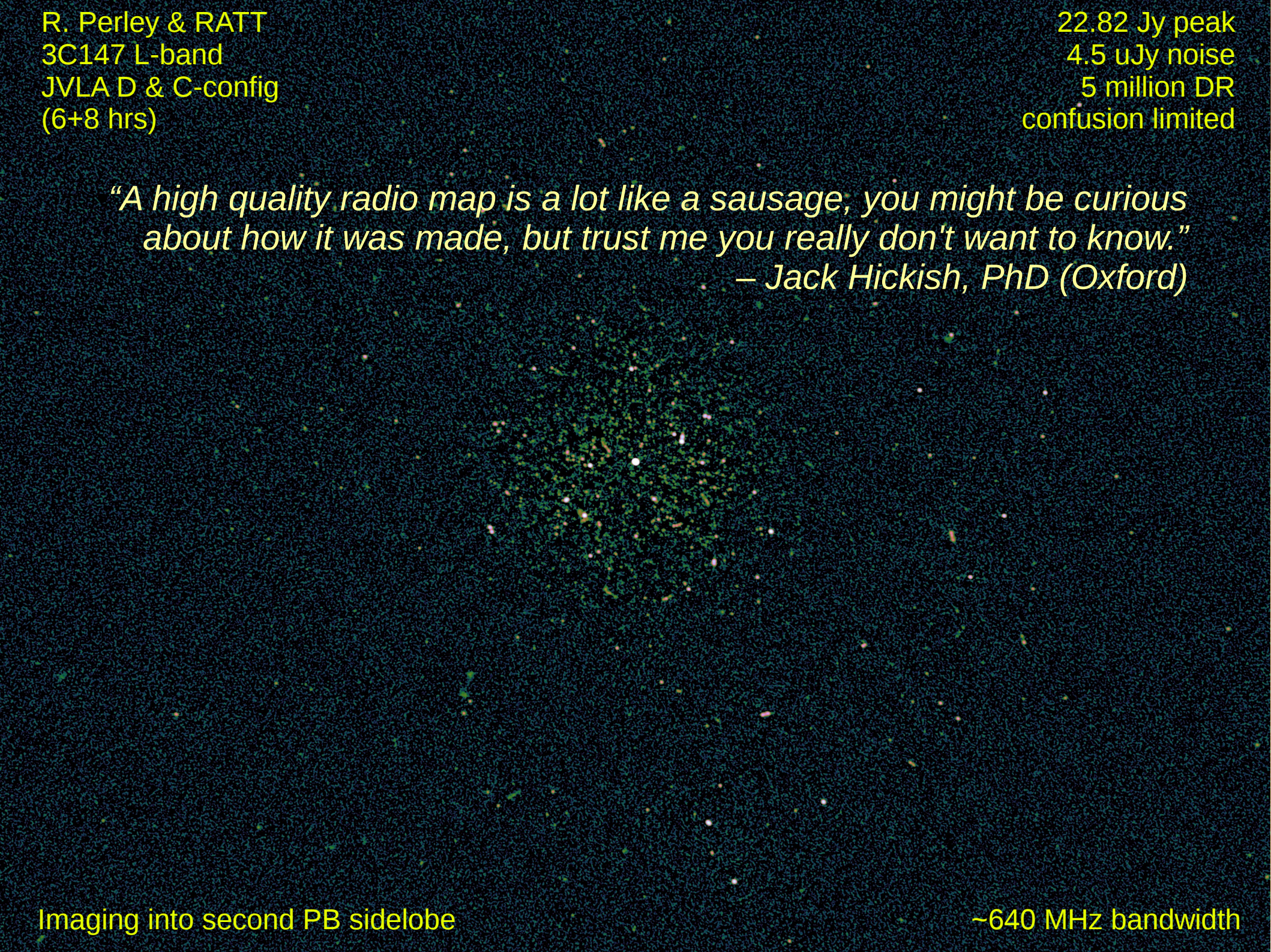
Extreme Interferometry

O. Smirnov
(Rhodes U. & SKA SA)

RATT

SKA AFRICA
SQUARE KILOMETRE ARRAY

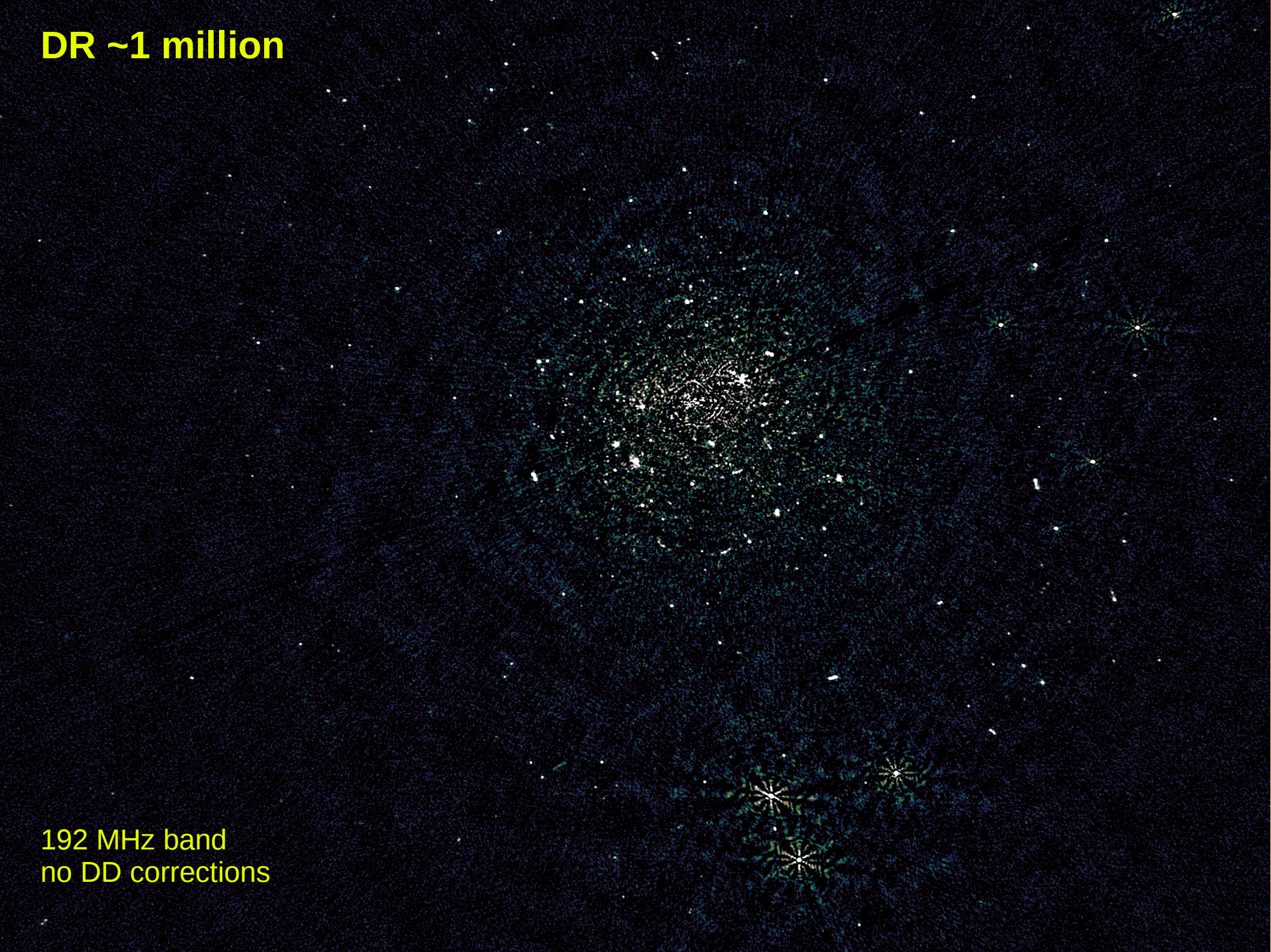

R. Perley & RATT
3C147 L-band
JVLA D & C-config
(6+8 hrs)
22.82 Jy peak
4.5 uJy noise
5 million DR
confusion limited
“A high quality radio map is a lot like a sausage, you might be curious about how it was made, but trust me you really don't want to know.”
– Jack Hickish, PhD (Oxford)
Imaging into second PB sidelobe
~640 MHz bandwidth

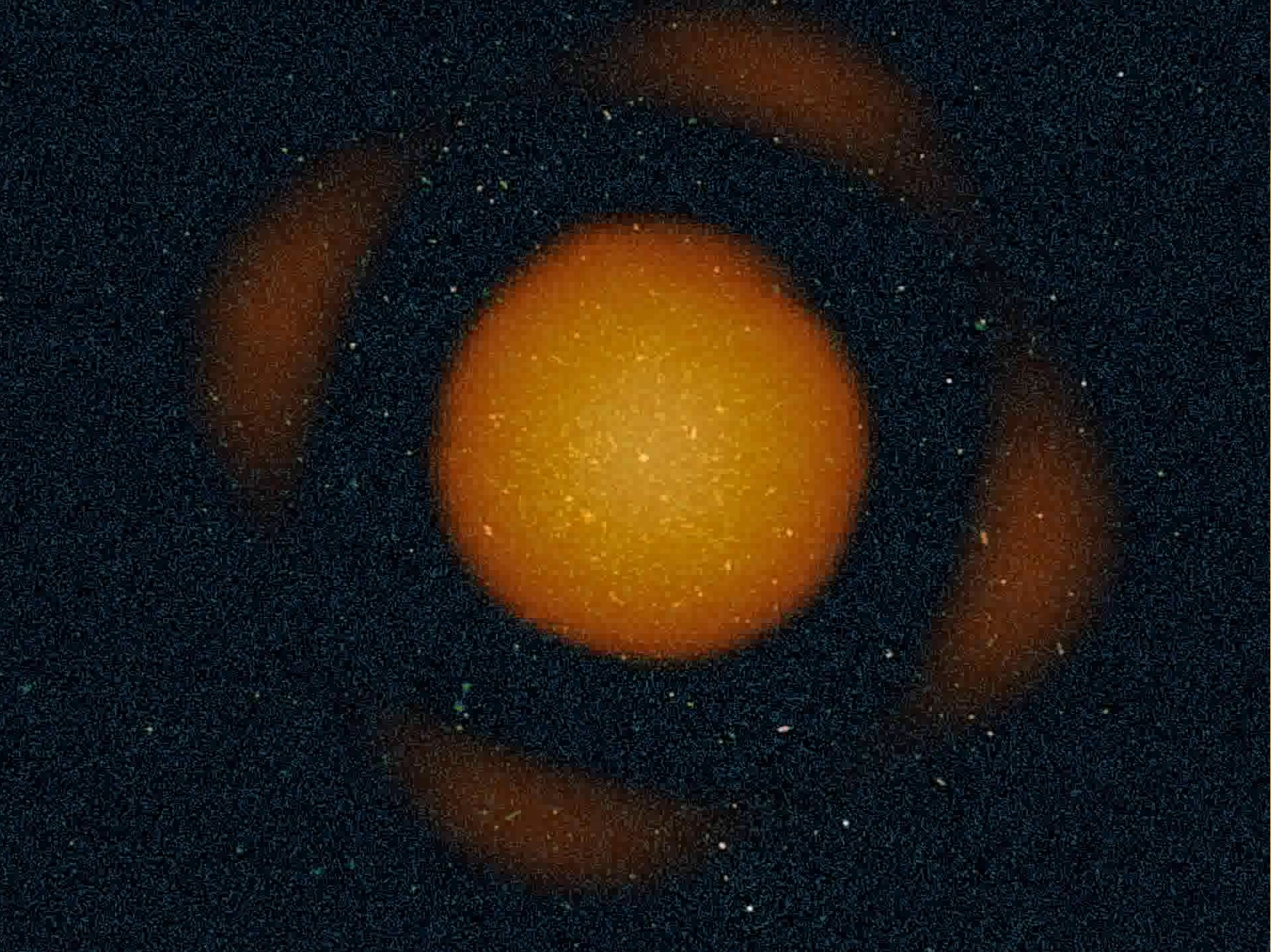
I. High Dynamic Range Imaging (or life inside the sausage factory)

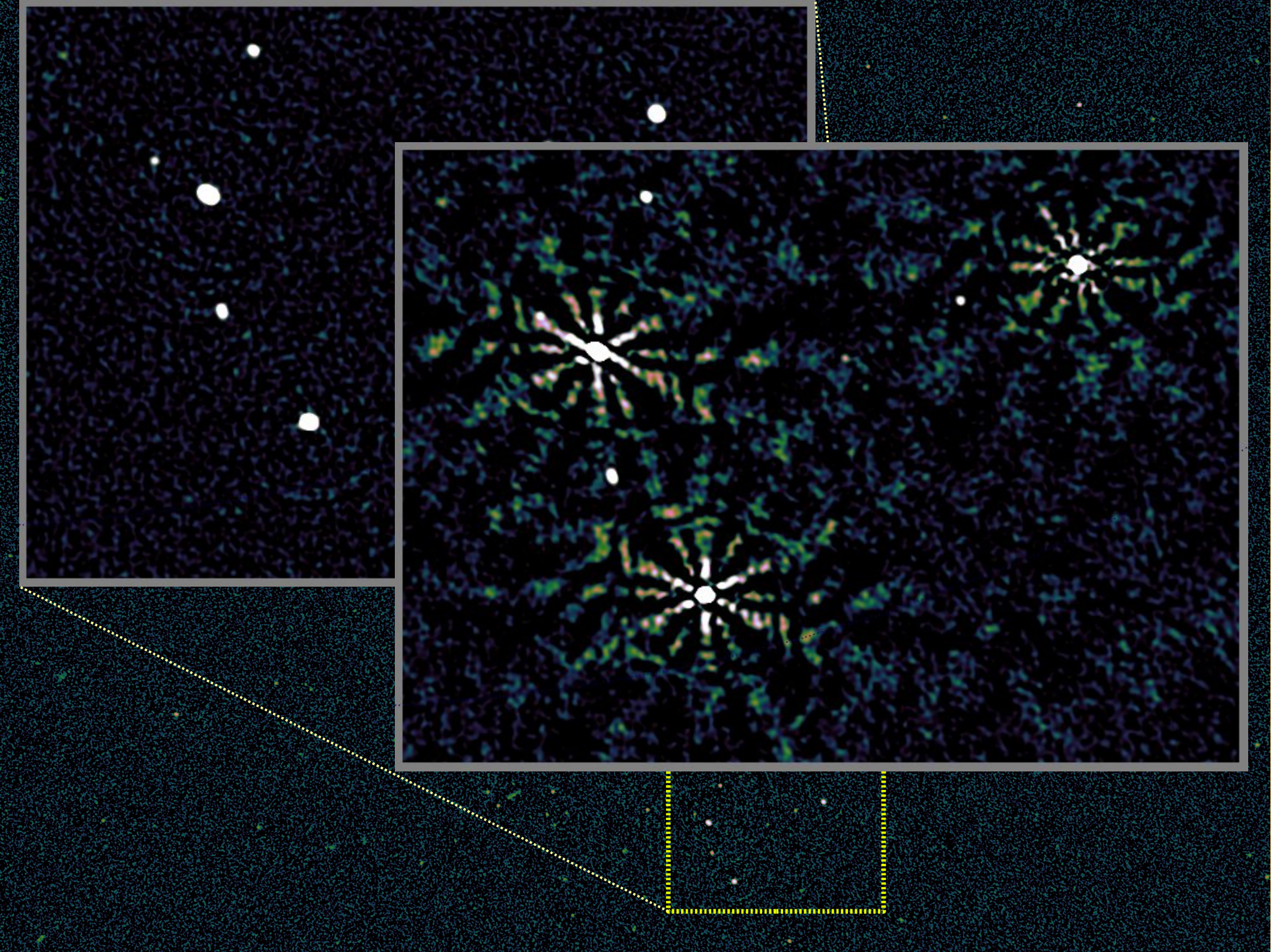
Why Do HDR

- Because we can
- Marketing & bragging rights
- Deconvolution & selfcal is by nature approximative & iterative
  - Robust against approximation also means that bugs can and do get swept under the carpet
  - HDR lifts the carpet
- An excellent debugging tool, the “canary” of calibration & imaging

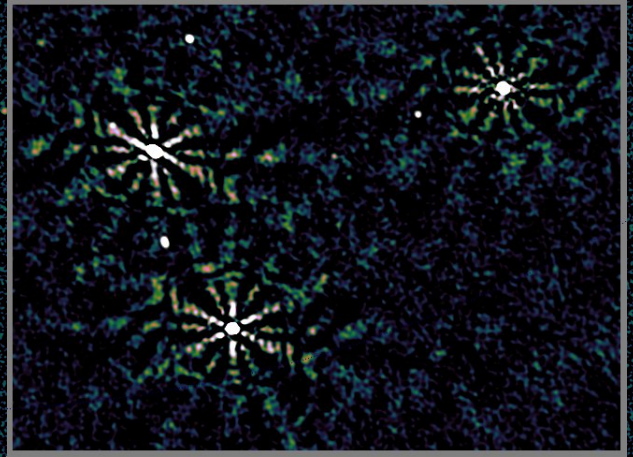

DR ~ 100 000
192 MHz band
no DD corrections

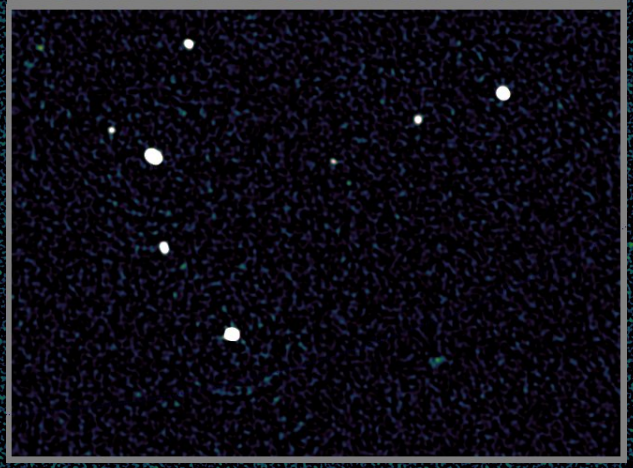

DR ~1 million
192 MHz band
no DD corrections

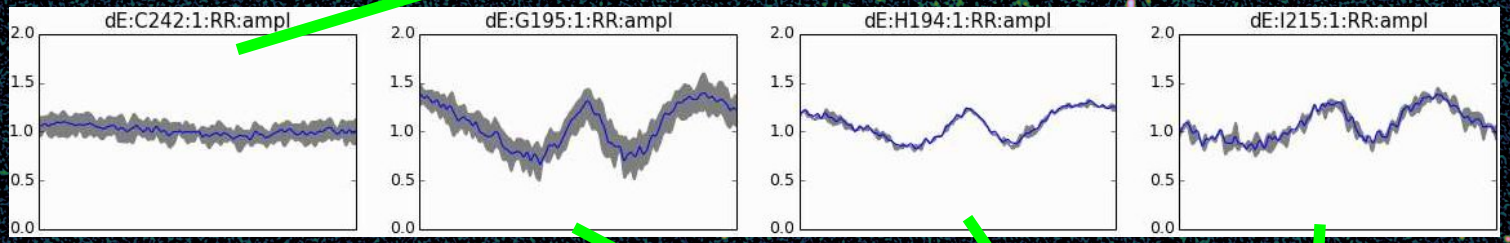




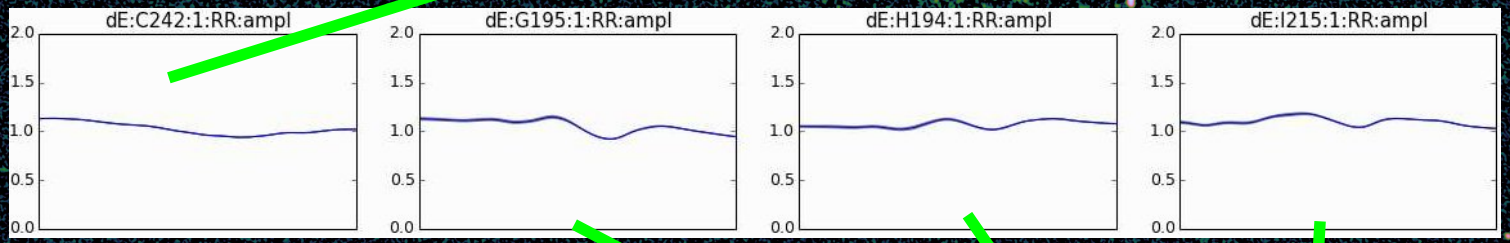
Example differential gain solutions for JVLA (2014 image)
Dominated by primary beam rotation





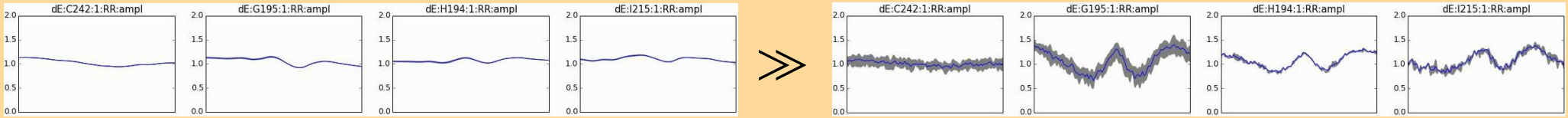


Example differential gain solutions for JVLA (2015 image)
Dominated by pointing error and PB pattern differences

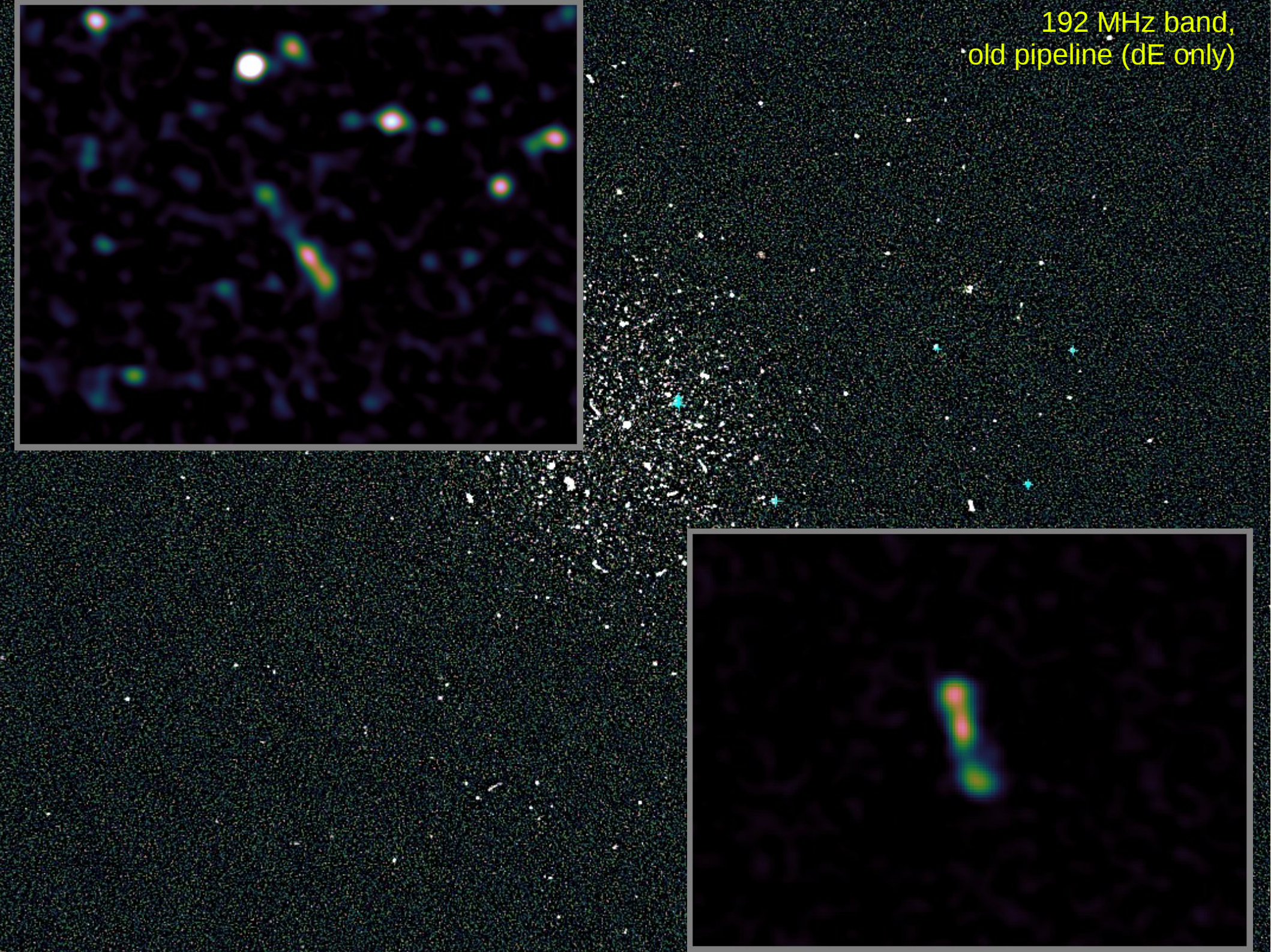


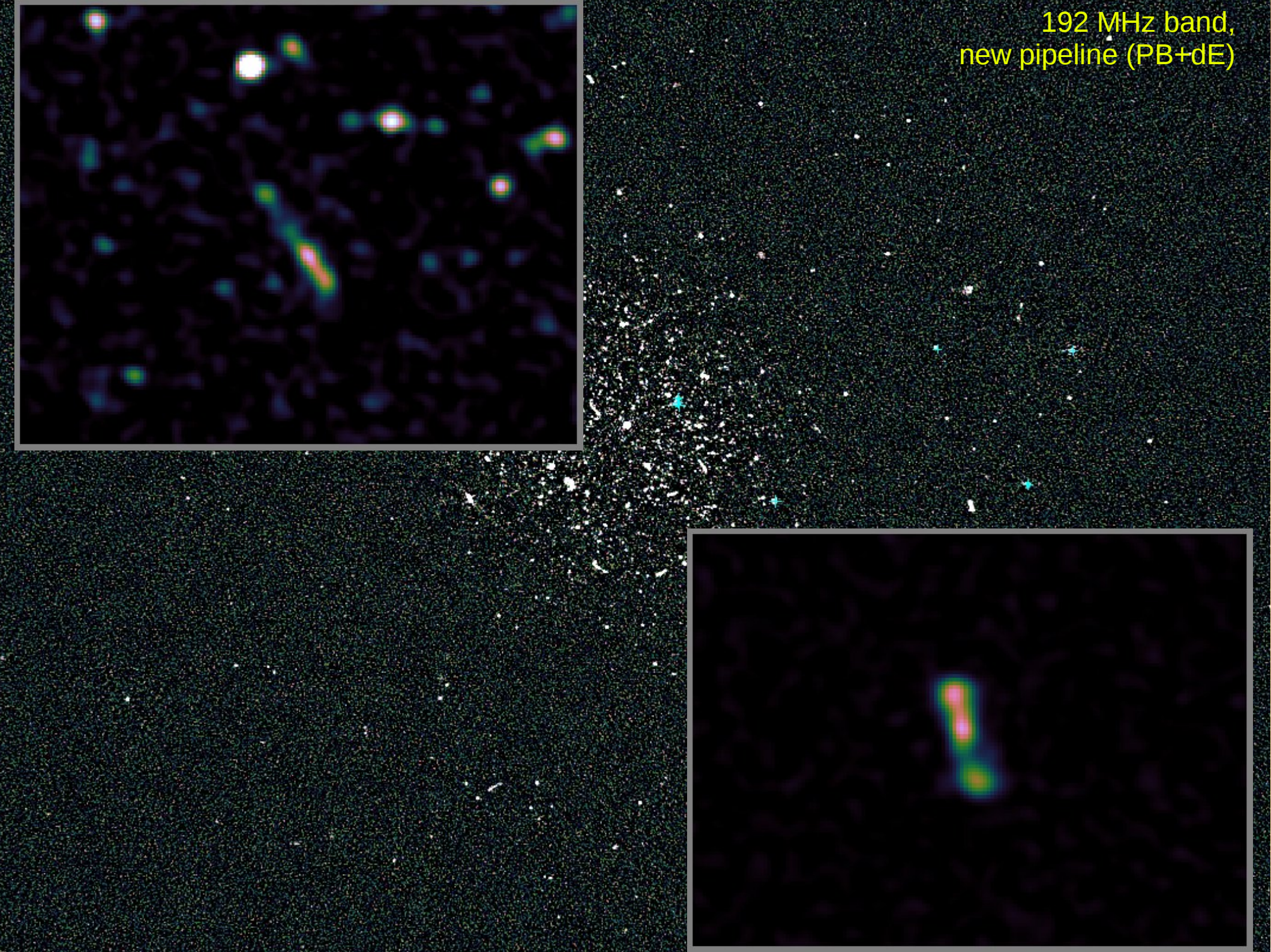
Platonic Ideal Of Calibration

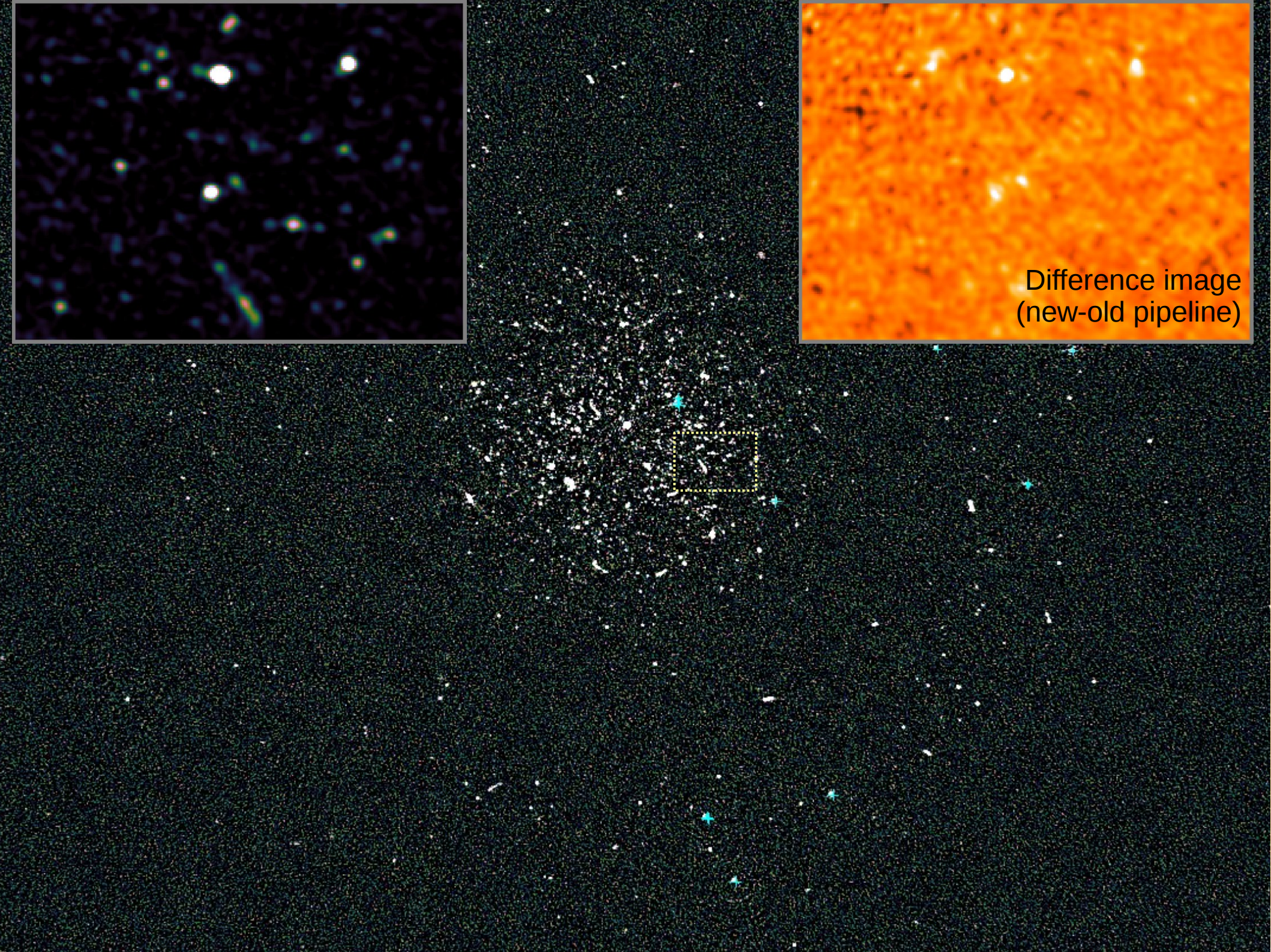
- Results of calibration:
  - Sky model, i.e. catalog of sky sources with their **intrinsic** properties (flux, spectrum, shape)
  - Best-fitting instrumental model
  - Noise-like residual map
- Differential gains: smooth and close to unity



  - Fewer degrees of freedom
  - Consequently, less source suppression

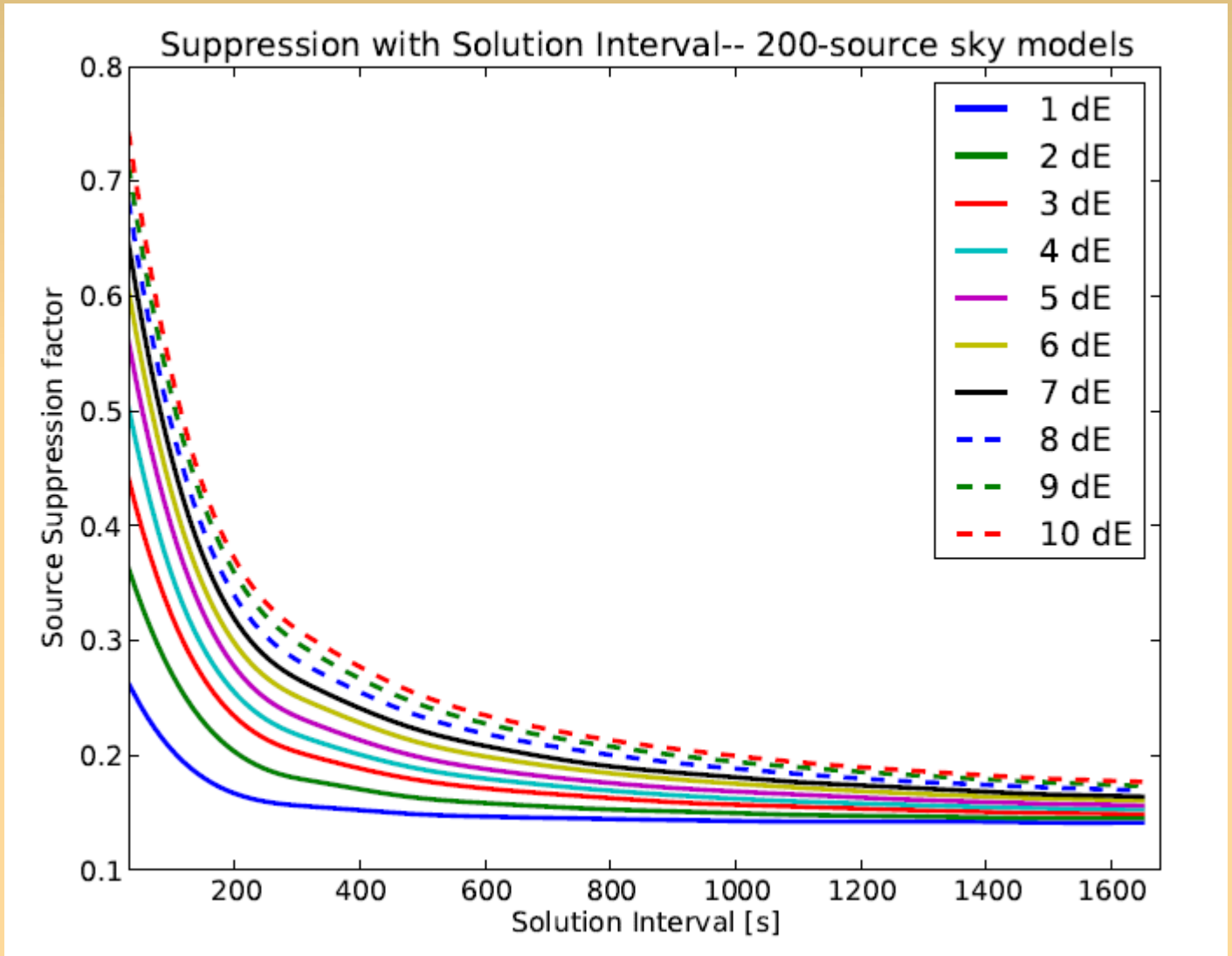

192 MHz band,
old pipeline (dE only)


192 MHz band,
new pipeline (PB+dE)


Difference image
(new-old pipeline)

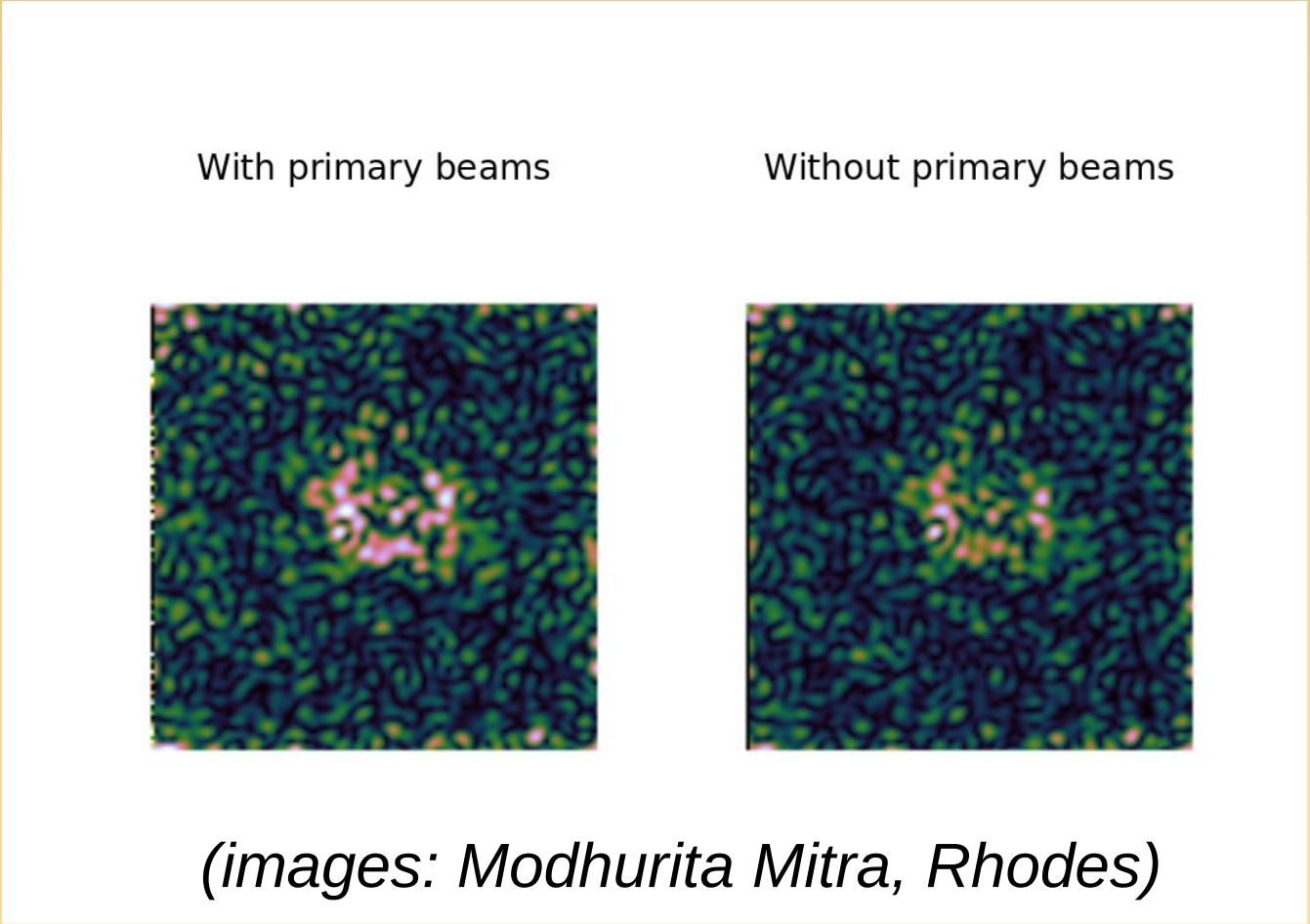
Source Suppresion

(Ridhima Nunhokee 2015, MSc thesis)



Galactic Polarized Foregrounds

- RM=0 polarized signal with PB (longer dE intervals) and without (shorter dE intervals)



(images: Modhurita Mitra, Rhodes)

3C147 Polarized Foregrounds

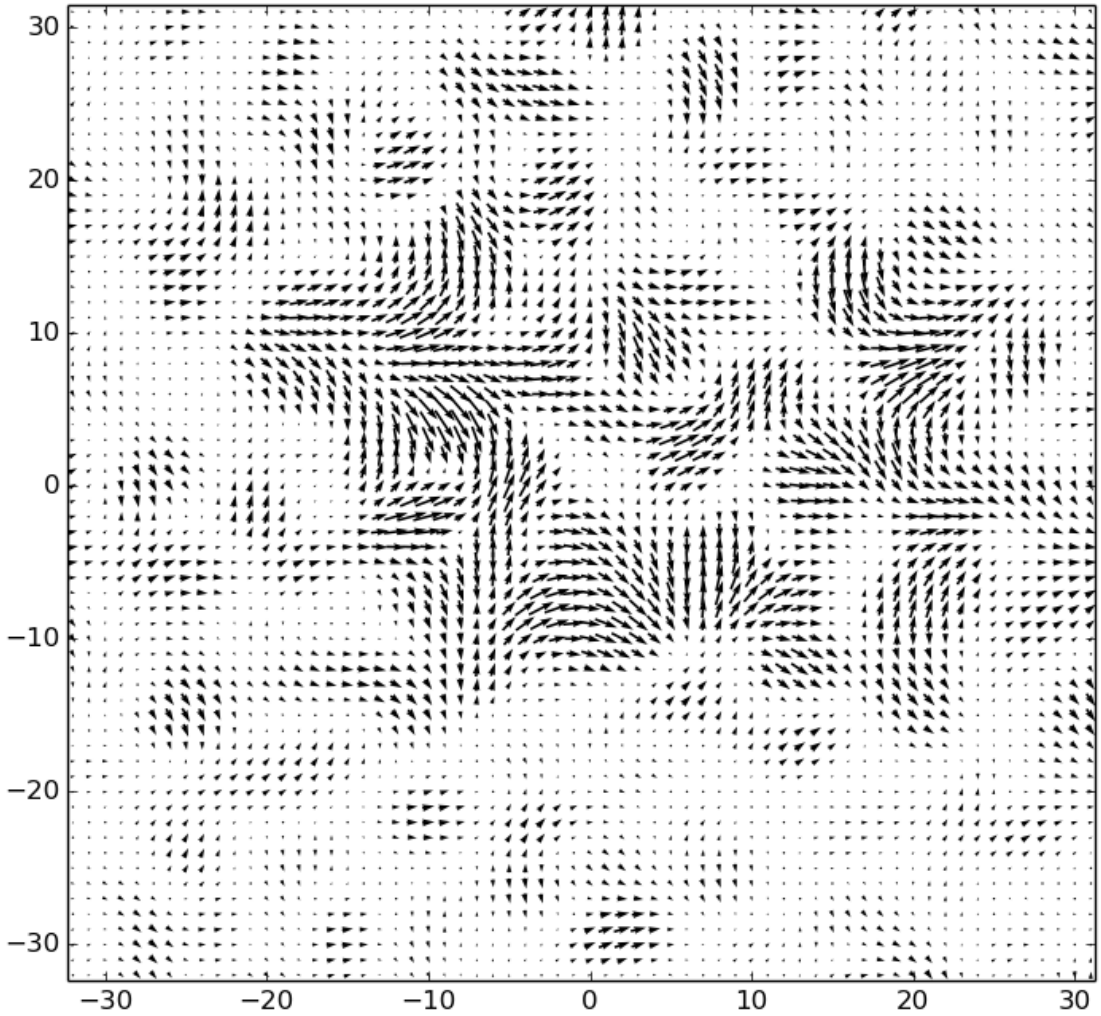
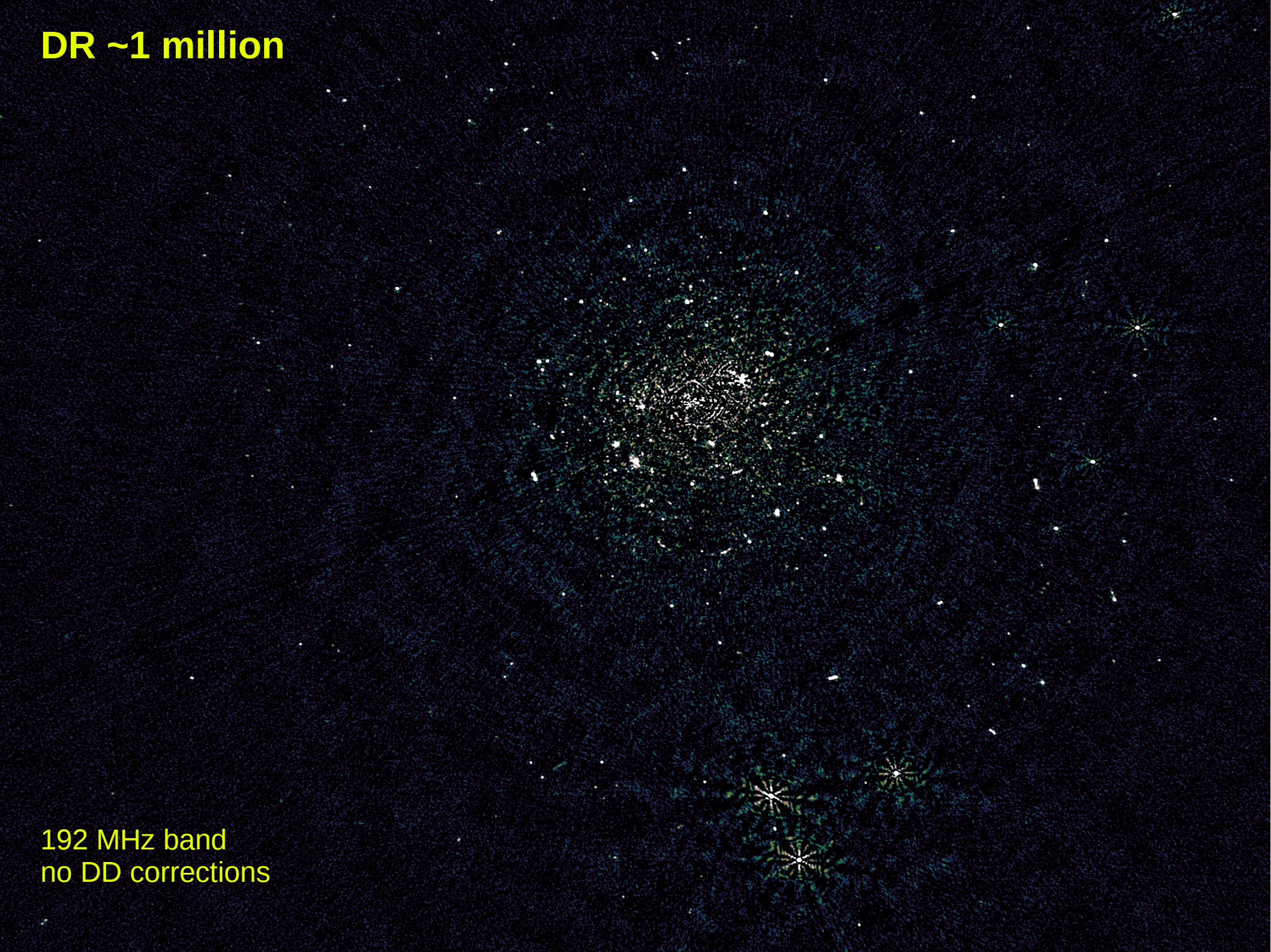


Image: Modhurita Mitra (Rhodes)

Diffgains Are Dangerous

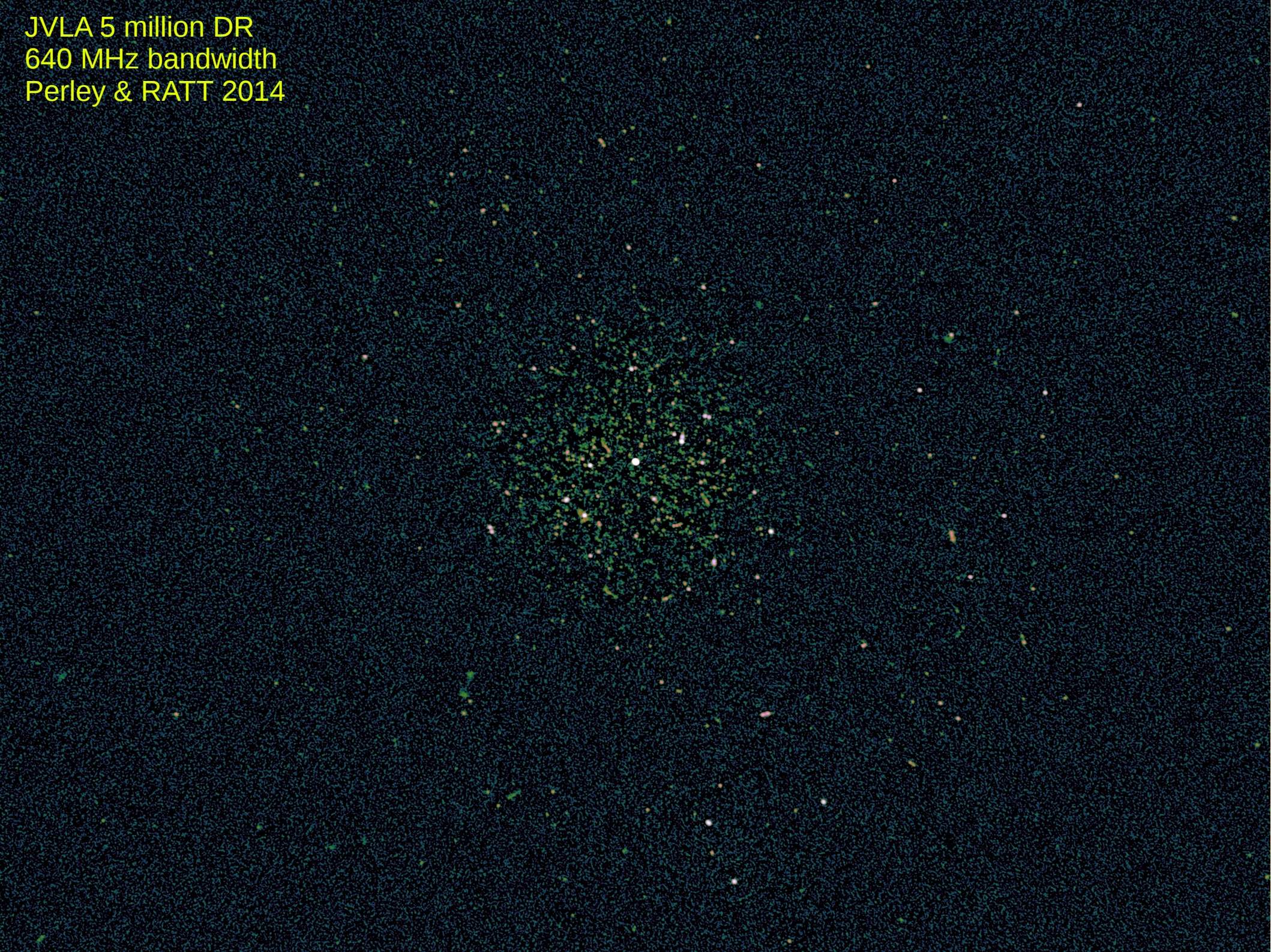
- Clean maps are addictive...
- ...but diffgains are dangerous and should be used sparingly
- 5M map has a **factor of ~60 fewer** degrees of freedom in the diffgains (compared to 2014 3M map)
- How many do you need?
  - Enough to meet your science goals
  - Simulations can help


DR ~1 million
192 MHz band
no DD corrections

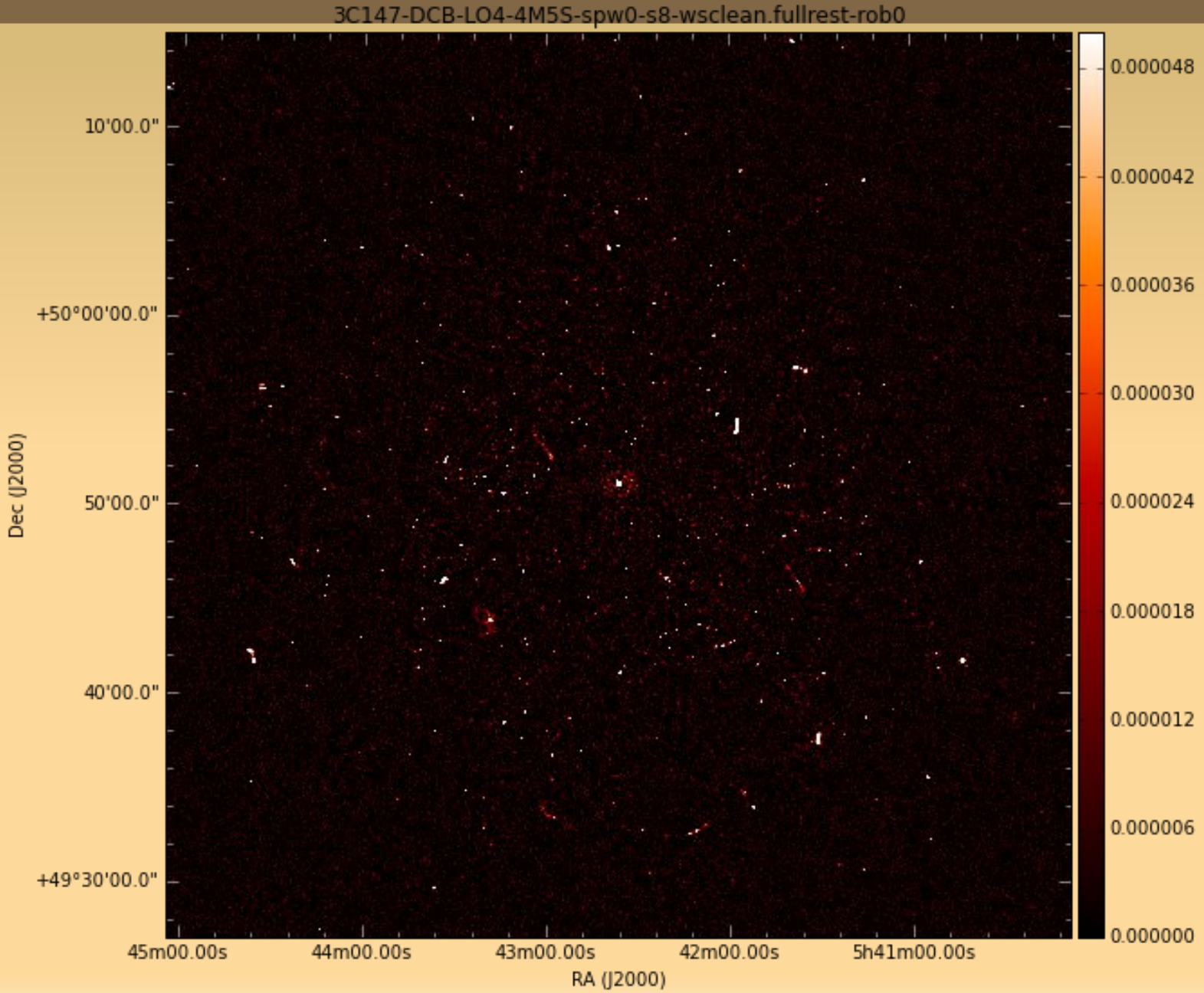

DR ~1 million
192 MHz band
primary beam corrected, **no diffgains**


DR ~3 million
192 MHz band
primary beam corrected, **no diffgains**

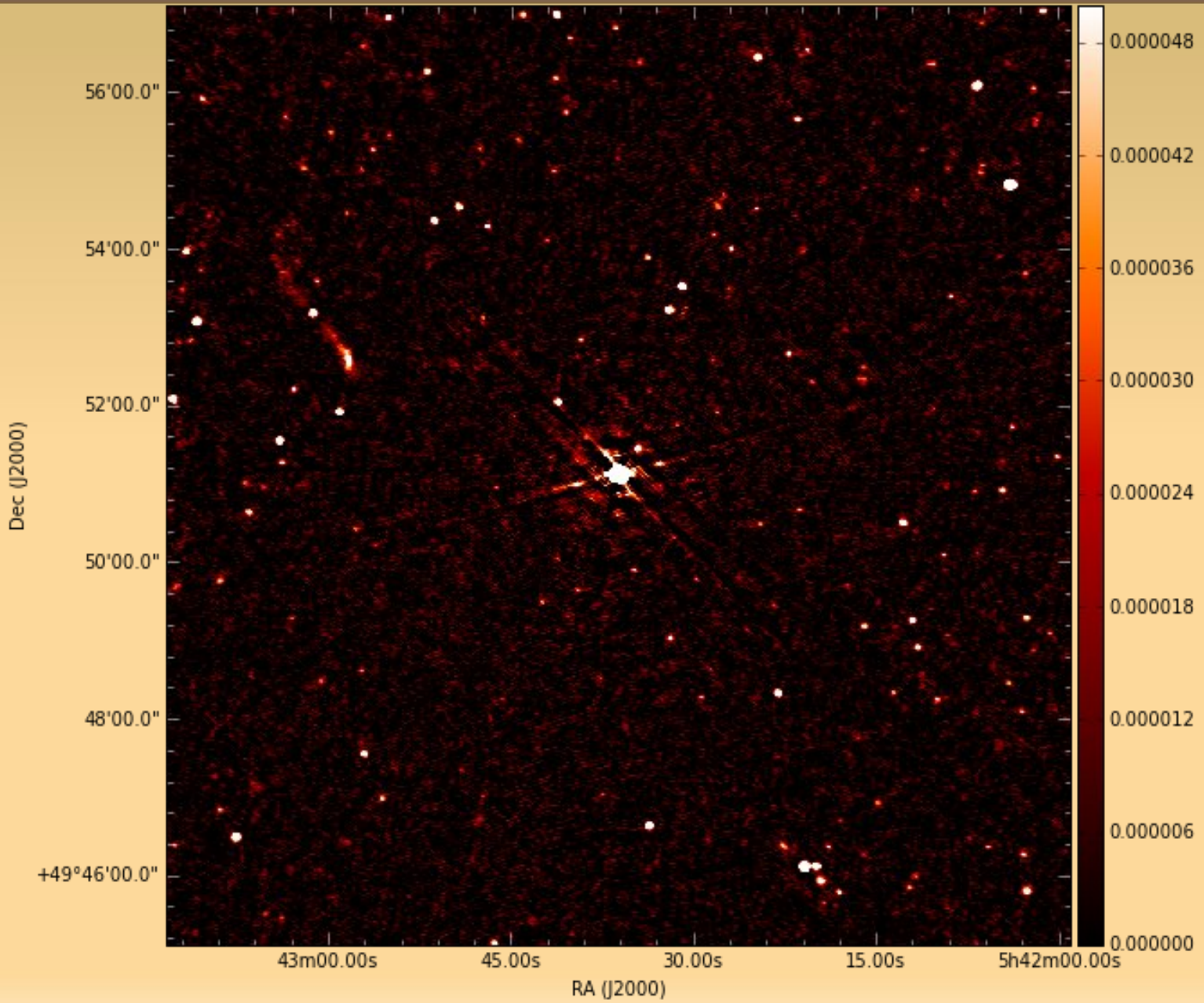

DR ~3 million
192 MHz band
primary beam+ diffgains corrected


JVLA 5 million DR
640 MHz bandwidth
Perley & RATT 2014

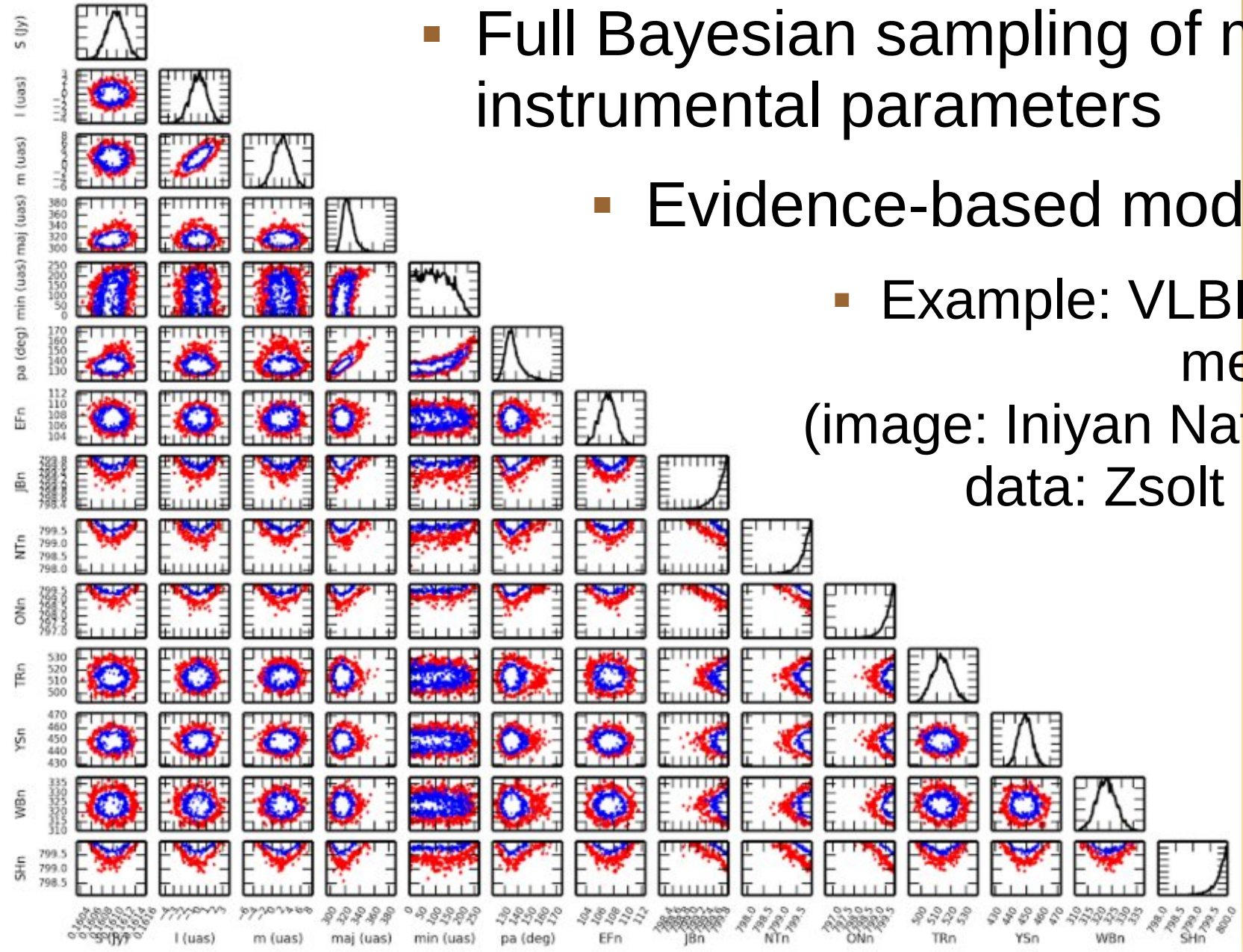
With BnA Data, 7M In Sight



Now Limited By Model Problems



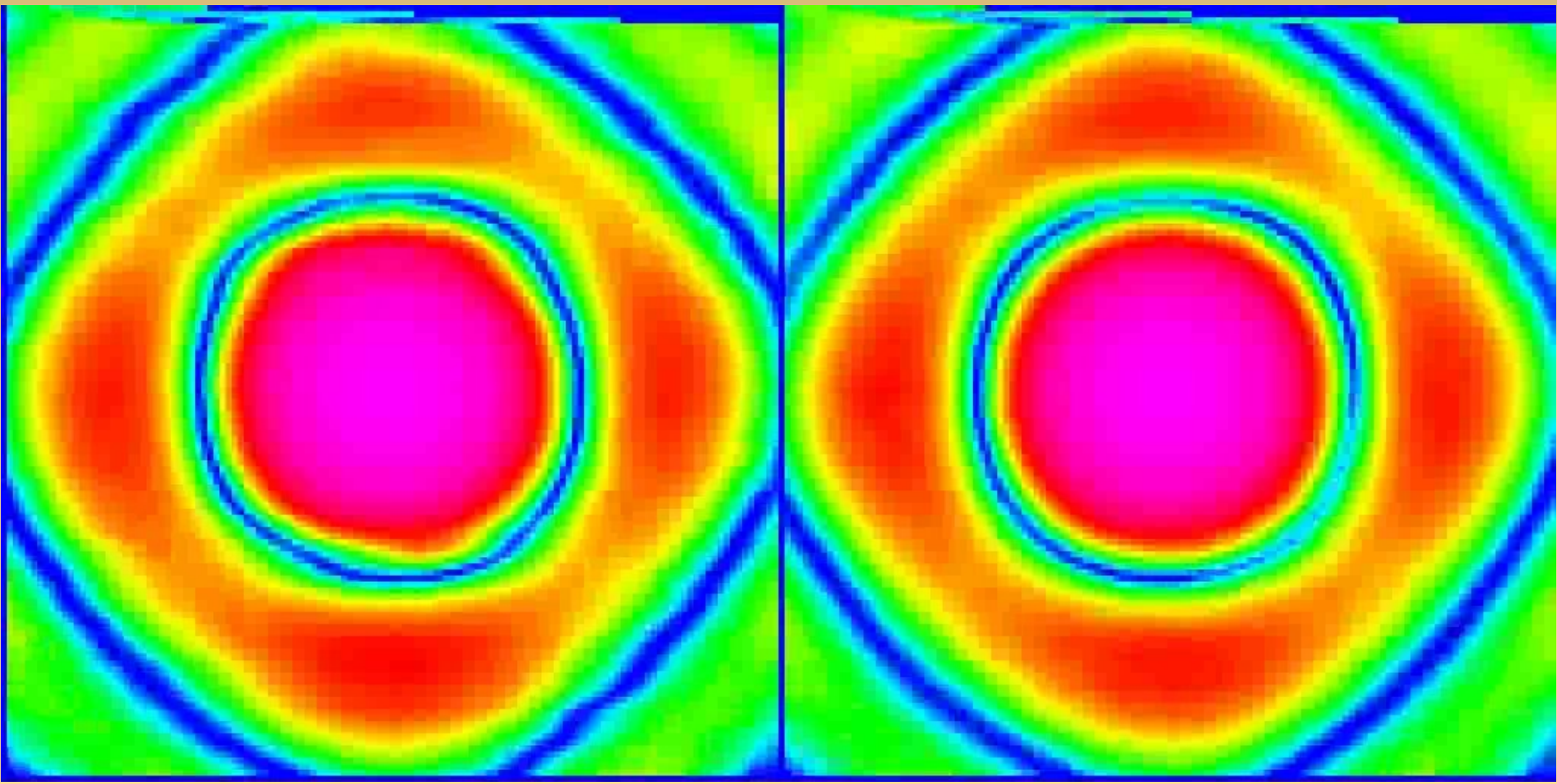
BIRO



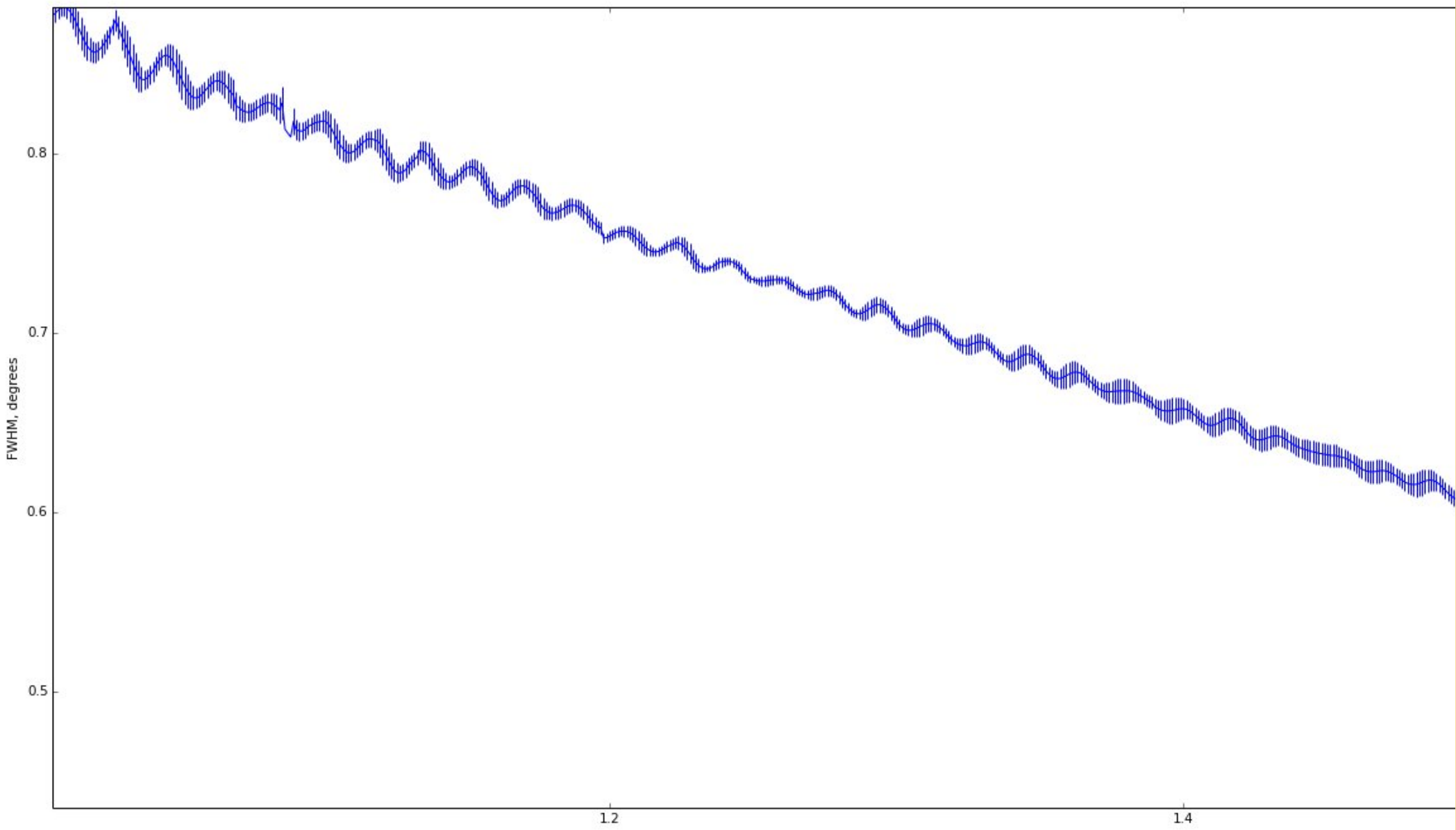
- Full Bayesian sampling of model + instrumental parameters
  - Evidence-based model selection
    - Example: VLBI quasar size measurements

(image: Iniyan Natarajan, UCT, data: Zsolt Paragi, EVN)

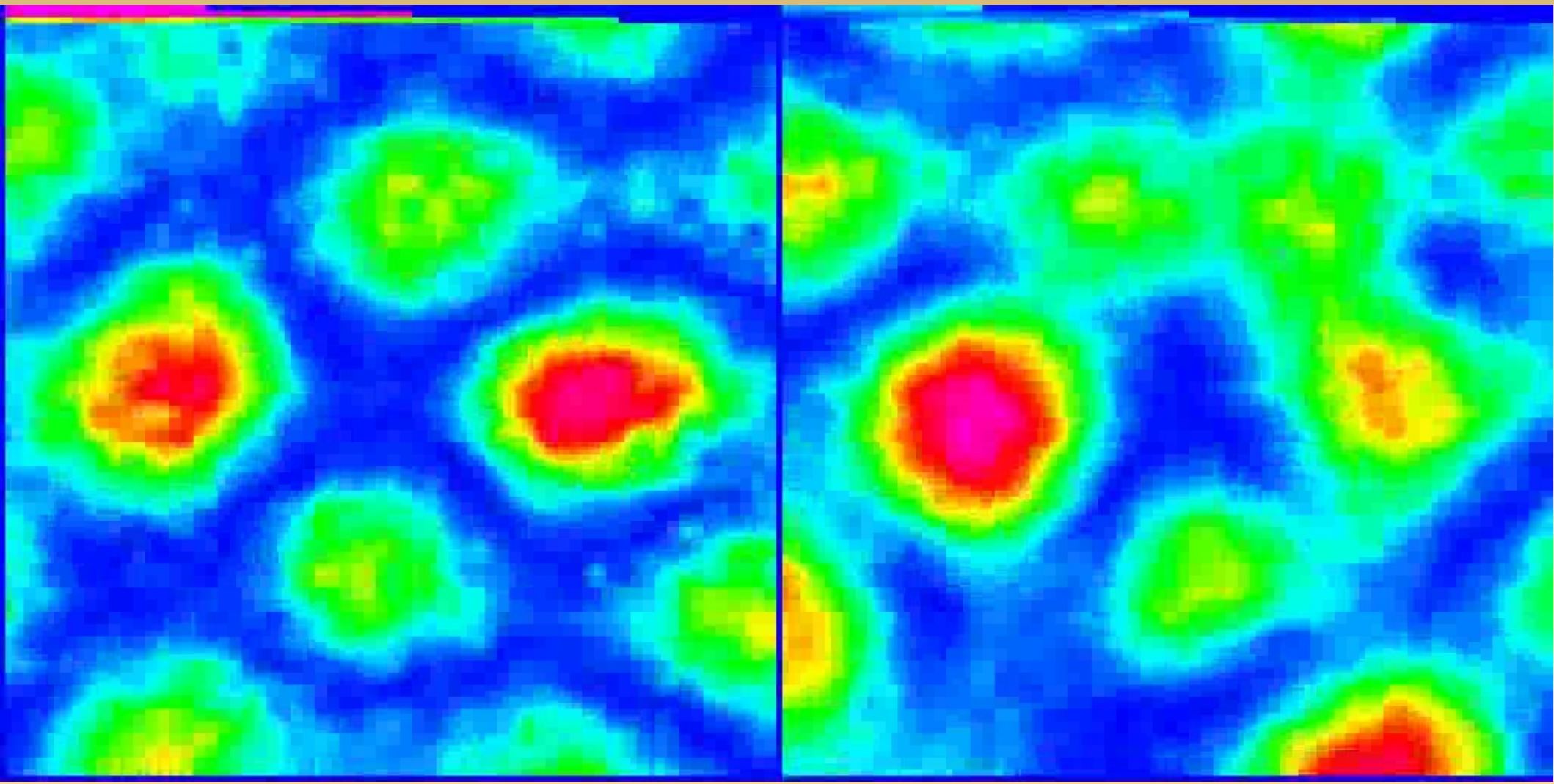
Holography: Antennas 5 & 28, LL (1 to 2 GHz)



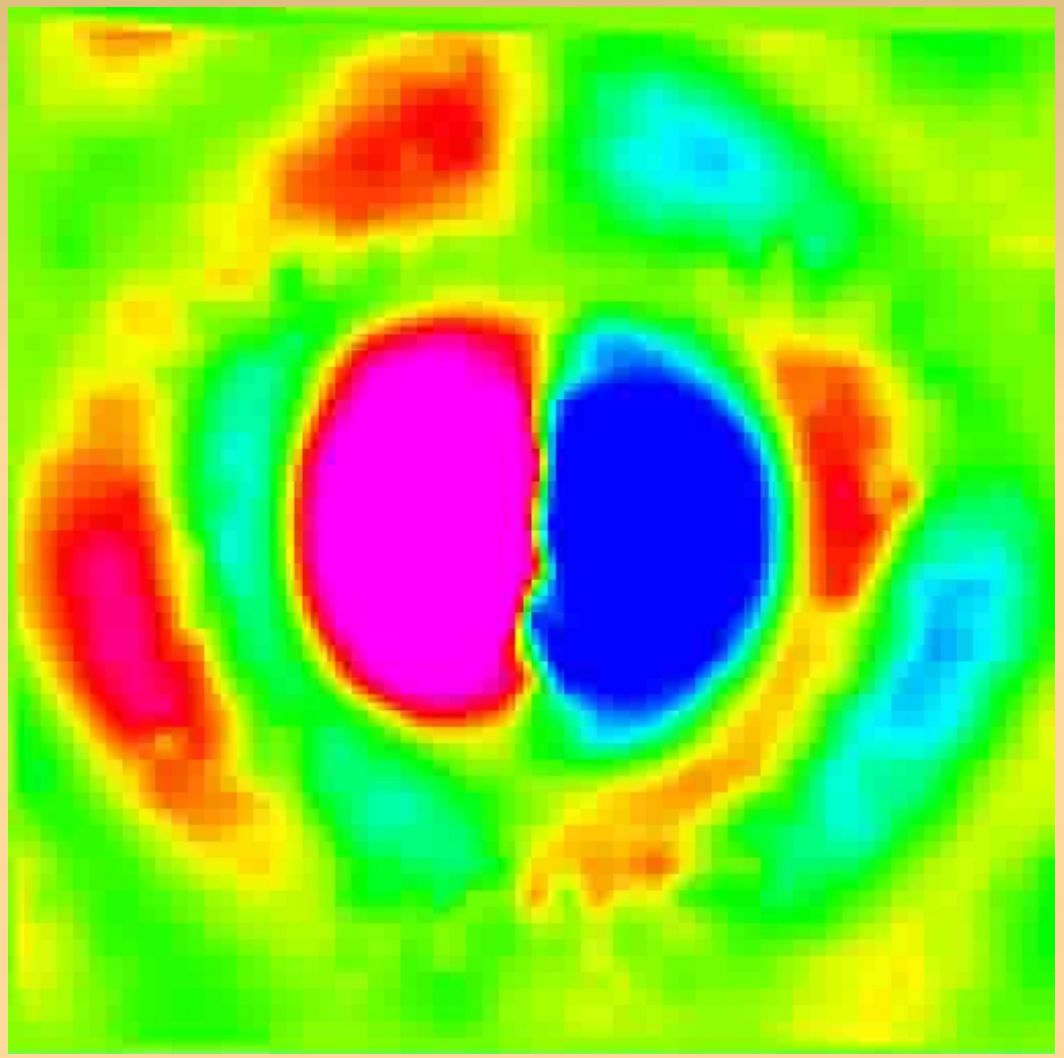
Beam Size Ripple



Holography: Antennas 5 & 28, LR (1 to 2 GHz)



Stokes V Beam

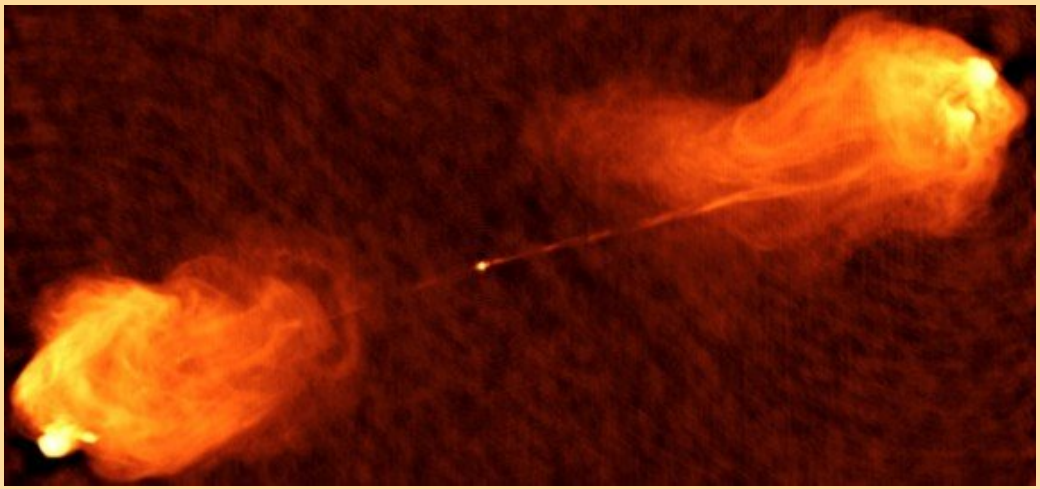


II. Cygnus A

- When DR is no longer a “luxury problem”
- 61h of JVLA data in A+B+C+D config, S-, C- X-, Ku-band
- Stretch goal of ~1M DR, need at least 100,000 to enable science

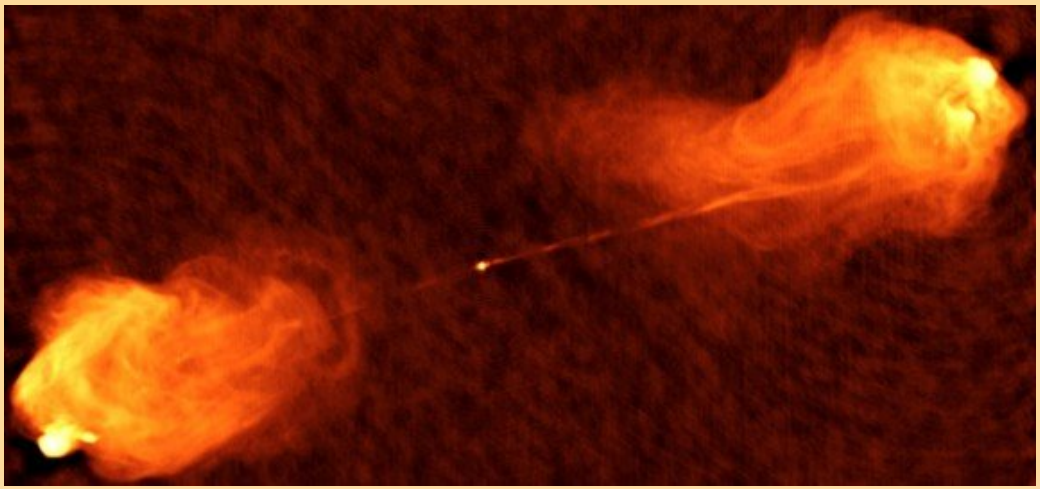
"This is an image of a supermassive black hole about a billion times more massive than the Sun emitting jets at close to the speed of light. If that doesn't get you up in the morning, I don't know what will."

– Ian Heywood

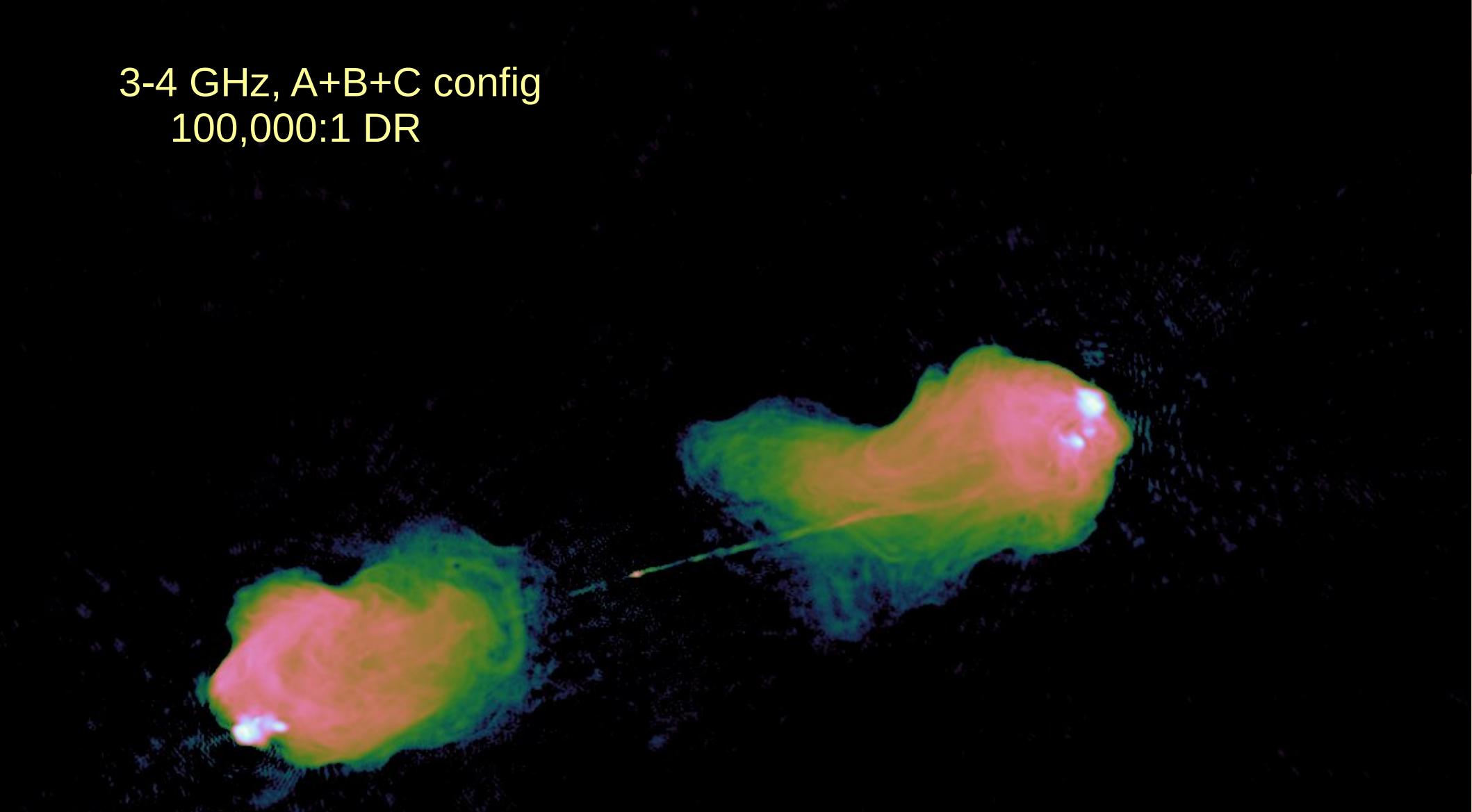


Cygnus A Challenges

- Bright hotspots in rotating primary beam
- Extremely complex structure
- DR limited to 10,000 with conventional selfcal



3-4 GHz, A+B+C config
100,000:1 DR



- Initial imaging (WSCLEAN+MORESANE, MT-MFS)
- Hotspot extraction (PyBDSM) & subtraction (MeqTrees)
- Imaging of residual visibilities (WSCLEAN)
- Model cube to model visibilities (lwimager)
- G-Jones calibration (MeqTrees)
- Hotspot dE-Jones calibration (MeqTrees)

CygA is a deconvolution problem

- CygA DR is entirely limited by ability to deconvolve complex extended emission
- (MS)CLEAN not up to the task
- Breakthrough was made by combining WSCLEAN (A. Offringa, ASTRON) with PyMORESANE (J. Kenyon, Rhodes & A. Dabbech et al., Obs. Cote d'Azur)
  - Fast gridding/degridding in WSCLEAN
  - Compressive sensing-based minor loop in MORESANE

III. The Imaging Bazaar

- **CASA clean** task: the most official JVLA imager
  - **lwimager**: the lightest & easiest imager
- **WSCLEAN** (A. Offringa, ASTRON): the fastest JVLA imager
  - Is evolving into an “imaging framework”
  - WSCLEAN+MORESANE
- **DDFacet** (C. Tasse, Obs. Paris & Rhodes)
  - the most flexible imager (and almost as fast, or faster)
- **awimager**: the LOFARiest imager
- **mt-imager** (U. Malta): fast GPU w-proj imager

DDFacet

- Facet-based imager developed by C. Tasse (Obs. Paris, formerly Rhodes & SKA SA)
- Being extended in collaboration with Rhodes
- Almost entirely in Python thus extremely flexible
  - Yet almost as fast (and sometimes faster) than WSCLEAN
- Highly parallelized
- **Can apply the primary beam**

File Image Plot Help

a: DefaultName.restored.fits 0 0.0001

b: **DefaultName.restored.fits** 0 0.0001

c: 3C147-LO4-4M5S-spw0-s1-wsclean.restored.fits 0 0.0001

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File Image Plot Help

a: **DefaultName.restored.fits** 0 0.0001

b: DefaultName.restored.fits 0 0.0001

c: 3C147-LO4-4M5S-spw0-s1-wsclean.restored.fits 0 0.0001

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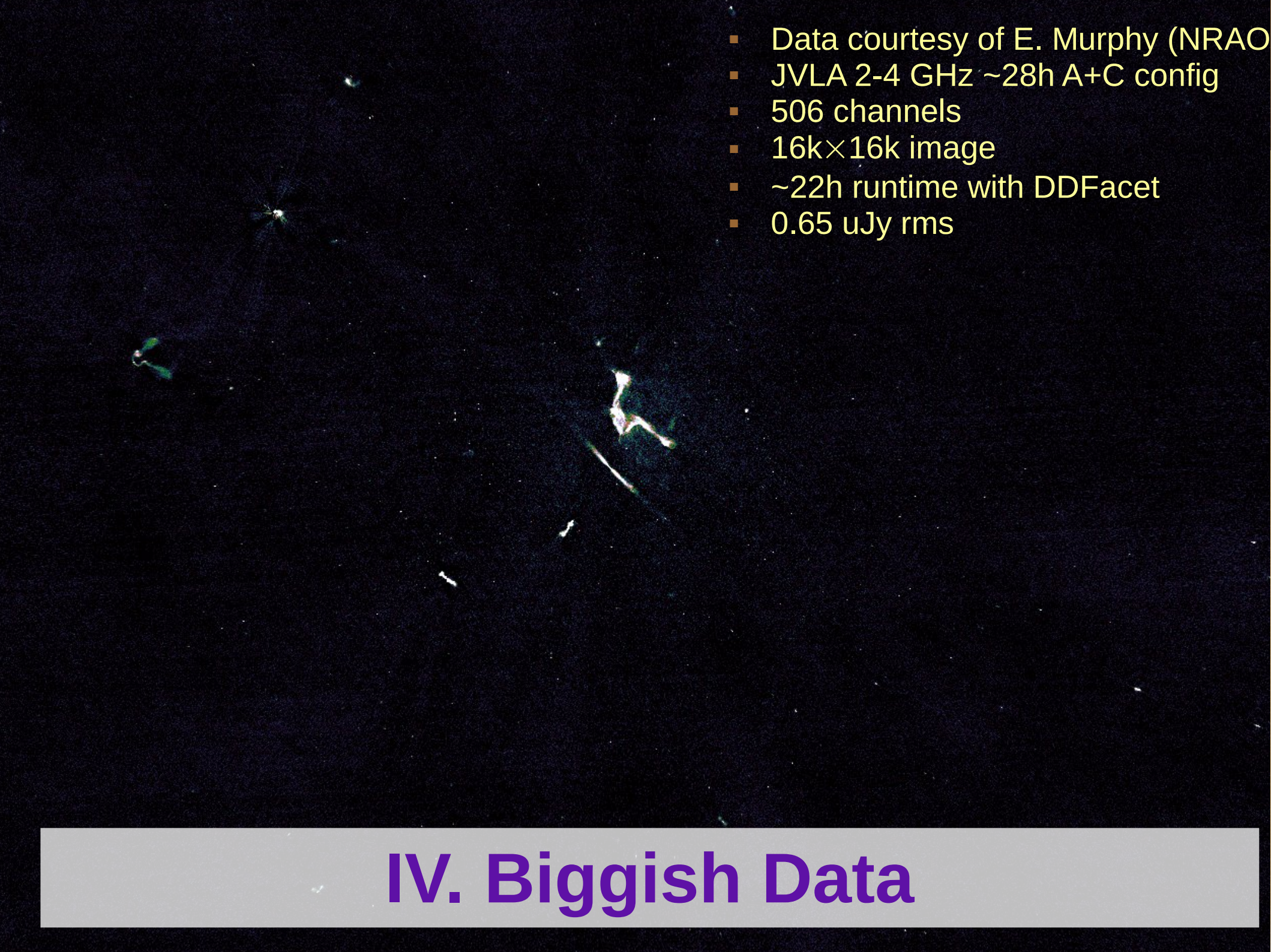
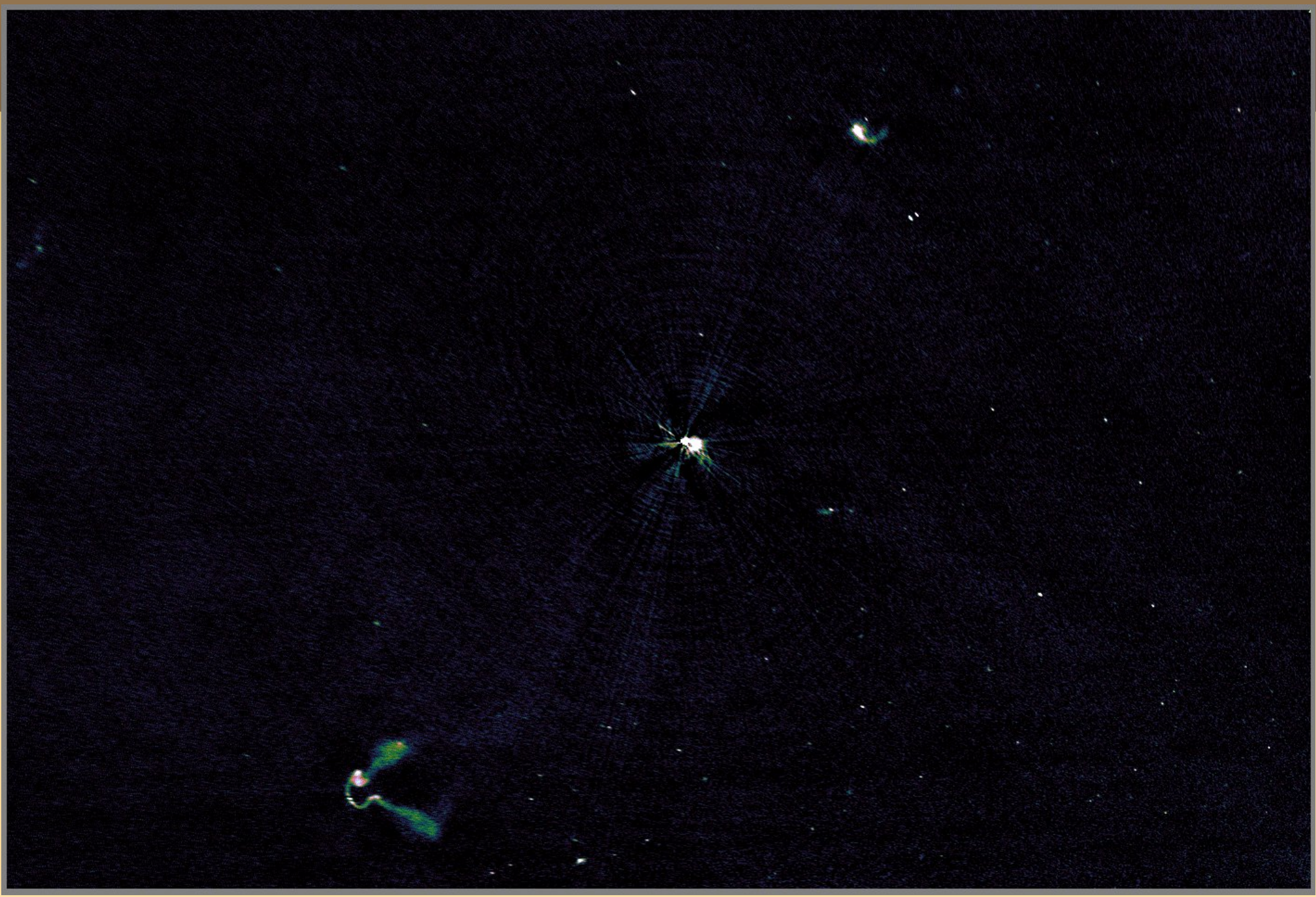


- Data courtesy of E. Murphy (NRAO
- JVLA 2-4 GHz ~28h A+C config
- 506 channels
- 16k×16k image
- ~22h runtime with DDFacet
- 0.65 uJy rms

IV. Biggish Data



Data Compression & FoI Shaping

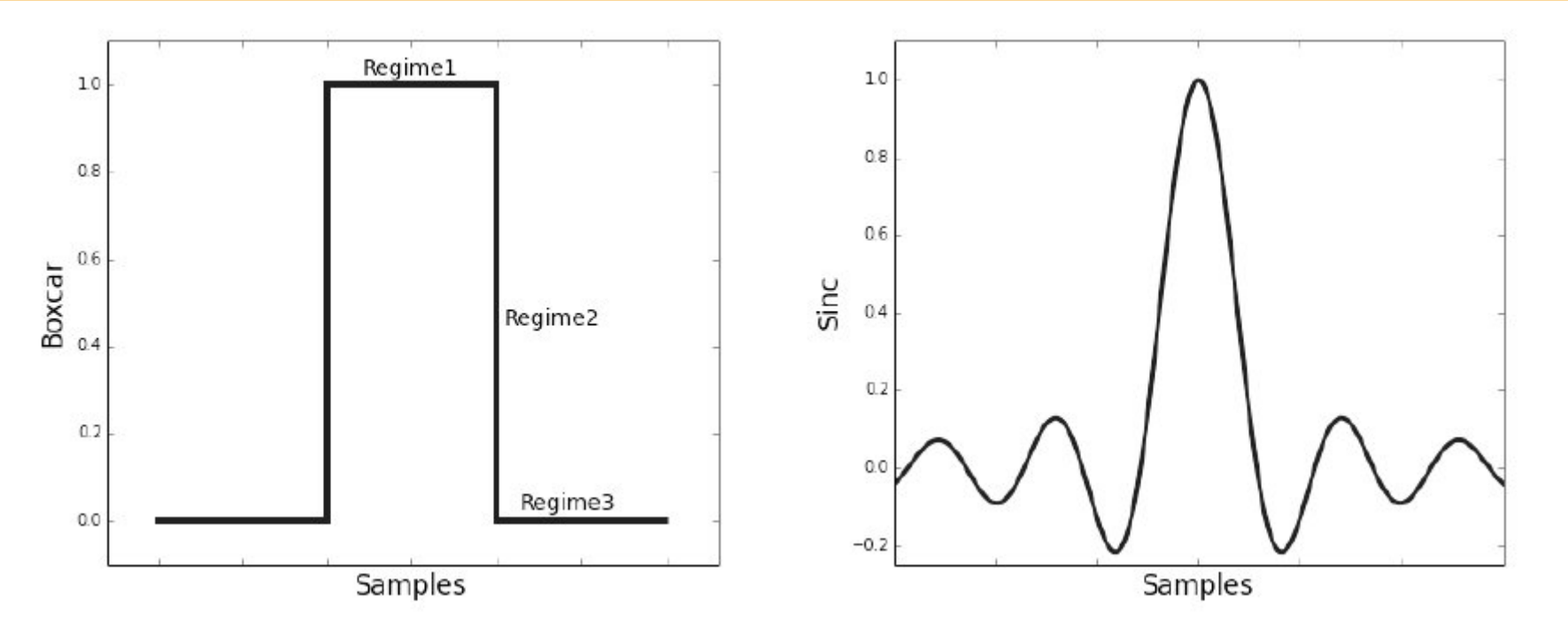
Mon. Not. R. Astron. Soc. **000**, 1–18 (2016) Printed 5 March 2016 (MN LATEX style file v2.2)

Using baseline-dependent window functions for data compression and field-of-interest shaping in radio interferometry

M.T. Atemkeng[1⋆], O.M. Smirnov[12], C. Tasse[31], G. Foster[12], J. Jonas[12]
[1] *Department of Physics and Electronics, Rhodes University, PO Box 94, Grahamstown, 6140, South Africa*
[2] *SKA South Africa, 3rd Floor, The Park, Park Road, Pinelands, 7405, South Africa*
[3] *GEPI, Observatoire de Paris, CNRS, Universite Paris Diderot, 5 place Jules Janssen, 92190 Meudon, France*

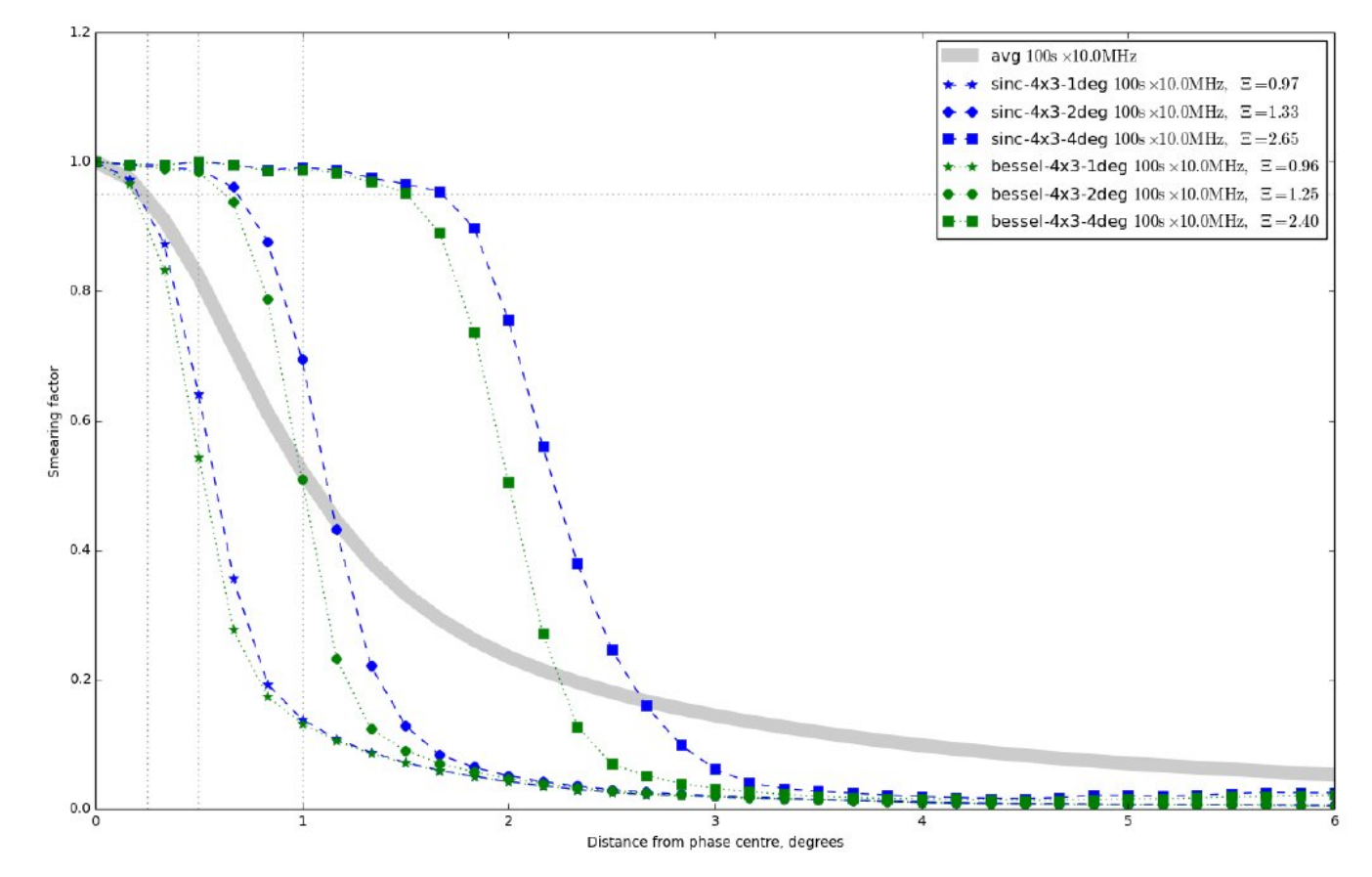
Averaging = Convolution

- Visibility averaging is convolution by a boxcar, followed by sampling... almost
- Worst possible filter response (sinc/Jinc...)



Matched Filters

- A matched filter will maximize SNR
- Window functions: sacrifice nominal sensitivity but decrease smearing
- Better suppression out of FoV



Conclusions

- MFAA: bring it on
- Plenty to do in the meantime...