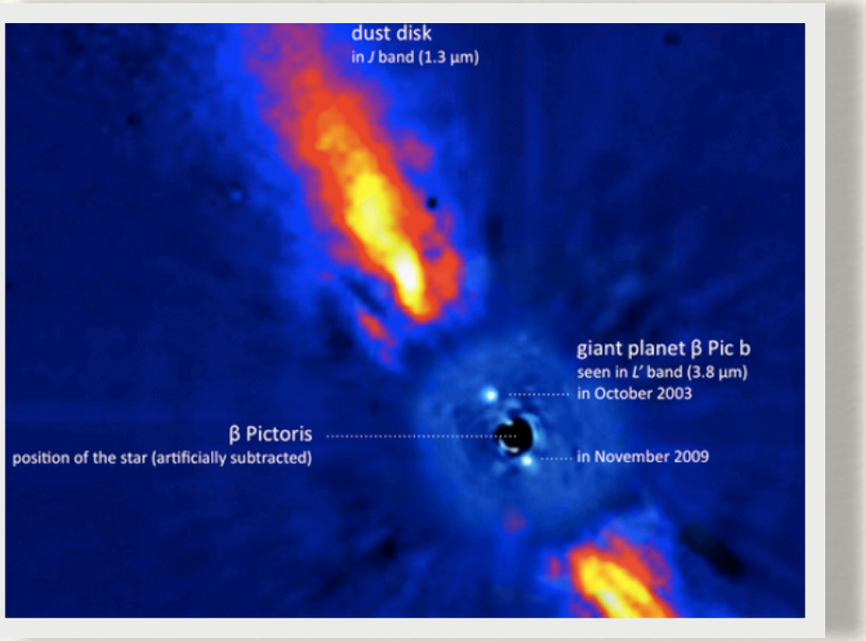
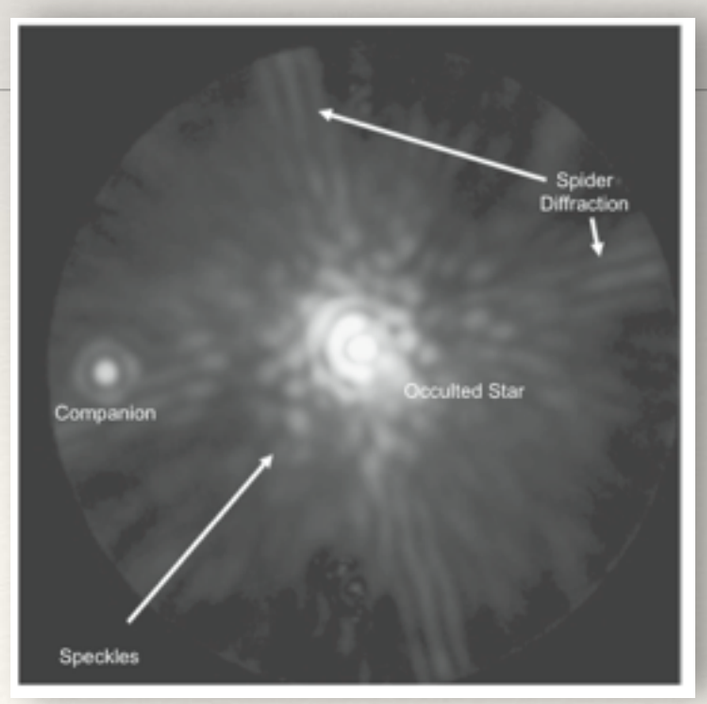


R. Claudi - INAF - Astronomical Observatory of Padova

DIRECT IMAGING OF EXTRASOLAR PLANETS

VI: INSTRUMENTATION



1st ADVANCED SCHOOL OF EXOPLANETARY SCIENCE
METHODS OF DETECTING EXOPLANETS
MAY 25-29, 2015 - VIETRI SUL MARE (SA)

Instrumentation

Instrument	Telescope	Wavelength (μm)	Ang. Resol. (mas)	Coronagraph
ACS	HST	0.2-1.1	20-100	Lyot
STIS	HST	0.2-0.8	20-60	Lyot
NAOS-CONICA	VLT	1.1-3.5	30-90	Lyot/FQPM
VISIR	VLT	8.5-20	200-500	-
SINFONI-SPIFFI	VLT	1.1-2.45	28-62	-
SPHERE	VLT	0.95-2.32	24-62	Lyot/APLC/FQPM
PUEO	CFHT	0.7-2.5	4-140	Lyot
CIAO	SUBARU	1.1-2.5	30-70	Lyot
OSIRIS	Keck I	1.0-2.4	20-100	-
AO-NIRC2	Keck II	0.9-5.0	20-100	Lyot
ALTAIR-NIRI	Gemini N.	1.1-2.5	30-70	Lyot
GPI	Gemini S.	0.9-2.4	24-62	Lyot/APLC
PALM-3000 PHARO	Hale 200”	1.1-2.5	60-140	Lyot/FQPM
PALM-3000 Project1640	Hale 200”	1.06-1.76	43-71	APLC
AO-IRCAL	Shane 120”	1.1-2.5	100-150	-

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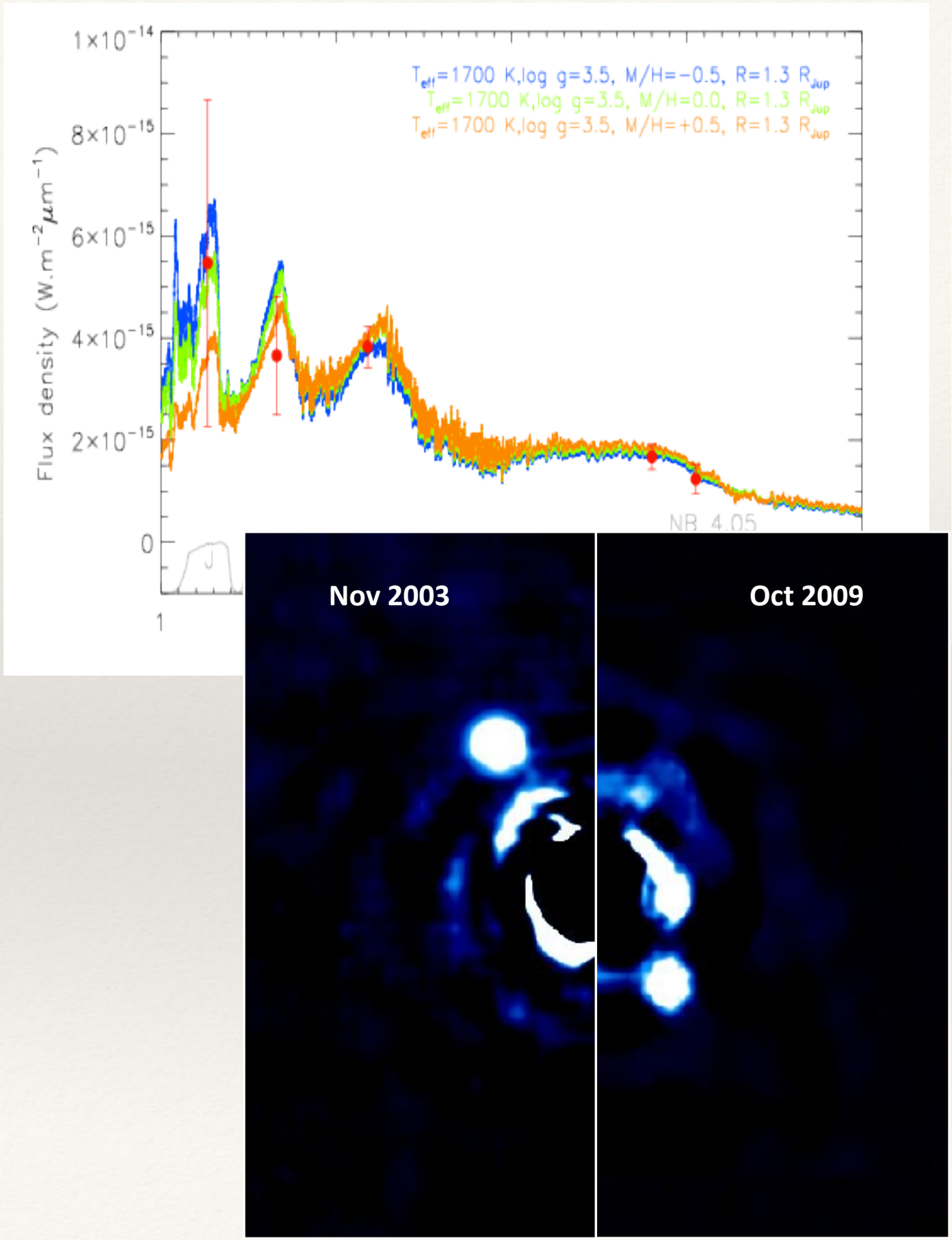
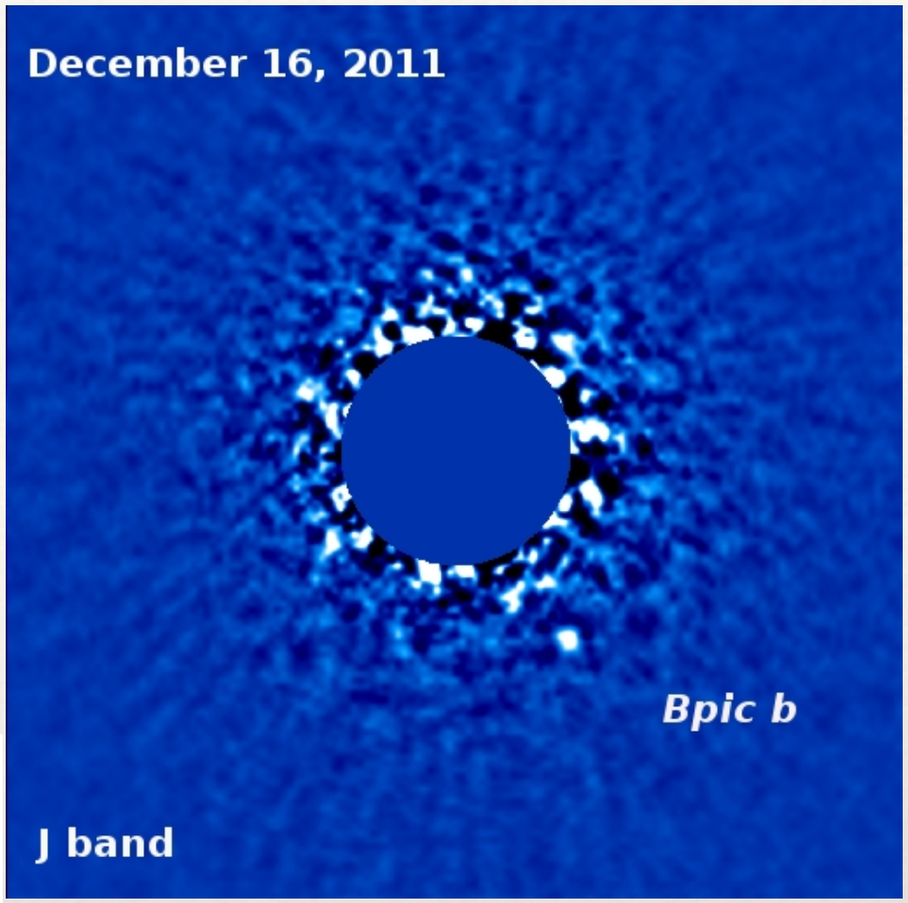
Nasmyth Adaptive Optics System
- Near Infrared Imager and Spectrograph CONICA

It was installed at the Nasmyth B focus of UT4 from 2001 through 2013. In 2014 it will be reinstalled on UT1 at the Nasmyth A. It provides adaptive optics assisted imaging, imaging polarimetry, coronography and spectroscopy, in the 1-5 micron range.

Lenzen, R. et al. 2003, SPIE 4841, 944 Rousset, G. et al. 2003, SPIE 4839, 140





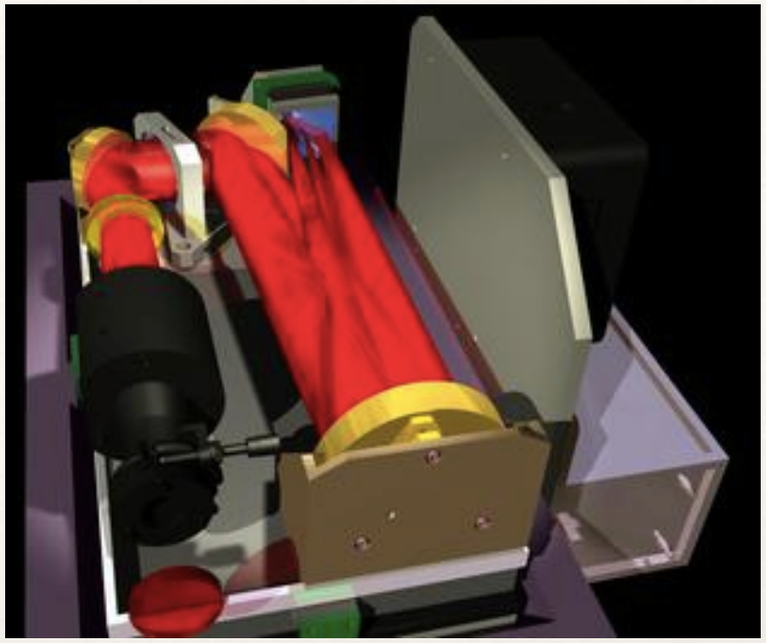
VLT/NaCo ADI imaging

Bonnefoy et al. 12

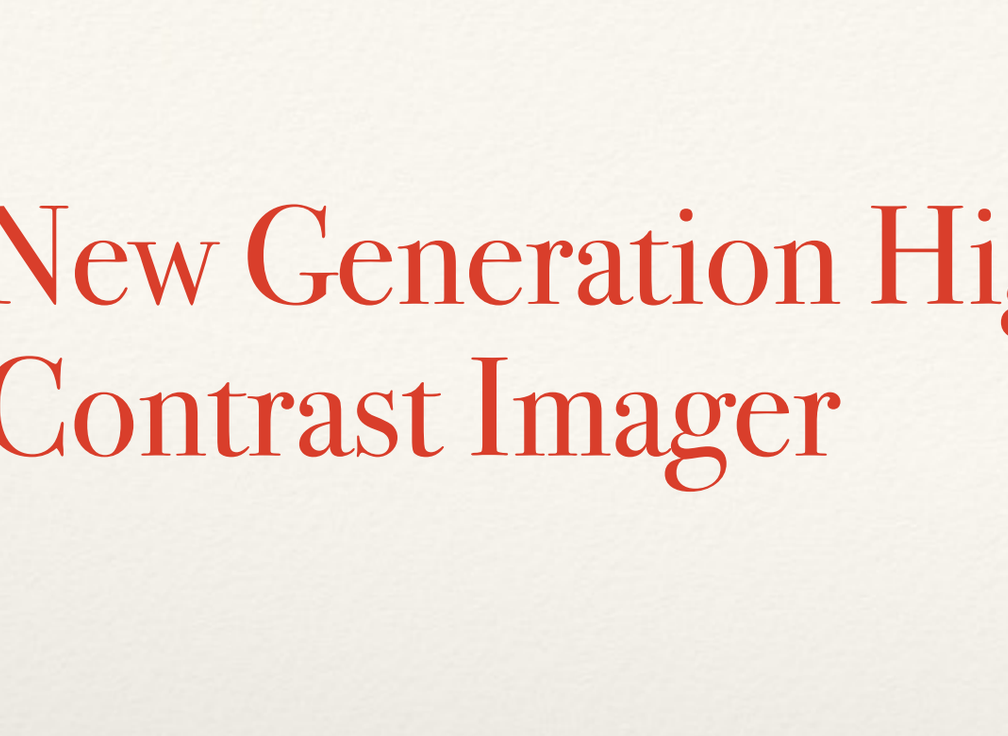
VLT/NaCo ADI imaging
L’-band, β Pic b

Lagrange et al. 09, 10
Bonnefoy et al. 10, Quanz et al. 10

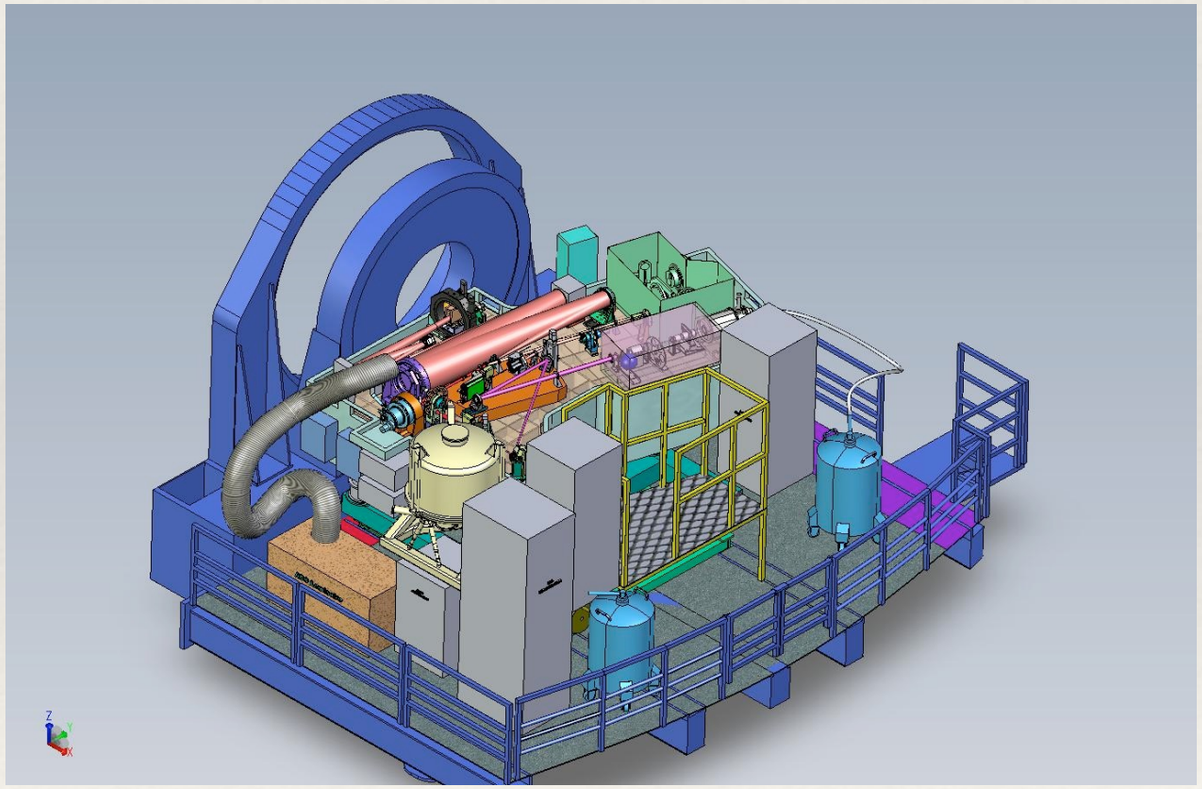
New Generation High Contrast Imager



Project 1640@PALOMAR



GPI@GEMINI



SPHERE@VLT

Project 1640: Palomar AO, Coronagraph & Integral Field Spectrograph

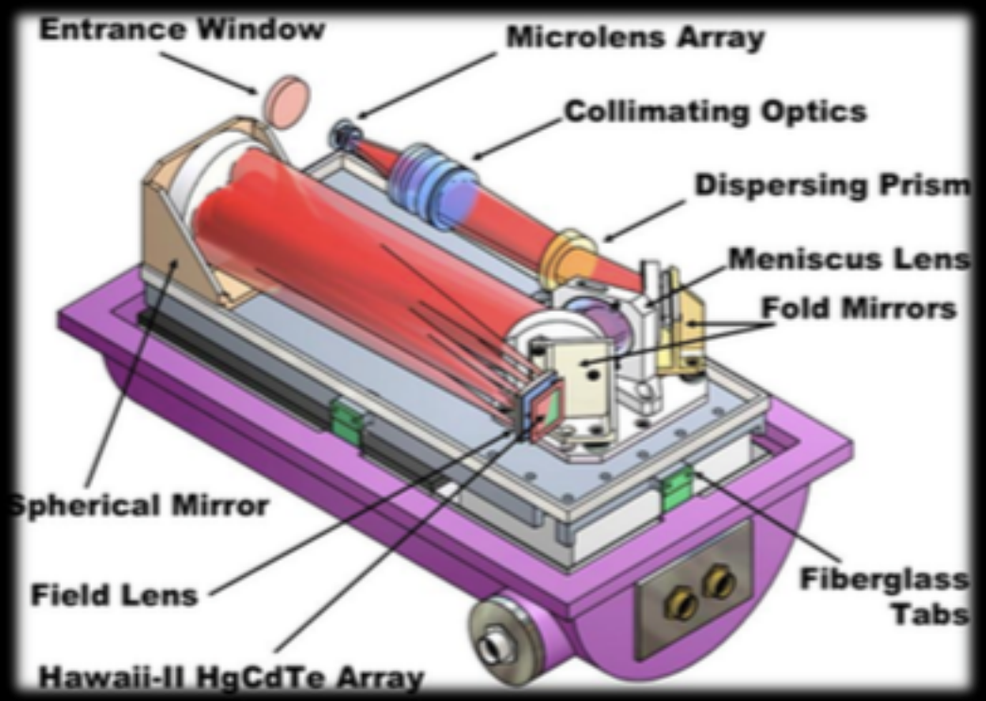
Hinkley et al., 2011b (PASP, 123, 74)

Project 1640: Palomar AO, Coronagraph & Integral Field Spectrograph

Key Features:

- 3,388 actuator AO system
- Wave Front Calibration Interferometer (JPL)
- YJH Imaging Spectrograph

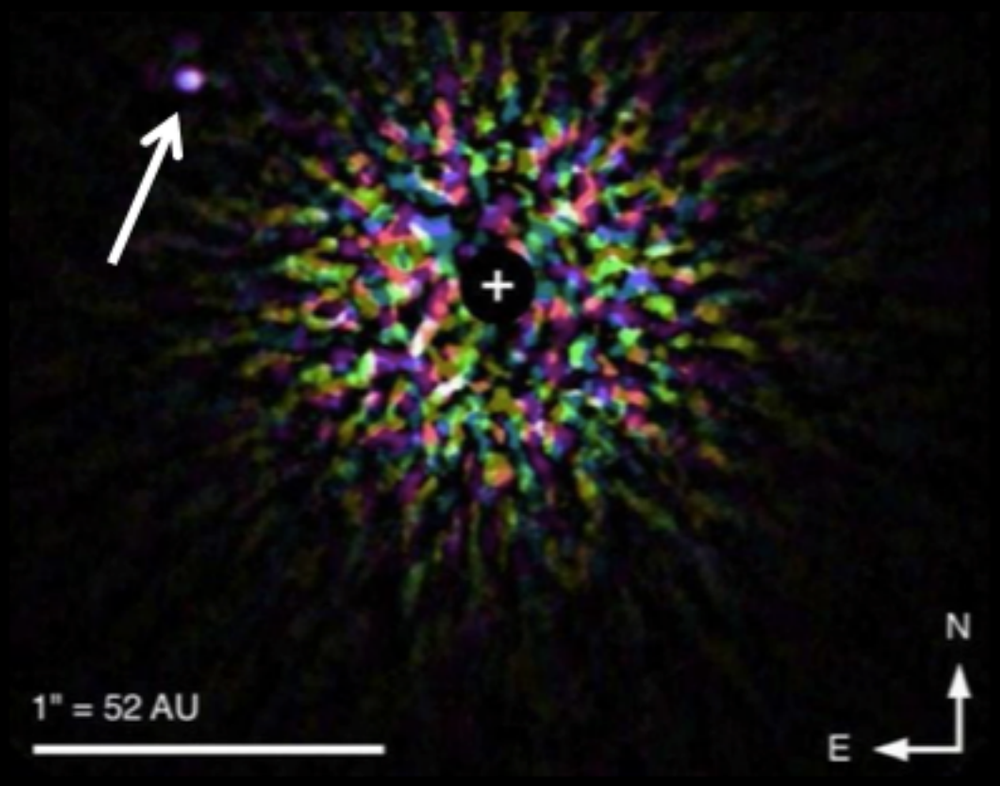
MKID Technology being integrated



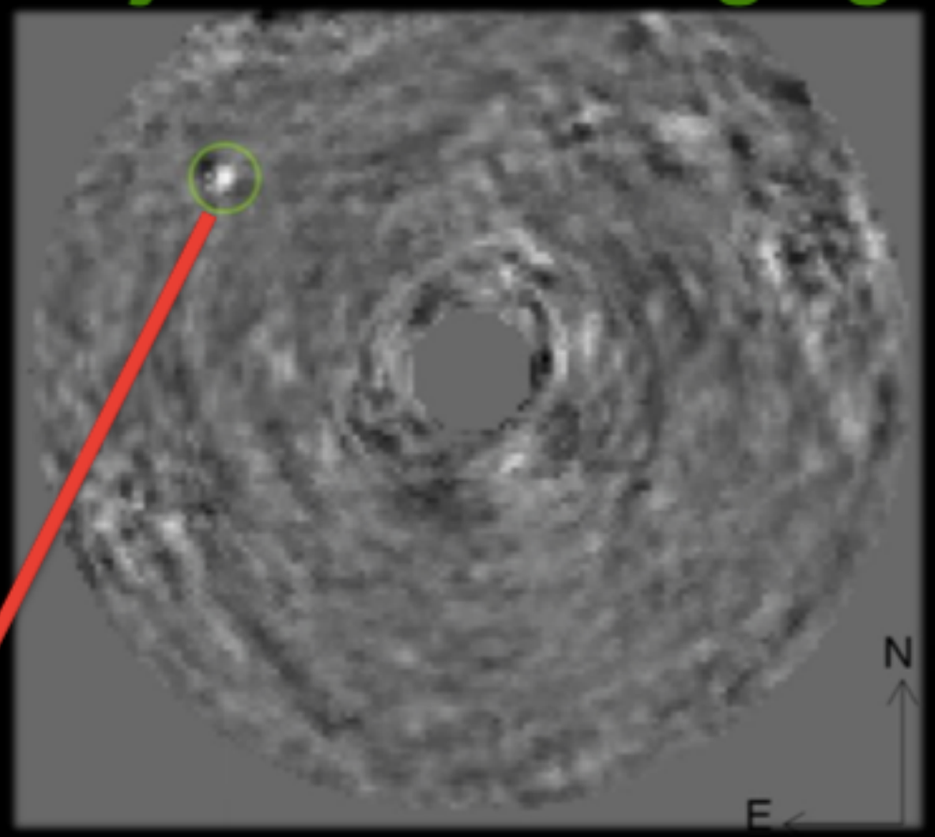
Hinkley et al., 2011b (PASP, 123, 74)

Kappa Andromedae

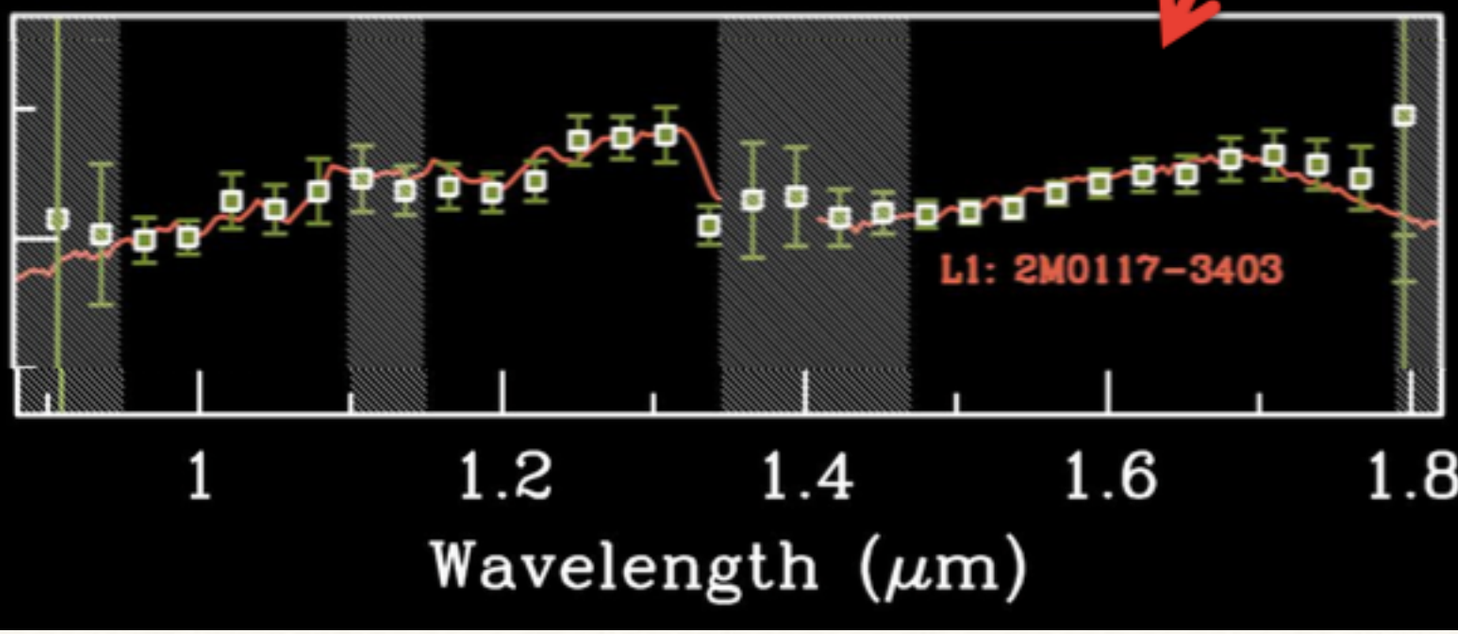
Subaru Discovery Image:
Carson et al (2013)



Project 1640 Imaging

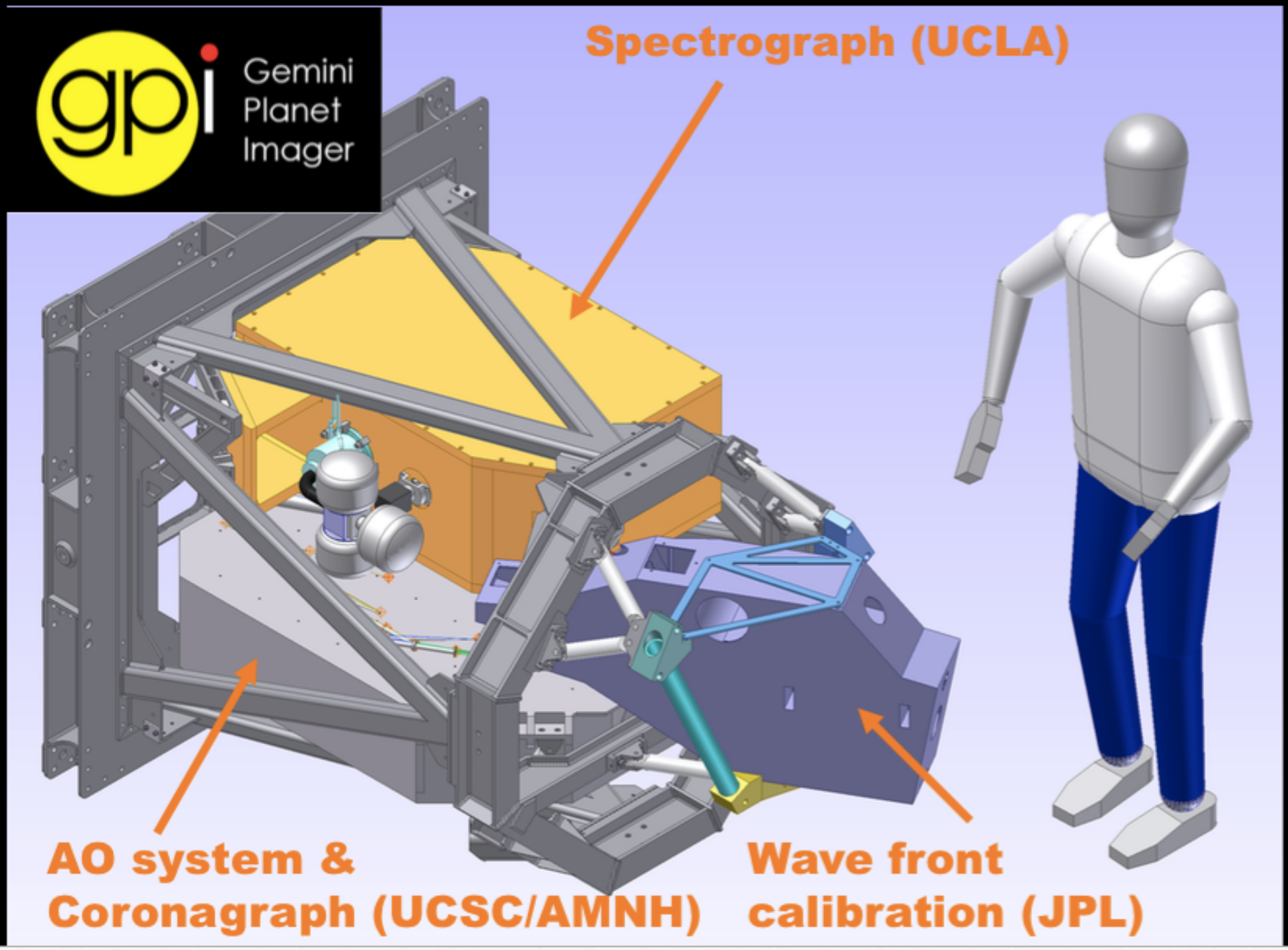


Project 1640 Spectrum



Hinkley et al. (2013)

Gemini Planet Imager

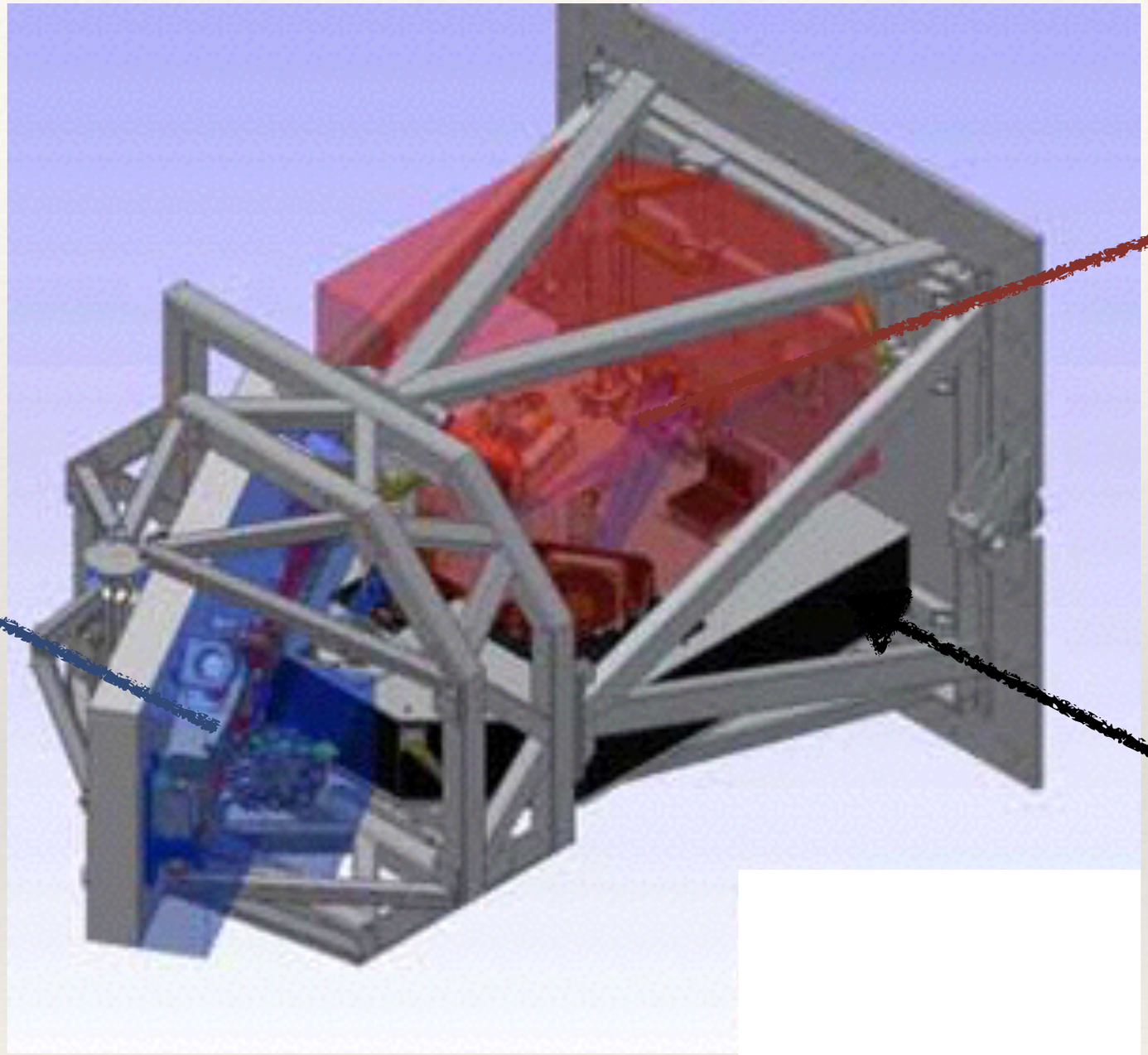


GPI Scientific Drivers

GPI will detect exoplanets in the outer regions (a > 5 AU) of the planetary systems of main sequence stars in the solar neighborhood.

- Establish directly the occurrence rate of planetary systems;
- Provide critical tests of the core accretion model, including a census of regions where gas giants can only form via gravitational instability;
- Shed light on the origin of hot Jupiters by finding planets that migrated outwards;
- Show whether or not the architecture of our own planetary system, with gas giants located between 5–10 AU is unique.

Gemini Planet Image



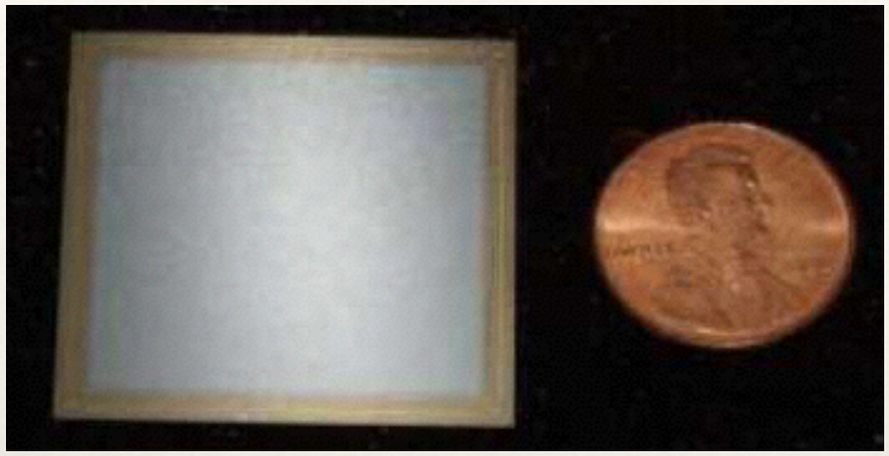
Calibration System

IFS System

Adaptive Optics System

http://planetimager.org/

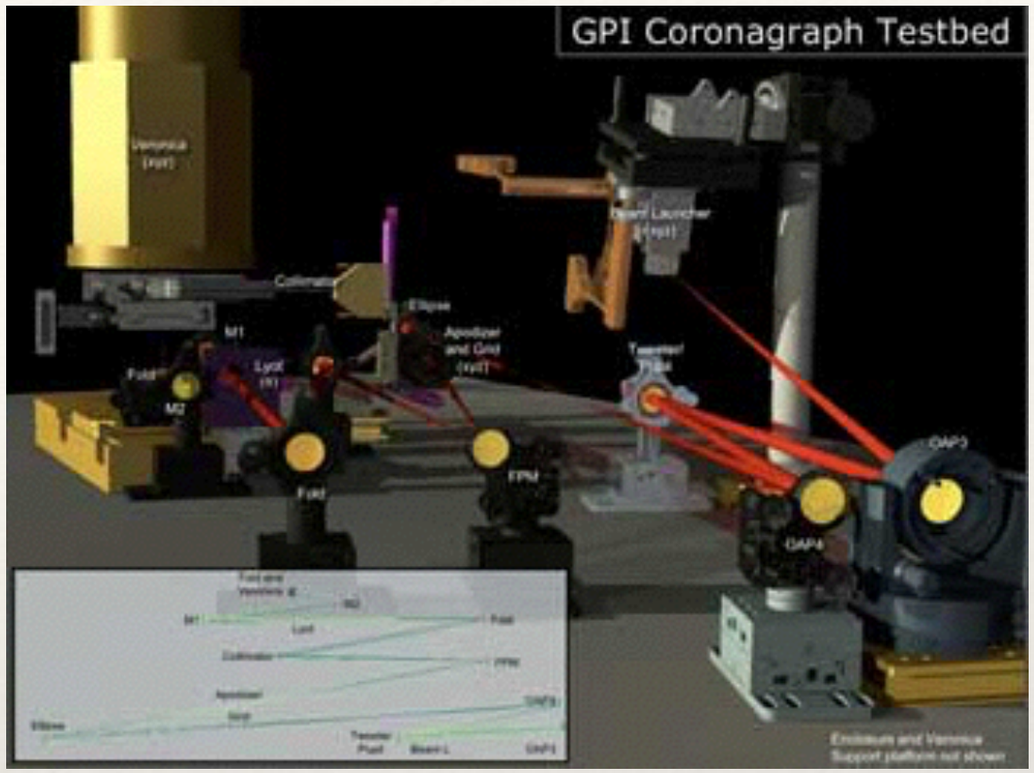
GPI's AO

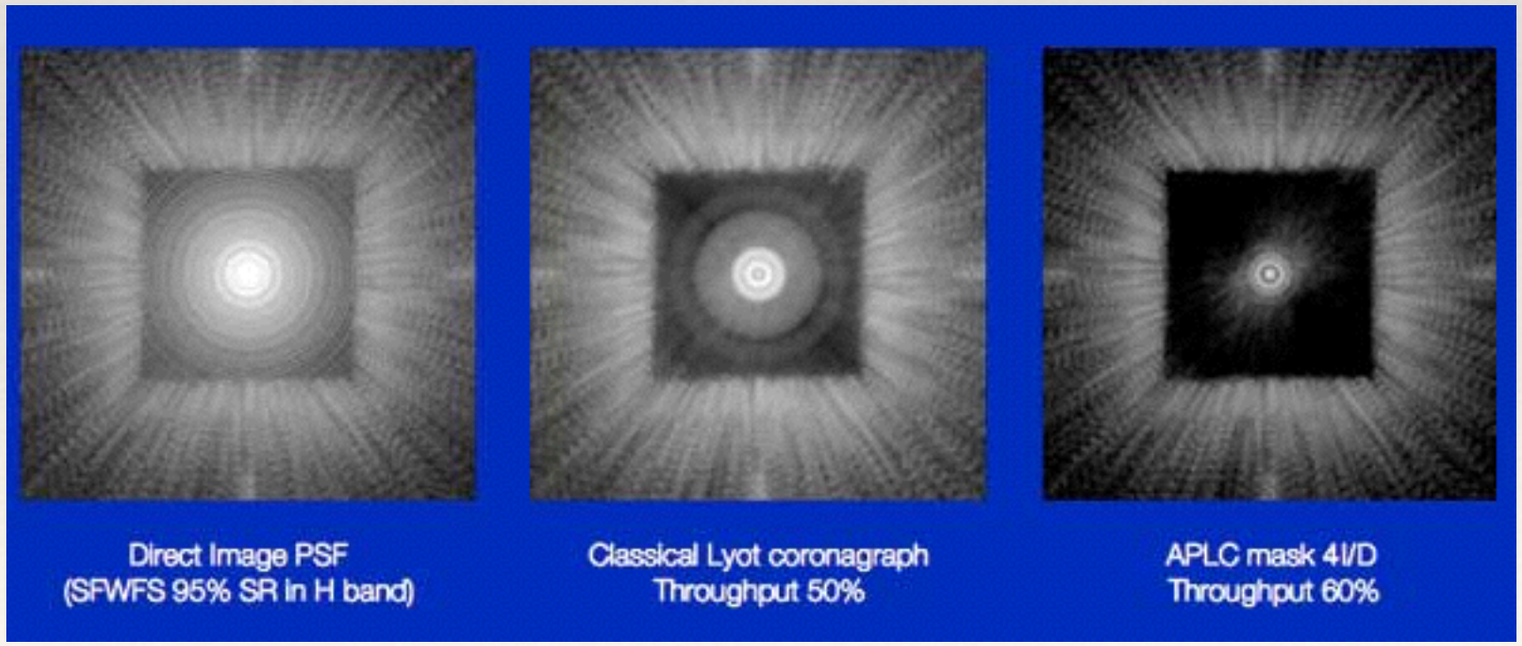


The heart of the GPI adaptive optics system is a MEMS deformable mirror. The image above shows an existing 64x64 element device that is slightly larger than a small coin.

http://planetimager.org/

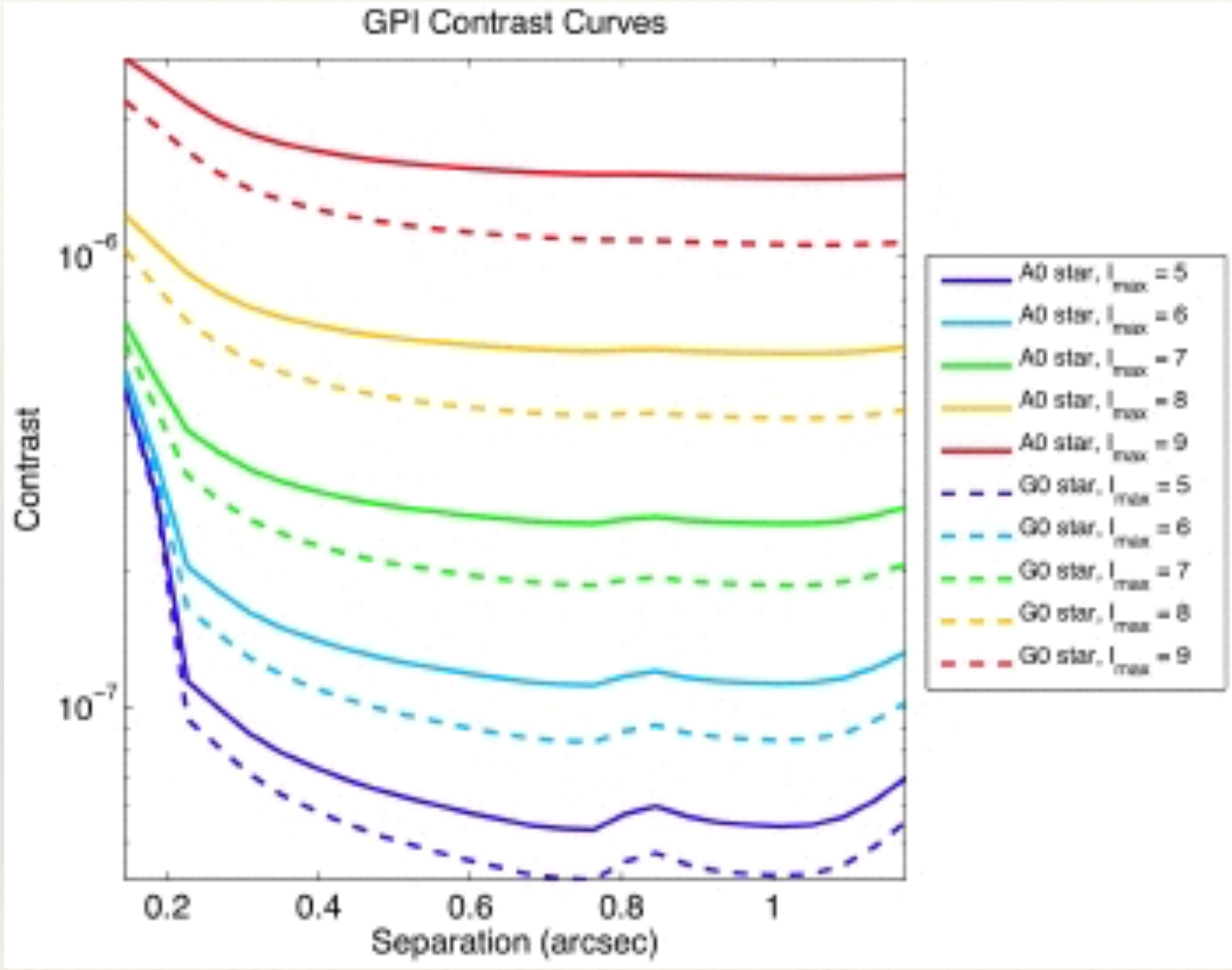
CORONAGRAPH





GPI's Performance

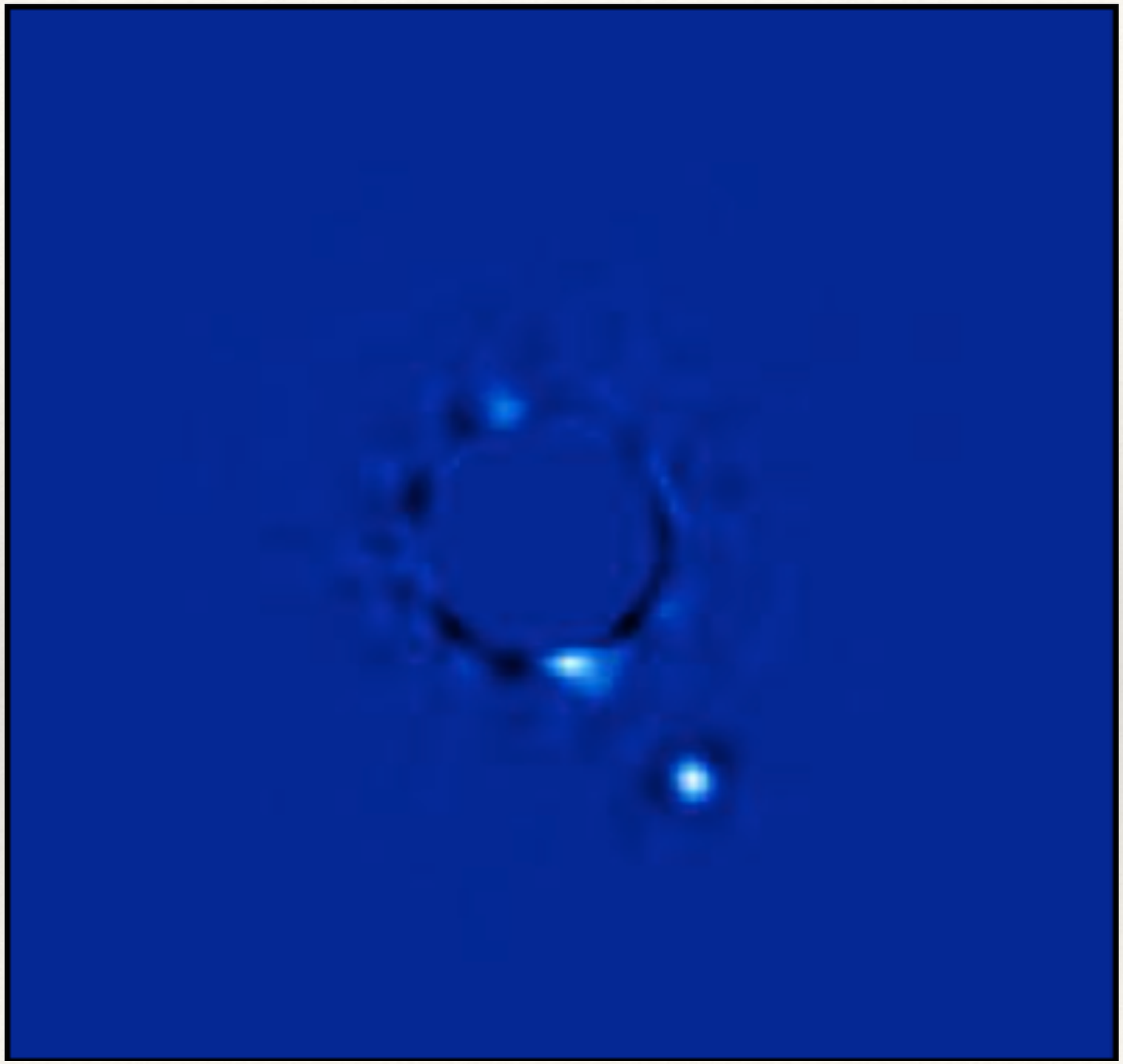
ADI plus SDI



http://planetimager.org/

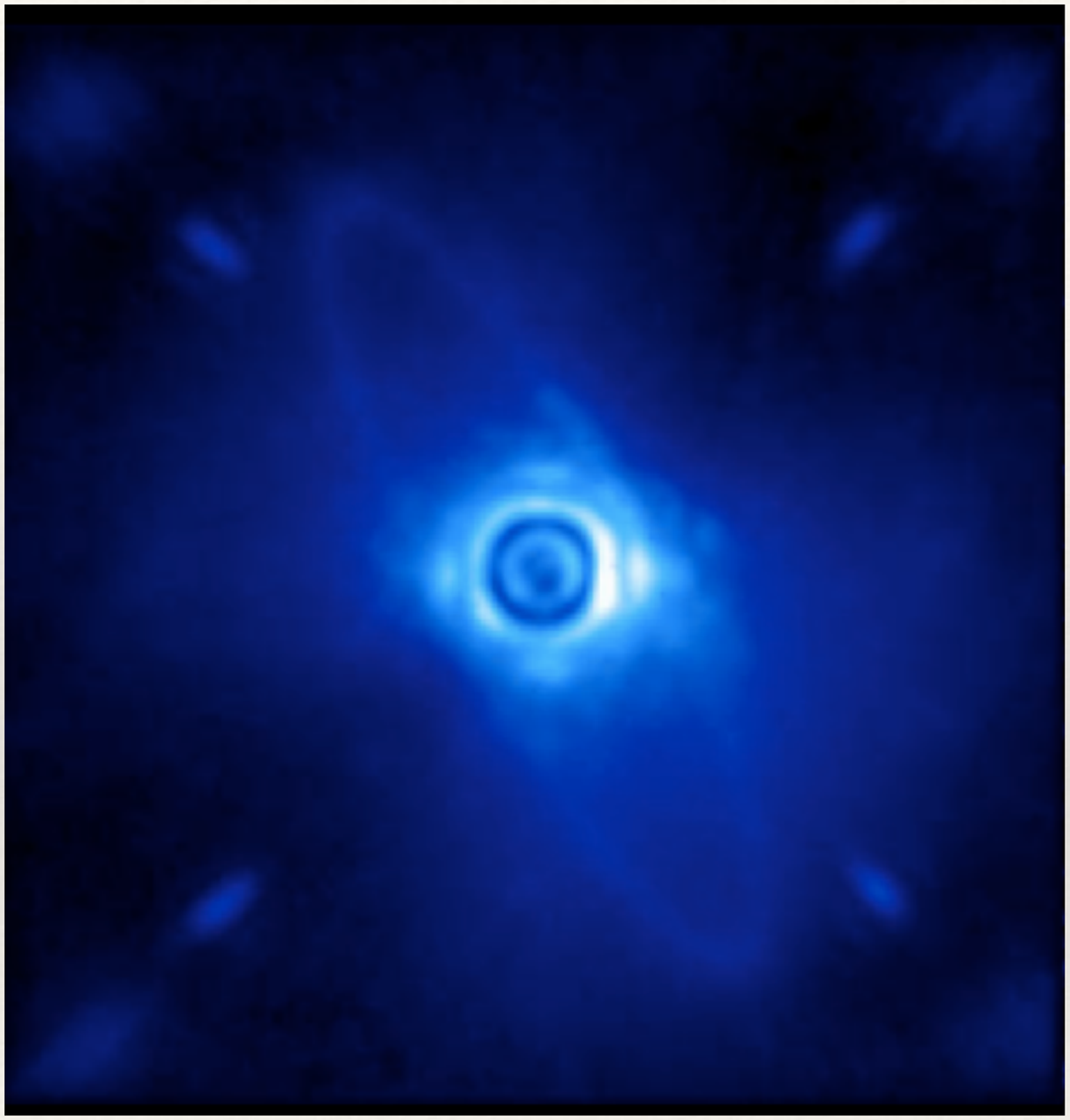
GPI's Performance

Beta Pic
H Band
1980 s

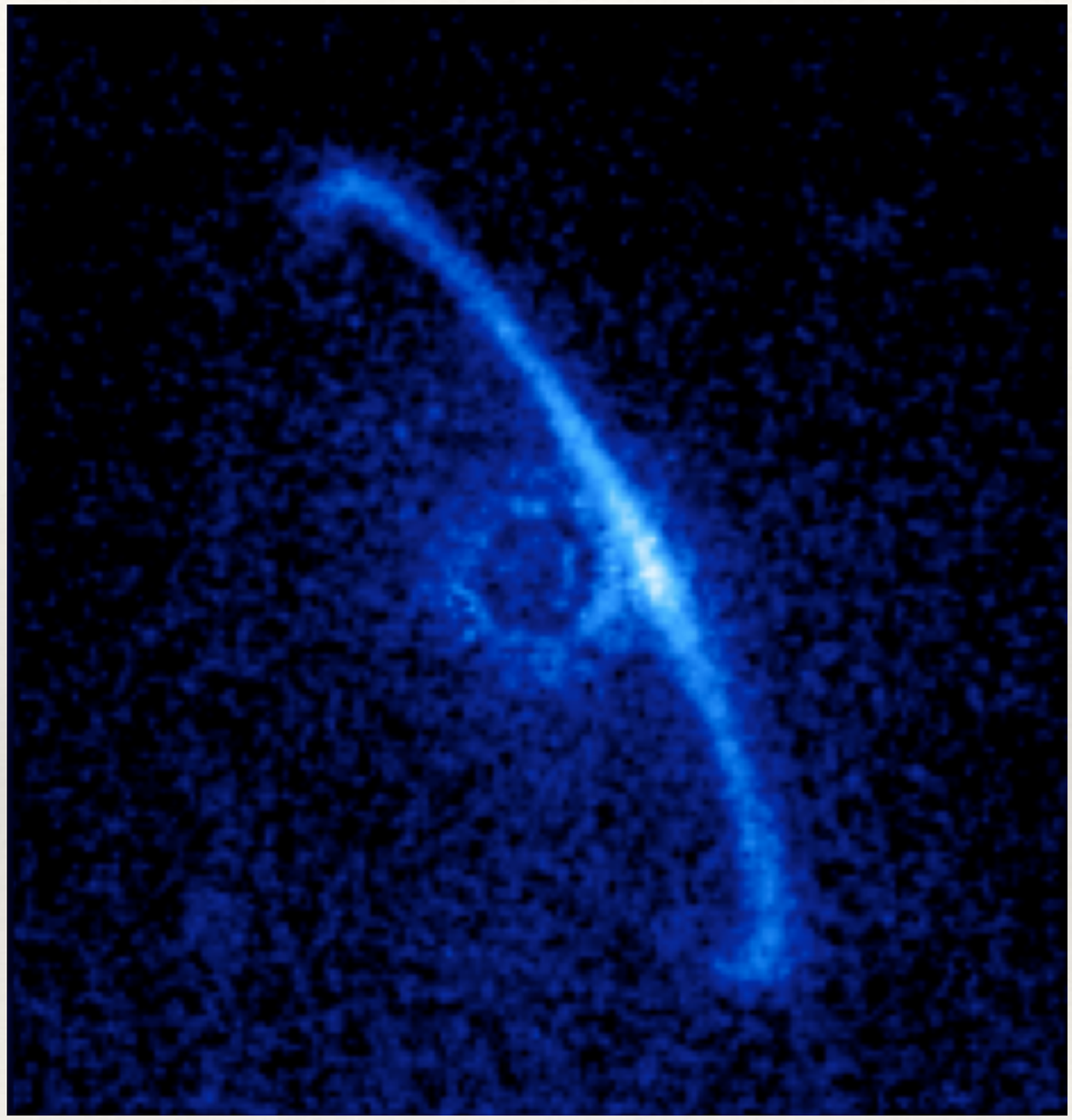


http://planetimager.org/

HR 4796A



Total Light

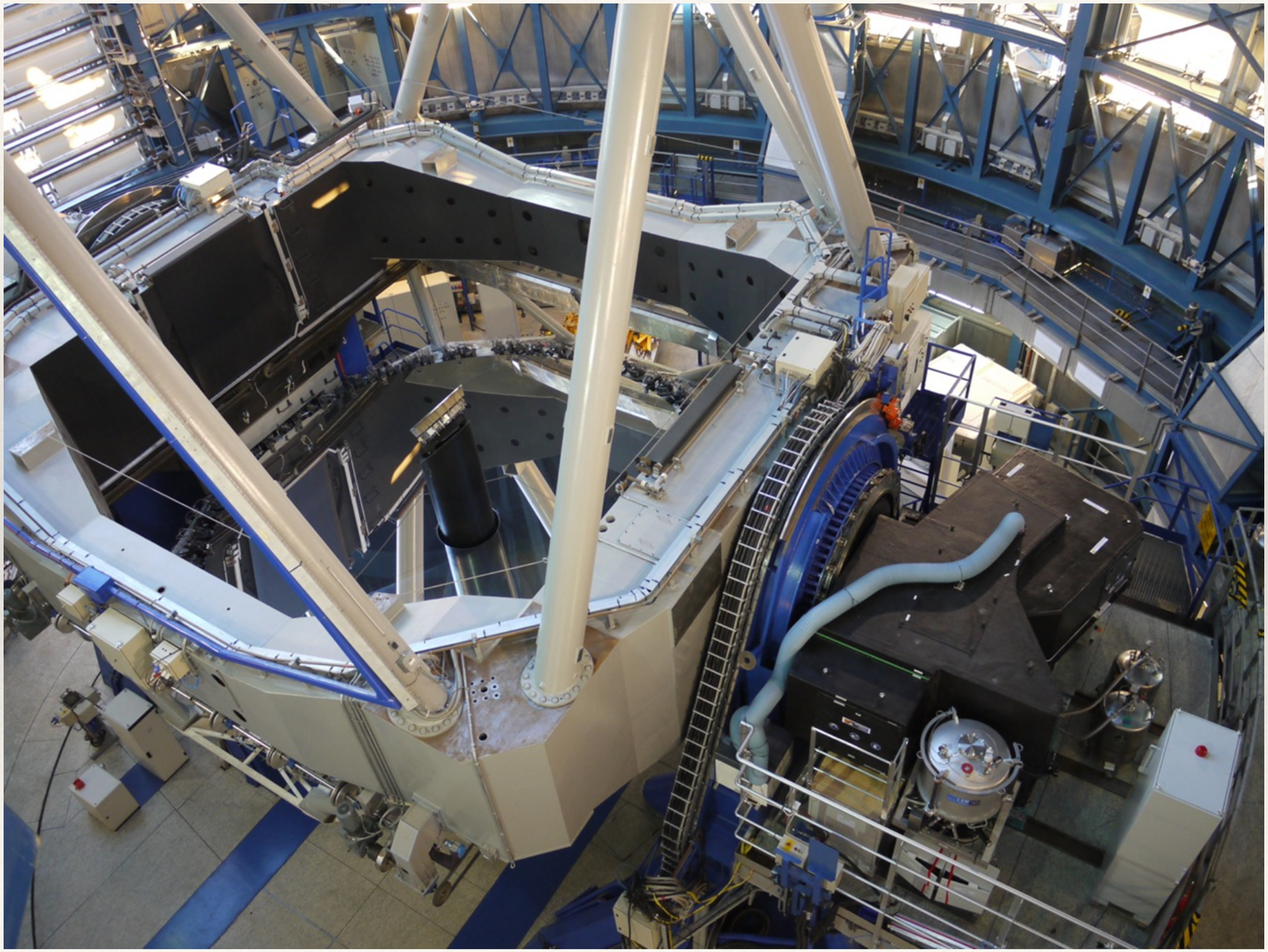


Polarised Light

http://planetimager.org/

Spectro-Polarimetric High-contrast Exoplanet Research

SPHERE



SPHERE Consortium

CNRS/LAOG (Grenoble, F)

CNRS/LAM (Marseille, F)

CNRS/LESIA (Paris, F)

CNRS/LUAN (Nice, F)

ESO (Garching, D)

ONERA (Paris, F)

INAF/ (Padova Observatory, I)

MPIA (Heidelberg, D)

Observatoire de Genève (CH)

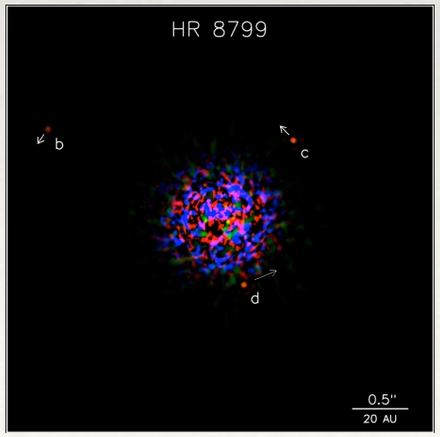
ETH (Zürich, CH)

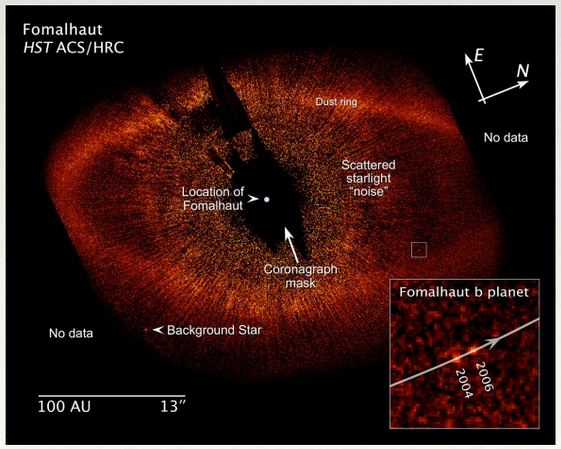
NOVA (Amsterdam, NL)

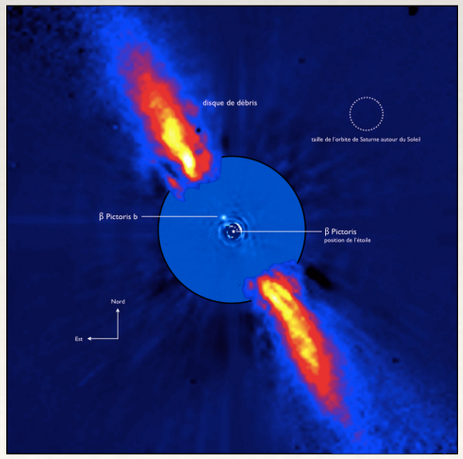
ASTRON (Amsterdam, NL)

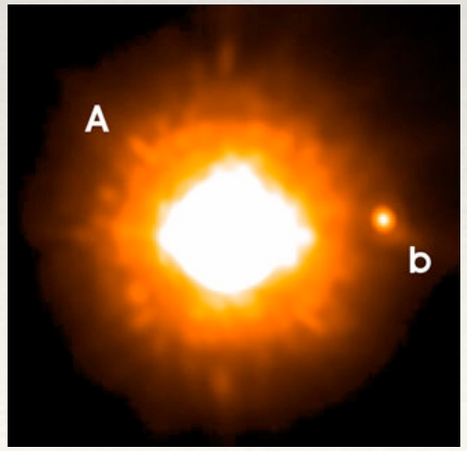
SPHERE Scientific Drivers

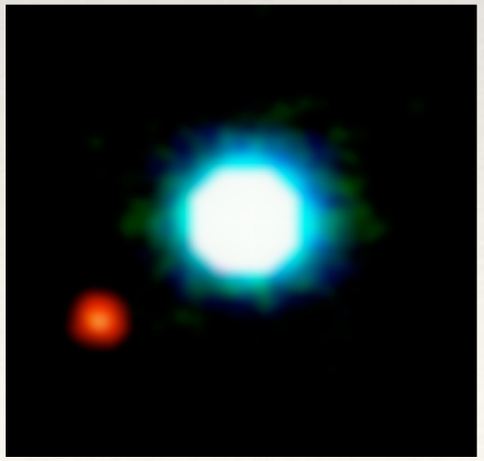
- ☑ High contrast imaging down to planetary masses
- ☑ Investigate large target sample: statistics, variety of stellar classes, evolutionary trends
- ☑ Complete the accessible period window
- ☑ First order characterization of the atmosphere (clouds, dust content, Methane, water absorption, effective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

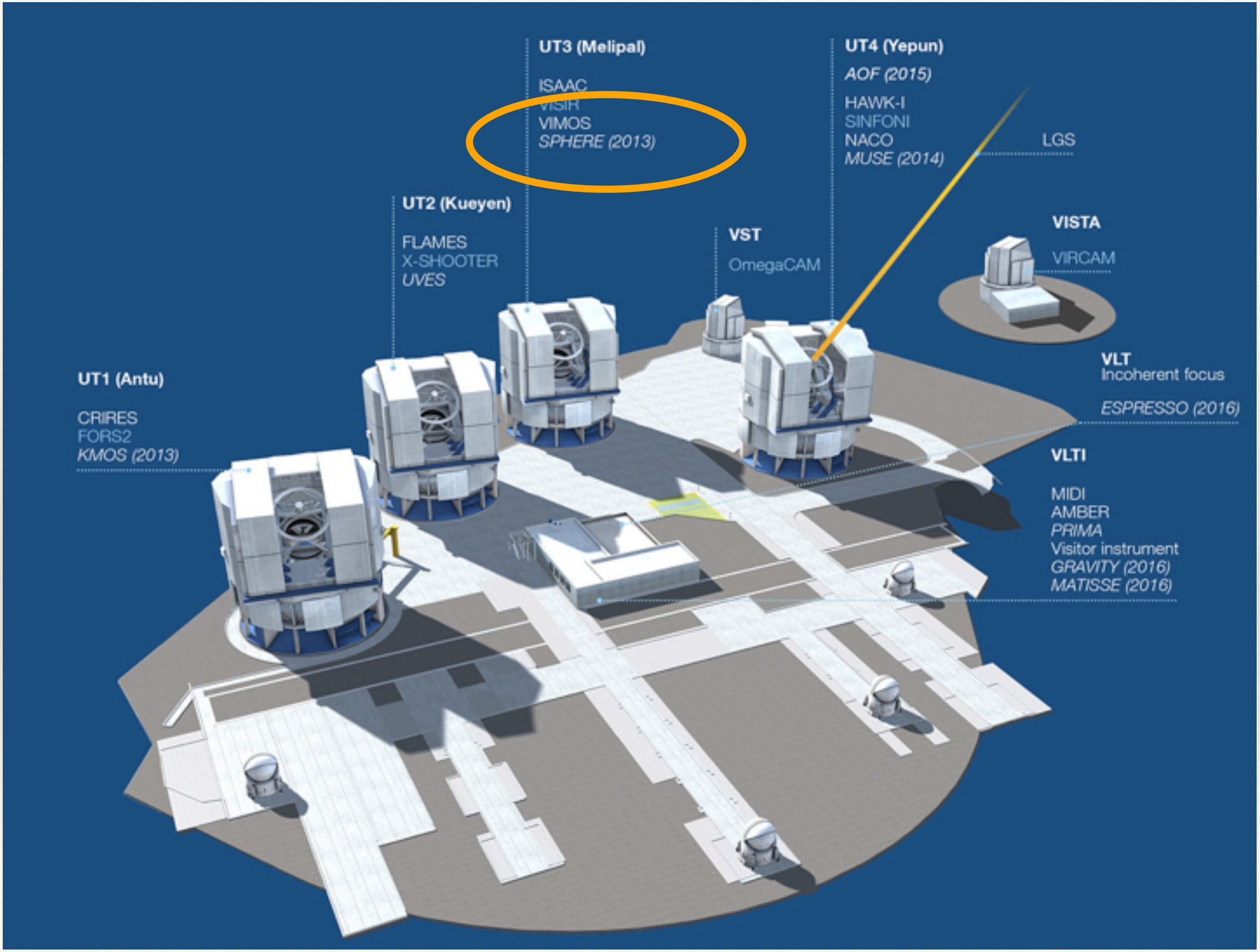








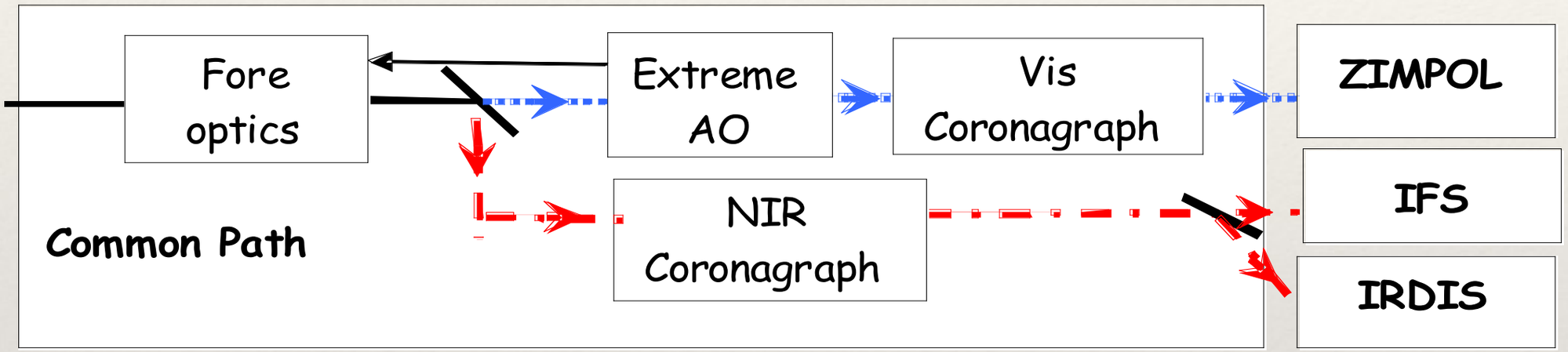



UT3 (Melipal)
ISAAC
VISIR
VIMOS
SPHERE (2013)
UT4 (Yepun)
AOF (2015)
HAWK-I
SINFONI
NACO
MUSE (2014)
LGS
UT2 (Kueyen)
FLAMES
X-SHOOTER
UVES
VST
OmegaCAM
VISTA
VIRCAM
UT1 (Antu)
CRIRES
FORS2
KMOS (2013)
VLT
Incoherent focus
ESPRESSO (2016)
VLTI
MIDI
AMBER
PRIMA
Visitor instrument
GRAVITY (2016)
MATISSE (2016)

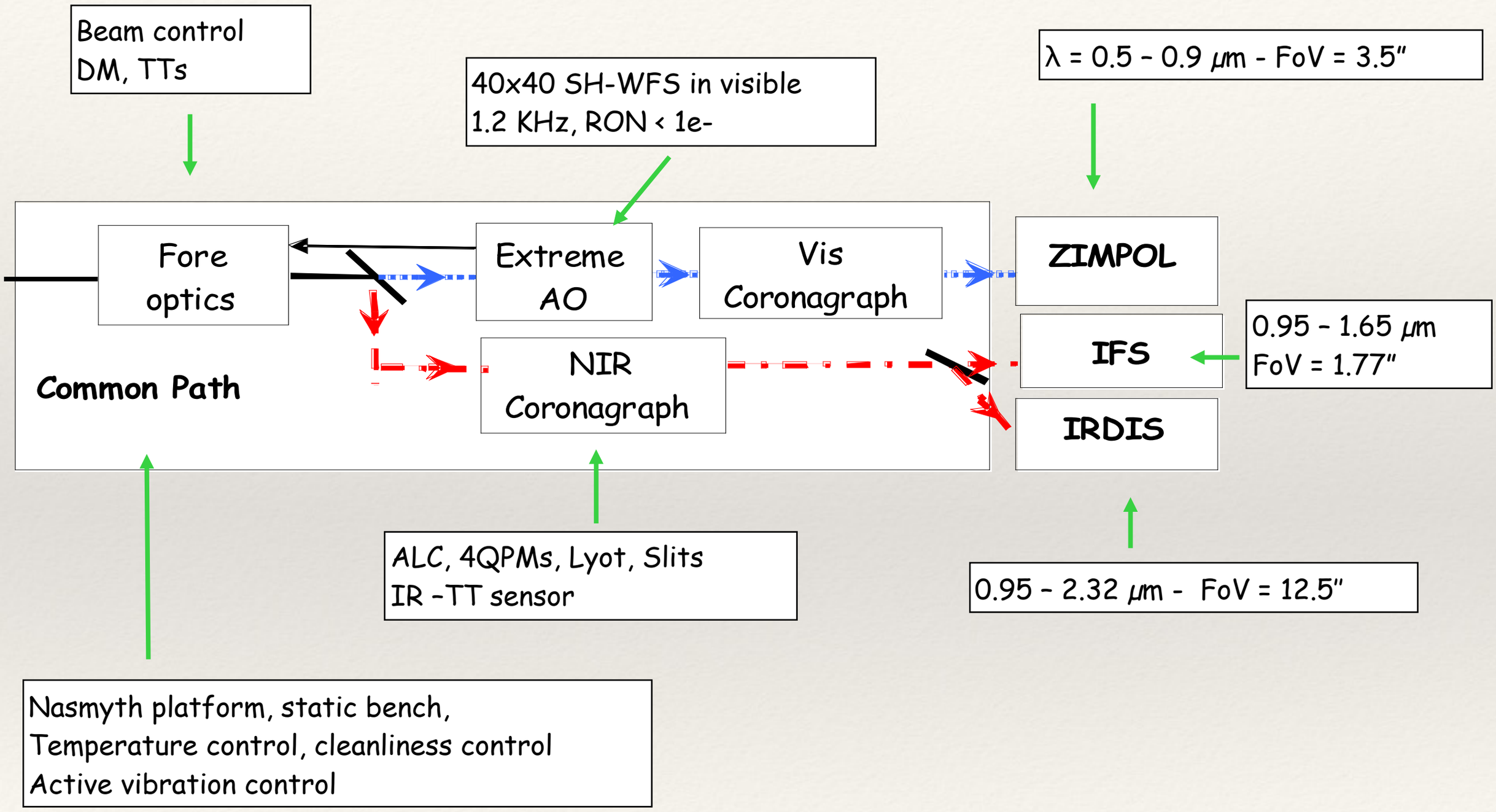
SPHERE Capabilities in Short

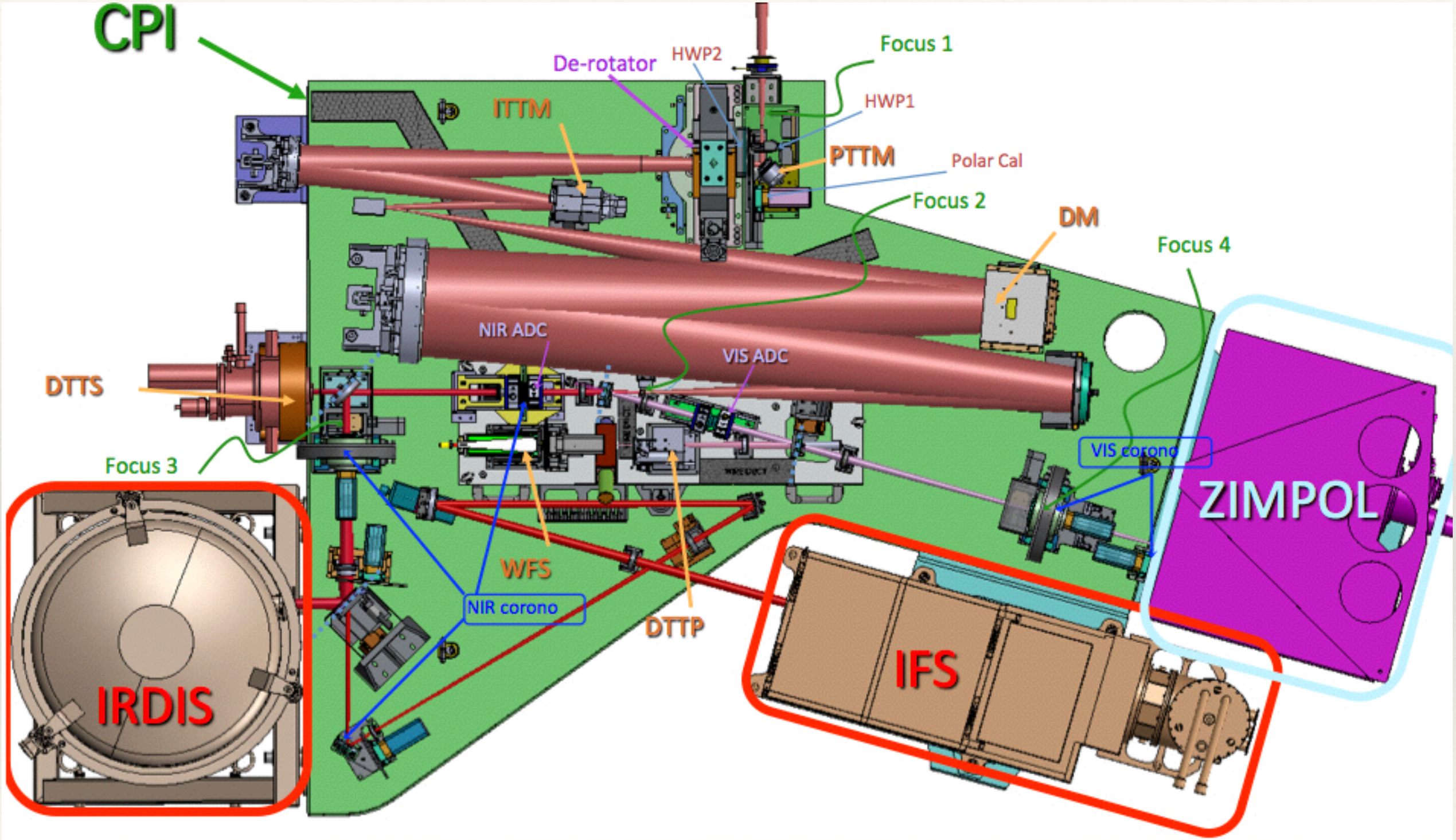
- High order, high stability AO (SAXO)
- NIR Dual band imaging (IRDIS)
- NIR Integral field spectroscopy (IFS)
- NIR Slit spectroscopy (R=50 and R=500) (IRDIS)
- High accuracy VIS differential polarimetry (ZIMPOL)
- NIR differential polarimetry (IRDIS)
- VIS and NIR classical imaging (ZIMPOL/IRDIS)

SPHERE Concept



SPHERE Concept

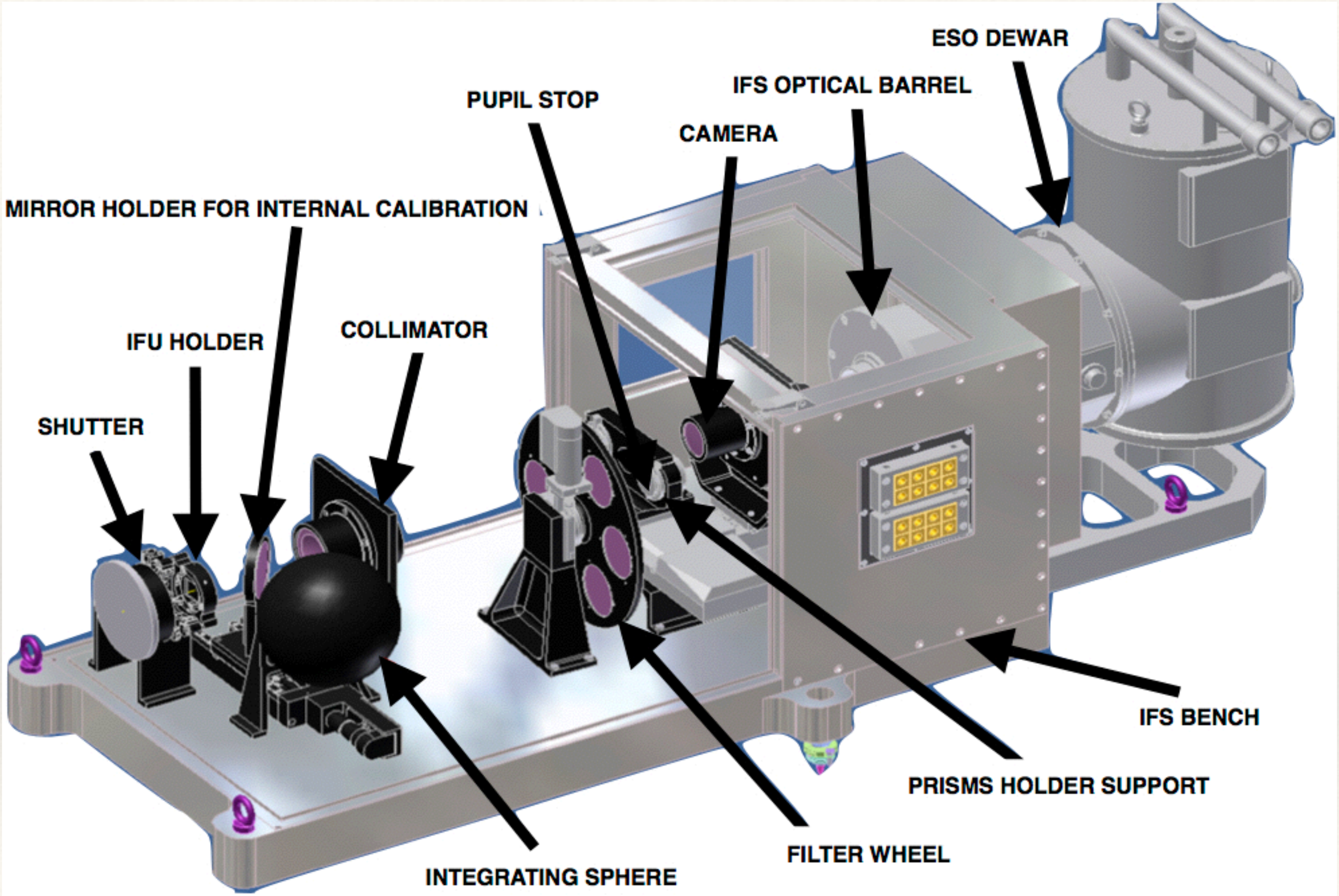




Beuzit et al., 2008, SPIE, 7014

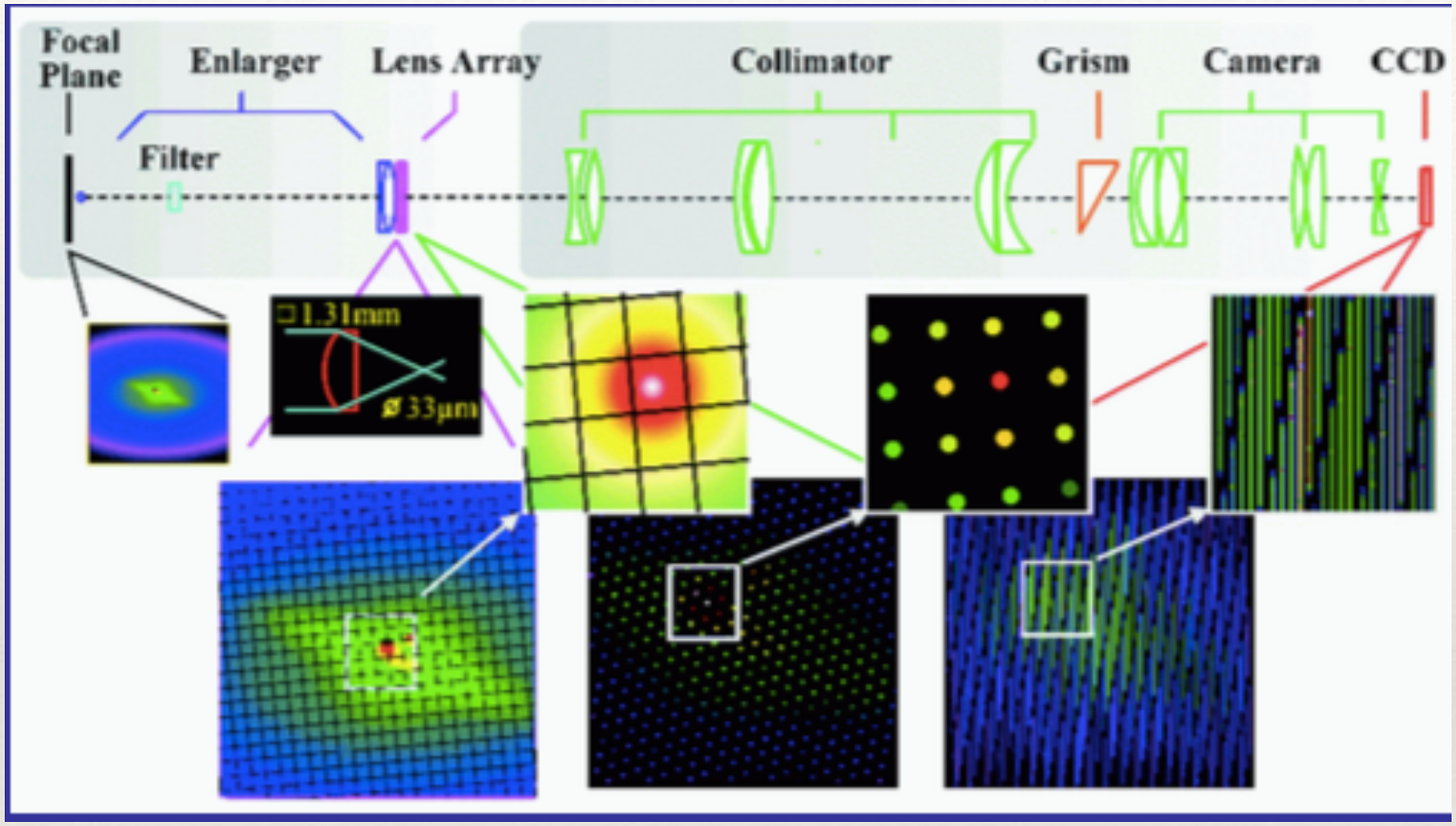
IFS Summary

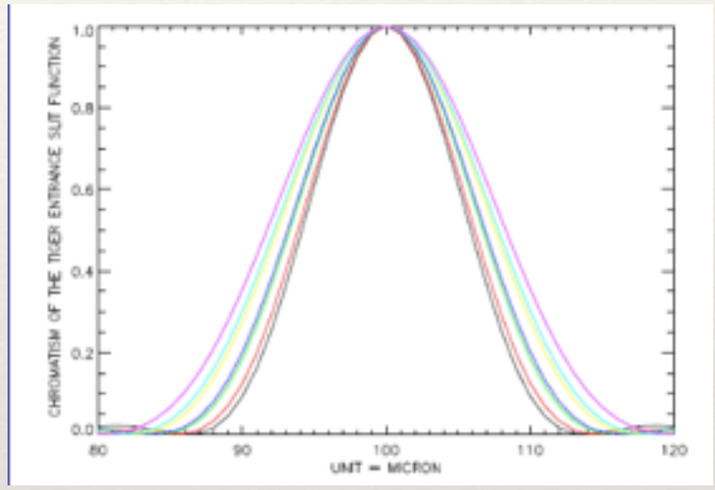
Observing mode	Integral field spectroscopy	
Spectral range	0.95–1.35 μm: R~50	0.95 – 1.65 μm: R~30
Sampling	$(12.25\ \text{mas})^2$ / spaxel (hexagonal grid), Nyquist at 0.95 μm. Resampled by the pipeline on a square with $(7.4\ \text{mas})^2$ / pixel.	
FOV	~ 1.73" x 1.73"	
Detector type	Hawaii II RG 2048x2048	
Coronagraph	None, or with classical or apodized pupil Lyot coronagraphs, 4QPM	
Stabilization	Pupil- or Field-stabilized	
WFS	Visible light	

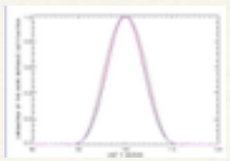


Claudi et al., 2008, SPIE, 7014

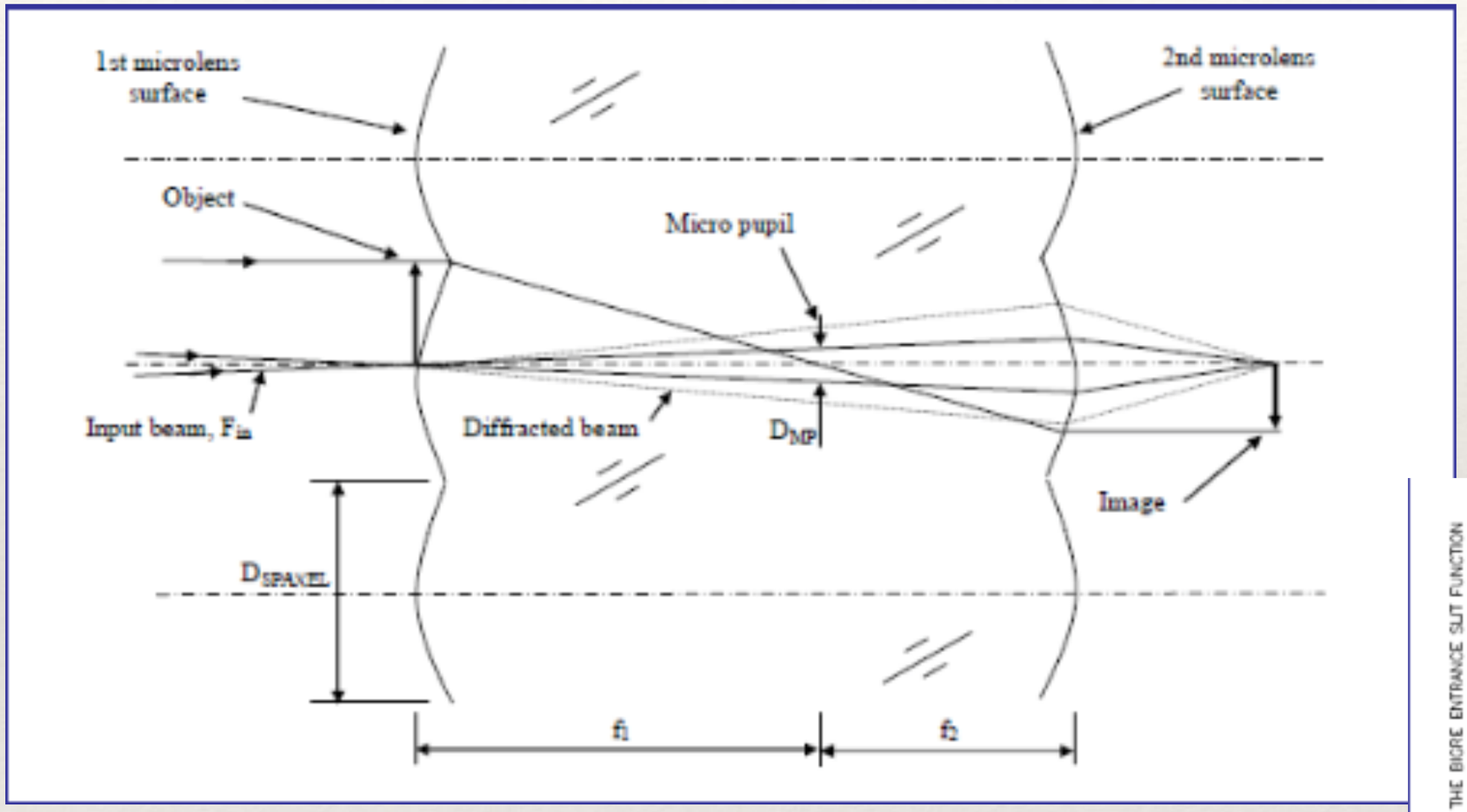
TIGRE vs BIGRE

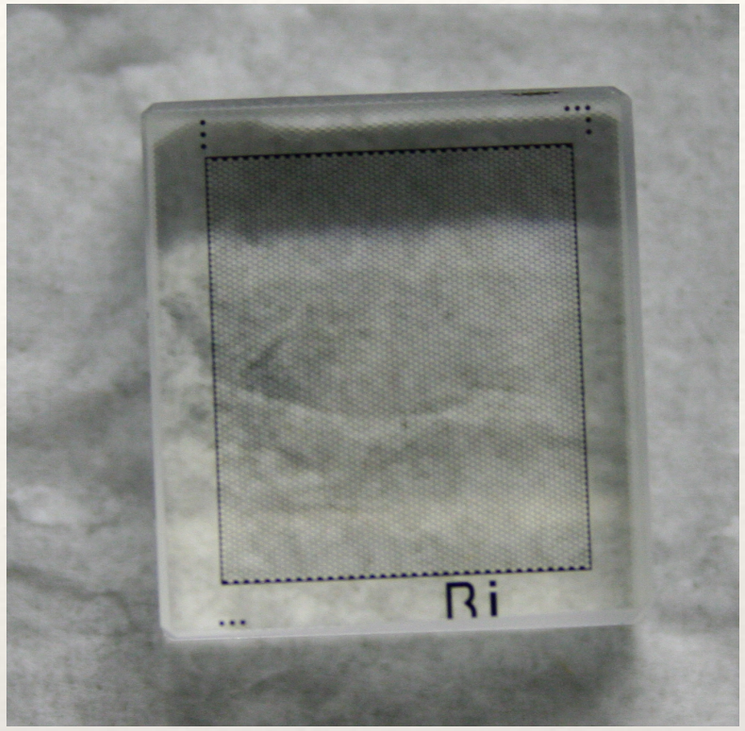


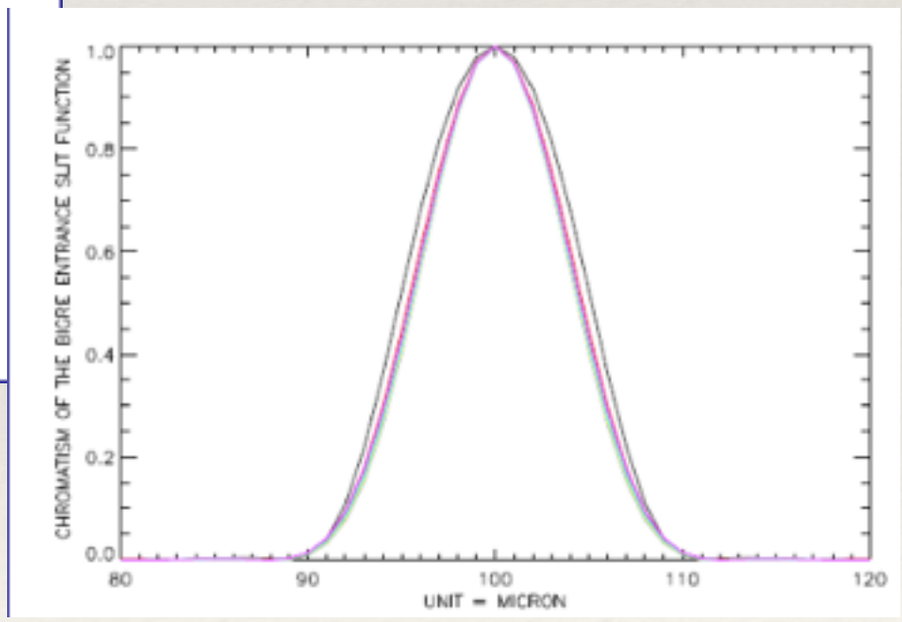


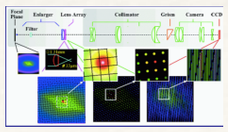


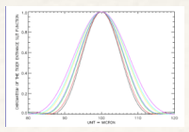
TIGRE vs BIGRE





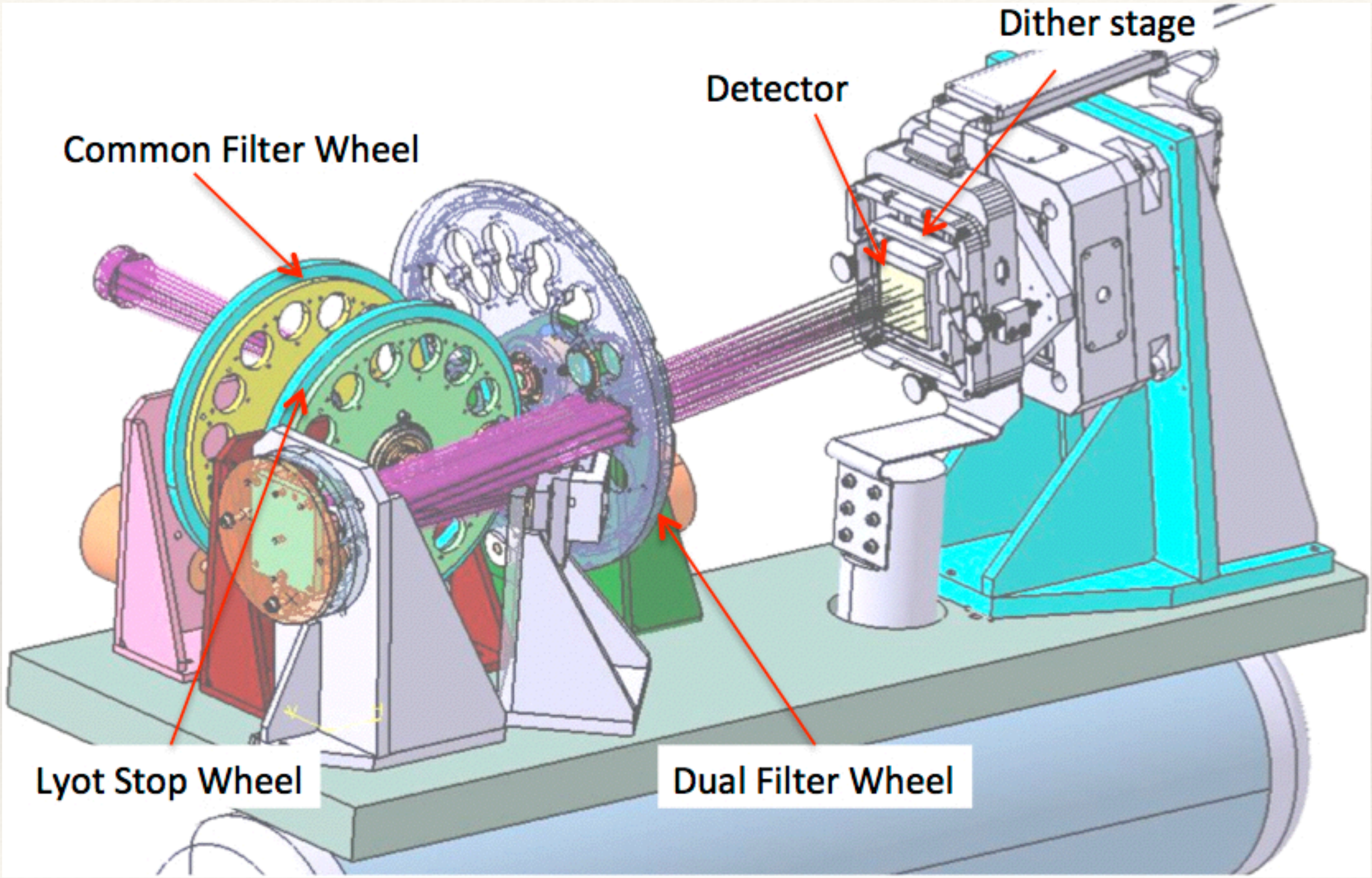






IRDIS Summary

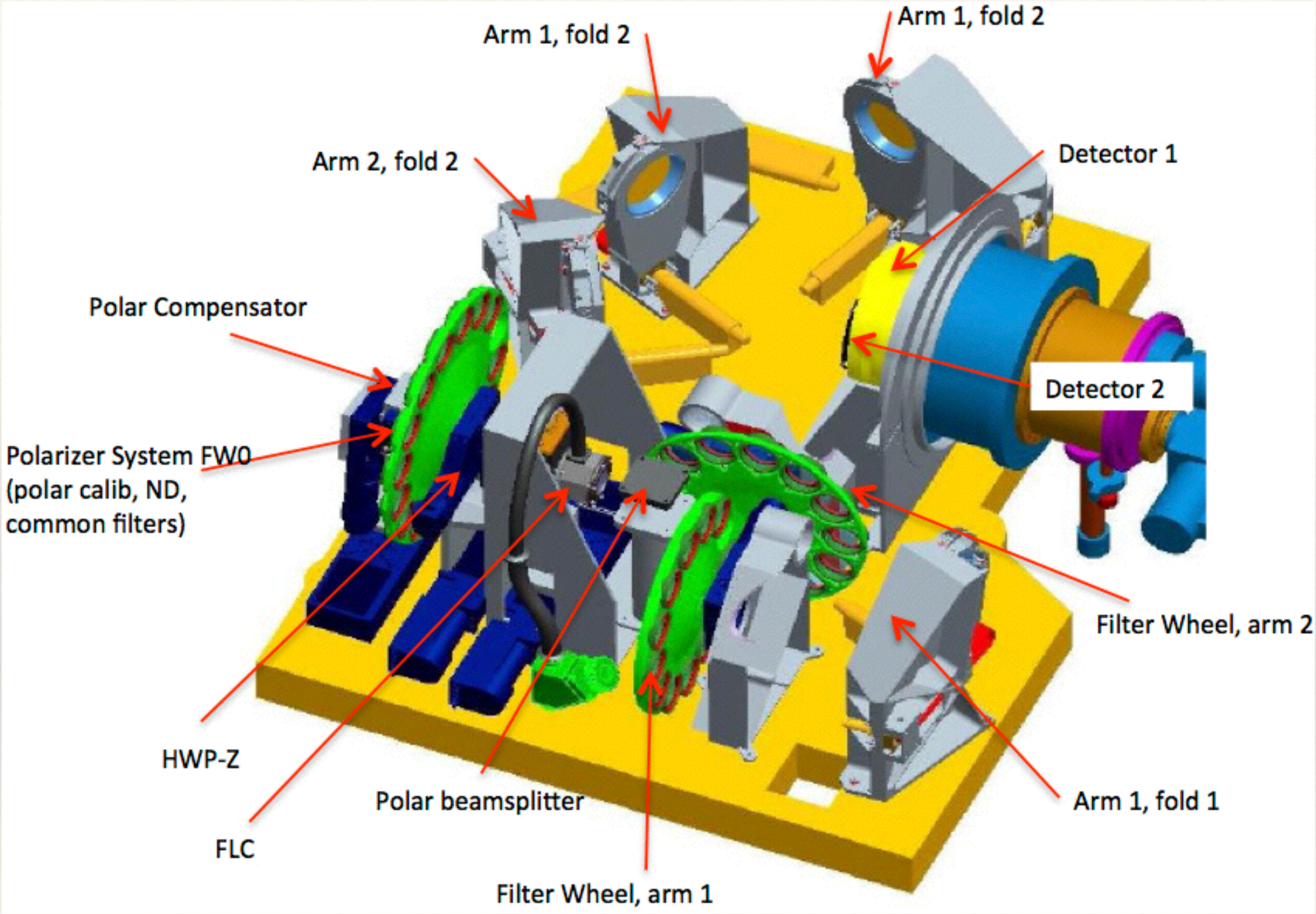
Observing modes	DBI, DPI, CI	LSS
Spectral range	0.95 – 2.32 µm: NB and BB filters	0.95 - 2.32 µm: R~50 0.95 - 1.65 µm: R~350
FOV	11” x 11”	11” slit
Coronagraph	None, or with classical or apodized pupil Lyot coronagraphs, 4QPM	Central blocking
Stabilization	Pupil- or Field-stabilized	Field stabilized
Sampling	$(12.25\ \text{mas})^2$ / pixel, Nyquist-sampled at 0.95 µm	
Detector type	Hawaii II RG 2048 x 1024	
WFS	Visible light	



Dohlen et al., 2008, SPIE, 2014

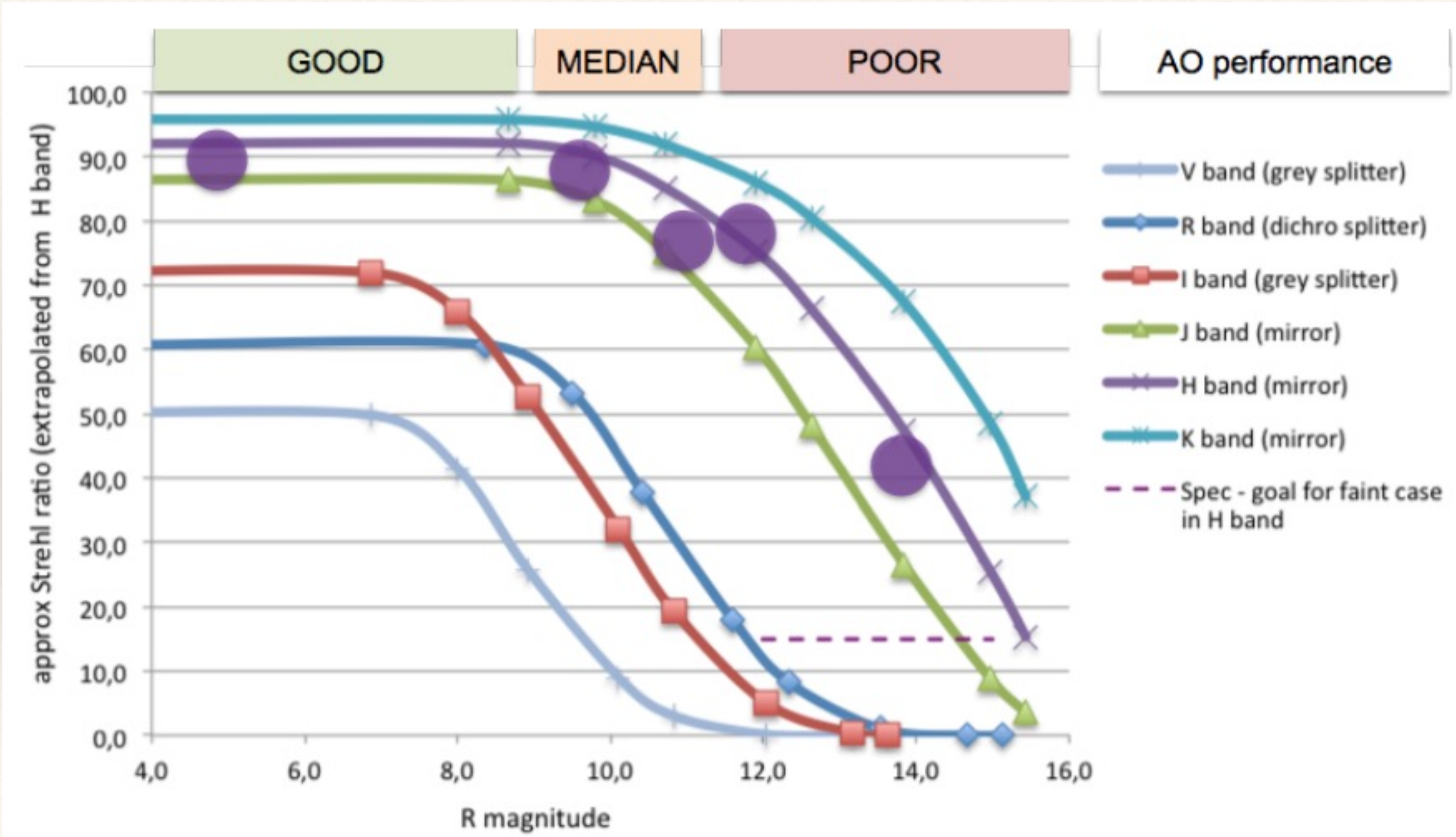
ZIMPOL Summary

Observing modes	Imaging, differential polarimetric imaging
Spectral range	500 – 900 nm in broad and narrowband filters
Sampling	$(7\ \text{mas})^2$ / pixel, diffraction-limited at λ >600 nm
FOV	3.5" x 3.5"
Linear polarization	Instrumental polarization <1%, polarimetric sensitivity < 0.1% with fast modulation, simultaneously on two CCDs
Stabilization	- Imaging: pupil or field stabilized. - Polarimetry: field stabilized, or fixed derotator with stable and minimized instrumental polarization.
Coronagraph	None, or with classical Lyot coronagraphs
WFS	Visible light shared between WFS and ZIMPOL: - Dichroic for R-band observation: (100% WFS outside R band / 100% R band to ZIMPOL) - Grey beam splitter: (20% WFS / 80% ZIMPOL), with AO limit lowered by ~1.74 mag

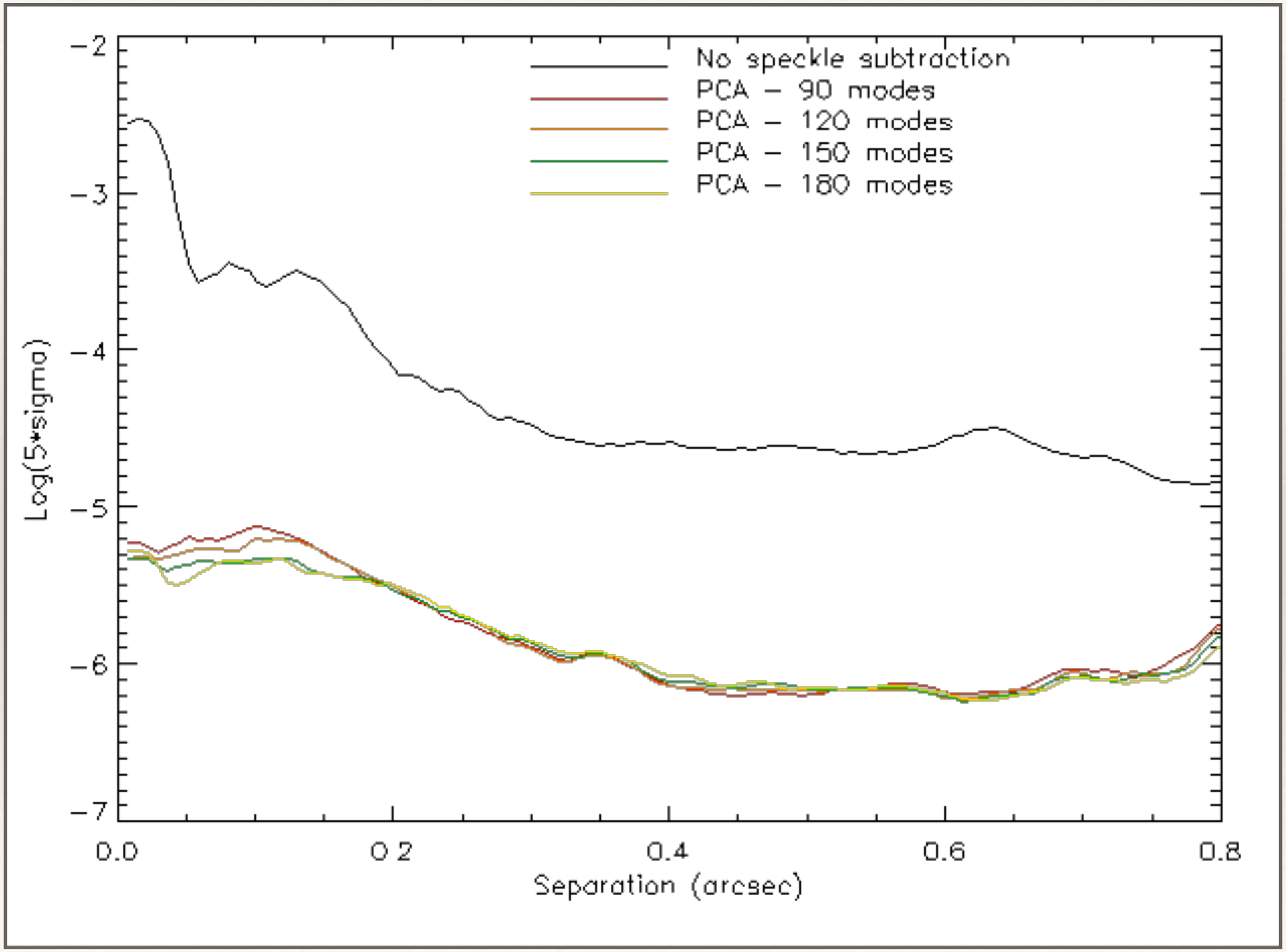


Thalmann et al., 2008, SPIE, 7014

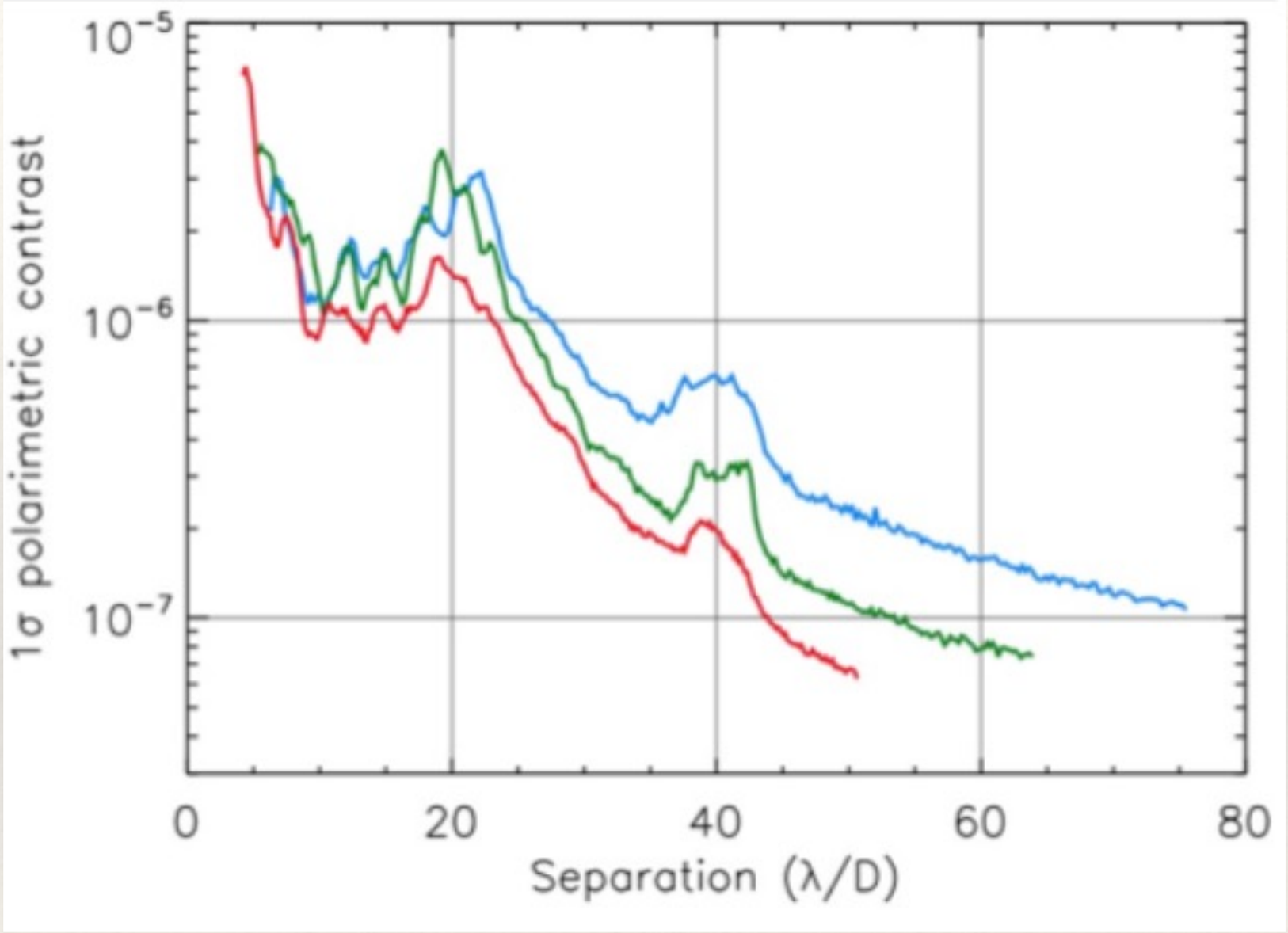
SPHERE SAXO Performance



IFS 5-sigma contrast: better than 10^{-6} at >0.3 arcsec (tau Cet)



Polarimetric contrast with ZIMPOL

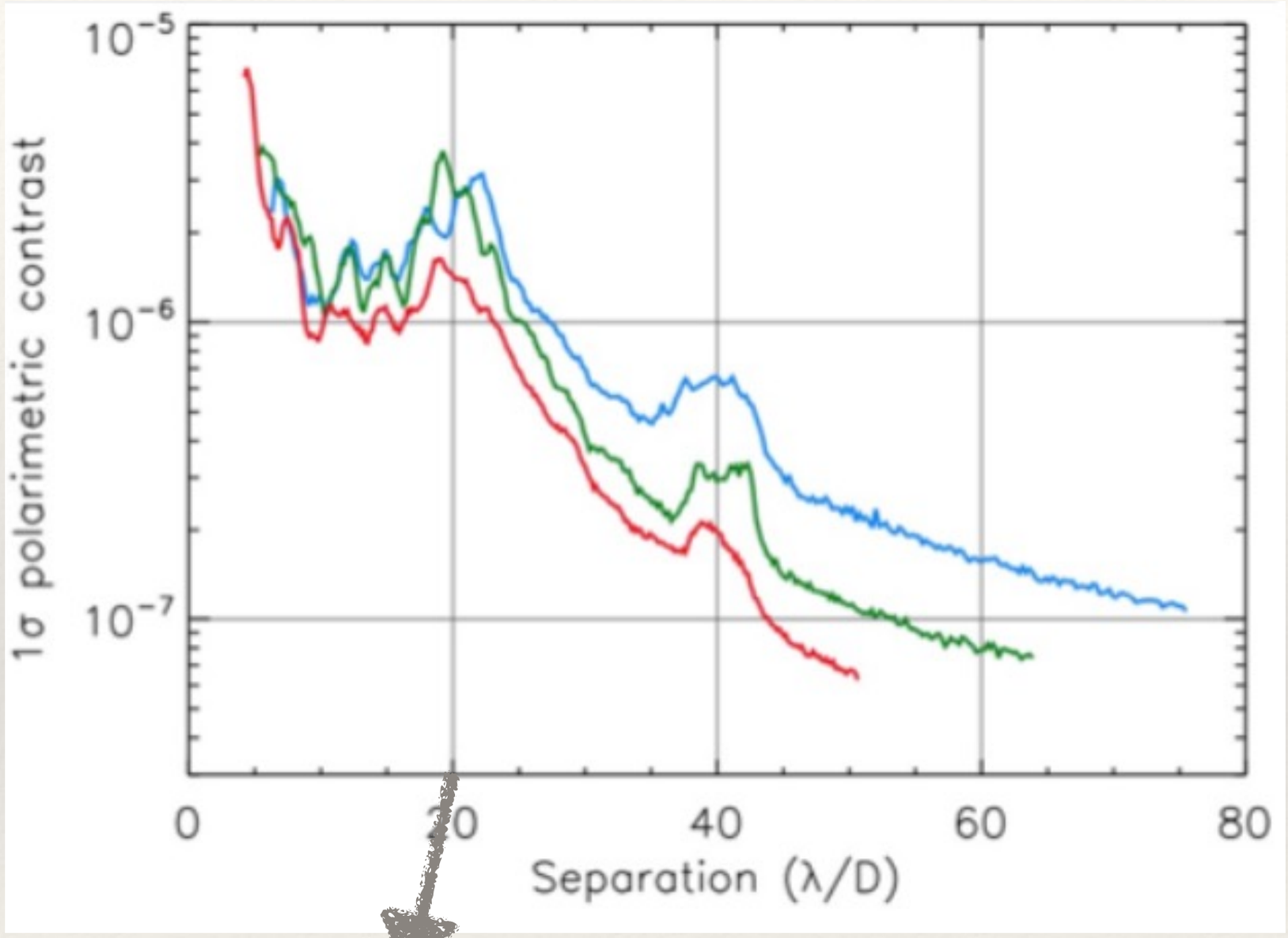


V

R

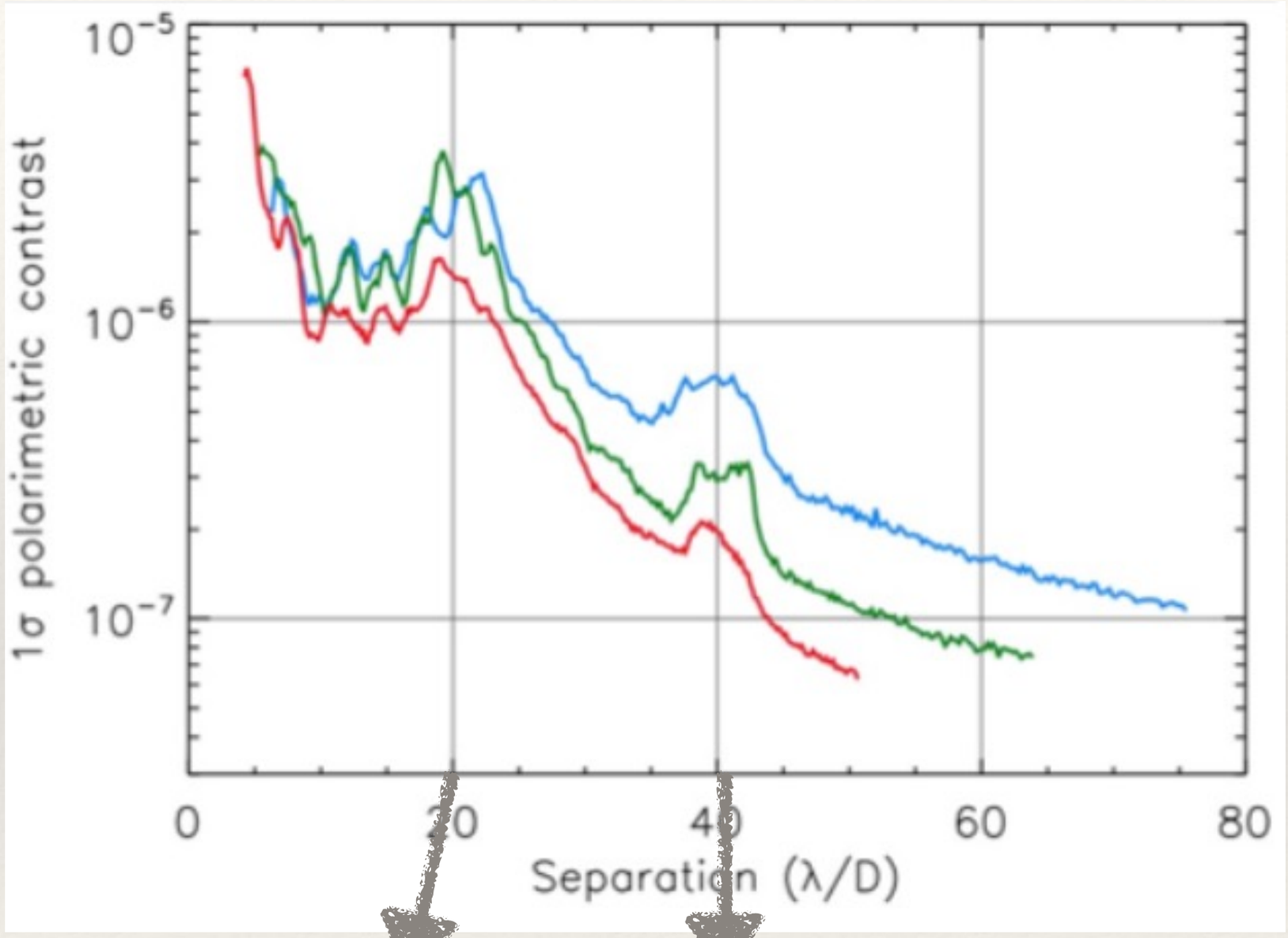
I

Polarimetric contrast with ZIMPOL



V	0.28
R	0.33
I	0.41

Polarimetric contrast with ZIMPOL



V	0.28	0.57
R	0.33	0.67
I	0.41	0.82

First new detection with SPHERE: HR7581B (an M dwarf companion to a K-giant)

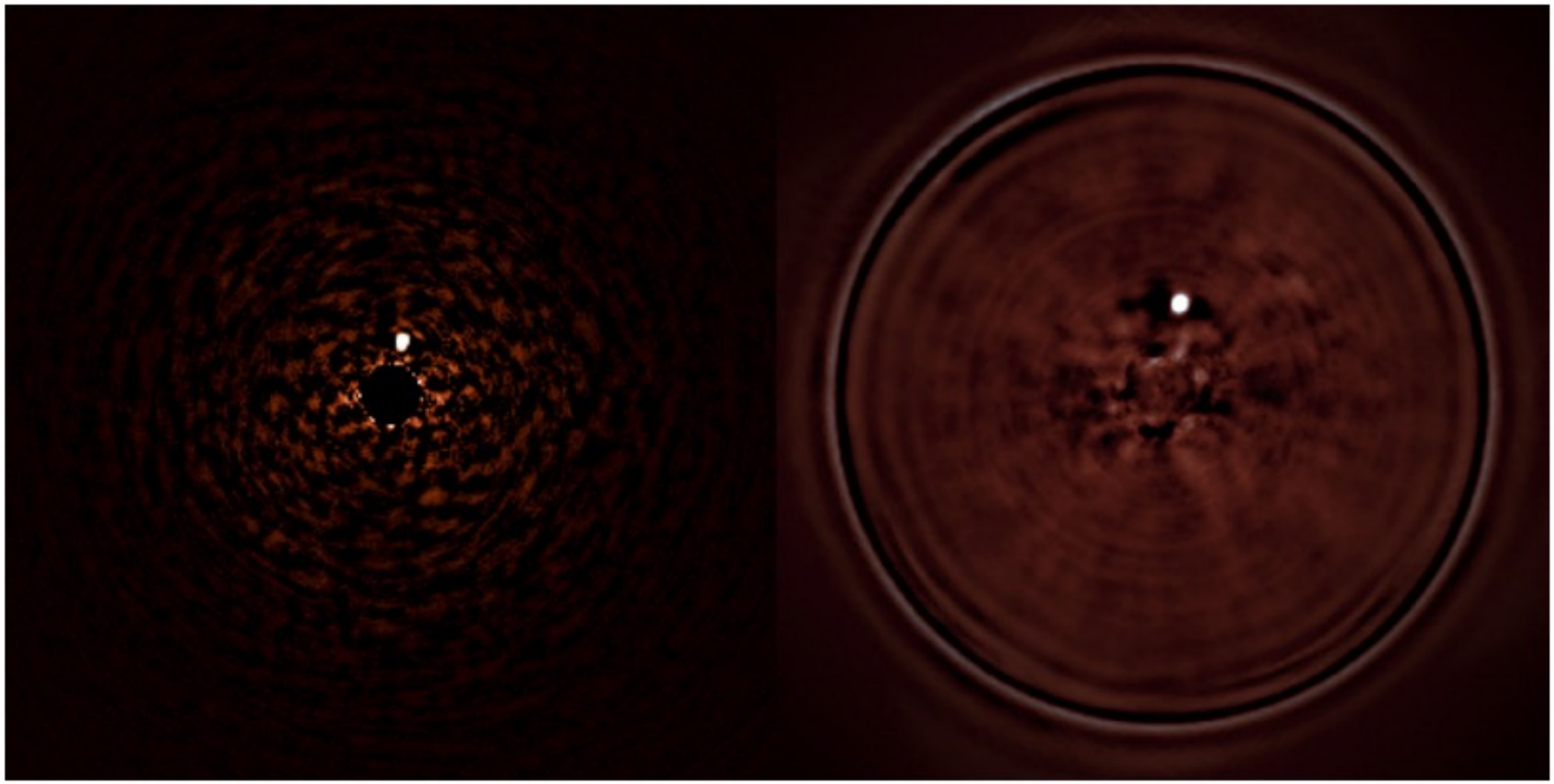


Figure 17: Detection in parallel by IRDIS (left) and IFS (right) of a faint companion at 0.24" around the bright star HR7581 (see ESO Press Release 1417, http://www.eso.org/public/news/eso1417/).

First new detection with SPHERE: HR7581B (an M dwarf companion to a K-giant)

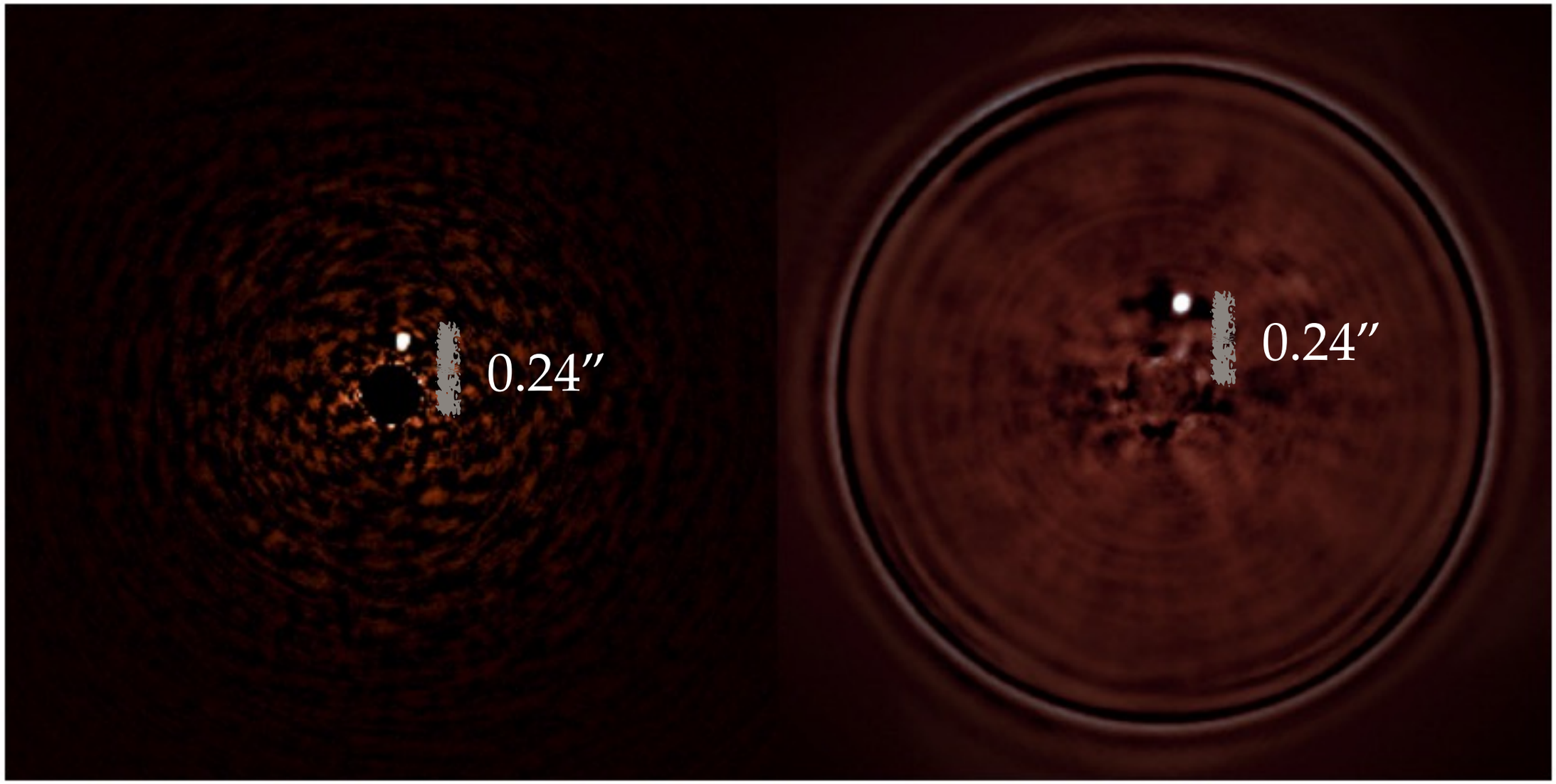
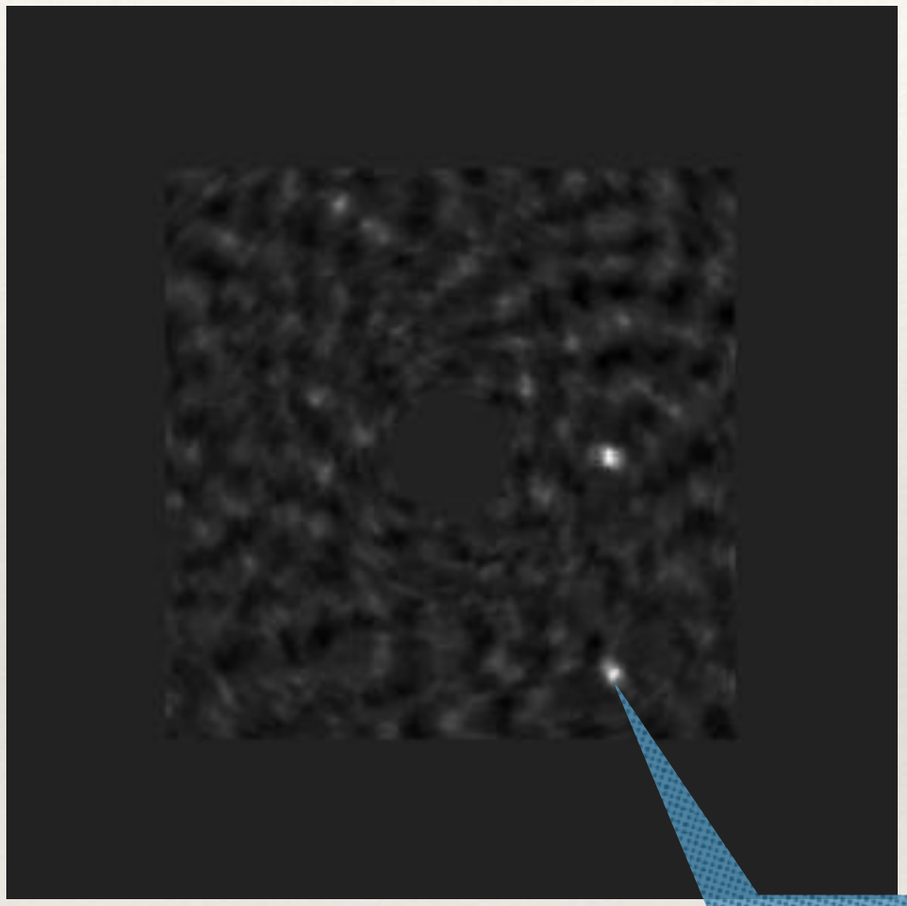


Figure 17: Detection in parallel by IRDIS (left) and IFS (right) of a faint companion at 0.24" around the bright star HR7581 (see ESO Press Release 1417, http://www.eso.org/public/news/eso1417/).

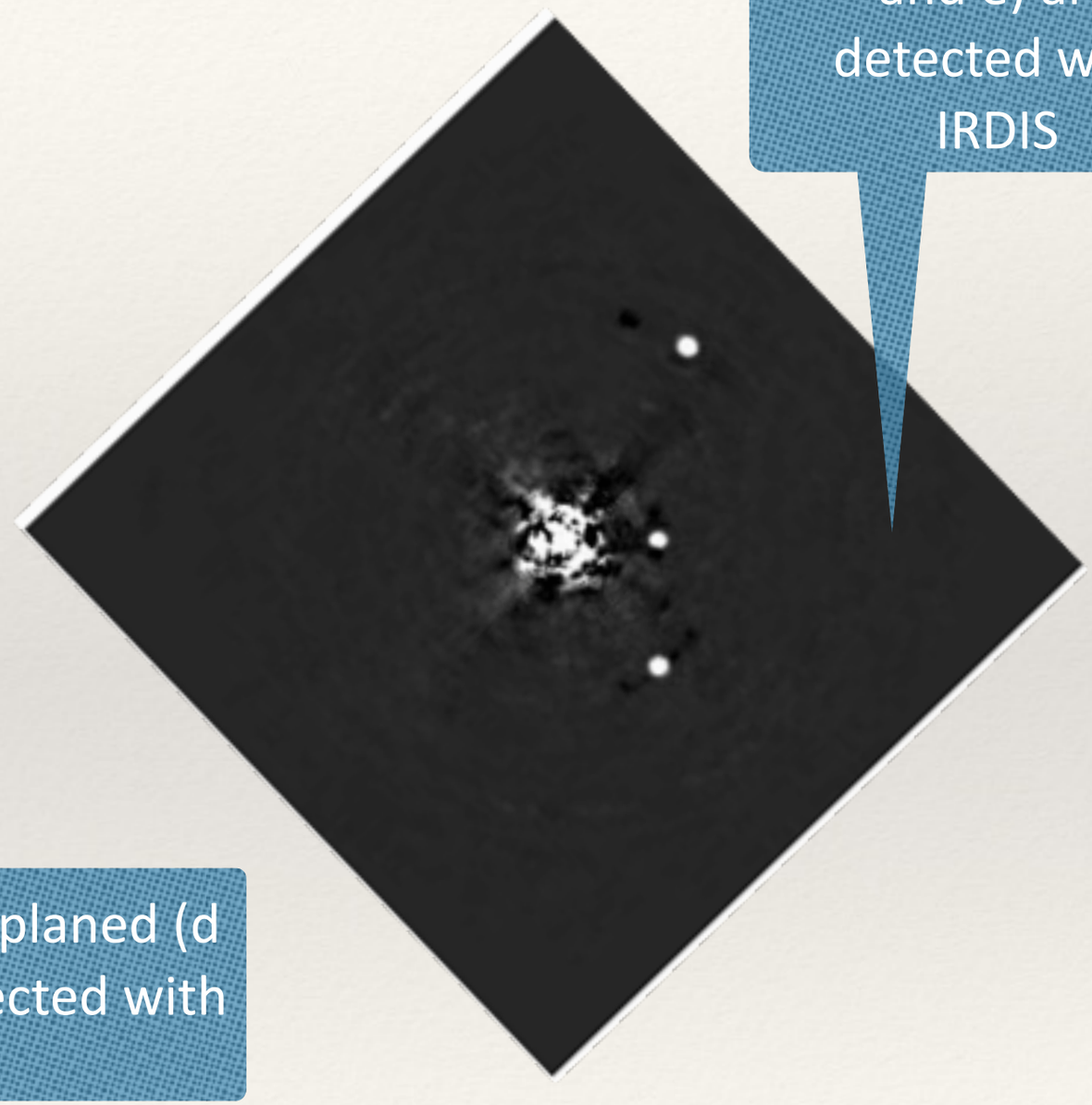
HR8799: a system with four planets

IFS: Y-H



The two inner planed (d and e) are detected with IFS

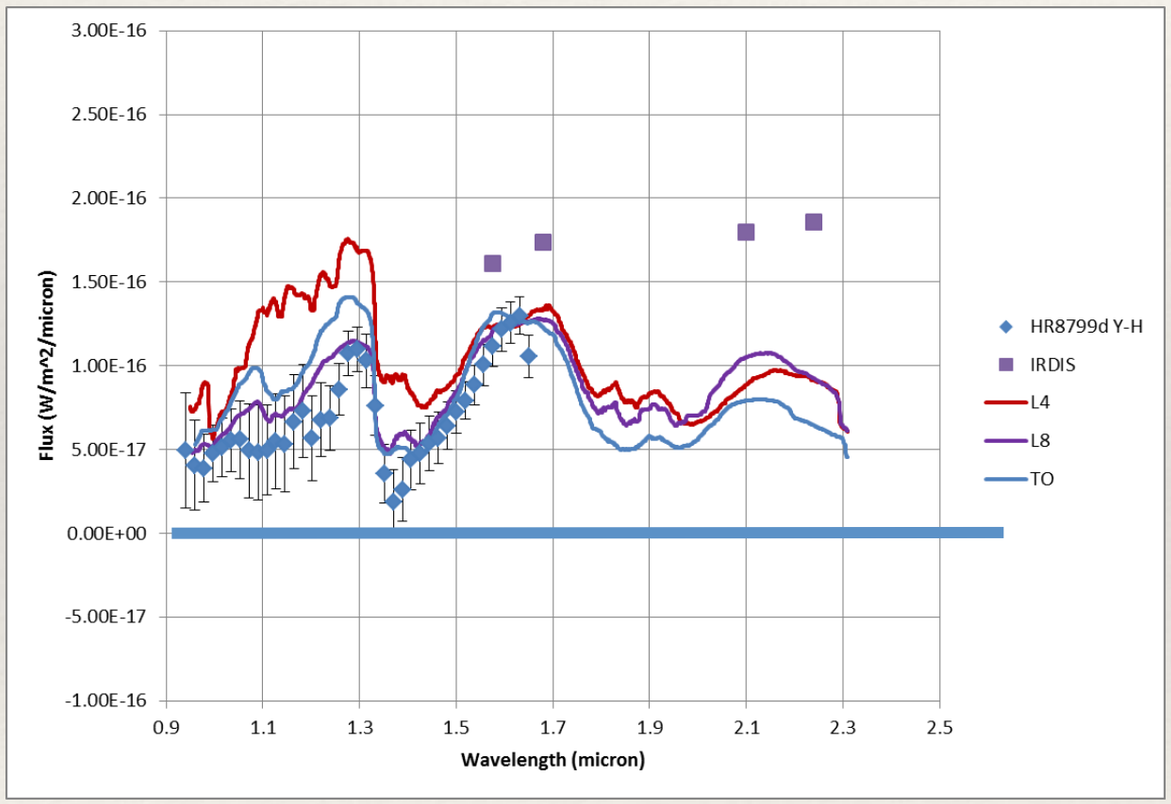
IRDIS: K1-K2



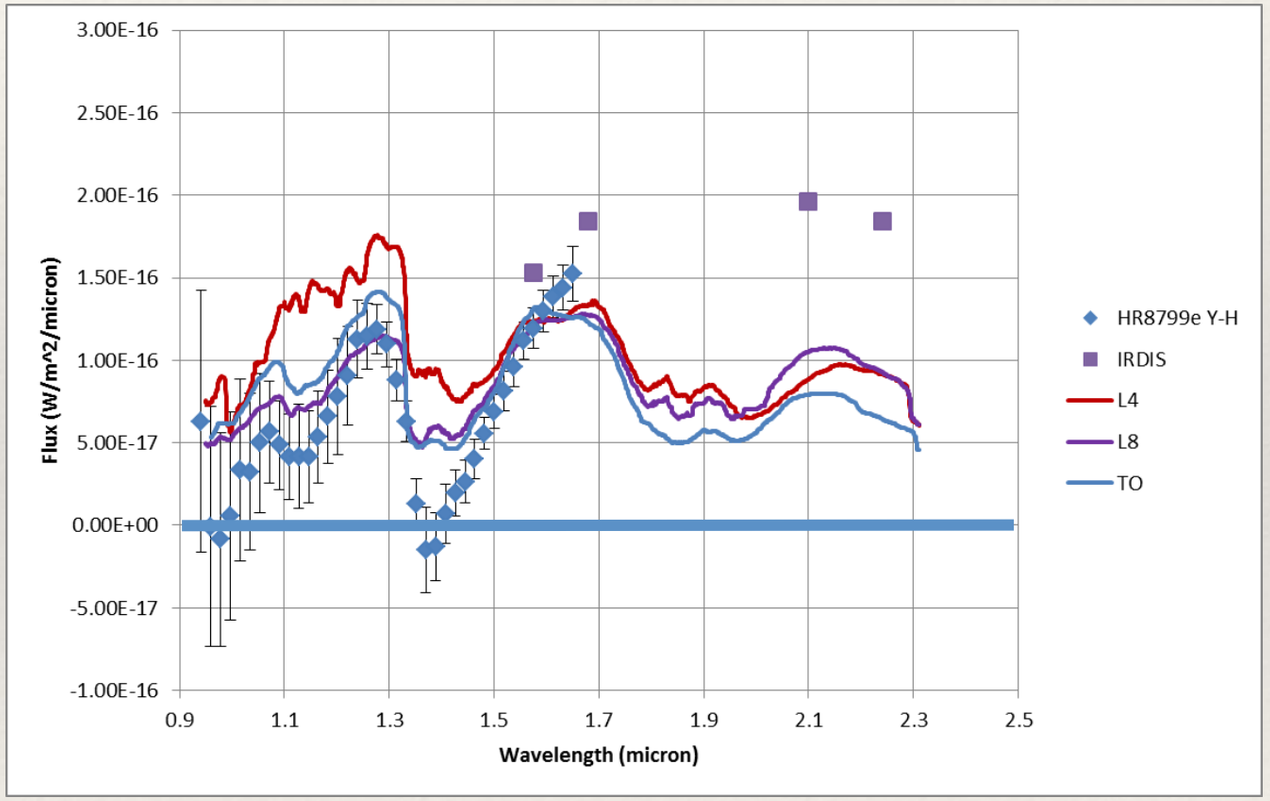
The three inner planed (c, d, and e) are detected with IRDIS

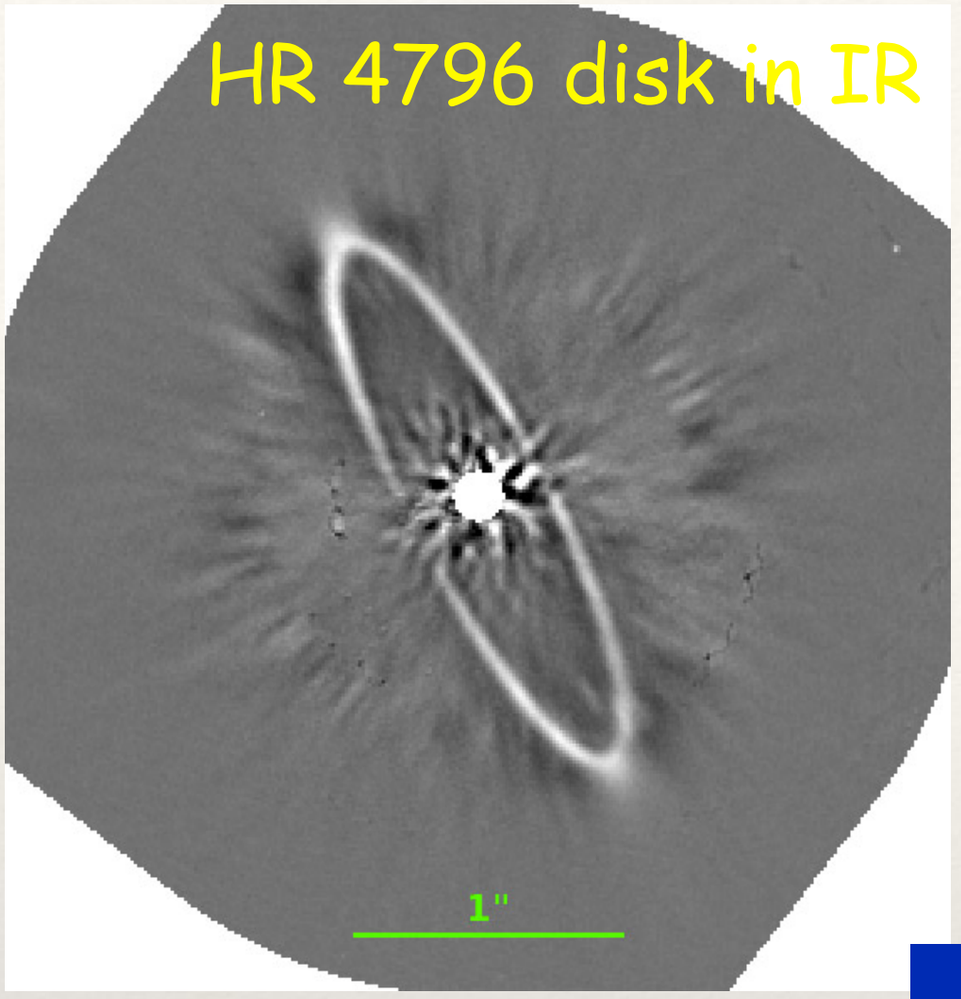
Spectra of planets of HR8799

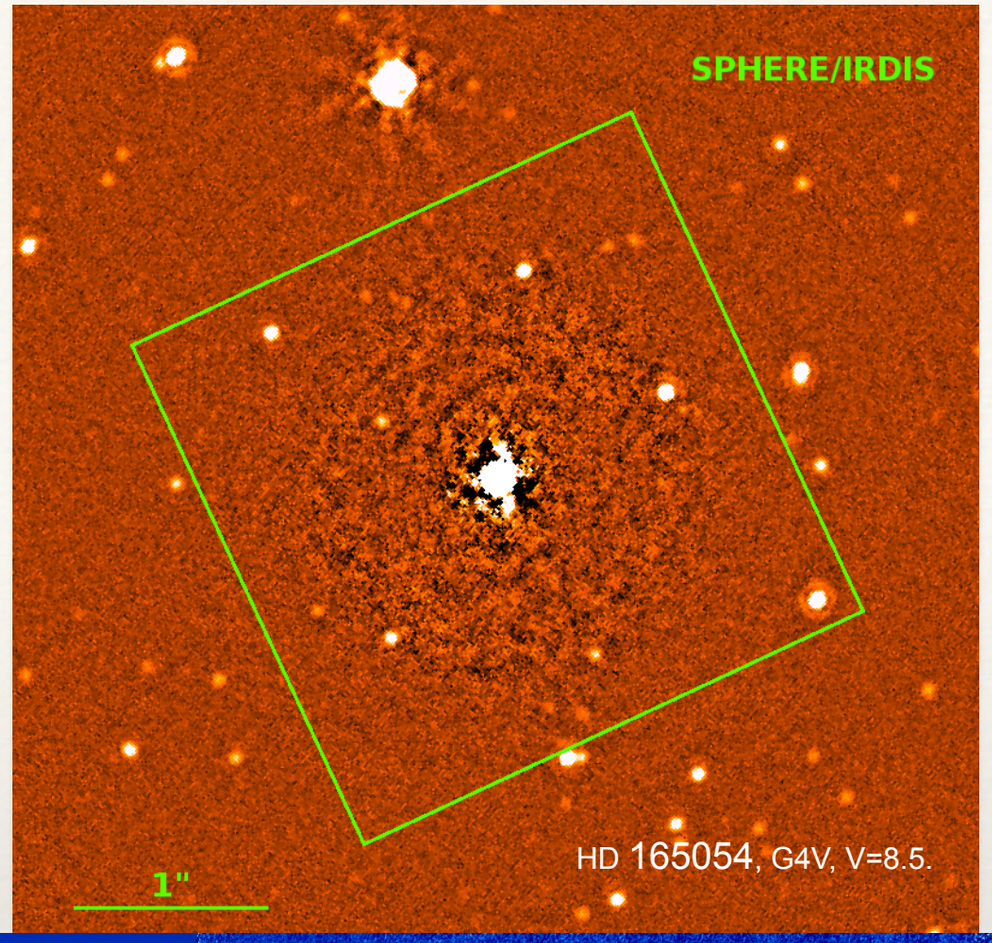
HR8799d

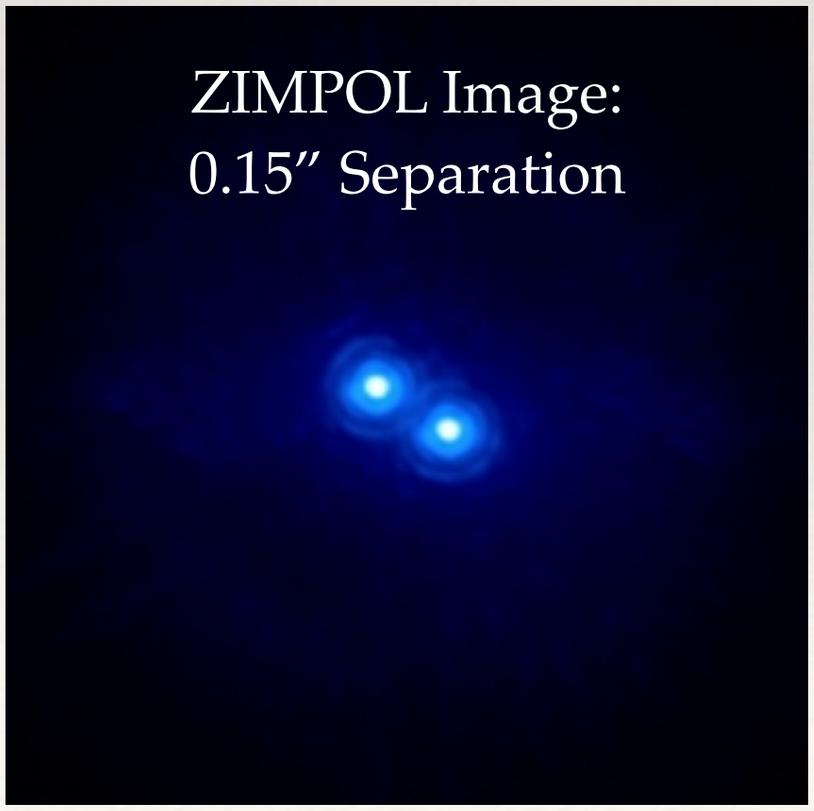


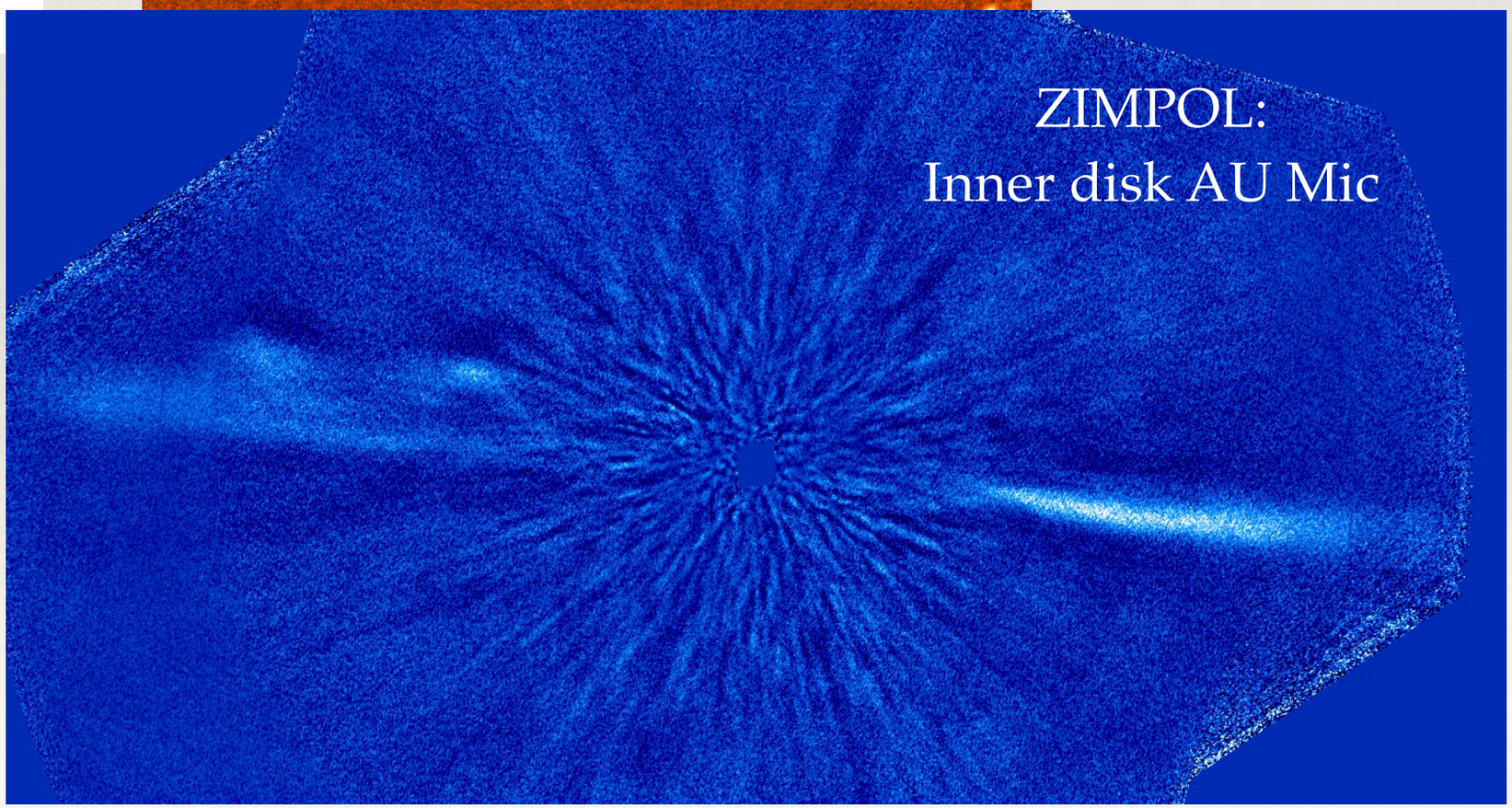
HR8799e



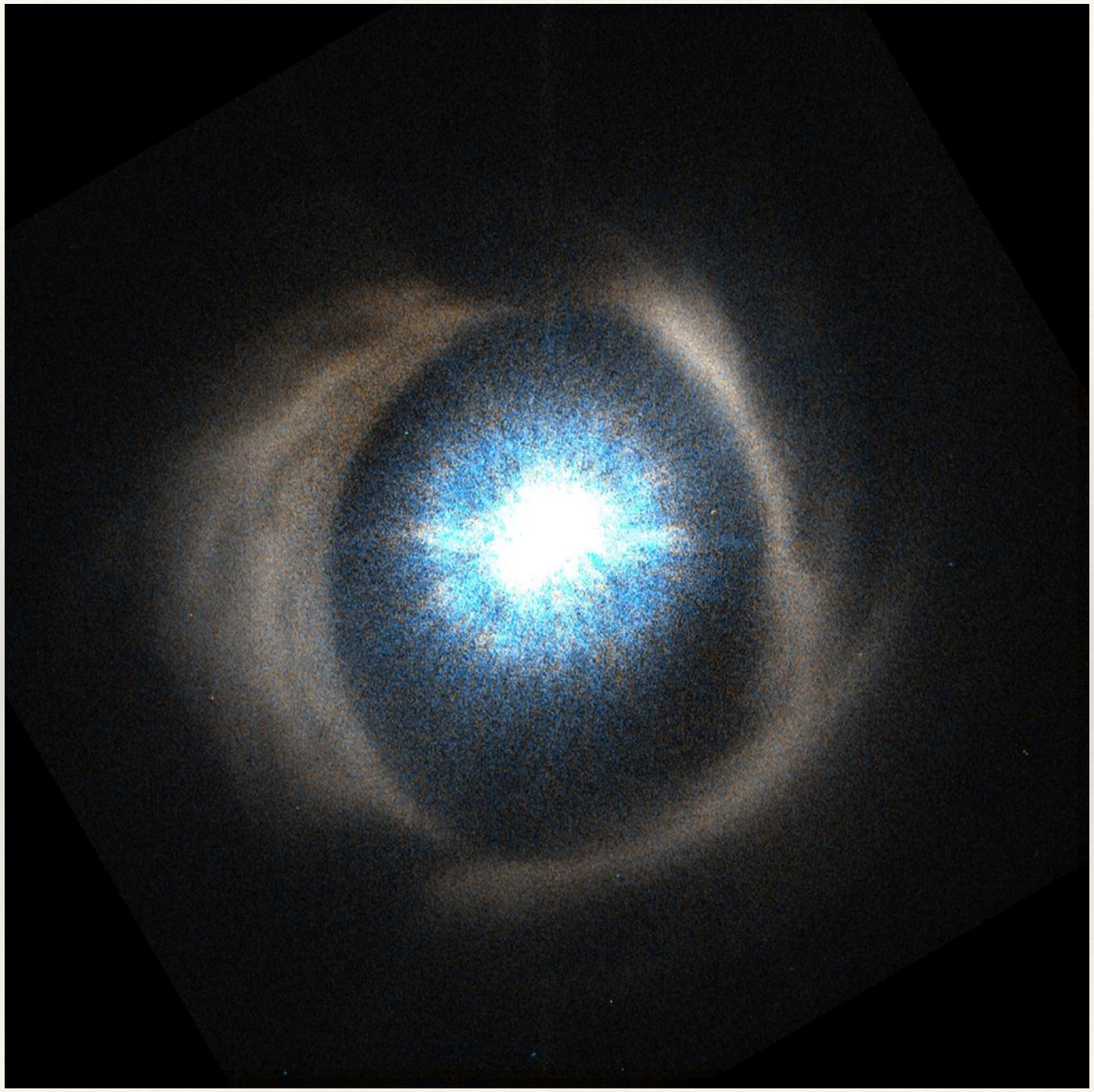

HR 4796 disk in IR
1"


SPHERE/IRDIS
1"
HD 165054, G4V, V=8.5.


ZIMPOL Image:
0.15” Separation


ZIMPOL:
Inner disk AU Mic

HD142527 : Zimpol polarized intensity in I' (48mn on-target integration)



HD142527 : IFS image Y-J