SPHERE

(Spectro-Polarimetric High-contrast Exoplanet REsearch)

A Planet Finder Instrument for the VLT

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and numerous participants from 12 European institutes !

IPAG, MPIA, LAM, ONERA, LESIA, INAF, Geneva Observatory,
LUAN, ASTRON, ETH-Z, UvA, ESO

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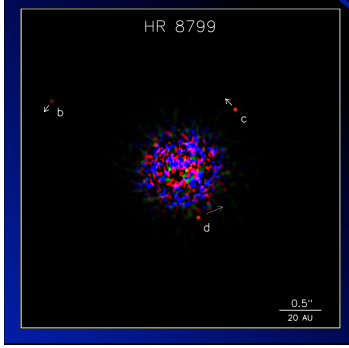
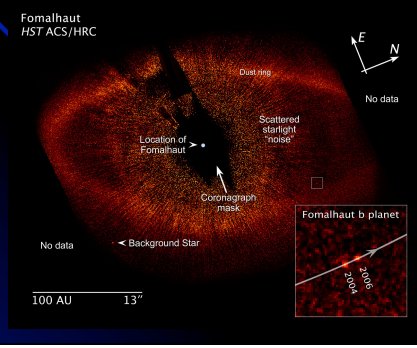
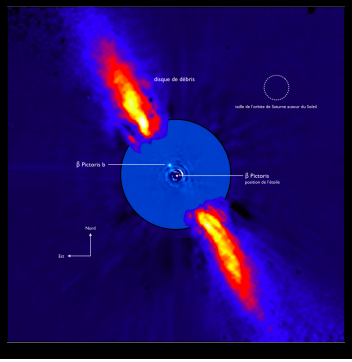
Science objectives

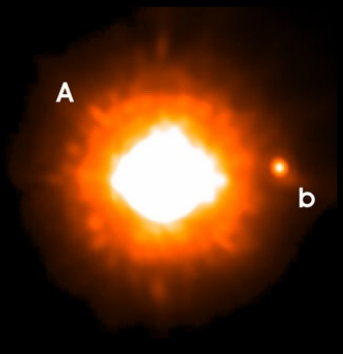
- High contrast imaging down to planetary masses
- Investigate large target sample: statistics, variety of stellar classes, evolutionary trends
- Complete the accessible period window
- First order characterization of the atmosphere (clouds, dust content, Methane, water absorption, effective temperature, radius, dust polarization)

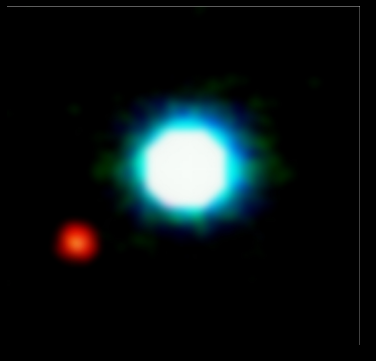
➔ Understand the **planetary system origins**











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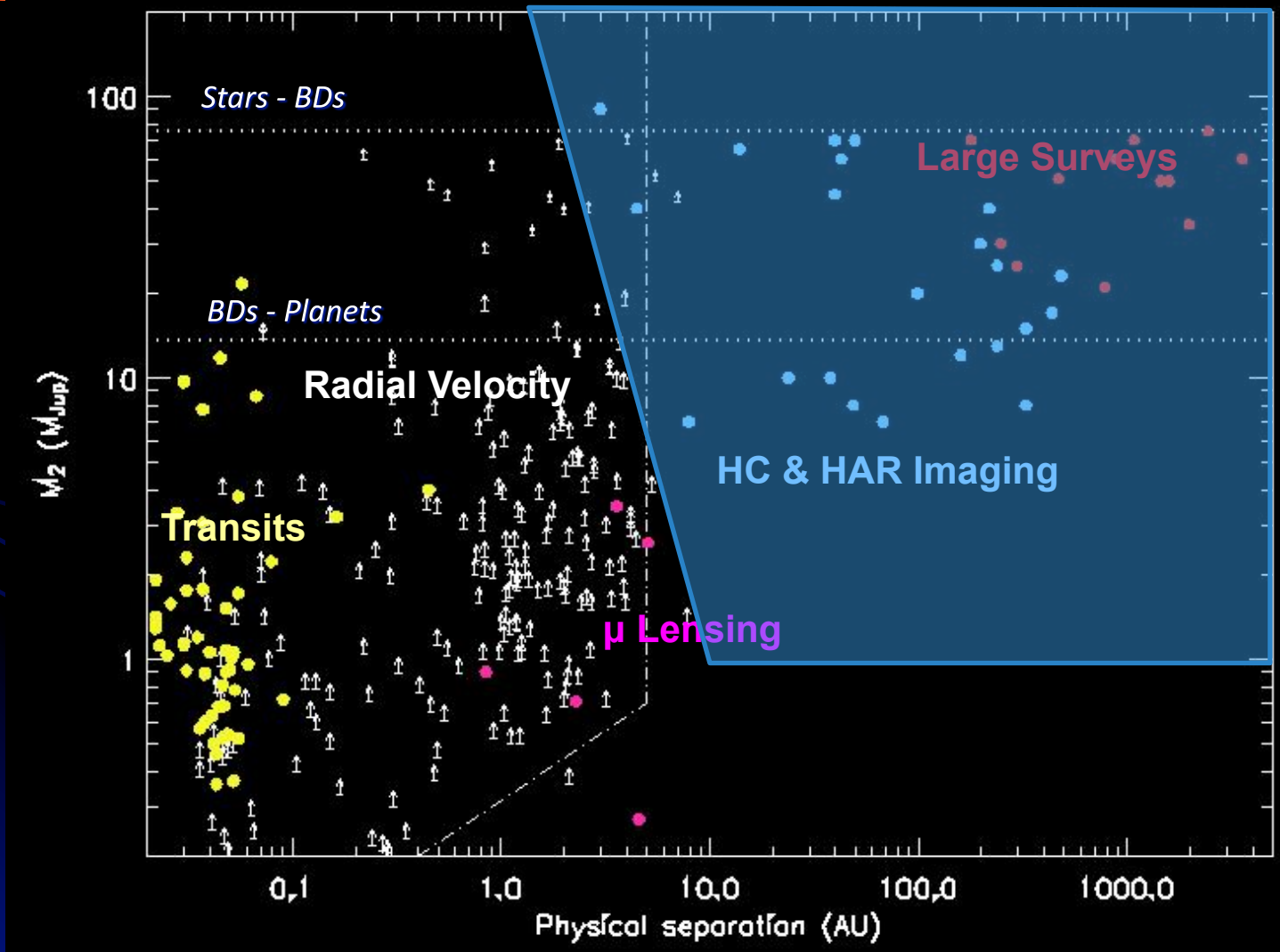
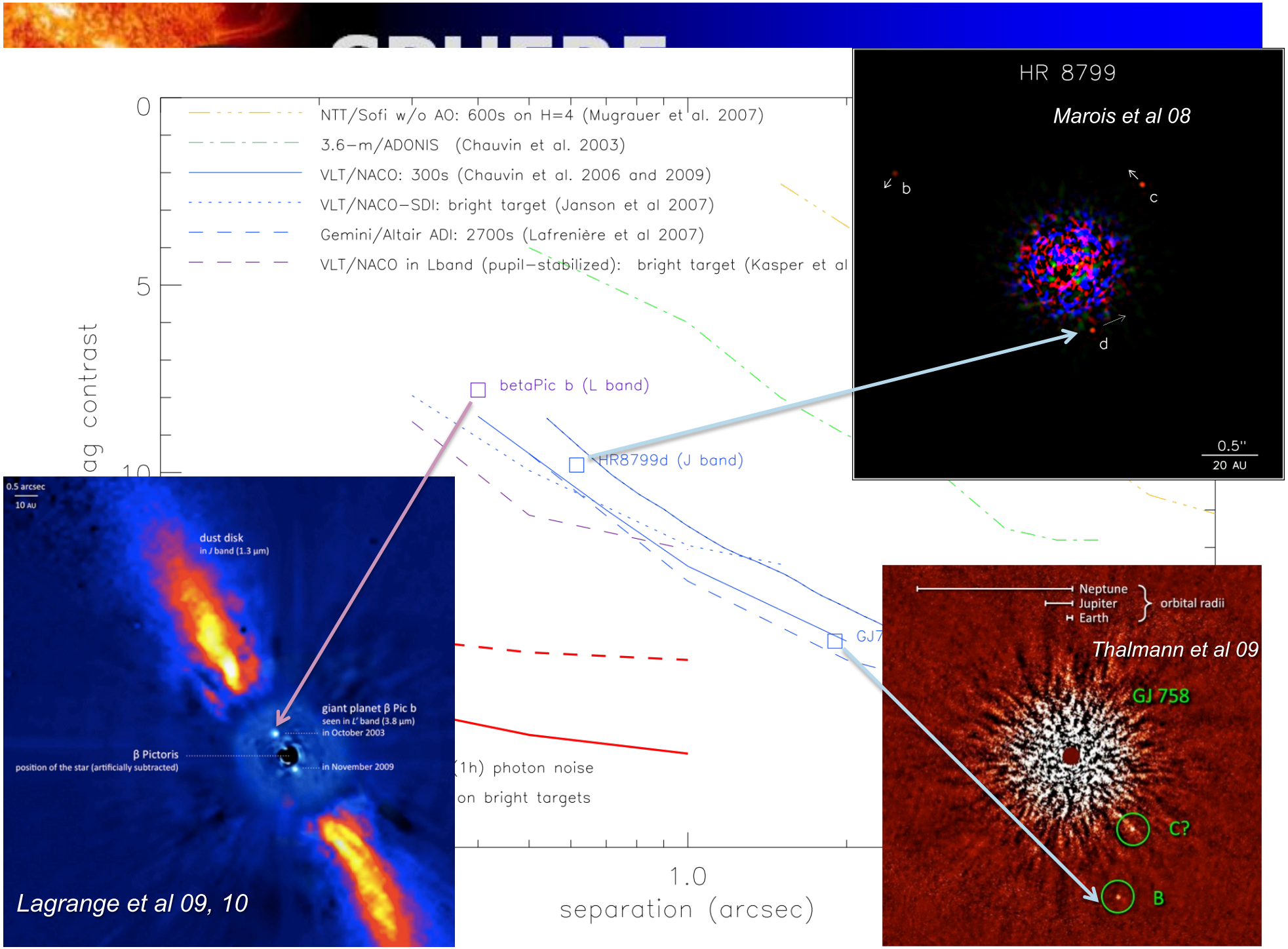
Science objectives




NTT/Sofi w/o AO: 600s on H=4 (Mugrauer et al. 2007)
3.6−m/ADONIS (Chauvin et al. 2003)
VLT/NACO: 300s (Chauvin et al. 2006 and 2009)
VLT/NACO−SDI: bright target (Janson et al 2007)
Gemini/Altair ADI: 2700s (Lafrenière et al 2007)
VLT/NACO in Lband (pupil−stabilized): bright target (Kasper et al
0
5
ag contrast
betaPic b (L band)
HR8799d (J band)
GJ7
(1h) photon noise
on bright targets
1.0
separation (arcsec)
HR 8799
Marois et al 08
b
c
d
0.5"
20 AU
0.5 arcsec
10 AU
dust disk
in J band (1.3 μm)
giant planet β Pic b
seen in L' band (3.8 μm)
in October 2003
β Pictoris
position of the star (artificially subtracted)
in November 2009
Lagrange et al 09, 10
Neptune
Jupiter
Earth
orbital radii
Thalmann et al 09
GJ 758
C?
B

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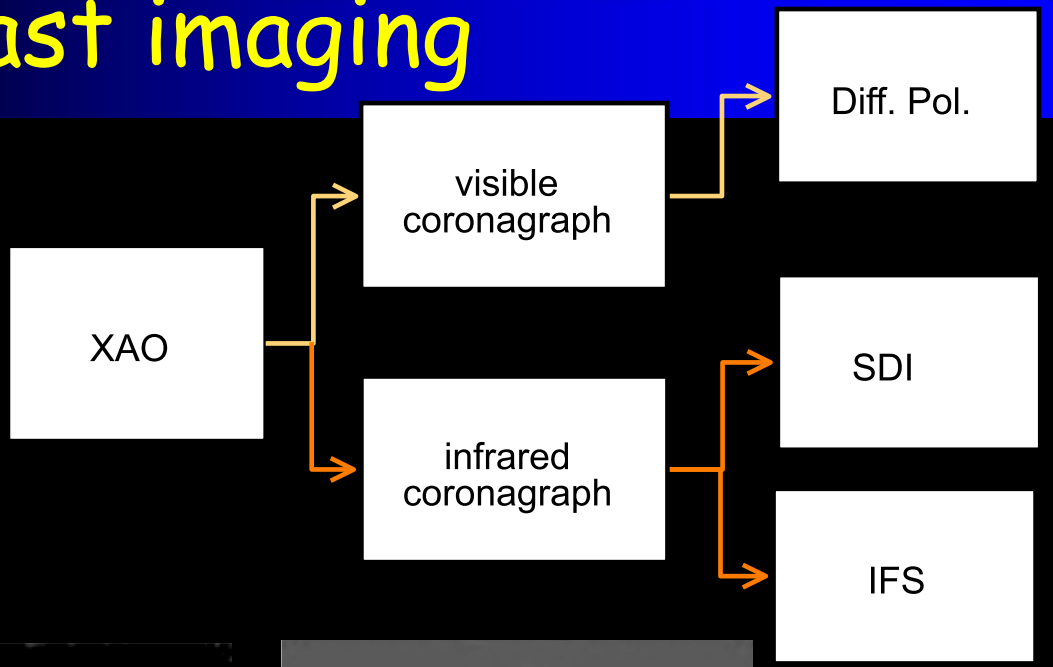
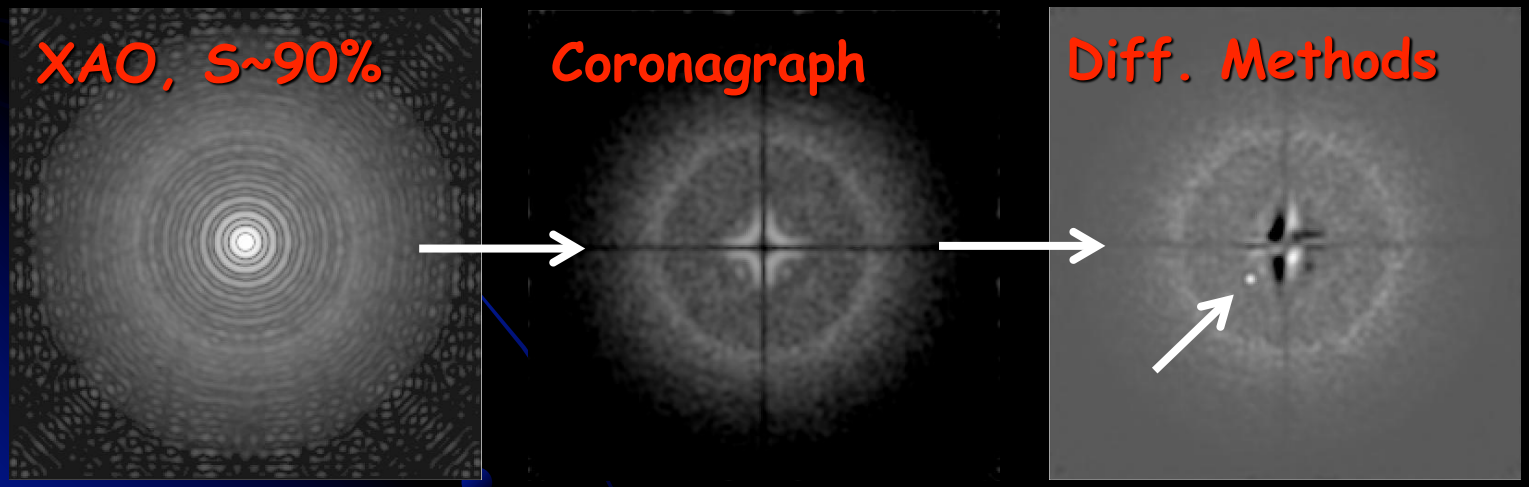
High contrast imaging

Highest contrast observations require **multiple correction stages** to correct for

- Atmospheric turbulence
- Quasi-static instrumental aberrations
- Diffraction Pattern





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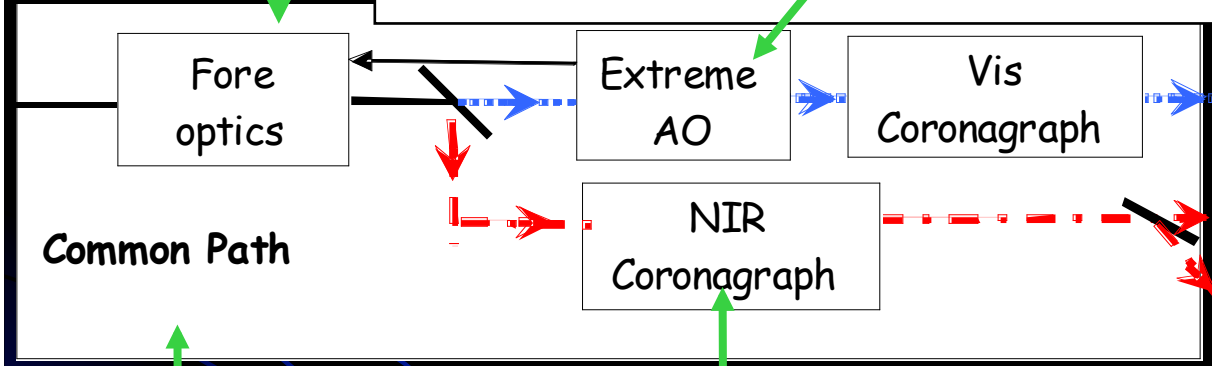
Concept overview

Beam control
(DM, TT, PTT, derotation)
Pola control
Calibration

High frequency AO correction (41x41 act.)
High stability : image / pupil control
Visible – NIR Refraction correction
FoV = 12.5"
40x40 SH-WFS in visible
1.2 KHz, RON < 1e-

Coronagraphic imaging:
Dual polarimetry, direct BB + NB.
λ = 0.5 – 0.9 μm,
λ/2D @ 0.6 μm, FoV = 3.5"



ZIMPOL

IFS

IRDIS

0.95 – 1.35/1.65 μm
λ/2D @ 0.95 μm,
Spectral resolution:
R = 54 / 33
FoV = 1.77"

Pupil apodisation,
Focal masks: Lyot, A4Q, ALC.
IR-TT sensor for fine entering

Nasmyth platform, static bench,
Temperature control, cleanliness control
Active vibration control

0.95 – 2.32 μm; λ/2D @ 0.95 μm
Differential imaging: 2 wavelengths,
R~30, FoV = 12.5"
Long Slit spectro: R~50 & 400
Differential polarization

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SPHERE: sub-systems main properties

	ZIMPOL	IRDIS	IFS
FoV	Sq 3.5" (instantaneous) Up to 4" radius (mosaic)	Sq 11"	Sq 1.77"
Spectral Range	0.5 – 0.9 µm	0.95 – 2.32 µm	0.95 – 1.35/1.65 µm
Spectral information	BB, NB	BB, NB Slit spectro: 50/400	50 / 30
Linear Polarisation	Simultaneous on same detector, x 2 arms, exchangeable	Simultaneous dual beam, exchangeable	x

Coronography: no /4Q / Lyot

Rotation at Nasmyth:

- Pupil-stab. (instrument fixed wrt tel.)
- Field-stab (slit spectro, long DIT…)
- No rotation: minimize crosstalk…)

AO sensitivity for high contrast: R=9.5 for NIR; R=9 for R; R=7.8 for whole VIS

Separation range where improved contrast: 2 - 20 λ/D, ie 30-300 mas in R, or 80 – 800 mas in H

Mode switching: not VIS and NIR in same night

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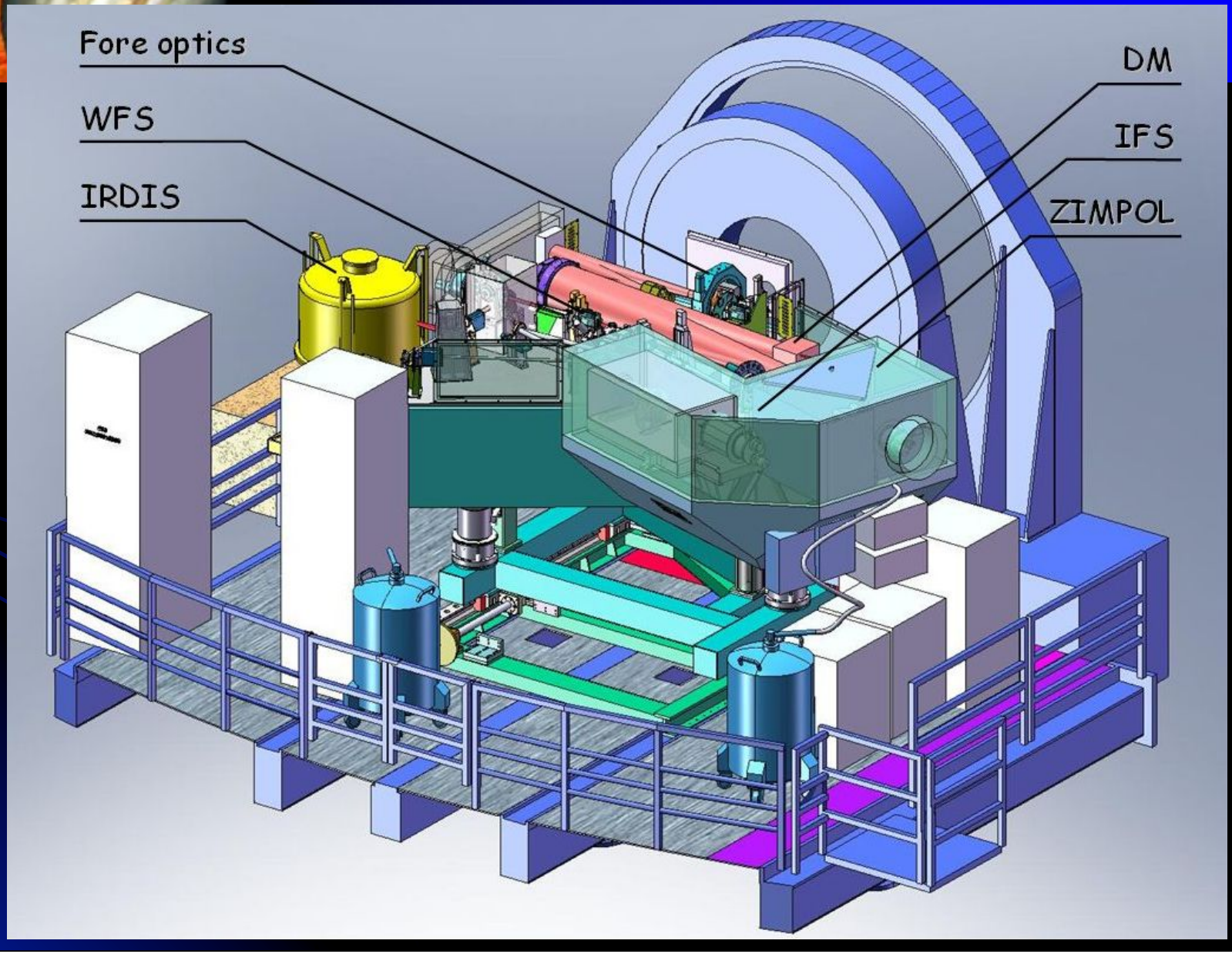

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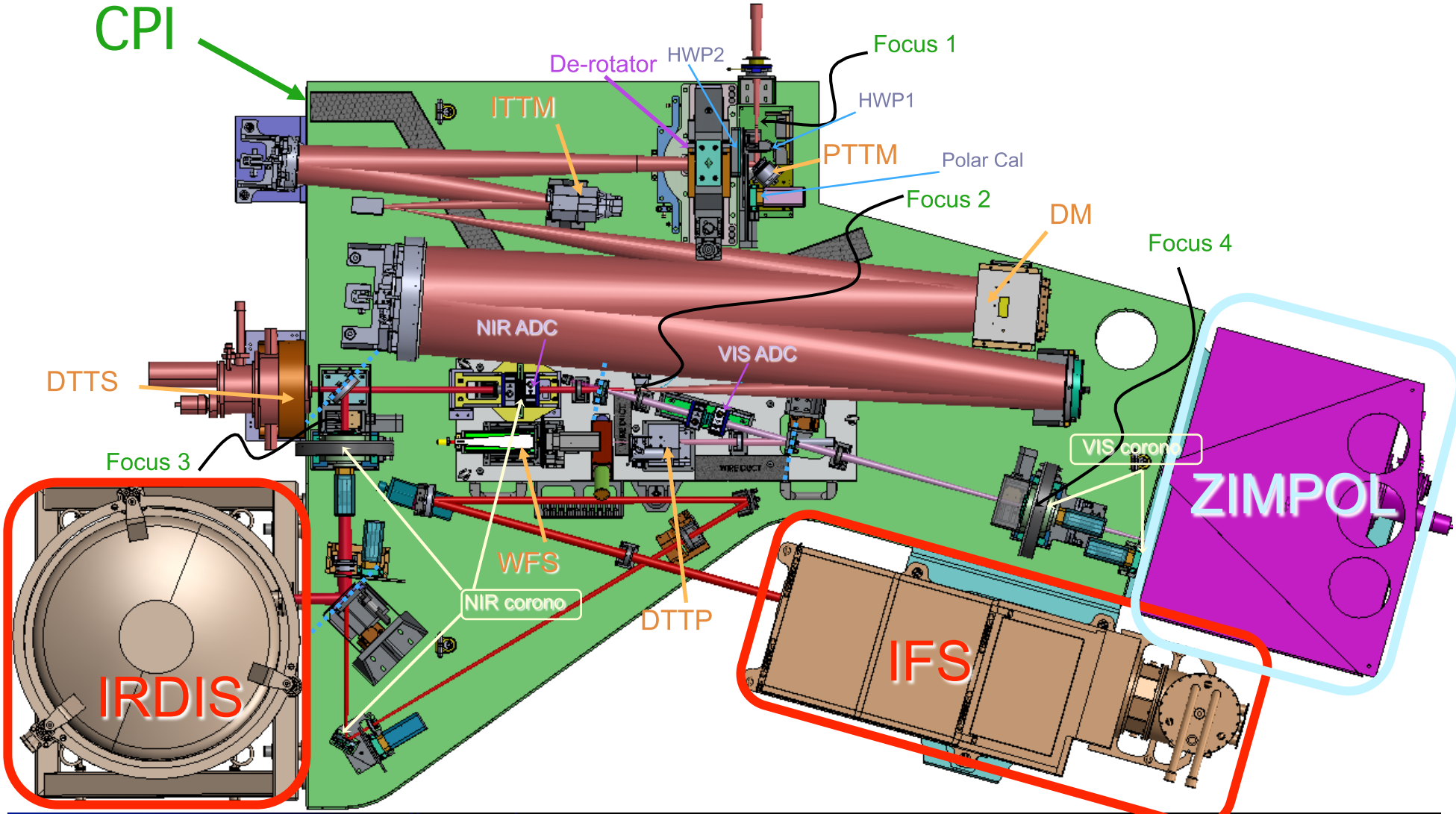
Implementation



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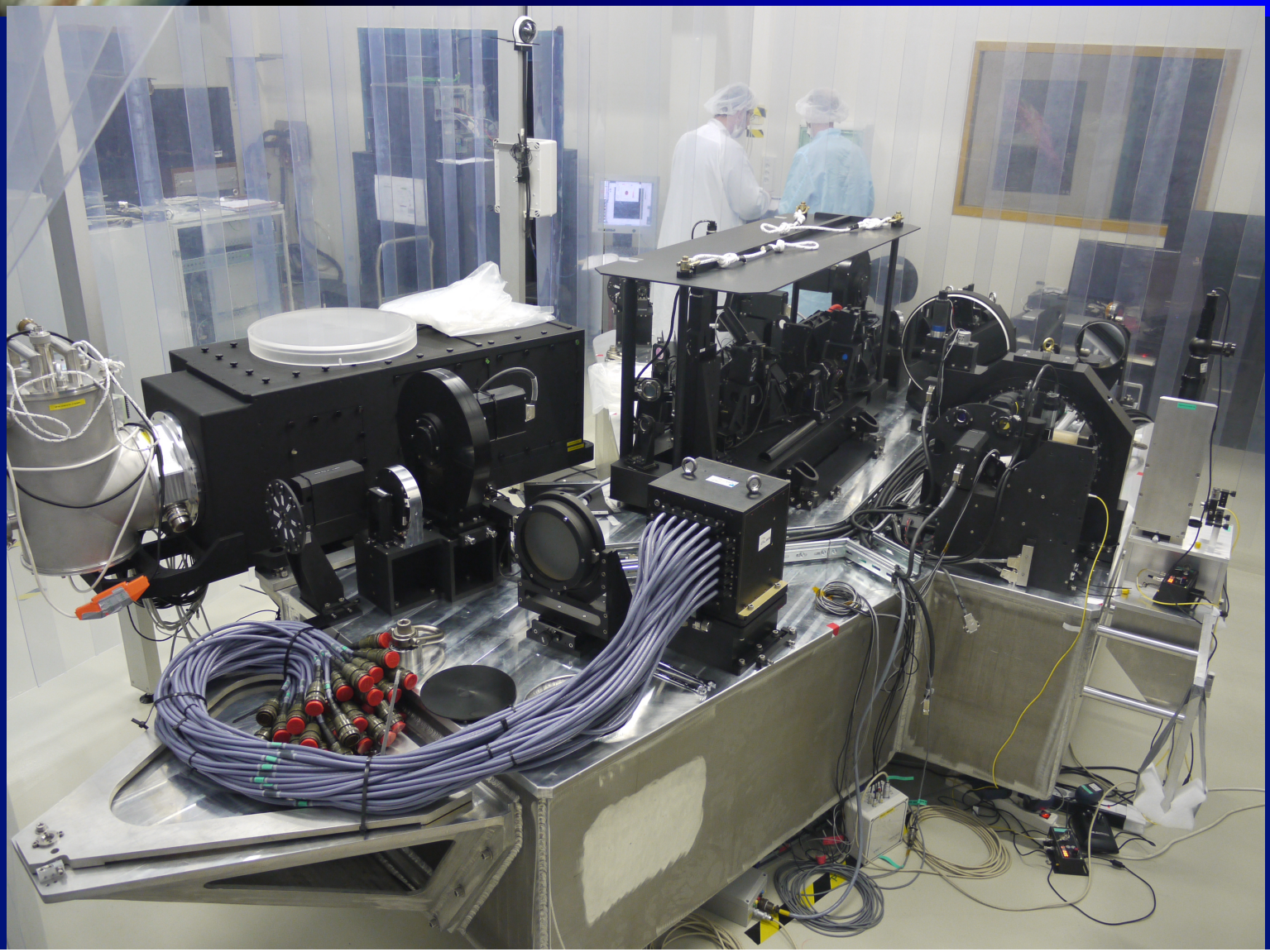
SPHERE final integration and test



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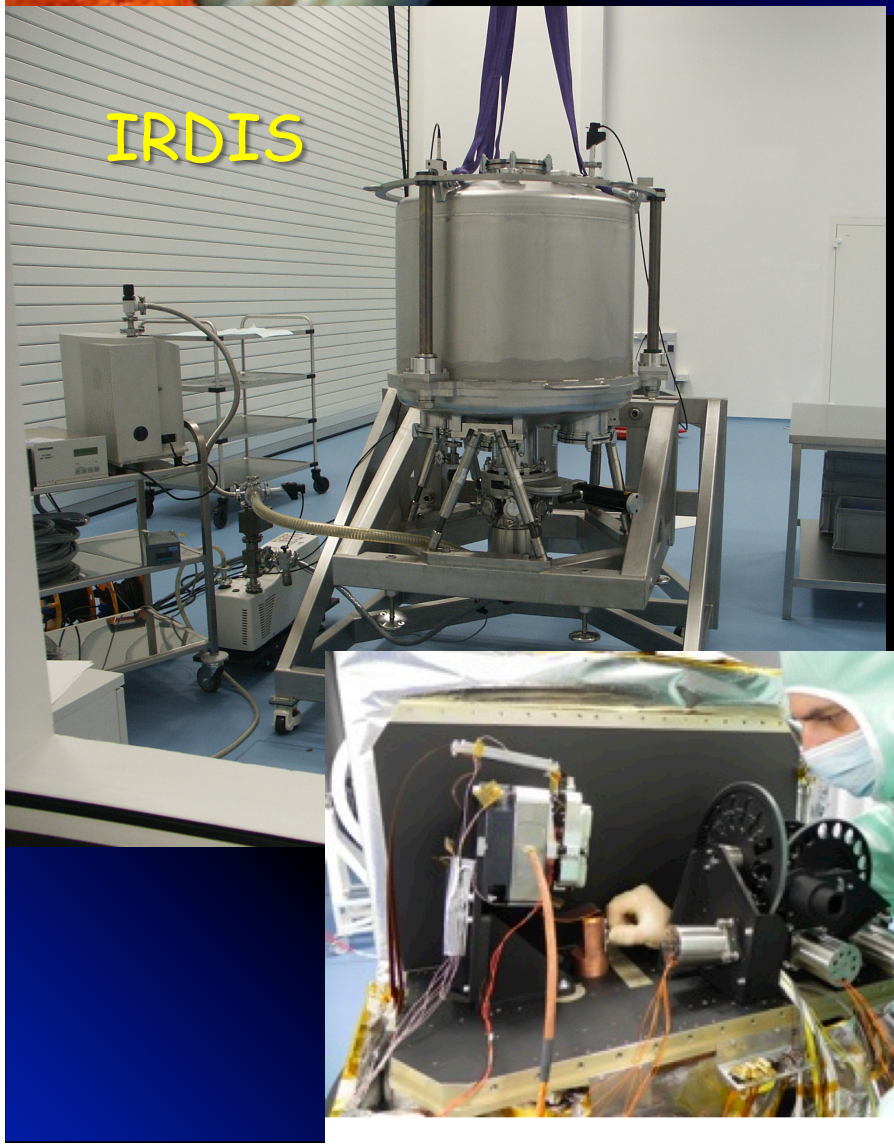
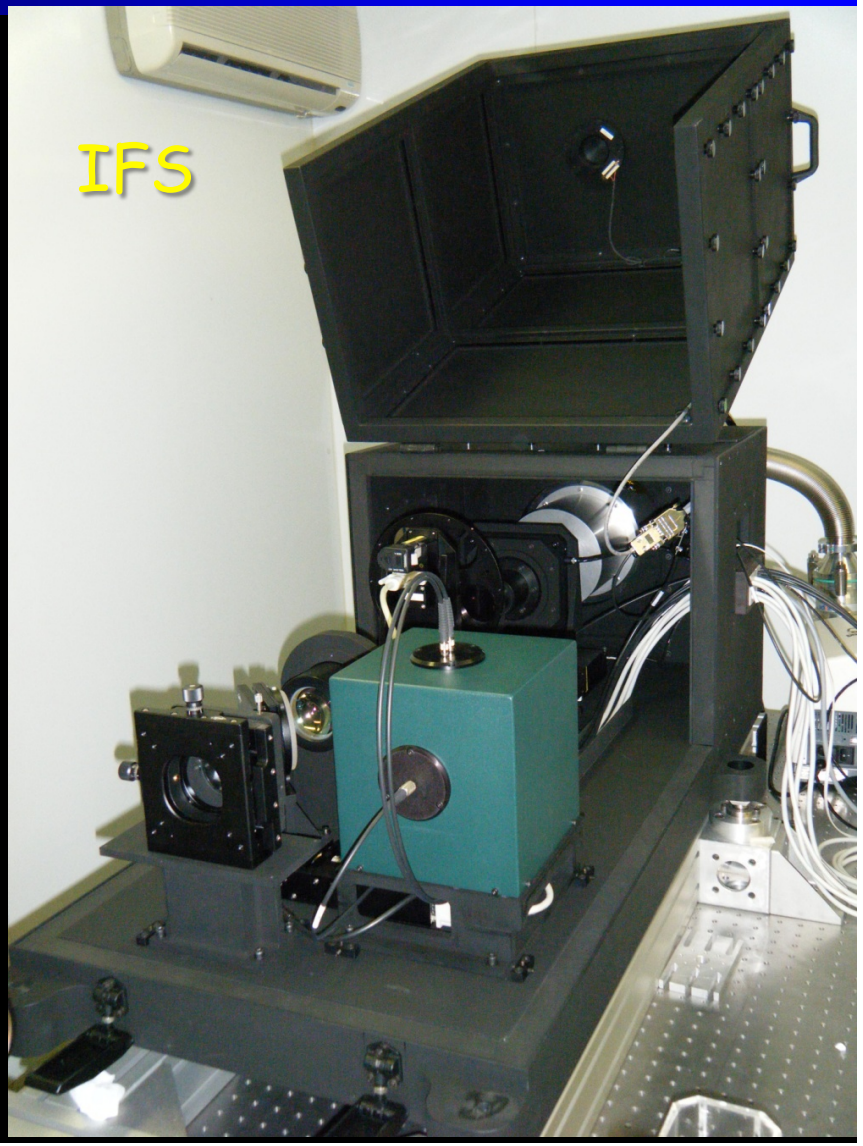
IR observing modes

IRDIS



IFS



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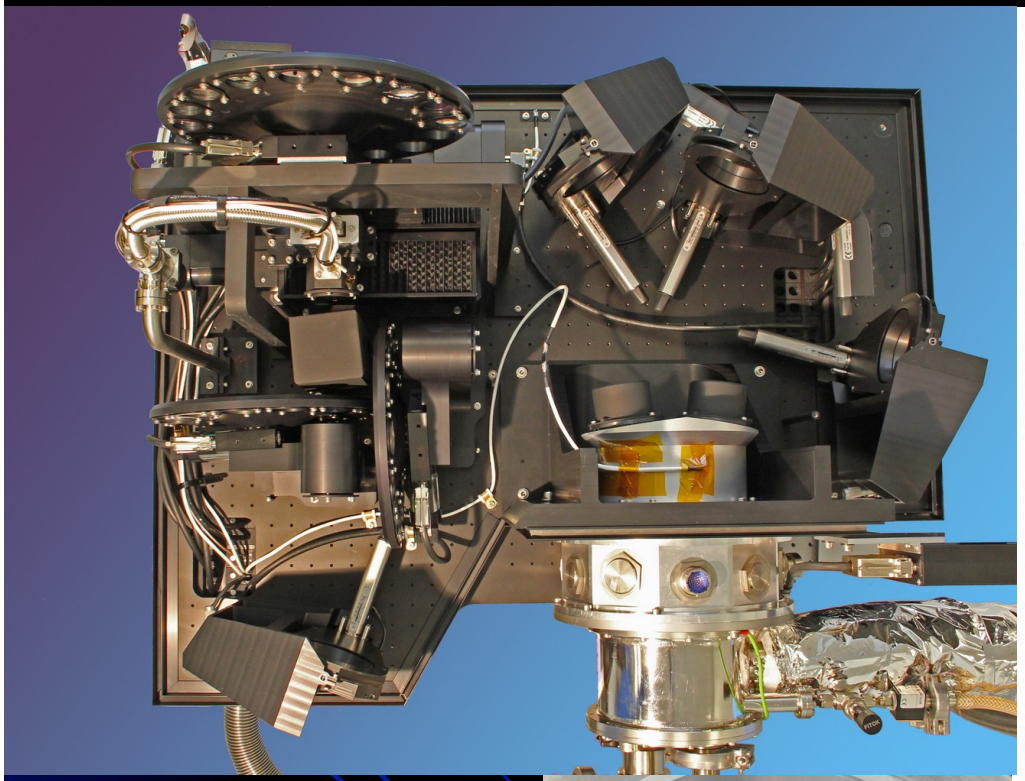
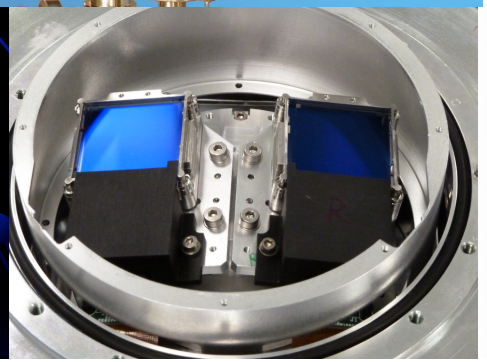
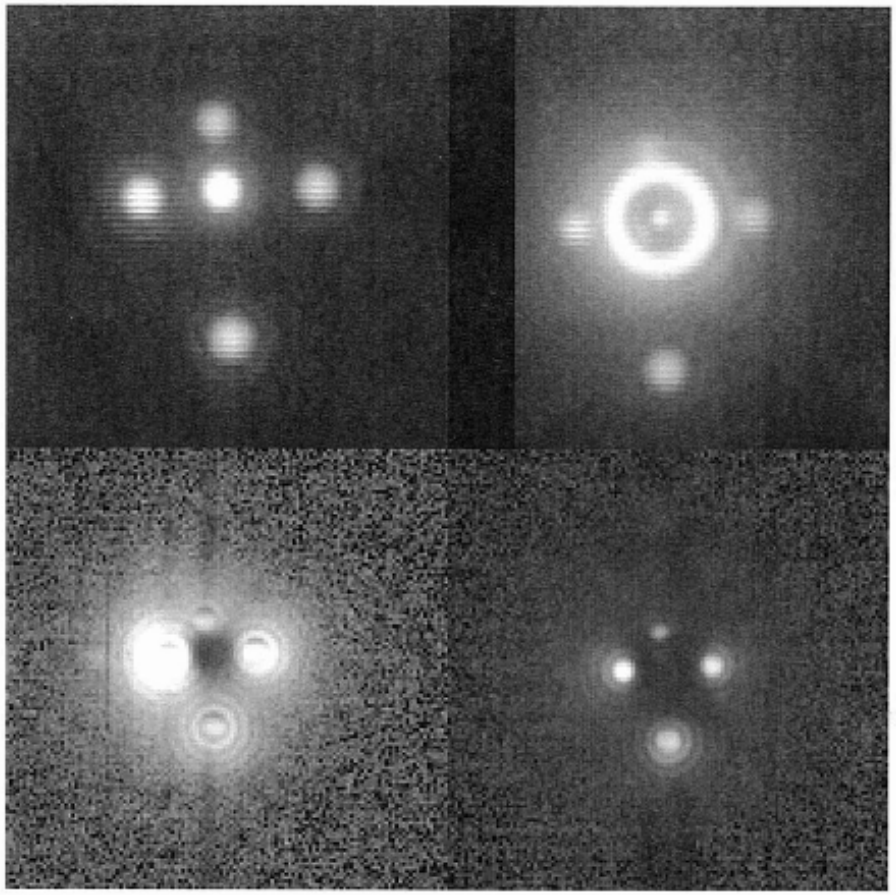
Visible observing modes



ZIMPOL





SP_12AUG10

Top Left: Intensity image with Star dimmed by ND3
Bottom Left: Polarization image of top left
Top Right: Coronagraphic intensity image of top left with ND3 removed
Bottom Right: Polarization image of top right

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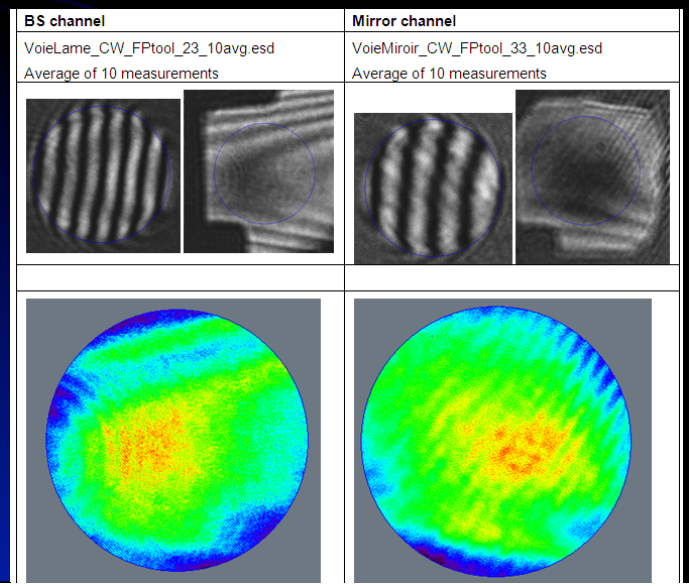
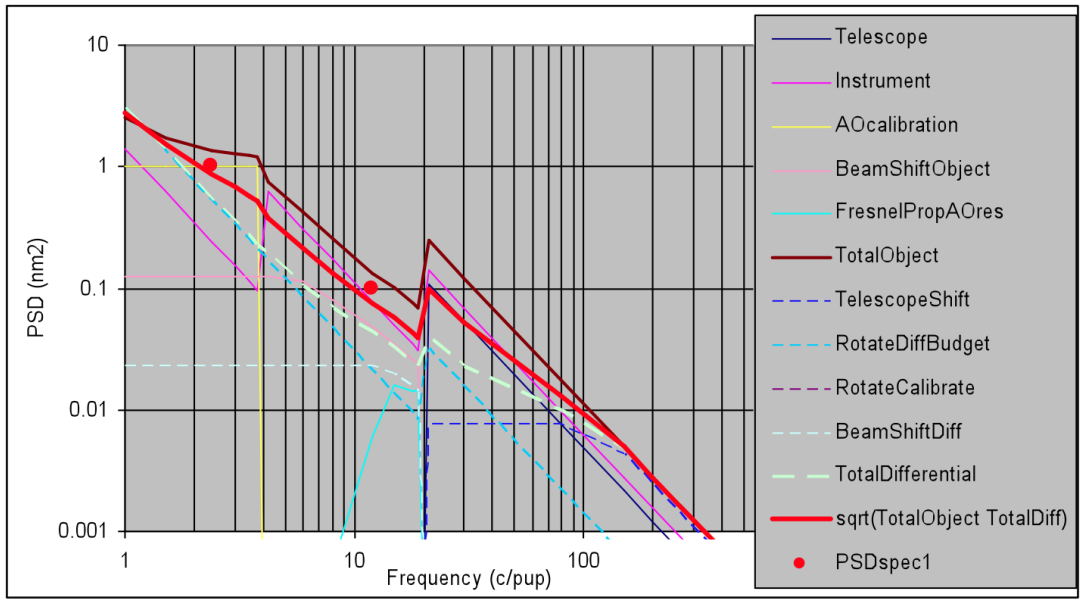
Challenges 1/3

System level

- ✓ From science to system analysis (fully dedicated instrument): new metrics, balance between different approachs, handling contemporary technologic dev[t] and research on instrument concepts in parallel
- ✓ End-to-end modelling required for critical system trade-offs
- ✓ Continuous monitoring of error budgets
- ✓ Data reduction/handling as part of instrument development





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Challenges 2/3

- Critical know-how: gathering expertise from various past instruments, lab demonstrations and R&D
  - ✓ Adaptive optics: -- > extreme AO (XAO)
  - ✓ Coronagraphy: optimized in high Sr regime and small inner working angle
  - ✓ Polarimetry in the hard way: very high accuracy, coupled with high constrast, and at Nasmyth focus
  - ✓ …

- Prototyping in early phases of development for the validation of new concepts (pupil stabilisation, spatial filtering…) as well as critical components (filters, coronagraphs, aspheric optics, DM, high …)

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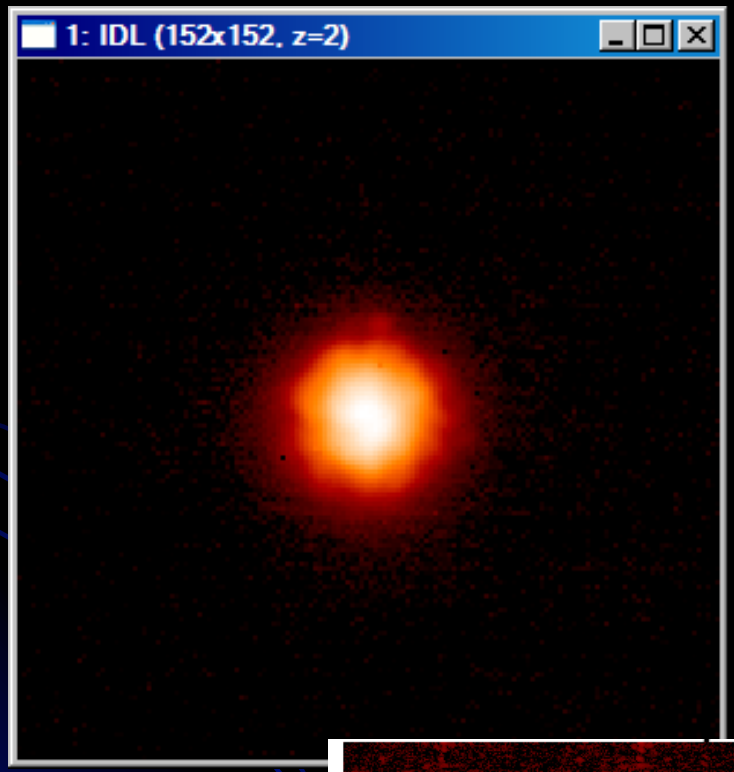
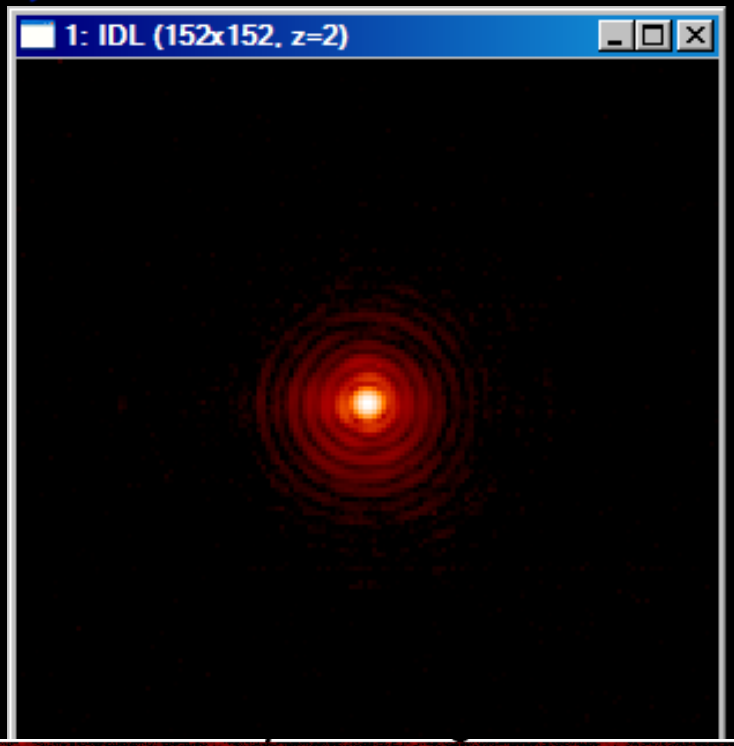
SAXO preliminary performance

- Raw Strehl Ratio 5.6% (OL) -- > 85% (CL)
- Object deconvolved Strehl Ratio 94% (CL)





Spatial filtering for anti-aliasing

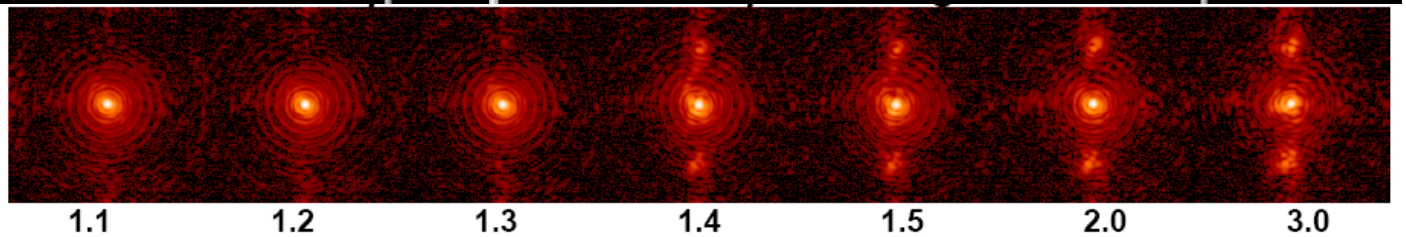


Figure 3-2: PSF, log scale. Closed-loop, gain 0.3 on HODM, 0.5 on ITTM. Left to right : spatial filter 1.1, 1.2, 1.3, 1.4, 1.5, 2.0, 3.0. Secondary peaks clearly appear as spatial filter

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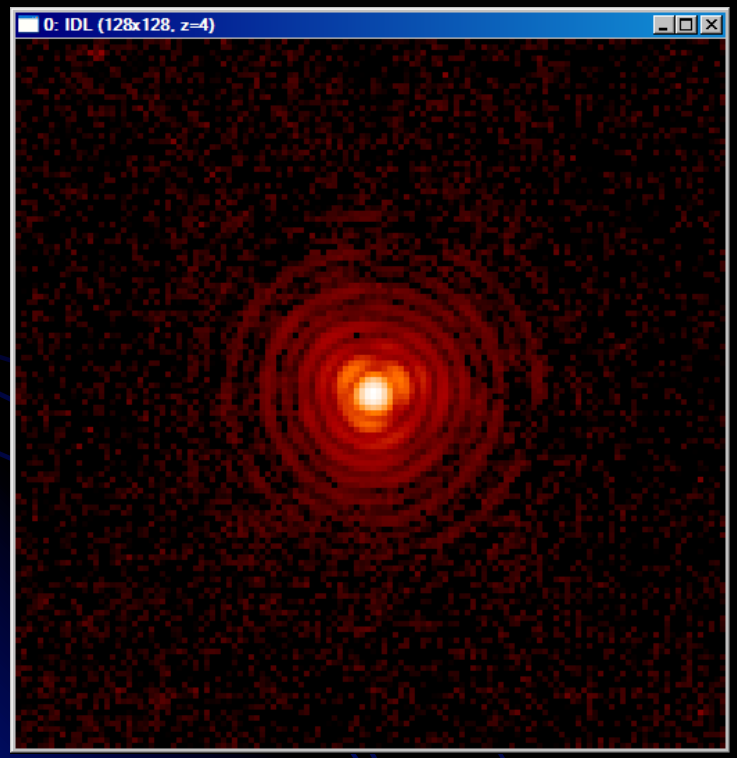
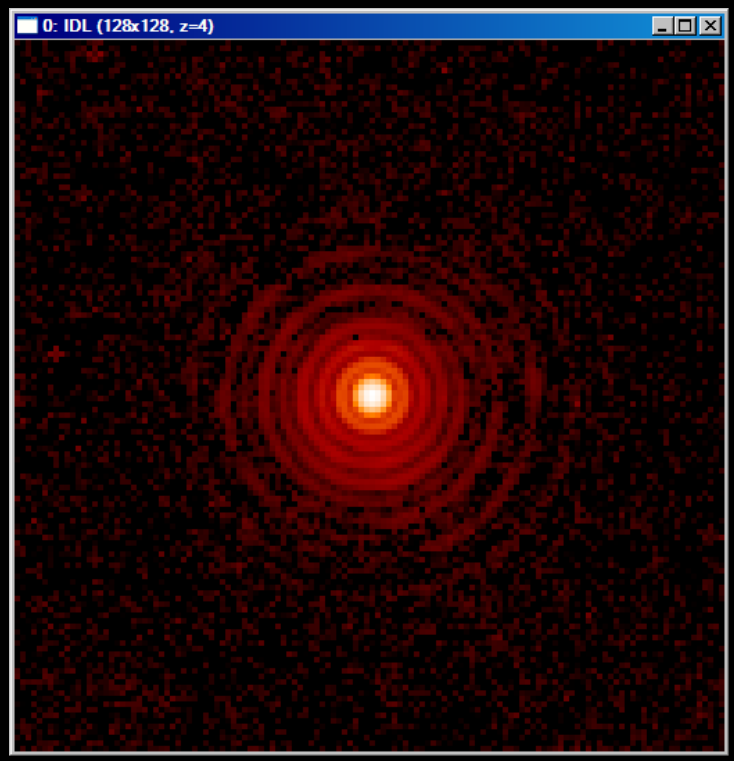
SAXO NCPA compensation

Fighting against **quasi-static instrumental speckle down to few nm rms level**:
measuring and compensating for Non Common-Path Aberrations (NCPA)



SR = 85.5% (no NCPA)



SR = 99.0% (with NCPA)

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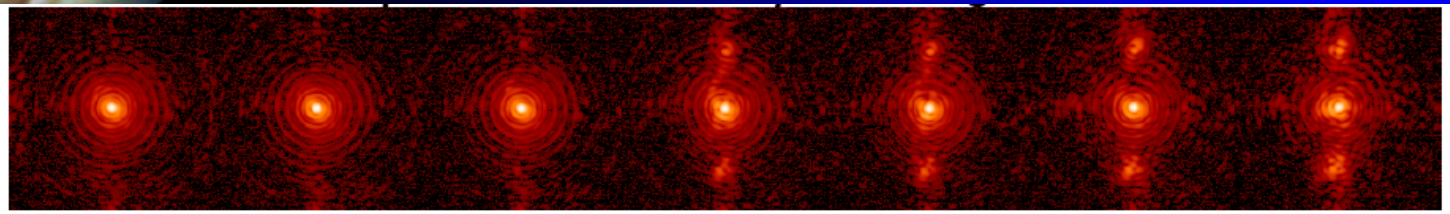
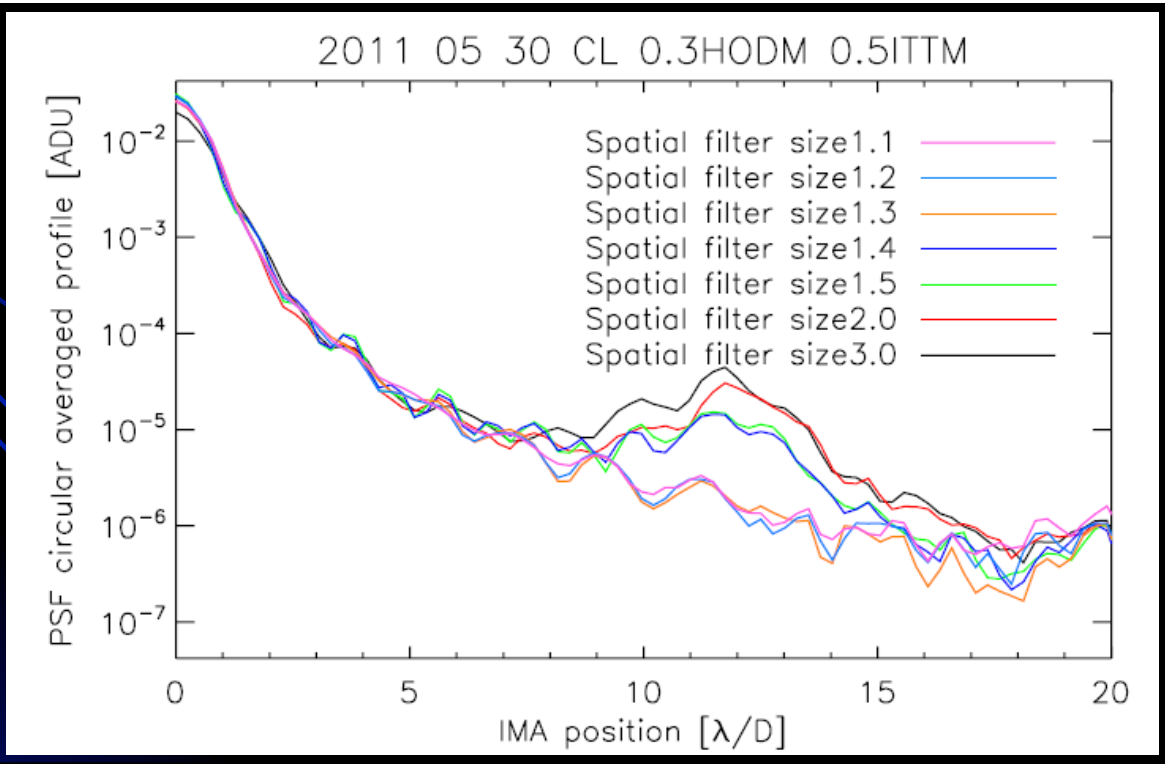
Spatial filter behaviour



1.1 1.2 1.3 1.4 1.5 2.0 3.0

Figure 3-2: PSF, log scale. Closed-loop, gain 0.3 on HODM, 0.5 on ITTM. Left to right : spatial filter 1.1, 1.2, 1.3, 1.4, 1.5, 2.0, 3.0. Secondary peaks clearly appear as spatial filter opens.



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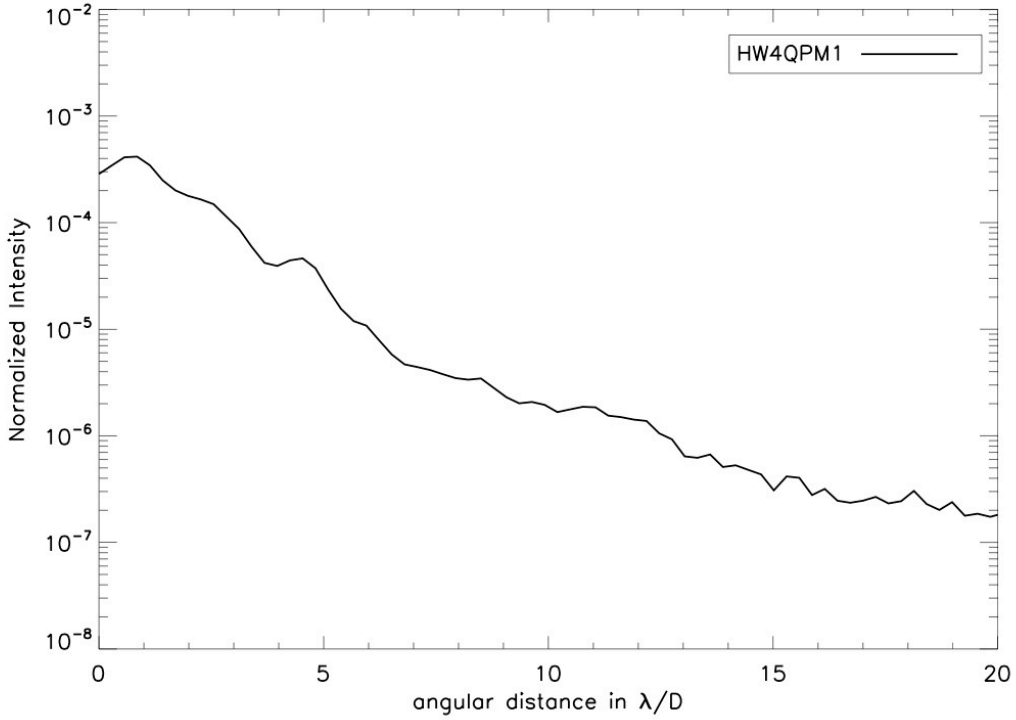
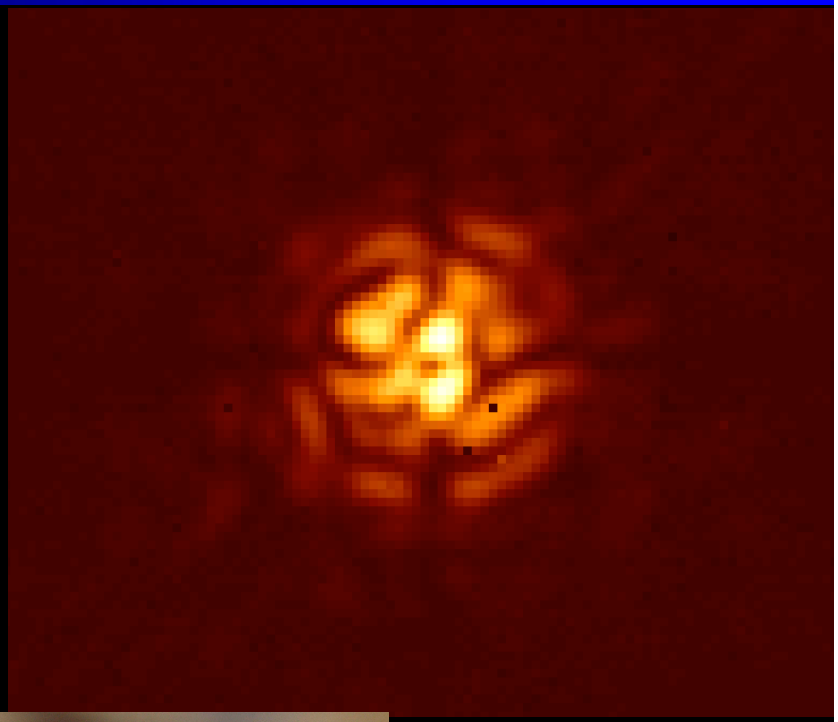
Coronagraphic performance

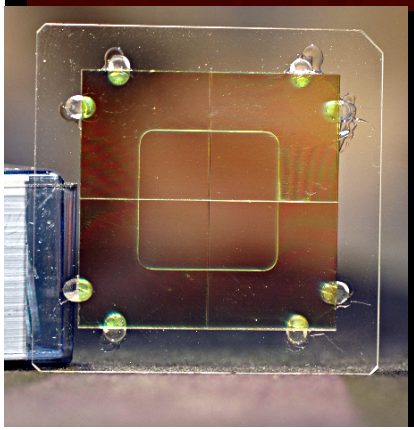
IRDIS Broadband H (1490-1780nm)

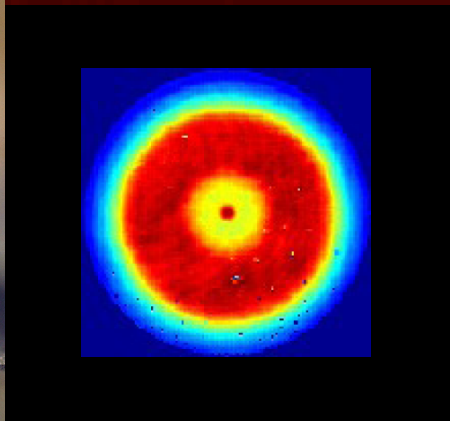
HW4QPM1

Total rejection factor = 513









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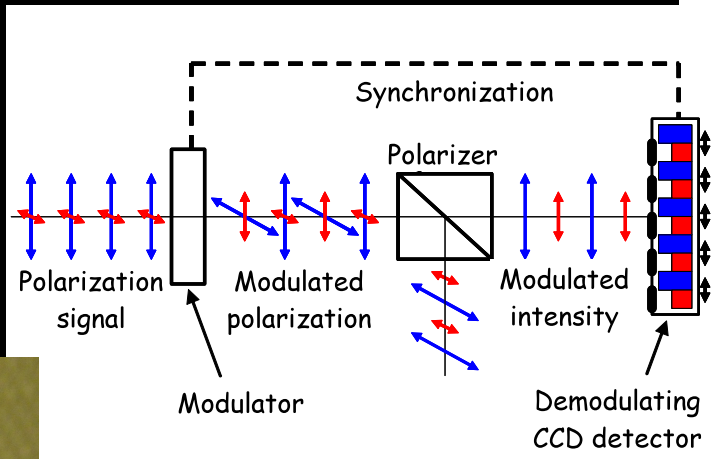
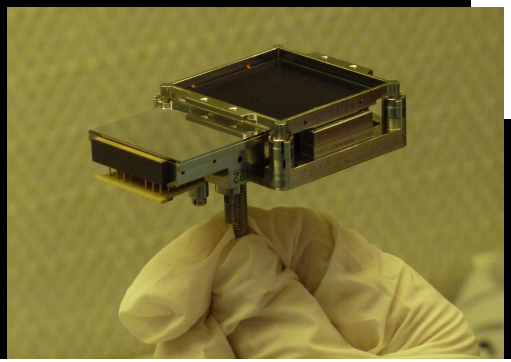
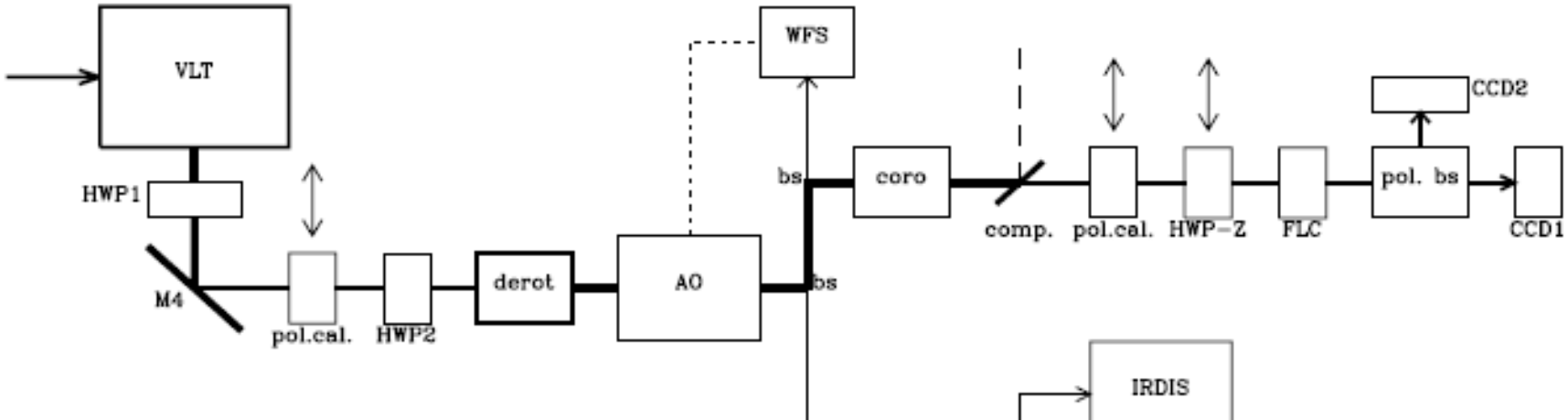
Differential polarimetry

- Decades of experience in Solar astronomy
- In a design optimizing transmission efficiency
- at Nasmyth focus: calibration scheme + on-line servo loop and compensation + instrument modeling
- + high image quality specifications





- Ferro-electric polarization modulator (1 kHz)
- Synchronous demodulating



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Challenges 3/3

- Initiating R&D with proper industrial partners
  - ✓ AO components
    - ✓ CILAS Deformable Mirror
    - ✓ E2V L3CCD for wave front sensing
  - ✓ Smart optics
    - ✓ CILAS/Fresnel for specific beamsplitter coatings
    - ✓ Halle for polarimetric components (FLC)
- ✓ Specific expertise in academic laboratories
  - ✓ AO components
    - ✓ Tip-tilt mirrors at LESIA
    - ✓ Real-time control at ESO and ONERA
  - ✓ Smart optics
    - ✓ Active aspheric mirrors at LAM

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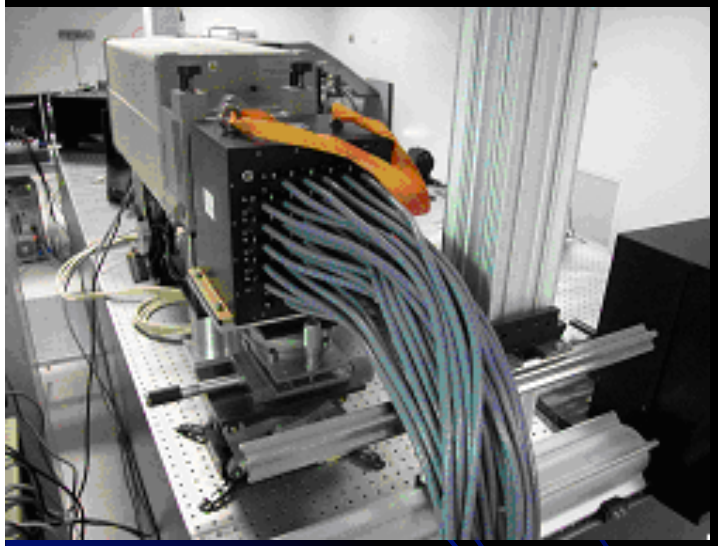
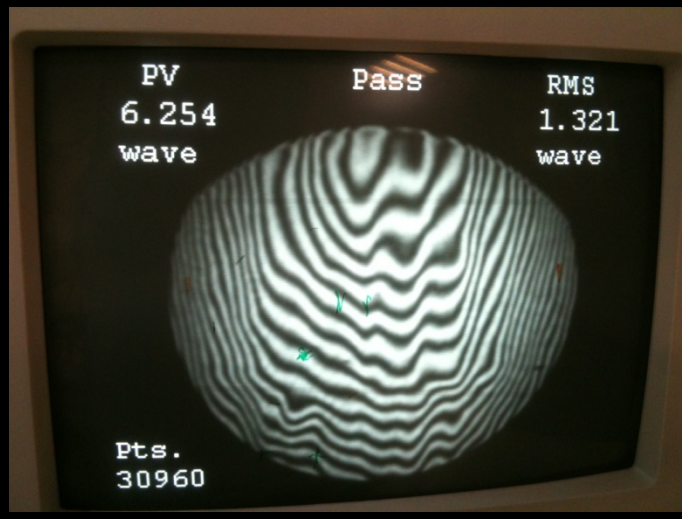
CILAS deformable mirror

CILAS DM developed in framework of Opticon/FP6/JRA1)



DM in front of Zygo, and power supply



First interferogram

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WFS camera

WFS camera (E2V detector, based on OCAM development in Opticon/FP6/JRA2)

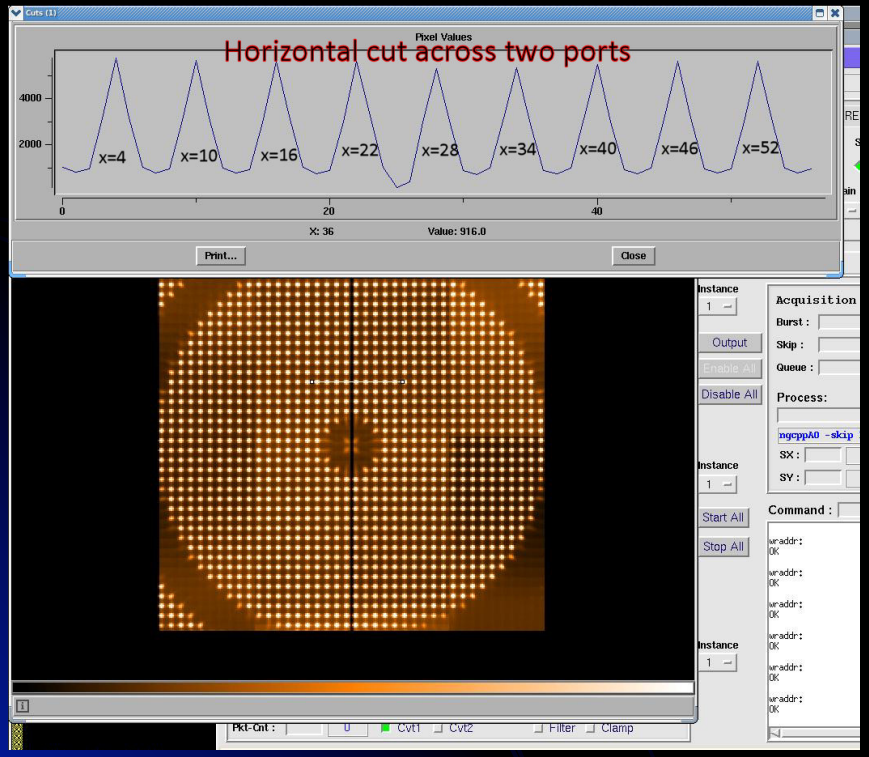
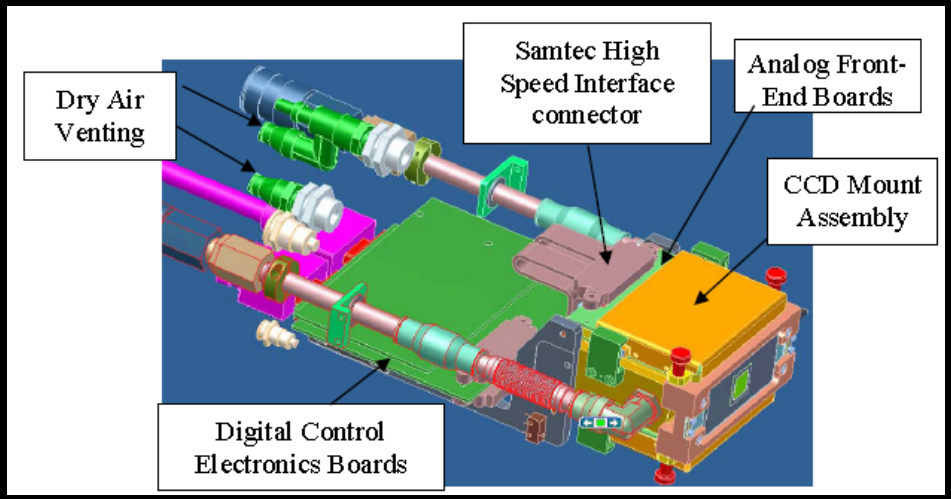
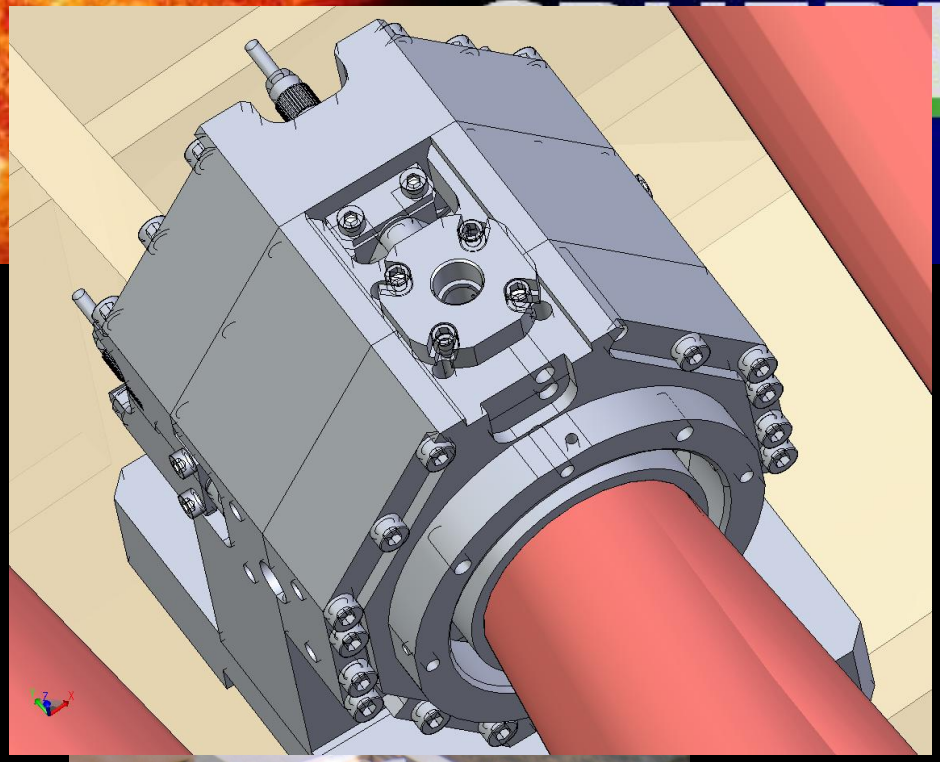
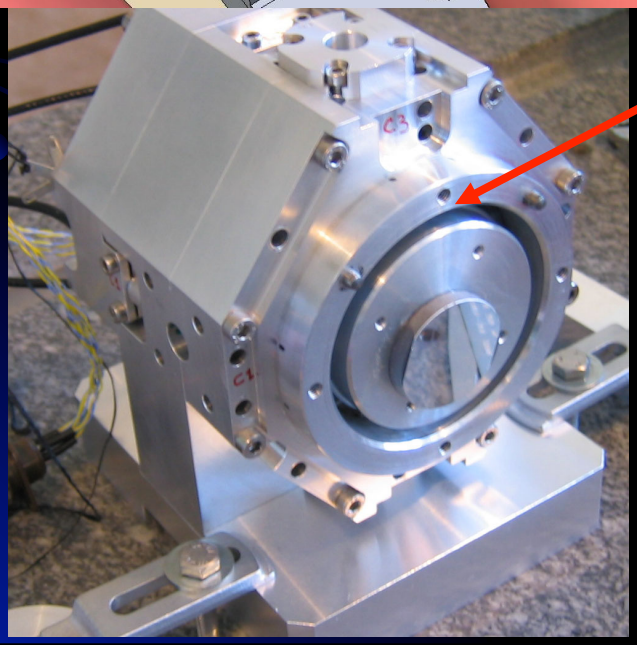


Image taken at 1200fps
1500fps seems possible
Noise at <1e
Over-illumination protection working

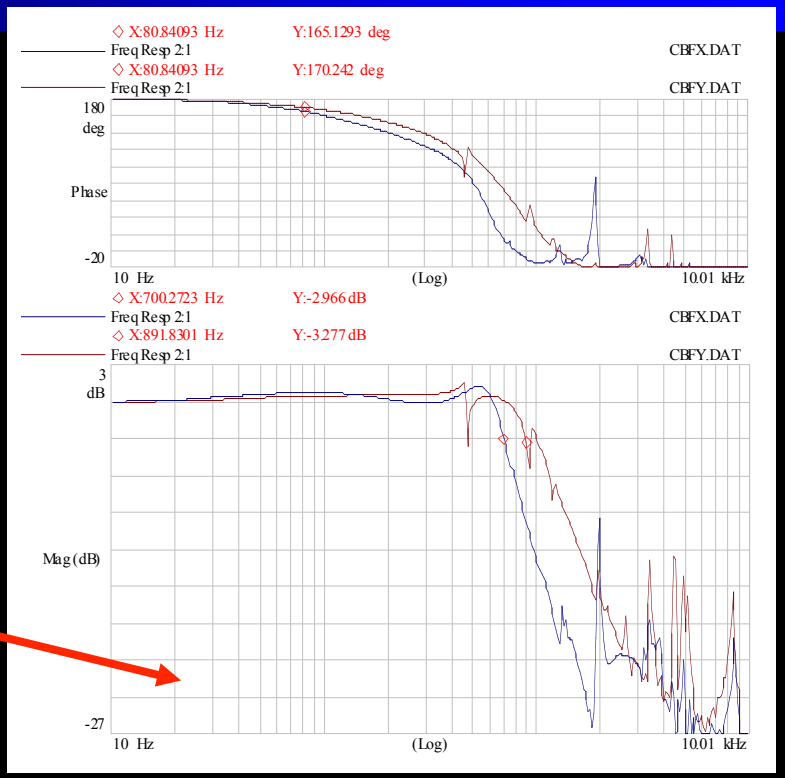


Fast Image Tip-tilt





prototype



- "X" bandwidth is 700 Hz at -3dB with a phase shift of -15° at 80Hz
- "Y" bandwidth is 891 Hz at -3dB with a phase shift of -10 ° at 80 Hz.
- Goal 1000Hz

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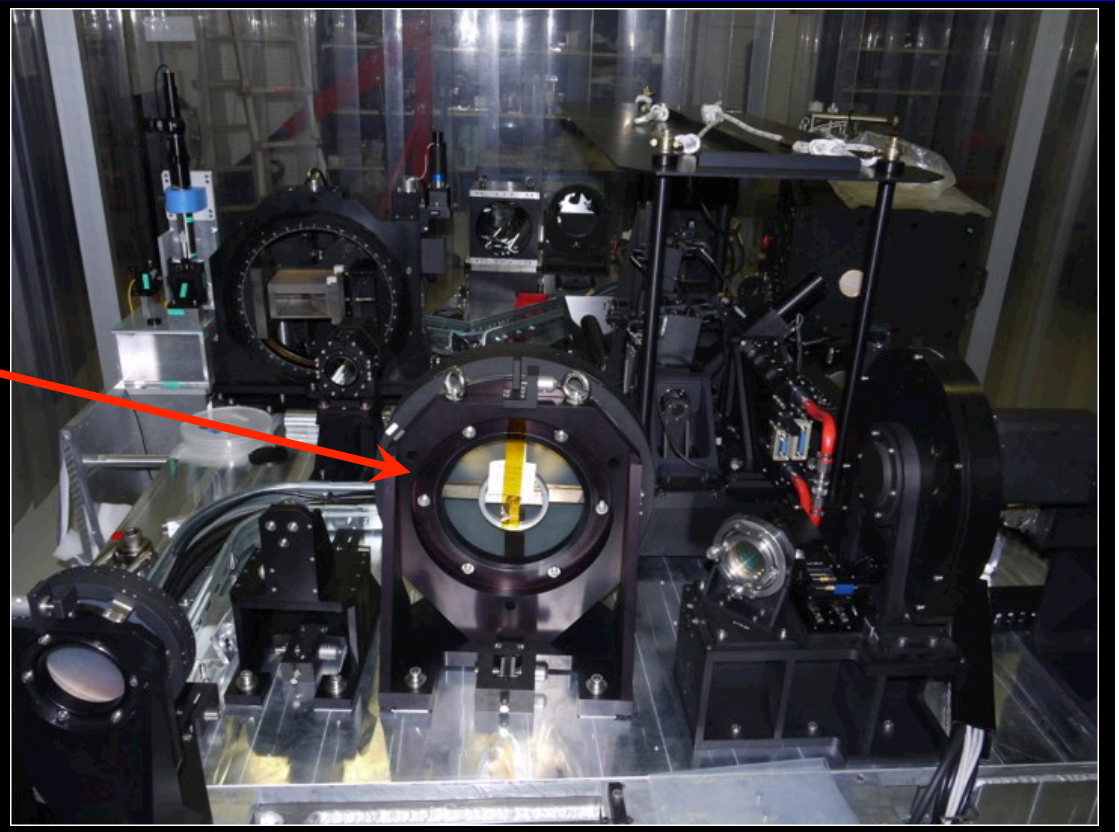
Active optics



Toric Mirror TM3 (400-mm)
surface error ranges:

LF	22 nm RMS (Sphe3)
MF	3.8 nm RMS
HF	3.1 nm RMS

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Conclusions

- Very challenging project !
- Now at final integration and caracterisation stage
- At Paranal end-2012, first light Spring 2013
- Main science outputs by ~2017 for both:
  - Large surveys for statistical approaches, broad target selection
  - In-depth characterization of specific systems
- Critical step before further exoplanet studies in the ELT era for
  - Technological development
  - System/calibration/operational experience
  - Scientific preparation on the given available target sample


SPH
190
226
218
Thank you !