

Netherlands Institute for Radio Astronomy

LOFAR data:

error analysis

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(with thanks to E. Mahony, K. Chyzy and others who I have borrowed/stolen slides from)

Outline



PROBLEM

• Data Errors

Calibration errors

SOLUTION

 Use the observation log (report) to track big issues (ex. bad antennas). Inspect data, flag as warranted.

 Does the model fit the data? Ionosphere an issue?

Image plane errors

 Deconvolution issues, residual data issues -> start at the top

Data Errors: inspection plots

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Connection problems at the start of the run

Learn more at: <u>http://www.astron.nl/radio-observatory/observing-capabilities/</u> <u>depth-technical-information/data-quality-inspection/data-qu</u>

Data Errors: RFI

Flagging always the first step!

- flag at high resolution



Data Errors: RFI

AOFlagger (André Offringa) flags data based on statistics: Before flagging After flagging 0.1 → Visibility (Jy) 0.01 0.001 134.34 134.36 Frequency (MHz) 134.3 134.32 134.38 134.42 134.44 134.4 134.46 10 Before flagging After flagging 1 0.1 → Visibility 0.01 0.001 0.0001 400 0 50 100 150 200 250 300 350 Time (s)

5

Data Errors: RFI





Data (Errors): Demixing

At low frequencies, visibilities are affected by the brightest radio sources on the sky - CygA, CasA, VirA, TauA, HerA, HydA - the "A-team"

- LBA: data almost always affected by CygA, CasA at least
- HBA: data affected if phase centre within 30 deg. of an A-team source or if elevation of A-team high. To make sure, simulation is needed.



Data (Errors): Demixing

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A-team needs to be removed from the visibilities - "demixing"

- Use model to subtract A-team from visibilities Data needs to be at sufficient resolution for this to work.

- Clip of flag A- team contribution.



Data Errors: visibilities



10,000



UVwave

30,000

20,000

40,000

50,000

Model fits the data?

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Model errors can be absorbed in the calibration process!







Frequency 💌 0 🚔 🕱 Legend 🕱 Polar 🗌 Unwrap phase 🛛 Gain:0:0:CS001HBA0 💌 Phase reference

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0.0125

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Gain:0:0:CS003HBA1

300

300

Gain:0:0:CS003HBA1

350

350

Inspect solution behaviour





Asymmetry in amplitude-phase plots indicates bad data





Amplitude solutions - stable and at expected value





Phase solutions should track well

Longest baselines can lose coherence at times due to the ionosphere





- LOFAR (very) large FoV (< 9deg across in LBA)
- 2D approximation no longer valid W projection
- Beam constantly changes A projection
- Wide bandwidth BW and time averaging smearing an issue
- Ionosphere no longer iso-planatic direction dependent effects
- Bright sources in the FoV a nuisance peeling

Imaging: W projection







1 SB - 0.2 MHz

10 SBs - 2 MHz





70 MHz 10 minutes



- Visibilities gridded as if they were monochromatic (in case MFS imaging is not used)
- If too much averaging in time/frequency is applied, smearing results
- Effect is larger the further one goes from the phase centre so especially important for LOFAR
- The need to mitigate these effects causes large LOFAR data sizes





Imaging: Ionosphere



1 and 2 - ionospheric phase error has no FoV dependence - self cal applicable

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3 and 4 ionospheric phase error varies across the FoV DDE important

Imaging: Ionosphere





Facet calibration - FACTOR van Weeren+ 2016, Williams+ 2016



Imaging: Peeling





Imaging beyond first null of beam lots of bright annoying sources

Imaging: Peeling







Can easily identify large errors in the u,v plane, but it's often difficult to find smaller errors

- Particularly true with LOFAR where many sources in the field of view make interpreting uvdist plots difficult!

- Remember: errors also obey the Fourier transform relation

- Large errors in the u,v plane can be virtually insignificant in the image plane

- Likewise, small undetectable defects in the u,v plane can be very obvious in the image plane





Fringes projected on to the sky for a short VLA baseline



Can use our knowledge of Fourier transform pairs to our advantage
Look for patterns/symmetries



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10 deg phase error for one antenna at one time

20% amplitude error for one antenna at one time



anti-symmetric ridges

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10 deg phase error for one antenna at all times

20% amplitude error for one antenna at all times



Another example of RFI (NCP observations):

No RFI



RFI centred at the pole



Imaging: how deep to clean?

Under-cleaned



Over-cleaned





Properly cleaned



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Residual sidelobes dominate the noise

Emission from second source sits atop a negative "bowl" Regions within clean boxes appear "mottled" Background is thermal noise-dominated; no "bowls" around sources.

Imaging: algorithms



Imaging: algorithms





Imaging: algorithms





Is the imaging science-worthy?







- Errors obey Fourier transform relation – use this to your advantage!

- Image artifacts can either come from bad u,v data which needs to be flagged, OR due to the deconvolution algorithm used -> choose wisely

If still in doubt, try FT back into visibility space to compare
 make sure you have the best skymodel possible

Summary



Beware of wide-field imaging effects:

- Need to use W-projection and A-projection
- Be careful not to average too heavily, can lead to bandwidth or time-smearing
- Direction dependent effects
- Are there any bright sources in the field you need to peel?

Can you do science with your image?

- Check the flux scale and source positions!

Summary



First flag obviously bad data in the u,v plane

- Make large, low resolution image first
- Identify potential issues (i.e. bright sources in the field)
- First check of flux scale (7C/VLSS/TGSS good catalogues to crossmatch with, in the future MSSS)
- Check that you have the best input skymodel possible

Start with a subset of data to reduce manually and work out the best strategy

References

VLA white book – Chapters 15, 18, 19

Lectures from previous synthesis imaging schools

- LOFAR data school 2014
- ERIS 2013 (http://www.astron.nl/eris2013/lectures.php)
- NRAO synthesis imaging workshop 2014 (https://
- science.nrao.edu/science/meetings/2014/14th-synthesis-imagingworkshop/ lectures)
- CSIRO radio astronomy school (

http://www.atnf.csiro.au/research/radio-school/2014/index.html)

Papers on w-projection and a-projection (Cornwell+ 2008; Bhatnagar+ 2008,2013; Offringa+ 2014)

Papers on direction-dependent calibration (Interna+ 2009,2014; van Weeren+ 2016; Williams+ 2016)

Thank you! Questions?

