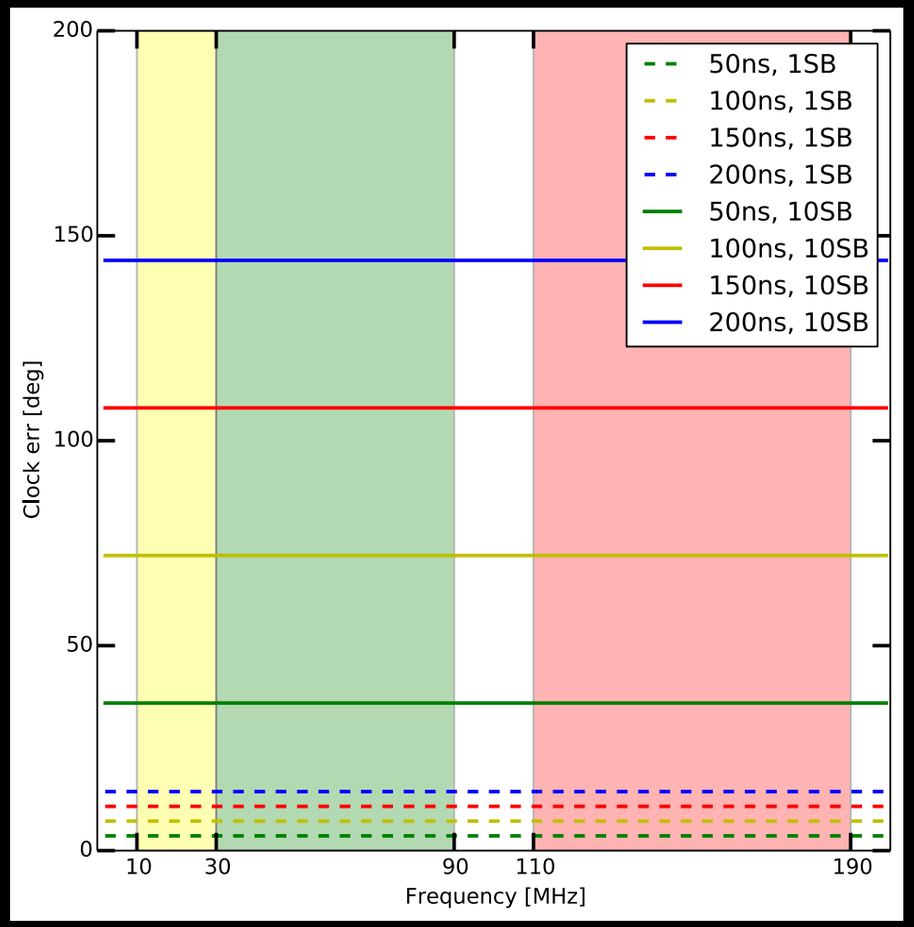
Francesco de Gasperin

Imaging with the LOFAR Low Band Antenna

LOFAR science workshop - 2/6/2015

Outline

- LBA vs HBA
- LBA: data reduction strategy
  - strong sources (Virgo A)
  - normal fields (Toothbrush)
- Future of LBA



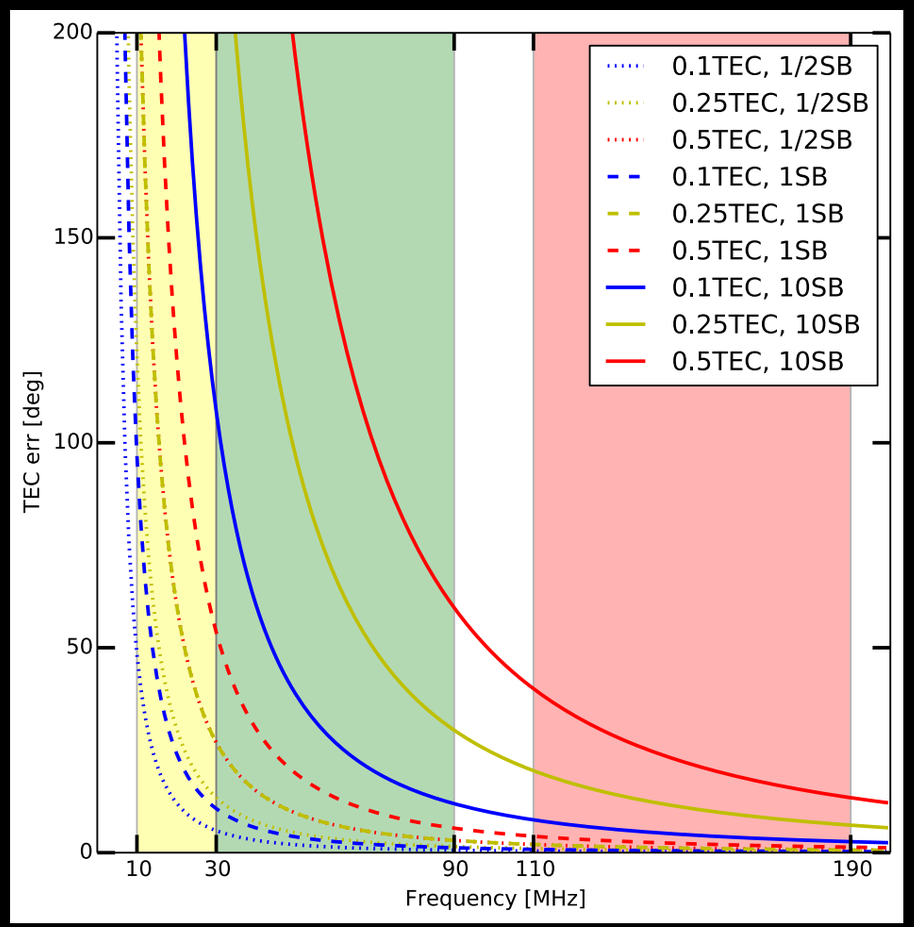
Clock

LBA vs HBA

30-80 MHz

110-190 MHz

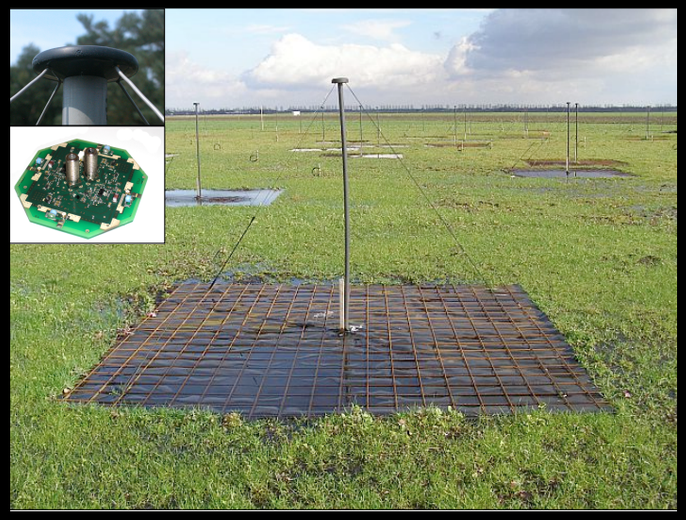
Clock is an issue if several SBs are combined



TEC is an issue if several SBs are combined, <40 MHz even in a single SB

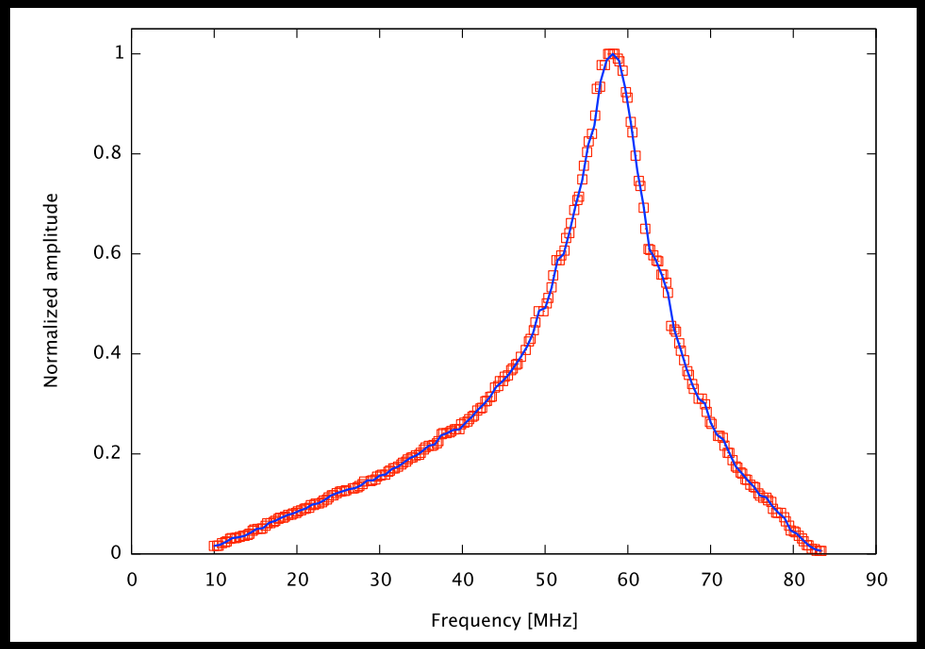
TEC is important for bad-ionosphere observations or high-fidelity images

TEC



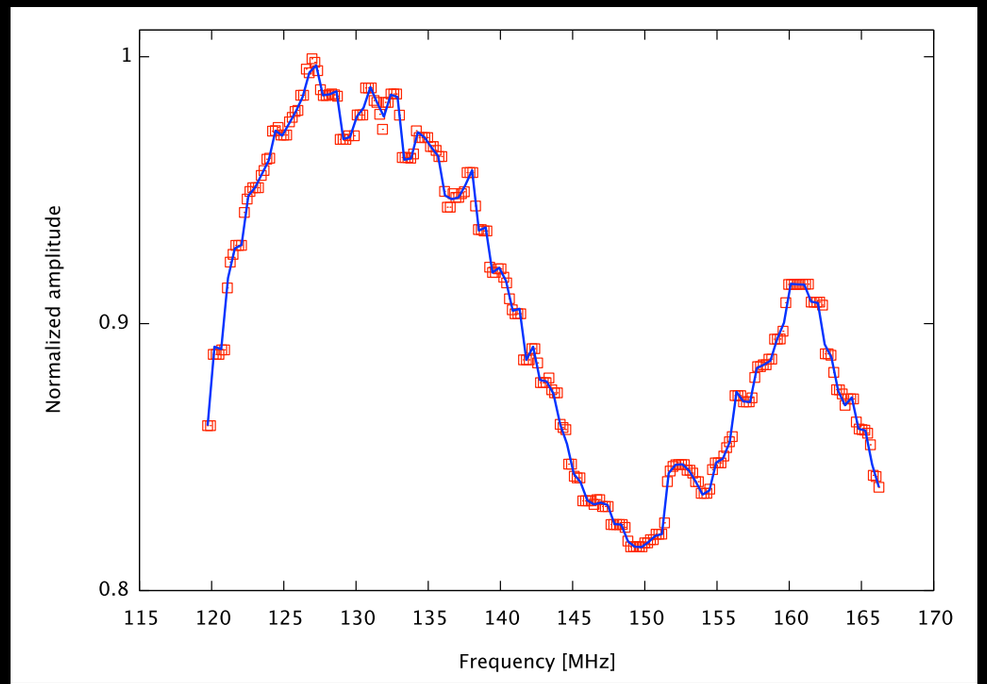
LBA vs HBA

Sensitivity: low, only stronger sources (>1Jy?) can be used for DDE



Bandpass is strongly peaked: strategy is frequency dependent

Sensitivity: good, can correct against 0.1 Jy source for DDE



Bandpass varies by <20%: strategy is frequency independent

LBA vs HBA

Data size: 1035 baselines,
<1GB per SB

Data size: 2850 baselines,
~few GB per SB

Low-res: doesn't need a very accurate model

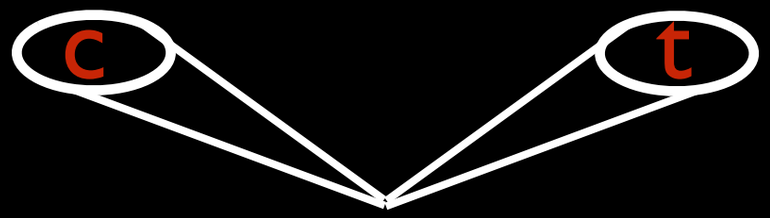
High-res: need a very accurate model

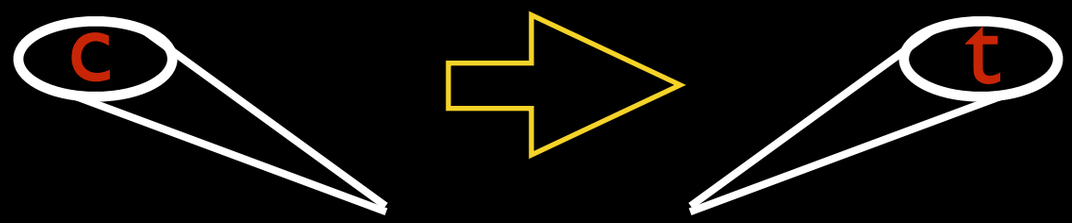
Sparse disposition

Ordered disposition
("ghost" beam issue)

Dual beam (calibrator+target)
continuously for the entire observation

Beam direction limited
interpolation/extrapolation required



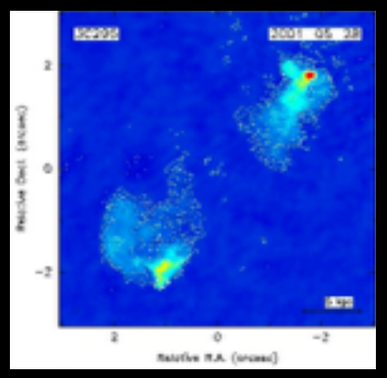


Strategy 1: strong target

Obs strategy: 244 SB on cal, 244 SB on strong target

Pre processing: demix + avg to 4 chan / 1 sec

Freq avg: avoid BW smearing + iono freq dependancy / Time avg: iono time variation



1: calibrator (3C295)

BBS on calibrator

Diag(G) + rot ang
<30 MHz: divide SB

LoSoTo

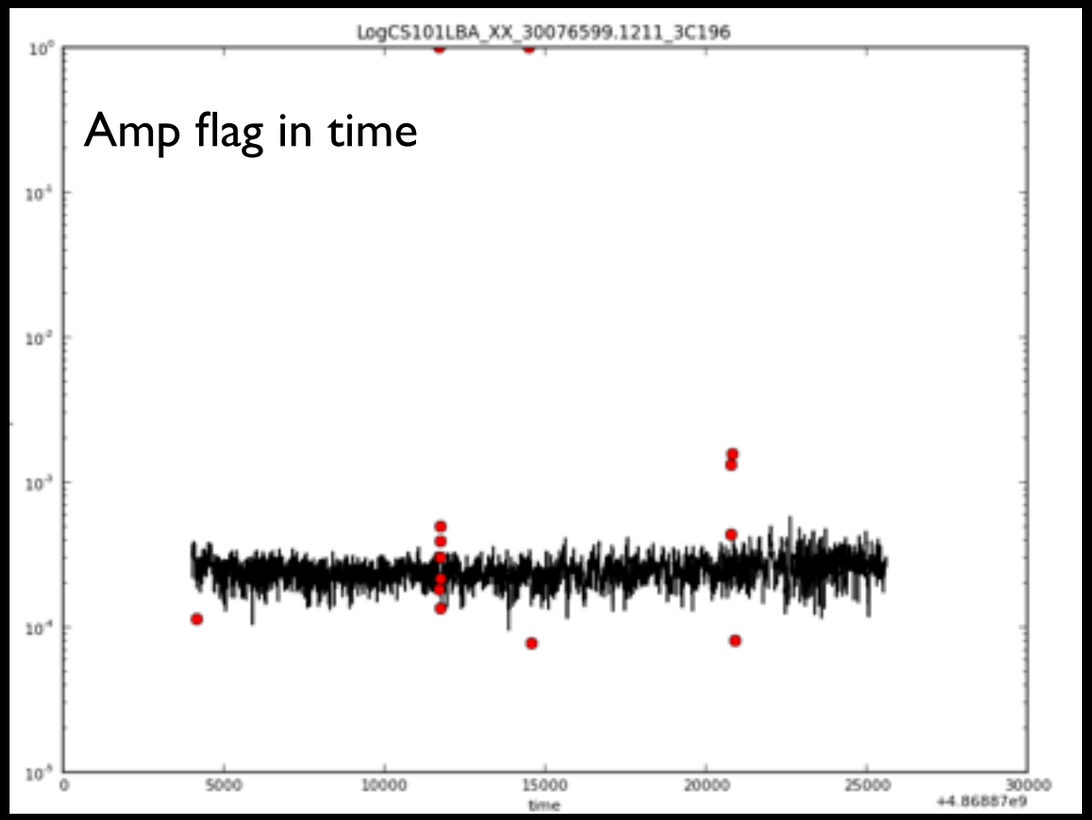
C-T separation (diagnostic) + flag

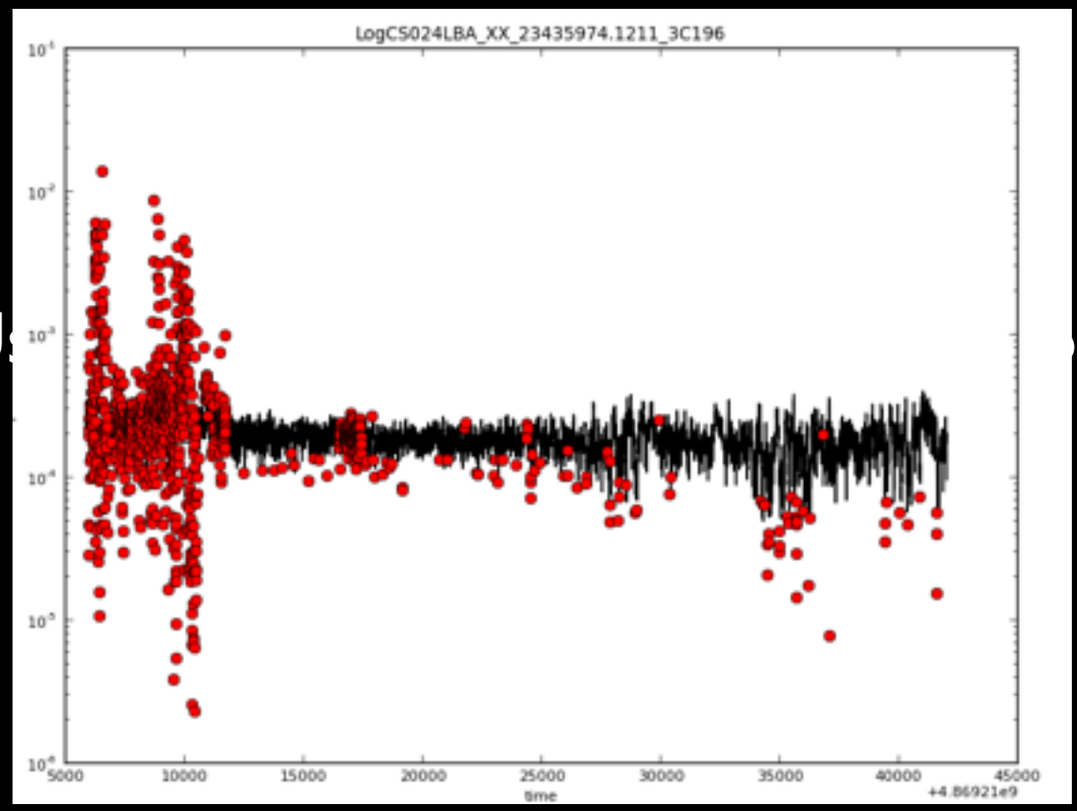
Cor on target

Transfer A+P (solve clock but dTEC)

Why rot ang is important?
Faraday rotation can move flux from XX/YY to XY/YX
even if we solve for full G we would have noisier data

All these steps are done SB per SB, easy to parallelise


LogCS101LBA_XX_30076599.1211_3C196
Amp flag in time
time
+4.86887e9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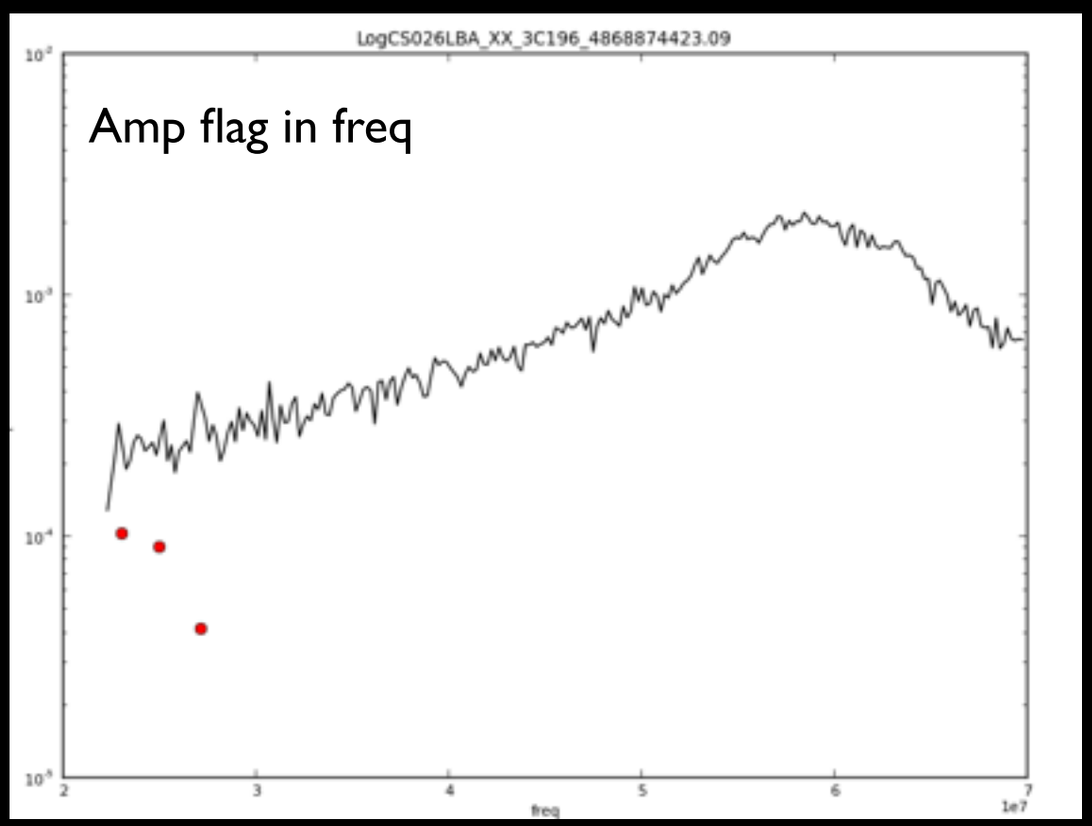
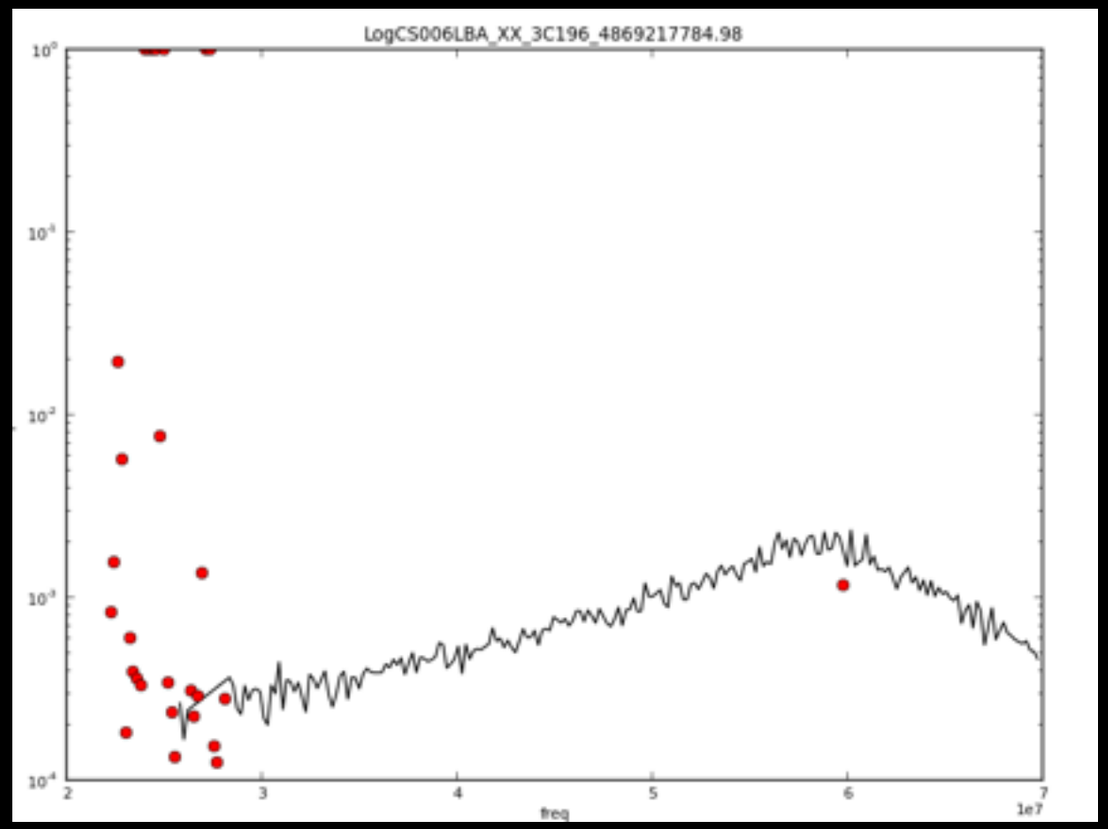
time
+4.86921e9


LogCS026LBA_XX_3C196_4868874423.09
Amp flag in freq
freq
1e7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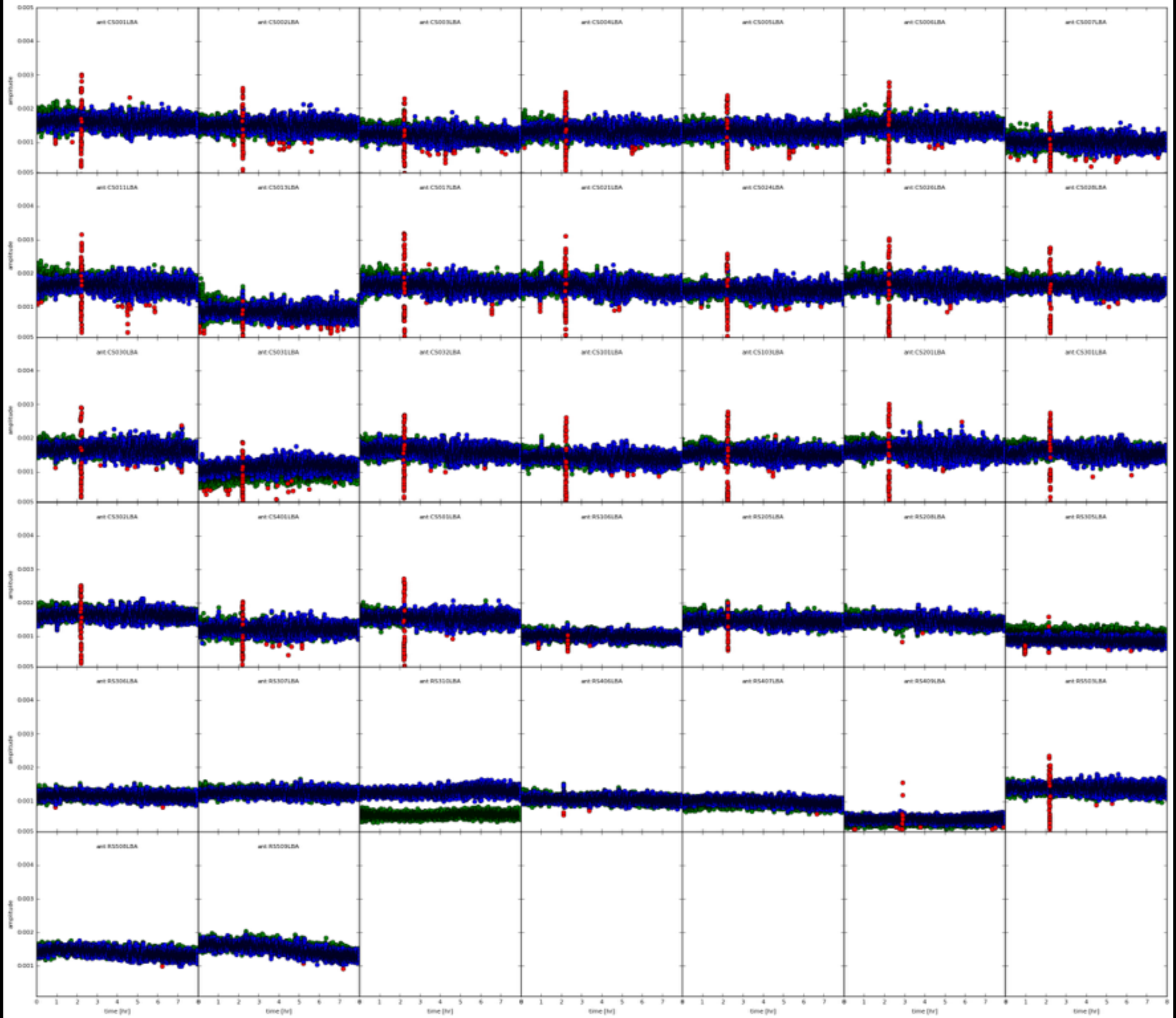
1e7


ant:CS001LBA
ant:CS002LBA
ant:CS003LBA
ant:CS004LBA
ant:CS005LBA
ant:CS006LBA
ant:CS007LBA
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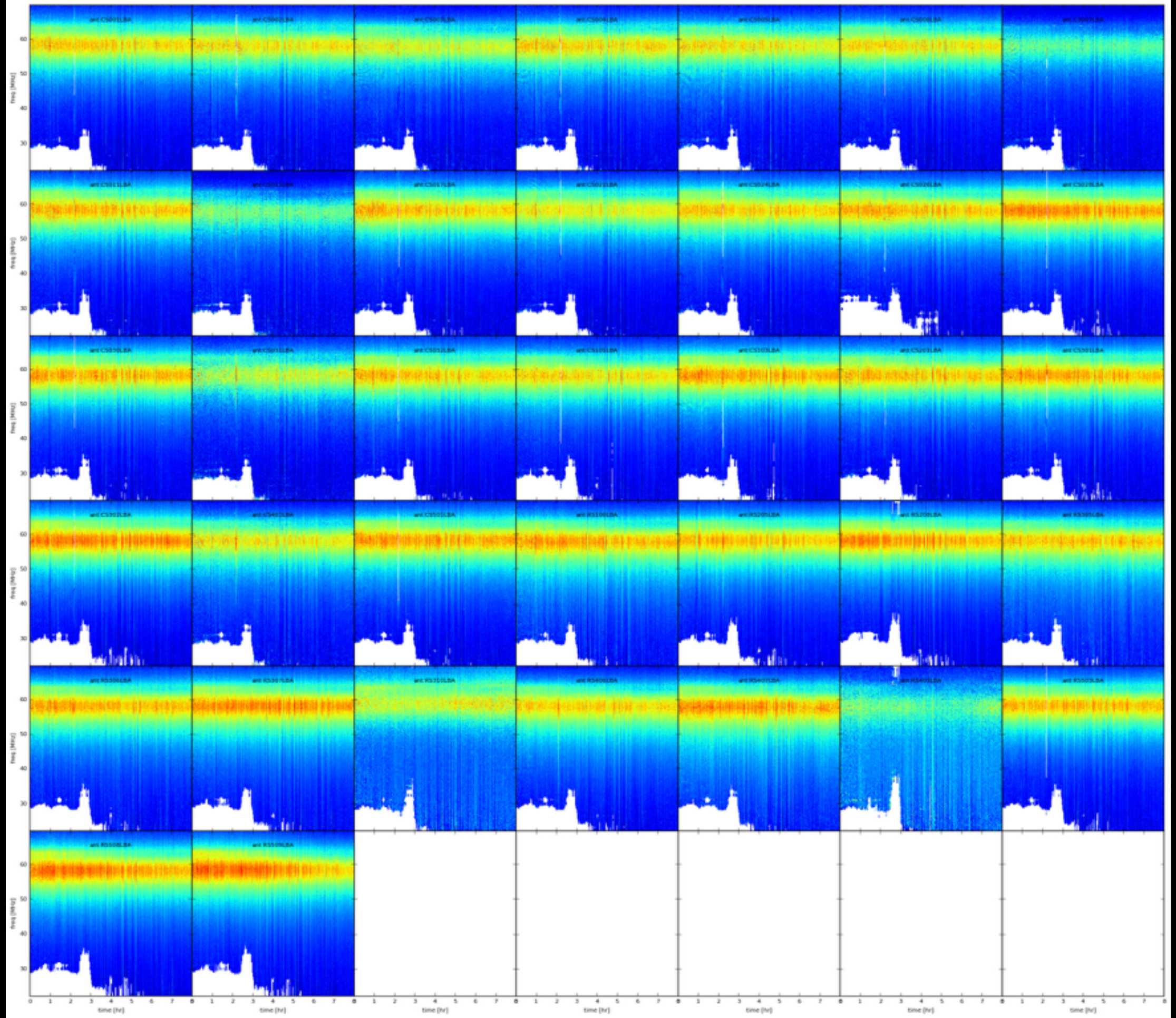
ant:CS013LBA
ant:CS017LBA
ant:CS021LBA
ant:CS024LBA
ant:CS026LBA
ant:CS028LBA
ant:CS030LBA
ant:CS031LBA
ant:CS032LBA
ant:CS101LBA
ant:CS103LBA
ant:CS201LBA
ant:CS301LBA
ant:CS302LBA
ant:CS401LBA
ant:CS501LBA
ant:RS106LBA
ant:RS205LBA
ant:RS208LBA
ant:RS305LBA
ant:RS306LBA
ant:RS307LBA
ant:RS310LBA
ant:RS406LBA
ant:RS407LBA
ant:RS409LBA
ant:RS503LBA
ant:RS508LBA
ant:RS509LBA
amplitude
time [hr]


ant:CS001LBA
ant:CS002LBA
ant:CS003LBA
ant:CS004LBA
ant:CS005LBA
ant:CS006LBA
ant:CS007LBA
ant:CS011LBA
ant:CS013LBA
ant:CS017LBA
ant:CS021LBA
ant:CS024LBA
ant:CS026LBA
ant:CS028LBA
ant:CS030LBA
ant:CS031LBA
ant:CS032LBA
ant:CS101LBA
ant:CS103LBA
ant:CS201LBA
ant:CS301LBA
ant:CS302LBA
ant:CS401LBA
ant:CS501LBA
ant:RS106LBA
ant:RS205LBA
ant:RS305LBA
ant:RS306LBA
ant:RS307LBA
ant:RS310LBA
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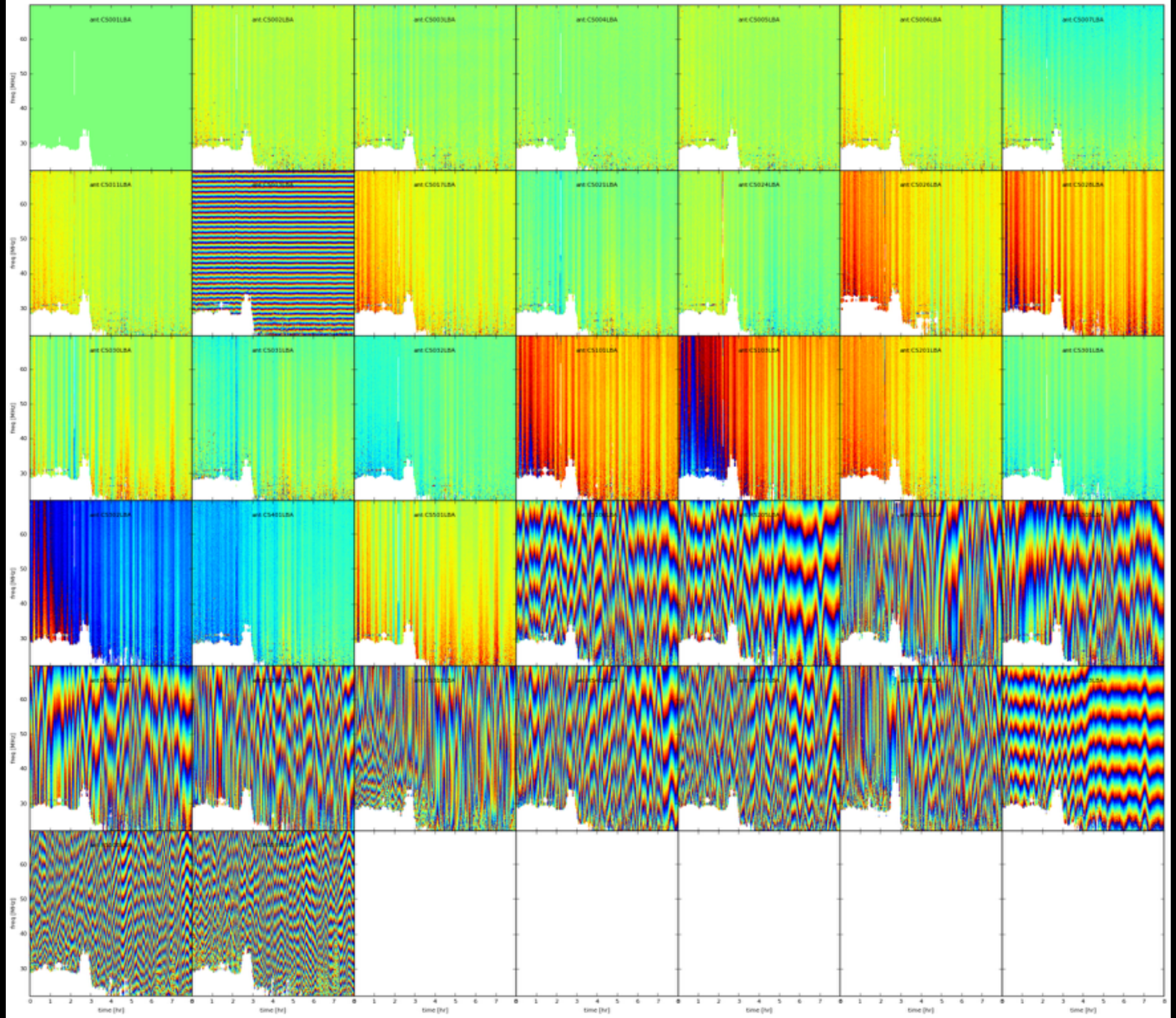
ant:RS508LBA
ant:RS509LBA
freq [MHz]
time [hr]


ant:CS001LBA
ant:CS002LBA
ant:CS003LBA
ant:CS004LBA
ant:CS005LBA
ant:CS006LBA
ant:CS007LBA
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ant:CS017LBA
ant:CS021LBA
ant:CS024LBA
ant:CS026LBA
ant:CS028LBA
ant:CS030LBA
ant:CS031LBA
ant:CS032LBA
ant:CS101LBA
ant:CS103LBA
ant:CS201LBA
ant:CS301LBA
ant:CS302LBA
ant:CS401LBA
ant:CS501LBA
freq [MHz]
time [hr]

On 1 SB every 10

II: self-cal loop

run time: 1 day per block

Convert to circular pol

Get rid of Faraday rotation (beam removed!)

Self-cal on target

Every 3 cycles

Image large field

Subtract large field

Every 3 cycles

Flagging

Imaging

10 times loop

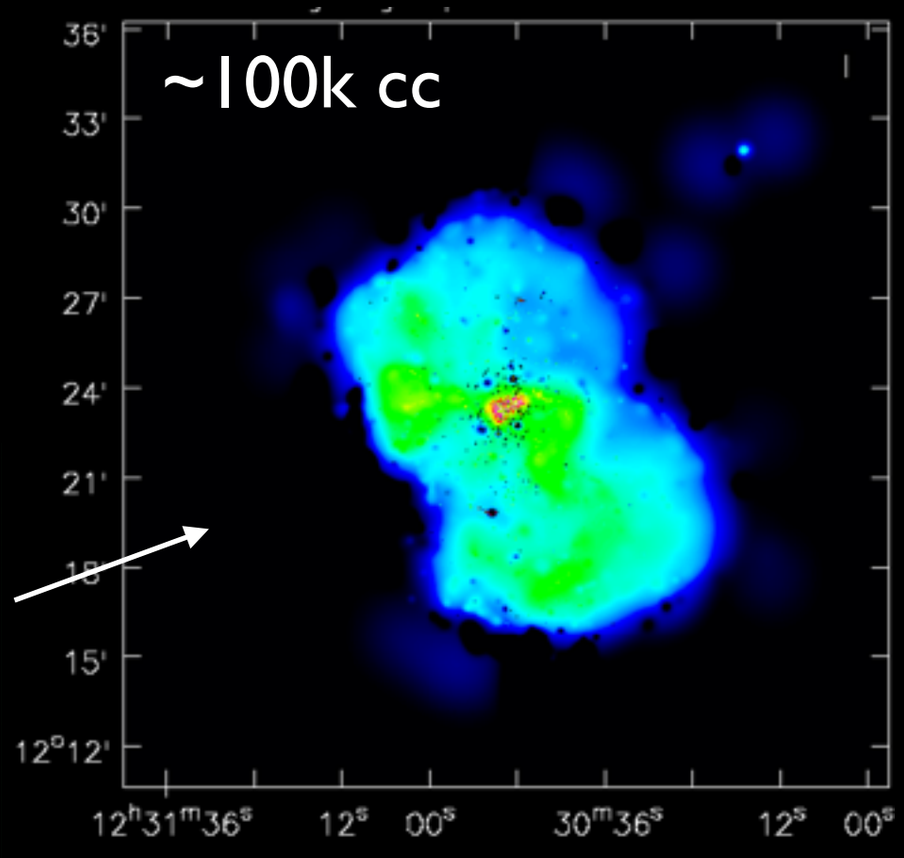
Add model

Use CC, faster and more precise (no need for the beam)
Use virtual concat

NDPPP sol+cor

Amp should be normalised to 1 (LoSoTo)

Fast+more stable but no rotation angle (circ pol: not important)



On 1 SB every 10

II: self-cal loop

run time: 1 day per block

Convert to circular pol

Get rid of Faraday rotation (beam removed!)

Self-cal on target

Every 3 cycles

Image large field

Subtract large field

Every 3 cycles

Flagging

Imaging

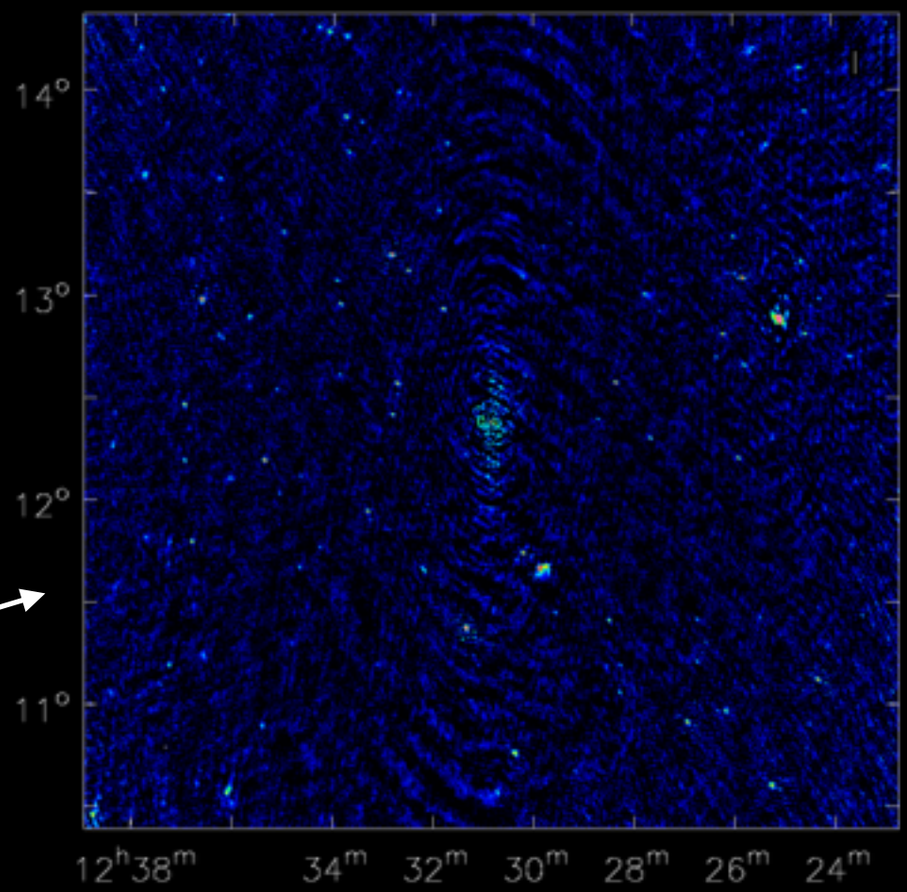
10 times loop

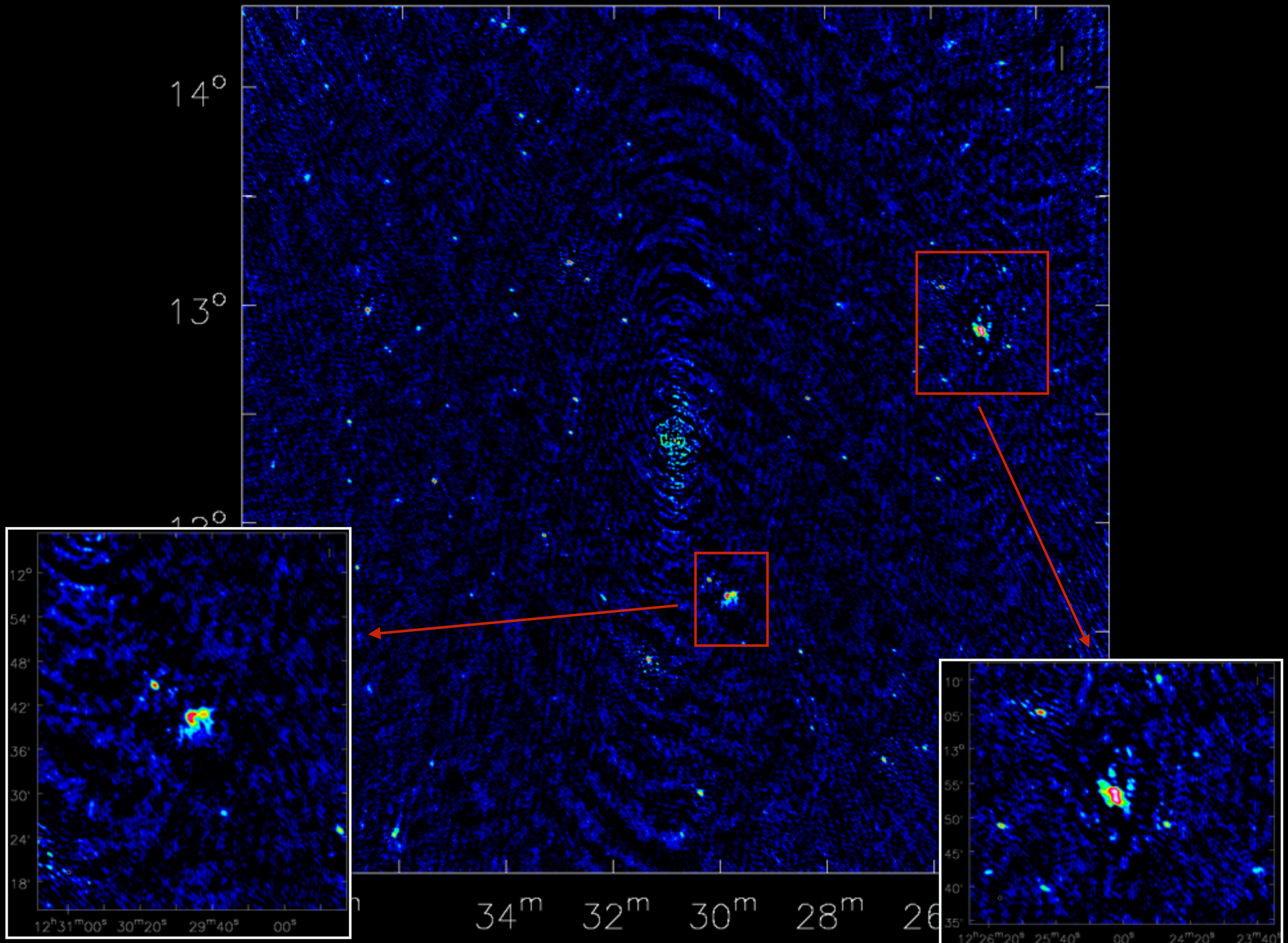
Sub target

Remove best available target model

Wide-field clean

5 x 5 deg, CASAclean, automasking
full-freq resolution




14°
13°
12°
34m
32m
30m
28m
12°
54'
48'
42'
36'
30'
24'
18'
12h31m00s
30m20s
29m40s
00s
10'
05'
13°
55'
50'
45'
40'
35'
12h26m20s
25m40s
00s
24m20s
23m40s

II: self-cal loop

run time: few days

Convert to circular pol

Get rid of Faraday rotation (beam removed!)

Self-cal on target

Every 3 cycles

Image large field

Subtract large field

Every 3 cycles

Flagging

Several times loop

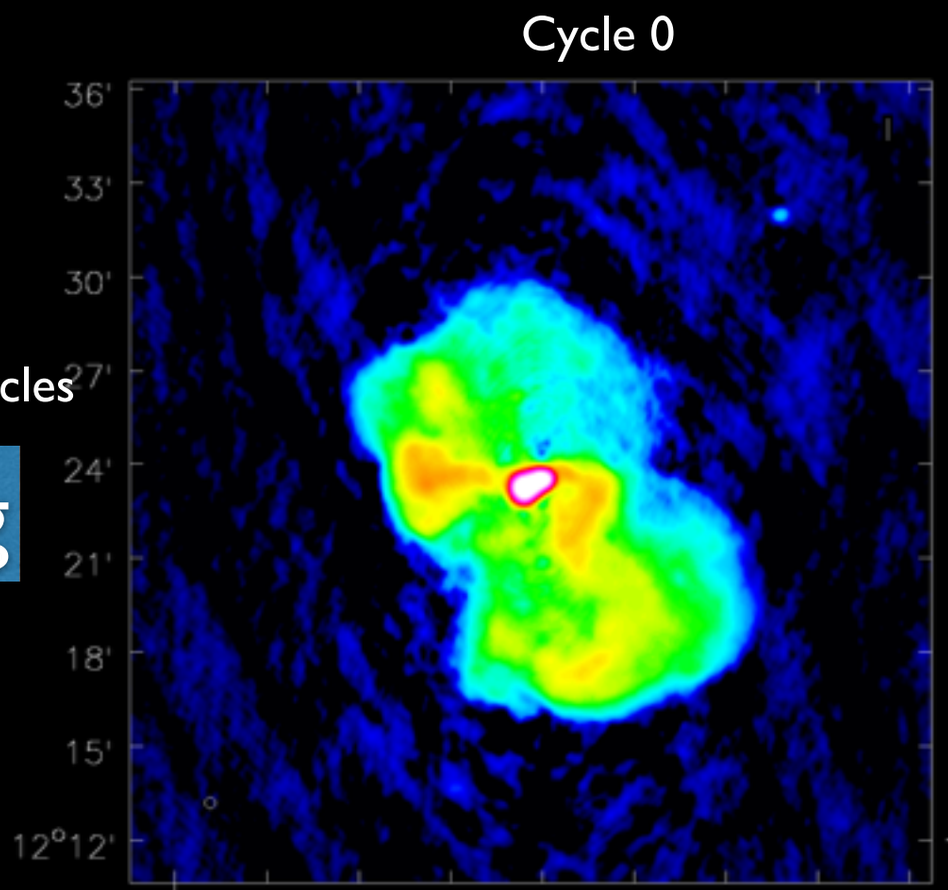
Imaging

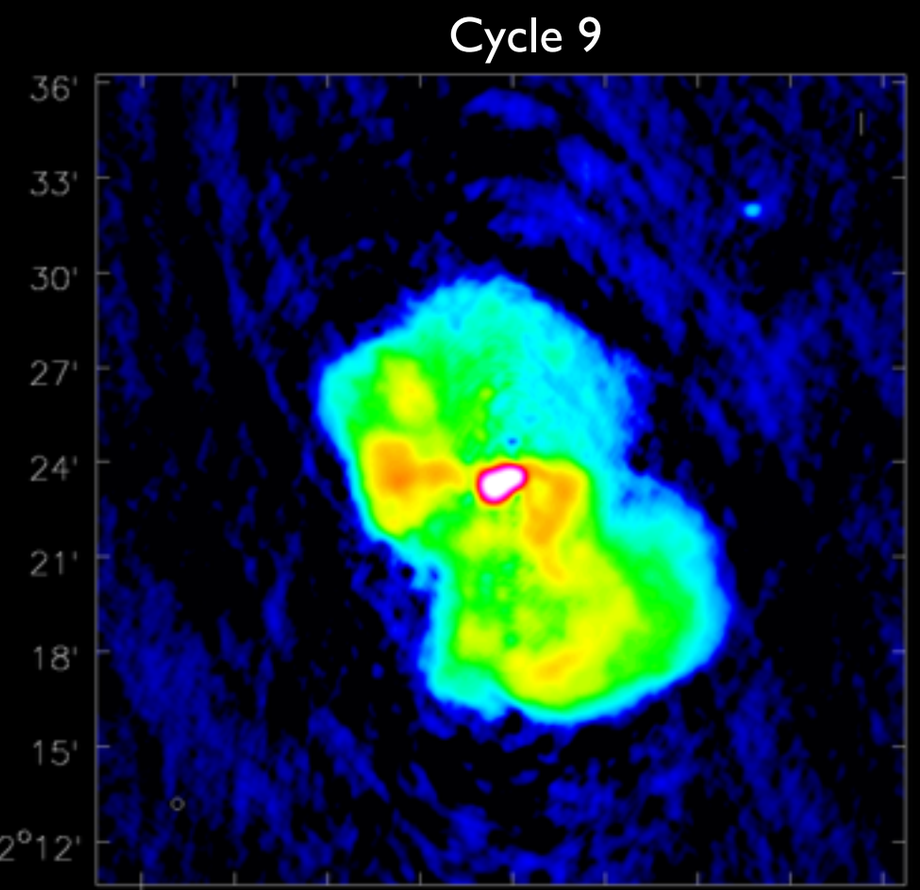
Concat and Clean

24 SBs to improve uv-coverage

1 ch/SB to speed up

very complex target, MS-MF is fundamental. Multiple runs with different scales also required

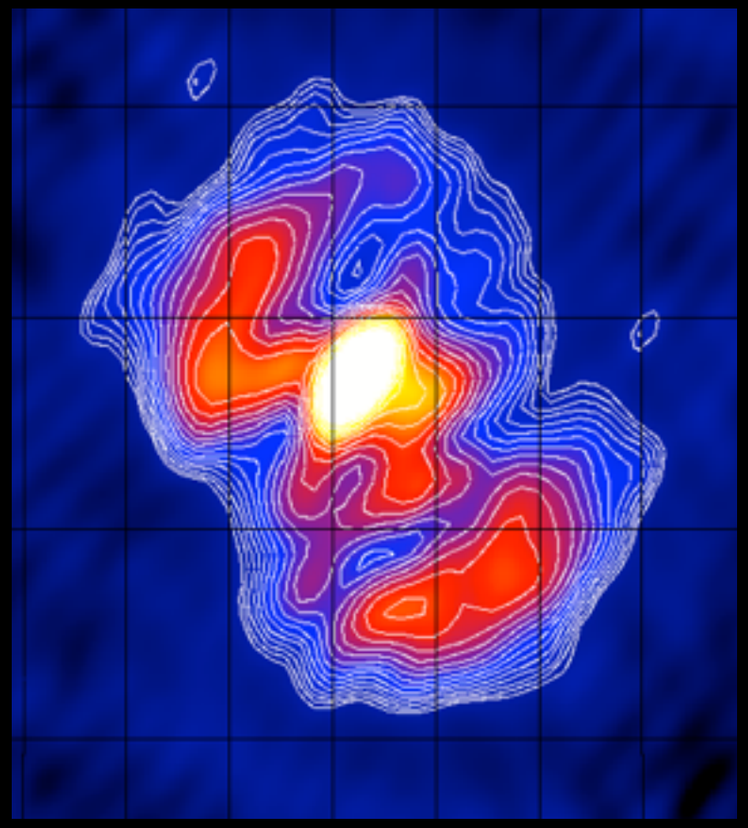




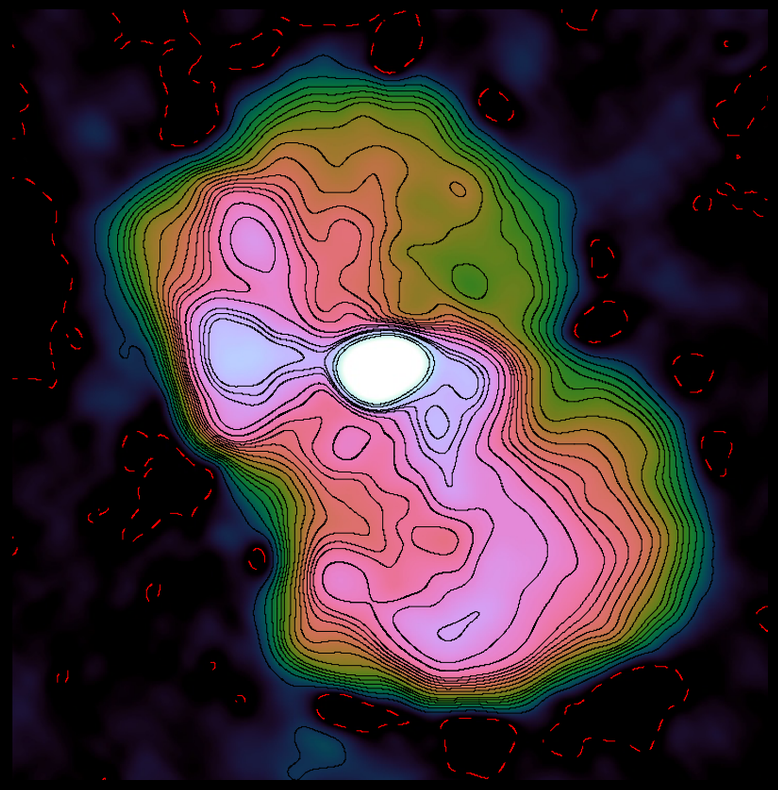
Virgo A
LOFAR LBA (46 MHz)
rms: 30 mJy/b
beam: 16”x17”
dyn range: 7500

Expected flux: 3120 Jy
Measured flux: 3004 Jy

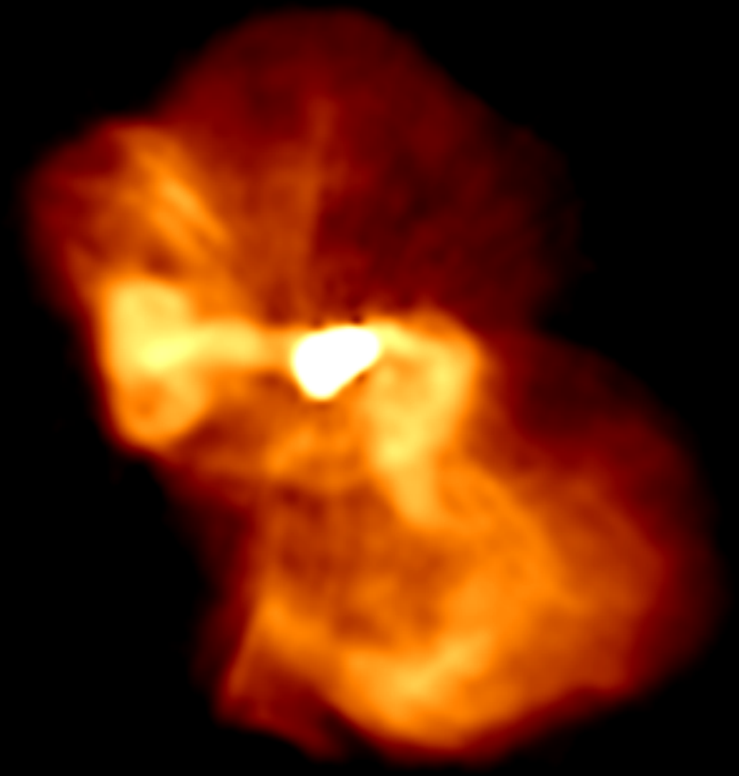
M87 with LOFAR LBA



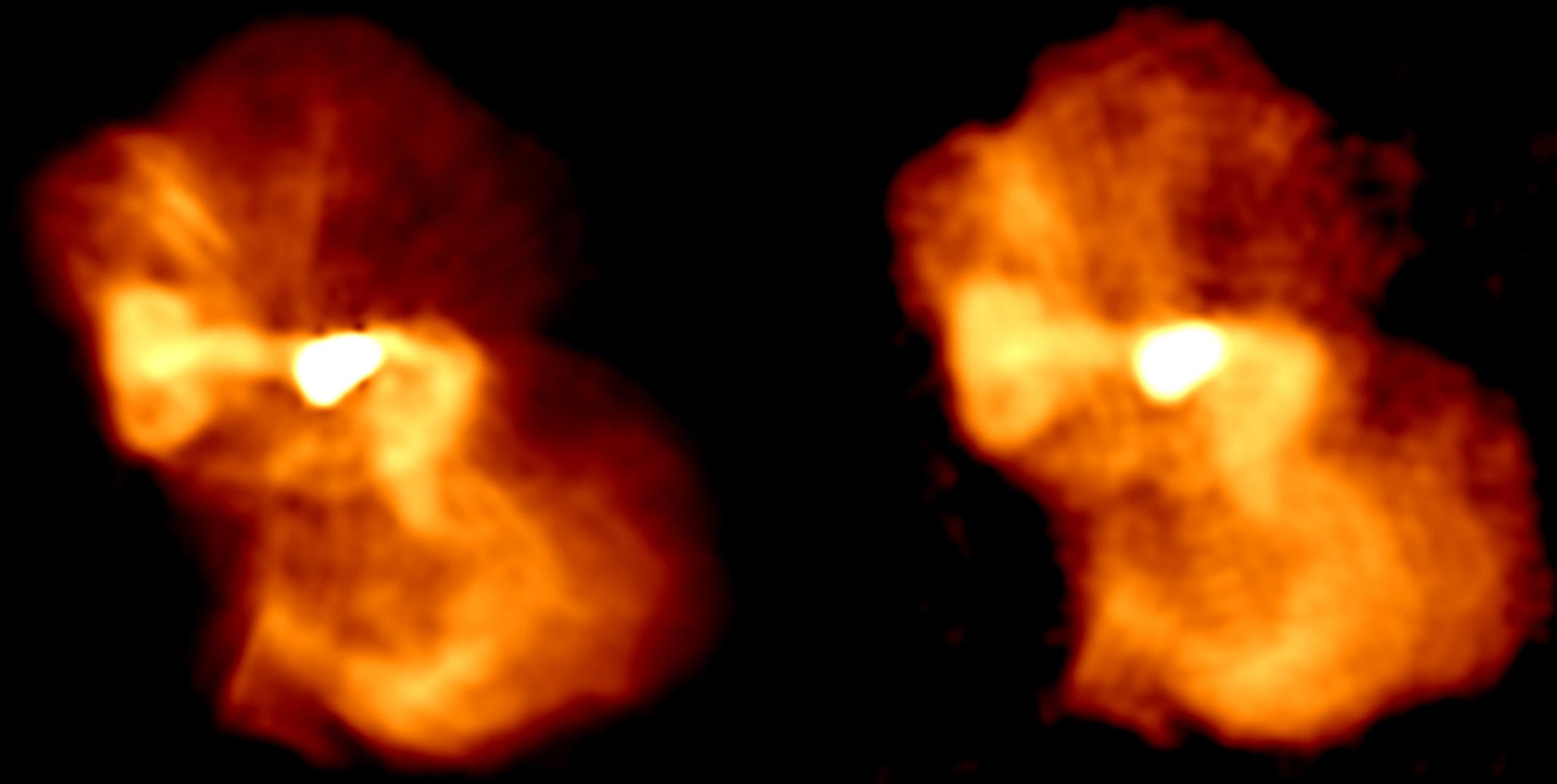
2010



2012

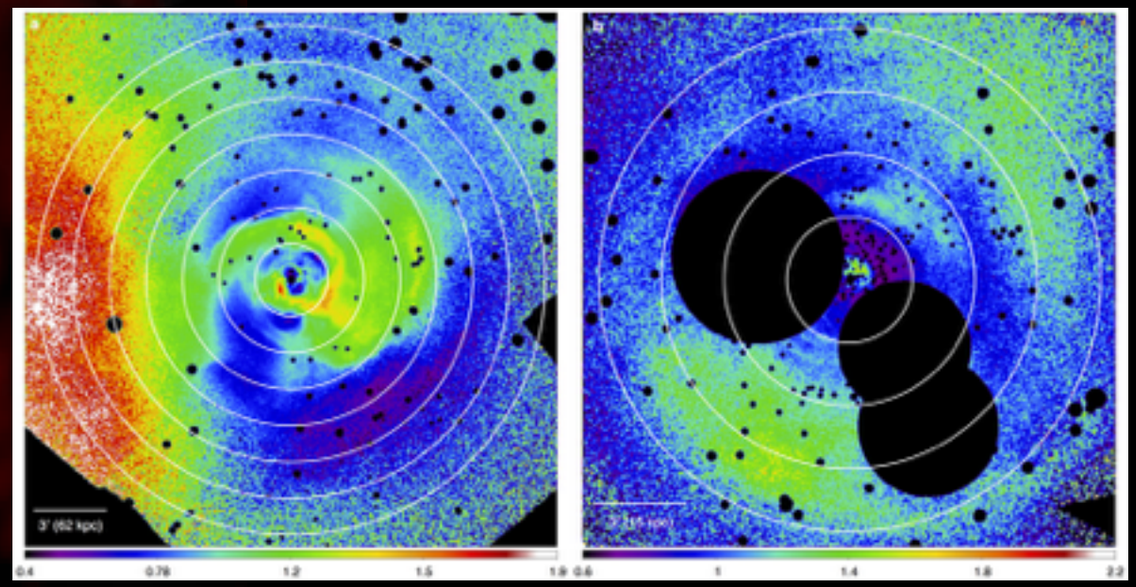


2015

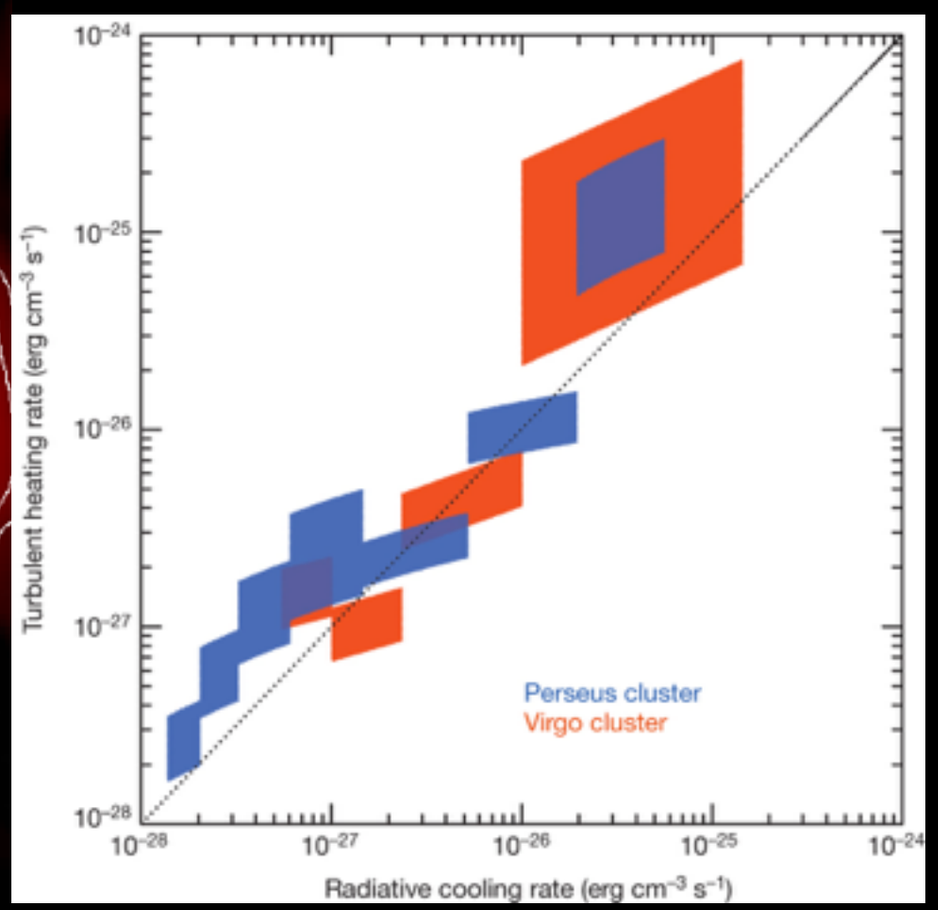


LOFAR 46 MHz

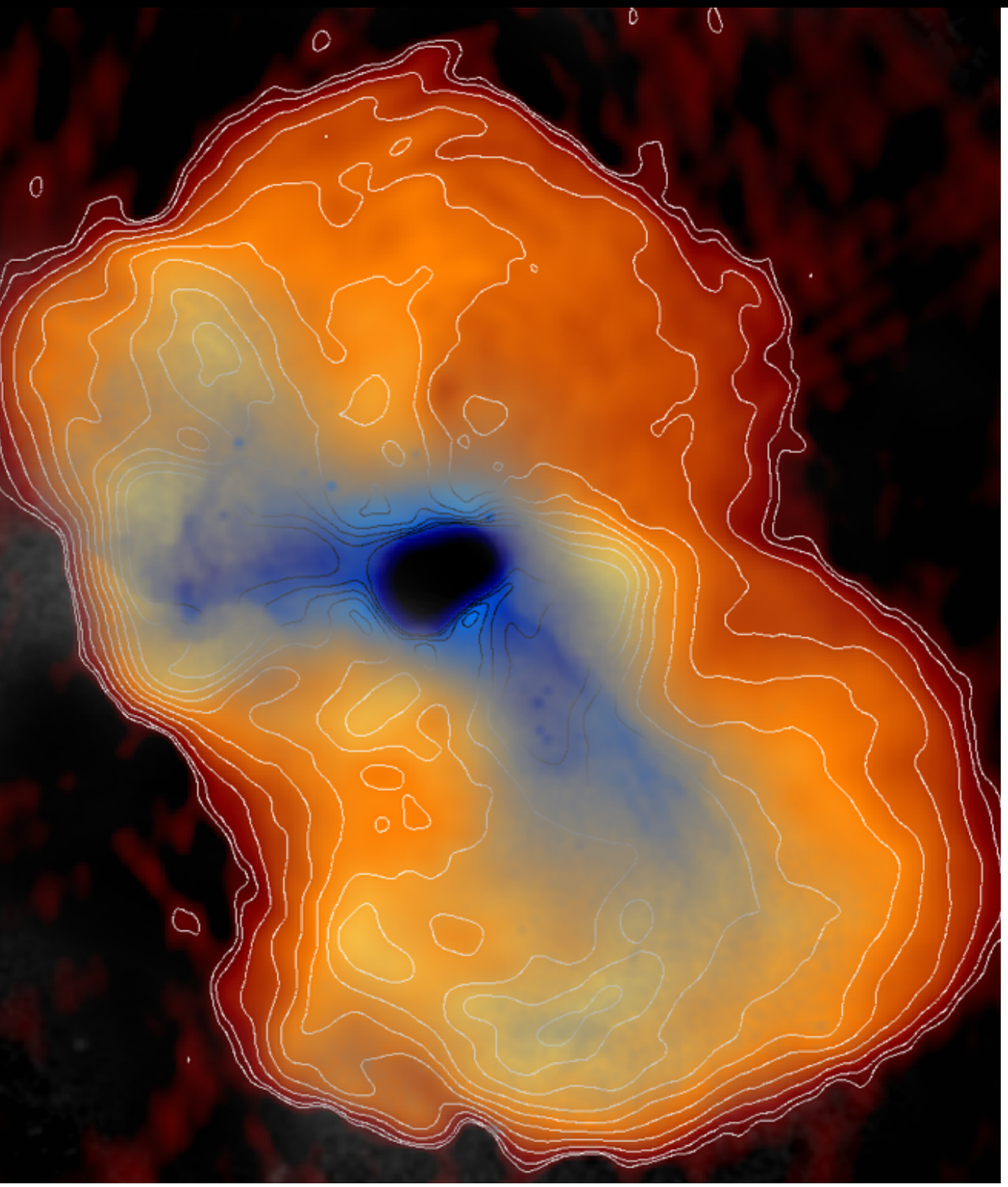
VLA 74 MHz

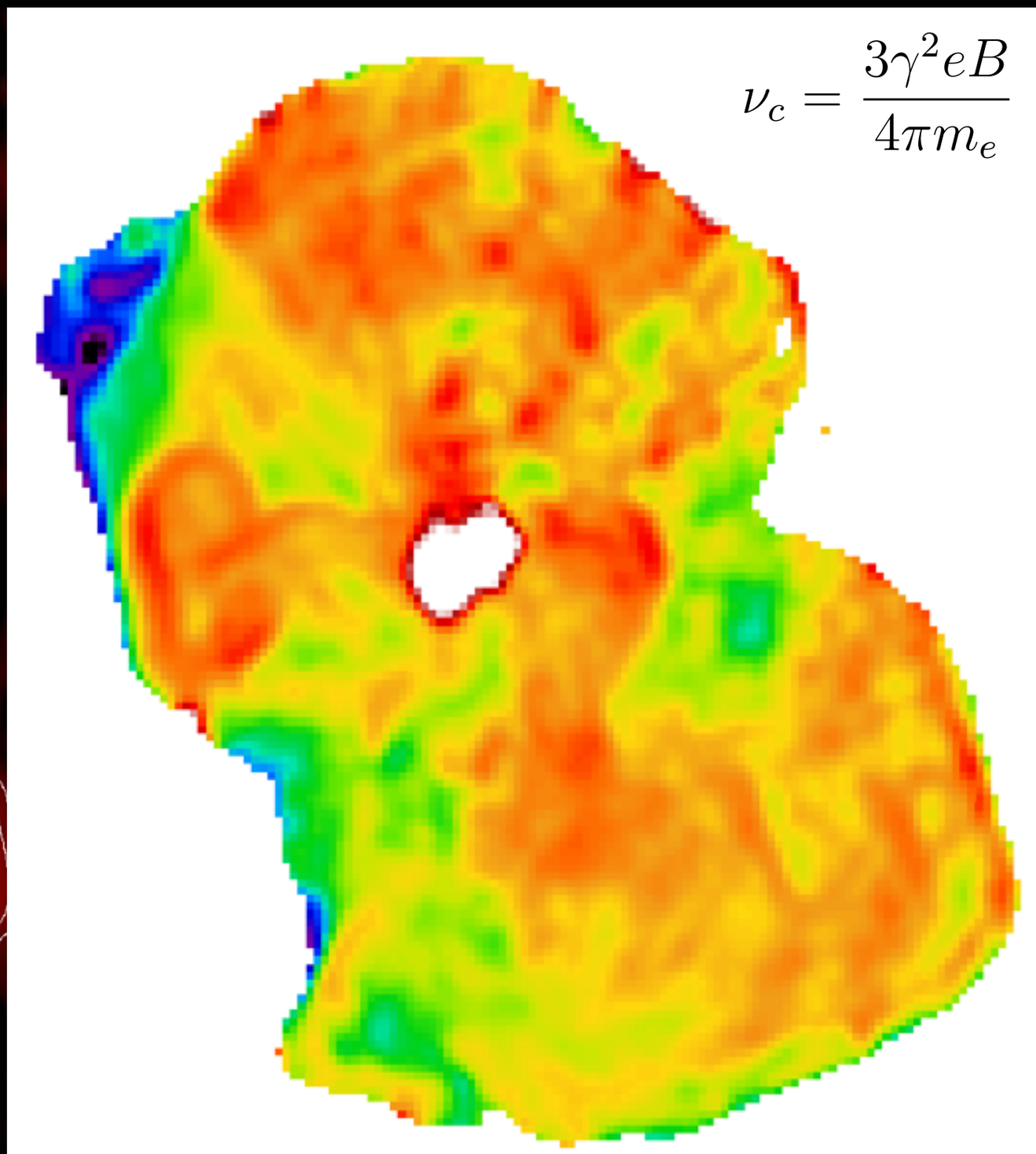


Zhuravleva+ 2014



46-330 MHz spectral index map





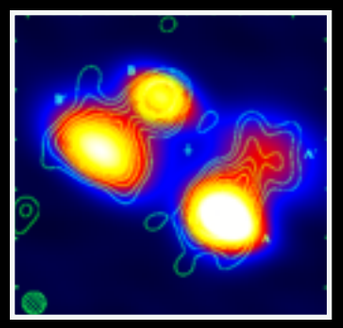
Curved injection+higher B? Reacceleration?

Strategy II: weak target

Obs strategy: 244 SB on cal, 244 SB on target

Pre processing: demix + avg to 4 chan / 1 sec

Same as for strong targets



1: calibrator (3C196)

BBS on calibrator

Diag(G) + rot ang
<30 MHz: divide SB

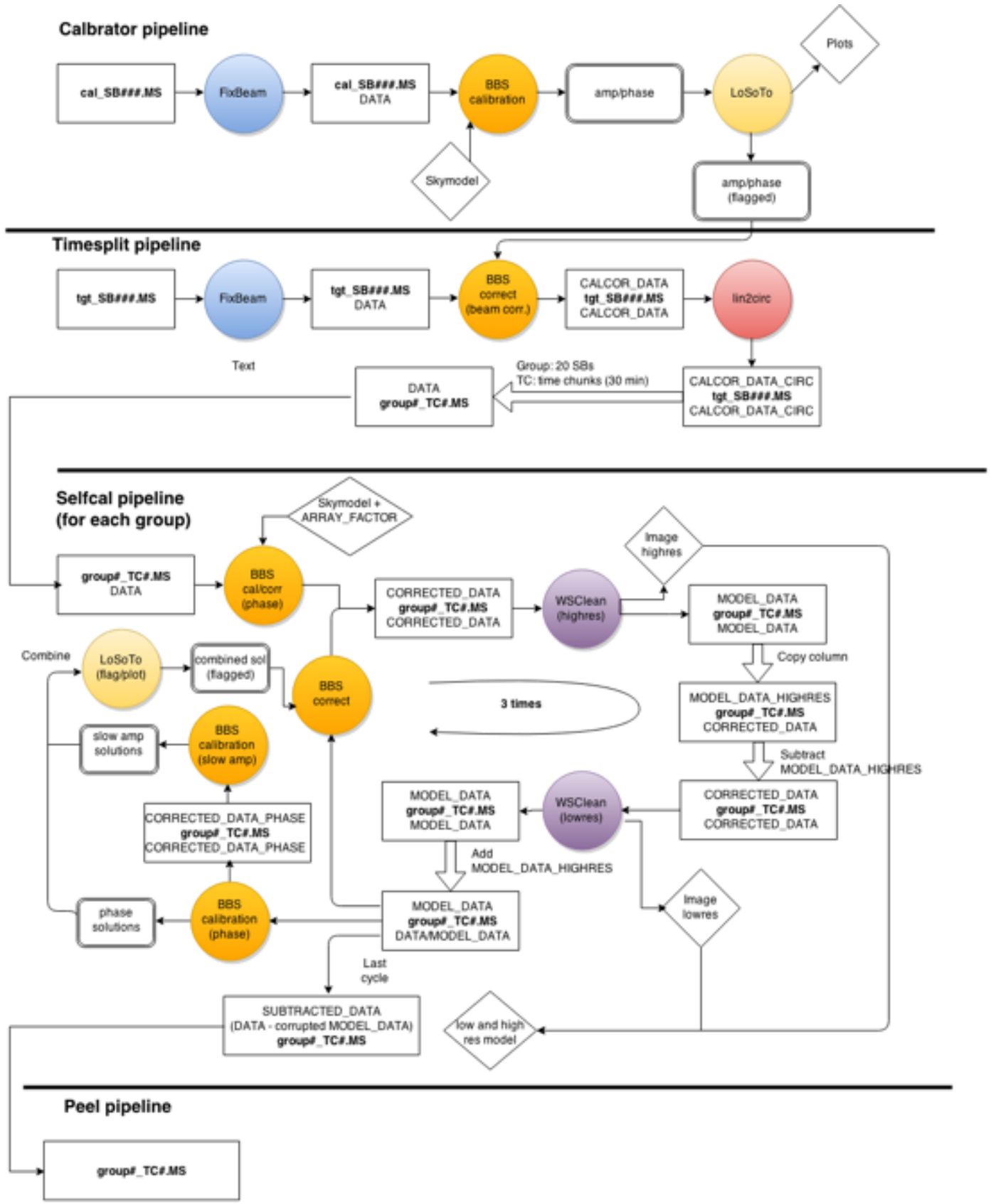
LoSoTo

C-T separation
(diagnostic) + flag

Cor on target

Transfer A+P (solve clock but dTEC)

Same pre-calibration of the strong target strategy



"your pipeline is very similar to a DDOS attack"

II: self-cal loop

On blocks of 20 SBs

Self-cal on target

Subtract field

To be repeated for each peel calibrator

Peel of bright source

BBS selfcal

Fast ScalarPhase+TEC and slow (5min) Gain

BBS selfcal

Fast ScalarPhase+TEC

Concat

10 SBs to improve S/N

Clean high-res

5x5 deg, WSclean, automasking

Clean low-res

15x15 deg, WSclean, automasking

3, 4 loop

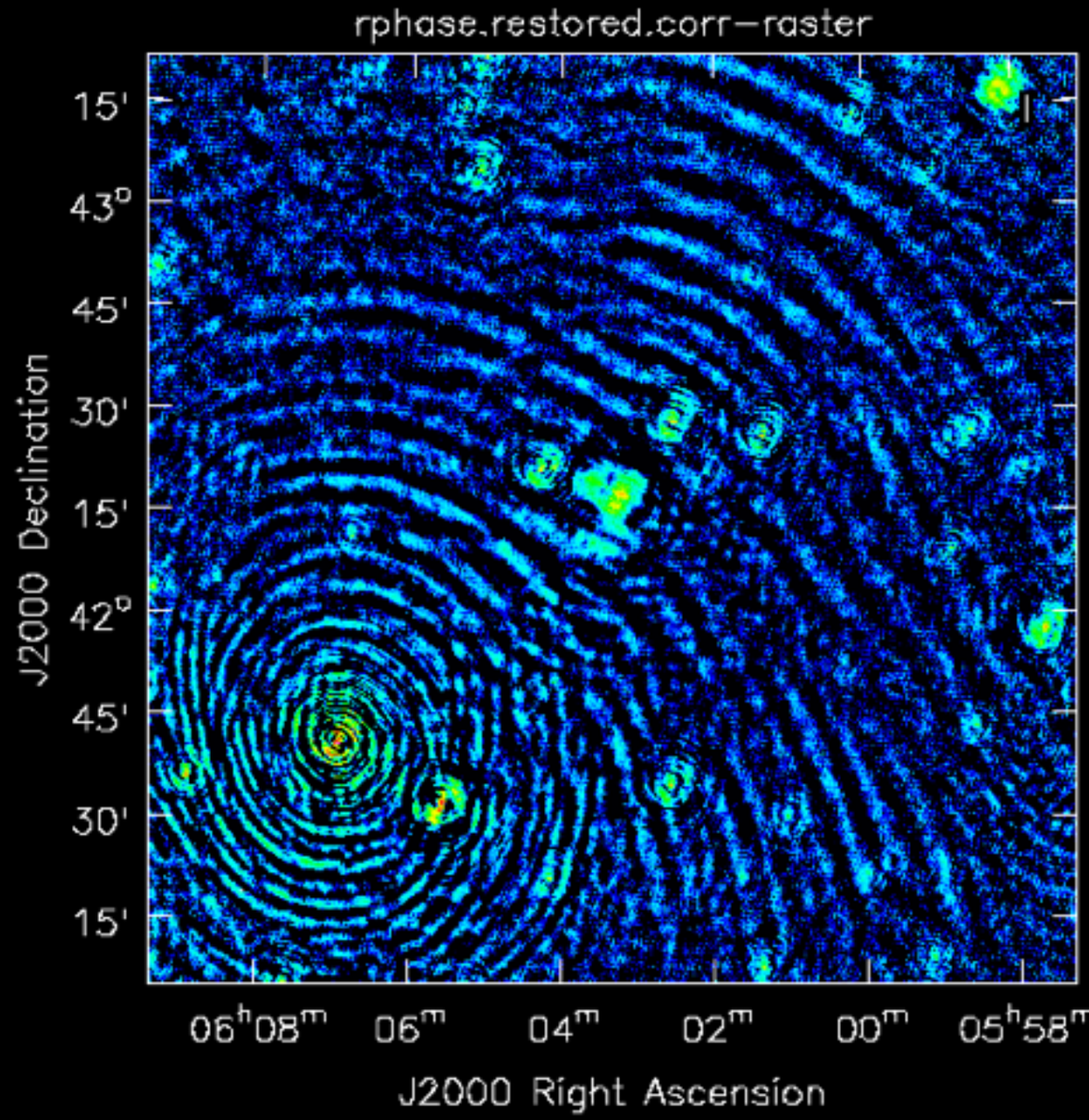
1, 2 loop

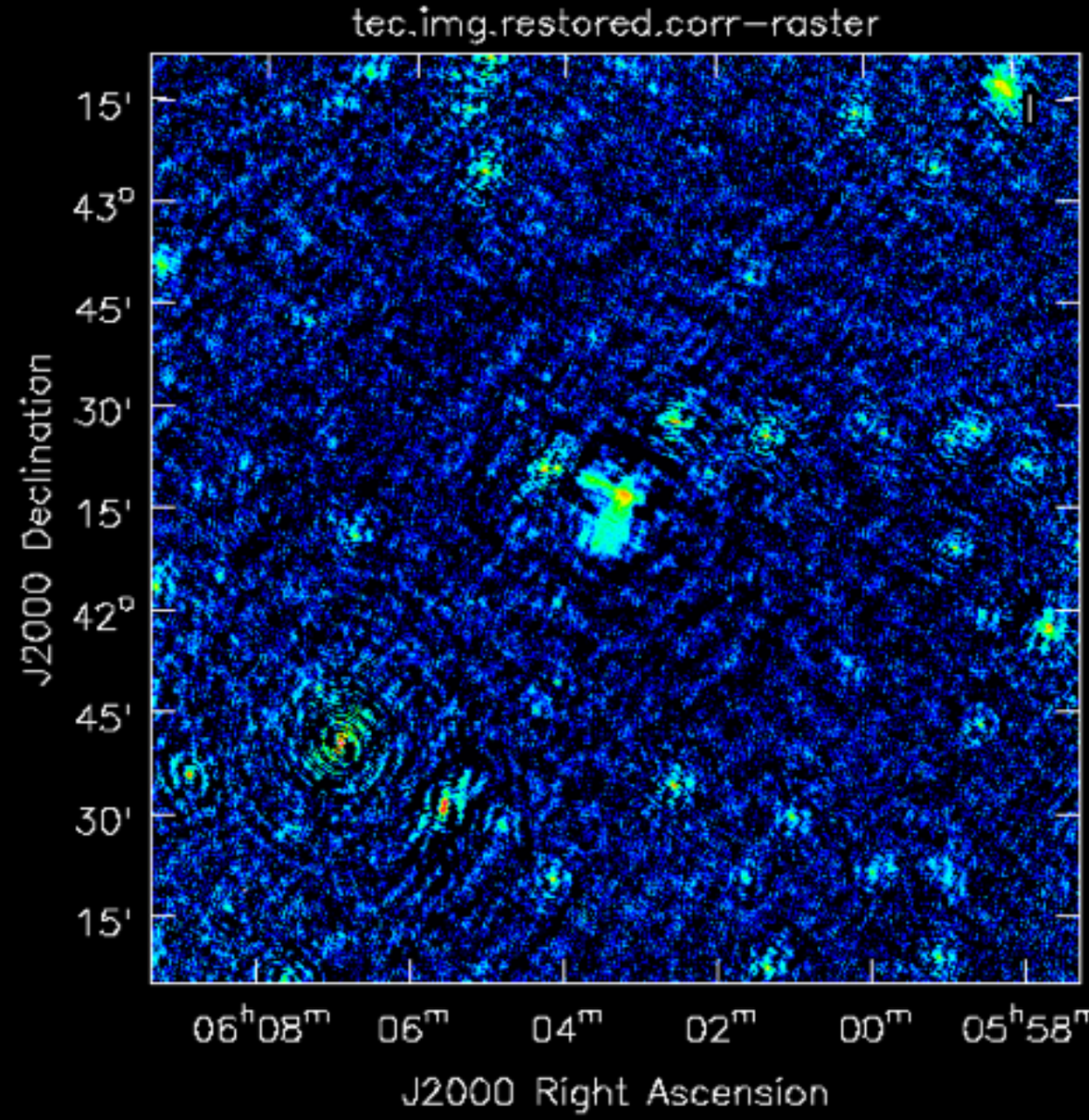
finally

Source subtraction

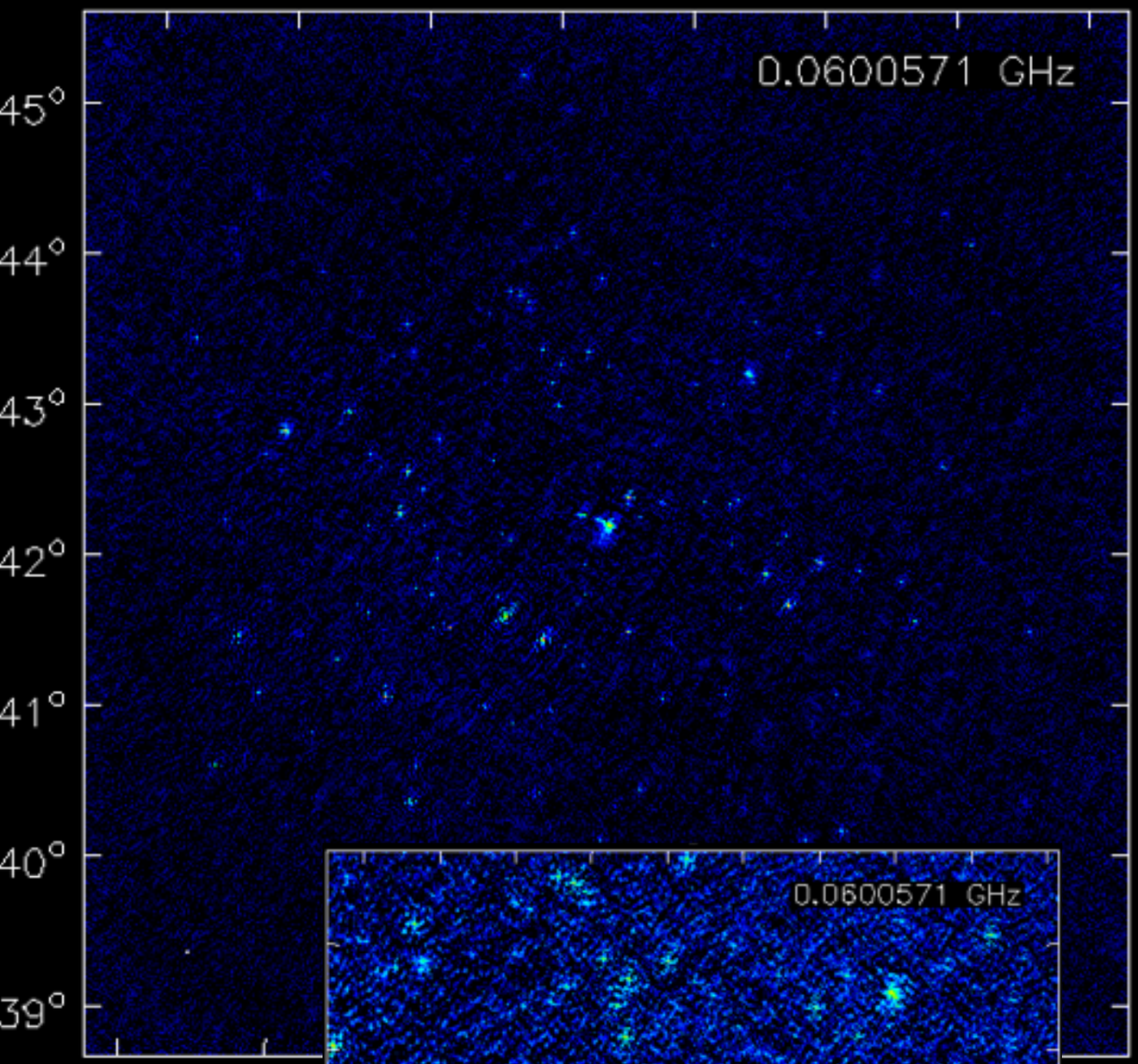
Leave an empty dataset + models every 10 SBs

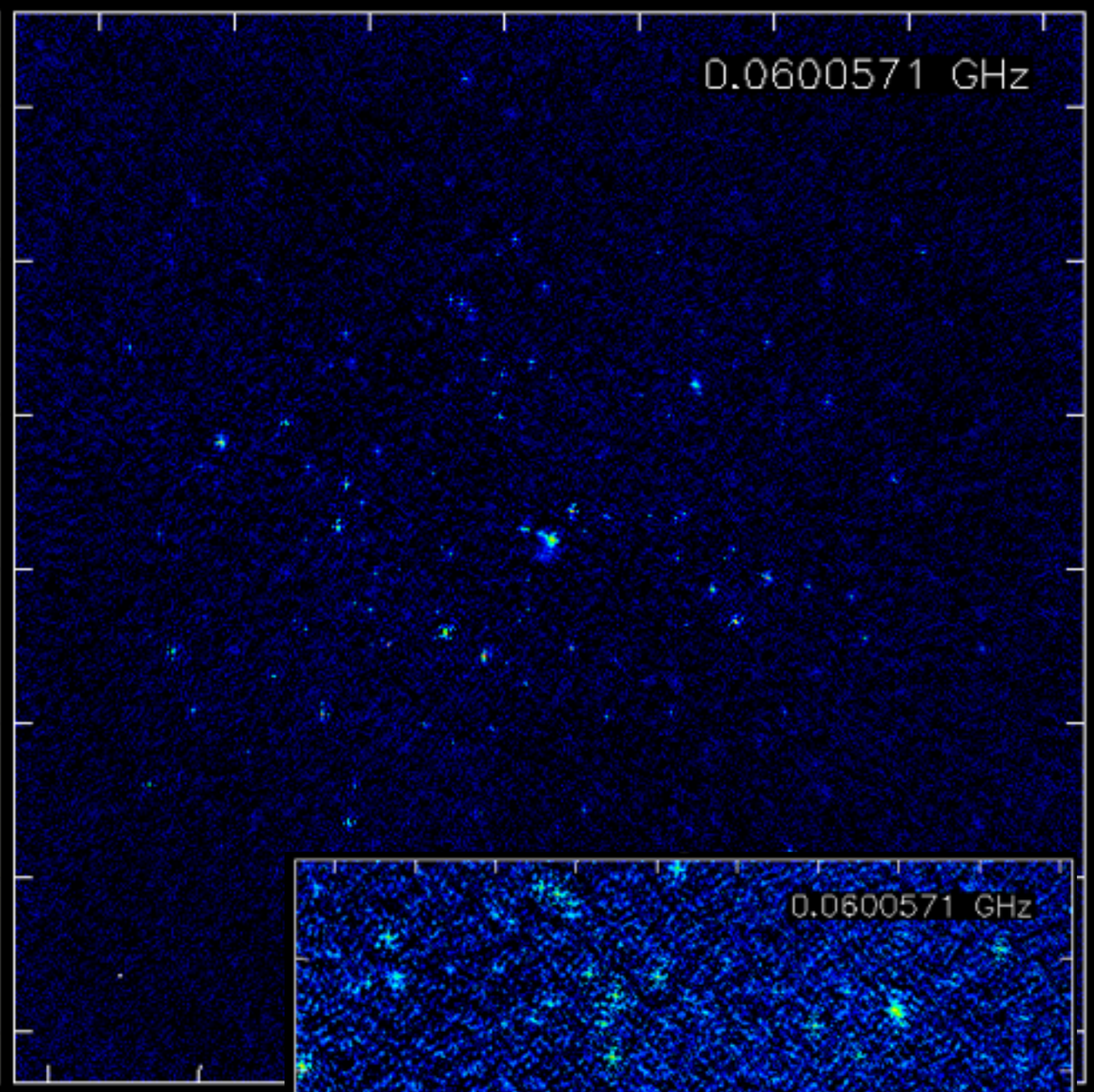
Is TEC important?

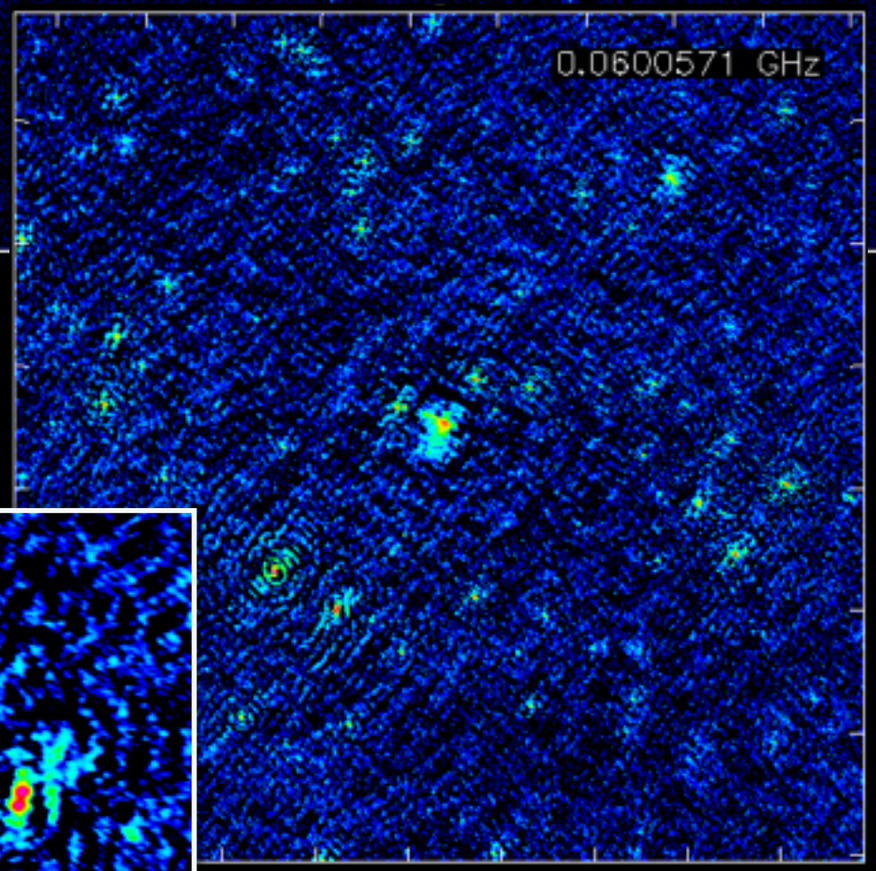


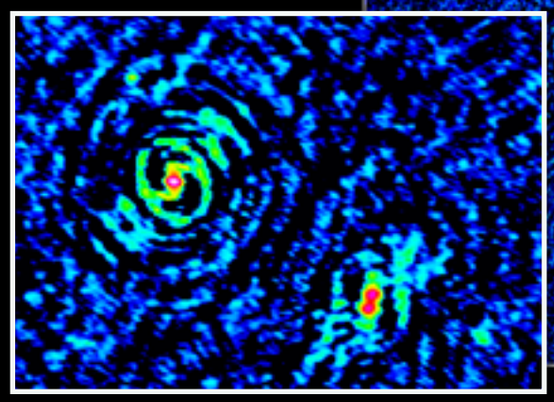


Credits: K. Emig



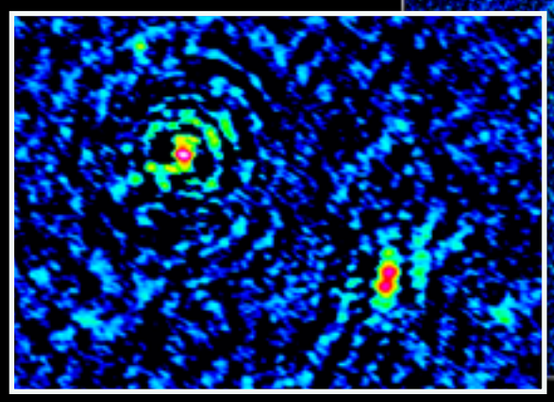


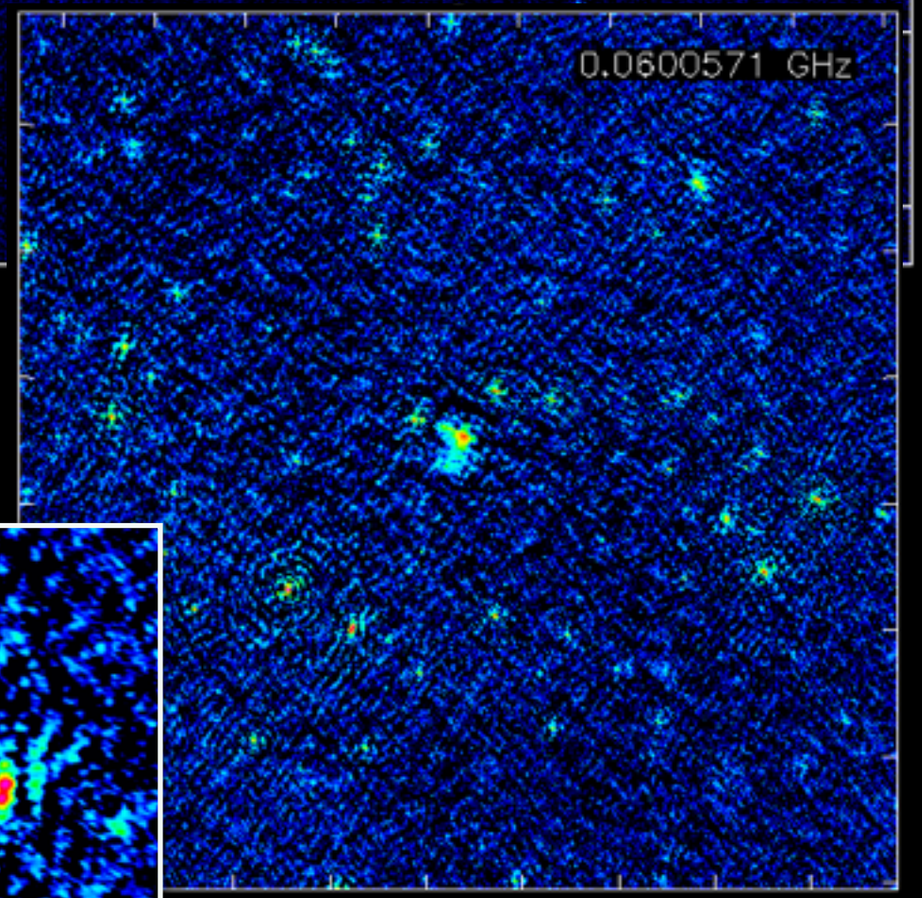




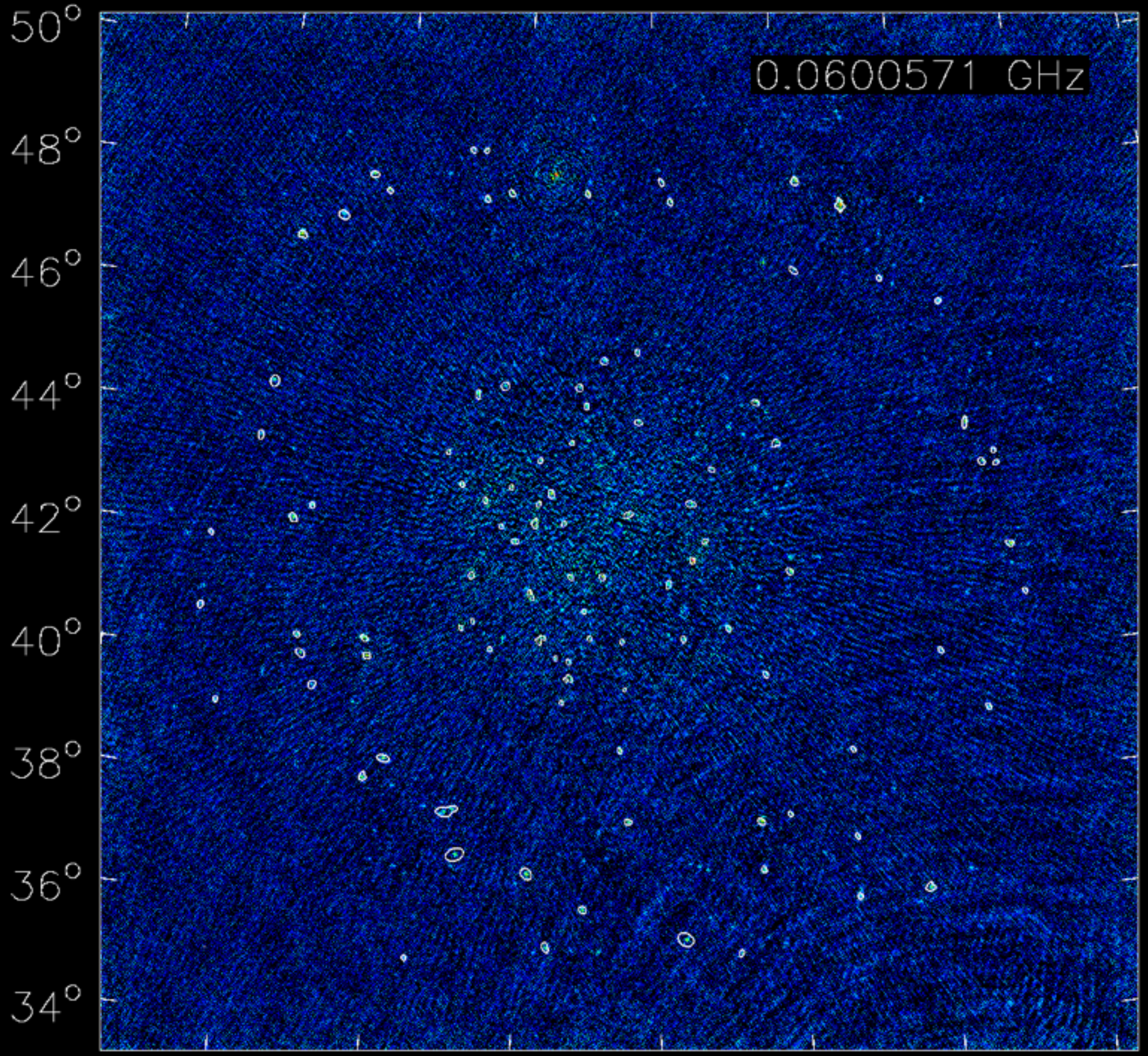
rms~7 mJy/b

b~22”x37”





b~60”x76”


0.0600571 GHz
50°
48°
46°
44°
42°
40°
38°
36°
34°
06h36m
24m
12m
00m
05h48m
36m
24r

II: self-cal loop

On all available SBs
(now tested on 30)

Self-cal on target

Subtract field

To be repeated for each peel calibrator

Peel of bright source

Concat + ph rotate

All SBs to improve S/N, PR in source dir and add model back

Clean

CASA (nterm=2), automasking, make initial CC model

BBS selfcal

Fast ScalarPhase+TEC and slow (5min) Gain

BBS selfcal

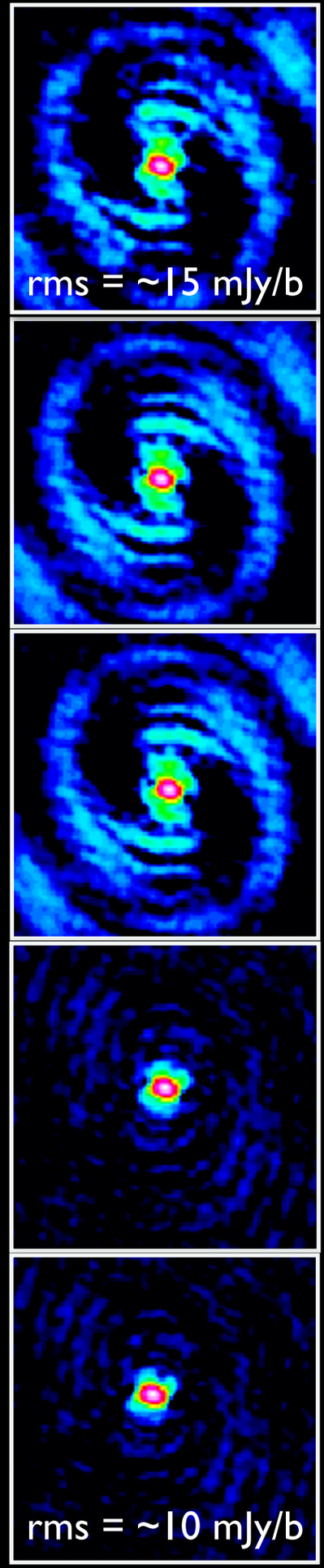
Fast ScalarPhase+TEC

Clean

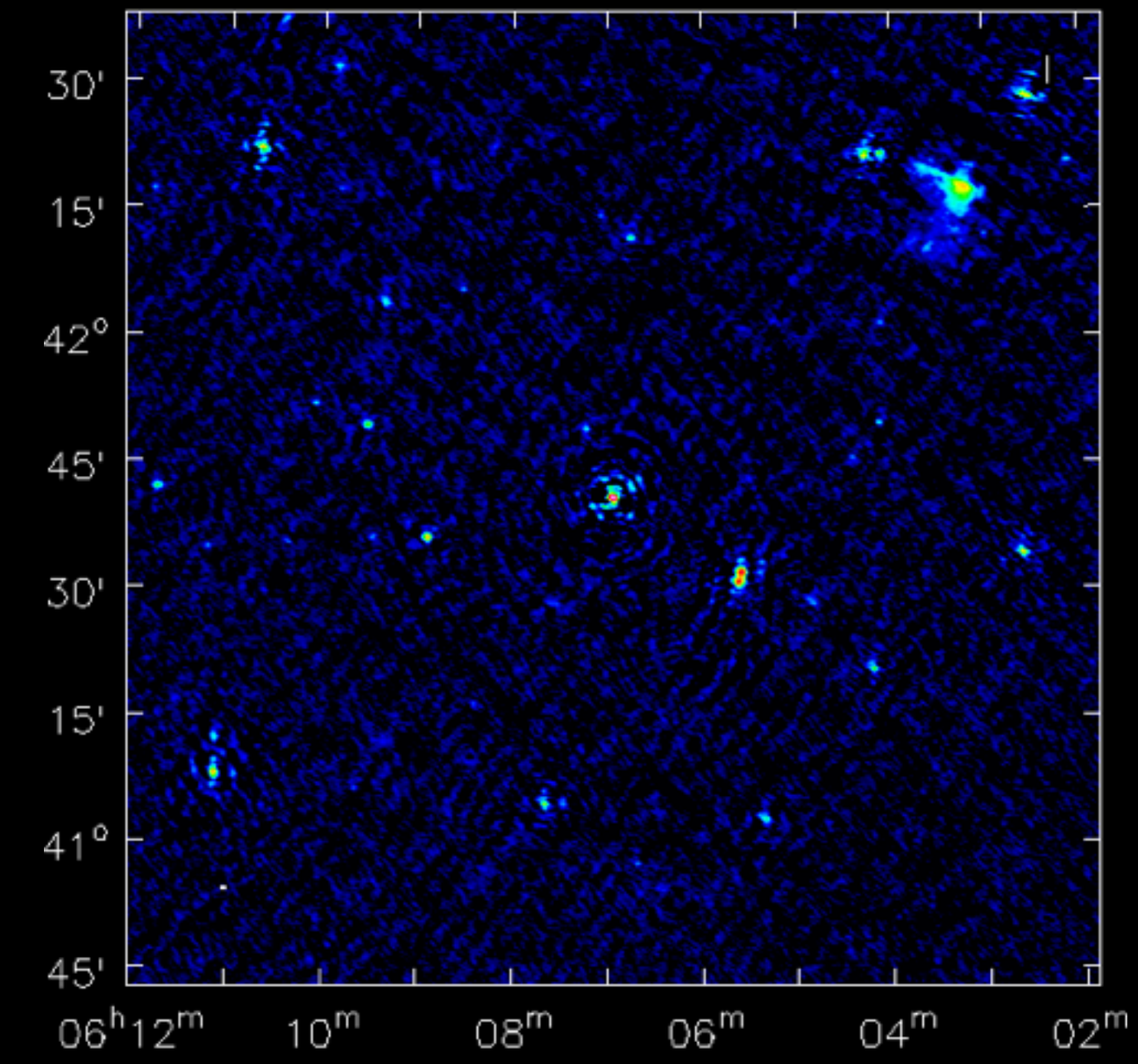
CASA (nterm=2), automasking

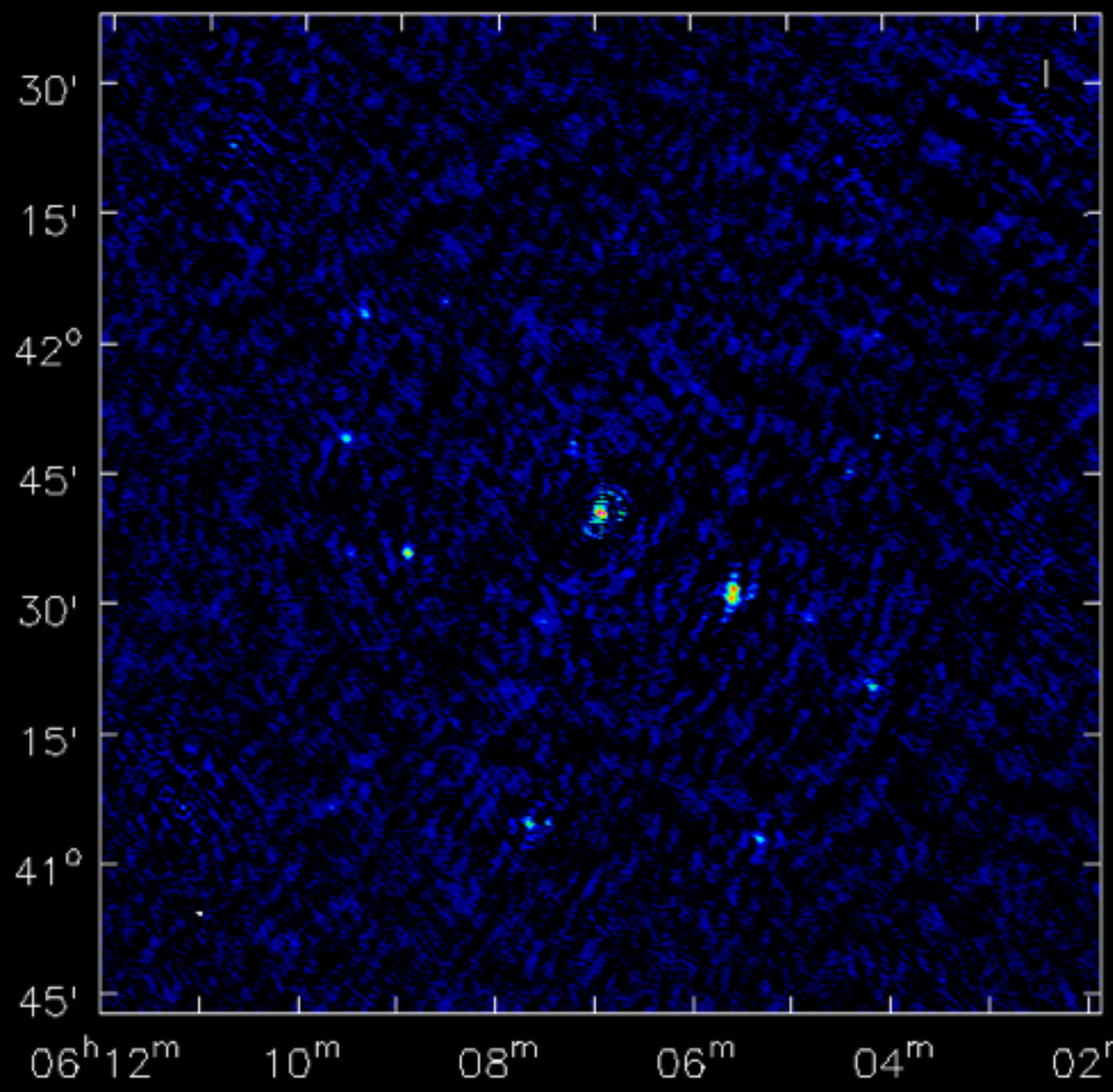
3, 4 loop

1, 2 loop



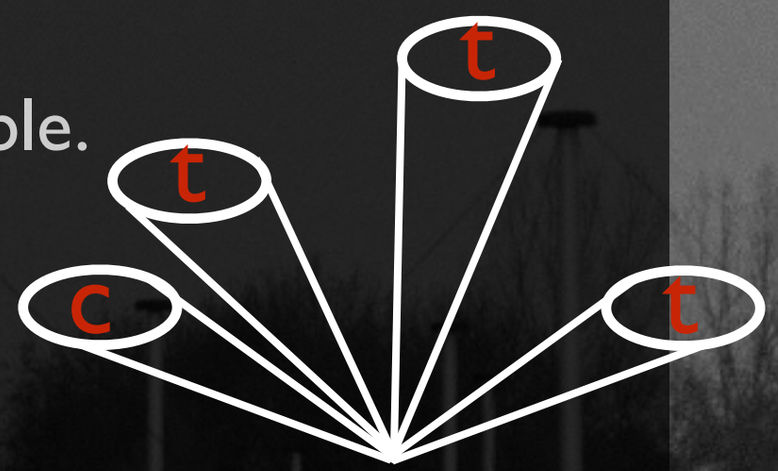
On a facet


30'
15'
42°
45'
30'
15'
41°
45'
06h12m
10m
08m
06m
04m
02m


30'
15'
42°
45'
30'
15'
41°
45'
06h12m
10m
08m
06m
04m
02m

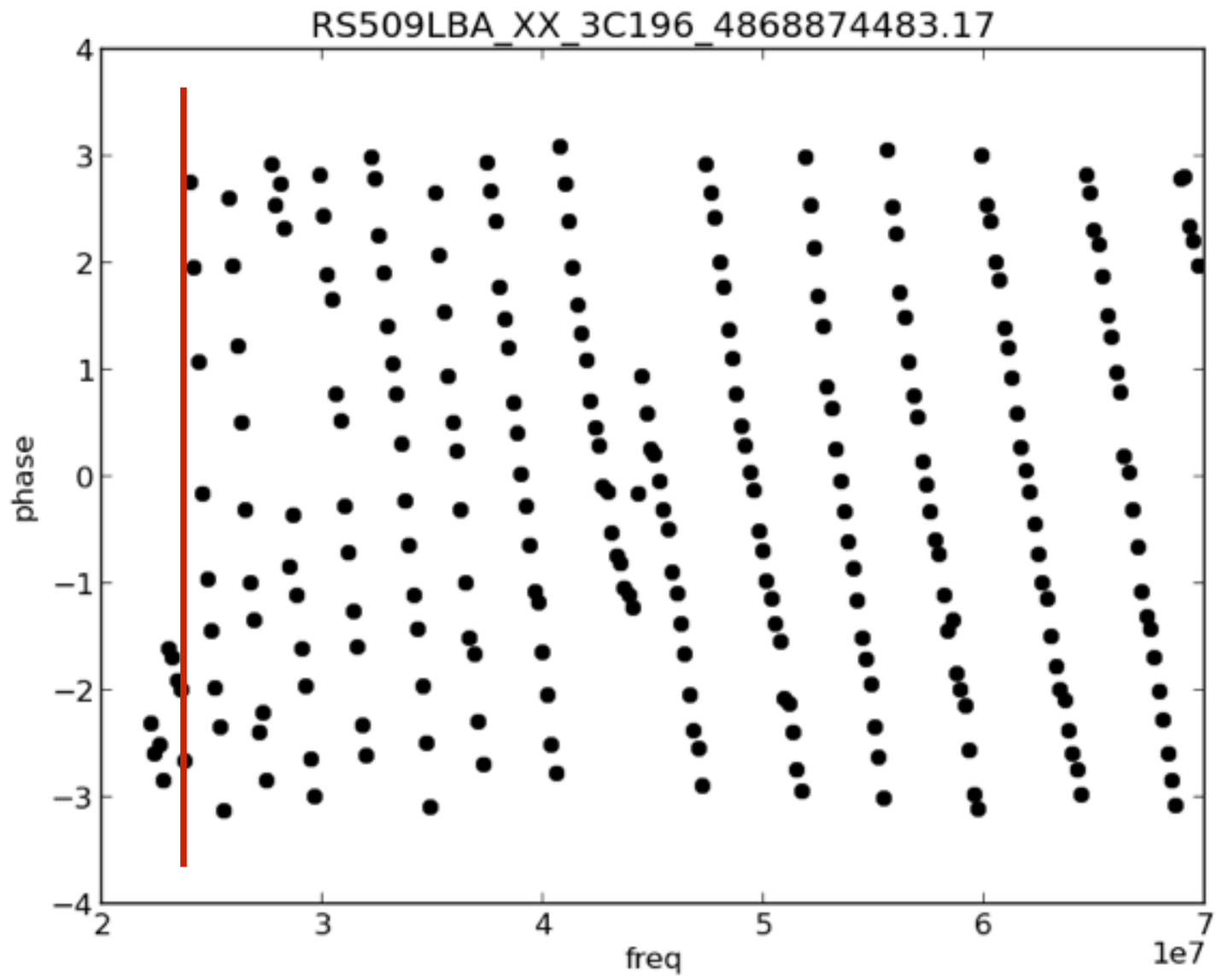
The future of LBA

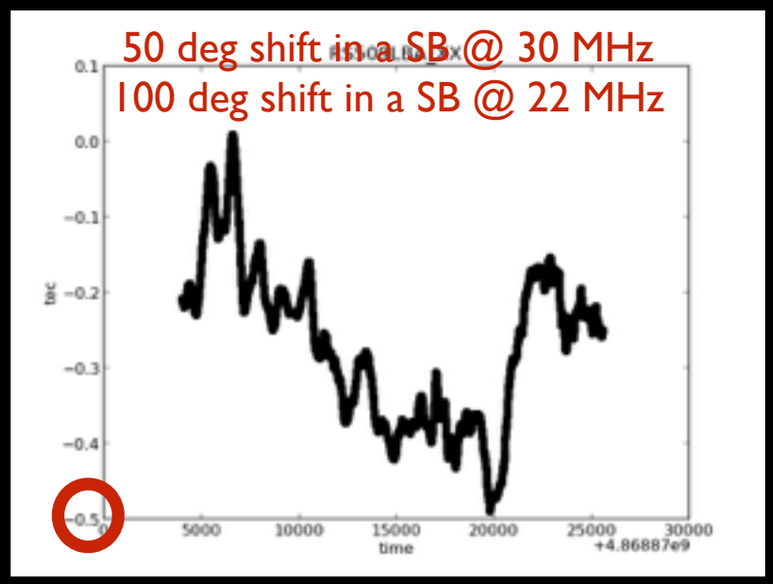
- In the SKA era, LBA will keep LOFAR unique
- Bad bandpass and low S/N are major issues.
  Data at very low-freq (<40 MHz) are hardly usable.



On-going projects:

- A-team observation with international stations
  (VirA & CygA done, CasA & TauA will come)
- LOFAR sky survey - LBA:
  - LBA_INNER (or maybe LBA_SPARSE)
  - Band limited to highest S/N region: max survey speed
    (1/3 of HBA time)
  - pipeline based on “weak target” example


RS509LBA_XX_3C196_4868874483.17
phase
freq
1e7
4
3
2
1
0
−1
−2
−3
−4
2
3
4
5
6
7


50 deg shift in a SB @ 30 MHz
100 deg shift in a SB @ 22 MHz
tec
time
+4.86887e9
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
5000
10000
15000
20000
25000
30000