HiRISE
Coupling SPHERE and CRIRES+ to characterise young giant exoplanets

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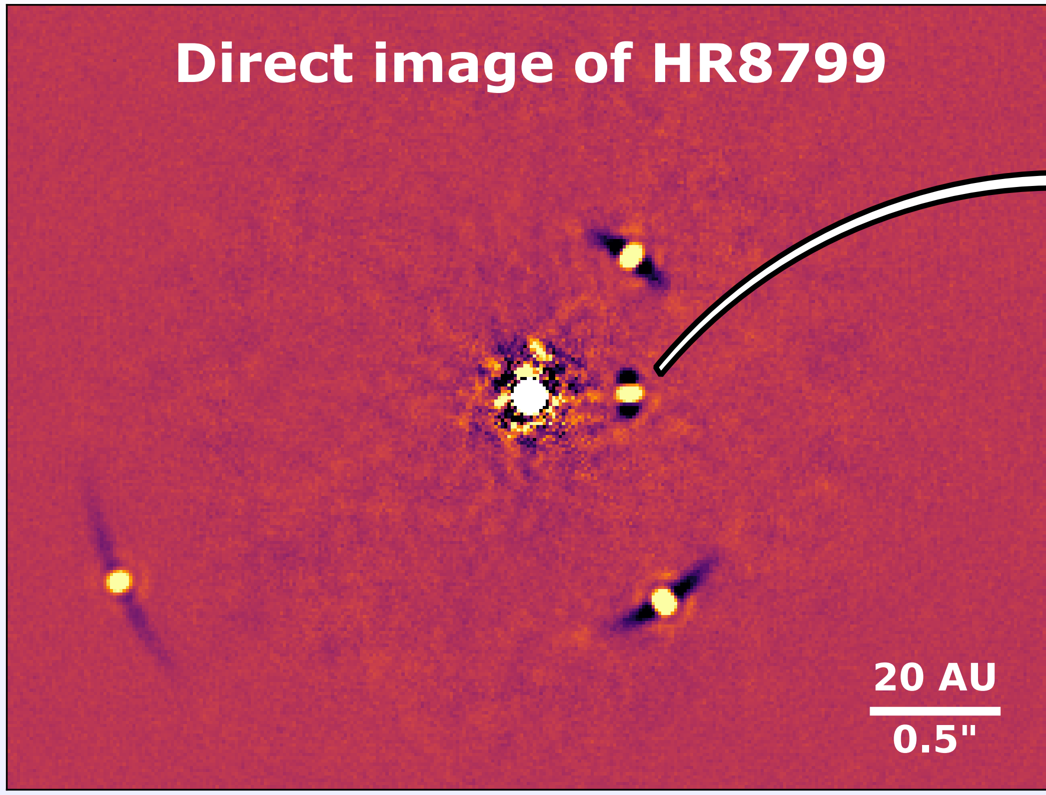
Atmospheric composition of exoplanets



Zurlo, **Vigan** et al. (2016)

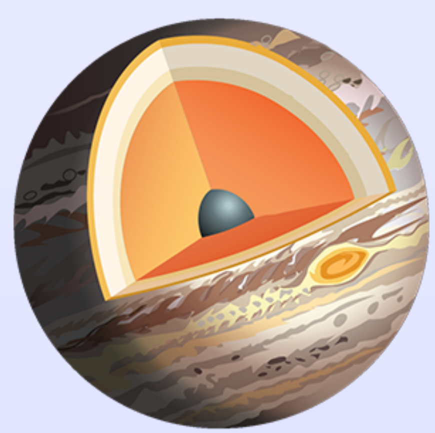
Giant exoplanets shape planetary systems

Giant:	> 1 M_{Jup}
Distant:	> 5 AU
Cold:	< 1500K

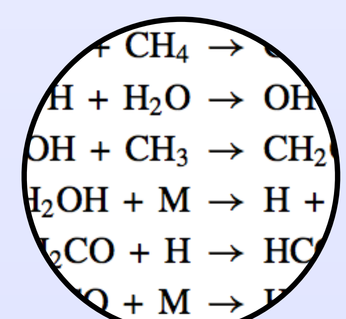
Outstanding questions to be answered with direct imaging

Formation & migration

Internal structure

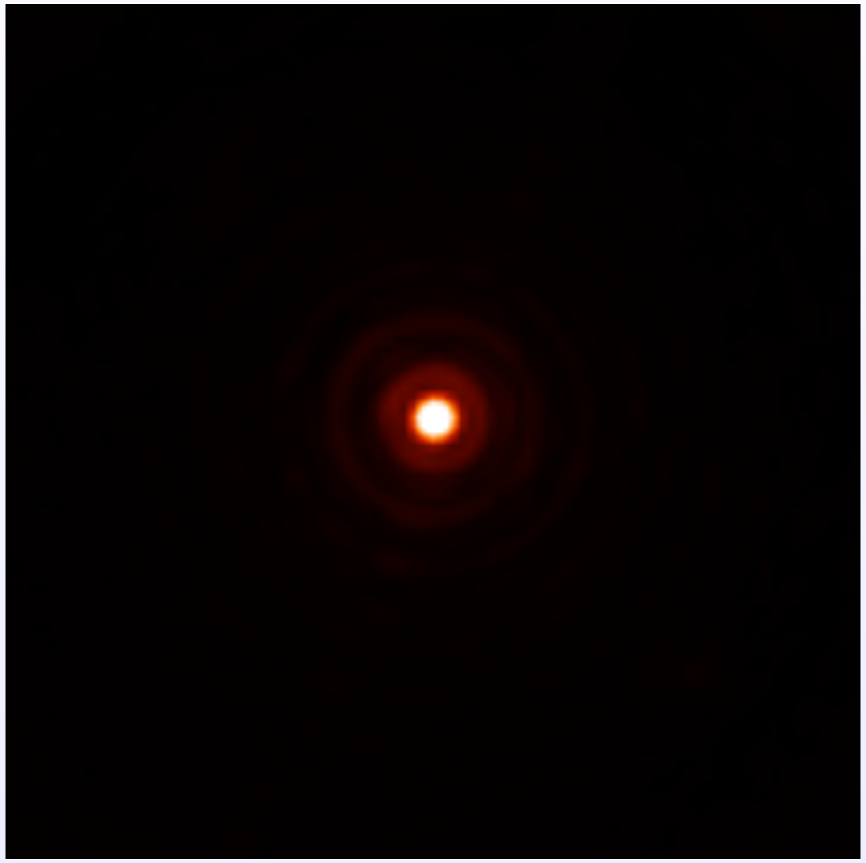


Atmosphere chemistry & dynamics

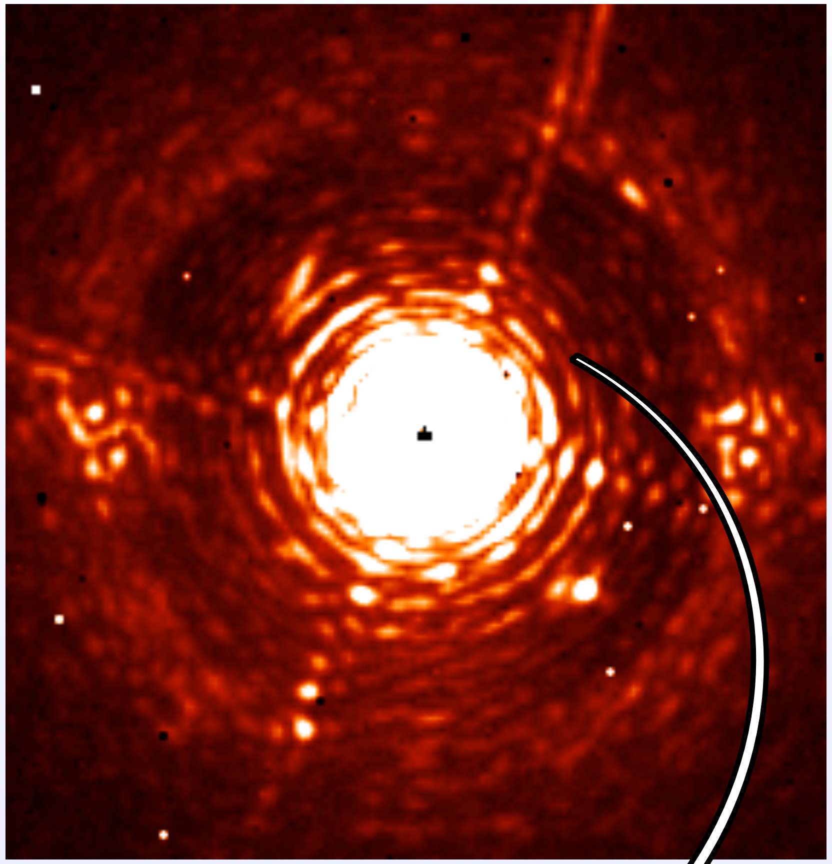


Extreme AO + coronagraphy in NIR

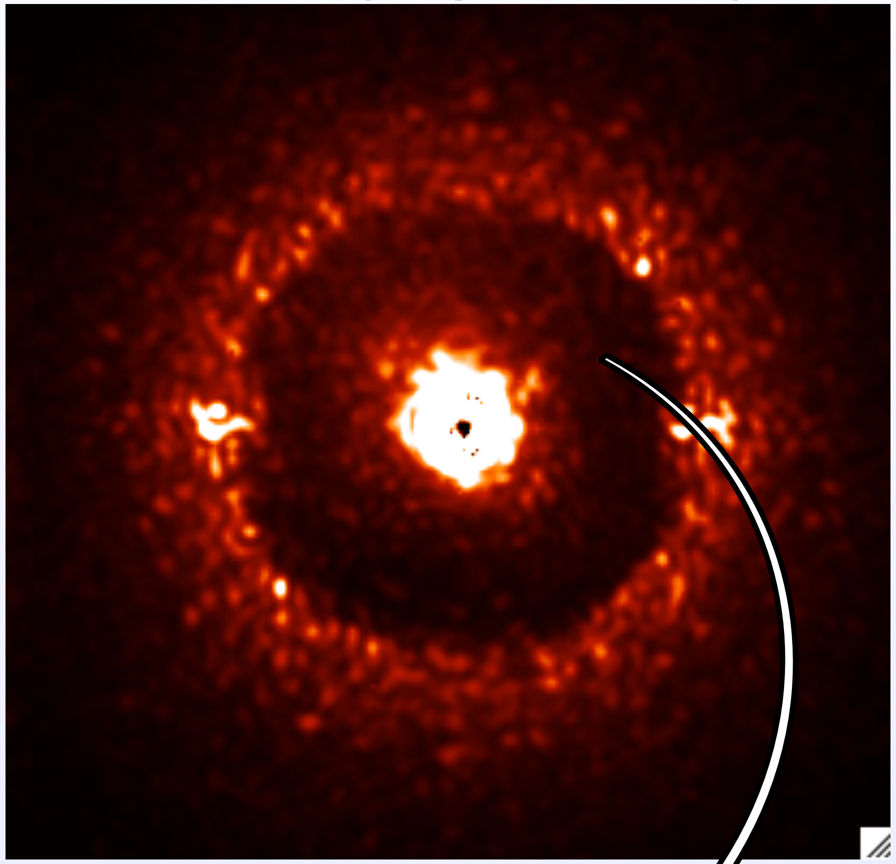
PSF



Saturated PSF



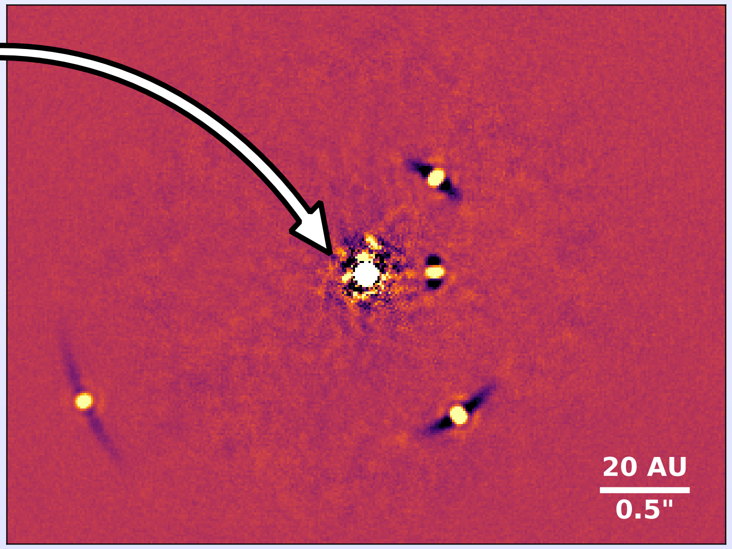
Coronagraphic image



Diffraction limited within 20 λ/D

10^{-4}-10^{-5} contrast in dark zone

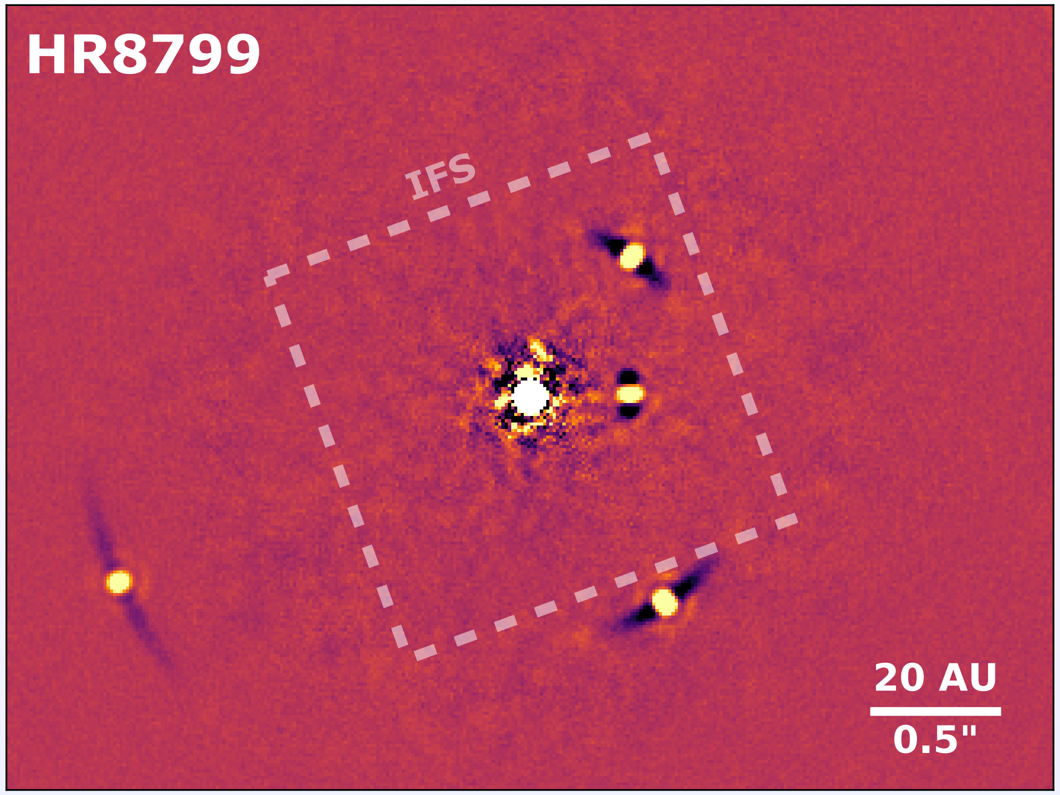
post-processing

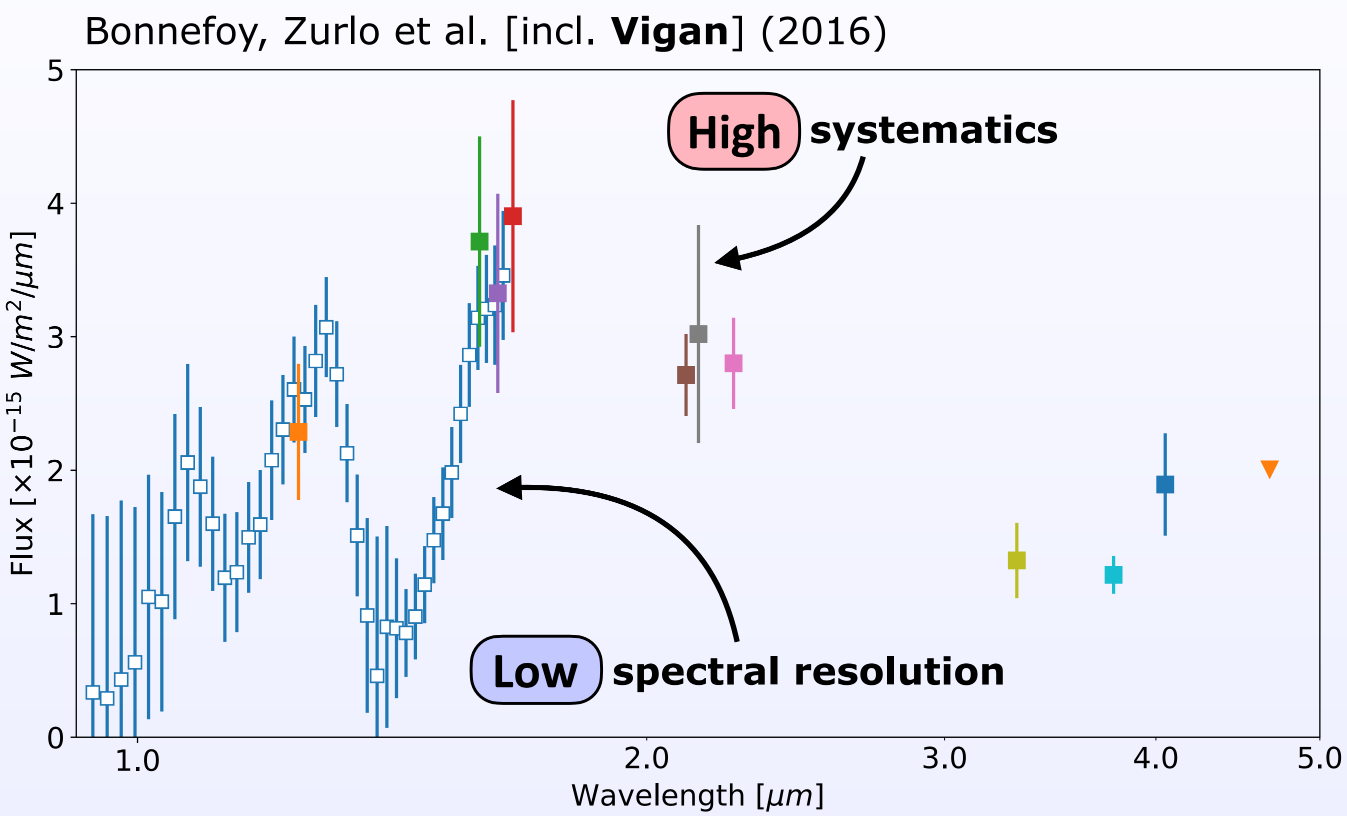


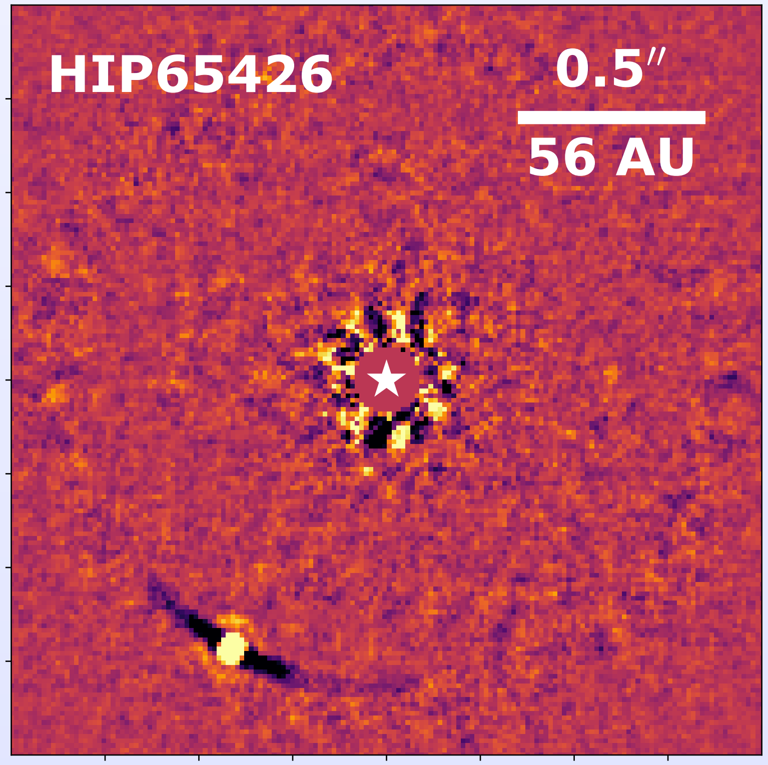
~10^{-5}-10^{-6} contrast down to 0.2"

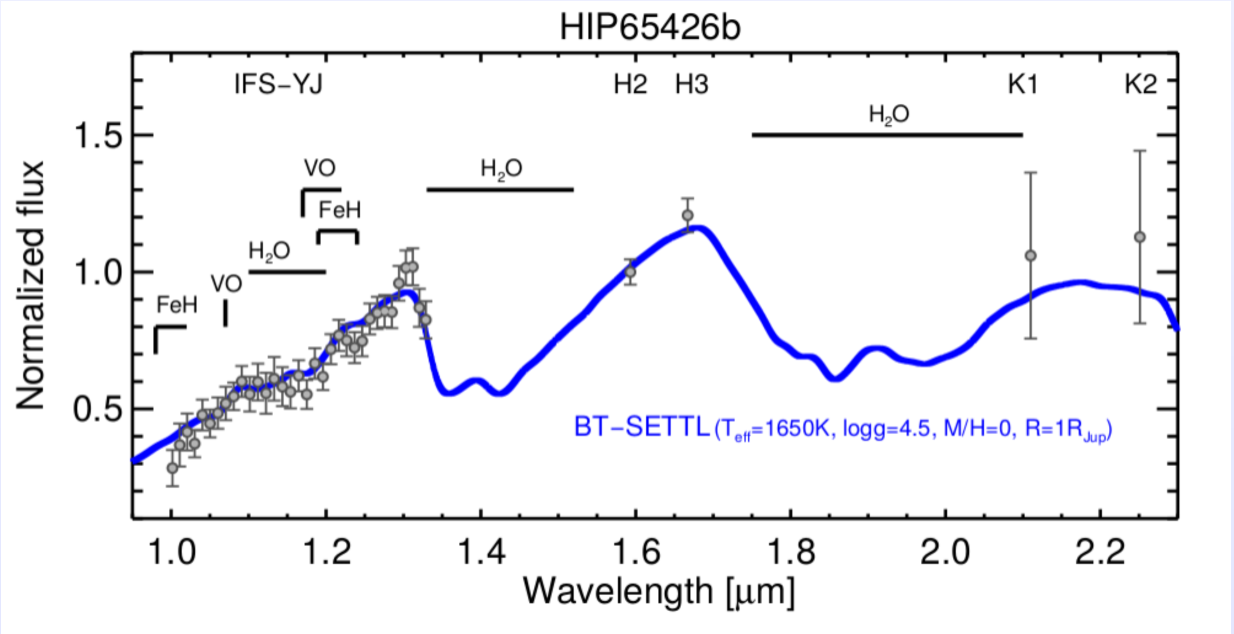
Enough to detect young giant exoplanets of a few Jupiter masses

Exoplanet characterisation with SPHERE



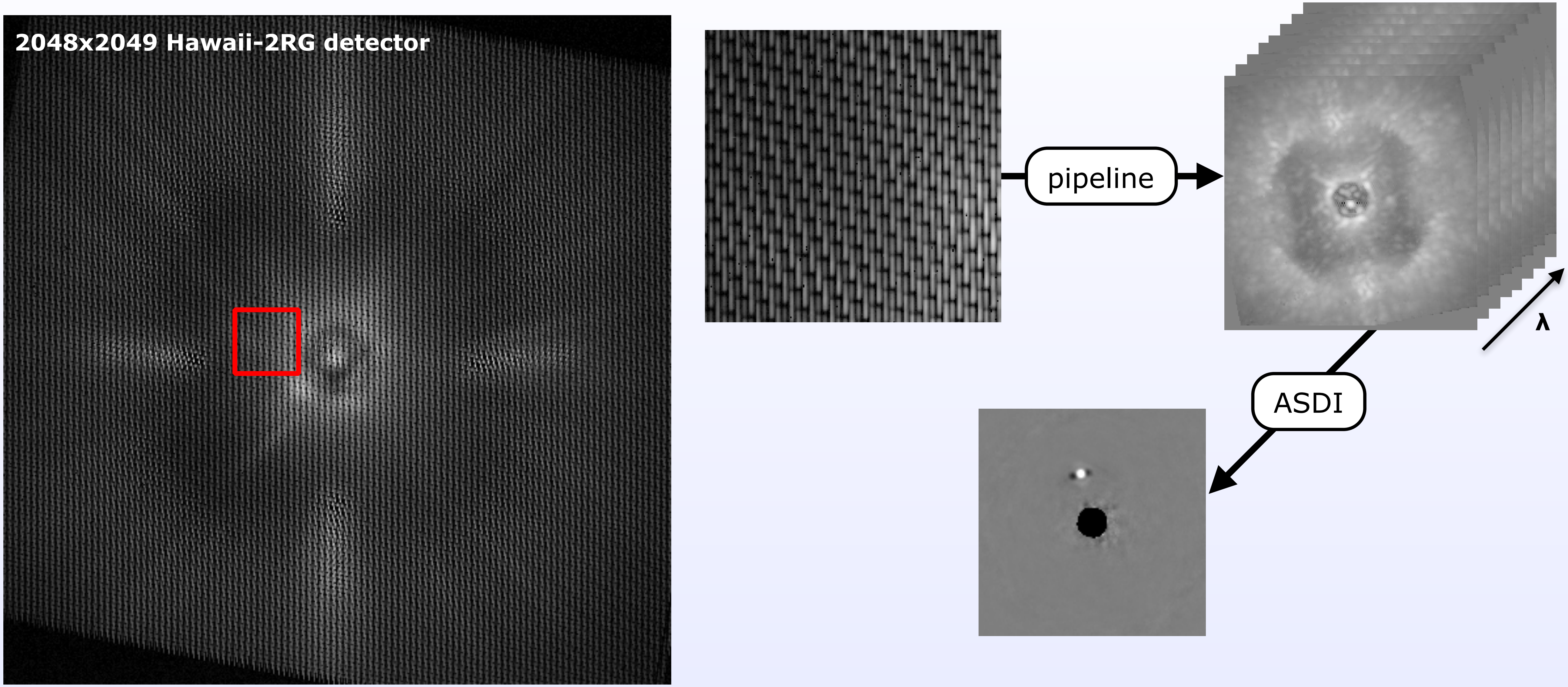






Resolution limited to R=50 for the IFS

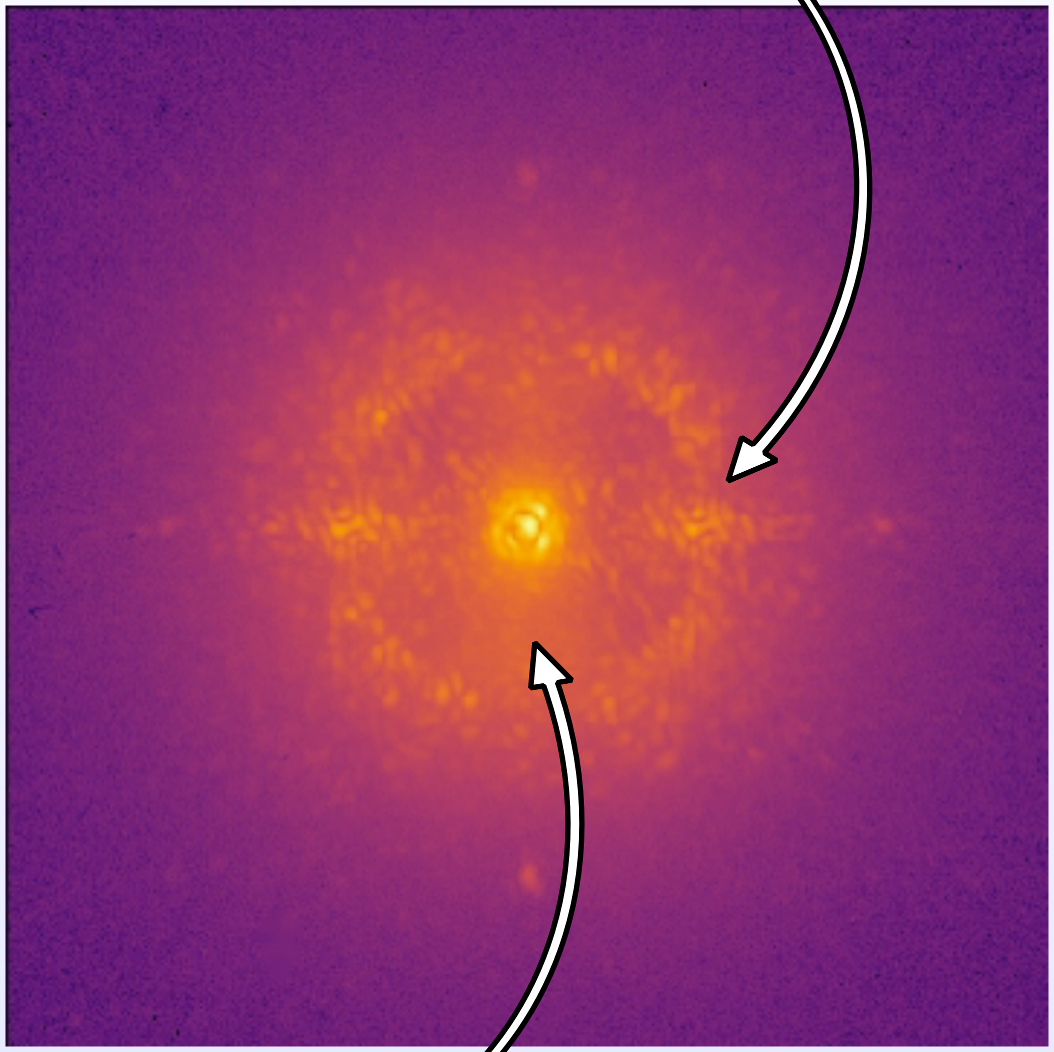
Low resolution by design

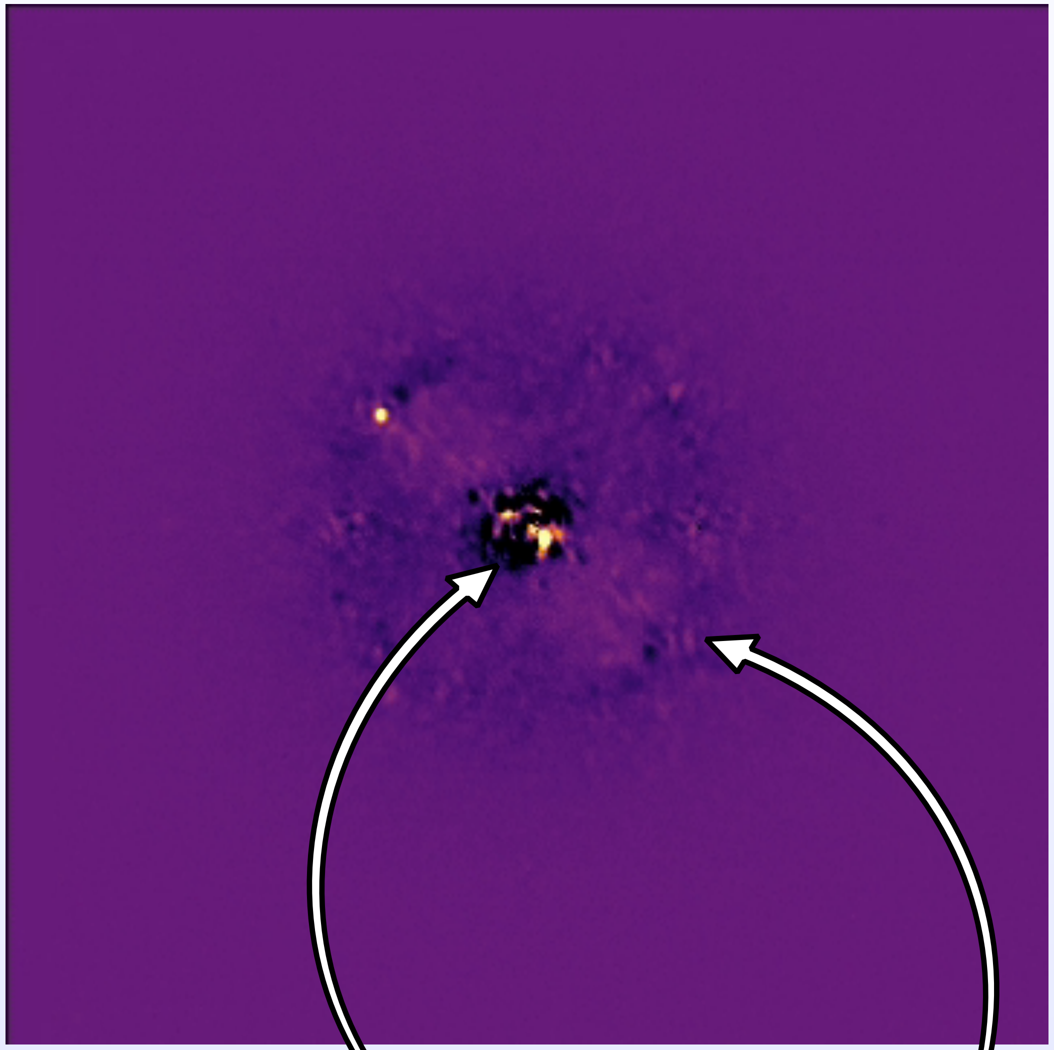


- IFS designed to **search for planets**: need for spatial & spectral information
  - Nyquist spatial sampling: 2 pixels/PSF at 0.95 µm
  - Number of pixels limited on a 2k*2k IR detector
- **Consequence:** maximum spectral resolution ~50 for YJ coverage (~30 for YJH)

Speckle noise limitation

long-lived, quasi-static speckles
cause by instrumental aberrations





AO residuals

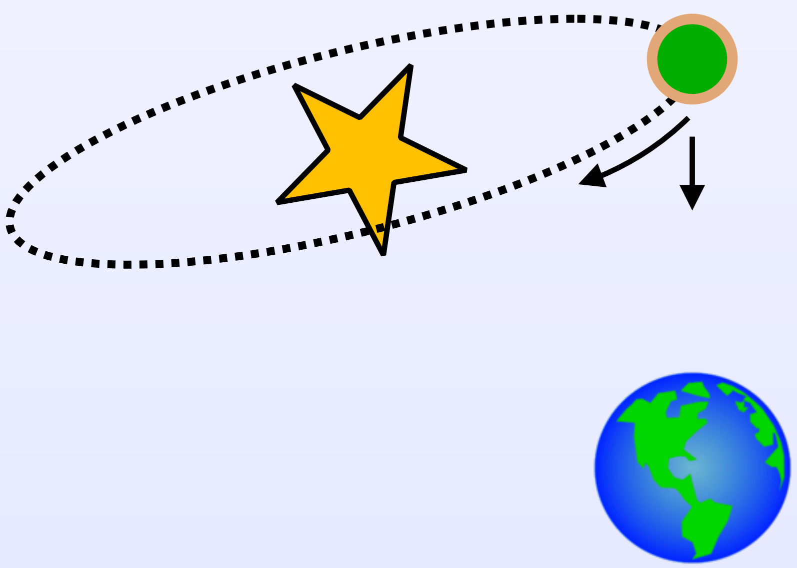
small variations because of
varying observing conditions,
thermal drift, etc

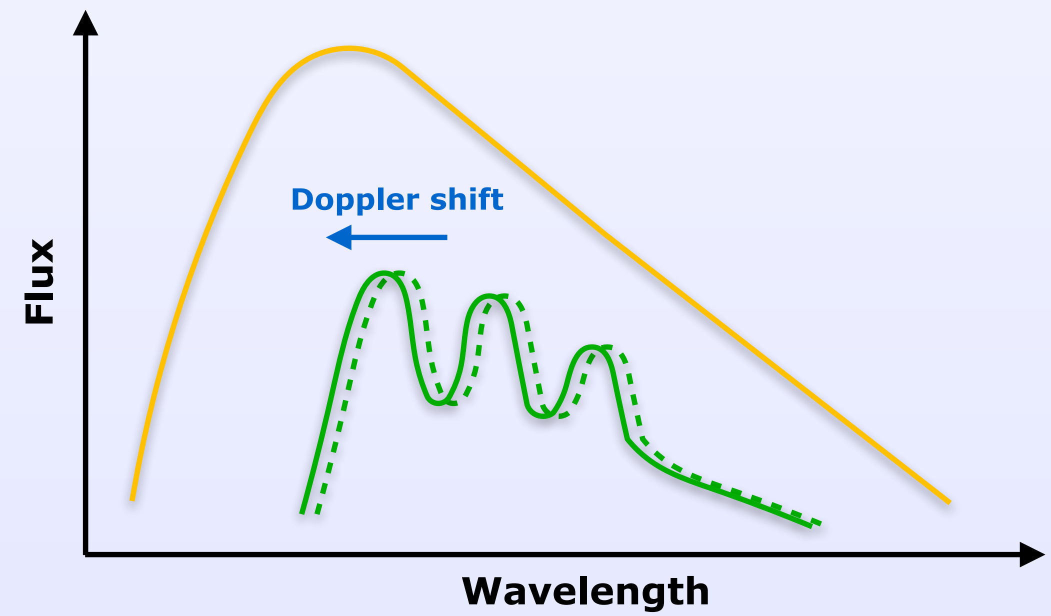
How to measure the signal of the planet lost in speckle noise?

Exoplanet direct detection techniques

Based on diversity intrinsic to or introduced in the data

- Angular diversity ➝ angular differential imaging (ADI, cADI, LOCI, KLIP, ANDROMEDA, ...)
- Spectral diversity ➝ spectral differential imaging (SDI, SD, SSDI)
- Polarimetric diversity ➝ polarimetric differential imaging (PDI, DPI)
- Velocity diversity ➝ high-resolution spectroscopy techniques



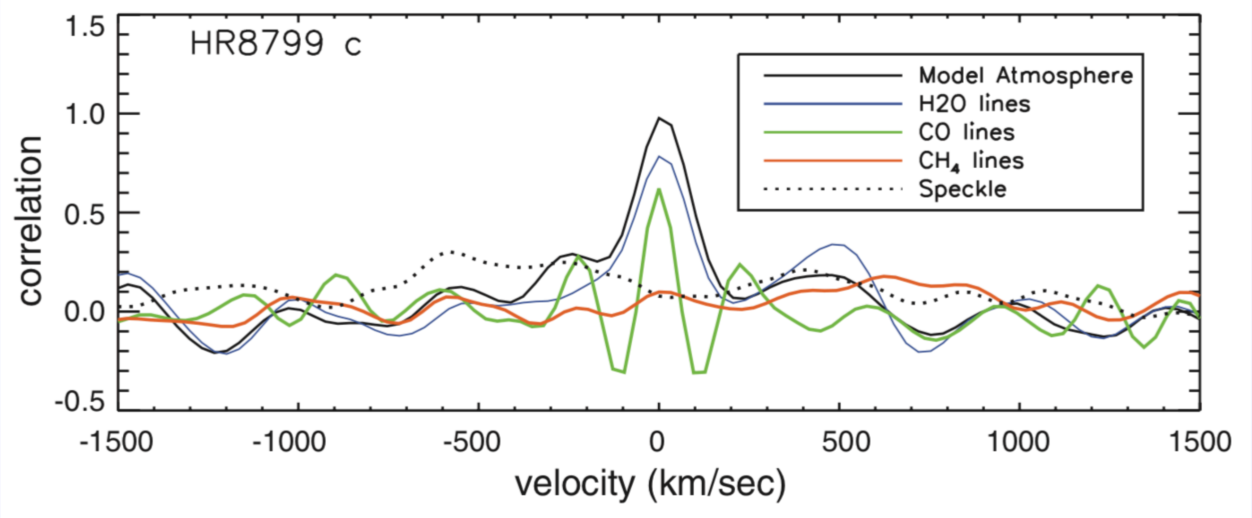


➝ Resolution of at least a few 10^3 or 10^4 needed
to resolve individual lines in the planet spectrum and detect its RV

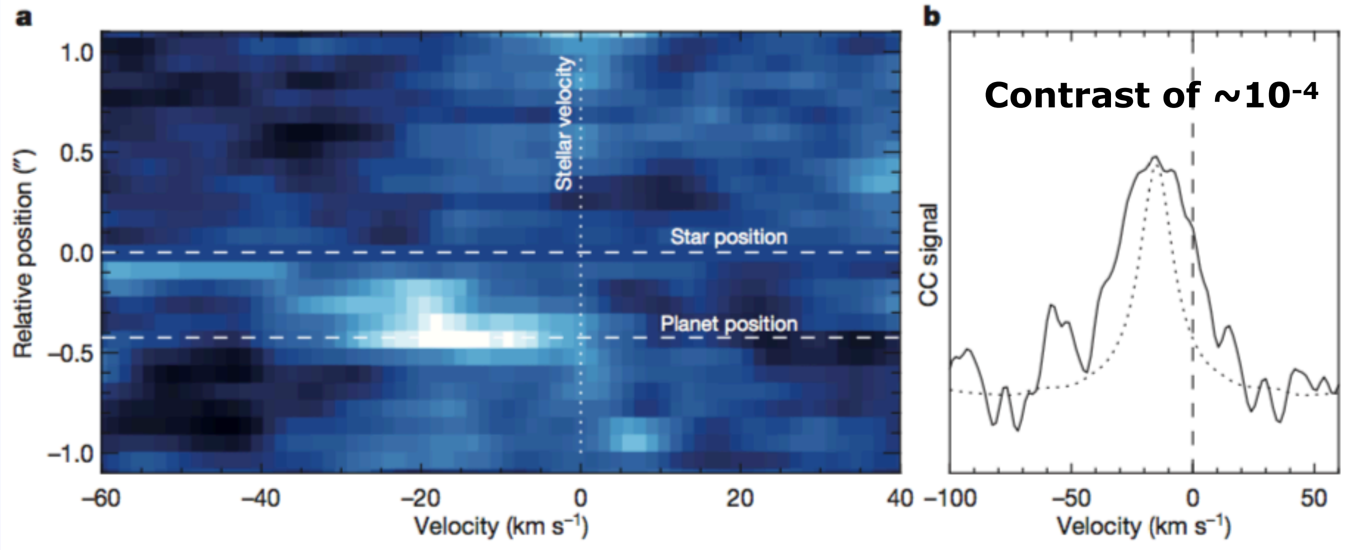
HCI and HRS for young exoplanets

- Nicely demonstrated on HR8799c and ß Pic b:

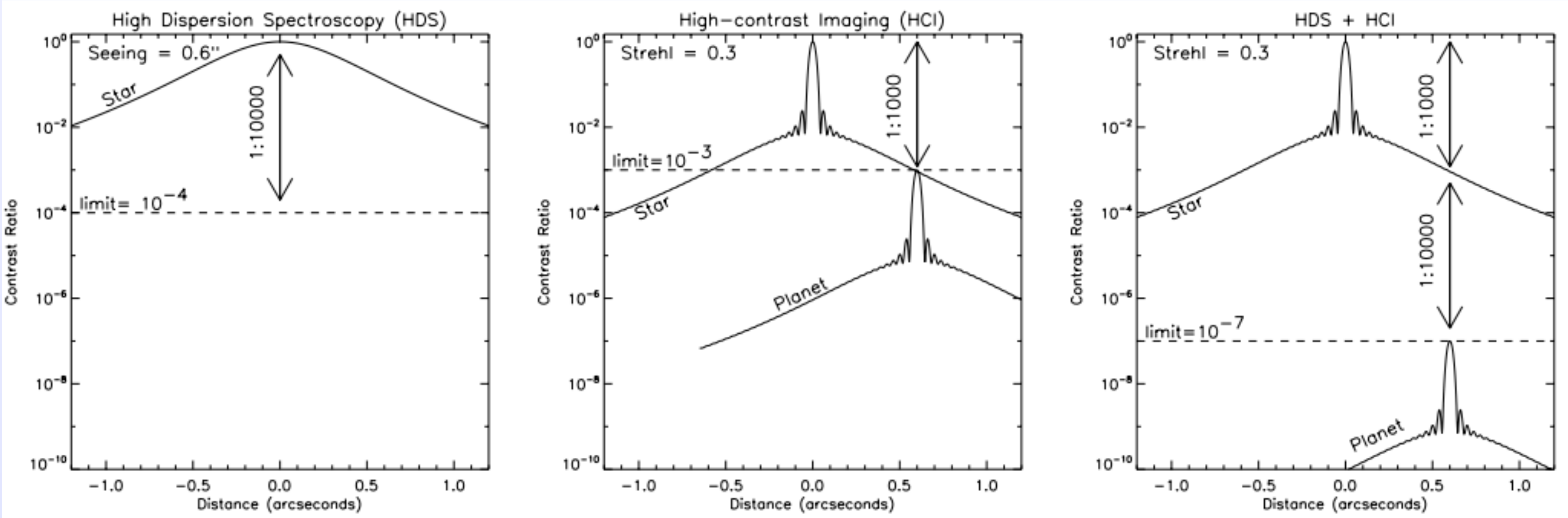
Konopacky et al. (2013)



Snellen et al. (2014)



- HCI + HRS: ideal combination to reach contrasts better than 10^{-6}



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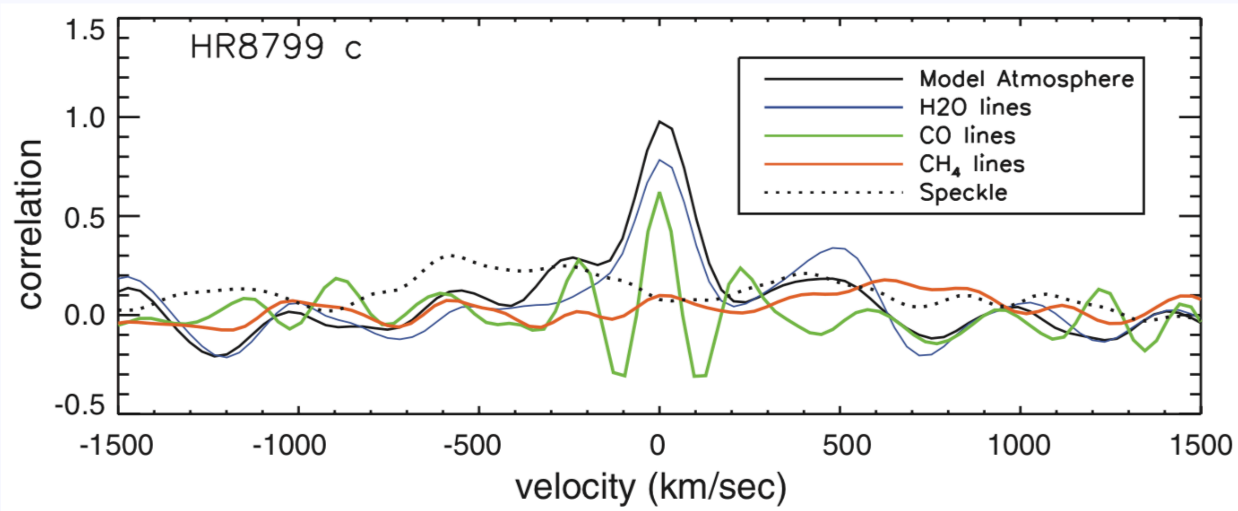

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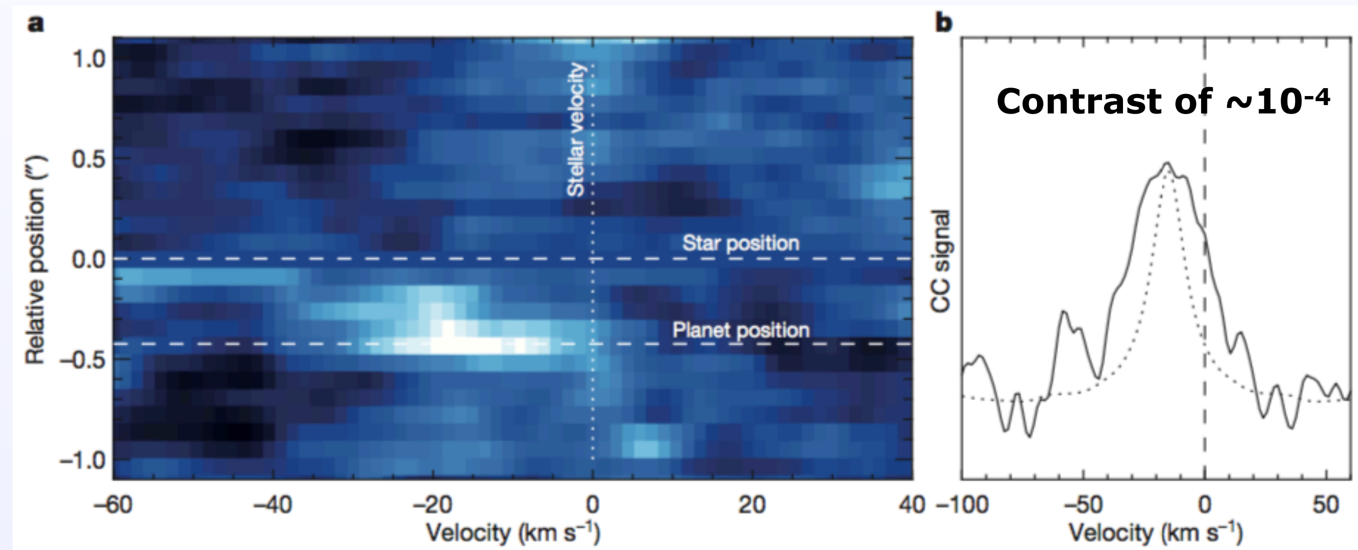

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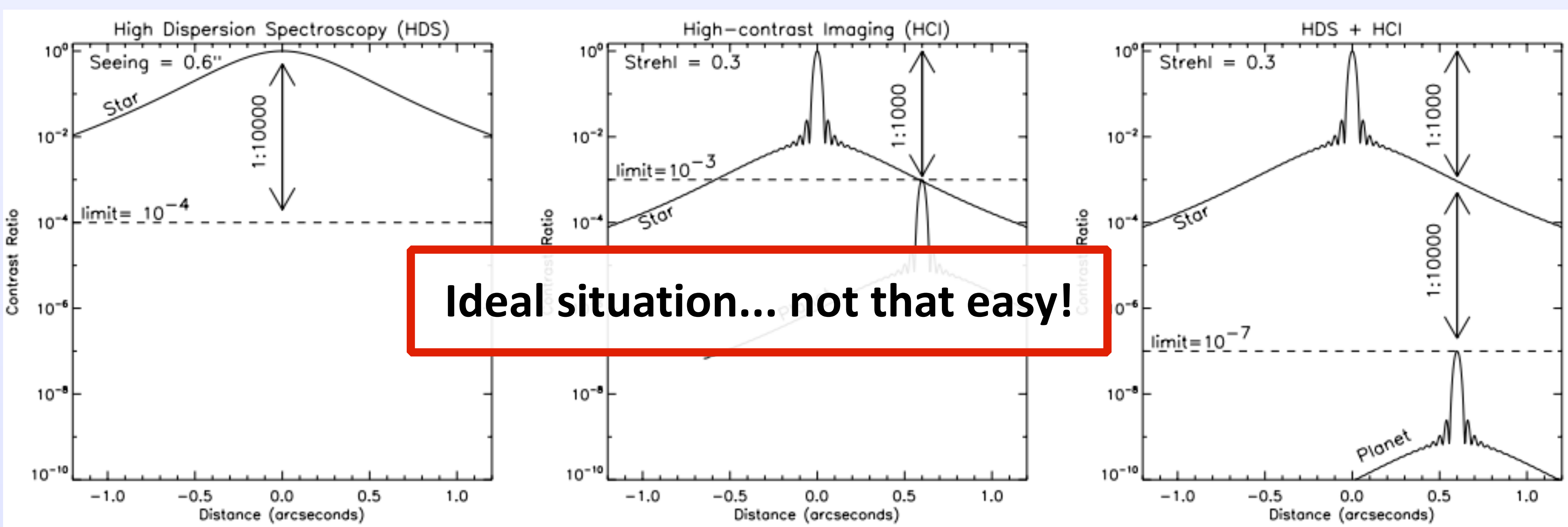
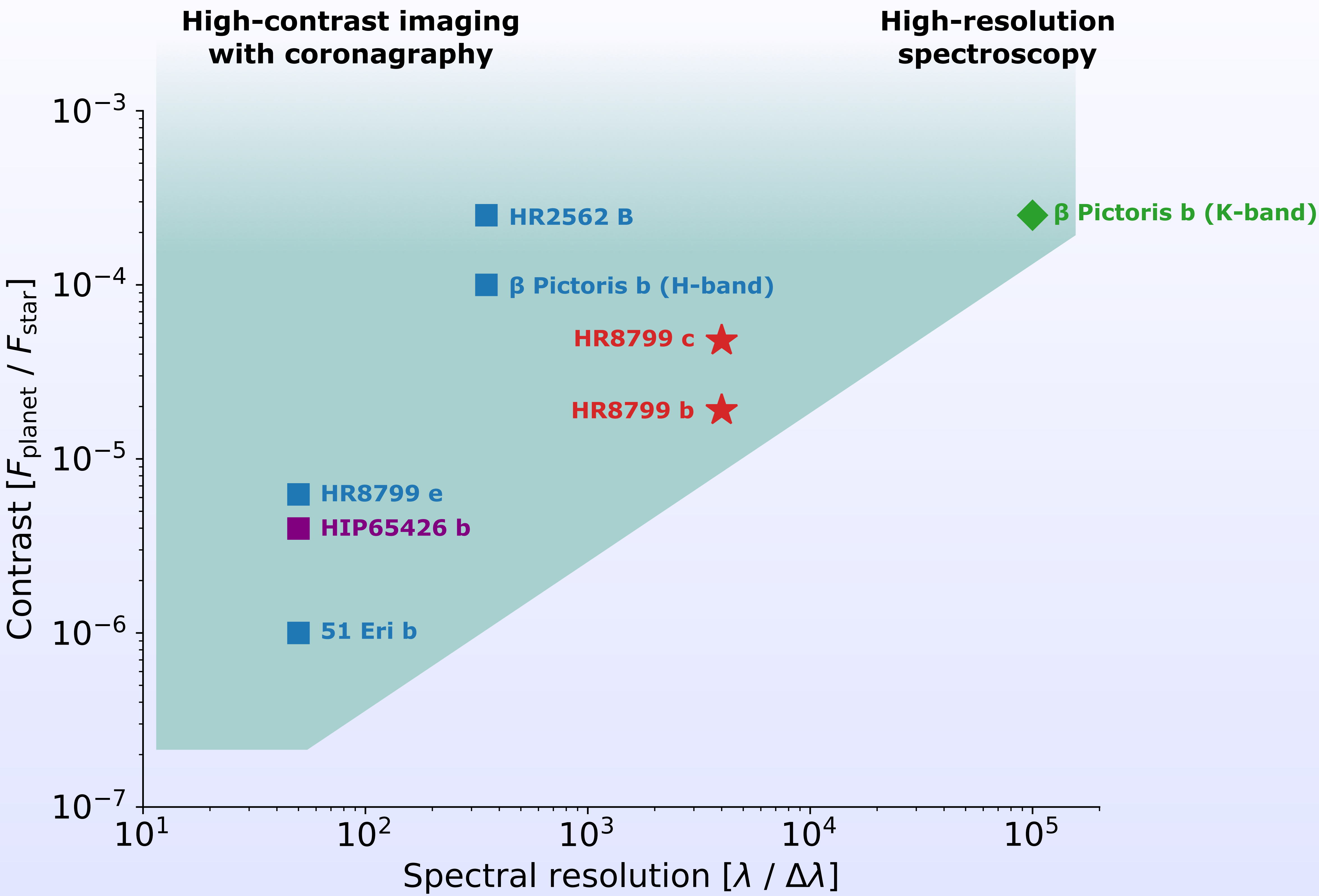


Ideal situation... not that easy!

Snellen et al. (2015)

Young exoplanets characterisation



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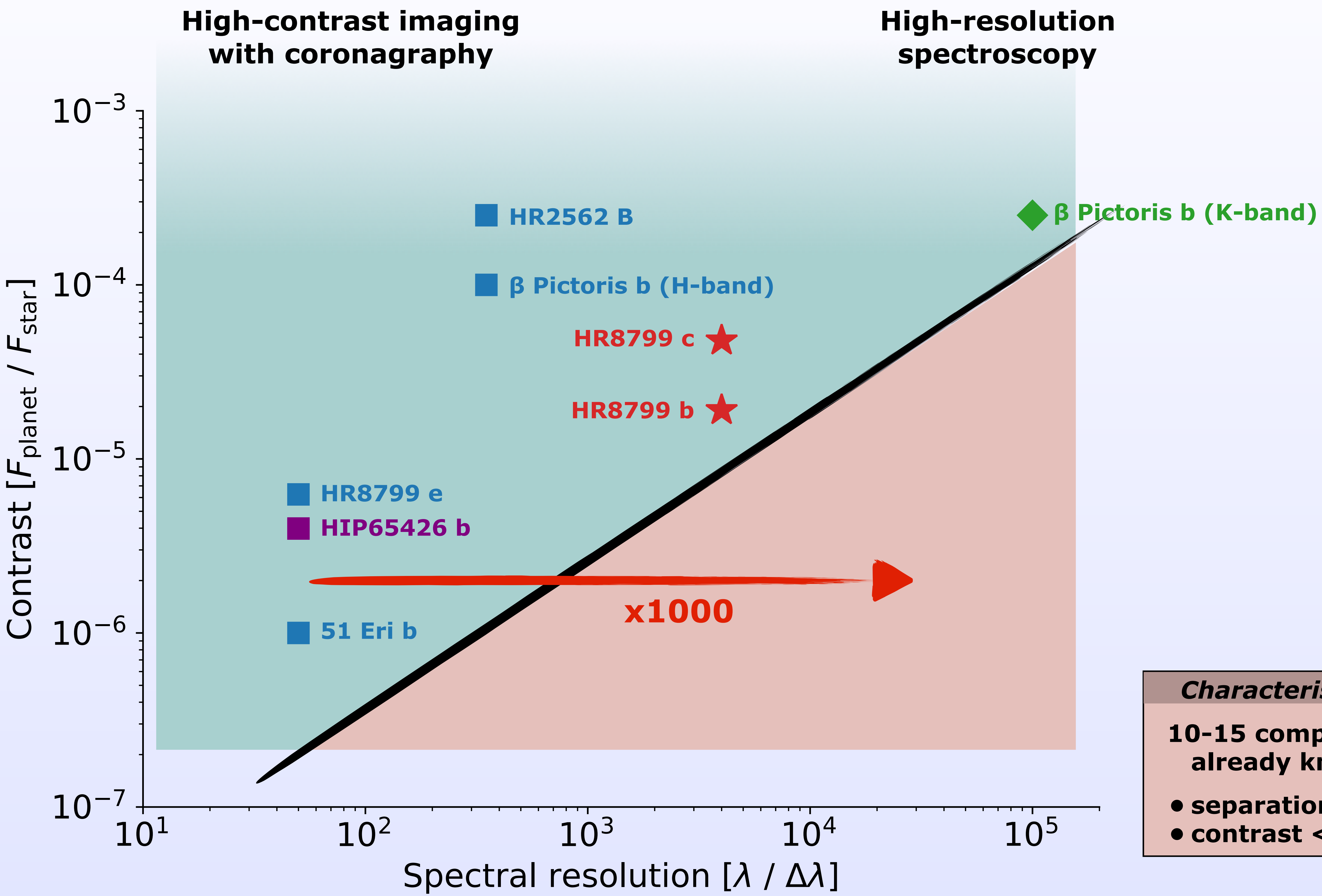


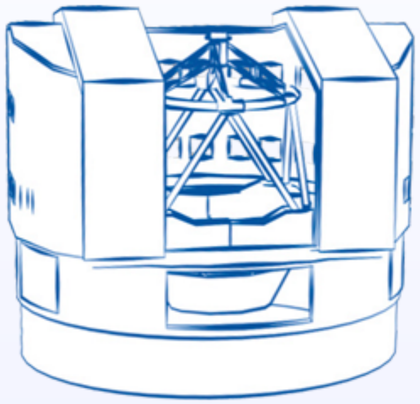
Characterisation

10-15 companions already known

- separation < 1"
- contrast < 10^{-4}

A unique window of opportunity

VLT/UT3



High-contrast exoplanet imager — SPHERE

High-resolution spectrograph — CRIRES+

SPHERE		CRIRES+
✔	**Extreme adaptive optics**	✘
✔	**Coronagraphy**	✘
Y J H K	**Spectral coverage**	Y J H K L M
50 - 350	**Spectral resolution**	50 000 - 100 000

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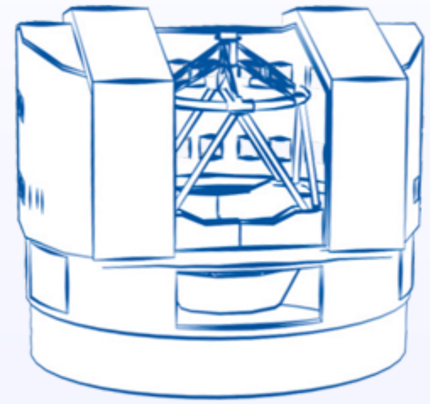

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HiRISE

Fiber coupling

Supported by ESO

erc

Supported by CRIRES+

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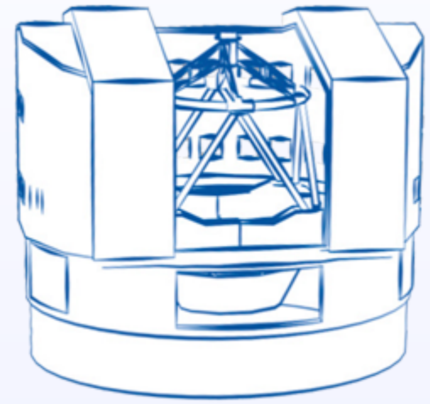

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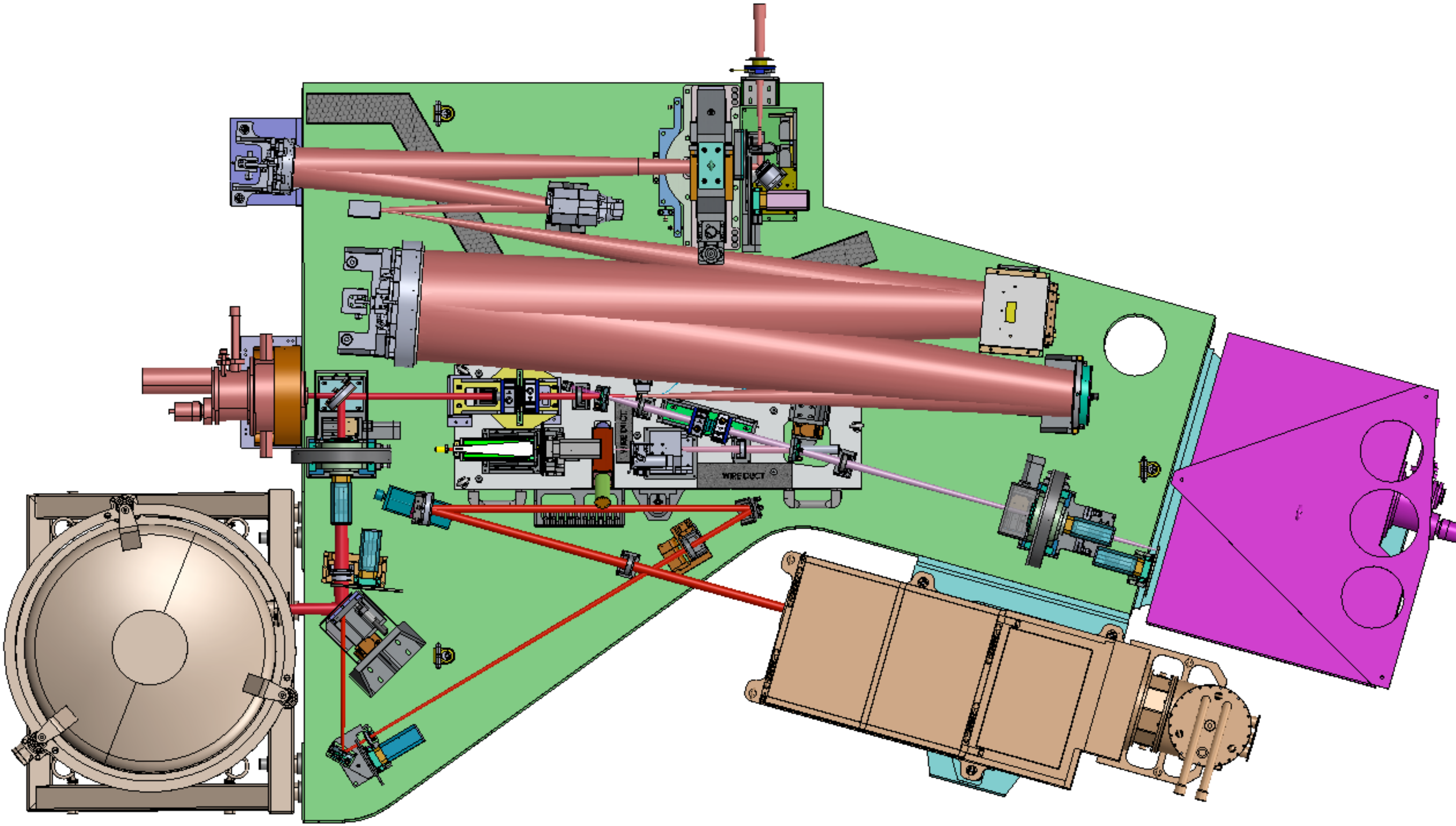
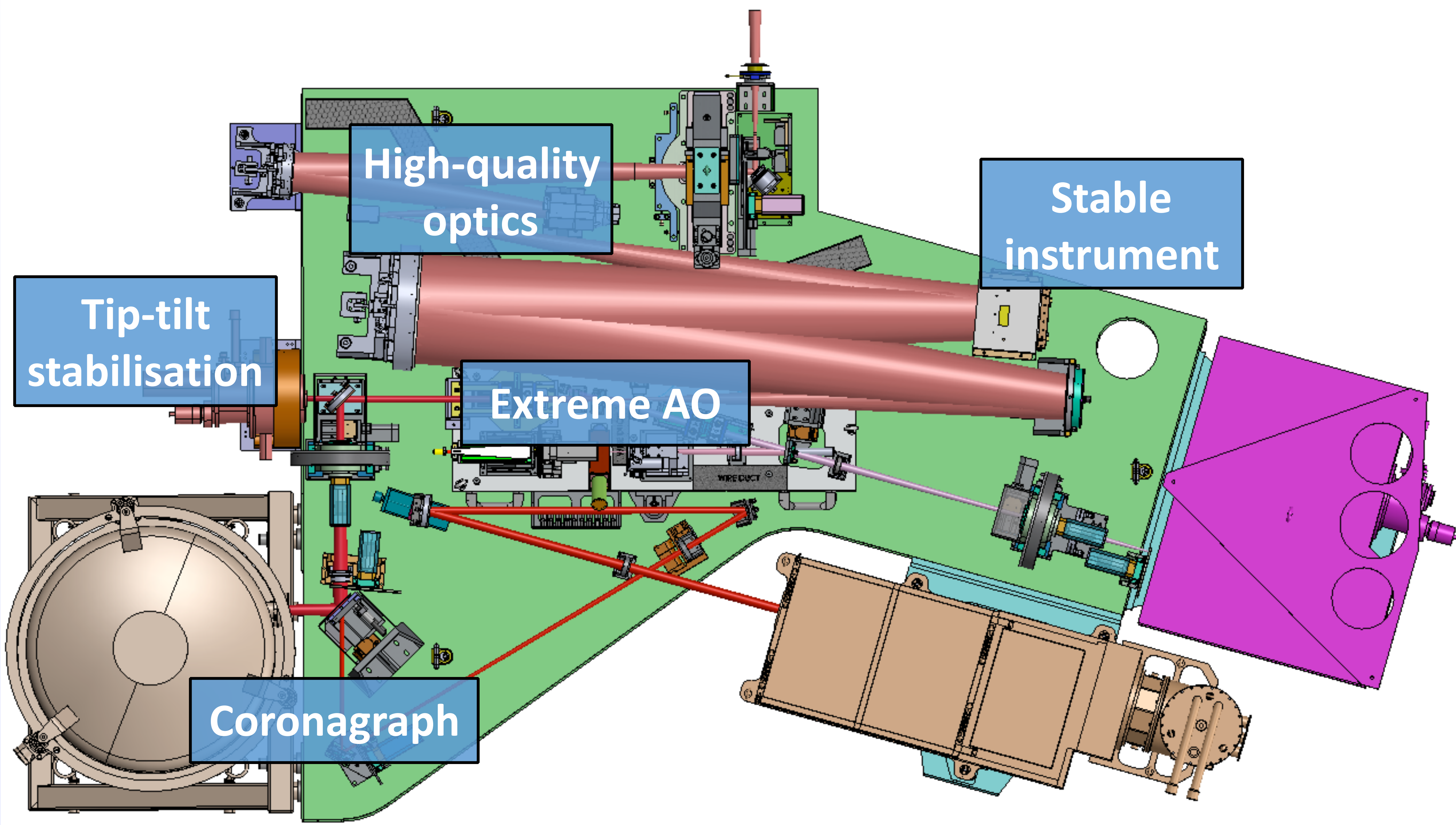
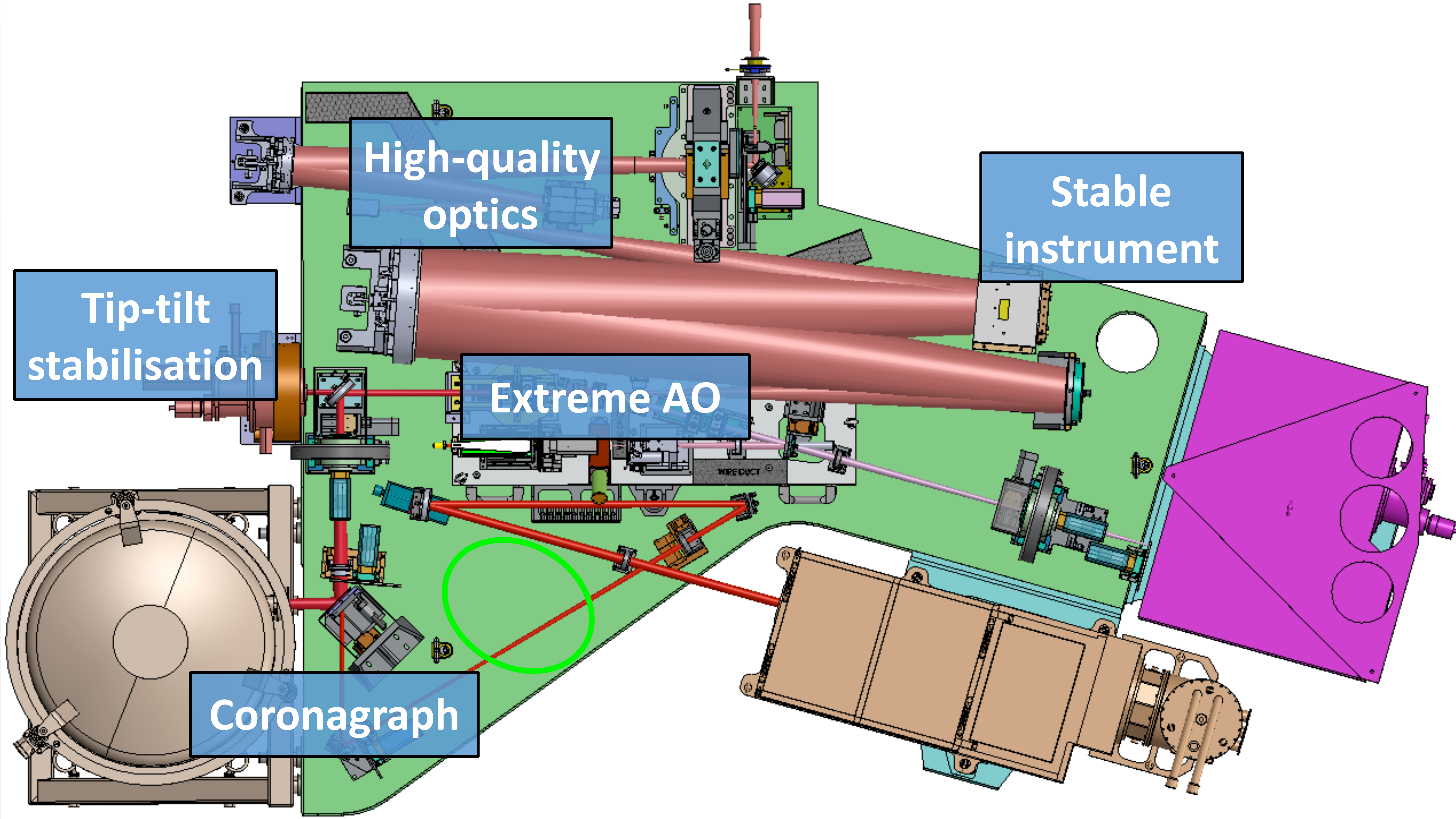
HiRISE fiber injection in SPHERE



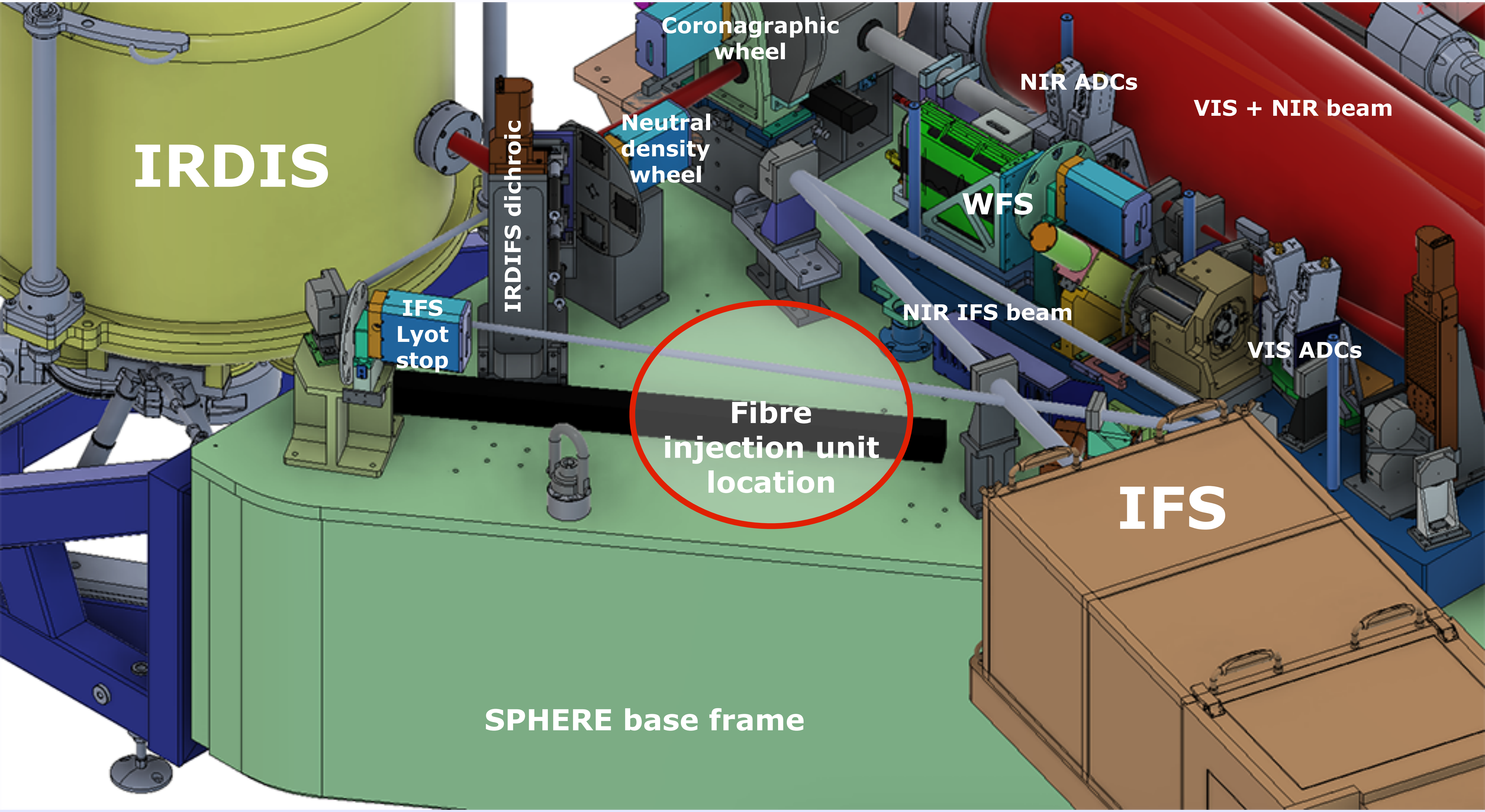
HiRISE fiber injection in SPHERE



HiRISE fiber injection in SPHERE



Mechanical implementation in CPI



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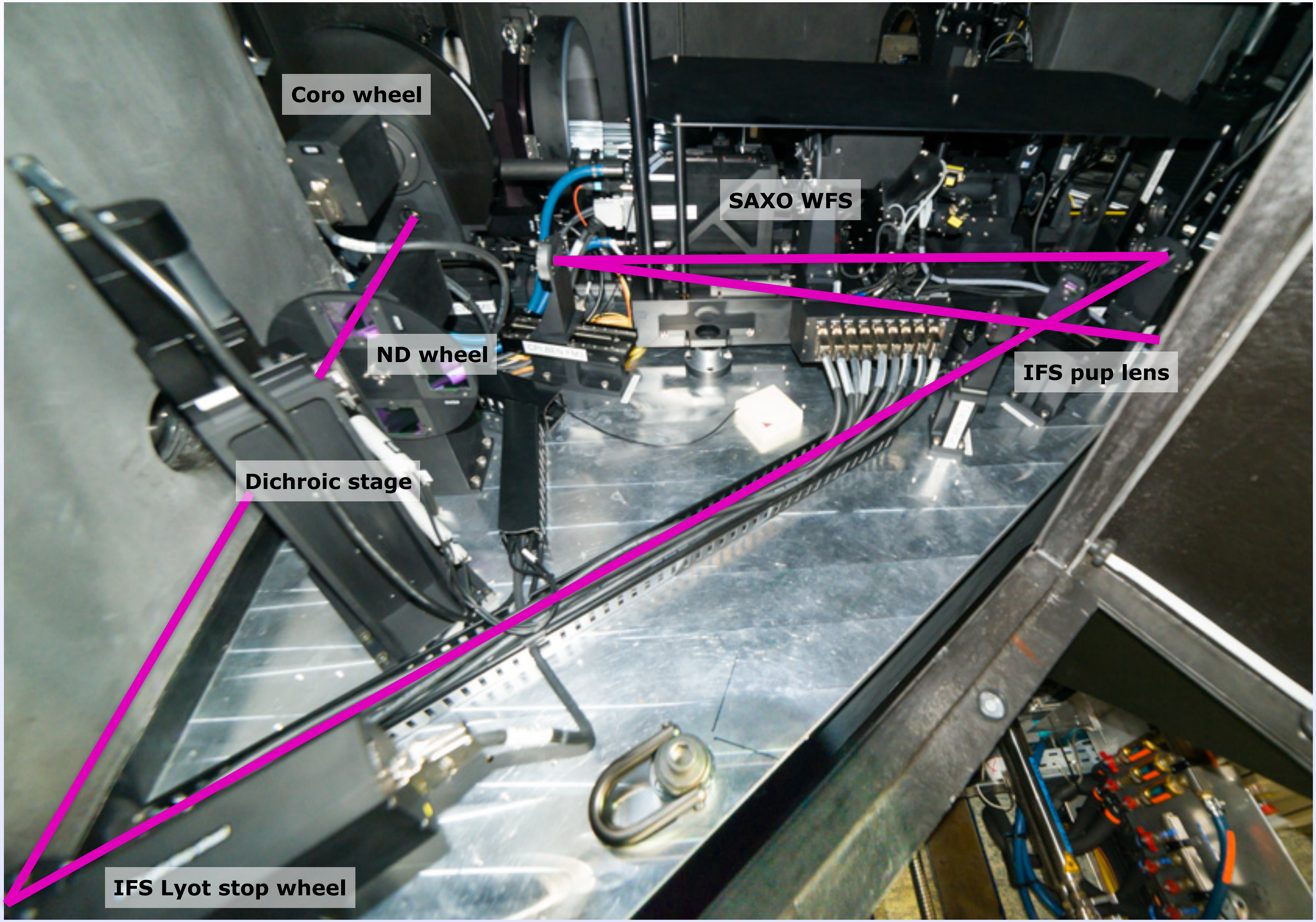
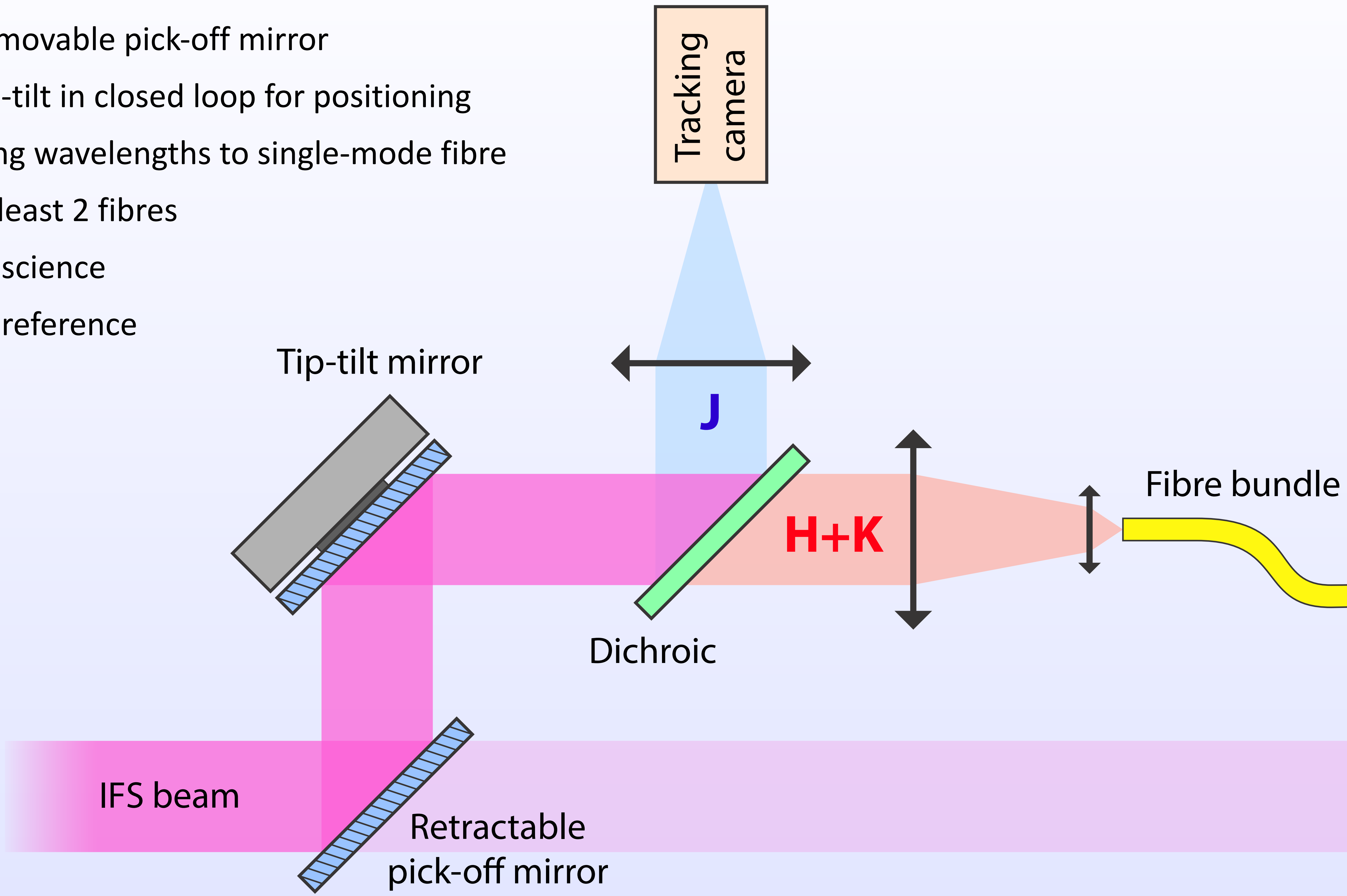


Concept

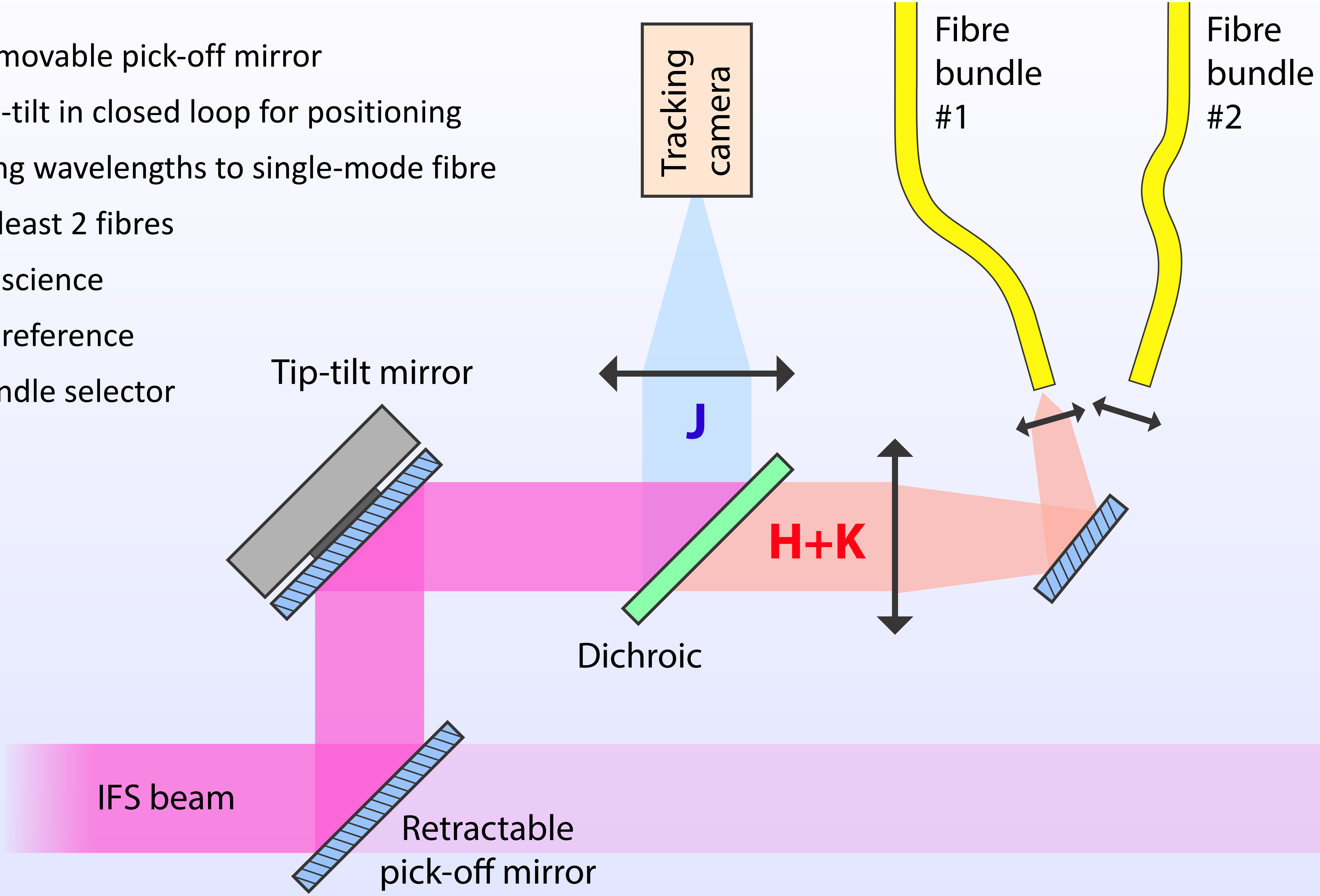
- Removable pick-off mirror
- Tip-tilt in closed loop for positioning
- Long wavelengths to single-mode fibre
- At least 2 fibres
  - science
  - reference



Inspired by Mawet et al. (2017)

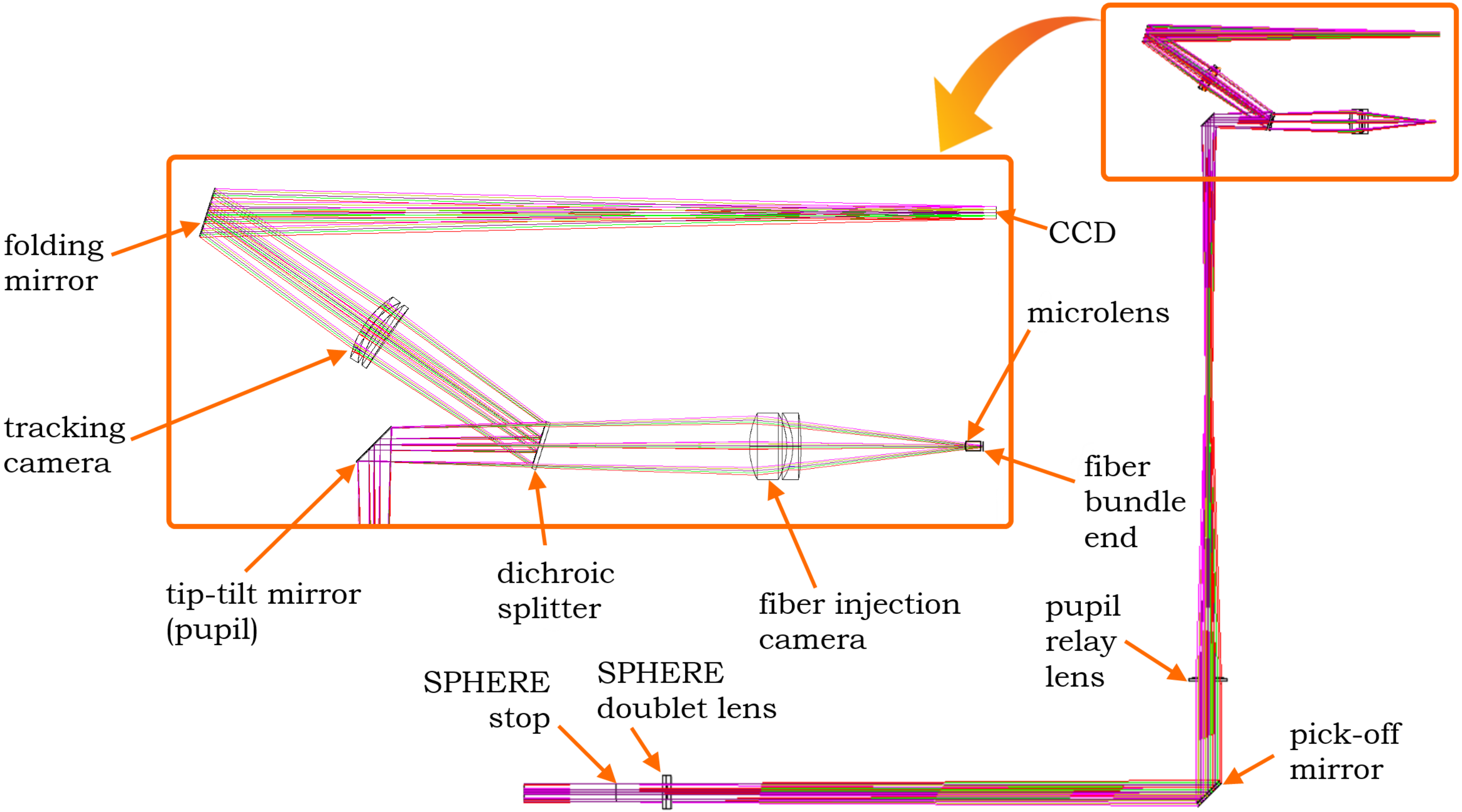
Alternative concept

- Removable pick-off mirror
- Tip-tilt in closed loop for positioning
- Long wavelengths to single-mode fibre
- At least 2 fibres
  - science
  - reference
- Bundle selector



Inspired by Mawet et al. (2017)

Optical design: tracking camera



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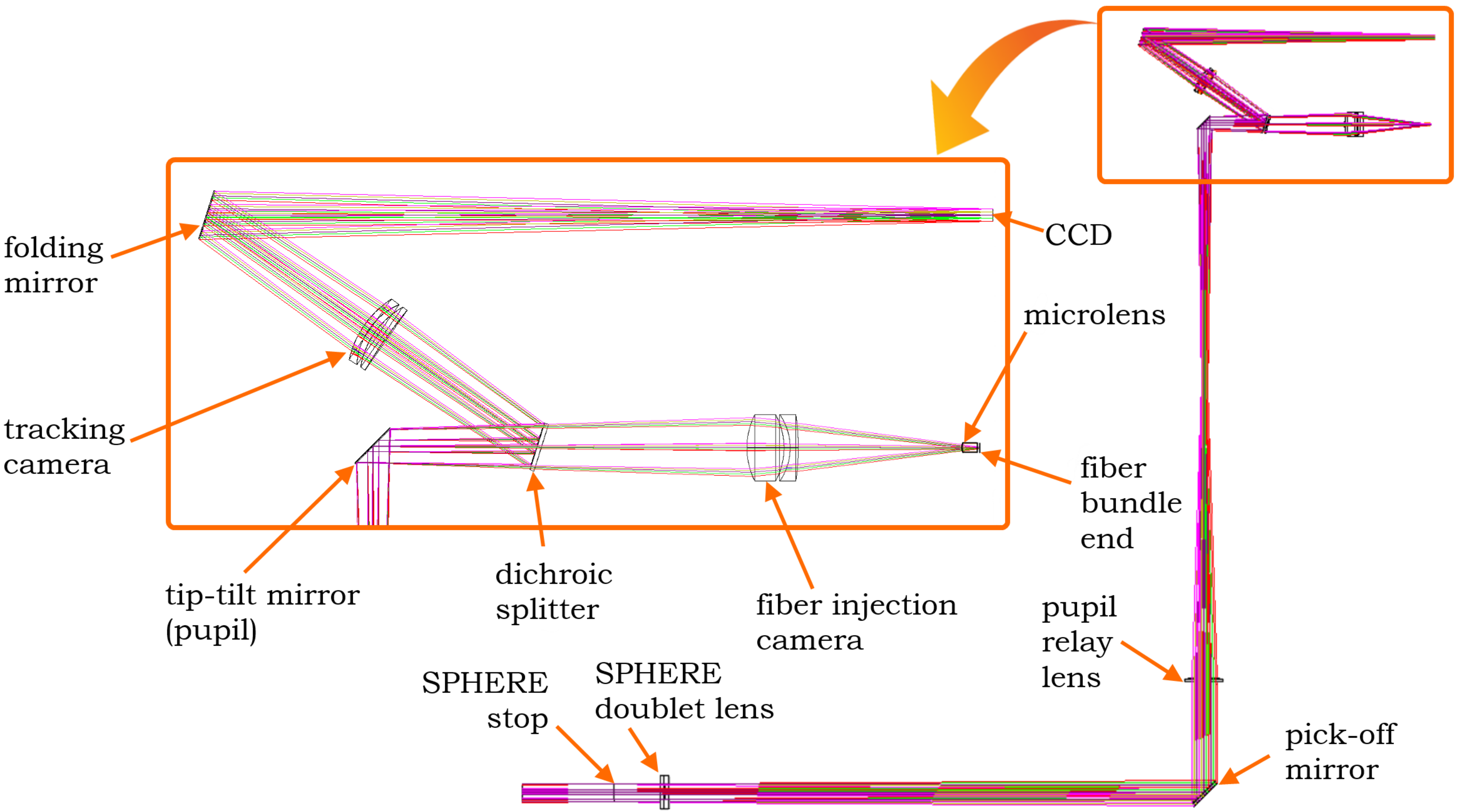
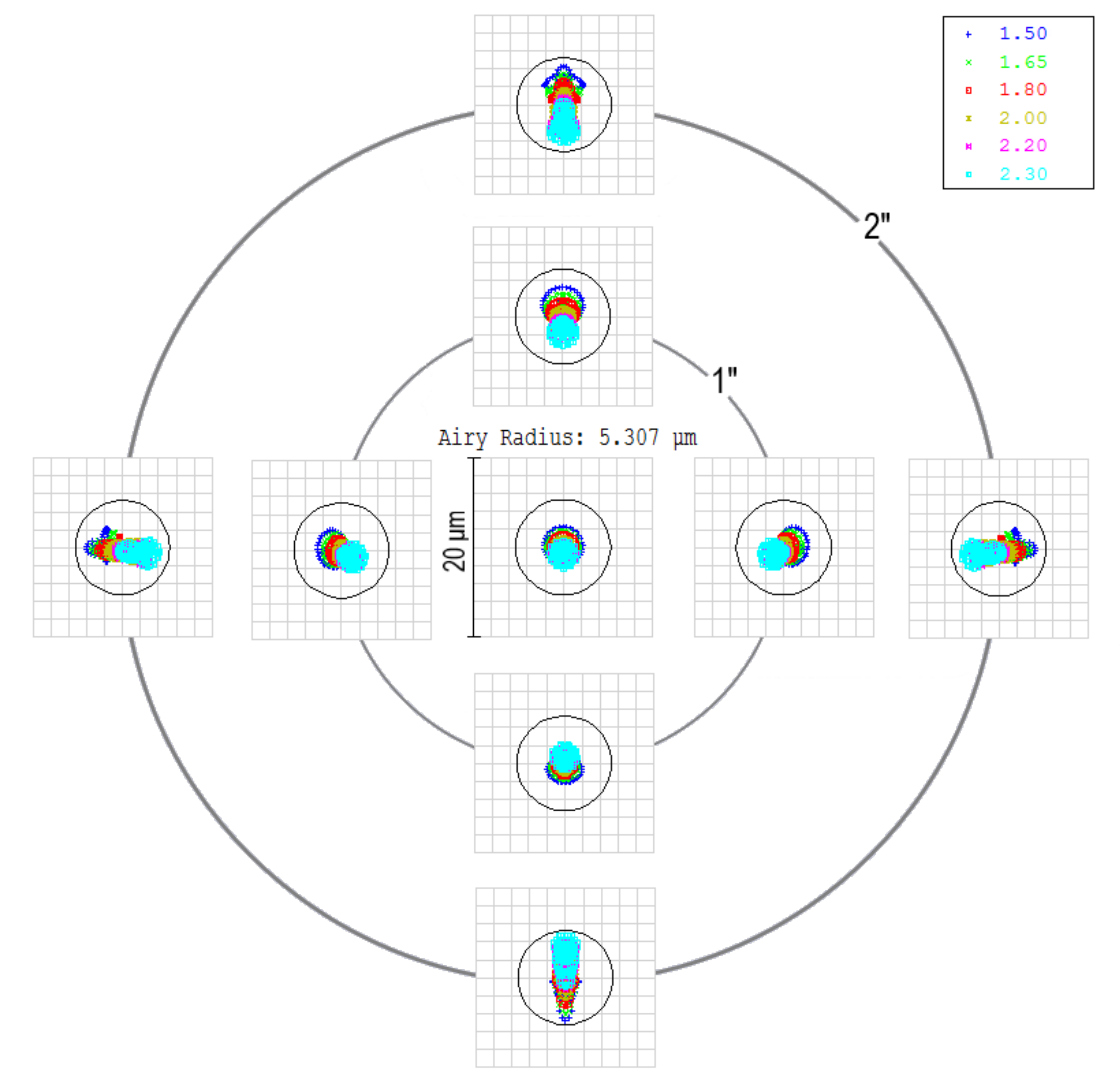
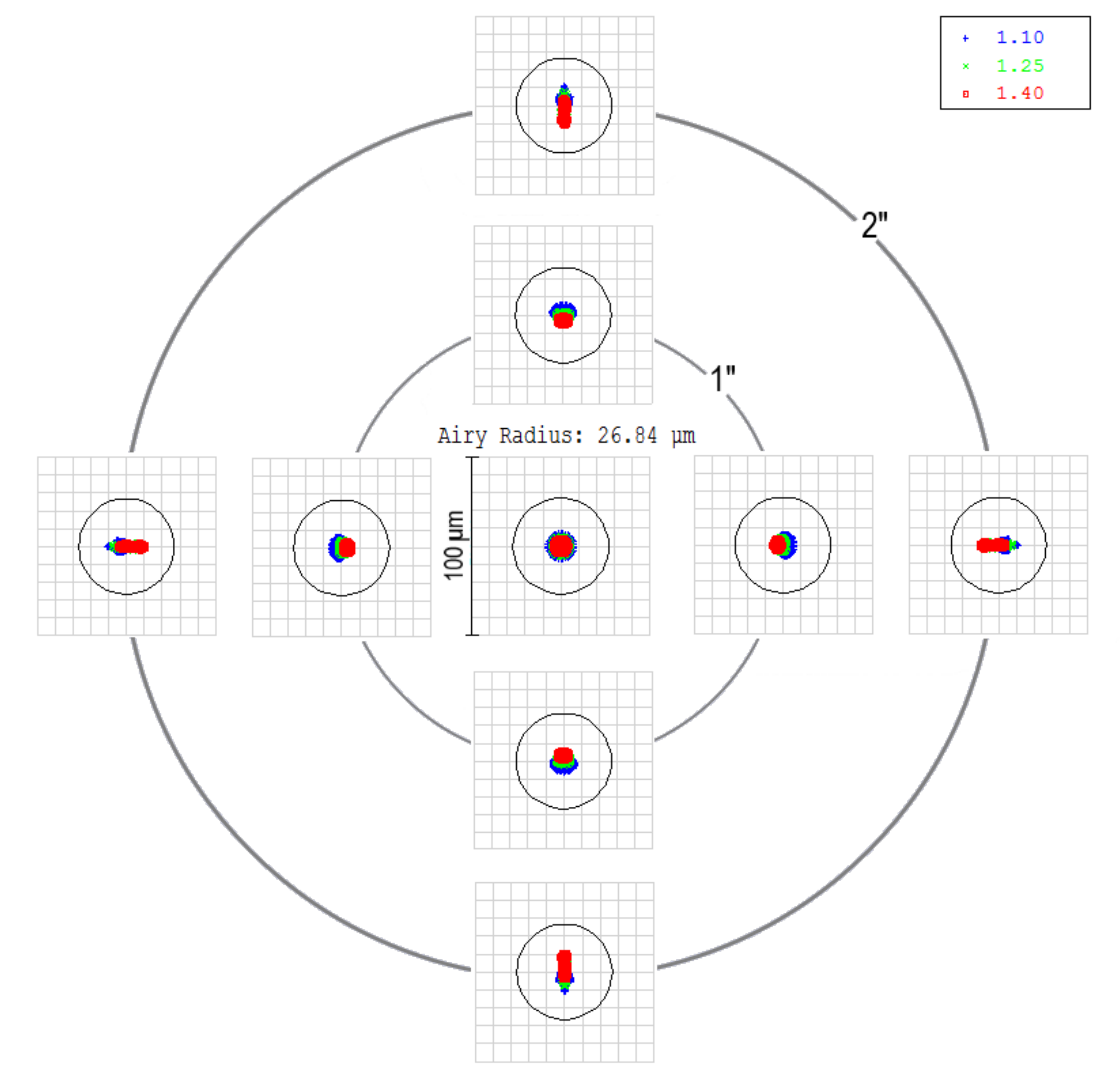


Optical design: fibre injection

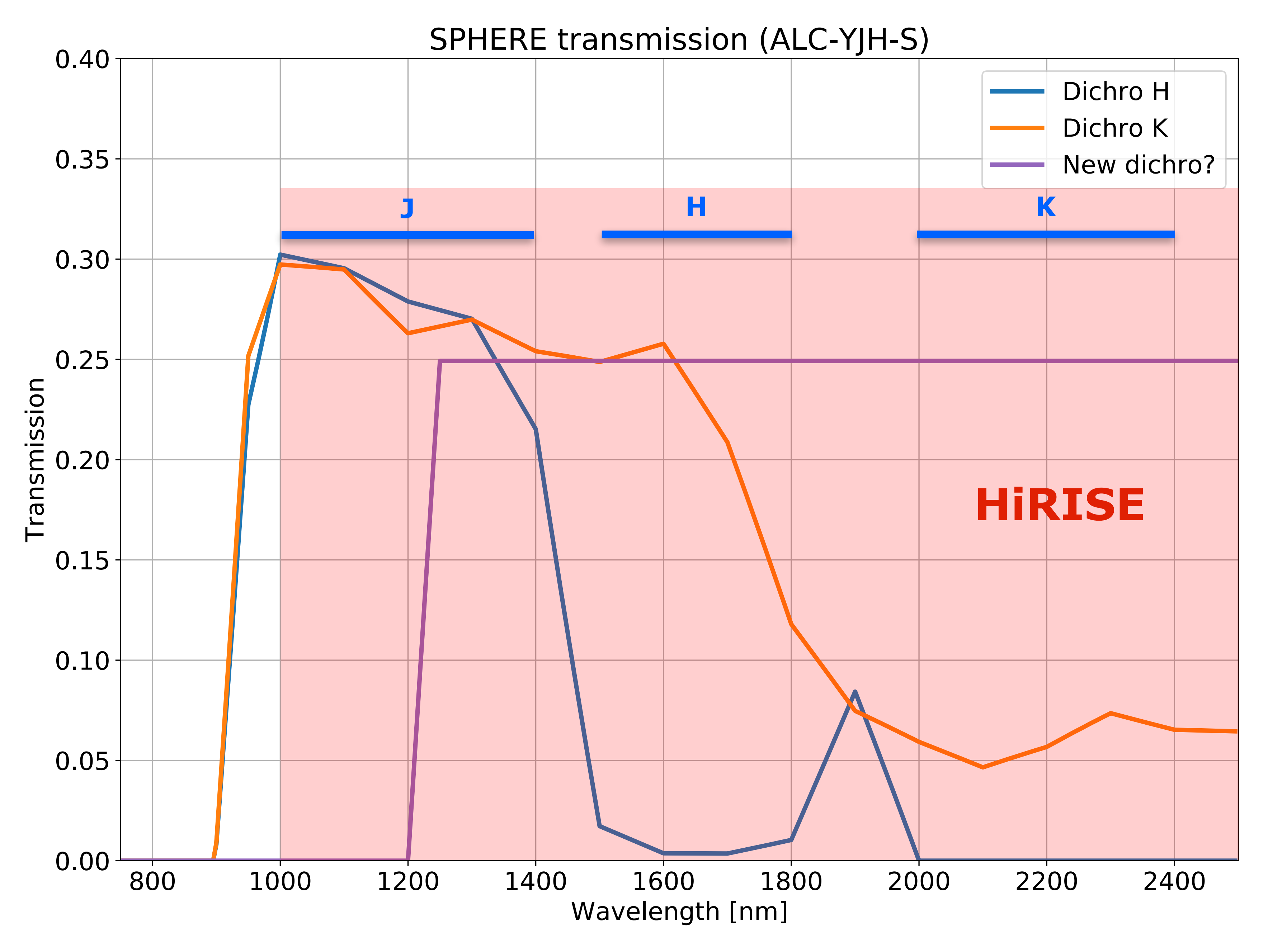
	Fibre	Tracking
F/#	2.9	20
Linear FoV	±1.58 mm	±0.23 mm
Angular @ SPHERE stop	±0.45°	±0.45°
FoV @ sky	±2 arcsec	±2 arcsec
Focal length from pick-off	204.75 mm	29.44 mm
Spectral range	1.1-1.4 um	1.5-2.3 um





Photon share issues: NIR dichroic

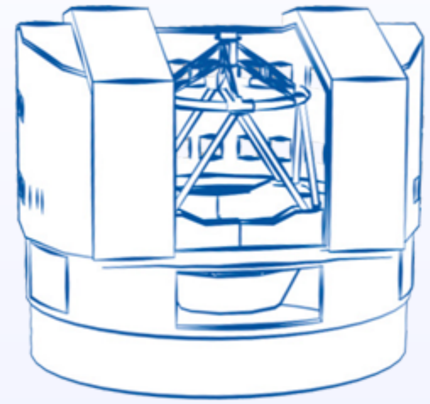
- implemented IFS modes:
  - IRDIFS: 0.96 - 1.34 µm
  - IRDIFS-EXT: 0.97 - 1.66 µm
- current dichroics not ideal
  - only 20% flux in K-band
  - new dichroic would be much better



Current dichroic not ideal... to be changed?

A unique window of opportunity

VLT/UT3



High-contrast exoplanet imager		High-resolution spectrograph
SPHERE		CRIRES+
✔	Extreme adaptive optics	✘
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Y J H K	Spectral coverage	Y J H K L M
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HiRISE

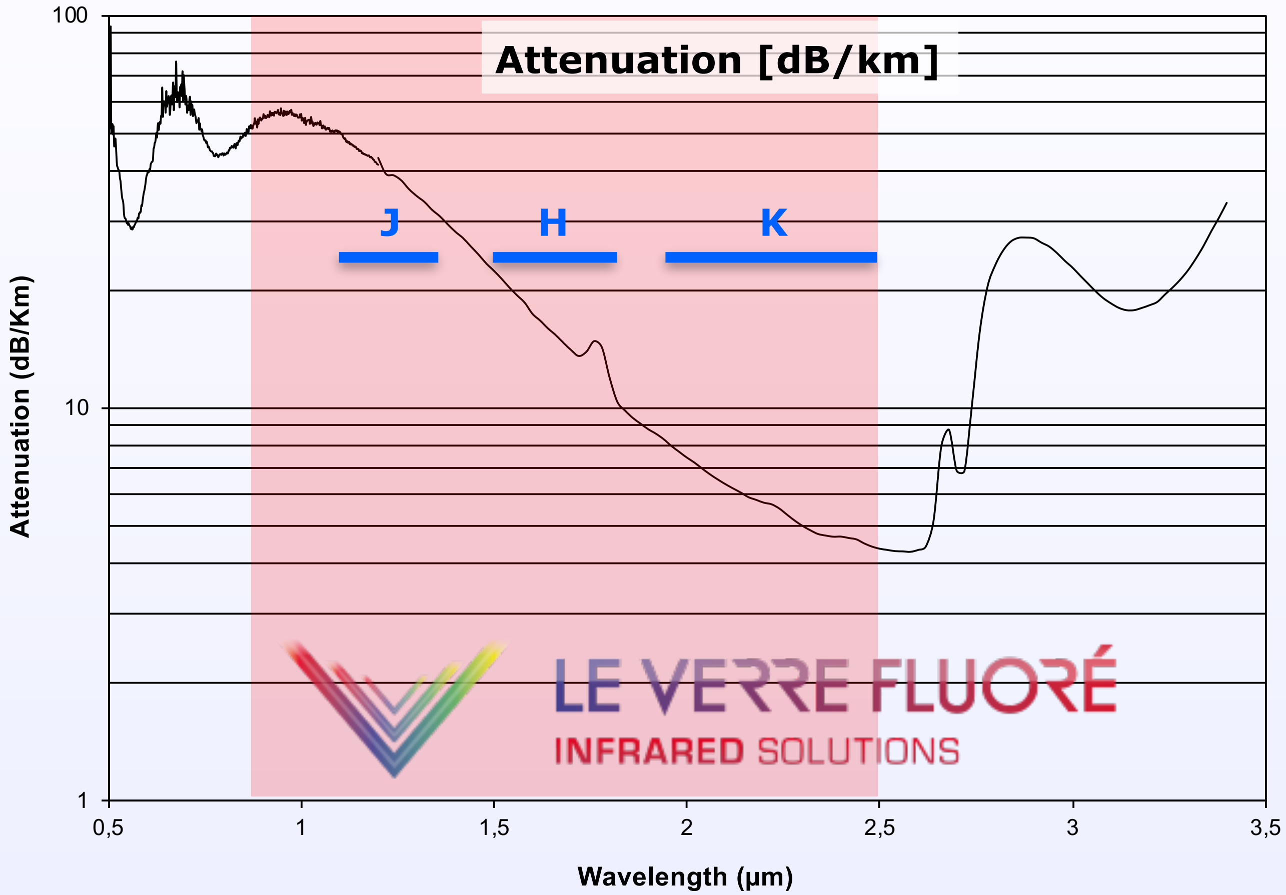
Fiber coupling

Supported by ESO

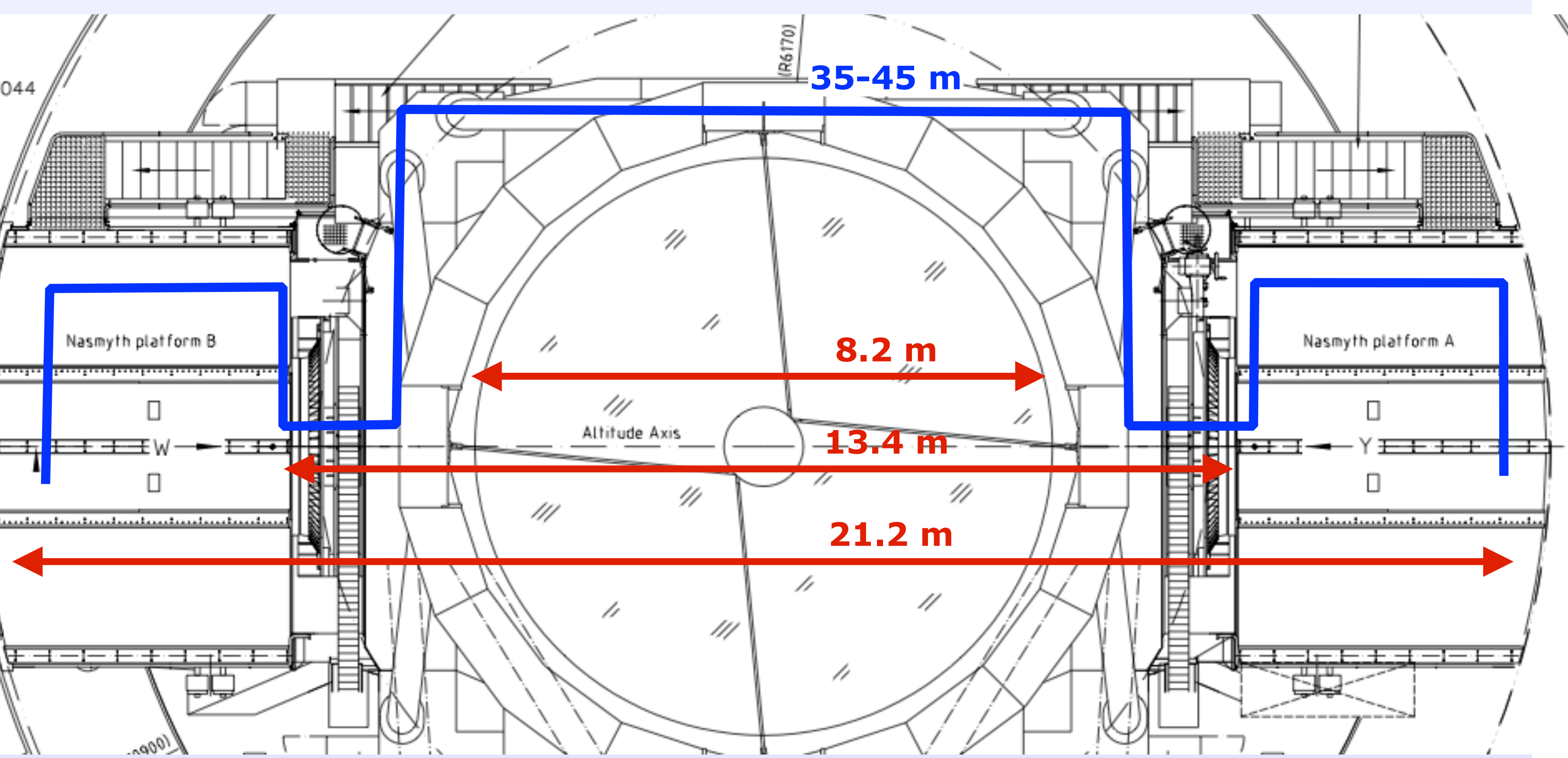
erc

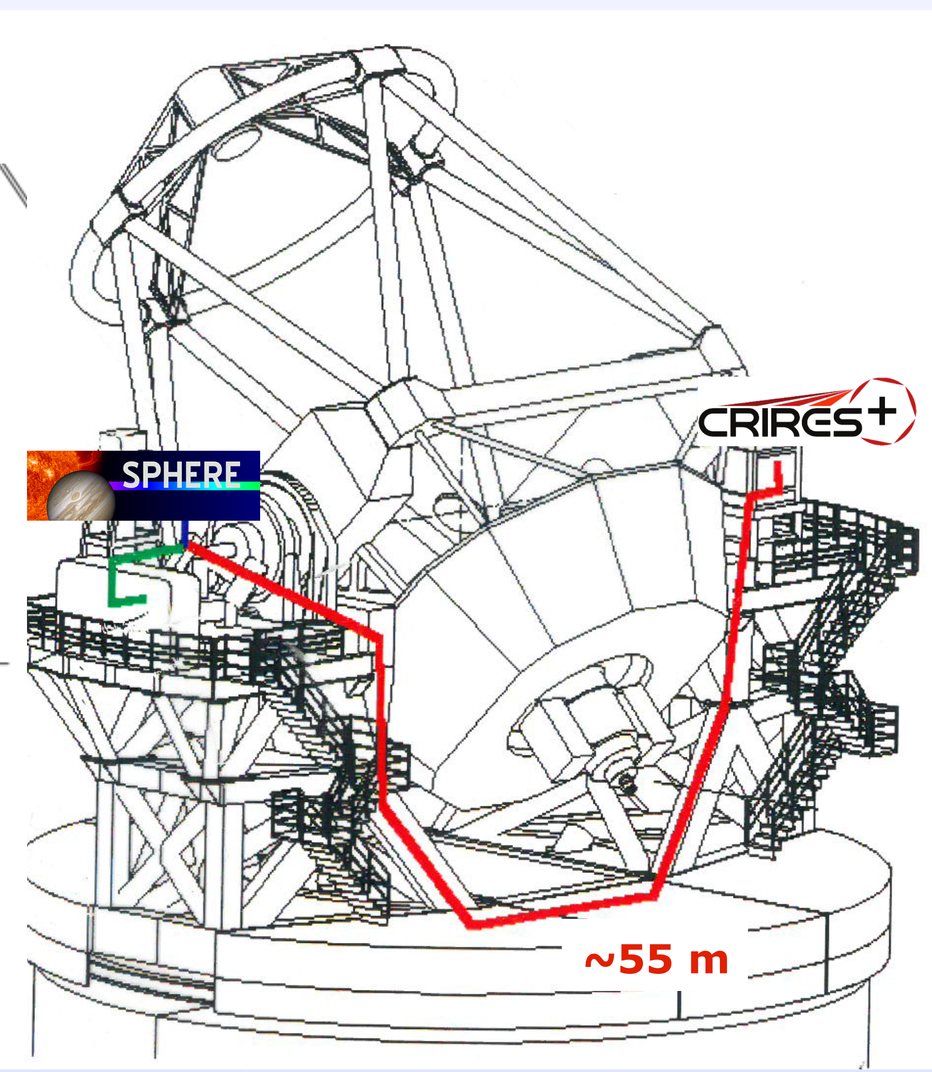
Supported by CRIRES+

NIR fibres for coupling

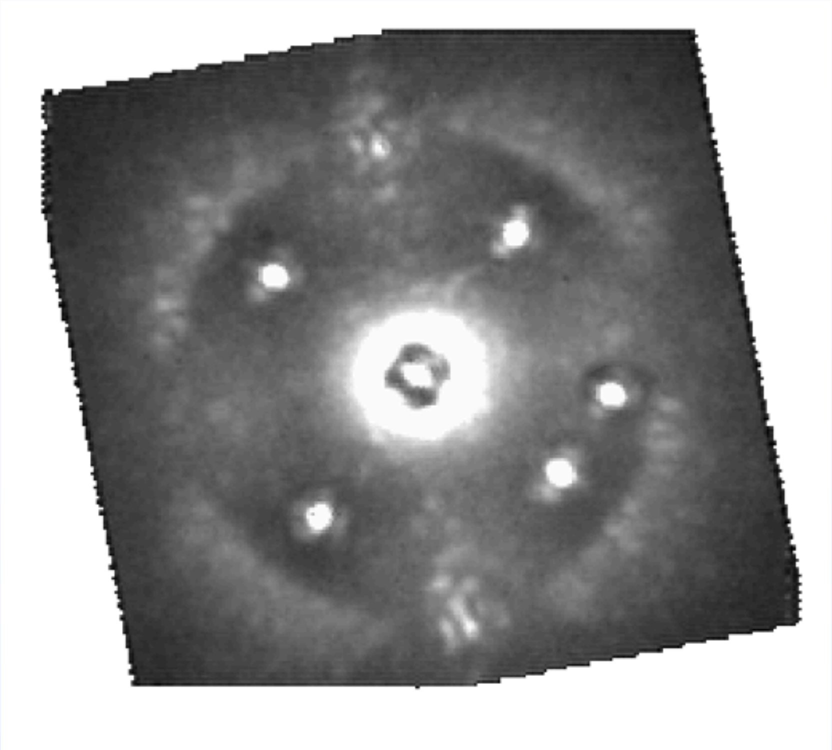


- ZBLAN fibers optimised for near-infrared
  - very high-transmission in H- and K-band
- Fibre bundle must go from Nasmyth A to Nasmyth B
- Similar setup already implemented for FLAMES
  - fibre length ~55 m





Number of fibres & geometry



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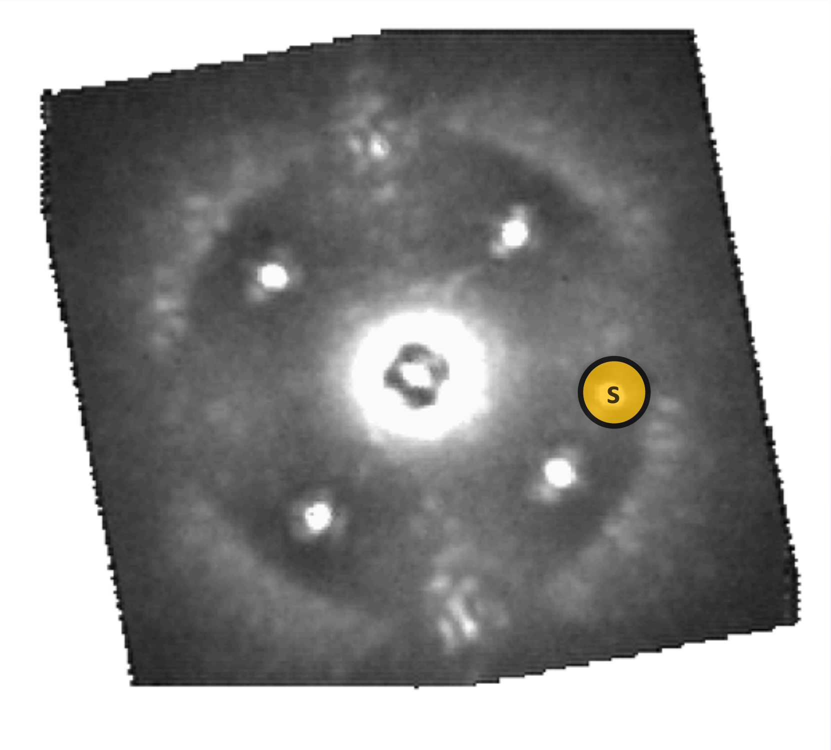

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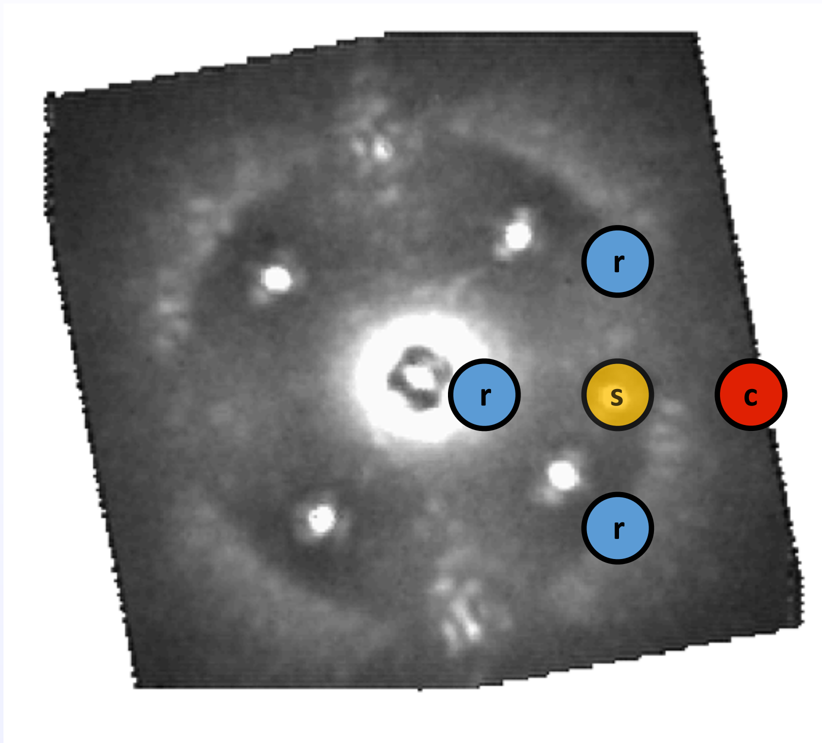
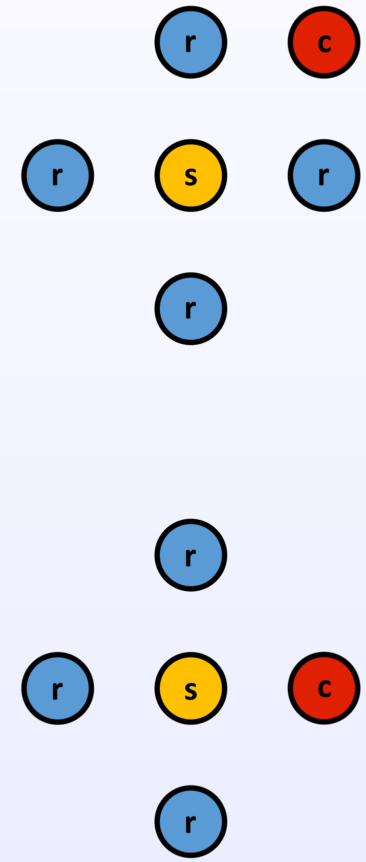
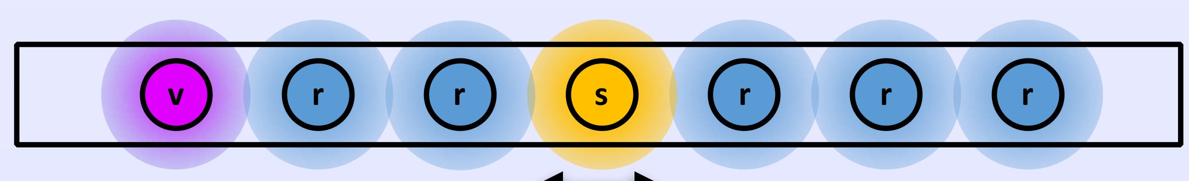


Possible geometries



SPHERE

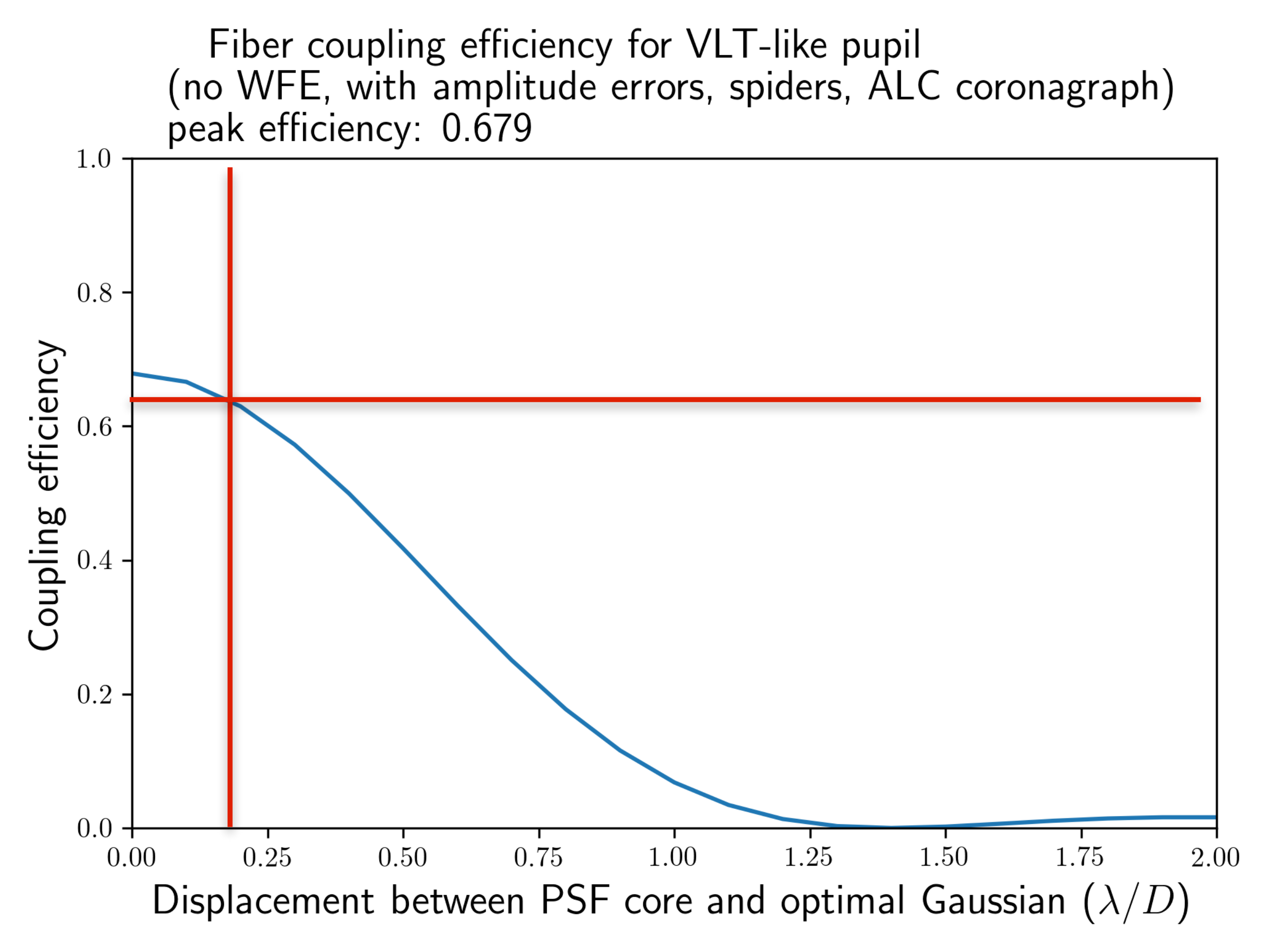


CRIRES+

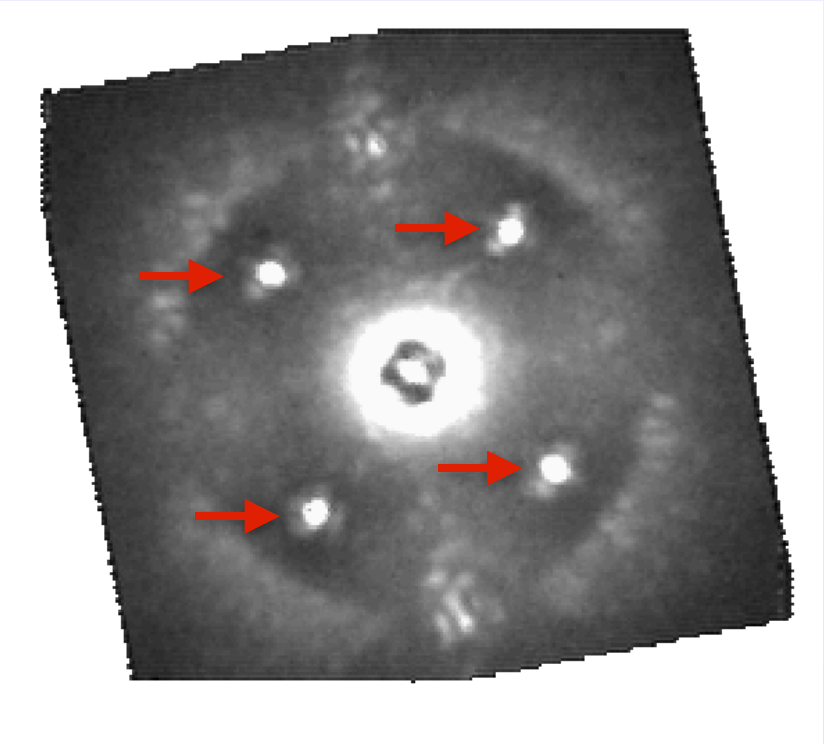
- At least 2 fibres needed: planet s + star r
  - More → better sampling of the speckles
- Need for a centring c fibre
- v fibre to stabilise CRIRES+ tip-tilt!

Fibre positioning

- **Most difficult issue: *make sure that the planet falls on the fibre***
- Required accuracy: probably better than 1/5th of λ/D



- Current approach: we move the **image** w.r.t. the **fibre**
- Calibration of the fibre/image motion:
  - using waffle spots in narrow band filter
  - internal or on-sky calibration? mix of both?



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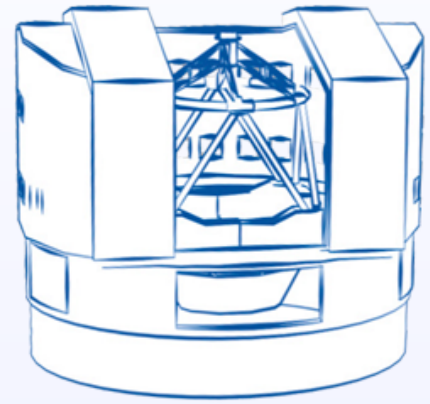

High-contrast exoplanet imager

SPHERE

High-resolution spectrograph

CRIRES+

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Y J H K	Spectral coverage	Y J H K L M
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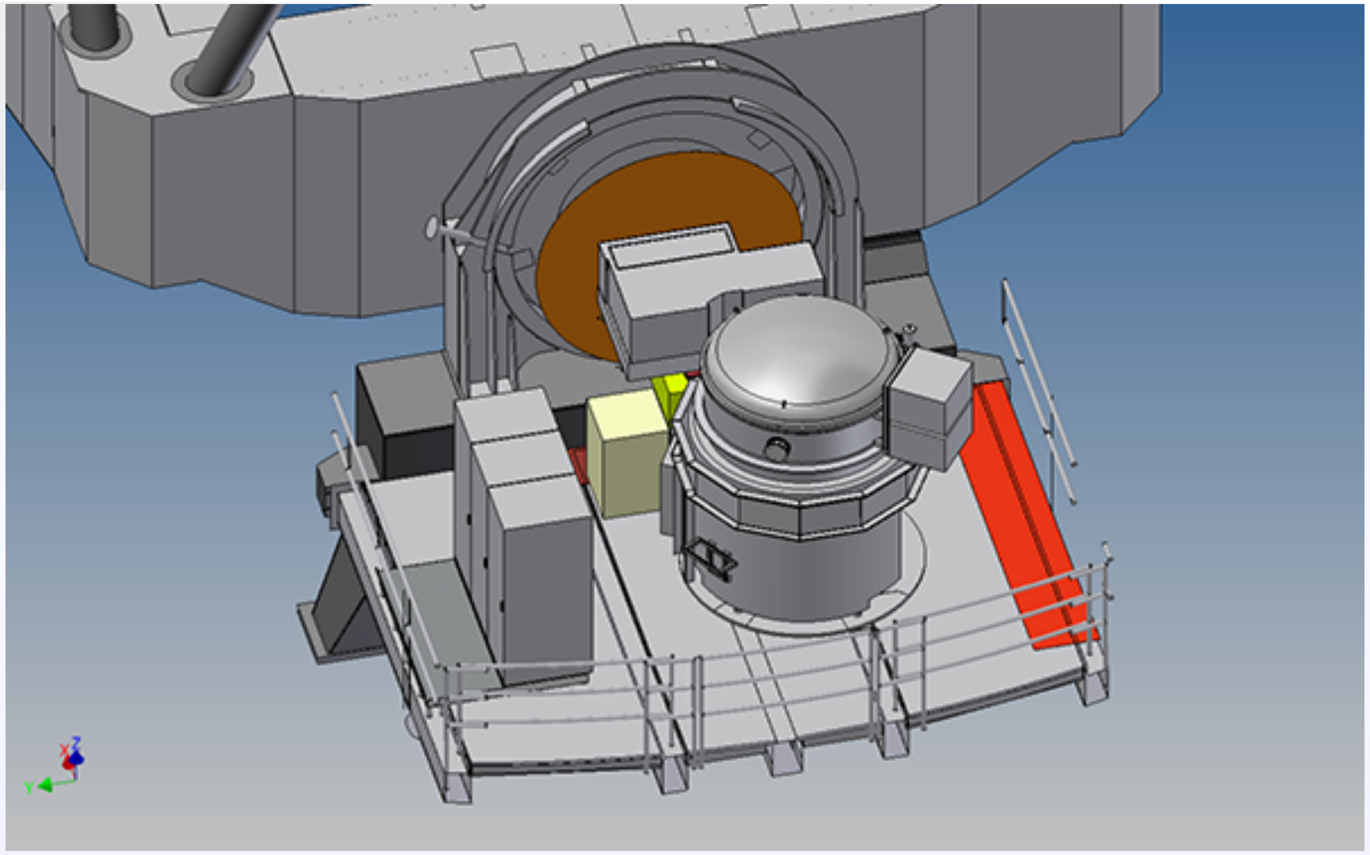
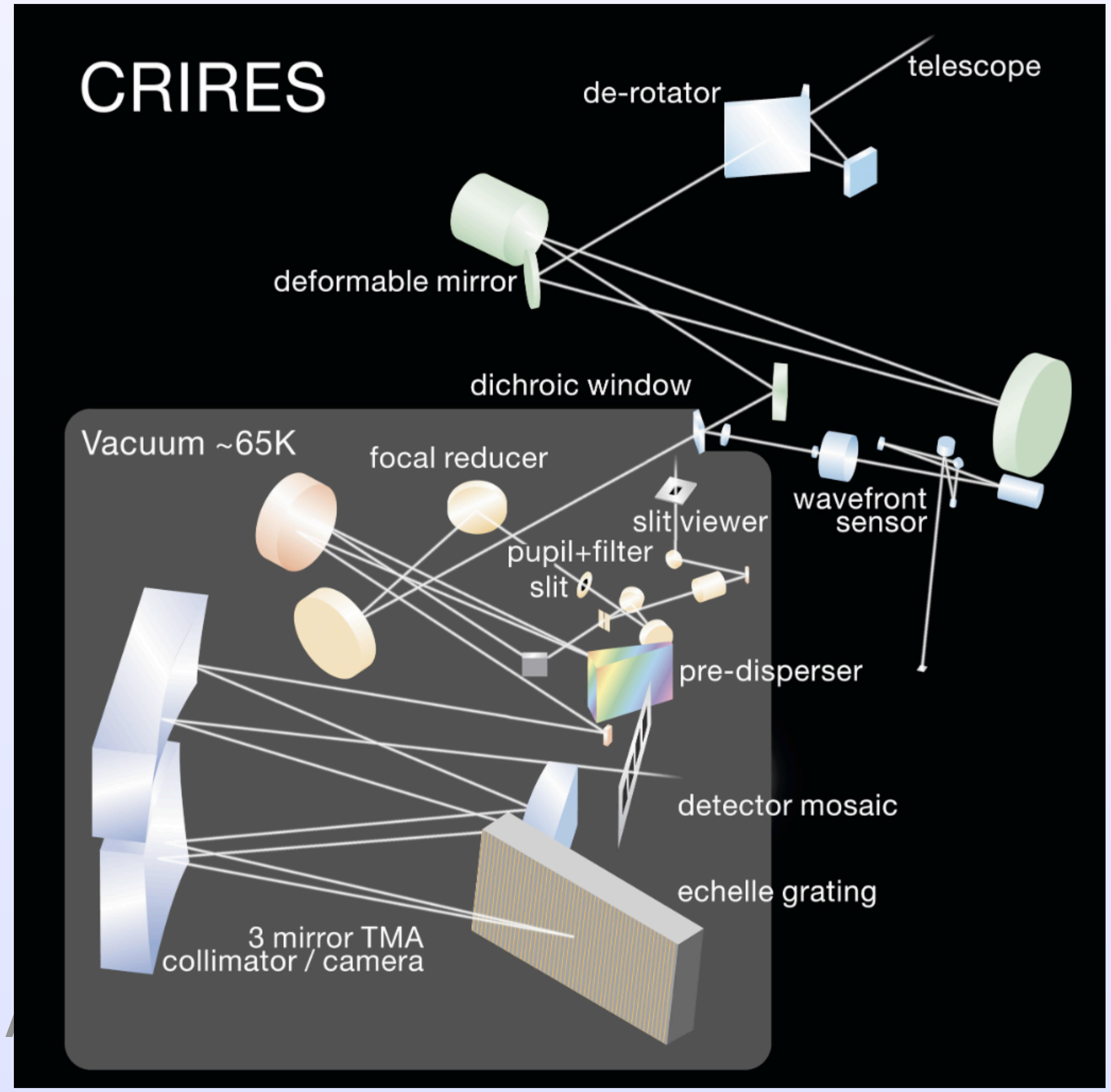
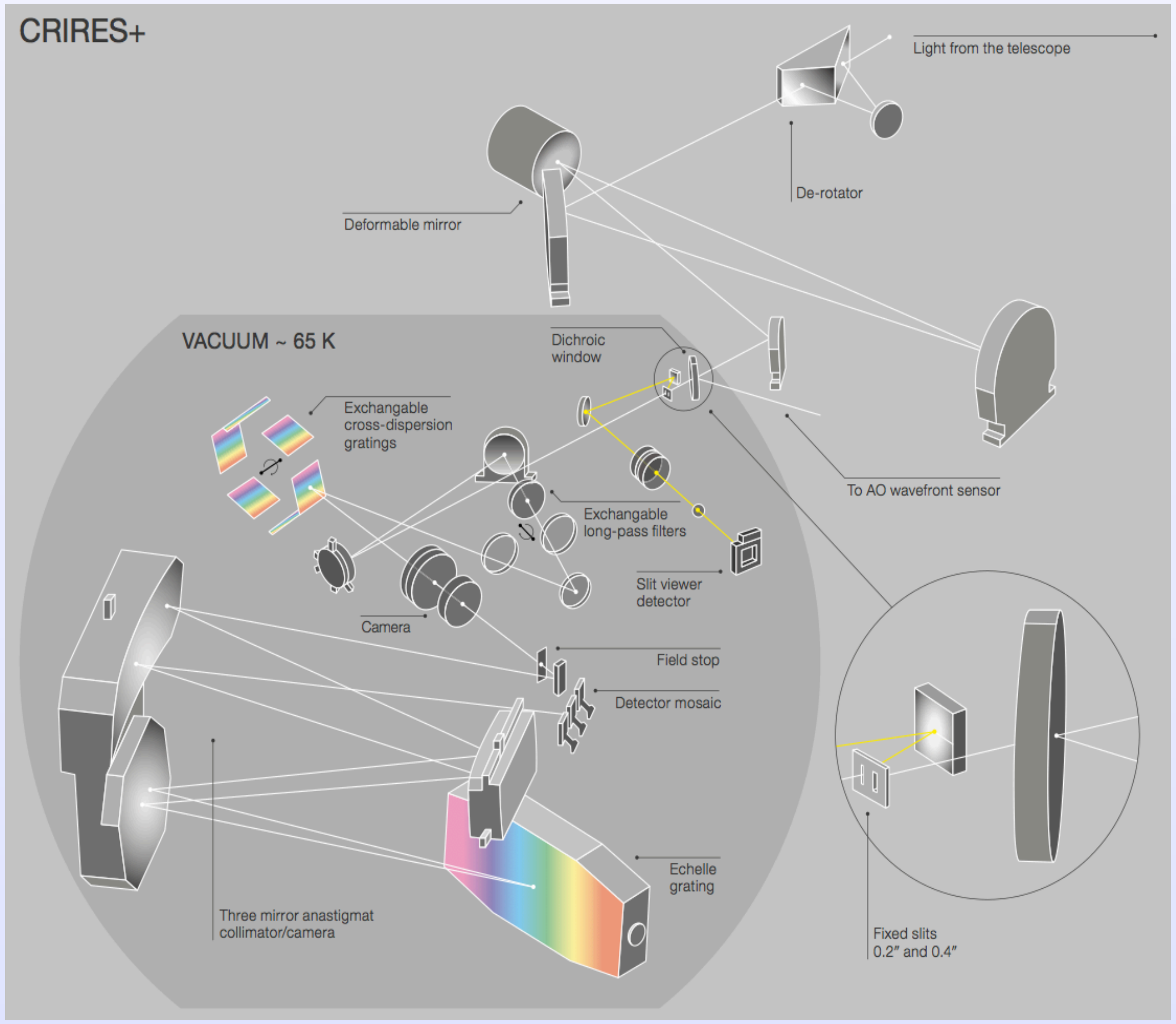
Supported by CRIRES+

CRIRES+

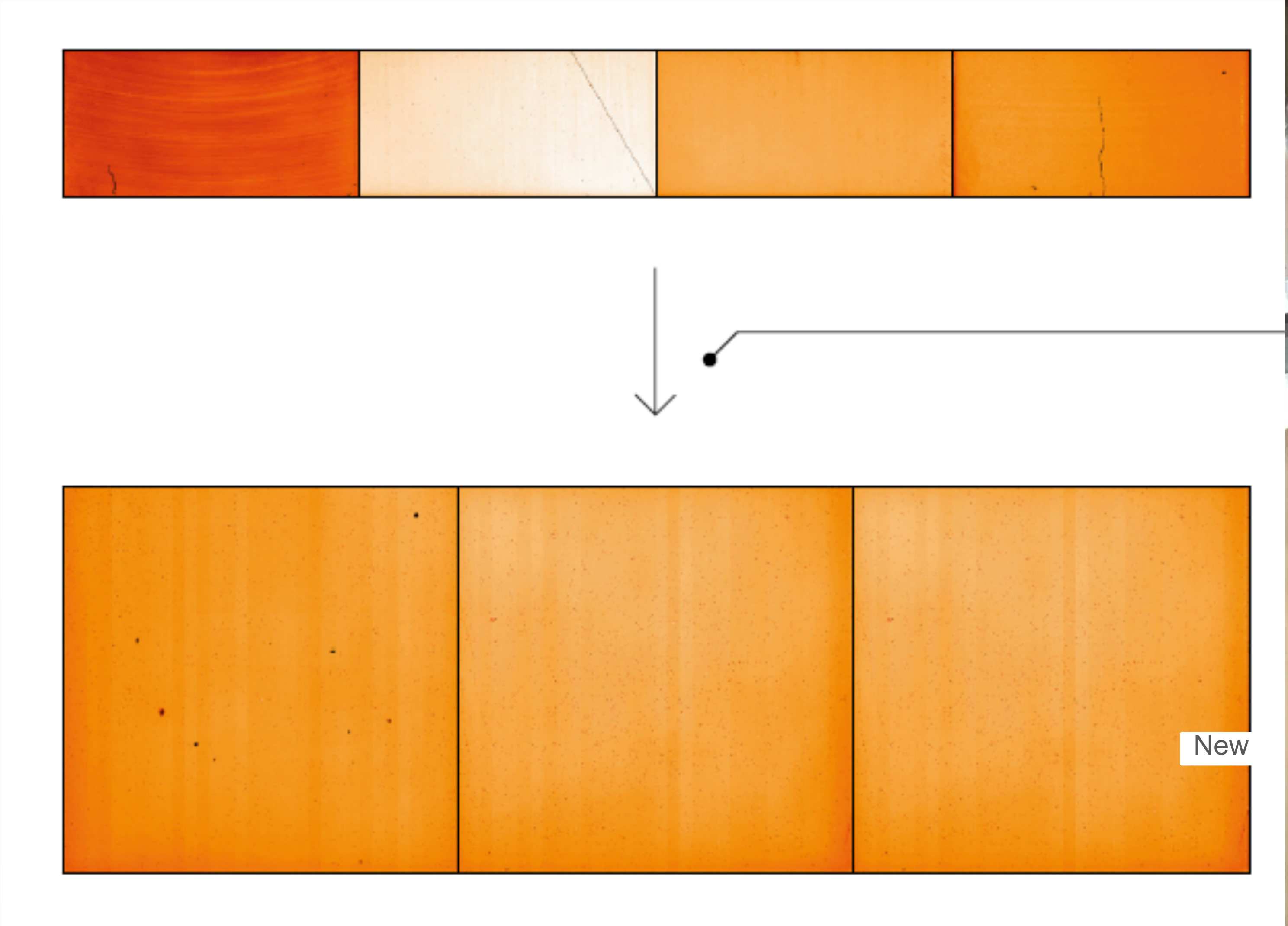
- NIR infrared echelle spectrograph
- Being upgraded to a cross-dispersion spectr.
  - new cross-dispersion gratings stage
  - new detectors
  - slit reduced from 40" to 10"

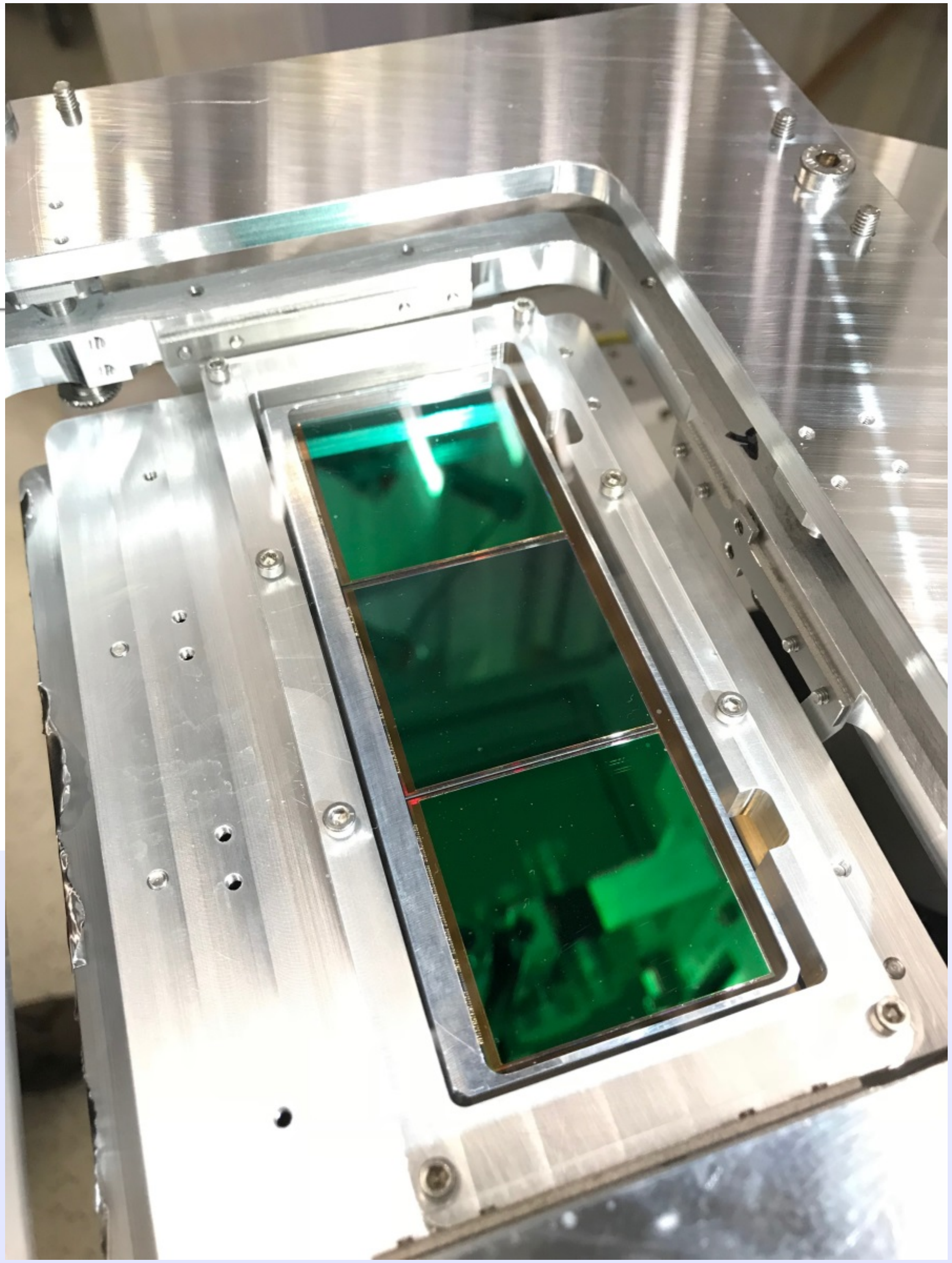






CRIRES+ detectors

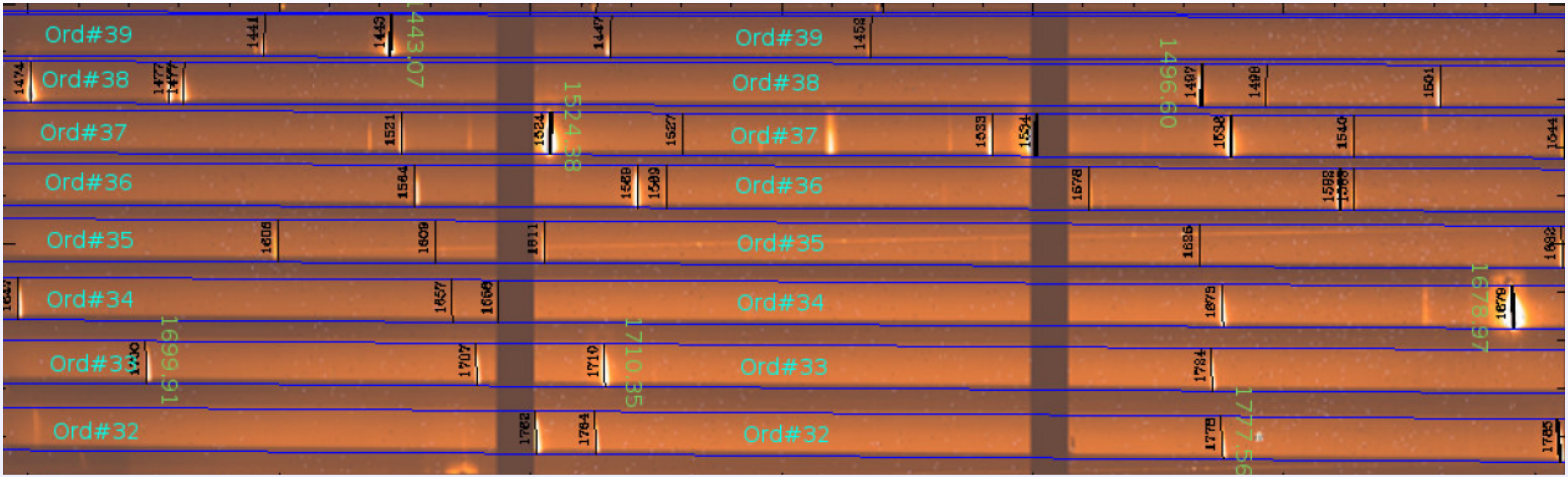




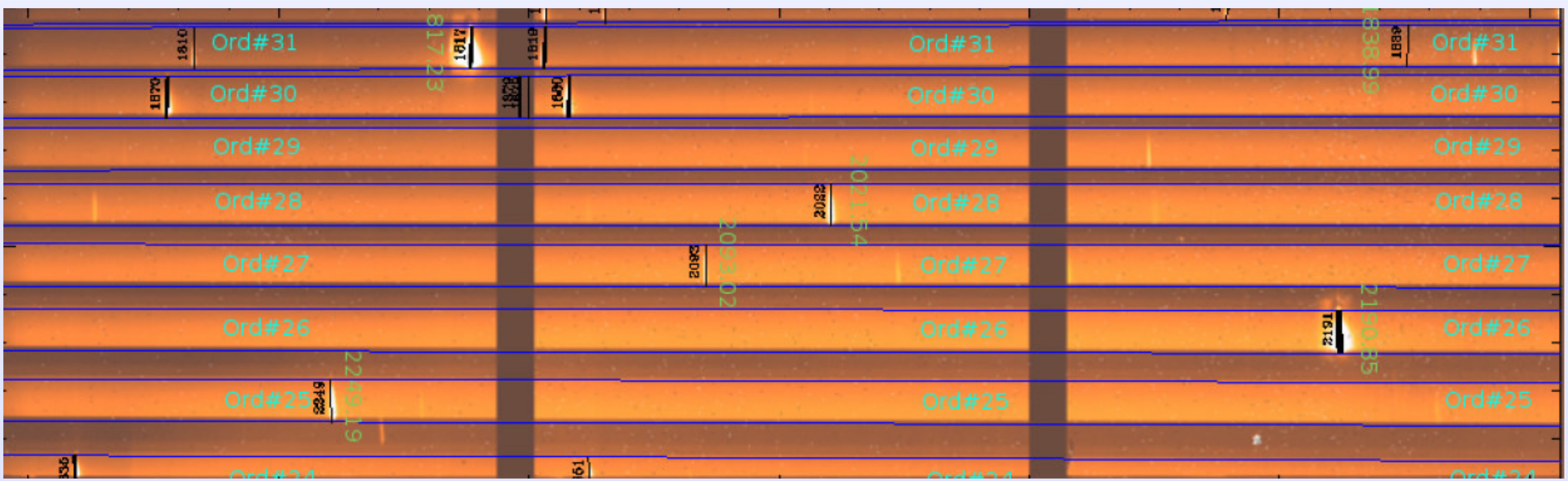
- 3 new Hawaii-2RG detectors
  - much better cosmetics
  - improved quantum efficiency
  - much more pixels!

CRIRES+ wavelength coverage

Almost a full band in a single observation!



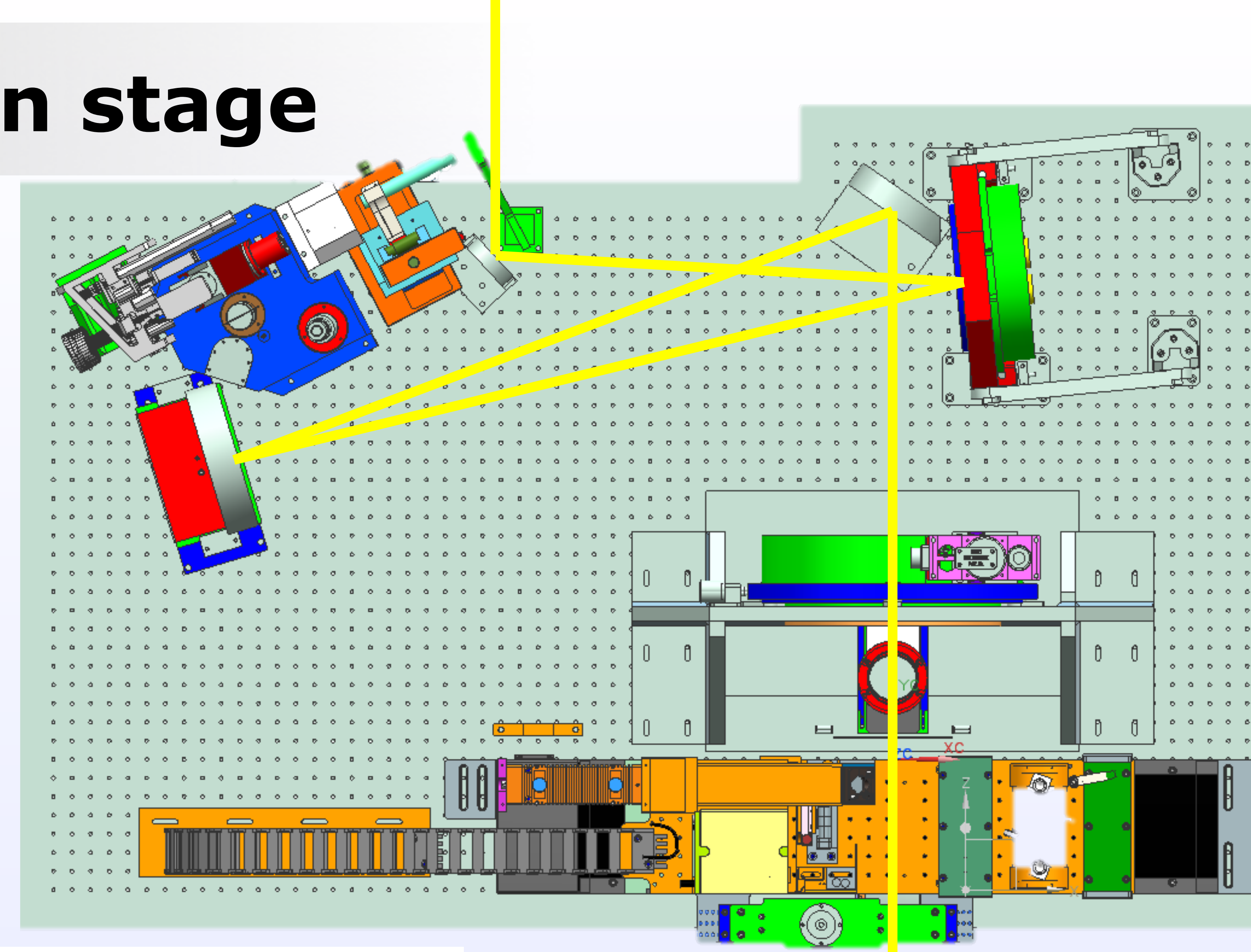
H

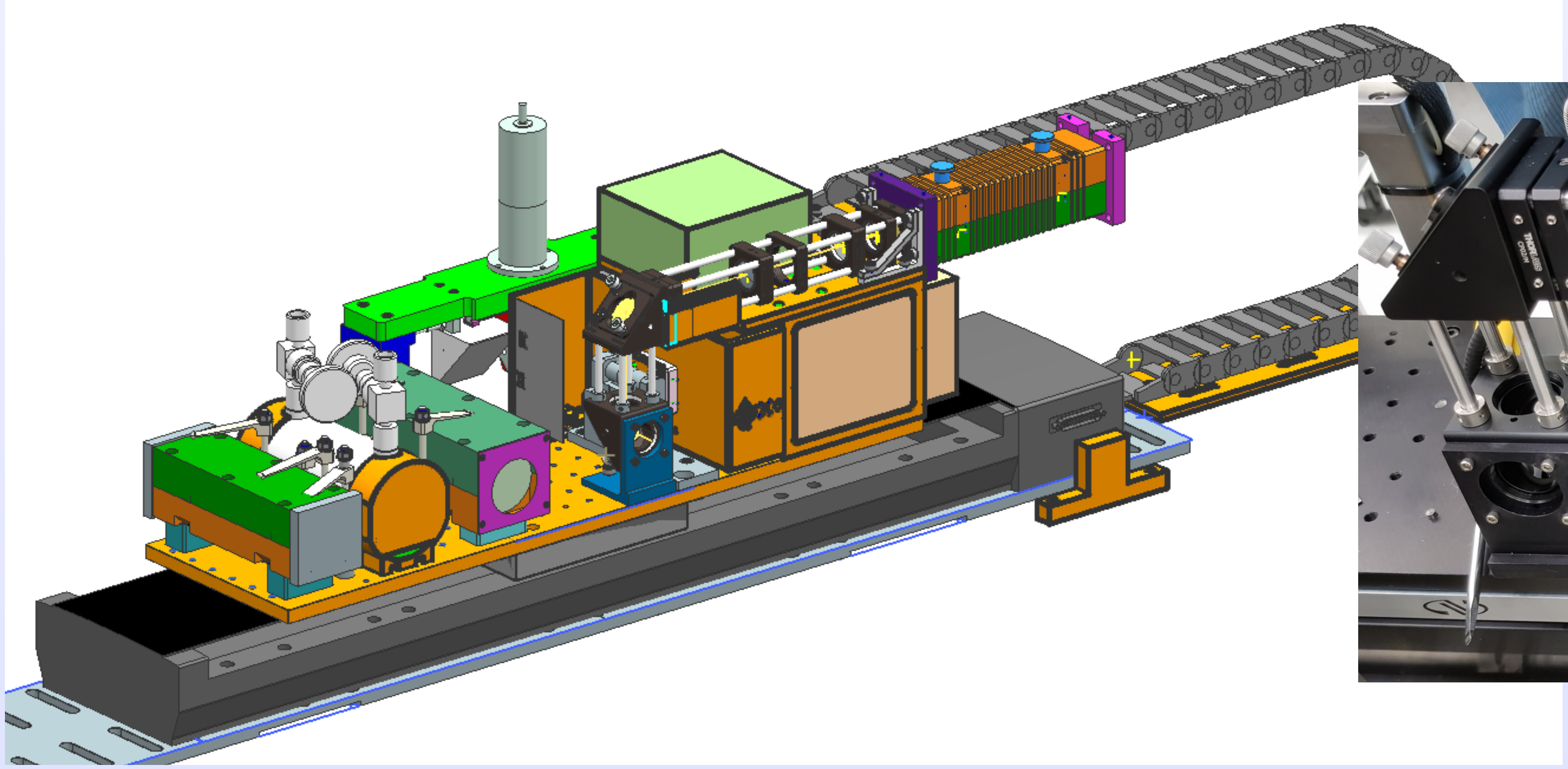


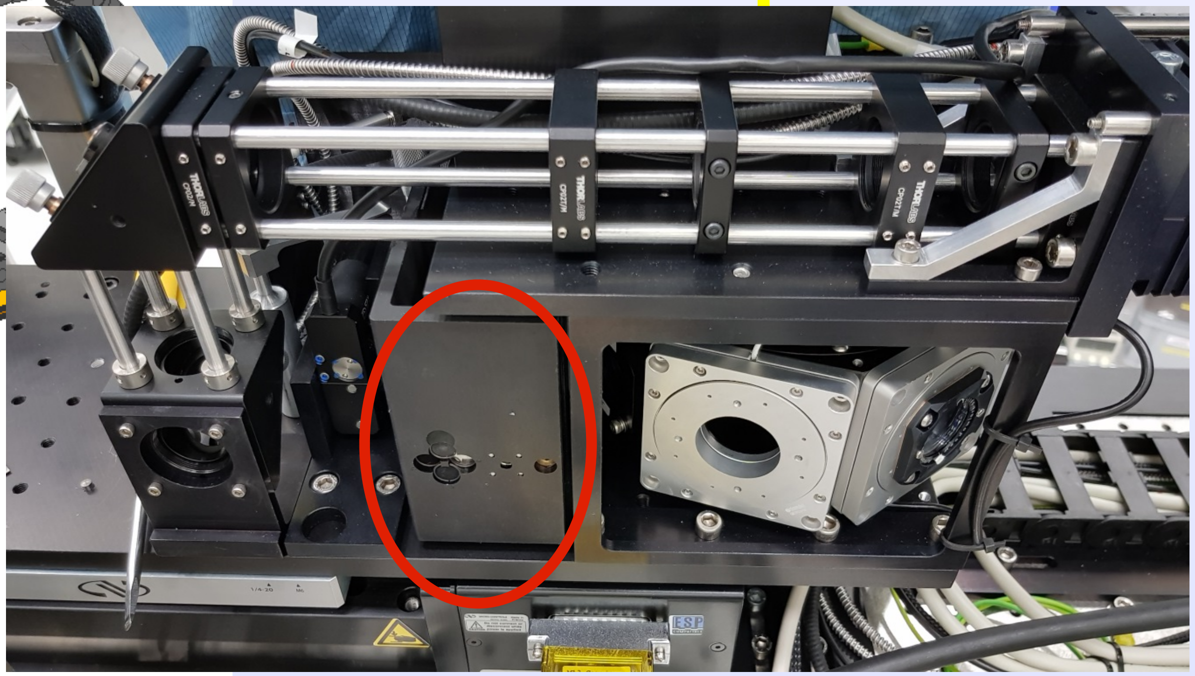
K

CRIRES+ calibration stage

- calibration stage in the warm part of the instrument
- AO system
- fibre output for calibration
  - could be used for SPHERE..
  - or new dedicated mount

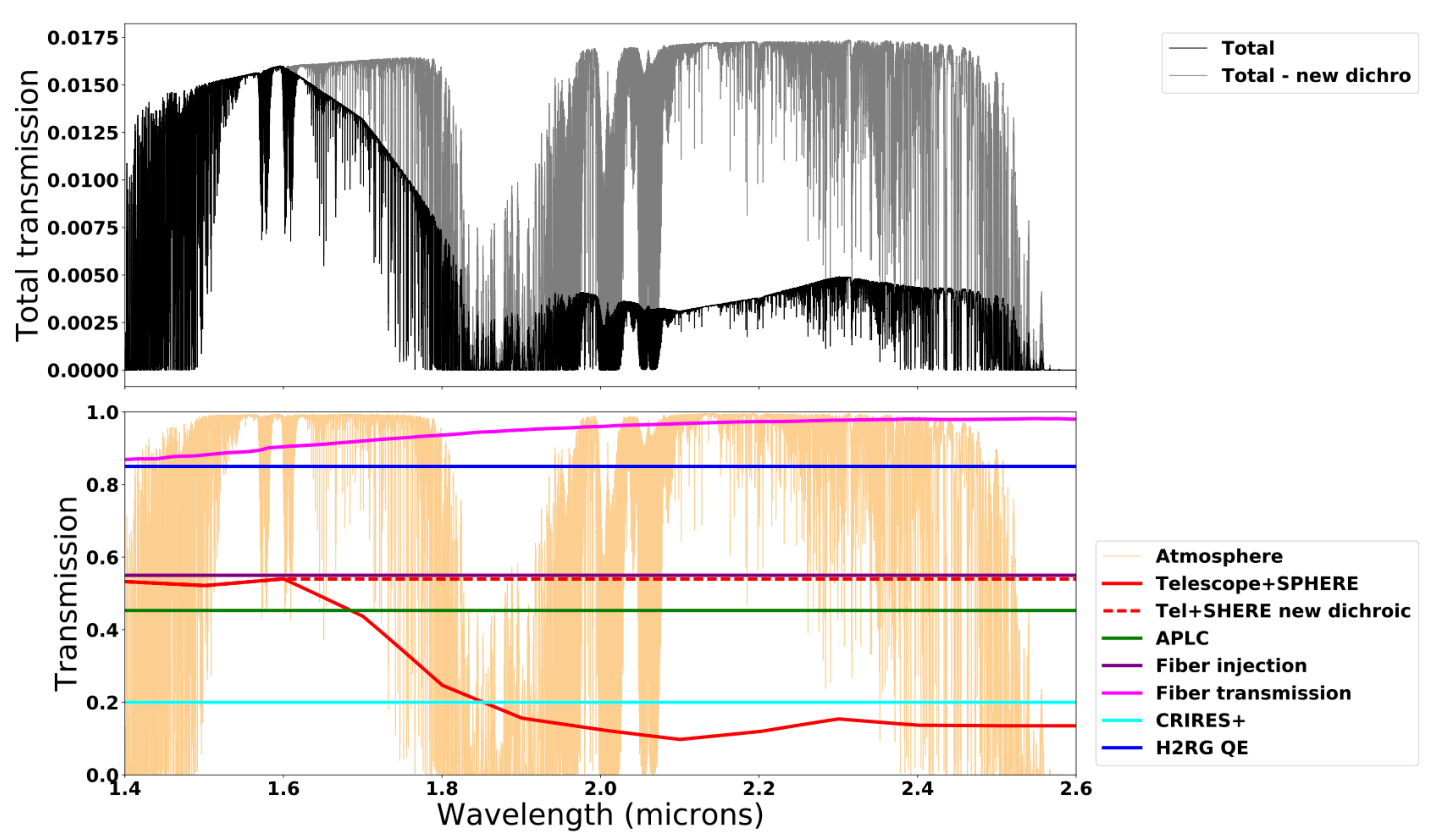






Performance simulations: transmission

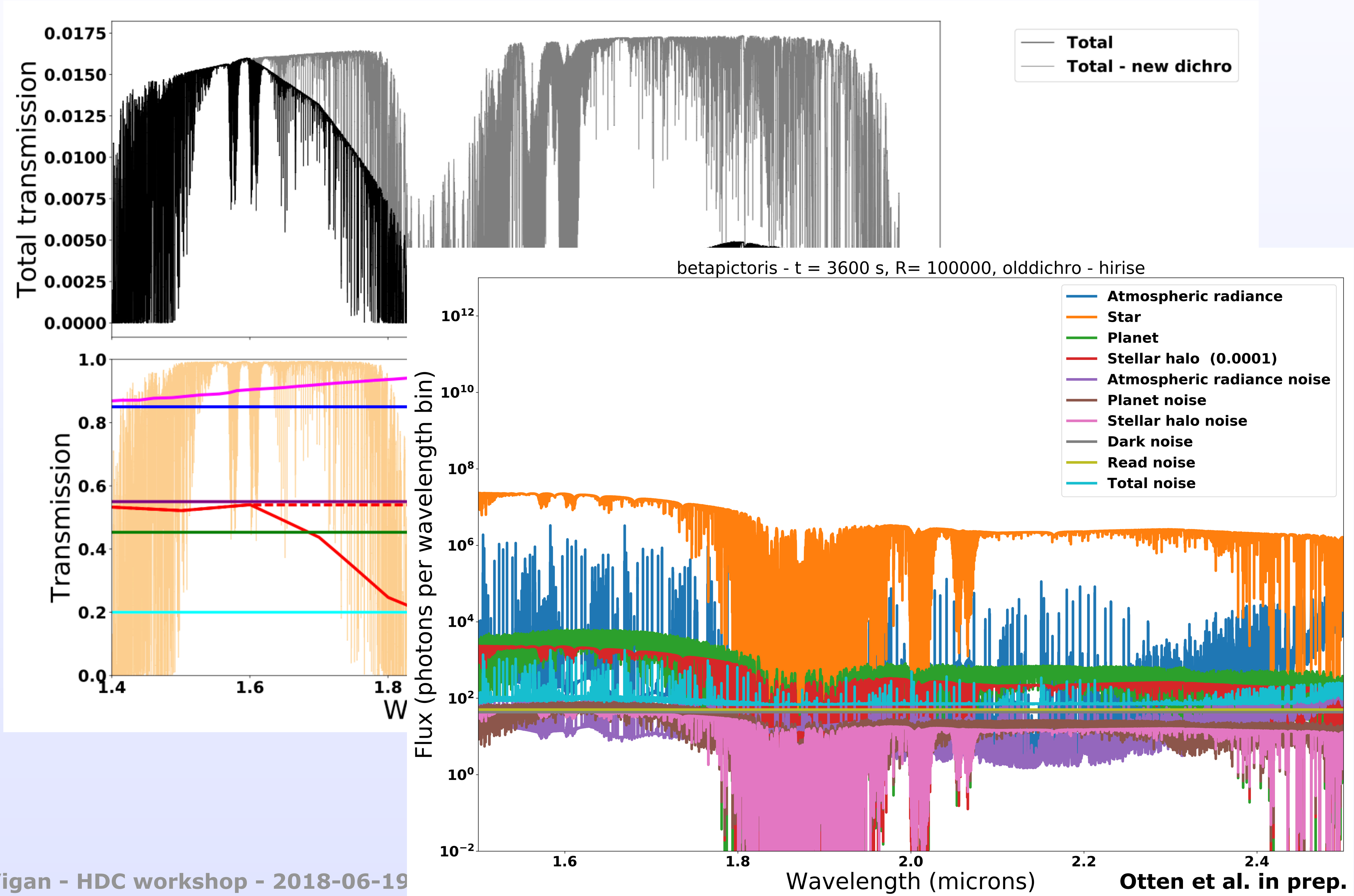
- photometric end-to-end model built by Gilles Otten



Otten et al. in prep.

Performance simulations: transmission

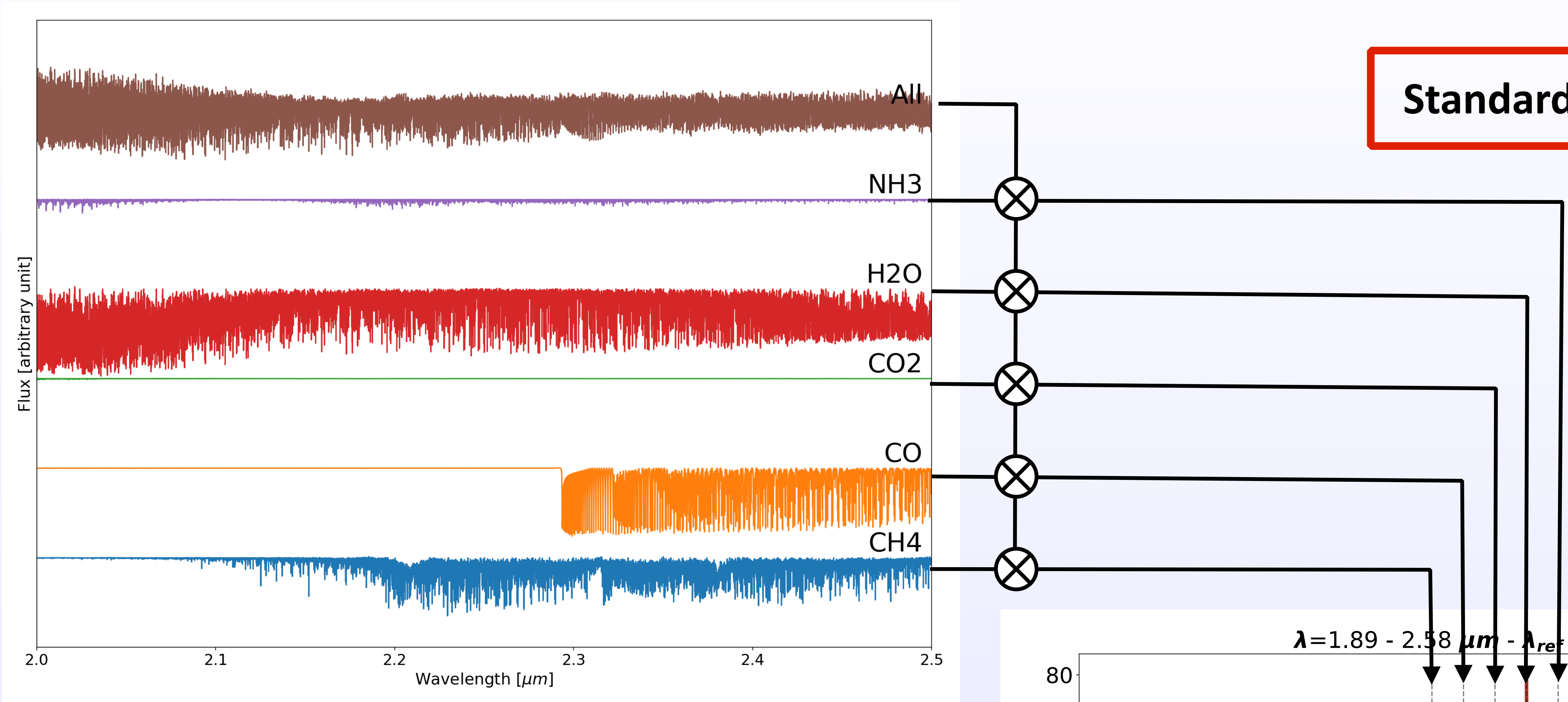
- photometric end-to-end model built by Gilles Otten



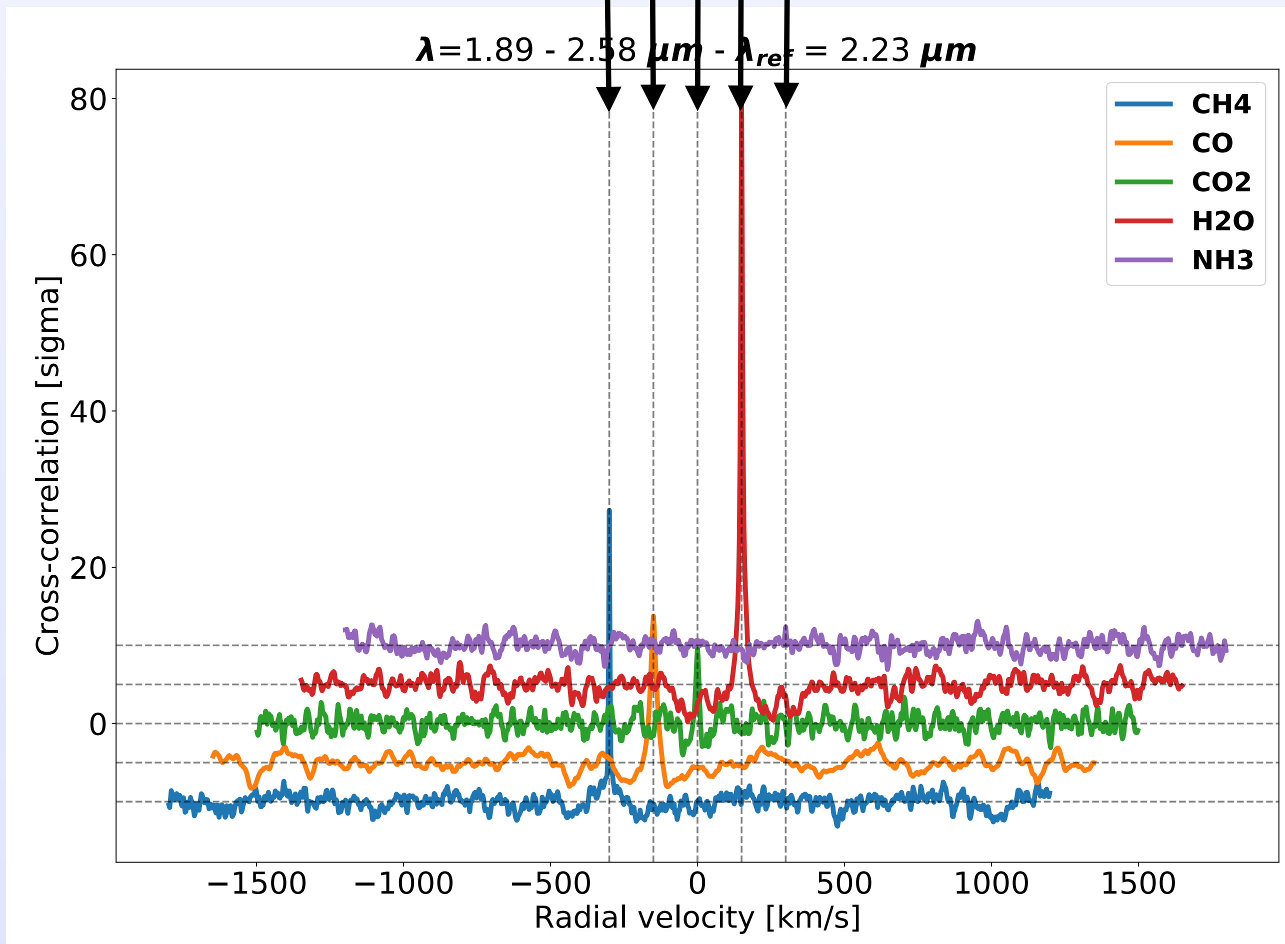
Otten et al. in prep.

Performance simulations: data analysis

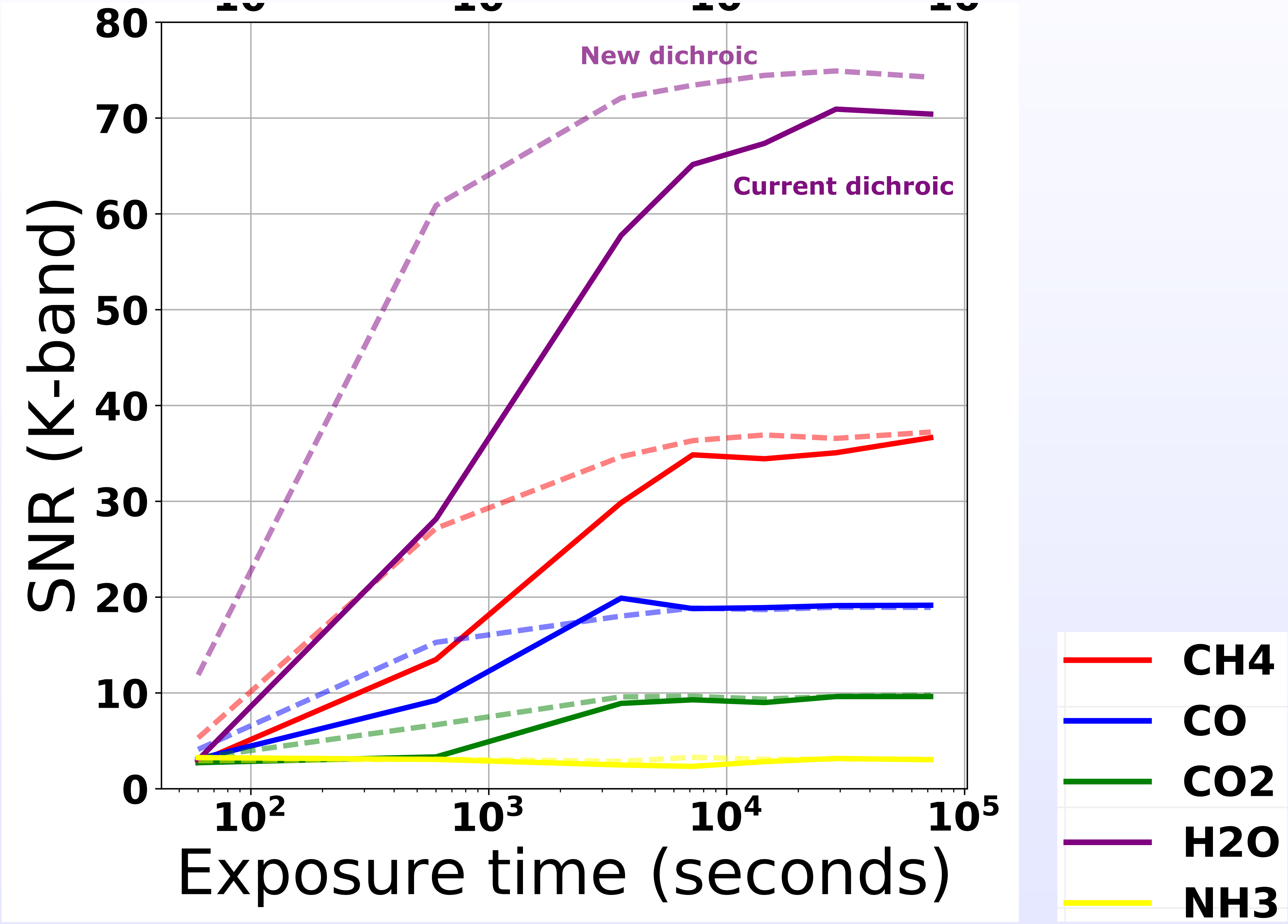
Standard CCF approach



ATMO models
Tremblin et al. (2015)
Philipps et al. in prep.

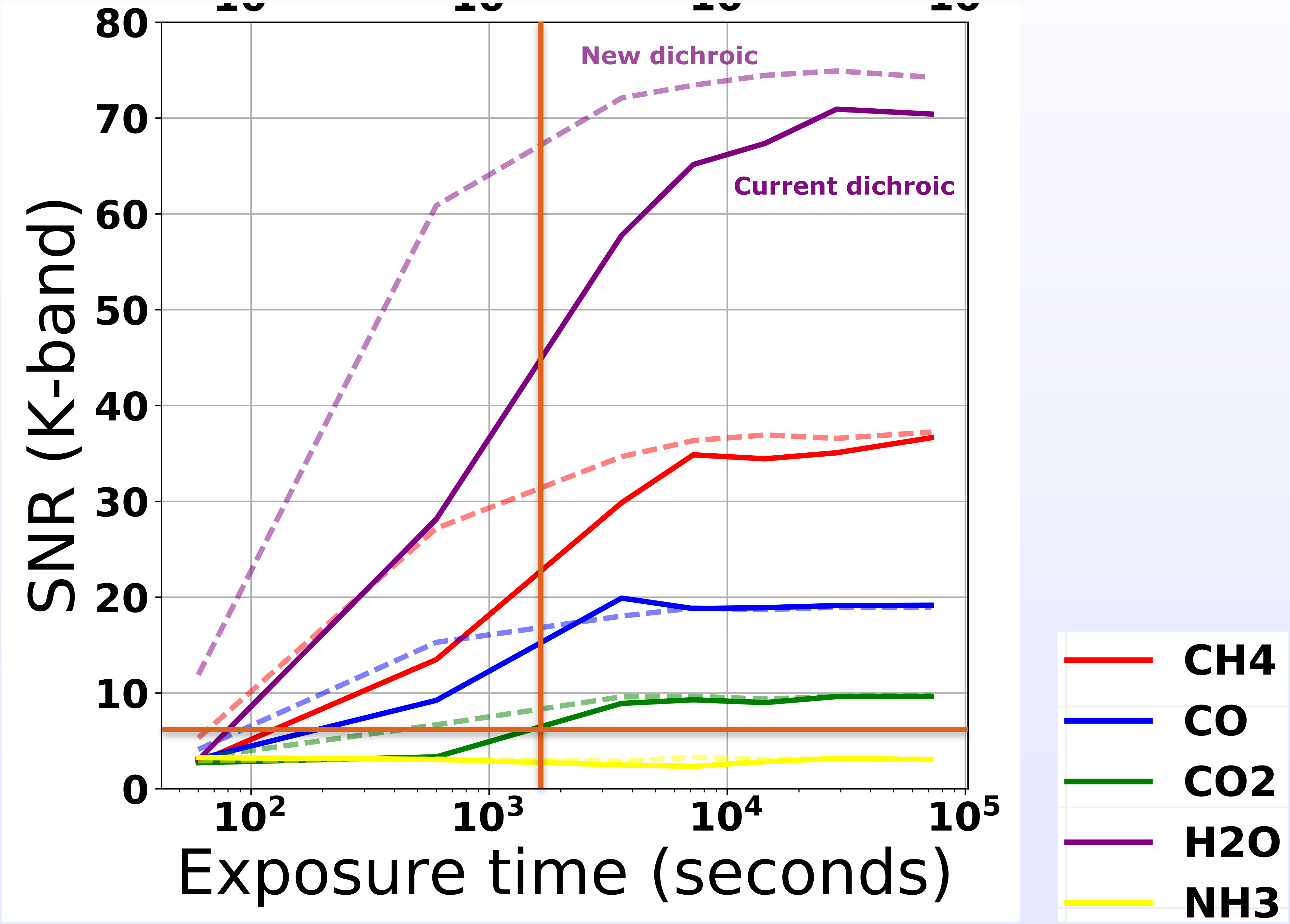


Performance simulations: results



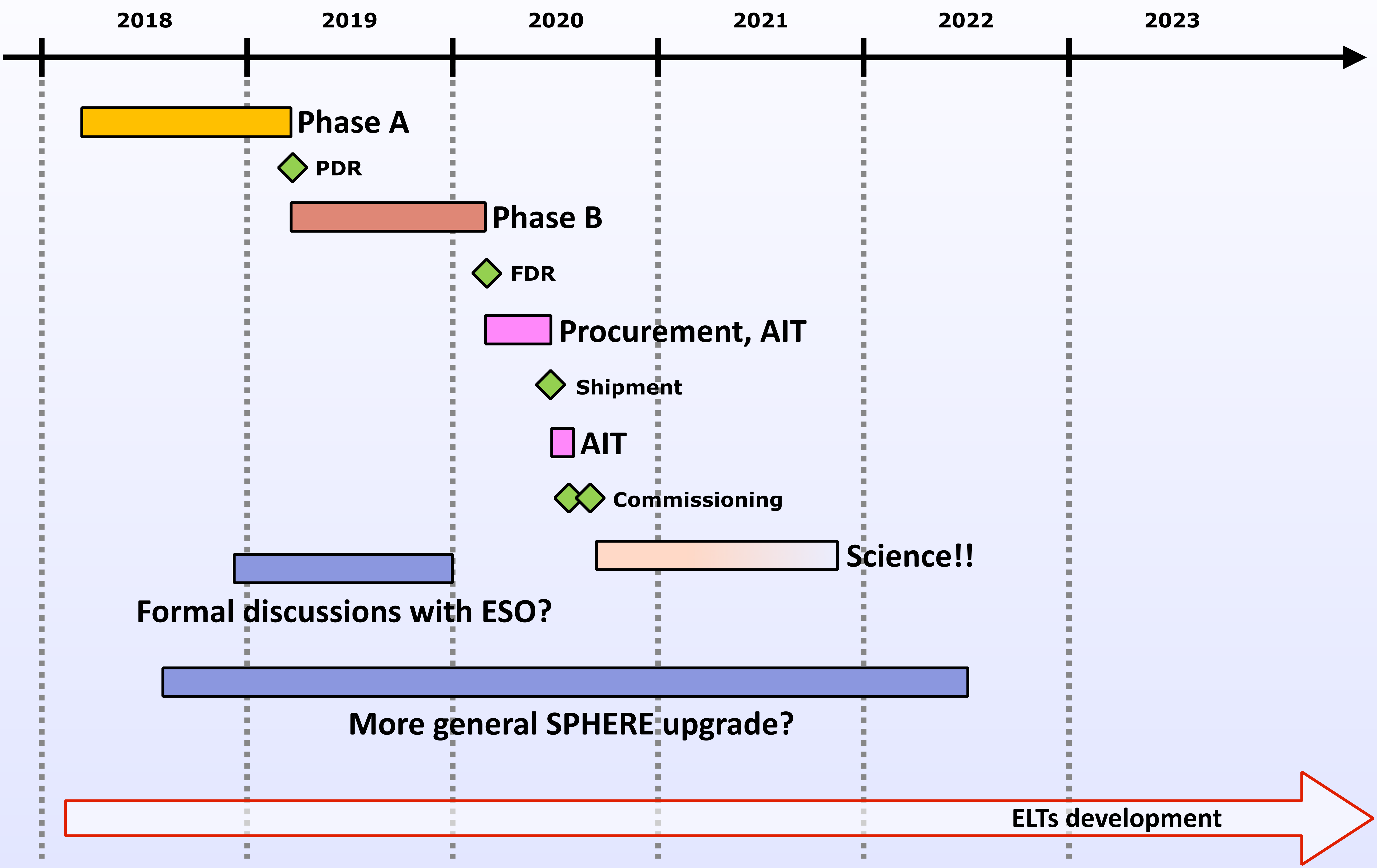
See more in Gilles' presentation!

Performance simulations: results



See more in Gilles' presentation!

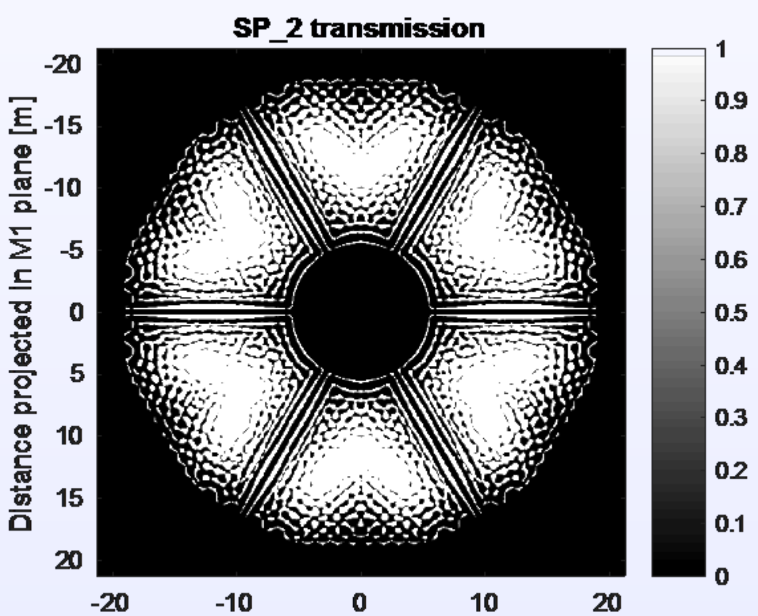
Possible timeline

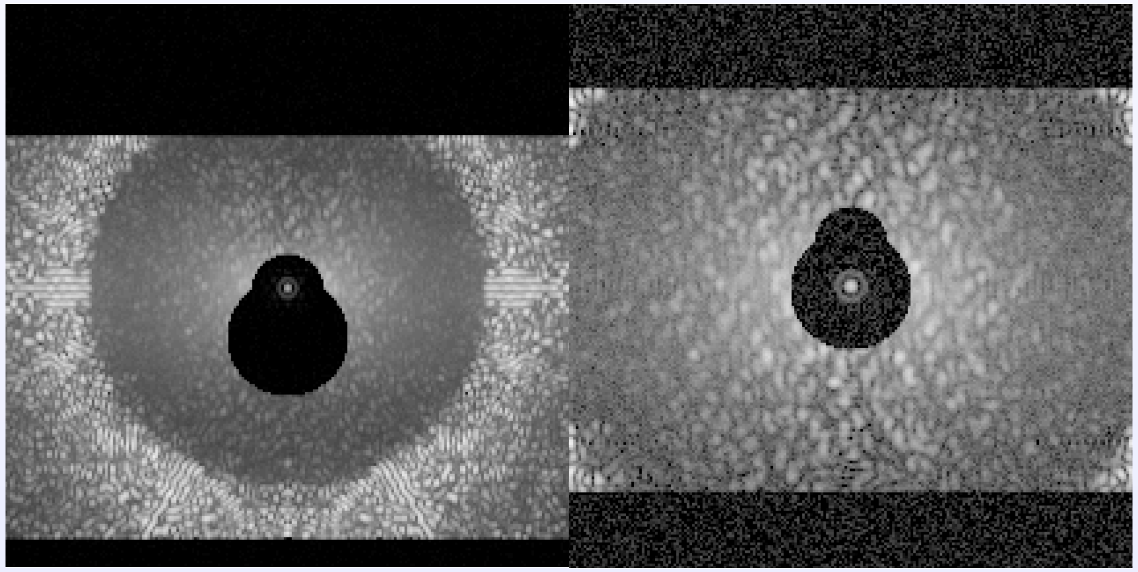


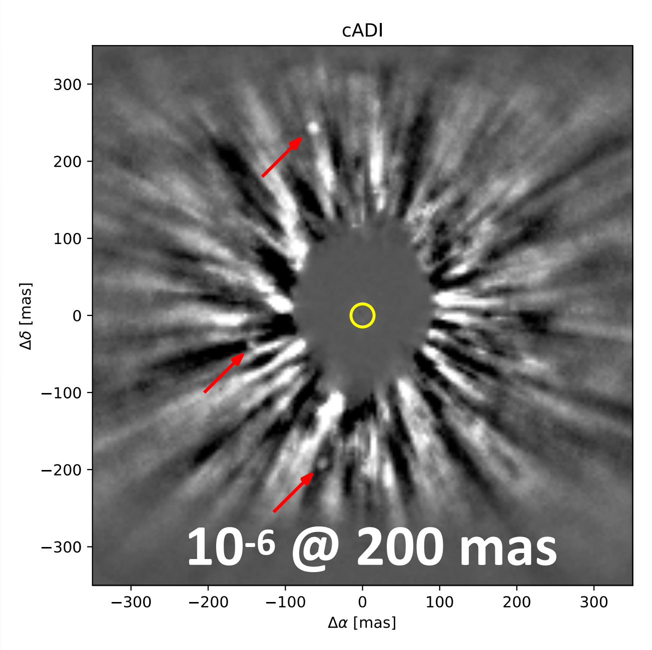
ELT/HARMONI

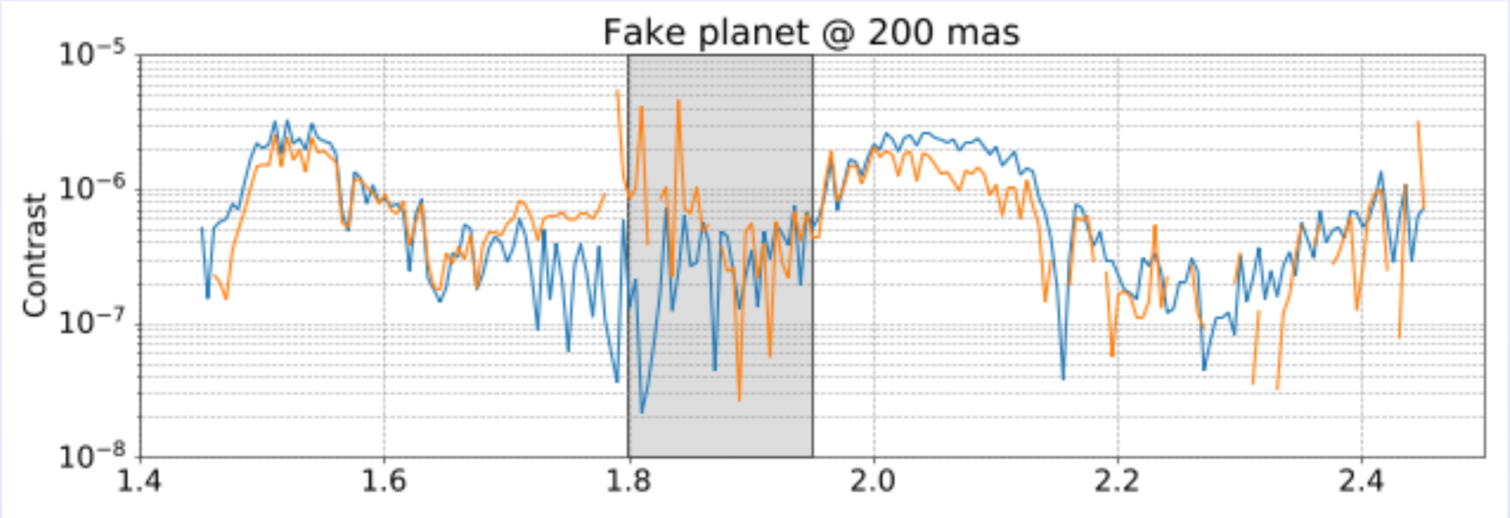
- first light ELT spectrograph
- SCAO
- high-contrast mode (shaped pupil)

Bands	Wavelengths [µm]	R
"V+R" or "I+z+J" or "H+K"	0.45-0.8, 0.8-1.35, 1.45-2.45	~3500
"I+z" or "J" or "H" or "K"	0.8-1.0, 1.1-1.35, 1.45-1.85, 1.95-2.45	~7000
"Z" or "J_high" or "H_high" or "K_high"	0.9, 1.2, 1.65, 2.2 (TBD)	~18000



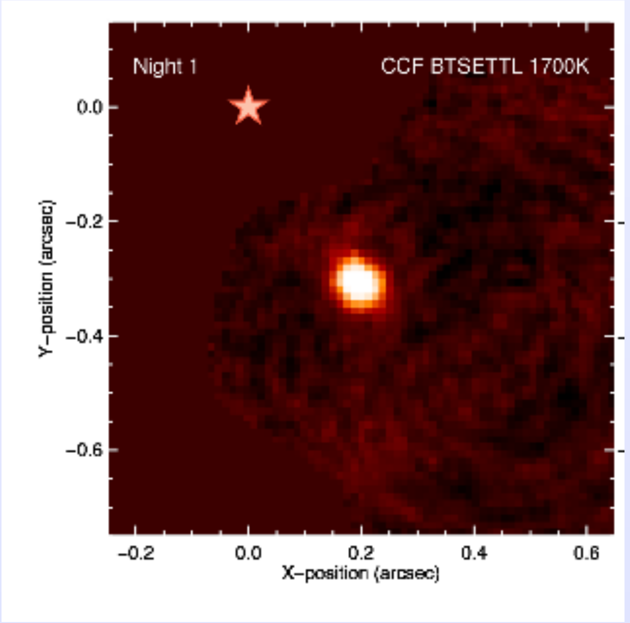






ANDROMEDA ADI analysis

Next step

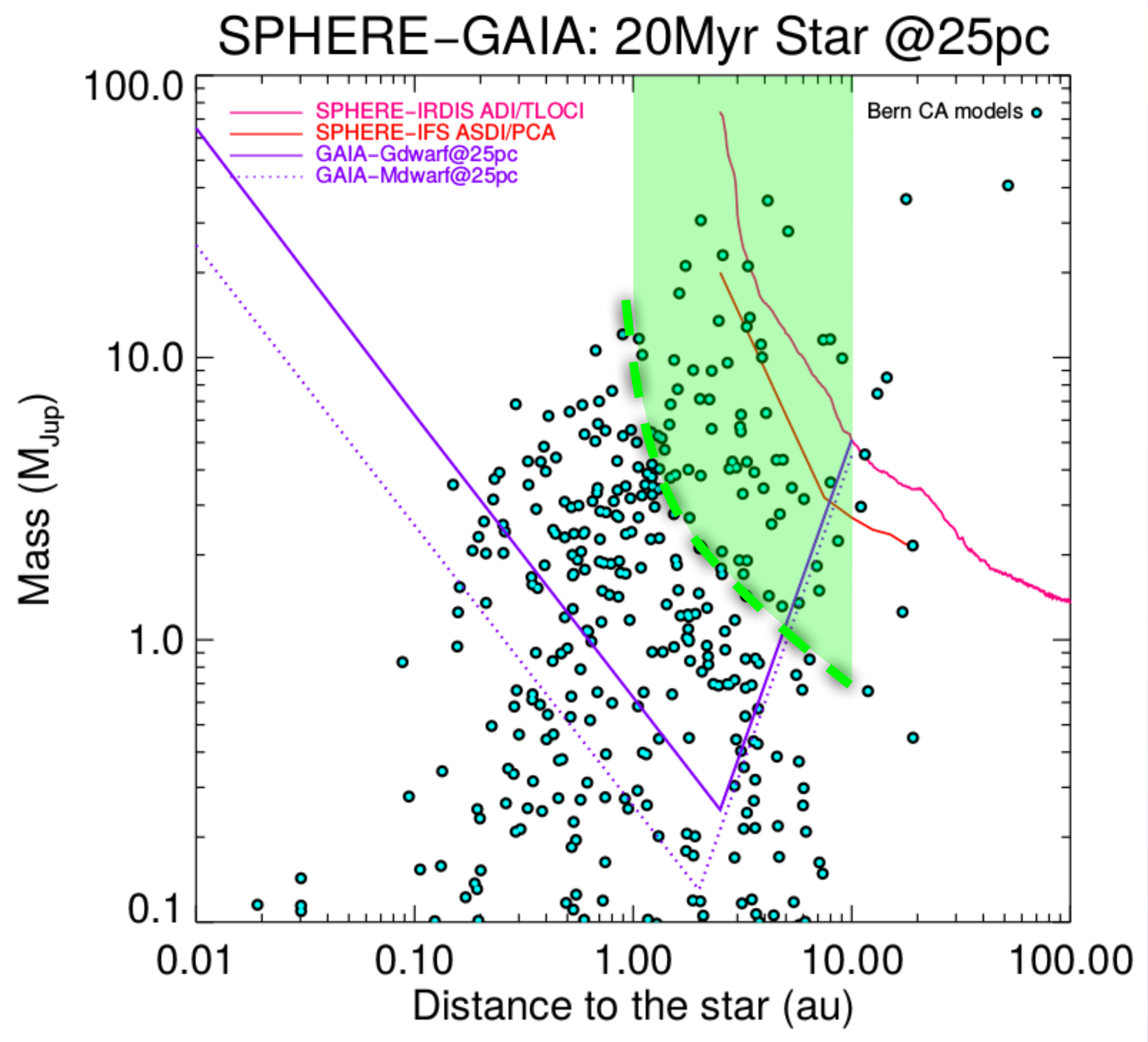


Hoeijmakers et al. 2018

ELT/HARMONI

HARMONI - Gaia / HARMONI - RV synergies

Mass - luminosity relationships !



Conclusions

- SPHERE and CRIRES+ is an opportunity to try testing HDC
- SPHERE / CRIRES+ coupling on-going
  - optical design almost ready
  - mechanical design starting
- Retrofiting instruments is not easy...
  - designing a system that does not interfere with the instrument
  - available space in SPHERE
  - throughput issues
  - very long length of NIR fibre
  - operational model
- Project not formally accepted by ESO yet
  - discussions will start at the end of phase A

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