Frequency structure in the WSRT primary beam (and their effects on very high DR images)

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CALIM, Dwingeloo, 26 Aug 2010

Outline

- Why is this interesting/important ?
- Issues in very high Dynamic Range (DR)
- Data processing
- The easy pointsource fields: 3C147 results
- The Perseus cluster, 3C84: a 30-year project
  - off-axis spectra in full polarization
  - Stokes I and polarized imaging
- Ghost structures in J1819+3845 (92cm)
- History of DR in 40 years of WSRT imaging
- Conclusions

Why is this interesting/important ?

We all want wide frequency bands (df/f >0.25-0.5)

We often want 60 dB or more (and always will have with SKA !)

Dish sidelobes at minus 30-40 dB → distant sources still 20-30 dB above noise

Hence we need very LARGE images (~ few 1000 PSF's)

LOFAR EoR project requires removing effects at 0.01 - 0.001 x (confusion) noise

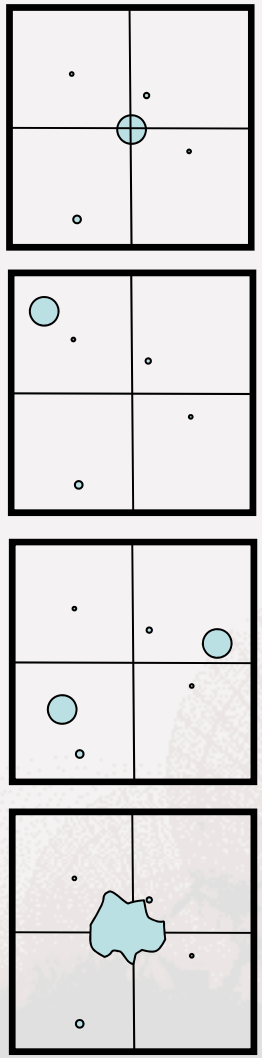
Questions guiding us:

Can we get away with polynomial fits for off-axis frequency response ? NO

Can we process this in time ? FOR WSRT YES, in ~ 10X OBS TIME

Do we understand all image effects (from selfcal, DDE's, imaging, closure errors) ?

Some issues in high dynamic range imaging



on-axis point source

off-axis point source

≥ **two** off-axis point sources

extended source

Dynamic Range: DR = peak flux / rms noise

source configurations and causes

✓ (mechanical) pointing	-	X	X	-
✓ non - isoplanatism (ionosphere)	-	-	X	-
✓ decorrelation (troposphere/ionosphere)	X	X	X	X
✓ closure errors (cross-talk, ...)	X	X	X	X
✓ non-linearity (RFI, ...)	X	X	X	X
✓ ghosts (Gibbs, image rejection..)	-	X	X	X
✓ polarization leakage instability	-	X	X	X
✓ deconvolution limitations	-	-	-	X
✓ variable sources	X	X	X	X
✓ software errors/deficiencies	X	X	X	X

From de Bruyn, CALIM-2, Capetown, Dec 2006

Some details about dataprocessing

Absolute calibration using pair of pol/unpol sources

Image and make DISCRETE (and, if needed, CLEAN) component models

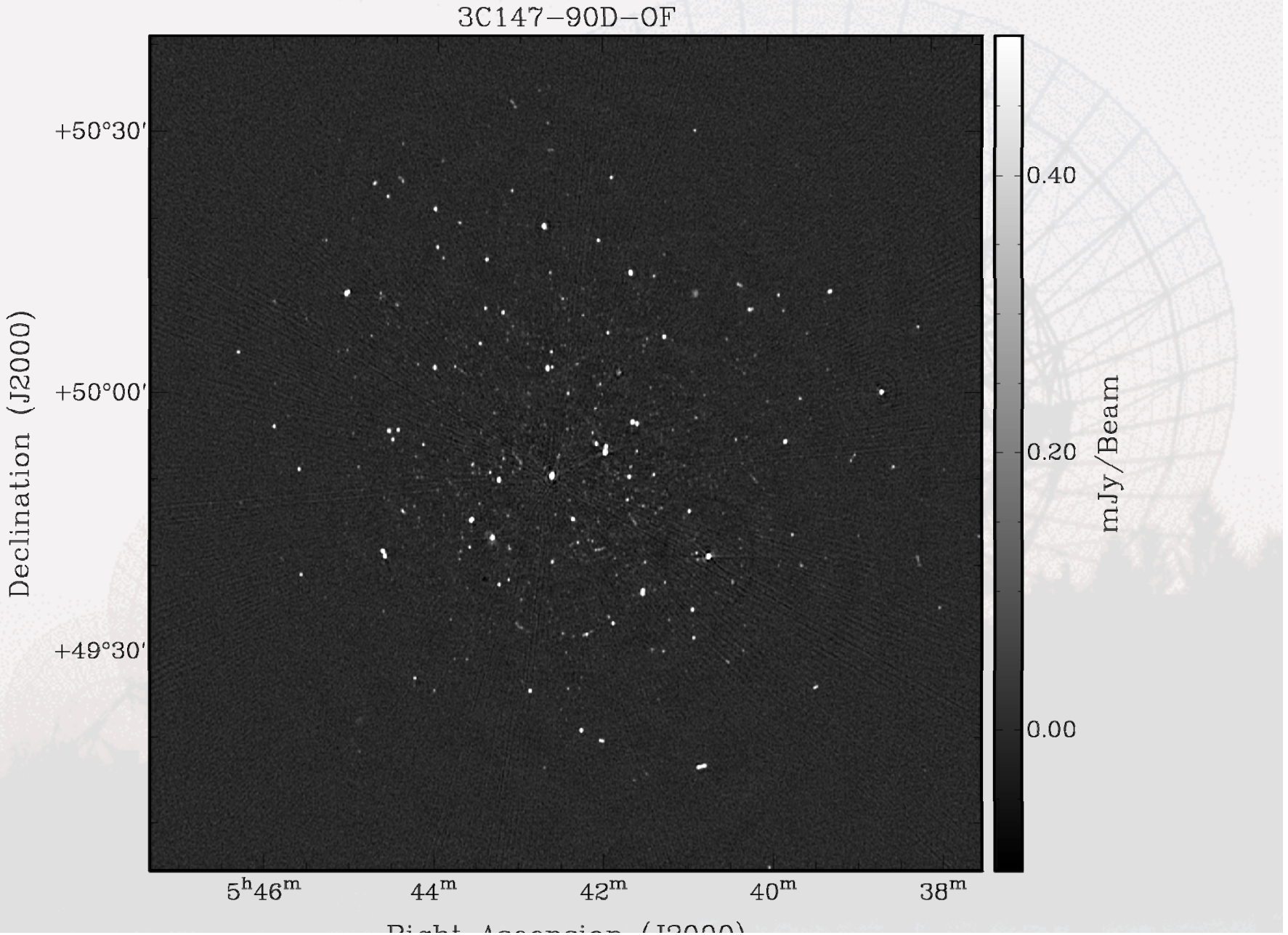
Update models (I,Q,U,V) in uv-plane & selfcalibrate Iterate ~ 3x

Additional internal polarization leakage calibration

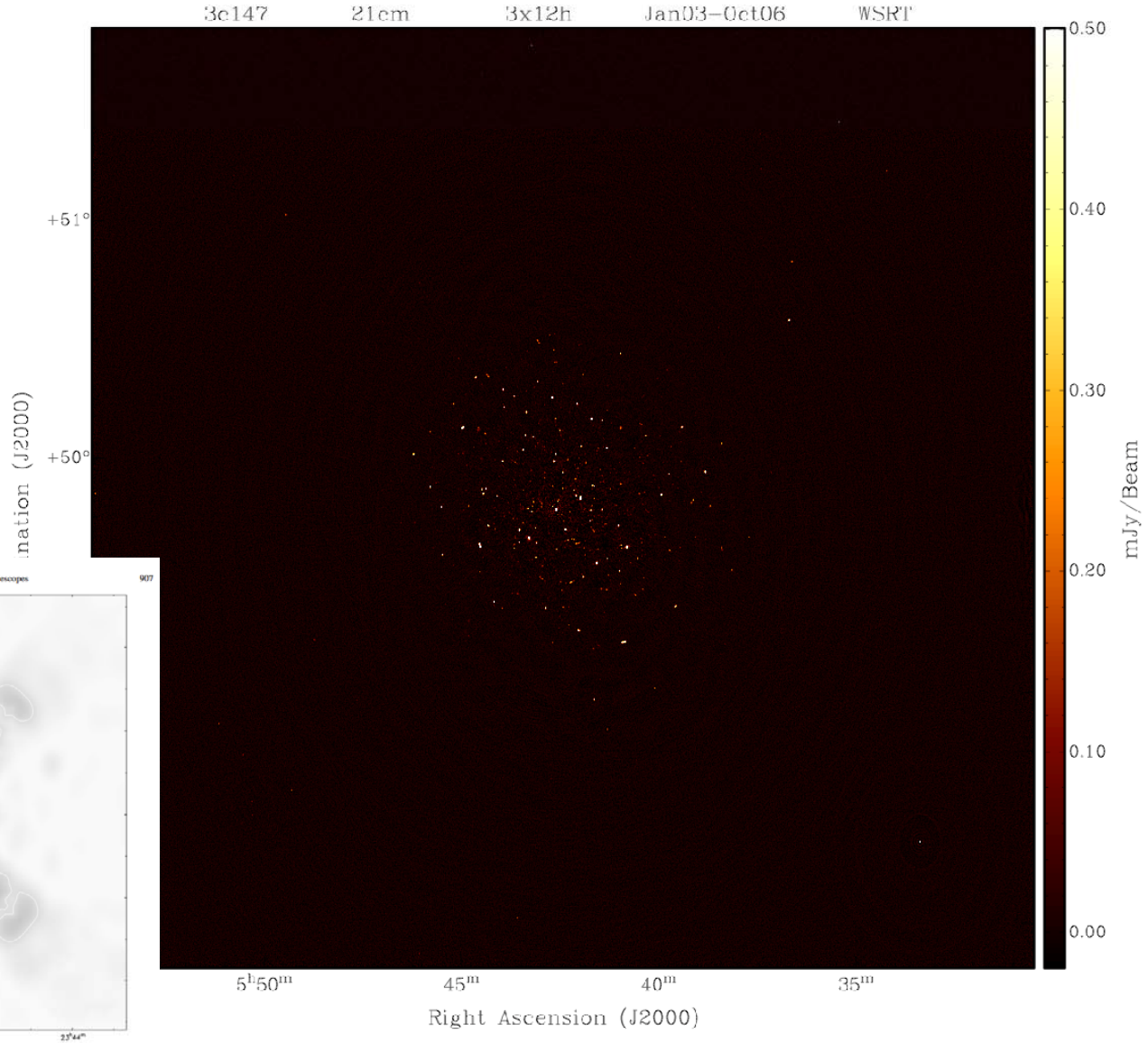
And do all this per frequency channel of 0.6 MHz wide: ➔ 8 x 28ch

All processing done in NEWSTAR using UNIX-pipelined scripts

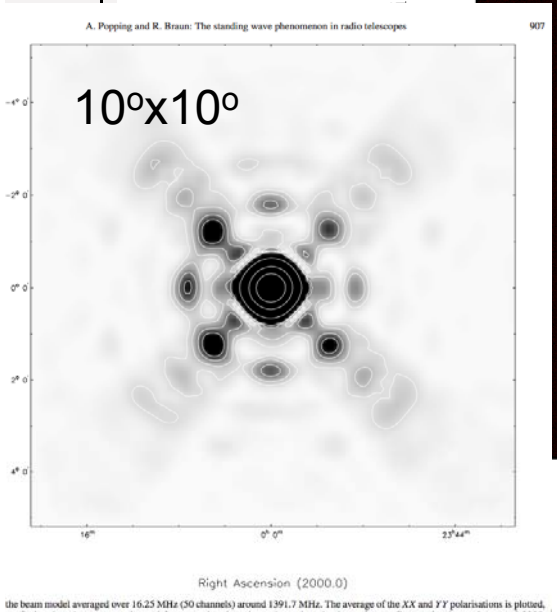
3C147 image at DR ~ 1500,000 : 1 (1x12h)



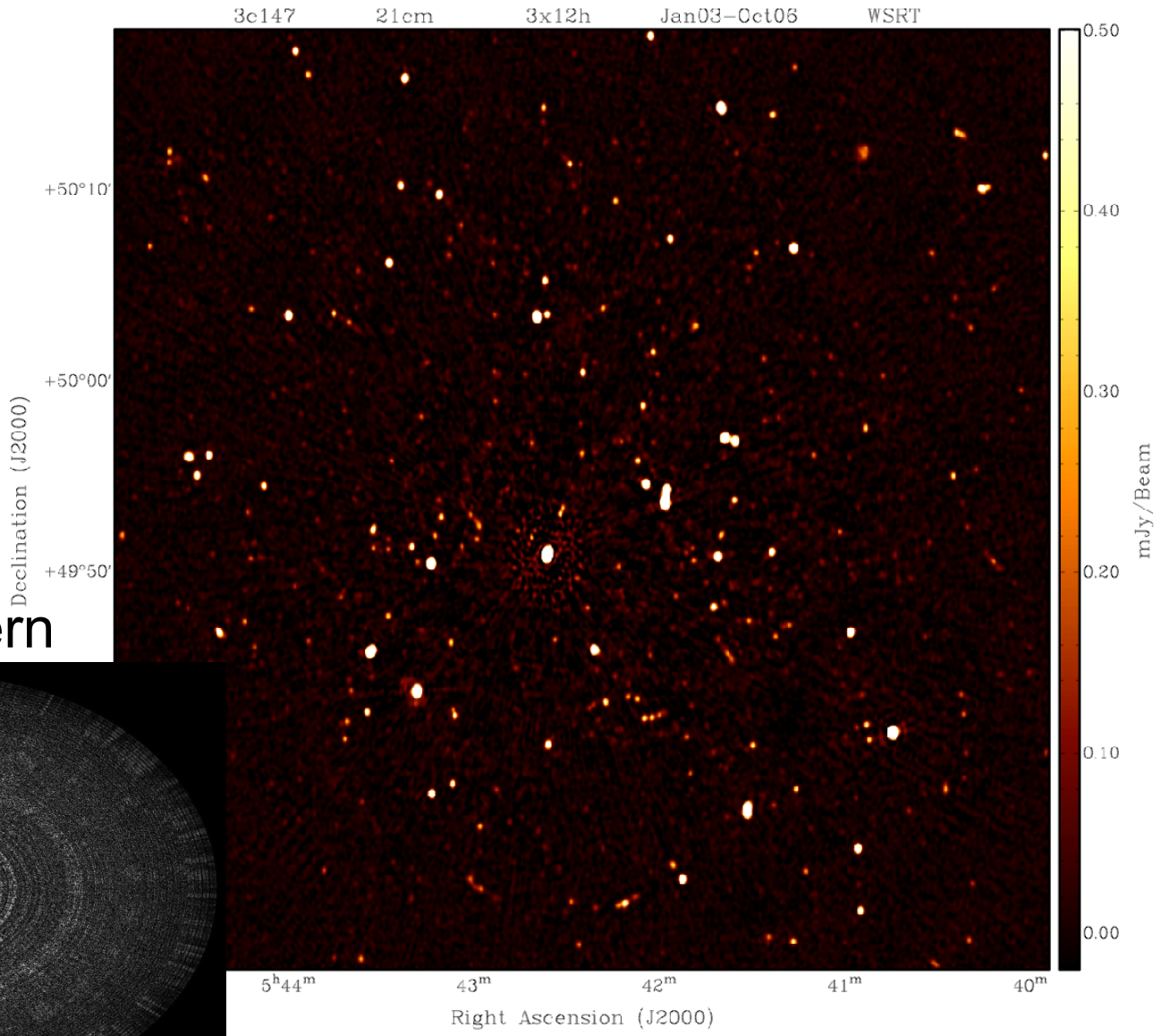
3C147 images at DR ~ 2000,000 : 1 (3x12h)



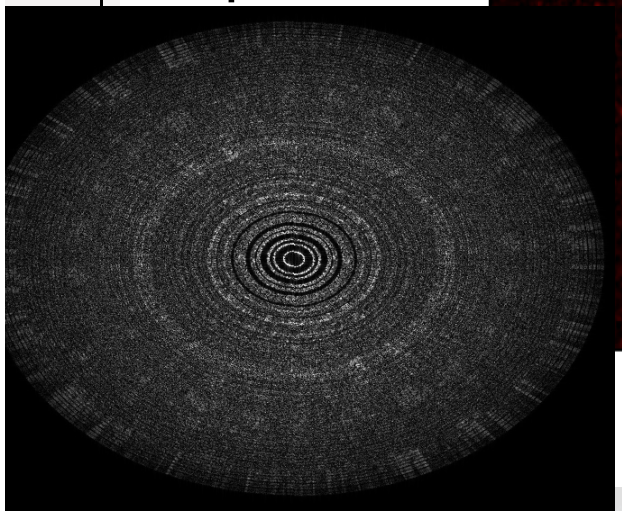
4º x 4º



3C147 images at DR~ 2,500,000 : 1 (3x12h)



FT error pattern

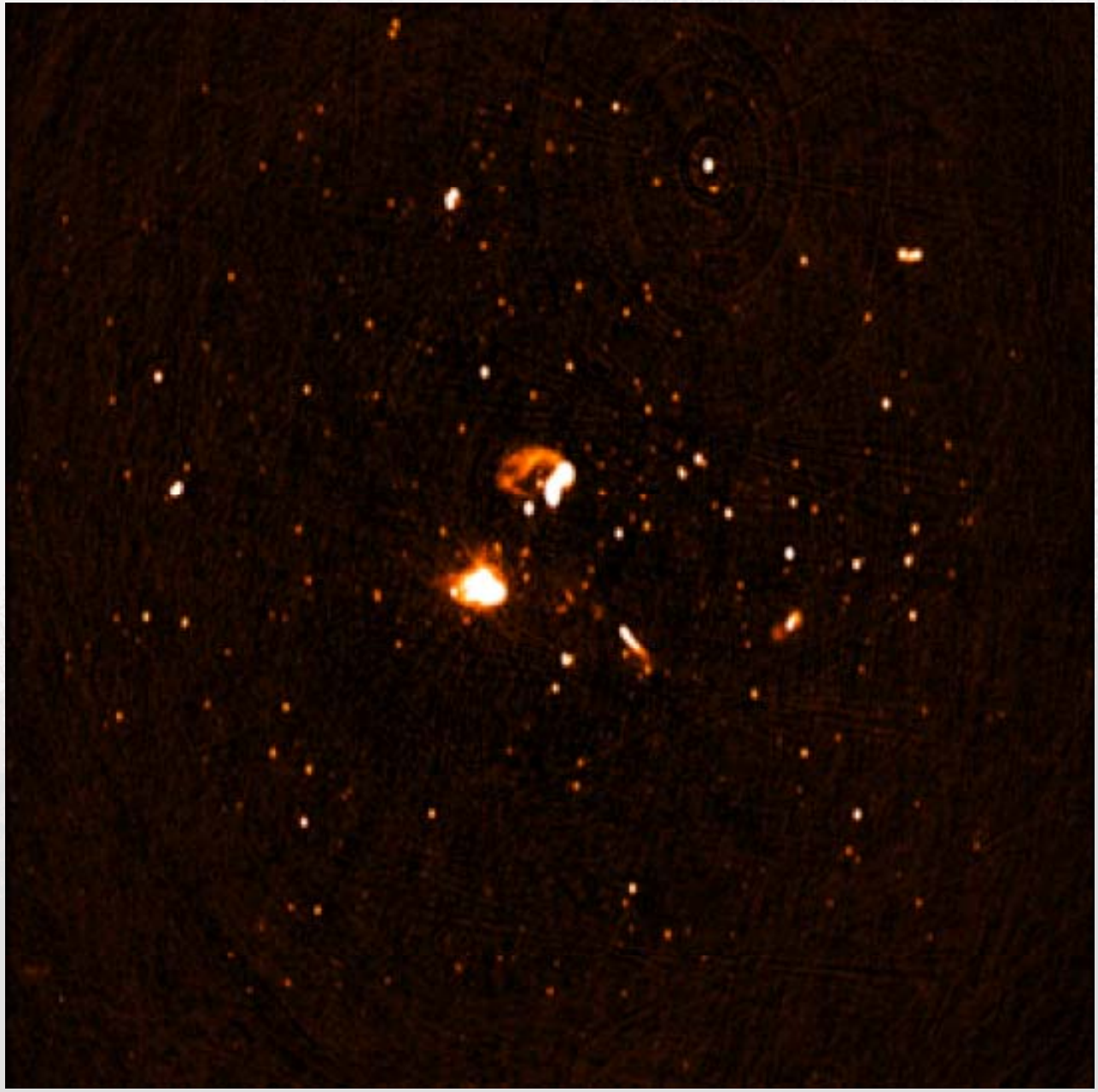


1º x 1º

22 Jy
8.5 µJy

Perseus cluster 92cm WSRT-1984

4^o x 4^o



Visualizing a million to one range in intensity

The Perseus cluster in six powers of 10

1994 data

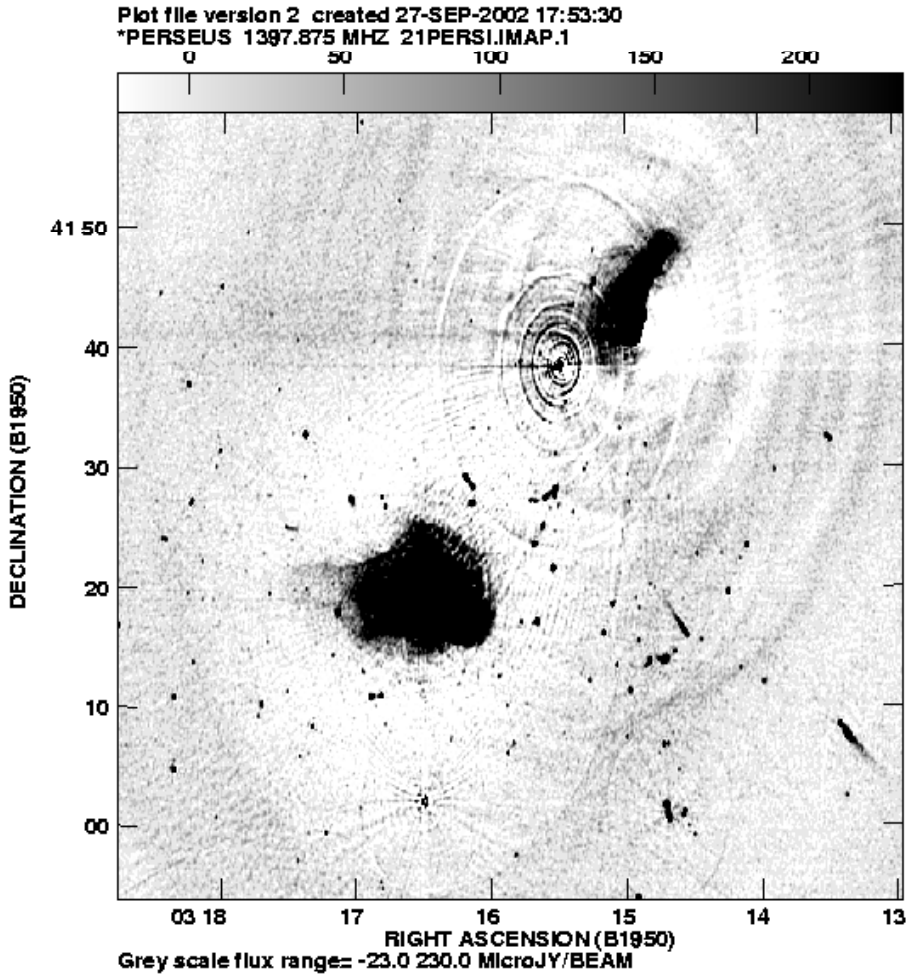
DCB - 8x5 MHz

21cm

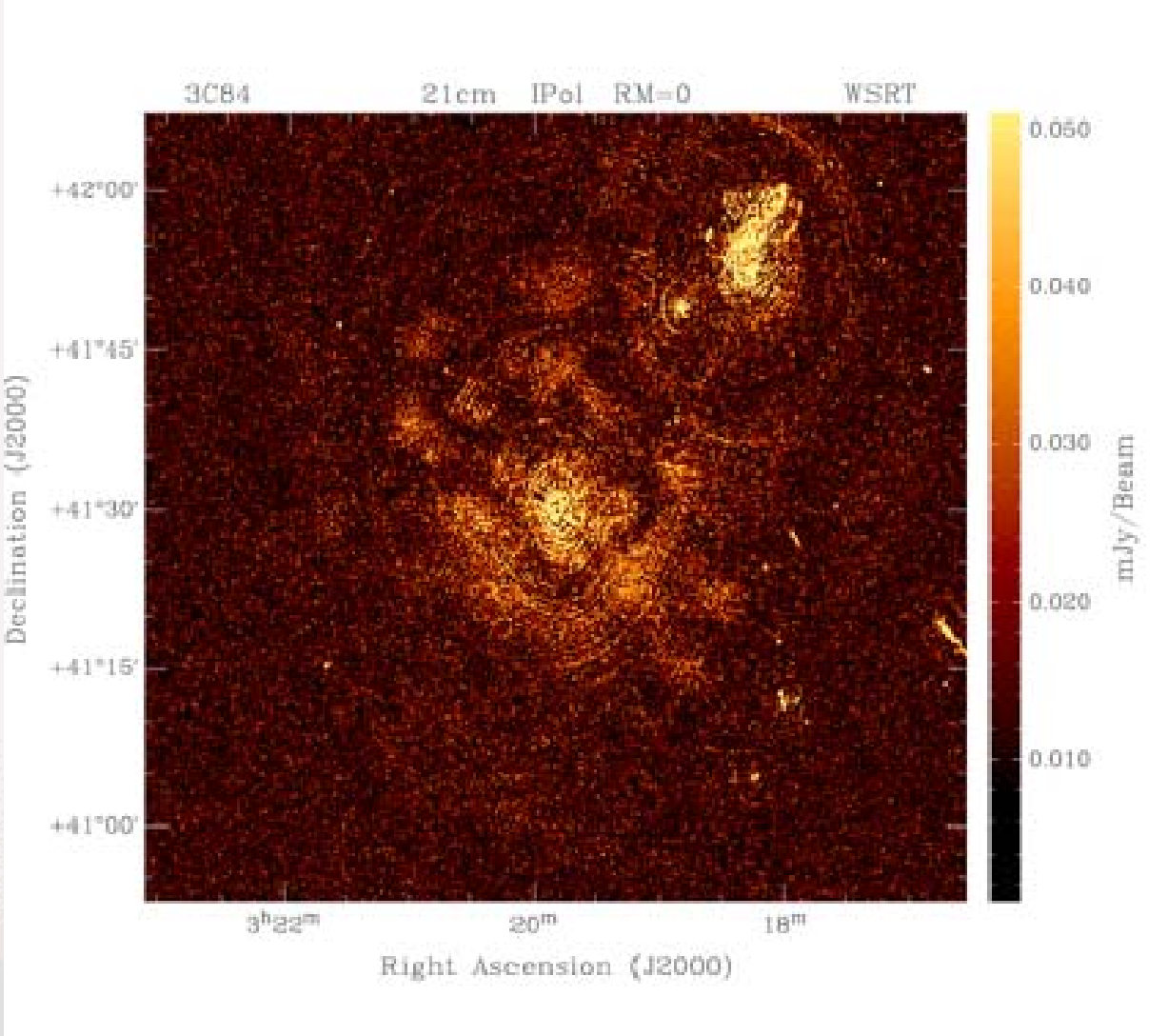
6x12h

'noise' ~ 25 μJy

DR: ~10^6 : 1



Polarized emission around Perseus A / NGC1275



Blobs of polarized emission near RM ~ 0

I-Peak ~ 22,000,000 μJy

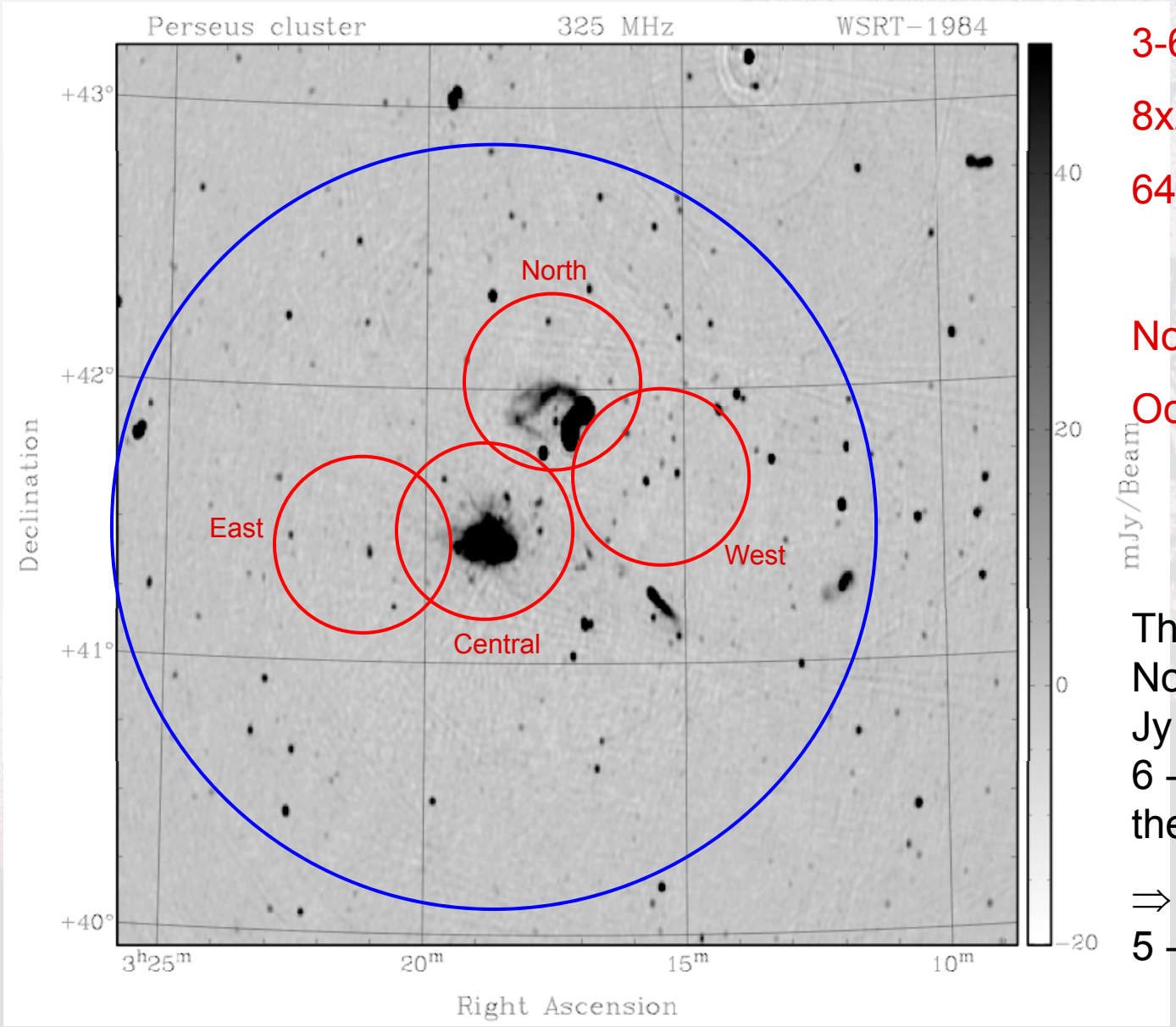
IPOL-noise ~ 20 μJy

Could emission be due due to Thomson scattering ??

(Sunyaev, 1982;

de Bruyn and Brentjens, 2005)

New 21cm pointings (on 92cm grey-scale)



3-6 x 12h per field

8x20 MHz

64ch x 4 pol

Nov '03 (C & W)

Oct '07 (E & N)

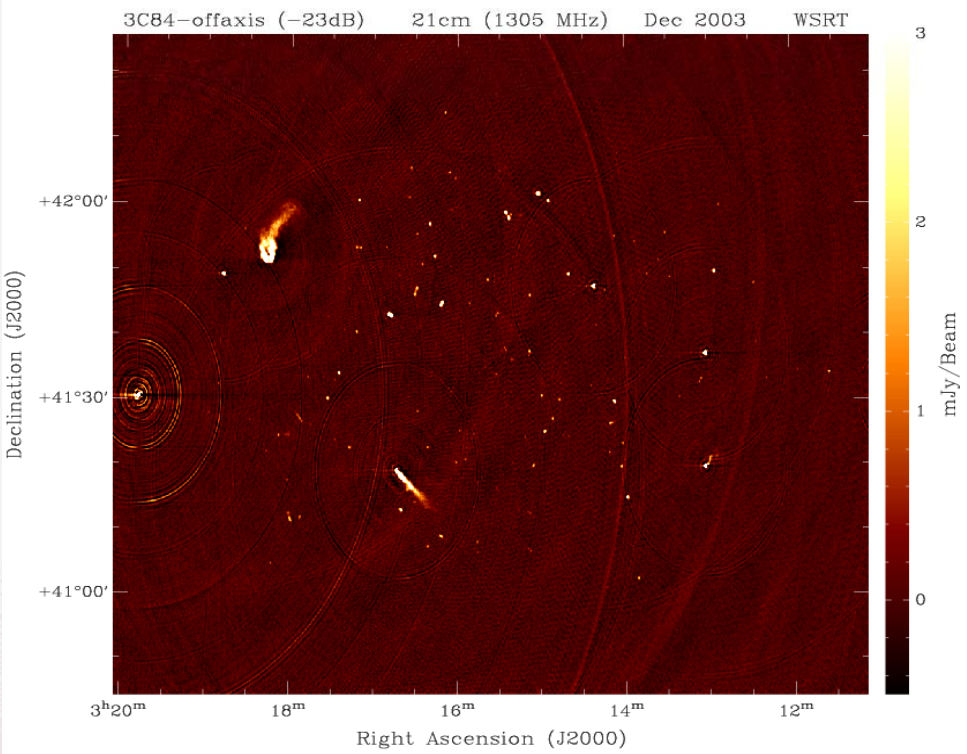
The West, East and North field had a 22 Jy source (3C84) at 6 - 13 - 23dB points of the primary beam

⇒ apparent fluxes of 5 - 0.5 - 0.15 Jy

Perseus - WEST

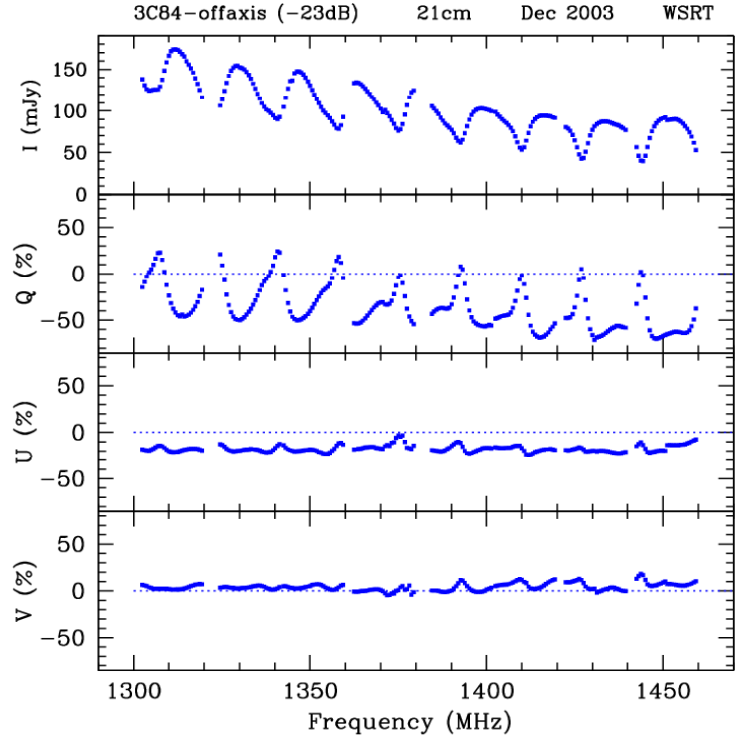
Raw image

Stokes I



Spectral passband

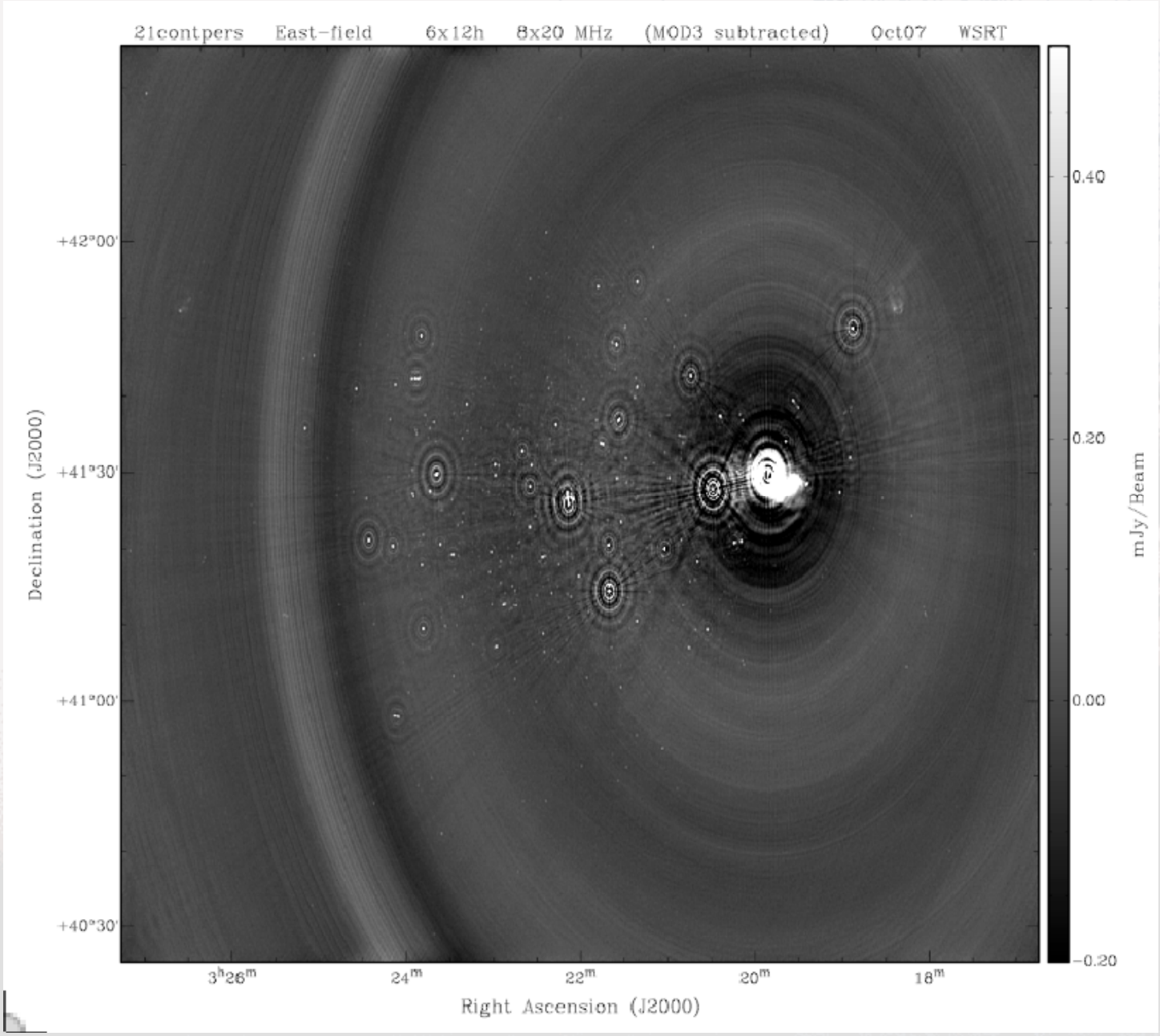
I,Q,U,V (frequency)



(see also Popping & Braun, 2008)

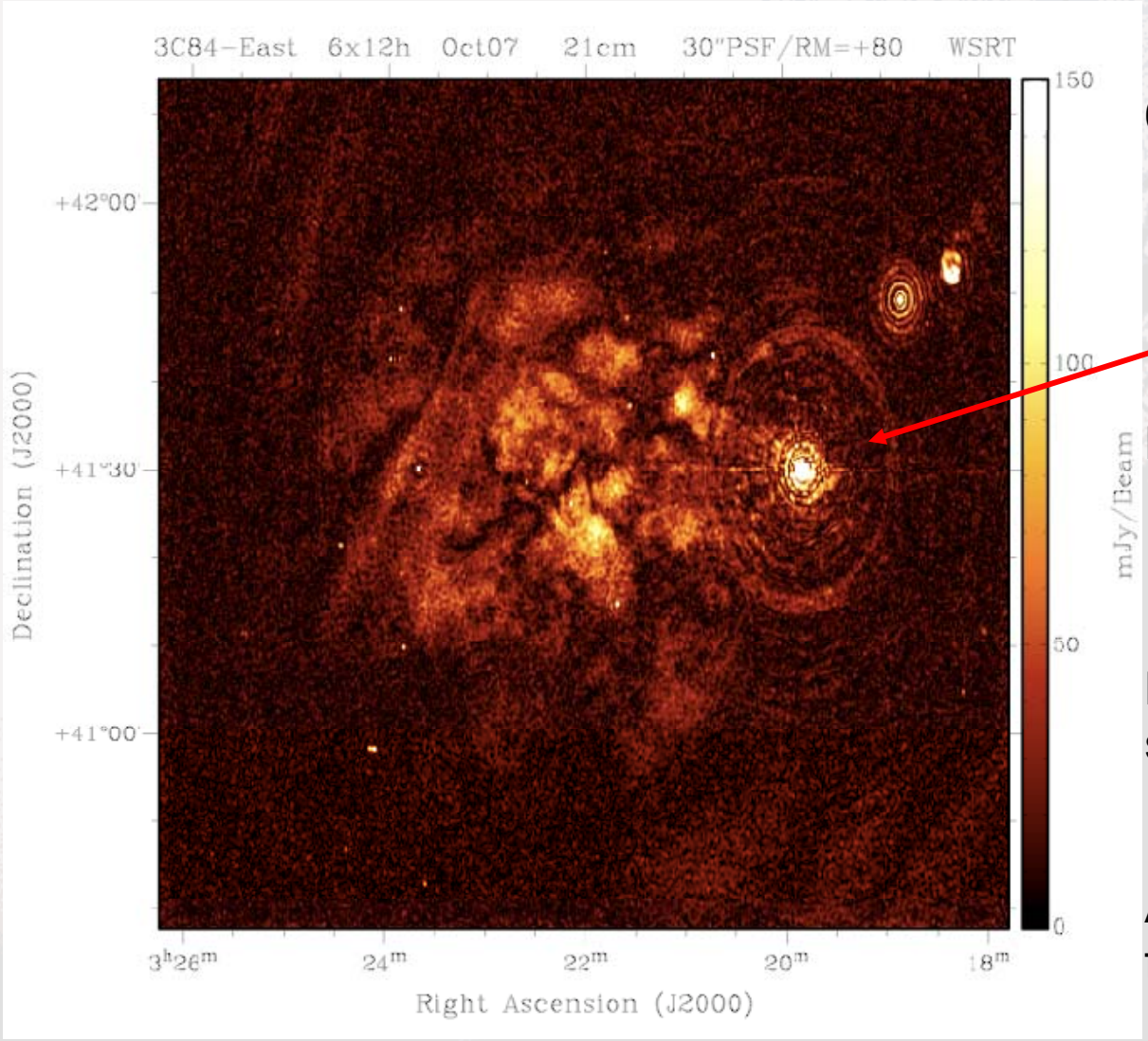
High DR requires **selfcal per 0.6 MHz channel !!**

Perseus-EAST



Initial phase of cal/imaging

Perseus - EAST



30”x45” smoothed image

6x12h (12m sampling)

I-peak ~ 5 Jy (3C84)

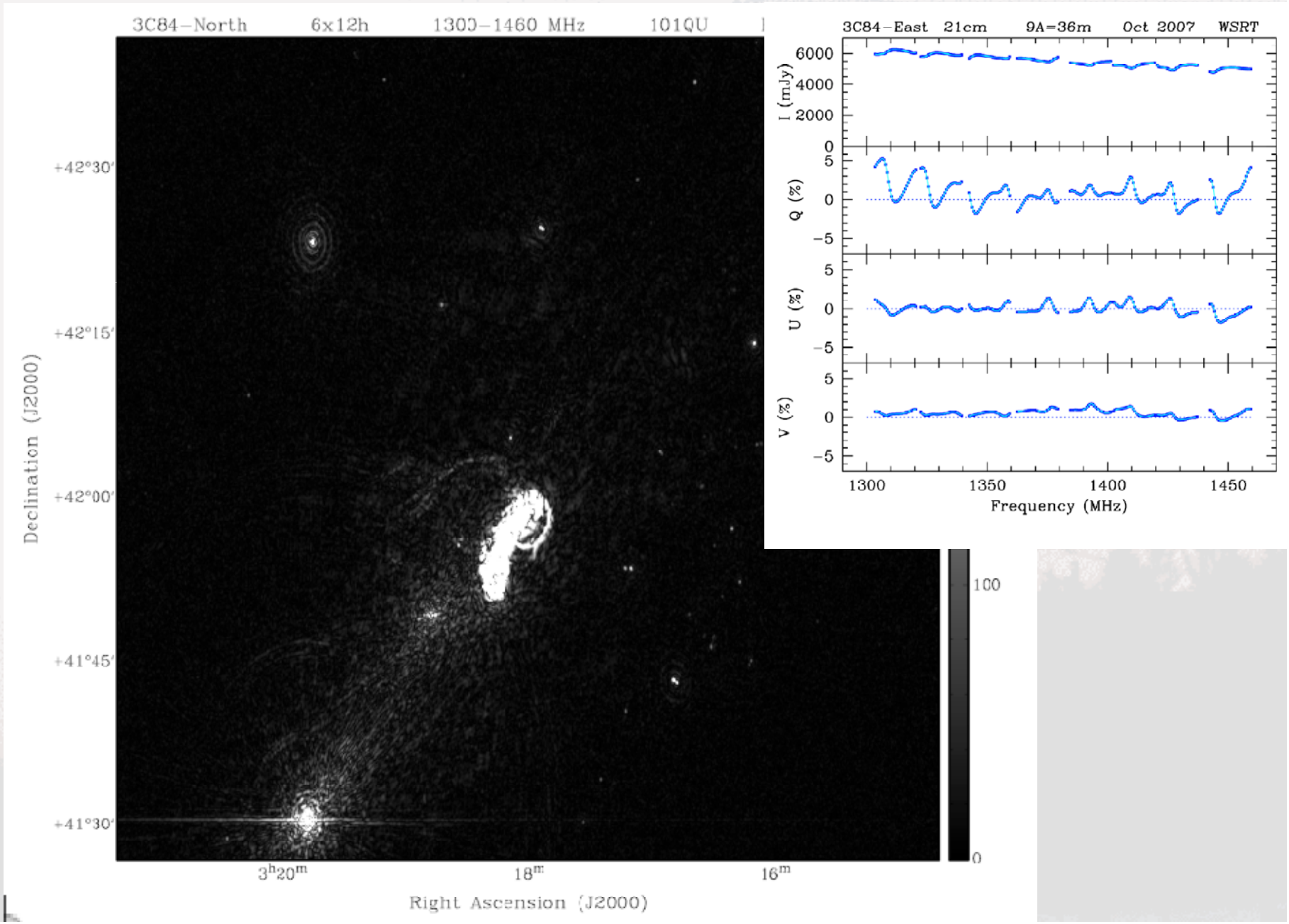
Pol-noise ~ 5-7 μJy/PSF

$\Rightarrow$ DR ~ 10^6 : 1

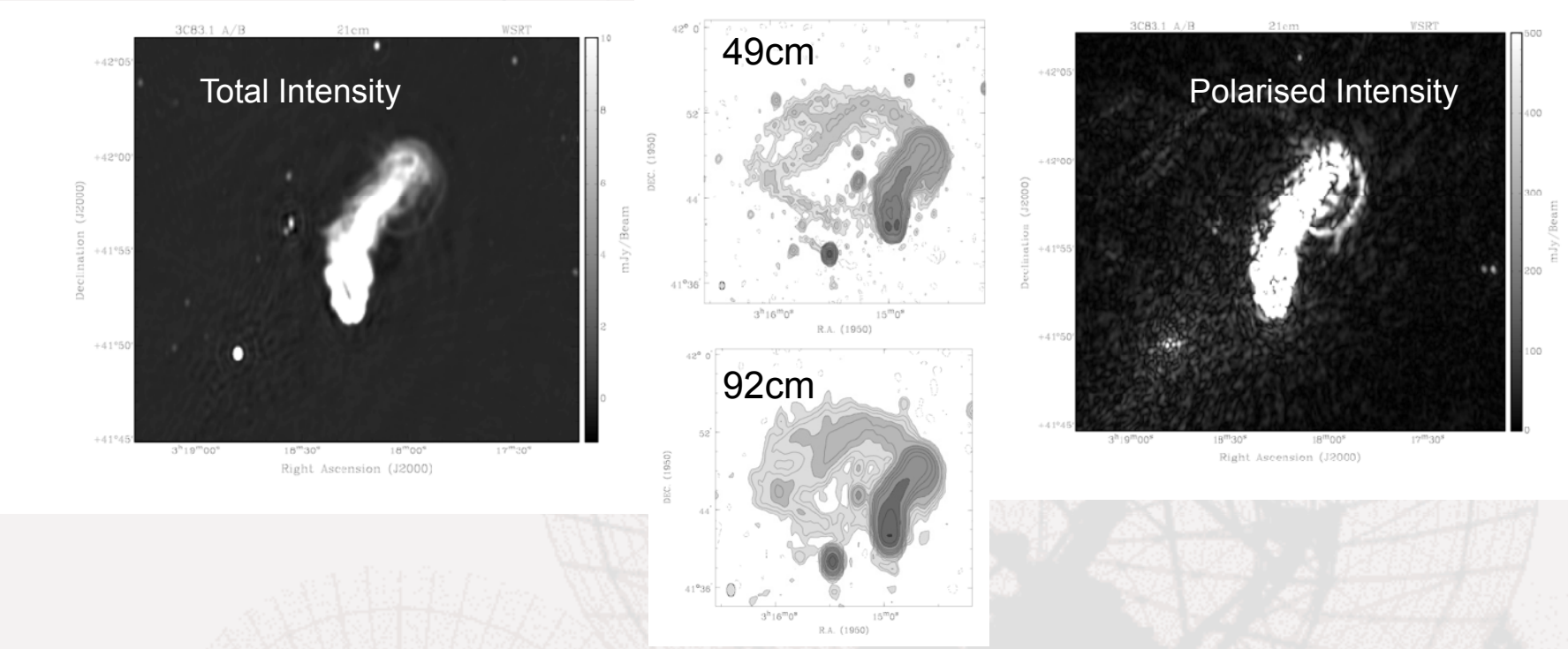
But here for an off-axis source !!

All probably Galactic foreground polarization

Perseus-NORTH



Perseus-NORTH



(Sijbring & de Bruyn, 1998)

Very complex field to process (NGC1265 polarization, 3C83.1A, 3C84)

A giant 'magnetic loop' ~ 60% polarized (!) with RM ~ 50 - 100 rad/m^2

Very thin and highly polarized ridges in OLD tail of NGC1265 !

Some more images on J1819+3845 ('Ghost-field')

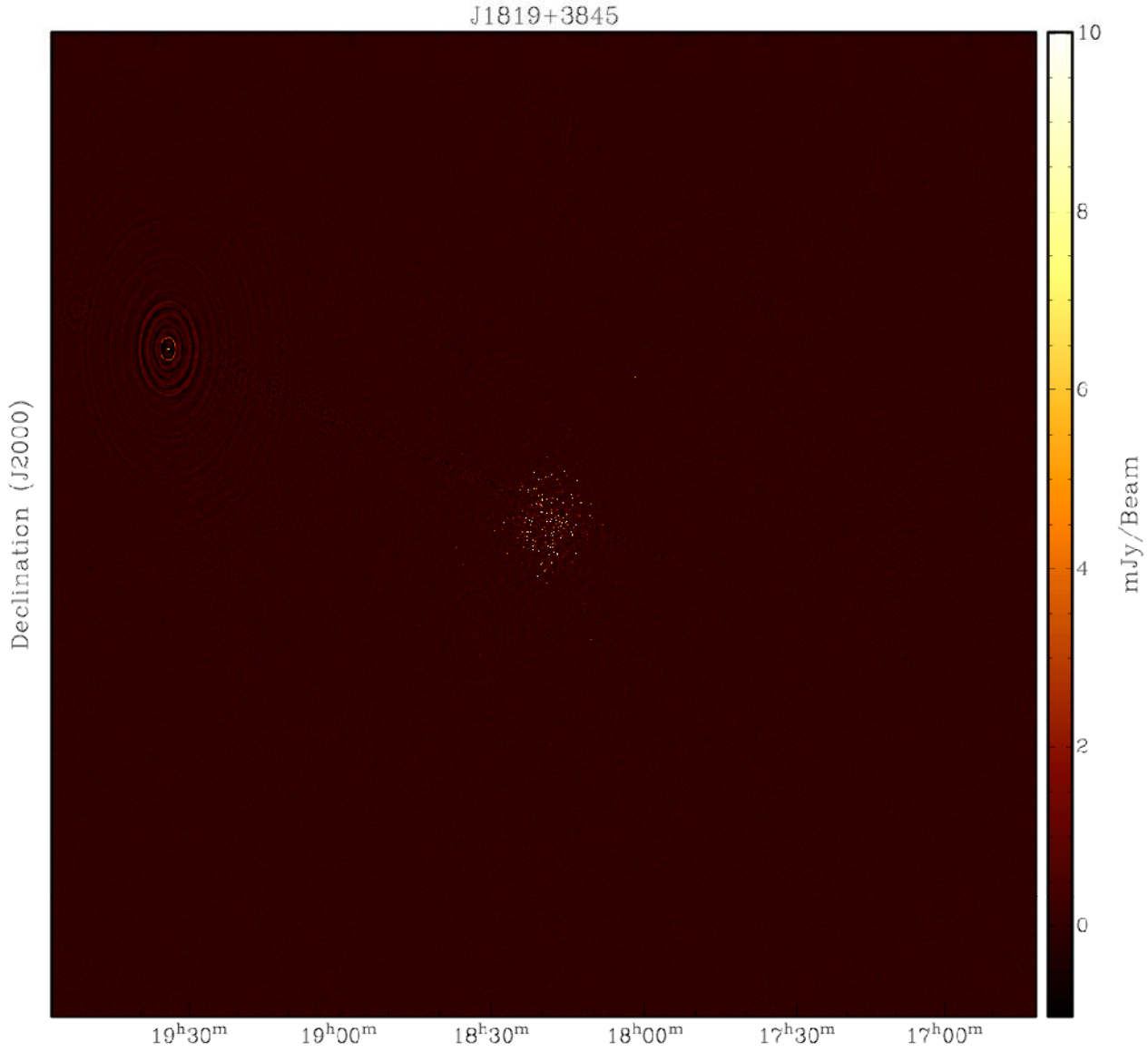
8192x8192

48°x48°

'

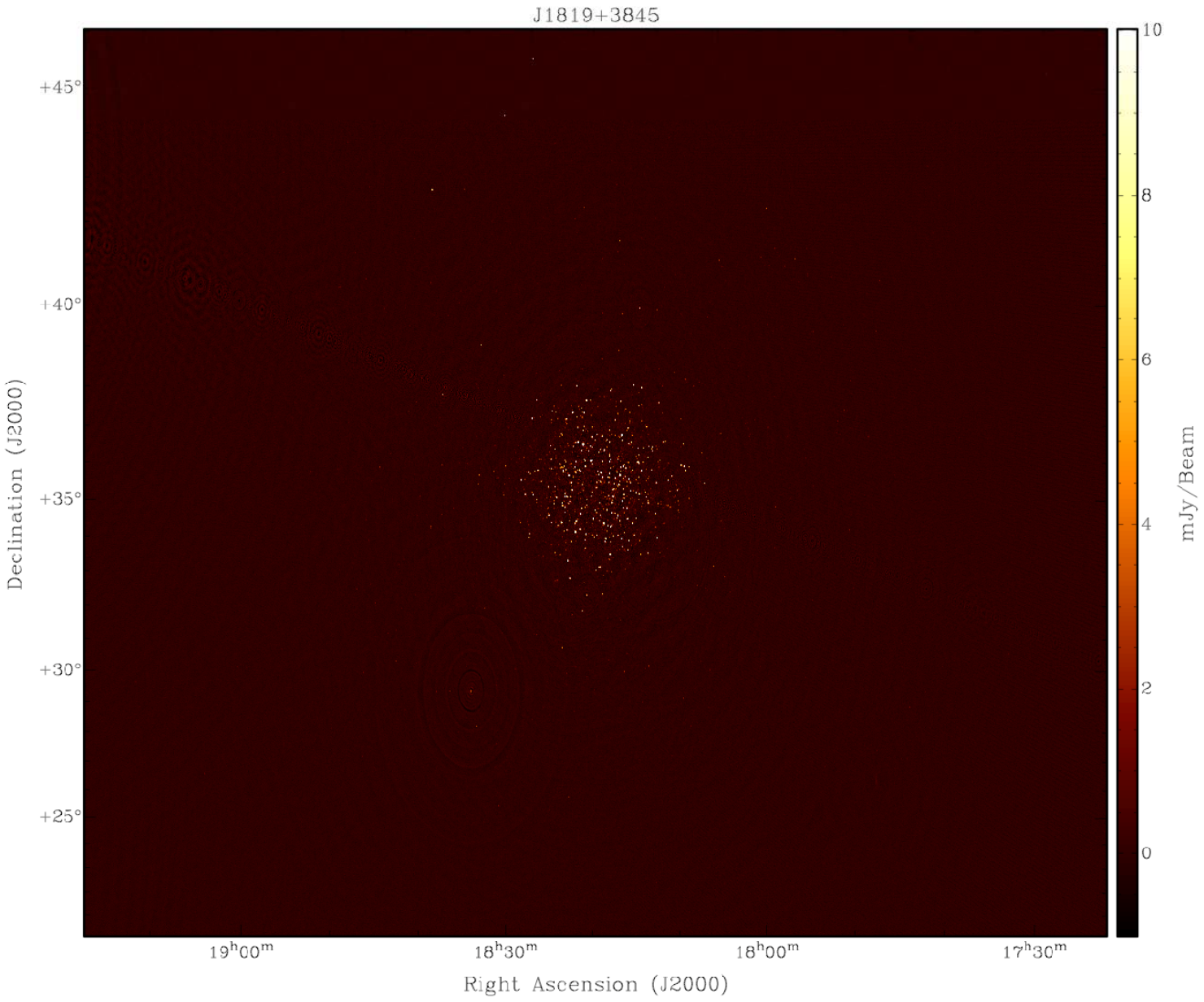
~ 85cm

328-376 MHz

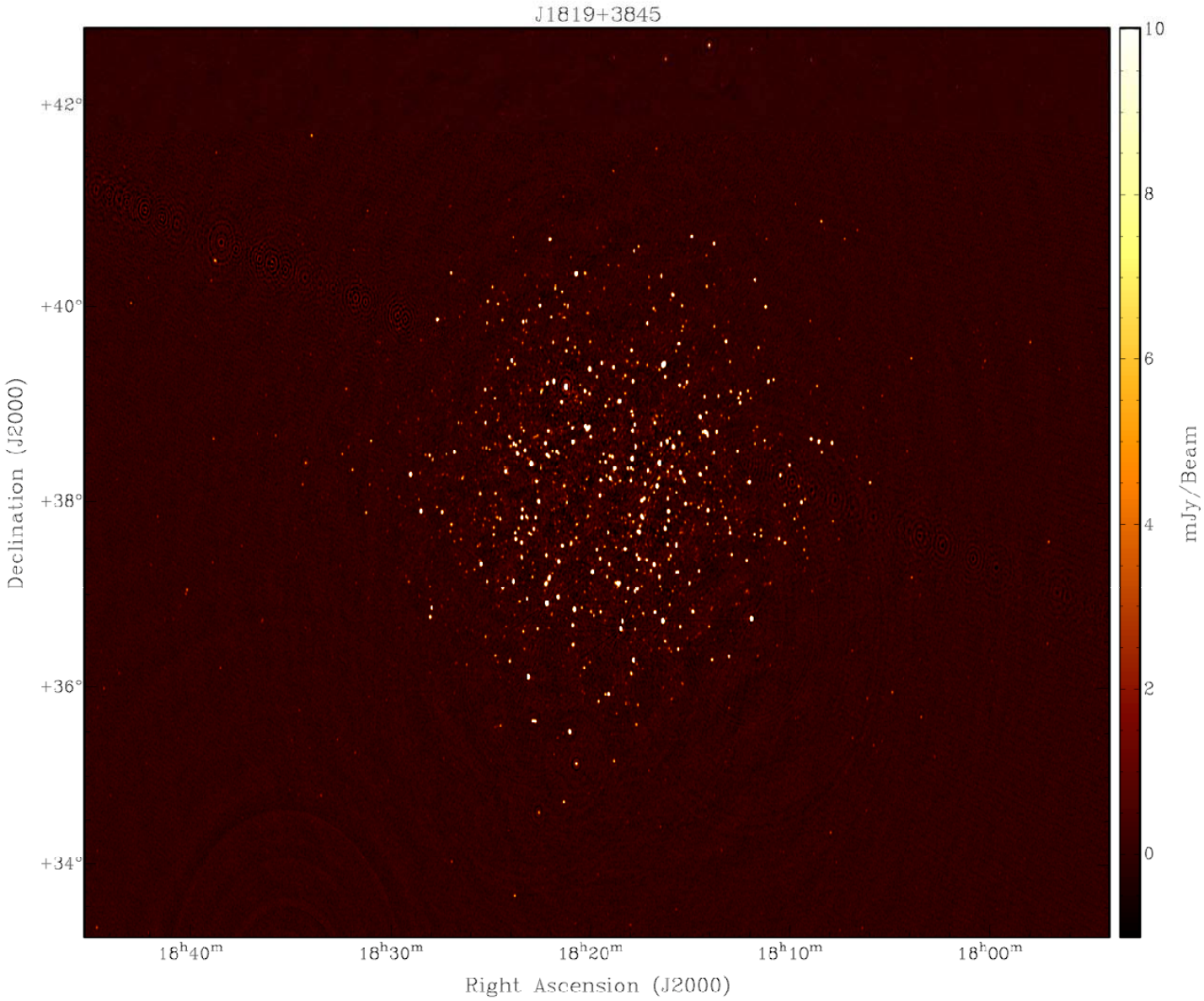


Some more images on J1819+3845 ('Ghost-field')

24°x24°

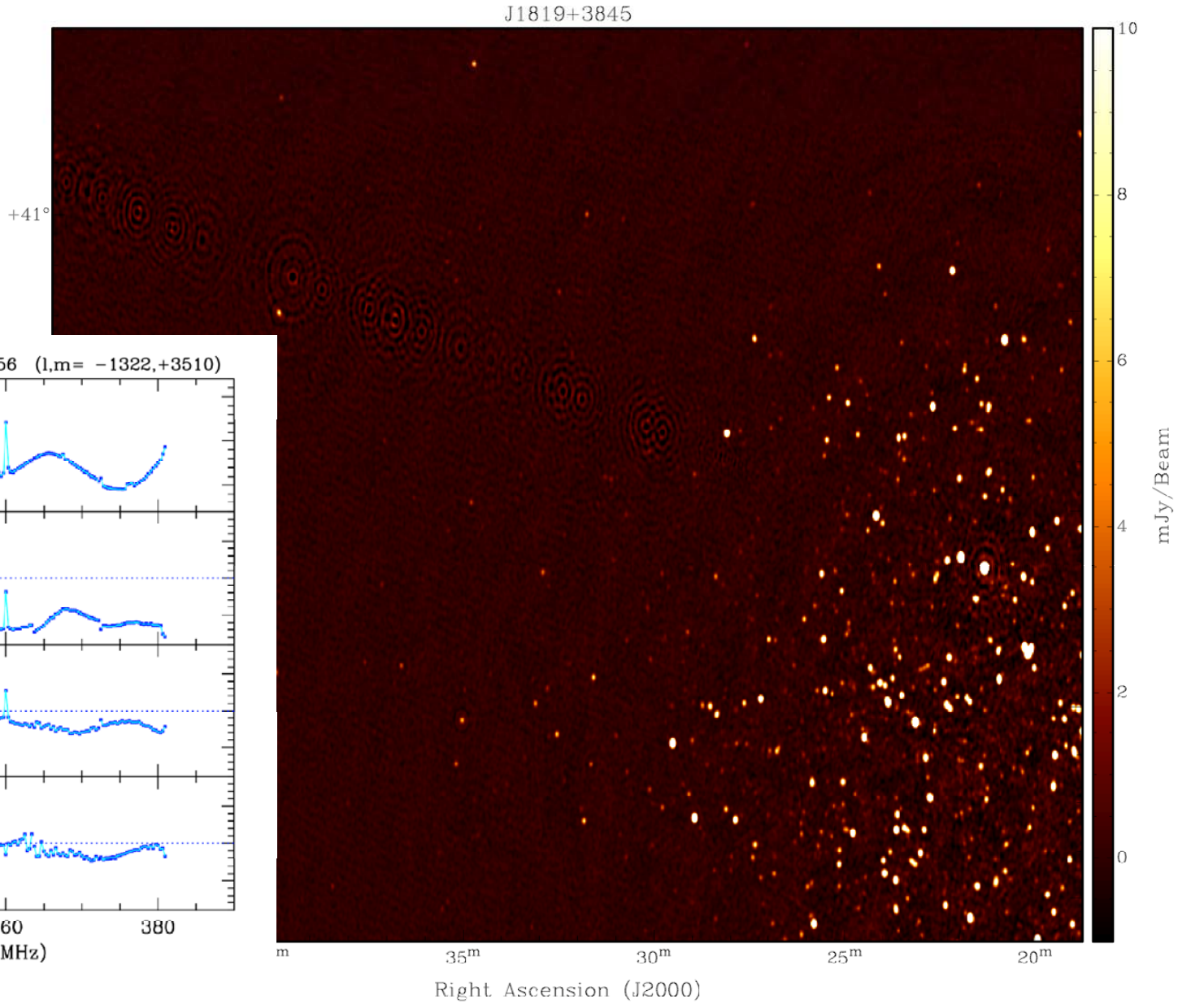


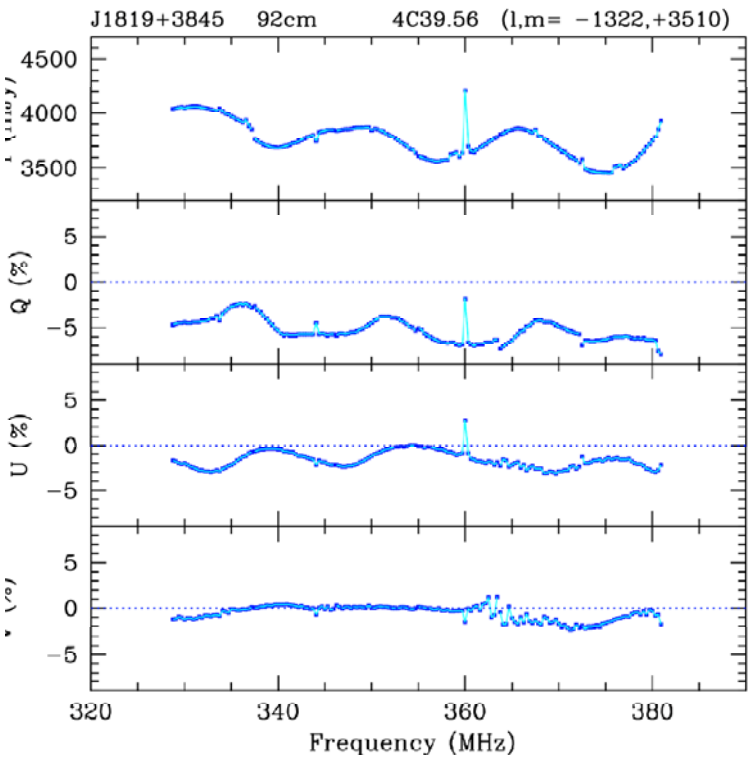
Some more images on J1819+3845 ('Ghost-field')



Some more images on J1819+3845 ('Ghost-field')

4°x4°





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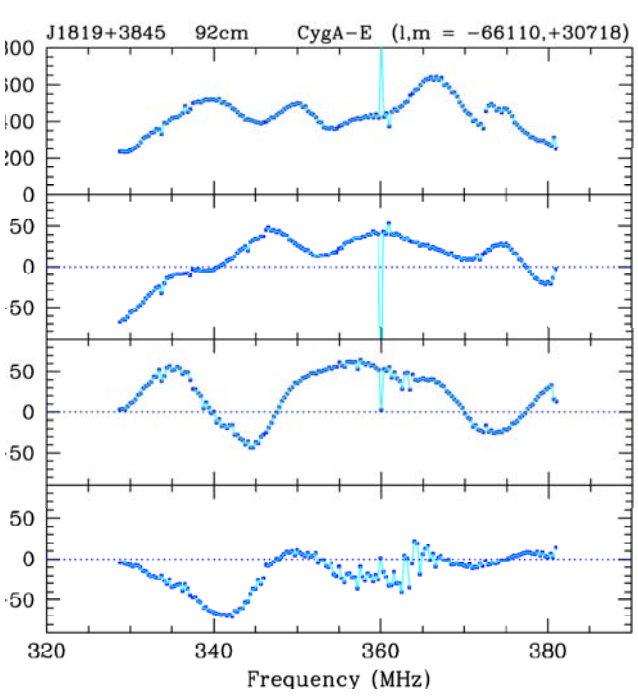
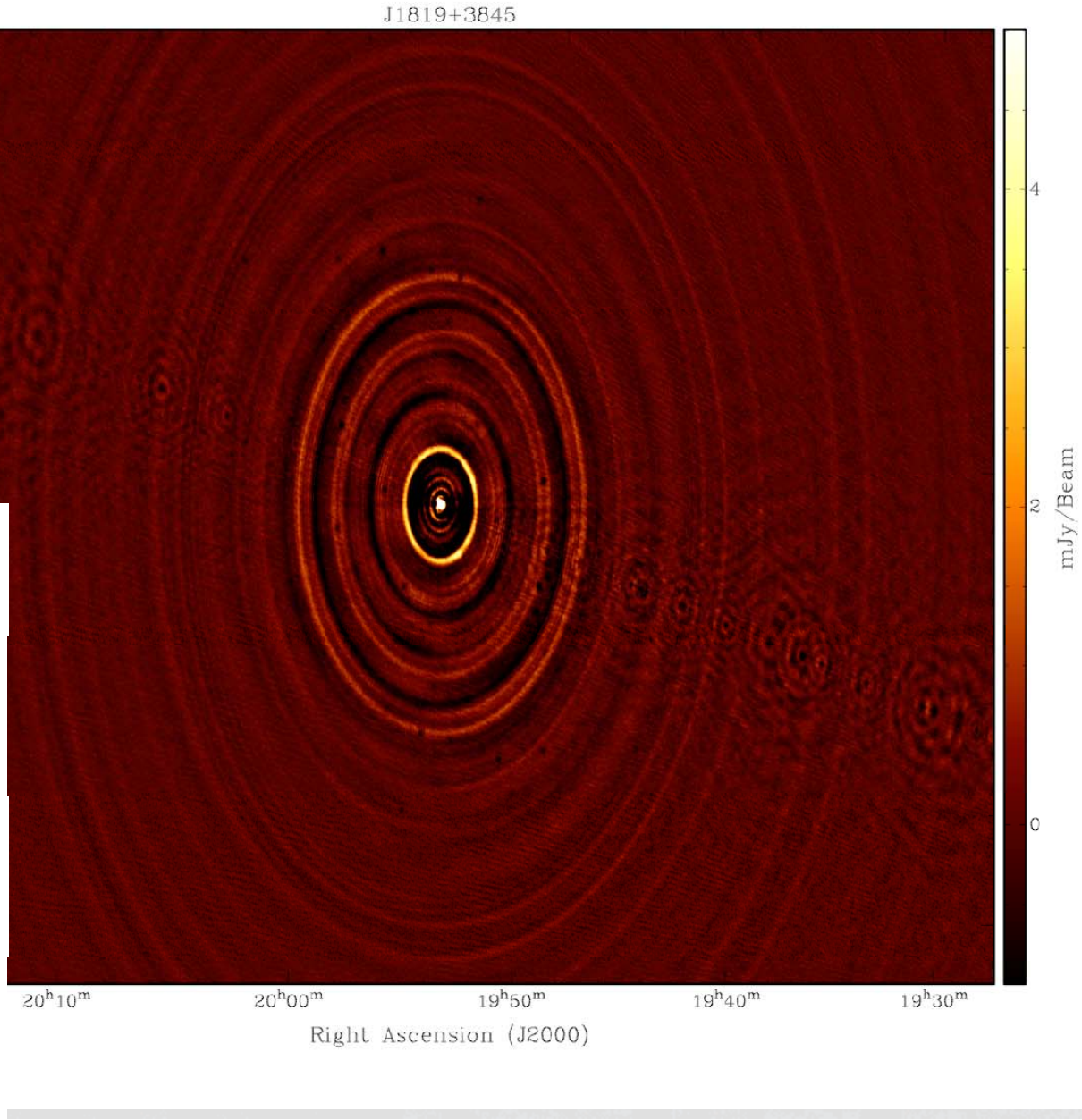
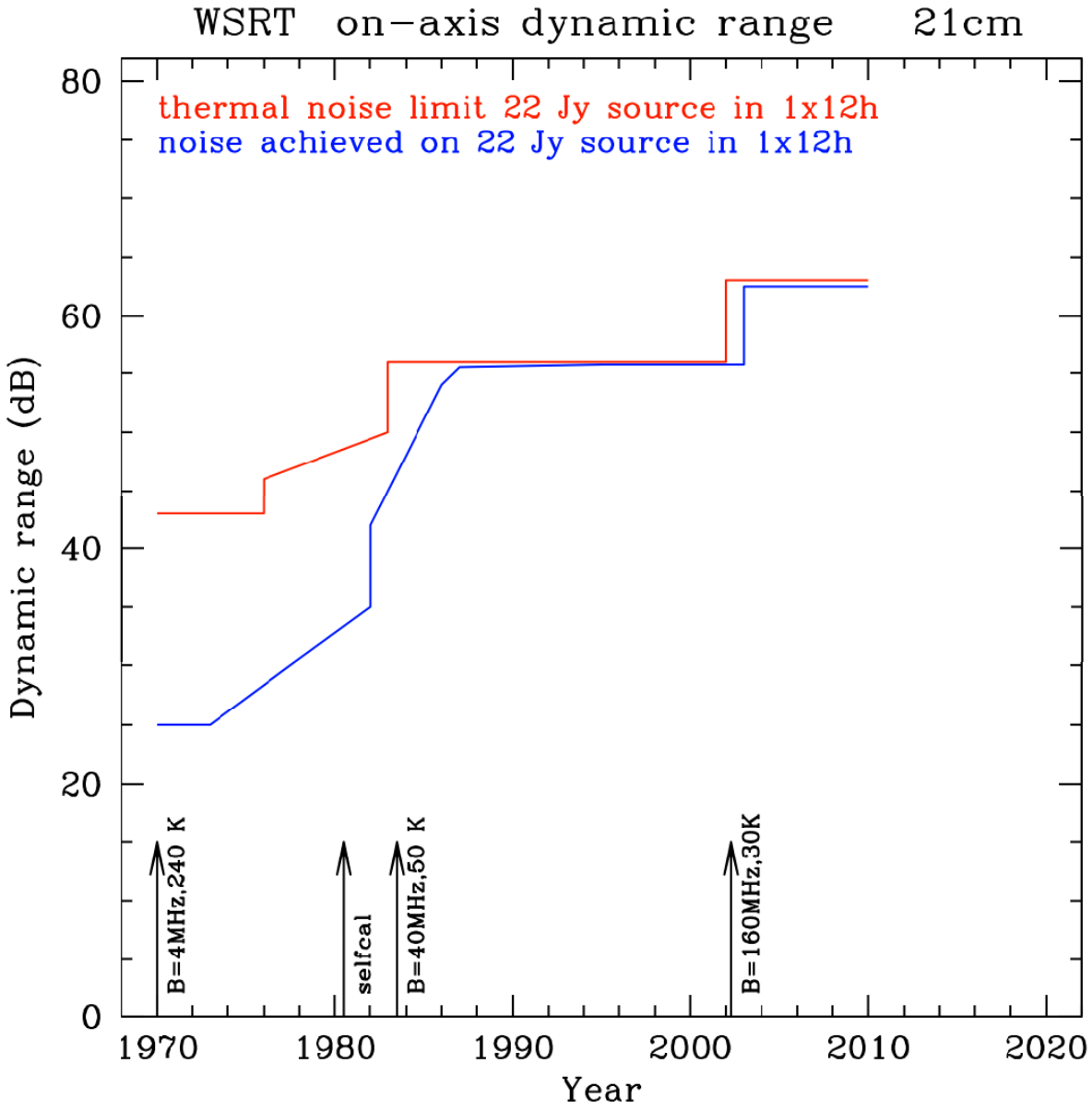




WSRT 21cm dynamic range over a 40 year period !



WSRT-40 Celebration

22 Oct 2010

Noordam & de Bruyn, 1982
Sybring thesis, 1993
de Bruyn, 1996
de Bruyn et al, 2010

Conclusions

- Reaching 5-10 μJy on > 1 Jy source fields requires narrow-band (~0.5 MHz) calibration
- Processing can be automated, and parallelized, but >> observing time
- Dynamic range on-axis $>10^6$:1, in both Stokes I and IPOL
- Dynamic range for strong sources off-axis almost as good as this
- DDEs can be included (cumbersome and painful !) but need new software ➔ MeqTrees (Oleg/Jan)

Encouraging facts:

- PAFs and ApertureArrays have much less PB-frequency structure
- WSRT dynamic range in 40 years follows thermal sensitivity