Report from the last MKSP polarization imaging busy week, November 4-6

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on behalf of the LOFAR MKSP

LOFAR status meeting, December 9, 2015

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LOFAR MKSP polarization busy weeks

New MKSP management structure

Need for proper polarization calibration and imaging with LOFAR.
$\rightarrow$ **Decision: restart dedicated polarization busy weeks.**

Polarization calibration busy weeks

LOFAR-specific polarization **calibration problems**.
Develop a working calibration **guideline**.

Polarization imaging & RM-Synthesis busy weeks

Develop strategies for LOFAR-specific **polarization imaging: advanced RM-Synthesis techniques, source finding, image analysis**. Test and develop needed software.

Overview

- Busy week focus: new PYRMSYNTH features (1) and polarization source finding (2). Lots of work in progress!
- First busy meeting at ASTRON. Very useful because of the chance for cross-discussion with non-core participants (thanks Michiel!).
- New particpant: Jamie Farnes from M. Haverkorn's group in Nijmegen. Our new appointed expert on source finding and much needed contact to the POSSUM polarization group

PYRMSYNTH *(Report bugs & issues on github or via mail to henrikju@astro.uni-bonn.de)*

A **python-based code** framework to perform **RM-Synthesis**, developed for the MKSP by M. Bell & H. Junklewitz. **Fast** using gridding and **FFTs**, and **C routines** where most needed. Enables **RMClean**. Many extra **features**.

Check out on **github** (https://github.com/mrbell/pyrmsynth):

> ## `pyrmsynth` - Python based RM Synthesis code including RMCLEAN
>
> *Current version:* 1.3.0 *Updated on:* 2015-06-22
>
> `pyrmsynth` performs RM-synthesis, either simply by Fourier transformation (to produce a dirty image) or using the RMCLEAN method as described by Heald, et al. (2009). It uses FFTs for the Fourier inversion and, as far as
>
> known to the authors, this is the only RM synthesis software around that does this. The Numpy FFTs

PYRMSYNTH I: Small new features & bugfixes

For details see the description of release 1.3.1 on github.

- Fixed major bug with coordinate axes in FITS output files. Now full WCS support.
- Some small other bugfixes with the FITS output, the spectral index input and the parameter file input.

PYRMSYNTH II: Include spectral information in PYRMSYNTH

Take into account spectral evolution in RM-Synthesis.
$\rightarrow$ Divide spectral function from Faraday spectrum.

Reminder

$$F(\phi, \lambda^2) = f(\phi)s(\lambda^2)$$

$$\frac{P(\lambda^2)}{s(\lambda^2)} = W(\lambda^2) \int_{-\infty}^{\infty} f(\phi) \exp 2i\phi\lambda^2 d\phi$$

Now implemented and being tested in PYRMSYNTH.

PYRMSYNTH II: Include spectral information

Simulations: much **better shape of the RM spread function** improves tails of peaks in Faraday spectrum. Important to **distinguish sources**, and especially to **identify out instrumental polarization**.

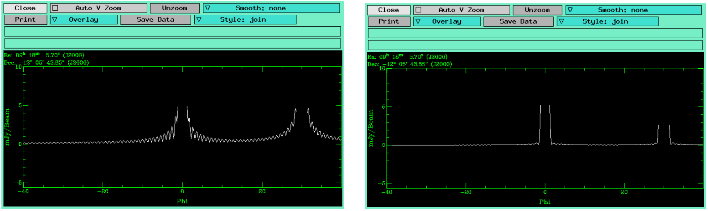


Figure: Left: without spectral index. Right: with spectral index.

PYRMSYNTH II: Include spectral information

Real data: we **started** now testing the new implementation on **real LOFAR data from a commissioning pulsar** with known spectral index, but **more investigations** are clearly needed.

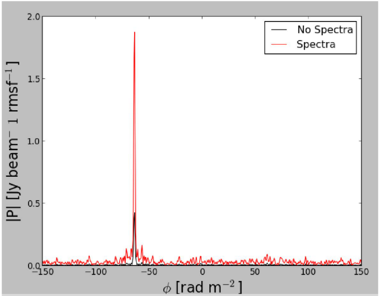


Figure: Real data test on commissioning pulsar.

PYRMSYNTH III: Testing image-weights

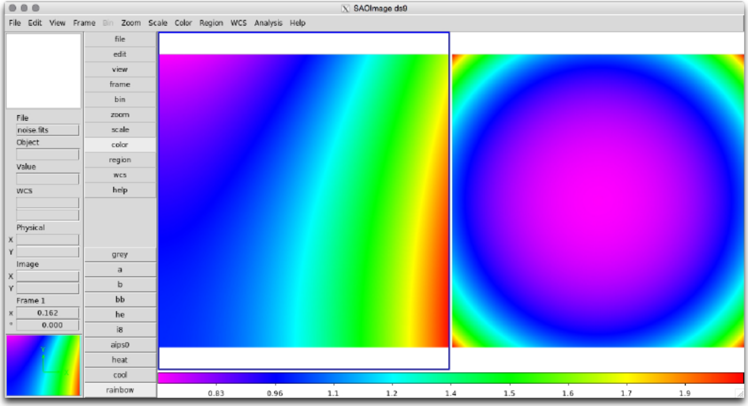
- Recently, we implemented **image-weights** like in aperture synthesis imaging: **natural weighting** (with noise estimate from Stokes V), **uniform weighting** (AIPS & CASA style), and **robust weighting** (CASA style). Still in development stage, not yet pushed to the public github page.
- Still trying to understand the effect and relate the behavior to standard imaging cases.
- More to come! We also take part in the **latest RM-challenge** using this version of PYRMSYNTH.

(LOFAR) polarization source finding: status and overview

- no fully developed software yet available. **No simple transfer** from 2D- Stokes I source finding: **non-Gaussian noise** statistics in P maps, **negative fluxes** in Q/U maps.
- **LOFAR specific:** it might be that simple 2D polarization source finding will be **severely restricted to impossible** because of the high degree of **instrumental polarization**.
- maybe full **3D source finding** in Faraday cubes? **Really better?**; expensive; no methods are available.
- so far, many tested codes (**excluding** AEGEAN), have **problems** with **high- and structured noise** scenarios.

2D-source finding I: results

- Tests of PyBDSM, Blobcat, and Aegean on simulated data with different noise & background characteristics:



2D-source finding I: results

- Tests of PyBDSM, Blobcat, and Aegean on simulated data with different noise & background characteristics:

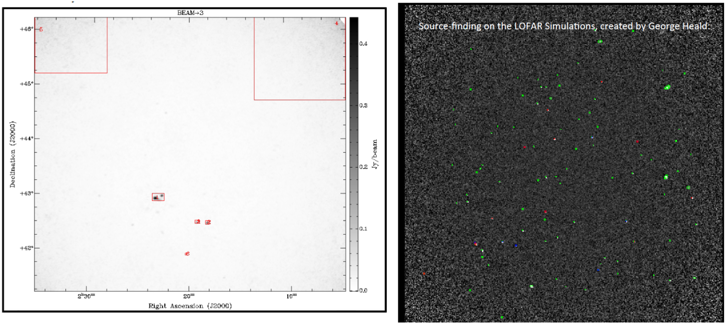


Figure: Left: Blobcat. Right: Aegean. (different data)

2D-source finding I: results

- Tests of PyBDSM, Blobcat, and Aegean on simulated data with different noise & background characteristics:
- So far: Aegean performs best overall (consisted with POSSUM experience). Still problems with PyBDSM. More experience and/or development needed.

2+X-D-source finding II: masked "3D" source finding using moments maps

Michiel's and Jamie's Idea: use different λ-averaged moments of Q, U, and P per pixel to identify those LOS with sufficient information to likely yield interesting structure in its Faraday spectrum. Then only perform RM-Synthesis on those LOS.

2+X-D-source finding II: some examples

- $< Q(\lambda) >$ is significant bright in source with little Faraday rotation.
- $std(U(\lambda))$ is significant in source with strong Faraday rotation.
- $< P(\lambda * 2) >$, the averaged polarized power, is a great indicator of noise-only pixels and instrumental polarization.
- **preliminary test results**: highly **complete**, but **unreliable** maps. But subsequent RM-Synthesis mostly can find the false positives. In simulations, reduction of number of pixels needed for RM-Synthesis down by **factors of several** 10^5.

2+X-D-source finding II: masked "3D" source finding

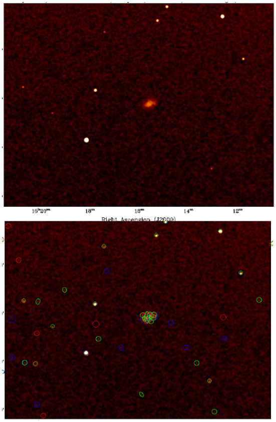


Figure: Moment maps, Lofar simulation.

2+X-D-source finding II: masked "3D" source finding

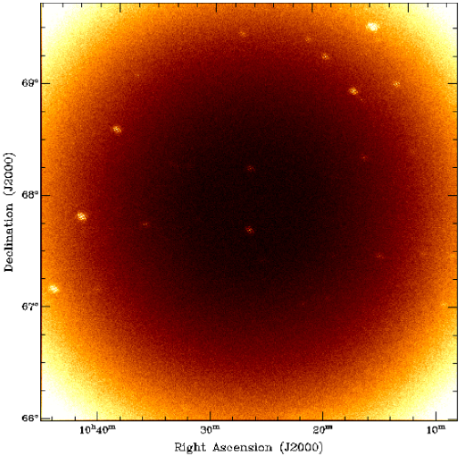


Figure: Averaged $P(\lambda^2)$ map from real data. Courtesy: C. Riseley.

Summary & outlook

- Further development and testing of new PYRMSYNTH features: spectral index and image weights.
- Continued testing of 2D polarization source finding. Focus: AEGEAN and PYBDSM. Do a proper completeness & reliability analysis of both.
- Investigate further Michiel's idea and other possibilities beyond simple 2D source finding.