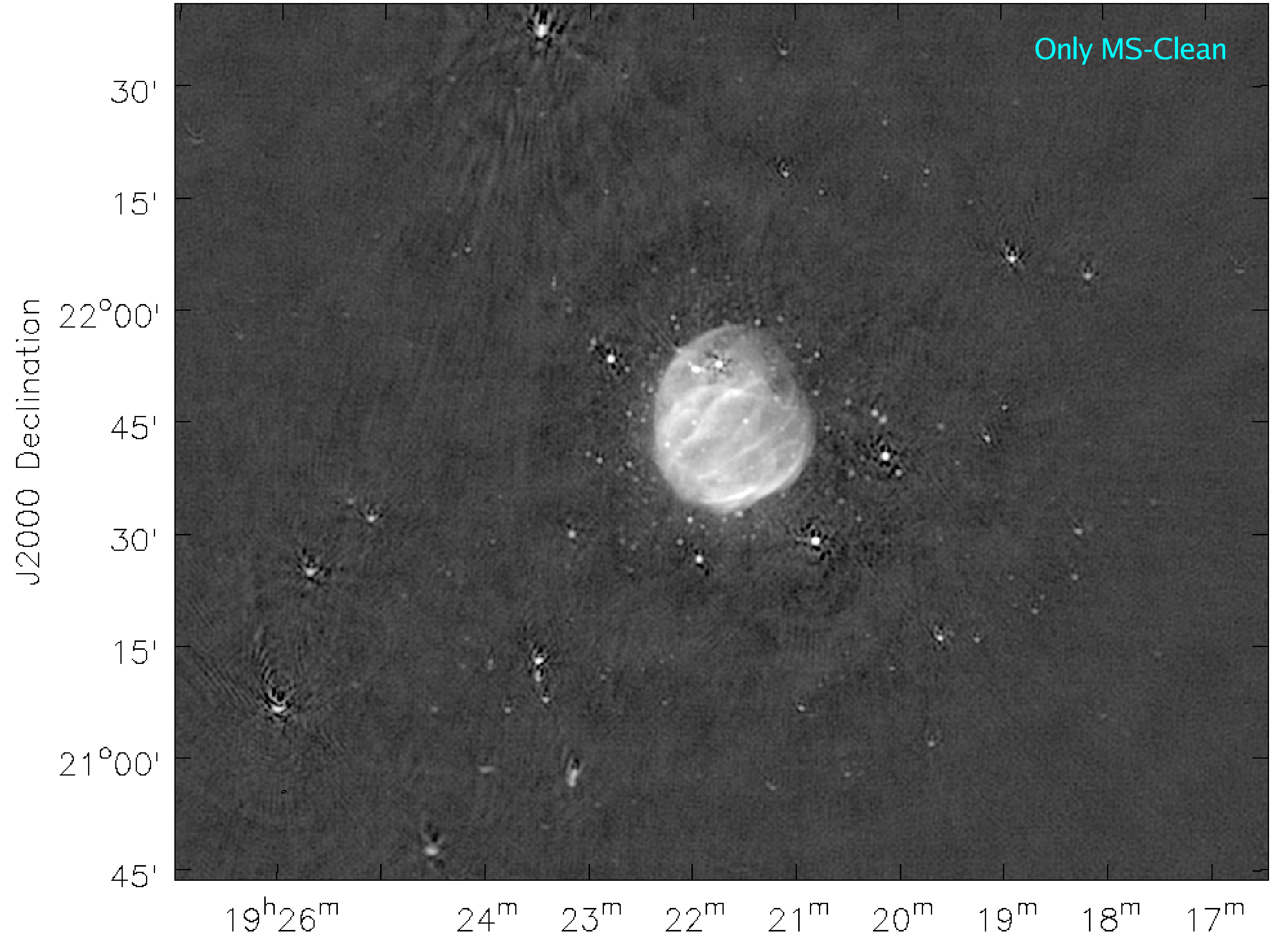
(2) Imaging Algorithms

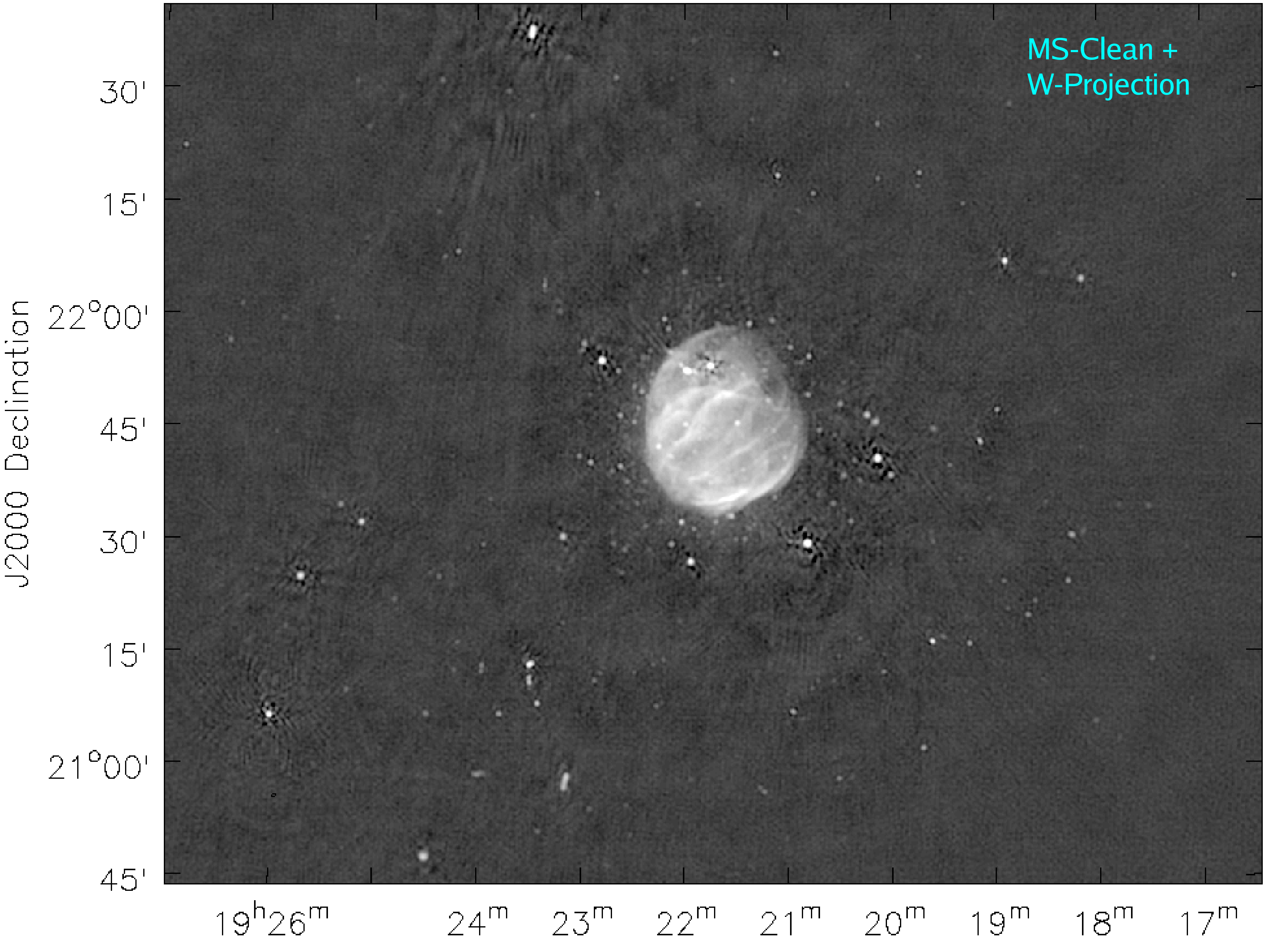
- Recap. of image-reconstruction methods
- Cube vs Continuum imaging (intensity and spectrum)

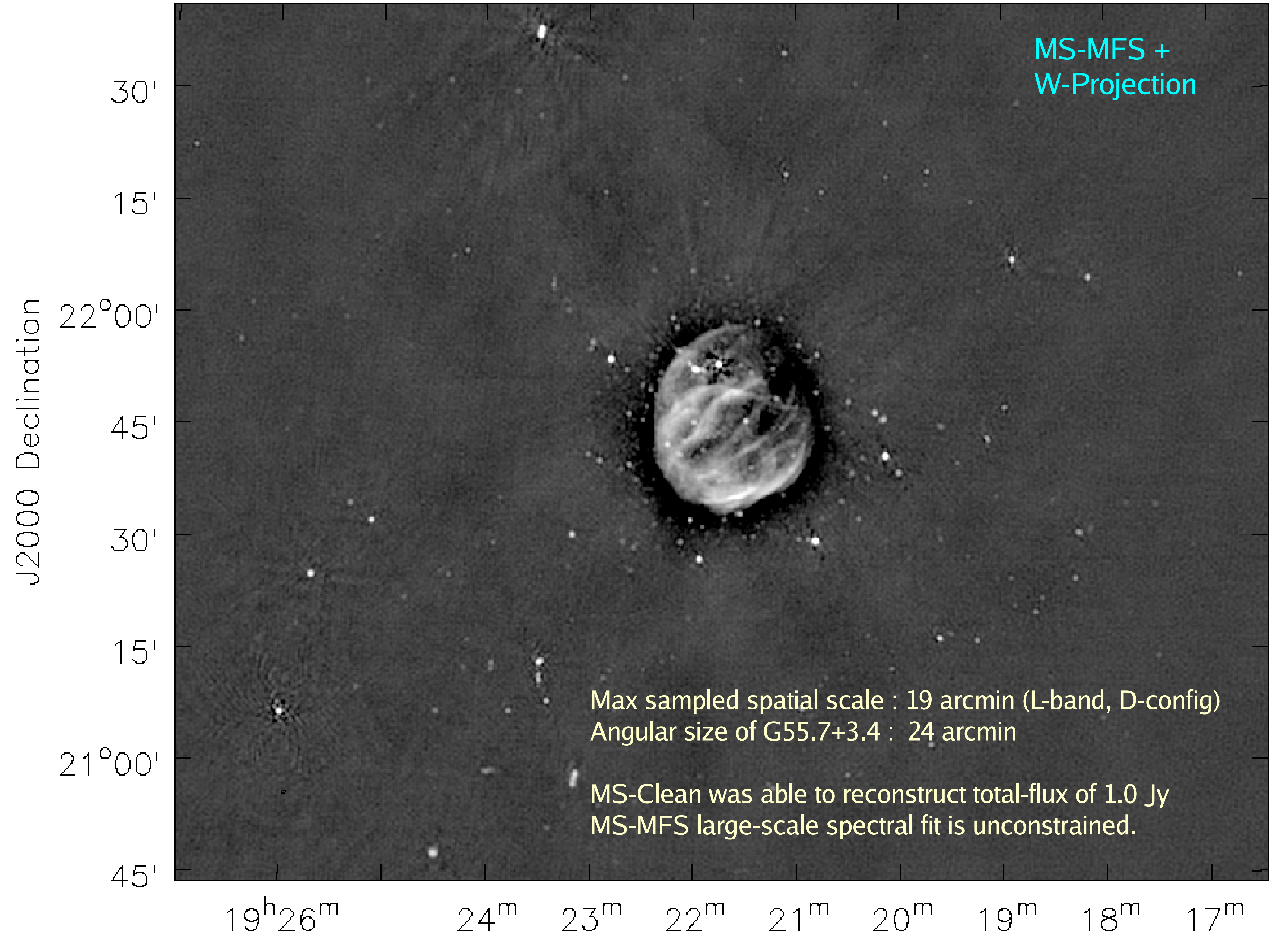
(3) Examples of various effects/corrections/errors

(4) Example of wide-band imaging trials on JVLA observations of a Galactic super-nova-remnant between 1-2 GHz.

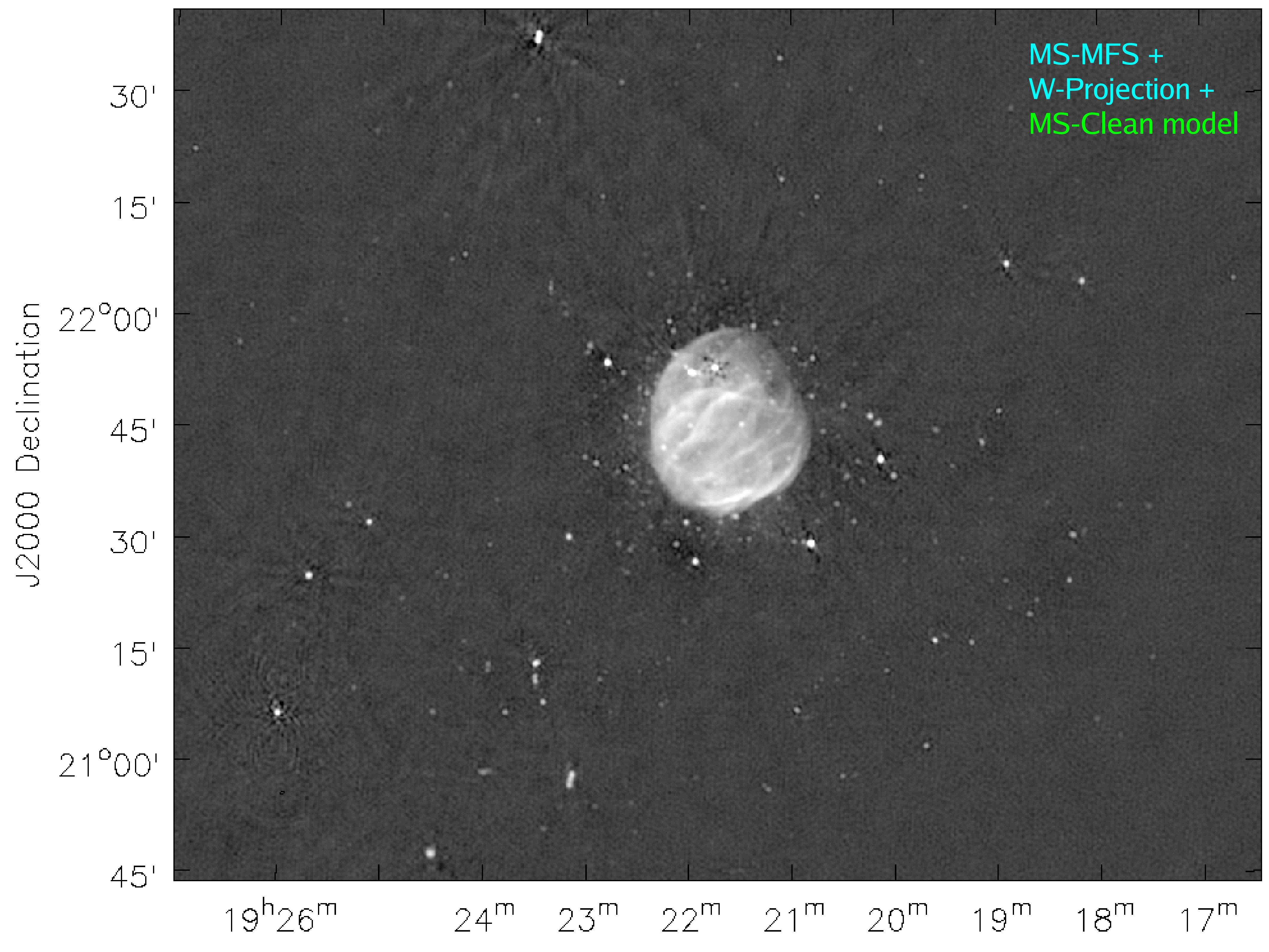

Example : SNR G55.7+3.4
7 hour synthesis, L-Band, 8 spws x 64 chans x 2 MHz, 1sec integrations
Due to RFI, only 4 SPWs were used for initial imaging (1256, 1384, 1648, 1776 MHz)
(All flagging and calibration done by D.Green)
Imaging Algorithms applied : MS-MFS with W-Projection
(nterms=2, multiscale=[0, 6, 10, 18, 26, 40, 60, 80])
Peak Brightness : 6.8 mJy
Extended Emission : ~ 500 micro Jy
Peak residual : 65 micro Jy
Off-source RMS : 10 micro Jy (theoretical = 6 micro Jy)
J2000 Declination
30'
15'
22°00'
45'
30'
15'
21°00'
45'
19h26m
24m
23m
22m
21m
20m
19m
18m
17m


Only MS-Clean
J2000 Declination
30'
15'
22°00'
45'
30'
15'
21°00'
45'
19h26m
24m
23m
22m
21m
20m
19m
18m
17m

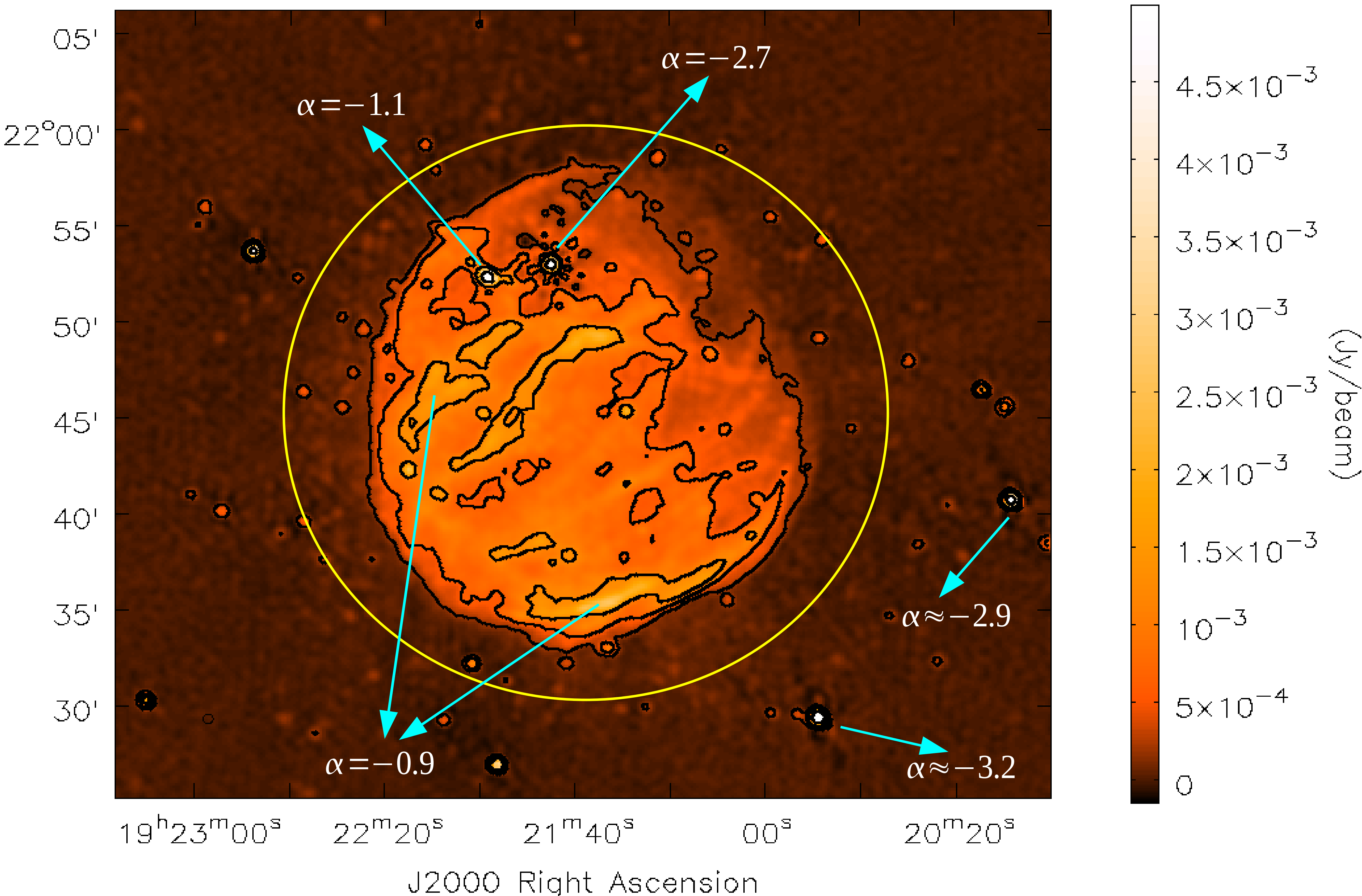

MS-Clean +
W-Projection
J2000 Declination
30'
15'
22°00'
45'
30'
15'
21°00'
45'
19h26m
24m
23m
22m
21m
20m
19m
18m
17m



MS-MFS +
W-Projection
Max sampled spatial scale : 19 arcmin (L-band, D-config)
Angular size of G55.7+3.4 : 24 arcmin
MS-Clean was able to reconstruct total-flux of 1.0 Jy
MS-MFS large-scale spectral fit is unconstrained.
J2000 Declination
30'
15'
22°00'
45'
30'
15'
21°00'
45'
19h26m
24m
23m
22m
21m
20m
19m
18m
17m


MS-MFS +
W-Projection +
MS-Clean model
J2000 Declination
30'
15'
22°00'
45'
30'
15'
21°00'
45'
19h26m
24m
23m
22m
21m
20m
19m
18m
17m

G55.7+3.4 : Supernova-Remnant + Pulsar



Example of wide-field sensitivity, because of wide-bandwidths

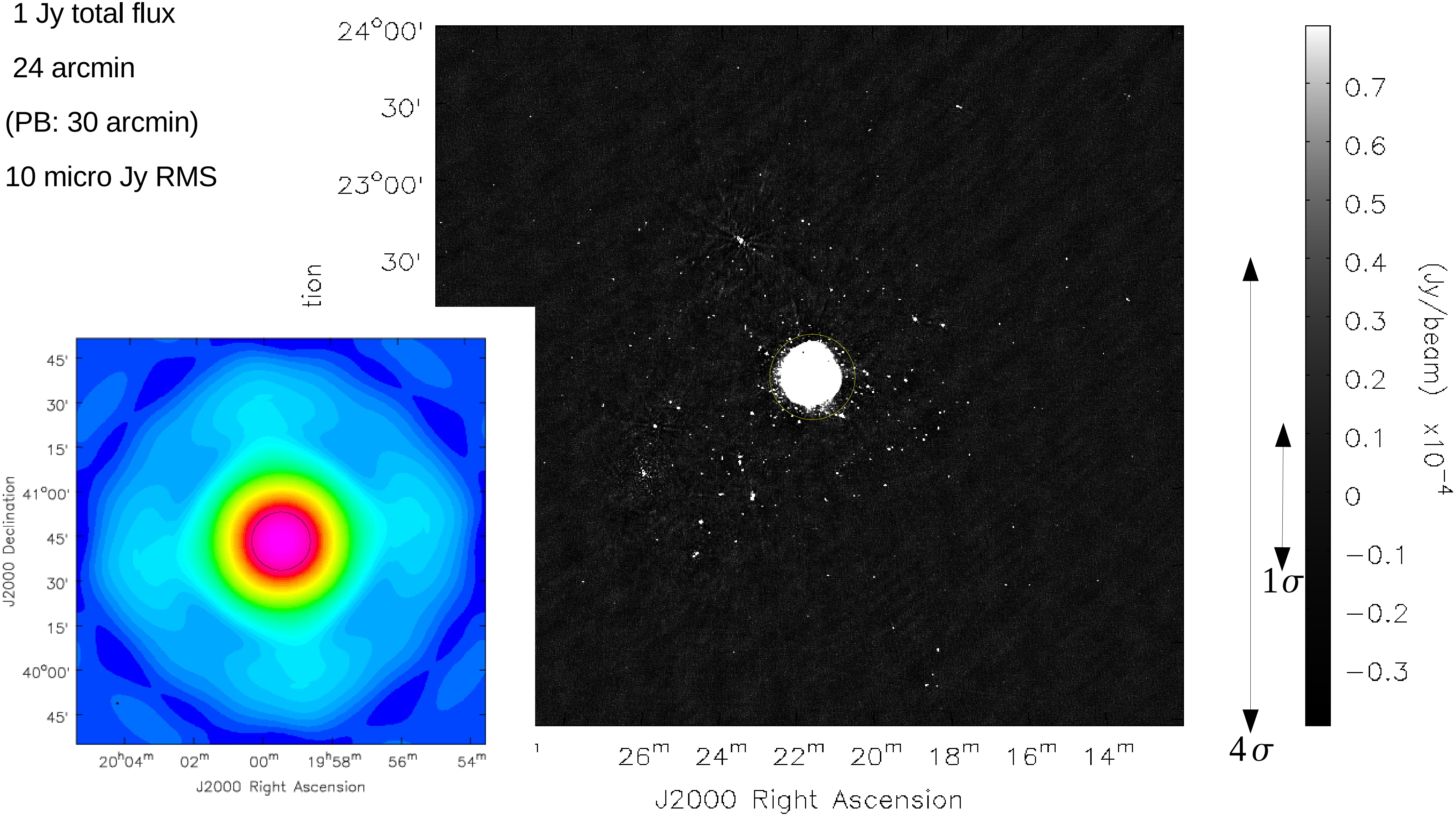
G55.7+3.4 : Galactic supernova remnant : 4 x 4 degree field-of-view from one EVLA pointing

1 Jy total flux

24 arcmin

(PB: 30 arcmin)

10 micro Jy RMS



Summary

Broad-Band Receivers

↓

Cube-Imaging (or per SPW) will suffice for a quick-look.

↓

Multi-Frequency-Synthesis for better sensitivity

↓

Reconstruct Intensity and Spectrum during Imaging

↓

Pay attention to the **many** sources of error in the model-fitting process.

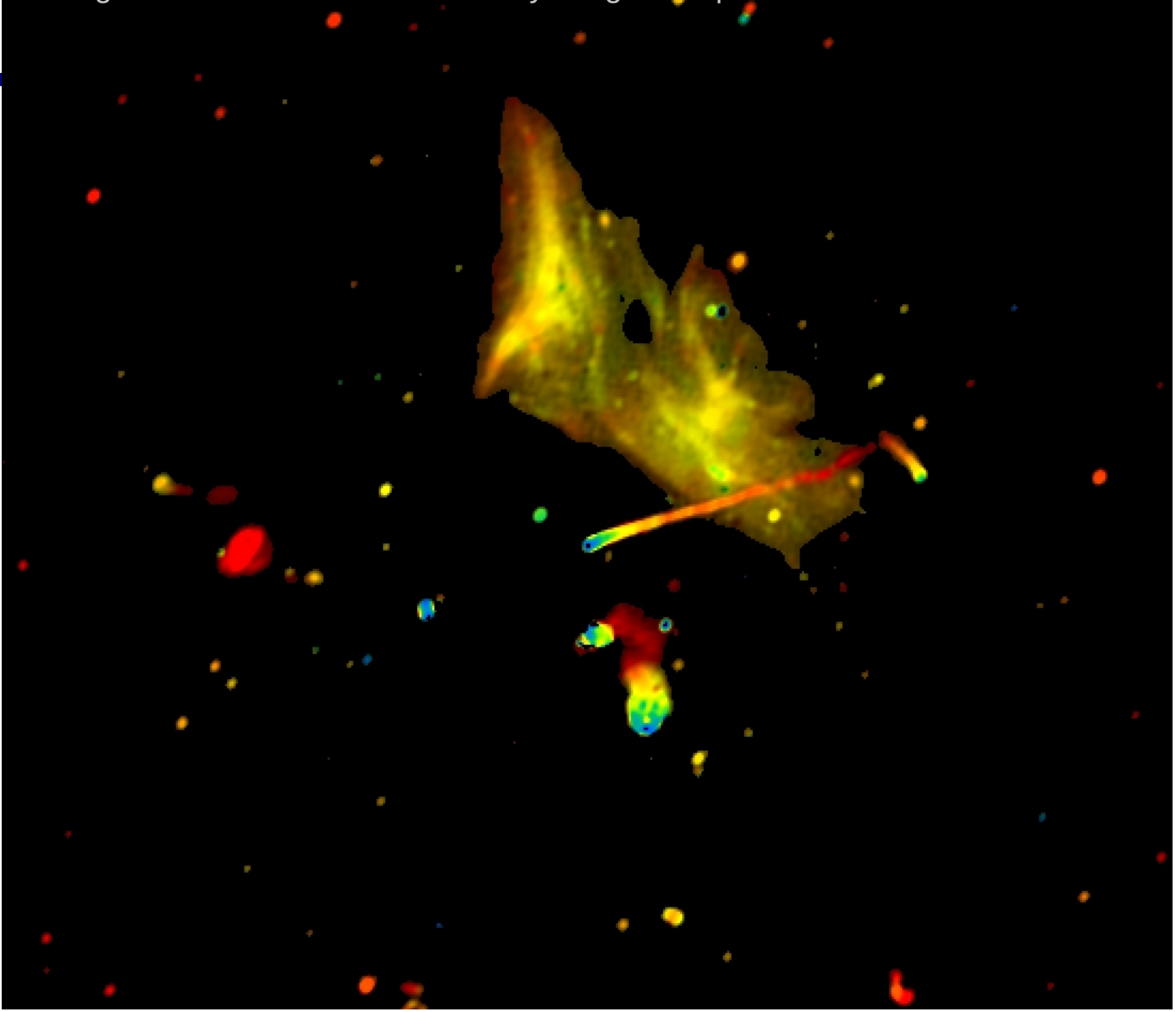
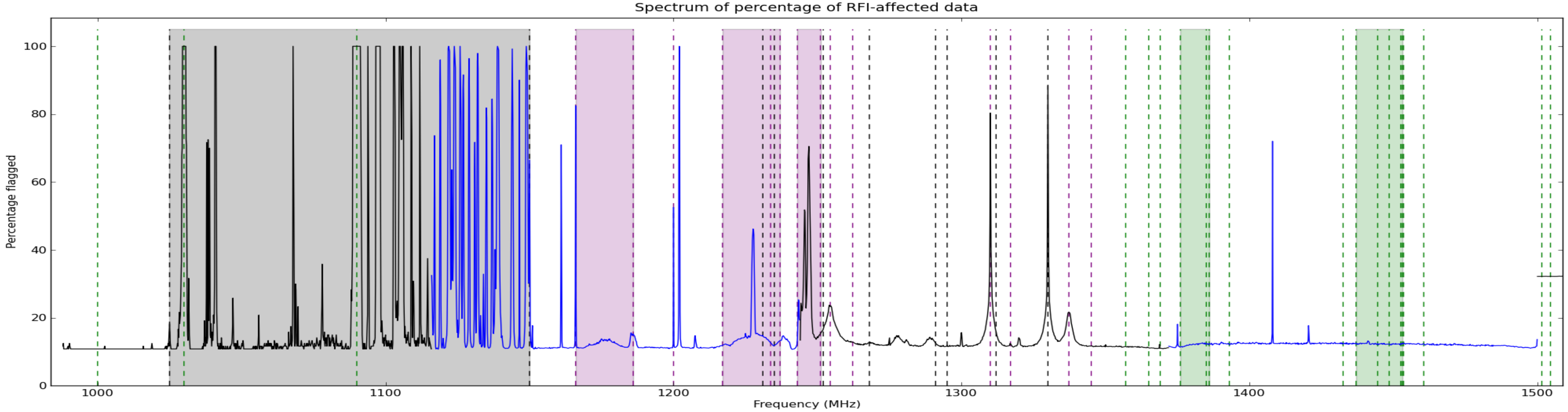


Image from Frazer Owen : Intensity-weighted Spectral Index of Abell 2256

If this is done correctly, you could get increased imaging sensitivity (over wide fields), high-fidelity high dynamic-range reconstructions of both spatial and spectral structure, all from a single wide-band observation.

Radio Frequency Interference and Flagging

Fraction of RFI-affected data vs Frequency



At L-Band, with the JVLA, you can use ~500 MHz with very rough flagging,
~800 MHz if done carefully.

Flagging RFI-affected data : Manual flagging,
Automatic flagging (several algorithms in use at different observatories)

(Loss of Data)

Subtracting RFI from data : Model the measurement-process of RFI.
Fit this model from the data, and subtract it out.

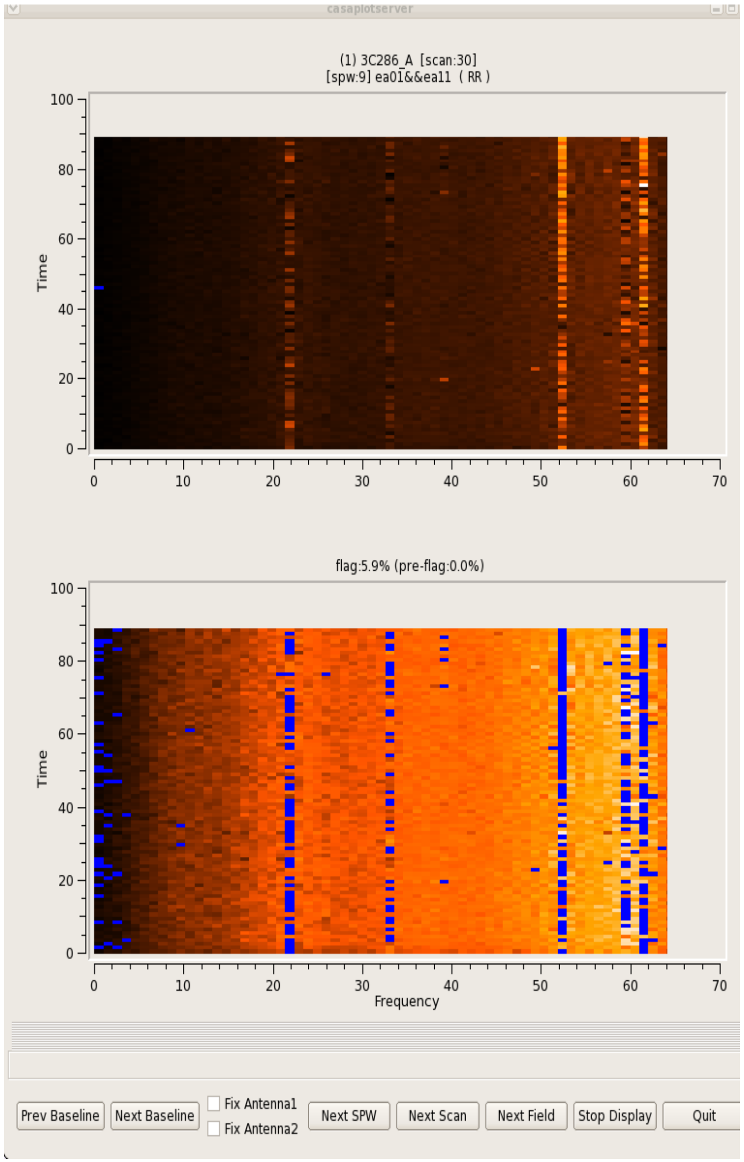
(Recovery of RFI-affected data)

Automatic RFI identification and flagging

TFCrop : Detect outliers on the 2D time-freq plane, (based on visibility amplitudes)

- Average visibility amplitudes along one dimension
- Fit a piece-wise polynomial to the base of RFI spikes
  -- calculate 'sigma' of data - fit.
- Flag points deviating from the fit by > N-sigma
- Repeat along the second dimension.

Can operate on un-calibrated data + one pass through MS
'testautoflag' in CASA 3.3. 'tflagdata, mode=tfcrop' in CASA 3.4



RFLAG : Detect outliers using a sliding-window statistics in time and frequency (real/imag)

- For each channel, calculate rms of real and imag parts of visibilities across a sliding time window.
- Calculate the mean-rms, and deviations of these rmss from the mean.
- Search for outliers
  (local rms > N x (median-rms + median-deviation)

Needs calibrated data + two passes through data.
"RFLAG"in AIPS. 'tflagdata, mode=rflag' in CASA 3.4