

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

Benoit Neichel on behalf of the
Working Group

Towa
The “AC

tion:
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 overall 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 ?

Context



Doc. Number:

Doc. Version:

Released on:

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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

Context



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Theme 1: Preparing for ELT observations

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catalogues

Performance and Point Spread Function (PSF)

instruments simulators

Exposure Time Calculator



Context



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Theme 1: Preparing for ELT observations



de the necessary infrastructure
nclude:

(PSF)

Context



Doc. Number:

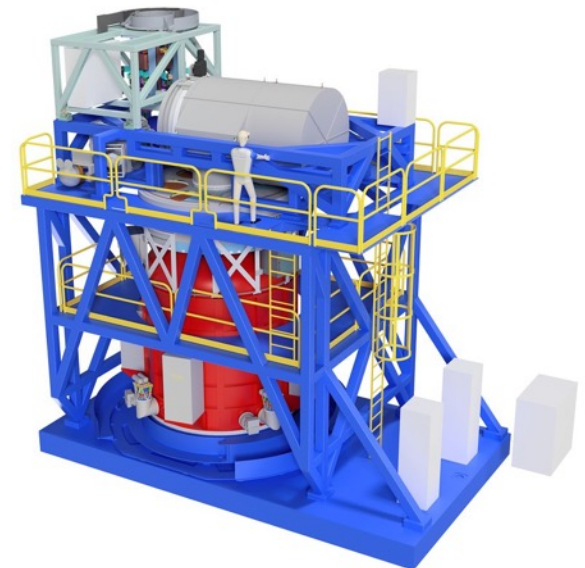
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Theme 1: Preparing for ELT observations



Context



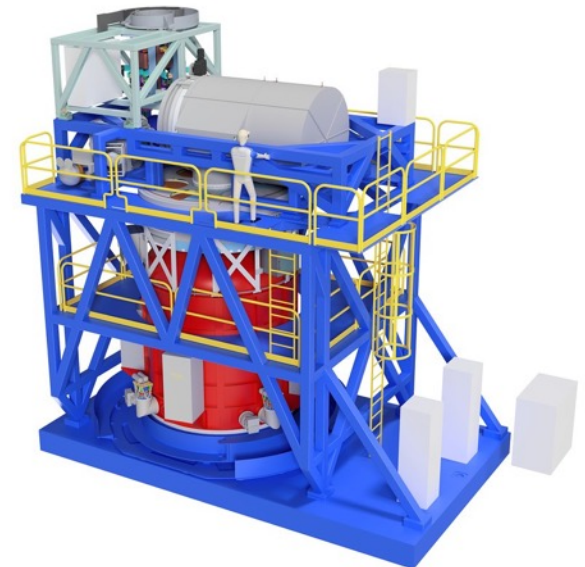
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Theme 1: Preparing for ELT observations



These Working Groups involve scientists from all the ELT instruments

Context



Doc. Number:

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

Rationale	<p>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 Encircled Energy [EE]).</p> <p>The aim of this WP are:</p> <ul style="list-style-type: none">• 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	<ol style="list-style-type: none">1. Algorithm for choosing the best NGS stars2. 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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(May be ok for SCAO)

Analytical

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Cons:

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- Some assumptions to be known

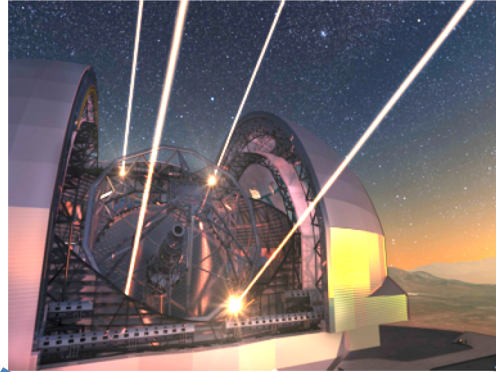
Ex. Tools:

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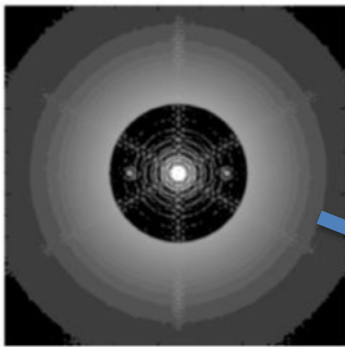
(Certainly required for MCAO, LTAO, as they will need to scan many constellations)

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

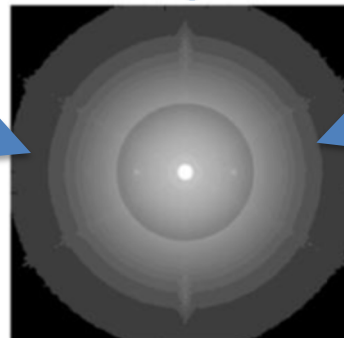
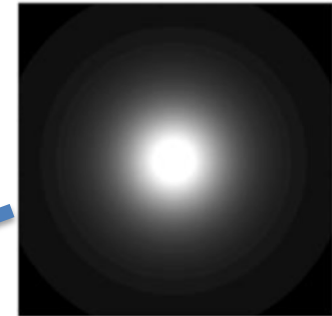
PSF Analytical Approach



Laser (High-Order) PSF

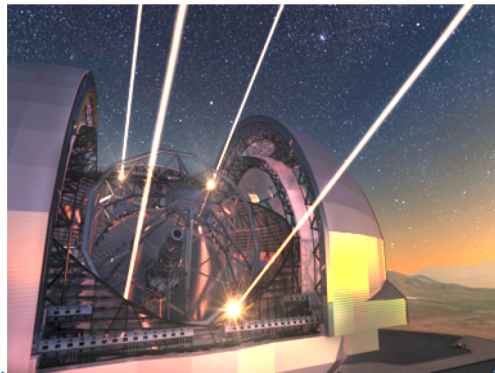


NGS (Low-Order) PSF

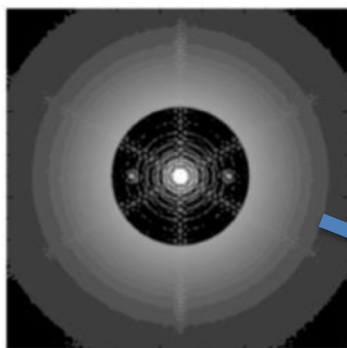


$$\text{PSF} = \text{PSF_HO} * \text{PSF_LO}$$

PSF Analytical Approach



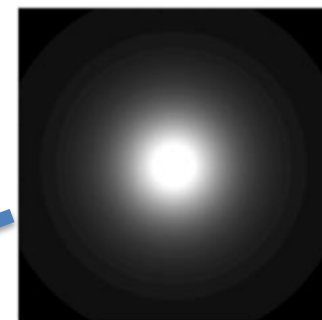
Laser (High-Order) PSF



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

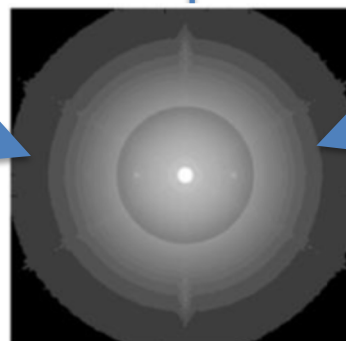
To a first order, this is mostly
constant.

NGS (Low-Order) PSF



Depends on
Cn2, seeing,
LO, **NGS**
constellation,
NGS flux.

To a first order, this is very variable.

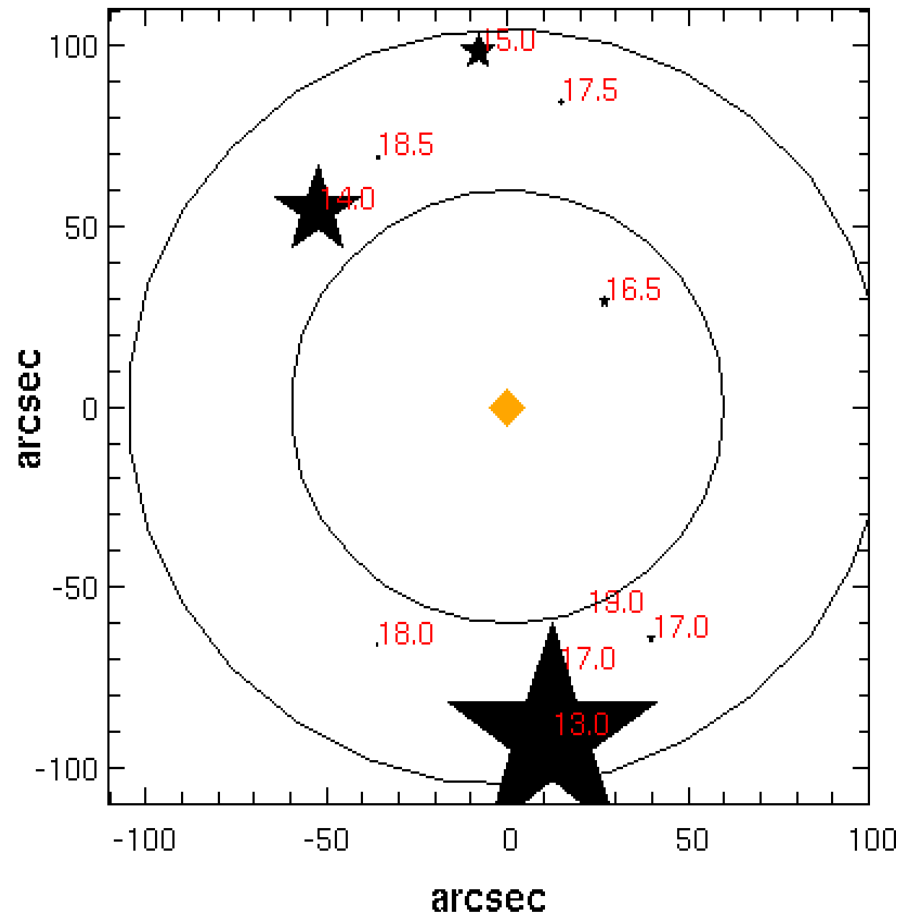


$$\text{PSF} = \text{PSF_HO} * \text{PSF_LO}$$

PSF Analytical Approach

Questions: How to find the best NGS asterism ?

How to get the LO PSF from this constellation ?



PSF Analytical Approach

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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 + Cn^2
 - 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



Compensation of the Null modes with the Gemini MCAO

Gemini Document RTP-AO-G0097

Francois Rigaut. February 29, 2000

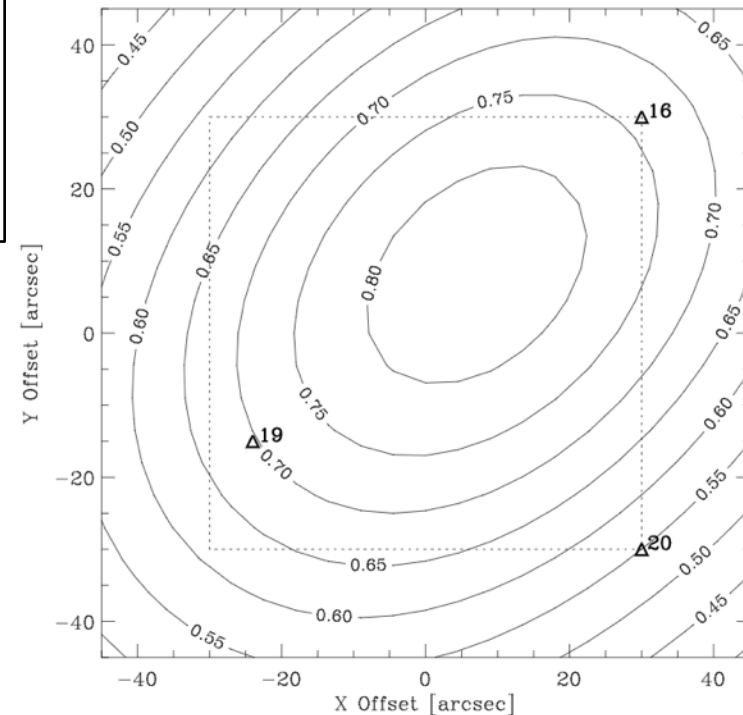
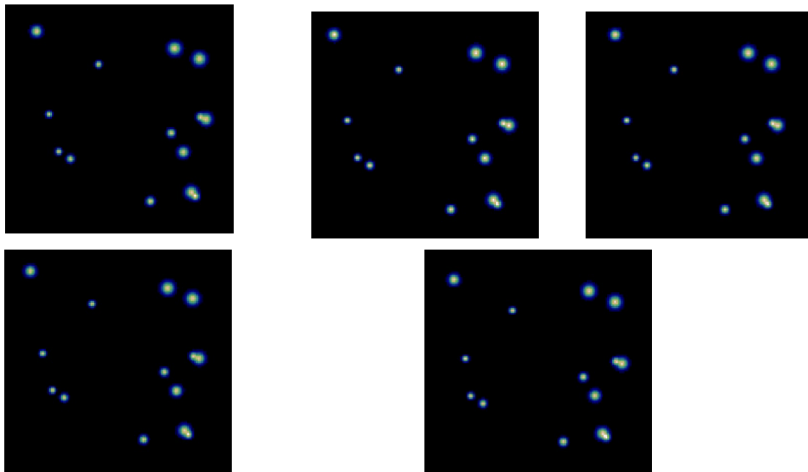
B. L. Ellerbroek and F. Rigaut

Vol. 18, No. 10/October 2001/J. Opt. Soc. Am. A 2539

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

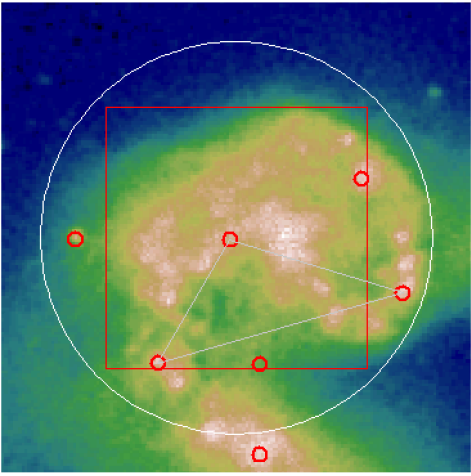
Tomography

Temporal

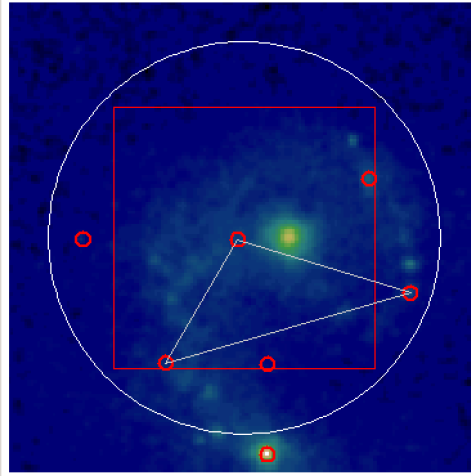
Noise

File Help

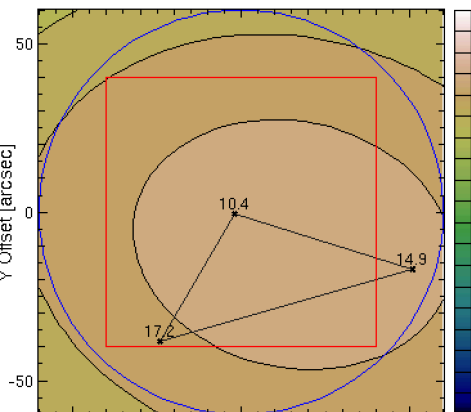
DSS image
System : 1 (12.2583, 39.3467)



2MASS image
System : 1 (-72.0000, -46.1573)



Strehl map



Target Selection

Target Catalog: NGC/IC Catalog

Stars Catalog: Nomad1

Search for Target: 12:01:54 -18:52:04

Search for Stars: mag: 8.0 to 18.5
Max num. of stars: 7

Find best asterism: Criteria: best of
avg rms

Performance in GSAOI FoV

Strehl map		avg	85.6	rms	1.8
-	+	min	79.9	max	88.1

- + Save

PSF Analytical Approach

Tomography

Temporal

Noise

The screenshot displays the MASCOOT software interface, which is used for PSF analysis. It is divided into several panels:

- Top Row:** Three panels showing 2MASS images of different target systems. Each panel includes a 'DSS image' and a '2MASS image' window. The systems are identified by their coordinates: System 1 (12.2583, 39.3467), System 1 (-72.0000, -46.1573), and System 1 (14.6225, -11.0889). The images show a central target with several surrounding stars, some of which are highlighted with red circles and connected by lines to form an asterism.
- Bottom Left:** A 'Strehl map' panel showing a contour plot of the Strehl ratio for the first system. The plot includes a red rectangle indicating the field of view (FoV) and a blue circle representing the target's position. The Strehl ratio values are labeled as 10.4, 14.9, and 17.2.
- Bottom Middle:** A 'Target Selection' panel with a 'Target Catalog' and 'Stars Catalog'. It includes search buttons: 'Search for...', 'Search for...', and 'Find best as...'. Below these is a 'Performance in GSAOI FoV' section with a 'Strehl map' table.
- Bottom Right:** A 'Target Selection' panel with a 'Target Catalog' set to 'NGC/C Catalog' and a 'Stars Catalog' set to 'Nomad1'. It includes search buttons: 'Search for Target', 'Search for Stars', and 'Find best asterism'. The search parameters are: '12:01:54 -18:52:04', 'mag: 8.0 to 18.5', and 'Max num. of stars: 7'. The 'Criteria: best of' is set to 'avg'. Below this is a 'Performance in GSAOI FoV' section with a 'Strehl map' table.

Performance in GSAOI FoV					
Strehl map					
-	+	avg	75.6	rms	10.7
-	+	min	46.2	max	88.5

Performance in GSAOI FoV					
Strehl map					
-	+	avg	75.6	rms	10.7
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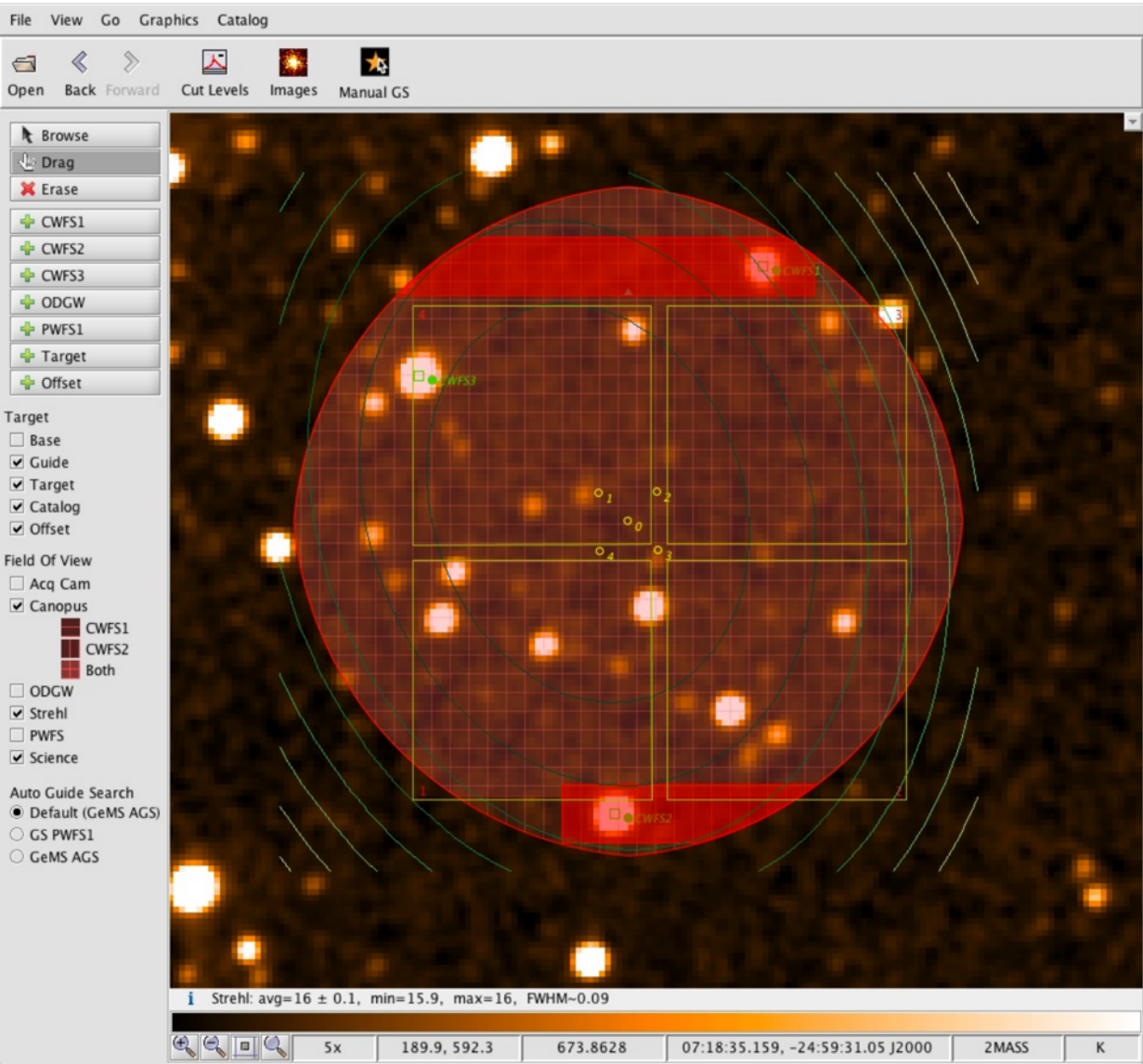
PSF Analytical Approach

Tomography

Temporal

Noise

Gemini Observing tool

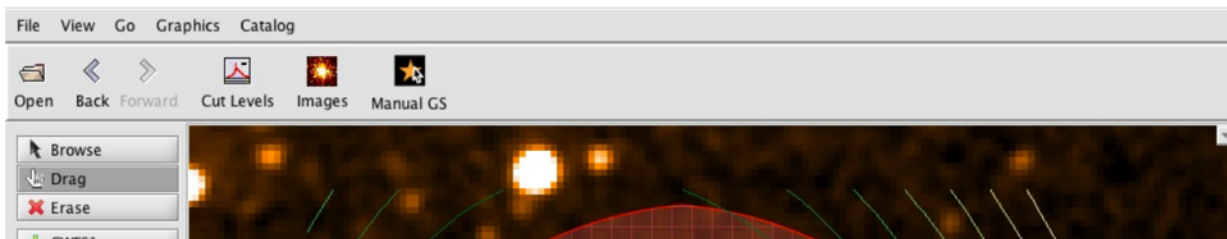


PSF Analytical Approach

Tomography

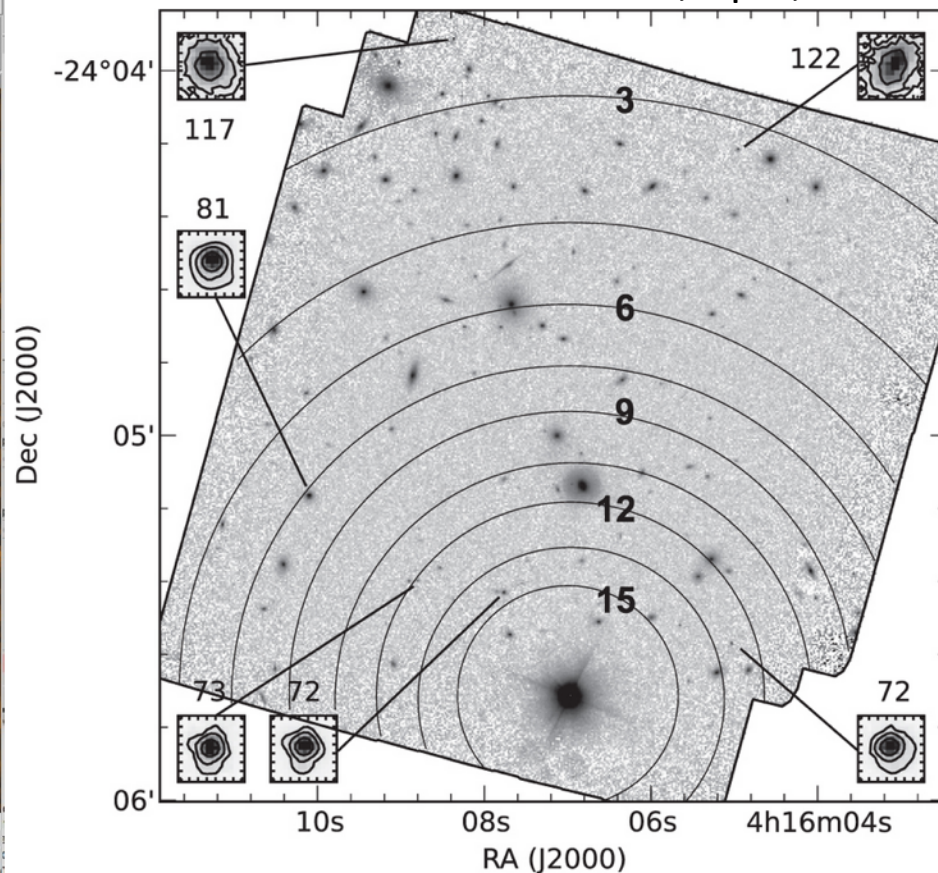
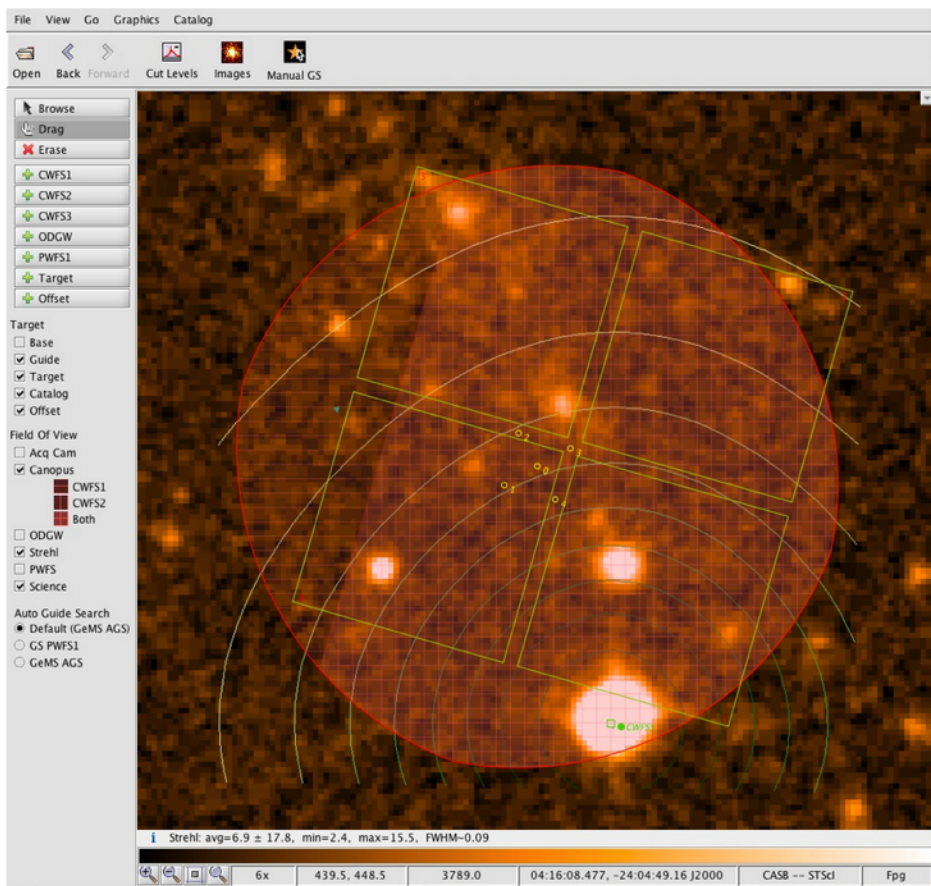
Temporal

Noise



Gemini Observing tool

Schrimer et al., ApJS, 2014



PSF Analytical Approach

Tomography

Temporal

Noise

we need to revisit those methods for the EELT



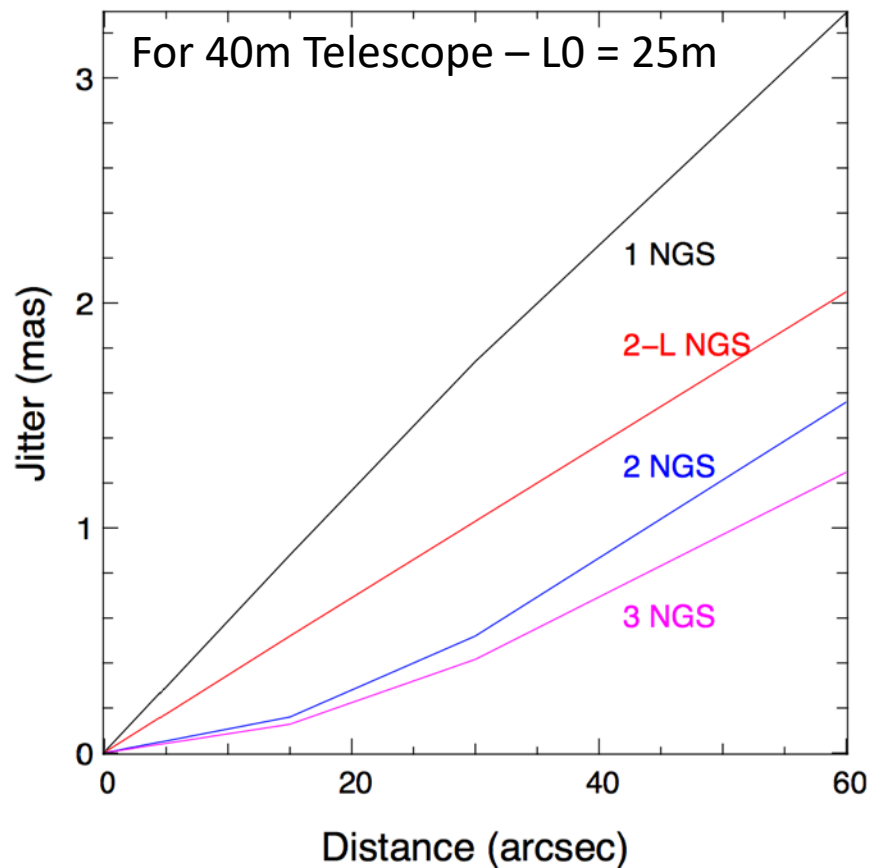
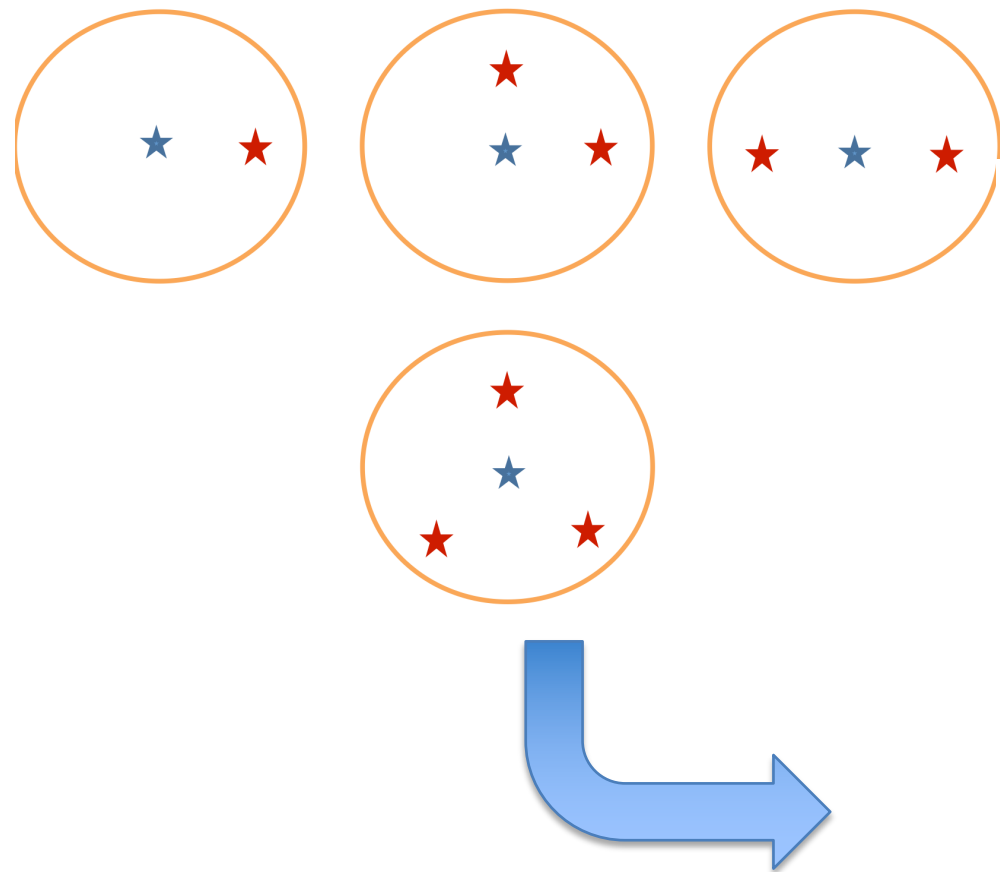
(So far we have mainly worked on this term)

NGS error budget

Tomography

Impact on residual jitter of different NGS constellation

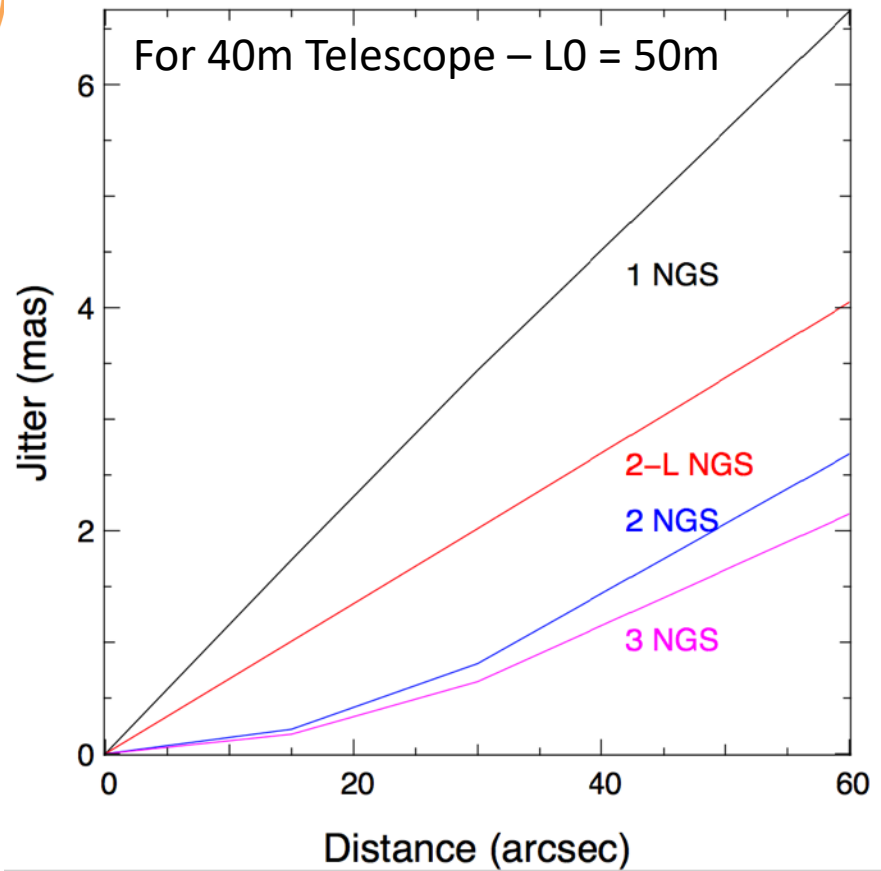
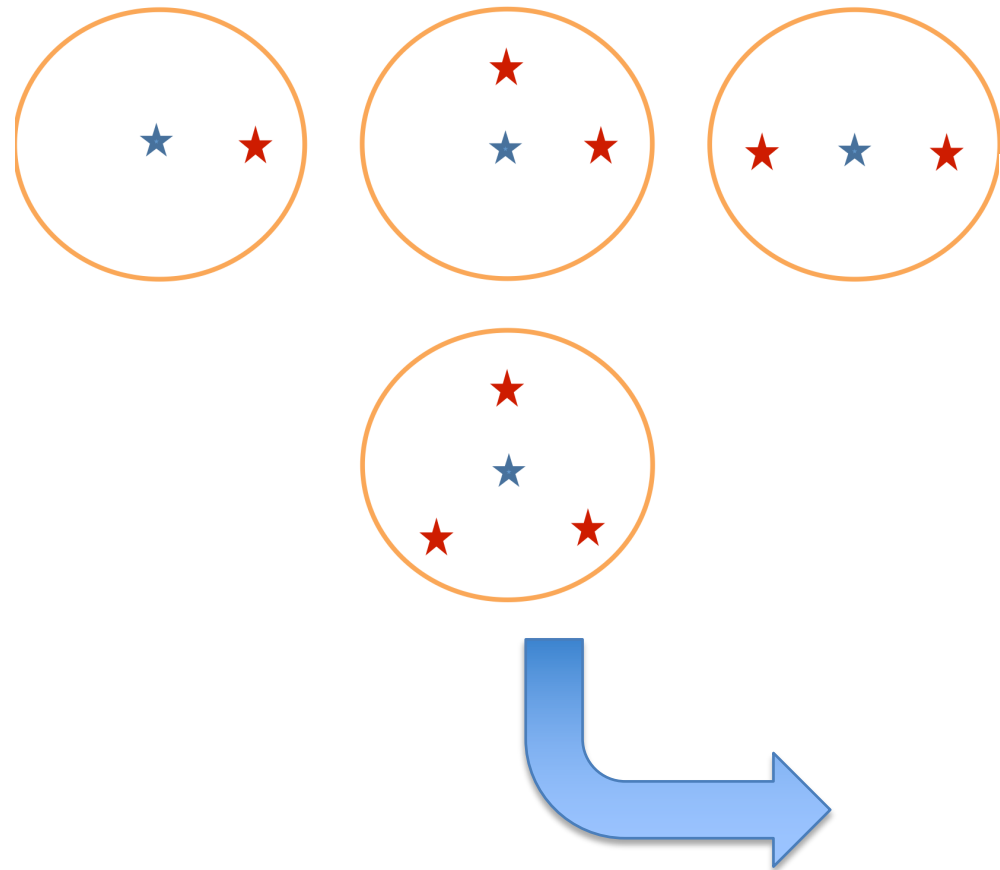
e.g. Sasiela, Chassat, Whiteley...



NGS error budget

Tomography

Impact on residual jitter of different NGS constellation



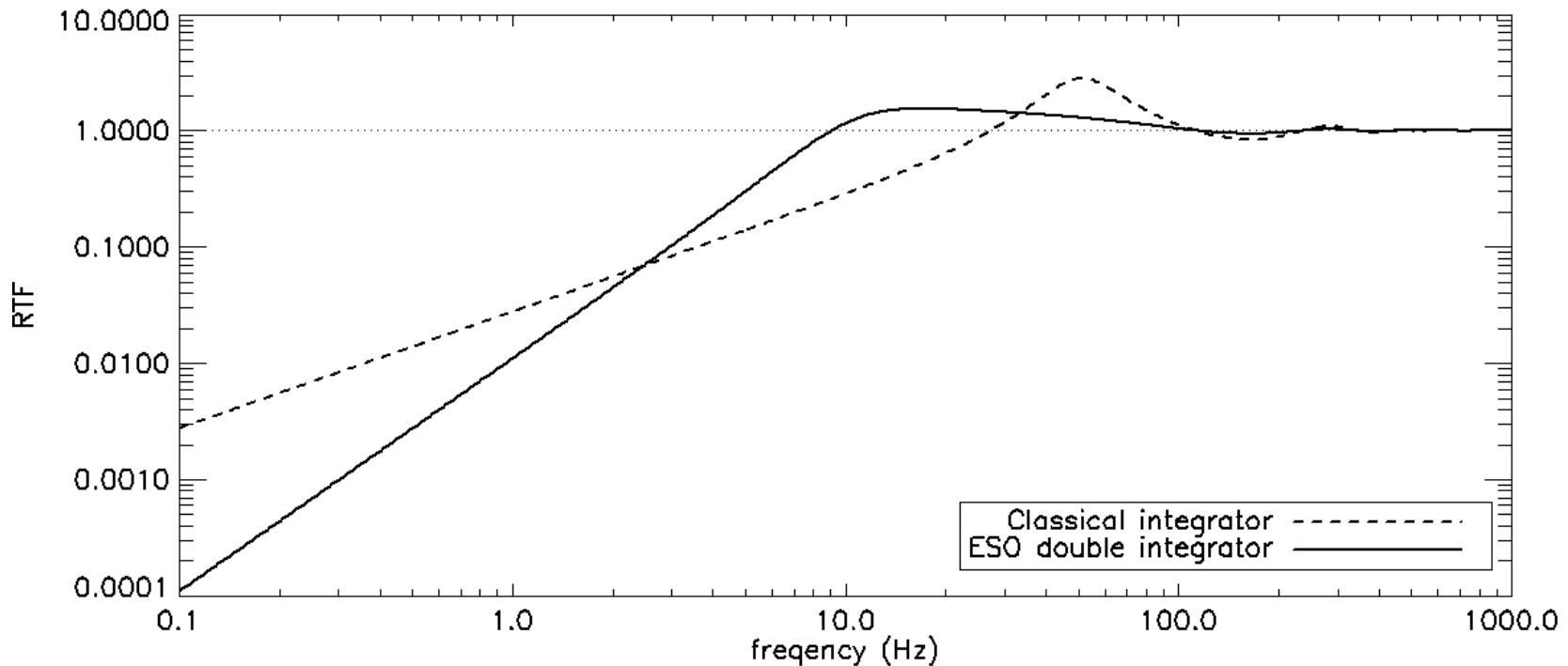
NGS error budget

Temporal

First need to determine the rejection transfer function.

It depends on the controller performance...

Assuming ELT scheme with M4/M5 we could have:



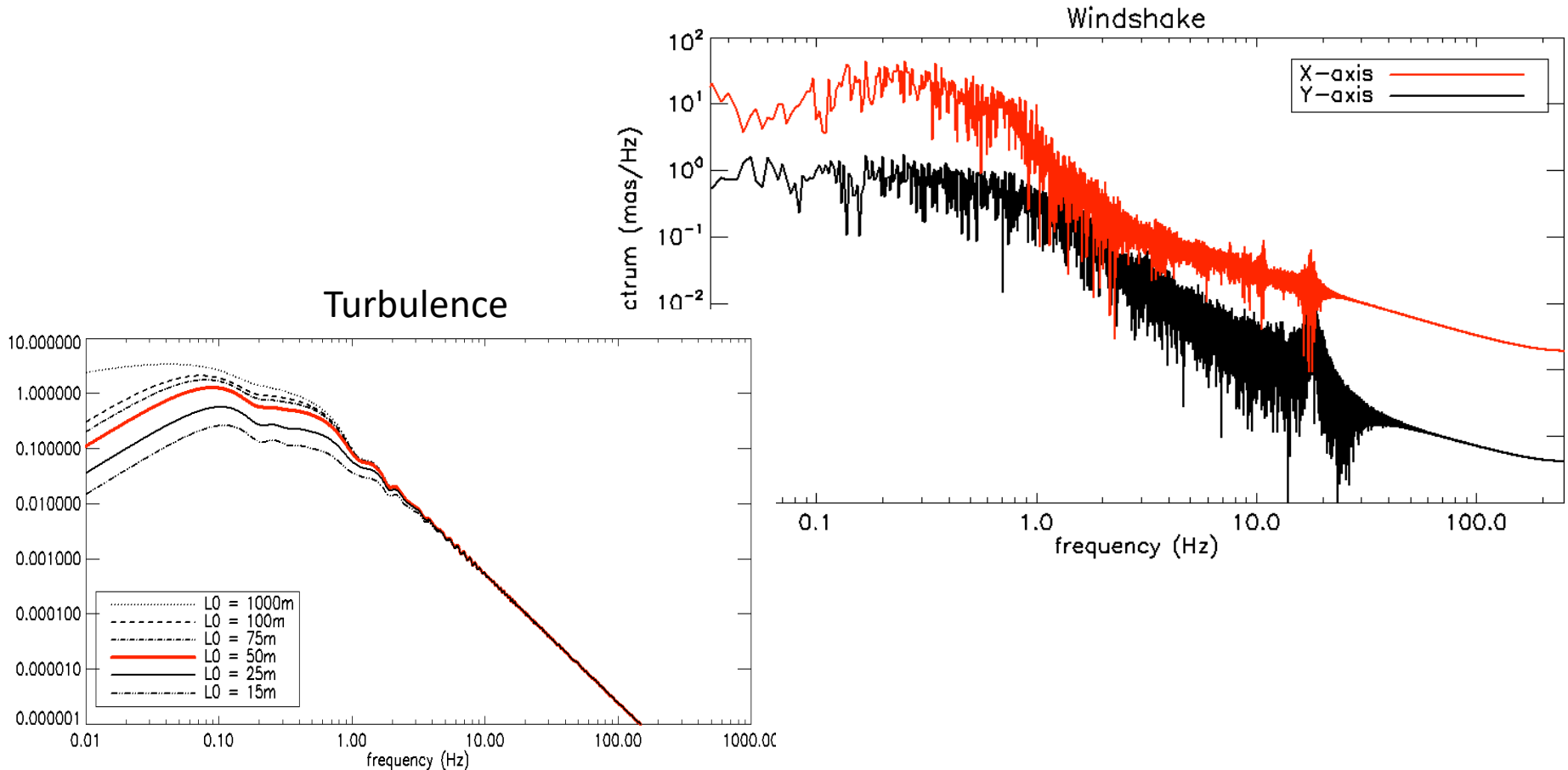
NGS error budget

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:



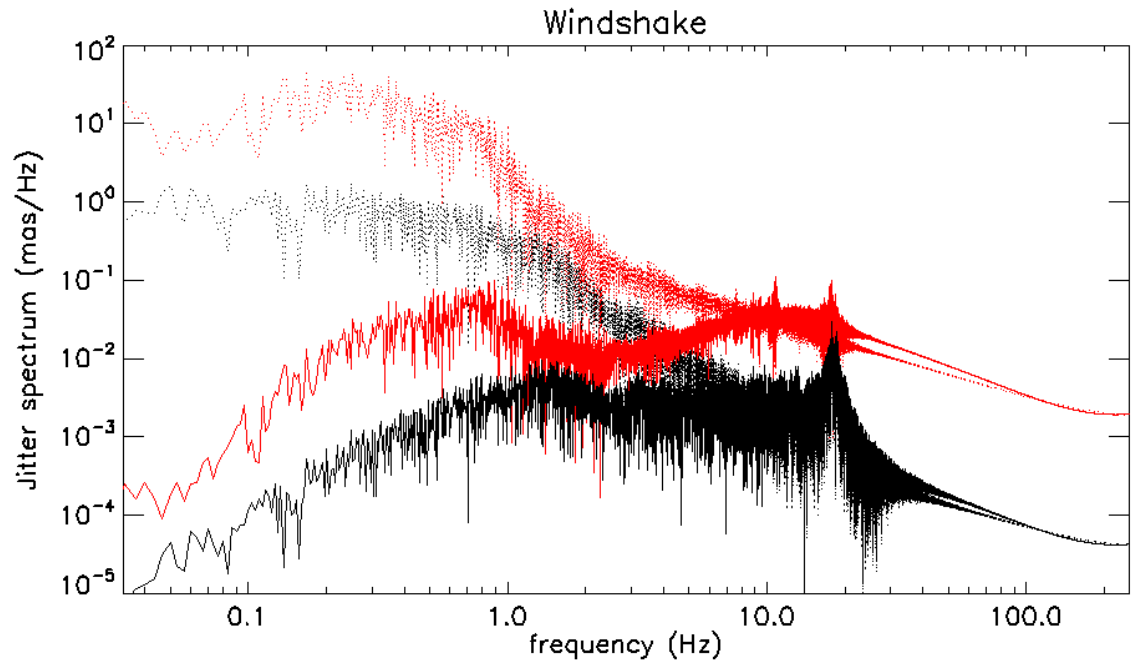
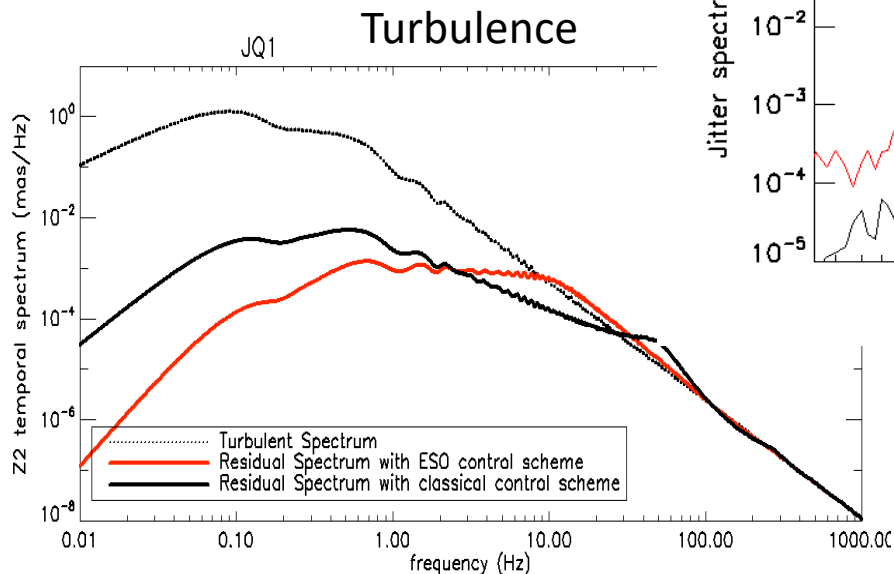
NGS error budget

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

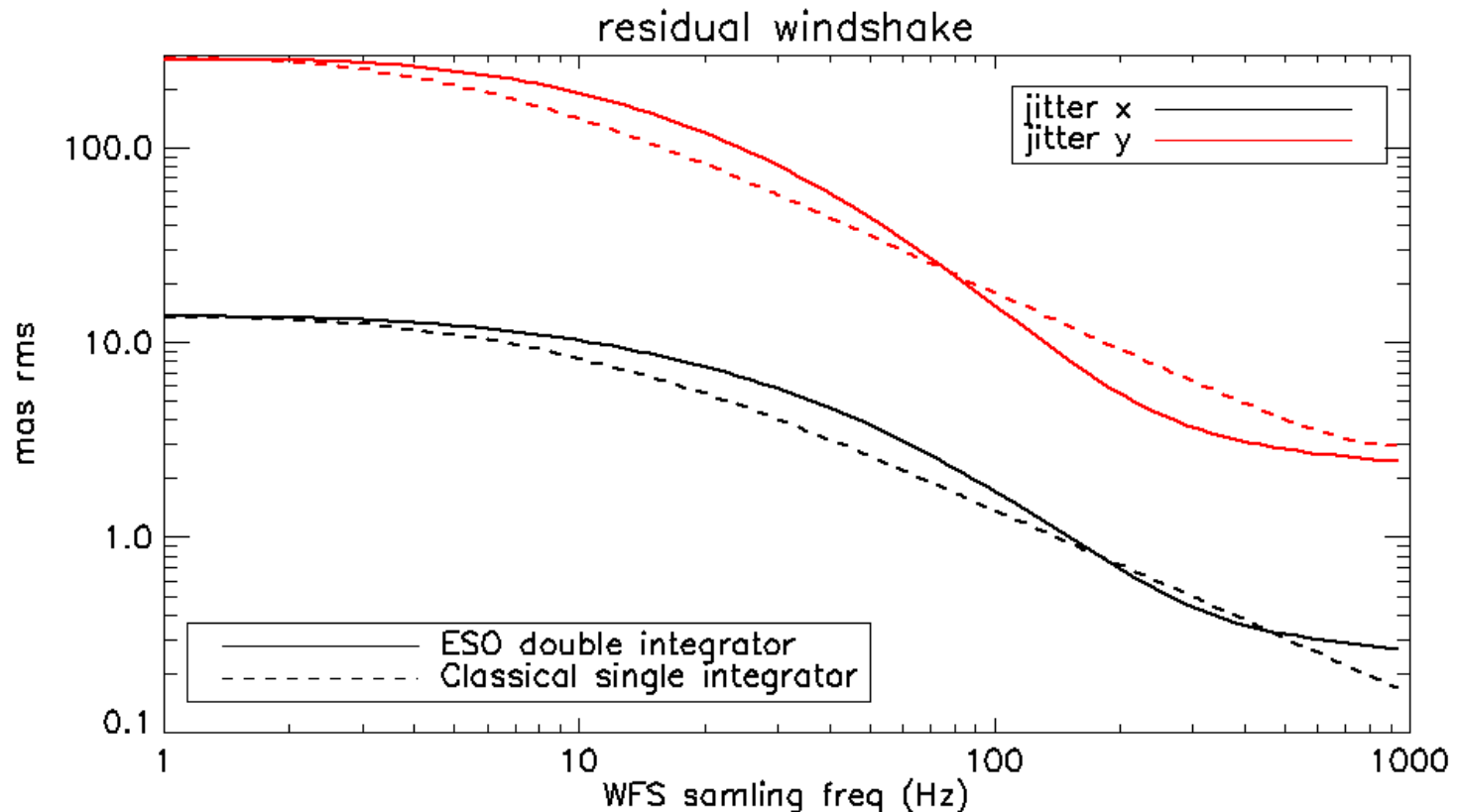
Temporal

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

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

Read-Out Noise

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

NGS error budget

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weighting
diffraction

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FWM of subap. PSF

$$\sigma_{total}^2 = \frac{(\sigma_{ph,sspup}^2 + \sigma_{ron,sspup}^2)}{N_{sspup,valid}}$$

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weighting
diffraction

Read-Out Noise

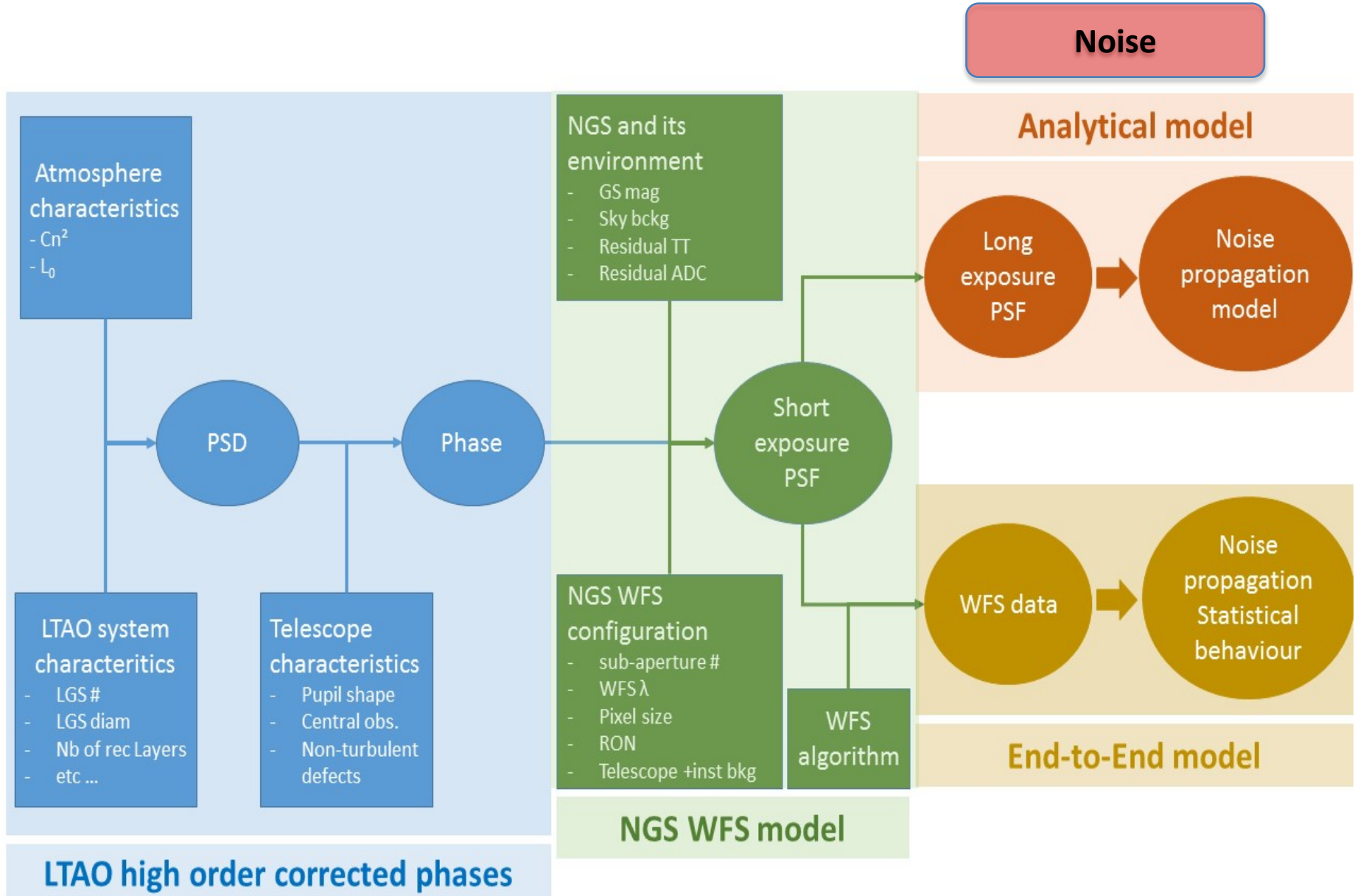
$$\sigma_{ron,sspup}^2 = \frac{\pi}{32 \ln(2)} \left(\frac{ron}{n} \right)^2 \left(\frac{(N_T^2 + N_w^2)}{N_D} \right)^2$$

FWM of subap. PSF

$$\sigma_{total}^2 = \frac{(\sigma_{ph,sspup}^2 + \sigma_{ron,sspup}^2)}{N_{sspup,valid}}$$

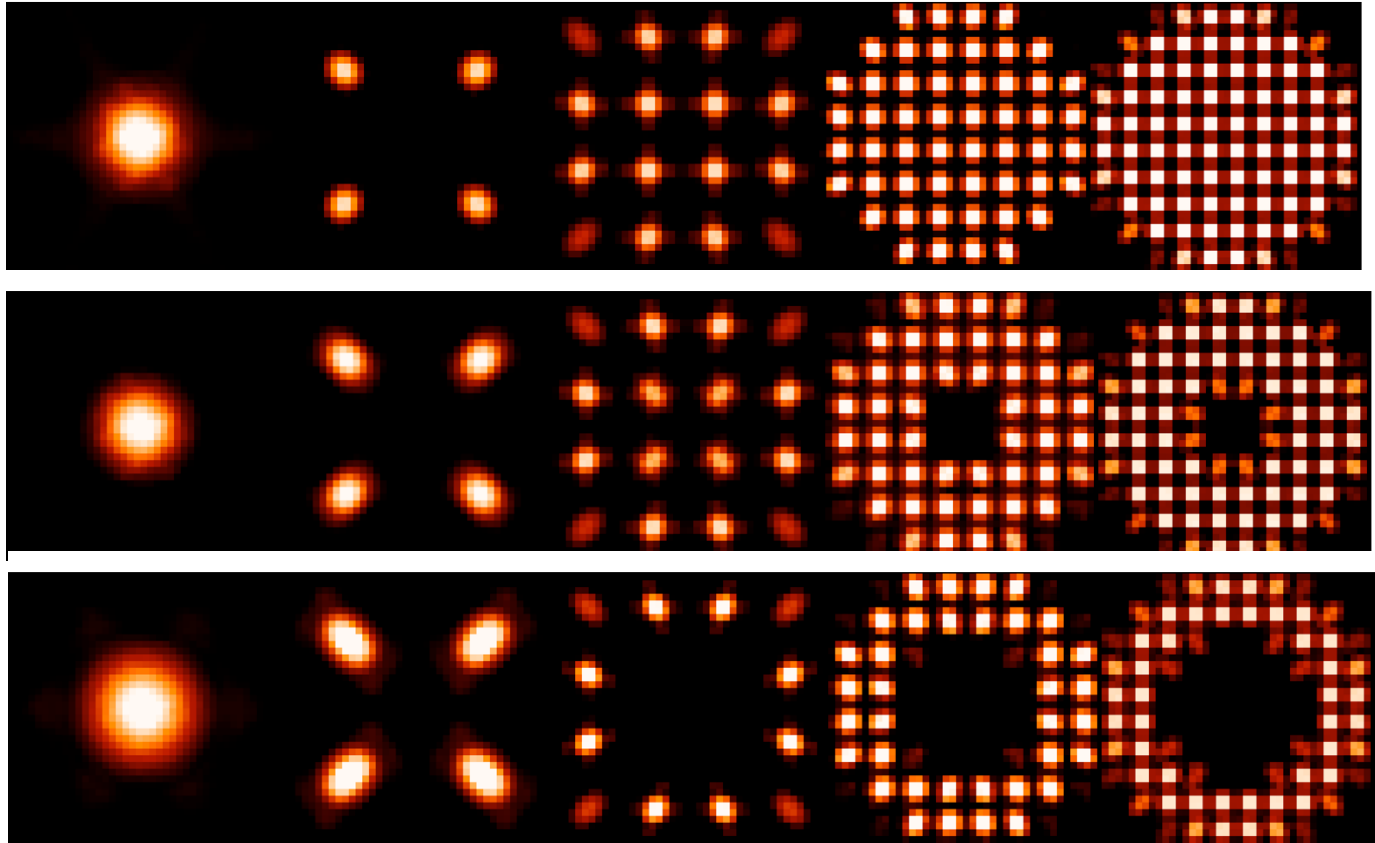
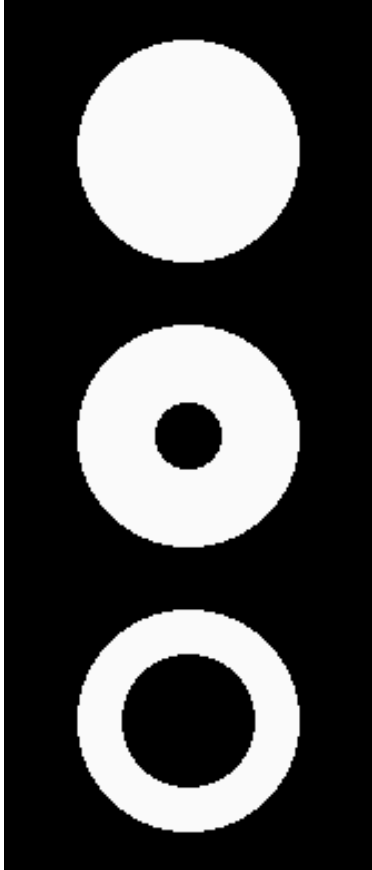
This is however not valid anymore in presence of residual turbulence.

NGS error budget



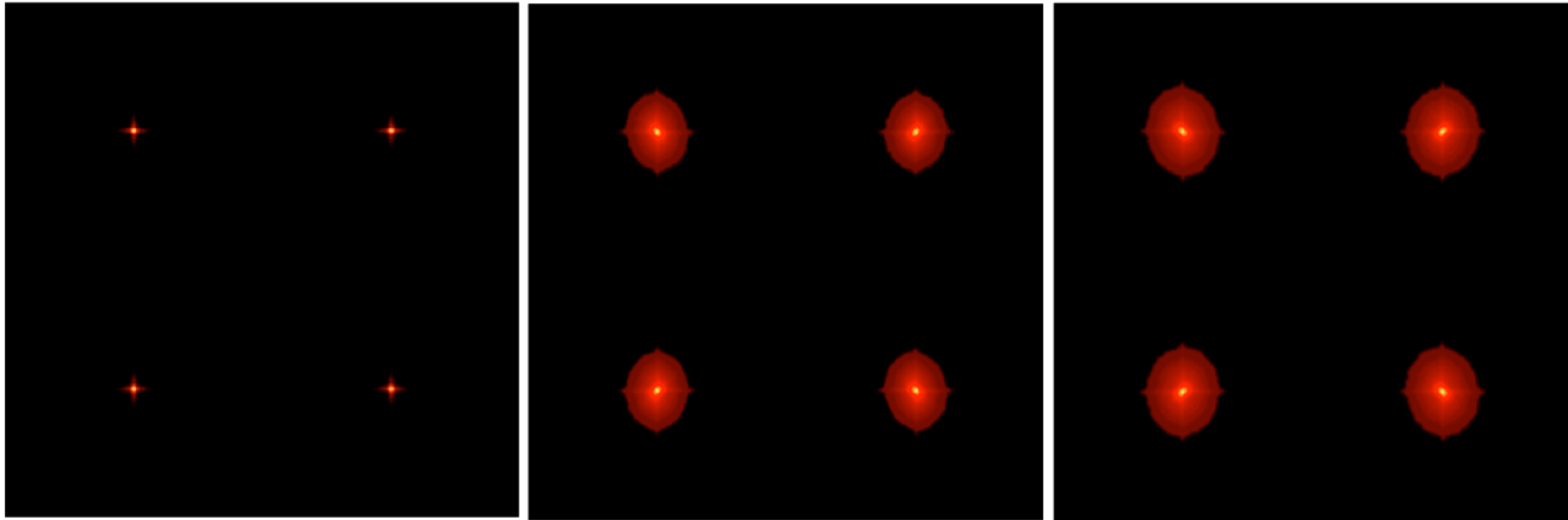
NGS error budget

Noise



Wok done by Thierry !!

NGS error budget



Increasing residual phase seen by the WFS

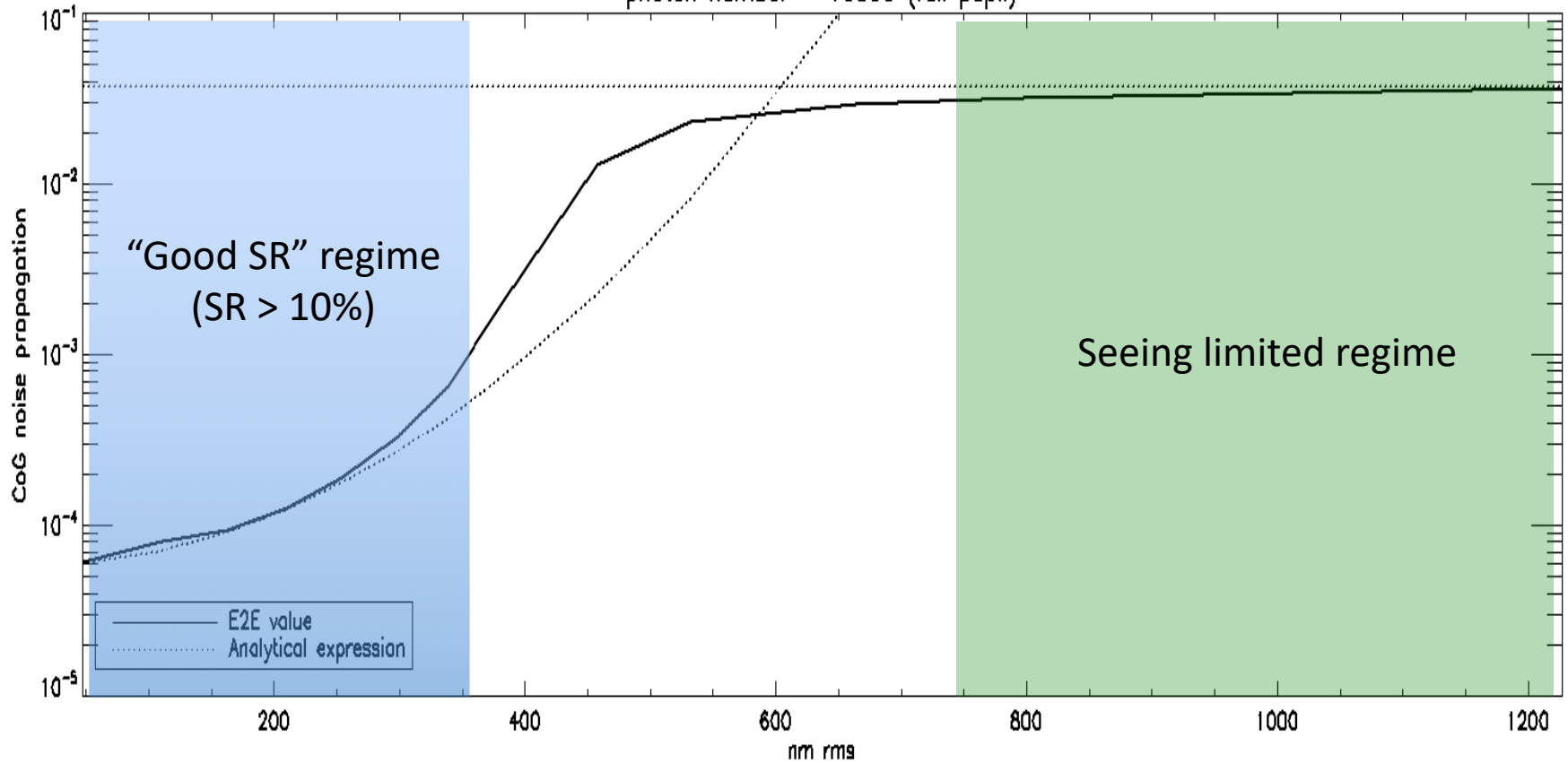
Good SR regimes

Seeing limited regimes

NGS error budget

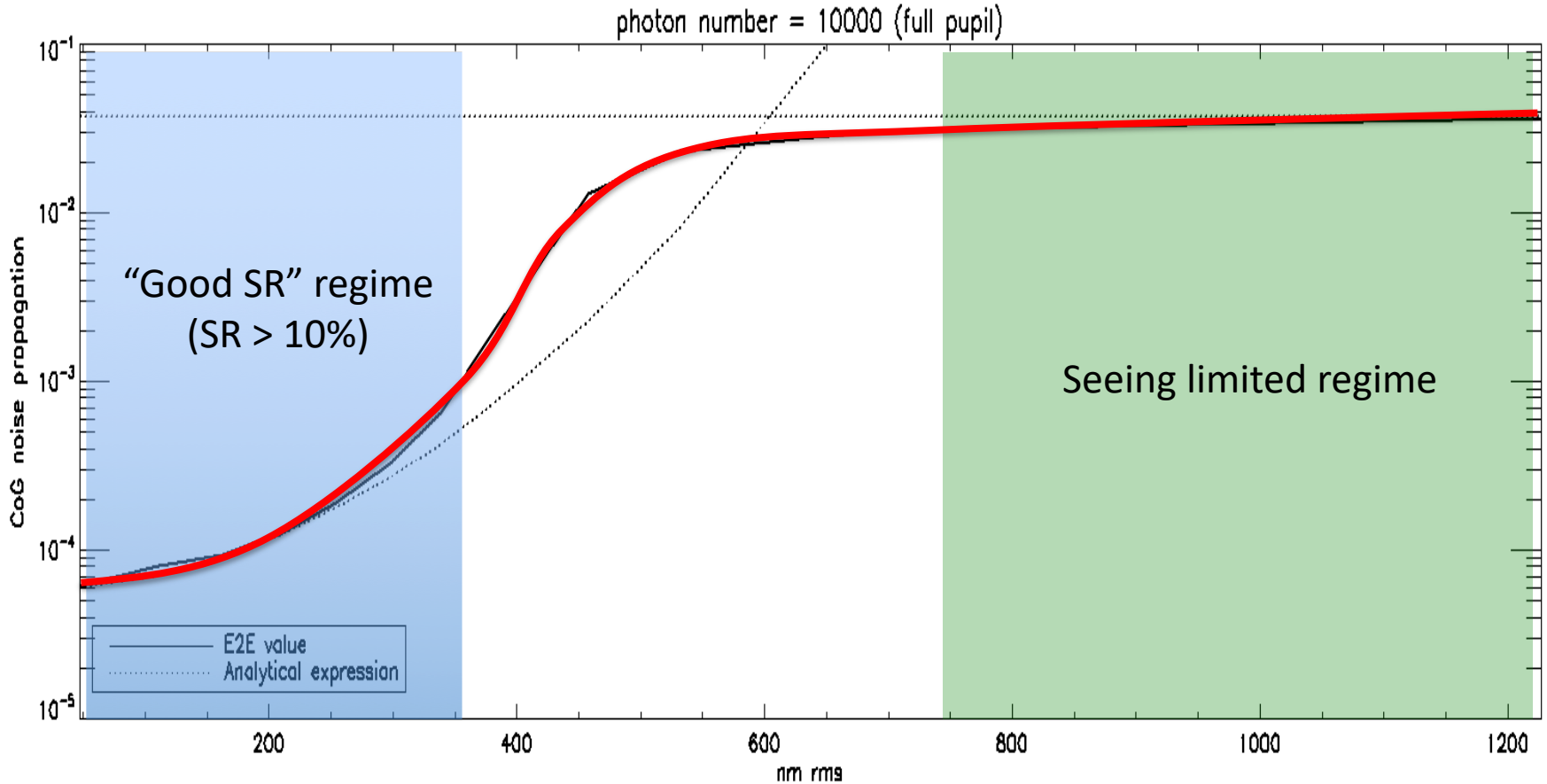
Noise

photon number = 10000 (full pupil)



NGS error budget

Noise



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

Context

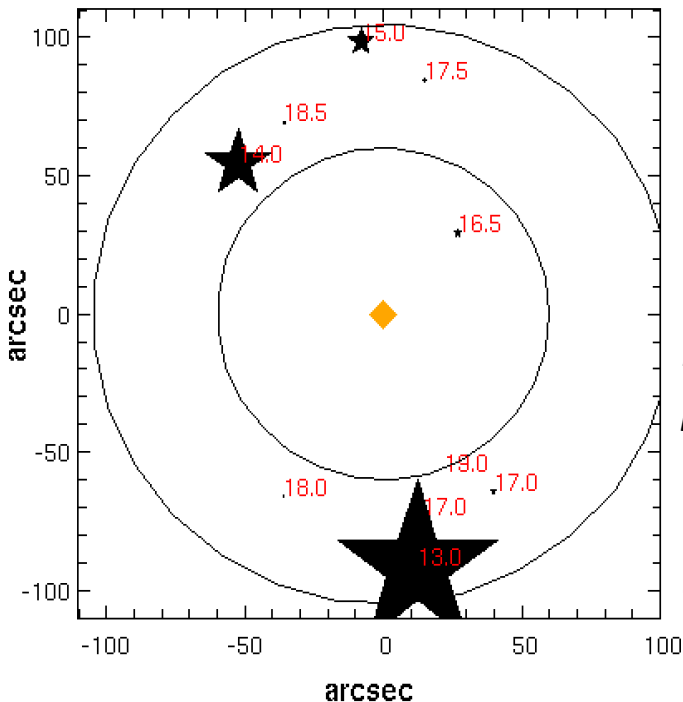
Tomography

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

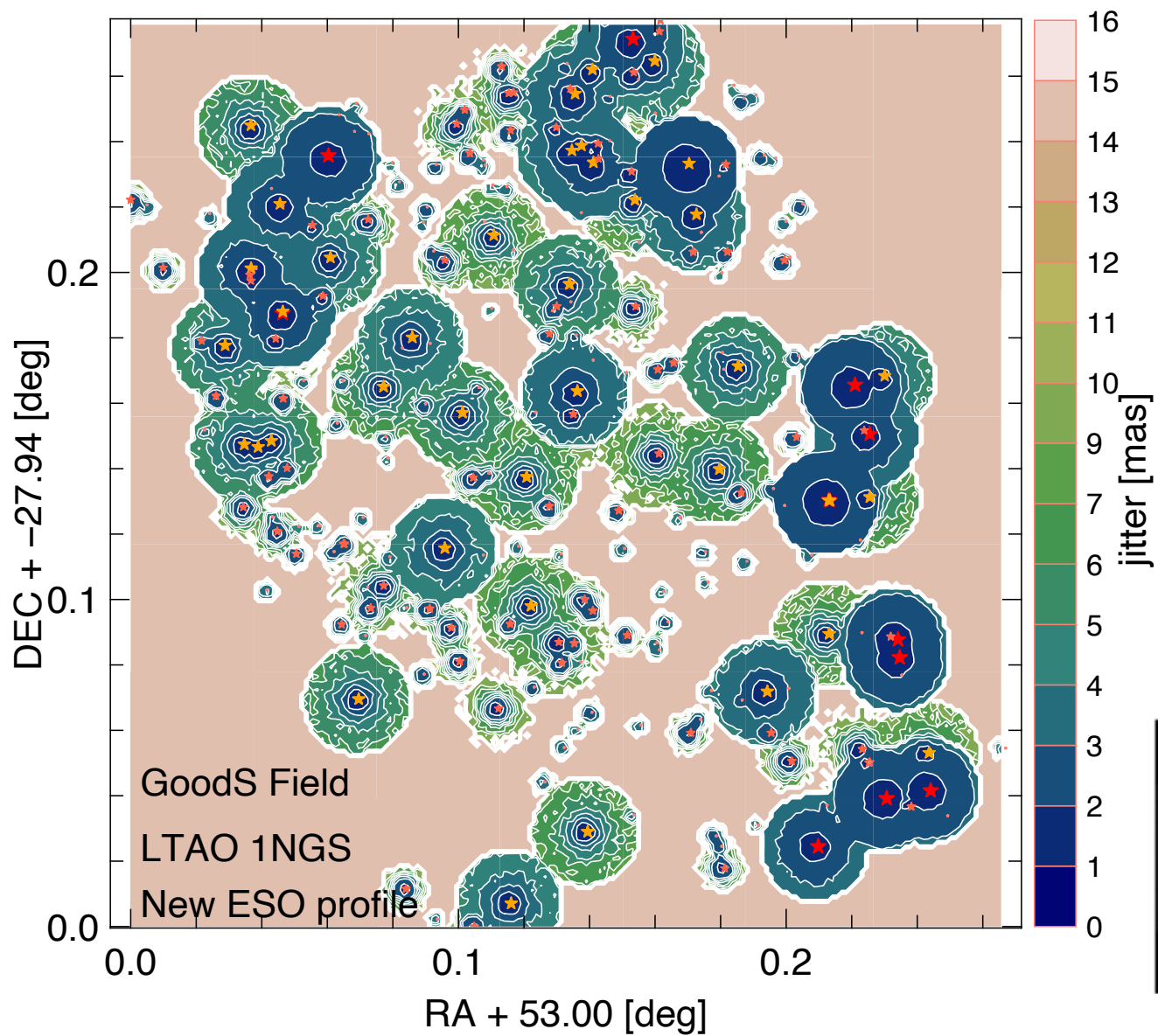
- Then simply sort the results by performance, and pick the best one !

Application to HARMONI (LTAO for the EELT)

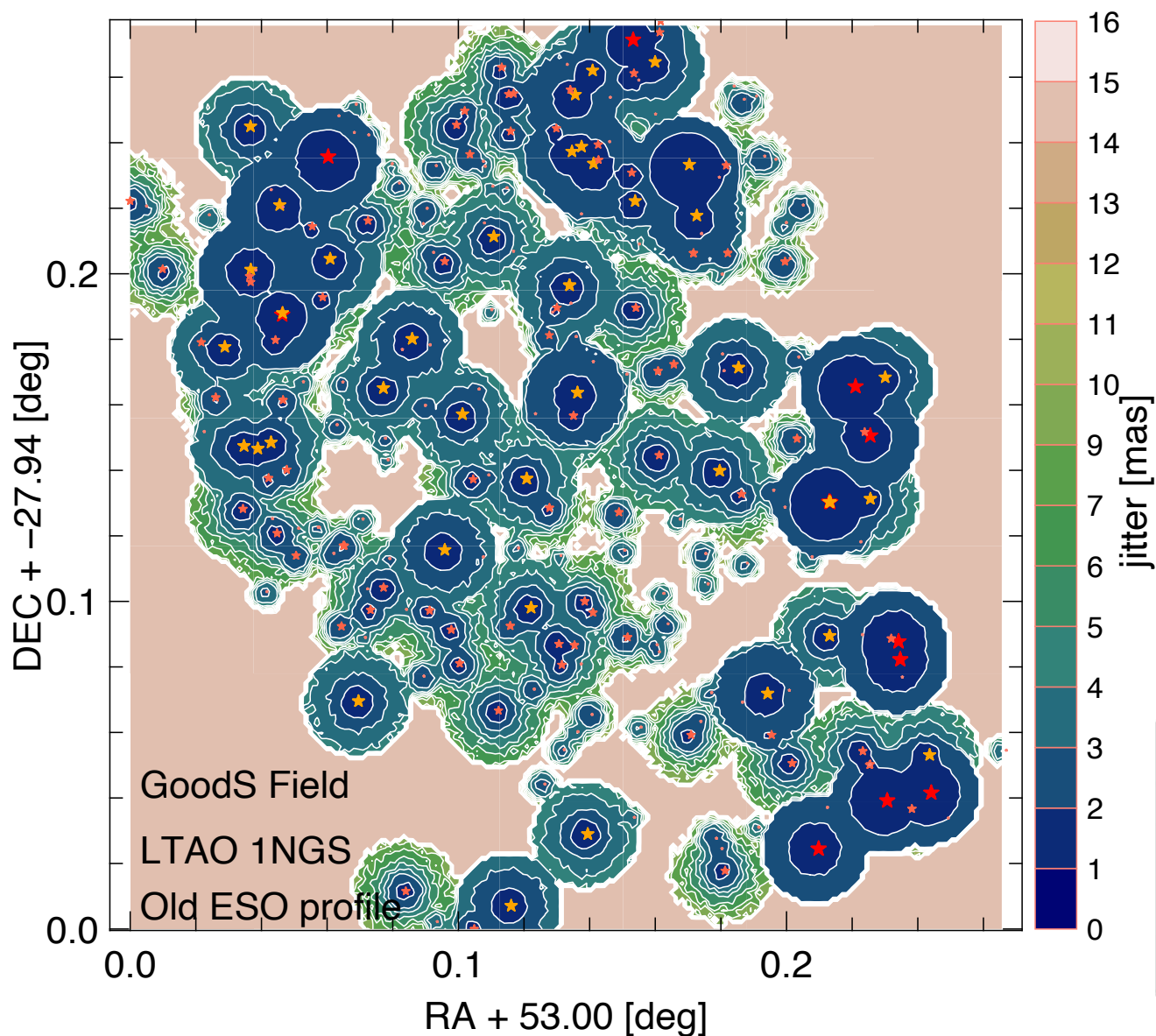
Test on “classical” cosmological fields



Application to HARMONI (LTAO for the EELT)

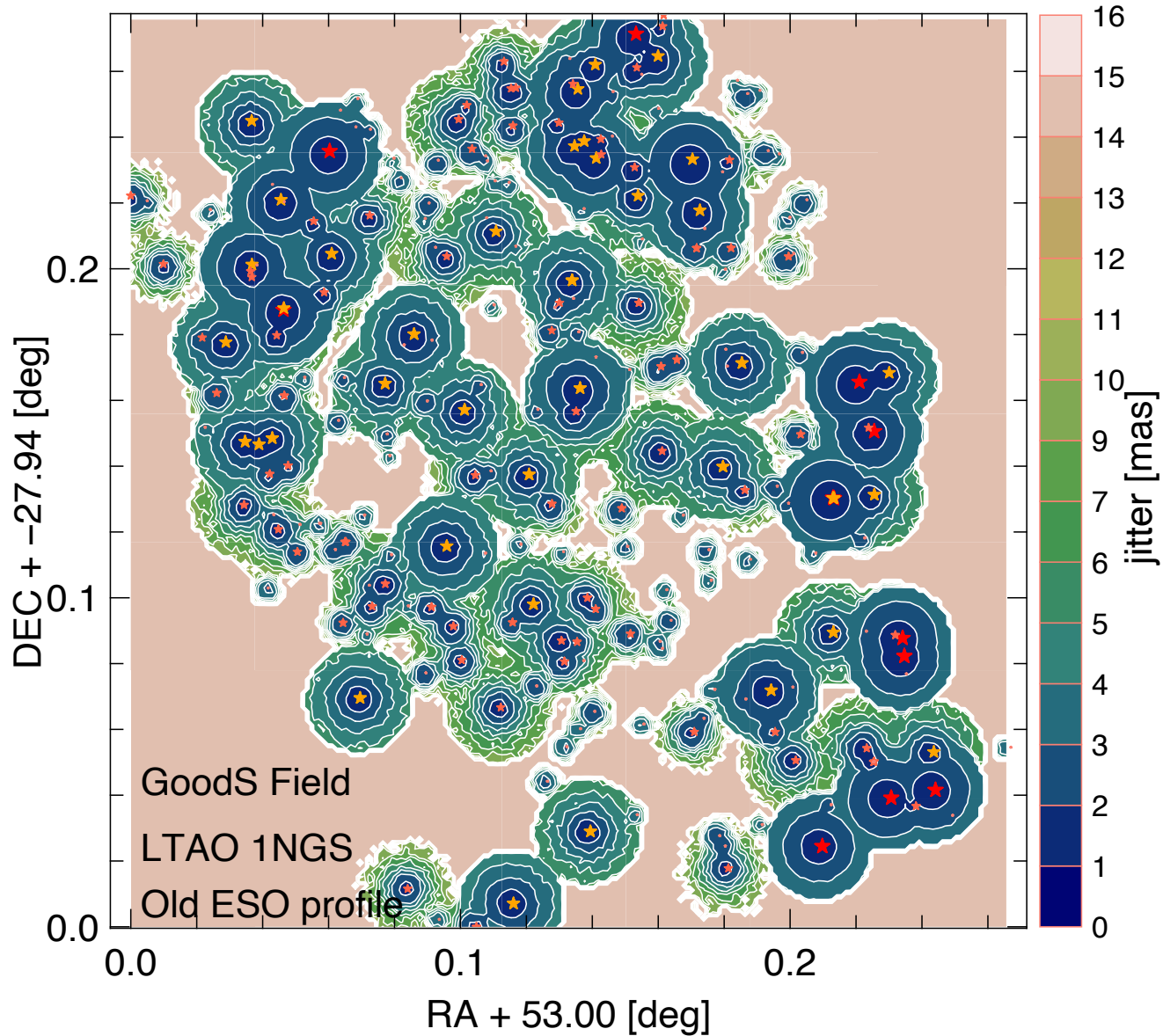


Application to HARMONI (LTAO for the EELT)



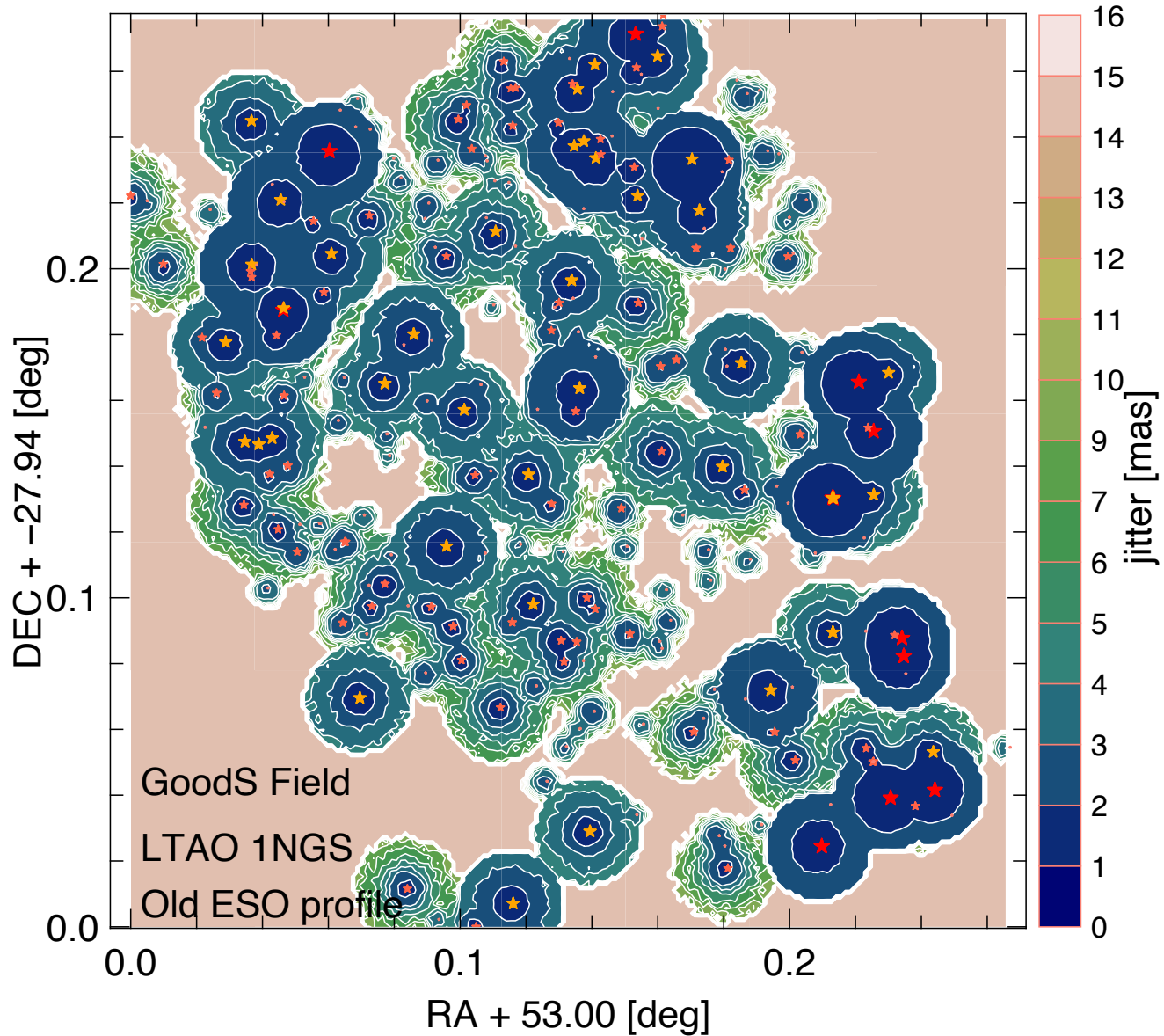
Impact of Cn2 profile (from old ESO to new 35 layers)

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 !**

