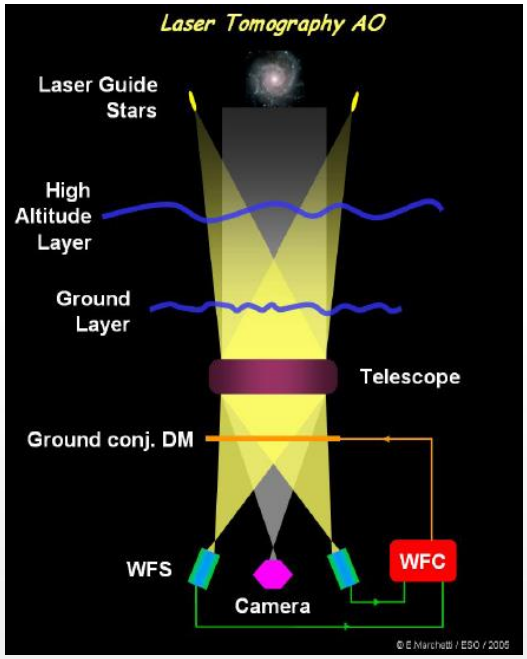
Tomographic errors for wide field AO systems on GSMTs

Impact on telescope design and ultimate performance

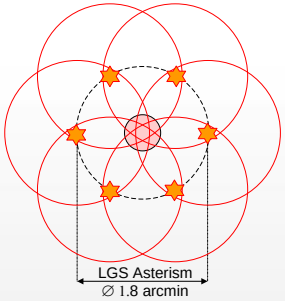
T. Fusco[1,2], B. Neichel[2], C. Correia[2], L. Blanco[1,2], A. Costille[2],
J.-F. Sauvage[1,2], J-M Conan[1], M Le louarn[3], J. Peaufique[3], N. Schwartz[4],
J. Osborn[5] E. Masciadri[6]

[1]ONERA, [2]LAM, [3]ESO, [4]UK-ATC, [5]UoDurham, [6]INAF

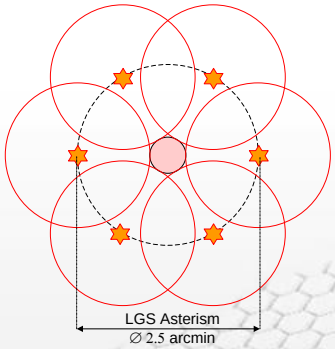
LGS assisted tomographic AO systems



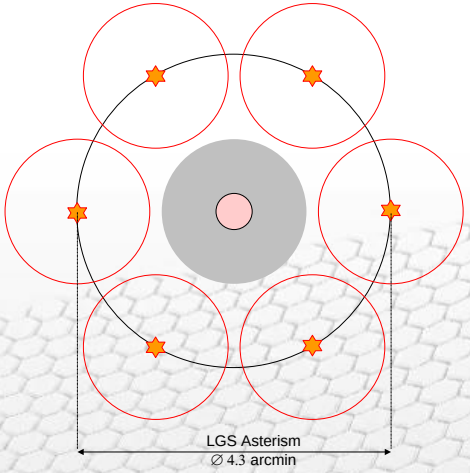
- Optimal performance
- LGS beam print overlap
  ⇒ >1m ∅ dichroic ⇒ Cost
- 30" ∅ Free from optics FOV requirement : Not Compliant



- ~Optimal performance
- LGS beam print overlap
  ⇒ >1m ∅ dichroic ⇒ Cost



- Sub-Optimal performance
- No print overlap ⇒ 6 small optics



30" ∅ Free from optics FOV

Turbulence volume estimation is a key aspect for such systems.

Key questions :

- How many LGS and where ?
- Sensibility to Cn^2 profile evolution ?
- Sensibility to turbulence model in RTC ?

Common problematic for

LTAO (HARMONI)
MCAO (MICADO/MAORY)
MOAO (MOSAIC)

LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

ONERA THE FRENCH AEROSPACE LAB

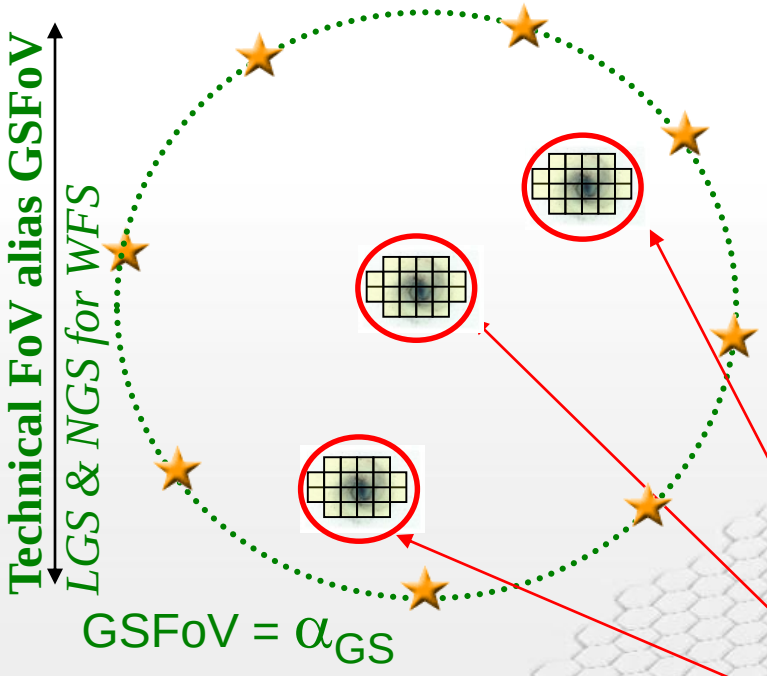
(simplified) error budget

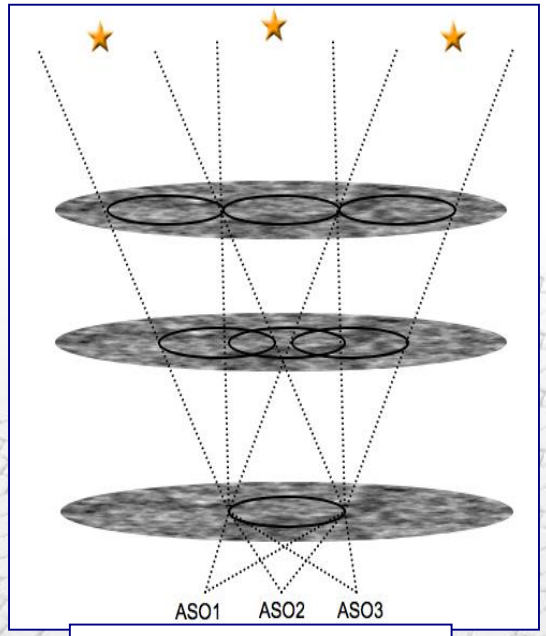
$$\sigma^2_{res} = \sigma^2_{fit} + \sigma^2_{aliasing} + \sigma^2_{temp} + \sigma^2_{diff\ ref} + \sigma^2_{chrom} + \sigma^2_{lgstomography}$$
$$+ \sigma^2_{noisepropag} + \sigma^2_{telescopeHF} + \sigma^2_{wfs\ lin} + \sigma^2_{sodiumstructurevar}$$
$$+ \sigma^2_{C_n^2\ model\ error} + \sigma^2_{noise\ model\ error} + \sigma^2_{DM\ saturation} + \sigma^2_{calibration\ error} + \sigma^2_{NCPA}$$

$\sigma^2_{lgstomography}$
- $C_n^2(h)$
- Number of guide stars
- Technical FoV (asterism diameter)

$\sigma^2_{C_n^2\ model\ error}$
- $C_n^2(h)$
- RTC model (number of reconstructed layers)

Tomographic reconstruction





$$\tilde{\phi}_{\alpha}^{mes} = \mathrm{M}\tilde{\phi}_{\alpha} + \mathrm{b}^{noise}$$

Scientific FoV = SFoV

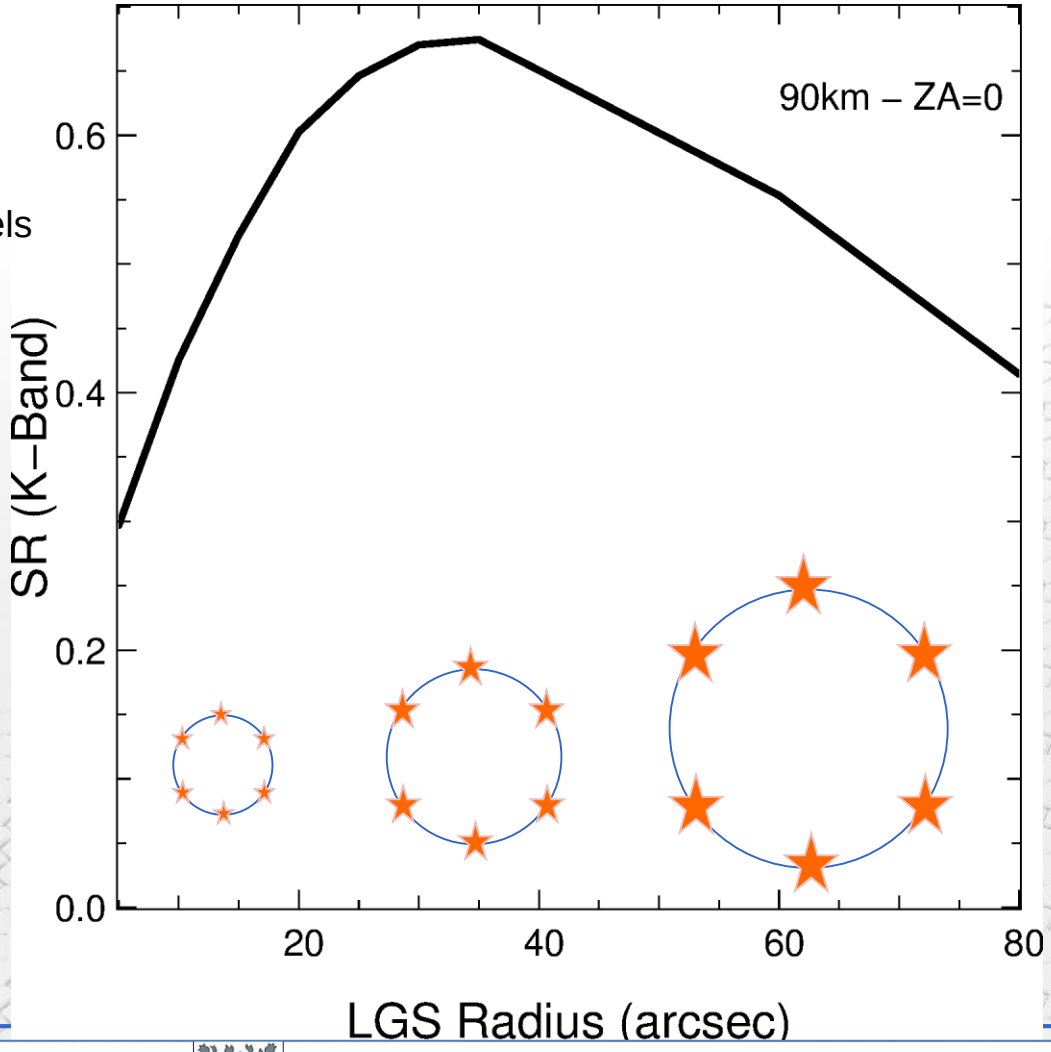
$$\varphi_{corr}^{DM} = \underbrace{P_{concept}^{SFoV}}_{\text{DM projection System dependant}} \underbrace{.W_{tomo}^{\alpha_{GS}} \cdot \Phi_{measurements}^{\alpha_{GS}}}_{\text{Tomographic reconstruction Common to all systems}}$$

Impact of LGS constellation

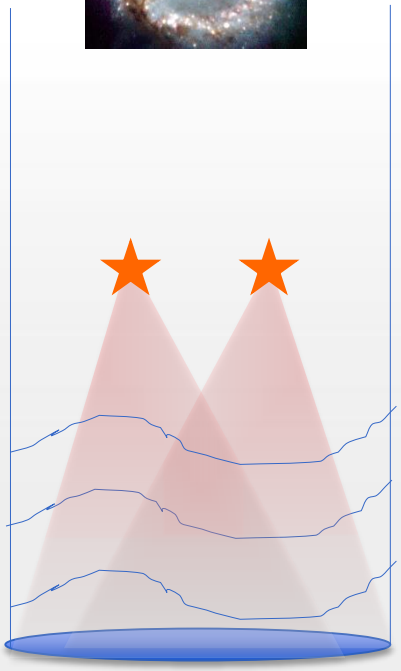
Full E2E simulation using OMAO originaly developed by R Conan – C Correia

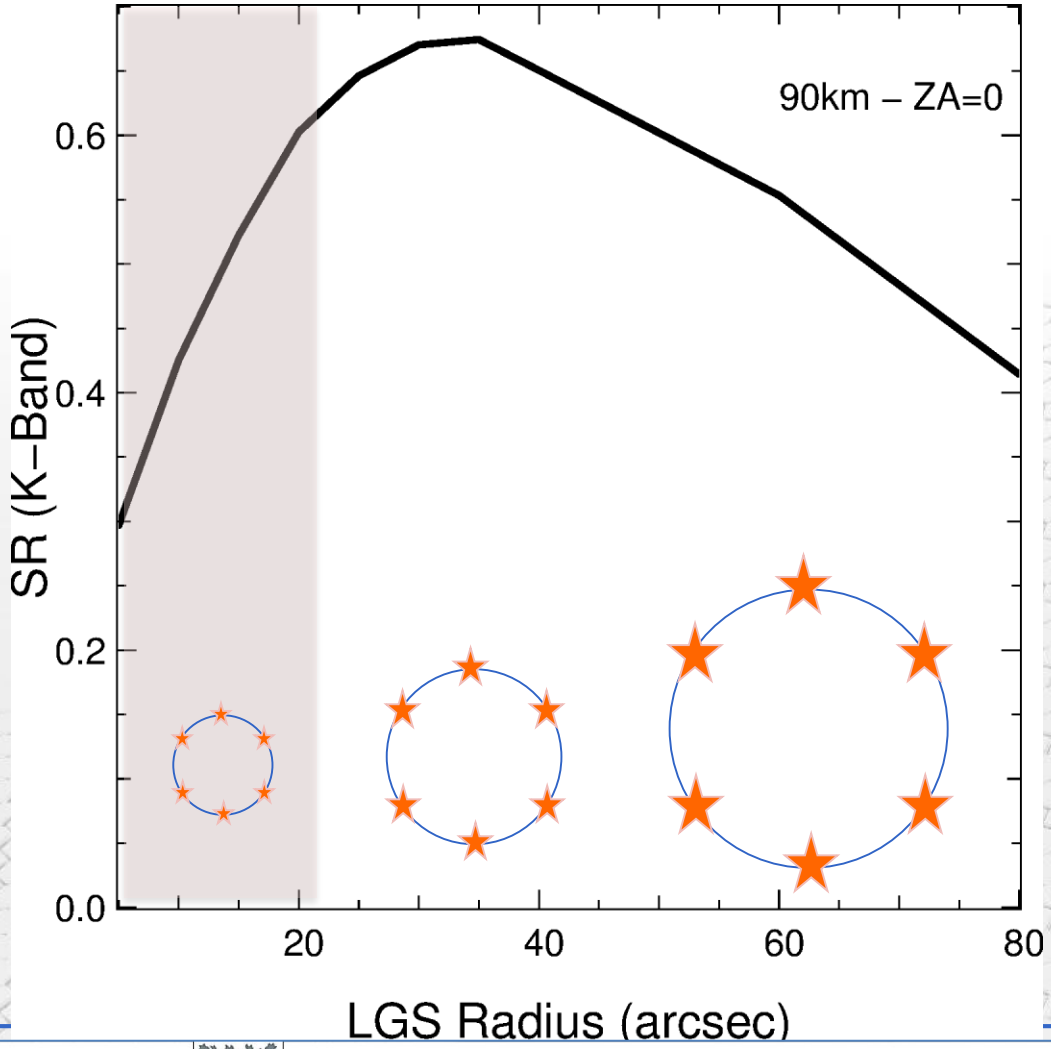
Cross-checked with various other E2E models

- DASP (Durham)
- OCTOPUS (ESO)
- ONERA IDL code
- YAO (F. Rigaut et al)

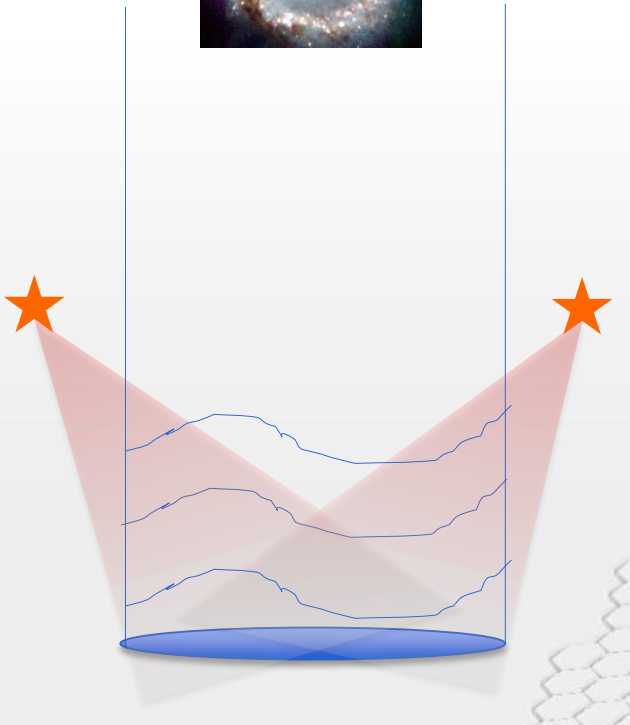


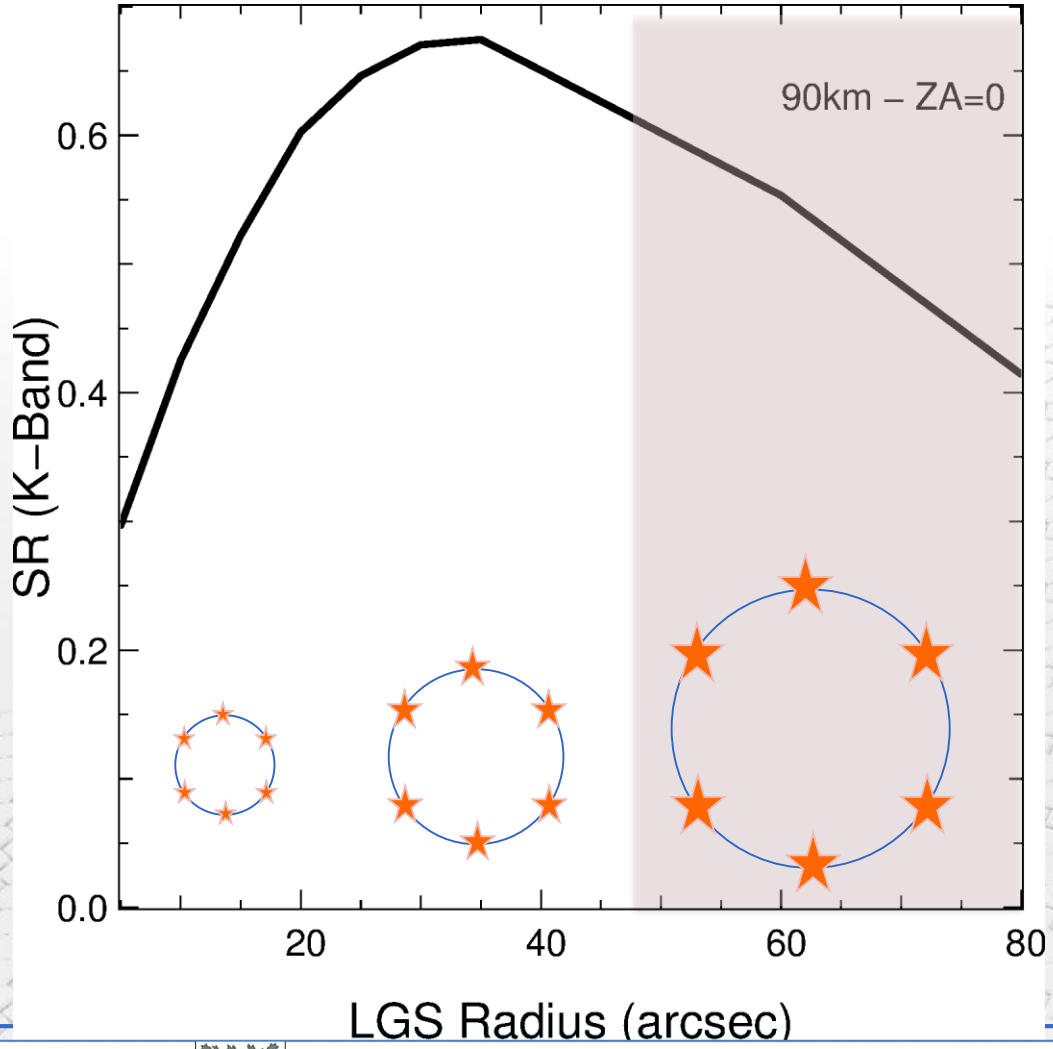
Impact of LGS constellation



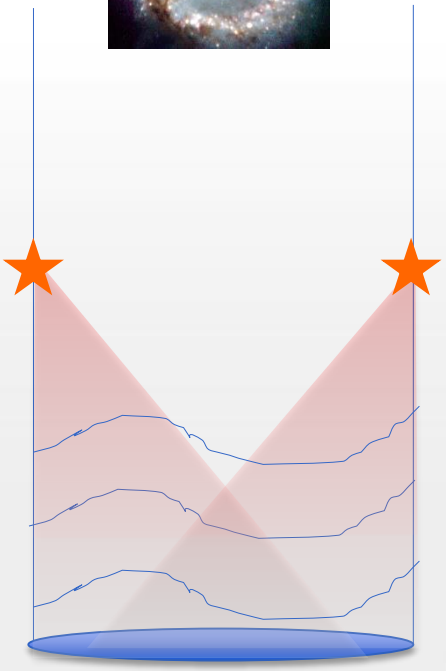


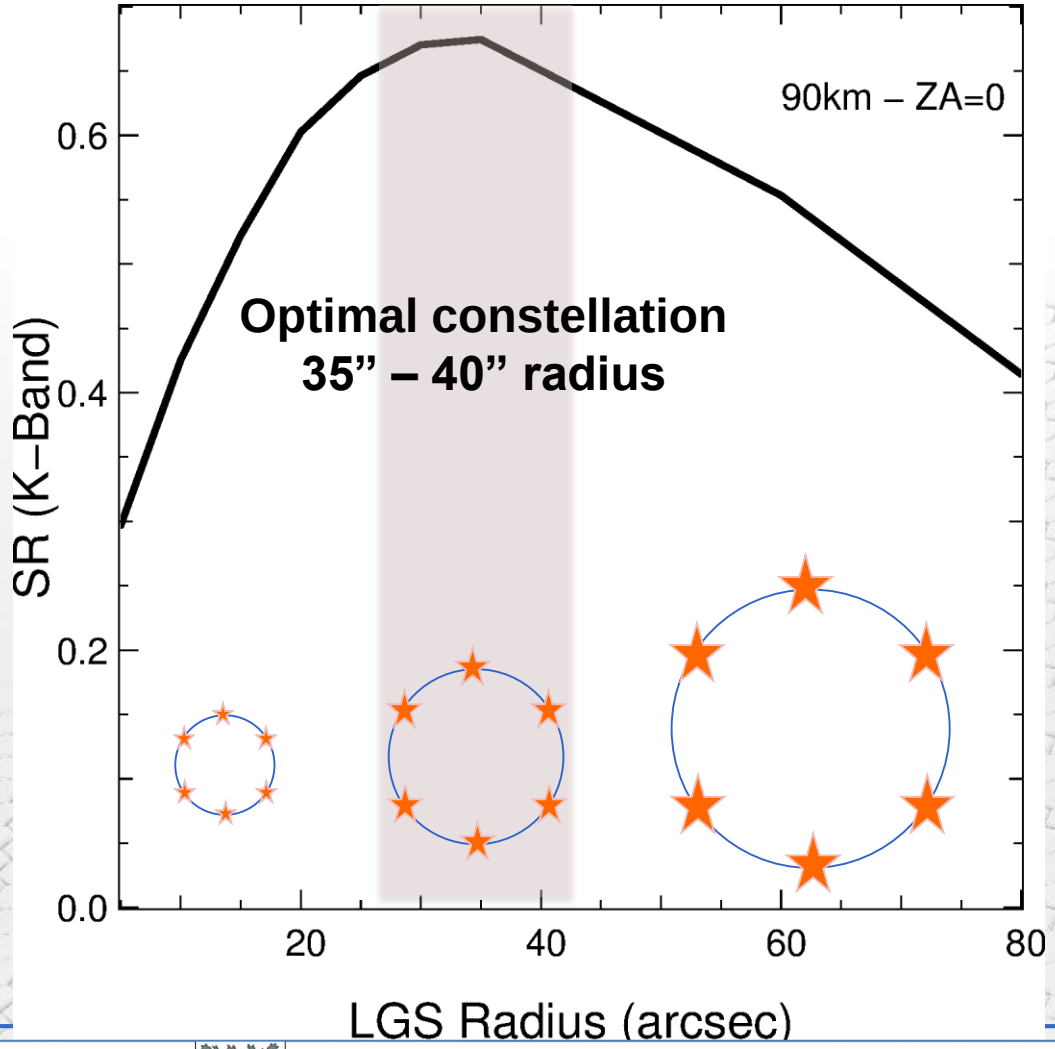
Impact of LGS constellation



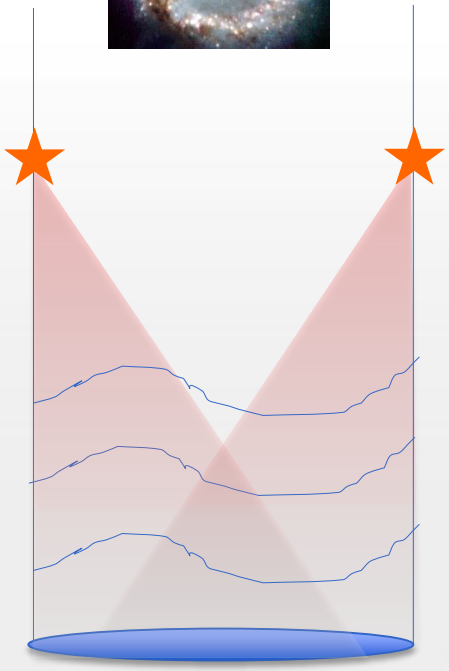


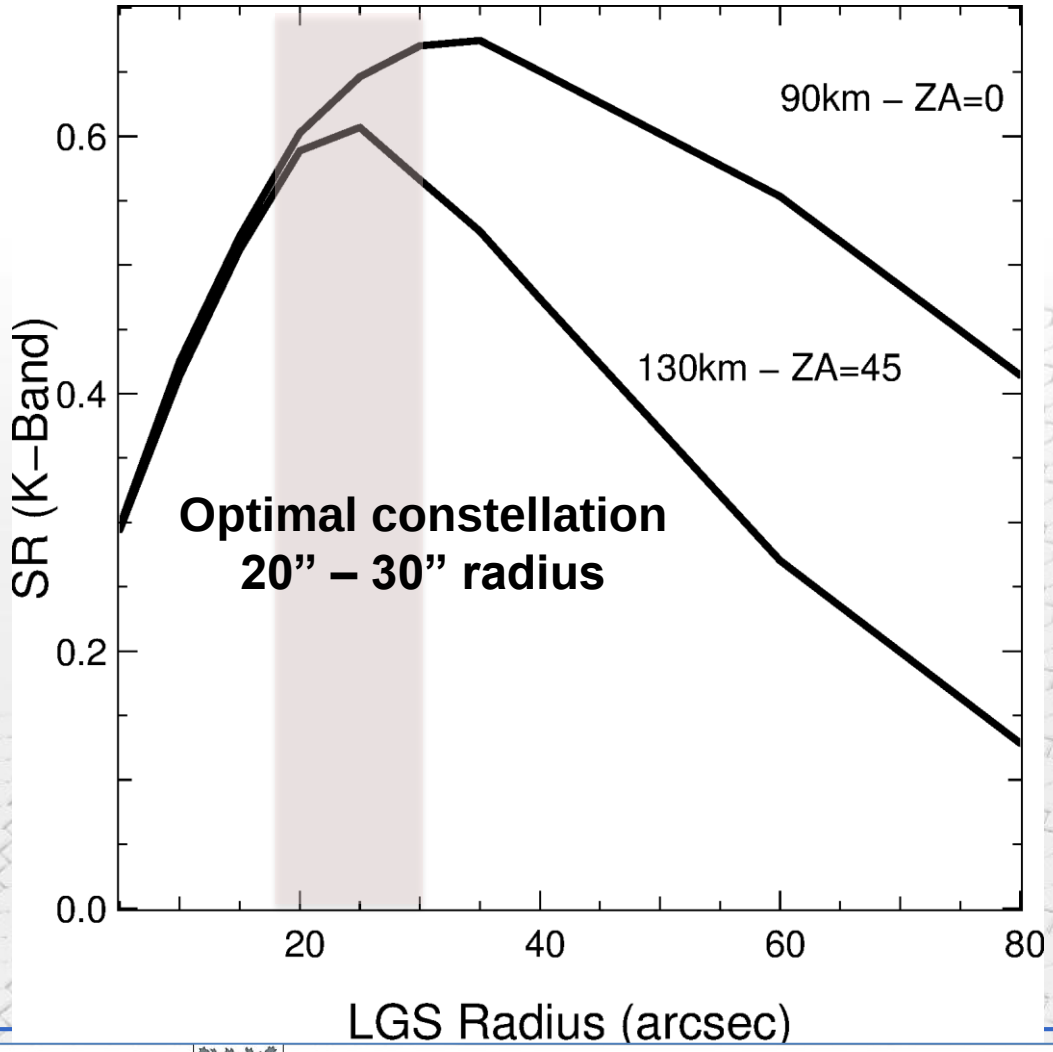
Impact of LGS constellation



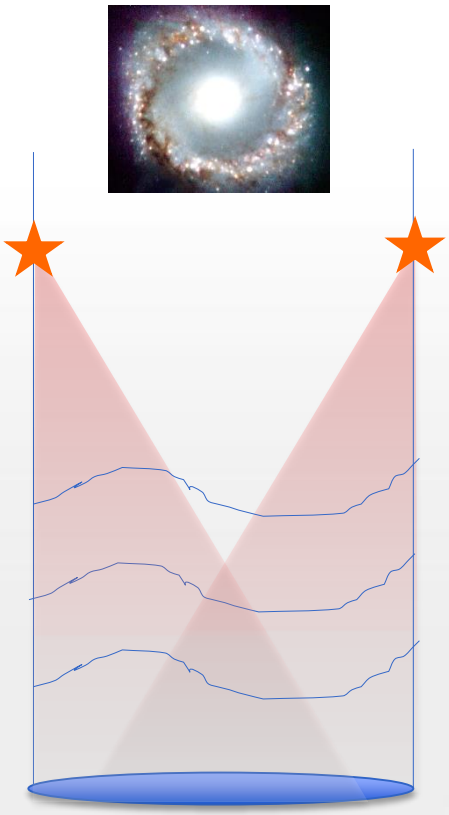


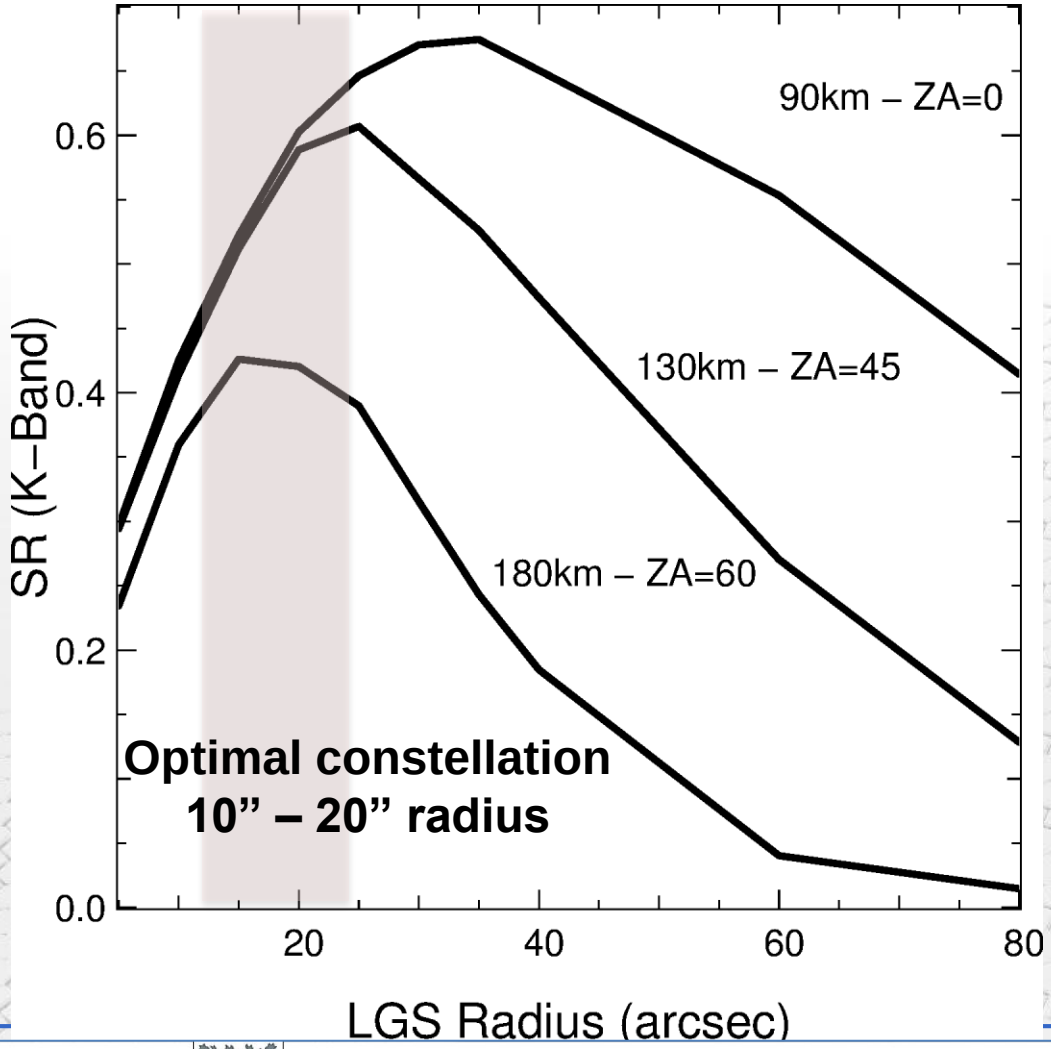
Impact of LGS constellation



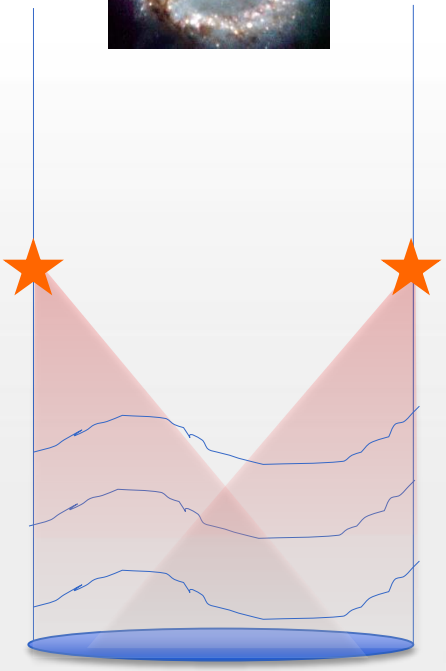


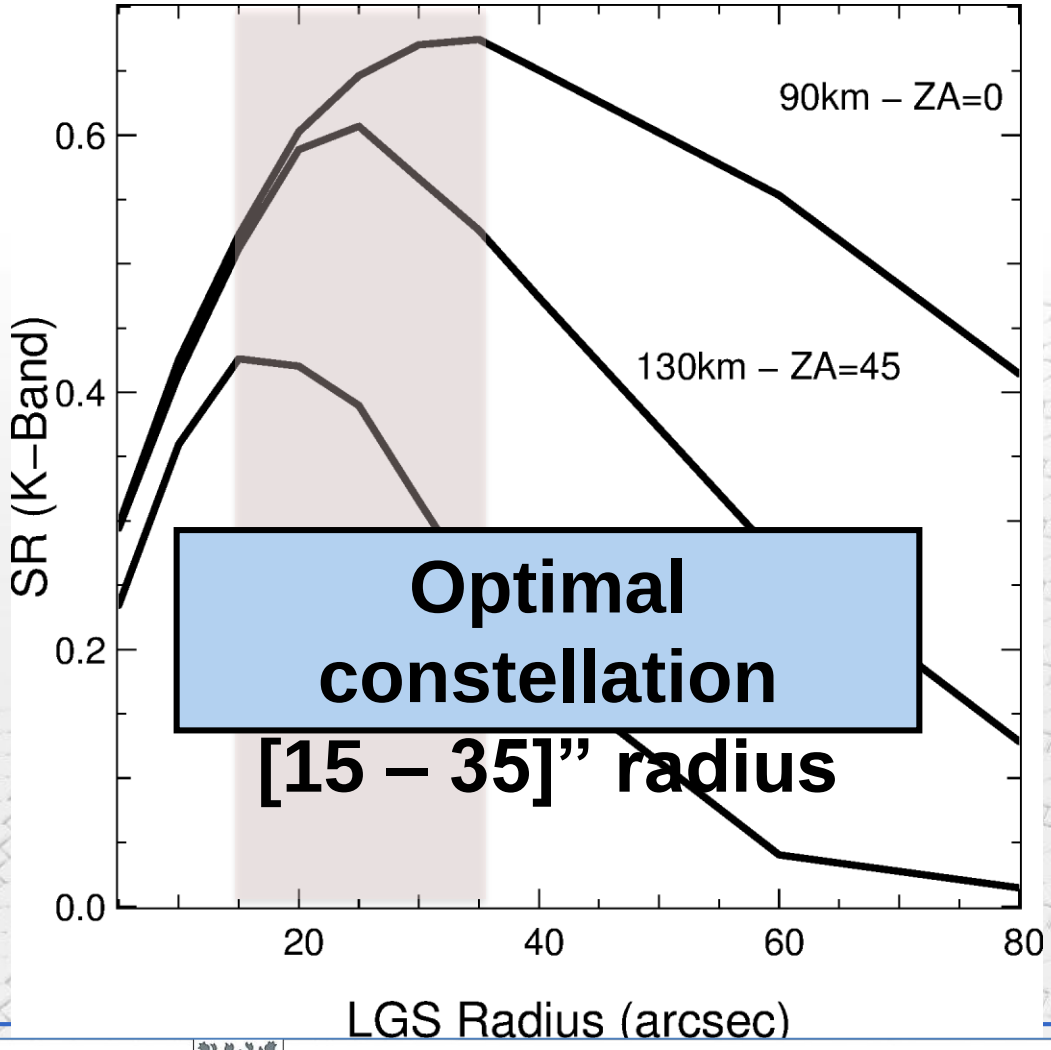
Impact of LGS constellation





Impact of LGS constellation





Optimal constellation

[15 – 35]” radius

Different tools for different purposes

E2E simulation

- Accurate
- Time consuming
- 1 point = a few hours

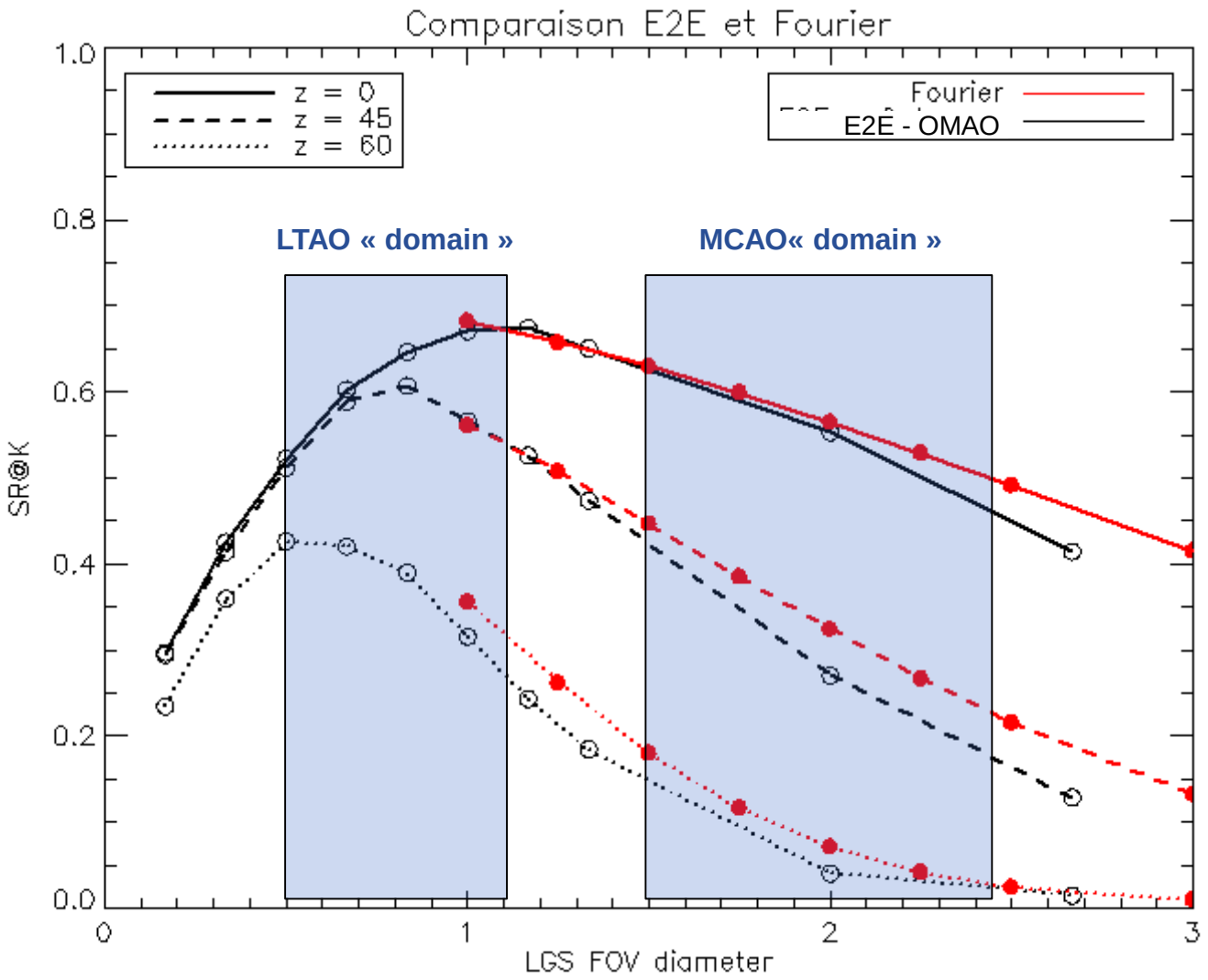
⇒ Good for critical choices

⇒ Final design

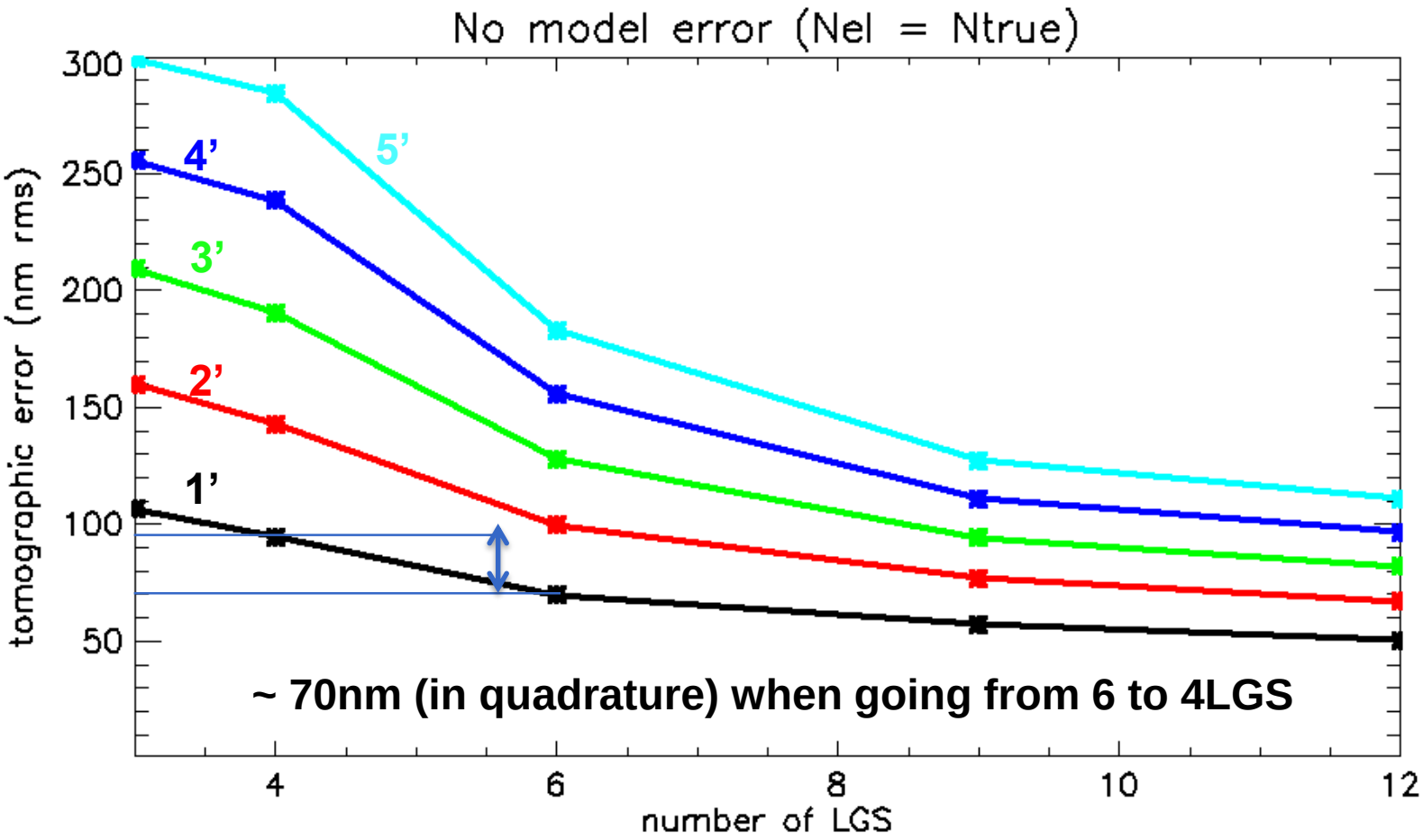
Fourier tools

- Simplified models
- (very) Fast
- Scan parameters space
- 1 point = a few seconds

⇒ Statistical studies

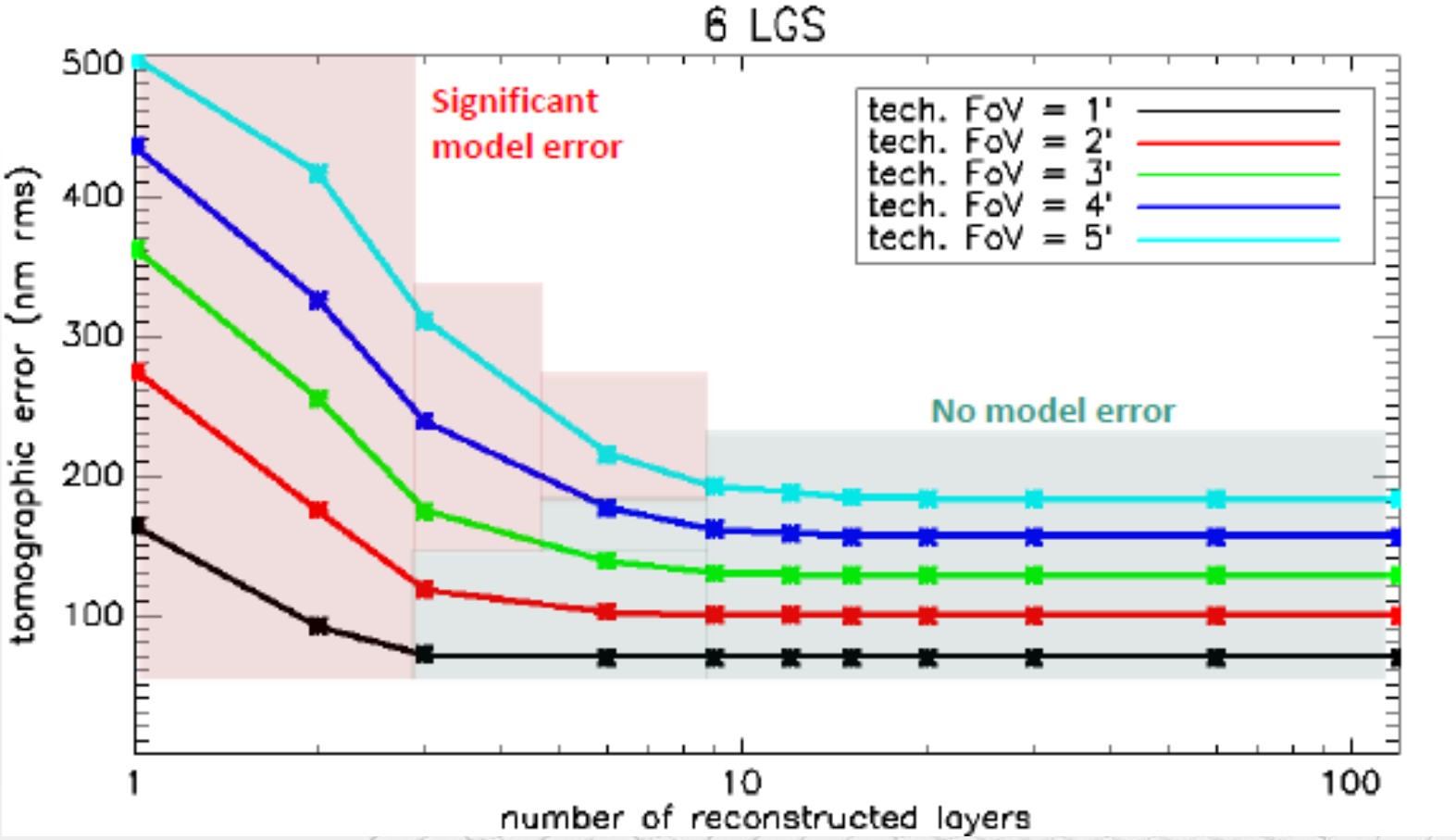


Impact of LGS number



- Small tech. FoV (a.k.a LTAO) => we can live with 4 LGS, 6 provides quasi-ultimate performance
- Large tech. FoV (a.k.a MCAO) => 6 LGS seems to be mandatory

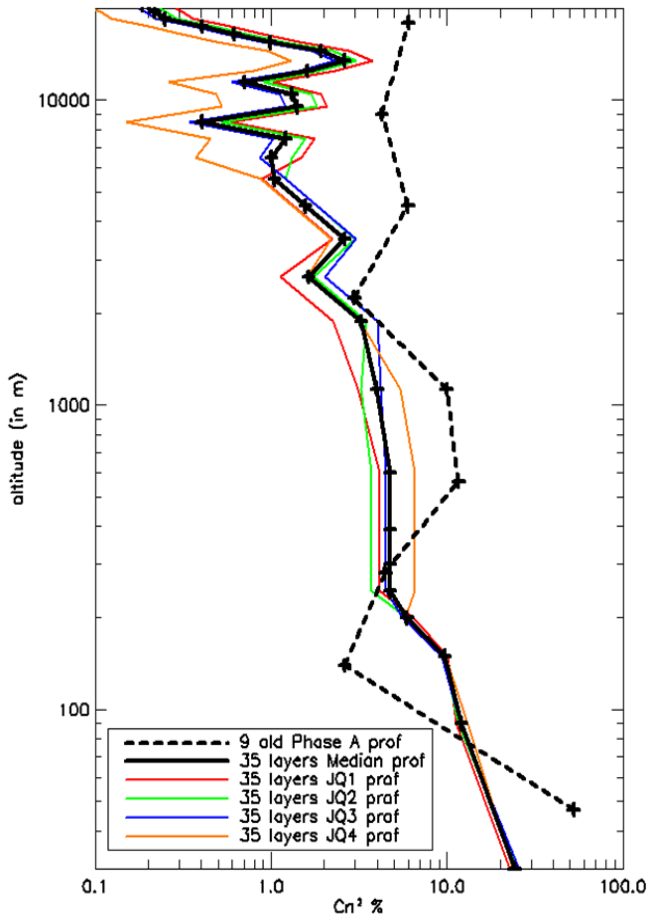
Impact of Cn² model in the reconstructor

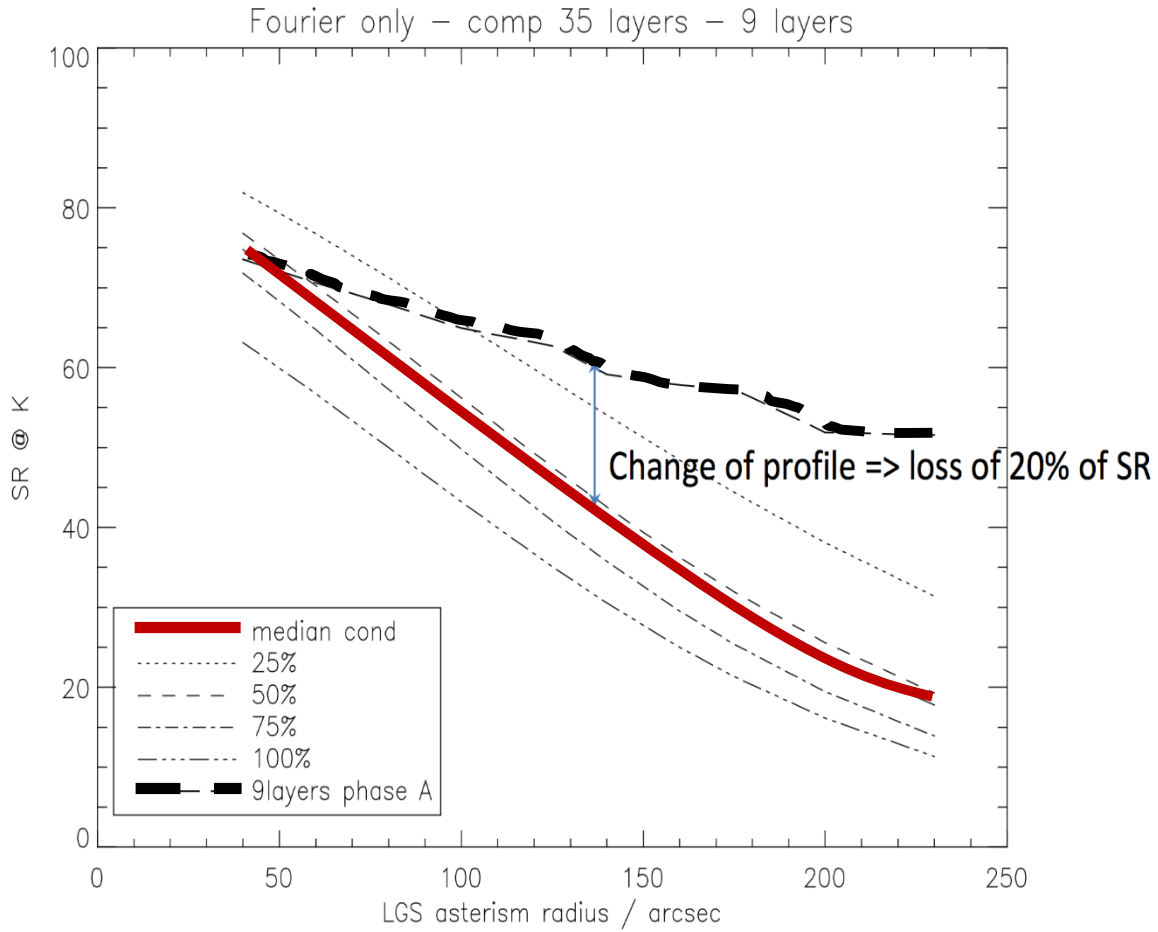


Cn² profile diversity : Why ?

- Diversity of Cn² profils and its impact on perfomance and system design
- Data
  - « average $C_n^2(\mathrm{h})$ »
    - Derived form data
    - Reference for design choices
  - Statistical $C_n^2(\mathrm{h})$
    - Representativness of your system performance
    - Range of operation
  - Short term evolution of $C_n^2(\mathrm{h})$
    - Design aspect (RTC)
    - Operation strategy

Impact of Cn² distribution (I)



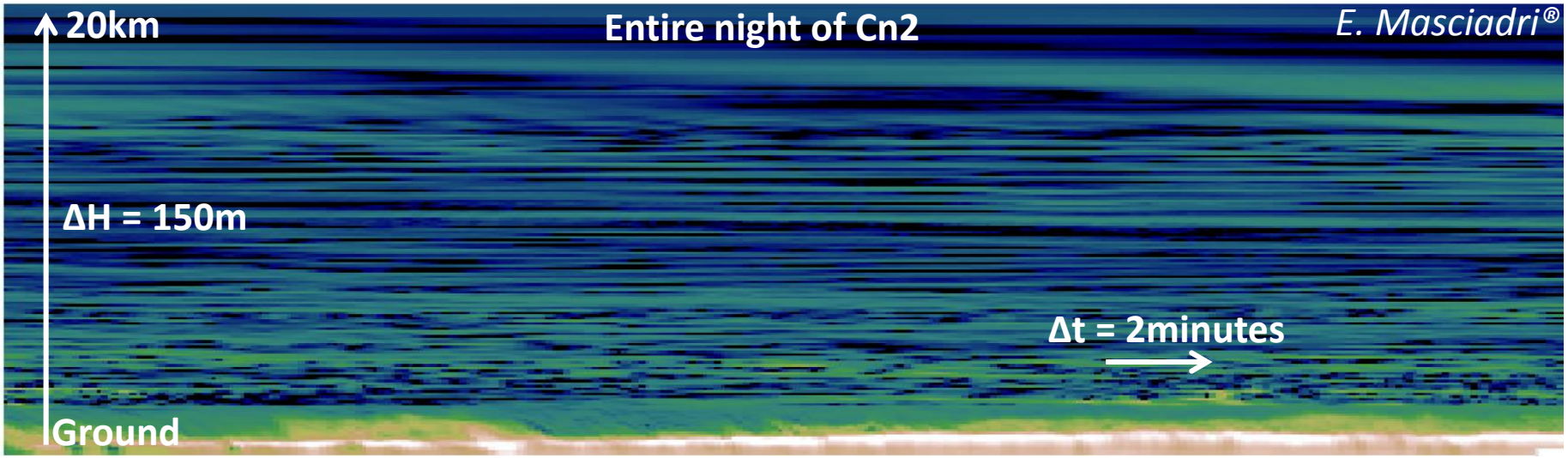


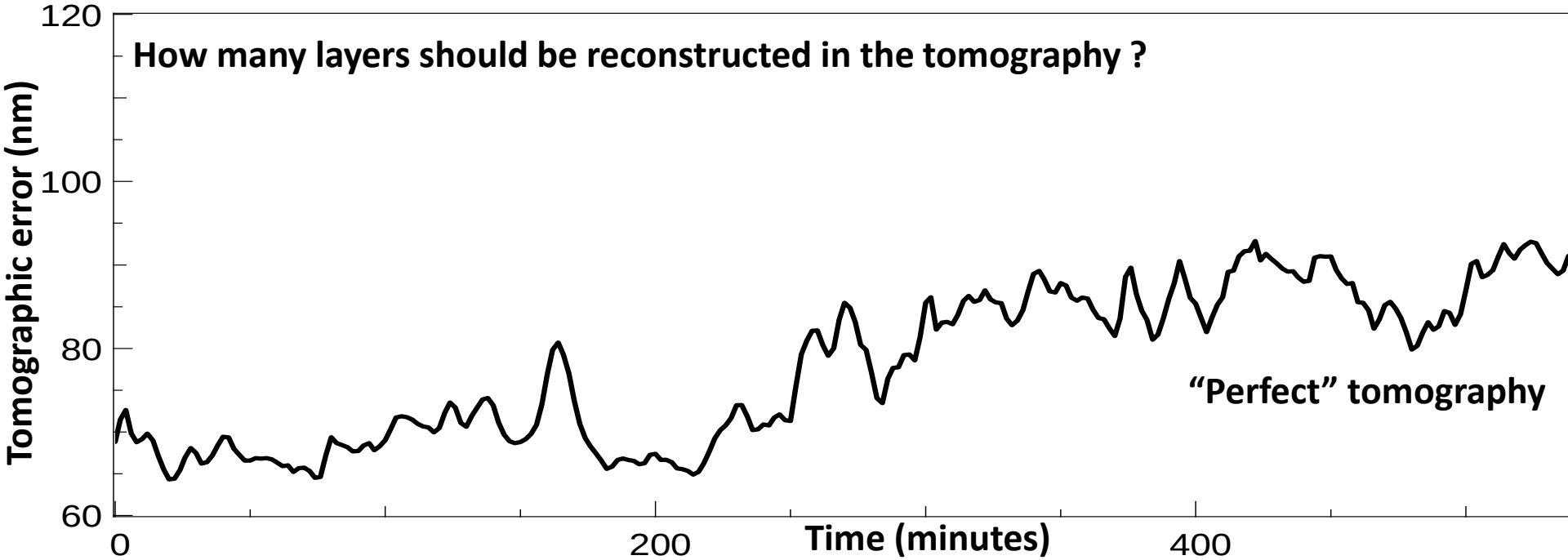
Same isoplanatic angle → Very different tomographic results

LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

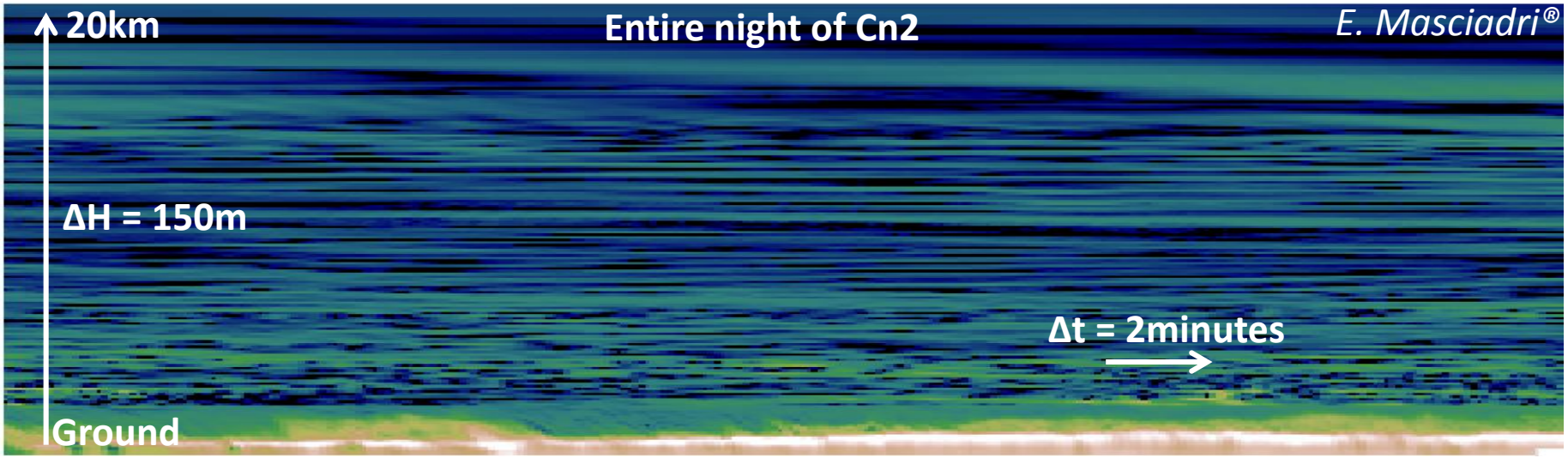
ONERA THE FRENCH AEROSPACE LAB

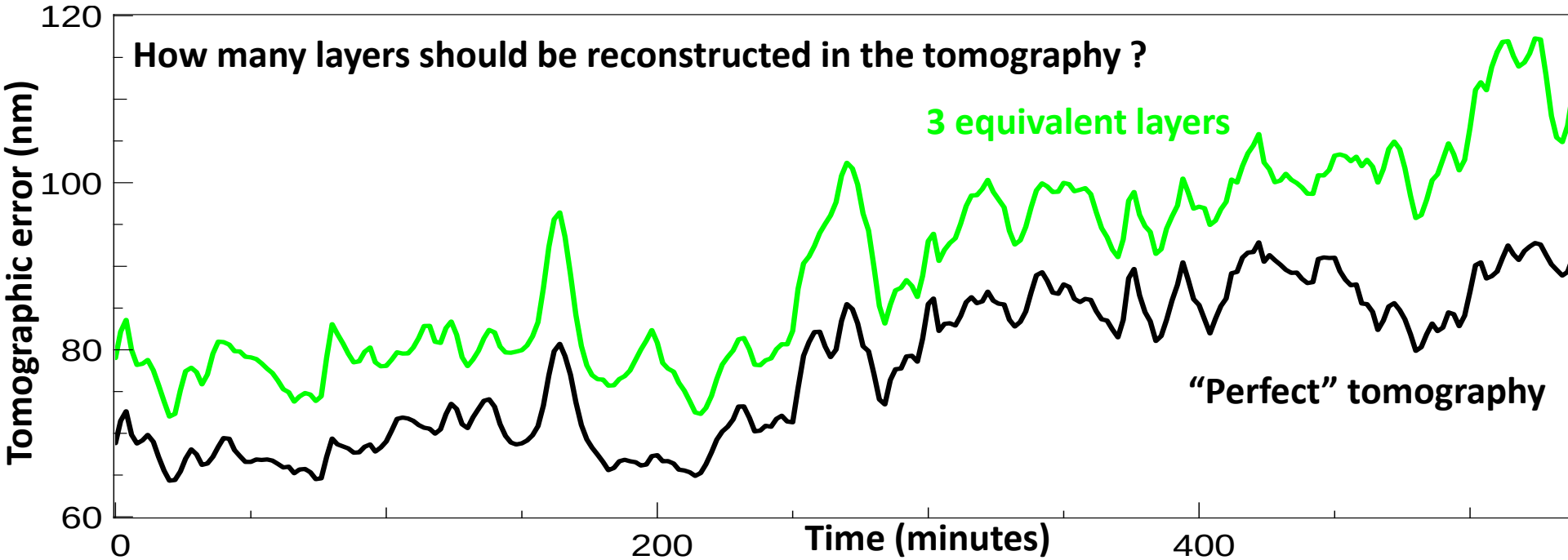
Sensitivity of tomography



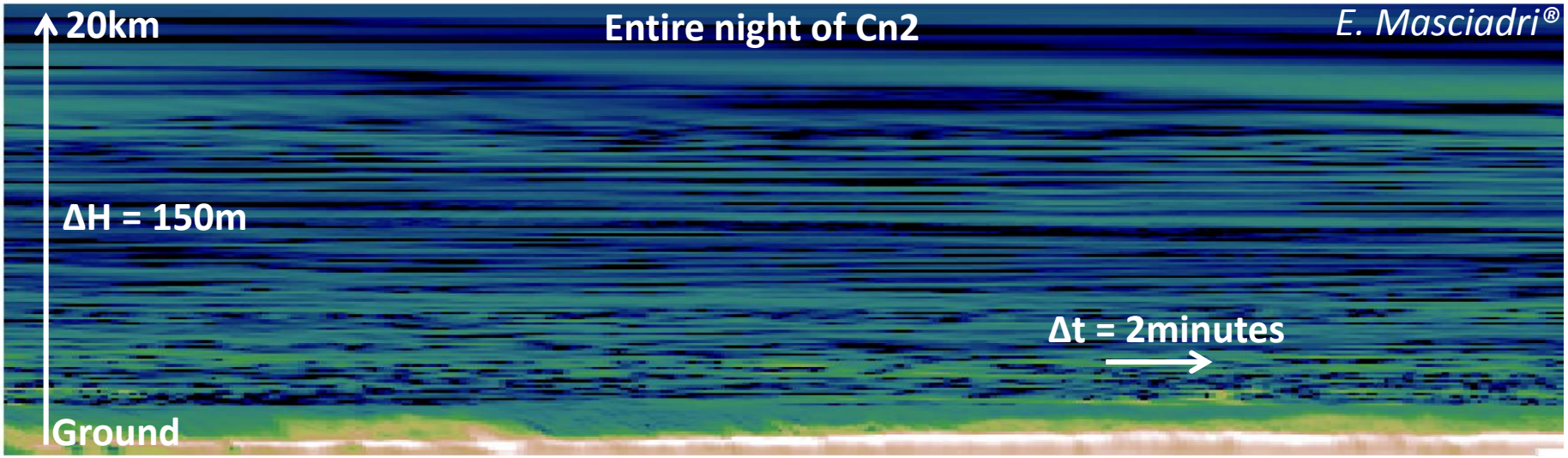


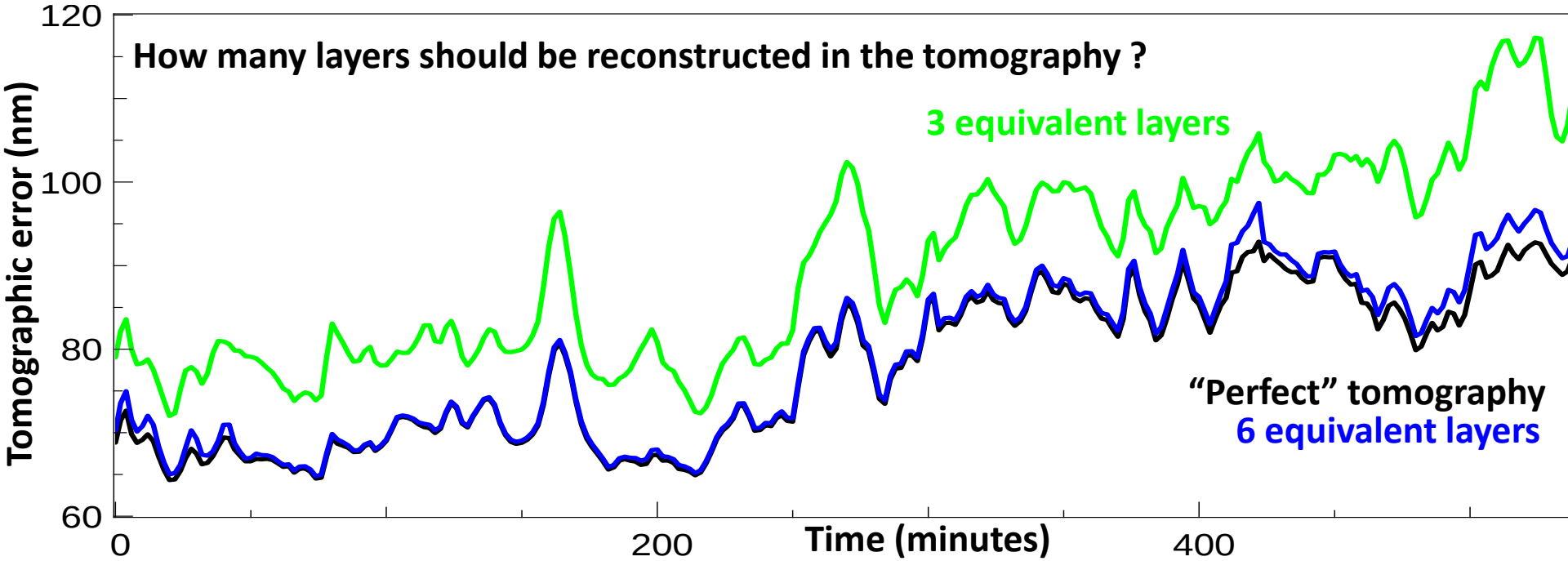
Sensitivity of tomography



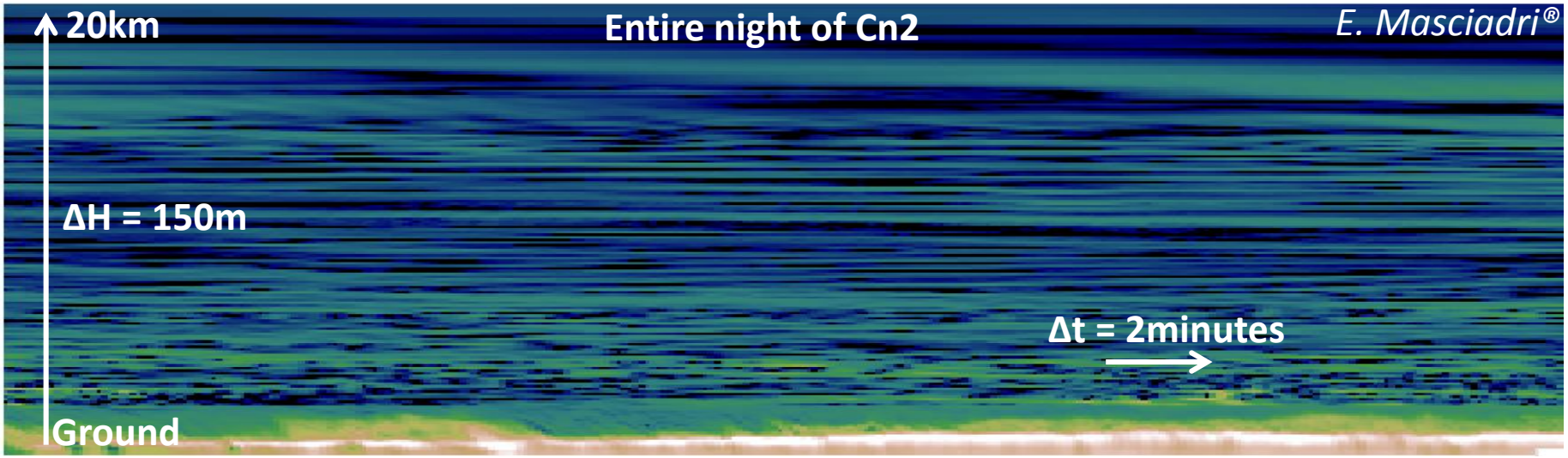


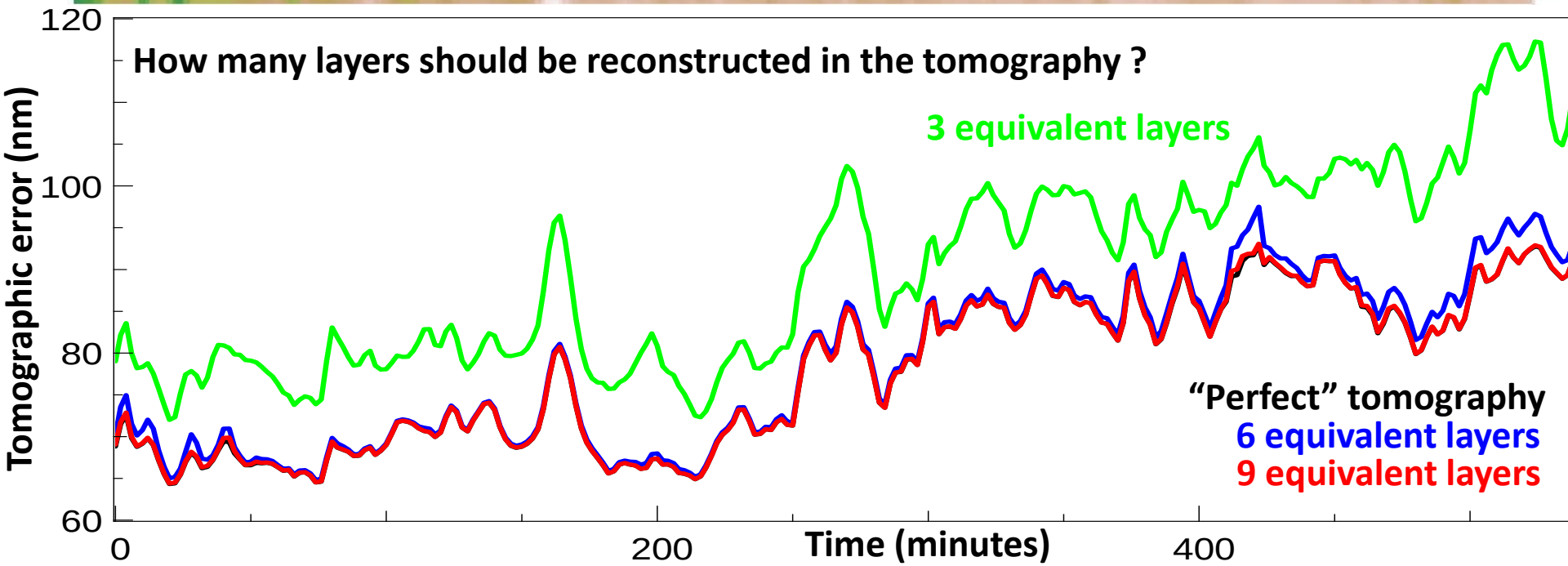
Sensitivity of tomography



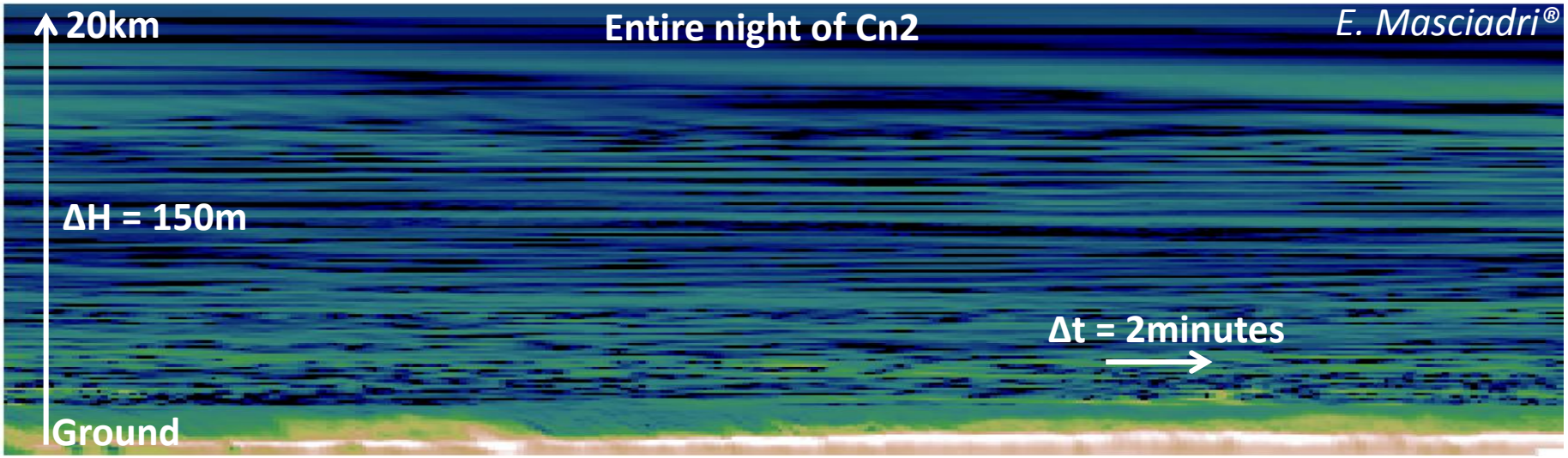


Sensitivity of tomography





Sensitivity of tomography



How often should we re-compute a tomographic reconstructor ?

Tomographic error (nm)

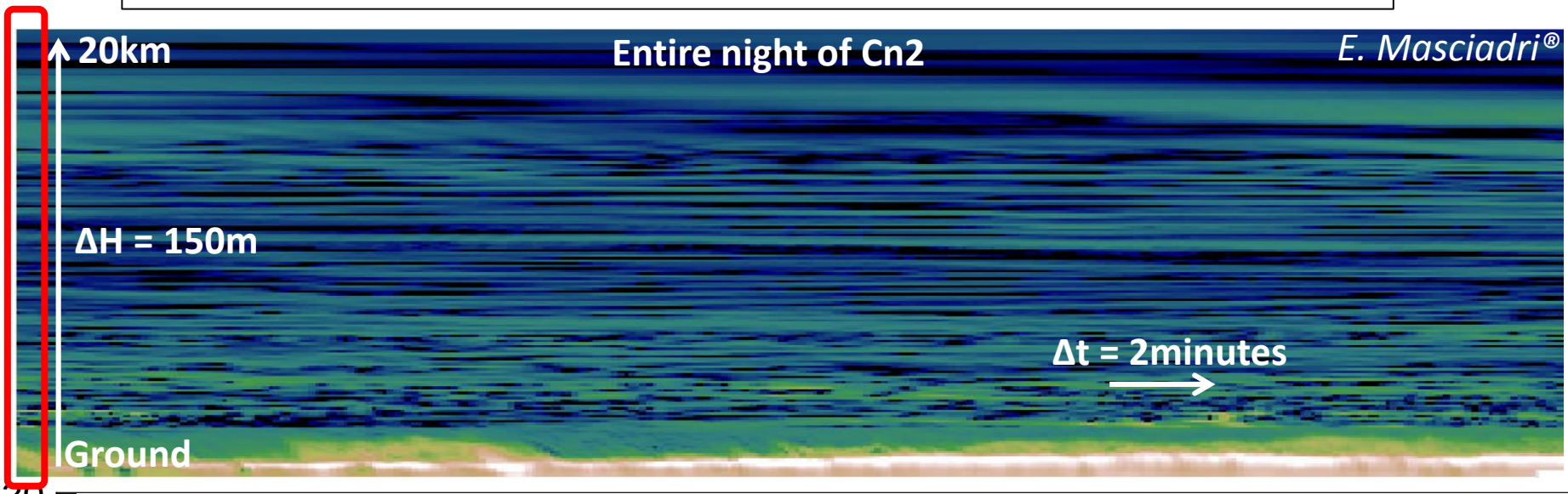
120
100
80
60

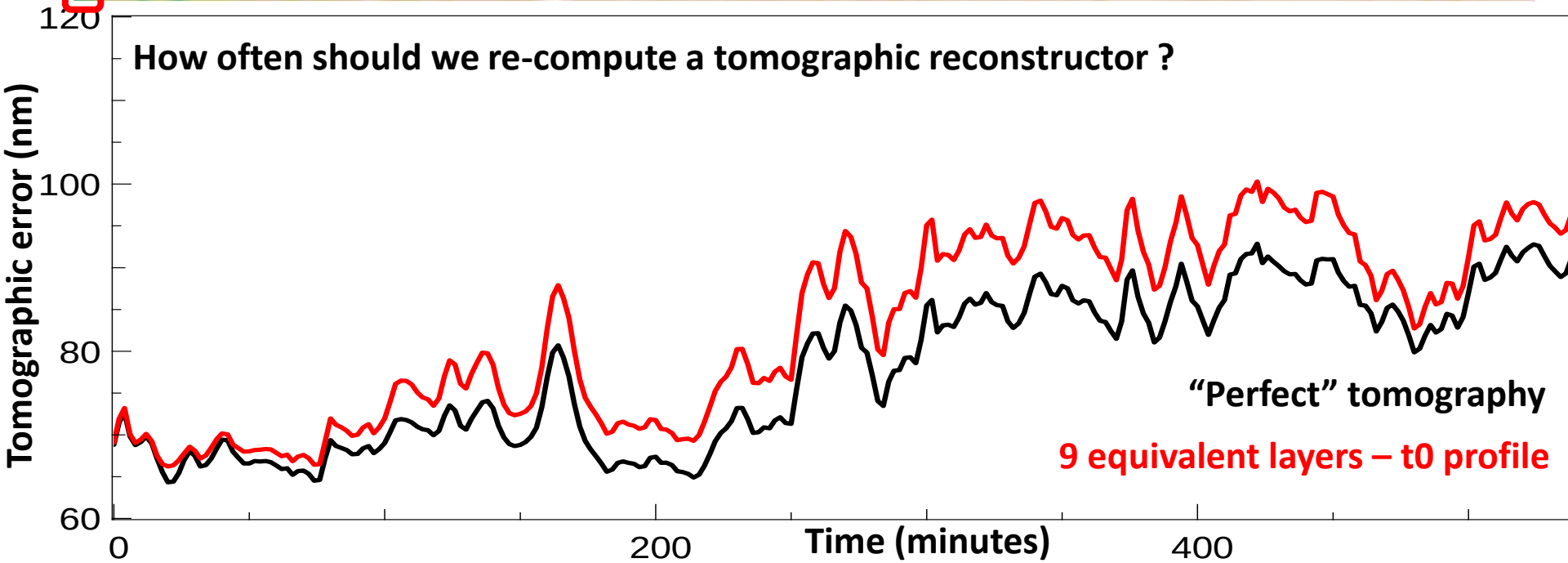
0
200
400

Time (minutes)

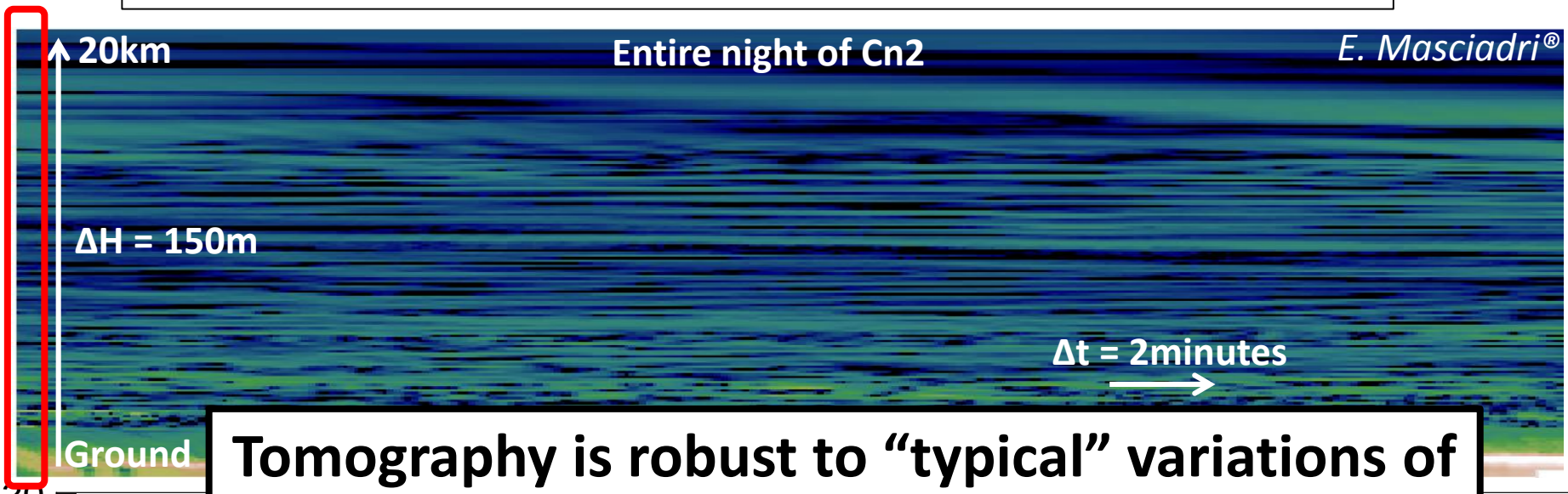
"Perfect" tomography

Sensitivity of tomography

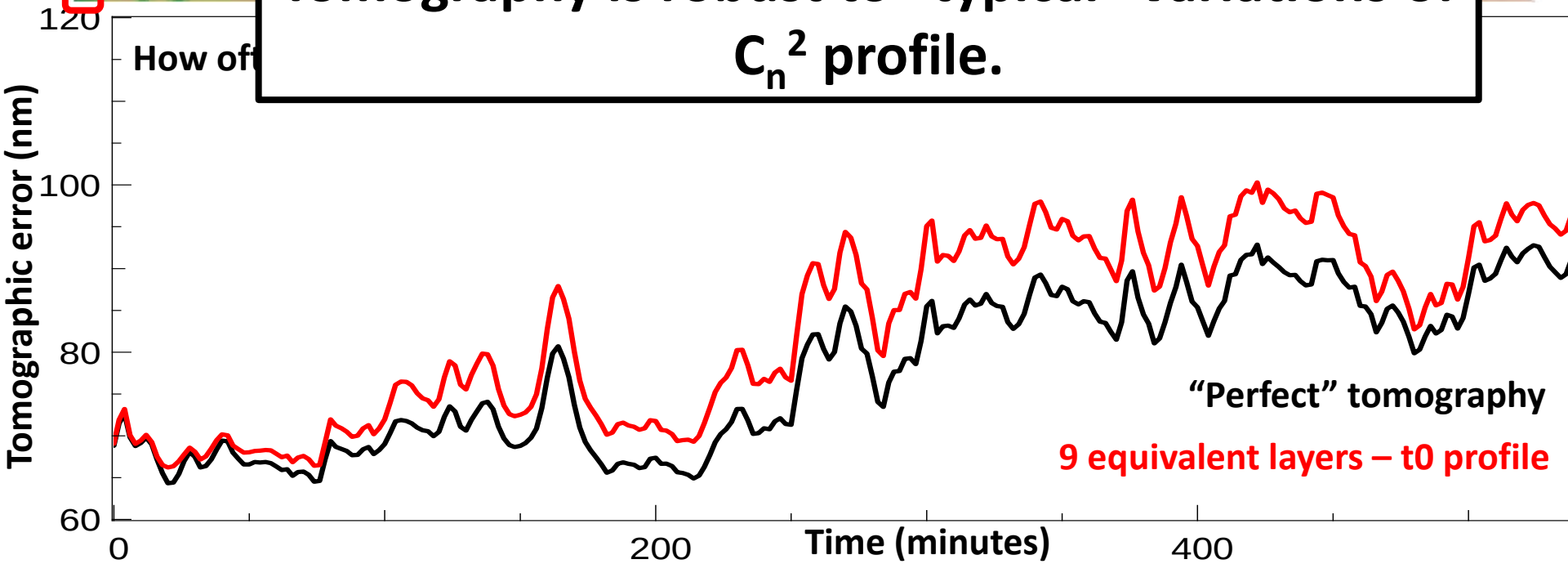




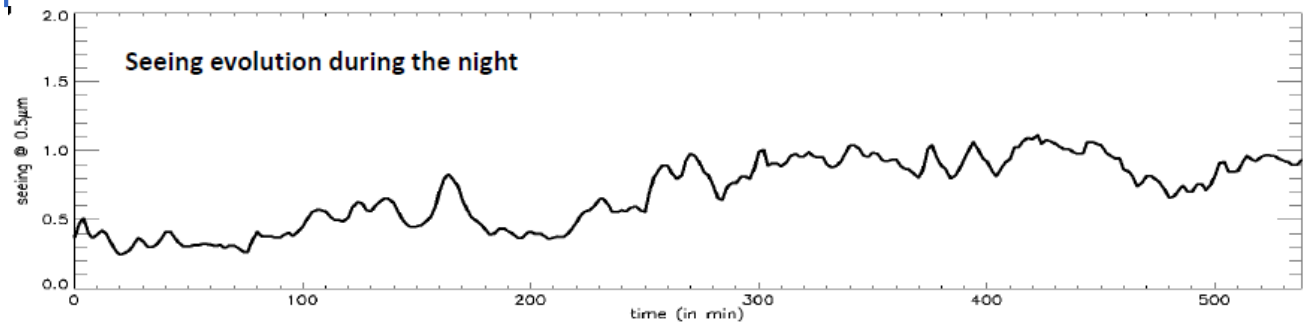
Sensitivity of tomography

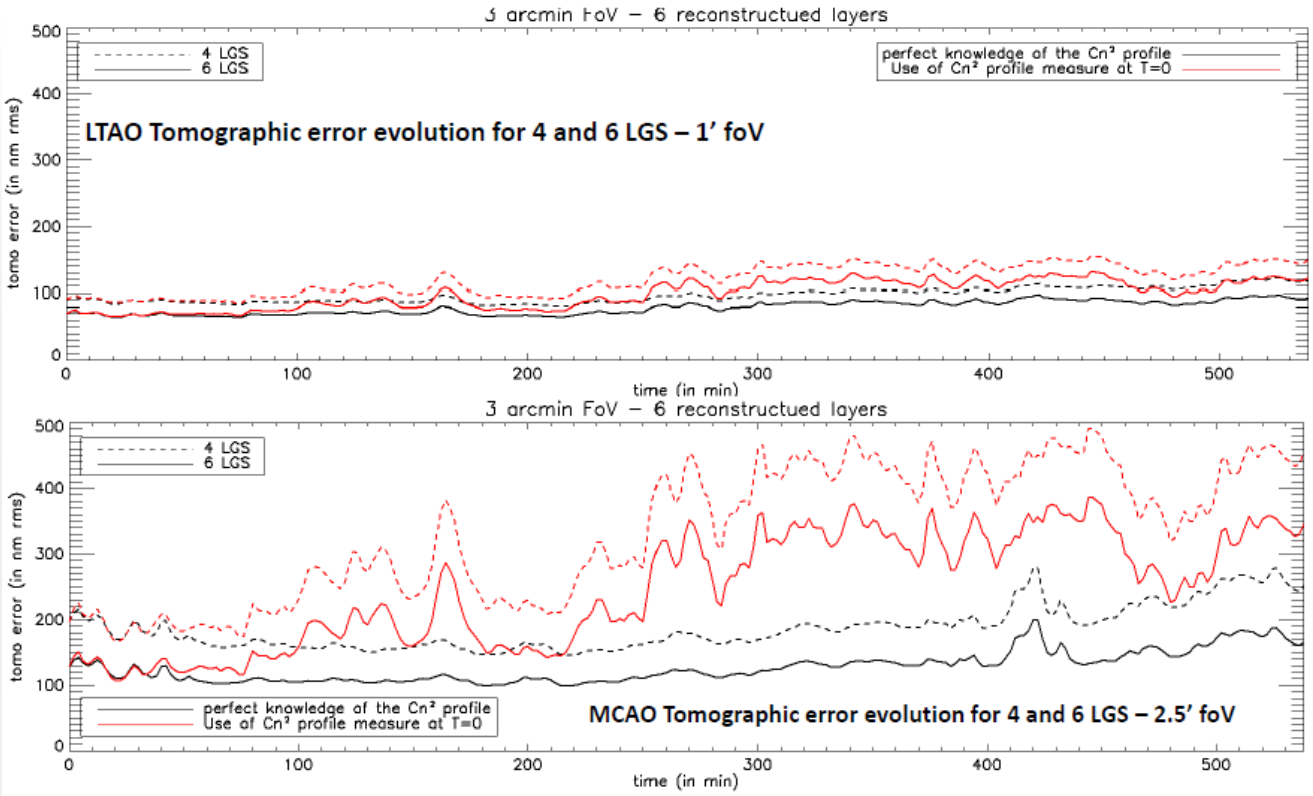


Tomography is robust to "typical" variations of C_n^2 profile.



Temporal evolution of Cn2





Tomographic error strongly correlated with seeing evolution (especially the model error)

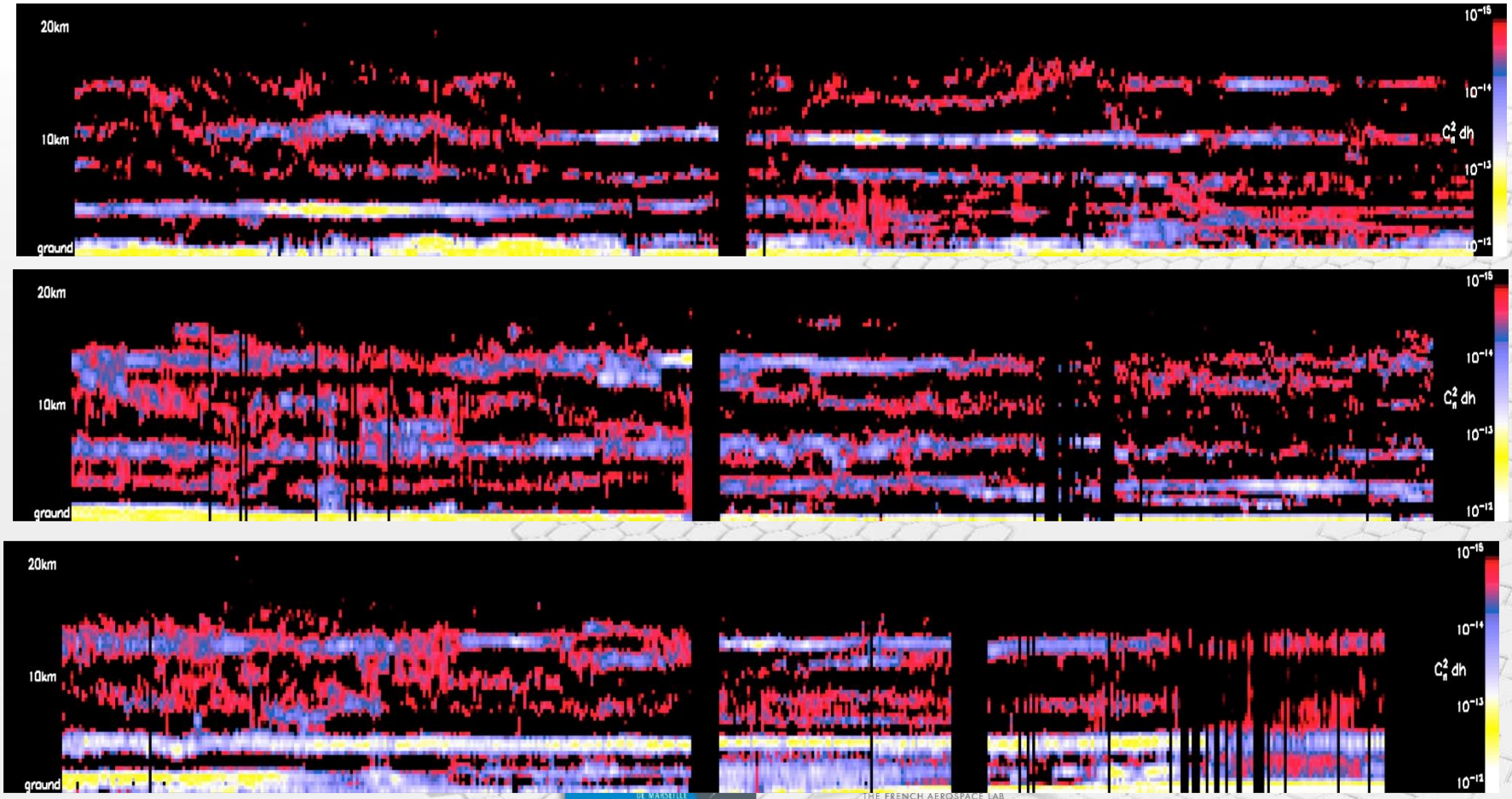
For 1' FoV : update on Cn² knowledge profile is required every few hours typically

For 3' FoV : update required every 30 min typically

Sensitivity of tomography

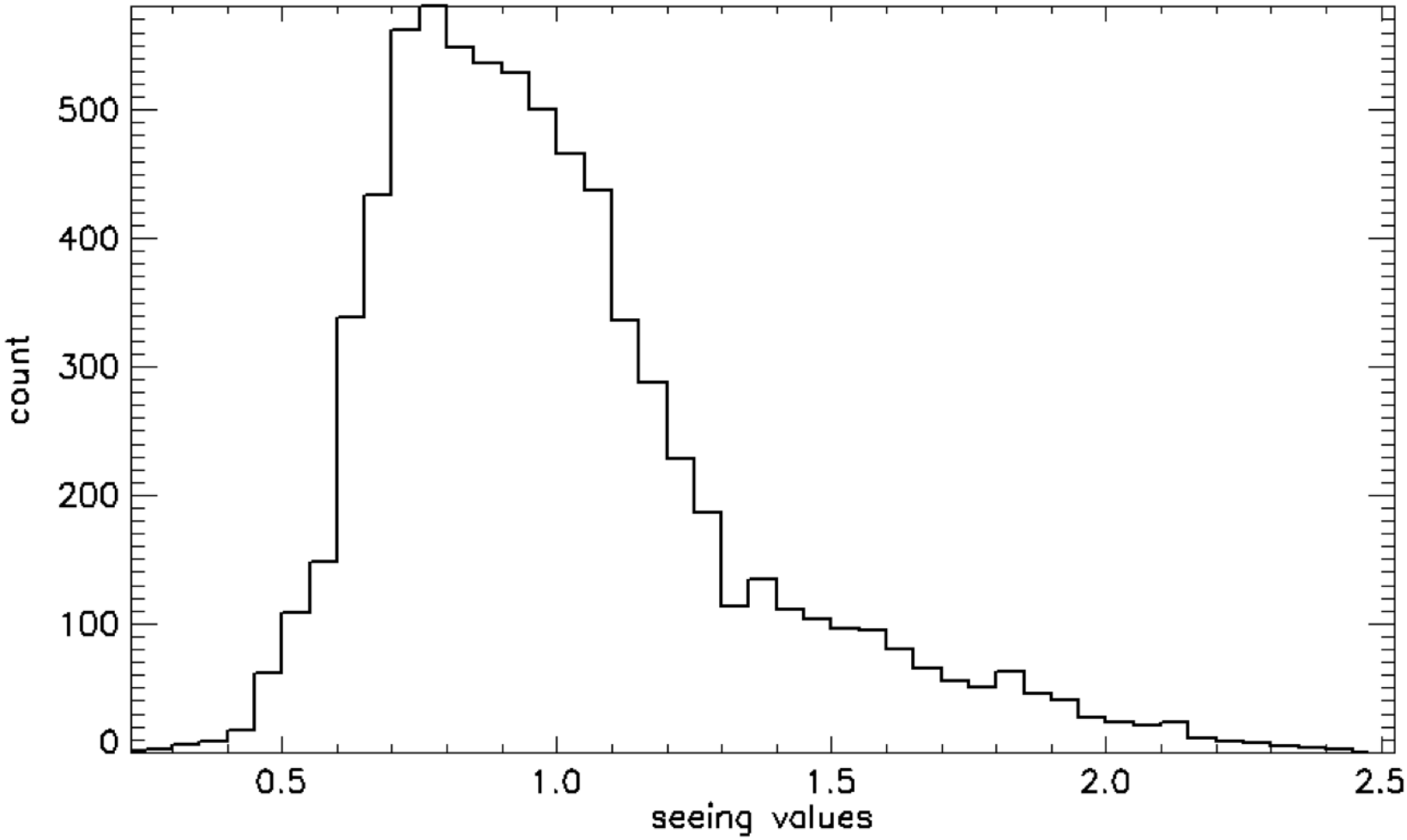
Same evaluation is repeated with more profiles:

- 6 SCIDAR night from James Osborn (acquired at Paranal in 2016)
- 20 G-SCIDAR night from Elena Masciadri (acquired in 2007 at Paranal)

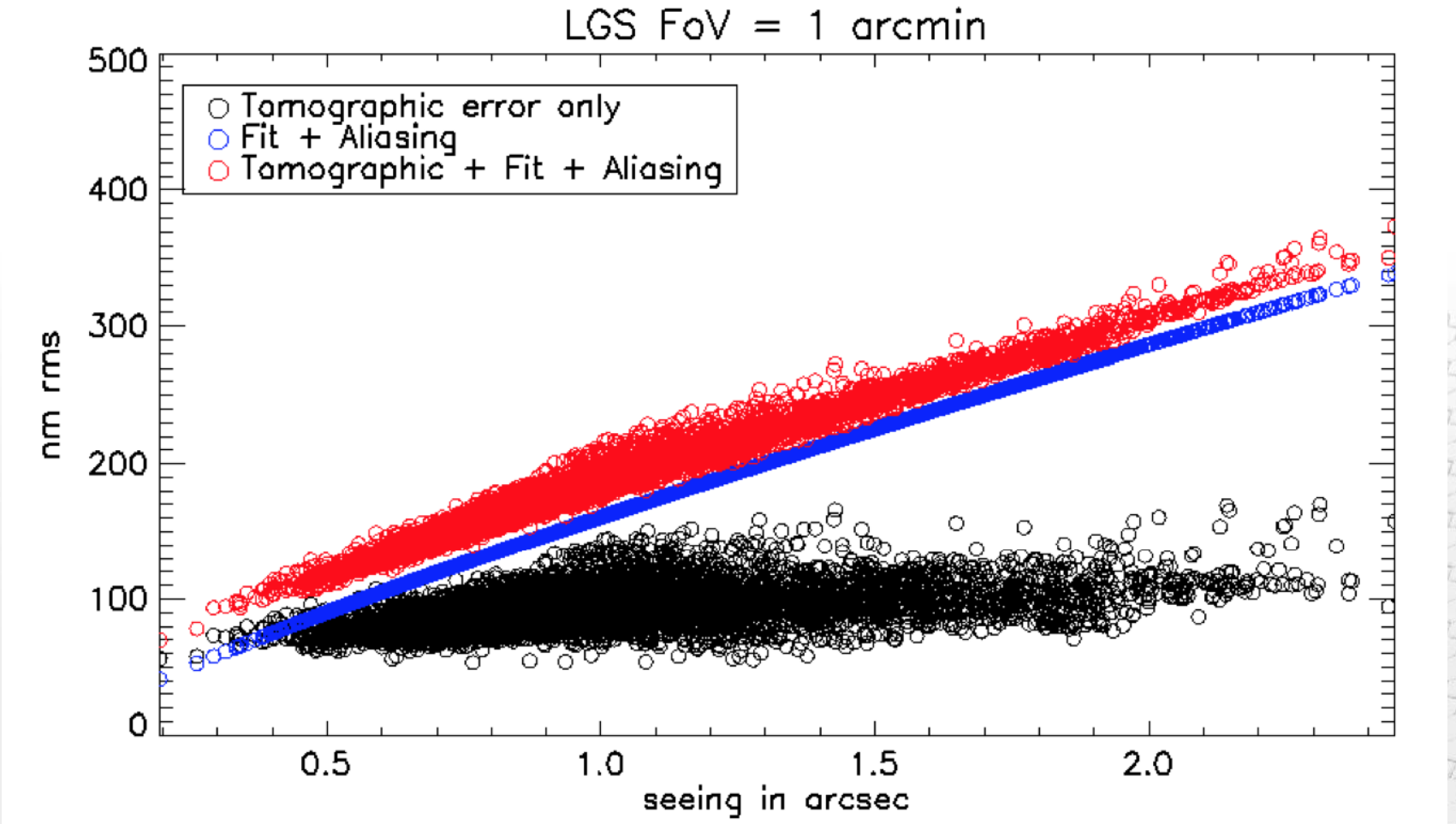


Sensitivity of tomography

- **20 Scidar night (2007)**
- **Between 200 and 500 Cn^2 profiles per night => 7503 profiles !!!!!!!**
- **Median seeing = 0.93”**



Sensitivity of tomography

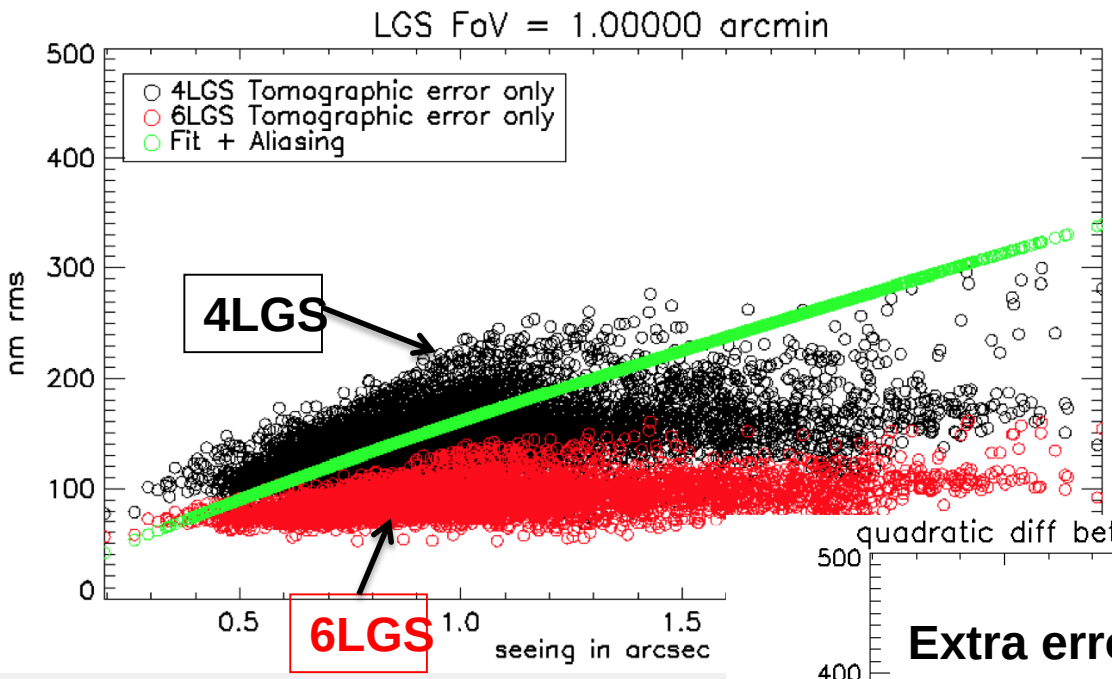


For LTAO => Seeing has a much larger impact on performance than Cn2 variations

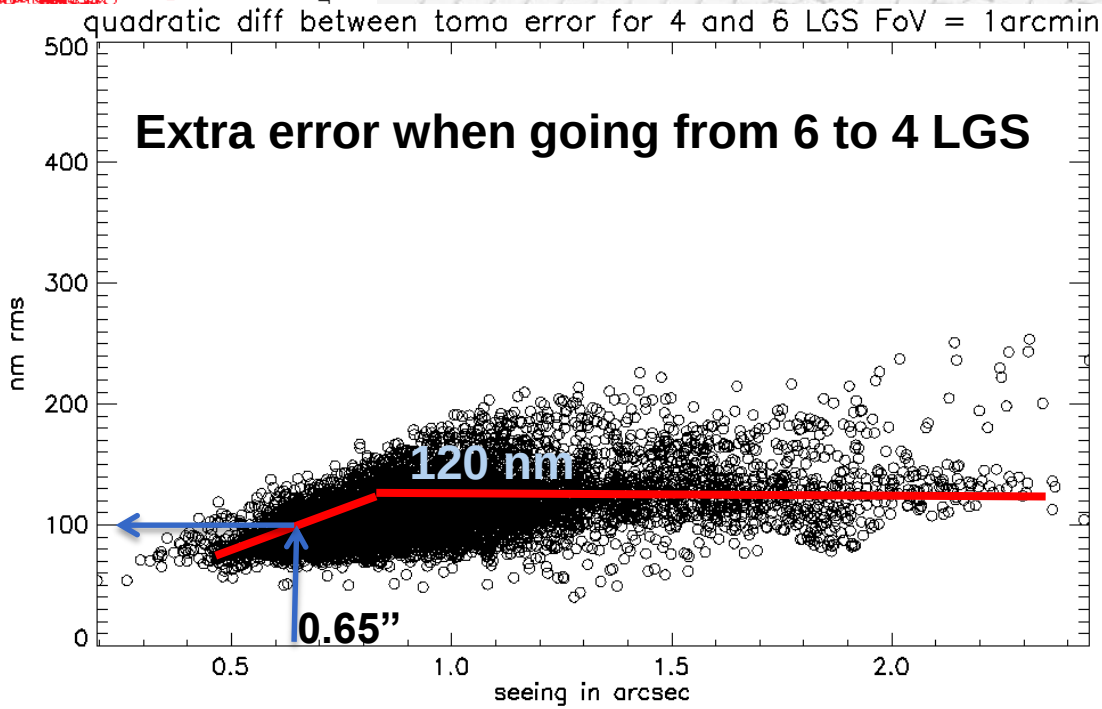
LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

ONERA THE FRENCH AEROSPACE LAB

6 vs. 4 LGS (revisited)

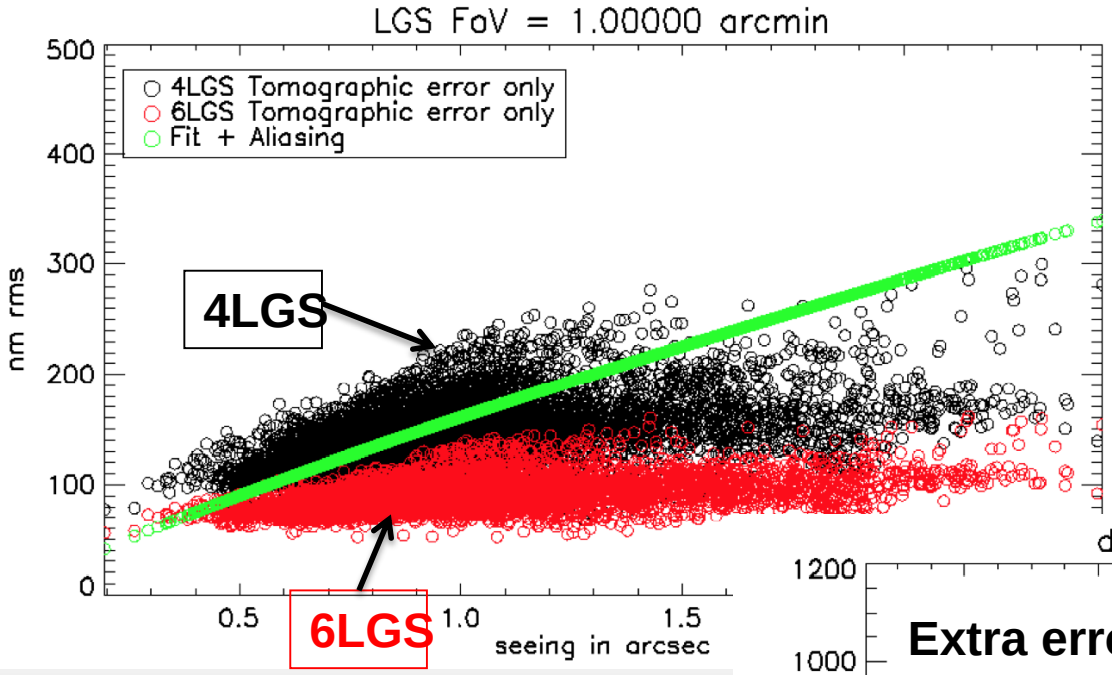


When using more (representative ?) profiles, we find more sensitivity when going from 6 to 4 LGS

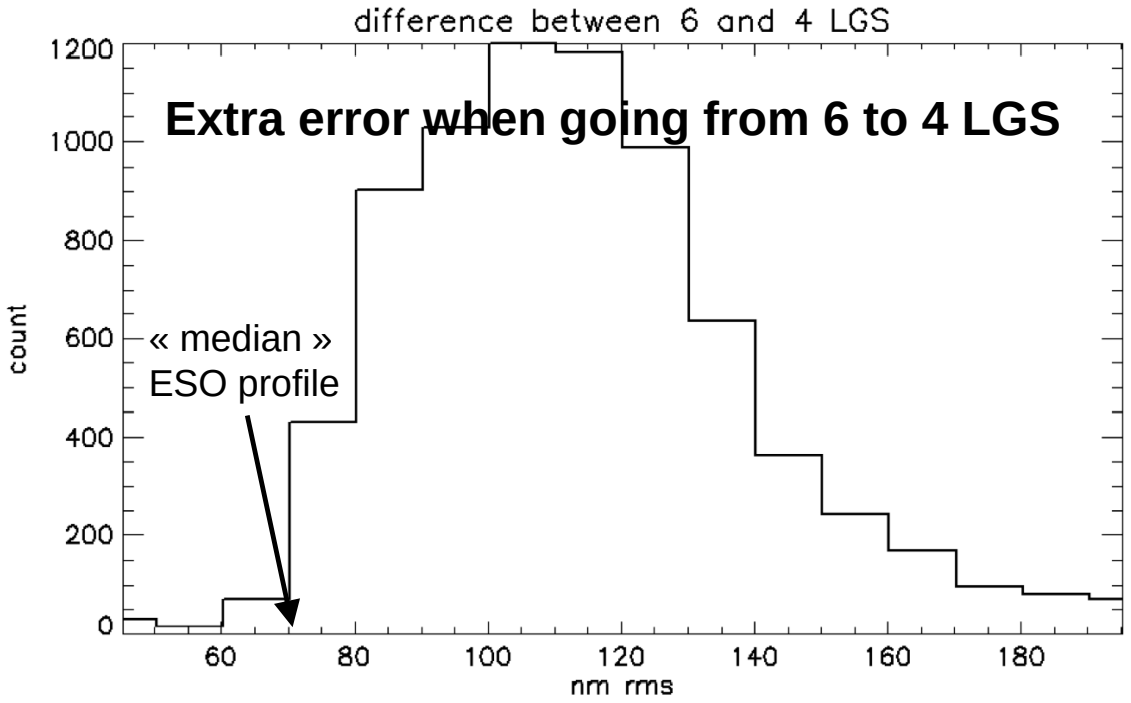


Importance of getting diverse inputs !

6 vs. 4 LGS (revisited)



When using more (representative ?) profiles, we find more sensitivity when going from 6 to 4 LGS



Importance of getting diverse inputs !

Take away messages

- **Sensibility to system and atmospheric parameters increases dramatically with the Technical FoV (TFoV)**

- **LTAO (TFoV = 1') can work with few LGS (down to 4) and does not require any accurate knowledge on atmospheric parameters**

- MCAO (TFoV ~ 2'-3') needs 6 LGS and is quite sensitive to Cn^2 mis-knowledge,

- **The use of high resolution profile (simulated or measured) is essential for the fine understanding and for an efficient design of tomographic AO systems**. In addition, its use during operation should allow a better telescope time scheduling as well as an interesting first guess for initialization of tomographic AO loop.

Perspective

Statistical study of tomographic error using combined Scidar and Meso-Nh datas => feedbacks for GMST (and in particular the ELT instruments) design and optimisation processes

LABORATORIO NAZIONALE ADONI OTTICA ADATTIVA

WaveFront Sensing in the VLT/ELT era II

2-4 October 2017
Padova, Italy

When
2-4 Oct 2017
Where
Padova (italy)
Web site:
https://www.ict.inaf.it/indico/event/521/
(or just Google the title…)