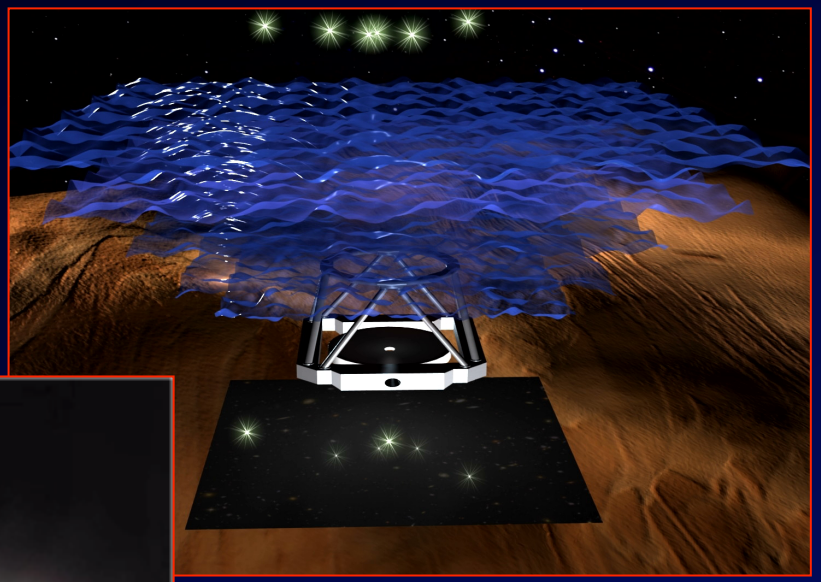
Pyramids, layers and no Laser Guide Stars…!



Roberto Ragazzoni
Carmelo Arcidiacono
Maria Bergomi
Alessandro Brunelli
Marco DIma
Jacopo Farinato
Demetrio Magrin
Valentina Viotto

Part I - Pyramids…

- Pyramids WFS has been introduced in 1995 (J.Mod.Opt. 43, 289)
- Pyramid WFS soon introduced as main (and then solely) WFS in AdOpt@TNG
- Just a number of practical reasons (and paternity…) to prefer to the obiquitous Shack-Hartmann
- Then in 1999….

Astron. Astrophys. 350, L23–L26 (1999)

ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

Sensitivity of a pyramidic Wave Front sensor in closed loop Adaptive Optics

R. Ragazzoni[1] and J. Farinato[2]

[1] Astronomical Observatory of Padova, vicolo dell'Osservatorio 5, 35122 Padova, Italy (ragazzoni@pd.astro.it)
[2] European Southern Observatory, Karl-Schwarzschild-Strasse 2, 83702 Garching bei München, Germany (jfarinat@eso.org)

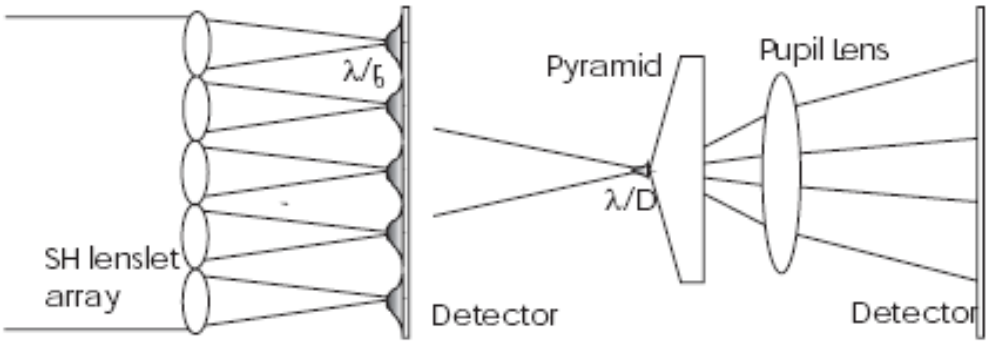


Fig. 1. The SH (left) and the pyramidic (right) WFS compared; both the WFS are shown in the perfectly close loop situation. When a tilt of the order of λ/D is introduced the efficiency of the pyramidic WFS is much larger because it acts *after* the recombination of the whole pupil light. In fact the movement of the spot is comparable to its size, while in the SH case all the spots will move of a fraction of their size.

Based on Heisenber uncertainty principle…

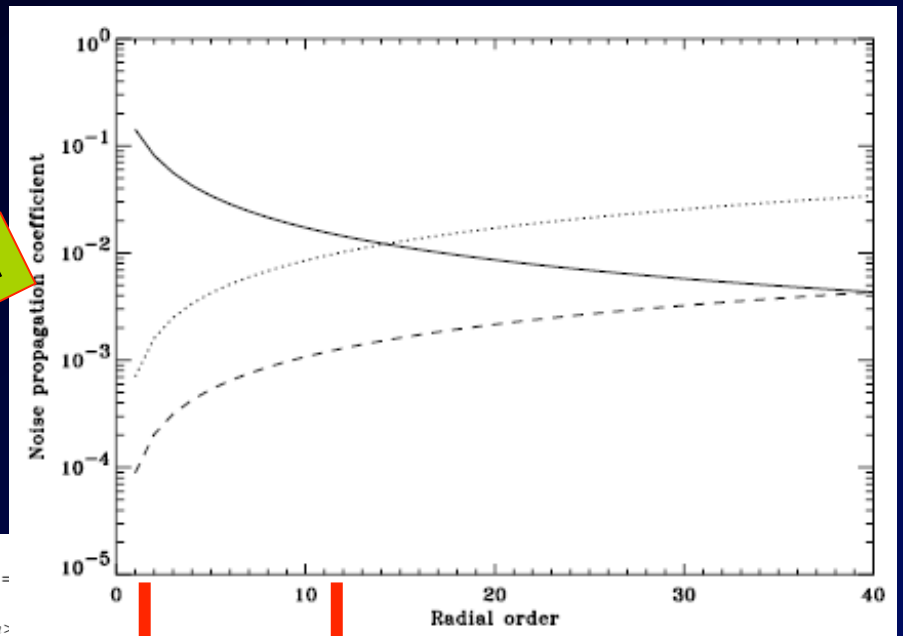
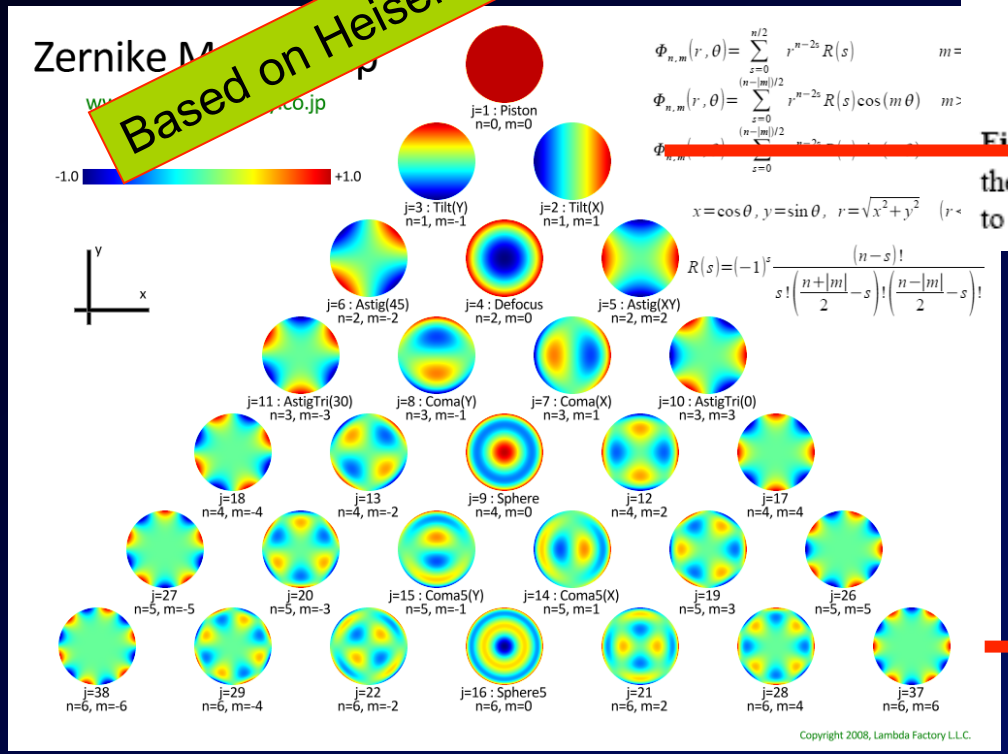


Fig. 3. Solid line: p_i vs. the radial order q for the SH case; dotted line: the same for the pyramidic case; dashed line: the same scaled in order to have the same integral area for the WF residual error.



…and we made a prediction!

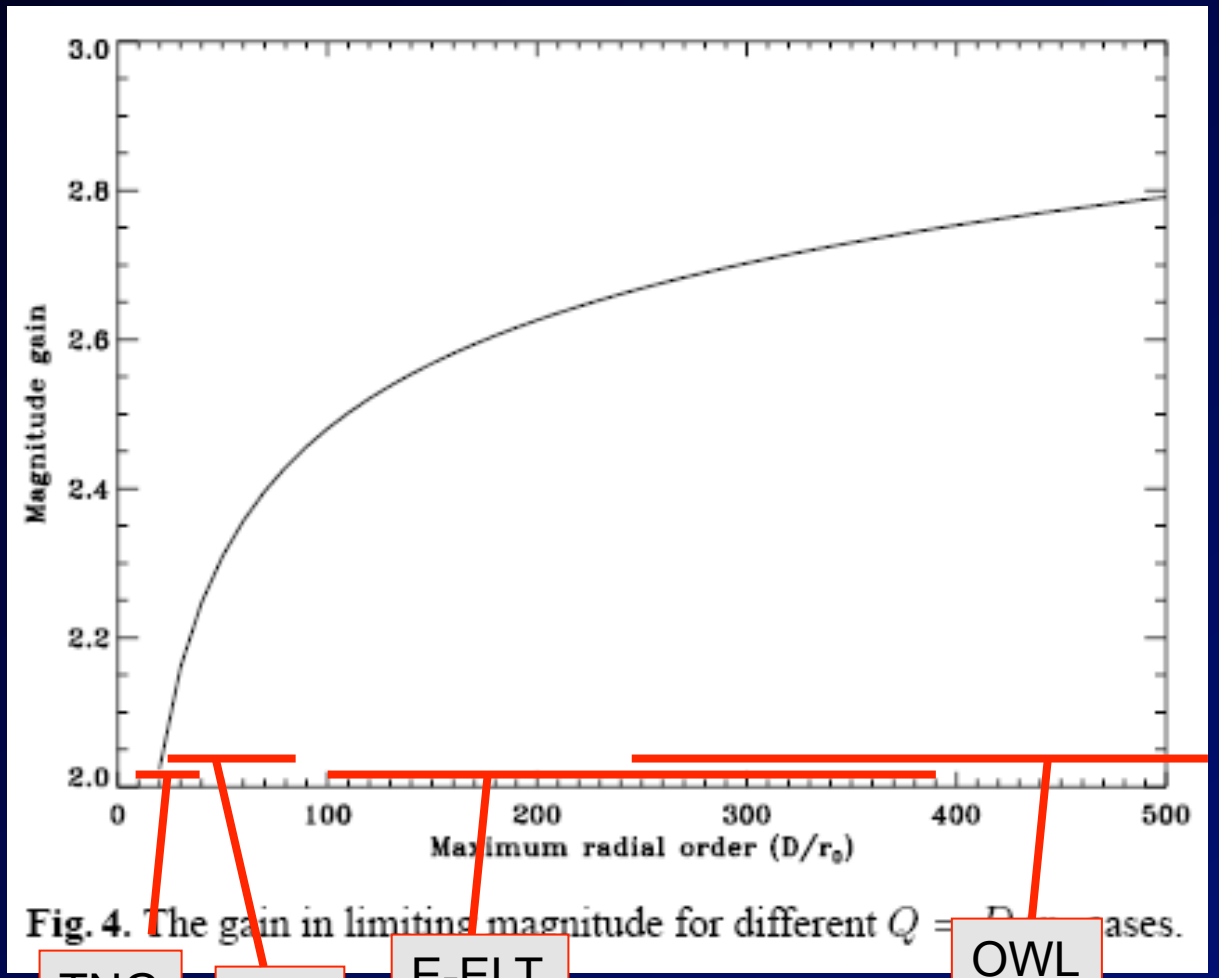


Fig. 4. The gain in limiting magnitude for different Q = D/r$_0$ cases.

…and we made a prediction!

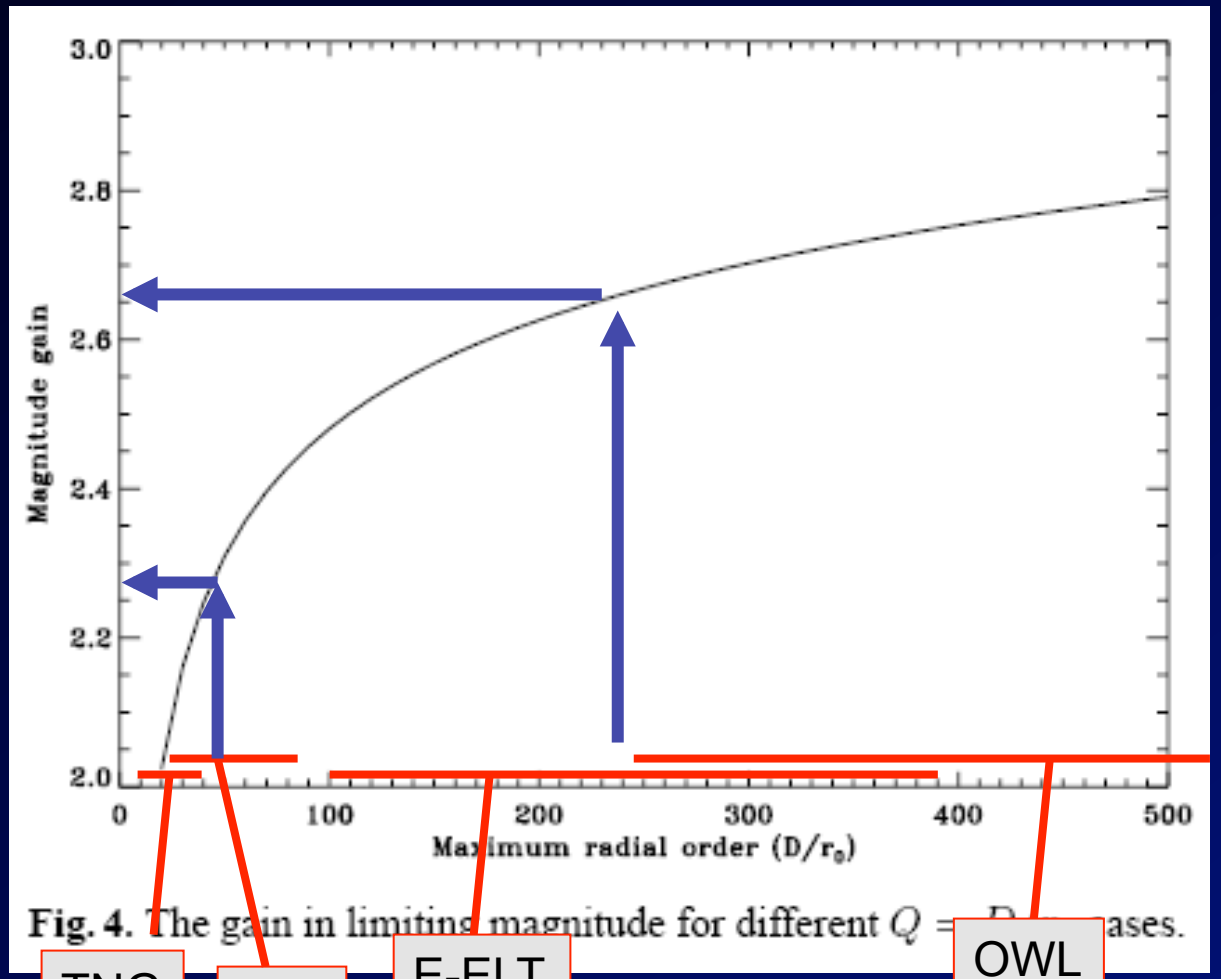


Fig. 4. The gain in limiting magnitude for different Q = D/r$_0$ cases.

…and we made a prediction!

This at least for the fraction of the light that fall diffraction limited on the pin of the pyramid…

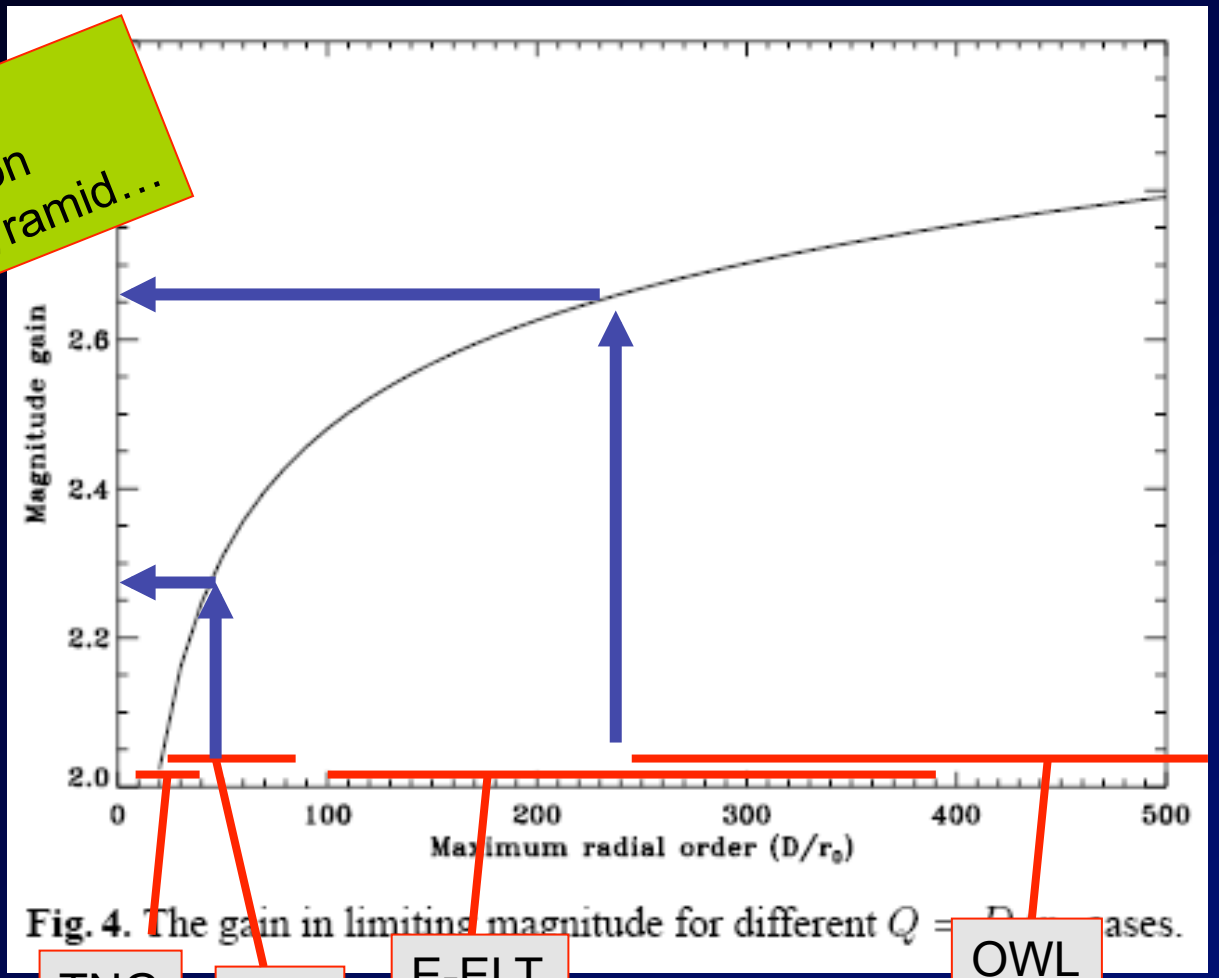
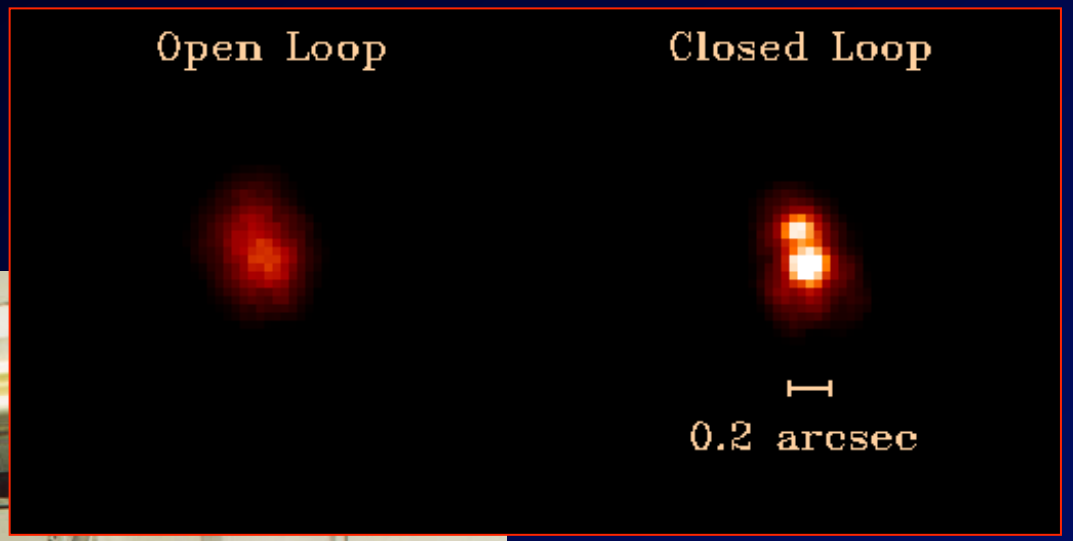


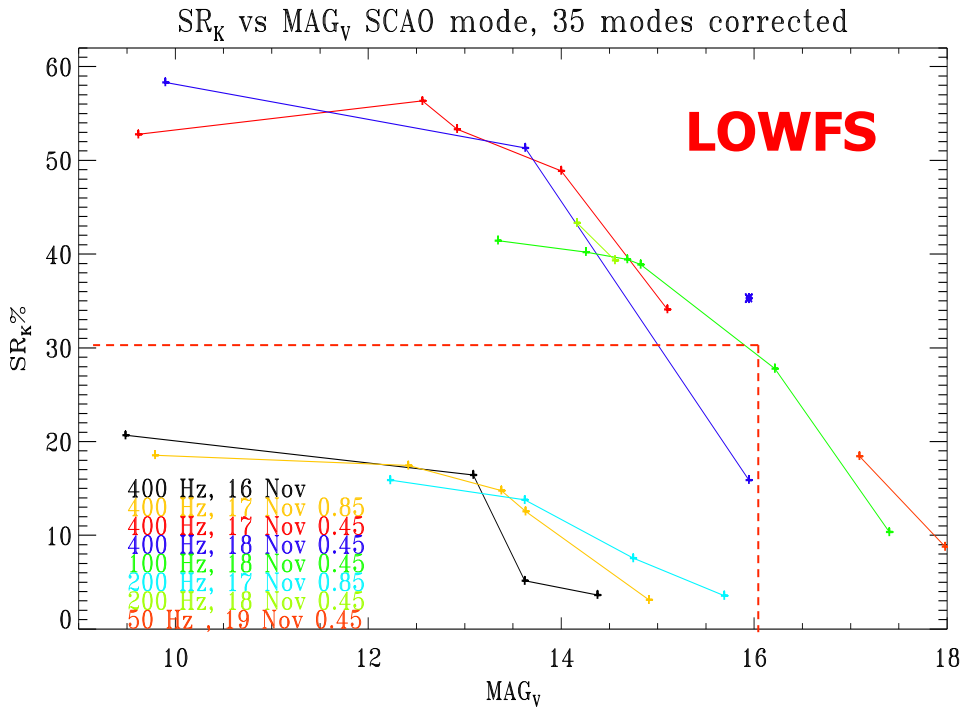
Fig. 4. The gain in limiting magnitude for different Q = D/r$_0$ cases.

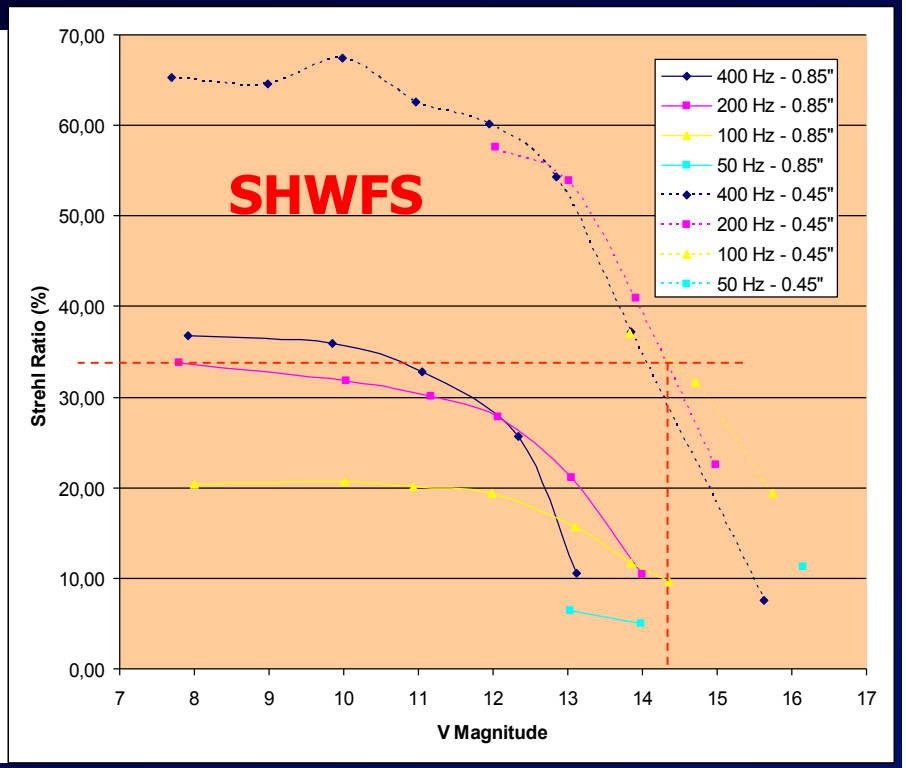
Then, in the night between 5 and 6 September 2001…



We also made a very rough experiment at TNG oscillating the pyramid by the “SH” amount…

vWFS on MAD vs 3SH…: FoV of single stars enlarger ~0.95arcsec!





Laboratory test in closed loop give evidence of higher limiting magnitude for the Layer Oriented WFS w.r.t the Star Oriented ~1.5 magnitude fainter

2009

PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, 122:63–70, 2010 January

PYRAMIR: Exploring the On-Sky Performance of the World's First Near-Infrared Pyramid Wavefront Sensor

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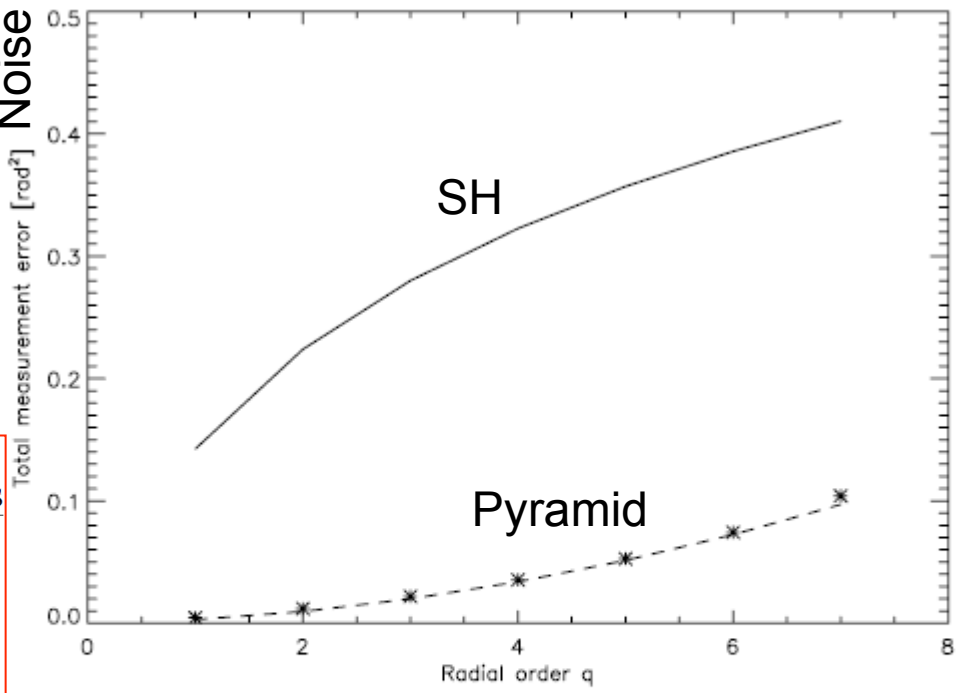

FIG. 8.—Measurement error coefficient for a correction of radial order with maximum radial order $Q = 7$. *Solid line* marks the theoretical error of a SHS under the same conditions, *dashed line* denotes the predictions by Ragazzoni & Farinato (1999), *asterisks* show our measurements. Note that the error bars vanish within the asterisks.

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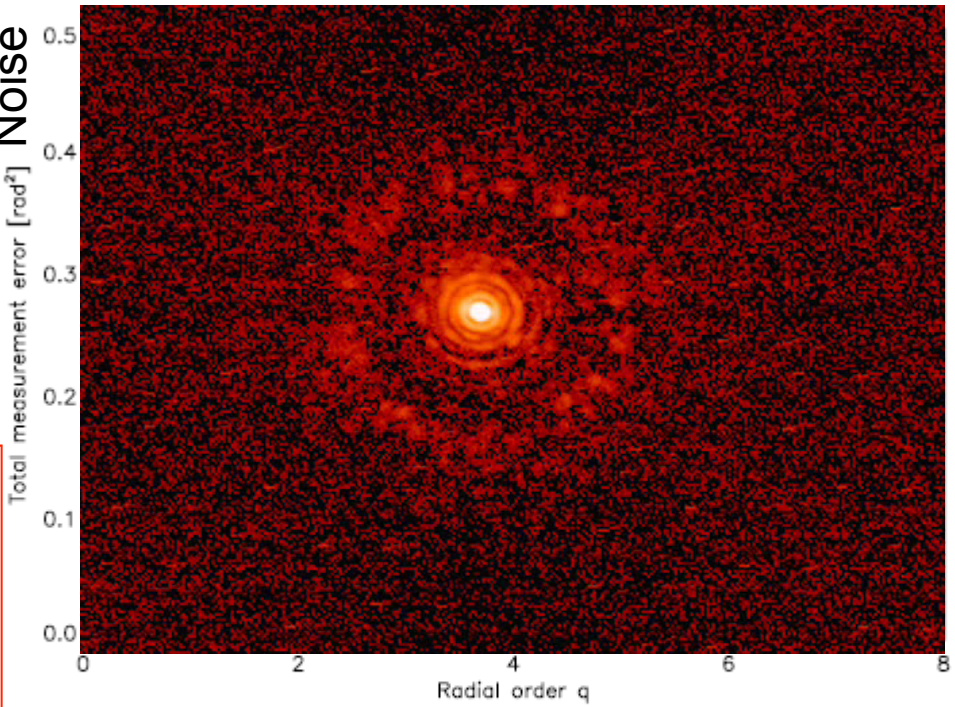
2009

Courtesy by Esposito on Behalf of the Arcetri team



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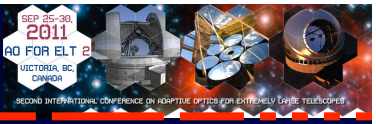
Pyramid WFS has been often questioned not just to be more sensitive than SH but even just to actually work…!!!

Quotations from this conference:

- "…we can implement some sensitive WFS like a Pyramid one…" (Norbert)
- "…which are pro and cons of roof WFS wrt the **classical** pyramid WFS…" (Brent)



Part II - Layers…

- Sketched in the 1999 conference in Backaskog for LGSs
- Tested in open loop on the sky at TNG (Nature 403, 54)
- Established in its final form at SPIE 2000 in Munich
- Proposed to ESO for MCAO demonstration (MAD) in 9/11…
- Potential to look for stars on a so much larger patch on the sky that…

1999

ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES
Astron. Astrophys. Suppl. Ser. 136, 205–209 (1999)
APRIL I 1999, PAGE 205

No Laser Guide Stars for adaptive optics in giant telescopes?

R. Ragazzoni
Astronomical Observatory of Padova, vicolo dell'Osservatorio 5, I-35122 Padova, Italy
e-mail: ragazzoni@pd.astro.it

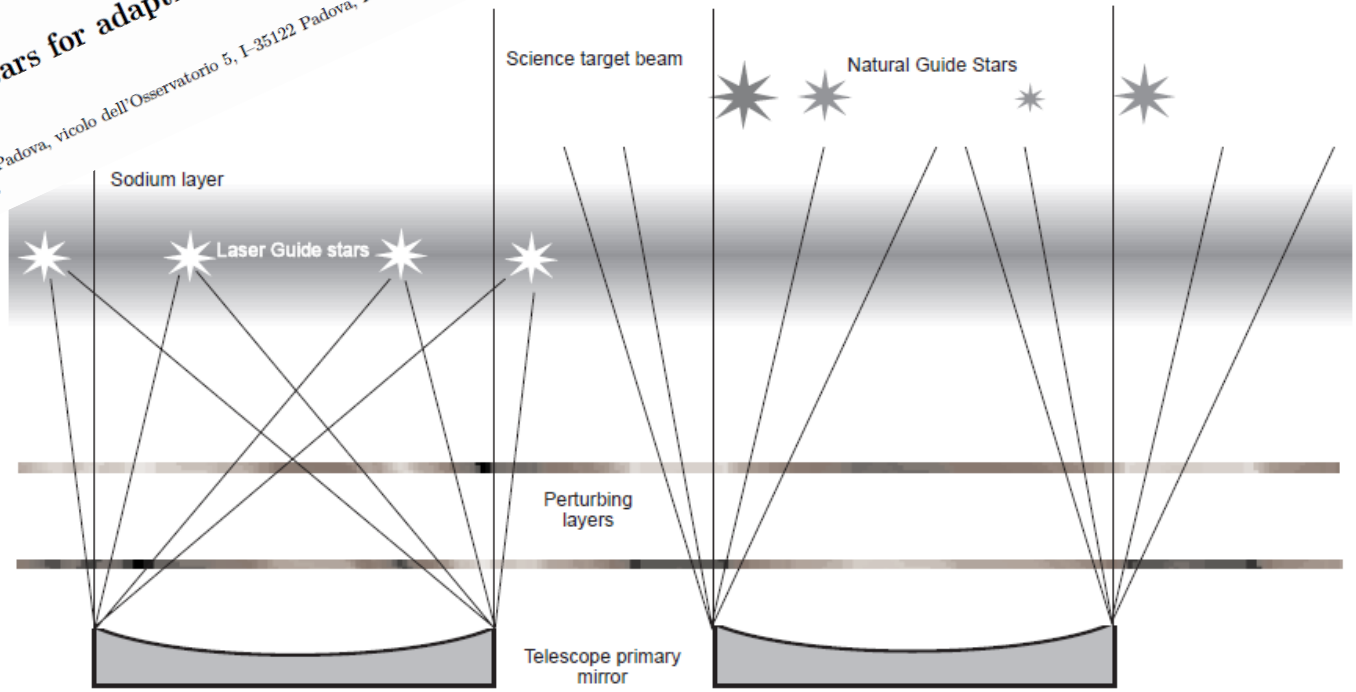
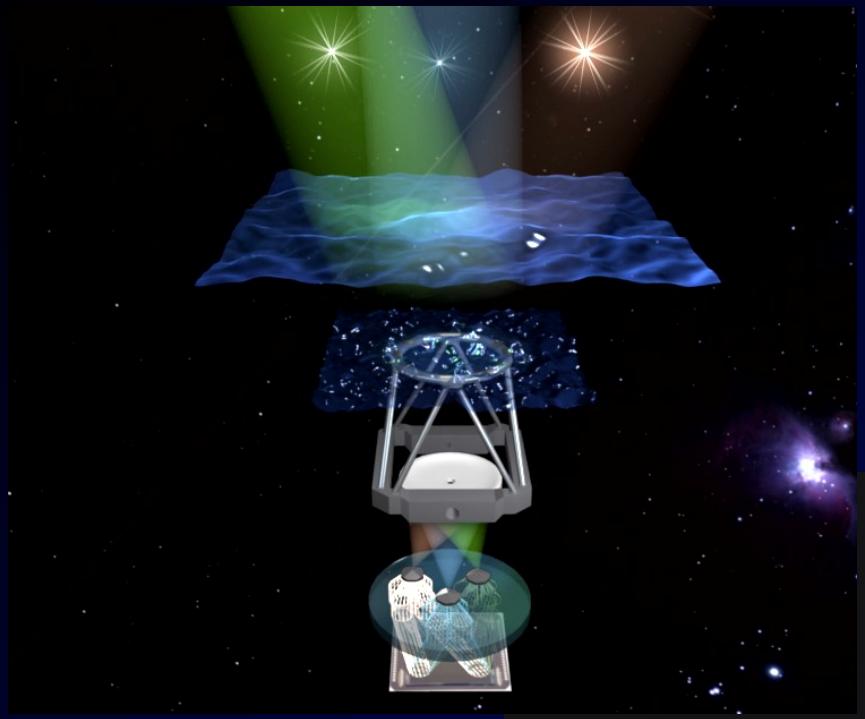
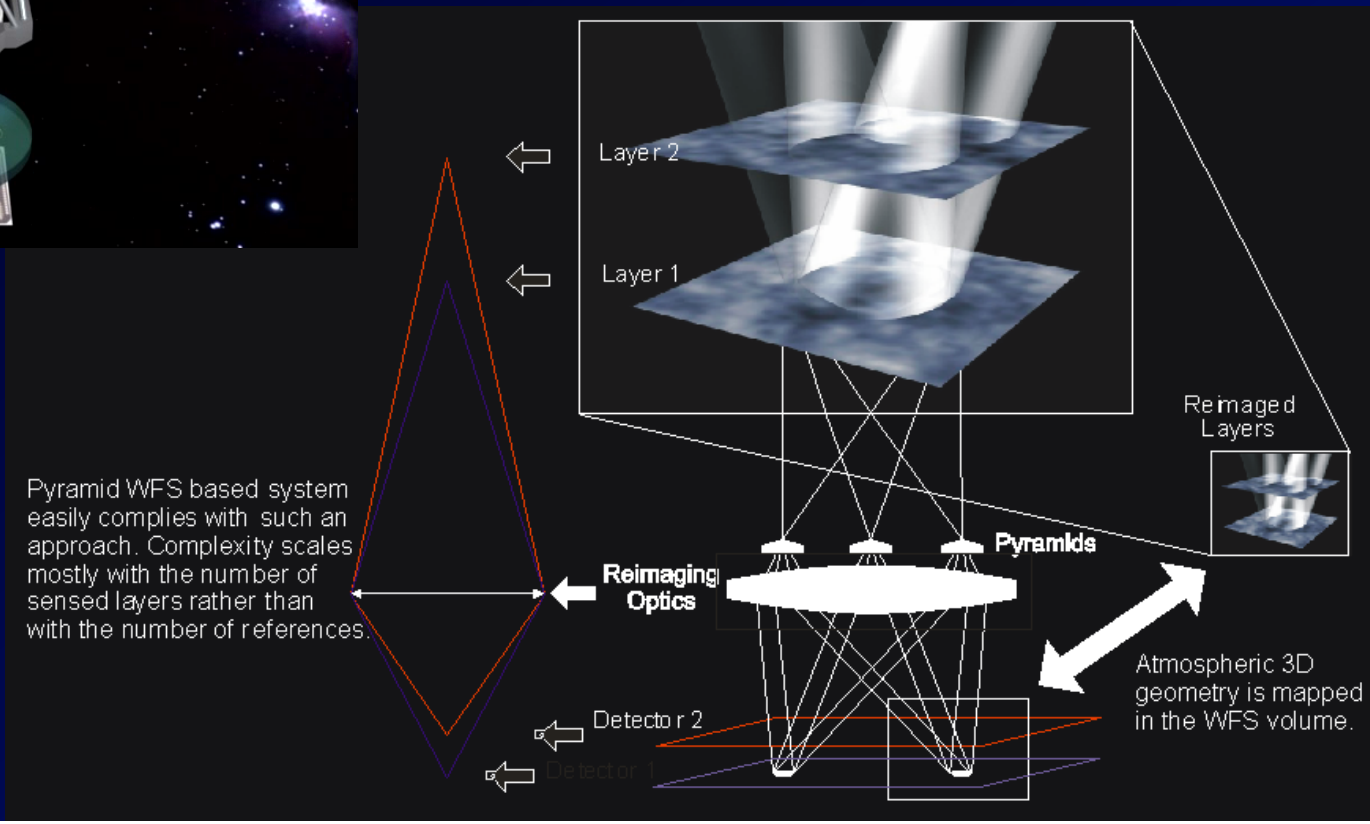


Fig. 1. In this schematic representation the LGS–based tomographic technique (left) is illustrated in a sectional view. In this case LGSs can be fired at some precise locations on the sky and some conical beams *explore* the various perturbing layers. Tilt is to be retrieved in some other way. On the right side the NGS–based case is briefly sketched: the stars have different brightness and are unevenly located on the sky. On the other hand the beams are cylindrical and tip–tilt is retained



MCAO Layer Oriented: the concept

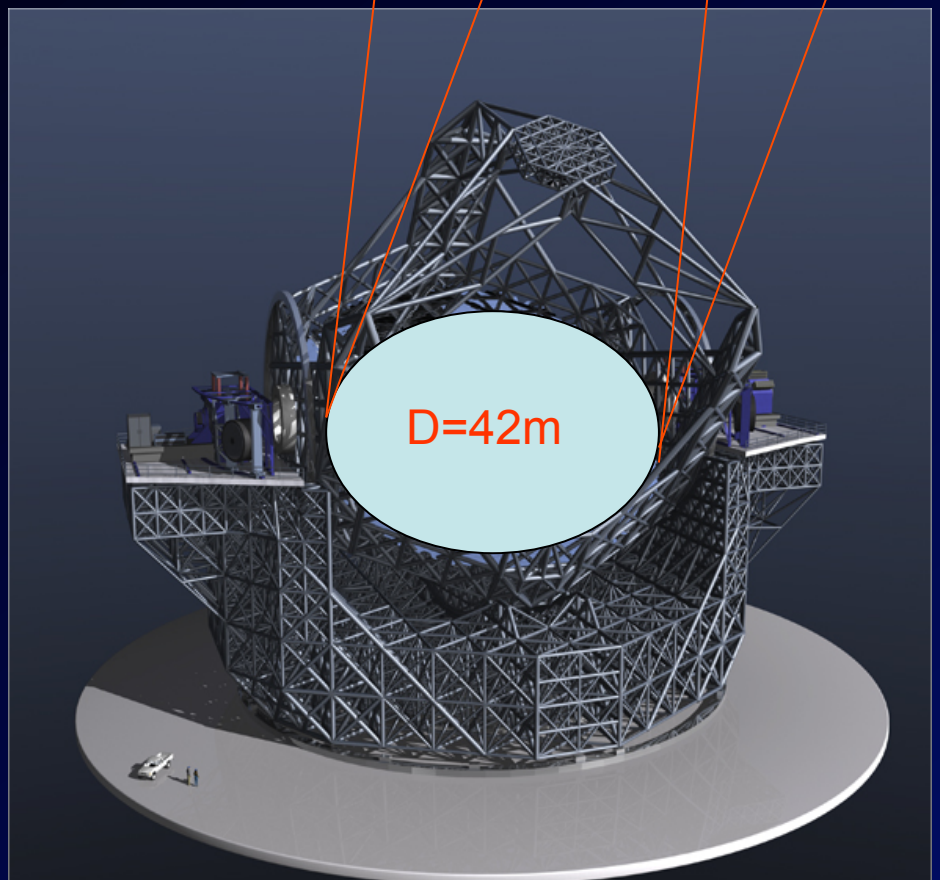


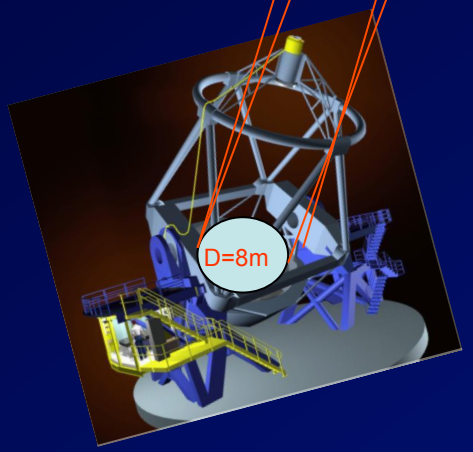
Turbulence layer

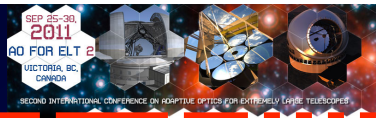
10km

10arcmin

2arcmin







Astrophysics in 2000

VIRGINIA TRIMBLE

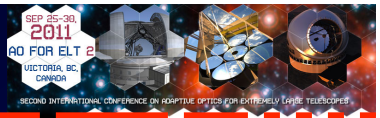
Department of Astronomy, University of Maryland, College Park, MD 20742; and Department of Physics and Astronomy, University of California, Irvine, CA 92697

AND

MARKUS J. ASCHWANDEN

Lockheed Martin Advanced Technology Center, Solar and Astro... Laboratory, Department L9-41, Building 252, 3251 Hanover Street, Palo Alto, CA 94... .com

Adaptive optics is for when you have only one telescope, though if it happens to be Keck II, images of 0″.02 are achievable first time out (Wizinowich et al. 2000). Even the comparatively petite SOR reaches 0″.05 resolution, though its users have had lots of practice (Angel & Fugate 2000, a minireview). Given how hard it is to find even a single guide star for A0, to the point where people make them with lasers, you might suppose that asking for multiple guide stars would render the whole thing impossible. In fact, multiple guide star adaptive optics can apparently be made to work over the entire sky (Ragazzoni et al. 2000, who note that the scheme was first proposed by Beckers 1989). Several other papers in this territory noted that some of their intellectual infrastructure had come from other papers by the same author. Under the circumstances, we think it ominous that he has moved to Chicago, where there are hardly enough guide stars to find your way around the Loop. Some additional papers reporting results achieved with adaptive optics and interferometry appear with their astronomical subjects, as someday clearly all such papers will.



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Being fixed in the meantime as Jacques now lives in starry nights Phoenix…

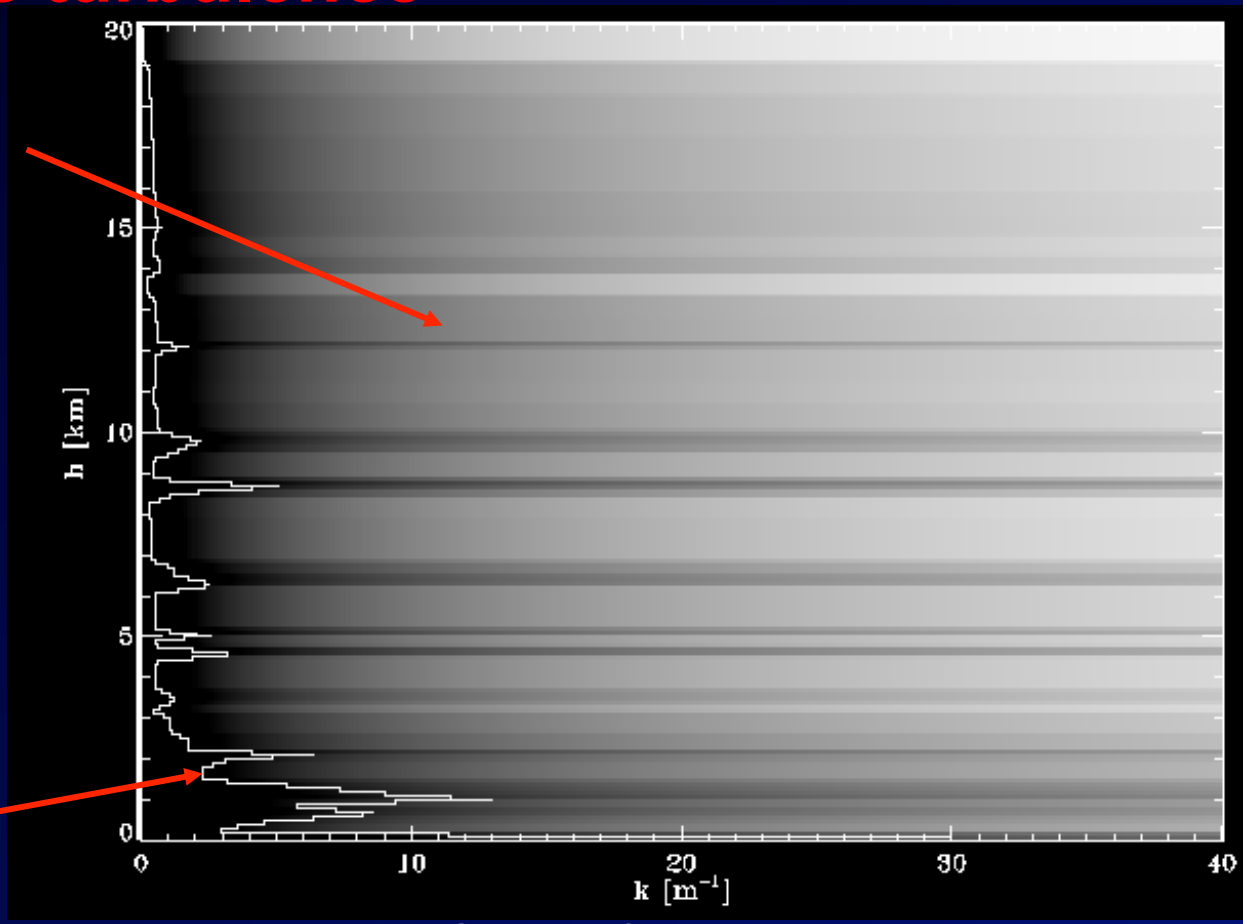
Geometry… geometry…

- In a remarkable series of papers Andrei shows that if you enlarge your FoV to correct *in closed loop* you will unavoidably correct less and less… (see for instance JOSA A 18 873, Venice 2001 conf…)
- And to use a large enough FoV you would need a lot of DMs making the idea impractical…
- *In closed loop*…!!!

A bi-dimensional rappresentation Of the atmospheric turbulence

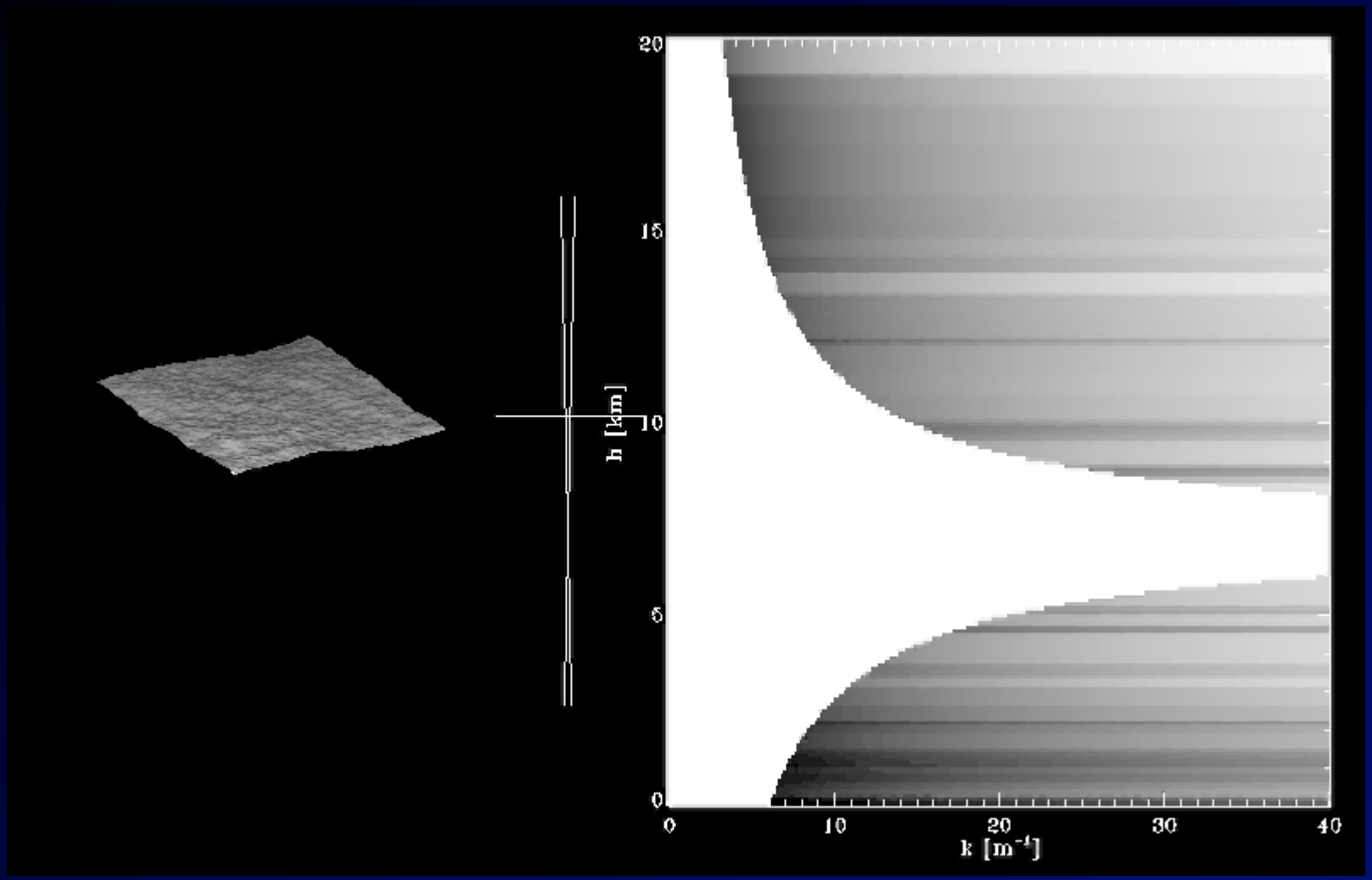
Power spectrum is kolmogorov profiled

Altitude

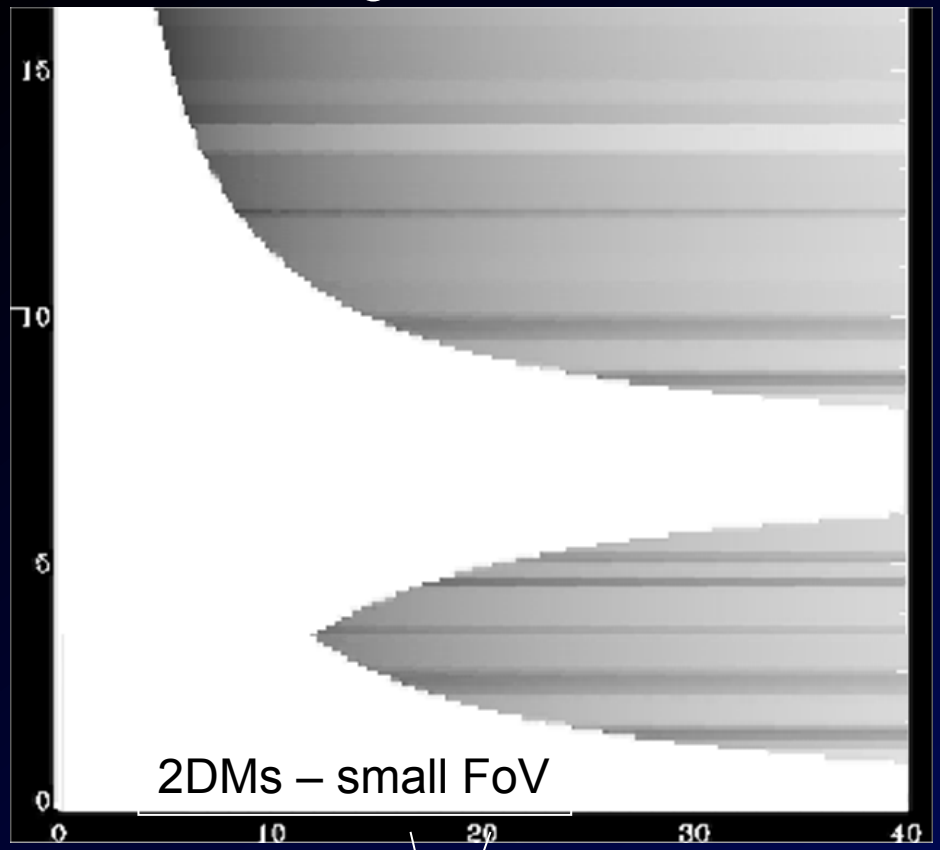


Spatial frequency

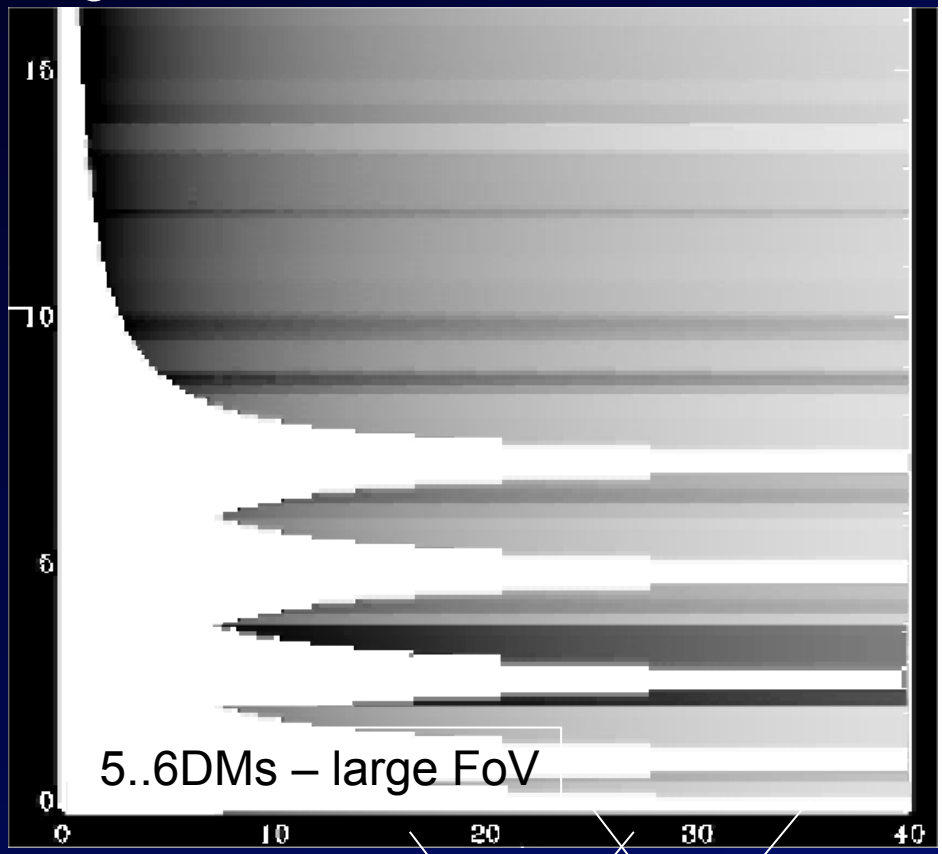
Profile as from Hubin et al. SPIE 4007, 1100 (mean Paranal)

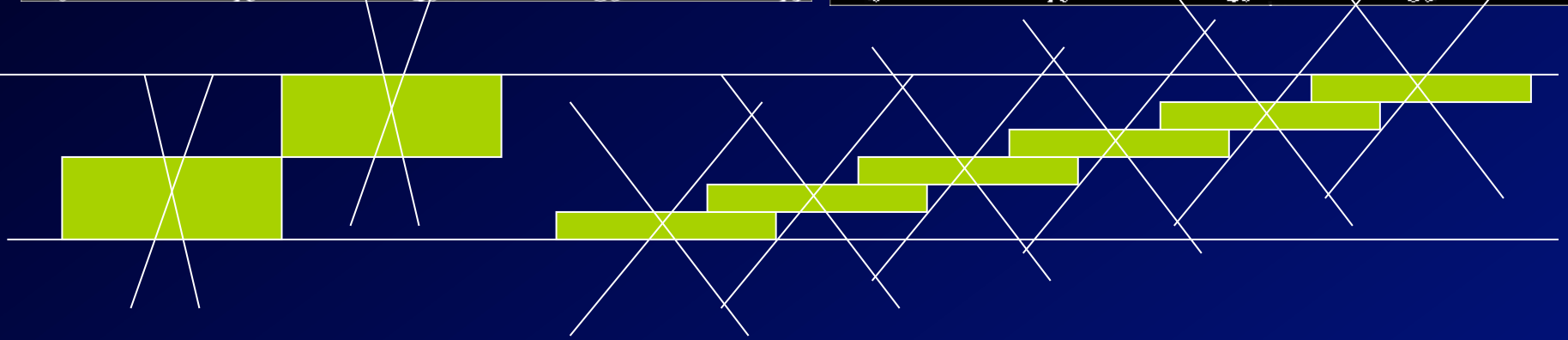

20
15
10
5
0
h [km]
0
10
20
30
40
k [m⁻¹]

Small FoV, large thickness, few DMs



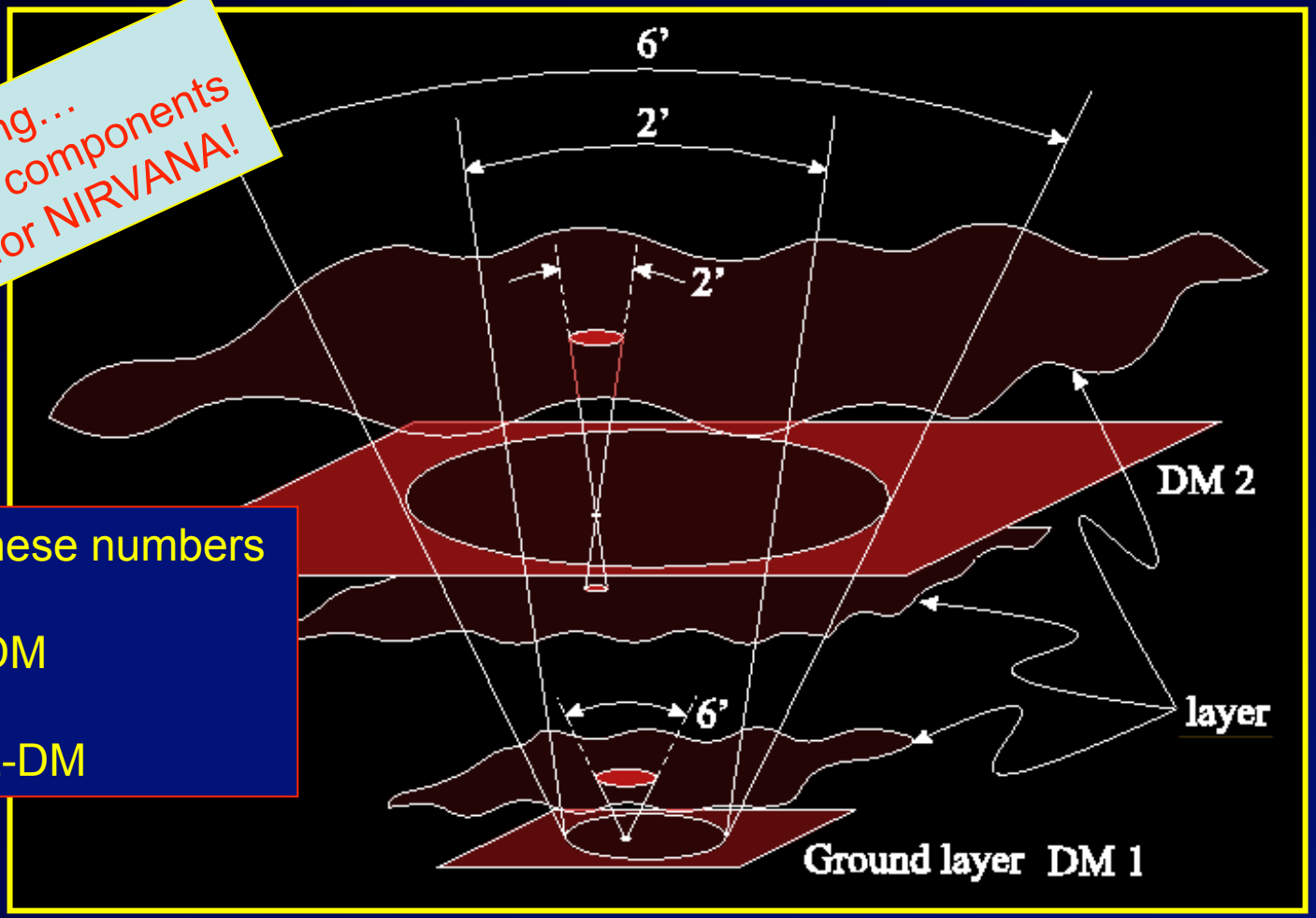
Large FoV, small thickness, more DMs



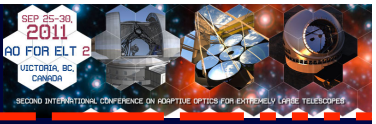


Multiple Field of View

Not just a drawing…
the two 6'WFS components
are the ones for NIRVANA!



But for a 30..42m these numbers can scales up to:
- 10' for the upper DM
- 20' for mid DM
- half degree for GL-DM

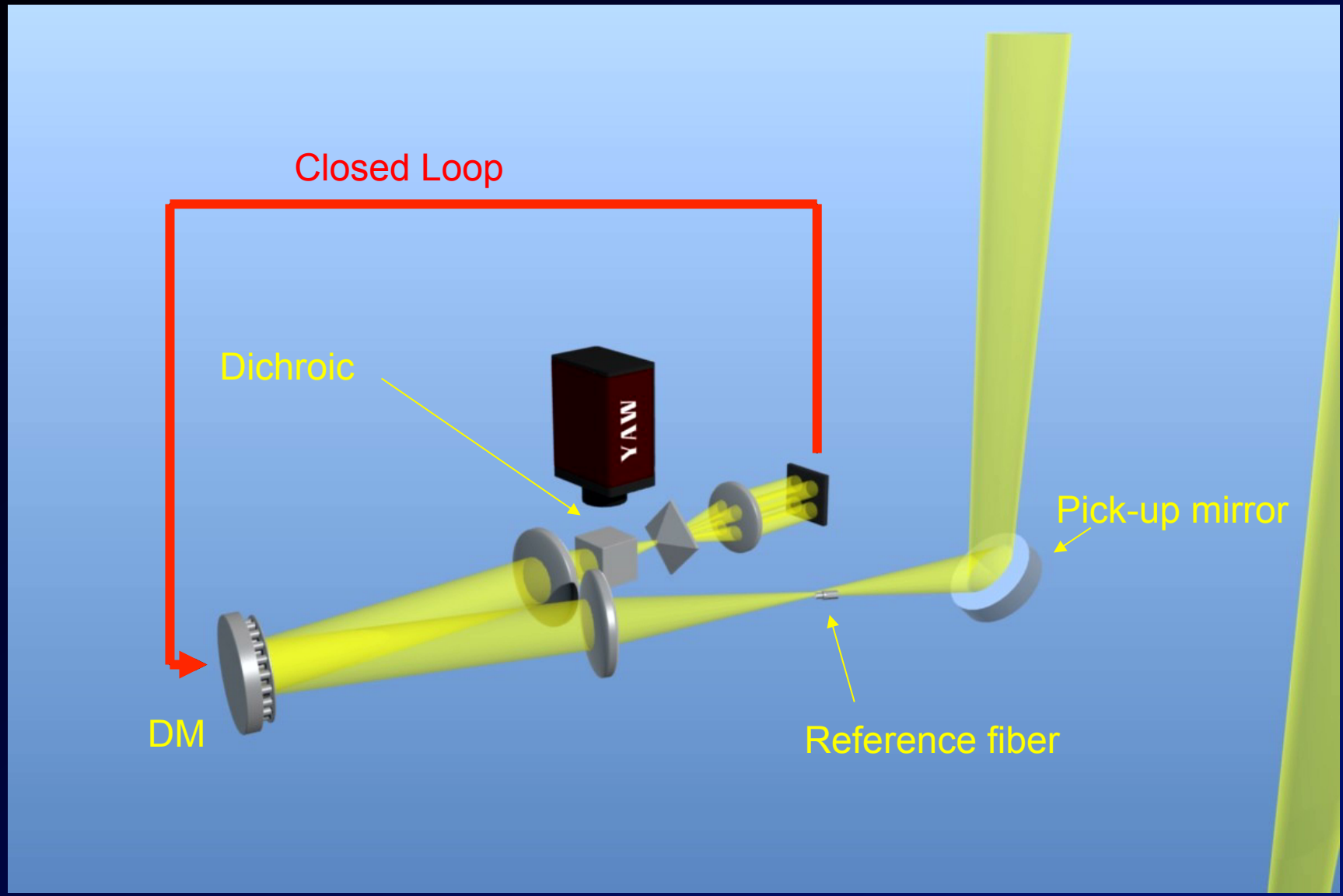


What if…

- The WaveFront Sensor would be extremely linear, so able to measure the absolute Wavefront and not just departure from zero…???
- So the system would not work in closed loop…! (Sounds familiar isn't it…???)
- In this way I could "close the loop" numerically and then decide what to do with the information of the 5..6..n "DMs"
- Introduction of the concept of "virtual DM" (although not the Miska's one for the definition of the interaction matrix…
- Nothing new… as Glenn said!!

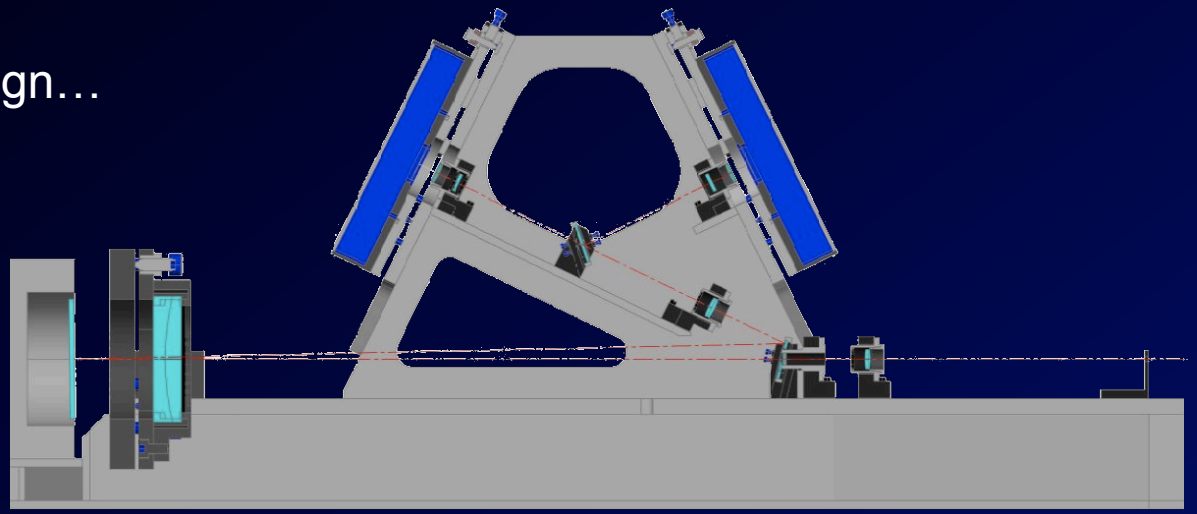
How to do that…???

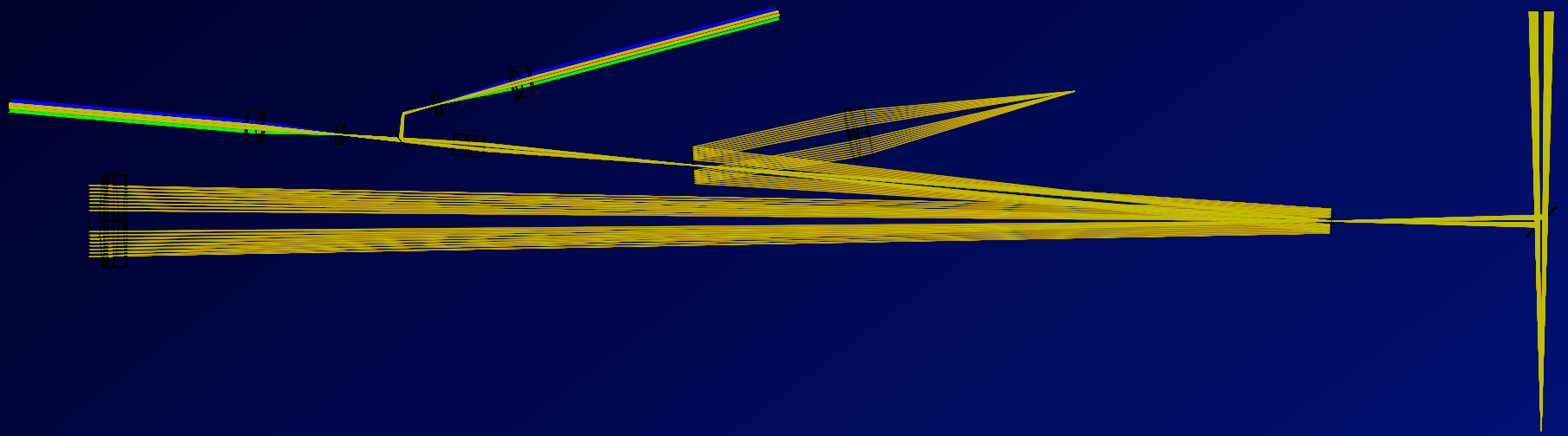
- It is doable (not even easy…) to make a polychromatic very linear WFS at the expense of sensitivity…
- The closest approximation is the YAW by Eric Gendron (insensitive to shape and size of the reference) but monochromatic and trading sensitivity for the linearity…
- …while we want to be sensitive, robust and maybe working in closed loop to take advantage of Pyramids et al…!!!



X

A real optomechanical design…





See the Poster by Demetrio Magrin et al…

Recipe…

- Make an MCAO system with a large enough number of virtual DMs to correct for a large FoV
- Find stars there (NGSs or LGSs, but guess what I prefer…) and fed a Very Linear WFS, maybe working in Closed Loop on a pyramid… ☺
- Extract from the virtual DMs information the one you need to correct your smaller FoV (or your MOAO directions)
- Close the loop using any kind of referencing

Part III - No Laser Guide Stars…

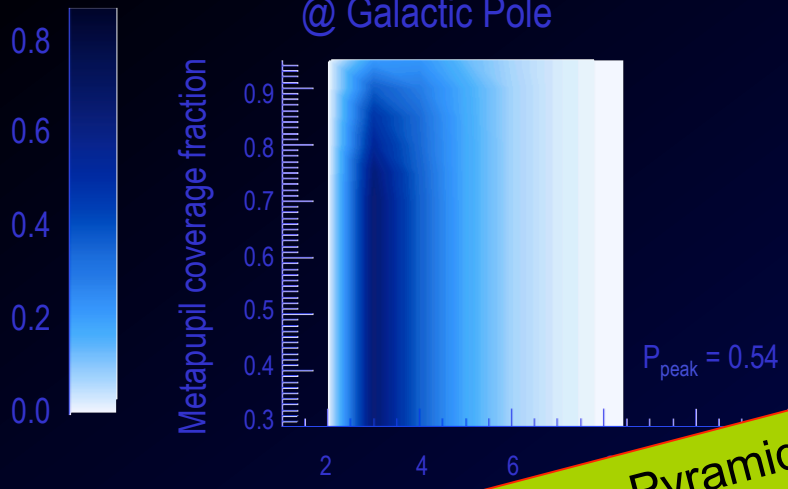
- The two arguments for LGSs being preferable to NGSs are:
  - Sky Coverage
  - PSF uniformity
- The arguments for NGSs being preferable to LGSs are:
  - Cheaper
  - Reliable
  - Safer
  - ….

Sky Coverage

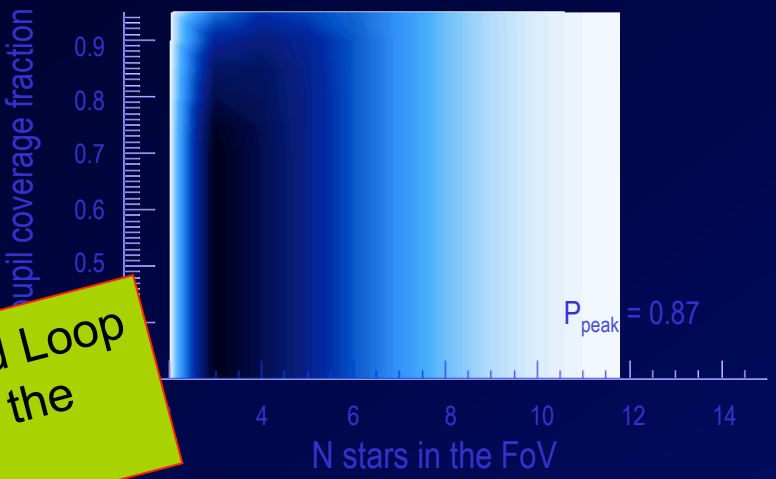
- We so much agree with Ric that we made LOST to assess Sky Coverage on real sky catalog…
- But I understand the key issue of science bias (I want to observe **that** object!)
- However the argument is true when the FoV where you statistically look for star is small in contrast with the 10’ (and even more if M-FoV would be allowed…)

Superior of 3,5,7 stars constellations results:

Limiting magnitude: R_{MAX} =14.25 mag @ Galactic Pole

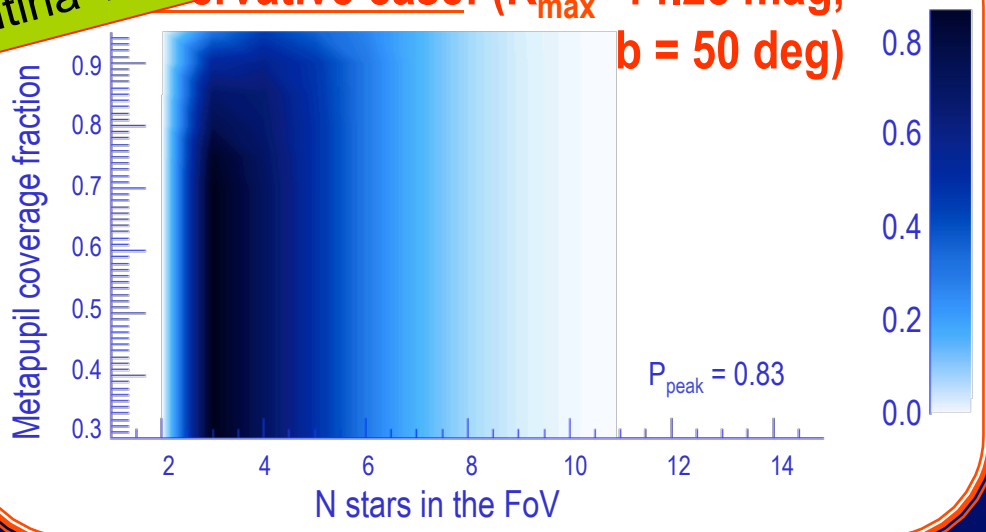


Limiting magnitude: R_{MAX} =15.25 mag @ Galactic Pole



Combining the gain of the Pyramid in Closed Loop and virtual DMs looking at 10arcmin…. See the Poster by Valentina Viotto et al…

…rvative case: (R_{max}=14.25 mag, b = 50 deg)



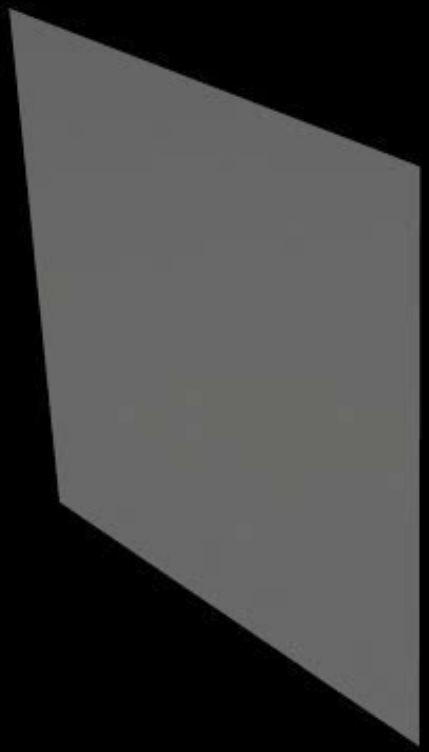
PSF Uniformity…

- That's right… so we should *compare* the uniformity of LGSs fixed pattern with the one of several stars in the 10'FoV….
- Having stars often away from the science FoV will probably lead to good uniformity (J. of Ragazzoni's conjectures, 2011)
- And I must note that several of the results obtained so far with MAD (SH mode) are obtained with Strehl variations as large as 5… (see for example MNRAS 391, 1650)
- LGSs MCAO also exhibits non uniformity…

Still LGSs can be useful…

- To keep busy Francois…
- To detect clouds…
- To make spectacular pictures (of the telescope and the laser)….
- To allow to speak with high rank military…

1000 Y/ms



1000Y/ms