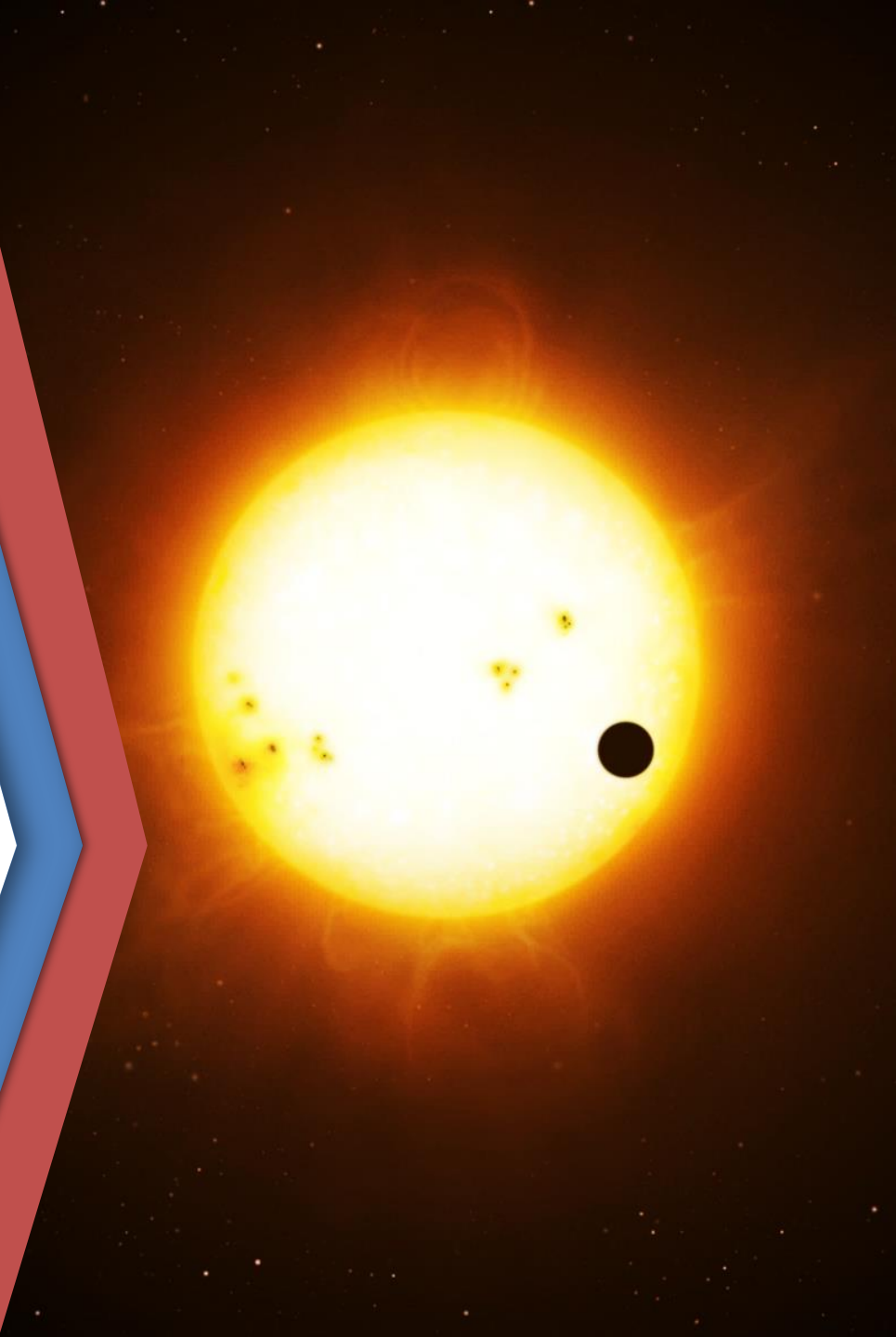
SHARK-NIR: the coronagraphic camera getting ready for the first-light at the LBT

Maria Bergomi

on behalf of the SHARK-NIR team

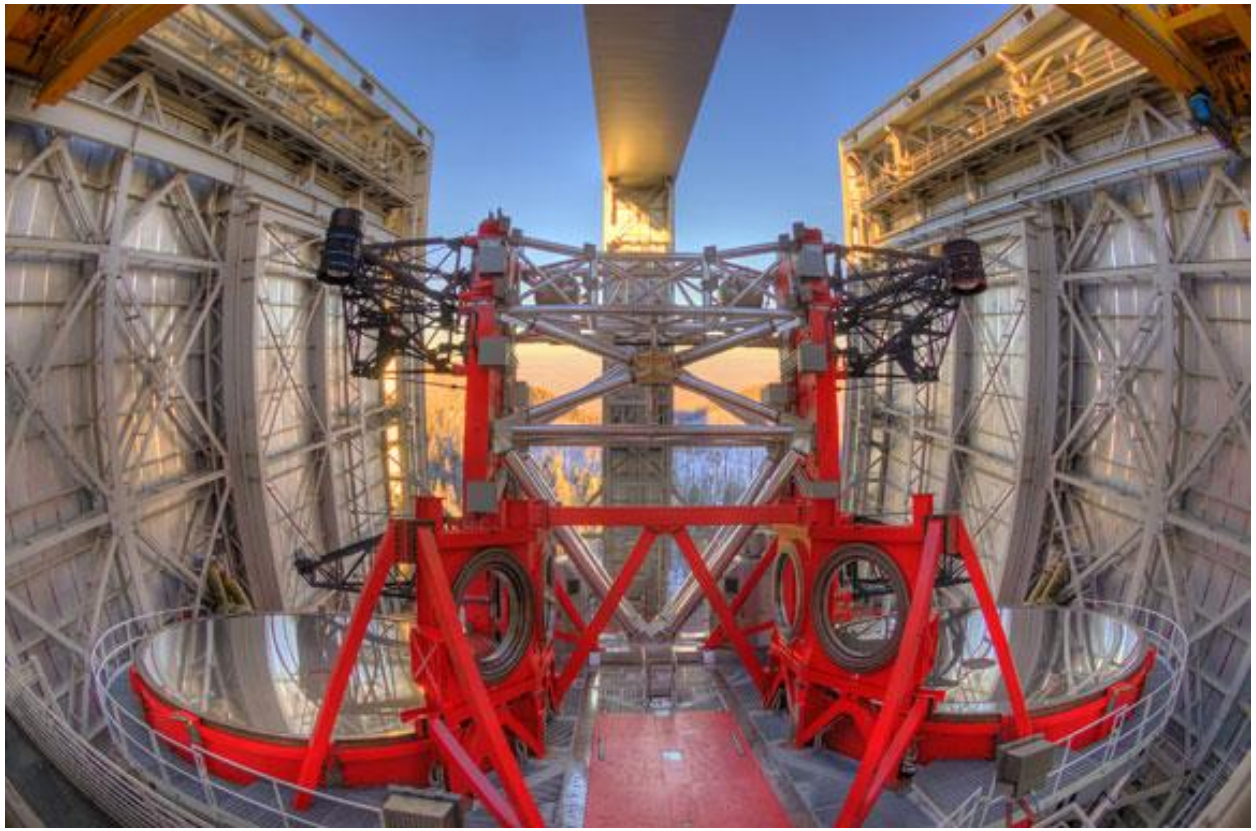
Roma – 17 Febbraio 2020

ASTROFISICA DI FRONTIERA CON L'OTTICA ADATTIVA ITALIANA
Roma, 17-19 febbraio 2020
Accademia Nazionale dei Lincei
indico.ict.inaf.it/event/955
ao2020@inaf.it



WHAT IS SHARK-NIR?

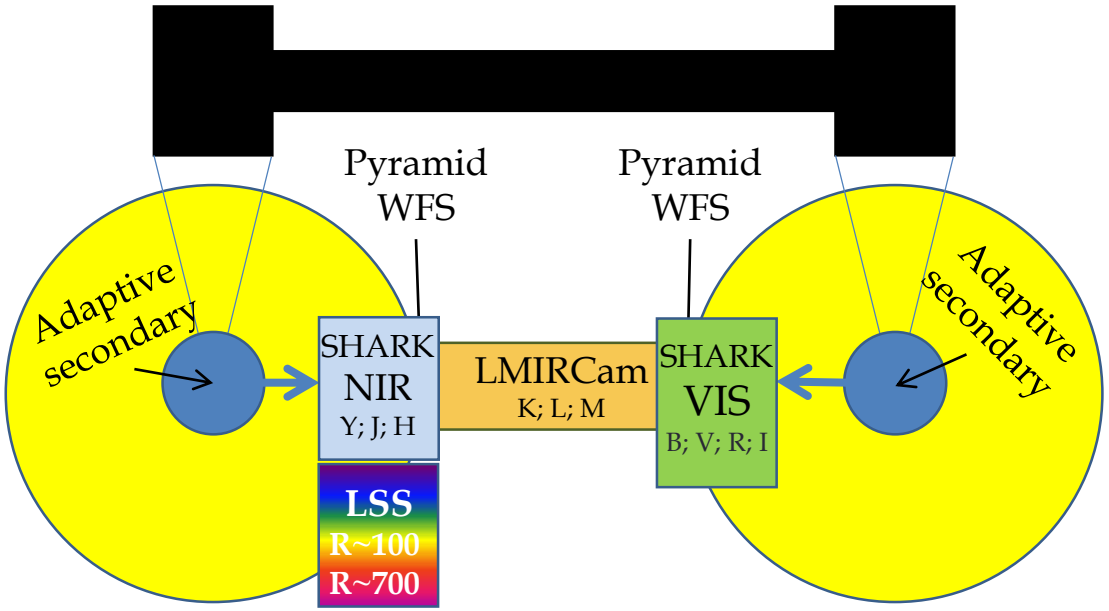
- Coronagraphic camera with also a spectroscopic channel (LSS), mainly dedicated to detection and characterization of exoplanets
- Takes advantage of the extreme adaptive optics correction of SOUL, allowing high resolution and contrast for direct imaging

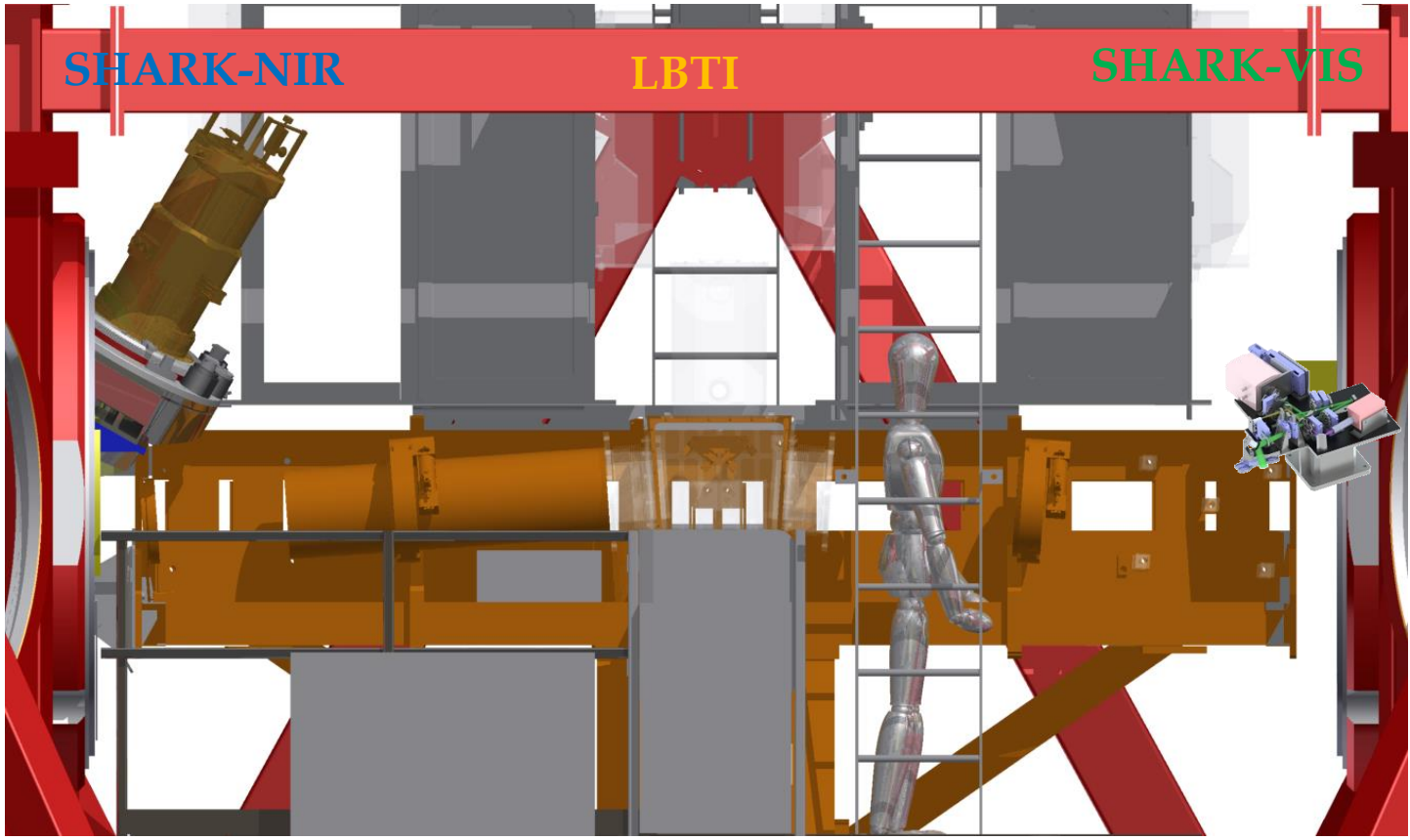


WHAT IS SHARK-NIR?

- Coronagraphic camera with also a spectroscopic channel (LSS), mainly dedicated to detection and characterization of exoplanets
- Takes advantage of the extreme adaptive optics correction of SOUL, allowing high resolution and contrast for direct imaging
- Synergy with other LBT instruments

  (SHARK-VIS; LMIRCAM of LBTI)

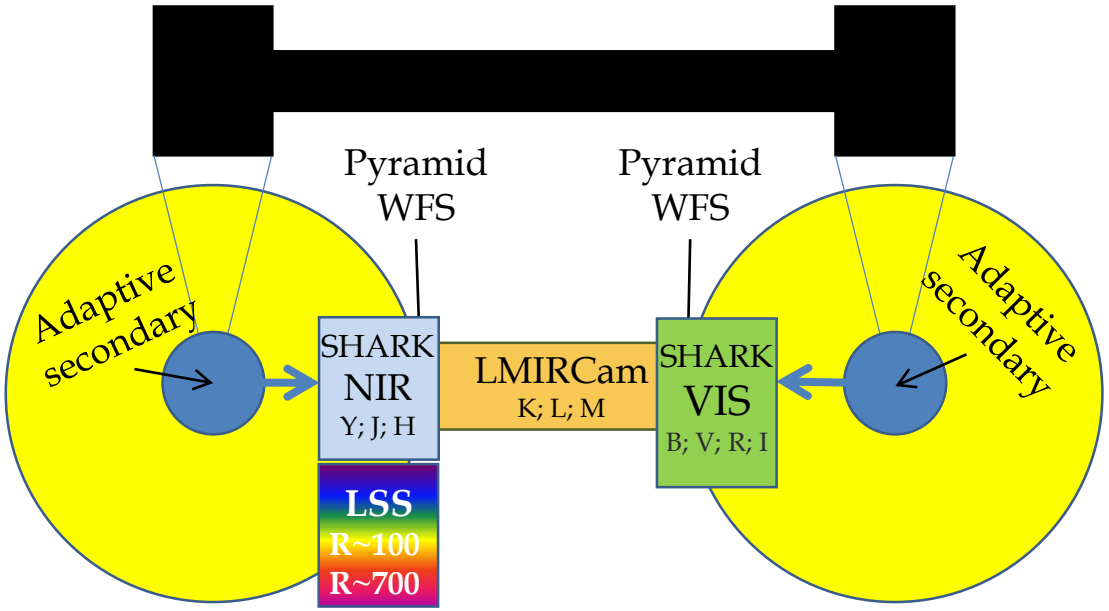


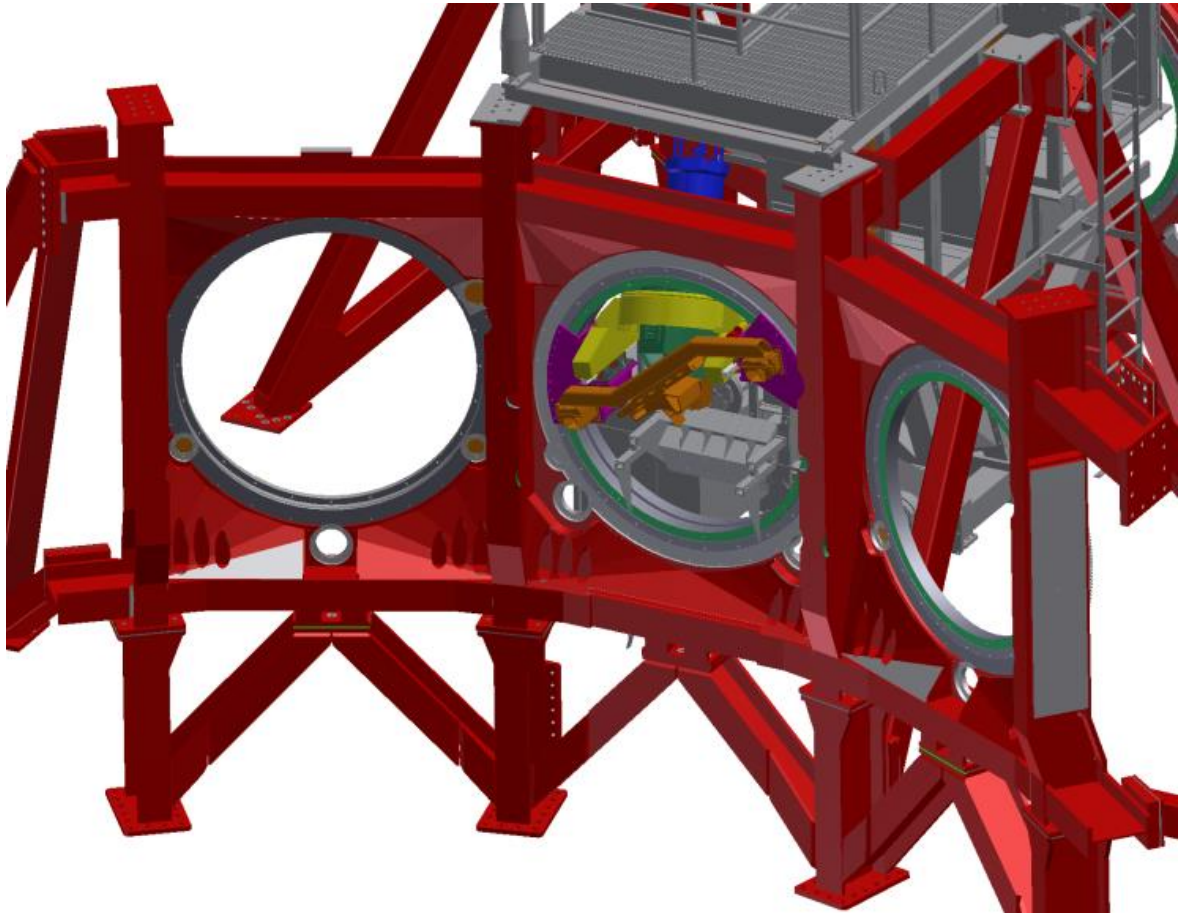


WHAT IS SHARK-NIR?

- Coronagraphic camera with also a spectroscopic channel (LSS), mainly dedicated to detection and characterization of exoplanets
- Takes advantage of the extreme adaptive optics correction of SOUL, allowing high resolution and contrast for direct imaging
- Synergy with other LBT instruments

(SHARK-VIS; LMIRCAM of LBTI)

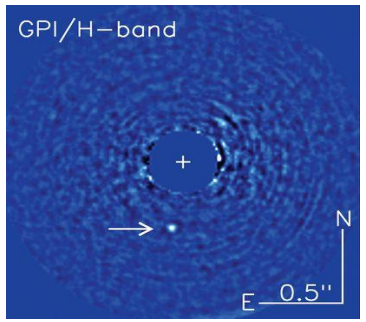




SCIENCE TARGETS

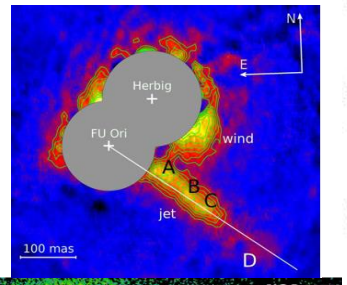
Main science target: direct imaging of exo-planets/BDs (detection and characterization):

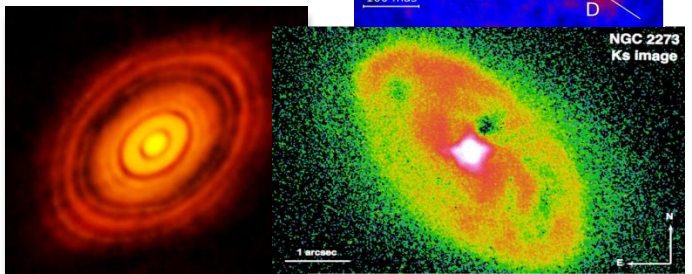
- require high angular resolution and contrast
- can be observed at different wavelength

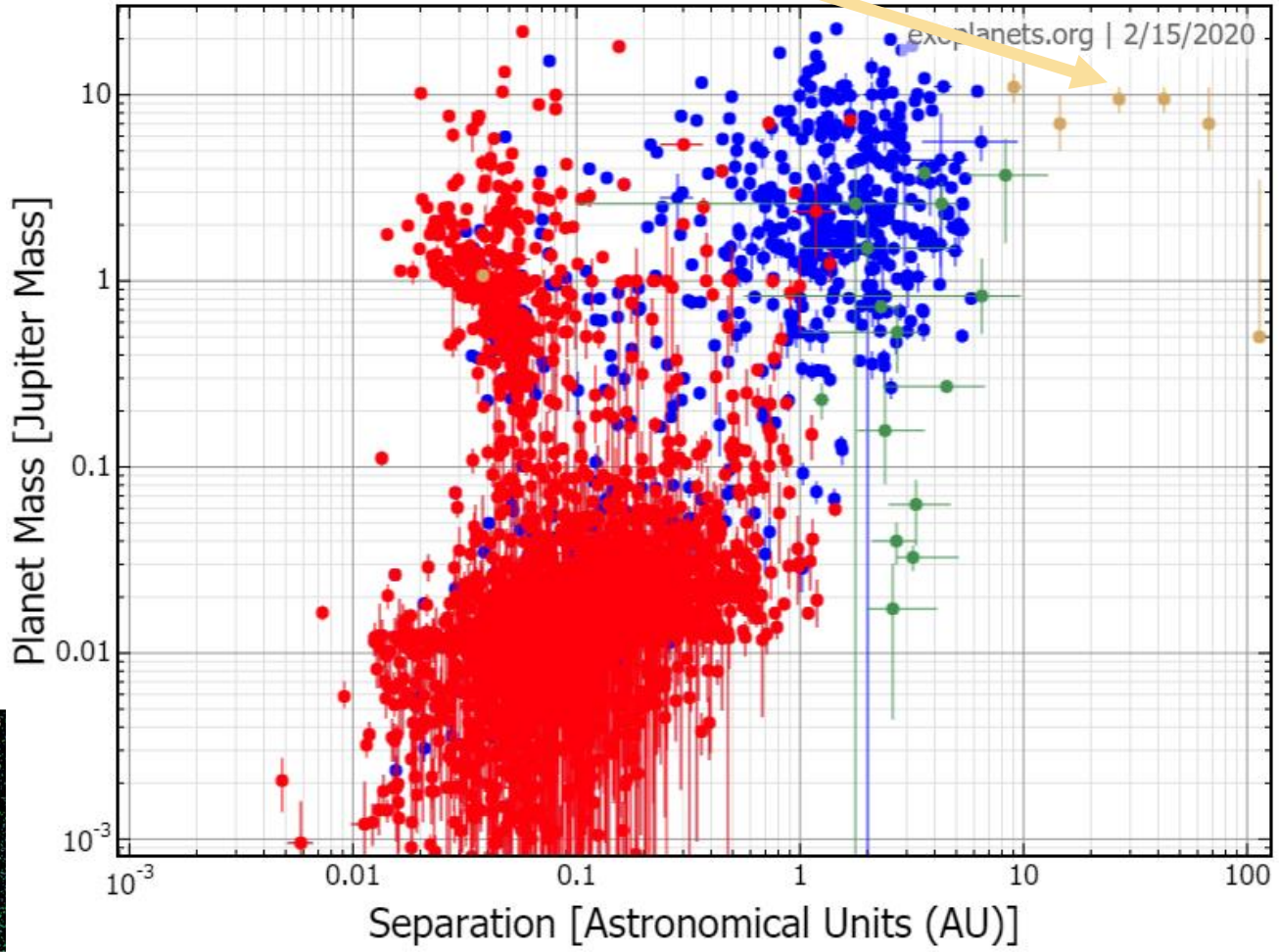


Other science:

- Protoplanetary disks
- Stellar jets
- AGN/QSOs
- Solar system bodies (Main belt & trans-neptunian obj.)







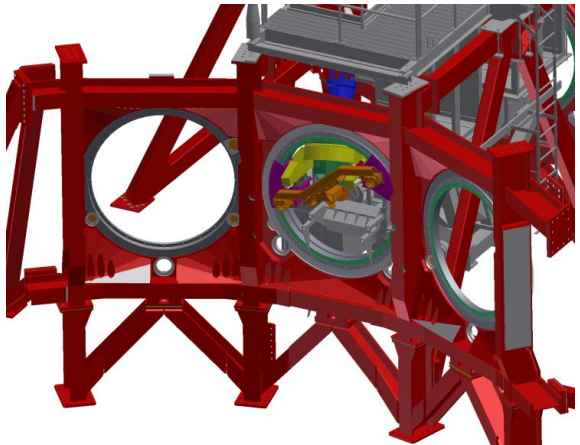
THE SHARK-NIR CONSORTIUM

- ✓Steward Observatory (LBTI interfaces, NIR camera sub-system)
- ✓MPIA (Motors electronics and SW design support)
- ✓IPAG (Coro mask design)
- ✓INAF-Brera (Dispersive elements design)
- ✓INAF-Trieste (Data archiving)
- ✓INAF-Arcetri (AO Interface)
- ✓INAF-Roma (Synergy with VIS Channel)
- ✓INAF- Padova (see next slide)
- ✓**Science team** (astronomers from 12 institutes, coordinated by Valentina D'Orazi)

THE Padova SHARK-NIR TEAM

- ✓PI: J. Farinato
- ✓System Engineer: V. Viotto
- ✓Project Manager: M. Bergomi
- ✓Optical design: **D. Greggio**, D. Magrin
- ✓Mechanical design: Tomelleri Srl with a local interface: L. Marafatto
- ✓Procurement: **M. Bergomi**, D. Greggio, D. Vassallo, V. D'Orazi, L. Marafatto
- ✓AIV Team: **L. Marafatto**, F. Biondi, E. Carolo, L. Lessio, G. Umbriaco, M.Bergomi, J. Farinato, M. Dima, D. Greggio, D. Vassallo, K. Radhakrishnan
- ✓ SW Team: **M. De Pascale**, A. Baruffolo, D. Ricci, B. Salasnich, D. Fantinel
- ✓**Data reduction**: **D. Mesa**, E. Carolo, D. Vassallo
- ✓Coronagraphic performance & simulation: **D. Vassallo**, E. Carolo
- ✓Science Team: **V. D'Orazi**, R. Gratton, S. Desidera

OPTO-MECHANICAL LAYOUT



Weight: 350 kg
Size: 1500 x 800 x 800 mm

INSTRUMENT SPECIFICATIONS

- **Wavelenghts**: 960-1700 nm Y, J, H bands
- **FoV**: 18'' x 18'', along the diagonal 25.5 ''
- Detector format used area: 1220 x 1220 pixel
- Airy Radius @ λ = 0.96 µm: 29 mas / 2 px (36 µm)
- **Plate-scale**: 14.5 mas/pixel
- Nominal **Strehl Ratio** (in all bands) > 98%
- Star magnitude: up to R=12

- **Observation modes**:
  - Imaging
  - Coronagraphic imaging
  - Long-slit coronagraphic spectroscopy
  - Dual-band simultaneous imaging

A SCIENCE CASE EXPLOITING THE CHARACTERISTICS OF SHARK-NIR

Planets in wide orbits of low-mass stars (K/M dwarfs)

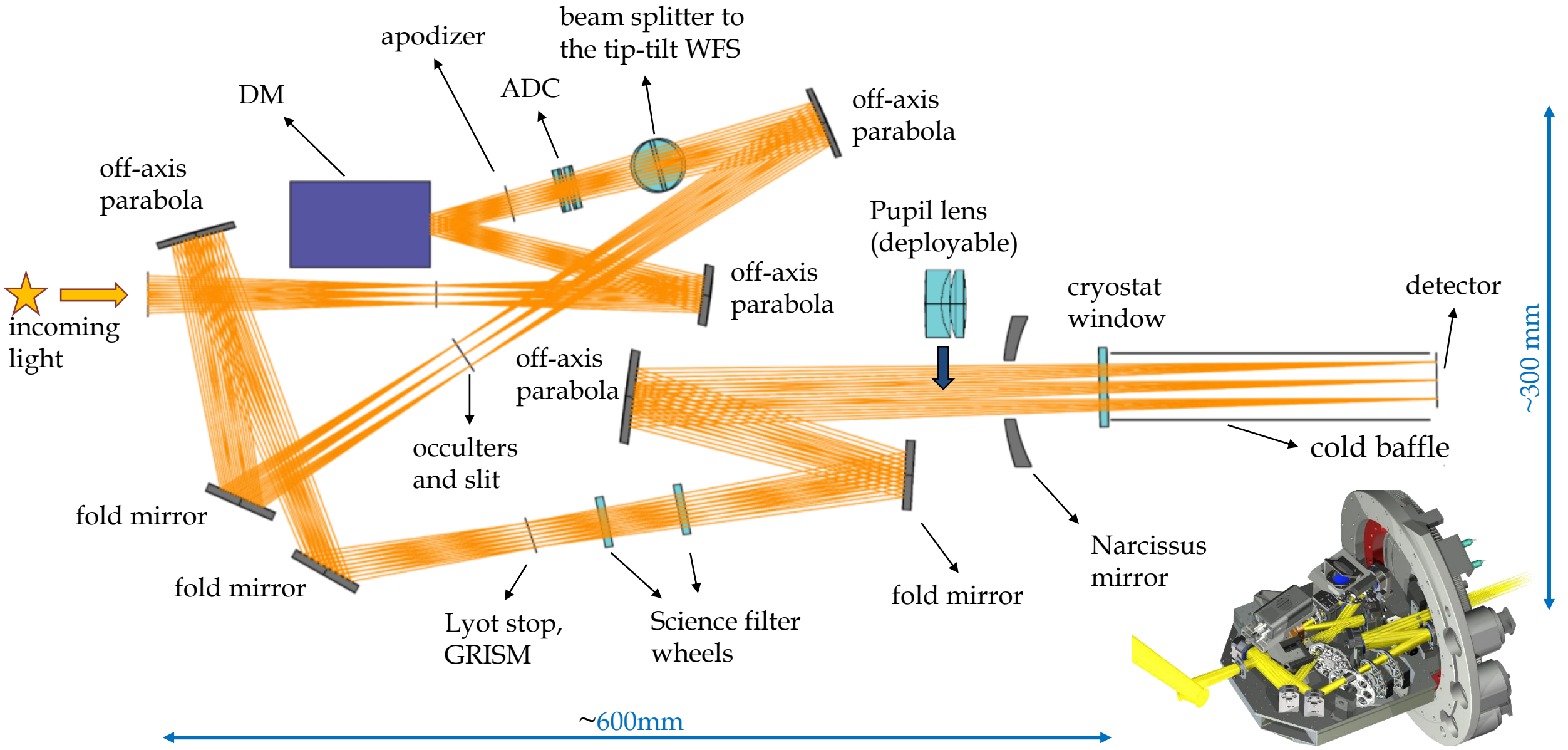
Most of the direct imaging surveys are **young stars**, as planets and brown dwarfs are **brighter** at young ages, and are usually photometrically variable on various timescales.

The identification and the physical properties of planets in their very early stages allows to obtain crucial information on the formation mechanisms (core accretion, disk instability) and study of the interactions between planets and disks.

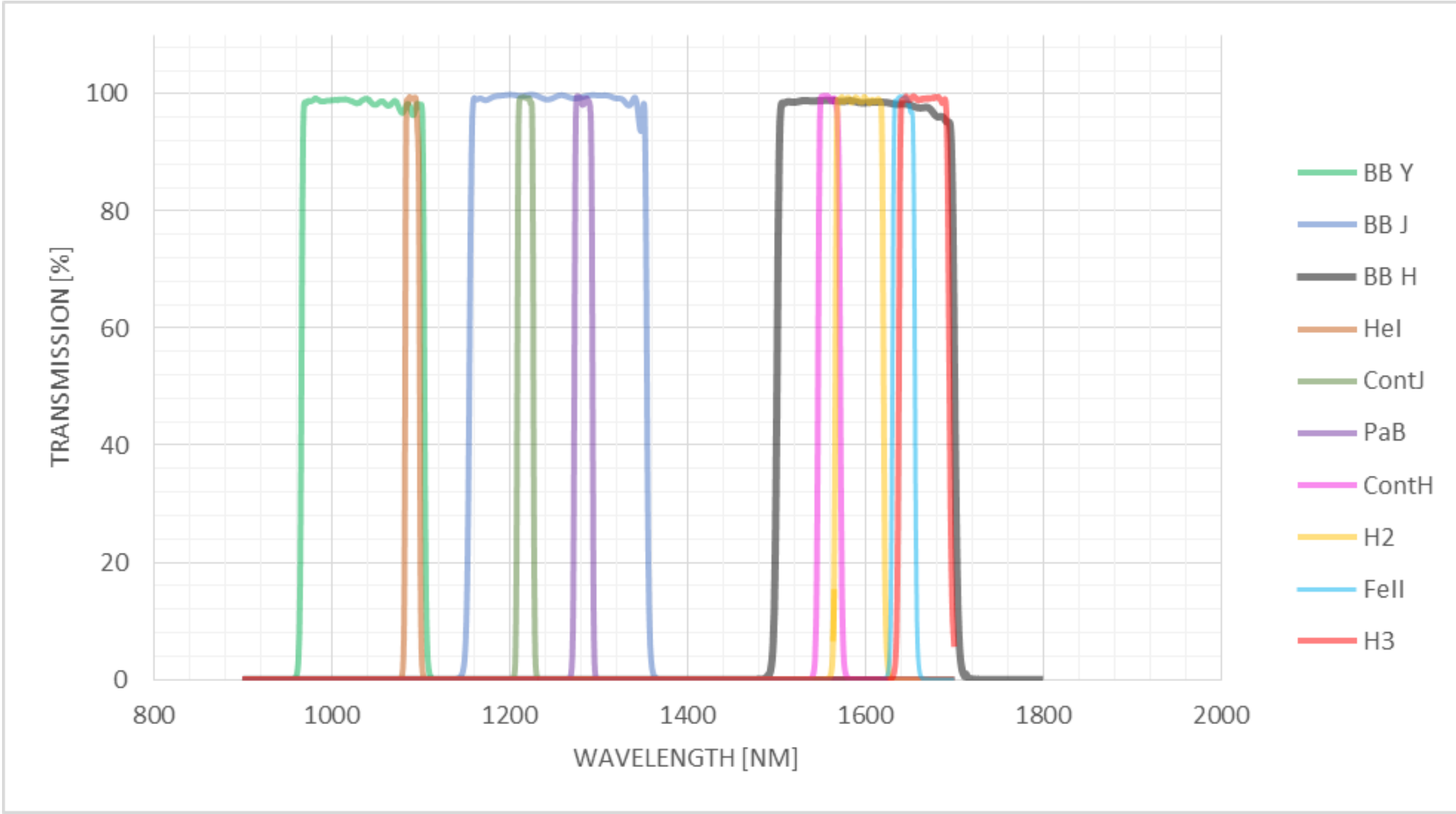
Simultaneous wavelength observation → no need for second epoch observation to confirm that the faint object close to the target star is bound rather than a background star.

LSS can be also used for confirmation

OPTICAL DESIGN



IMAGING: SCIENTIFIC FILTERS



THE HIGH-CONTRAST IMAGING FORMULA

How do we obtain high contrast in the vicinity of such bright stars?

XAO correction	+	→	*External: SOUL*
Optimized wavefront control strategy	+	→	*Internal: TT and NCPA compensation*
Coronagraph(s)	+	→	*Internal: Shaped Pupils, Gaussian, 4QPM*
Post-processing pipeline	=		
High contrast			

THE HIGH-CONTRAST IMAGING FORMULA

How do we obtain high contrast in the vicinity of such bright stars?

XAO correction	+	→	*External: SOUL*
Optimized wavefront control strategy	+	→	*Internal: TT and NCPA compensation*
Coronagraph(s)	+	→	*Internal: Shaped Pupils, Gaussian, 4QPM*
Post-processing pipeline	=		
High contrast			

WAVEFRONT CONTROL

A deformable mirror to correct for instrumental aberrations and to stabilize the PSF

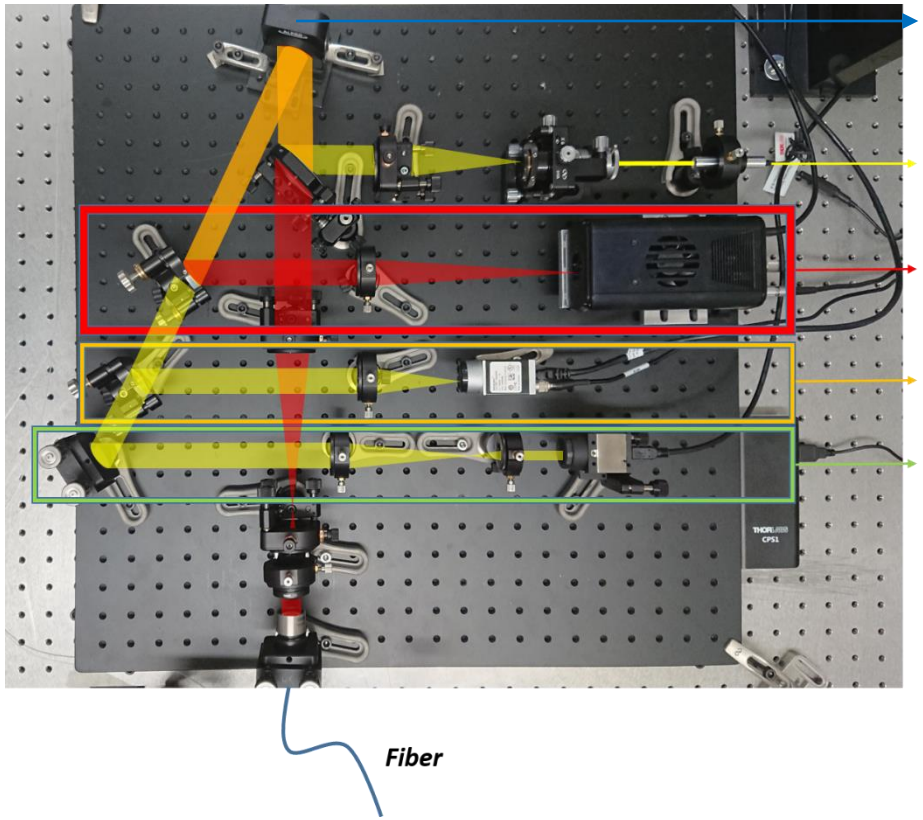
WFS Camera

- InGaAs camera (C-RED2)
- Sensitive in the full SHARK-NIR waveband (**0.96-1.7 µm**)
- Frame-rate up to **14 kHz** (with 32X32 px window)
- Low RON (<30 e^-)
- **3-5 mas** precision up to **R=10 @ 1KHz**

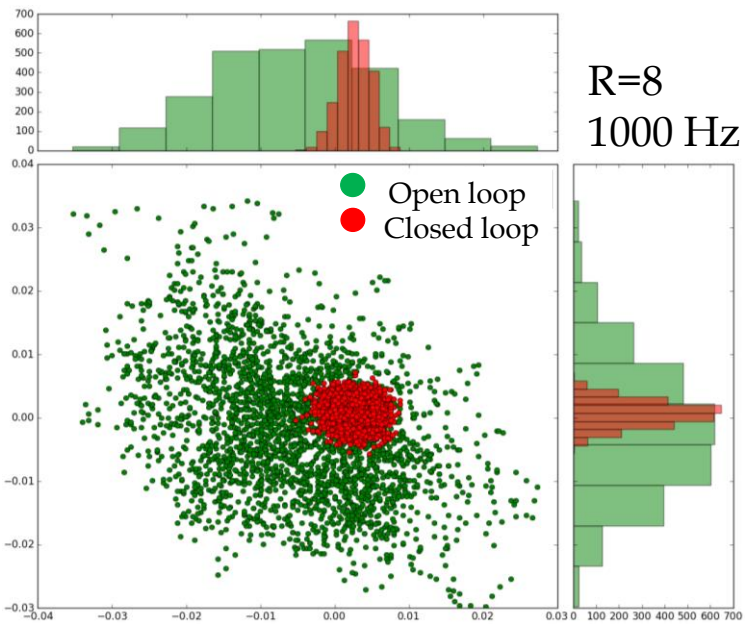
Deformable Mirror

- ALPAO DM 97-15
- **97 actuators**, 13.5 mm pupil, up to **2 kHz** speed
- NCPA can be corrected internally without affecting pyramid's performance
- NCPA measured with phase diversity on science image

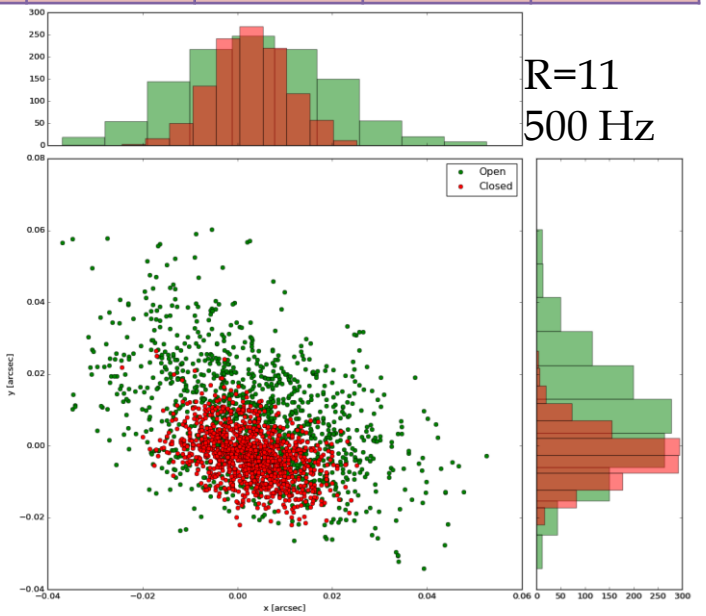
WAVEFRONT CONTROL



R magnitude	Frame rate [Hz]	Injected vibrations		
		15 mas	10 mas	5 mas
Mag 8	500	5.7	4.6	2.1
	1000	3.2	1.5	1.2
Mag 9	500	5.9	4.1	2.3
	1000	3.3	3.2	2.9
Mag 10	500	6.8	4.3	2.8
	1000	---	---	---
Mag 11	500	7.5		



R=8
1000 Hz



R=11
500 Hz

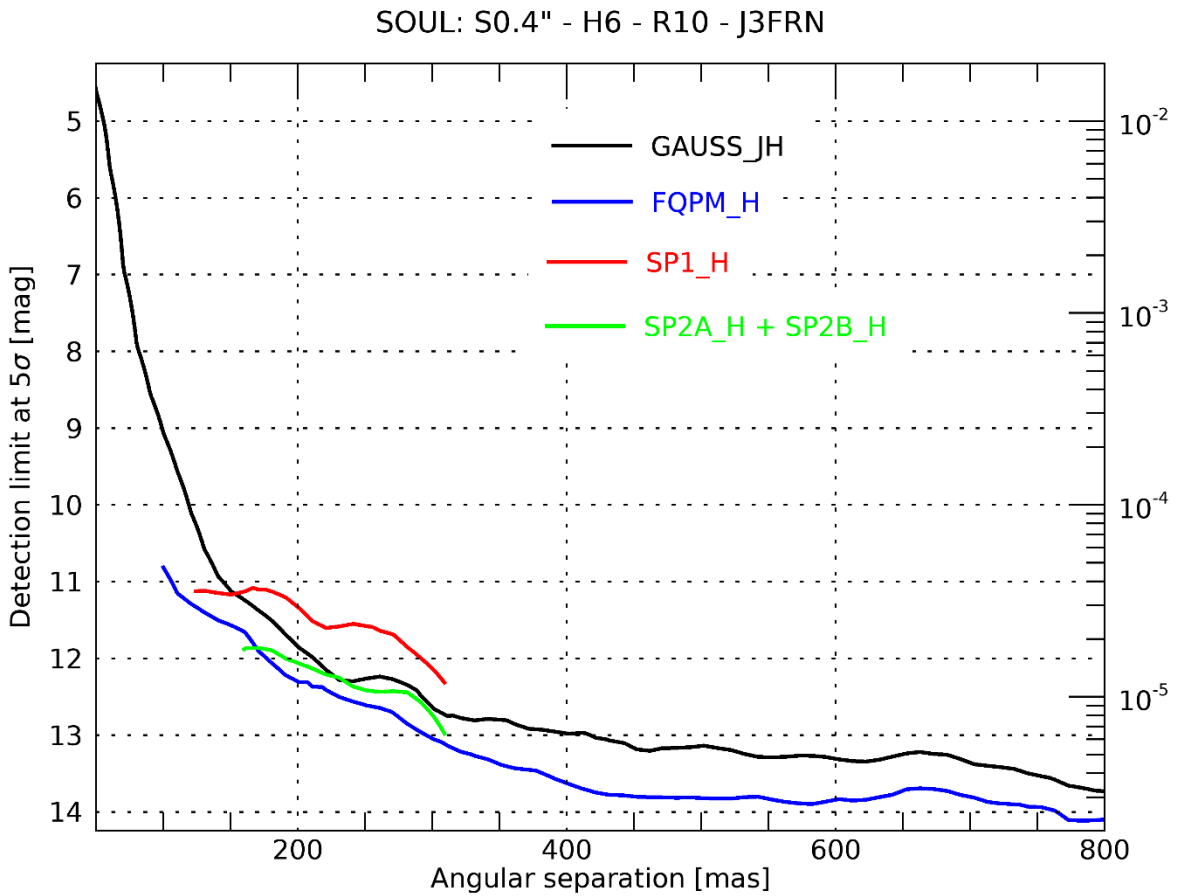
THE HIGH-CONTRAST IMAGING FORMULA

How do we obtain high contrast in the vicinity of such bright stars?

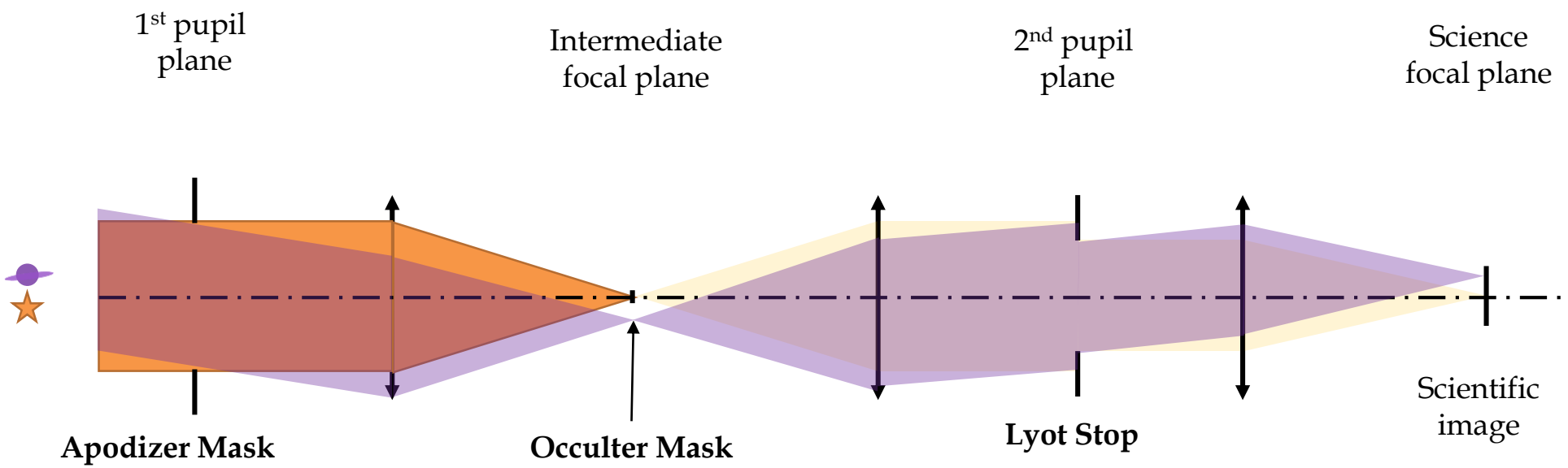
XAO correction	+	→	*External: SOUL*
Optimized wavefront control strategy	+	→	*Internal: TT and NCPA compensation*
Coronagraph(s)	+	→	*Internal: Shaped Pupils, Gaussian, 4QPM*
Post-processing pipeline	=		
High contrast			

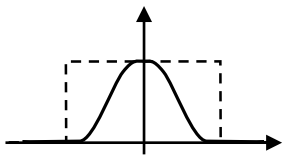
CORONAGRAPHIC PERFORMANCE

5-σ detection limit in H band for seeing 0.4", Rmag=10 with SOUL

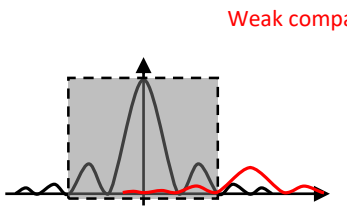


CORONAGRAPHS

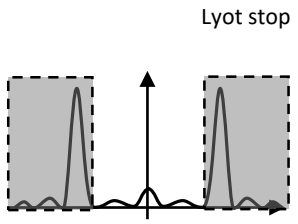




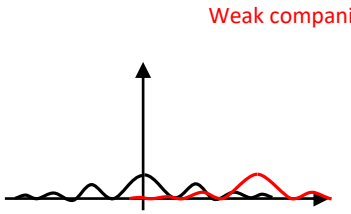
Vary intensity profile



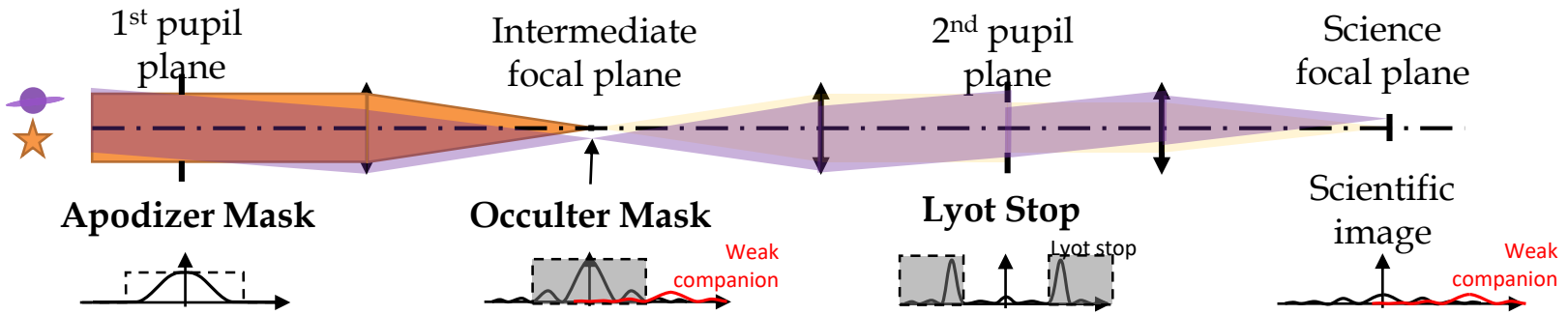
Block star light



Remove diffraction

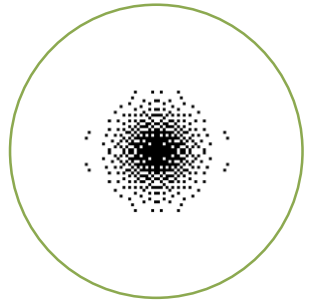


CORONAGRAPHS - GAUSSIAN

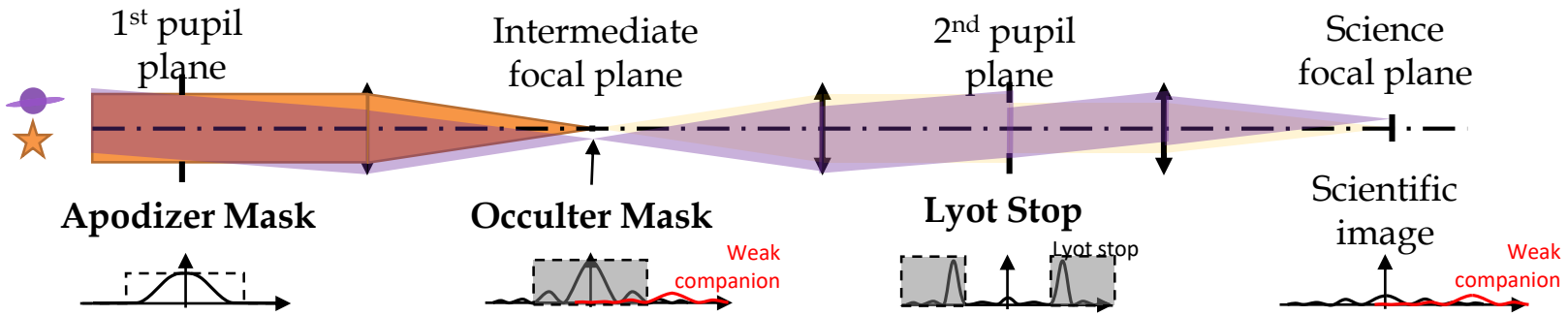


Field stabilized mode (de-rotator ON) requires circular symmetric masks

- ✓ Gaussian Lyot
- ❑ Optimized for both J and H band
- ❑ Whole FoV
- ❑ Contrast 10^{-4} –10^{-5}
- ❑ Robust to low-order aberrations, misalignments and jitter



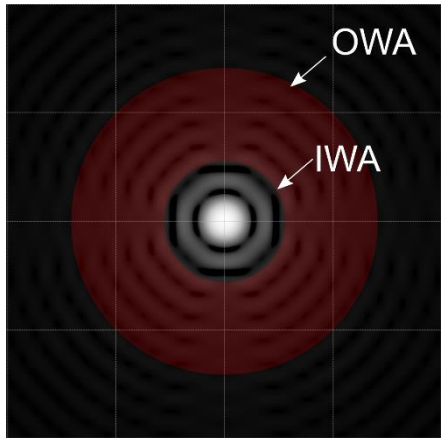
CORONAGRAPHS – SHAPED PUPILS

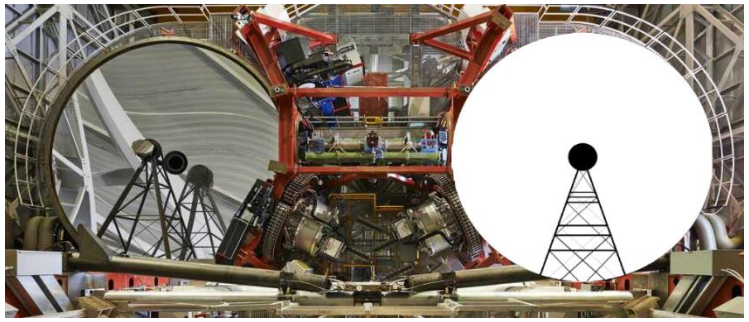


Pupil stabilized mode (de-rotator OFF)

- ✓ Shaped pupil
- ❑ Working in H band
- ❑ Small FoV
- ❑ High contrast (10^{-5}) near the star
- ❑ Robust to low-order aberrations, misalignments and jitter

CORONAGRAPHS – SHAPED PUPILS





SHAPED PUPIL

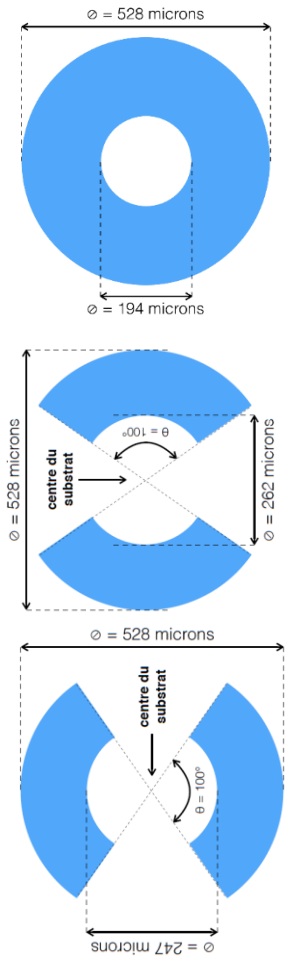
IWA [mas] :	100
OWA [mas] :	320
Contrast :	$2x10^{-5}$
Throughput :	22%
Disc. Space :	360°

IWA [mas] :	140
OWA [mas] :	320
Contrast :	$1x10^{-7}$
Throughput :	26%
Disc. Space :	220°

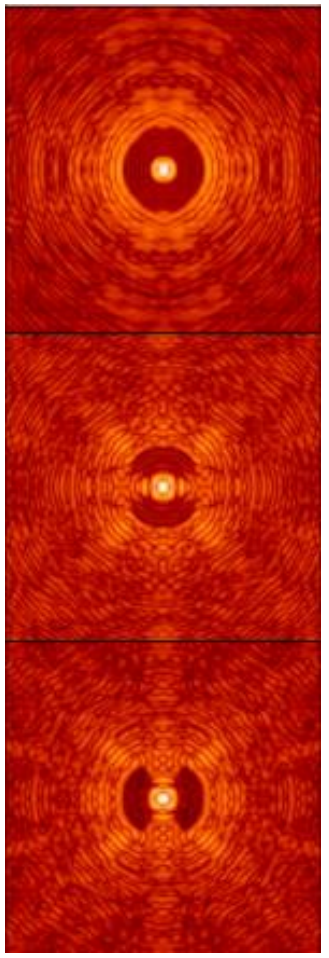
IWA [mas] :	140
OWA [mas] :	320
Contrast :	$1x10^{-7}$
Throughput :	26%
Disc. Space :	220°

Apodizer

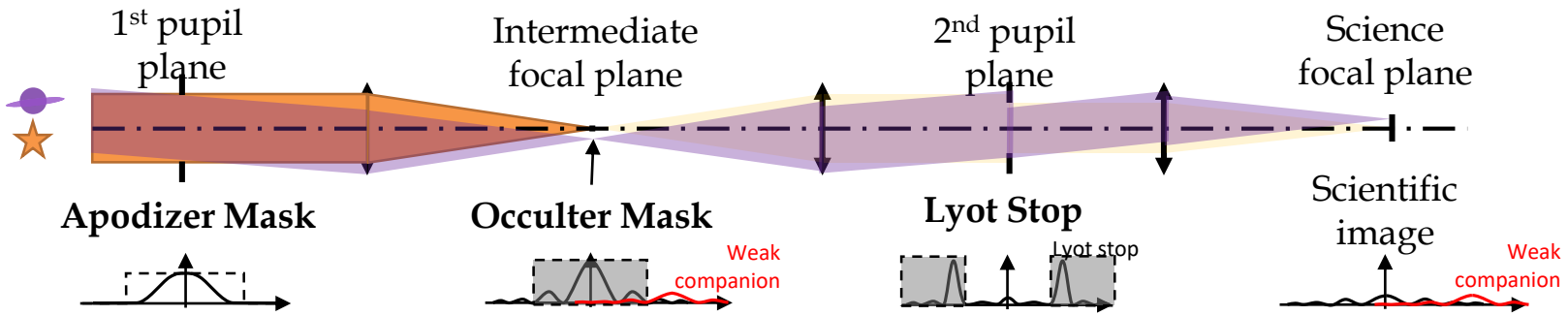
Occult. Mask



PSF



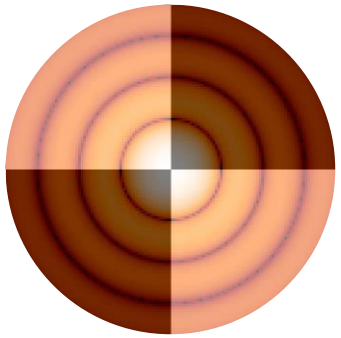
CORONAGRAPHS - FQPM



Pupil stabilized mode (de-rotator OFF)

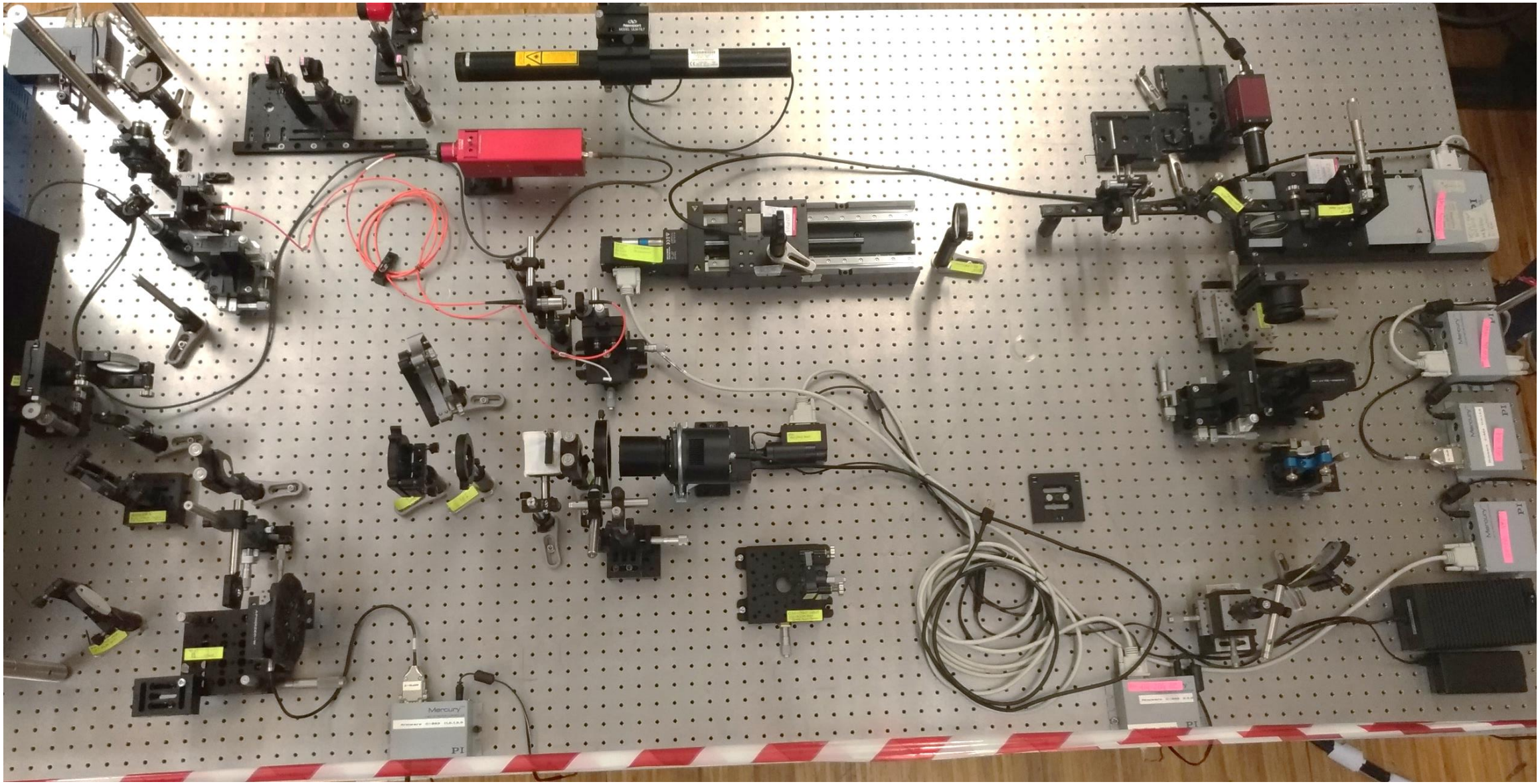
✓ Four-Quadrant Phase Mask

- ❑ Working in H-band
- ❑ Whole FoV
- ❑ Very small IWA (from 2 Lambda/D)
- ❑ Contrast 10^{-5}
- ❑ High throughput



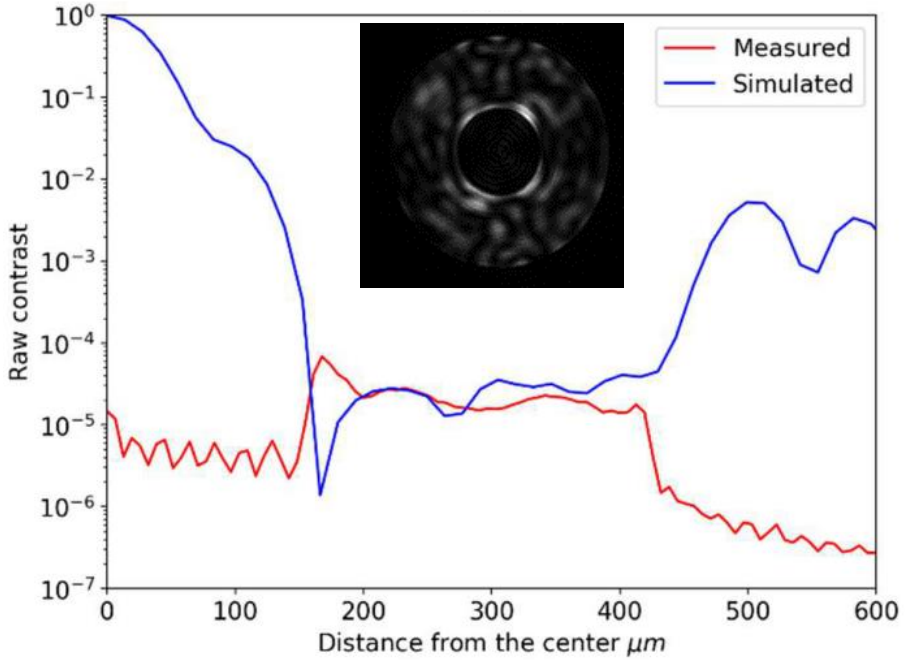
- ❑ But more sensitive to misalignments/jitter

CORONAGRAPHS – IN THE LAB

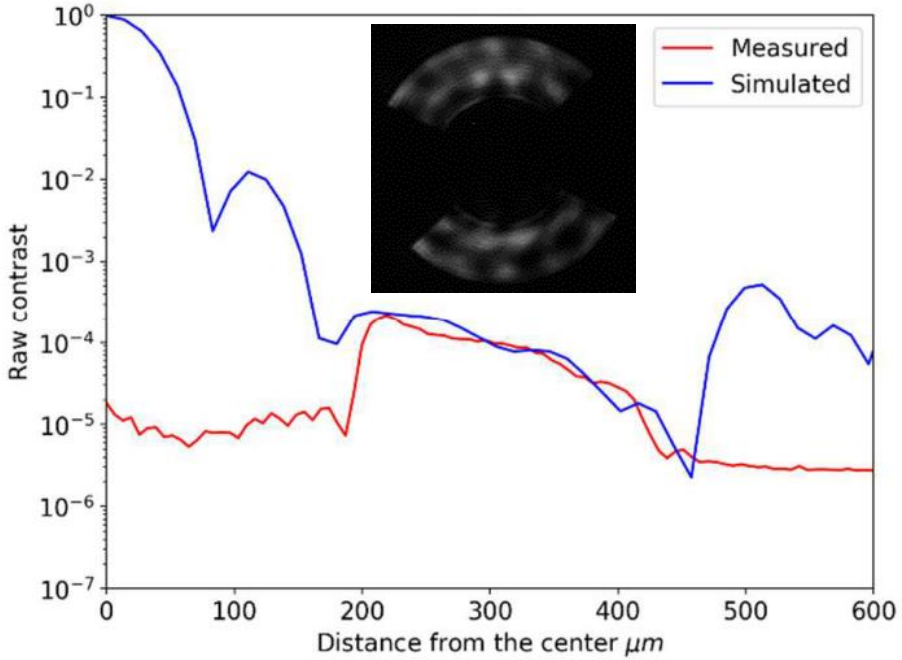


CORONAGRAPHS – SPs IN THE LAB

SP1 APO+CORO

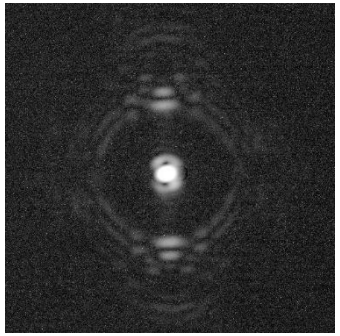


SP2b APO+CORO

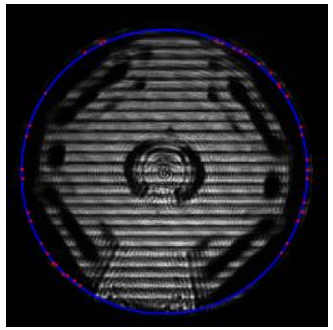


APO - PUPIL PLANE

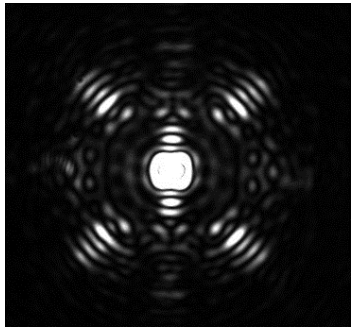
PSF PLANE



APO - PUPIL PLANE

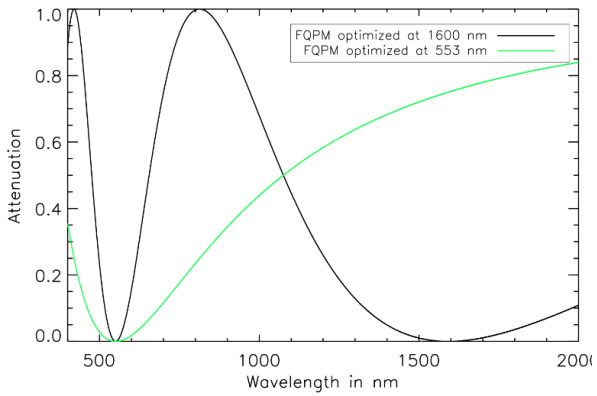


PSF PLANE

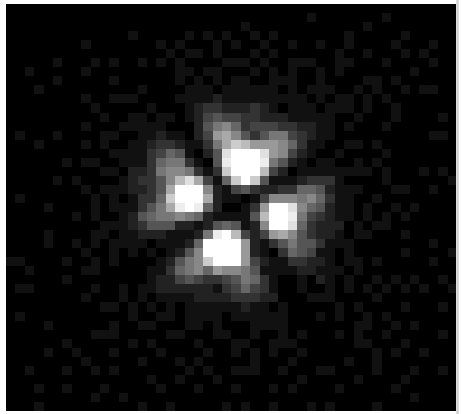


CORONAGRAPHS – FQPM IN THE LAB

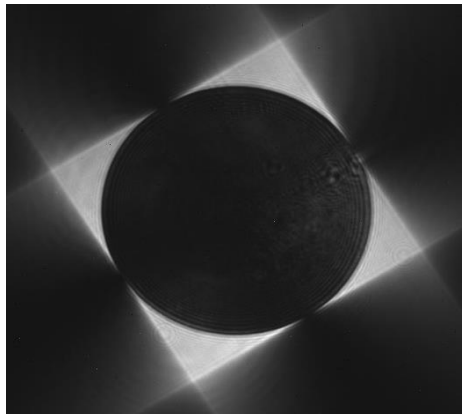
Designed by Observatoire de Paris (LESIA)



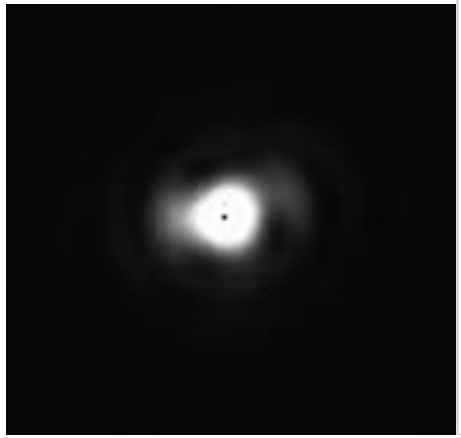
FP w/o Lyot Stop

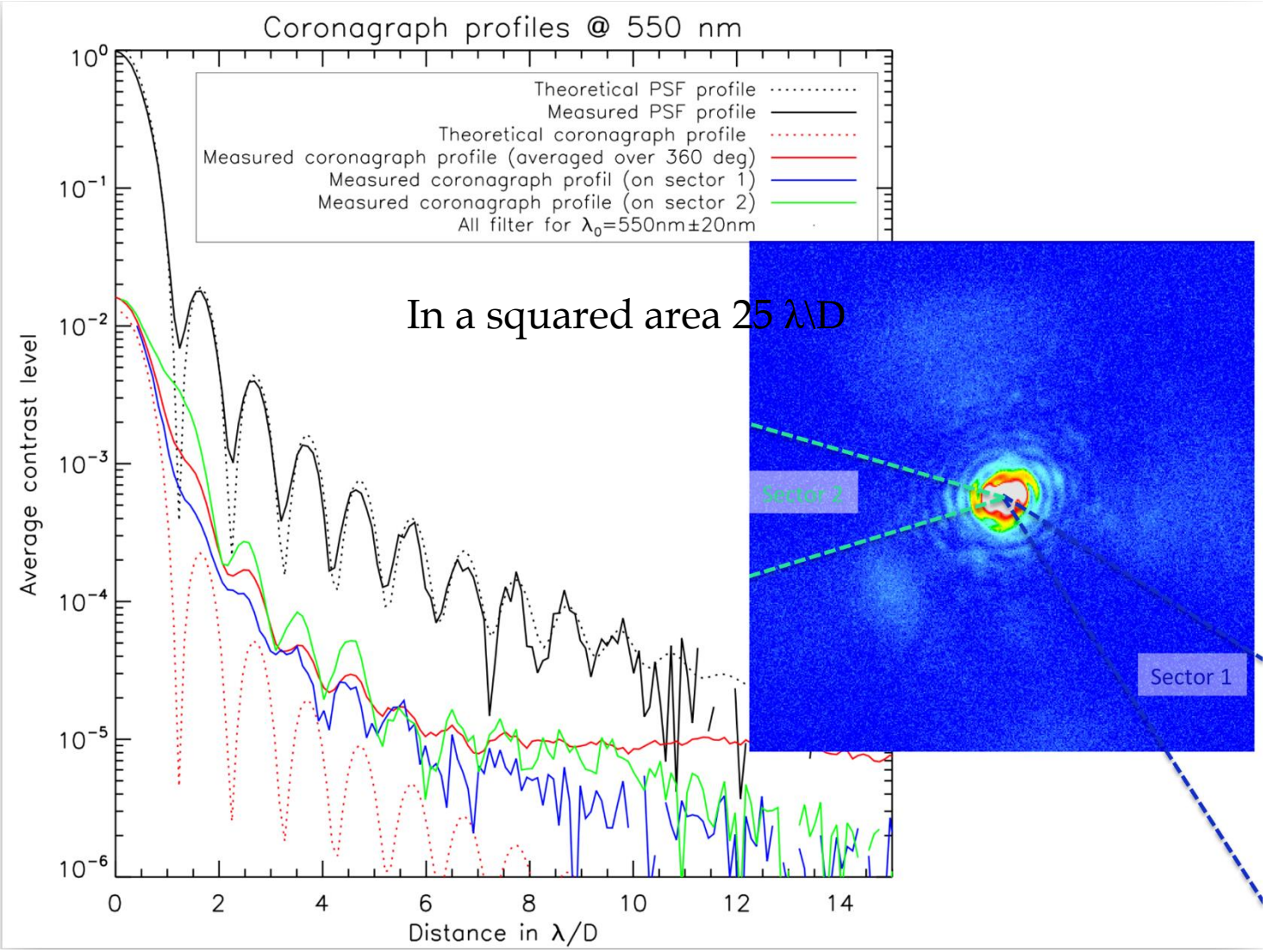


Pupil plane



FP w/ Lyot Stop





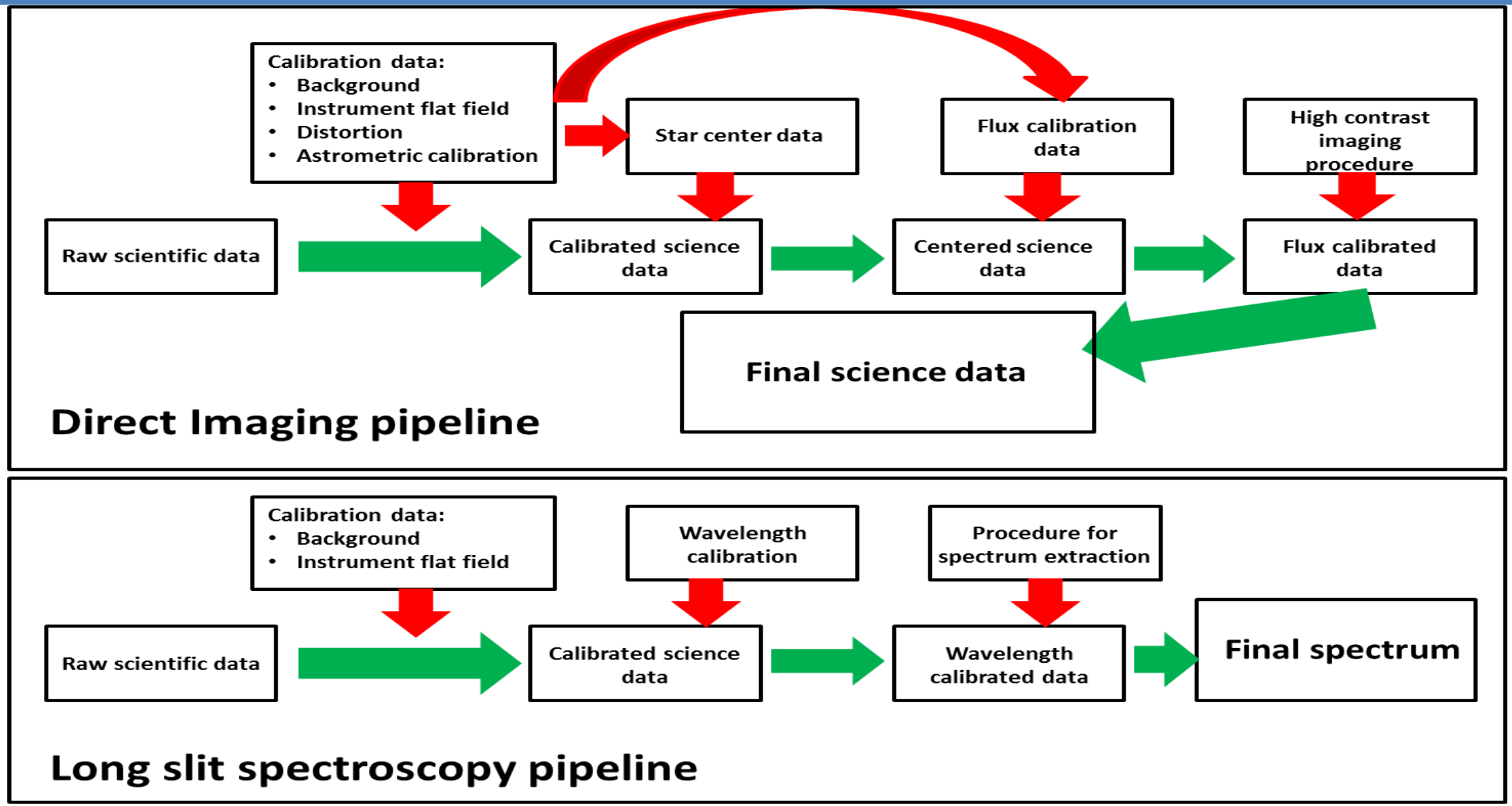
THE HIGH-CONTRAST IMAGING FORMULA

How do we obtain high contrast in the vicinity of such bright stars?

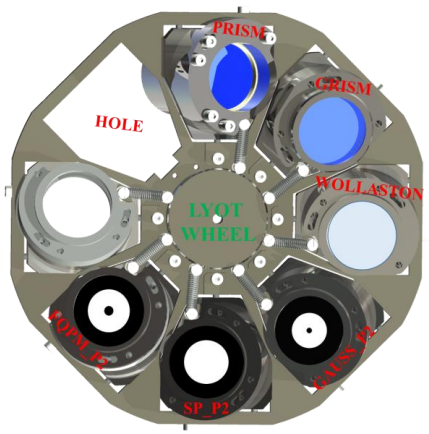
XAO correction	+	→	*External: SOUL*
Optimized wavefront control strategy	+	→	*Internal: TT and NCPA compensation*
Coronagraph(s)	+	→	*Internal: Shaped Pupils, Gaussian, 4QPM*
Post-processing pipeline	=		

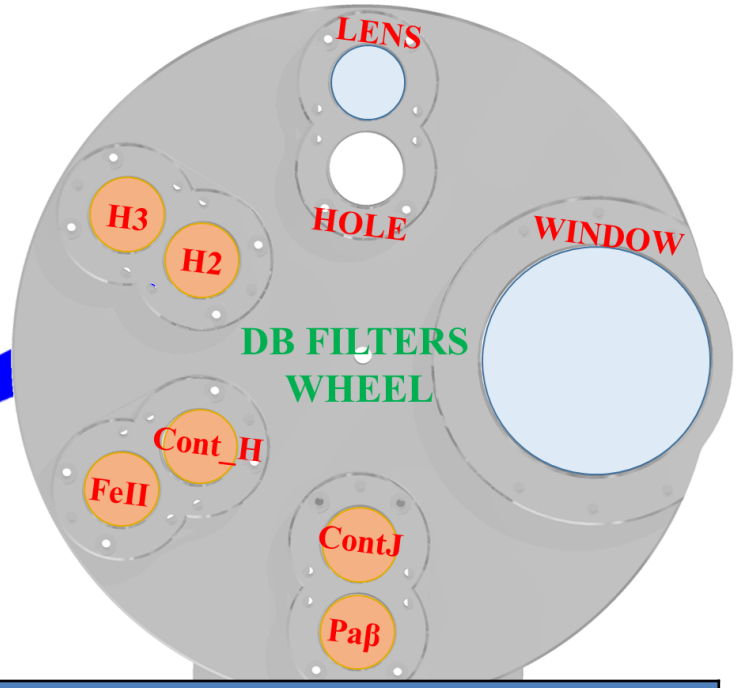
High contrast

SHARP – The SHARK pipeline



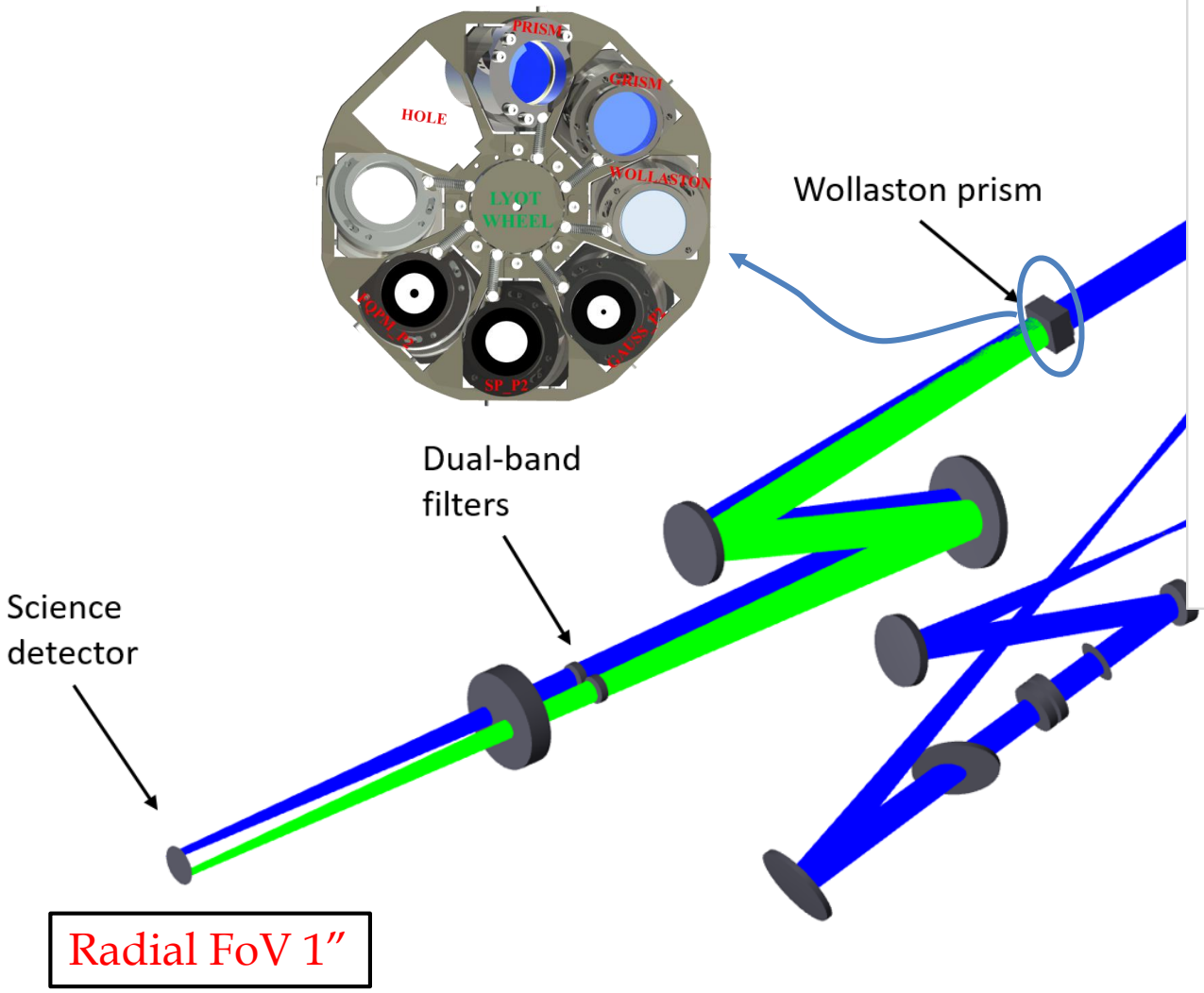
DUAL BAND IMAGING MODE

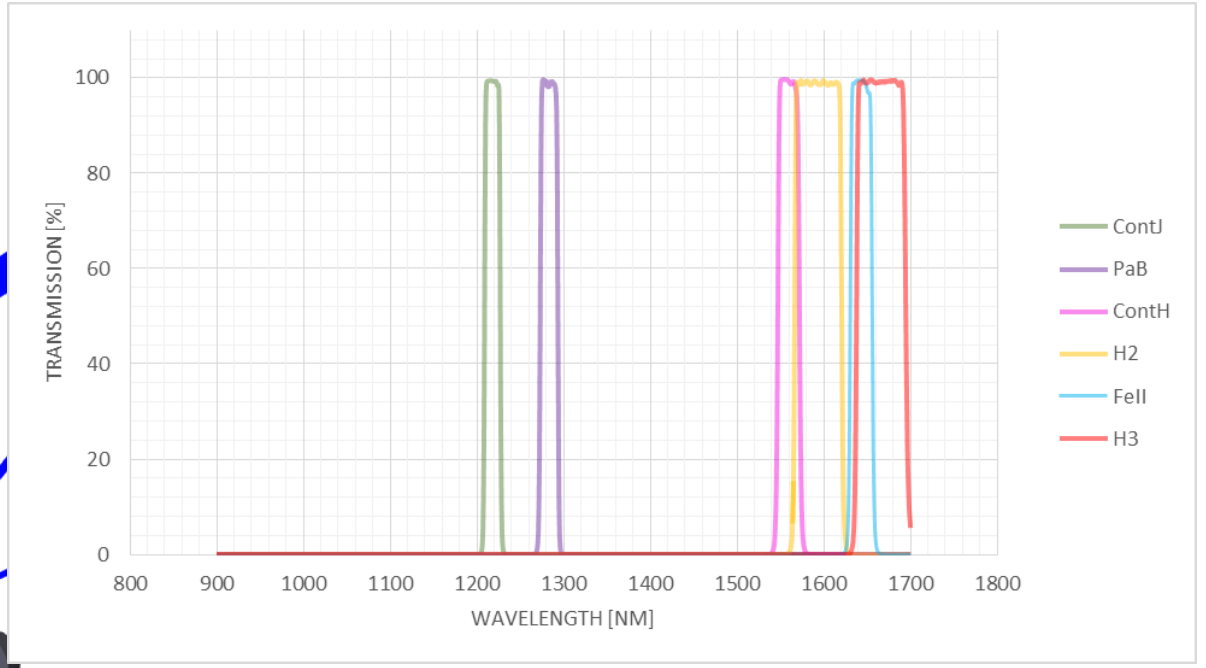




DUAL BAND FILTERS				
Name	λ_1 [nm]	$\Delta\lambda_1$ [nm]	λ_2 [nm]	$\Delta\lambda_2$ [nm]
HOLE (no DBI)	-	-	-	-
H2-H3	1593	53	1667	56
ContJ-Pa β	1216	18	1282	21
ContH-Fe II	1558	25	1644	26
Phase diversity	Window		Defocusing lens	

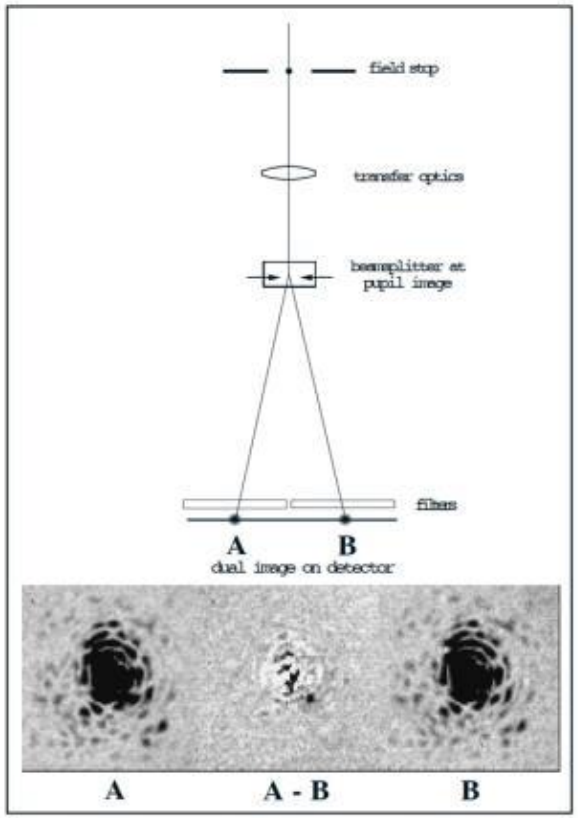
DUAL BAND IMAGING MODE





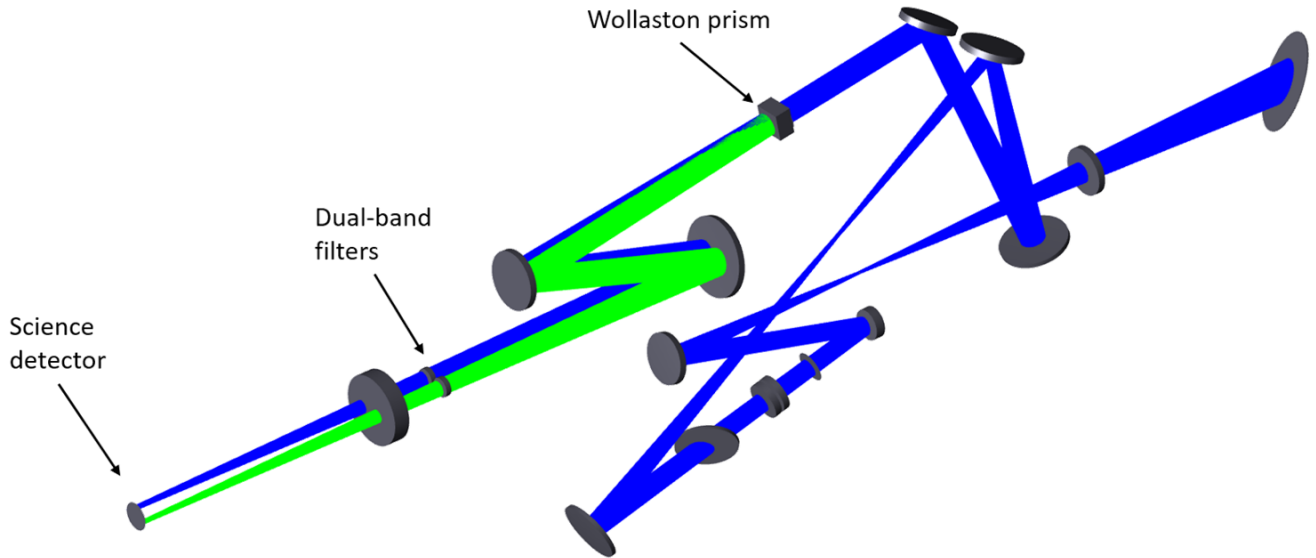
DUAL BAND FILTERS				
Name	λ_1 [nm]	$\Delta\lambda_1$ [nm]	λ_2 [nm]	$\Delta\lambda_2$ [nm]
HOLE (no DBI)	-	-	-	-
H2-H3	1593	53	1667	56
ContJ-Pa β	1216	18	1282	21
ContH-Fe II	1558	25	1644	26
Phase diversity	Window		Defocusing lens	

DUAL BAND IMAGING MODE SCIENCE EXAMPLE



WHEN: In the case where planetary objects have strong molecular features in their spectrum, whereas the host star has a relatively flat spectrum (e.g. T-Type sub-stellar objects showing deep molecular absorption bands caused by H2O, CH4 and NH3).

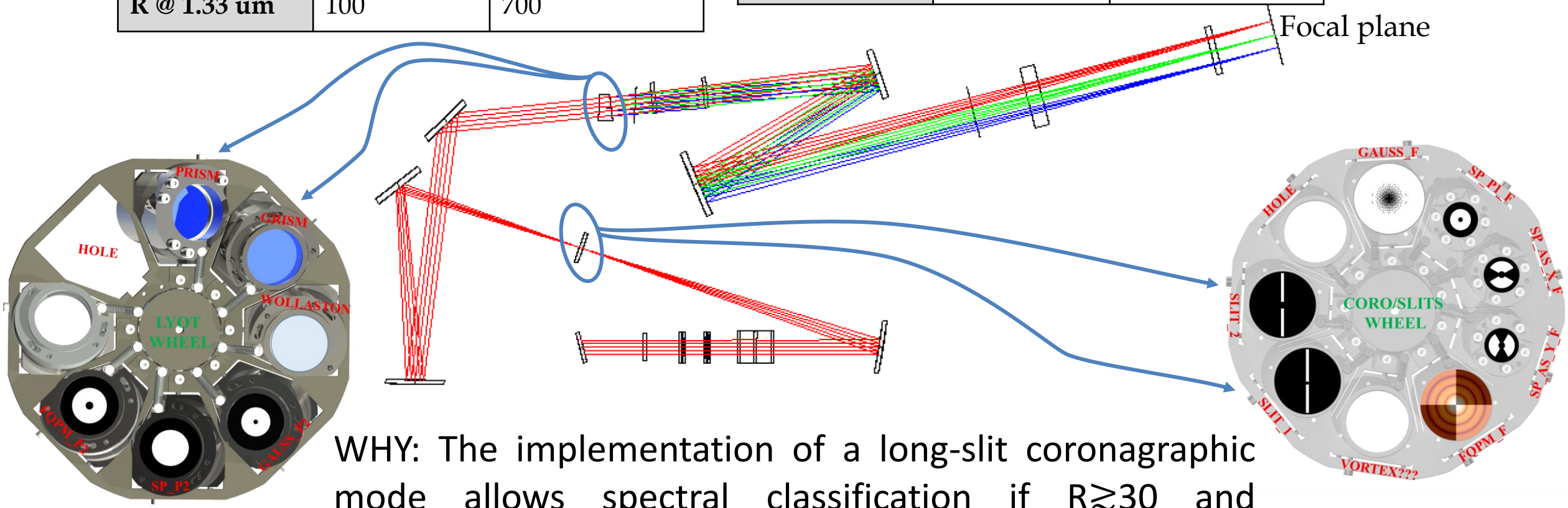
HOW: By simultaneously acquiring two images of a system at two close wavelengths located around one of these sharp features and subtracting them, the star contribution can be partially eliminated, and the planet signal revealed



SPECTROSCOPIC MODE (LSS)

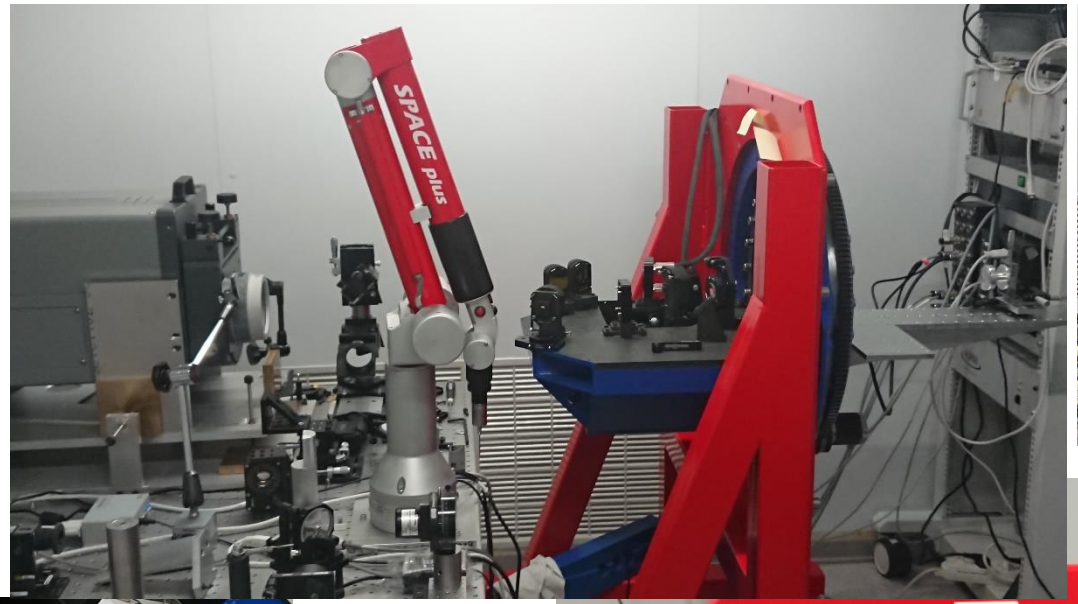
DISPERSIVE ELEMENTS		
	Low Res	Medium Res
Dispersing element	Prism	Grism
R @ 1.33 um	100	700

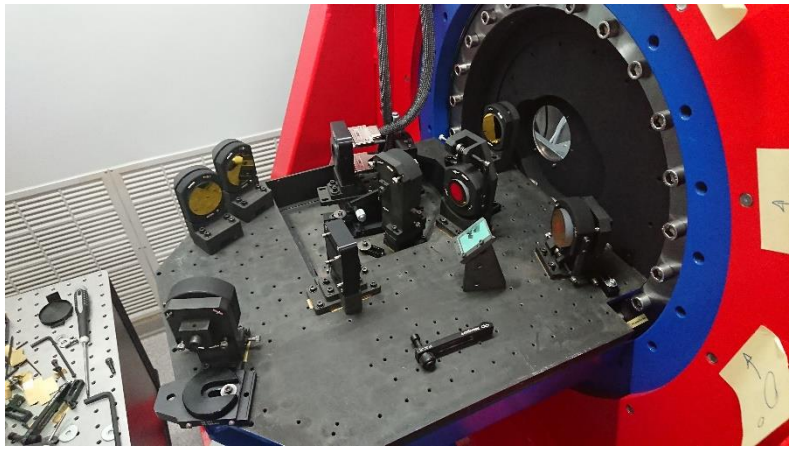
CORO SLITS WITH OCCULTER		
	Slit width	Occulter size
Coro slit 1	100 mas	100 mas
Coro slit 2	100 mas	200 mas

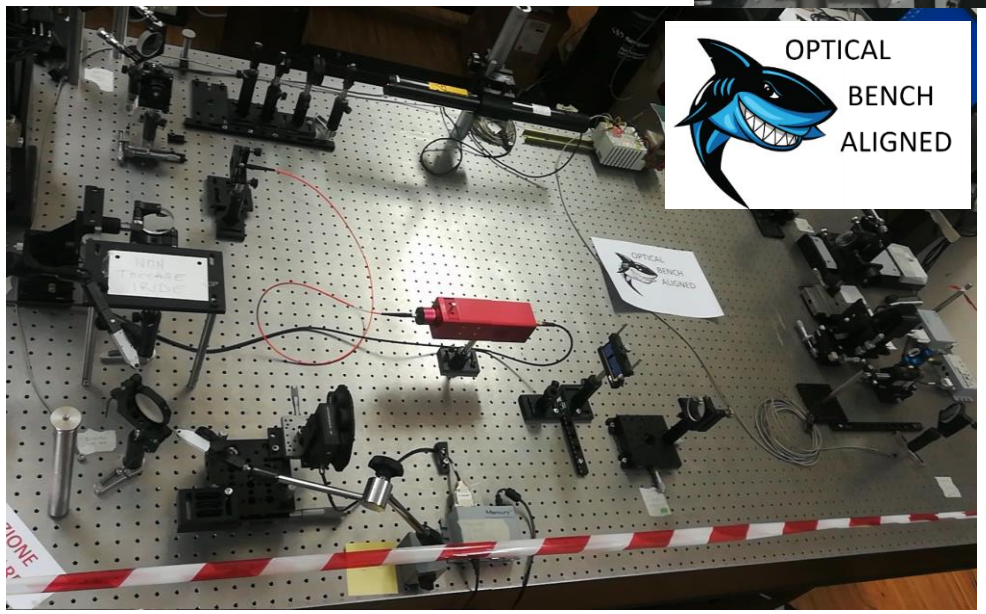


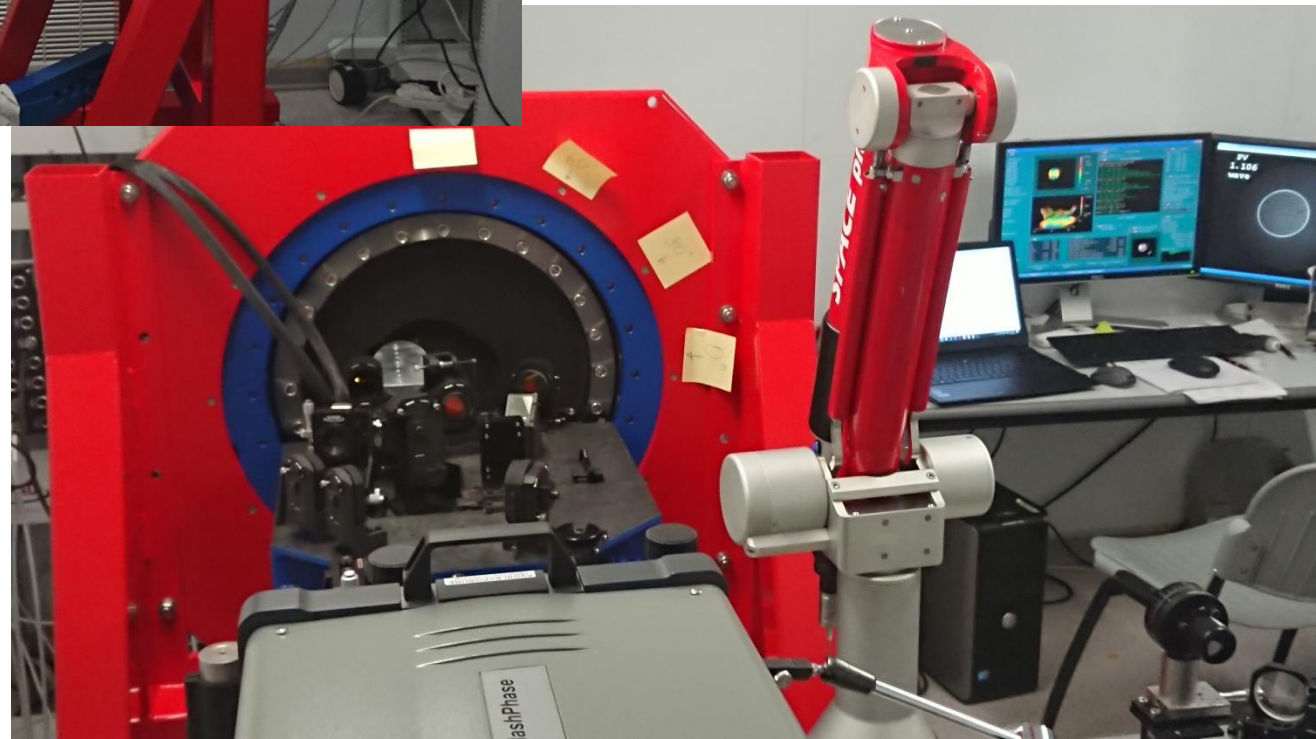
WHY: The implementation of a long-slit coronagraphic mode allows spectral classification if R≳30 and molecular band + atomic feature identification if R≳100

CURRENT SNAPSHOTs FROM THE CLEAN ROOM & LABs @OAPD

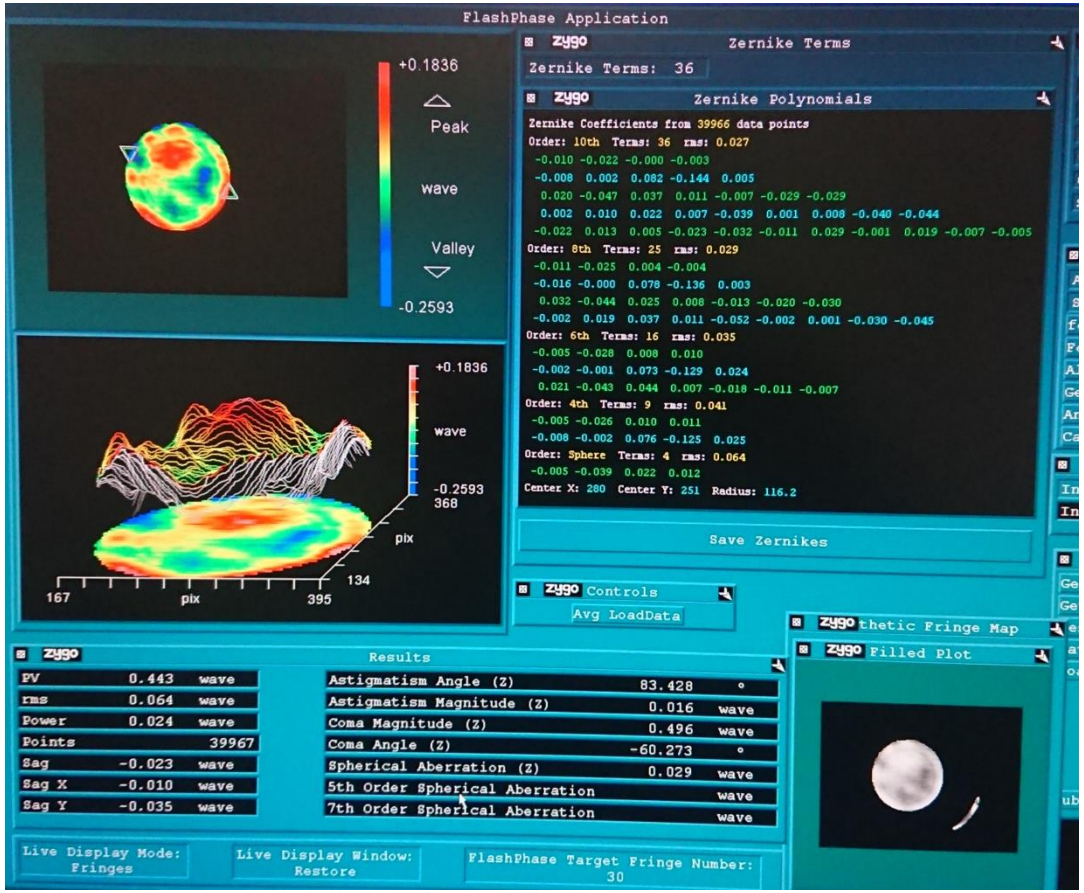


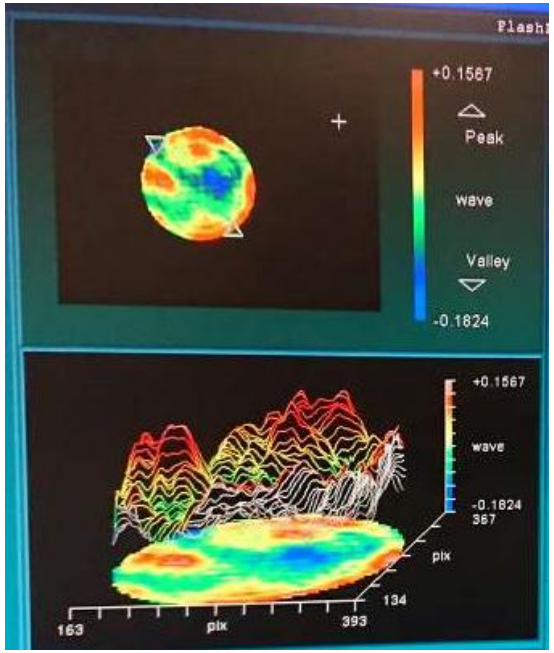


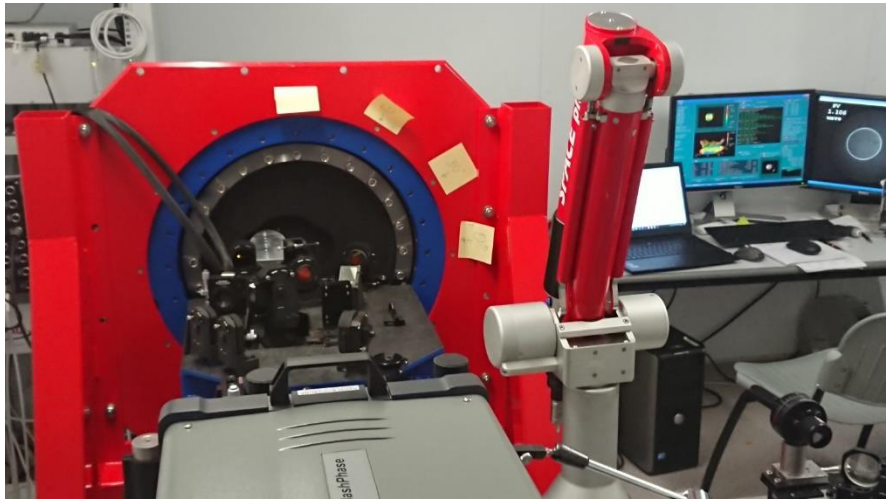




CURRENT SNAPSHOTs FROM THE CLEAN ROOM & LABs @OAPD







Main optical path aligned. Residual of the order of about 20 nm rms → 99% SR in J band

Verified also off-axis 7.5“ obtaining consistent values

MILESTONES

2016	Feb.	Conceptual Design Review end
2017	Jan.	Final Design Review
2017	Apr.	FDR delta review
2017	Jul.	Board approval
2017	Aug.	Start of procurement phase
2017	Nov.	Start of AIV phase with component tests
2017	Nov.	Delivery of the Electronics Rack from MPIA to INAF
2018	Oct.	Delivery of the coronagraphic masks from IPAG to INAF
2020	Jan.	Delivery of the NIR camera sub-assembly from SO to INAF
2020	May.	Delivery of dispersive element
2020	Jun.	End of SW MAIT
2020	Jun.	End of AIV phase
2020	Jul.	PAE review
2020	Sep.	Instrument arrival at LBT
2020	Sep.	Instrument pre-commissioning at LBT
2020	Nov.	Start of commissioning at LBT
202	Jul.	SHARK-NIR in operation

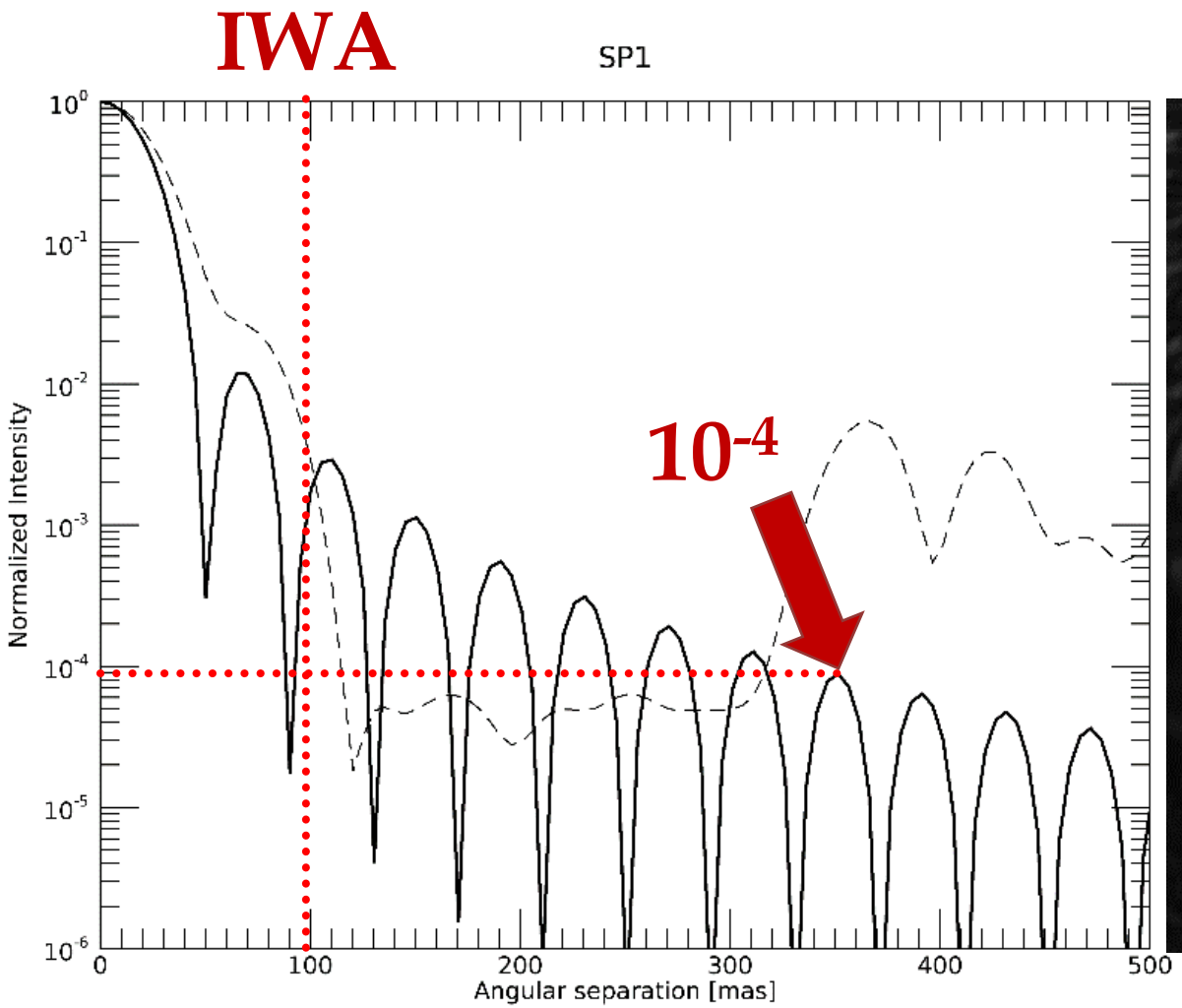
DON'T MISS the UPCOMING SHARK SCIENCE MEETING!!!

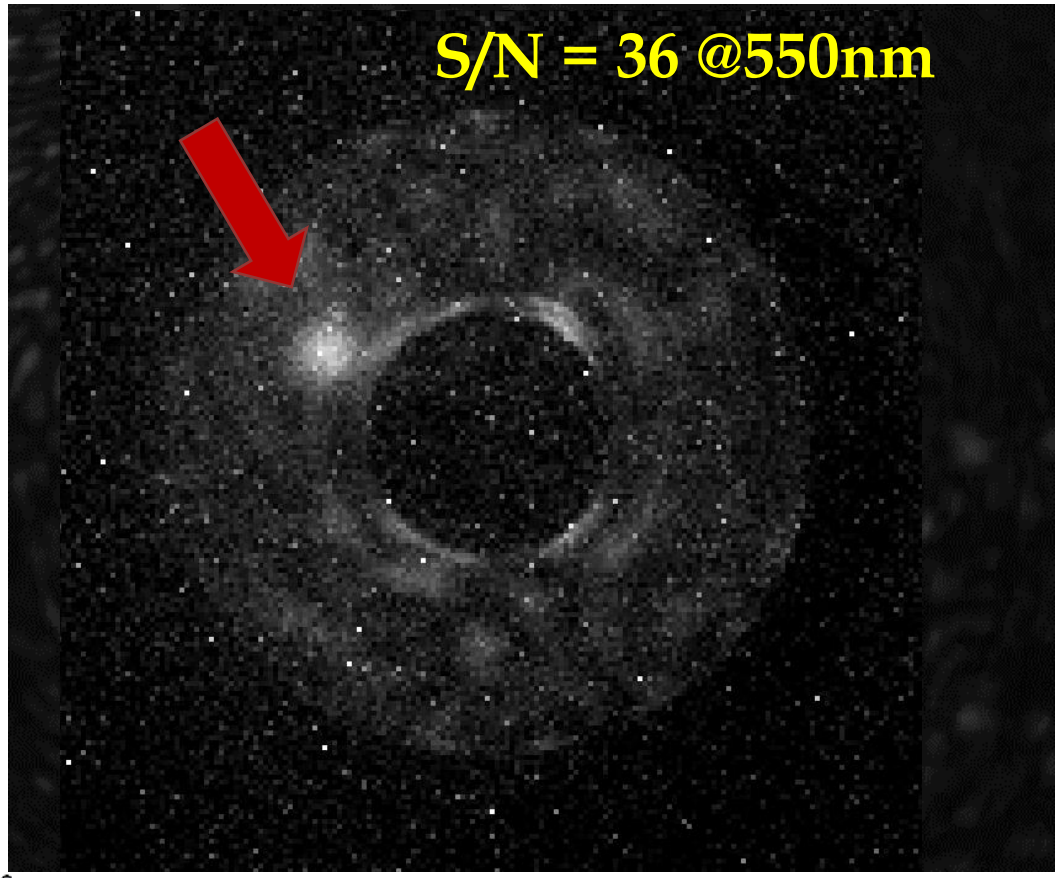
6-8 April 2020
INAF Headquarters, Monte Mario, Rome

The aim of this meeting is to bring the SHARK community together (including new members!) in order to discuss the observational strategy, the time sharing, and both corroborated and new science cases.

Thank you for your attention!

CORONAGRAPHS – SP IN THE LAB FAKE PLANET





Thank you for your attention!

Thank you for your attention!

SHINS – SHARK-NIR INstrument control Software Templates

```
<ObservationBlock
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://www.oapd.inaf.it/sharknir
    ObservationBlock.xsd"
    OBID="TestID"
    ProgramID="TestProgID"
    PIName="El Condor"
    PIID="TestPIID">
  <Template>
    <TPLID>SHARKNIR_obs_lss_telluric</TPLID>
    <TPLName>Telluric calibration</TPLName>
    <DetectorSetup>
      <DIT>2.34</DIT>
      <NDIT>1</NDIT>
    </DetectorSetup>
    <InstrumentSetup>
      <CoroImaFieldStabComb>LR_LSS_Dist</CoroImaFieldStabComb>
      <SCI_FILT_W1>BB_J</SCI_FILT_W1>
      <ADC_Mode>OFF</ADC_Mode>
      <DROT_Mode>OFF</DROT_Mode>
      <DROT_PosAng>34.56</DROT_PosAng>
    </InstrumentSetup>
  </Template>
</ObservationBlock>
```

- SHINS will use templates to run observations
- SHINS will receive XML files by LBTO *Queue*
  - List of template scripts to be executed
  - Values for the script parameter