

Direct characterization of young giant exoplanets at high spectral resolution

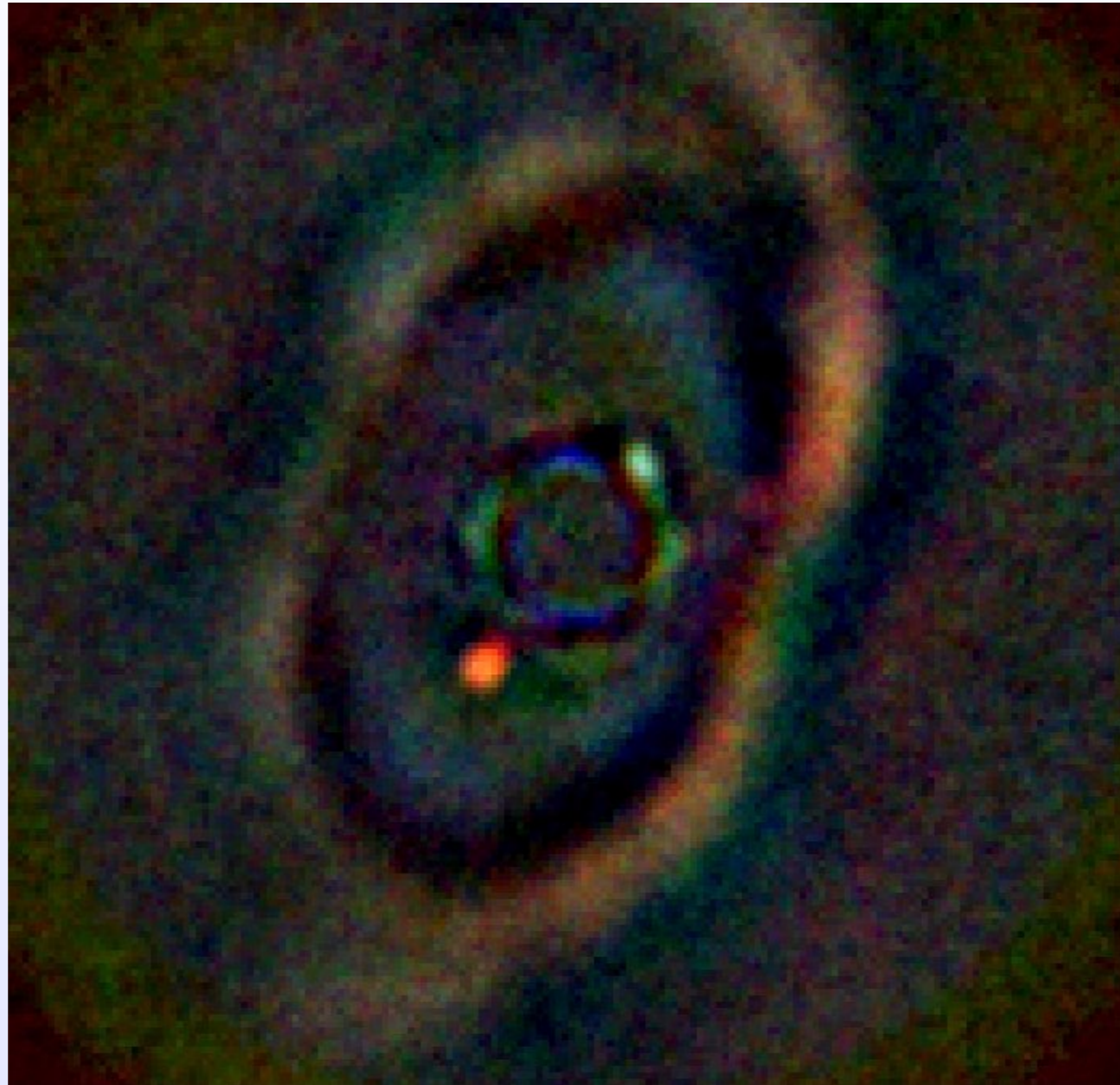
Arthur Vigan

Laboratoire d'Astrophysique de Marseille (LAM)
Centre National de la Recherche Scientifique (CNRS)

LAM: A. Vigan, M. El Morsy, M. Lopez, G. Otten, J. Garcia, J. Costes, E. Muslimov, A. Viret, Y. Charles, A. Costille, M. Houllé, A. Abinanti, P. Balard, J.-A. Benedetti, P. Blanchard, J.-L. Beuzit, E. Choquet, P. Cistofari, K. Dohlen, T. Ely, N. Garcia, M. Jaquet, F. Jaubert, J. Le Merrer, R. Pourcelot, C. Sehim, N. Tchoubaklian, P. Tomlinson / **University of Göttingen:** H. Anwand-Heerwart, A. Reiners / **ESO Charching:** G. Zins, J. Paufique, U. Seemann, R. Dorn, M. Kasper, D. Popovic / **ESO Paranal:** L. Blanco, E. Fuenteseca, L. Pallanca, R. Schmutzer, A. Smette, J. Valenzuela Soto / **University of Exeter:** M. Phillips, I. Baraffe / **Laboratoire Lagrange:** M. N'Diaye, R. Pourcelot / **Durham:** G. Murray / **Padova:** S. Desidera / **IPAG:** A.-L. Maire, S. Rochat

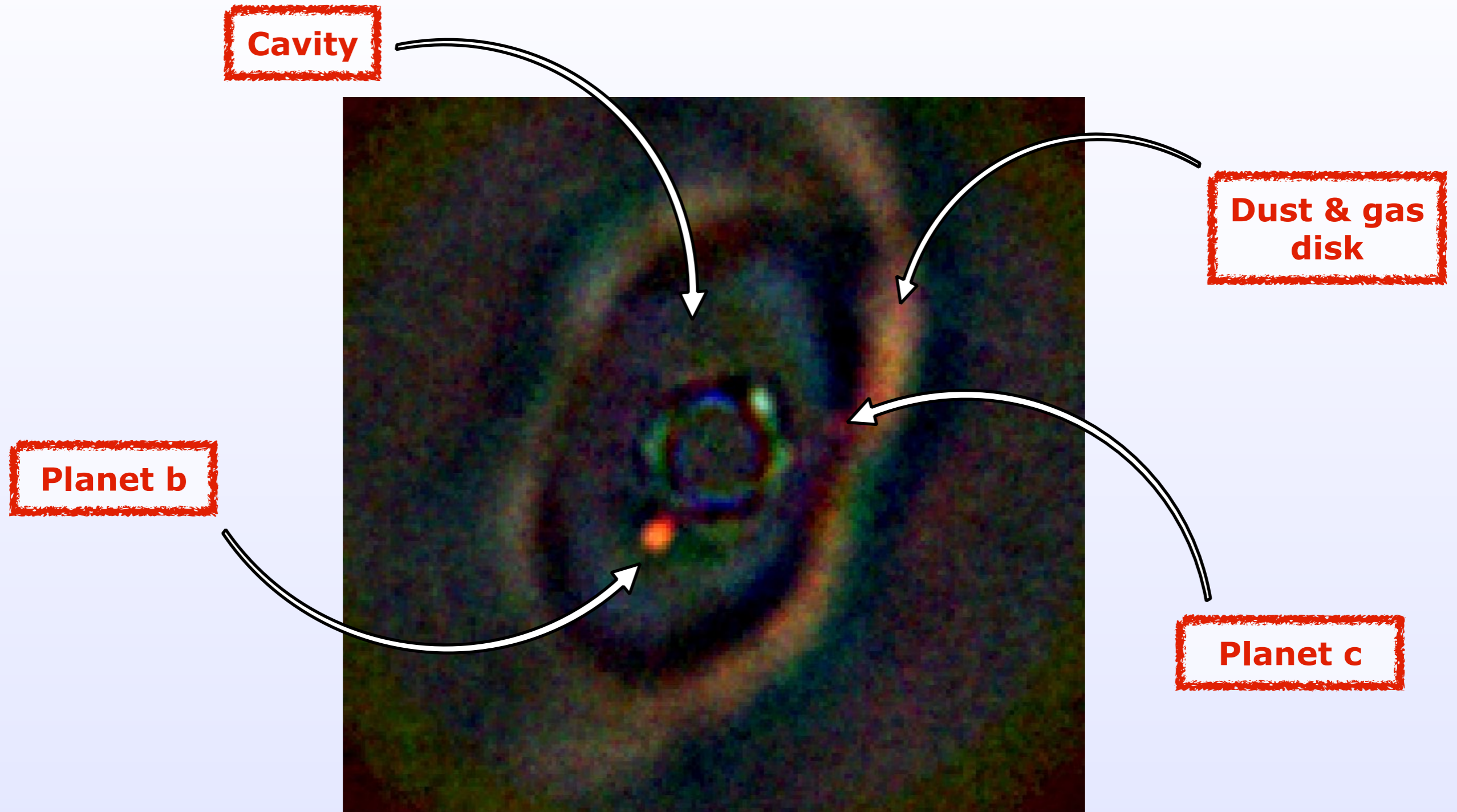


Direct imaging of exoplanetary systems



PDS 70 - Keppler et al. (2018)

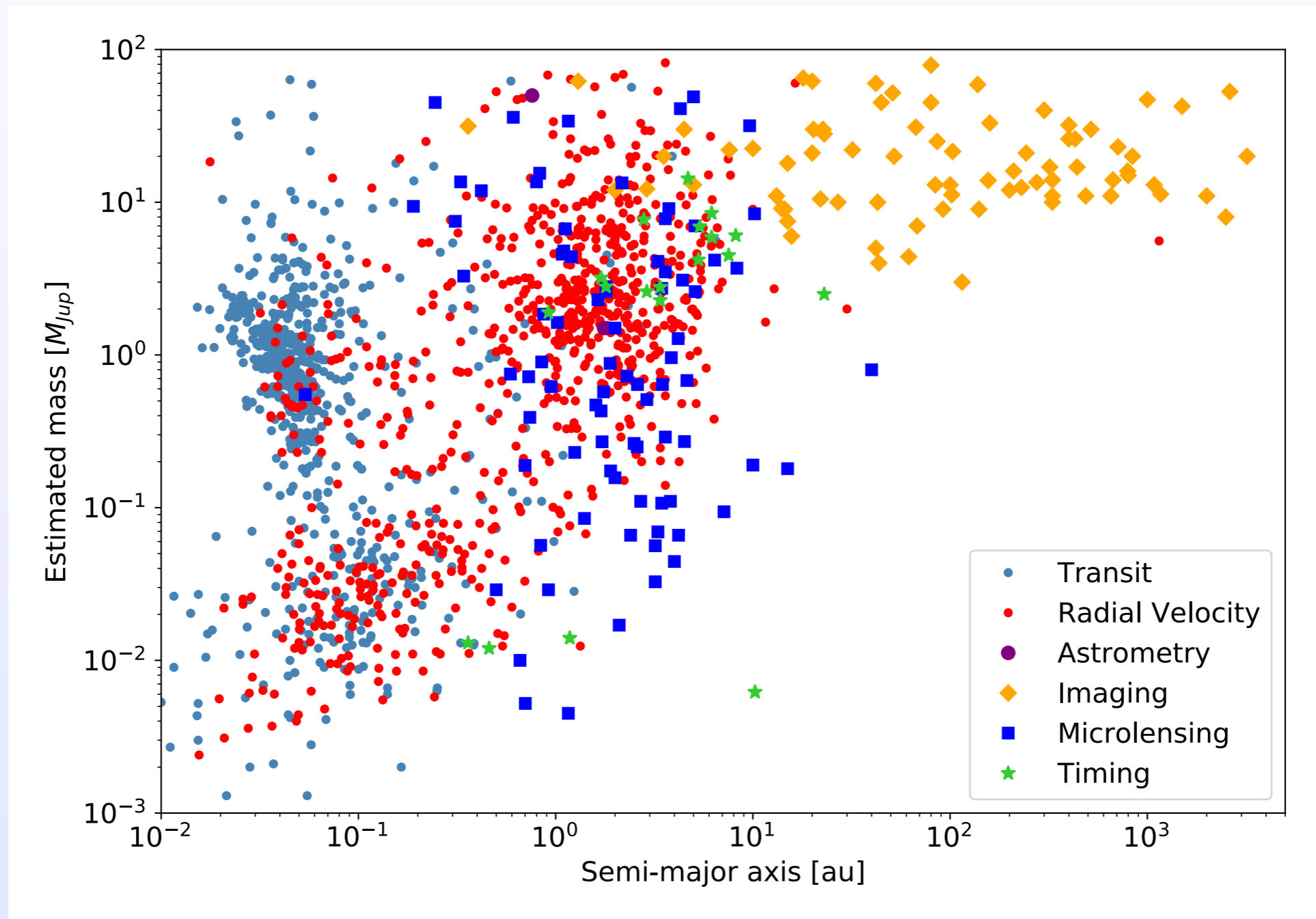
Direct imaging of exoplanetary systems



PDS 70 - Keppler et al. (2018)

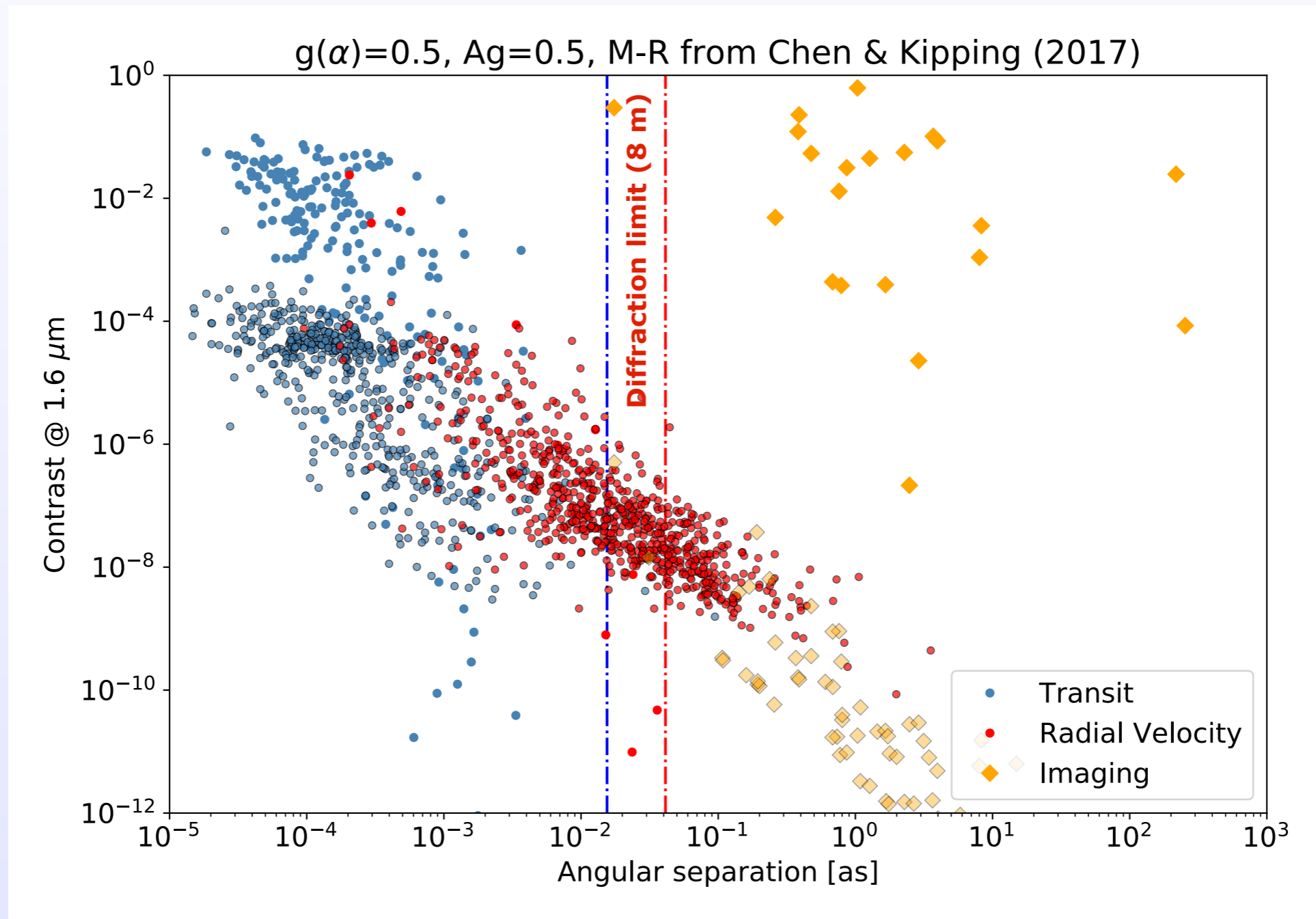
Direct imaging: the challenge

Physical units



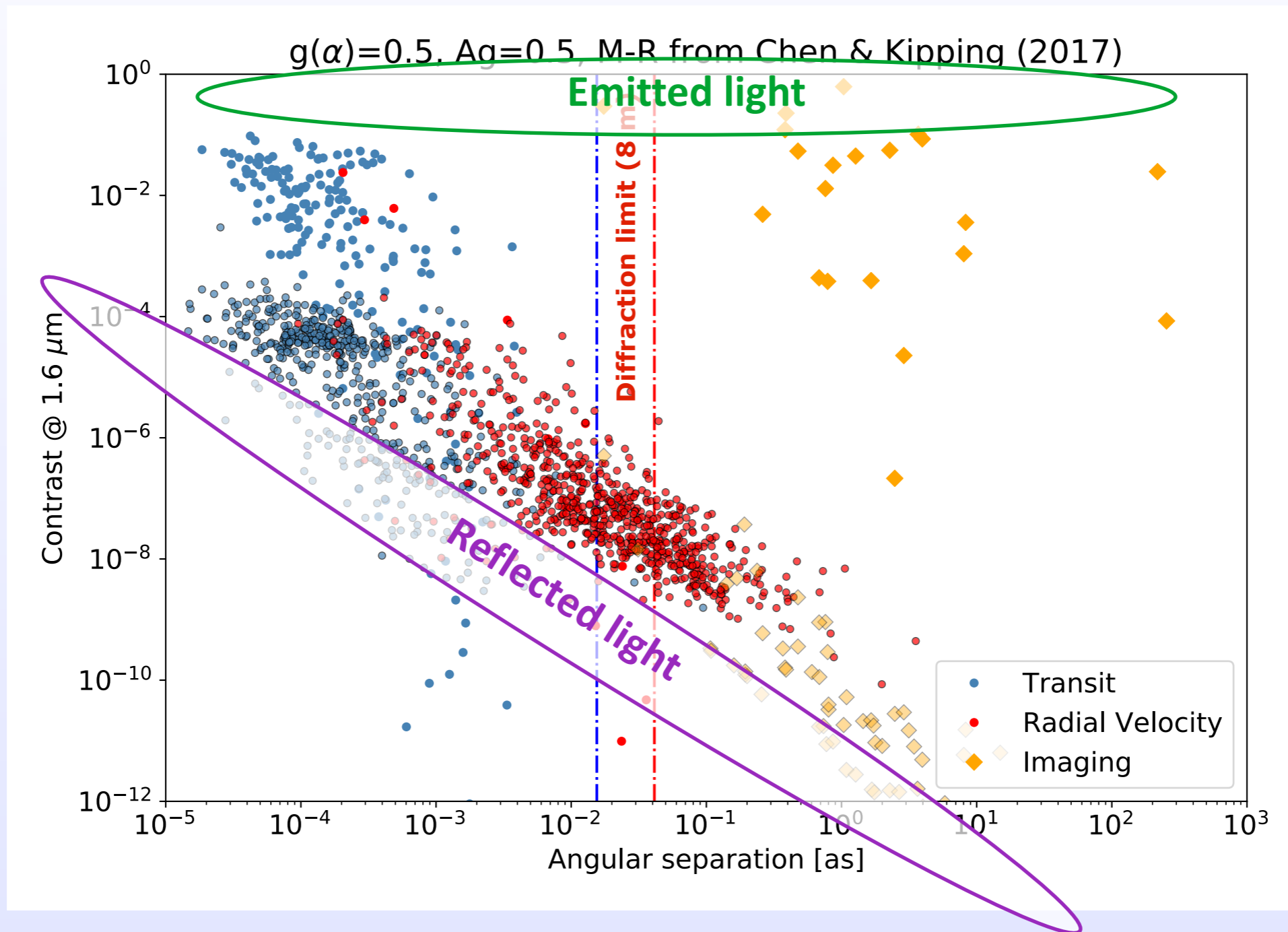
Direct imaging: the challenge

Observables



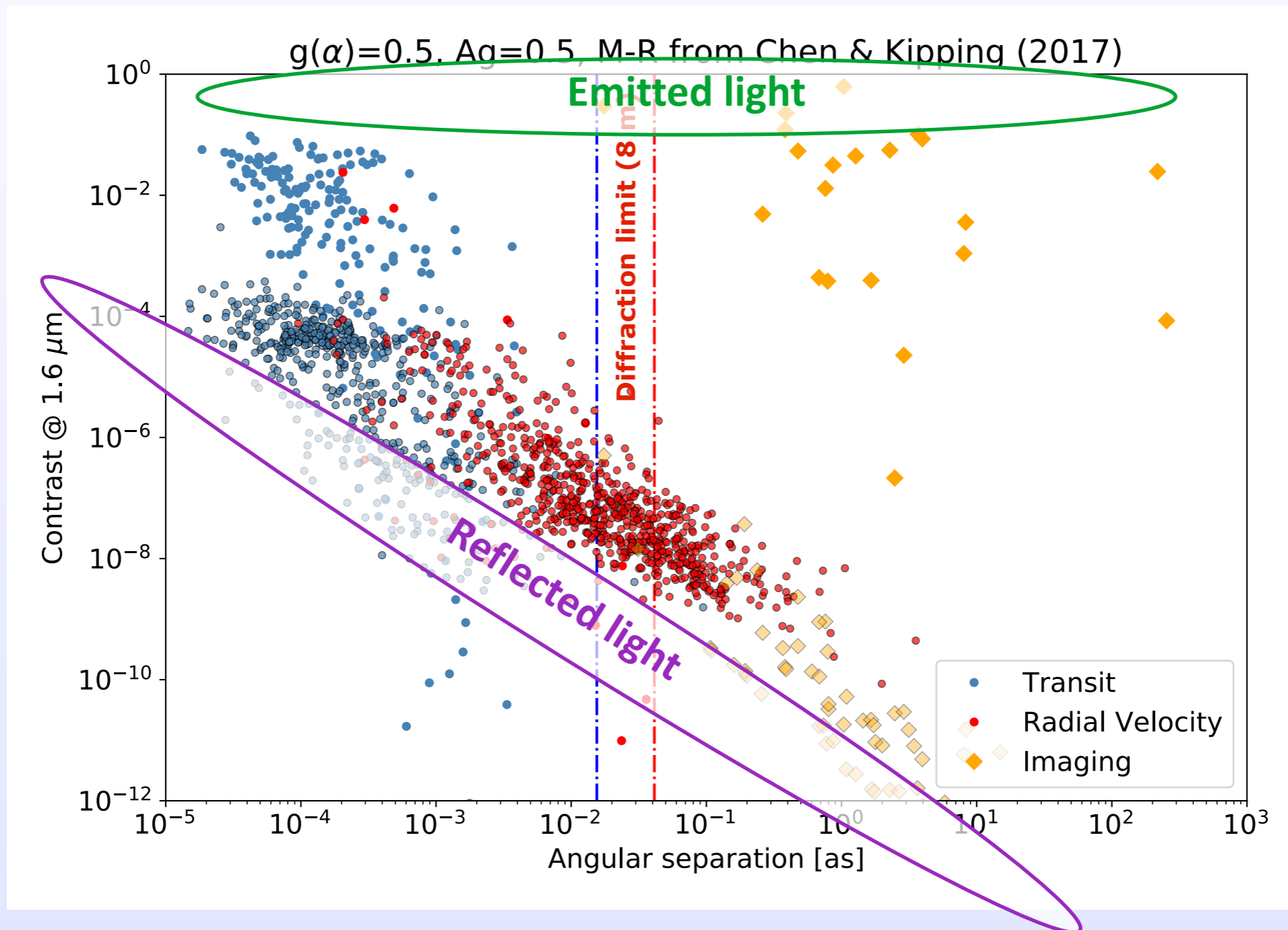
Direct imaging: the challenge

Observables



Direct imaging: the challenge

High-angular resolution

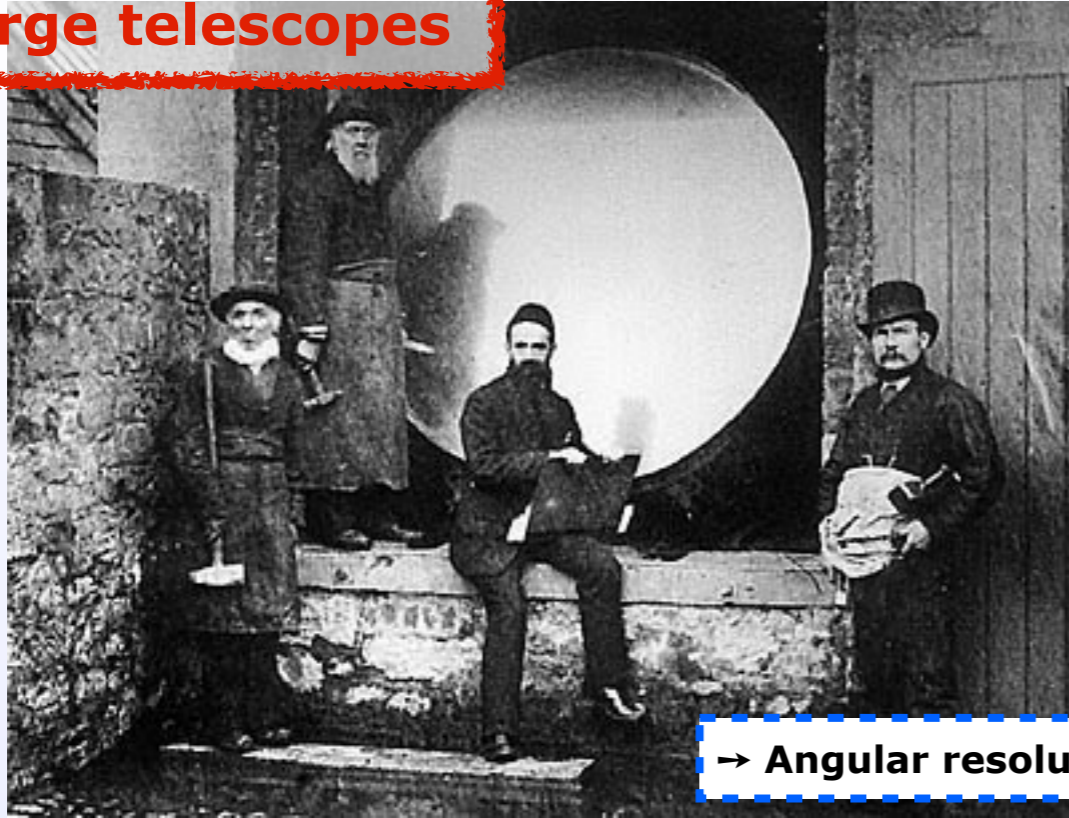


High-contrast

Direct imaging recipe

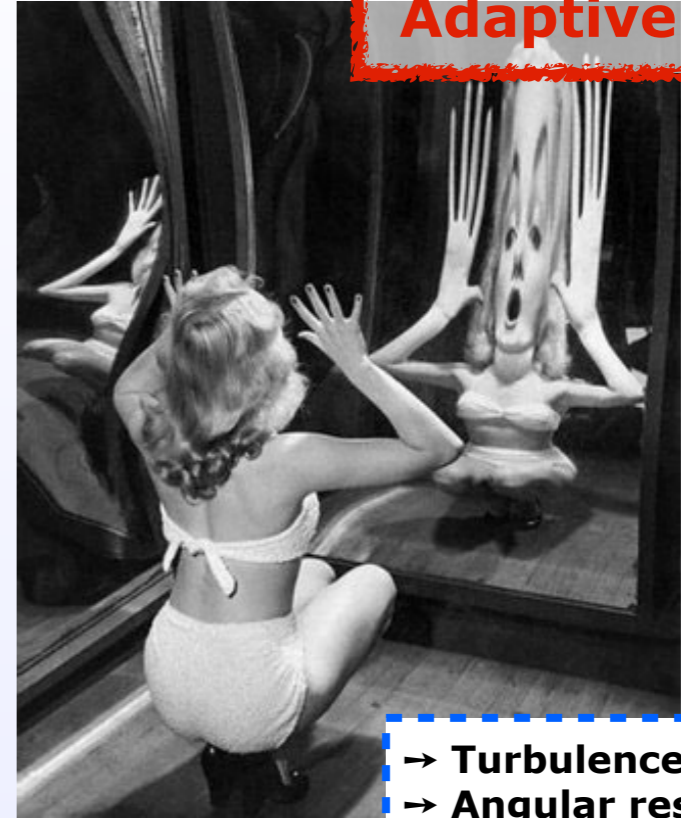
Direct imaging recipe

Large telescopes



→ Angular resolution

Adaptive optics



→ Turbulence correction
→ Angular resolution

→ Contrast



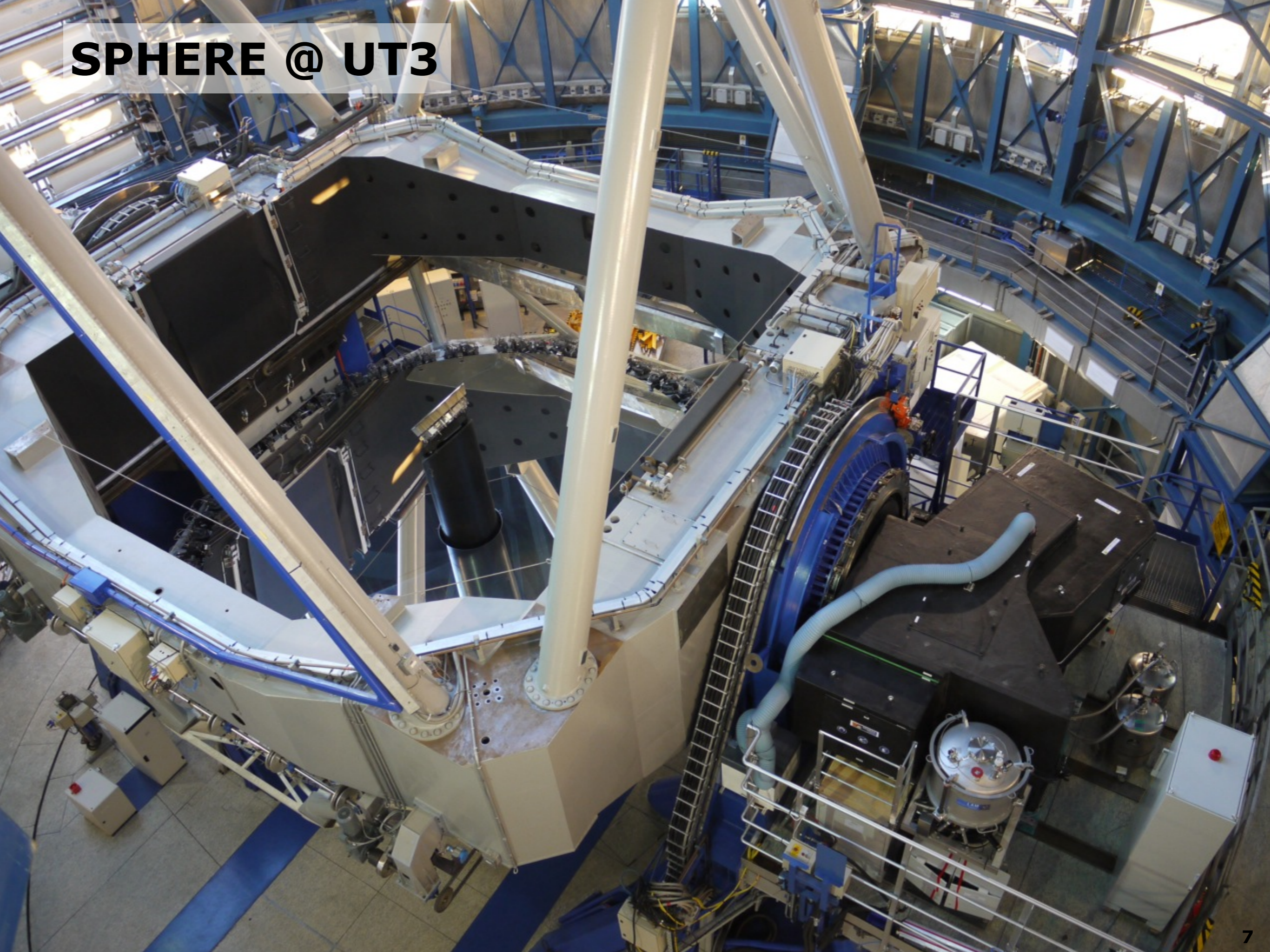
Algorithms

→ Contrast

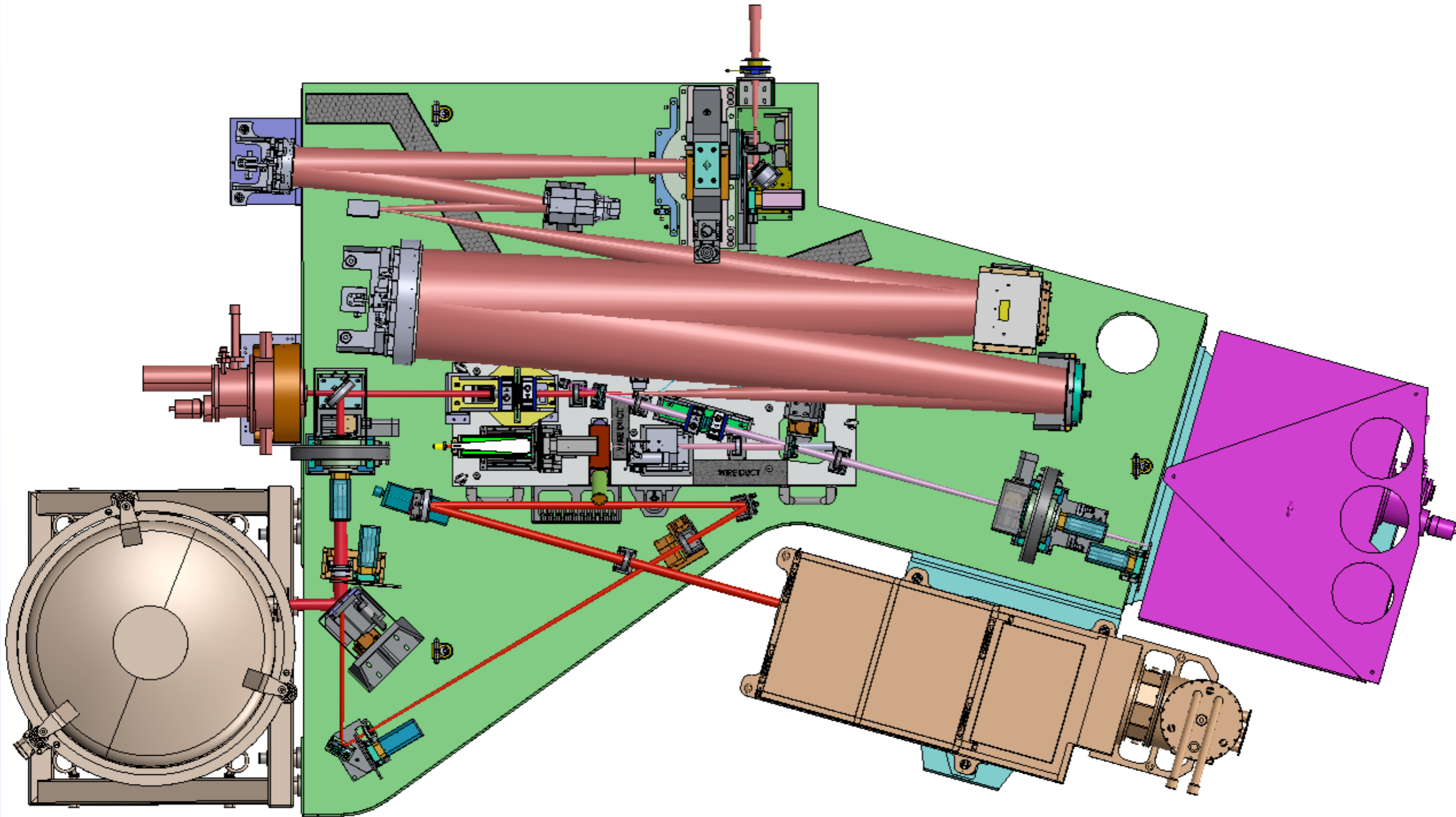


Coronagraphs

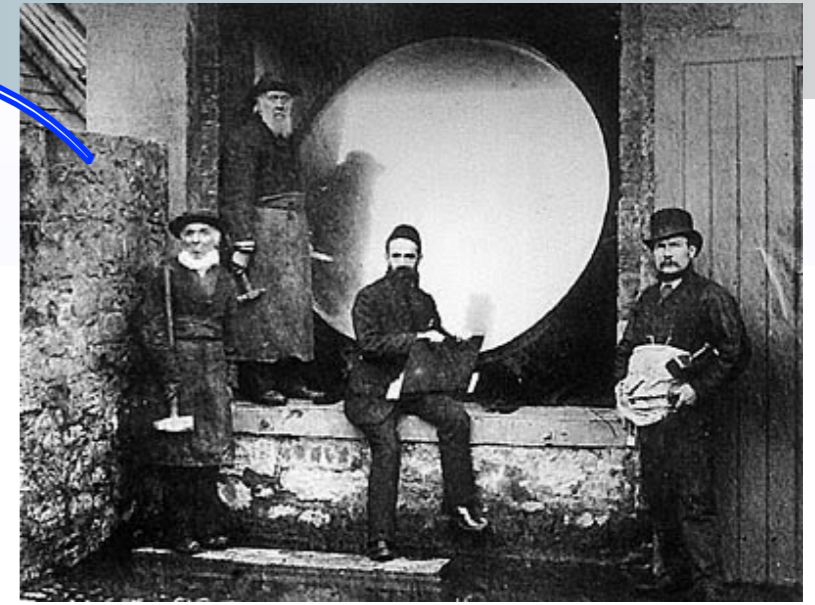
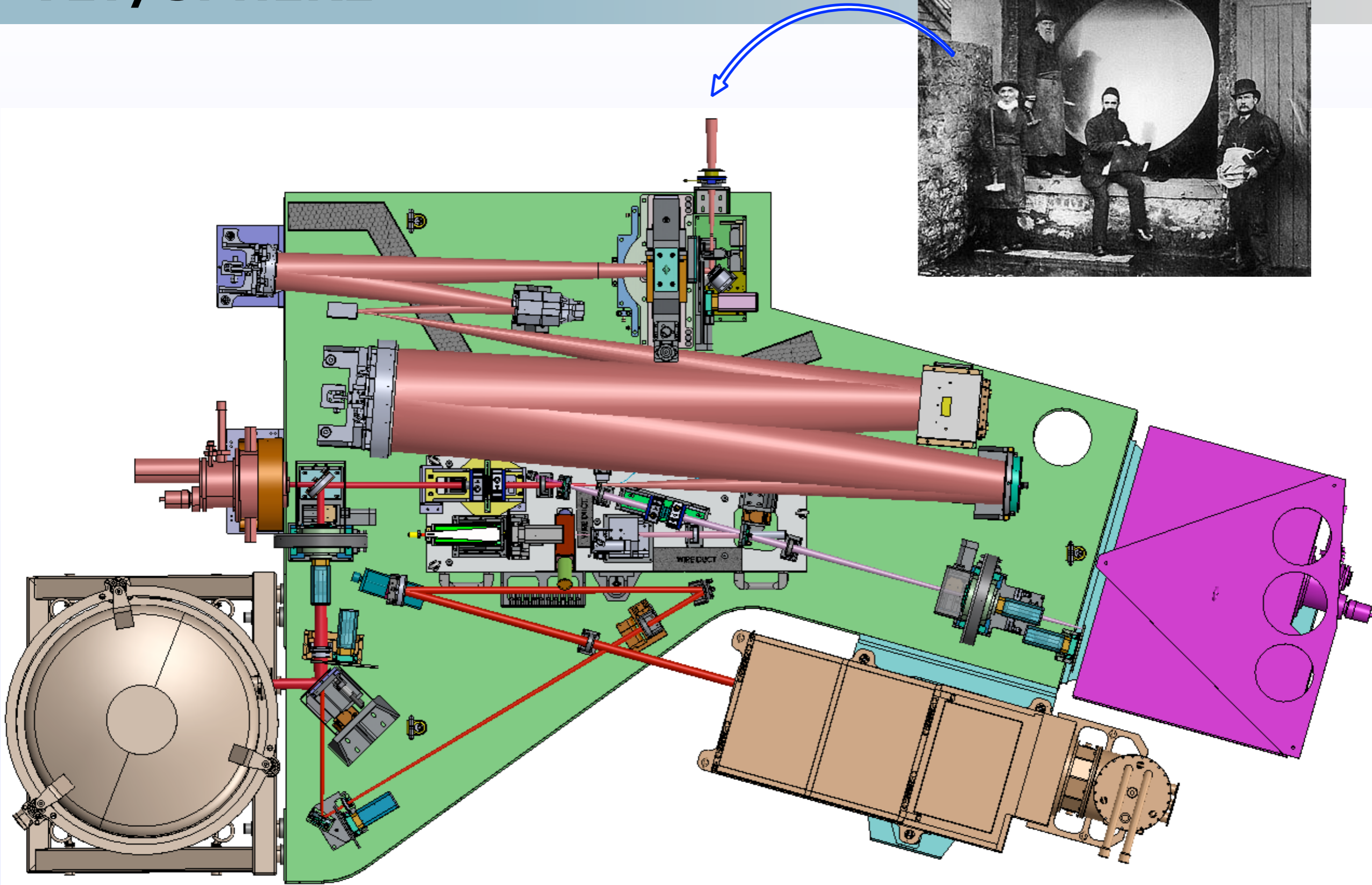
SPHERE @ UT3



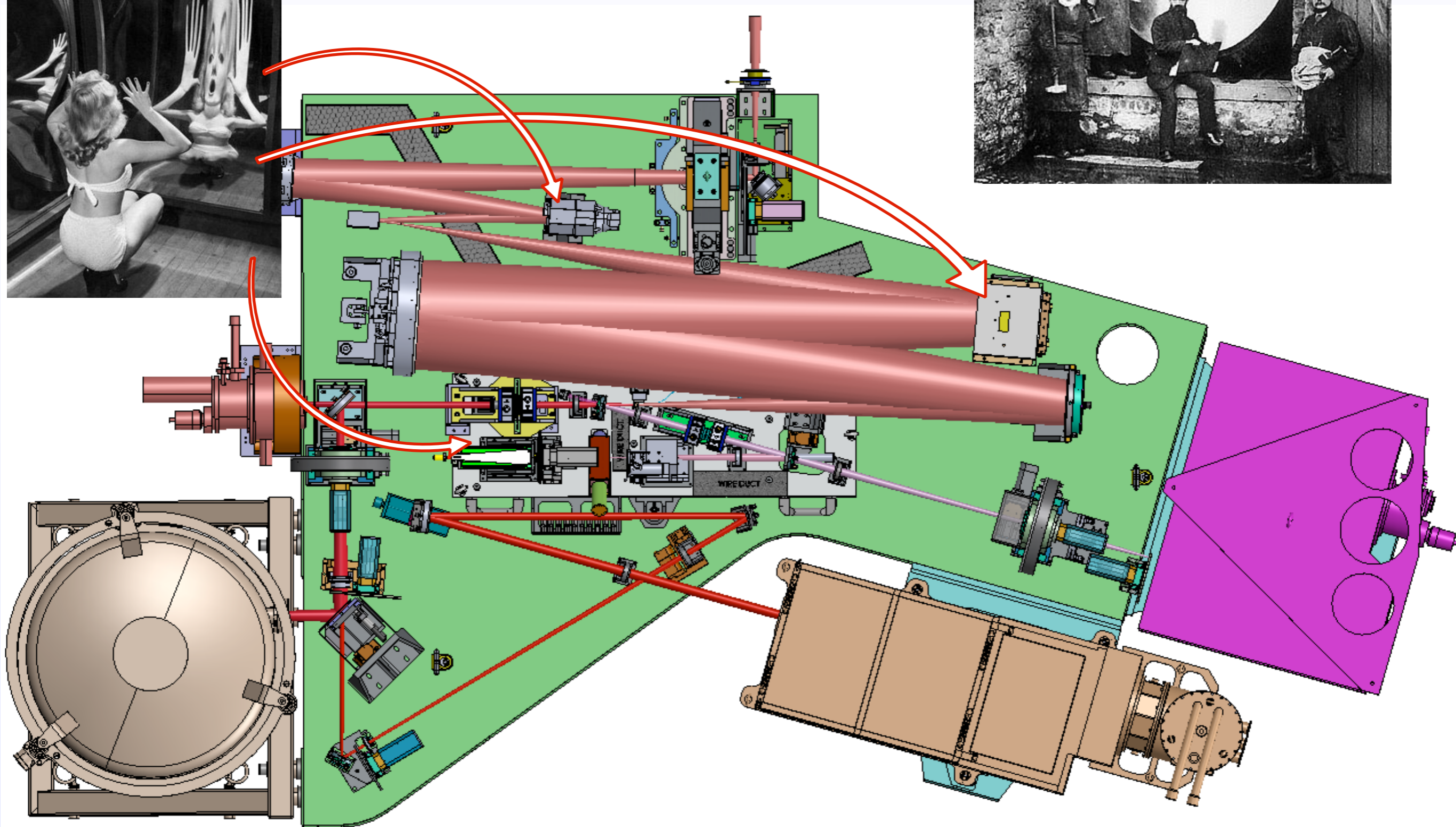
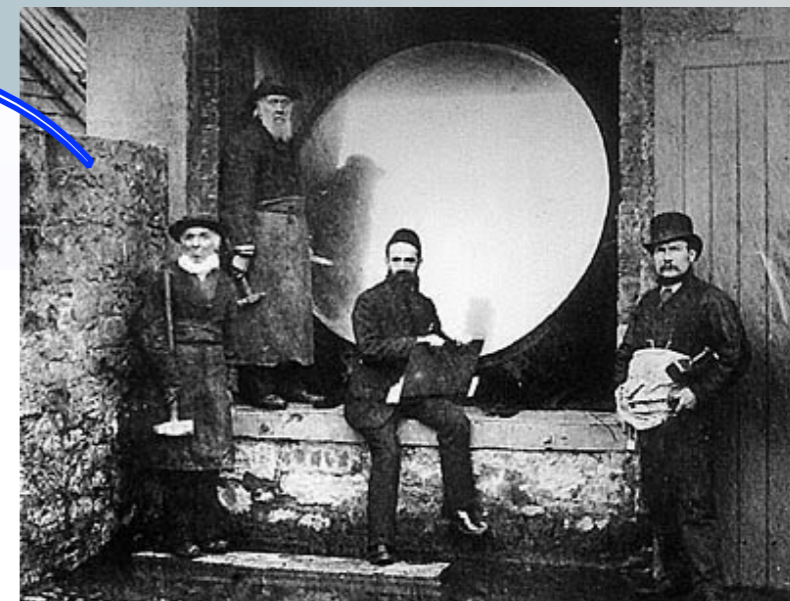
VLT/SPHERE



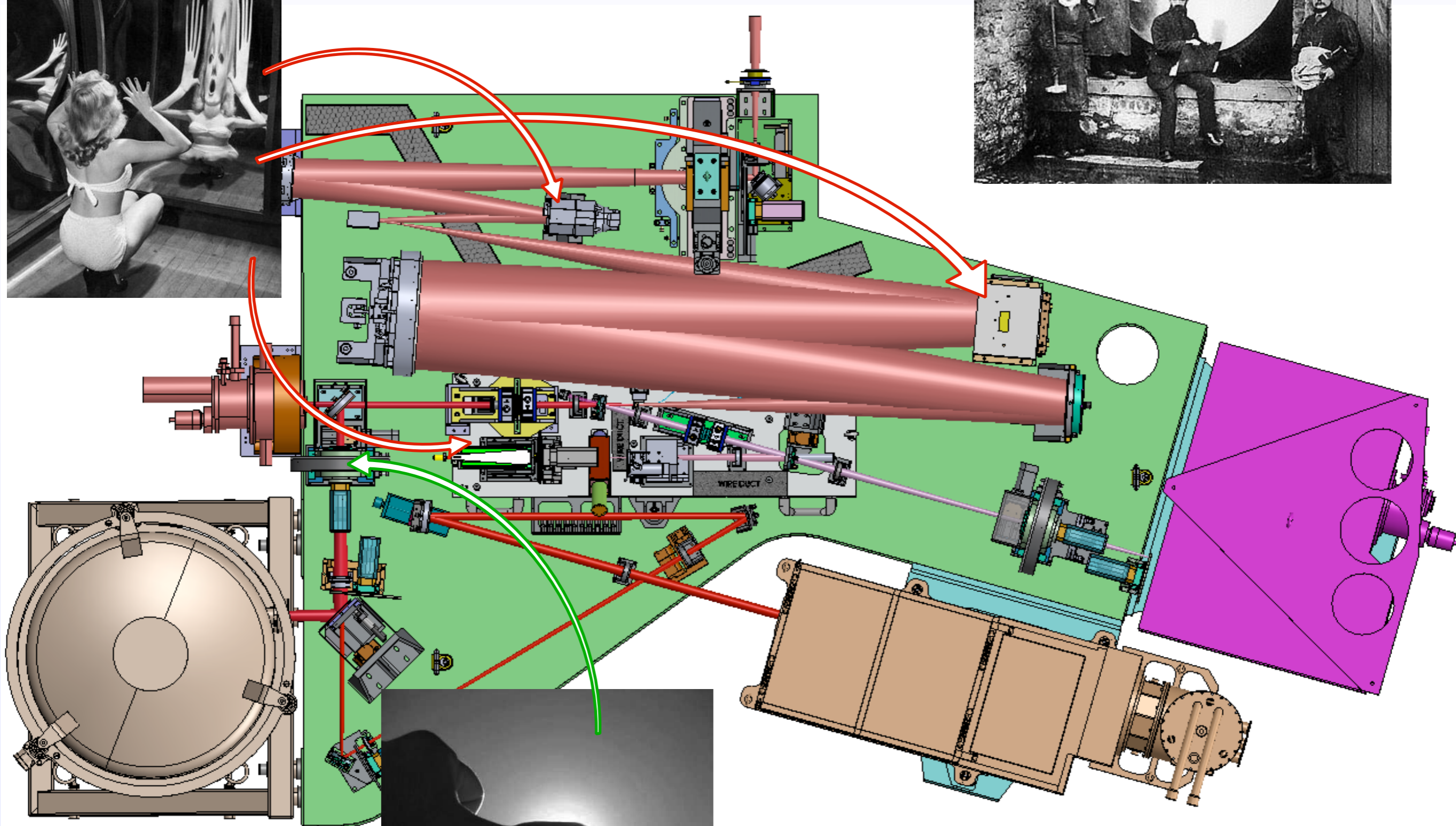
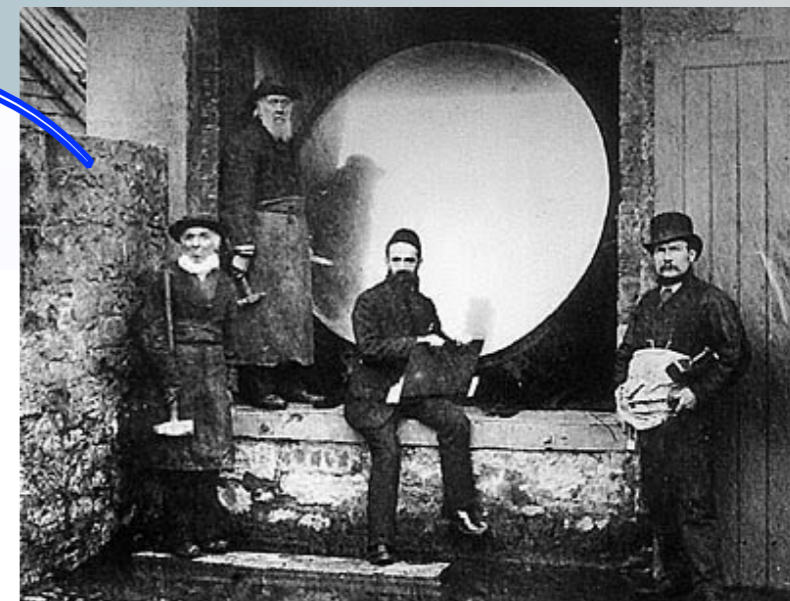
VLT/SPHERE



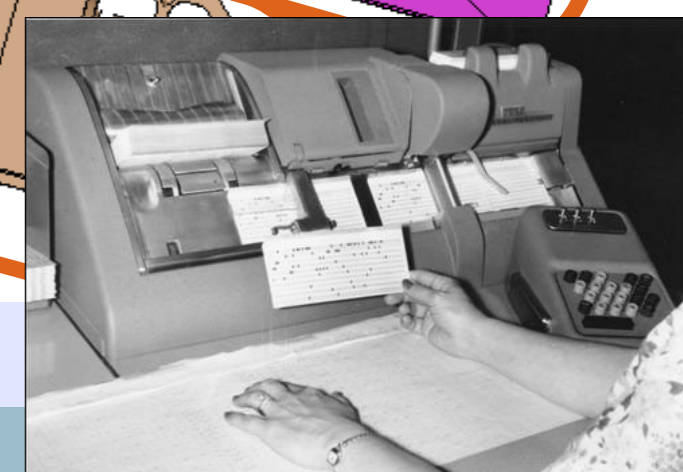
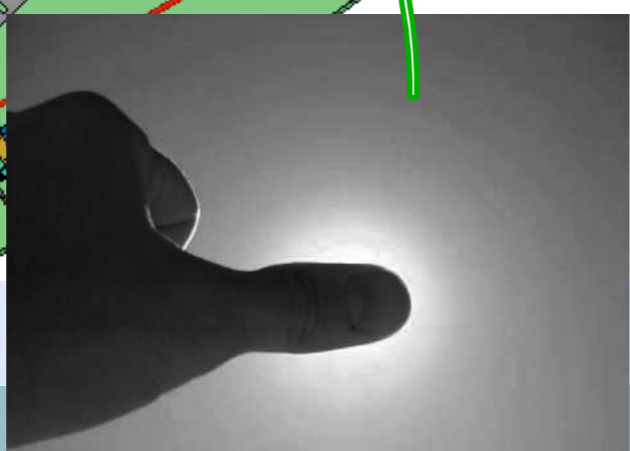
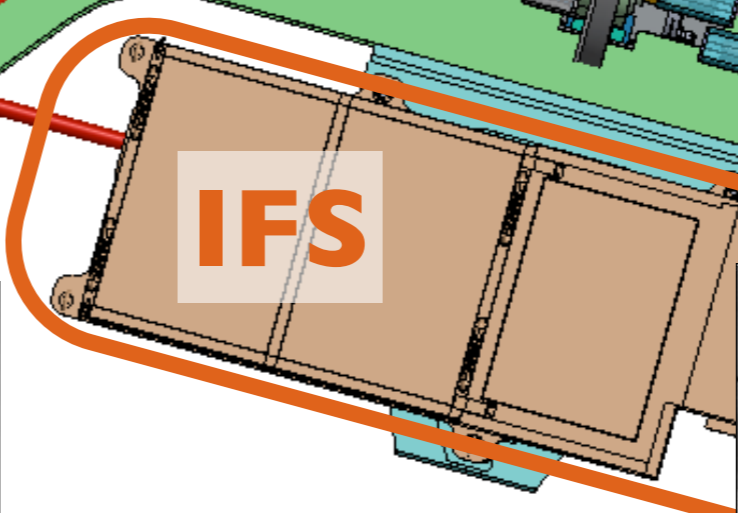
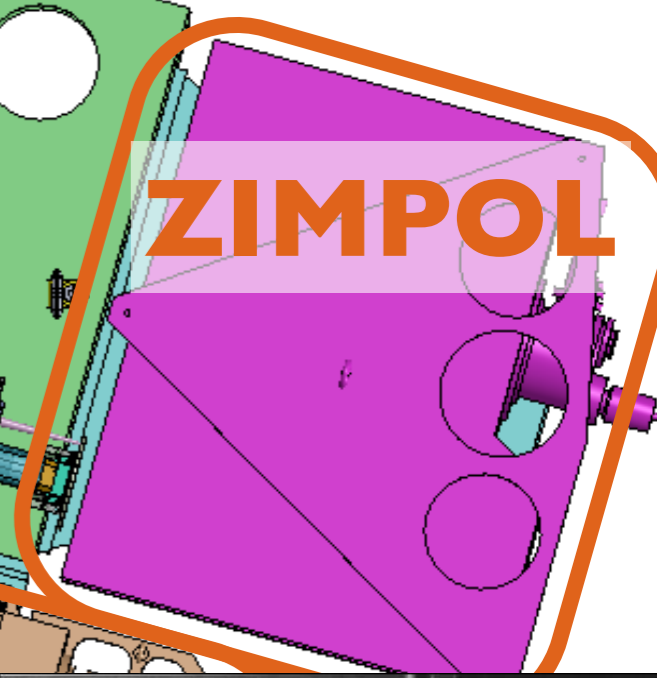
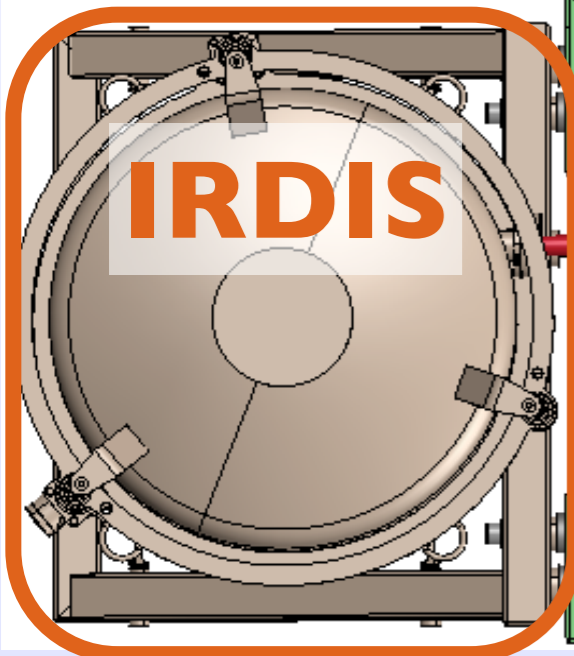
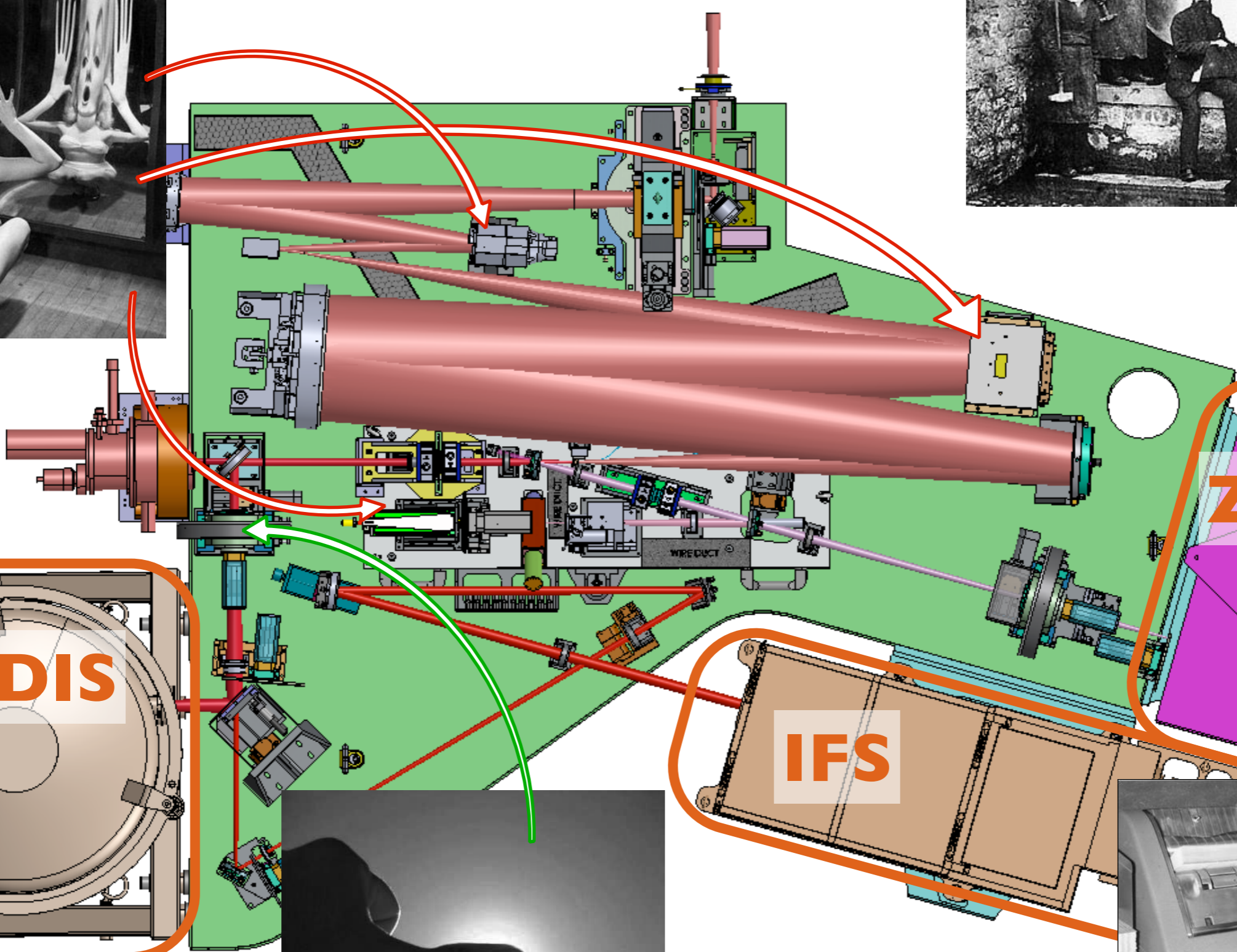
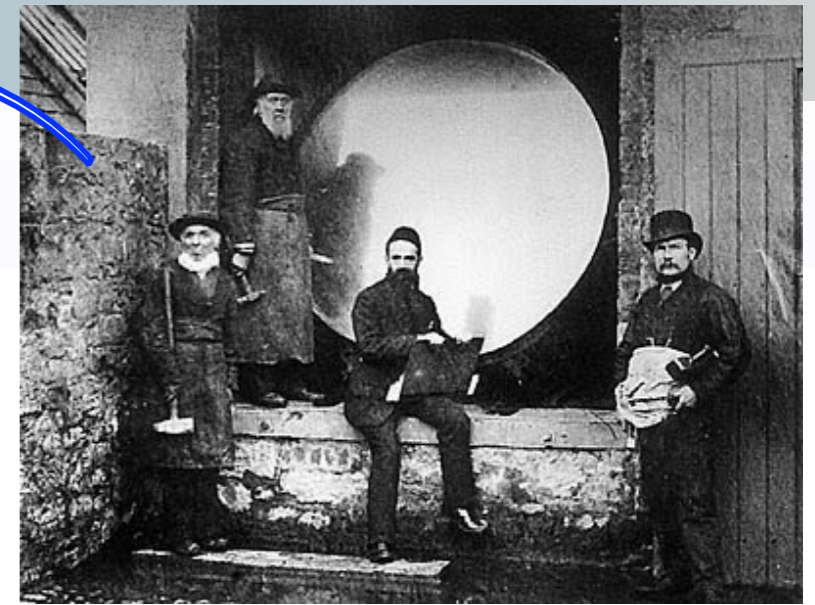
VLT/SPHERE



VLT/SPHERE



VLT/SPHERE



Direct imaging recipe

Seeing-limited PSF

✗ Adaptive optics
✗ Coronagraph

Diffraction-limited PSF

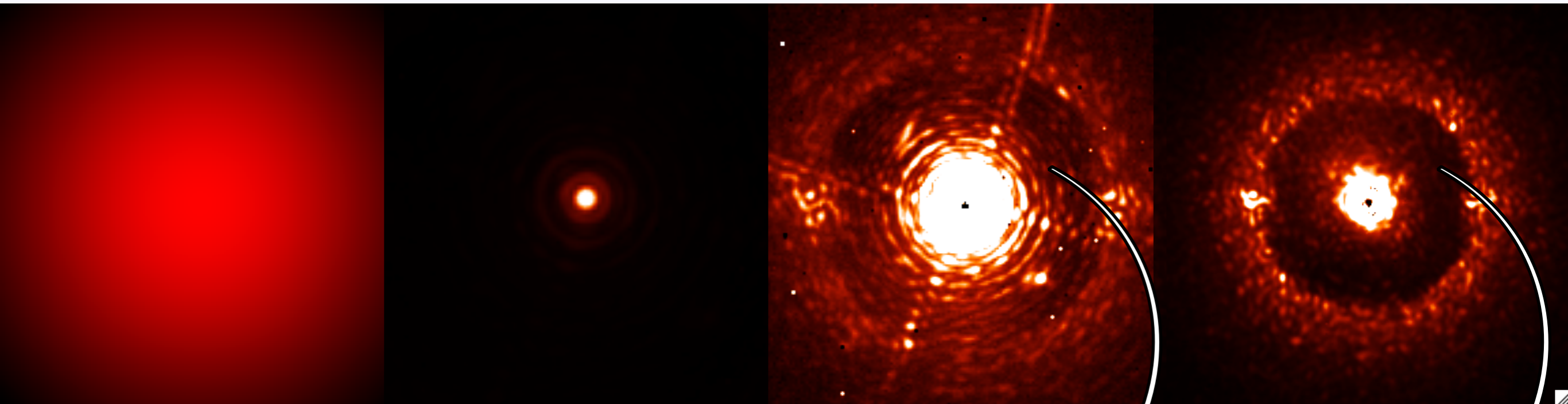
✓ Adaptive optics
✗ Coronagraph

Diffraction-limited PSF

✓ Adaptive optics
✗ Coronagraph

Coronagraphic image

✓ Adaptive optics
✓ Coronagraph

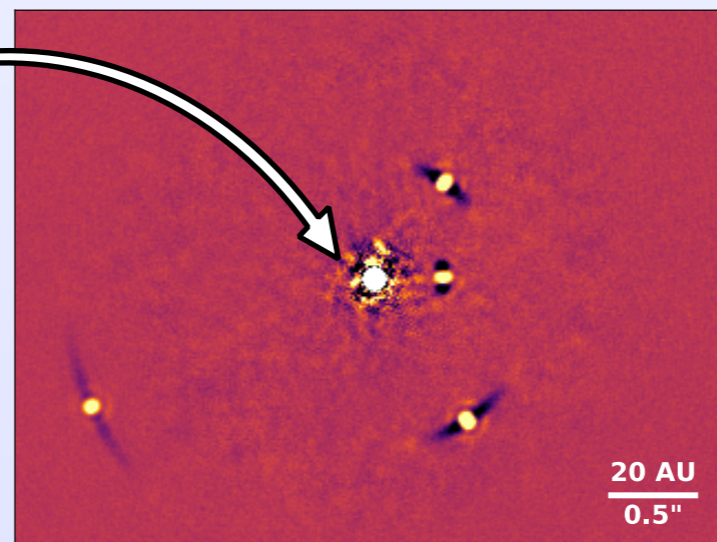


Diffraction limited
within $20 \lambda/D$

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

$\sim 10^{-5}$ - 10^{-6} contrast down to $0.2''$

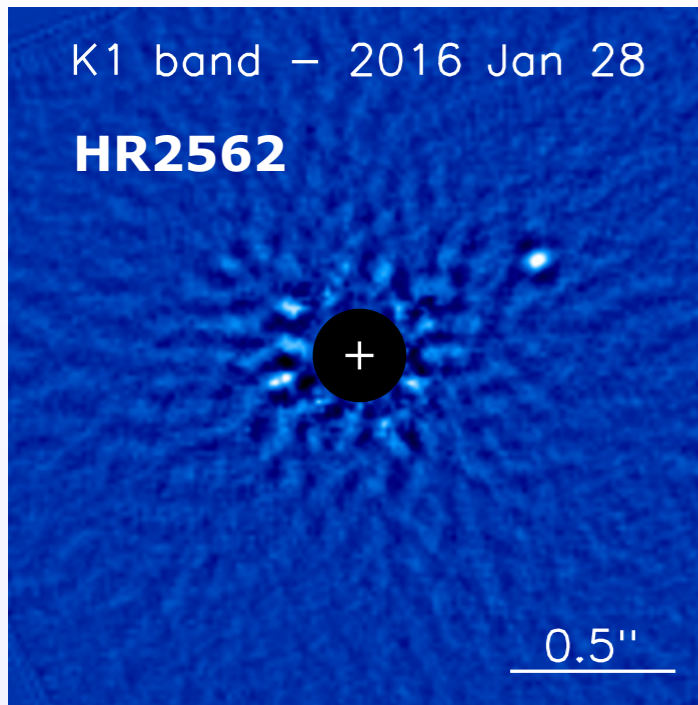
Enough to detect young giant exoplanets
of a few Jupiter masses



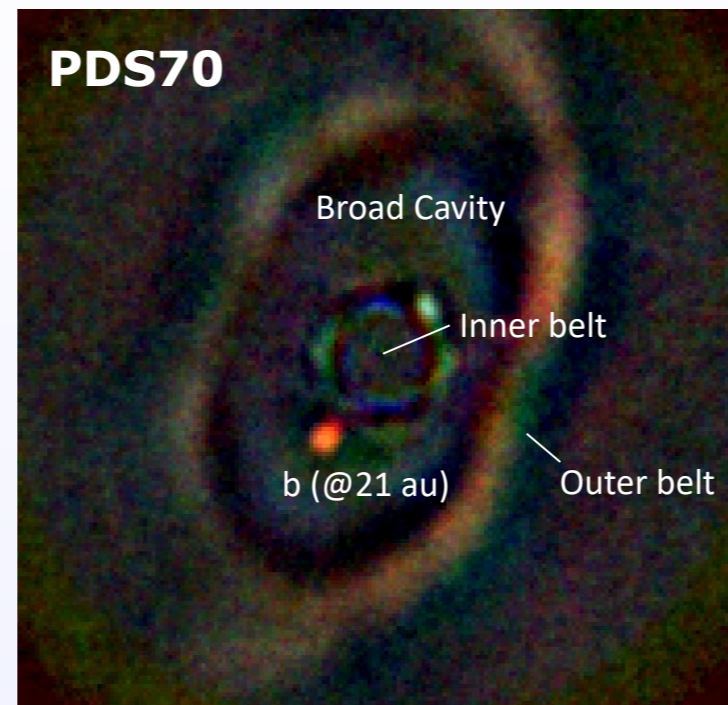
post-processing

Populations analysis

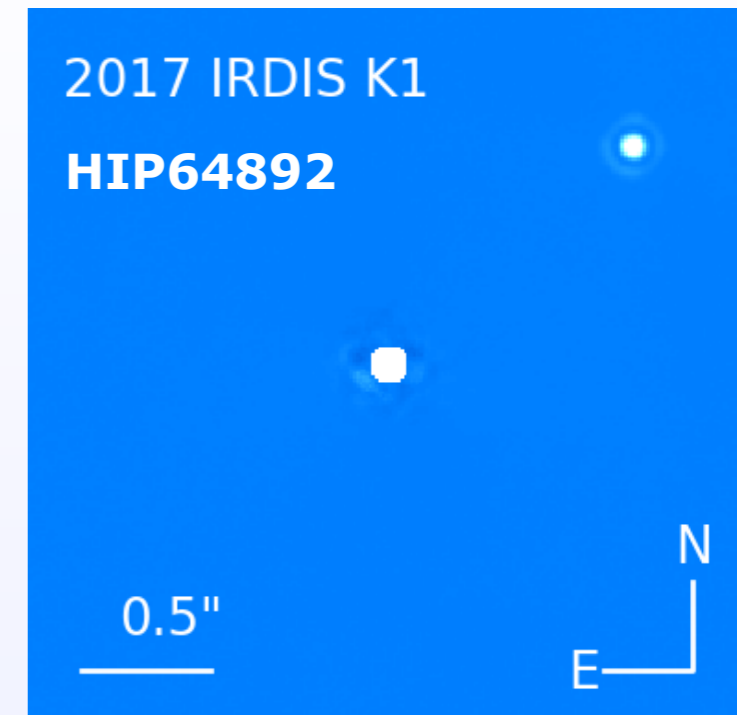
Nielsen et al. (2019)
Vigan et al. (2021)



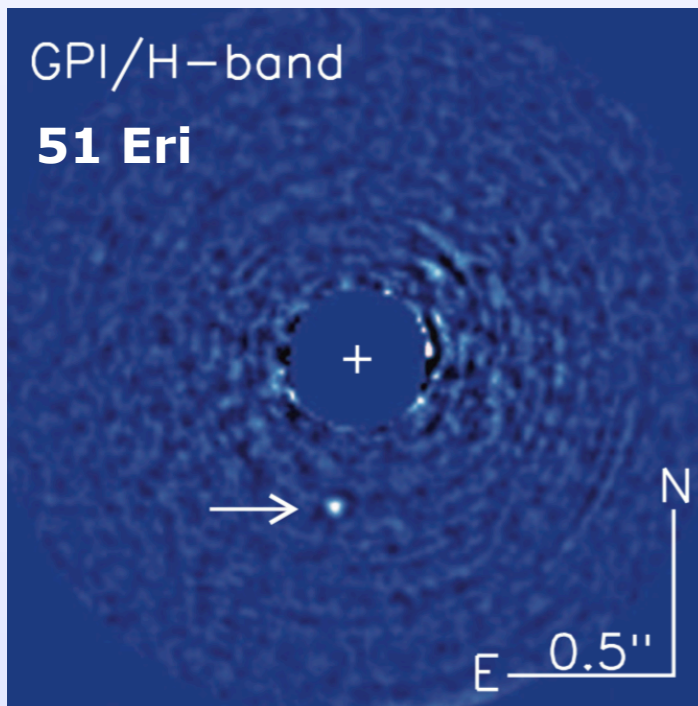
Konopacky et al. 2016



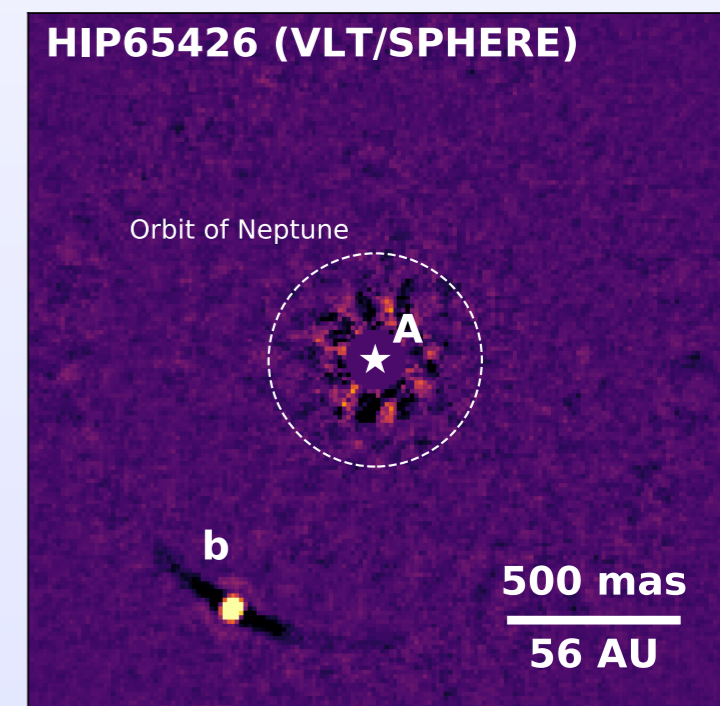
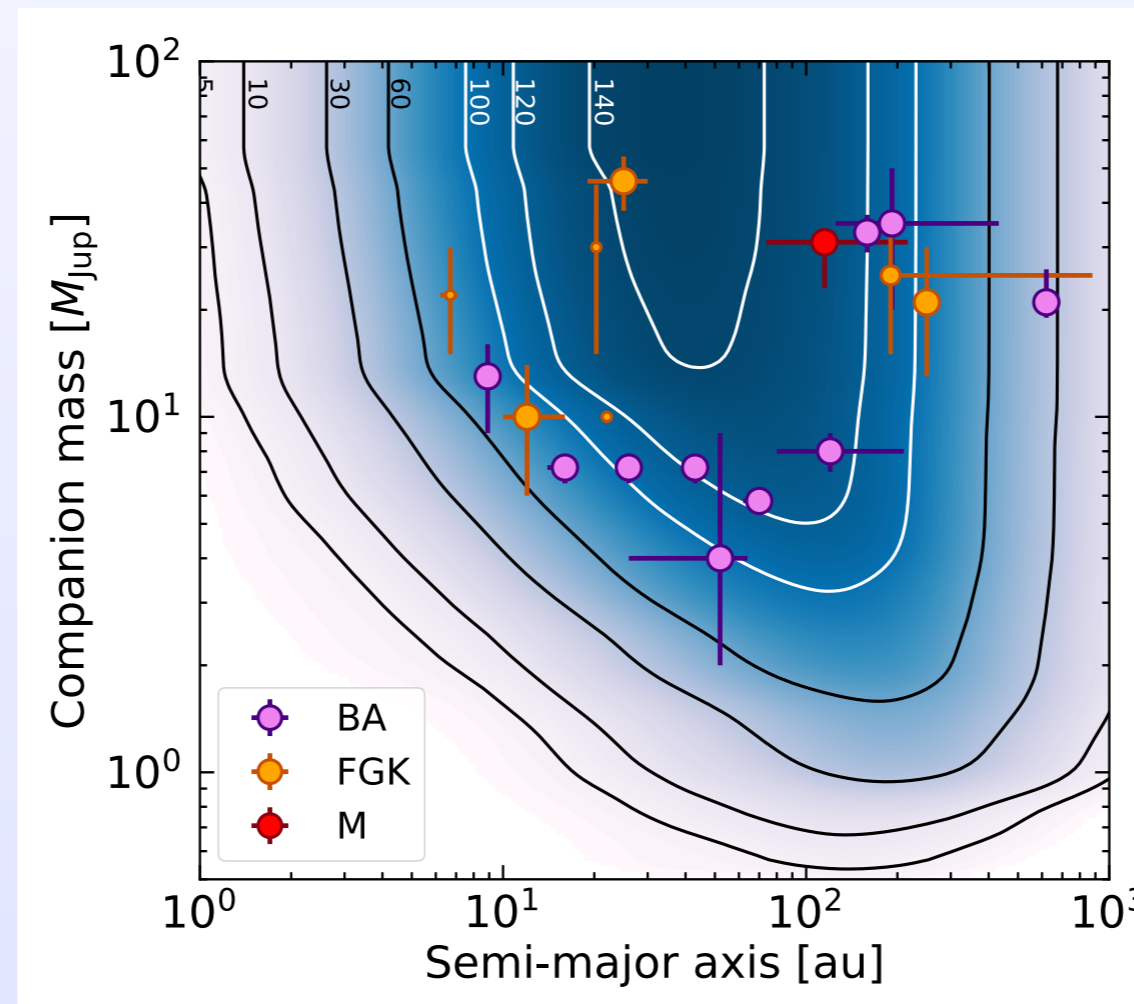
Keppler et al. 2018



Cheetham et al. 2018



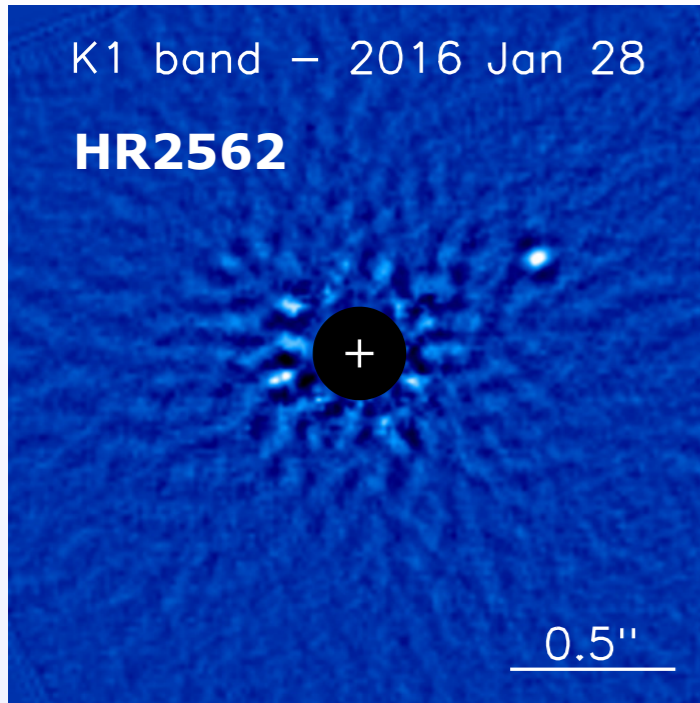
Macintosh et al. 2015



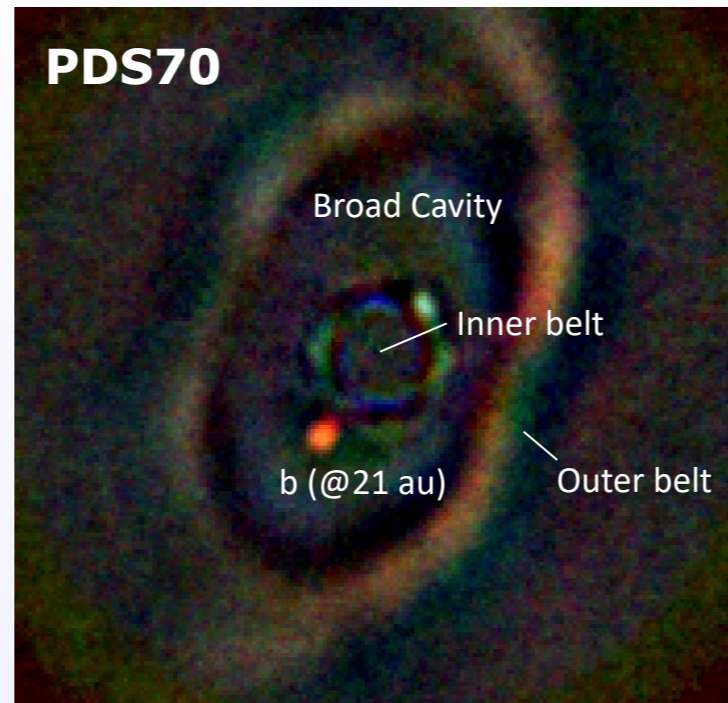
Chauvin et al. 2017

Populations analysis

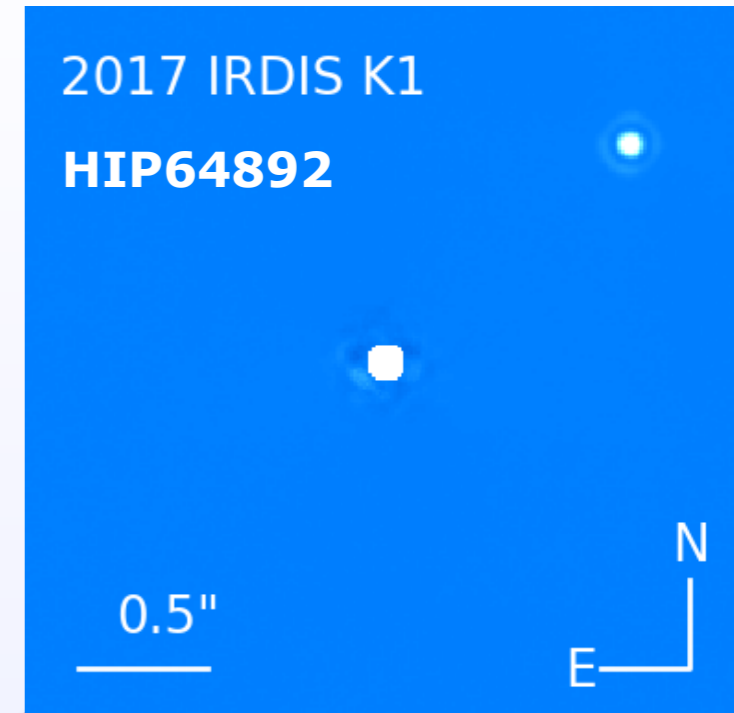
Nielsen et al. (2019)
Vigan et al. (2021)



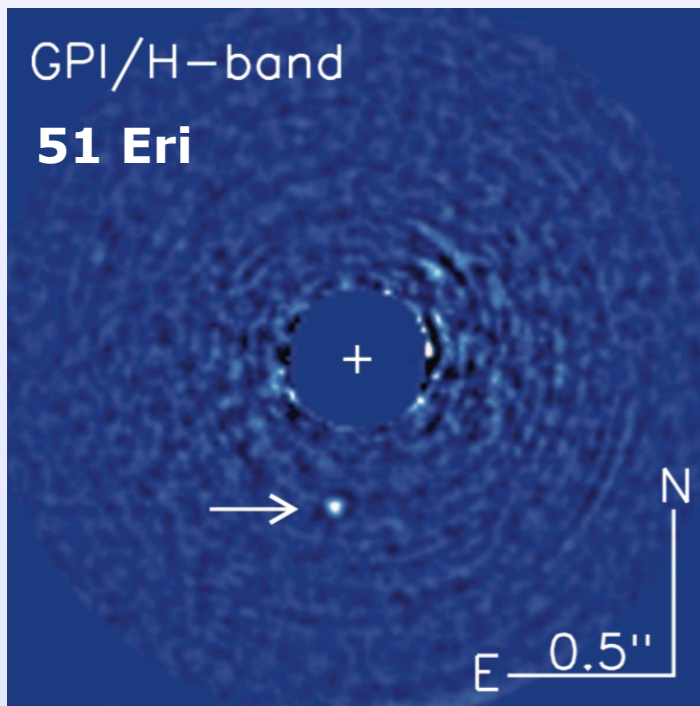
Konopacky et al. 2016



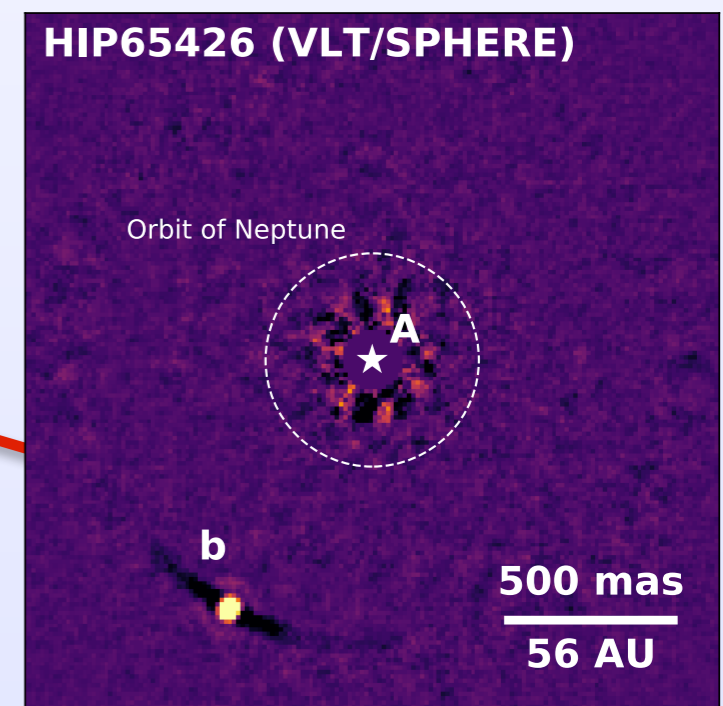
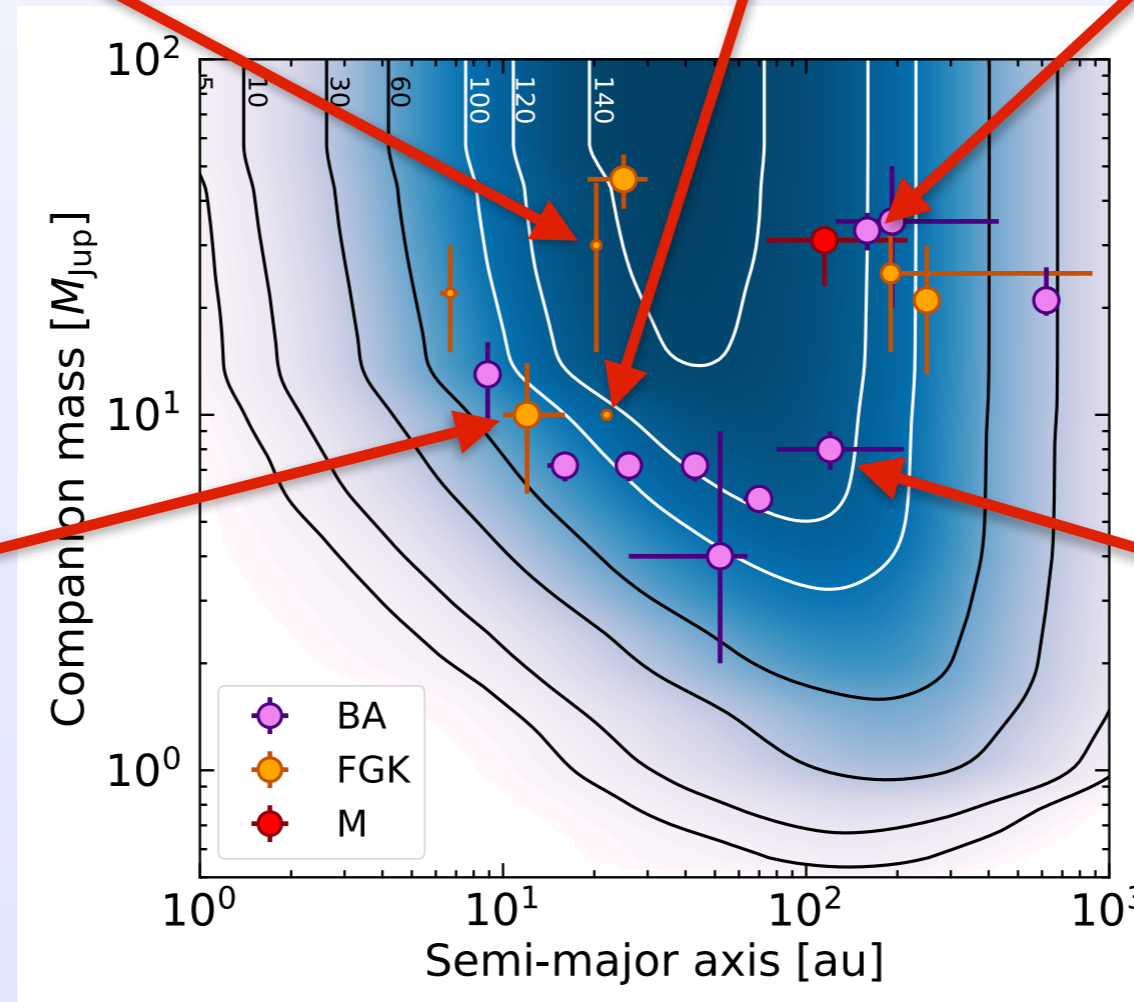
Keppler et al. 2018



Cheetham et al. 2018



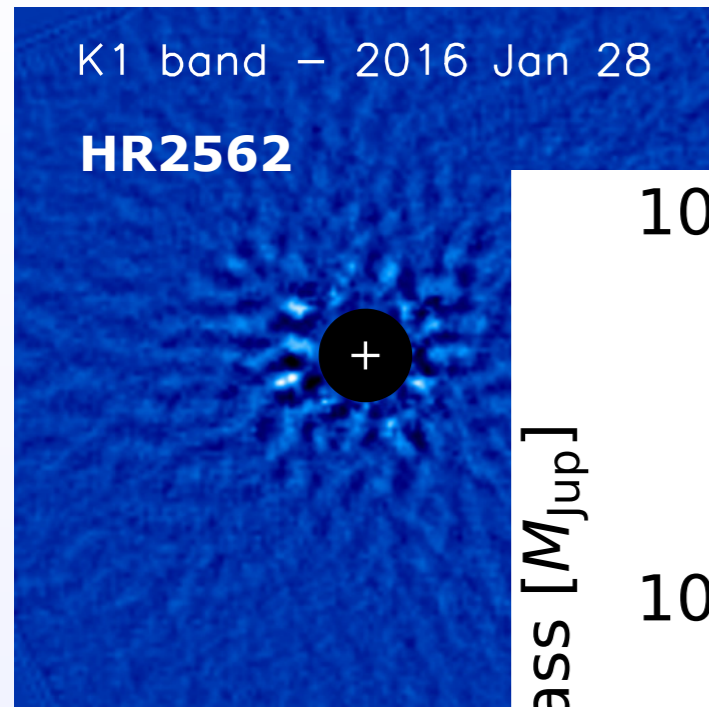
Macintosh et al. 2015



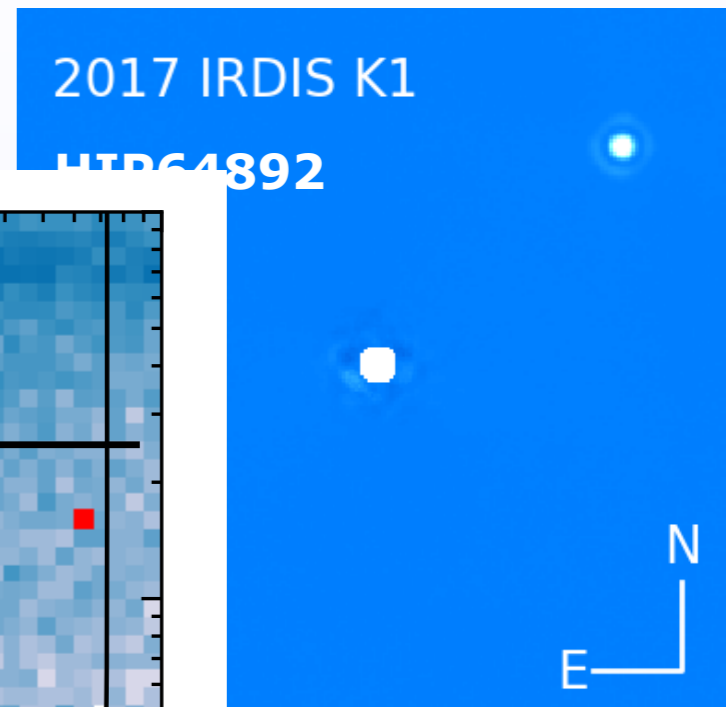
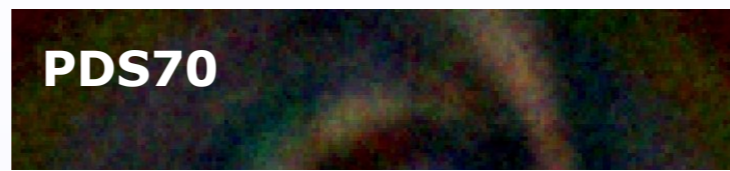
Chauvin et al. 2017

Populations analysis

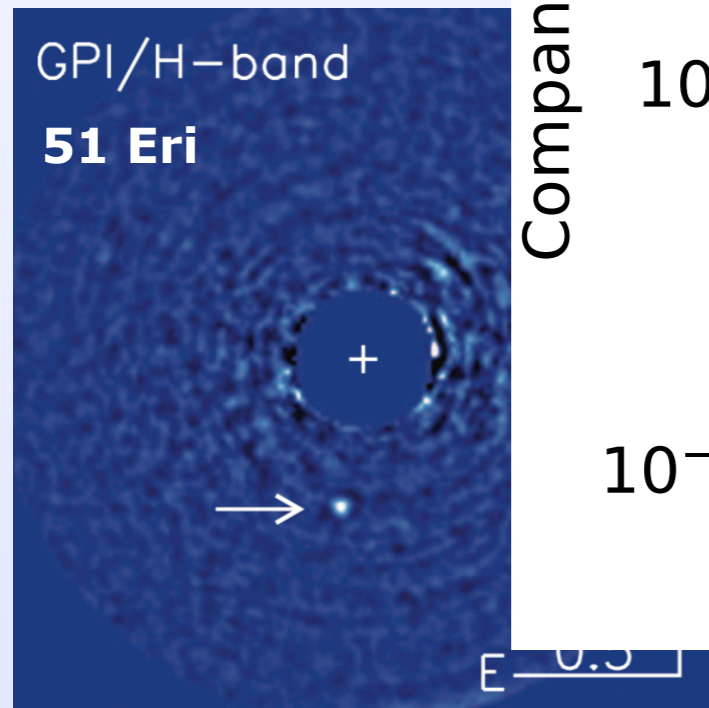
Nielsen et al. (2019)
Vigan et al. (2021)



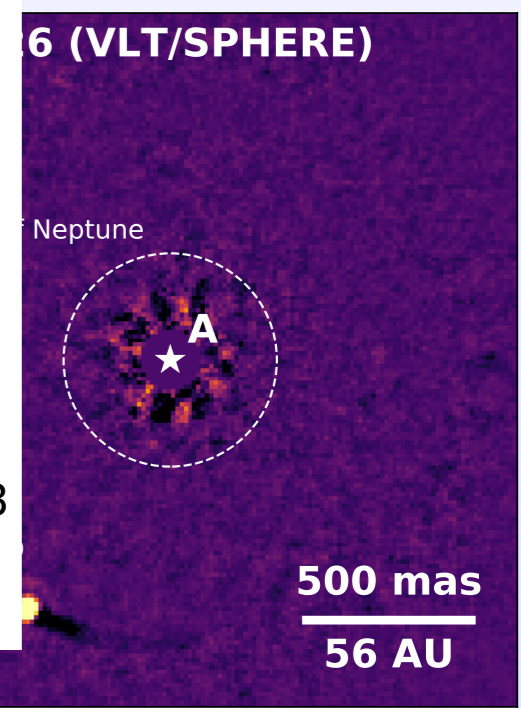
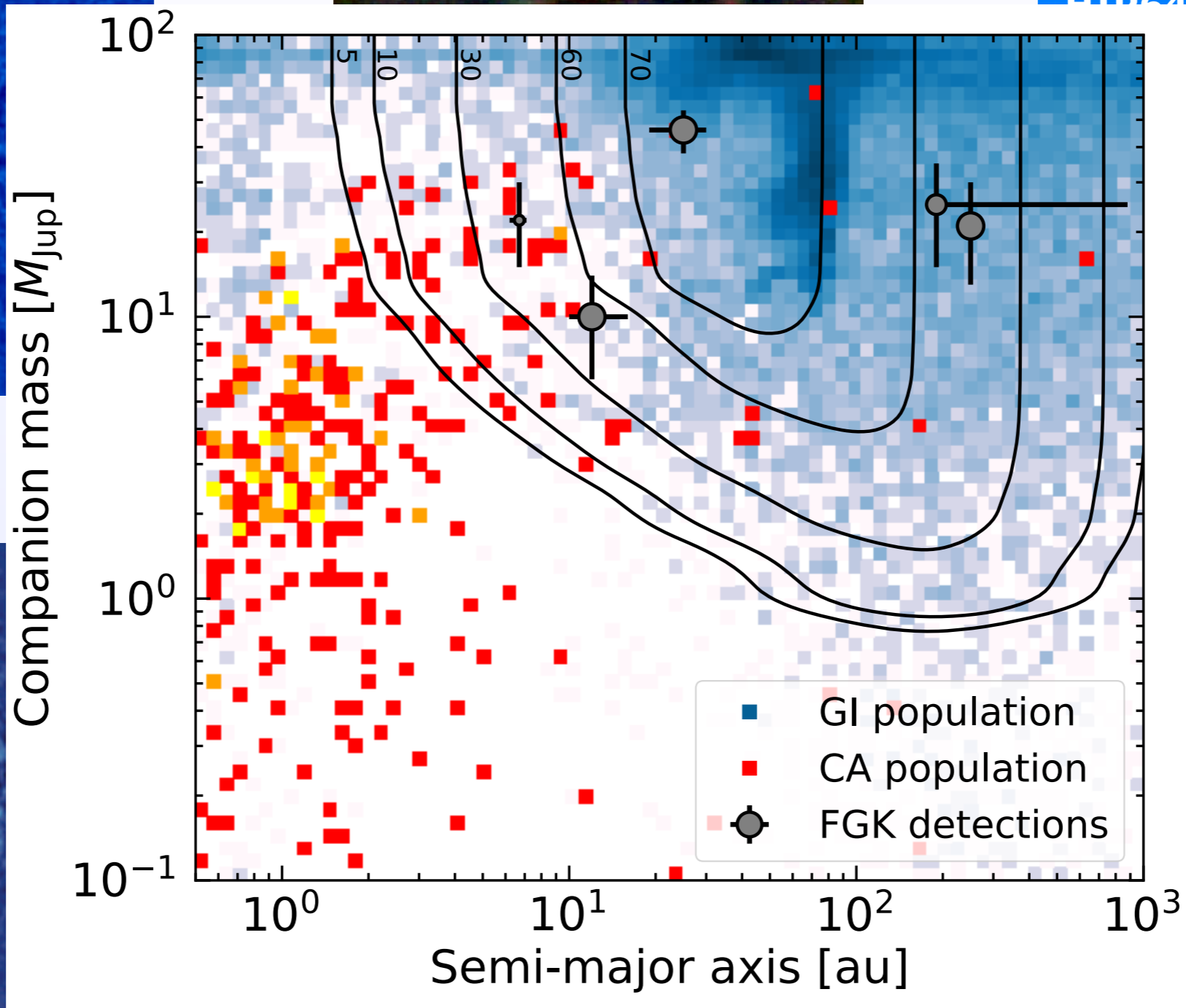
Konopacky et al. 2016



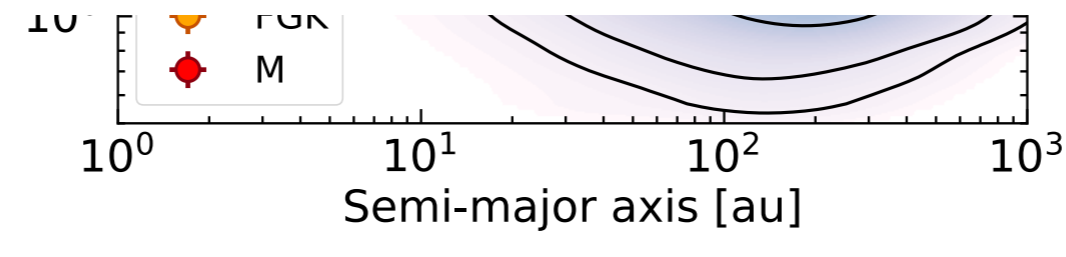
1 et al. 2018



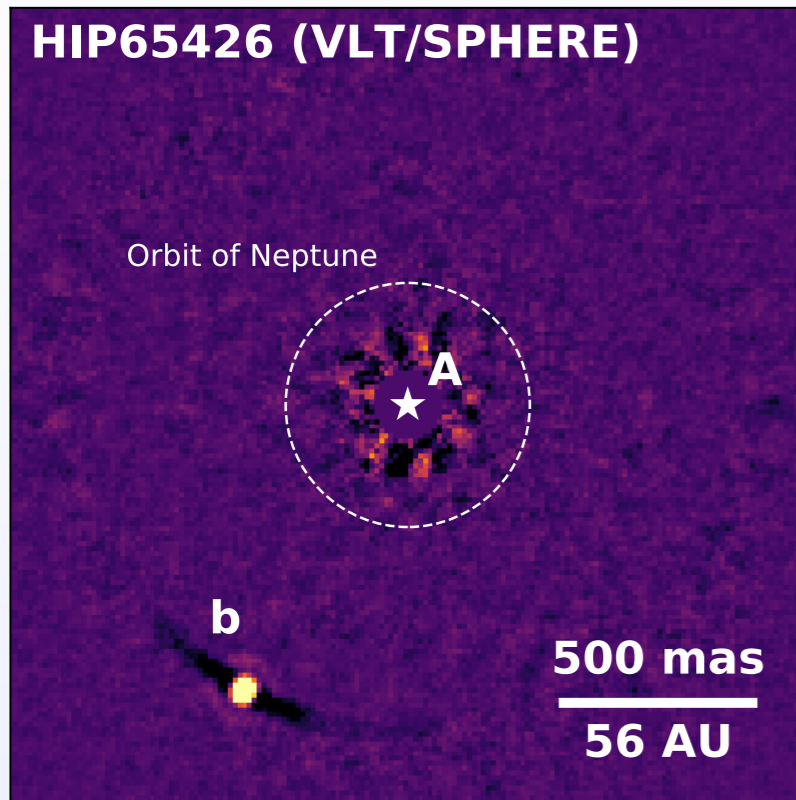
Macintosh et al. 2015



Chauvin et al. 2017

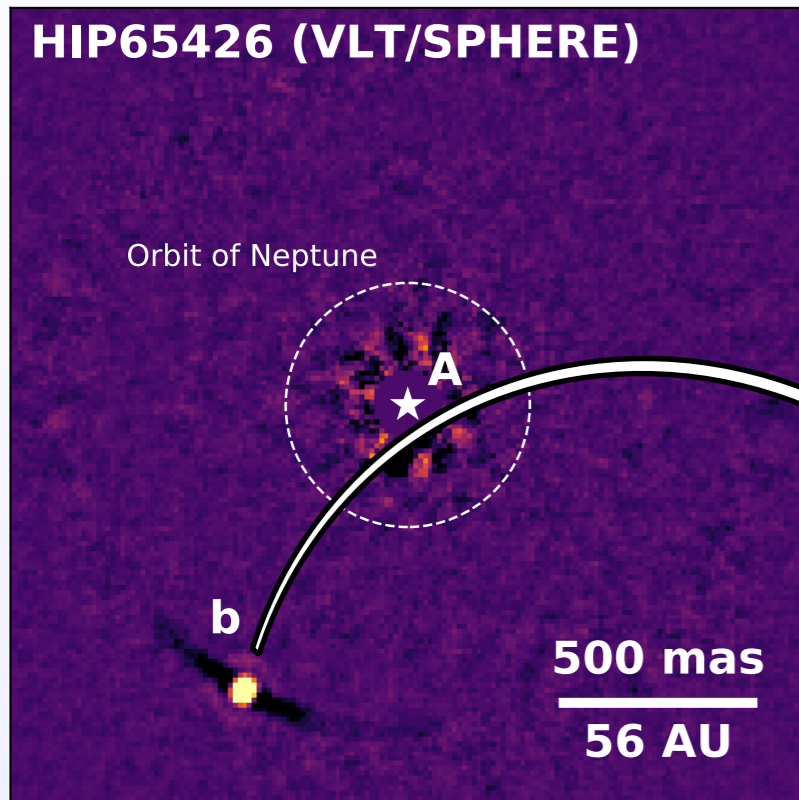


Detections with high-contrast instruments



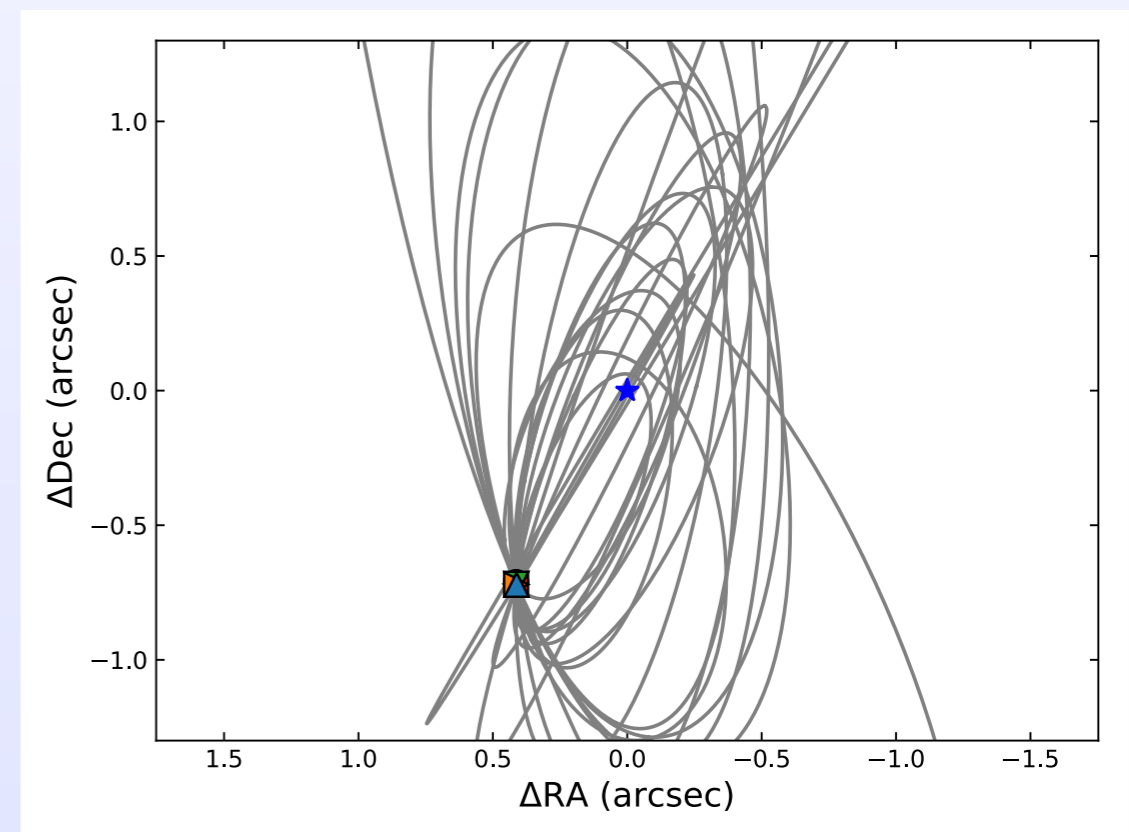
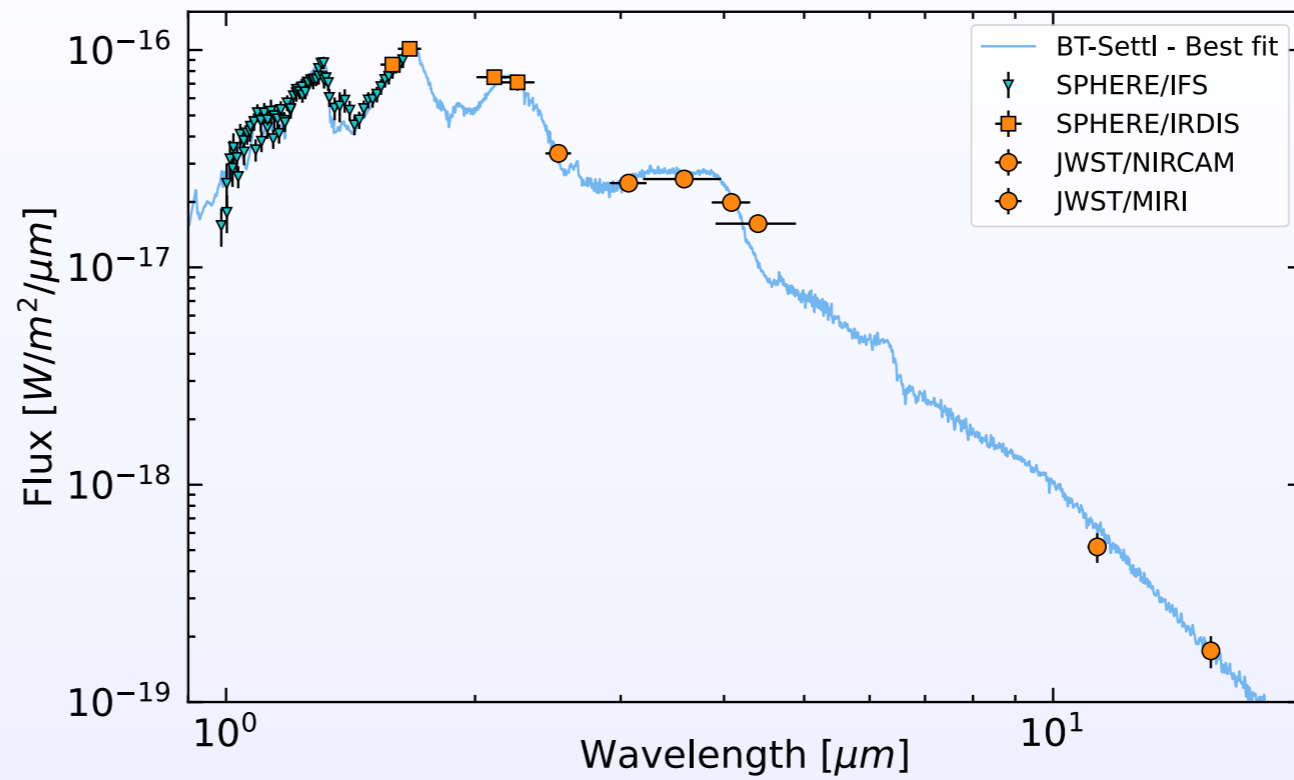
Chauvin et al. 2017

Detections with high-contrast instruments

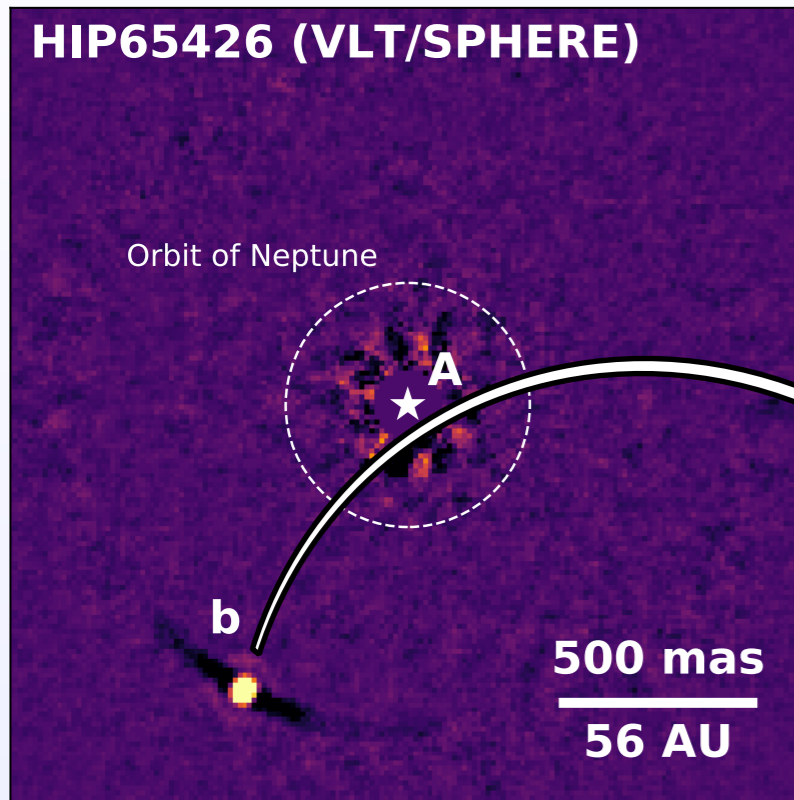


Chauvin et al. 2017

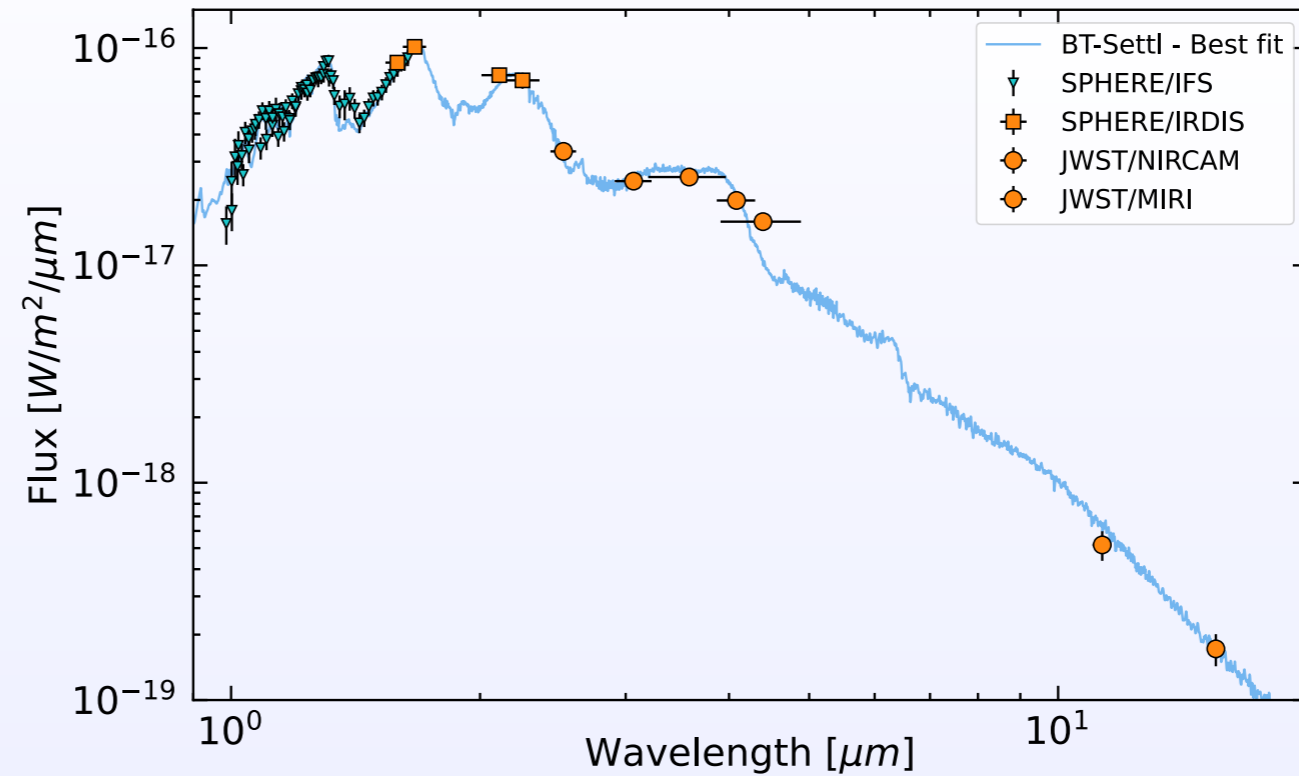
**Very low resolution
Just enough for first order
characterisation!**



Detections with high-contrast instruments

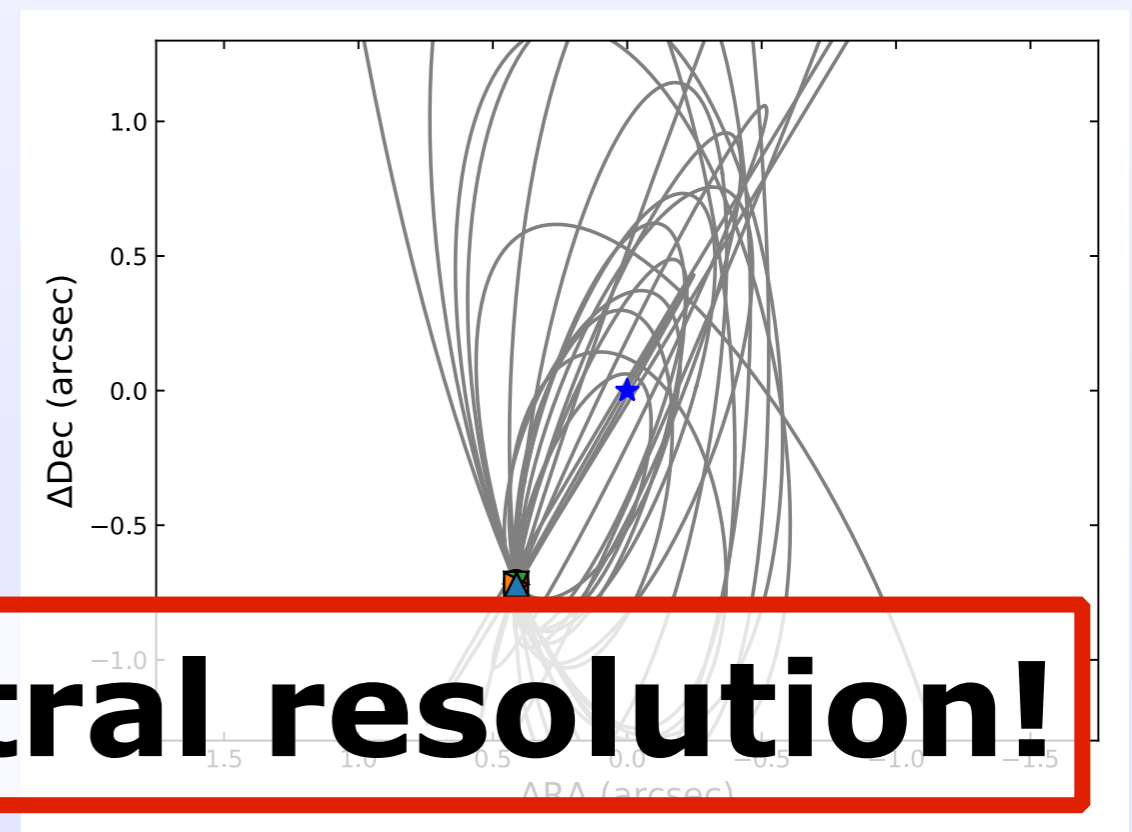


Chauvin et al. 2017

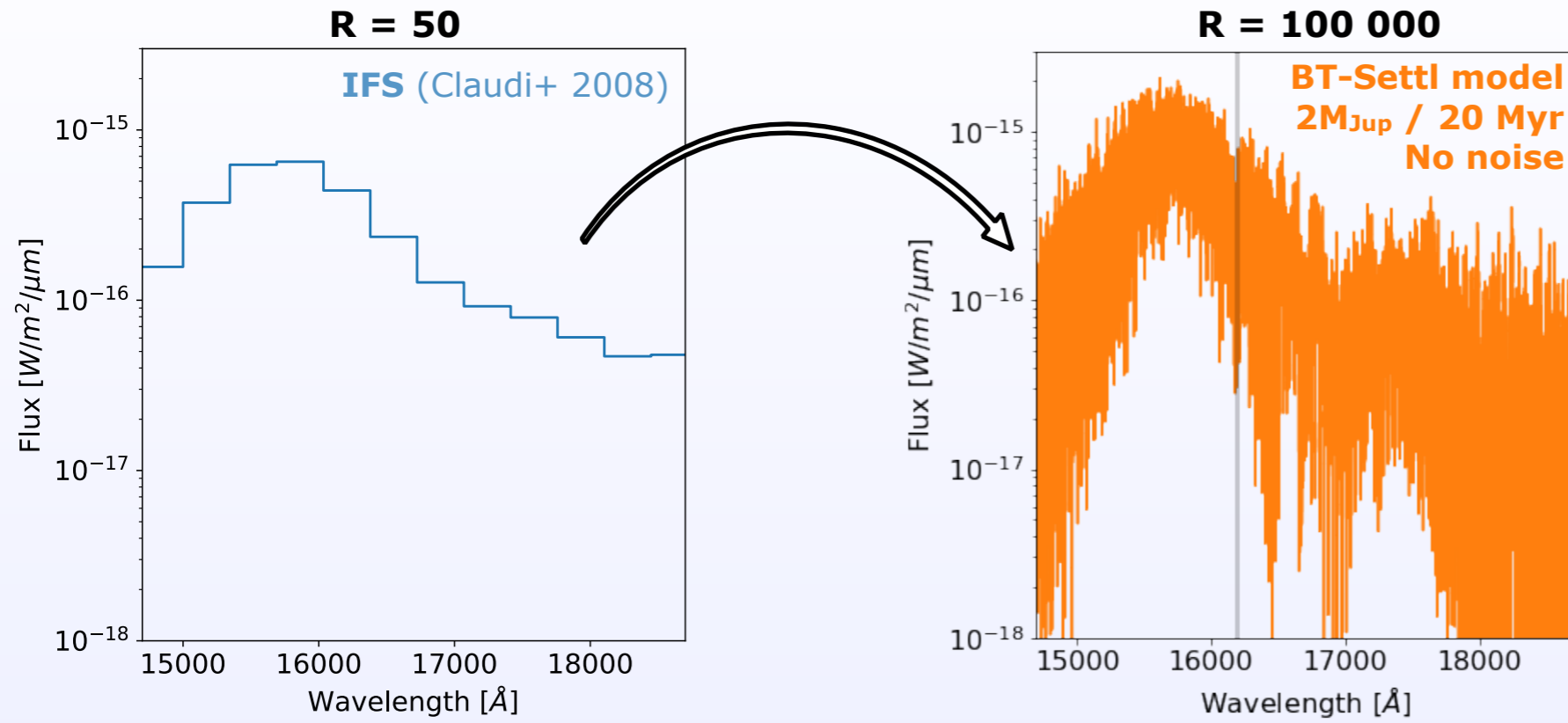


Very low resolution
Just enough for first order
characterisation!

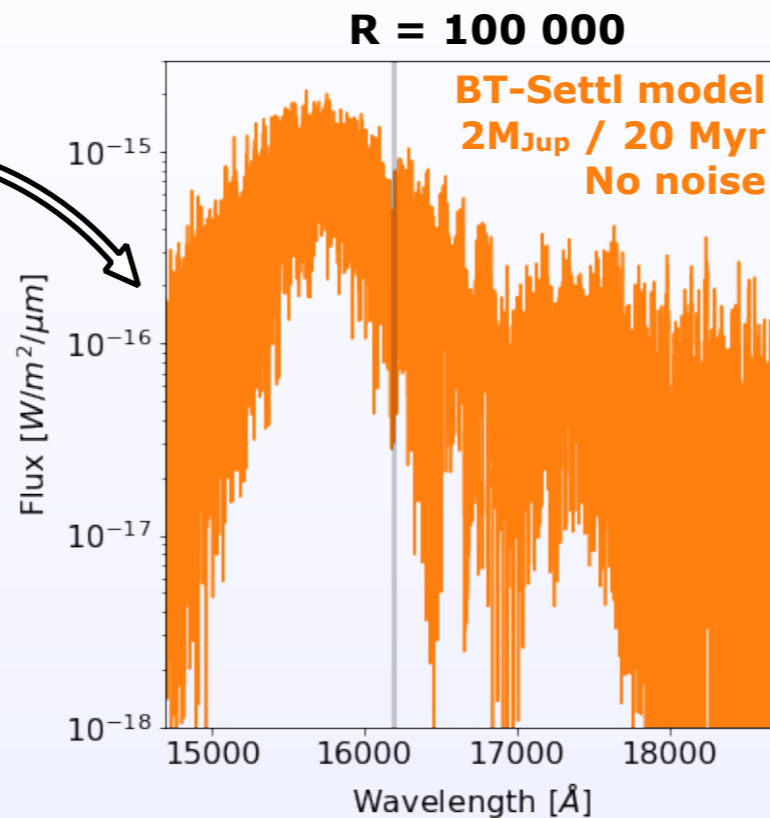
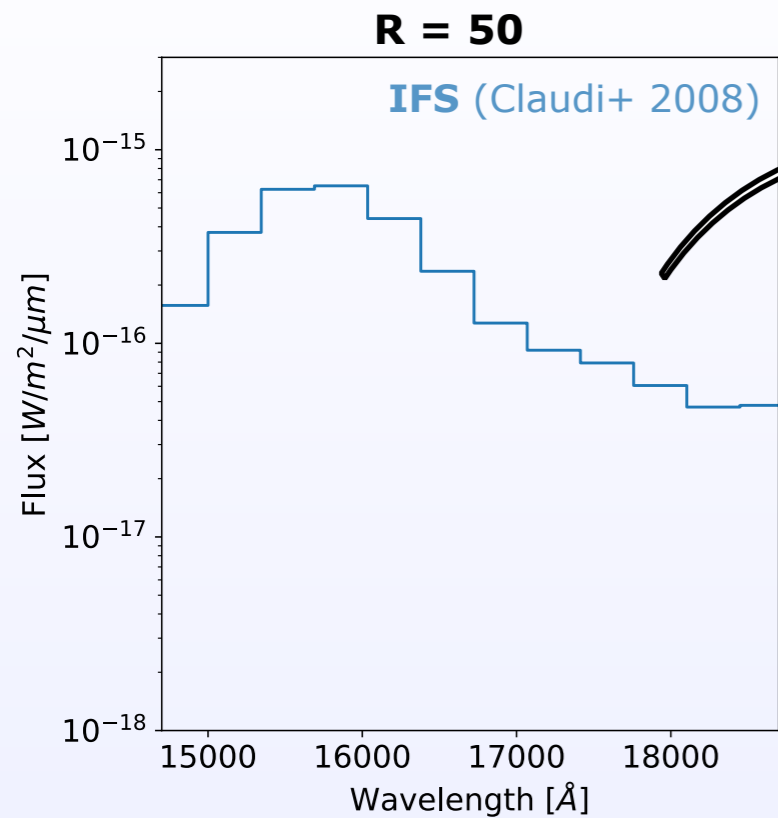
Need for high spectral resolution!



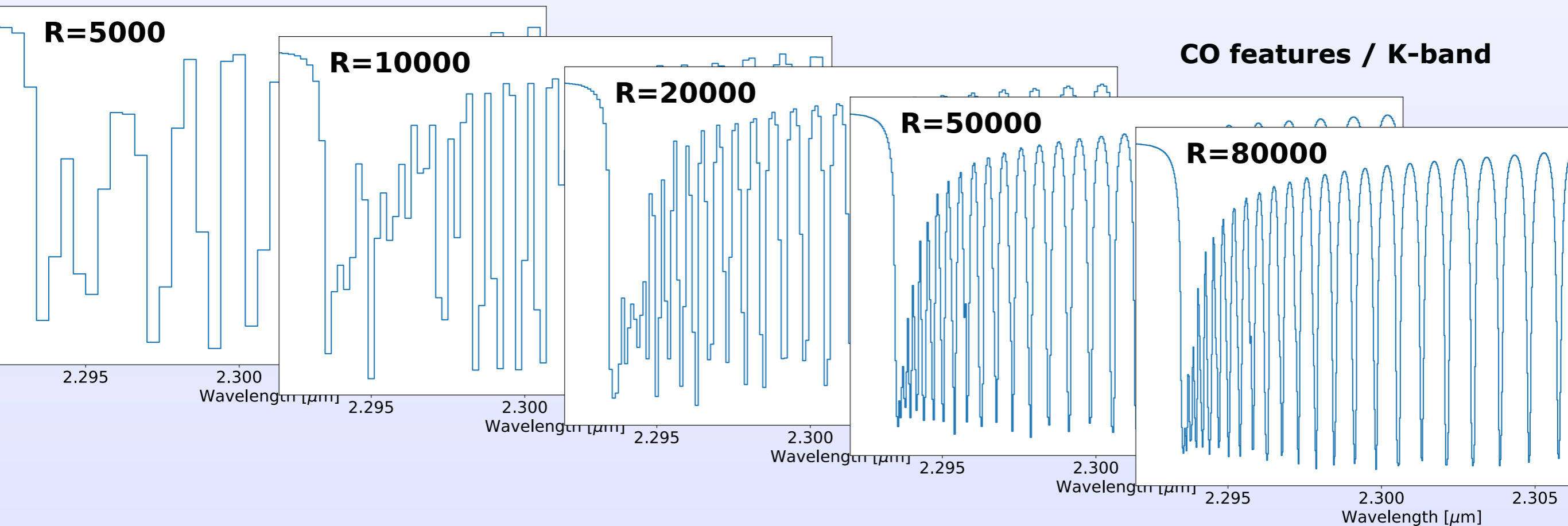
Spectral content



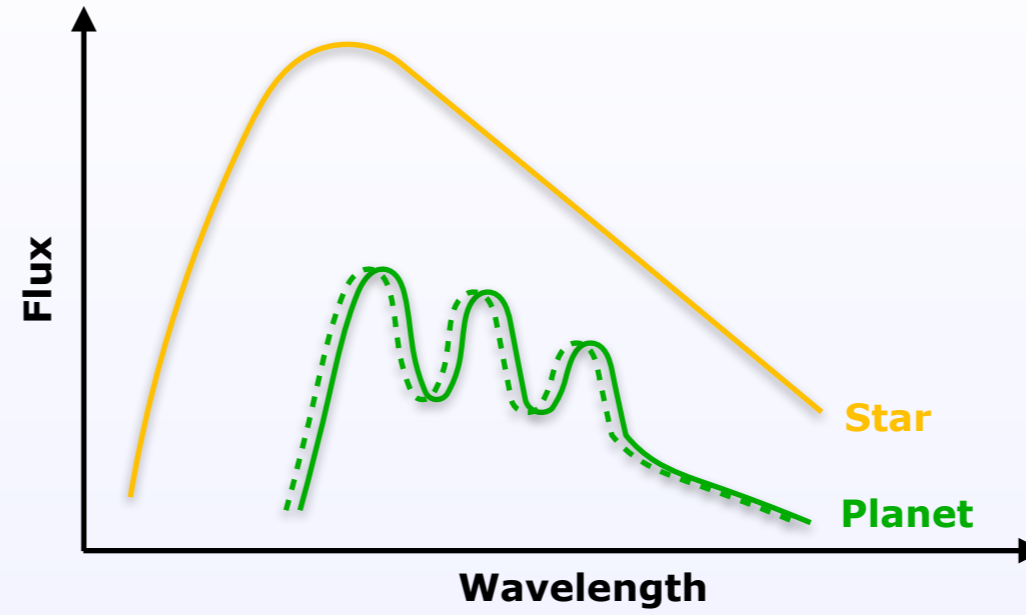
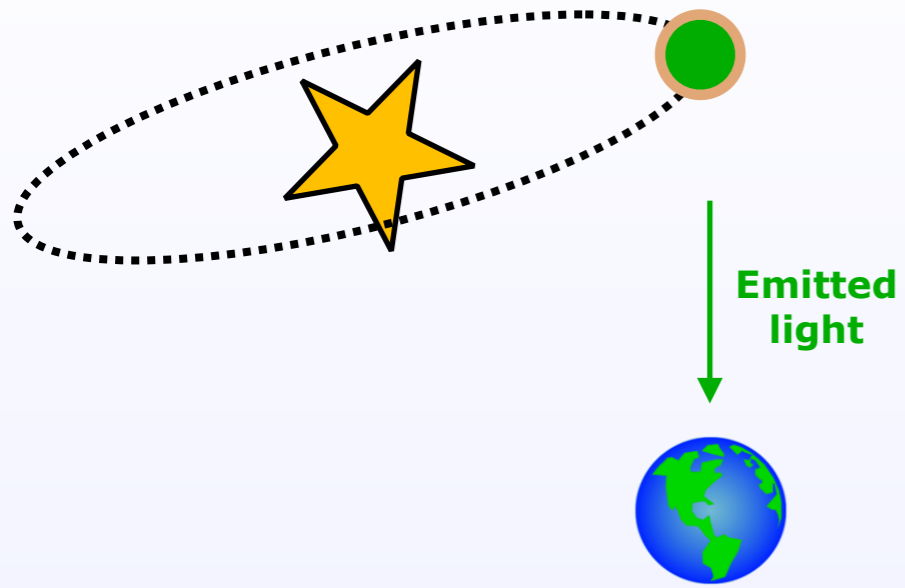
Spectral content



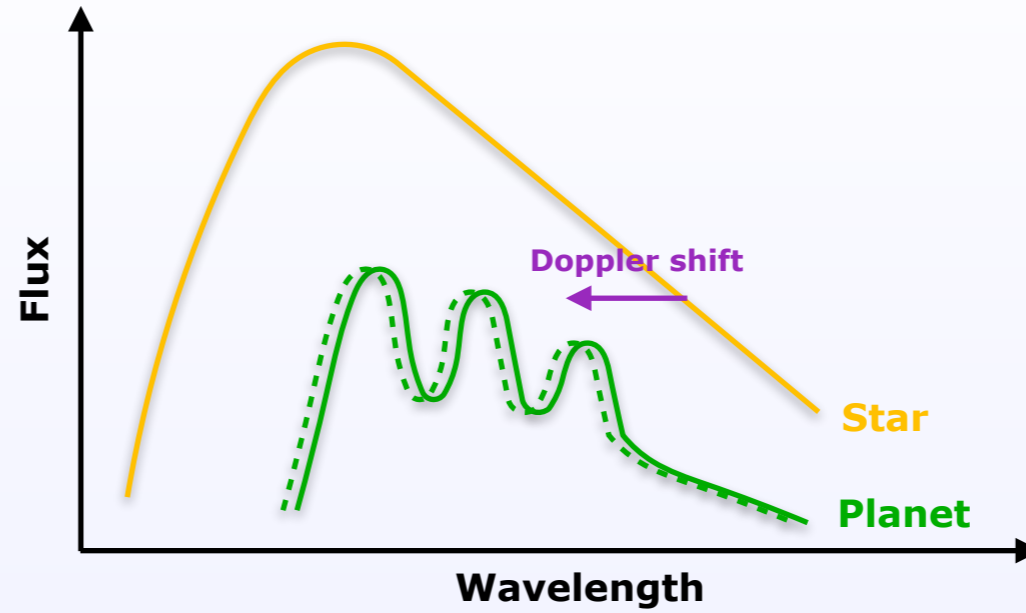
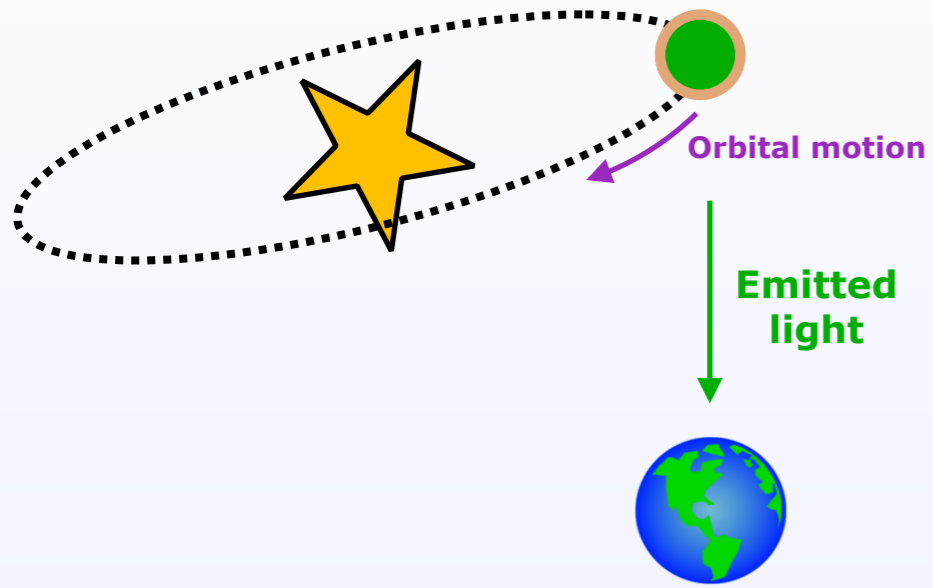
**Requires
 $R \gg 10\,000$**



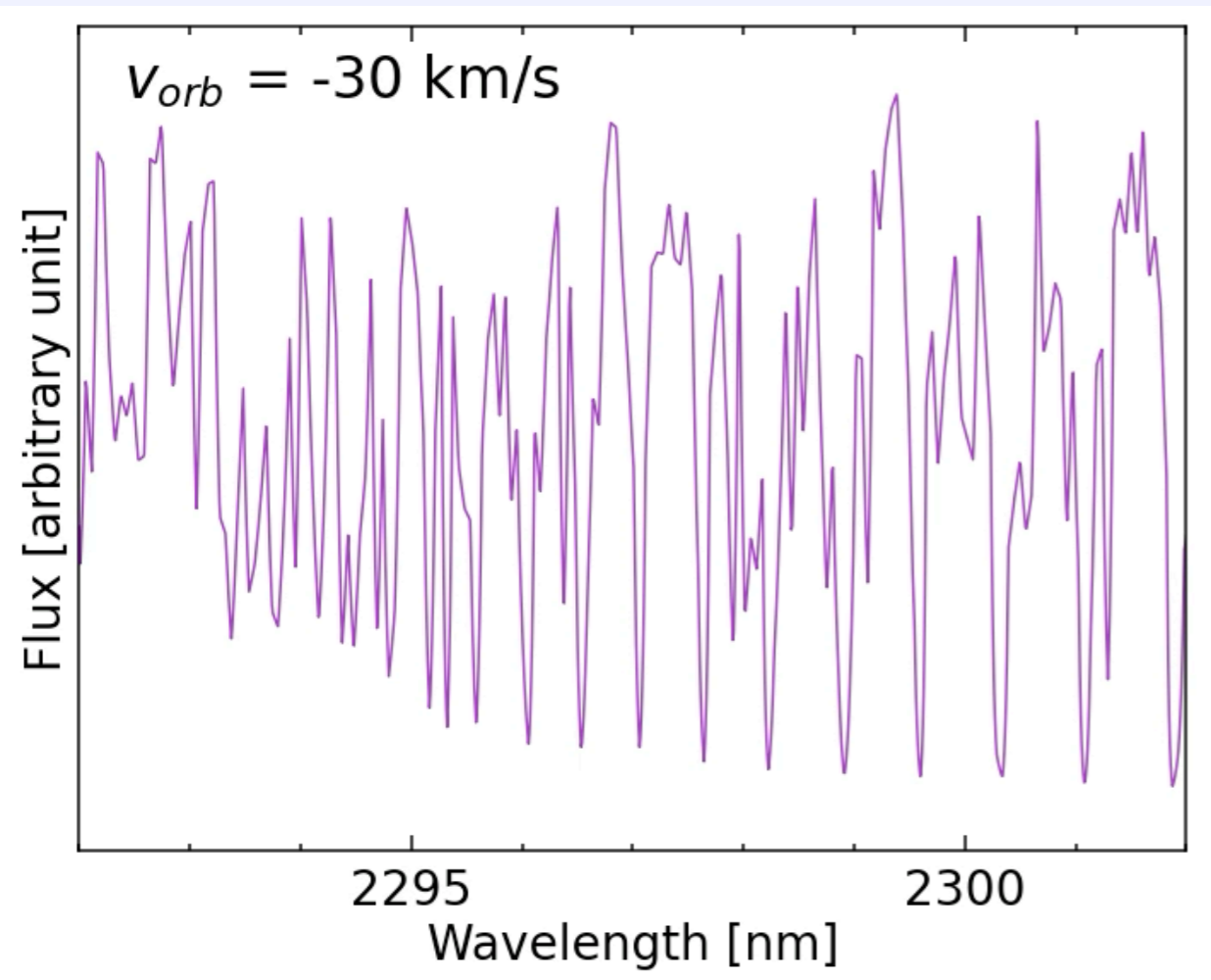
Orbital and rotational information



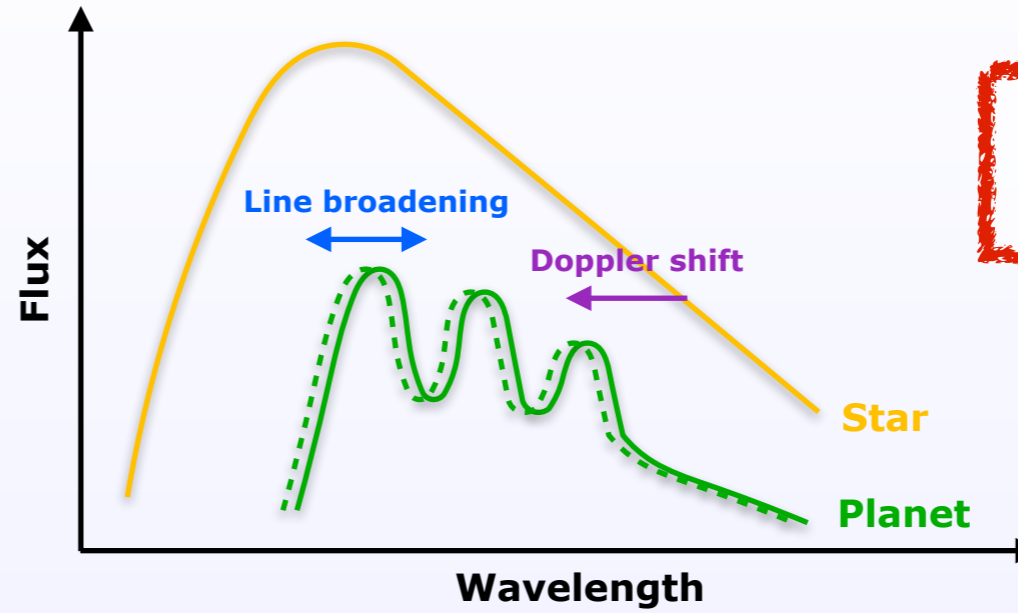
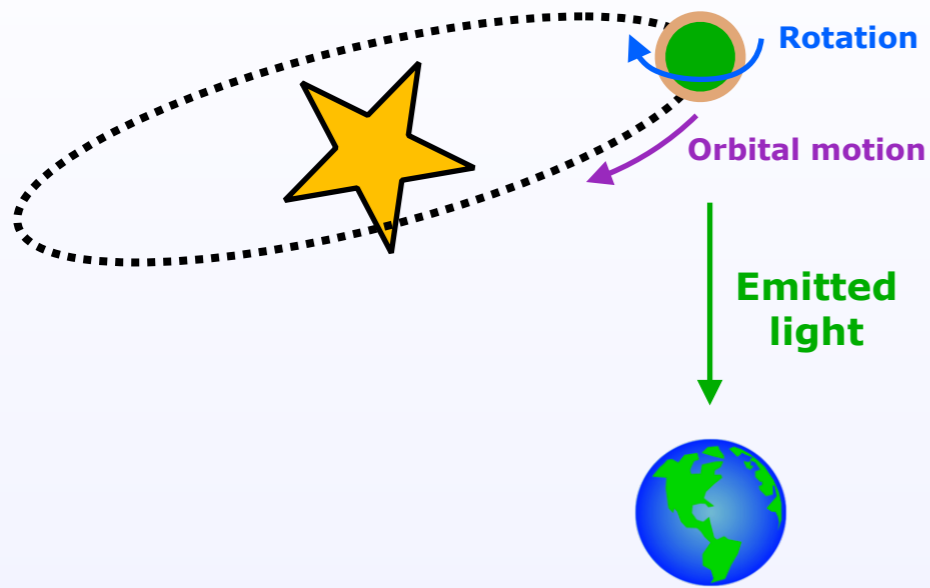
Orbital and rotational information



Effect of orbital motion



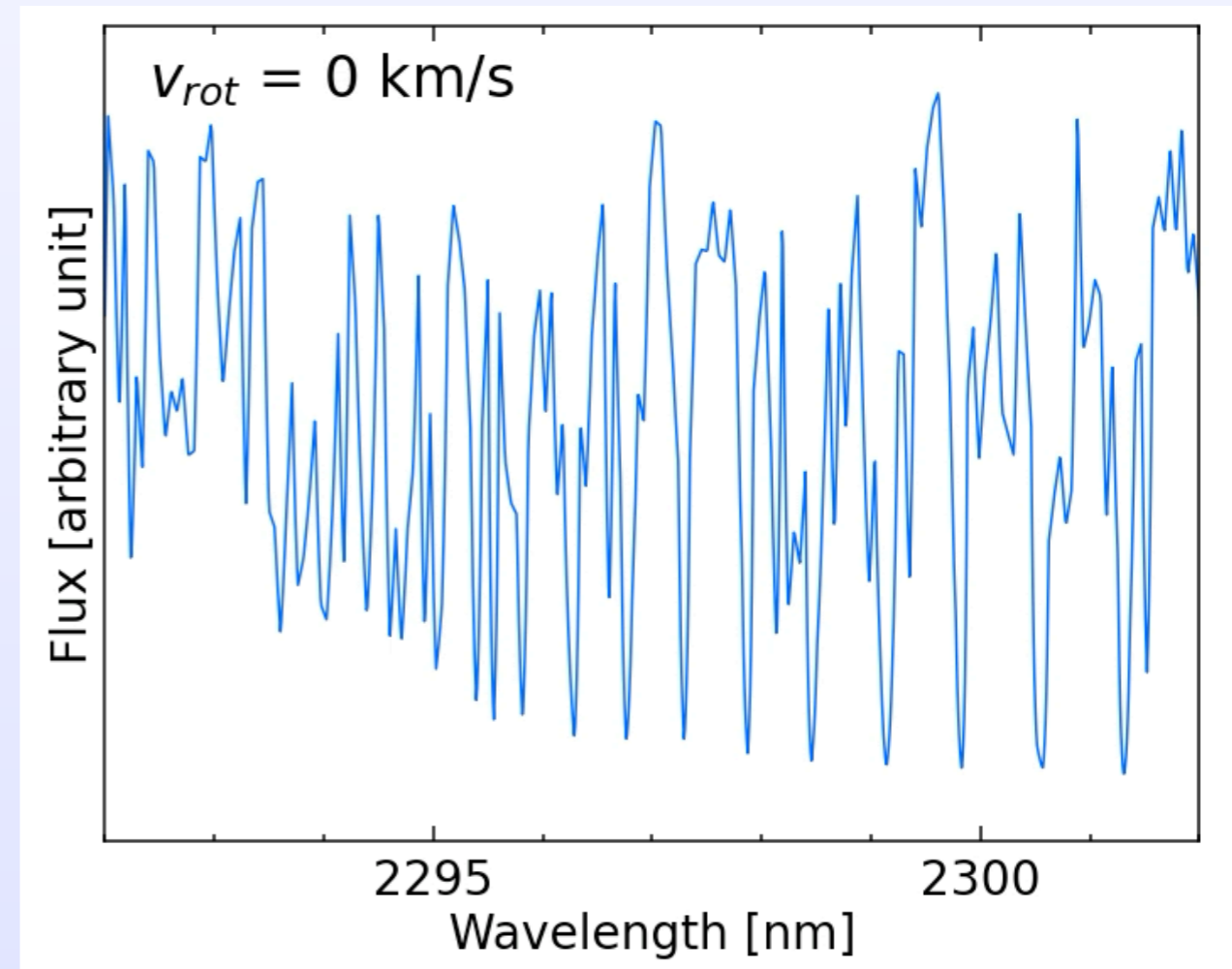
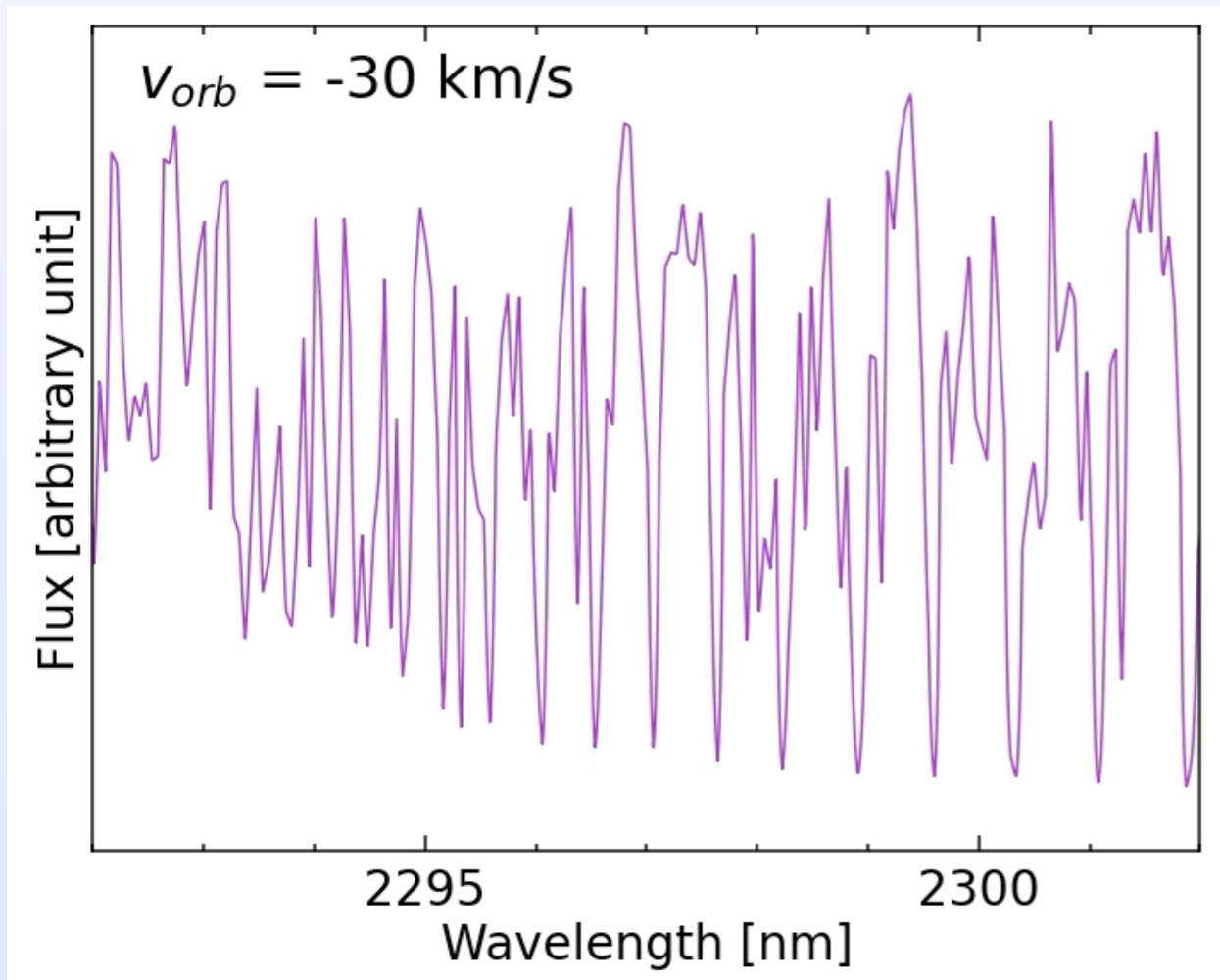
Orbital and rotational information



Requires
 $R \gg 30\,000$

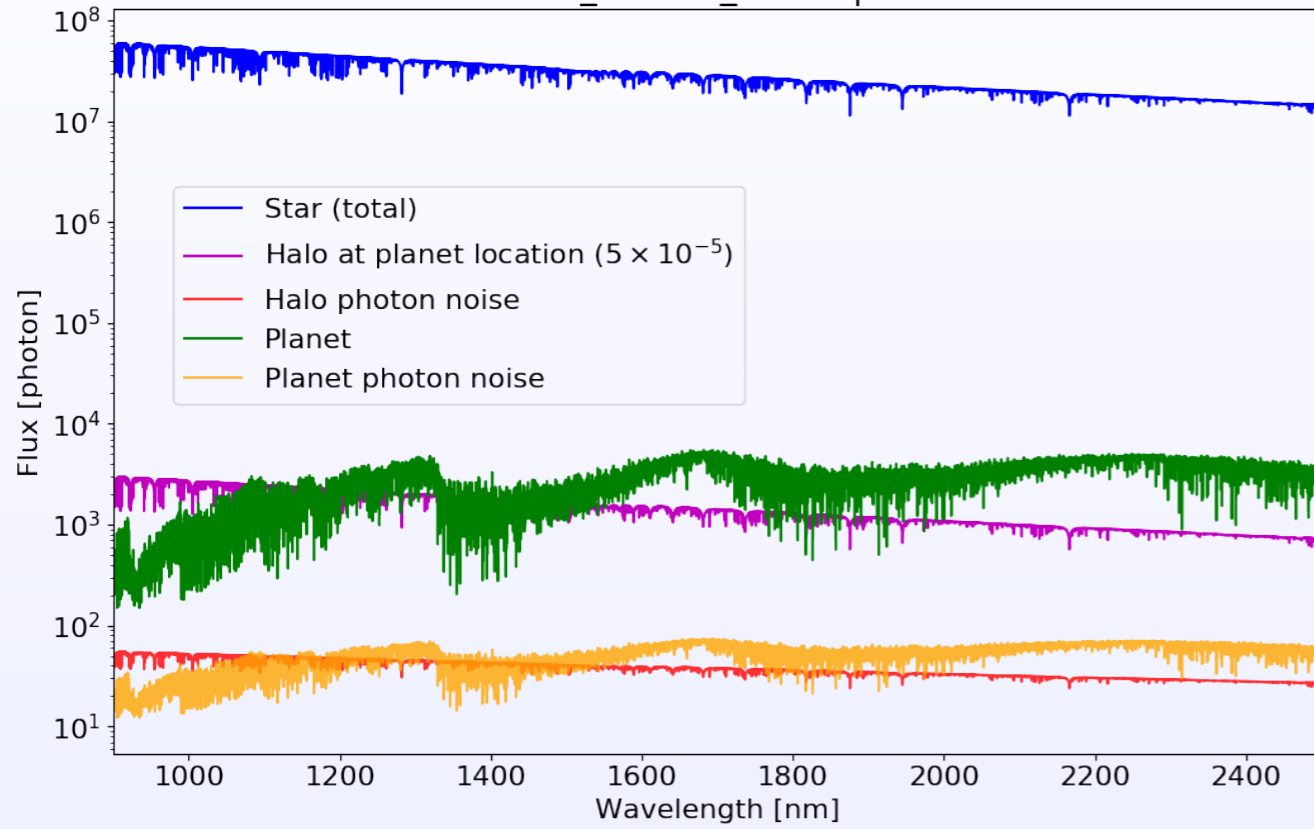
Effect of orbital motion

Effect of rotation

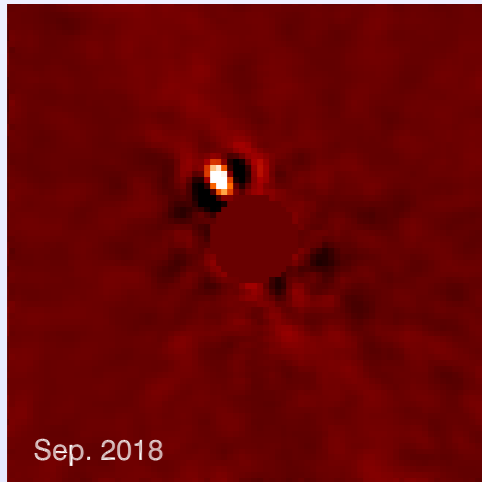
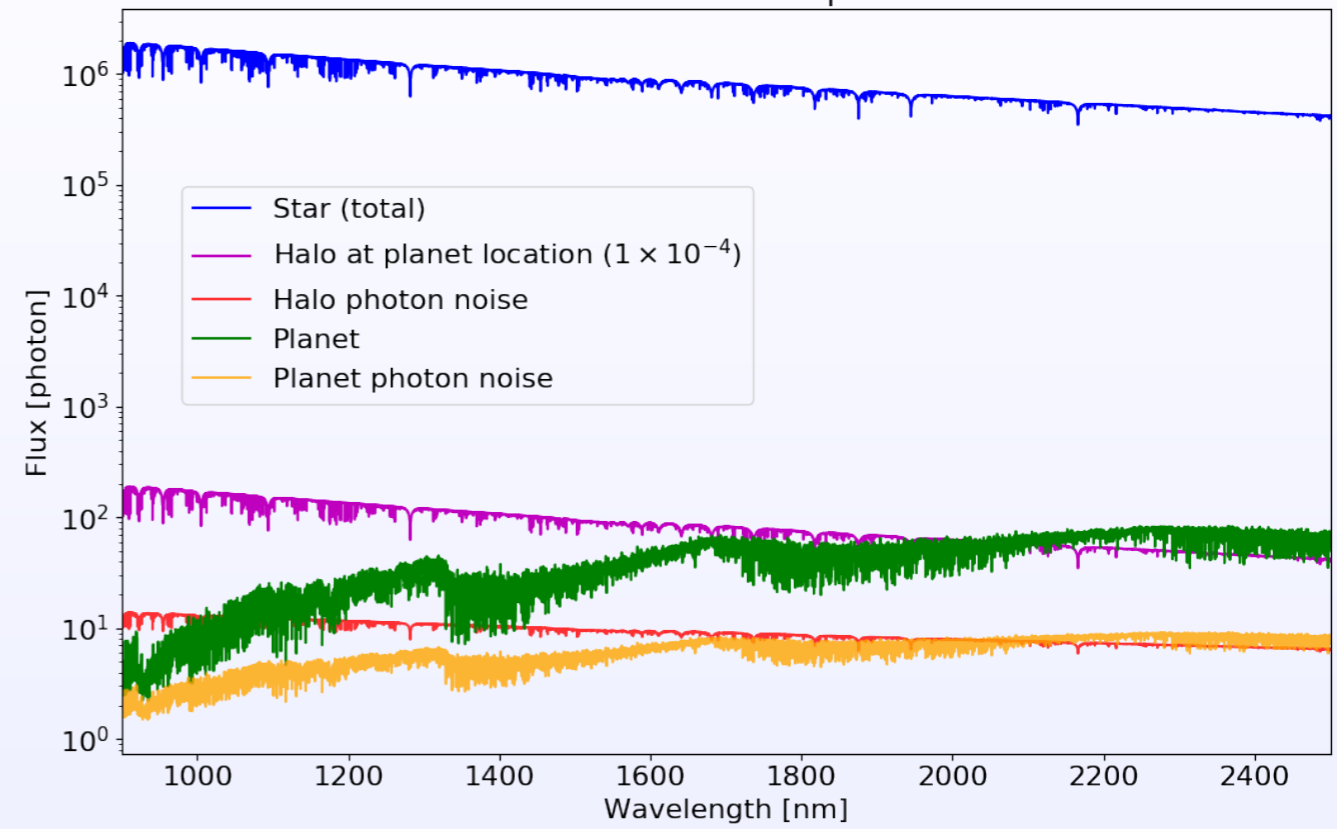


A few numbers...

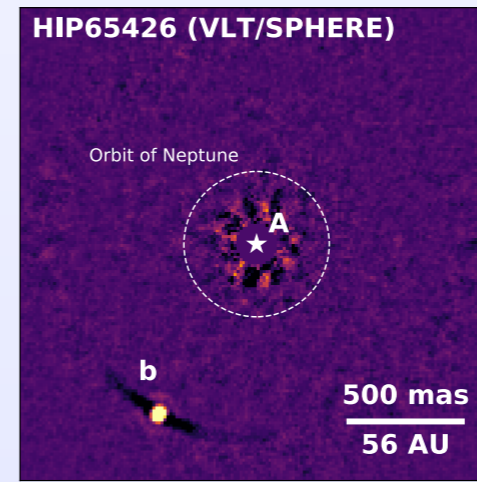
SPHERE+CRIRES - beta_Pictoris_b - Texp = 1.0hr - R = 100000



SPHERE+CRIRES - HIP65426b - Texp = 1.0hr - R = 100000

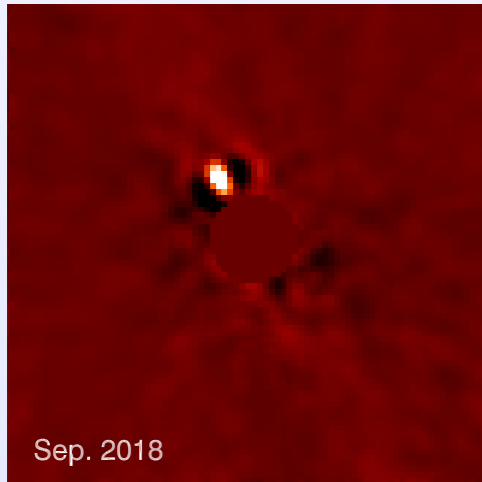
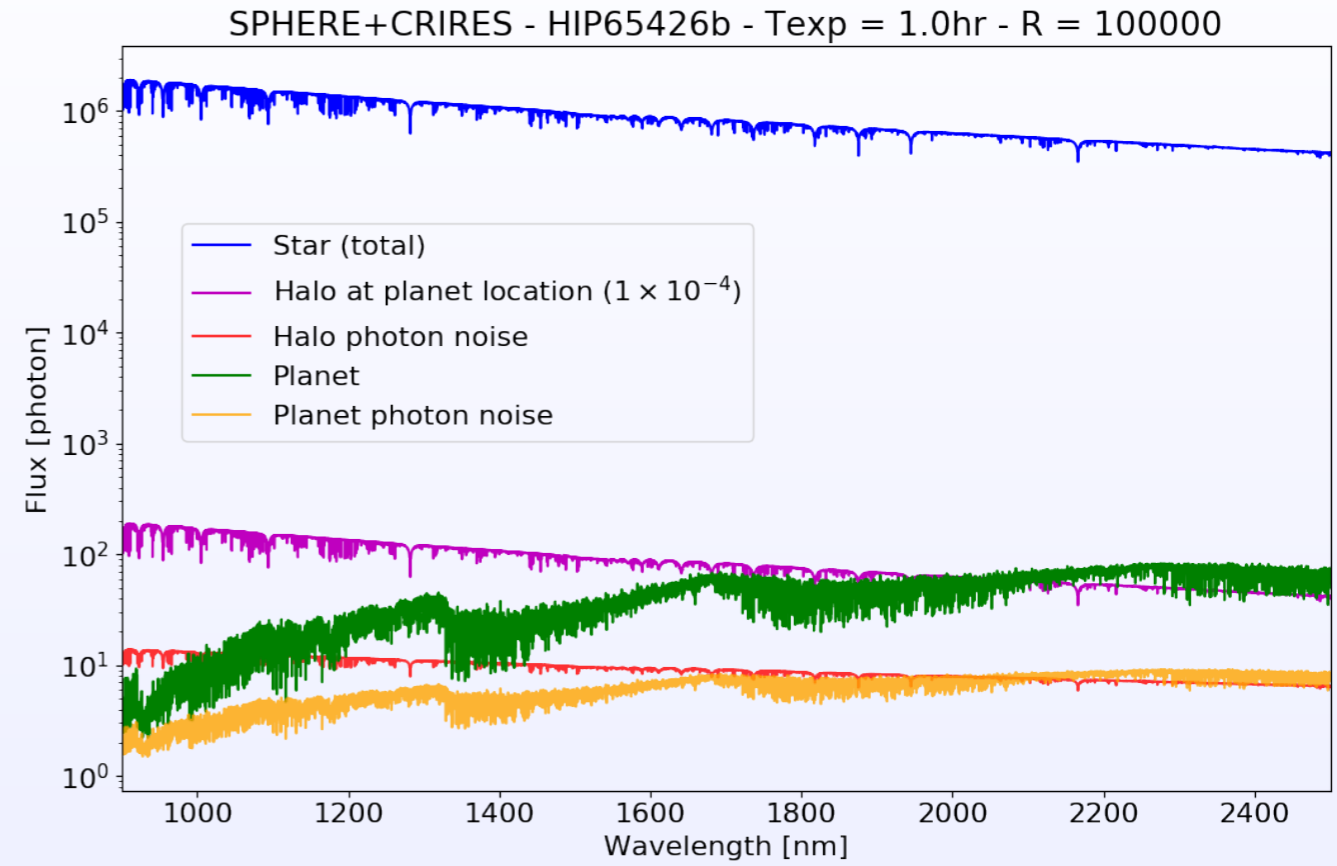
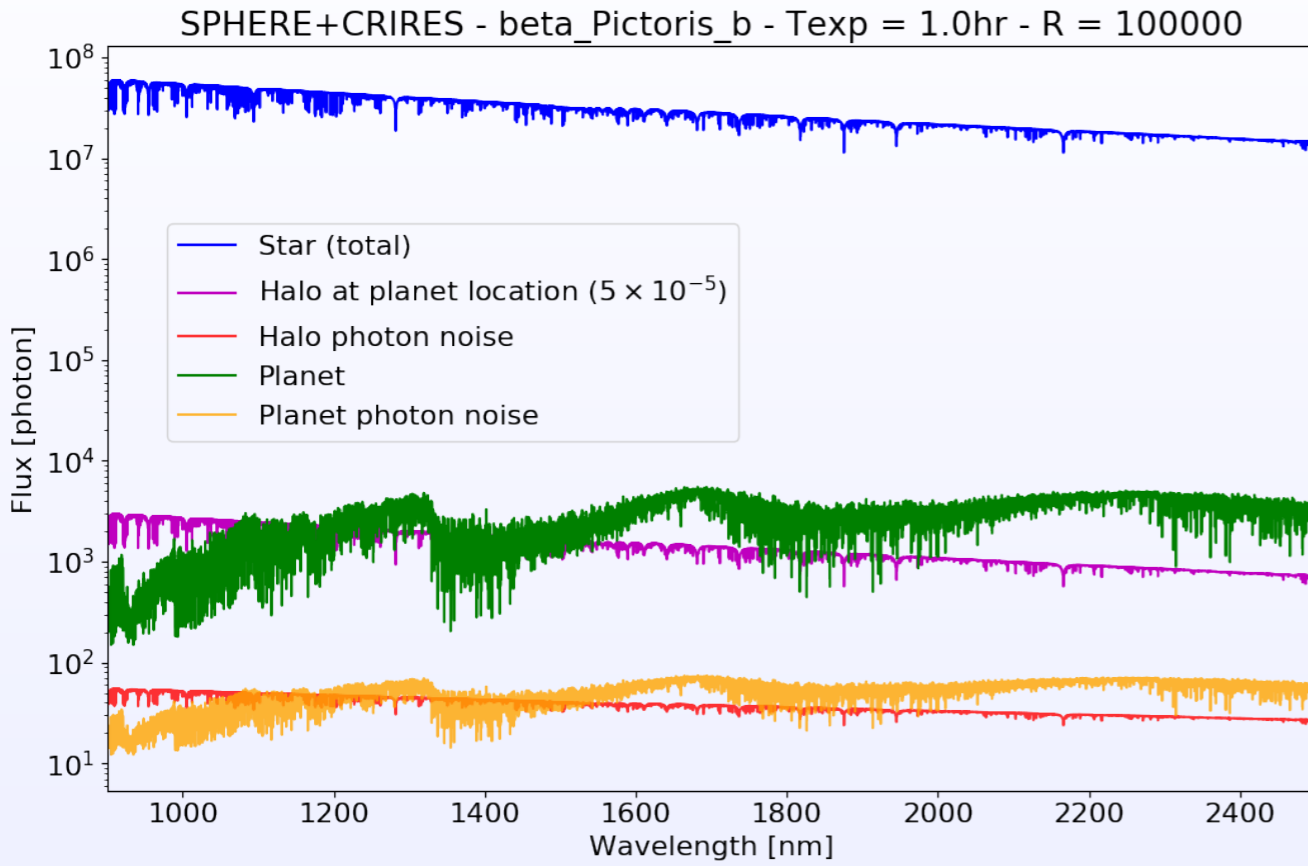


>1000 photon/channel
SNR > 100

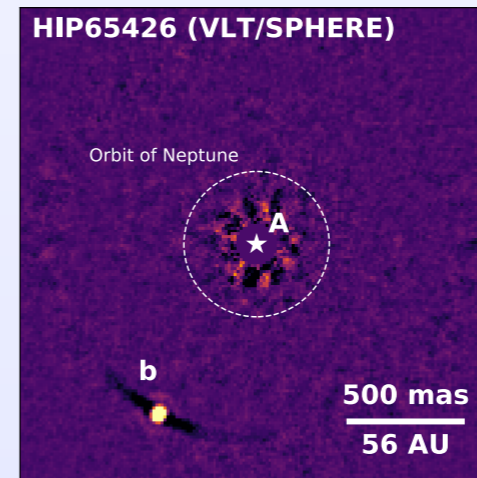


>10 photon/channel
SNR > 10

A few numbers...



>1000 photon/channel
SNR > 100



>10 photon/channel
SNR > 10

It's hard!!

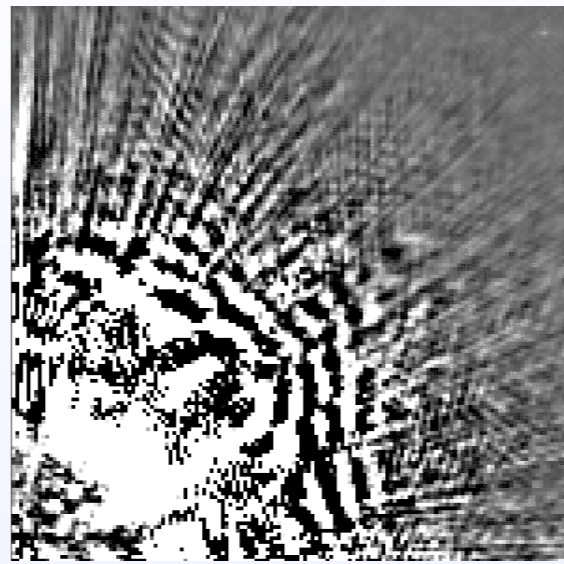
Boost in detection

HST/ACS simulation

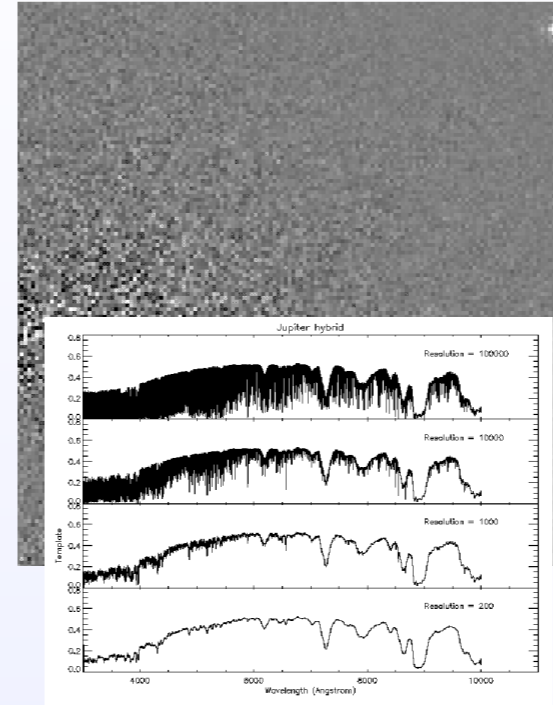


Sparks & Ford (2002)

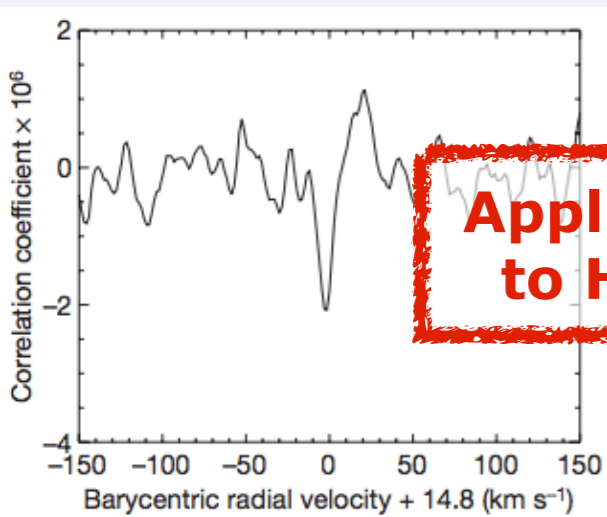
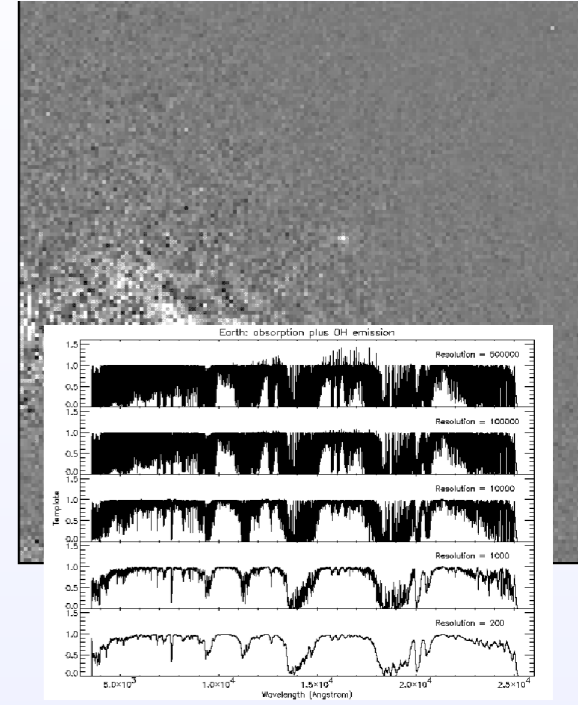
Roll-subtraction (=ADI)



Jupiter template CCF

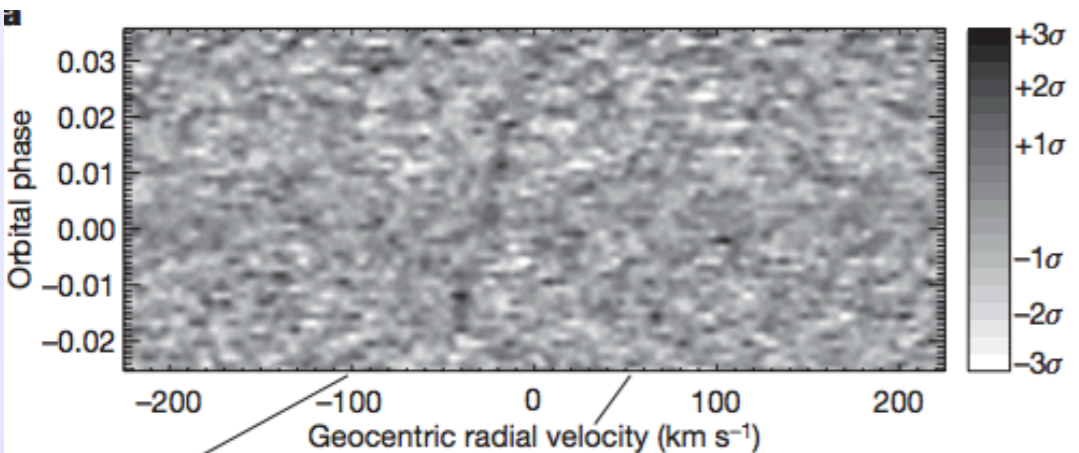


Bright Earth template CCF

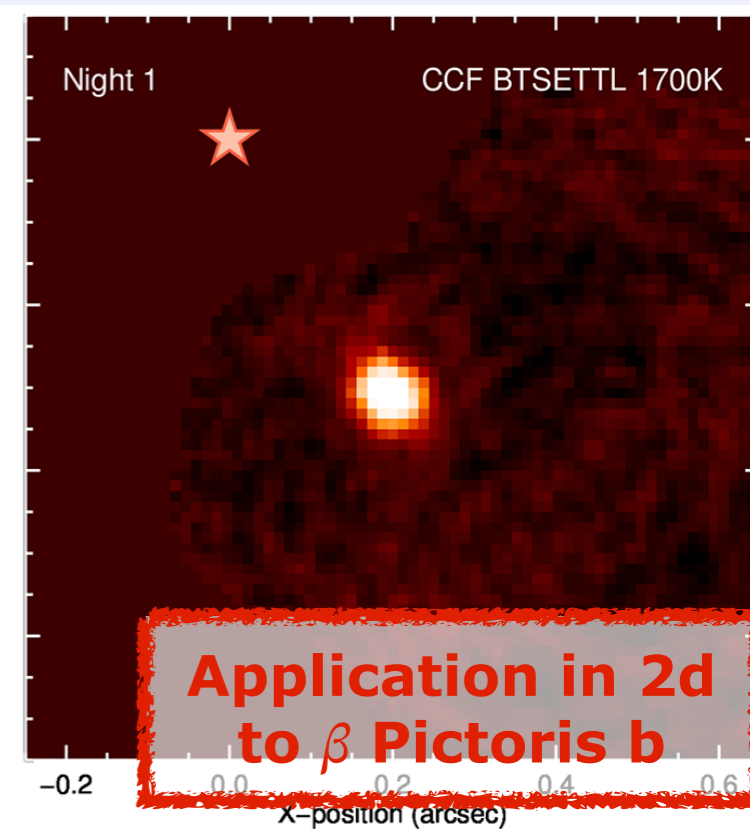
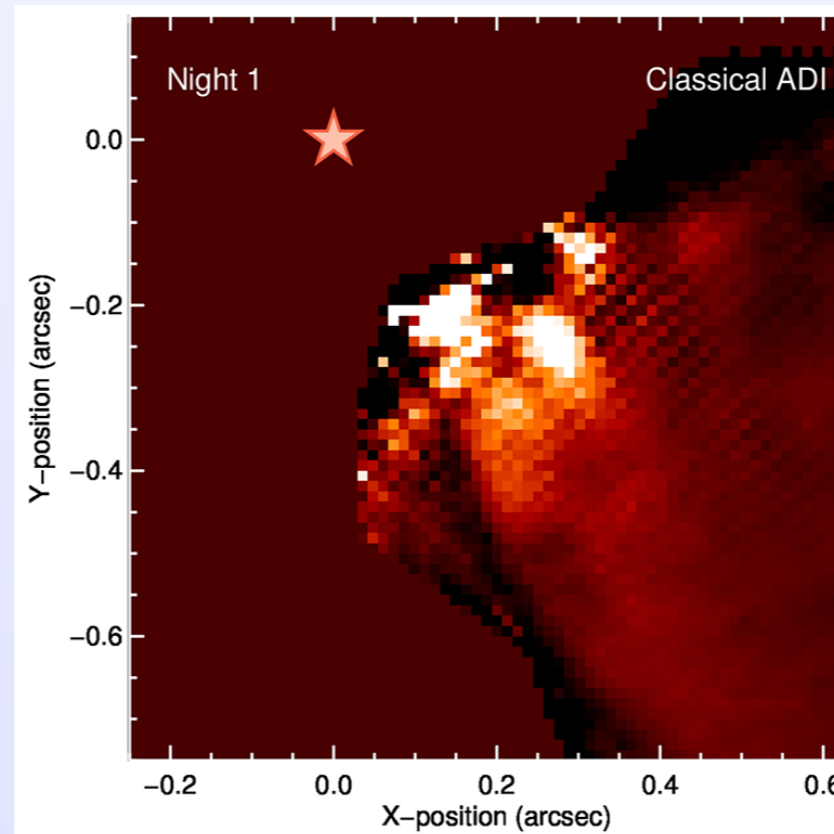


Application in 1d
to HD209458b

Snellen et al. (2010)

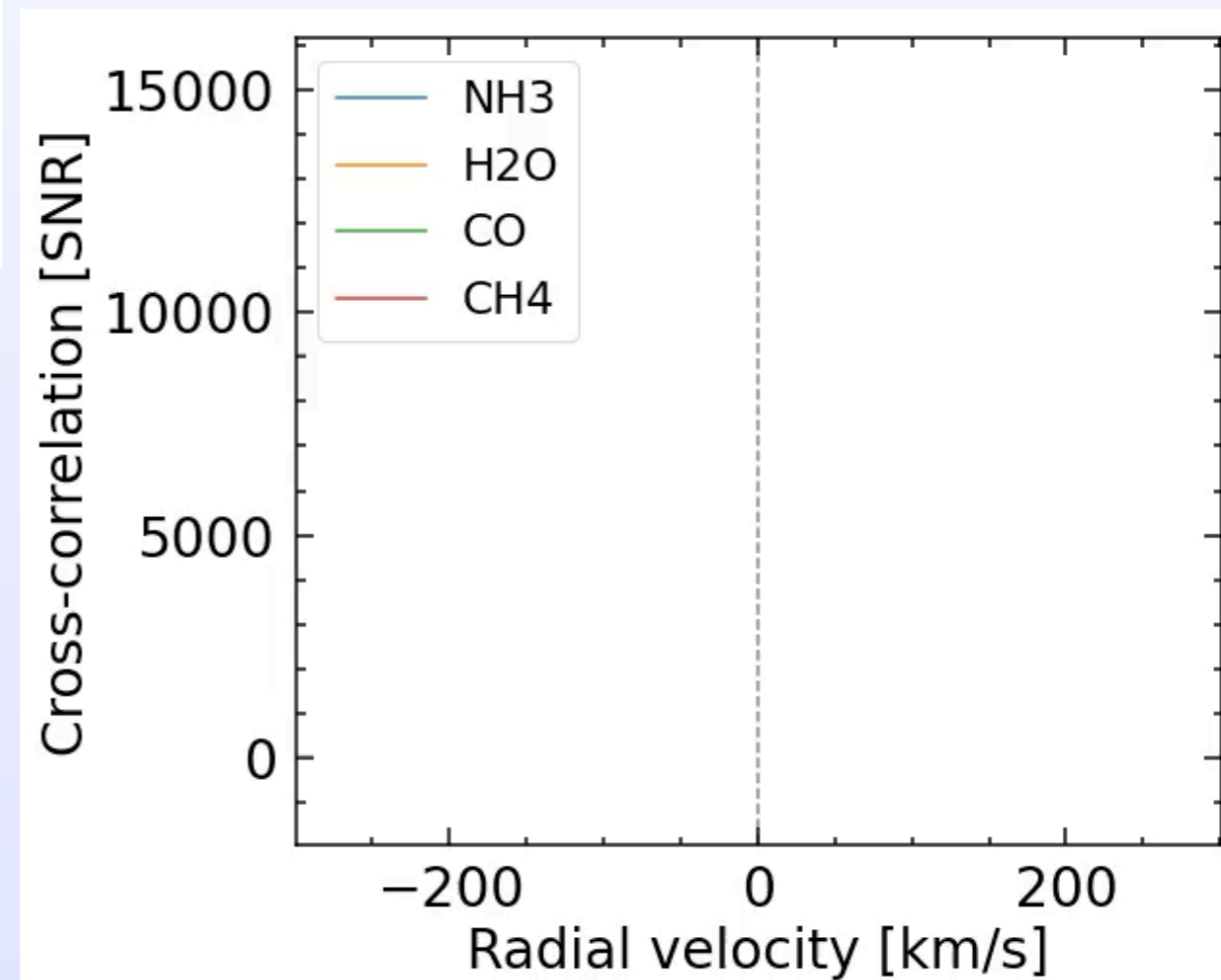
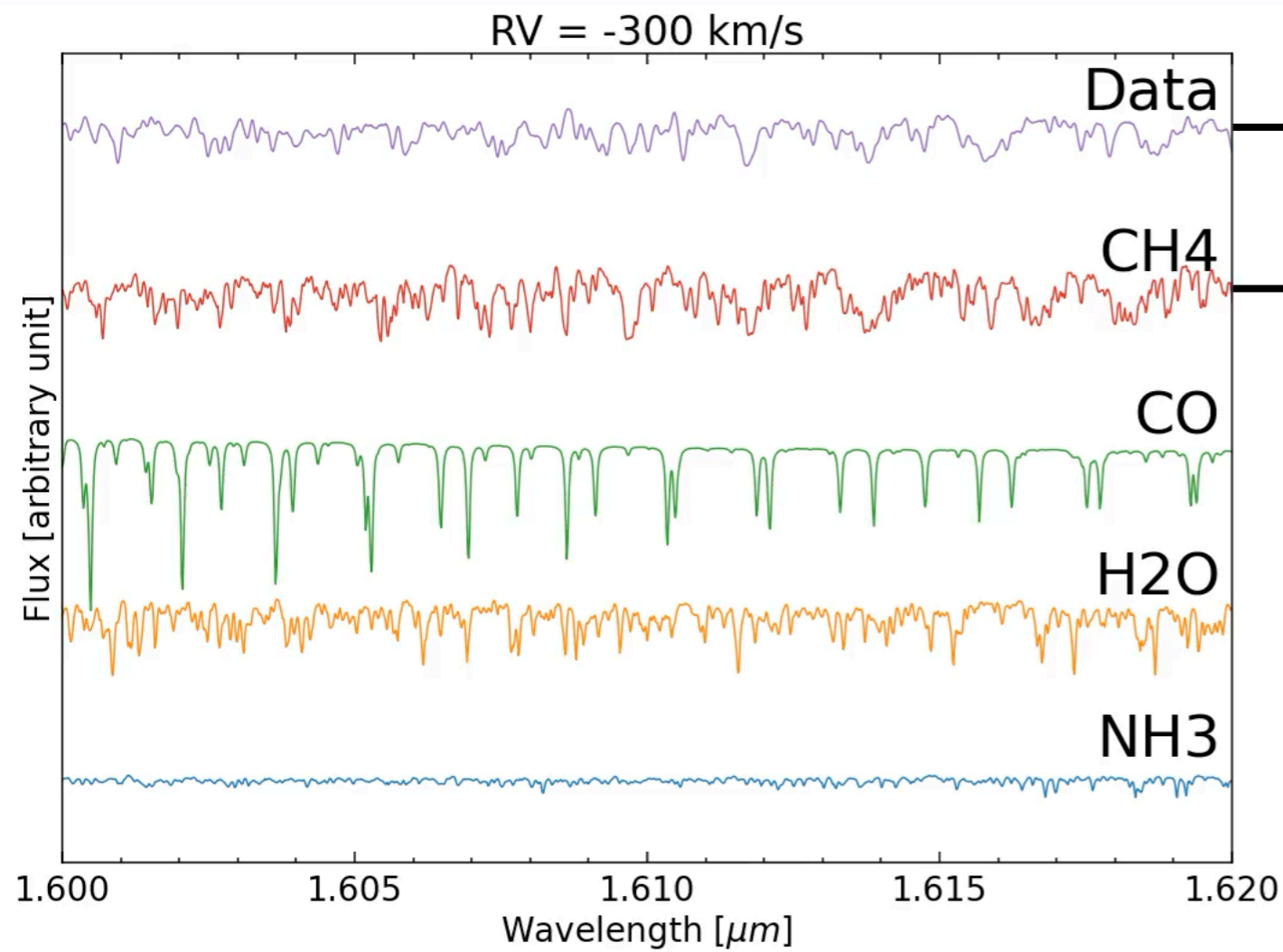


Hoeijmakers et al. (2016)

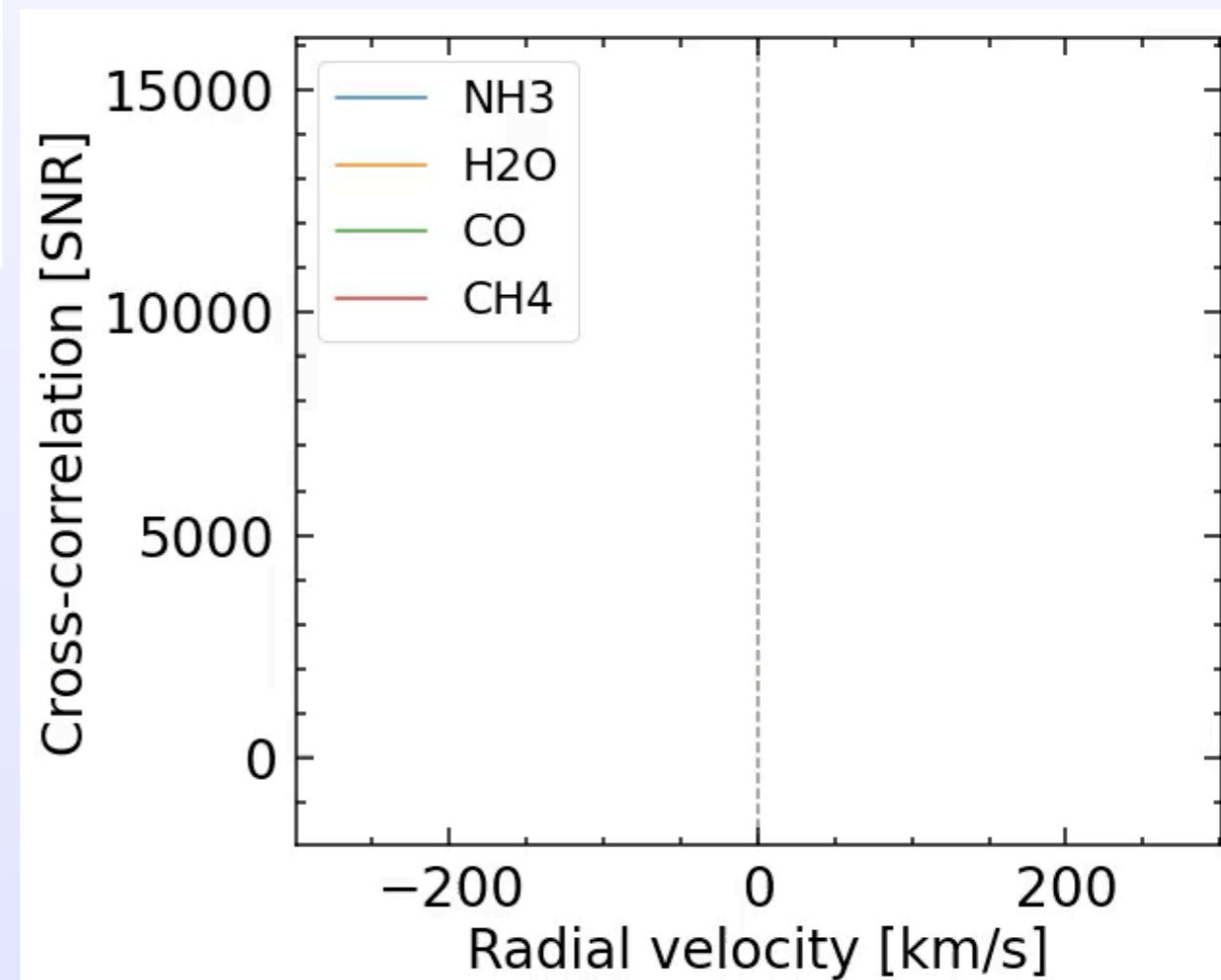
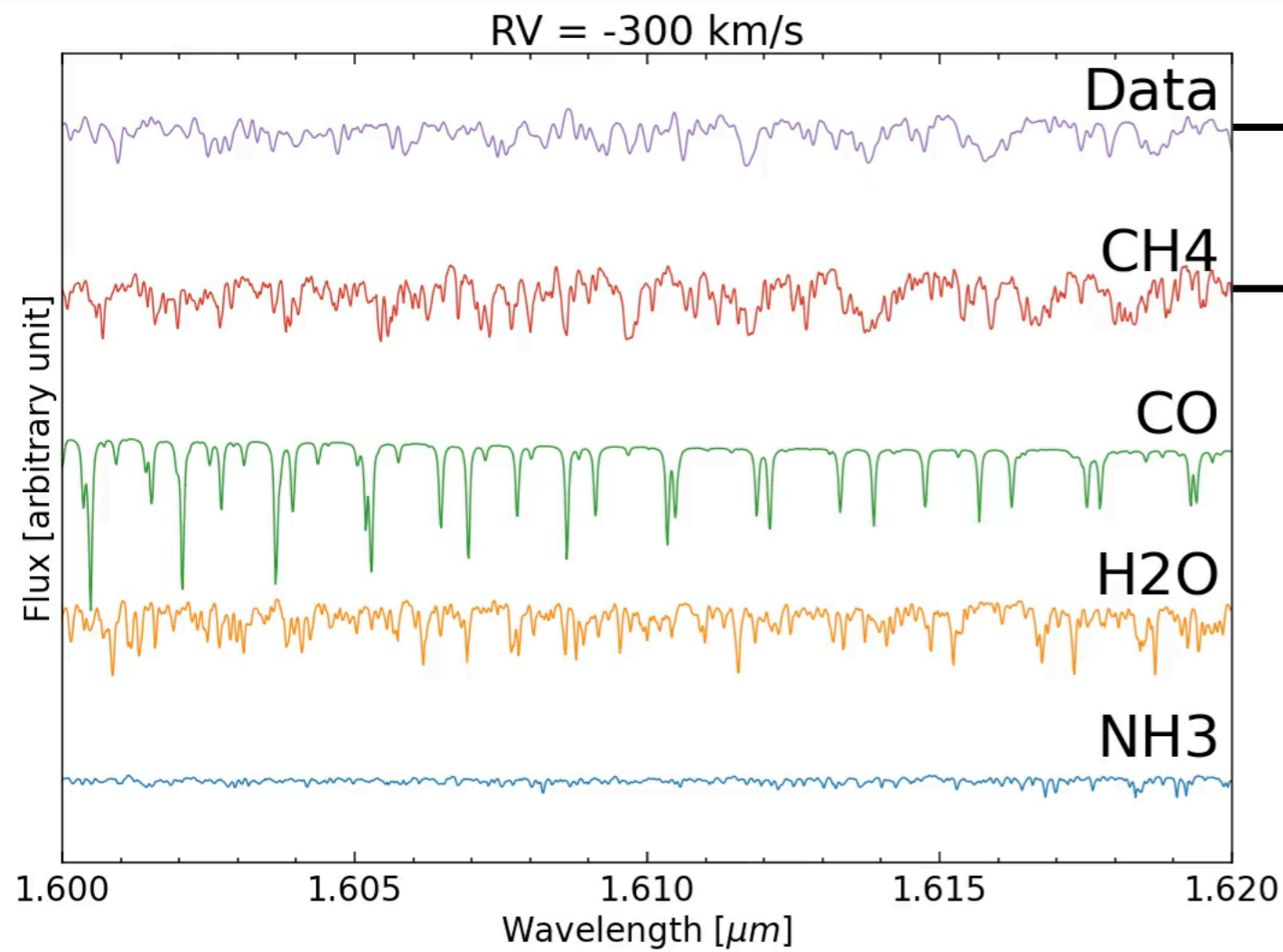


Application in 2d
to β Pictoris b

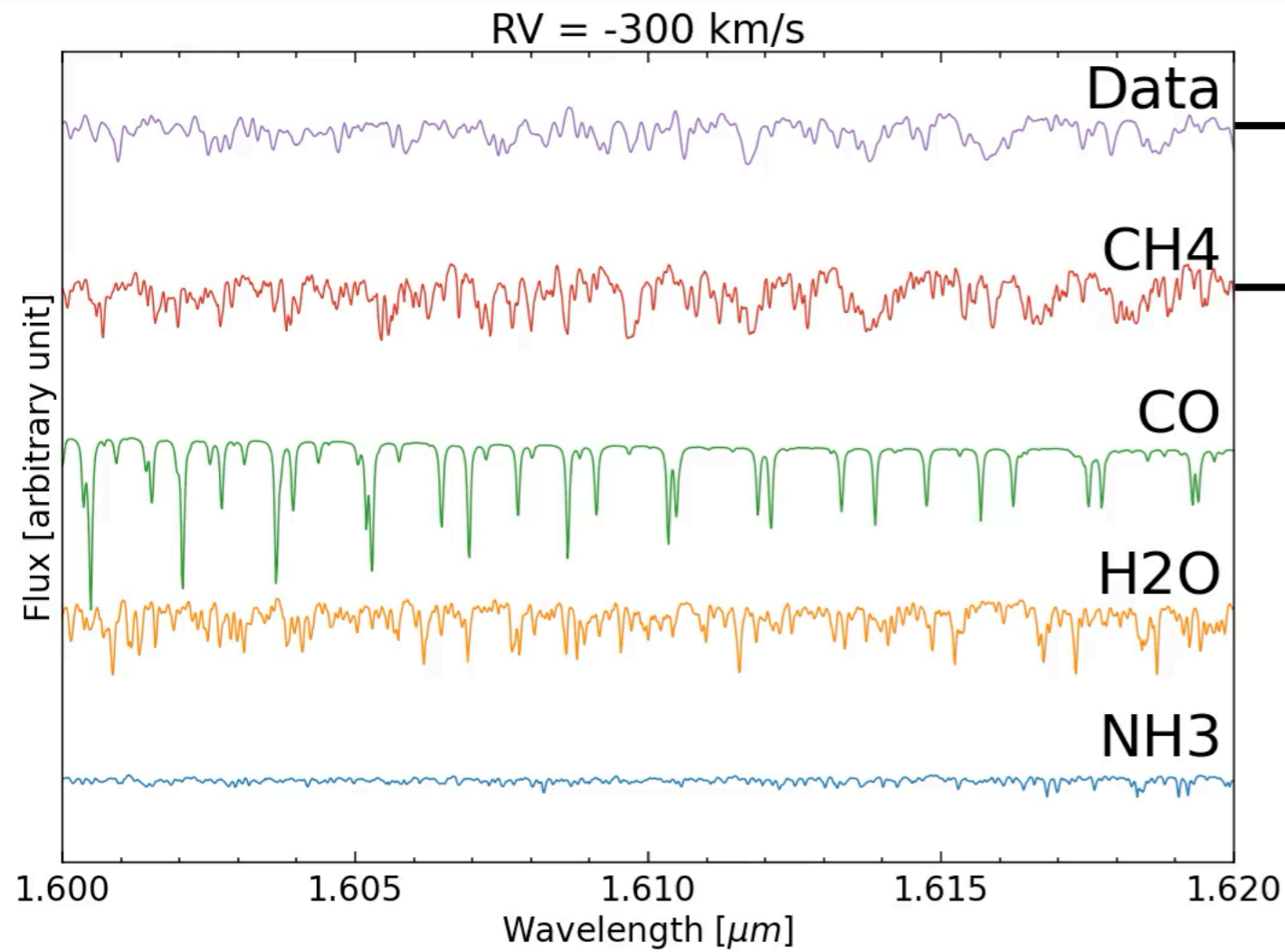
Boost in detection



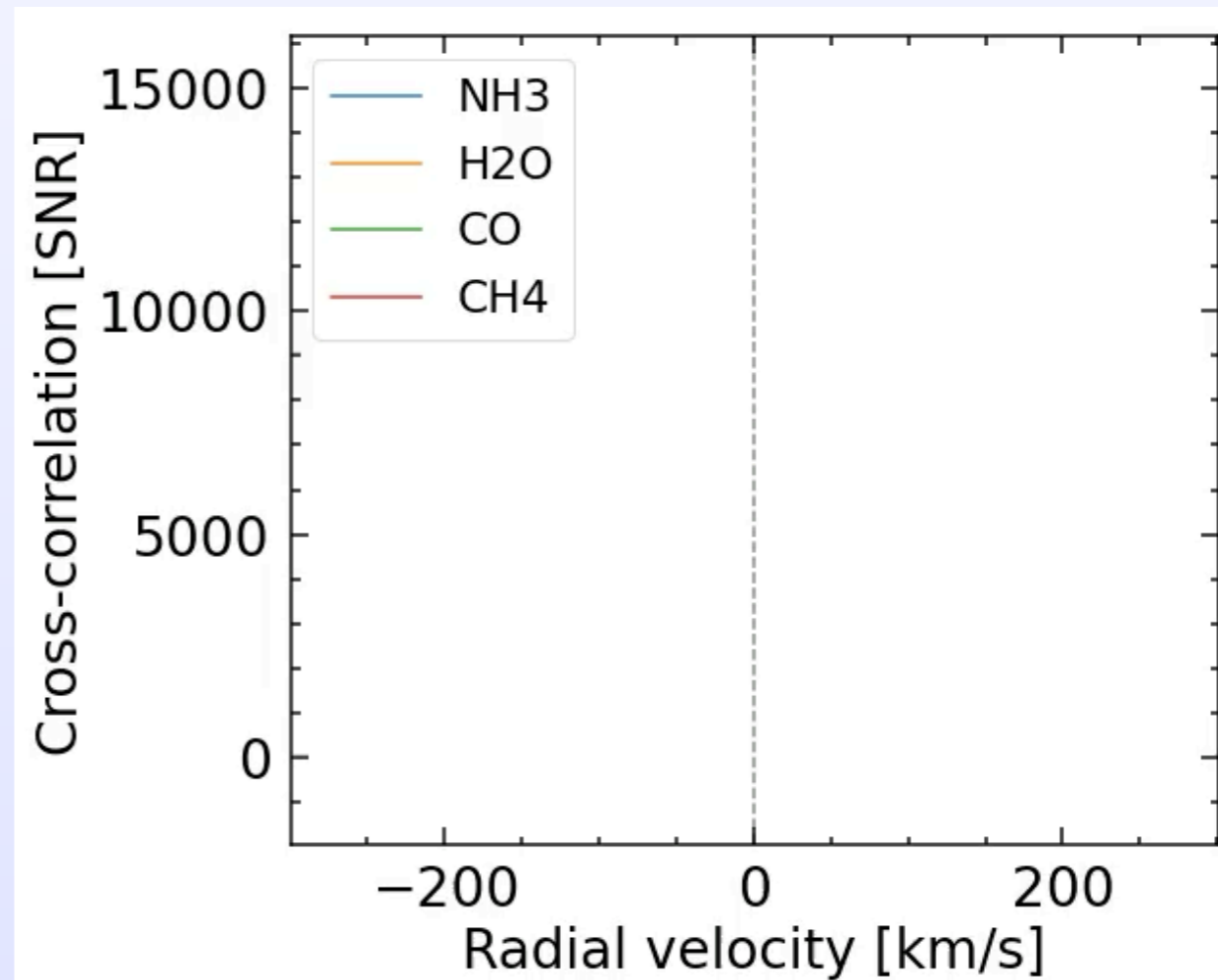
Boost in detection



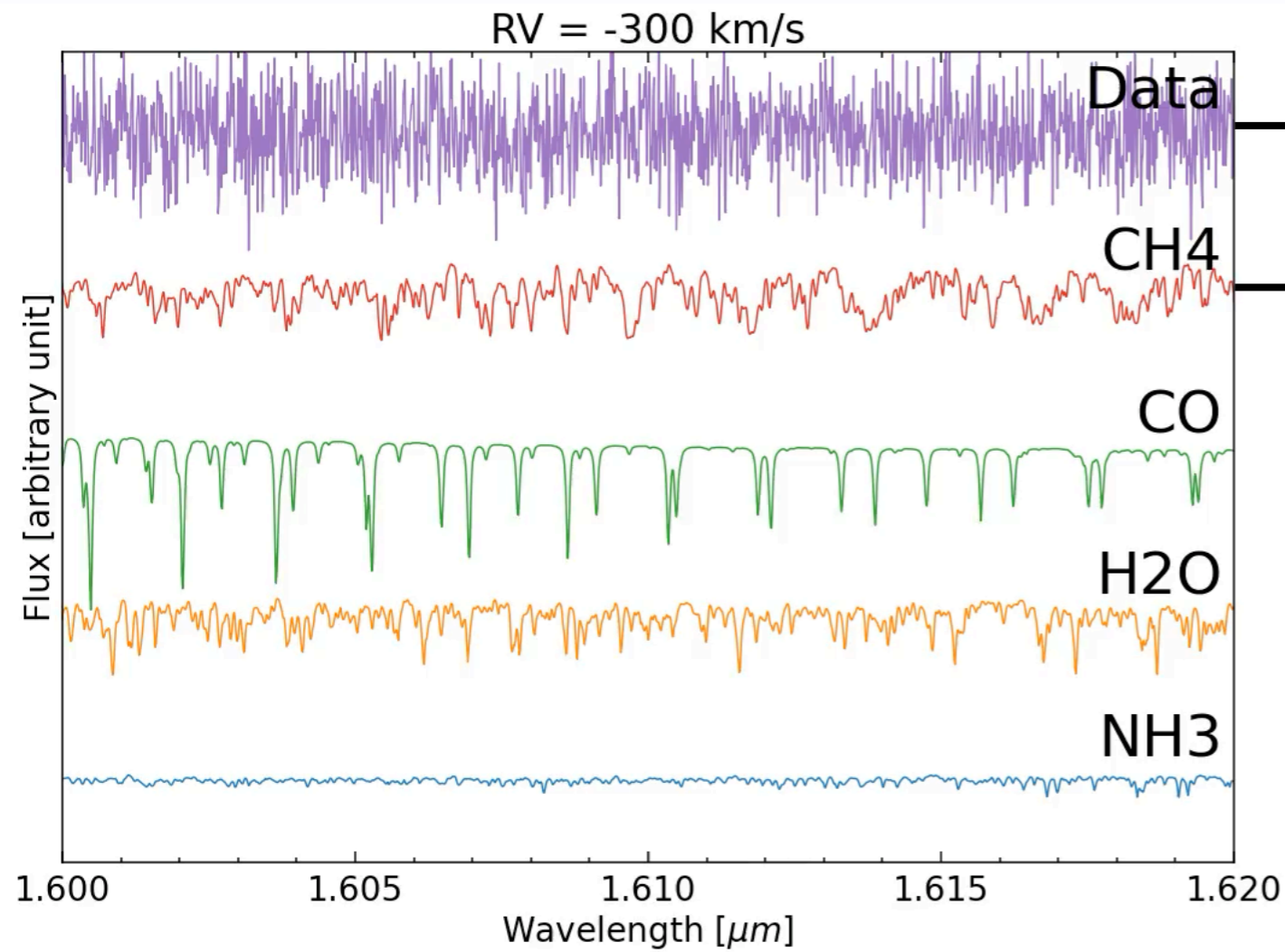
Boost in detection



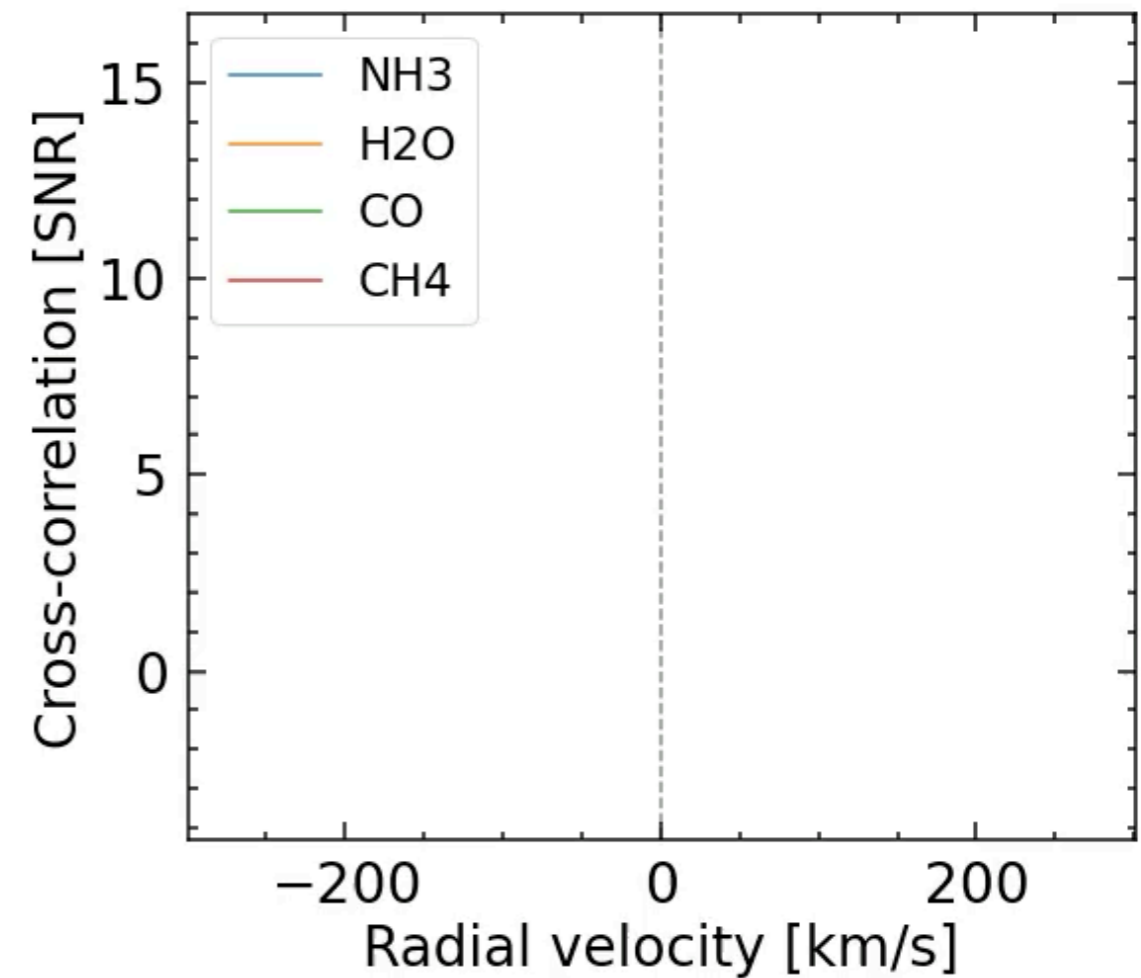
**Cross-correlation
boosts the signal!**



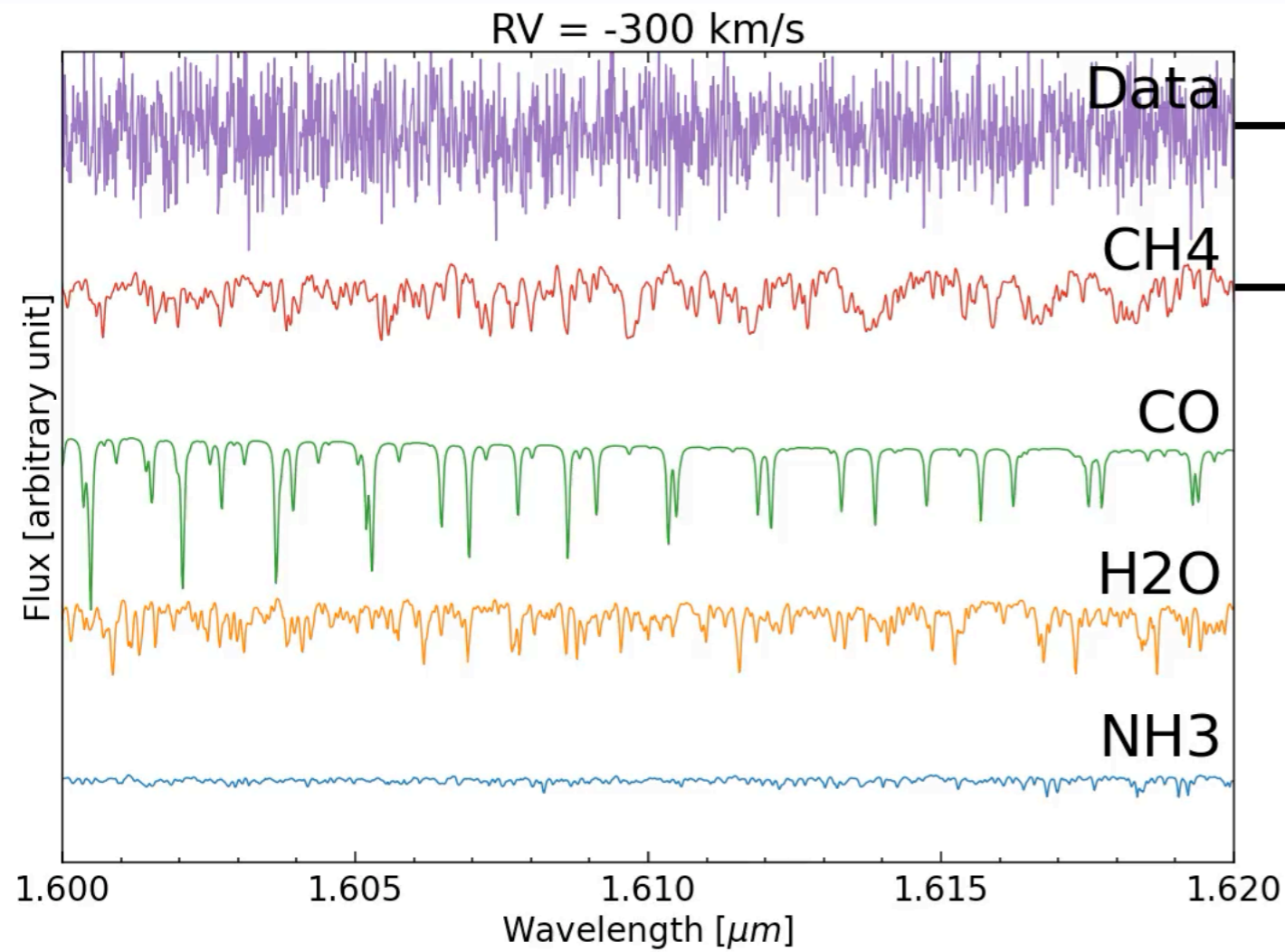
Boost in detection



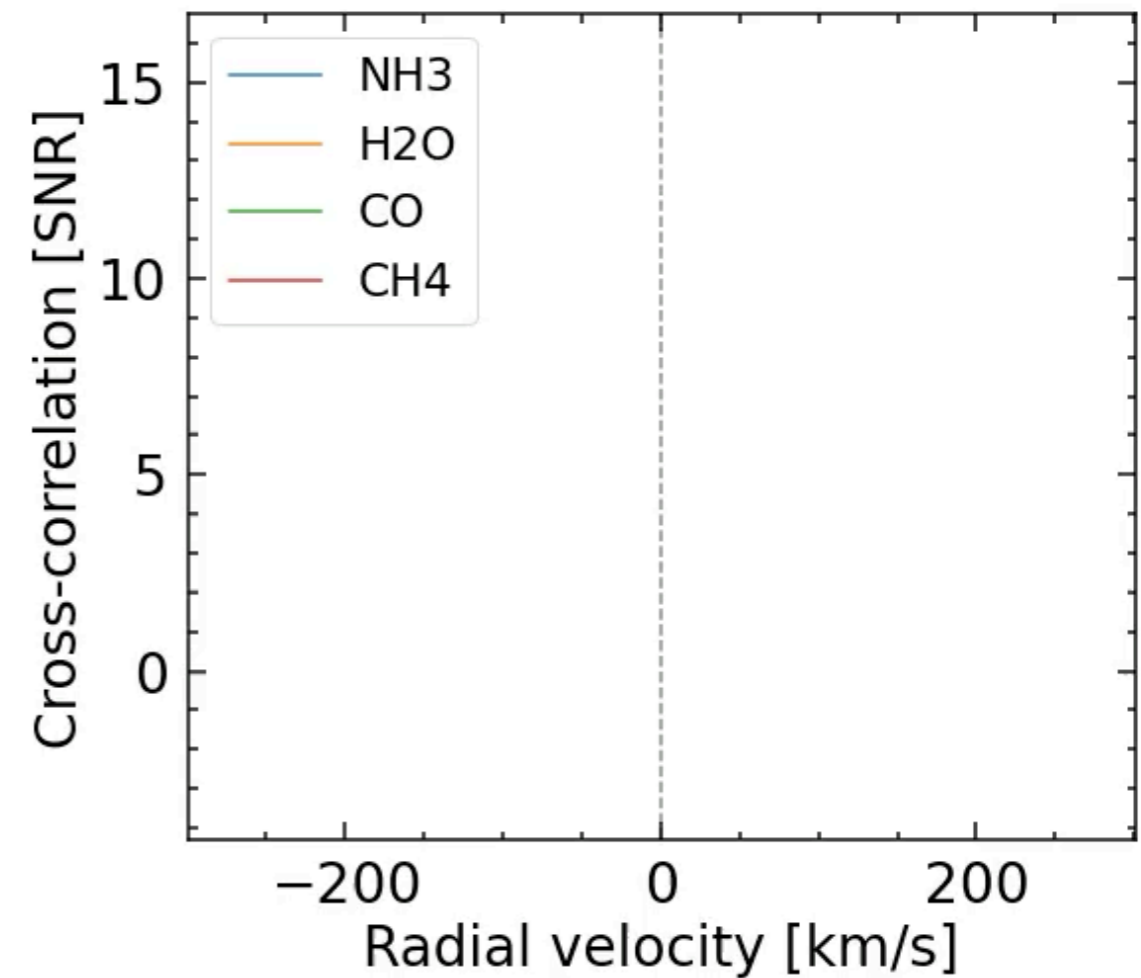
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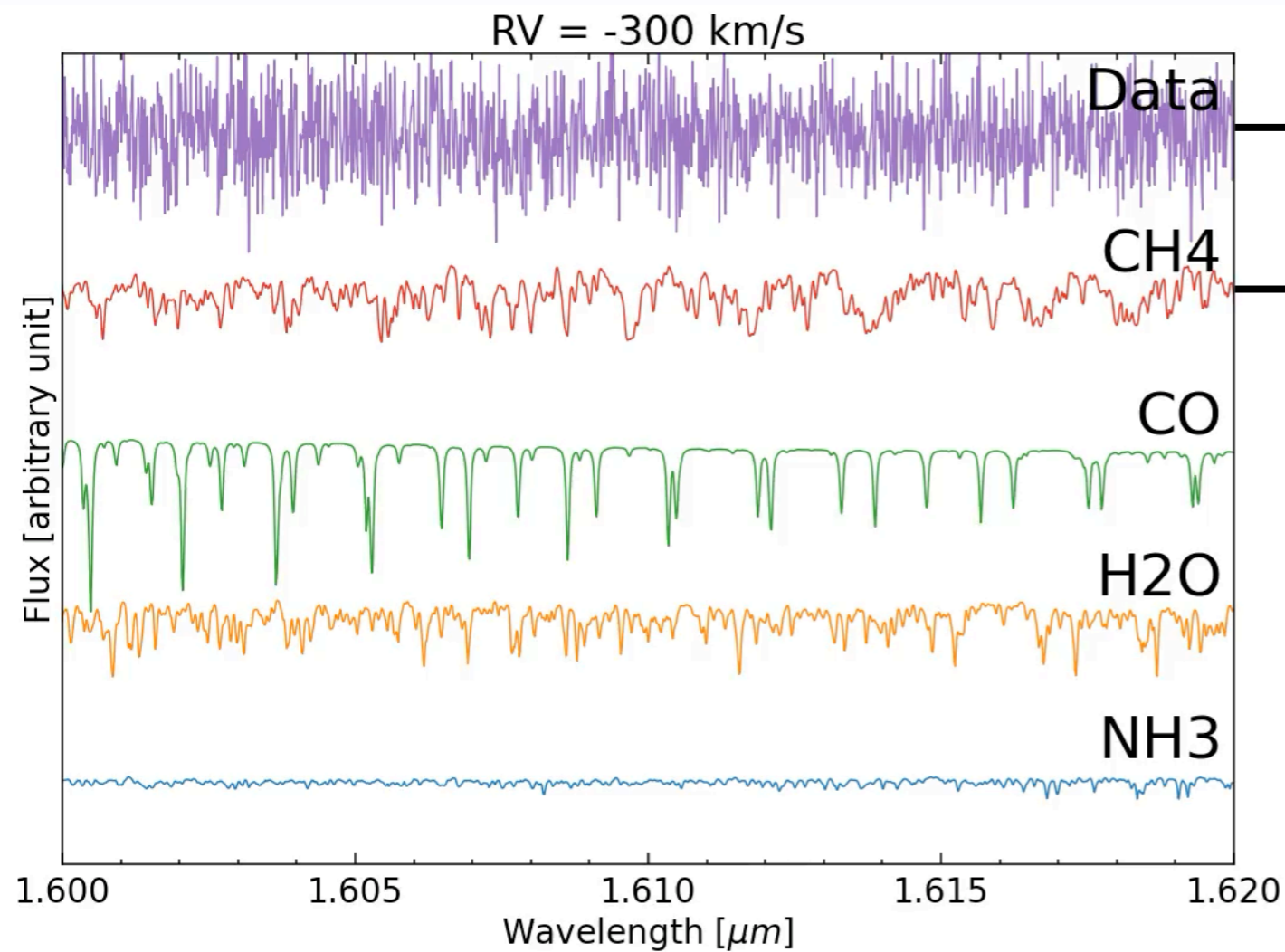
Boost in detection



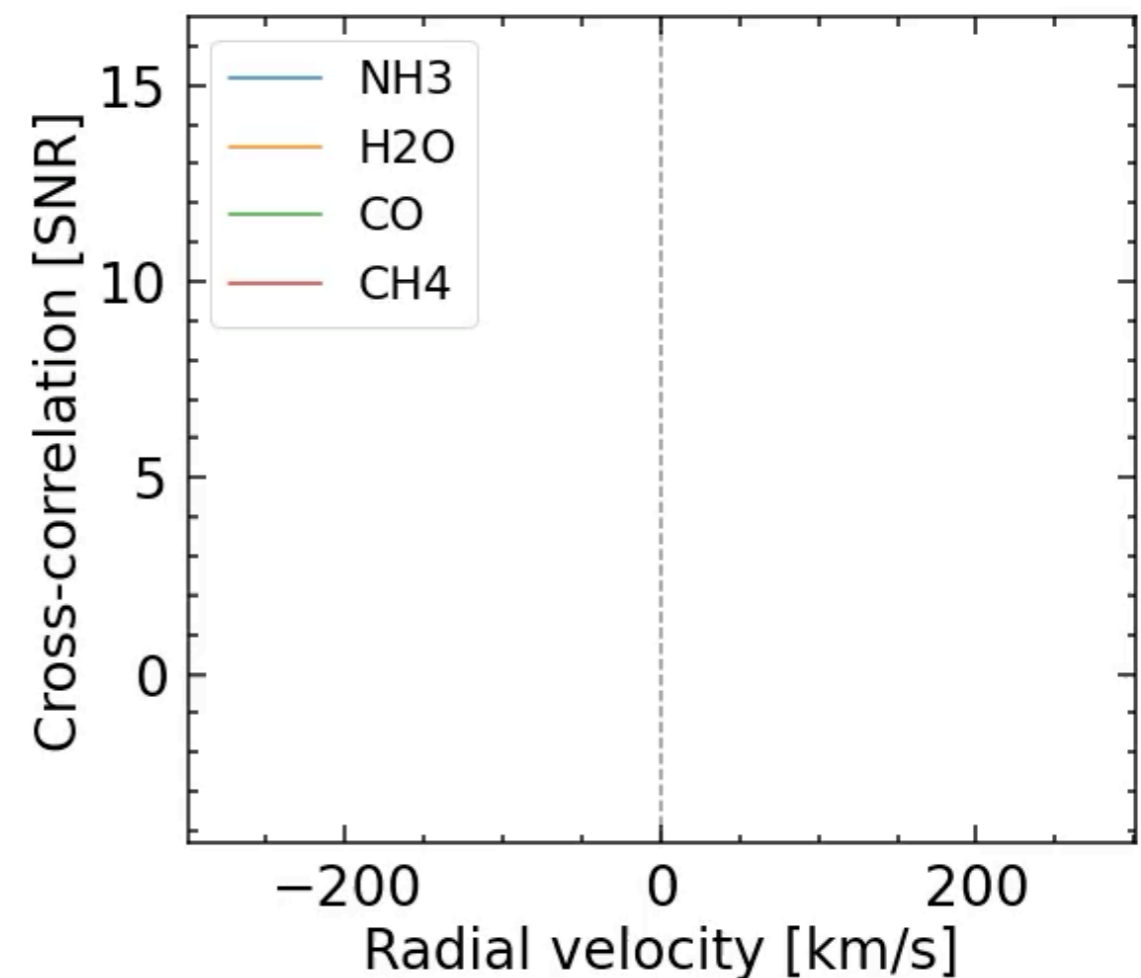
**Cross-correlation
boosts the signal!**



Boost in detection



**Cross-correlation
boosts the signal!**



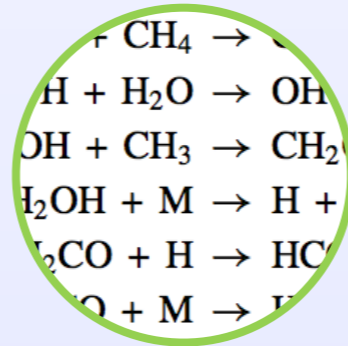
$$S/N = \frac{S_{\text{planet}}}{\sqrt{S_{\text{star}} + \sigma_{\text{bg}}^2 + \sigma_{\text{RN}}^2 + \sigma_{\text{dark}}^2}} \sqrt{N_{\text{lines}}}$$

Snellen et al. (2015)

Exoplanet science at high resolution



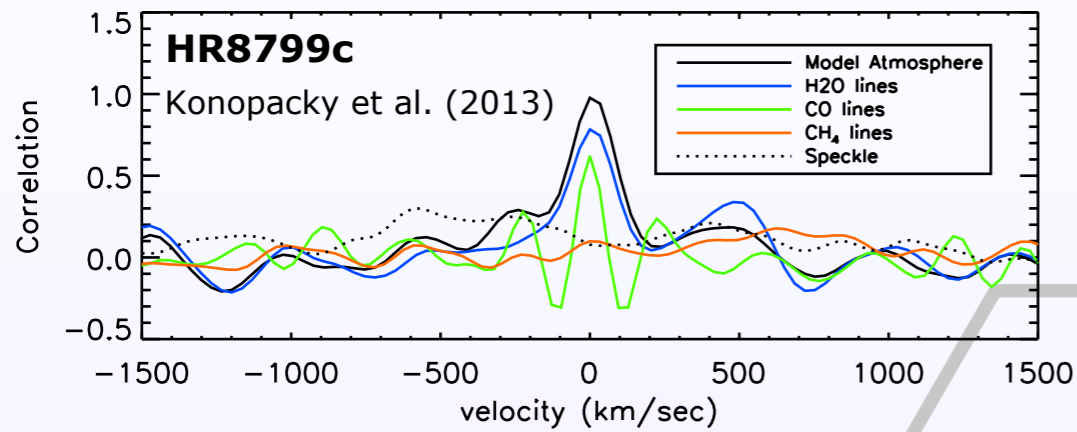
**Formation,
migration & evolution**



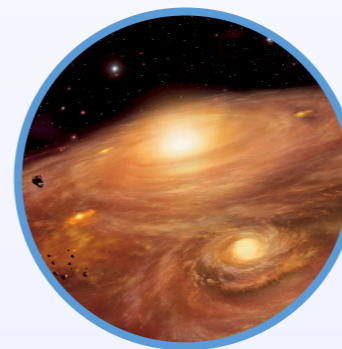
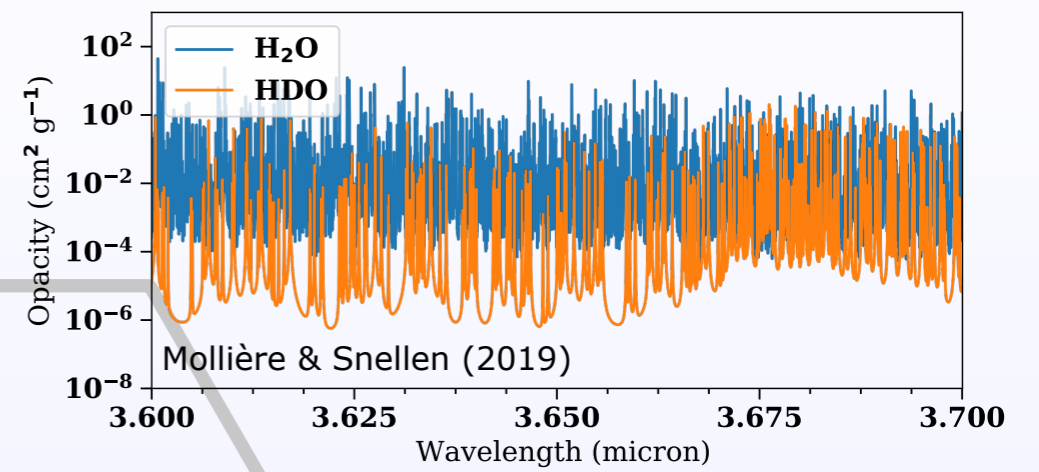
**Atmospheric
chemistry & dynamics**

Exoplanet science at high resolution

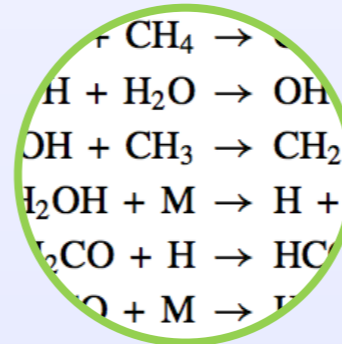
Molecules detection



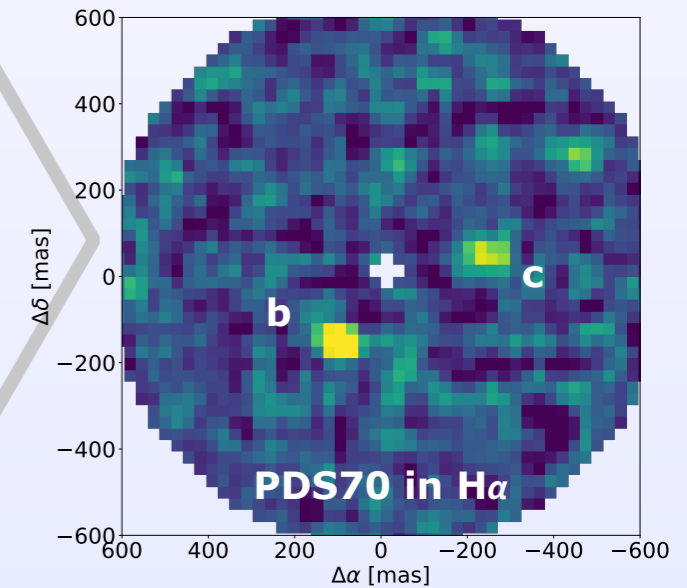
Isotopologues detection



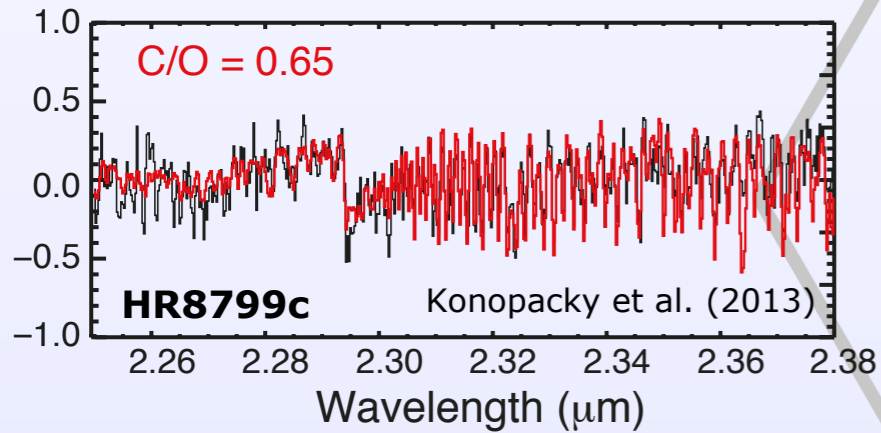
Formation, migration & evolution



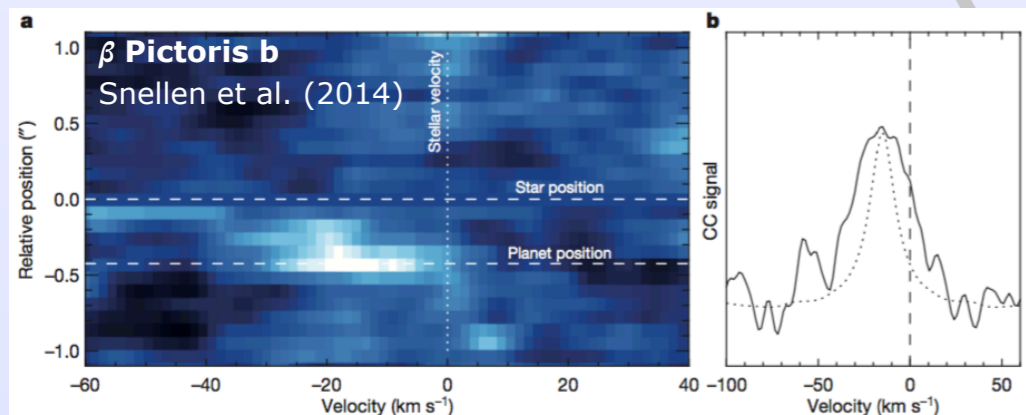
Accretion lines



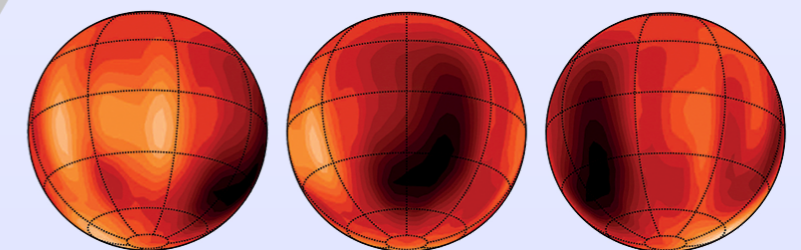
Abundances determination



Orbital and rotational velocity

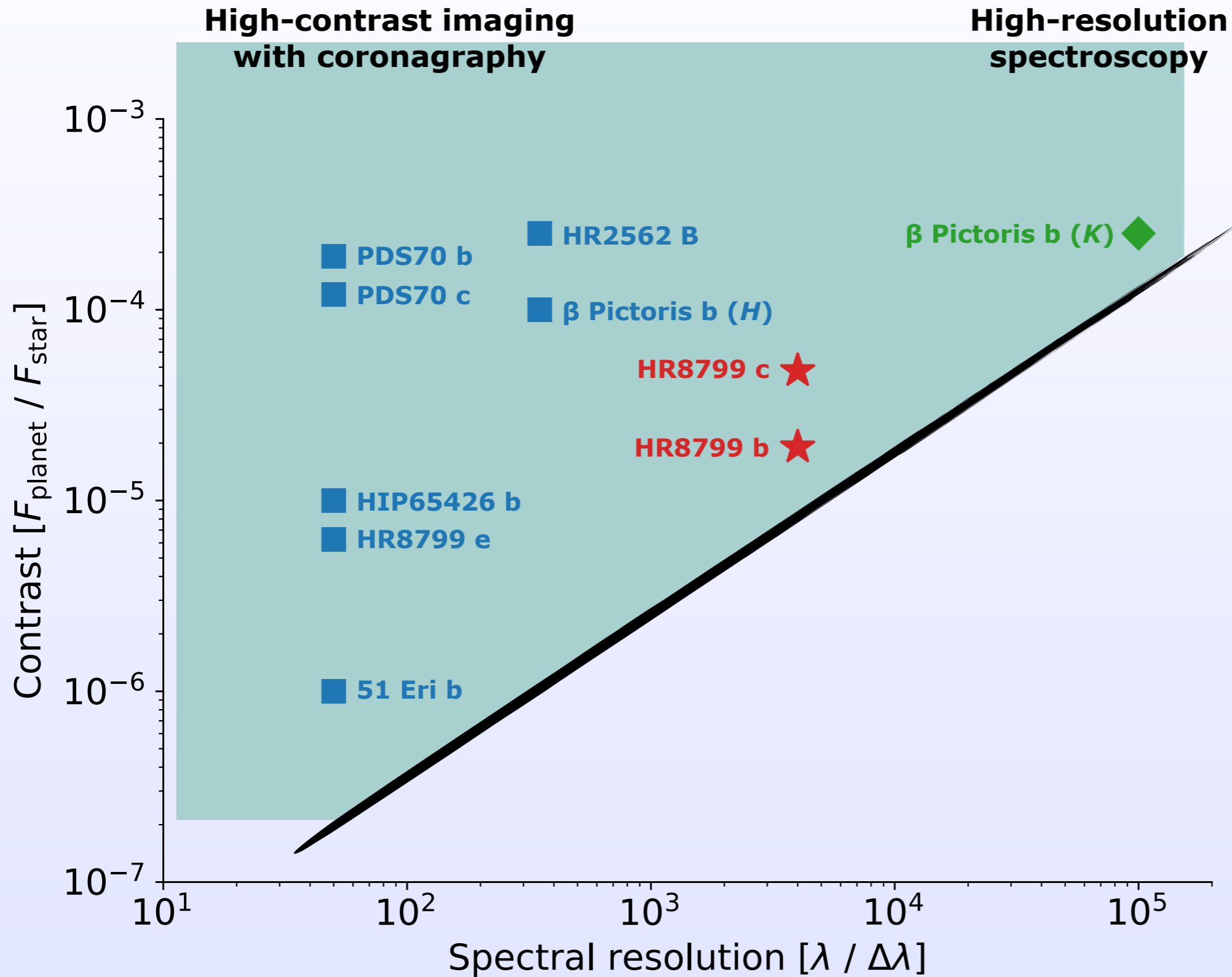


Variability & Doppler imaging

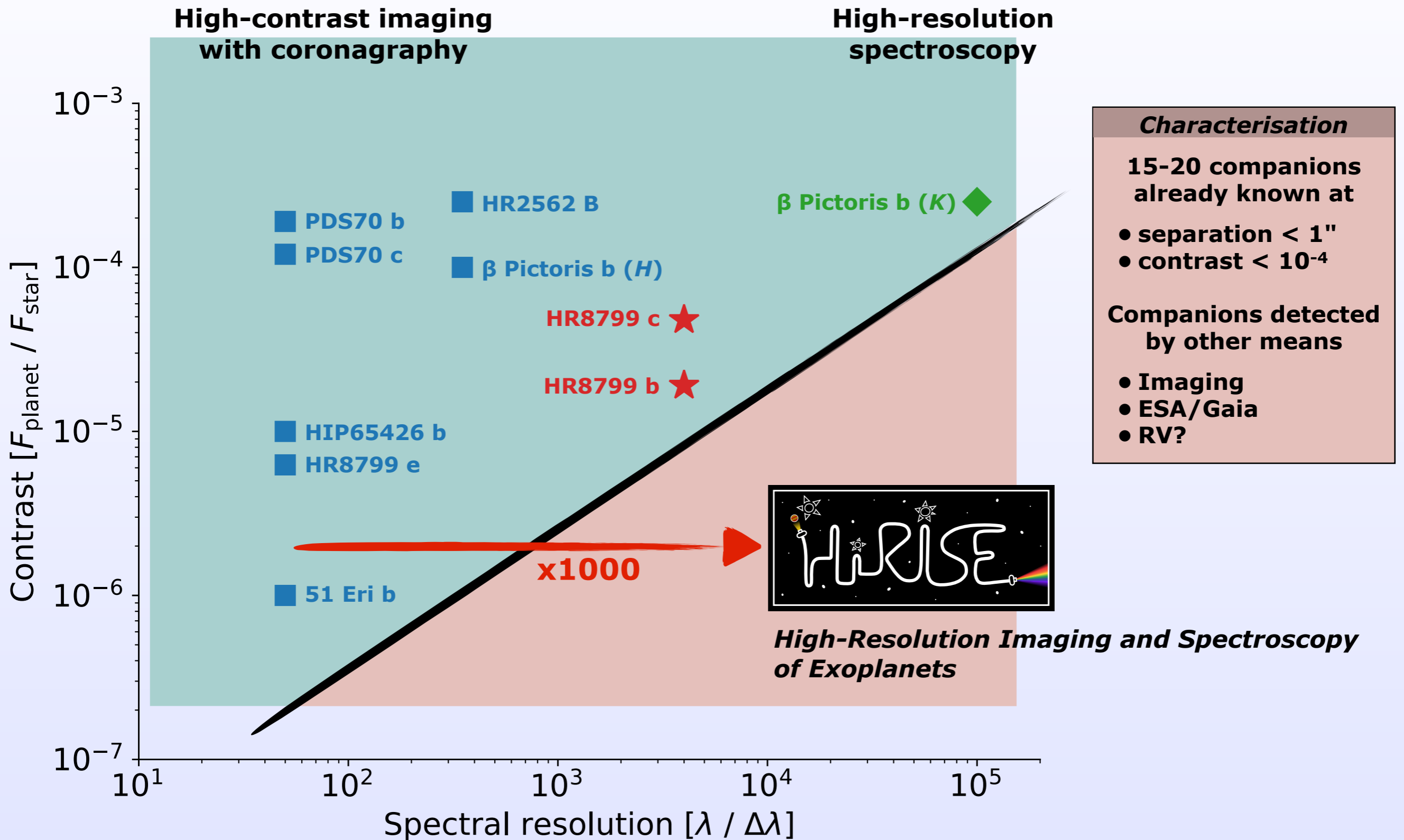


Luhman 16B (Crossfield et al. 2014)

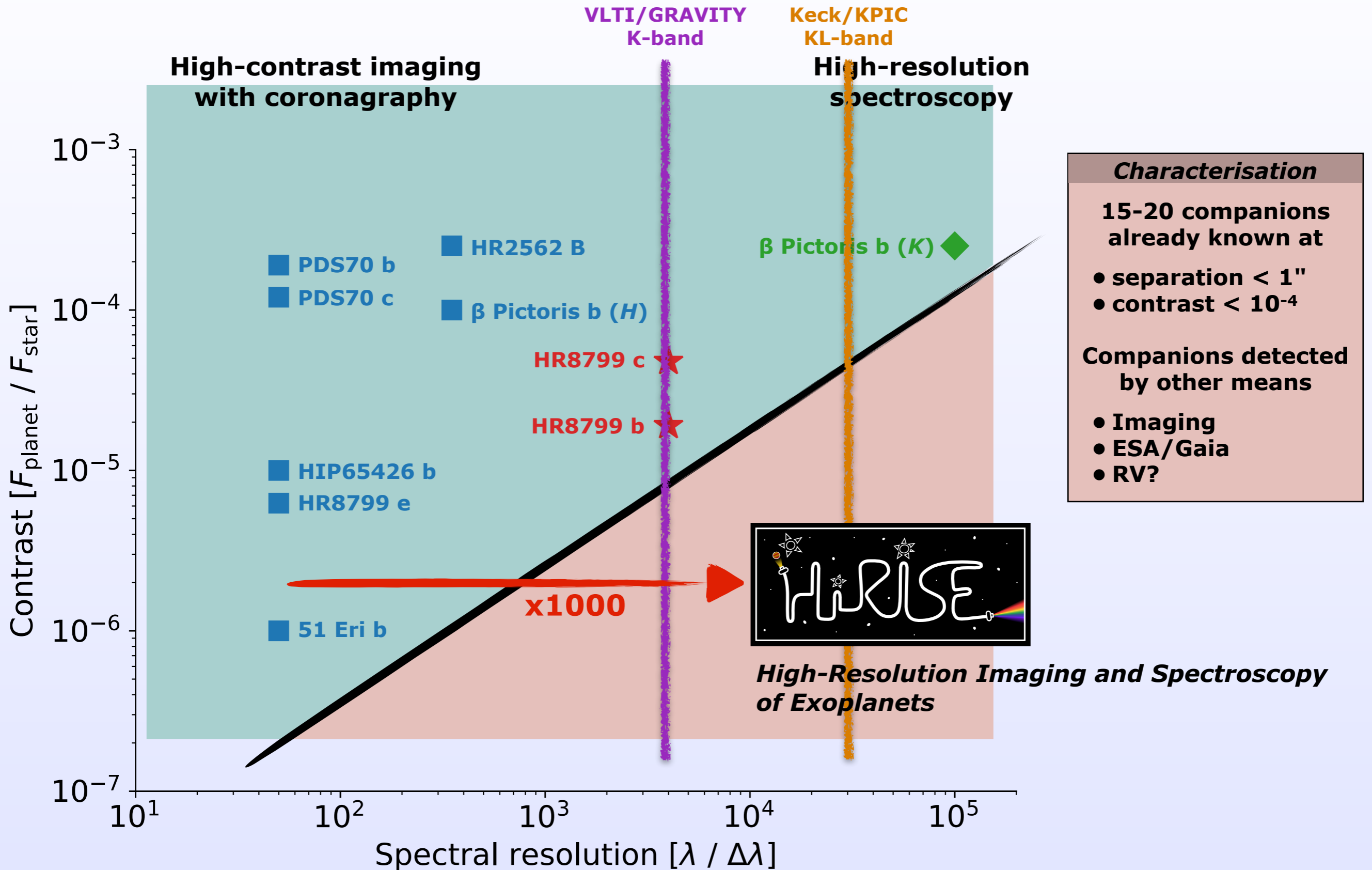
Young exoplanets characterisation in near-IR



Young exoplanets characterisation in near-IR



Young exoplanets characterisation in near-IR



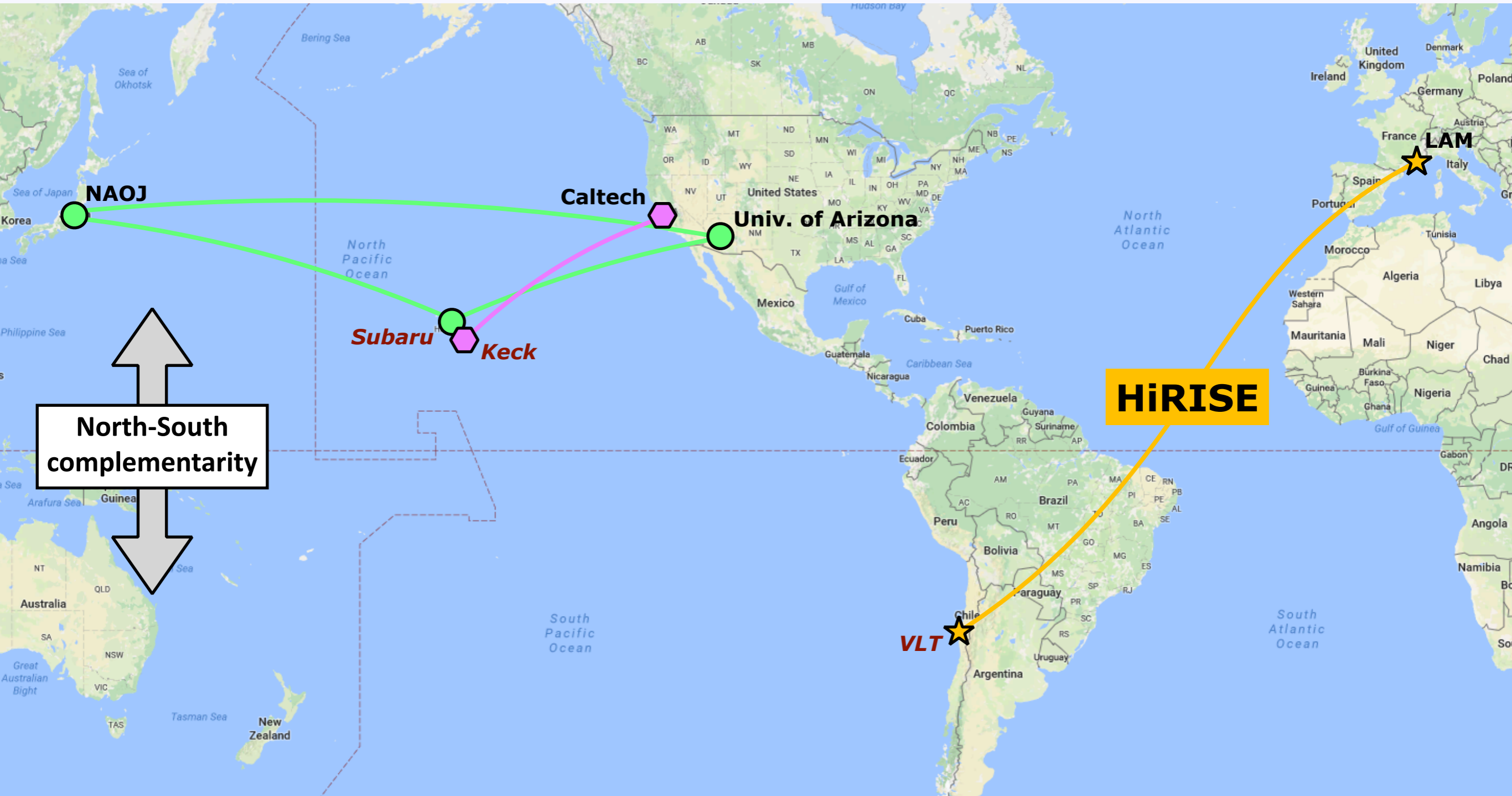
A European opportunity in the South

Existing instruments on 8-10 m telescopes with ExAO:

⬡ *Keck/KPIC*: D. Mawet, Caltech *[on-sky since 2020!]*

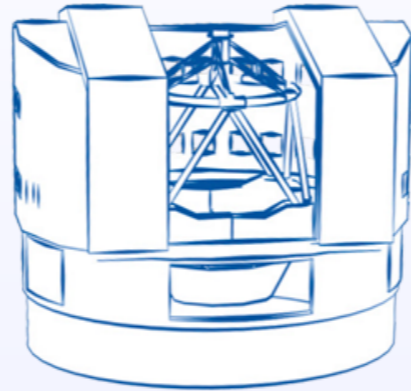
● *Subaru/REACH*: T. Kotani, NAOJ *[on-sky since 2020!]*

★ *VLT/HiRISE*: A. Vigan, CNRS/LAM



A unique window of opportunity

VLT/UT3



High-contrast exoplanet imager



High-resolution spectrograph



Y J H K

50 - 350

Extreme adaptive optics

Coronagraphy

Spectral coverage

Spectral resolution

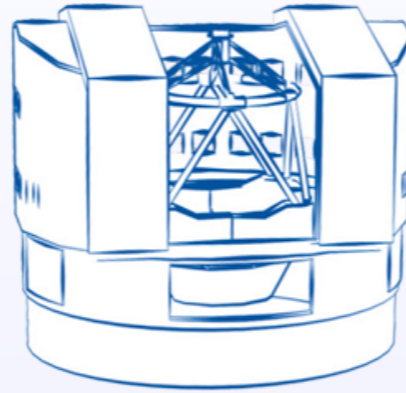


Y J H K L M

50 000 - 100 000

A unique window of opportunity

VLT/UT3



High-contrast exoplanet imager



High-resolution spectrograph



Y J H K

50 - 350

Extreme adaptive optics

Coronagraphy

Spectral coverage

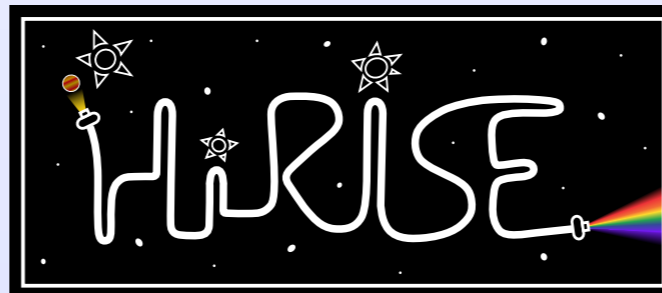
Spectral resolution



Y J H K L M

50 000 - 100 000

Fiber coupling



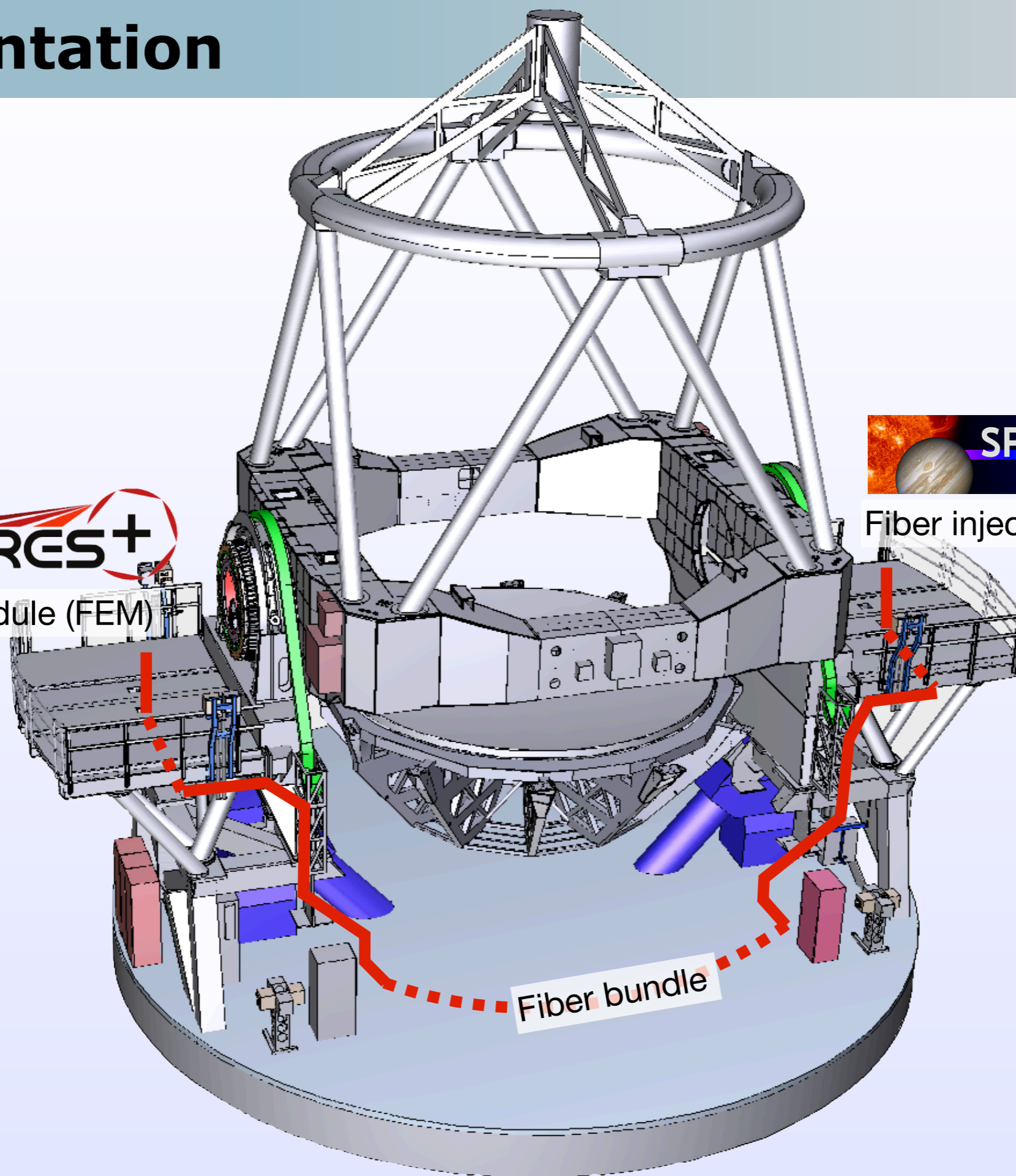
Implementation



Fiber extraction module (FEM)



Fiber injection module (FIM)



Fiber bundle

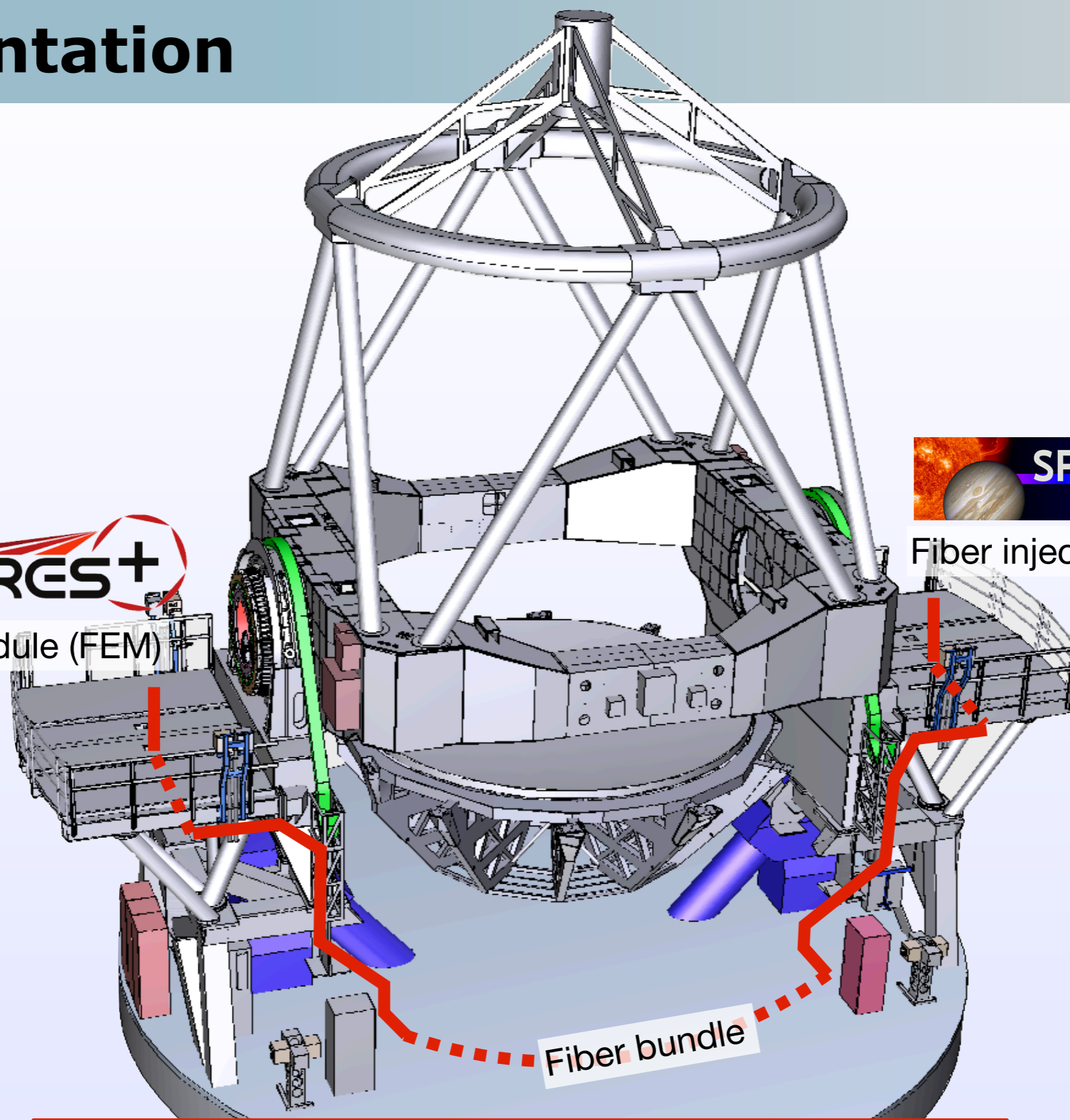
Implementation



Fiber extraction module (FEM)



Fiber injection module (FIM)



Fiber bundle

Is it really worth it?

Performance and trade-off study

Scientific requirements

The instrument must:

- sci.req.1** Enable direct characterization of companions in less than 1 night
- sci.req.2** More efficient than CRIRES standalone for the same science case
- sci.req.3** Provide access to H band and, if possible, to K band

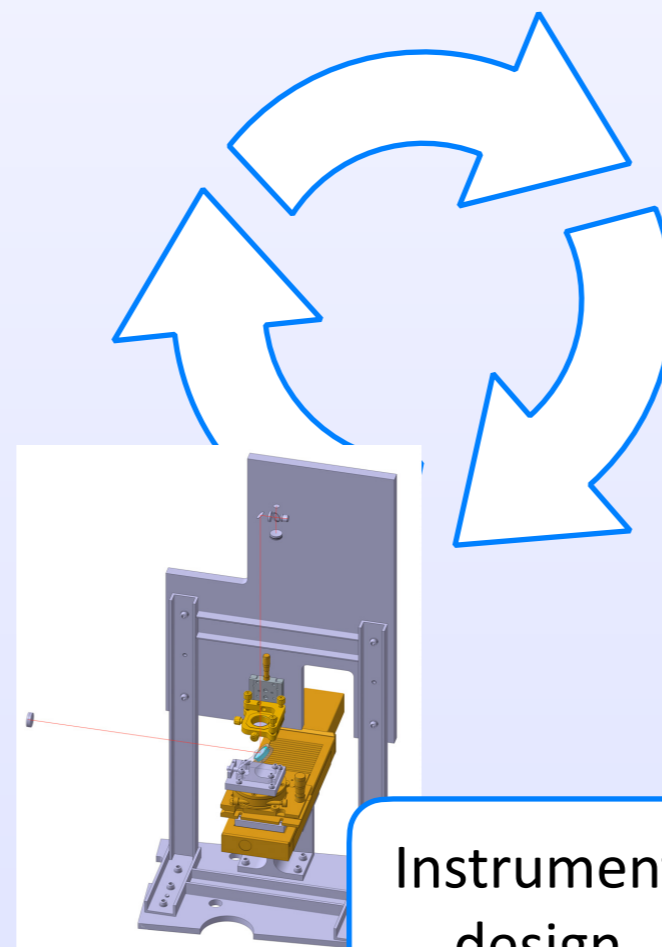
Technical requirements

The instrument must:

- tech.req.1** Have no impact on regular operations of SPHERE, CRIRES, or UT3
- tech.req.2** Induce no modification of hardware used in regular operations
- tech.req.3** Be compatible with ESO and VLT standards

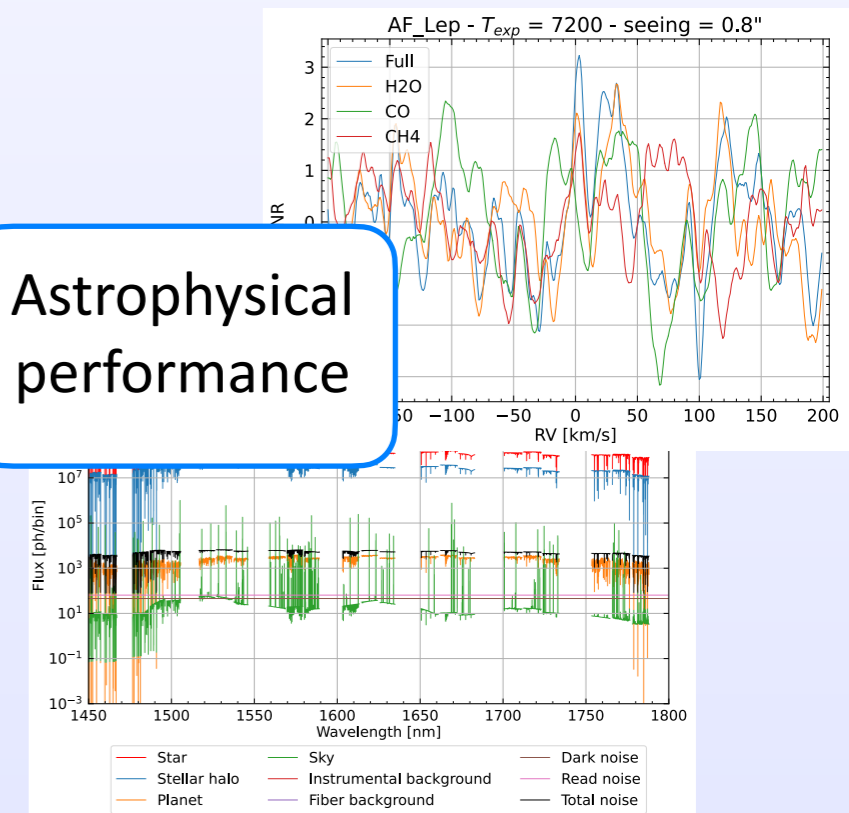
Simulation model

```
1 #!/usr/bin/env python
2 import sys
3 import os
4 import simpleknn
5 from bigfile import BigFile
6
7 if __name__ == "__main__":
8     trainCollection = 'toydata'
9     nimages = 2
10    feature = 'f1'
11    dia = 3
12
13    testCollection = trainCollection
14    testset = testCollection
15
16    featureDir = os.path.join(rootpath, trainCollect
17                               simpleknn.load_model(os.path.join(fe
```



Instrument design

Astrophysical performance



Performance and trade-off study

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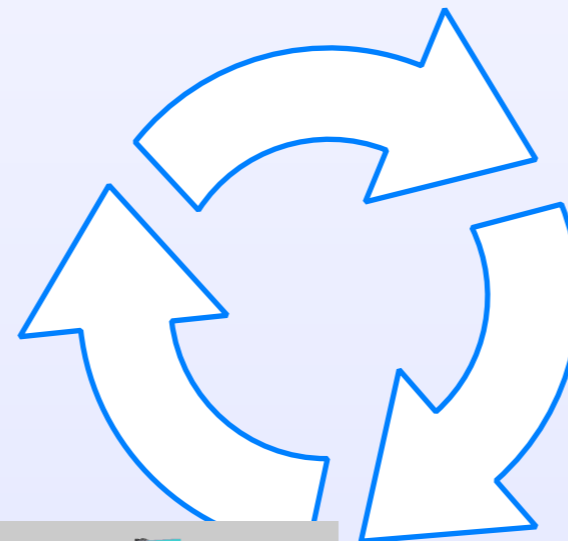
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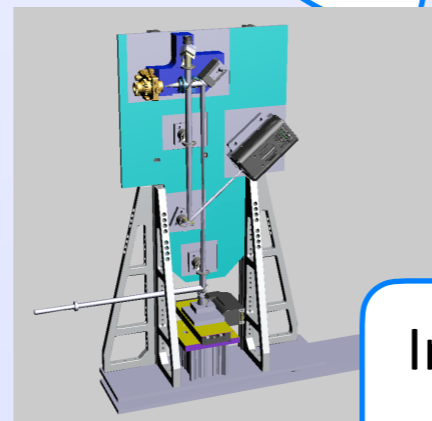
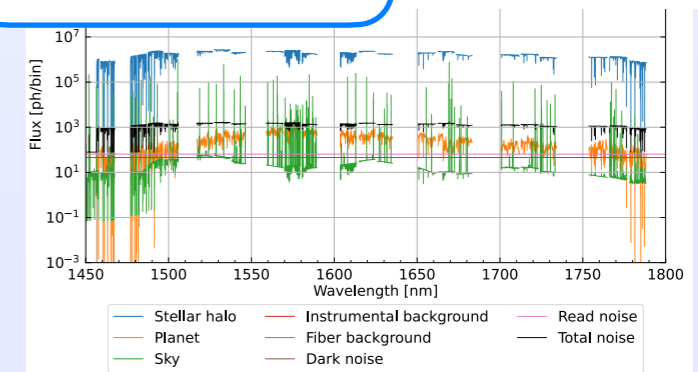
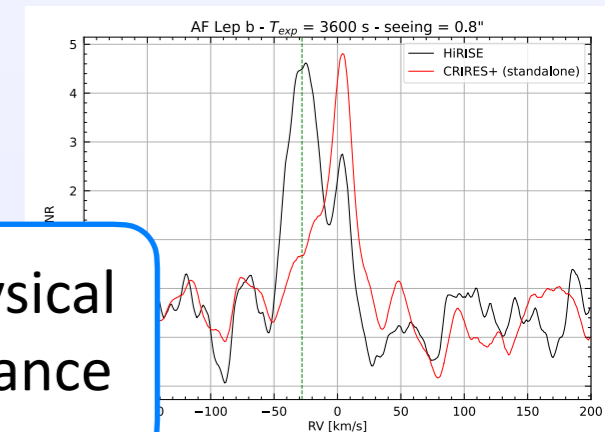
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Astrophysical performance



Instrument design

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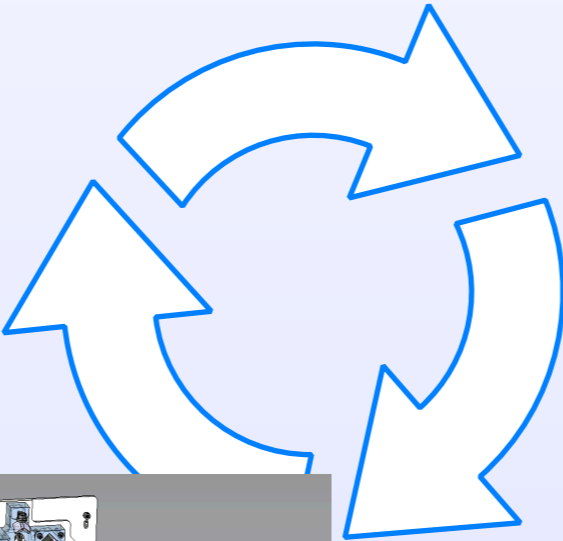
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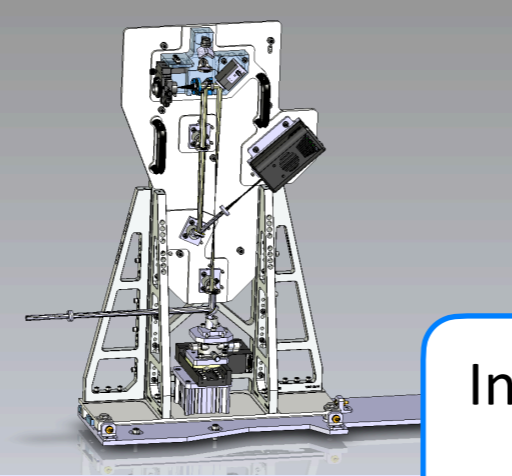
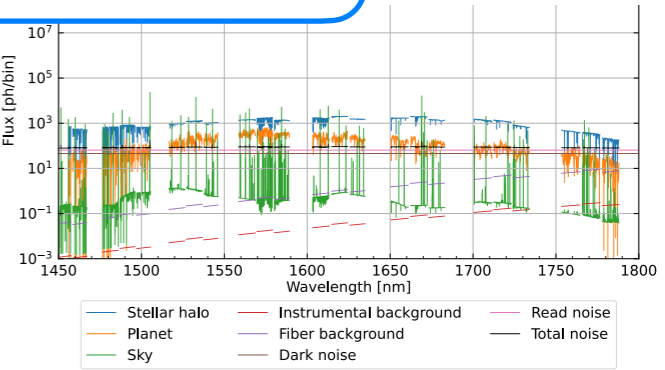
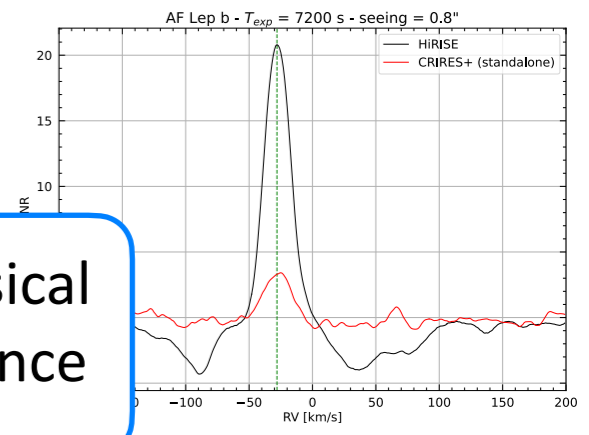
```
Everything Else | ANSI | PC
1 imported by process:36076
2 invoked __main__ by process:36076 global variable is:5
3 invoked in __main__ block by process:36076 global variable is:6
4 imported by process:49344
5 imported by process:78156
6 invoked __mp_main__ by process:49344 global variable is:5
7 invoked __mp_main__ by process:78156 global variable is:5
8 initialize:49344
9 initialize:78156
10 in process(49344) global variable
11 in process(49344) global variable
12 in process(78156) global variable
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14 in process(78156) global variable
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16 in process(49344) global variable
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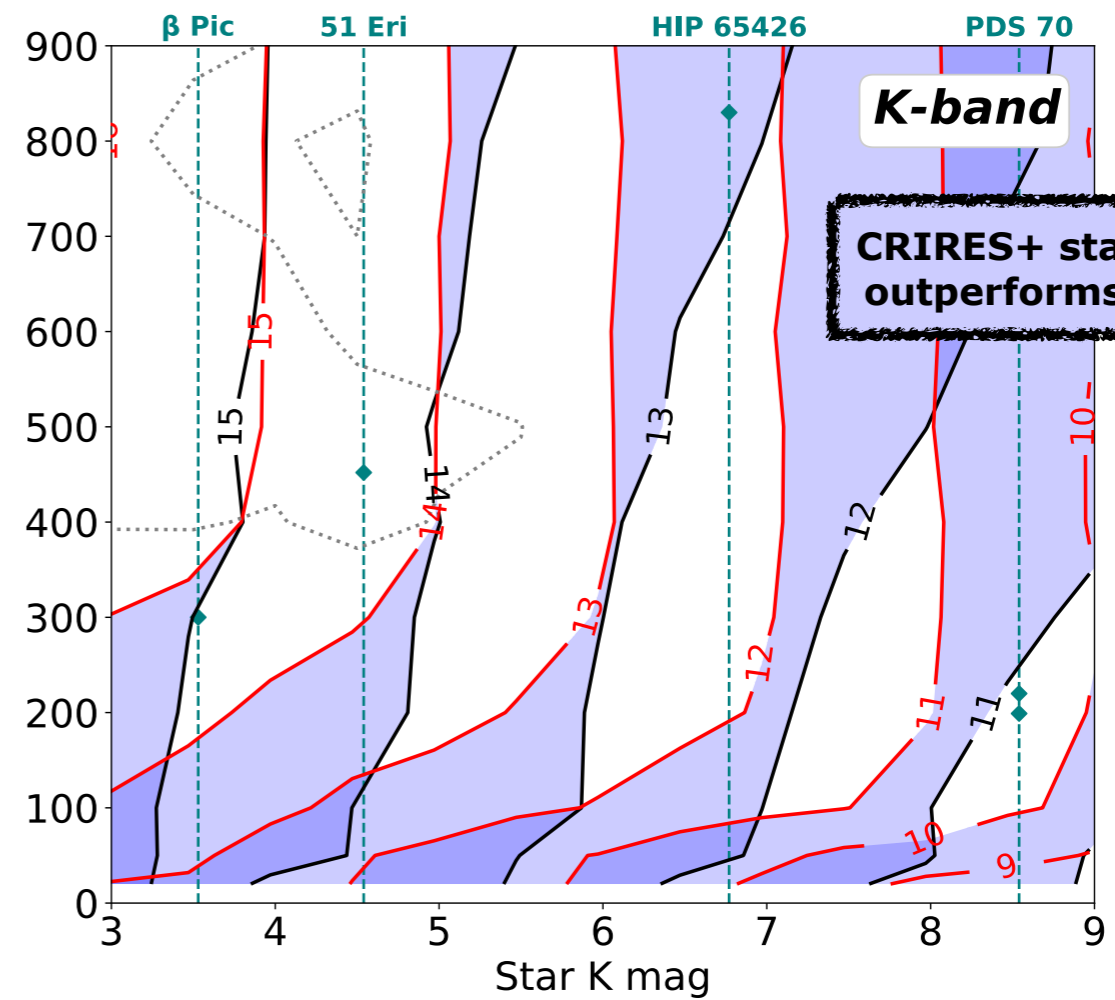
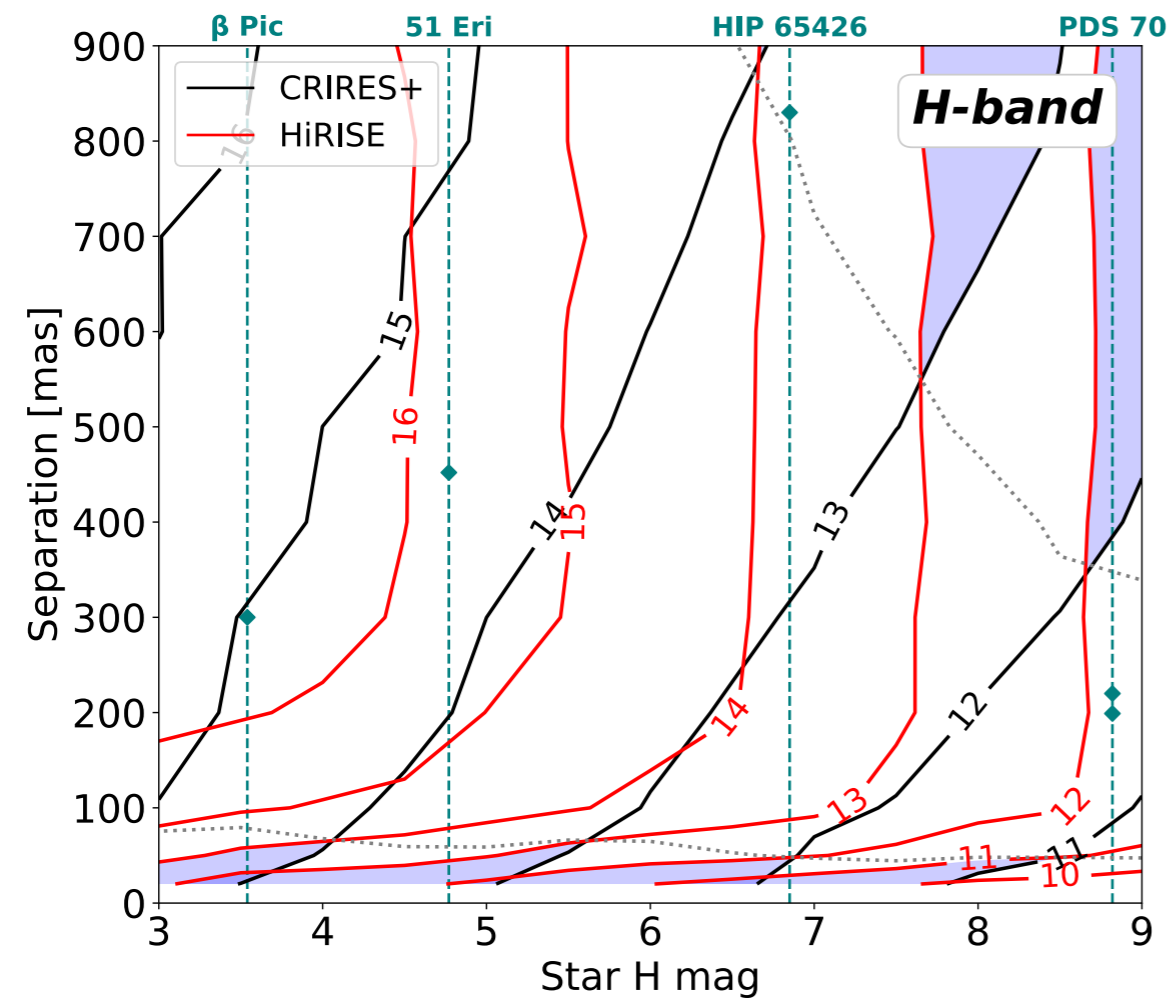


Astrophysical performance



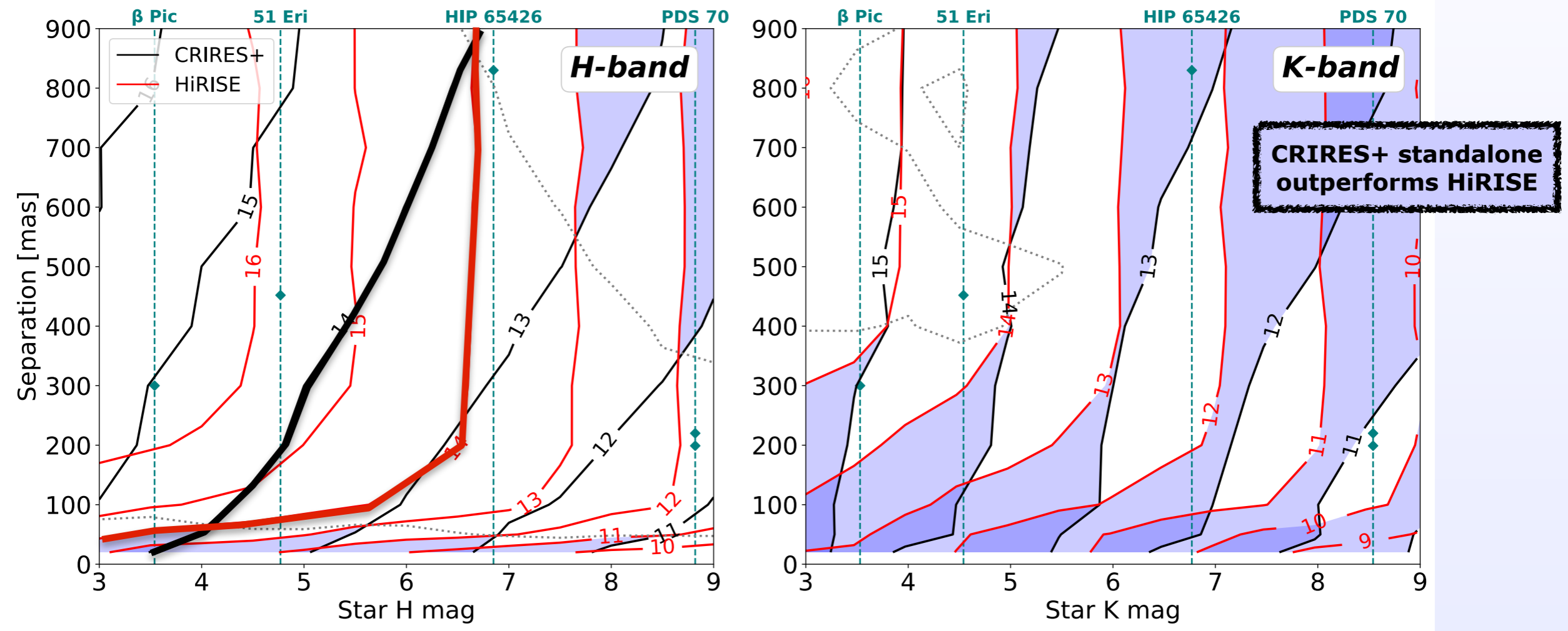
Instrument design

Performance analysis



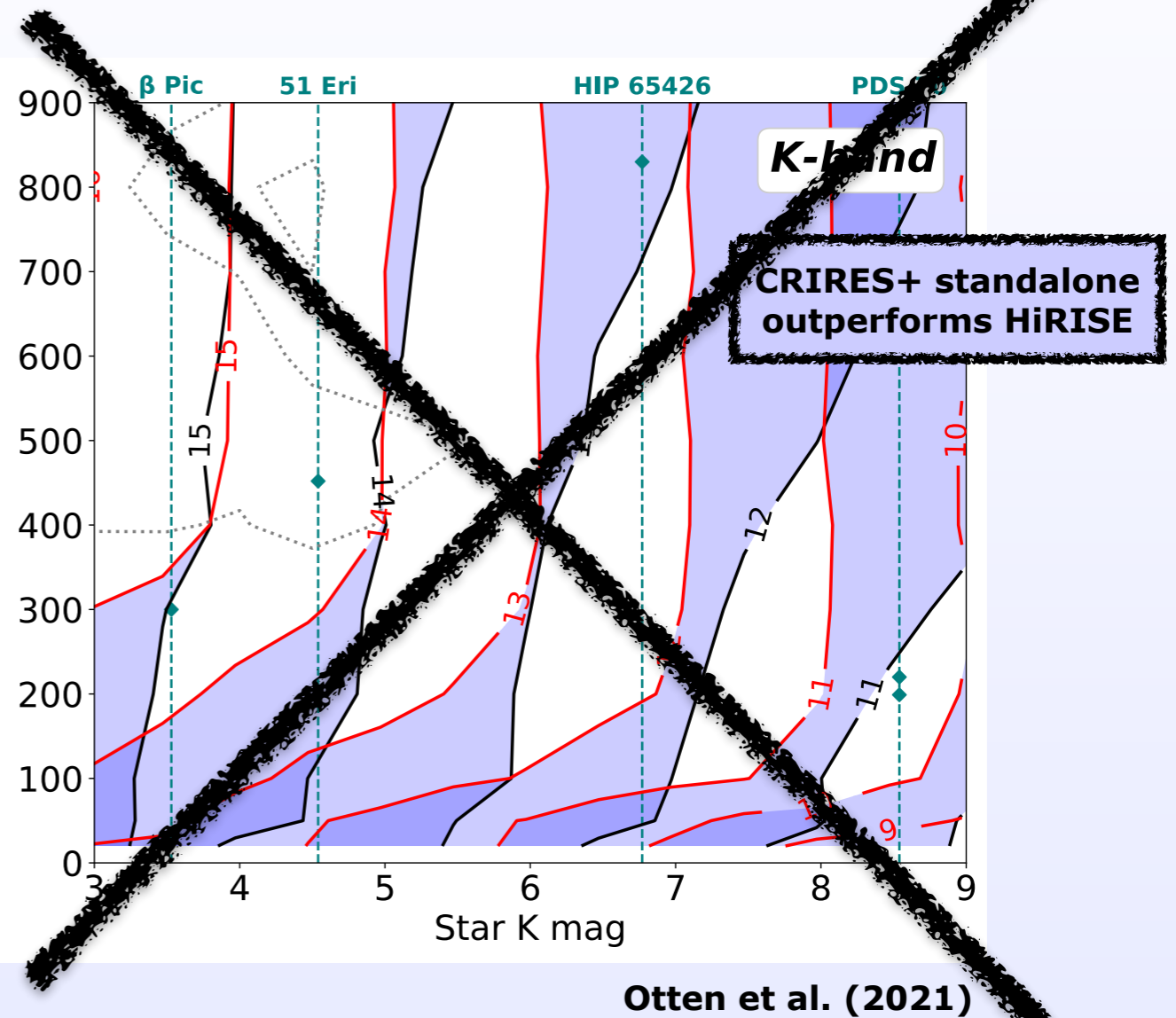
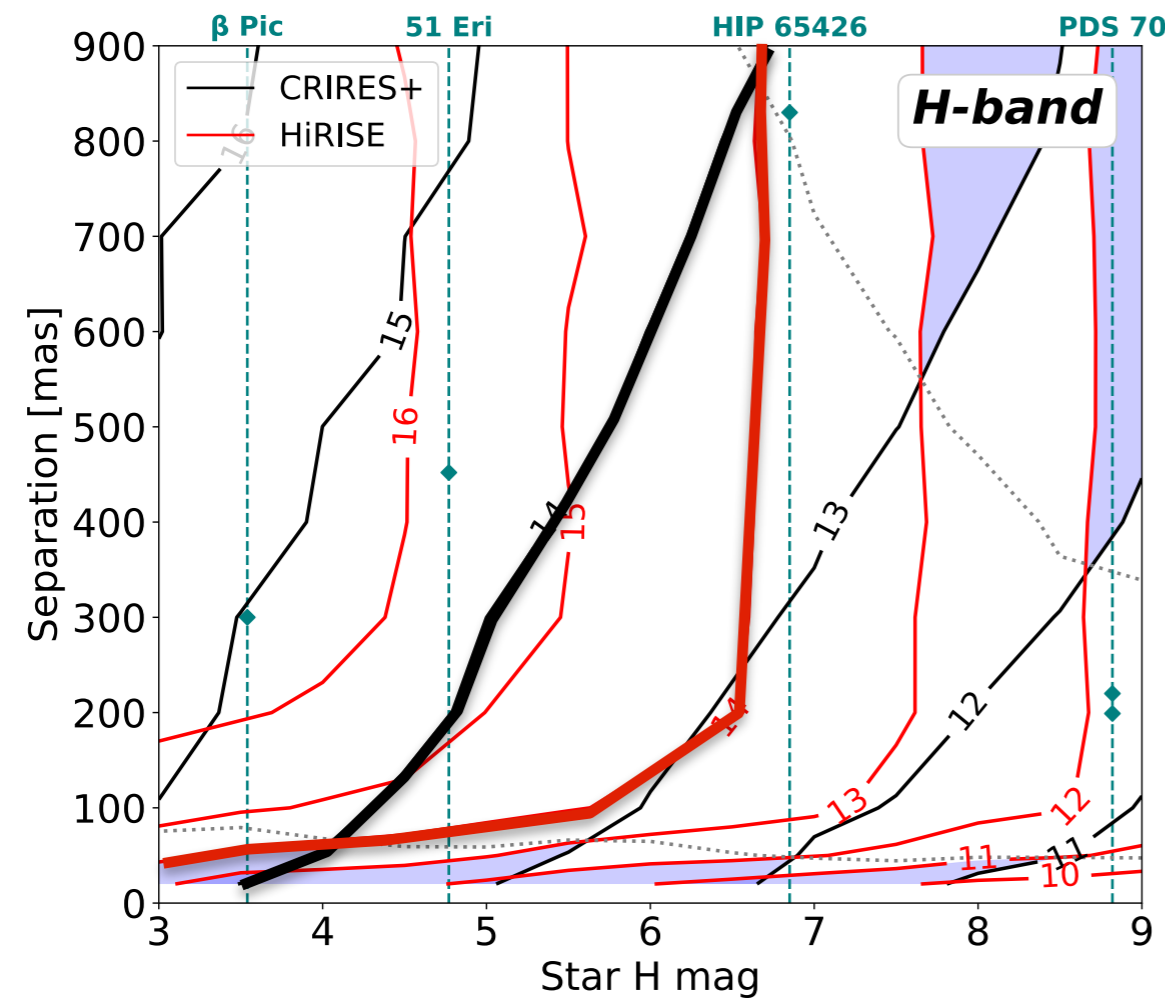
Otten et al. (2021)

Performance analysis



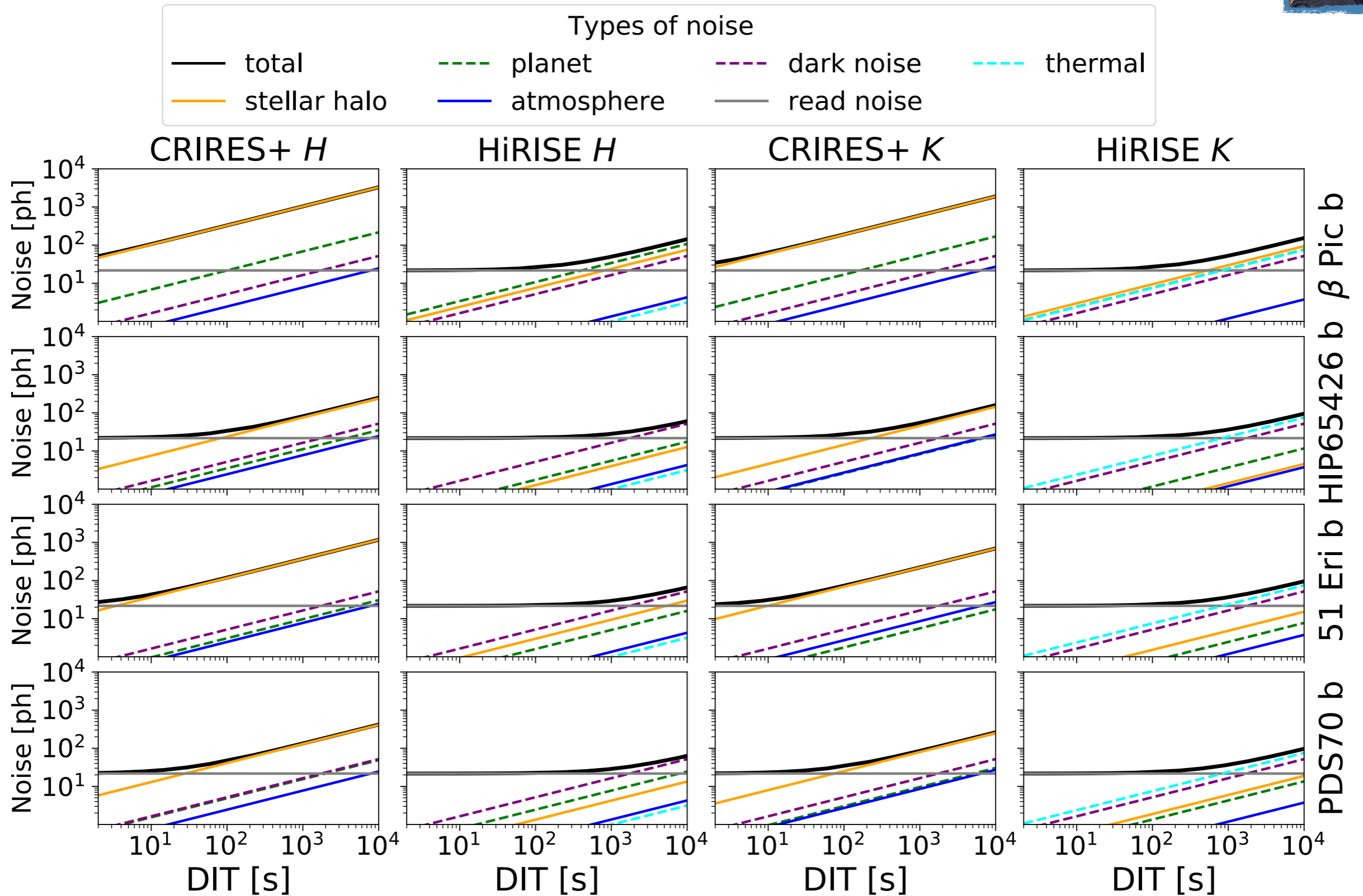
Otten et al. (2021)

Performance analysis



It is worth it in the H band!

Performance analysis

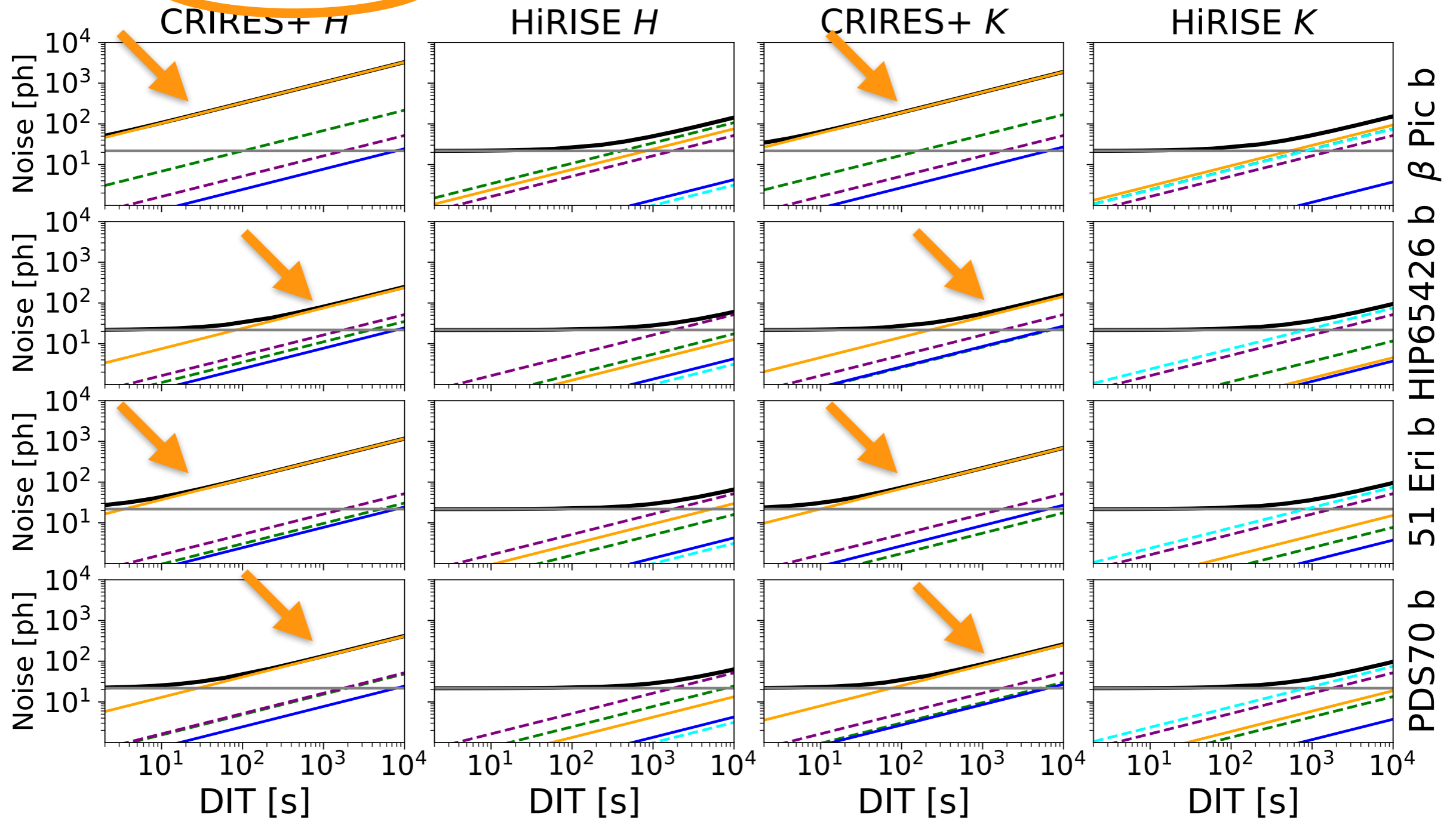
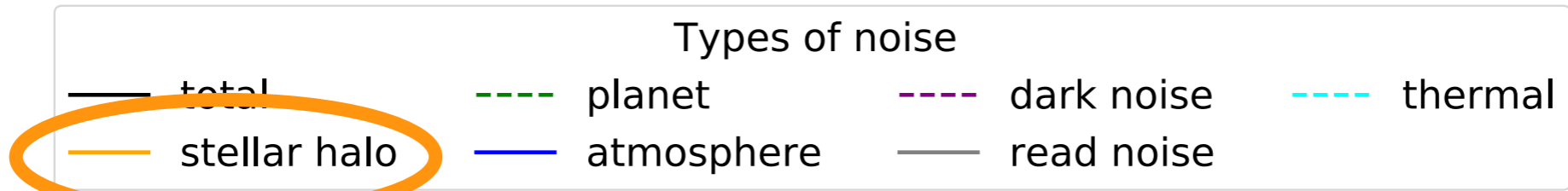


Otten et al. (2021)

Performance analysis

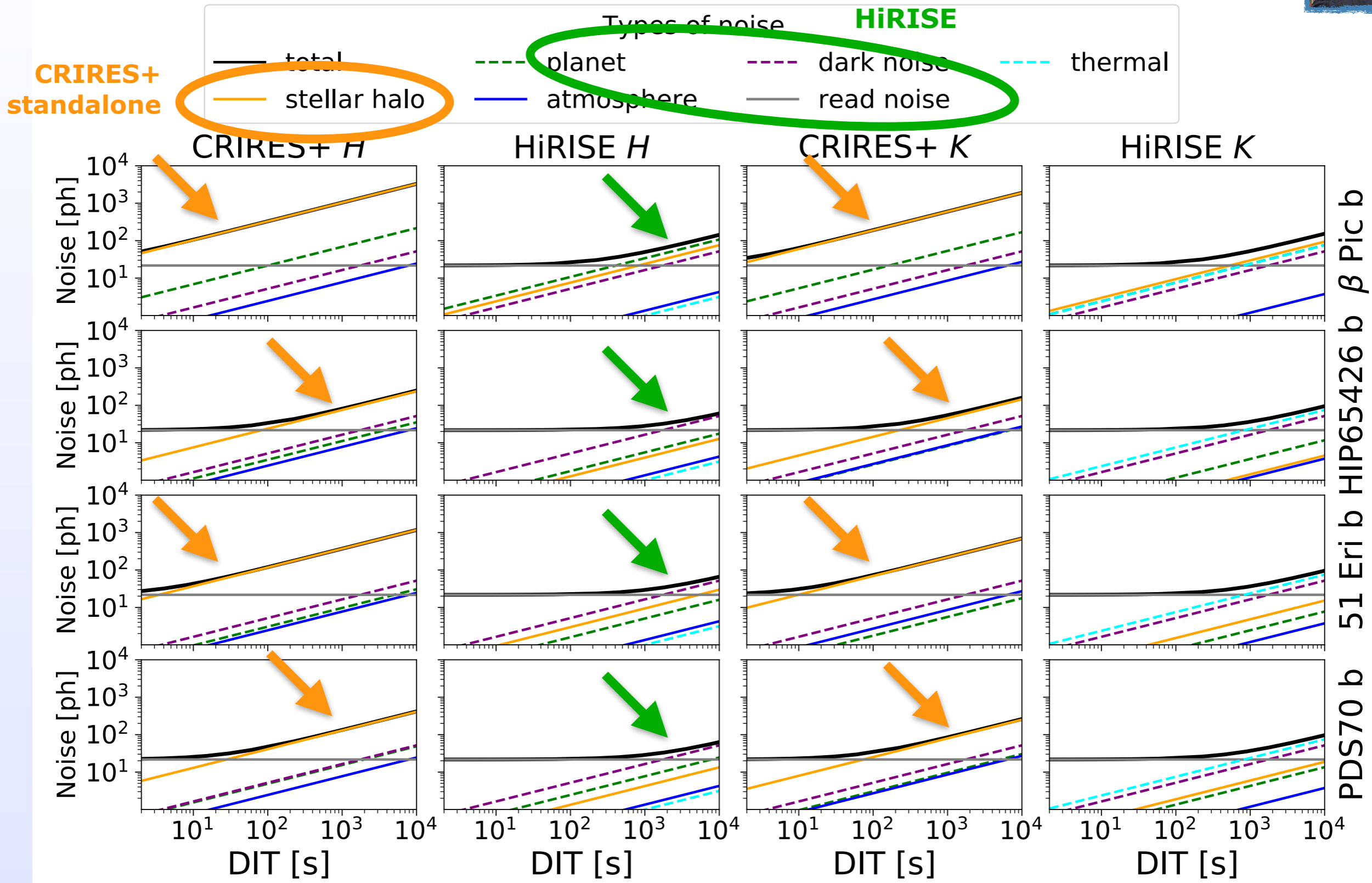
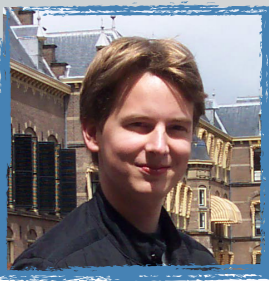


CRIRES+ standalone



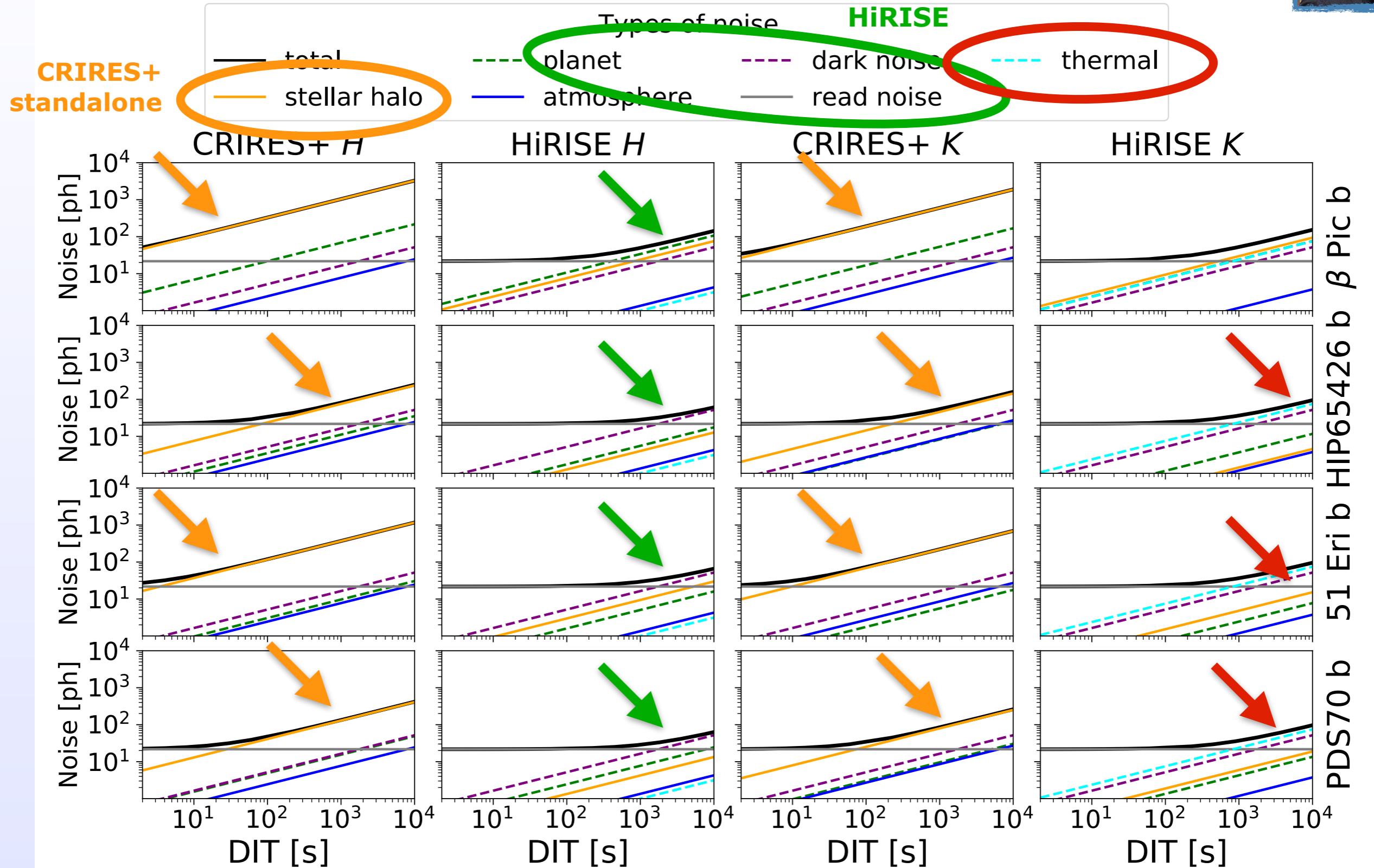
Otten et al. (2021)

Performance analysis



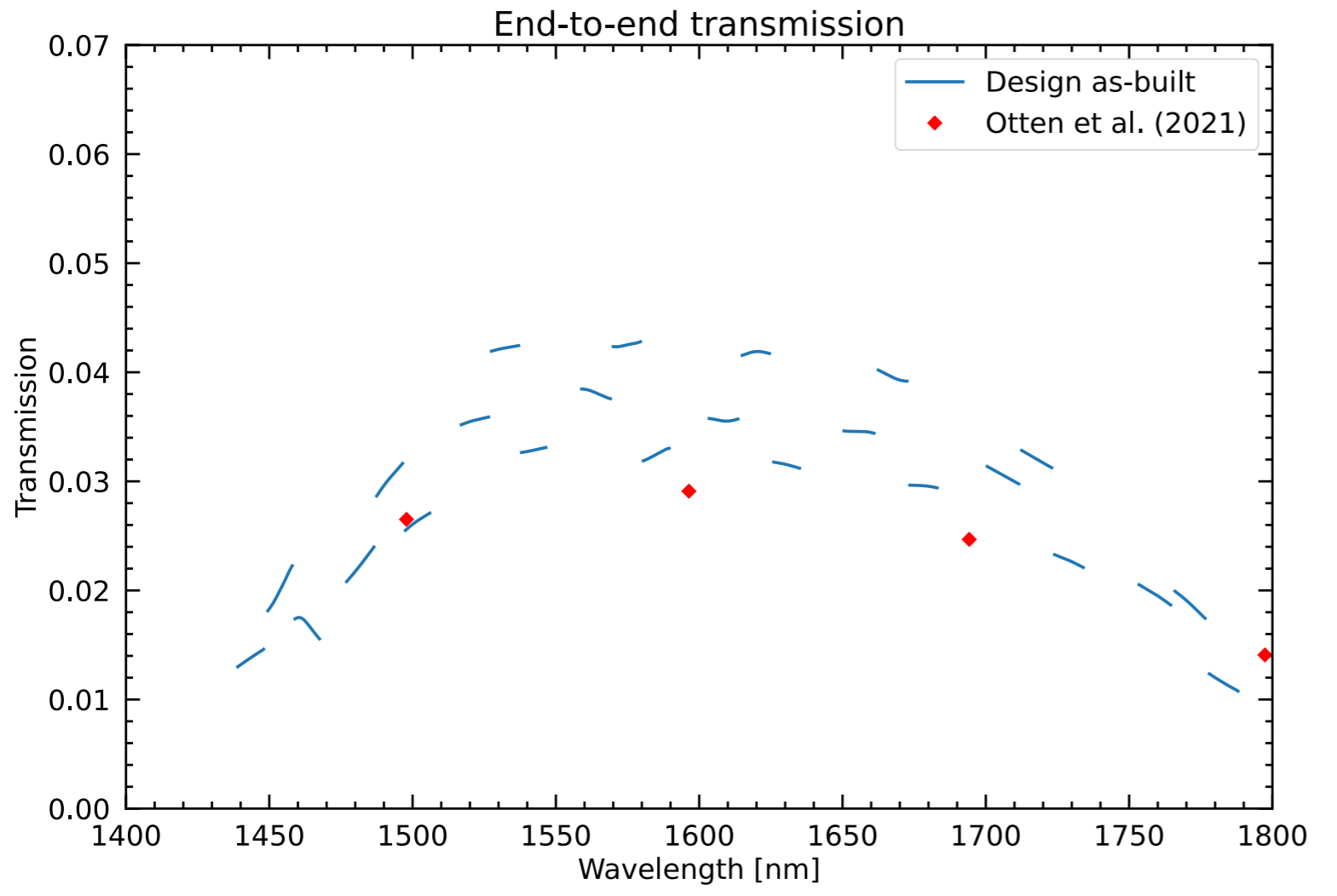
Otten et al. (2021)

Performance analysis

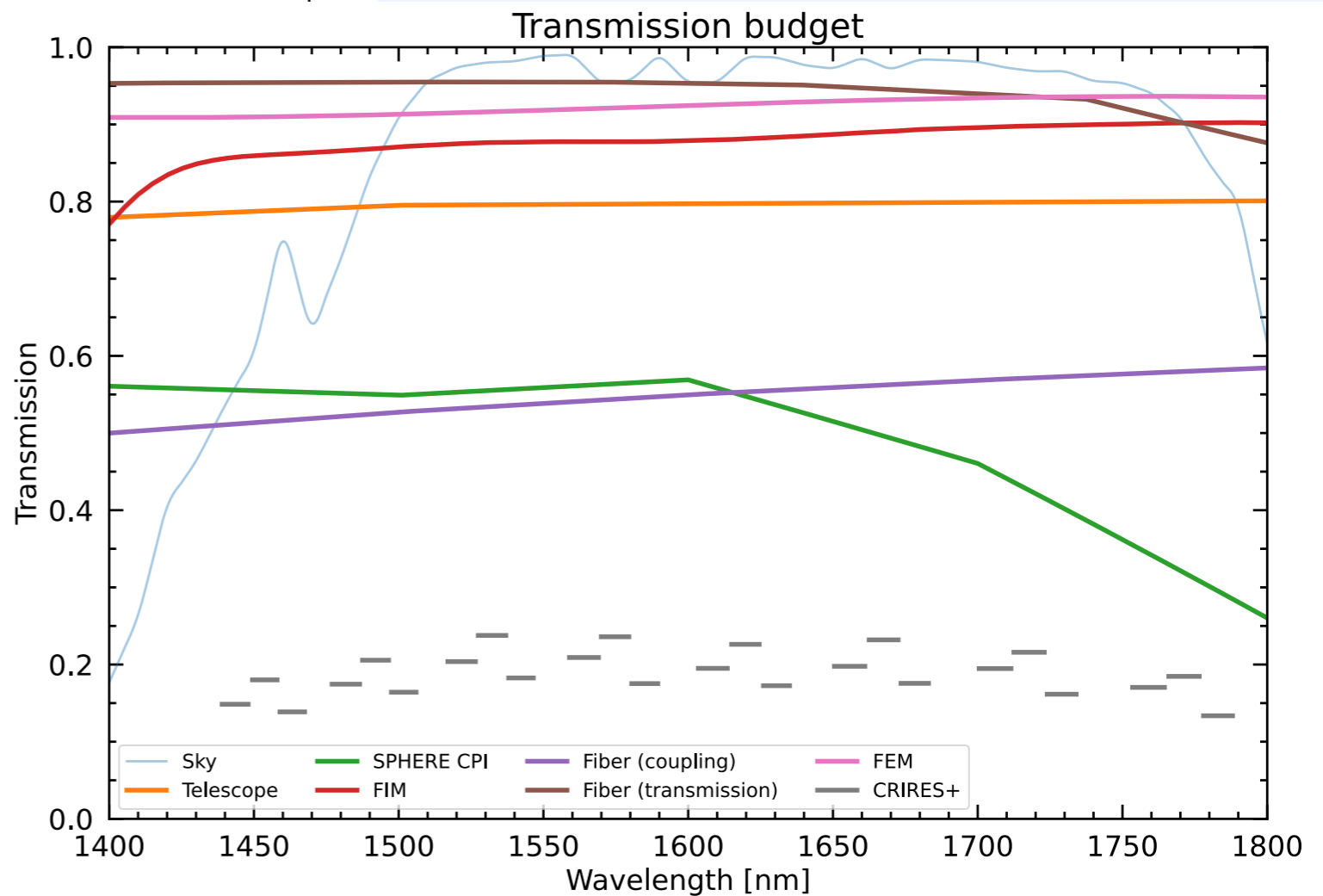
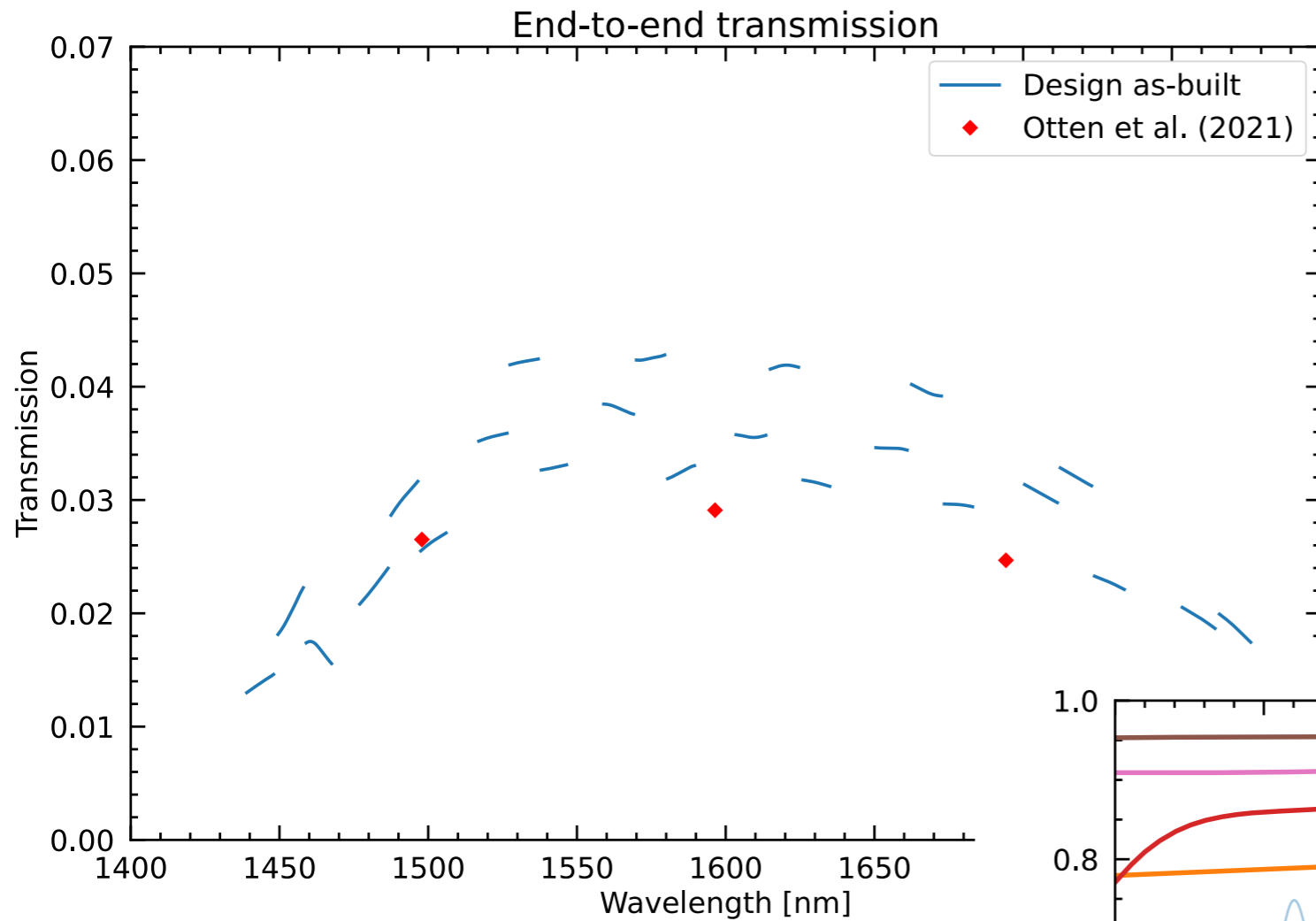


Otten et al. (2021)

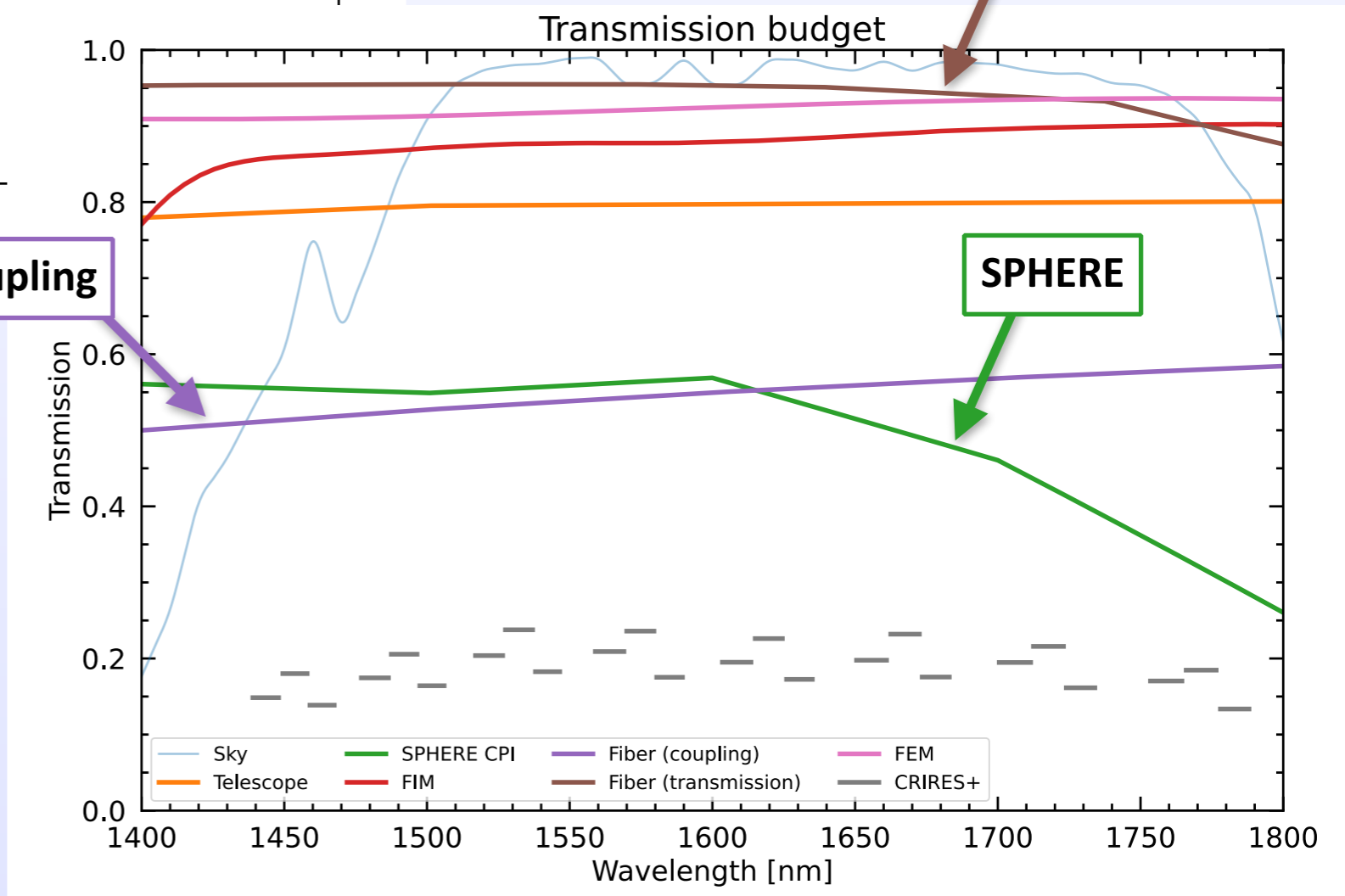
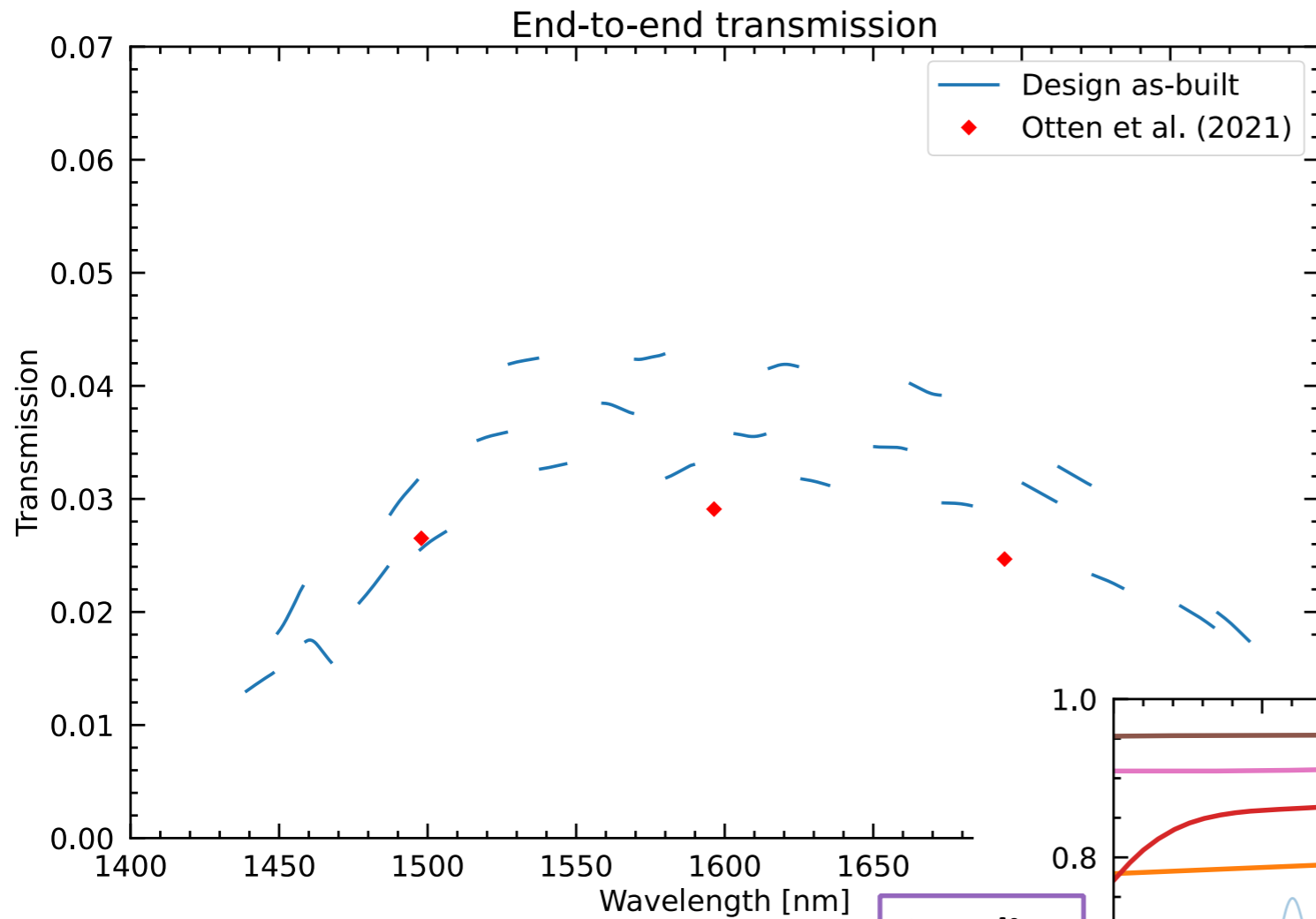
Transmission budget

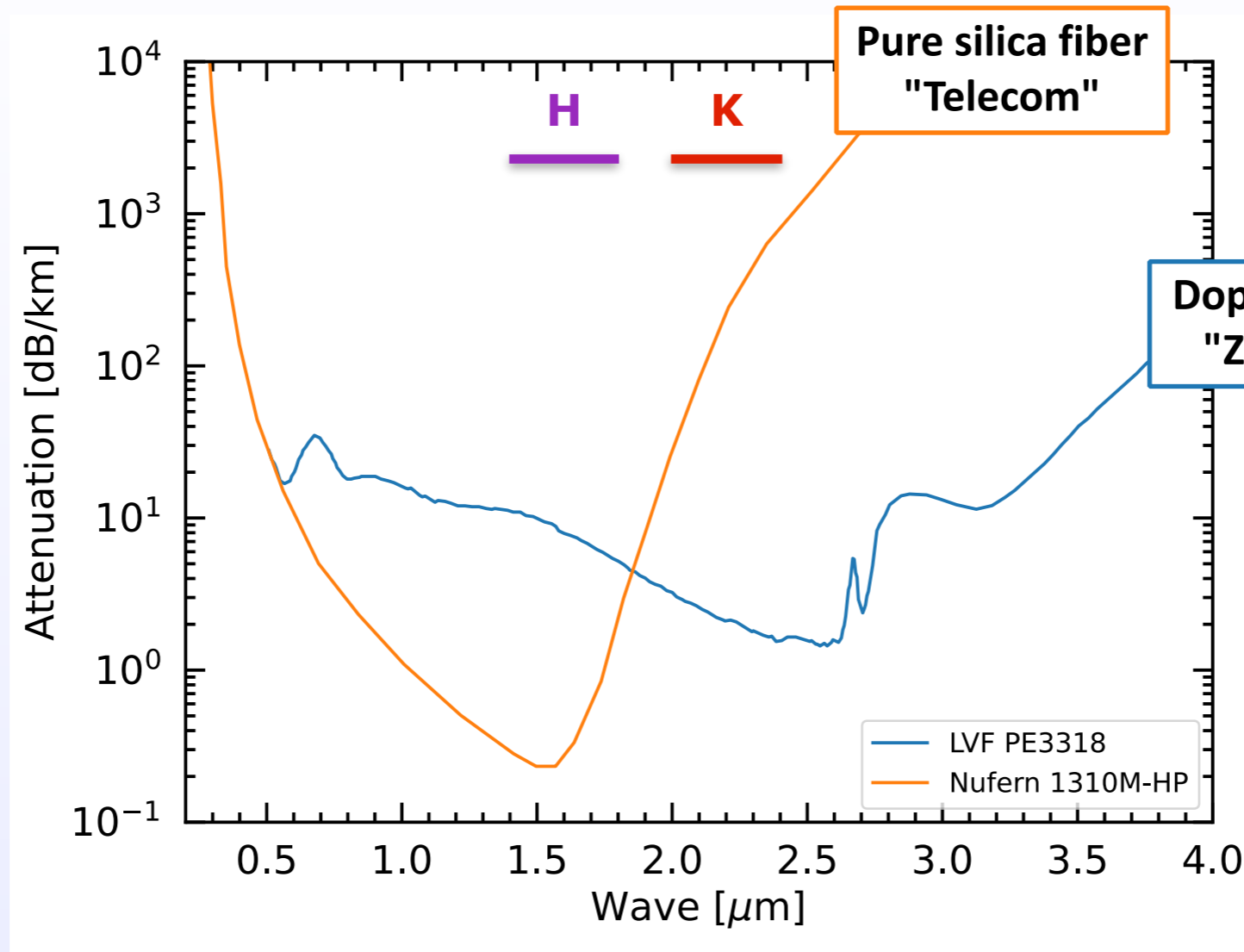


Transmission budget



Transmission budget





Advantages

Drawbacks

ZBLAN

Transmission in K band

(Supposedly) fragile

Very expensive (~100 €/m)

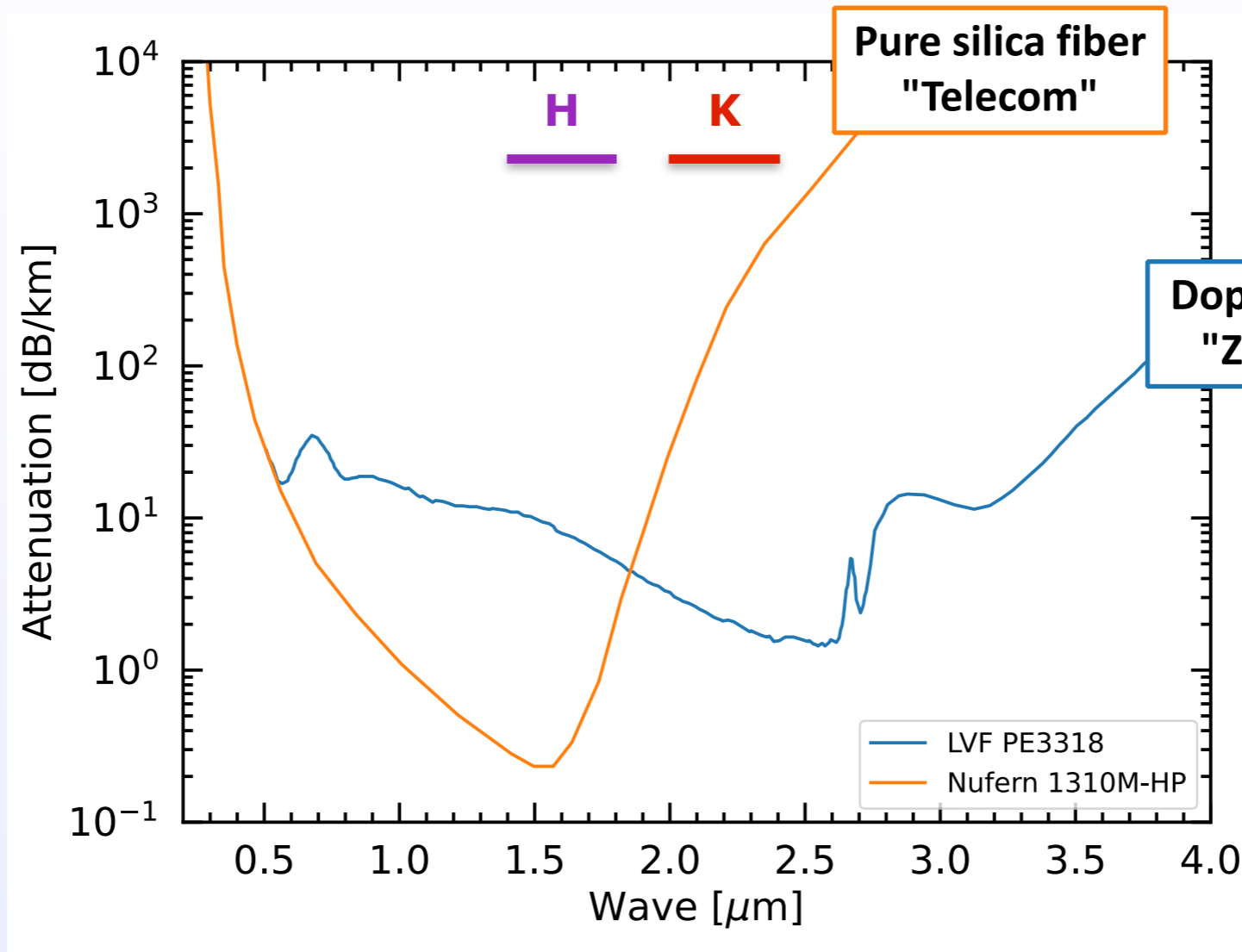
Transmission in H band

Telecom

Transmission in H band

Extremely cheap (~1 €/m)

Transmission in K band



Advantages

Drawbacks

ZBLAN

Transmission in K band

(Supposedly) fragile

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Transmission in H band

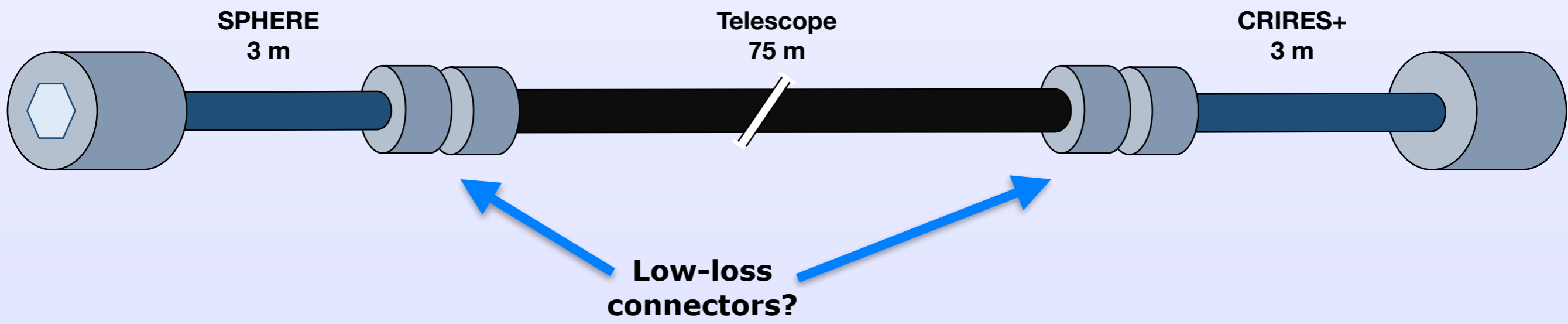
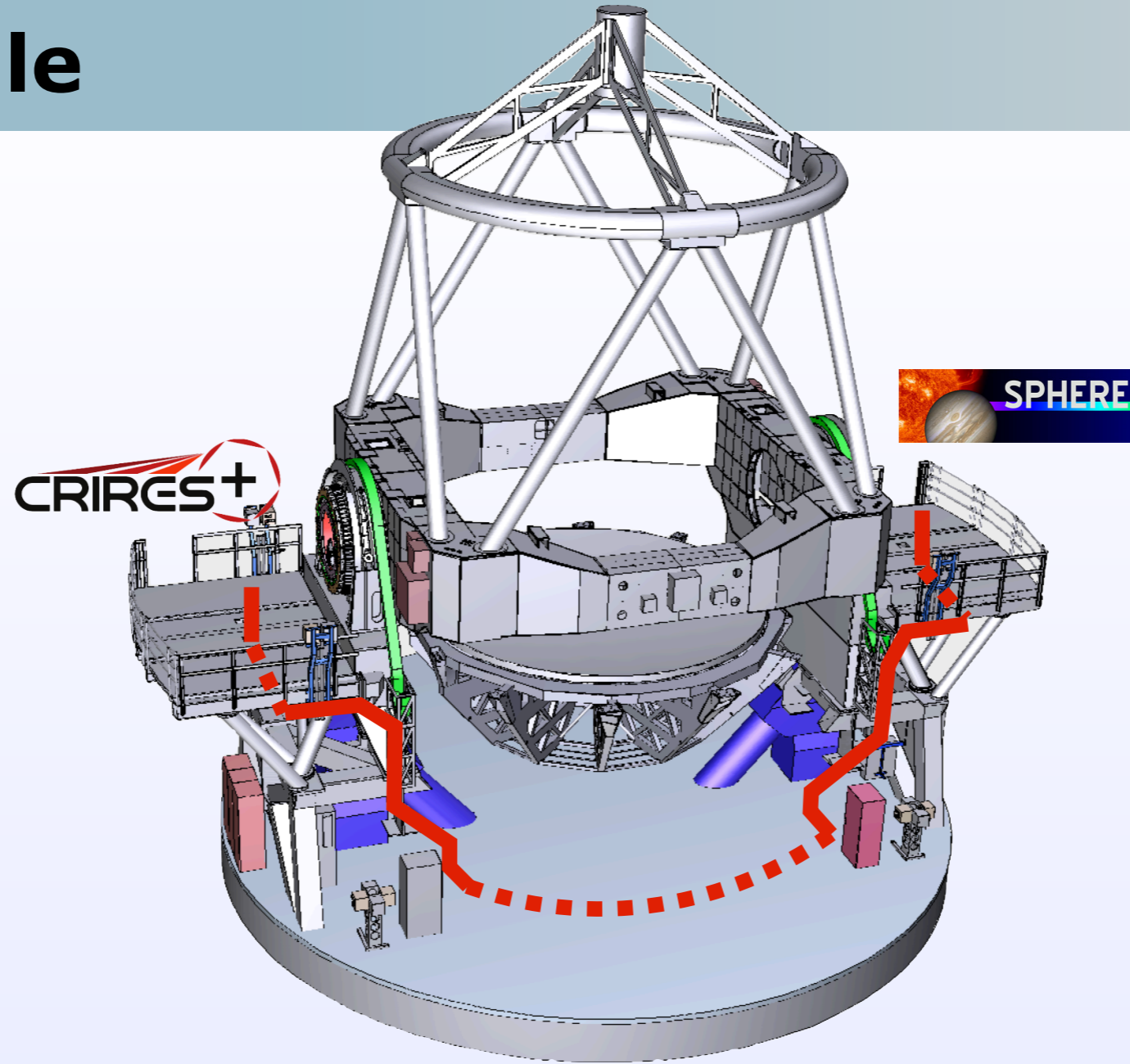
**Final choice:
Telecom fiber**

Telecom

Transmission in H band

Extremely cheap (~1 €/m)

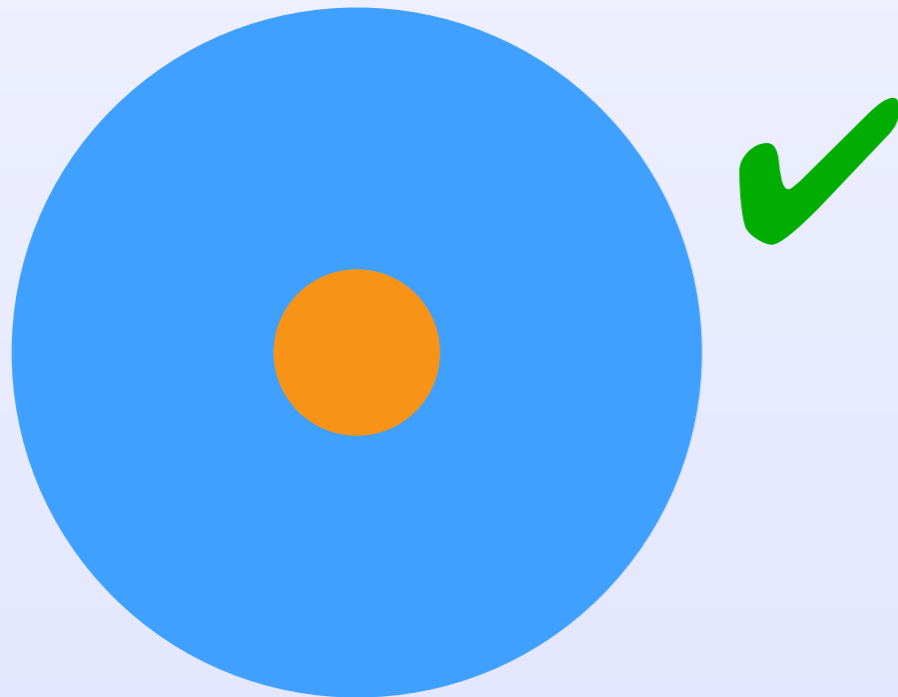
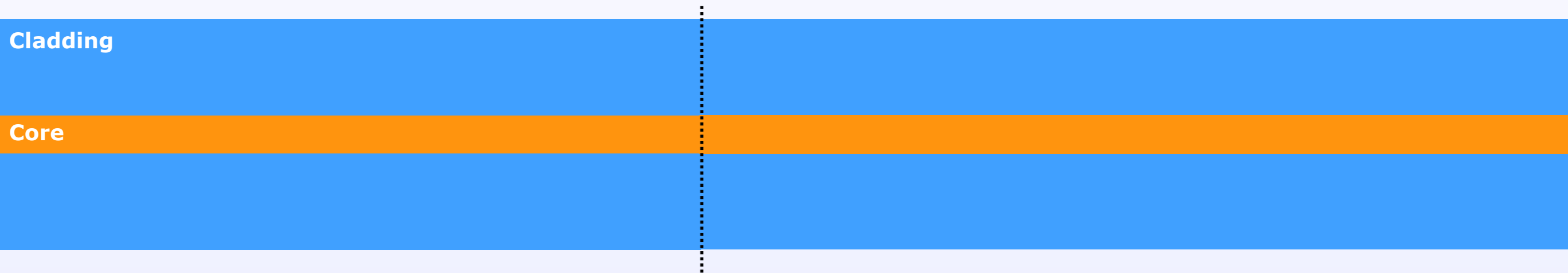
Transmission in K band



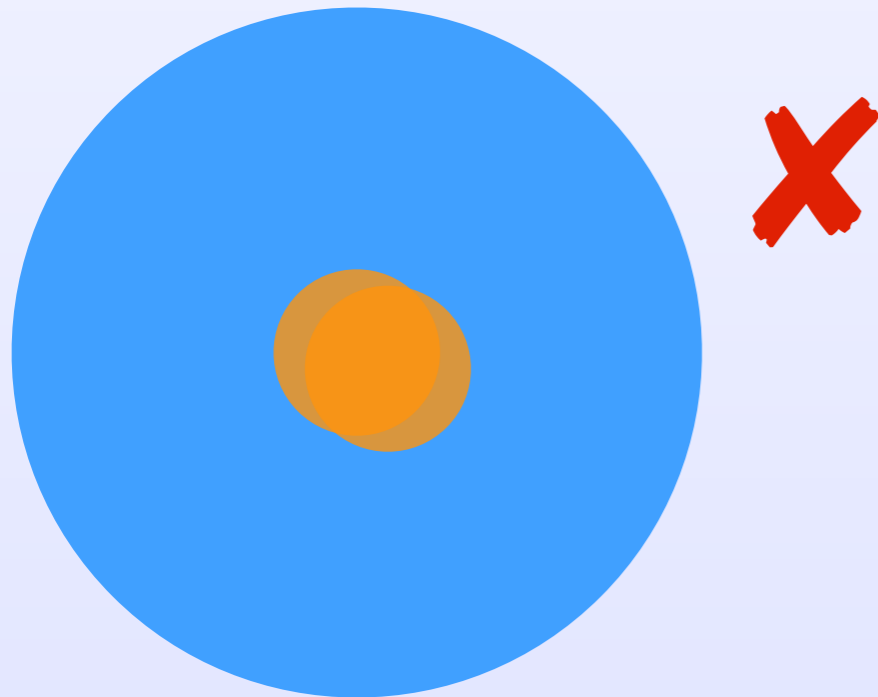
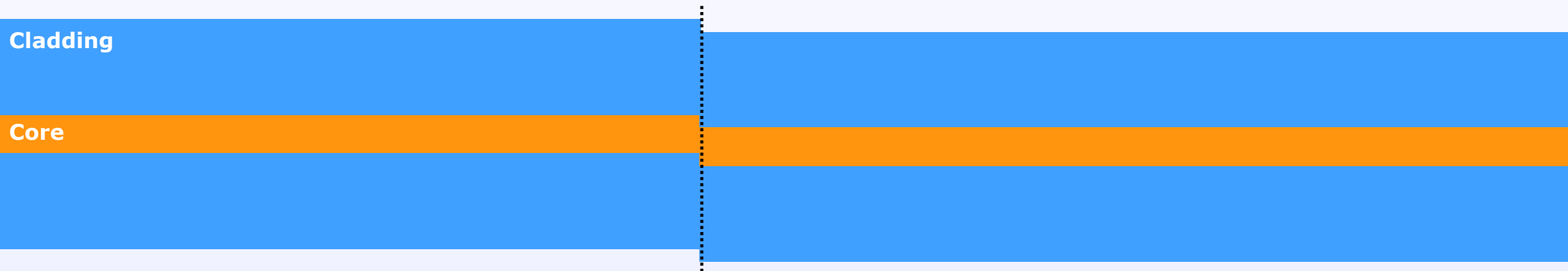
Problem: single-mode fibres have very small cores! Typically 4-8 μm



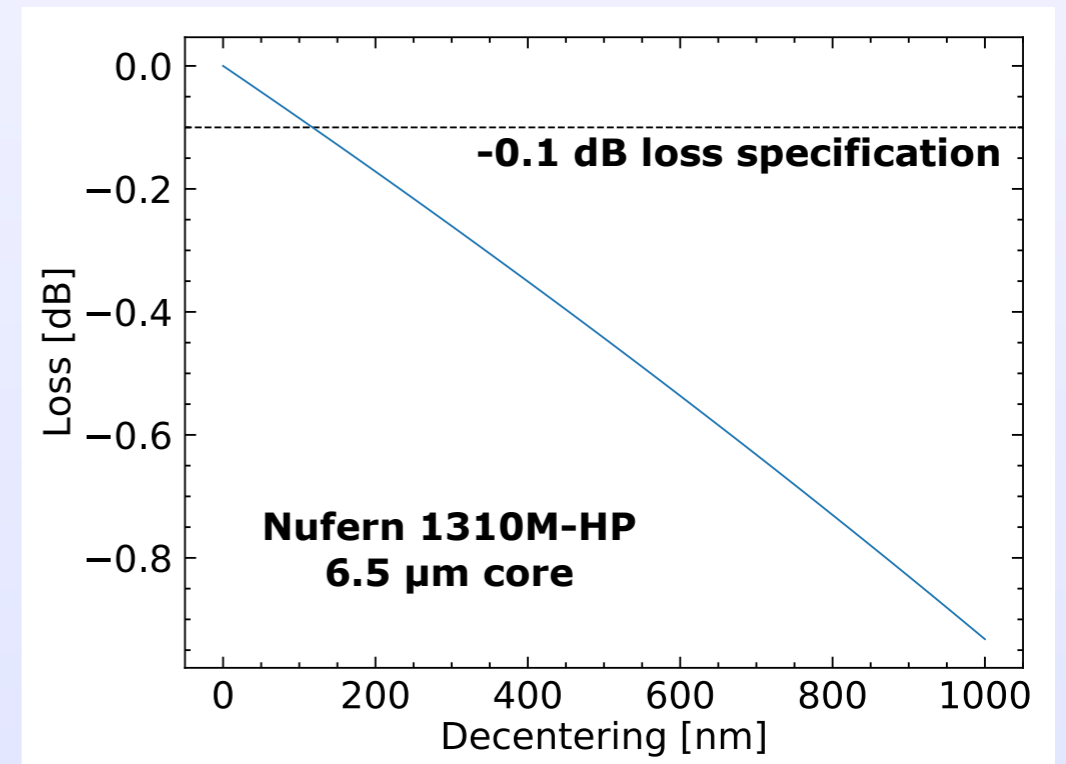
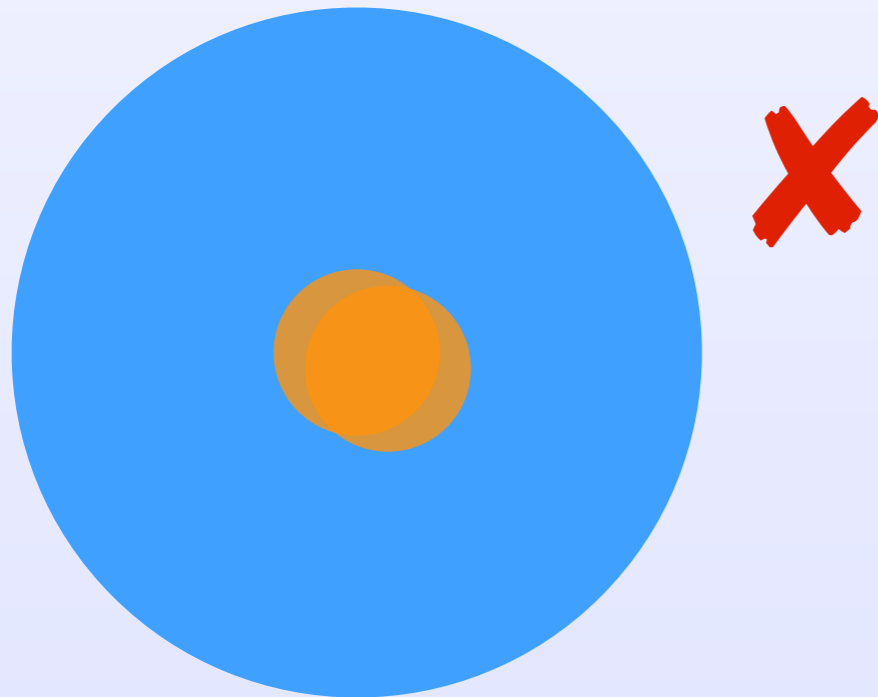
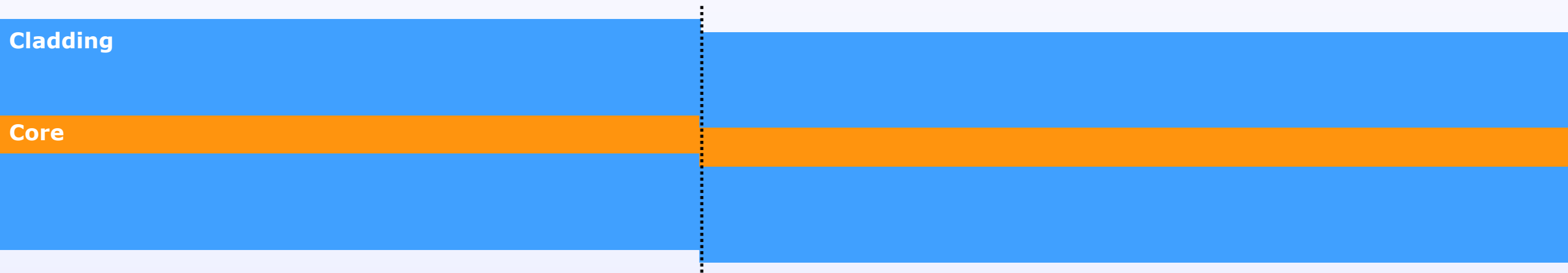
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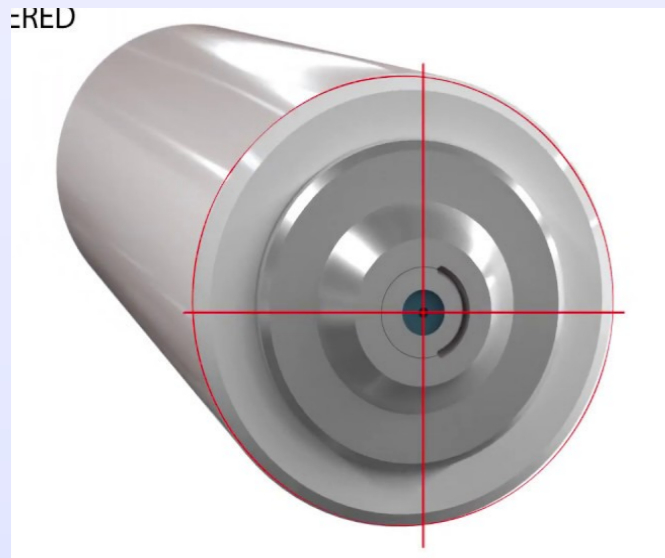
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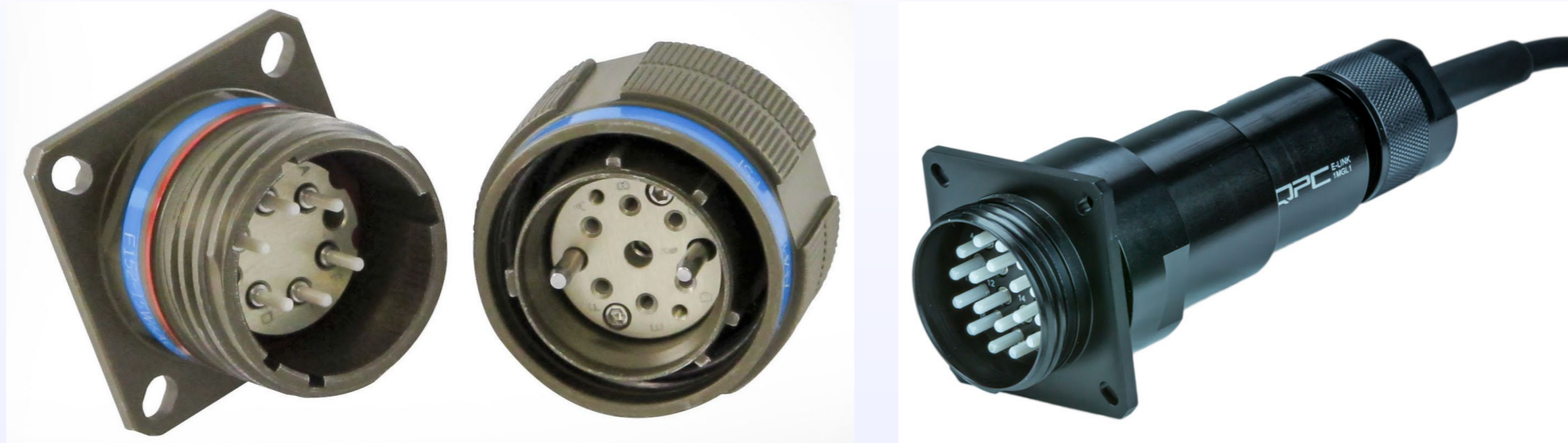
- Rugged connectors with repeatable connection exist...



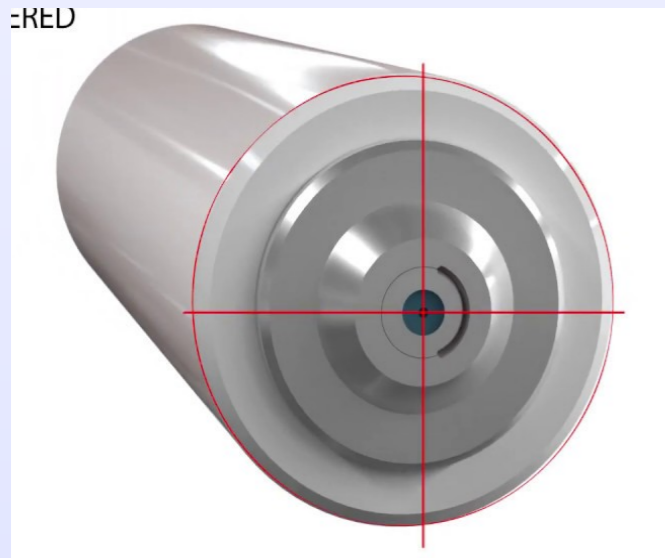
- ... but they need properly aligned fibres in the first place
- Only solution on the market: Diamond SA, Active Core Alignment → very (very) expensive



- Rugged connectors with repeatable connection exist...



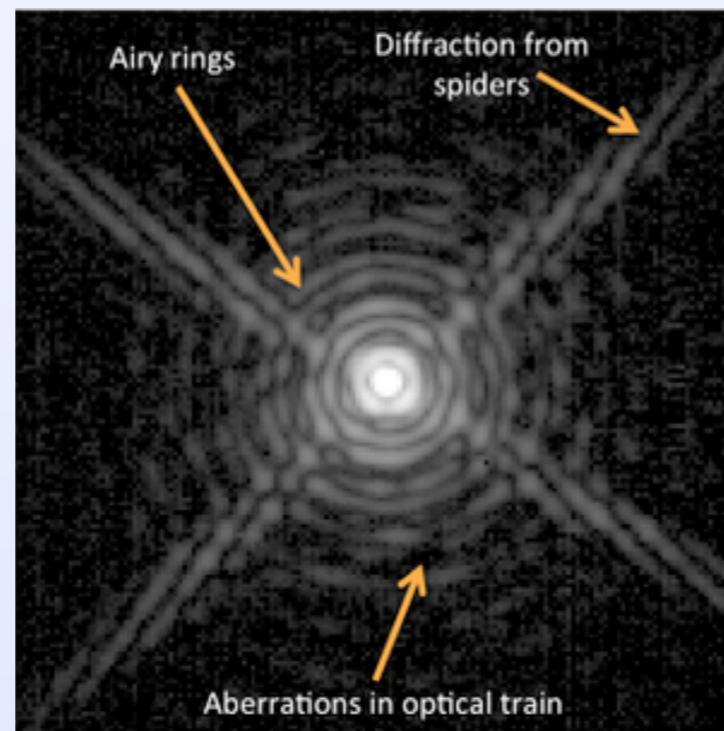
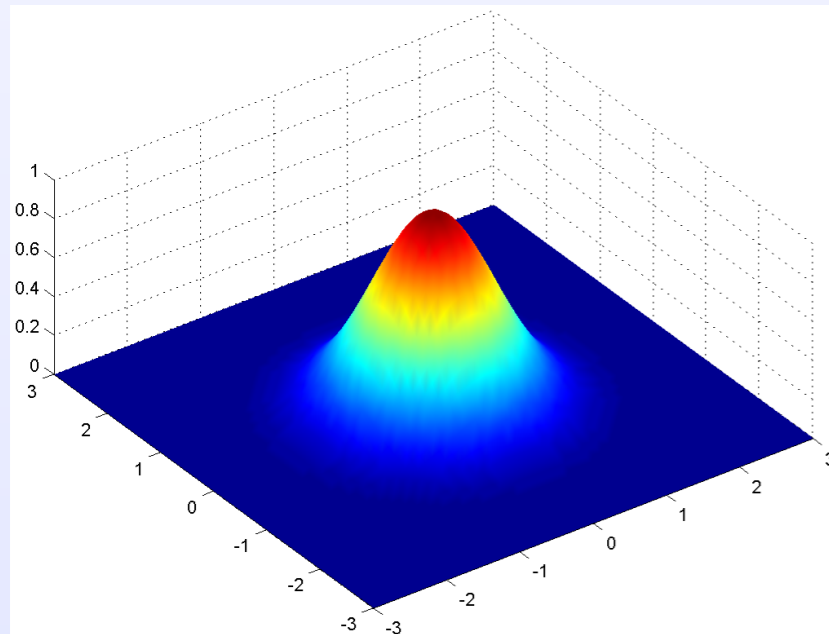
- ... but they need properly aligned fibres in the first place
- Only solution on the market: Diamond SA, Active Core Alignment → very (very) expensive



**Final choice:
No connectors**

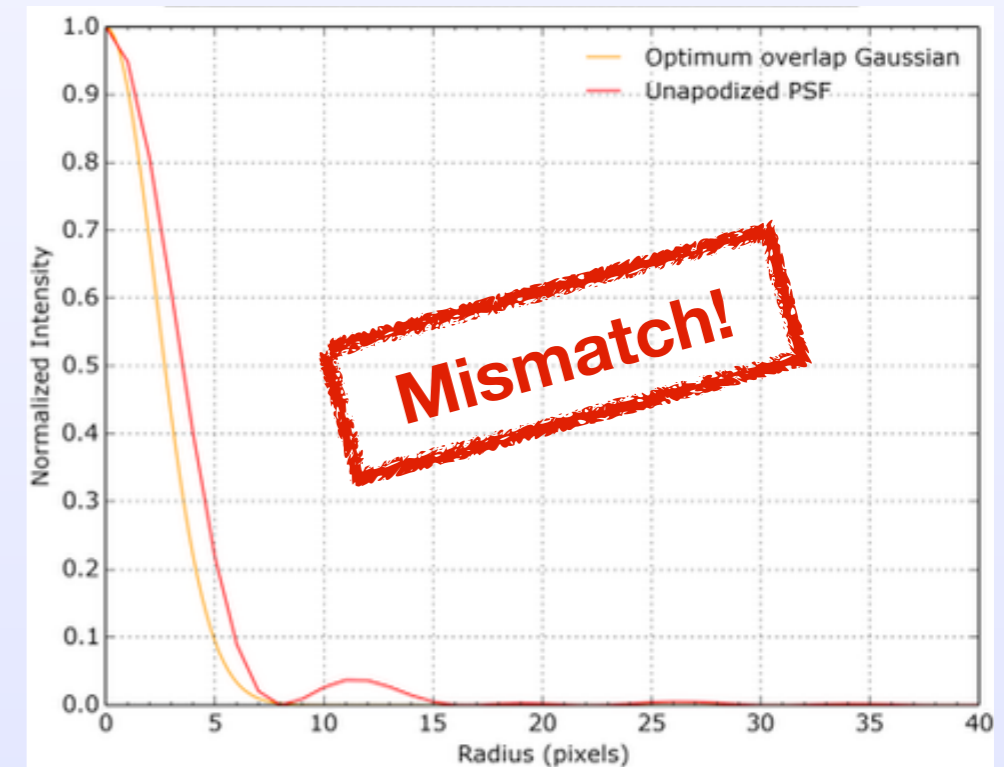
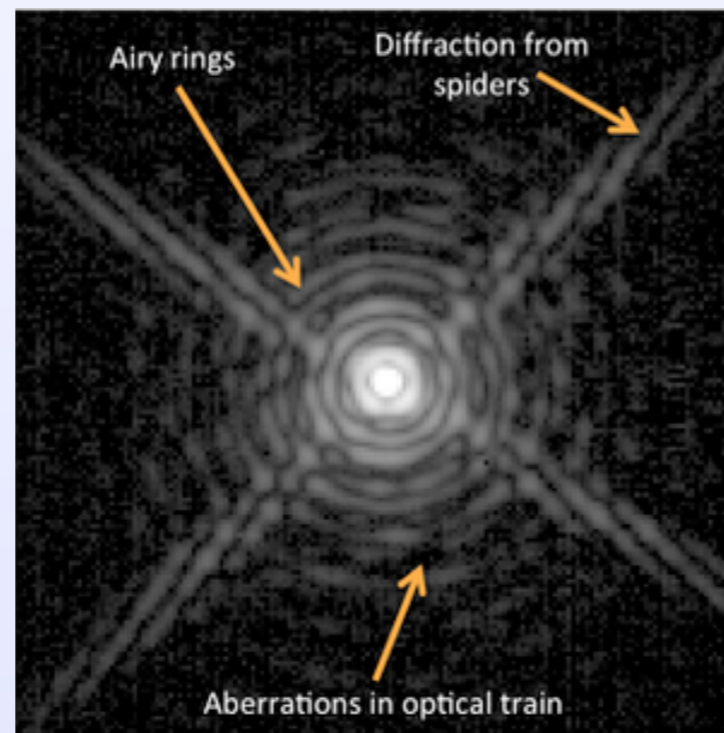
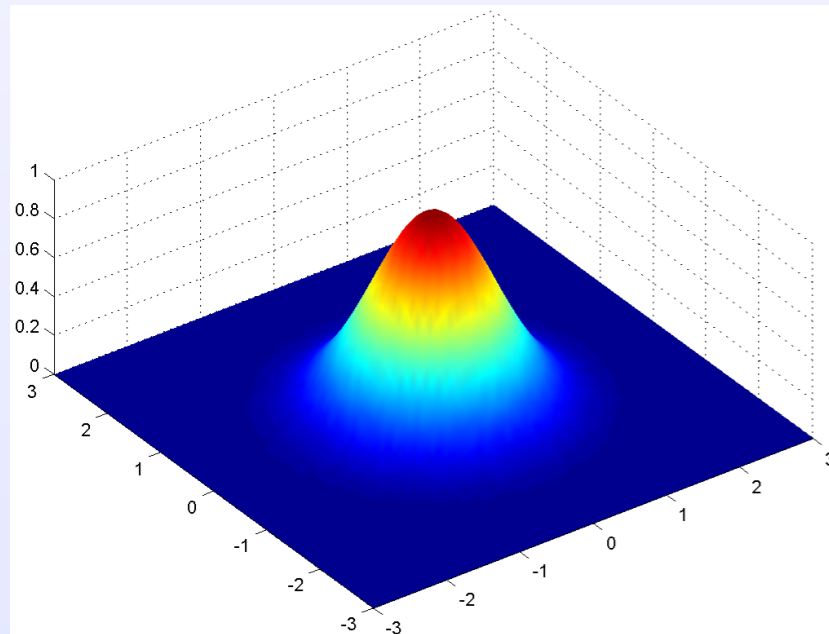
How much stellar/planetary light can you inject into an SMF?

- Single-mode fiber:
 - EM_{00} mode is quasi-Gaussian
- Telescope PSF:
 - Obstructed pupil + spiders
 - Complicated pattern



How much stellar/planetary light can you inject into an SMF?

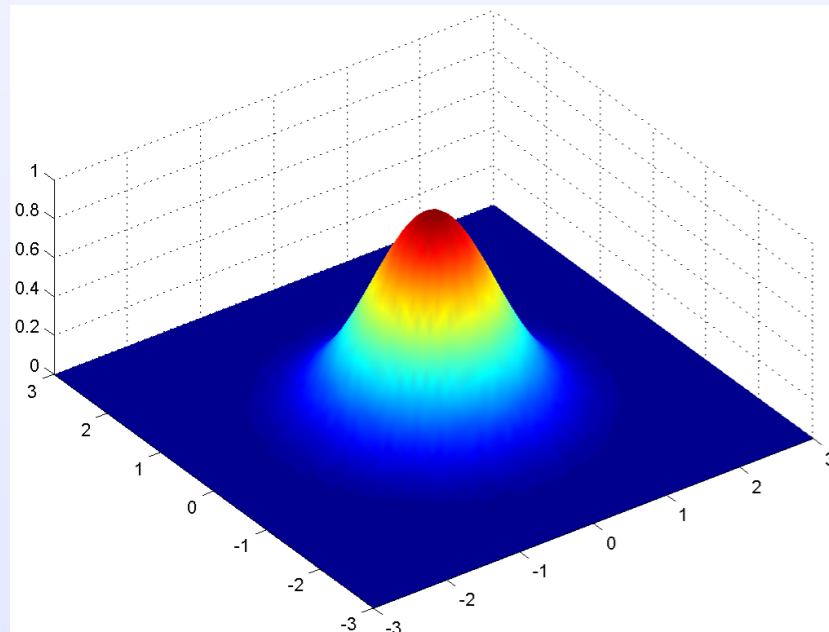
- Single-mode fiber:
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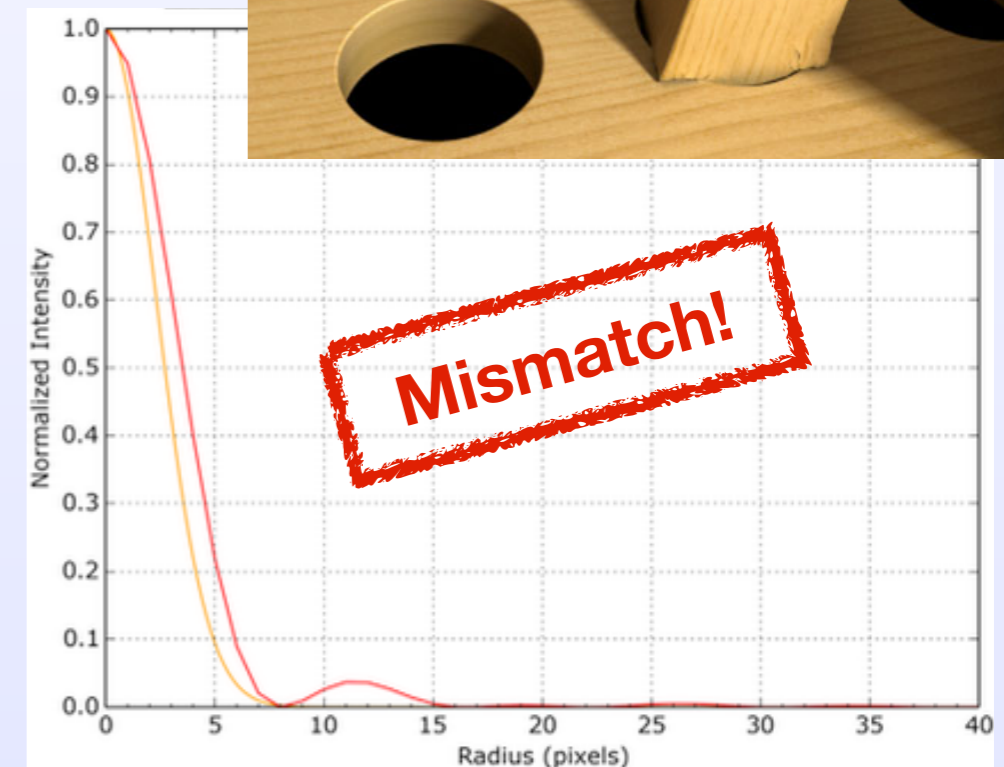
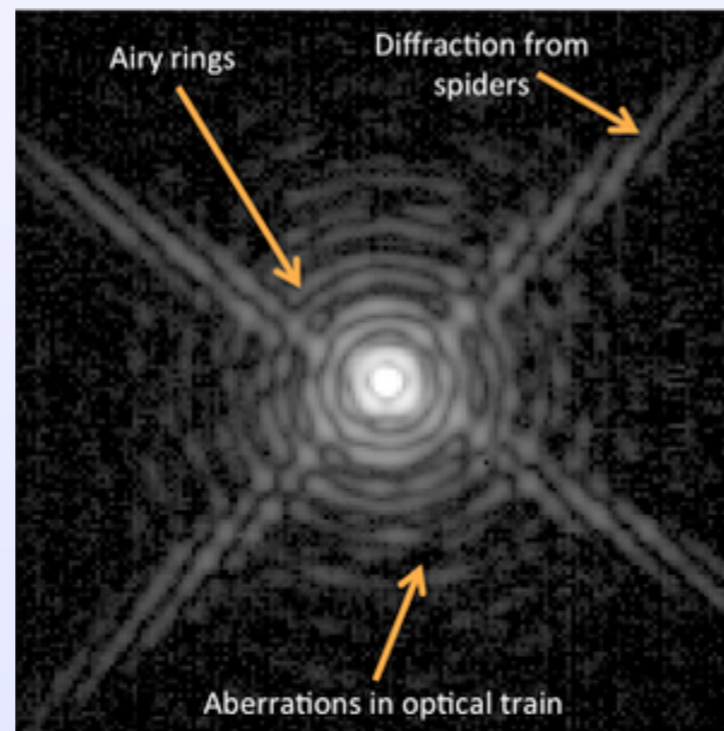
Jovanovic et al. (2017)

How much stellar/planetary light can you inject into an SMF?

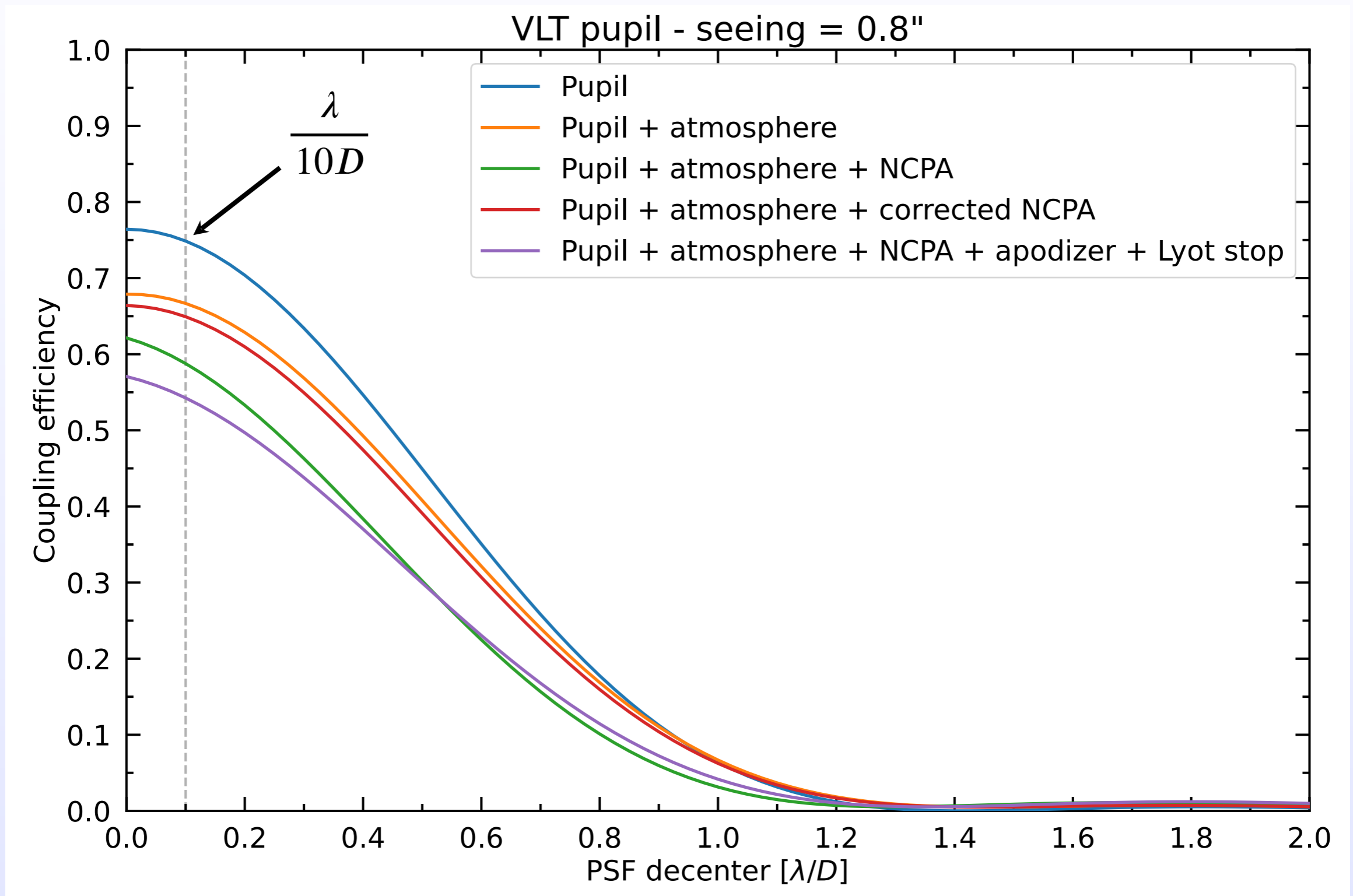
- Single-mode fiber:
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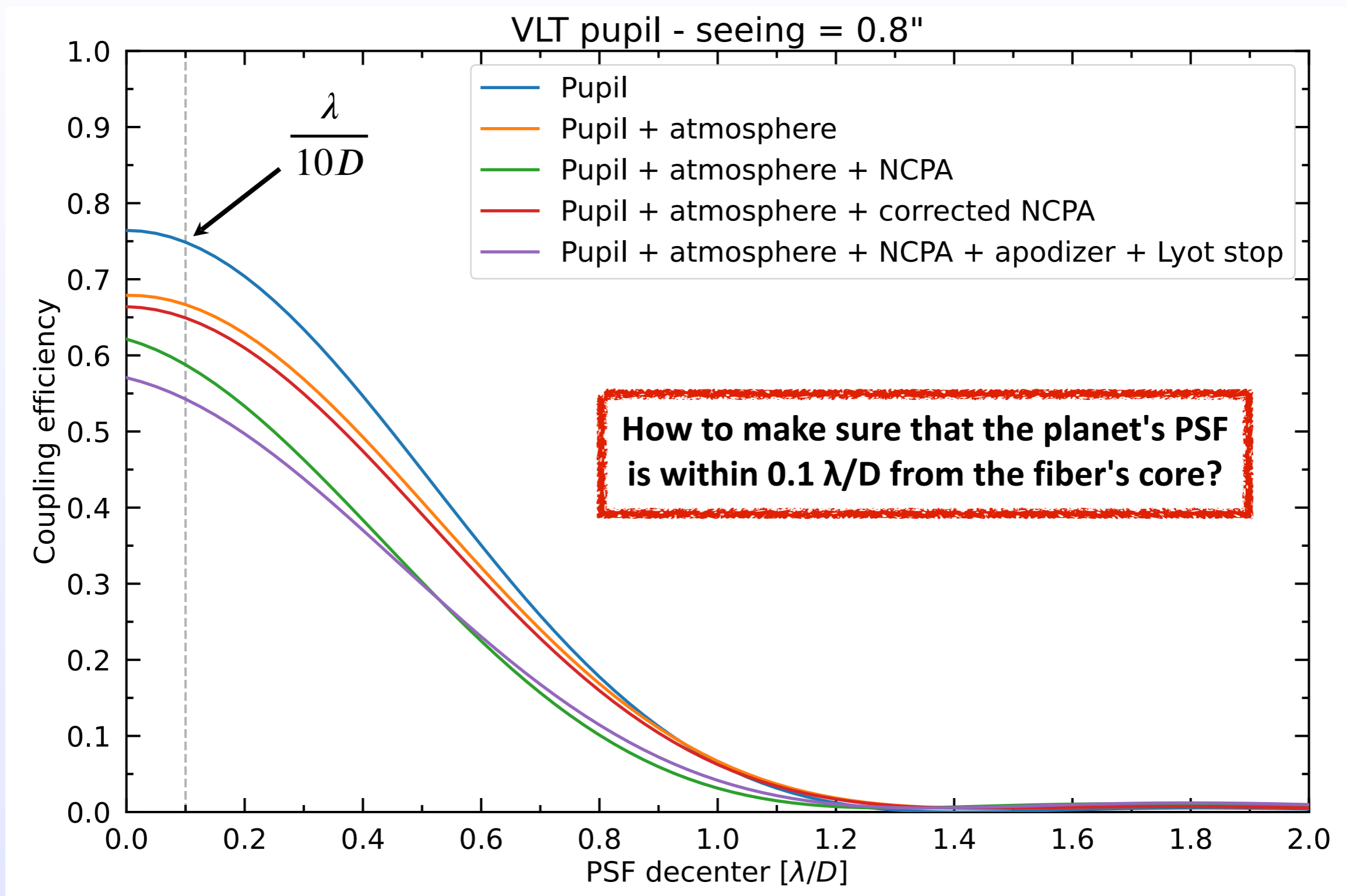


- Telescope PSF:
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 - Complicated pattern

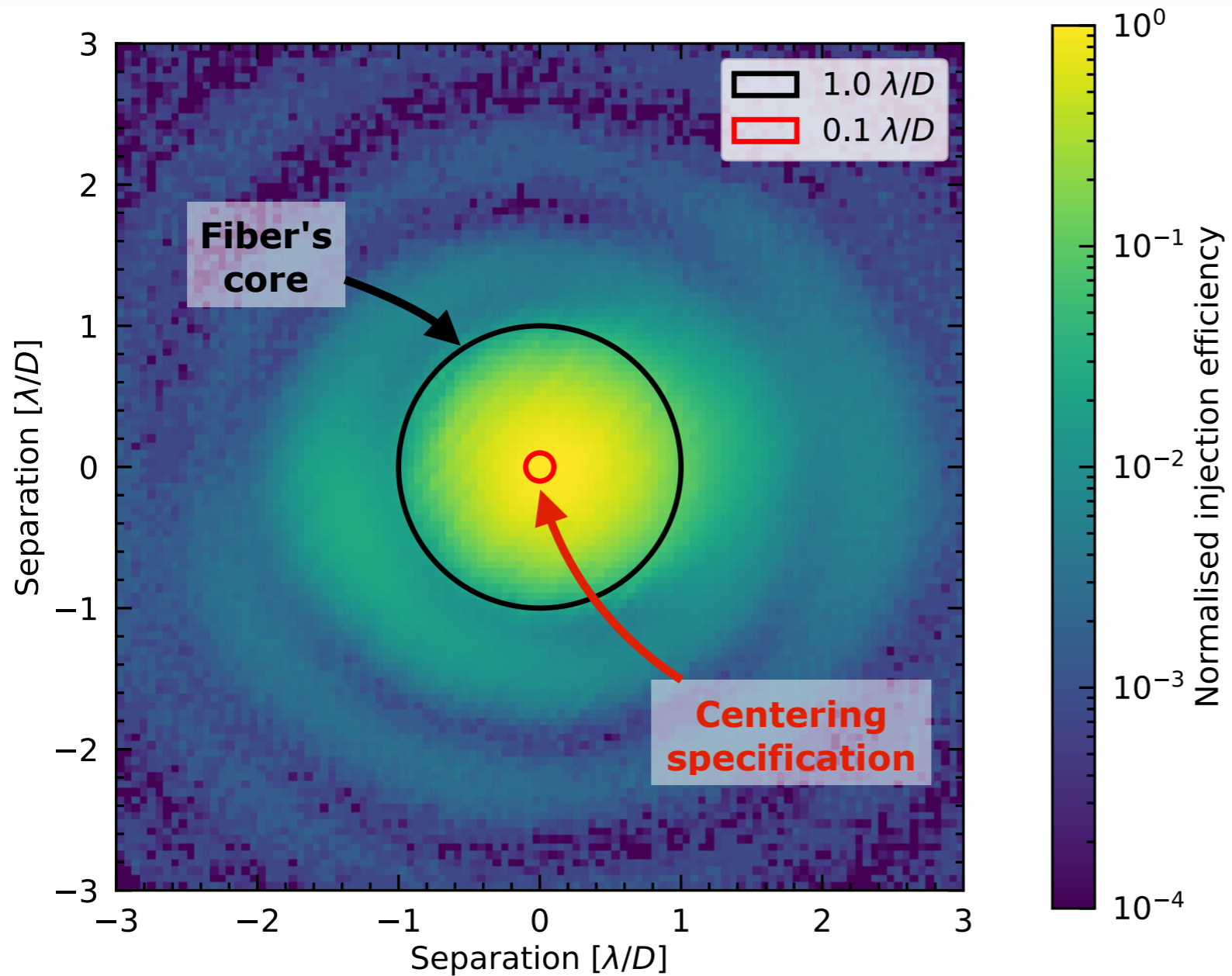


Jovanovic et al. (2017)



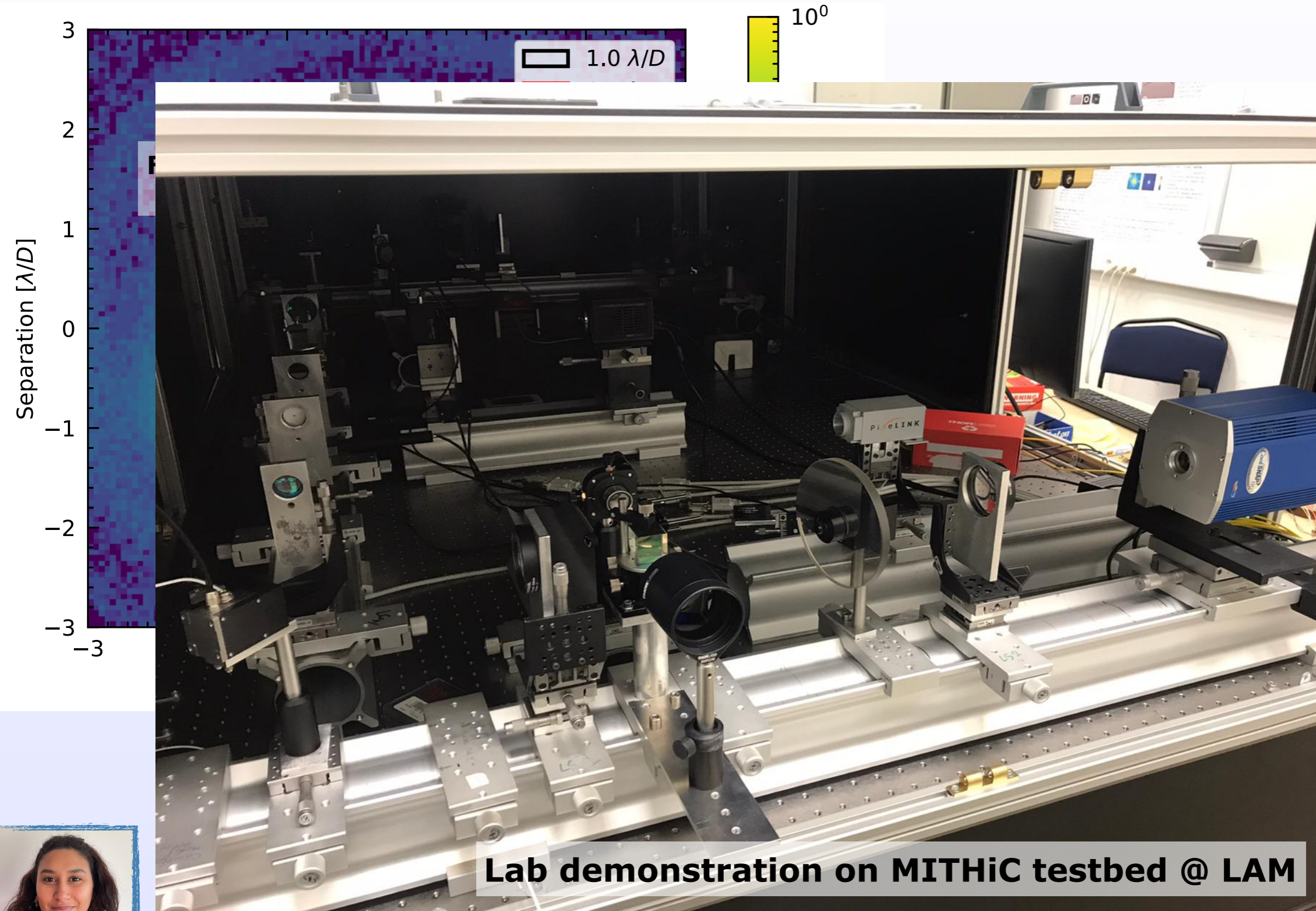


PSF centering: an operational challenge



PSF centering: an operational challenge

Coupling

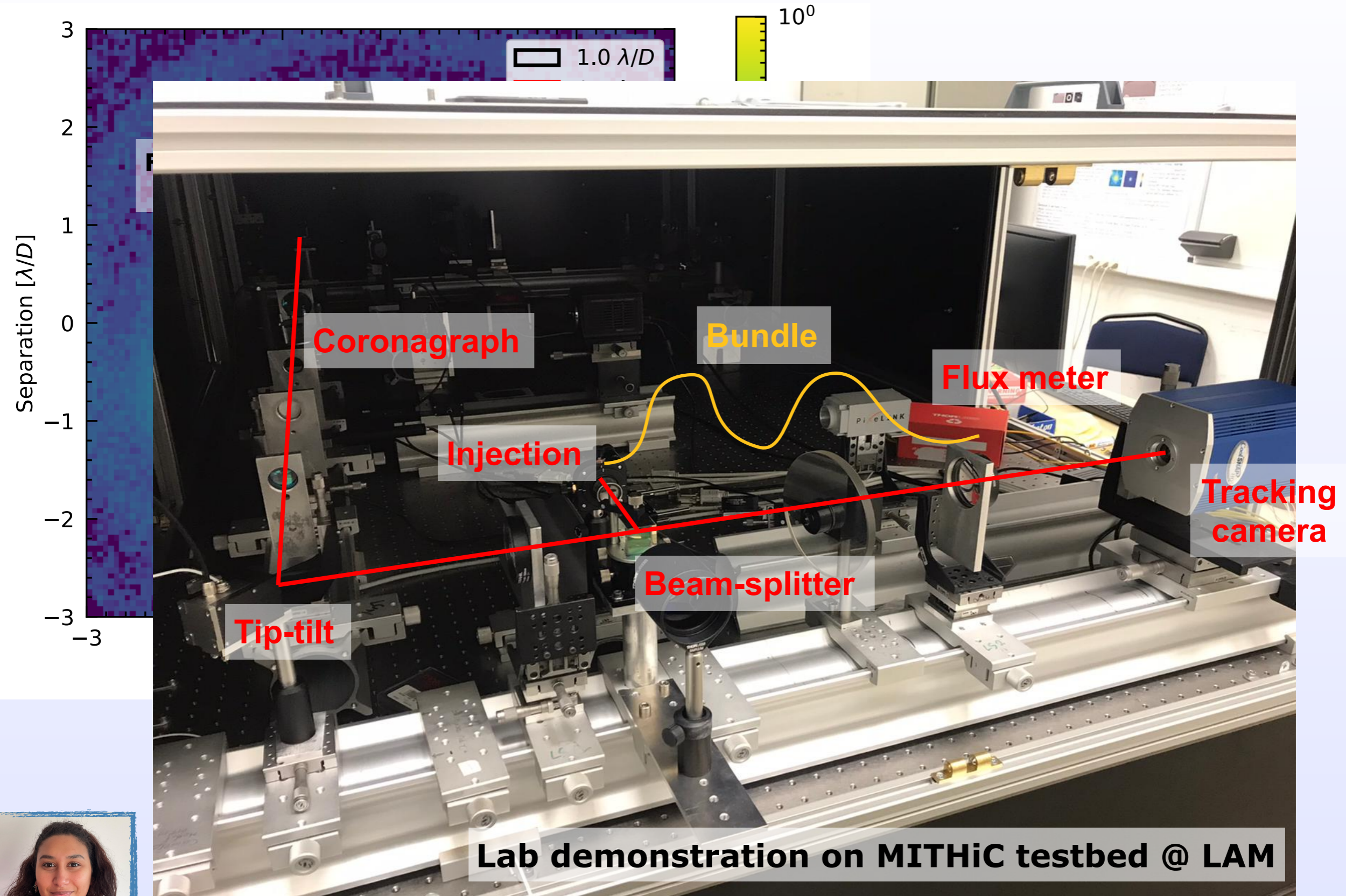


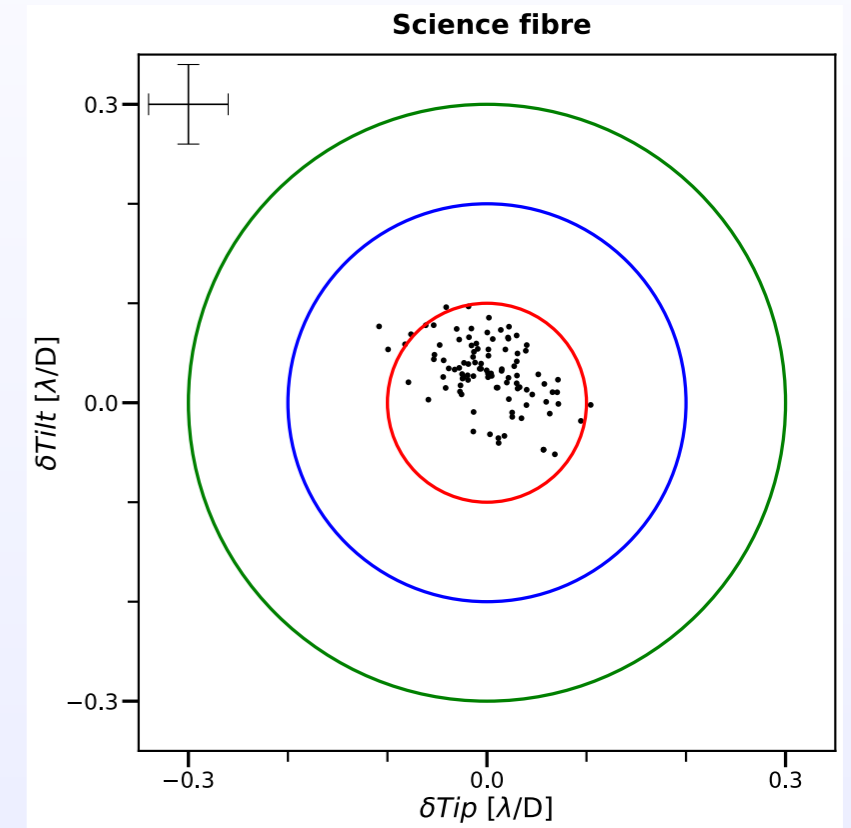
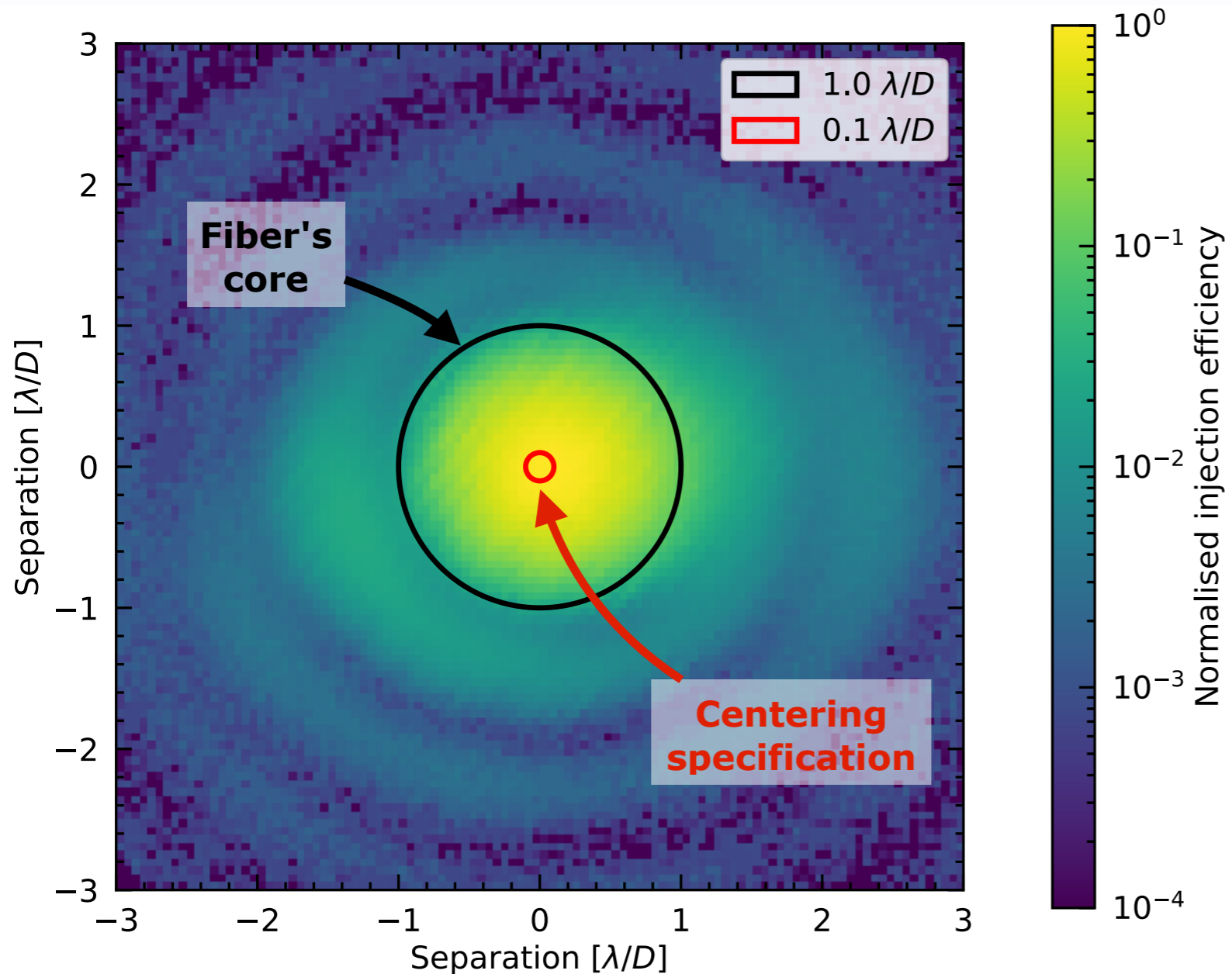
Lab demonstration on MITHiC testbed @ LAM



PSF centering: an operational challenge

Coupling





El Morsy et al. (2022)

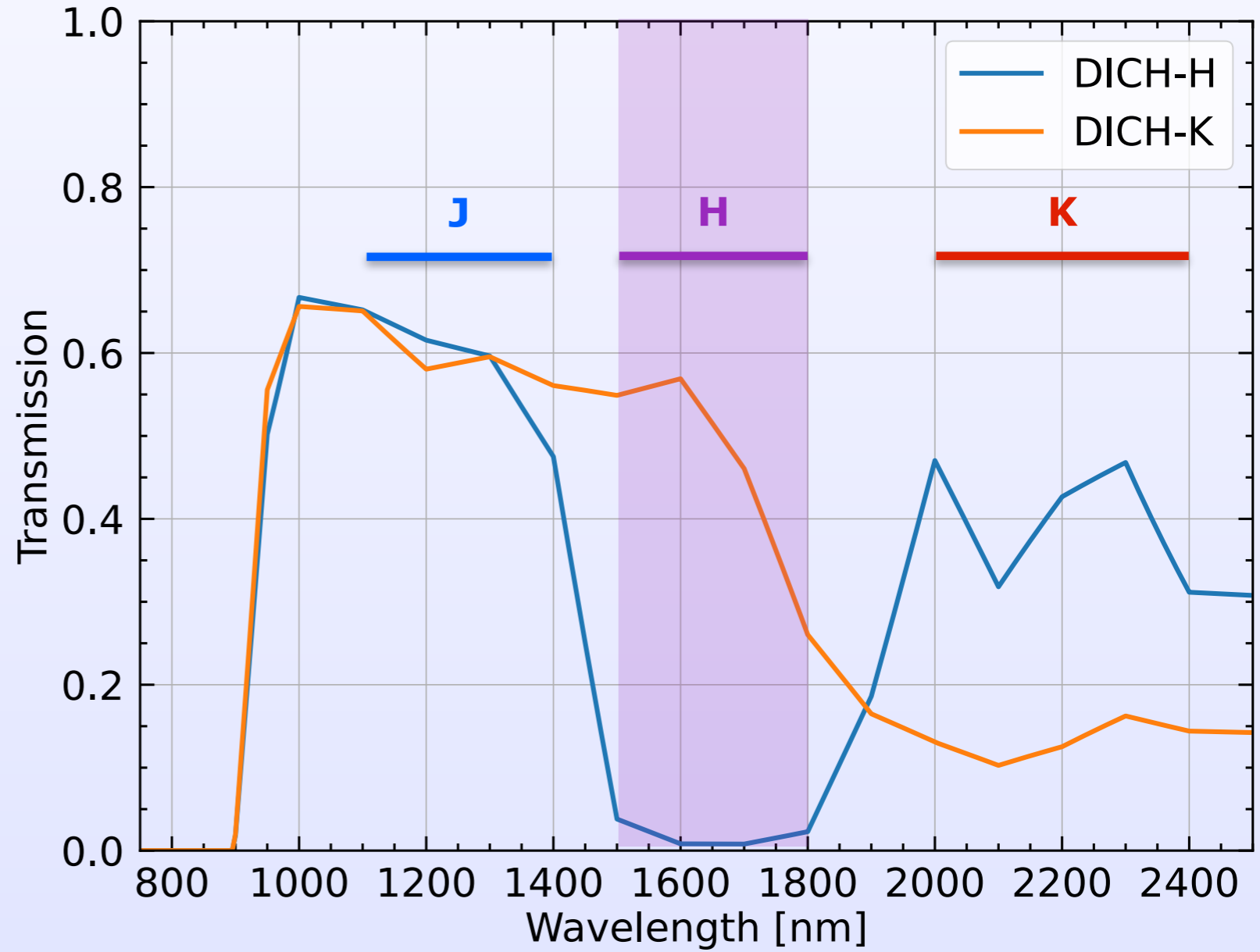
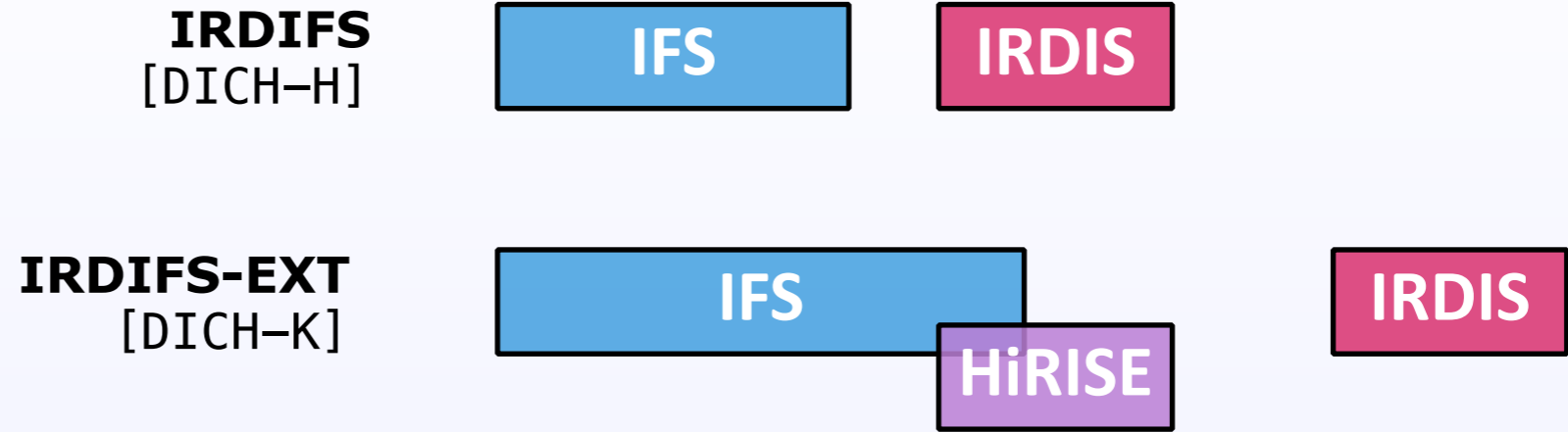
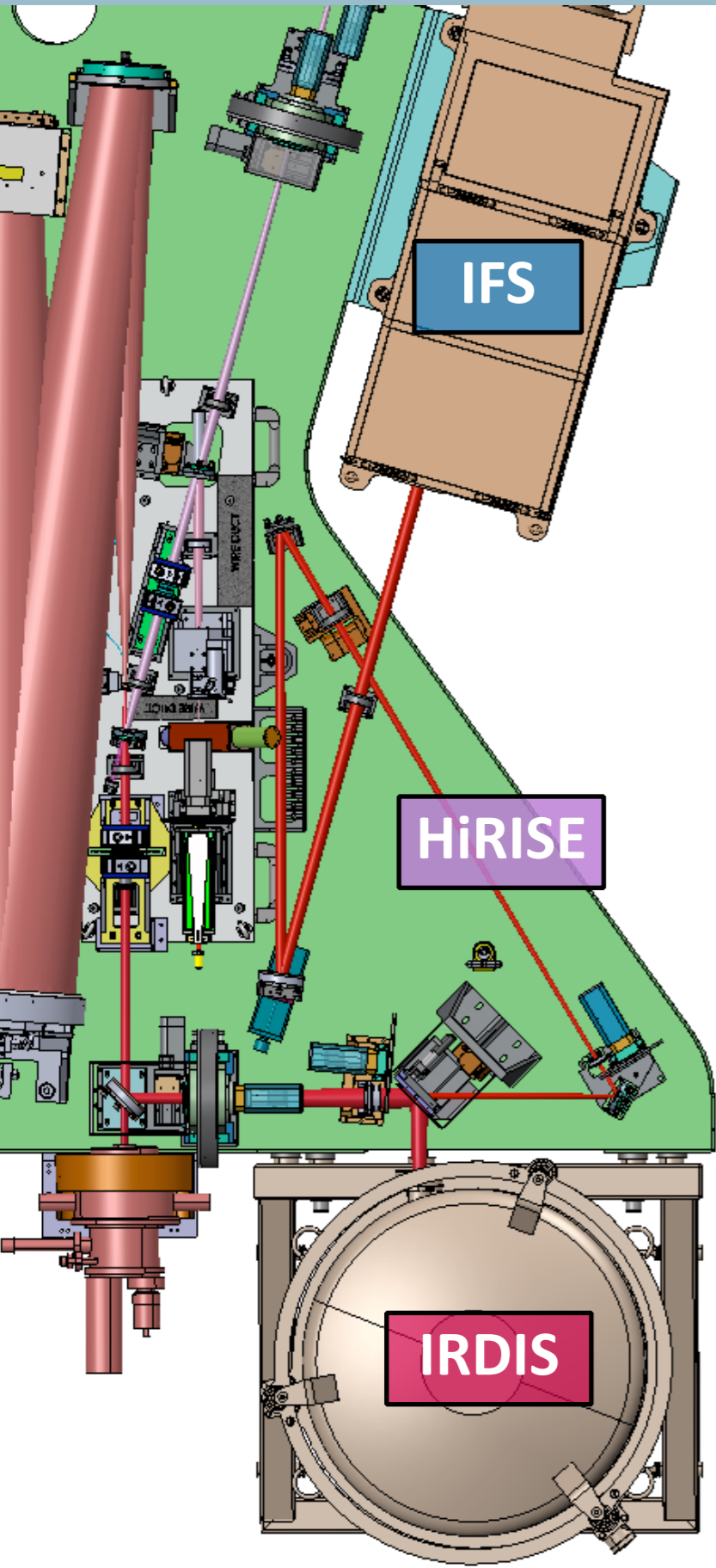
For the planet:

- $0.1 \lambda/D$ feasible, but challenging!
- $0.2 \lambda/D$ is a good baseline



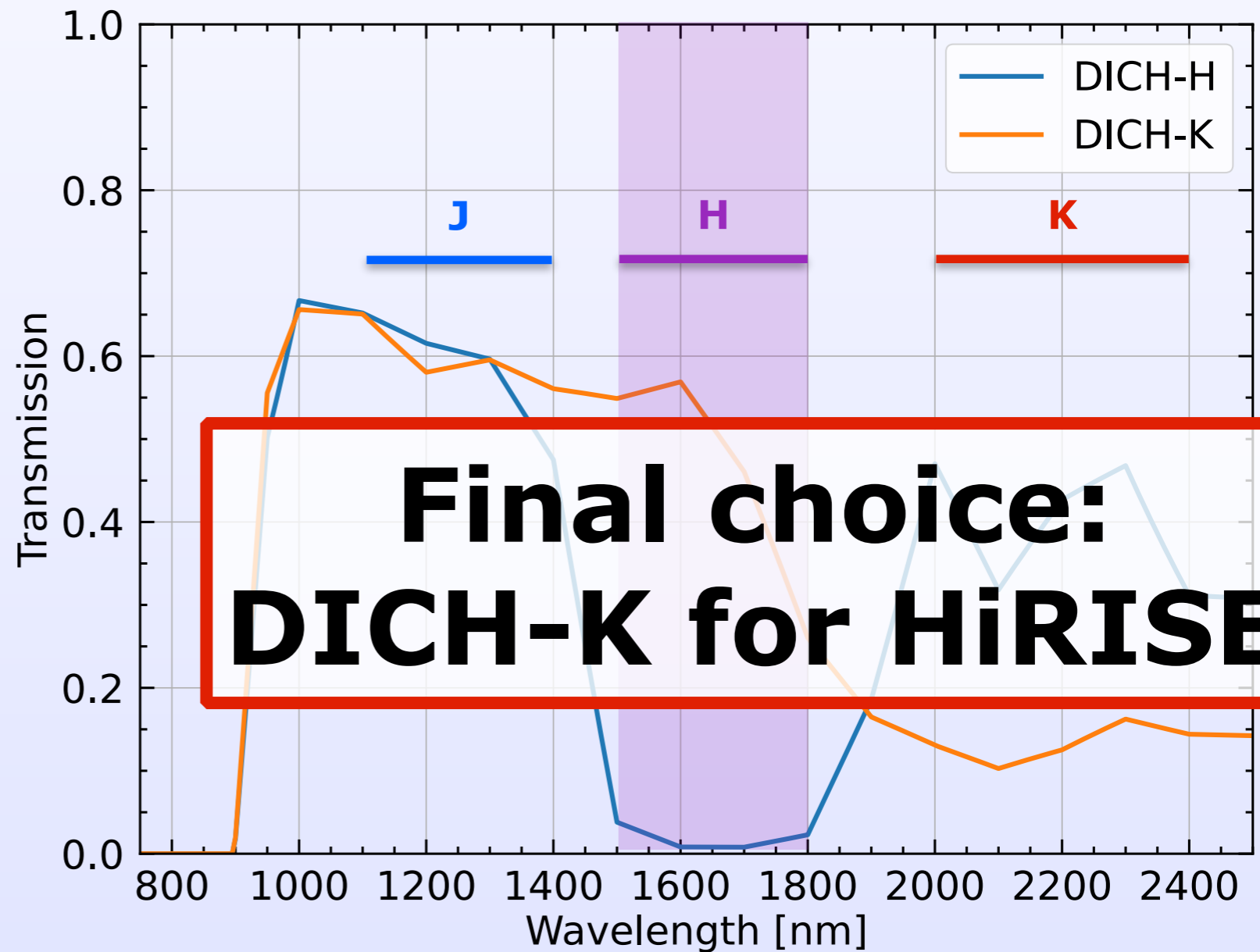
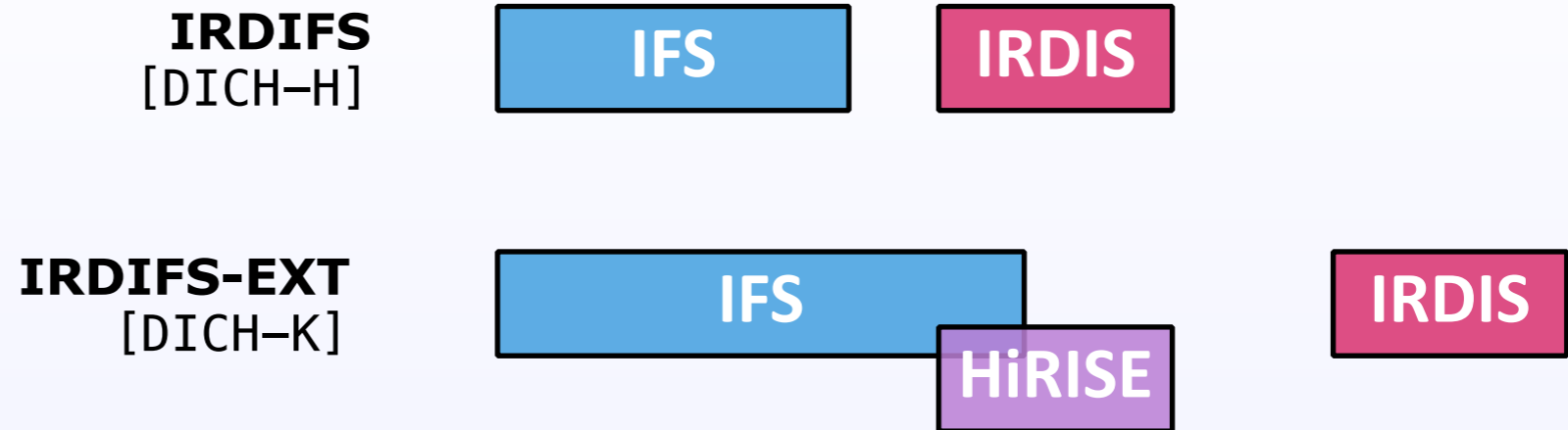
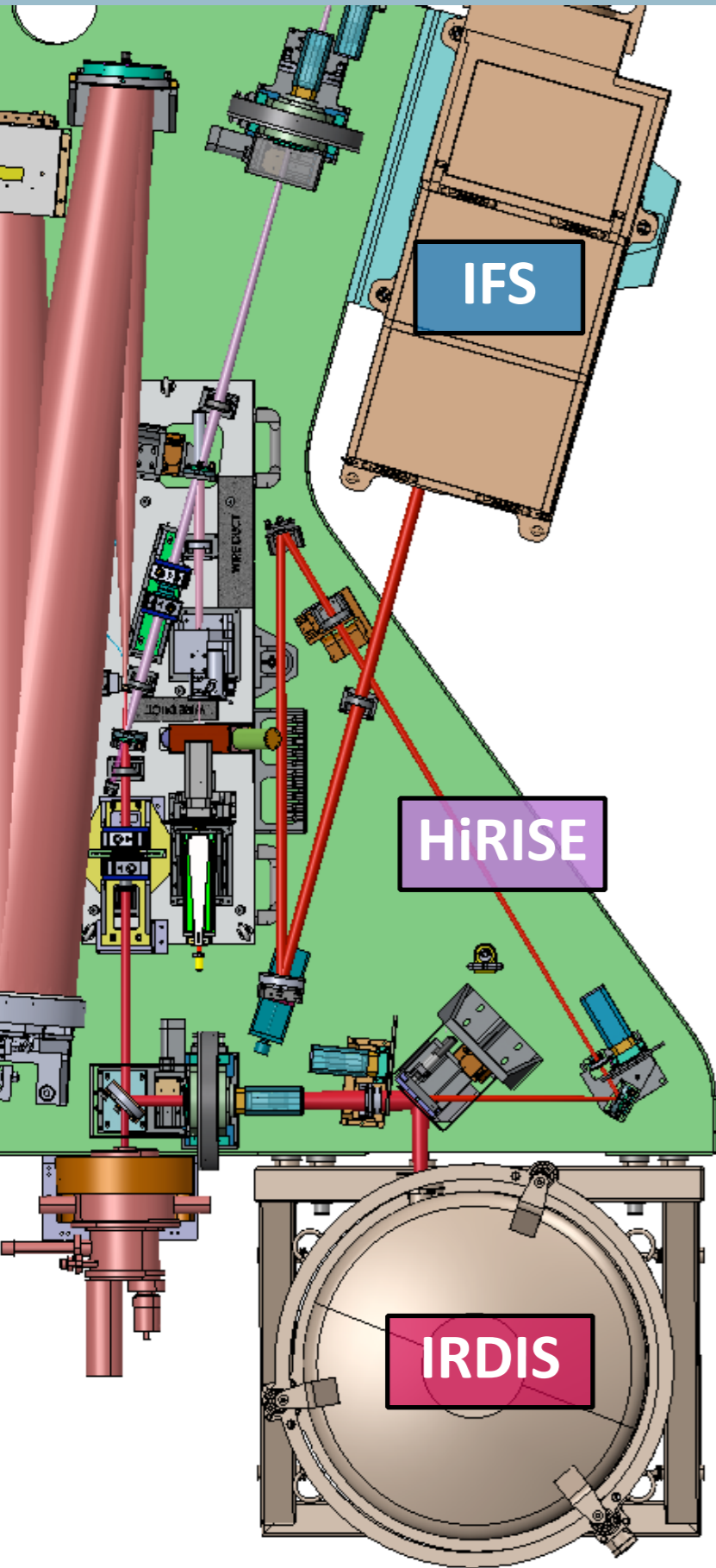
Photon sharing in SPHERE

SPHERE



Photon sharing in SPHERE

SPHERE

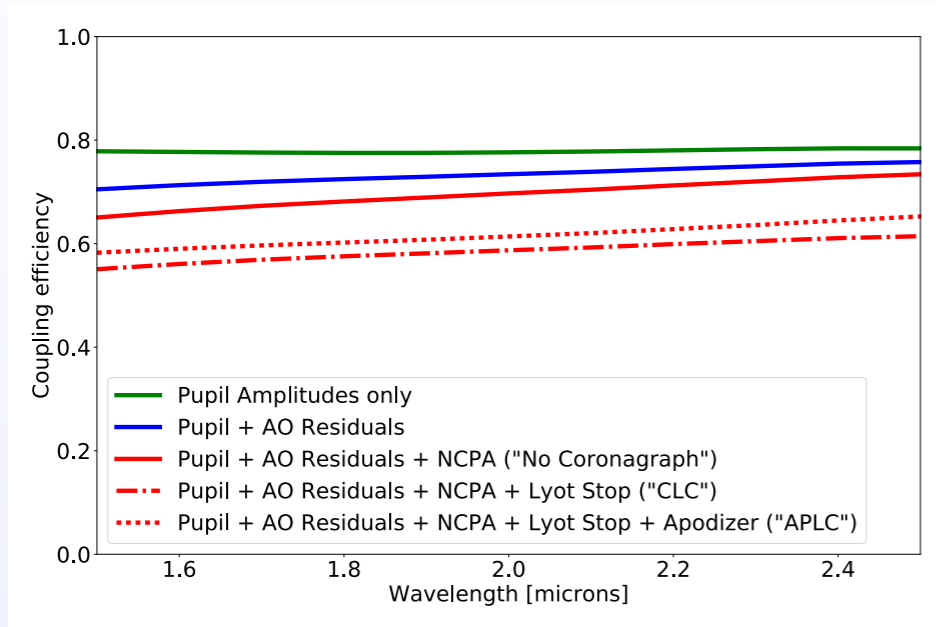


**Final choice:
DICH-K for HiRISE**

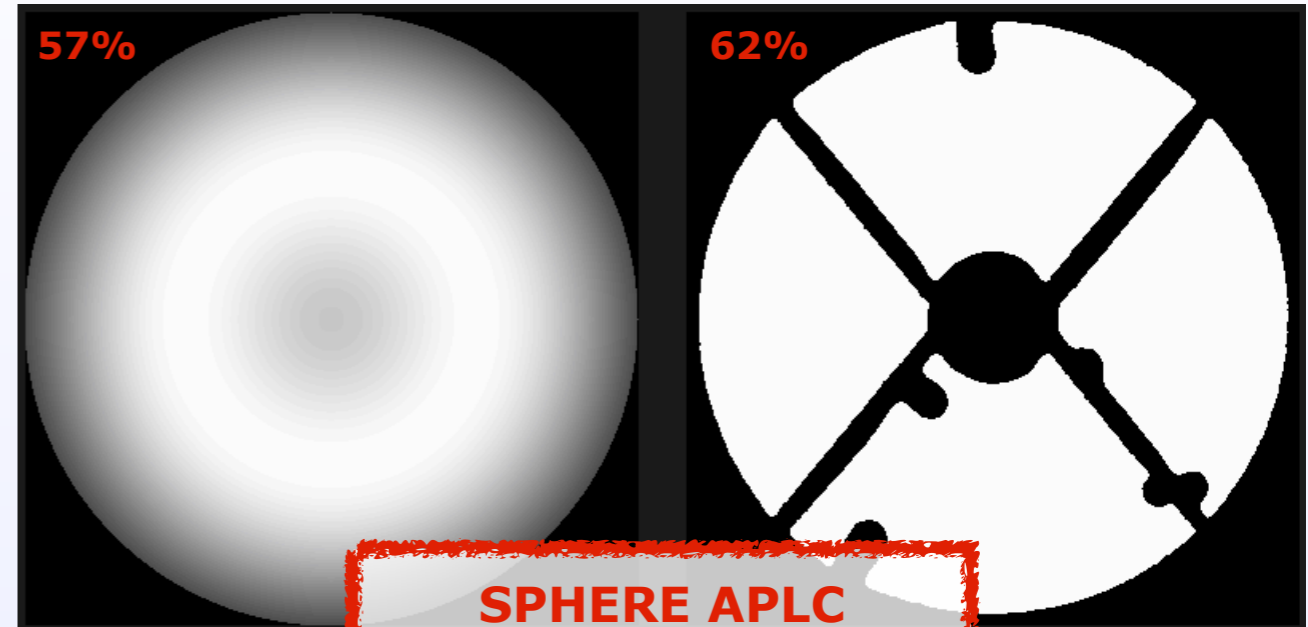
To have or not to have [a coronagraph]?

SPHERE

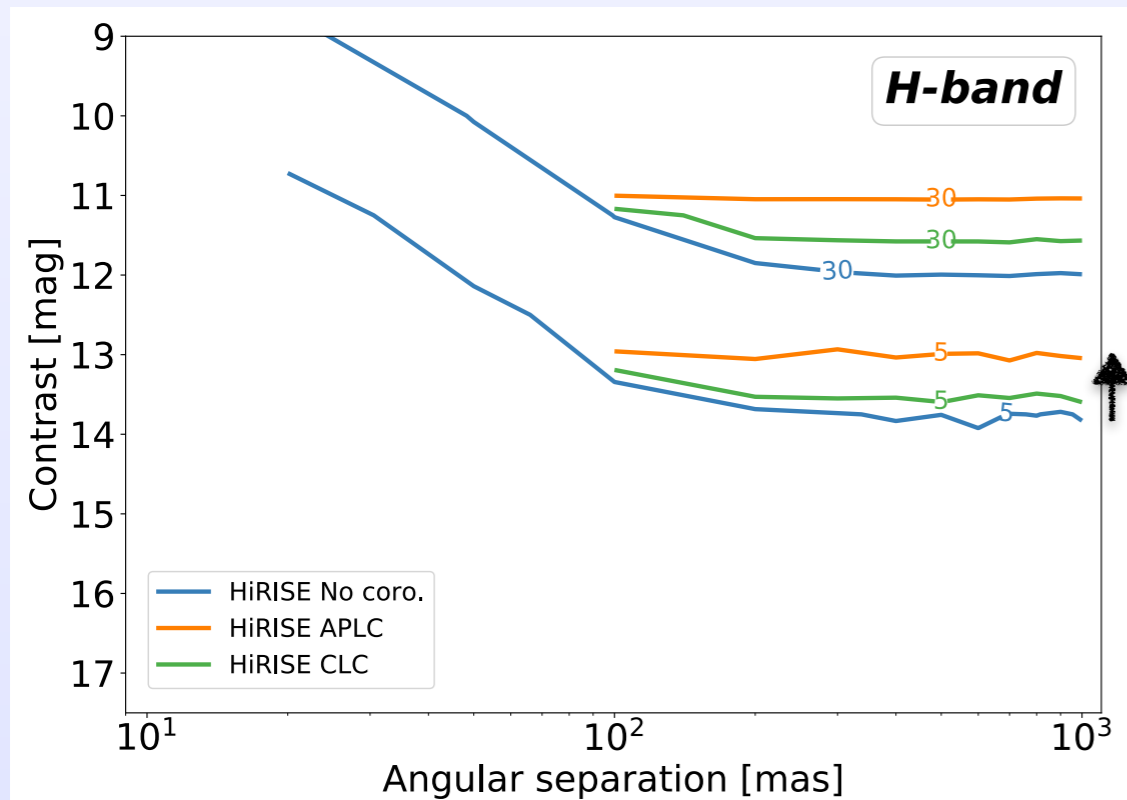
Coupling efficiency



Transmission



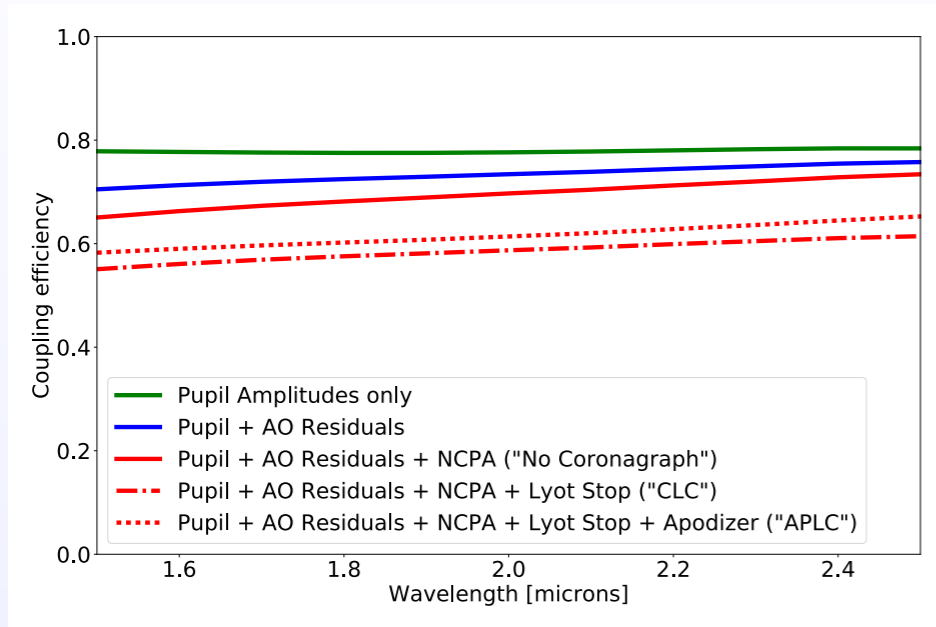
SPHERE APLC
<40% of the total flux is transmitted!!



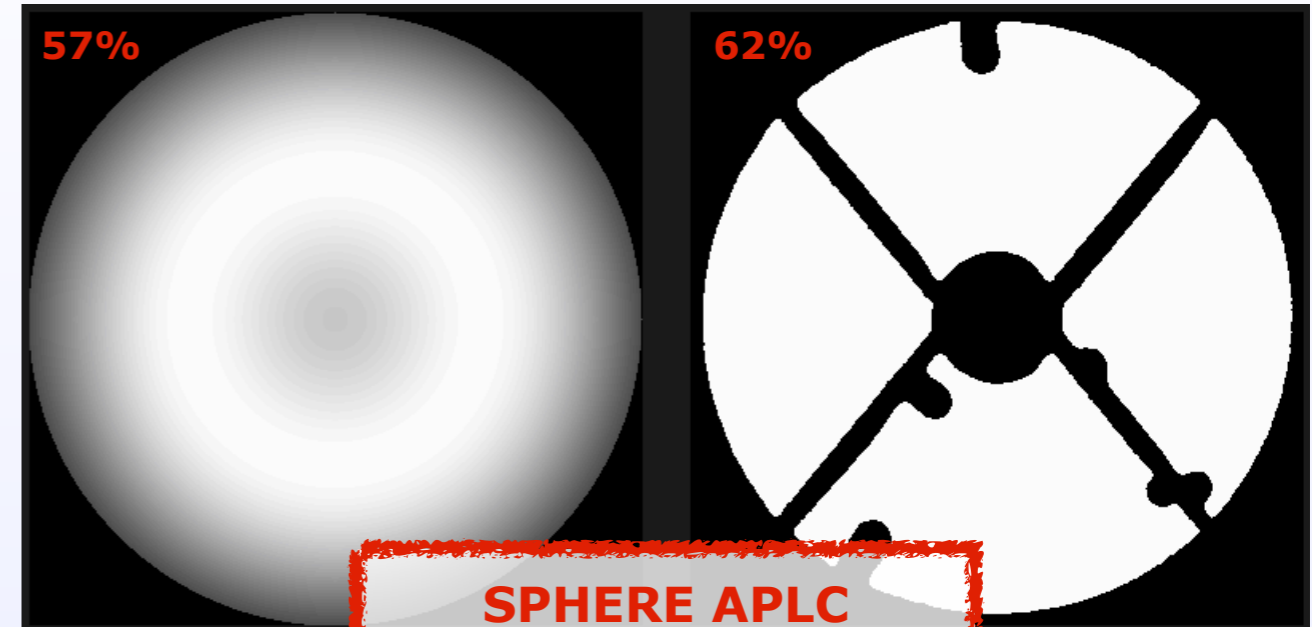
To have or not to have [a coronagraph]?

SPHERE

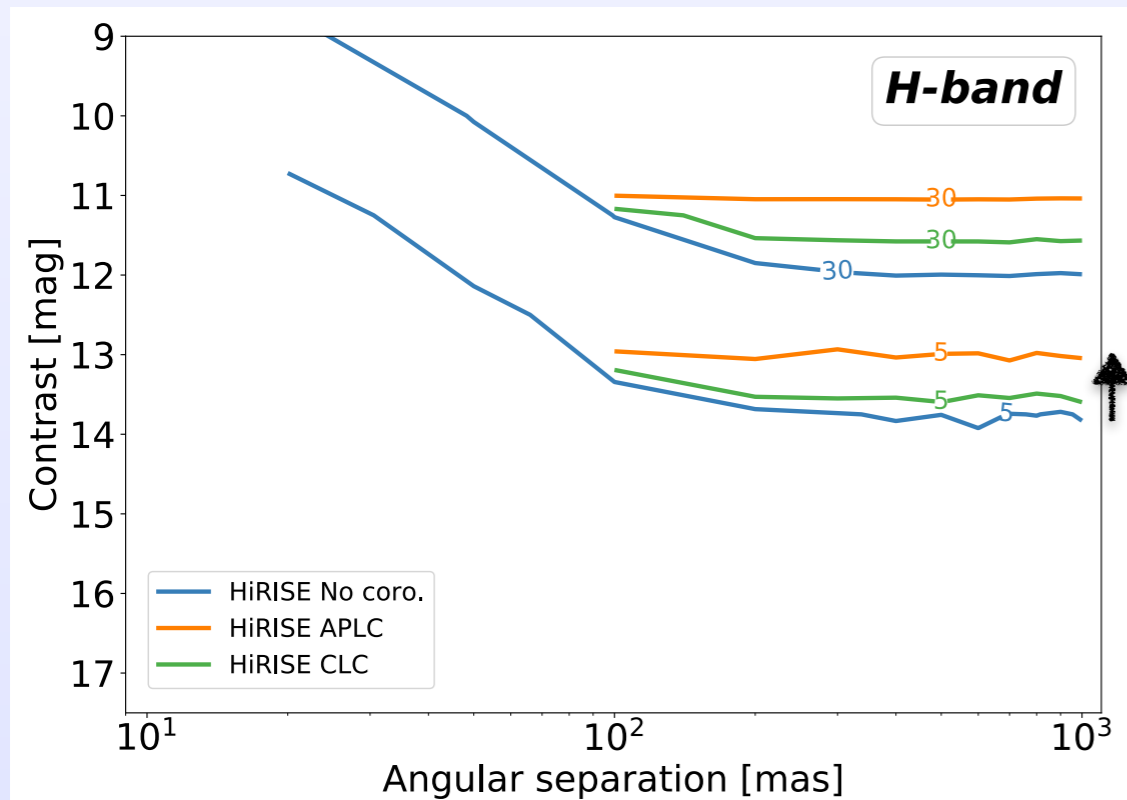
Coupling efficiency



Transmission



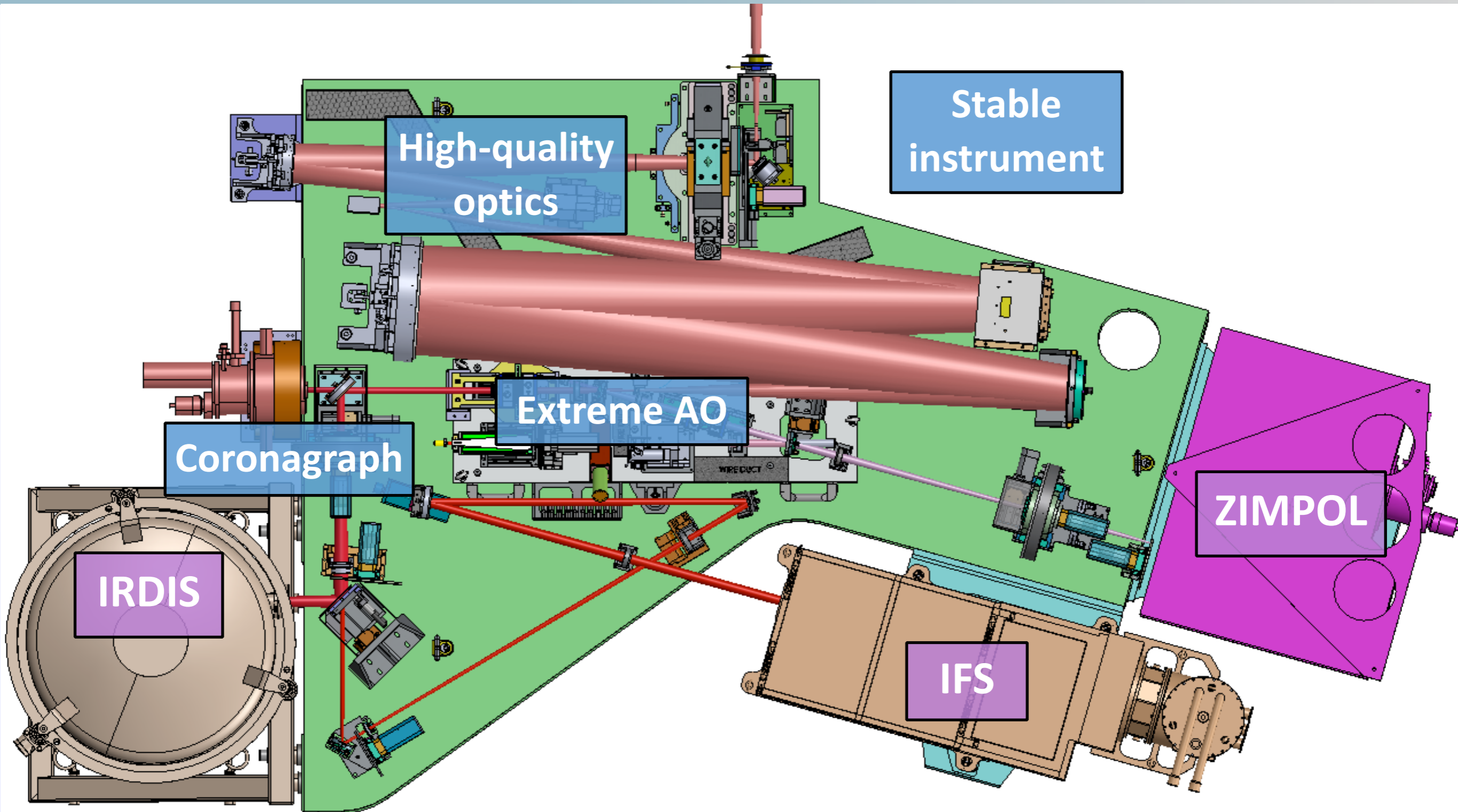
SPHERE APLC
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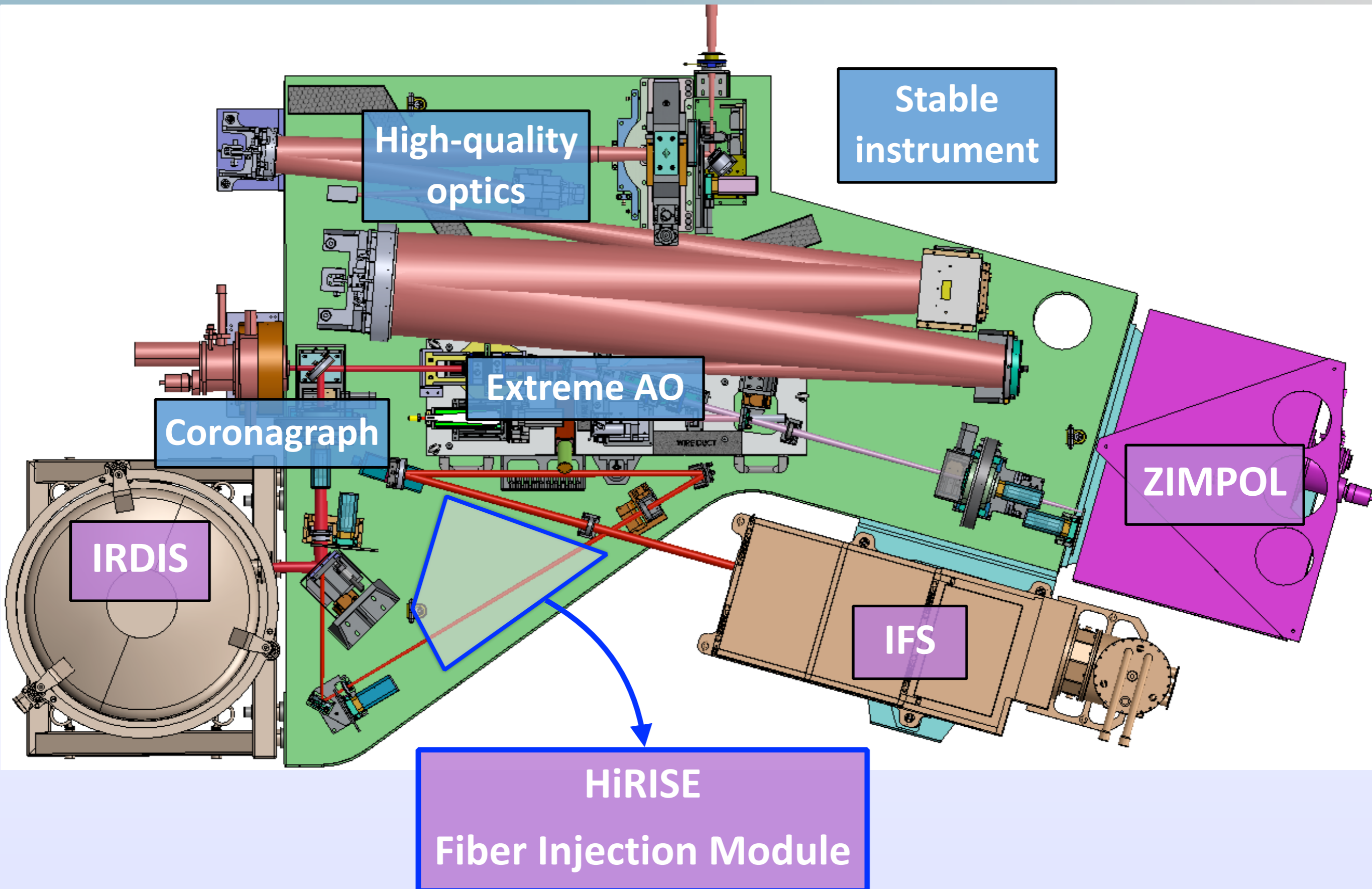
Final choice:
No coronagraph



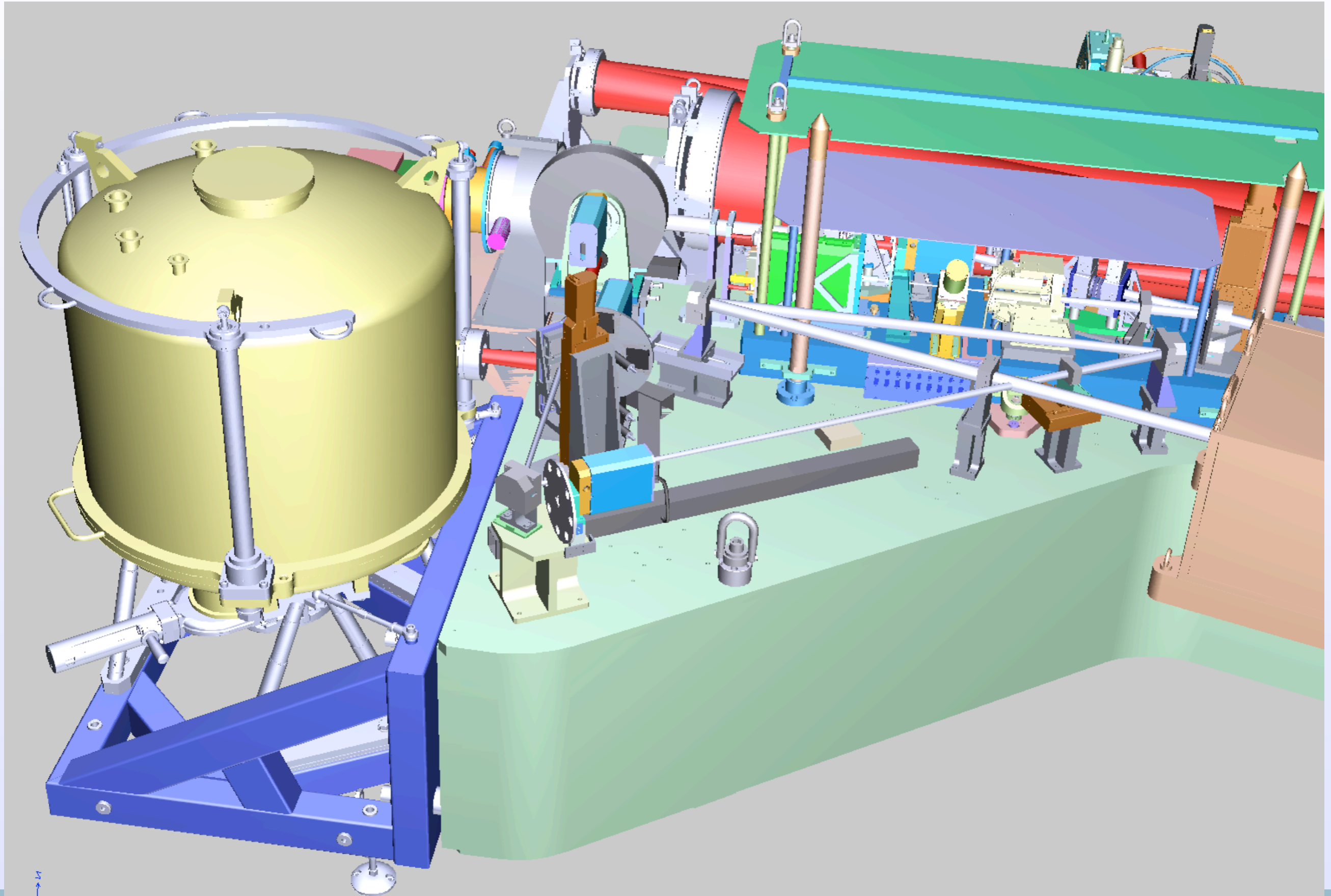
Fiber injection module



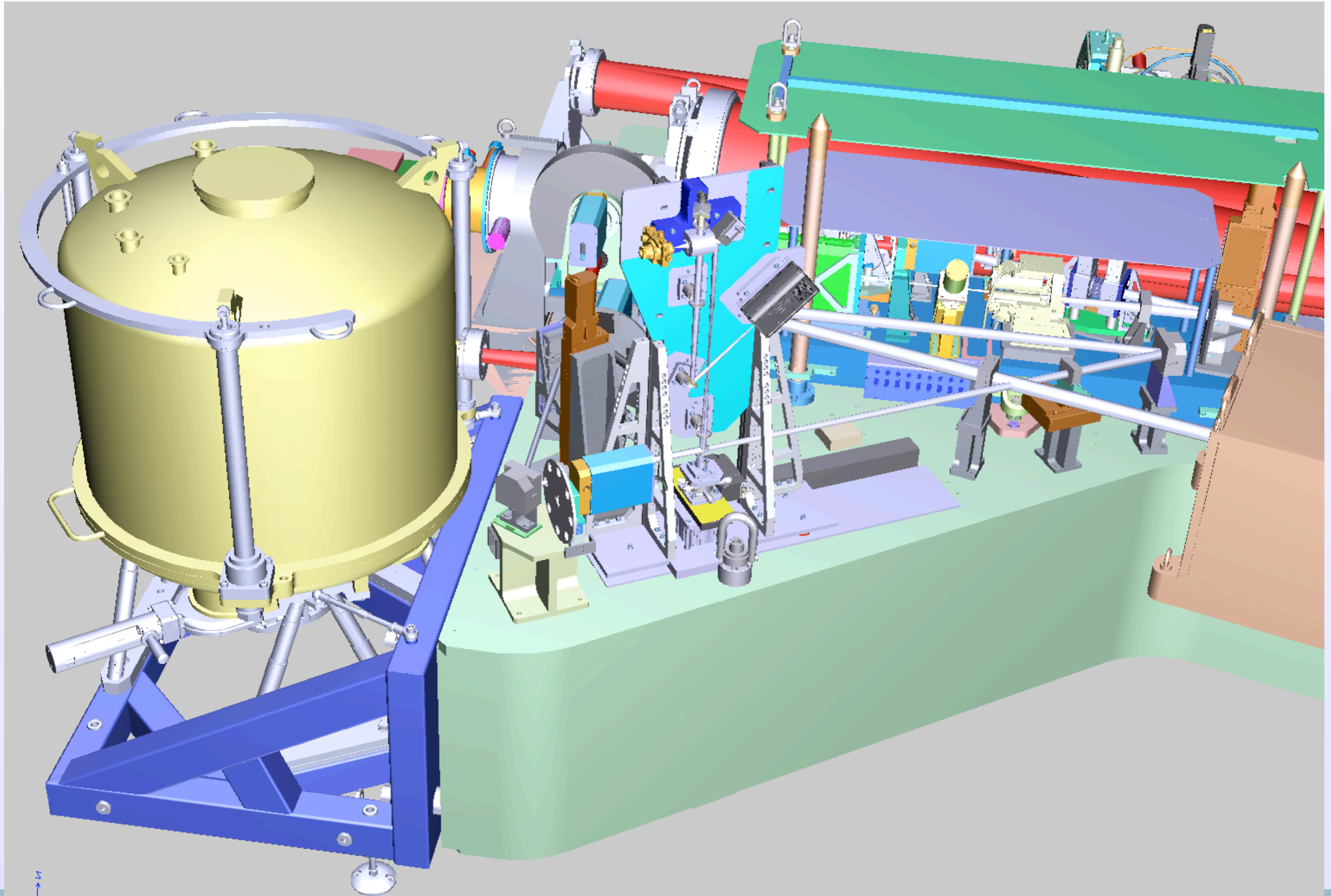
Fiber injection module

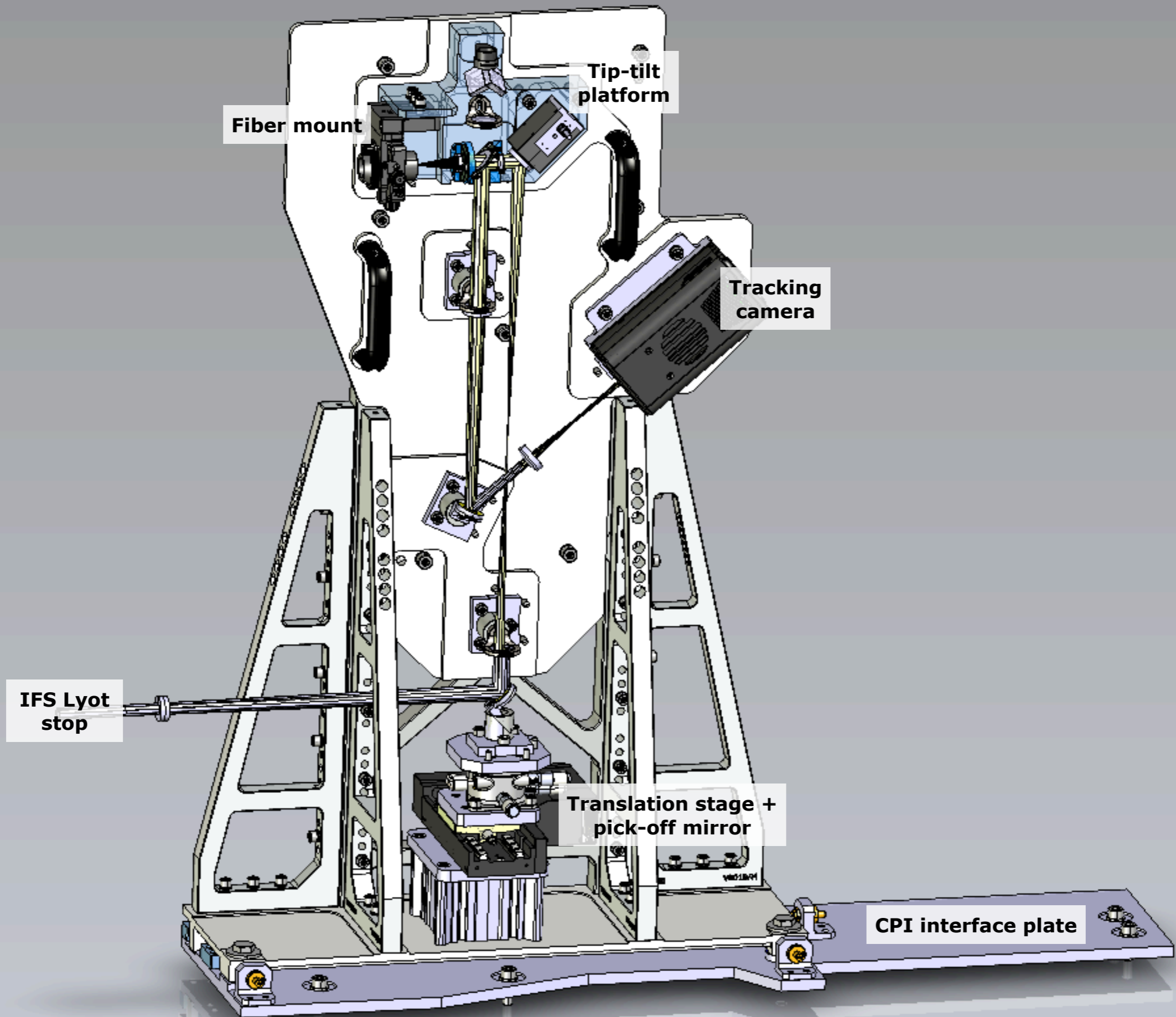


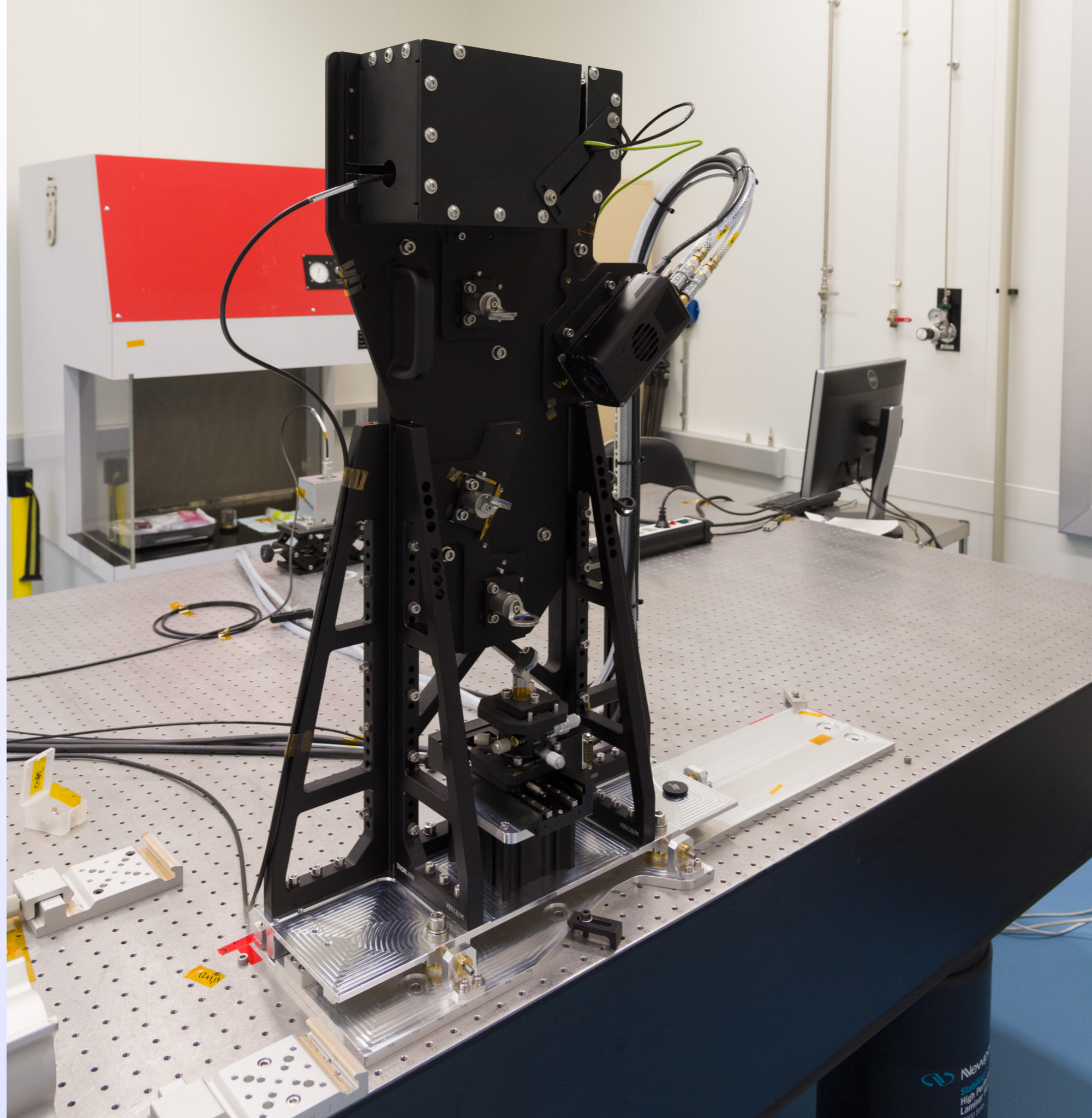
Fiber injection module



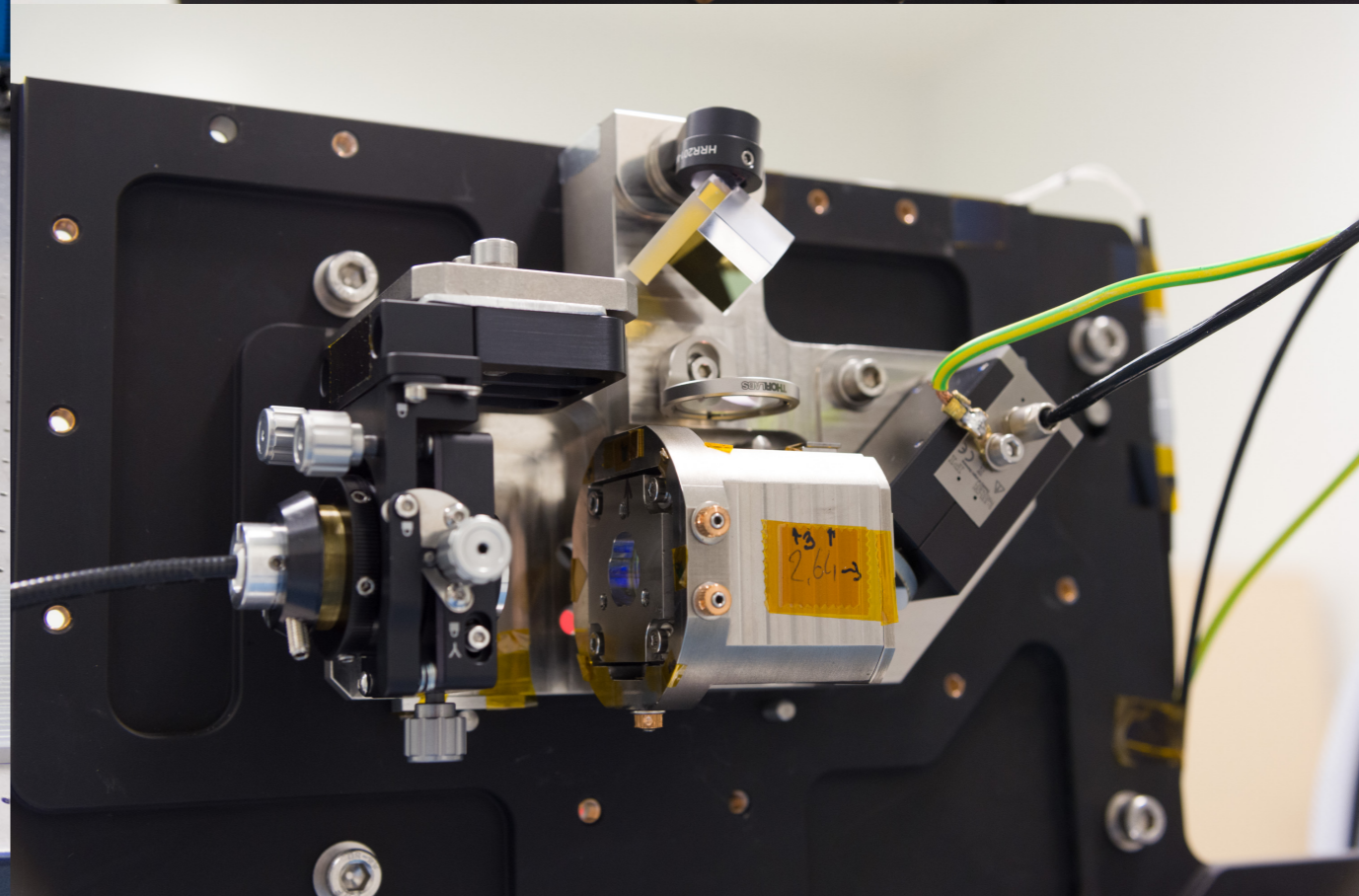
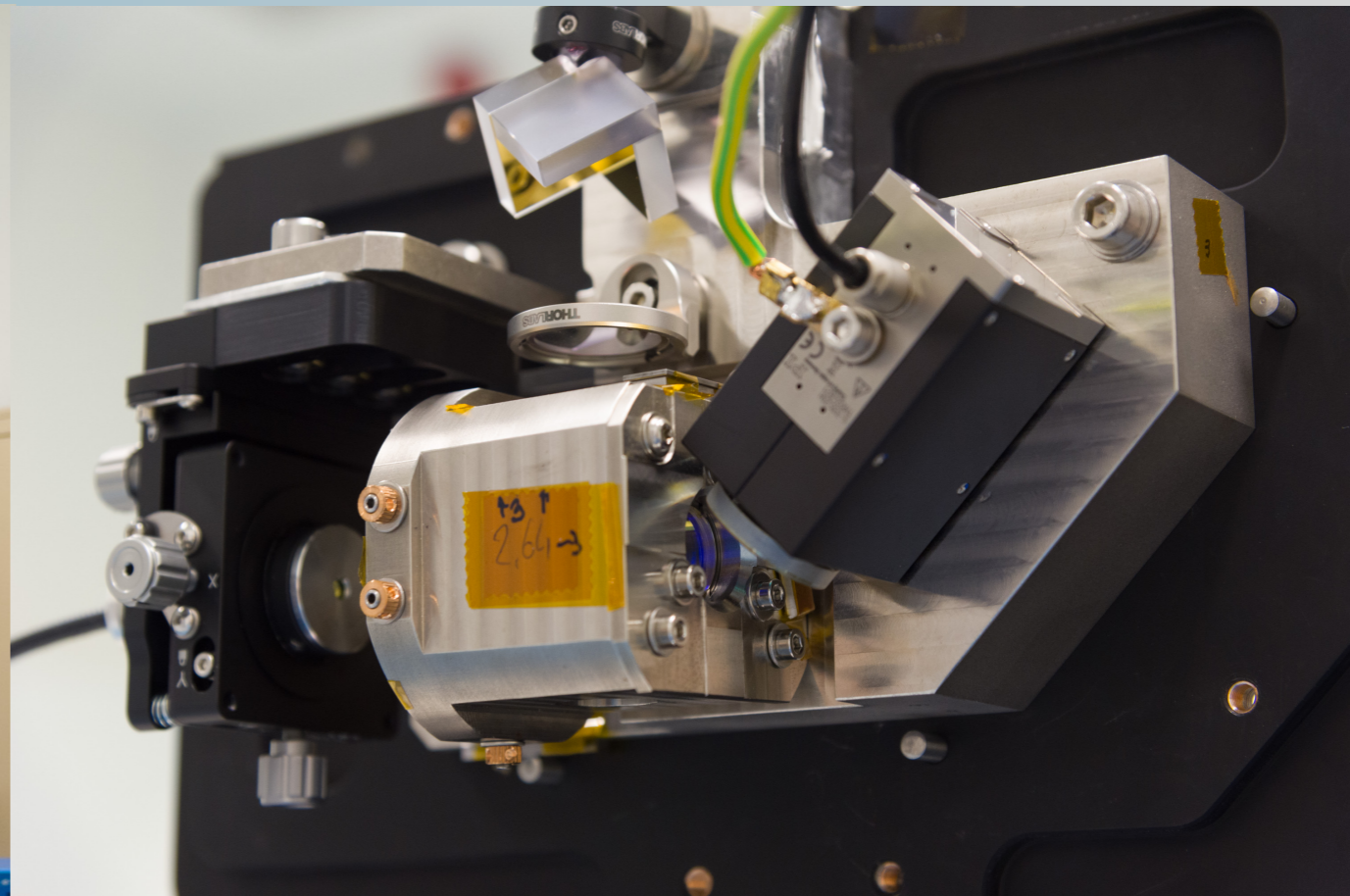
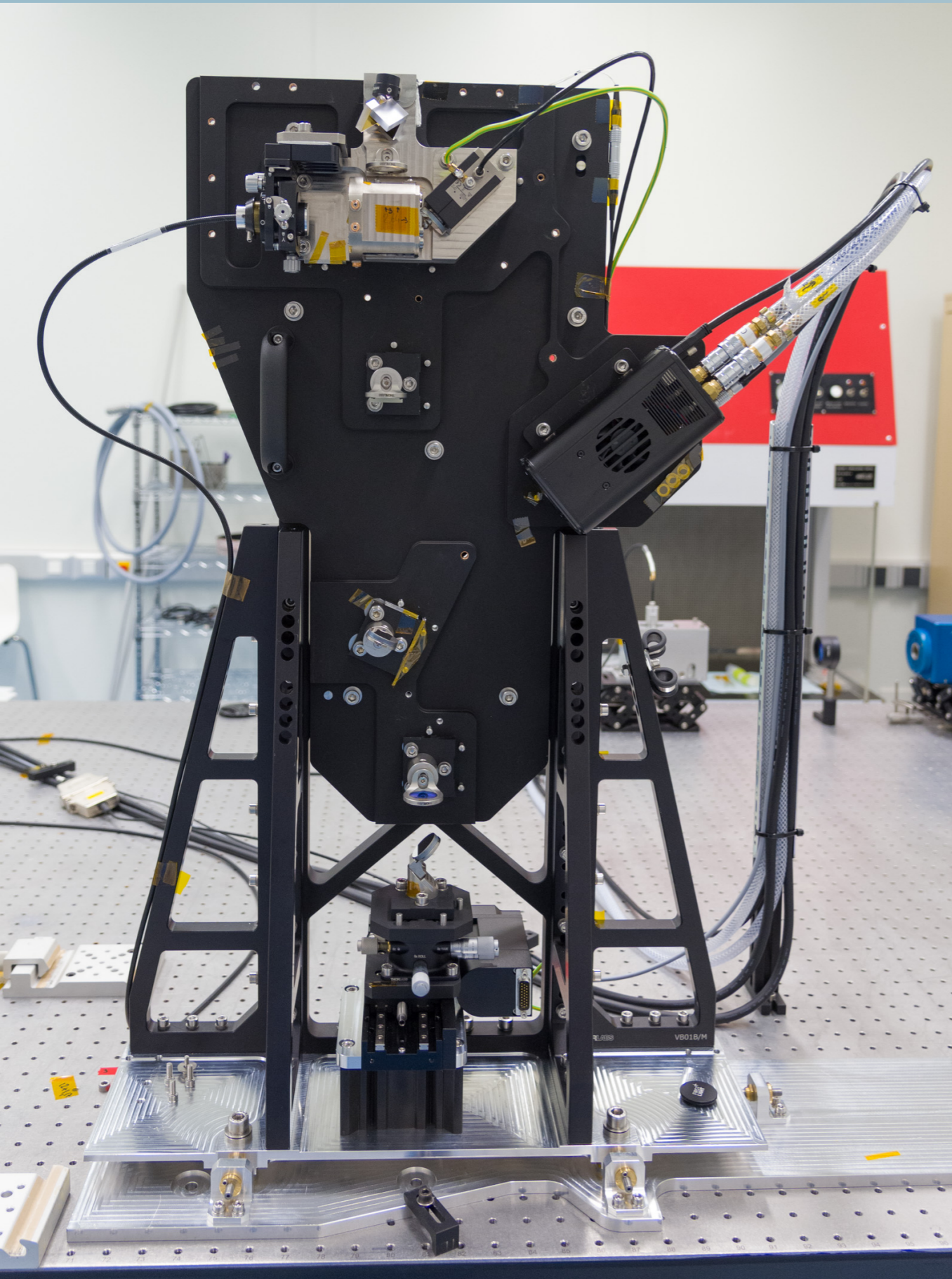
Fiber injection module







Fiber injection module



Fiber injection module



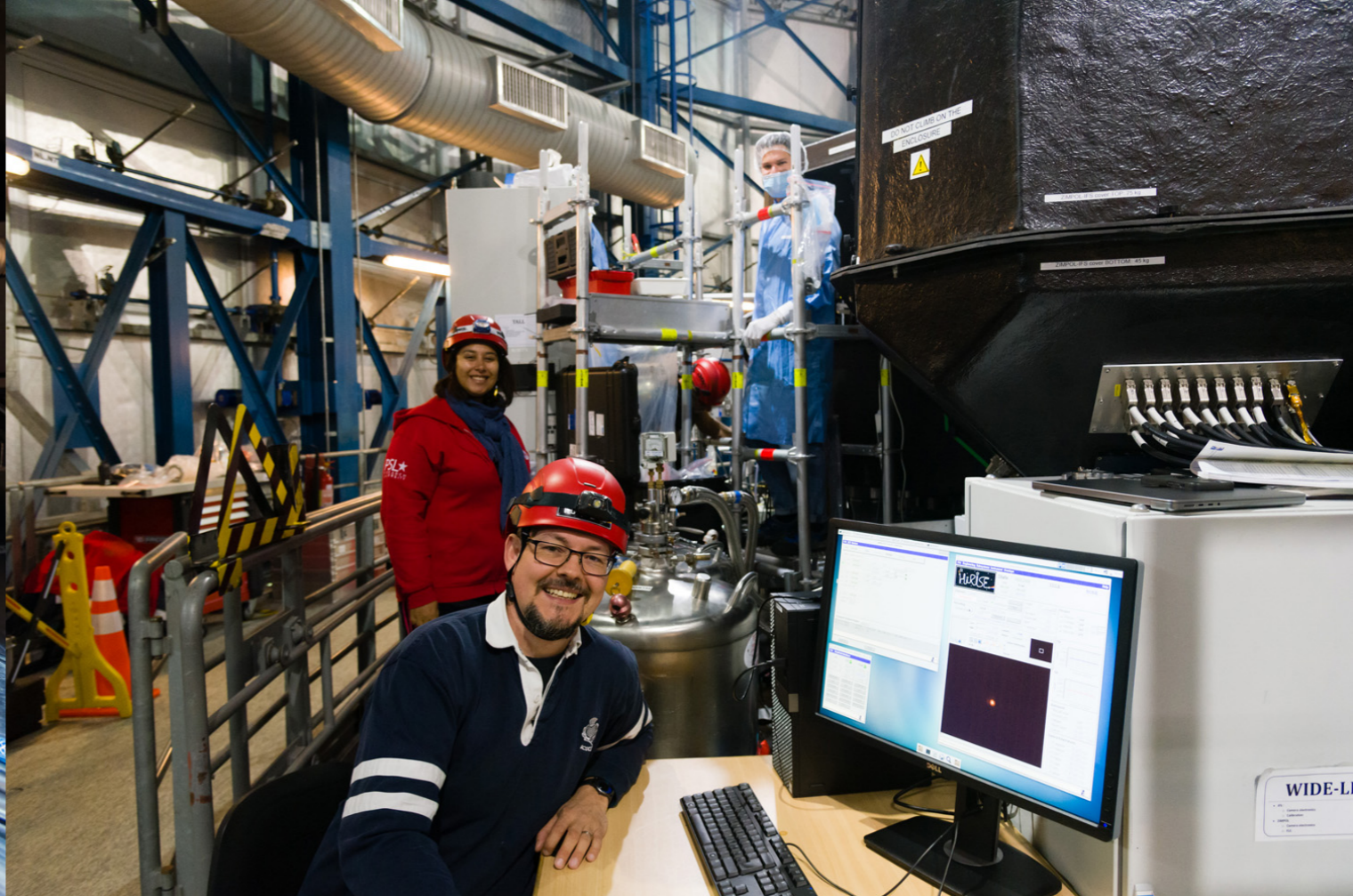
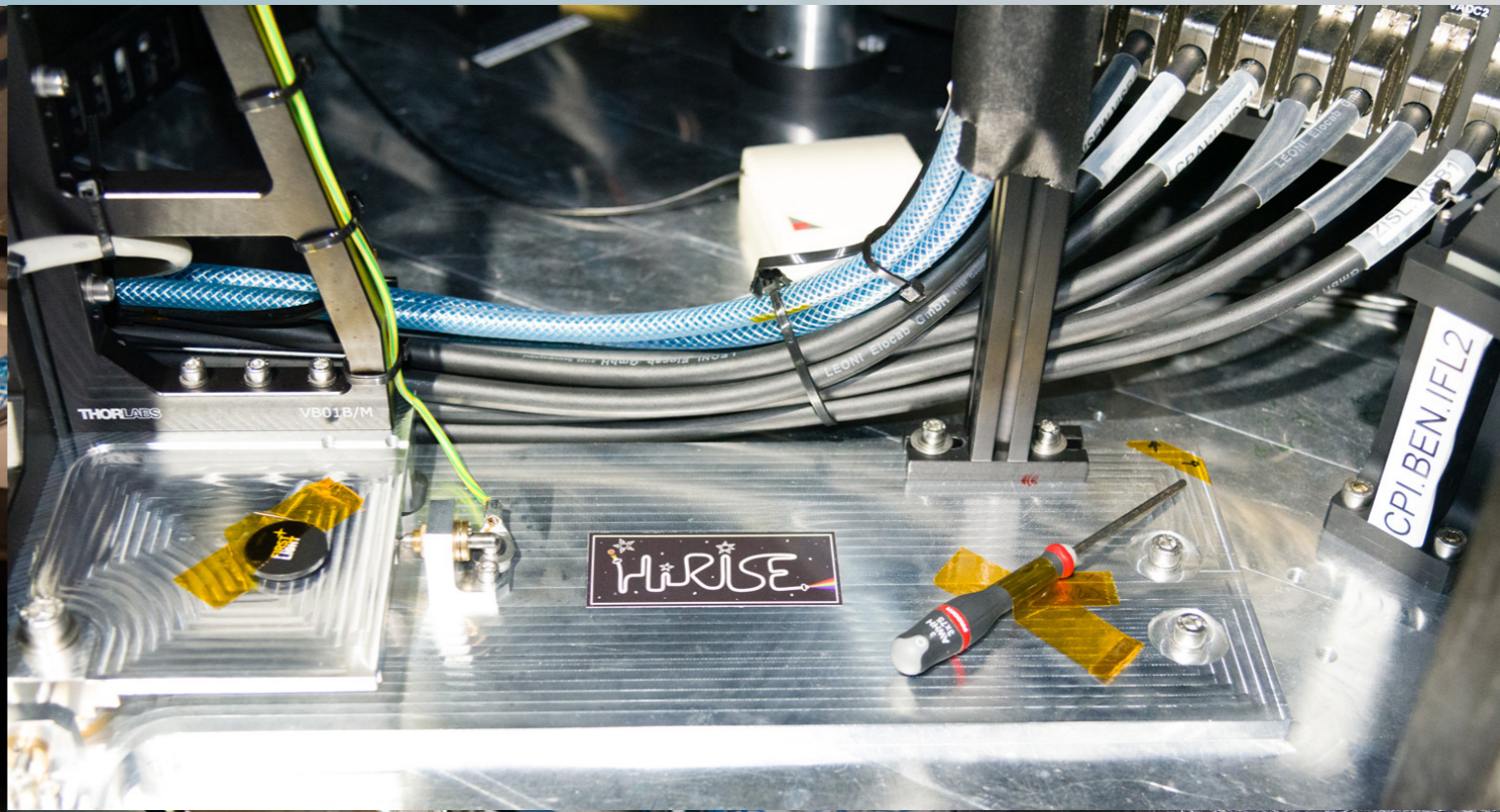
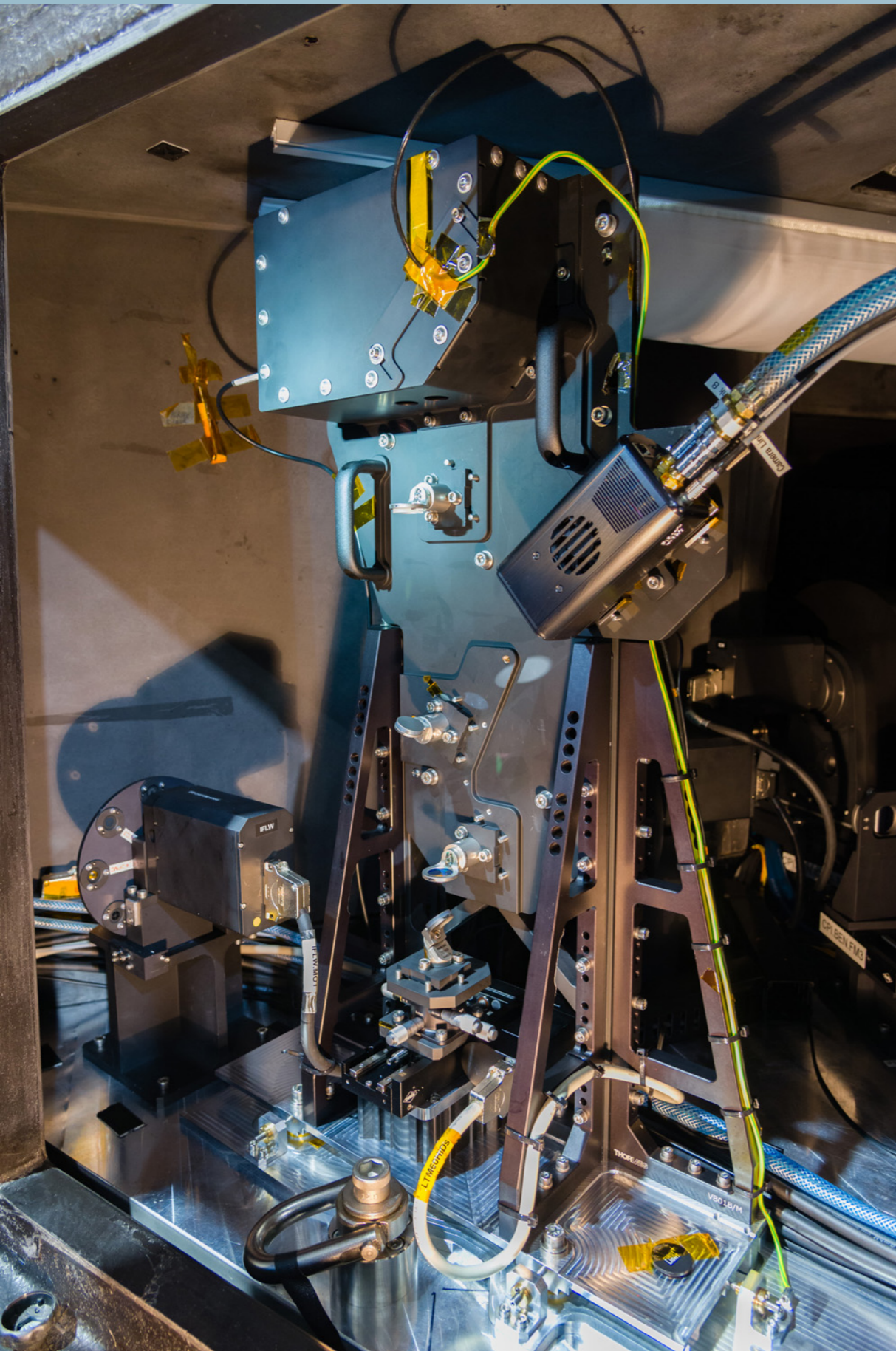
Fiber injection module



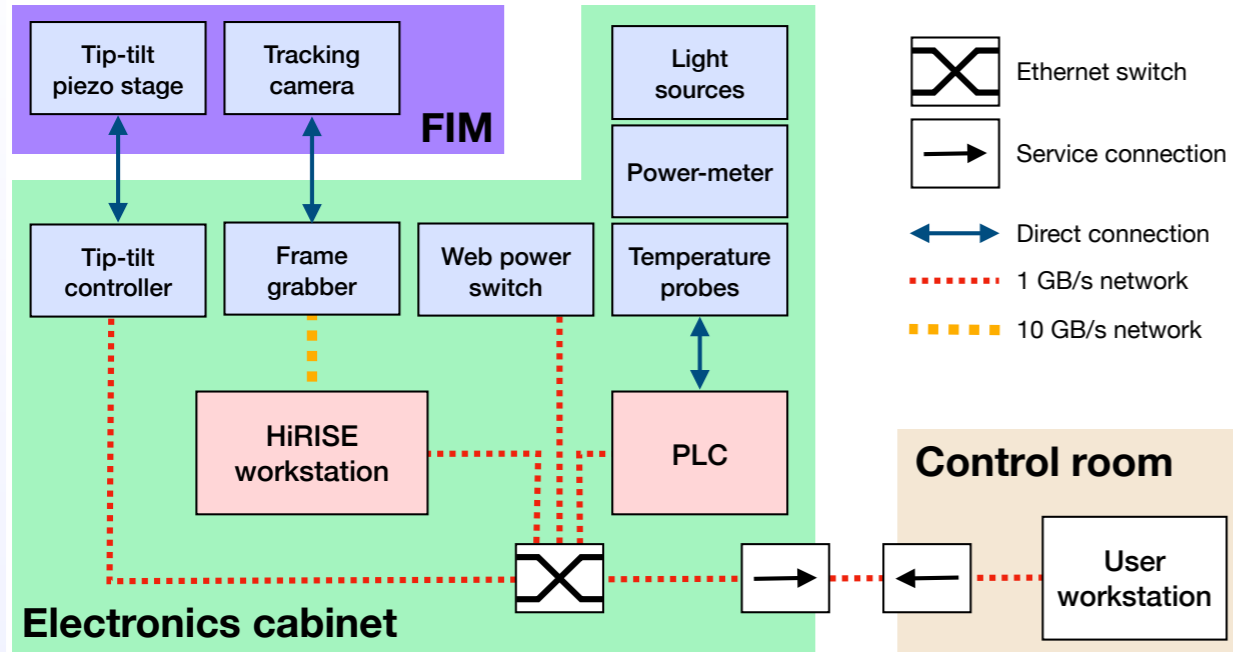
Fiber injection module



Fiber injection module

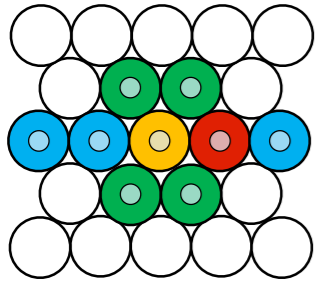


Electronics cabinet



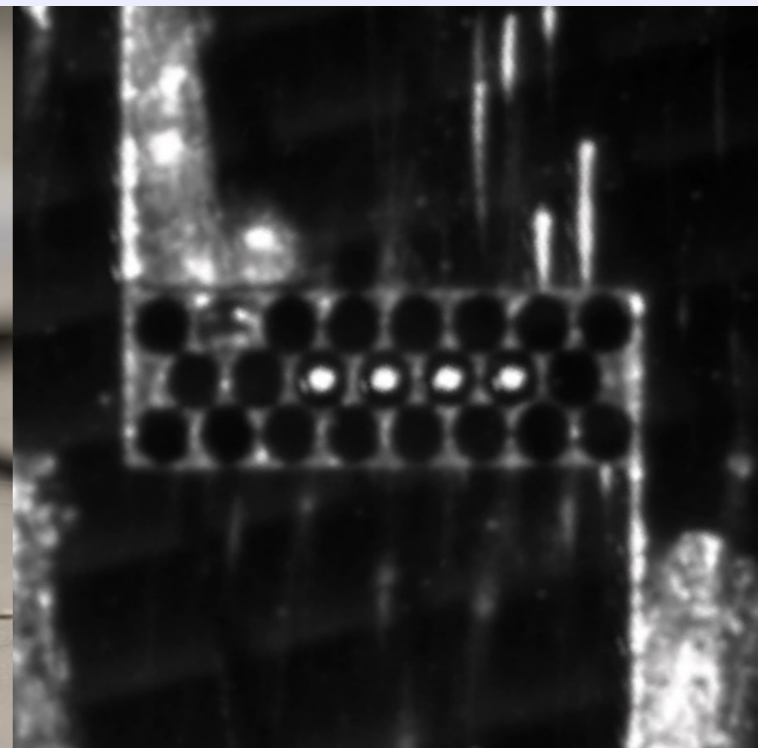
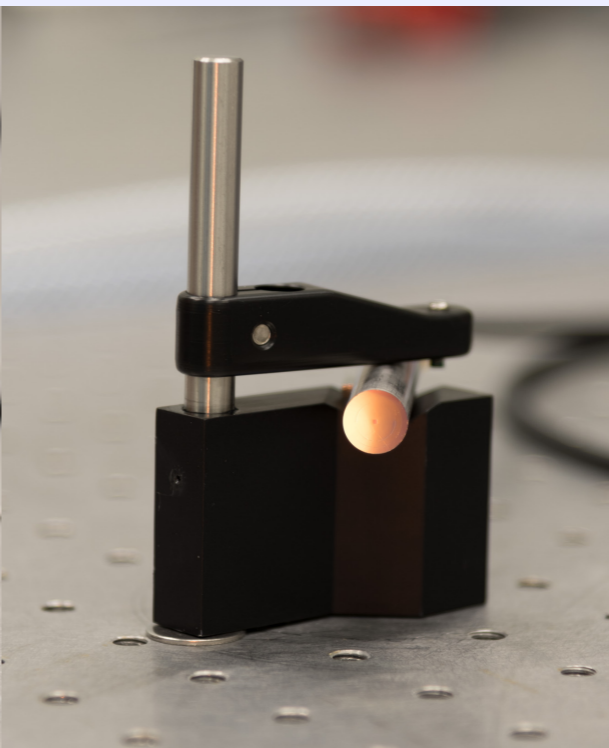
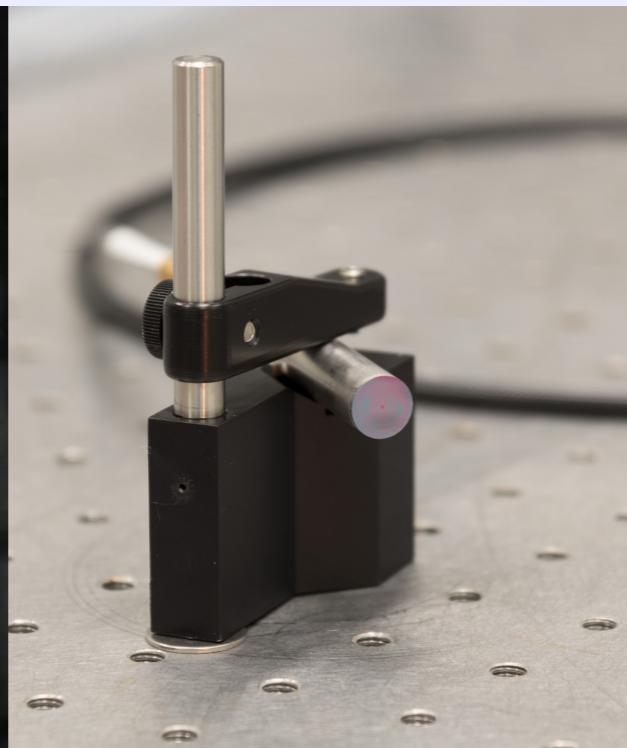
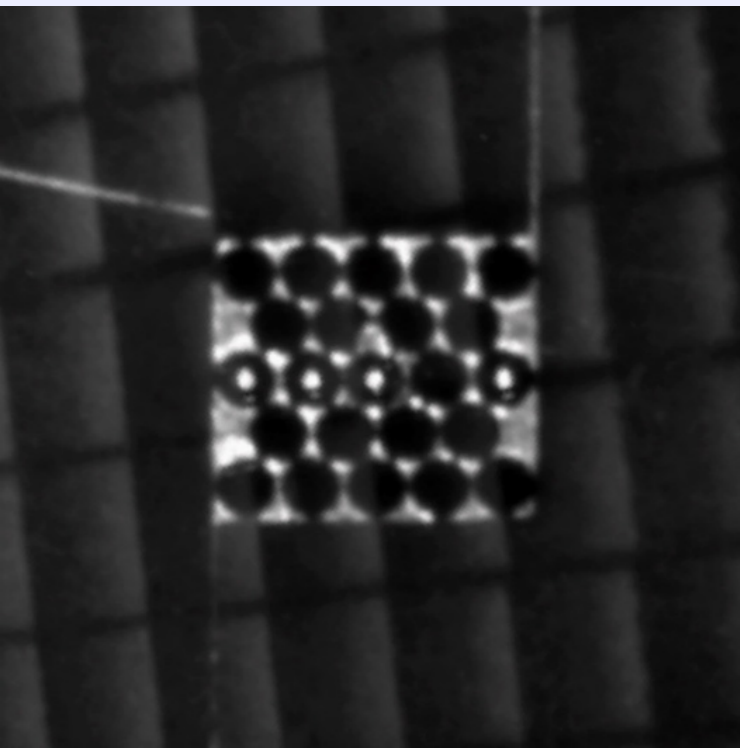
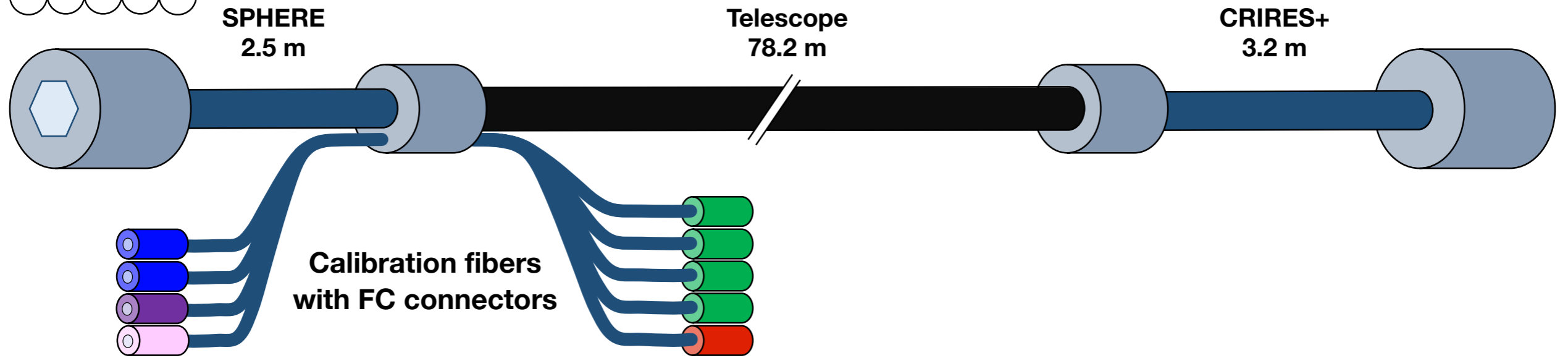
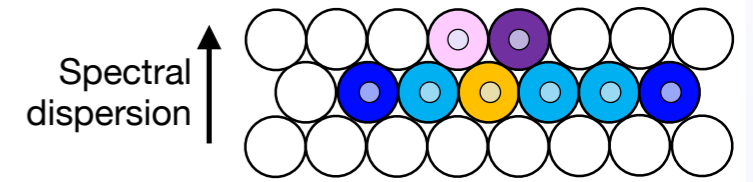
A complex fiber bundle

Input geometry
AR coated 1250-1850 nm

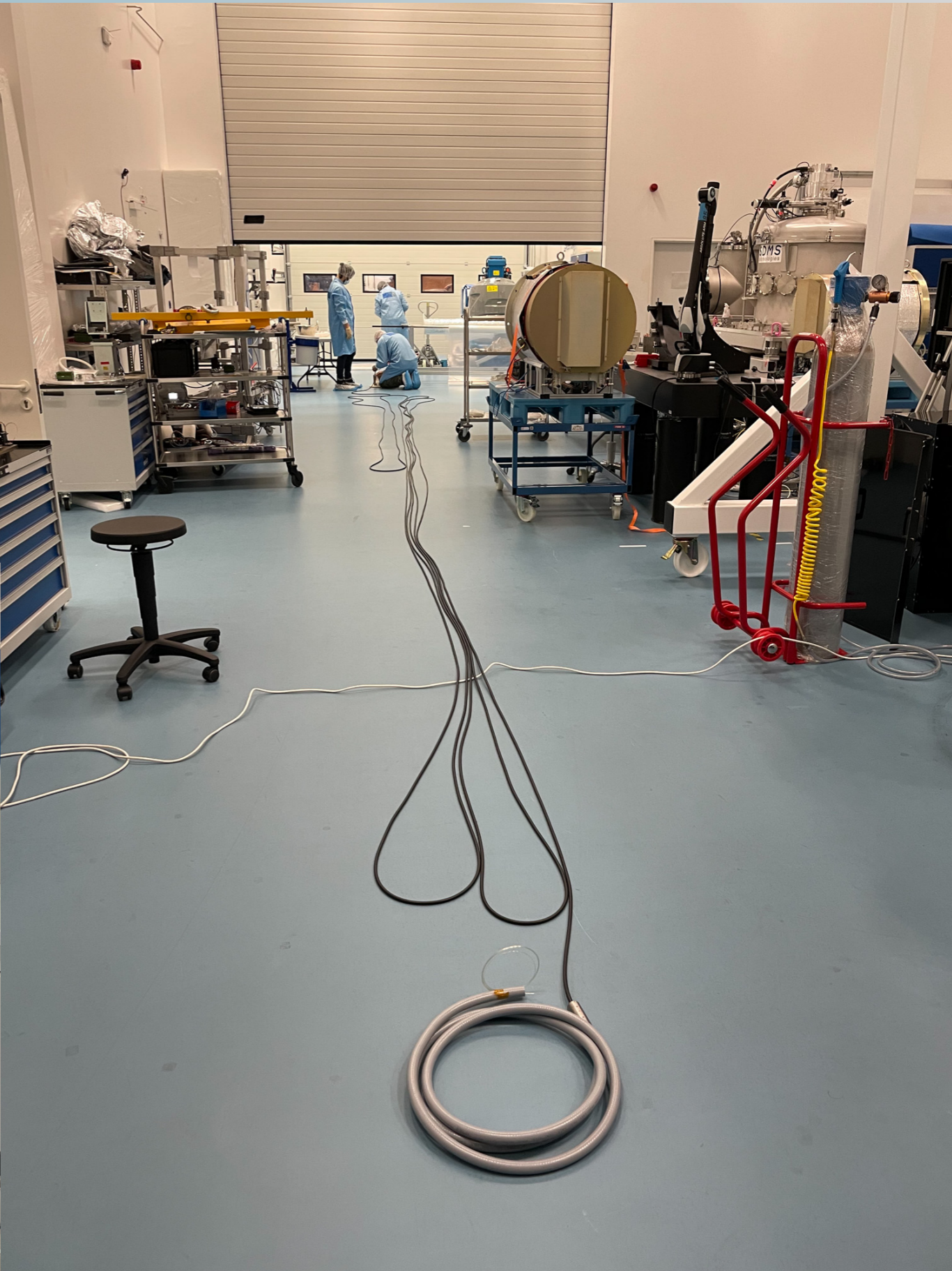


- | | | | |
|--|------------------|--|--------------------|
| | Science fiber | | Feedback fibers |
| | Reference fibers | | AO MMF guide fiber |
| | Dummy fibers | | AO SMF guide fiber |
| | Centering fiber | | Side fibers |

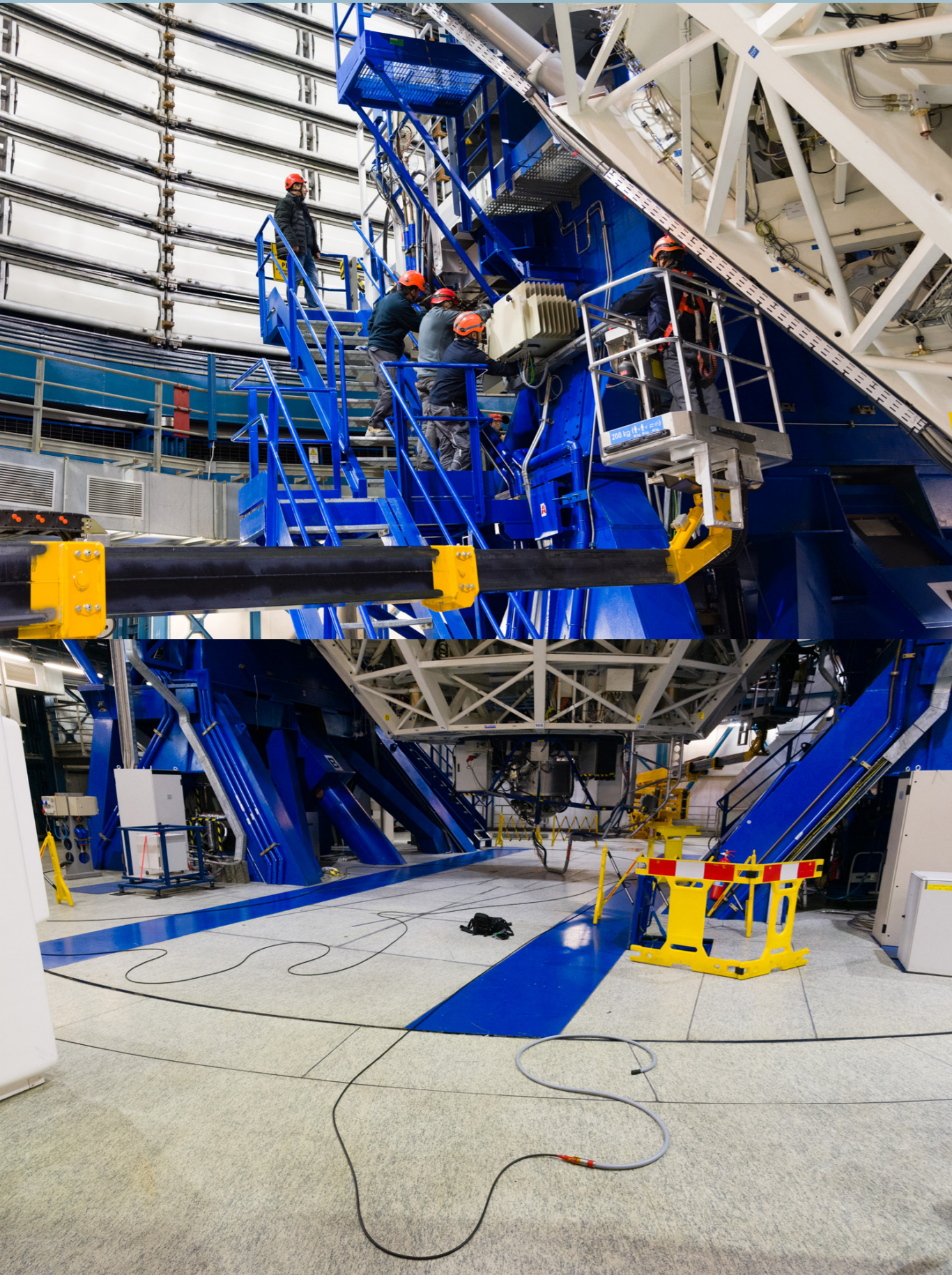
Output geometry
AR coated 800-1850 nm



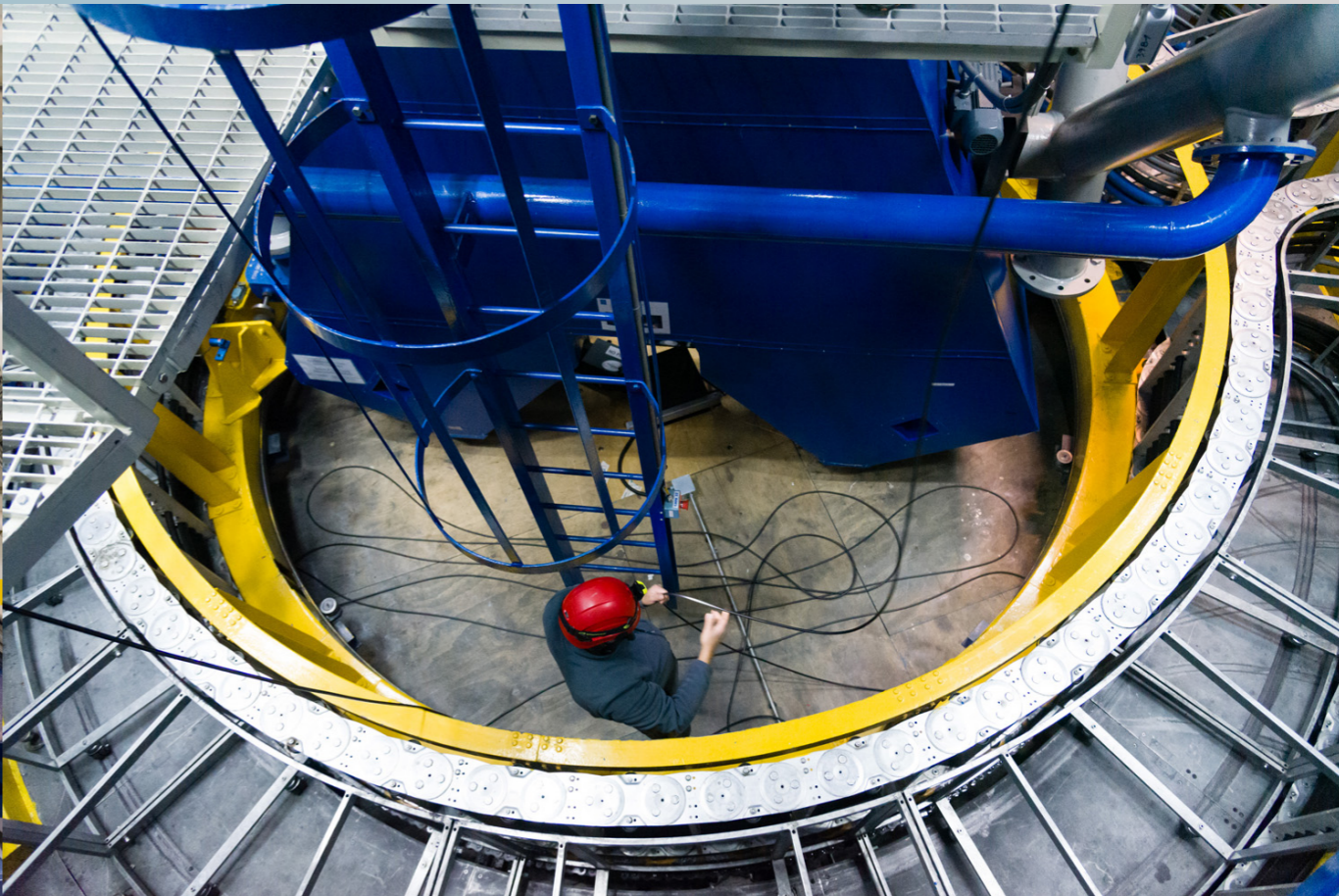
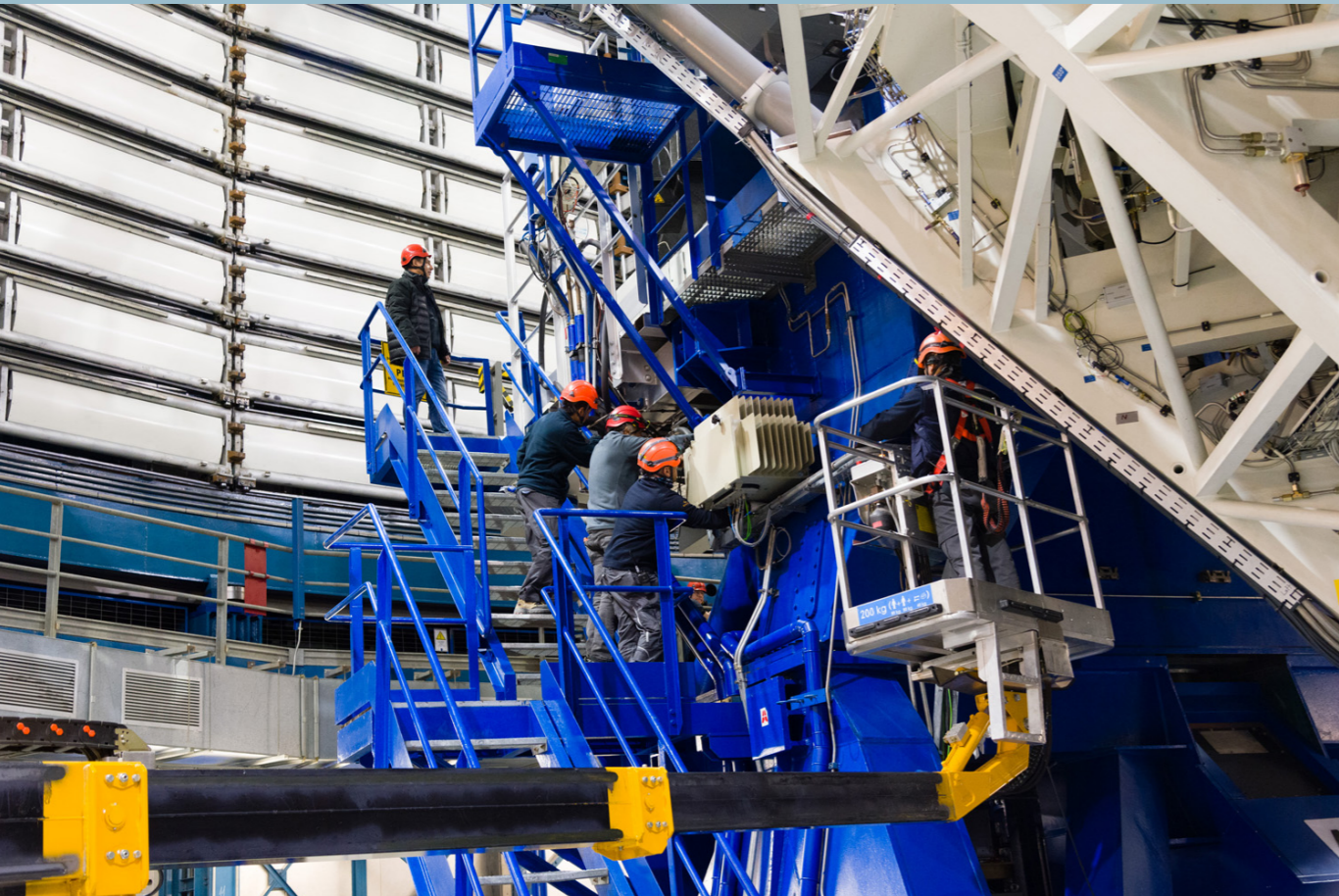
A complex fiber bundle



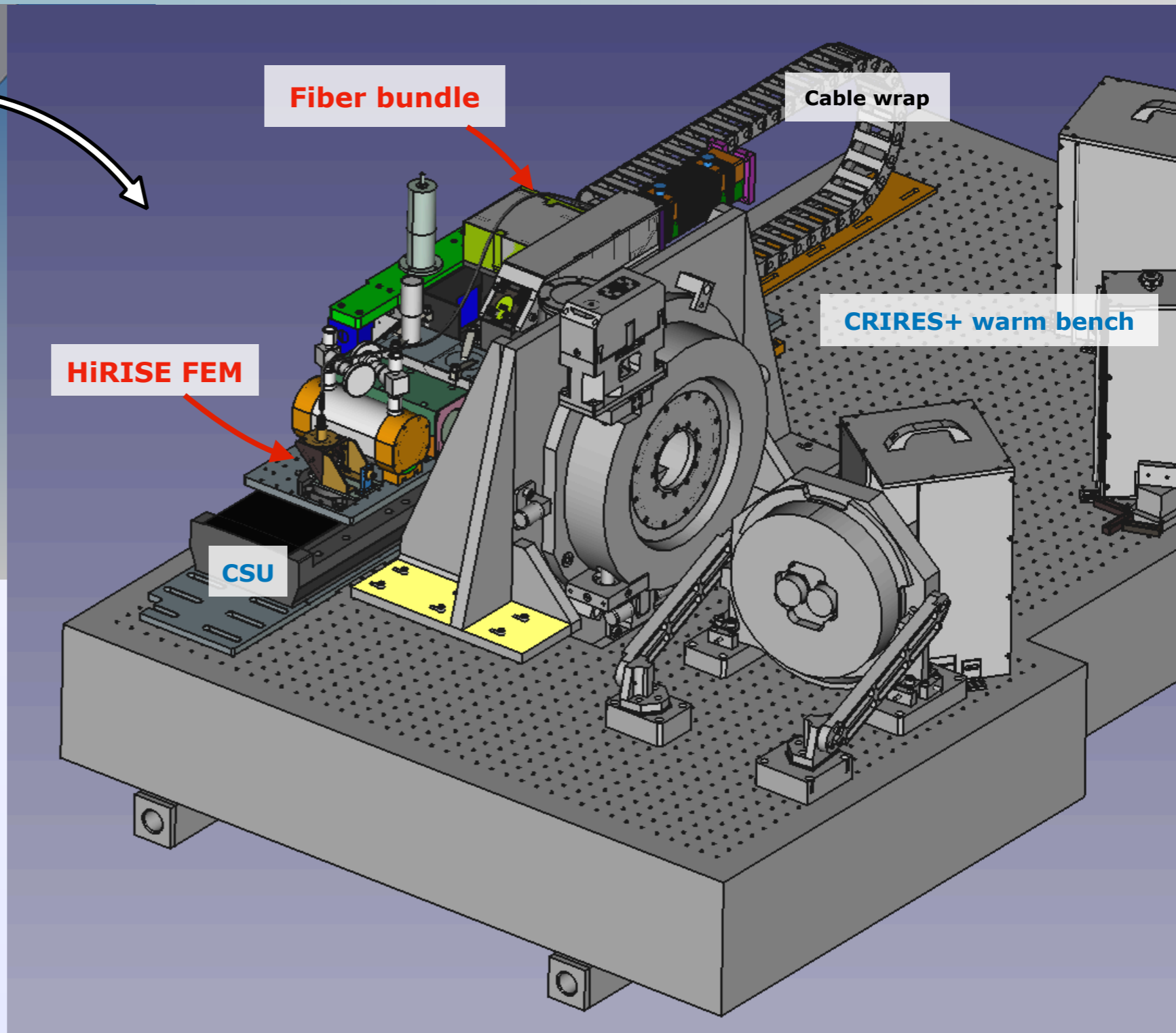
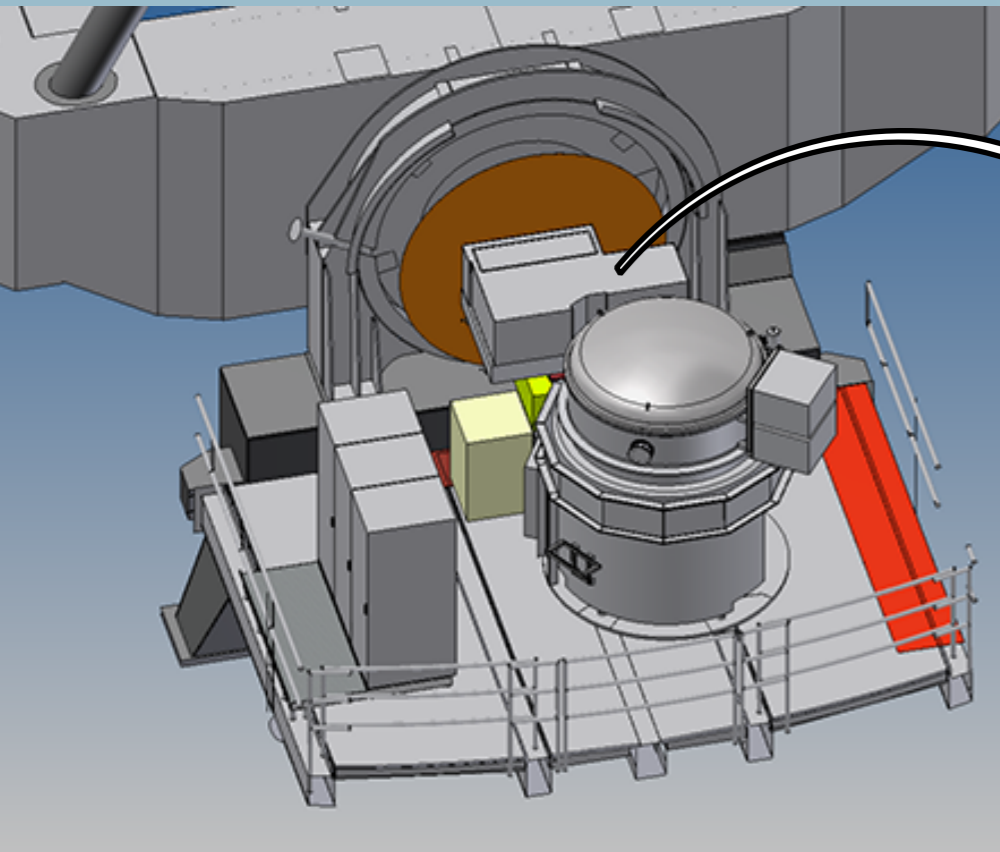
A complex fiber bundle



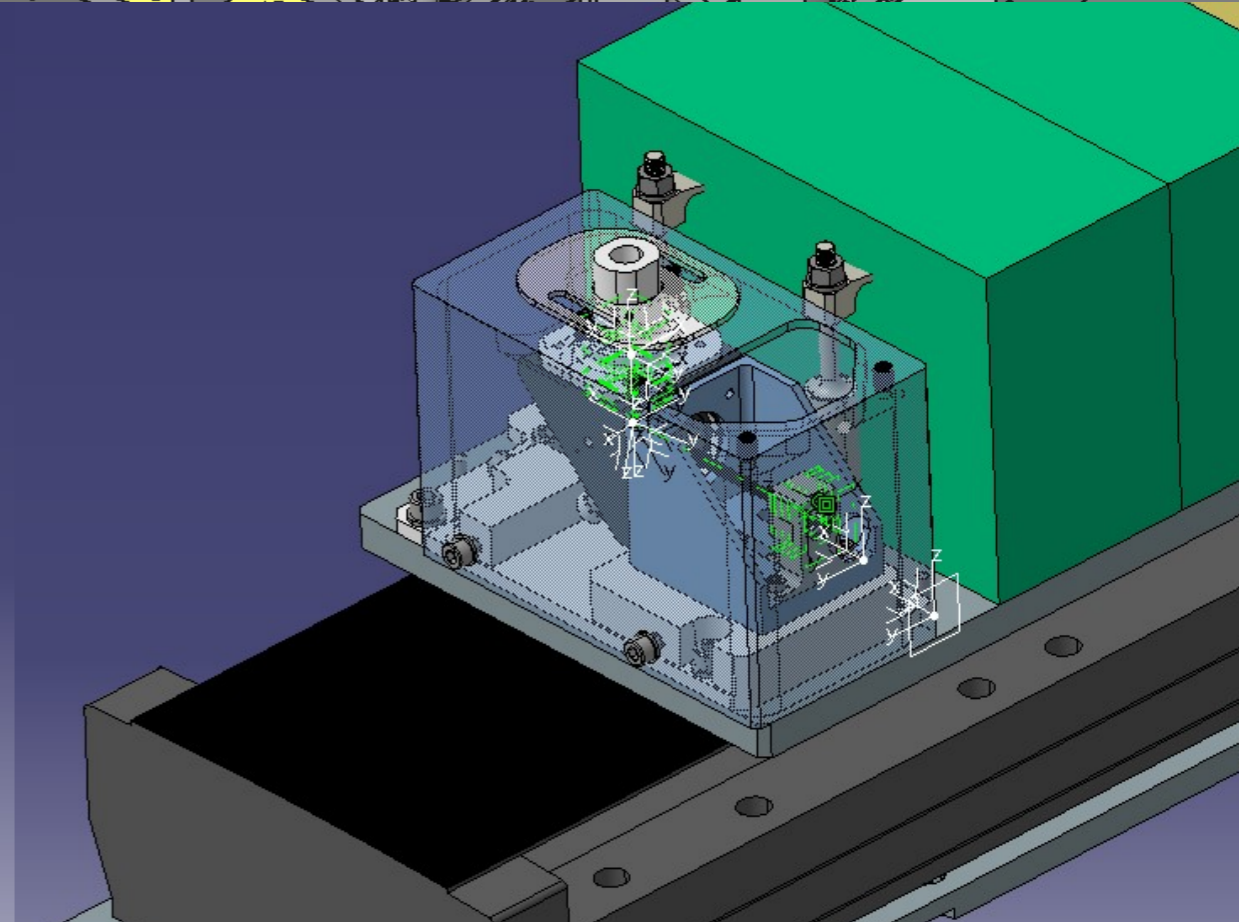
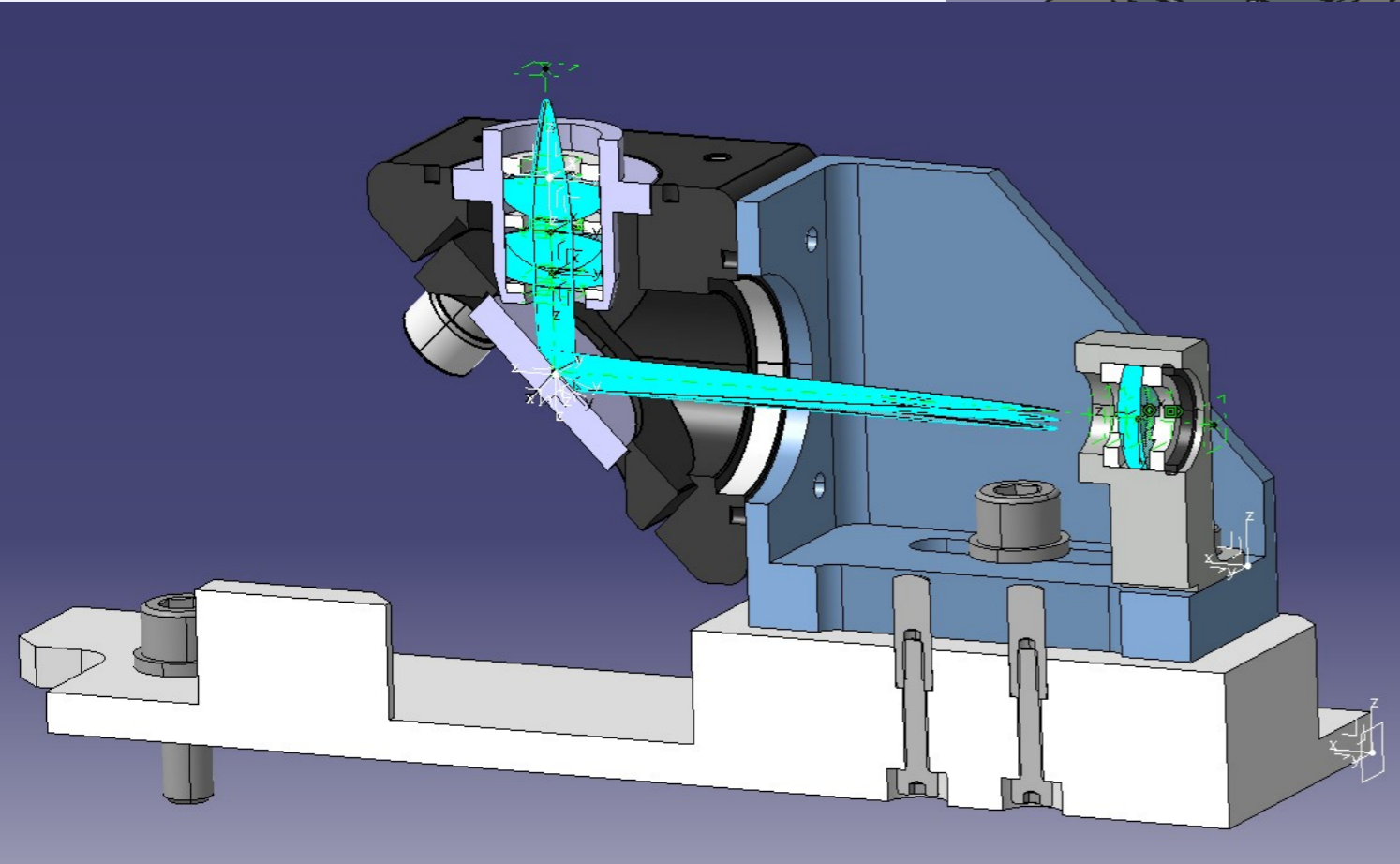
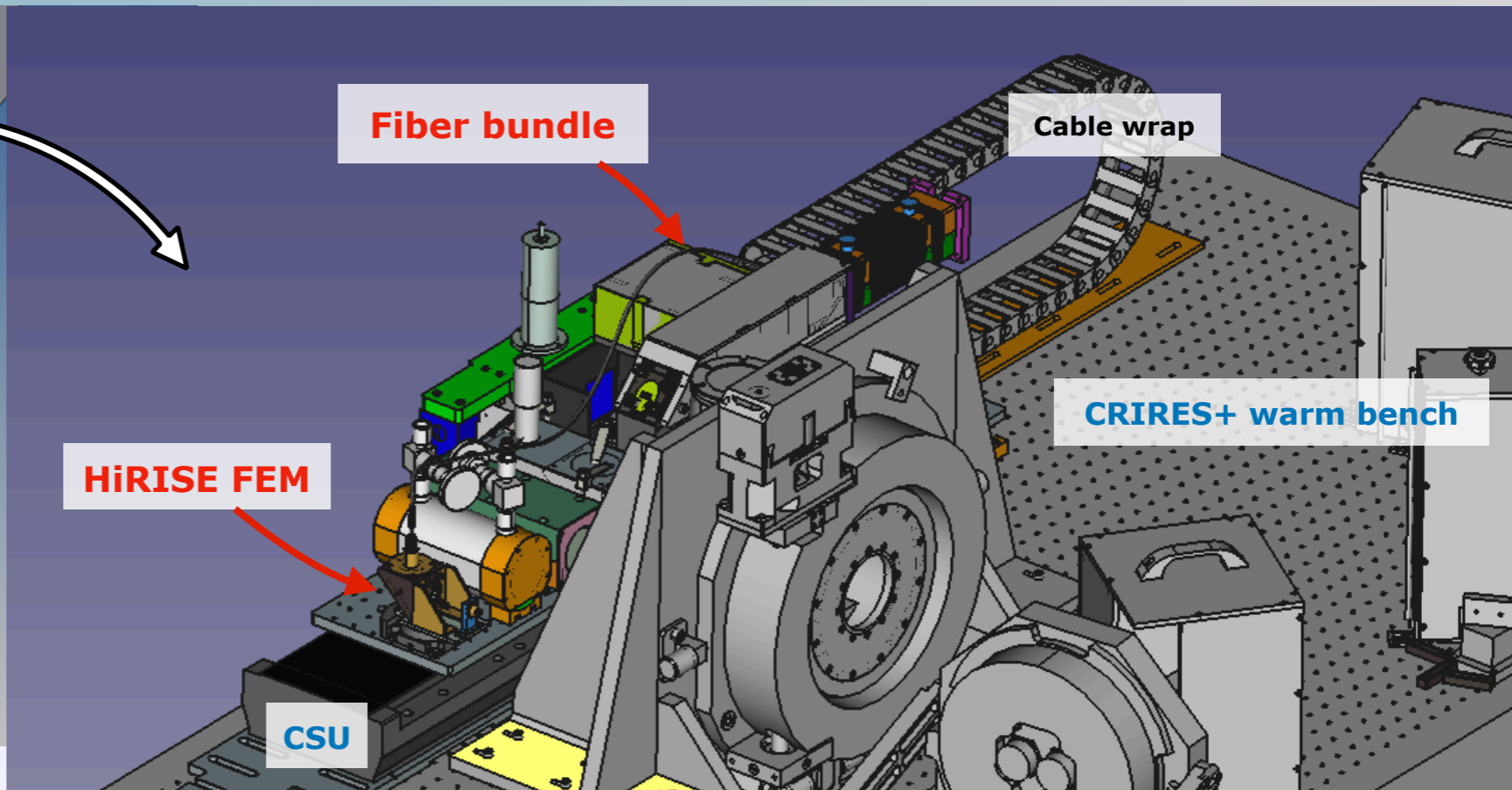
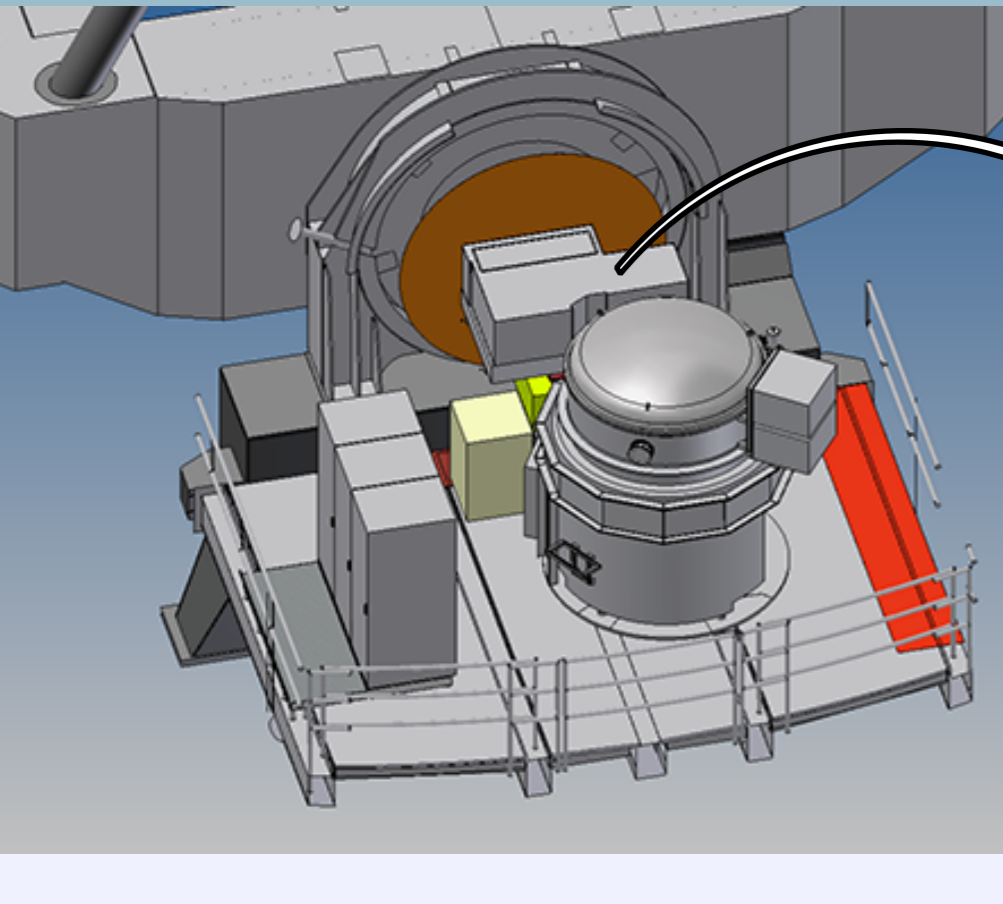
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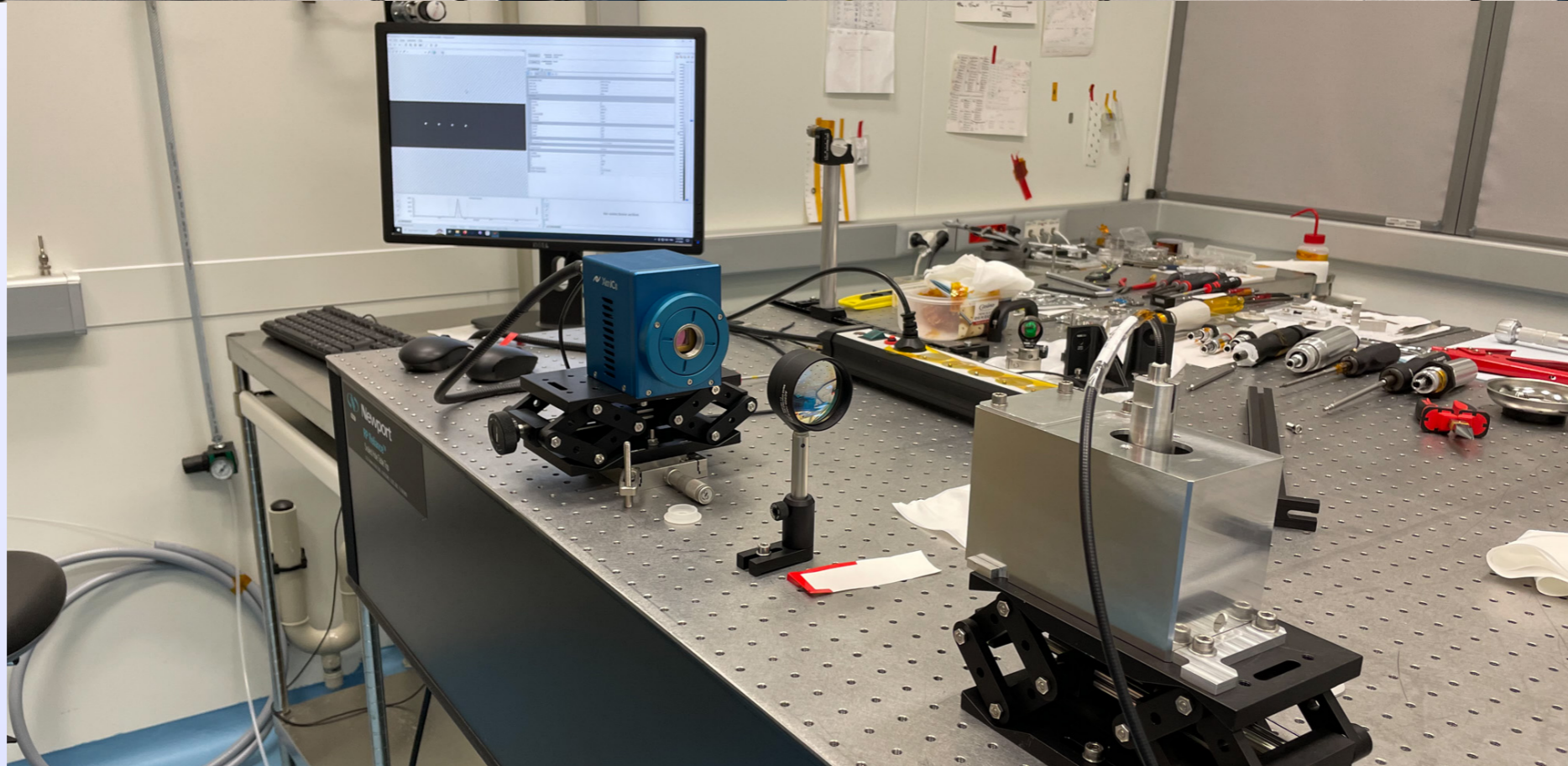
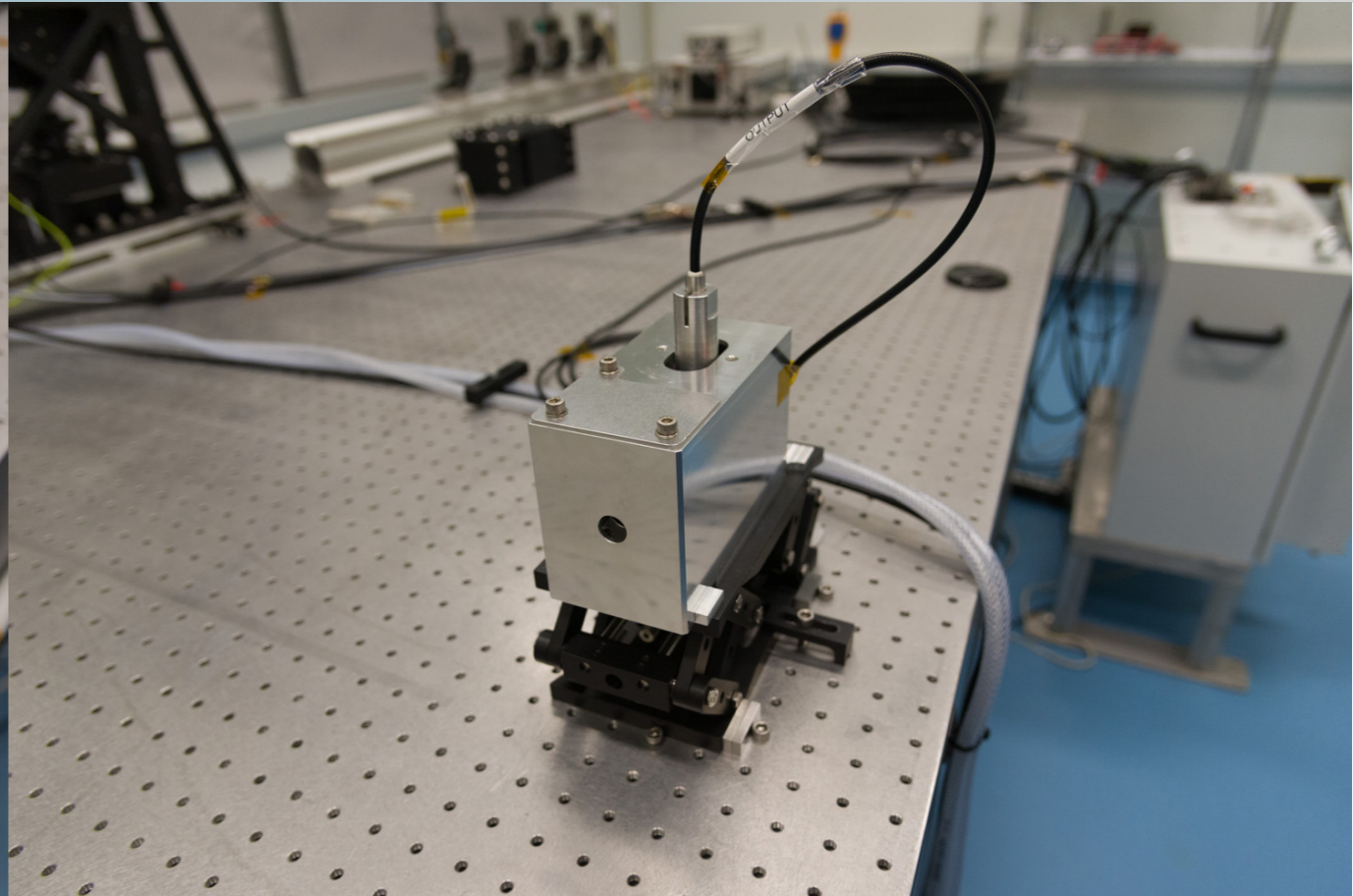
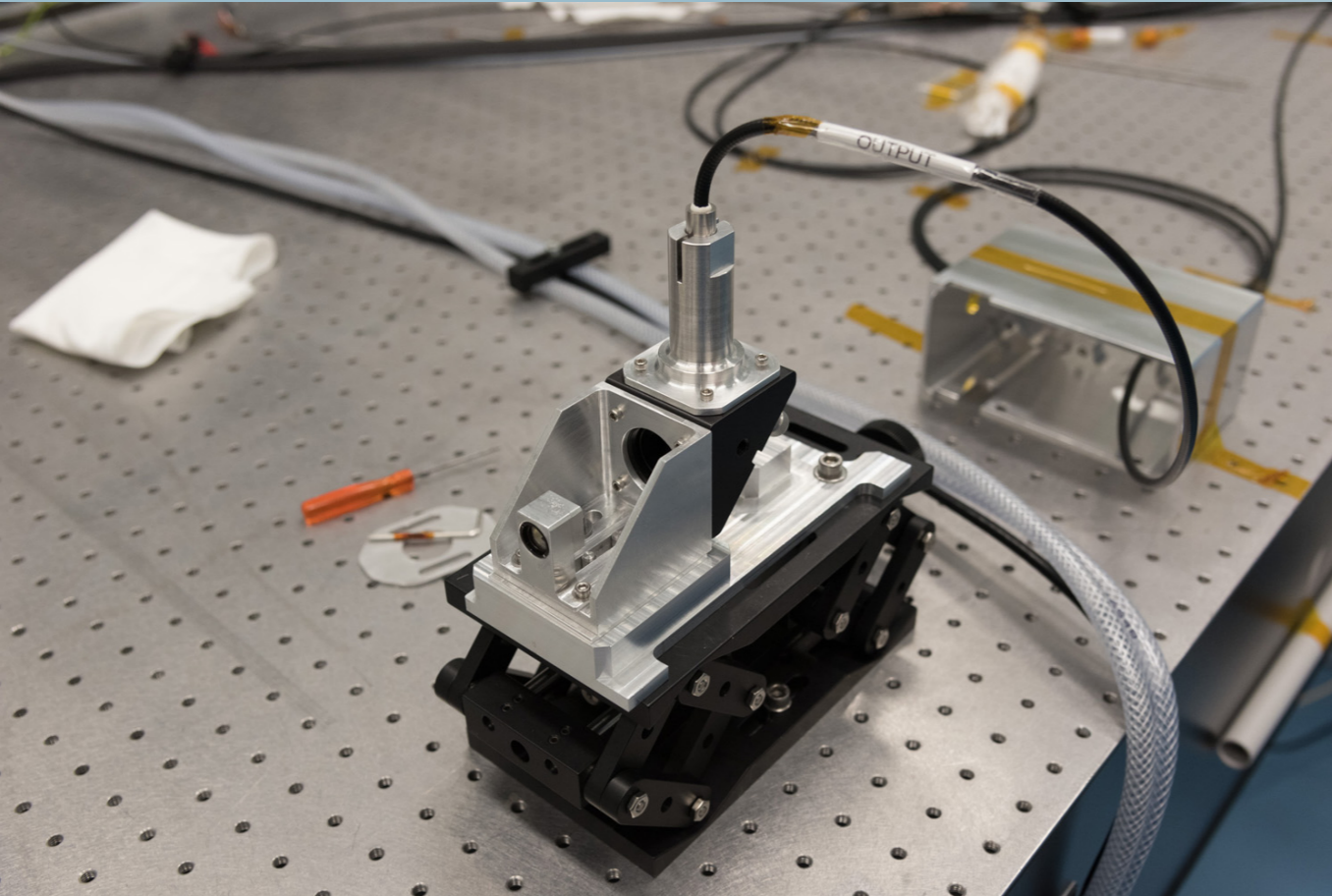
Fiber extraction module



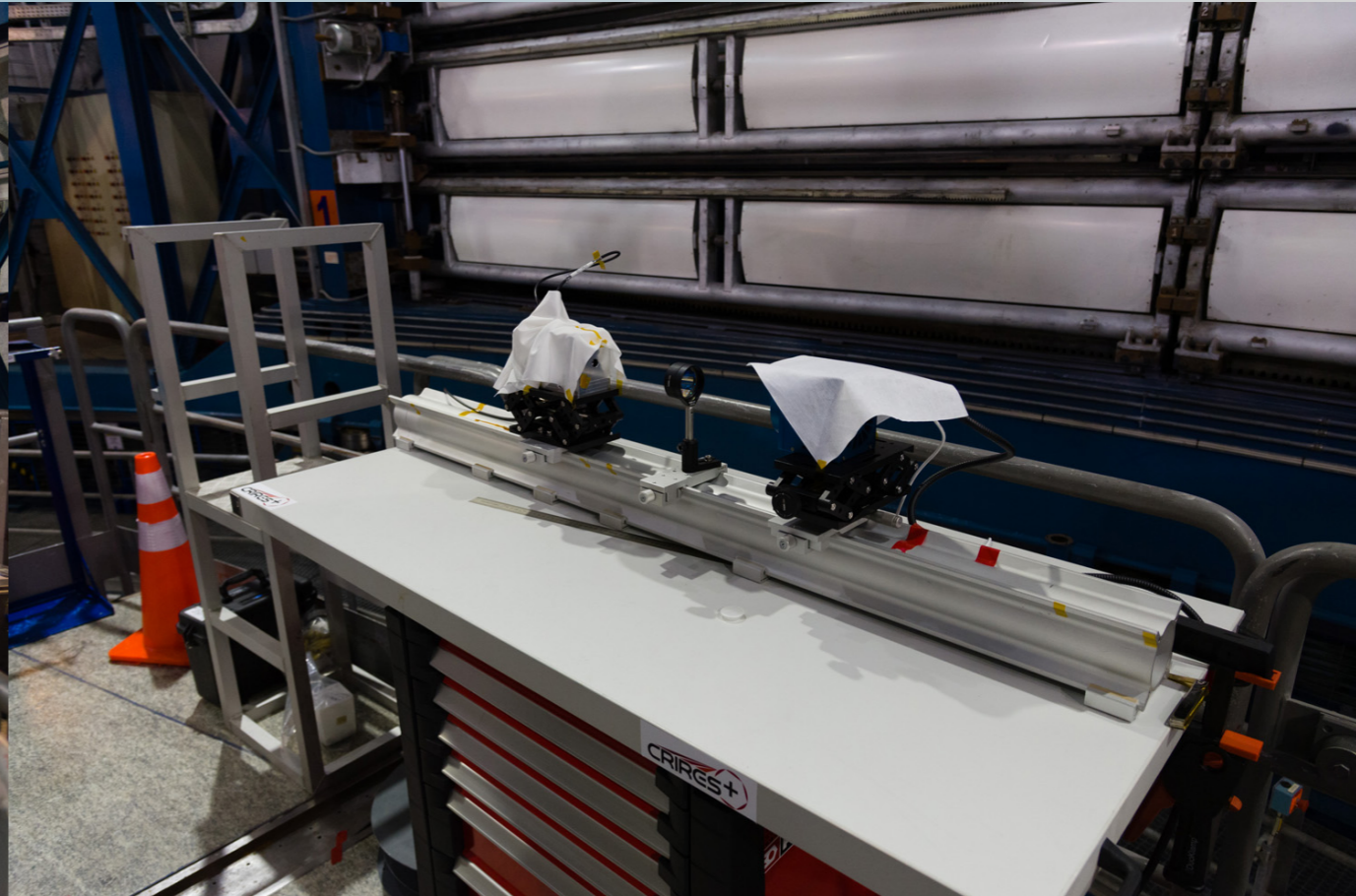
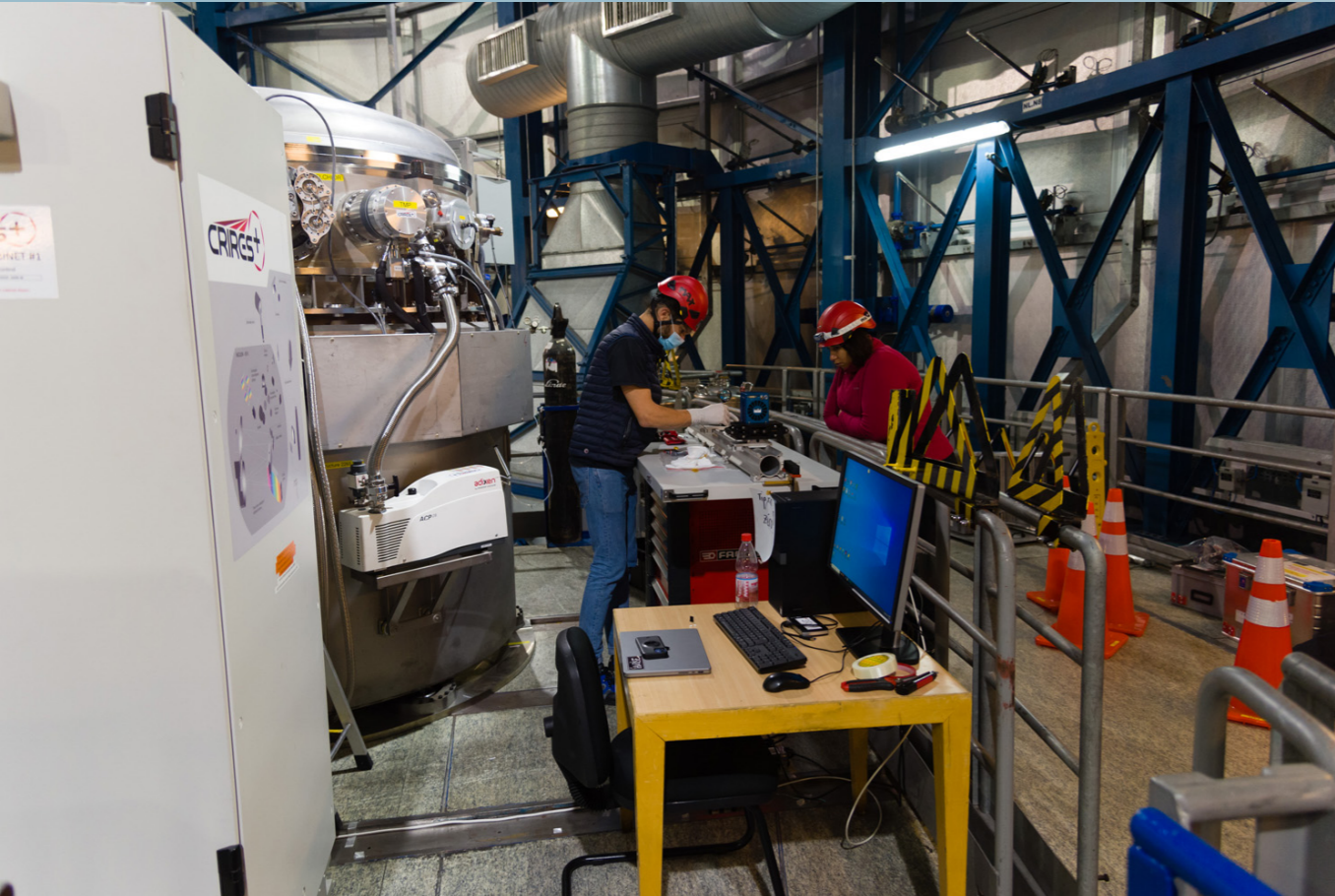
Fiber extraction module



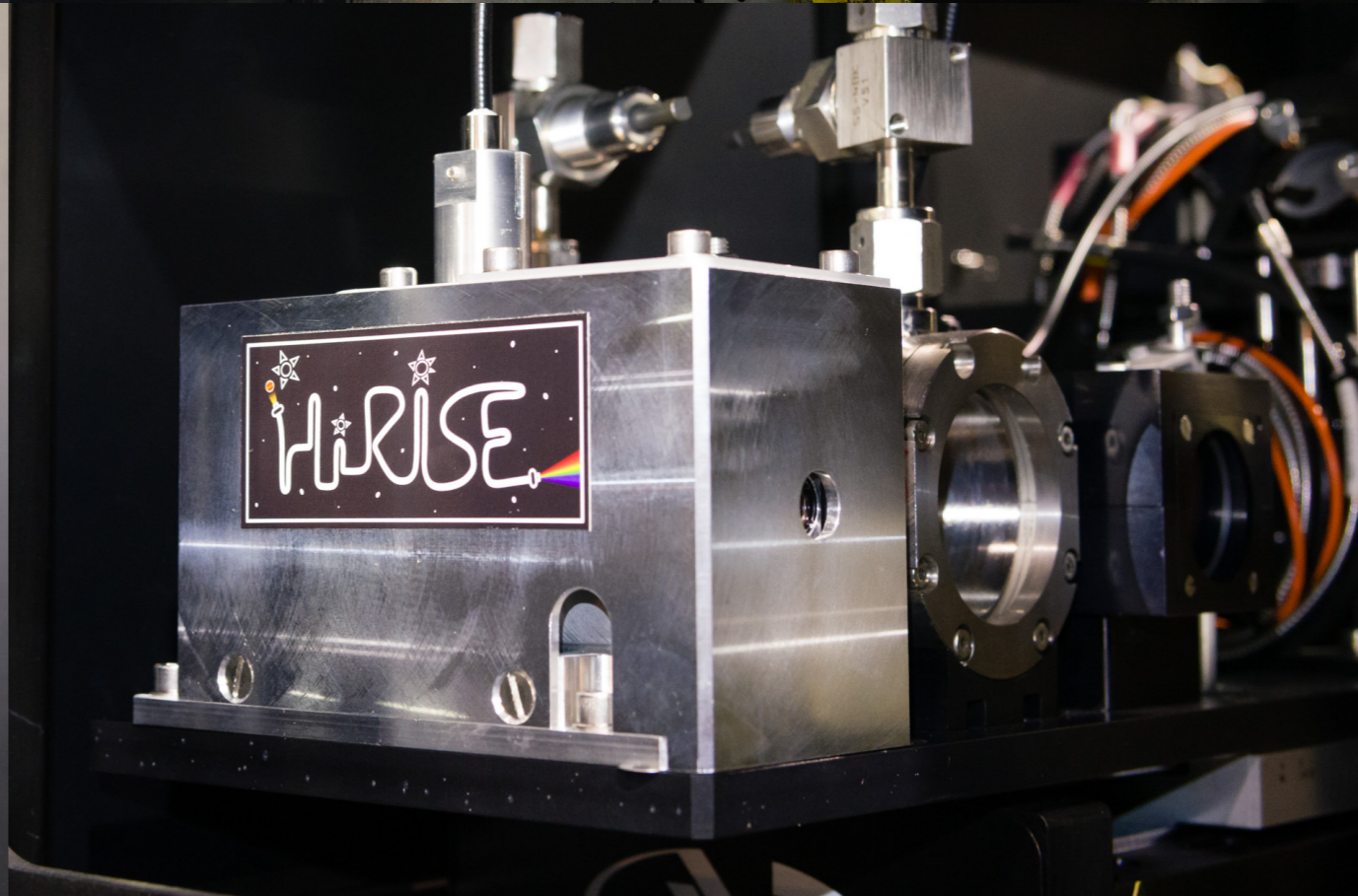
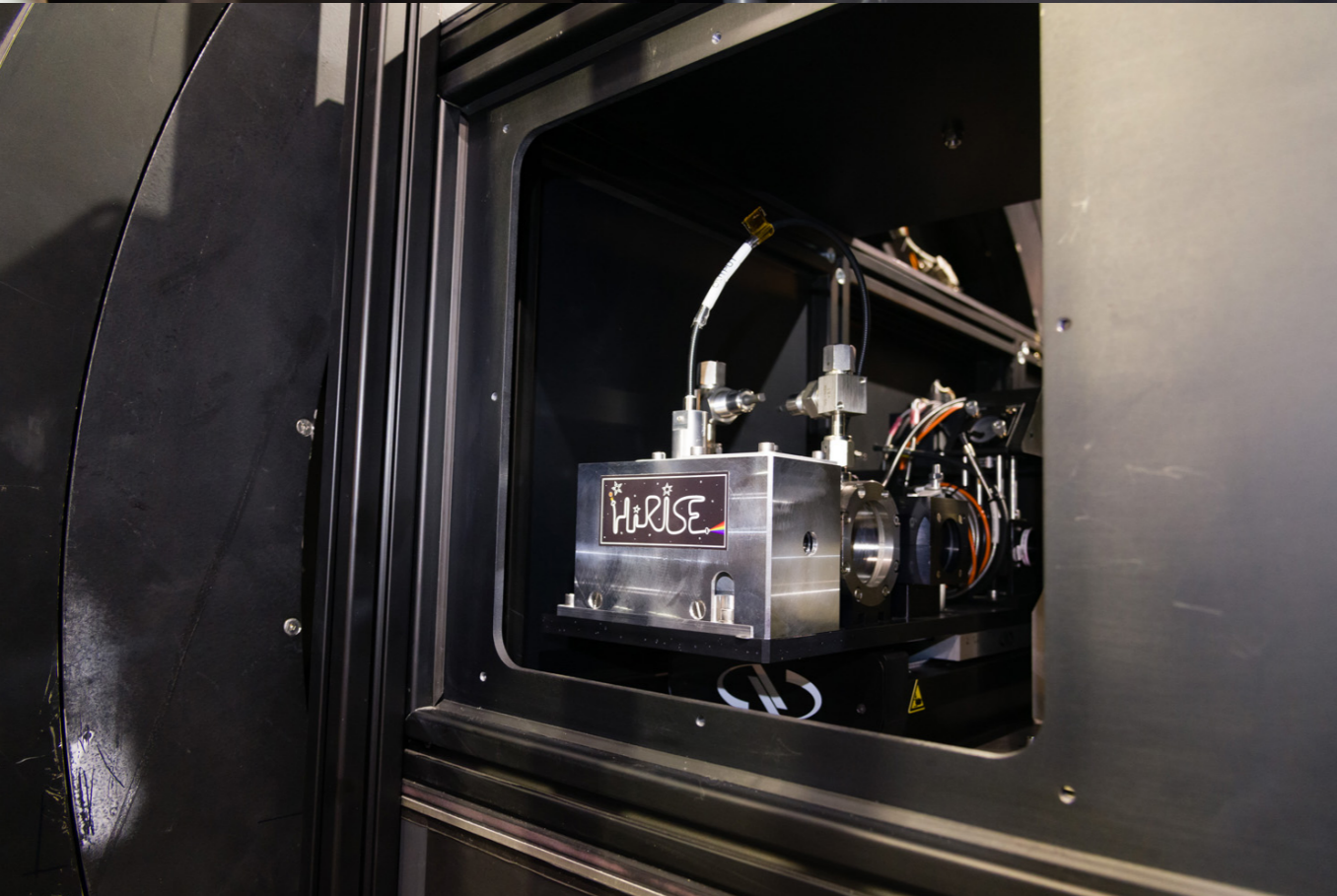
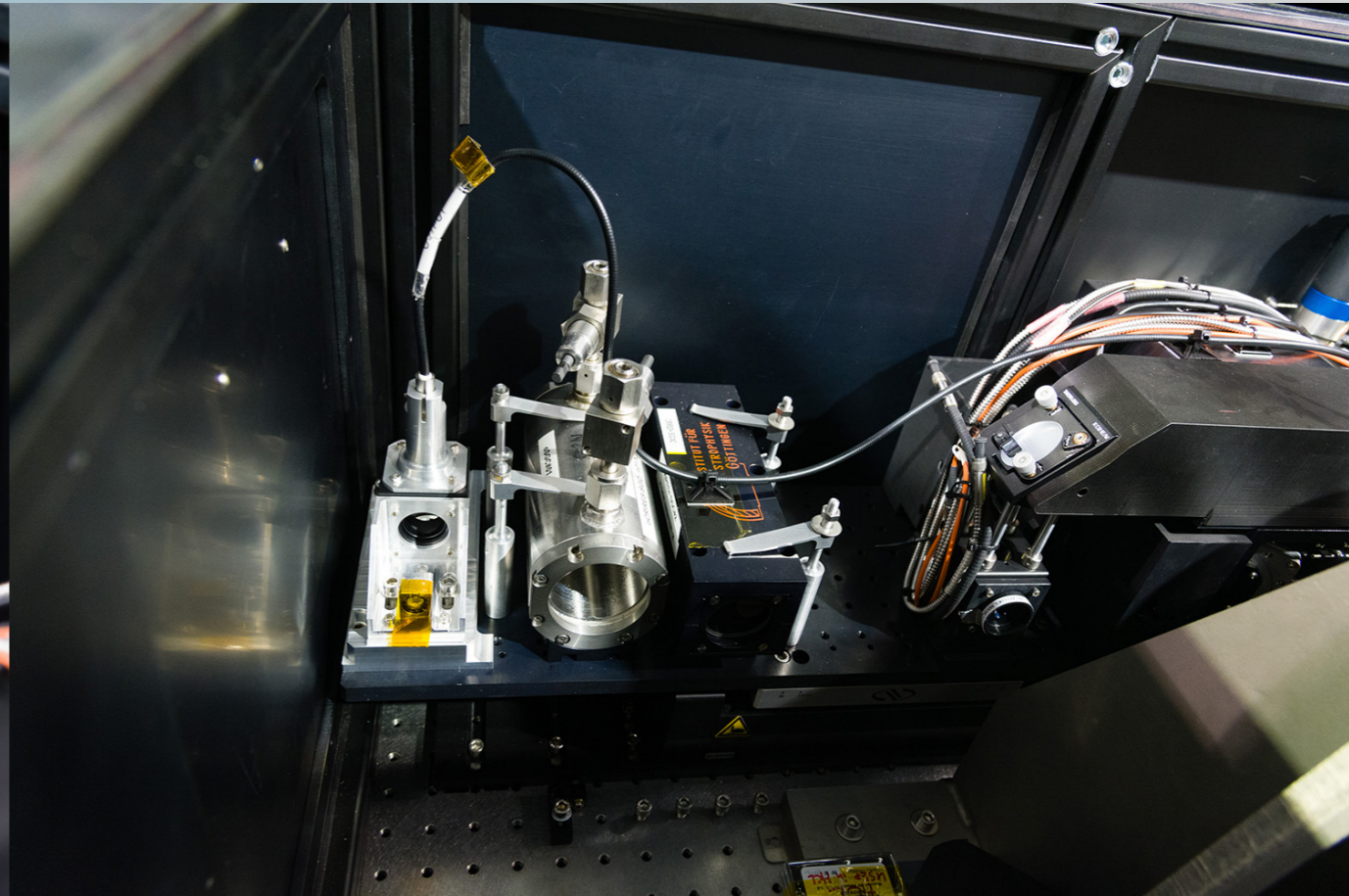
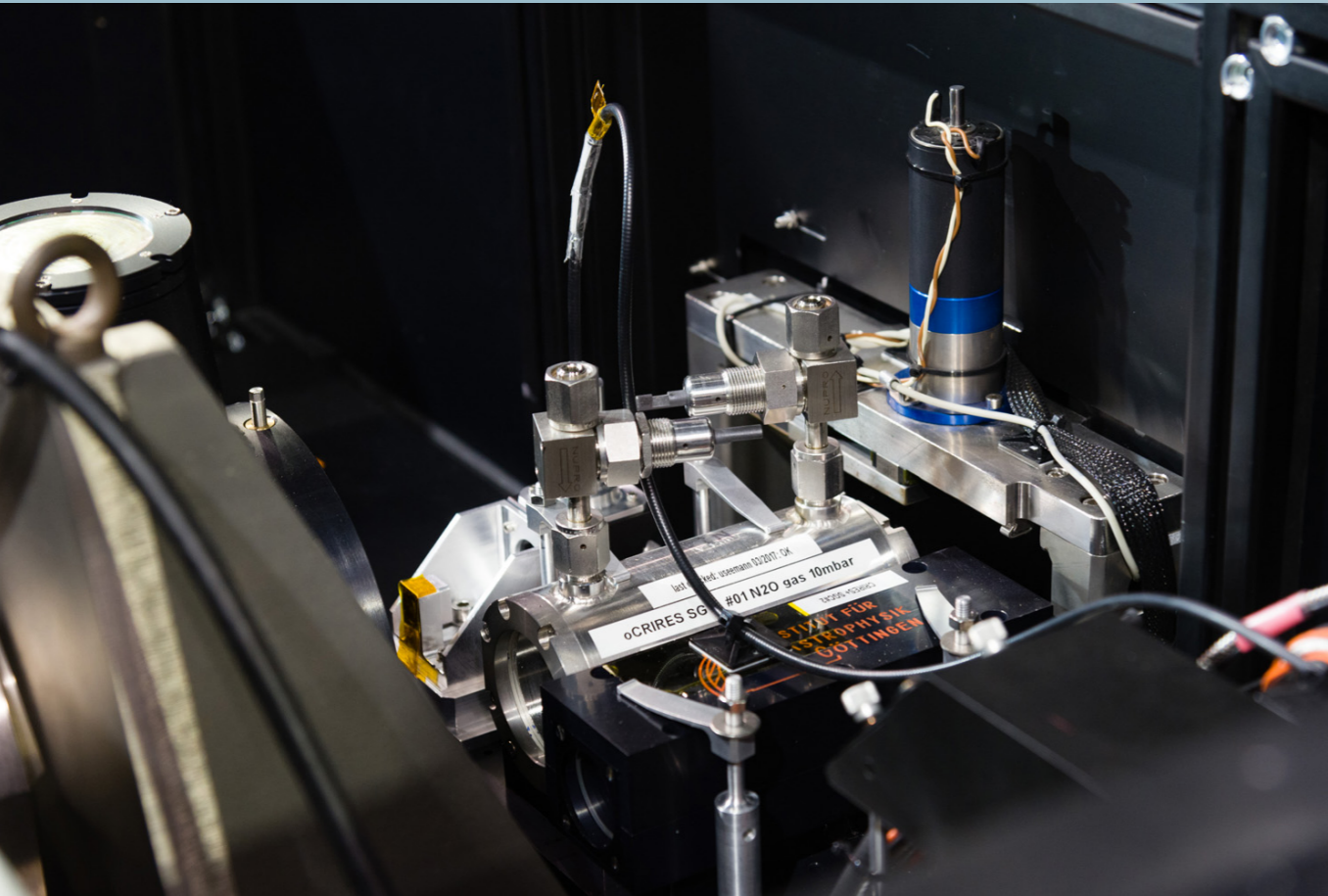
Fiber extraction module



Fiber extraction module

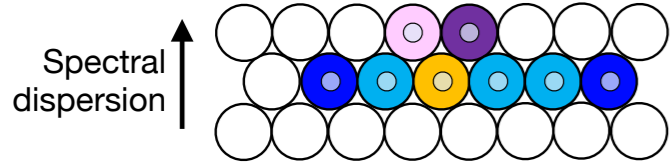


Fiber extraction module

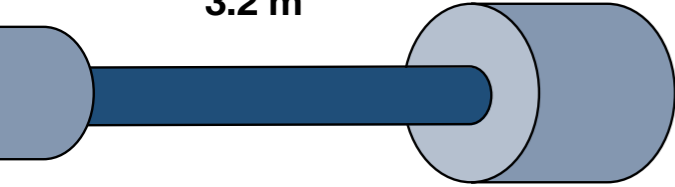


Light into the CRIRES spectrograph

Output geometry
AR coated 800-1850 nm



CRIRES+
3.2 m

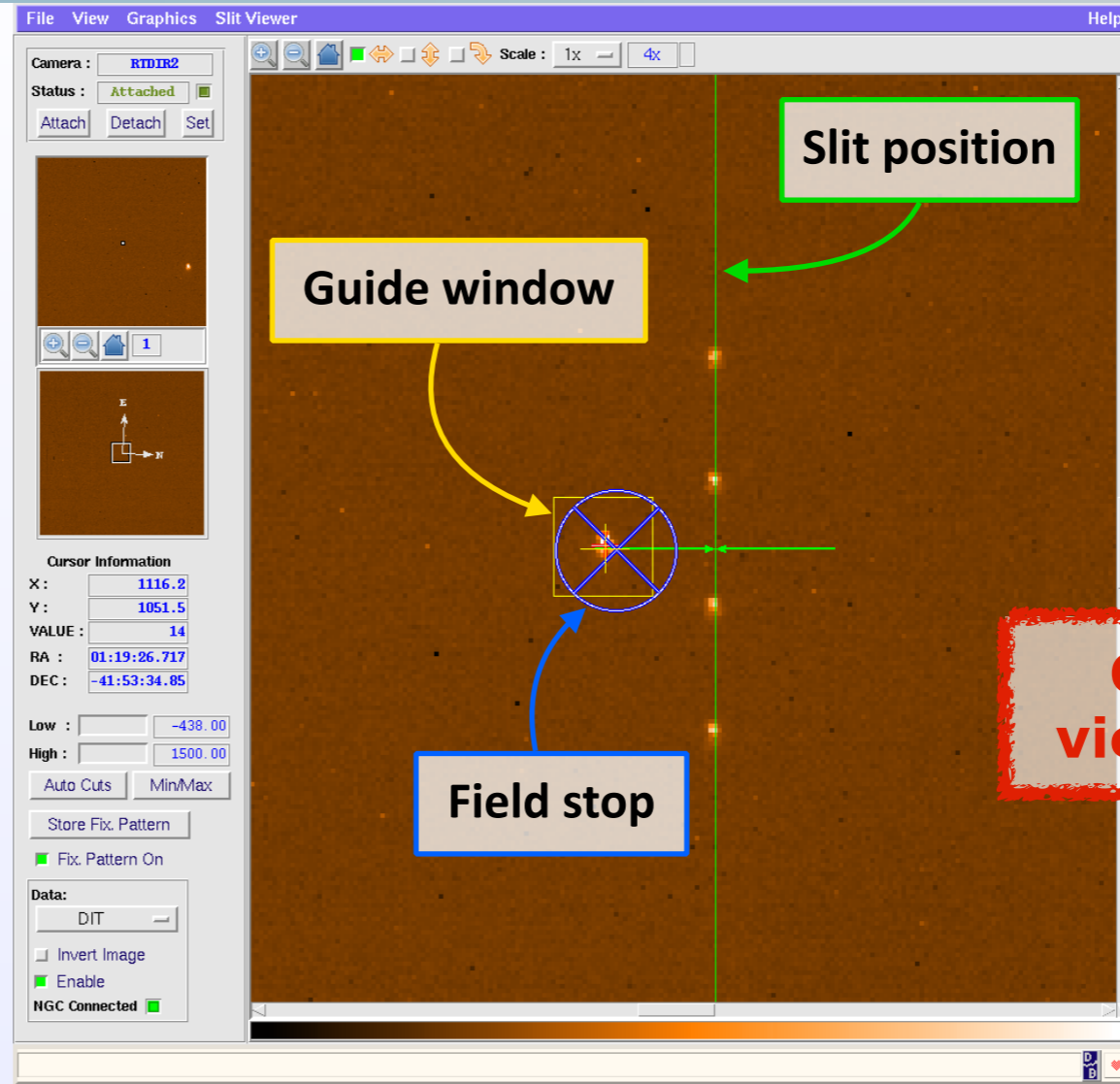
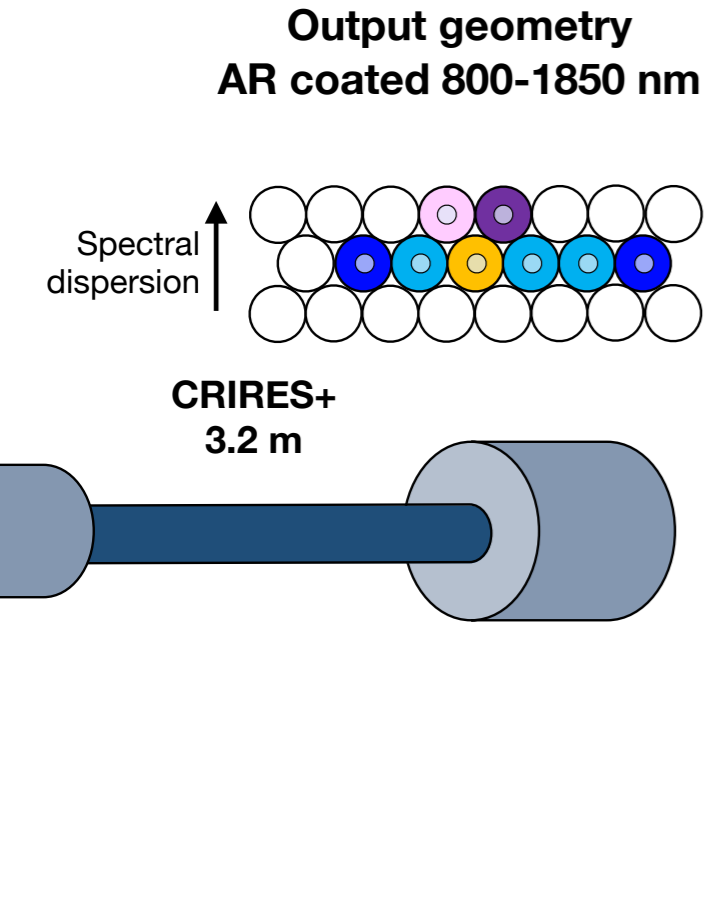


The screenshot shows the 'CRIRES slit viewer camera' software interface. The main window displays a large, dark brown image of the spectrograph's output. On the left side, there is a control panel with the following elements:

- Camera: RTDIR2
- Status: Attached
- Buttons: Attach, Detach, Set
- Cursor Information:
 - X: 1093.0
 - Y: 945.5
 - VALUE: 20
 - RA: 01:19:26.978
 - DEC: -41:53:33.84
- Low: -438.00
- High: 1500.00
- Buttons: Auto Cuts, Min/Max
- Store Fix. Pattern
- Fix. Pattern On (checked)
- Data: DIT
- Invert Image (unchecked)
- Enable (checked)
- NGC Connected (checked)

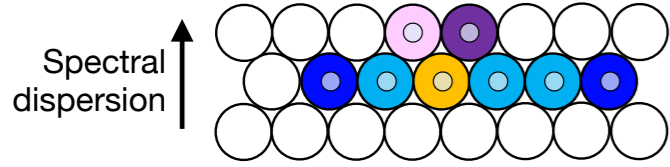
CRIRES slit viewer camera

Light into the CRIRES spectrograph

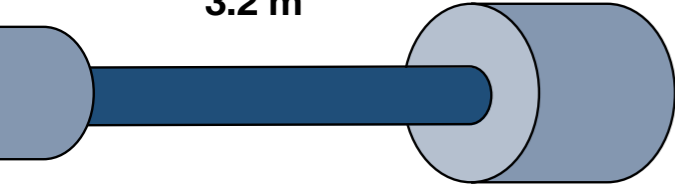


Light into the CRIRES spectrograph

Output geometry
AR coated 800-1850 nm



CRIRES+
3.2 m



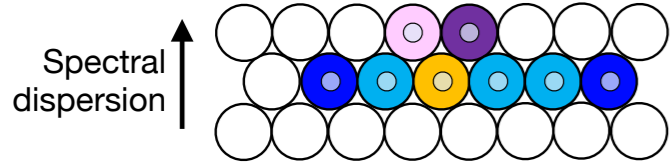
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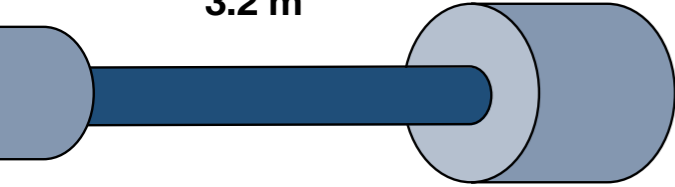
CRIRES slit viewer camera

Light into the CRIRES spectrograph

Output geometry
AR coated 800-1850 nm



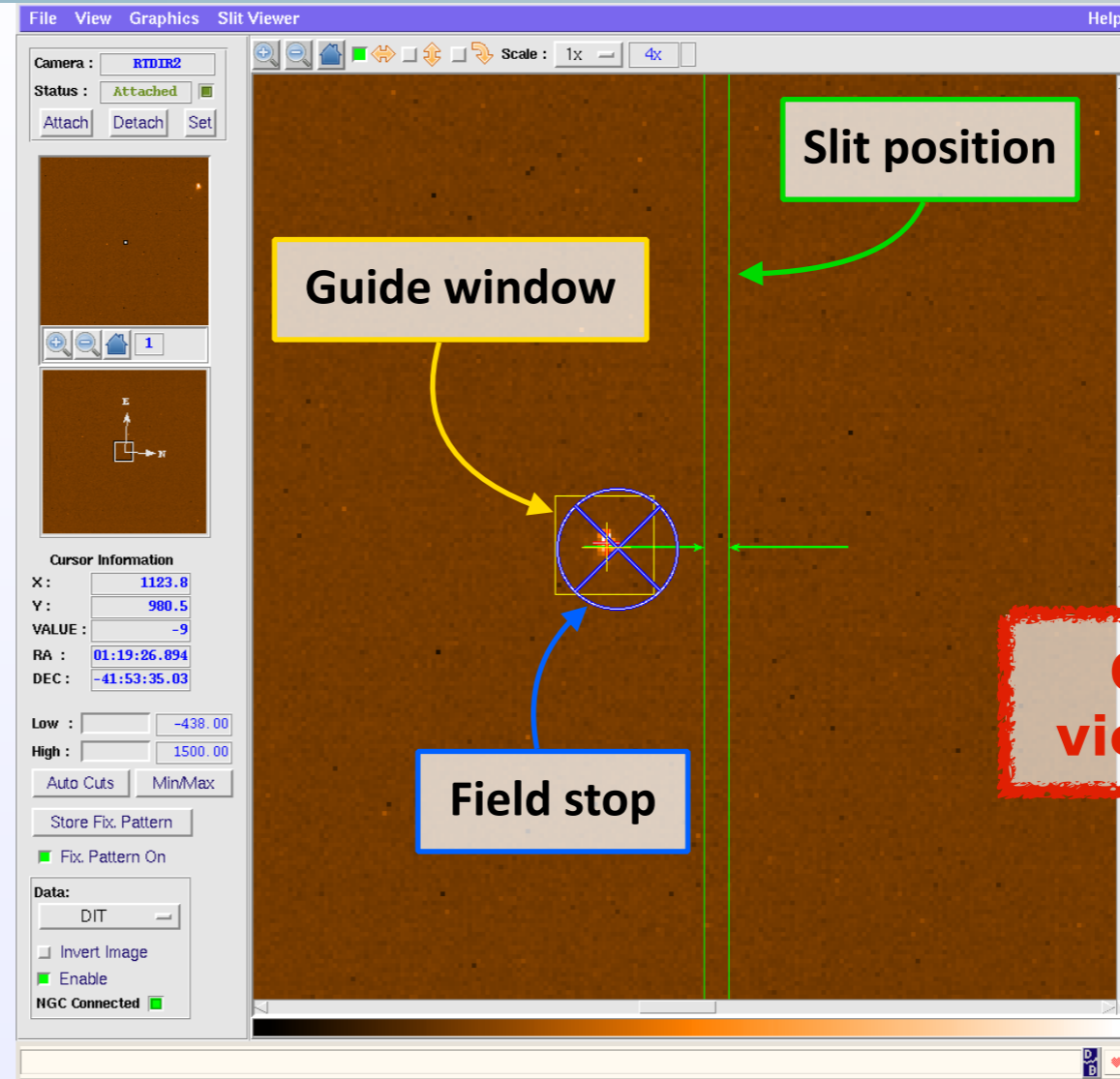
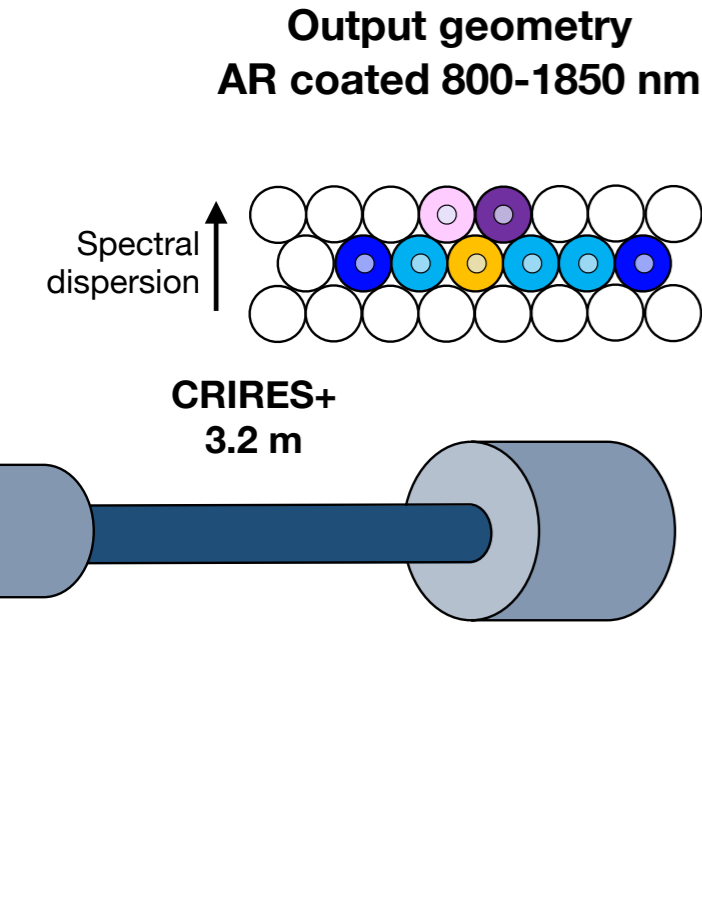
CRIRES+
3.2 m



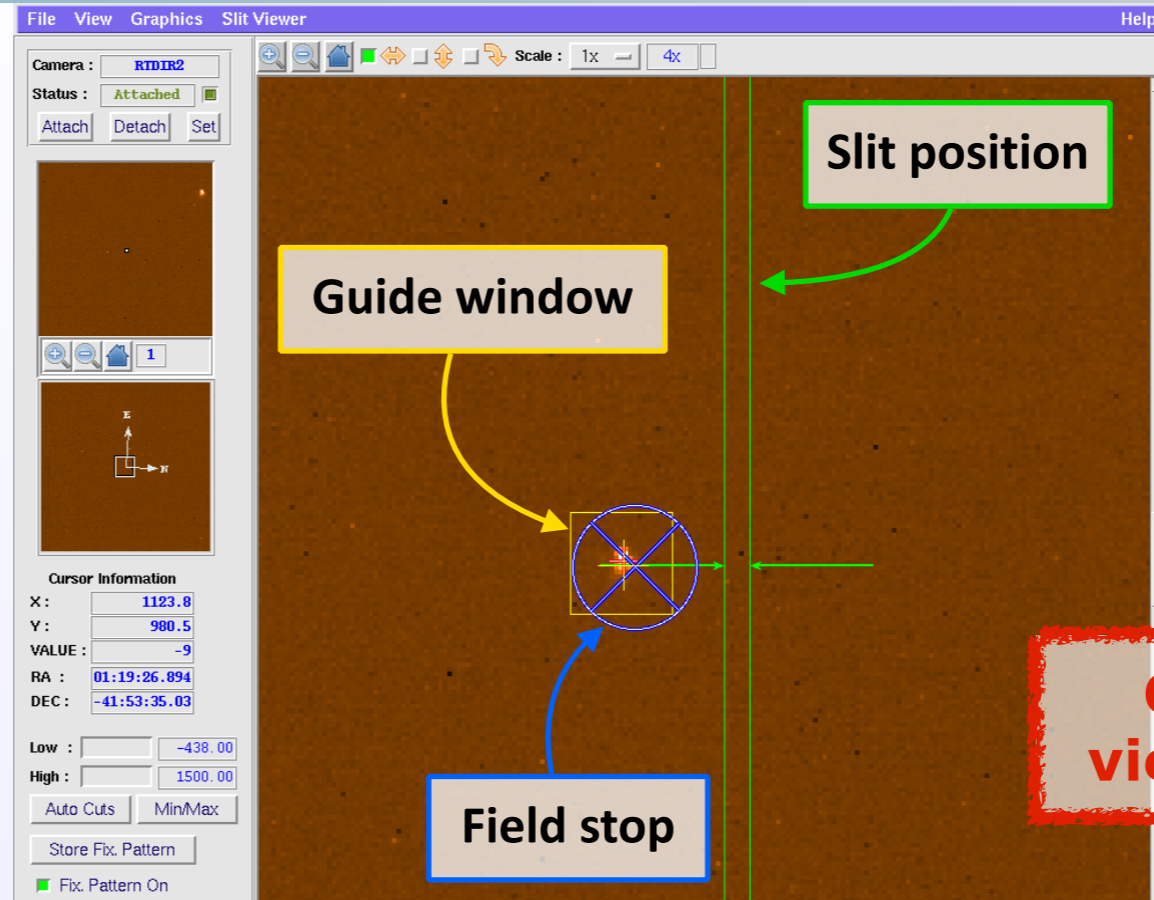
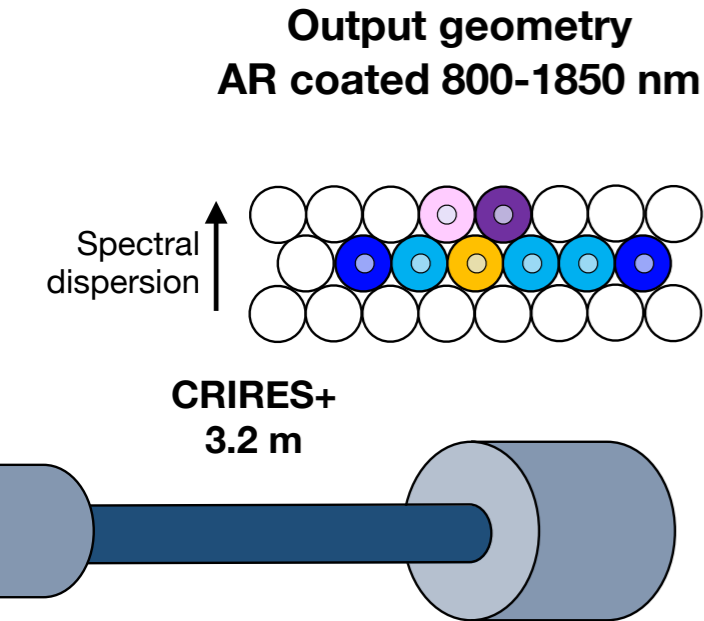
The screenshot shows the 'Slit Viewer' software interface. The main window displays a dark brown field with a bright orange star. The interface includes a menu bar (File, View, Graphics, Slit Viewer, Help), a camera status panel (Camera: RTDIR2, Status: Attached), and a control panel with buttons for Attach, Detach, and Set. A cursor information panel shows X: 1070.0, Y: 1064.2, VALUE: 45, RA: 01:19:26.681, and DEC: -41:53:33.14. There are also input fields for Low and High values, and checkboxes for 'Fix. Pattern On', 'Invert Image', and 'NGC Connected'. A red box on the right side of the image contains the text 'CRIRES slit viewer camera'.

CRIRES slit
viewer camera

Light into the CRIRES spectrograph

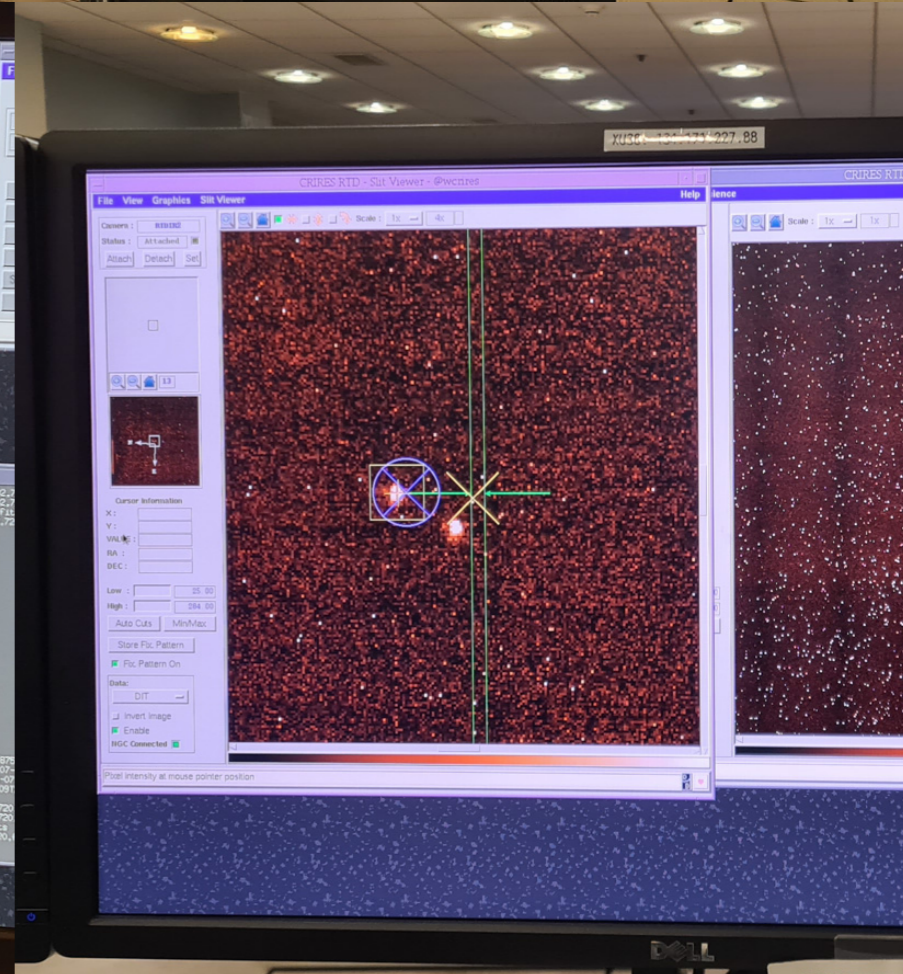
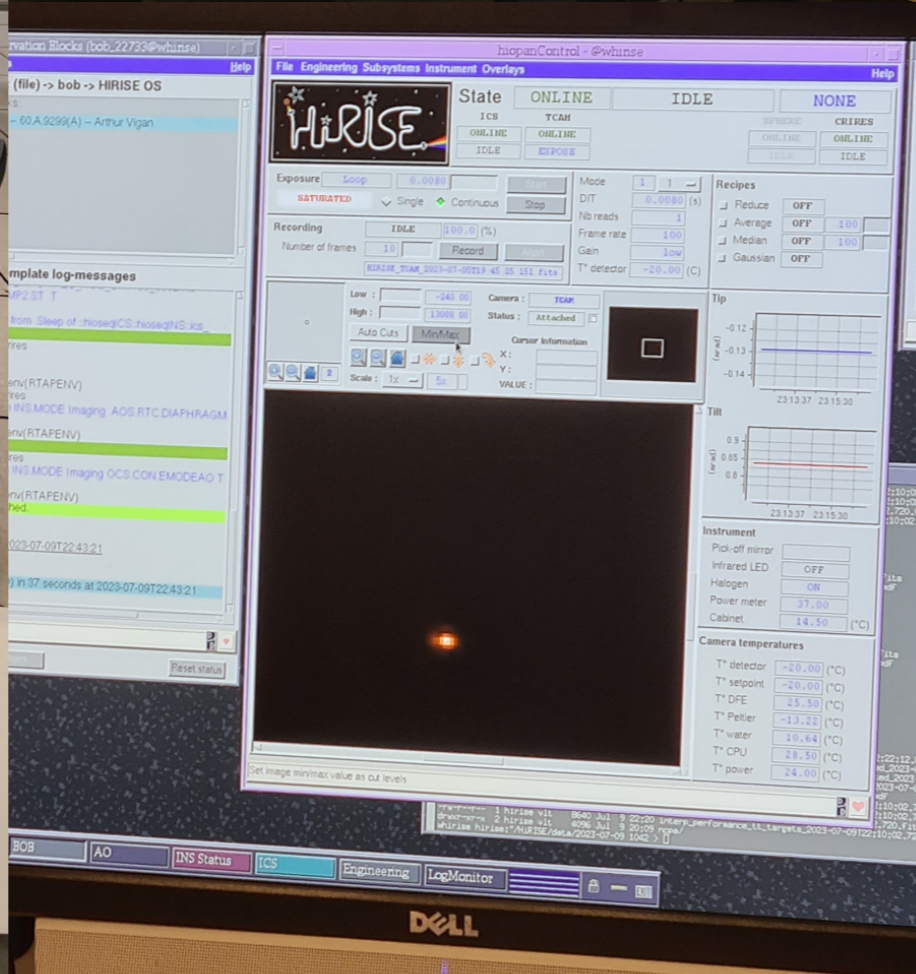


Light into the CRIRES spectrograph

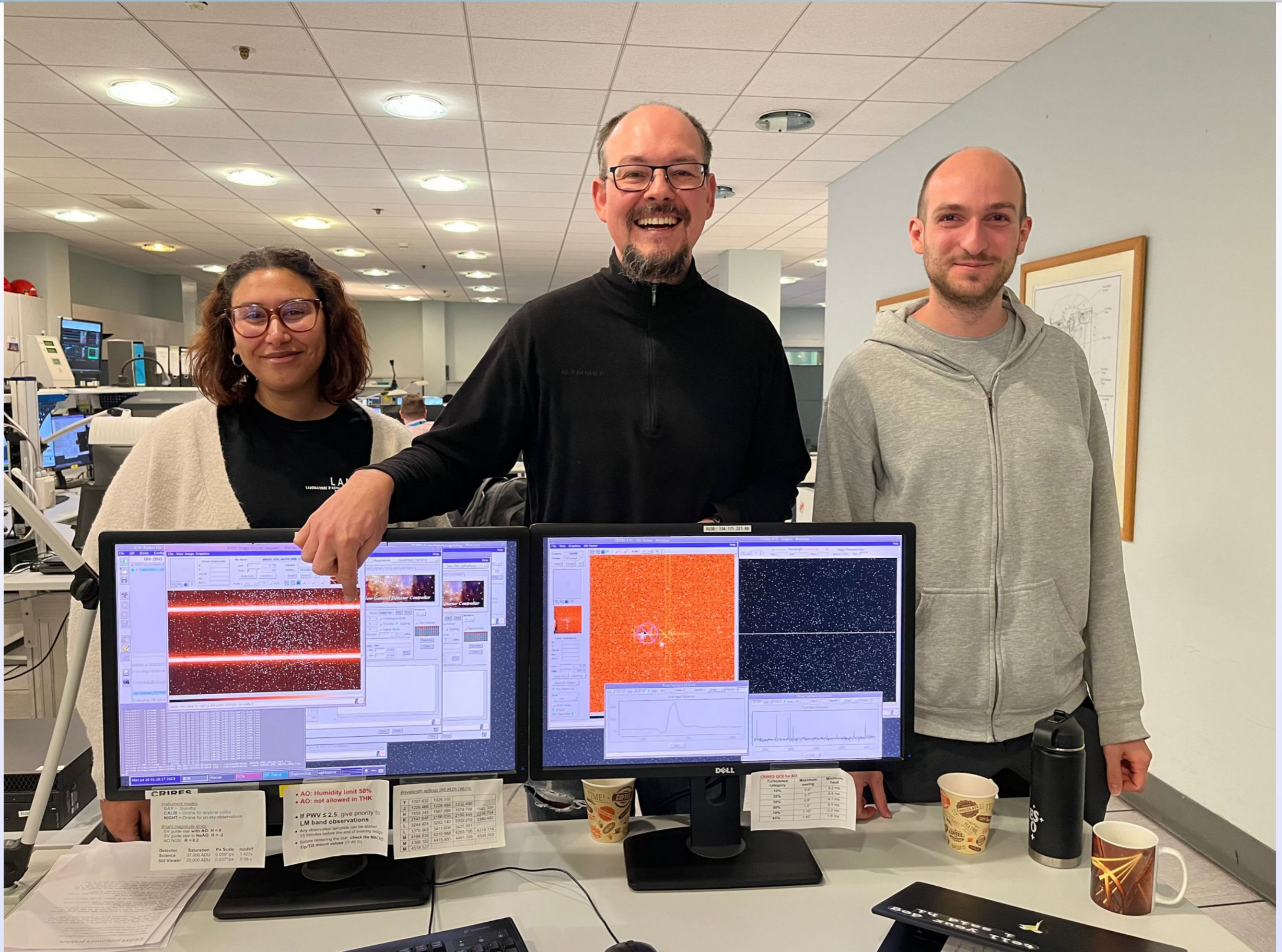


CRIRES science
detector #2

First light!



First light!



CRIFES
Instrument modes:
DAY = Standby
CALB = Online for daytime calls
NIGHT = Online for on-site observations
Bright magnitude limit:
SV guide star with AO: H = 0
SV guide star w/ NGAO: H = -2
AO NGS: R = 0.2
Detector Saturation Px Scale minDIT
Science: 37,000 ADU 0.057"/px 1.42"
Site Viewer: 20,000 ADU 0.037"/px 0.08 s

• AO: Humidity limit 50%
• AO: not allowed in THK
• If PWV ≤ 2.5 , give priority to LM band observations
• Any observation template can be started 15 minutes before the end of evening twilight
• Before centering the star, check the MCAO Tip/Tilt reset values (if AO off)

Wavelength settings (NS BLN CH1,2,3)
Y 1027.632 1029.310
J 1226.466 1228.488 1232.490
H 1369.245 1367.090 1374.798 1340.339
K 2147.640 2156.056 2192.449 2256.794
L 3244.424 3262.143 3302.210 3340.432
M 4196.830 4210.968 4265.706 4318.114
N 4368.182 4415.605 4461.105 4504.083
M 4518.527

CRIFES OCS for AO

Turbulence category	Maximum seeing	Minimum TauD
10%	0.8"	3.2 ms
20%	0.9"	4.4 ms
30%	0.8"	4.1 ms
40%	1.0"	3.6 ms
50%	1.15"	2.2 ms
60%	1.40"	1.8 ms

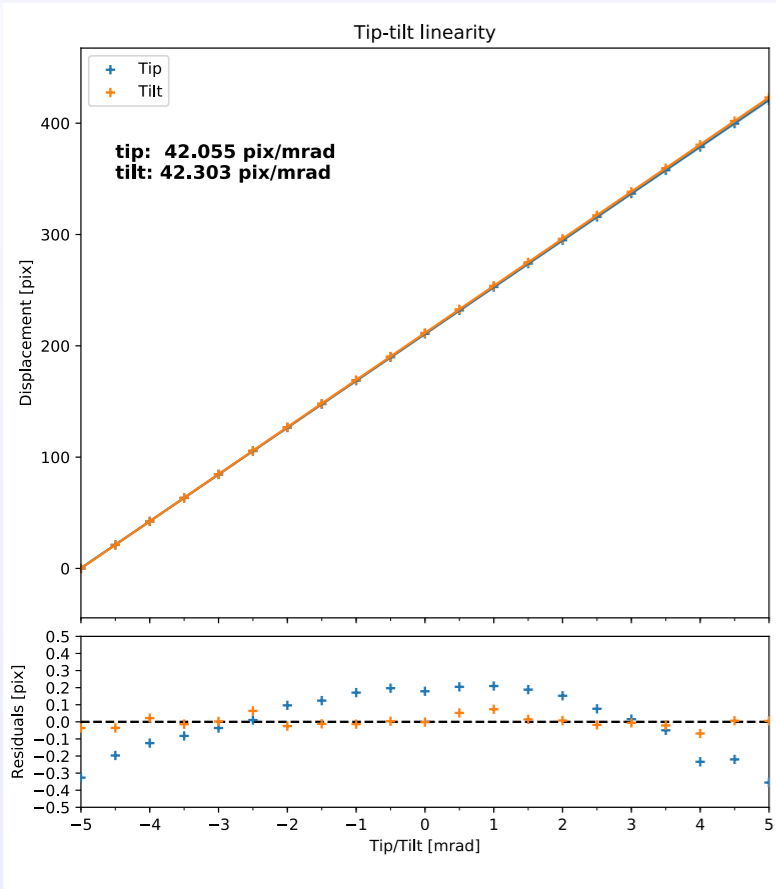
Operations: daytime calibrations

Daytime

Operations: daytime calibrations

Daytime

Tip-tilt mirror
linearity

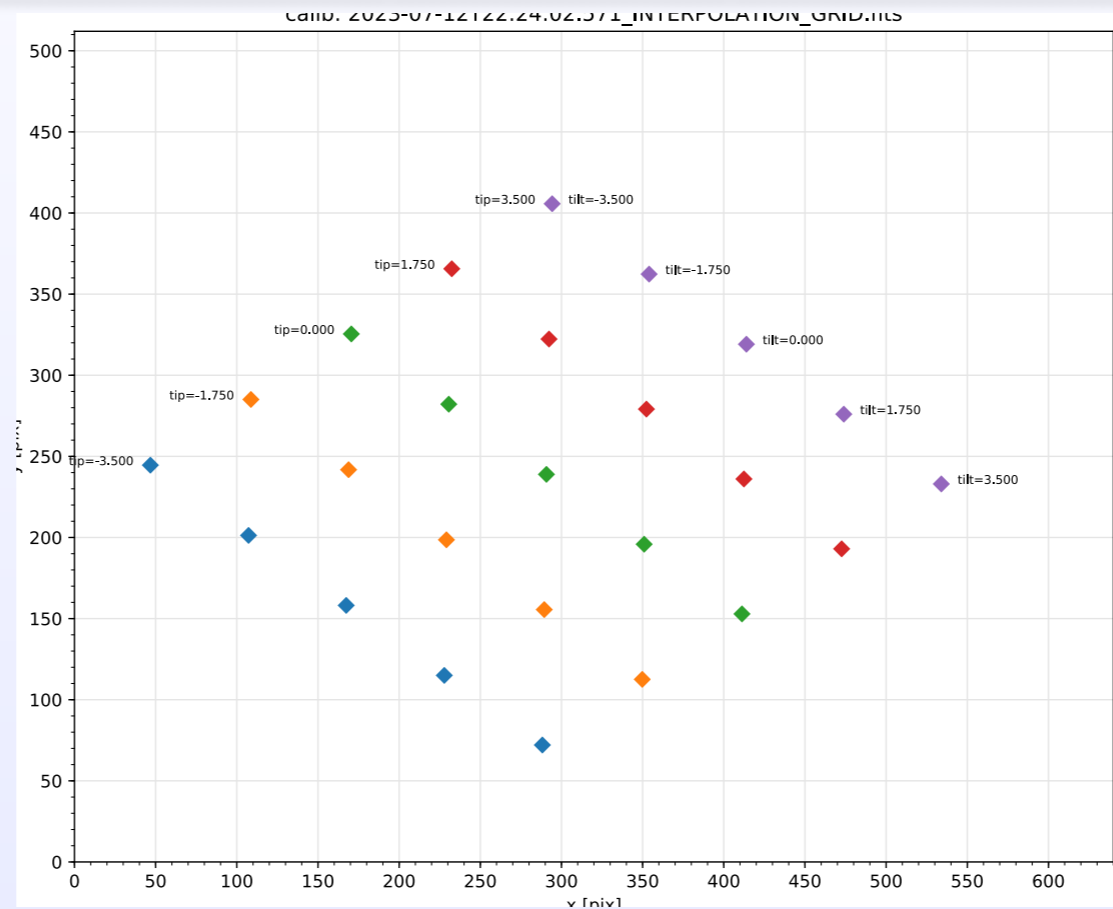
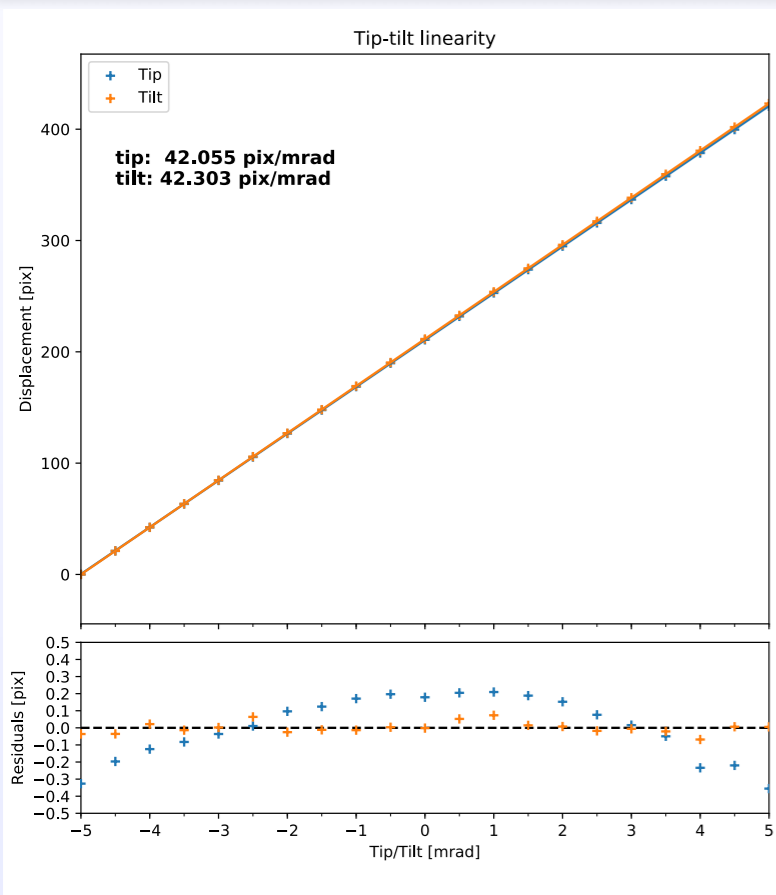


Operations: daytime calibrations

Daytime

Tip-tilt mirror
linearity

Tip-tilt mirror
interpolation
matrix



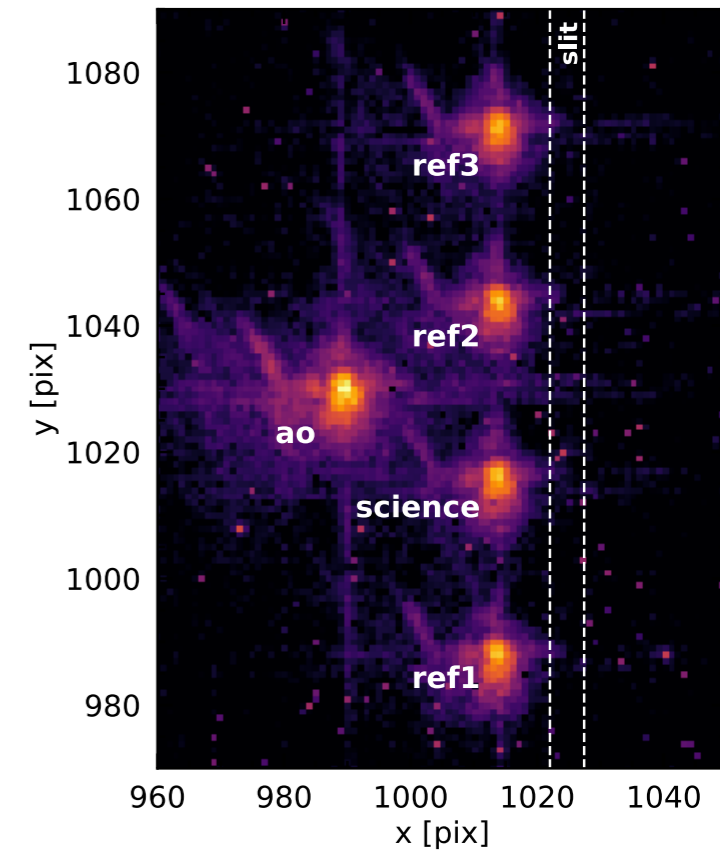
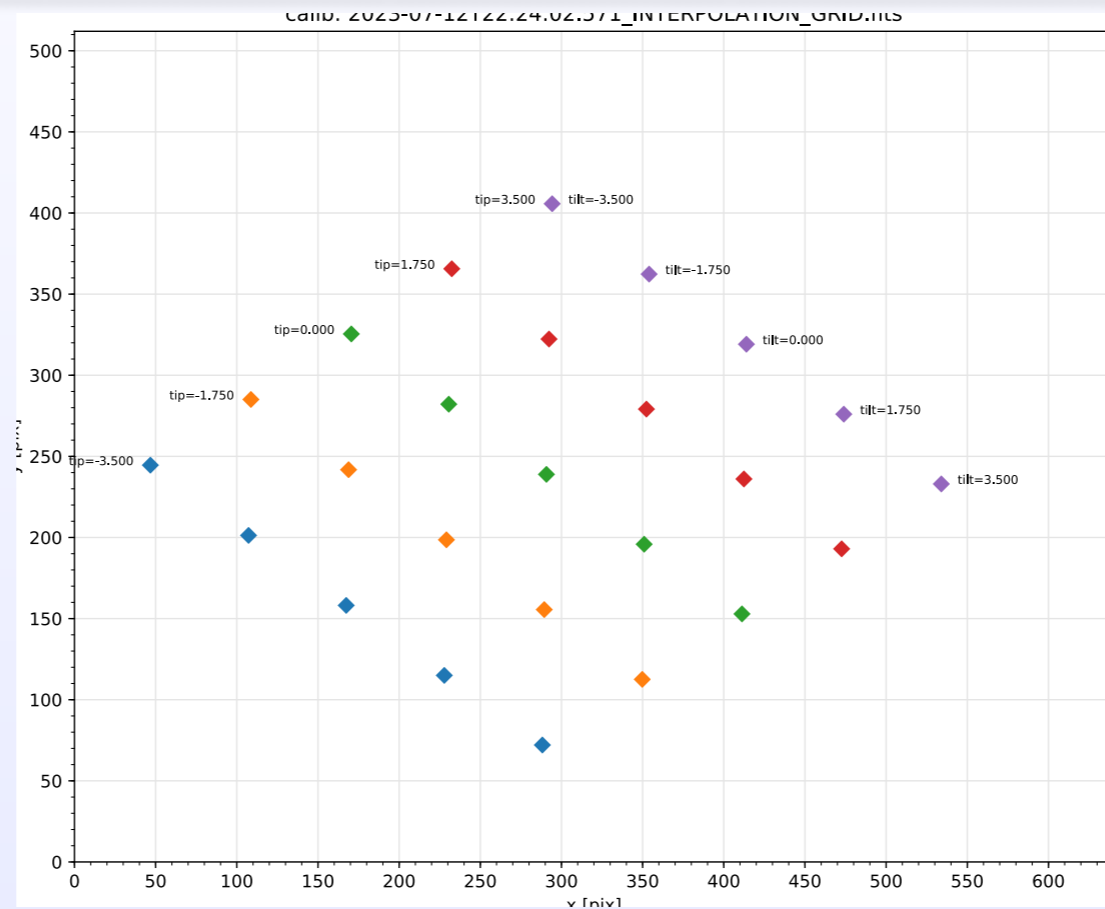
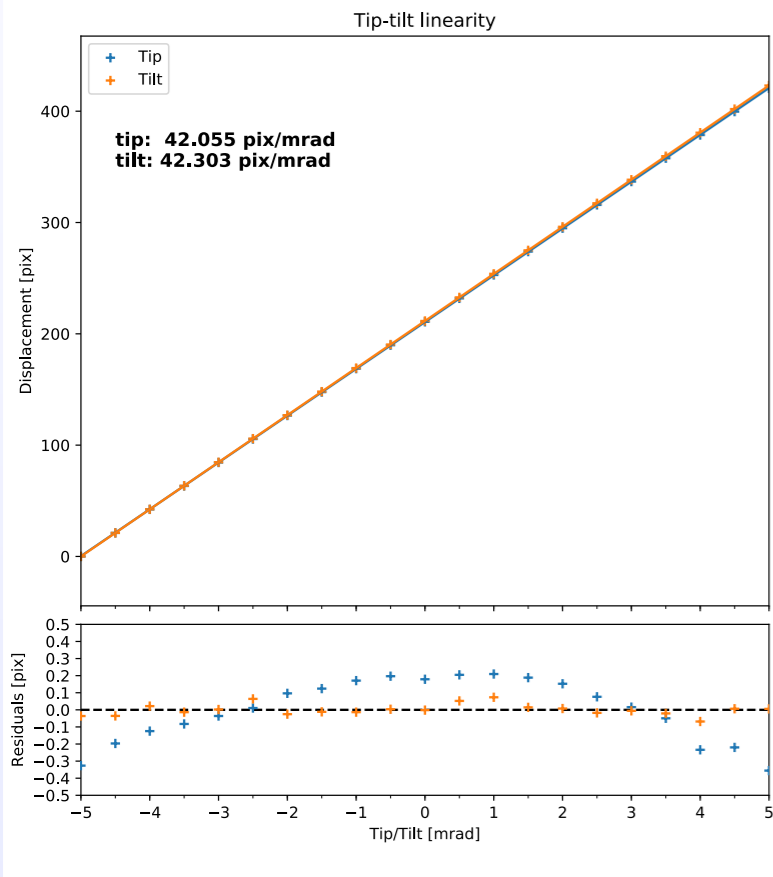
Operations: daytime calibrations

Daytime

Tip-tilt mirror
linearity

Tip-tilt mirror
interpolation
matrix

Fibers
location on slit
viewer



Operations: daytime calibrations

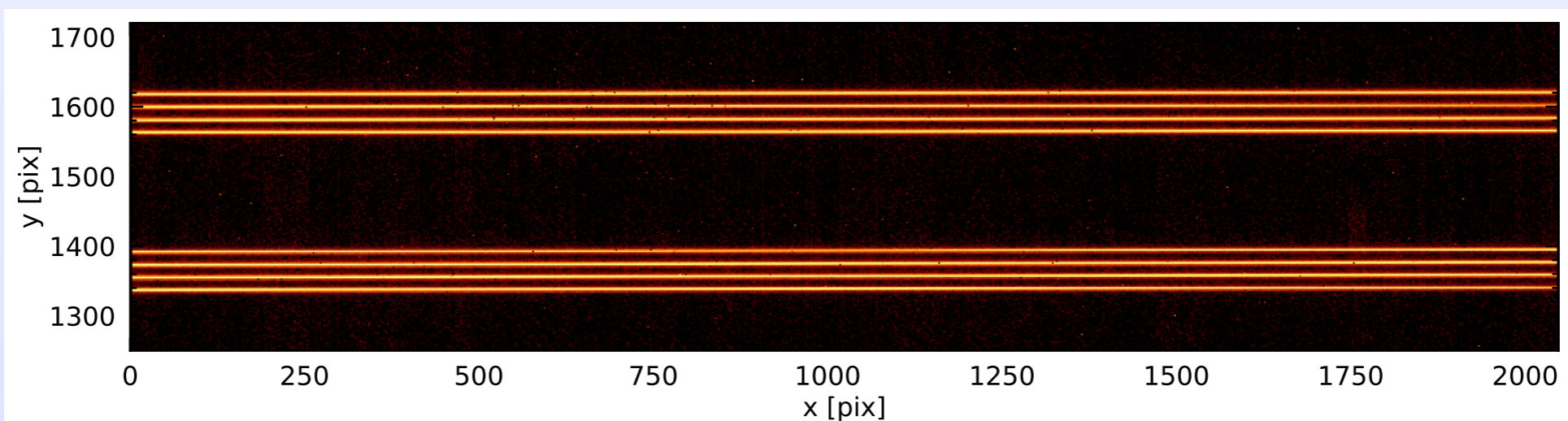
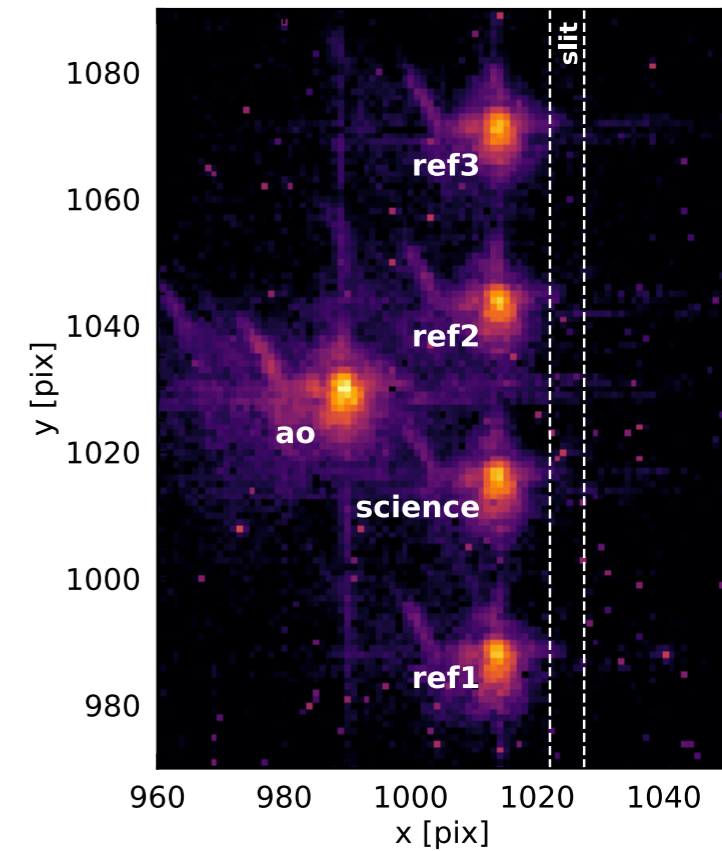
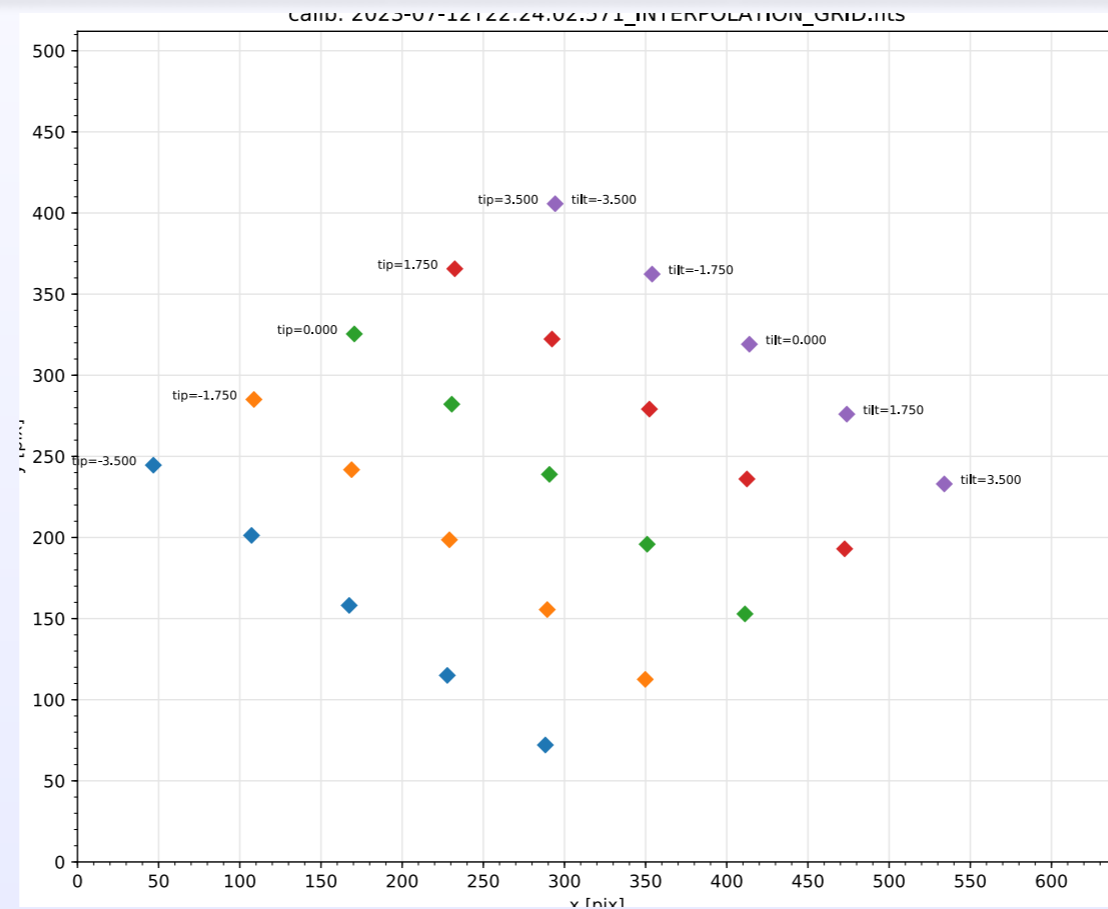
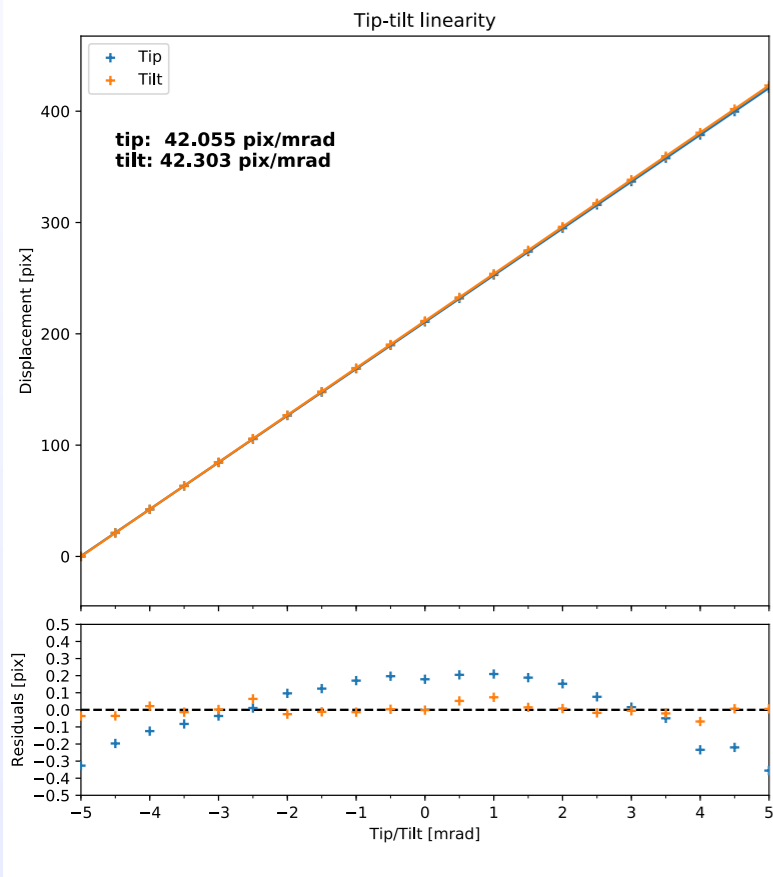
Daytime

Tip-tilt mirror
linearity

Tip-tilt mirror
interpolation
matrix

Fibers
location on slit
viewer

Fibers trace
on science
detector



Operations: target acquisition

Daytime

Tip-tilt mirror
linearity

Tip-tilt mirror
interpolation
matrix

Fibers
location on slit
viewer

Fibers trace
on science
detector

SPHERE
acquisition

FIM setup

Switch to
internal source

Injection map
on C fiber

Switch to S
fiber

Injection
optimisation
+ offset

Switch to sky

Science data
acquisition

Nighttime

Operations: target acquisition

Daytime

Tip-tilt mirror linearity

Tip-tilt mirror interpolation matrix

Fibers location on slit viewer

Fibers trace on science detector

SPHERE acquisition

FIM setup

Switch to internal source

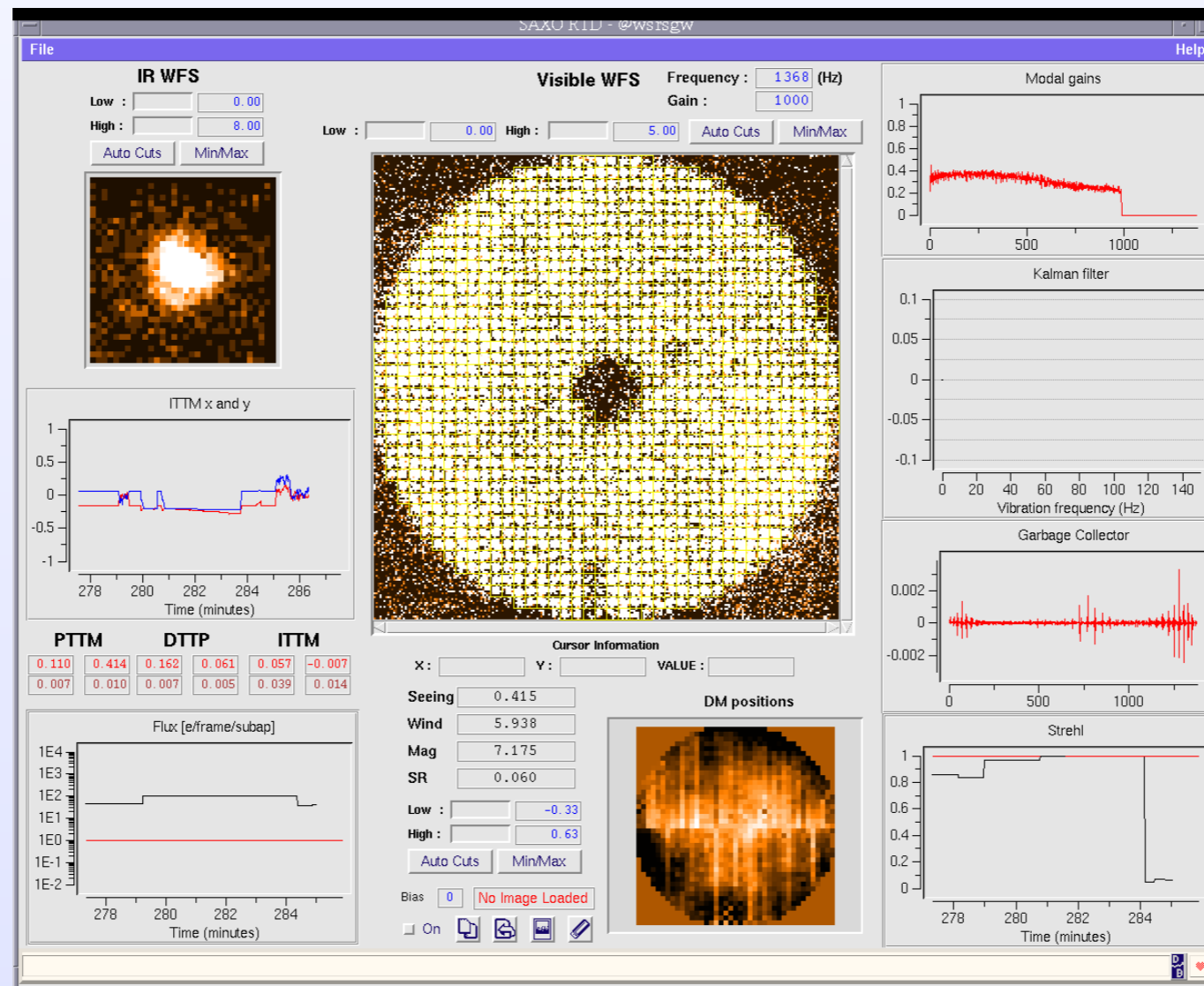
Injection map on C fiber

Switch to S fiber

Injection optimisation + offset

Switch to sky

Science data acquisition



Nighttime

Operations: target acquisition

Daytime

Tip-tilt mirror
linearity

Tip-tilt mirror
interpolation
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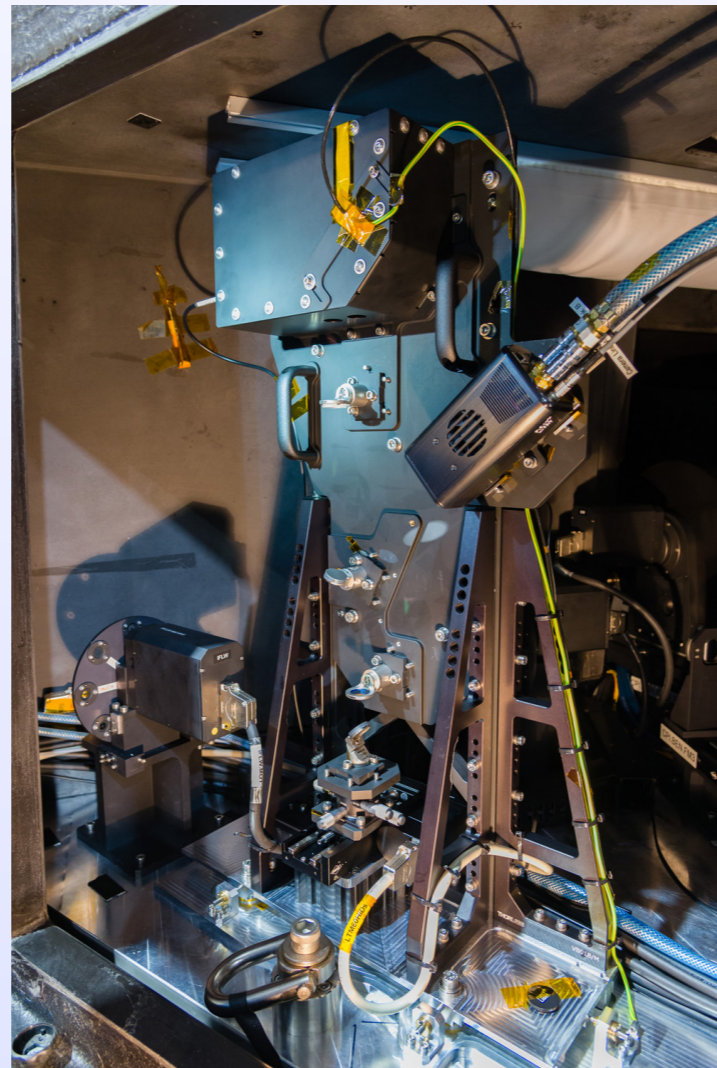
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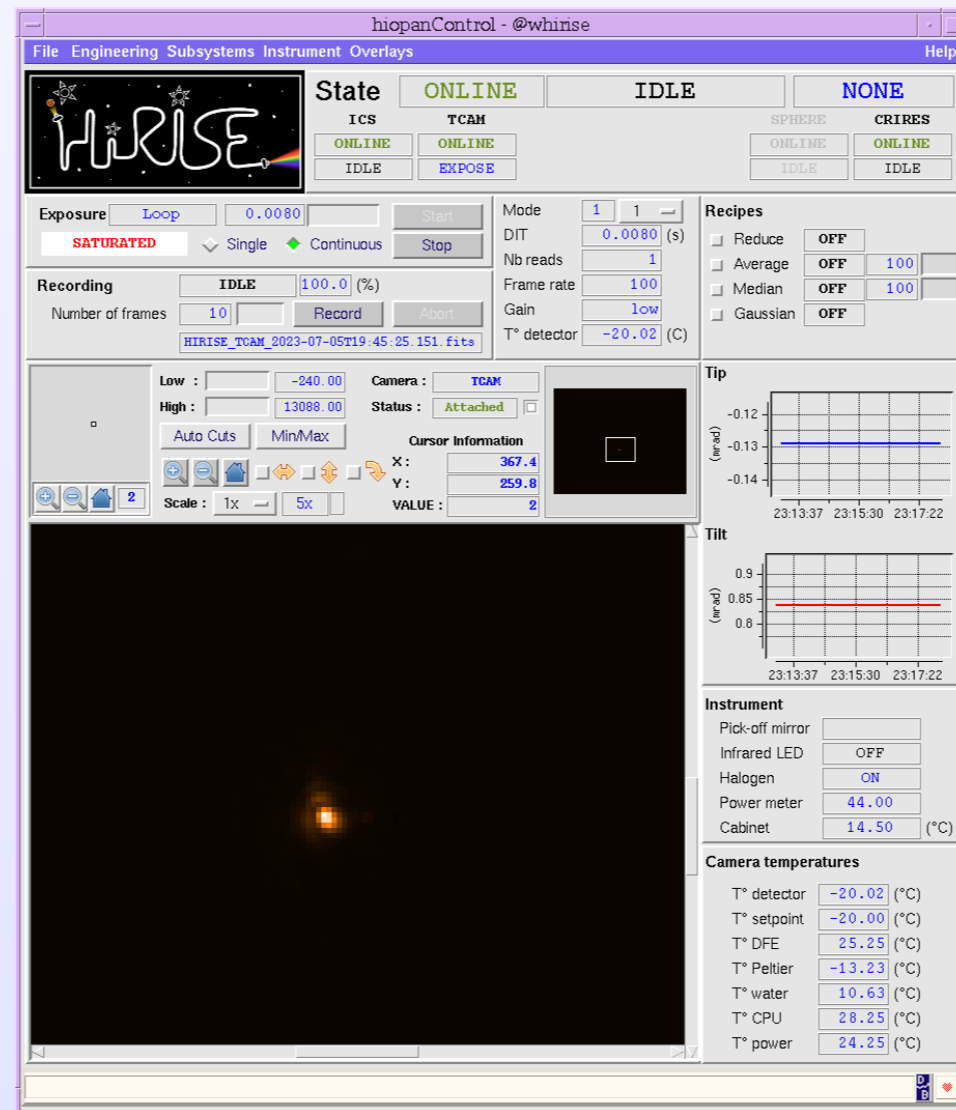
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Science data acquisition



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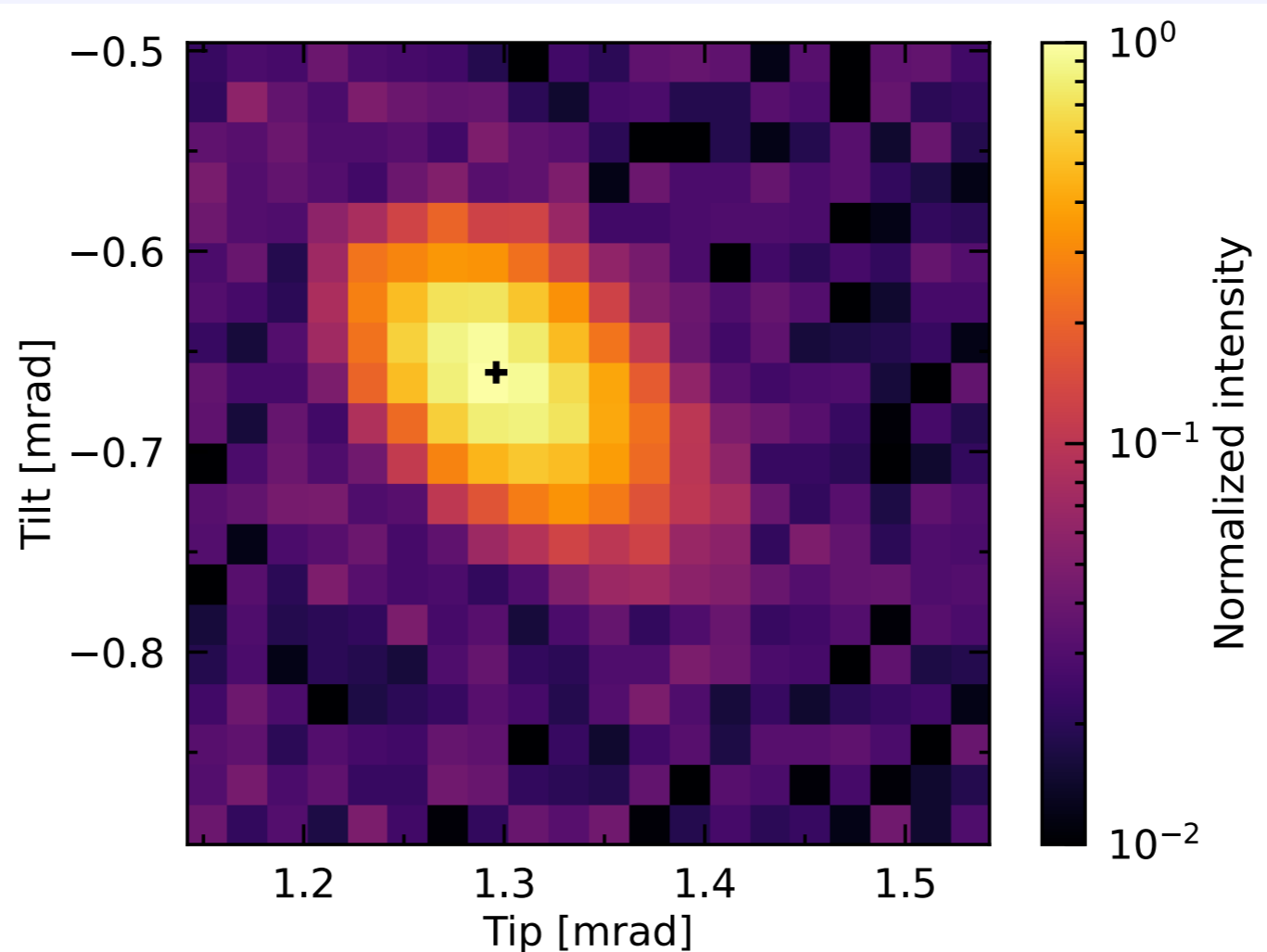
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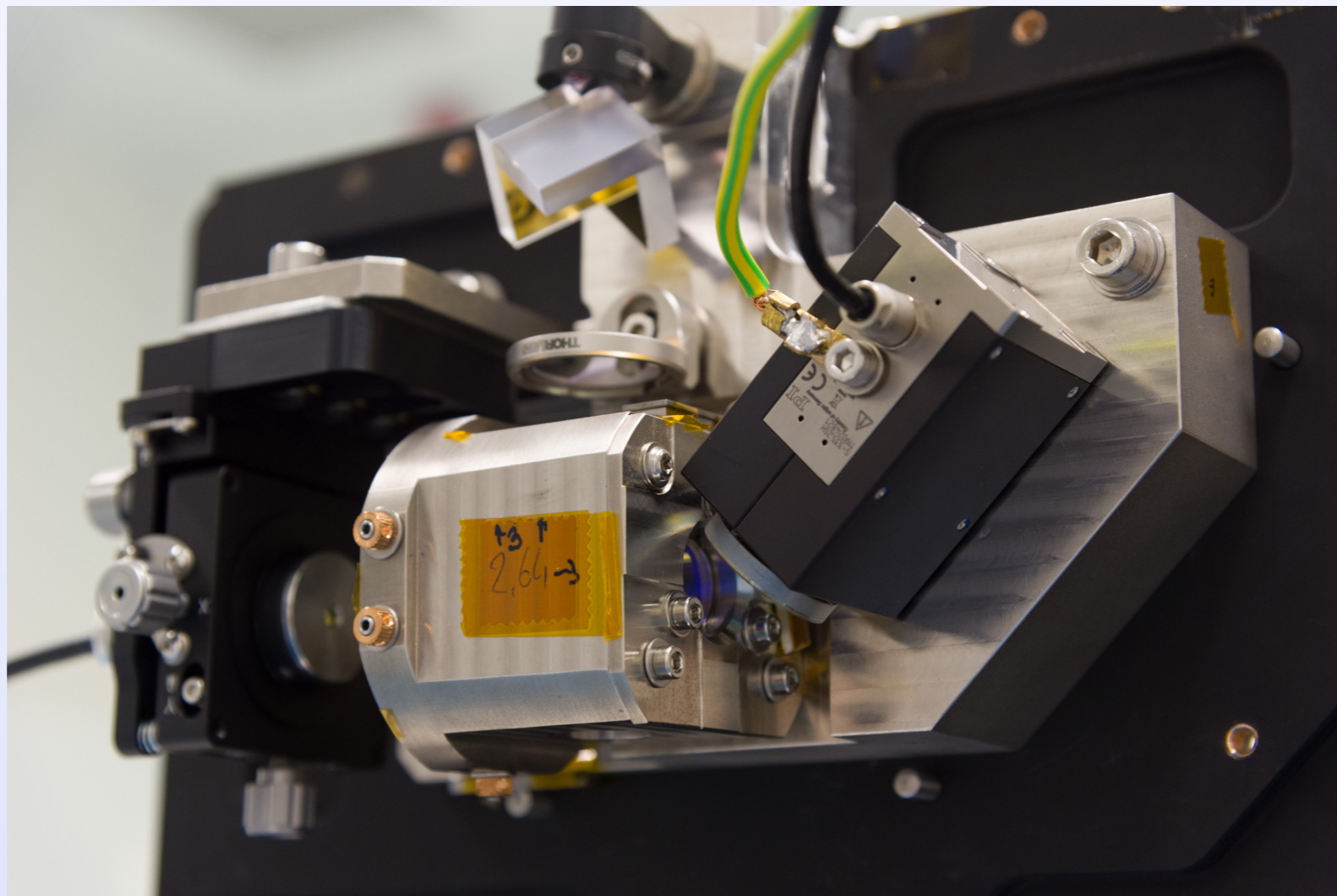
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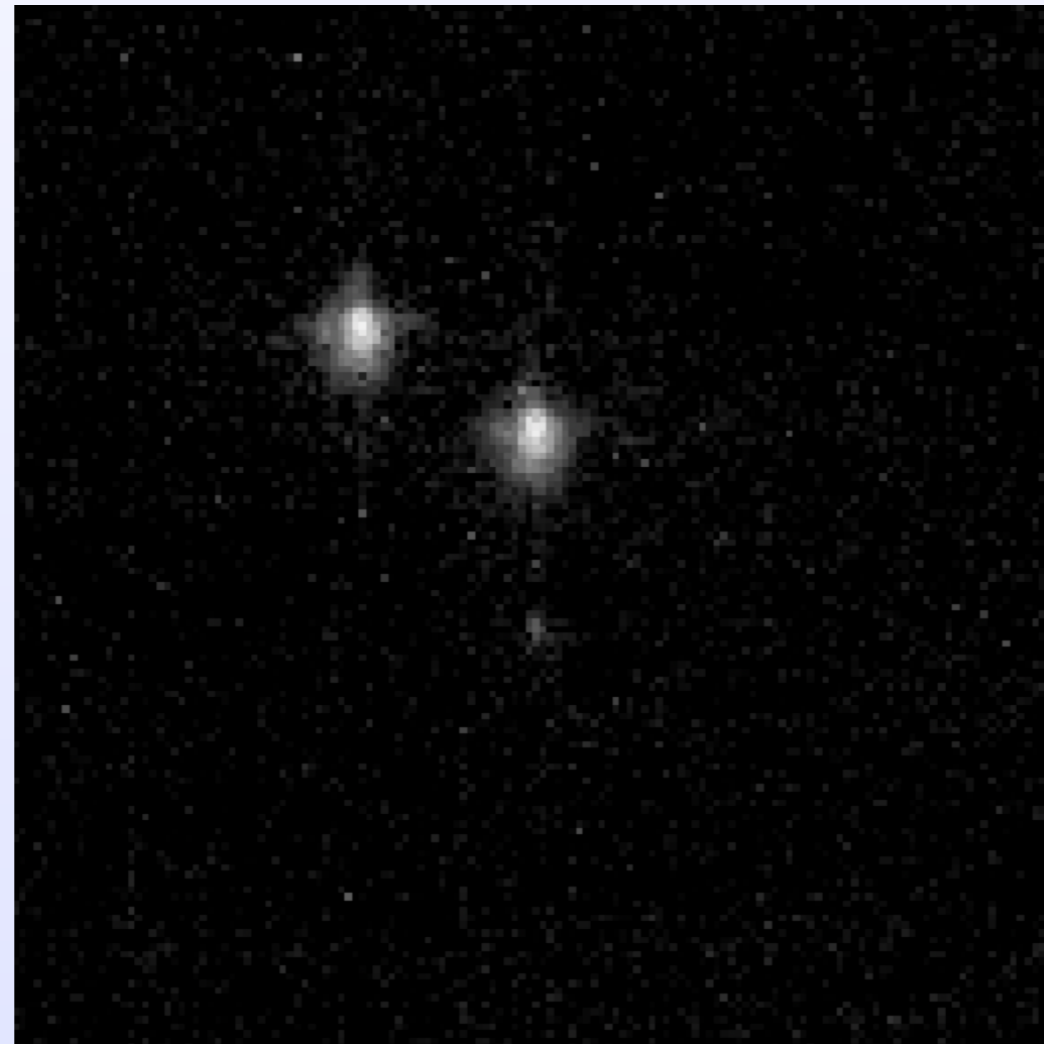
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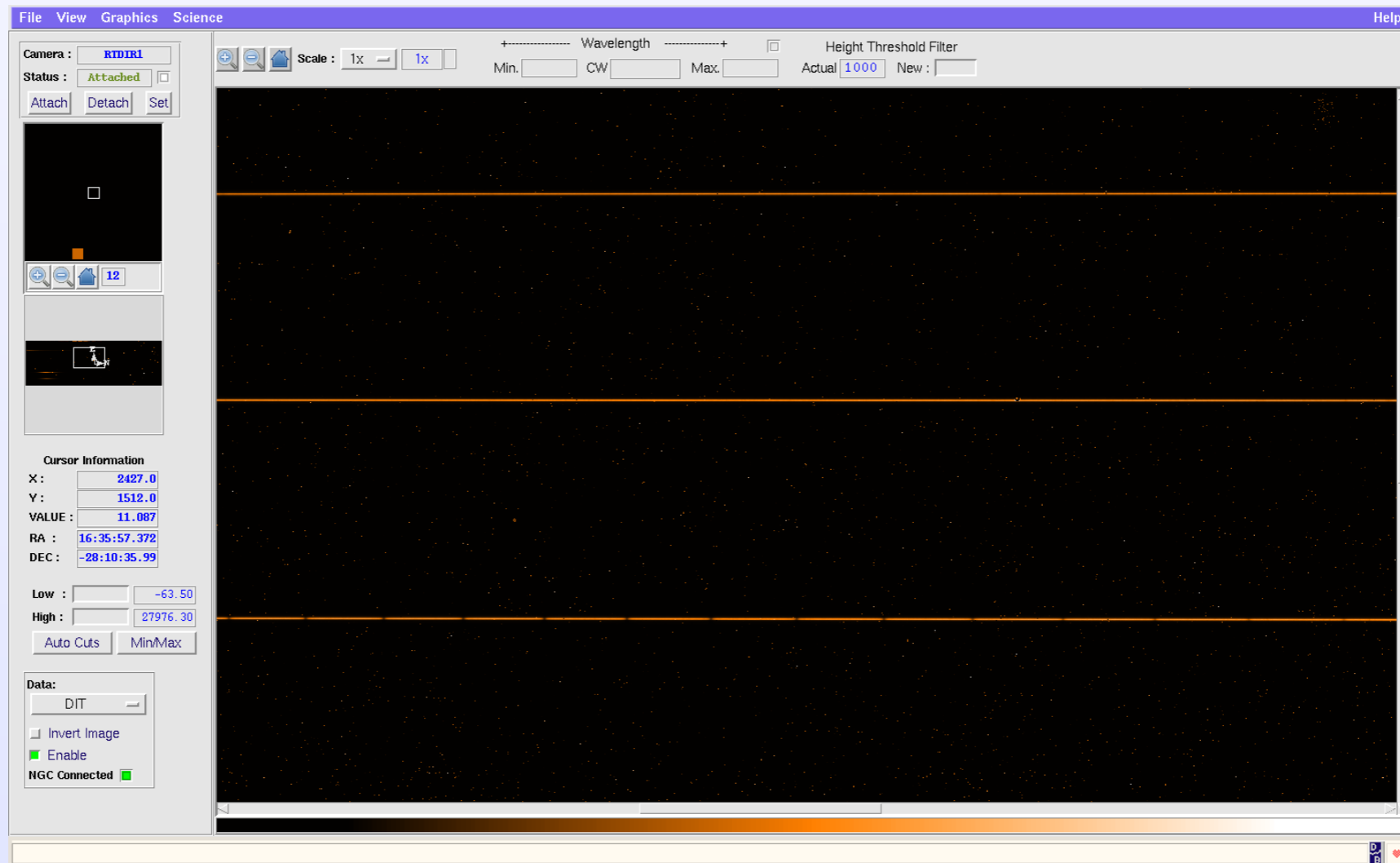
Injection map
on C fiber

Switch to S
fiber

Injection
optimisation
+ offset

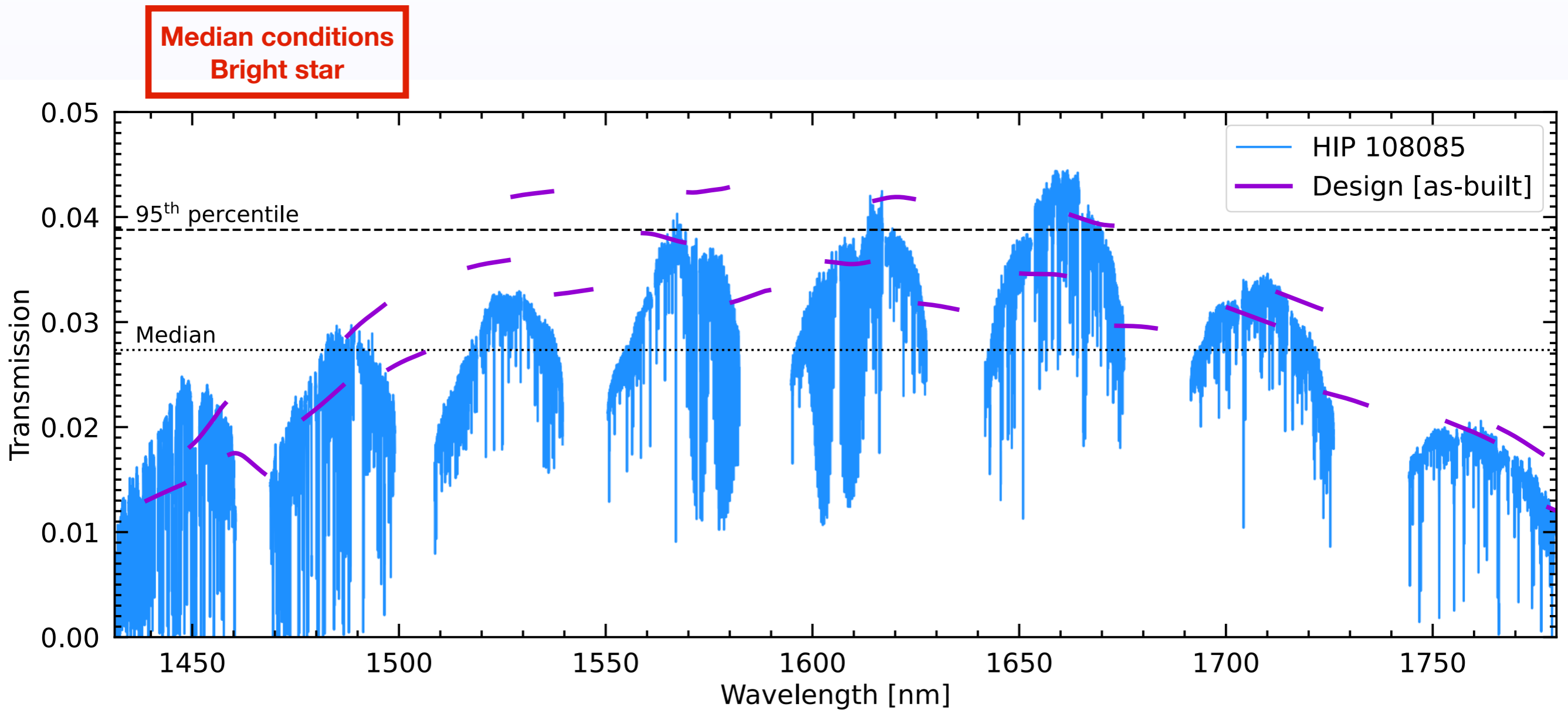
Switch to sky

Science data
acquisition



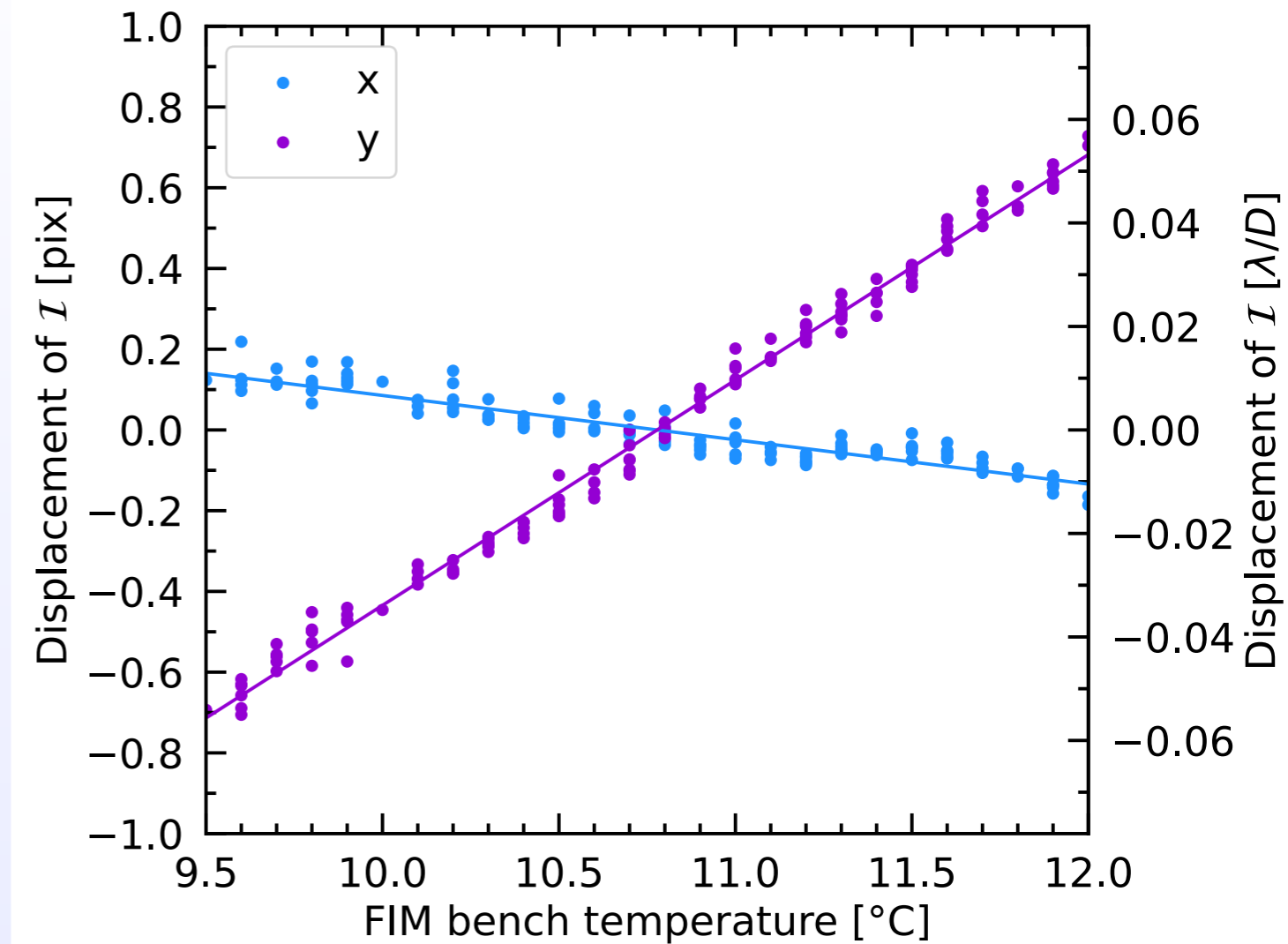
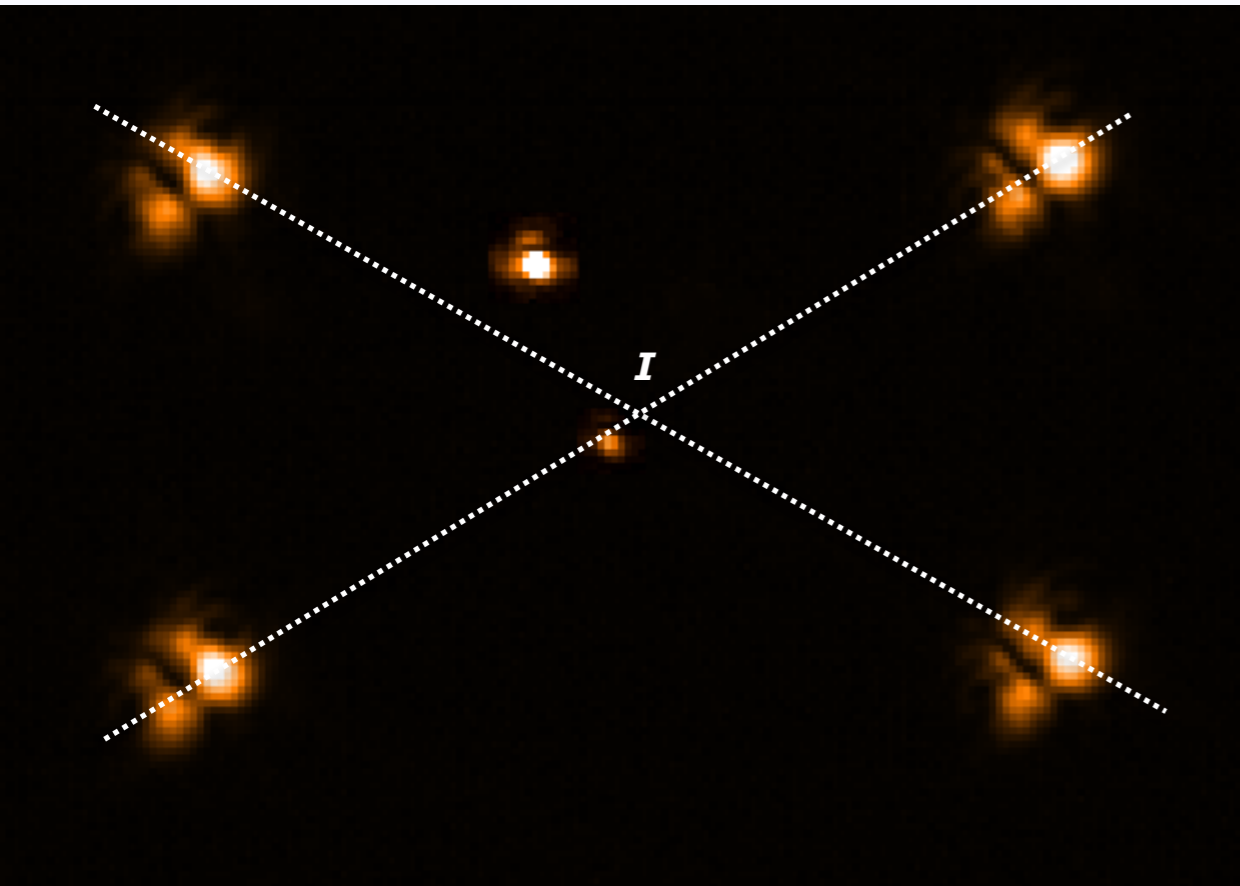
Nighttime

Commissioning results: transmission



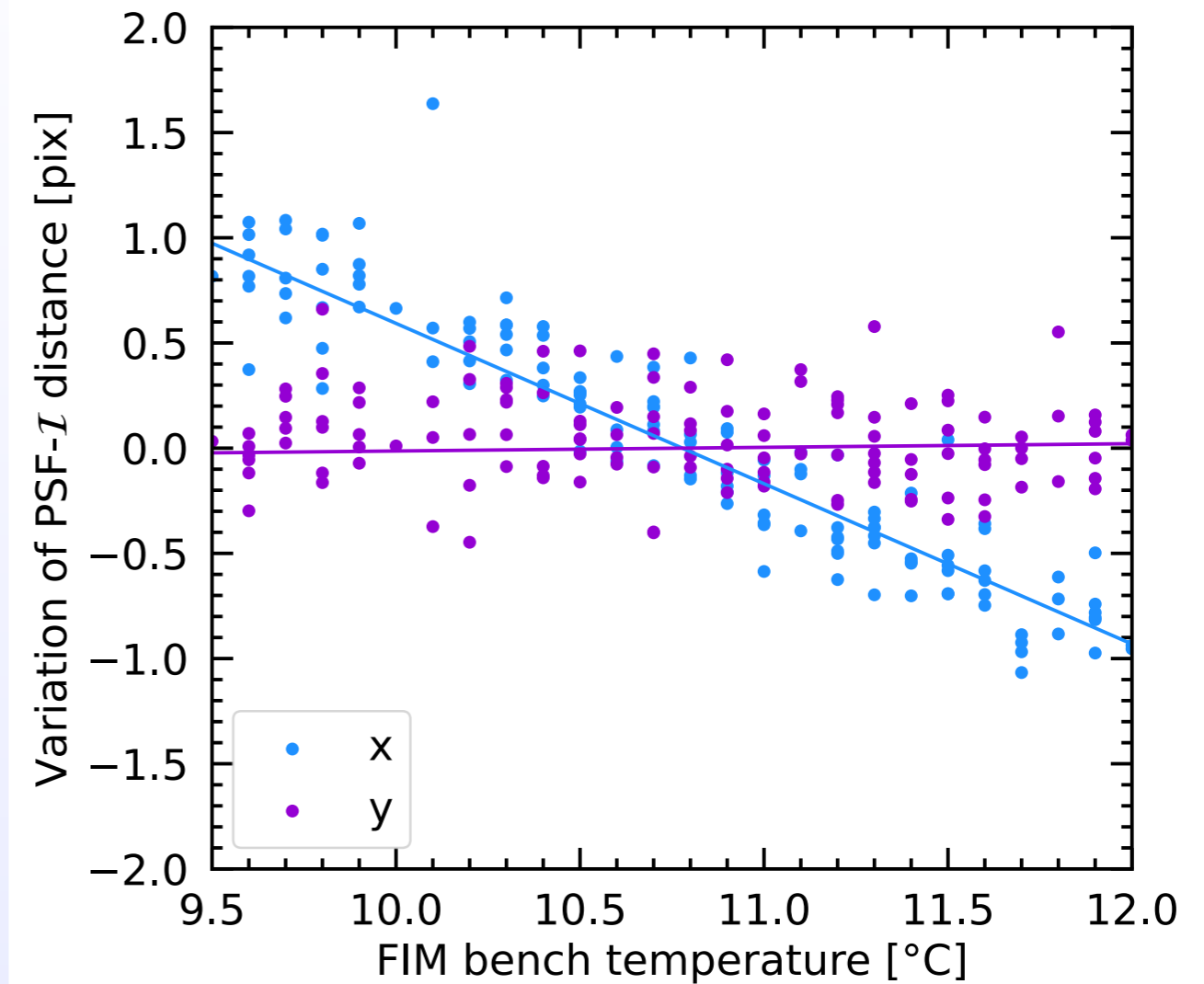
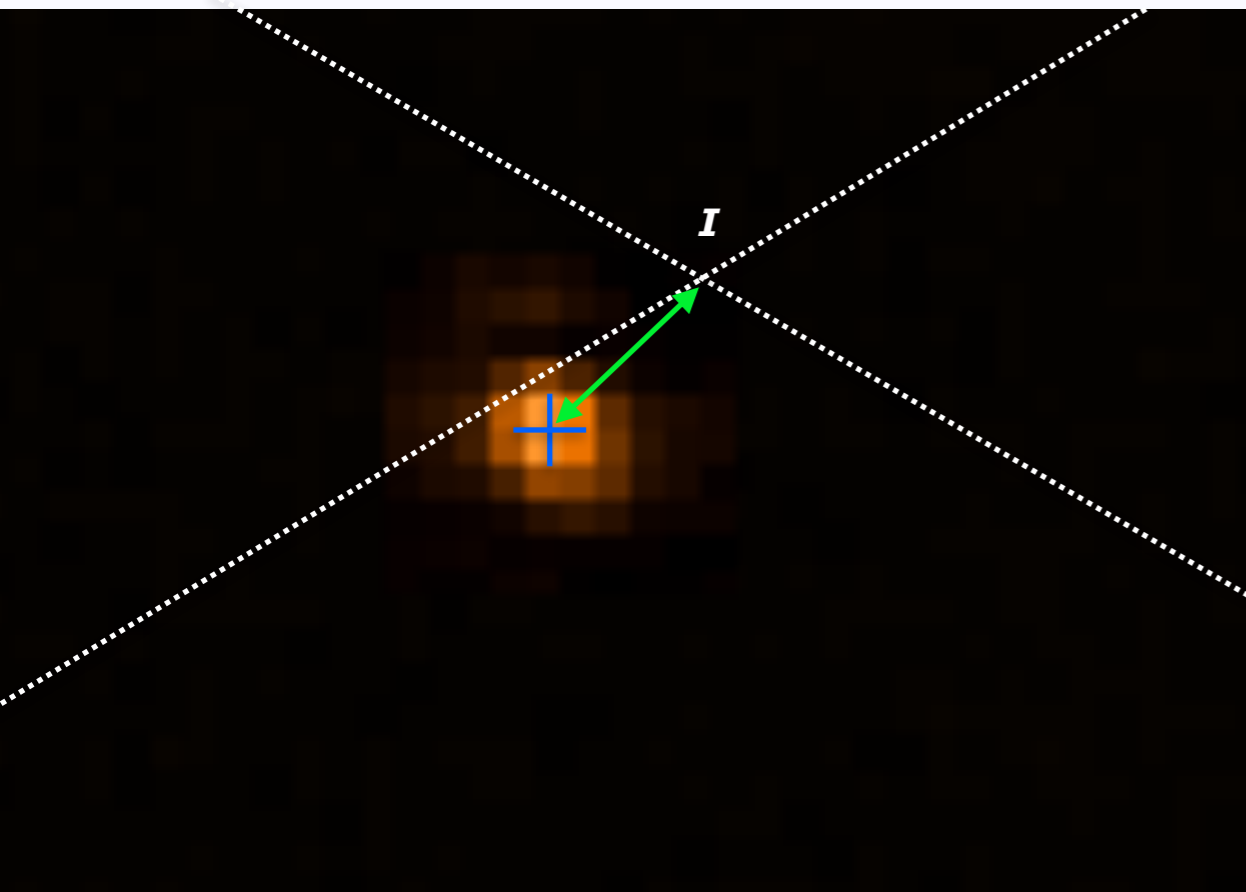
End-to-end transmission exactly within specifications

Commissioning: stability



The science PSF moves a lot with temperature

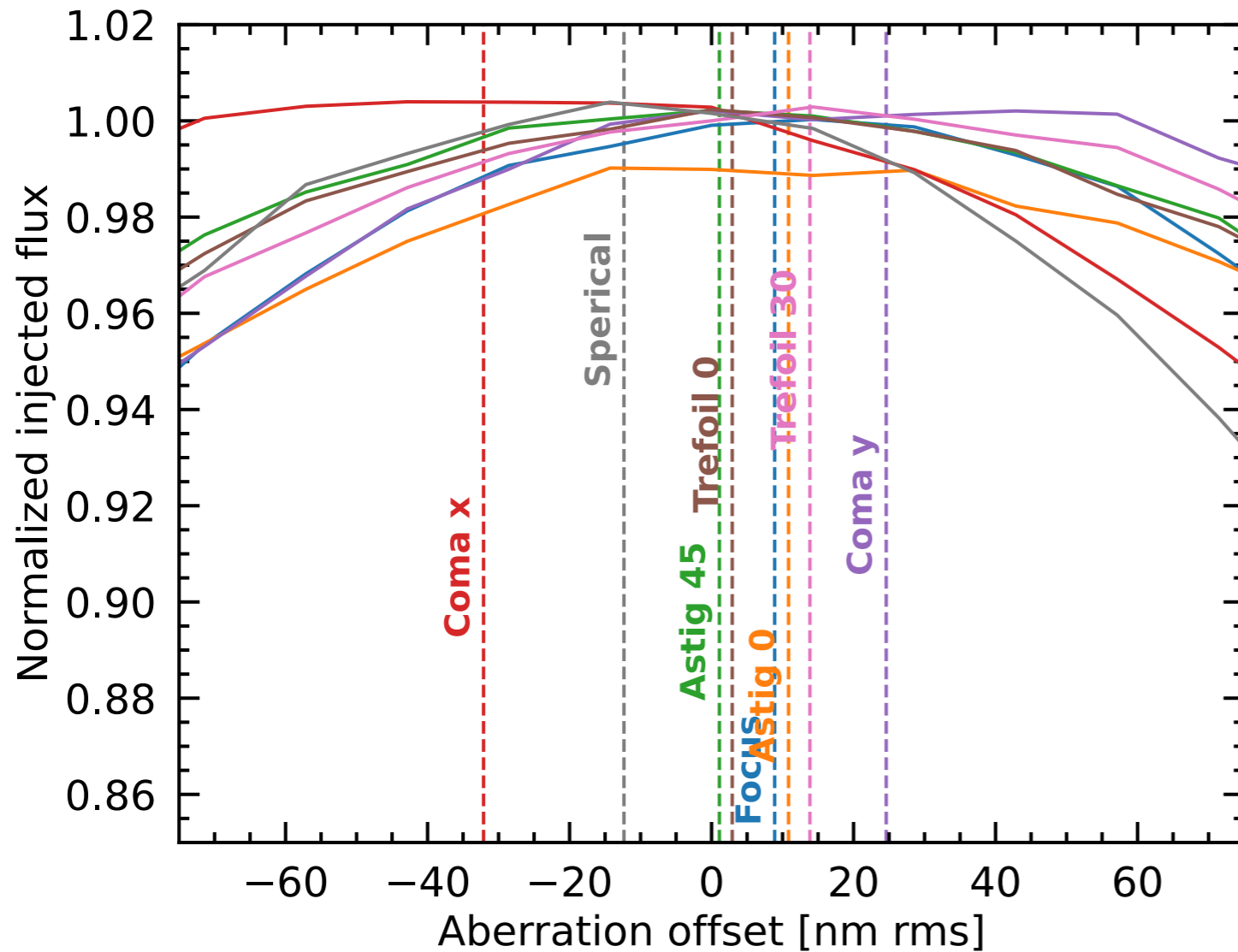
Commissioning: stability



The science PSF moves a lot with temperature

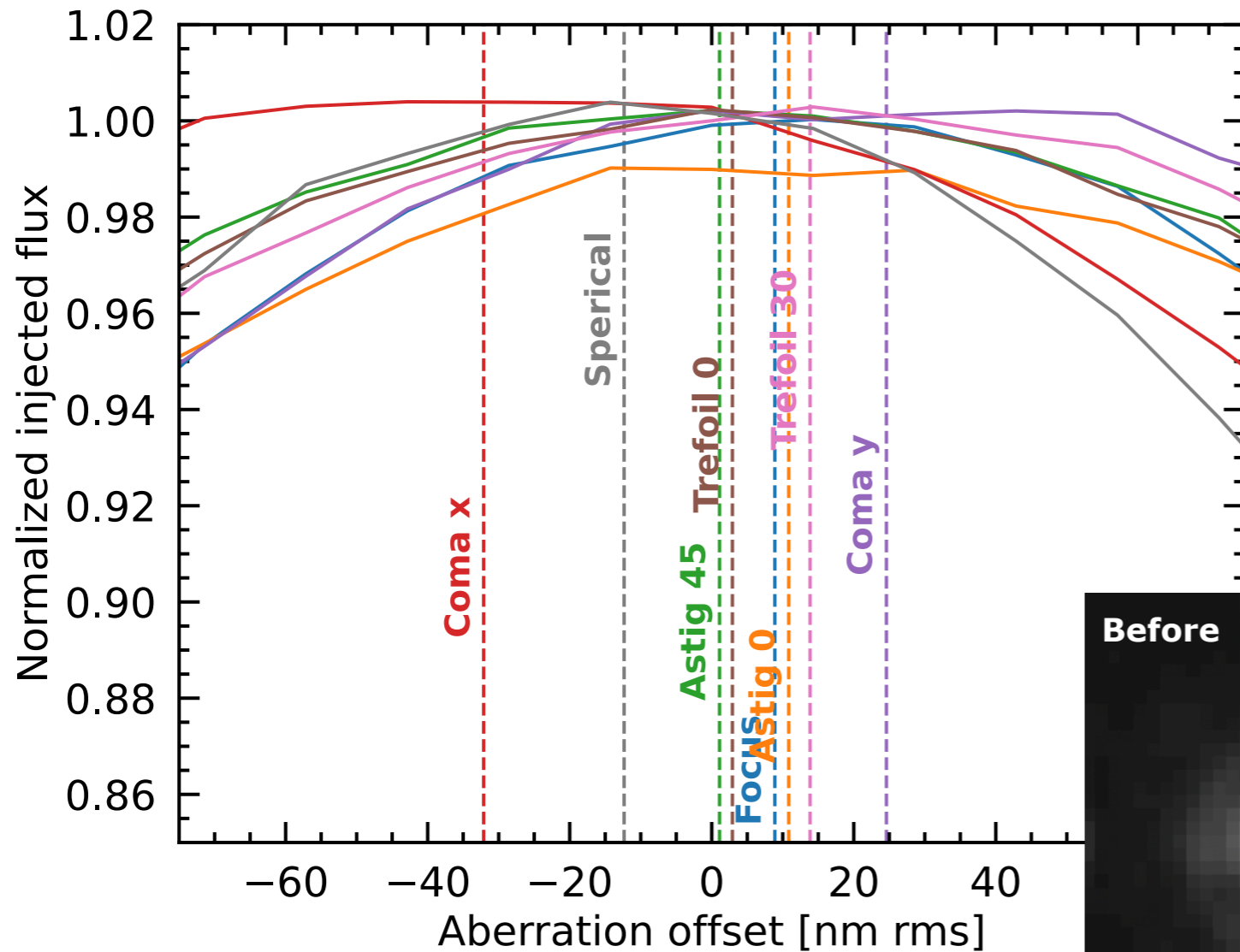
Motion compensation is NOT straightforward

Commissioning: NCPA

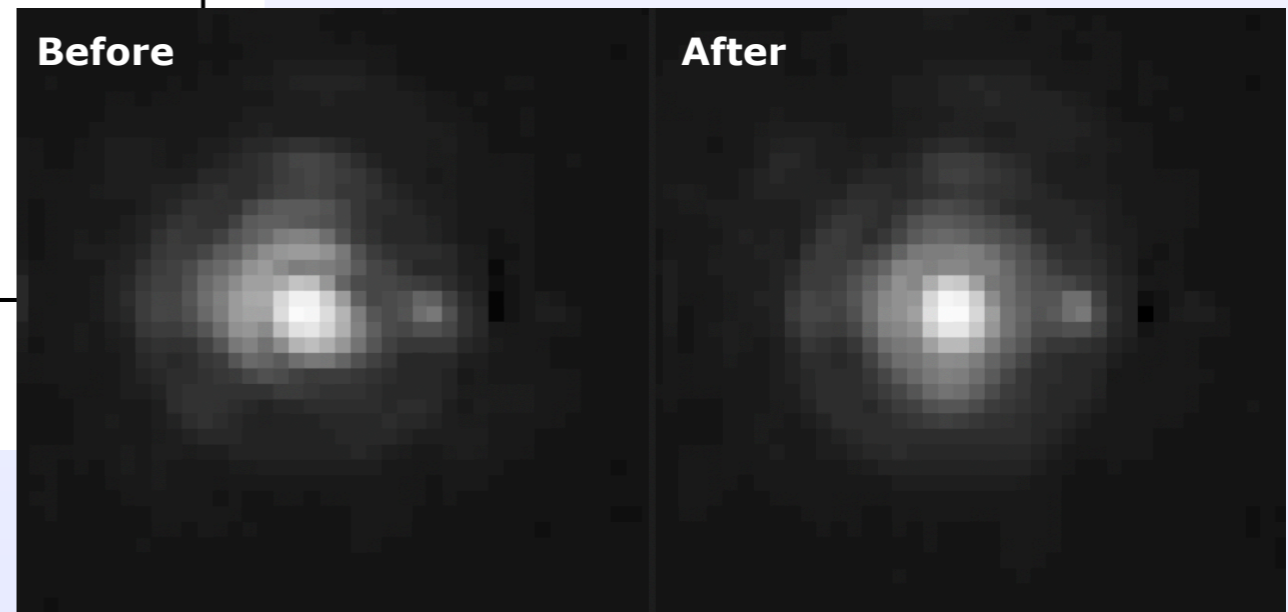


Level of NCPA is acceptable and no major gain expected from compensation

Commissioning: NCPA

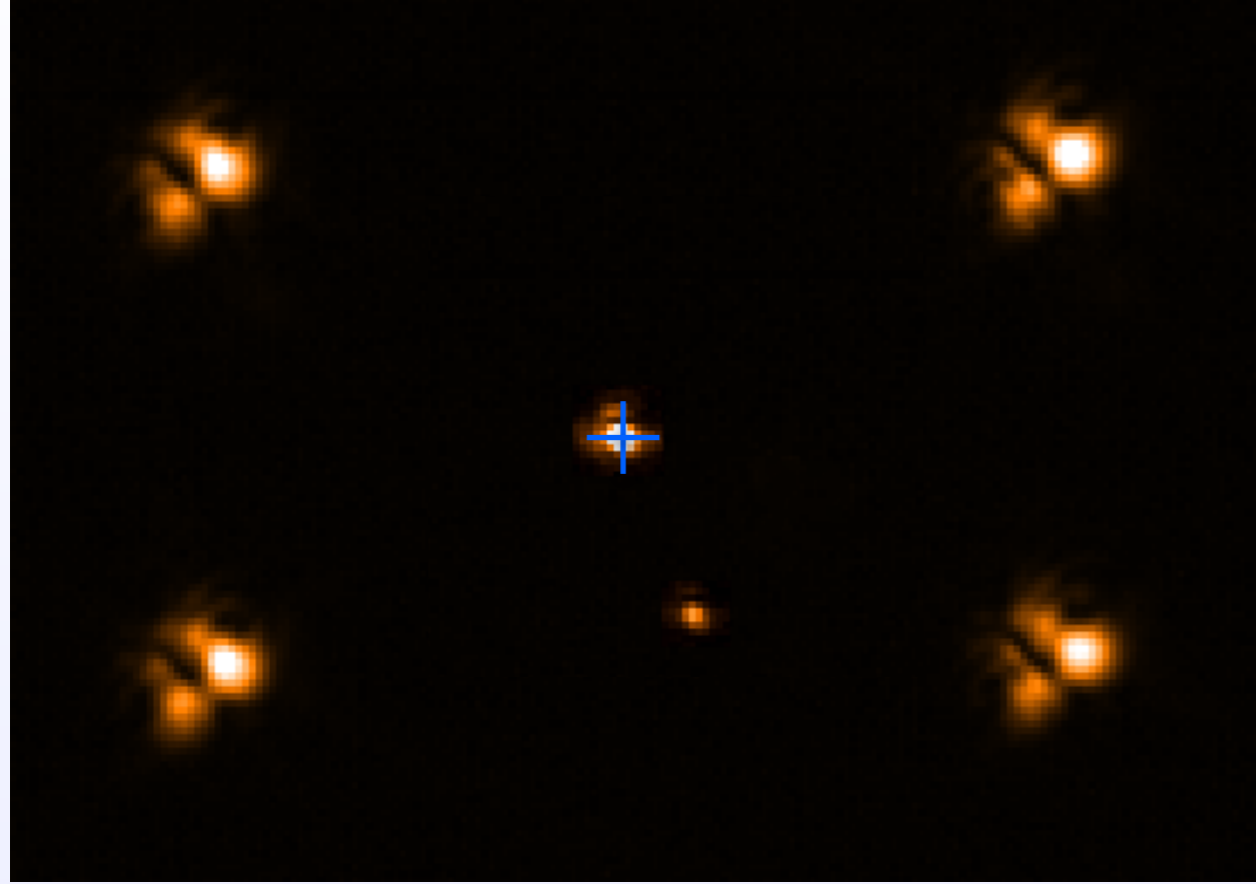


Optimisation on FIM camera

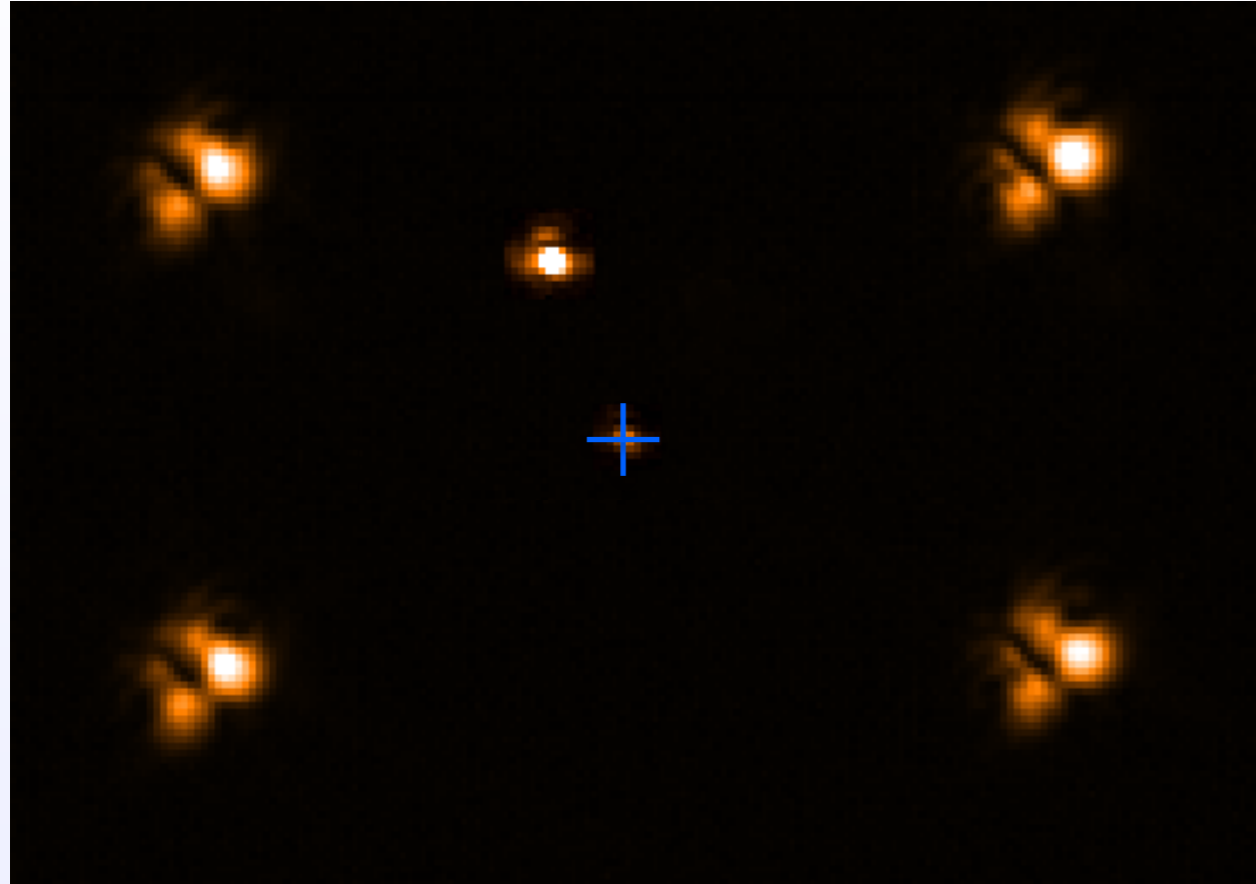


Level of NCPA is acceptable and no major gain expected from compensation

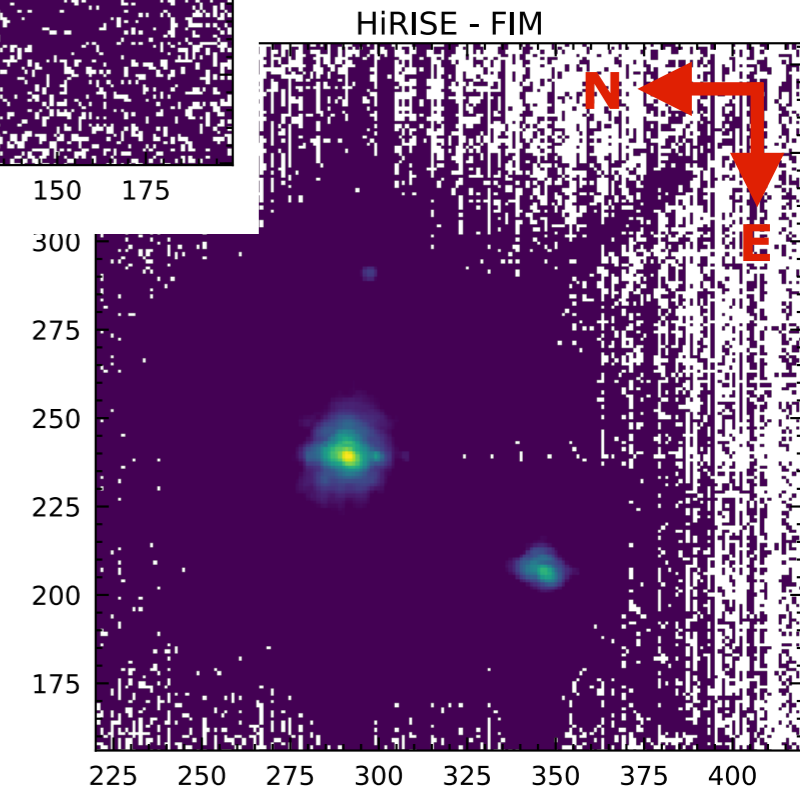
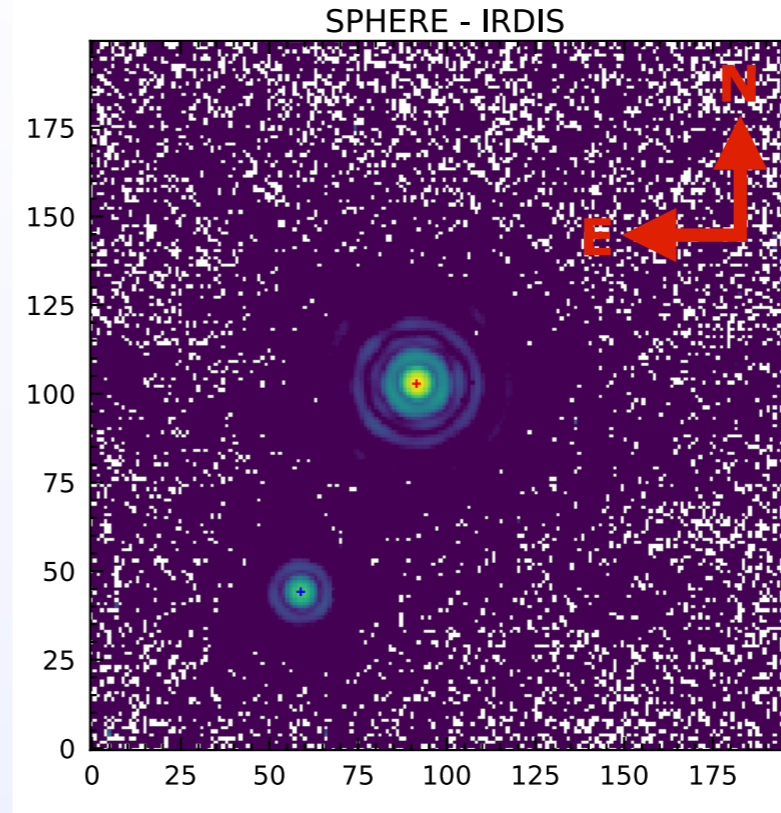
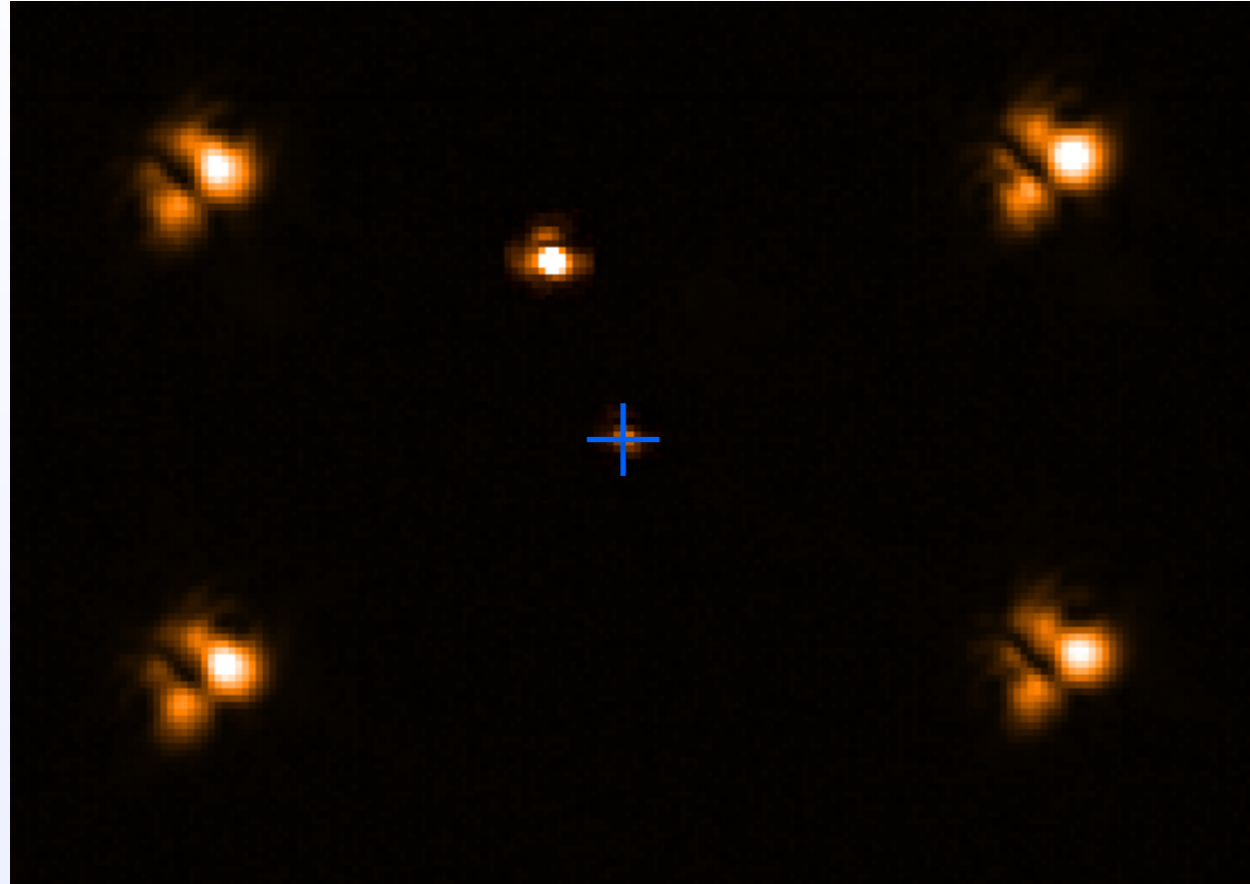
Commissioning: astrometry



Commissioning: astrometry



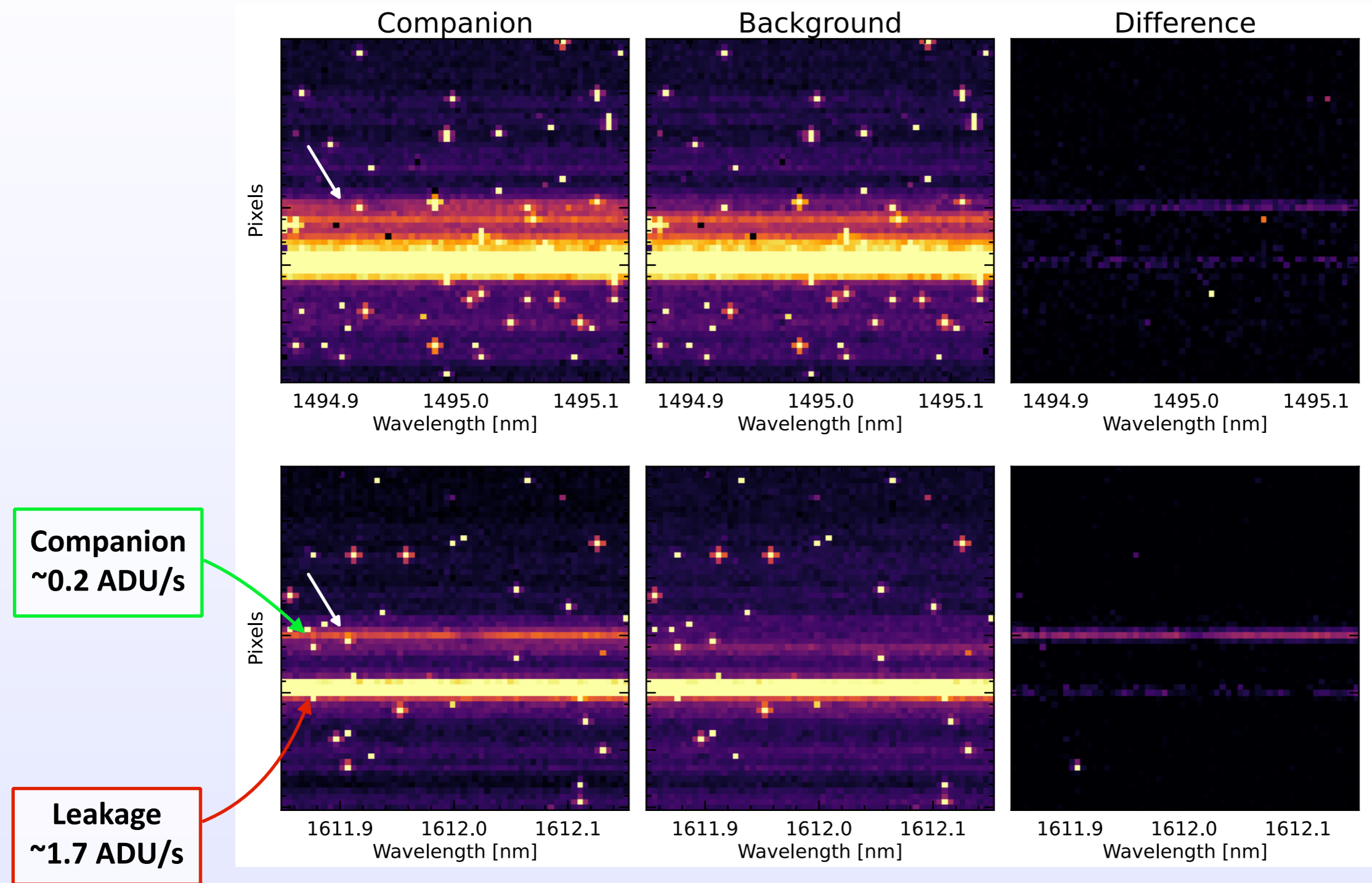
Commissioning: astrometry



- North correction = $90.40^\circ \pm 0.08^\circ$
- Pixel scale = 12.805 ± 0.027 mas/pix

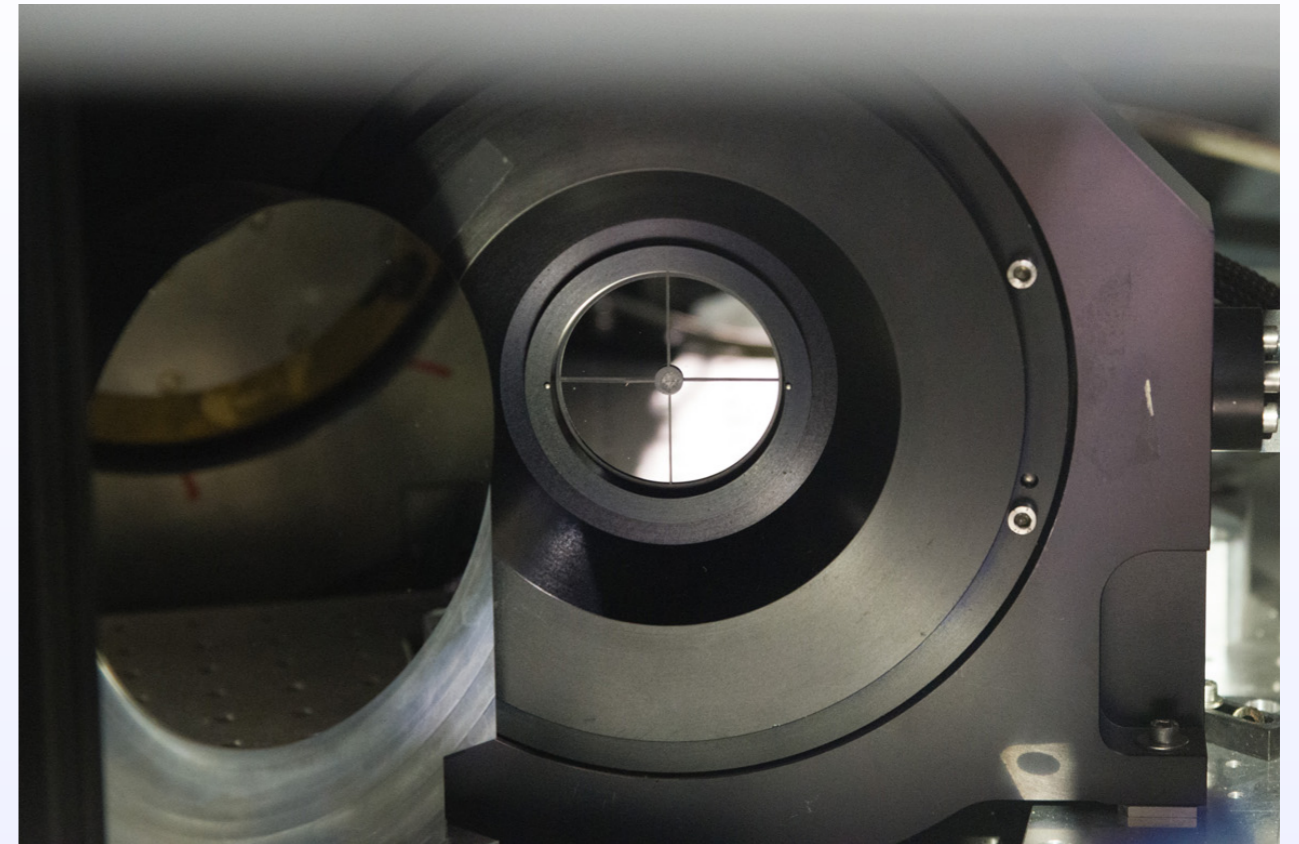
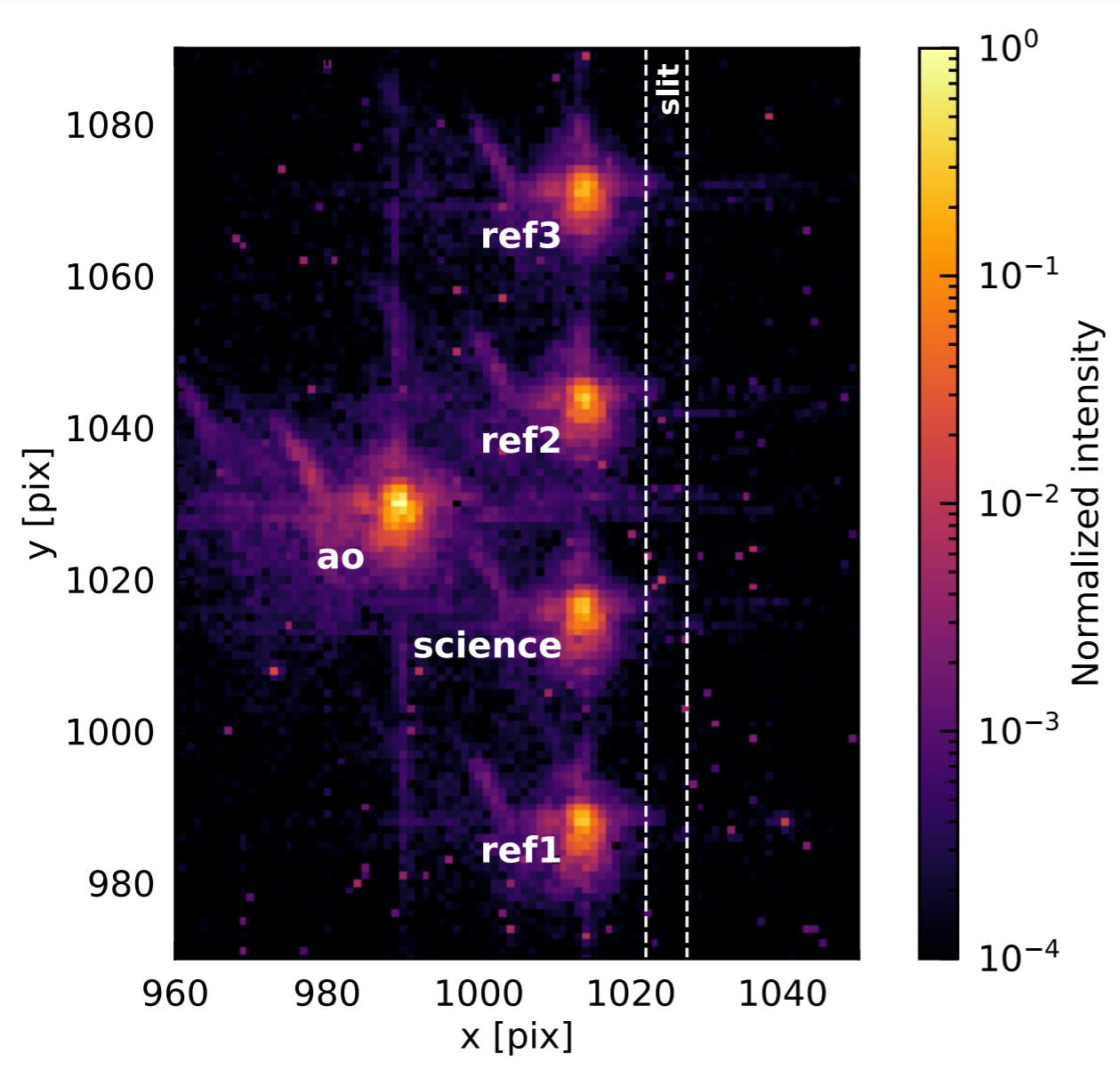
Cross-calibration strategy with SPHERE/IRDIS

Commissioning: AO guide fiber leakage



MACAO guide fiber leaks inside the slit

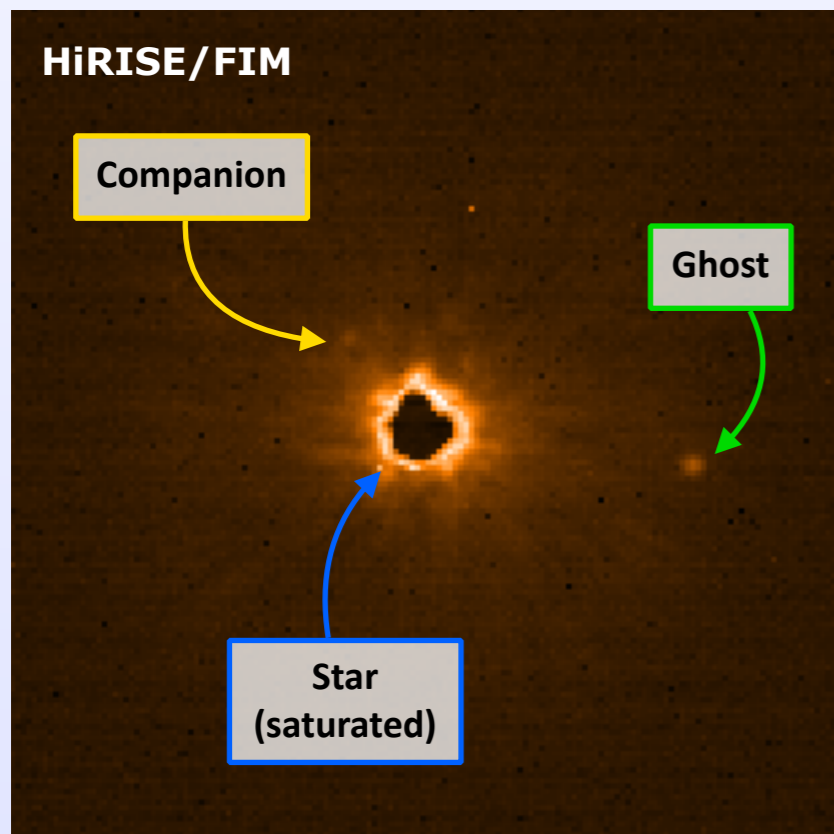
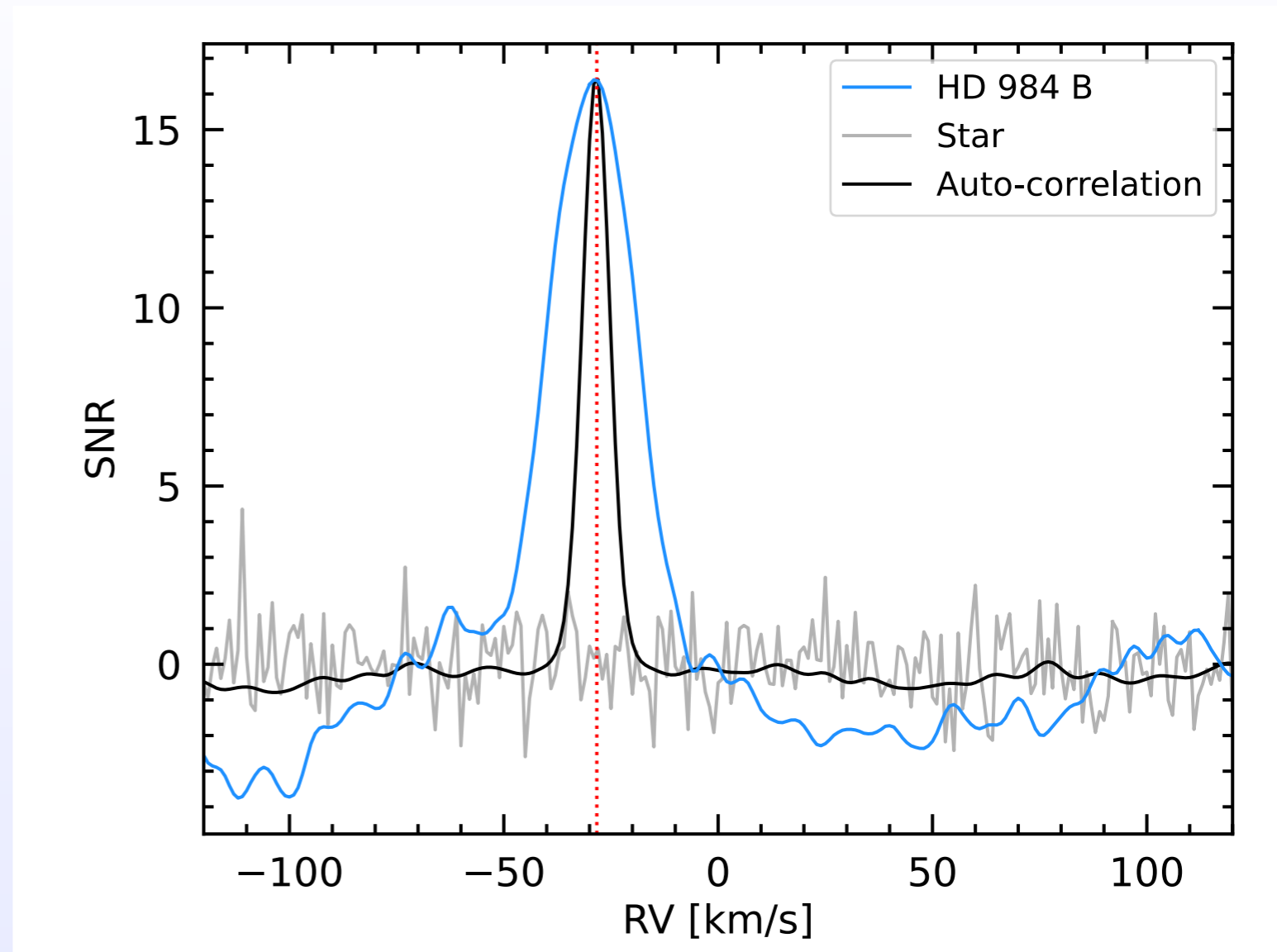
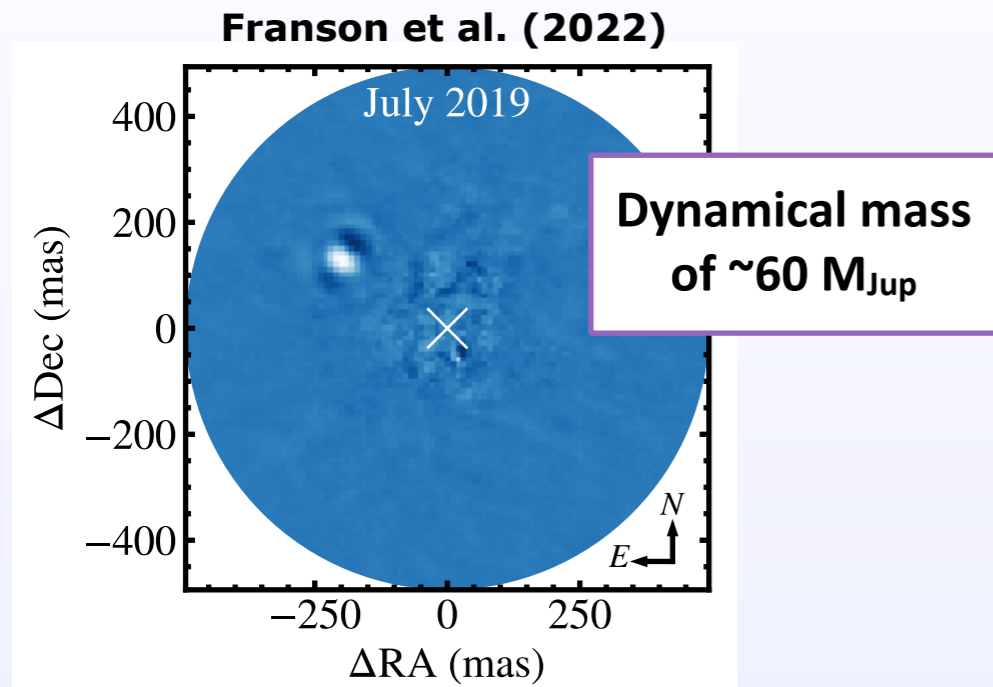
Commissioning: AO guide fiber leakage



Mitigation strategy already foreseen

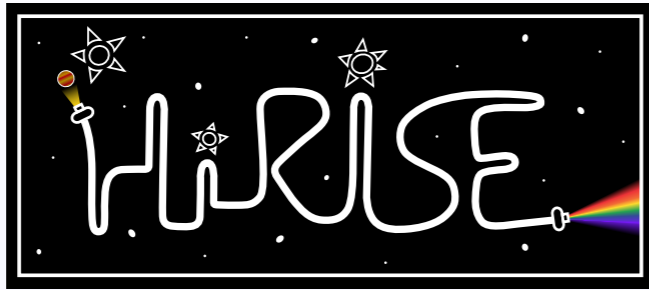
Commissioning: a first detection of HD984 B

Discovery: Meshkat et al. (2015)



- Least-square CCF analysis
- BT-Settl model at $T_{\text{eff}} = 2700\text{K}$
- $v_{\text{orb}} \sin i = -31 \text{ km/s}$, $v_{\text{rot}} \sin i = 13 \text{ km/s}$
- Value in agreement with KPIK data (Costes et al. in prep.)

Conclusions & prospects

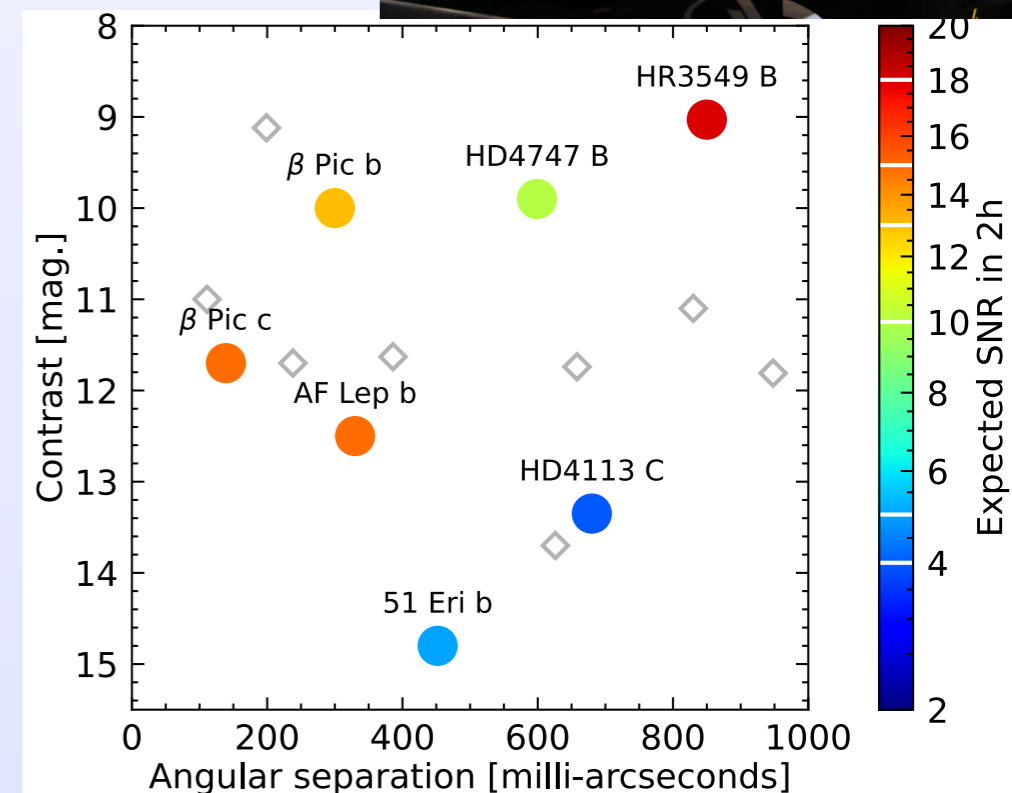
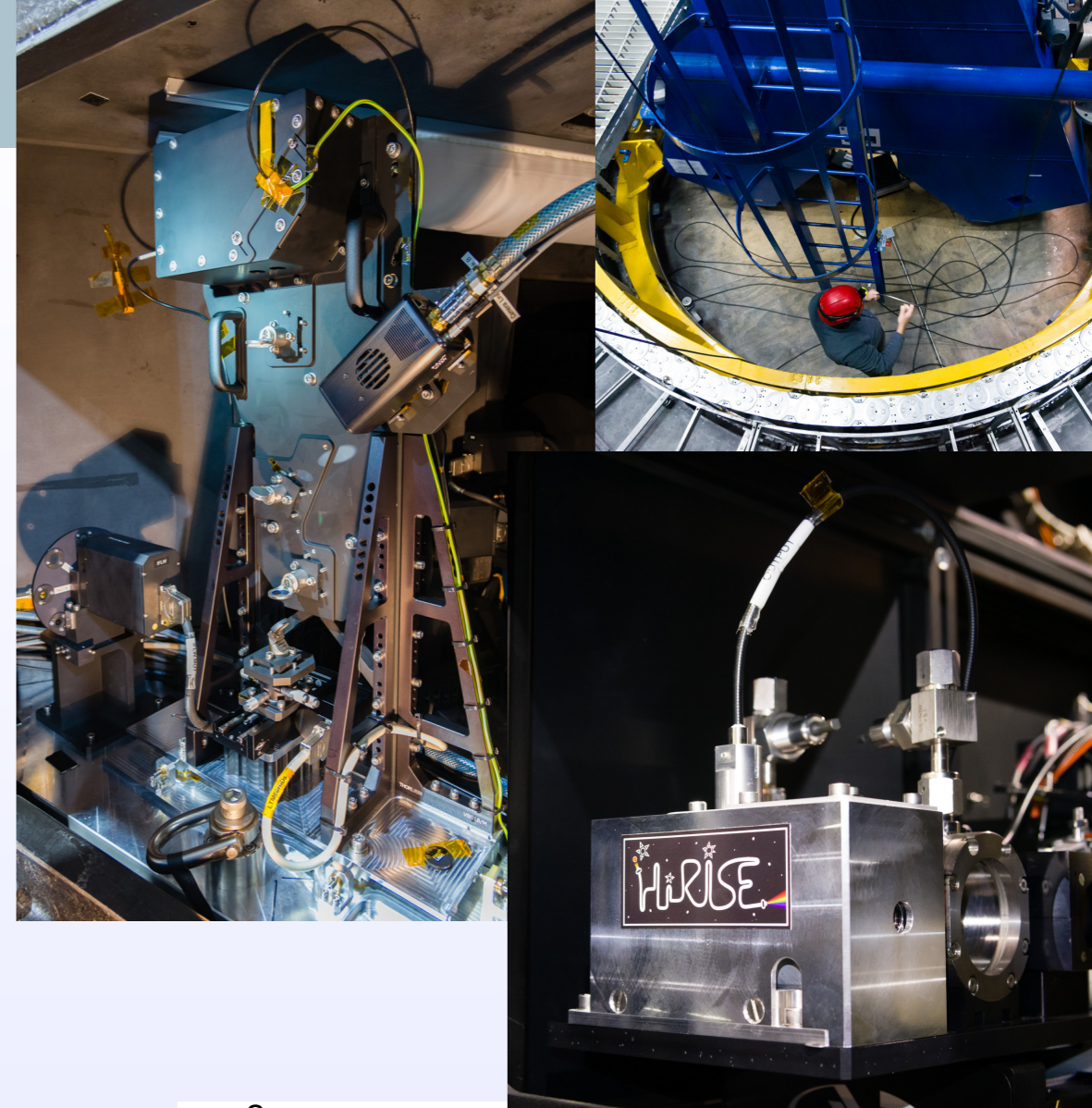


1. High-spectral resolution of directly-imaged exoplanets

- Unique opportunity on VLT/UT3!
- Coupling between SPHERE and CRIREs+ in H band
- Visitor instrument on the VLT
- First light in July 2023

2. HiRISE survey

- New opportunities for understanding of exoplanets
- 3 nights in November 2023
- Large programme to be submitted in P114



HiRISE core team



- +Graham Murray
- +Gérard Zins
- +Jérôme Paufigue
- +Ulf Seemann
- +Heiko Anwand-Heerwart
- +Mark Phillips

