# Pyramid optical gain, how we manage it @Large Binocular Telescope


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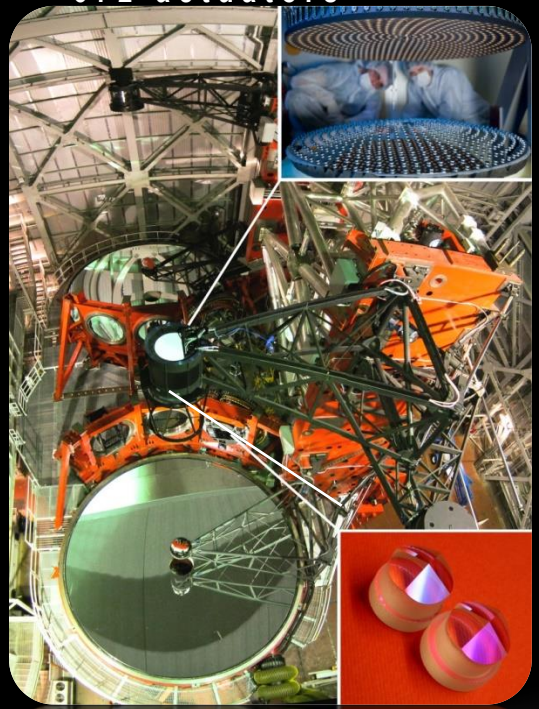
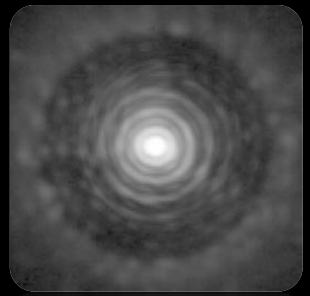
# SCAO AT LBT (HISTORICAL CONTEXT)

## FLAO & SOUL

**2x Adaptive secondary**
**672 actuators**

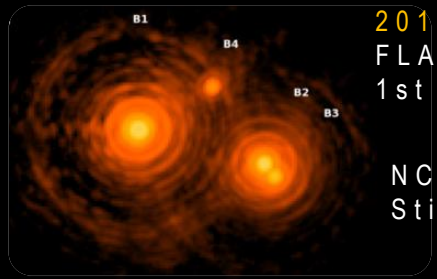


**4x Pyramid WFS**
**30x30SA 40x40SA**



2010
FLAO+IRTC
1st Ligth

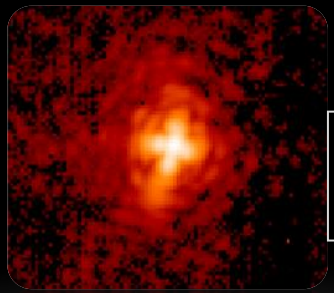
N. Hubin:
«NCPA?»
S. Eposito:
«No, thanks!»



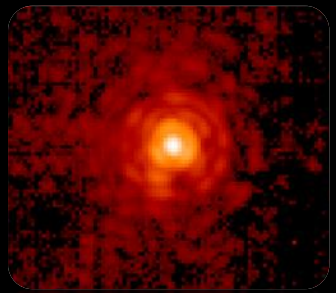

2011-2013
FLAO+PISCES
1st science

NCPA?
Still ok!

2015
FLAO-LUCI2 (N30 camera)



NCPA compensation?
Yes, please!



# NCPA & PYRAMID WFS

*2015 Esposito+ AO4ELT4 concept and first results*
*2020 Esposito+ A&A detailed paper*

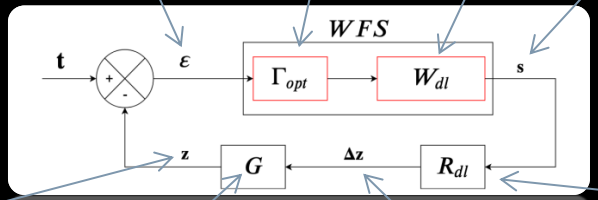
Pyramid modal optical gain in partial correction

Residual wavefront

Pyramid DL sensitivity

WFS singal

SCAO LOOP




Absolute commands

AO loop integrator

Differential commands

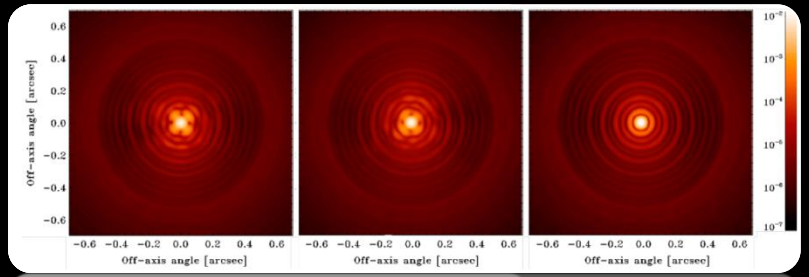
Recontruction matrix

WF offset we obtain

$$w_{\text{off}} = -\Gamma_{\text{opt}}^{-1} z_0$$

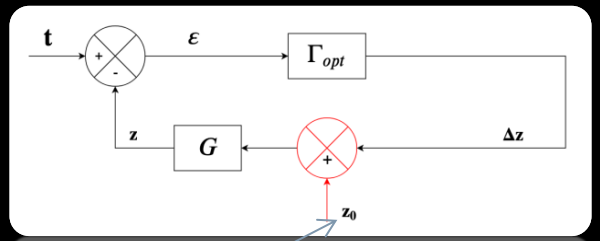
WF offset we want to apply

UNcorrected OVERcorrected CORRECTED



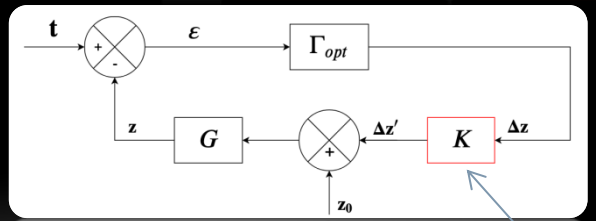

$K = \Gamma_{\text{opt}}^{-1}$

WF OFFSET




**Modal vector NCPA compensation.**

The **same for all** WFS binning and modulations




Optical gain compensator

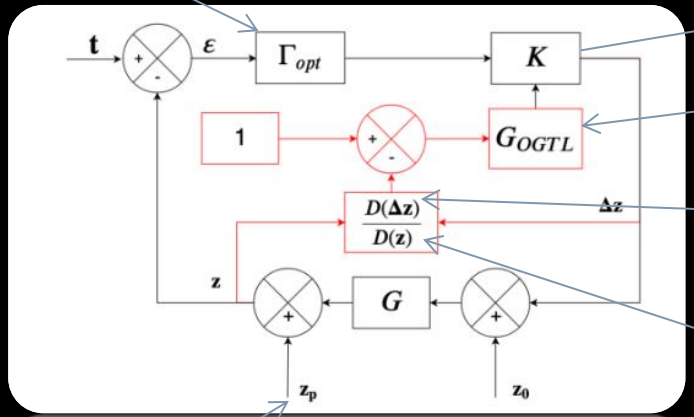
$$w_{\text{off}} = -K^{-1}\Gamma_{\text{opt}}^{-1} z_0.$$

# $\Gamma_{OPT}$ TRACKING LOOP

*2015 Esposito+ AO4ELT4 concept and first results*
*2020 Esposito+ A&A detailed paper*

Depends on residual WF.
Variable with
NGS brightness and seeing

Measurment
and tracking
needed




Active $\Gamma_{opt}$
conpensation

Gopt tracking
loop

Demodulation of
differential
commands

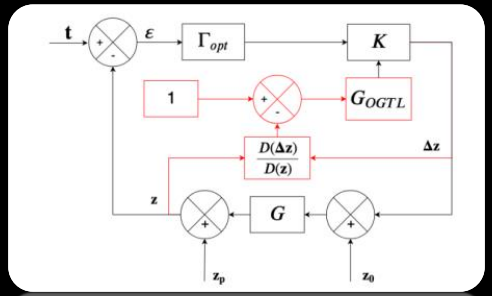
Demodulation of
absolute commands

Probe signal on absolute commands
Sinusoidal modulation of amplitude

# $\Gamma_{OPT}$ BASIC IMPLEMENTED

*2015 Esposito+ AO4ELT4 concept and first results*
*2020 Esposito+ A&A detailed paper*

Simplified approach → no modal optical gain




$z_p$ = 1 mode sinusoidally modulated in amplitude

$\Gamma$opt = $I \cdot G_{opt}$

**K** = $I \cdot k_{opt}$

**S'** = **S**/$k_{opt}$ → slope vector normalized by scalar

Parameters:

- #collected frames = 1000
- probe signal amplitude = 20nm WF
- probe signal mode = 30
- probe signal frequency = 80Hz
- Integrator gain = 0.3

Typical performance:

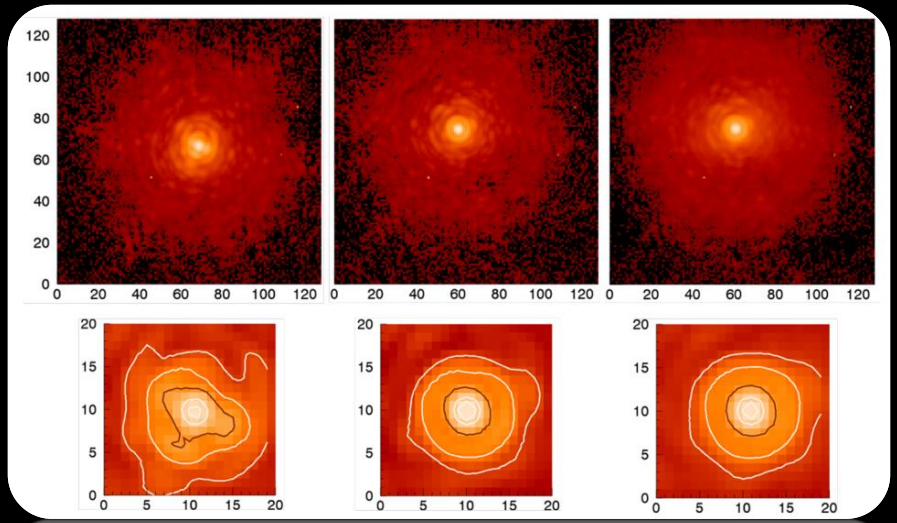
- settling time ~ 30s (AO@1.7kHz)
- noise on $G_{opt}$ = 1%

# $G_{OPT}$ & NCPA ONSKY 2015

*2020 Esposito+ A&A*

NCPA correction under different seeing

| Uncorrected | Corrected | Corrected |
|---|---|---|
| seeing 0.86'' | seeing 0.86'' | seeing 1.06'' |
| SR(H) = 47% | SR(H)= 70% | SR(H)= 58% |



Test on science target
globular clustertarge cut 3''x3''
R12, 150modes

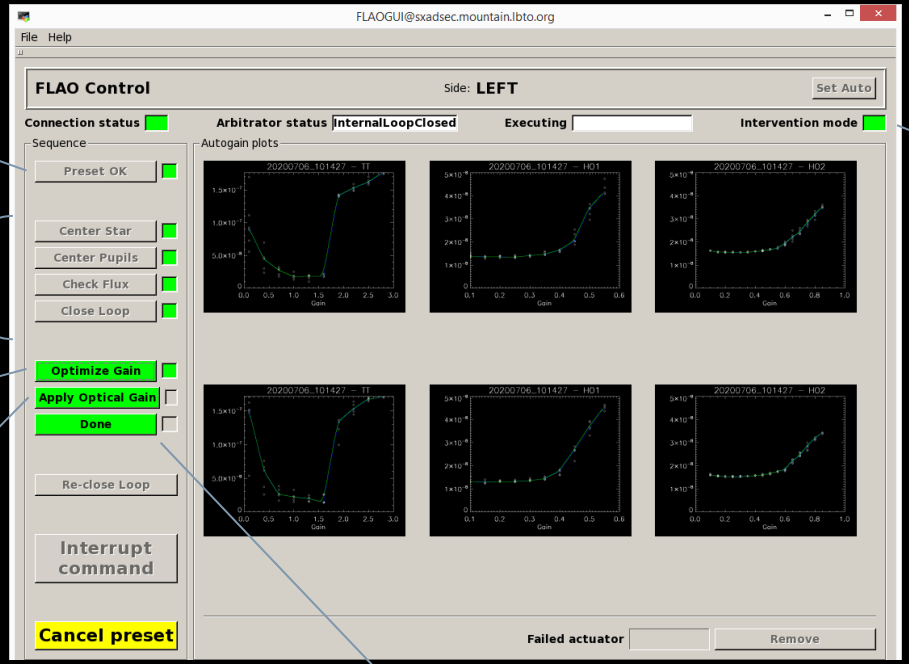
# ADDING $G_{OPT}$ TO AO SEQUENCE

**Preset**
NGS info from TCS
nominal AO config

**AO loop setup**
- NGS acquisition
- Pupil centering on WFS
- Verify the NGS flux
- Low gain closed loop

**AO gain optimization**
- Sweep modal gains
  3 groups: TT+med+high
- Idenify minimum of
  modal residuals

**Gopt correction**
- Gopt measurement
  w/o corrrection
- AO gain renormalized by Gopt
- Slope normalization
- Enable gopt tracking loop

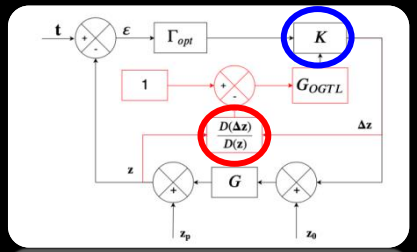


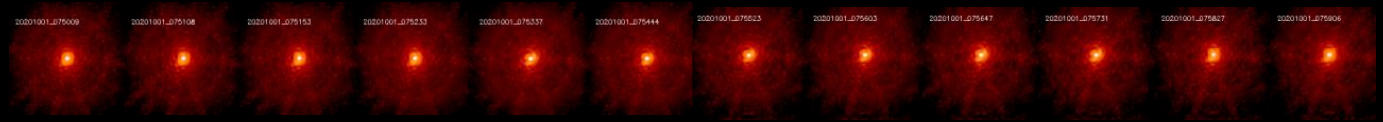

**2 modes**
- Automatic:
  no touch,
  just look
- Intervention:
  click each step
  free to repeat
  or jump

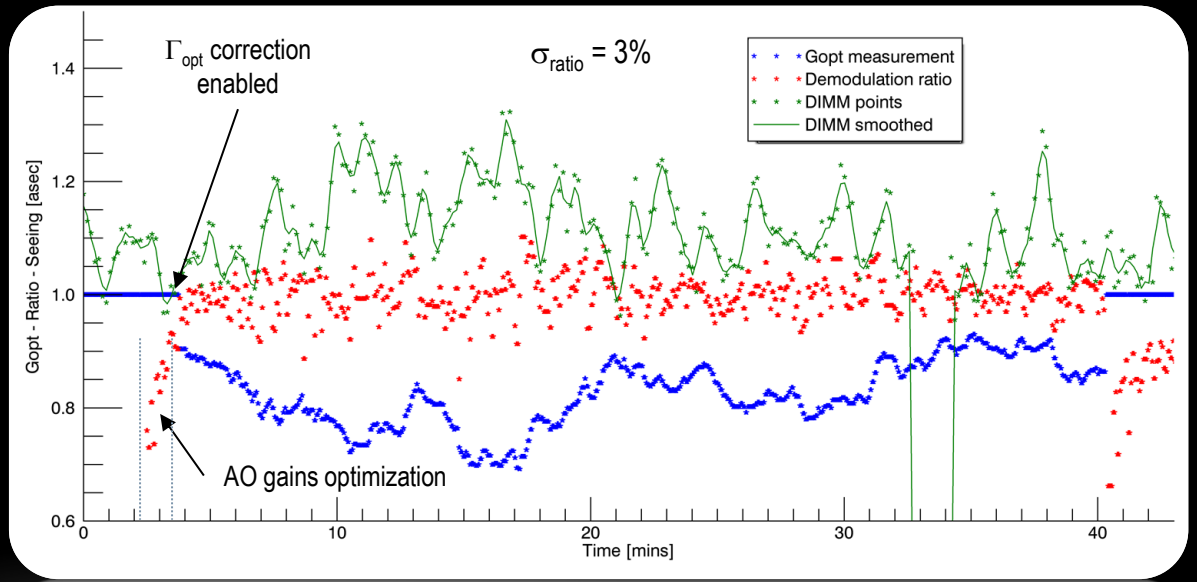
OK, let's start with insturment integration

# $G_{OPT}$ TRACKING ON SKY

R8.5 and «jumpy» seeing – 500modes, 1.7kHz



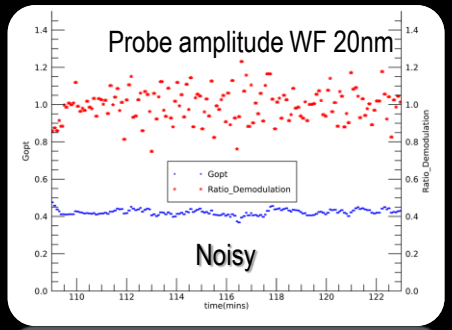


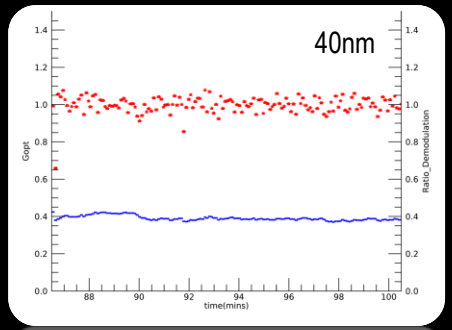

- Gopt value changes with the seeing anti-correlated
- Ratio gives a merit function of the tracking loop
- Ratio std here 3% -> gopt error <3% (loop TF)
- Limited bandwidth following the fast seeing changes (settling time 30s)

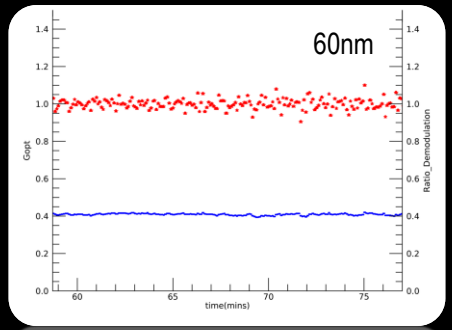
# $G_{OPT}$ ON FAINTER NGS

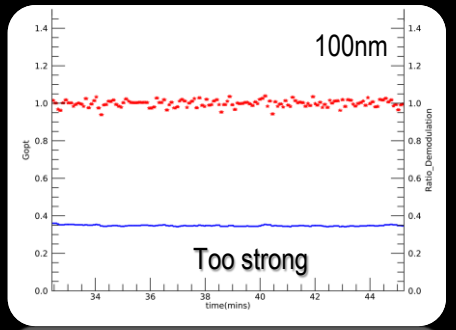
R15 + probe of 20nm WF → noisy measuerement

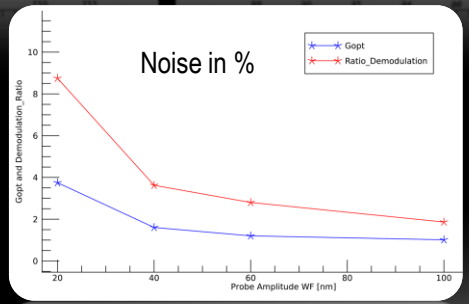
Closed dome testing
with fixed simulated seeing 0.75''



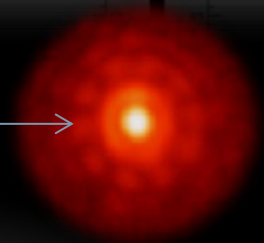



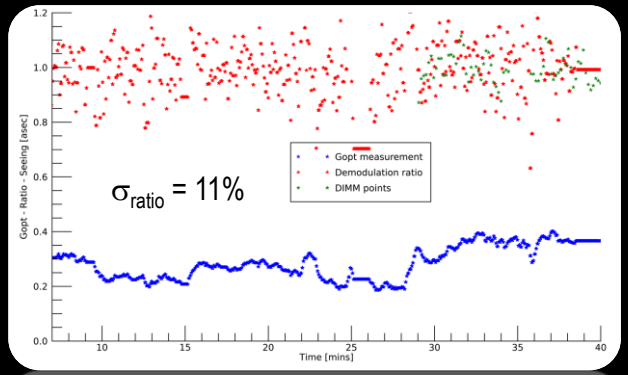

Marks of
probe signal



PSF (Ks)

# $G_{OPT}$ WITH FAINTER NGS ON SKY

R14.2 (double)– Bin 3x3 (13x13 SA), 90 modes, 770Hz
Prob amp 40nm



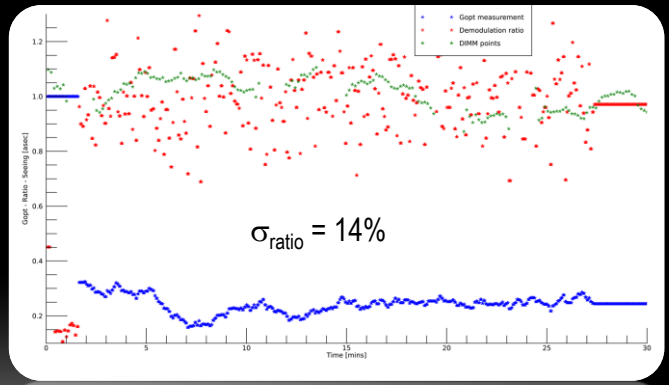

Effective NCPA compensation

Uncorrected
SR(Ks) = 45%


Corrected
SR(Ks)= 51%


R15.3 – Bin 4x4 (10x10 SA)
54 modes, 390Hz
Probe amp 60nm

SR(Ks)= 20%

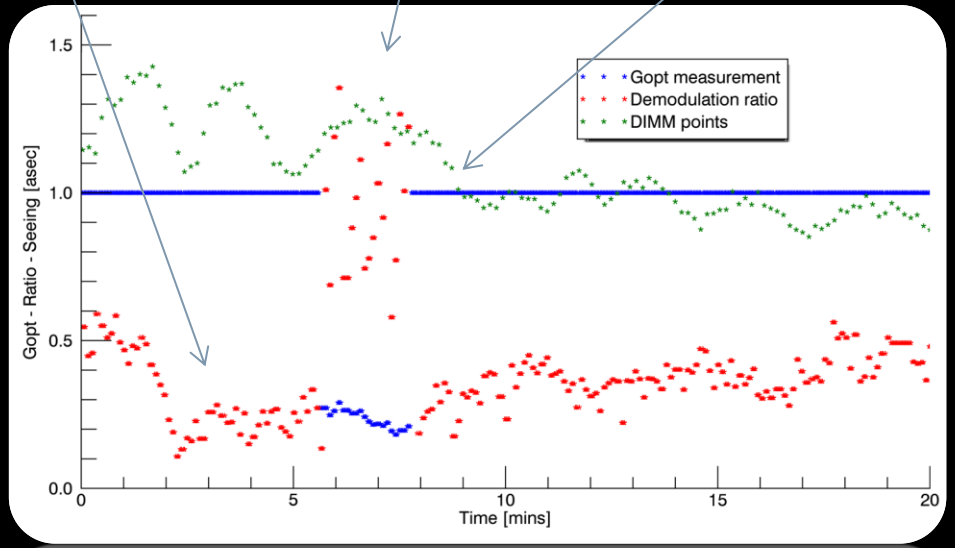
# $G_{OPT}$ TRACKING FAILURE

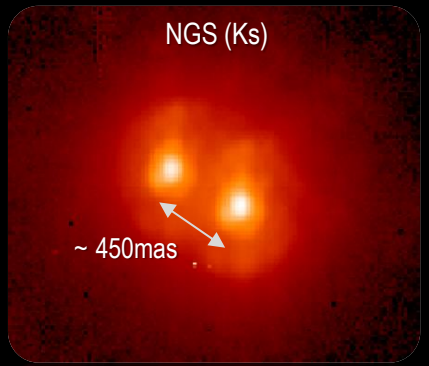
R15.0 – Bin 3x3 (13x13 SA), 90 modes, 316Hz

Gopt measure ok
no correction

Enabling Gopt,
**scary jumps**!

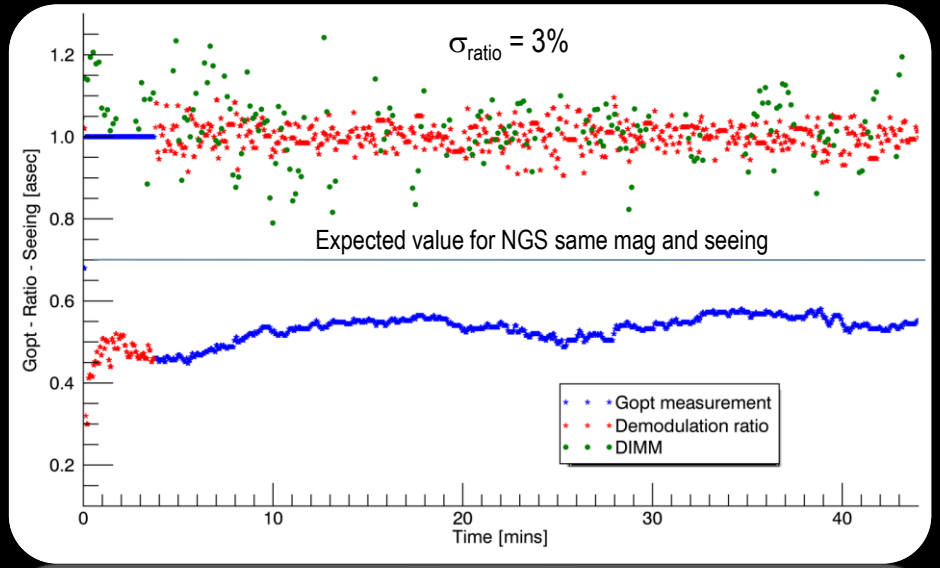
Gopt correction disabled
for data acquisition



# $G_{OPT}$ WITH RESOLVED OBJECTS

Asteroid (45) Eugenia
150mas Vs DL 20mas: small but well resolved
Bin 2x2 (20x20 SA), 250 modes, 950HzProb amp 30nm



# CONCLUSION

- LBT routine observations uses Gopt correction & tracking
  - low order NCPA rejection is good
  - NGS R<15.5
  - small extened object tested (150mas)

- Gopt correction weakness identified:
  - Fast and wide seeing changes
  - Multiple stars with similar flux

- Work in progress on «Modal Gain Machine»:
  Gendron/Léna gain optimization + modal Gopt tracking