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An on-line turbulence profiler for the VLT's adaptive optics facility (AOF)

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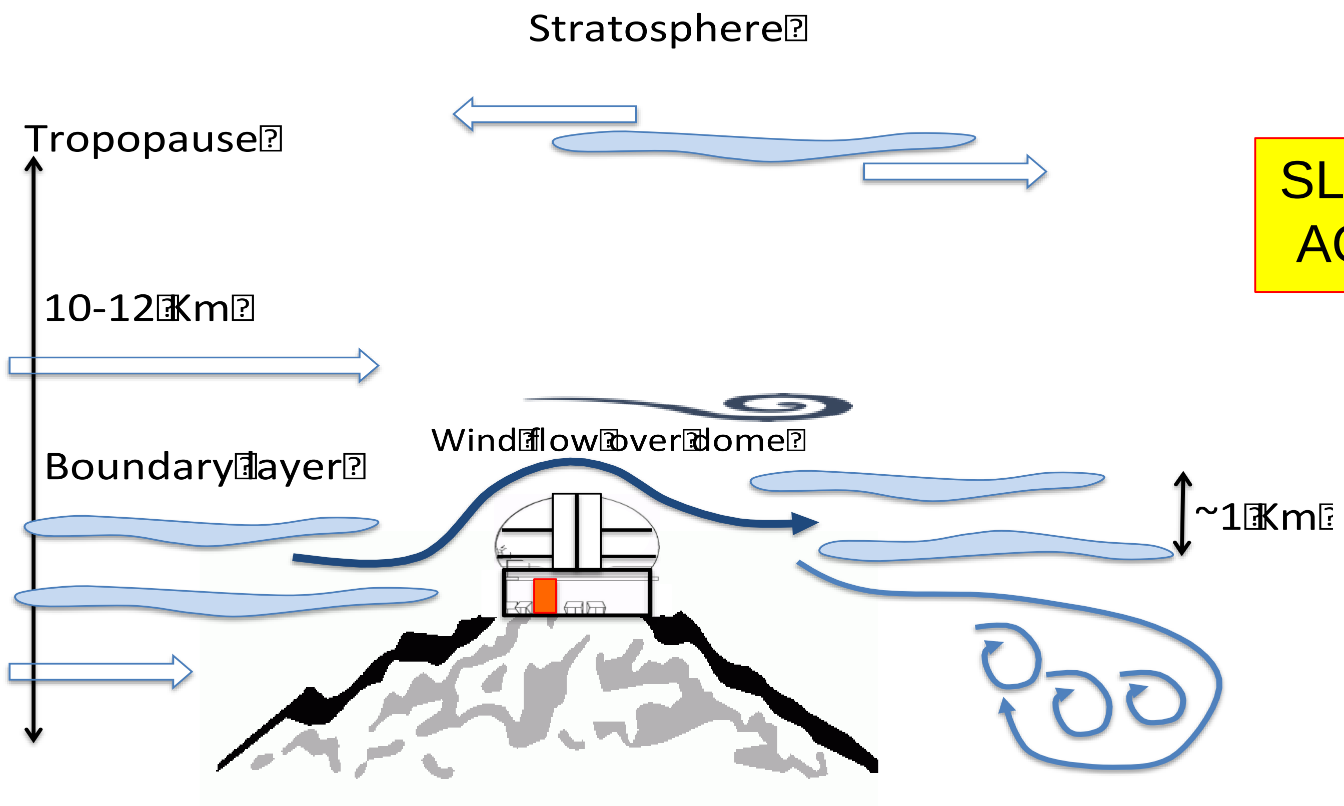
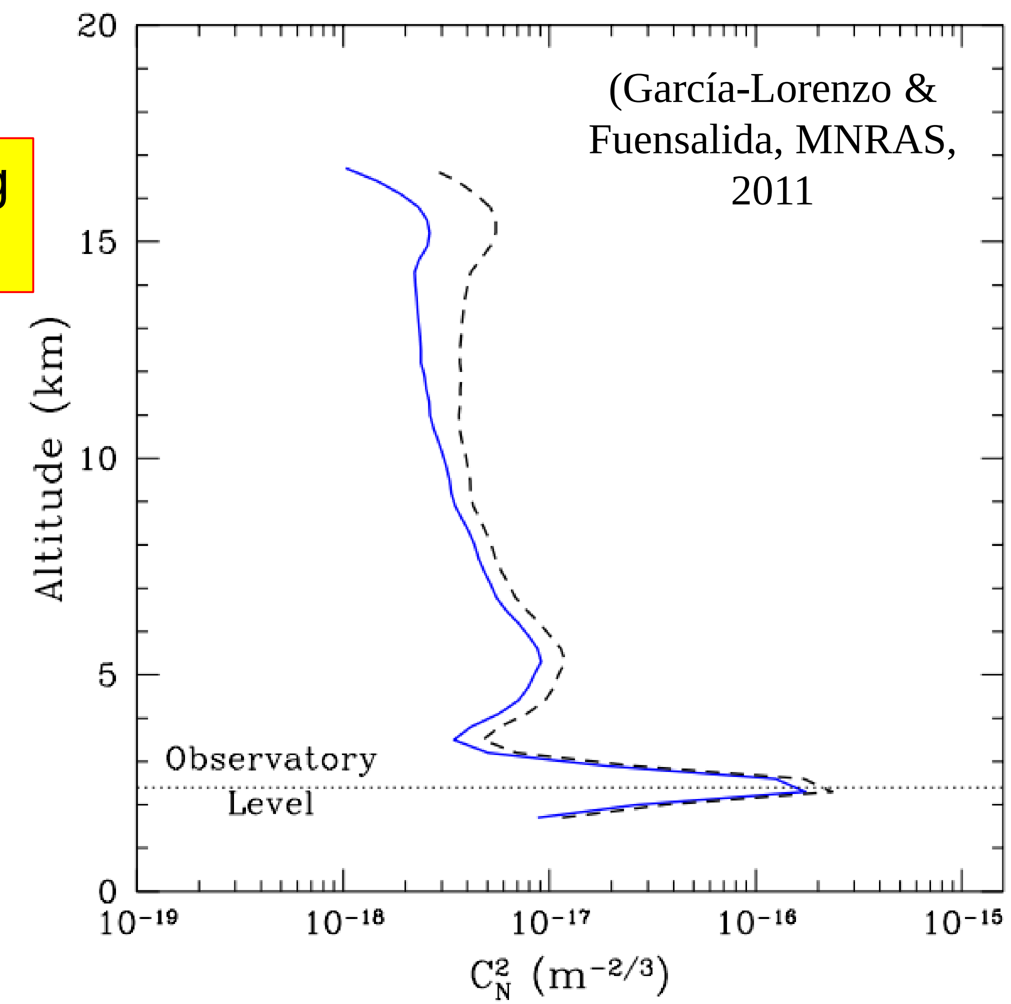
“Embedded” (on-line) turbulence profilers

(profilers using WFS of telescopes’ facility instruments)



SLODAR using AO WFS data

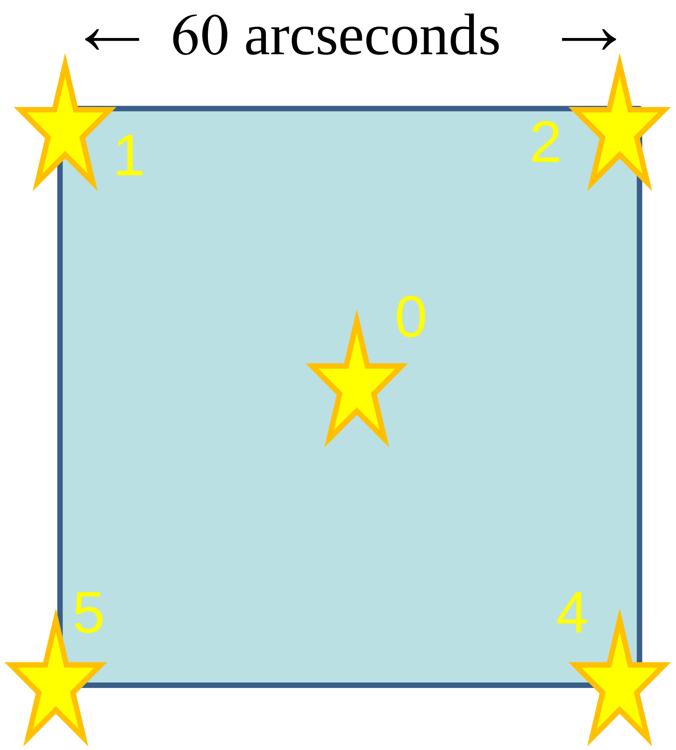


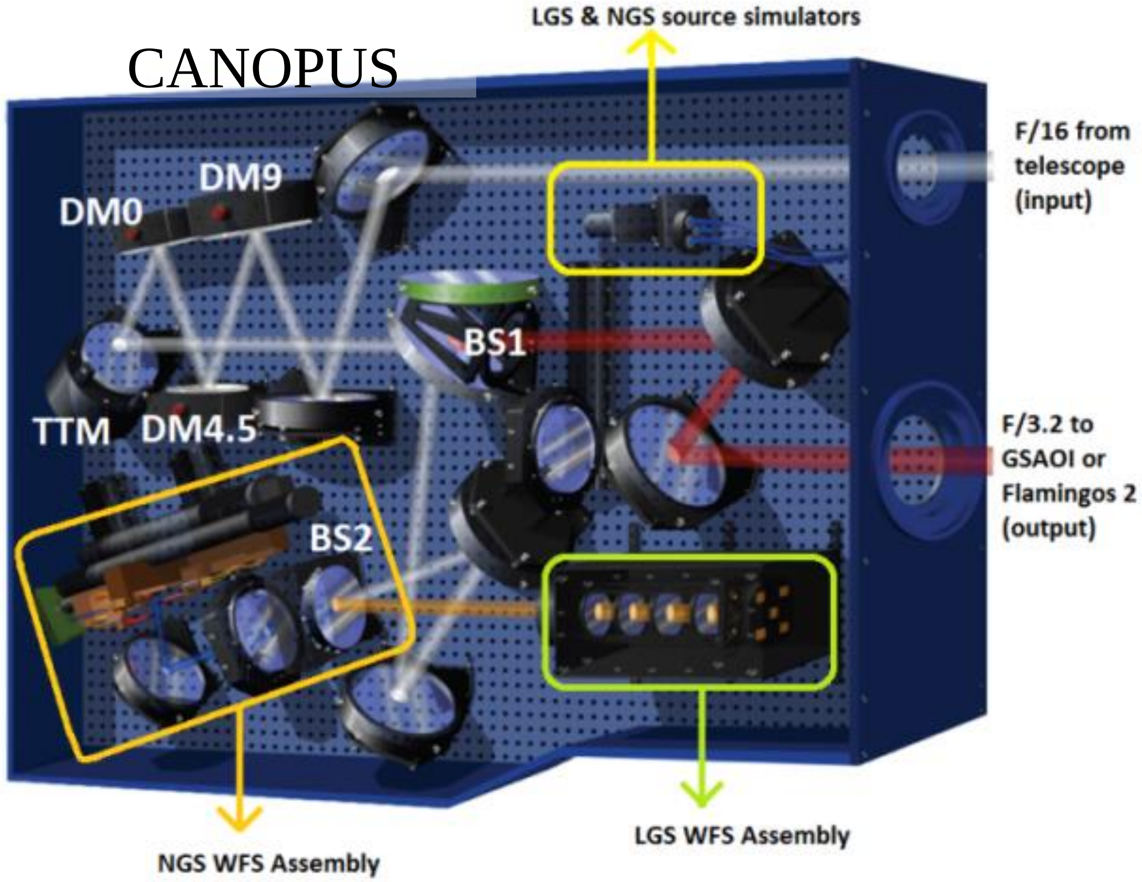
Motivation for embedded profilers:

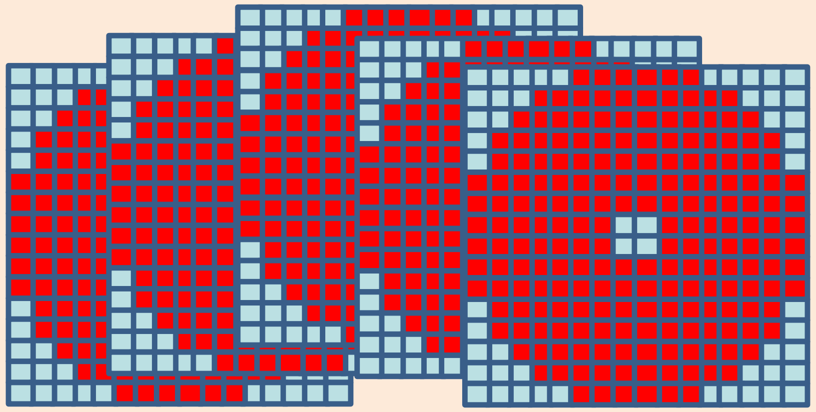
- An on-line profiler can help to characterize the performance of the AO system
- Predictive control via estimation of wind speed and wind direction
- Gather turbulence statistics of the site
- Characterization of the telescope environment (dome seeing, vibrations, mis-reg.)
- Optimize tomographic reconstructors and conjugation altitudes for DMs according to Cn^2 (h), L_0(h), wind, dome seeing, etc.

A Profiler for GeMS (Gemini-South MCAO System)

(The beginning)







5 WFSs

- 16x16 grid Shack-Hartmann
- 204 active subapertures (total: 1020)
- sampling rate <= 800 Hz

3 DMs

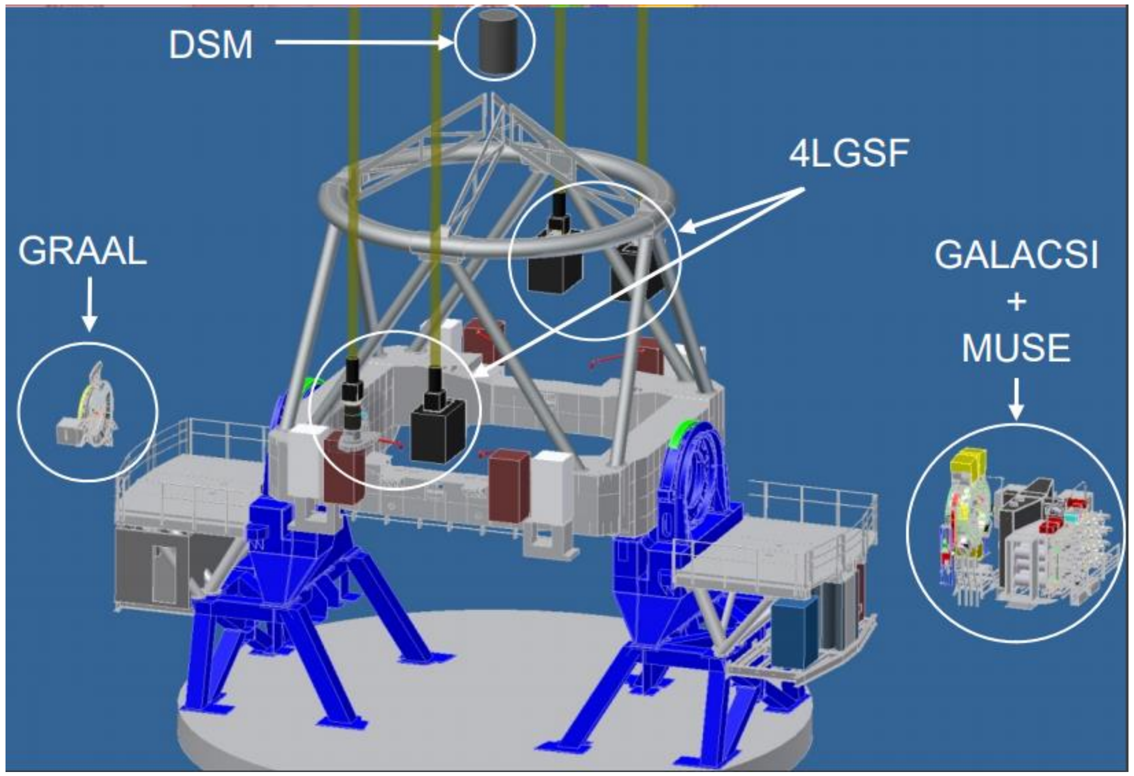
- 917 actuators in total
- 684 valid actuators (seen by the WFSs)
- 233 extrapolated actuators

Problems with GeMS profiler

- Resolution in altitude limited by subaperture diameter.
- Strong effect of $L_0(h)$ on accuracy, specially for layers near the ground or system operating under strong dome turbulence conditions.
- When trying to isolate individual layers, there are multiple functions to deconvolve the cross-correlation image (depending on height and outer-scale), so it is not a practical approach.
- Long processing time (*t* > 7 mins).

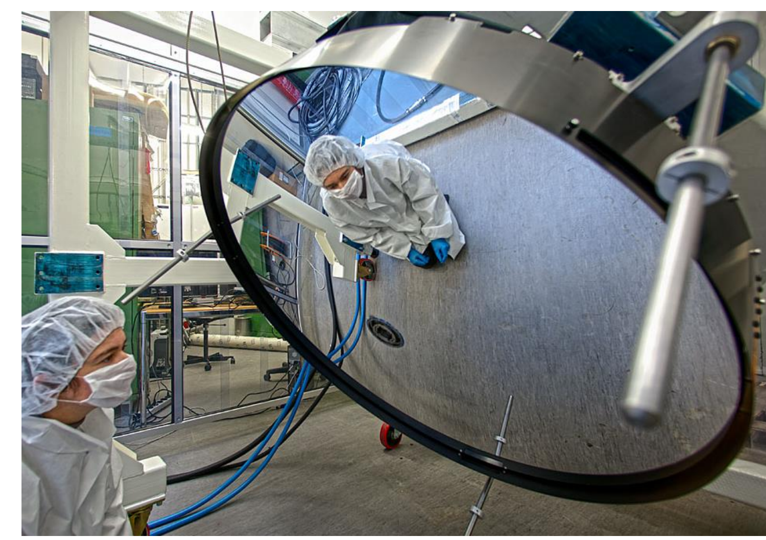
Main conclusion: including $L_0(h)$ in every step of the profiling process **is a must**.

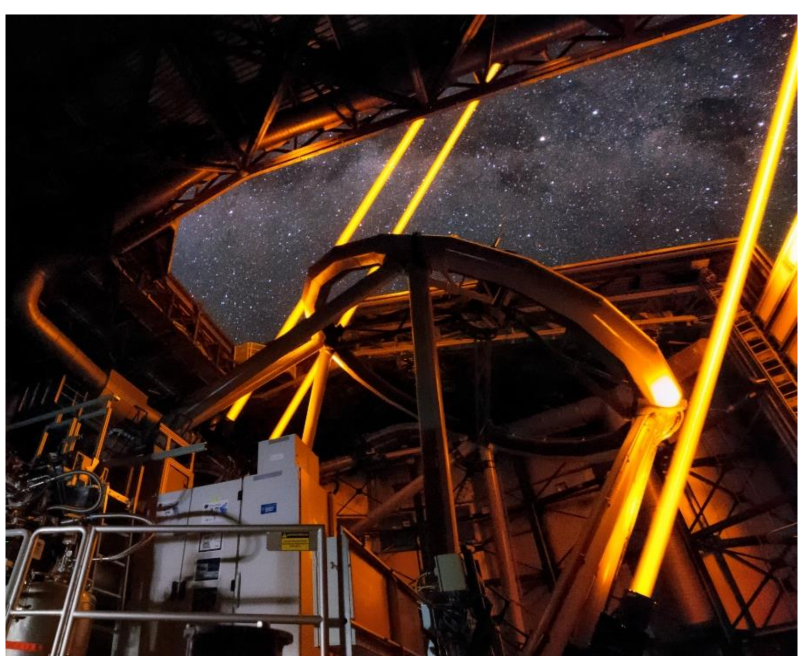
An On-line Profiler for ESO's Adaptive Optics Facility (AOF)

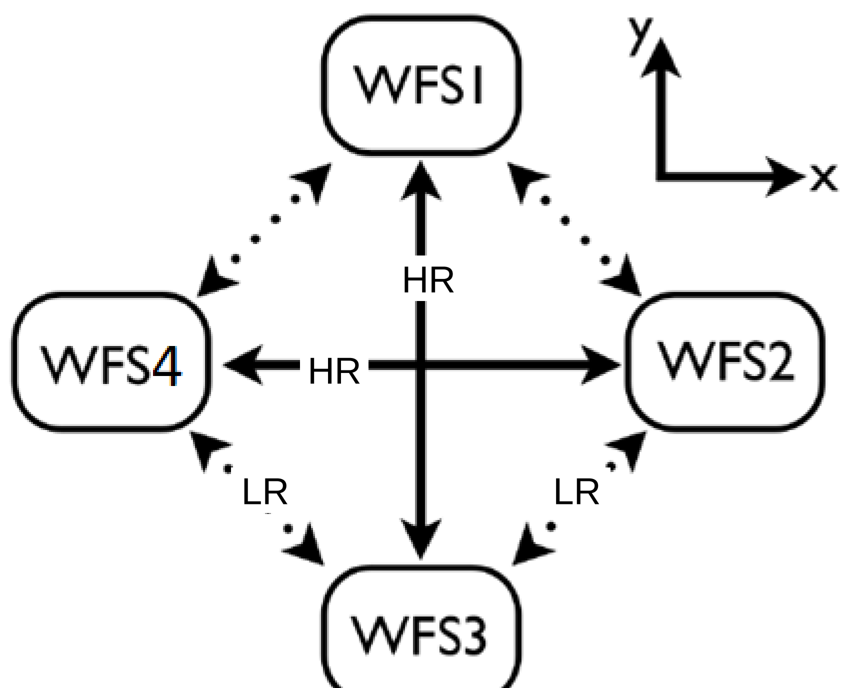


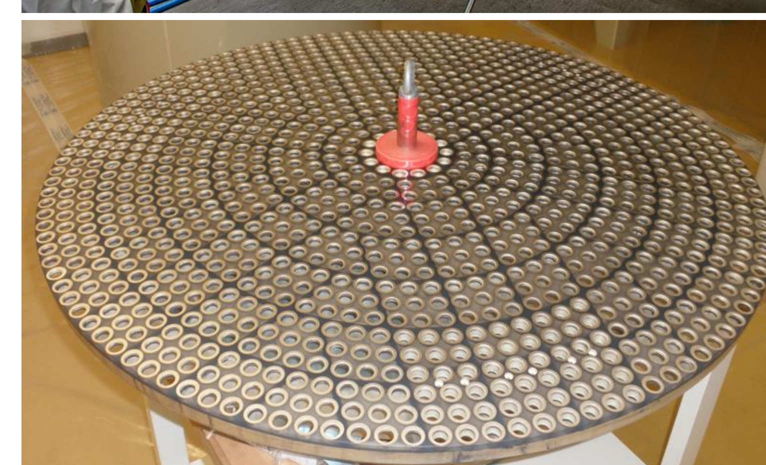
AOF main characteristics:

- 3 operational modes: GALACSI x 2 and GRAAL
- 4 sodium laser asterism
- WFSs: 40 x 40 subapertures (20cm diameter)
- Deformable secondary mirror (1170 actuators)









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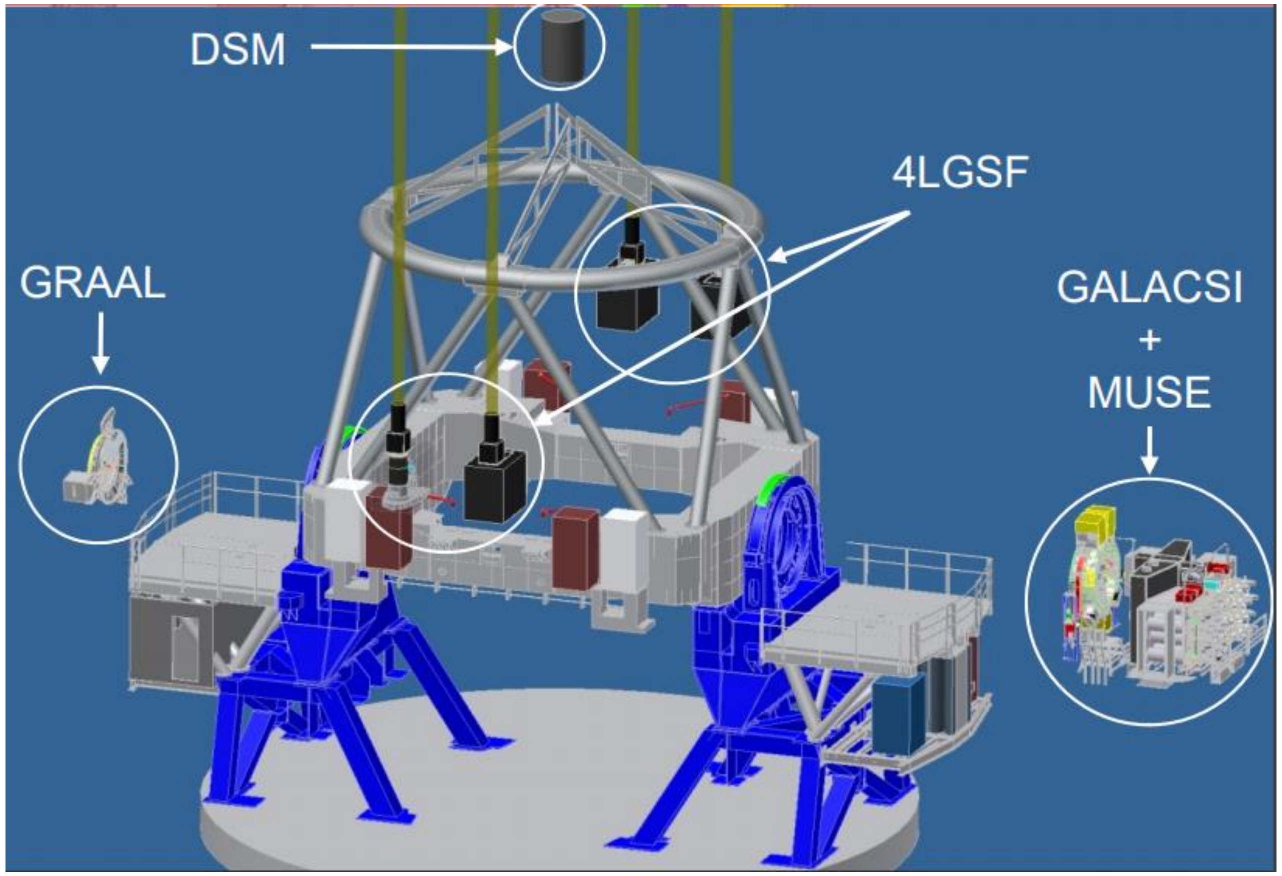
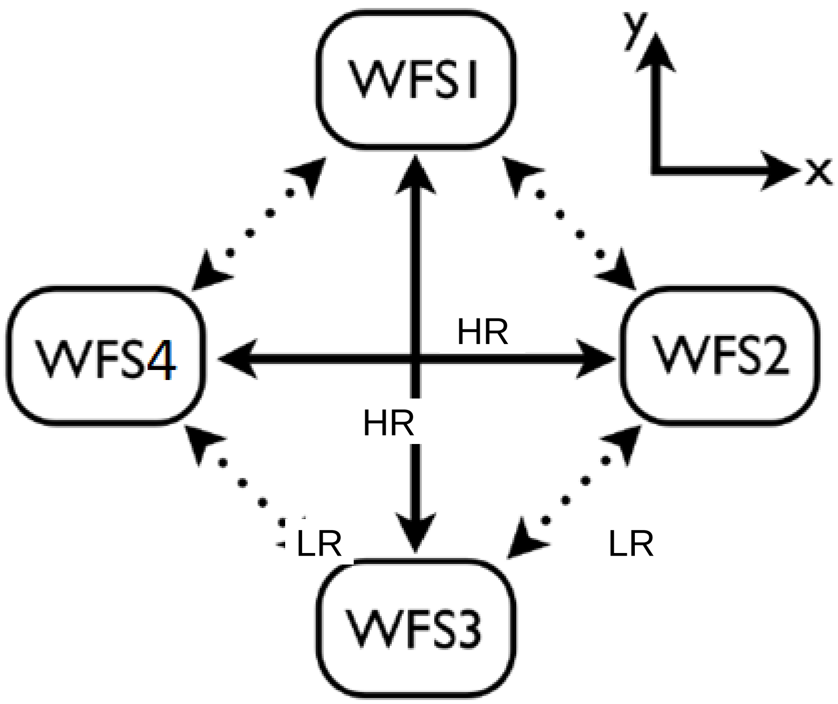


GALACSI is the AO system developed to increase the performance of the MUSE instrument, a panoramic integral-field spectrograph working at visible wavelength.

GRAAL feeds HAWK-I, a NIR imager (0.85 - 2.5 µm). The science field of view is 7.5 arcmin square. GRAAL compensates for the lowest layers of the atmospheric turbulence (up to ~ 2 km.

ESO’s Adaptive Optics Facility (AOF)



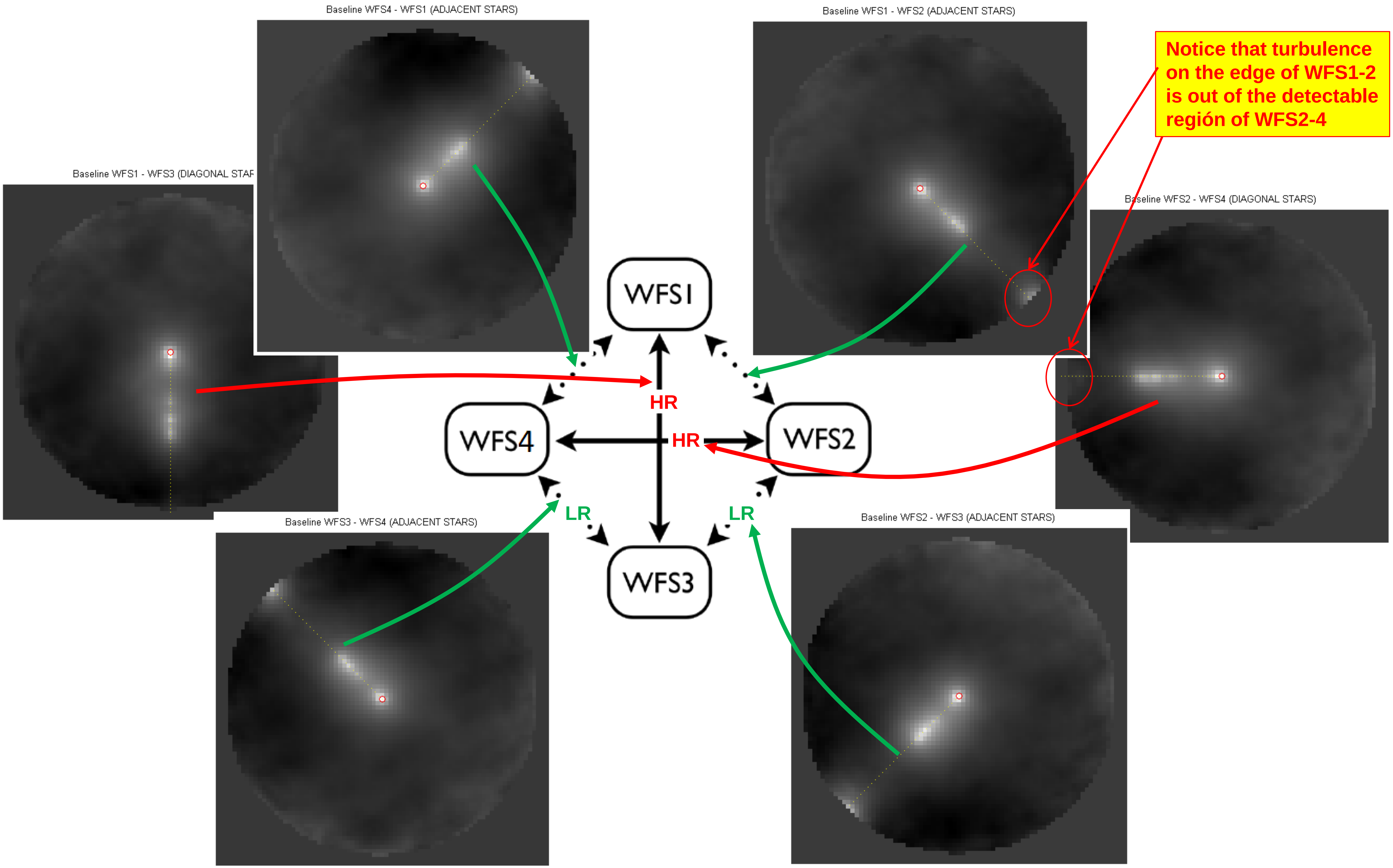
AOF main characteristics:

- 4 sodium laser asterism
- WFSs: 40 x 40 subapertures, 20cm diameter
- 2 altitude resolutions (star separations)
- Deformable mirror for GLAO and LTAO
- 3 operational modes: GALACSI x 2 and GRAAL

	Low Resolution (LR) Baseline			High Resolution (HR) Baseline		
AOF Mode	θ_{LR}	$h_{max,LR}$	δh	θ_{HR}	$h_{max,HR}$	δh
	[“]	[km]	[km]	[“]	[km]	[km]
GAL NFM	14.1	-	-	20	24.5	1.7-0.9
GAL WFM	90.6	12.4	0.55-0.41	127.8	9.14	0.28-0.22
GRAAL	492	2.49	0.102-0.096	696	1.76	0.05-0.049

Range is due to the LGS cone effect

The method: Cross-Correlations of Pseudo Open Loop Slopes (POLS) for pairs of WFSs

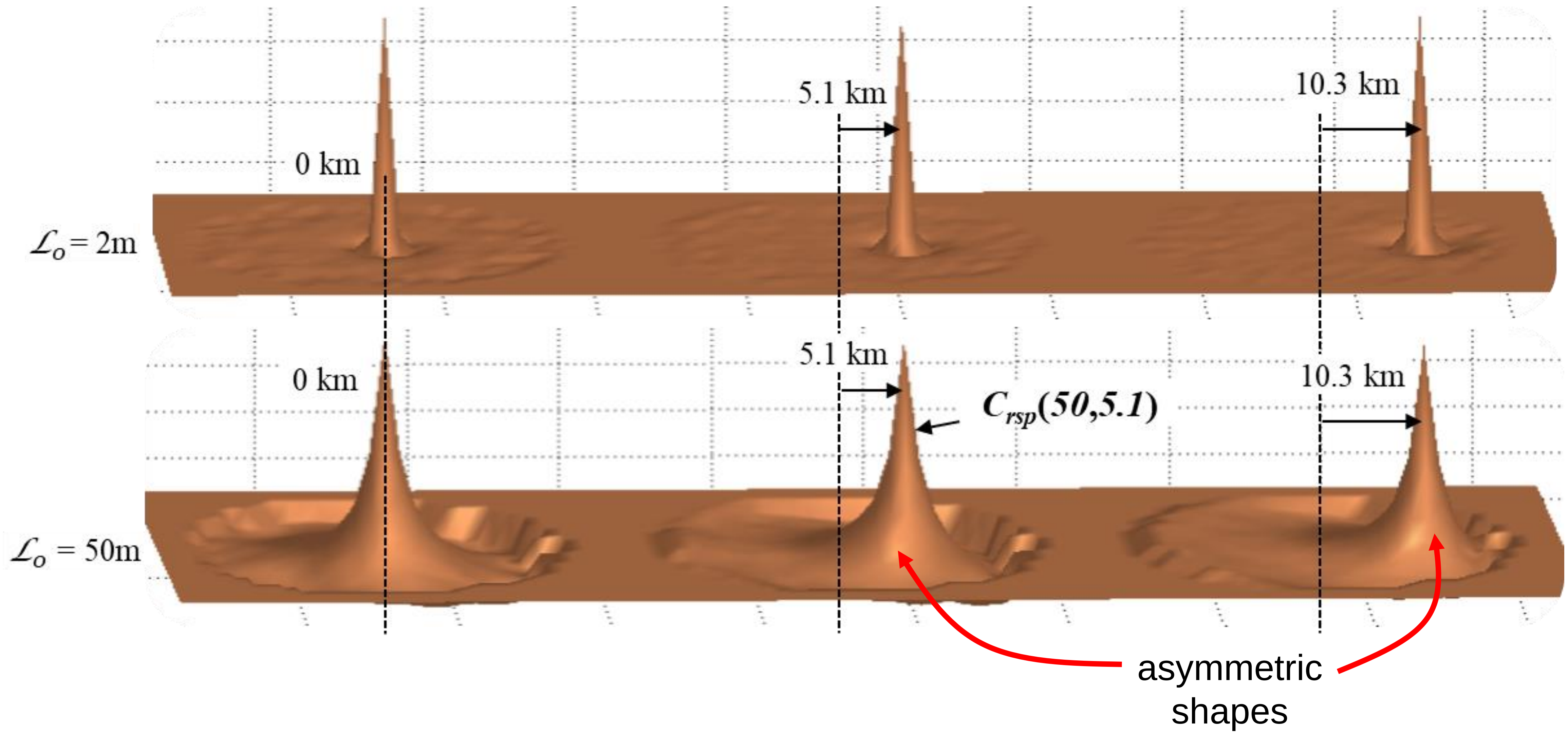


The method: Reference or response functions

The first step in the profiling technique is to generate (only once) the reference functions: cross-correlations between pairs of WFSs POLS for different values of layer height and outer scales.

A grid of 33 altitude divisions and 12 outer-scale values is constructed

- Discrete values for $\boldsymbol{h}$: $\{1{:}N\}\cdot\Delta h$, N is chosen ≈ 80% of maximum number of bins
- Discrete values for $\mathcal{L}_o$: {1, 2, 3, 4, 6, 8, 11, 16, 22, 32, 50, 100}

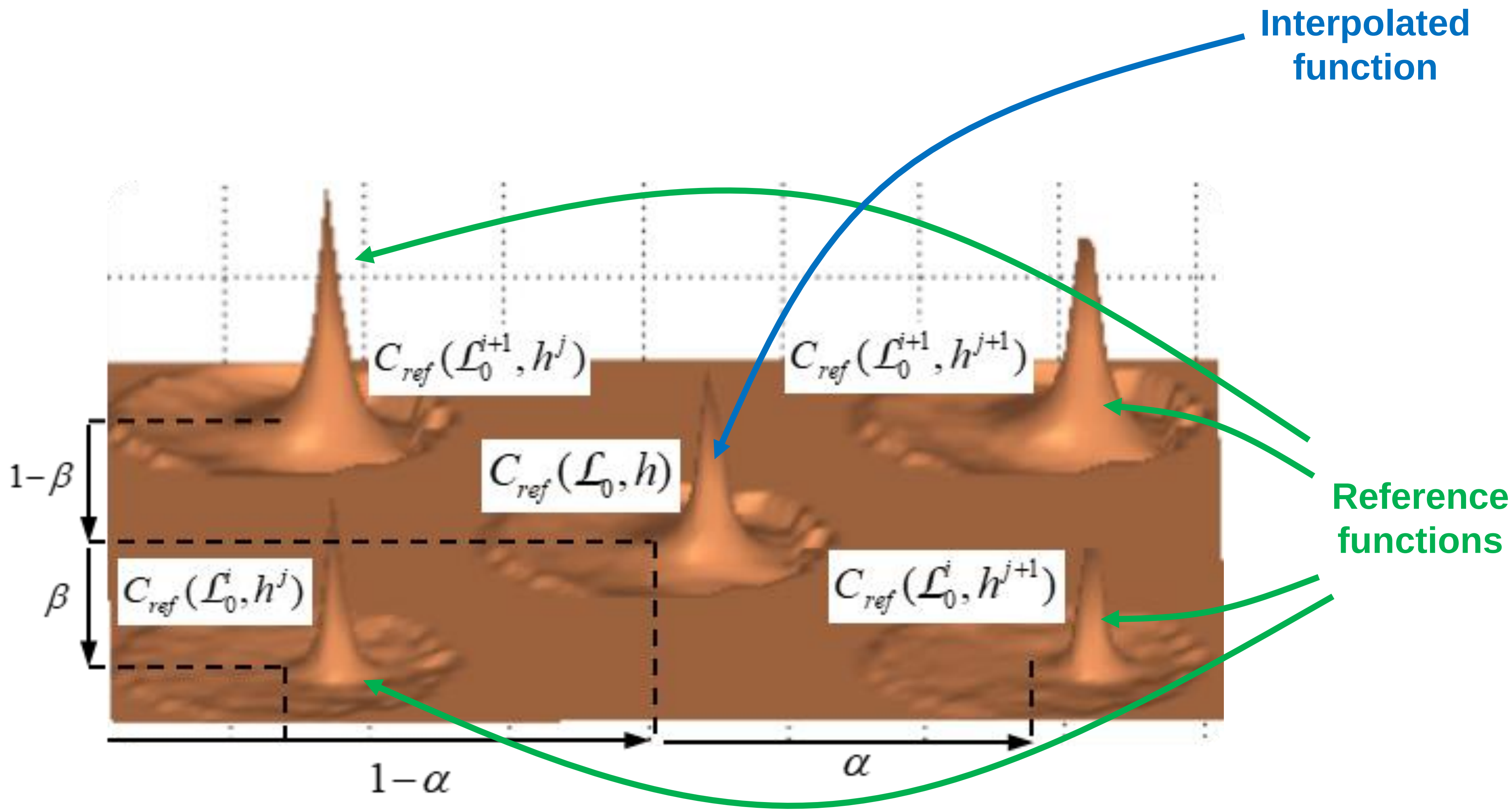


Guesalaga et al, MNRAS, 2017

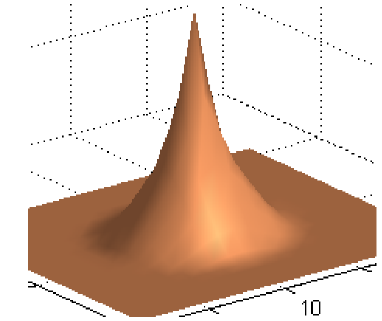
The method: Search for minimum using interpolated functions from reference grid

Search for minimum:
$$\underset{\omega,\mathcal{L}_0,h}{Min}\left\langle\left(C_{meas}-\sum_{i=1}^{N_Z}\omega_i\cdot C_{ref}^{i}(\mathcal{L}_0,h)\right)^2\right\rangle$$

Interpolation:
$$C_{ref}(\mathcal{L}_0,h)=\left((1-\alpha)\cdot C_{ref}(\mathcal{L}_0^i,h^j)+\alpha\cdot C_{ref}(\mathcal{L}_0^{i+1},h^j)\right)\cdot(1-\beta)+\left((1-\alpha)\cdot C_{ref}(\mathcal{L}_0^i,h^{j+1})+\alpha\cdot C_{ref}(\mathcal{L}_0^{i+1},h^{j+1})\right)\cdot\beta$$

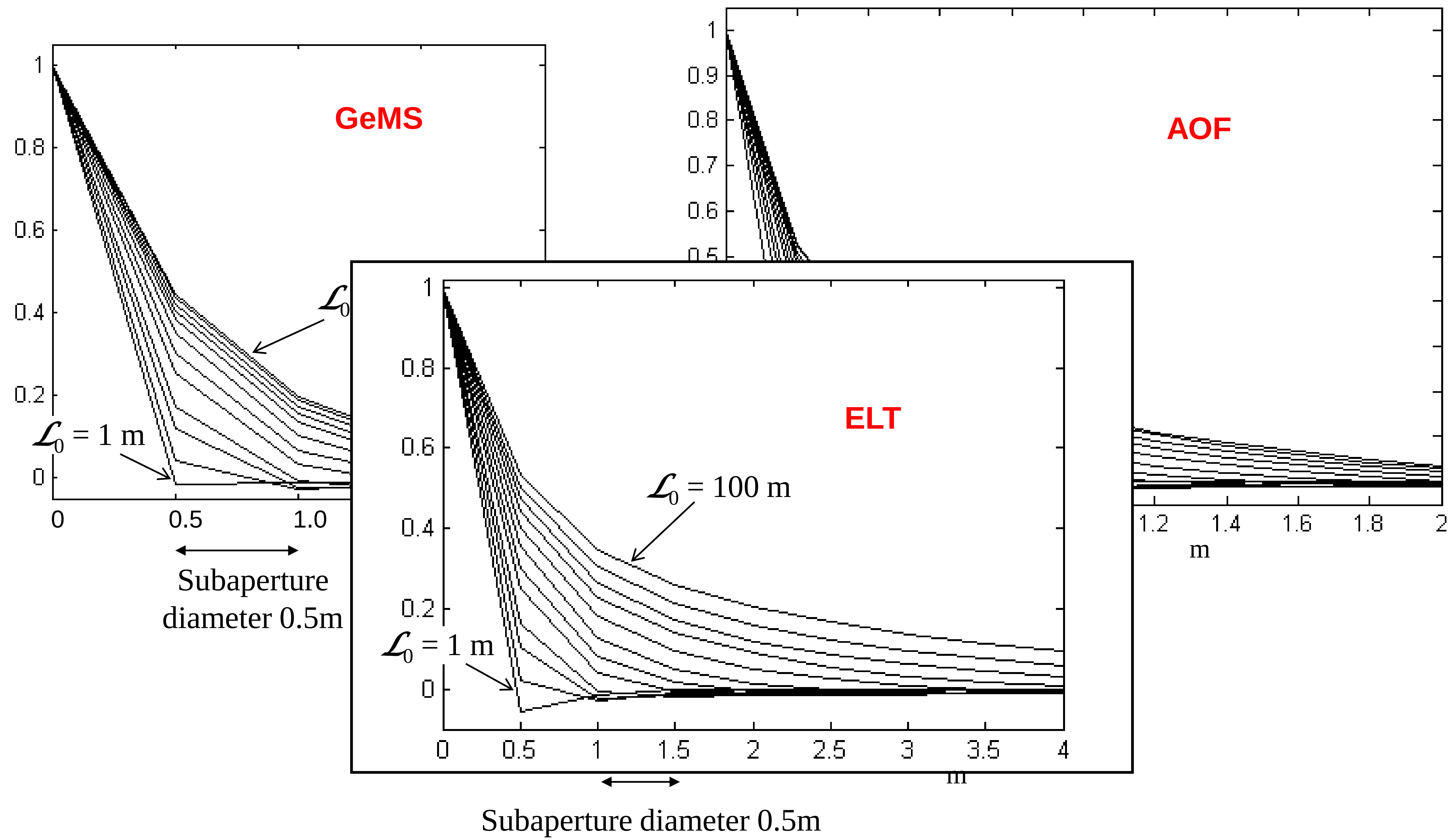


The method: Choice of $\mathcal{L}_o(h)$ for the response functions in the reference grid

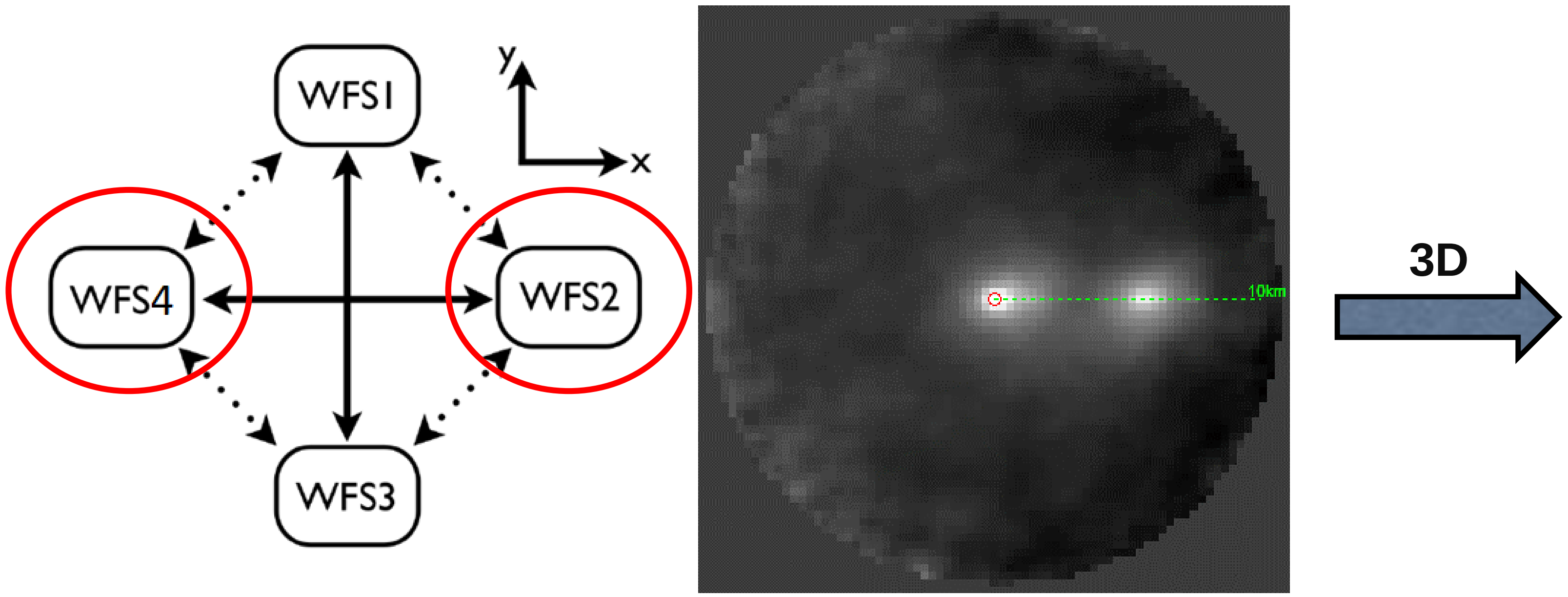


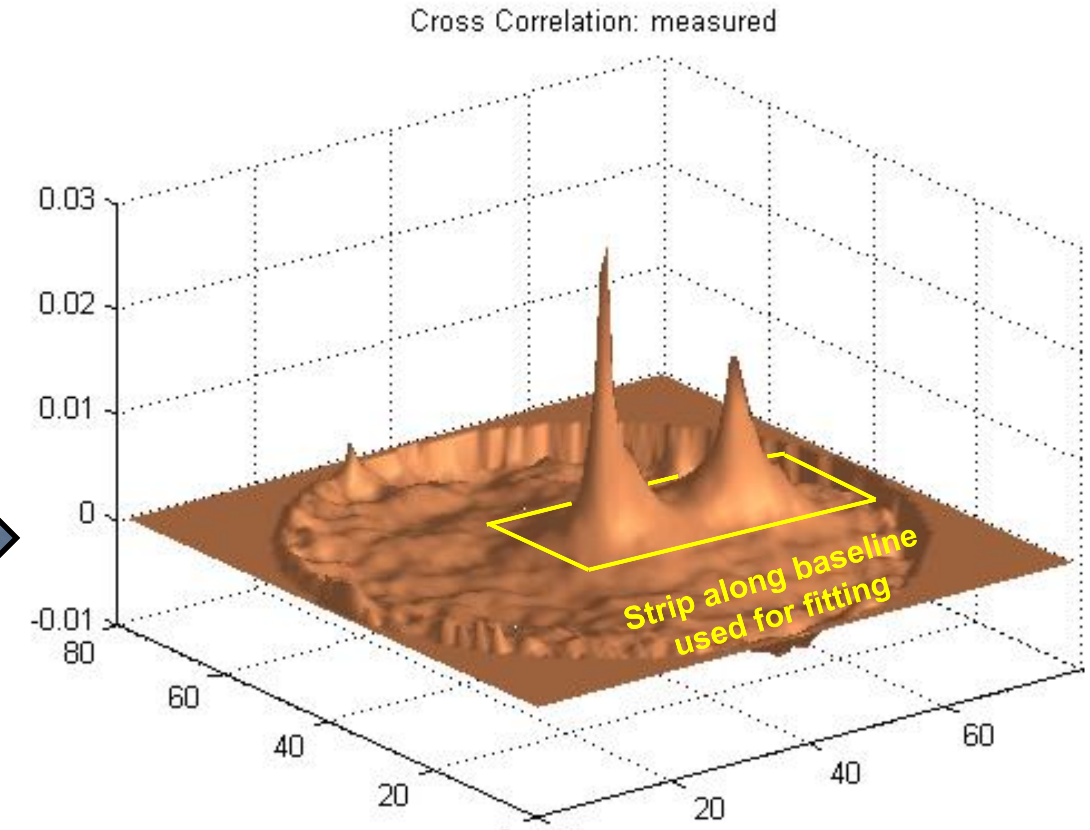
Discrete values for $\mathcal{L}_o$: {1, 2, 3, 4, 6, 8, 11, 16, 22, 32, 50, 100}

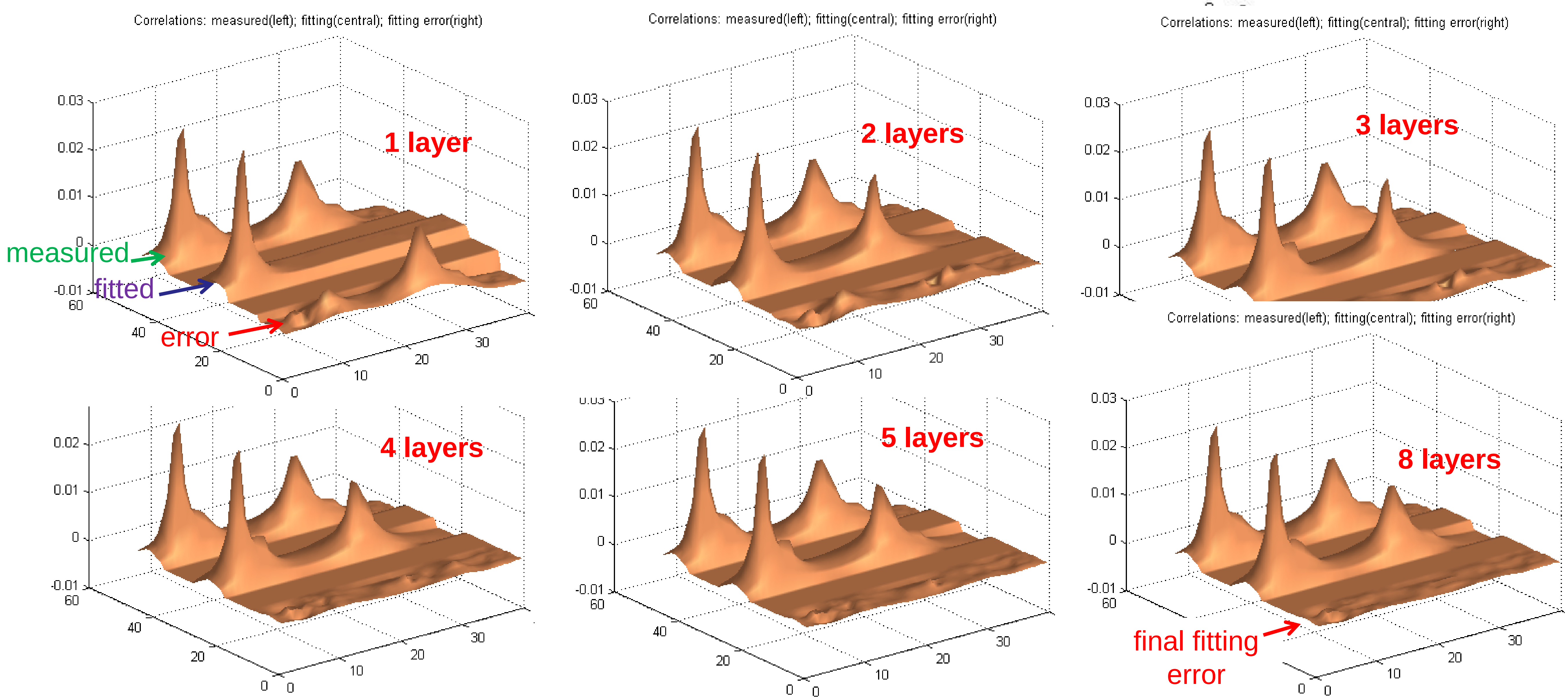
Discrete values for $\boldsymbol{h}$: $\{1{:}N\}\cdot\Delta h$, N is chosen ≈ 80% of maximum number of bins



The method: Fitting sequence

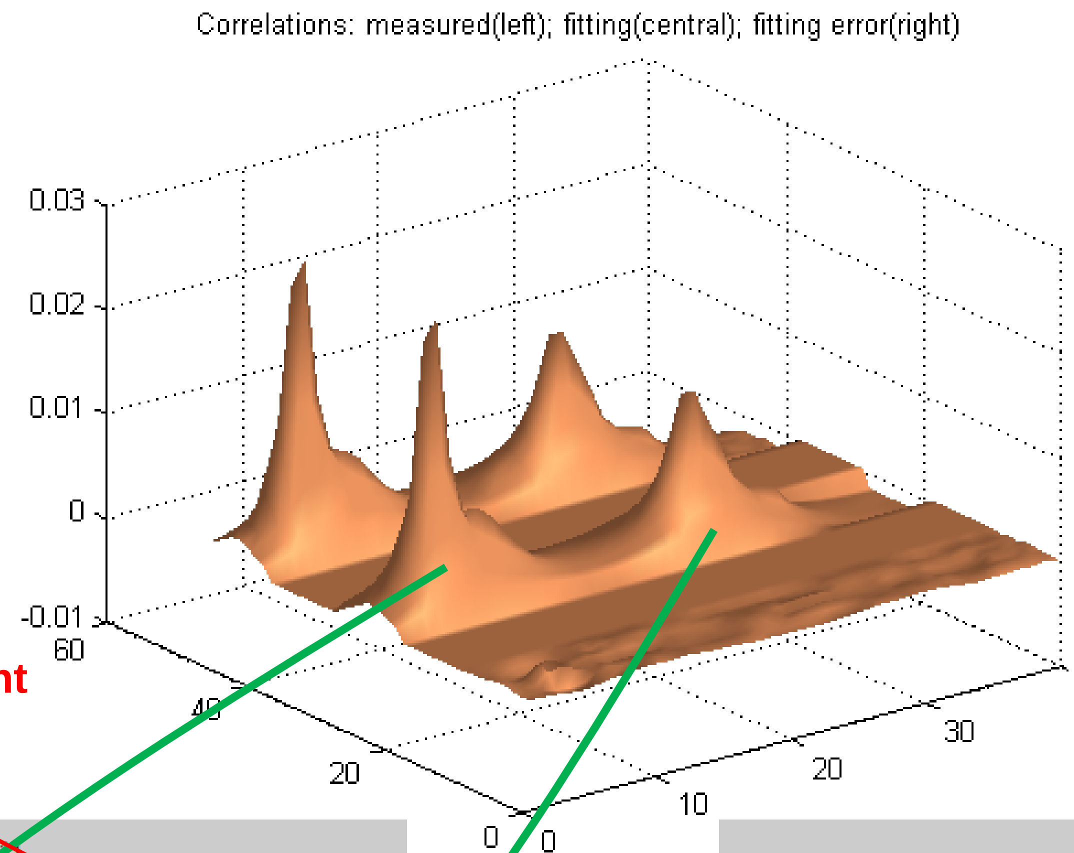


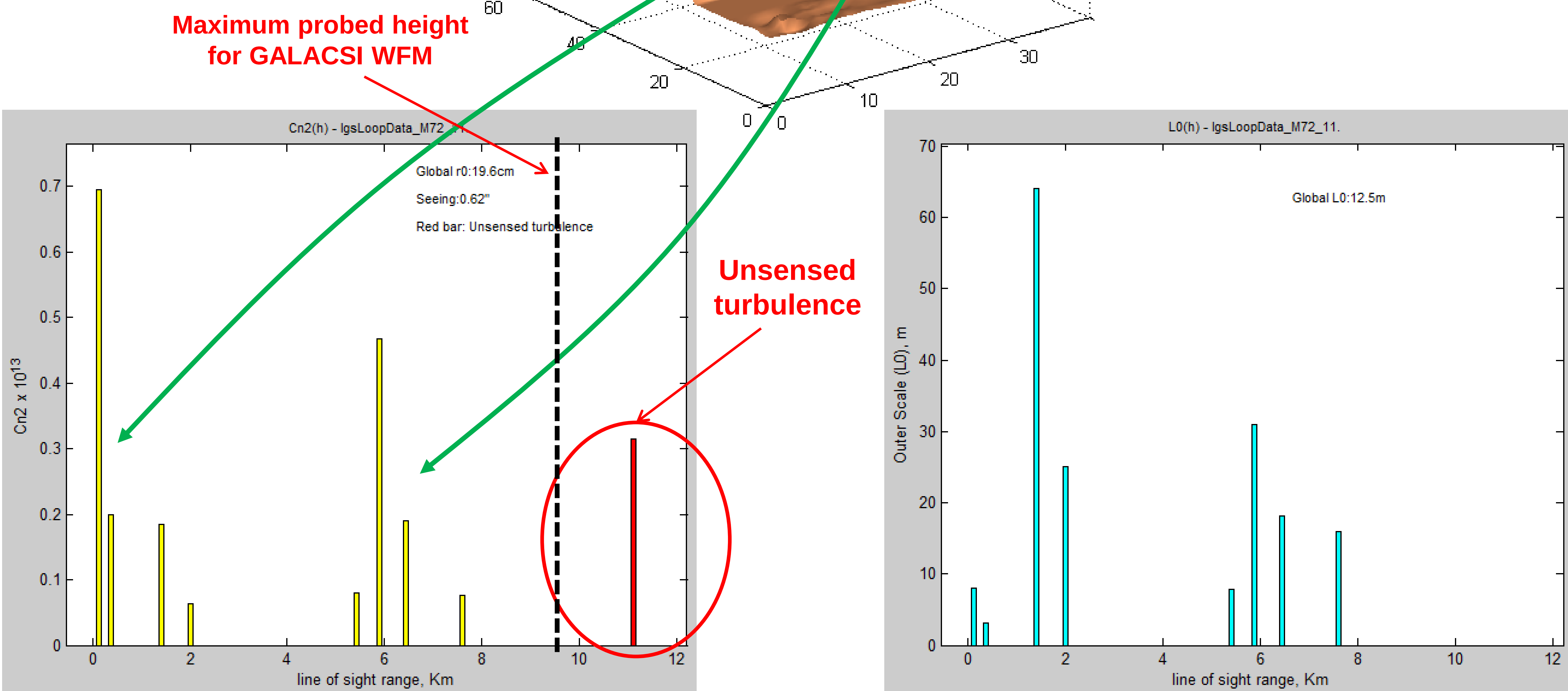




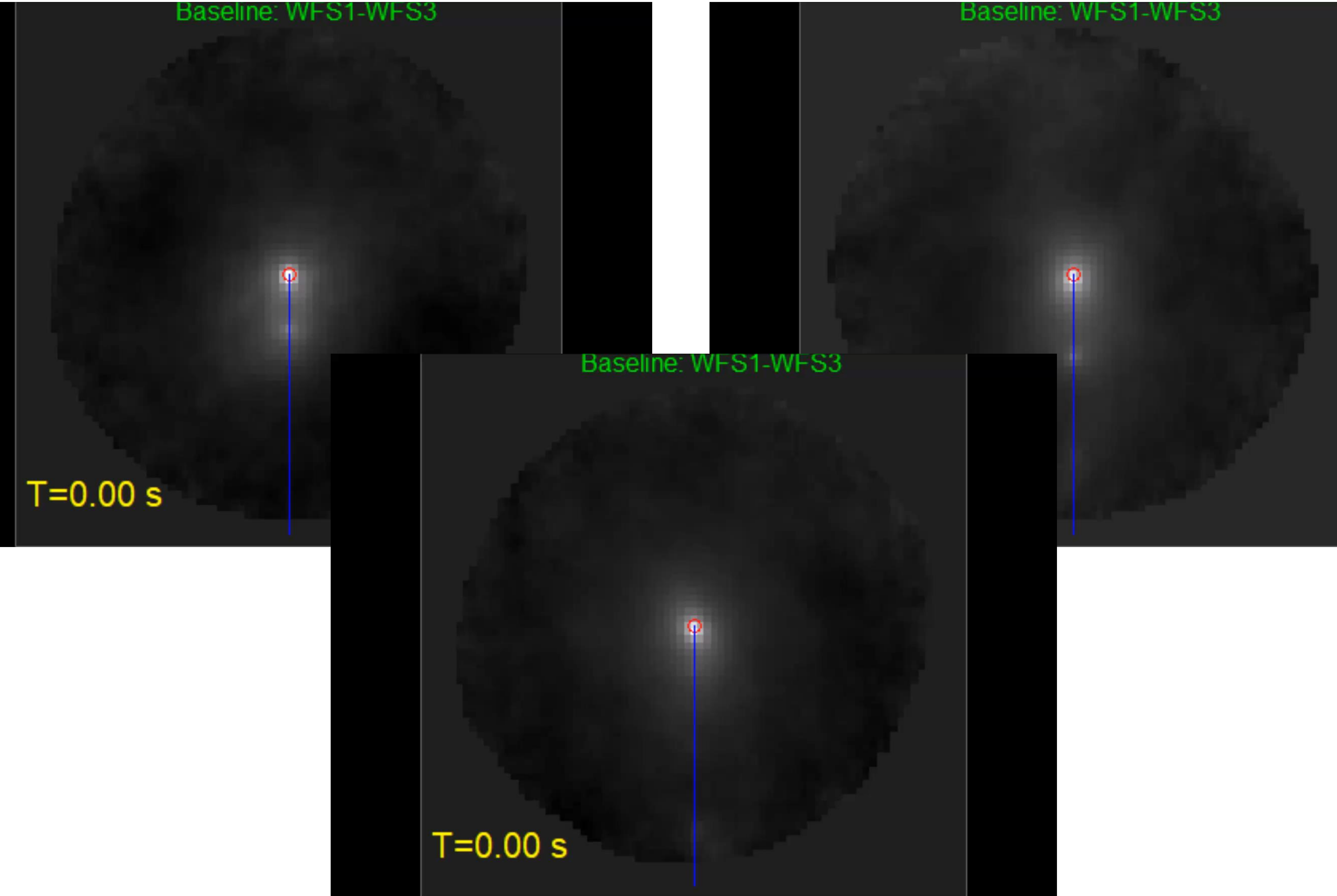
The method: Fitting sequence

Mode:
GALACSI - WFM

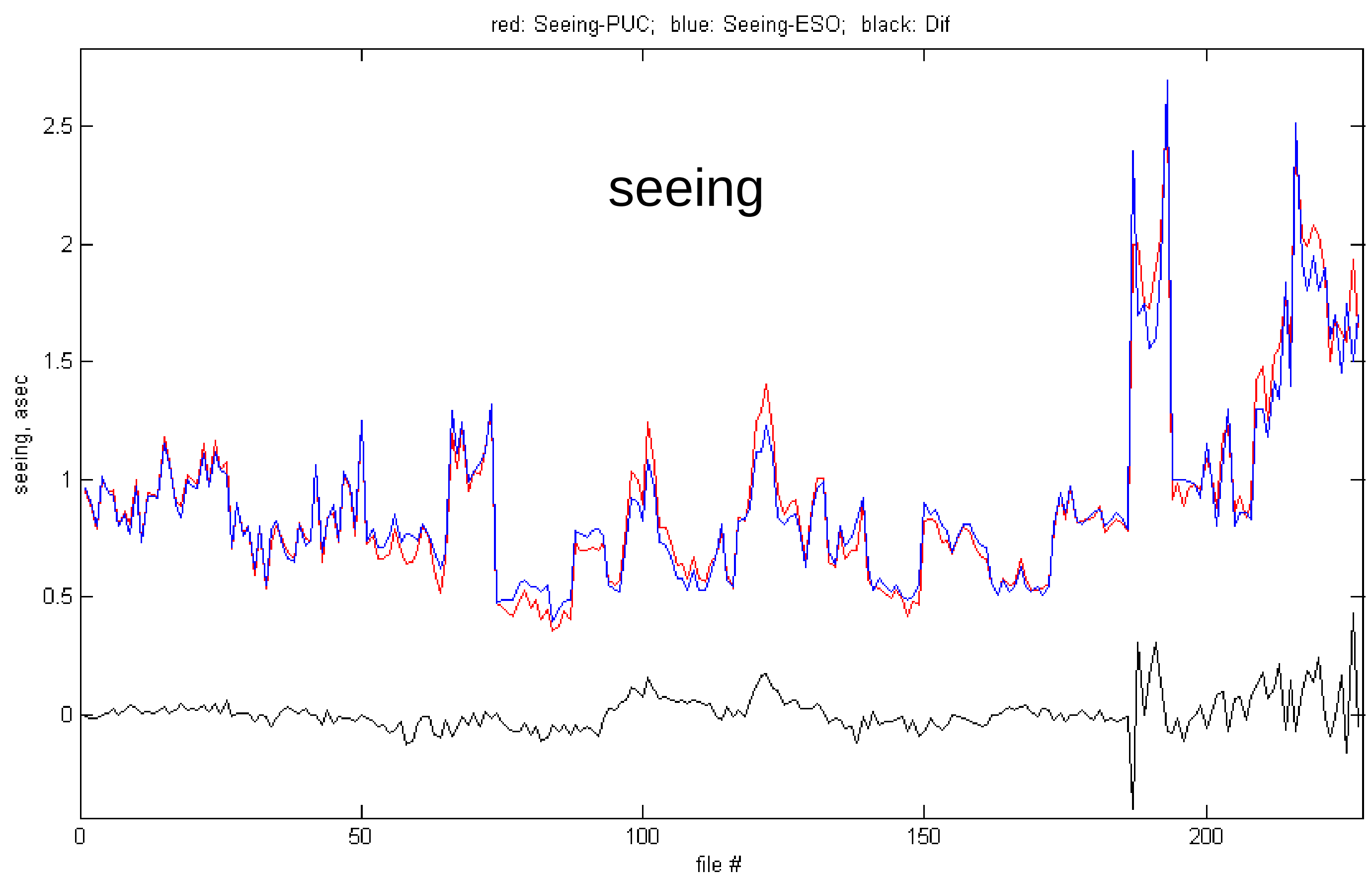


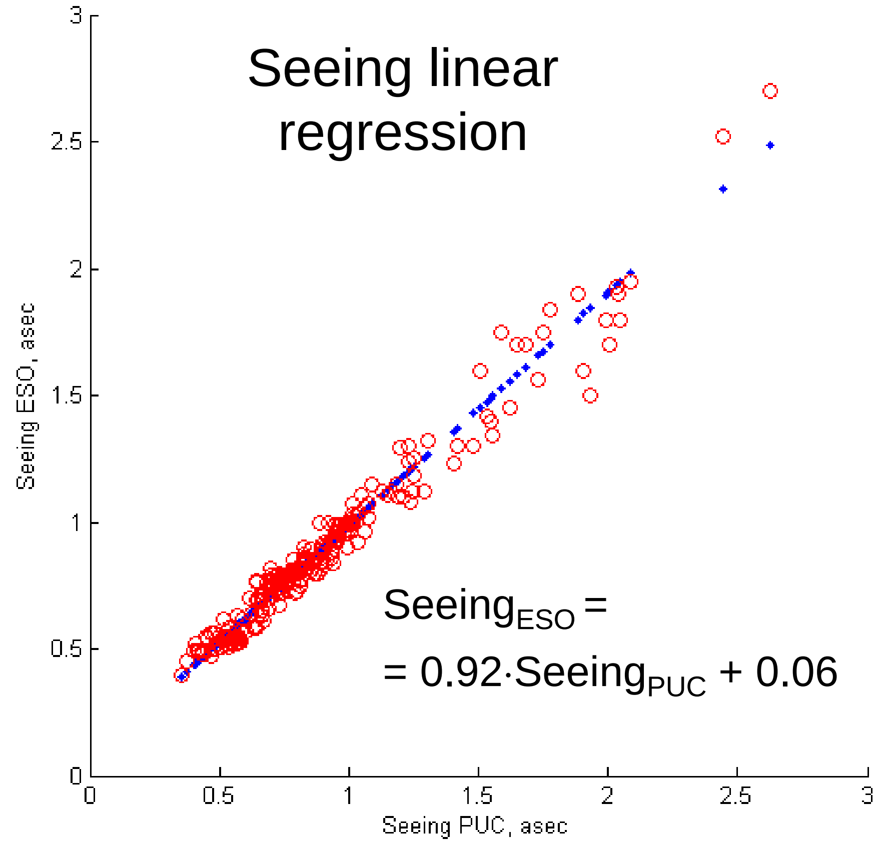


The method: Temporal Cross-Correlation (wind speed)

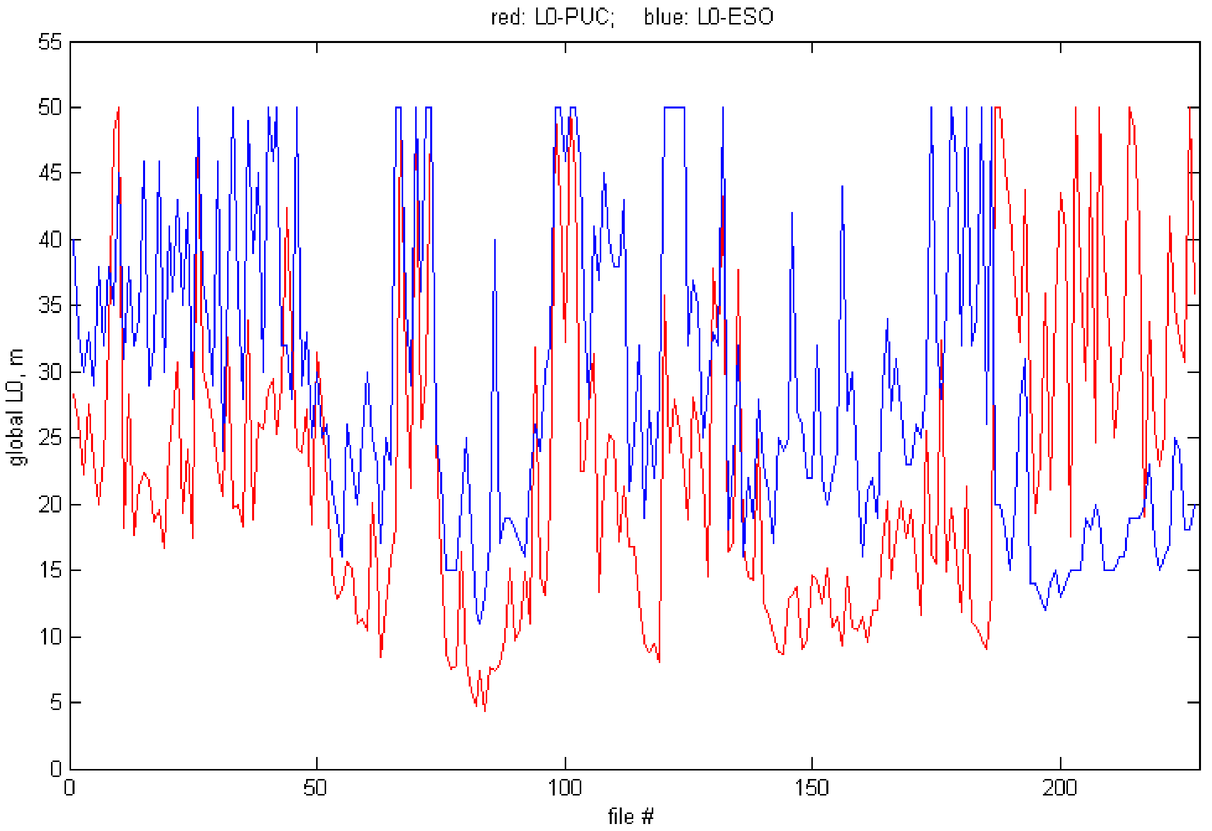


Comparison against an independent technique for seeing & global L_0 (mode: GALACSI–WFM)



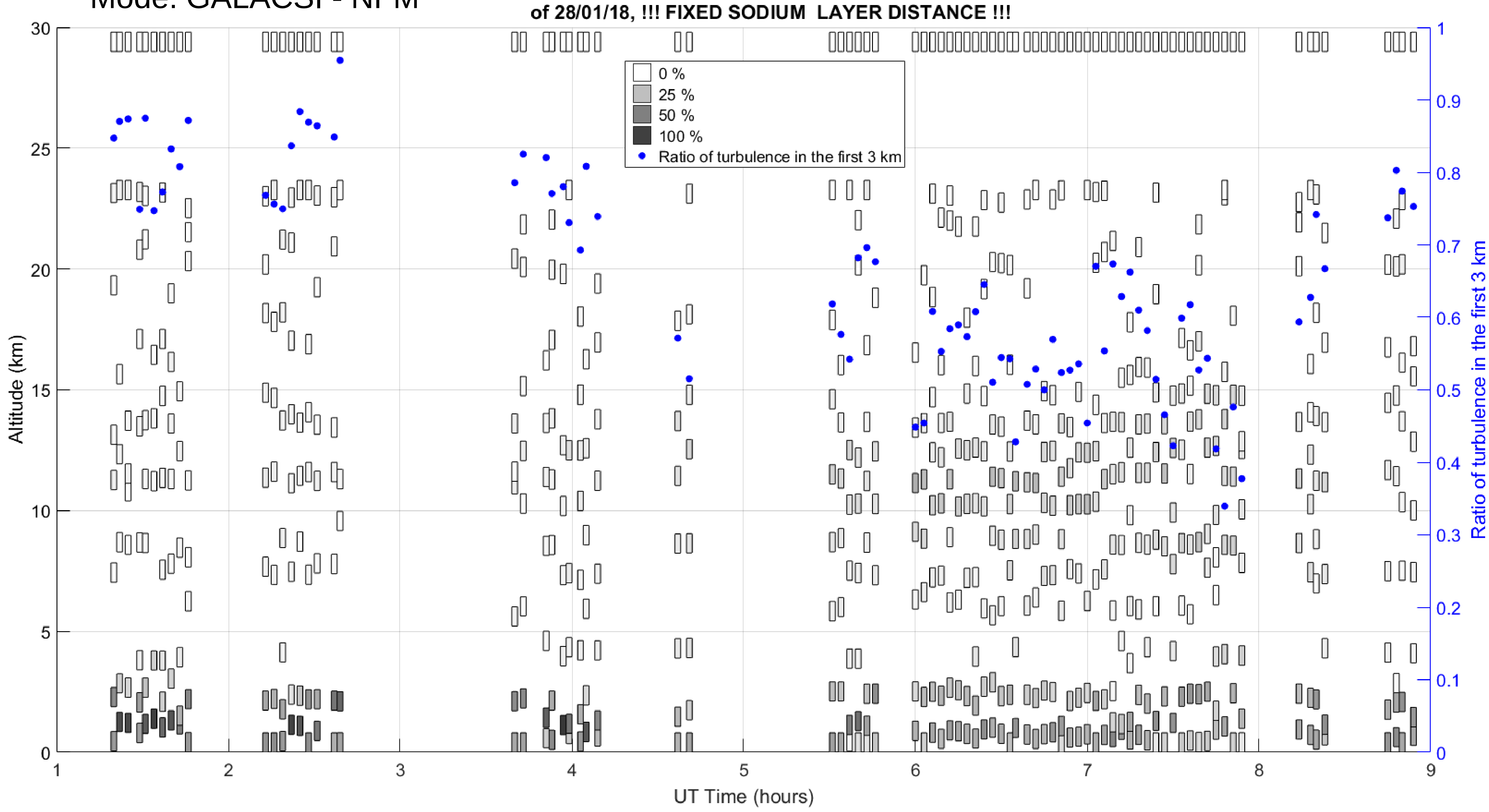


Global outer-scale



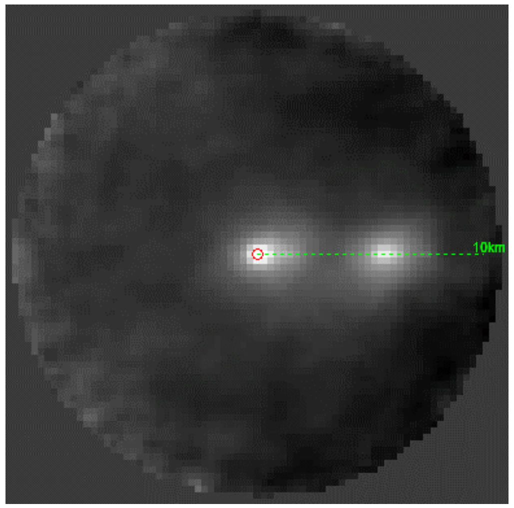
Implementation in SPARTA (AOF's RTC)

Mode: GALACSI - NFM

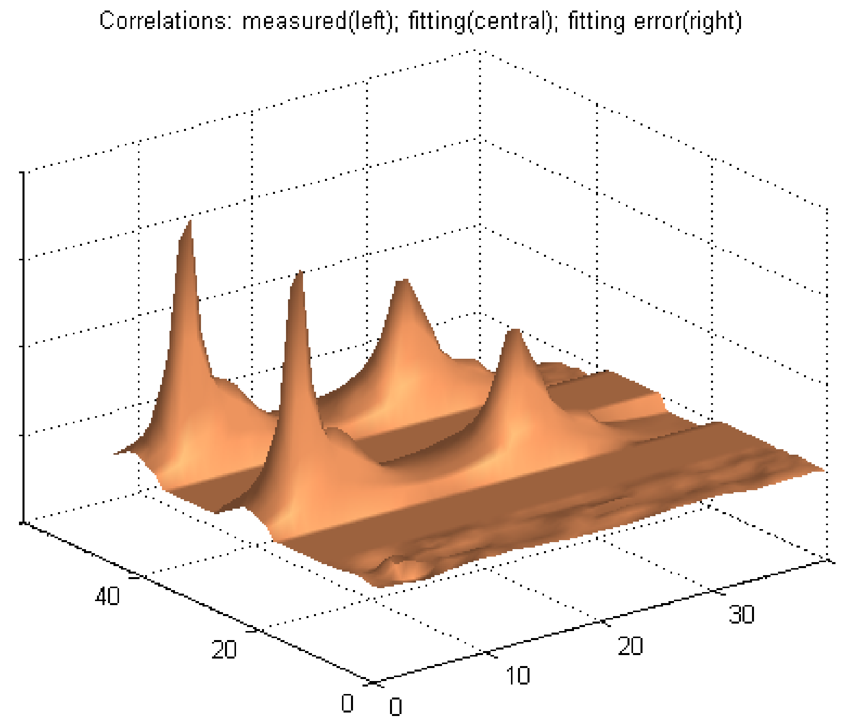


But life's never easy …

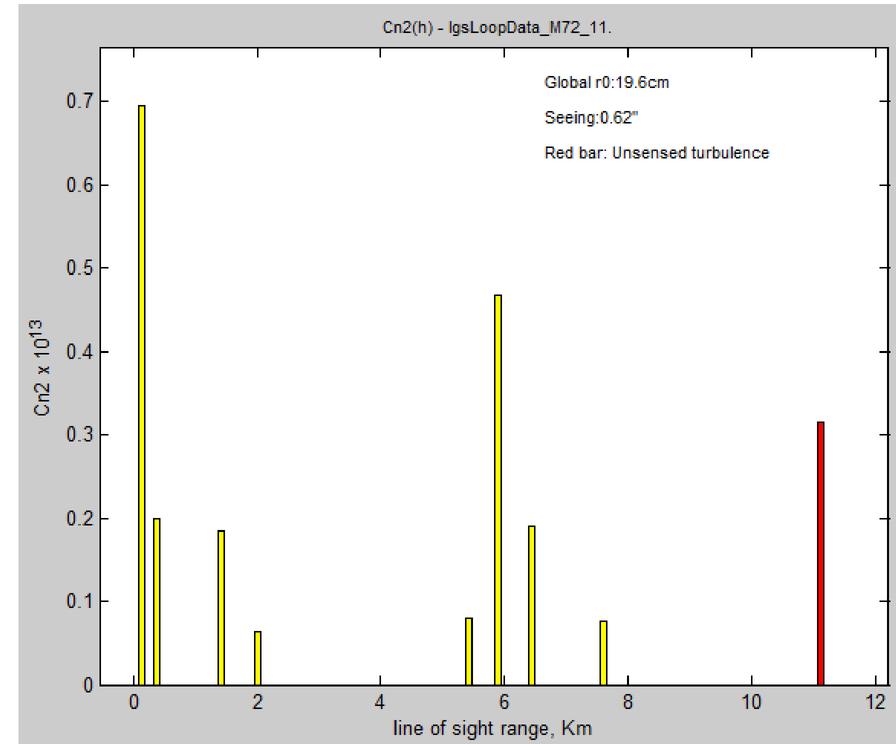
Typical GALACSI sequence
WFM & NFM



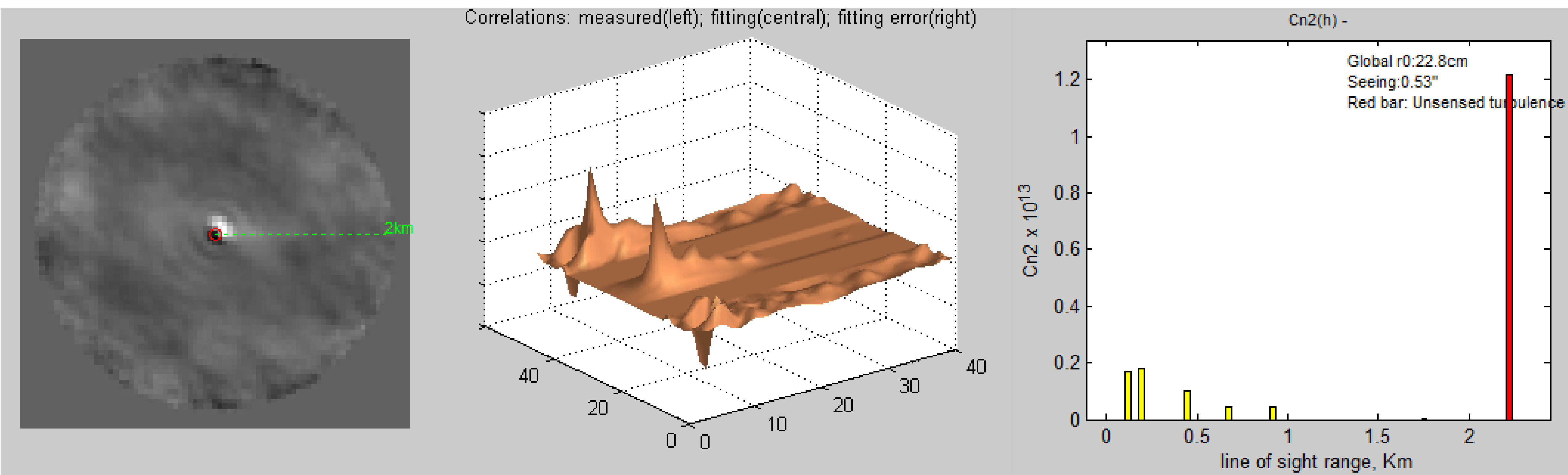
3D



Profiler

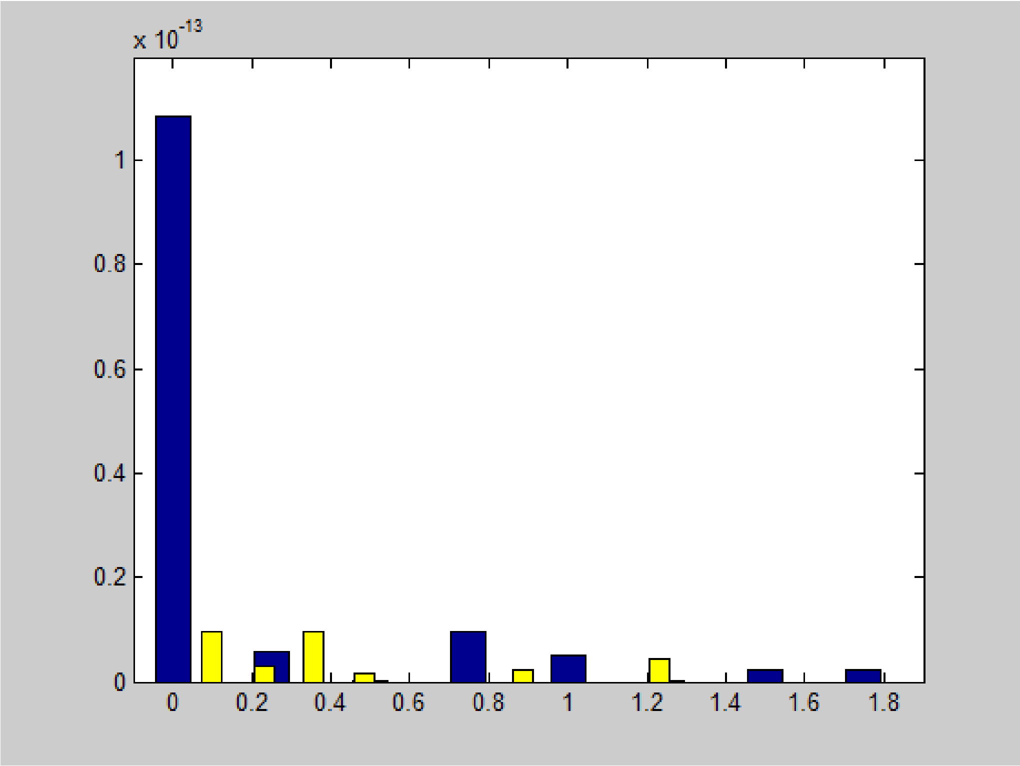


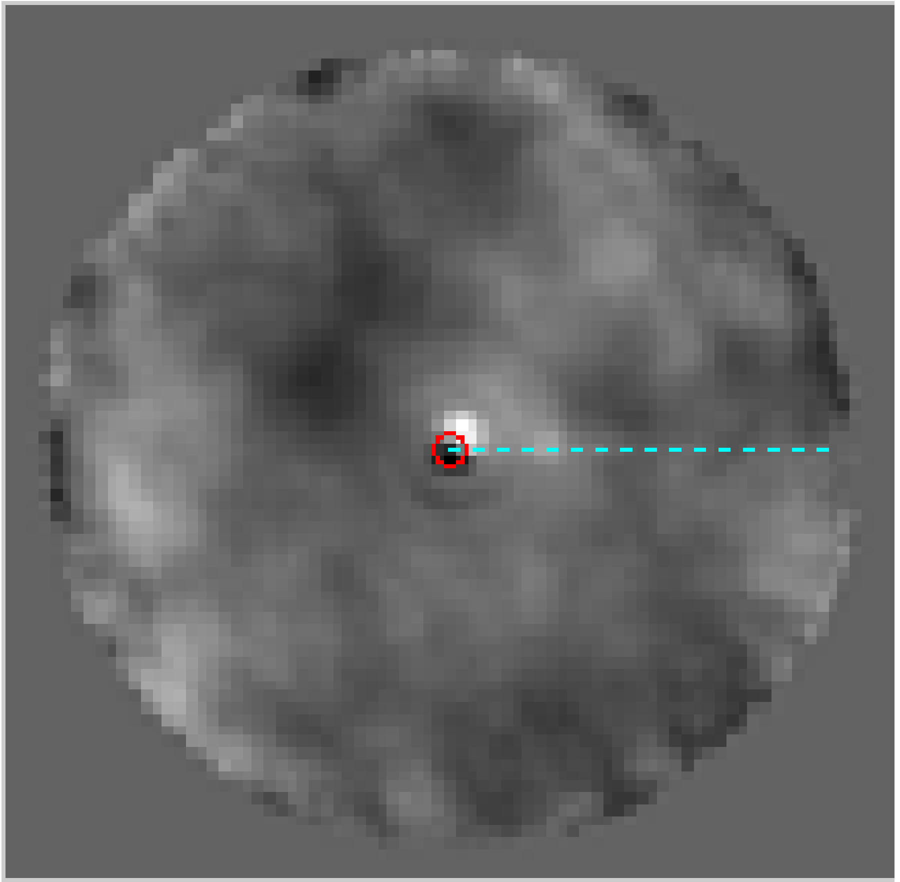
Mode: GRAAL

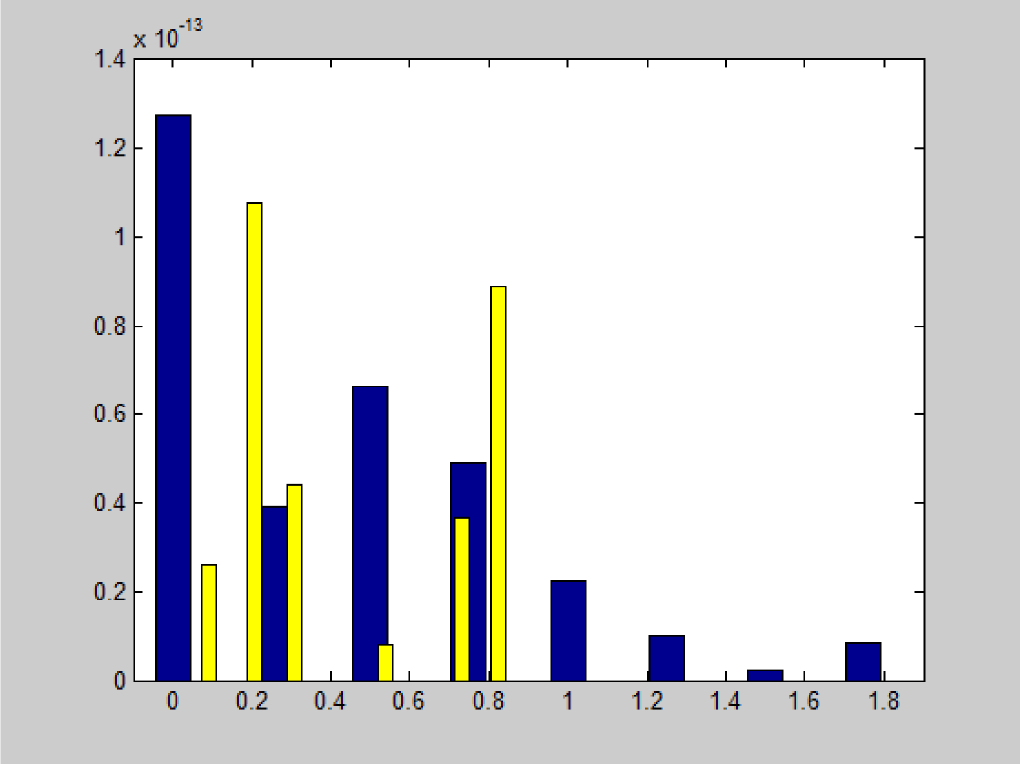


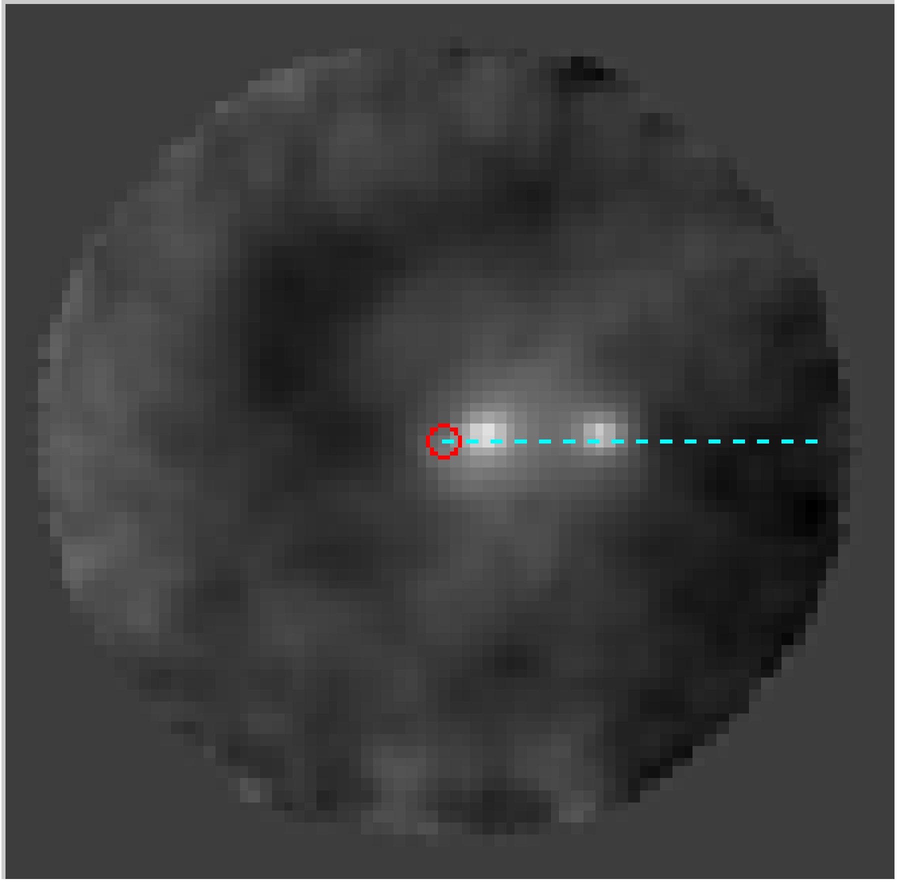
Comparisons with Stereo-Scidar (GRAAL mode)

Examples of mis-registrations









Conclusions for turbulence profiling

- The information exists for accurate profiling (in quantity and quality)
- Profiles for C_n^2, L_0 and wind direction & magnitude are currently in use in the AOF (automatic wind profiles under development)
- Including the outer scale in the profiling methods <u>is a must</u>
- In the ELT, the outer scale estimation will be essential
- Reliable estimation of larger outer scales is limited to 3 or 4 times the diameter of the telescope (30m for the VLT; 150m for the ELT)
- Processing times compatible with system operation (t < 2 mins @ 8 layers)
- A comprehensive comparison with simultaneous with Durham’s Stereo-SCIDAR data is coming soon