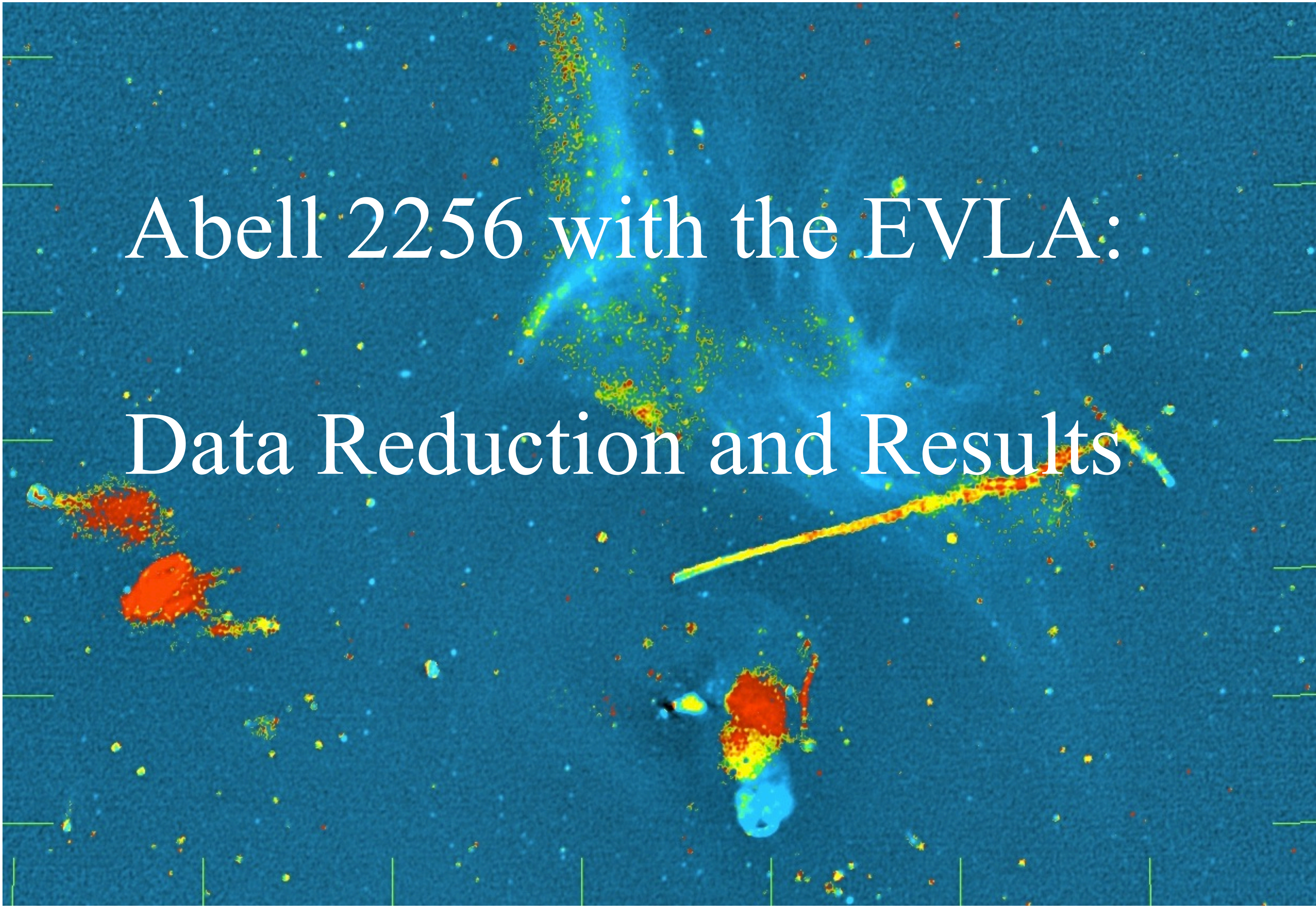
Abell 2256 with the EVLA:

Data Reduction and Results



Practical Limitations of this talk

- Data reduction with the EVLA is too complicated to describe in full detail in a < 1 hour talk.

- I will assume some knowledge of how one reduced data from the old VLA and try to hit the high points of the new reduction techniques.

- Some of those (e.g. MSMFS imaging and RM Synthesis) are at least a full talk themselves so I will only briefly describe the techniques themselves and how to use them.

Talk Structure

1) Basic Reductions

2) Imaging

3) RM Synthesis

Associated Results for A2256 after 2), 3)

Reduction Techniques/ Abell 2256 Contributers

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EVLA data reduction

- Evolving Situation
- Right Now need combination of AIPS/CASA
- < 8 GHz AIPS for basic calibration, CASA for imaging, AIPS for RM Synthesis
- Eventually CASA will do it all but has some holes now

AIPS, OBIT,CASA

- AIPS, right now, is most complete package for calibration (especially Appendix E) http://www.aips.nrao.edu/CookHTML/Cookbook.html

- OBIT useful, especially for data loading into AIPS (BDF2AIPS in AIPS): http://www.cv.nrao.edu/~bcotton/Obit.html

- CASA is the future but right now only best for wide-band, wide-field imaging: Best current reference for CASA: https://science.nrao.edu/facilities/evla/early-science/data-reduction-workshop September 2011/program

Data Loading from Archive

1) Can load data directly into CASA or make UVFITS file for AIPS.

2) Better way is to ask permission from help desk to download SDM-BDF and then run BDFLIST and BDF2AIPS in AIPS to load data directly into AIPS. Needs OBIT installed and run on Linux machine.

AIPS Calibration/Editing

- Online Cookbook appendix E is best reference.

- Mostly like VLA, but with additions for wide bandwidths and new hardware.

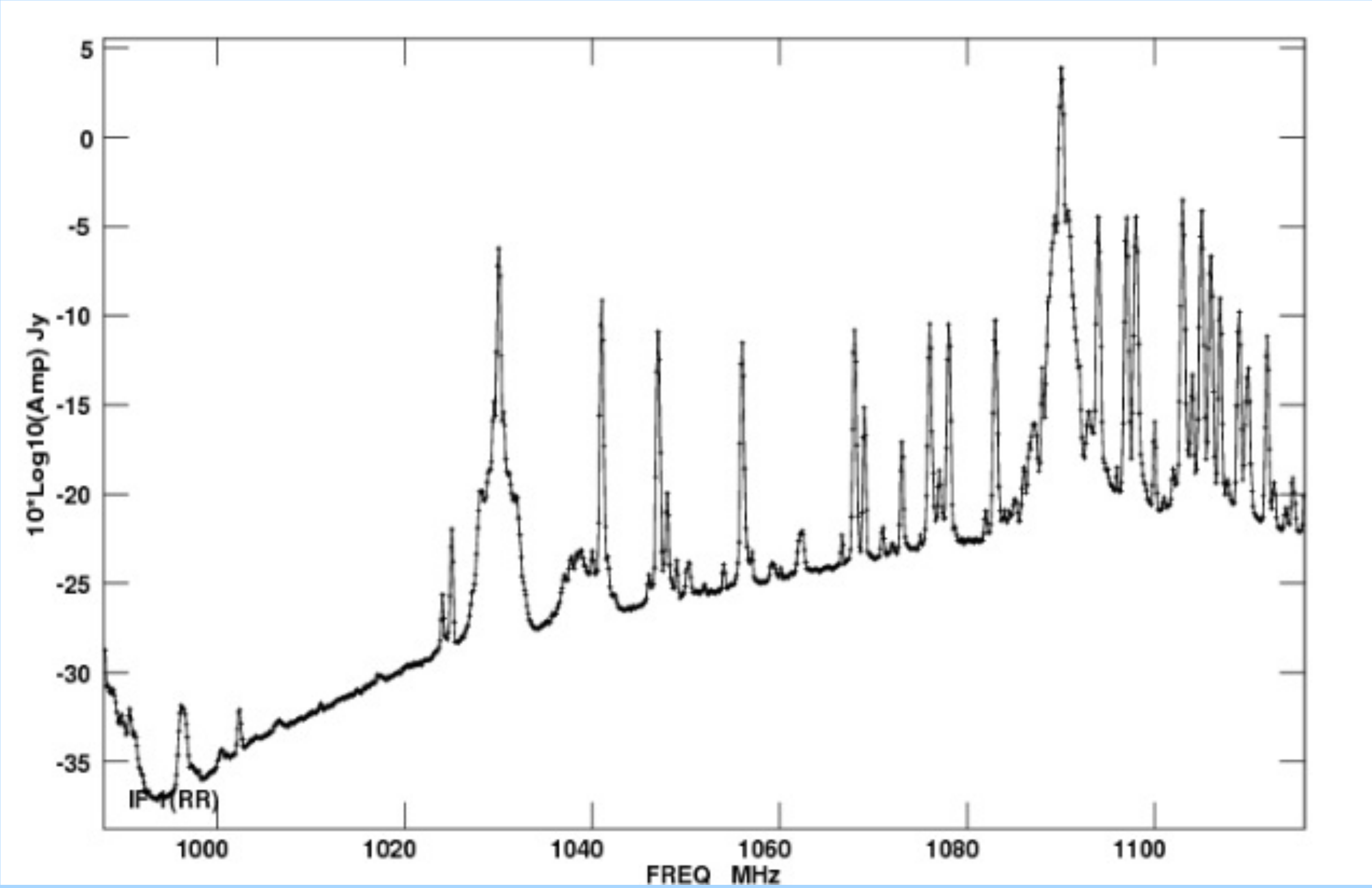
- UV editing: UVFLG, RFLAG, EDITA.

- UV data weights: REWAY.

RFI in L-band (1-2 GHz)

At first look, RFI situation looks hopeless but it turns out it is not so bad.

RFI in Lband (1-2 GHz)



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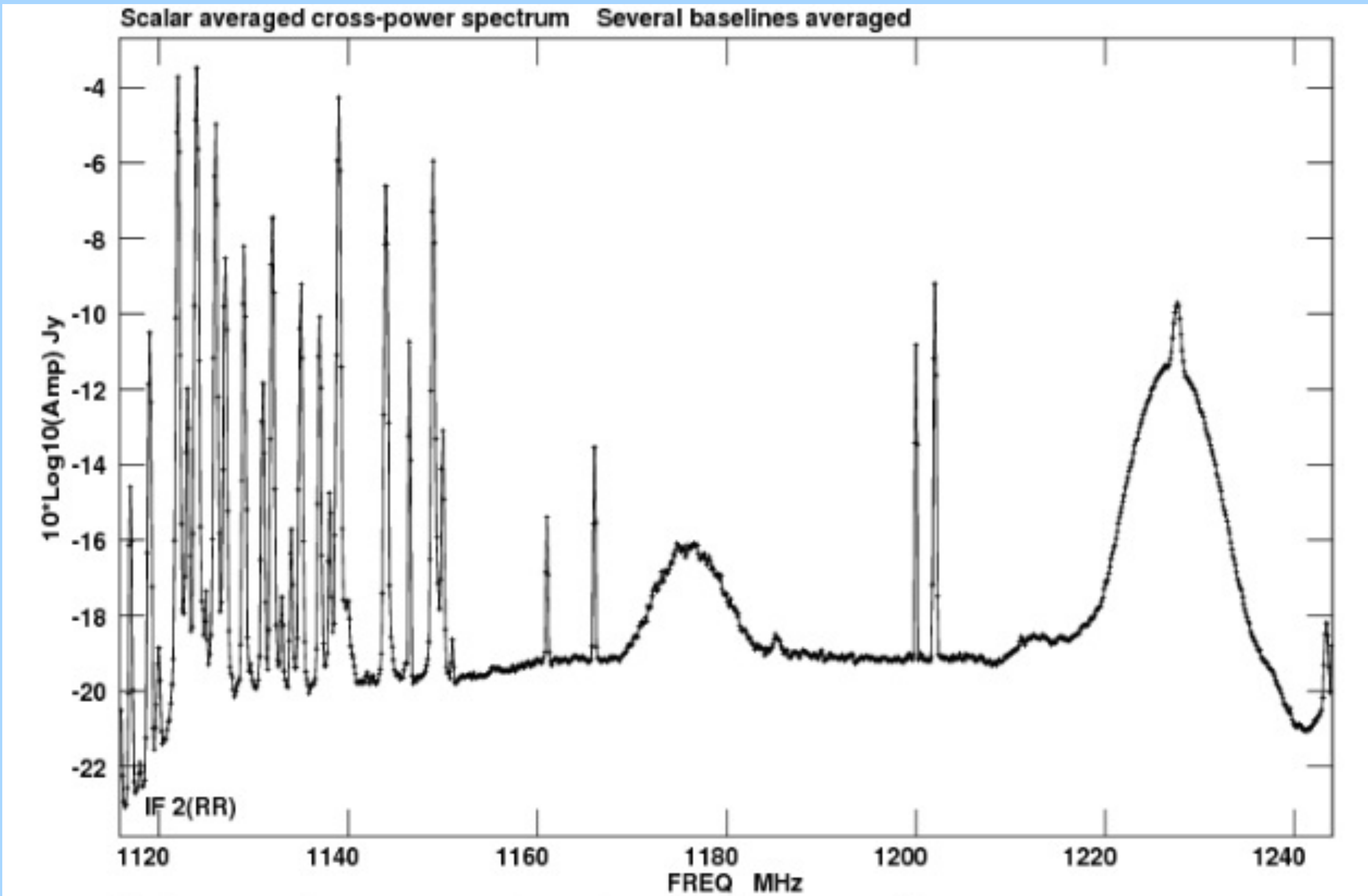
RFI in Lband (1-2 GHz)



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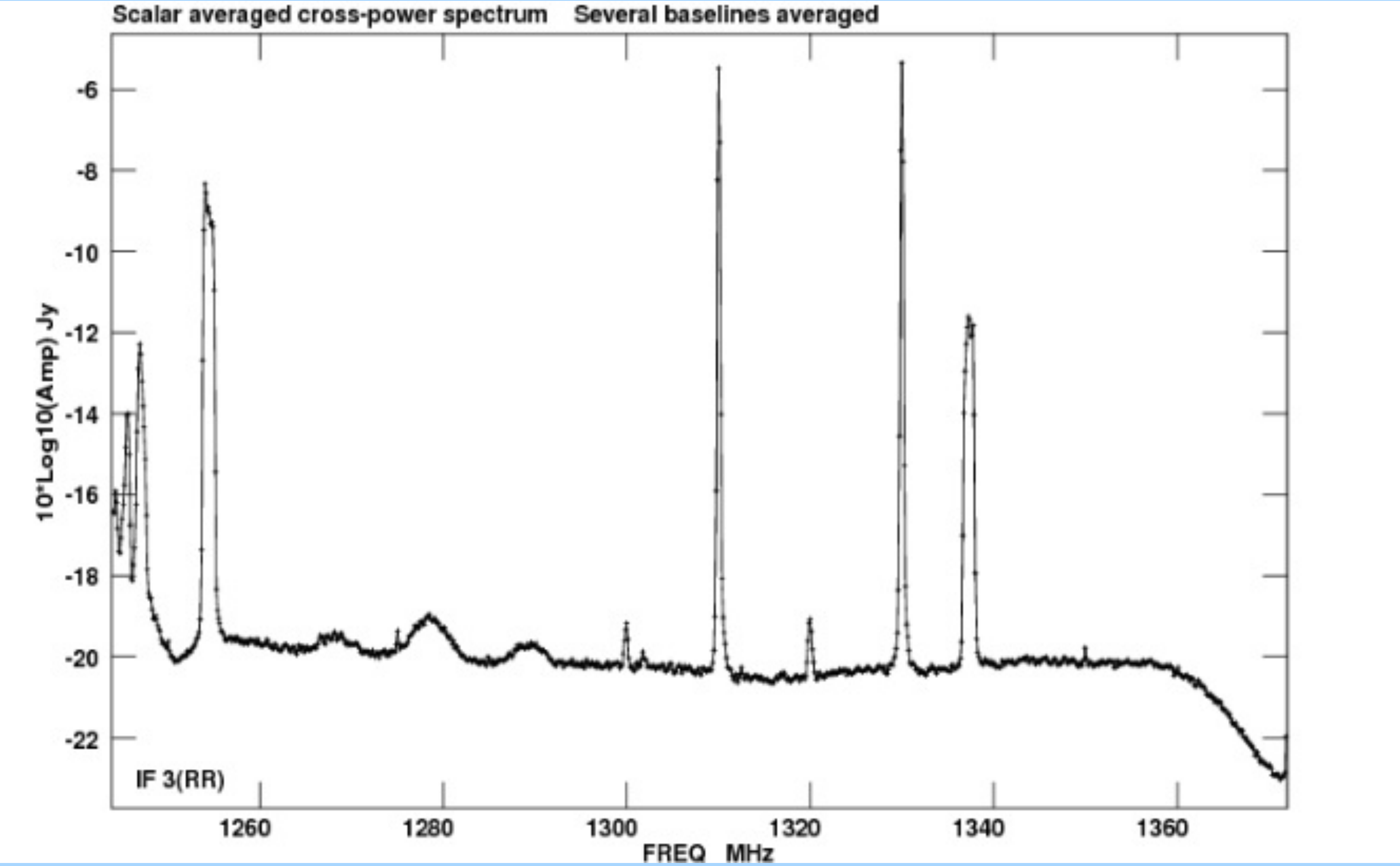
RFI in Lband (1-2 GHz)



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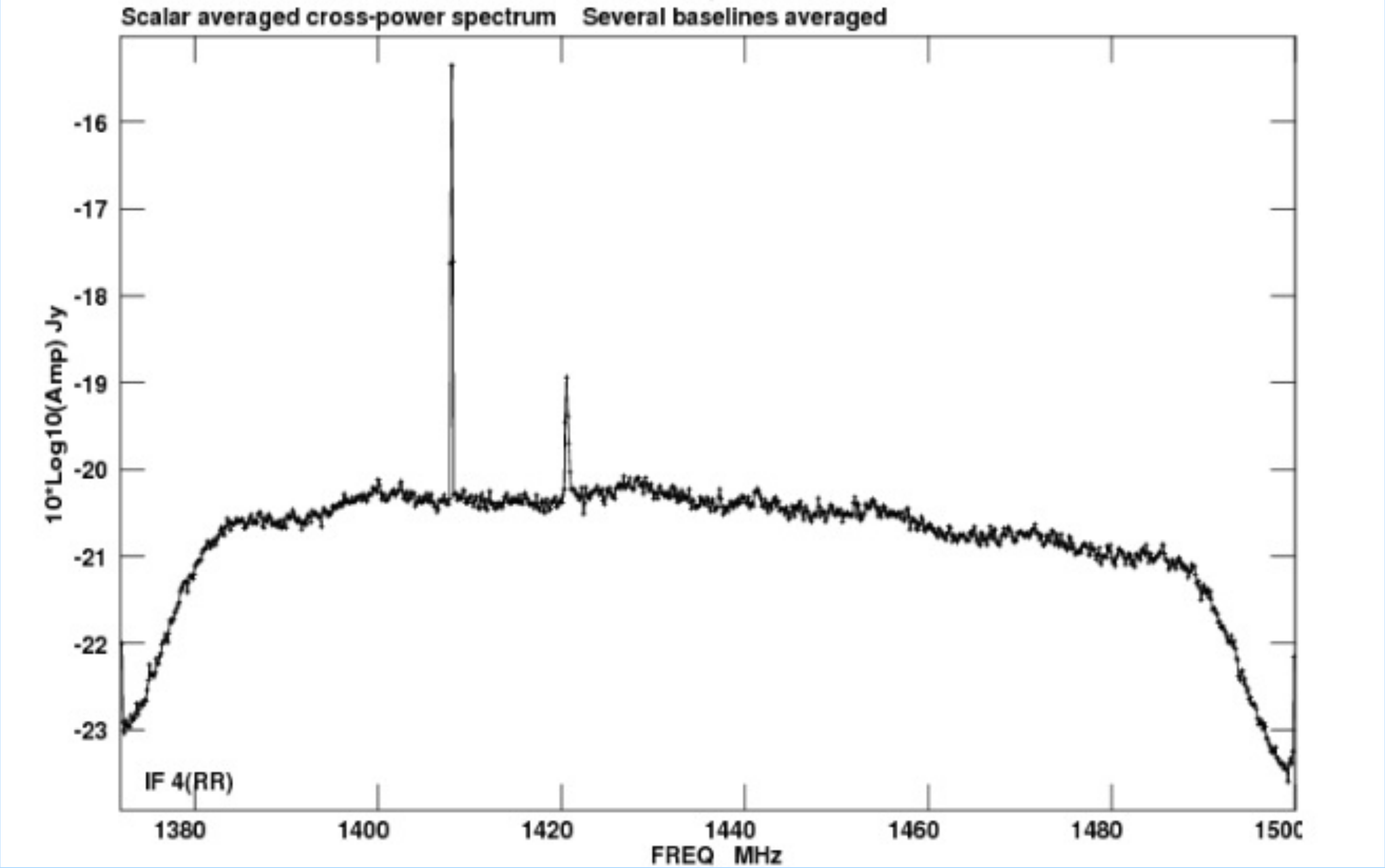
RFI in Lband (1-2 GHz)



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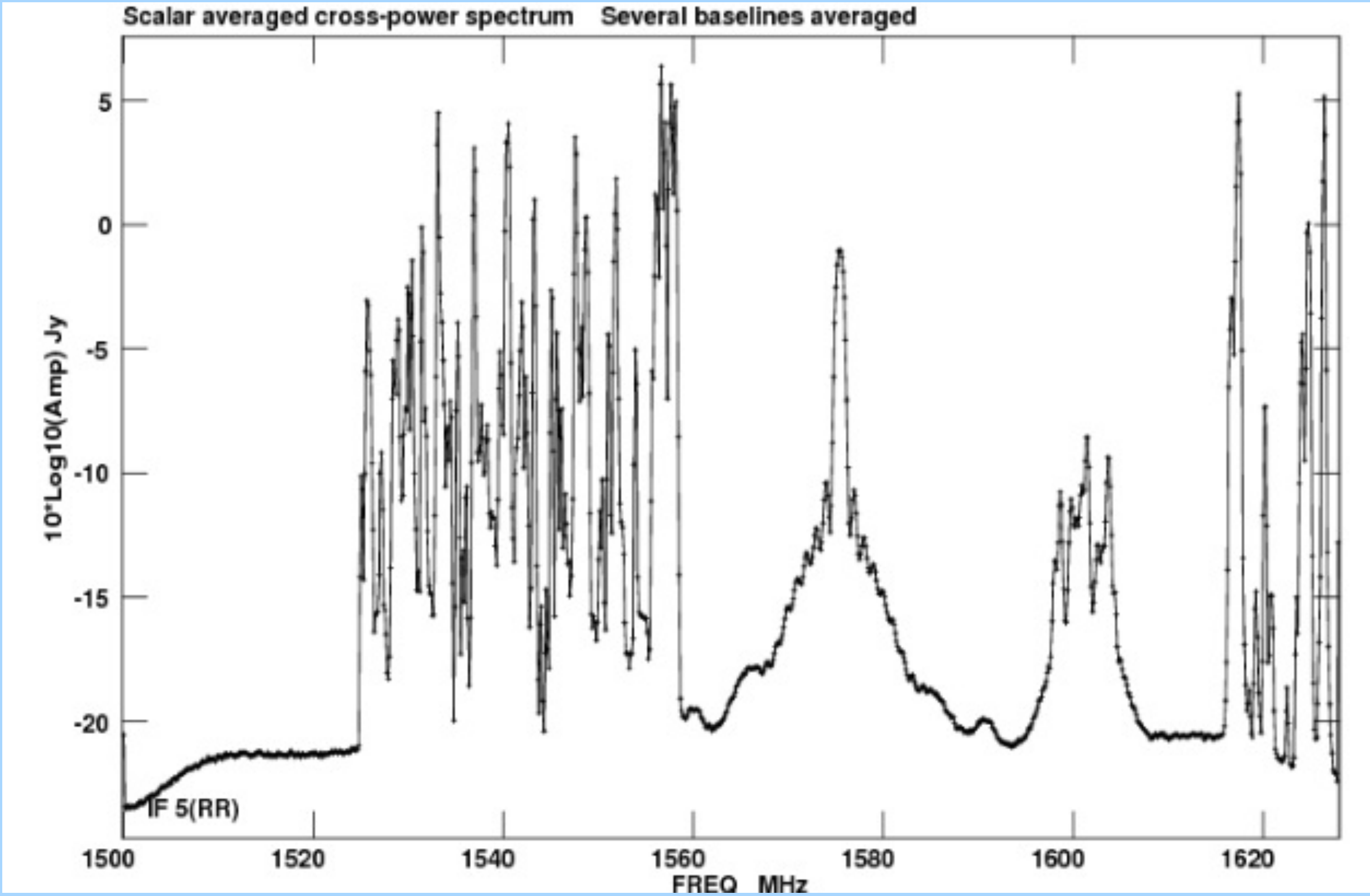
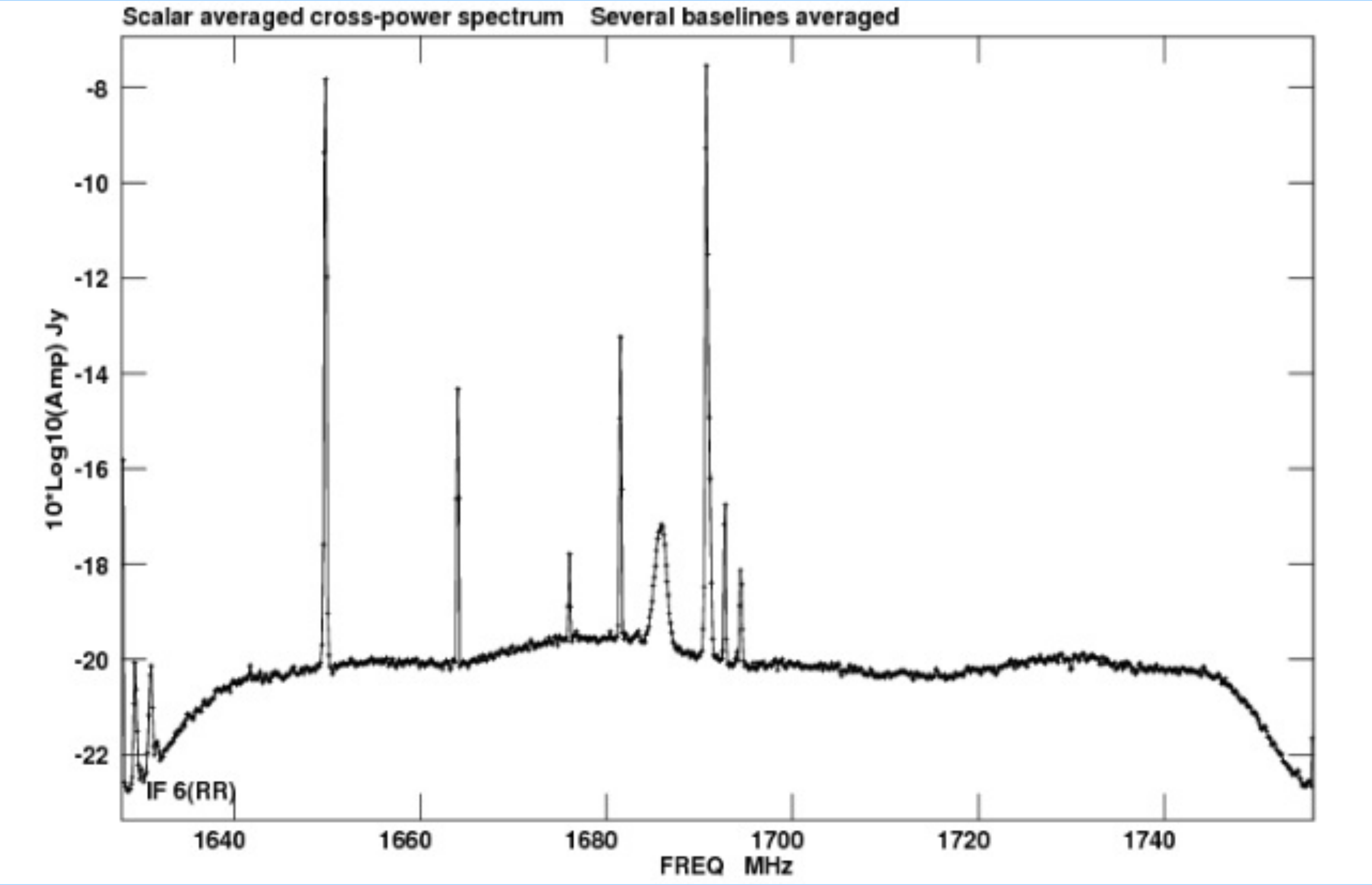
RFI in Lband (1-2 GHz)



RFI in Lband (1-2 GHz)



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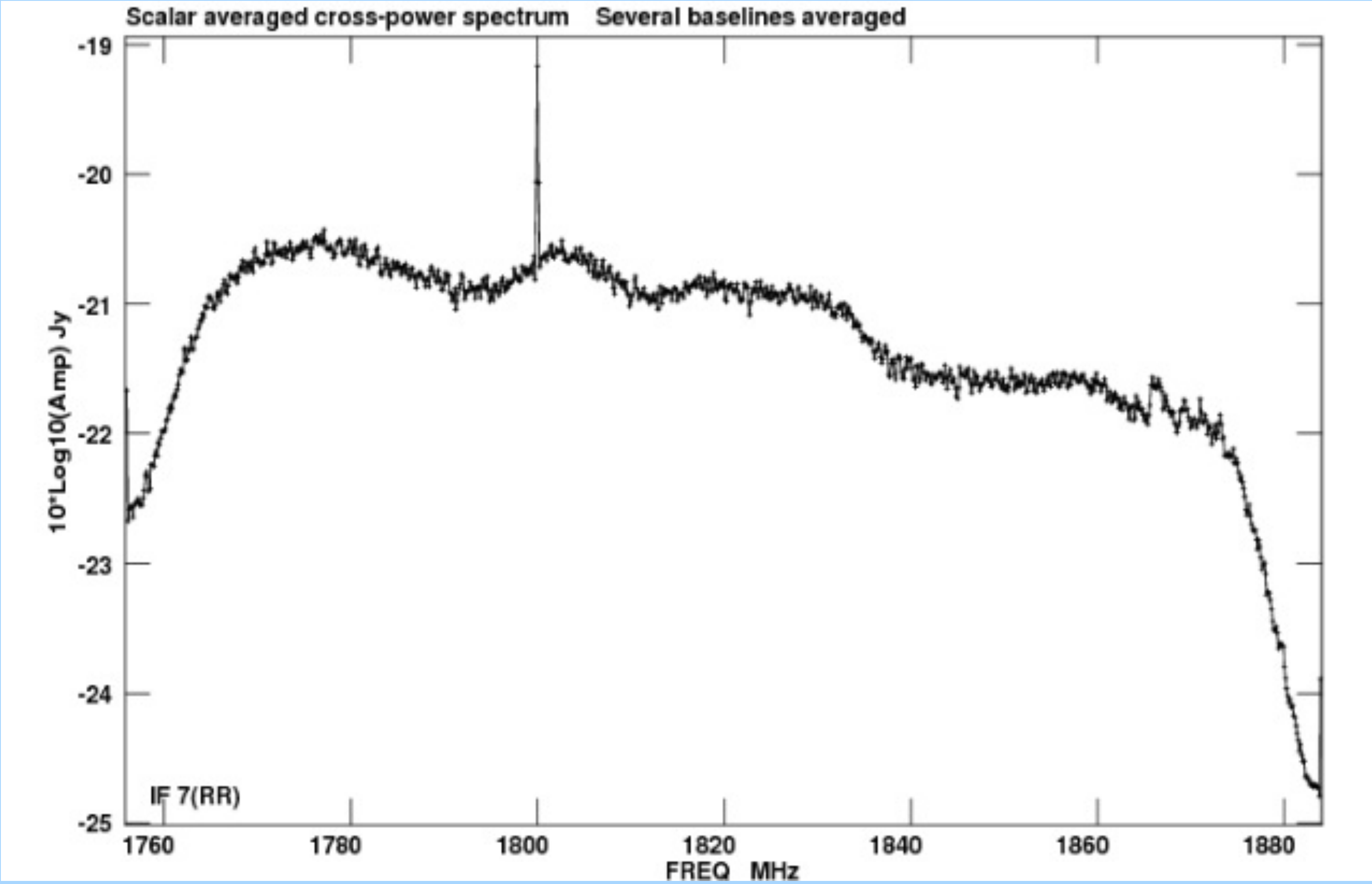
RFI in Lband (1-2 GHz)



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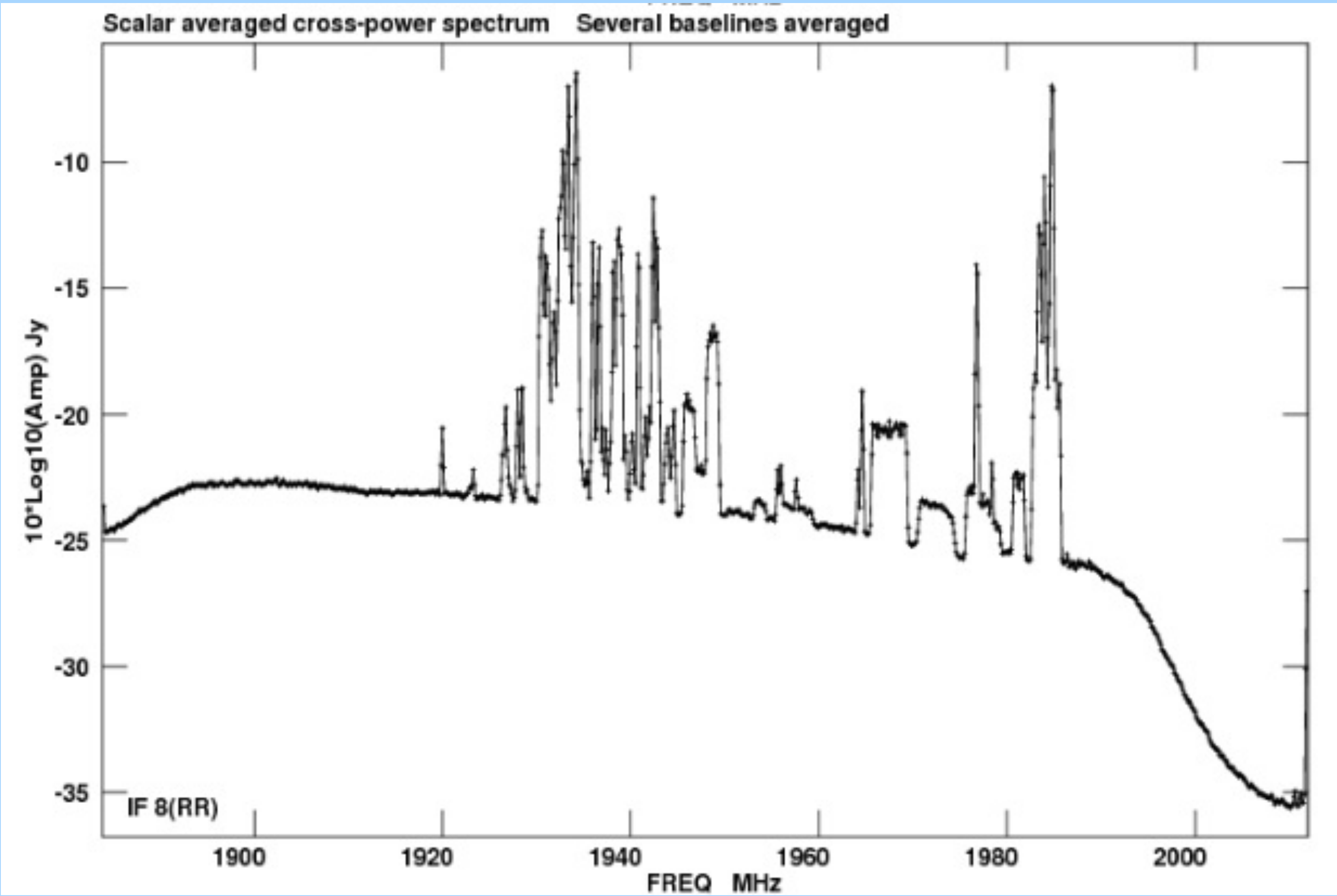
RFI in Lband (1-2 GHz)



Bandpass magic

- Vector averaging works wonders !

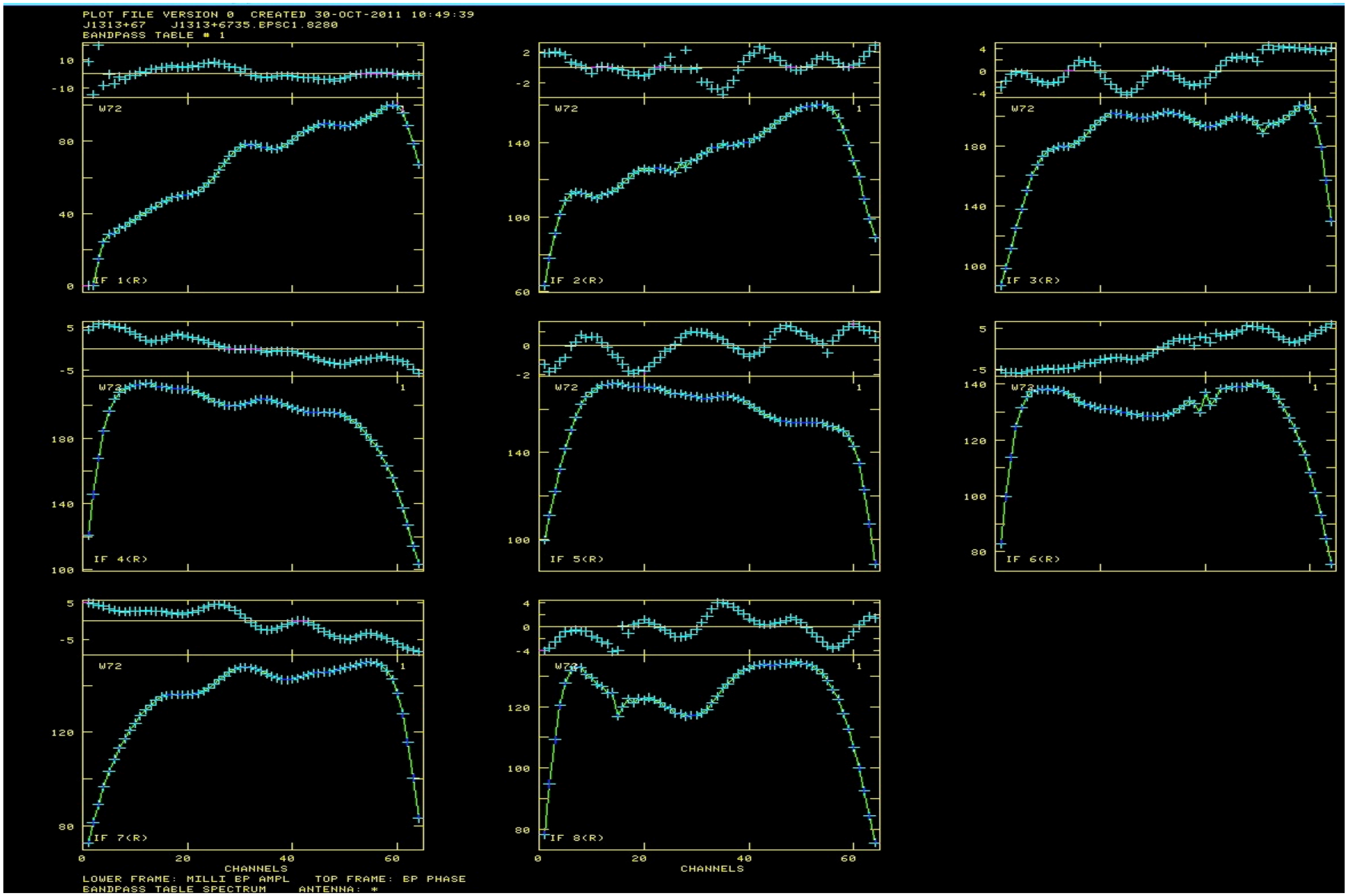
- Instead of using a single observation of a bright bandpass calibrator, use multiple observations of the phase calibrator for BPASS.

- Split out the phase calibrator with only delay corrections from FRING.

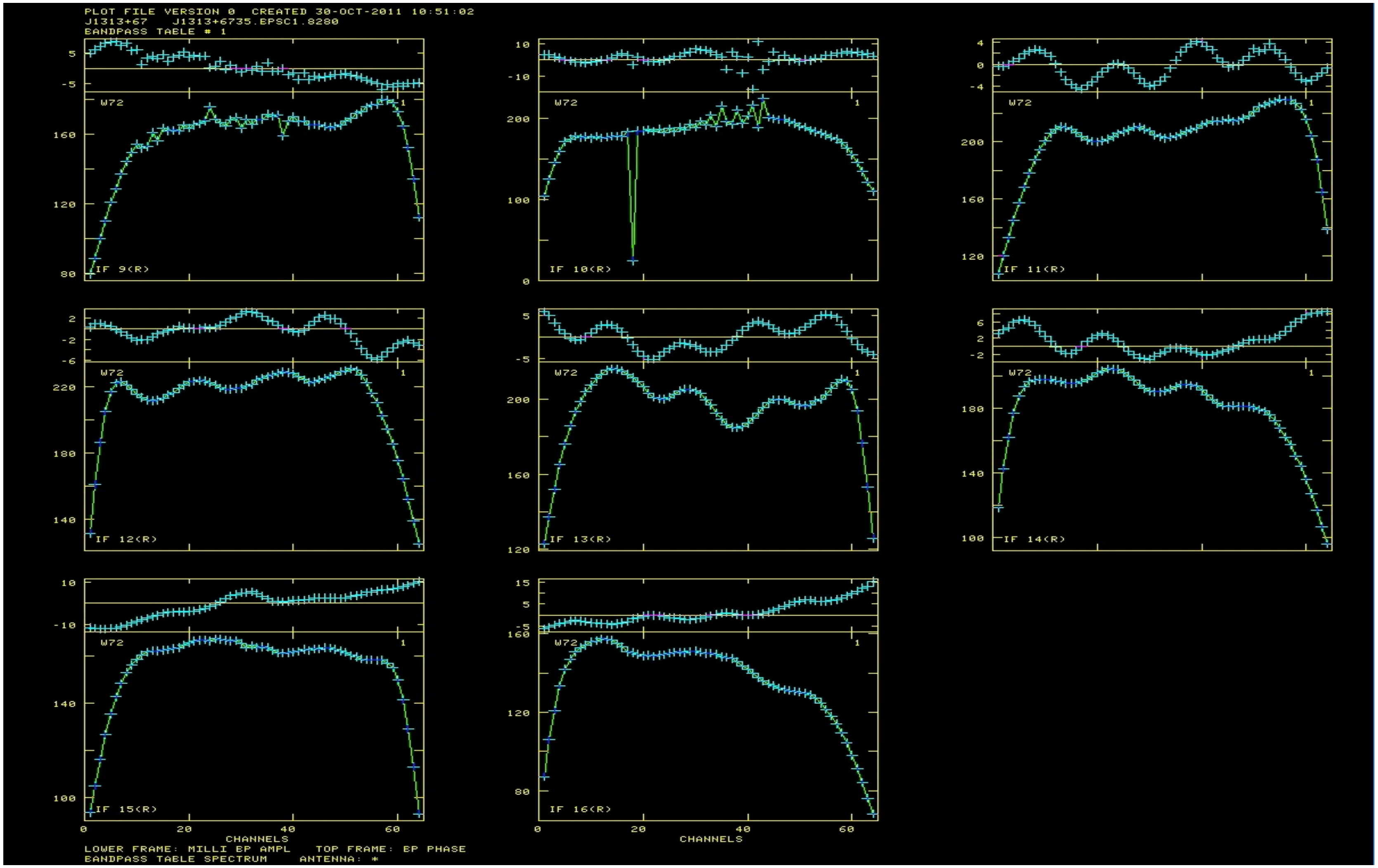
- Phase-only calibrate with a point source model, no editing.

- Calculate a global bandpass with all the data using BPASS.

BPASS magic


PLOT FILE VERSION 0 CREATED 30-OCT-2011 10:49:39
J1313+67   J1313+6735.EPSC1.8280
BANDPASS TABLE # 1
IF 1(R)
IF 2(R)
IF 3(R)
IF 4(R)
IF 5(R)
IF 6(R)
IF 7(R)
IF 8(R)
CHANNELS
LOWER FRAME: MILLI BP AMPL   TOP FRAME: BP PHASE
BANDPASS TABLE SPECTRUM   ANTENNA: *

BPASS magic


PLOT FILE VERSION 0 CREATED 30-OCT-2011 10:51:02
J1313+67   J1313+6735.EPSC1.8280
BANDPASS TABLE # 1
W72
IF 9(R)
IF 10(R)
IF 11(R)
IF 12(R)
IF 13(R)
IF 14(R)
IF 15(R)
IF 16(R)
CHANNELS
LOWER FRAME: MILLI EP AMPL   TOP FRAME: EP PHASE
BANDPASS TABLE SPECTRUM   ANTENNA: *

RFLAG

- RFLAG uses short-timescale vector rms on each baseline versus time (ideally from cross polarizations) to identify and flag RFI

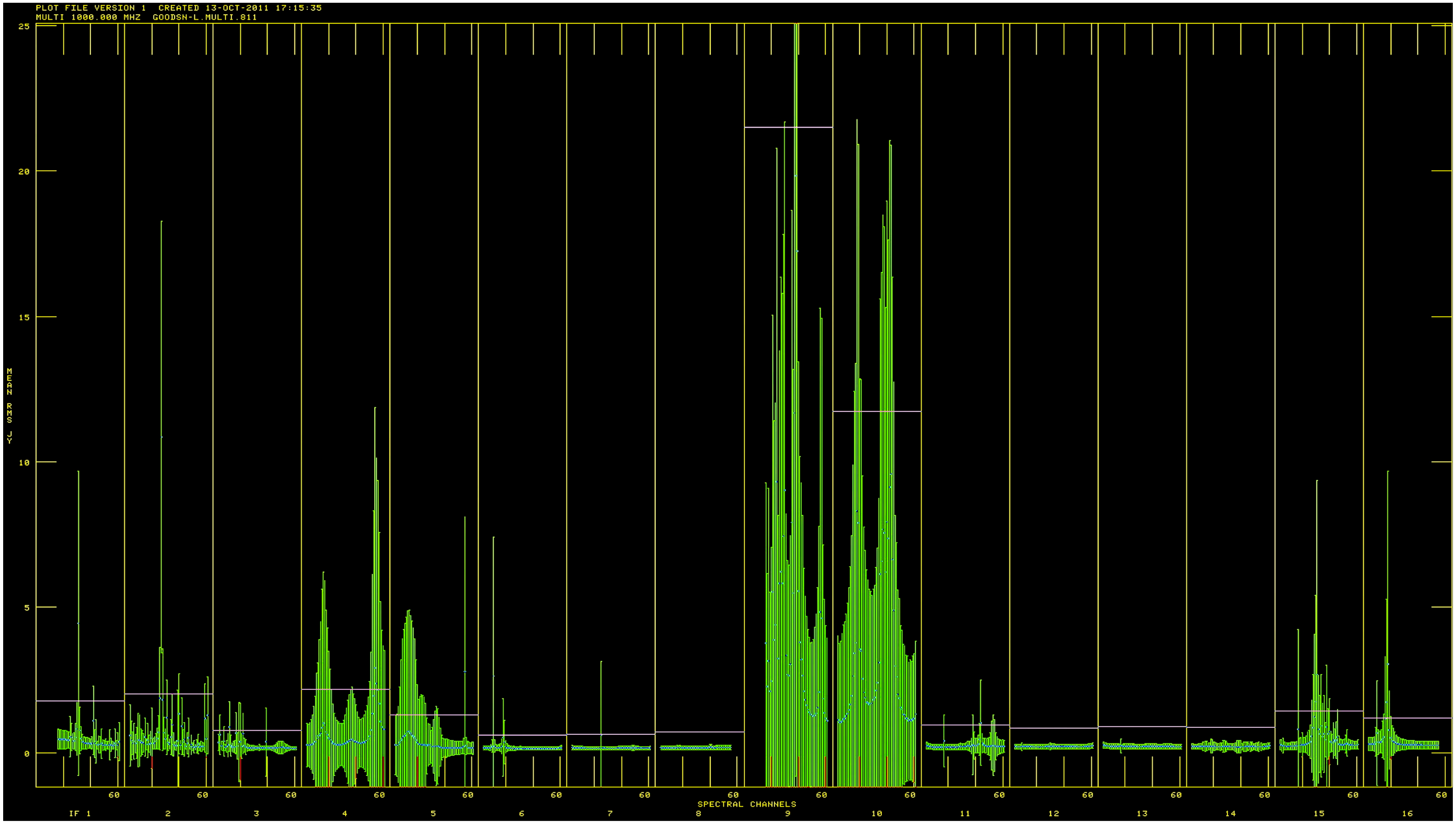
- Only needs bandpass calibration for calibration.

- First run makes a plot and suggests cutoff level for each subband.

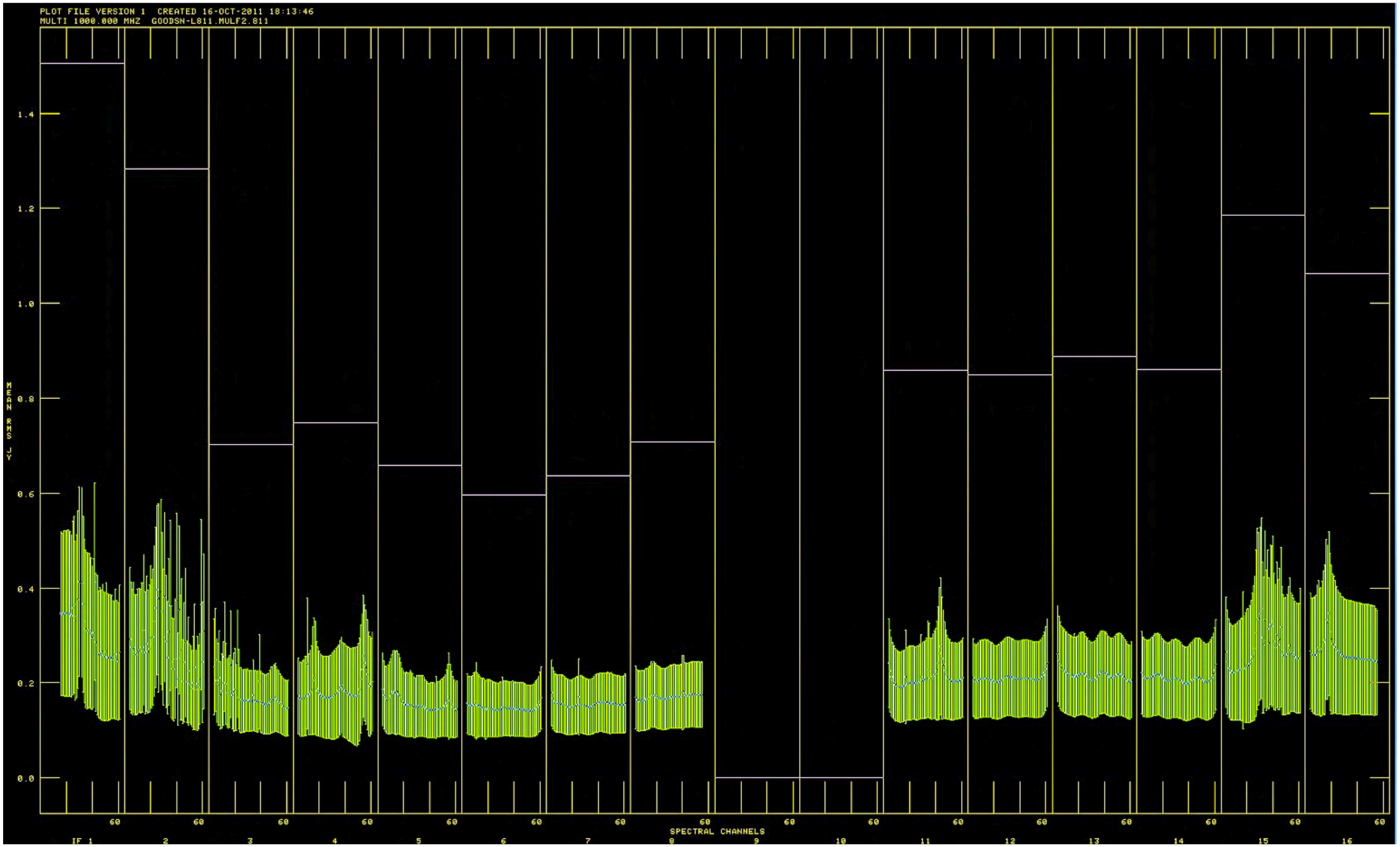
- Second run makes flag-table

- Then can run make the plot again using flags and perhaps run flag step again.

Before RFLAG



After RFLAG



PLOT FILE VERSION 1 CREATED 16-OCT-2011 18:13:46
MULTI 1000.000 MHZ GOODSN-L811.MULF2.811
MEAN RMS JY
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
SPECTRAL CHANNELS
IF 1

REWAY

Even after RFLAG, residual interference can still be a problem.

To make the best image one needs to adjust the UV weights to take into account the noise from the interference and other effects, e.g. dynamic range, antenna gain, receiver noise, as function of baseline, time, polarization and frequency.

REWAY calculates a rolling spectral rms in each subband for each baseline and polarization versus time and assigns a new weight to each visibility.

This calculation has the result of down-weighting bad time periods and assigning lower weights to less sensitive subbands.

Polarization Calibration in AIPS

1) RLDLY in order to correct for the R-L delay

2) VLATECR procedure to correct for ionospheric RM

3) PCAL to correct for instrumental polarization probably with SPECTRAL option. POSSM to review results

4) RLDIF to calibrate polarization position angle with a known source.

1), 2) only in AIPS now.

MSMFS Imaging: Multi-Scale, Multi-Frequency Synthesis

1) Solves for NxM images at once factored into N Taylor series frequency terms + M spatial scales.

2) N frequency terms: i.e. total intensity at a reference frequency (e.g 1.5 GHz for L-band), spectral index, spectral curvature.

3) M scales: e.g. 0 pixels (like regular clean), 3 pixels, 10 pixels etc. (like multi-scale in AIPS IMAGR).

4) Deconvolution algorithm not like "clean", more like MEM.

MSMFS Imaging: Multi-Scale, Multi-Frequency Synthesis

1) Only in CASA “clean” task.

2) Necessary to combine full EVLA wideband data into one image.

3) Produces both total intensity and spectral index images.

4) Uses W-projection, so no 3D faceting needed

5) Eventually will also correct for 2D primary beam during imaging (A-projection)

Imaging Total Intensity, Wide-band, (Wide-field) AIPS-Calibrated Data In CASA

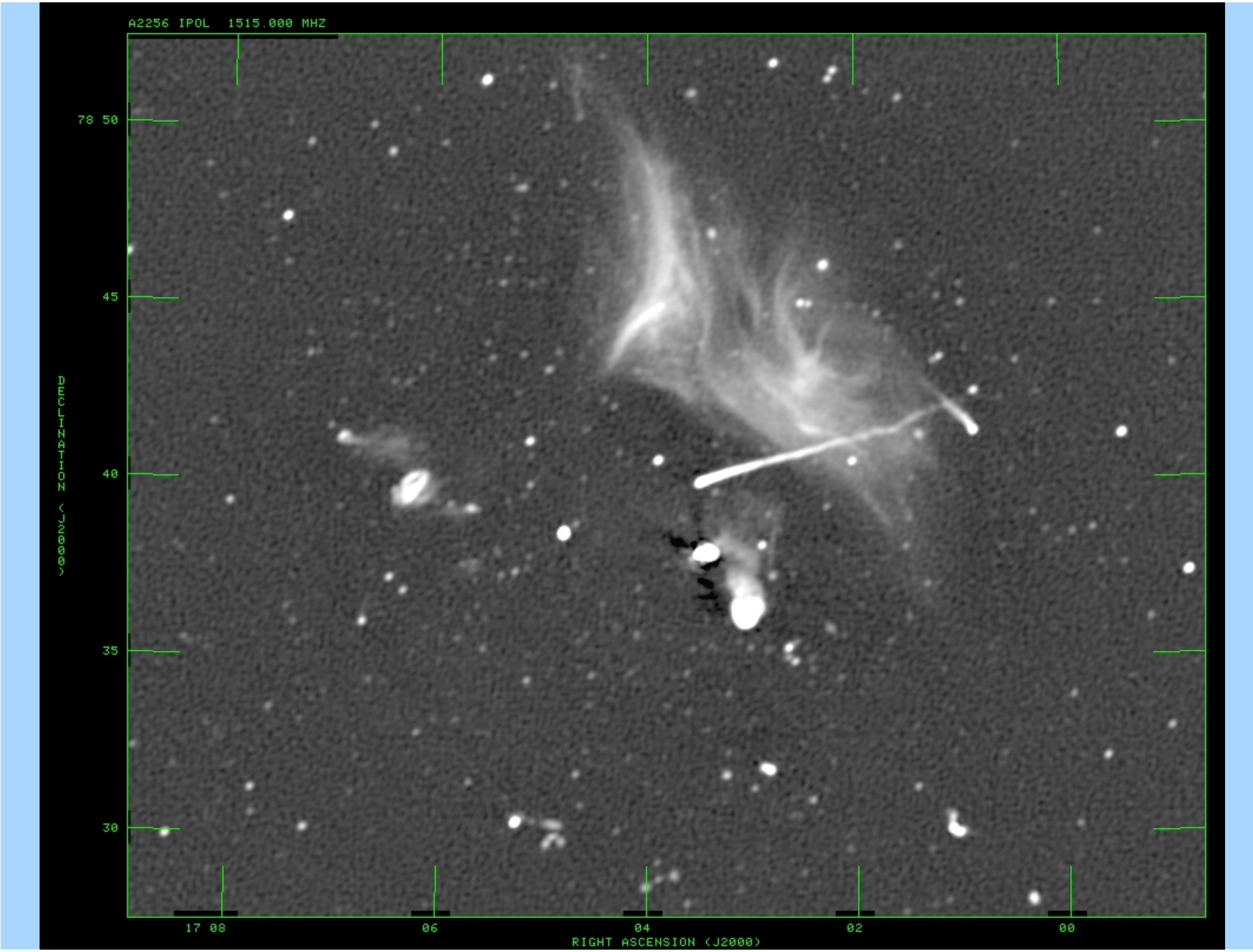
1) Write UVFITS file with AIPS (FITTP).

2) Read UVFITS file in CASA ms with importuvfits.

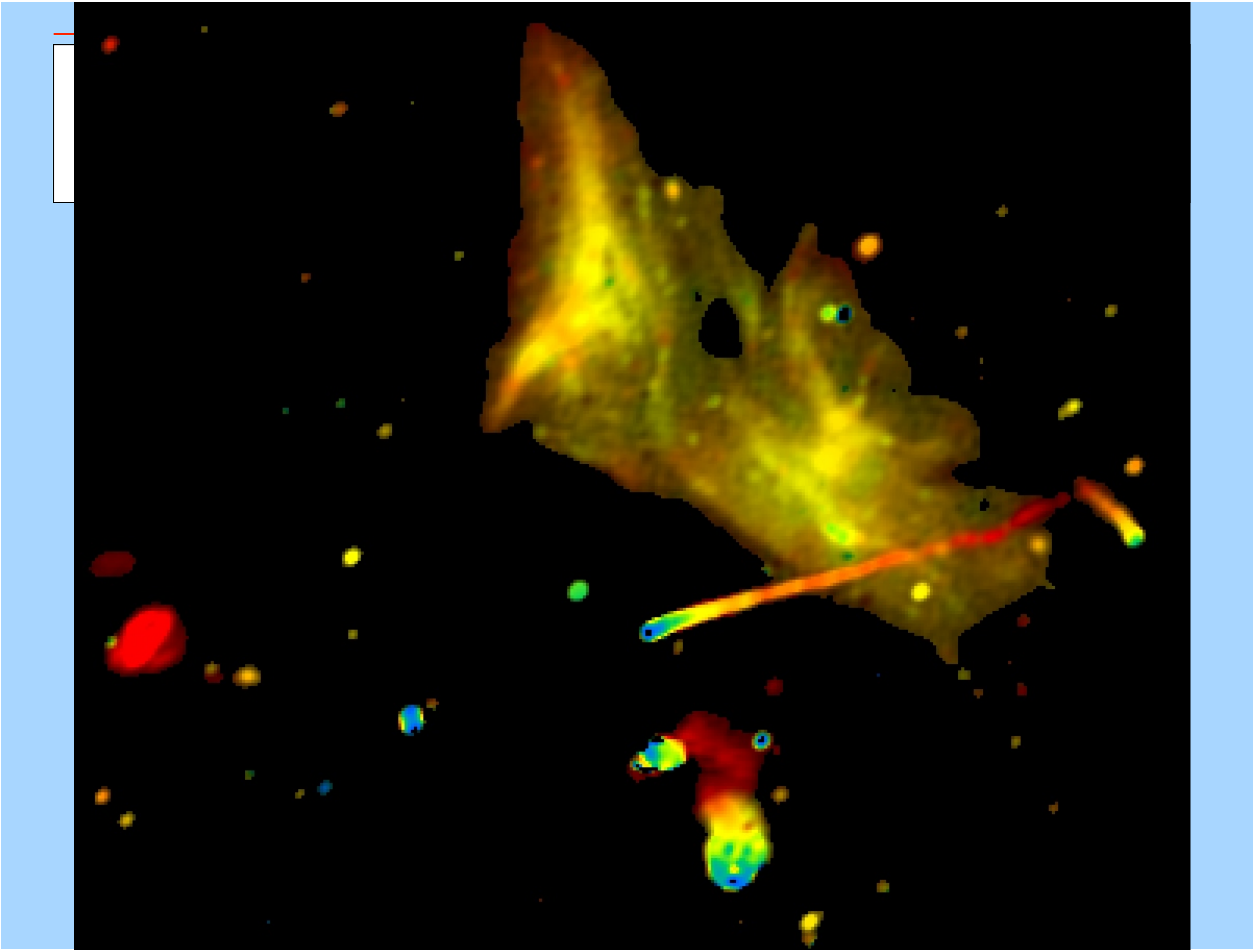
3) Sort ms into optimum order:

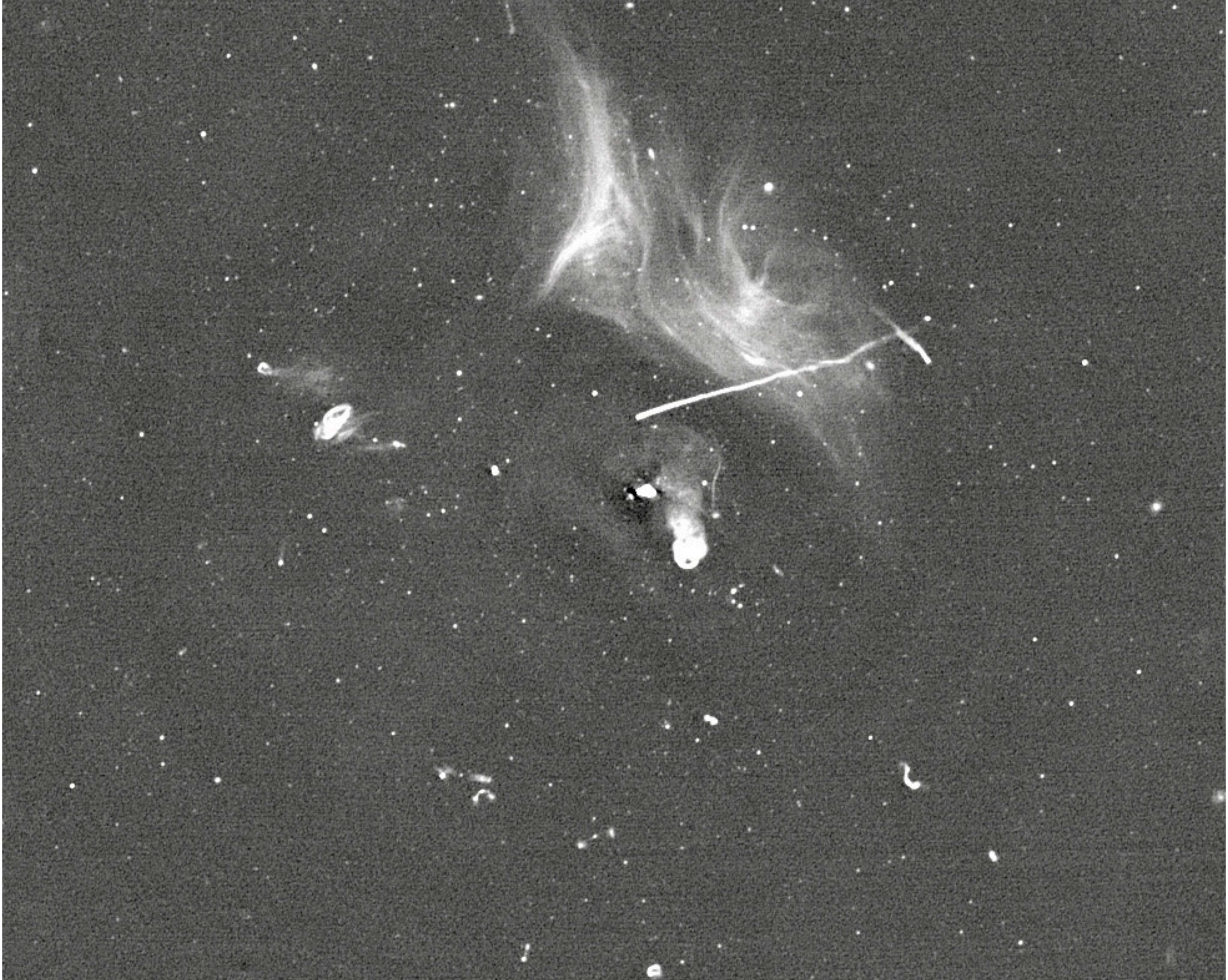
```
from recipies.sortOrder import setToCasaOrder
setToCasaOrder(<inputMS>, <outputMS>)
```

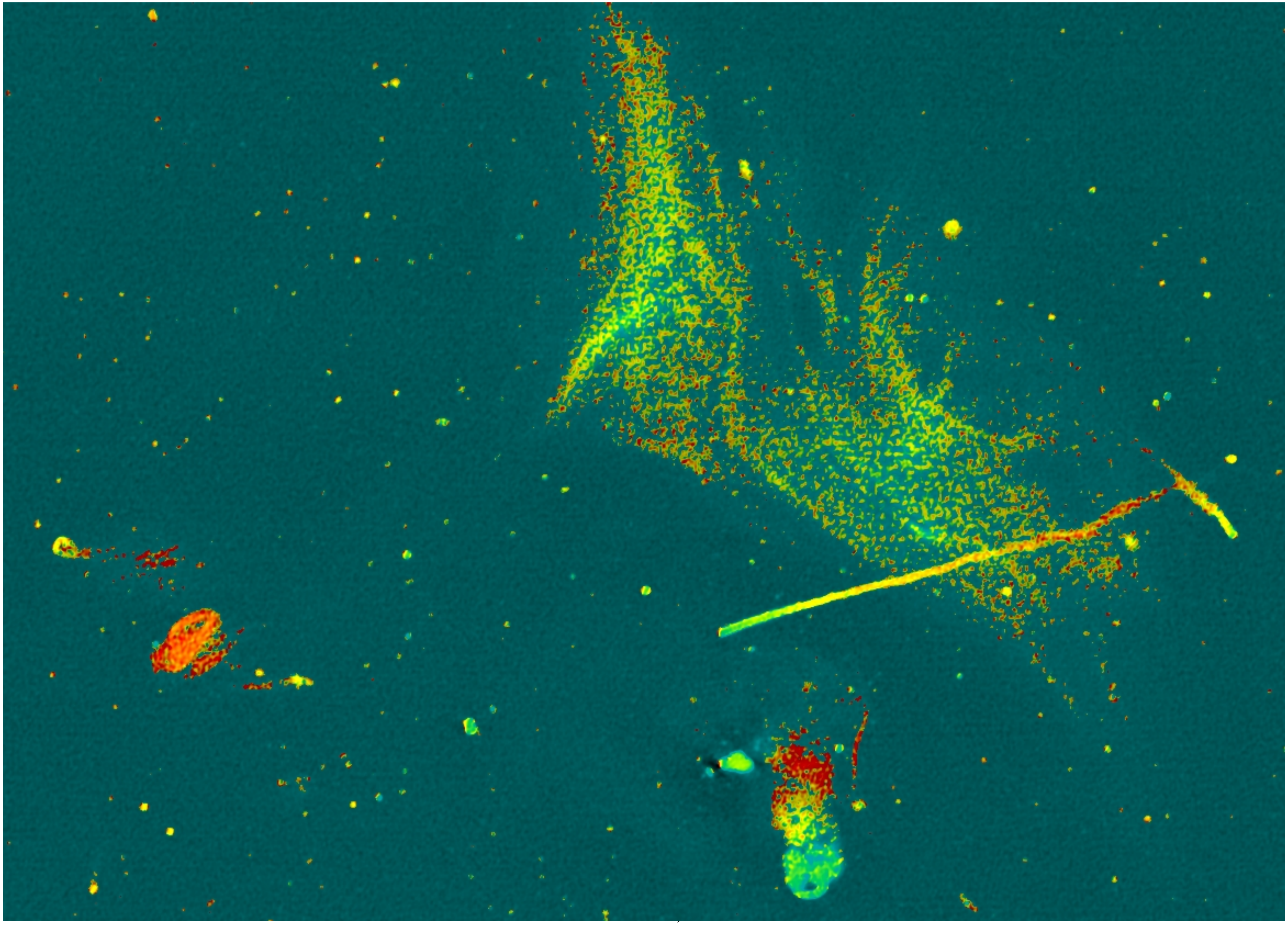
4) Run clean with nterms=2, rarely if ever is nterms=3 useful.

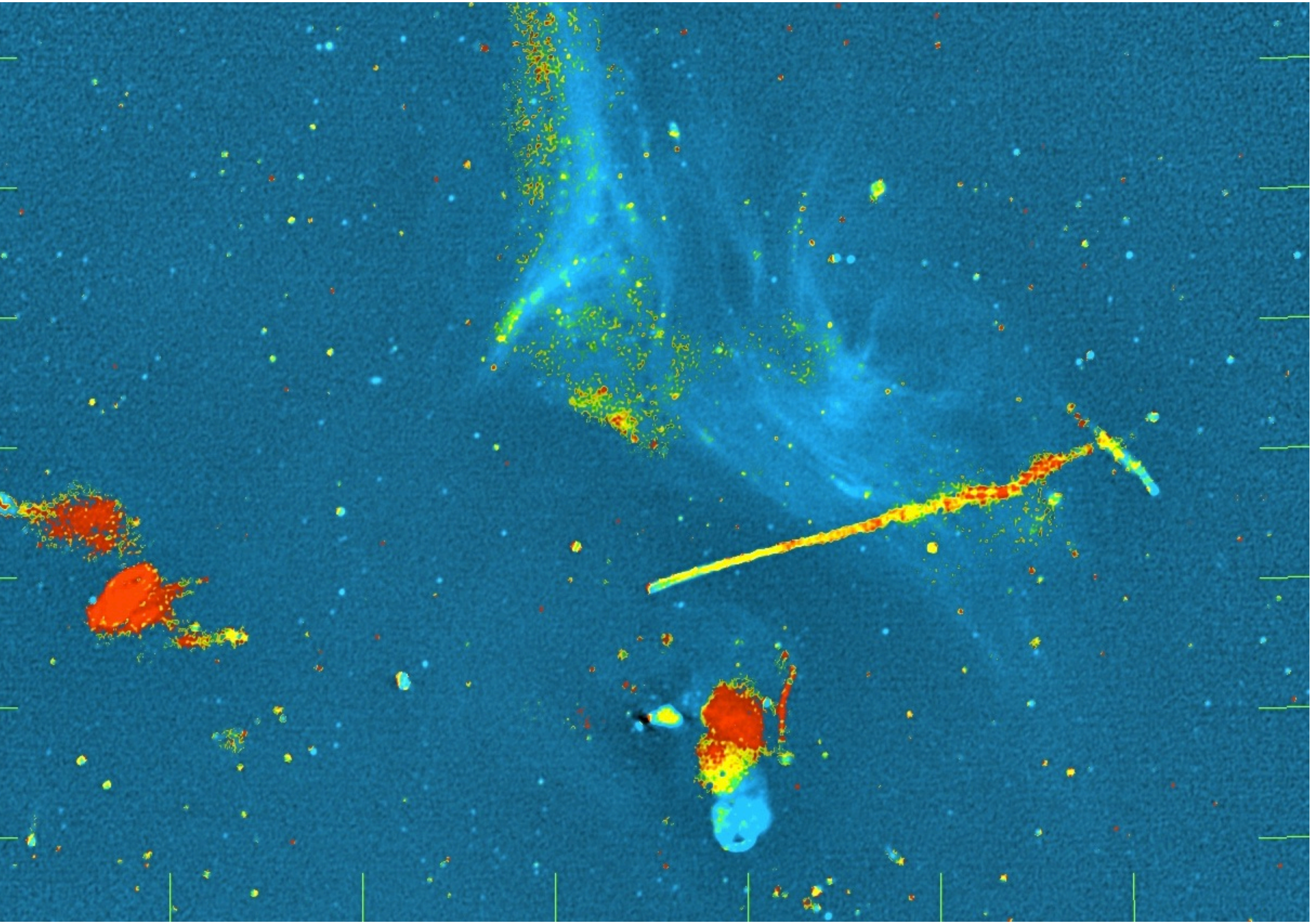


A2256 IPOL 1515.000 MHZ
78 50
45
40
35
30
DECLINATION (J2000)
17 08
06
04
02
00
RIGHT ASCENSION (J2000)









Rotation Measure Synthesis

Following George Heald, IAU Sym 259, 591

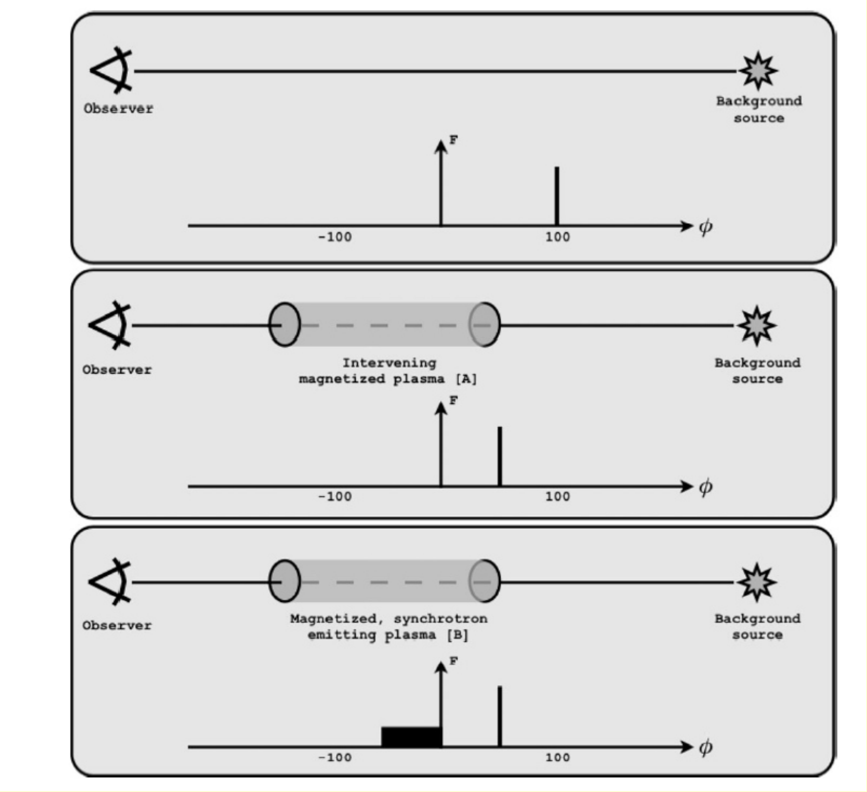
$$\mathrm{RM} = 0.81 \int_{\mathrm{source}}^{\mathrm{observer}} n_e \vec{B} \cdot \mathrm{d}\vec{l},$$

$$\chi(\lambda) = \chi_0 + \mathrm{RM} \cdot \lambda^2$$

$$P(\lambda^2) = pIe^{2i\chi}$$

$$P(\lambda^2) = \int_{-\infty}^{+\infty} F(\phi) e^{2i\phi\lambda^2} \mathrm{d}\phi$$

$$F(\phi) = \int_{-\infty}^{+\infty} P(\lambda^2) e^{-2i\phi\lambda^2} \mathrm{d}\lambda^2$$



Rotation Measure Synthesis

Traditional measurement of Rotation Measures toward radio sources with the VLA was done by fitting polarization position angles in a small number of bands vs Lambda^2.

With many more frequencies this approach is not efficient and can lead to very wrong answers and interpretation.

RM synthesis, developed by Brentjens and de Bruyn, is a better approach, although it has it's own issues.

- Brentjens, M. A. & de Bruyn, A. G., 2005, A&A, 441, 1217-1228

RM Synthesis is available in AIPS using FARS, AFARS and DOFARS

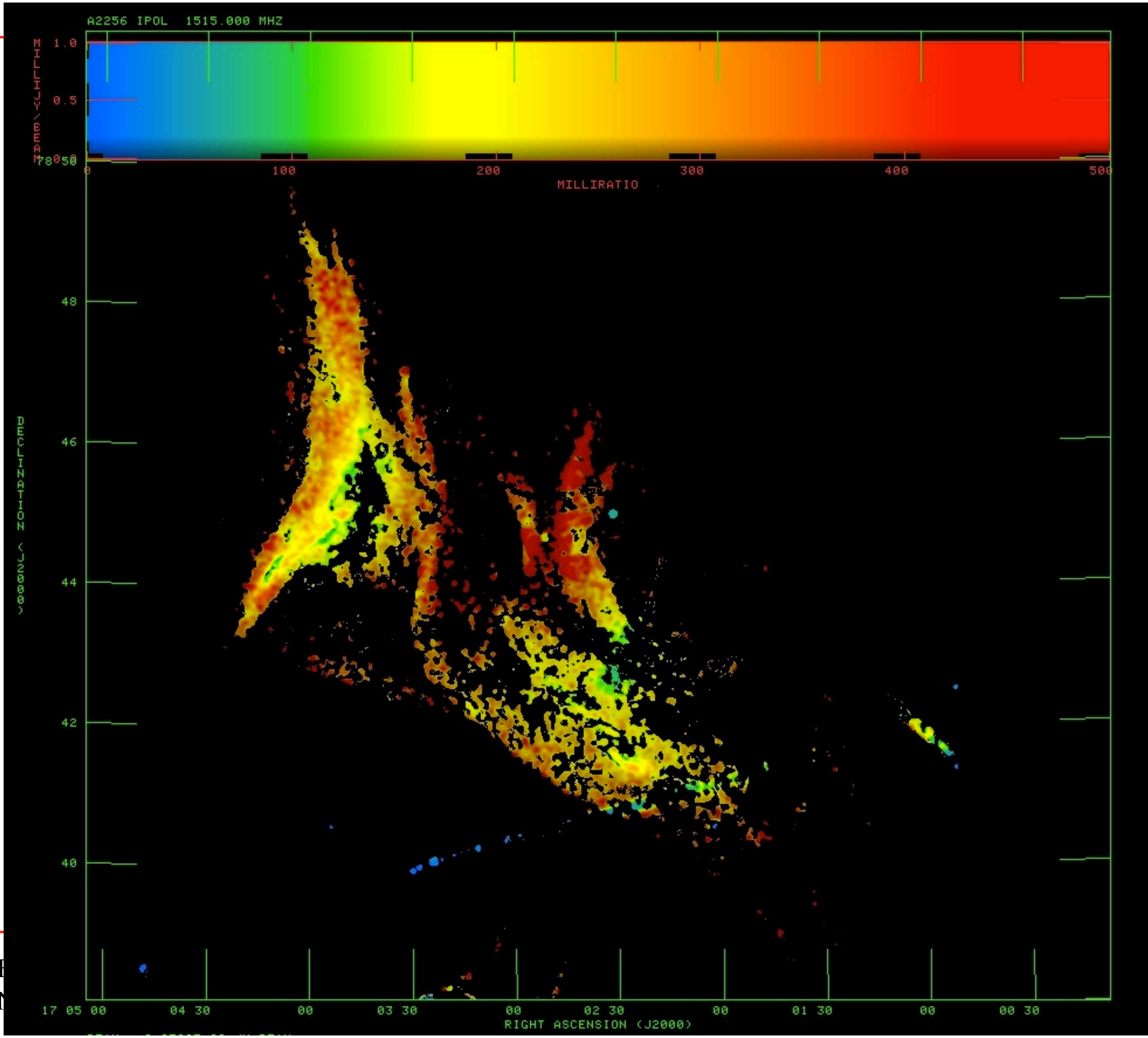
RM Synthesis is not available in CASA yet and may not be available for some time.

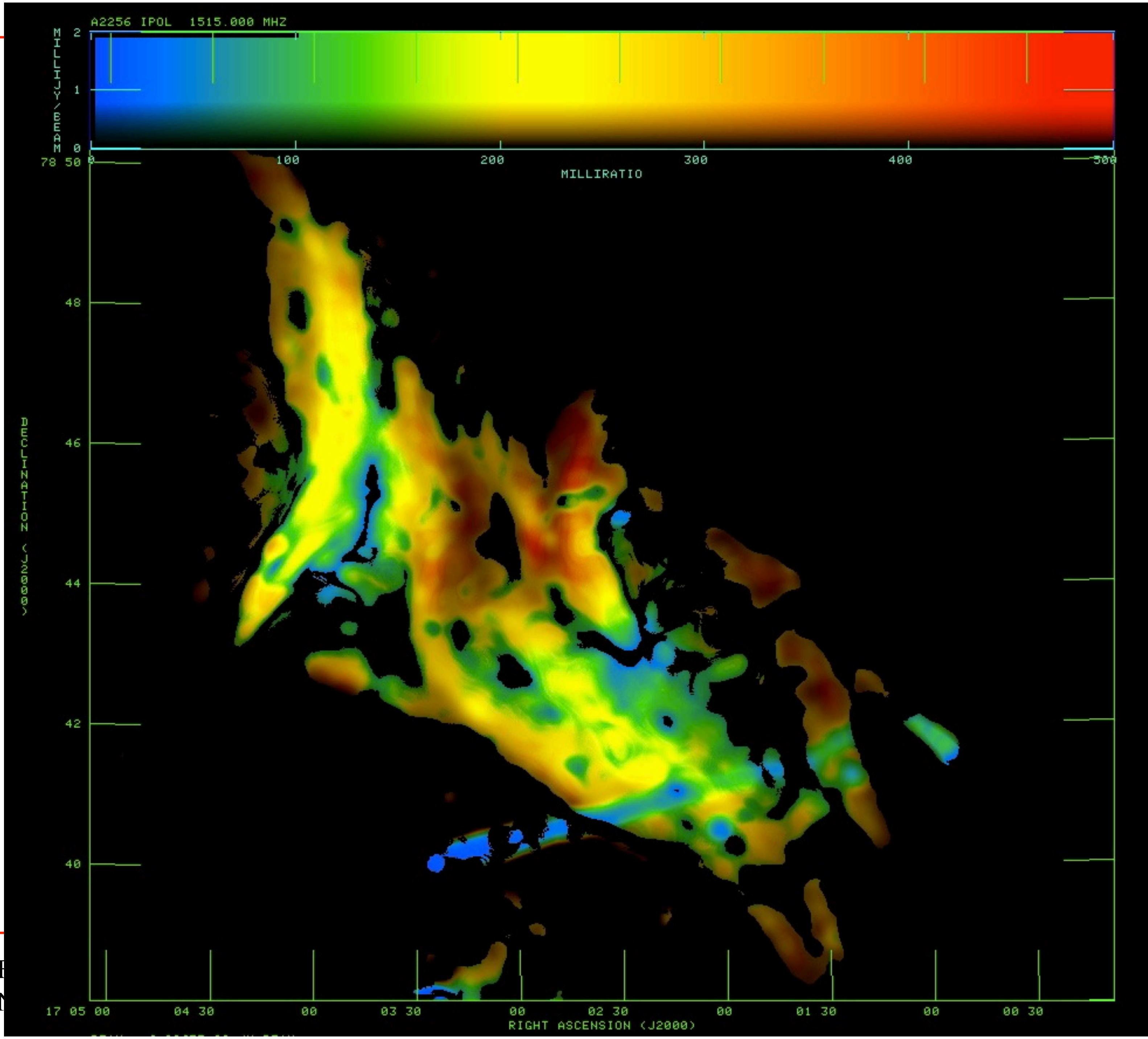
RM Synthesis in AIPS

FARS is the basic task for RM synthesis. DOFARS is a procedure which uses FARS and performs various other steps which are necessary before and after FARS. The inputs to DOFARS are cubes of Q and U images versus frequency. (RA, Dec ,frequency)

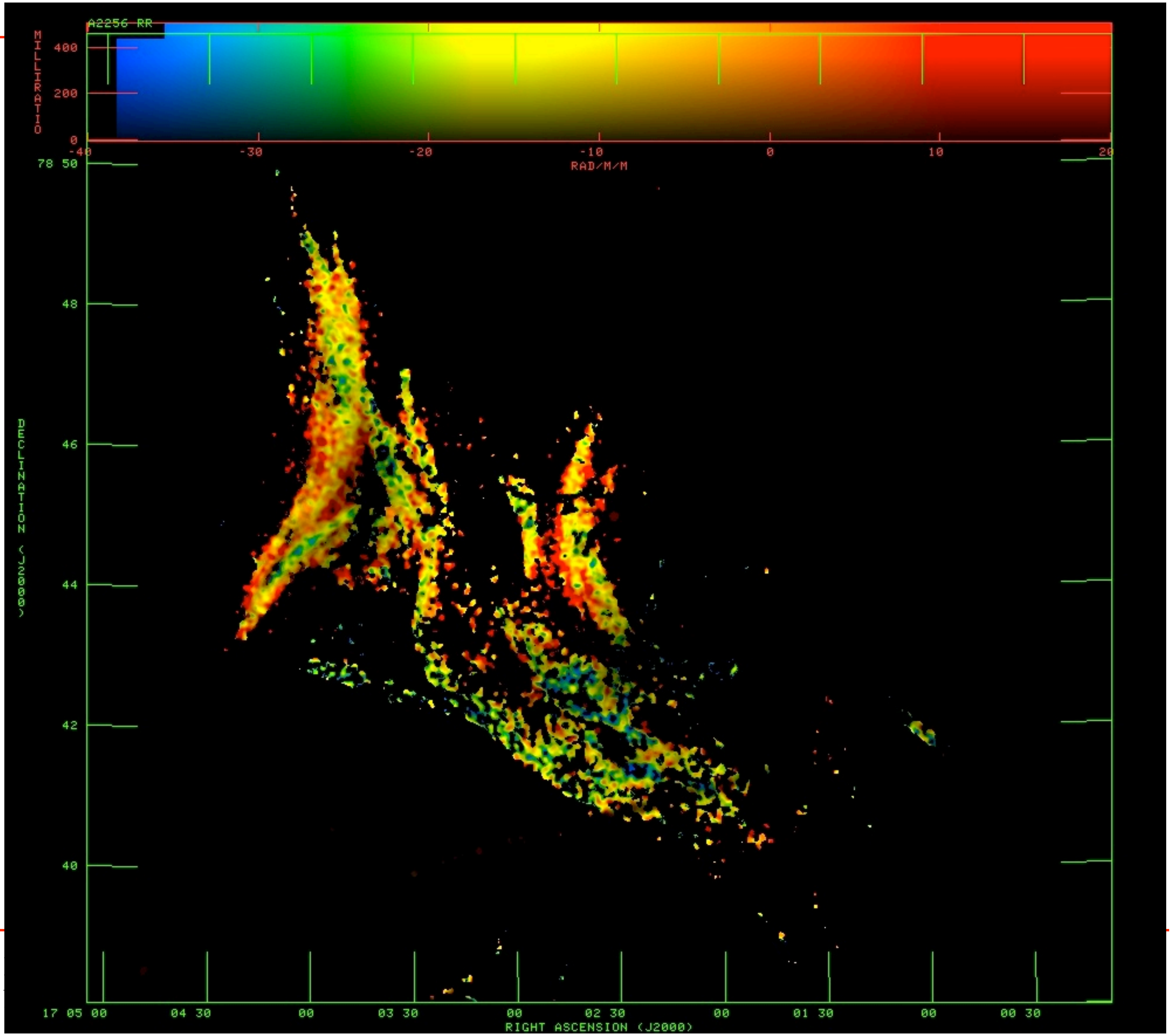
FARS produces cubes with planes of amplitude and phase corresponding to a weighted sum of the input Q and U cubes assuming different rotation measures (RA, Dec, RM)

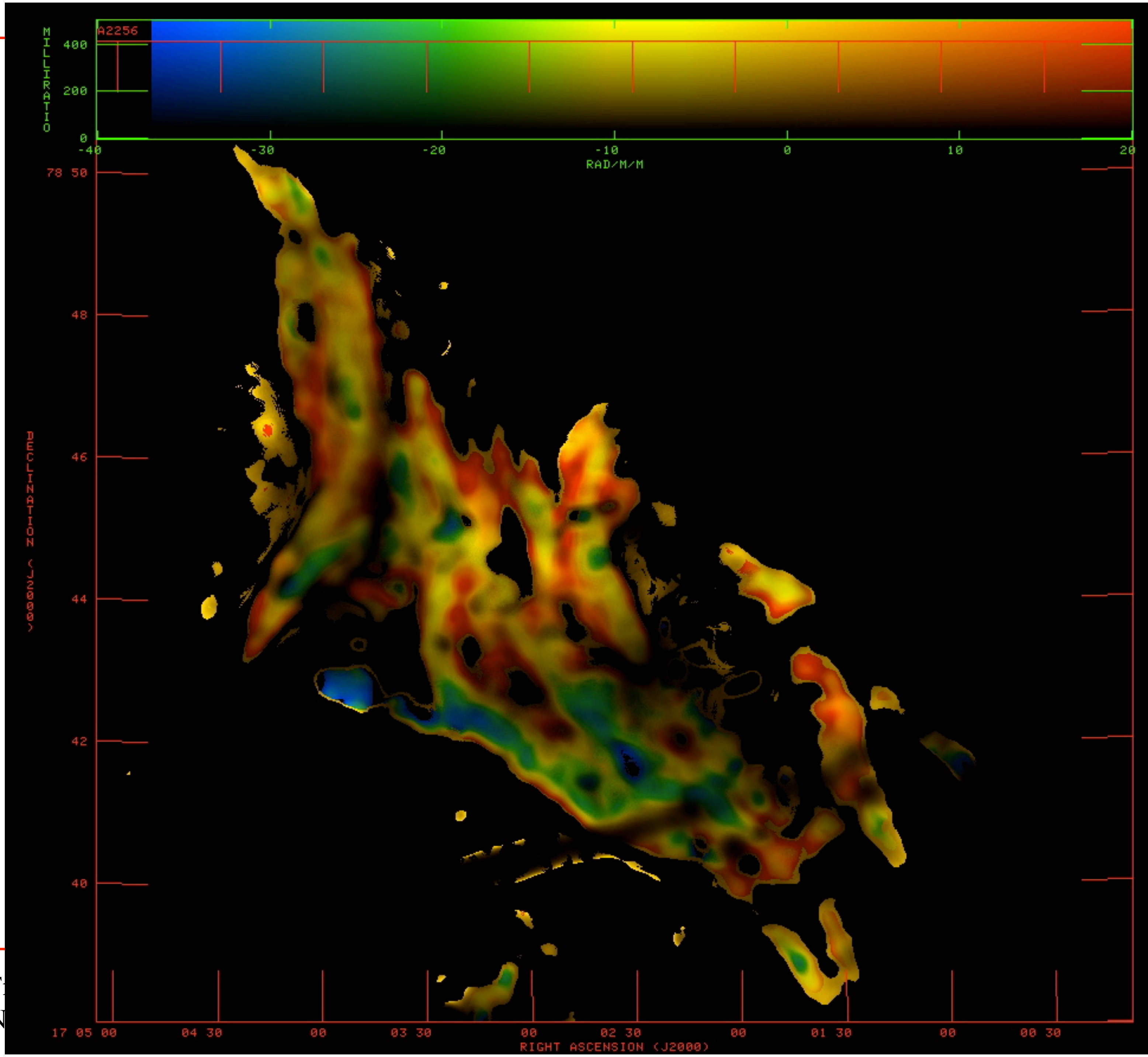
AFARS finds the the peak amplitude in the RM cube for each x and y and outputs an (RA, Dec) image of 1) the maximum amplitude, and 2) the corresponding RM.


A2256 IPOL 1515.000 MHZ
MILLIJY/BEAM
1.0
0.5
MILLIRATIO
0
100
200
300
400
500
DECLINATION (J2000)
48
46
44
42
40
RIGHT ASCENSION (J2000)
17 05 00
04 30
00
03 30
00
02 30
00
01 30
00
00 30



A2256 IPOL 1515.000 MHZ
MILLIJY/BEAM
MILLIRATIO
DECLINATION (J2000)
RIGHT ASCENSION (J2000)

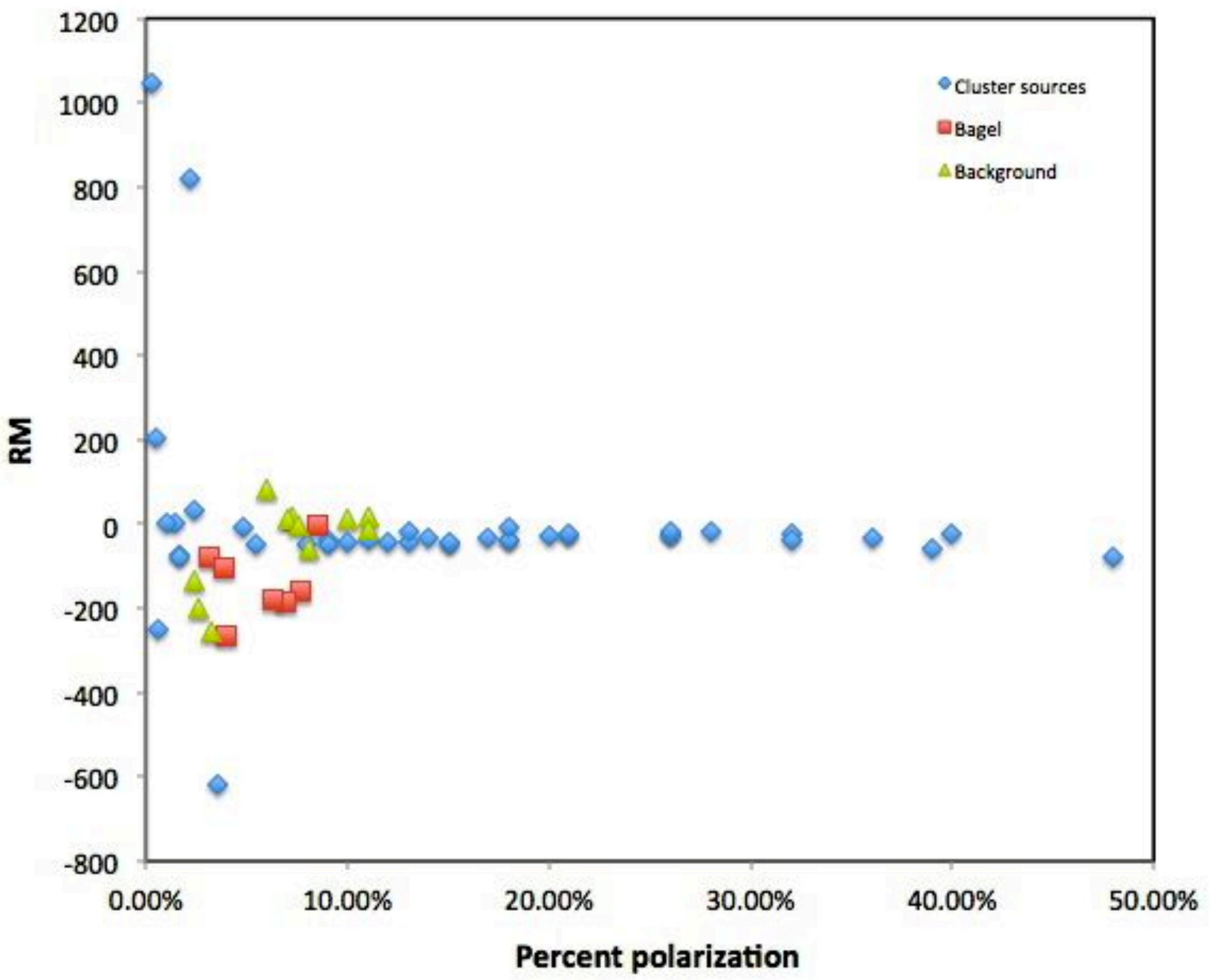

A2256 RR
MILLIRATIO
400
200
0
-40
-30
-20
-10
0
10
20
RAD/M/M
78 50
48
46
44
42
40
DECLINATION (J2000)
17 05 00
04 30
00
03 30
00
02 30
00
01 30
00
00 30
RIGHT ASCENSION (J2000)


A2256
MILLIRATIO
400
200
0
-40
-30
-20
-10
0
10
20
RAD/M/M
78 50
48
46
44
42
40
DECLINATION (J2000)
17 05 00
04 30
00
03 30
00
02 30
00
01 30
00
00 30
RIGHT ASCENSION (J2000)

Fr 0
N

Polarization Results

1) Fewer background polarized sources than expected, ~8 so far; mostly slightly higher z, FRI's. RM~+/- 200; mostly not very near the cluster core. Likely these are intrinsic RM's so not good probes of the cluster.
2) Cluster members show some high RM's 200-1000 rad/m^2 but tails of some sources show smaller values consistent with galactic value.



RM
1200
1000
800
600
400
200
0
-200
-400
-600
-800
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
Percent polarization
Cluster sources
Bagel
Background

Large Relic

- Large relic shows RM's of 0 to +50 rad/m^2 relative to the galactic background.
- N-S RM gradient.
- Fractional polarization ~0 to 50 or 60%
- Some filaments are unresolved, < 2 kpc in diameter.
- Could still be a shock but published RM results seem to be contradicted, more complicated.

Conclusions

EVLA has changed what we can learn about Clusters and Radio Galaxies.

New data reduction techniques are needed to produce the images necessary to harvest this knowledge.

MSMFS and RM Synthesis are important new tools to use and to understand (like self-cal and clean were for the original VLA).

We now have a path to produce results from these new data but it is not smooth yet and will improve with time.

Lots of good stuff will come in the next few years.