

The Polarization Calibration scheme for LOFAR Beamformed Data

(formerly known as “PTSD”)

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LOFAR, tied-array beam



Tile beam

Coherent
combination
(voltages summation, phase
information maintained)

Station beam

Coherent
combination
(voltages summation, phase
information maintained)

Core beam

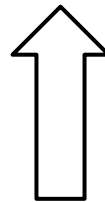
LOFAR, tied-array beam



Tile beam

Coherent
combination
(voltages summation, phase
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Station beam



Core beam

Coherent
combination
(voltages summation, phase
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Polarization and Flux calibration, beamforming

- **Beam calibration** (wrongly assumed to be the polarization calibration)
 - DreamBeam (<https://dreambeam.readthedocs.io/en/latest/>)
 - EveryBeam (<https://everybeam.readthedocs.io/en/latest/>)
- **Flux calibration** → Kondratiev et al. 2016, error bars ~50% of the calculated value

Pulsar-based polarization calibration

Jones matrix

$$\rho = \langle \vec{e} \times \vec{e}^H \rangle$$

Coherency matrix

$$\rho' = J \rho J^H$$

Congruence transformation via Jones matrix

$$J = |J|^{(1/2)} B R$$

Left polar decomposition

$$B^H = B, |B| = 1$$

Boost

$$R^H = R^{-1}, |R| = 1$$

Rotation

Pulsar-based polarization calibration

Britton 2000

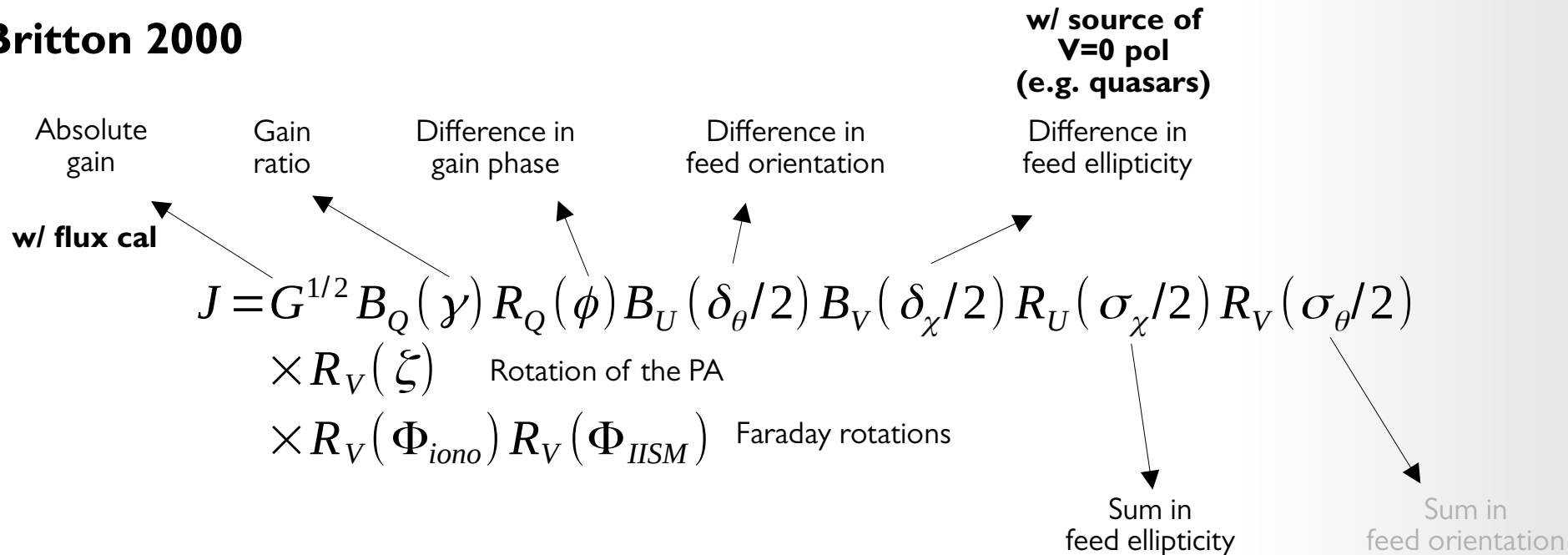
$$\begin{aligned}
 J = & G^{1/2} B_Q(\gamma) R_Q(\phi) B_U(\delta_\theta/2) B_V(\delta_\chi/2) R_U(\sigma_\chi/2) R_V(\sigma_\theta/2) \\
 & \times R_V(\xi) \quad \text{Rotation of the PA} \\
 & \times R_V(\Phi_{iono}) R_V(\Phi_{IISM}) \quad \text{Faraday rotations}
 \end{aligned}$$

Absolute gain Gain ratio Difference in gain phase Difference in feed orientation Difference in feed ellipticity

Sum in feed ellipticity Sum in feed orientation

Pulsar-based polarization calibration, single dishes

Britton 2000



Pulsar-based polarization calibration, single dishes

Measurement Equation Modeling (MEM), van Straten 2004

- Observation of a polarized pulsar across a large amount of parallactic angles
- Pulsar polarization profile unknown
- 16 highly-polarized phase bins chosen within the pulsar profile
- Analytical PA variation for single dishes
- $\rho' = J \rho J^H \times 16 \times N_{\text{HA}}$
- 4x16 dofs for ρ' , 7 dofs for $J \rightarrow$ overdetermined system

Pulsar-based polarization calibration, LOFAR

MEM applied to LOFAR

- Observation of a polarized pulsar across a large amount of parallactic angles
- Pulsar polarization profile unknown
- 16 highly-polarized phase bins chosen within the pulsar profile
- **PA variations + projection effects + correction for the coordinate reference system**
→ **dreambeam**
- $\rho' = J \rho J^H \times 16 \times N_{\text{HA}}$
- 4x16 dofs for ρ' , 7 dofs for J → overdetermined system

Pulsar-based polarization calibration, LOFAR

Data

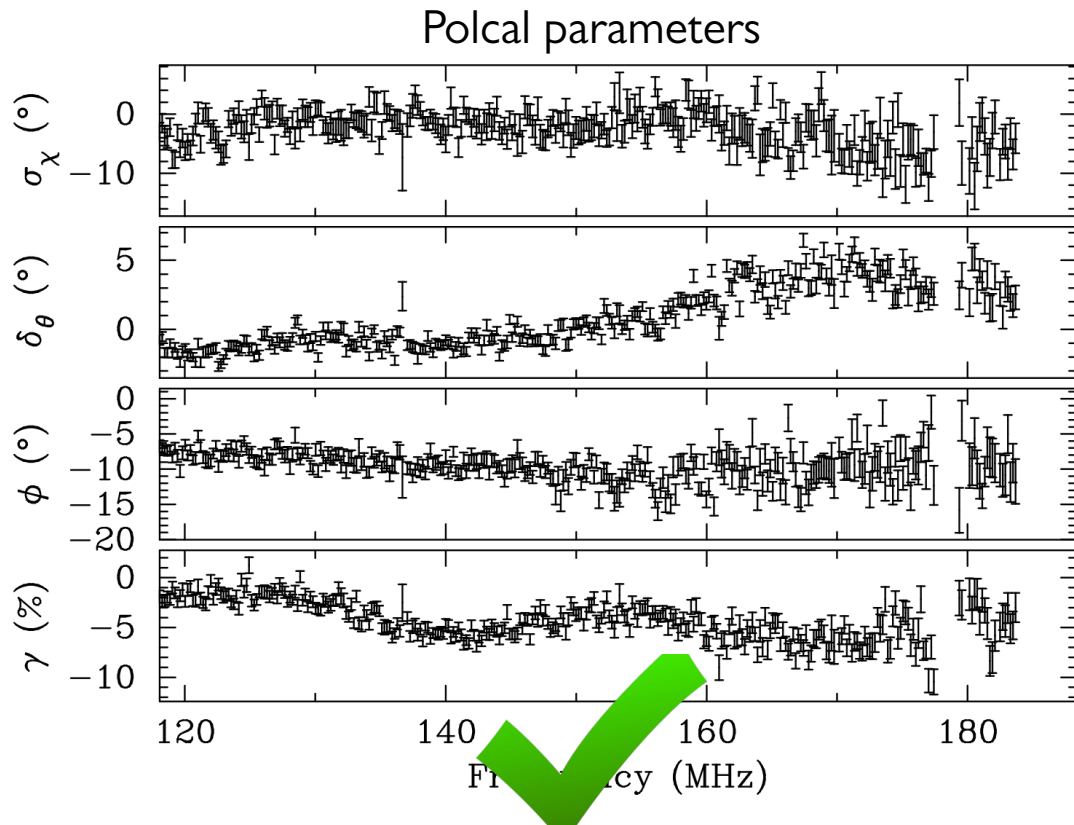
- ~6h, DE601 observations of J1921+2153, the first pulsar

Diagnostics

- “Reasonable” polcal parameters
- Absence of the $RM=0$ polarization peak
- Polarization Light Curve (PLC) @ small elevation – PLC @ $\sim$ zenith = 0
- Bayesian Information Criterion

Pulsar-based polarization calibration, LOFAR

Classical model (elevation-independent polcal)

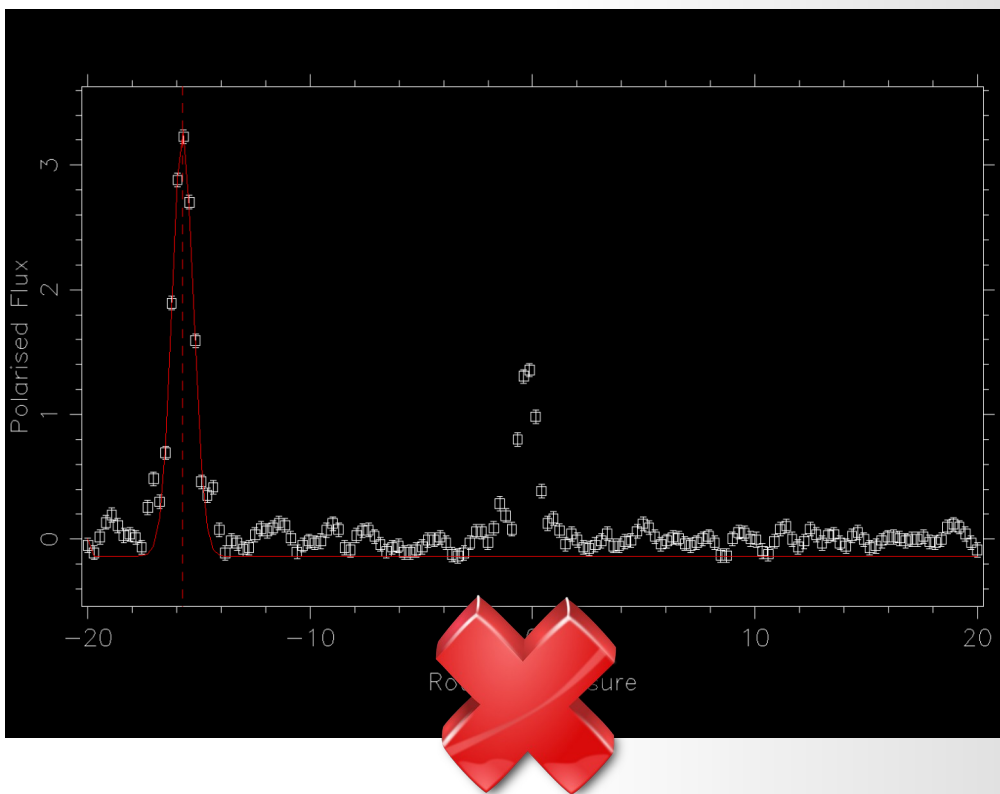
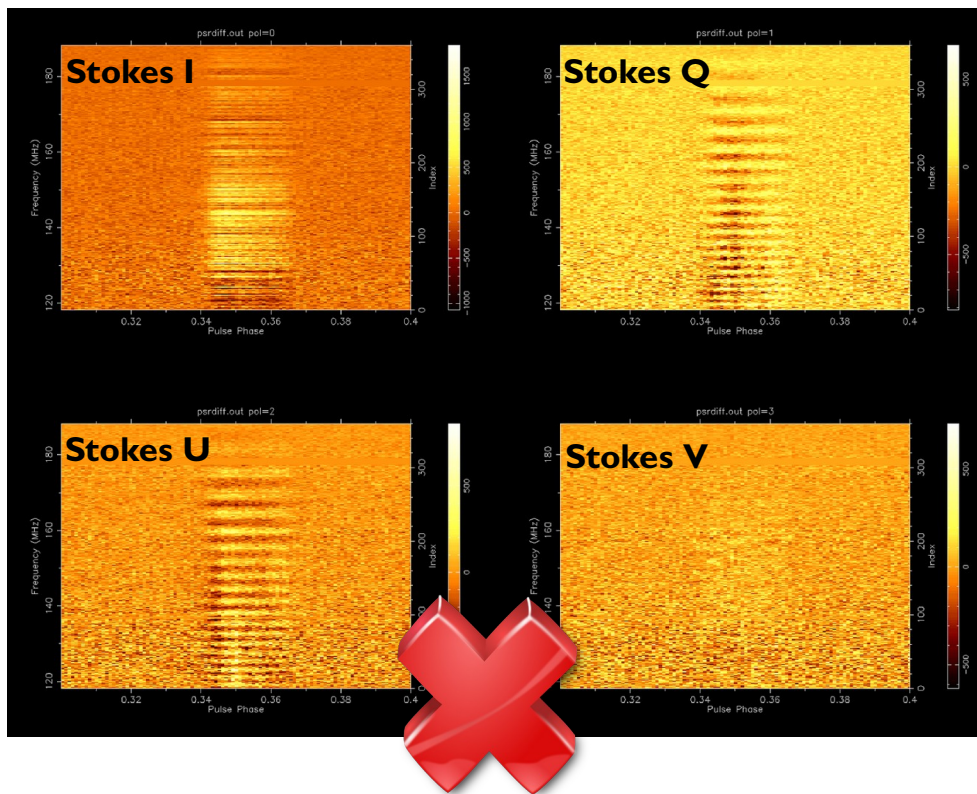


Pulsar-based polarization calibration, LOFAR

Classical model (elevation-independent polcal)

PLC(small elevations)-PLC($\sim$ zenith)

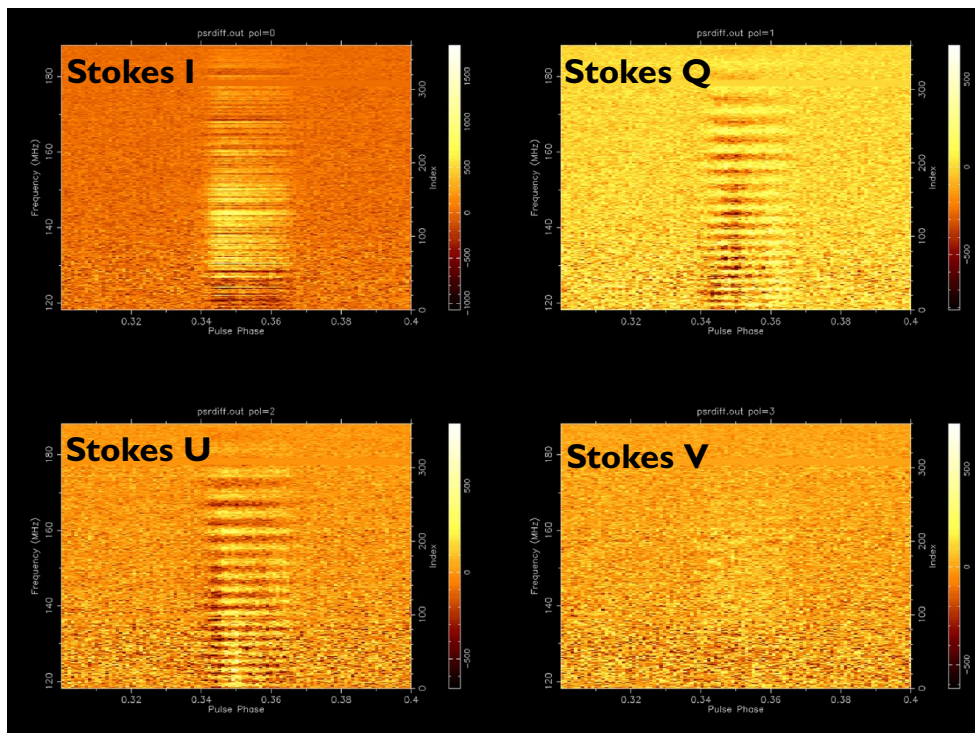
RM spectrum



Pulsar-based polarization calibration, LOFAR

PLC(small elevations)-PLC(~zenith)

Approximately 'beating'
to a $-17f^2$ rad/m²
rhythm (suspicious)



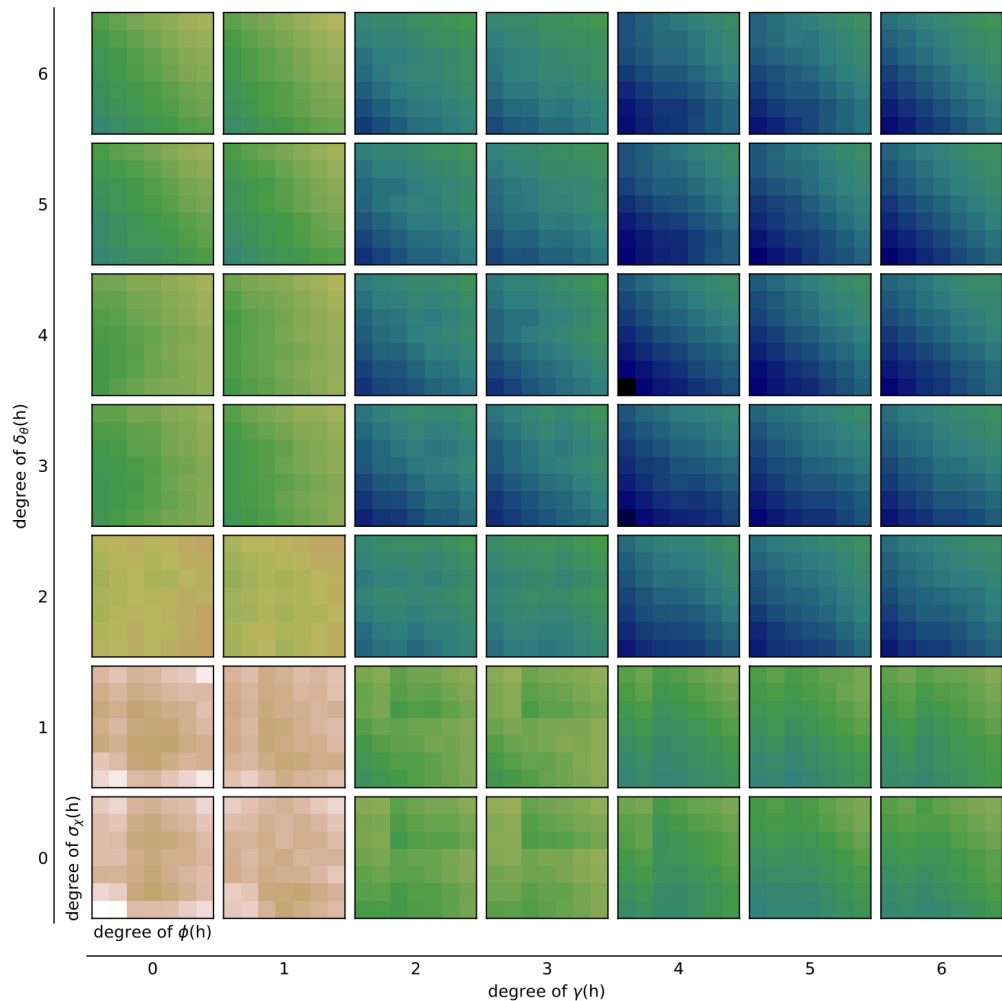
Possibly related to:

- A f^2 -dependent, elevation-dependent R_V (related to σ_θ)
- Elevation-dependent B_Q and B_U (related to γ and δ_θ)

Pulsar-based polarization calibration, LOFAR

“BIC model comparison,
assuming that any combination
of γ , ϕ , δ_θ , and σ_χ can vary
with HA with a polynomial
order ranging from 2 to 7”

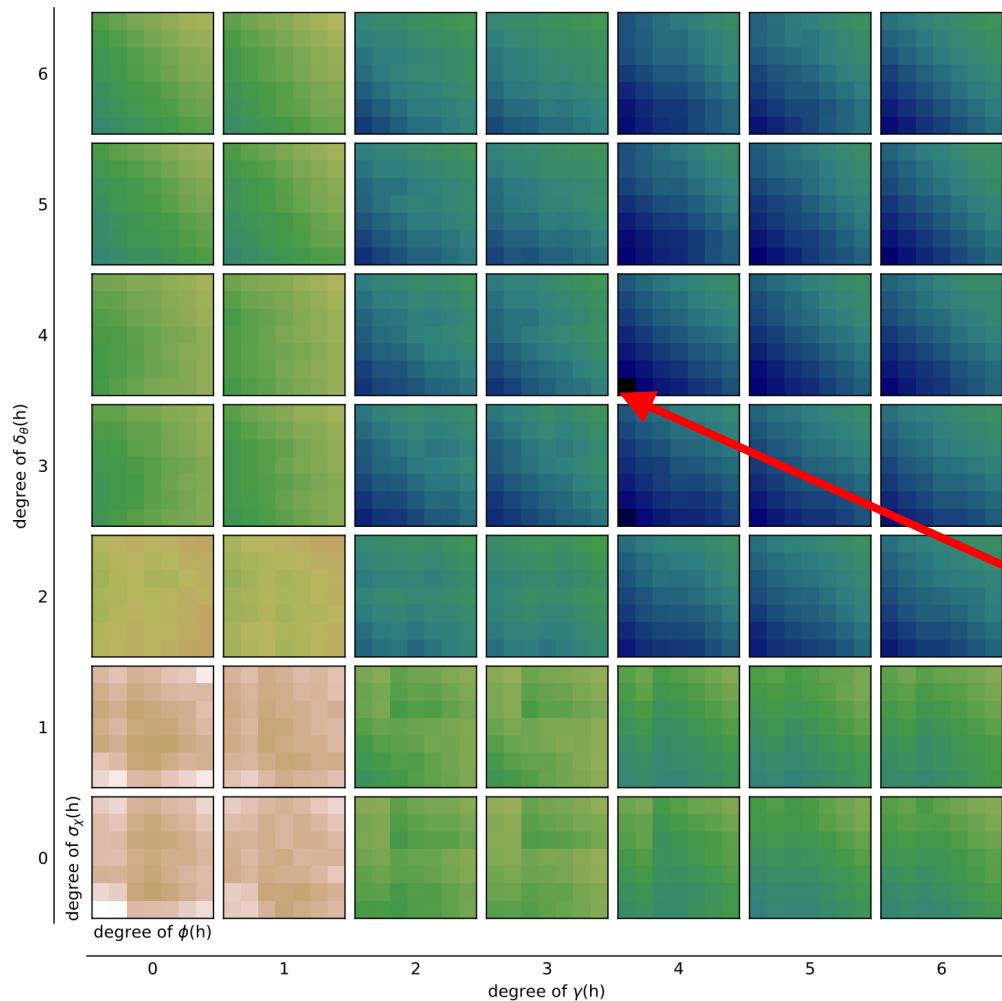
Pulsar-based polarization calibration, LOFAR



“BIC model comparison,
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order ranging from 2 to 7”

1296 combinations

Pulsar-based polarization calibration, LOFAR



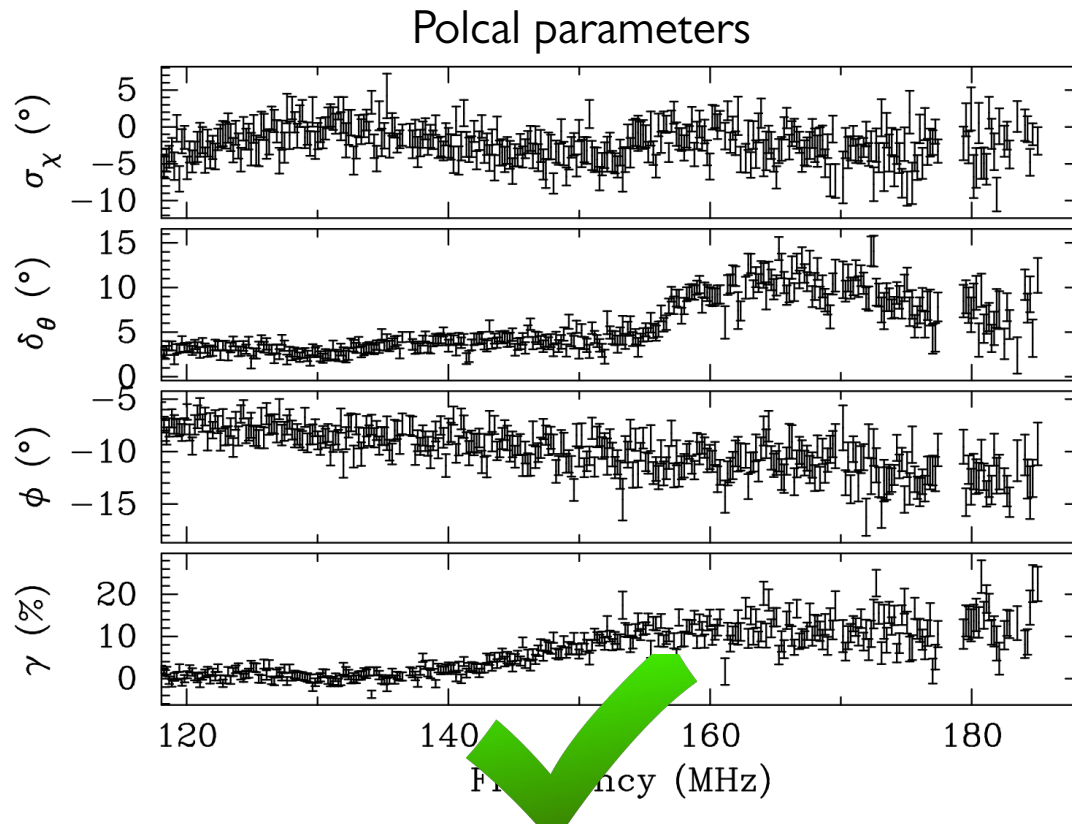
“BIC model comparison, assuming that any combination of γ , ϕ , δ_θ , and σ_χ can vary with HA with a polynomial order ranging from 2 to 7”

1296 combinations

$\gamma(\text{HA}) \rightarrow 4^{\text{th}}$ order polynomial
 $\phi(\text{HA}) \rightarrow \text{constant}$
 $\delta_\theta(\text{HA}) \rightarrow 4^{\text{th}}$ order polynomial
 $\sigma_\chi(\text{HA}) \rightarrow \text{constant}$

Pulsar-based polarization calibration, LOFAR

Upgraded model – 4th order polynomial in HA for γ and δ_θ

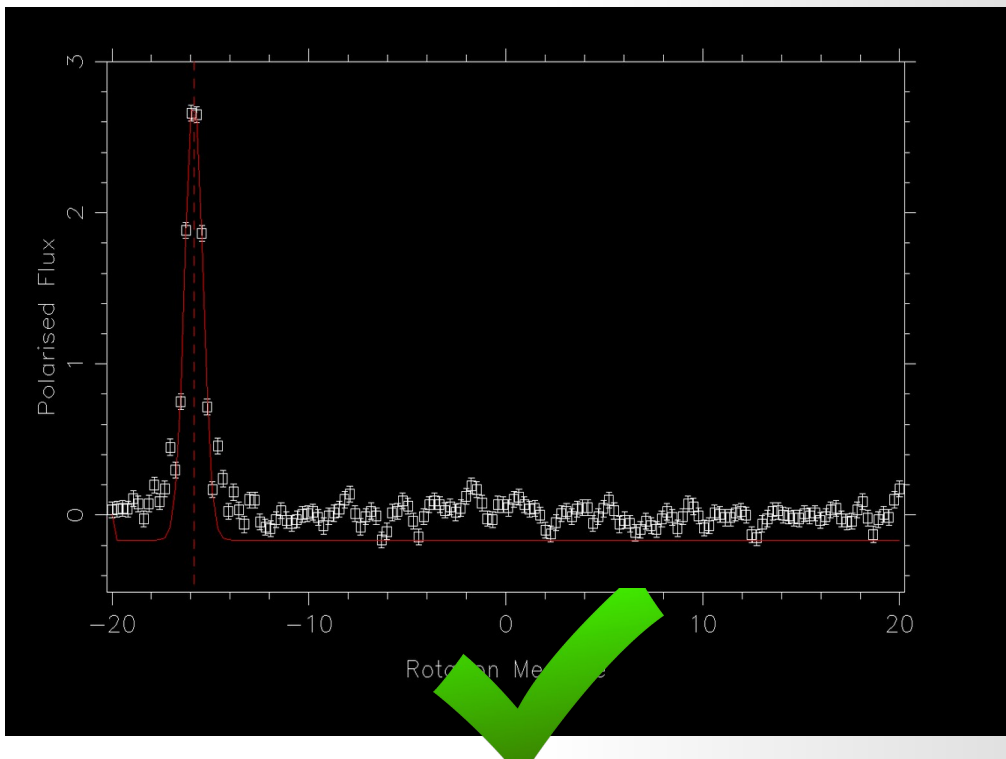
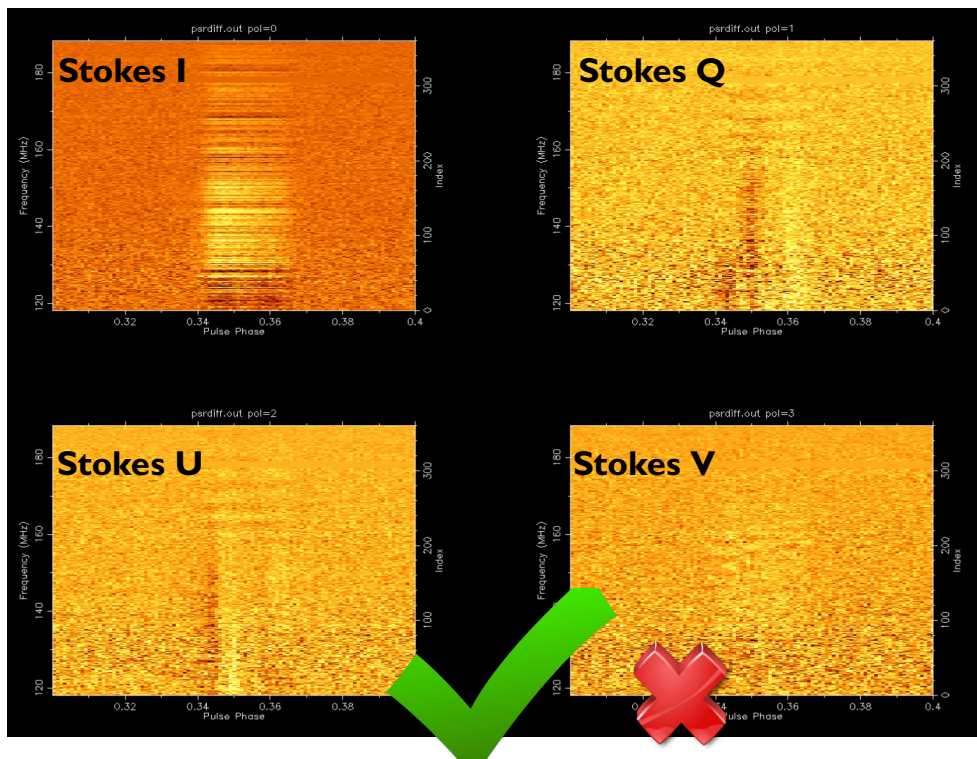


Pulsar-based polarization calibration, LOFAR

Upgraded model – 4th order polynomial in HA for γ and δ_θ

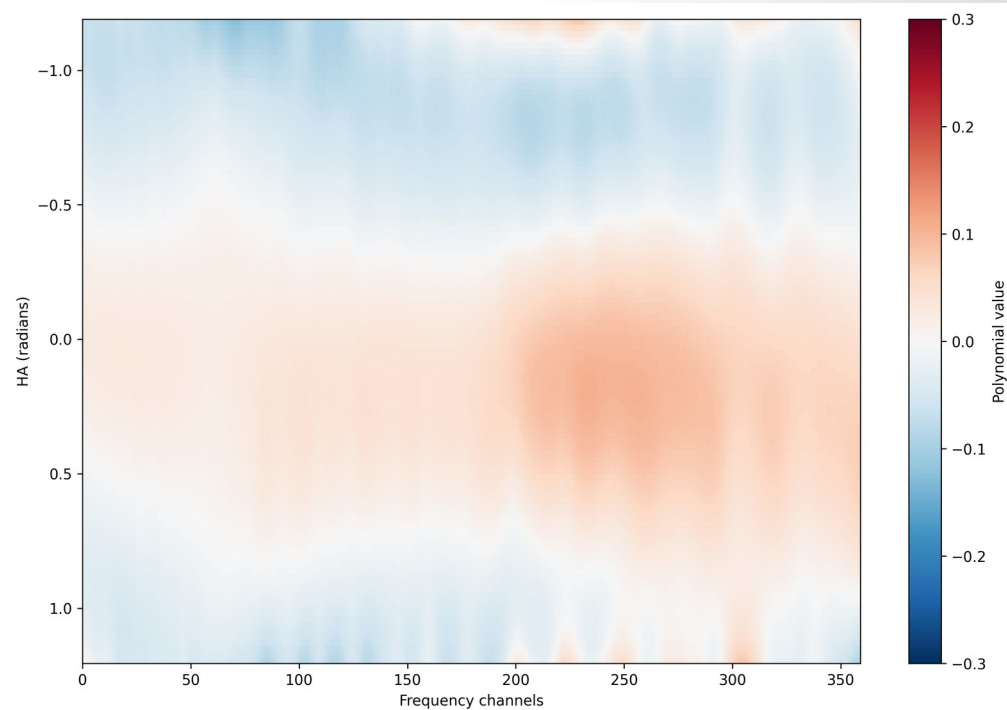
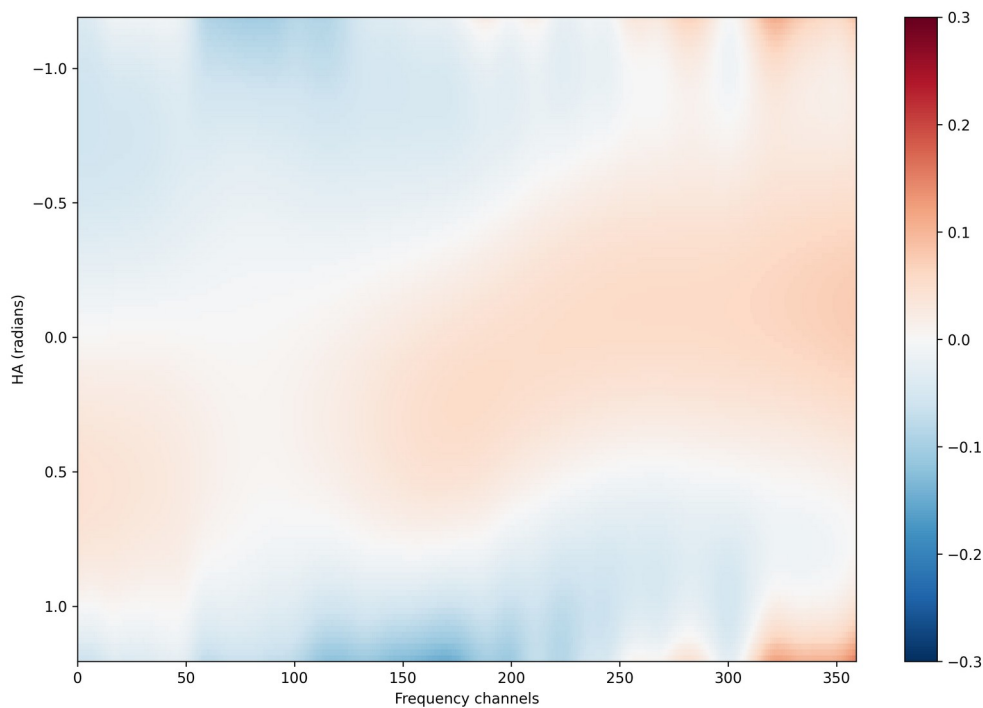
PLC(small elevations)-PLC($\sim$ zenith)

RM spectrum



Pulsar-based polarization calibration, LOFAR

Upgraded model – 4th order polynomial in HA for γ and δ_θ



Conclusions (?)

- ~~Give me a beam model, I want to do polarimetry and I have been working on polcal and ionosphere since forever~~

Conclusions (?)

- 4th order polynomial with HA needed in the Q-U boost parameters
- This is *not* a polarization calibration business. It comes from residual, uncorrected projection effects from the beam model (dreamBeam, everyBeam)
- Something new is in production (by Pietro Bolli from the Observatory of Arcetri)
- If this doesn't work, we can plan to go backwards → solve the issue of fluctuation absorption, slice the beam with pulsar tracks and calibrate it

To be continued (with LOFAR2.0)