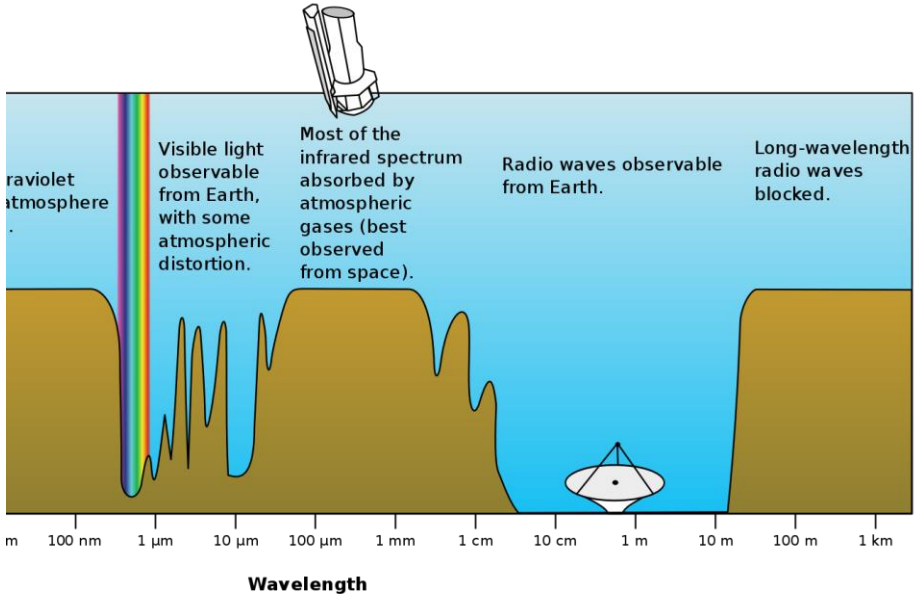
High resolution imaging at ultra-low frequencies with LOFAR

Christian Groeneveld

Supervisors: Reinout van Weeren

Frits Sweijen

- High resolution (~1 arcsec)
- Ultra-low frequencies (~50 MHz)
- LOFAR



Source: NASA

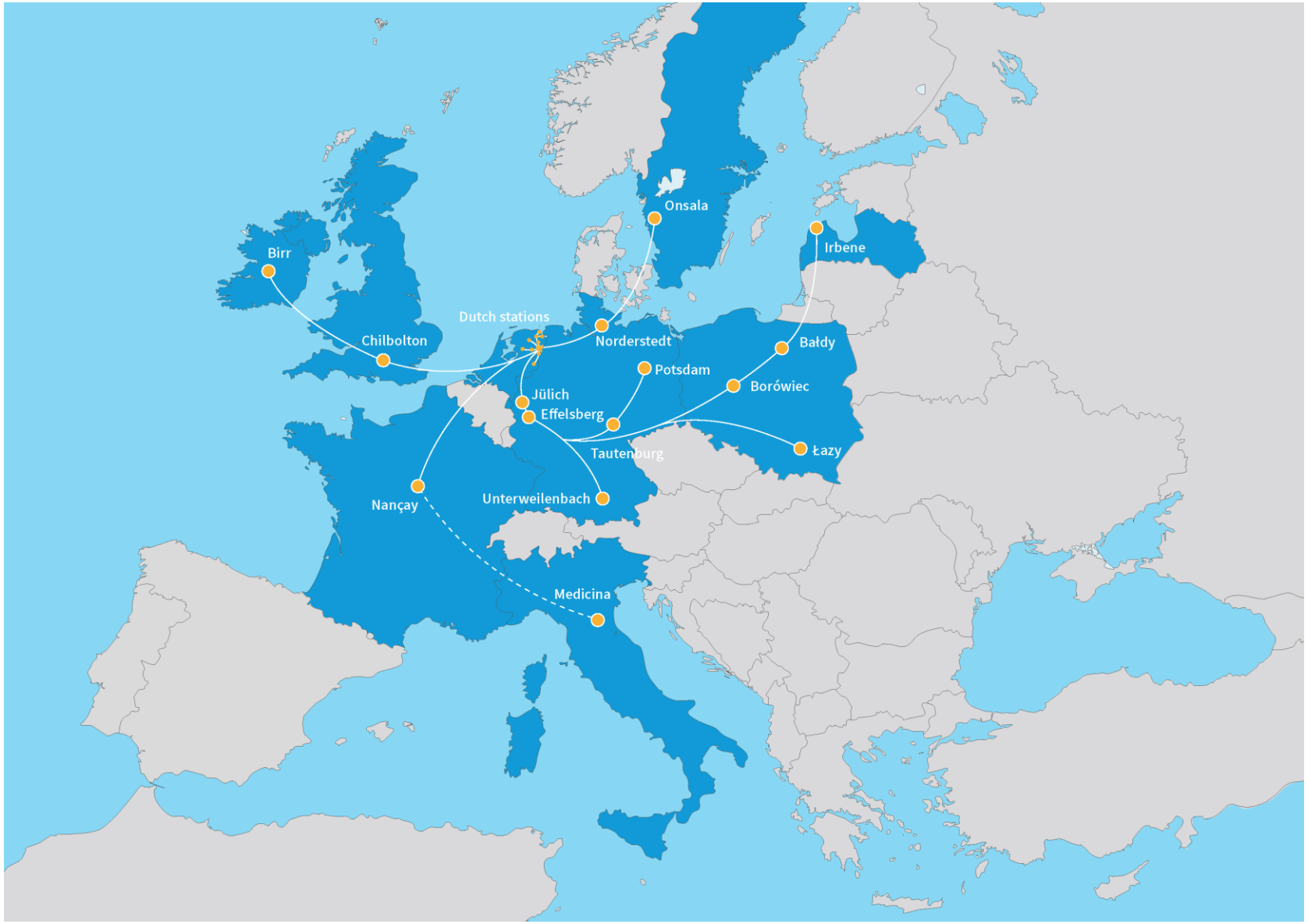
Source: astron.nl

LOFAR

- Largest baseline ~1900 km

L/D:

- @ 50 MHz: ~0.7”
- @ 30 MHz: ~1”



Source: astron.nl

Challenges

- Calibration!

- Ionosphere
- Phase shift:
  - Time dependent
  - Frequency dependent
  - Direction dependent
  - Antenna dependent

But why?

- First look at this frequency window
- Radio jets: AGN activity history
- Proof of concept for LBA VLBI with LOFAR

How

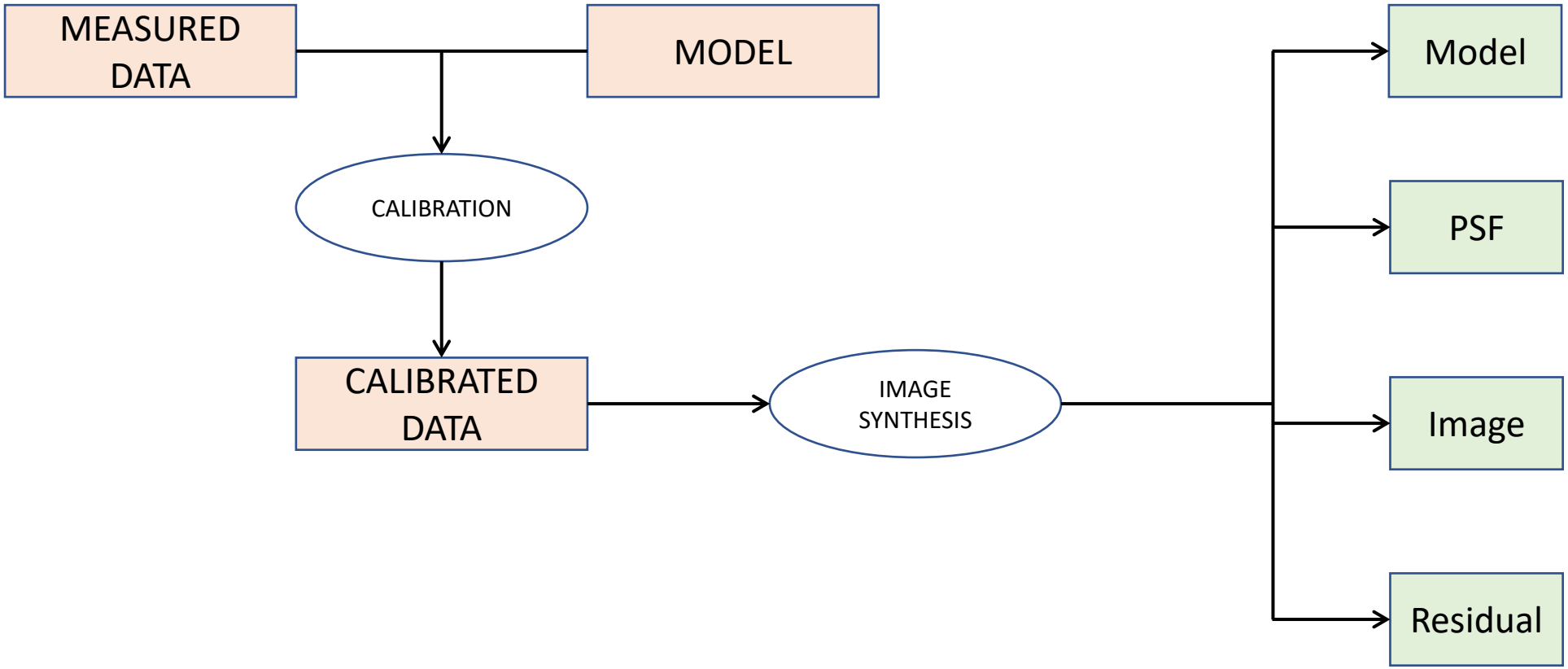
- Self-calibration
  - Gains per antenna
  - (model) visibilities per antenna pair

- 3 compact, bright sources
  - 3C 273, 3C 295, 3C 196
  - ~100 Jy

Self-calibration with LOFAR

$$\sum_{time} \sum_{m<n} w_{mn} |V_{mn}^{actual} - g_m g_n^* V_{mn}^{model}|$$

TMS (11.8)



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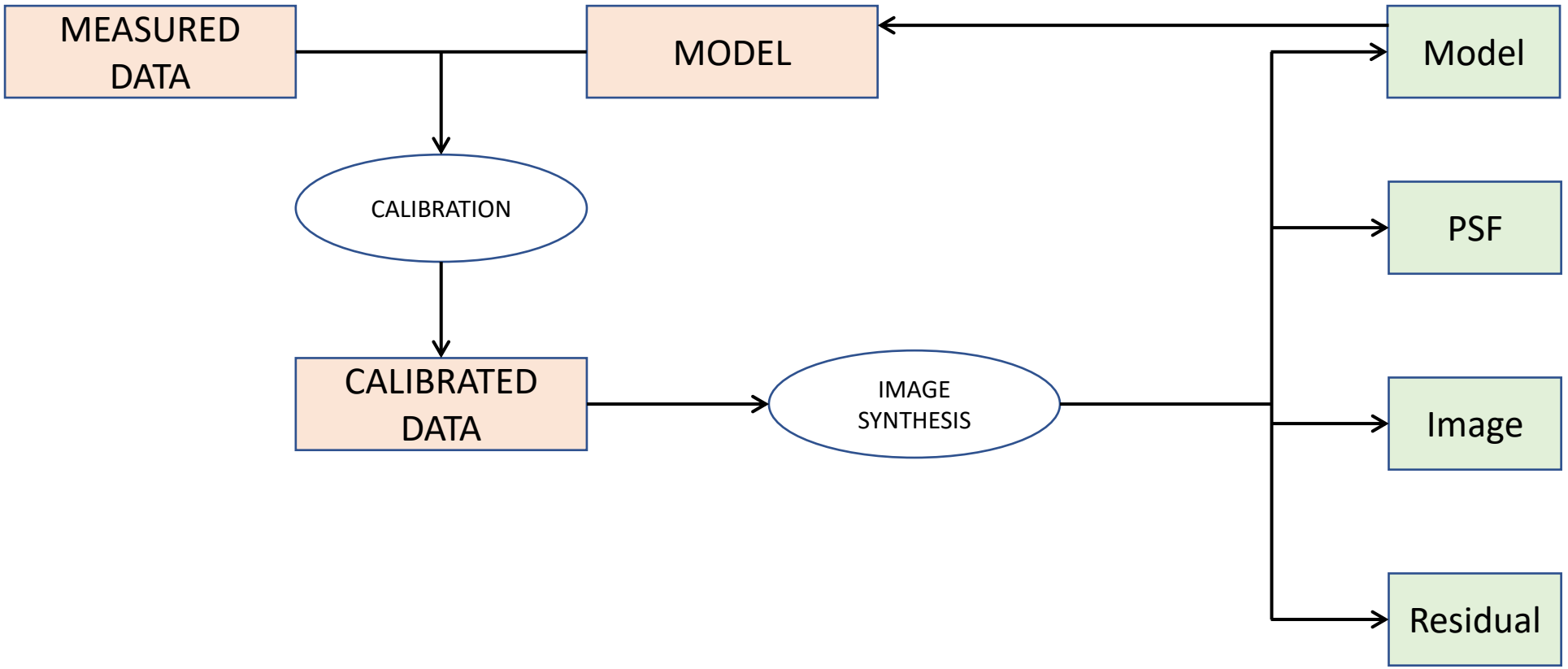
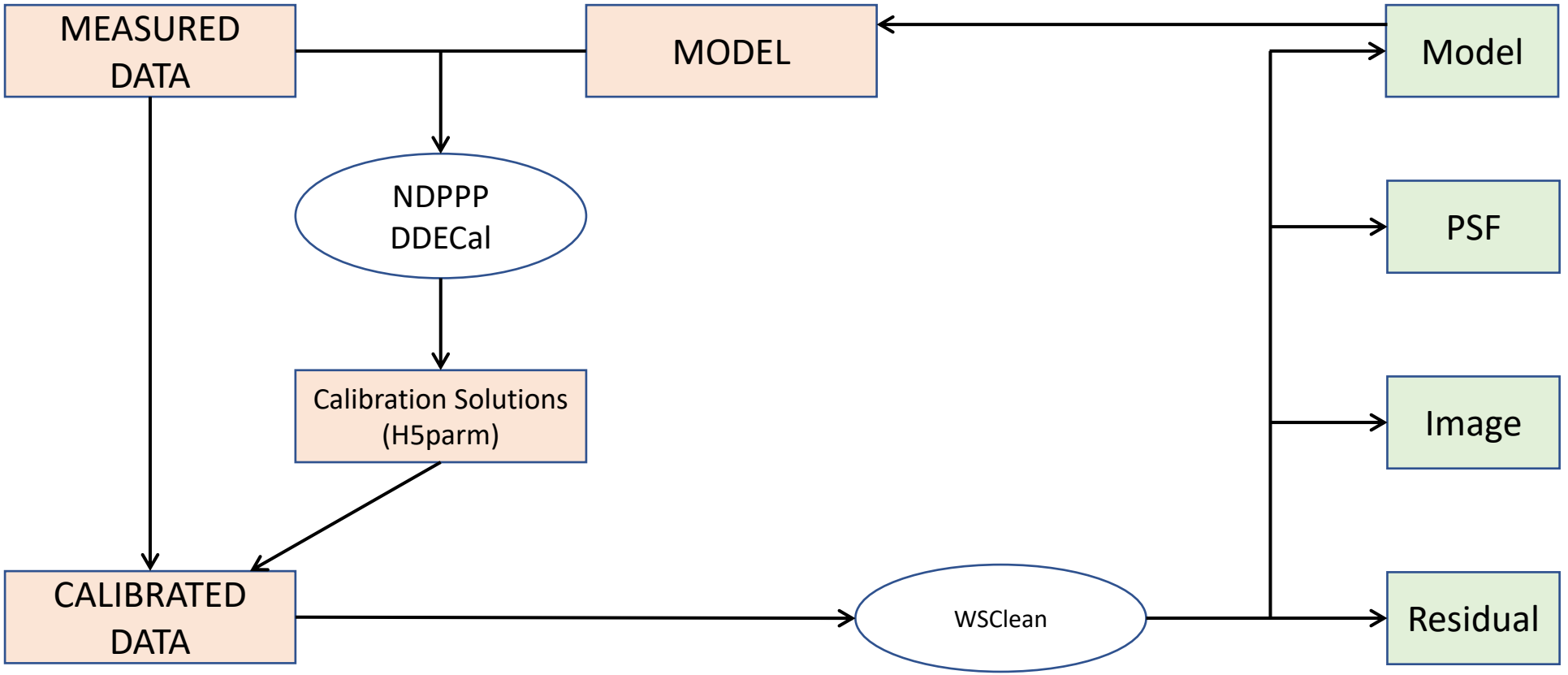
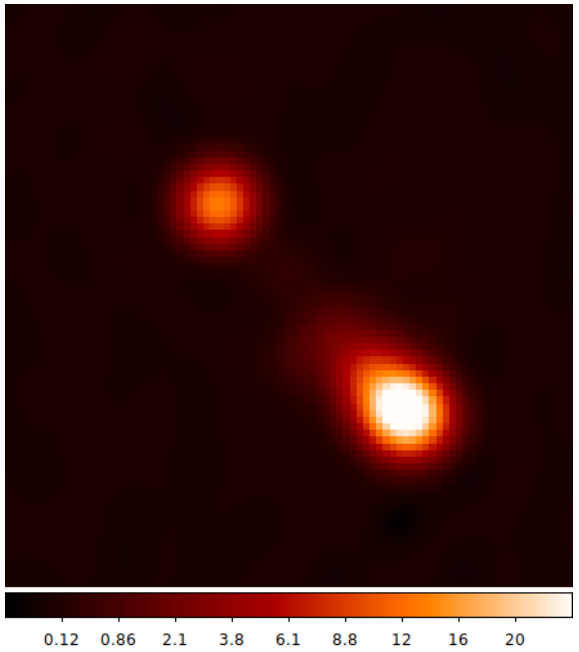


Self-calibration with LOFAR

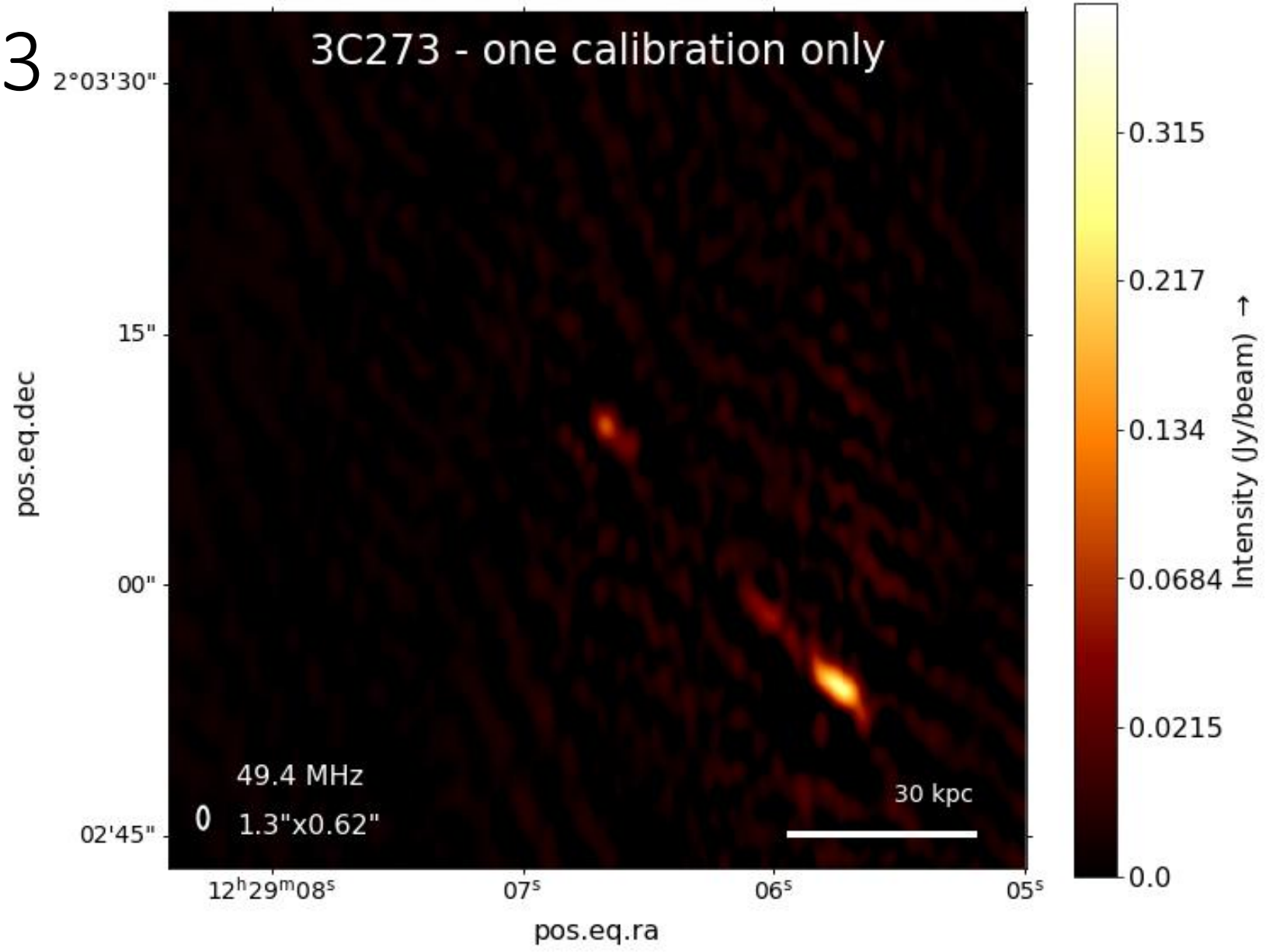
$$\sum_{time}\sum_{m<n} w_{mn}|V_{mn}^{actual} - g_m g_n^* V_{mn}^{model}| \qquad \textit{TMS (11.8)}$$



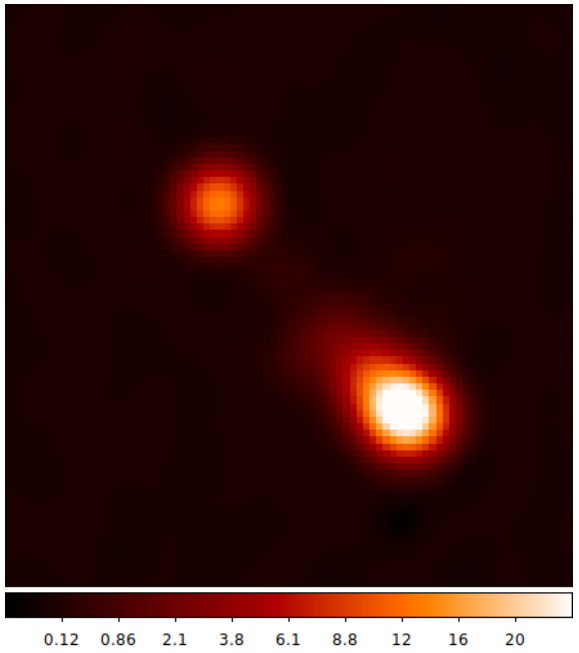
Results – 3C 273



VLA P-band
Credit: Perley, Taylor (1991)



Results – 3C 273



VLA P-band
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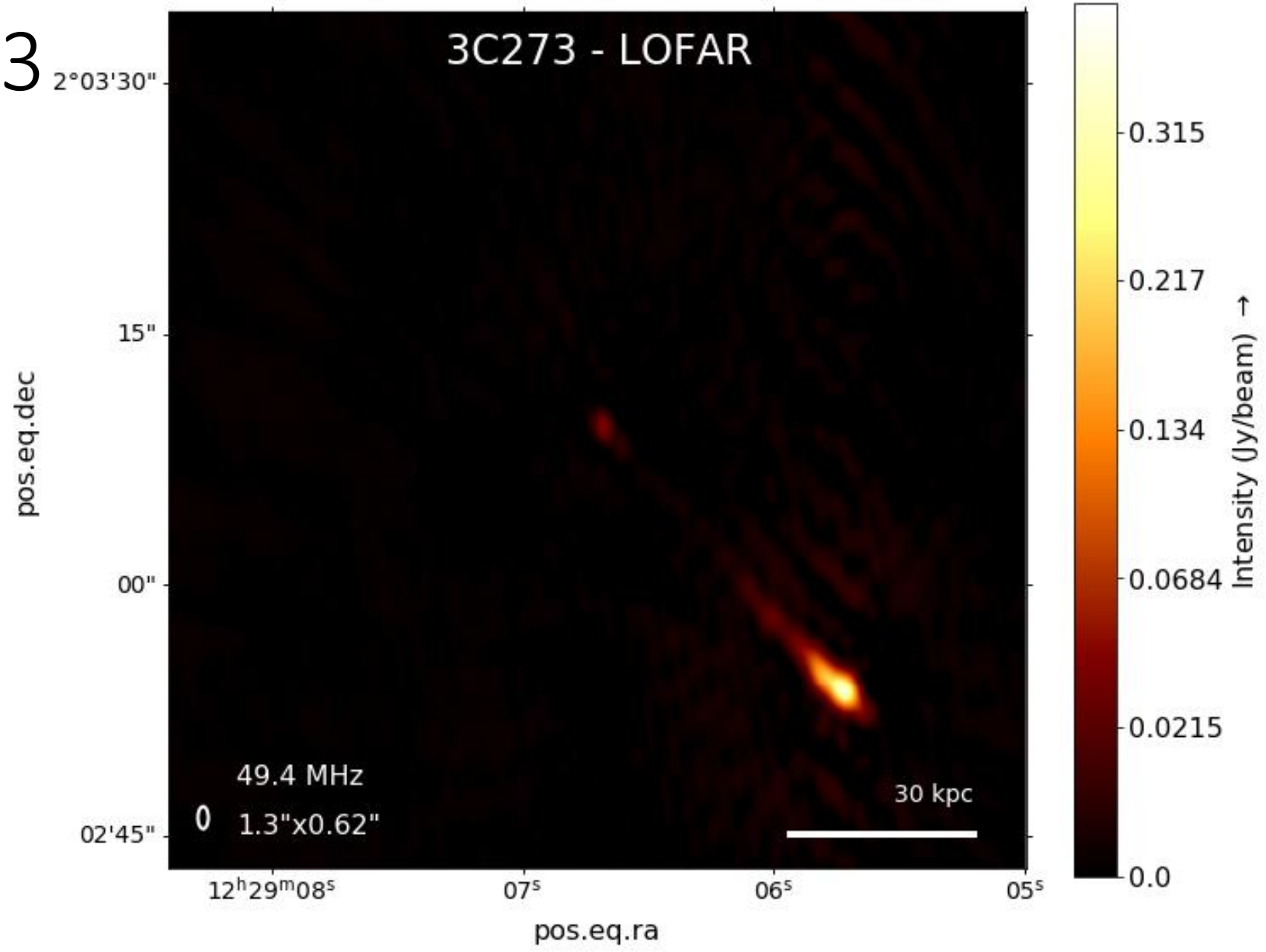
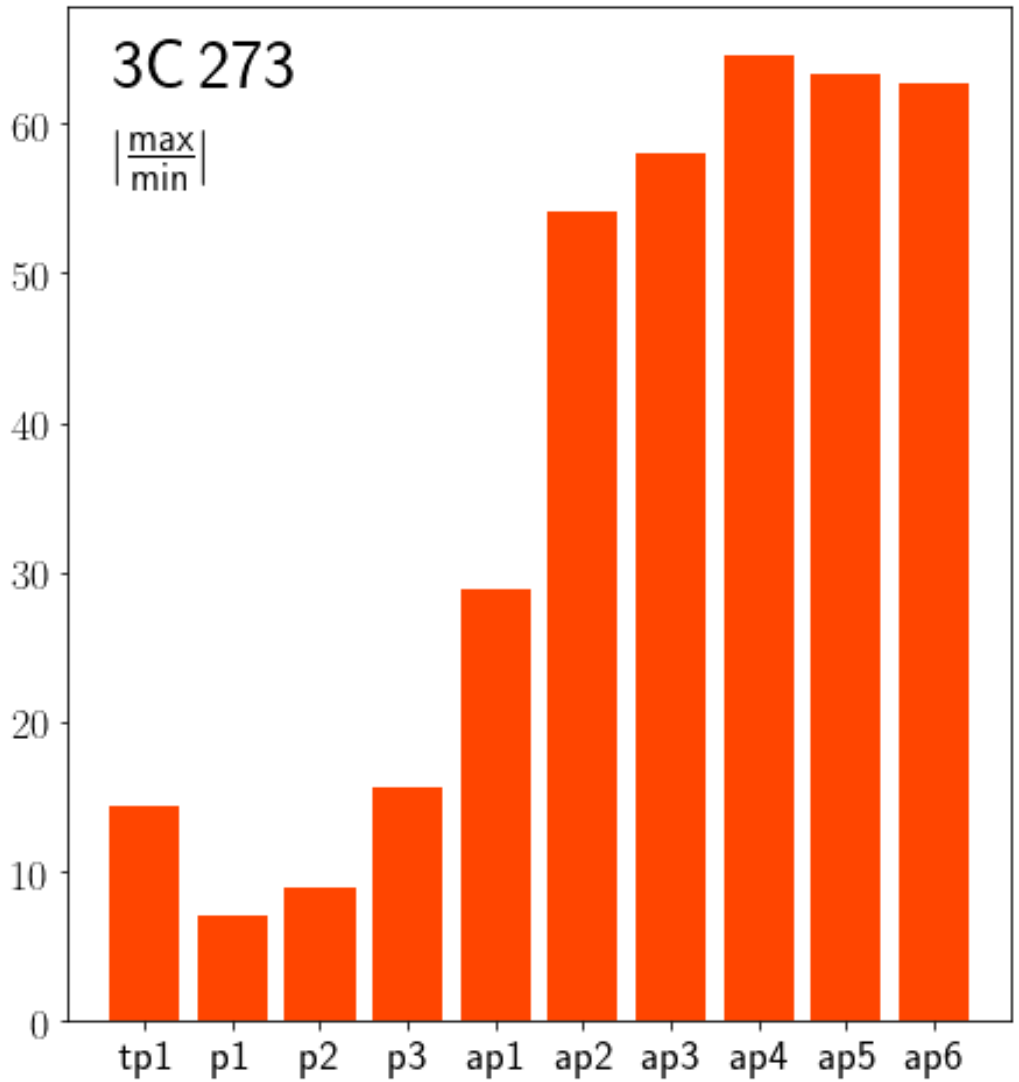
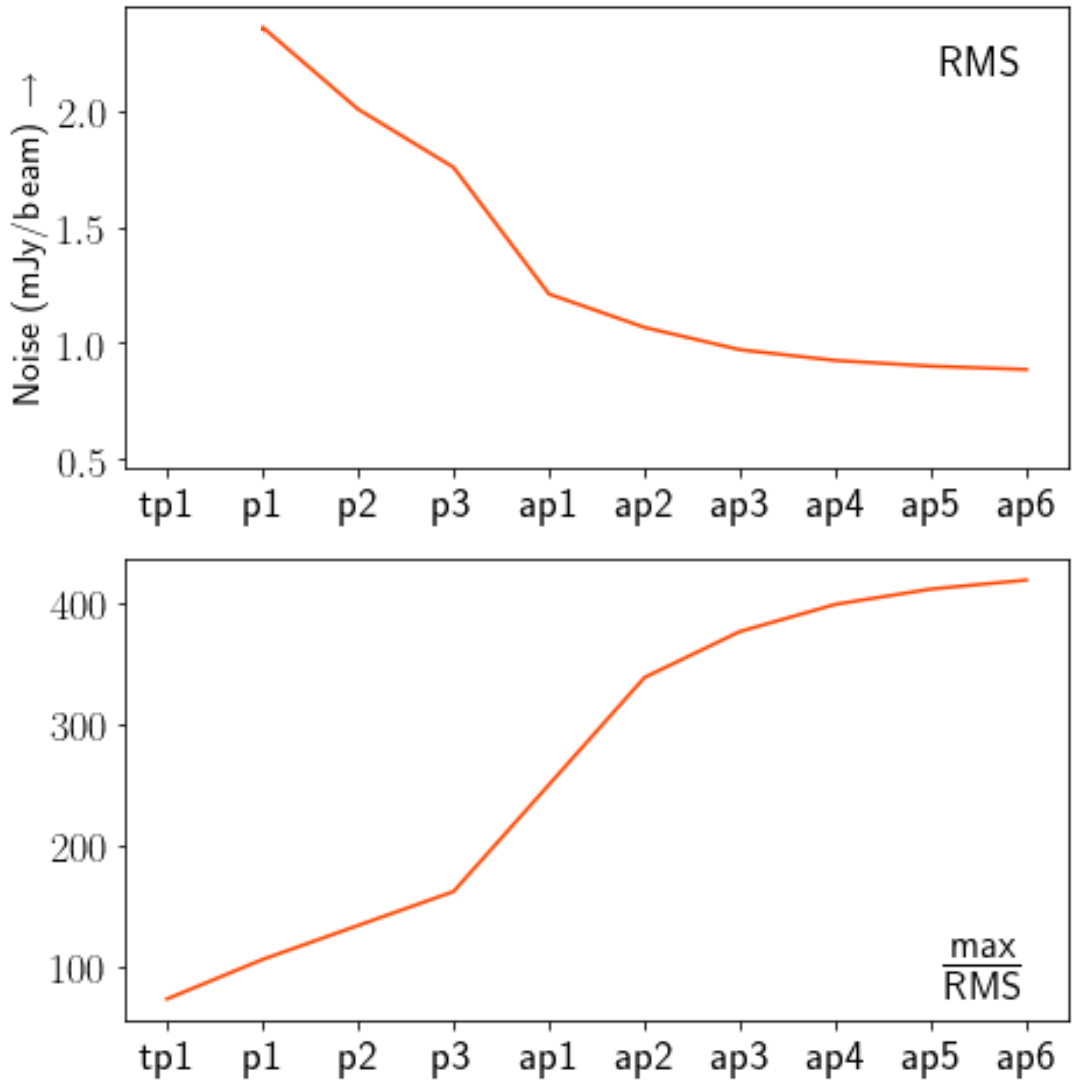
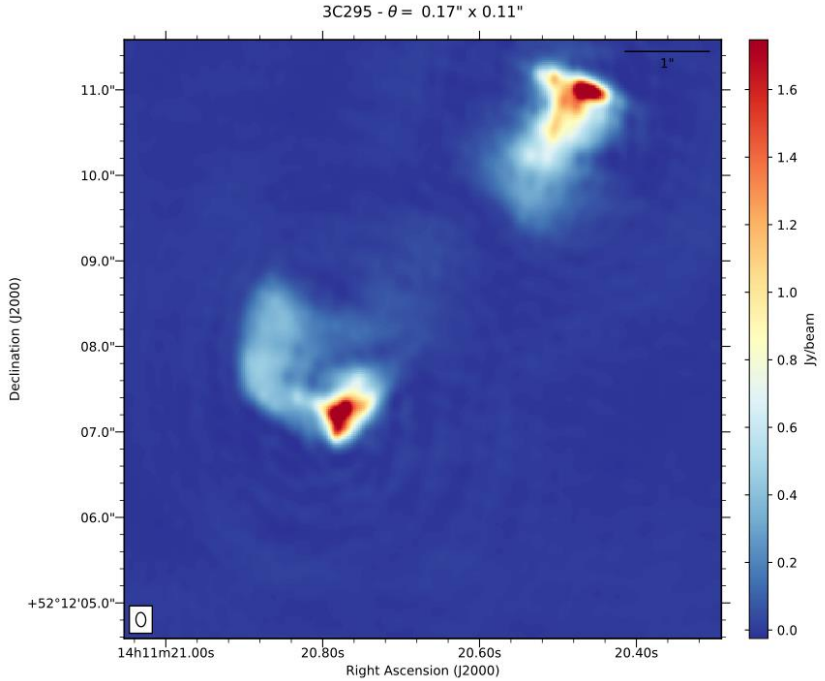


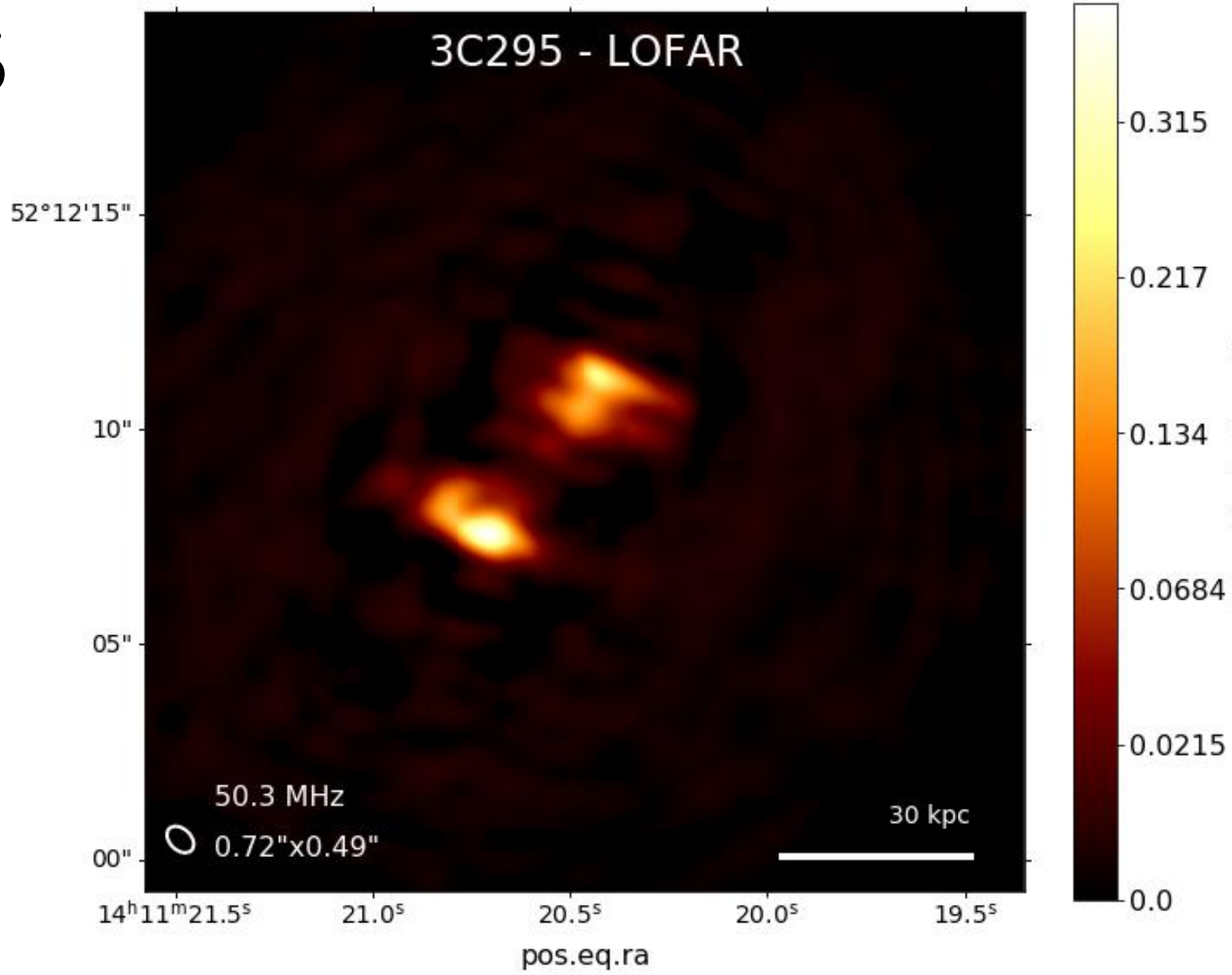

3C 273
|max/min|
0
10
20
30
40
50
60
tp1
p1
p2
p3
ap1
ap2
ap3
ap4
ap5
ap6


RMS
Noise (mJy/beam) ↓
0.5
1.0
1.5
2.0
100
200
300
400
max/RMS
tp1
p1
p2
p3
ap1
ap2
ap3
ap4
ap5
ap6

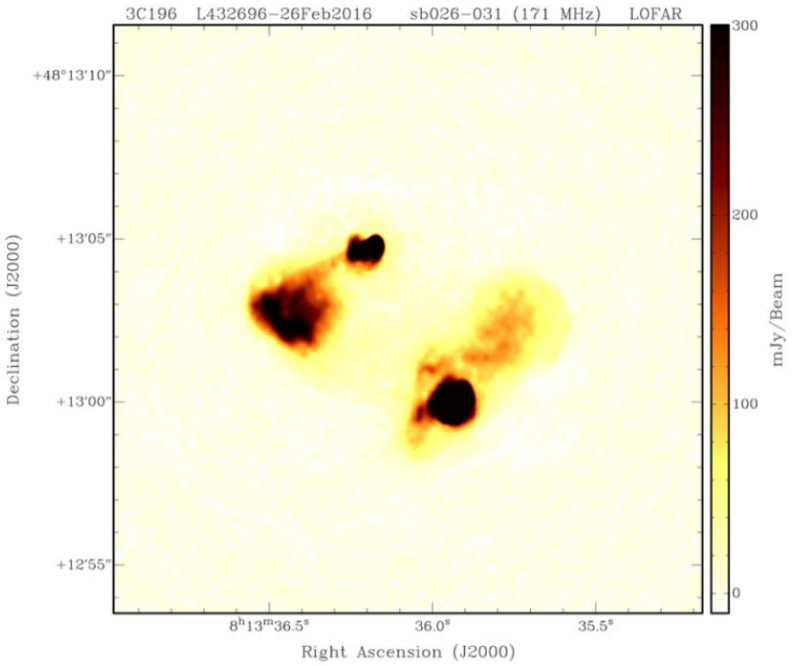
Results – 3C 295



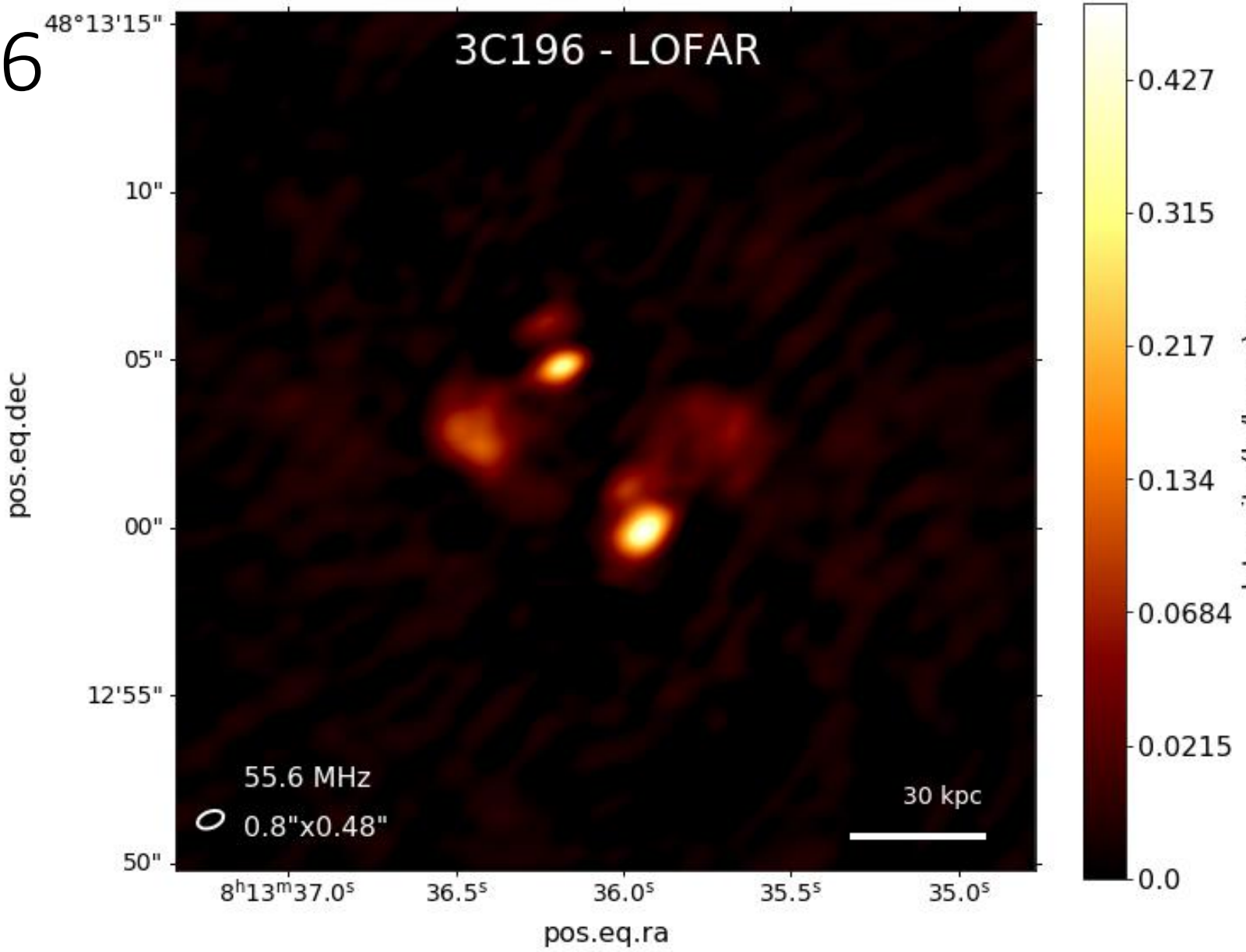
Credit: Frits Sweijen



Results – 3C 196

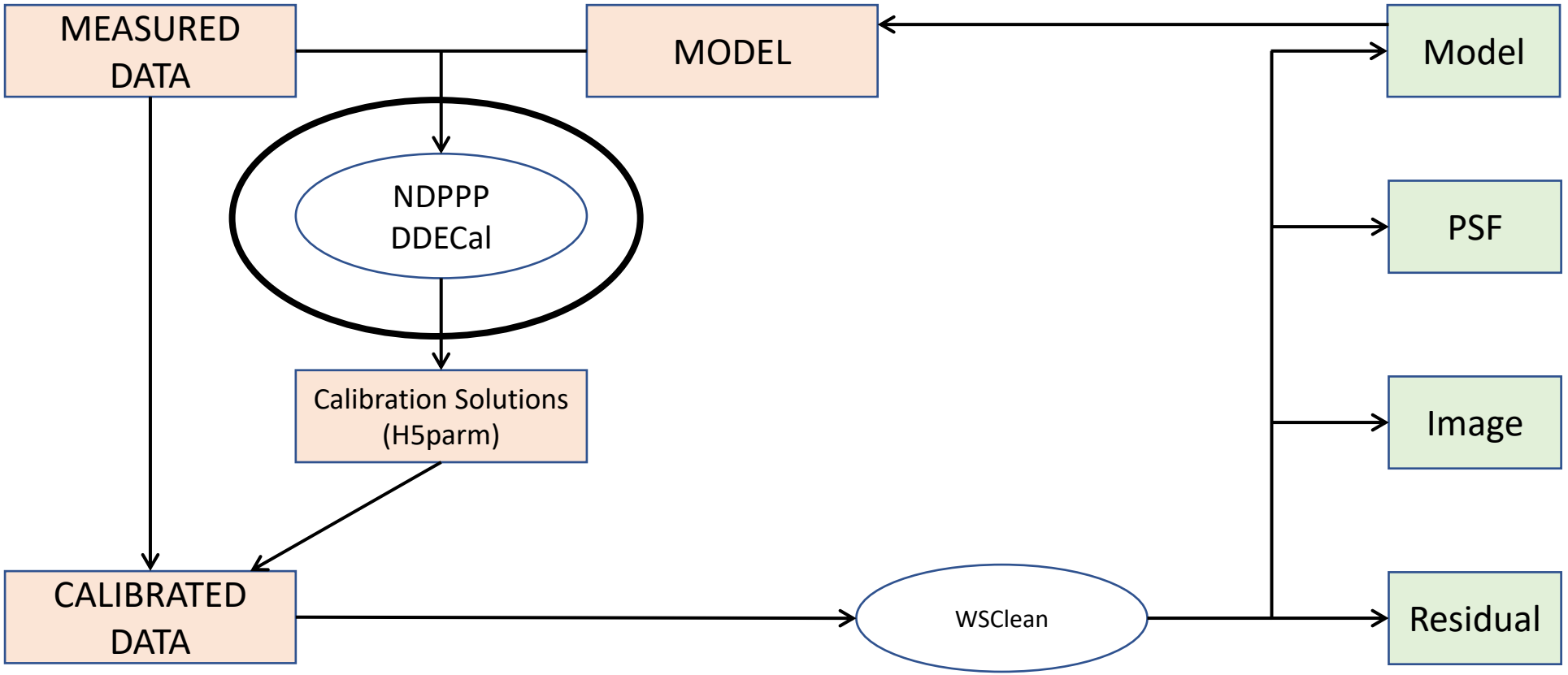


Credit: Ger de Bruyn



Self-calibration with LOFAR

$$\sum_{time}\sum_{m<n} w_{mn}|V_{mn}^{actual} - g_m g_n^* V_{mn}^{model}| \qquad \textit{TMS (11.8)}$$



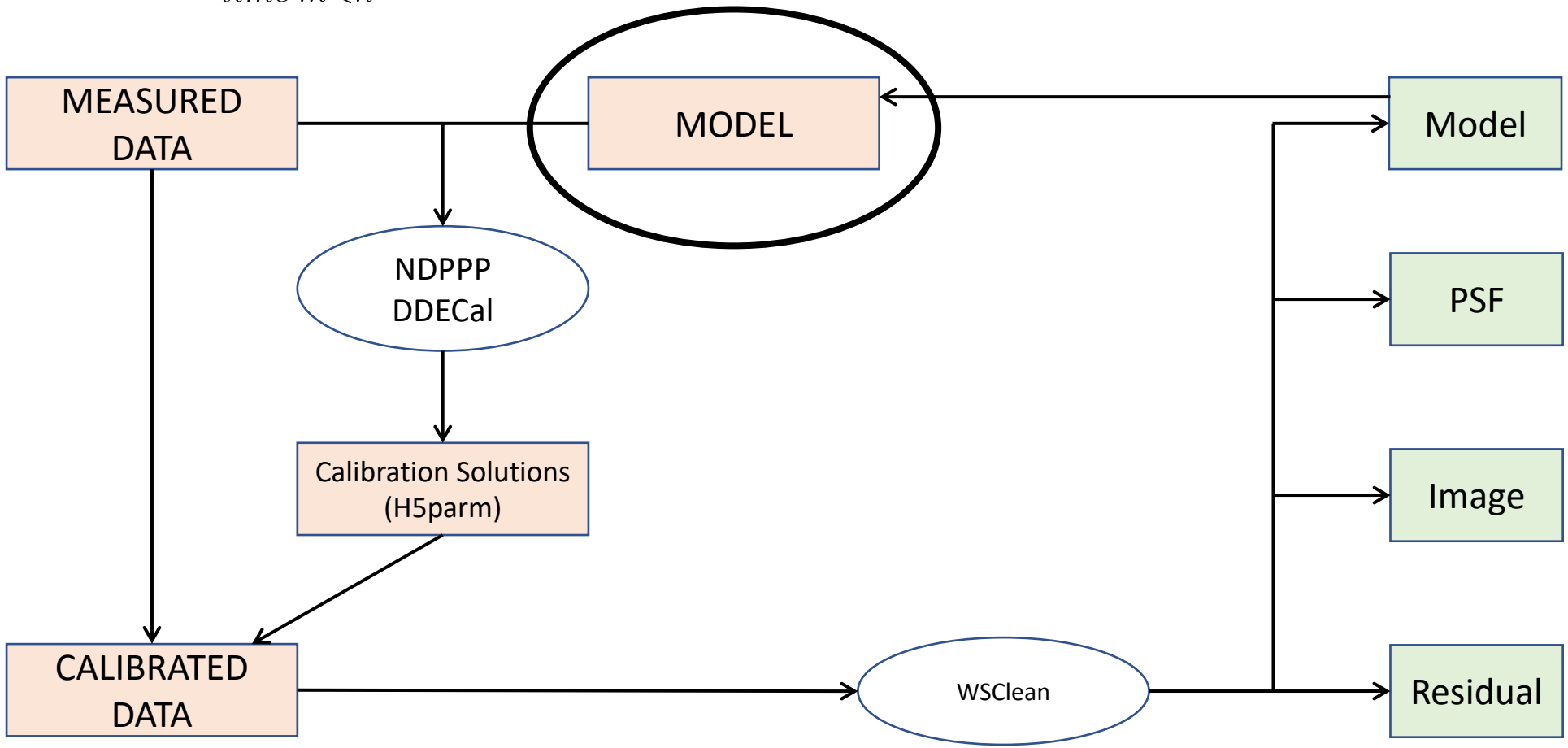
Calibration Constraints

- More DOF to less DOF
  - Diagonal (amplitude+phase)
  - Phase-only
  - TEC: Ionosphere-constraint phase-only (additional frequency constraint)

- Begin with TEC, then few times Phase-only, then Diagonal

Self-calibration with LOFAR

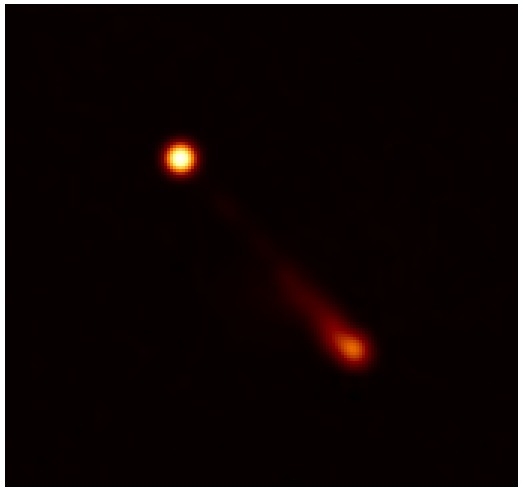
$$\sum_{time}\sum_{m<n} w_{mn}|V_{mn}^{actual} - g_m g_n^* V_{mn}^{model}|$$ *TMS (11.8)*

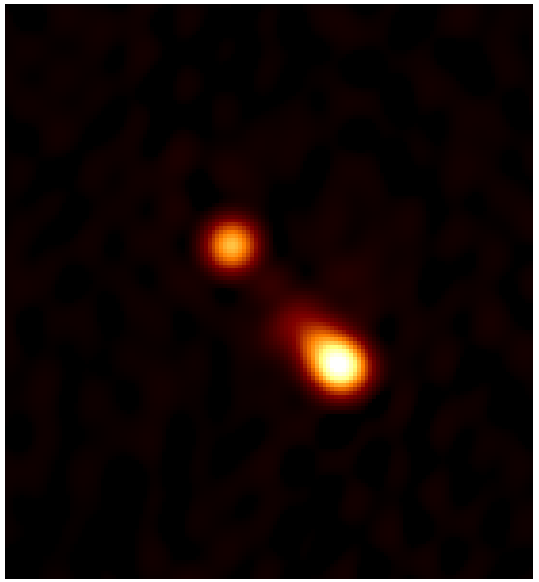


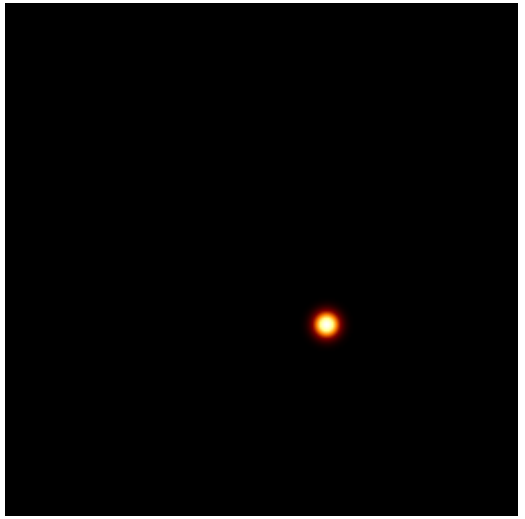
Model dependency

- Initial model

- 3C 273 as an example

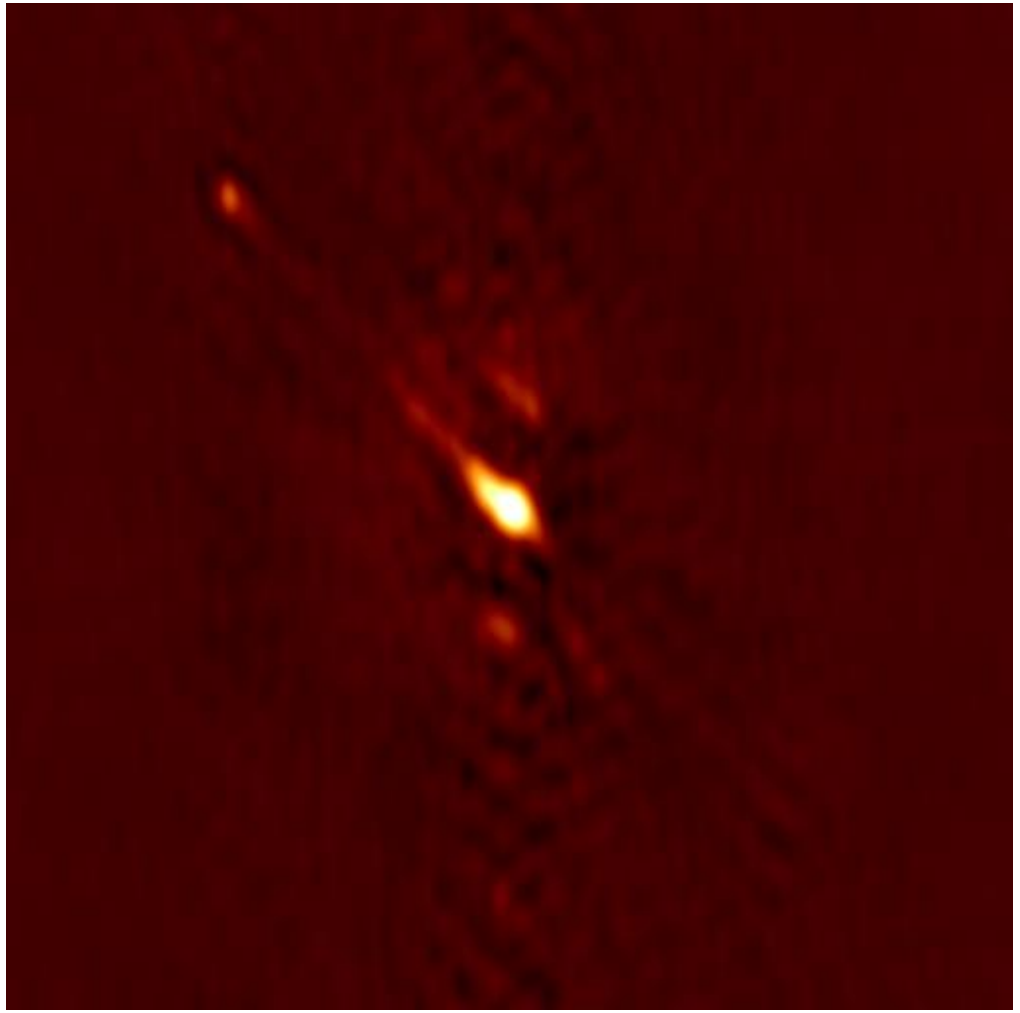




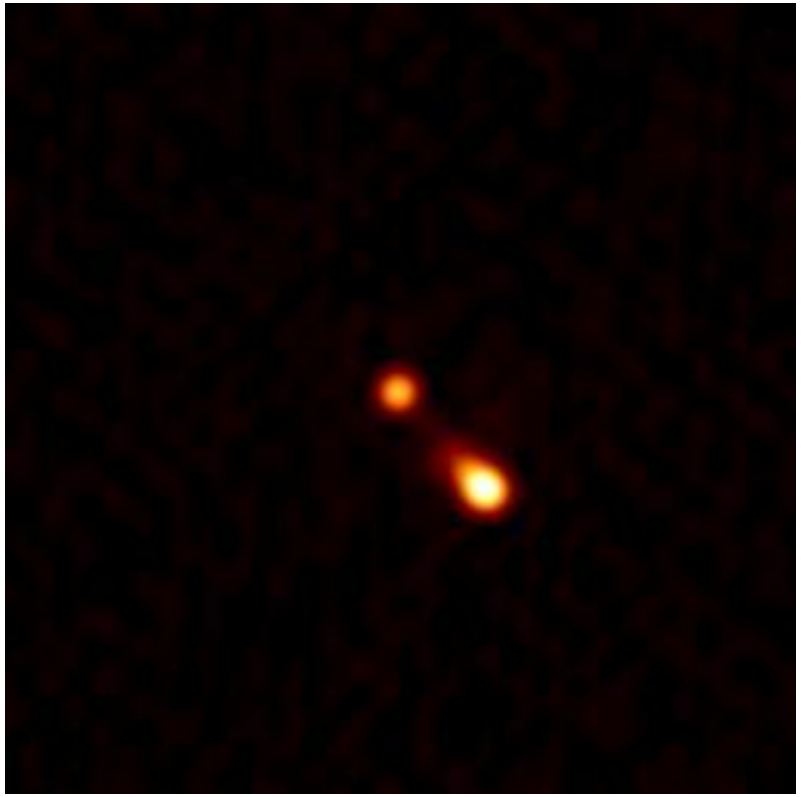


Model dependency – 3C 273

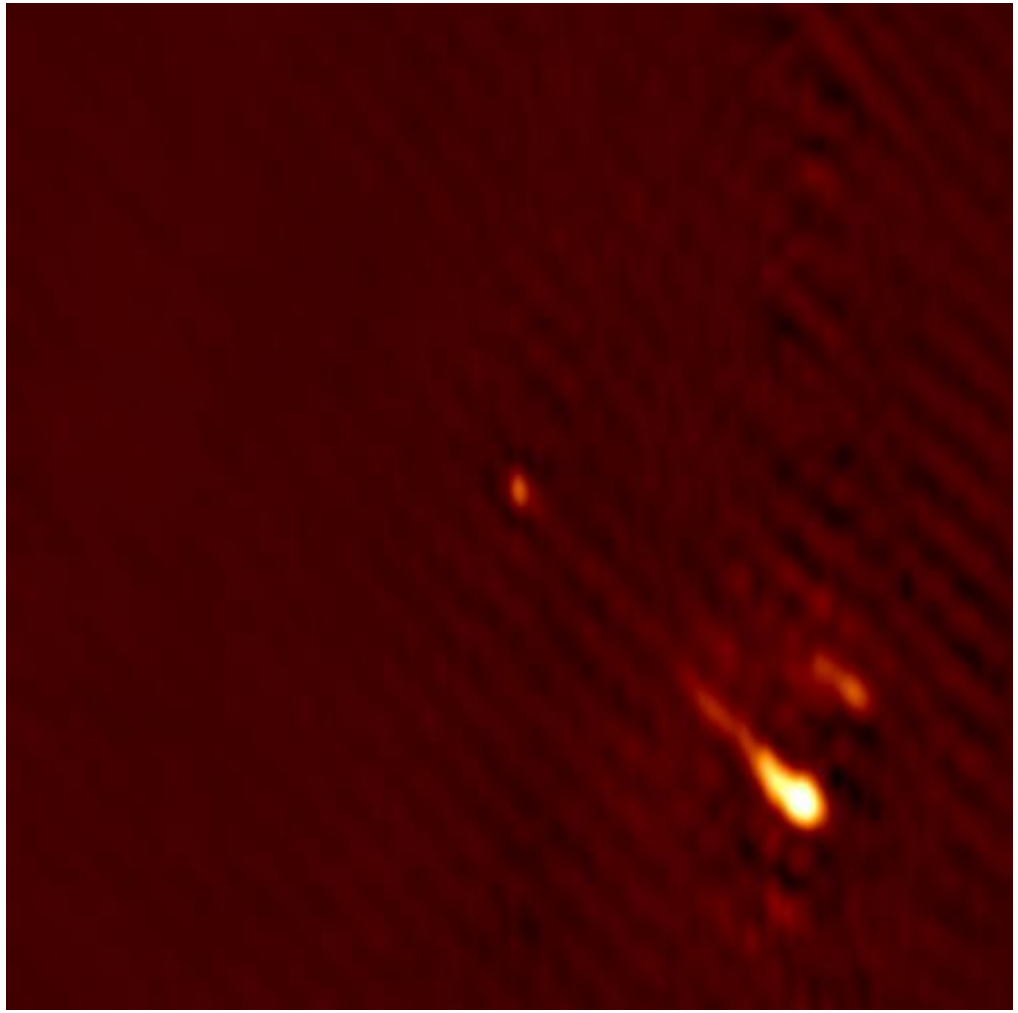
1 GHz



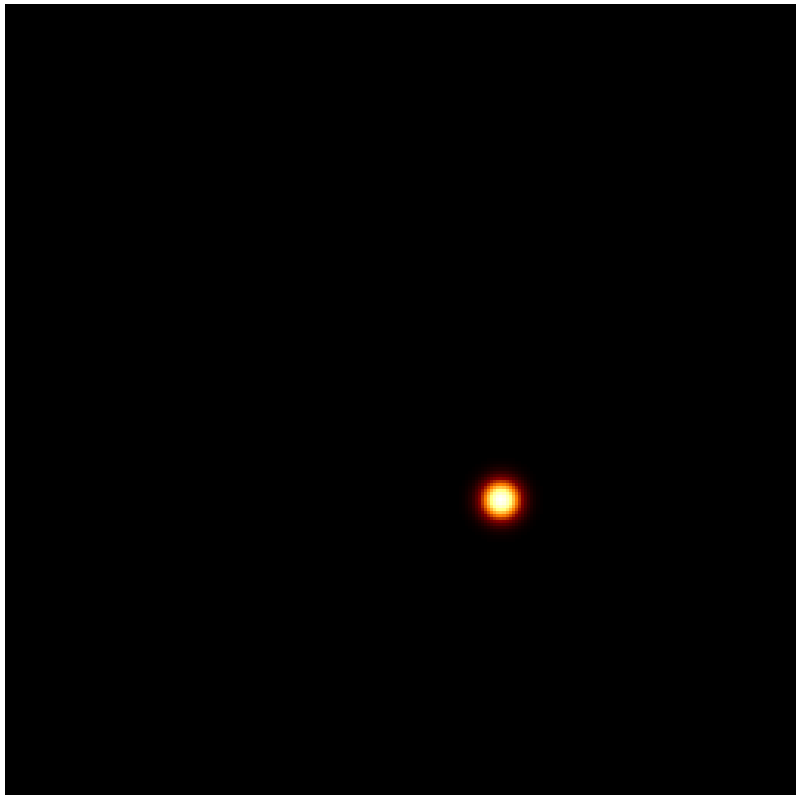
Model dependency – 3C 273

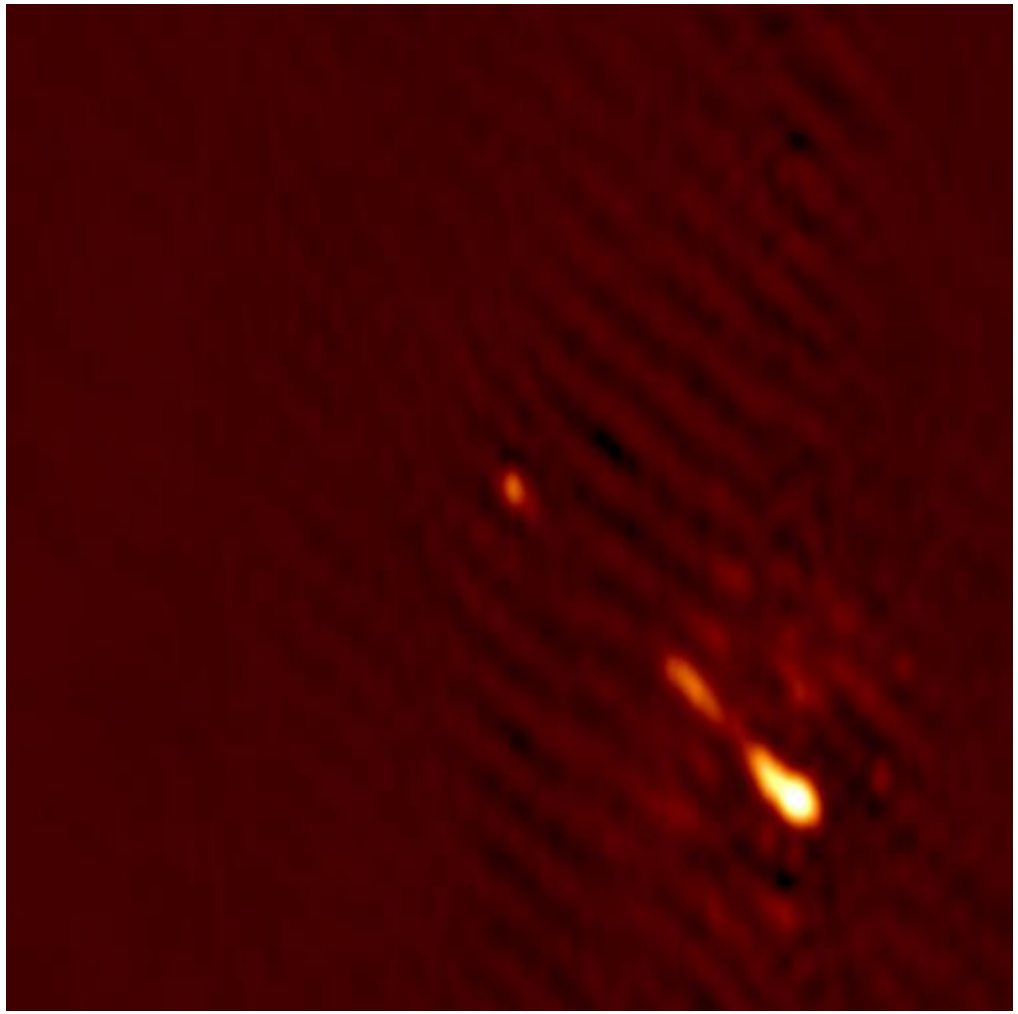


300 MHz



Model dependency – 3C 273





Model dependency

- Initial model
- 3C 273 as an example
- Brightest spot in model must correspond with data!

Conclusion/Outlook

- LOFAR LBA VLBI works!
- Works best on bright (>100Jy) compact (unresolved) sources
- Doesn’t depend too much on initial model
- Many more sources