SPHERE

(Spectro-Polarimetric High-contrast Exoplanet REsearch)

A Planet Finder Instrument for the VLT

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LUAN, ASTRON, ETH-Z, UvA, ESO

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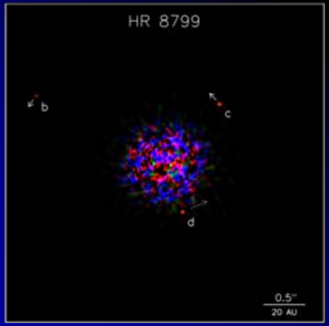
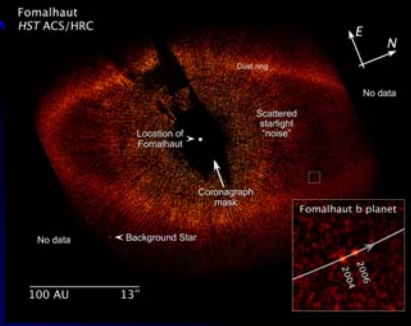
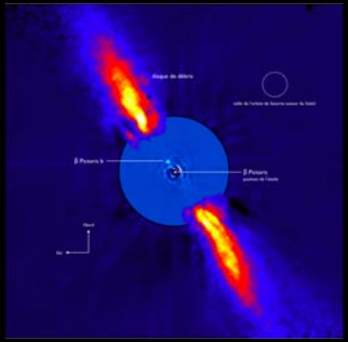
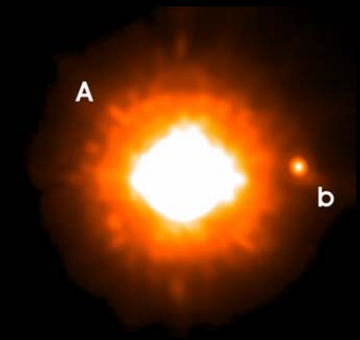
Science objectives

- 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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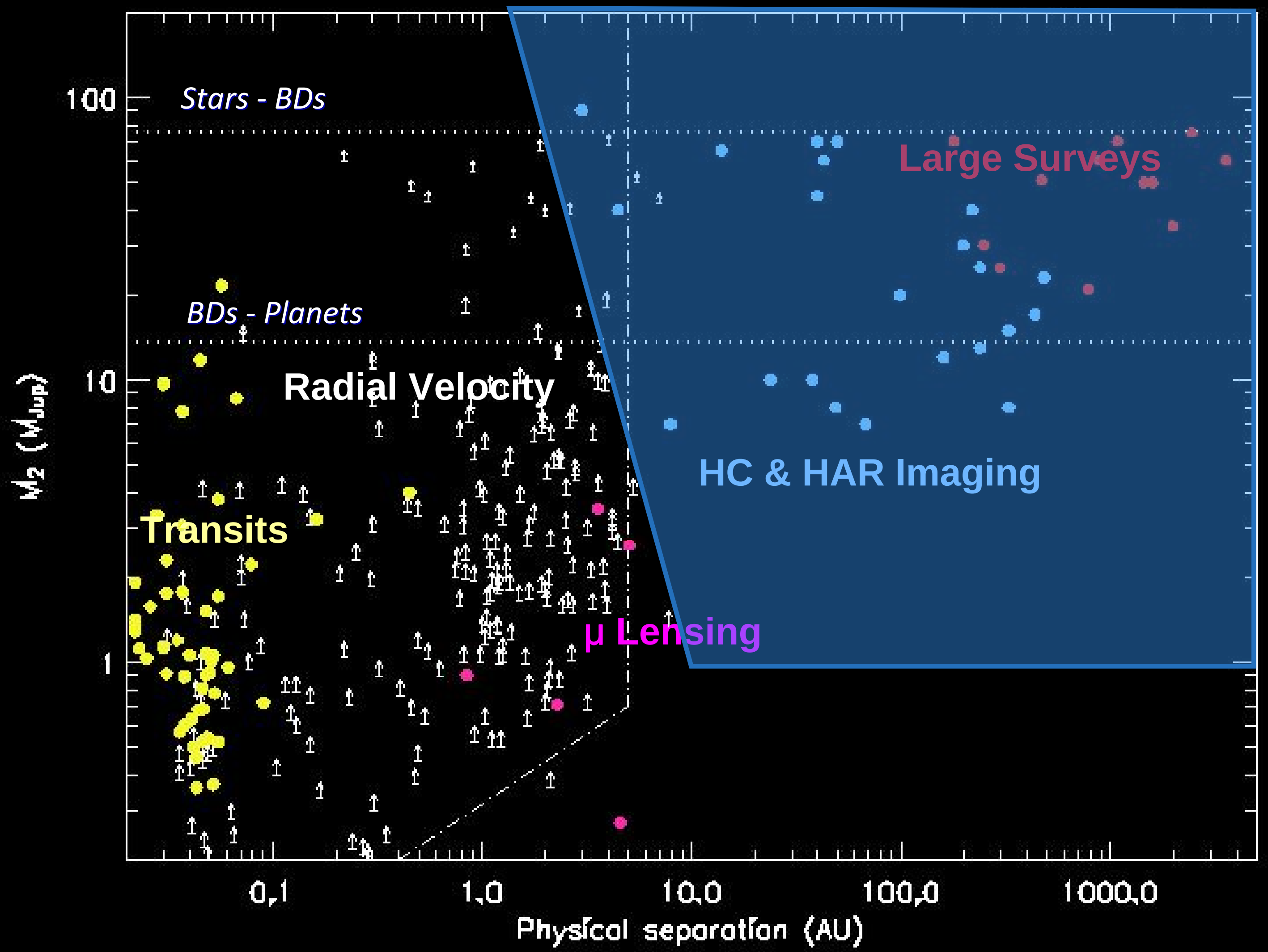
Science objectives



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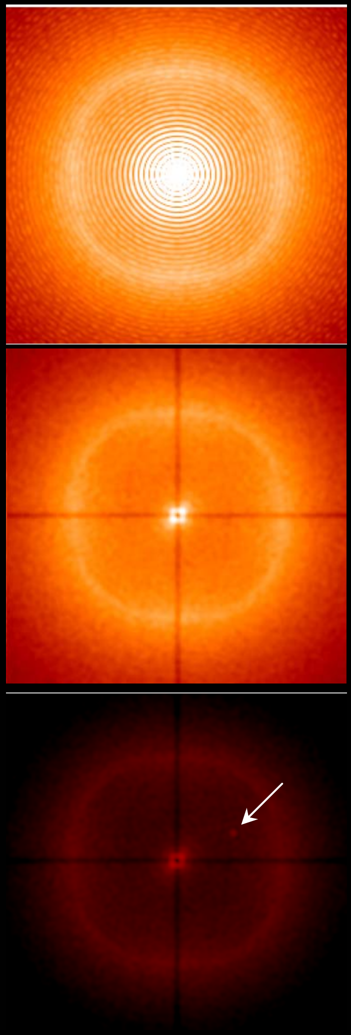
High level requirements

- Scientific requirements
  - ✓ Gain up to 2 orders of magnitude in contrast as compared to current instrumentation
  - ✓ Reach short separations: 0.1″ – 3″ (1- 100AU)
  - ✓ Survey a large number of targets
- High contrast detection capability
  - ✓ Extreme AO (turbulence correction)
    - ✓ feed coronagraph with well corrected WF
    - ✓ SR ~ 90% in H-band
  - ✓ Coronagraphy (removal of diffraction pattern)
    - ✓ high dynamics at short separations
  - ✓ Differential detection (removal of residual defects)
    - ✓ calibration of non common path aberrations
    - ✓ pupil and field stability
    - ✓ smart post processing tools
- High sensitivity
  - ✓ optimal correction up to V ~ 9-10



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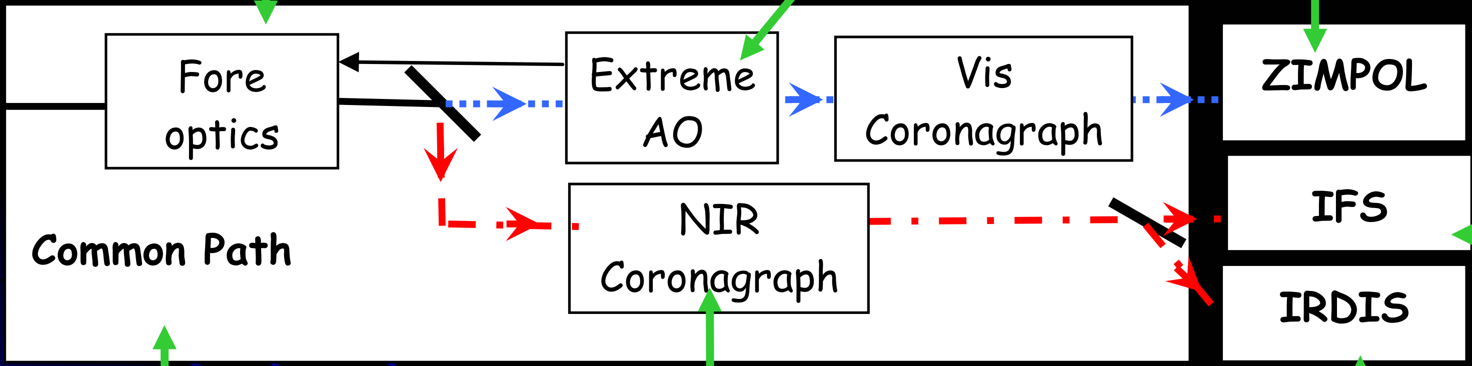
Concept overview

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"



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

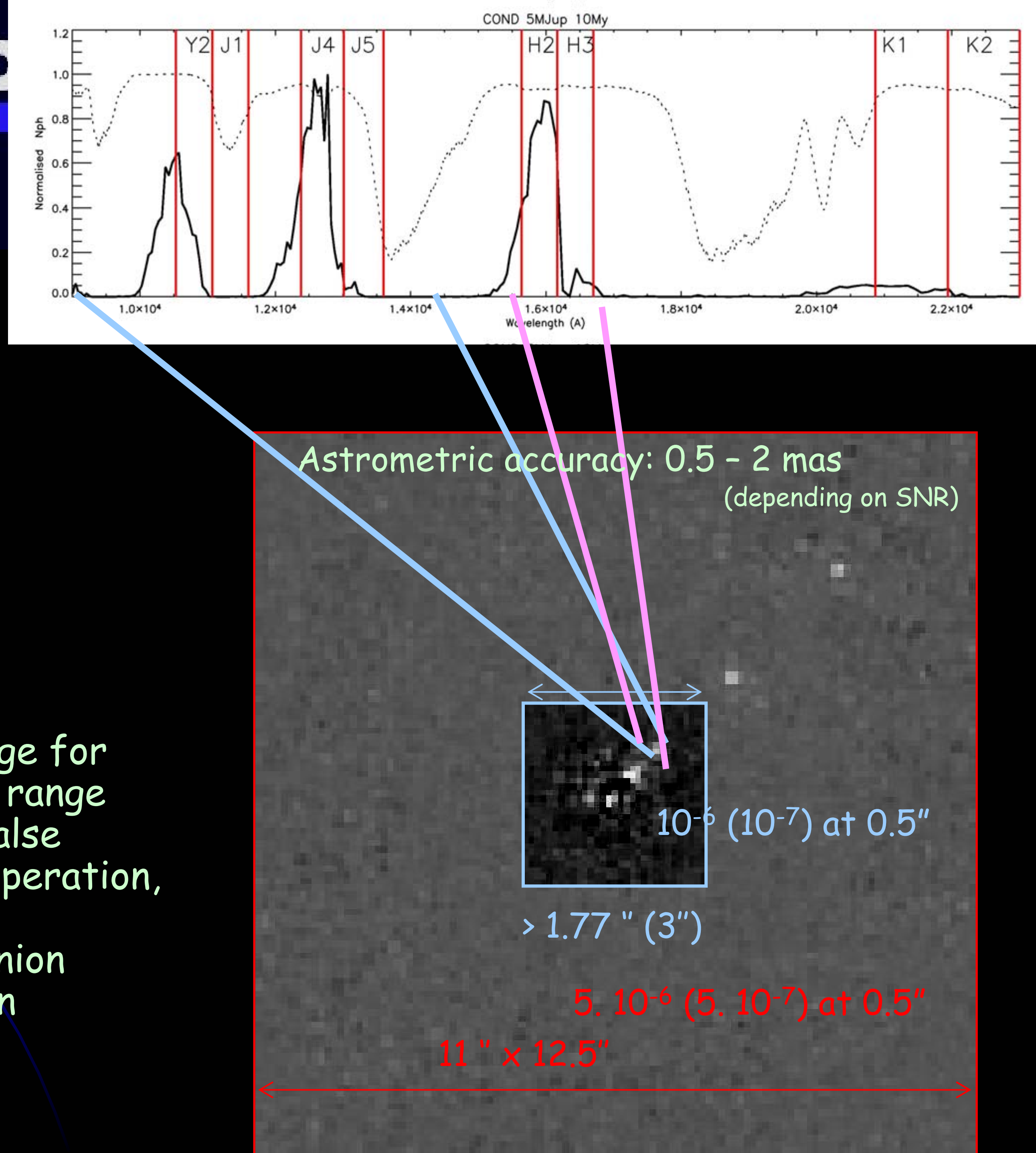
0.95 – 2.32 μm; λ/2D @ 0.95 μm
Differential imaging: 2 wavelengths,
R~30, FoV = 12.5"
Long Slit spectro: R~50 & 400
Differential polarization

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

Combined use and advantages of IRDIS/DBI and IFS

Simultaneous use of
Y-J band with IFS
Dual imaging in H

- ✓ Multiplex advantage for field and spectral range
- ✓ Mutual support: false alarm reduction, operation, calibration
- ✓ Immediate companion early classification



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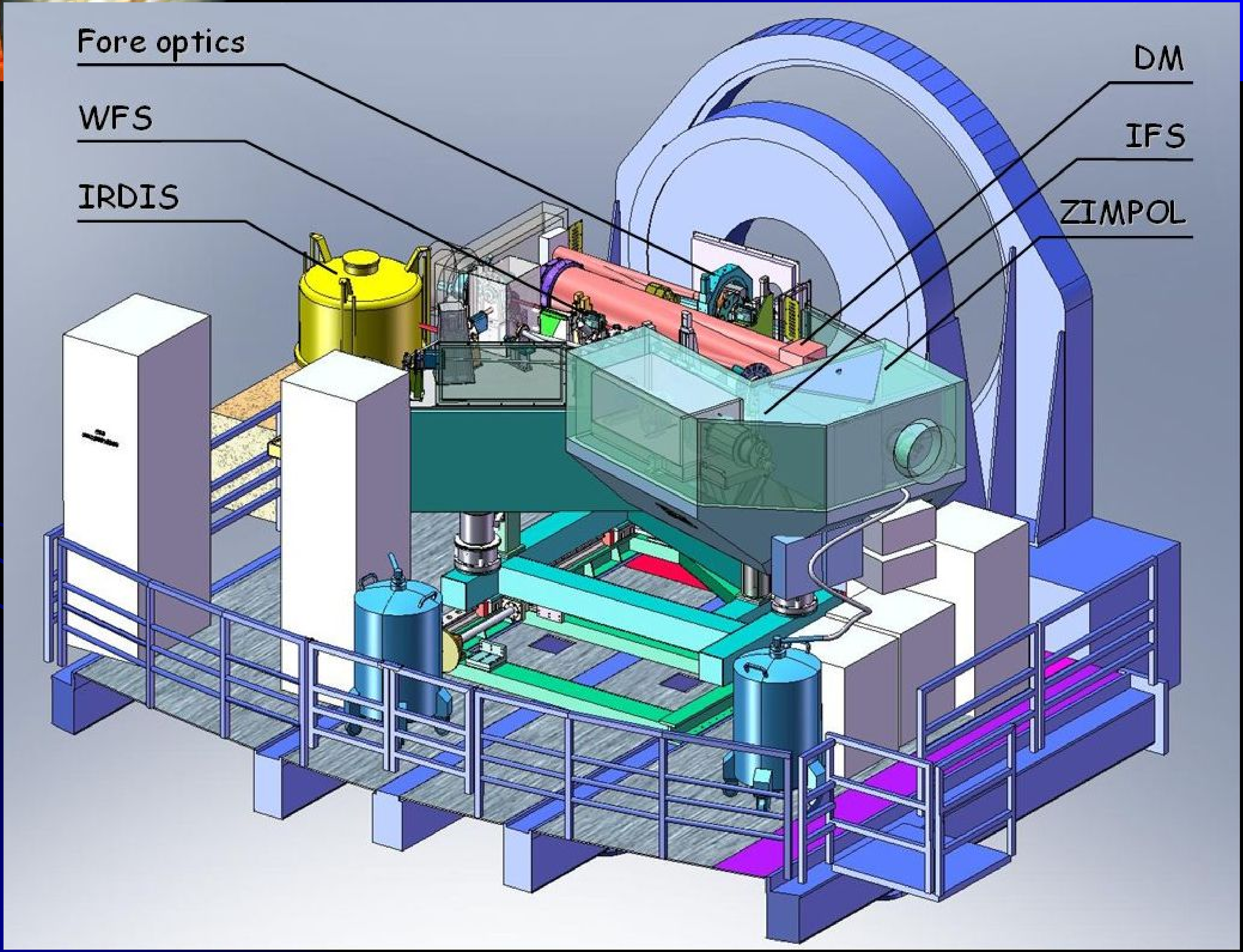

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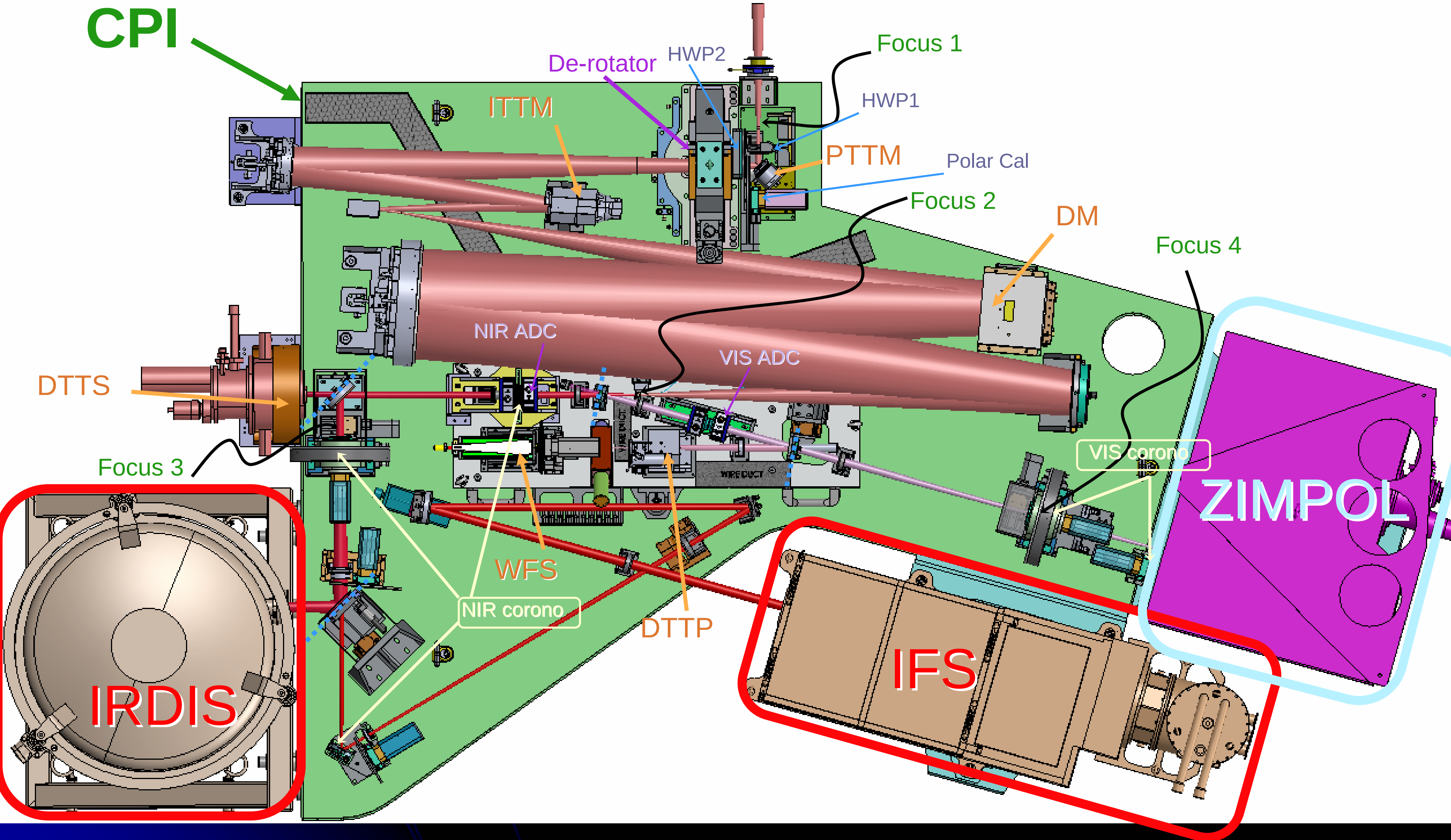
Implementation



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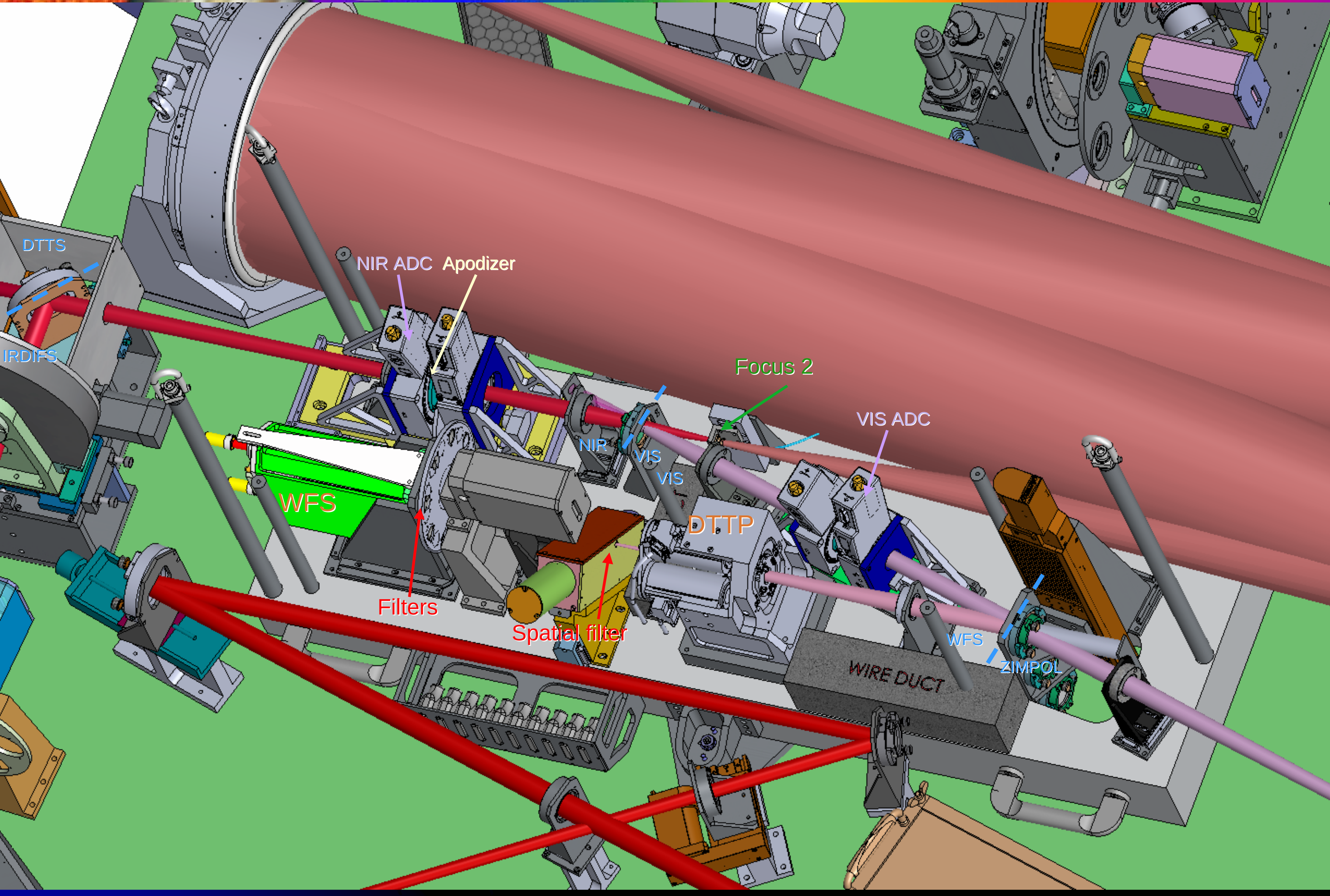
DTTS
IRDIFS
NIR ADC
Apodizer
Focus 2
VIS ADC
NIR
VIS
VIS
WFS
DTTP
Filters
Spatial filter
WFS
ZIMPOL
WIRE DUCT

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AO system

- Correct for turbulence
  - ✓ provide a corrected area of 1.5-2 arcsec diameter
  - ✓ 60 nm rms on corrected modes => (90% SR in H for typical Paranal conditions)
  - ✓ Residual jitter smaller than ±3 (goal 1.5) mas rms
  - ✓ Optimal perf for V-mag GS < 9 (goal 10)
  - ✓ Good correction (better than NAOS) for GS mag < 12 (goal 15)
- To ensure system stability
  - ✓ Optical axis wrt to coronagraphic device < **0.5 mas (goal 0.2)**
  - ✓ Beam shift on optical surfaces < **0.2% (goal 0.1) of the full pupil diameter**
  - ✓ Non common path aberrations (down to coronagraph device) < **15 nm rms**
- To provide useful data for image post-processing
  - ✓ Storage of WFS and control data
  - ✓ Estimation of turbulence and system critical parameters
  - ✓ Measurement of IRDIS internal defects (differential aberrations)

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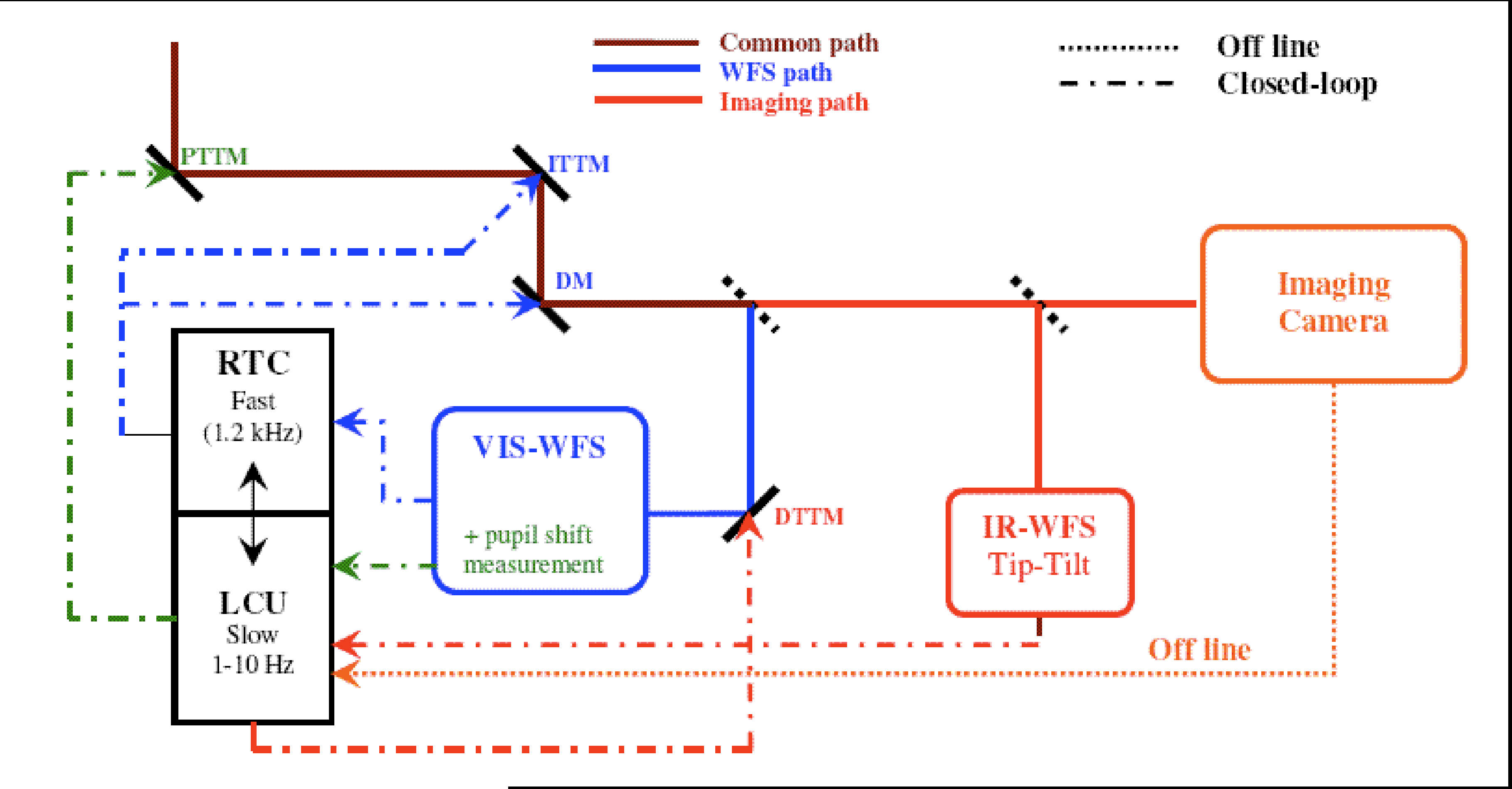
AO System



- SPARTA: Standard Platform for Adaptive optics Real Time Applications

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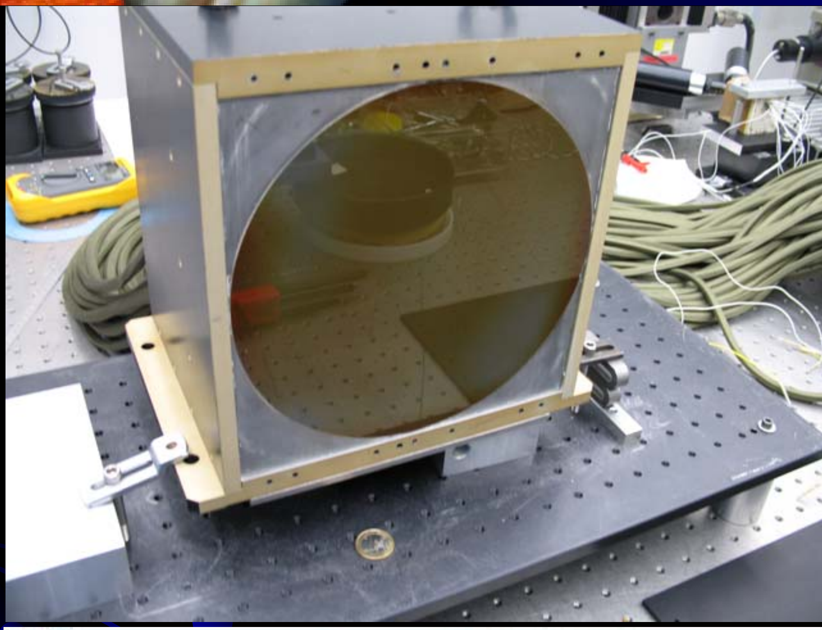
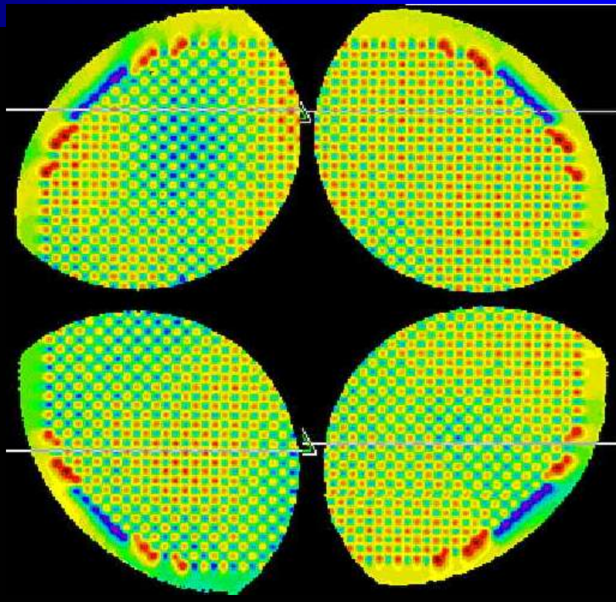
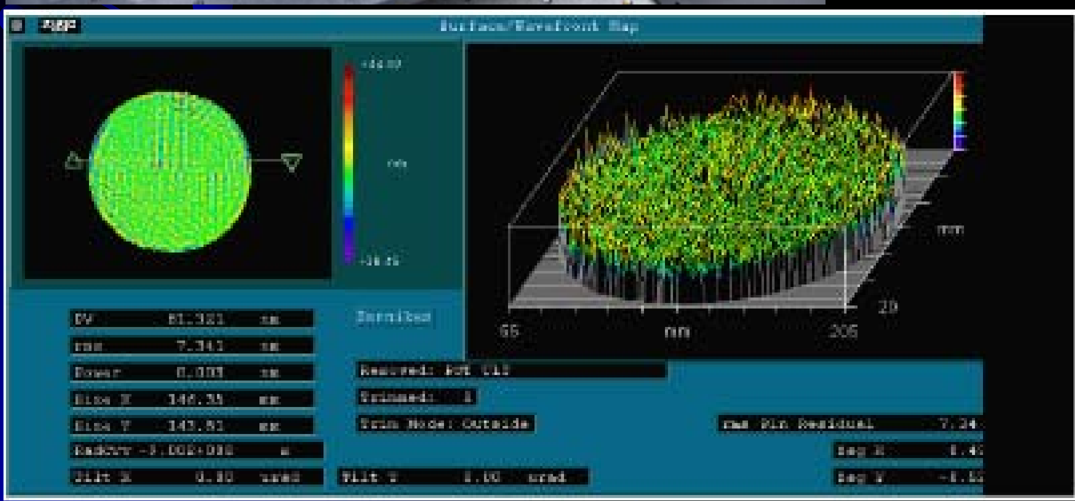
SPHERE Deformable Mirror

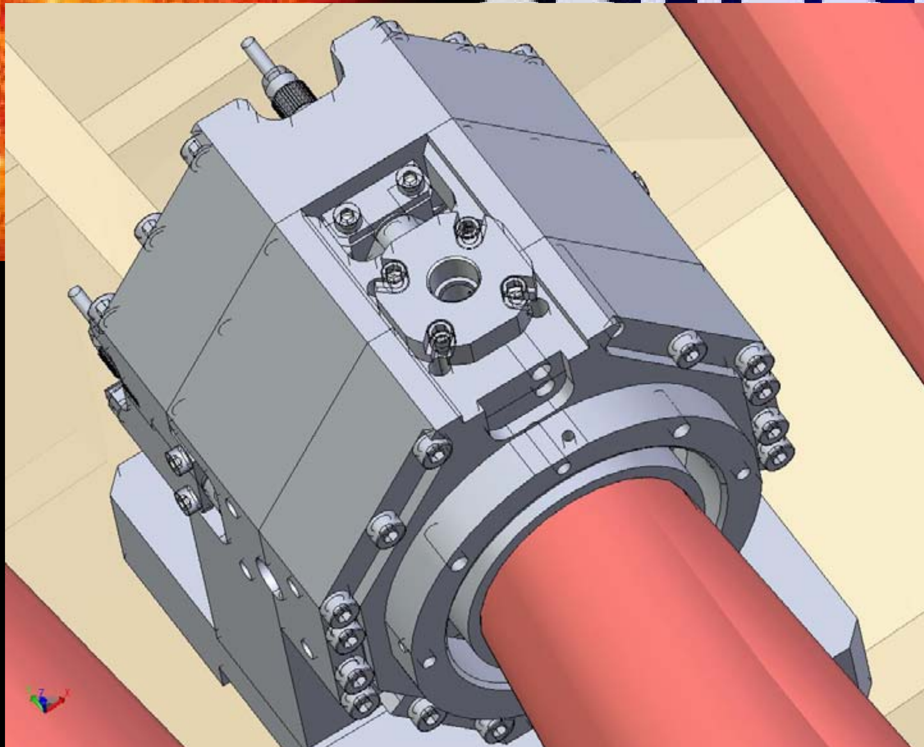


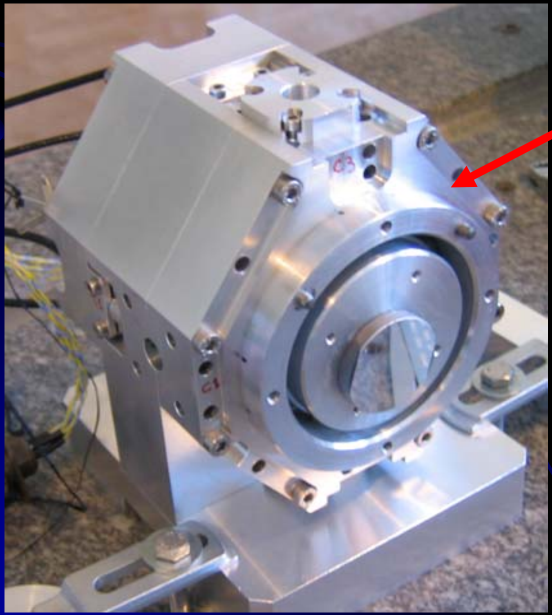




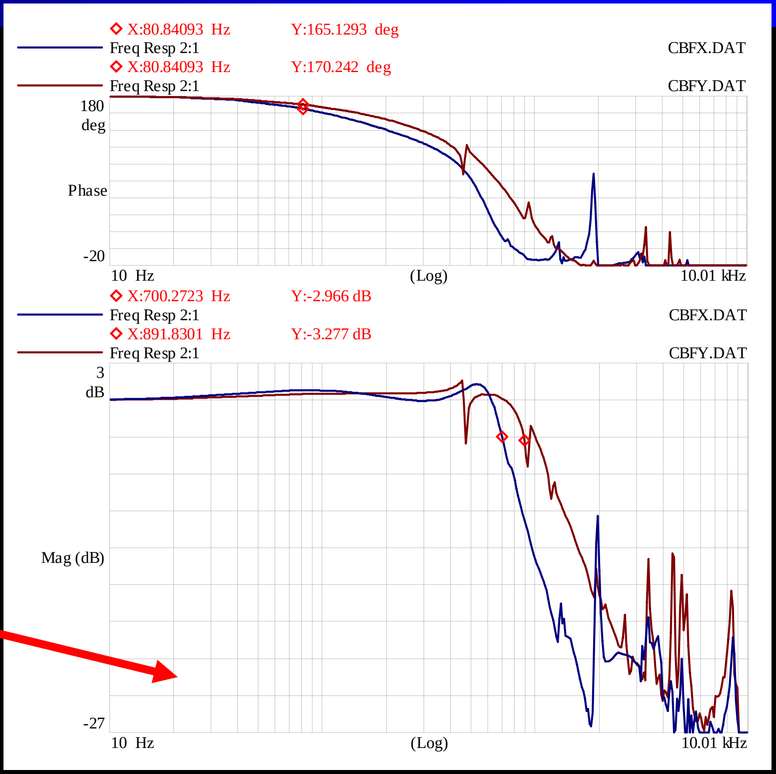
- ✓ CILAS piezo-stack DM delivered end 2007
- ✓ Surface quality: 5nm rms

Fast Image Tip-tilt





prototype



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

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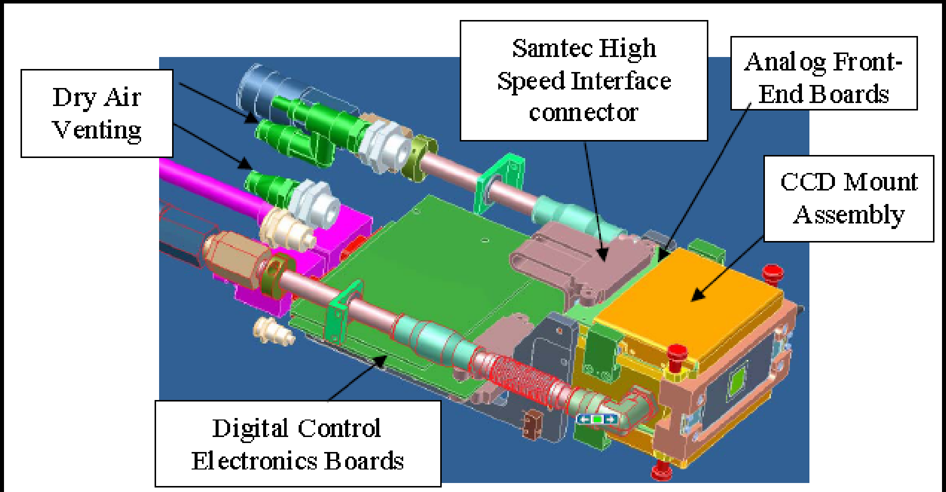
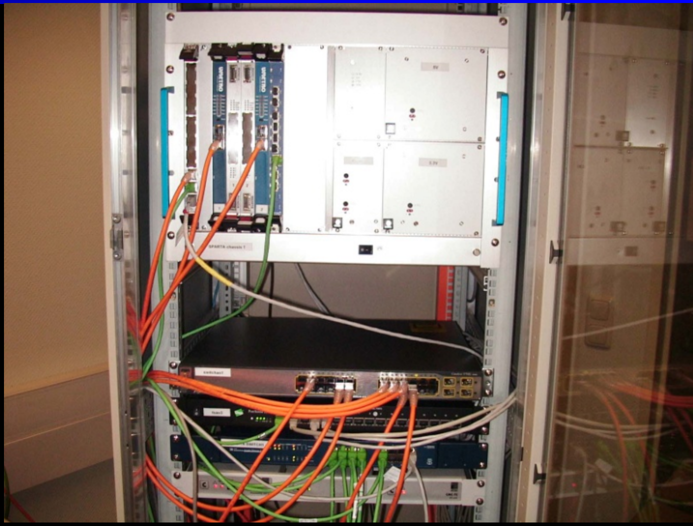
1.2 kHz, CCD220-based wavefront sensor

- Benefits from the Opticon JRA1 reasearch program (EU funded)
- Common with the VLT AO-facility
  1. pixels, square 24 µm
  2. 100% fill factor and 240x240 square grid array of pixels.
  3. low read noise of < 1 e-/pixel and goal of 0.1 e-/pixel.
  4. range of operating frame rates from 25 frames/s (fps) to 1200fps
- NGC development (ESO)
- Spatially Filtered SH
  - Optimization of the spatial filter size
  - Study of BB impact
  - WCOG : confirmation of the gain in perf (simulation & experimentation)



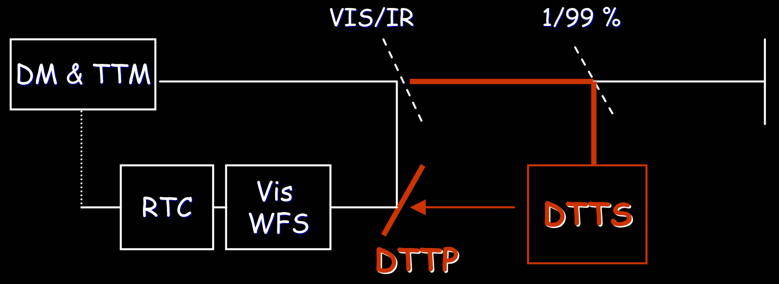
Main components – RTC



- Based on SPARTA platform
  - Consortium specifications (+ algo)
  - ESO development
- Main features
  - very small global delay (~ 1ms) + large number of actuators
  - hybrid control law
    - LQG (Kalman filter based) for TT
    - OMGI for higher modes
  - additional features to deal with SAXO specificities (DTTS, PTTS)
- Status
  - Specifications OK
  - Development:
    - Various version (drops) available for SPHERE during SPARTA development => optimization of the AIT period => reduction of risks and planning drifts.
    - First version to be delivered mid-July 2009

Main components – Aux. sensors

- Differential Tip-Tilt Sensor
  - IR camera located just before the coronagraph mask
  - 1 to 10 % of the IR flux for this sensor
  - WCoG measurement
  - control of a diff. tip tilt plate
  - closed loop scheme – 1-10 Hz
  - additional capability: focus check between two observations
  - Could potentially be used to implement on-line phase diversity (see L Mugnier pres.)



- Pupil Tip-Tilt Sensor
  - Use of SH data (sub-aperture. intensities)
  - PTTM close to the entrance focal plane
  - Closed loop scheme
  - Frame rate ~ 0.1 Hz
  - Residual beam shift < 0.2 % of the full pupil diameter

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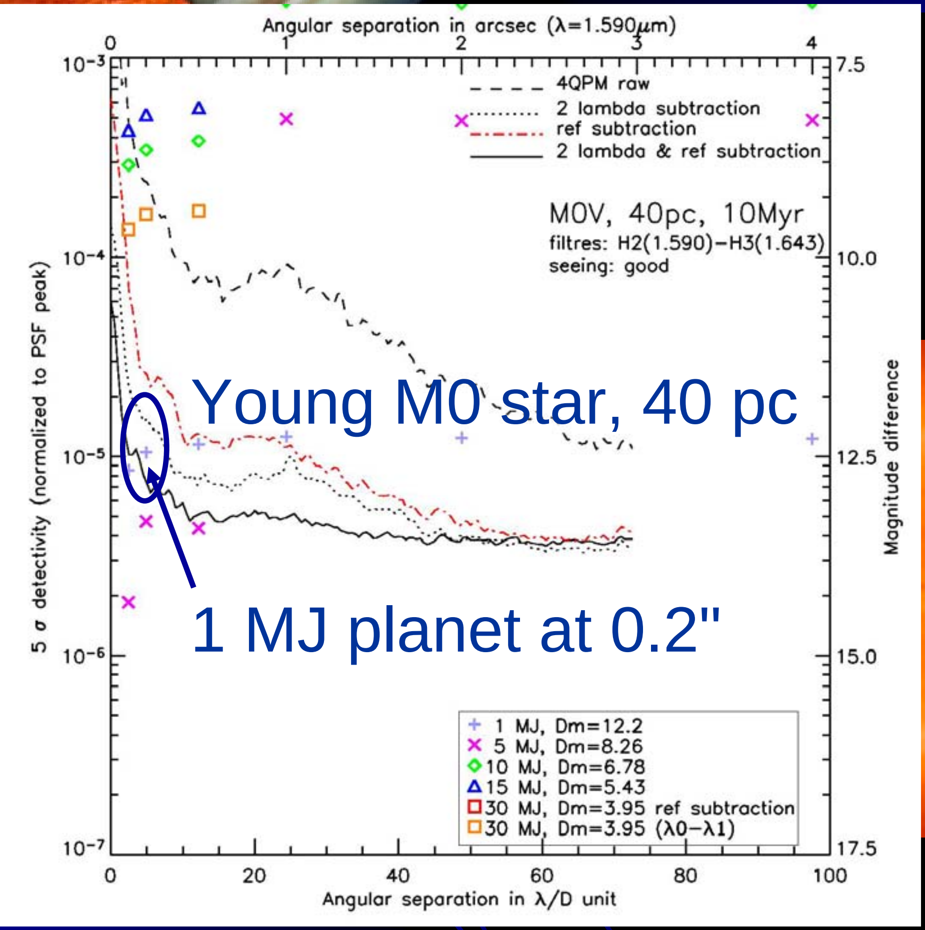
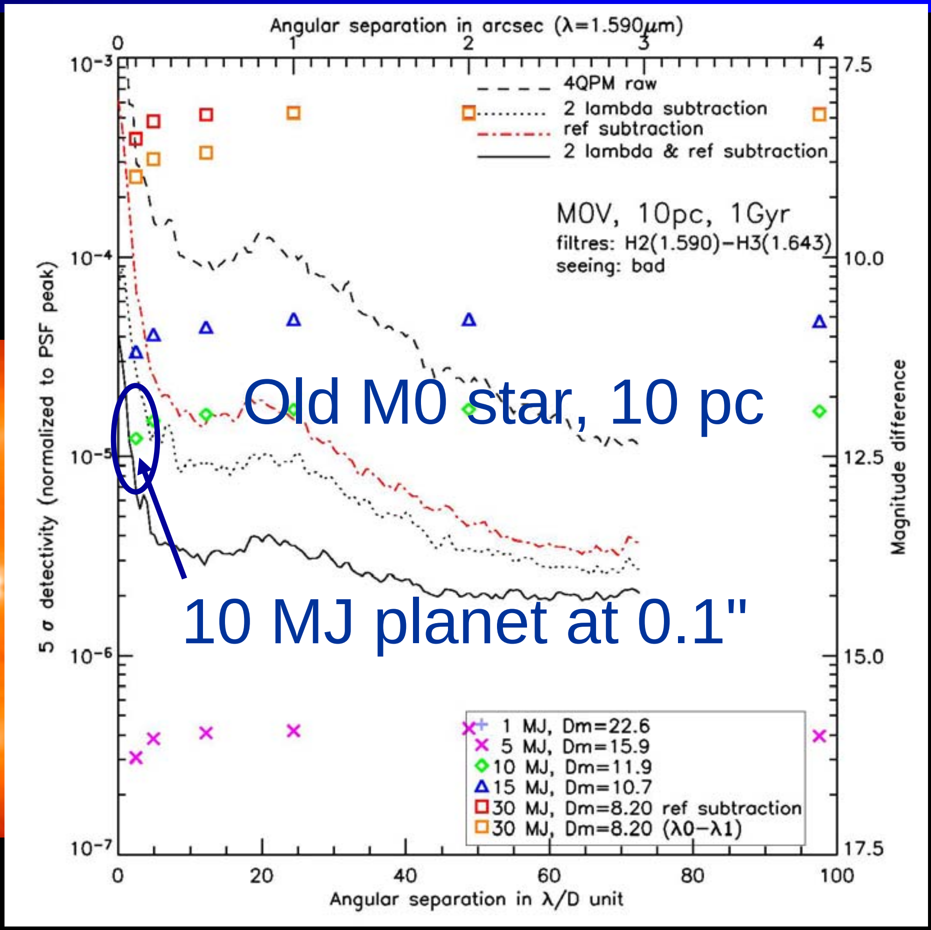
IRDIS dual beam imager





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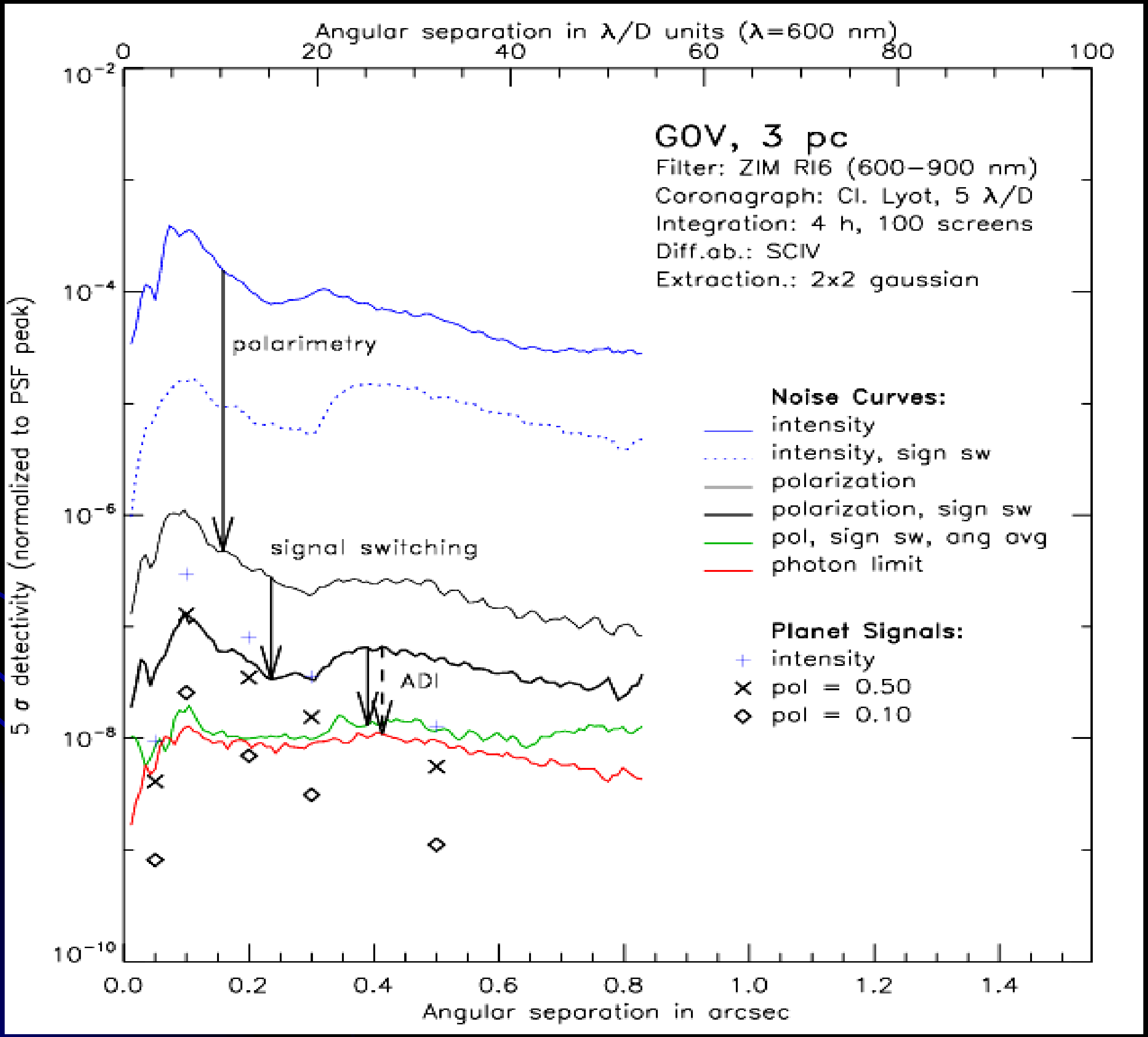
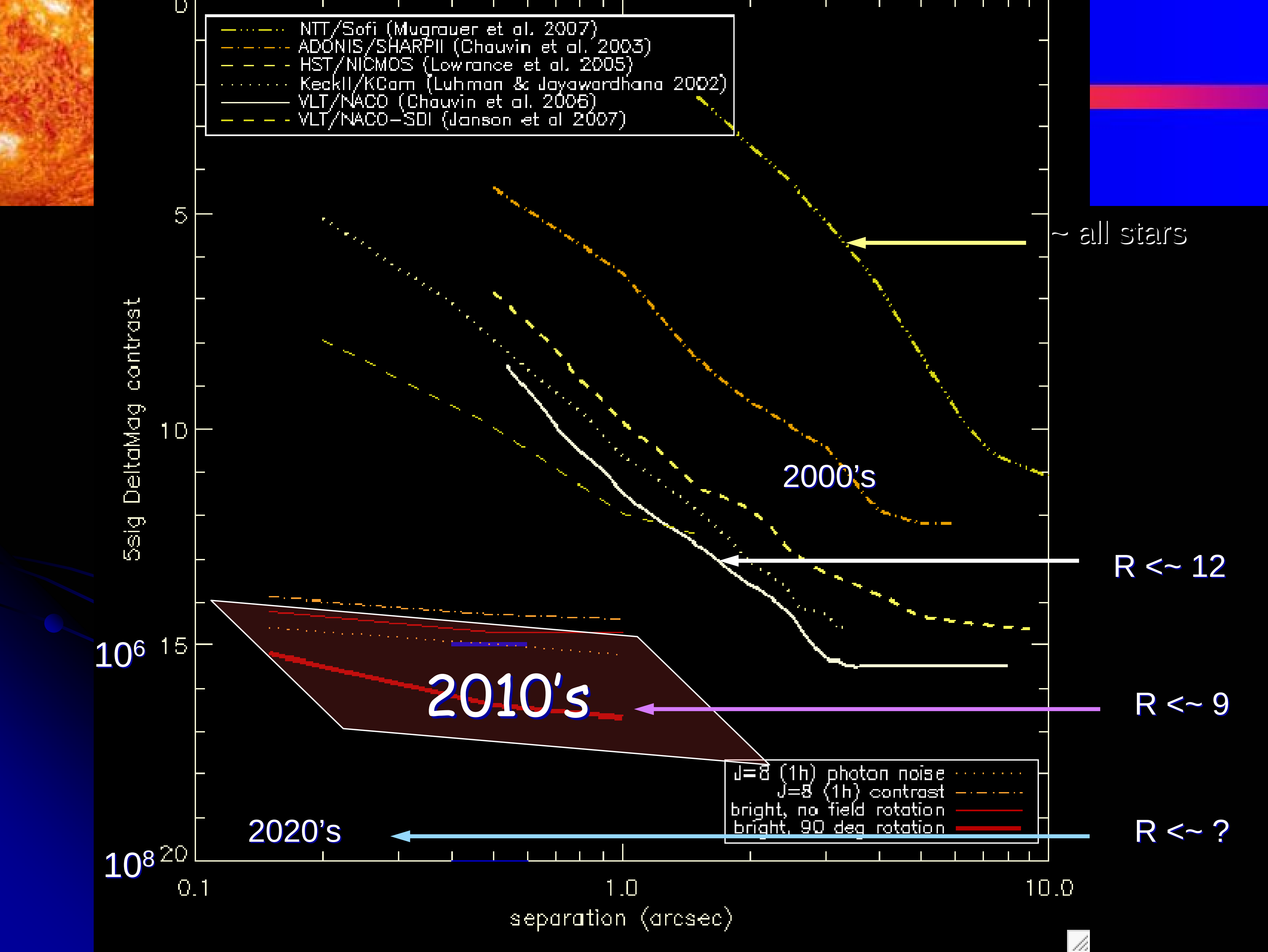
ZIMPOL performance





NTT/Sofi (Mugrauer et al. 2007)
ADONIS/SHARPII (Chauvin et al. 2003)
HST/NICMOS (Lowrance et al. 2005)
KeckII/KCam (Luhman & Jayawardhana 2002)
VLT/NACO (Chauvin et al. 2006)
VLT/NACO-SDI (Janson et al 2007)
~ all stars
2000's
R <~ 12
2010's
R <~ 9
2020's
R <~ ?
J=8 (1h) photon noise
J=5 (1h) contrast
bright, no field rotation
bright, 90 deg rotation
5sig DeltaMag contrast
5
10
15
20
10^6
10^8
0.1
1.0
10.0
separation (arcsec)

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Conclusions

- Very challenging project !
- Now at manufacturing stage
- At Paranal in early 2011
- Main science outputs by ~2015 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

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Thank you !

N_{act} - F_{samp} - $\Delta\lambda$: the necessary trade-offs

	GAINS	LOSSES
• N_{act}	↗ Corrected area $\propto N_{act}$ ↗ Contrast (profil $\propto (N_{act})^{-8/3}$)	↘ WFS Flux $\propto (N_{act})$ ⇨ Loss in limit mag
• F_{samp}	↗ Contrast $\propto (F_{samp})^2$	↘ WFS Flux $\propto (F_{samp})^{-1}$ ⇨ Loss in limit mag
• $\Delta\lambda$ (WFS-im)	↘ Noise effects $\propto \Delta\lambda^{-2}$ WFS spectral bandwidth VIS detector ⇨ Gain in limit mag ⇨ ↗ contrast	↗ Chromatism effects ⇨ ↘ contrast

⇨ **Complex trade-offs:** depends on scientific requirements (ultimate contrast, number of targets) and atmospheric conditions

SAXO error budget

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- 41x41 actuators => corrected area +/- 0.82" in H
- "Simplified" Error budget (nm rms) for SAXO

Error sources	Low frequencies (nm)		High frequencies (nm)	
Seeing	0.65	0.85	0.65	0.85
total for atmospheric limitations	11	14	9	11
total for DM errors	11 (7)	13 (9)	52	63
Total for temporal errors	19 (15)	23 (18)	-	-
Total for residual aliasing error	20 (13)	32 (23)	-	-
Total for noise related errors	42 (35)	44 (36)	-	-
Total for mis-calibration errors	10 (5)	10 (5)		
TOTAL for the AO main AO loop	54 (43)	62 (49)	52.8	64.0

→ 41x41 act.
→ 1.2 KHz
→ Filtered SH-WFS
→ EMCCD, WCoG, BB WFS
→ NCPA comp.

- Telescope/instrument defects
  - in the corrected area : static / quasi-static => fully corrected by AO
  - high freq : no correction - included in the global system error budget