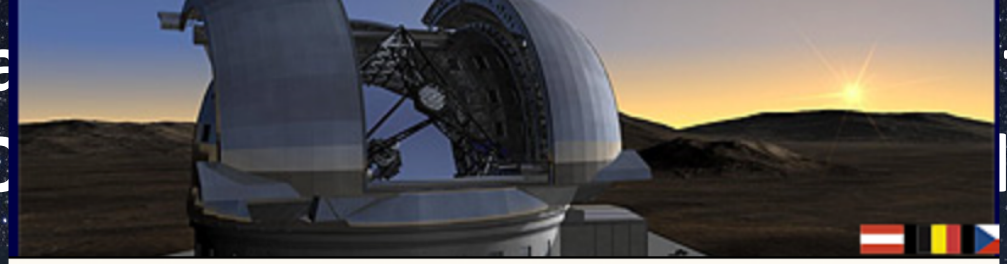
Toward ELT observations Preparation: The "AO performance and PSF simulations" Working Group

Benoit Neichel on behalf of the Working Group

Towa tion: The "AC lations"



ESO TWiki > ELTScience Web > AO_performance > MembersA

Members of the AO perf WG

- Benoit Neichel - Coordinator (LAM)
- Guido Agapito (INAF-Arcetri)
- Cedric Plantet (INAF-Arcetri)
- Carmelo Arcidiacono (INAF-Padova)
- Ric Davies (MPE)
- Thierry Fusco (ONERA)
- Olivier Beltramo-Martin (LAM)
- Fraser Clarke (Oxford)
- Tim Morris (Durham)
- Yann Clenet (Obs. Paris - LESIA)
- Sylvain Oberti (ESO)
- Pascal Hibon (ESO)
- Olivier Hainaut (ESO)
- Jean-Marc Conan (ONERA)
- Roy Boekel (MPIA)
- Pascal Ballester (ESO)
- Thomas Bierwirth (ESO)

And for the overal organization of the WGs:

- Michele Ciracusuolo (ESO)
- Remco Van Der Burg (ESO)

Context

There will be only 1 ELT => Each photon counts.

How to optimize the operations so we make the best use of this big machine ?

Theme 1: Preparing for ELT observations

The working groups and tasks under Theme 1 aim to provide the necessary infrastructure to prepare and execute observations with the ELT. These include:

- **WP1.1:** Star catalogues
- **WP1.2**: AO performance and Point Spread Function (PSF)
- **WP1.3**: Instruments simulators
- **WP1.4**: Exposure Time Calculator

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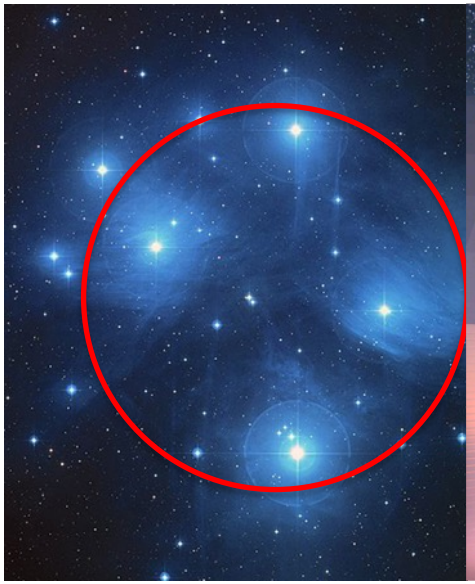
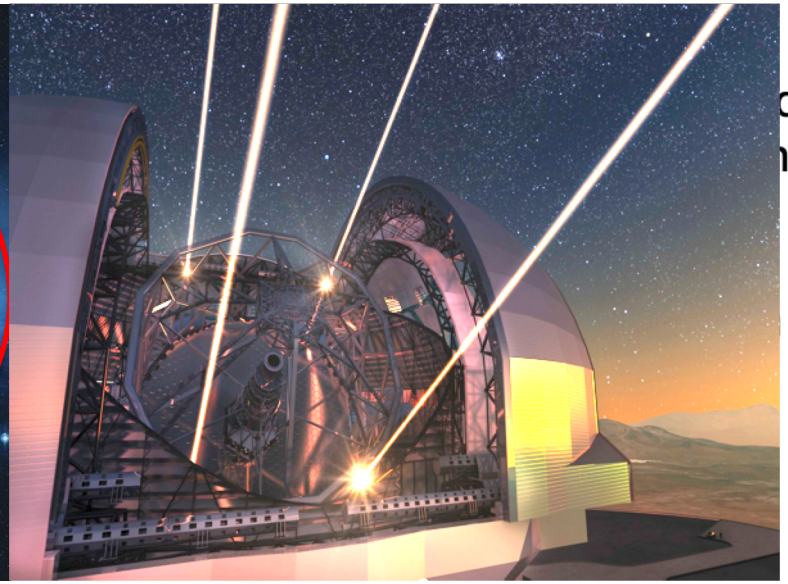
Theme 1: Preparing for ELT observations

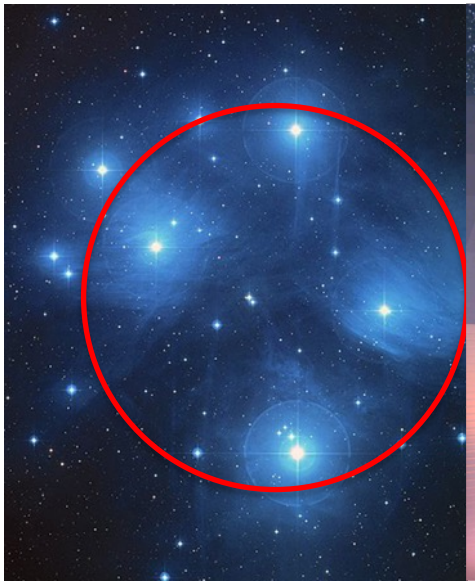


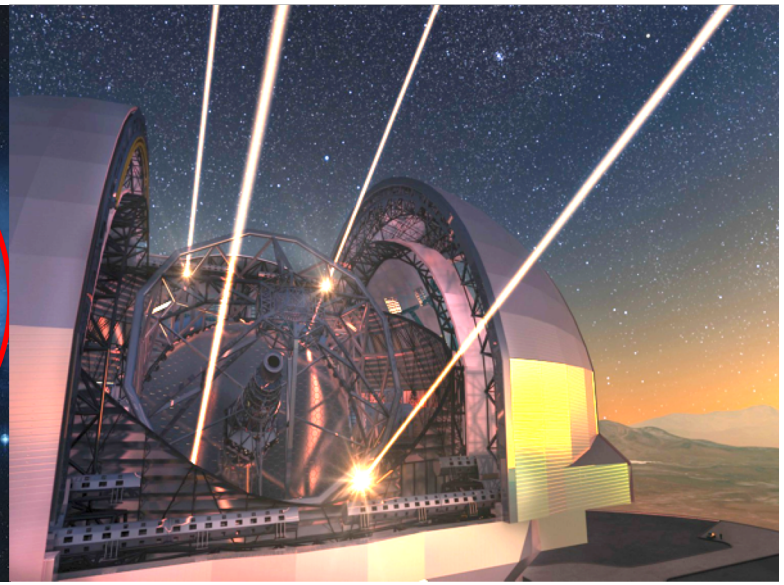


de the necessary infrastructure
nclude:

(PSF)

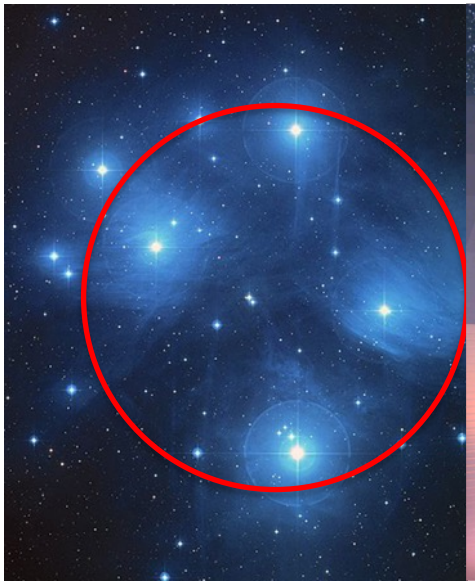
Theme 1: Preparing for ELT observations

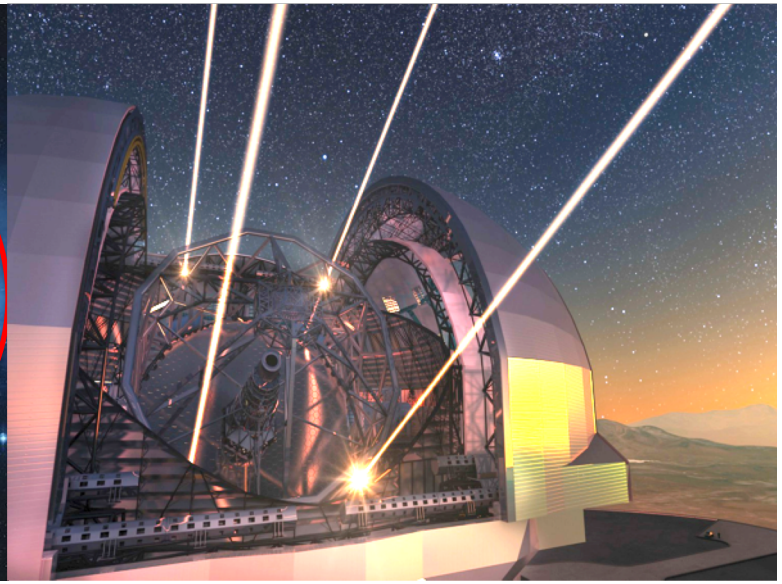




Context

Theme 1: Preparing for ELT observations





These Working Groups involve scientists from all the ELT instruments

Context

Theme 1: Preparing for ELT observations

The working groups and tasks under Theme 1 aim to provide the necessary infrastructure to prepare and execute observations with the ELT. These include:

- **WP1.1:** Star catalogues
- **WP1.2**: AO performance and Point Spread Function (PSF)
- **WP1.3**: Instruments simulators
- **WP1.4**: Exposure Time Calculator

WP1.2: AO performance and Point Spread Function (PSF)

Rationale	The AO performance of the ELT significantly depends on the available natural guide stars. In each of the observing modes (e.g SCAO, MCAO, LTAO), the brightness of the NGSs, their asterism, and distance from the science target will give significantly different AO performances (quantified by e.g Strehl ratio [SR] or Engircled Energy [EE]). The aim of this WP are: • To define an algorithm capable of choosing the best combination of star(s) available in the field of view (provided by WP 1.1 Star Catalogues) to give the best AO performance • Generate the Point Spread Function (PSF) expected for the observation for a given observing mode and a given set of environmental conditions (e.g. seeing, water vapour, etc.).
Deliverables	1. Algorithm for choosing the best NGS stars 2. Generate the expected PSF for a give observation

Need first to define a simulation strategy

Strategy for AO Simulation

Full E2E

Pros:
- Very accurate
- Able to model specific effects

Cons:
- Convergence time is slow
- Require a lot of computing power

Ex. Tools:
- OOMAO, PASSATA, COMPASS, YAO, SOAPY, …

Analytical

Pros:
- Very fast
- No need for big computer

Cons:
- Not able to model all aspects
- Some assumptions to be known

Ex. Tools:
- FAST, PAOLA, CIBOLA, …

(And we can think on using hybrid methods, mixing E2E and analytical)

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Ex. Tools:
- OOMAO, PASSATA, COMPASS, YAO, SOAPY, …

(May be ok for SCAO)

Analytical

Pros:
- Very fast
- No need for big computer

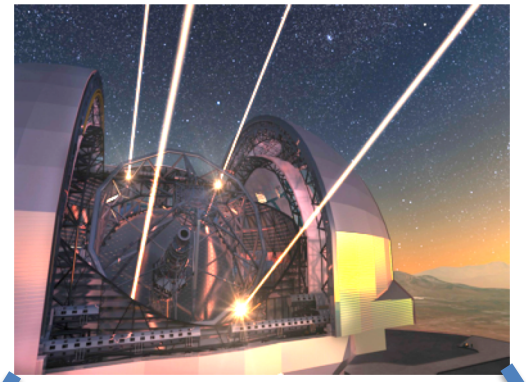
Cons:
- Not able to model all aspects
- Some assumptions to be known

Ex. Tools:
- FAST, PAOLA, CIBOLA, …

(Certainly required for MCAO, LTAO, as they will need to scan many constellations)

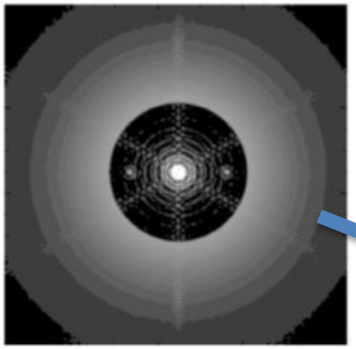
(And we can think on using hybrid methods, mixing E2E and analytical)

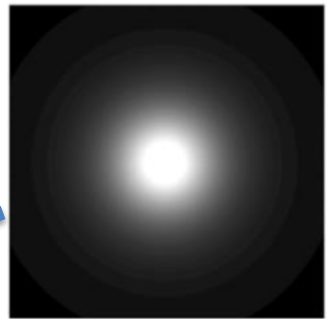
PSF Analytical Approach

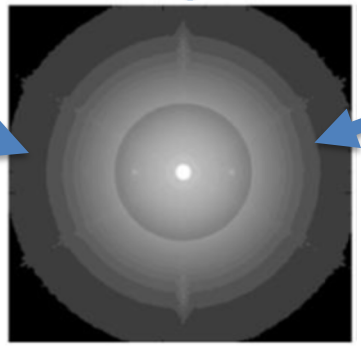


Laser (High-Order) PSF

NGS (Low-Order) PSF

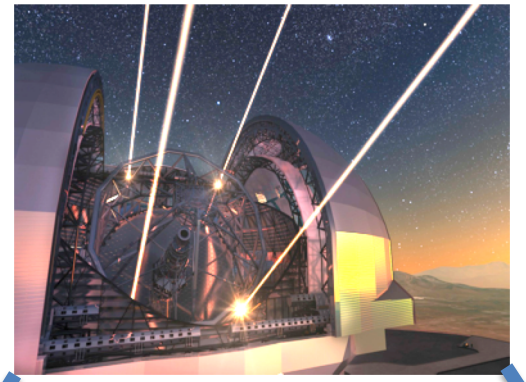






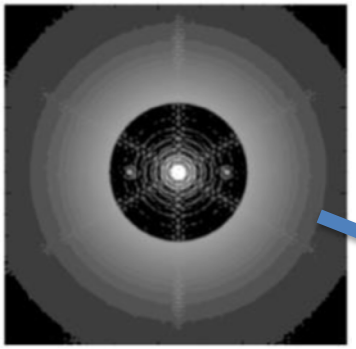
PSF = PSF_HO * PSF_LO

PSF Analytical Approach



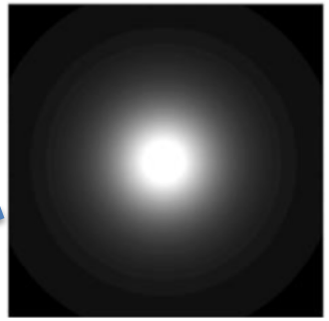
Laser (High-Order) PSF

Depends on Cn2, seeing, L0, LGS constellation, LGS flux.



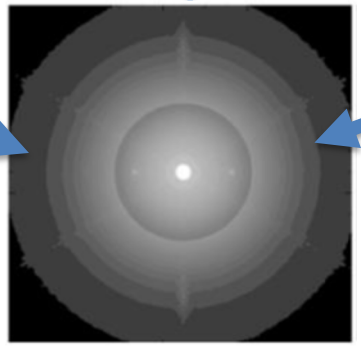
To a first order, this is mostly constant.

NGS (Low-Order) PSF



Depends on Cn2, seeing, L0, NGS constellation, NGS flux.

To a first order, this is very variable.

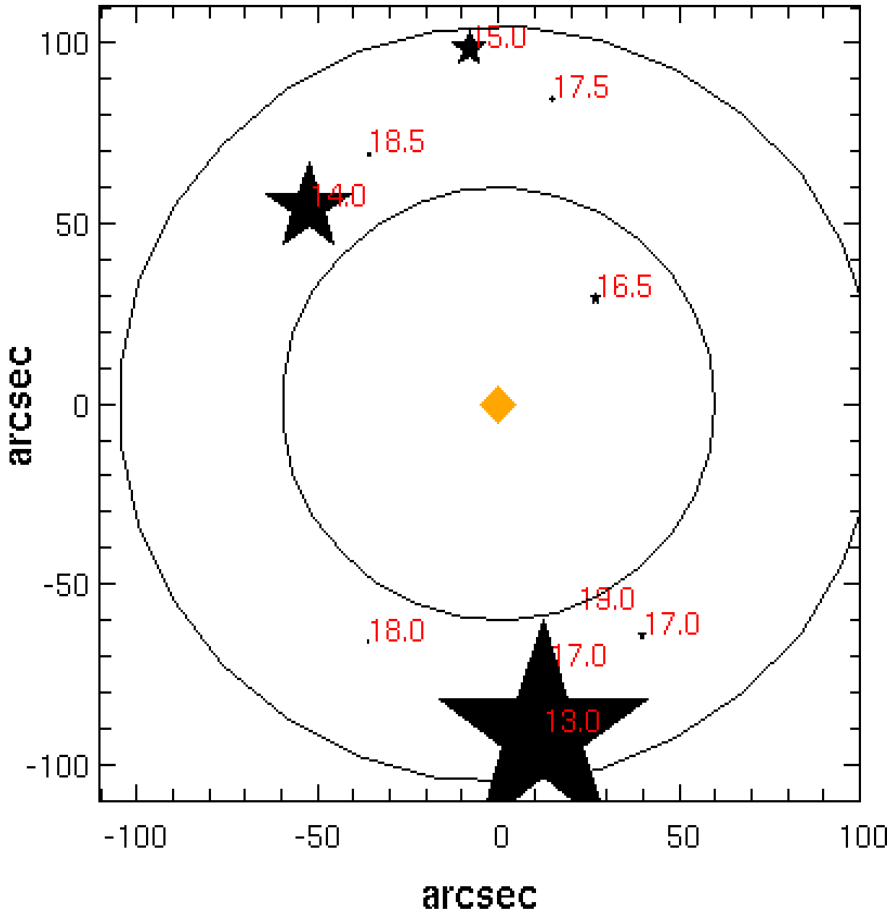


PSF = PSF_HO * PSF_LO

PSF Analytical Approach

Questions: How to find the best NGS asterism ?

How to get the LO PSF from this constellation ?



PSF Analytical Approach

Questions: How to find the best NGS asterism ?
How to get the LO PSF from this constellation ?

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

Simulation strategy:

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

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

PSF Analytical Approach

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PSF Analytical Approach

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

GEMINI

Compensation of the Null modes with the Gemini MCAO

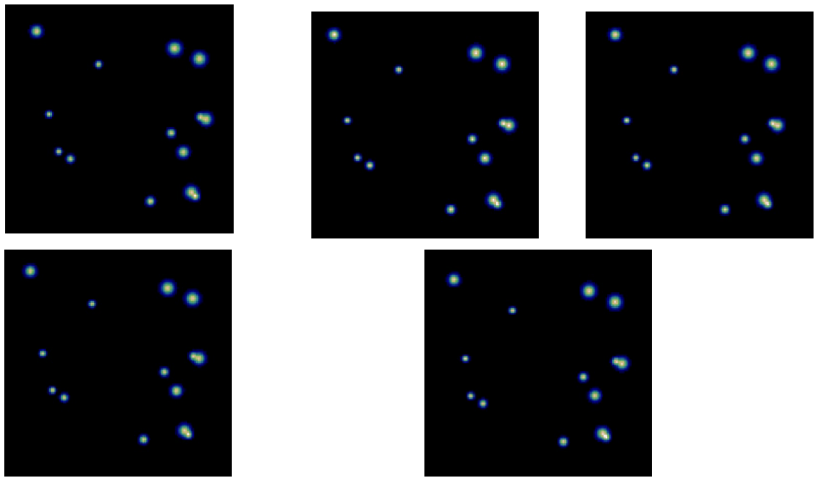
Gemini Document RTP-AO-G0097

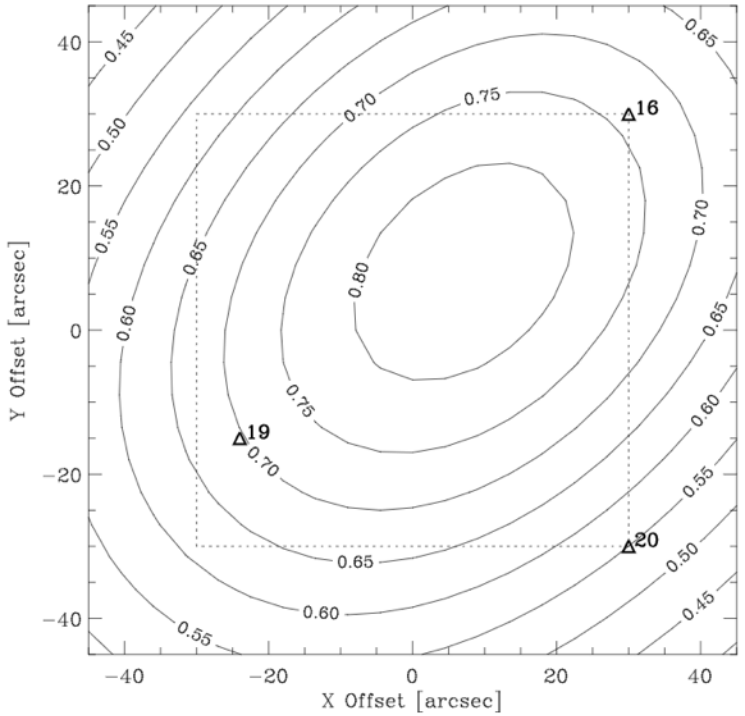
Francois Rigaut. February 29, 2000

Methods for correcting tilt anisoplanatism in laser-guide-star-based multiconjugate adaptive optics

Brent L. Ellerbroek and François Rigaut

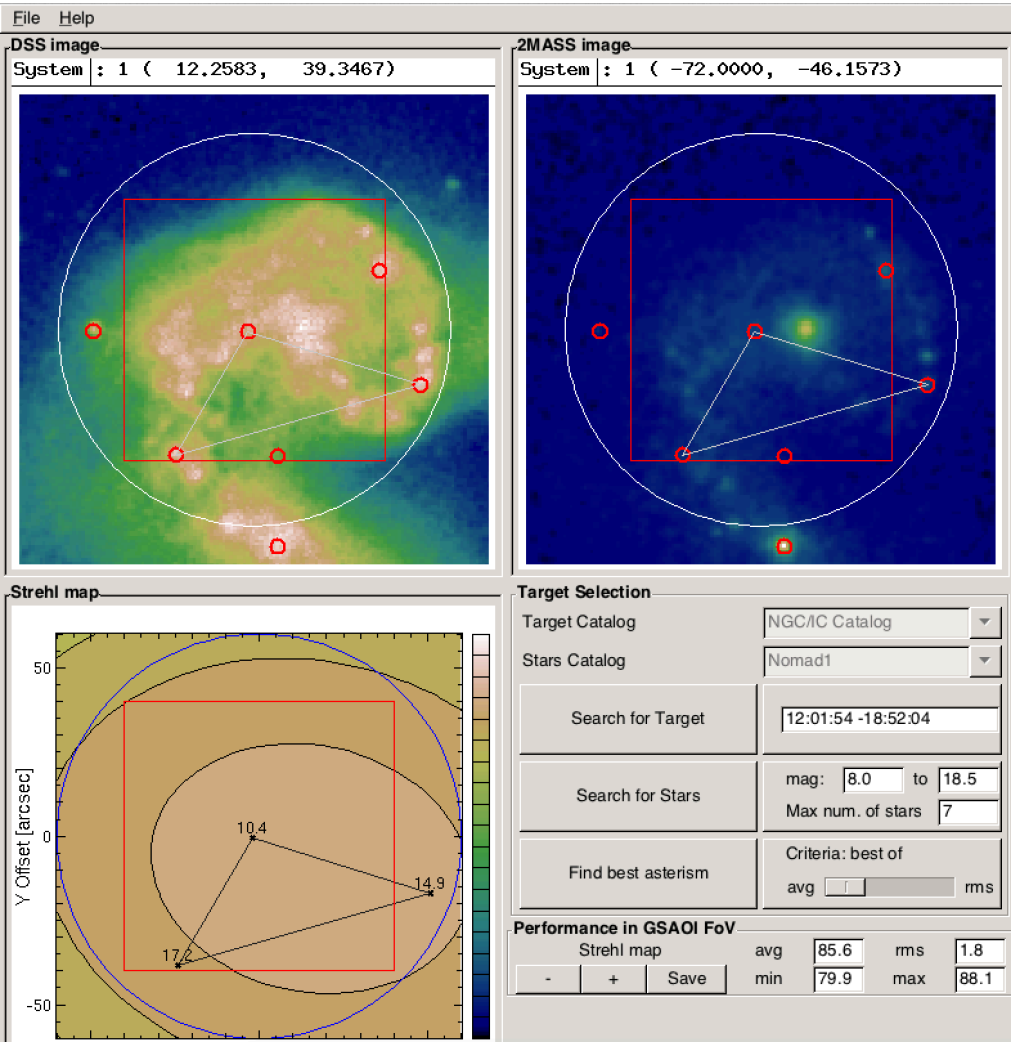
Gemini Observatory, 670 North A'ohoku Place, Hilo, Hawaii 96720





PSF Analytical Approach

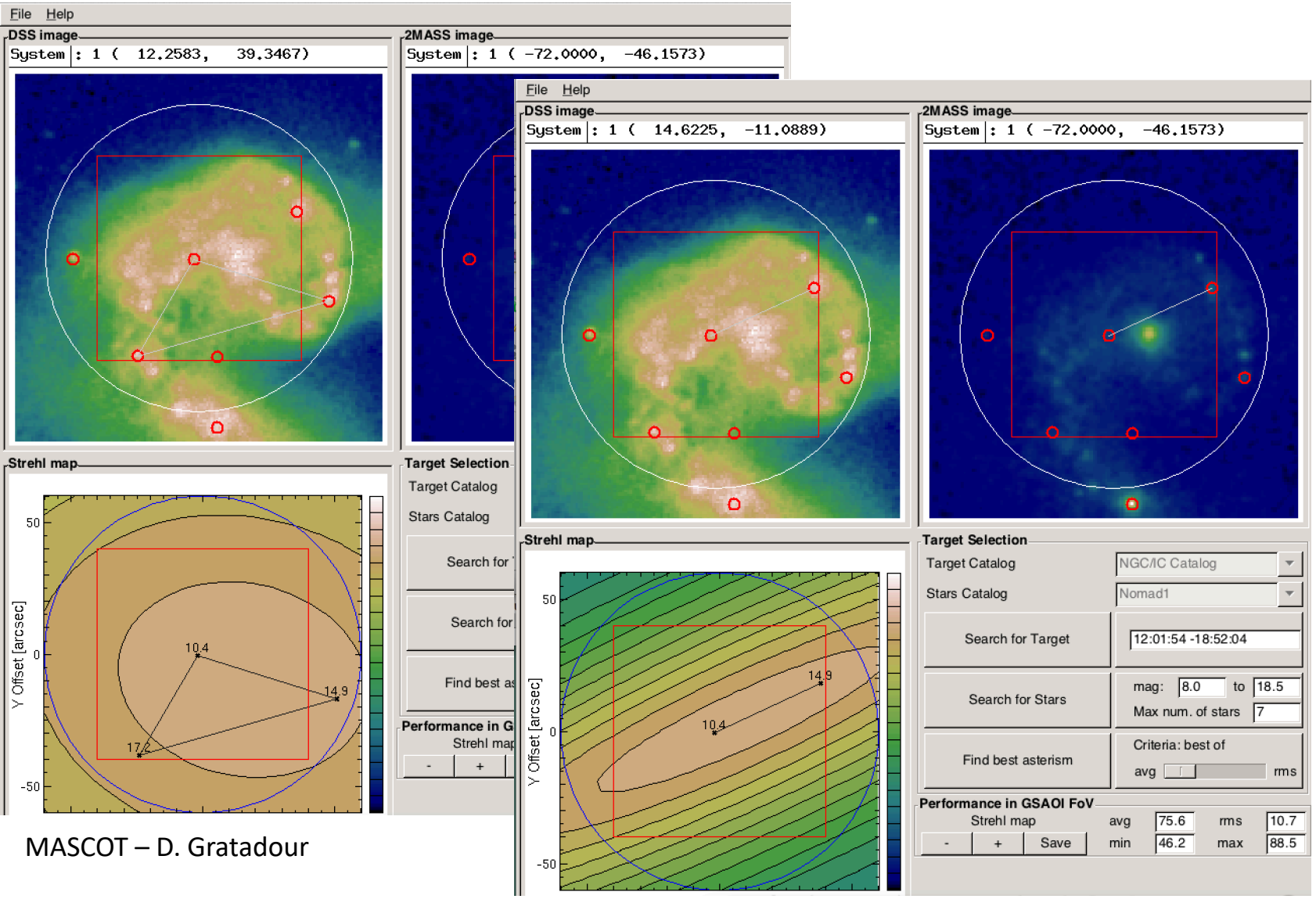
Tomography | **Temporal** | **Noise**



MASCOT – D. Gratadour

PSF Analytical Approach

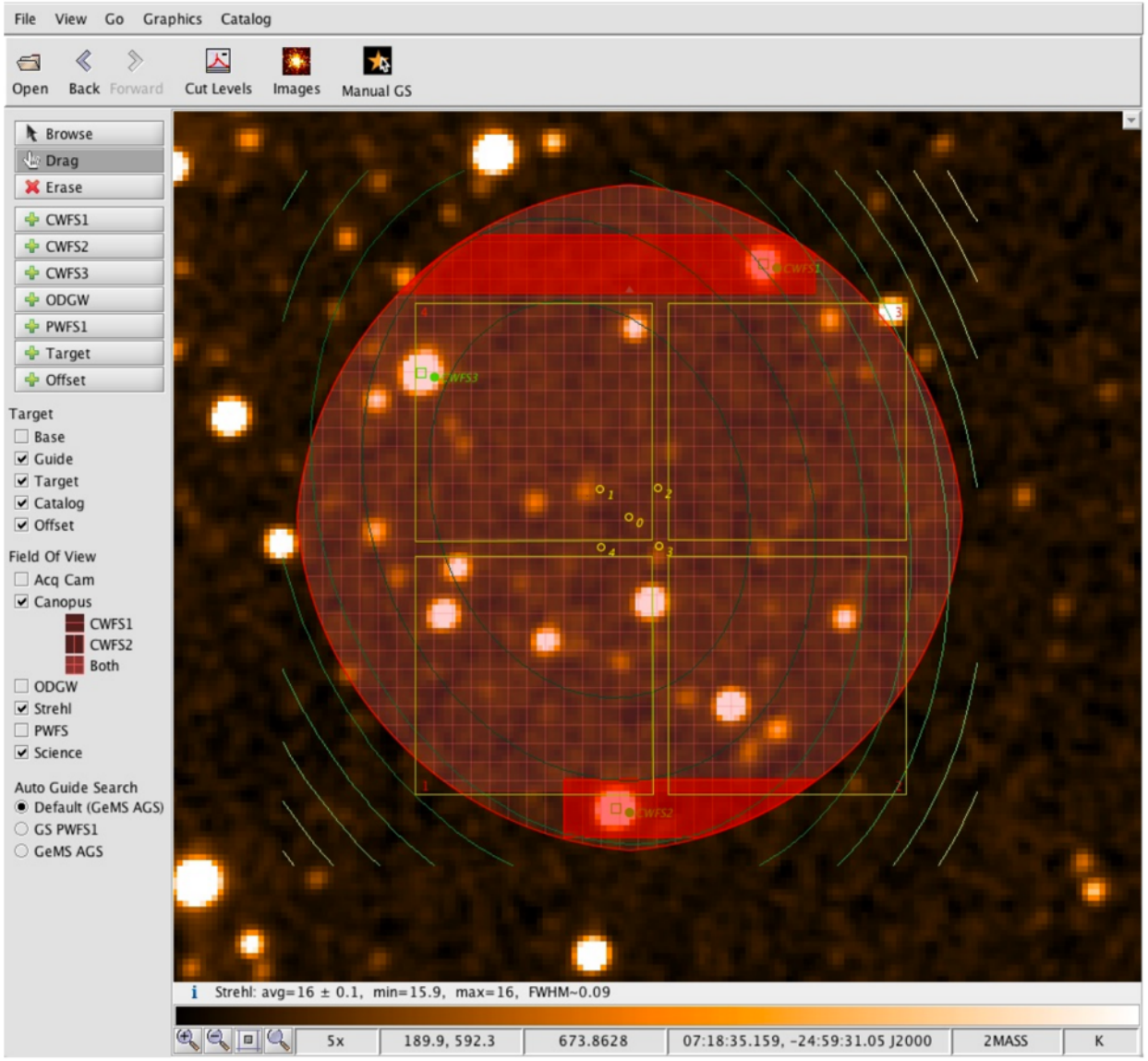
Tomography | **Temporal** | **Noise**



MASCOT – D. Gratadour

PSF Analytical Approach

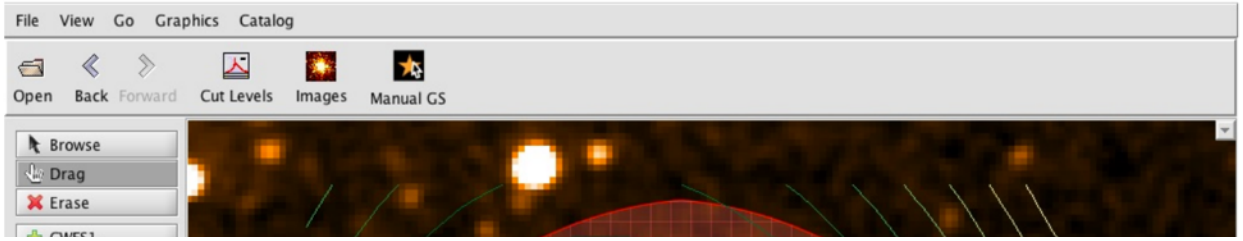
Tomography | **Temporal** | **Noise**



Gemini Observing tool

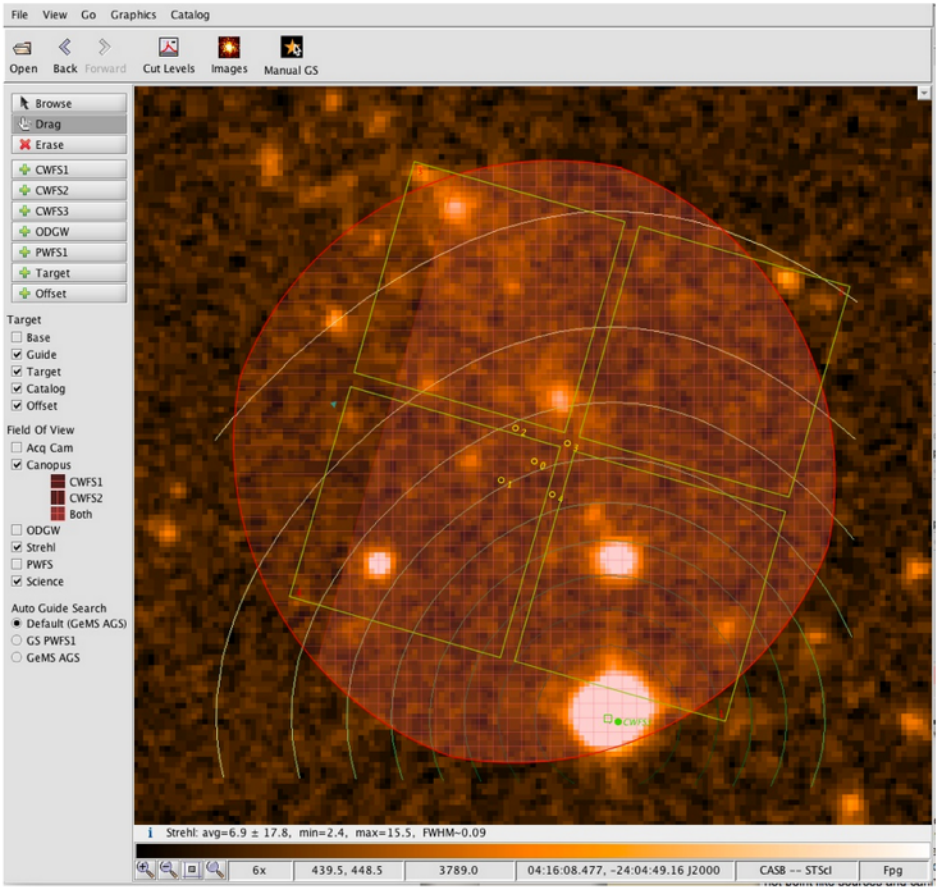
PSF Analytical Approach

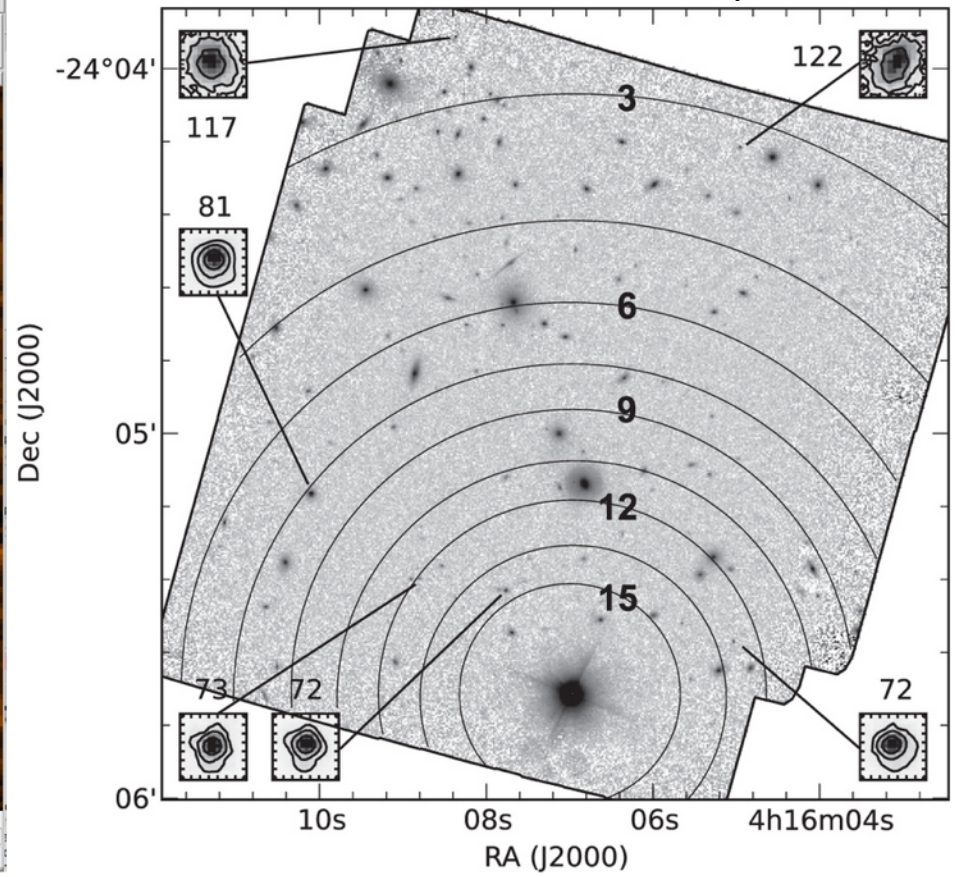
Tomography | **Temporal** | **Noise**



Gemini Observing tool

Schrimer et al., ApJS, 2014





PSF Analytical Approach

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

we need to revisit those methods for the EELT

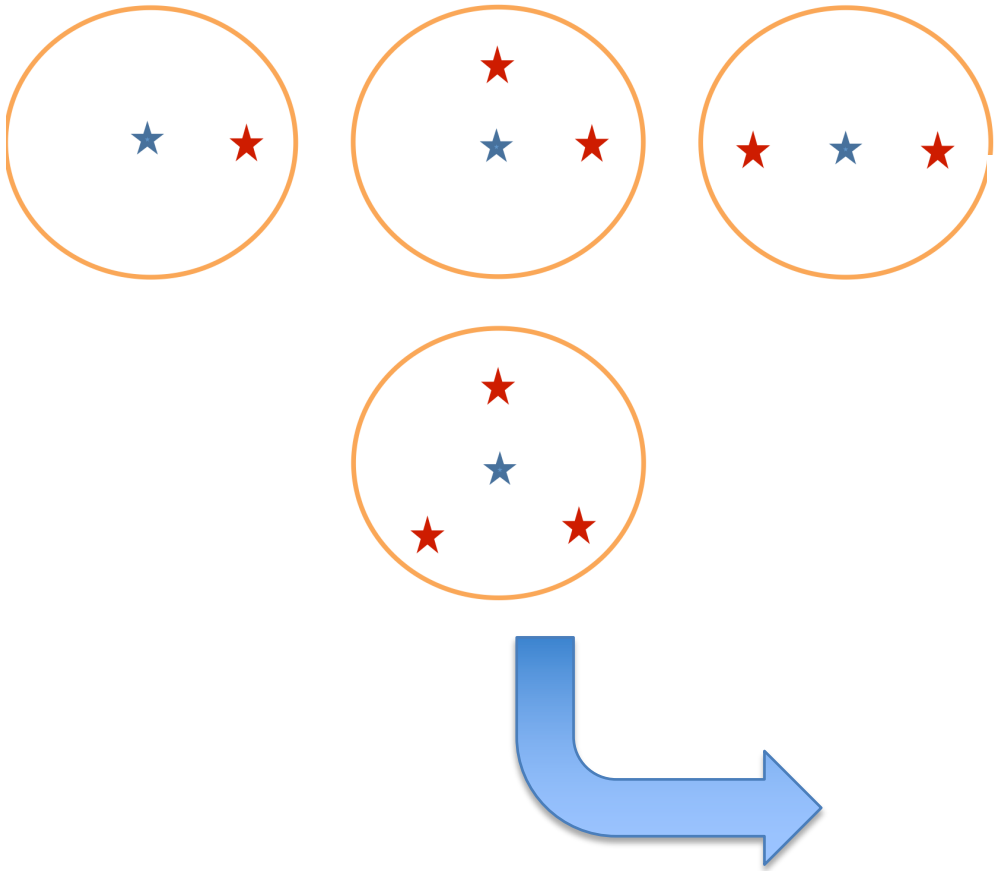
(So far we have mainly worked on this term)

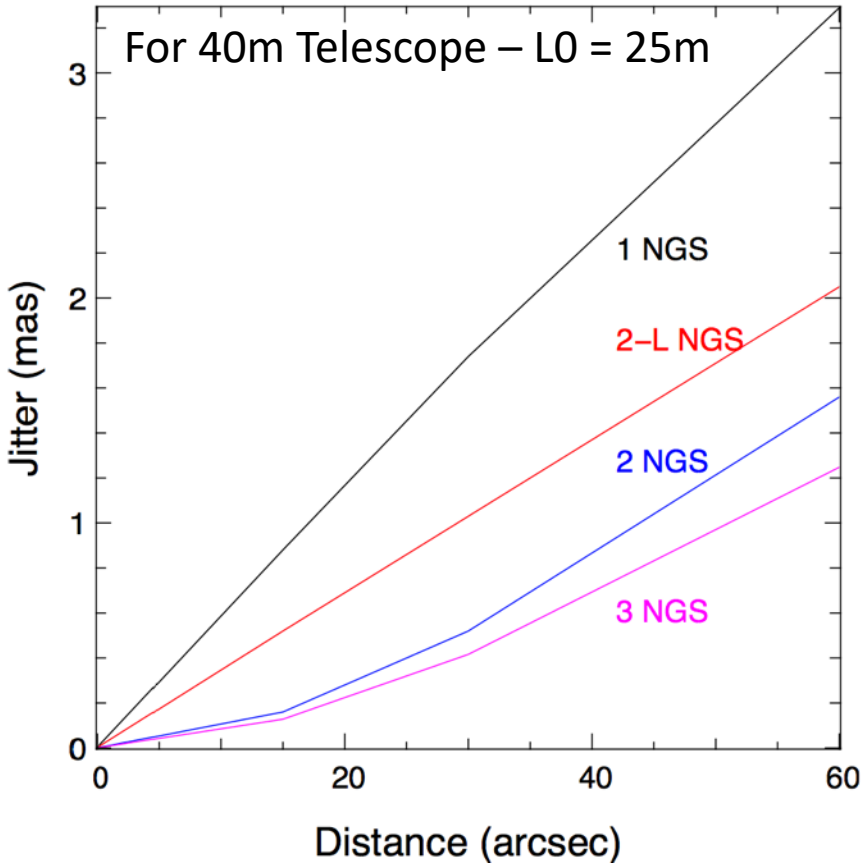
NGS error budget

Tomography

Impact on residual jitter of different NGS constellation

e.g. Sasiela, Chassat, Whiteley…





NGS error budget

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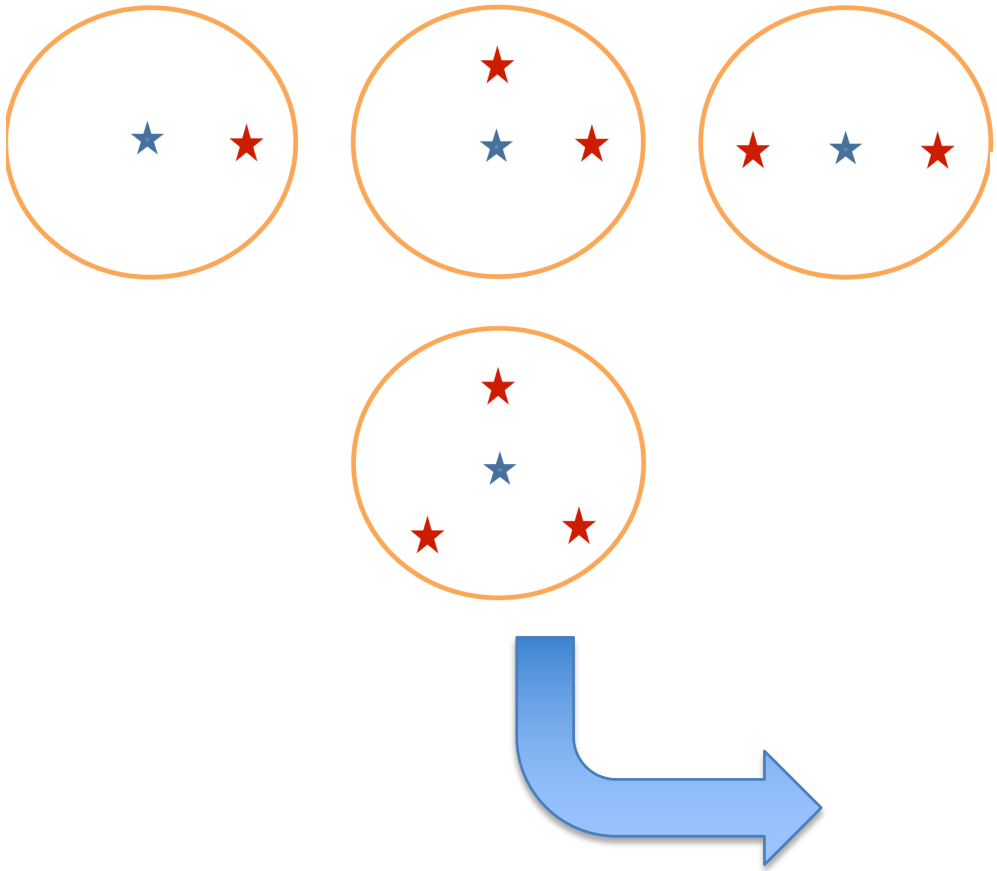
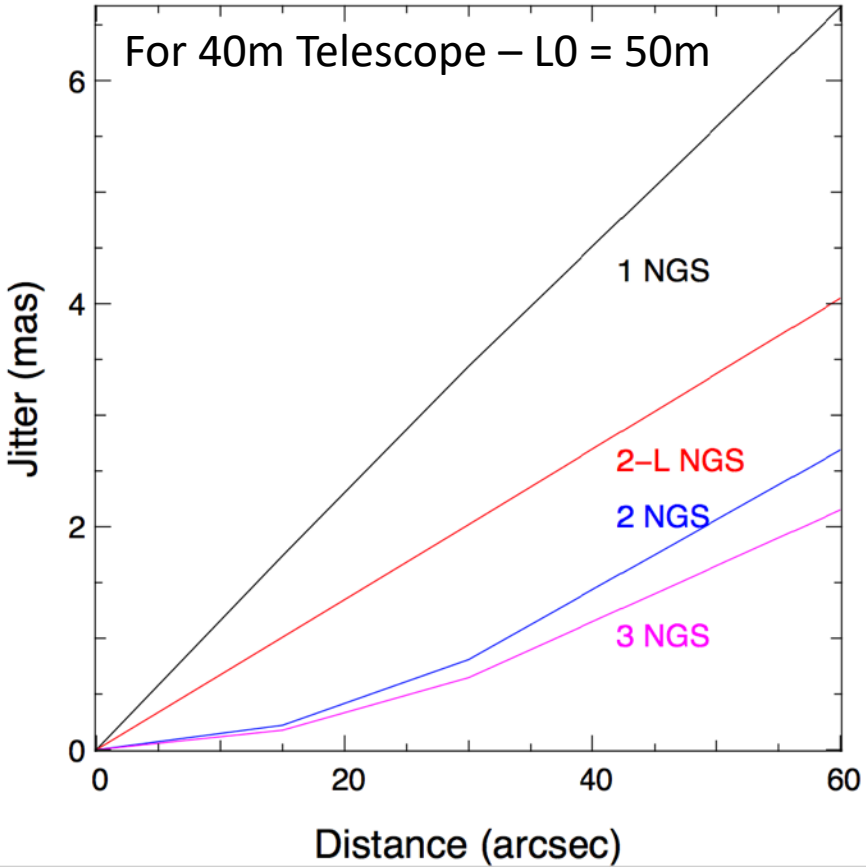




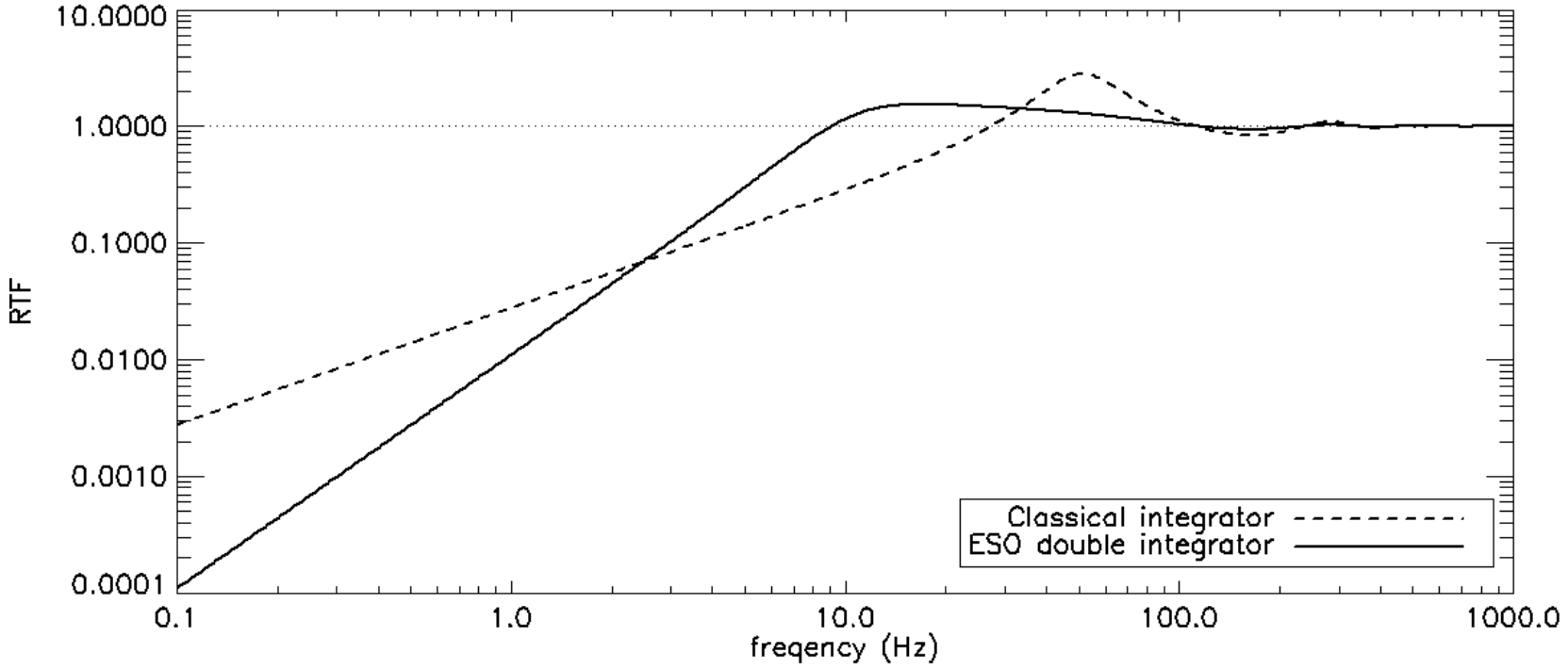
NGS error budget

Temporal

First need to determine the rejection transfer function.

It depends on the controller performance…

Assuming ELT scheme with M4/M5 we could have:



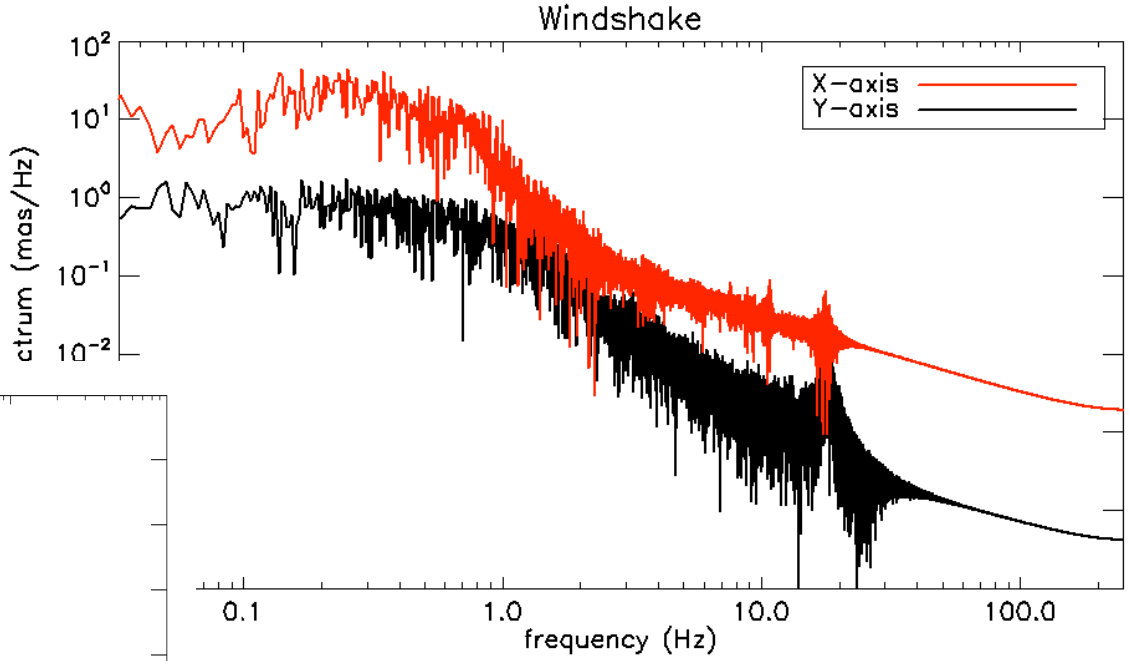
NGS error budget

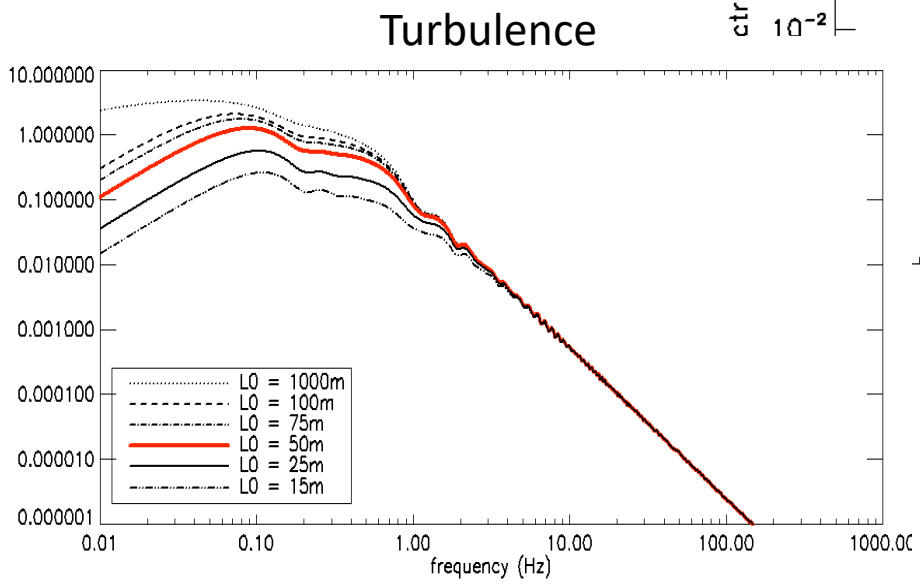
Temporal

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:





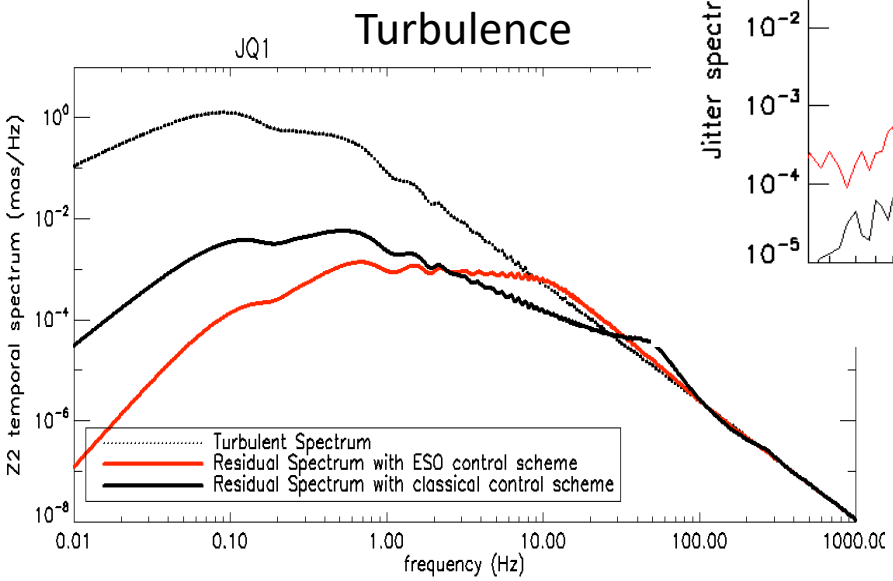
NGS error budget

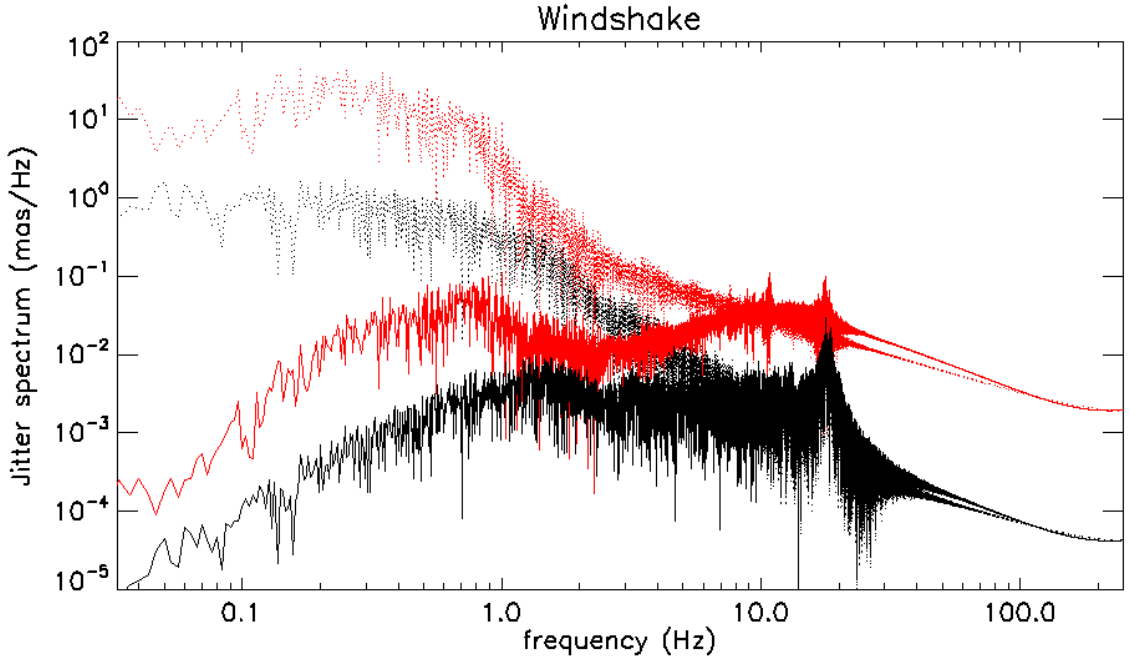
Temporal

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

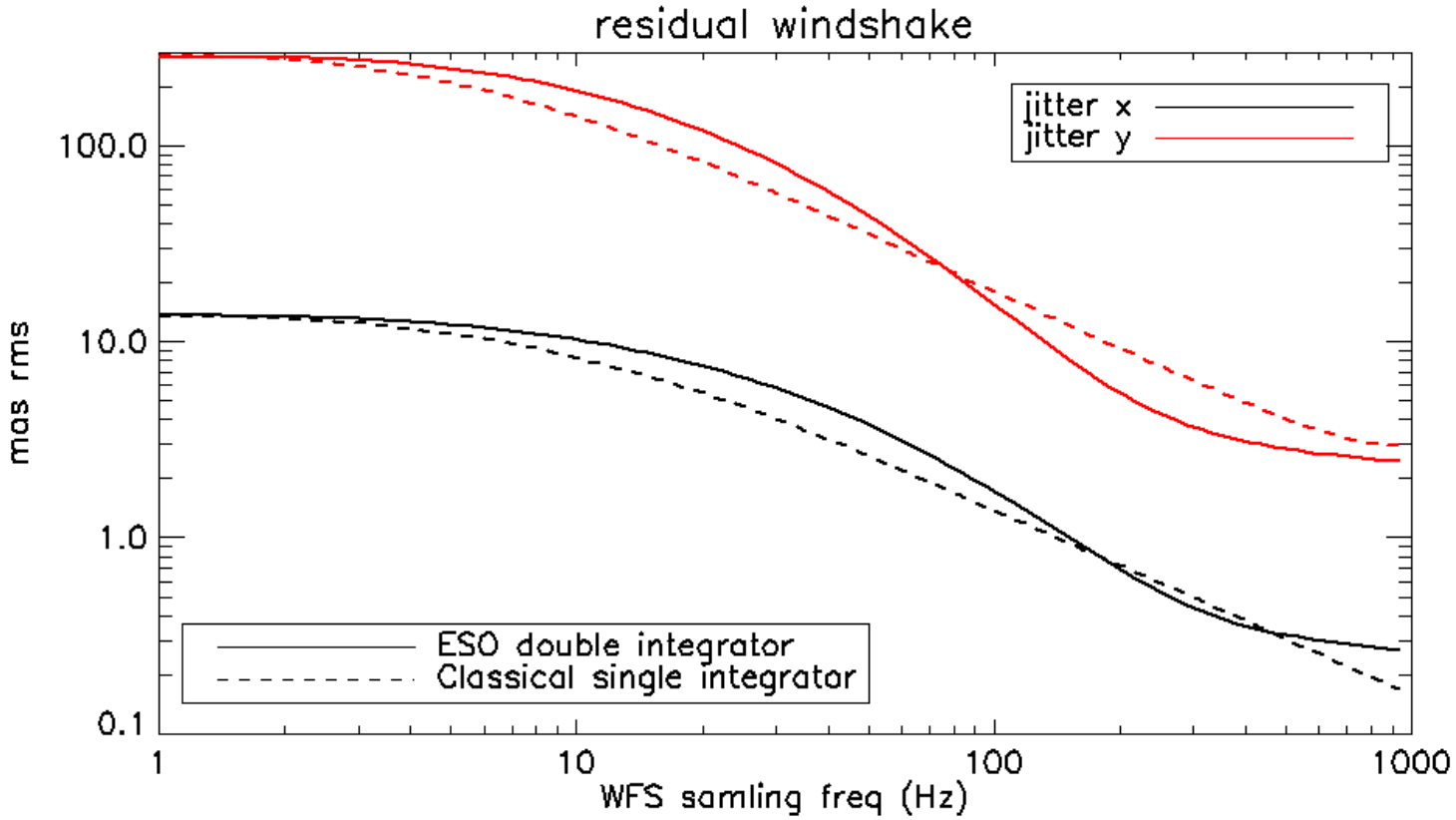
Temporal

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.

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

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FWM of subap. PSF

$$\sigma^2_{total} = \frac{\left(\sigma^2_{ph,sspup}+\sigma^2_{ron,sspup}\right)}{N_{sspup,valid}}$$

NGS error budget

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weighting

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Read-Out Noise

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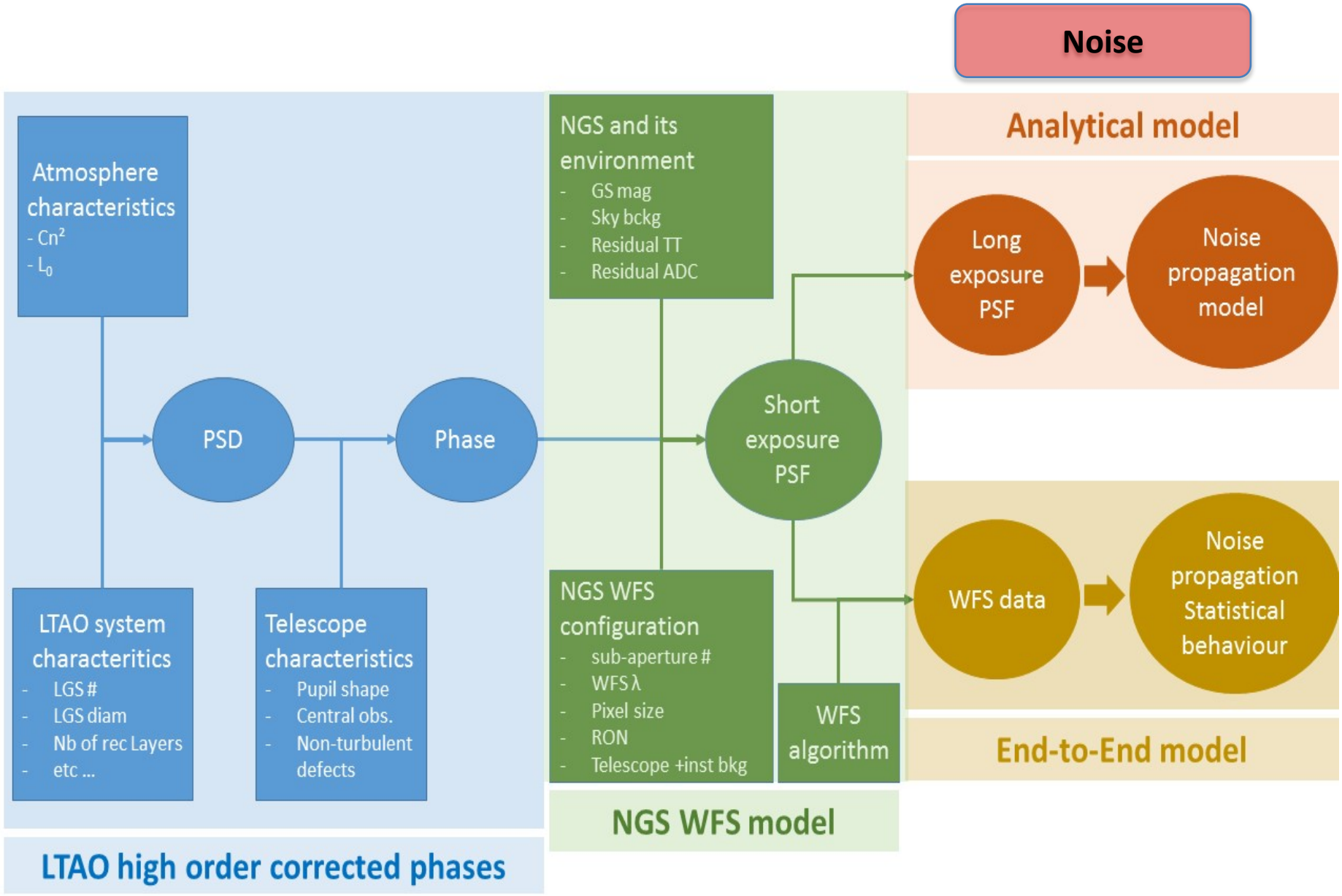
$$\sigma^2_{total} = \frac{\left(\sigma^2_{ph,sspup}+\sigma^2_{ron,sspup}\right)}{N_{sspup,valid}}$$

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

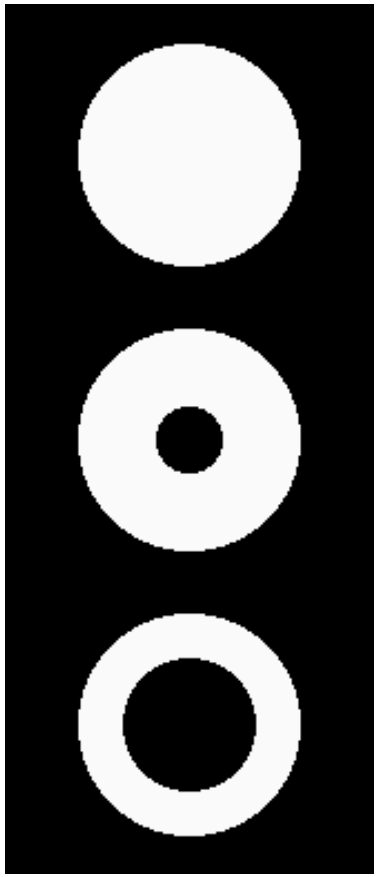
NGS error budget

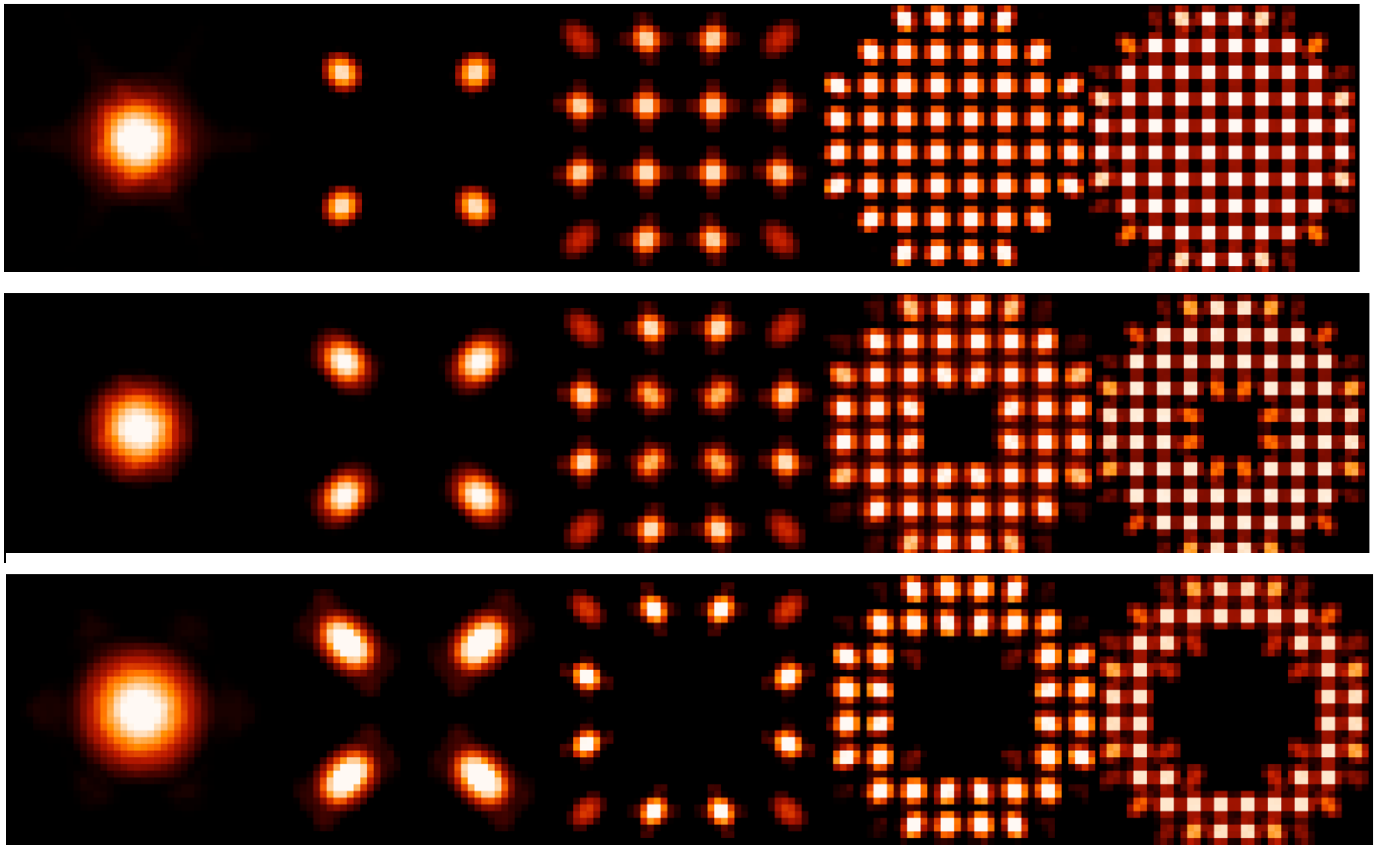


Wok done by Thierry !!

NGS error budget

Noise





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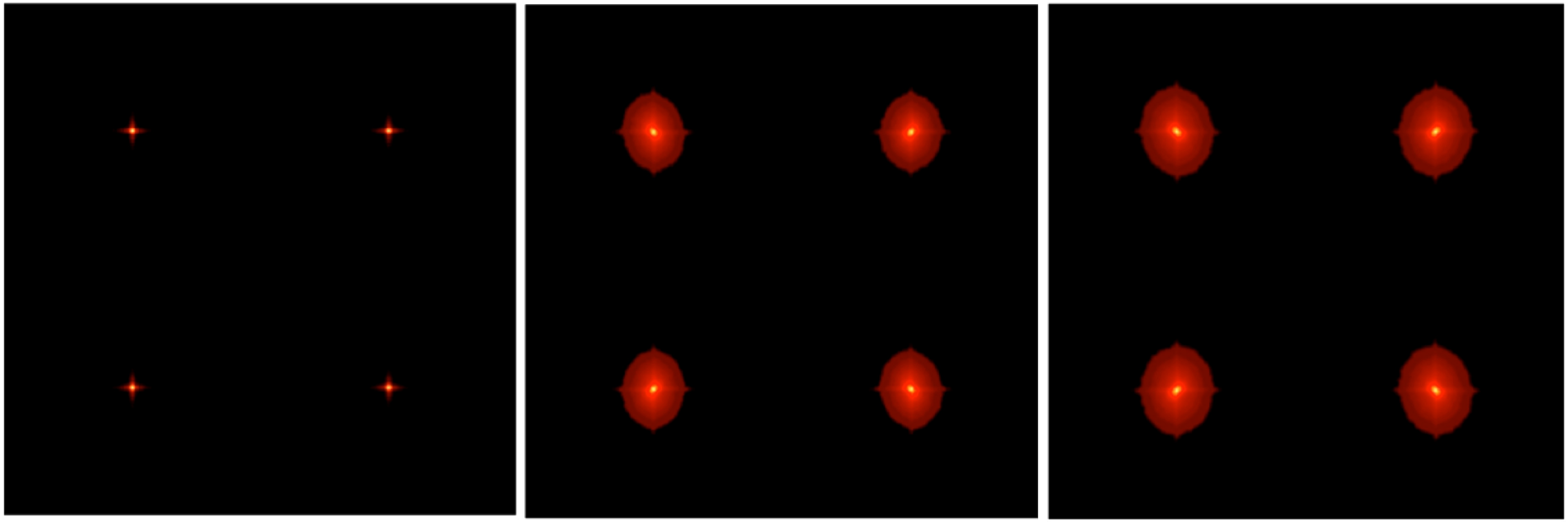


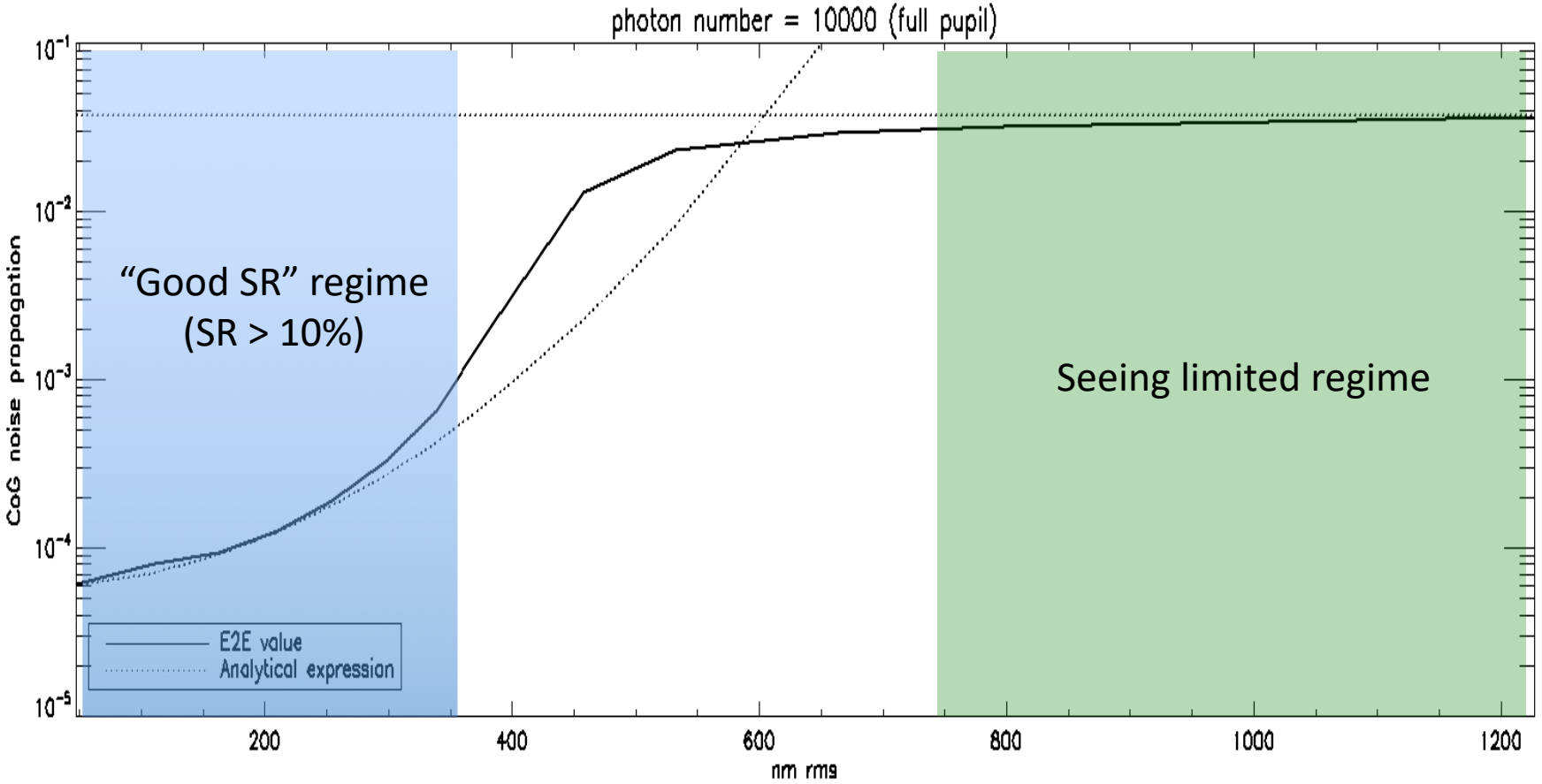
Increasing residual phase seen by the WFS

Good SR regimes

Seeing limited regimes

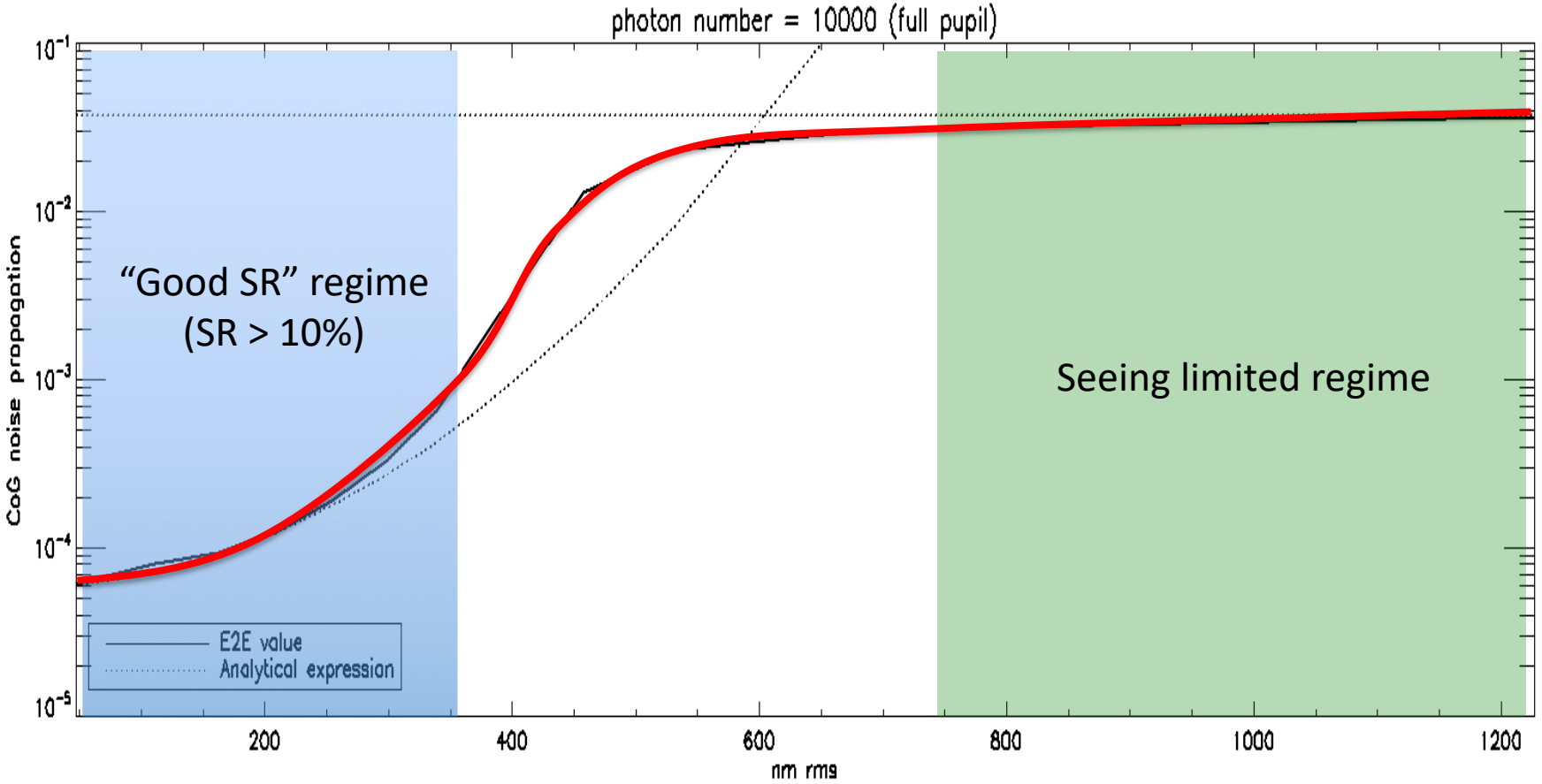
NGS error budget

Noise



NGS error budget

Noise

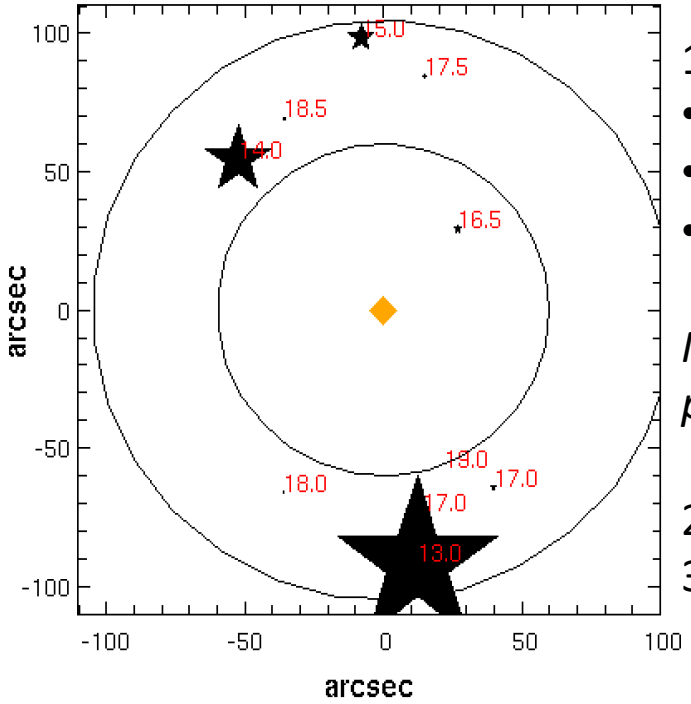


$$\sigma^2_{tot,all\ mas} = \left(\frac{N_T}{N_D}\right)^2 \sigma^2_{tot,SR\ mas} + \left(1 - \left(\frac{N_T}{N_D}\right)^2\right) \sigma^2_{tot,FWHM\ mas}$$

Context

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

Questions: How to find the best NGS asterism ?
How to get the LO PSF from this constellation ?



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

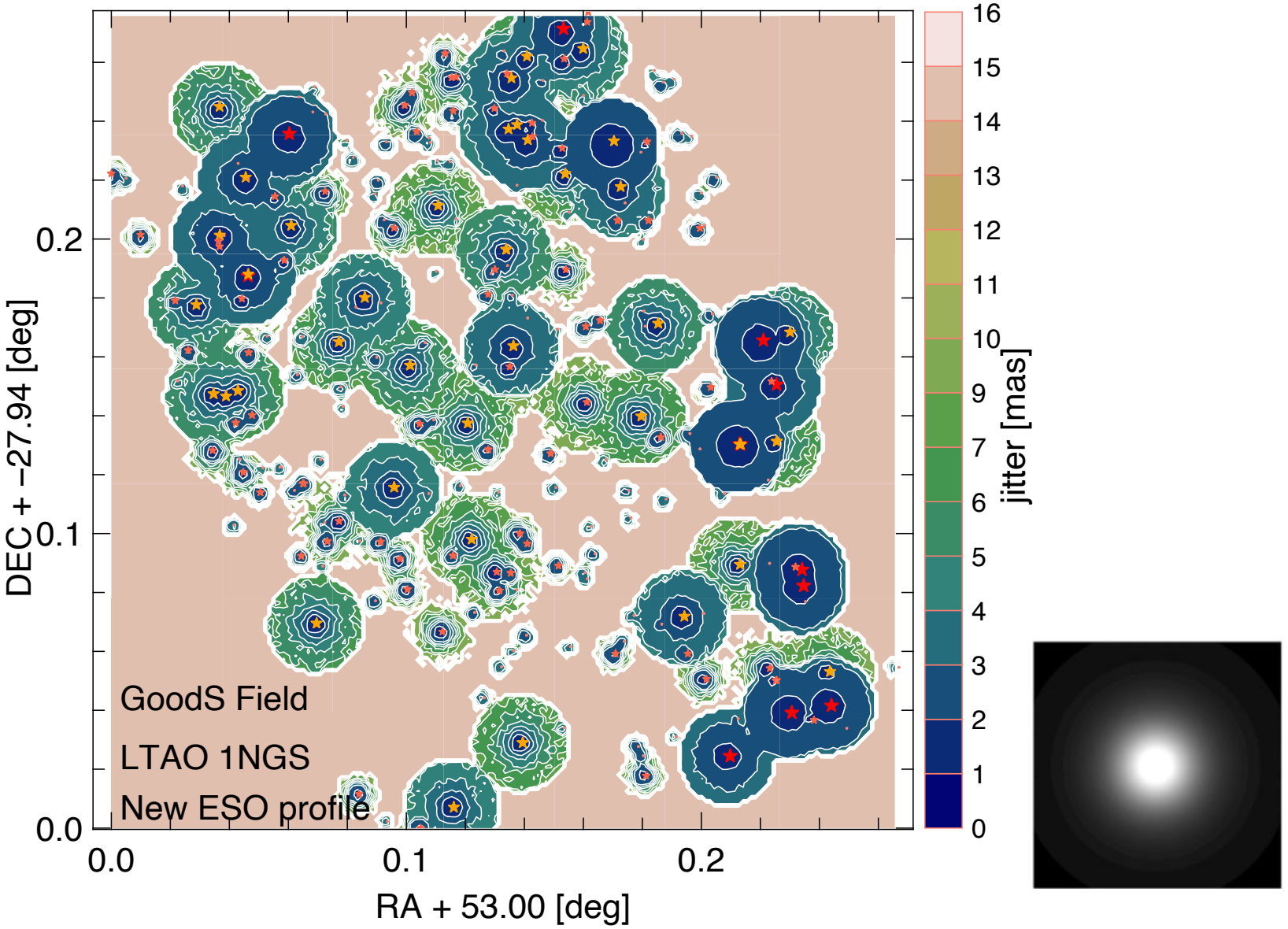
2. Reproduce the process for each pair of stars
3. Reproduce the process for each 3NGS constellation available

- Then simply sort the results by performance, and pick the best one !

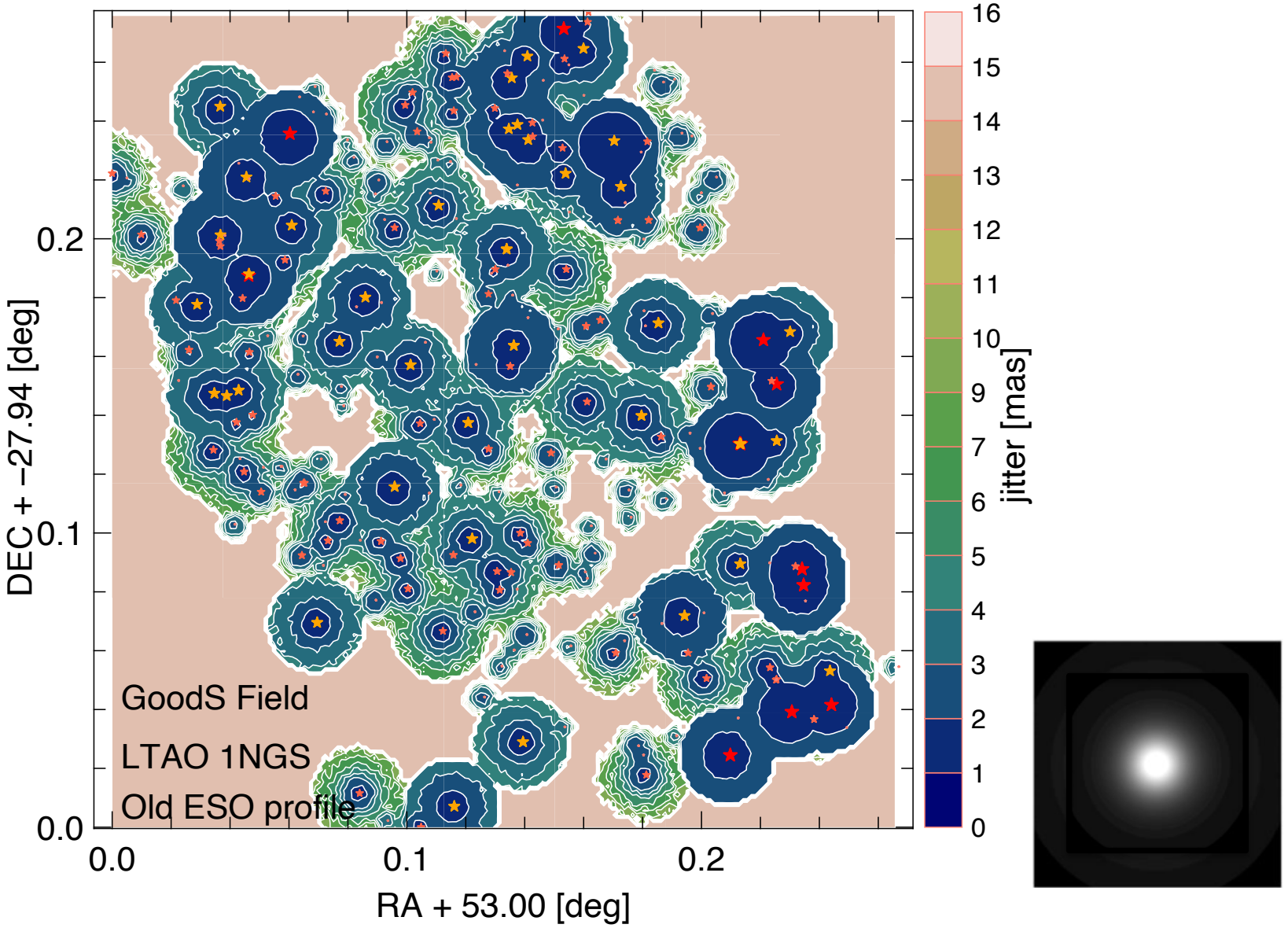
Application to HARMONI (LTAO for the EELT)

Test on “classical” cosmological fields

Application to HARMONI (LTAO for the EELT)

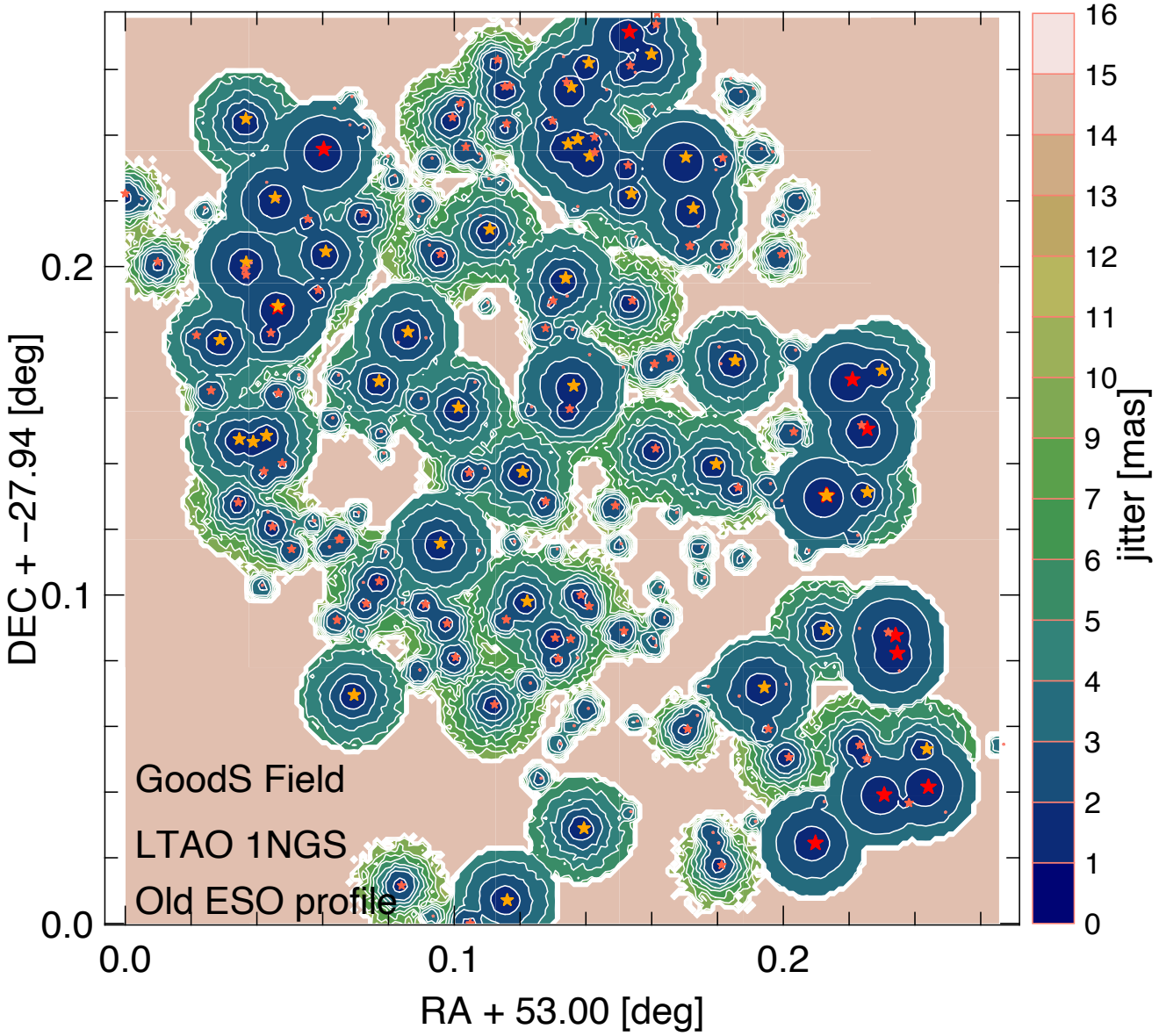


Application to HARMONI (LTAO for the EELT)



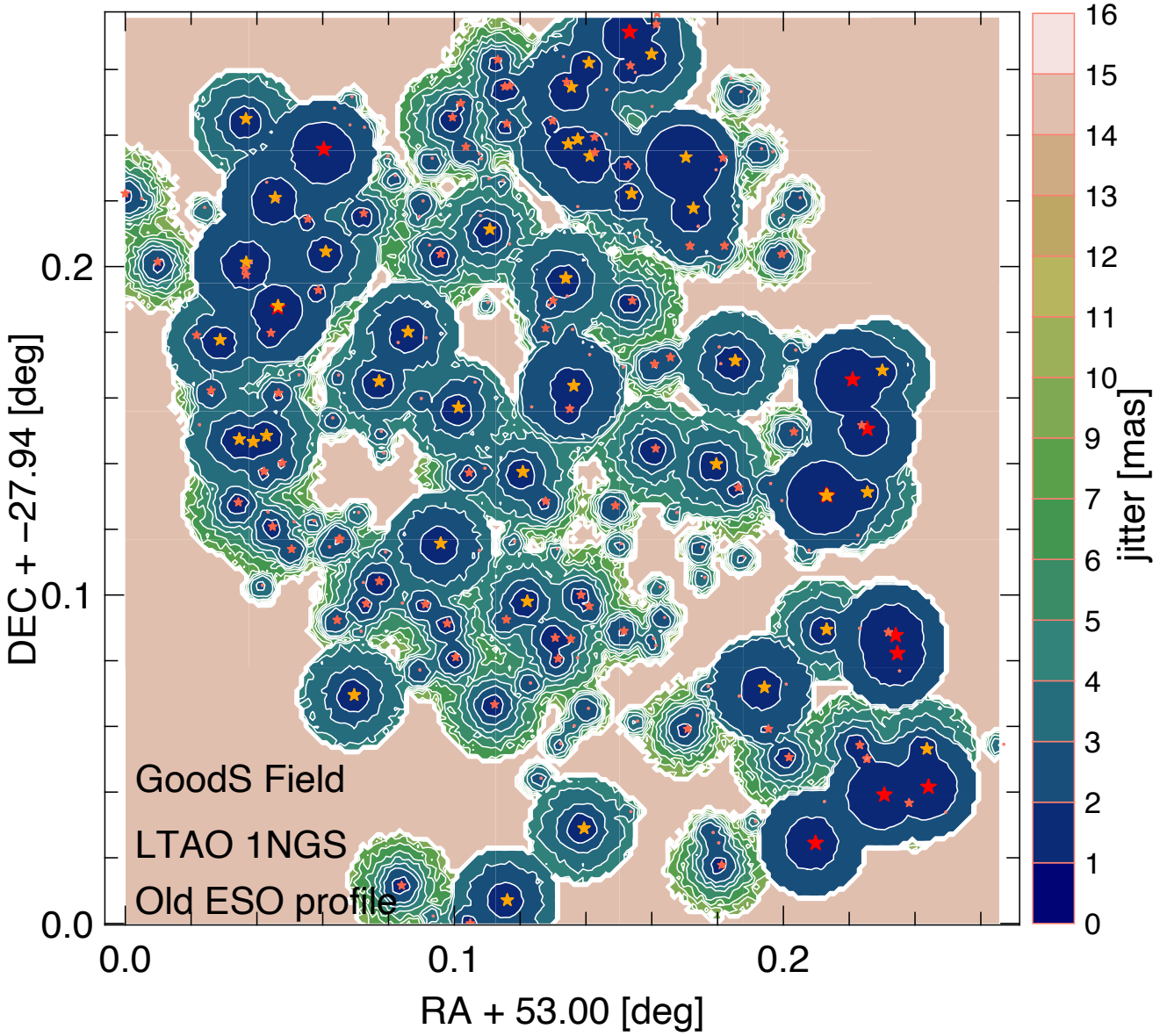
Impact of Cn2 profile (from old ESO to new 35 layers)

Application to HARMONI (LTAO for the EELT)



Impact L0 (from 50m to 25m)

Application to HARMONI (LTAO for the EELT)



Impact L0 (from 50m to 25m)

CONCLUSIONS

Deliverables	1. Algorithm for choosing the best NGS stars 2. Generate the expected PSF for a give observation

- First steps will be to explore the simulation tools available and define the strategy
- Some solutions already exists on the market, but probably will need to develop specific tools
- **Work has just started !**