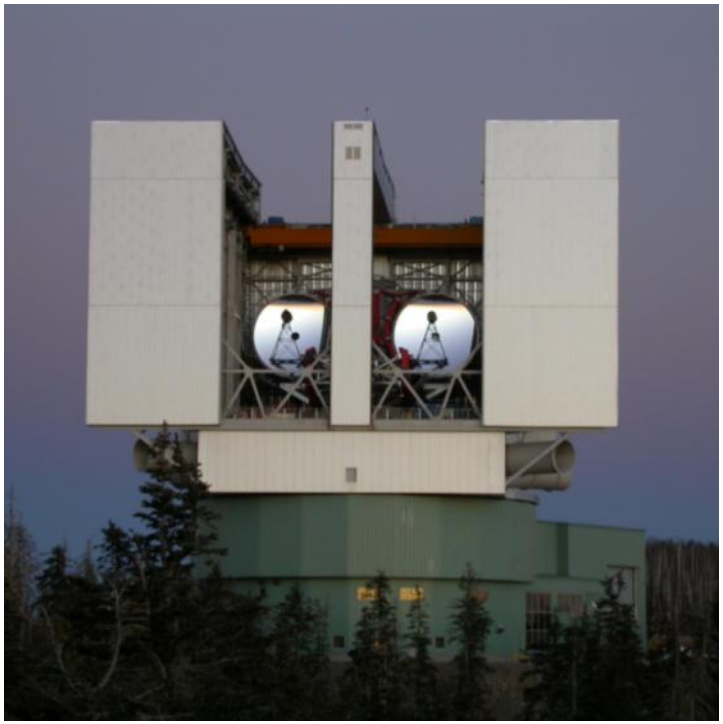
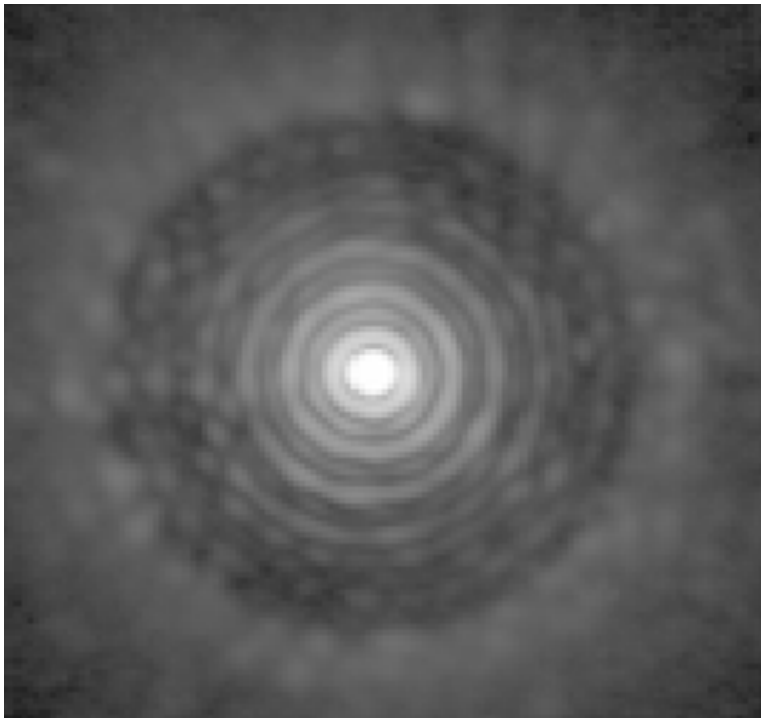




# The LBT AO system On-Sky results

**A presentation about the main results obtained during the First Light Adaptive Optics system (FLAO) commissiong phase, and some toughts about the possible impact of the LBT experience.**

Presented by: **S. Esposito**

**AO4ELT 2, 25-30 Sep. Victoria, Canada , 2011**

# First Light Adaptive Optics system (FLAO) main partners

Arcetri Observatory

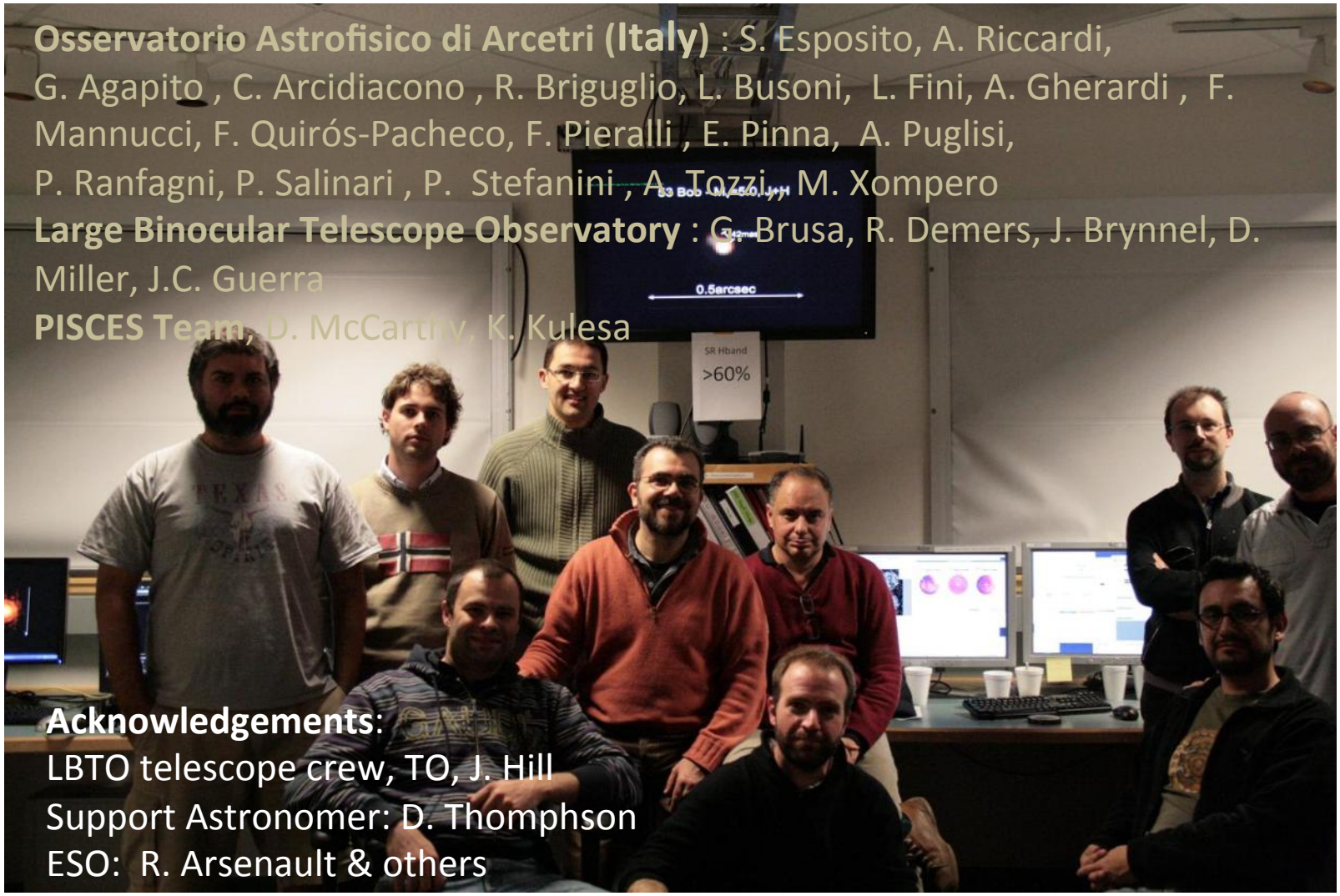
LBTO project

Steward Observatory

ADS International

MicroGate

# Main contributors:




**Osservatorio Astrofisico di Arcetri (Italy)** : S. Esposito, A. Riccardi, G. Agapito , C. Arcidiacono , R. Briguglio, L. Busoni, L. Fini, A. Gherardi , F. Mannucci, F. Quirós-Pacheco, F. Pieralli , E. Pinna, A. Puglisi, P. Ranfagni, P. Salinari , P. Stefanini , A. Tozzi , M. Xompero

**Large Binocular Telescope Observatory** : G. Brusa, R. Demers, J. Brynnel, D. Miller, J.C. Guerra

**PISCES Team**, D. McCarthy, K. Kulesa

**Acknowledgements**:
LBTO telescope crew, TO, J. Hill
Support Astronomer: D. Thomphson
ESO: R. Arsenault & others

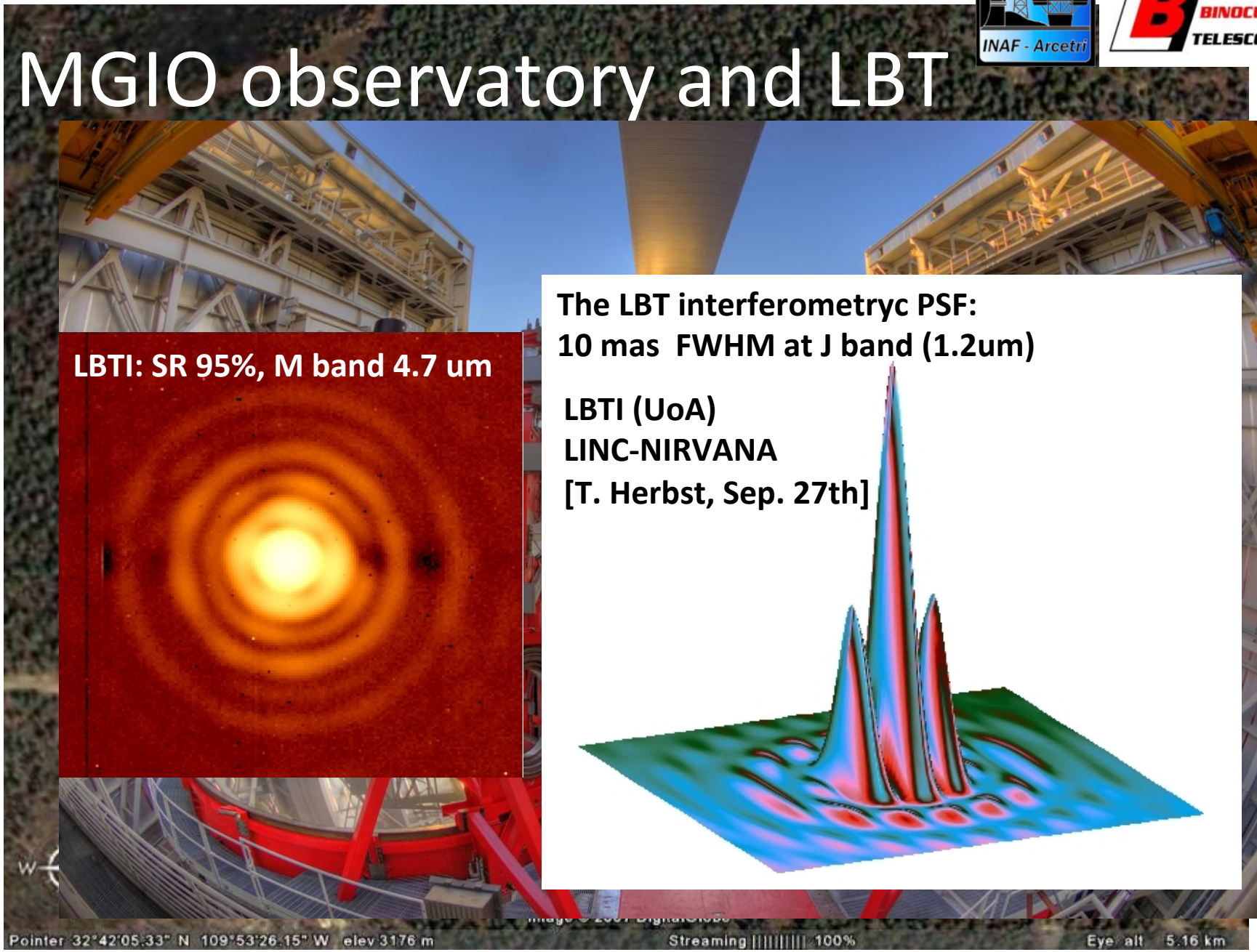
# Talk summary

- **FLAO system outline**
  -The LBT AdSec
  -The Pyramid Wavefront Sensor

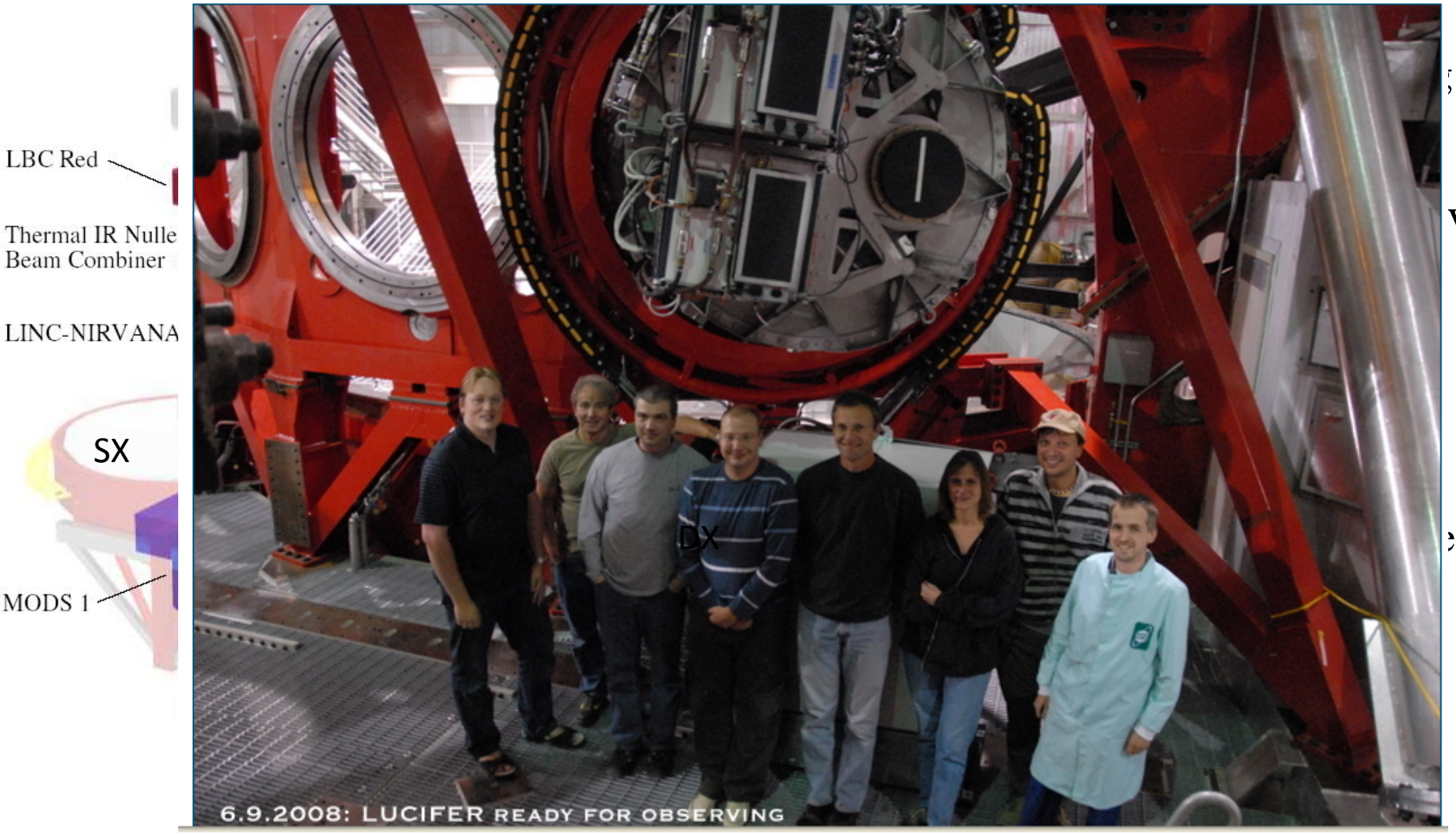
- **System on sky performance**
  **-**Corrected images
  -SR vs. mag and seeing

- **First scientific observations**

# MGIO observatory and LBT



# The LBT NIR imager/spectrograph LUCIFER




**Initial Scientific Observation carried out with PISCES NIR camera**

# The LBT First Light Adaptive Optics system (FLAO) rationale

## Adaptive secondary:

A few reflecting surfaces
Allows for high number of actuators
Reduced sensitivity to failed actuators
A single DM for multiple focal stations

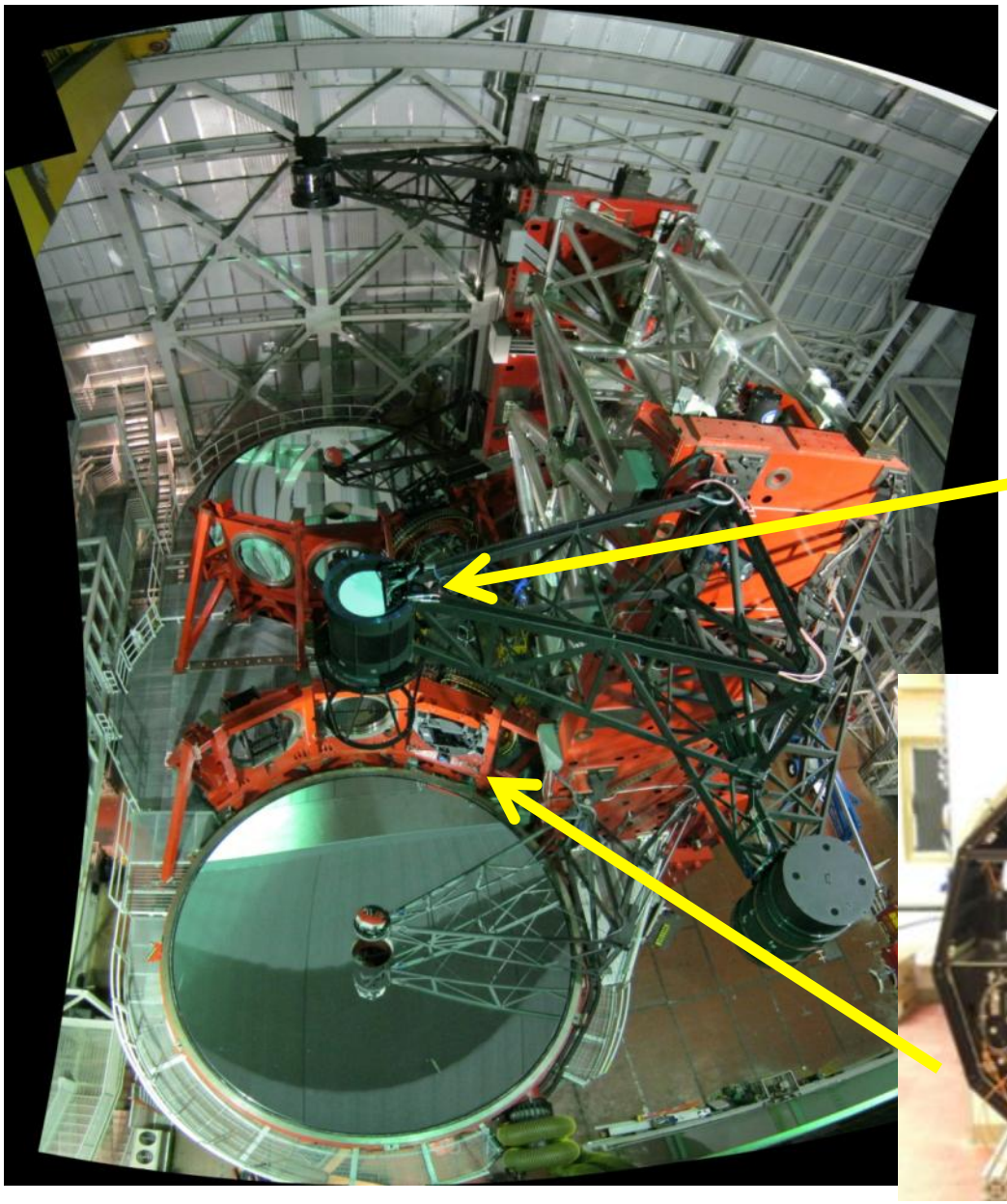
First unit mounted in 2000 on 6.5m MMT telescope with 336 actuators

## Pyramid sensor:

More sensitive in faint end of SH
Less affected by aliasing in bright end of SH
Adjustable subaperture size (CCD on chip binning)
A small CCD (80x80) for 30x30 subaperures

First unit mounted on 3.6 TNG telescope 8x8 subaps. in 1997.

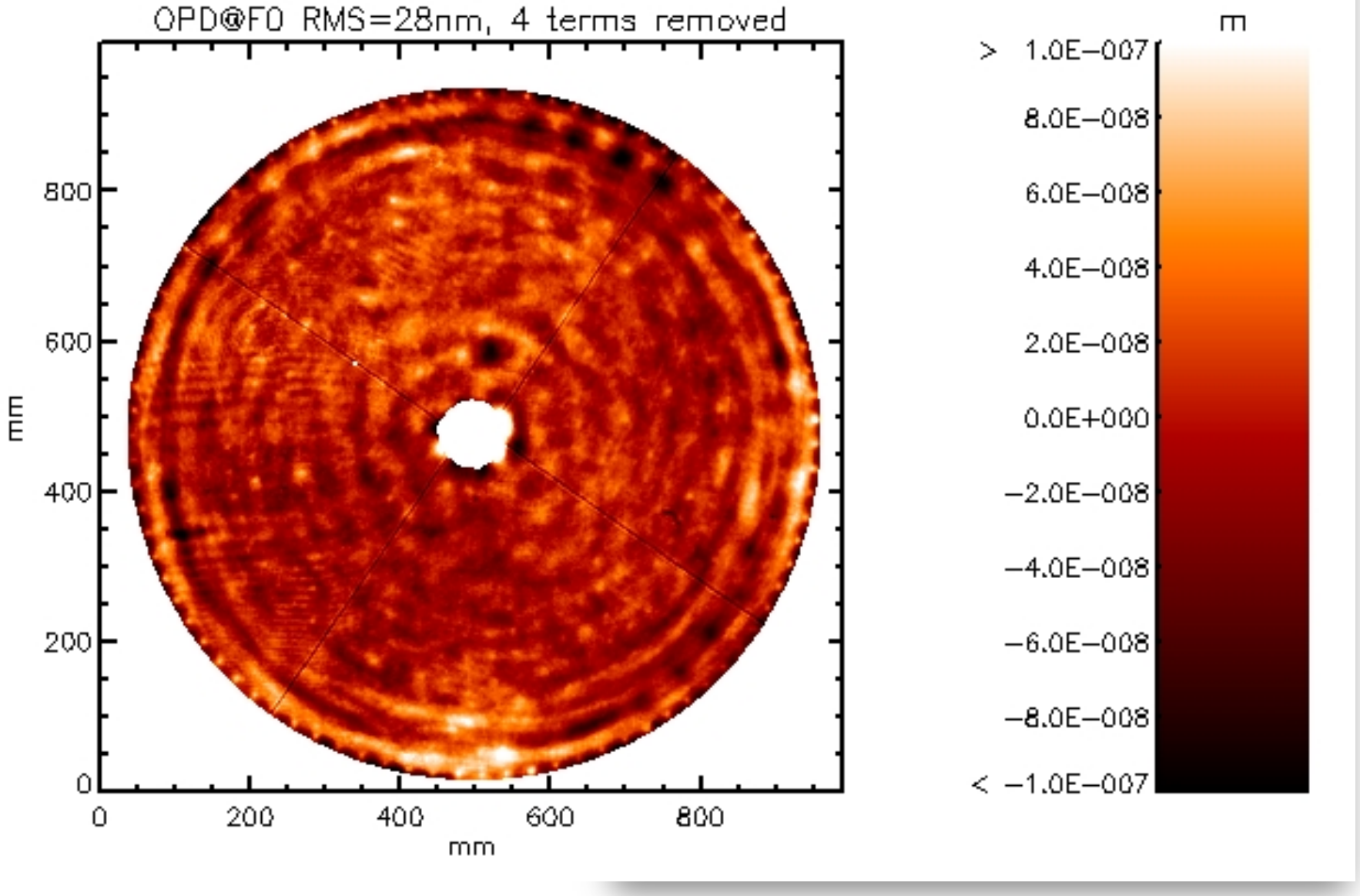
# FLAO#1 system installed



The adaptive secondary mirror with the thin shell covered

The Pyramid wavefront sensor in the AGW unit

# The LBT672 unit

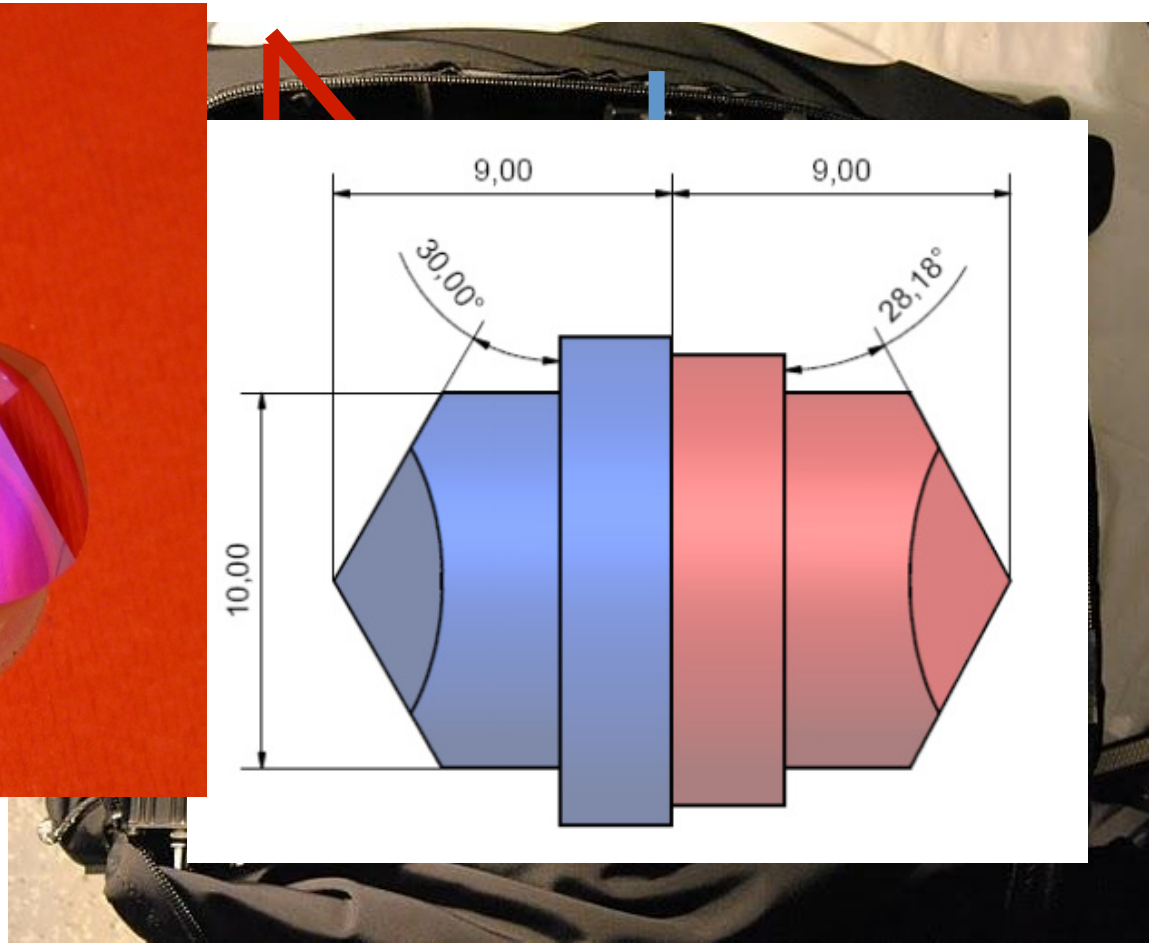


# The LBT pyramid WFS

WFS concept, [R. Ragazzoni, 1996]
TNG AO, [R. Ragazzoni, 1997]
LBT AO&WFS, [S. Esposito, 2003]

**WFS main specs.:**

- 30x30 to 5x5 subap.
- Tilt mod. ± 2-6 $\lambda/D$
- 1Kfps max [30x30subap.]

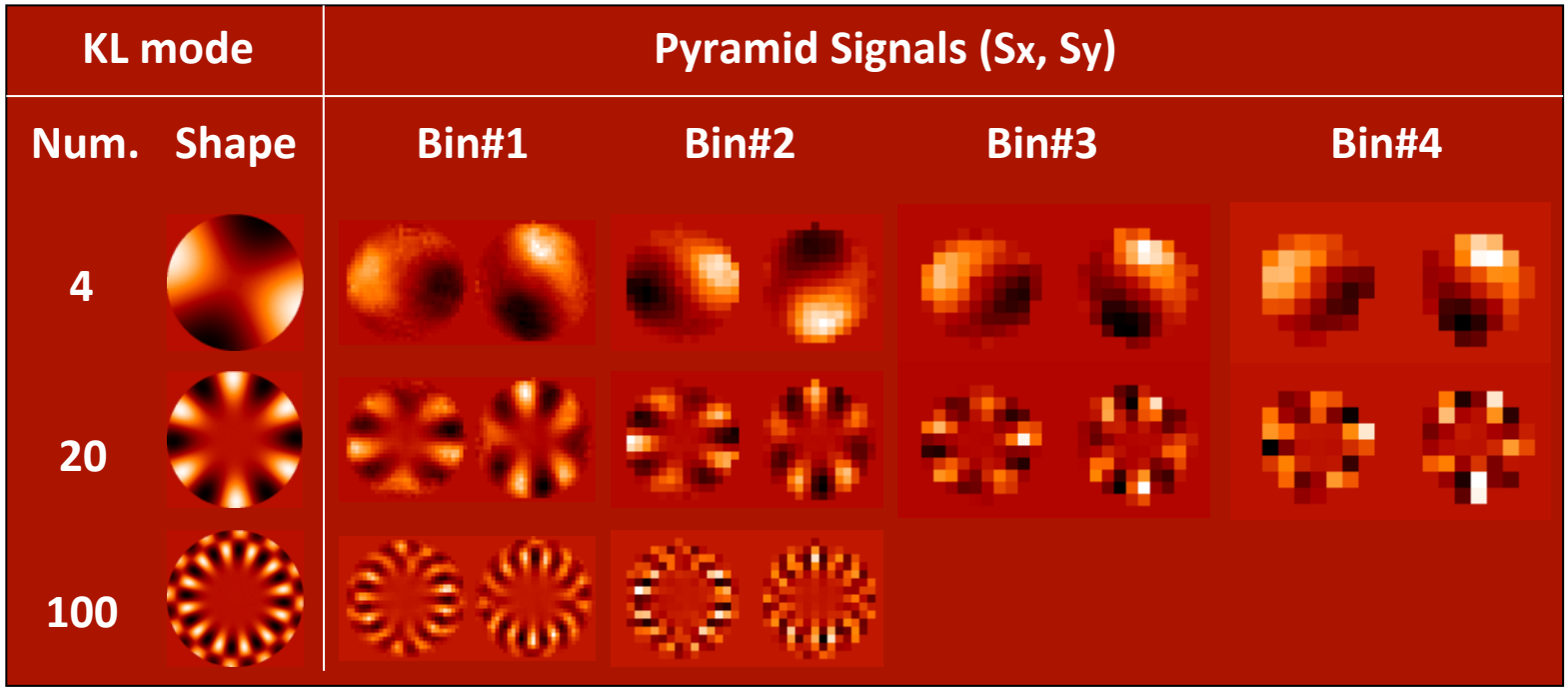



Input beam from LBT

(below 600nm)

# Adjusting IM to AO reference star magnitudes

The # of modes is adjusted to reference star magnitude. This is done by reducing the # of subaperture using WFS CCD on-chip binning.




| Ref. star mag R | Bin Mode | Sampling [#subaps] | # of subaps. | Max # of modes | Pyr. Modulation [±λ/D] |
|---|---|---|---|---|---|
| <10 | 1 | 30x30 | 678 | 496 | 2 (3) |
| 10-14 | 2 | 15x15 | 177 | 153 | 3 |
| 14-15 | 3 | 10x10 | 72 | 66 | 6 |
| >15 | 4 | 7x7 | 48 | 36 | 6 |

# LBT FLAO#1 development table

| | Star date | end date | days total | Persons | person-days total | total | |
|---|---|---|---|---|---|---|---|
| system tel. inst. & first test | 09-Feb | 17-Mar | 37 | 7 | 263 | | |
| 1st daytime run | 10-May | 26-May | 17 | 5 | 90 | | |
| 1st night time run | 27-May | 03-Jun | 8 | 9 | 69 | | |
| 2nd daytime run | 04-Jun | 18-Jun | 15 | 4 | 54 | | |
| 2nd nightime run | 19-Jun | 25-Jun | 7 | 7 | 49 | | |
| | | | | | | 525 | **2010** |
| 3rd daytime run | 19-Sep | 27-Sep | 9 | 7 | 58 | | |
| 4th run (day/night) | 12-Oct | 28-Oct | 17 | 4 | 59 | | |
| 5th run (day/night) | 14-Nov | 28-Nov | 15 | 5 | 70 | | |
| 6th run (day only) | 12-jan | 22-Jan | 11 | 4 | 41 | | |
| 7th run (day/night) | 01-Jun | 21-Jun | 21 | 3 | 63 | | **2011** |
| | | | | | | 291 | |

Including FLAO / PISCES activities (day/night)

| System | Acceptance Europe | Tel. installed | Comm. start | Comm. end |
|---|---|---|---|---|
| FLAO#1 | Dec 2009 | Feb-Mar-2010 | May 2010 | Oct 2011 |
| FLAO#2 | May 2011 | Jun-Sep 2011 | Dec 2011 | TBD |

# Controlling the FLAO system

Load a particular flat on the secondary mirror.

**1s**

Set ref. star nominal co-ordinates, magnitude and color. Use of system look-up tables.

**60s**
**120s**

Command to acquire the reference star moving the WFS stages.

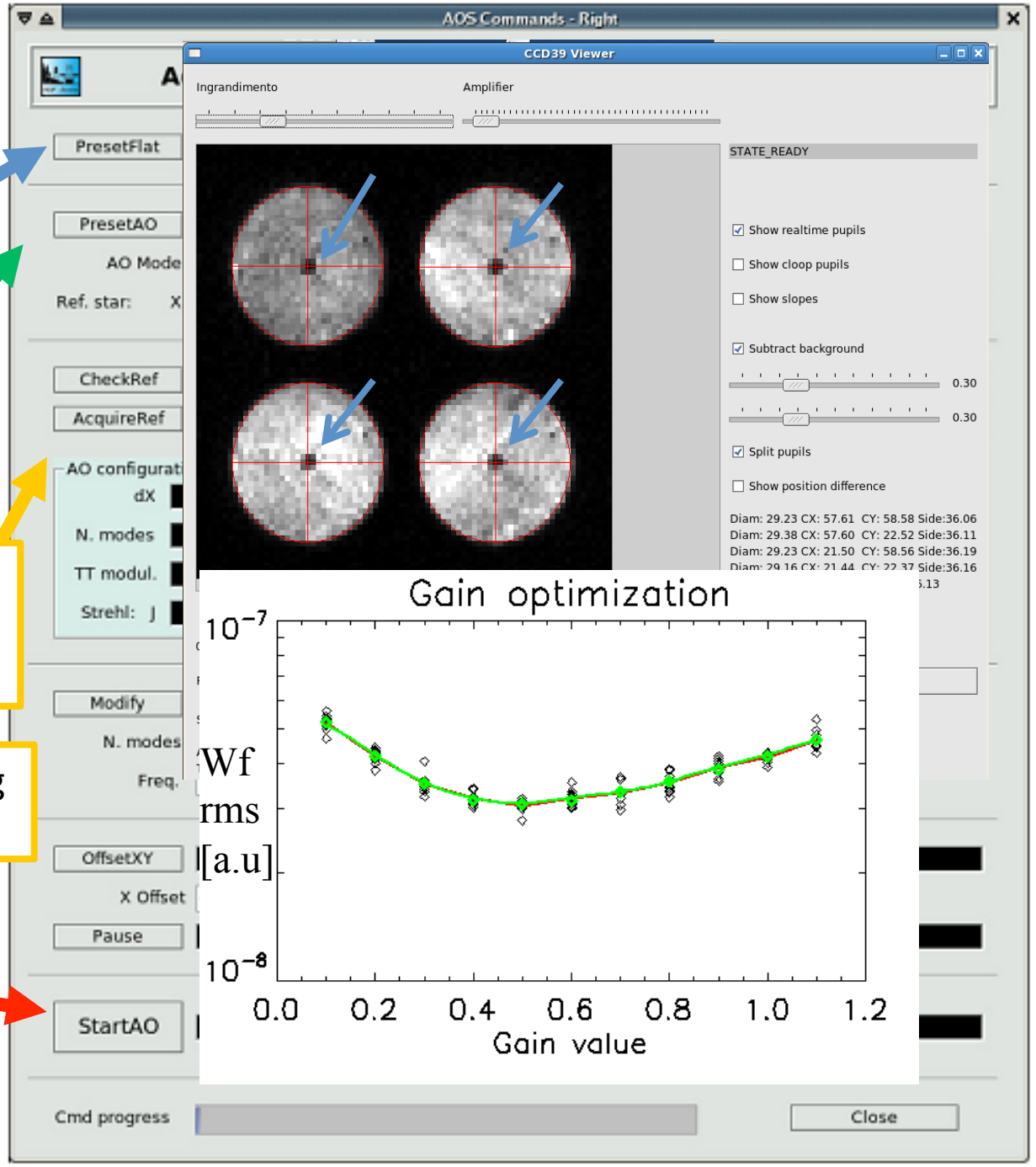
**15s**
**30s**

Adjust pupil position using CL with first 10 modes.

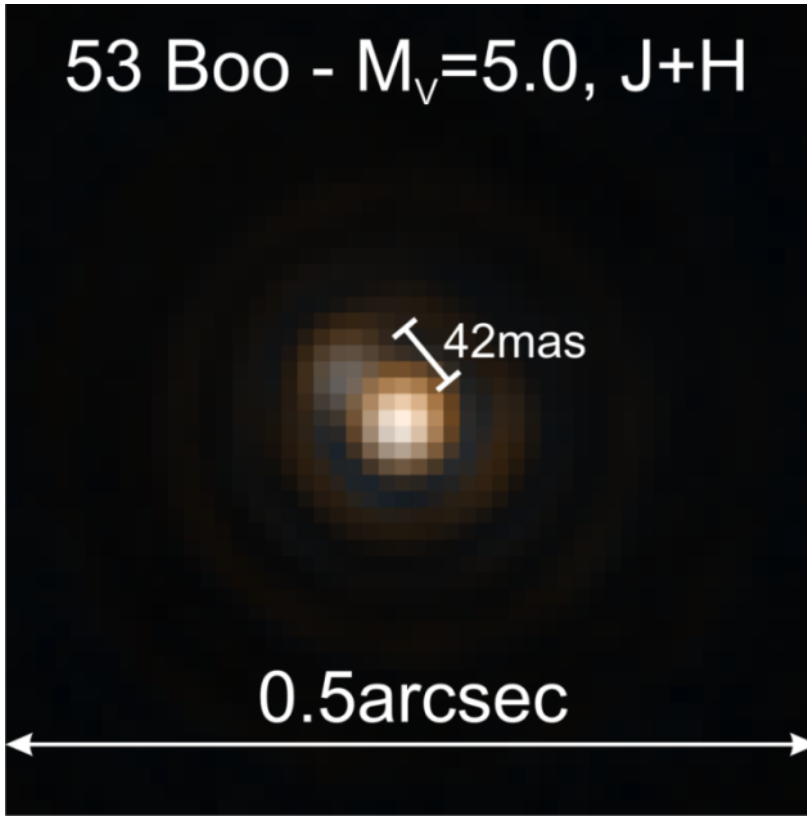
Command to start closed loop

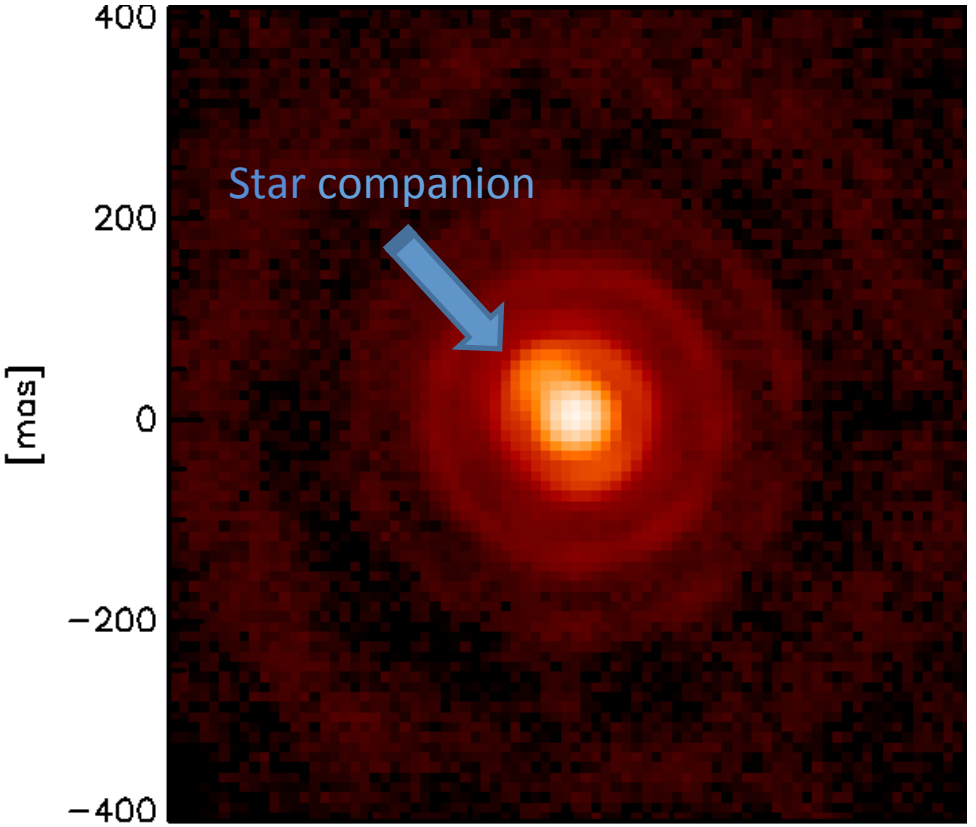
**3s**
**10s**

Optimize gains using temporal sweep.



# May2010: first on sky results, a 40mas separation binary




**FLAO parameters**
30x30 subaps
400 corrected modes
1Khz frame rate

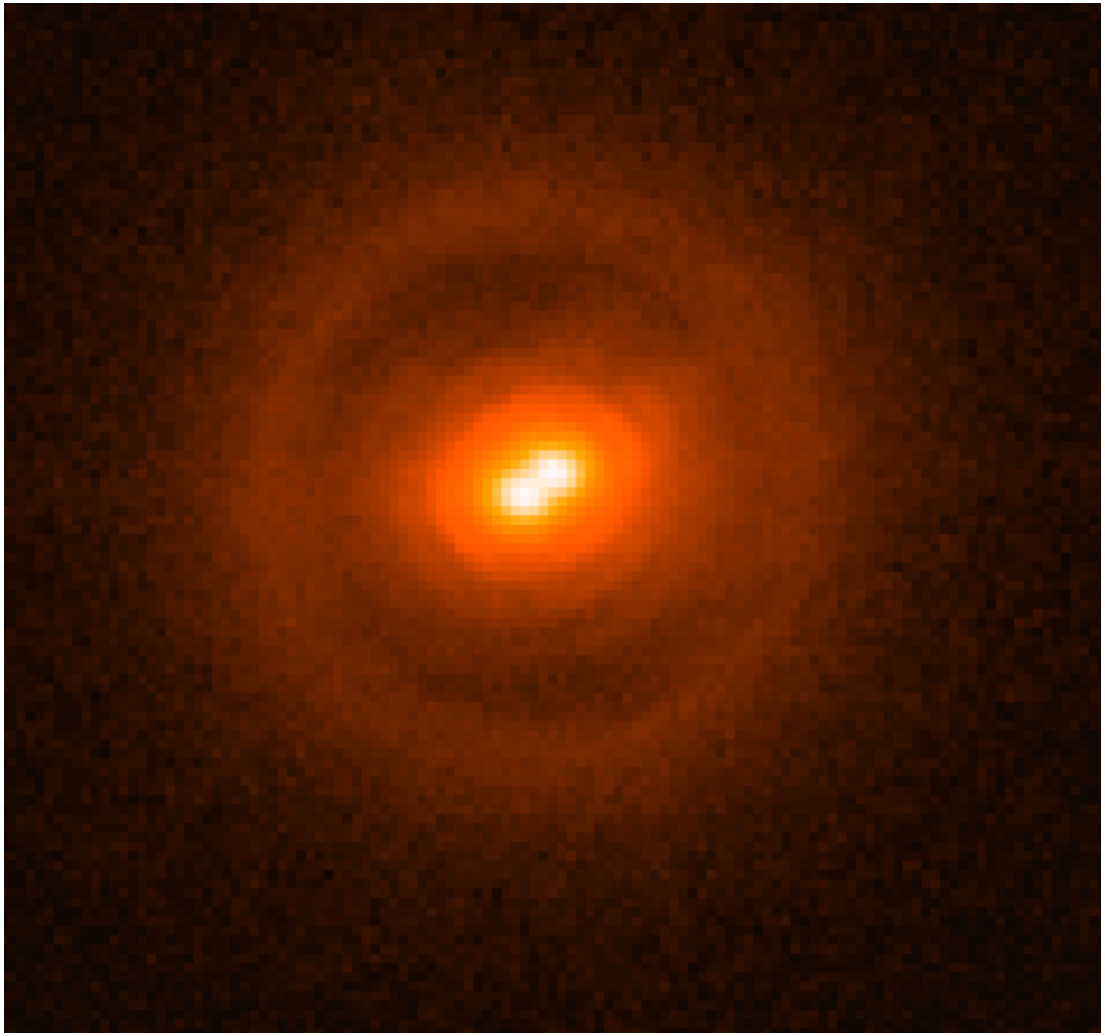
**Image data**
H band
4s exposure time
SR > 60% (no correction for 2nd star flux)

# A second example:

Target: HD111525
FeII filter (1.65um)
Star magR 9.5

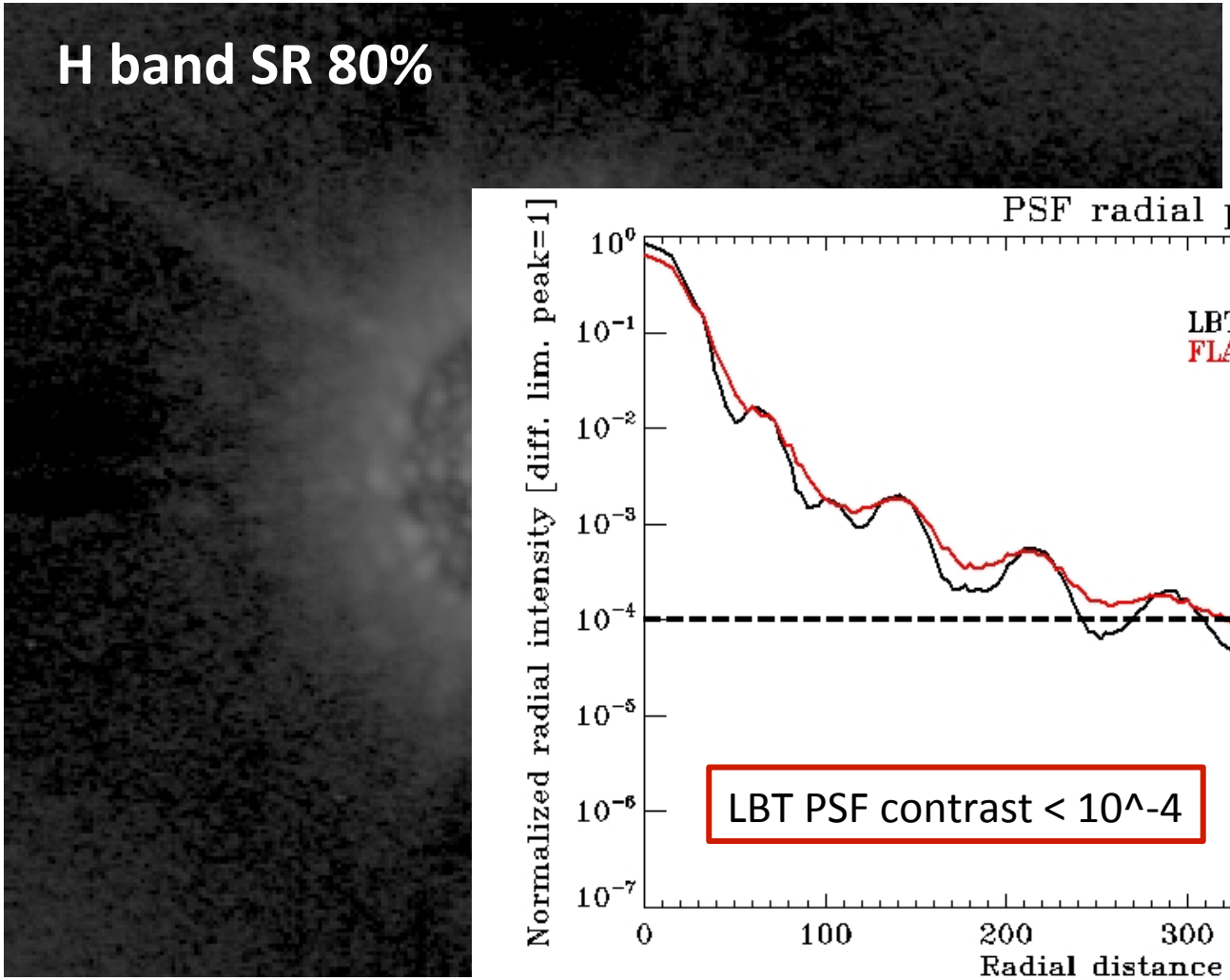
**FLAO parameters**
30x30 subaps
400 corrected modes
1Khz frame rate

Star separation is 80mas, the two companions have almost equal brightness. FoV 147x173 pixel (2.6x3.1 arcsec). The star was not know to be a binary.



**Test for focusing the PISCES camera !!!**

# High SR images..(H band)







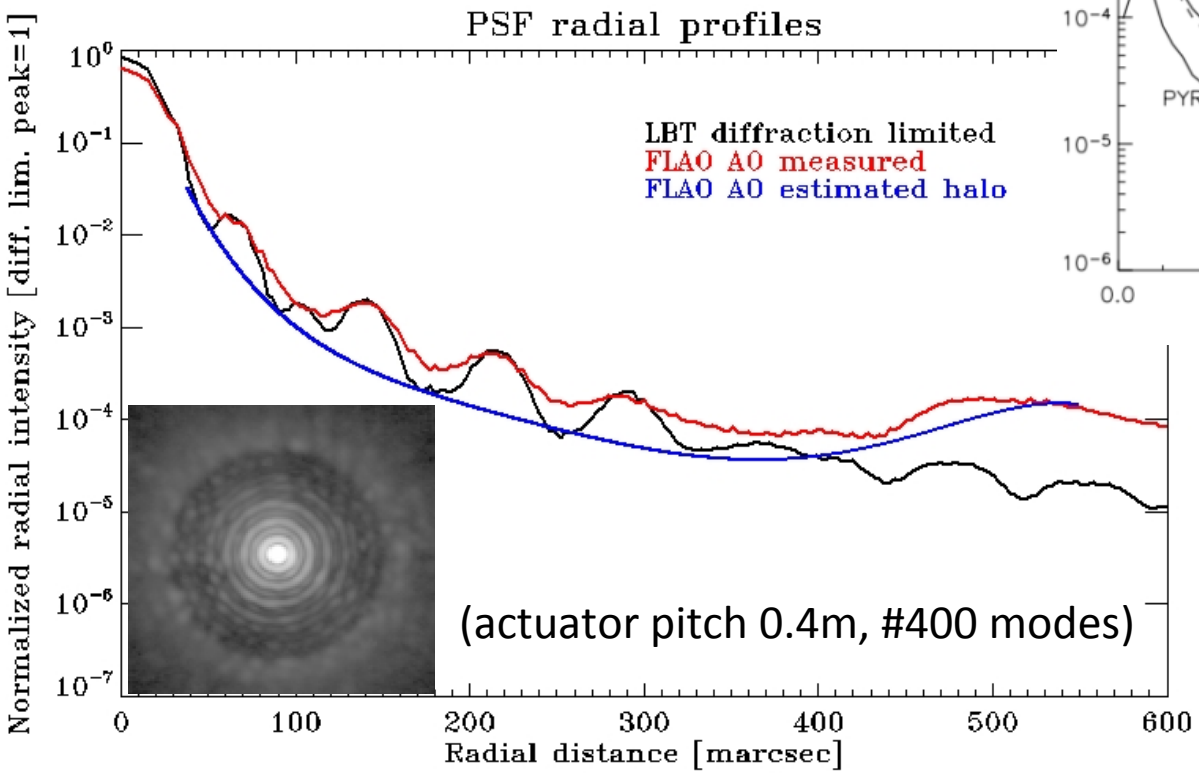
**The reference: HD175658,** R =6.5, H=2.5

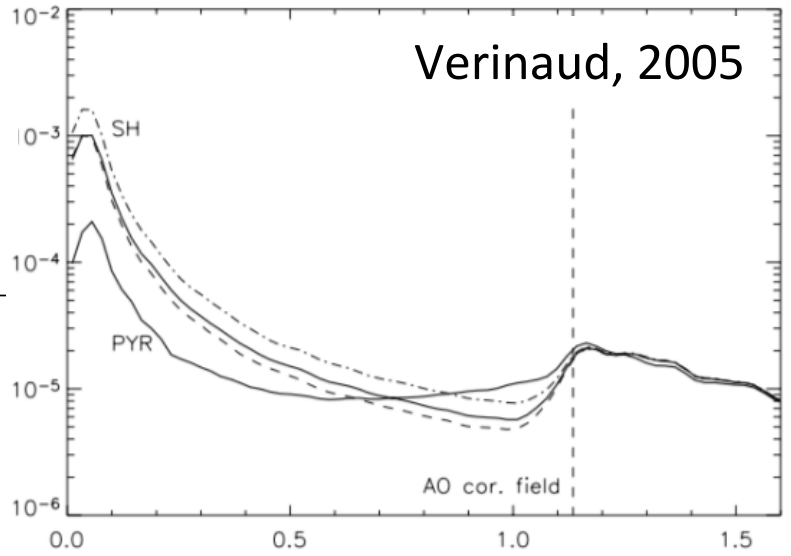
**The atmosphere**: seeing 0.9 arcsec V band

**FLAO parameters**: 1KHz, 30x30 subaps, 400 corrected modes

# LBT PSF residual halo

PSF_AO ≈ PSF_DL+Residual_Halo



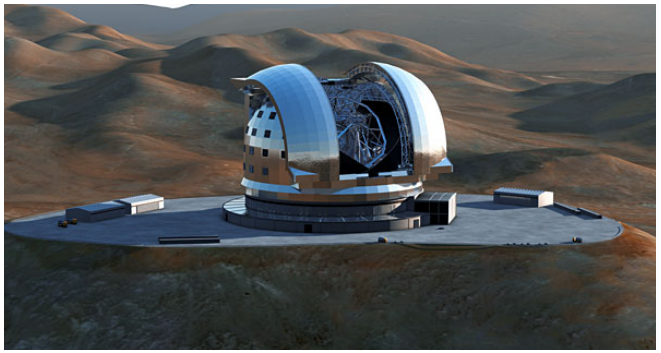



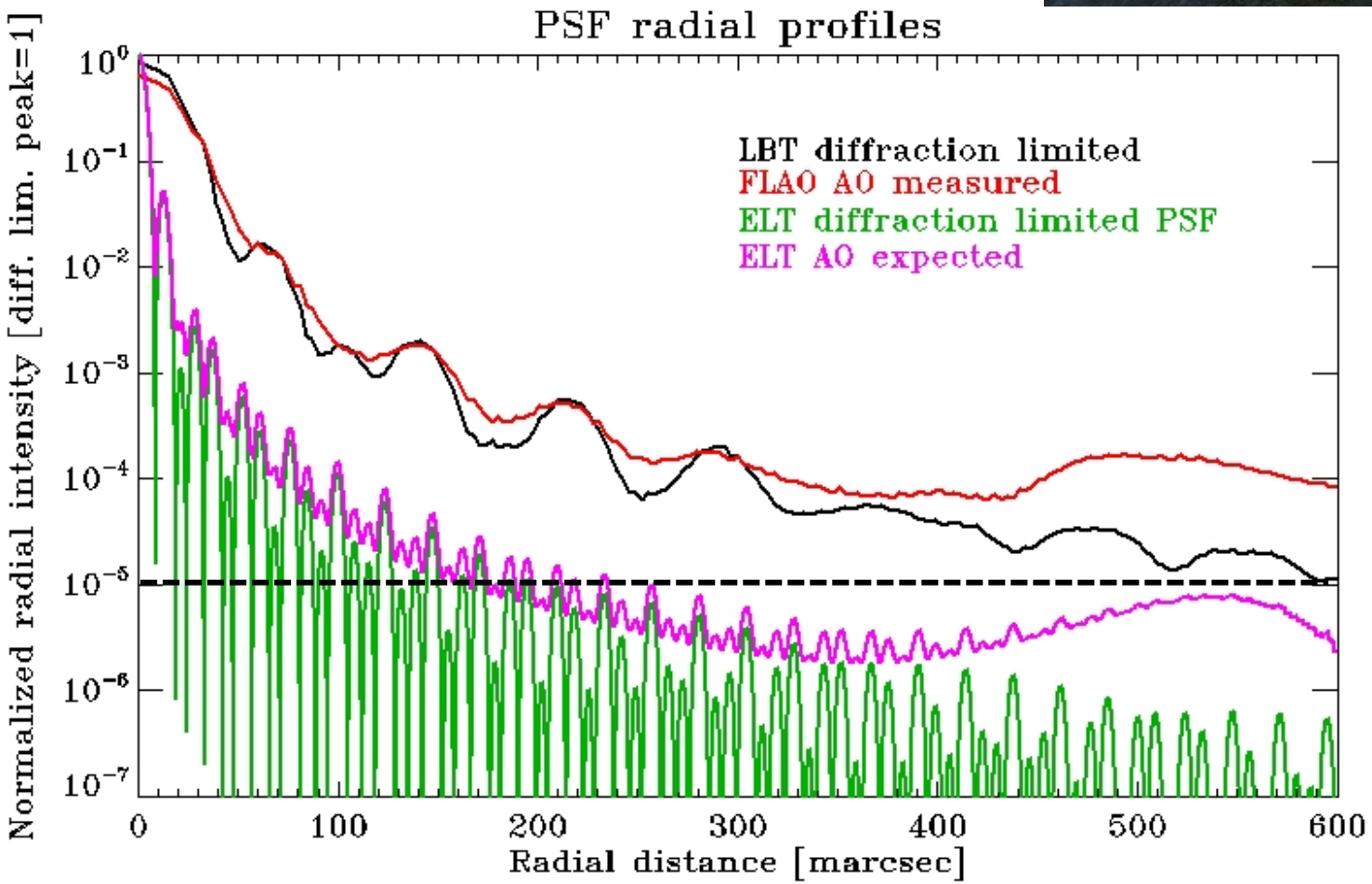

arcsec
(actuator pitch 0.2m)

LBT PSF dark region demonstrated on sky the pyramid sensor reduced sensitivity to aliasing.

# Scaling LBT PSF to E-ELT

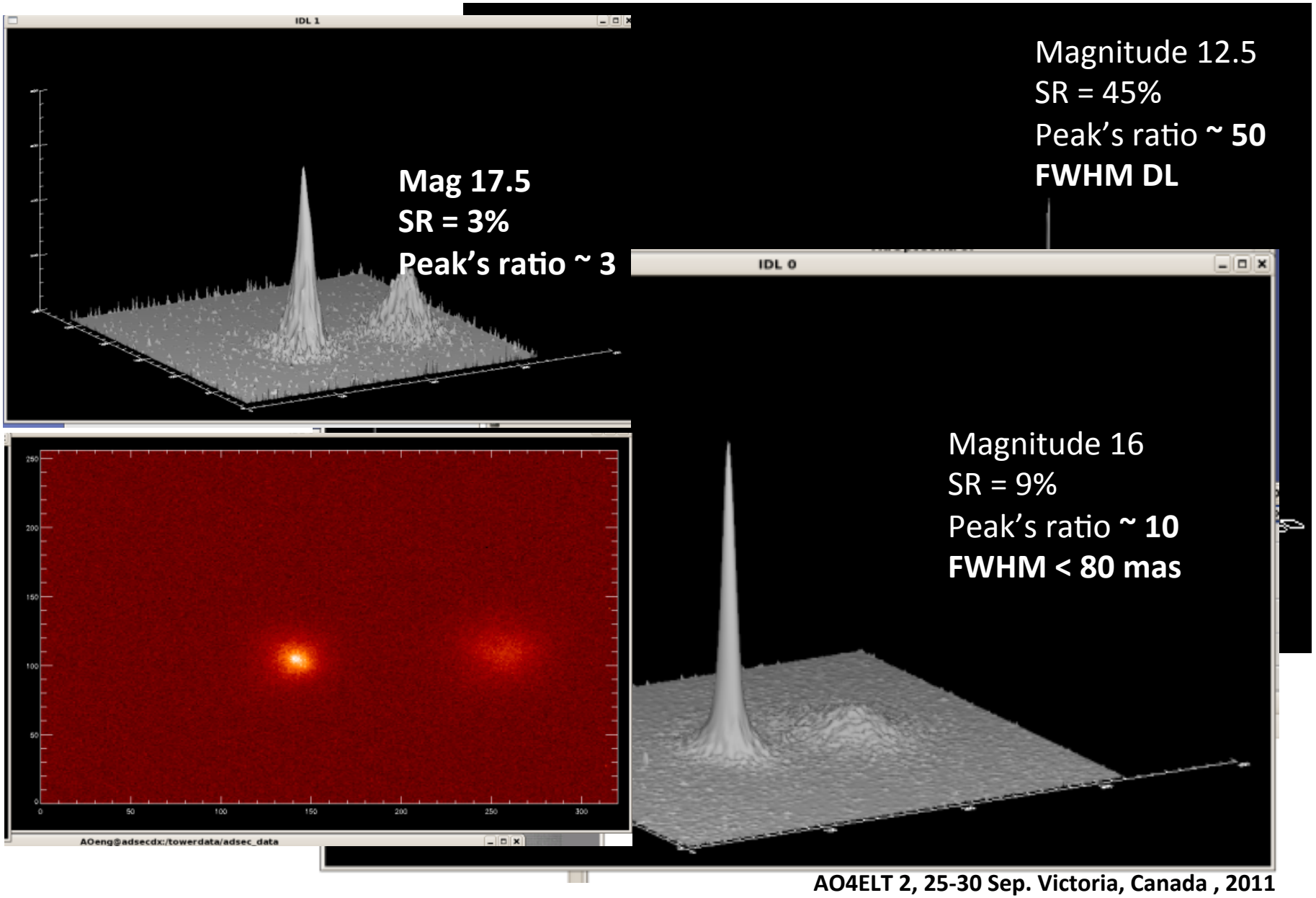
EELT with ~ 80x80 acts (M4) and modulated pyramid WFS (0.5m actuator pitch)






PWFS+M4 (~ 6000acts) see F. Quiros [Wednesday 28th , 14:40]

# Other images from commissioning (H band)

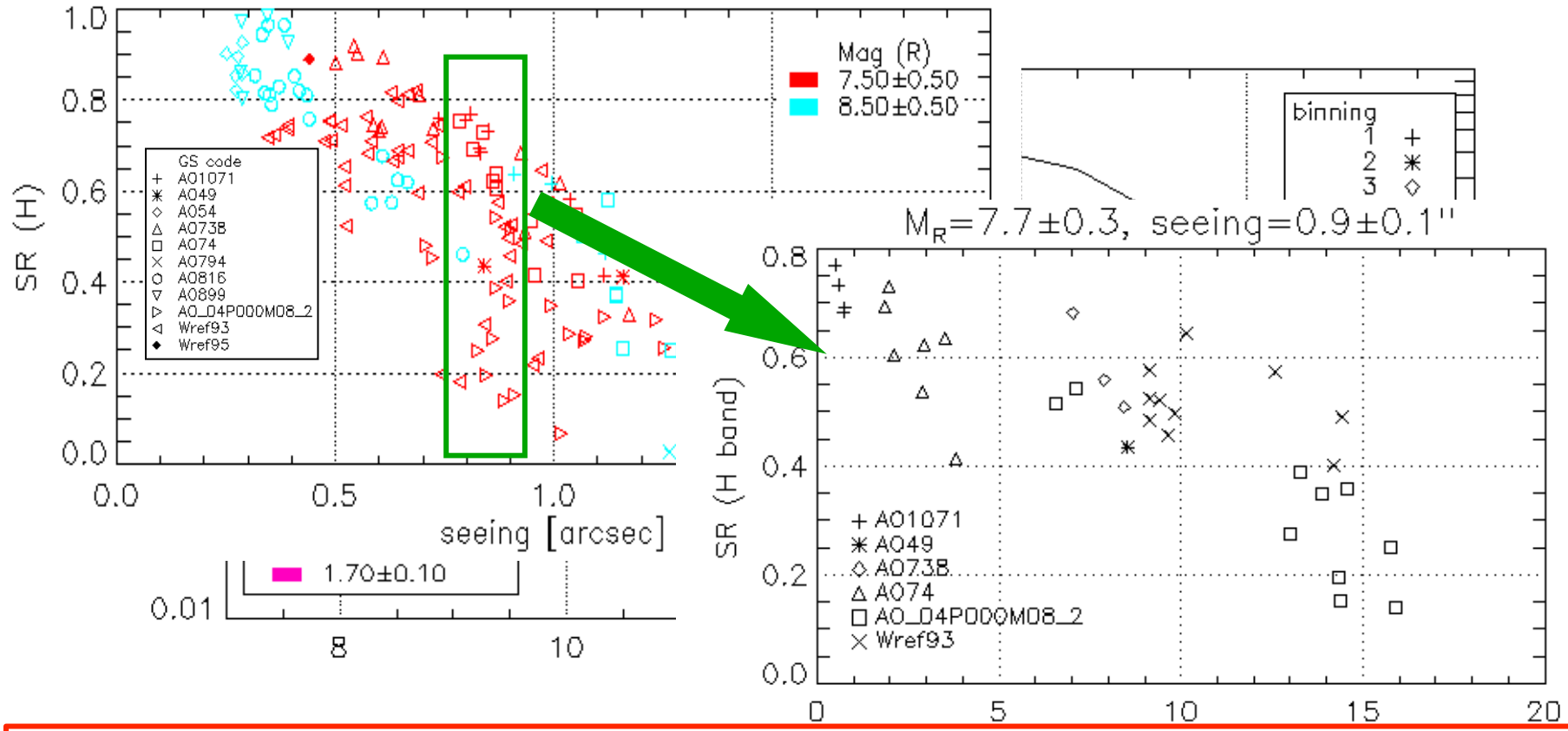


# H band SR VS. Guide star magnitude

- ❖ symbols: on sky measured values, seeing value is color coded
- ❖ Simulation estimates, seeing of 0.6”, 0.8”, 1.0”, 1.2”, 1.5”

SR values measured with IRTC LBT camera (Foppiani et al., 2011)

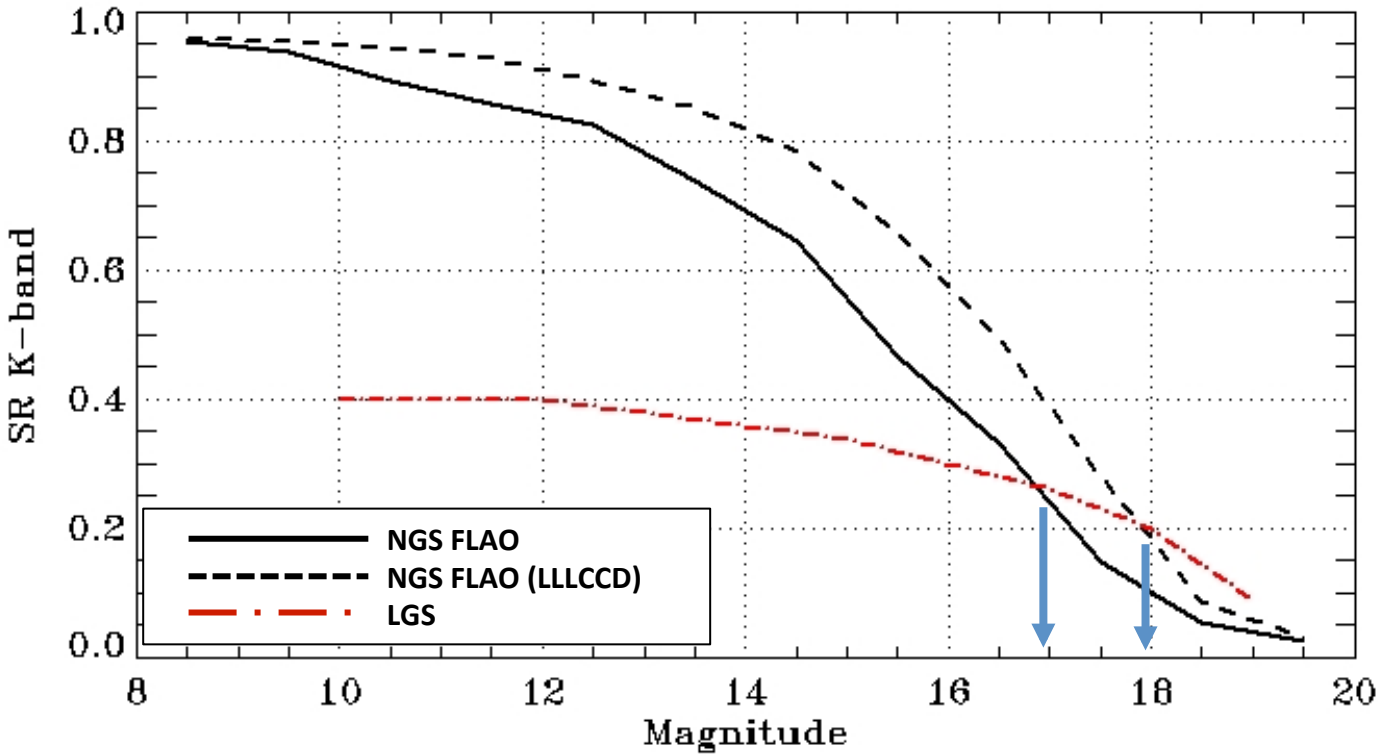
NOTE: Black points have no seeing estimate




- FLAO#1 commissioning end date October 2011 (handover to LBTO)

# Improving NGS AO performance with LLLCCD

Use of a Low Light Level CCD (L3CCD) to remove RON improves performance of NGS based AO system [Carbillet, 2010], about 1 mag improvement in faint end. This in turns improves Sky Coverage.

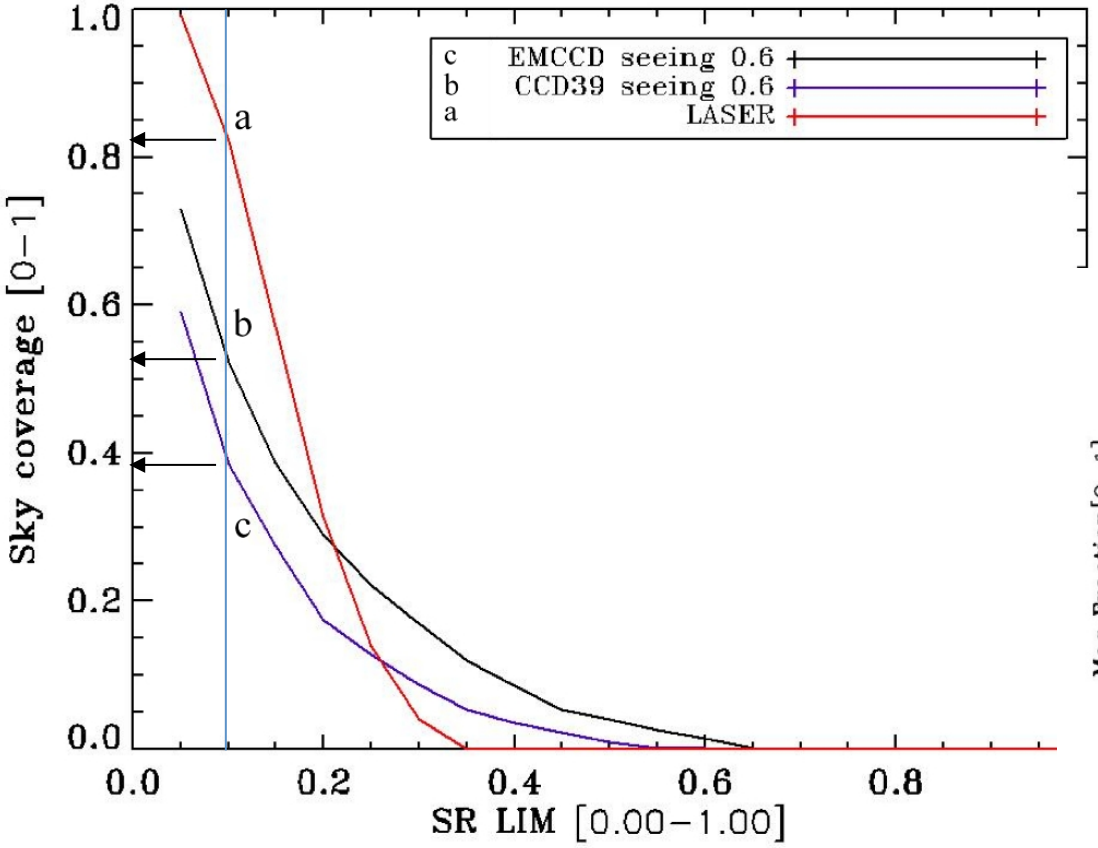



- Seeing 0.6 arcsec
- Wind 15m/s
- Cn2 profile, (Masciadri 2010, Mt. Graham)

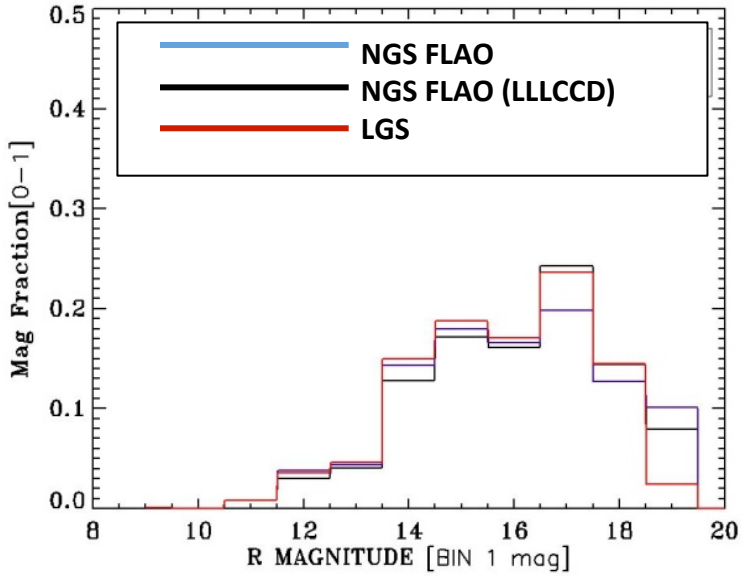
NGS AO achieves similar performance to LGSs system at faint end.

# Sky Coverage example (K band)

Sky Coverage computed for a sample of 830 galaxies at z~3 in 16 different fields located at high galactic latitude [Steidel, 2003].




- Seeing 0.6 arcsec
- Wind 15m/s
- Cn2 profile, (Masciadri 2010, Mt. Graham)

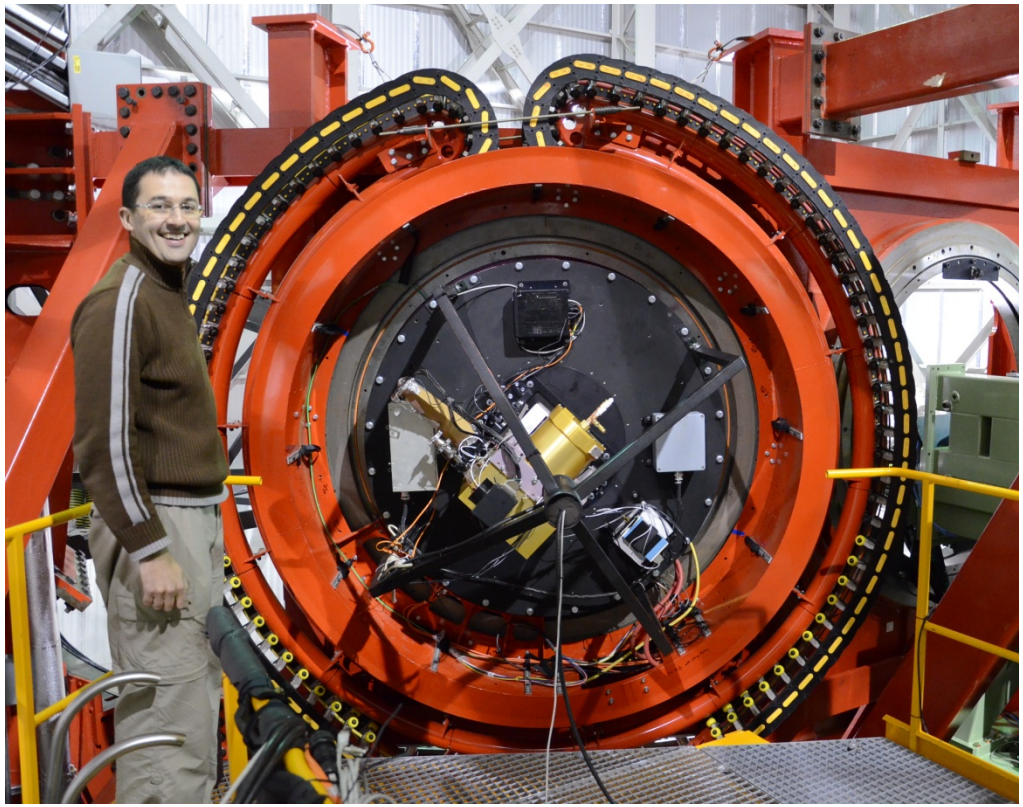



LGS & NGS Sky Coverage is found comparable in such example

# First astronomical observations: PISCES

## Performance summary:

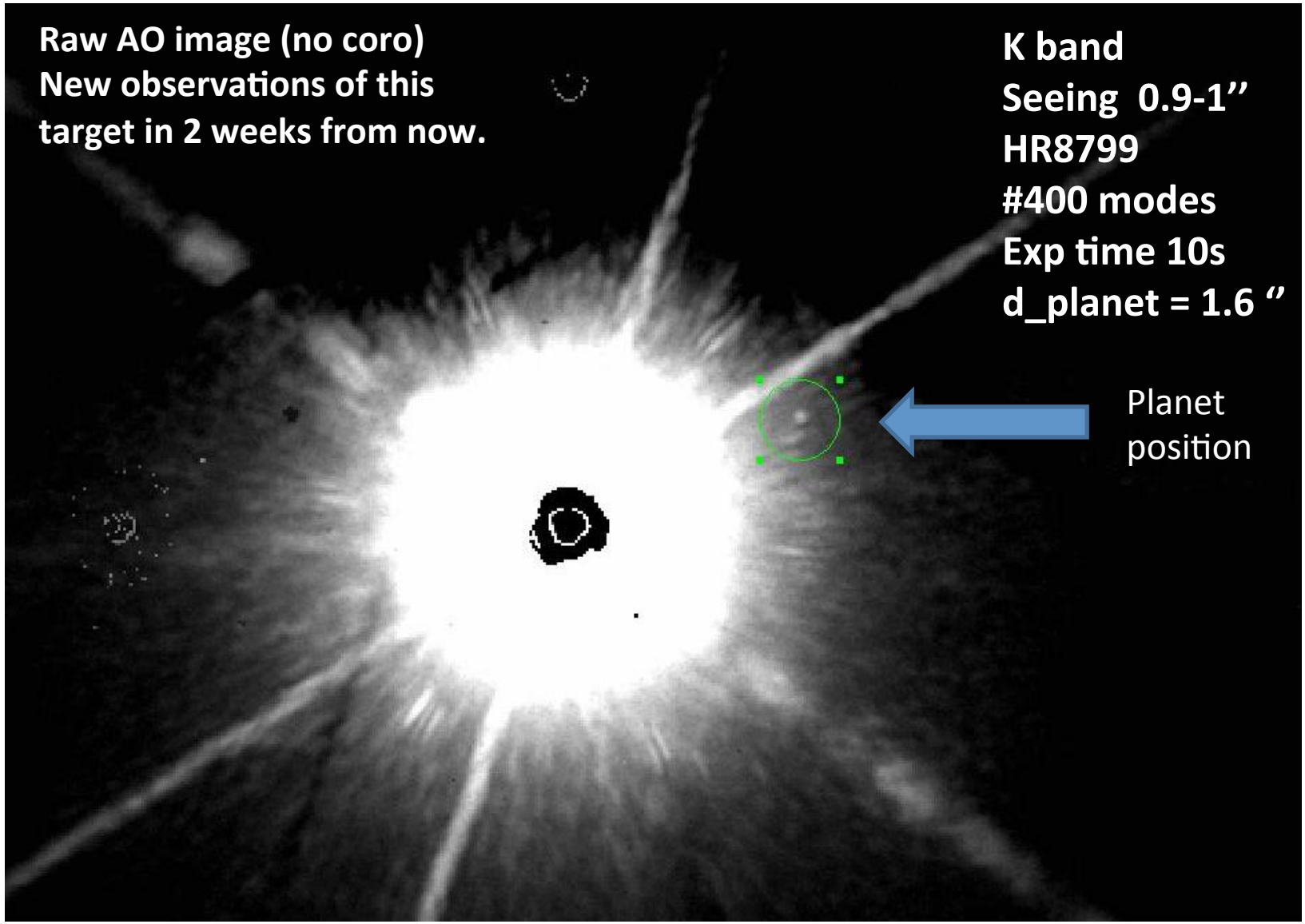
| Parameters. | Detector. |
|---|---|
| Format. | 1024x1024 |
| Plate scale. | 18.2mas/pix |
| Wavelength. | 1-2.2μm |
| Quantum efficiency. | >50% (60% in J,H,K) |
| Dark current | 0.02 e-/s/pix |
| Read noise. | ~17e |
| Gain. | ~4.3e/ADU |
| Pixel defects. | <2% |
| Strehl Ratio. Arcetri tool | 0.75 |



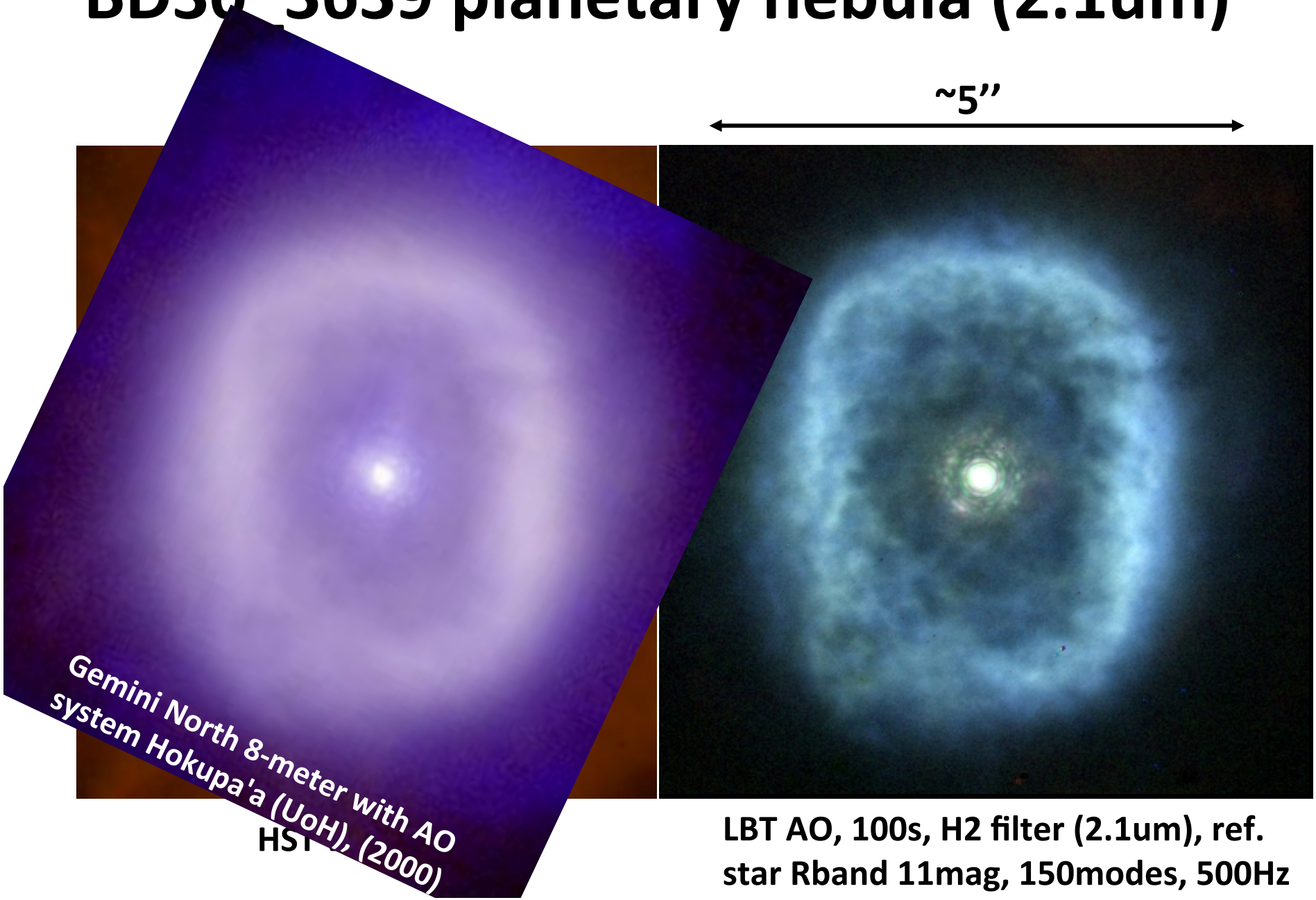
| Available filters | | | | | | | |
|---|---|---|---|---|---|---|---|
| J | H | Ks | FII (1.64 um) | H2 (2.12 um) | BrΥ | 2.086 | 2.140 |

Possibility to install a mask at the pupil location (apodizing mask)

# High contrast images .... (HR8799)

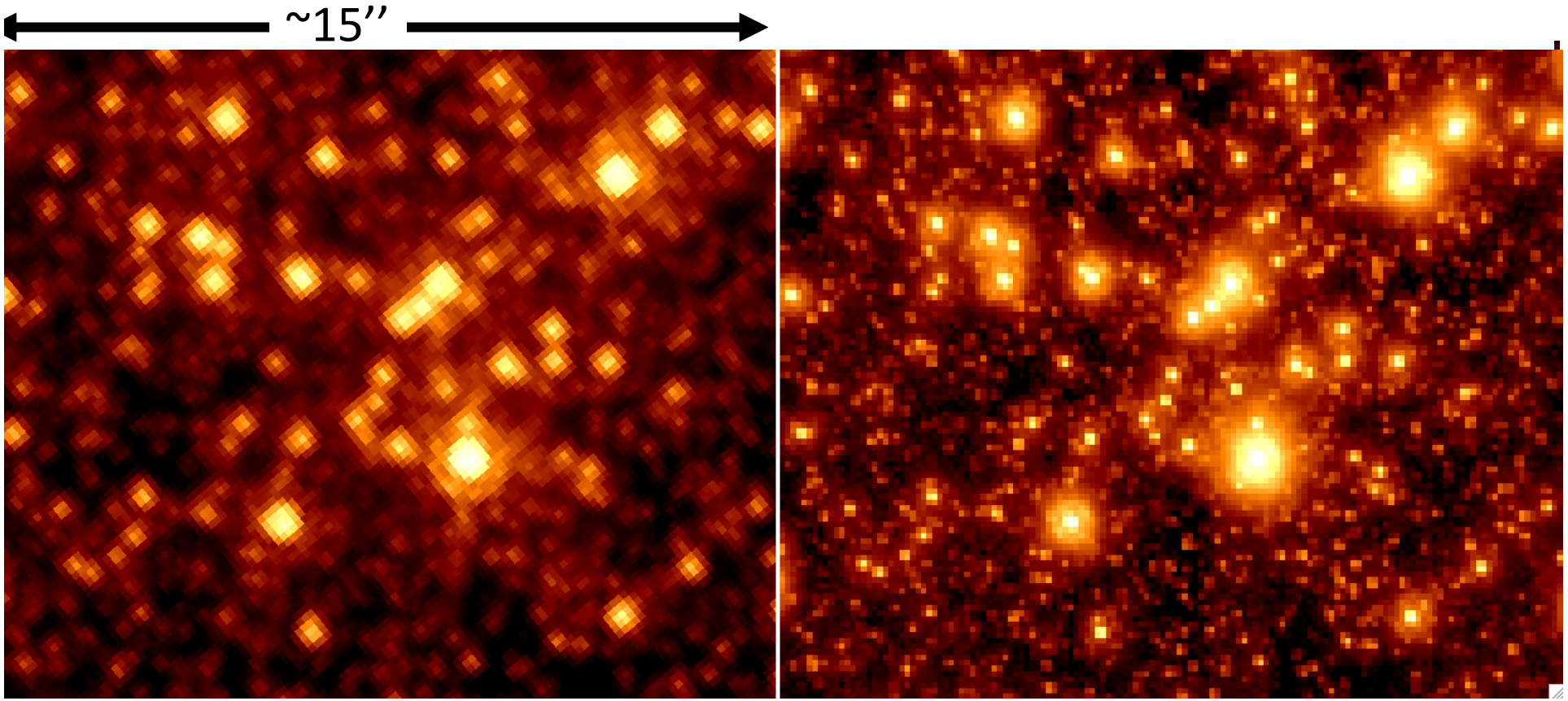


# BD30_3639 planetary nebula (2.1um)




LBT AO, 100s, H2 filter (2.1um), ref. star Rband 11mag, 150modes, 500Hz

# The Globular cluster M92

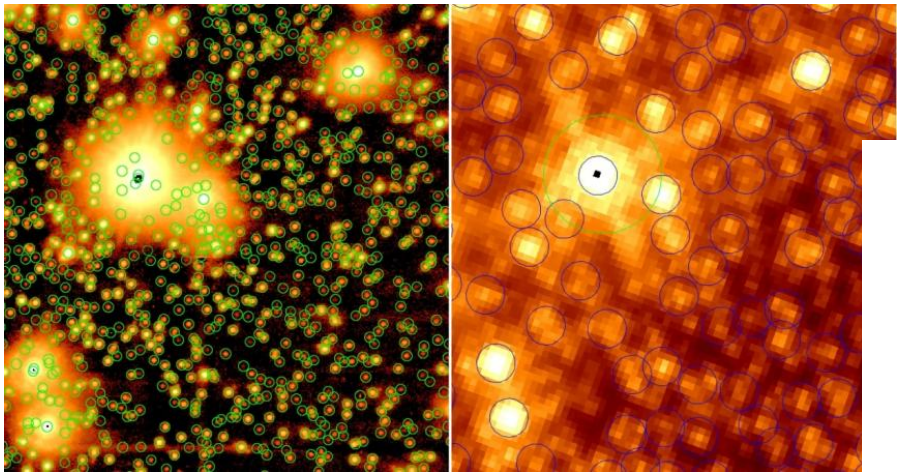



**HST WFPC3, H band, 21 min**

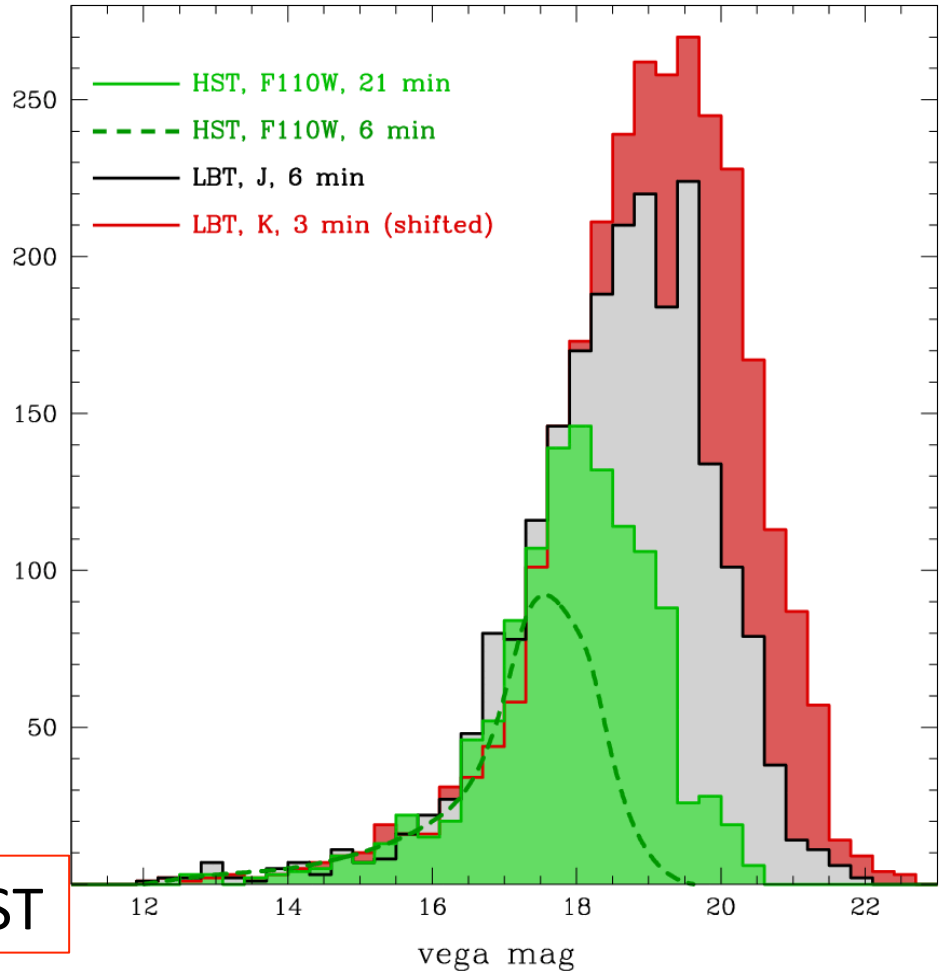
**LBT+FLAO, H band, 8 min**

**Main data:** Rmag 11.5, 0.7'' seeing,
**AO settings:** 0.5KHz, 15x15 subaps, 153 corrected modes

# Star counts in M92



Measuring a color magnitude diagram for M92 globular cluster




Counts taken in the same 20x20 arcsec image in the center of the globular cluster.

- HST J counts 890, 21 minutes
- LBT J counts 1969, 6 minutes
- LBT K counts 3300, 3 minutes

LBT J images 2 mag deeper than HST

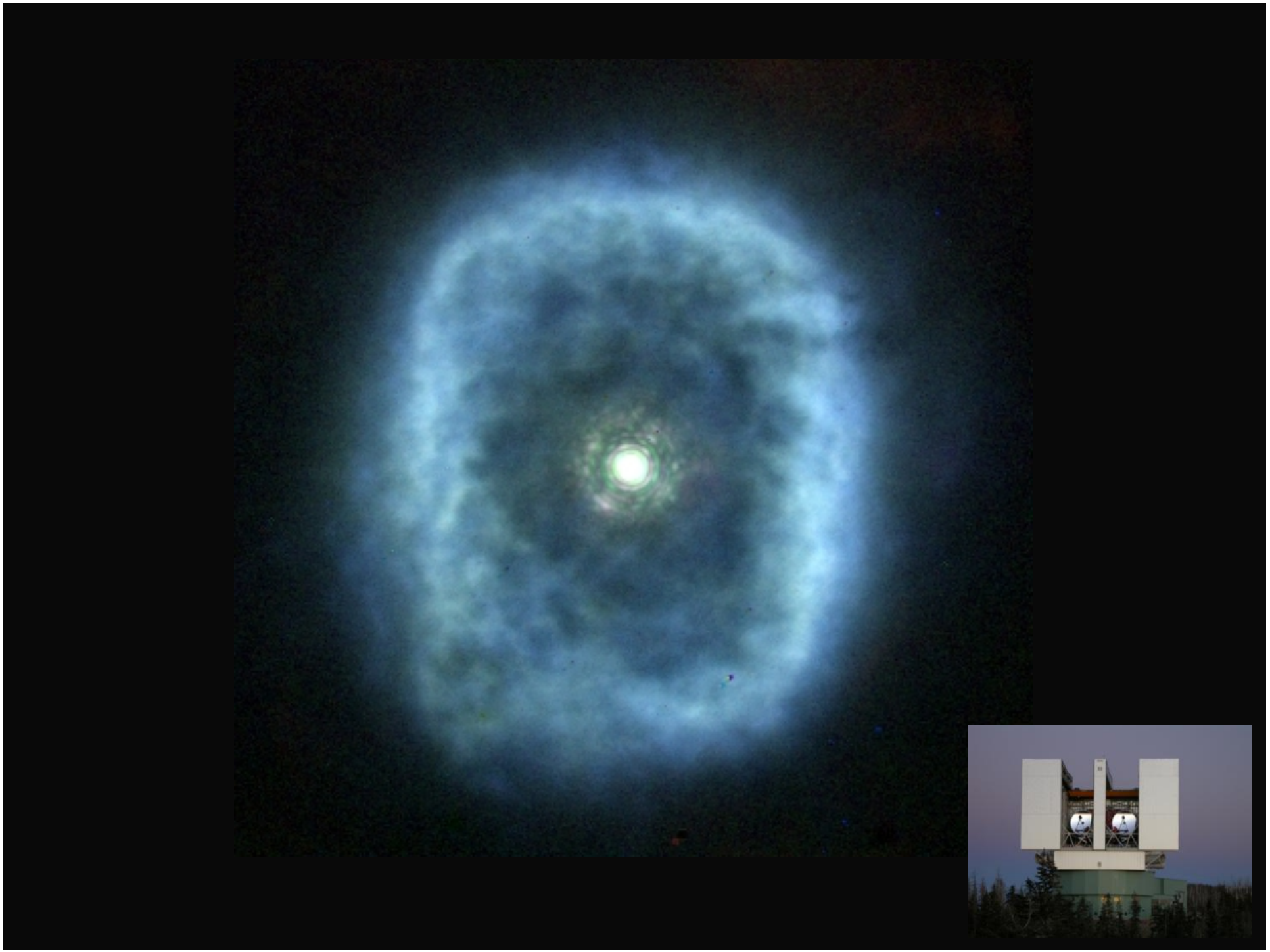
# Conclusions

The LBT AO system moved a step forward in high resolution astronomy: >80% SR (H band) and 10^-4 contrast. AO loop closed at 17.5 mag.

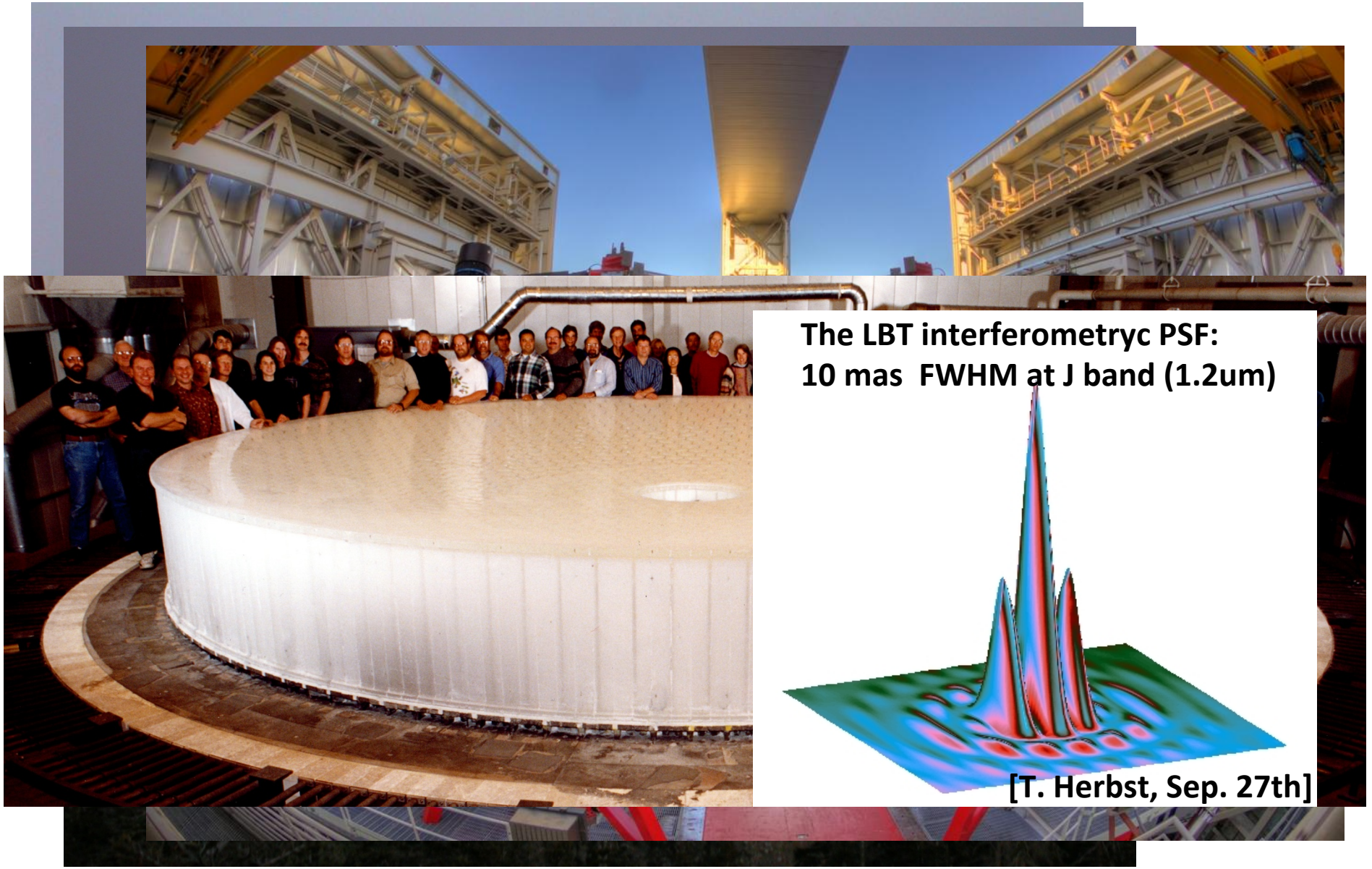
Adaptive secondary and pyramid sensors qualified as mature components for future telescopes and ELTs.

First scientific images taken in June 2011, data reduction started. Initial results for M92: star counts outperform HST results.

The LBT results requires revisiting a well known issue:
use of NGS vs. LGS AO systems for 8m and possibly ELT telescopes.



# The LBT telescope: two 8.4m mirrors.



The LBT interferometryc PSF:
10 mas FWHM at J band (1.2um)

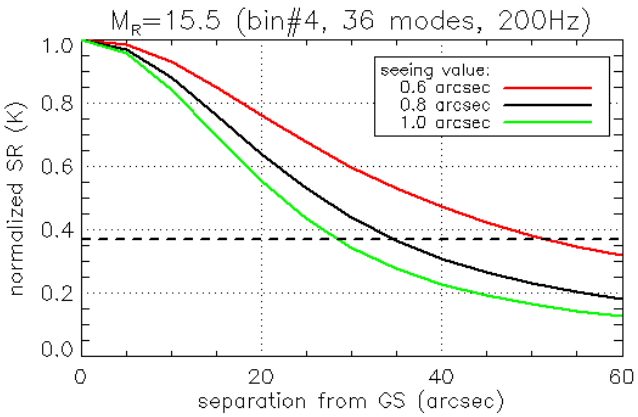


[T. Herbst, Sep. 27th]

# Sky Coverage example

Sky Coverage computed for a sample of 830 galaxies at z~3 in 16 different fields located at high galactic latitude [Steidel, 2003].

- LGS: 75 arcsec isokinetic angle
- NGS: 40 arcsec isoplanatic angle for 0.6 arcsec seeing



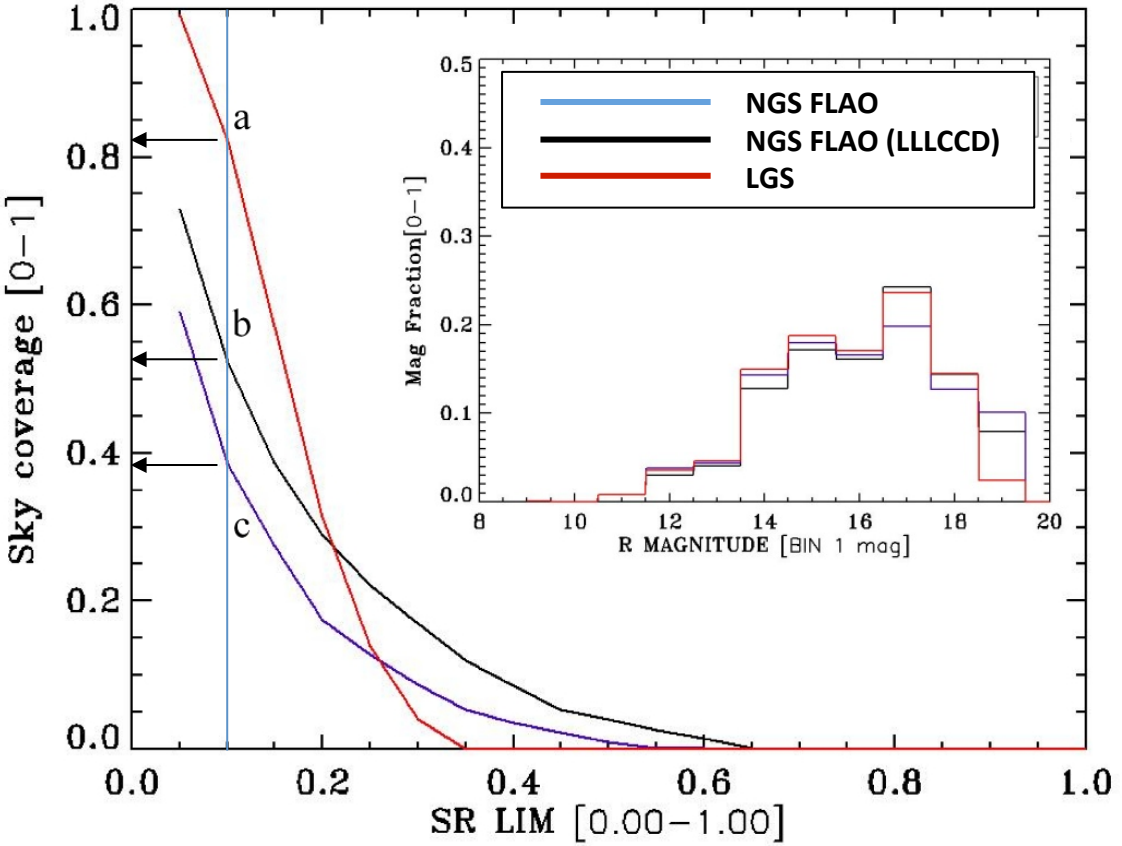

K band:

| Seeing (arcsec) | 0.6 | 0.8 | 1.0 |
|---|---|---|---|
| Effective $\theta_0$ (arcsec) | 53 | 35 | 28 |
| On-Axis SR (%) | 48 | 35 | 23 |

Cn2 prof. Masciadri et al. 2010

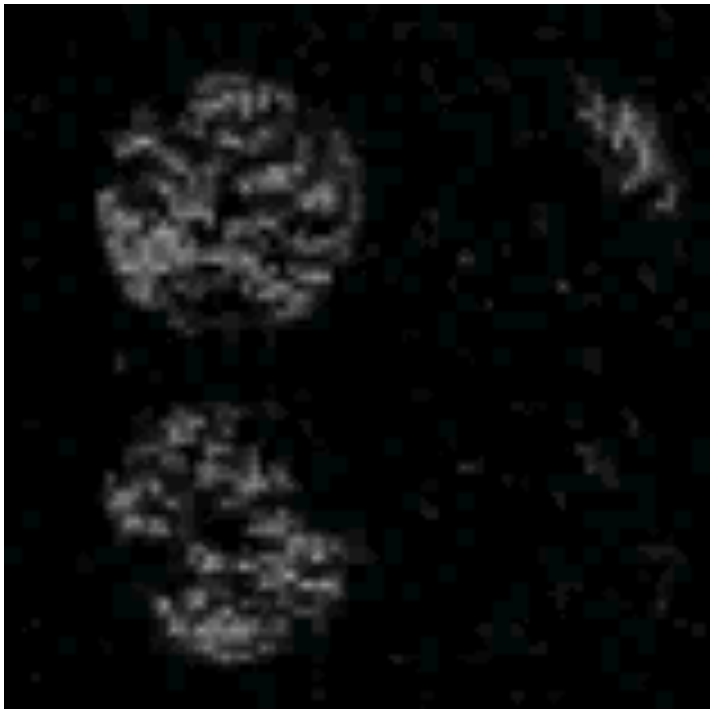
Sky coverage is comparable….

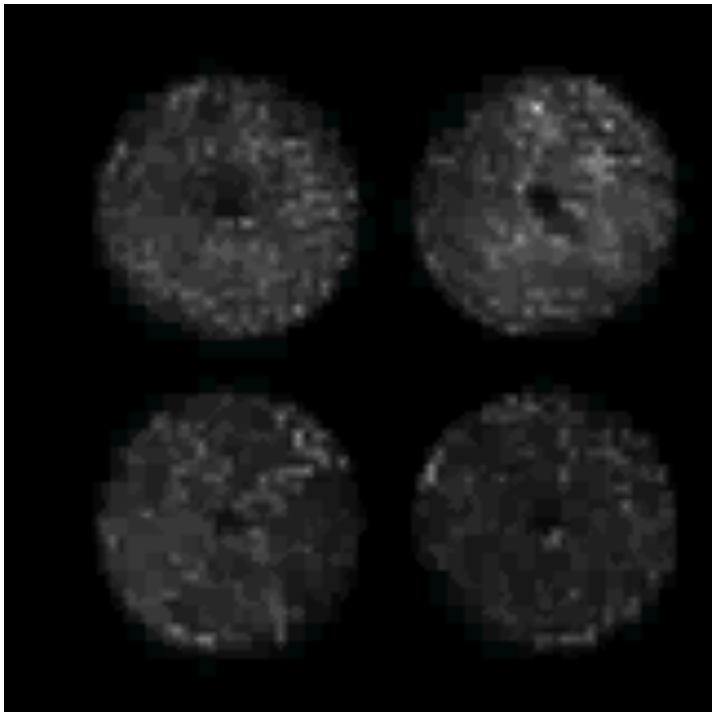
K band SR




LGS di enrico ?

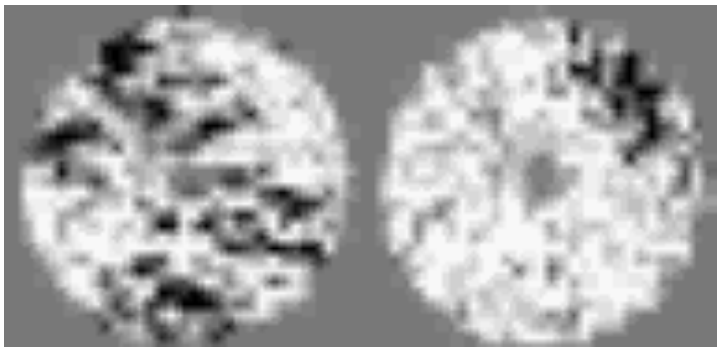
# WFS on sky signals





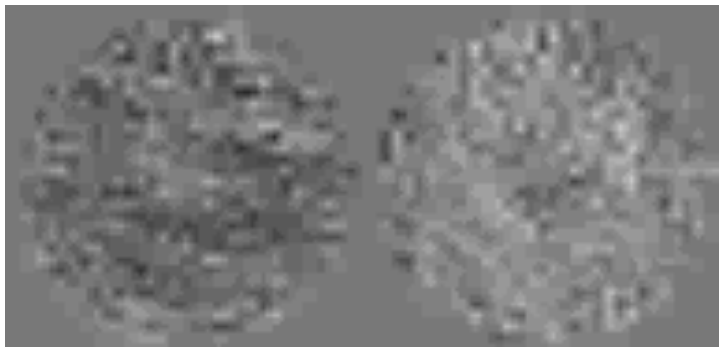
The four pupil images as seen in the LBT WFS with 30x30 subaps.

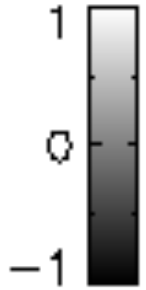
[dw/dx] [dw/dy]



Open loop signals

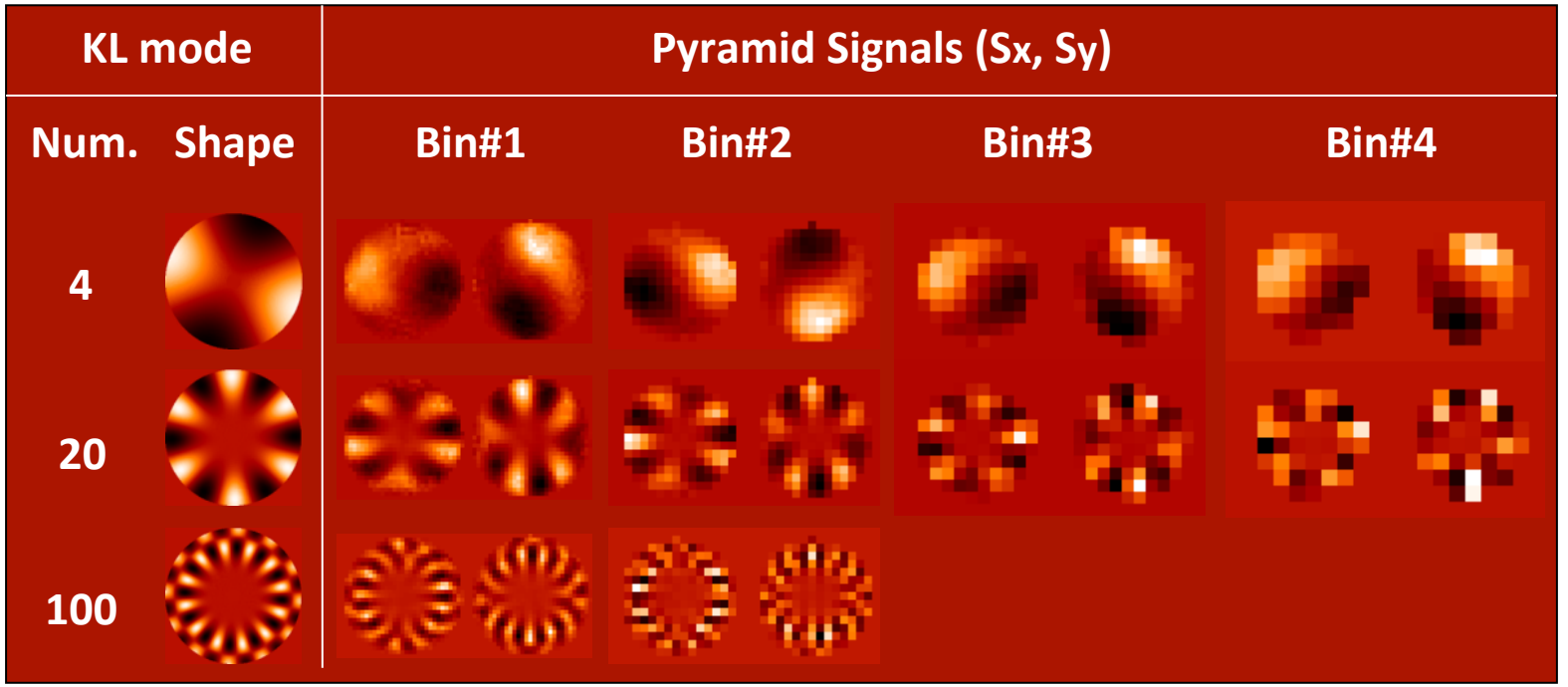
[dw/dx] [dw/dy]






Closed loop signals

# IM vs star magnitudes

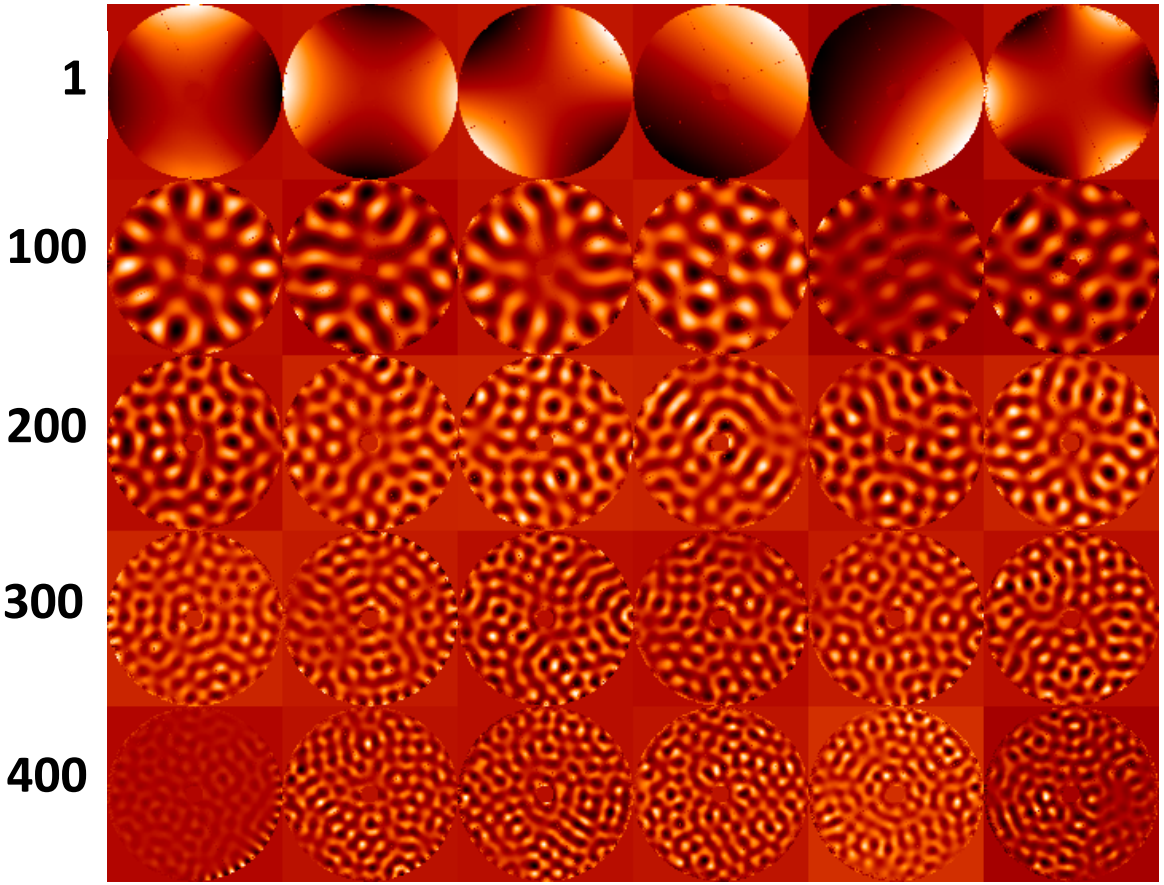


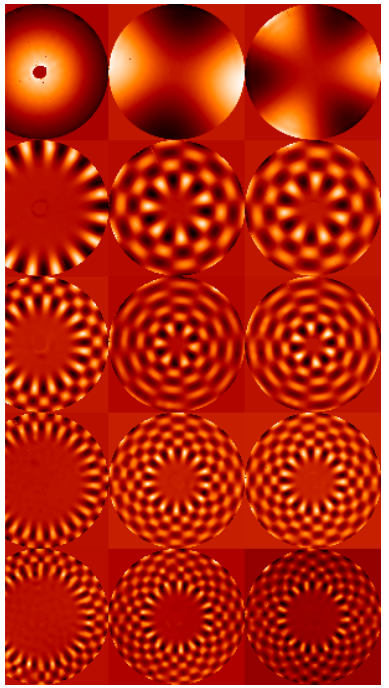

| Ref. star mag R | Bin Mode | Sampling [#subaps] | Num. of valid subaps. | Max num of modes | Pyr. Modulation [±λ/D] |
|---|---|---|---|---|---|
| <10 | 1 | 30x30 | 678 | 496 | 2 (3) |
| 10-14 | 2 | 15x15 | 177 | 153 | 3 |
| 14-15 | 3 | 10x10 | 72 | 66 | 6 |
| >15 | 4 | 7x7 | 48 | 36 | 6 |

# AO modal base: KL modes

Measurements of adaptive secondary modal influence functions using a phase-shifting interferometer (512x512 pupil sampling points)

odes (measured)



rmalized in the
al loop