Methods of foreground mitigation in the EoR

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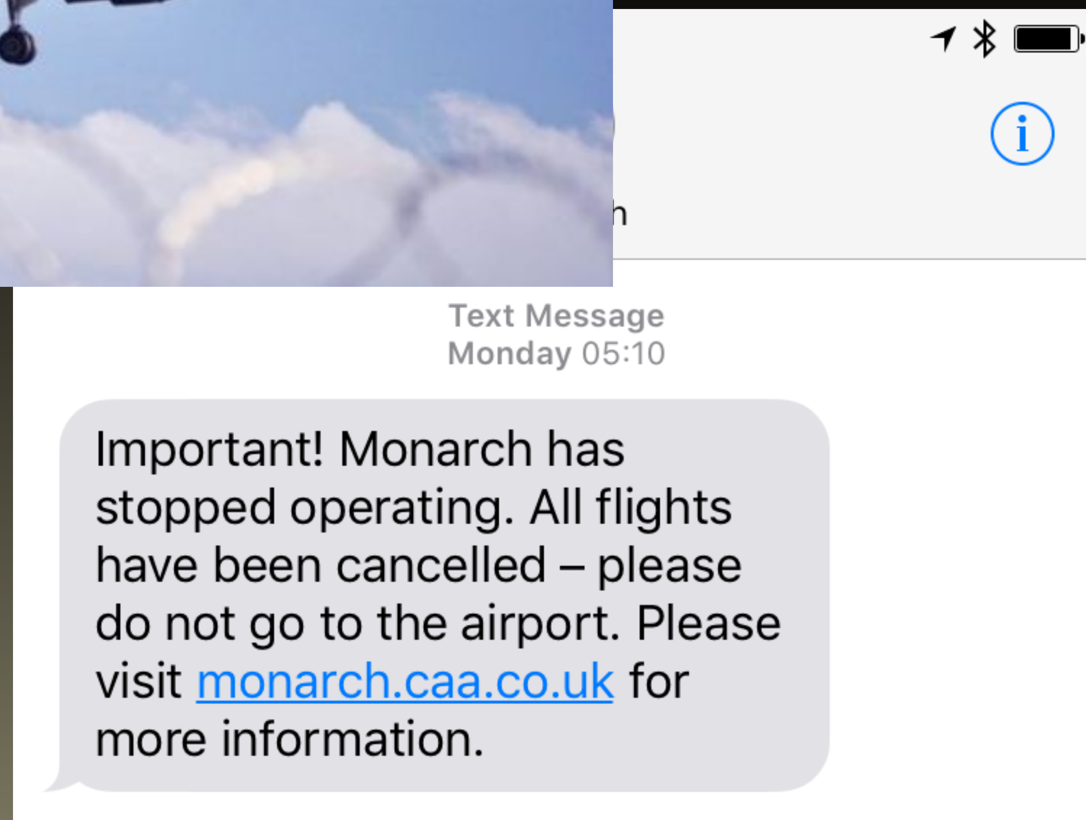
Text Message
Monday 05:10
Important! Monarch has stopped operating. All flights have been cancelled – please do not go to the airport. Please visit monarch.caa.co.uk for more information.


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Dawn
EoR
Epoch
Coffee
Foreground
foreground
October
Results
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Lunch
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observations
Galactic
Dubrovnik
21-cm
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simulations
multi-wavelength
stars/galaxies
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Day
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Extragalactic
MWA
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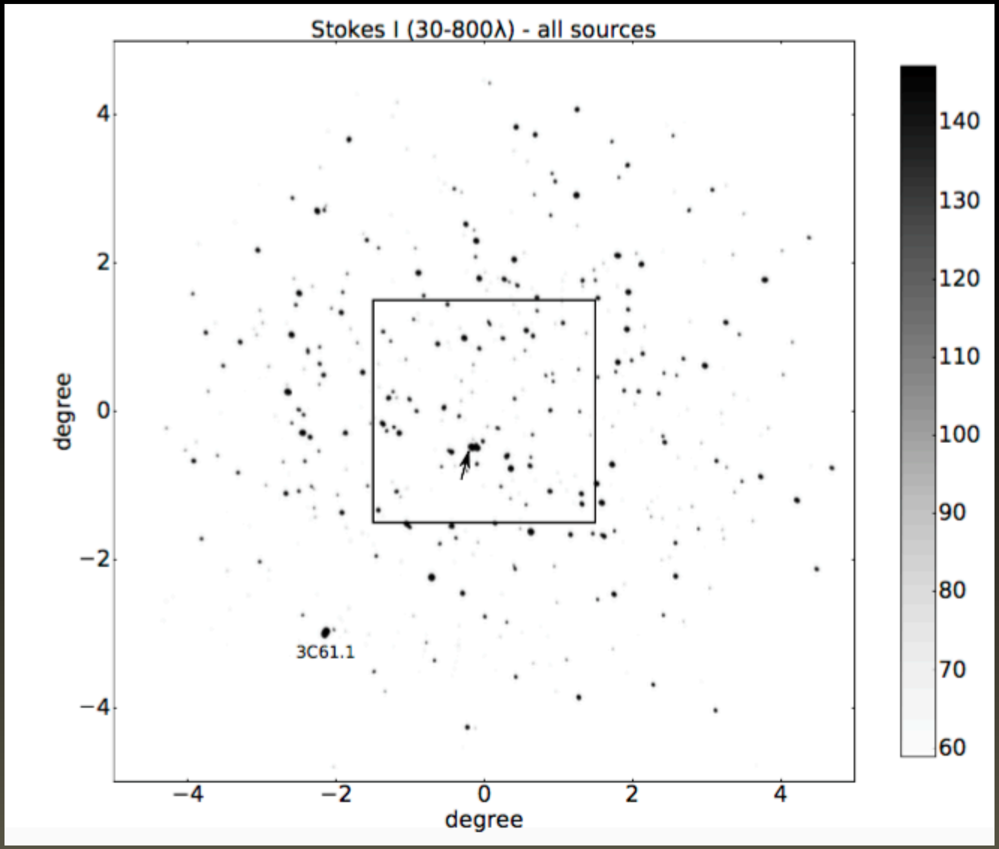
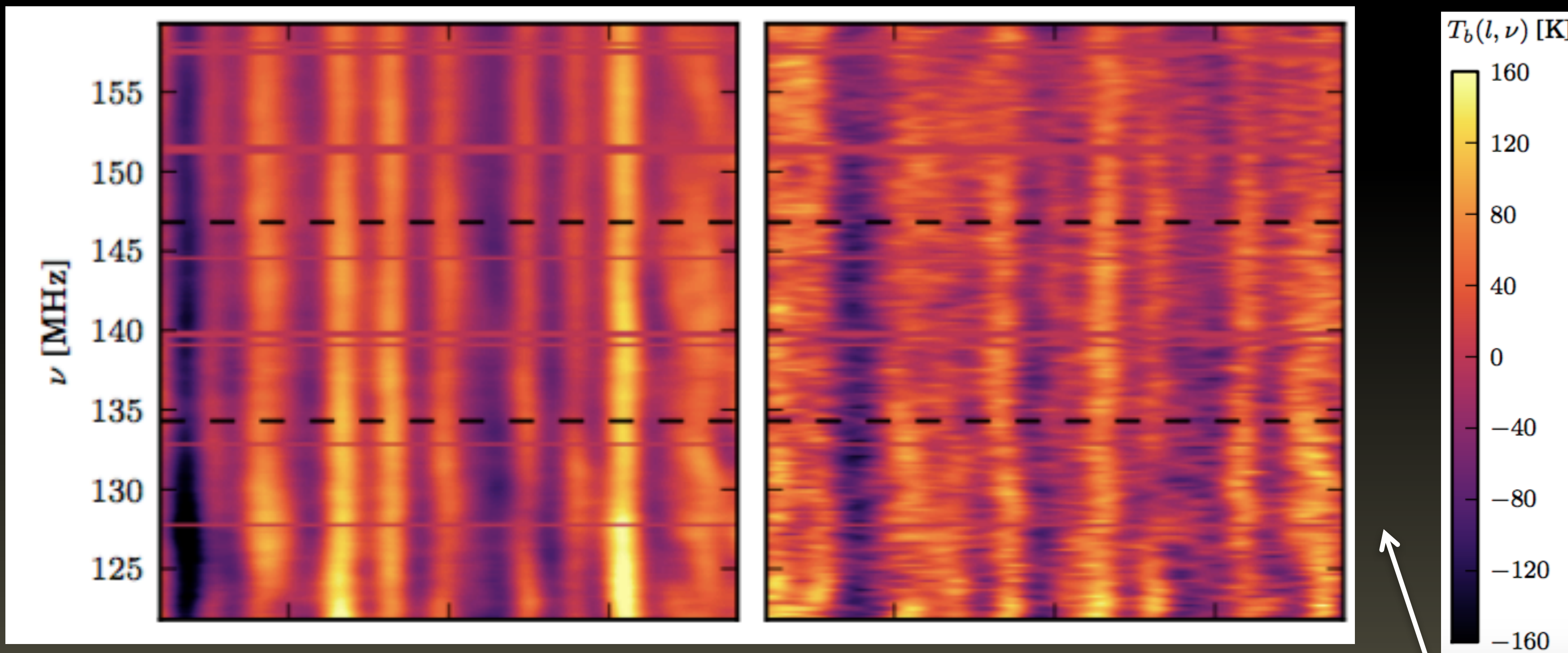


- Generally peeled away above a certain magnitude cut off,
- Happens as part of calibration, MWA will remove on order of 100 bright sources whereas LOFAR use a sky catalogue to calibrate, removing tens of thousands of sources

Patil et al. 2017, 838(1), 65
Intensity in mJy/beam

Bright Point Sources

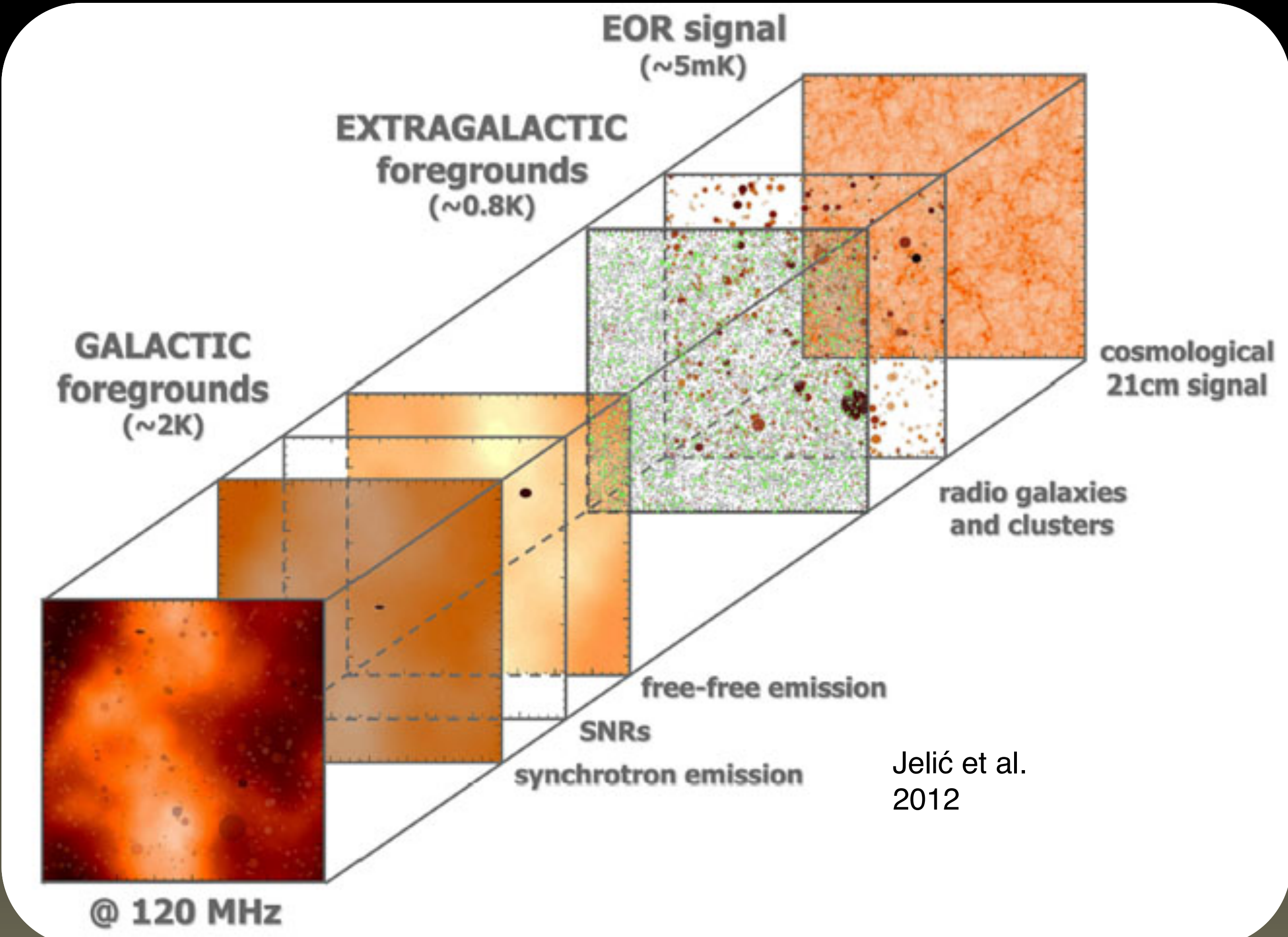


Left: After removal of only 3C61.1
Right: Whole sky model subtracted, scale x 10

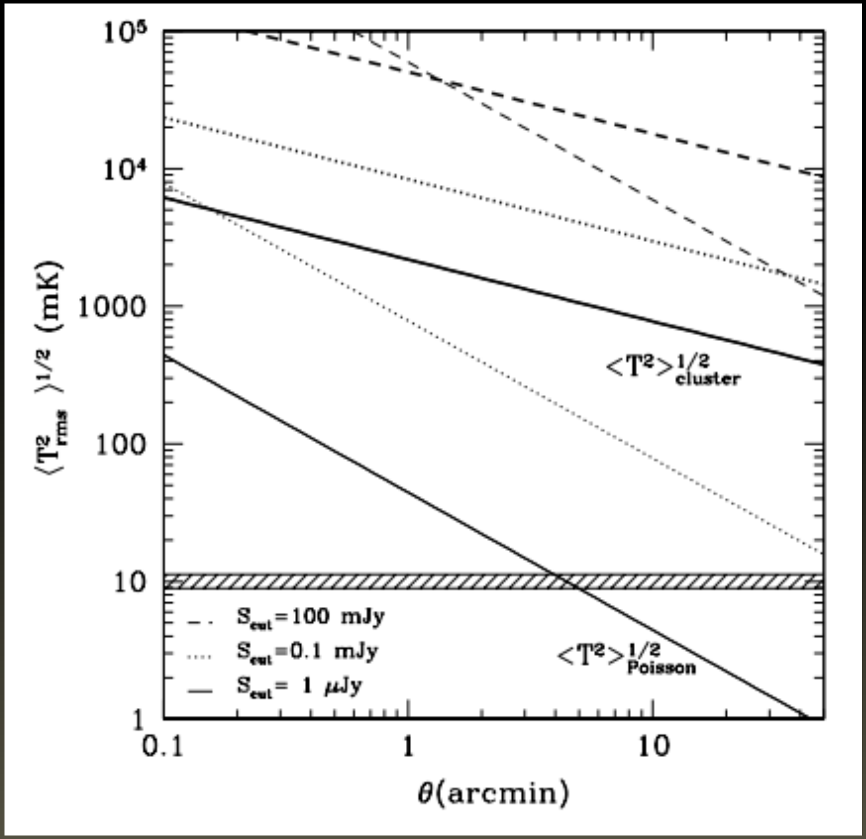
Patil et al. 2017, 838(1), 65

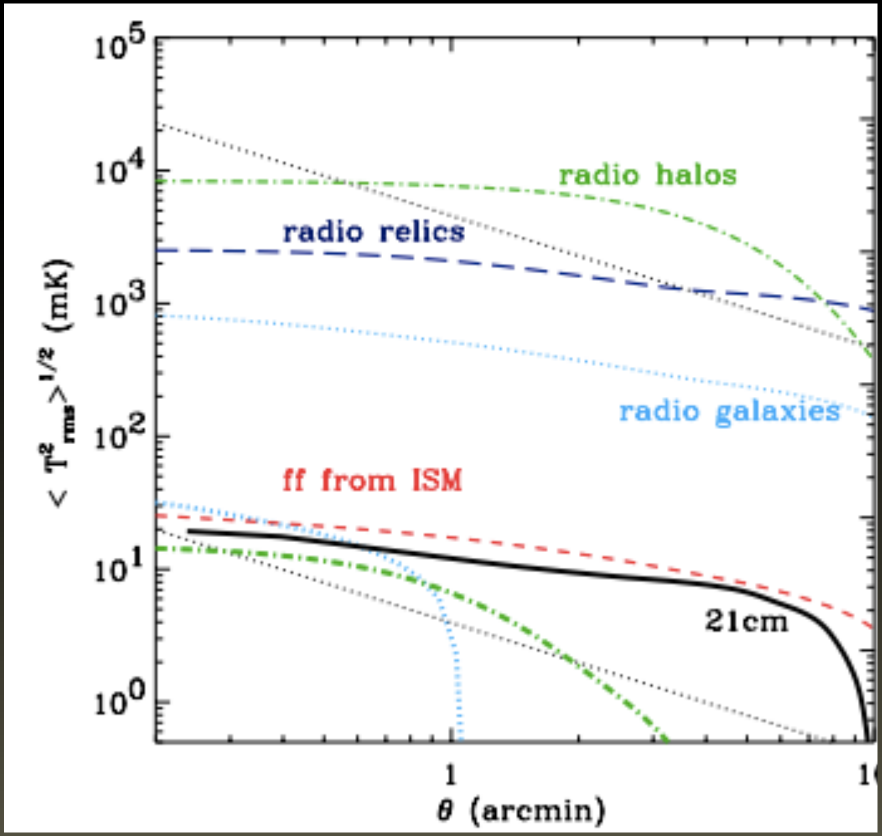
Horizontal lines are RFI excisions

Bright Source Calibration and RFI Mitigation



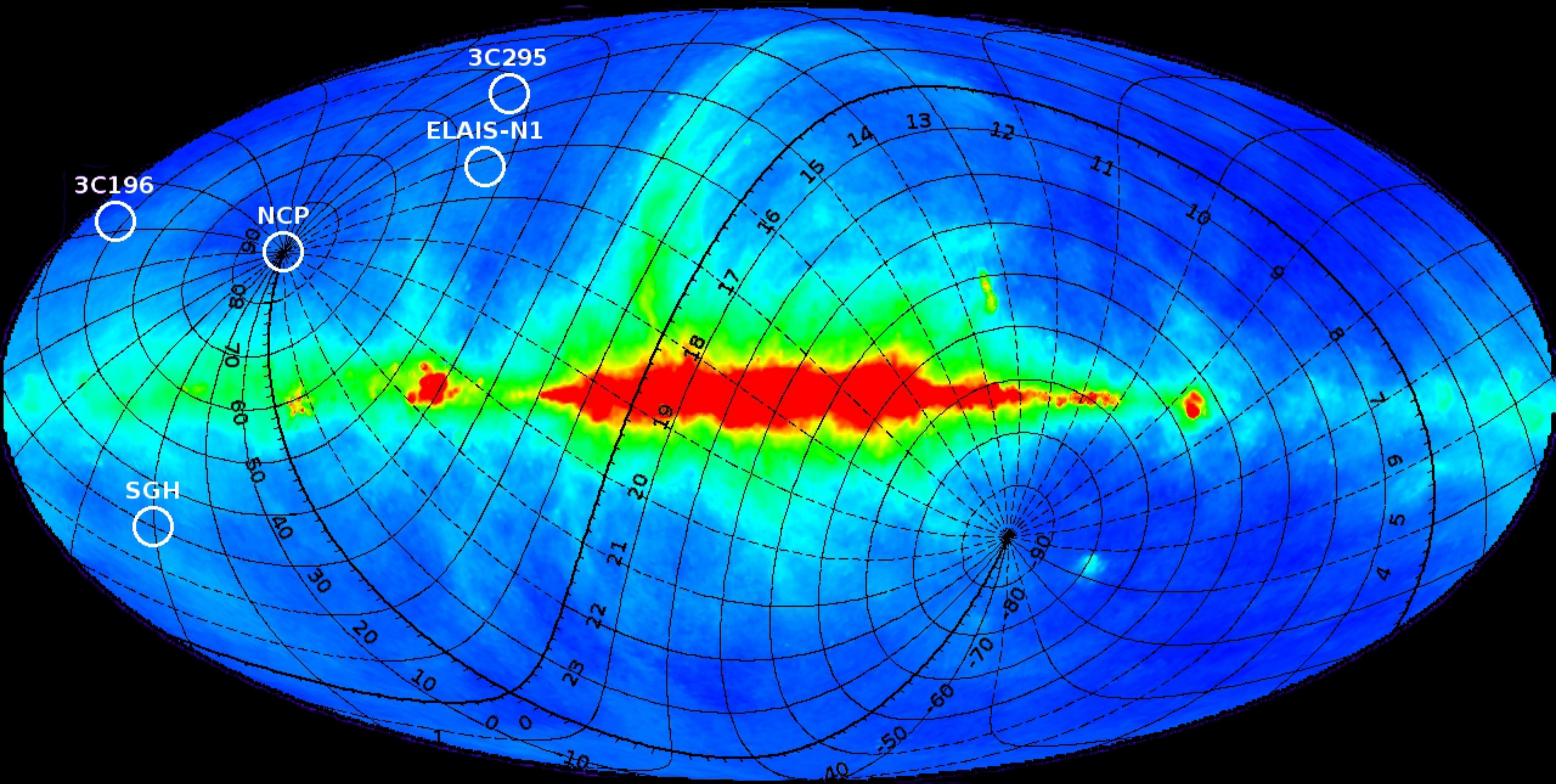
Jelić et al.
2012





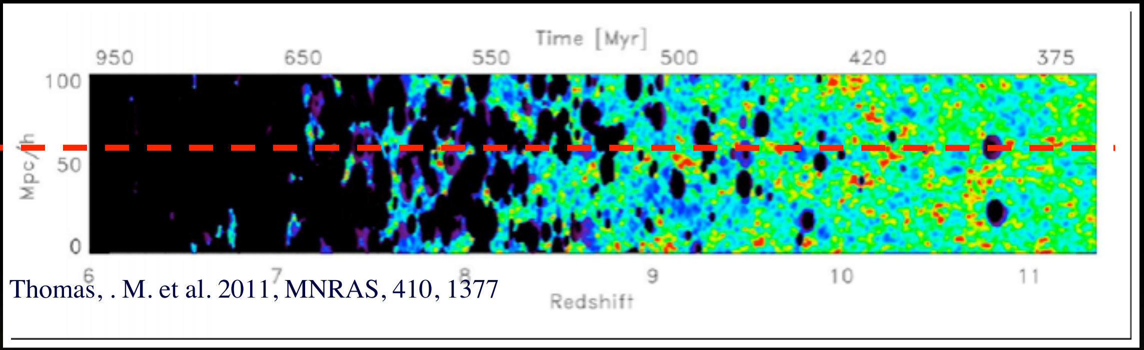
Di Matteo et al 2002, ApJ, 564 : 576-580

Di Matteo et al 2004, MNRAS, 355(4) :1053-1065

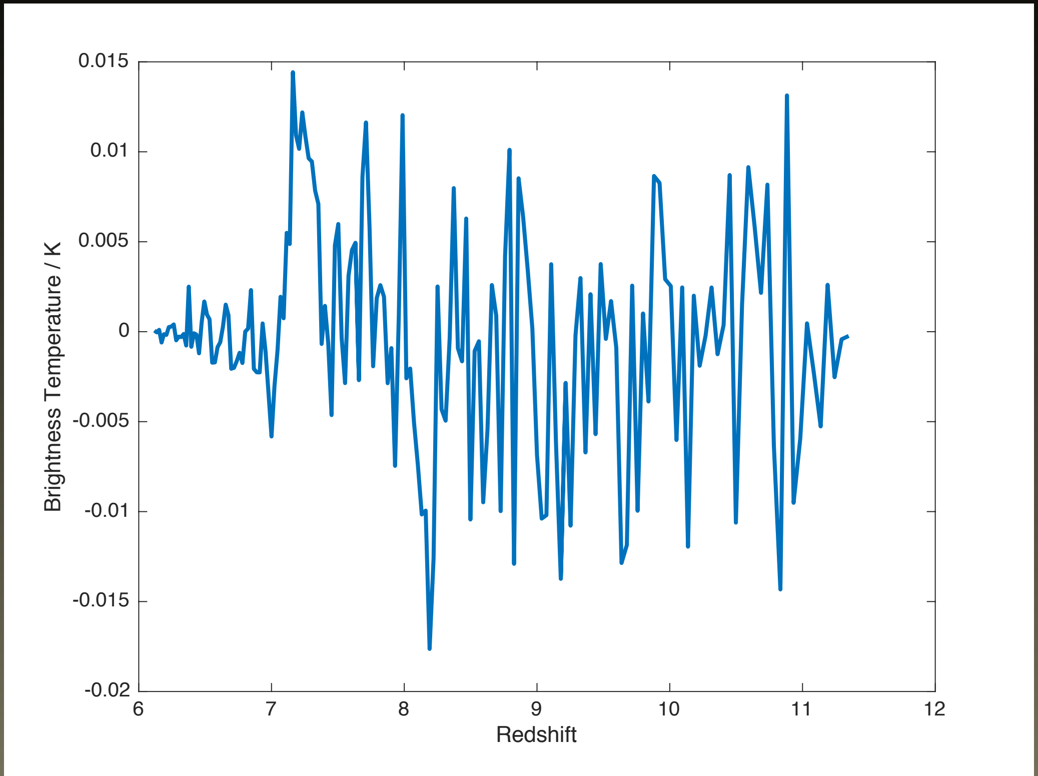


Haslam 408MHz map with LOFAR fields superimposed, credit to V. Jelić

The 21-cm signal shape



Thomas, . M. et al. 2011, MNRAS, 410, 1377



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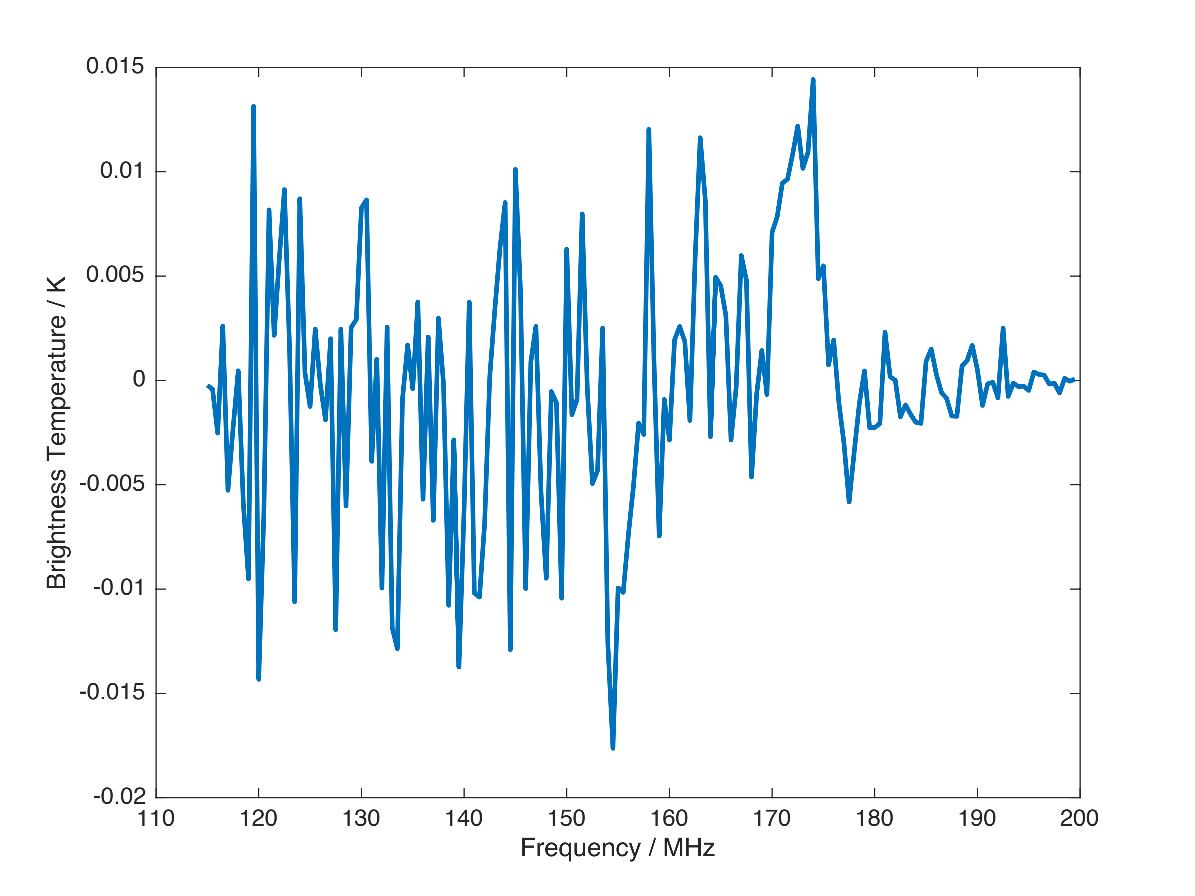

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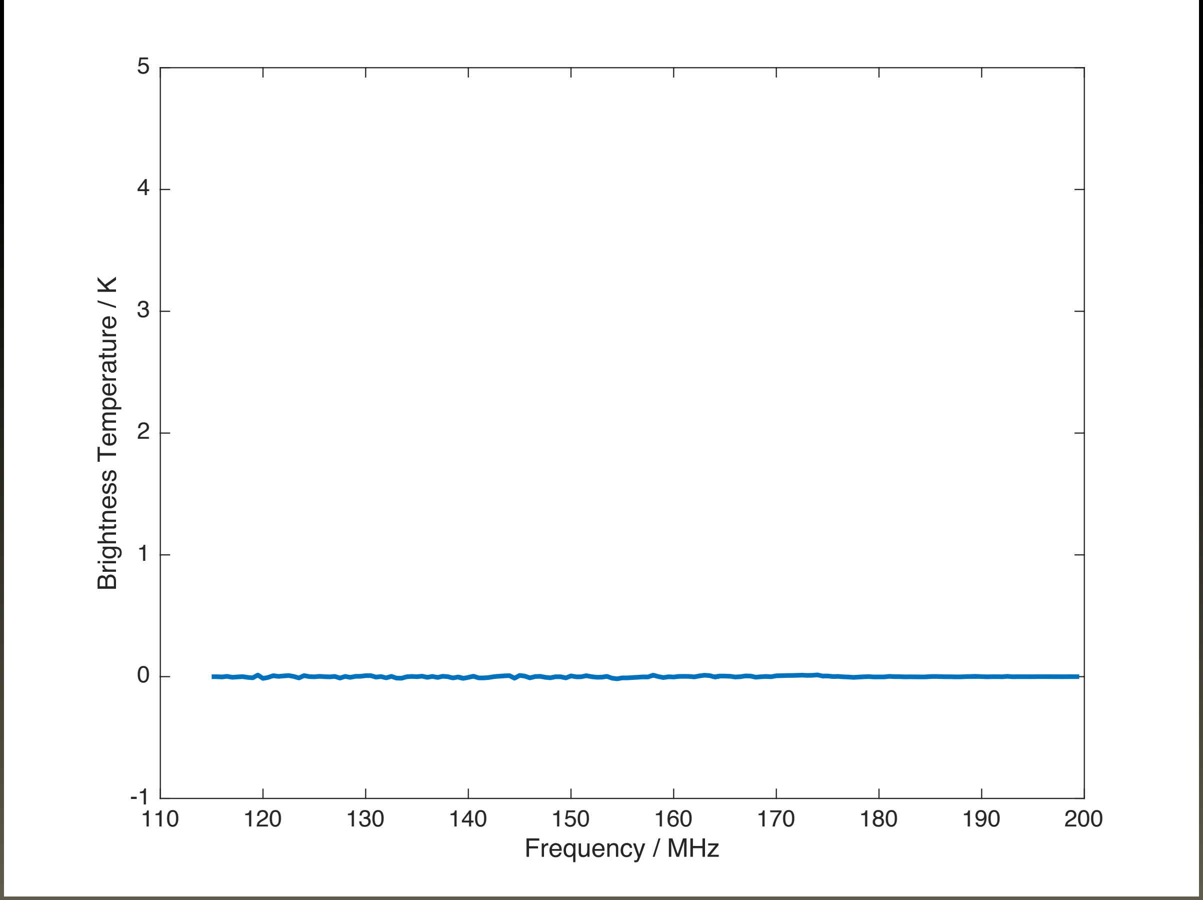

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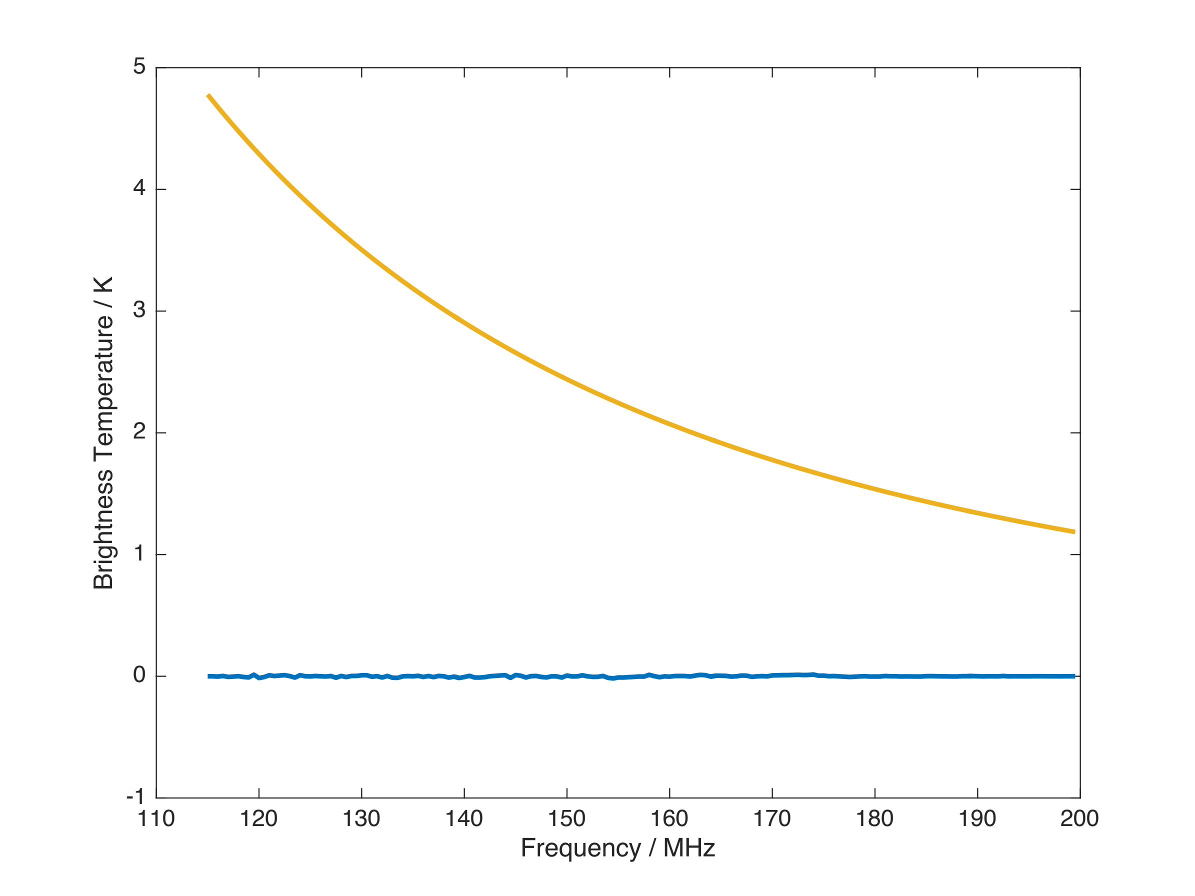
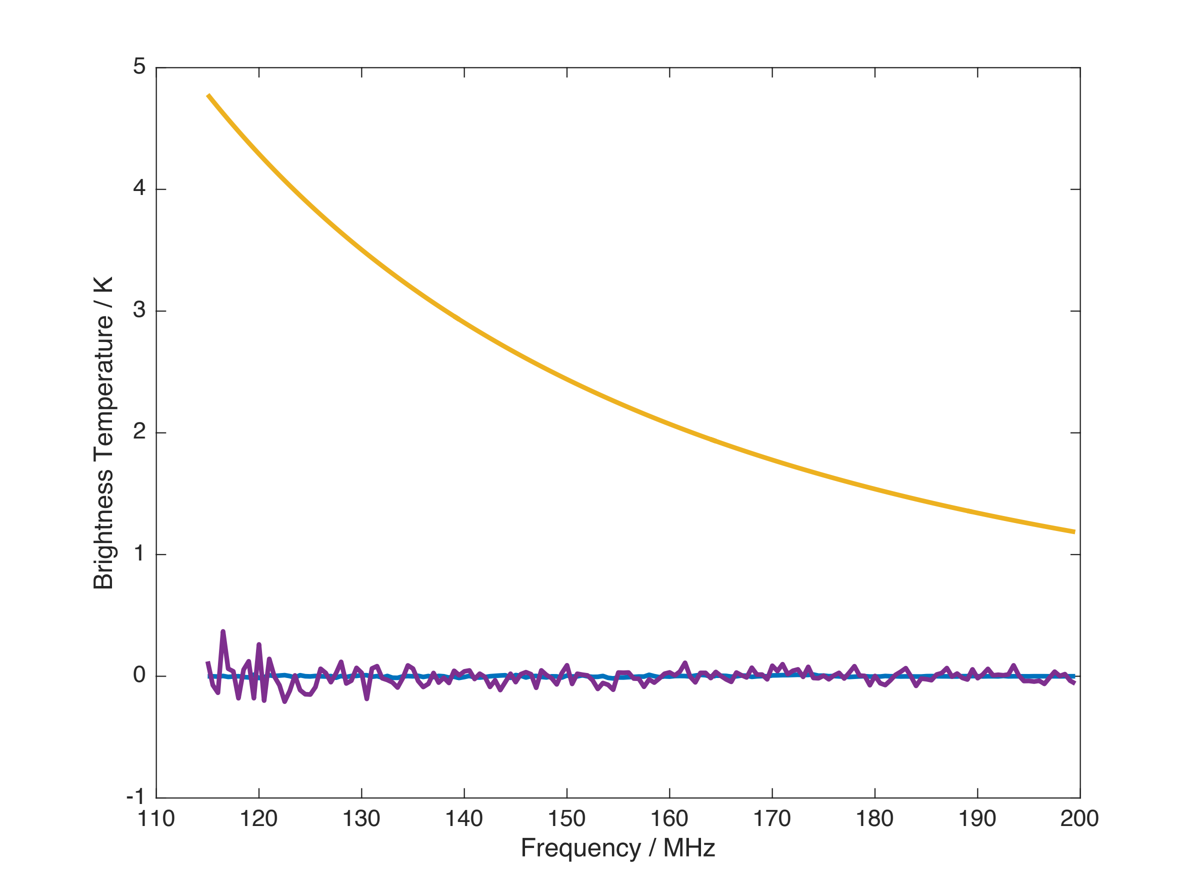
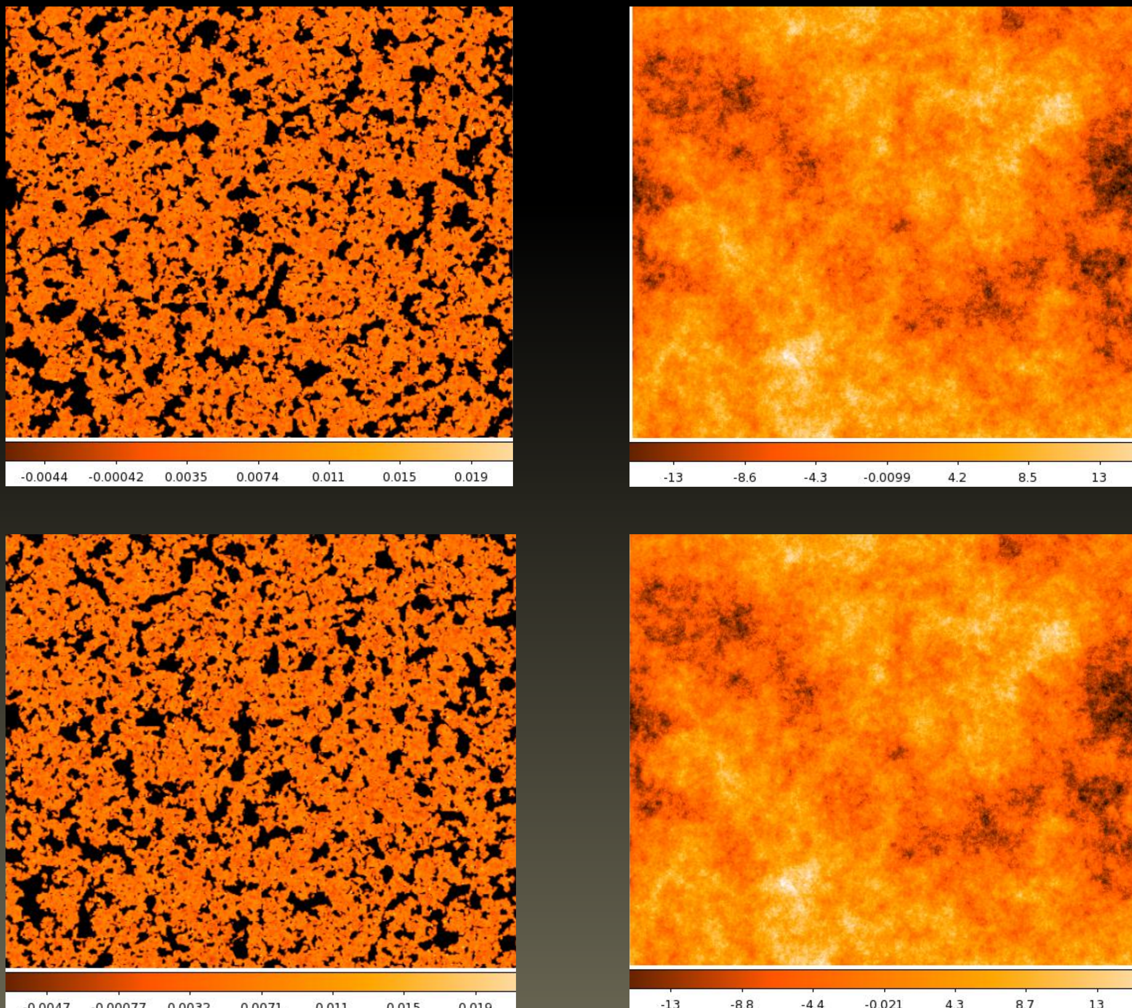


The 21-cm signal shape



Correlating Frequency Slices

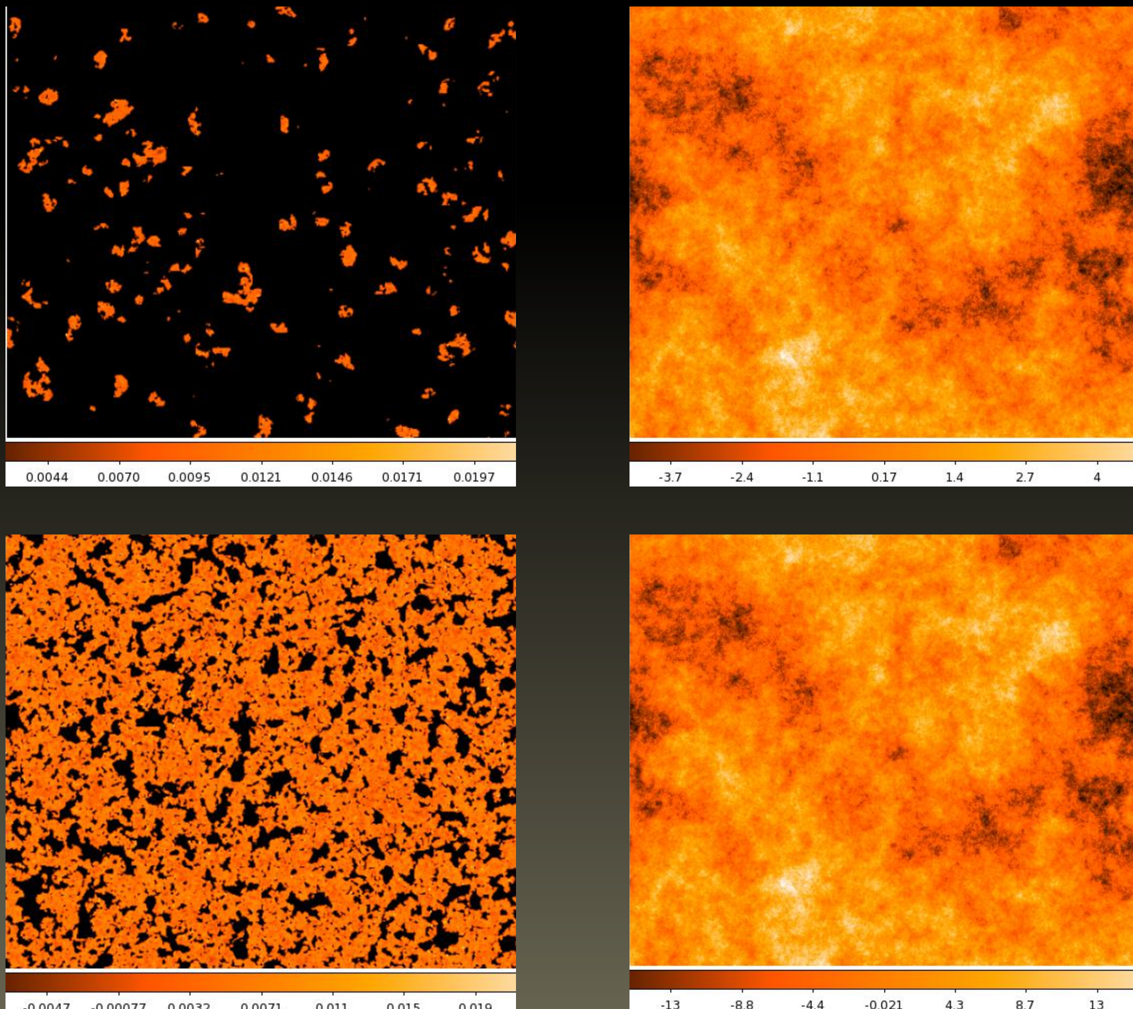


Use the correlation between two channels to separate out correlated signal (foregrounds), thus removing them.

Zaldarriaga et al. 2004, ApJ, 608 : 622-635

See also Santos et al. 2004, ApJ, 625 : 575-587

Correlating Frequency Slices



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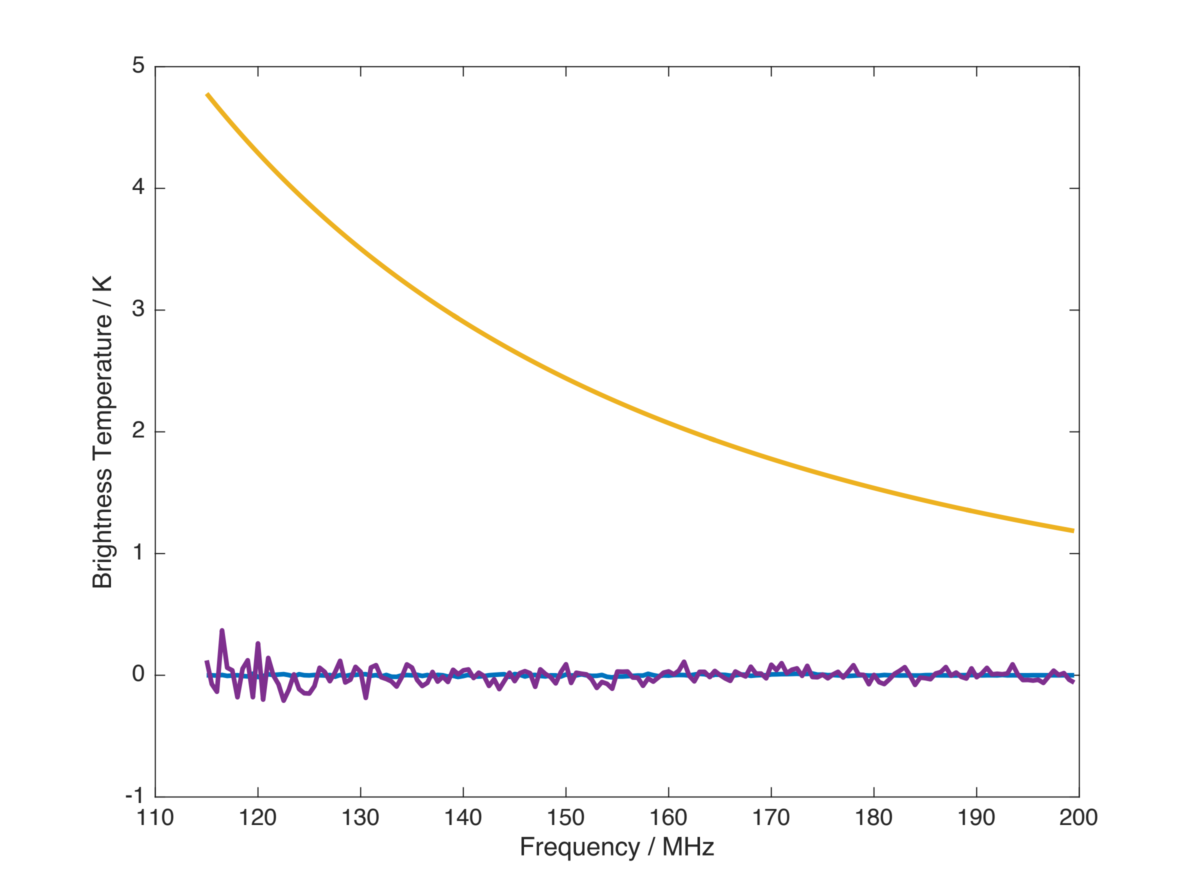
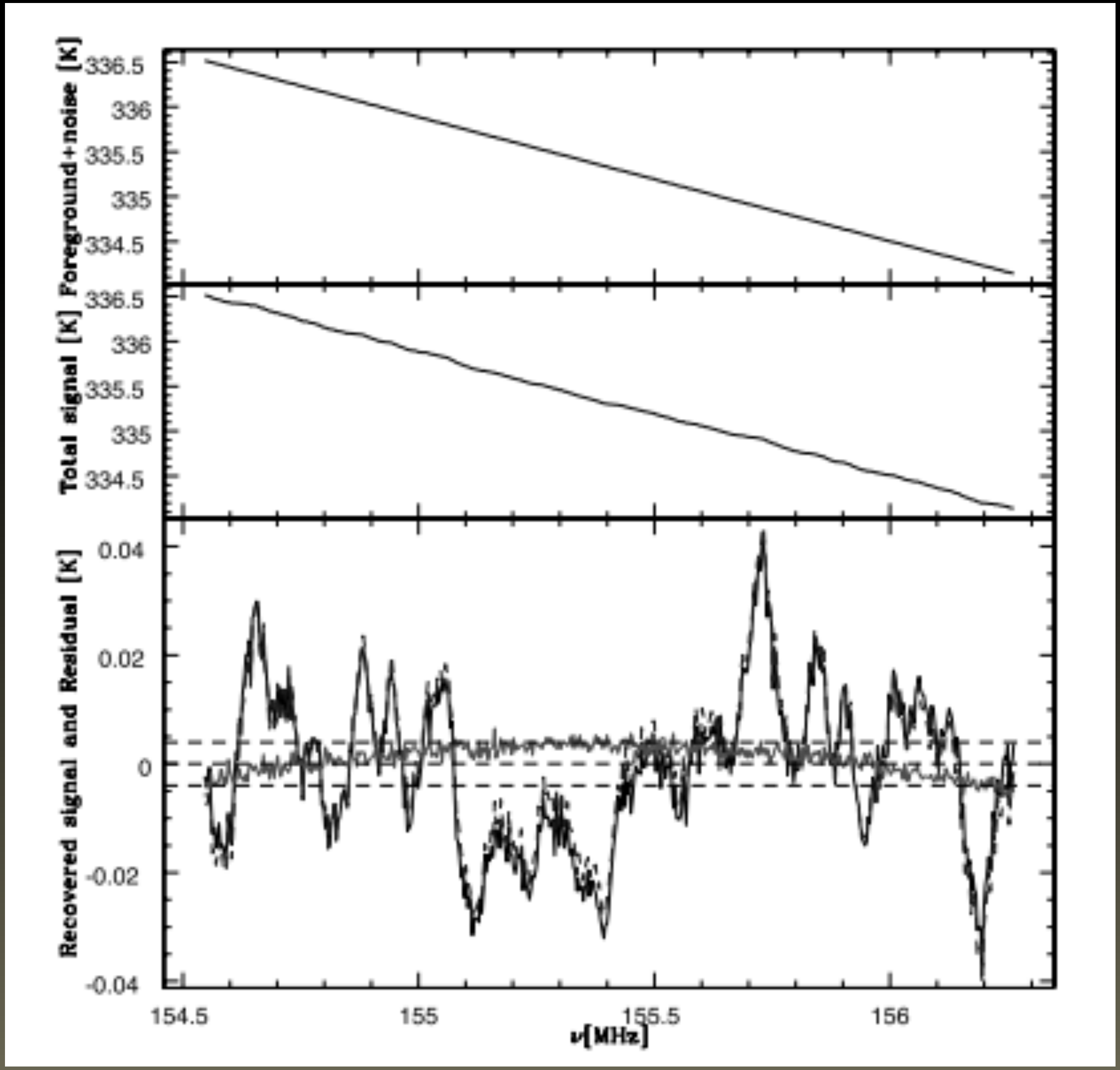


Polynomial Fitting

Santos et al. 2005; Wang et al. 2006; McQuinn et al. 2006; Bowman et al. 2006; Jelic et al. 2008; Gleser et al. 2008; Liu, Tegmark & Zaldarriaga 2009; Liu et al. 2009; Petrovic & Oh 2011; Liu & Tegmark 2011 …...



Wang et al. 2006, ApJ, 650, 529-537

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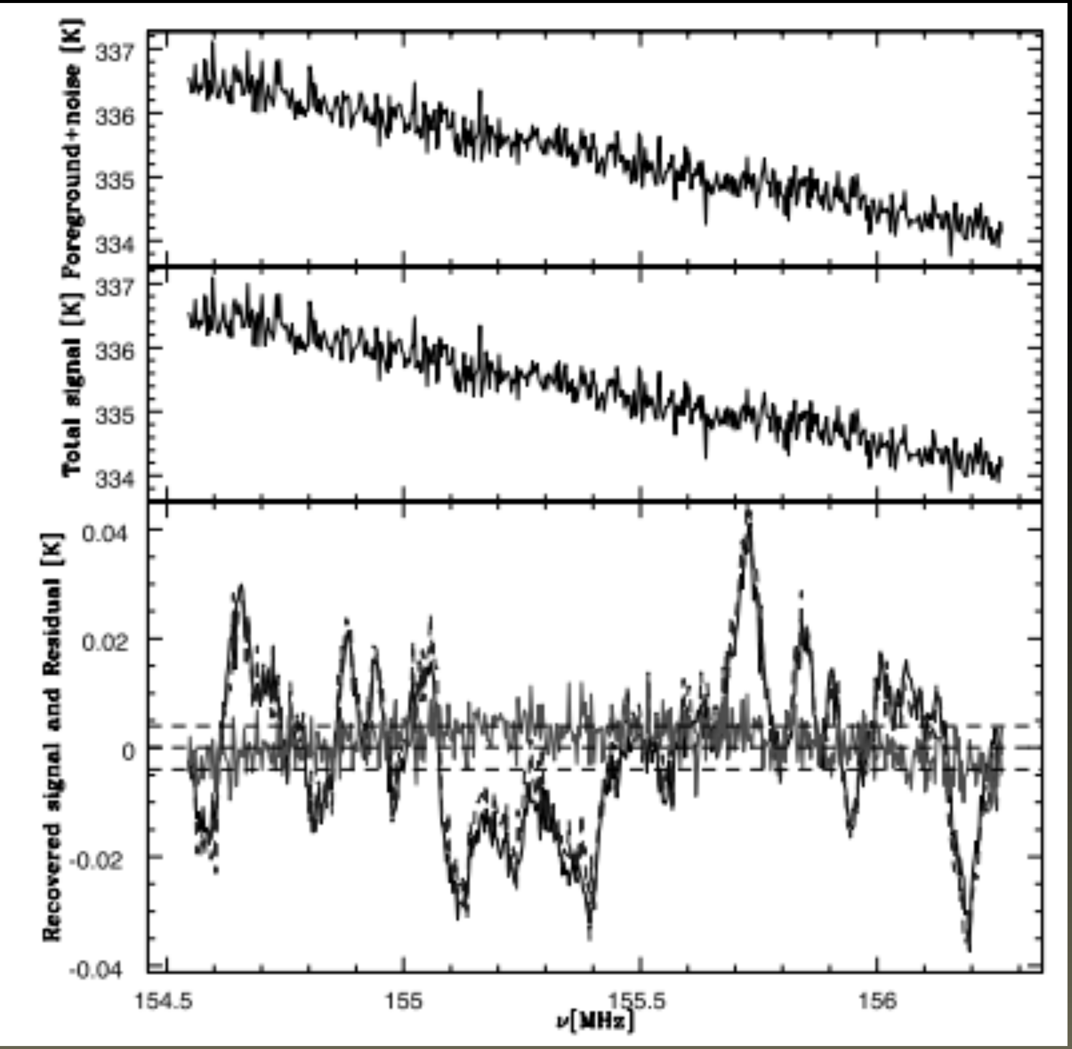
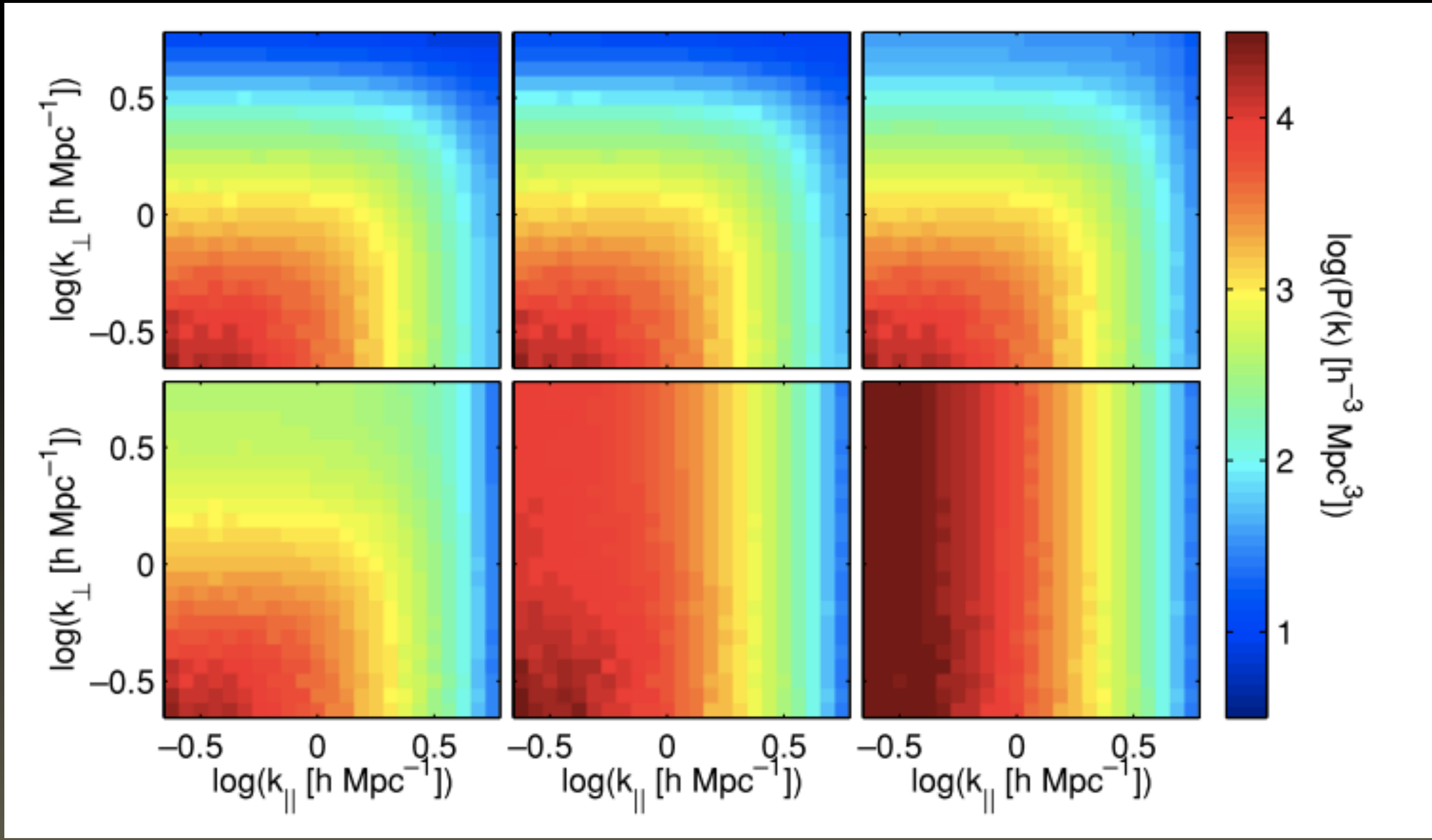


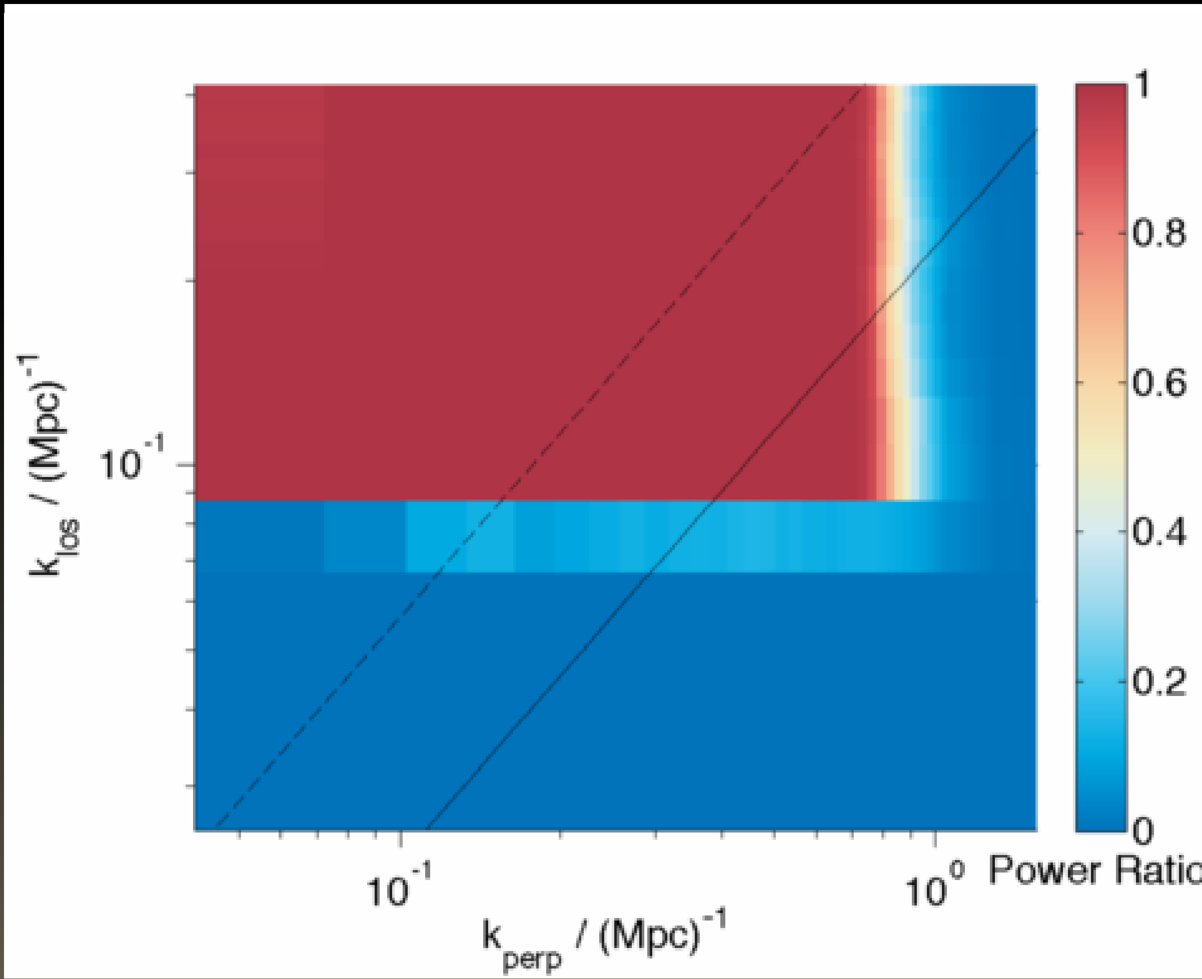
Wang et al. 2006, ApJ, 650, 529-537

Polynomial Fitting



Gleser et al. 2006, MNRAS,
391 : 383-398

But what if the foreground signal isn’t smooth?



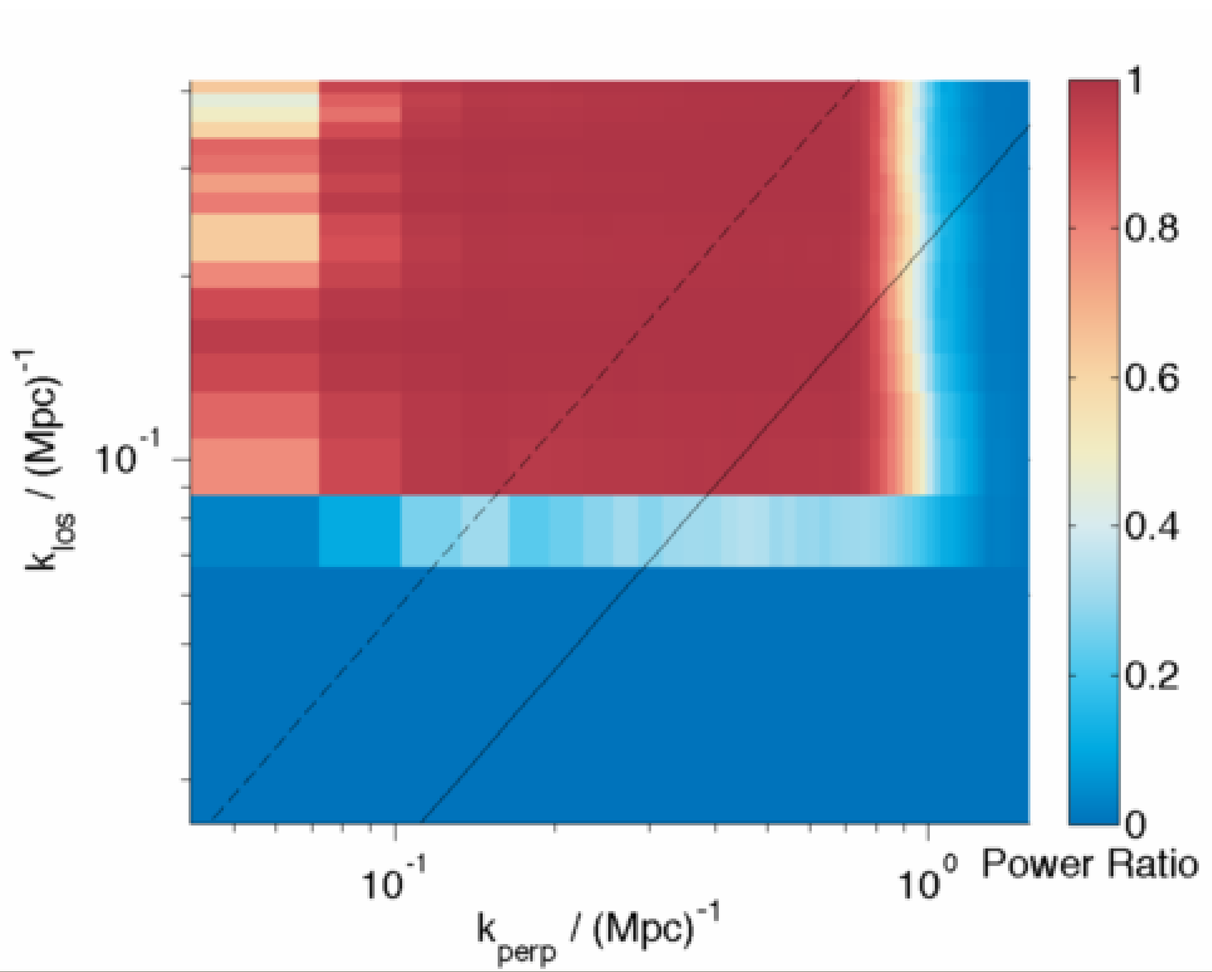
Ratio = cs / (fg + cs)

cs = cosmological signal

fg = foregrounds

i.e. red is GOOD

Chapman et al. 2016



Ratio = cs / (fg + cs)

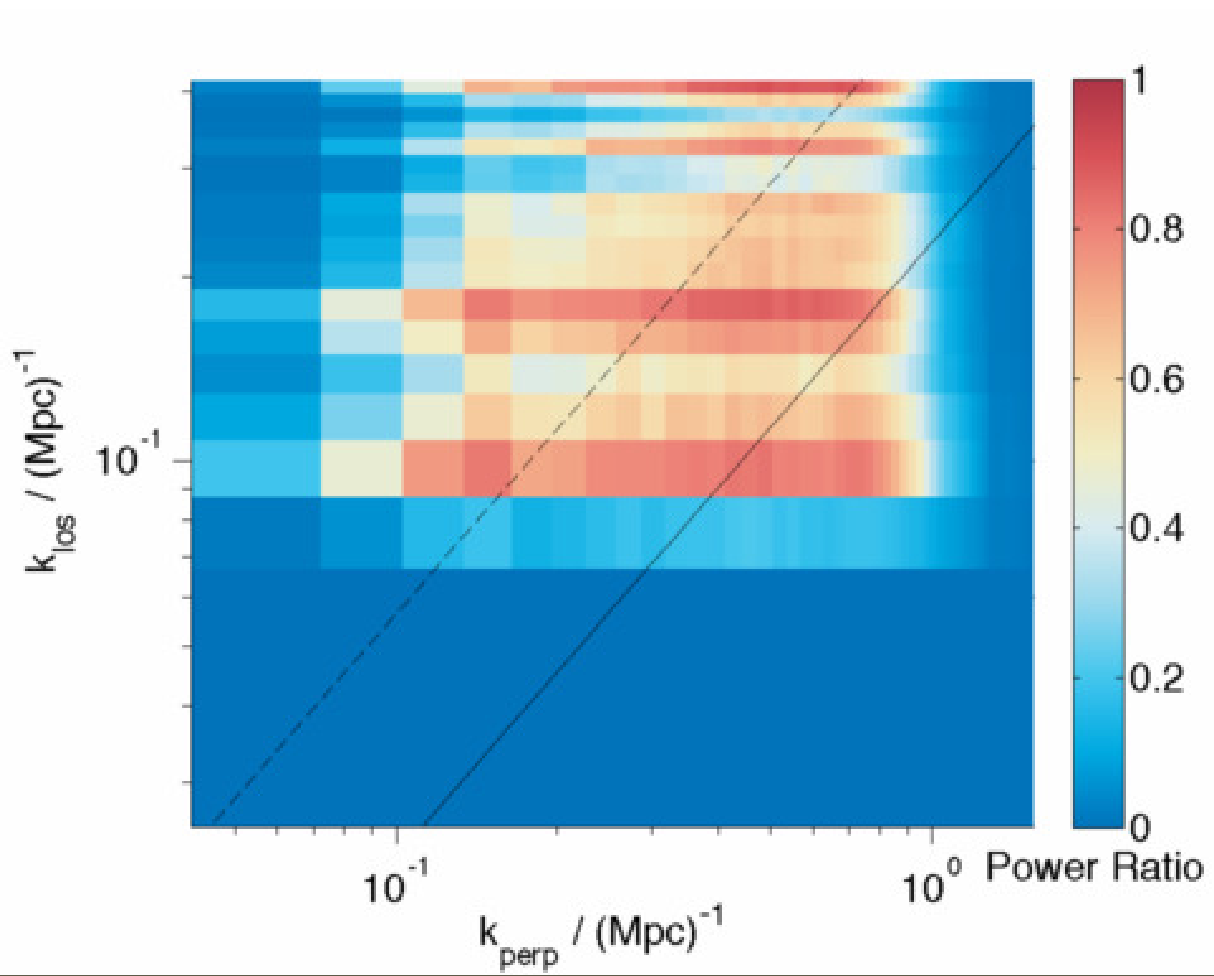
cs = cosmological signal

fg = foregrounds

i.e. red is GOOD

0.1% wiggle along the line of sight

Chapman et al. 2016



Ratio = cs / (fg + cs)

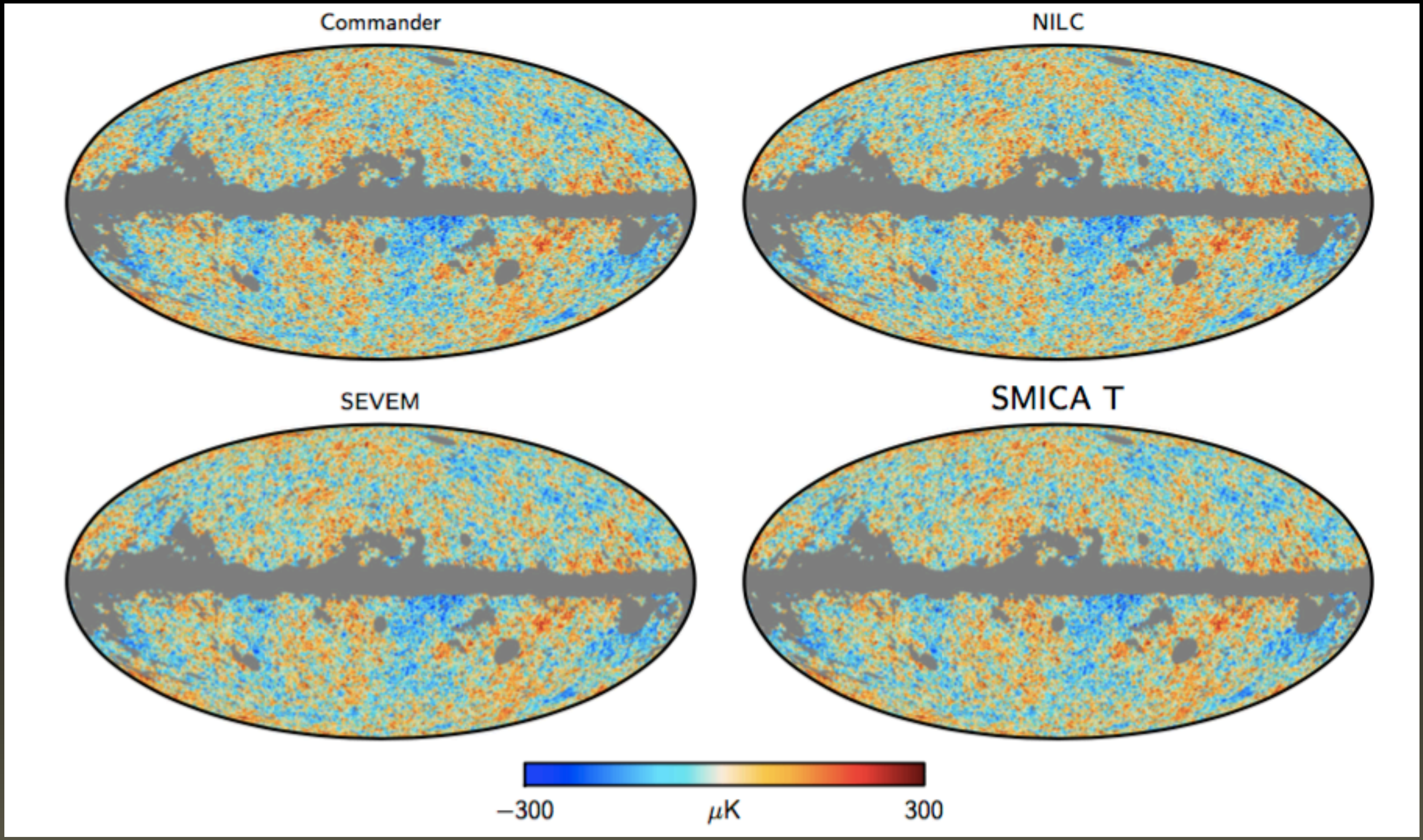
cs = cosmological signal

fg = foregrounds

i.e. red is GOOD

1% wiggle along the line of sight

Chapman et al. 2016



Planck 2015 results. IX, 2015, A&A, 594,A9

CCA: See Anna Bonaldi’s talk

FastICA *– Hyvärinen A., 1999, IEEE Trans. on Neural Networks, 10,626;Hyvärinen A., Karhunen J., Oja E., 2001, Independent Component Analysis. John Wiley and Sons)*

$x = \mathbf{A}\,s + n$

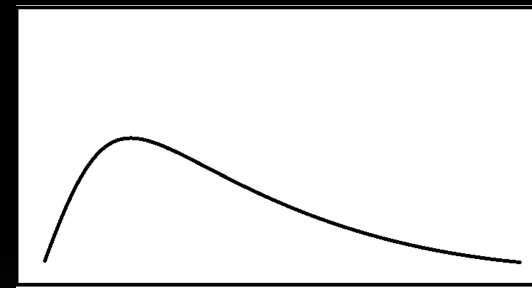
- x - observed data vector
- s - statistically independent components of x.

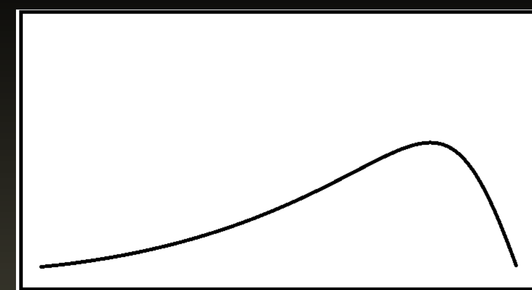
- n is the noise
- **A** - mixing matrix

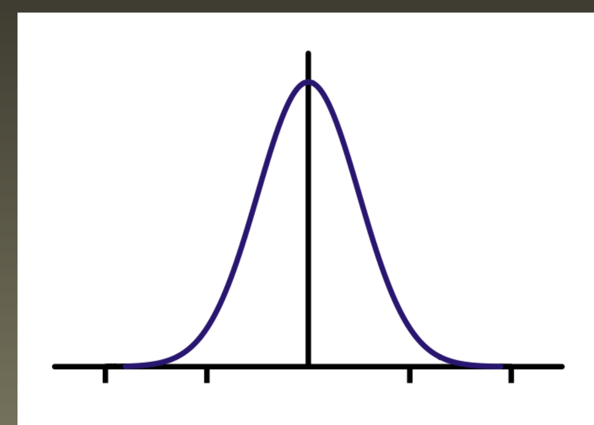
If we can find a matrix **W** such that $s = \mathbf{W}\,x$ we have effectively sorted a mixed signal into its individual components

FastICA *– Hyvärinen A., 1999, IEEE Trans. on Neural Networks, 10,626;Hyvärinen A., Karhunen J., Oja E., 2001, Independent Component Analysis. John Wiley and Sons)*

“Probability Distribution Function (PDF) of a mixture of independent components is more Gaussian than the PDF of any individual component.”

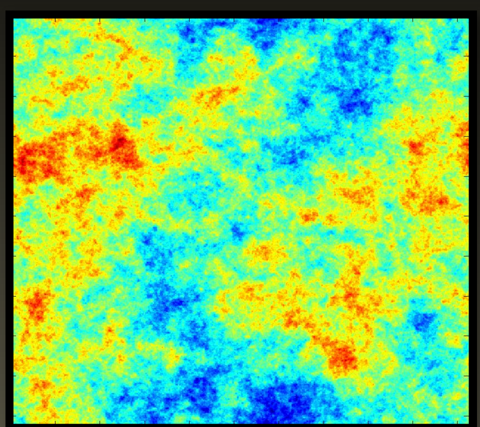


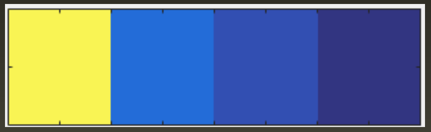


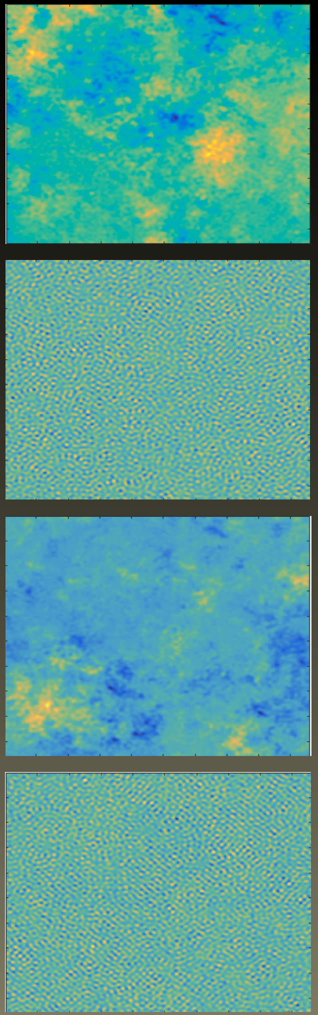


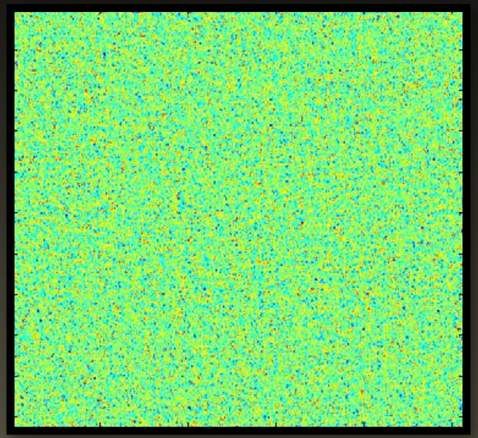
The Mixing Model

$$X = AS + n$$









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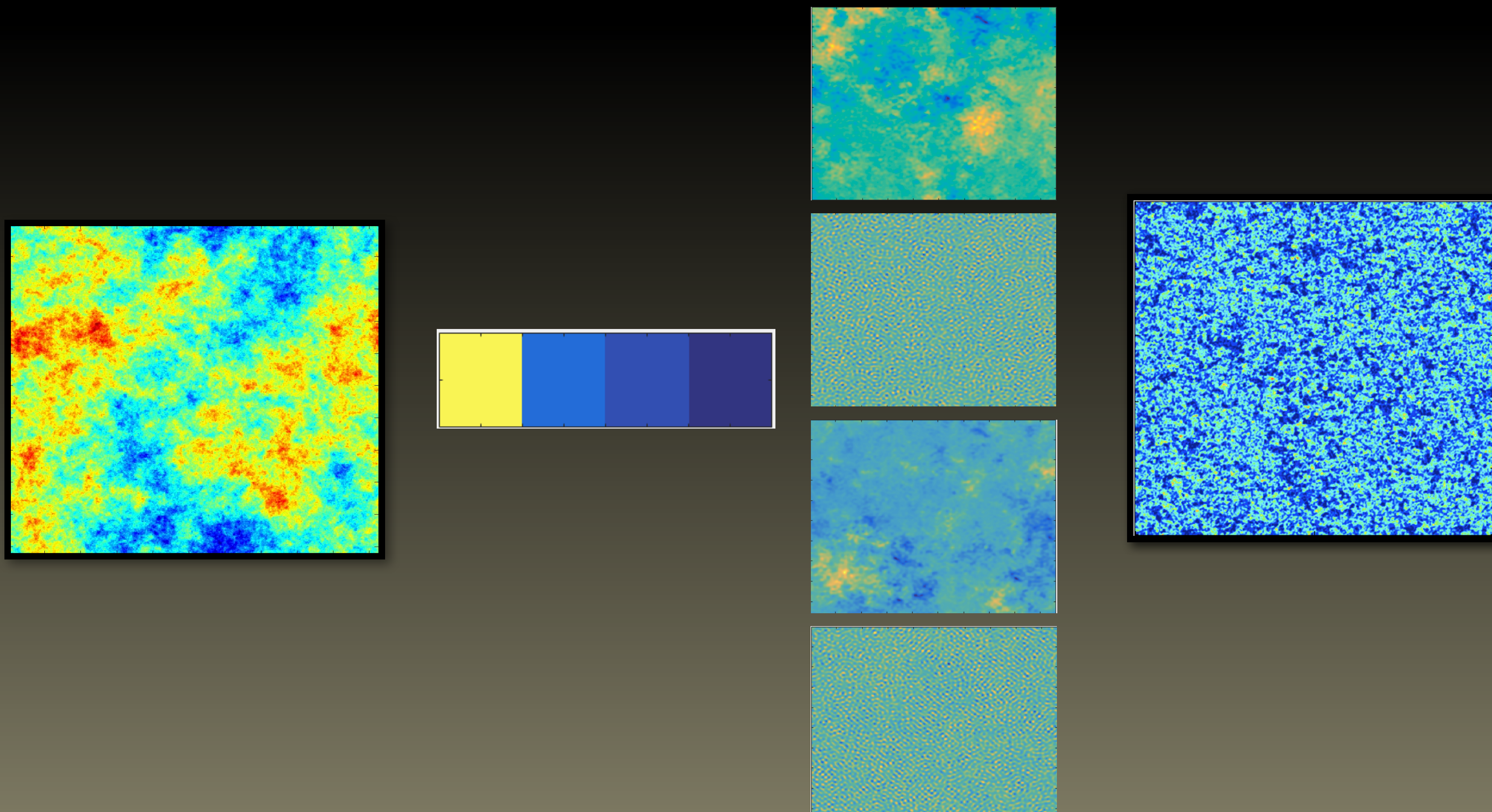
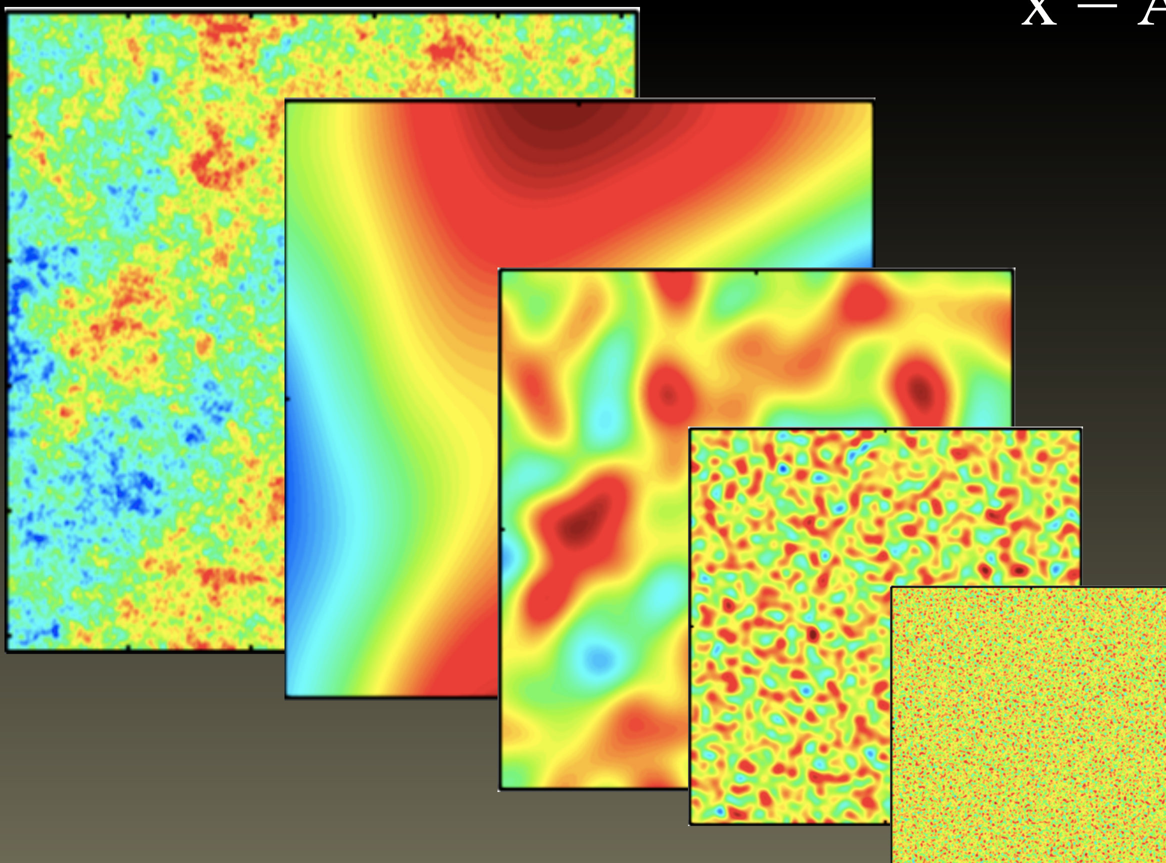


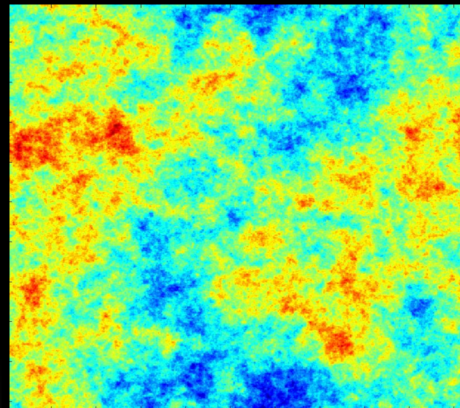
GMCA *– (Bobin J. et al., 2008, Statistical Methodology, 5, 307; Bobin J. et al., 2007, Image Processing, IEEE Transactions on, 16, 2662)*

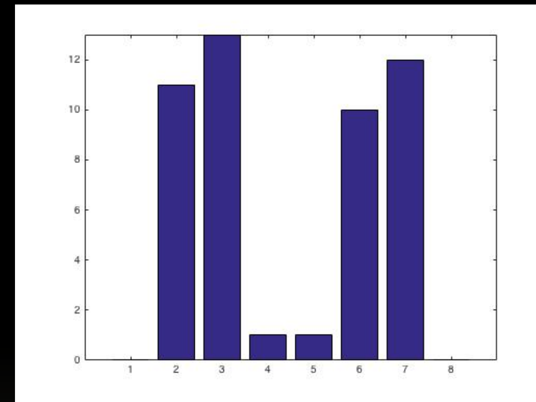
$$x = \mathbf{A}\, s + n$$

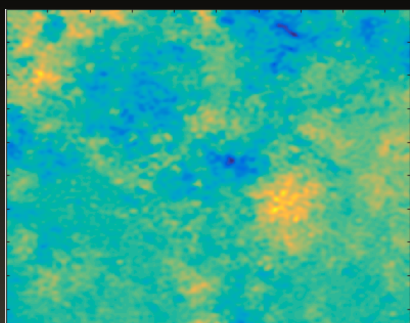
$$s_j = \sum_{k=1}^{D} \varphi_{jk}$$

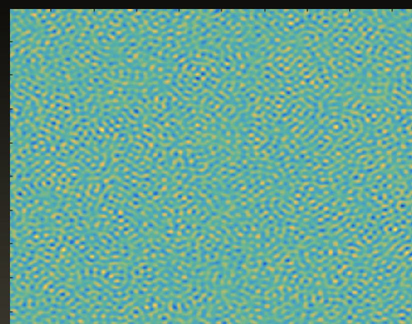


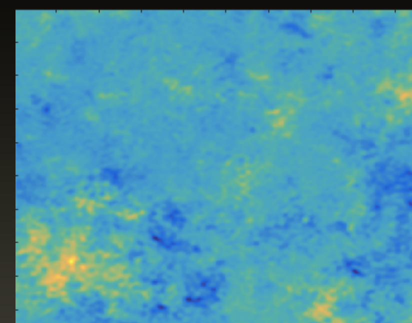
With the independent components unlikely to have the same few non-zero coefficients one could then use this sparsity to more easily separate the mixture.

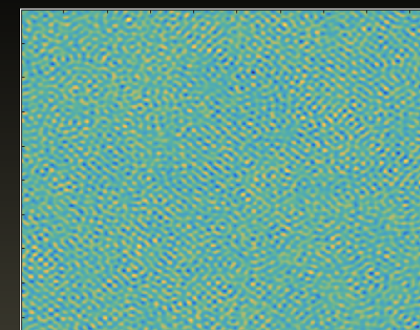


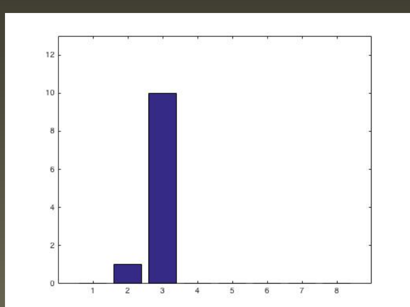

0 2 4 6 8 10 12
1 2 3 4 5 6 7 8







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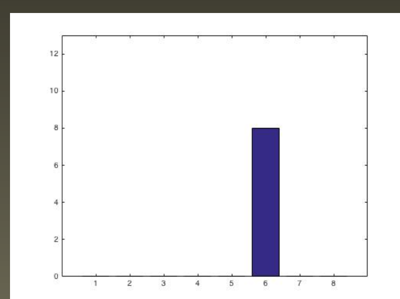
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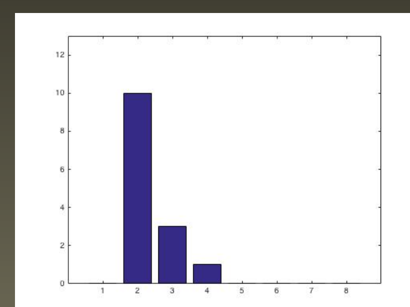
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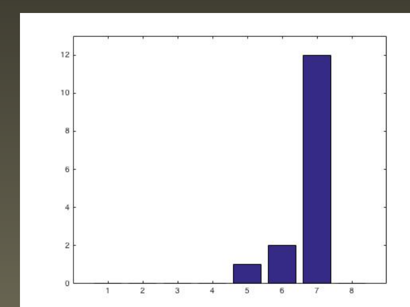
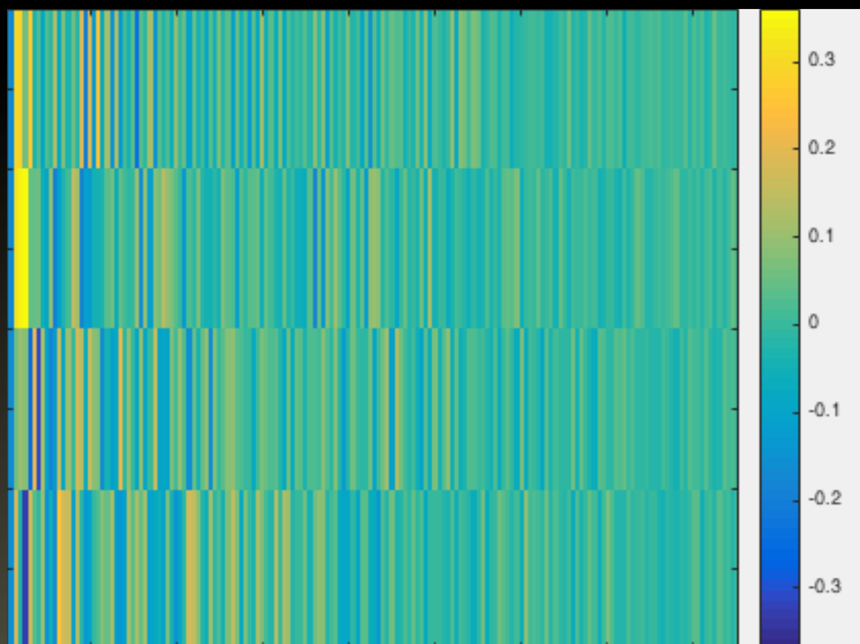
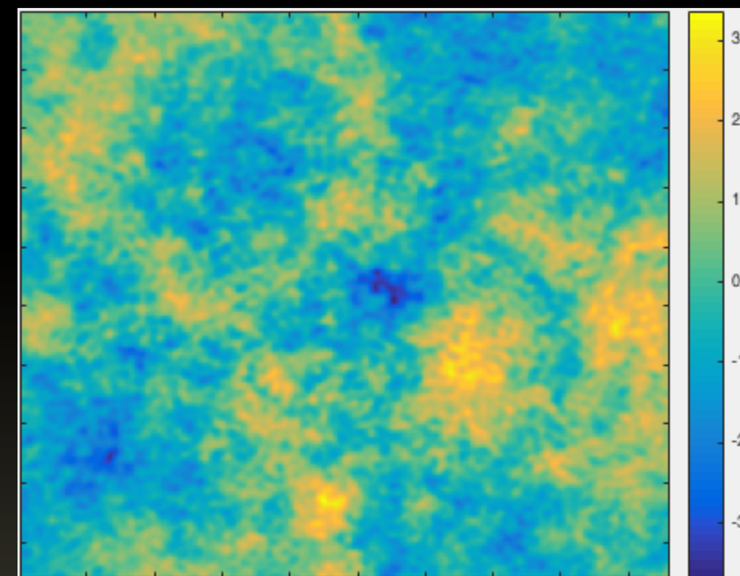
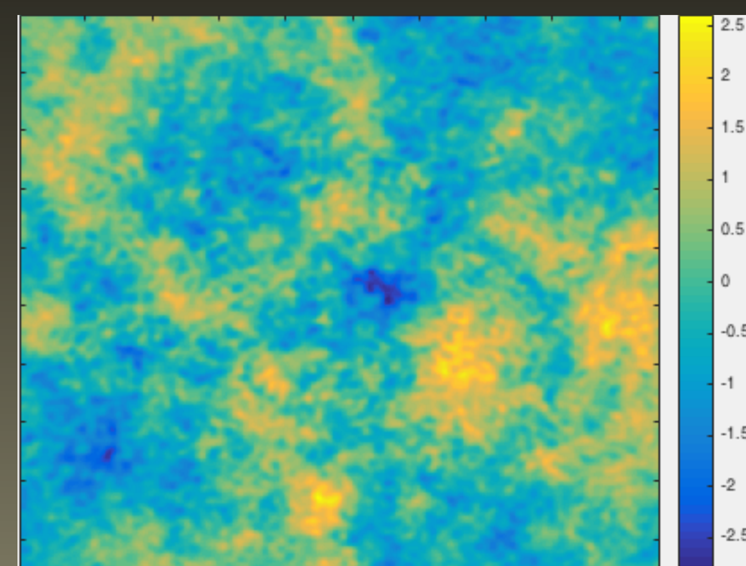

0 2 4 6 8 10 12
1 2 3 4 5 6 7 8

A



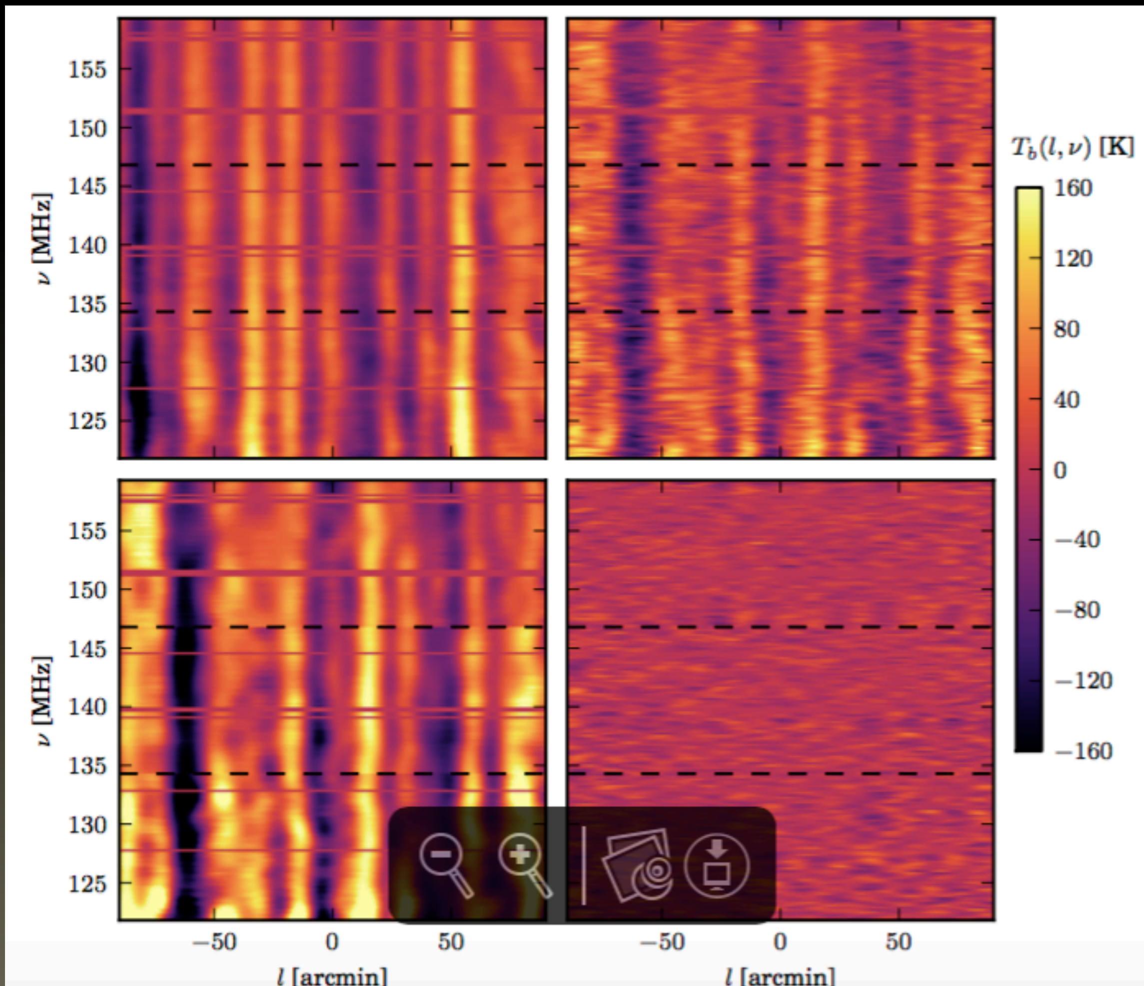
S



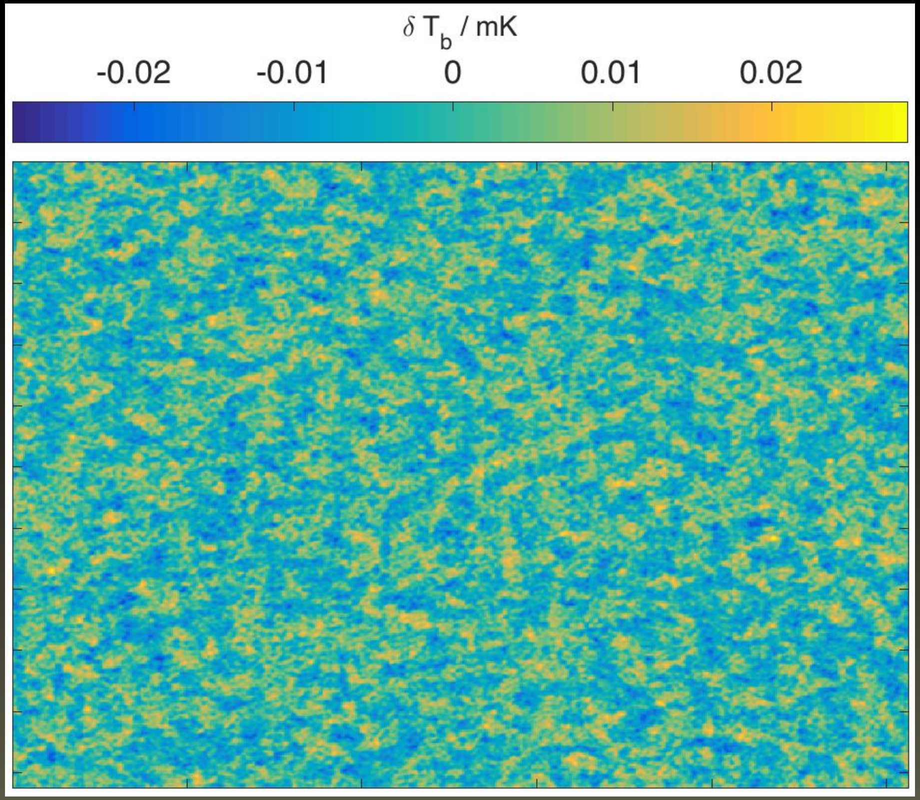


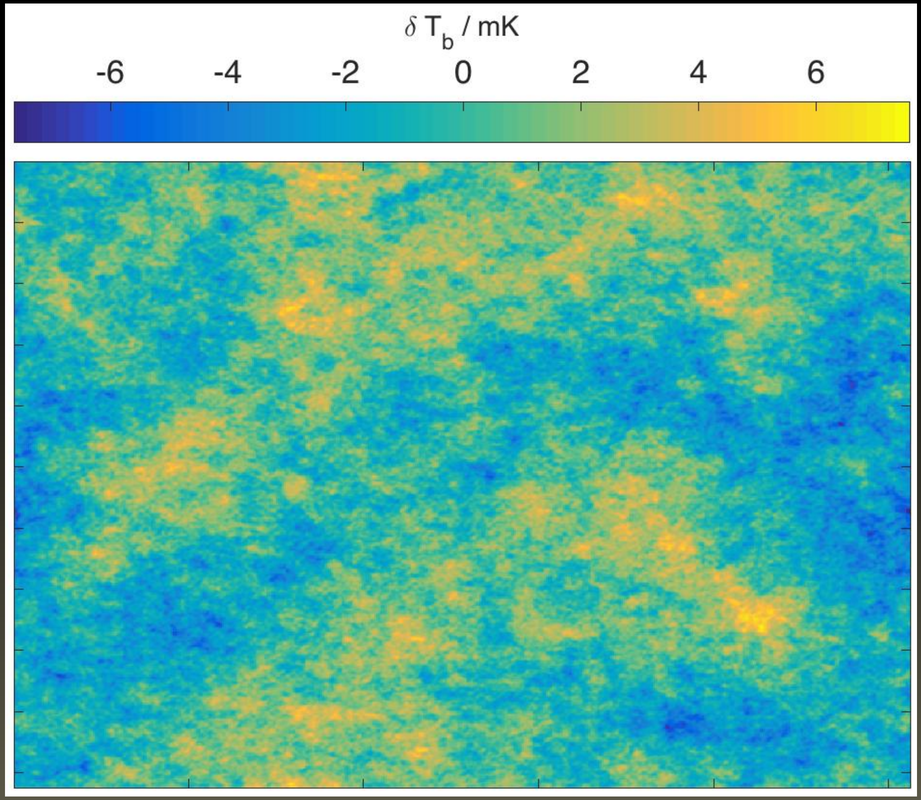
$$X = A\,S + n$$

Patil et al. 2017, 838(1), 65



Results – 10 degree^2 maps



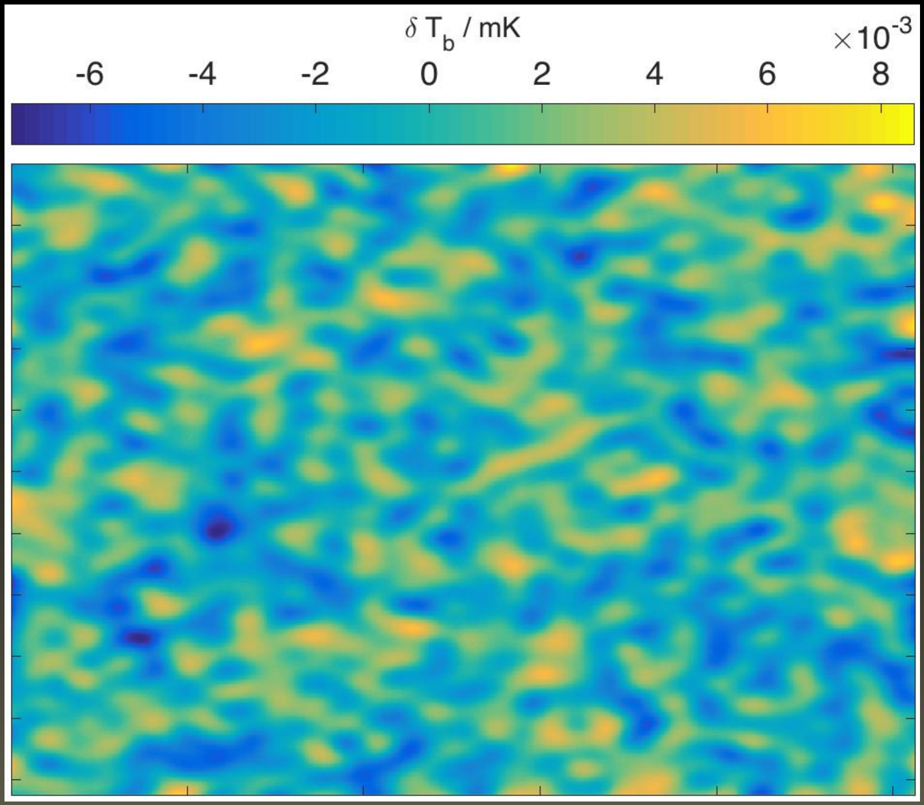


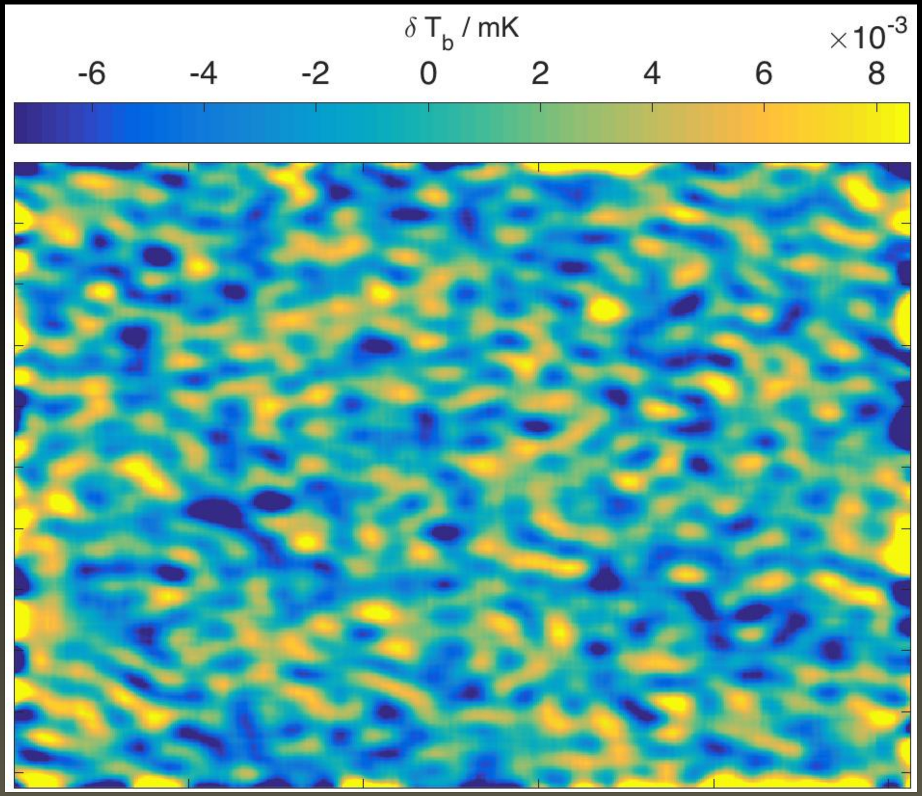
Left: simulated cosmological signal

Right: Total signal

See: Chapman et al. 2013

Results – maps

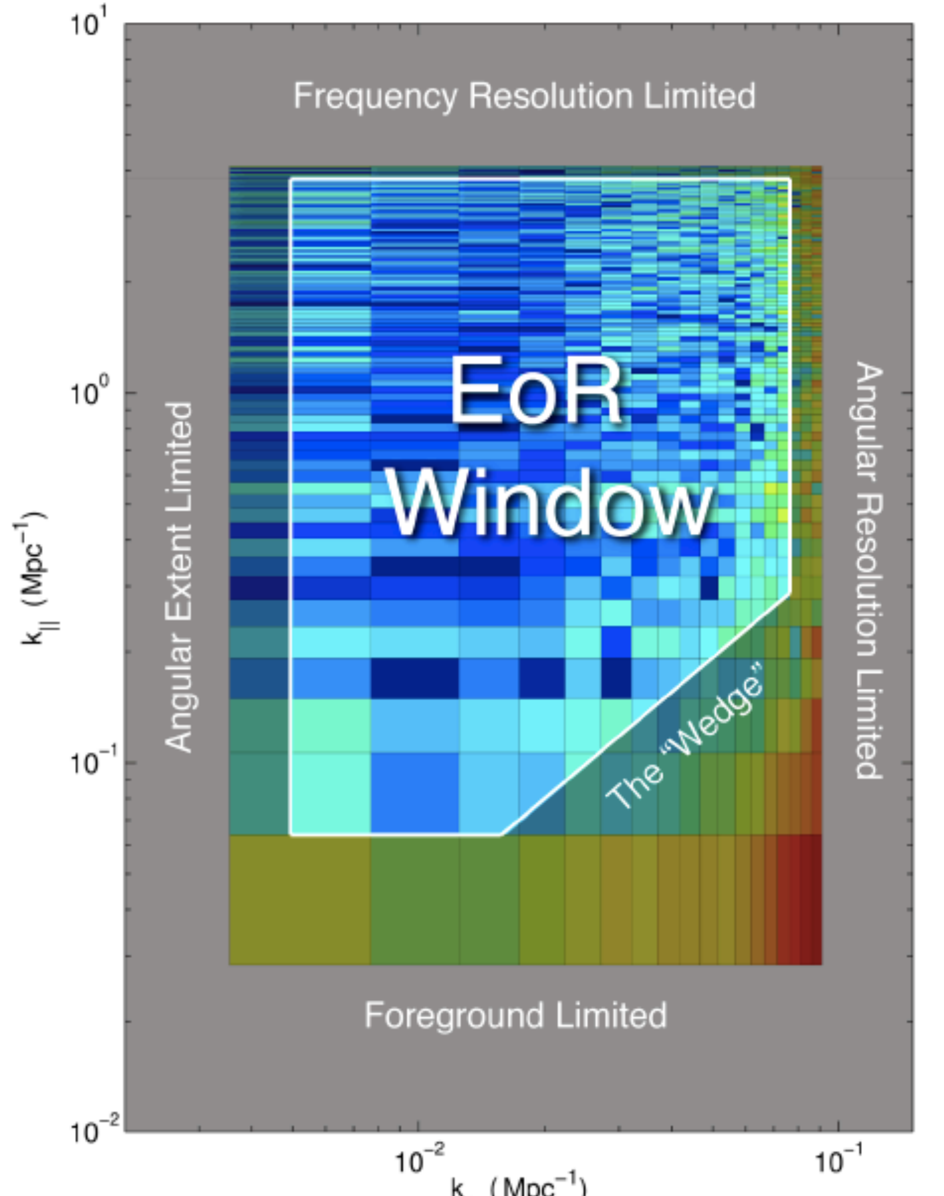




Left: simulated cosmological signal smoothed by 20 arcmin kernel

Right: data after foreground removal smoothed, Correlation coeffs of around 70-80%

See: Chapman et al. 2013



Dillon et al 2013

Foreground **avoidance** only uses the EoR window.

Foreground **suppression** downweights scales according to a foreground model.

PAPER: Ali et al., AJ, 809 61, August 2015

MWA: Dillon et al. Phys. Rev. D 91, 123011 (19 June 2015); Trott et al., AJ, 818, Feb 2016

Foreground removal, suppression and avoidance are complementary

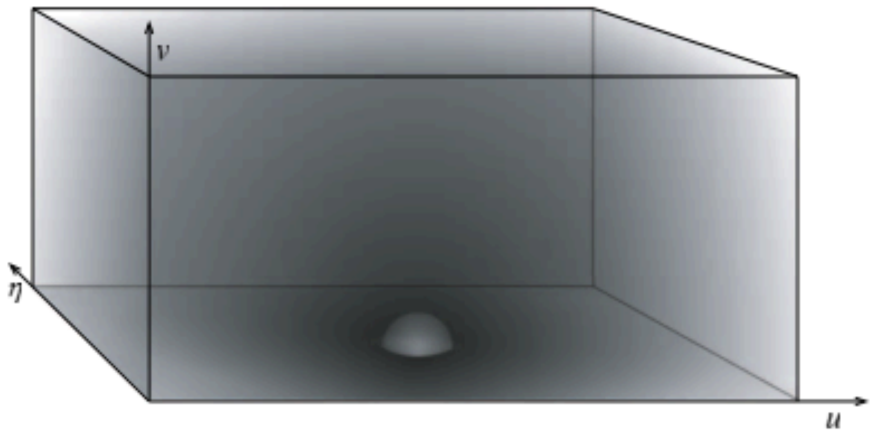


FIG. 3.—Cartoon of the $\langle I(u, v, \eta)\rangle$ distribution of the EOR signal. Notice the spherical symmetry of the EOR signal as compared to the strong separable-axial symmetry of the residual foreground sources as shown in Figs. 4 and 5. This symmetry difference can be used as a handle for separating the EOR signal from the residual foreground contamination.

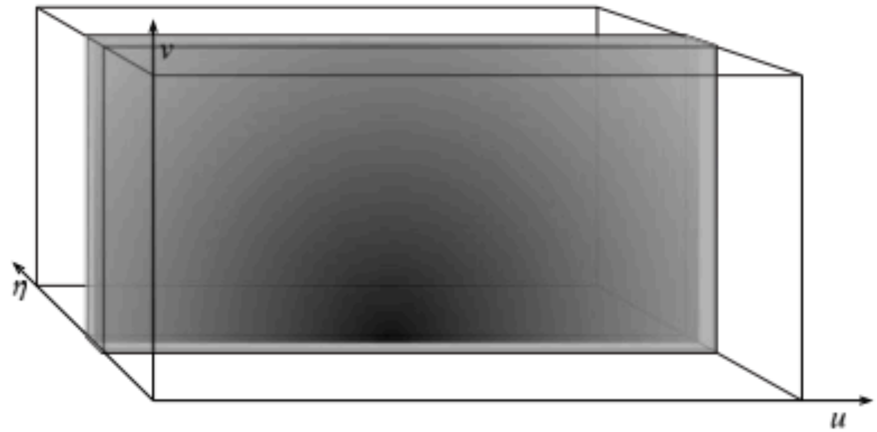
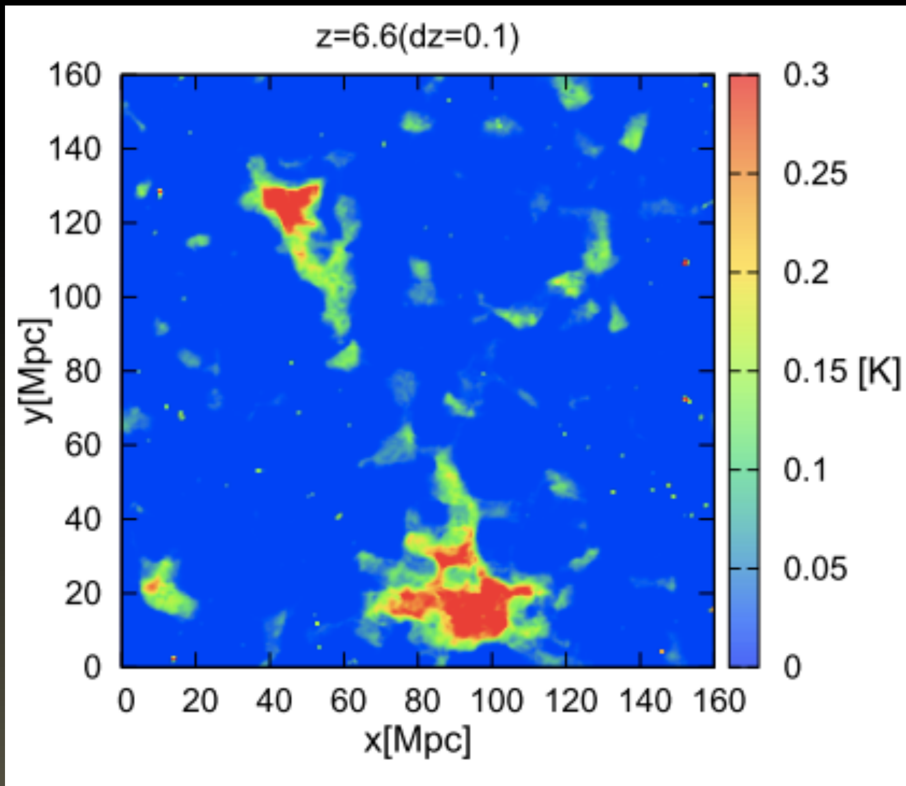


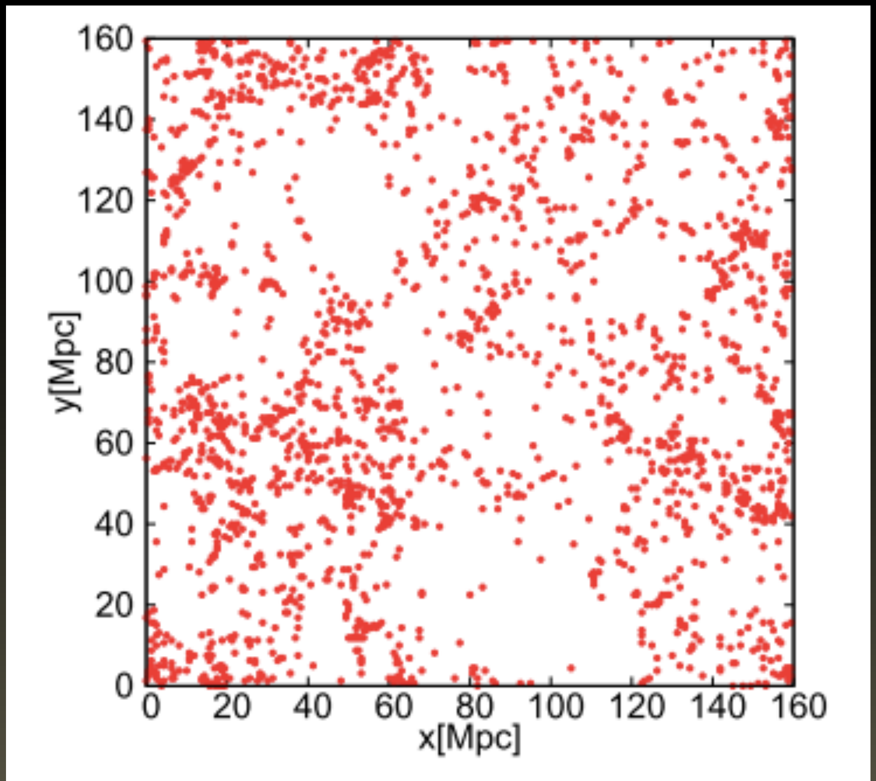
FIG. 4.—Cartoon of the $\langle I(u, v, \eta)\rangle$ distribution of the residual faint galaxy foreground. While there is significant power in the spatial directions u and v (Di Matteo et al. 2002), the spectral smoothness of the faint galaxy residual foreground leads to a strong separable-axial symmetry with the contribution concentrated at small η values.

Morales & Hewitt 2004, ApJ, 615(1), 7-18

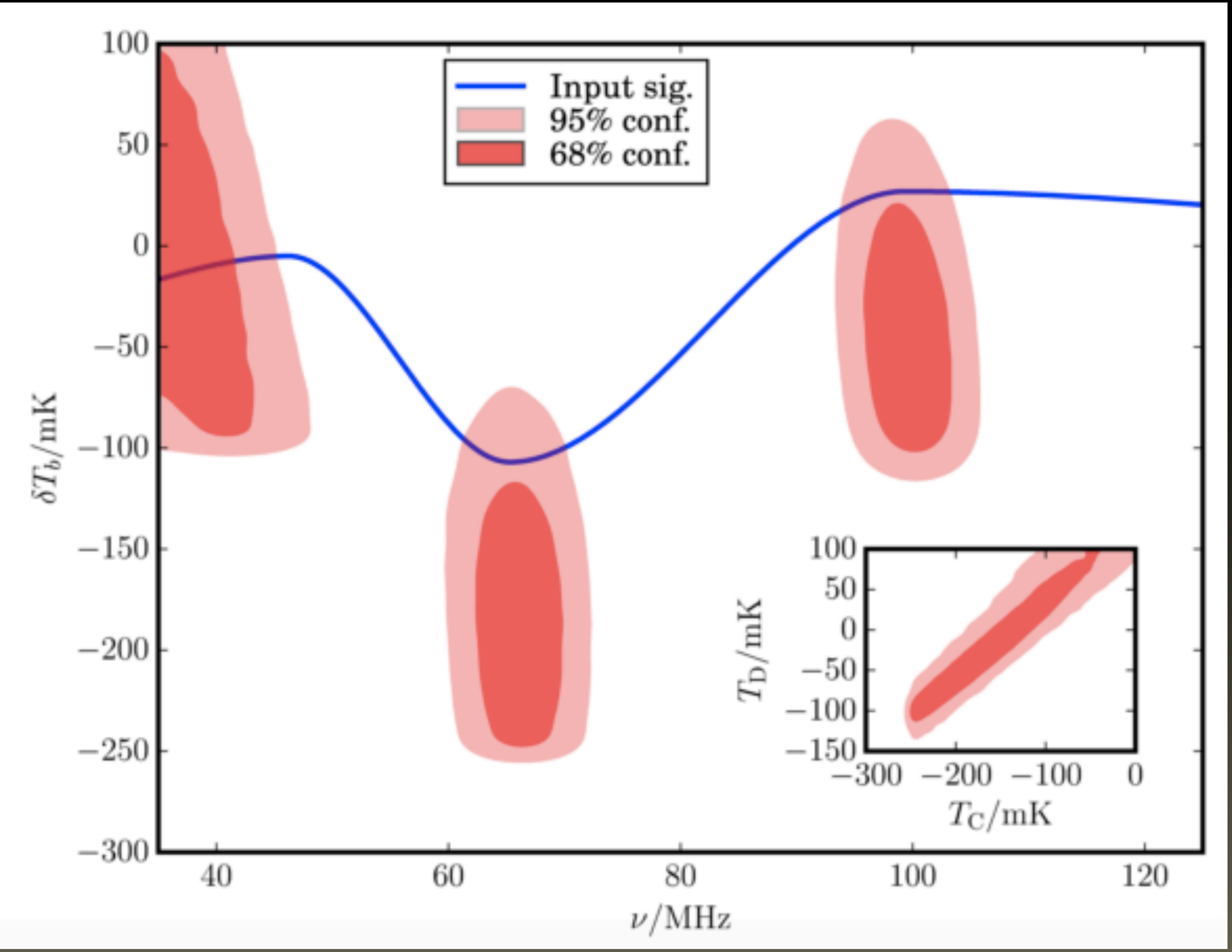
Residual foreground removal via. symmetry

Cross-Correlations



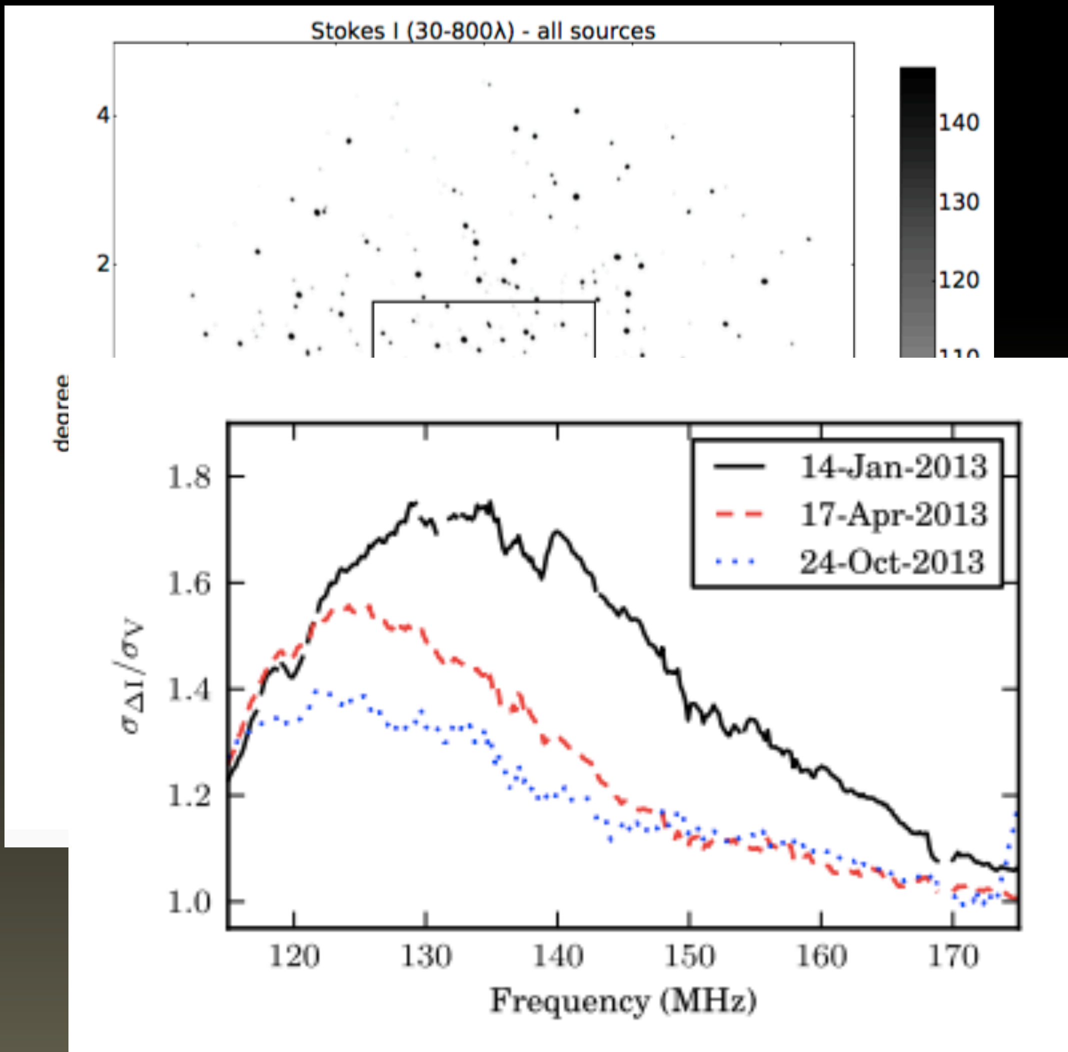


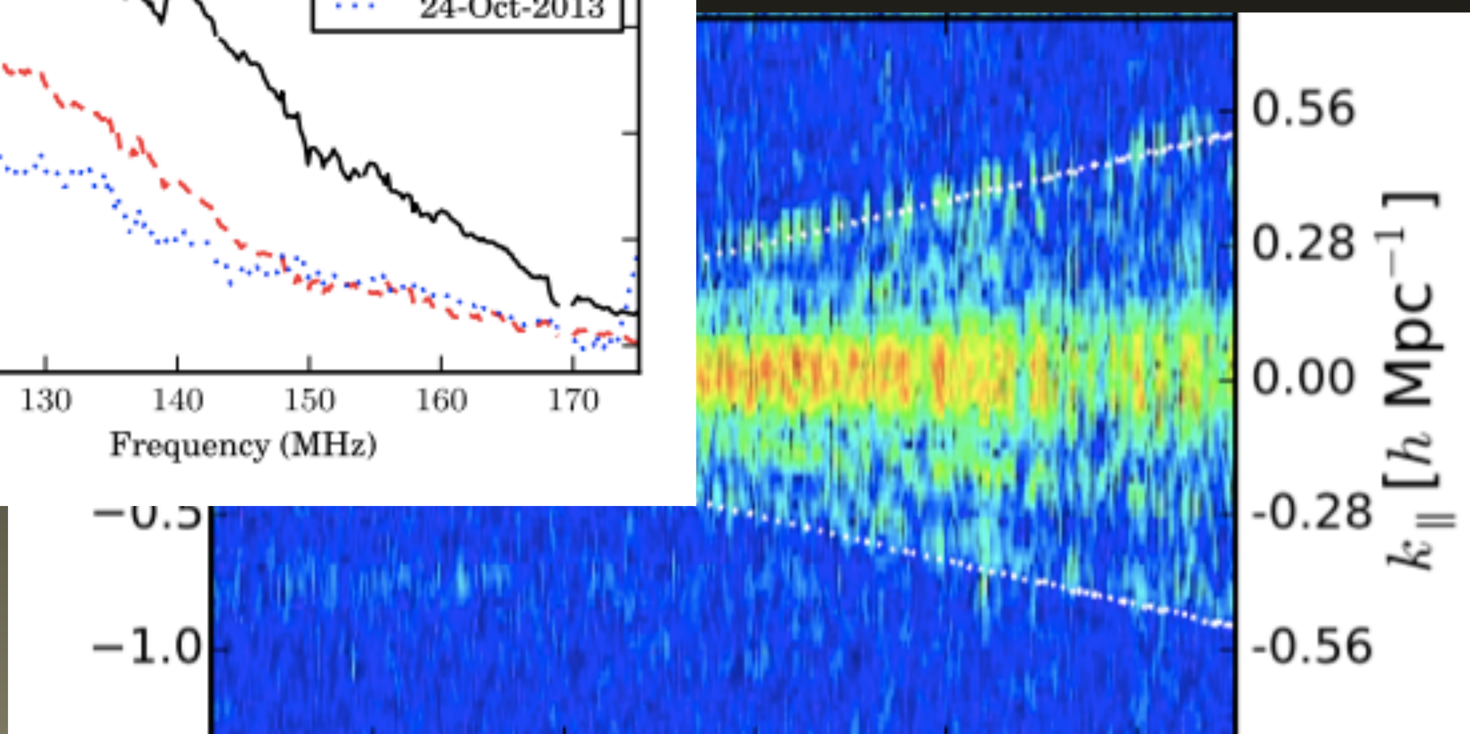
Kubota et al., 2017, astro-ph::1708.06291



Harker et al. 2015, MNRAS, 449(1), L21-25

Global Signal



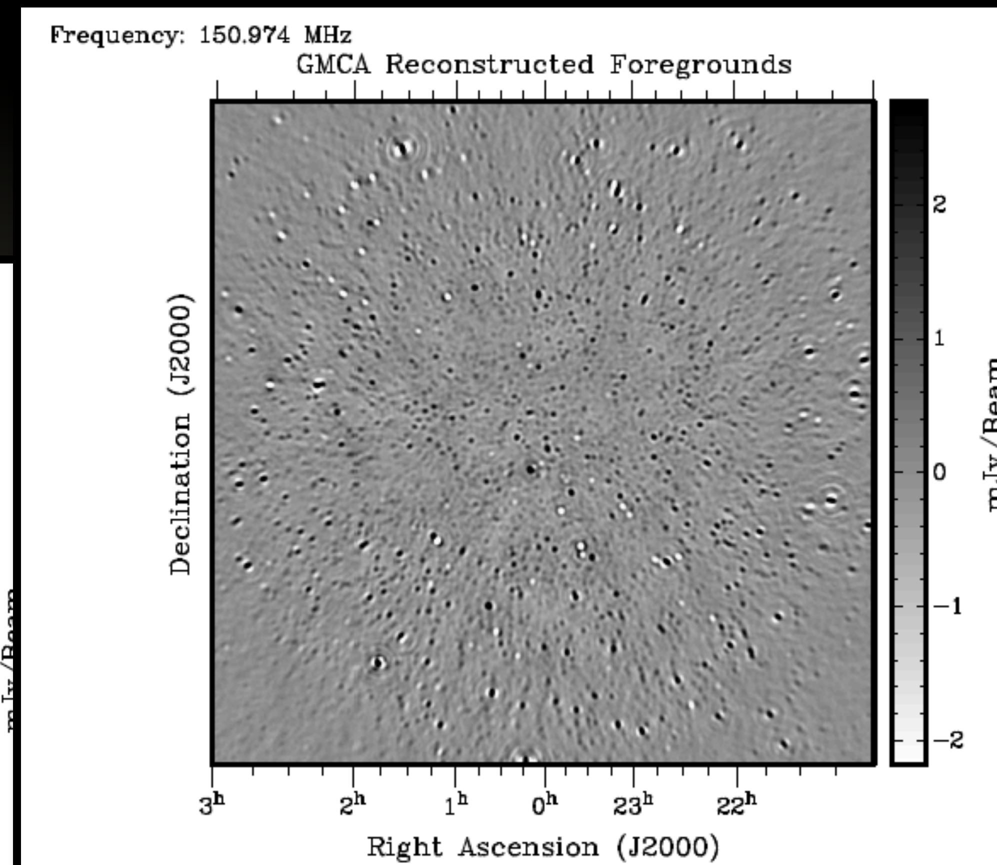


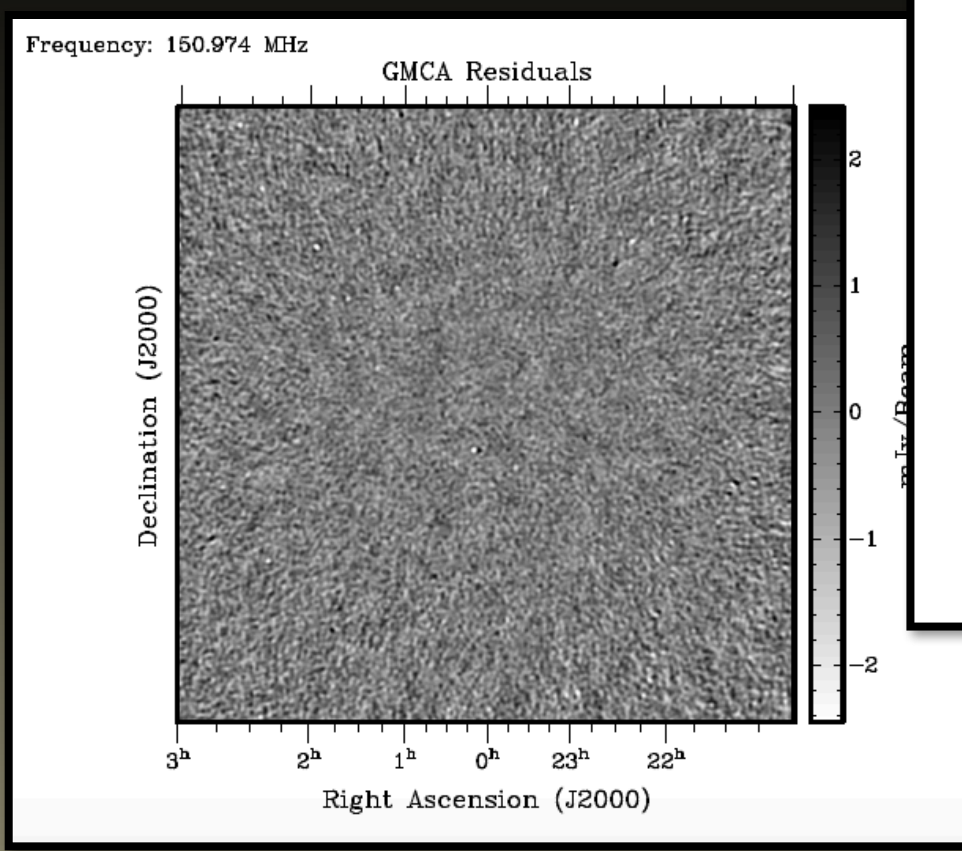
Patil et al. 2017, 838(1), 65
Thyagarajan et al. 2015, ApJ, 807(2), L28
Patil et al. 2016, MNRAS, 463(4), 4317-4330

Foreground mitigation depends
on good calibration
and perhaps vice versa…?

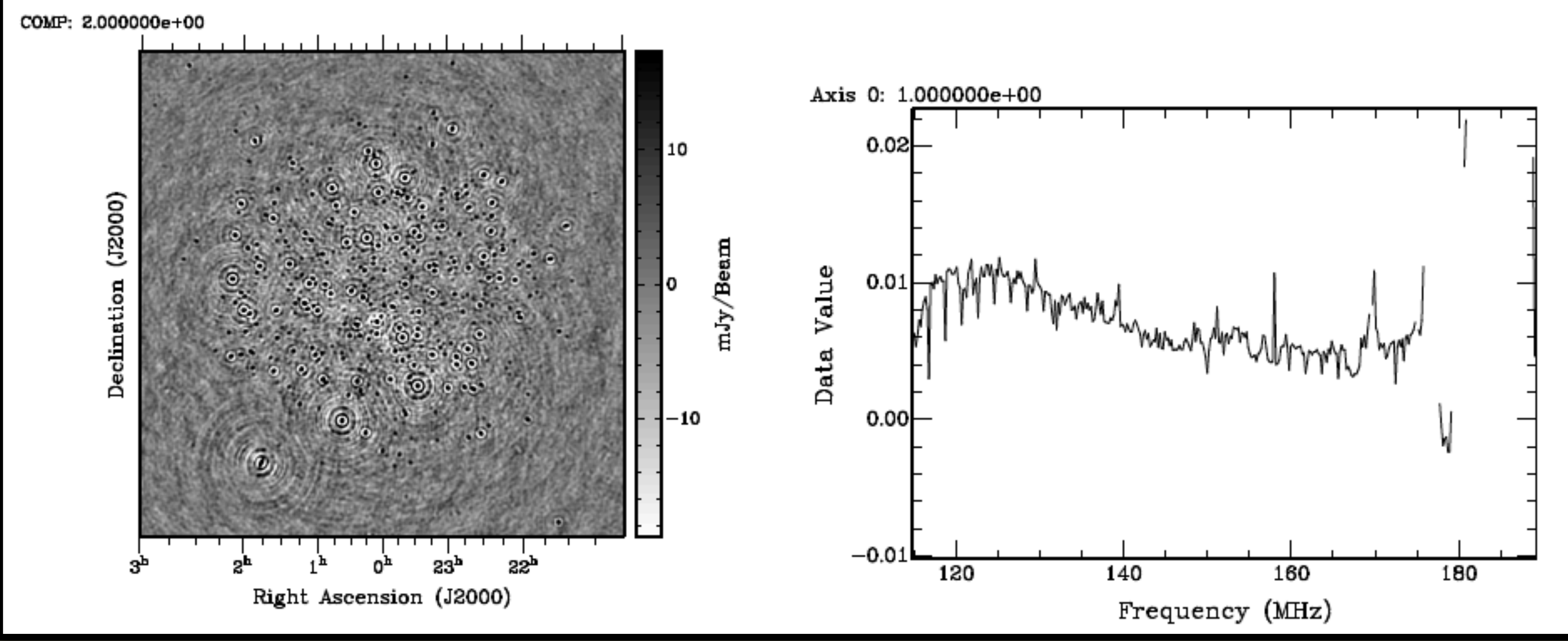
GMCA on LOFAR data

54hr data on NCP field

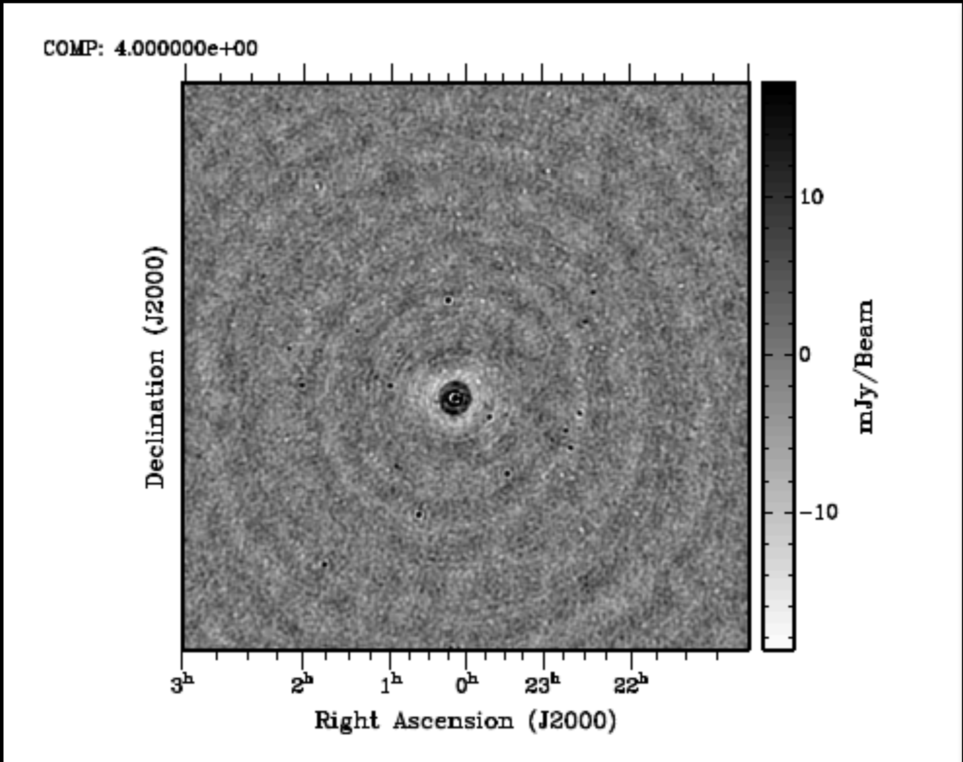


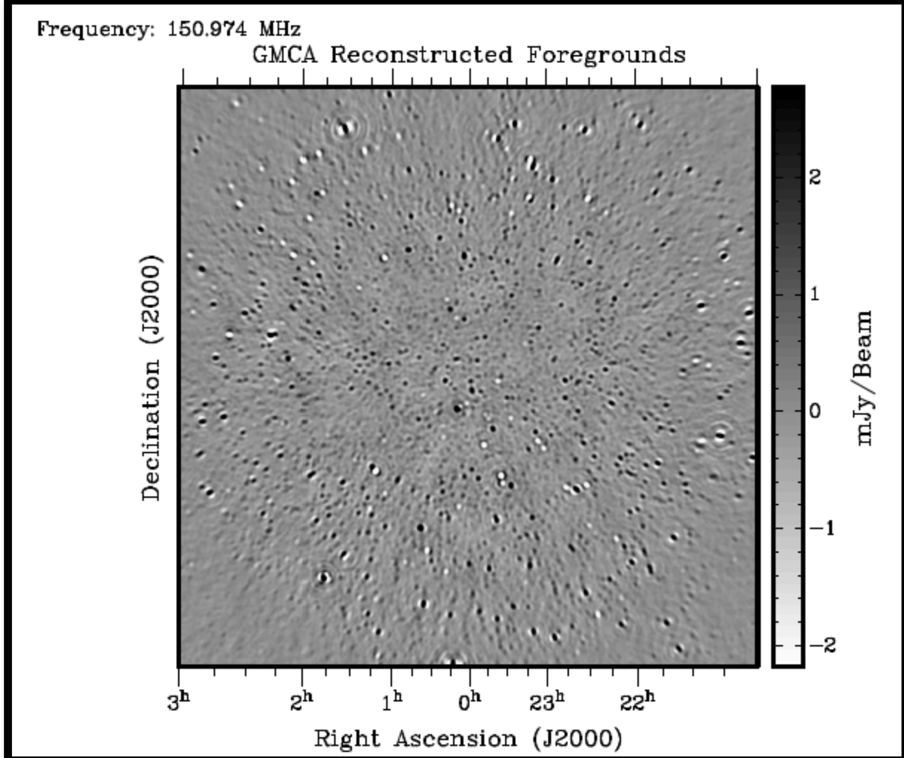


GMCA components of LOFAR data

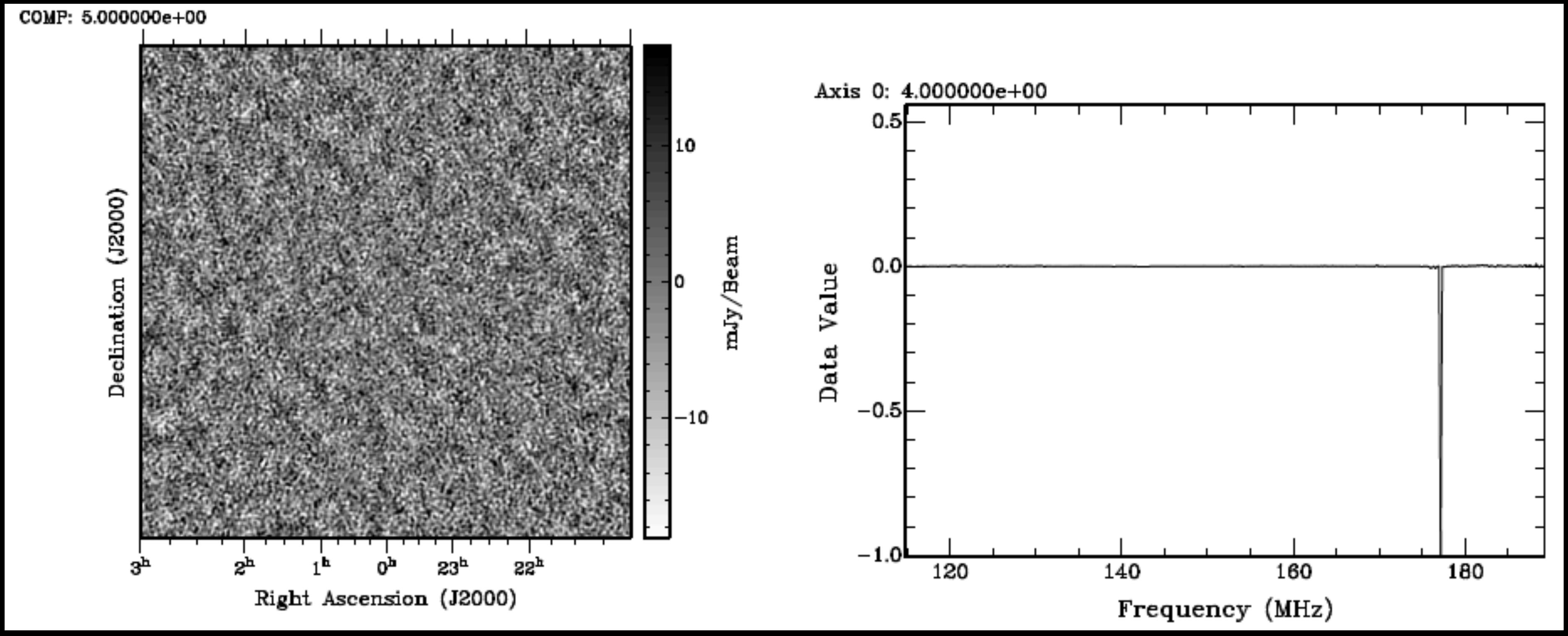


GMCA components of LOFAR data

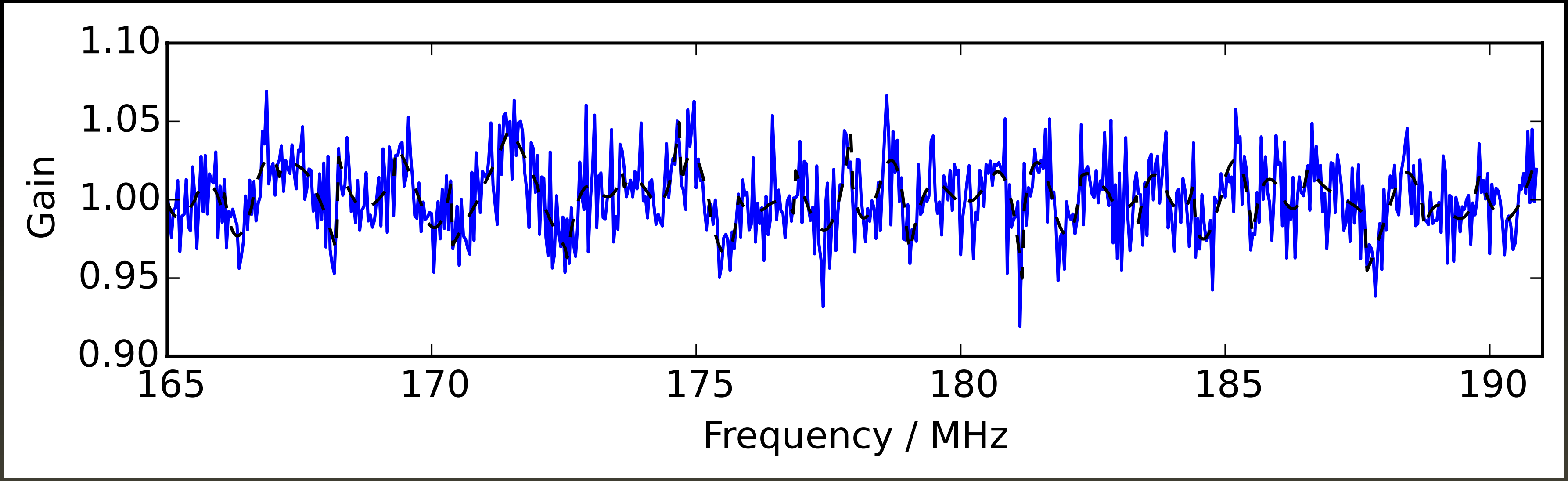




GMCA components of LOFAR data



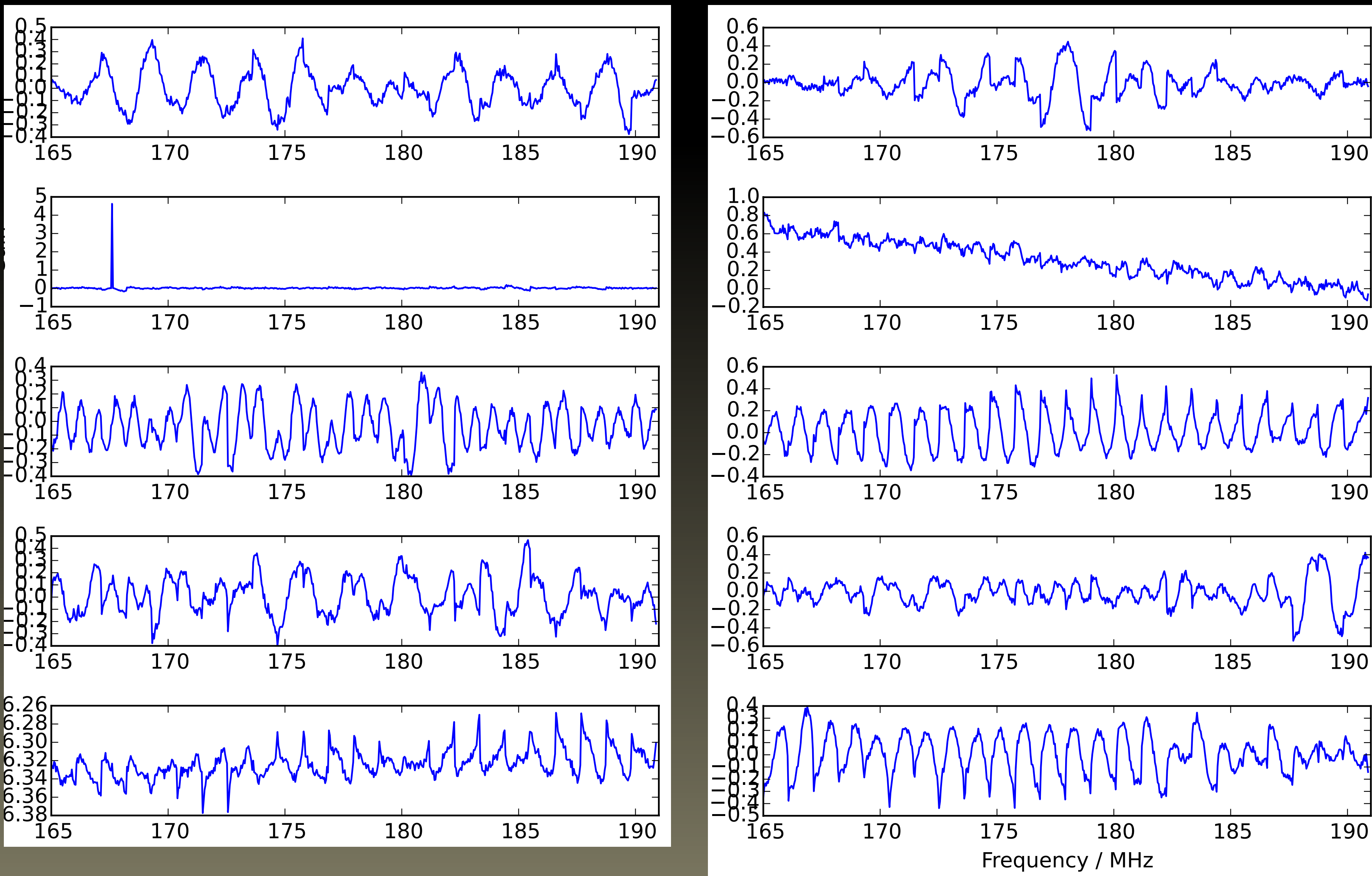
MWA calibration data

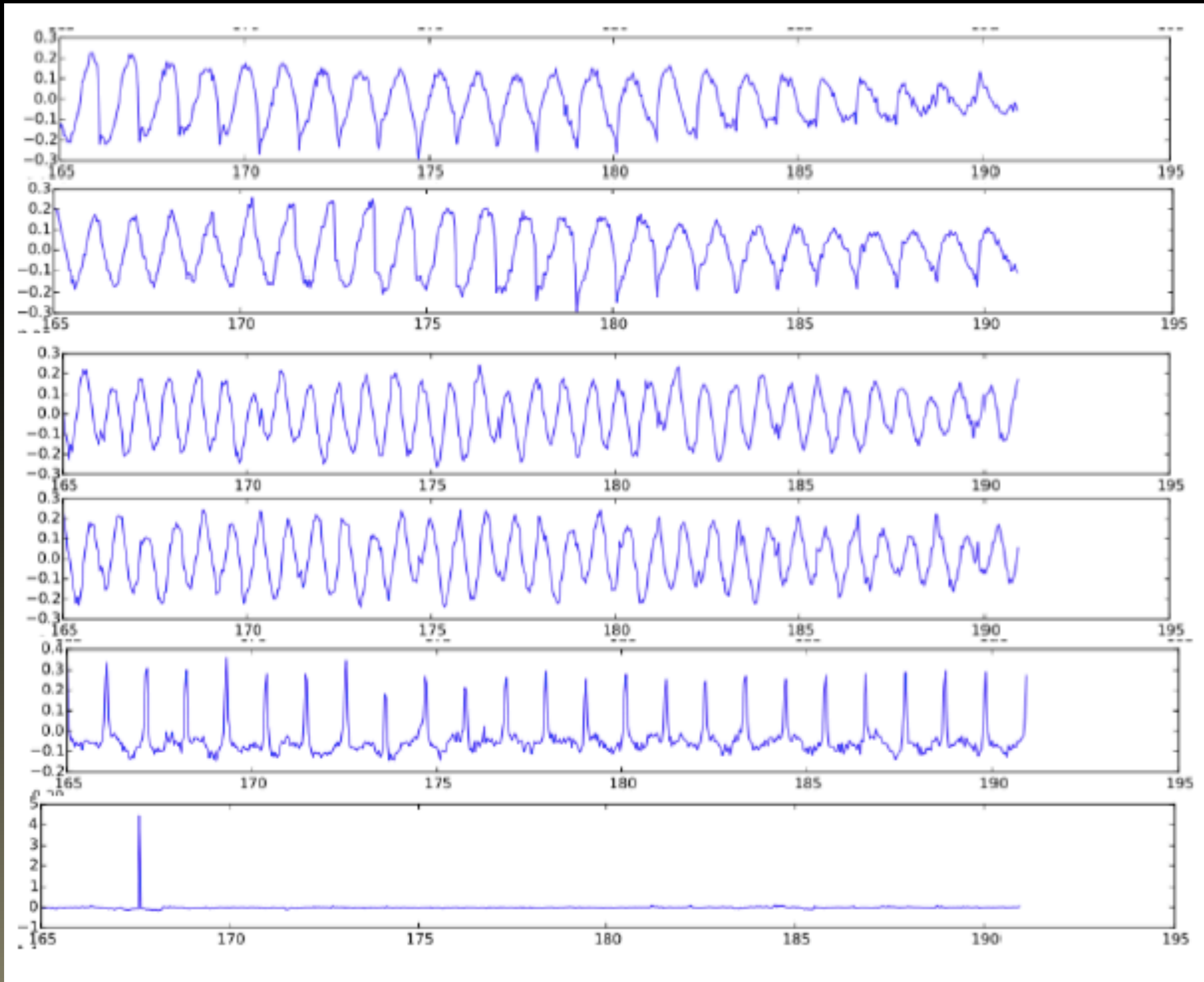


Raw data – blue

RTS solutions - black

ICA components of MWA calibration data




0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
165
170
175
180
185
190
195
0.4
5
4
3
2
1
0
−1

Summary

- Foreground mitigation is complicated by our incomplete knowledge of the instrument
- Foreground mitigation methods are not mutually exclusive
- Foreground removal methods could be part of a feedback loop with calibration


IAUS333
Reionization
Cosmic
Dawn
Foreground
EoR
Epoch
Coffee
October
signal
reionization
Galactic
foreground
21-cm
21cm
Dubrovnik
Lunch
Results
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Exploring
emission
Neutral
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HERA
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structure
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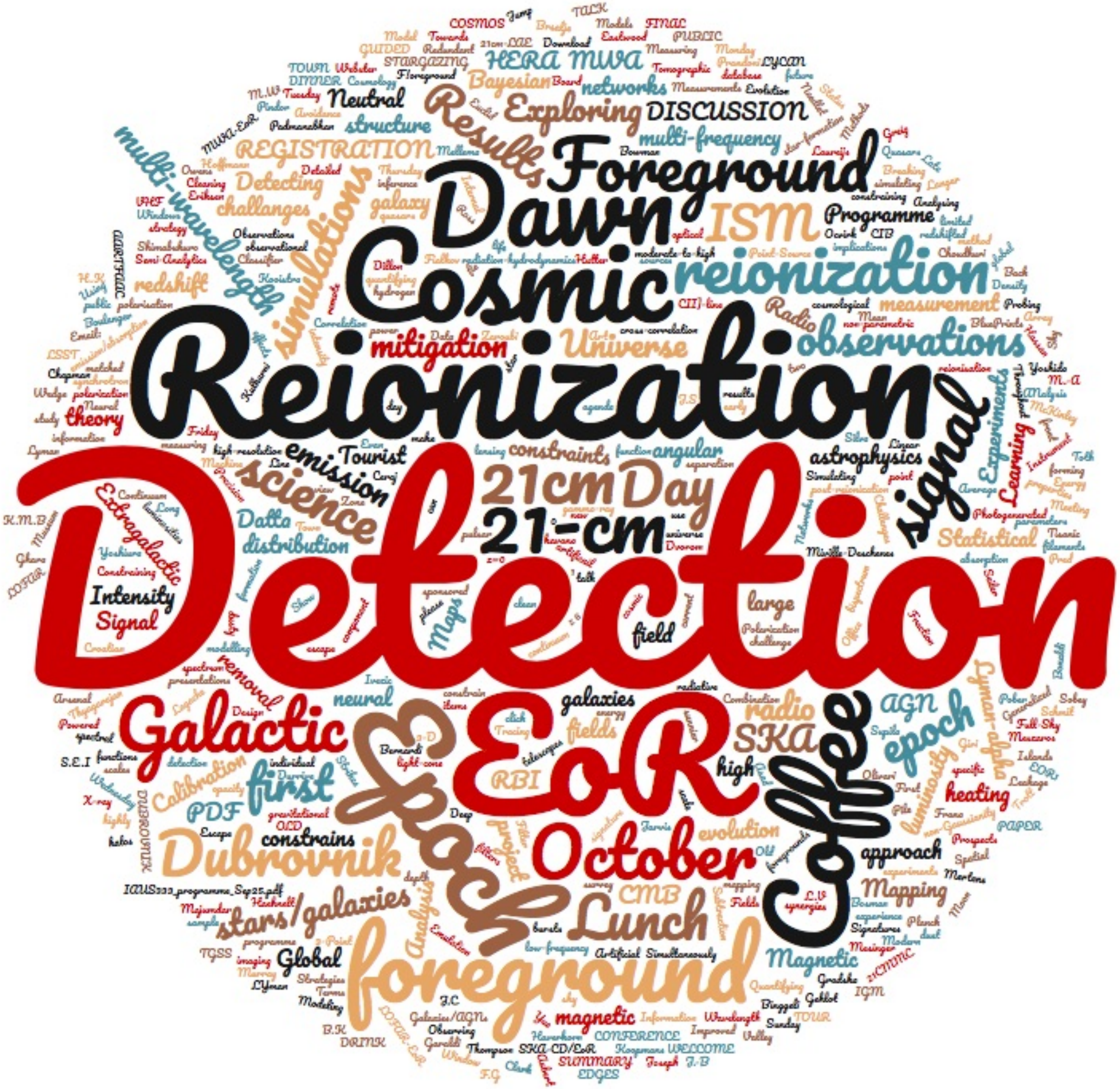
Tourist
theory
Lyman-alpha
galaxy
neural
CMB
challanges
galaxies
constraints
radio
fields
Maps
heating
measurement
Global
Bayesian
constrains
large
AGN
multi-frequency
redshift
Magnetic
magnetic
Intensity
astrophysics
approach
luminosity
Signal
Experiments
Learning
Analysis
field
angular
Radio
project
RBI
high



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magnetic

Methods of foreground mitigation in the EoR

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Thank you!

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