SKA Italy, 26th of November 2025

Advancing polarization calibration in LOFAR beamformed data

A stepping stone towards SKA Low

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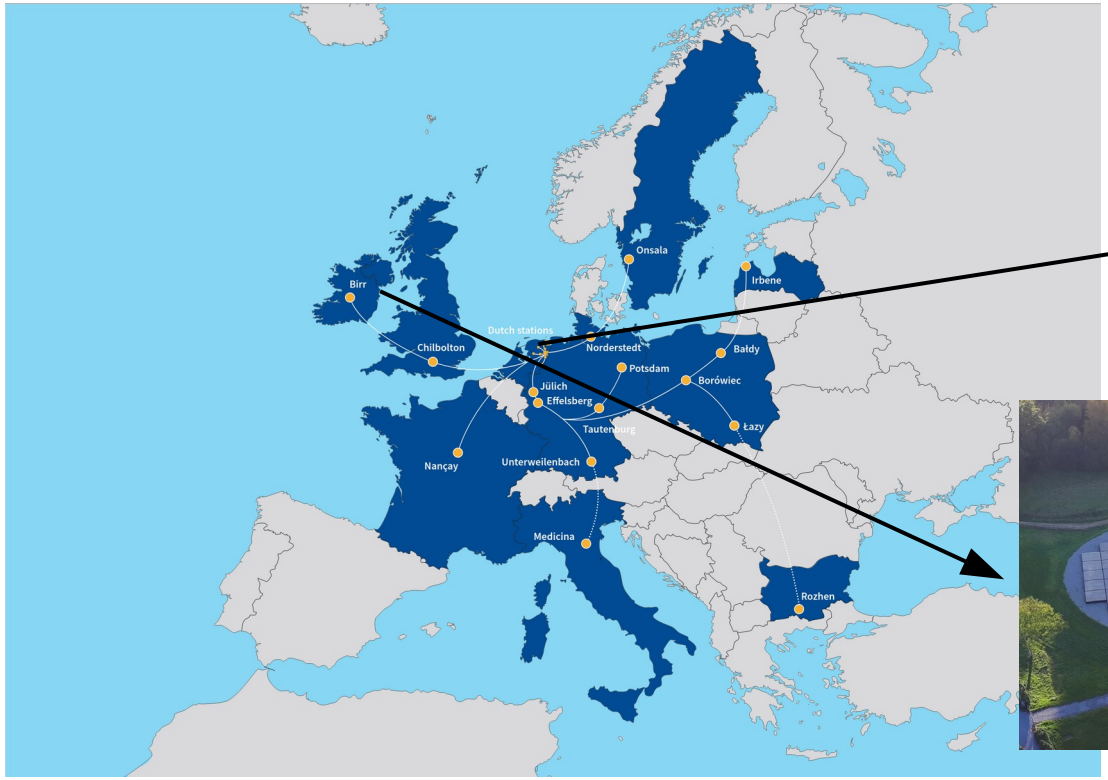
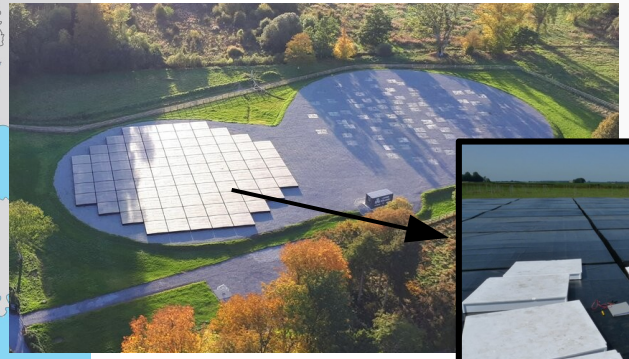
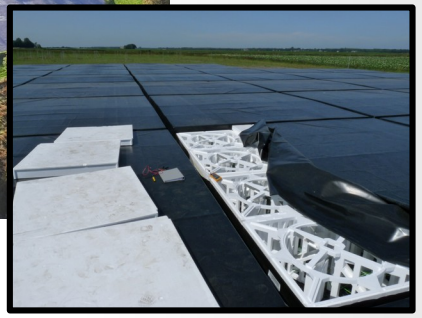
LOFAR, Core and International Stations, HBAs







High **B**and **A**ntennae
100 – 240 MHz

LOFAR, tied-array beam

Tile beam → **Station beam** → **Core beam**

Coherent combination
(voltages summation, phase Information maintained)

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(voltages summation, phase information maintained)

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

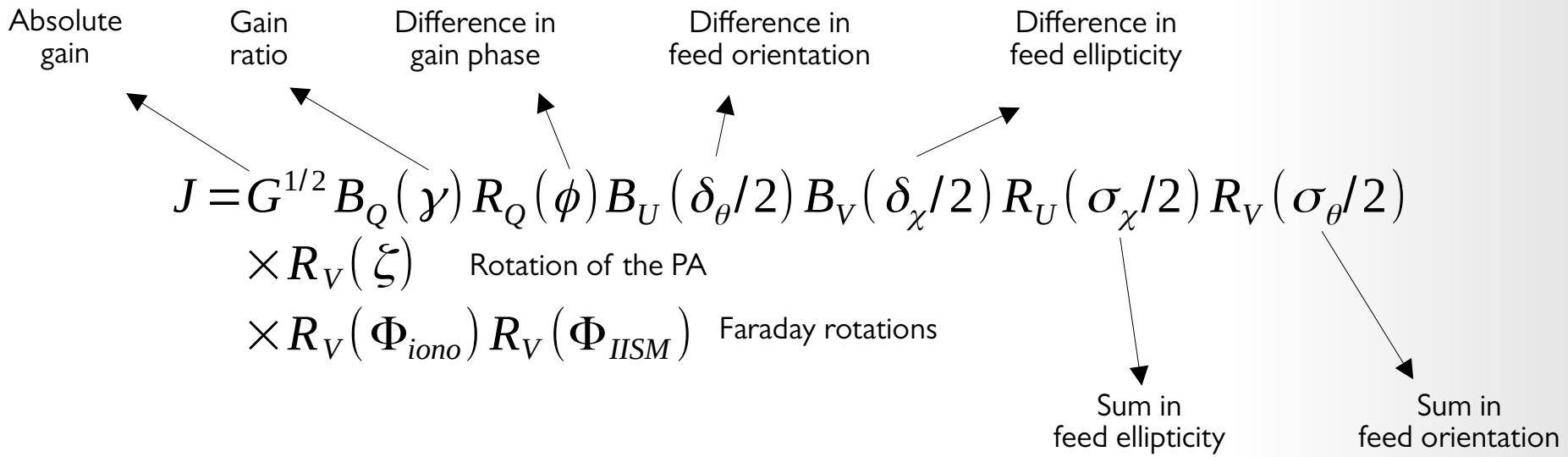
$$J = |J|^{(1/2)} B R$$ Left polar decomposition

$$B^{H} = B, |B| = 1$$ Boost

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

Pulsar-based polarization calibration

Britton 2000



Pulsar-based polarization calibration, single dishes

Britton 2000

w/ source of V=0 pol

Absolute gain

Gain ratio

Difference in gain phase

Difference in feed orientation

Difference in feed ellipticity

w/ flux cal

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

Sum in feed ellipticity

Sum in feed orientation

Pulsar-based polarization calibration, single dishes

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
- $\rho' = J\,\rho\,J^H$ X 16 X N_{HA}
- 4x16 dofs for ρ', 7 dofs for J → 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`**
- $\rho' = J \rho J^H$ X 16 X N_{HA}
- 4x16 dofs for ρ', 7 dofs for J → overdetermined system

Pulsar-based polarization calibration, LOFAR

Data

- ~7h x 2 DE601 observations of J1921+2153, the first pulsar

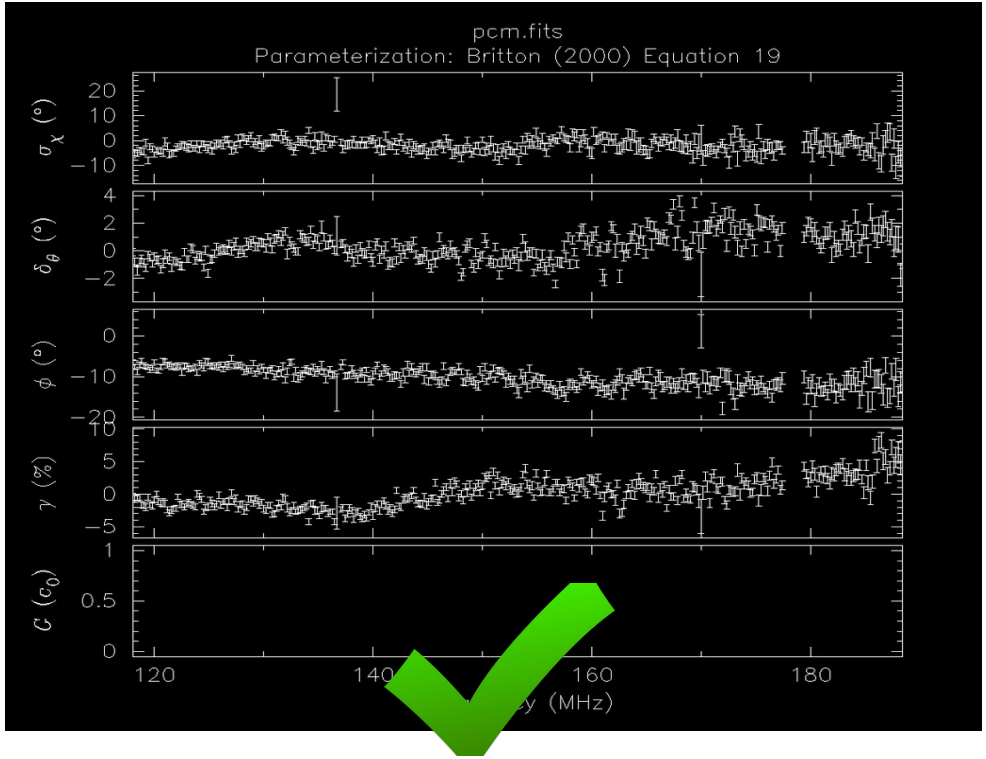
Diagnostics

- Reasonable polcal parameters
- Stability of the pulsars' Polarization Light Curve (PLC) with elevation
- Absence of the RM=0 polarization peak
- PLC(small elevations) – PCL(~zenith)=0

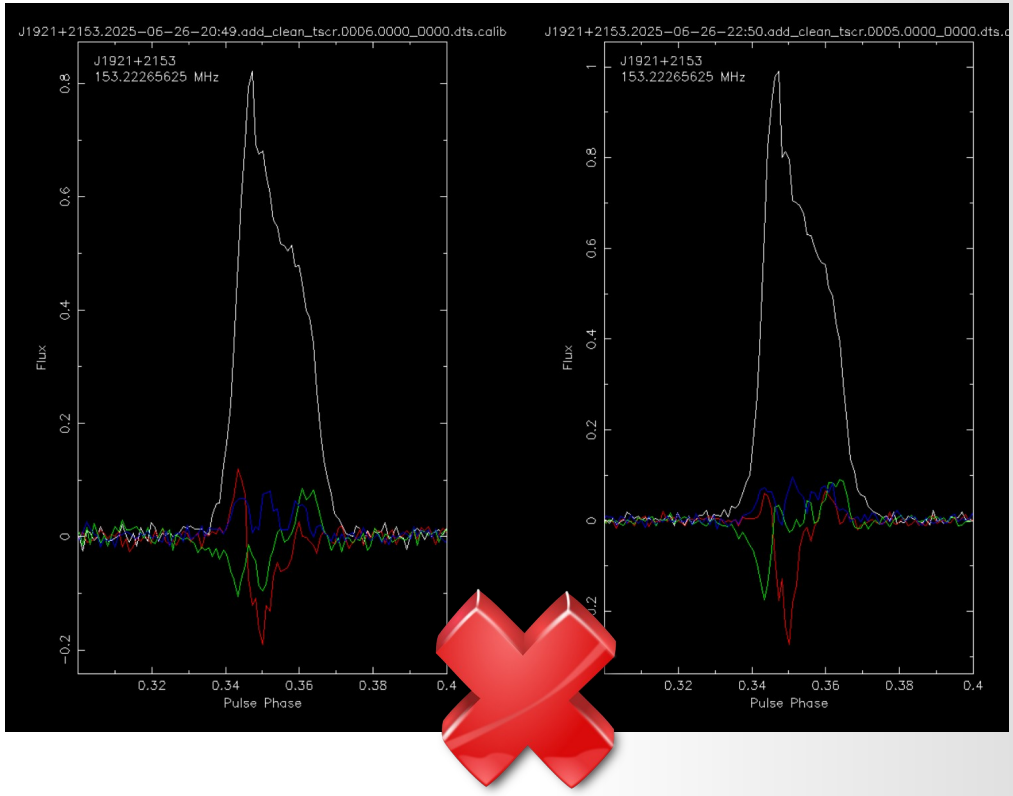
Pulsar-based polarization calibration, LOFAR

Classical model (elevation-static polcal)

Polcal parameters



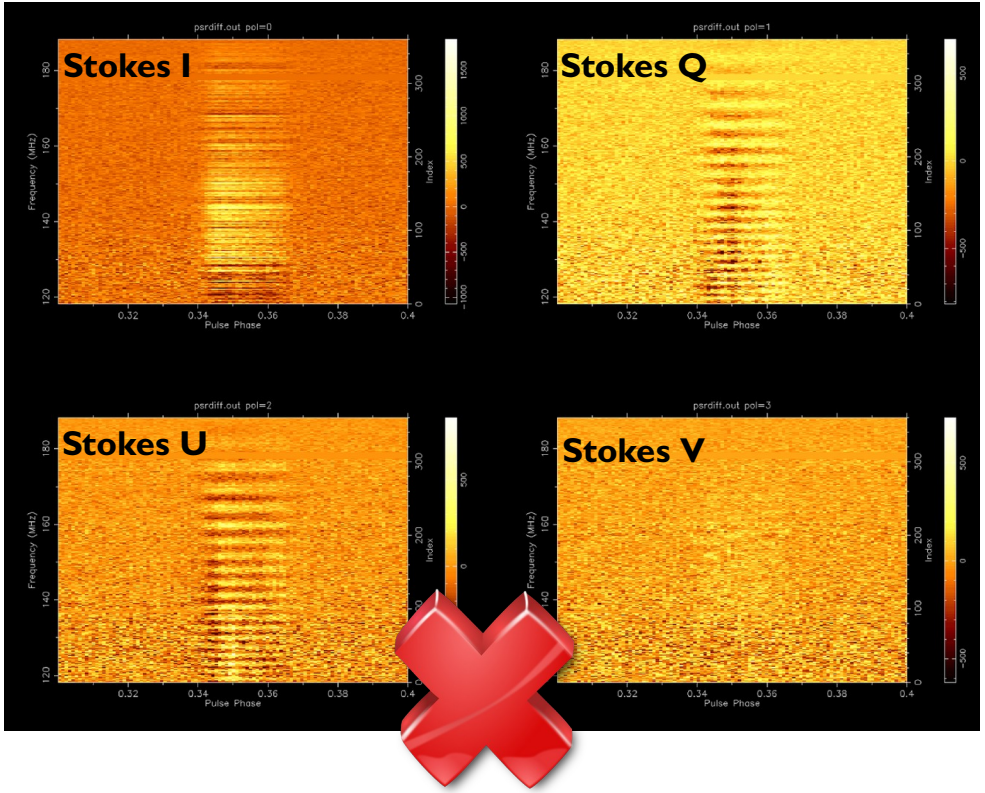
PLC at different elevations



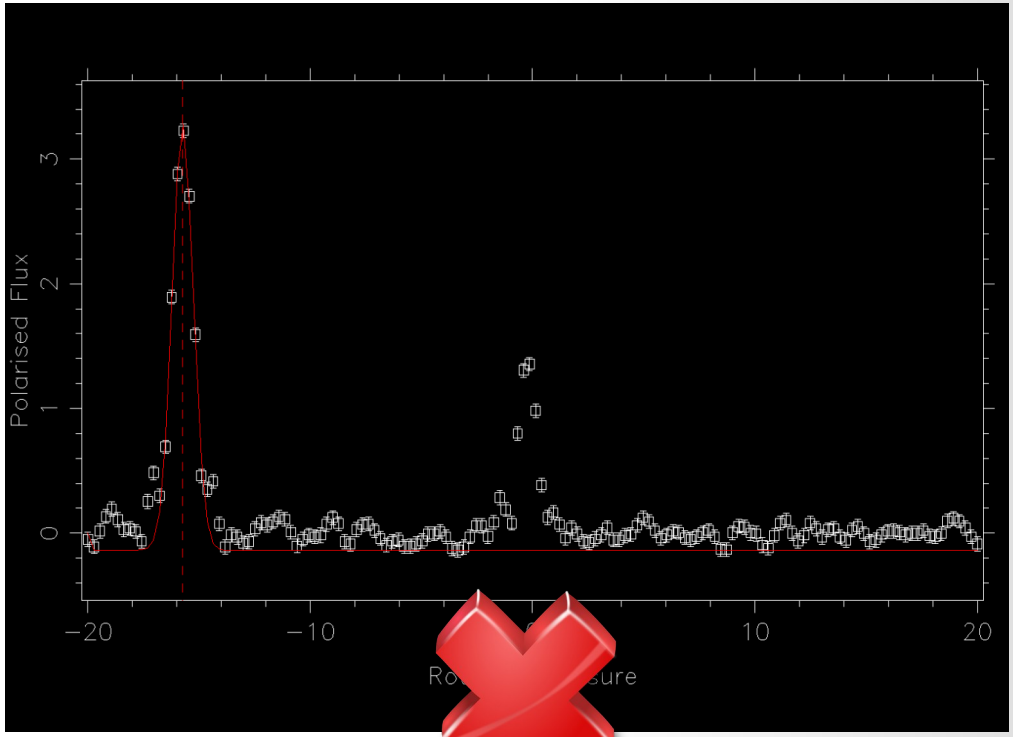
Pulsar-based polarization calibration, LOFAR

Classical model (elevation-static polcal)

PLC(small elevations)-PLC(~zenith)



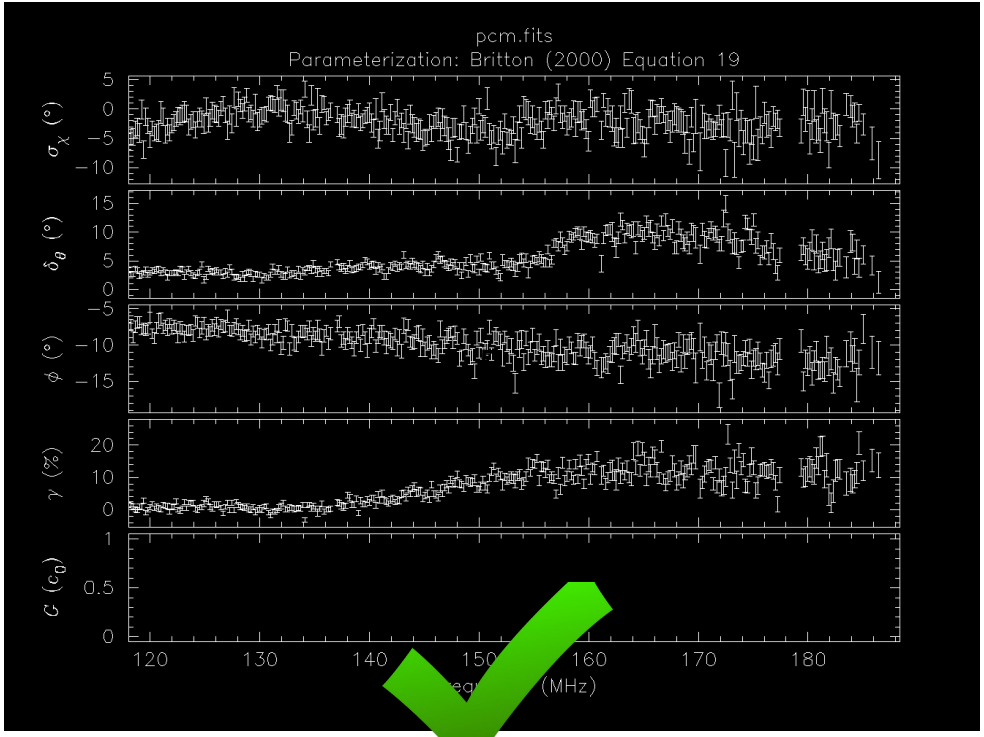
RM spectrum



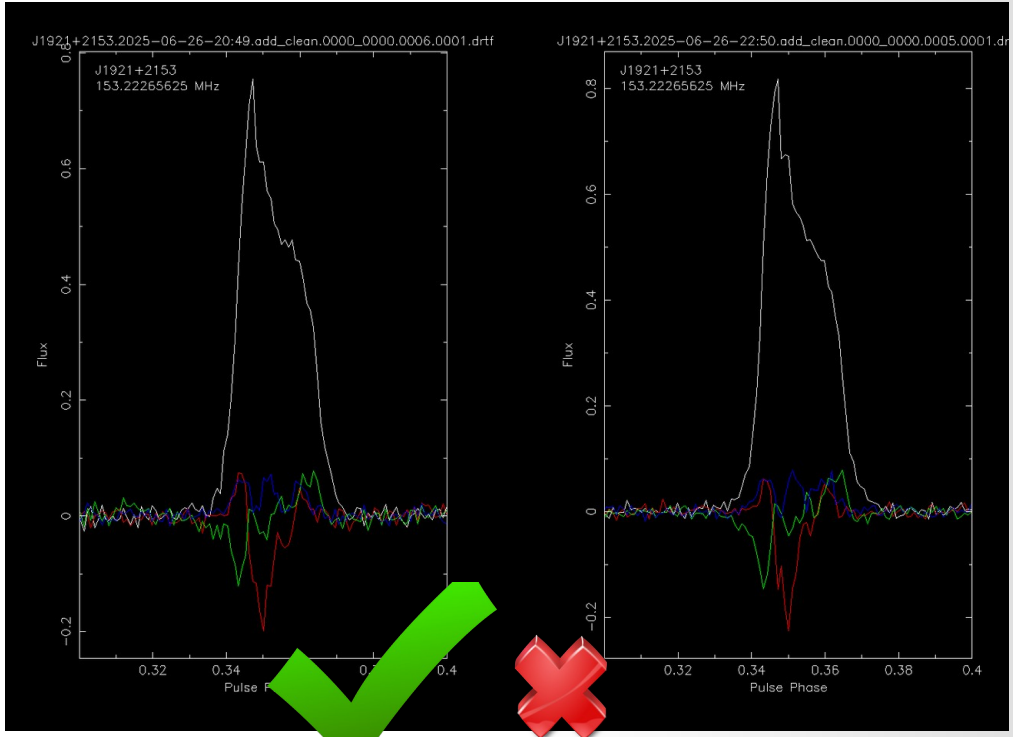
Pulsar-based polarization calibration, LOFAR

Upgraded model (elevation-dependent γ and δ_θ)

Polcal parameters



PLC at different elevations



Pulsar-based polarization calibration, LOFAR

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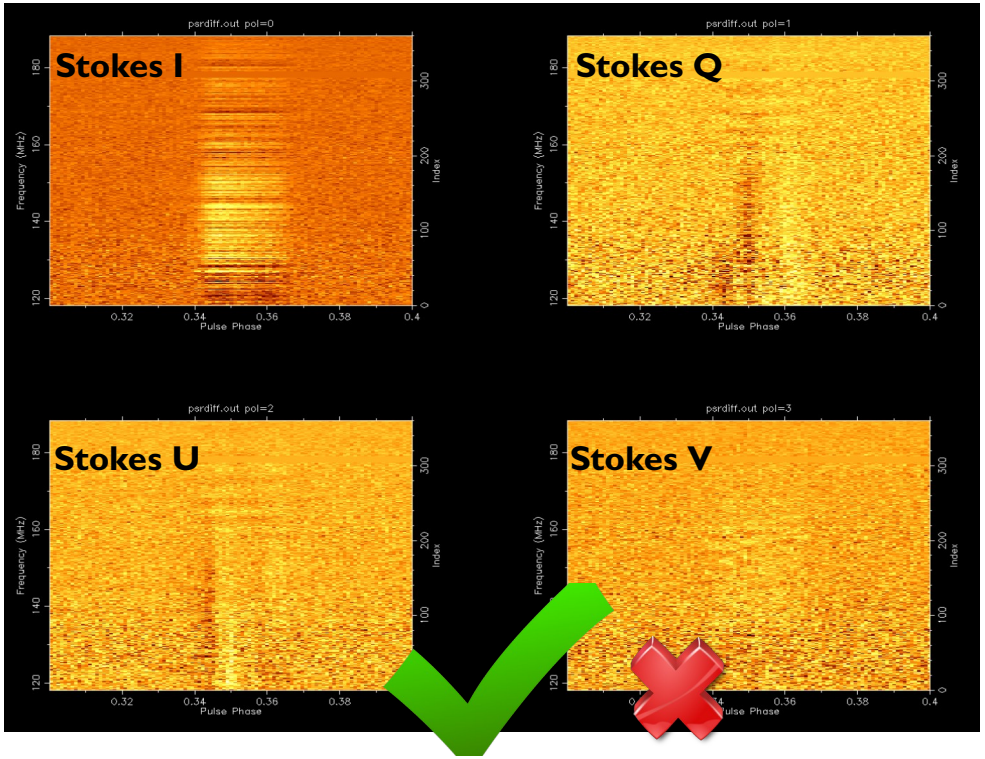
PLC(small elevations)-PLC(~zenith)



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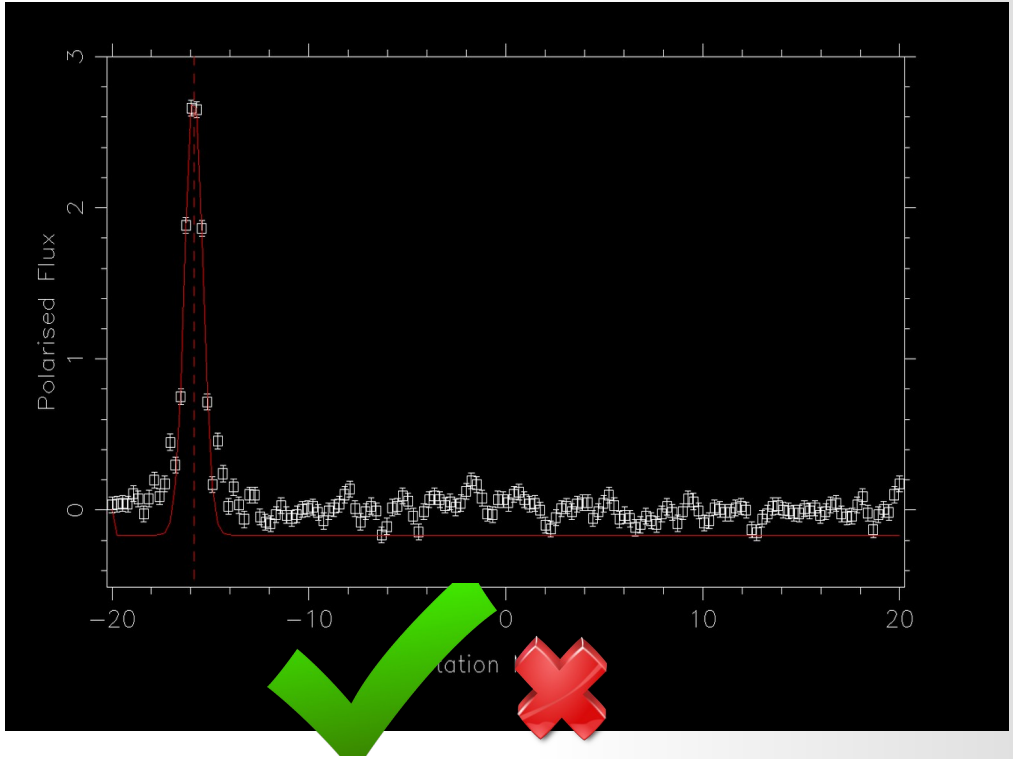

Thank you for your attention