# NGS Strategies and sky coverage for LGS-assisted instruments on ELTs

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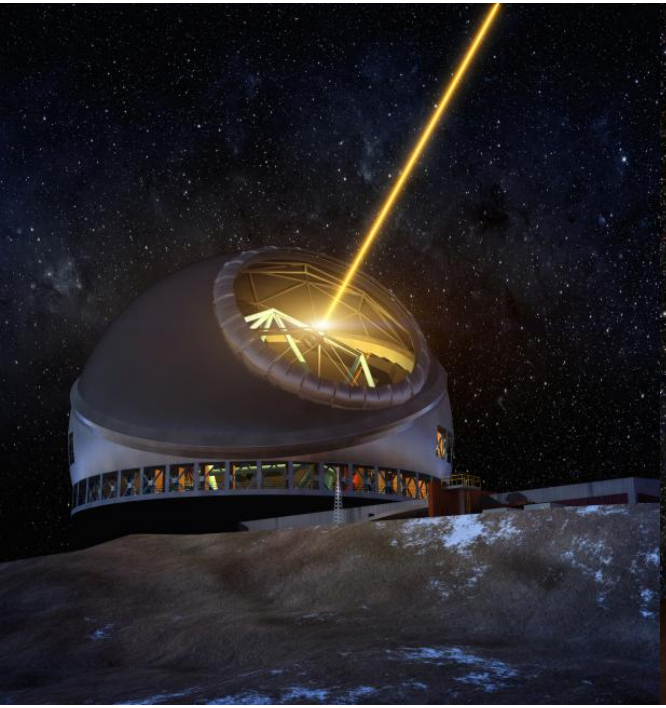
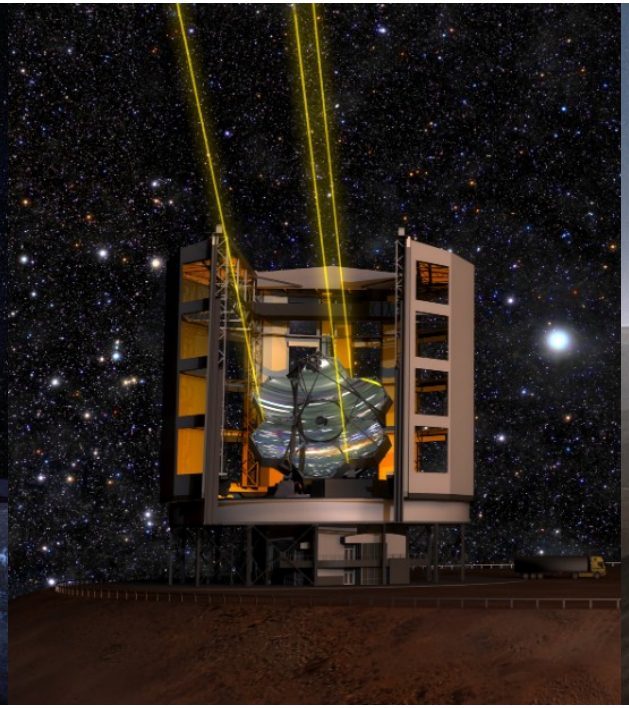
ONERA
THE FRENCH AEROSPACE LAB

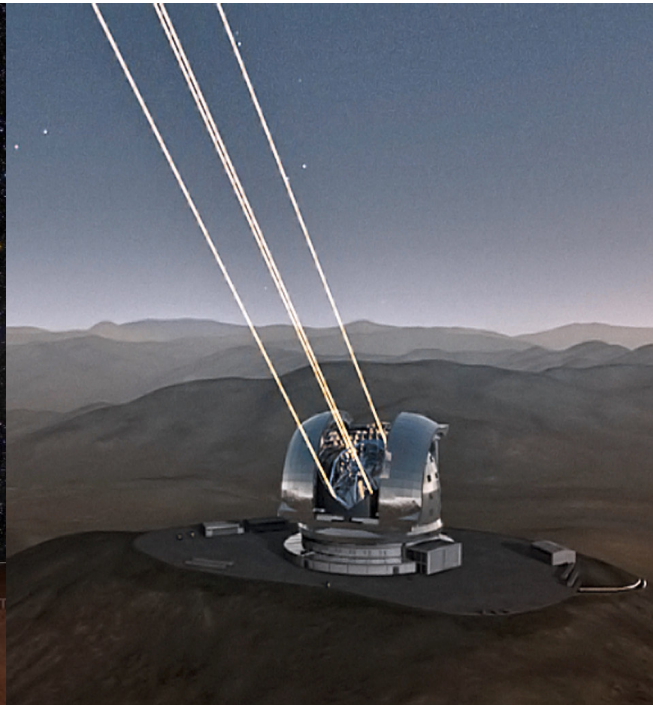
WFS workshop – Padova – Oct. 2017

# Context

## All ELTs are planning to use multiple-LGS for Wide Field AO







## Why is that ??

# Context

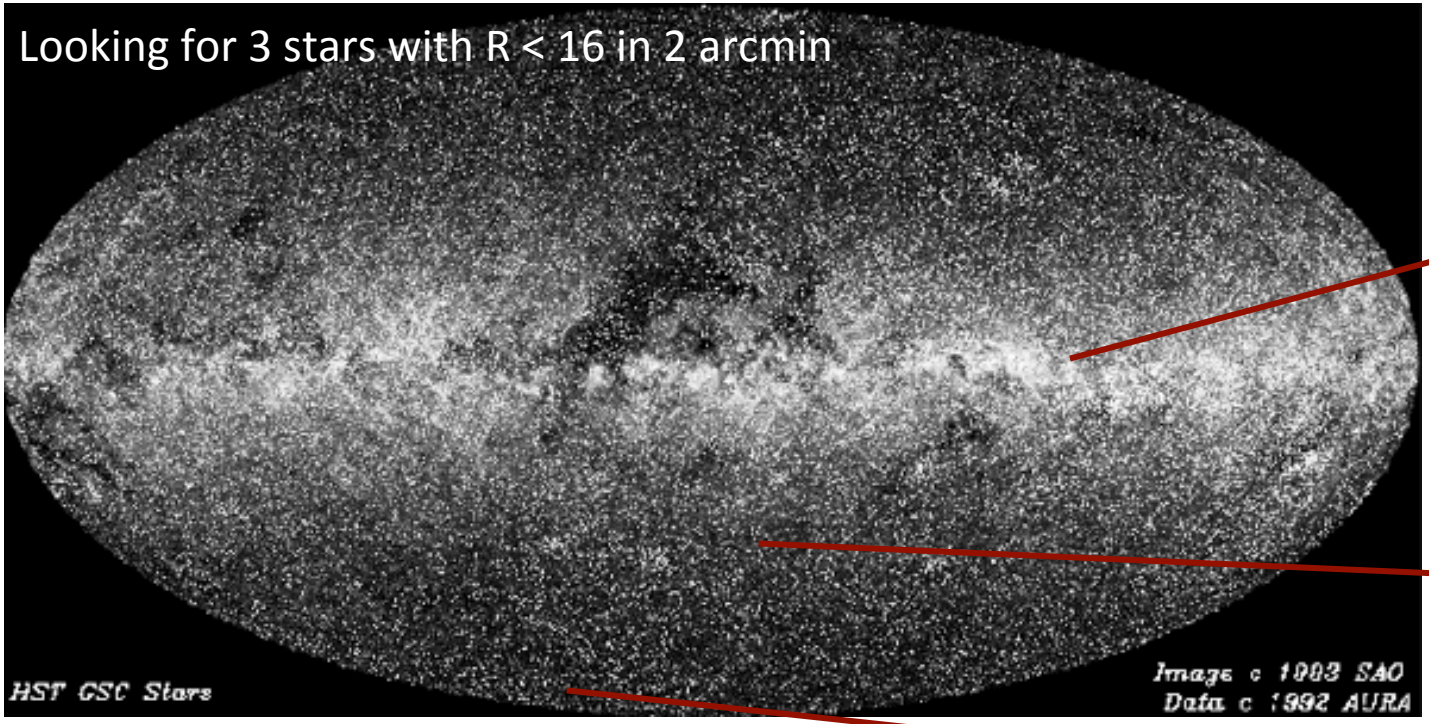
**Because lasers are cool – and make nice PR movies…**

Video by J. Kolb

# Context

## Lasers are required to get the sky coverage

How many Natural Guide Stars are available ?




10%

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0.1%

Unless you go for GMCAO, you need LGSs…

# Context

**However… Lasers suffer from some fundamental limitations**

**Natural Guide Star are required to complement LGS measurements…**


**This will drive the sky coverage of LGS-assisted AO systems**

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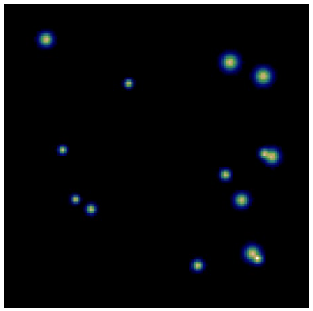
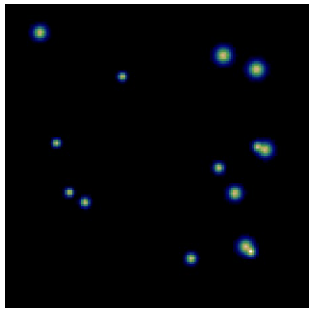
**Natural Guide Star are required to complement LGS measurements…**


**This will drive the sky coverage of LGS-assisted AO systems**

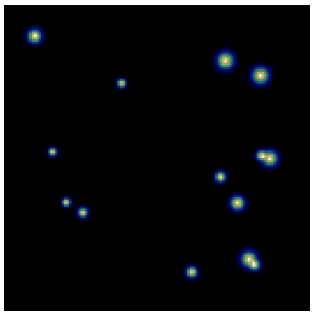
**Fortunately, only few modes need to measure:**

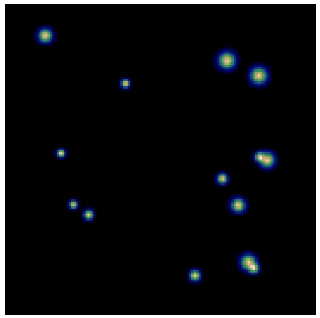


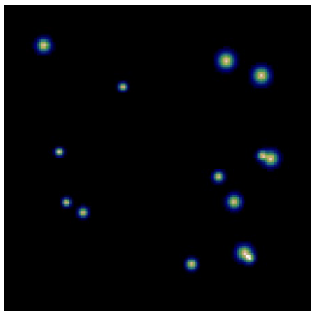
Tip



Tilt

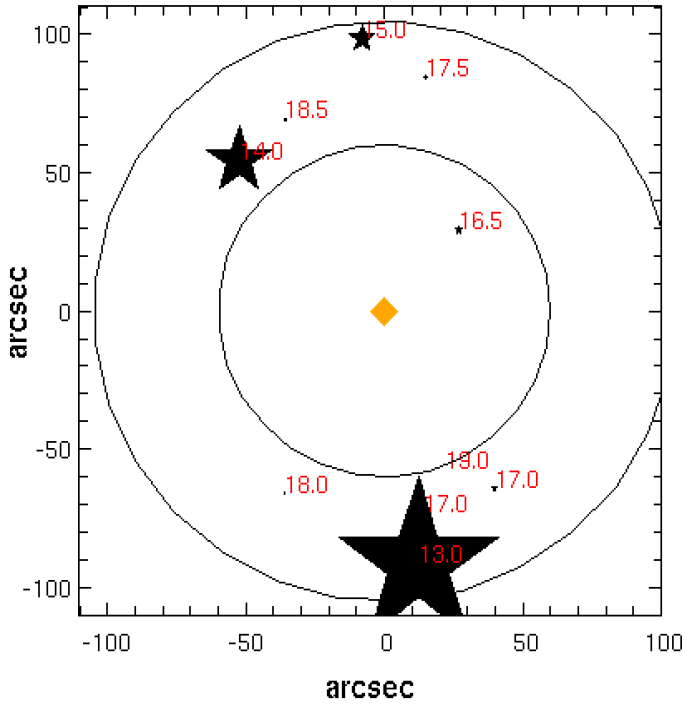






# Context

**<u>Question</u>: how to estimate the sky coverage (or residual error on low order modes) for LGS assisted instruments ?**




**It depends on many parameters…**

*the number of NGS we use, their magnitude, their configuration, the WFS characteristics (noise, spatial and temporal sampling) and of course, on the environment (seeing, L0, telescope windshake, …)*

# Context

**<u>Question</u>: how to estimate the sky coverage (or residual error on low order modes) for LGS assisted instruments ?**

**It depends on many parameters… let's try to simplify it…**

## <u>Simulation strategy:</u>

Residual errors are computed in an "error budget" fashion:

- **<u>Tomography</u>**: depends on the distance (and number) of the NGSs + Cn2
- **<u>Temporal errors</u>**: this only depends on the NGS loop frequency.
- **<u>Noise propagation</u>**: This depends both on the distance and magnitude of the stars, as well as the WFS choice…

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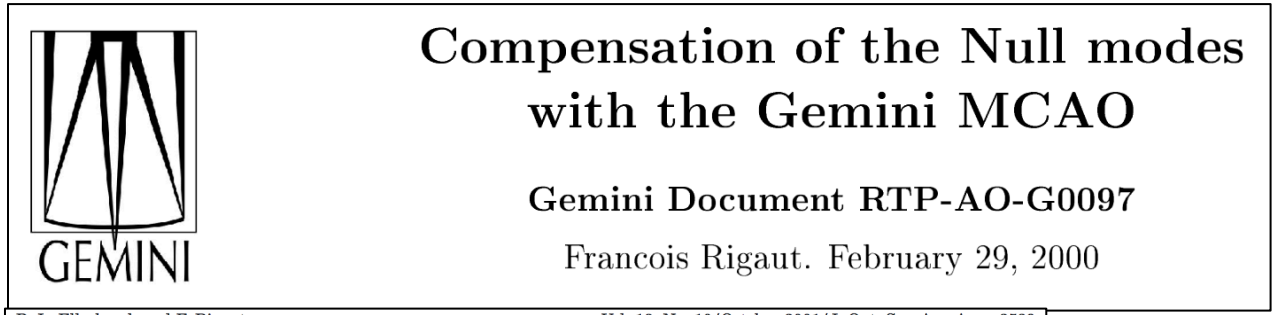
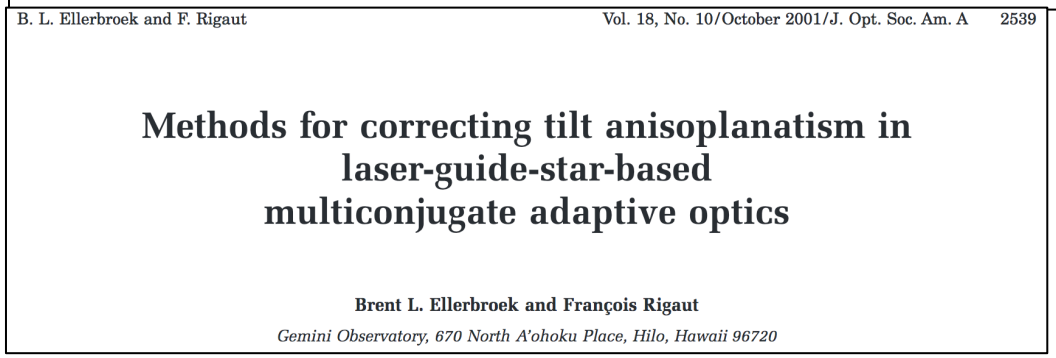
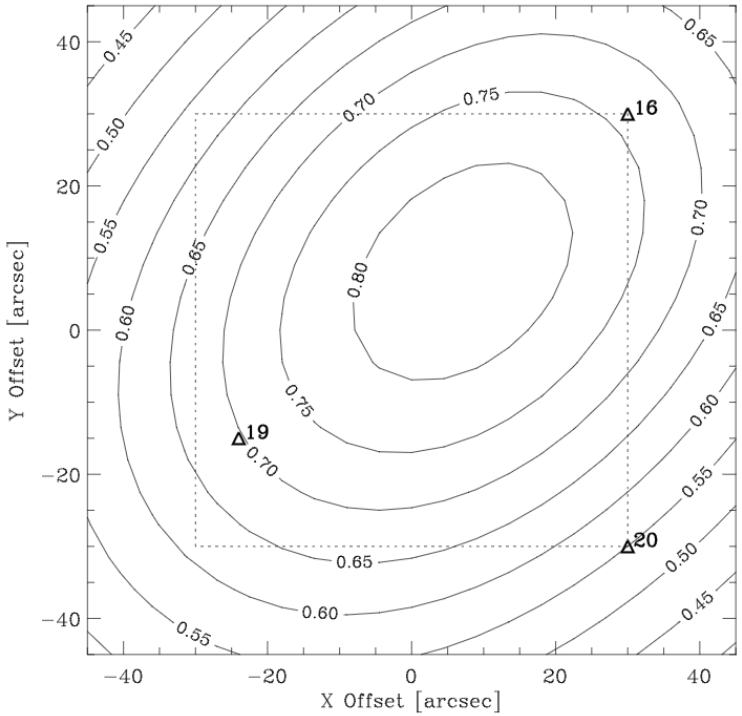
**Tomography** | **Temporal** | **Noise**



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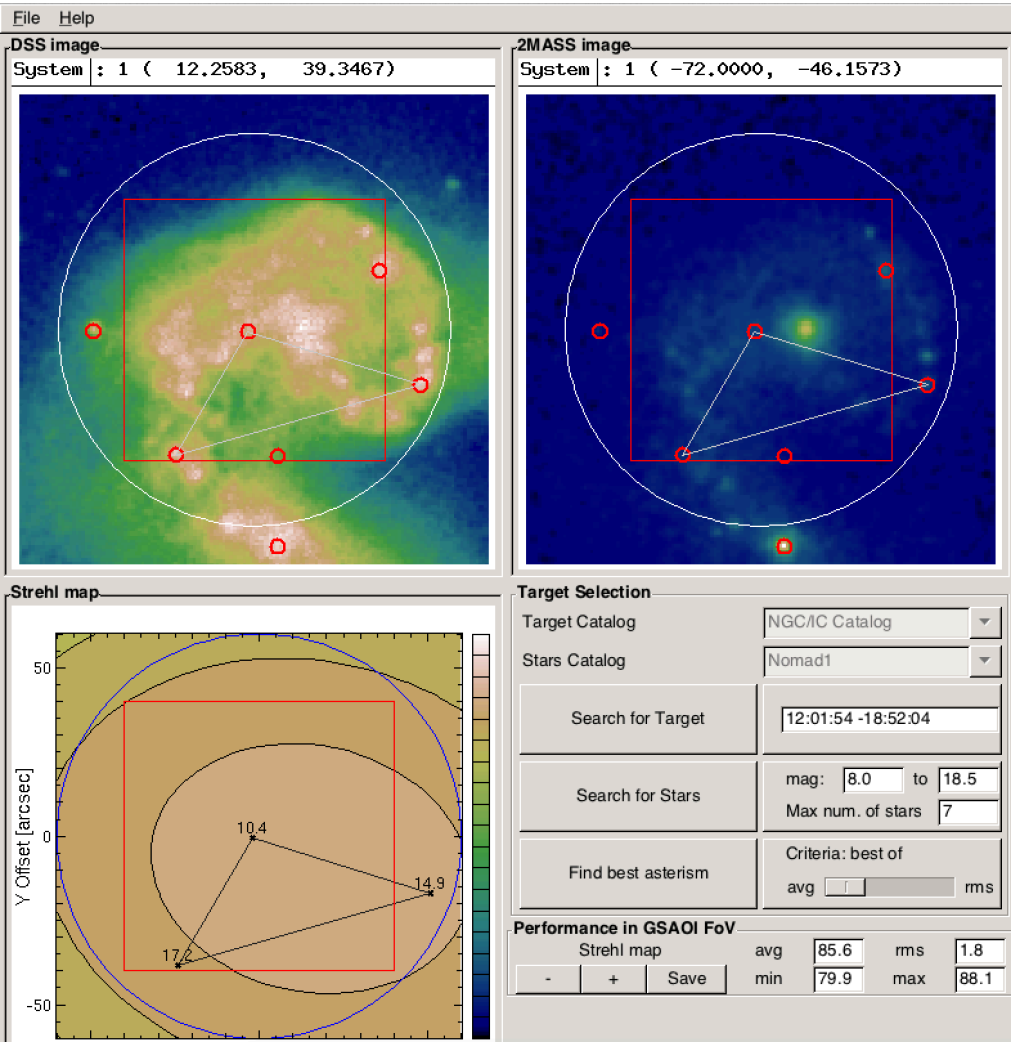
**Tomography** | **Temporal** | **Noise**



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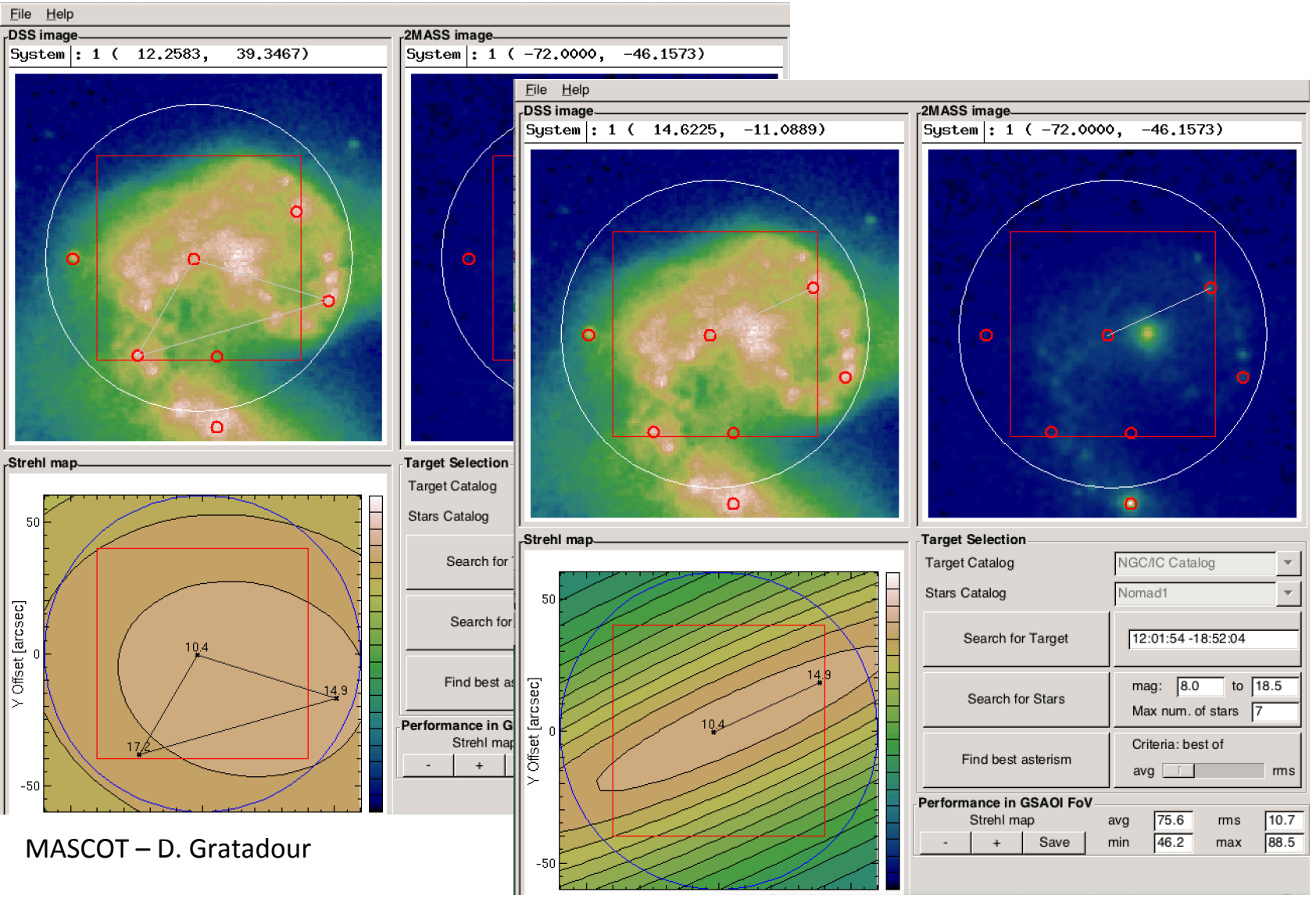
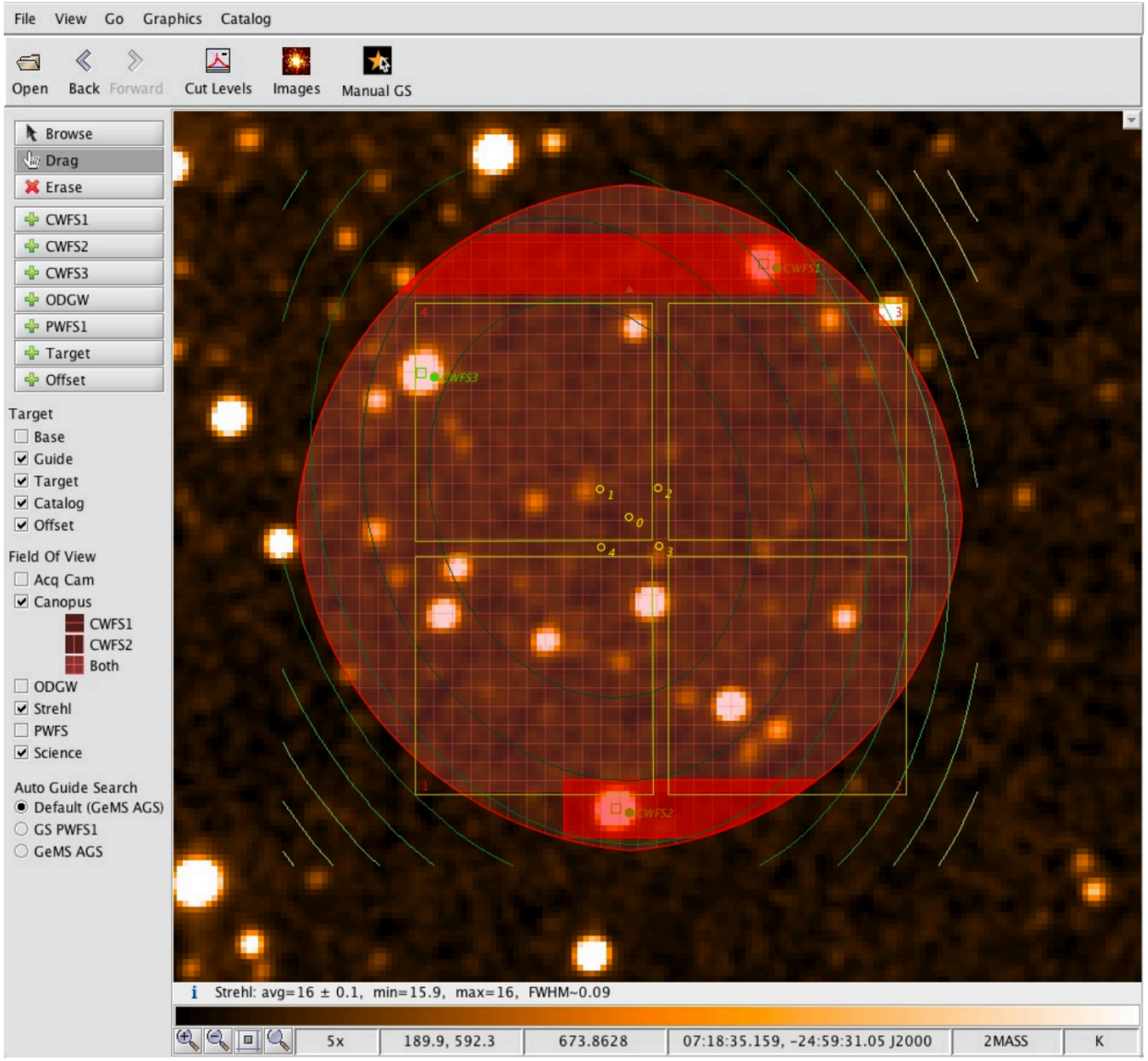



MASCOT – D. Gratadour

# Context

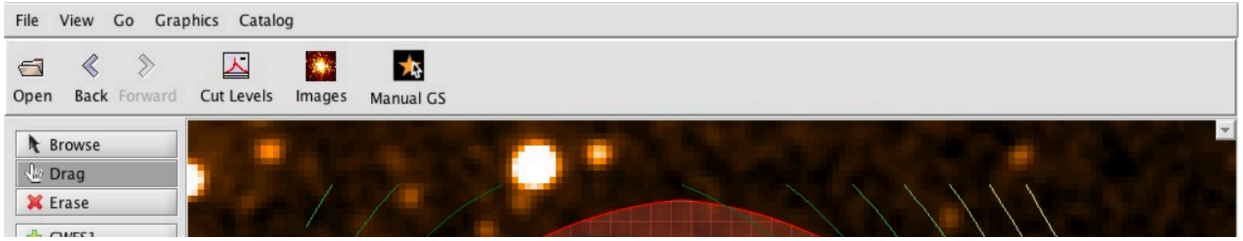
**Tomography** | **Temporal** | **Noise**



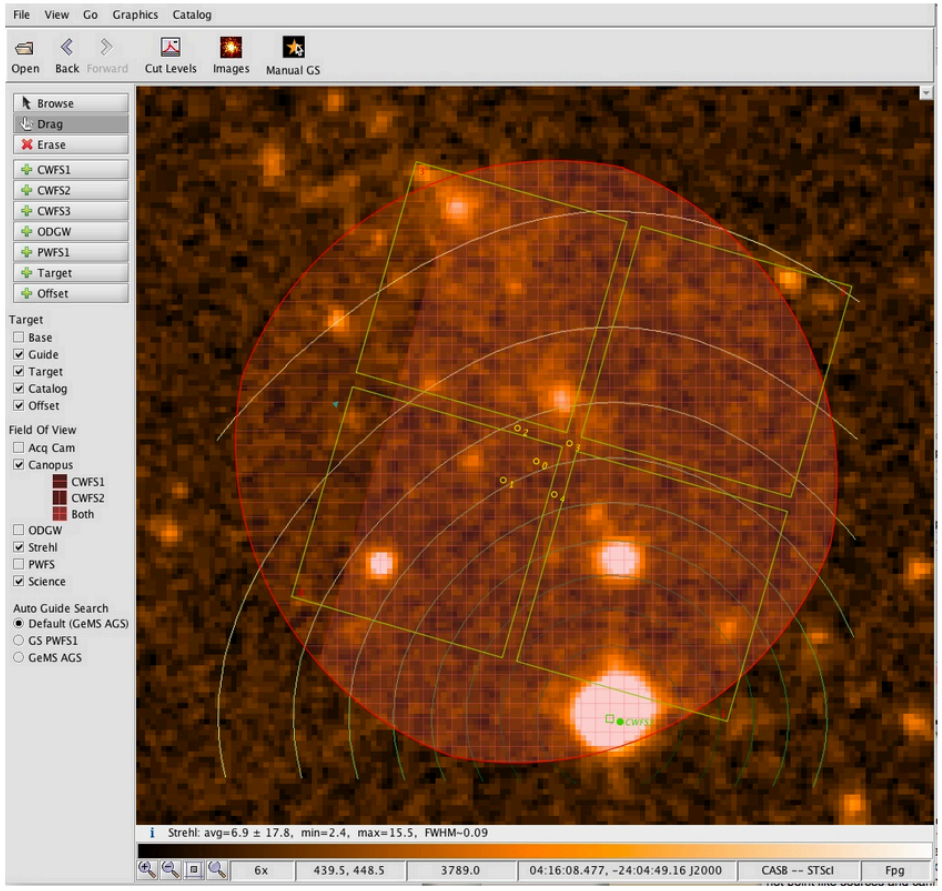

**Gemini Observing tool**

# Context

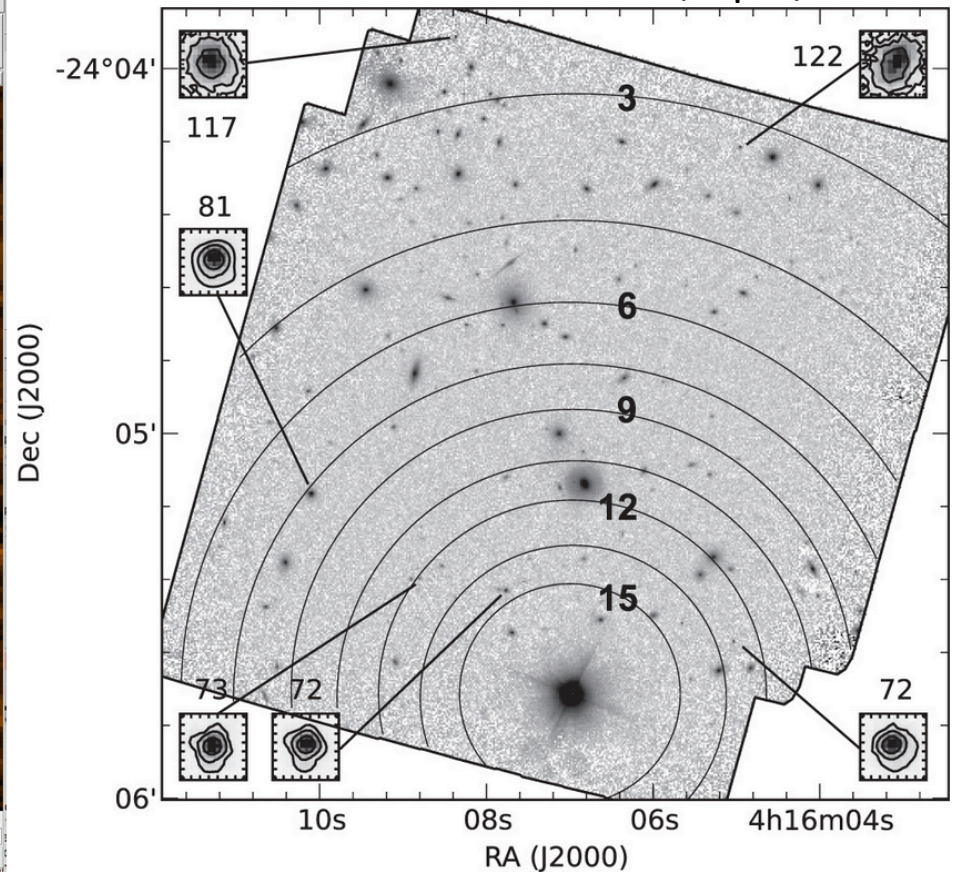
**Tomography** | **Temporal** | **Noise**




**Gemini Observing tool**




Schrimer et al., ApJS, 2014



# Context

**Tomography** | **Temporal** | **Noise**

**we have revisited those methods for the EELT**

We have mainly worked on this term

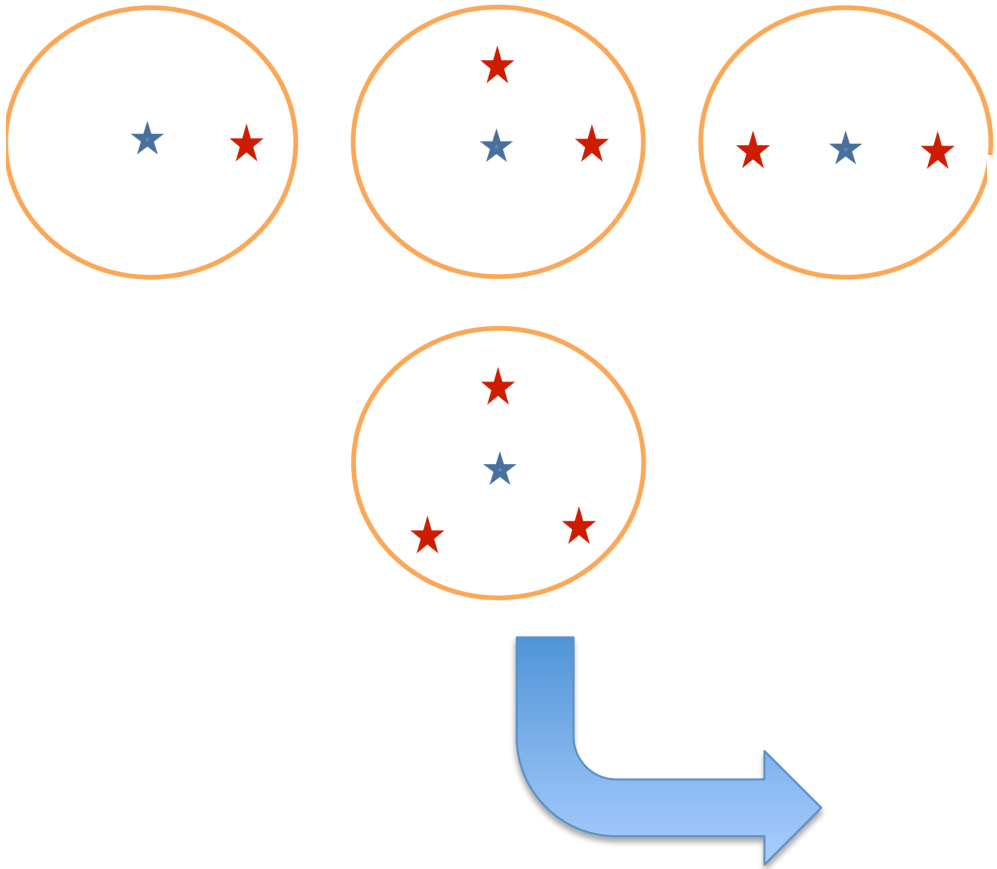
(but we'll review the 3 terms in the following slides)

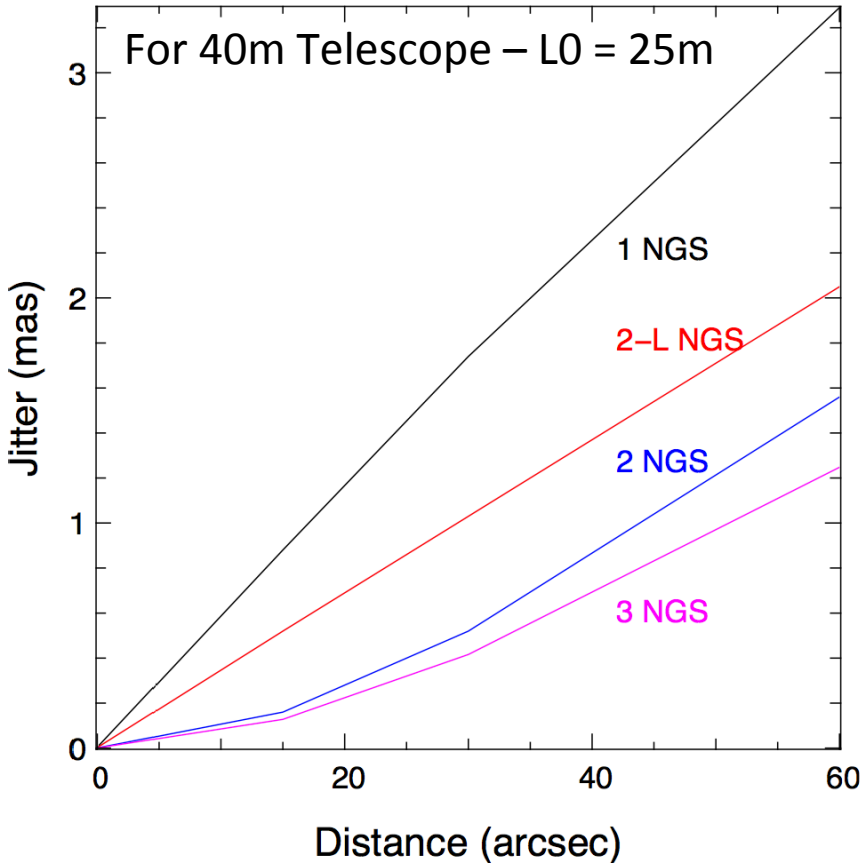
# NGS error budget

**Tomography**

## Impact on residual jitter of different NGS constellation

*e.g. Sasiela, Chassat, Whiteley…*





# NGS error budget

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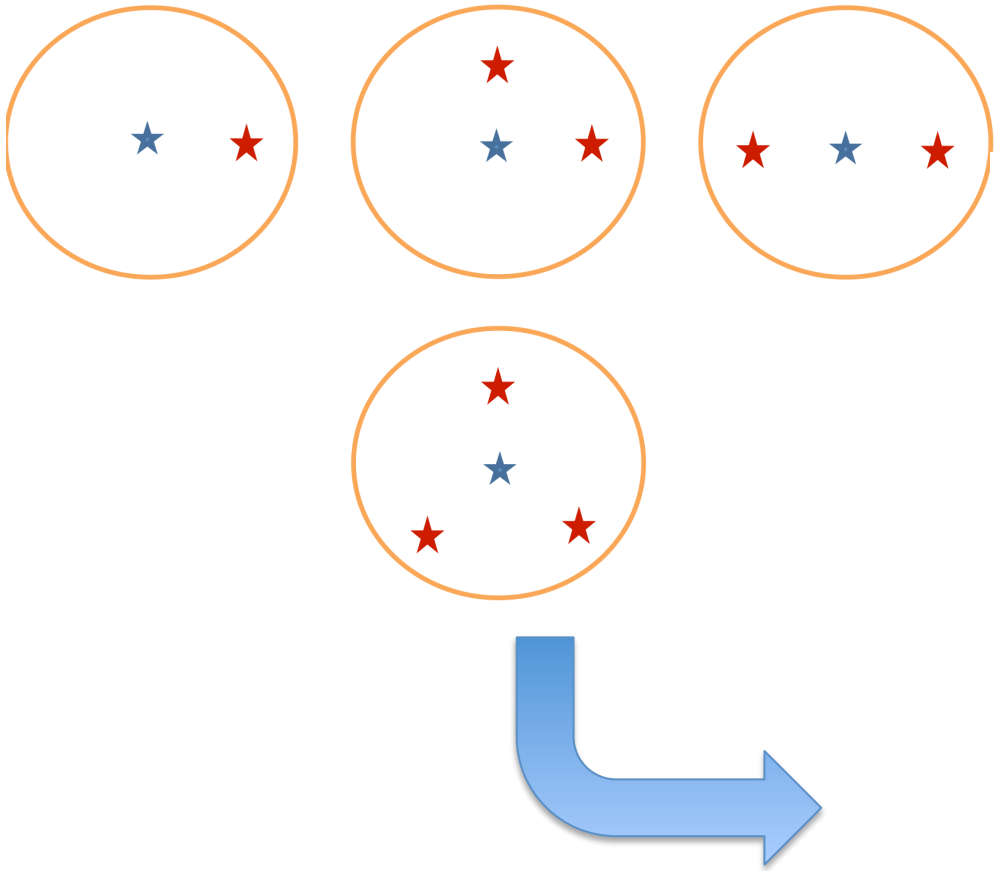
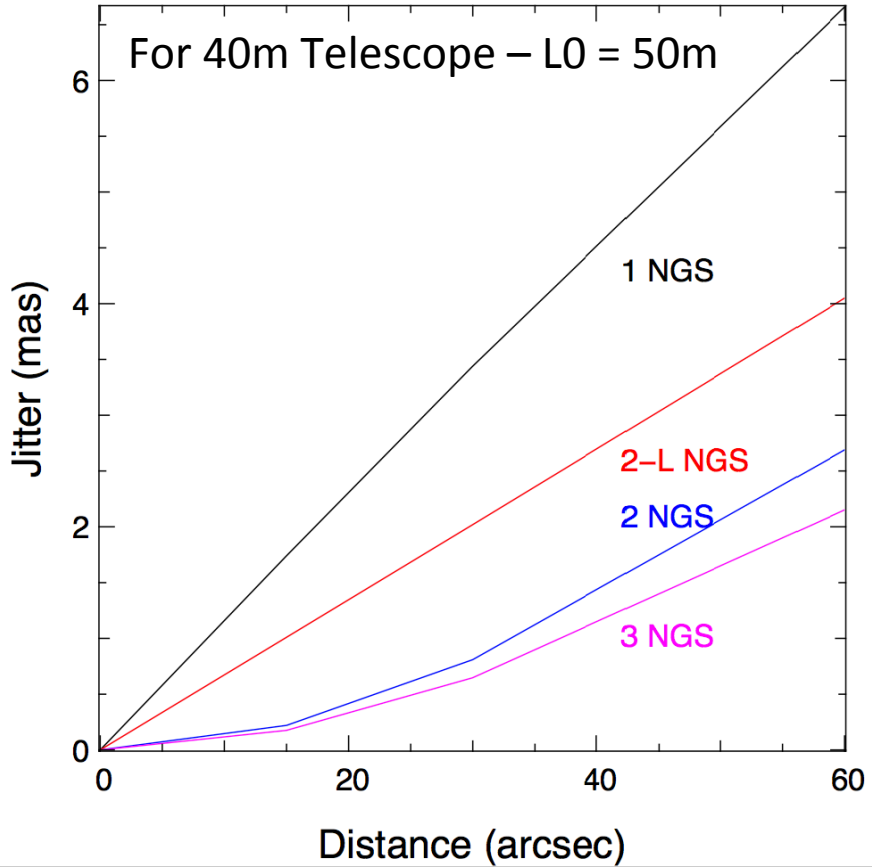




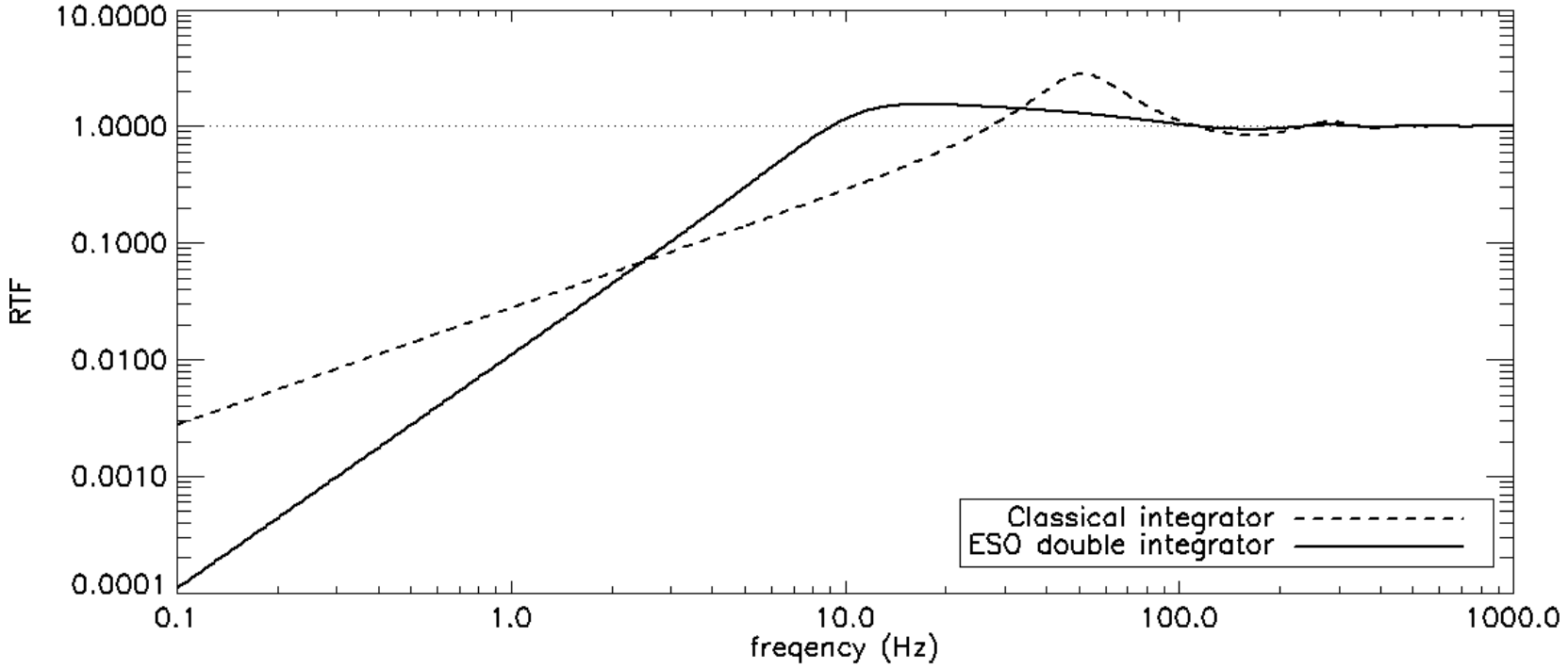
# NGS error budget

**Temporal**

**First need to determine the rejection transfer function.**

It depends on the controller performance…

Assuming ELT scheme with M4/M5 we could have:



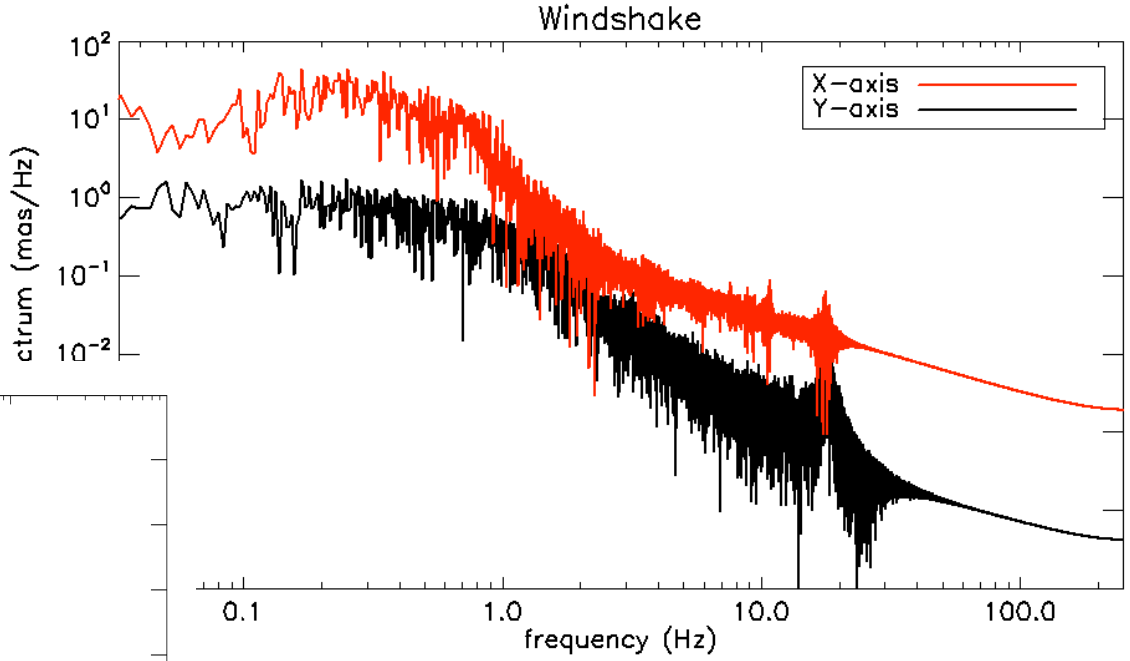
# NGS error budget

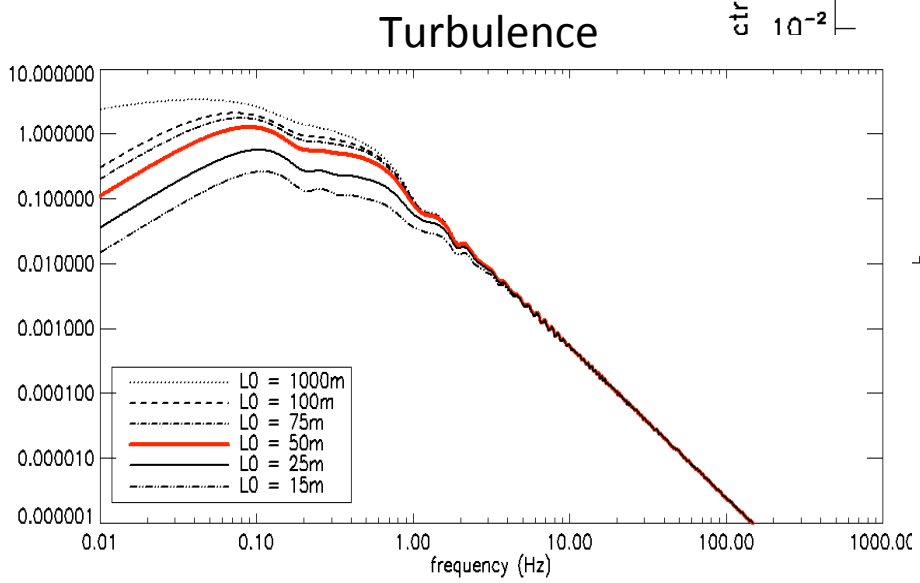
**Temporal**

**First need to determine the rejection transfer function.**

**Then, need to know the inputs, it may be Turbulence and Windshake**

Still assuming an EELT configuration, we have:

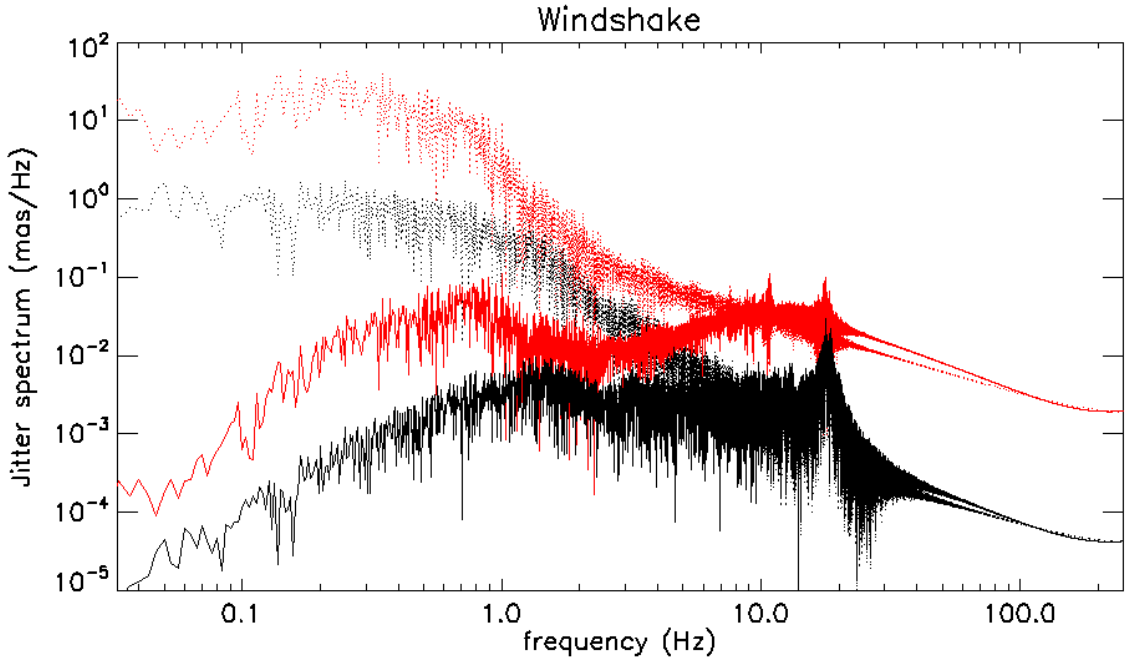


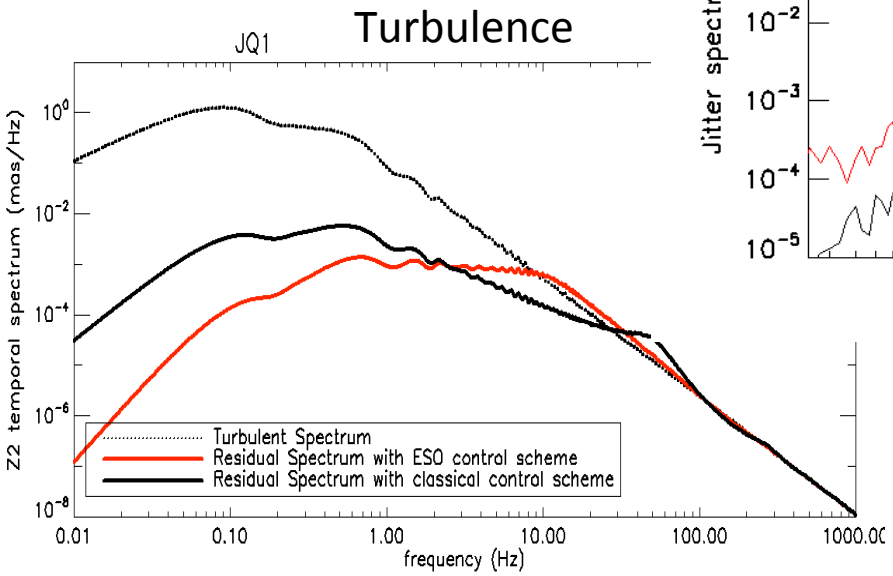



# NGS error budget

**Temporal**

**First need to determine the rejection transfer function.**
**Then, need to know the inputs, it may be Turbulence and Windshake**
**Finally, simply apply the rejection:**



# NGS error budget

**Temporal**

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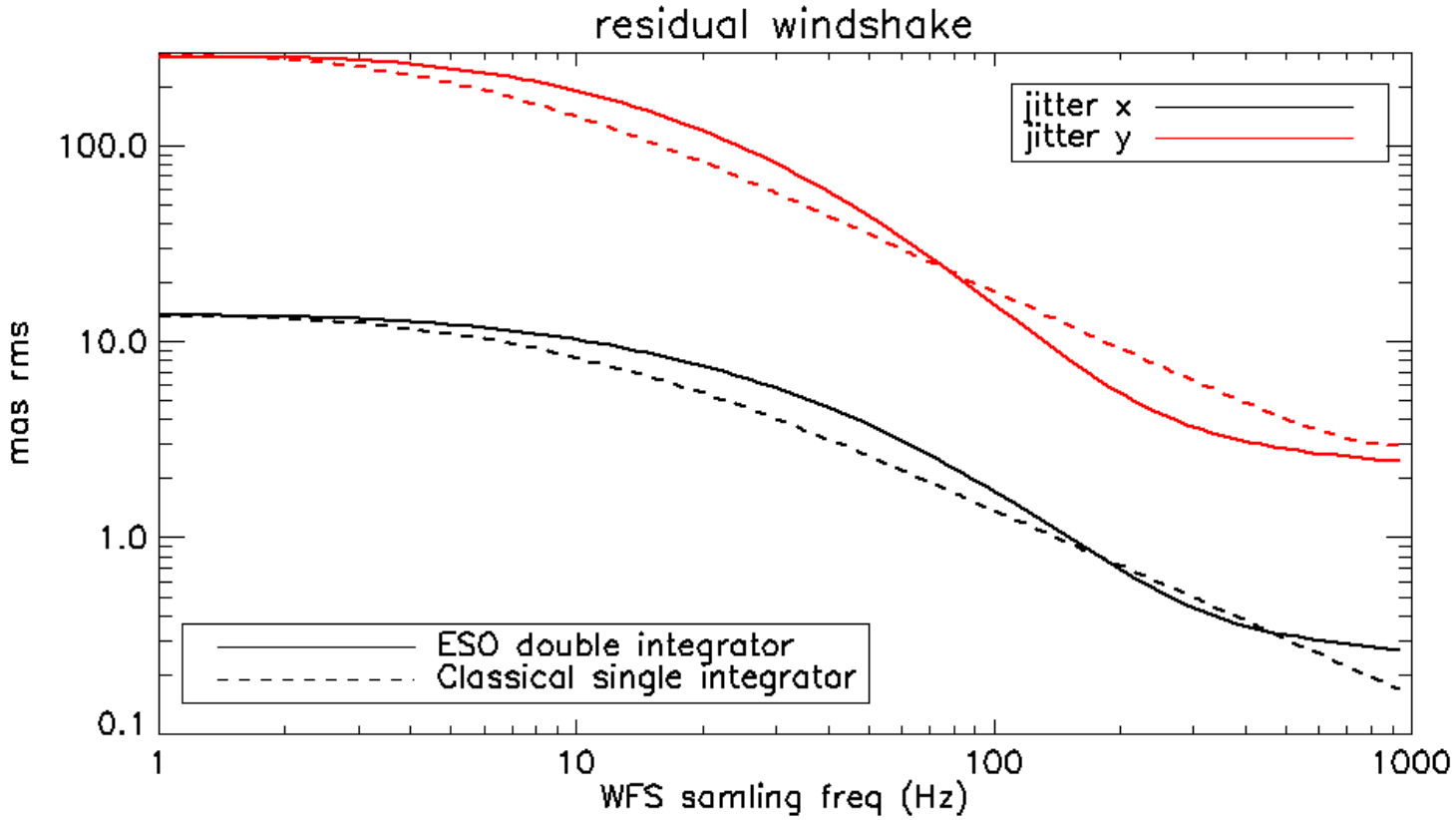
**Then, need to know the inputs, it may be Turbulence and Windshake**

**Finally, simply apply the rejection.**

**Eventually – play with the NGS gain, and loop frequency**



# NGS error budget

**Noise**

Noise depends first of all on the WFS strategy chosen.

For instance, for SH, noise coefficients have been well studied, and are defined as:

*e.g. Rousset et al., Nicolle et al.*

**Photon Noise**

$$\sigma^2_{ph,sspup} = \frac{1}{2\ln(2)}\frac{1}{n}\left(\frac{N_T^2}{N_D^2}\right)\left(\frac{\left(N_T^2+N_w^2\right)}{\left(2N_T^2+N_w^2\right)}\right)^2$$

**Read-Out Noise**

$$\sigma^2_{ron,sspup} = \frac{\pi}{32\ln(2)}\left(\frac{ron}{n}\right)^2\left(\frac{\left(N_T^2+N_w^2\right)}{N_D}\right)^2$$

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weighting

diffraction

**Read-Out Noise**

FWM of subap. PSF

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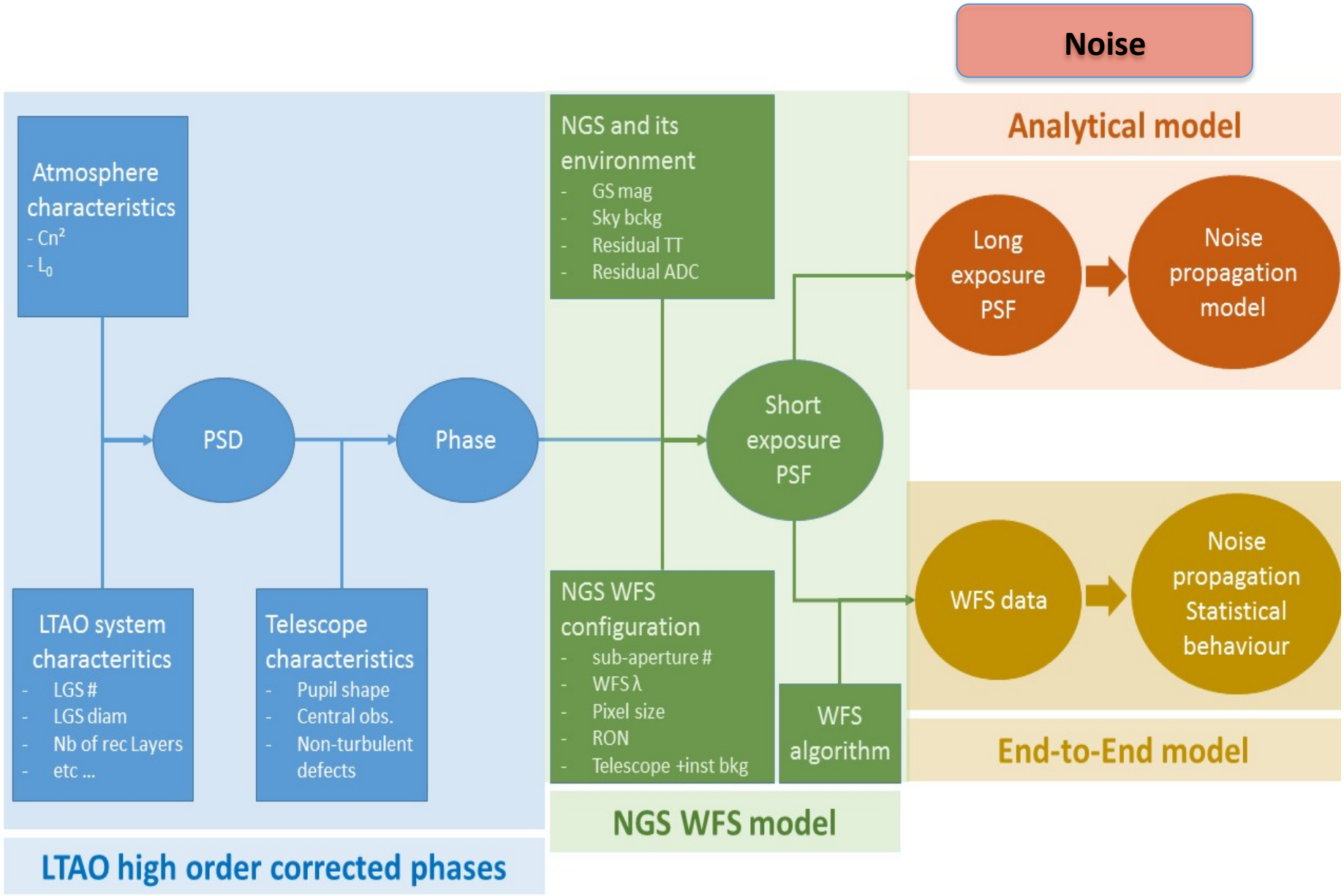
This is however not valid anymore in presence of residual turbulence.

# NGS error budget




Wok done by Thierry !!

# NGS error budget

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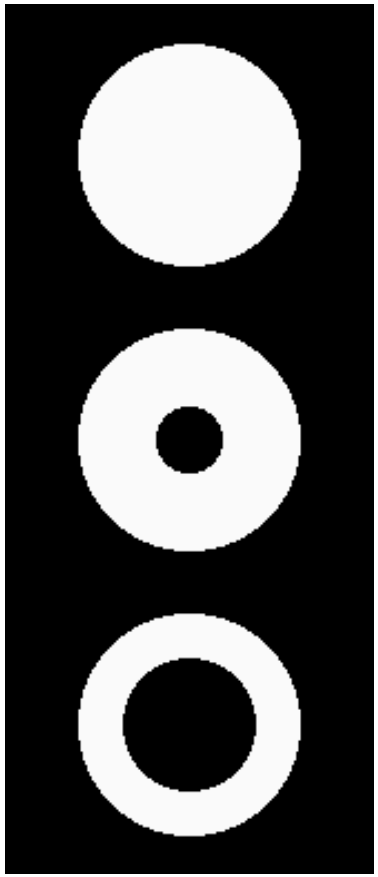

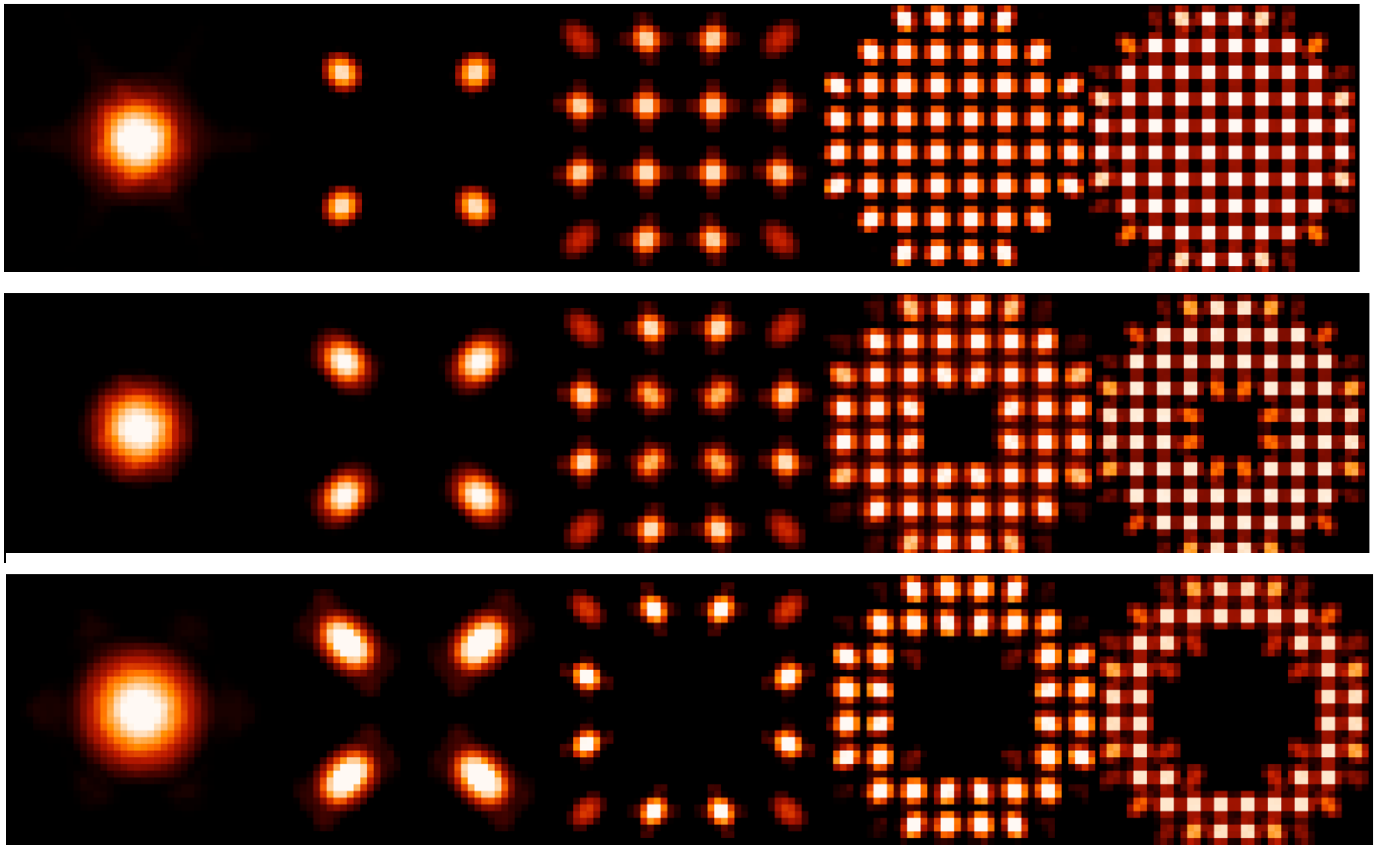

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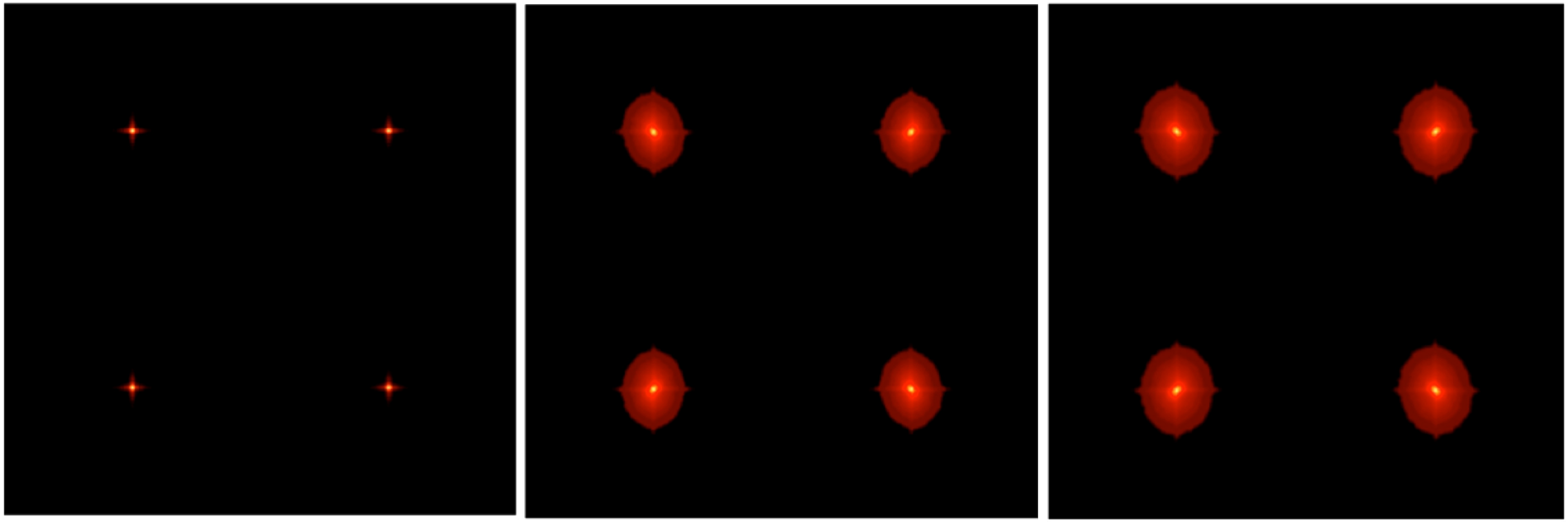


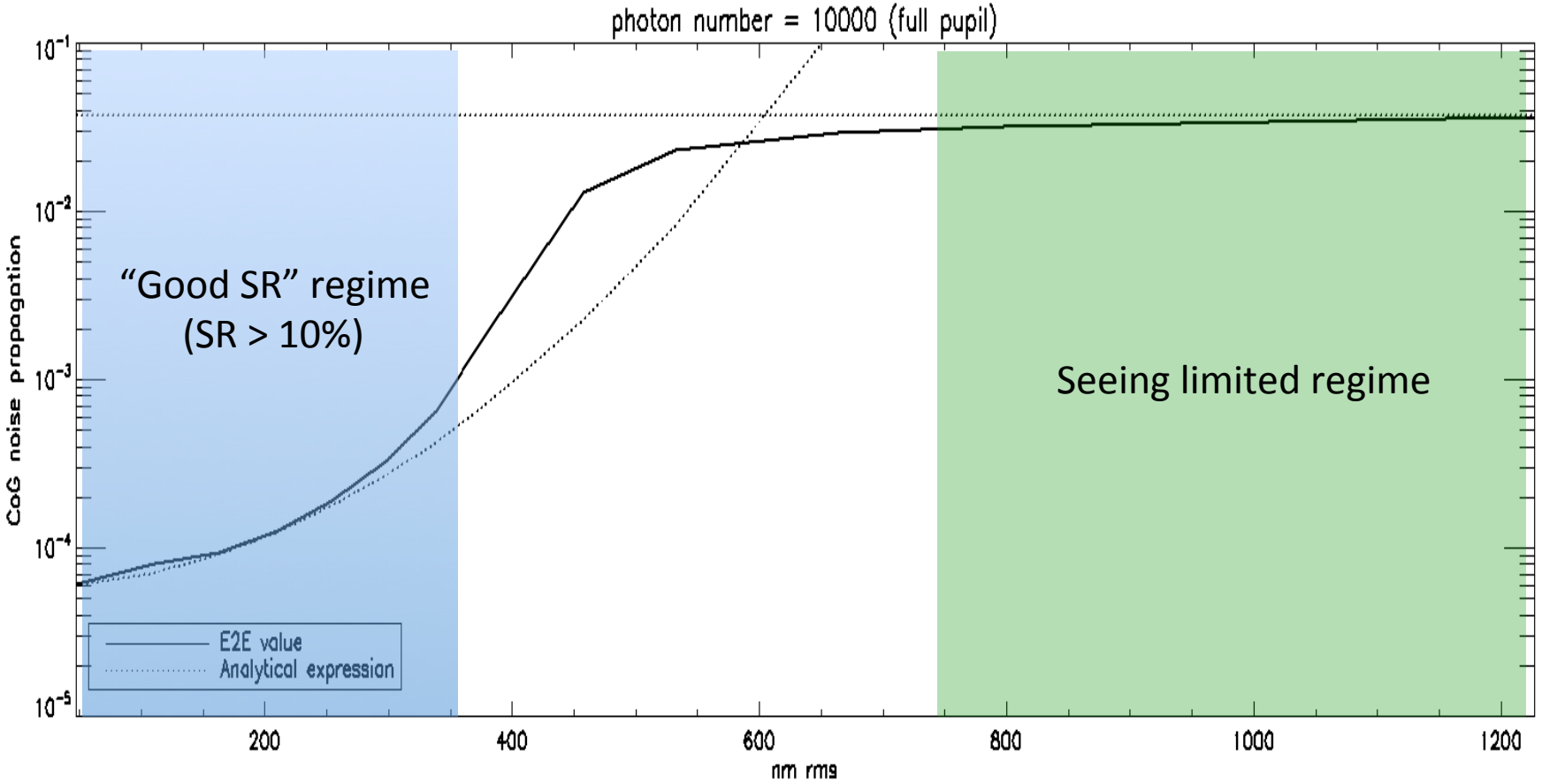
Increasing residual phase seen by the WFS

Good SR regimes

Seeing limited regimes

# NGS error budget

**Noise**



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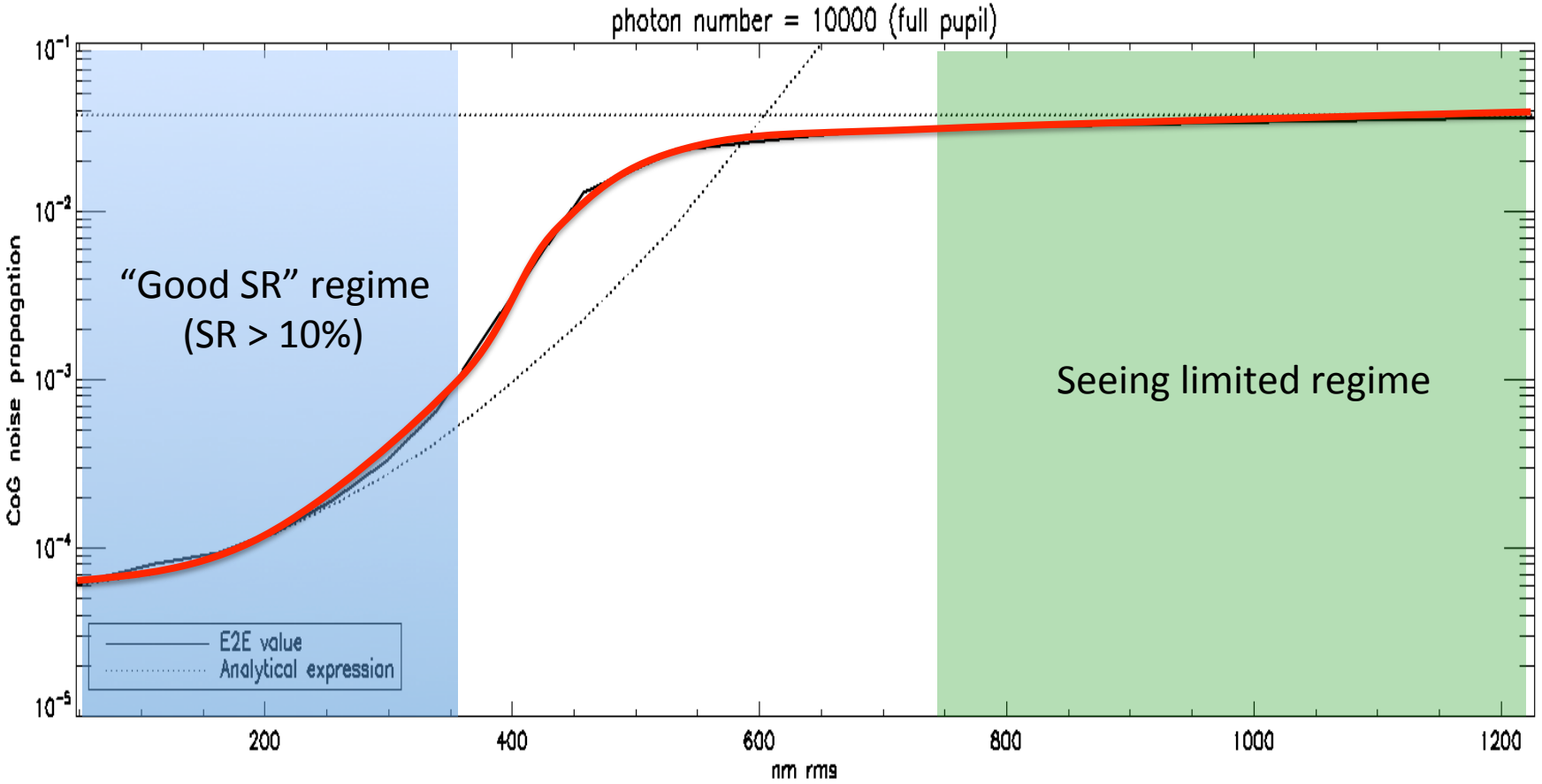
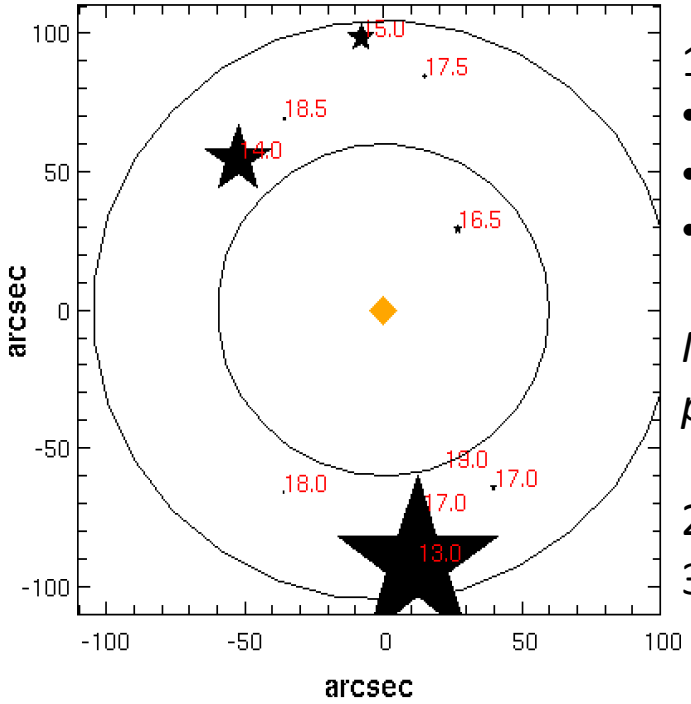



$$\sigma^2_{tot,all\ mas} = \left(\frac{N_T}{N_D}\right)^2 \sigma^2_{tot,SR\ mas} + \left(1 - \left(\frac{N_T}{N_D}\right)^2\right) \sigma^2_{tot,FWHM\ mas}$$

# Context

**Tomography** | **Temporal** | **Noise**

## Question: how to estimate the sky coverage (or residual error on low order modes) for LGS assisted instruments ?




1. For a given field, we can compute, for each star:
   - The anisoplanatism
   - The temporal error
   - The noise coefficient

*Note: an optimization between noise and temporal error can be performed*

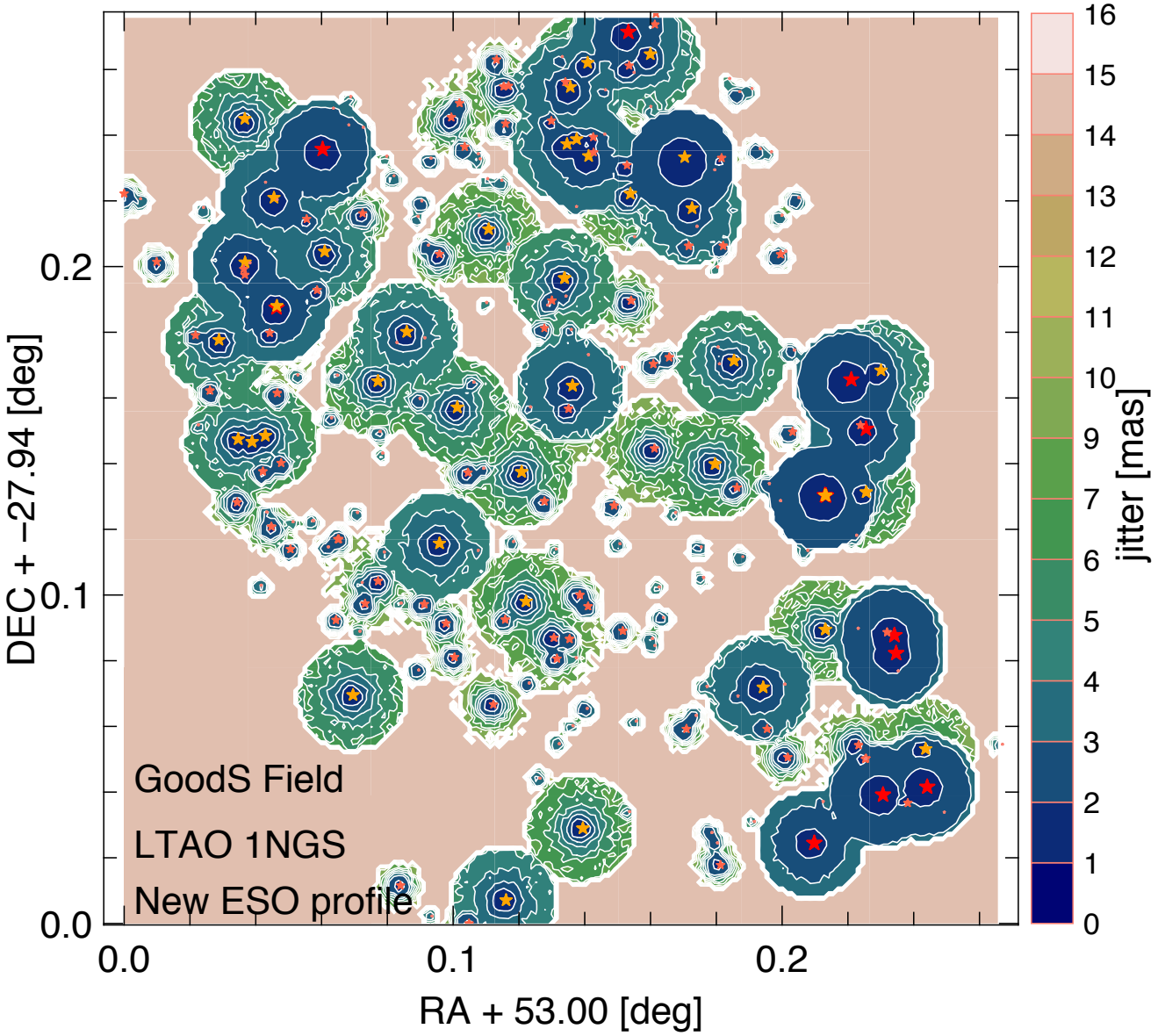
2. Reproduce the process for each pair of stars
3. Reproduce the process for each 3NGS constellation available

- This can be done on synthetic fields, generated from star distribution statistics
- This can de bone on real fields

# Application to HARMONI (LTAO for the EELT)

Test on “classical” cosmological fields

# Application to HARMONI (LTAO for the EELT)



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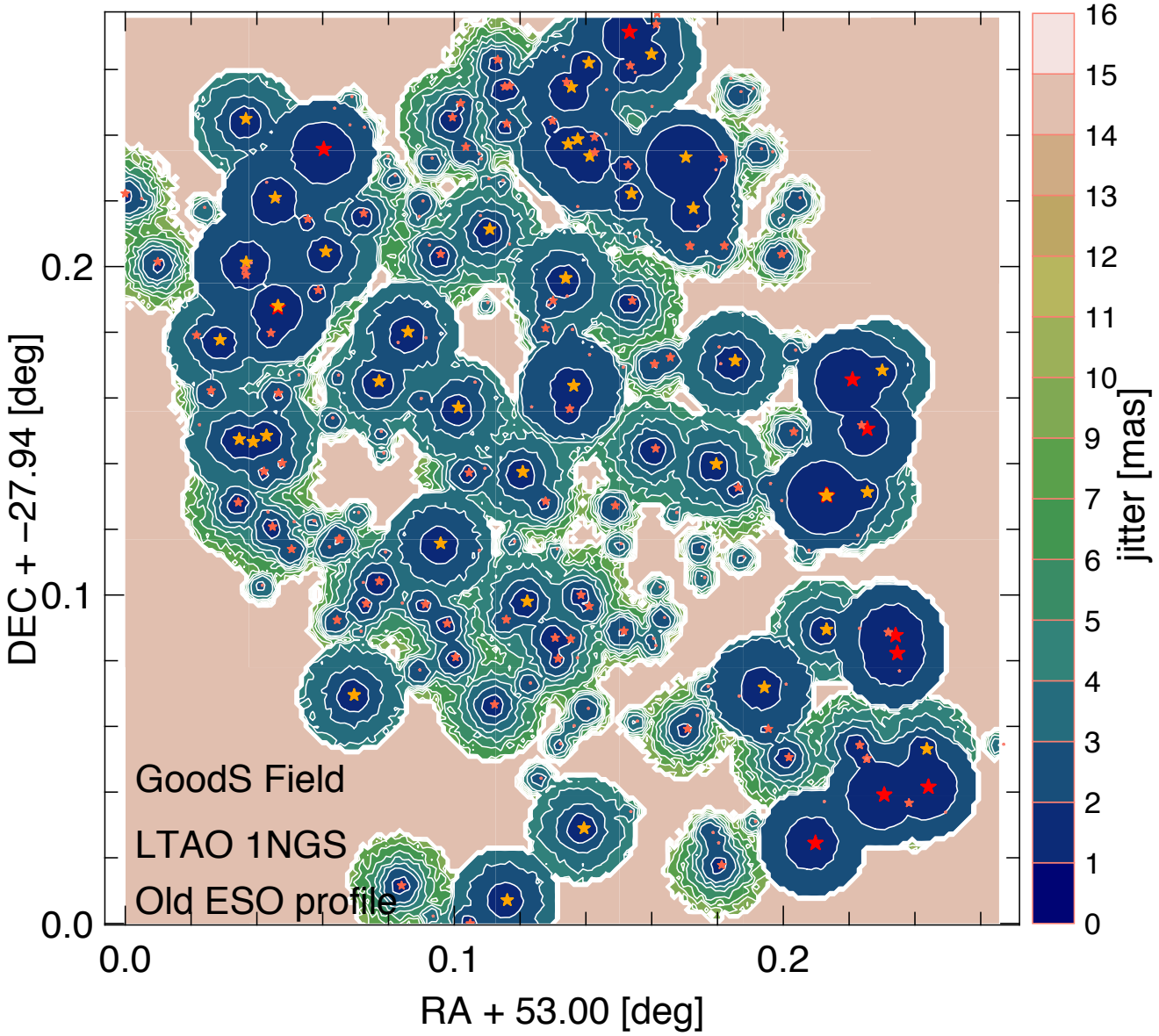
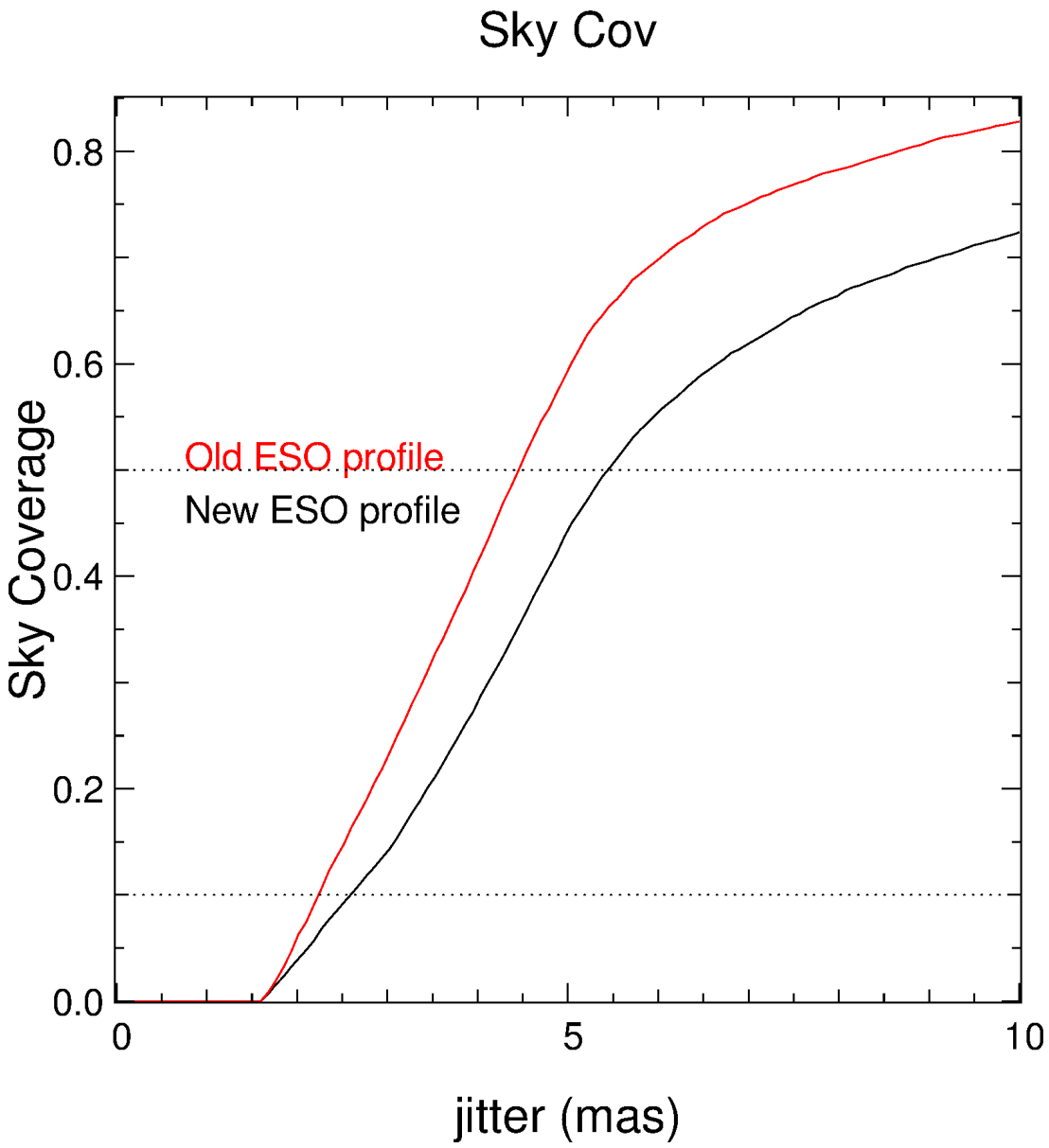



Impact of Cn2 profile (from old ESO to new 35 layers)

# Application to HARMONI (LTAO for the EELT)



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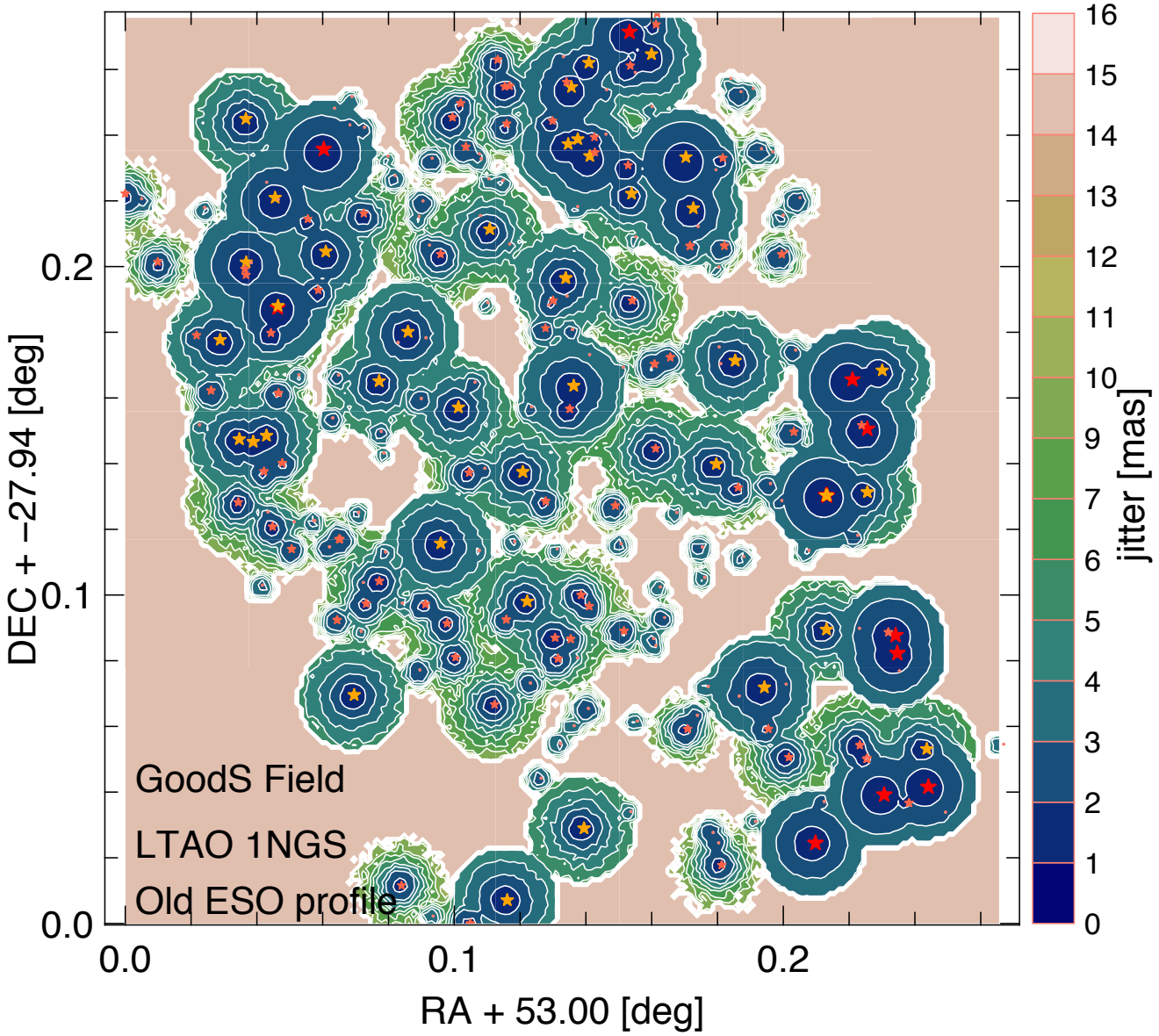
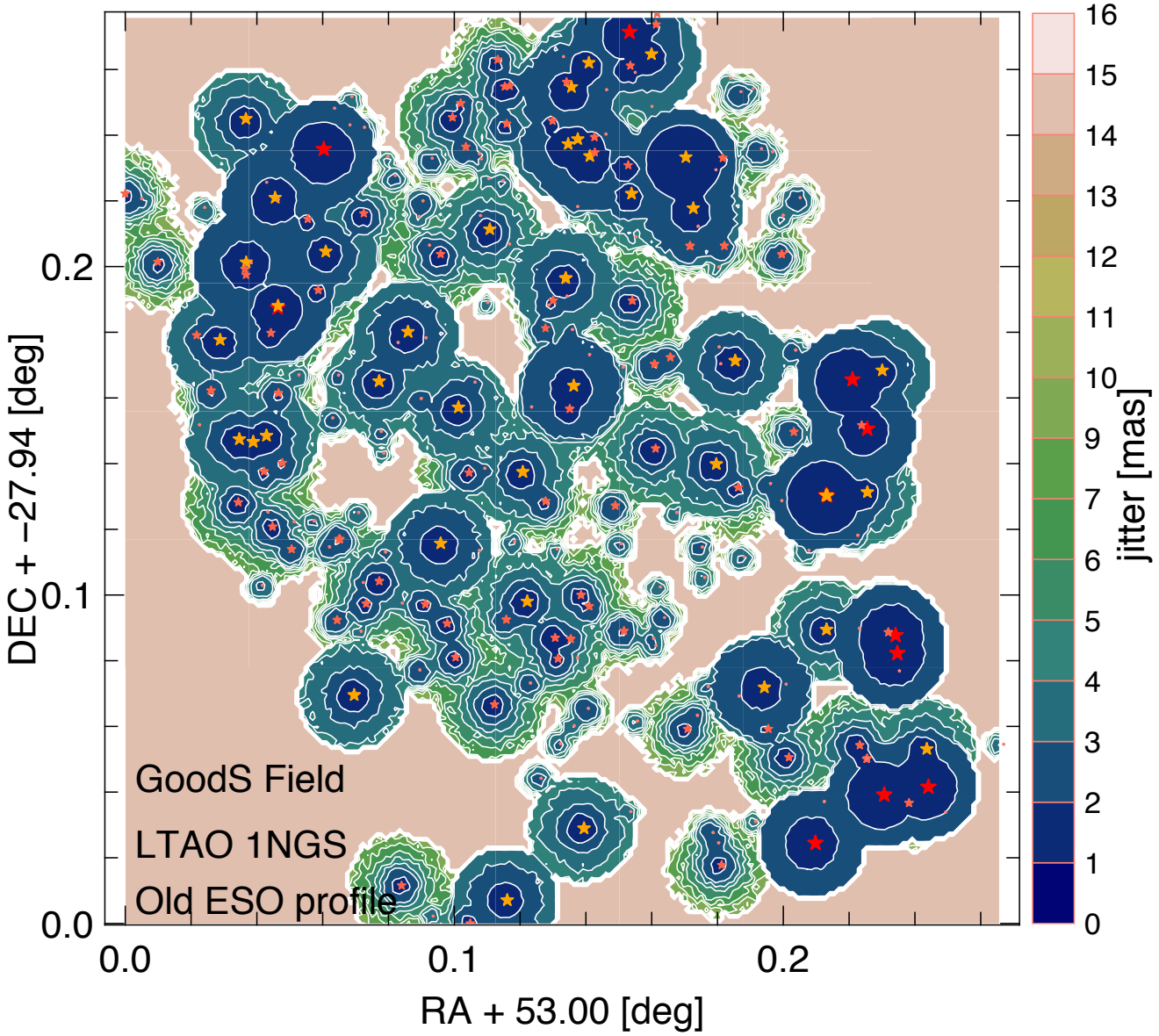



Impact L0 (from 50m to 25m)

# Application to HARMONI (LTAO for the EELT)

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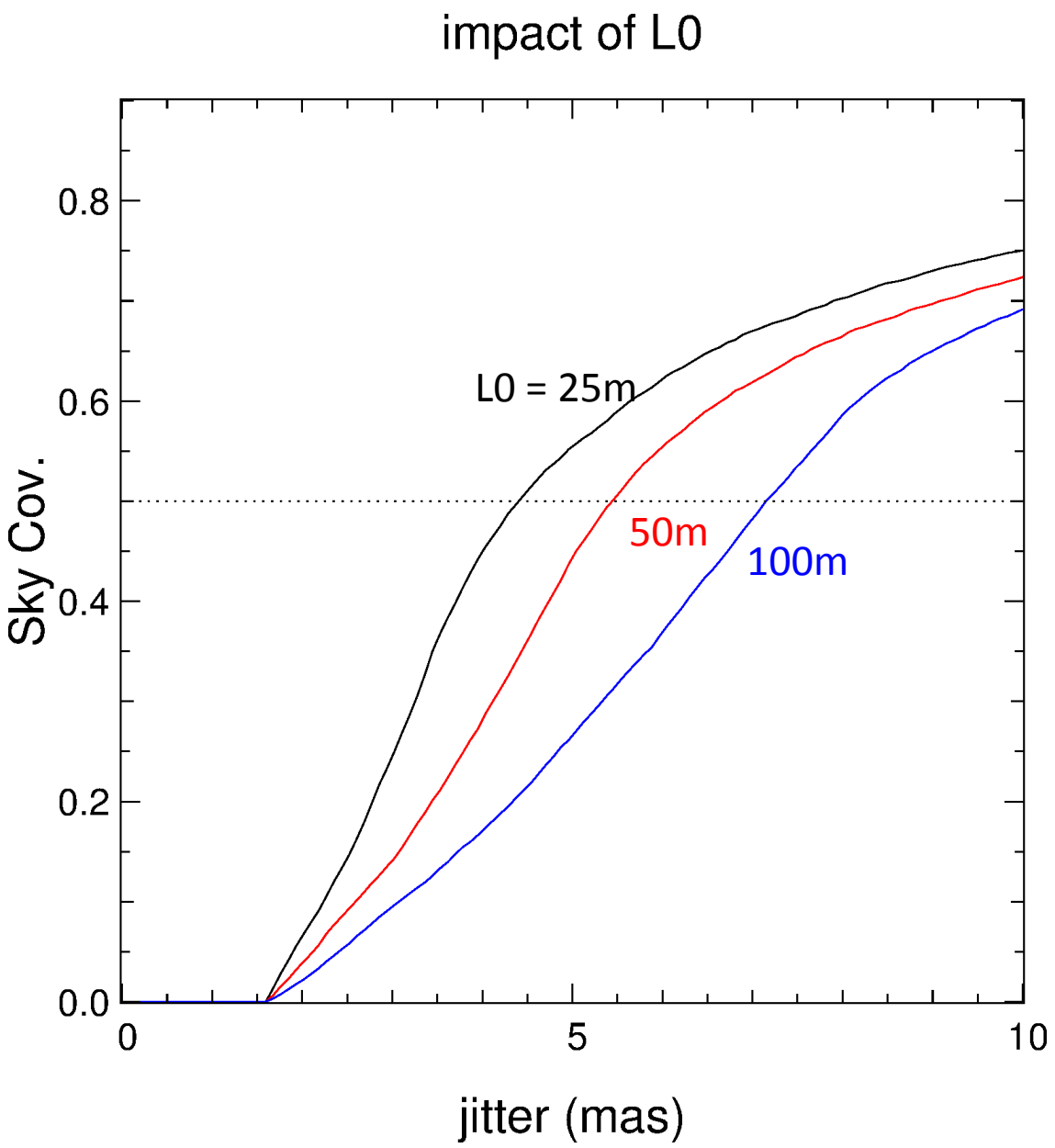
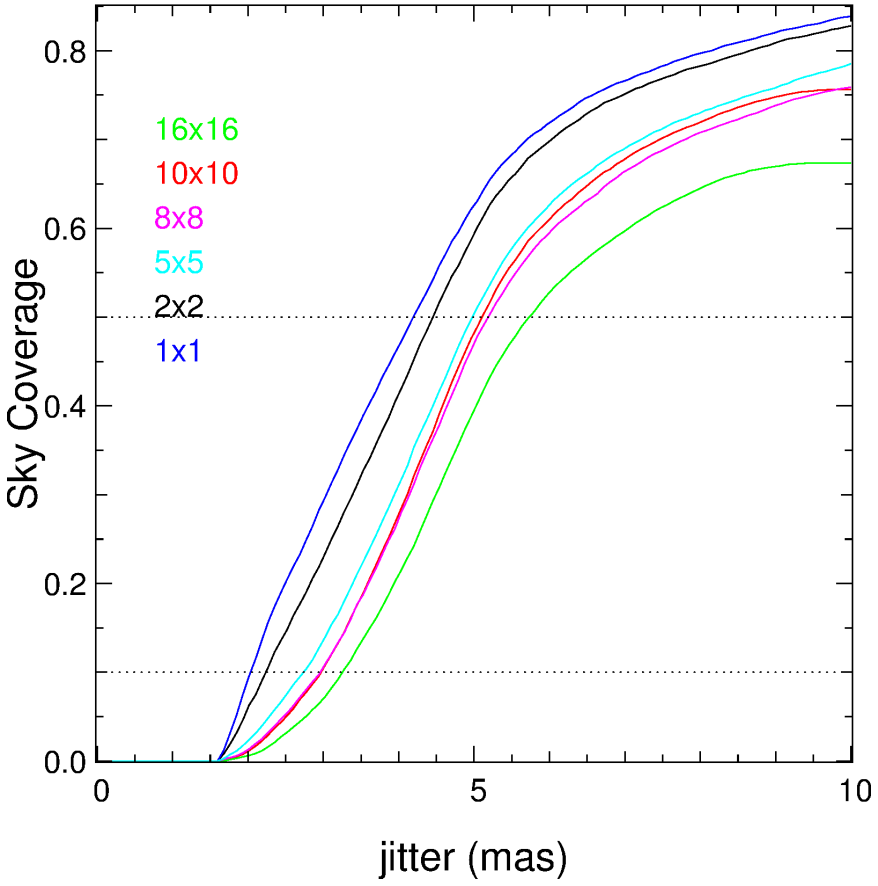


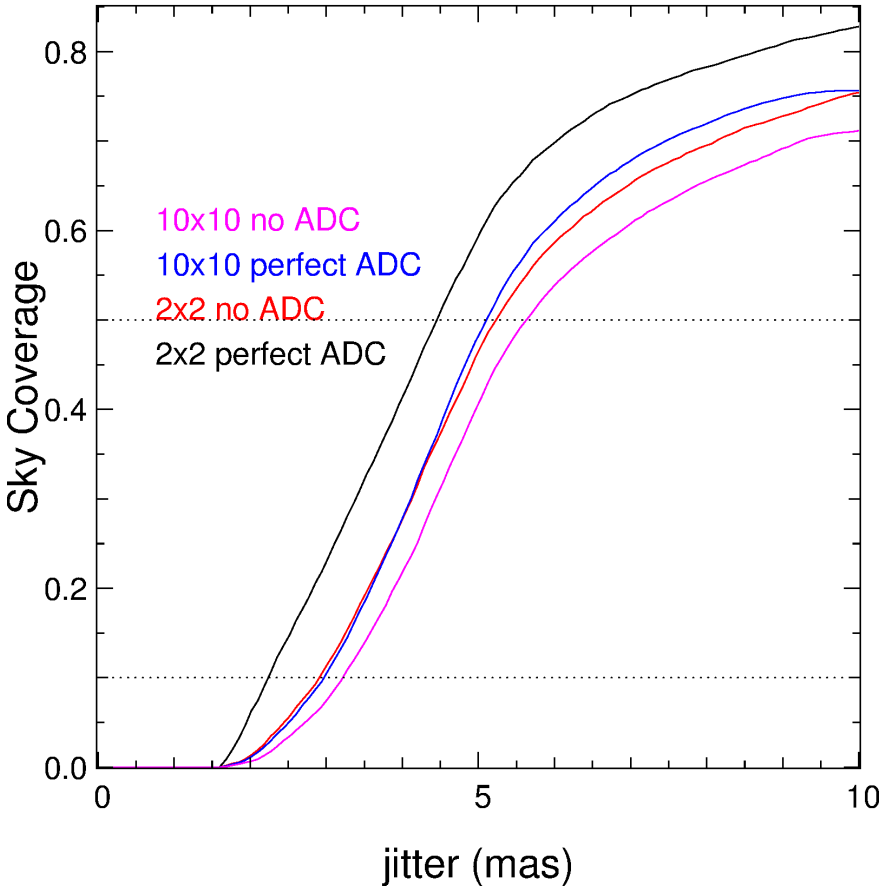
# Application to HARMONI (LTAO for the EELT)

## System trade-off

### # of subaps

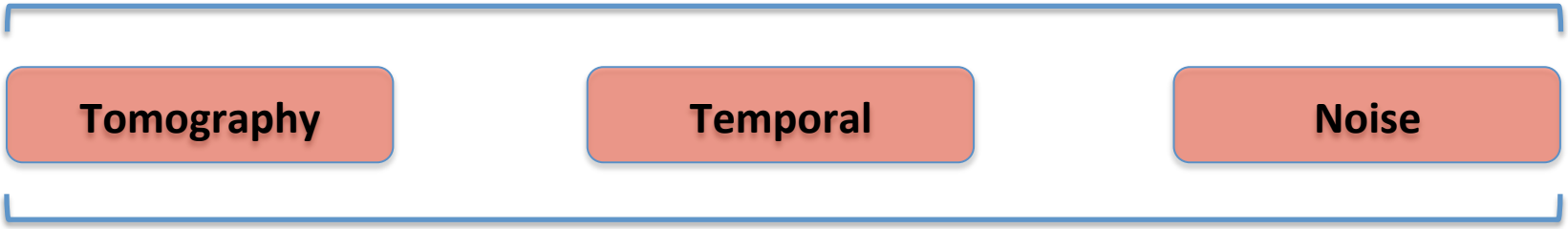



### Impact of ADC



# CONCLUSIONS

**How to estimate the sky coverage (or residual error on low order modes) for LGS assisted instruments ?**




We have improved the noise model to account for residual turbulence, and other effects like ADC, pupils, etc…

*So far we have considered full decoupling of NGS vs. LGS, but algorithms to take advantage of the higher-order (measured by the LGS) to improve further the could be envisioned (e.g. Gilles, Correia et al. (sort of PSF reconstruction in the NGS path)).*