What kind of performances can we hope for ELT?

Rather than "assuming" performances I prefer to describe

requirements derived from science priorities

technology goals proposed for the ELT FP6 studies

potential performances (if the studies are succesful)

subjects

- Performance of AO
    - performance for planet-finding
    - performance at visible wavelengths
- Field-of-view attainable
    - in seeing-limited modes (imaging & spectroscopy)
    - in corrected modes
- Emissivity

AO performance for planet-finding

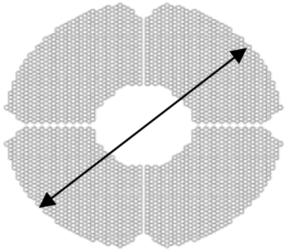
The ELT science objective identified in Marseille is not simply "planet-finding" but ***the study of a large sample of earth-like planets***

This science goal has implications on:

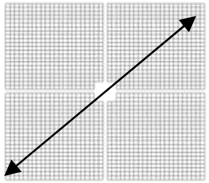
Telescope size (50-100m)
Segmentation geometry (segment size, shape, gap)
Site selection (r_0 τ_0)

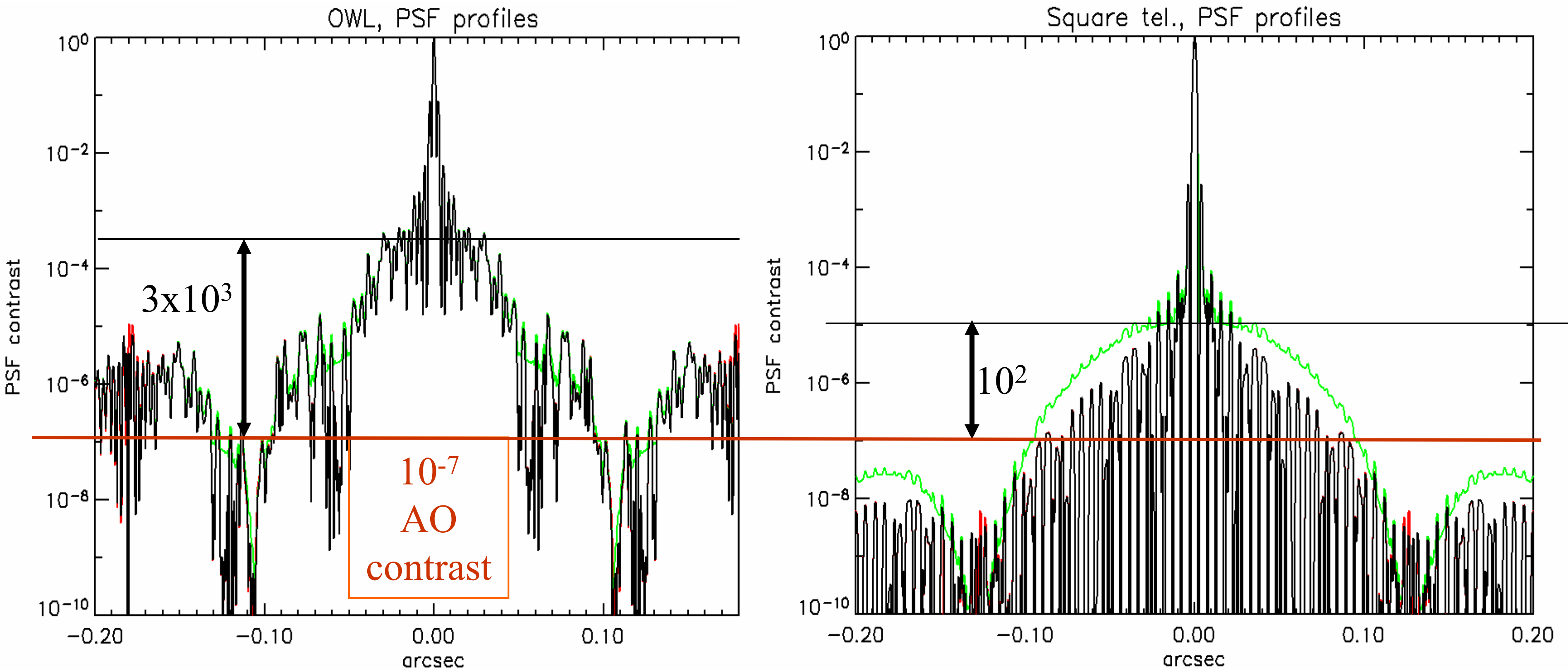
And, concerning AO, on:

Actuator density (~100/m^2)
Segment differential piston control (~ 2 nm rms)
Control bandwidth (> 2 kHz)



"100 m" analitical PSFs





Black, no gaps — Red, 10mm gaps — **Green, 23nm rms wf piston**

Coronagraphy can remove most of the structure, *BUT NOT Δ-PISTON*

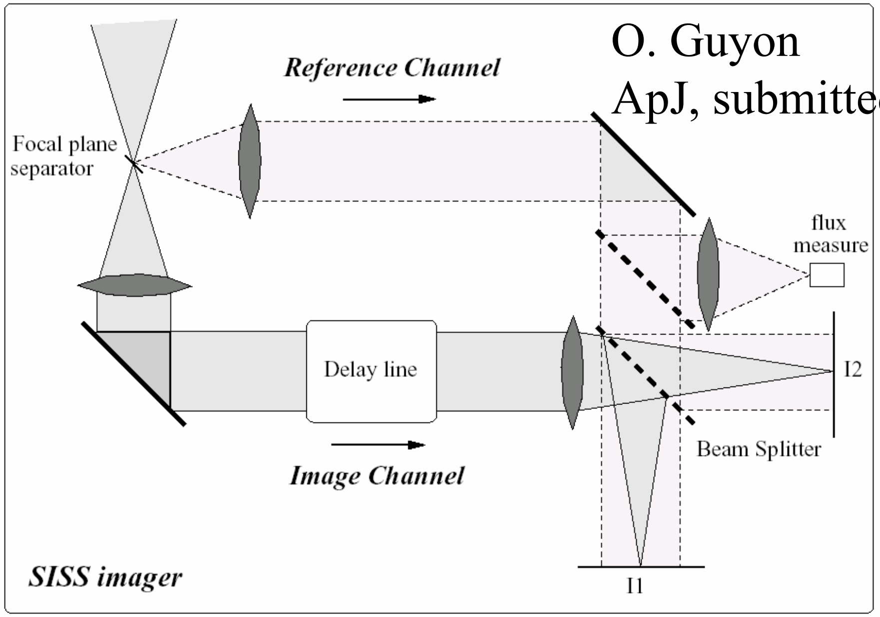
Is Piston Error the *show stopper*?

Segment differential piston error sends light mostly within an angle α ~ λ/d (d=segment size)
To reduce the piston problem we could:

- **use much larger segments**, to obtain α ~ 20-30 mas (d >5 m at V)
  (doesn't work at longer wavelength)
- **use much smaller segments**, to obtain α > 1000 mas (d< 0.2 m at V)
  (this works well in principle, but the number of segments diverges and their control becomes a new big problem)
- ***reduce piston rms error by ~ an order of magnitude*** (from ~20 nm to ~ **2 nm rms wf**)
  Scaling from Esposito et Al. 2003 one finds that 2 nm rms WF differential piston error can be measured by a Pyramid WFS on a star of mag ~ 8 with sufficient bandwidth (tens of Hz) to control segment vibrations and atmospheric terms.

Differential piston MUST (and can) be controlled adaptively!

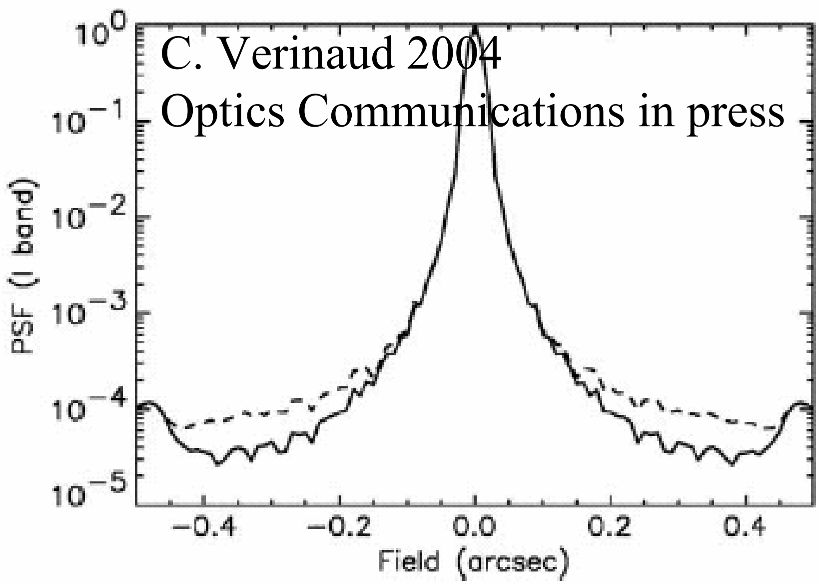
A field in fast evolution: recent progress



O. Guyon
ApJ, submitted

SISS (Synchronous Interferometric Speckle Subtraction) = Specles are coherent with the central source, Planets are not!

The SISS technique can provide photon noise limited planet detection even in the presence of strong and rapidly varying specles in the field. SISS can be combined with coronagraphy and Closed-loop speckle suppression



C. Verinaud 2004
Optics Communications in press

Fighting Aliasing

The dominant term in AO residual is due to aliasing of non-corrected high spatial frequencies. Using a Pyramid WFS instead of a SH WFS can Reduce the scattered light by a factor of ~4
Spatial filtering can be added . . .work in progress

AO for planets: most relevant FP6 studies

Approved

(Opticon Joint Research Activities)

- Within JRA1: "Second Generation Adaptive Optics for 8-10m Telescopes"
  - **WP 2.1: Extreme AO** (XAO) design for **VLT**
  - **WP 3.10**: High Order WFS Experimental Study.

Proposed

(Technology development towards a European Extremely Large Telescope, EELT)

- Within Work Package 9000, (~ 10 M€)
  - WP 9300: Large format, high density DMs R&D (~ 5 M€))

  which includes:

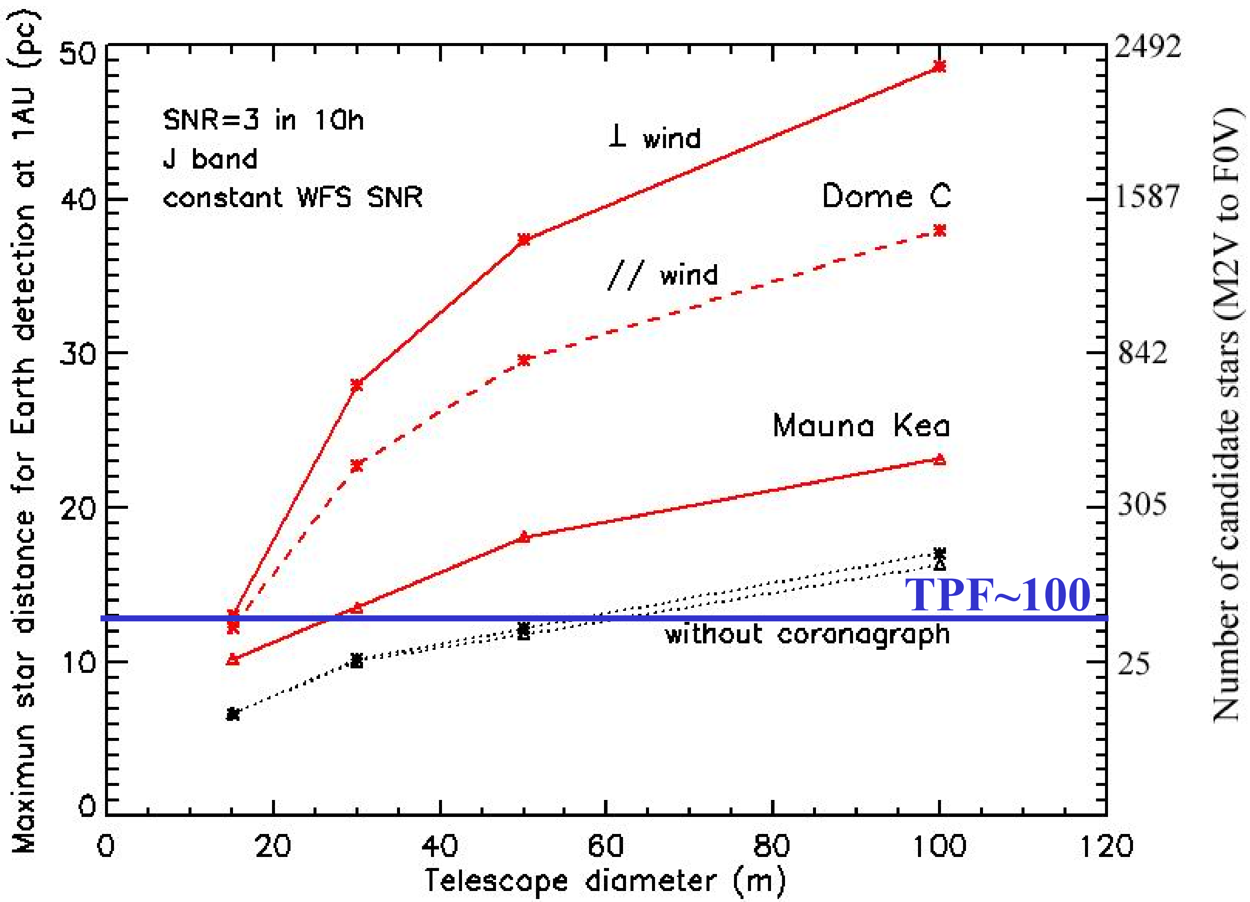
  - Development and Prototyping of large adaptive mirrors,
    (for monolithic or segmented secondary and primary mirrors)
  - Development and prototyping of buttable piezo-actuated deformable mirrors

Potential performances

With a **~ 30 m** telescope
at “Mauna Kea”
one **could explore** at short
wavelength the entire
TPF (goal) sample
of **~ 100 stars**
in **1000 hours**

With a **100 m** telescope
in “Antarctica” one could
obtain **R > 1000 spectra**
of the
TPF sample
at short wavelength
(R to K)
in **1000 hours**

O. Lardiere et Al. 2003



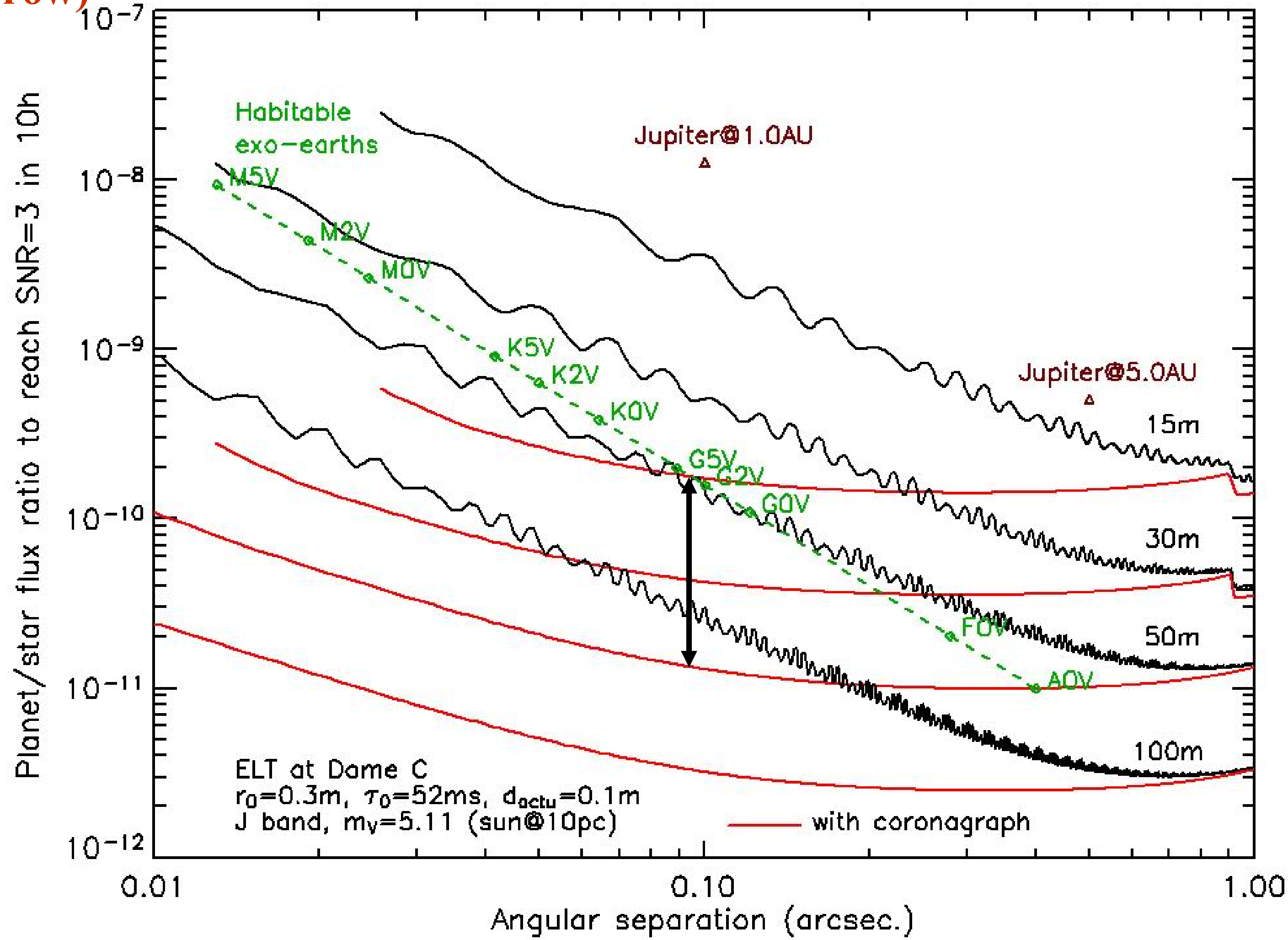
Potential performances (Lardiere et Al. 2003)

In Antarctica @ "DomeC"

Example (see black arrow)

The Sun-Earth system
At 10 PC
Would be detected
In J filter ($R_J = 4$)
By a 50 m telescope
with ~2x10^5 actuators
In ten hours
At S/N ~ 30.
(in 6 min at S/N 3)

Spectroscopy with
S/N ~ 5 (per sp. el.)
At R=144
[$R= R_J *(30/5)^2$]
Would also require
About ten hours

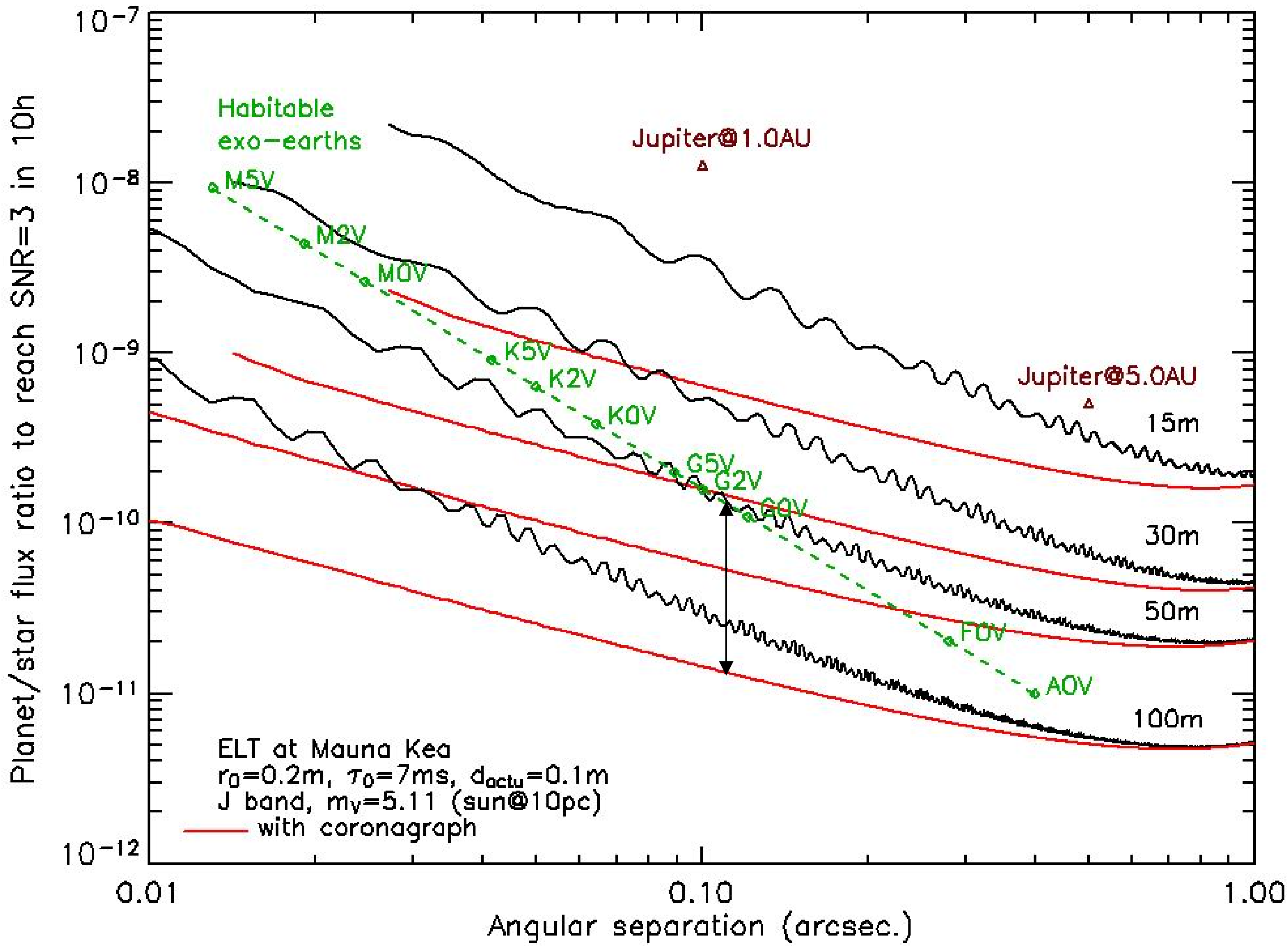


Potential performances (Lardiere et Al. 2003)

@ "Mauna Kea"

Same Solar case,
Same arrow (factor 10)
Same performances

Now one needs:
A 100 m telescope
with ~ 10^6 actuators



AO at visual wavelength

Science requirements:

Resolving and studying stellar populations in distant galaxies is the main driver for AO at short wavelength.

This goal has implications on:

Telescope size (50-100m)

Site selection (r_0 τ_0 h_0)

And, concerning AO, on:

Corrected field (~1/2 arc min MCAO)

Strehl ratio (>30%)

(total) actuator density (~50/m^2 =30+10+10)

AO at visible wavelengths: most relevant FP6 studies

(Studies mentioned in "AO for planets" +)

Approved

(Opticon Joint Research Activities)

- Within JRA1: "**Second Generation Adaptive Optics For 8-10 M Telescopes**
  - **WP 2.2, 2.3, 2.4, 2.5 : L/NGS MCAO** design for the **VLT, LBT, GTC**
  - WP 3: Enabling technology for 2nd generation/ELT AO systems.

Proposed

(Technology development towards a European Extremely Large Telescope, ELT)

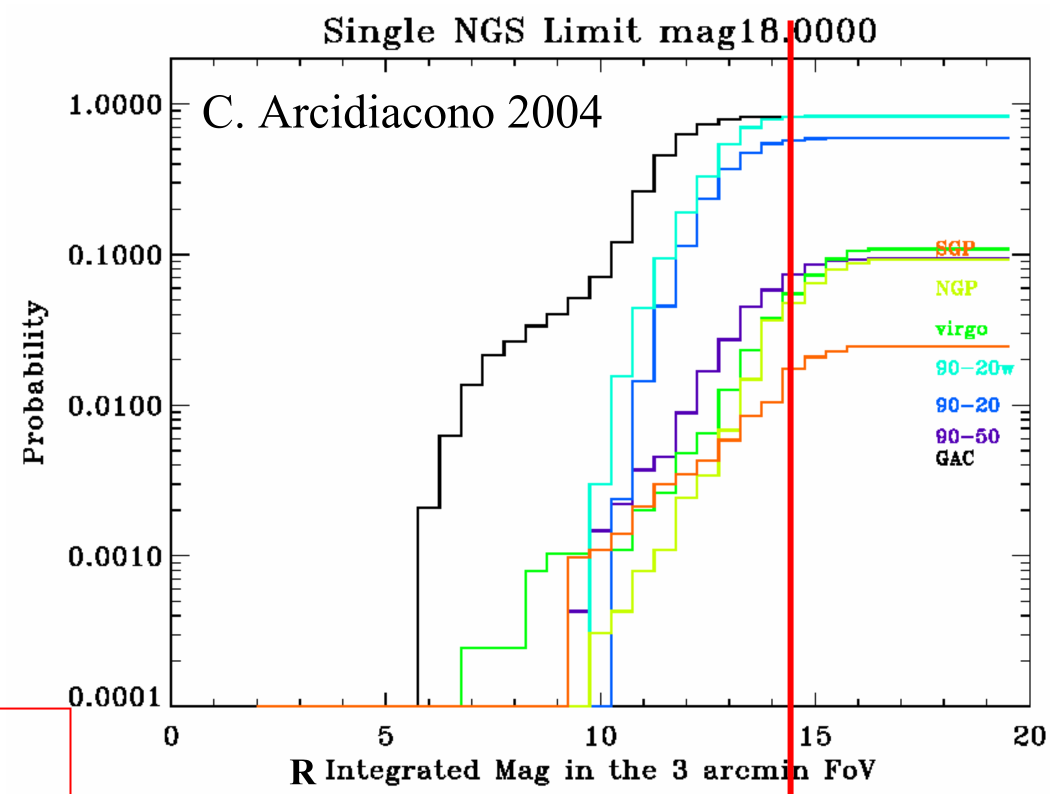
- Within Work Package 9000, (~ 10 M€)
  - WP 09100 100m-Layer WFS experiment
  - WP 09200 AO & MCAO design for ELTs
  - WP 09400 Novel AO concepts (includes LGS)
  - WP 09500 AO & MCAO simulations
  - WP 09600 Algorithms for reconstruction & control
  - WP 11100 MOMSI (Multi-Object and Multi-field Spectrometer and Imager for operation with MCAO in the NIR/optical)

AO performance at visible wavelengths (NGS)

Single Conjugate AO:
Even a partial success of the technical developments for Exoplanet AO would allow **excellent Strehl ratio** (~80%) at visual wavelengths **near bright stars** (m_R <12).

MCAO
(Numerical, LO, triple conjugate)
The best one could do is:
- < 1 arcminute field at V
- ~ 30% Strehl (trade-off with field) with
- < 25 NGS (each with m_R <18)
- 6 arcmin Ground Layer Field
- 3 arcmin High Layers Field

~5% sky coverage @ NGP, ~10% @Virgo Cluster



$r_{0\text{-high}}$=40cm

"Seeing limited" (optical, NIR) field requirements

Science requirements:

High redshift galaxy clustering and dark matter distribution drive the seeing limited field requirements (>10 arcmin)

This goal has implications on:

Telescope size (50-100m)
Site selection
Instrument design

Relevant studies

Proposed

(Technology development towards a European Extremely Large Telescope, ELT)

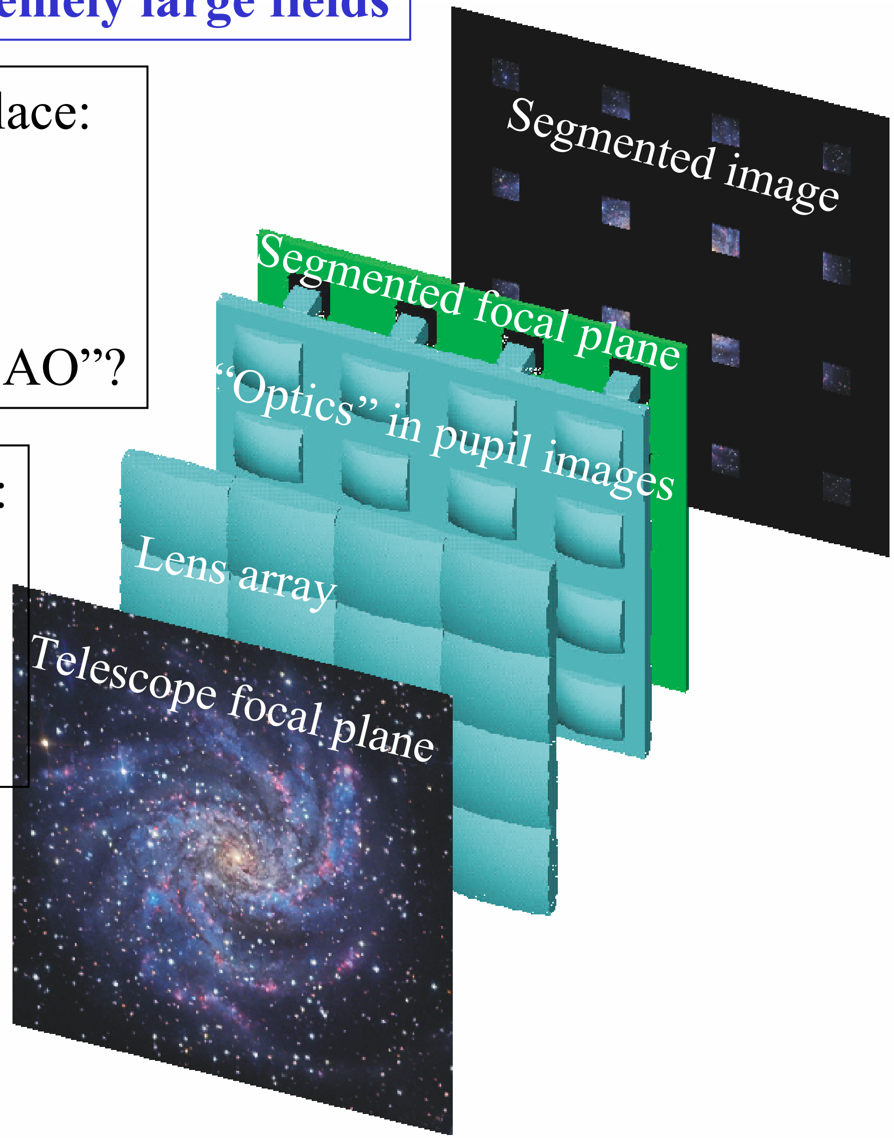
- Within Work Package 11000 (Instrumentation)
  - WP 11100: WFSPEC (Wide-Field seeing-limited or Boundary-layer-corrected Optical/NIR Spectrometer)
  - WP 11200: Other design prospection
- Within Work Package 12000 (Site Characterization)
  - Characterization of sites (including Antarctica)

"Seeing limited" field of view (in imaging and spectroscopy)

The ***Fly-Eye concept*** (Ragazzoni et Al. 2004) opens the perspective of **extremely large fields**

In the "**segmented focal plane**" one can place:
- imaging detectors
- fiber feeds (IFUs, . . .)
- any array of (compact) instruments
- . . . maybe even "local double-conjugate AO"?

The **"optics"** near pupil images is used for:
- correcting (static) field aberrations
- compensating atmospheric dispersion
- filtering
- re-imaging on the appropriate pixel scale



Boundary layer correction: Field requirements

Science requirements:
Same as "seeing limited",
High redshift galaxy clustering and dark matter distribution drive the field requirements

This goal has implications on:

Telescope configuration (Gregorian?)
Site selection (boundary layer r_0 ,h)
Instrument design

And, concerning AO, on:

Main corrector (adaptive secondary?)

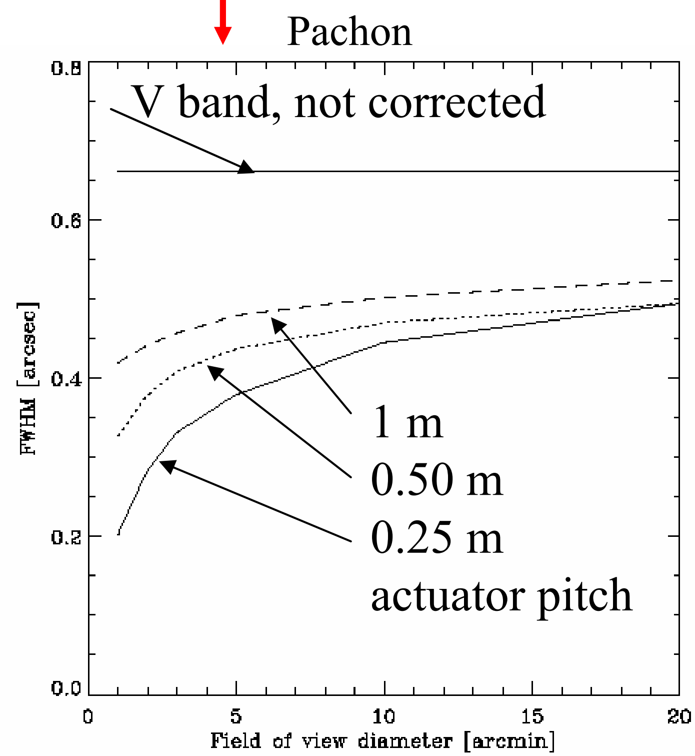
Relevant studies

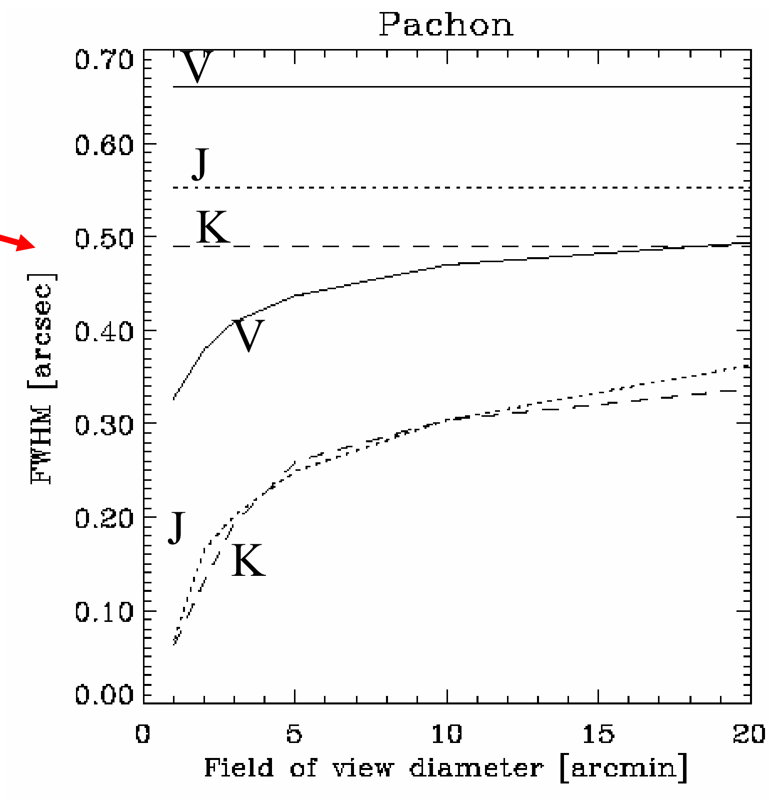
All already mentioned in previous lists:

- Adaptive secondary mirrors (monolithic or segmented)
- Techniques for MCAO
- Site characterization
- Instruments

Potential performances (F. Rigaut 2002)

Temperate sites





Antarctic Plateau sites:
> 10 arcmin at V
with 0.1 arcsec FWHM
???

Emissivity

In the Thermal IR

(λ>2 µm)

AO is "easy"

Therefore a single corrector

(without re-imaging, like a secondary or the primary adaptive mirror)

is the solution.

Summary of optimum telescope configurations

Exoplanets:
- **Two** telescope mirrors (off-axis, square pupil)
- **One** corrector (order **100/m^2**, segmented as M1)

Optical-NIR Bound. Lay.
- **Two** telescope mirrors (~ any configuration)
- **One** corrector (order **20/m^2**, for boundary layer)

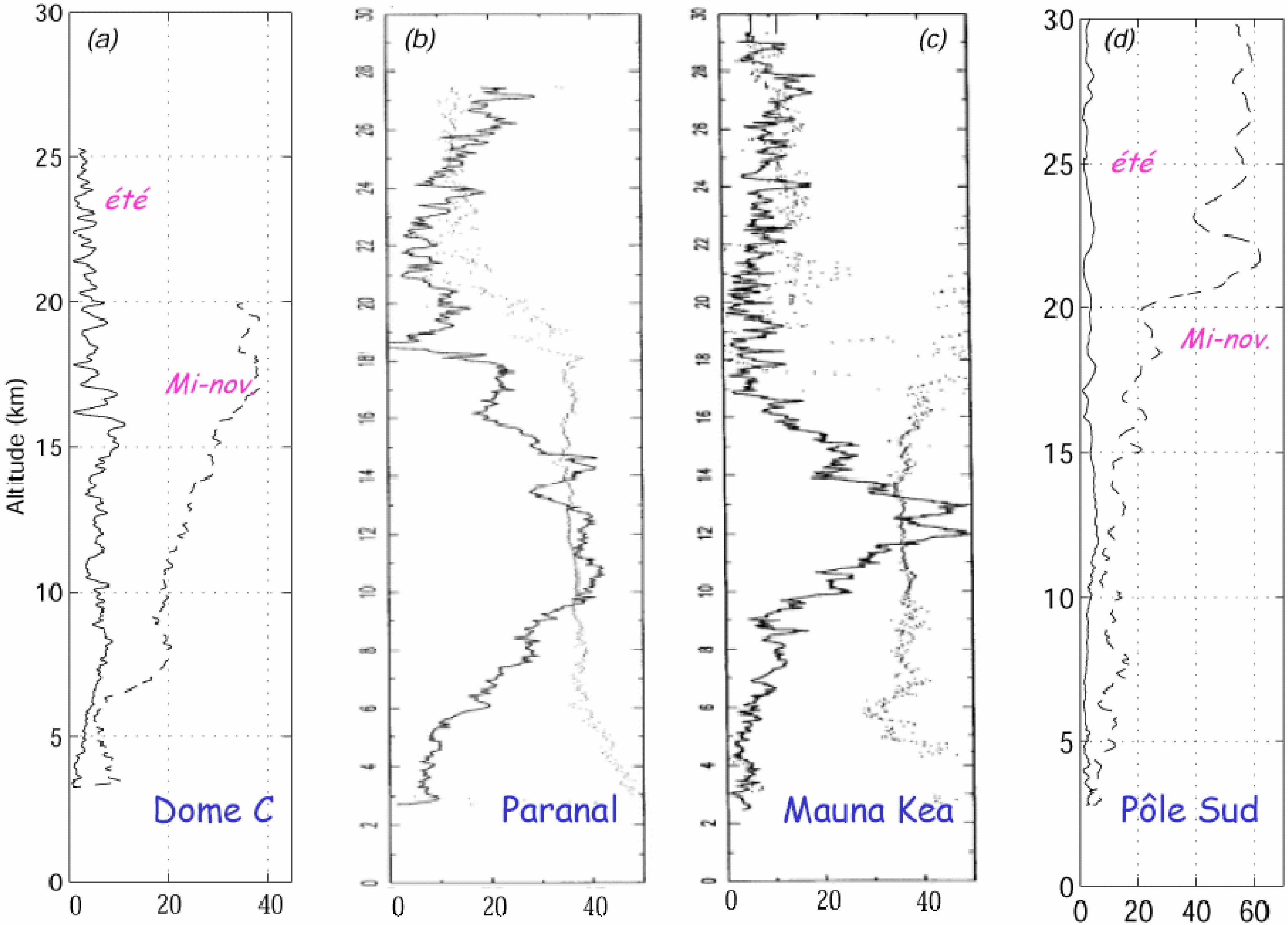
"Thermal" IR
- **Two** telescope mirrors (~ any configuration)
- **One** corrector (order **10/m^2**)

Visual AO
- **(≥) Two** telescope mirrors (four would be better)
- **(≥) Three** correctors (highest order ~ **30/m^2**)

A two mirror telescope with one corrector in the telescope
of order **100/m^2**
can do all the above
(add two post-focus correctors of order **10/m^2** for Visual AO)

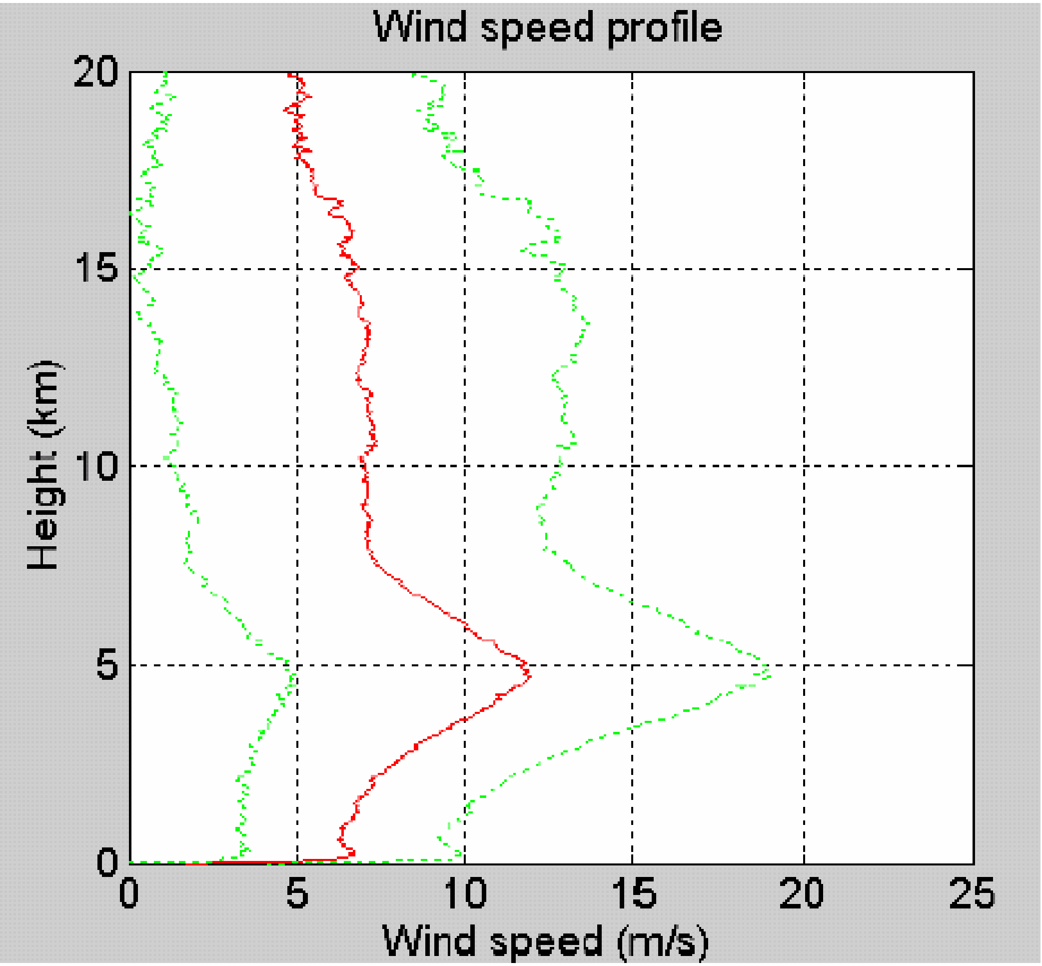
What is special about Antarctica: Wind profiles

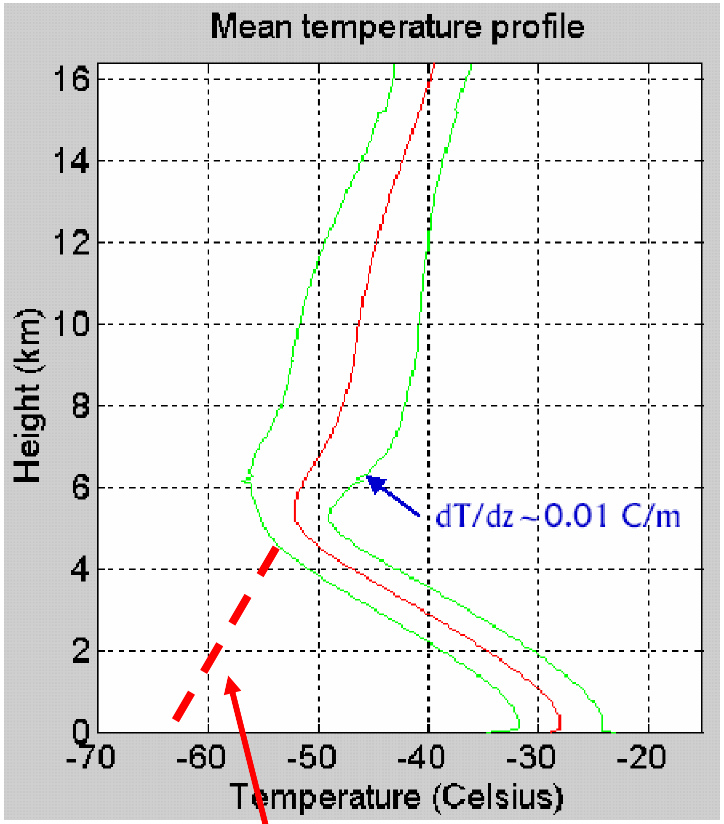
(http://www-astro.unice.fr/Aristidi_HRA_20040309Nice.pdf)



What is special about Antarctica: Low (summertime) tropopause

(http://www-astro.unice.fr/Aristidi_HRA_20040309Nice.pdf)

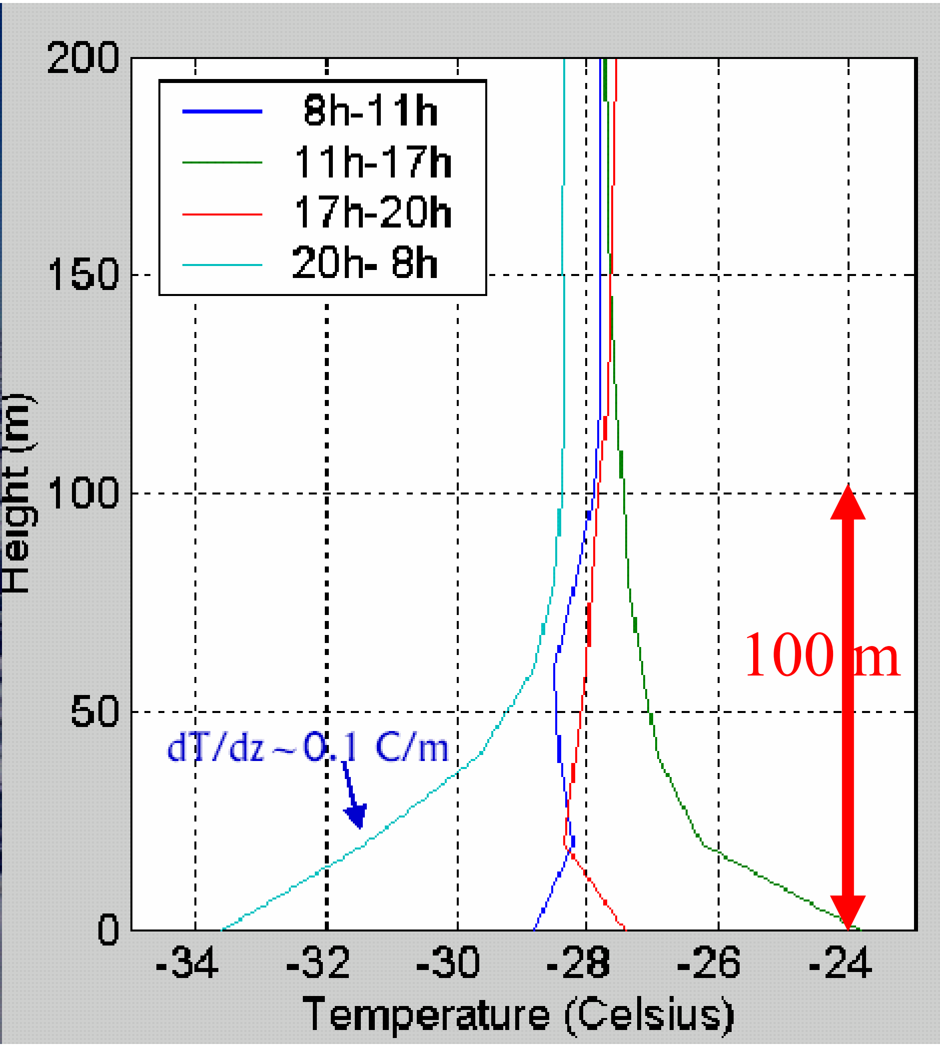


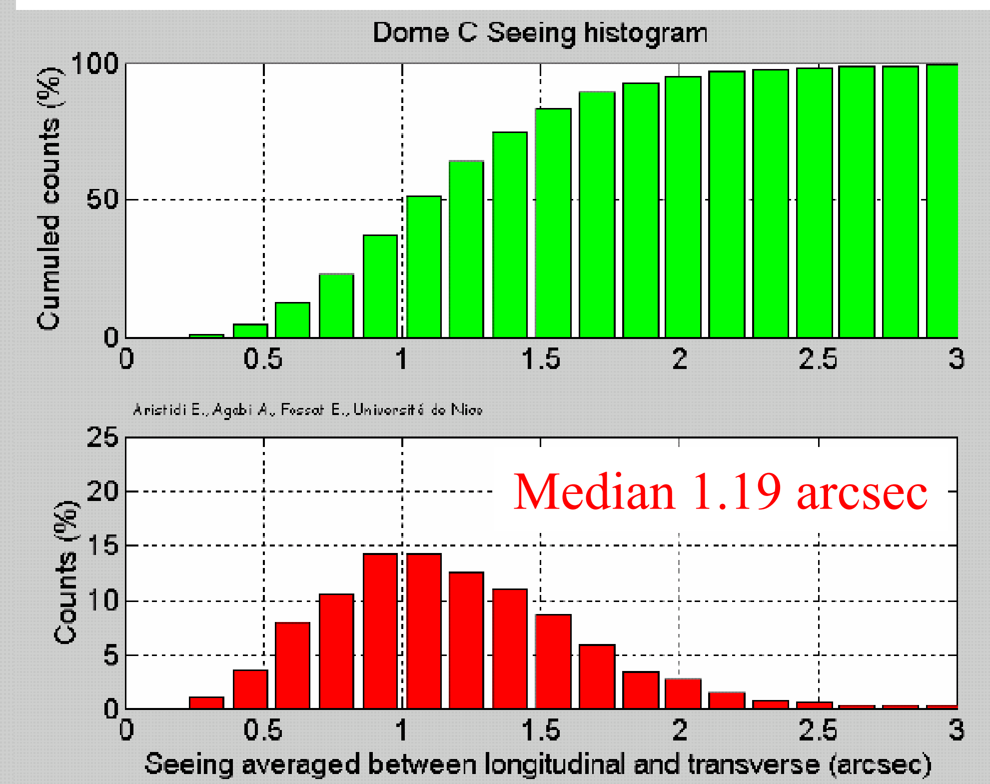


No tropopause in wintertime??

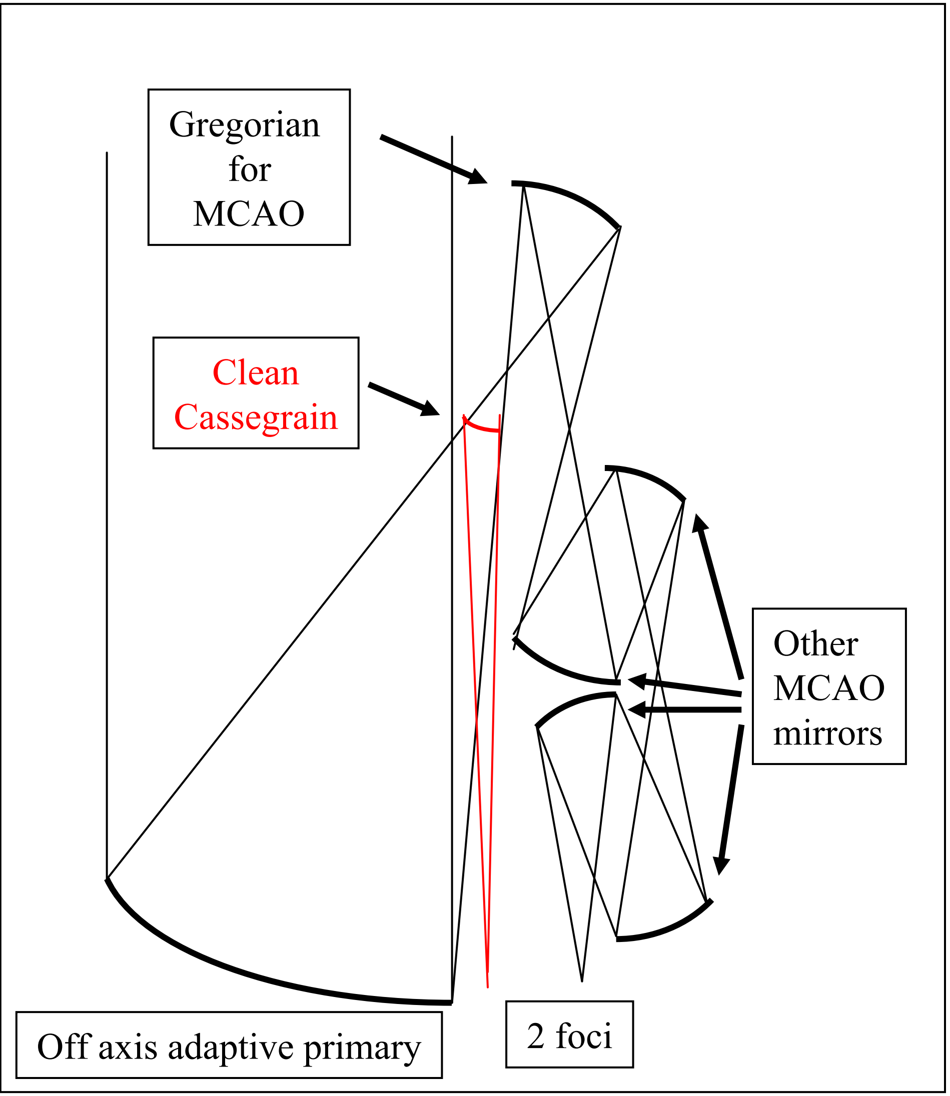
What is special about Antarctica: VERY thin boundary layer

(http://www-astro.unice.fr/Aristidi_HRA_20040309Nice.pdf)





Can we have everithing with a single telescope?



Why not?

- Choose the Primary for exoplanets: (square adaptive segments, off-axis)
- use a small flip-in Cassegrain secondary for a super-clean, small field, focal station
- Use an adaptive Gregorian and two (or more) additional adaptive mirrors for MCAO
- AND
- ***Place the telescope in Anctartica!***