PASEO Meeting

July 15-16, 2010, Socorro - NM

EVLA Specific Algorithms R&D

S. Bhatnagar

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

Overview

- Outline of the talk
  - Overview of the issues requiring new algorithms research
    - Wide-band imaging + off-axis effects
  - Status and plan for algorithms R&D (EVLA Memo #139 & #122)
    - Progress so far
    - Various algorithmic dependencies
    - Staged deployment recognizing the available resources
  - Connection between algorithms R&D and HPC
  - Issues and challenges: Research, required software development, etc.
- Conclusions
  - Initial algorithms for wide-band and wide-field imaging developed
    - Work required for testing and then deployment in production software
  - Begin using HPC frame work to reduce run-time and related algorithmic issues
  - Begin exploring full Stokes imaging and calibration
  - Development & testing progress tied to status of EVLA commissioning

Algorithms R&D

- New algorithm are required to realize the EVLA project goals
  - However some scientific results possible with existing software tools as well
- New scientific capabilities with large bandwidths
  - Unprecedented sensitivity
  - High resolution wide-band spectroscopy
  - Spectral index imaging at unprecedented sensitivity and detail
  - Rotation Measure (RM) Synthesis

- Algorithms R&D is resource limited
  - Personal assigned on an ad-hoc basis by the NRAO management
  - Currently seconded to the ASC, NM operations
  - Current focus on EVLA specific problems
  - Many areas of overlap with ALMA
  - Possible change of focus/emphasis on the longer term

Imaging issues

- Project requirements: Full beam, full bandwidth, full Stokes imaging with the EVLA

- Algorithmic R&D requirement:
  - Wide-band issues (2:1 Bandwidth ratio)
    - Accounting for the frequency dependence of the sky-emission (MFS)
    - Polarization dependence of the sky (RM-Synthesis)
  - Wide-field issues
    - PB-rotation with Parallactic Angle
    - First order: Frequency dependence of the PB
    - Second order: Polarization dependence of the PB
  - Full-field, wide-band issues
    - Instrumental: PB Rotation, frequency & polarization dependence

      +

    - Sky: Frequency and polarization dependence of the sky

Calibration issues

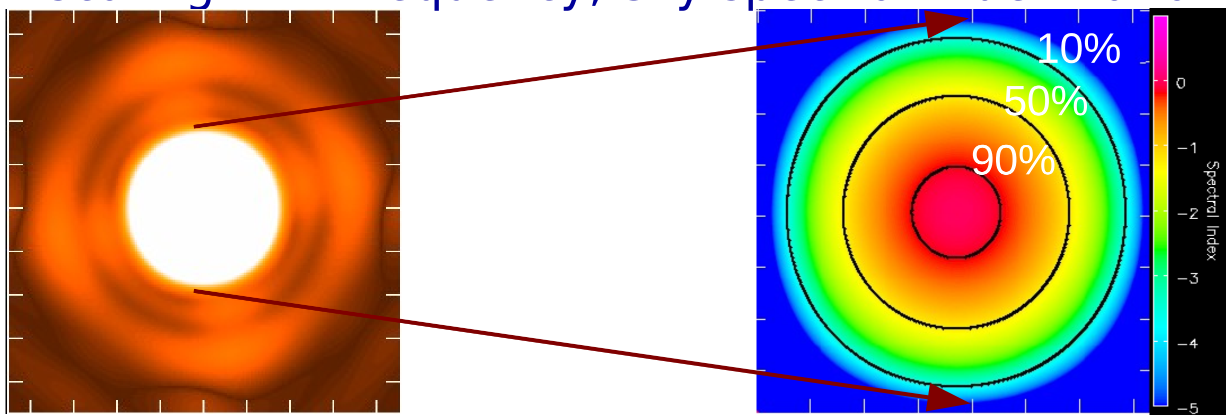
- Algorithmic R&D requirement:
  - On-axis (Direction independent)
    - wide-band bandpass calibration
      - Time varying bandpass
    - Frequency dependent polarization calibration
      - Time varying component
  - Off-axis (Direction dependent)
    - Frequency dependence of the PB
    - Time dependence of the PB: Antenna pointing errors, shape,...
    - Ionosphere (L/S Band), atmosphere
    - Beam polarization
  - RFI
    - Auto-/semi-automatic flagging
    - Weak RFI: research problem

Plan

- EVLA Memos
  - EVLA Memo #122 (Owen, 2008), #139 (Bhatnagar, 2009)
- Wide-band, narrow-field (Stokes-I)
  - Decouple sky frequency dependence from instrumental (PB)
  - MS-MFS: Develop and test (Rao Venkata's thesis (2010))
- Wide-band, narrow-field, full-Stokes
  - RM-Synthesis (Kogan et al.)
- Wide-band, wider-field
  - PB effects dominate
    - A-Projection algorithm to correct for time- and freq- dependence
    - Extensions for full-polarization mode
  - Mosaicking: Overlap with ALMA (Golap, Bhatnagar,...)
- Full sensitivity, full-field, full-polarization
  - Combine: MS-MFS + A-Projection + RM-Synthesis

Wideband Effects

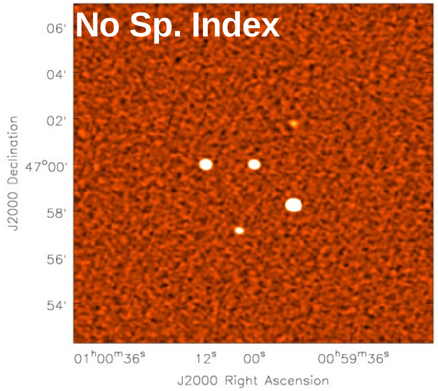
- Frequency dependence
  - PB scaling with frequency, Sky spectral index variations

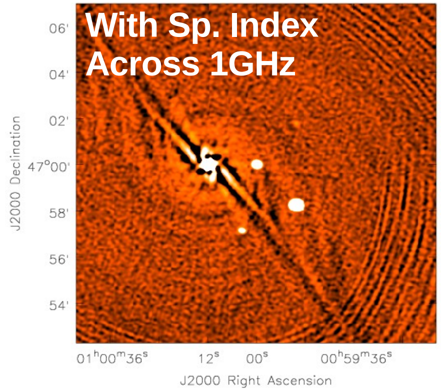


Wide-band Power Pattern

Static-PB main-lobe spectral index

PB Effects

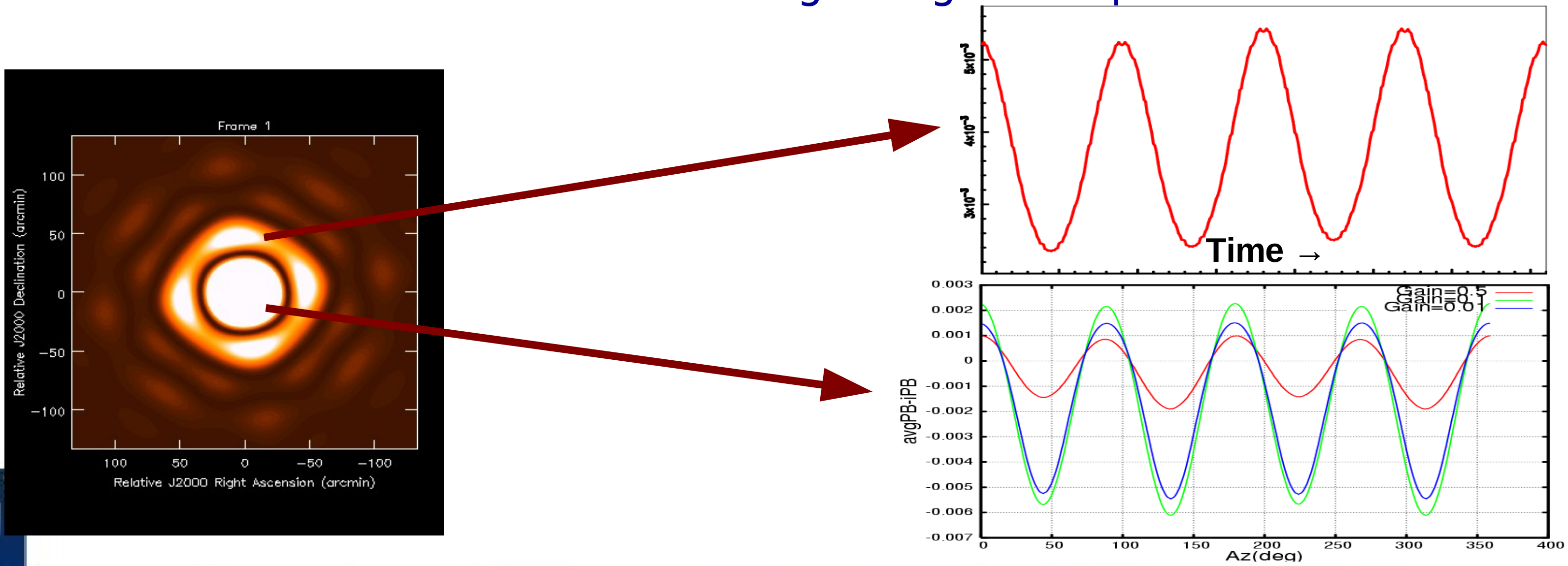




Sky Effects

Time varying effects

- Time dependence of the PB
  - Rotation with Parallactic angle is the dominant effect
  - In-beam maximum error ~10% point: DR limit fewx10000:1
  - Errors in main-lobe, due to strong sources in the first side-lobes: 3x-5x higher
    - Less of a problem for single-pointing observations at >C band
    - But similar errors for mosaicking at higher frequencies



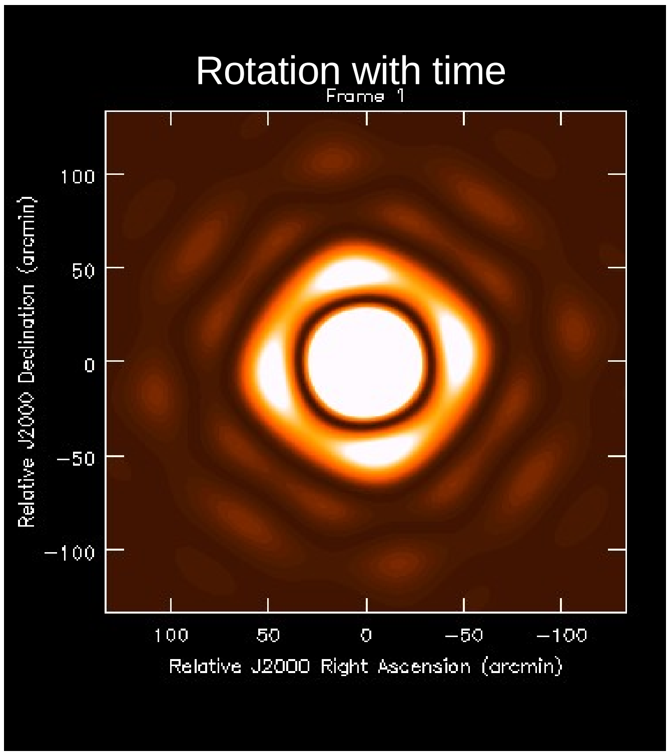
Limits due to bandwidth

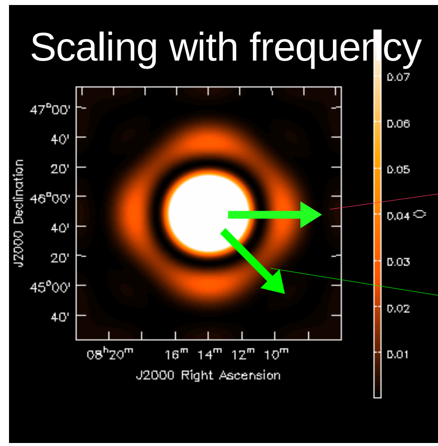
- Wide-band effects
  - Instrumental: PB scales by 2X is strongest error term
  - Sky: Varying across the band – needs to be solved for during imaging (MFS)
- Time varying effects
  - PB rotation with time
  - Pointing errors
  - Beam polarization
- Errors due to wide-band and time-varying direction dependent effects are of similar order
  - Imaging dynamic range to ~ few x 10^{3-4}
- Improved spectral index imaging, RM-imaging not possible without algorithms for wide-band issues

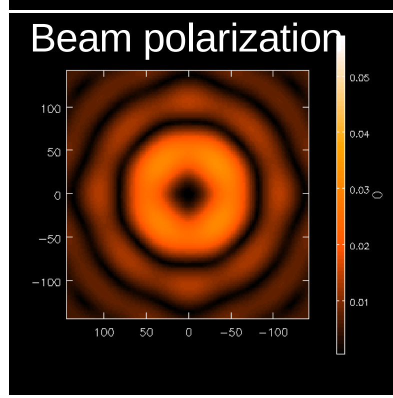
EVLA

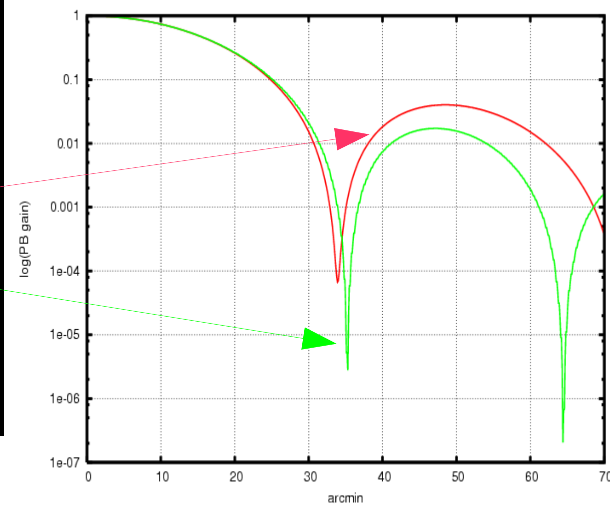
Instrumental effects

- Time, frequency and polarization dependence of the PB









Sources of time variability

- PB rotationally asymmetric
- PB rotation with PA
- PB scaling with frequency
- Antenna pointing errors

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EVLA

Progress (follow-up from last year)

- Approach to problem solving:
  - Algorithms R&D (SNR per DoF, error propagation, HPC, ...)
  - Proof-of-concept test via realistic simulations
  - Implementation & testing with real data
- Wide-band imaging MS-MFS [Sci. Testing]
  - Major part of U. Rao Venkata's thesis: [Done! (2010)]
- Wide field imaging
  - W-Projection algorithm: [In use/published, IEEE, 2008]
  - PB corrections
    - Basic algorithm: AW-Projection algorithm: [Testing/published, A&A, 2008]
    - PB freq. Scaling [In progress]
    - All-Stokes PB correction [Initial investigations]
  - Pointing SelfCal: [Sci. Testing]

[Bhatnagar et al., EVLA Memo 84]

Papers in preparation

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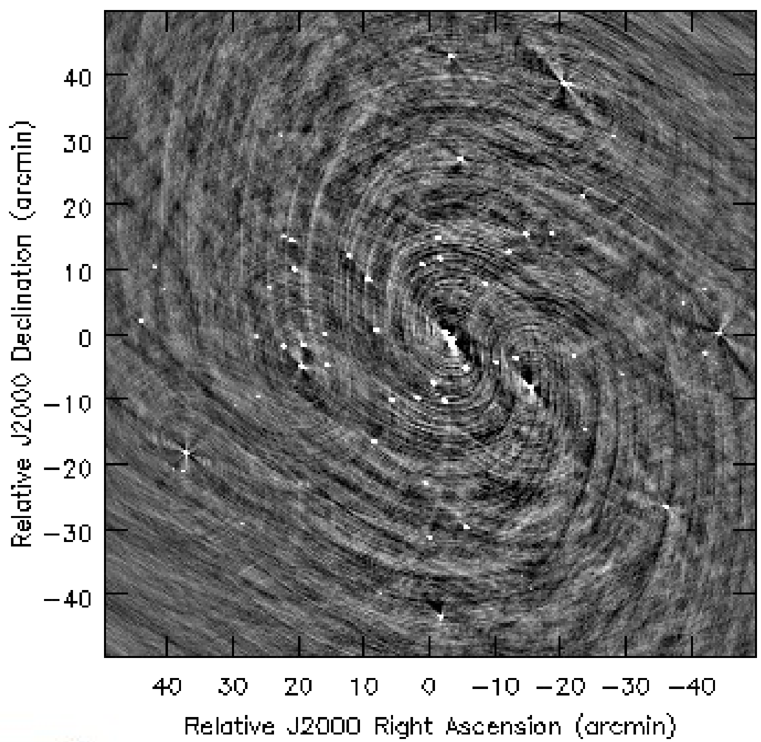
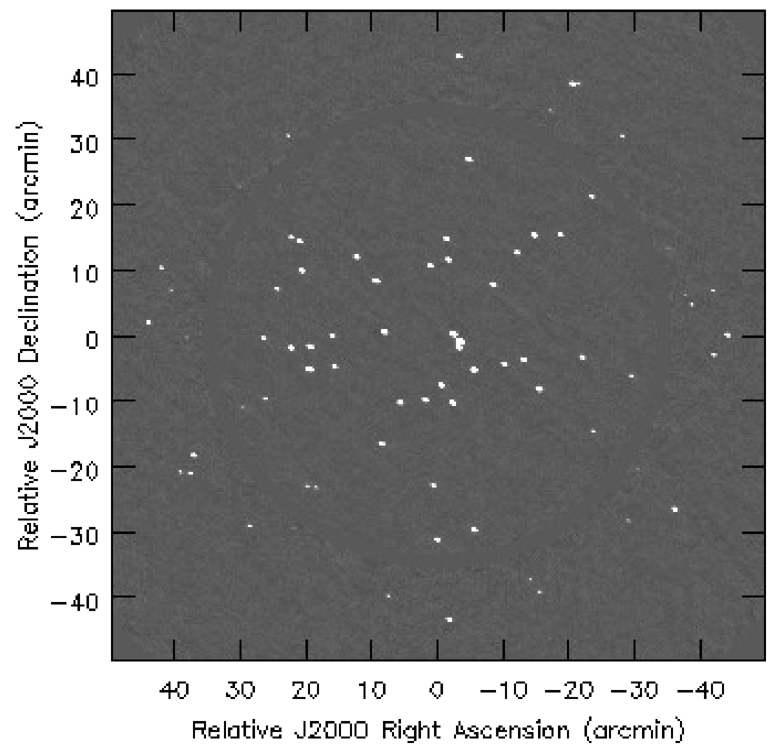
Correction for pointing errors and PB rotation: Narrow band

Before correction

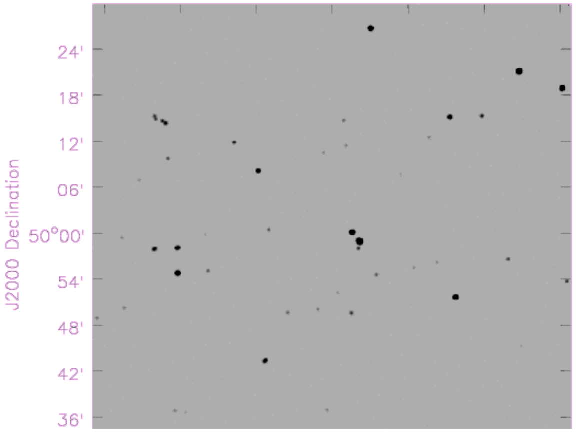


After correction



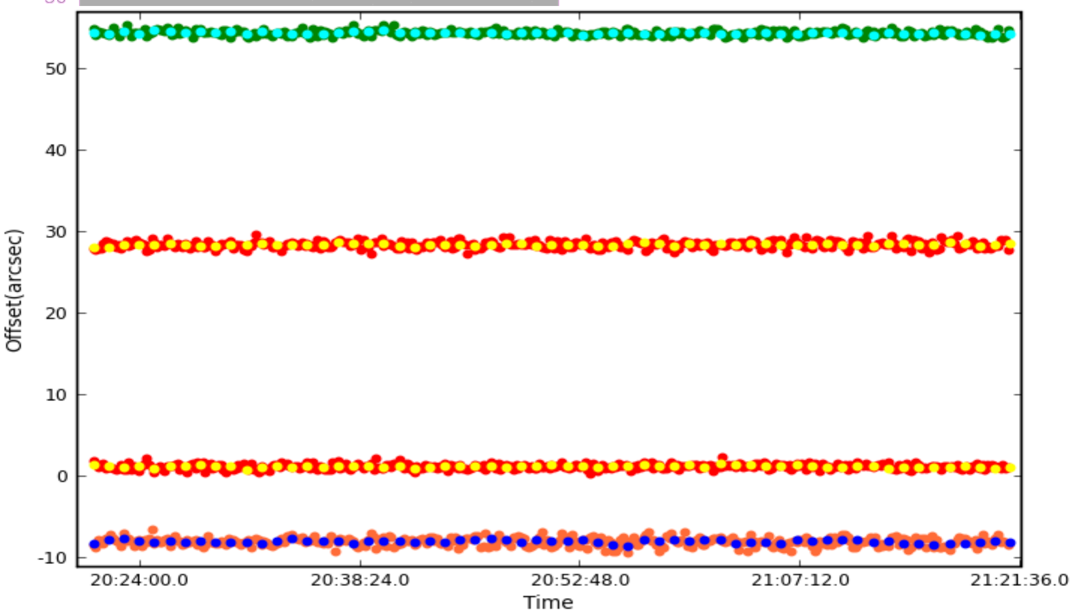
(Bhatnagar et al., EVLA Memo 100 (2006), A&A (2008))

Pointing SelfCal



- Model image: 59 sources from NVSS.
- Flux range ~2-200 mJy/beam

(Bhatnagar et al., EVLA Memo 84)

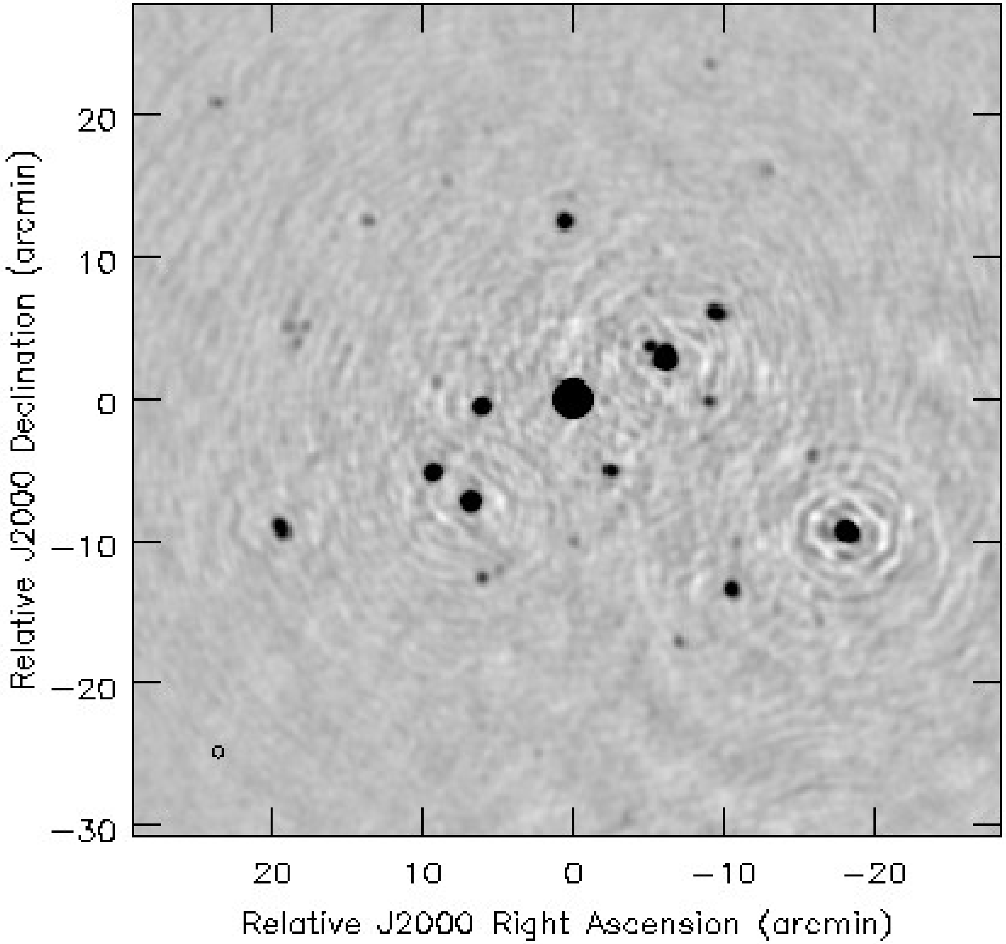


- Typical antenna pointing offsets for VLA as a function of time

- Over-plotted data: Solutions at longer integration time

- Noise per baseline as expected from EVLA

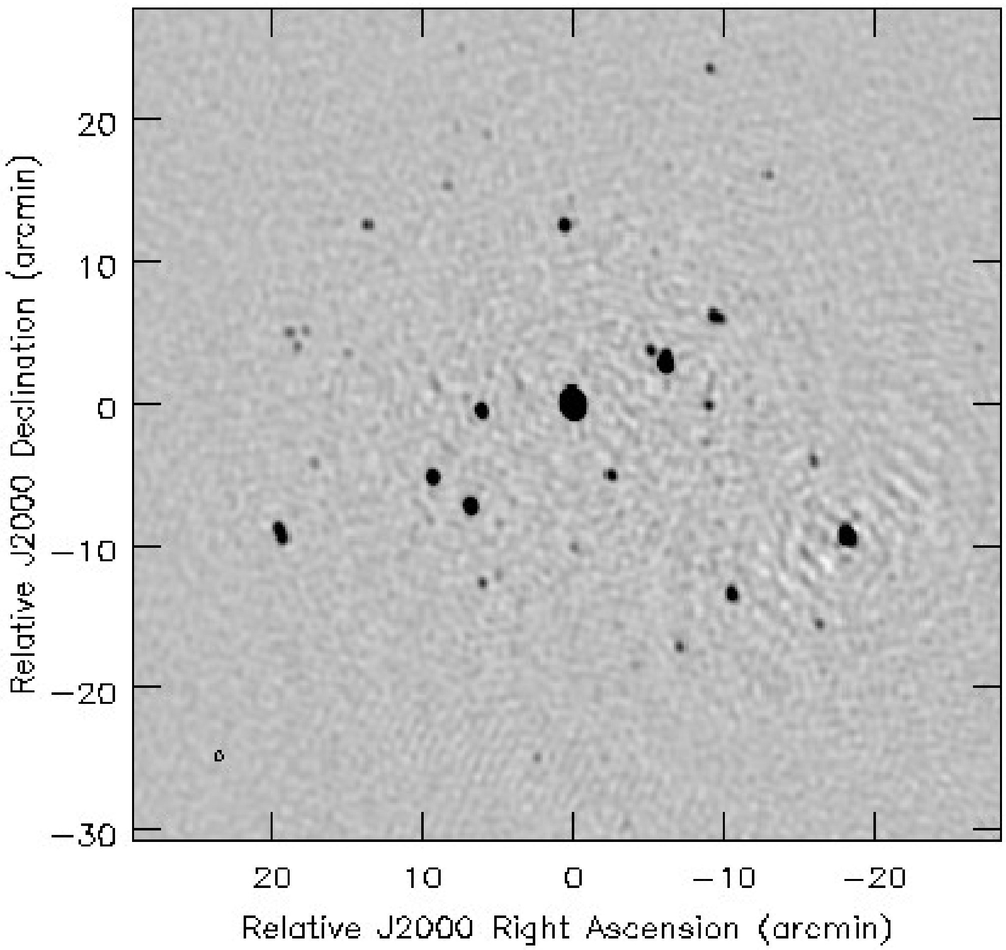
L-band: Stokes-I before correction



- 3C147 field at L-Band with the EVLA
- Only 12 antennas used
- Bandwidth: 128 MHz
- ~7 hr. integration

- Dynamic range: ~700,000:1

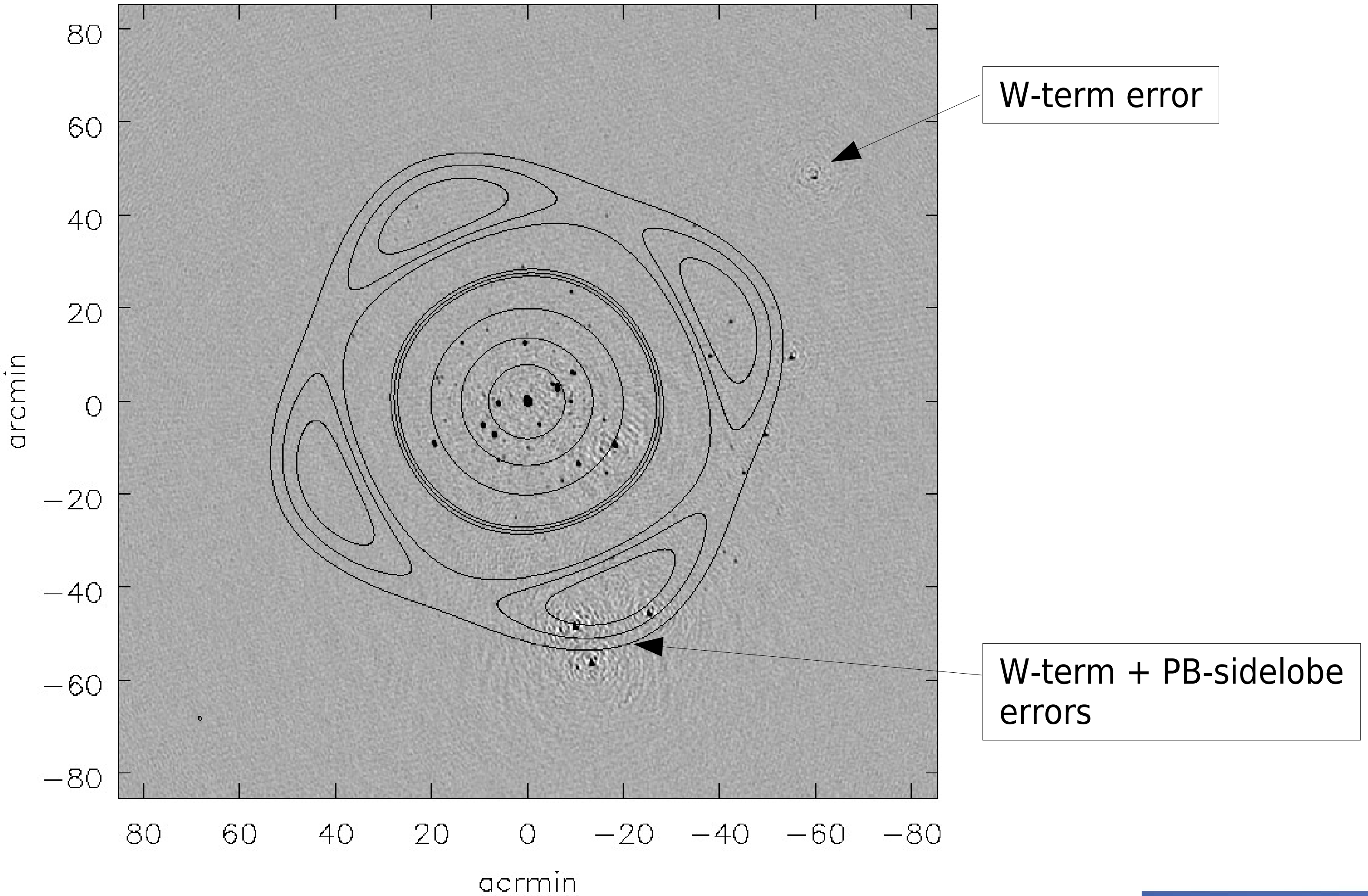
L-band: Stokes-I after correction



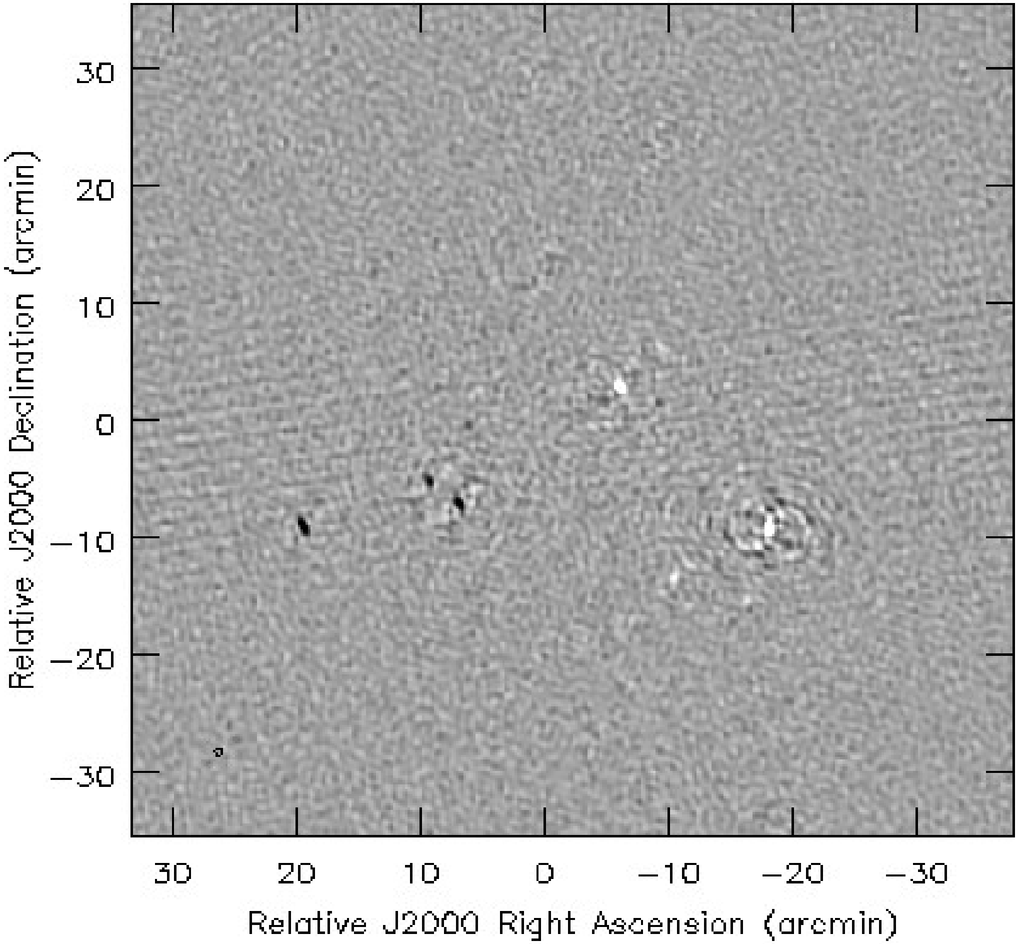
- 3C147 field at L-Band with the EVLA
- Only 12 antennas used
- Bandwidth: 128 MHz
- ~7 hr. integration

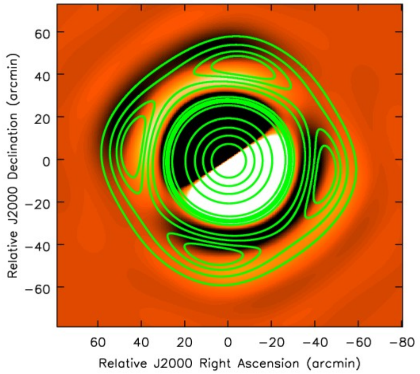
- Dynamic range: ~700,000:1

Full field: Stokes-I

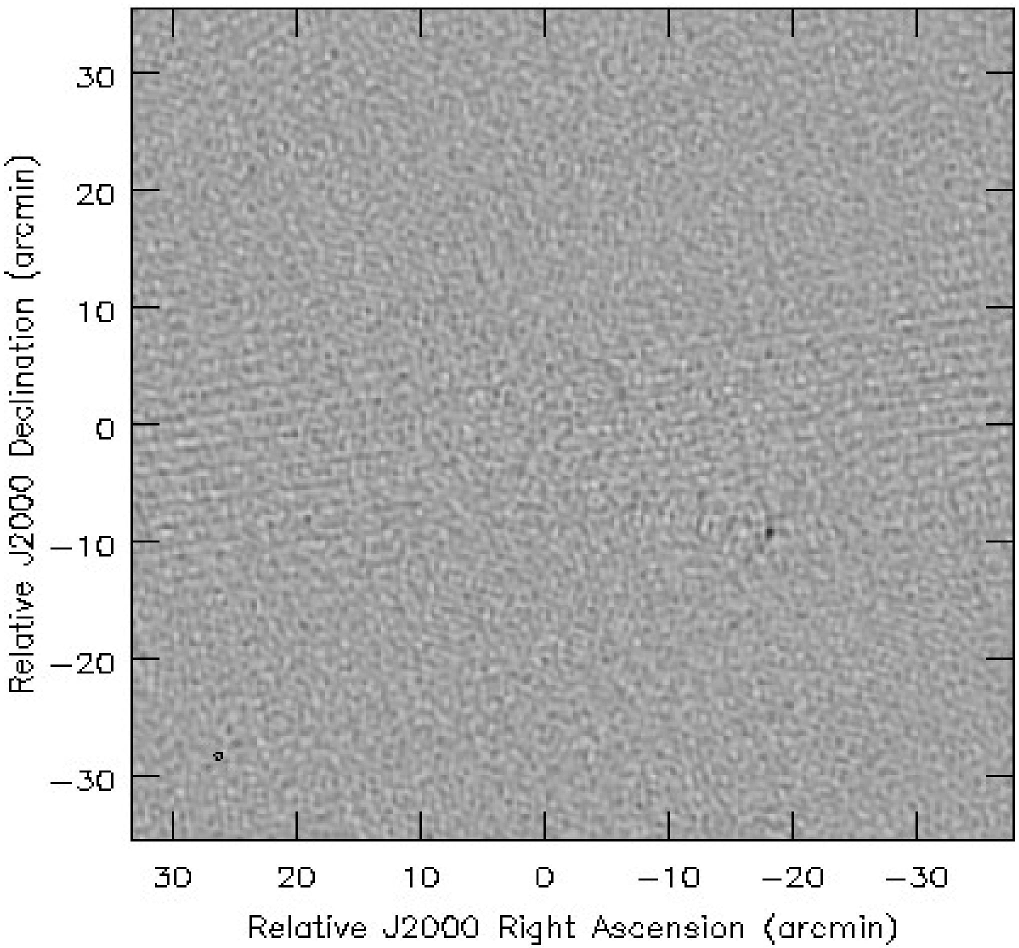


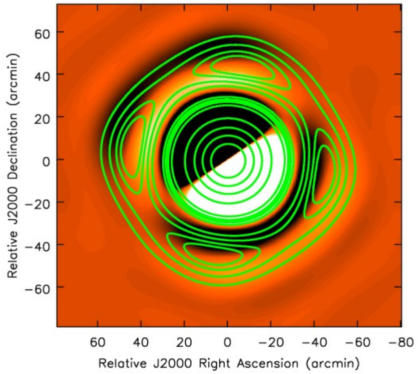
L-band: Stokes-V before correction



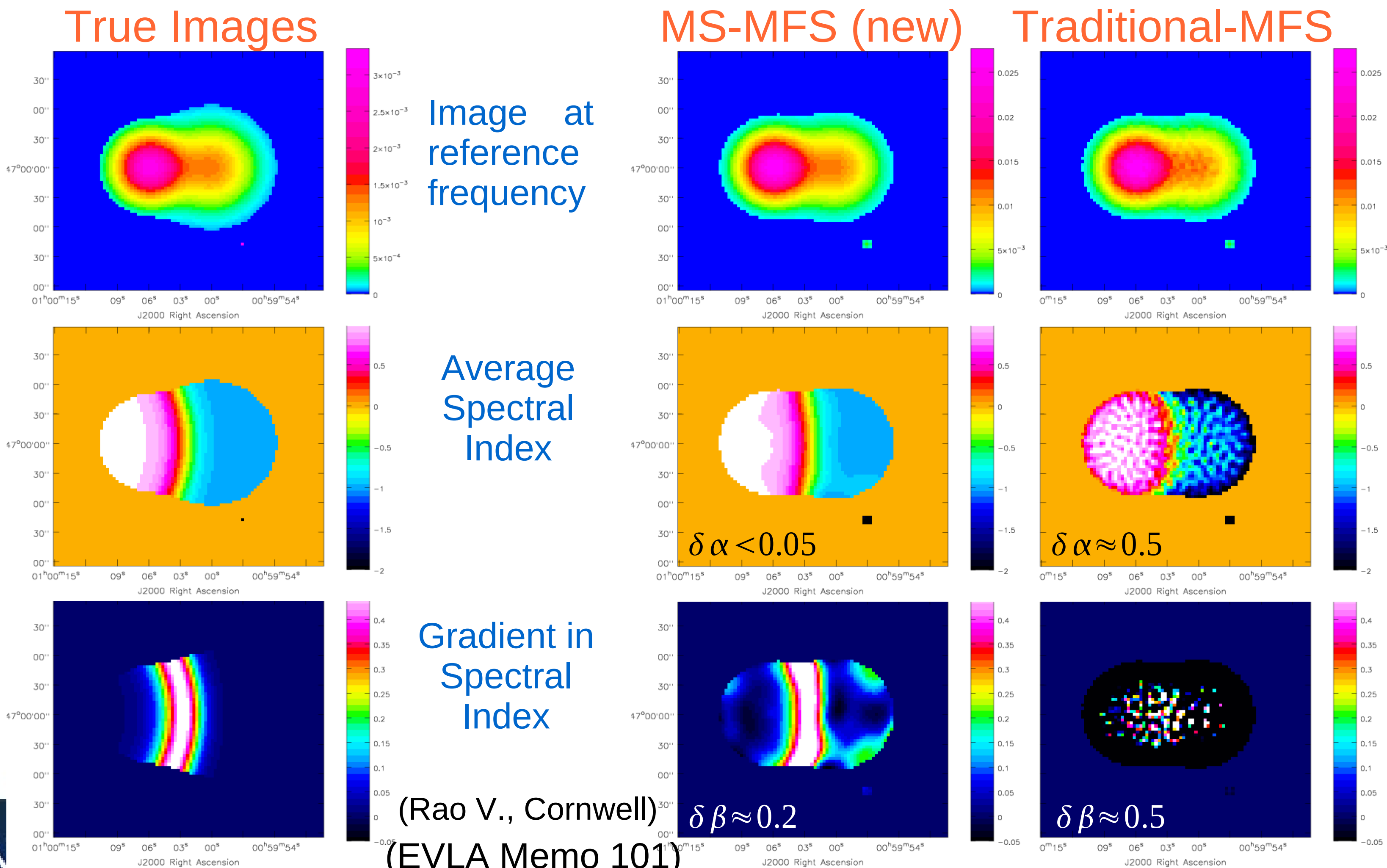


L-band: Stokes-V after correction



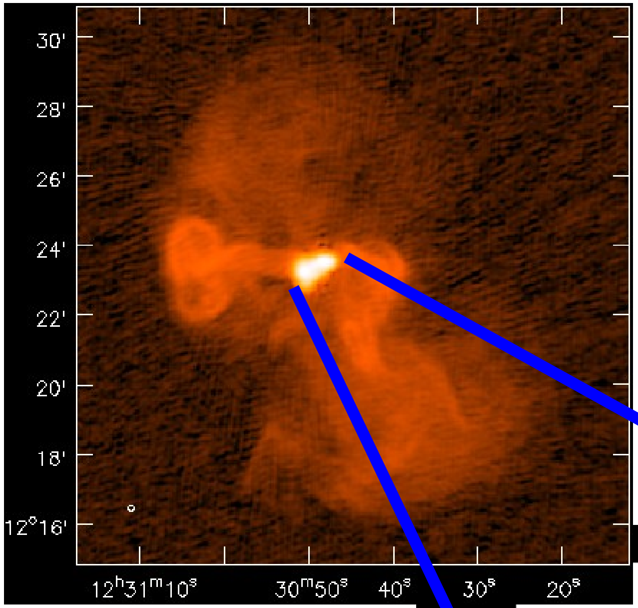


Extending MFS: Basics algorithm



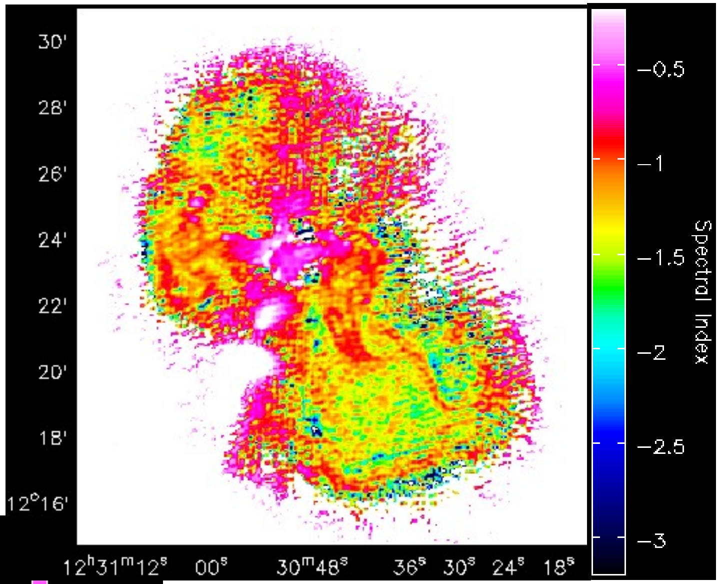
(Rao V., Cornwell)
(EVLA Memo 101)

Application to M87

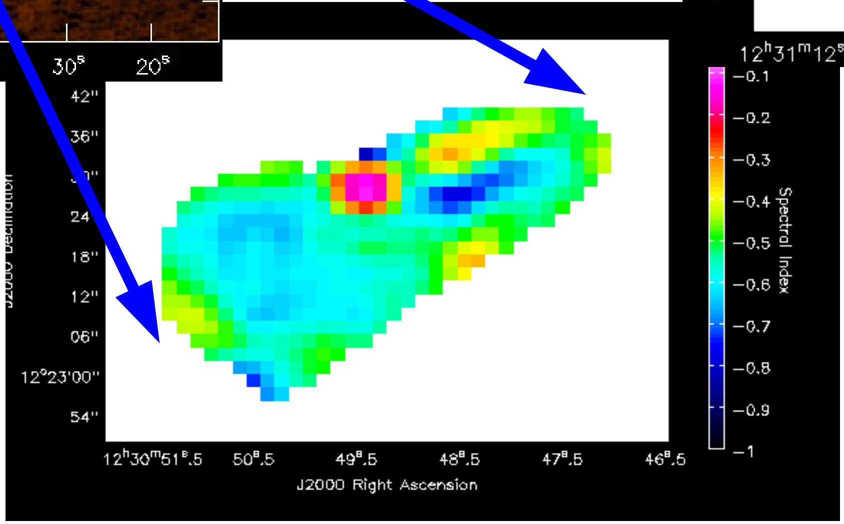


Stokes-I

(Rao Venkata,
Eilek, Owen)

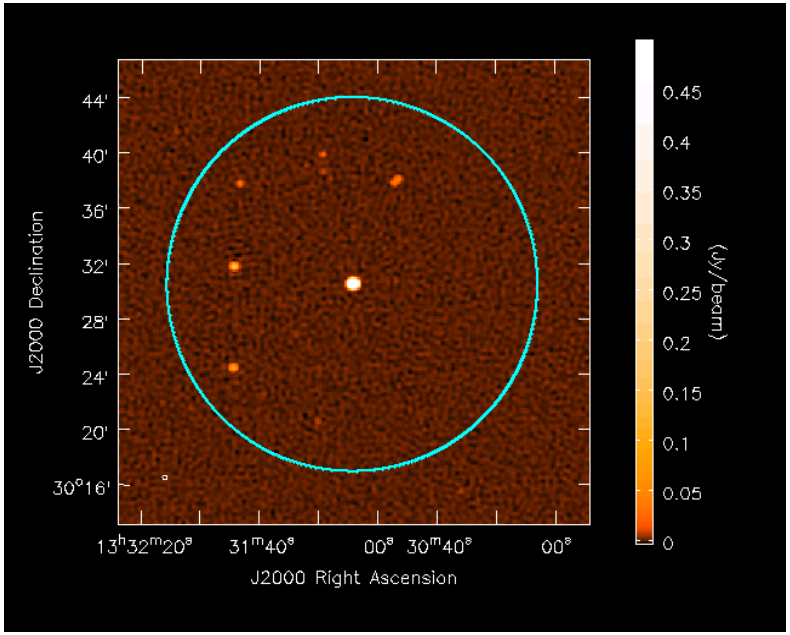


Sp. Ndx.
(No PB correction)



Sp. Ndx. variation

Wide-field, wideband: PB corrections

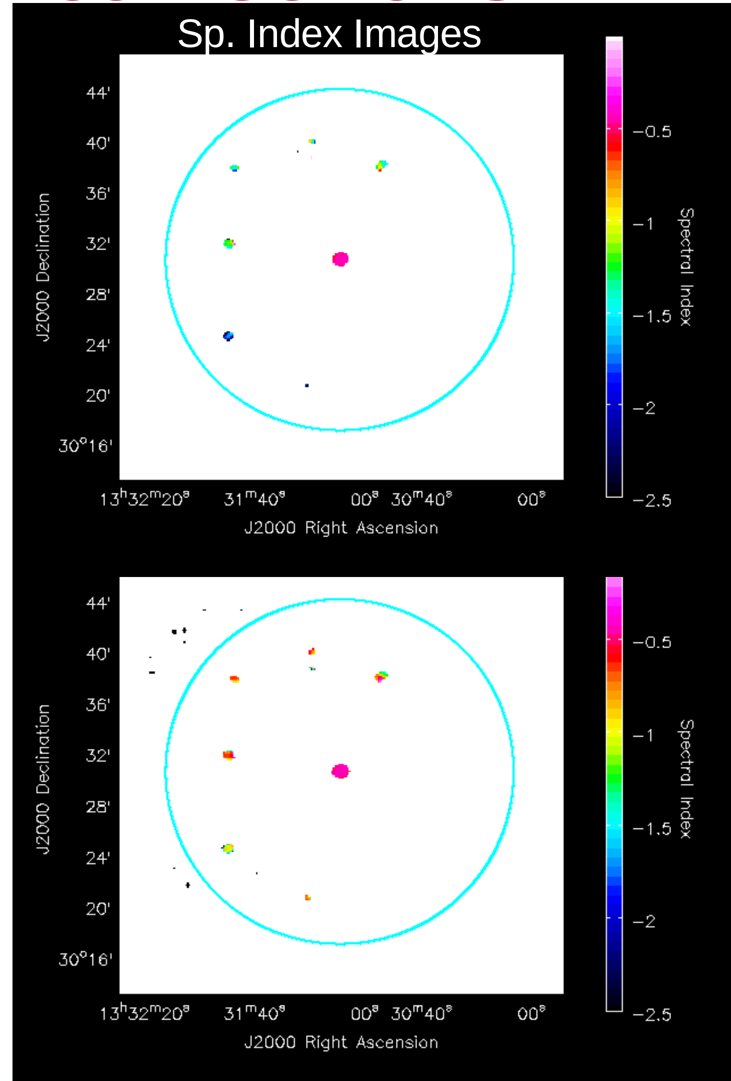


3C286 Stokes-I

(Rao Venkata, Bhatnagar)

Before
PB correction

After
PB correction



Computing & I/O load: Single node

- Tests done with 100 GB, 512 Channels, 4K x 4K x 512 Stokes-I imaging

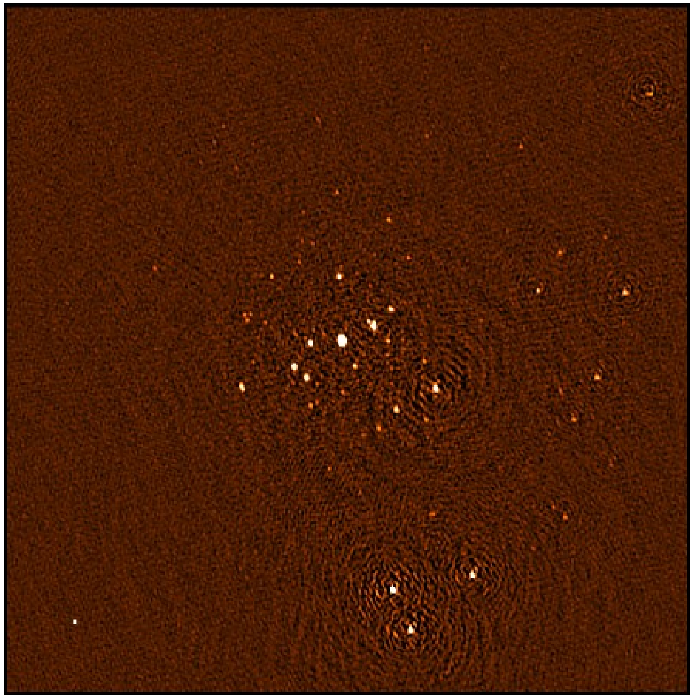
- Conclusions:
  - Sequential processing is I/O dominated
  - Image deconvolution is the most expensive step
    - Most expensive part of imaging is the Major Cycle
  - Exploit data parallelism as the first goal

- Where possible, data size reduction with integration in time and/or frequency may allow processing on a high-end desktop

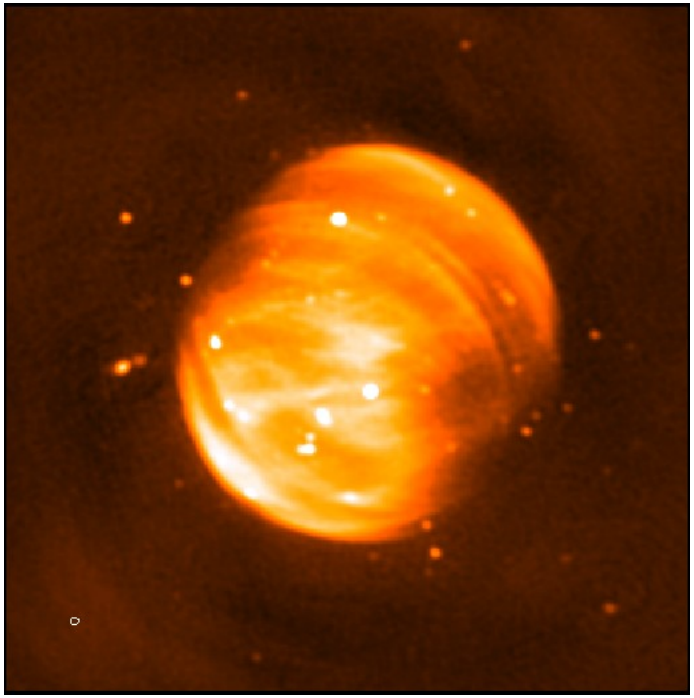
- Total effective I/O ~1 TB (due to iterations) – details in the next talk

Challenges

- A wide range of imaging and calibration challenges



Deep imaging, of otherwise simple "blank" fields

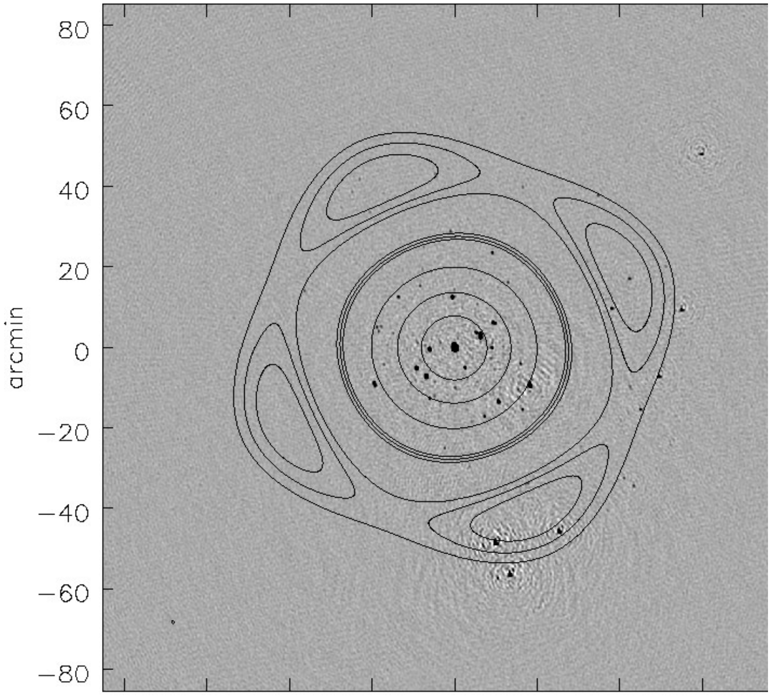


Wide-band high sensitivity imaging of fields with complex emission

EVLA

Challenges

- A wide range of imaging and calibration challenges



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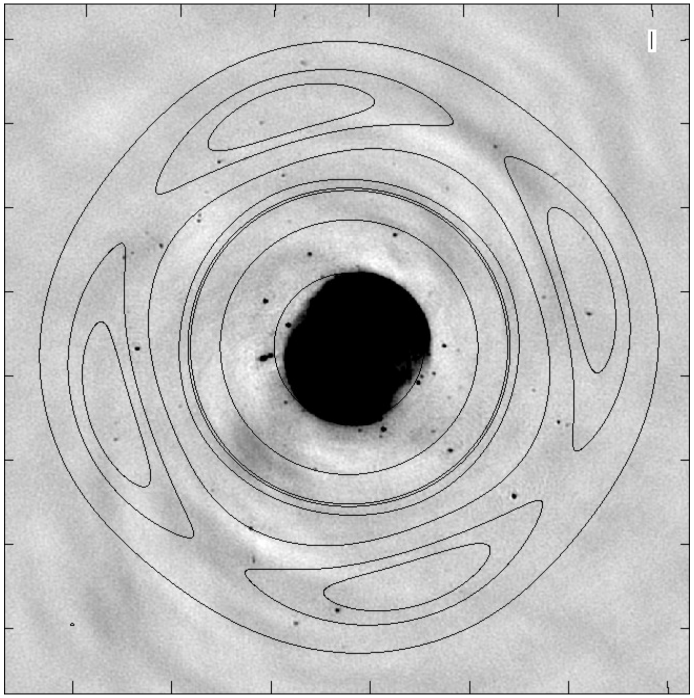

Wide-band high sensitivity imaging of fields with complex emission

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Challenges

- Demands of production-line software (casapy) and software for R&D are incompatible
  - Stability vs flexibility
  - Regular user needs vs. advanced user needs

- Need for better integration of algorithm R&D needs and production software (CASA/casapy) short and long term development plan
  - Algorithms R&D software needs
    - Support software (e.g. visualization, build-system, etc.) needs often different

- Need more developers
  - Need more scientists enthusiastic about using/learning new tools, techniques and methods
  - Currently "testers heavy" situation

Challenges

- Need advanced users/testers with skills and willingness to test new code/algorithms
  - Skill set/expertise/experience level of testers of R&D code very different from those for testing production code

- Need to better align CASA development plan, algorithms development plan and the project plan for enabling scientific capabilities
  - E.g. pipeline processing vs manual processing/visualization

- Improve accuracy and speed of information dispersal to the community