General Overview

(?)

“Calibration and imaging is months of extreme boredom, punctuated by moments of extreme terror.”

- *From the collected sayings of Gen. Overview, as recorded by his faithful adjutant Maj. Issues*

Calibration Is Terribly Boring

- Fact: 90 (95? 99?)% of the time calibration is extremely boring
  - And 95% of the people want to get it over with and just do their science
- Reference calibration has been completely automated
  - CASA JVLA & ALMA pipelines
  - IDIA processMeerKAT pipeline
  - AperCal
  - MeerKATHI
- Given a stable enough instrument (and a trouble-free frequency band), that's all the 95% needs 95% of the time
  - see several examples of MeerKAT images from Russ's talk
  - but DDEs
  - but LOFAR...
  - but LOFAR-VLBI...
  - but GMRT...
  - but APERTIF...
- Boring calibration does not mean boring images

A Result Of Boring Calibration

(Ian Heywood, Oxford U. & Rhodes)

Aug 2016: GW170817 Goes Boom

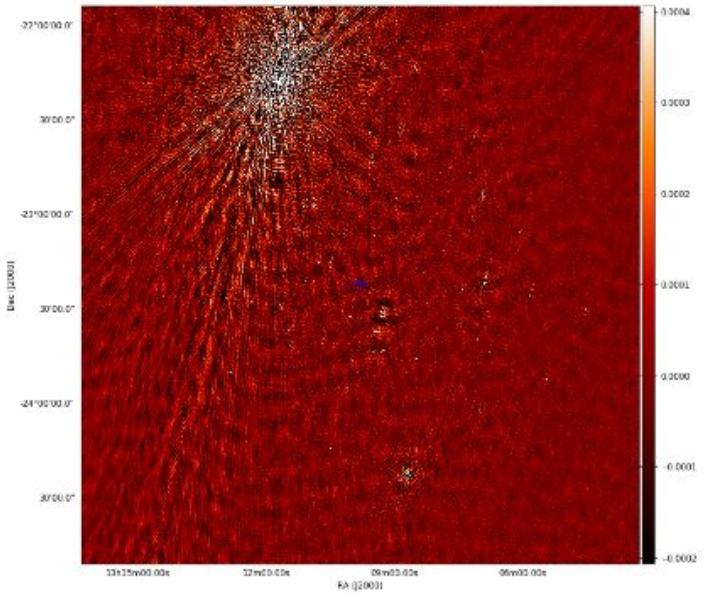
- “There’s nothing quite as useless as a radio source.”

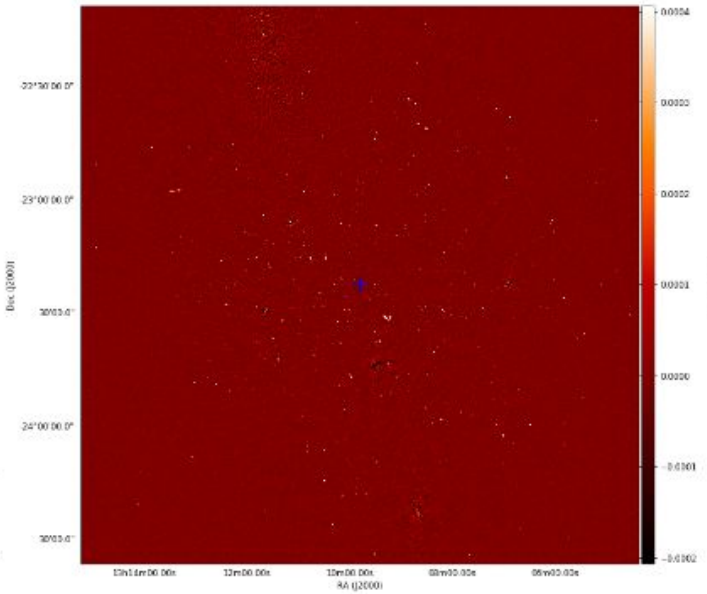
  -- Jim Condon
- “Unless it’s a big blooming 3C source skulking around your primary beam first null.”

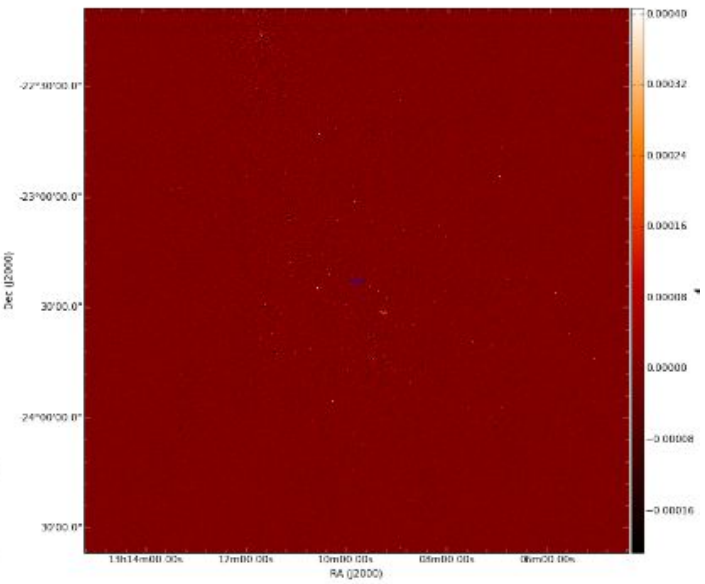
  -- Maj. Issues
- Initial MeerKAT-16 observations completely dominated by 3C283 sitting around the first null of the primary beam
  - Bad luck?
  - “Once is misfortune. Twice is coincidence. Three times is enemy action.”

Bring Out The Big Guns: Peeling

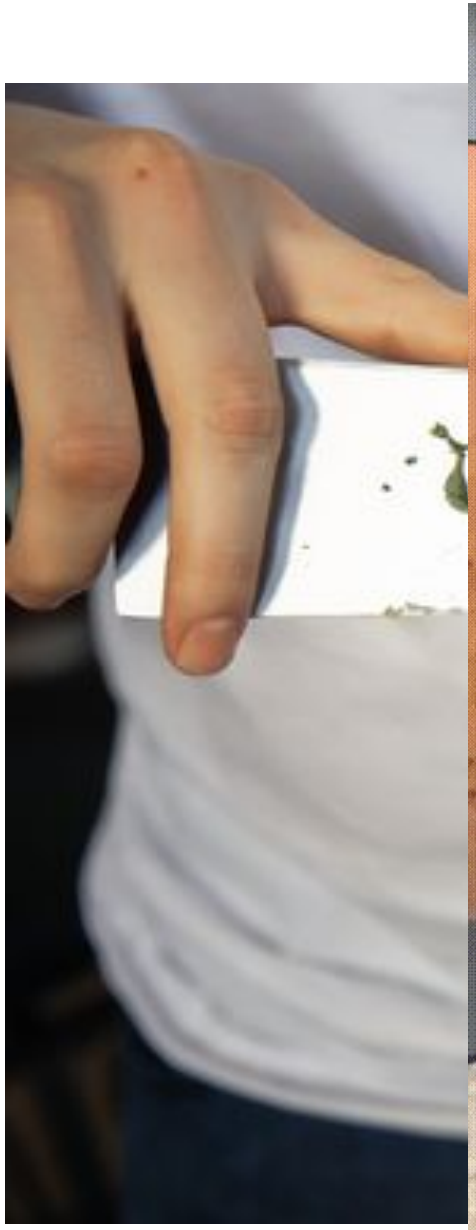
- “Old-school” peeling: solve towards brightest troublesome source & subtract
  - Routine procedure by now, can be done by many tools
- 3C283: we have a reliable sky model
- Does it work? Yes…

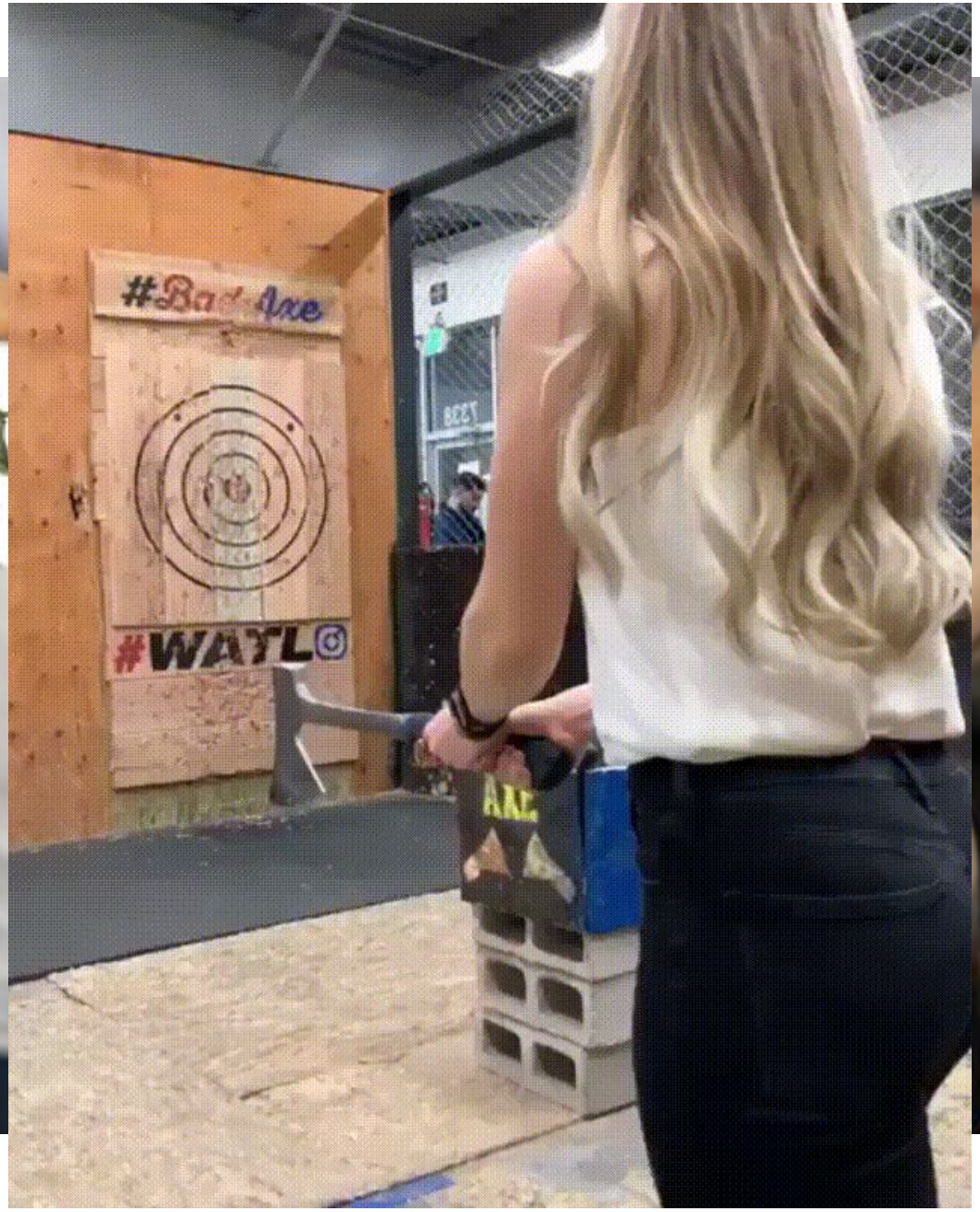






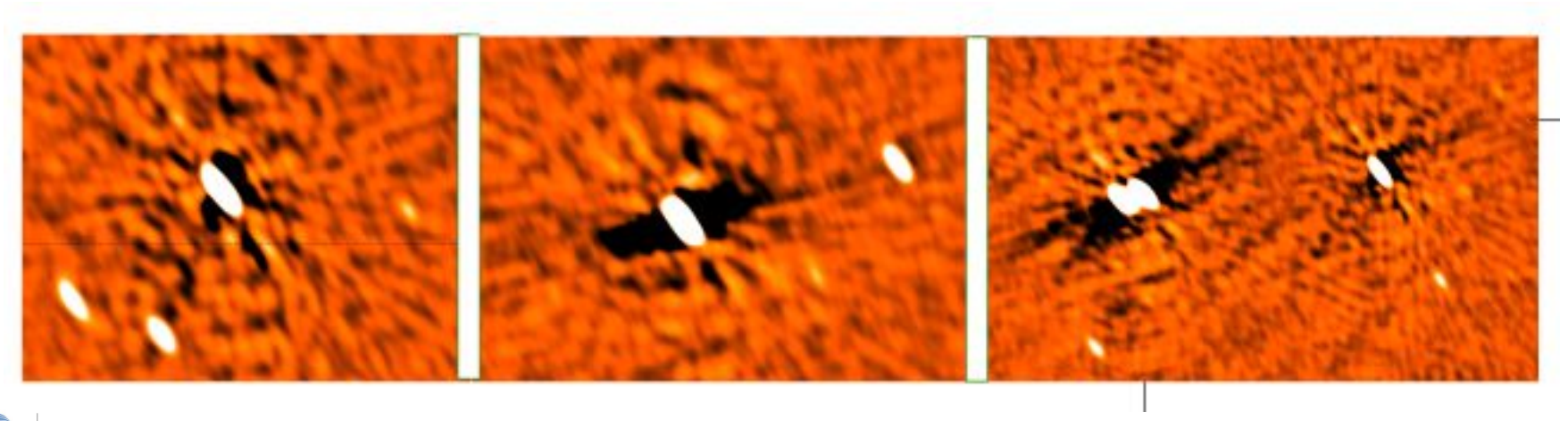
What Could *Possibly* Go Wrong?





The Dangers Of Peeling

- Need to use high time/freq cadence to account for the behaviour of the beam in the null
  - SNR not a problem
  - …proliferation of degrees of freedom in the solution is
- Introduces negative halos (“gremlin ears”) around many sources
- A type of ghost
- Need to peel cleverly…



Peeling Safely & Cleverly

- Include a model for the rest of the field as you peel
- Do direction-independent (DI) selfcal & direction-dependent (DD) solutions simultaneously…
  - …but with a different time/frequency cadence
- Use a primary beam model if you've got one
- Subtract offending source (using DD solutions), correct the residual visibilities (containing the rest of the flux) using DI solutions
- The radio interferometer measurement equation (RIME) tells you how to do it mathematically
  - …just need to be able to coax the software to do it
  - Need a flexible implementation of the RIME + fast solver
  - See Kenyon PhD thesis (2019)

CUBICAL – fast radio interferometric calibration suite exploiting complex optimization

J S Kenyon ✉, O M Smirnov, T L Grobler, S J Perkins

Monthly Notices of the Royal Astronomical Society, Volume 478, Issue 2, August 2018, Pages 2399–2415, https://doi.org/10.1093/mnras/sty1221

Published: 11 May 2018 **Article history** ▾

CubiCal: Bespoke RIMEs

$$\mathbf{V}_{pq} = \mathbf{G}_p(\mathbf{dE}_p\mathbf{E}_p\mathbf{M}^{(1)}_{pq}\mathbf{E}^H_q\mathbf{dE}^H_q + \mathbf{M}^{(2)}_{pq} + \ldots)\mathbf{G}^H_q$$

Solvable DI gain

Solvable DD gain

Primary beam model

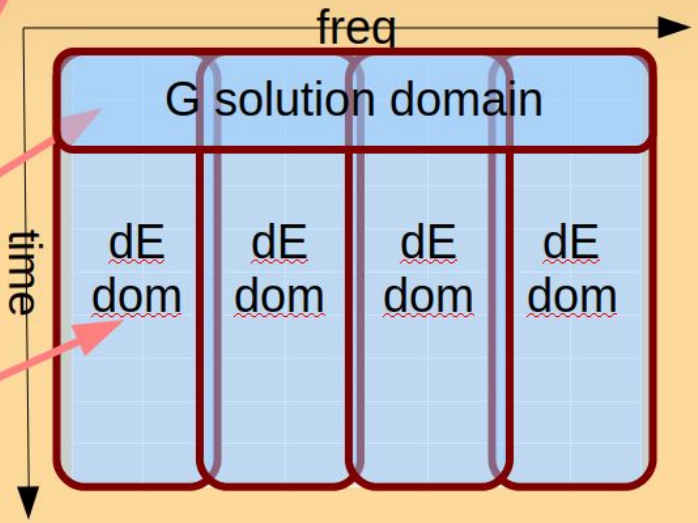
3C283 model (from catalog)

Primary beam model

Solvable DD gain

"Rest of field" model (from imager)

Solvable DI gain




```
$ gocubical foo.ms
   --model-list 3C283.txt:MODEL_DATA
   --sol-jones G,dE
   --g-time-int 2 --g-freq-int 1000
   --de-time-int 80 --de-freq-int 20  --de-fix-dir 1
   --out-subtract-dirs 0
```

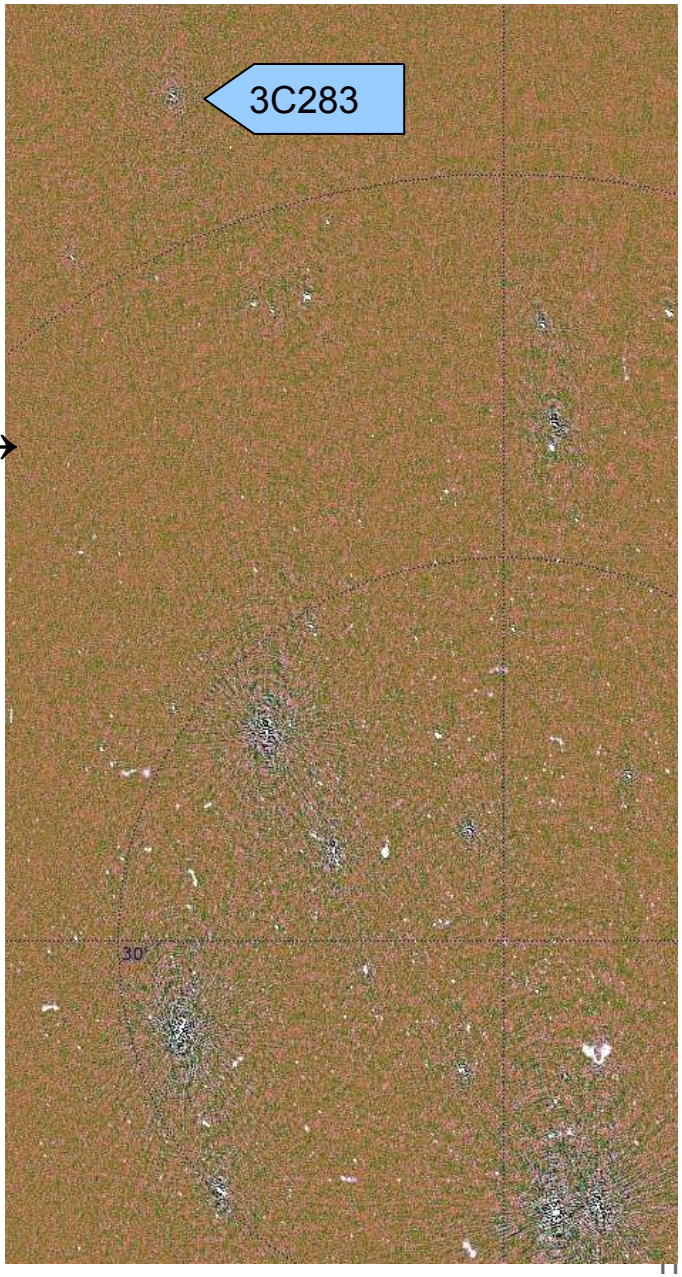
no dE on MODEL_DATA

subtract only 3C283

Peeling & De-gremlining

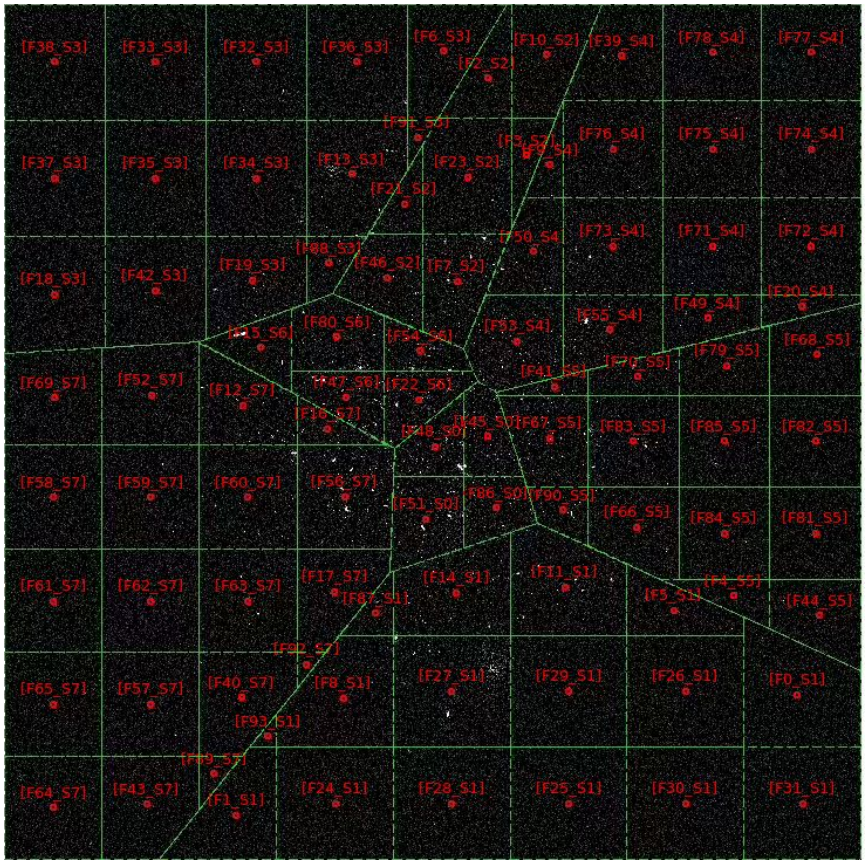
← regular peeling

peeling w/CubiCal →



DDFacet + killMS

- Originated by Cyril Tasse (Rhodes ➔ Obs. Paris Meudon)
- Further development in collaboration with OPM & Rhodes & SARAO & LOFAR Surveys
- killMS: solves for per-tessel direction-dependent gains
  - Kalman filters or solvers
- DDFacet: applies DD-effects per-facet during imaging
  - from known beam model and/or killMS solutions
- Used in the LoTSS pipeline
  - & MeerKAT
  - & VLA
  - & ATCA
  - & APERTIF
  - & GMRT



A&A 611, A87 (2018)

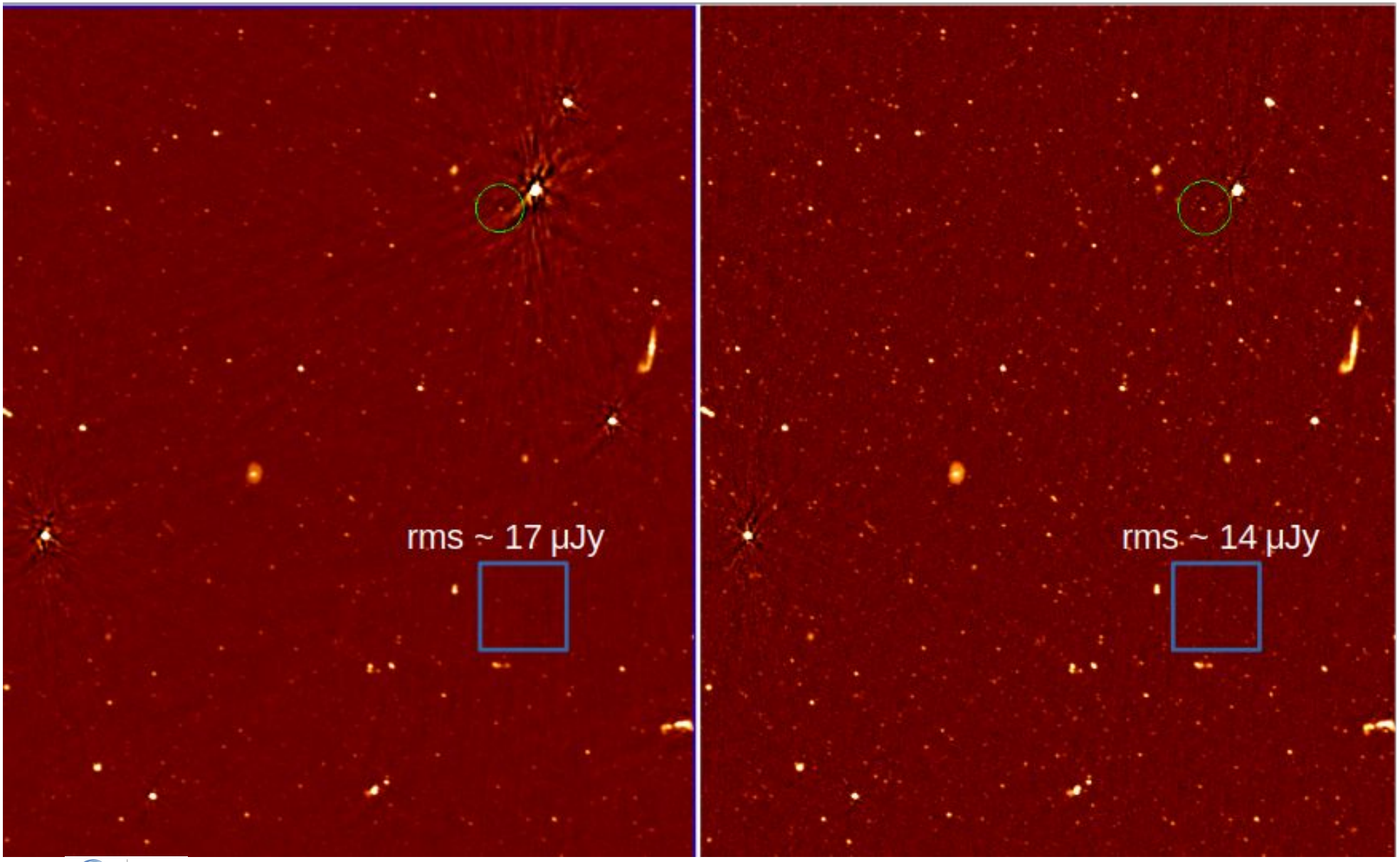
Faceting for direction-dependent spectral deconvolution

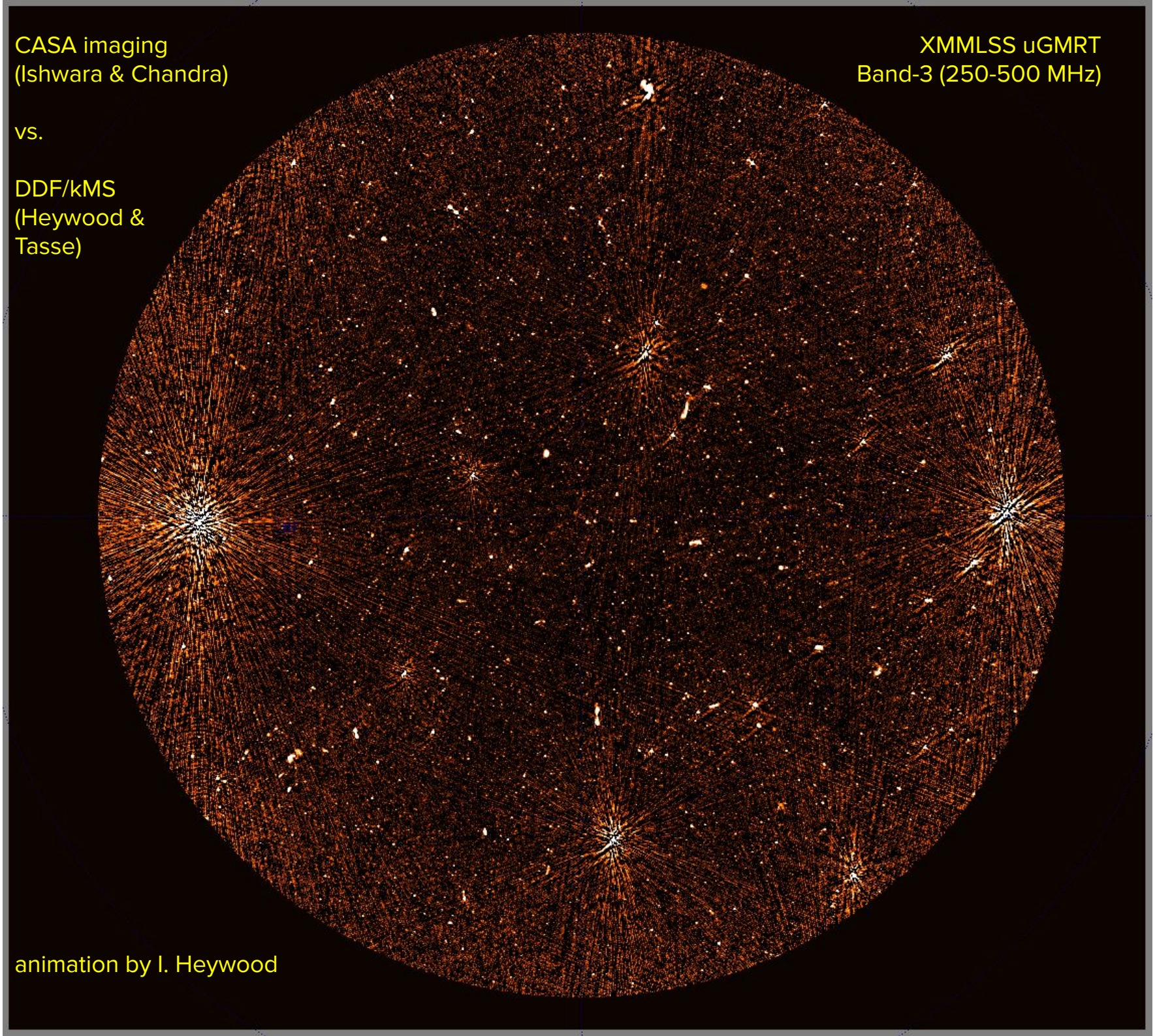
C. Tasse[1,2], B. Hugo[2,3], M. Mirmont[8], O. Smirnov[2,3], M. Atemkeng[2], L. Bester[3], M. J. Hardcastle[4], R. Lakhoo[5,6], S. Perkins[3] and T. Shimwell[7]

XMMLSS with uGMRT band-3 (250-500 MHz)

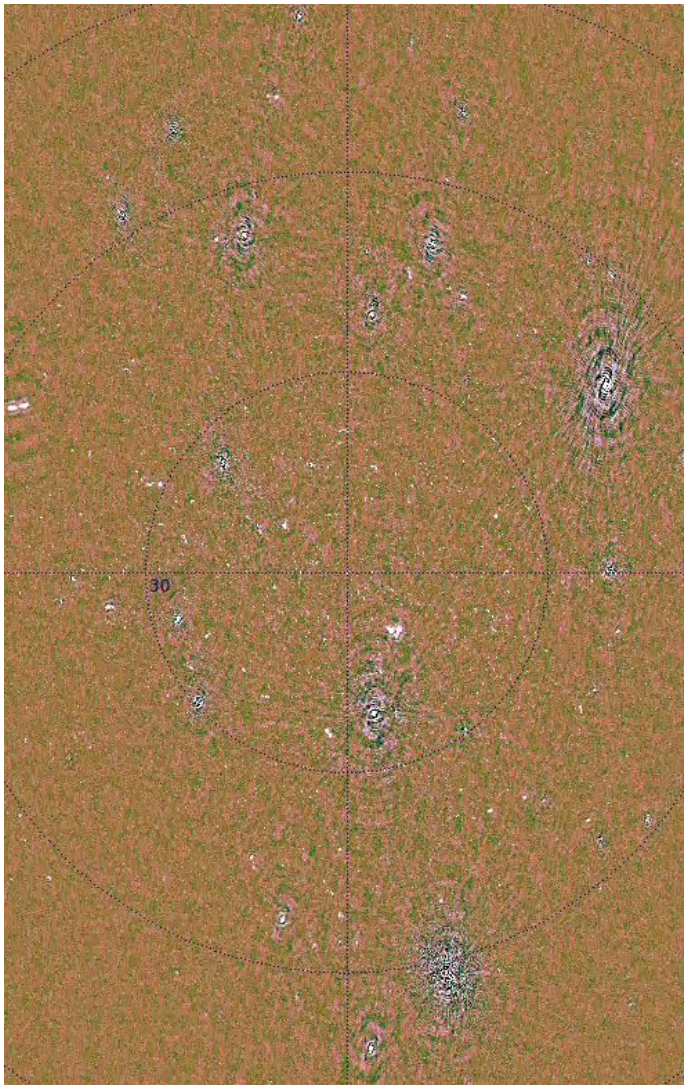
Normal casa imaging (*Ishwara-Chandra*)

DDF/KillMS (*Ian Heywood+Cyril Tasse*)

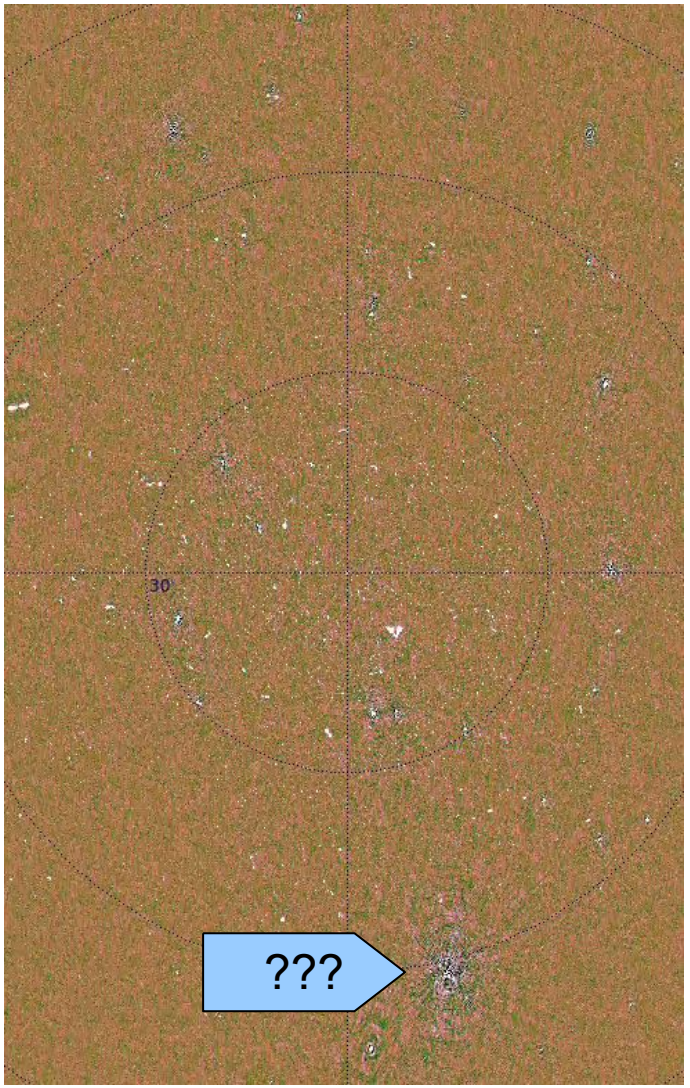



CASA imaging
(Ishwara & Chandra)
vs.
DDF/kMS
(Heywood &
Tasse)
XMMLSS uGMRT
Band-3 (250-500 MHz)
animation by I. Heywood

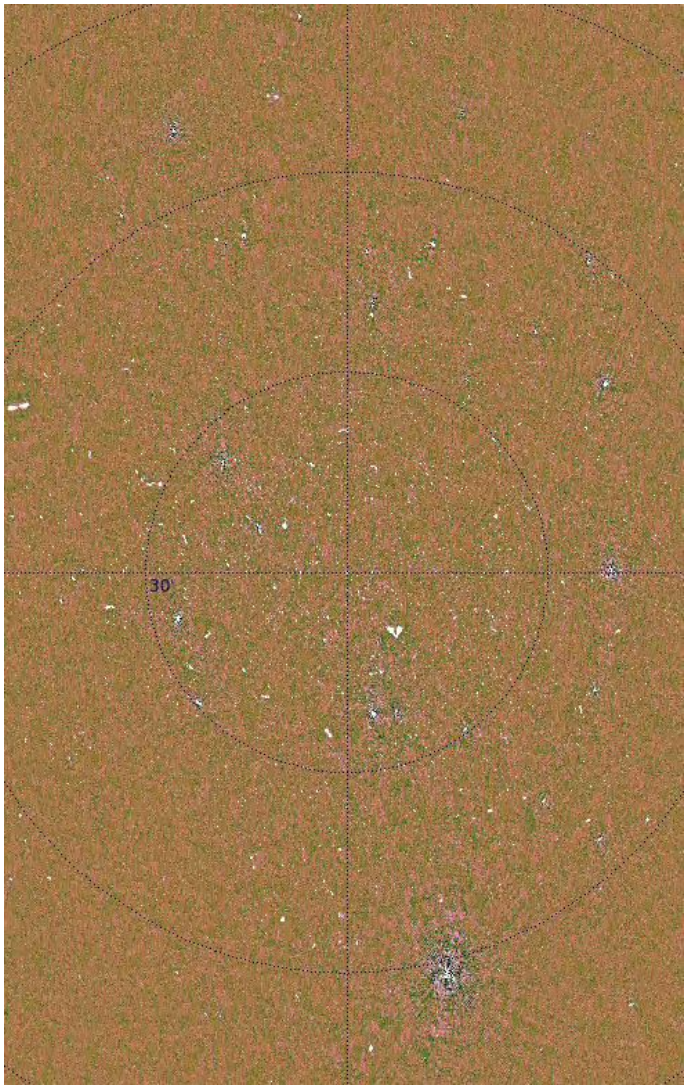
DDFacet With MeerKAT PB Model



DDFacet, no PB model
power-law source spectra



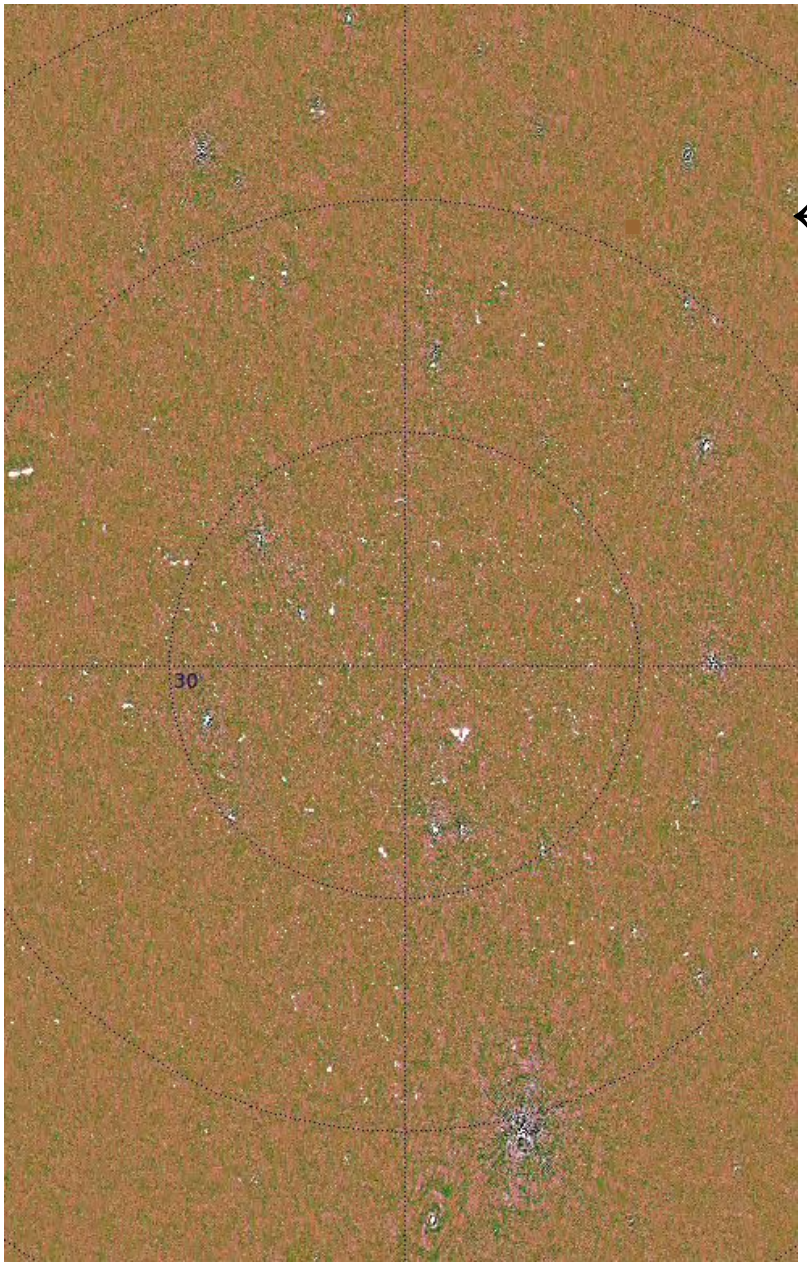
DDFacet, with PB model
power-law source spectra



WSCLEAN, no PB model
5th deg polynomial spectra

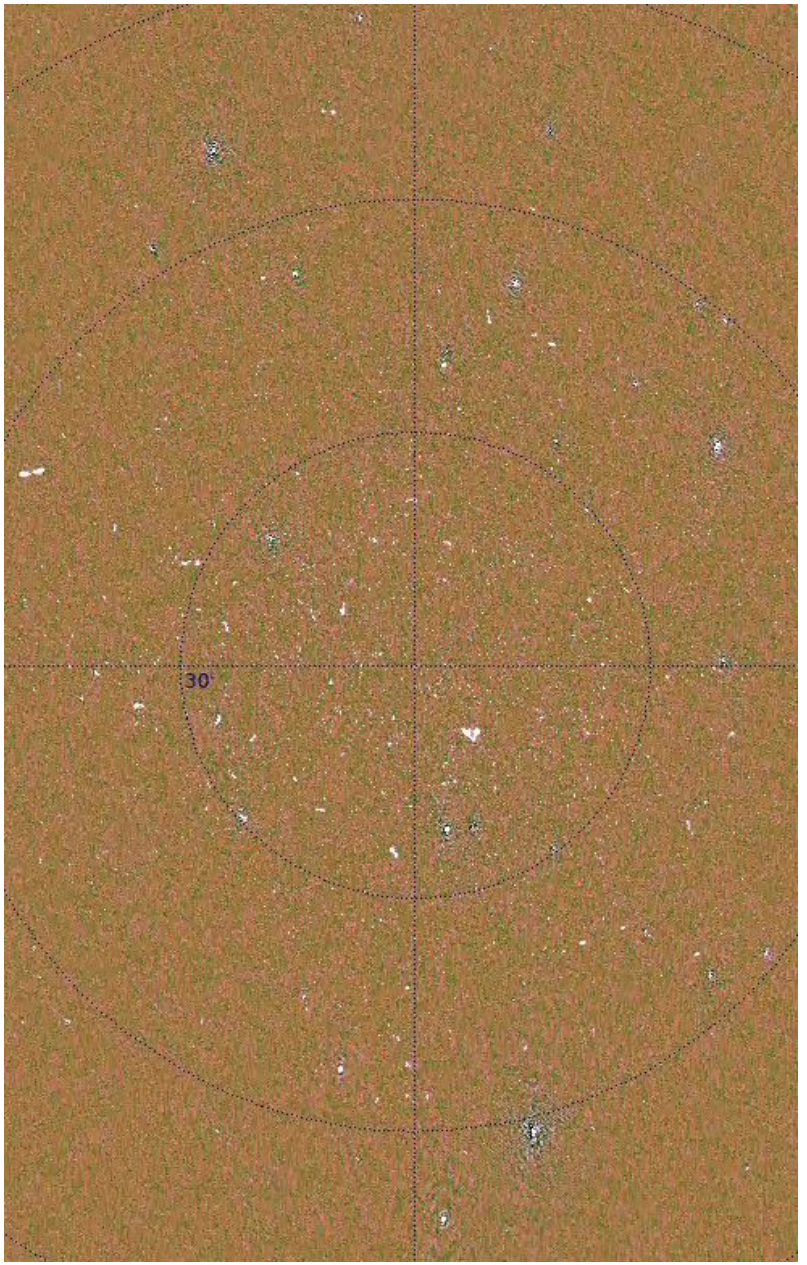
RATT NRF SARAO

DDFacet/killMS: NGC4993 field

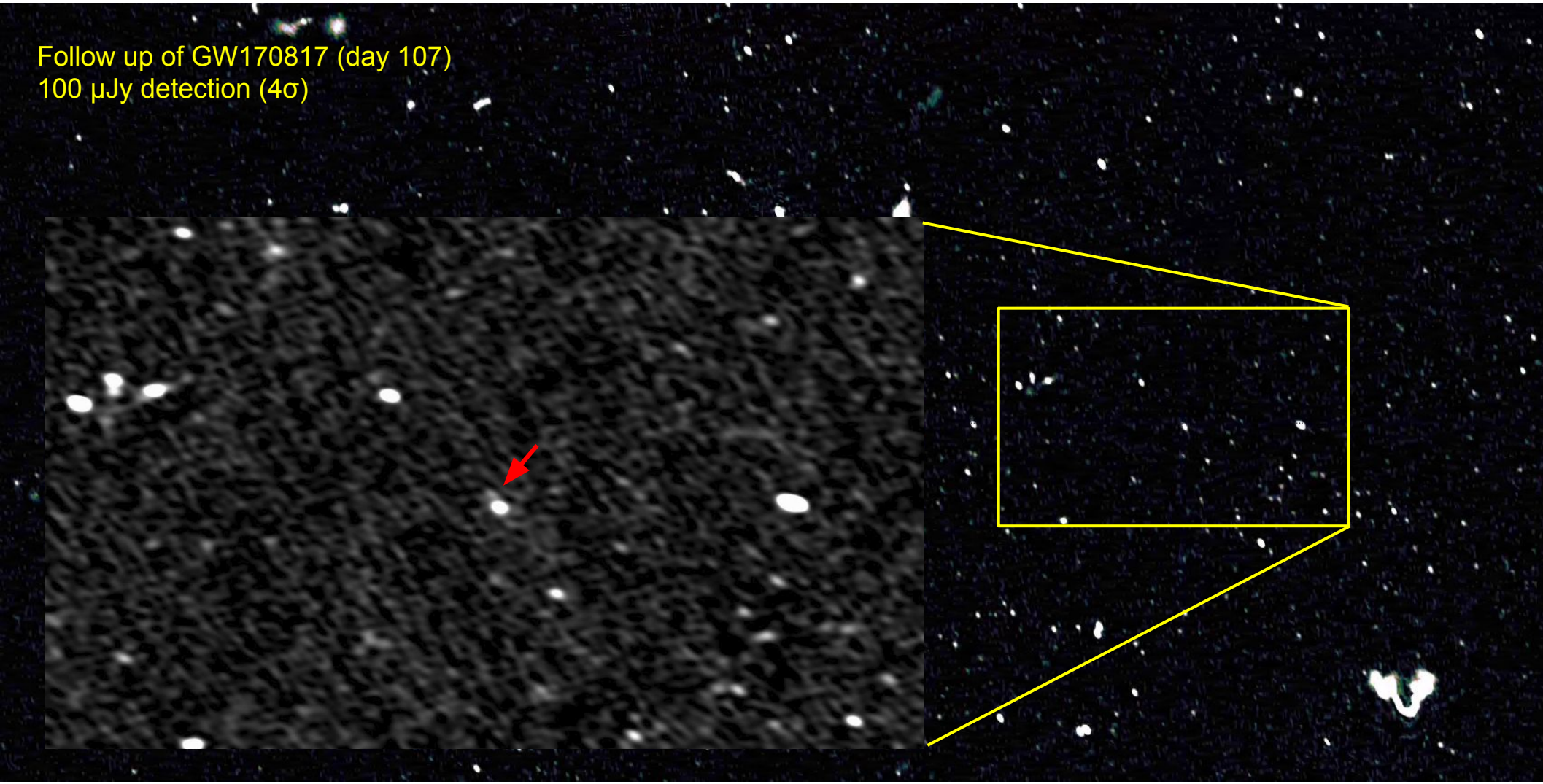


← pre killMS

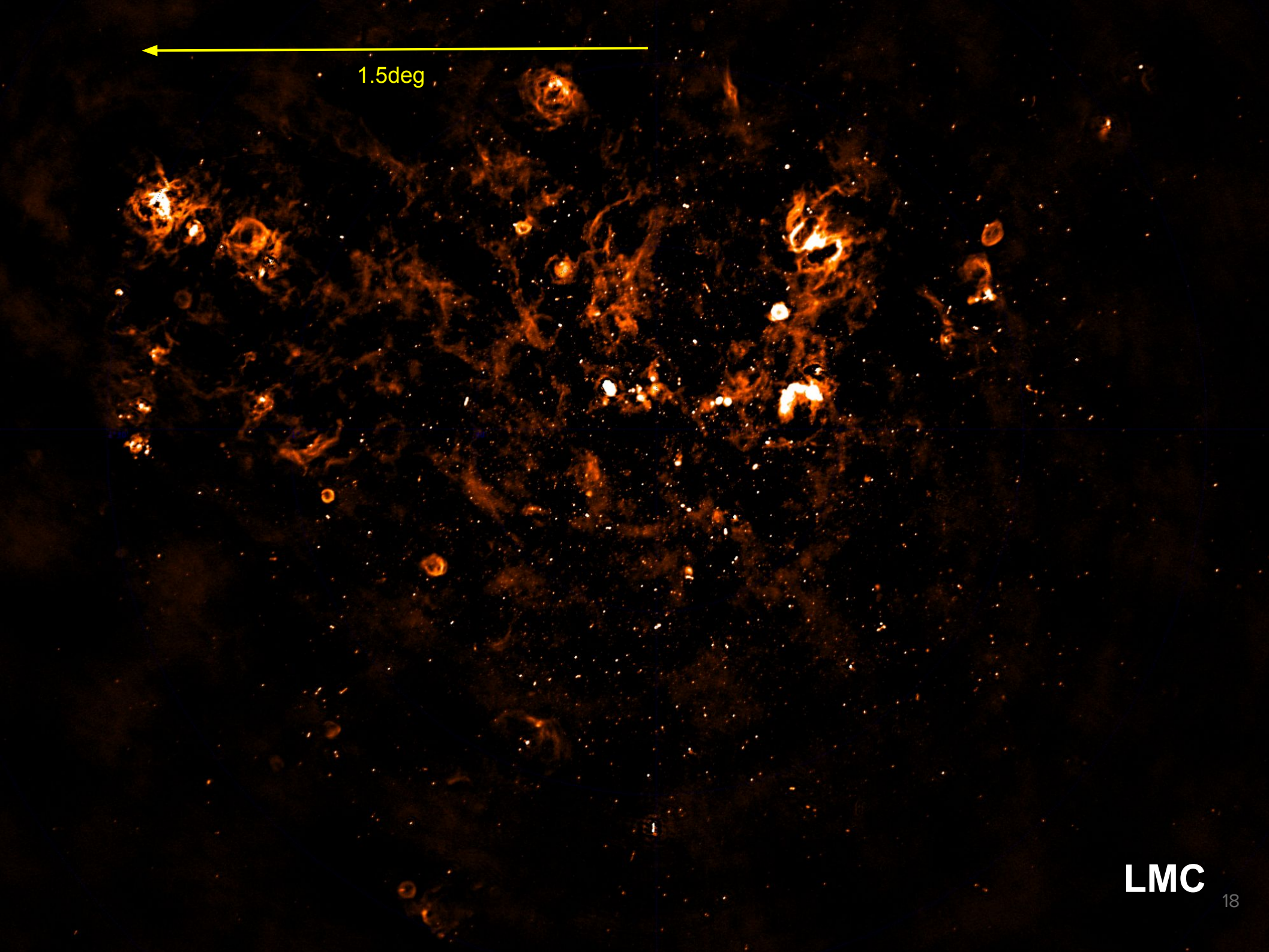
post killMS →

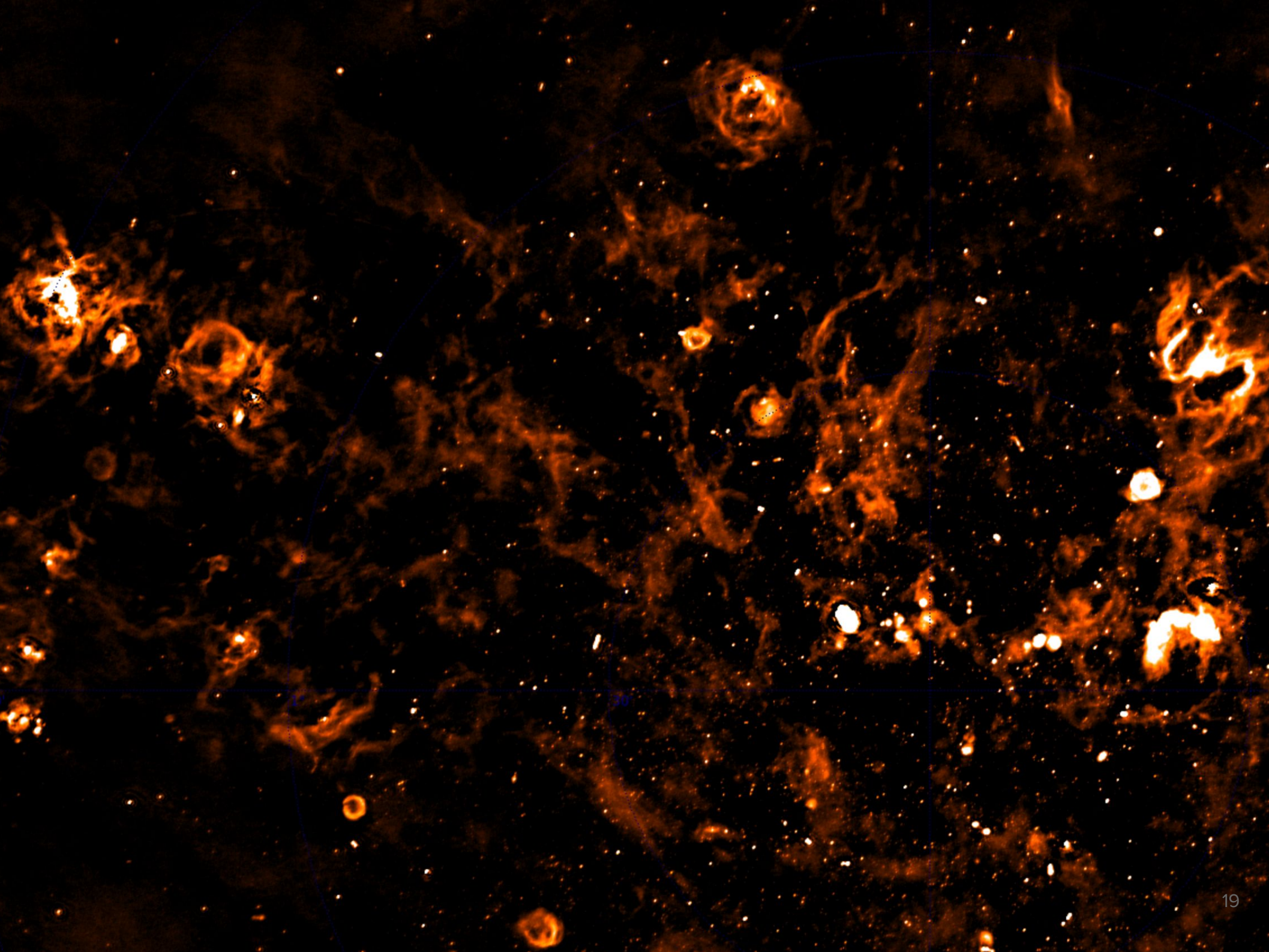


Detection!



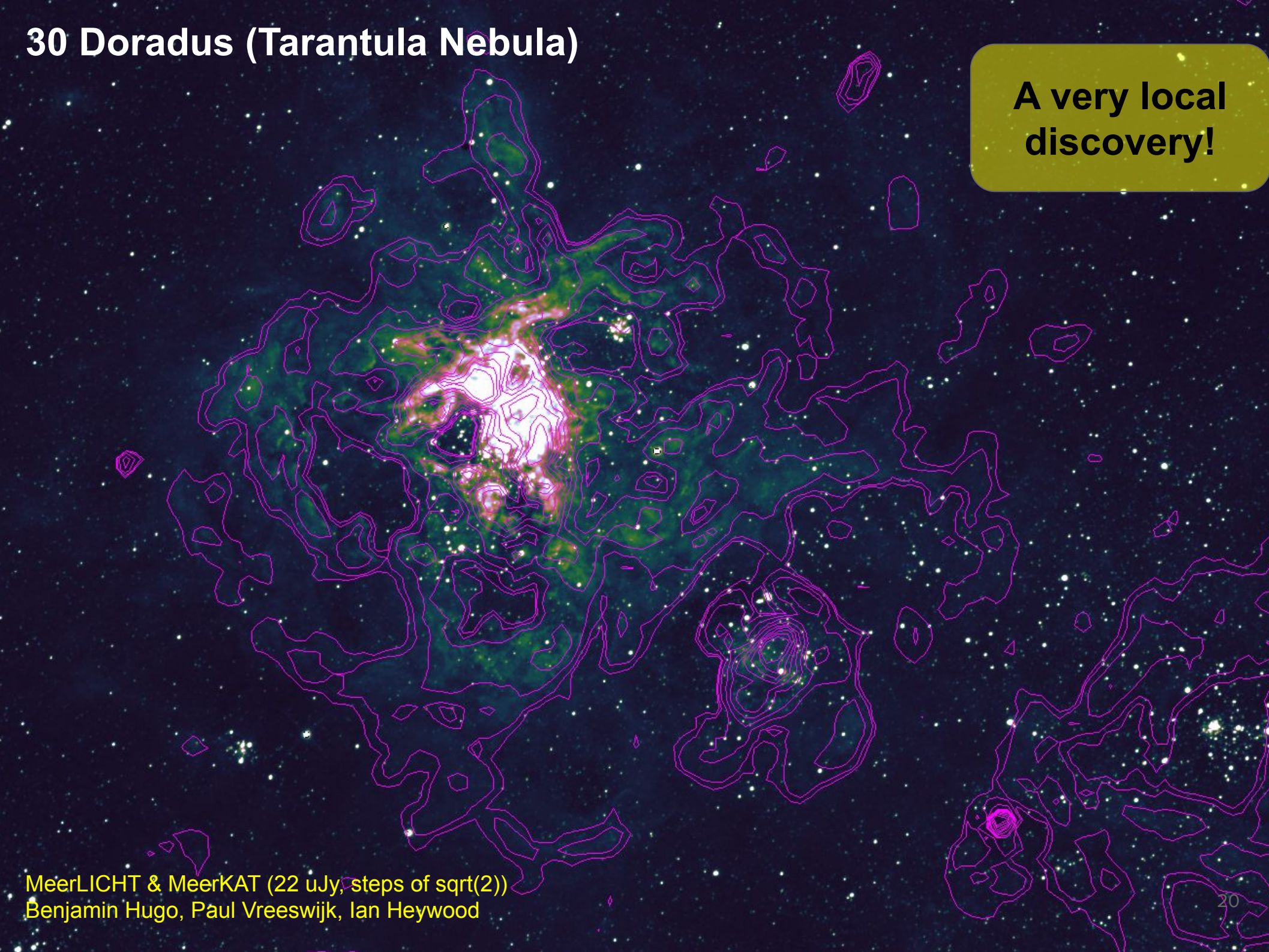
- Subsequent follow-up over multiple epochs
- See upcoming paper by Makhathini et al.


1.5deg
LMC



30 Doradus (Tarantula Nebula)

A very local discovery!



MeerLICHT & MeerKAT (22 uJy, steps of sqrt(2))
Benjamin Hugo, Paul Vreeswijk, Ian Heywood

FROM: *Mem. Acad. Roy. des Sciences.*, 1755, pp. 286–296[8].

On the Nebulous Stars of the Southern Sky

by MR L'ABBÉ DE LA CAILLE

"The Stars which are called nebulous offer to the eyes of Observers so varied a spectacle that their exact and detailed description could occupy an Astronomer for a long time and cause Philosophers to make many curious reflections. As strange as are those nebulae which we can see in Europe, those which are in the vicinity of the southern Pole concede them nothing either in number or form. I am going to outline here an account and a list: this essay may help those who have the equipment and leisure to study them with long telescopes. I would have greatly wished to have given something more detailed and instructive for this article but, other than ordinary telescopes of 15 to 18 feet focal length, those which I had at the Cape of Good Hope were not adequate nor convenient for this kind of research. Those who would take the trouble to examine what occupied me during my visit to that country will easily see that I did not have enough time to make these kinds of observations.

"I first observe that three kinds of nebulae can be distinguished in the heavens; the first is no more than a whitish, ill-defined area, more or less luminous and of a very irregular shape: these patches are quite similar to the nuclei of faint, tail-less comets.

"The second class of nebulae comprises Stars which are only nebulous in appearance and to the naked eye, but when seen in the telescope, show up as a cluster of distinct Stars, although very close to each other.

"The third class is that of Stars which are actually accompanied by or surrounded with white patches or by nebulae of the first class.

De la Caille's Observatory Today

(Strand Street, Cape Town)

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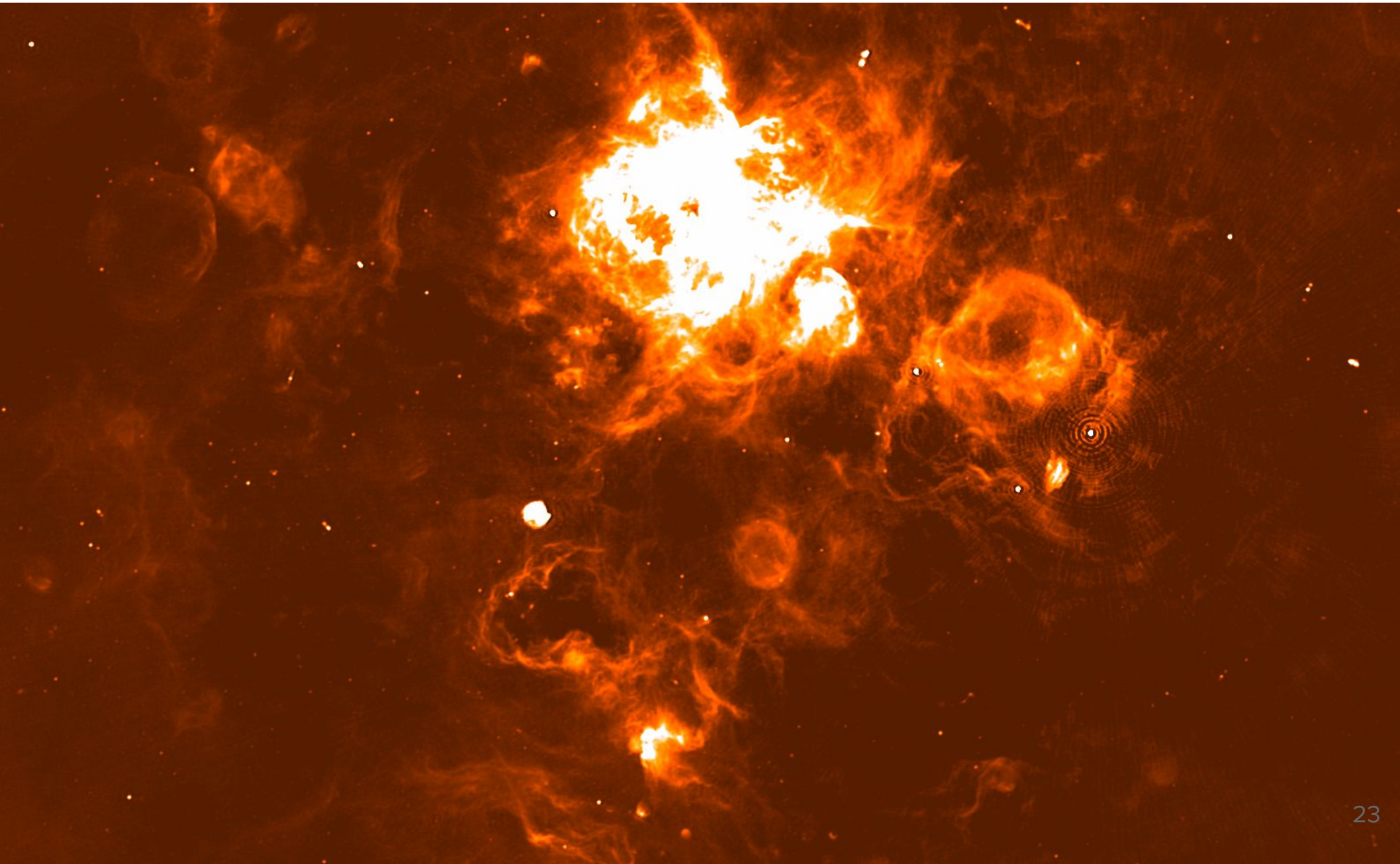
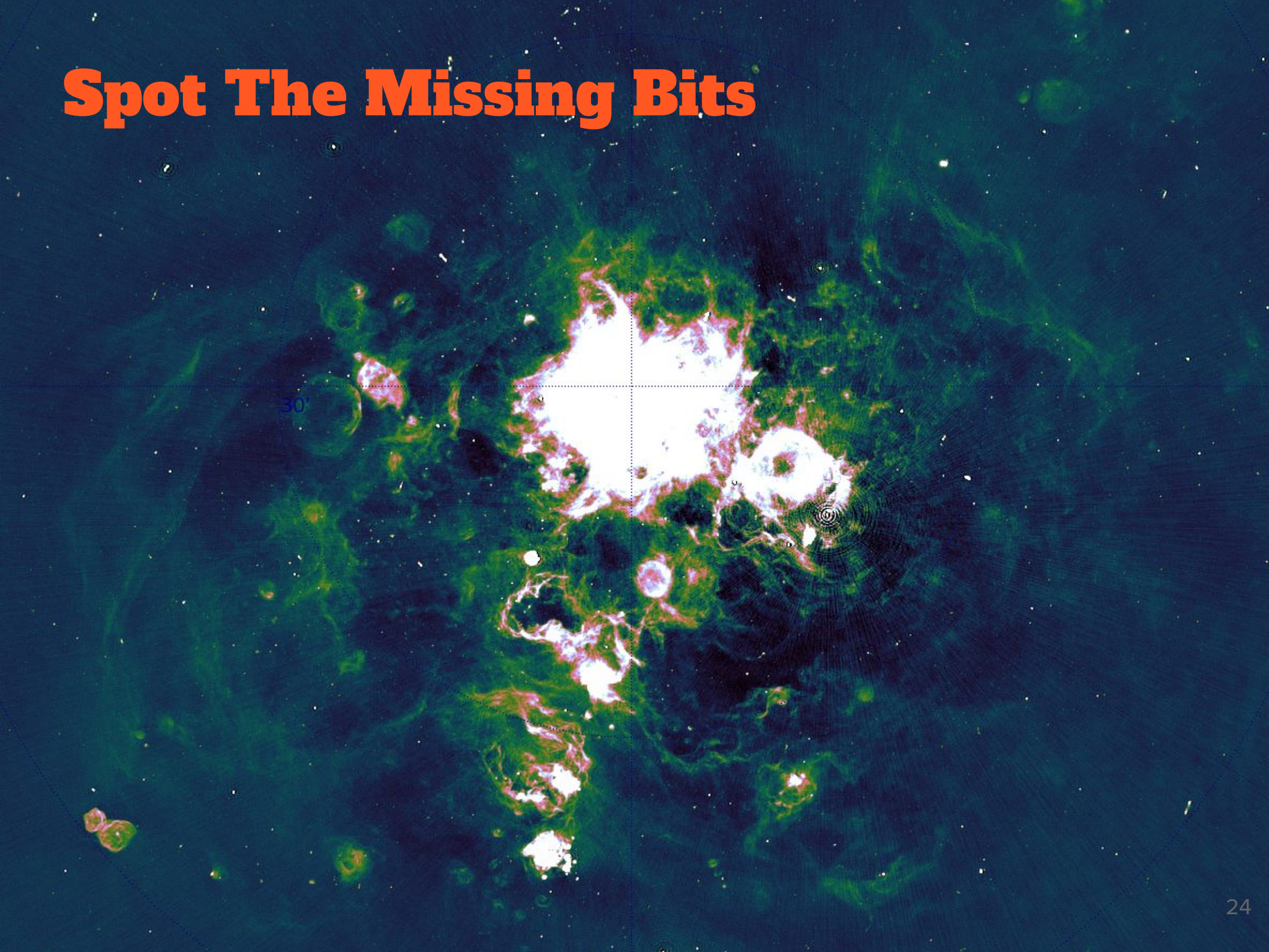
Pointing To Tarantula



Spot The Missing Bits



Multiscale Works (?)

- For 30Dor, multiscale clean the extreme complexity of the image
- No negati
- But it took

fresh from my inbox...

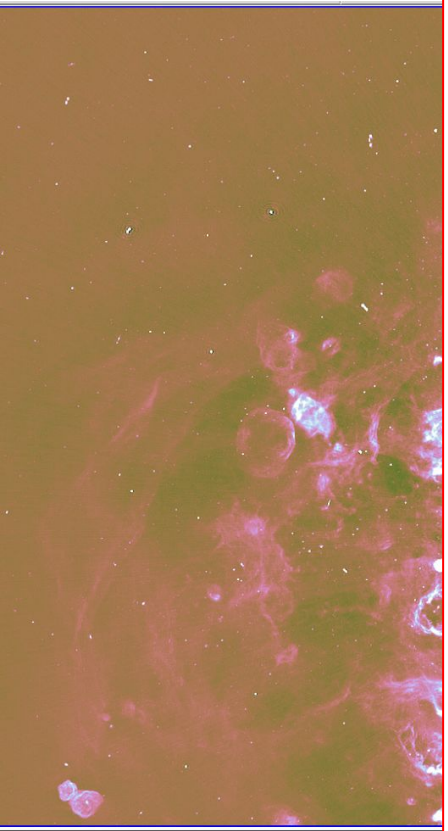
Our issue is that we do not clearly understand how multiscale cleaning works. For now, our experience comes from different trials and errors. Here is a summary:

- without multiscale cleaning we do not recover the diffuse emission of the lobes

- with multiscale cleaning in automatic mode an image is not recovered. It appears that wsclean over-cleans(?) all signal, but we do not understand why.

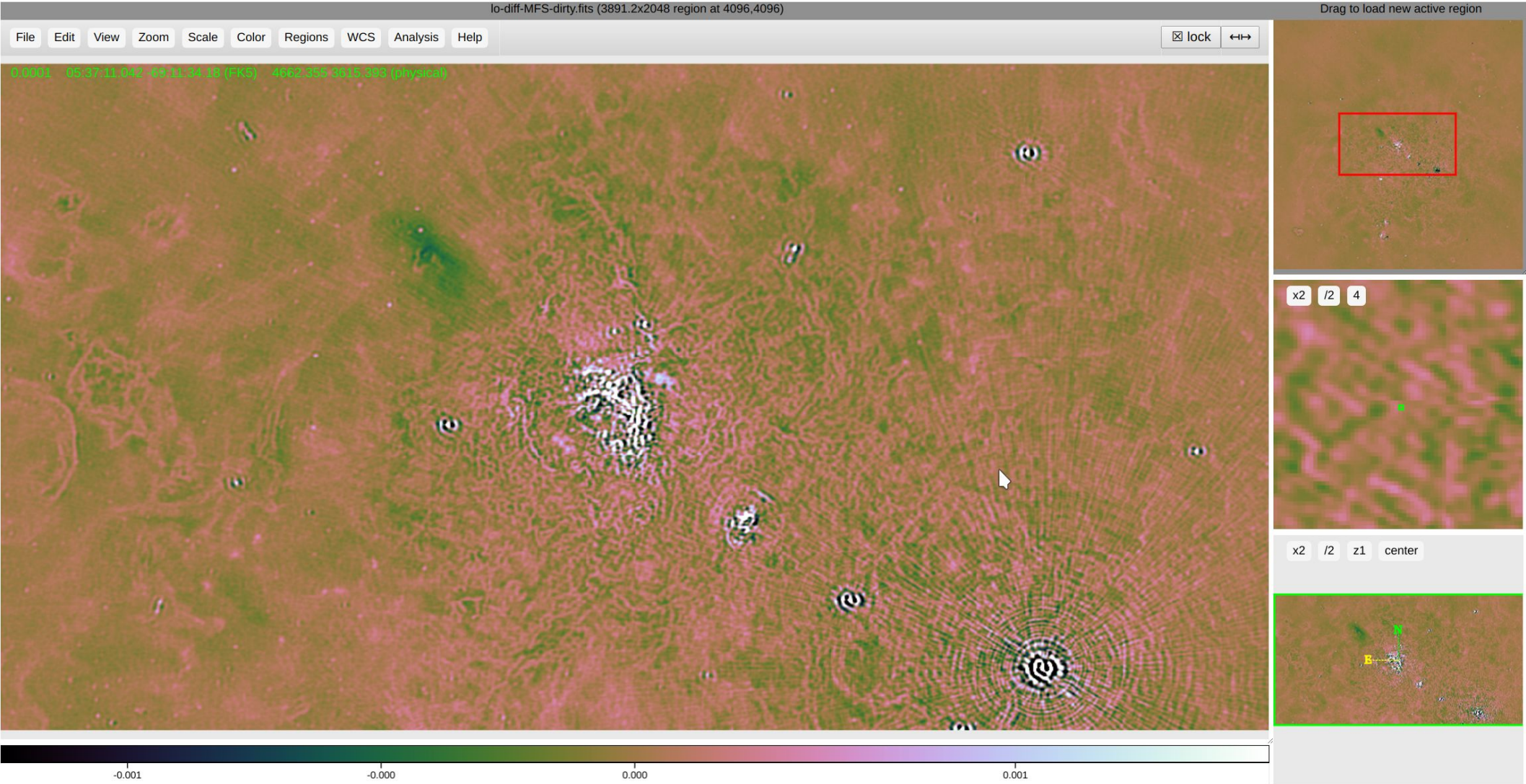
- setting scales by hand in pixels we make the good image. The scales are quite arbitrary, and fined tuned via try and error.

We were wondering if during the upcoming busy week you will have some time to explain us the principles of multiscale cleaning and look in depth to why some scales produce a good result (and others do not) on

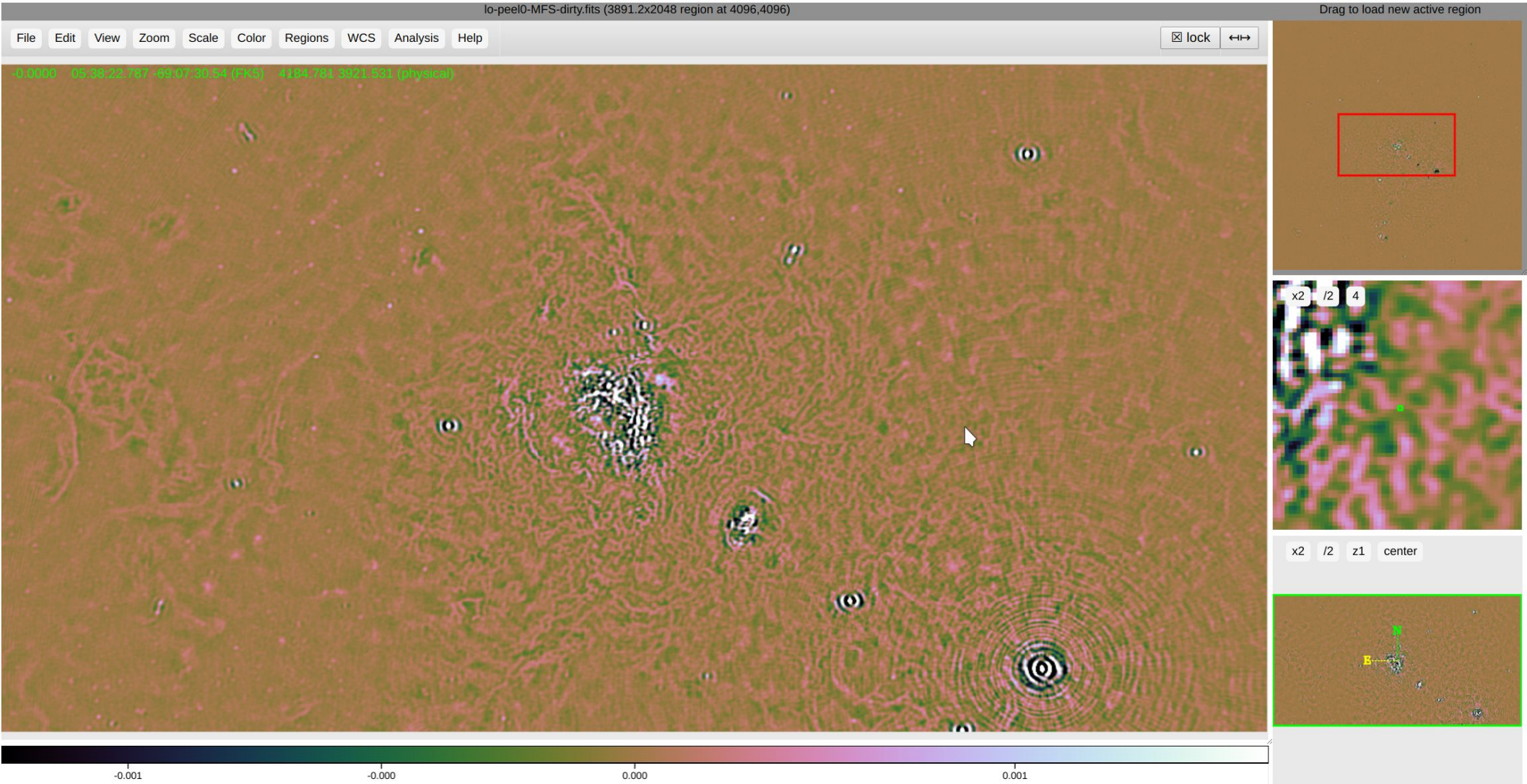



Big Danger
START
GOAL
Put the soccer ball inside the box.
MAIN MENU
HINTS
HELP
SORT PARTS BY:
All
Scenery
Gear
Rope
Balls
Walls
Electric
Fire
Laser
Critter
Program
Misc.
HIDE OPTIONS
Clear Parts
Save/Load
Locking
Test Run
Preferences
Environm

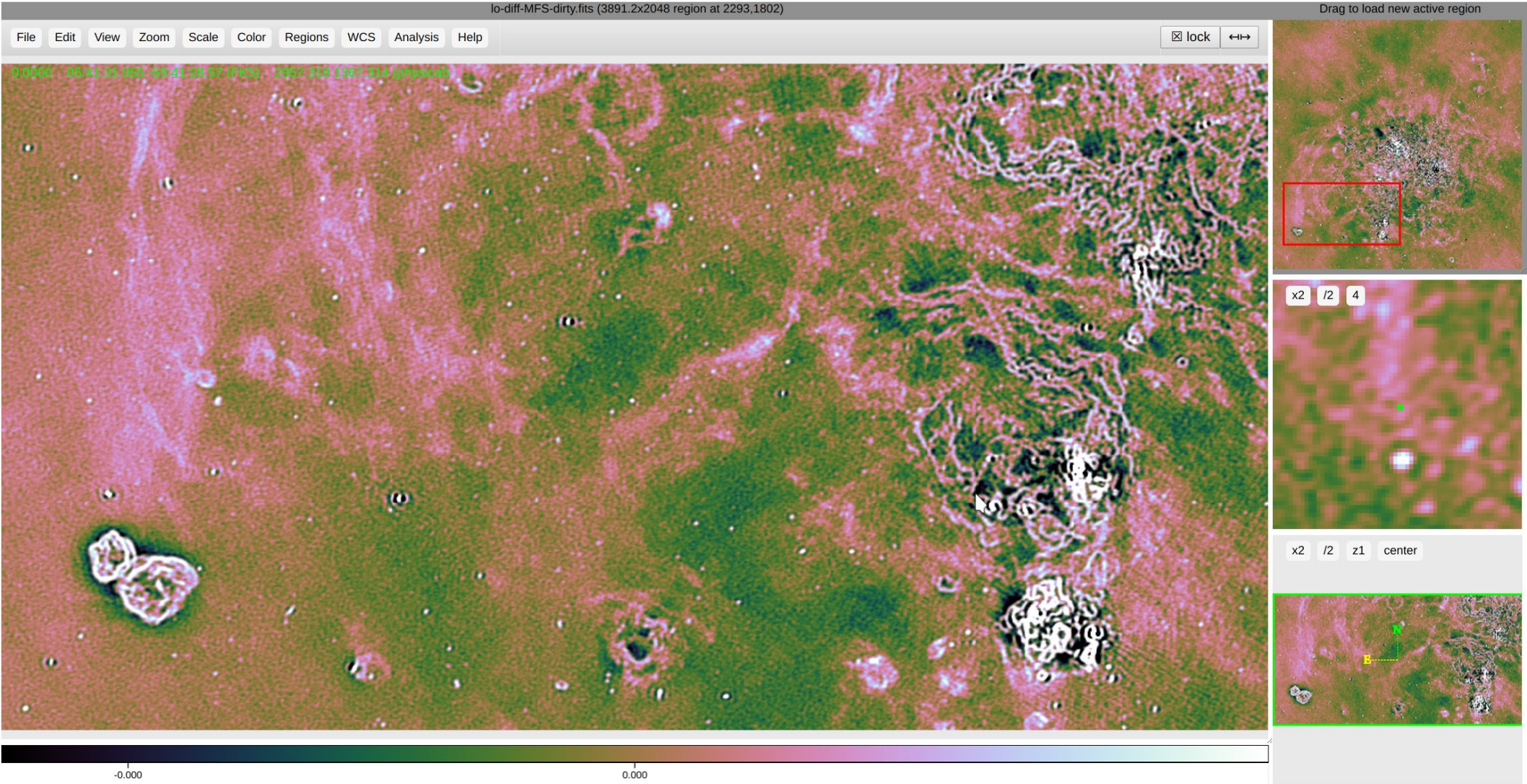
Residuals = Data - Model



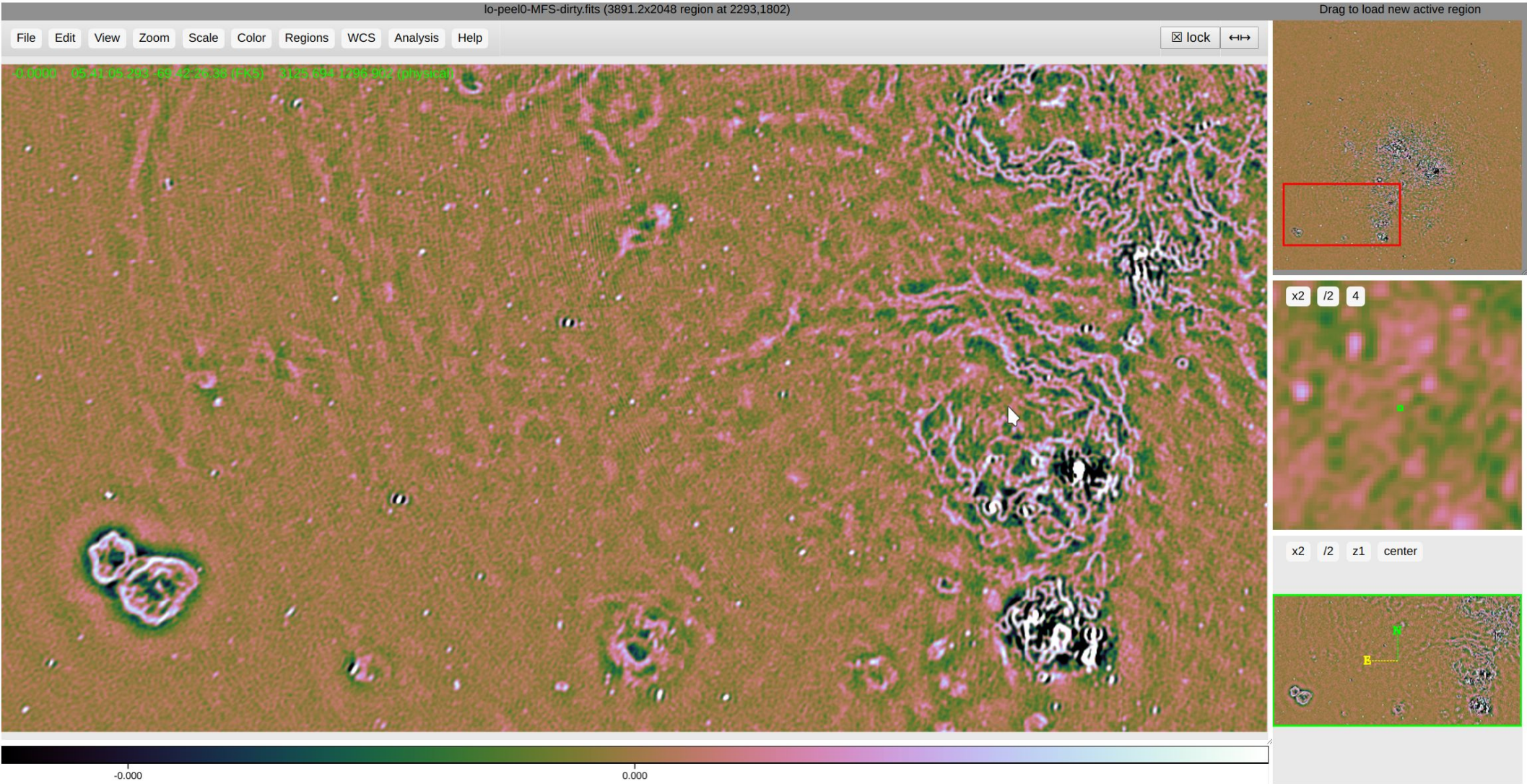
Residuals: Phase Selfcal



Residuals = Data - Model



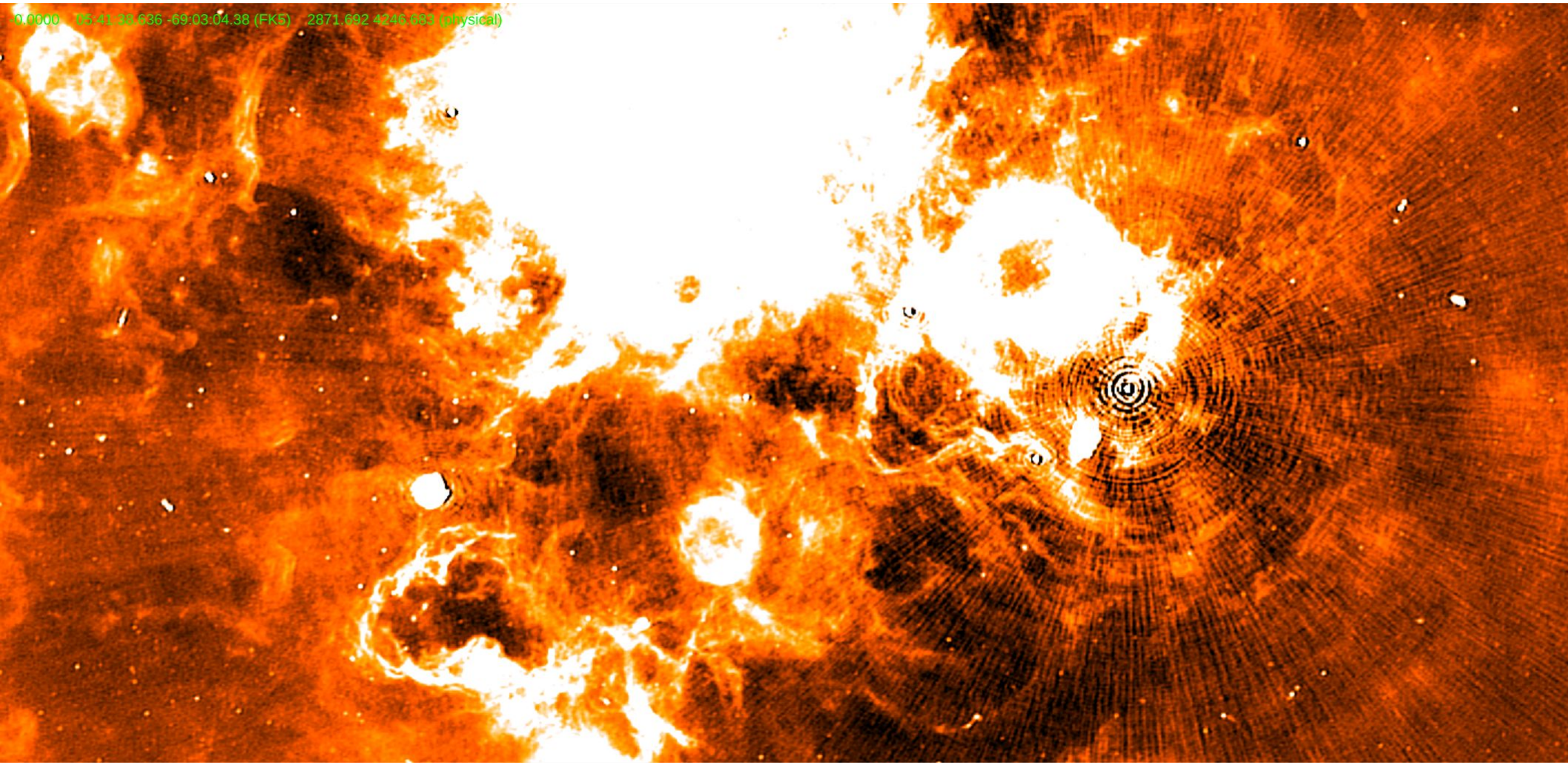
Residuals: Phase Selfcal



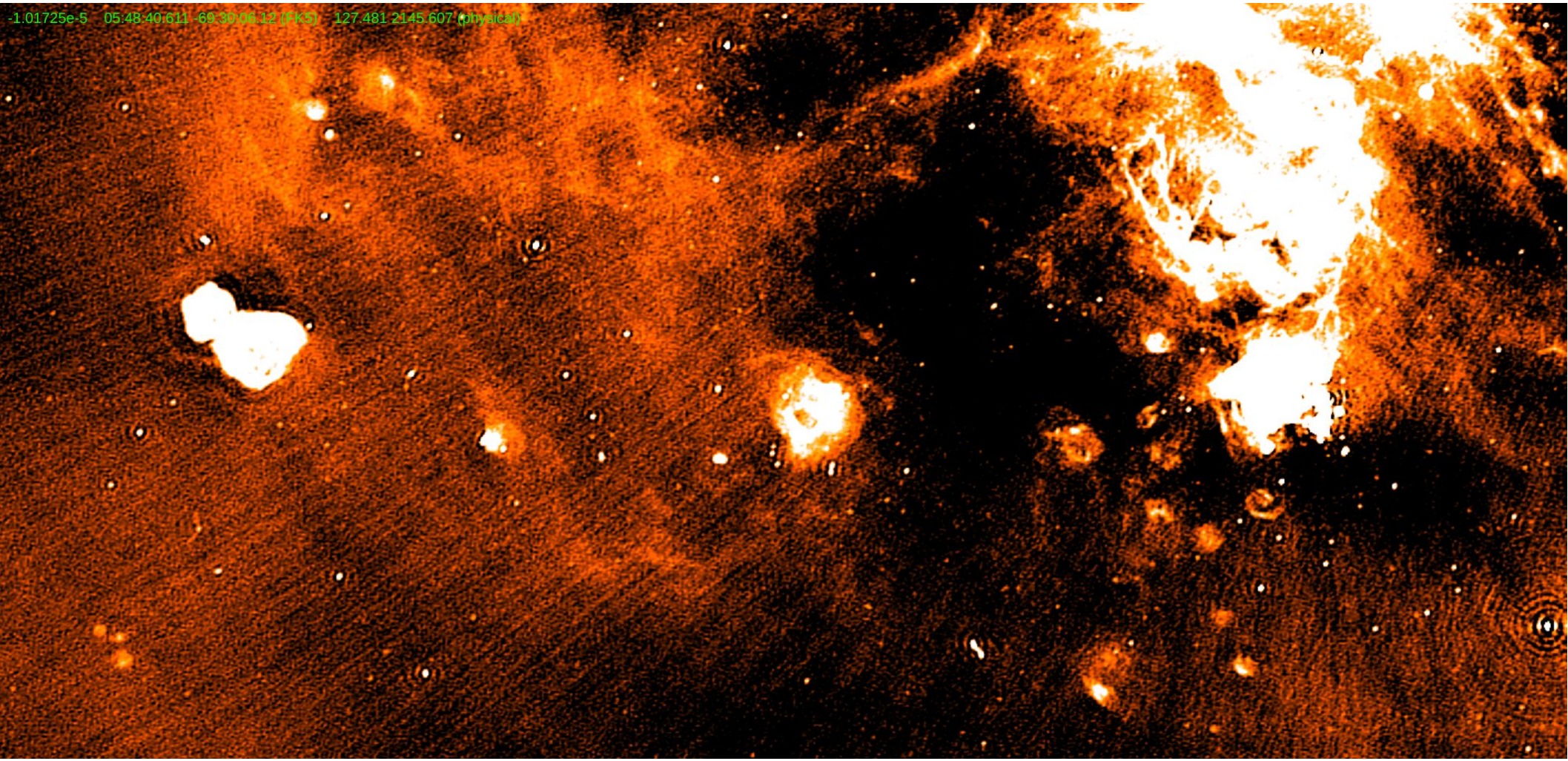
Flux Suppression

- Even “conservative” direction-independent phase-only self-cal can sometimes hoover up unmodelled flux with alarming efficiency
  - this is before we even get to DD calibration
- Speculative: the effect is more pronounced with complex fields
  - hints of different regimes depending on SNR and model complexity
  - we did detect the GW170817 afterglow, after all…
  - see upcoming paper by Sob et al.
- Robust solvers not necessarily a panacea
  - (only sometimes)
- LoTSS mitigated this problem by baseline restrictions and a-posteriori solution smoothing
- For complex fields, deep models are essential before starting selfcal!
- Deconvolution extremely important
- Even better would be to combine deconvolution & calibration into one process…

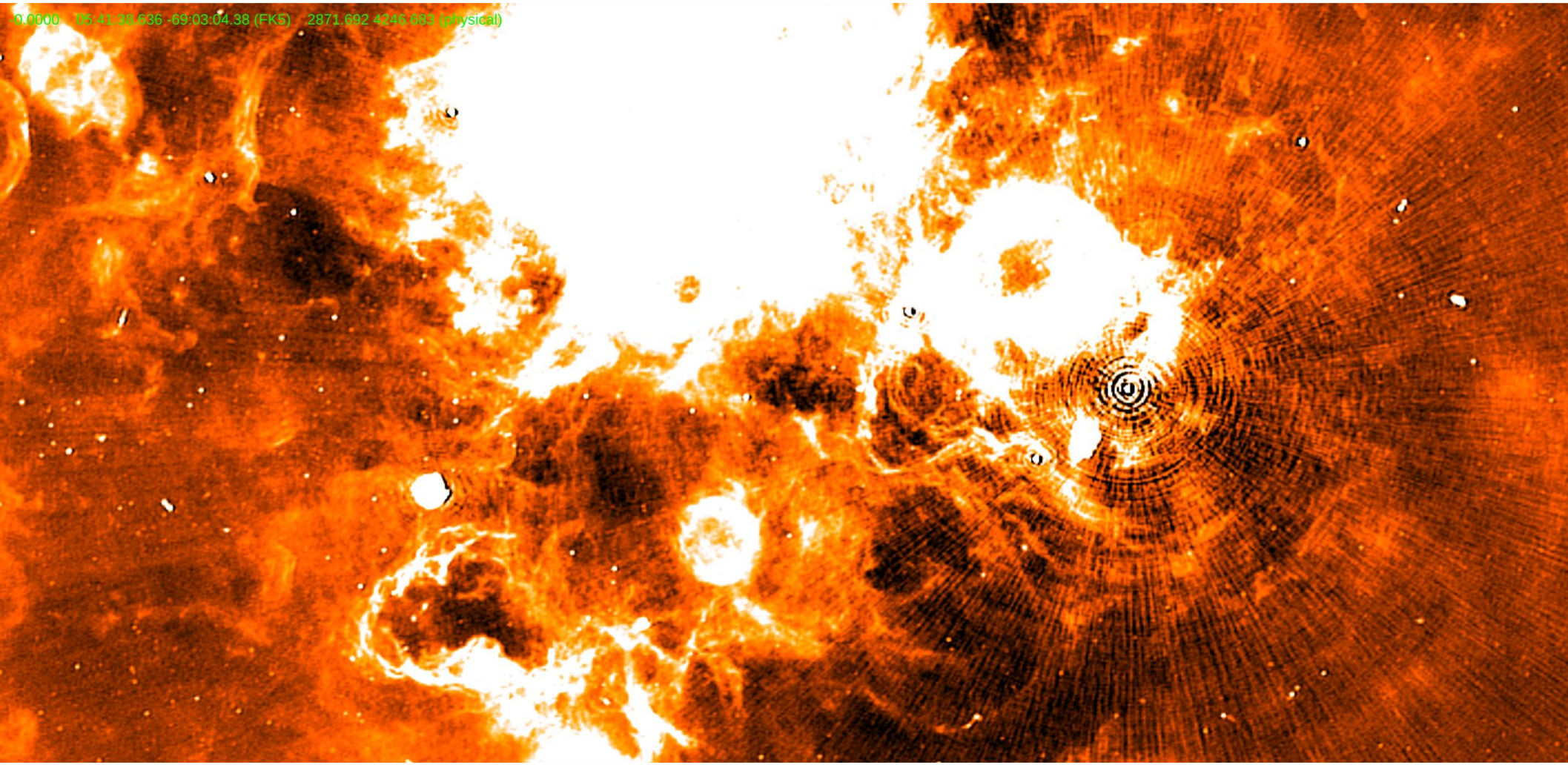
DDEs(?) In Tarantula



DDEs In Tarantula (2)



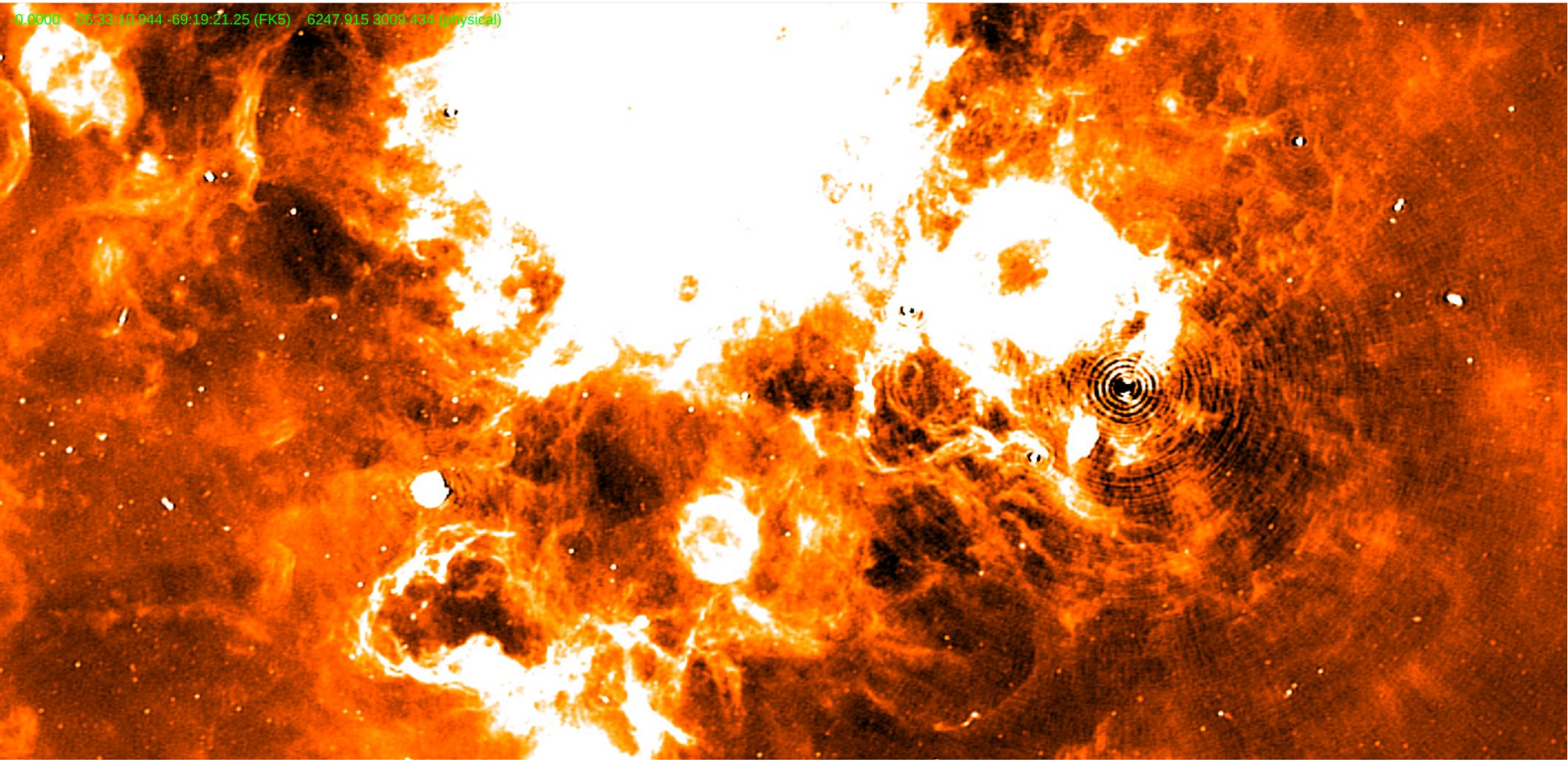
Peeling?



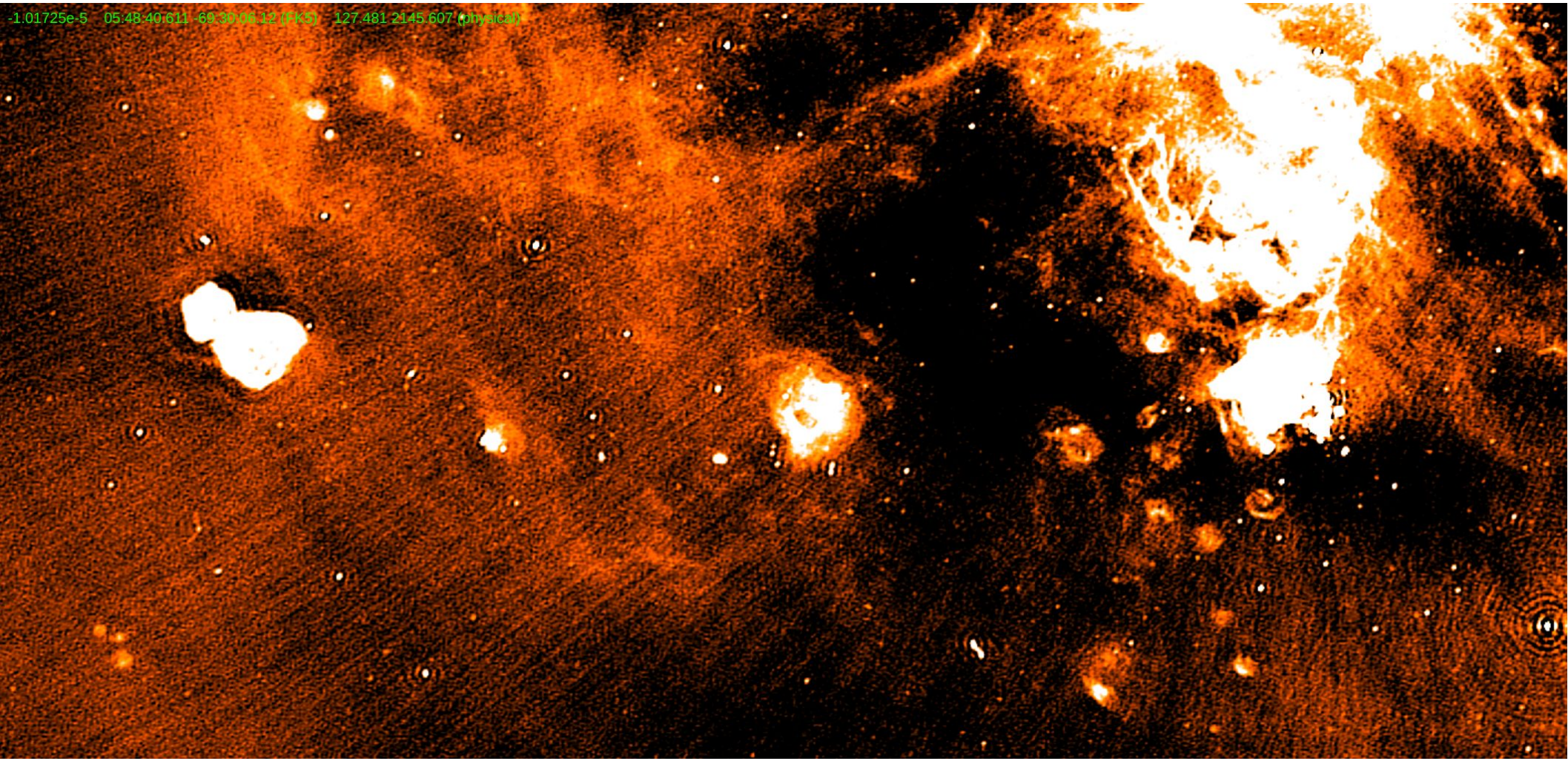
crystalball: predict subset of clean components into PEEL_DATA

CubiCal: `--model-list MODEL_DATA+-PEEL_DATA:PEEL_DATA`

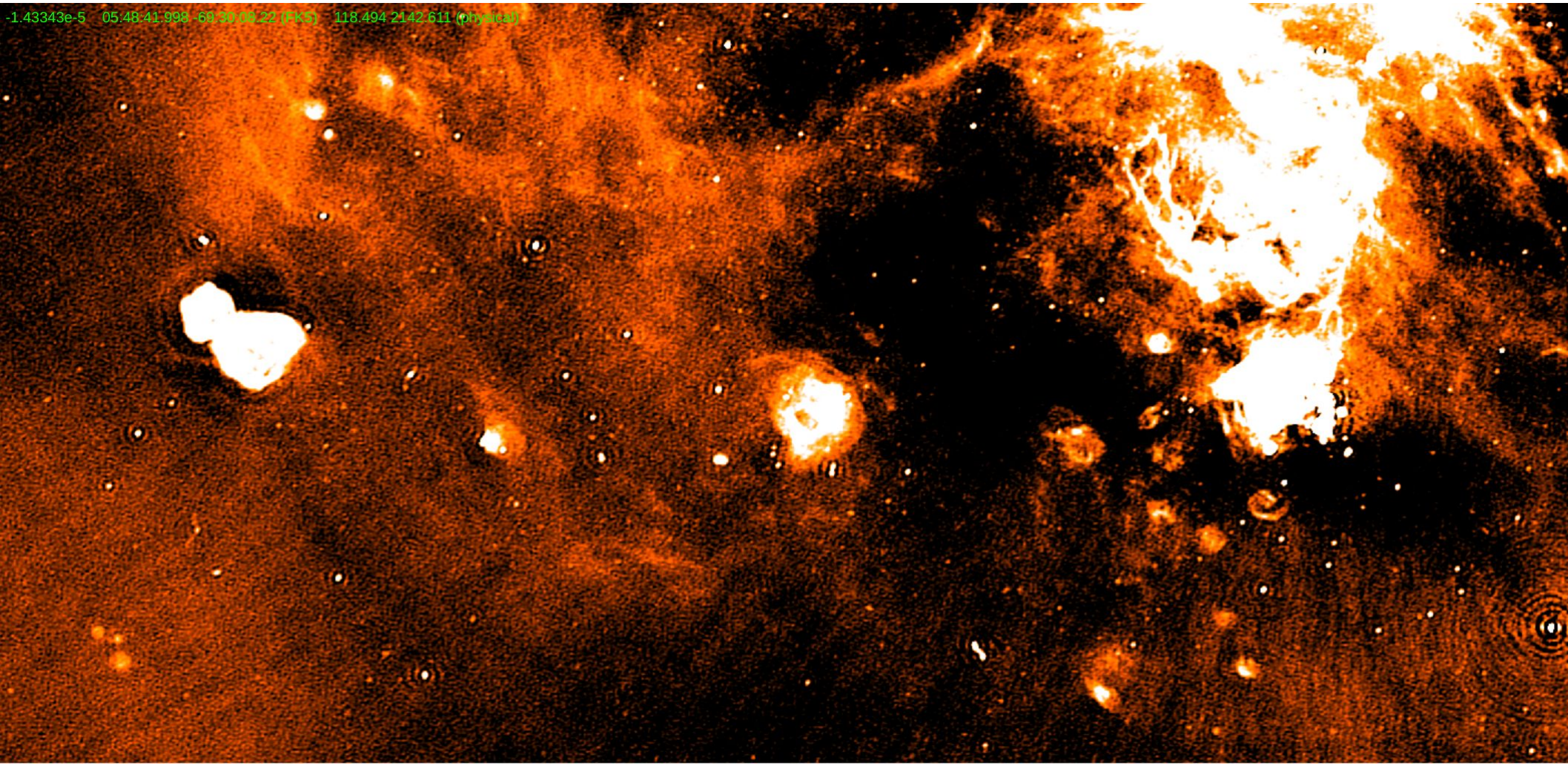
Peeling!



Peeling?



Peeling!



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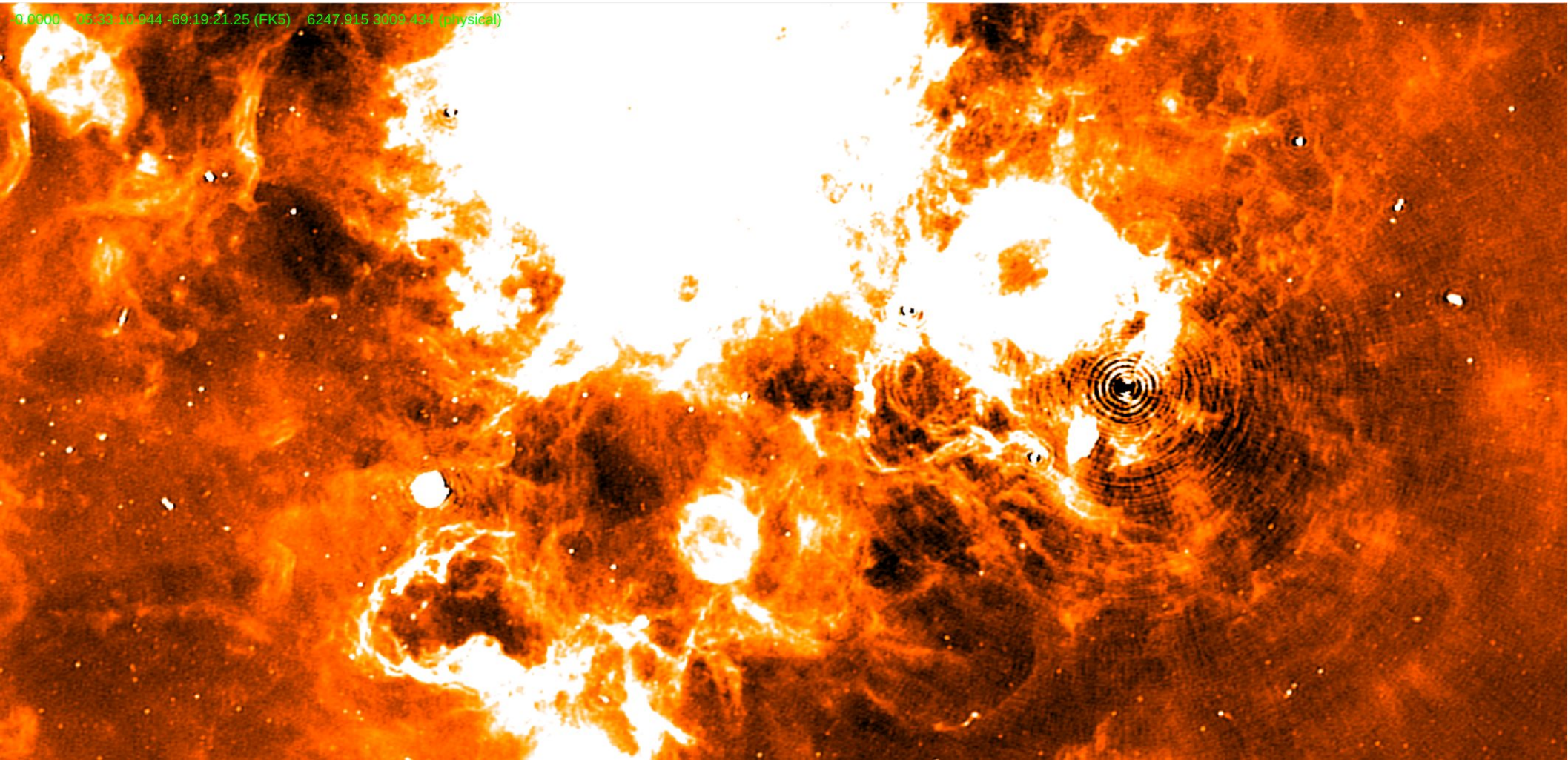
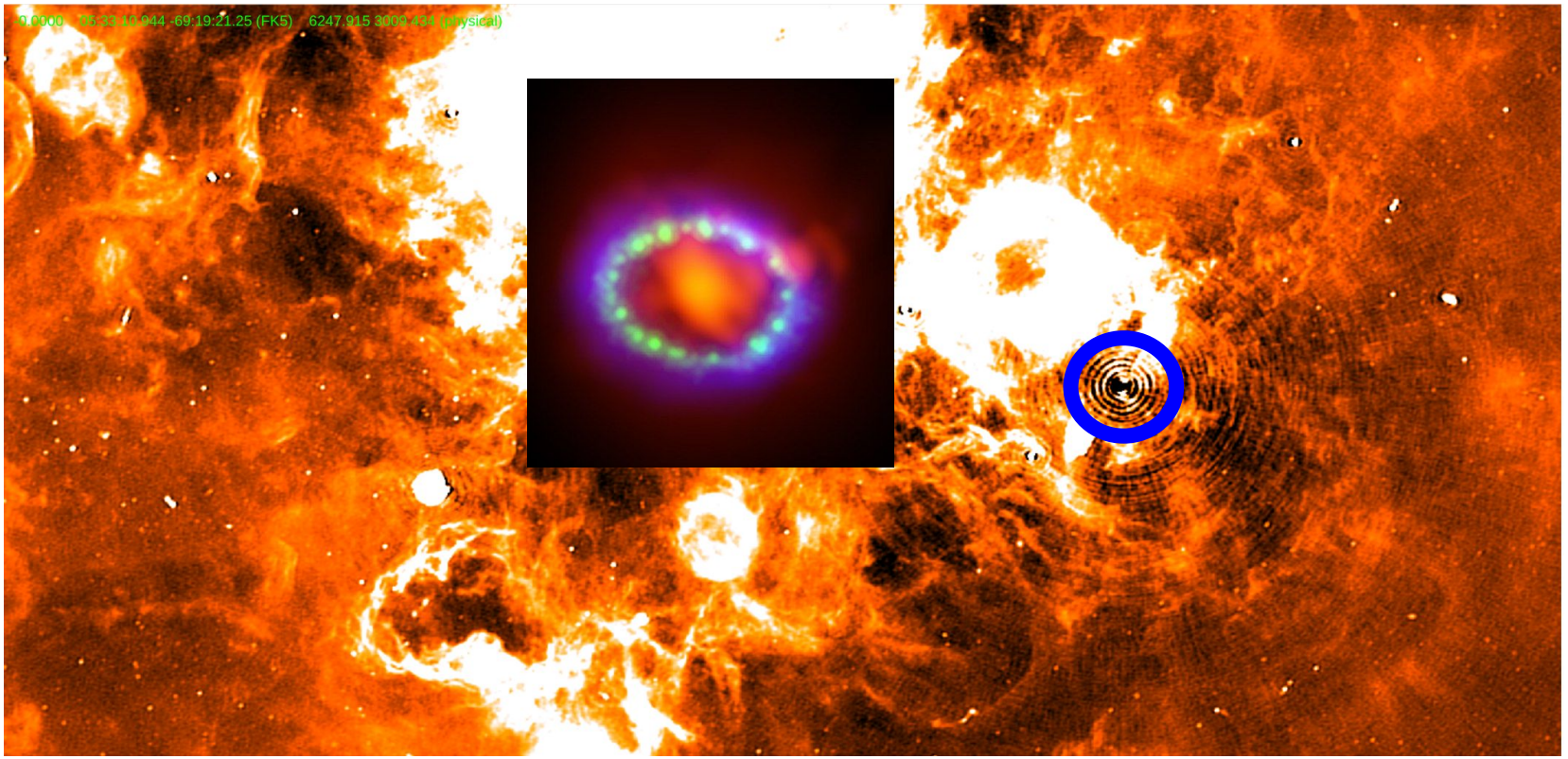
Though Artefacts Remain...



SN1987A



- “There’s nothing quite as useless as a radio source.”

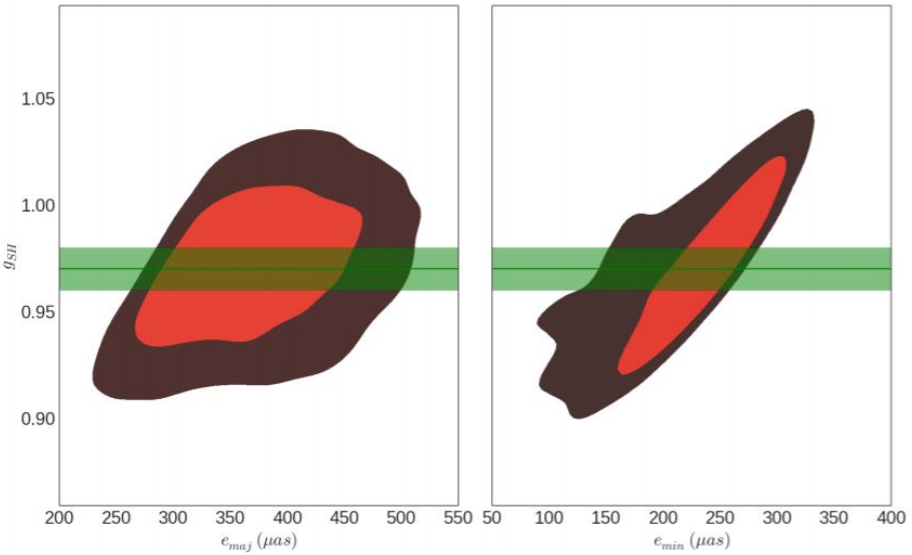
  -- Jim Condon

- “Unless it’s a big blooming 1Jy supernova remnant at ¼ of your PSF size.”

  -- Maj. Issues

If DDEs Don't Get You, Slightly Resolved Sources Will

- Slightly resolved sources are very poorly modelled by any variant of CLEAN
- Troublesome if sufficiently bright
- Noordam Conjecture: "If it's bright enough to cause trouble, it's bright enough to be solved for."
- Bayesian approaches:
  - MCMC and such
  - Can recover sub-PSF source structure and characterize degeneracies w.r.t. calibration solutions
-



Resolving the blazar CGRaBS J0809+5341 in the presence of telescope systematics

Iniyan Natarajan ✉, Zsolt Paragi, Jonathan Zwart, Simon Perkins, Oleg Smirnov, Kurt van der Heyden

Monthly Notices of the Royal Astronomical Society, Volume 464, Issue 4, February 2017, Pages 4306–4317, https://doi.org/10.1093/mnras/stw2653

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CS Meets Cyg A

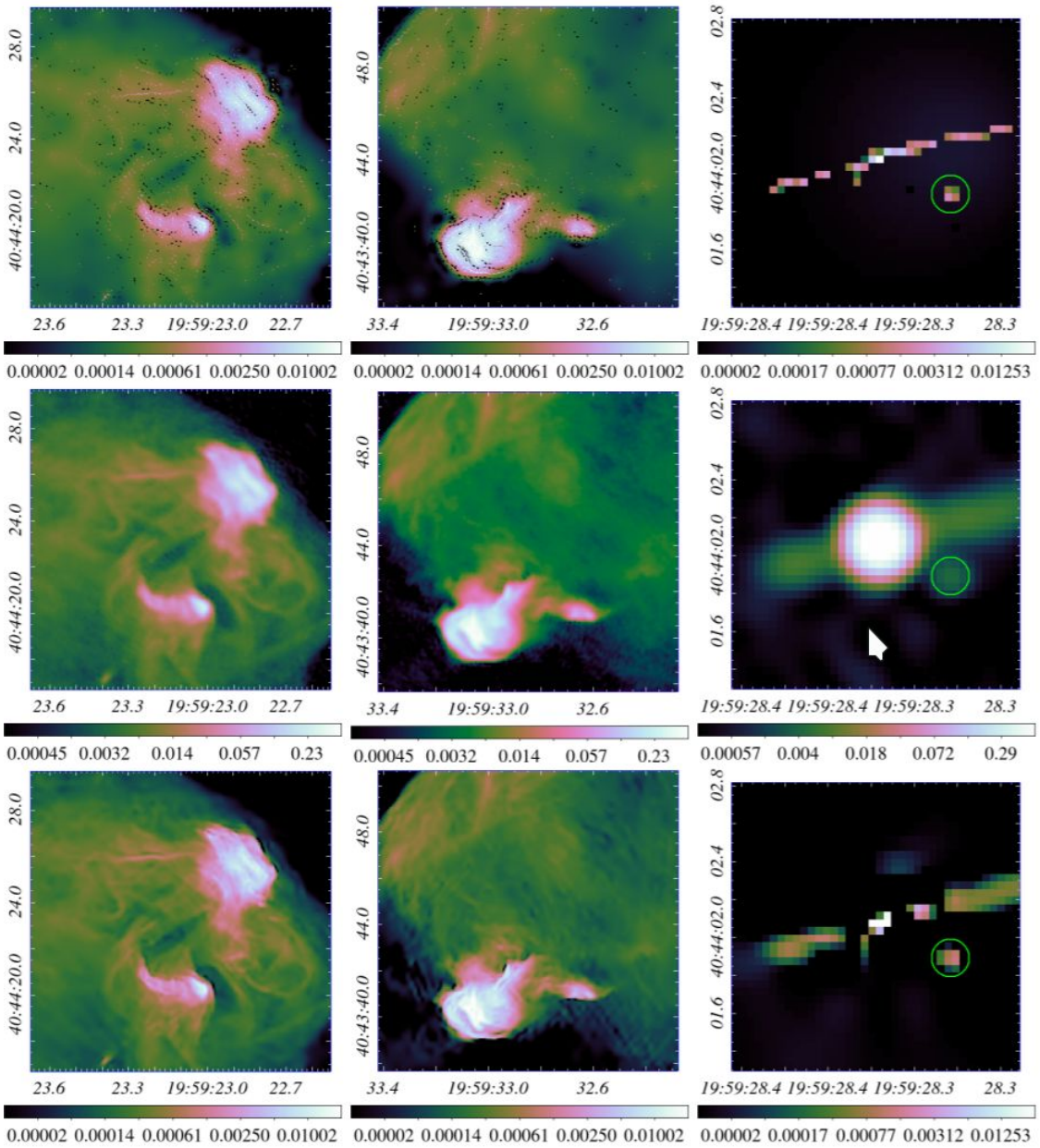
Cyg A X-band data (VLA A+B+C), zoom into hotspots (right, middle) and core (left)

Top: multiscale CLEAN model

Middle: restored image

Bottom: CS-derived model image

Note the secondary SMBH (Perley et al. 2017) visible in all images. Detected by R. Perley in X-band CLEANed images.



Cygnus A super-resolved via convex optimization from VLA data

A Dabbech ✉, A Onose, A Abdulaziz, R A Perley, O M Smirnov, Y Wiaux

Monthly Notices of the Royal Astronomical Society, Volume 476, Issue 3, 21 May 2018, Pages 2853–2866, https://doi.org/10.1093/mnras/sty372

Published: 13 February 2018 **Article history** ▾

CS Super-resolves Cyg A

Cyg A C-band data (VLA A+B+C), zoom into hotspots (right, middle) and core (left)

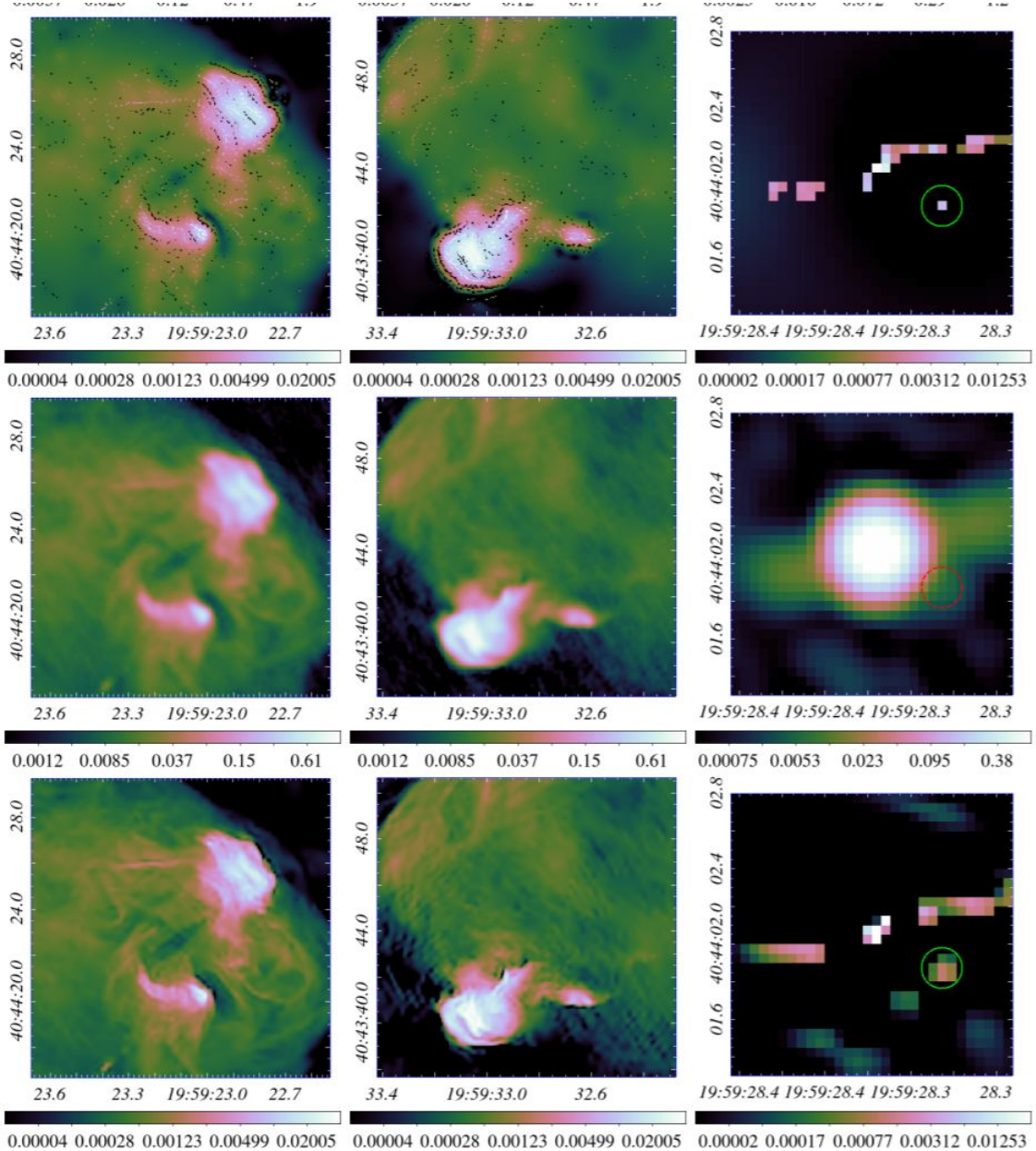
Secondary SMBH clearly recoverable in lower resolution data.

Super-resolution: features smaller than the PSF can be detected (Marti-Vidal 2012)

$$\theta \sim \mathrm{PSF}/\sqrt{\mathrm{SNR}}$$

...except now it can be done robustly and systematically.

Time to start thinking about adaptive pixel sizes??



In Conclusion

“If the mountaine will not come to Mahomet, Mahomet will goe to the mountaine.”

-- ancient Turkish proverb (as quoted by Sir Francis Bacon)