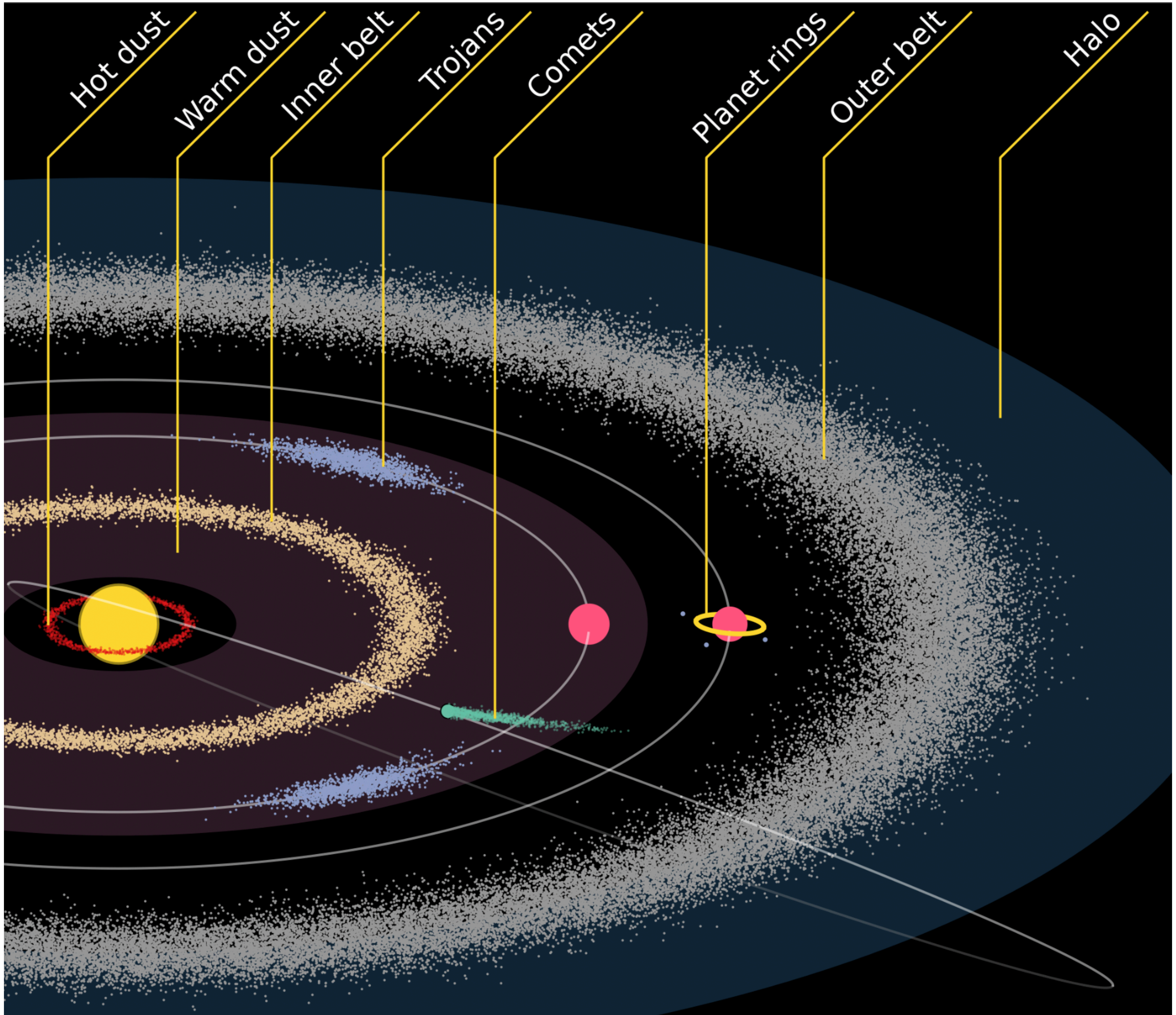
Debris disk modeling of Beta Pic and correlations in MATISSE data

Philippe Priolet
PhD student

Supervised by Jean-Charles Augereau et Julien Milli

Université Grenoble Alpes
IPAG

What are debris disks?



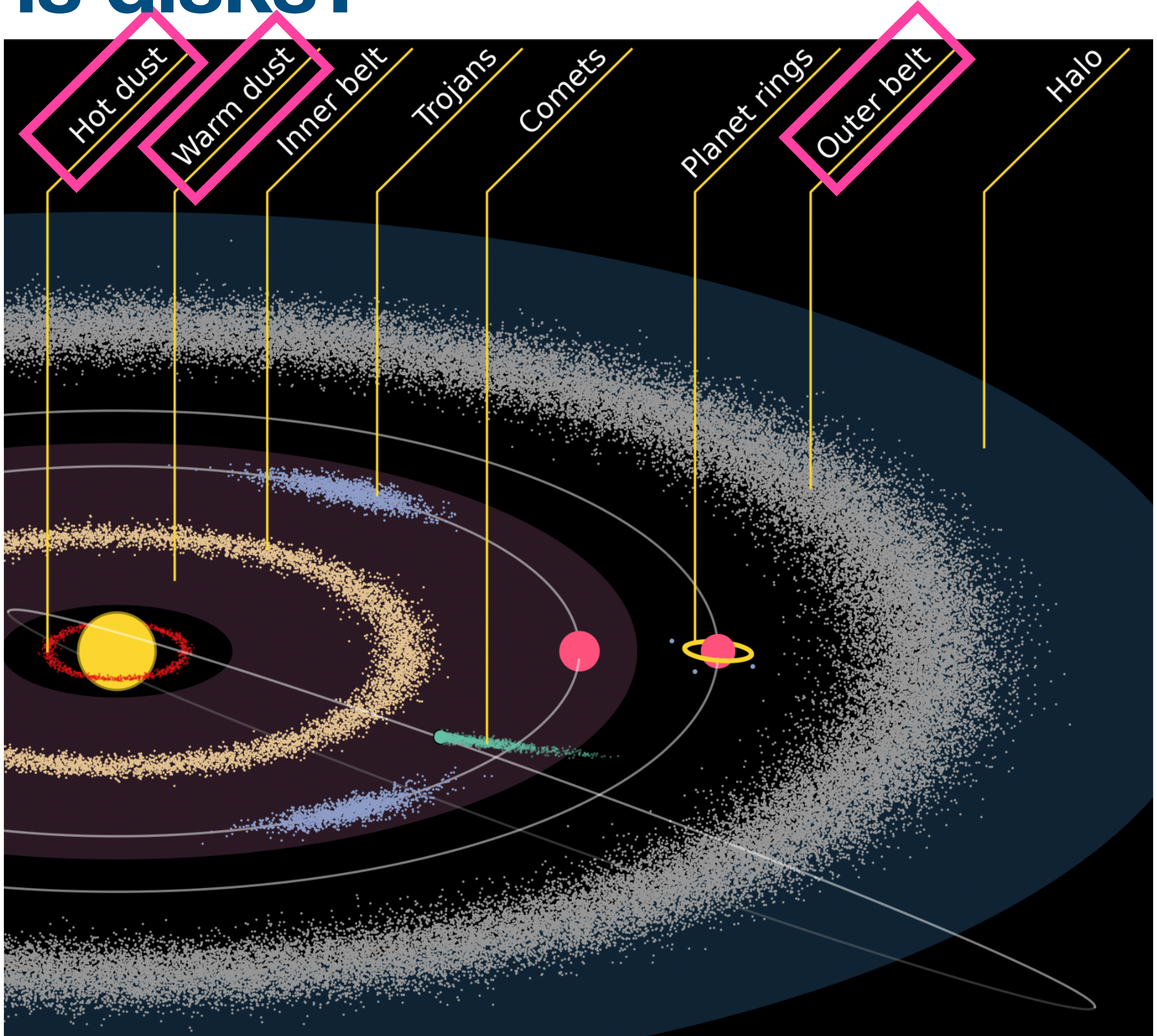
Pearce 2024

What are debris disks?

Hot belt ~ 1000K

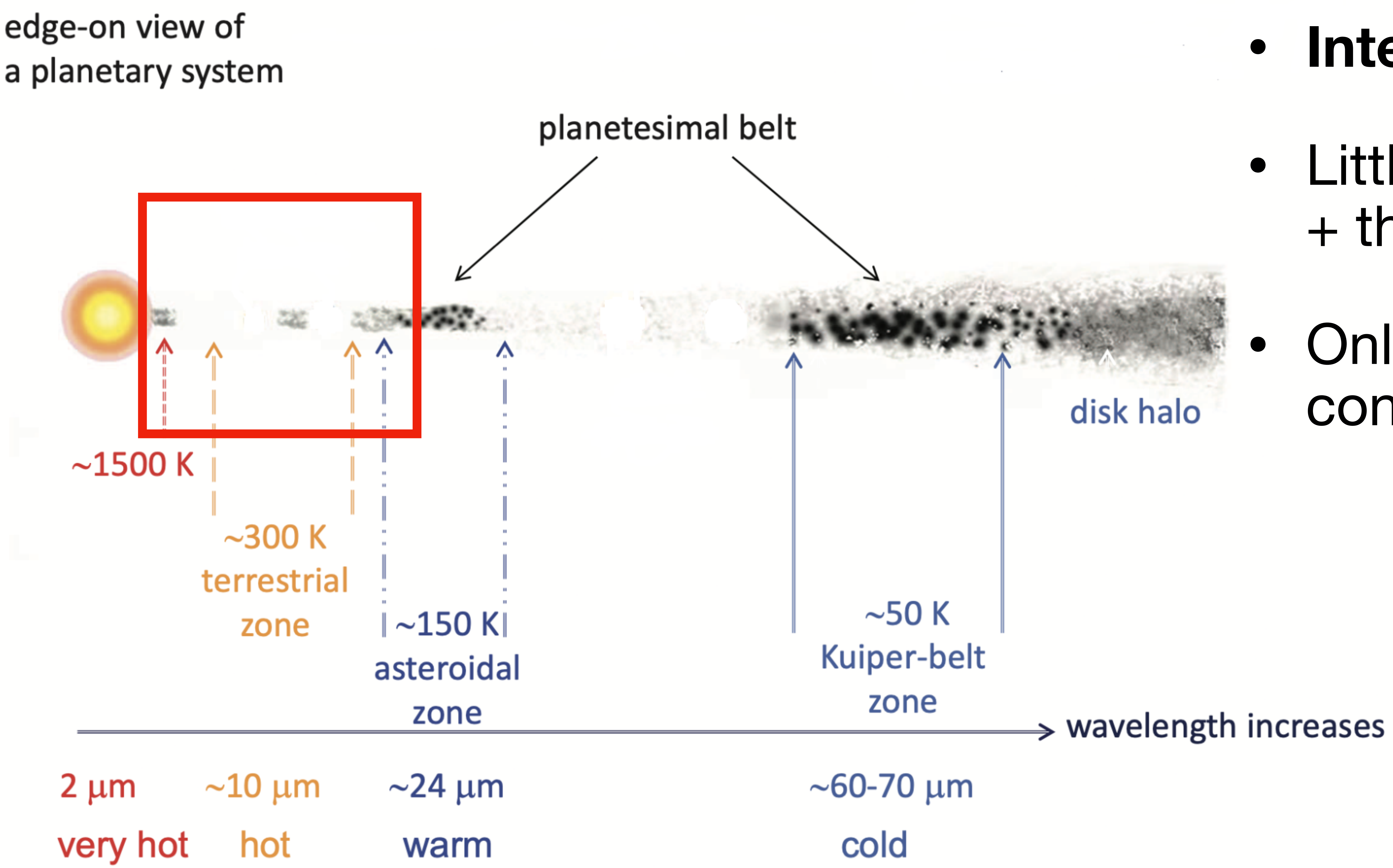
Warm belt ~ 100-300K

Cold belt ~ 50K



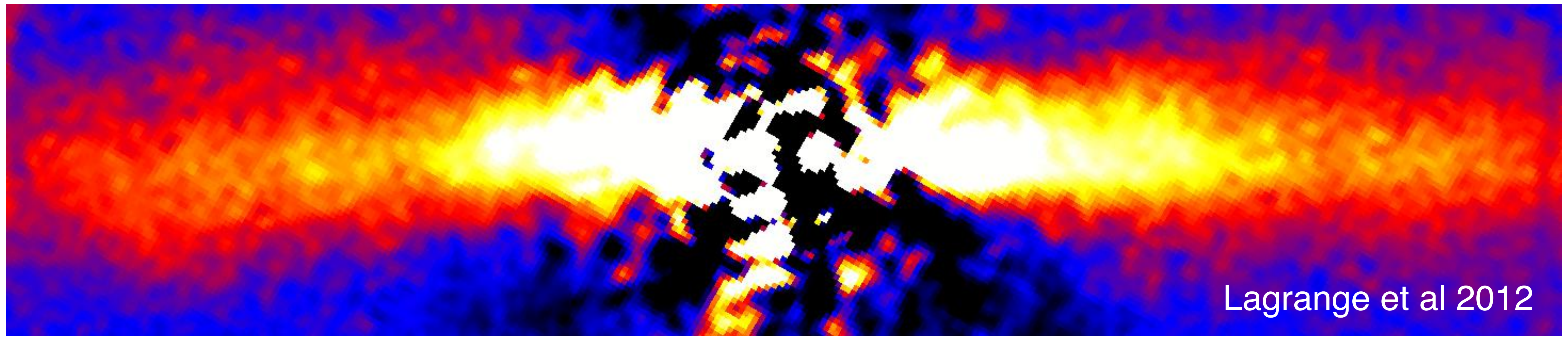
Pearce 2024

Exozodiacal dust



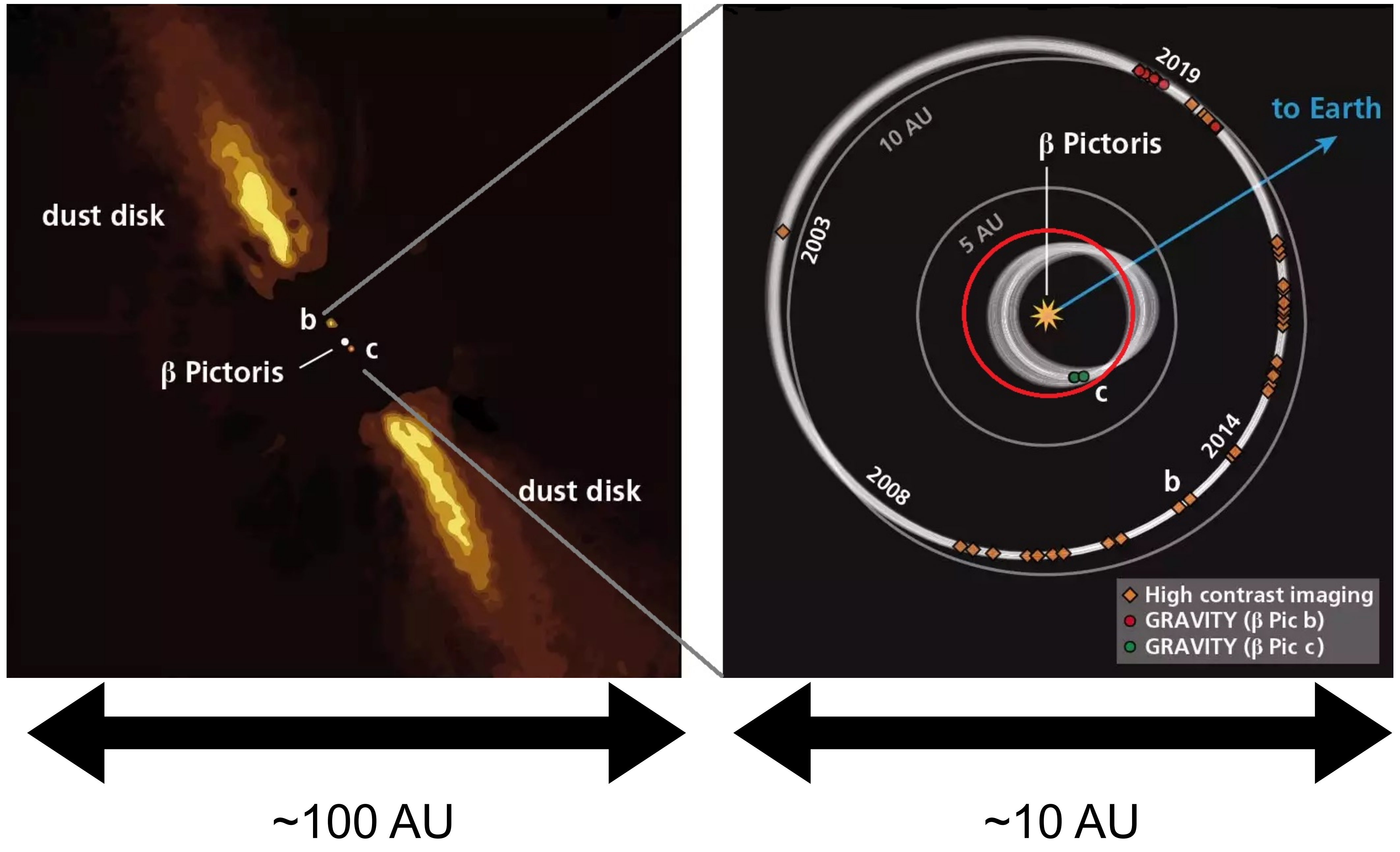
- **Internal region**: Mostly **unconstrained**
- Little information on the dust properties + their spatial distribution.
- Only the flux coming from this region is constrained.

Beta pictoris



GRAVITY Collaboration / Axel M. Quetz, MPIA Graphics Department

- **Edge-on** debris disk
- **Detected exozodi** (PIONIER, GRAVITY)
- Exo-cometary activity.

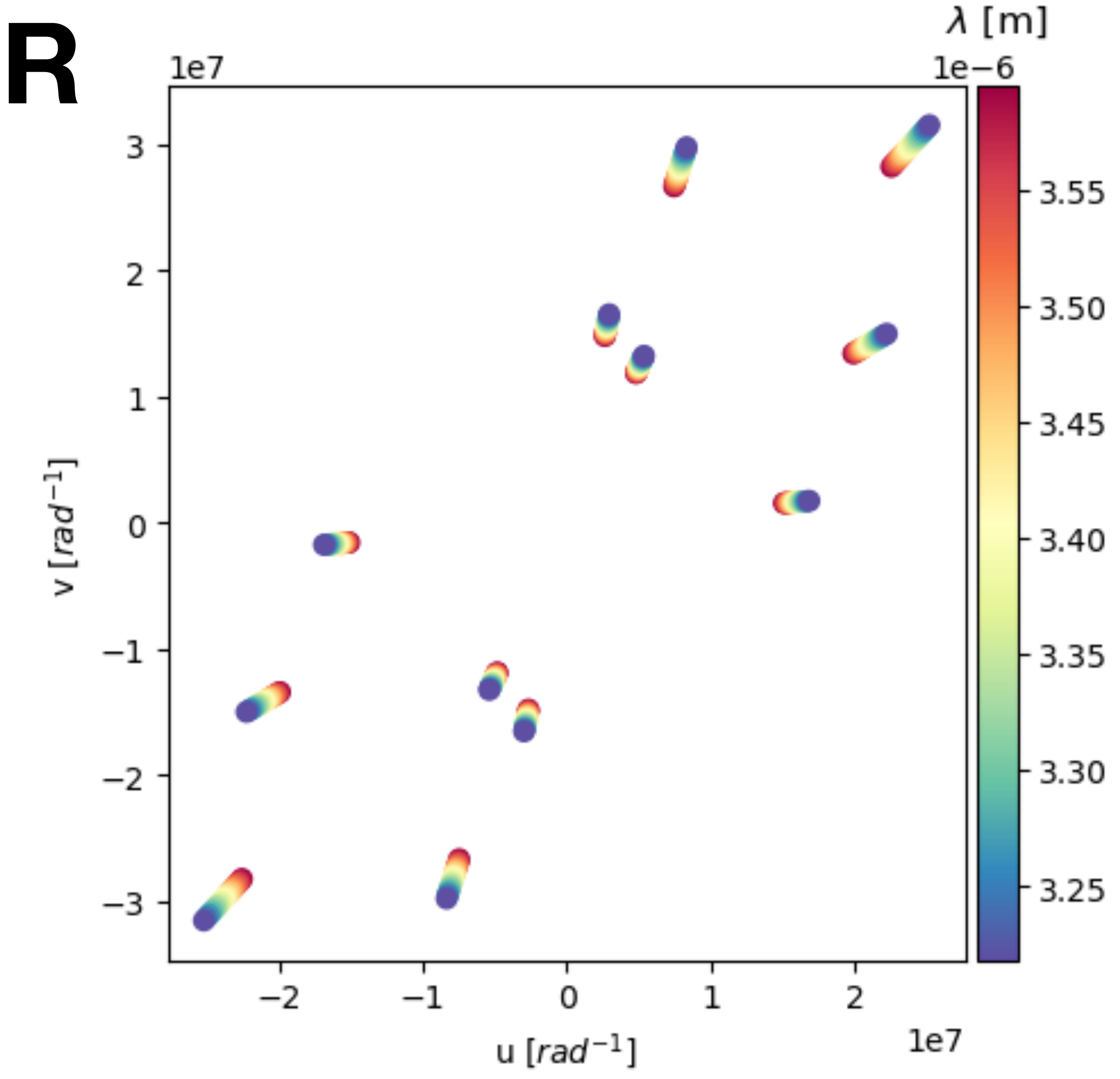


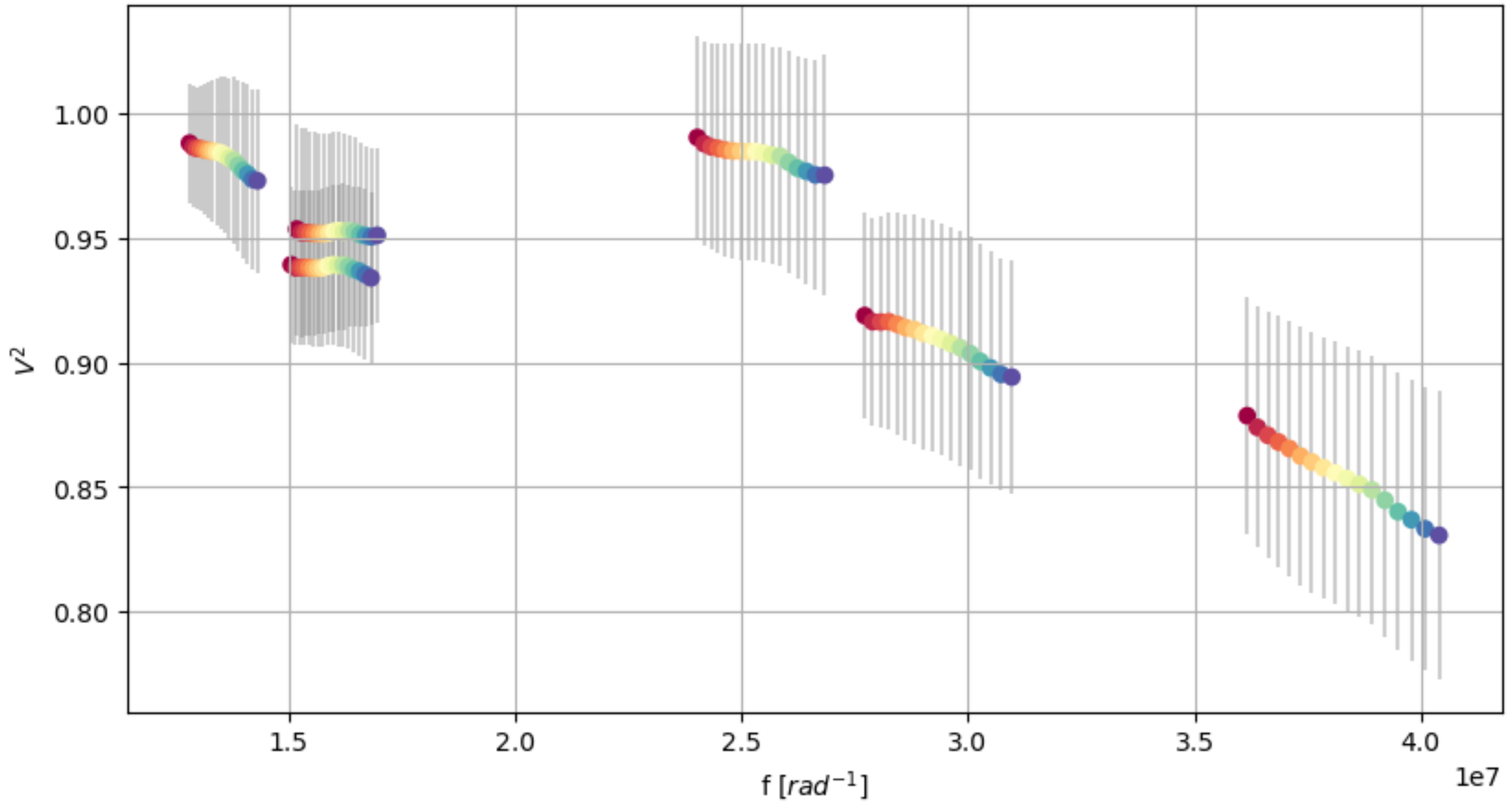
Observations

- **MATISSE (L-band):**
    - 4 observations
        - 3 in 2021
        - 1 in 2022
- We also have **PIONIER** and **GRAVITY** observations.

MATISSE

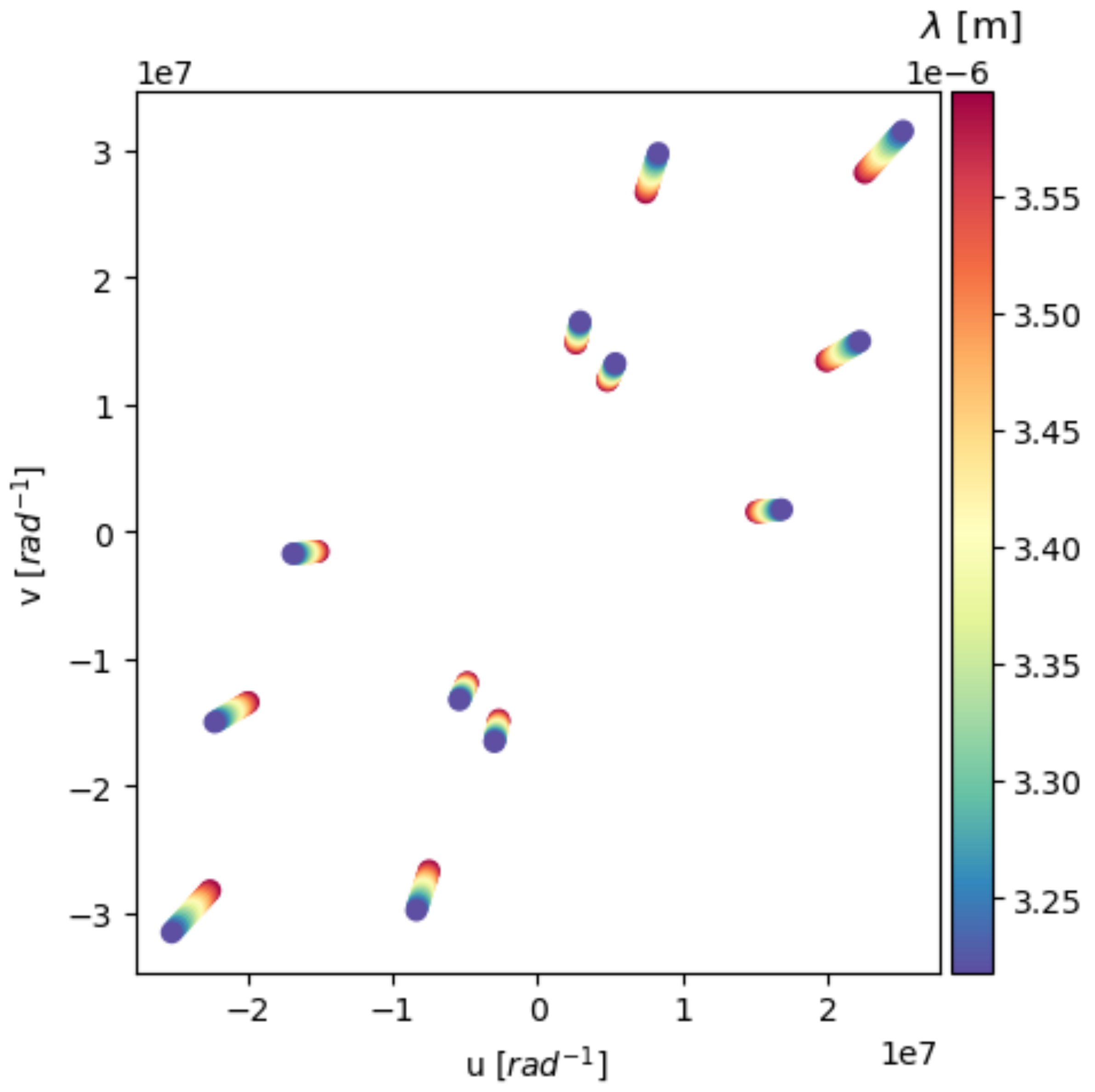
Date	Baselines	Seeing (")	Tau_0 (ms)
08/01/2021	UTs	0.85	6.03
16/01/2021	large medium	0.55	5.60
28/01/2021	small	0.56	8.28
14/10/2022	small	0.67	7.5

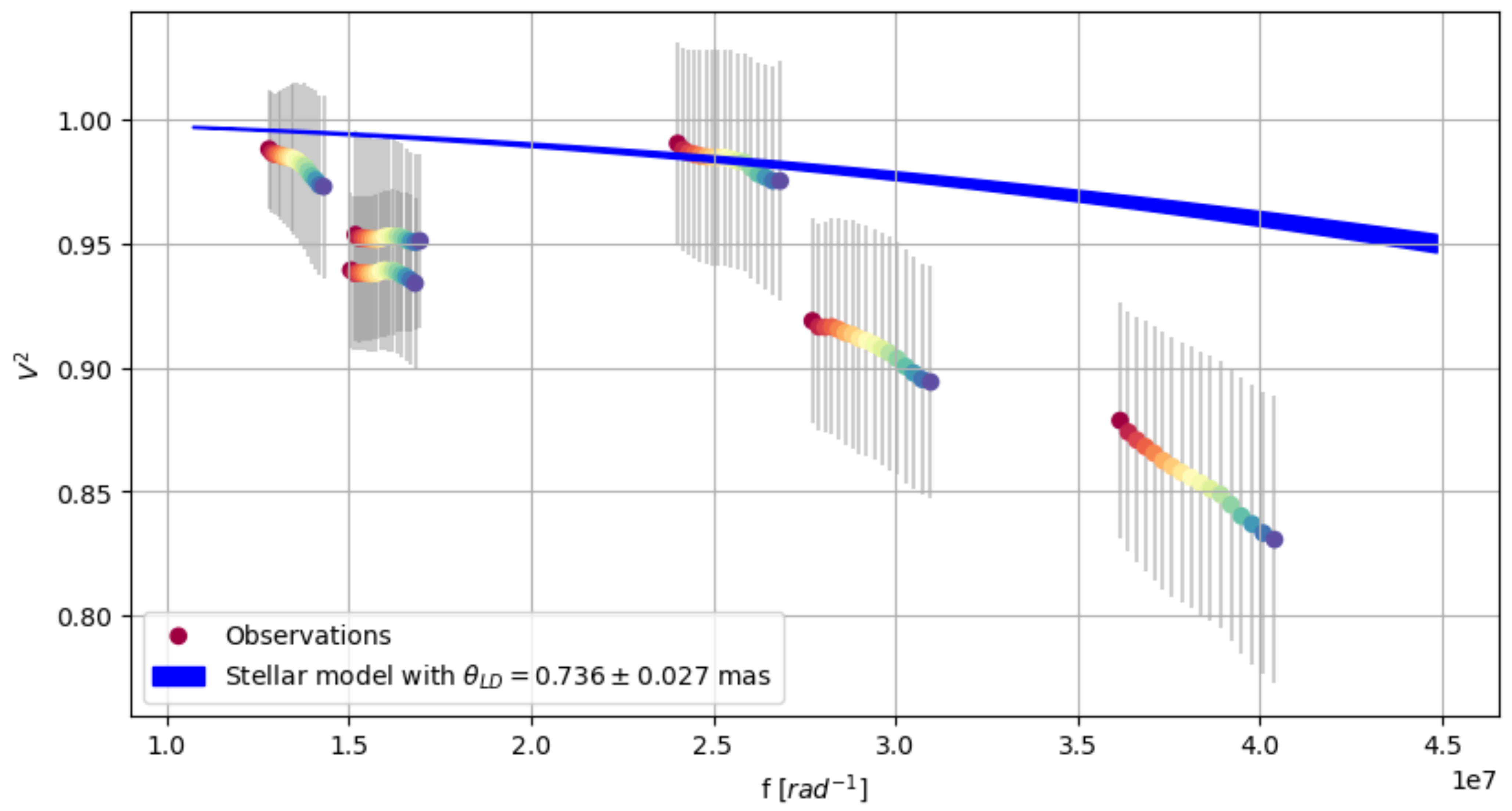




A resolved object around Beta Pic

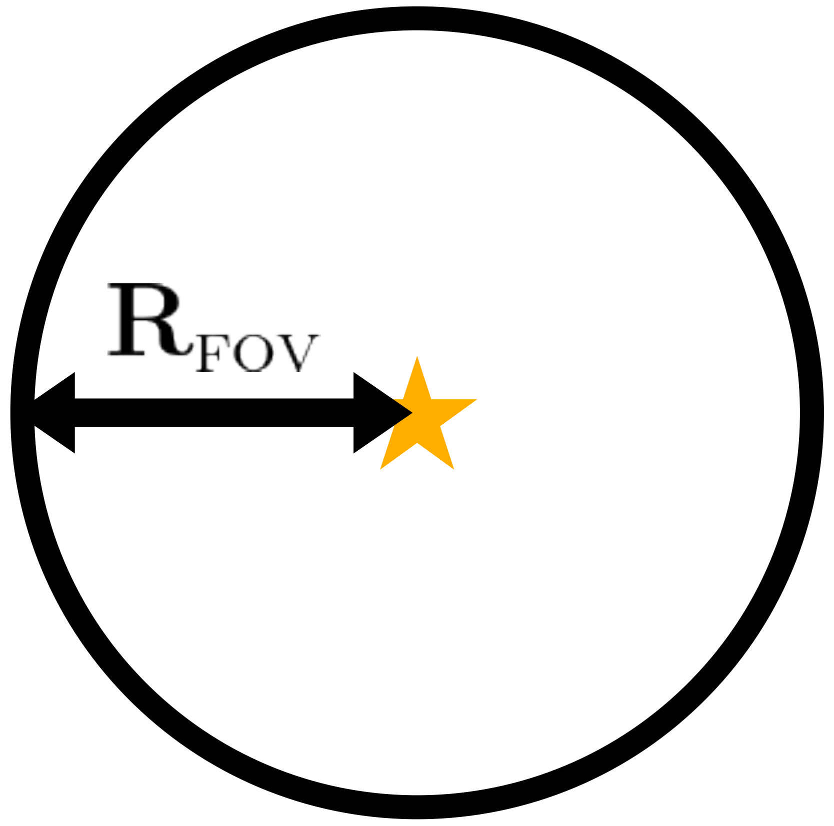
- Visibility **deficit** with respect to the stellar visibility.





$$\mathbf{R}_{\mathrm{FOV,UT}} \approx 0.85\ \mathrm{AU}$$

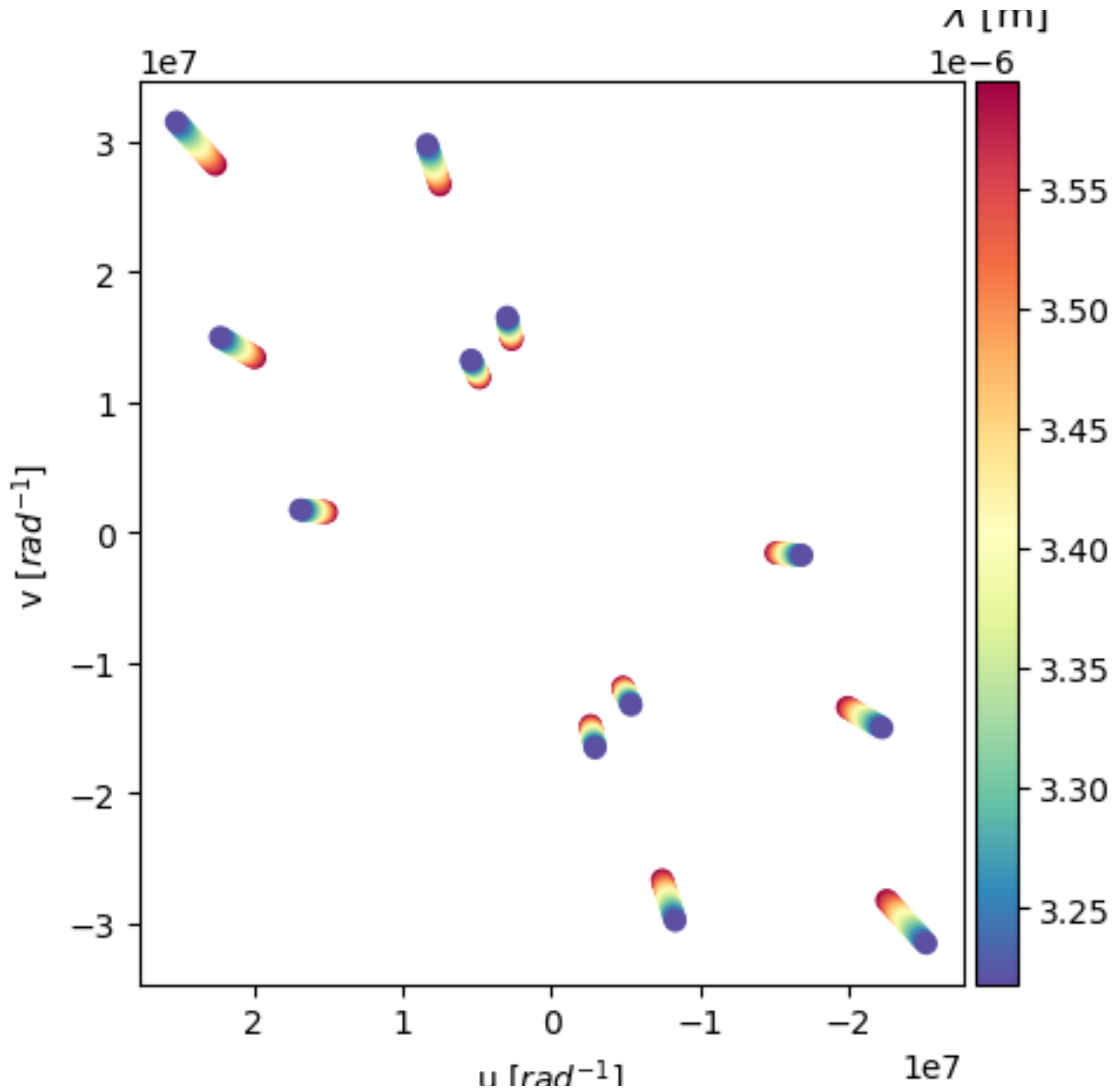
$$\mathbf{R}_{\mathrm{FOV,AT}} \approx 3.5\ \mathrm{AU}$$

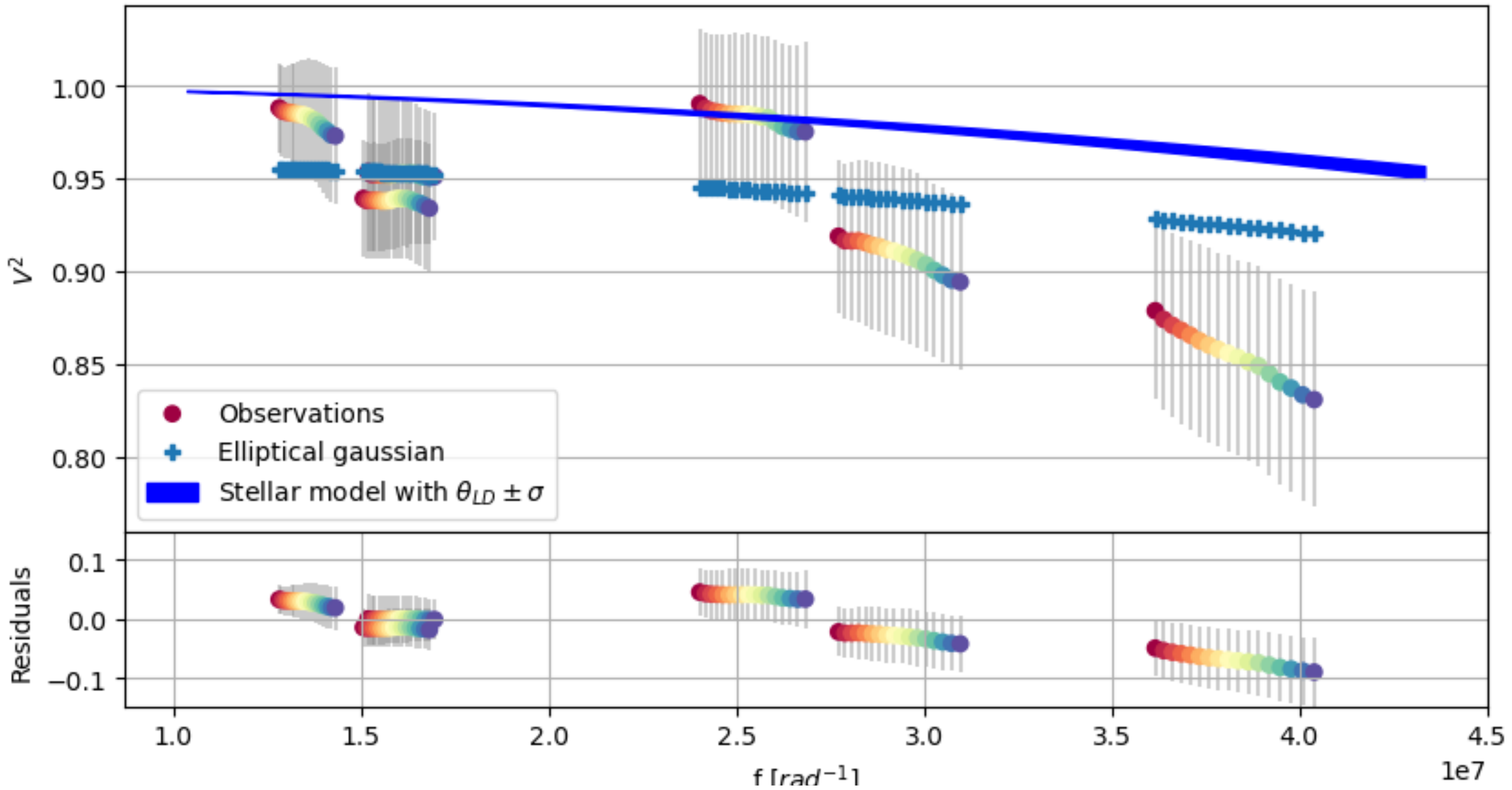


Homogeneous dust

MATISSE

- Close to **null residuals**
- A circumstellar emission is **detected.**
- Absil et al. 2006, Ertel et al. 2014, etc.

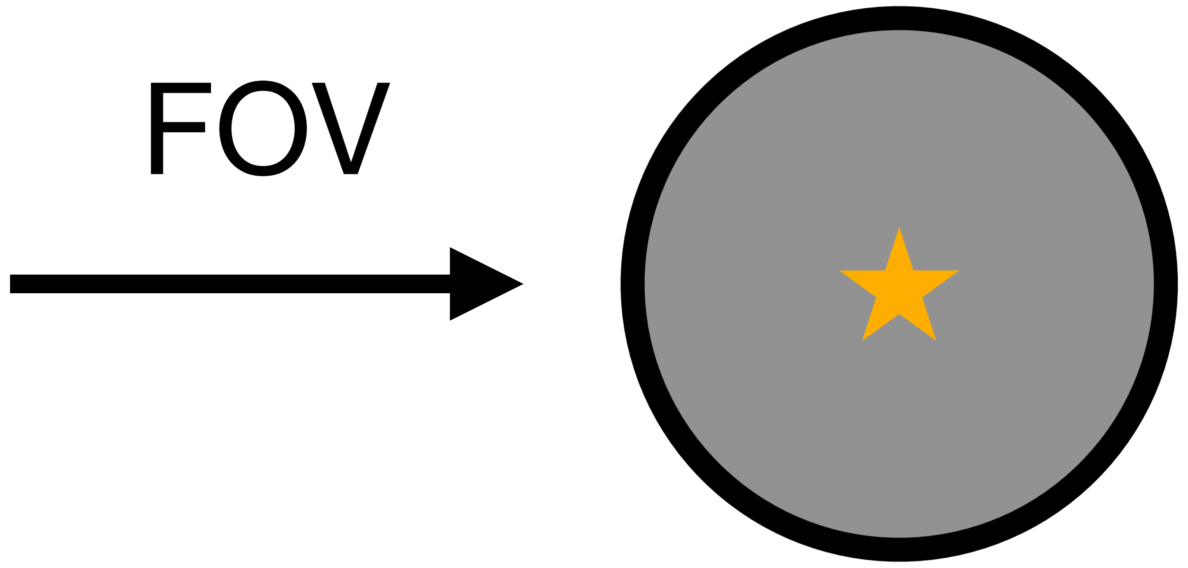




$$V_{obs}^2 = (1 - 2f)V_{\star}^2$$

$$f = 2.09 \pm 0.38\%$$

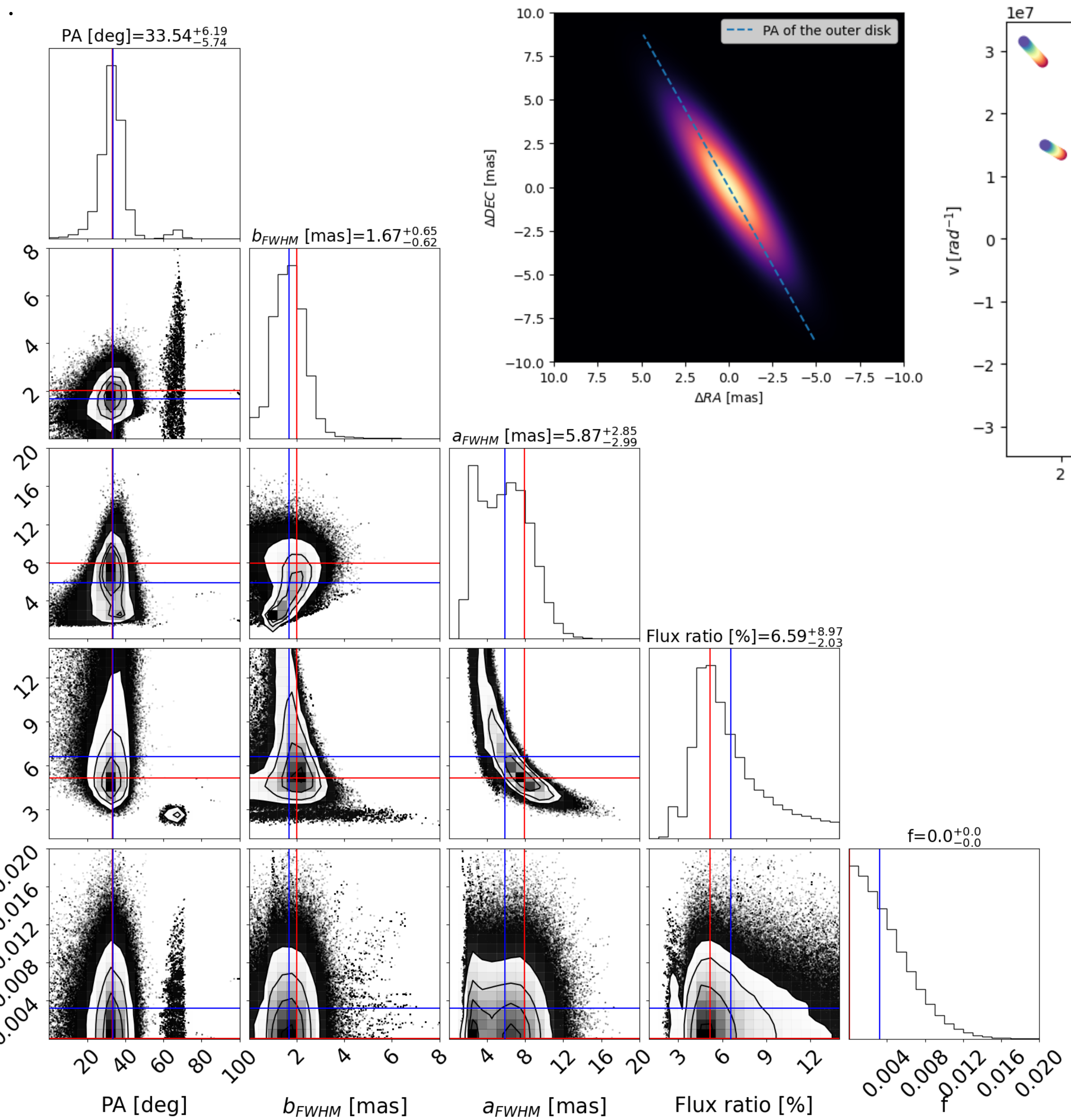
Year	Flux ratio [%]	χ^2	χ^2_r
08/01/2021	2.09 ± 0.38	73	12.2
16/01/2021	1.93 ± 0.27	17	2.8
28/01/2021	2.49 ± 0.08	4.6	0.77
14/10/2022	1.28 ± 0.37	111	18.5

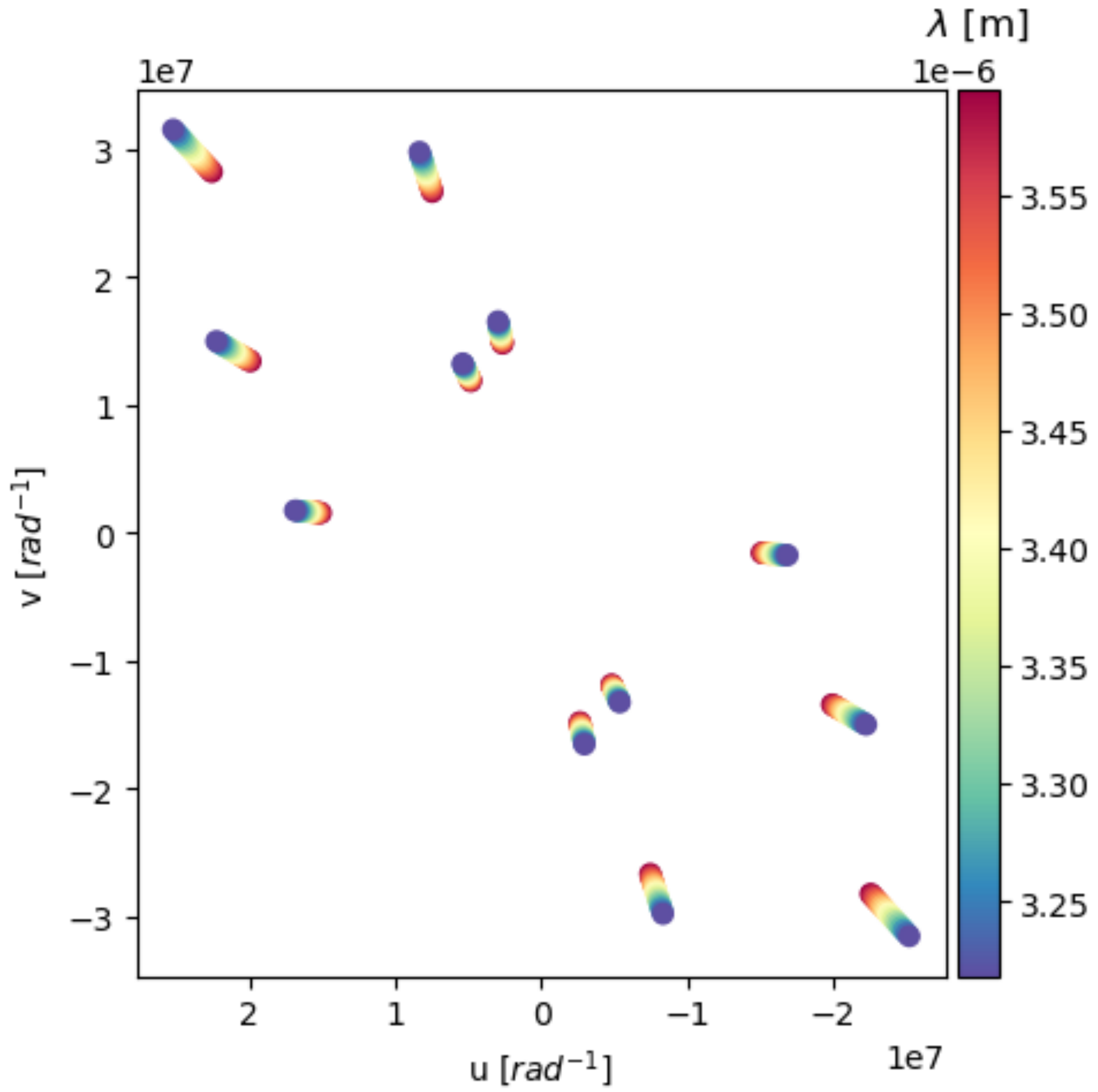


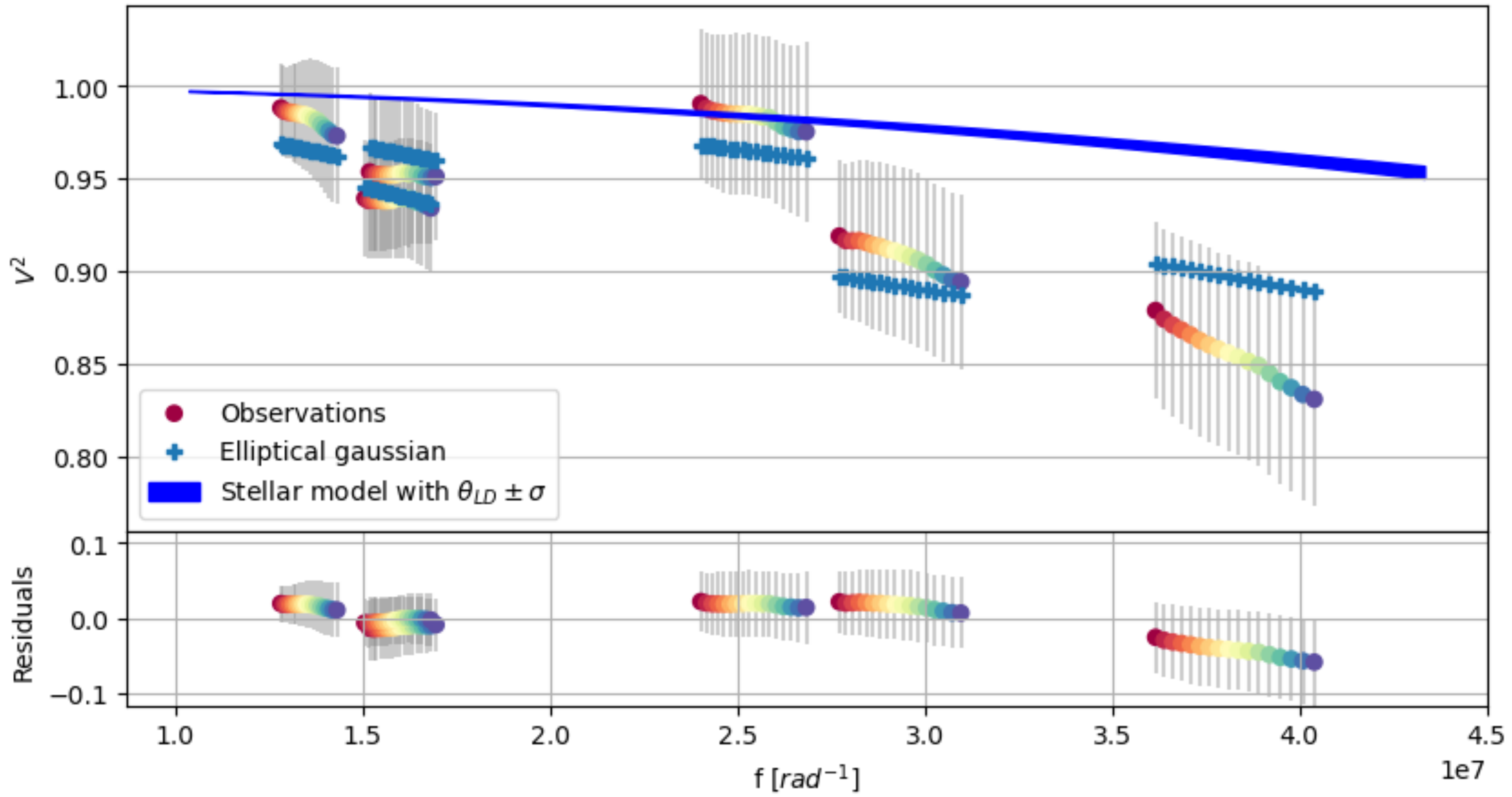
2D elliptical gaussian model

MATISSE

- Based on **zodiacal dust models** by Giese et al. (1986)







PA [deg]	$\mathbf{a}_{FWHM}$ [AU]	$\mathbf{b}_{FWHM}$ [AU]	**Flux ratio** [%]
$34.0^{+32.5}_{-3.9}$	$0.114^{+0.055}_{-0.058}$	$0.032^{+0.013}_{-0.012}$	$6.5^{+9.0}_{-2.0}$

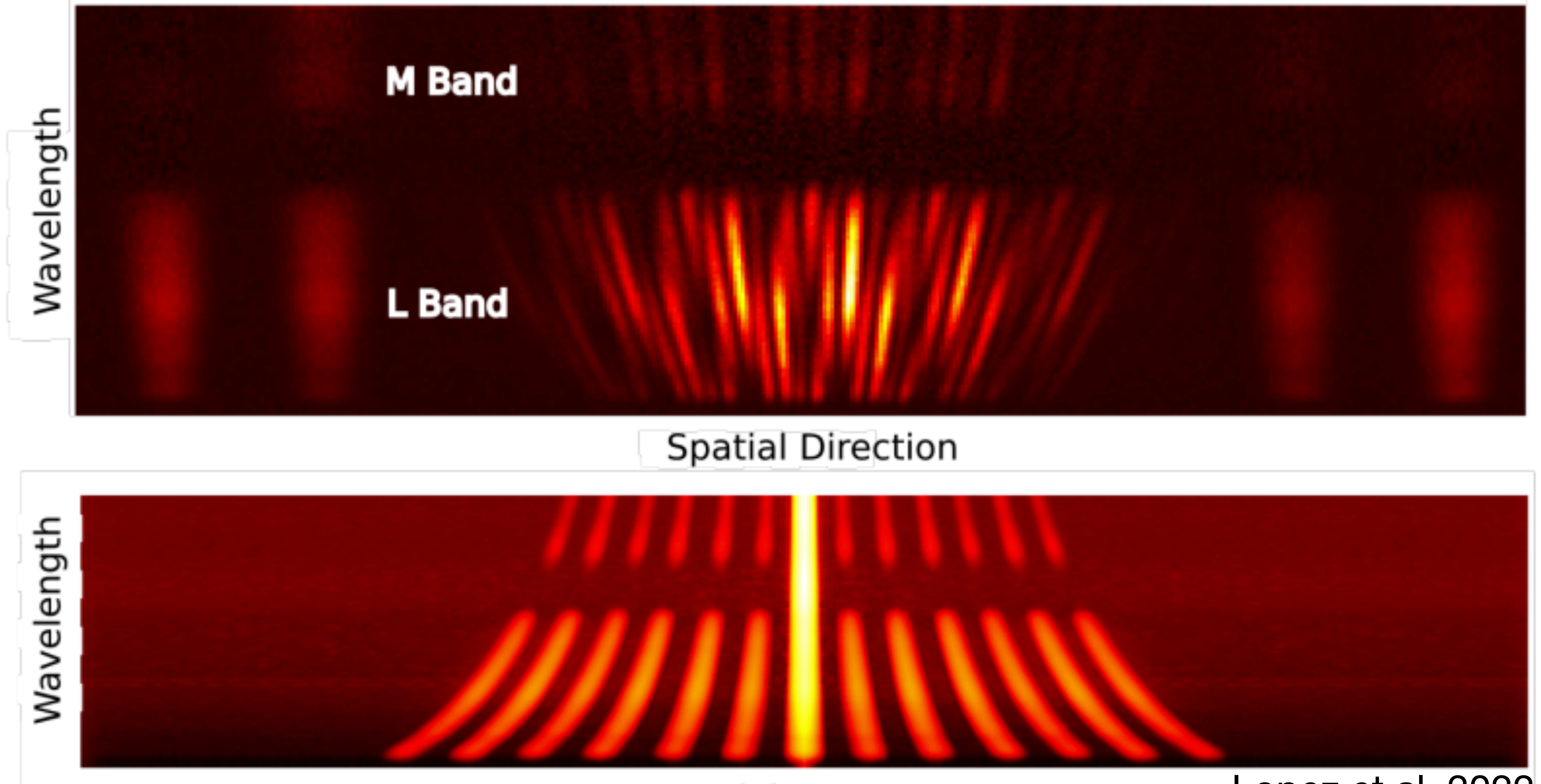
$$\chi^2 = 24$$

$$i_{tilt} = 70.9 \pm 9.0 \text{ deg}$$

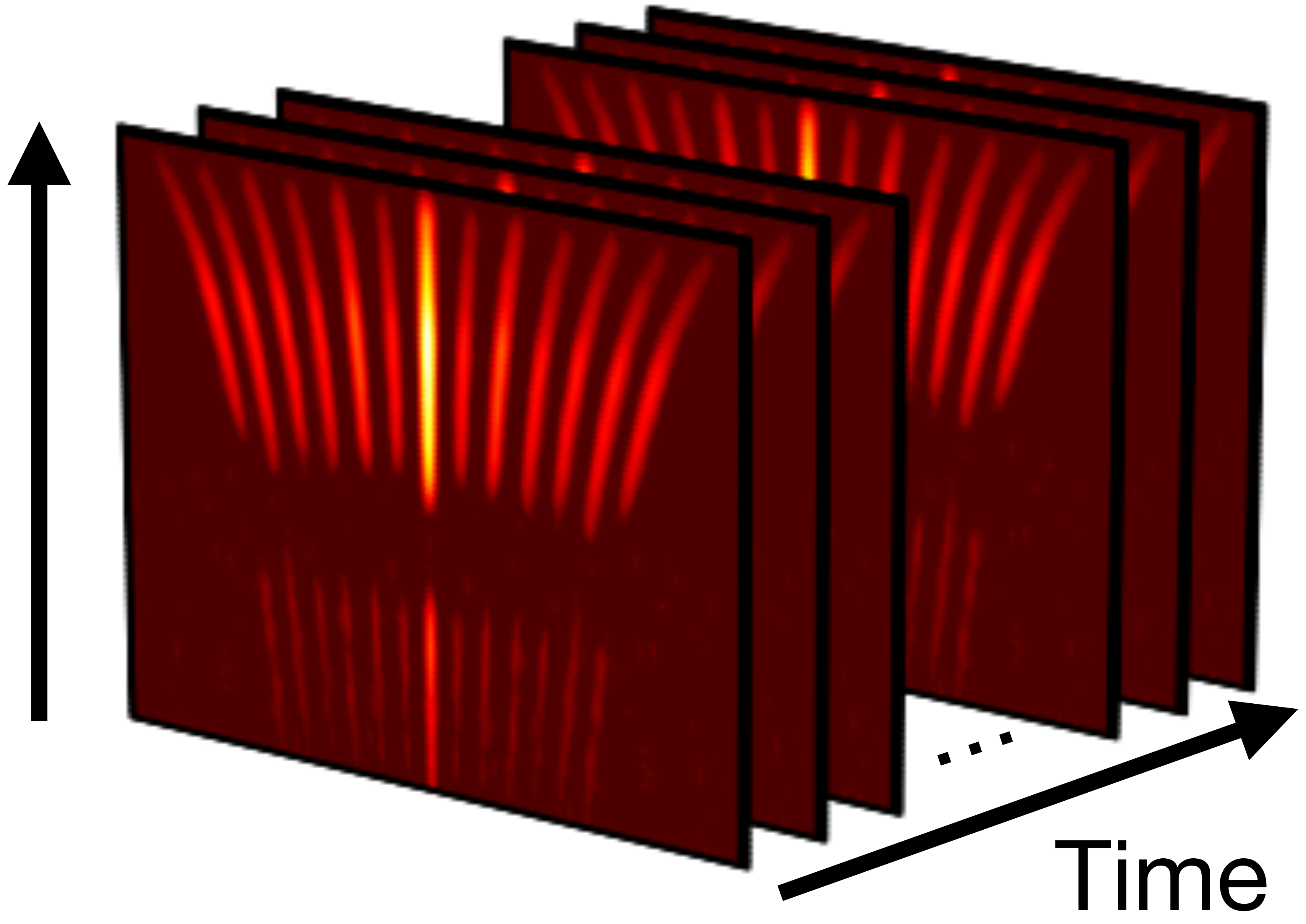
Correlations in MATISSE data

Intermediate files

- **Photometry** frames
- **Correlated flux** frames
- This is the last step where observations are handled **frame by frame.**
- We **propagate** the correlation matrix to the visibilities.



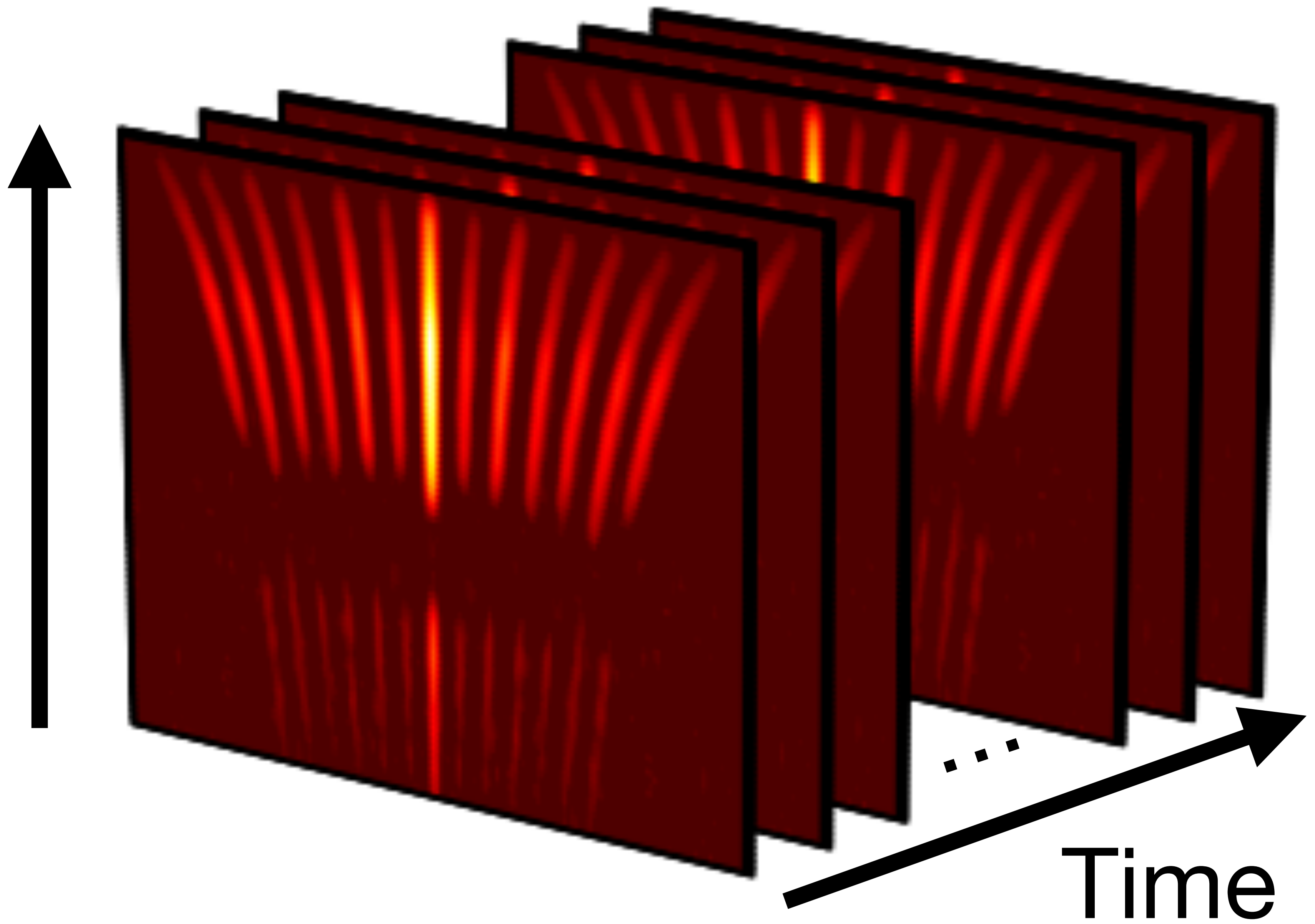
Lopez et al. 2022

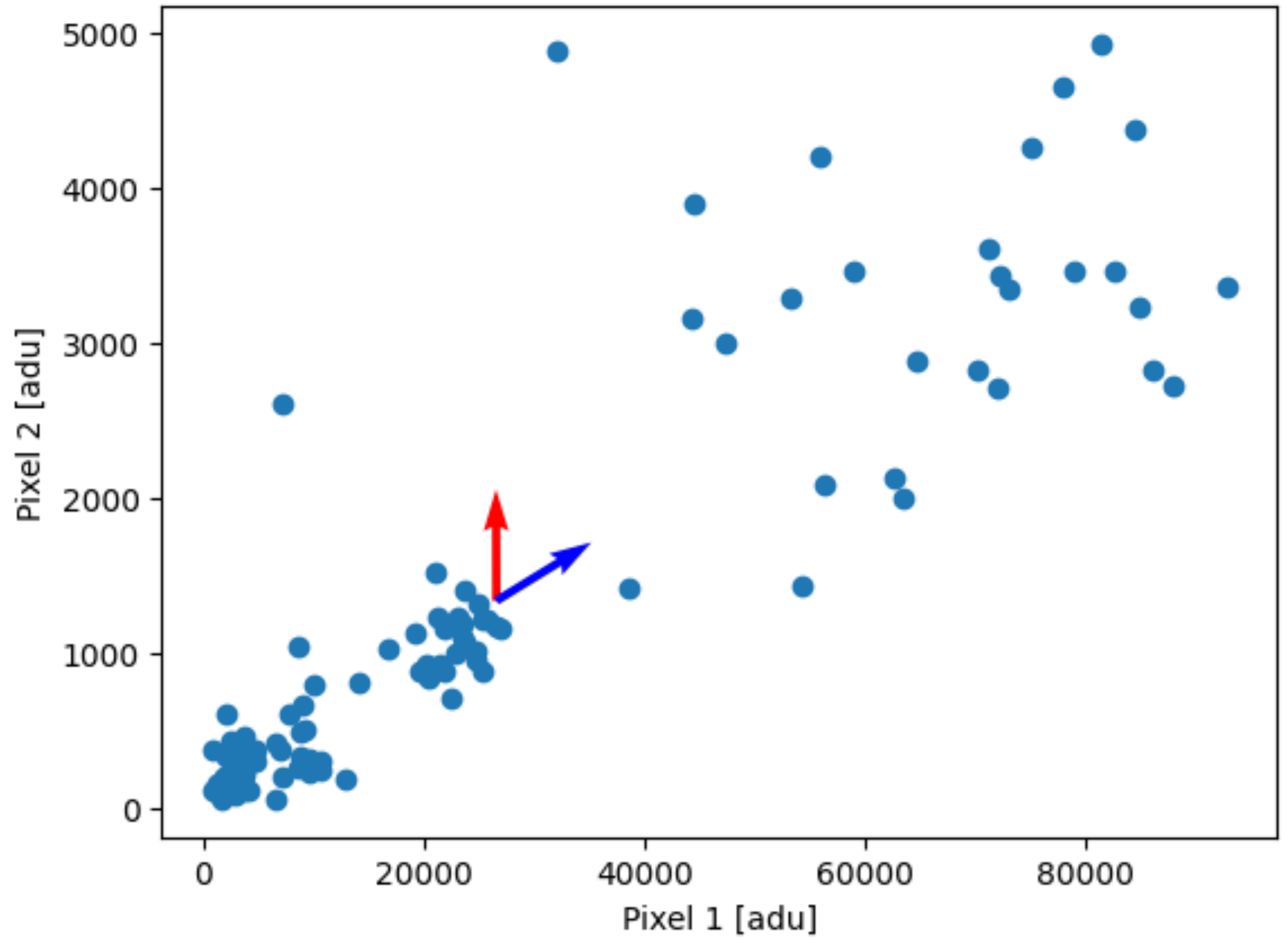


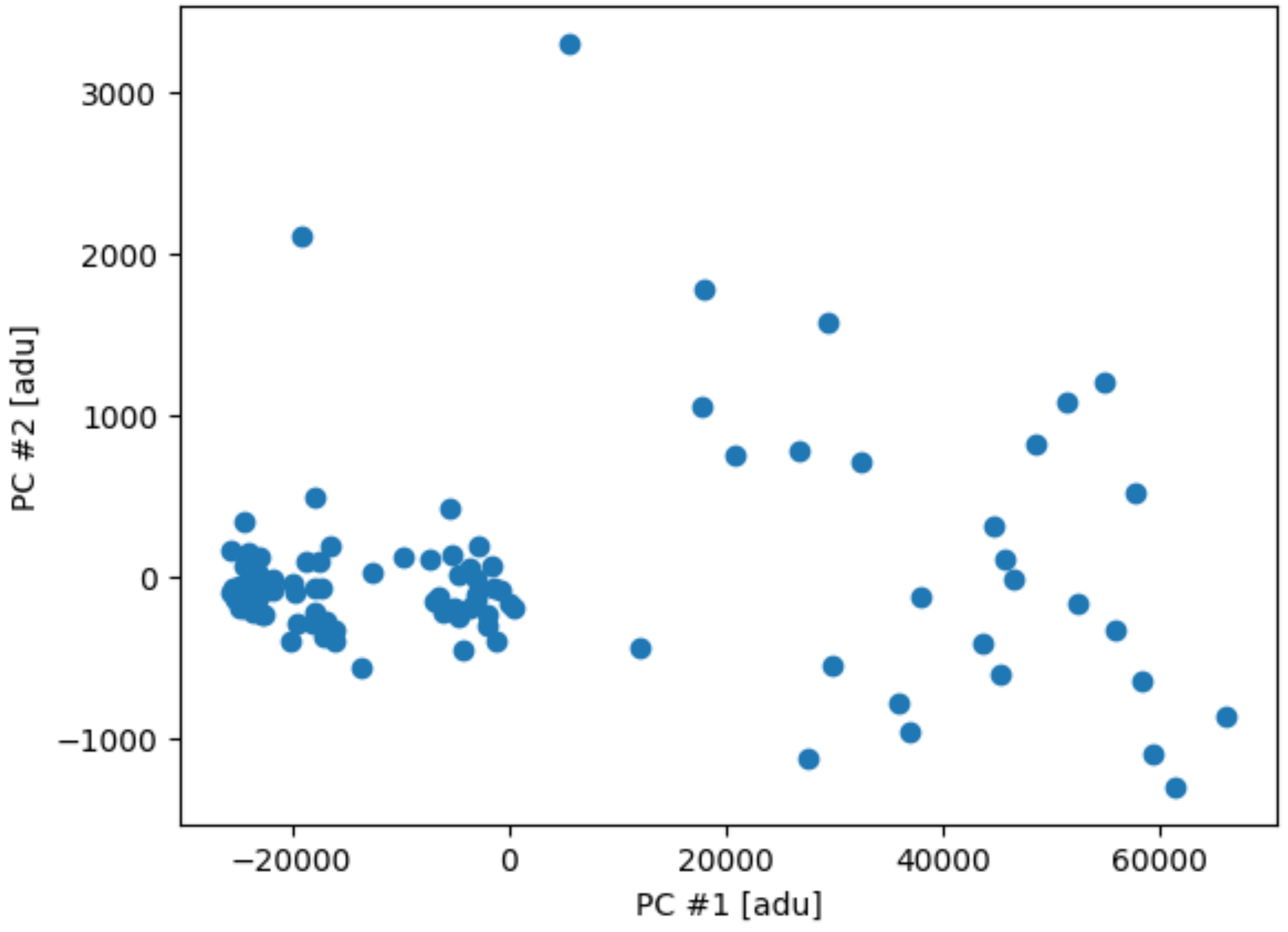
$$V_{ij}^2(\lambda) = \frac{C_{ij}^2(\lambda)}{\sum_x \left\langle P_{ij}(x,\lambda,t)\right\rangle_t} \qquad C_{ij}^2(\lambda) = \sum_u \left\langle |I(u,\lambda,t)|^2 - \beta \right\rangle_t$$

Propagating the correlation matrix

- 1. Deriving the probability distribution that each pixel follows.
    - **PCA**

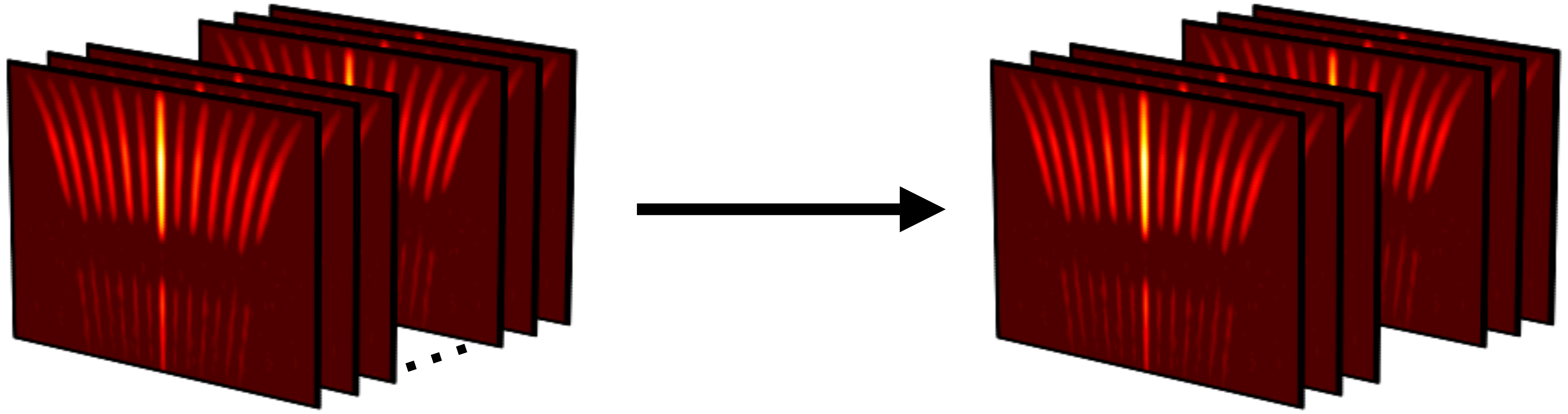






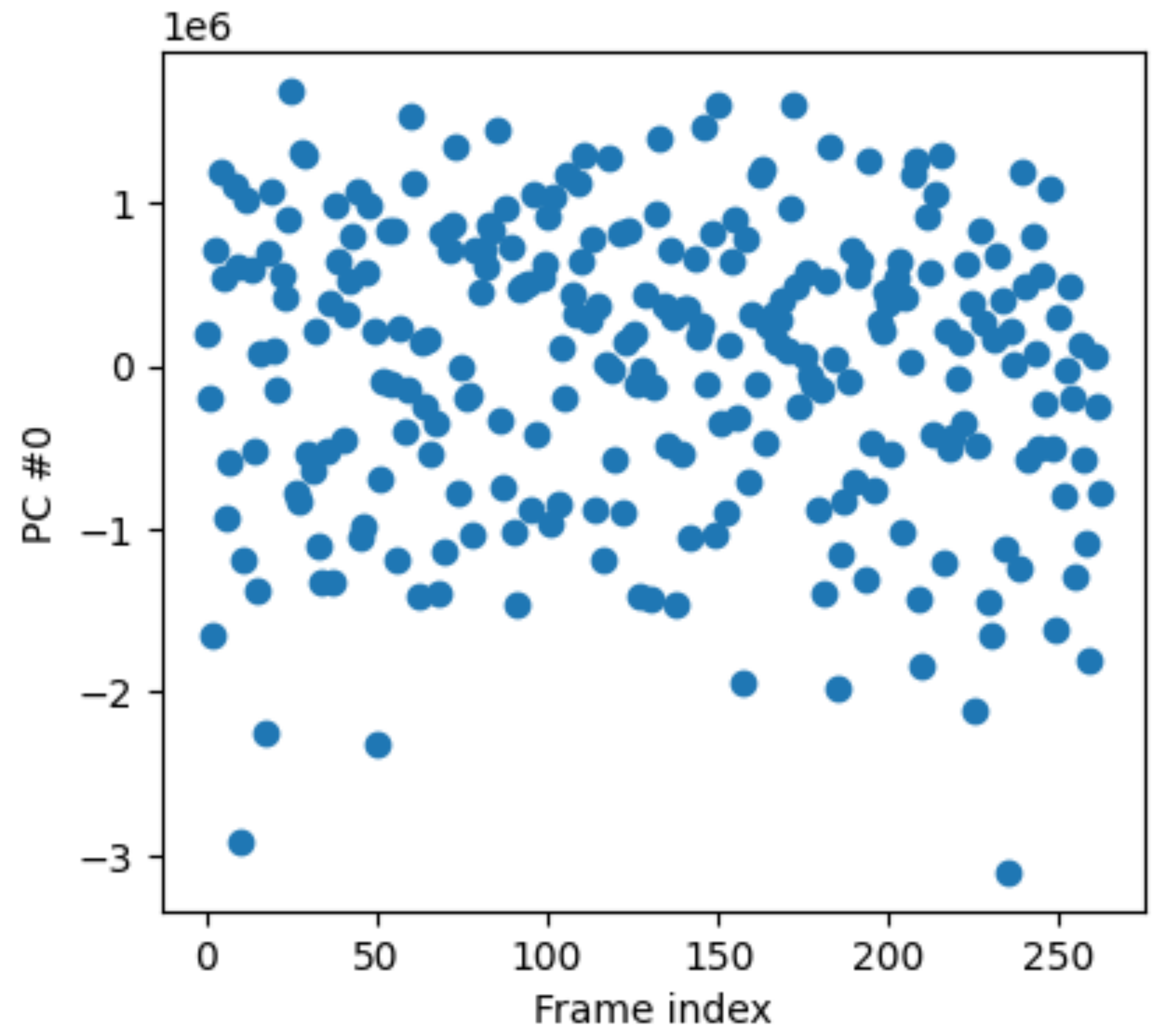
Propagating the correlation matrix

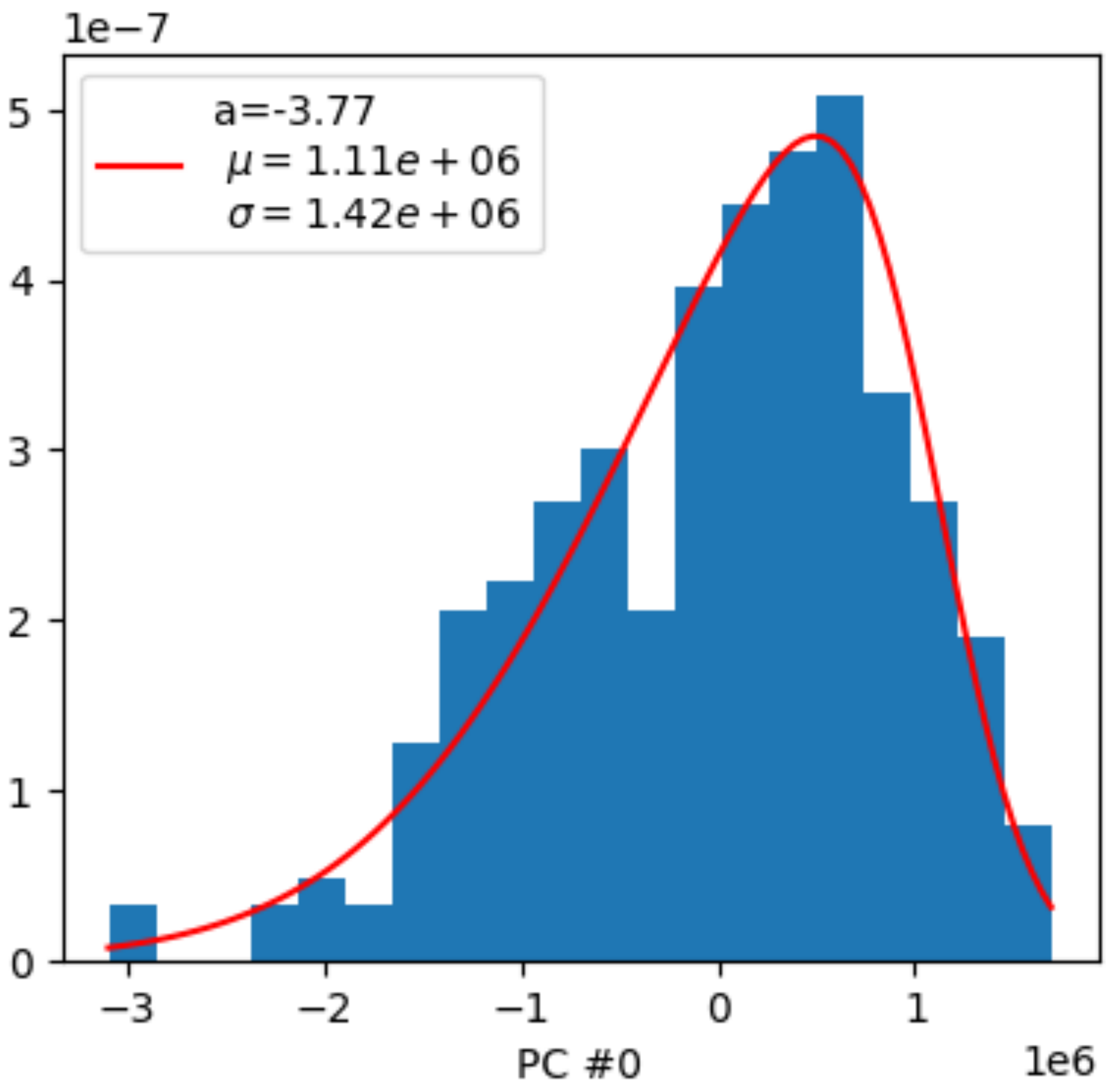
- 2. Generating new synthetic frames that follow the same distribution.



Real frames

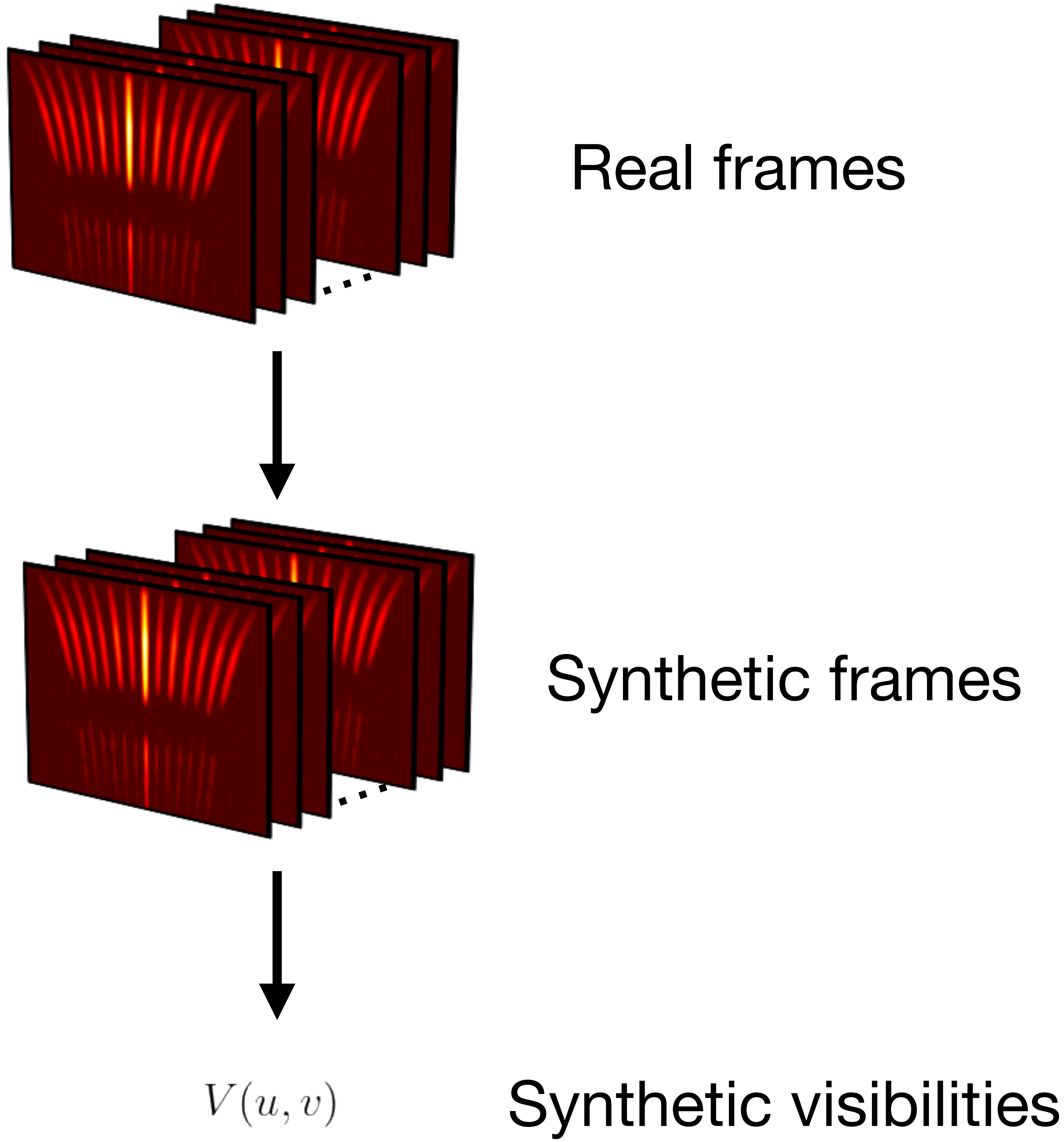
Synthetic frames



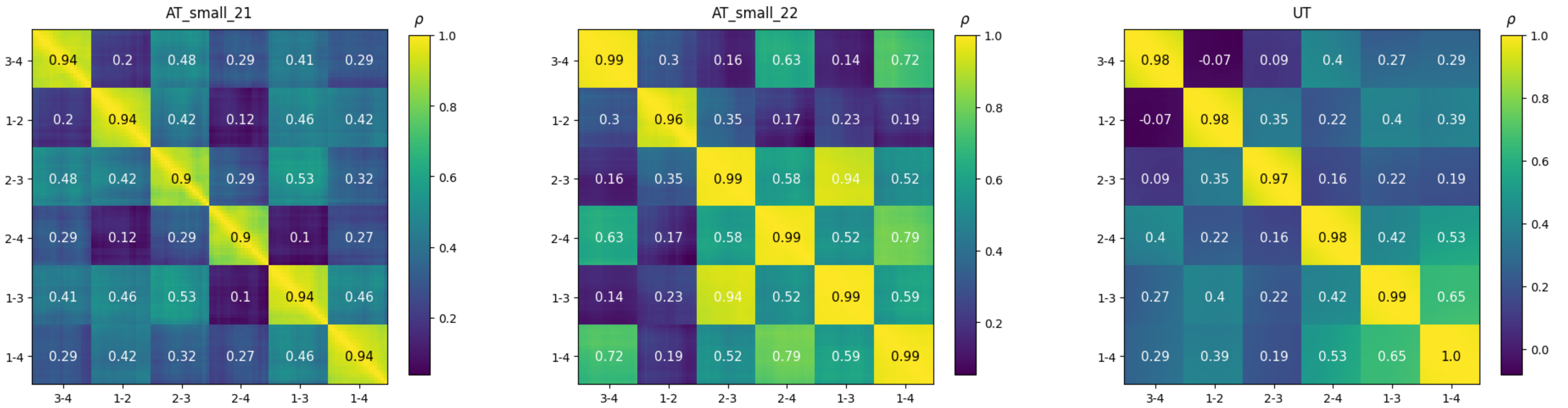


Propagating the correlation matrix

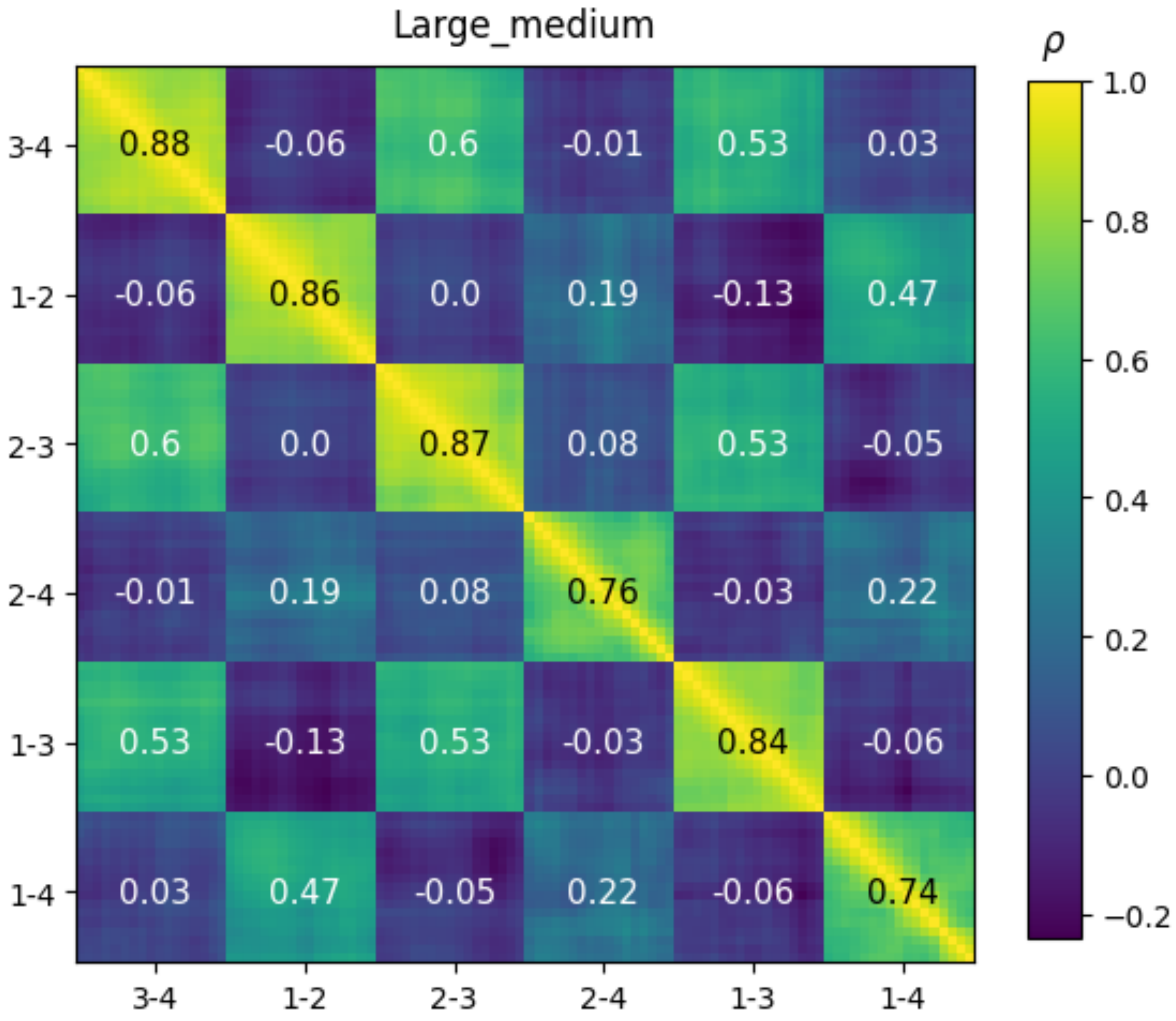
- 1. Deriving the probability distribution that each pixel follows.
- 2. Generating new synthetic frames that follow the same distribution.
- **3**. Processing with DRS to obtain visibilities.
- **4**. Calculating correlation matrices from the set of visibilities.



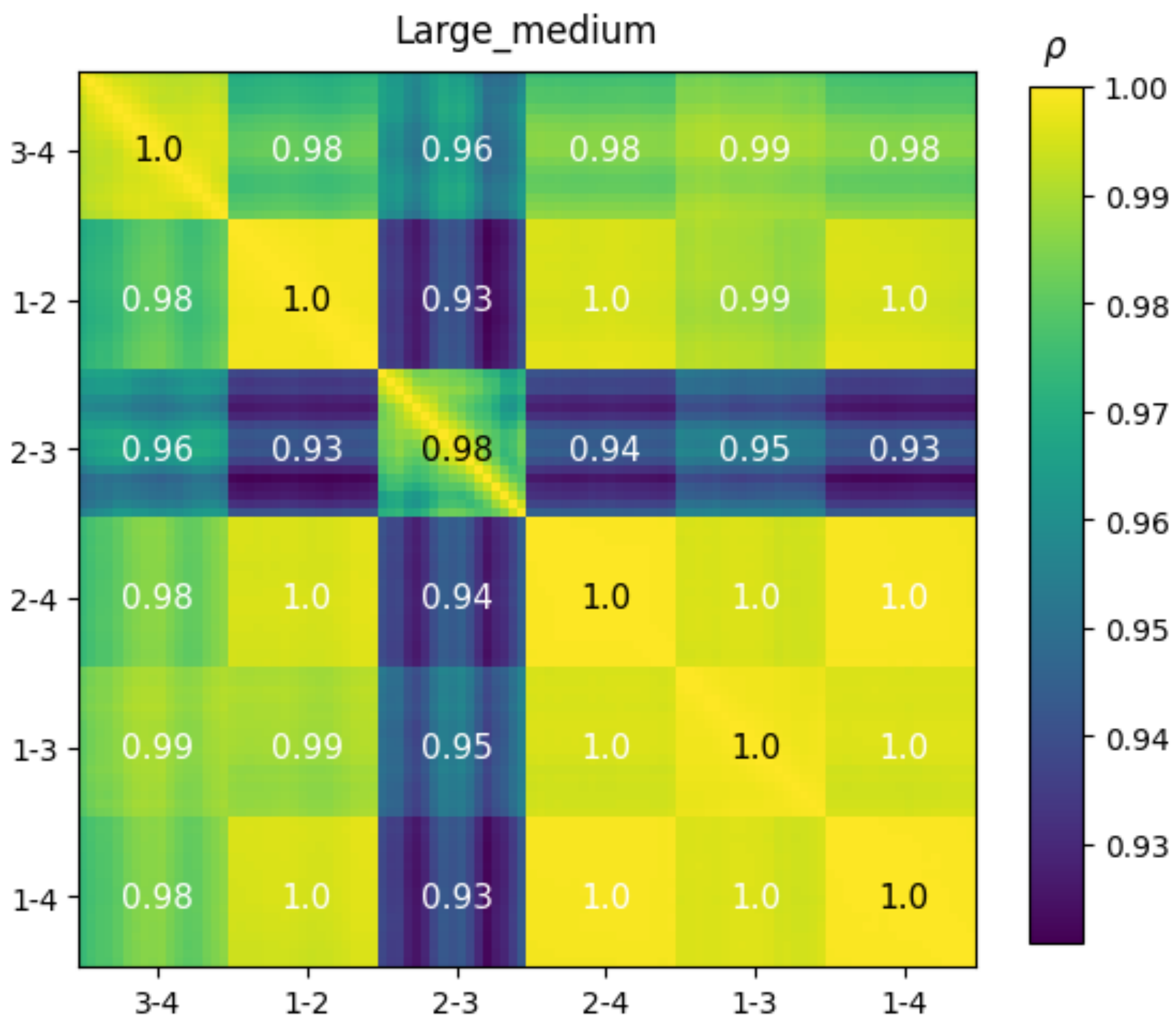
Results: Correlation matrices



Impact of calibration error

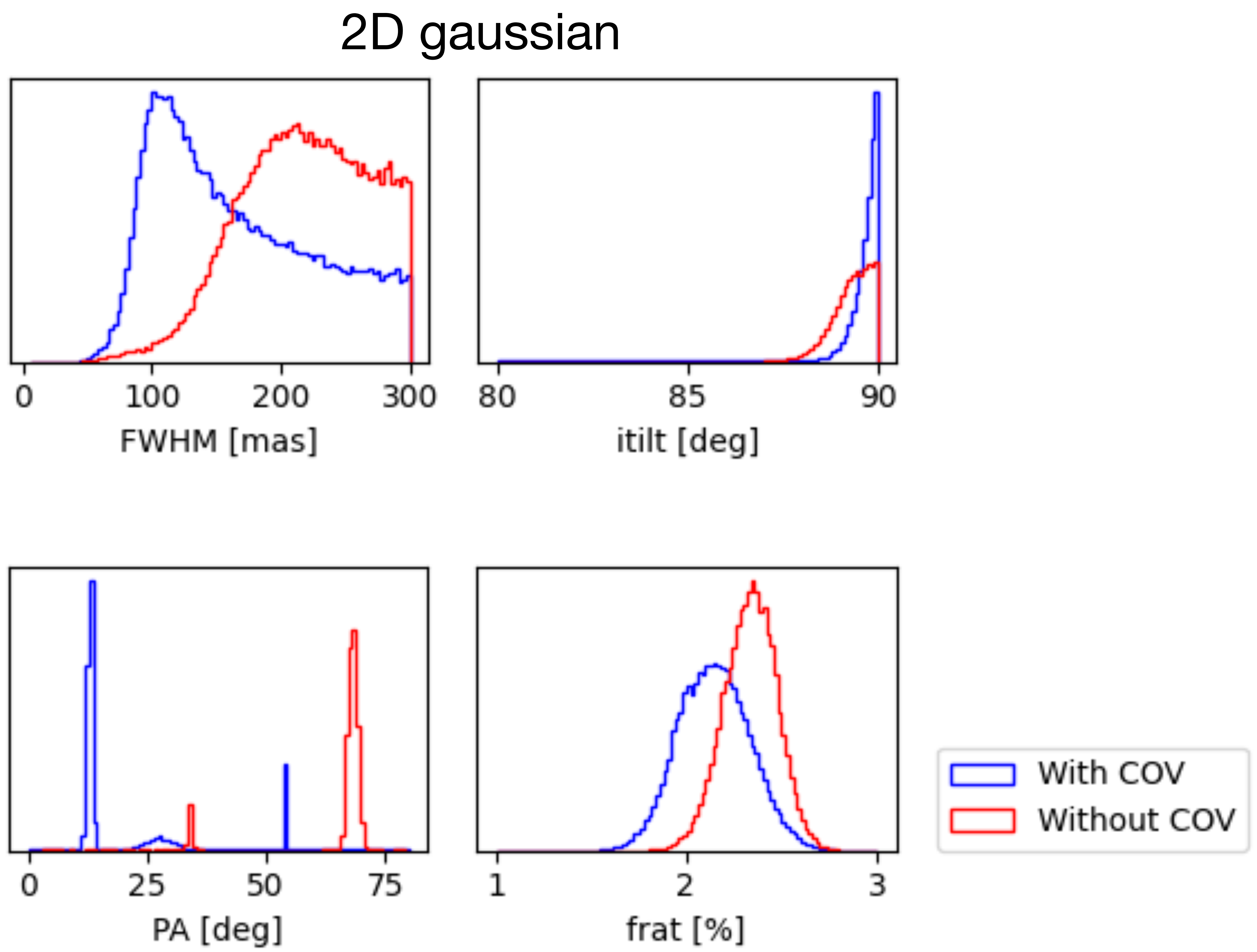


Propagating the error on the angular size of the calibrator.



Results: Impact on exozodi model fitting

- Impact on the median value of the distribution
- Impact on the shape/ variance of the distribution.
- Especially important for low u-v coverage



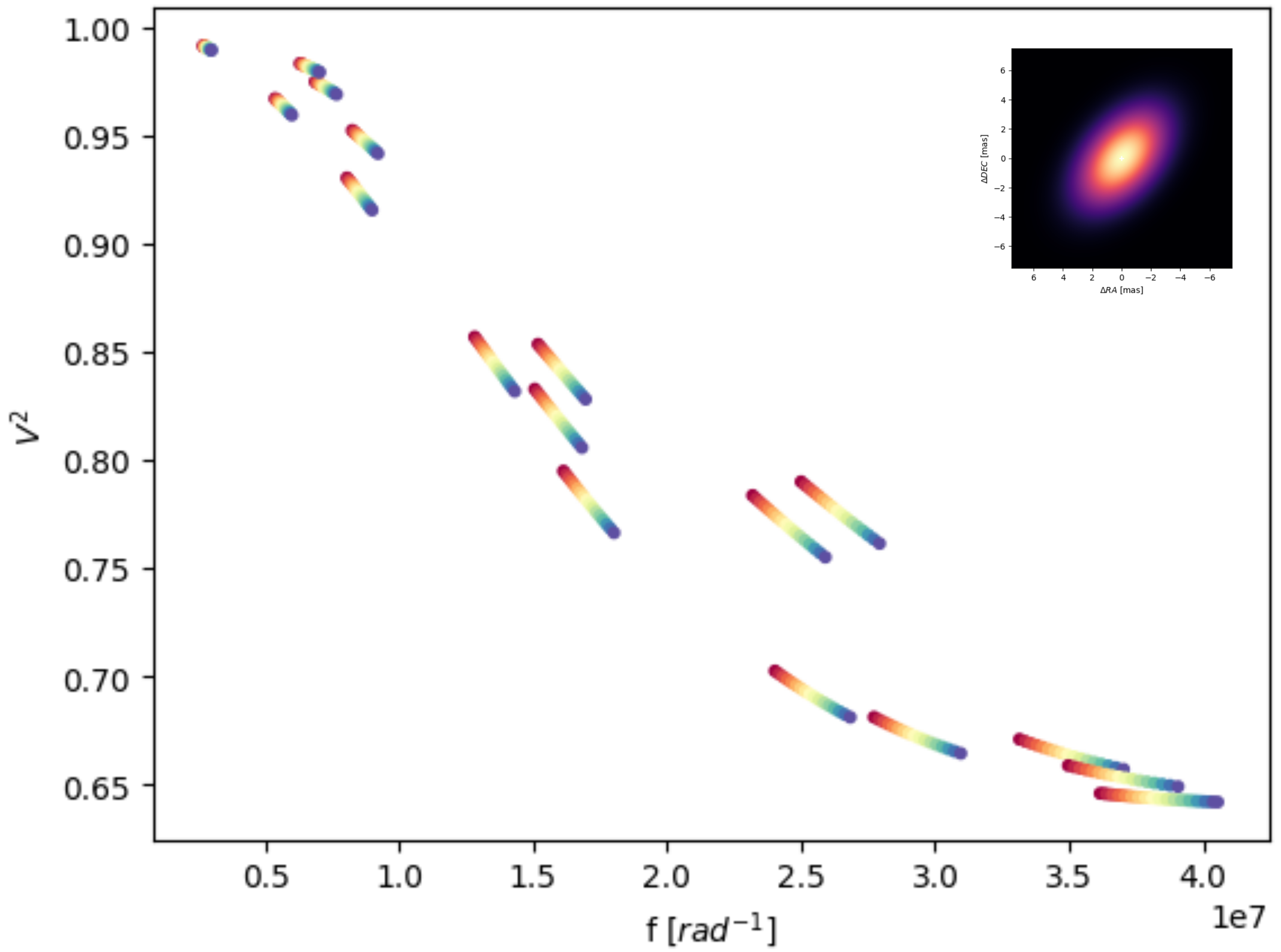
Results: Impact on model fitting

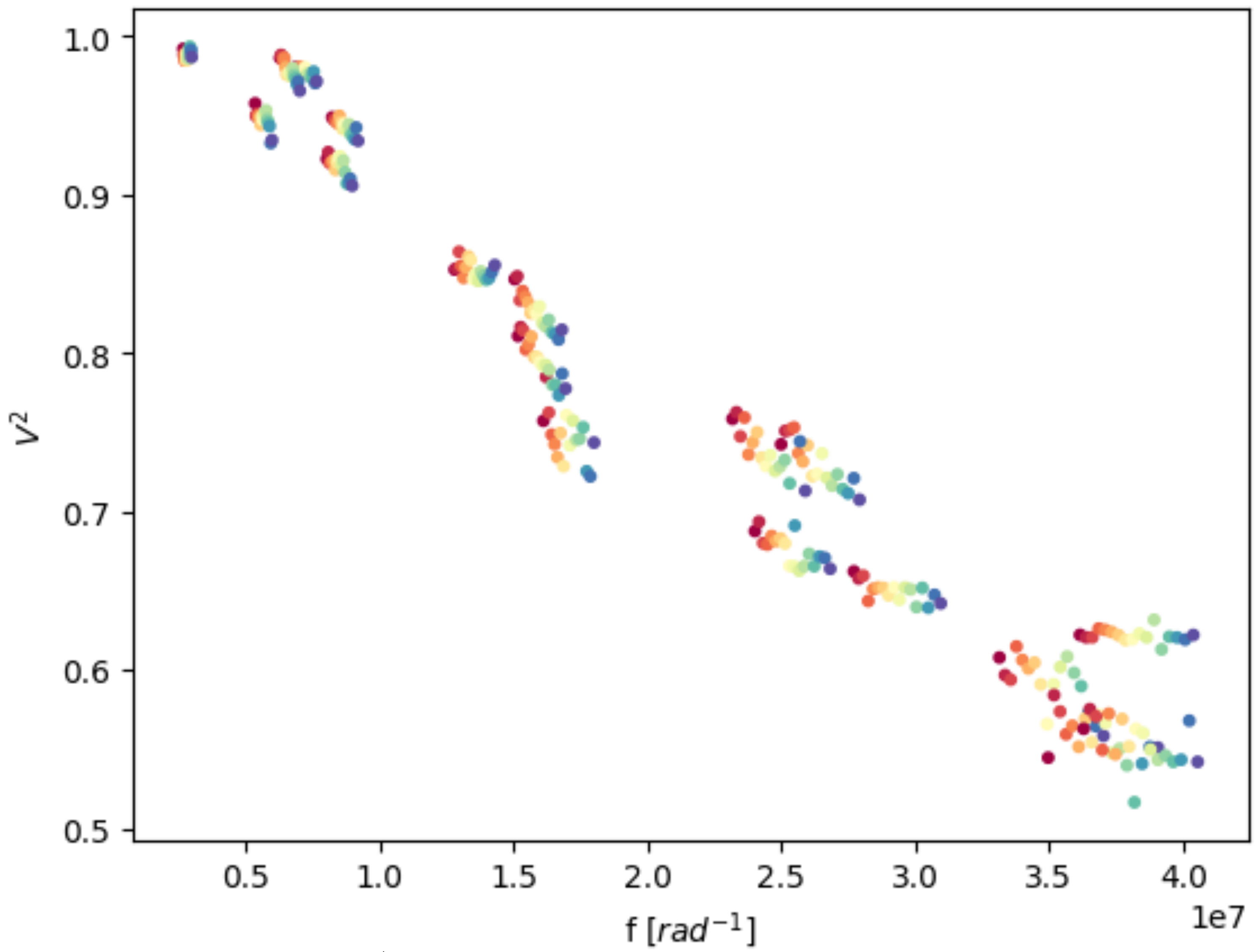
- We generate model **visibilities** using the covariance matrices of the real observations.

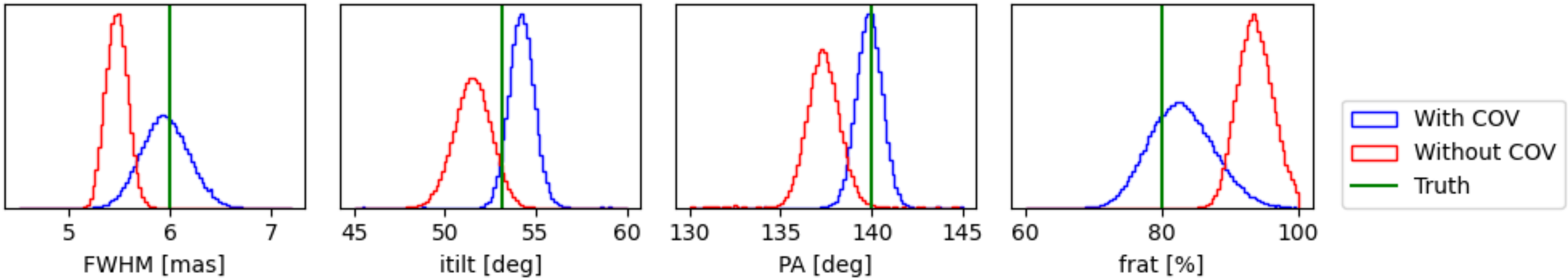
- We try to **retrieve** the input parameters in two ways:

  - Assuming the errors are independent.

  - Assuming they are correlated.

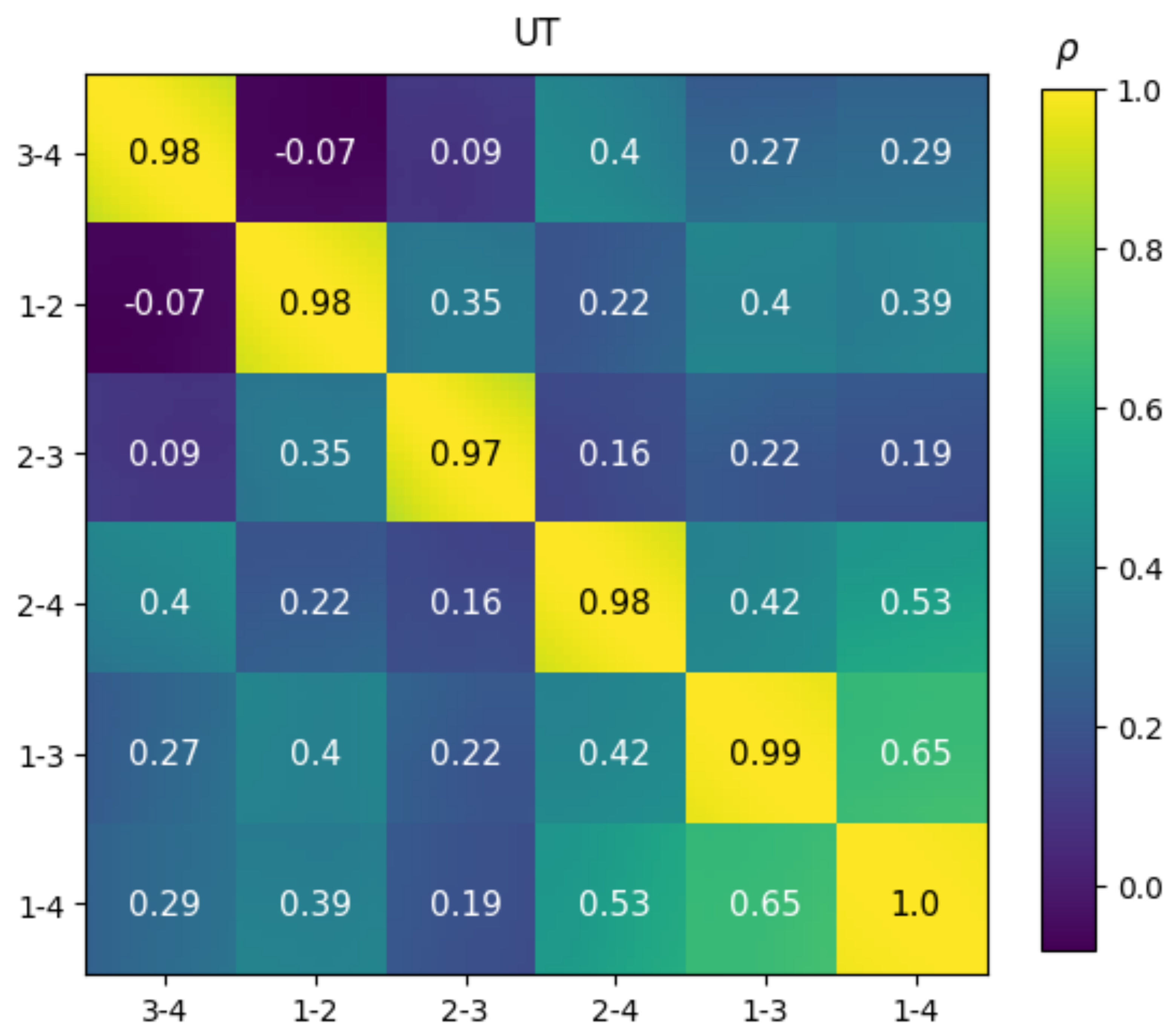






Conclusions and perspectives

- We developed a method to systematically generate correlation matrices of MATISSE data
  - Correlations have a **strong impact** on model fitting.
  - **MATISSE data might be highly correlated**, especially **between spectral channels.**
  - **Calibration induces strong correlations.**



Thank you!

Comments and questions are always appreciated