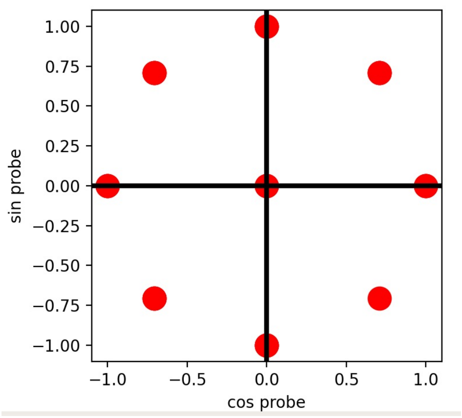
Pairwise probing model for identification

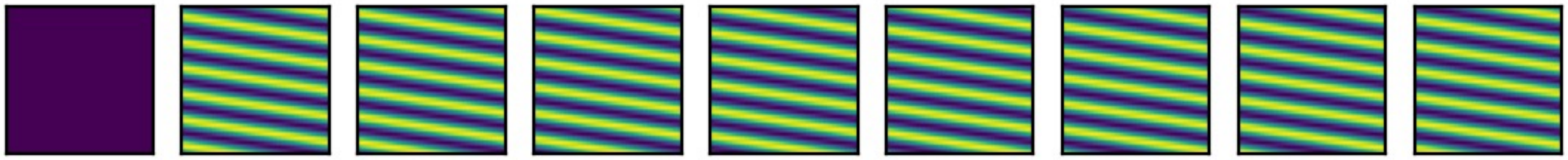
Vincent’s quick notes, March 2021

Starting from the data cubes

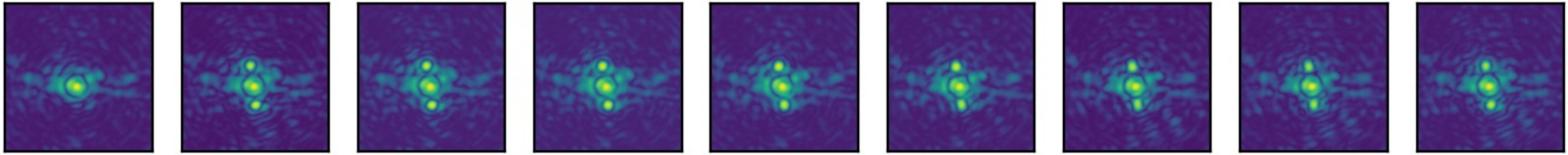
- 6 cubes - 3 non-coronagraphic unsaturated, 3 coronagraphic saturated with ~2.5 10^{-7} dark hole



- Each cube contains independent probing patterns for 25 cos/sin Fourier pairs
- Each pair is a sequence of flat DM +8 probes at π/4 shifts.
- e.g probe sequence for one pair:



- e.g. data (non coronagraphic, log scale)



Reduction

- We have probing redundancy - “Probing the probes”

- We can attempt to fit E_0, p_1, p_2, Inc, all at the same time.

- 7 real unknowns for 9 measurements $E_0,\ p_1,\ p_2 \in \mathbb{C};\ \mathrm{Inc} \in \mathbb{R}^+$

- Minimization criterion (?) - least squares in image space

$$\min[E_0,\ p_1,\ p_2,\ \mathrm{Inc}] \sum_{i=0}^{8} \left(\mathrm{PSF_i} - |E_0 + \alpha_i p_1 + \beta_i p_2|^2 - \mathrm{Inc}\right)^2$$

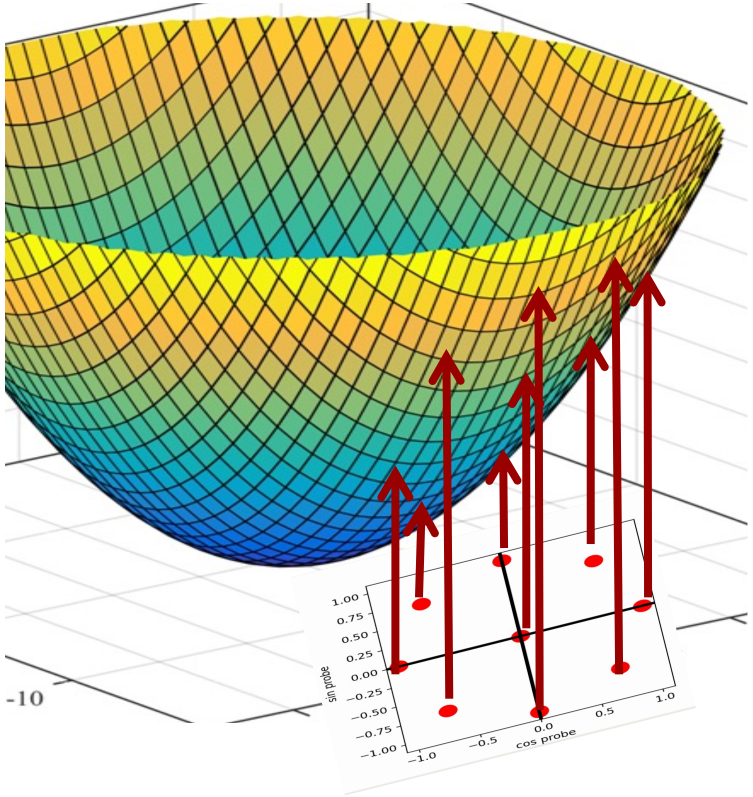
- This LS problem is independent on every pixel - spatial reg. could be considered.

- Final goal: p_1, p_2 are the G matrix coefficients between this pixel and that mode pair

The linear reduction trick

- **Classical approach**: feed the previous equation into a non-linear LS solver
- Geometric vision: find where our grid of 9 points

describes the canonical paraboloid $|E|^2 + \text{Inc}$



- **Coordinate change** approach:

Assume a change of coordinates such that

$$E_0 = [0,0],\ p_1 = [1,0] \ \text{ and } p_2 = [0,1]$$

LS-fit a generic paraboloid in this basis

$$\min[A-F]\sum_{i=0}^{8}\left(\text{PSF}_\text{i} - [Ax^2 + 2Bxy + Cy^2 + 2Dx + 2Ey + F]\right)^2$$

Perform the inverse coordinate change by finding the minimum, the eccentricity, etc, of

$$Ax^2 + 2Bxy + Cy^2 + 2Dx + 2Ey + F$$

Much faster because its a linear LS problem

But doesn’t like boundary conditions - so if it doesn’t work, we just throw the pixel away.

Problem symmetries and reduction hypotheses

- Physically / mathematically:

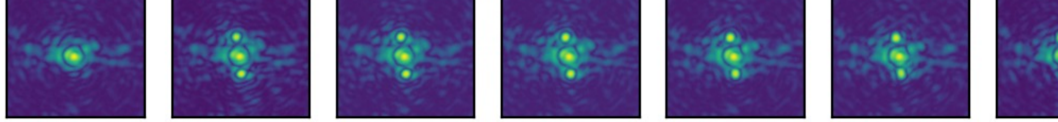
E is only defined up to a complex rotation + complex conjugation

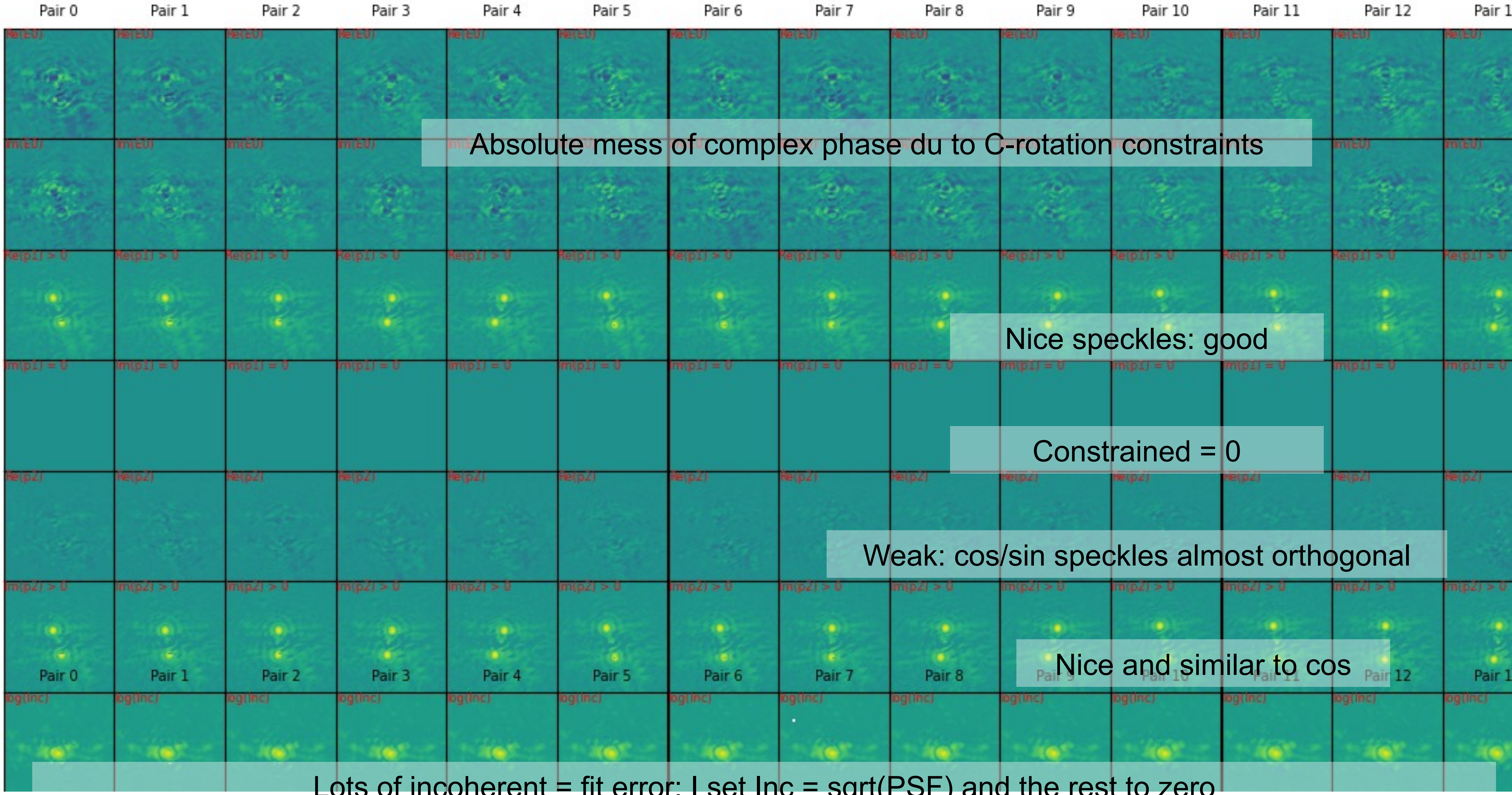
Solved with the following:

- No constraint on E_0
- p_1 must be real and positive
- $Im(p_2) > 0$ - but no constraint on $Re(p_2)$

- Inc > 0... if Inc < 0 at the end of the fit, results are discarded.

Lots of data - Non-corona unsaturated 1/2





Absolute mess of complex phase du to C-rotation constraints

Nice speckles: good

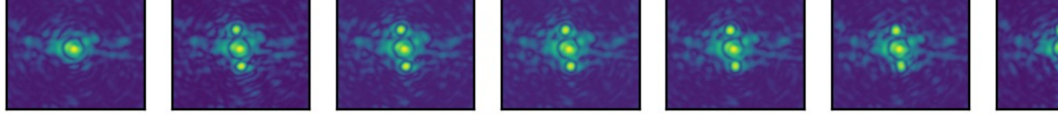
Constrained = 0

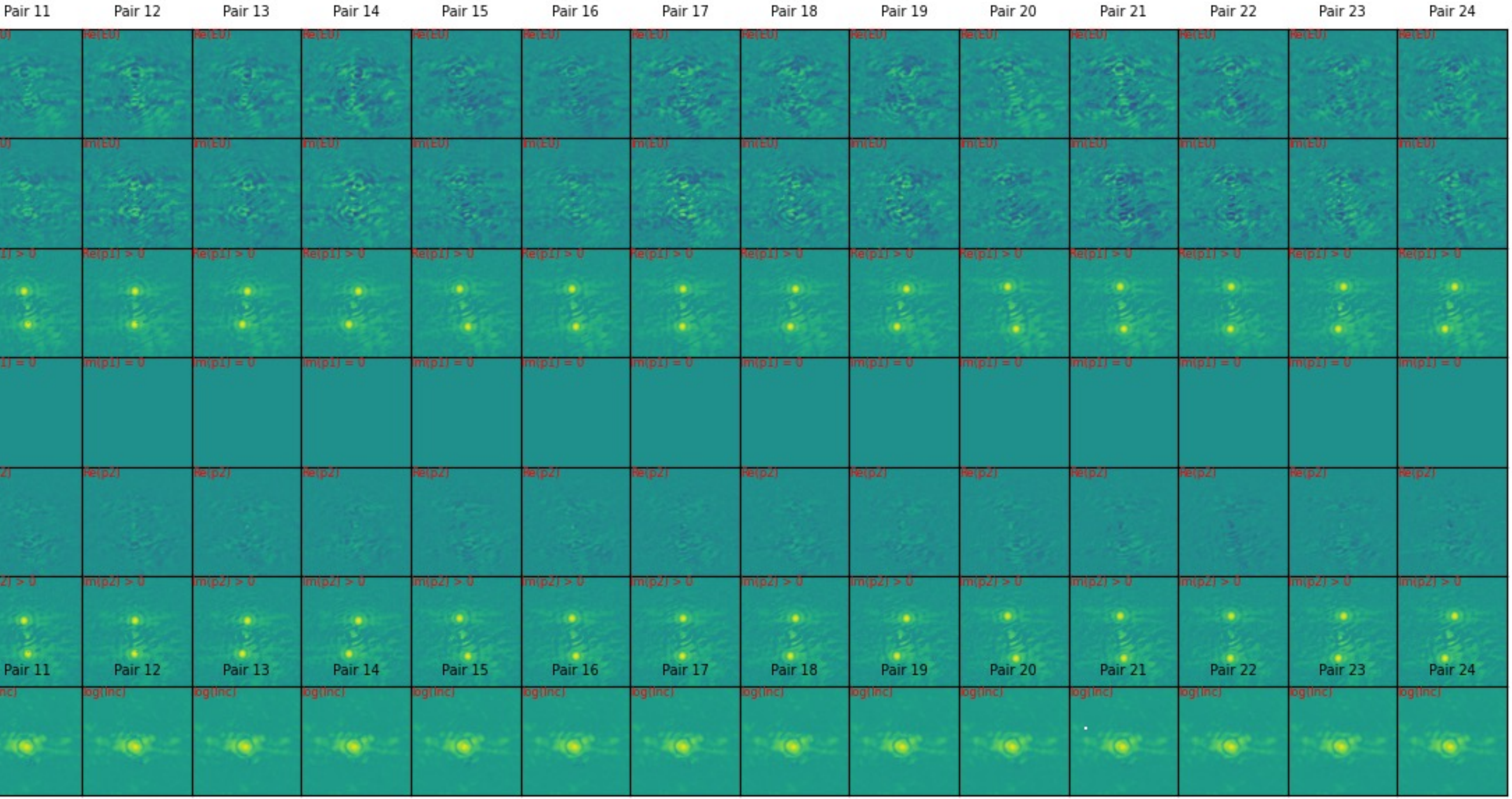
Weak: cos/sin speckles almost orthogonal

Nice and similar to cos

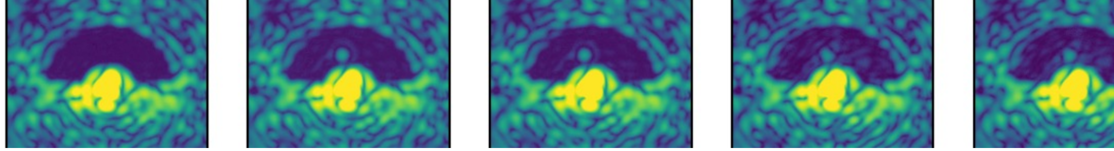
Lots of incoherent = fit error: I set Inc = sqrt(PSF) and the rest to zero

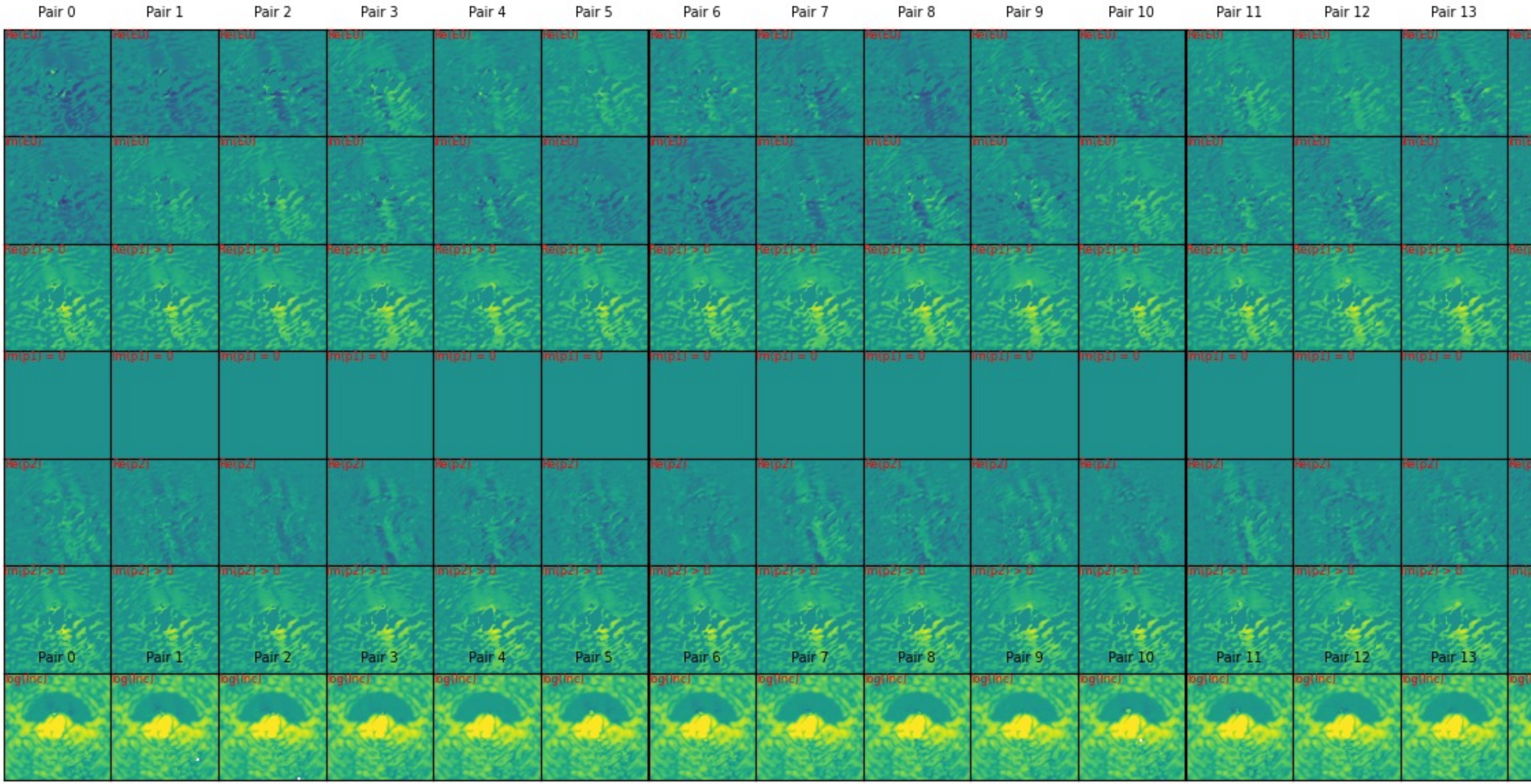
Lots of data - Non-corona unsaturated 2/2



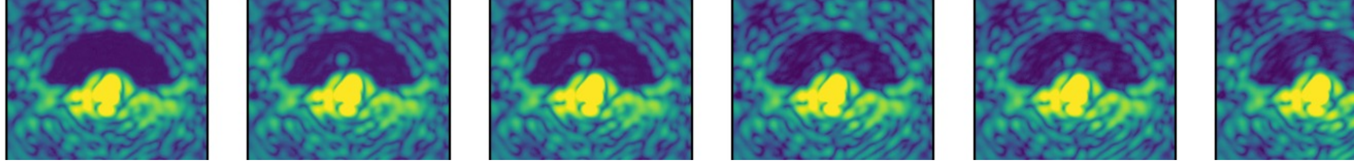


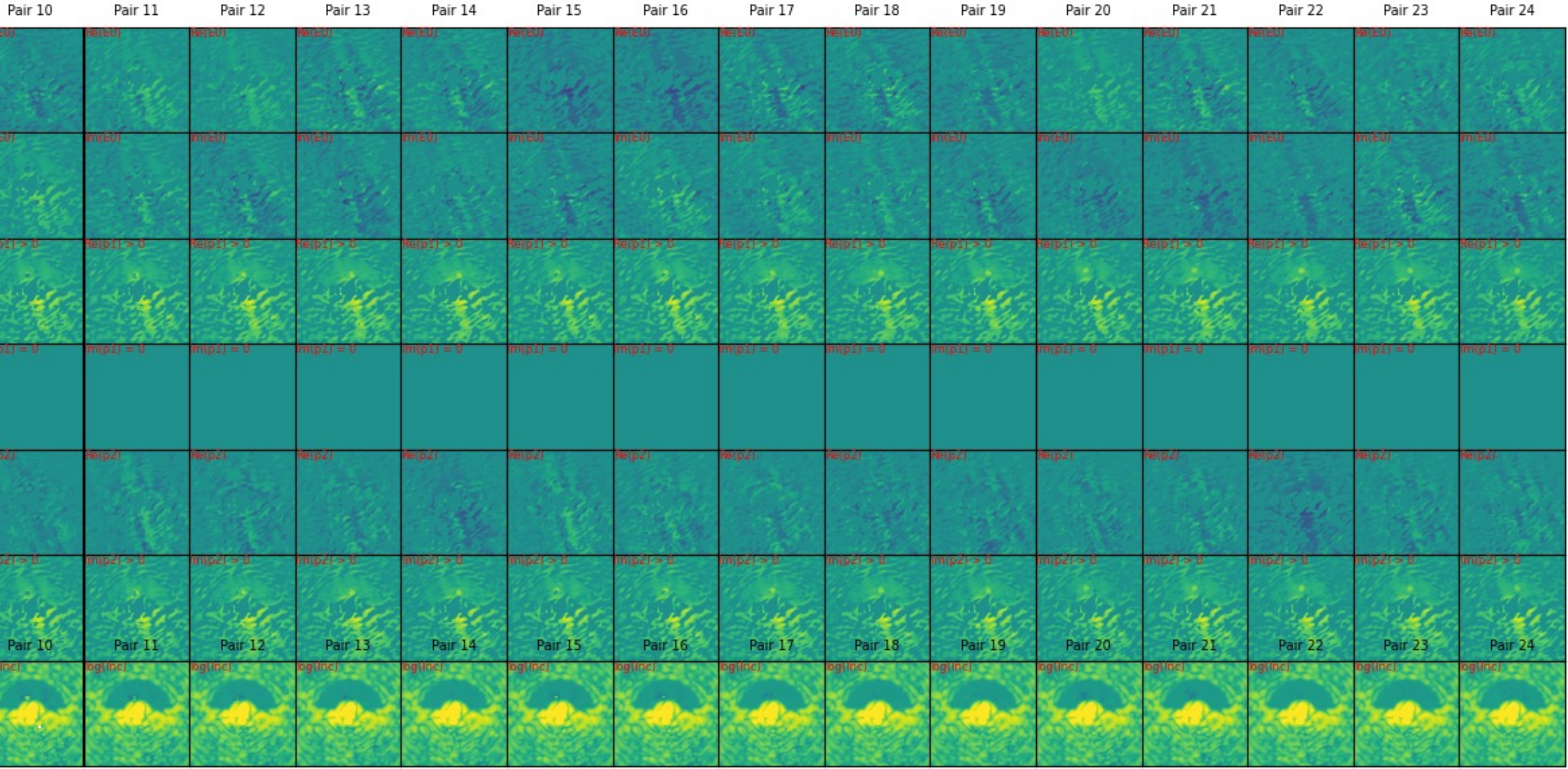
Lots of data - Coronagraphic 1/2



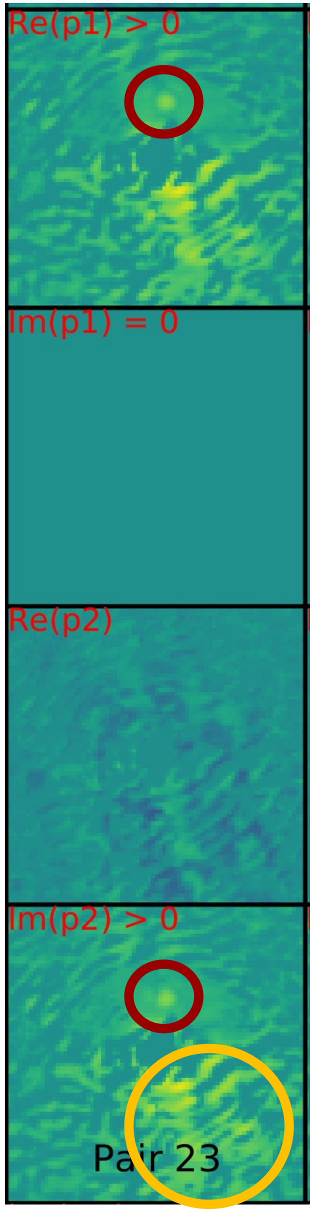


Lots of data - Coronagraphic 2/2



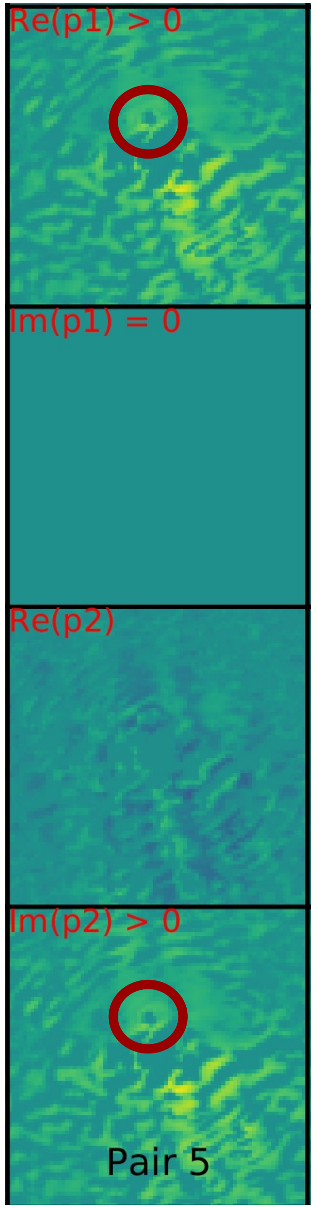


The coronagraphic dataset isn't too good



Speckles well within
the DH are well registered

Also note a decent bright field
response in this area



But speckles too close to the core
don't work too well.

Fit works across the DH
but the fails exactly where the
speckle is !

Don't know why.
Mathematical or physical, no idea.

Next steps

Simulations (more in the next slide)

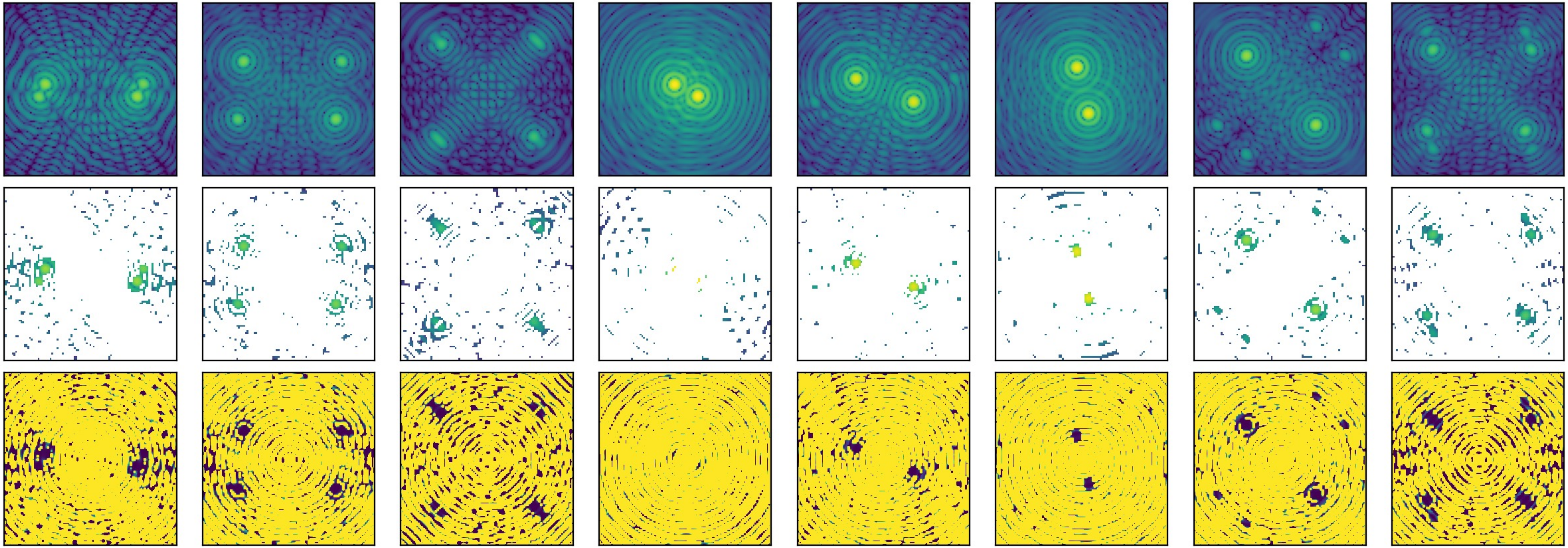
- Ongoing parallel work in **simulations** (unsaturated, unaberrated)
    - Extensive set of probing on a full Fourier basis (using a 17x17 DM, 144 cos/sin pairs)
    - Designing and testing algorithms with a quick iteration cycle
    - Access to the true G matrix
- Try to assemble a **measured** G matrix (with simulation data, then maybe real data)
    - Hard point: complex rotation consistency to build G
    - Good match (simulator) on coefficient complex amplitude. Not checked thoroughly.
- Then try to dig a dark hole with it
- Attempt iterative G-matrix learning methods using the error between successive digging steps.

With the bench dataset

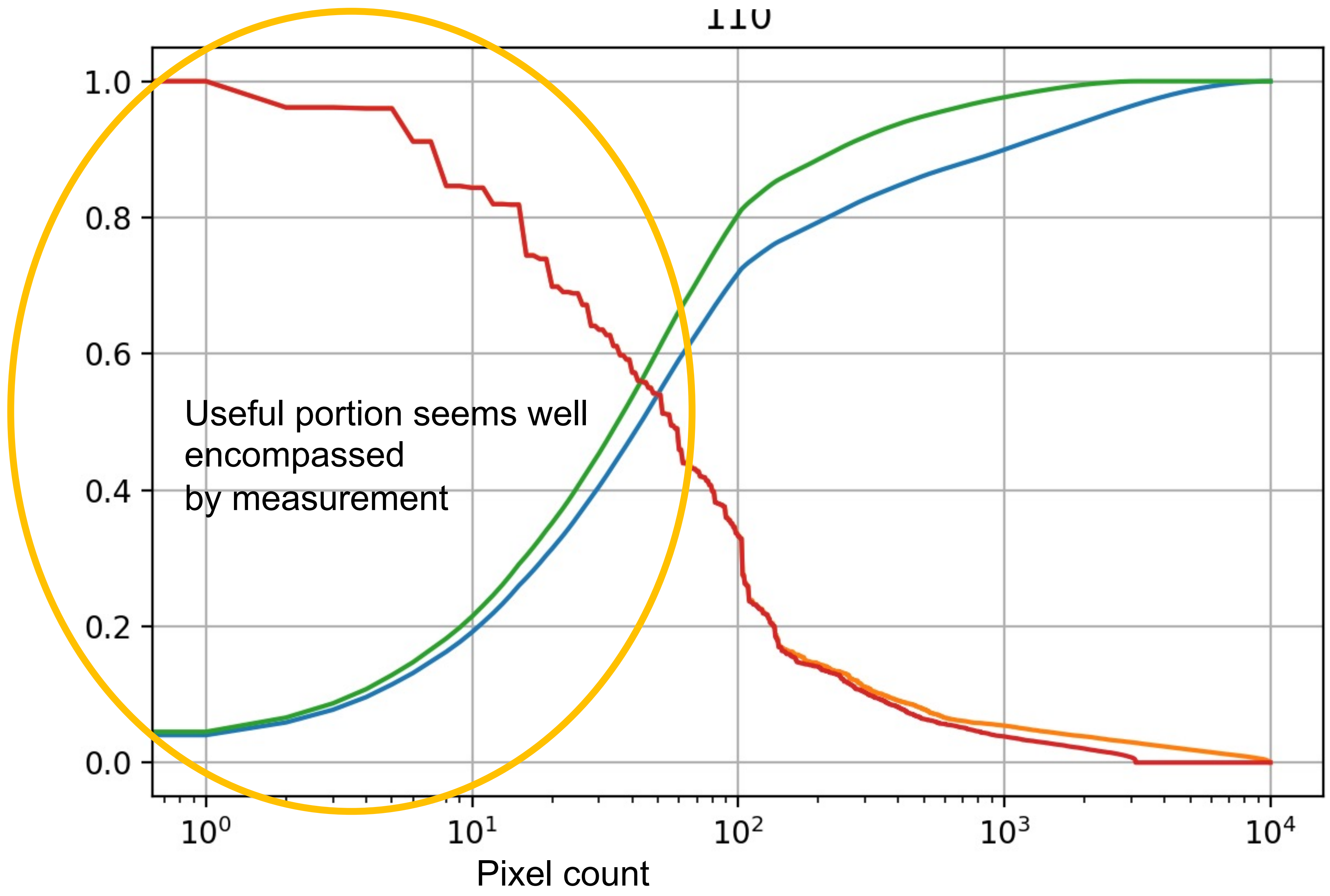
- Could use a reality check against the existing model
- Figure out the next steps. More Fourier modes ?

G matrix amplitude from simulations

Log complex amplitude for a few modes
Truth (top), and measurements (middle) - log scale
Relative difference (bottom) - lin scale [0 - 0.1]
Majority of pixel where that doesn't work ! Lack of incoherent background could be causing a slight glitch too.
BUT where it works, the coefficient magnitude is quite correct: errors of 10^{-4}-10^{-3} near speckle center



Final note: all the important coefficient are fitted (one mode)



Cumulative quadratic sum of G matrix column for this mode:
blue: True; green: Meas

Sorted, normalized to max pixel G coeff value for this mode
orange: True; red: Meas.

Sims: 100x100 = 10^4 pixels