Cross-Polarization Gain Calibration of VGOS Antennas

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TU Wien, MPIfR

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Vienna|Austria

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X
Y

VGOS

Correlator

X
Y

VGOS

XX YY XY YX ← Polarization Products

Complex gain differences between X and Y
→ Calibration!

HOPS

Stokes I `fourfit -P I ...`

Fringe-Fitting → **VGOSDB**

Building Stokes I for VGOS

Two main approaches:

- Stokes *I* (Barrett et al. 2019): *"Pseudo-Stokes I"*

$$I'_{ab} = (X_a X_b + e^{i(\varphi_a - \varphi_b)} Y_a Y_b) \cos\Delta + (X_a Y_b e^{-i\varphi_b} - Y_a X_b e^{i\varphi_a}) \sin\Delta$$

Δ : Parallactic angle difference between antennas a and b
$\varphi_{a,b}$: Phase of Y w.r.t. X at antenna a, b

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- PolConvert Martí-Vidal *et al.* 2016

$$\begin{bmatrix} I+V & Q+\mathrm{i}U \\ Q-\mathrm{i}U & I-V \end{bmatrix}_{\mathrm{ab}} = C_{\odot+} \begin{bmatrix} 1 & 0 \\ 0 & \rho_{\mathrm{a}} \end{bmatrix} \begin{bmatrix} XX & XY \\ YX & YY \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & \rho_{\mathrm{b}}^* \end{bmatrix} C_{+\odot}$$

  where $\rho_{\mathrm{a,b}}$ is the cross-polarization gain (amplitude and phase) between X and Y at antenna a, b. It is derived by least-squares fitting.

The VGOS R&D session er2201

Background:

- Stokes *I* fringe-fitting of VGOS data requires calibration of the complex gain differences between the two linear feeds of each antenna.

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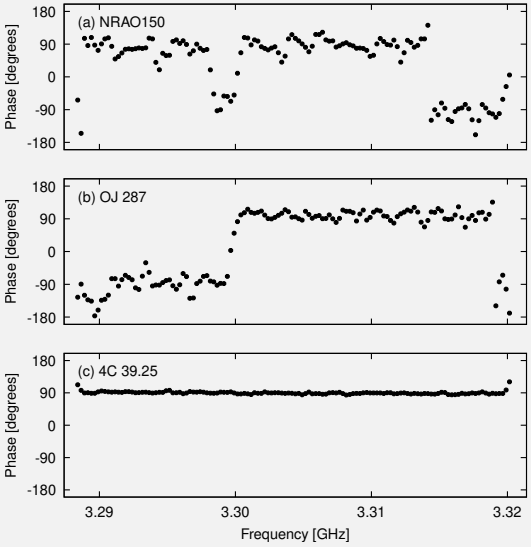
Cross-bandpasses from different calibrators



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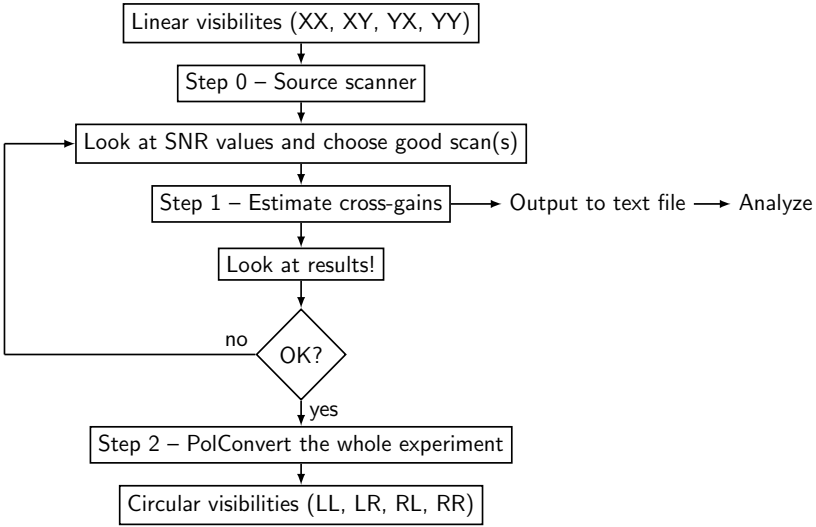
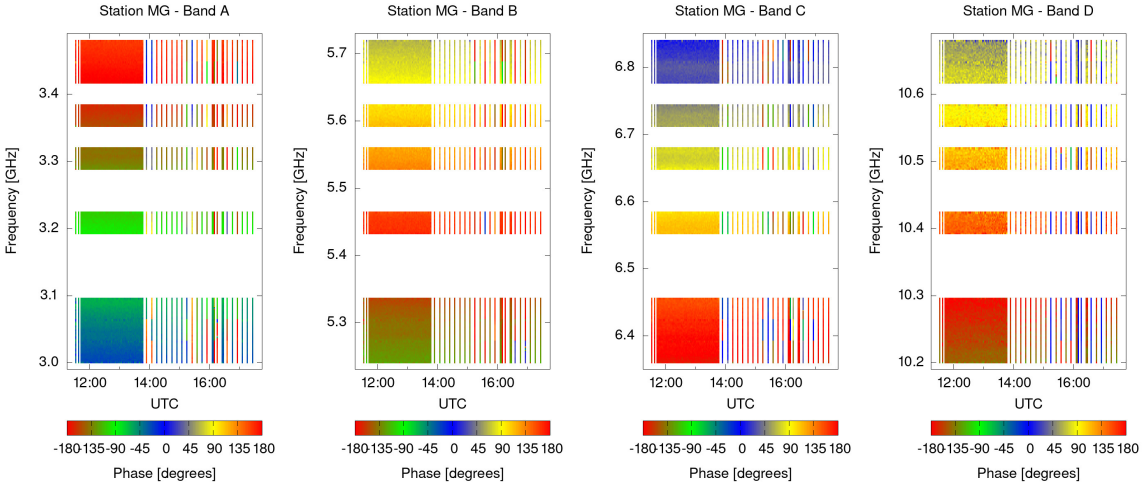
3. Determine optimal duration and observing geometry for calibration scans.
4. Model the intrinsic source polarization.
5. In addition, check two other candidates: NRAO150 and OJ287.

Using PolConvert to estimate the cross-polarization gains





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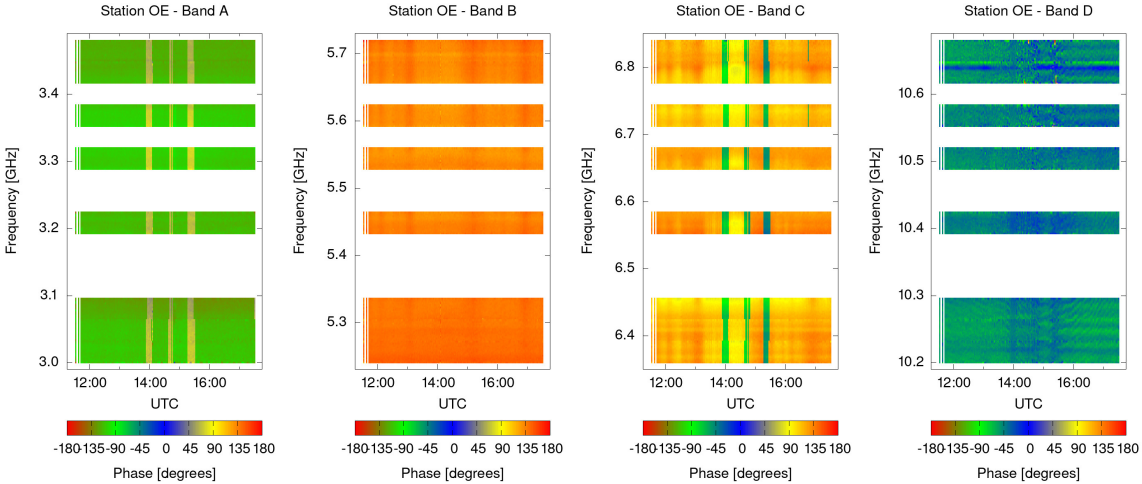

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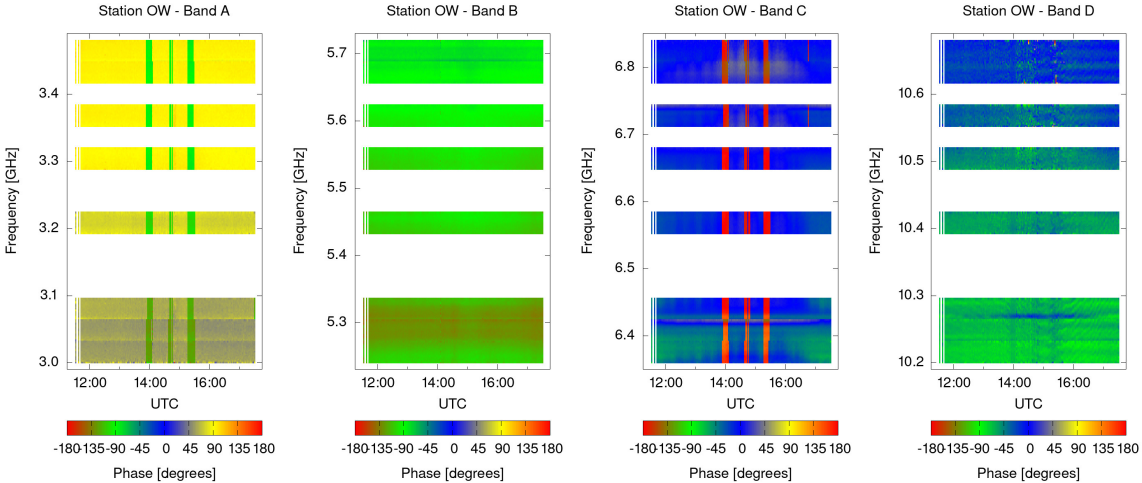

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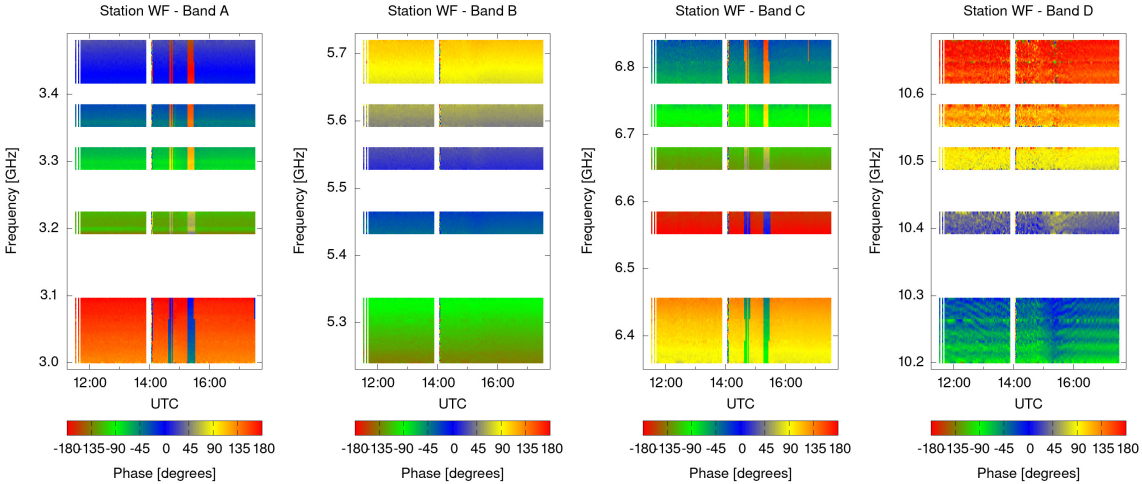

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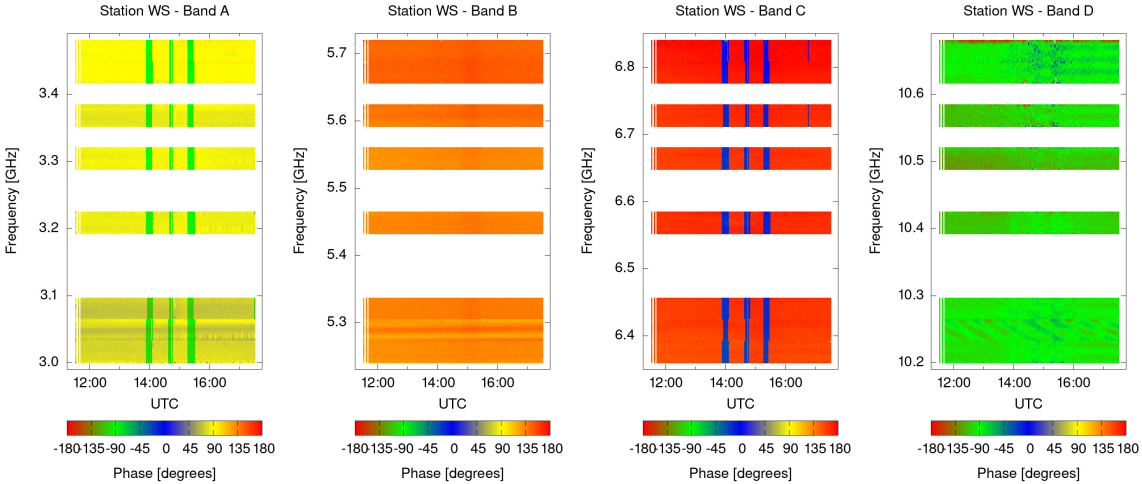

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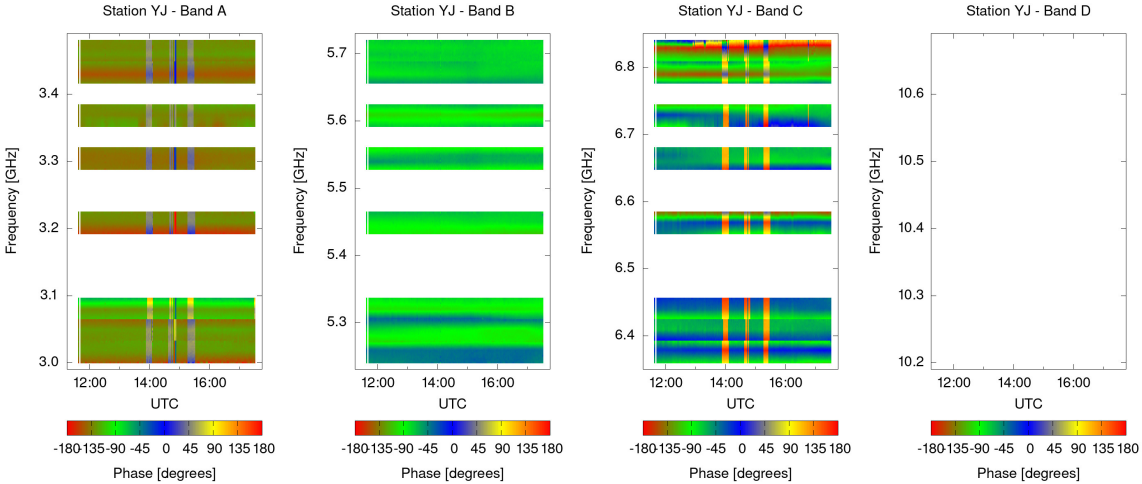

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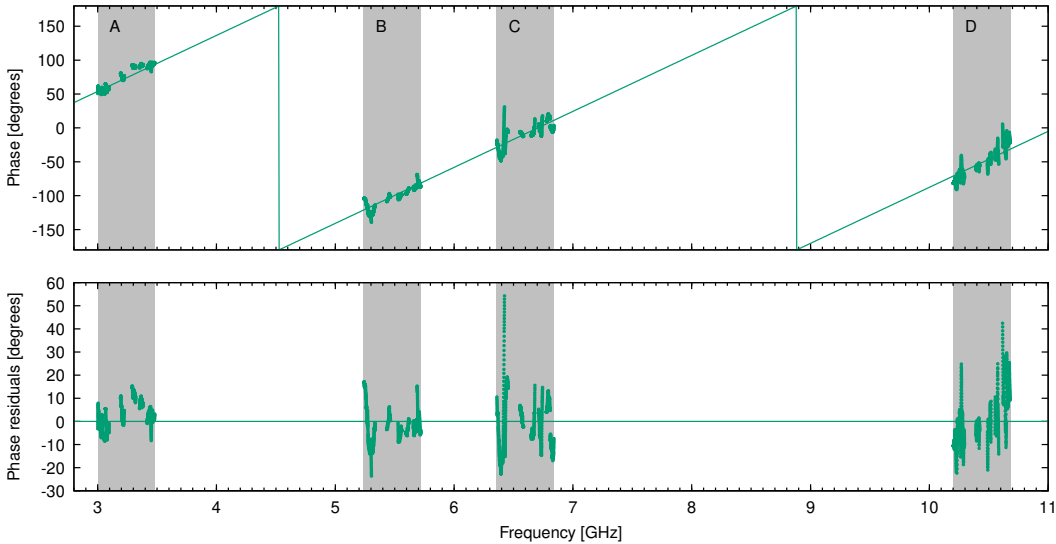


Group delay between X and Y: $\tau = 229.5 \pm 0.2$ ps

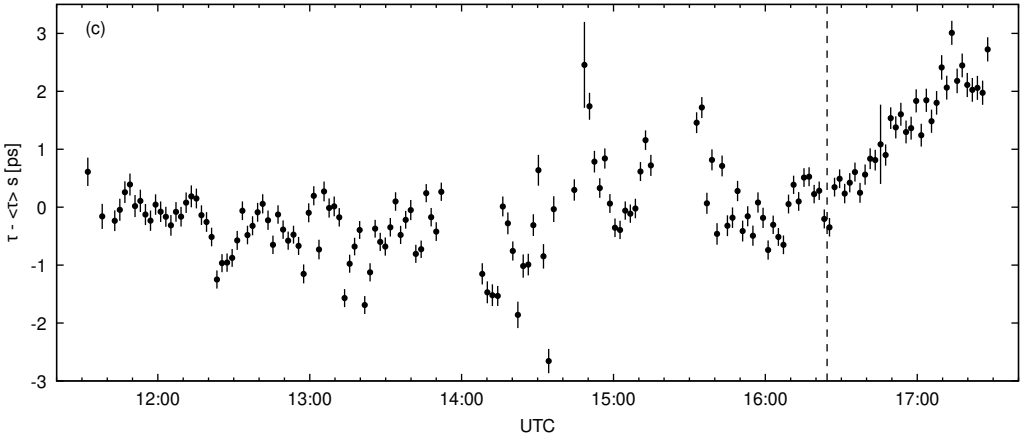


Fig. 13 (bottom panel) of Jaron *et al.* (2024)

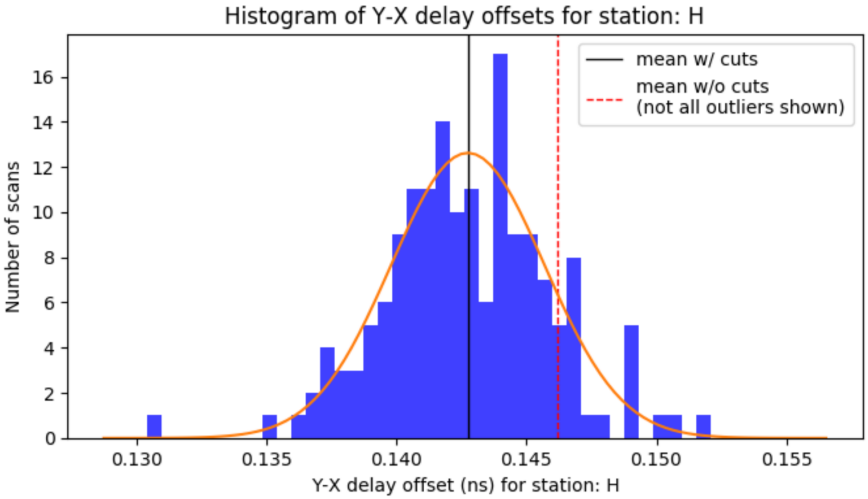
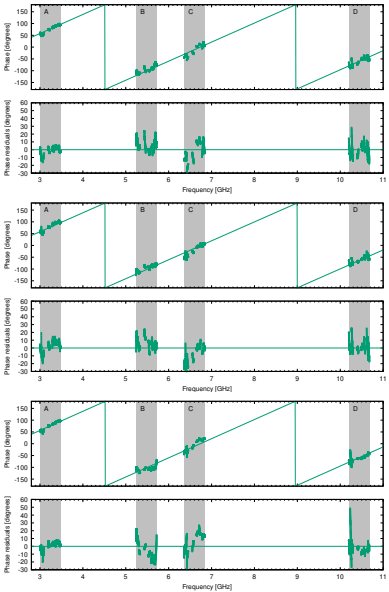


Fig. 4 (top panel) of the Haystack VGOS Manual



Cross-bandpass solutions for Onsala West from observations of 4C 39.25 in other EU-VGOS sessions.

- Top: ev9189. 2019 July 08
- Middle: ev9203. 2019 July 22
- Bottom: ev9217 2019 August 05

To first order, cross-bandpasses can remain remarkably stable over several years.

Fig. 15 in Jaron *et al.* (2024)

Follow-up session VR2303

Objectives:

- Flux selected survey of radio sources.
- **Find more calibrator sources.** ← Topic of today
- Measure cross-polarization bandpasses of more VGOS antennas.
- Investigate source structure of selected sources.
- Search for circular polarization in the radio emission from AGN.
- High SNR also allows to investigate atmospheric variability.

24-hours VGOS session VR2303

- 100 sources, AGN mainly selected by their radio fluxes.
- Observed from August 24 18:00 UTC until August 25 18:00 UTC, 2023.
- Scan length: 2 minutes.
- Network: Hb, K2, Nn, Oe, Ow, Sa, Wf, Ws, Yj, Is. Gs, Mg scheduled but not observed.
- Problem: Sa did not record VGOS Band A (due to RFI).
- Correlated in Vienna (128 and 160 channels, $\sim$200 GB). Raw data still there (283 TB).
- Did not use phase-cal signal in PolConvert.

Measuring the goodness of the solutions

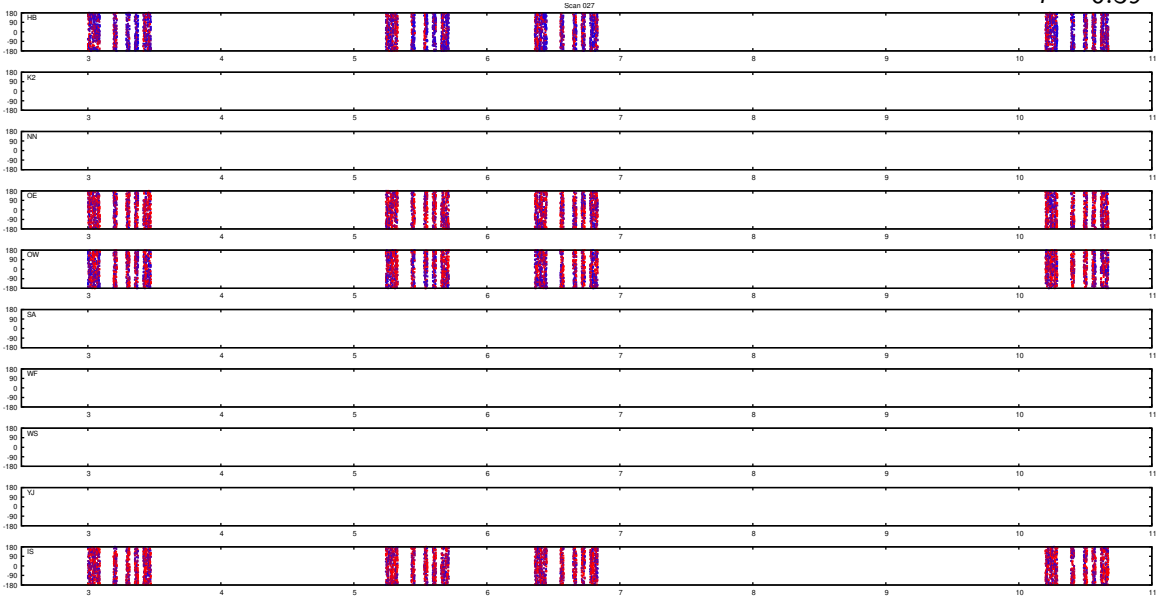
- Cross-polarization bandpasses are given in terms of amplitude A and phase ϕ.
- How to quantify the noisiness?
- Solution: Express gains as complex numbers $z = A\cos\phi + \mathrm{i}A\sin\phi$, and compute distance between adjacent points ($z \in \mathbb{C}$, $\mathrm{i}^2 = -1$).

$$r = \frac{1}{2LMN} \sum_{i=1}^{L} \sum_{j=1}^{M} \sum_{k=2}^{N} \sqrt{(\mathfrak{Re} z_{ijk} - \mathfrak{Re} z_{ijk-1})^2 + (\mathfrak{Im} z_{ijk} - \mathfrak{Im} z_{ijk-1})^2} \tag{1}$$

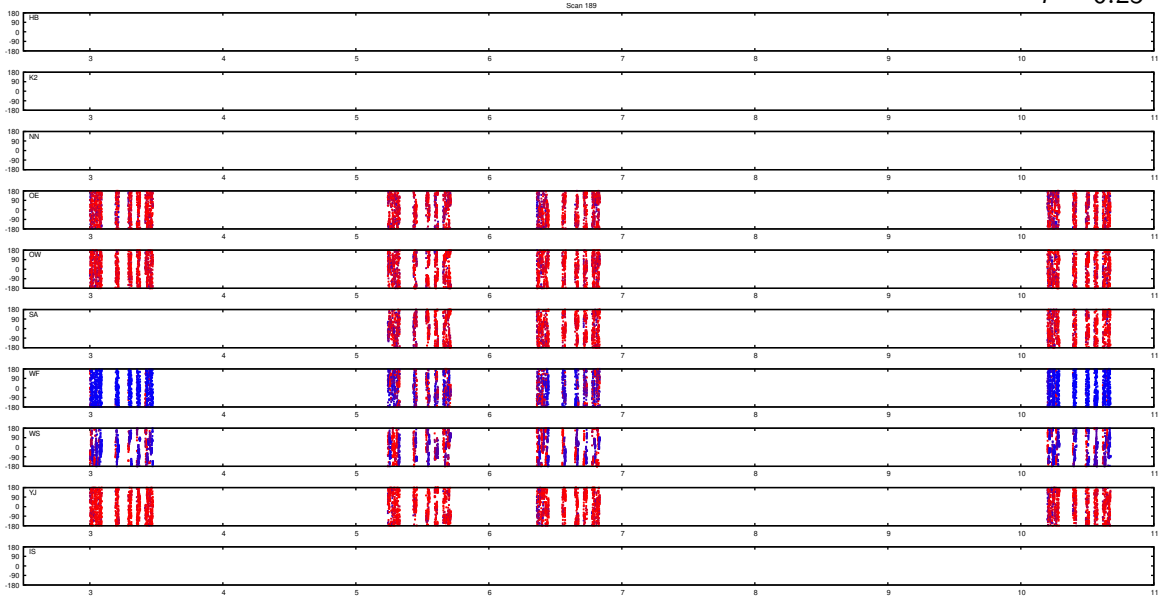
L Number of stations (up to 10),
M Number of sub-bands (32),
N Number of channels (160).

Additional factor 2, so $r \in [0, 1]$. For the moment: $A = 1$ (neglect amplitudes).

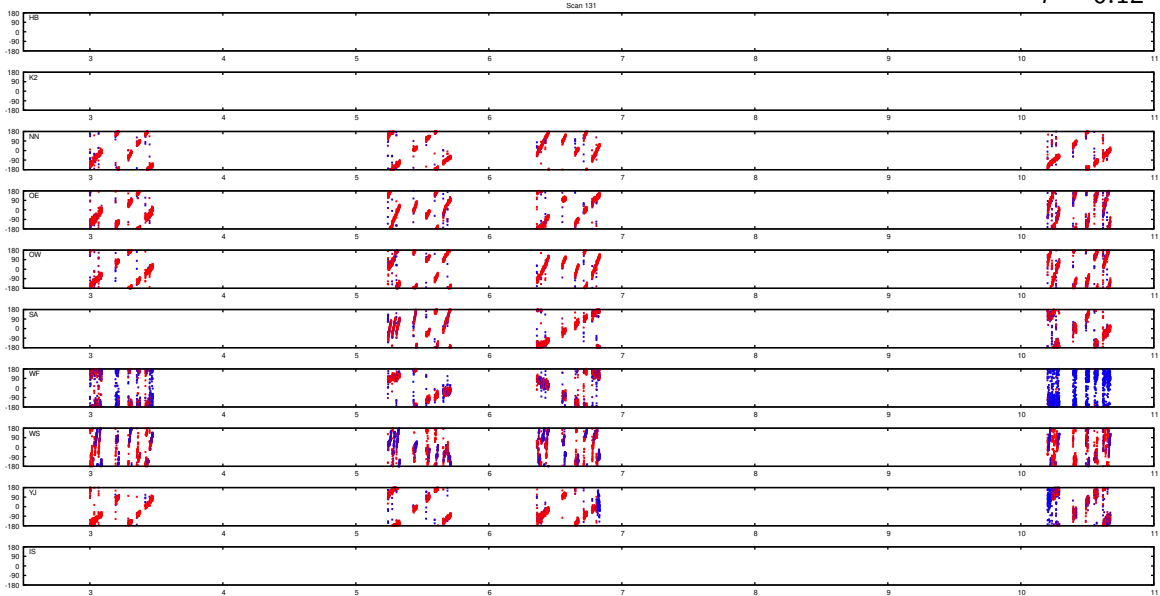
$r = 0.39$



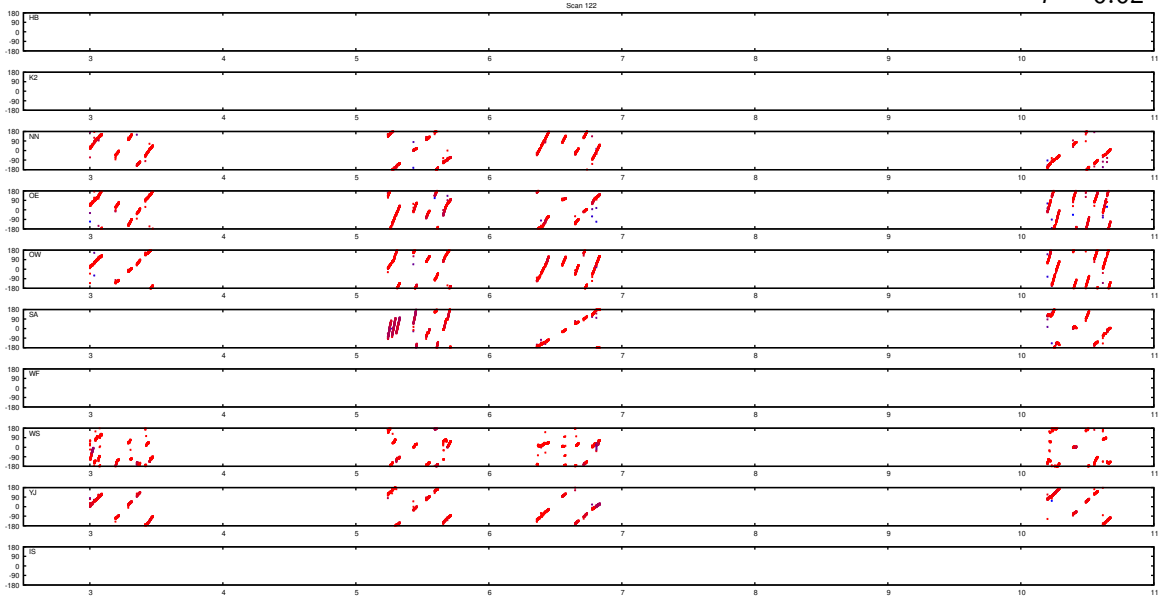
$r = 0.25$

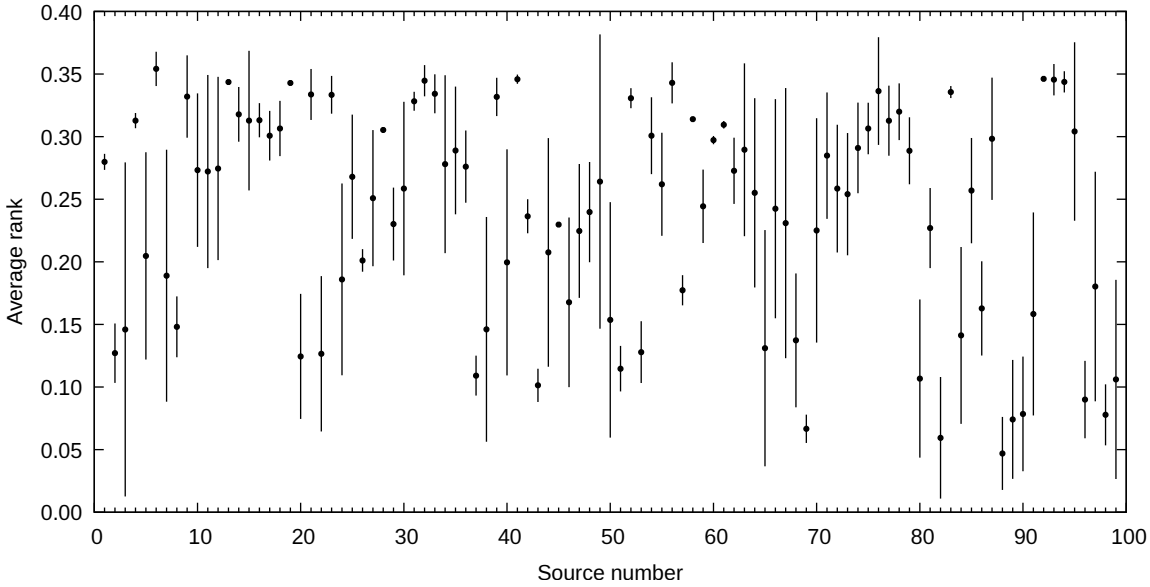


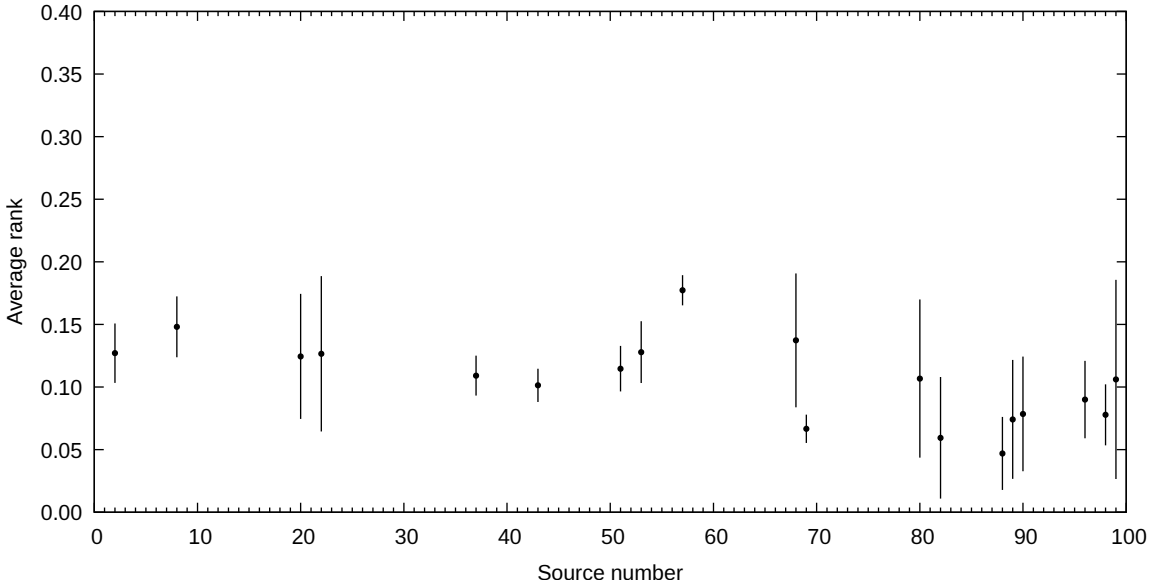
$r = 0.12$



$r = 0.02$




Average rank
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0
10
20
30
40
50
60
70
80
90
100
Source number


Average rank
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60
70
80
90
100
Source number

VGOS Cross-Polarization Gain Calibrator List (preliminary)

Source	Rank	Error	S^*_{RFC} [Jy]
3C454.3	0.05	0.03	12.3
3C279	0.06	0.05	13.4
2201+315	0.07	0.01	2.1
3C84	0.07	0.05	23.4
OJ287	0.08	0.02	3.2
4C39.25	0.08	0.05	9.2
NRAO150	0.09	0.03	5.5
1156+295	0.10	0.01	1.8
VR422201	0.11	0.08	2.9
3C273B	0.11	0.06	22.6

Source	Rank	Error	S^*_{RFC} [Jy]
1044+719	0.11	0.02	1.3
1803+784	0.11	0.02	2.2
0552+398	0.12	0.05	3.5
0607-157	0.13	0.06	4.0
0059+581	0.13	0.02	2.4
1928+738	0.13	0.02	3.3
2155-152	0.14	0.05	3.2
~~0212+735~~	~~0.15~~	~~0.02~~	~~2.9~~
~~2013+370~~	~~0.18~~	~~0.01~~	~~2.6~~

*Average radio flux density derived from the Radio Fundamental Catalog (RFC2023b)

Conclusions

- Cross-polarization bandpass calibration is a key element in VGOS fringe-fitting.
- Analysis of er2201 has shown that there is *systematic* short-term variability on $\sim$ hours time-scales.
- On time-scales of $\sim$ years cross-bandpasses can remain stable, to first order.

  Jaron *et al.* 2024, Radio Science, Volume 59, Issue 4

- Follow-up session vr2303 has been observed, analysis in progress.
- A preliminary list of cross-bandpass calibrator sources has been determined (for PolConvert).
- Caveat: Requirements for Haystack pipeline and PolConvert are different!