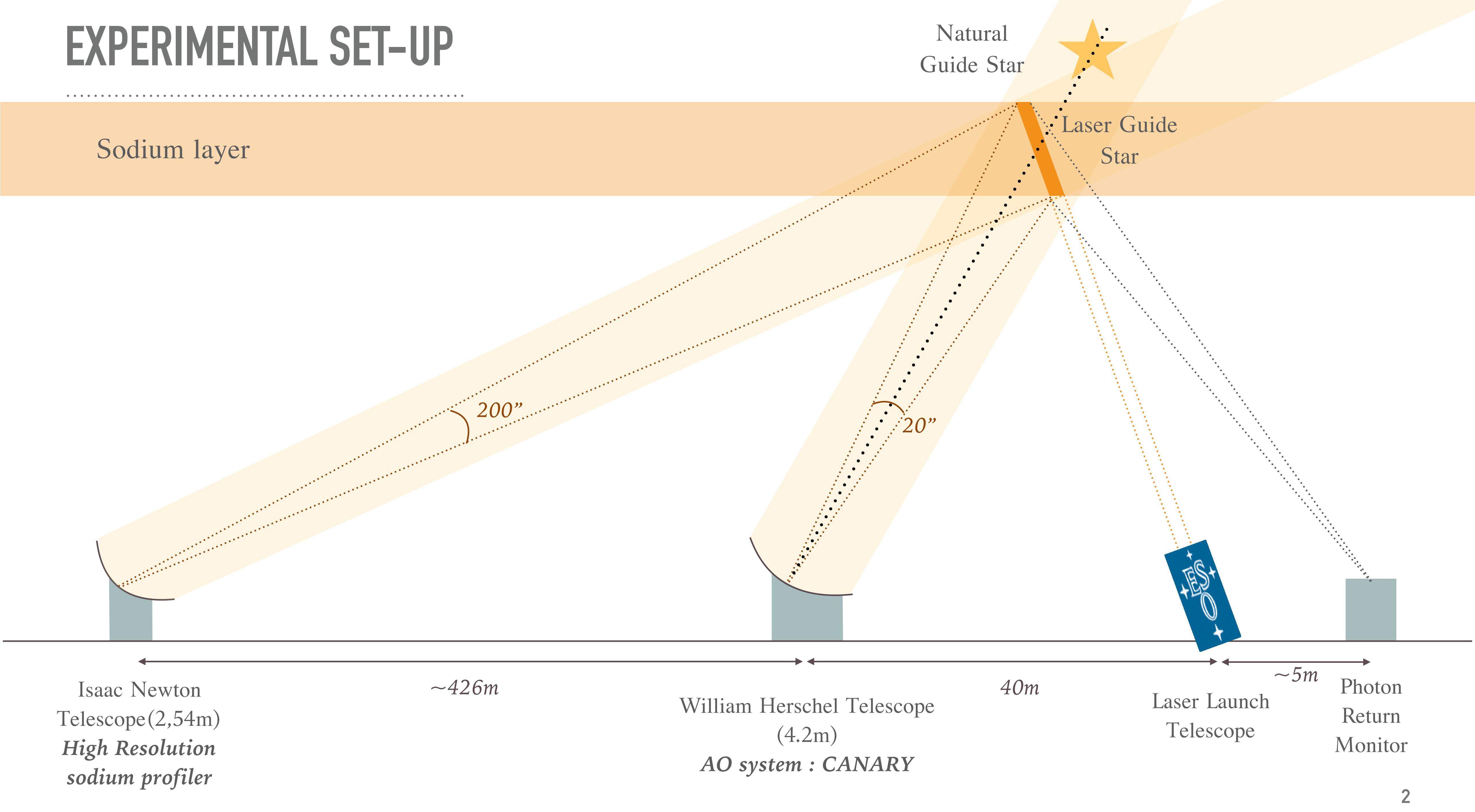




ON-SKY ELONGATED LGS WAVEFRONT SENSING USING CANARY

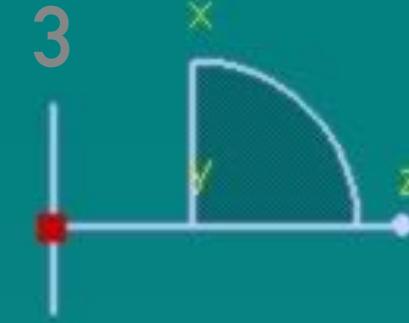
Lisa Bardou, Eric Gendron, Gérard Rousset, Damien Gratadour, Alastair Basden, Domenico Bonaccini Calia, Tristan Buey, Mauro Centrone, Fanny Chemla, Jean-Luc Gach, Deli Geng, Zoltán Hubert, Douglas J. Laidlaw, Tim Morris, Richard Myers, James Osborn, Andrew Reeves, Matthew Townson, Fabrice Vidal

EXPERIMENTAL SET-UP

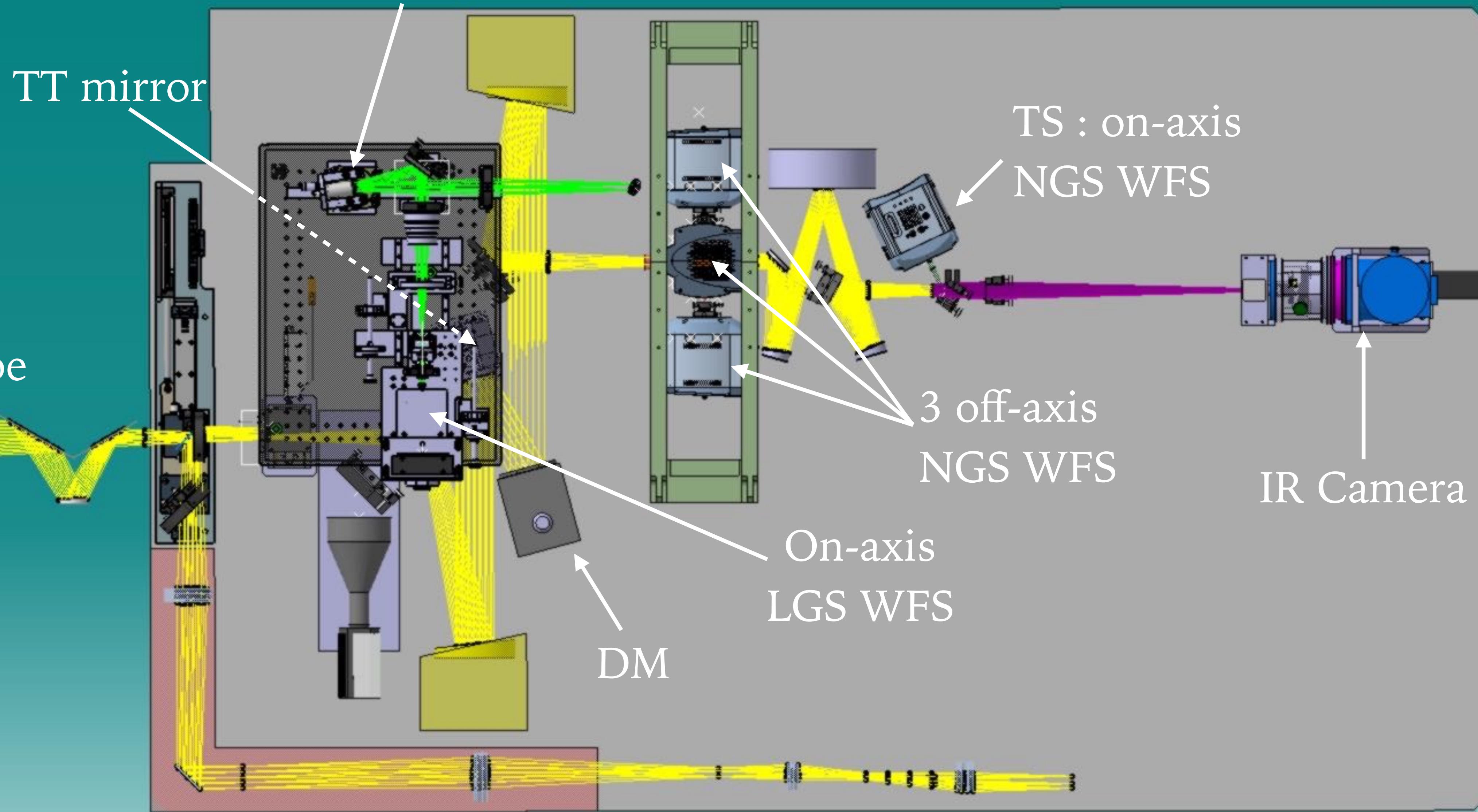


AO SET-UP

Steering mirror :
laser jitter
stabilisation

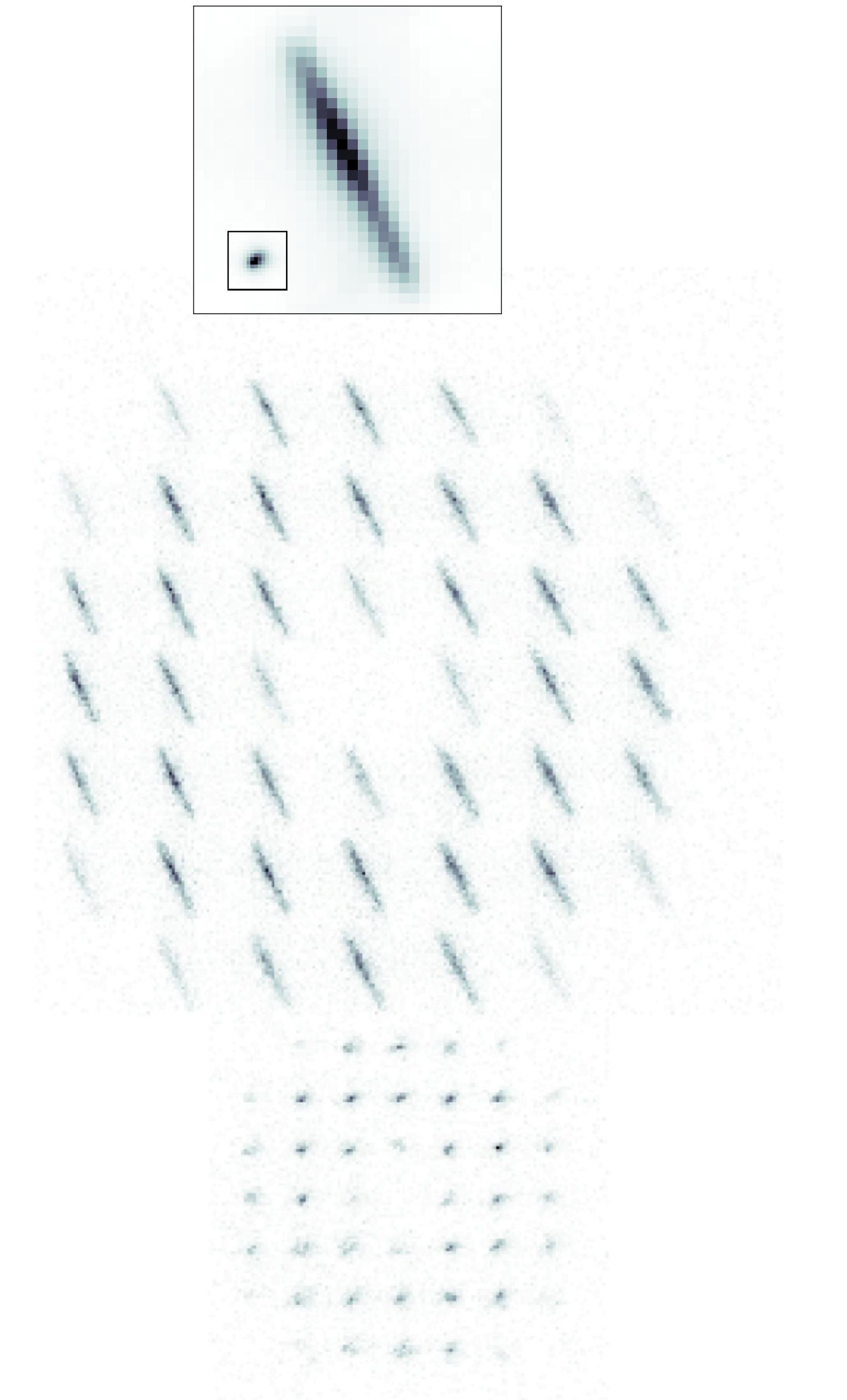


Telescope



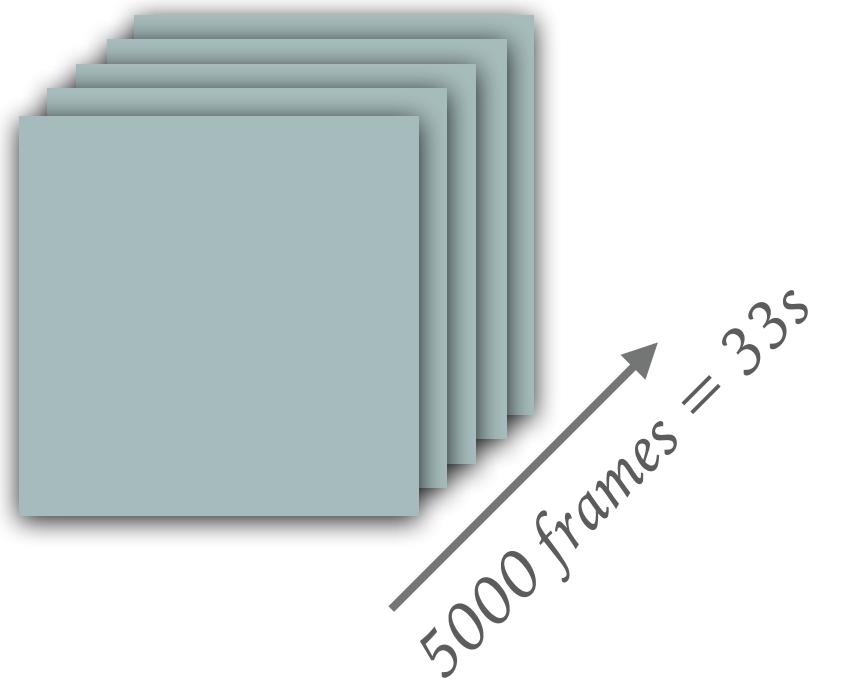
WFS CHARACTERISTICS

	TS	LGS WFS
Camera	ANDOR EMCCD 128 x 128	OCAM EMCCD 240 x 240
RON (e-/frame)	0.24	0.25
WF sampling	7x7	7x7
pixel scale ("/pixel)	0.24	0.65
FOV (")	3.87	19.5

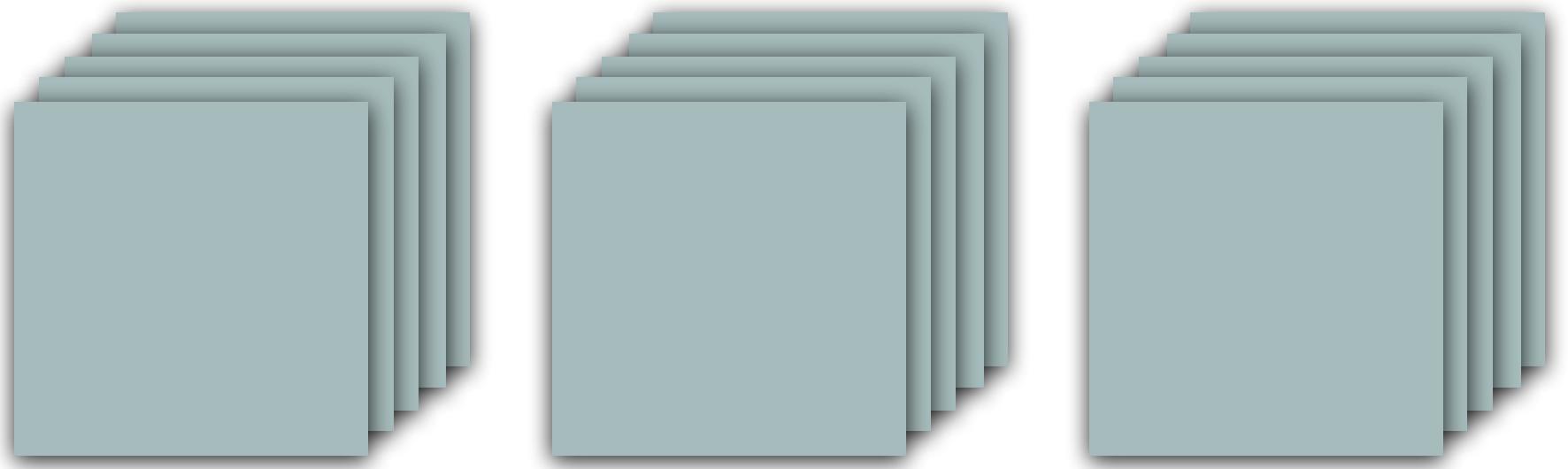


DATA FORMAT

- Acquisition:

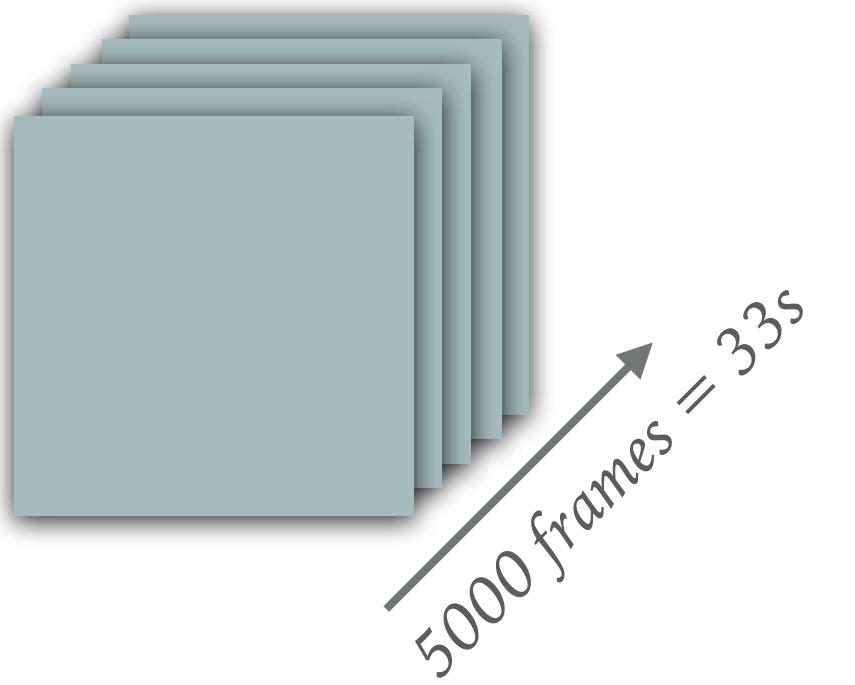


- Acquisition sequence: ~ 20 min



DATA FORMAT

- Acquisition:



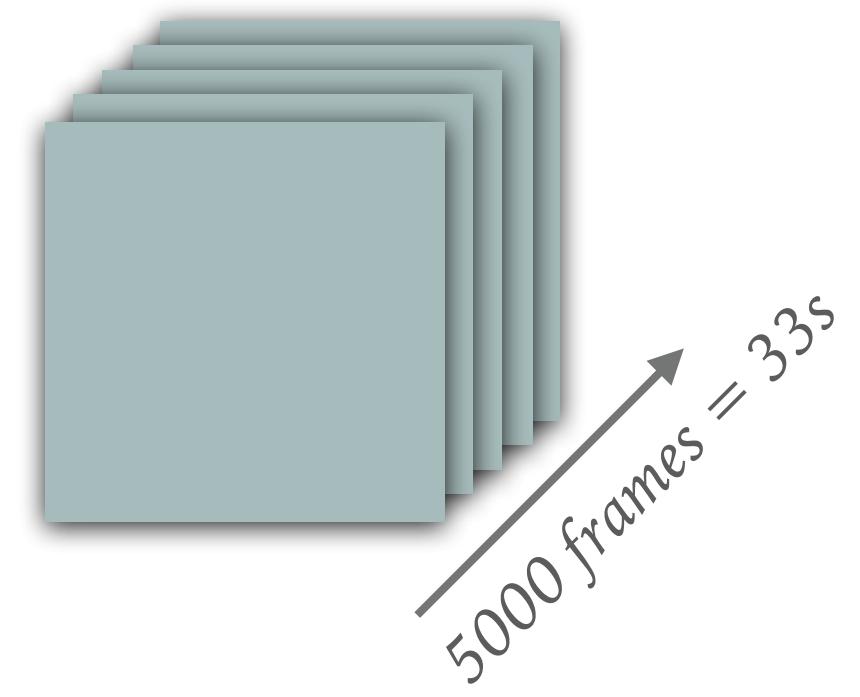
- Acquisition sequence: ~ 20 min



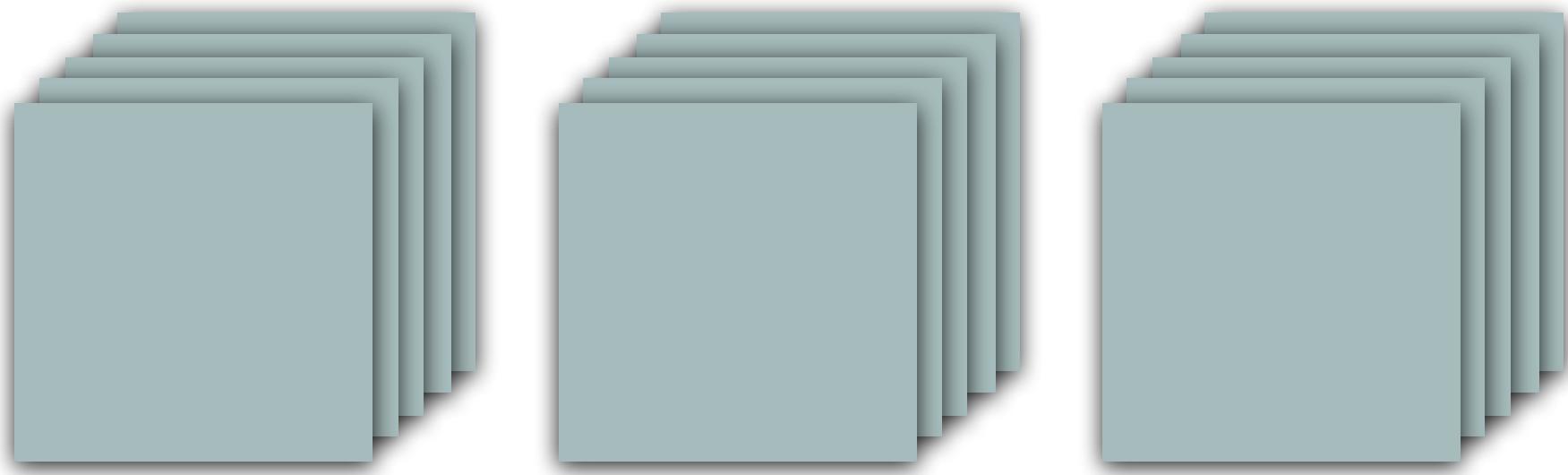
- Centroid gain estimation via TT dithering

DATA FORMAT

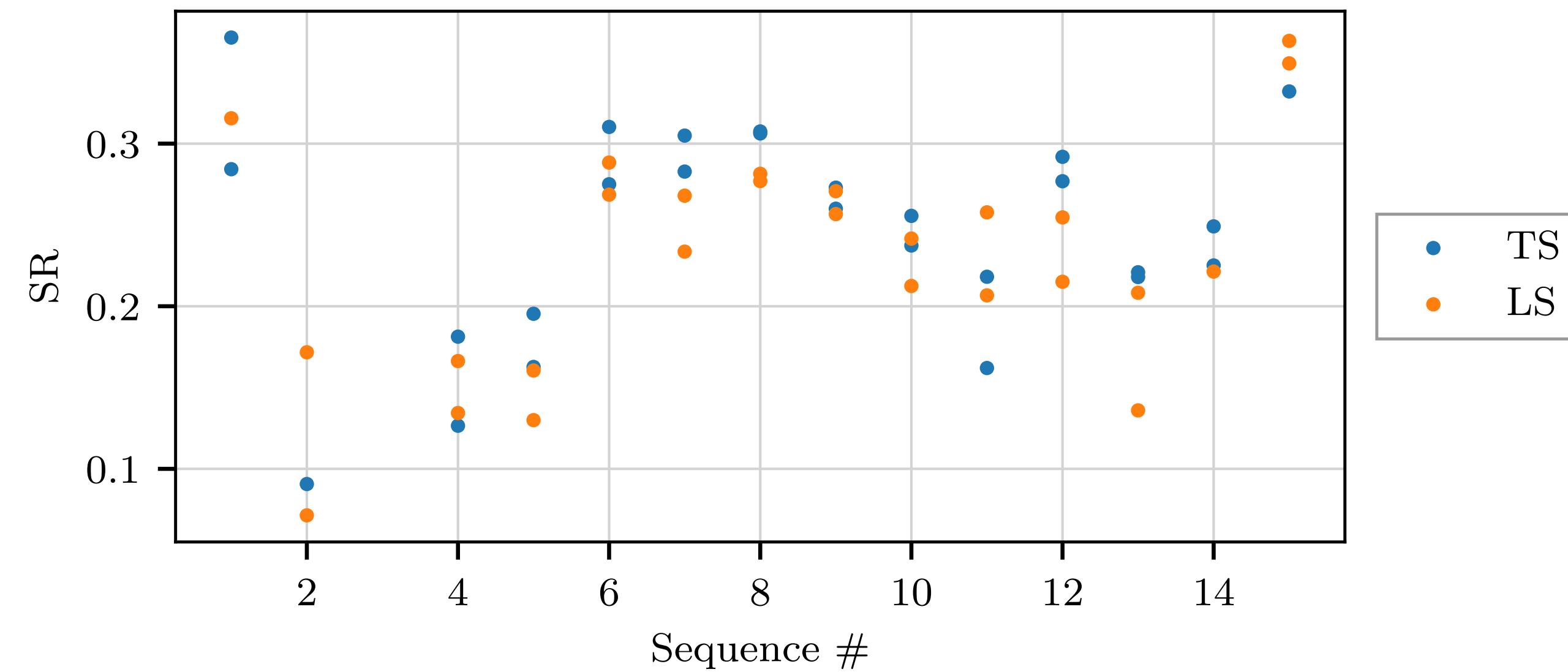
- Acquisition:



- Acquisition sequence: ~ 20 min

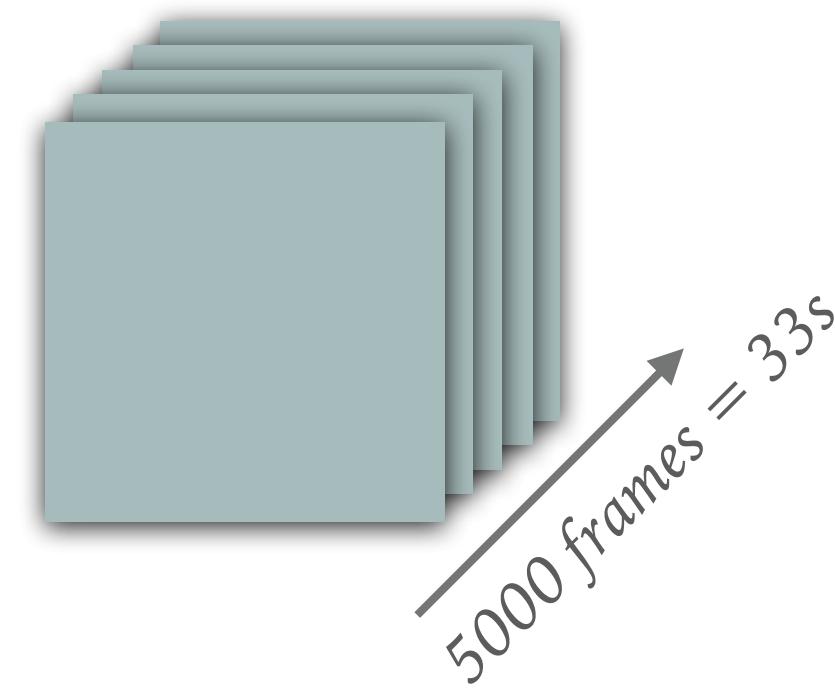


- Centroid gain estimation via TT dithering
- Strehl ratio measurement

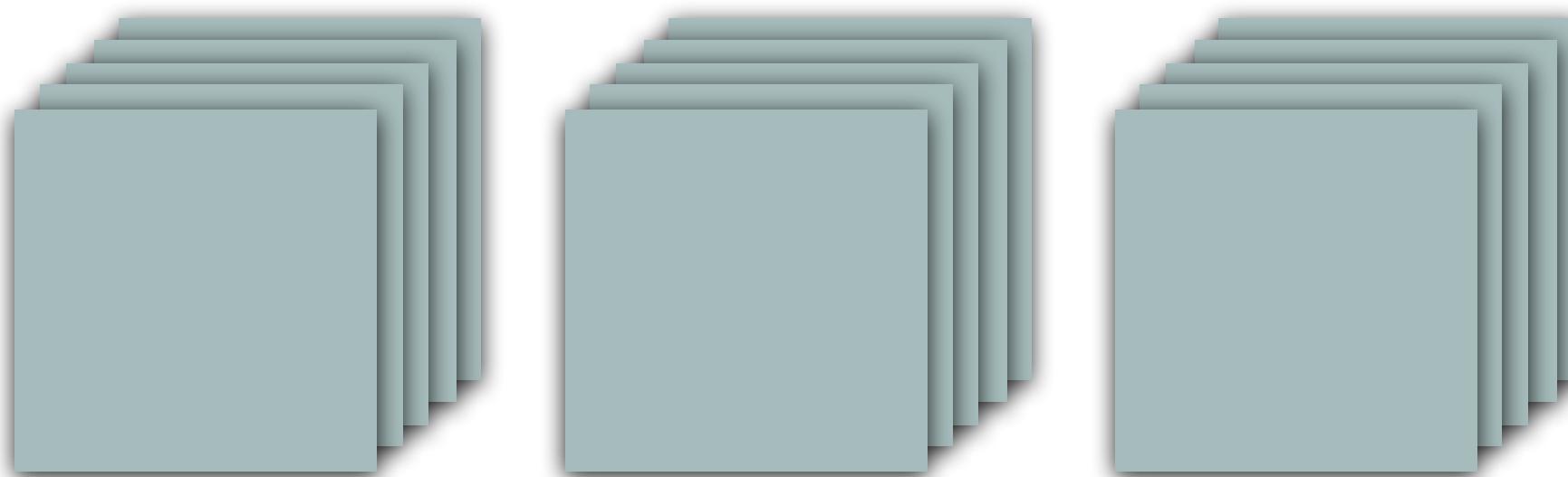


DATA FORMAT

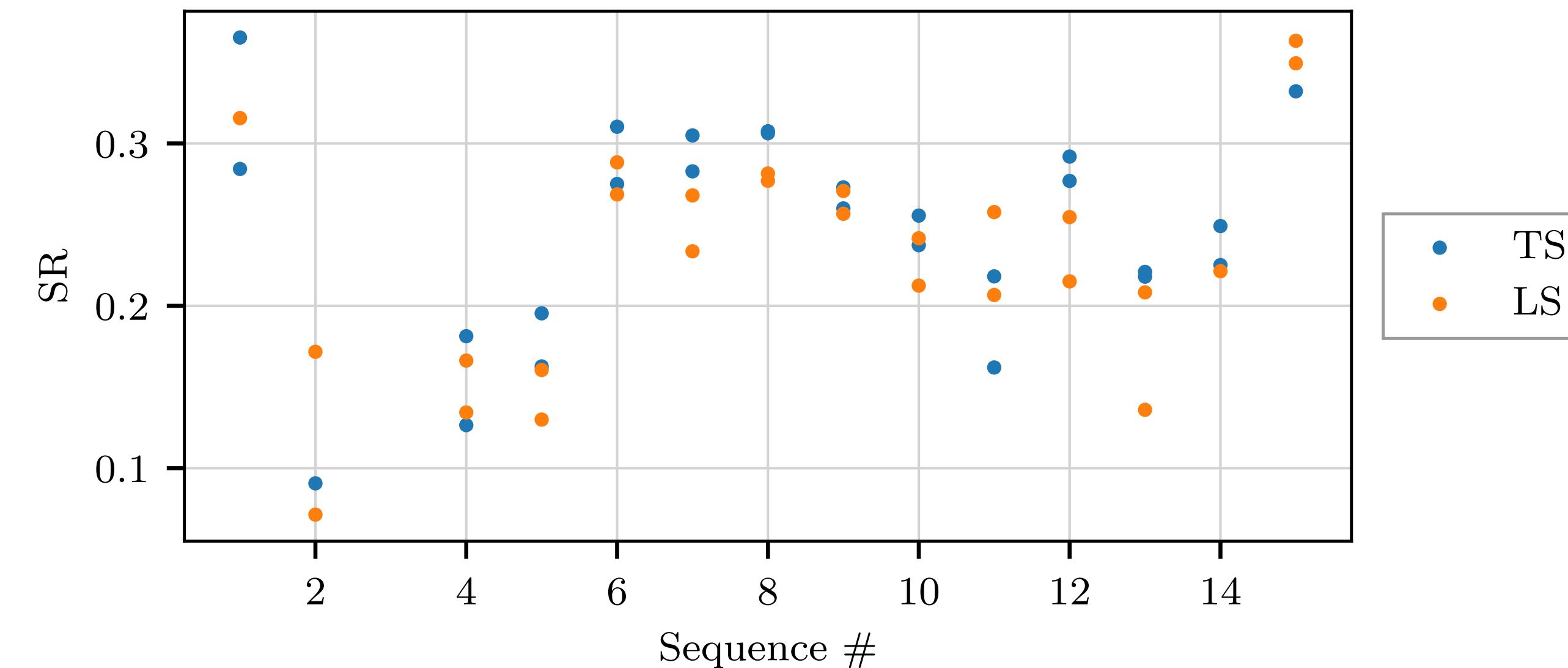
- Acquisition:



- Acquisition sequence: ~ 20 min

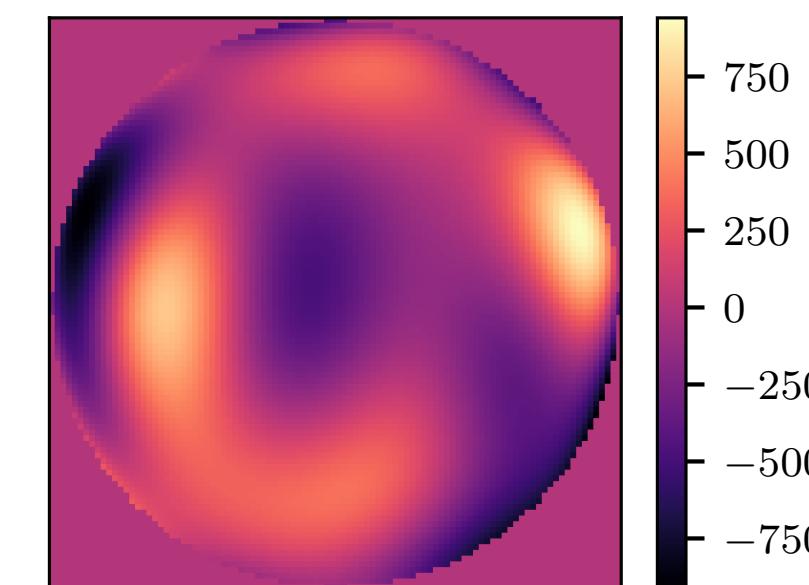


- Centroid gain estimation via TT dithering
- Strehl ratio measurement
- On-sky reference slopes for LGS WFS



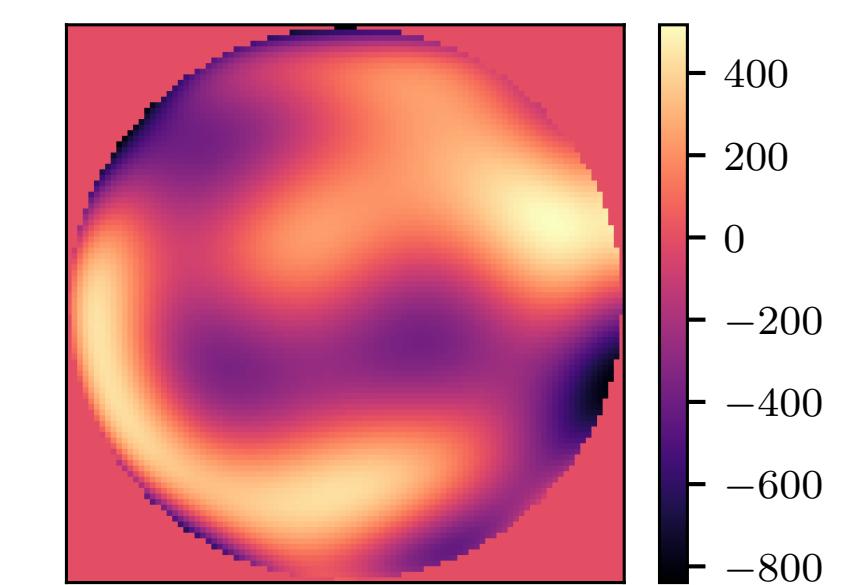
Bench reference slopes - on sky reference slopes

28/09 - 23h13



285 nm rms

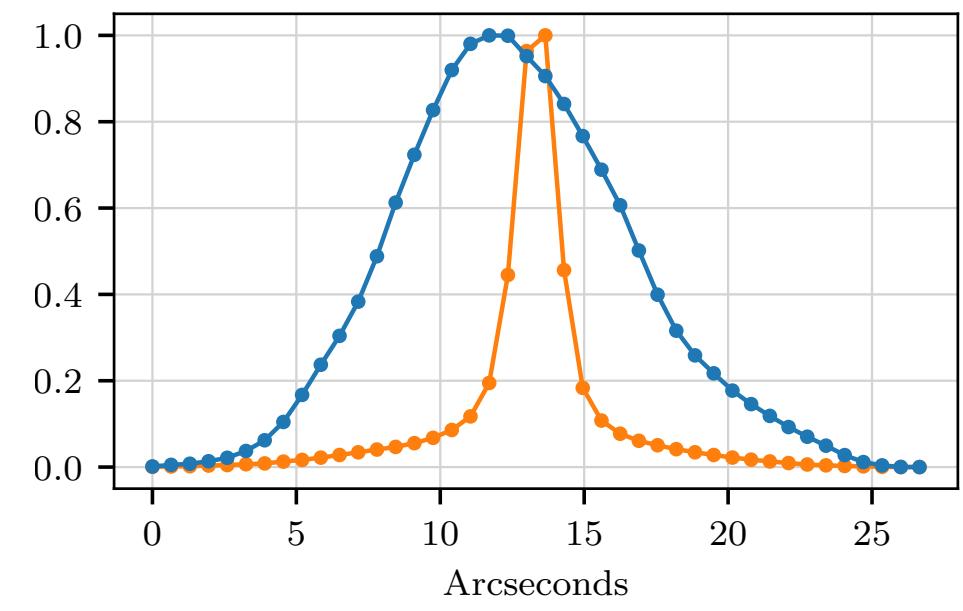
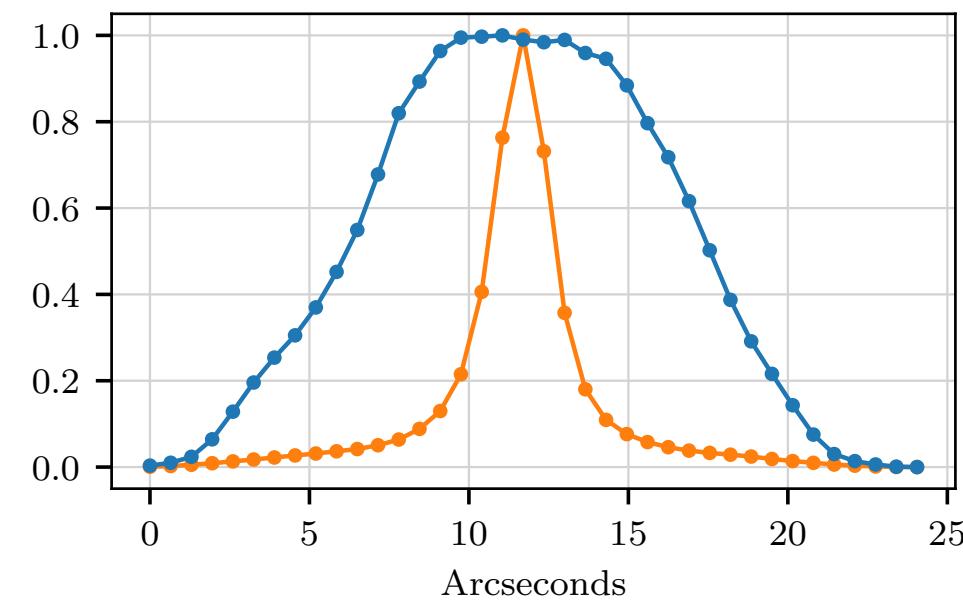
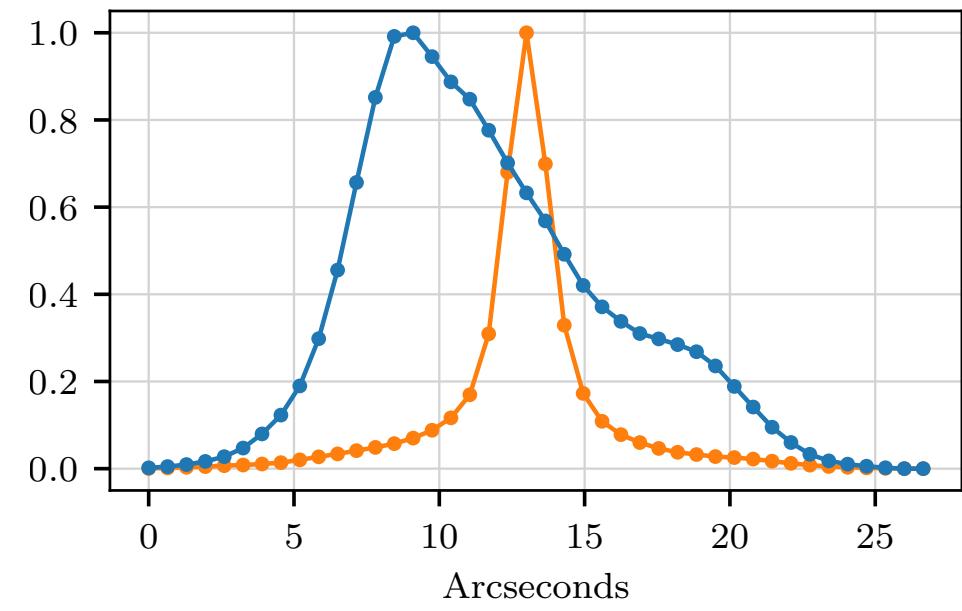
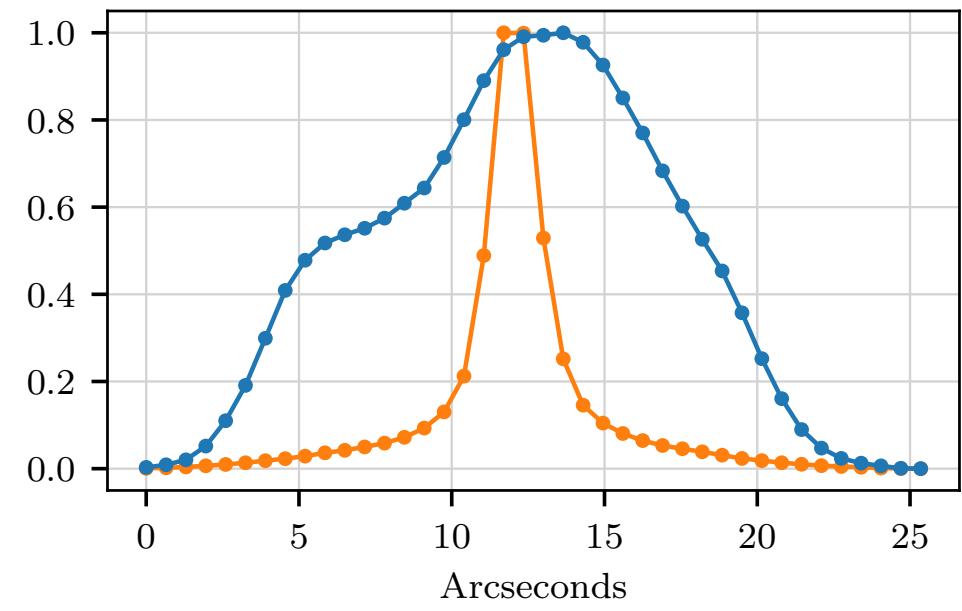
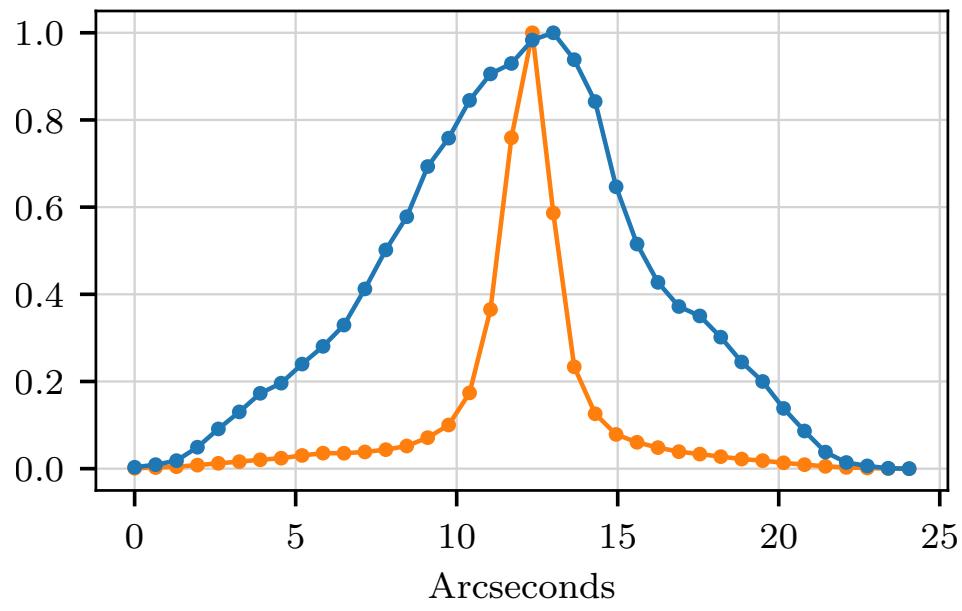
29/09 - 05h50



230 nm rms

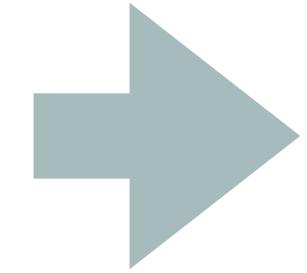
DATA EXAMPLE

	28/09 - 5h51	28/09 - 21h22	28/09 - 23h13	29/09 - 05h50	02/10 - 02h07
elongation 20% (")	15.9	17.0	15.0	16.8	14.0
FWHM (")	2.0	1.9	1.8	2.2	1.6
LLT distance (m)	36	38	33	36	35

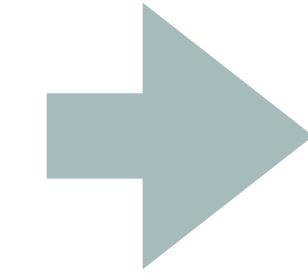


DATA PROCESSING

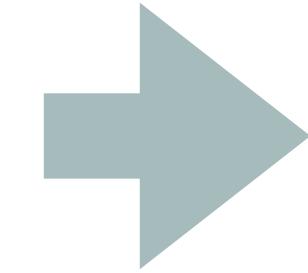
Images



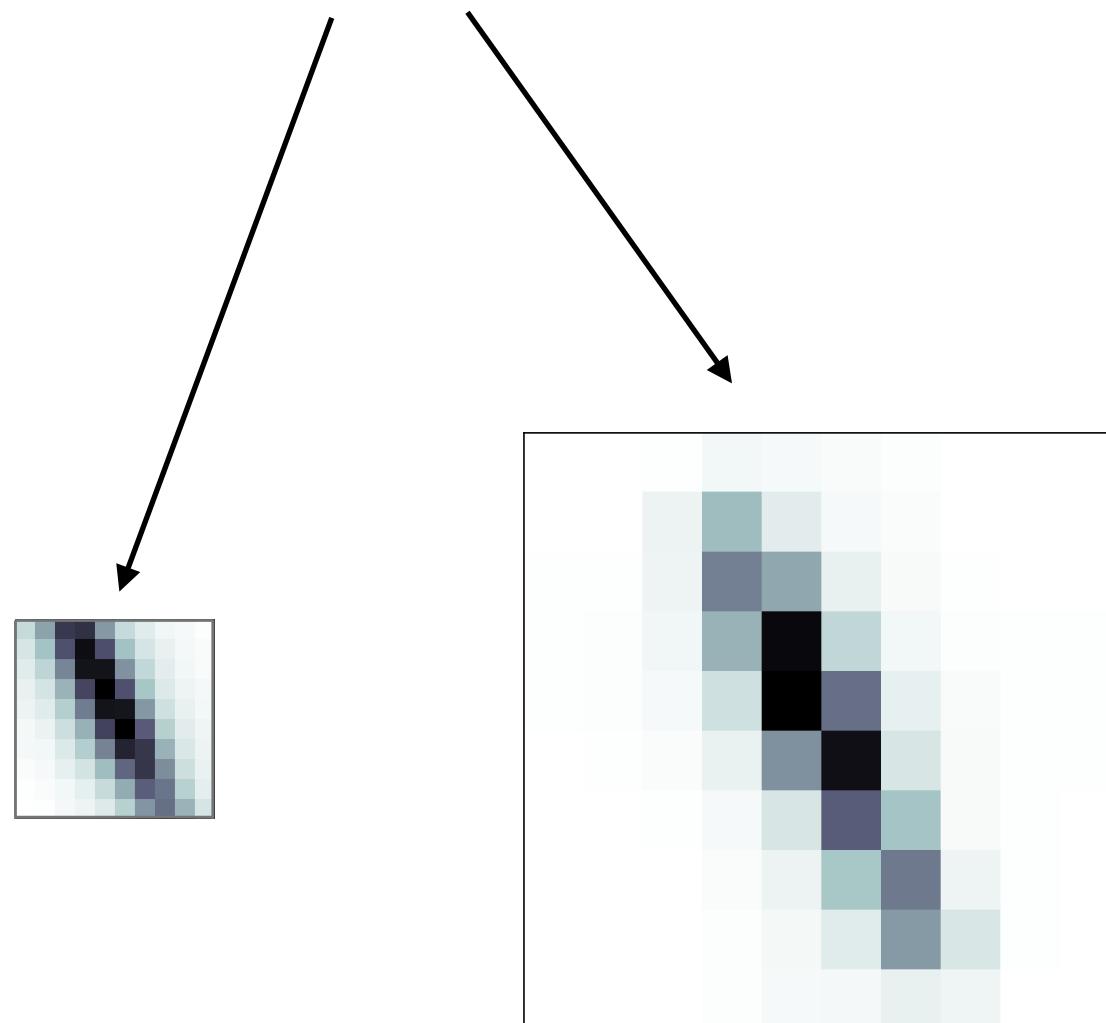
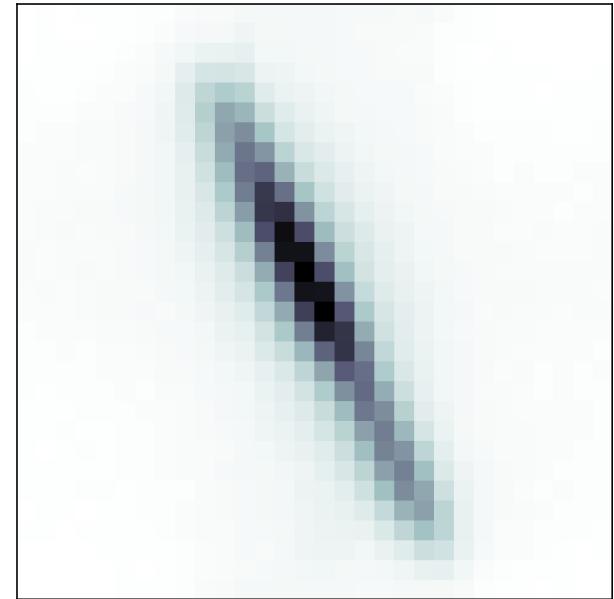
Slopes



Centroid gain
correction

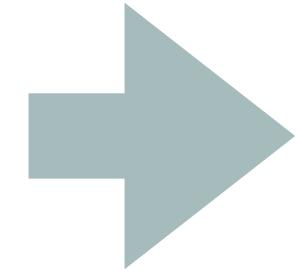


Wavefront
reconstruction

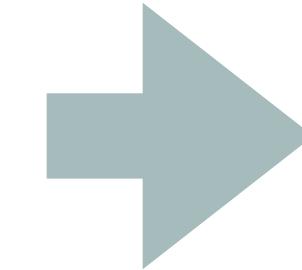


DATA PROCESSING

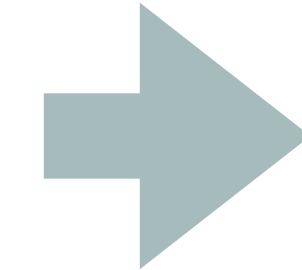
Images



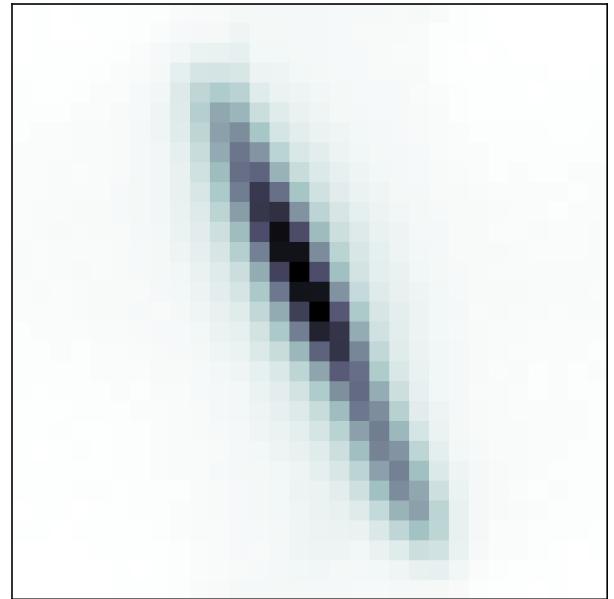
Slopes



Centroid gain
correction



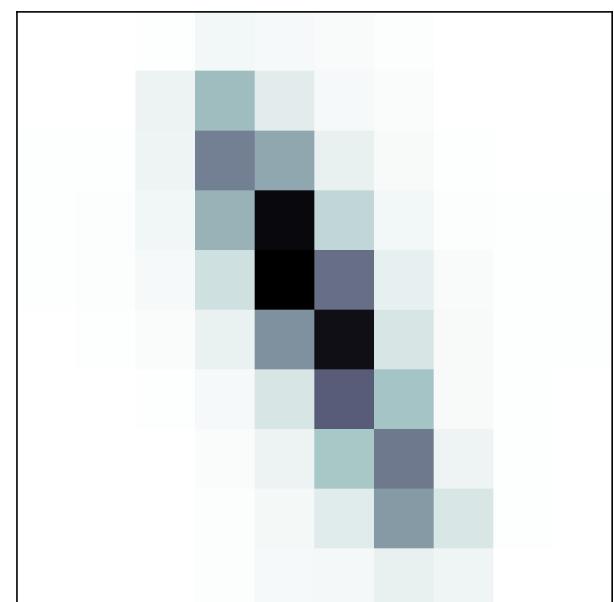
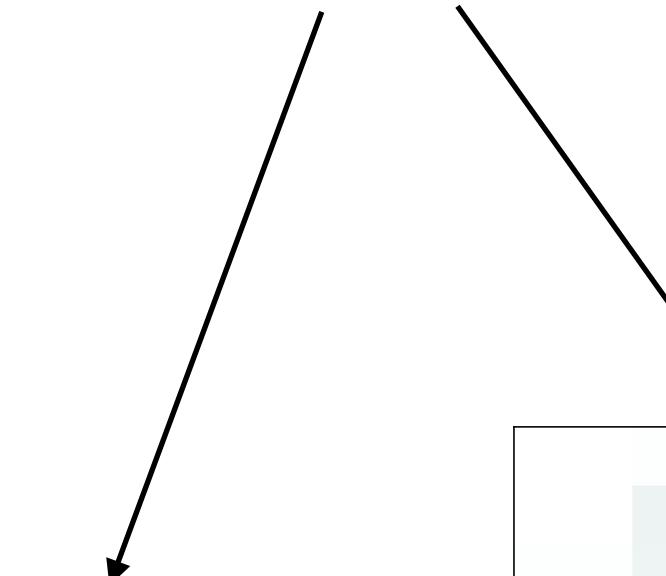
Wavefront
reconstruction



- Thresholded center of gravity

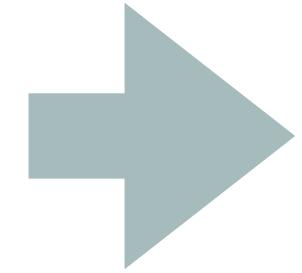
OR

- Correlation

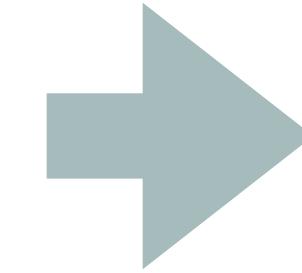


DATA PROCESSING

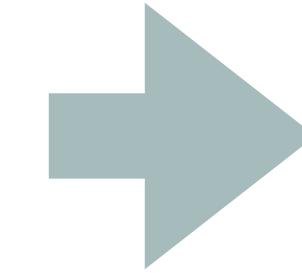
Images



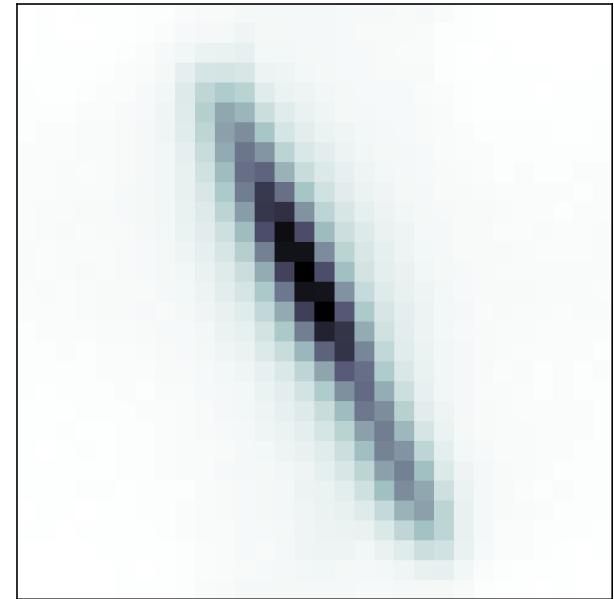
Slopes



Centroid gain
correction



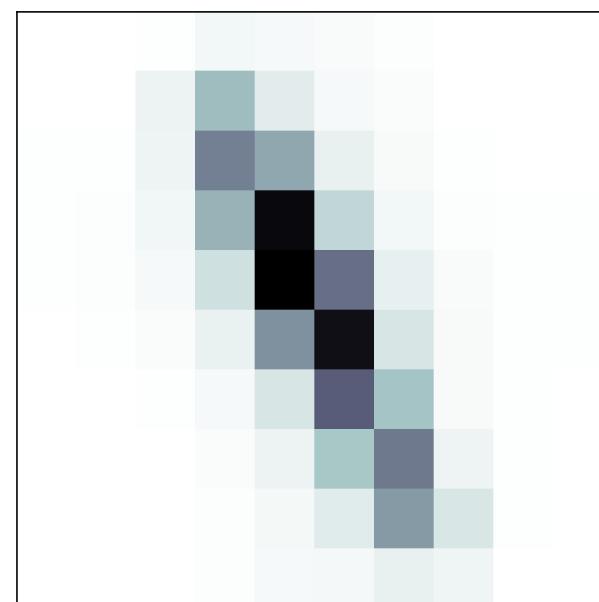
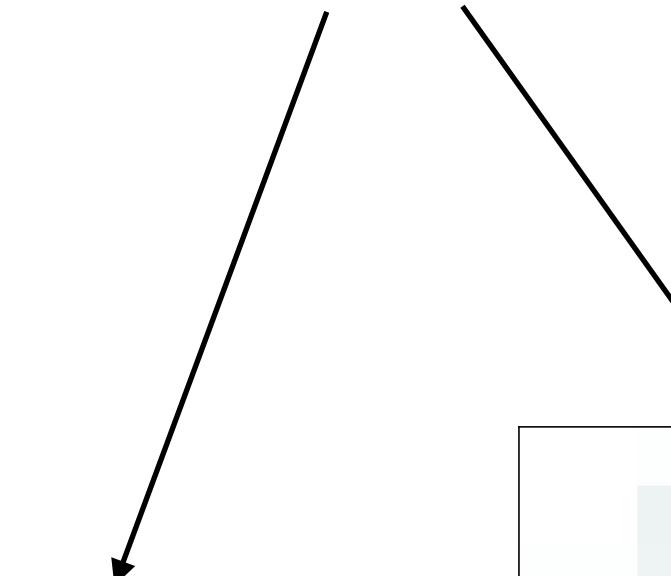
Wavefront
reconstruction



- Thresholded center of gravity

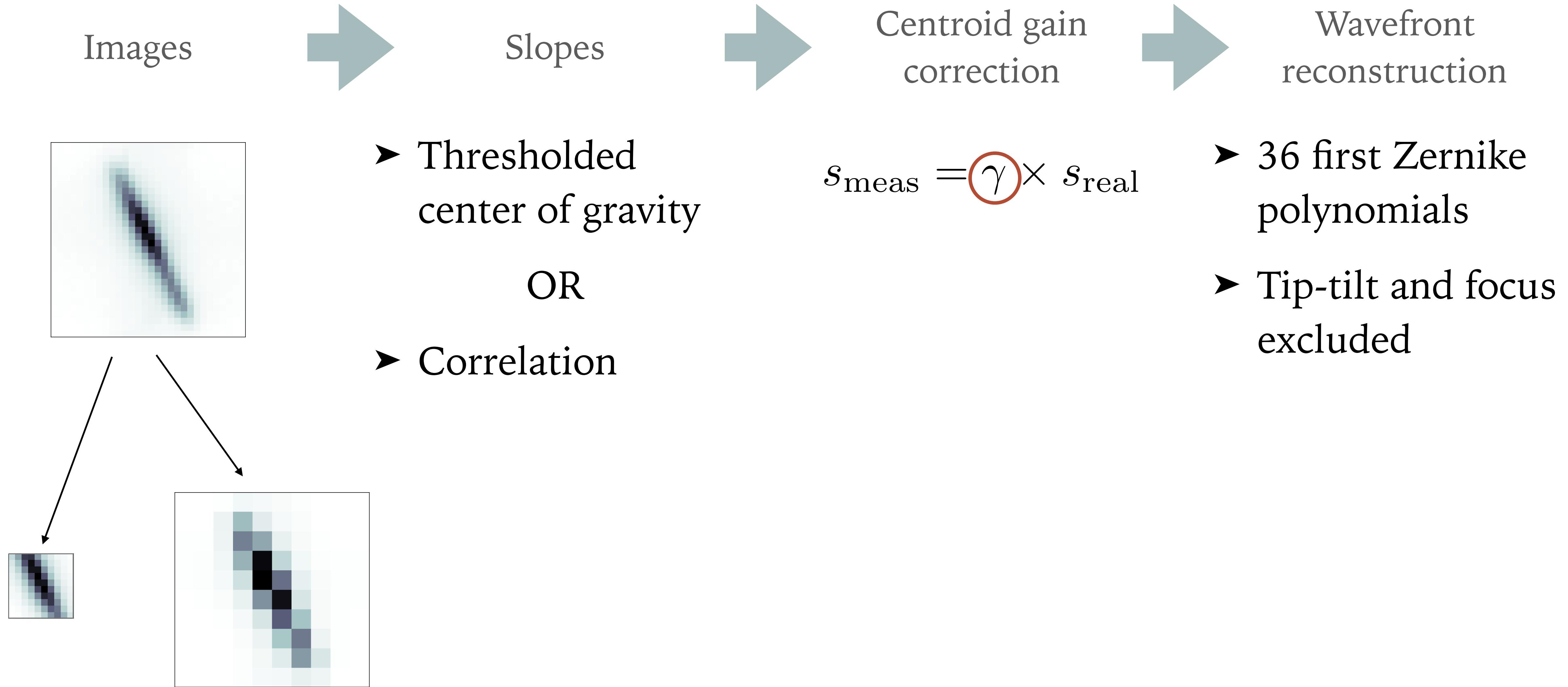
OR

- Correlation



$$s_{\text{meas}} = \gamma \times s_{\text{real}}$$

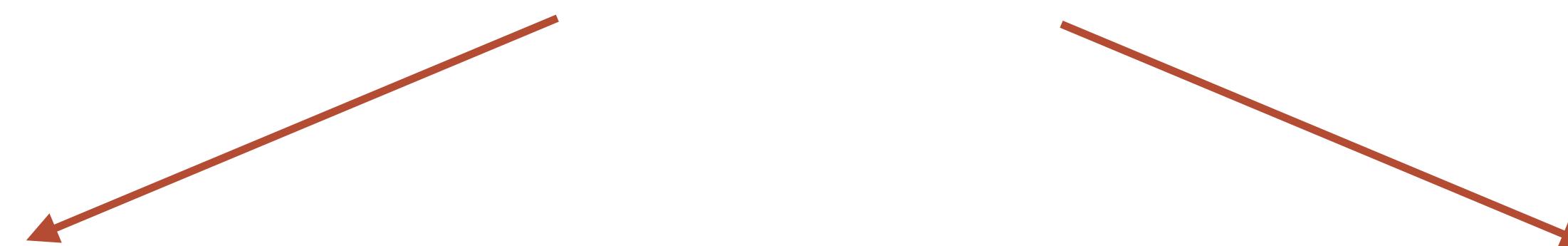
DATA PROCESSING



ERROR BREAKDOWN

- Analysis of the temporal average of the spatial variance of the wavefront difference between TS and LGS

$$\langle \sigma_{\phi^{TS} - \phi^{LGS}}^2 \rangle_{time}$$



- Dynamic component : temporal variance of the spatial variance of the WFD

$$\begin{aligned} &= \\ \text{TS noise} &+ \text{LGS WFS noise} + \text{Cone effect} \\ &+ \text{residual dynamic error} \quad \langle \sigma_{\Delta\phi}^2 \rangle_{ELGS}^{\text{dyn}} \\ &\text{due to the elongation :} \end{aligned}$$

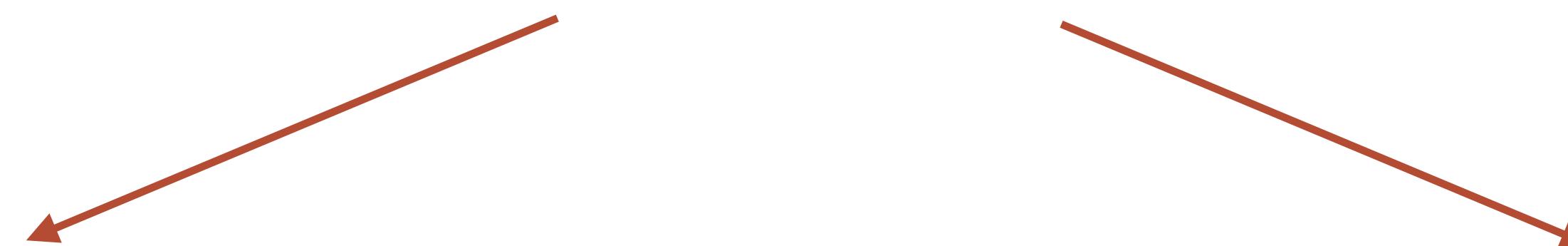
- Static component : spatial variance of the temporal mean of the WFD

$$\begin{aligned} &= \\ \text{LGS WFS reference slopes} &- \text{TS reference slopes} \\ &+ \text{residual static error} \quad \langle \sigma_{\Delta\phi}^2 \rangle_{ELGS}^{\text{stat}} \\ &\text{due to the elongation :} \end{aligned}$$

ERROR BREAKDOWN

- Analysis of the temporal average of the spatial variance of the wavefront difference between TS and LGS

$$\langle \sigma_{\phi^{TS} - \phi^{LGS}}^2 \rangle_{time}$$



- Dynamic component : temporal variance of the spatial variance of the WFD

$$= \\ \text{TS noise} + \boxed{\text{LGS WFS noise}} + \text{Cone effect}$$

+ residual dynamic error
due to the elongation : $\langle \sigma_{\Delta\phi}^2 \rangle_{ELGS}^{dyn}$

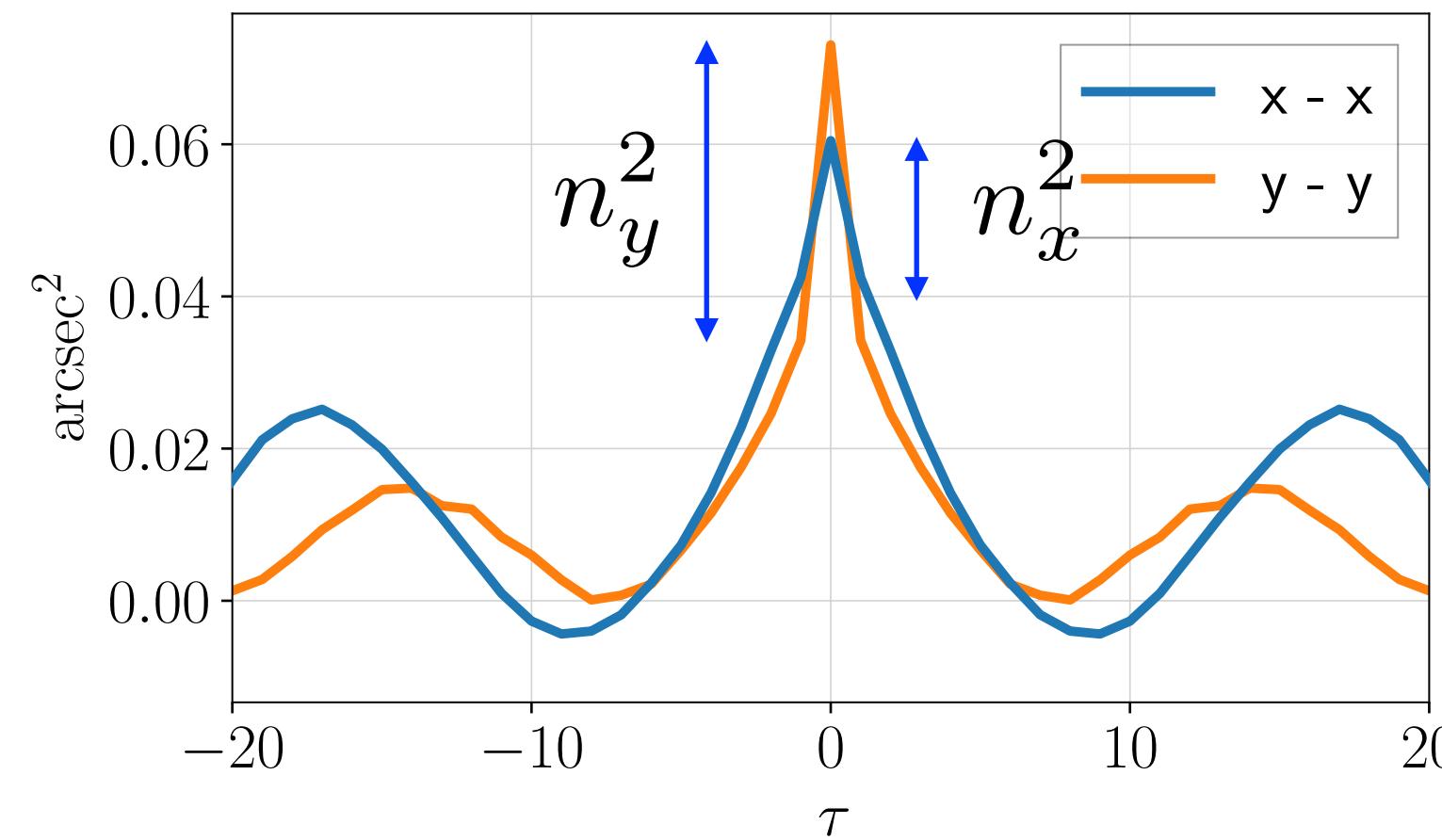
- Static component : spatial variance of the temporal mean of the WFD

$$= \\ \text{LGS WFS reference slopes} - \text{TS reference slopes}$$

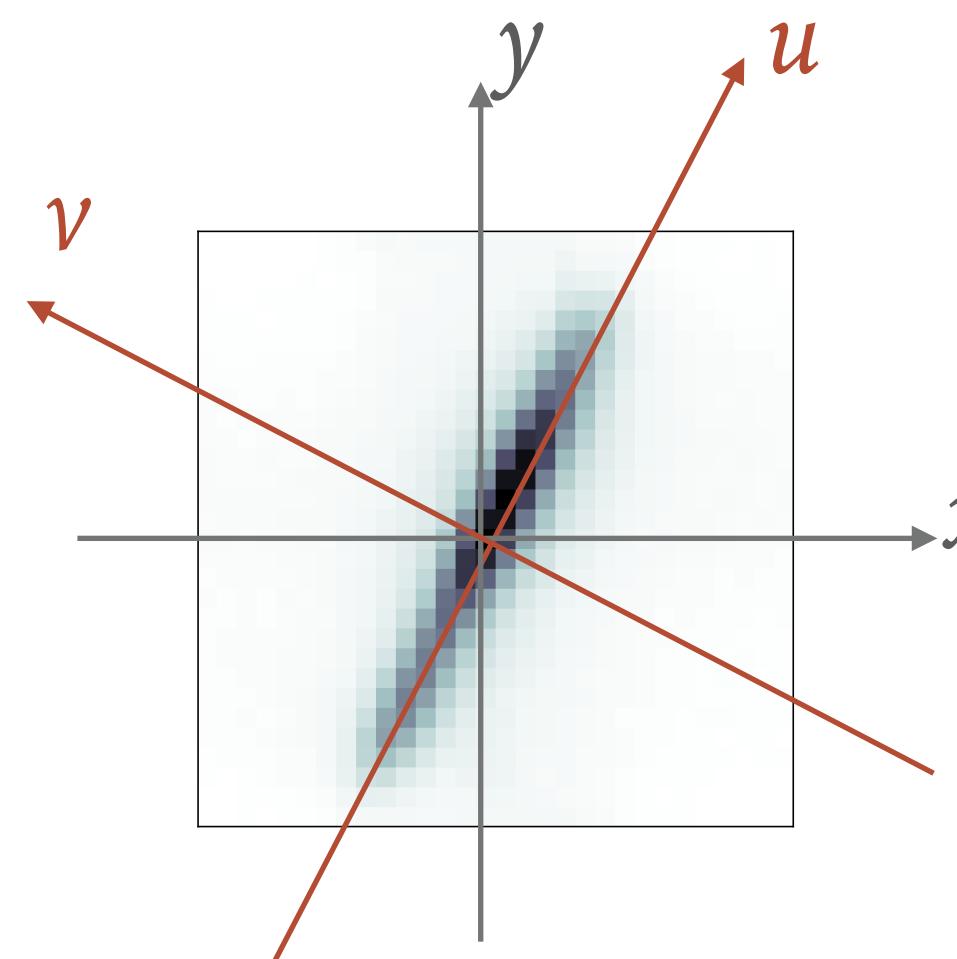
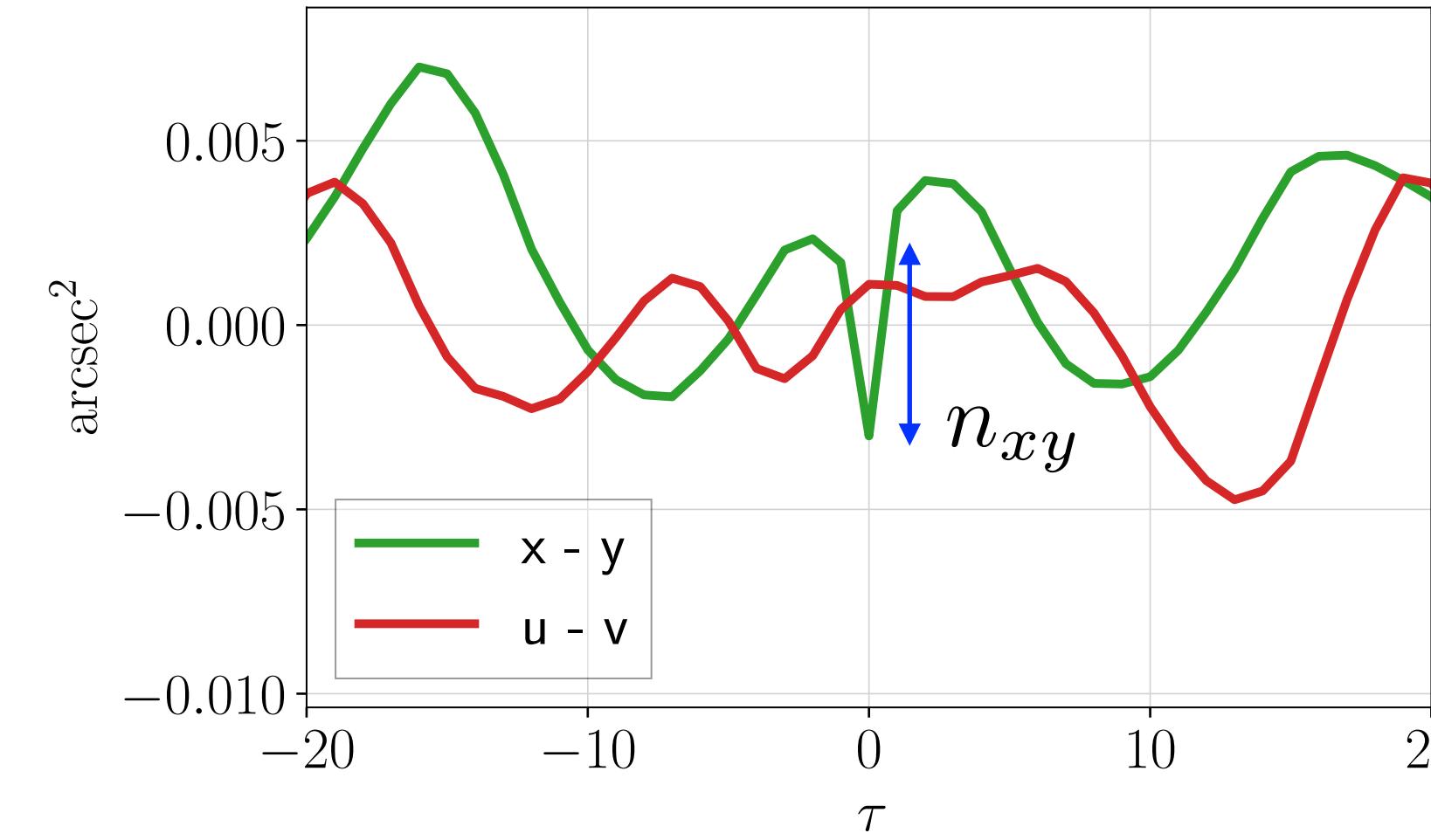
+ residual static error
due to the elongation : $\langle \sigma_{\Delta\phi}^2 \rangle_{ELGS}^{stat}$

LGS WFS NOISE

Slopes temporal auto-correlation

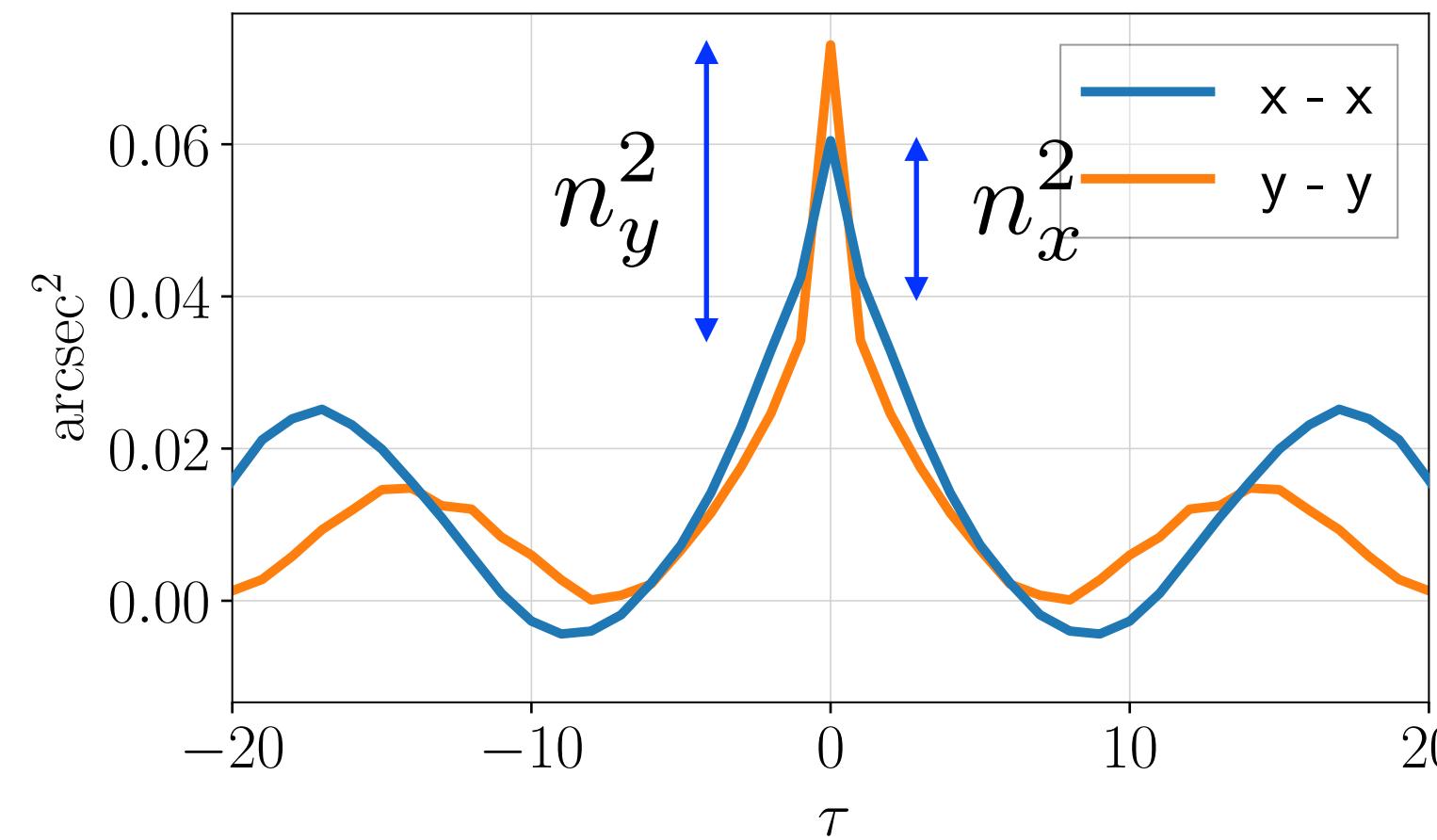


Slopes temporal cross-correlation

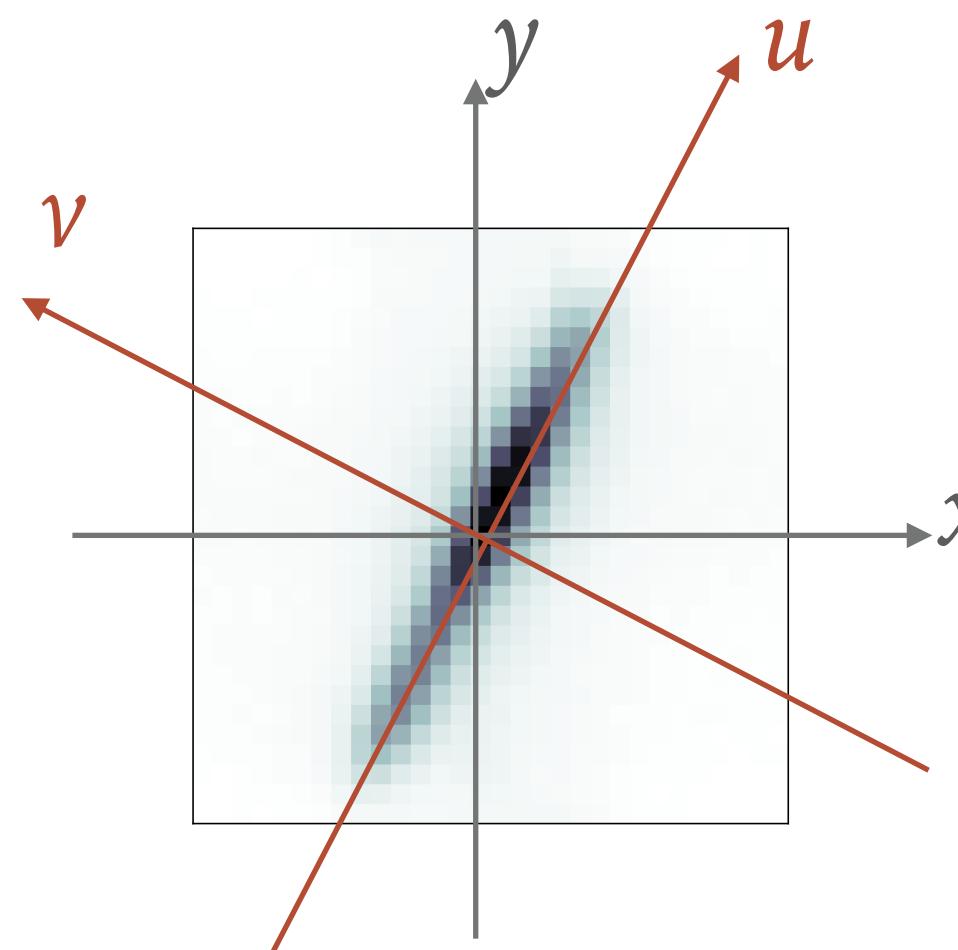
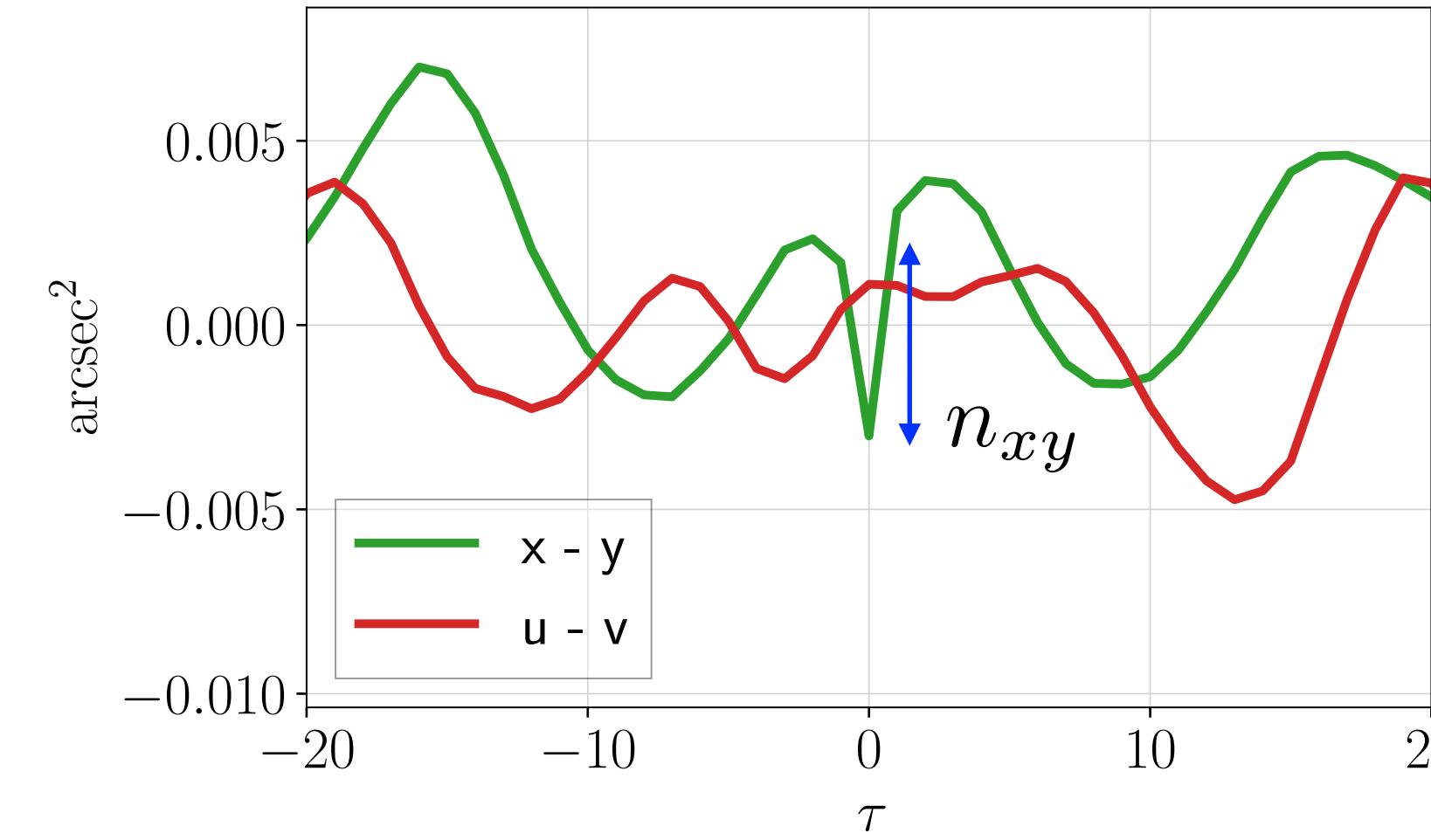


LGS WFS NOISE

Slopes temporal auto-correlation



Slopes temporal cross-correlation

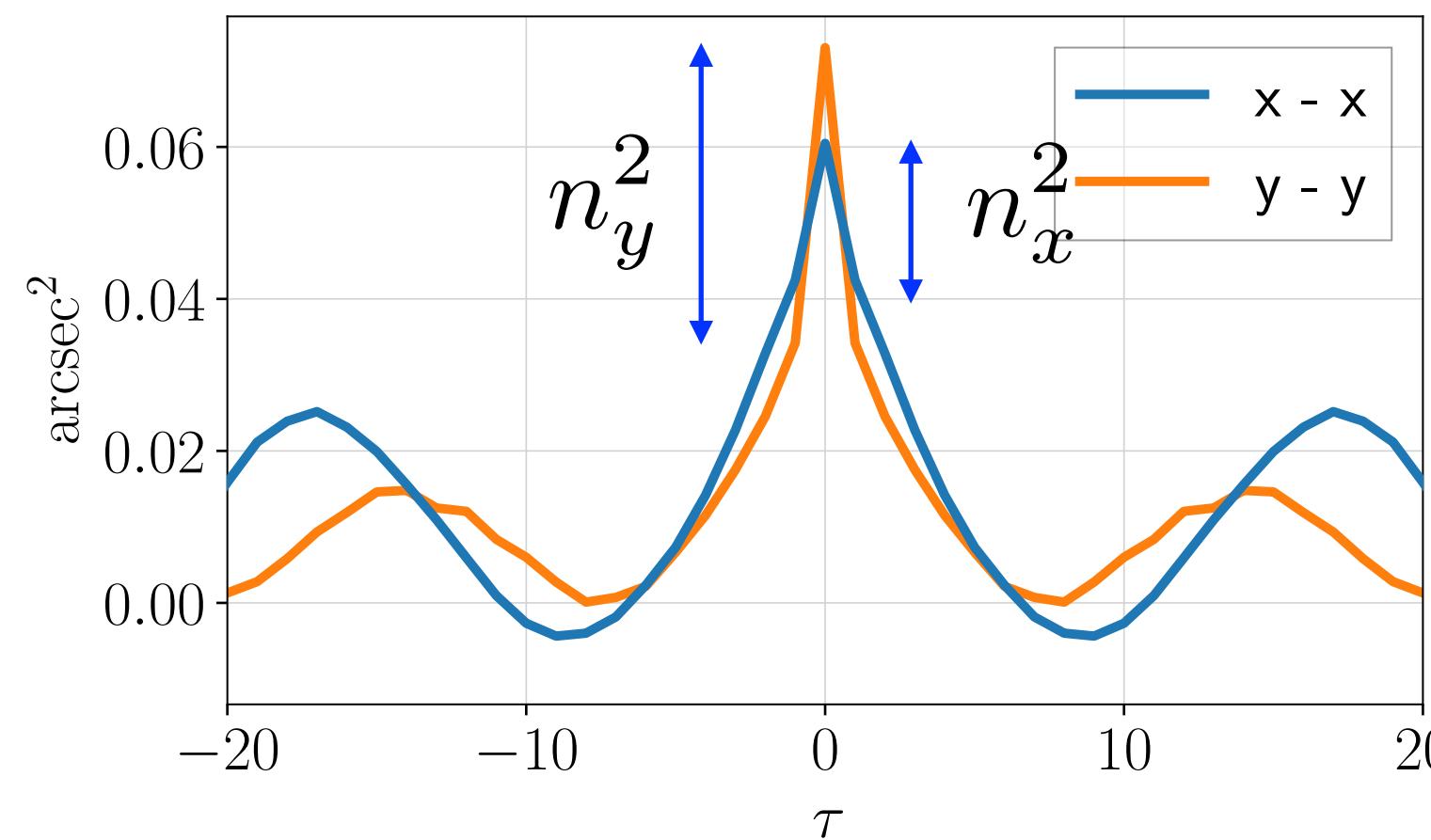


$$\begin{pmatrix} n_x^2 & n_{xy} \\ n_{xy} & n_y^2 \end{pmatrix} \longrightarrow \begin{pmatrix} n_u^2 & 0 \\ 0 & n_v^2 \end{pmatrix}$$

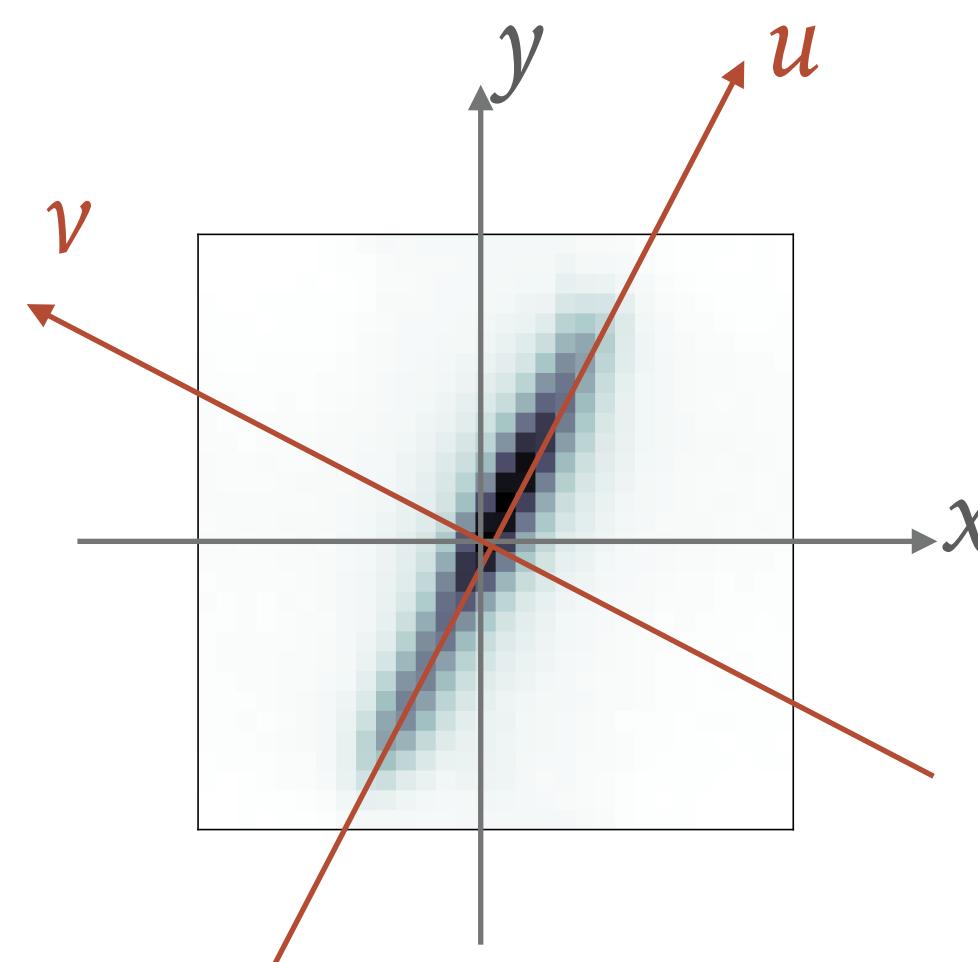
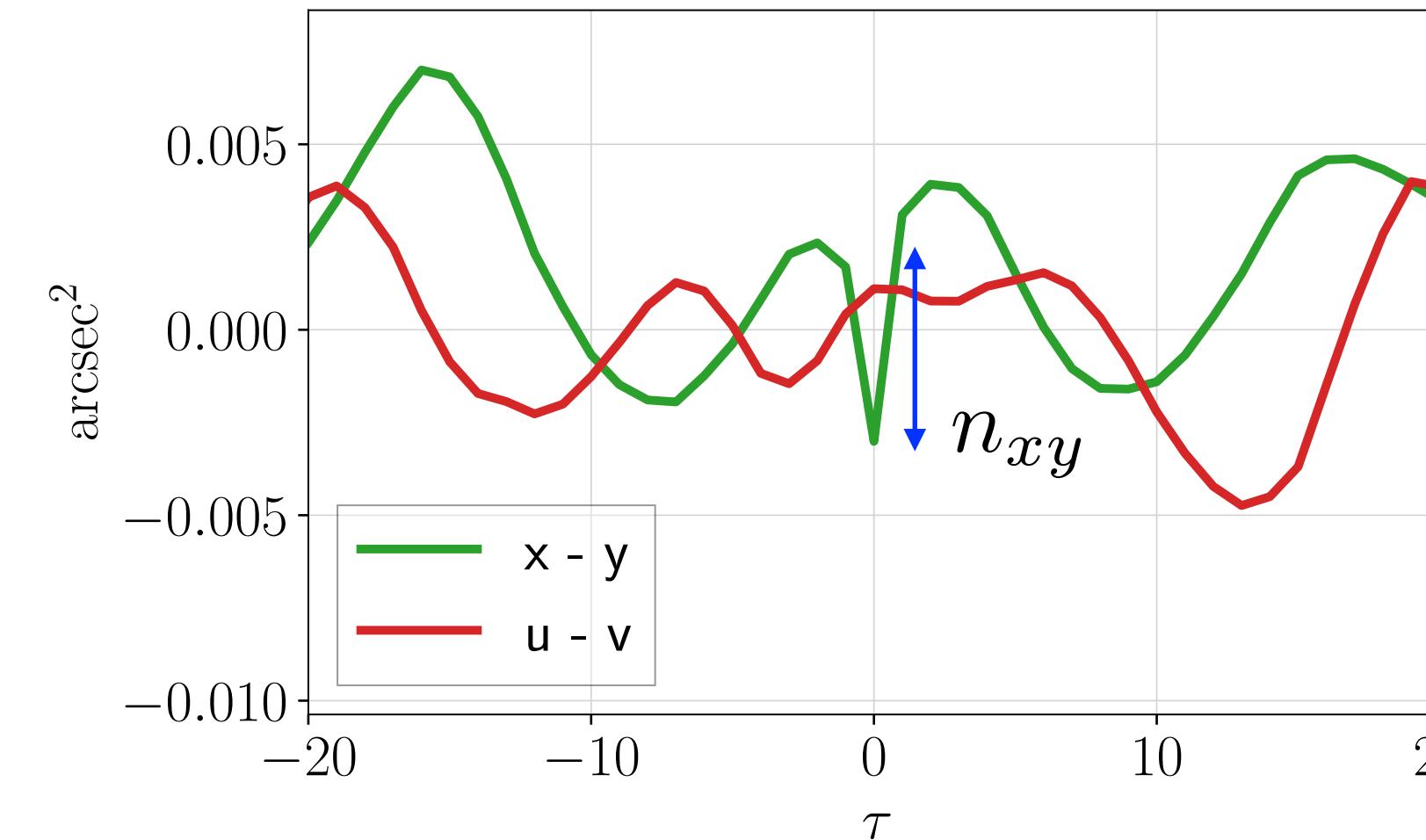
diagonalisation

LGS WFS NOISE

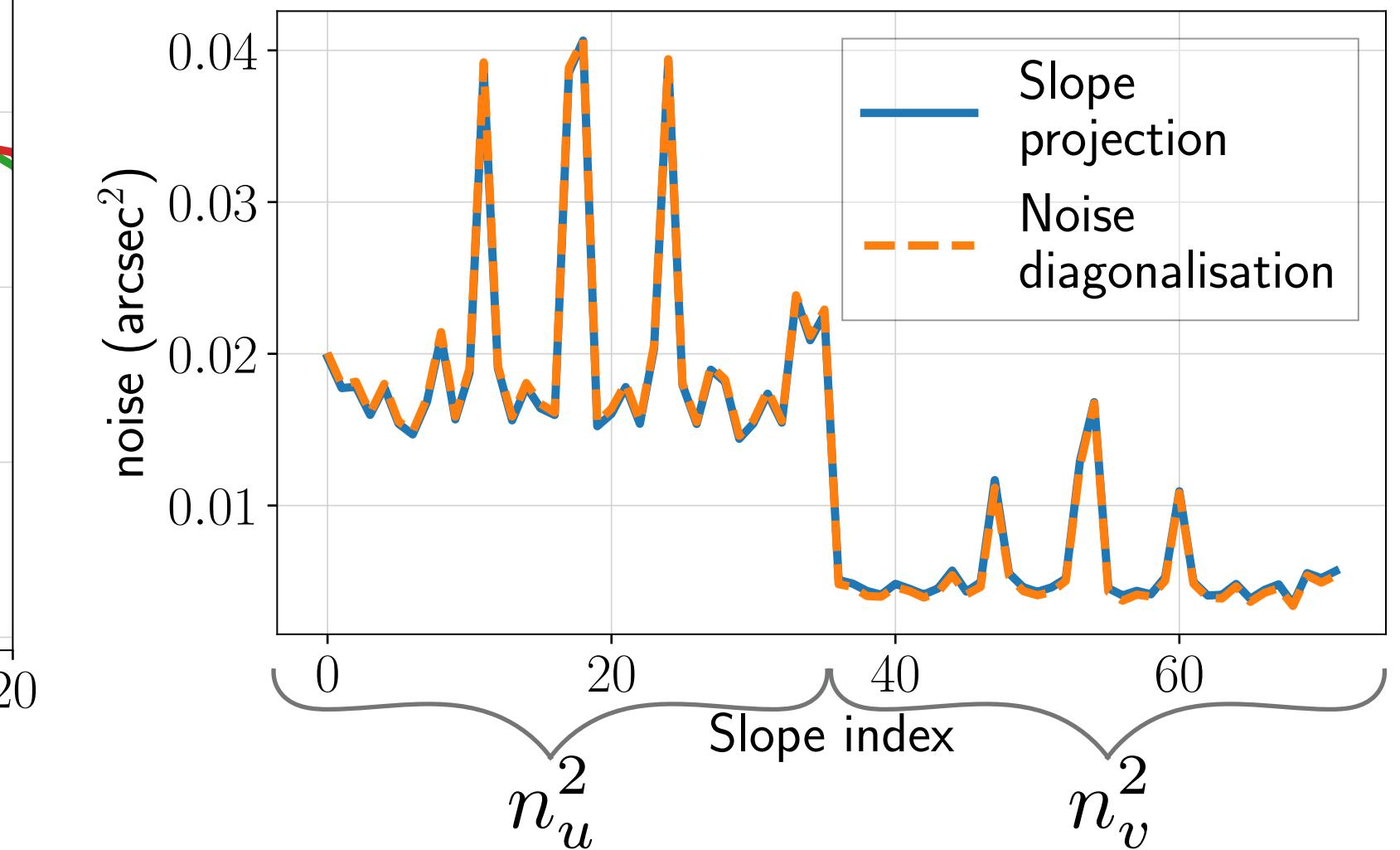
Slopes temporal auto-correlation



Slopes temporal cross-correlation

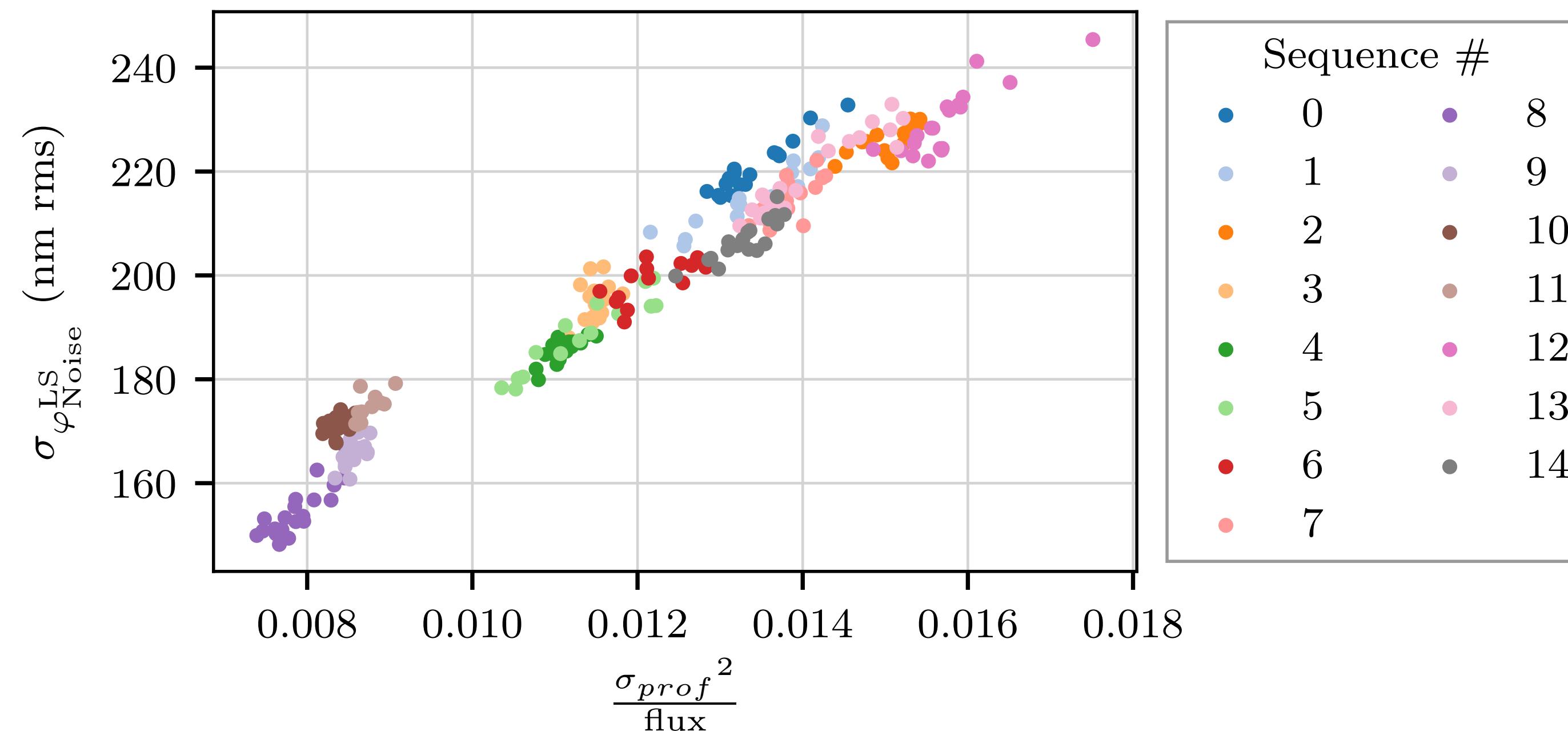


$$\begin{pmatrix} n_x^2 & n_{xy} \\ n_{xy} & n_y^2 \end{pmatrix} \xrightarrow{\text{diagonalisation}} \begin{pmatrix} n_u^2 & 0 \\ 0 & n_v^2 \end{pmatrix}$$



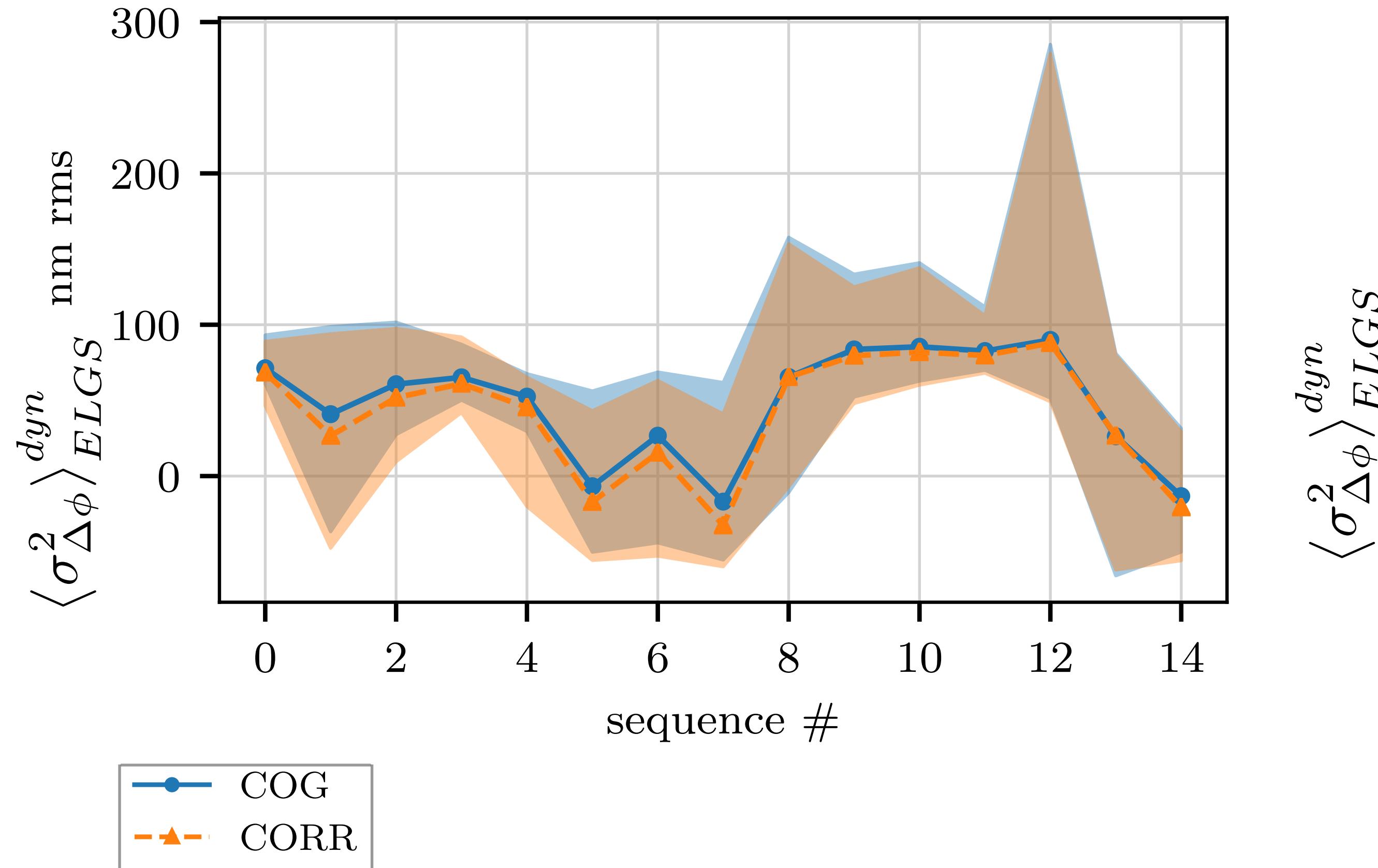
➤ Consistent noise behaviour

LGS WFS NOISE



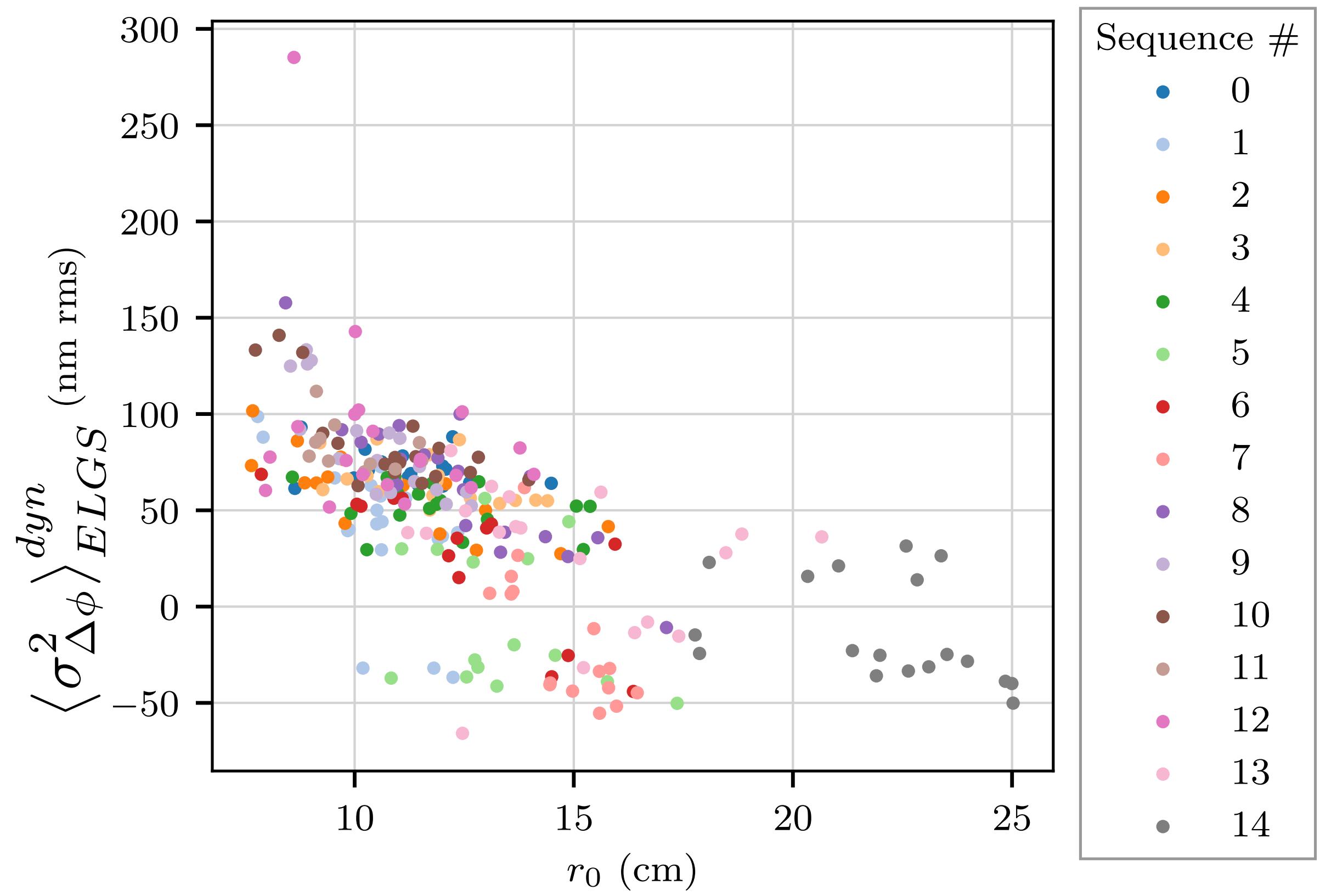
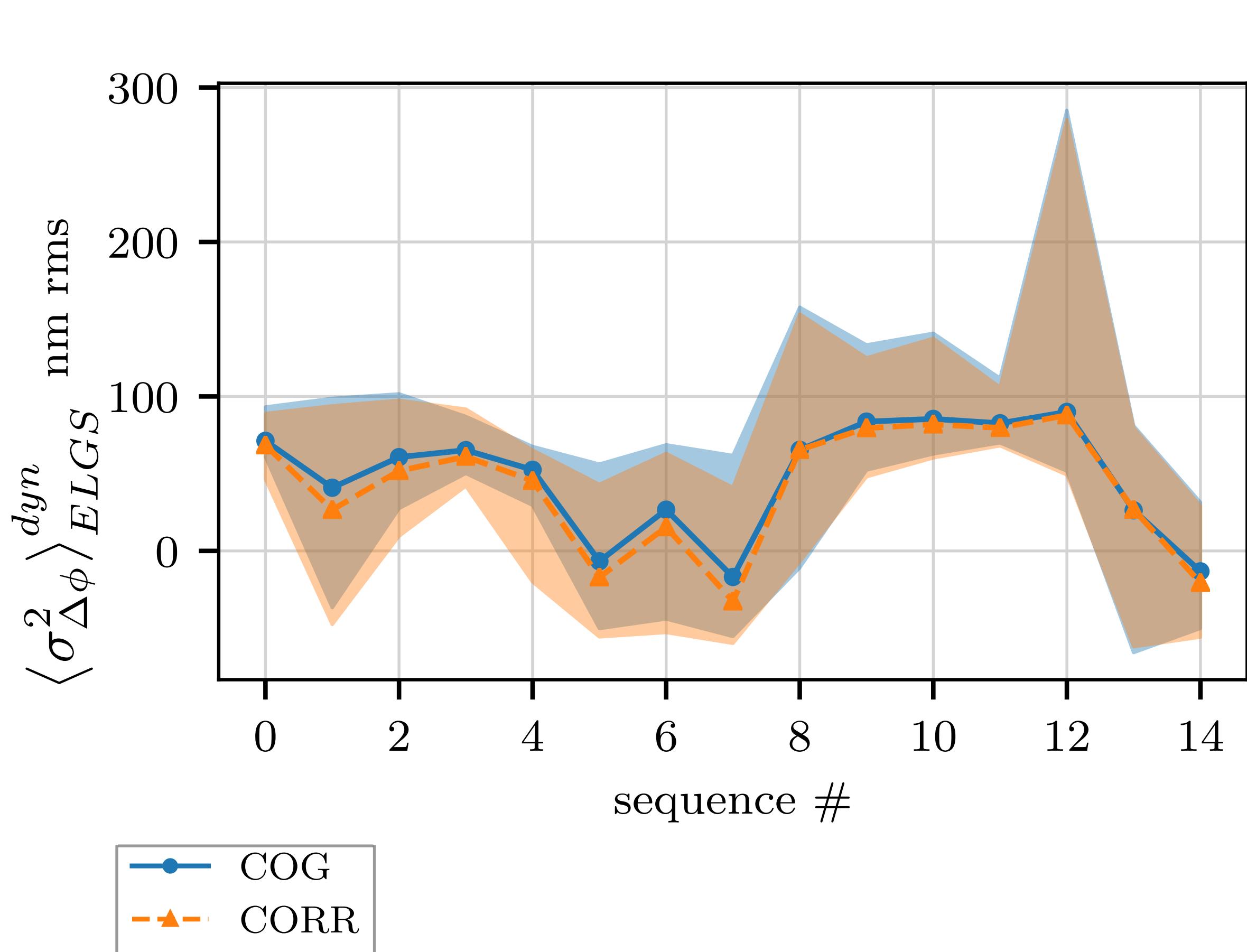
➤ Noise depends primarily on sodium profile and flux

DYNAMIC RESIDUAL ERROR

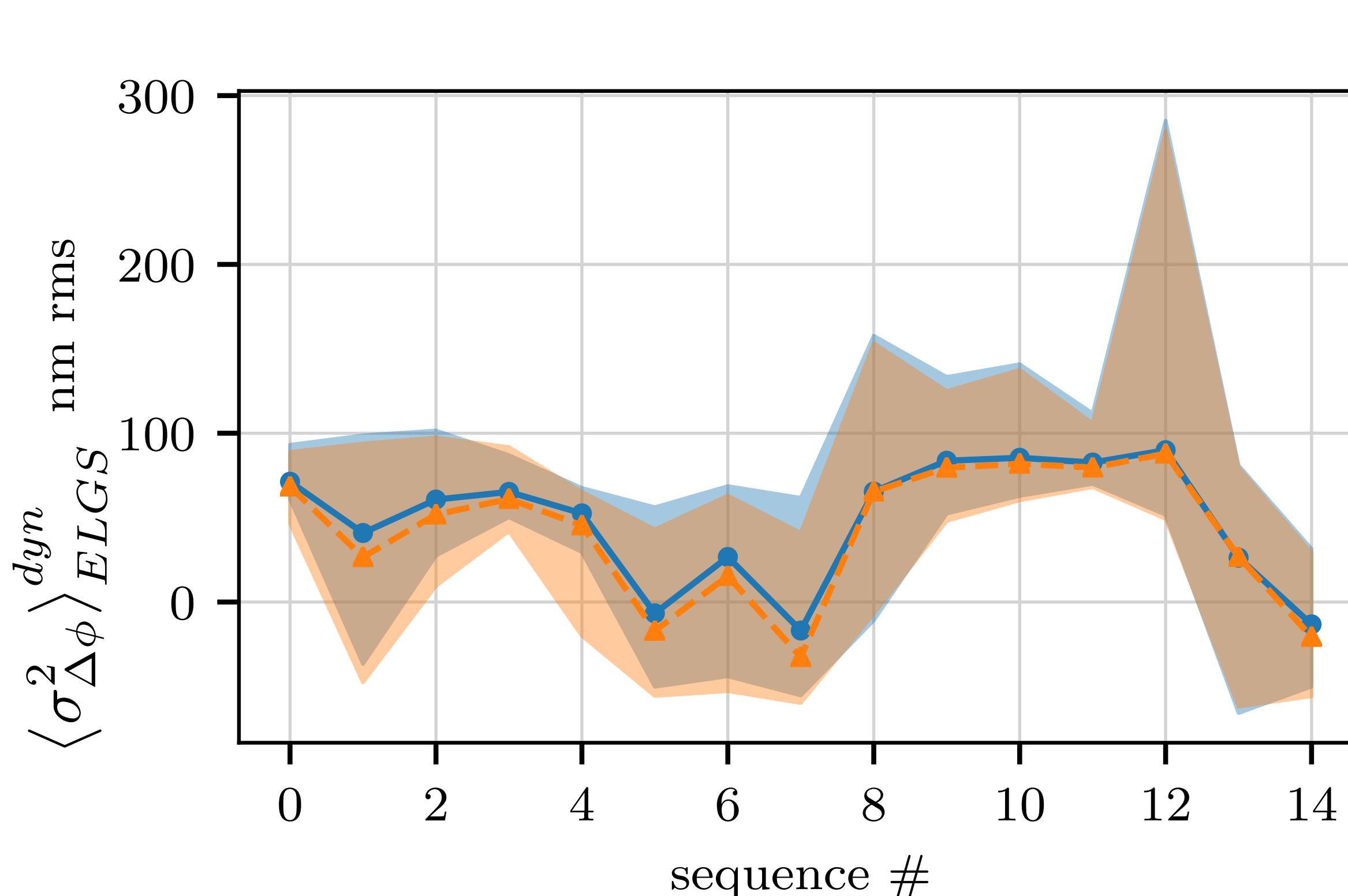


$$\langle \sigma_{\Delta\phi}^2 \rangle_{ELGS}^{dyn}$$

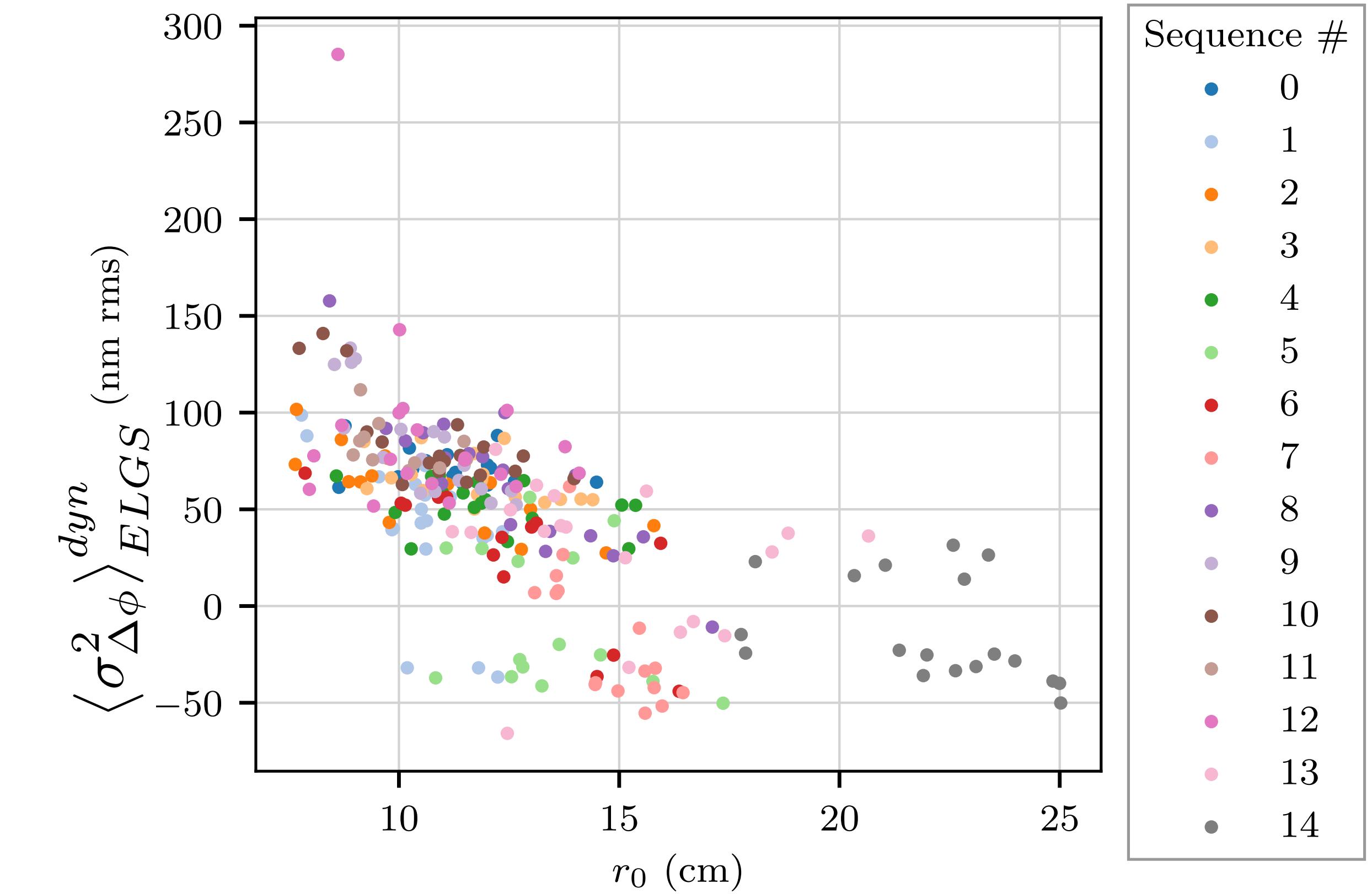
DYNAMIC RESIDUAL ERROR



DYNAMIC RESIDUAL ERROR

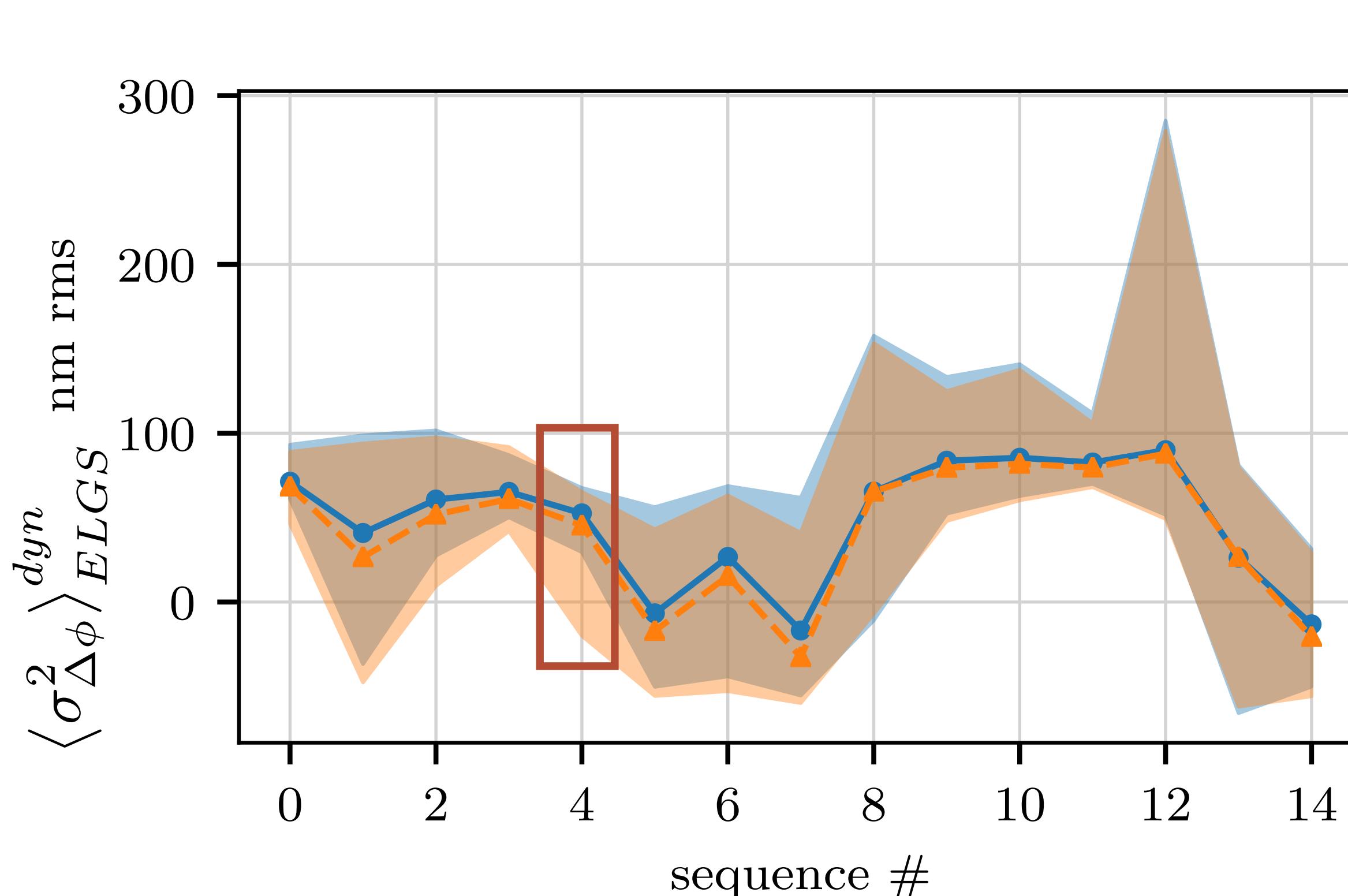


● COG
▴ CORR

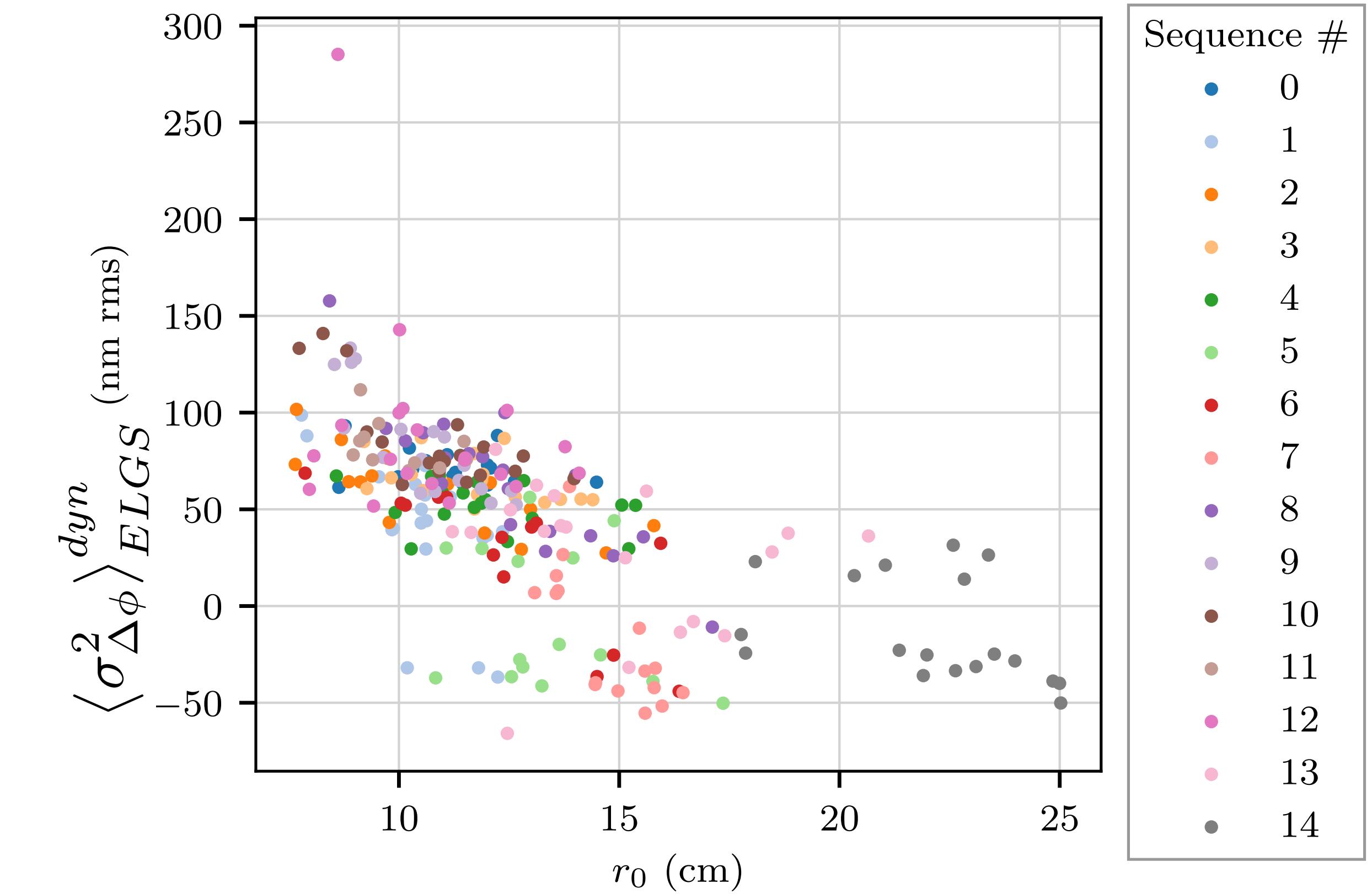


- Residual error reaches 0 nm rms
- Variations linked to seeing

DYNAMIC RESIDUAL ERROR

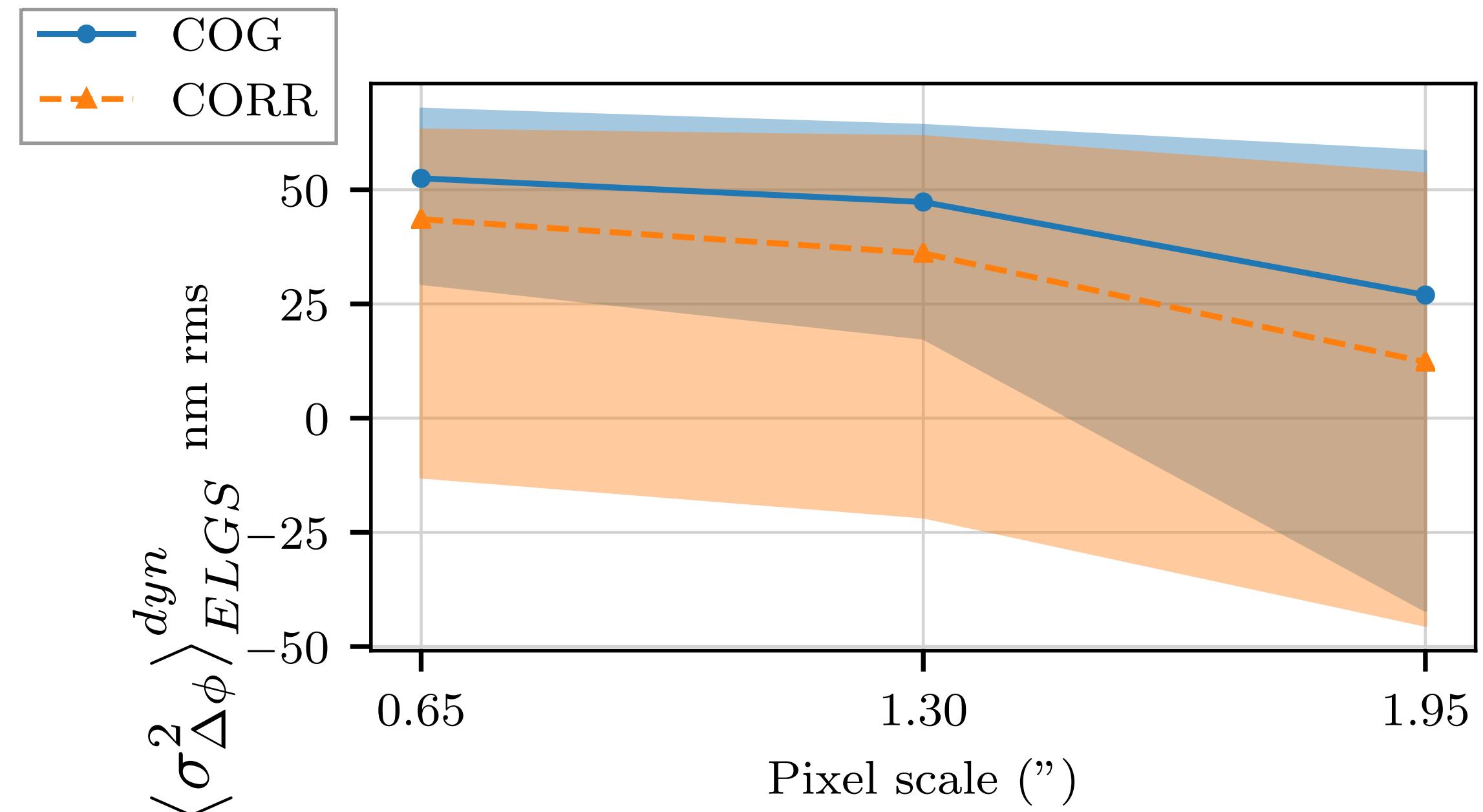
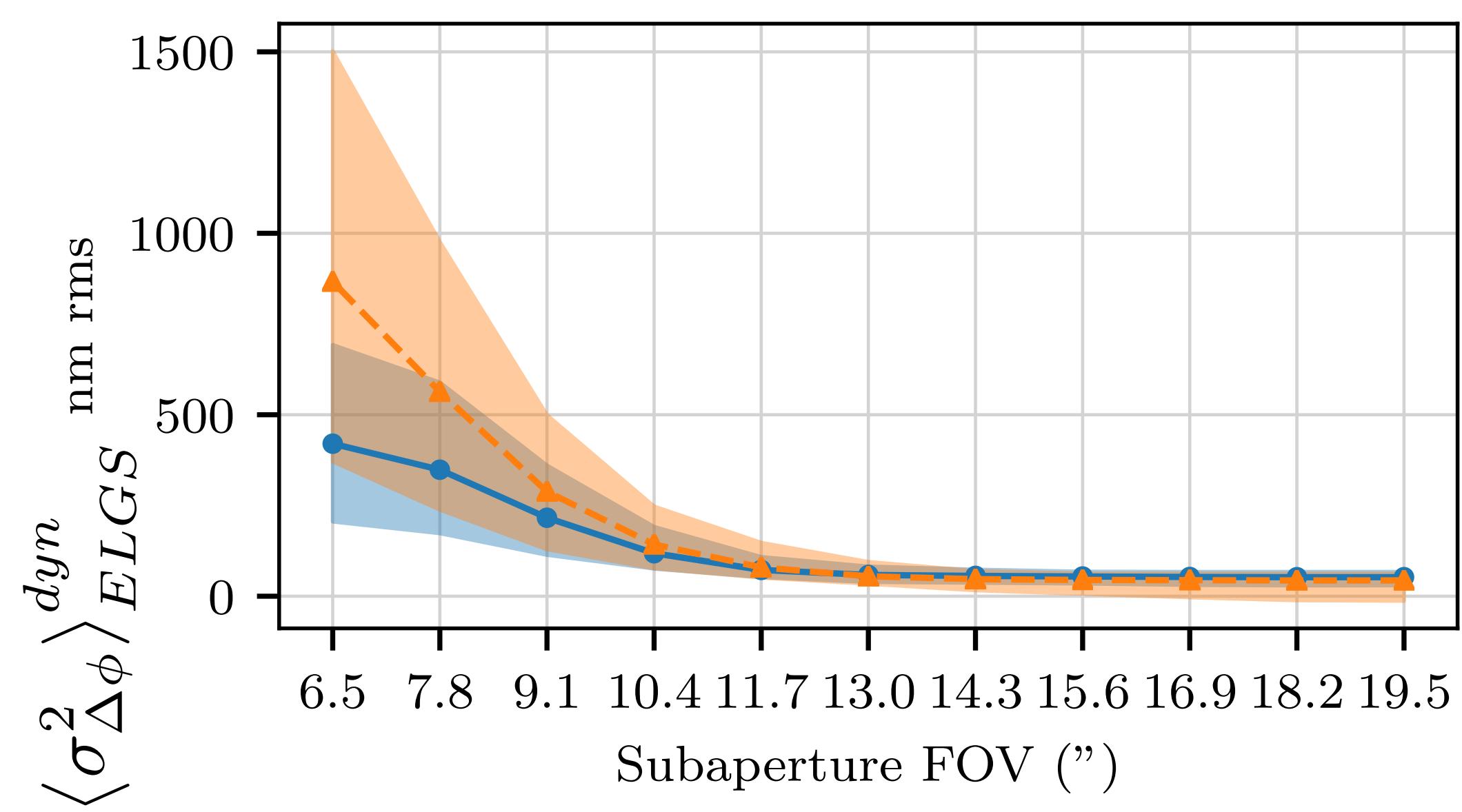


—●— COG
—▲— CORR



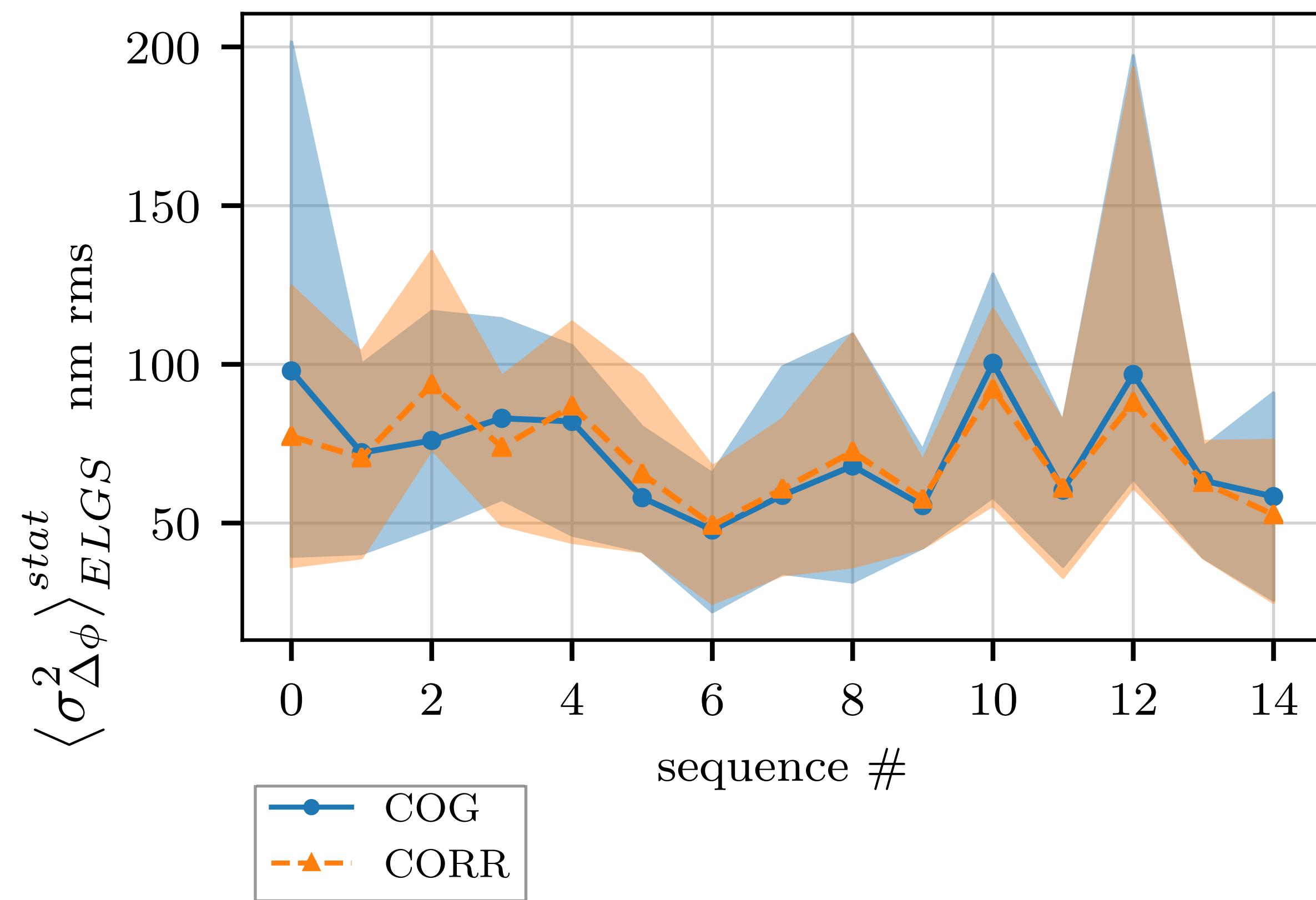
- Residual error reaches 0 nm rms
- Variations linked to seeing

DYNAMIC RESIDUAL ERROR

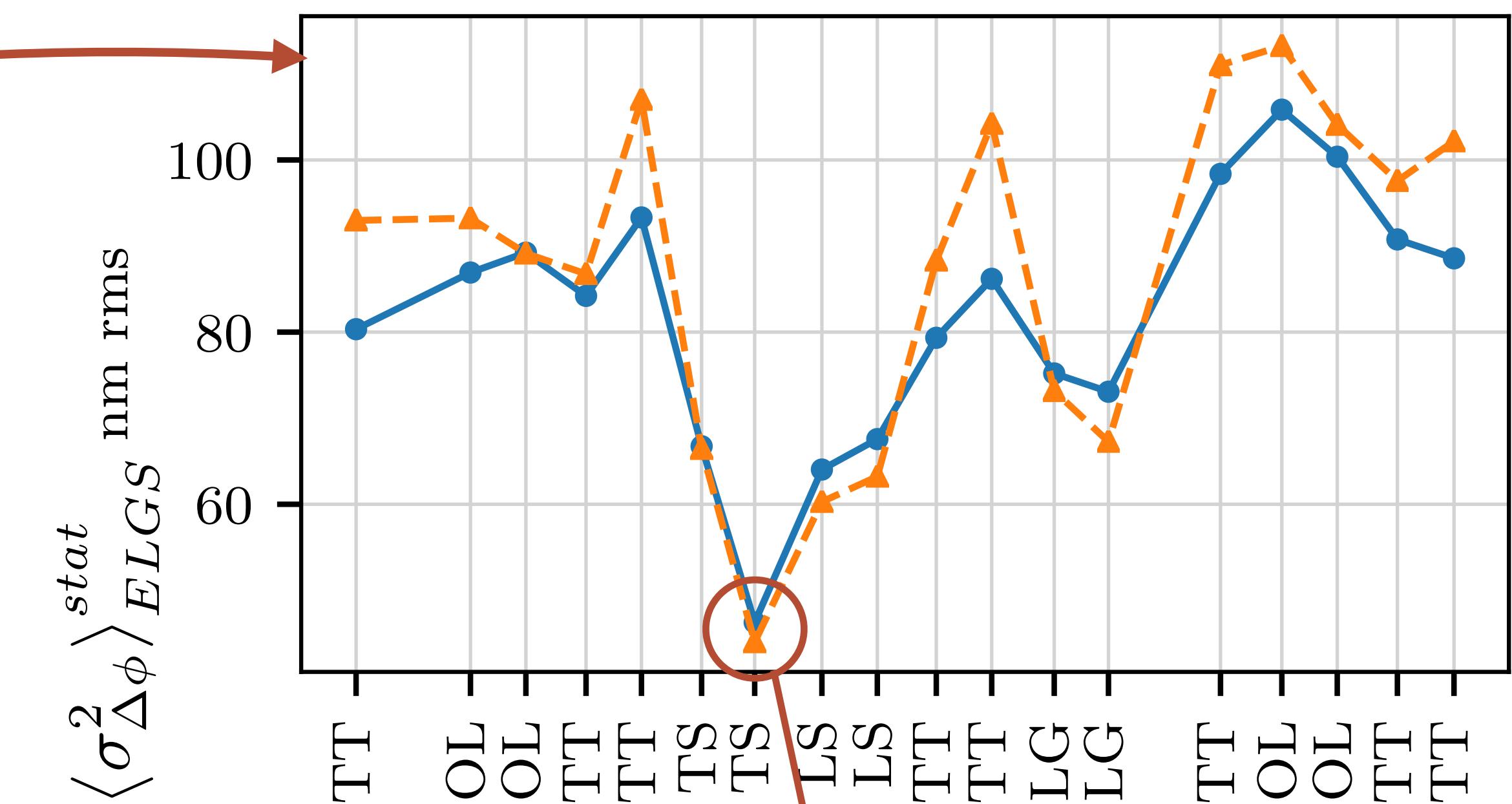
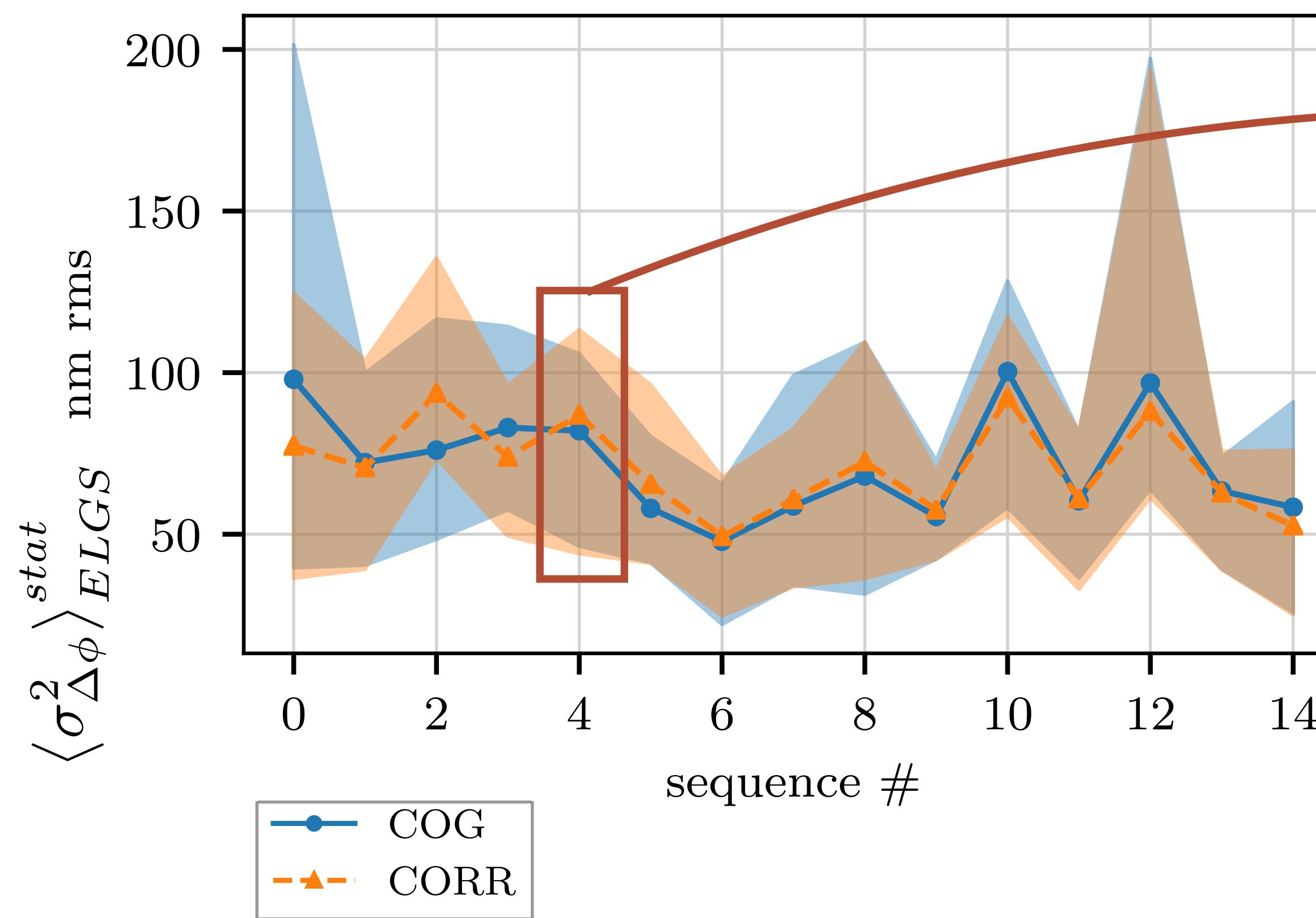


- Error rises when the FOV reduces
- Error constant with pixel scale increase

STATIC RESIDUAL ERROR

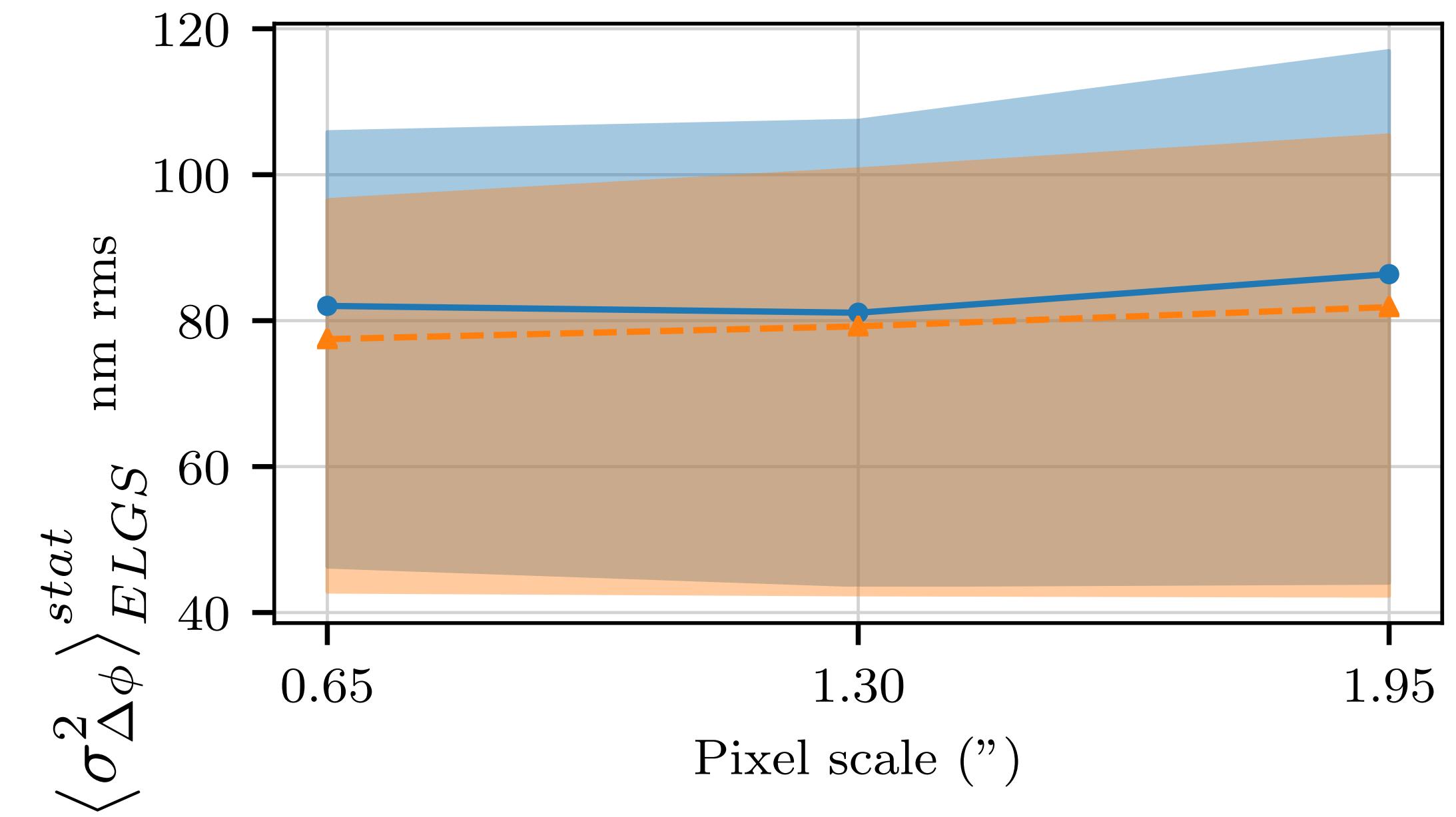
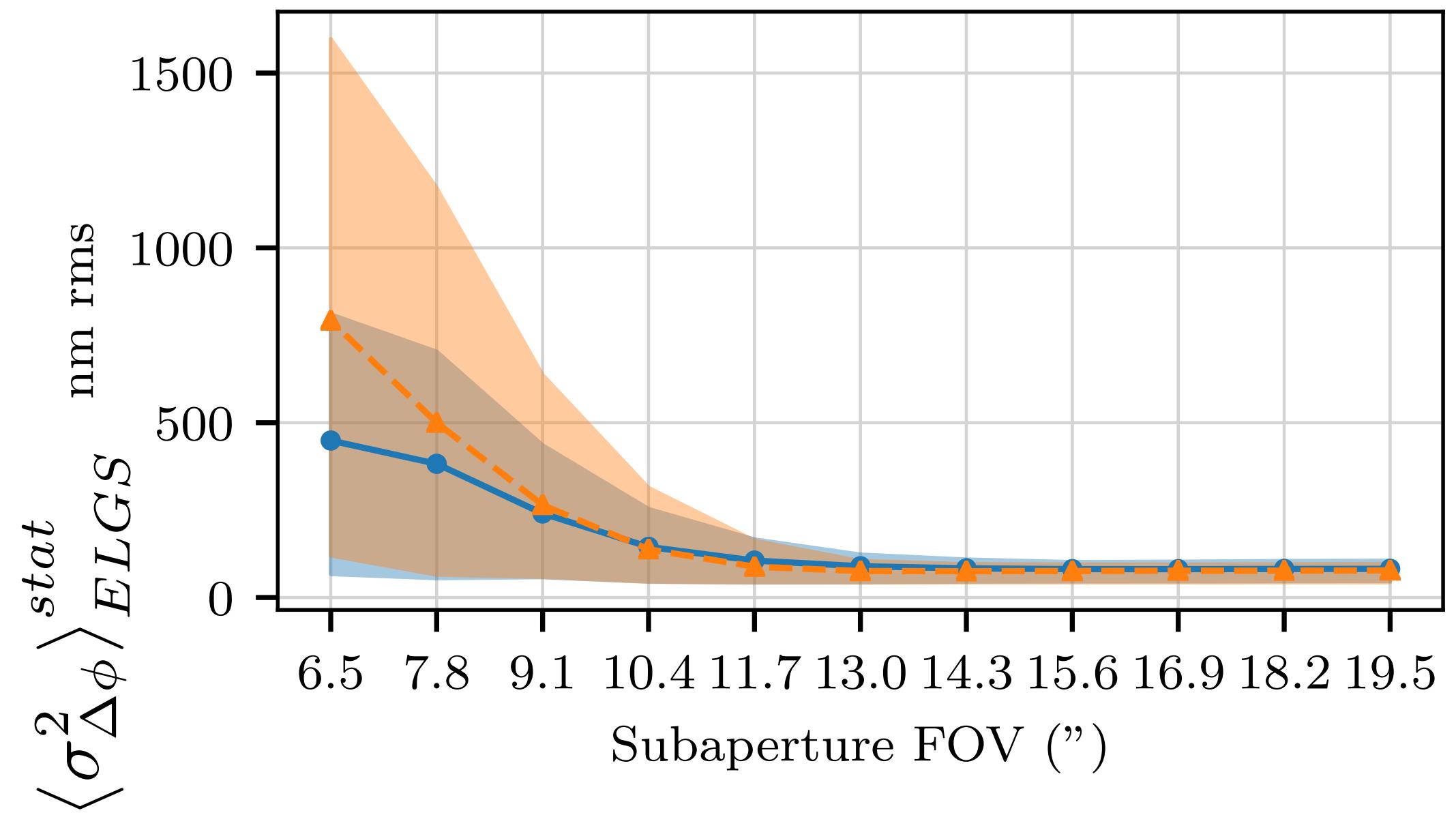


STATIC RESIDUAL ERROR



*On sky LGS WFS
reference slopes
measurement*

STATIC RESIDUAL ERROR



- Error rises when the FOV reduces
- Error constant with pixel scale increase

CONCLUSIONS AND PROSPECTS

- Conclusions:
 - Noise behaviour consistent with theory
 - Dynamic residual error close to 0 nm rms
 - Need TS to calibrate static terms on sky
 - Large pixels scales don't impact the residual errors
 - Truncation of the spots leads to increase of residual errors
- Prospects:
 - Deeper analyses of the residual errors
 - Full pupil simulations

Thank you for your attention

