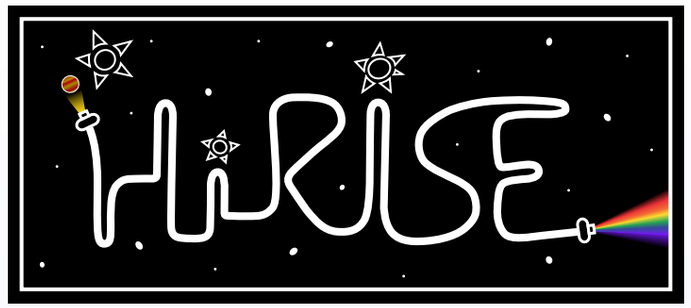
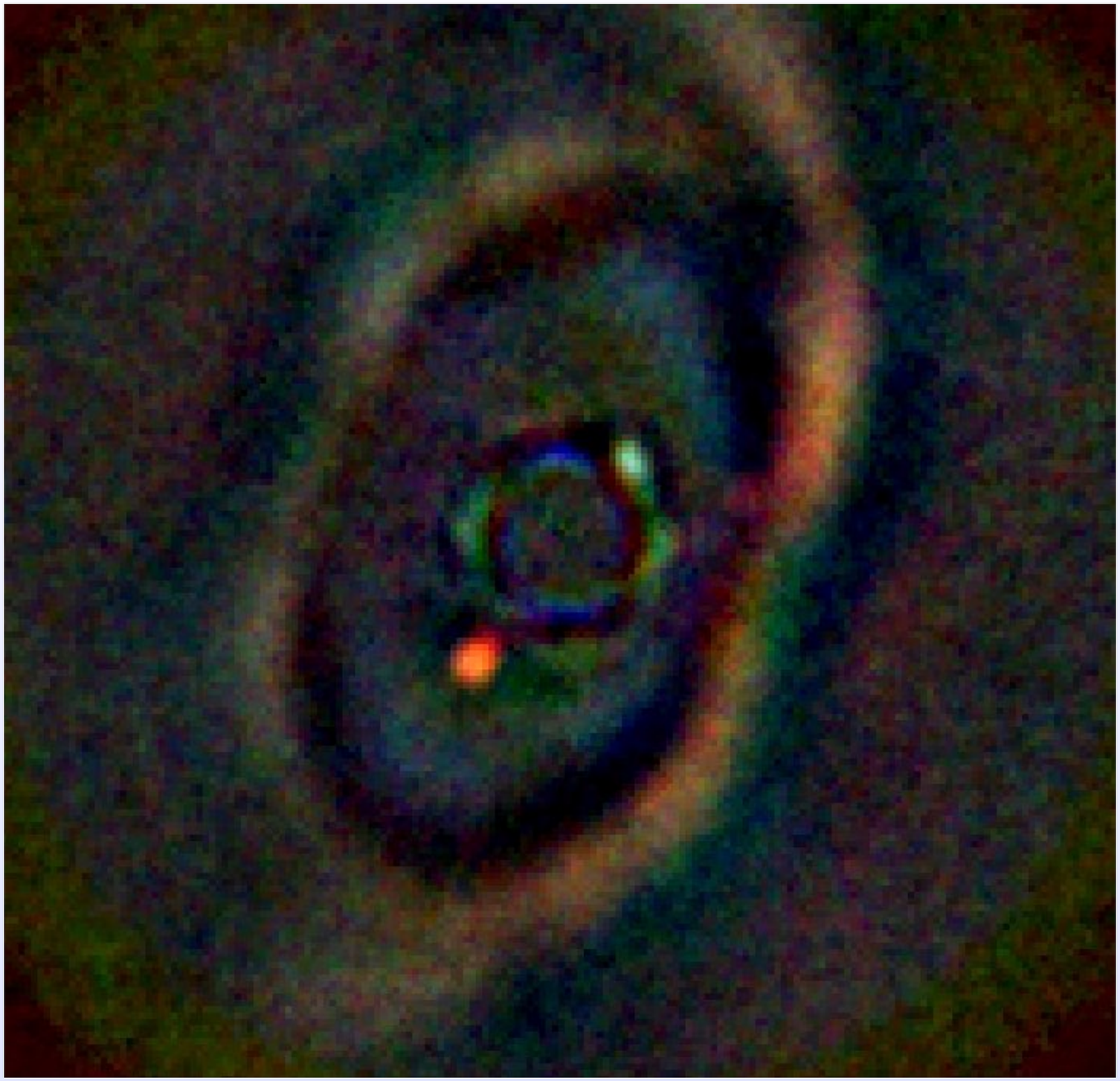


Bringing high-spectral resolution to SPHERE with a fiber coupling to CRIRES+

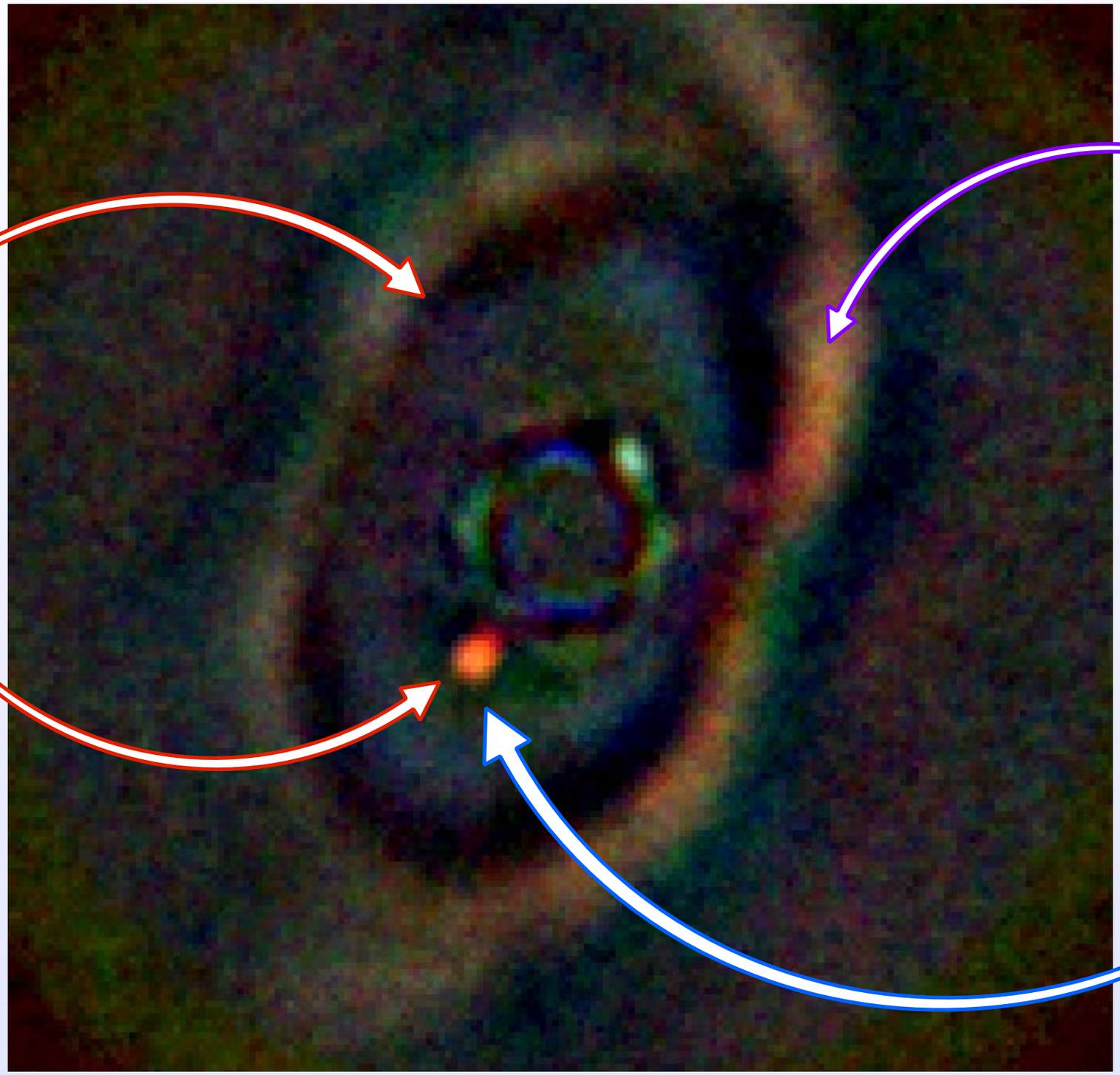
Arthur Vigan
Laboratoire d'Astrophysique de Marseille (LAM)
Centre National de la Recherche Scientifique (CNRS)

LAM: A. Vigan, G. Otten, E. Muslimov, Y. Charles, K. Dohlen, R. Pourcelot, J.-L. Beuzit, M. Houllé, E. Choquet, N. Tchoubaklian, J.-F. Sauvage, P. Cristofari, P. Tomlinson / **University of Göttingen:** U. Seemann, A. Reiners / **ESO:** M. Kasper, R. Dorn, J. Milli, G. Zins, P. Figueira / **University of Exeter:** M. Phillips, I. Baraffe / **IPAG:** D. Mouillet, A. Carlotti / **Laboratoire Lagrange:** M. N'Diaye, R. Flamary, D. Mary / **LESIA:** A. Boccaletti, B. Charnay

Direct imaging of exoplanetary systems



Direct imaging of exoplanetary systems

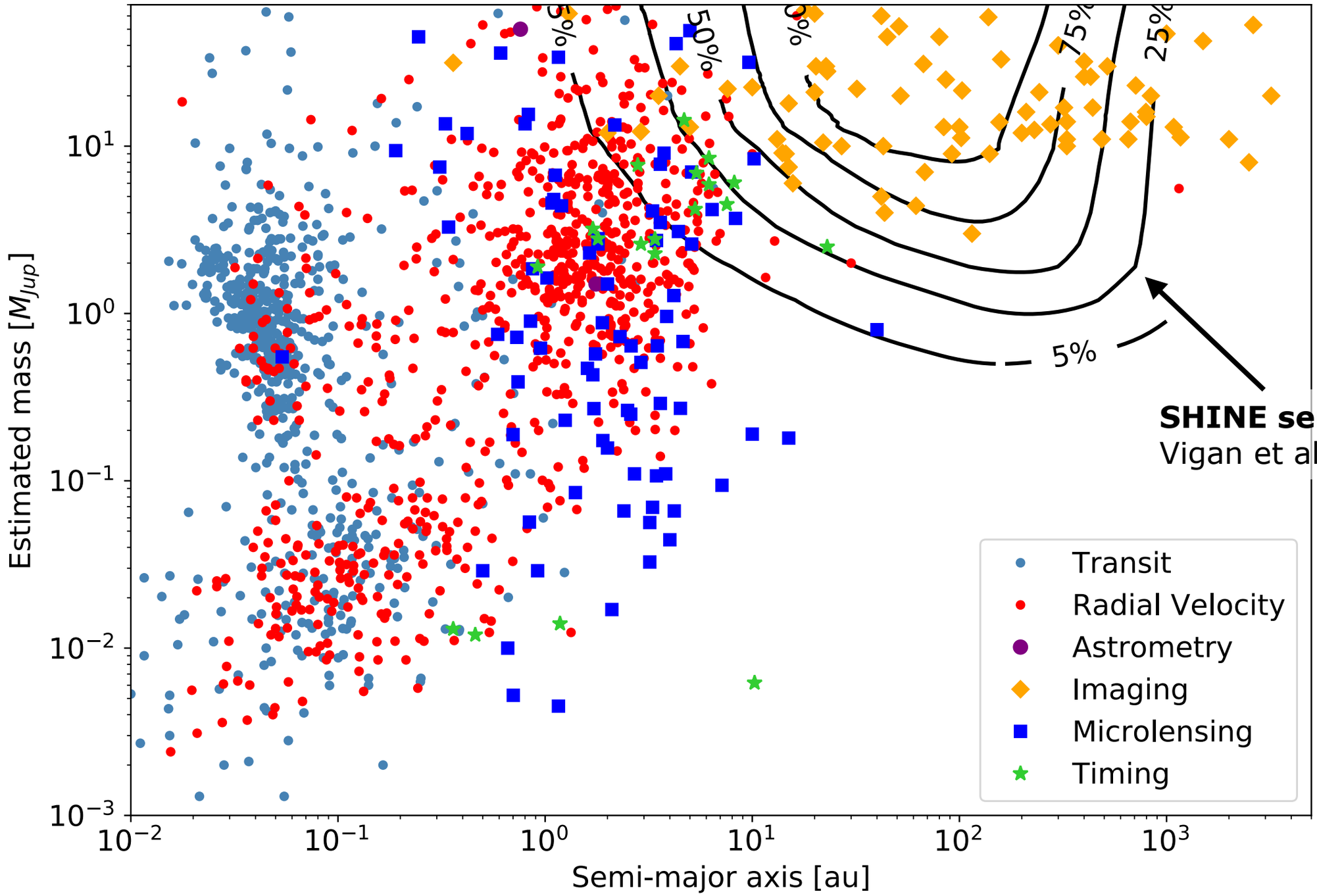


System architecture

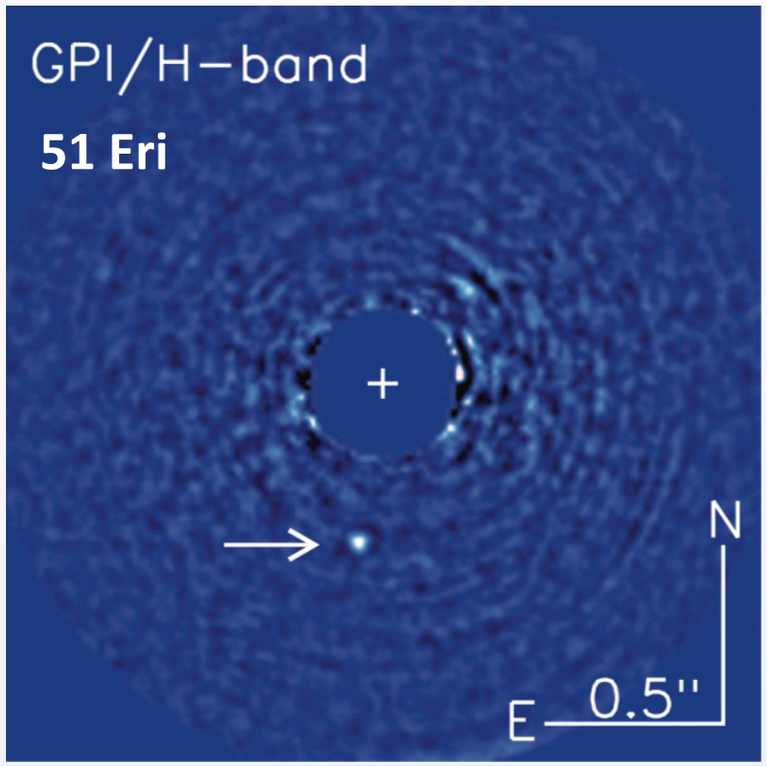
Dust properties

Planet composition

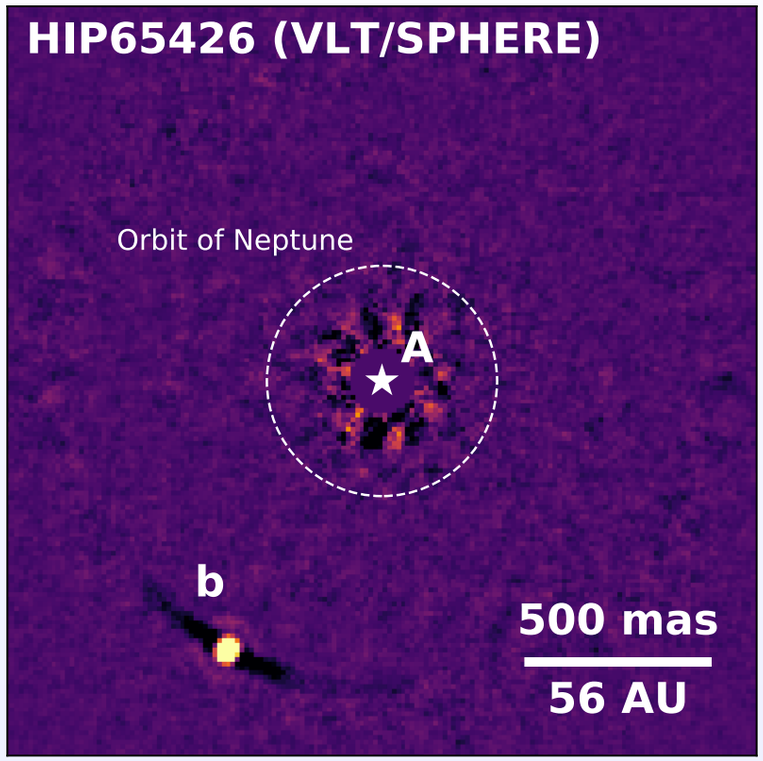
Direct imaging of exoplanetary systems



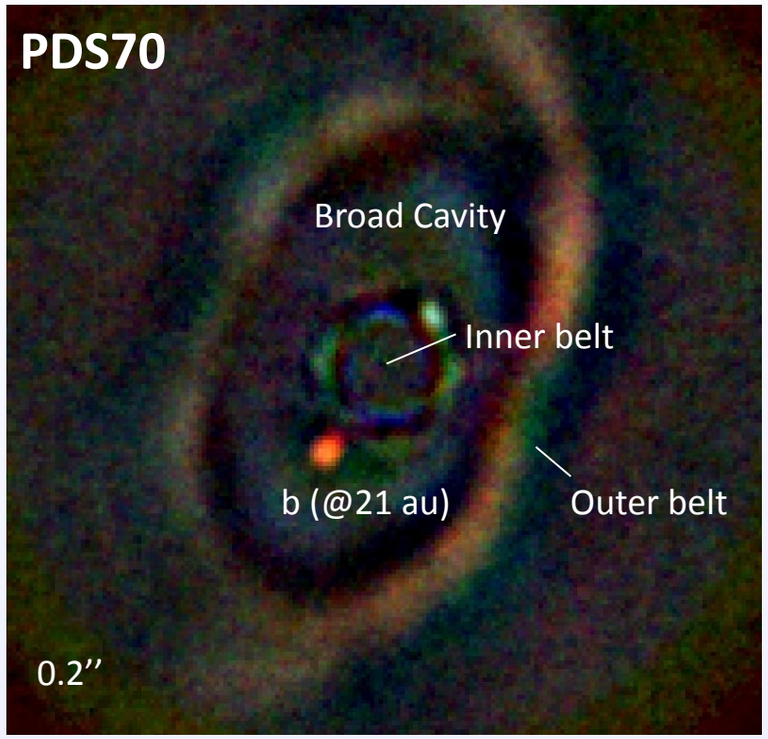
New SPHERE and GPI detections



Macintosh et al. 2015

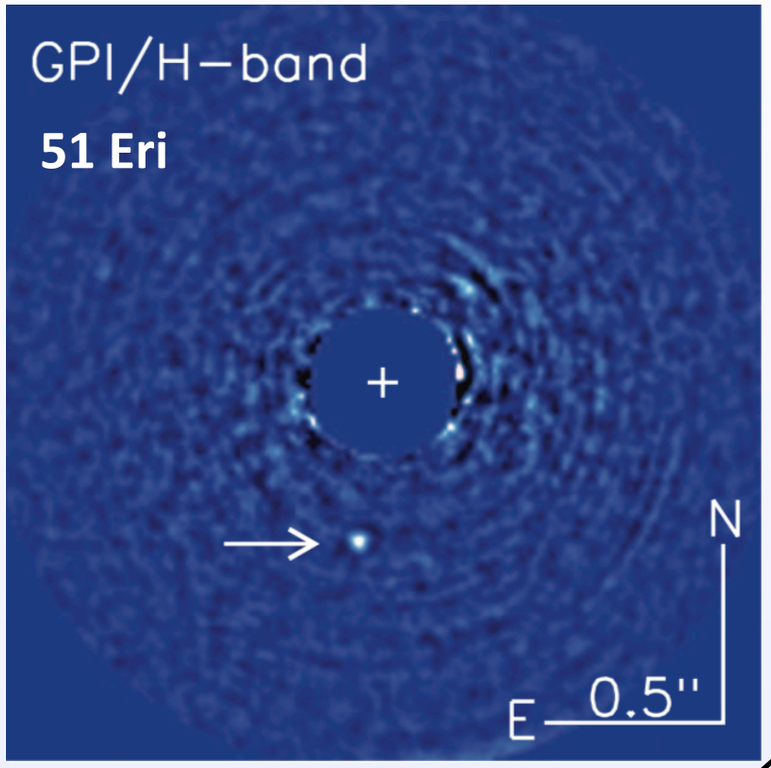


Chauvin et al. 2017

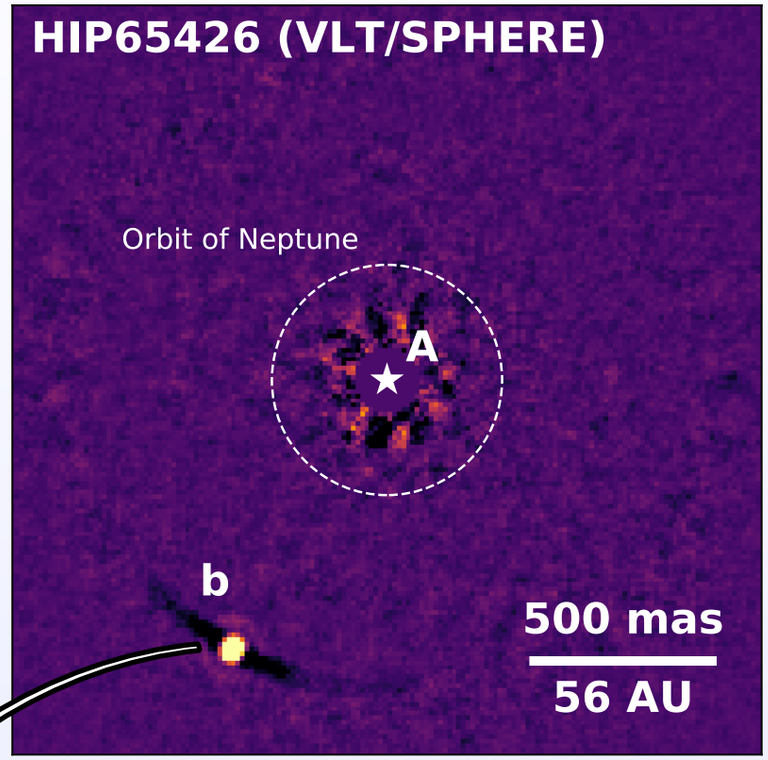


Keppler et al. 2018

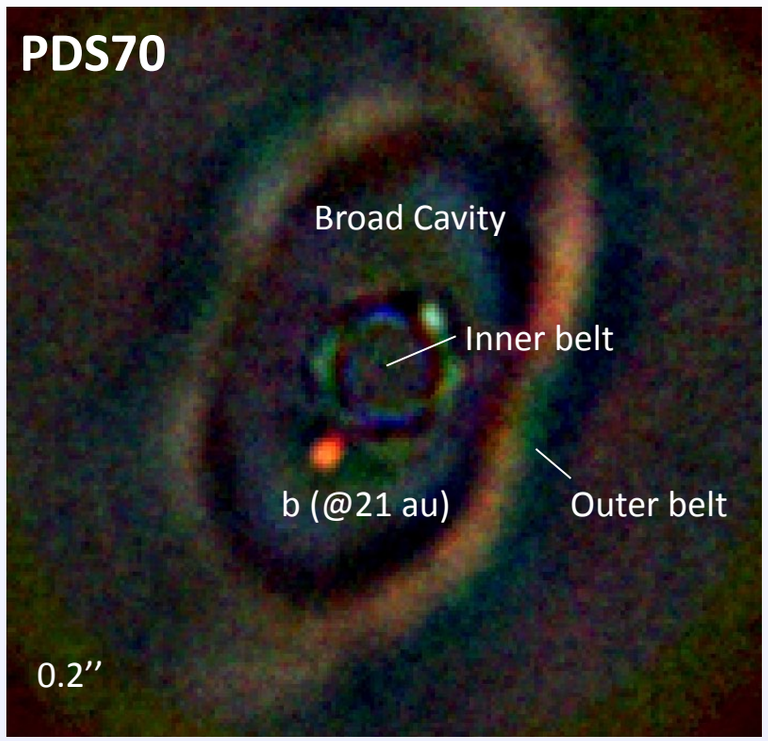
New SPHERE and GPI detections



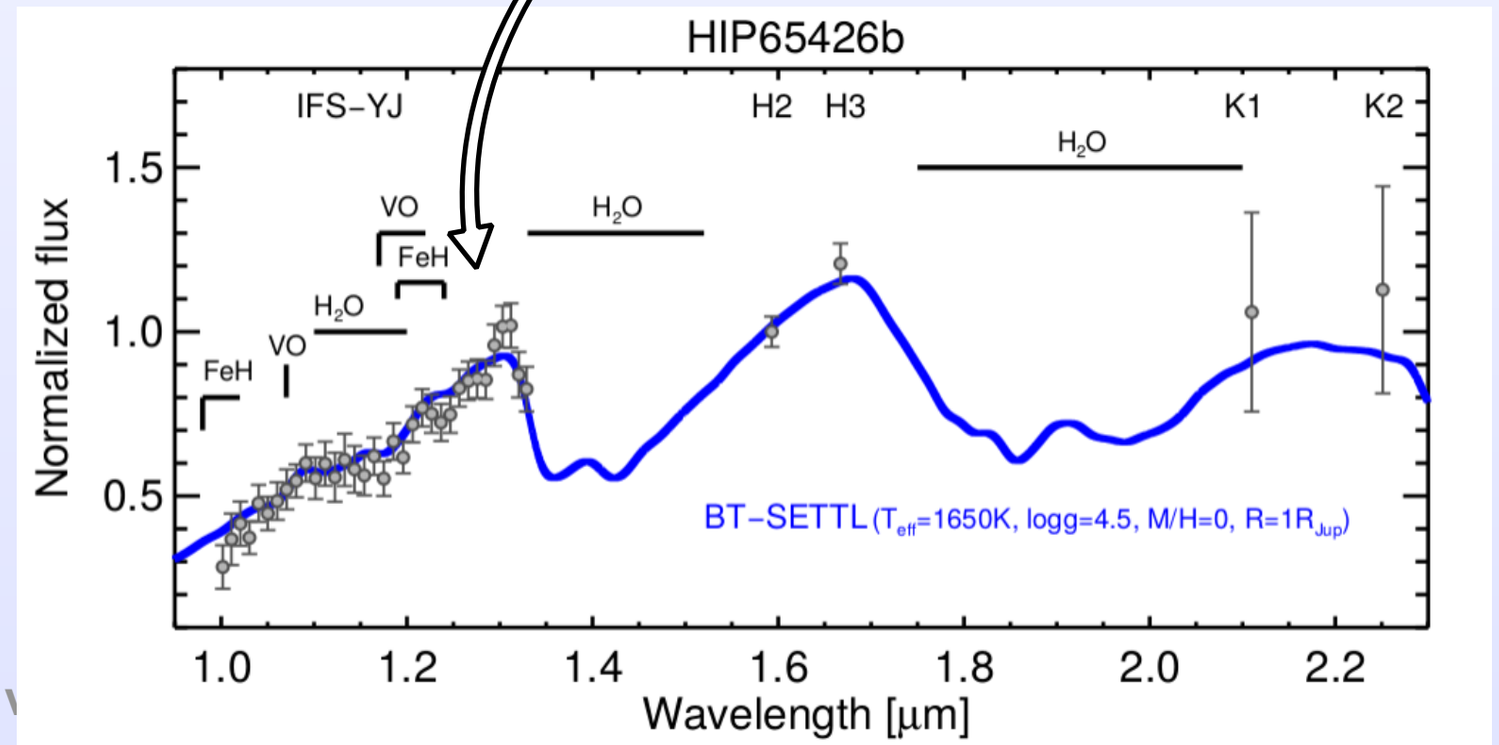
Macintosh et al. 2015



Chauvin et al. 2017



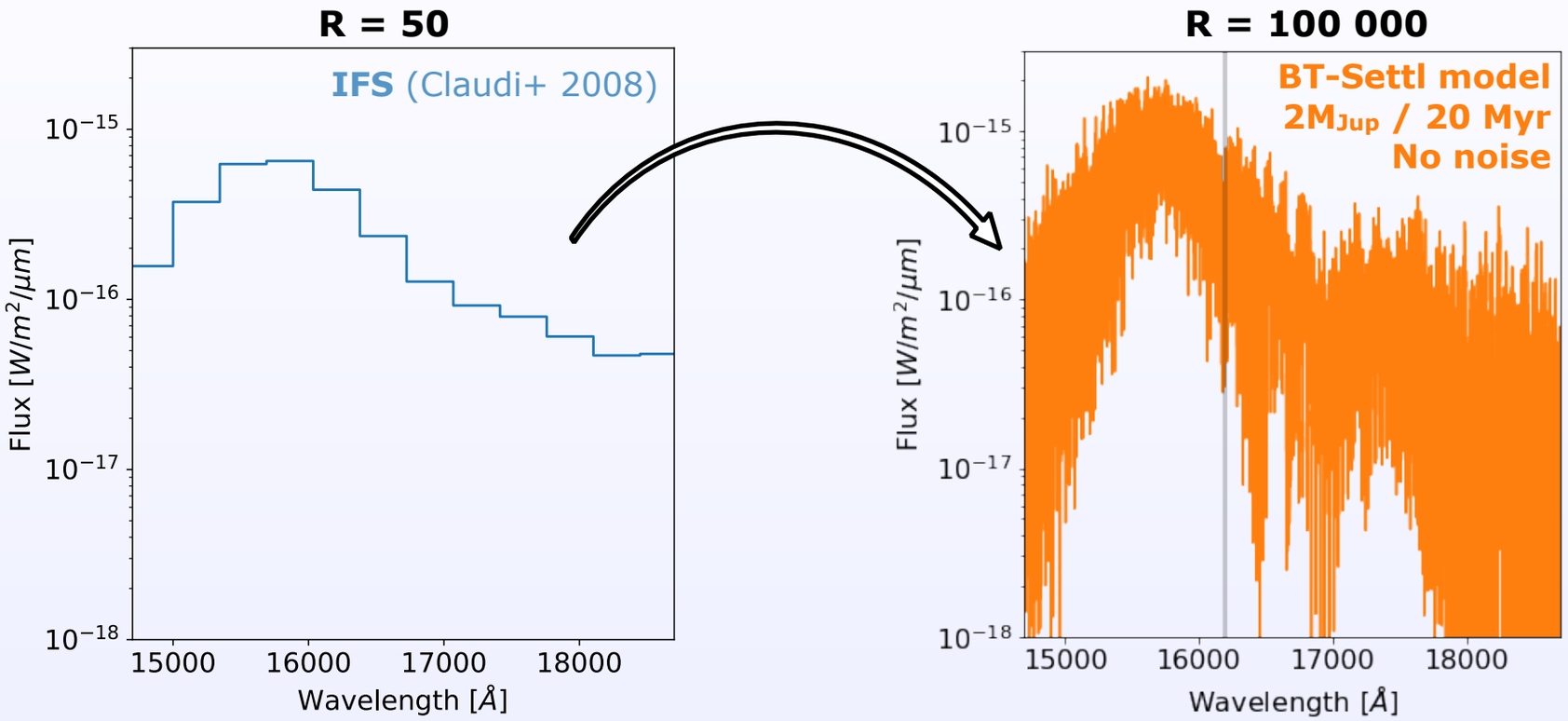
Keppler et al. 2018



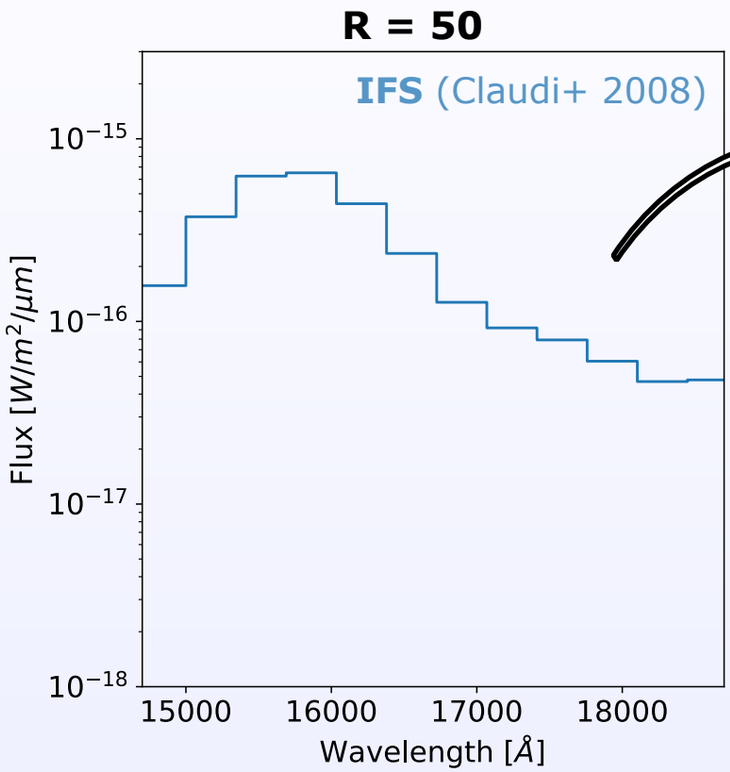
Very low resolution spectroscopy!

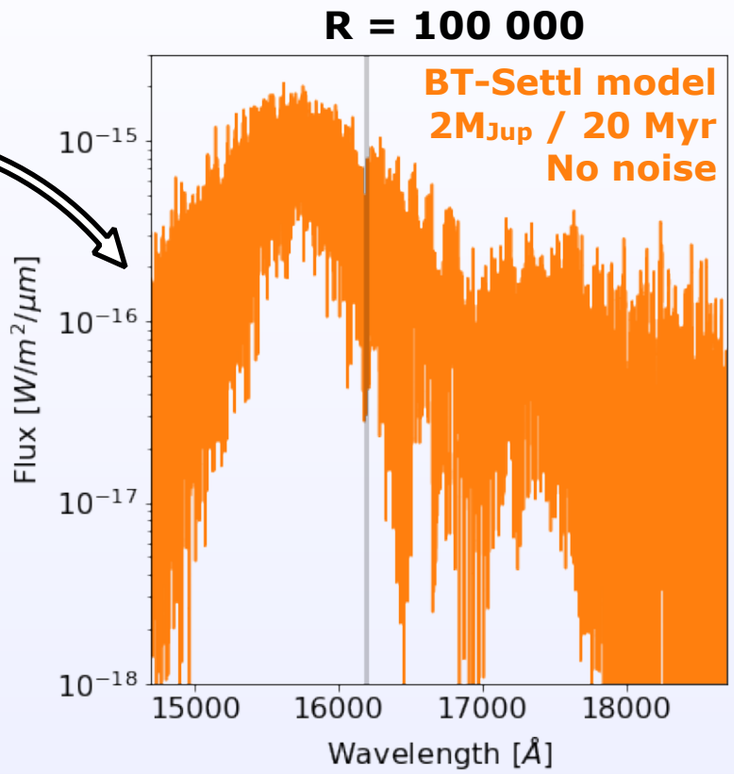
→ First order characterisation

Characterisation at high-spectral resolution



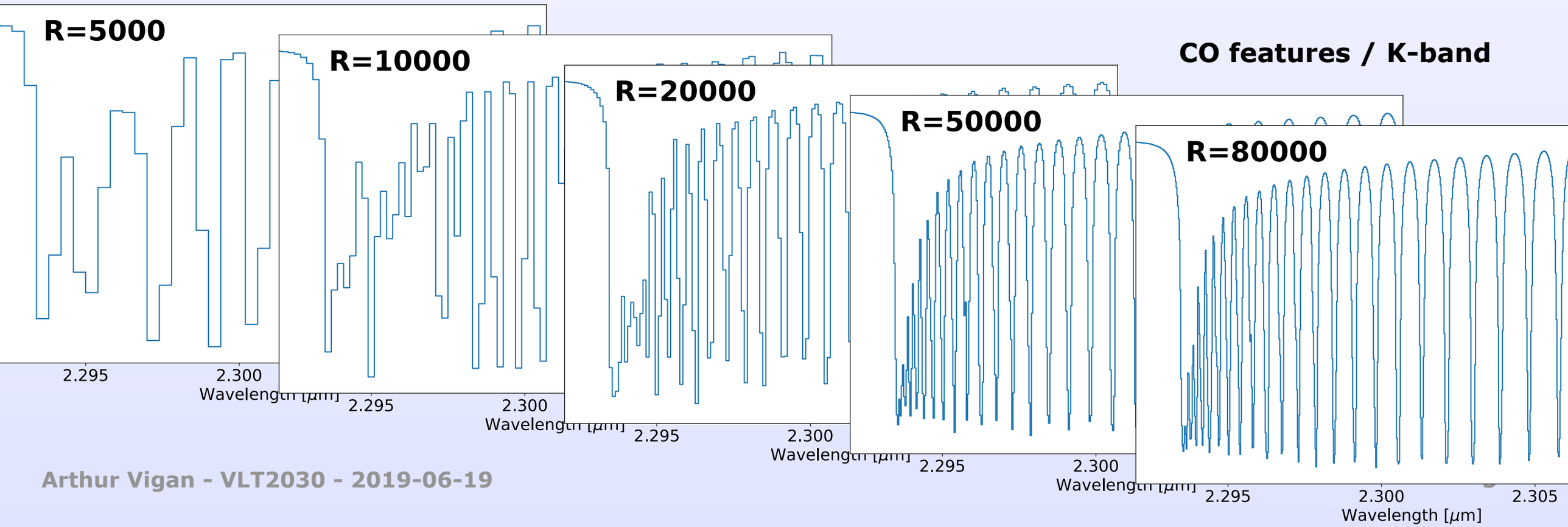
Characterisation at high-spectral resolution



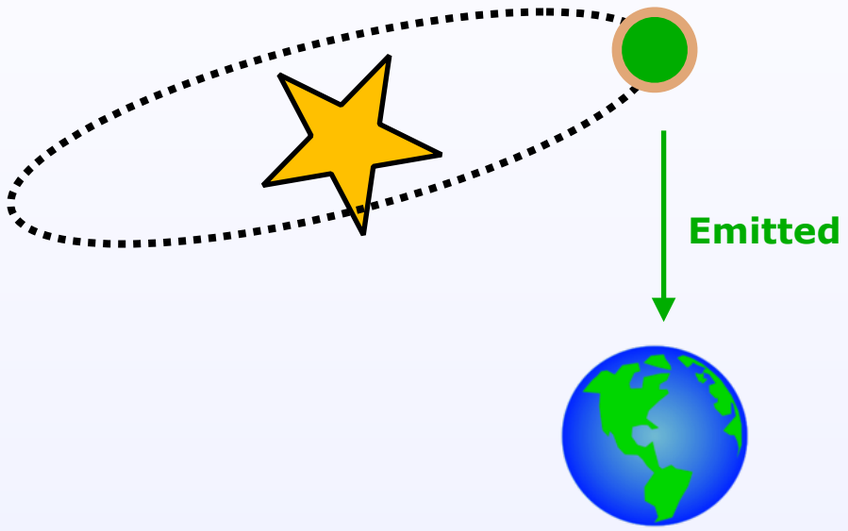


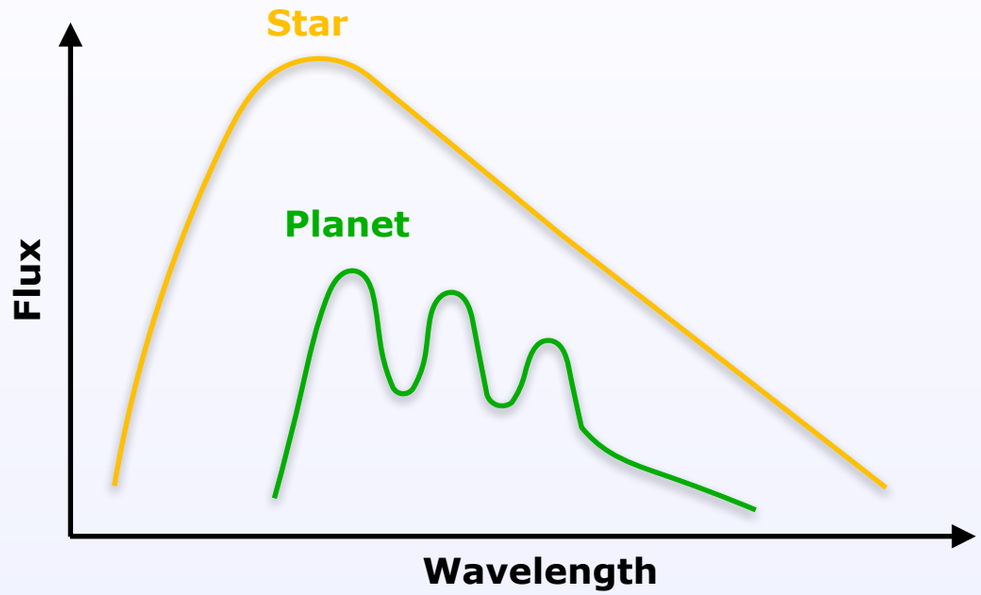
Requires
R ≫ 10 000

CO features / K-band

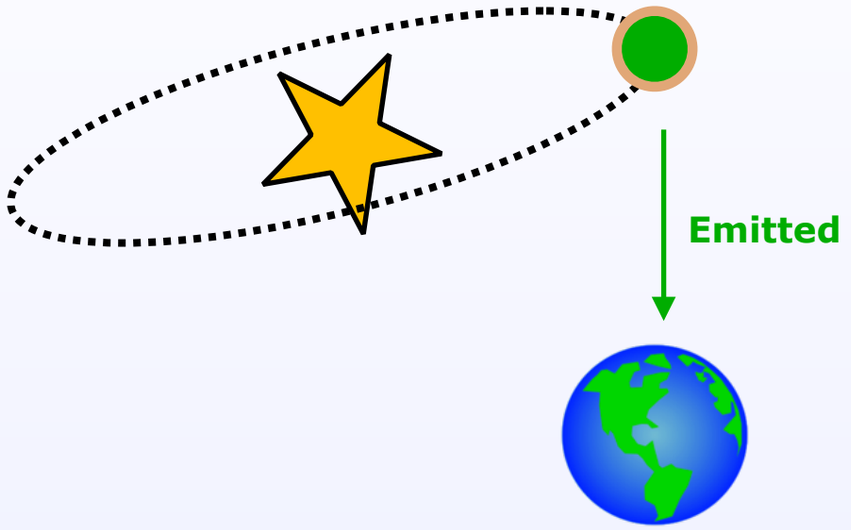


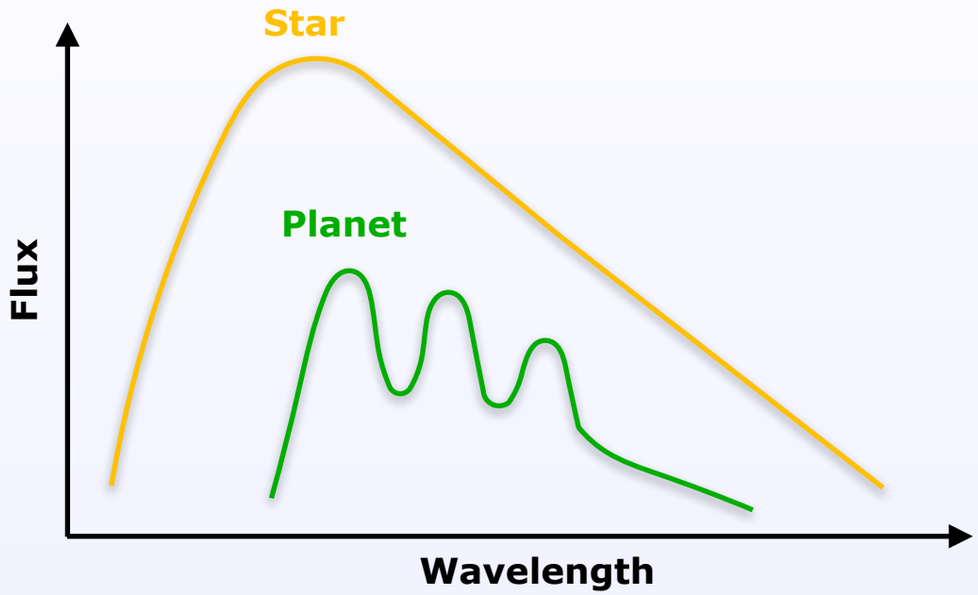
Detection boost at high-spectral resolution



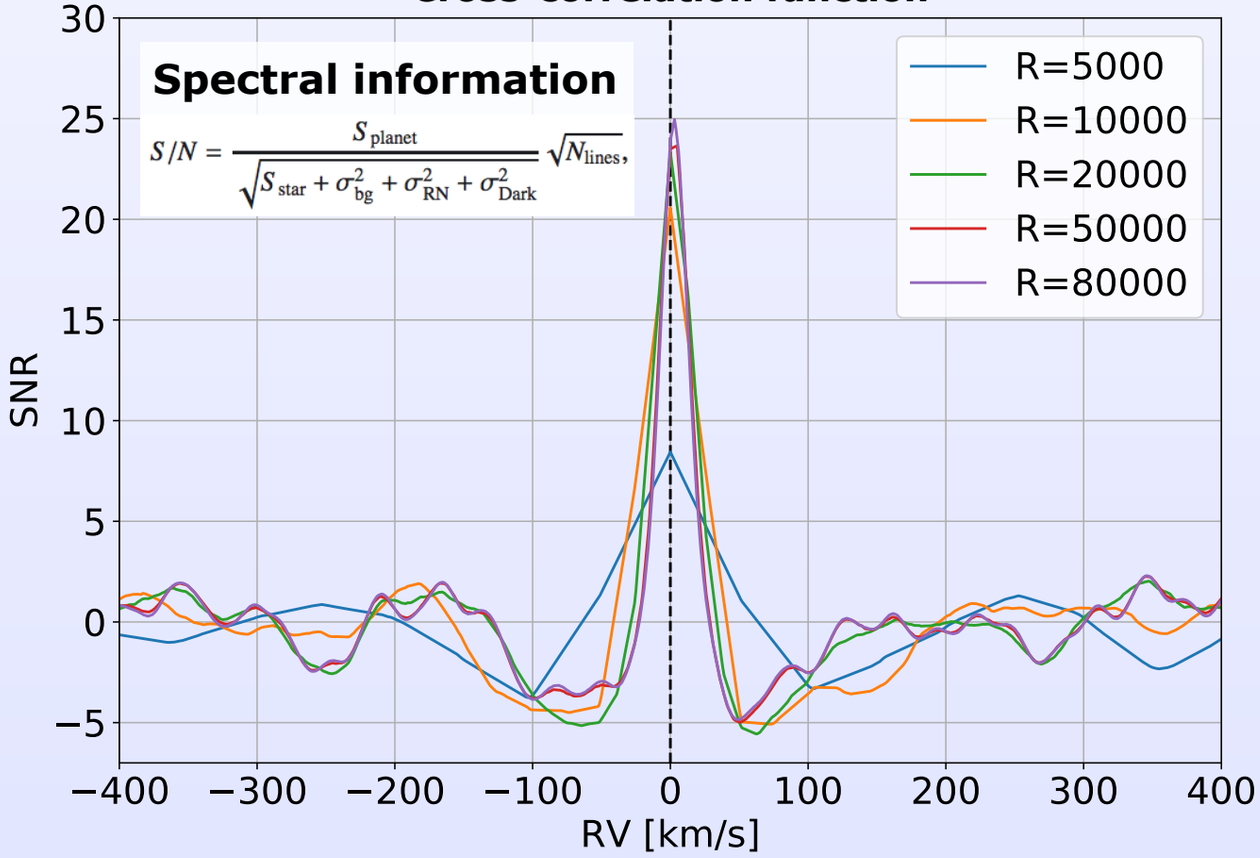


Detection boost at high-spectral resolution

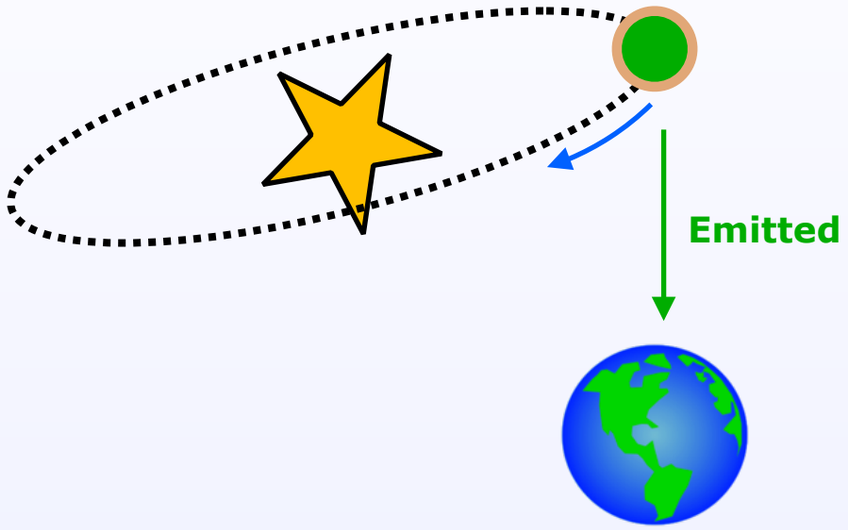


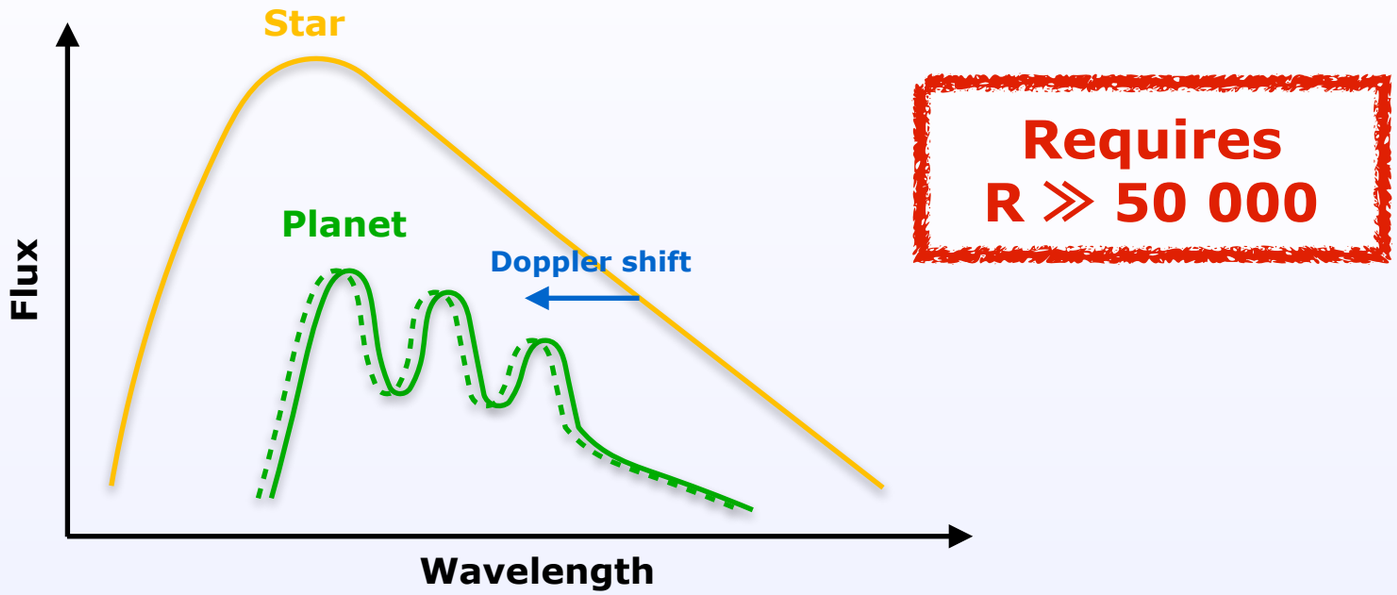


Cross-correlation function



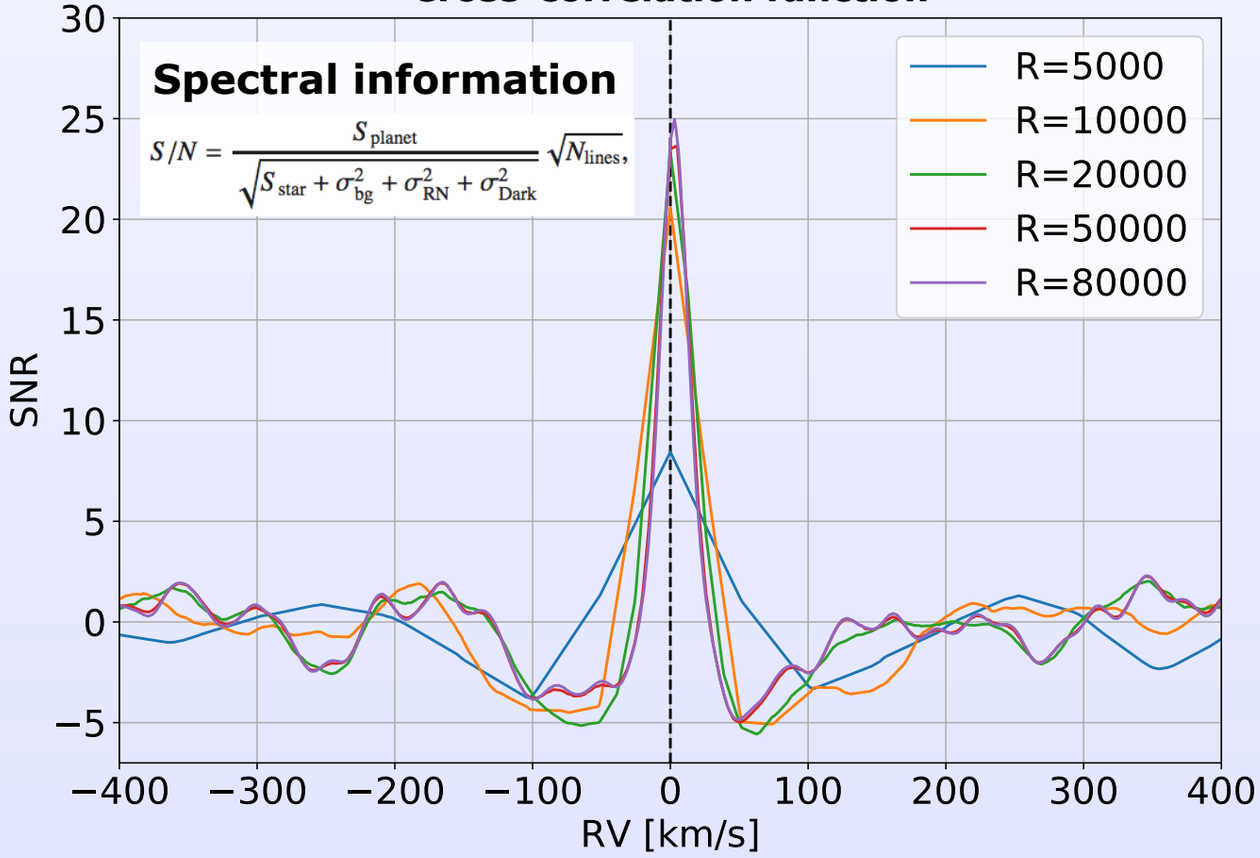
Detection boost at high-spectral resolution





Requires
$R \gg 50\,000$

Cross-correlation function



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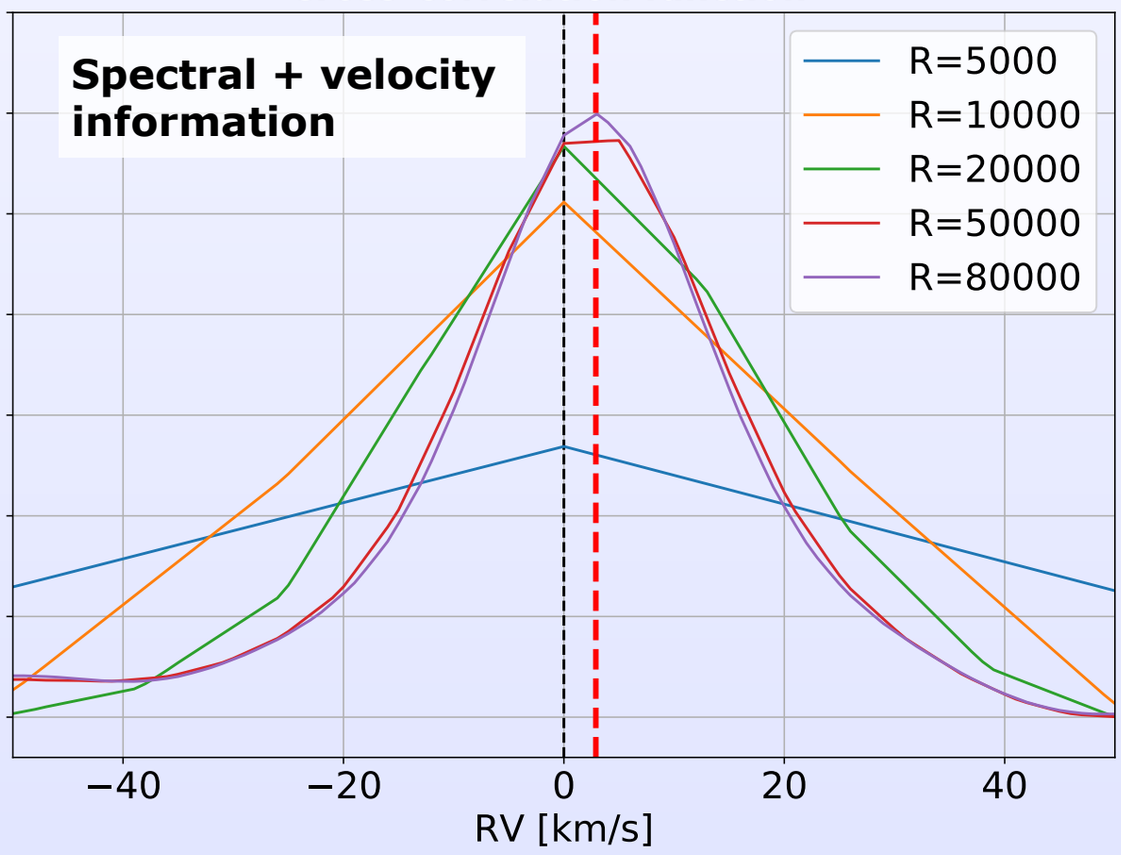
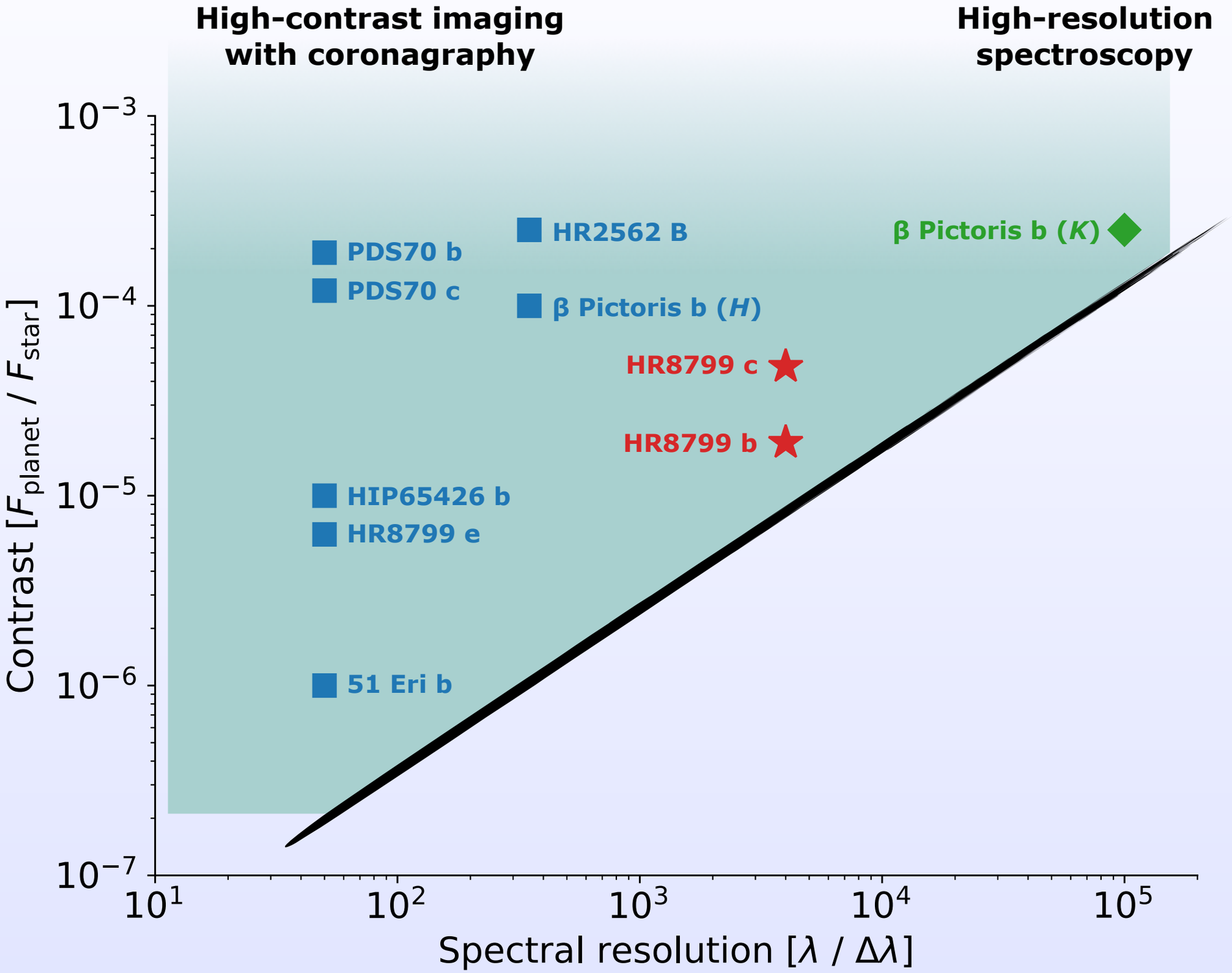
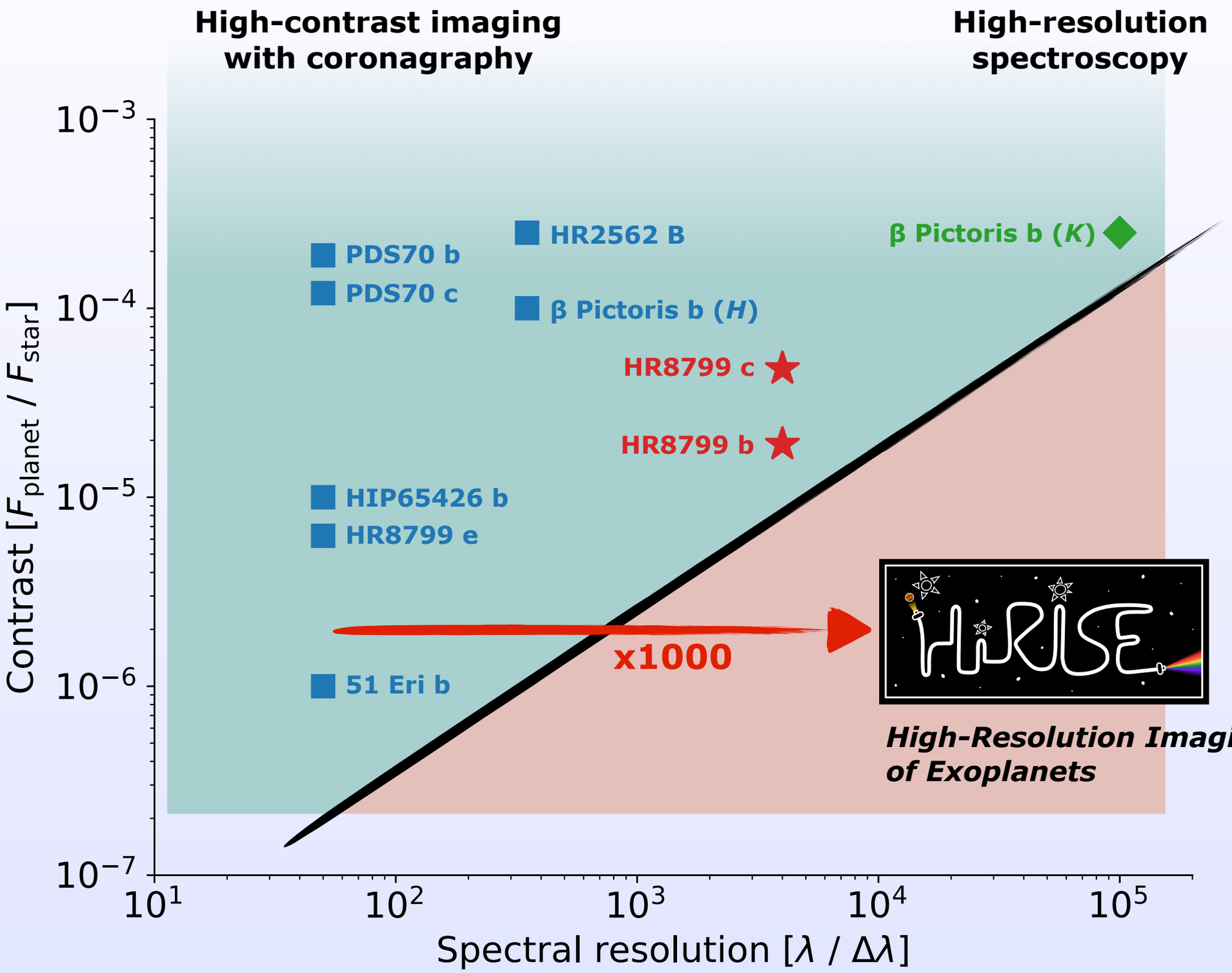


Young exoplanets characterisation in near-IR



Young exoplanets characterisation in near-IR



Characterisation

10-15 companions already known at

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

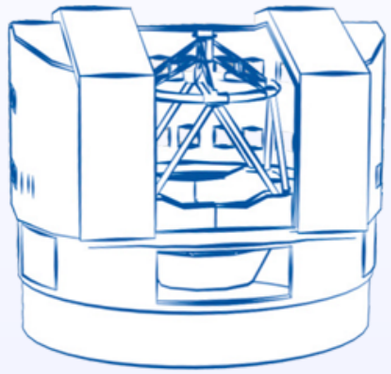
Companions detected by other means

- **Imaging**
- **ESA/Gaia**
- **RV?**

High-Resolution Imaging and Spectroscopy of Exoplanets

HiRISE: a unique window of opportunity

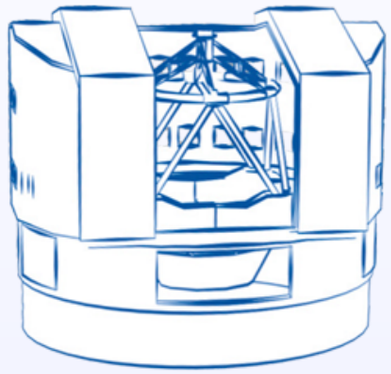
VLT/UT3



High-contrast exoplanet imager		High-resolution spectrograph
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**

HiRISE: a unique window of opportunity

VLT/UT3



High-contrast exoplanet imager

SPHERE

High-resolution spectrograph

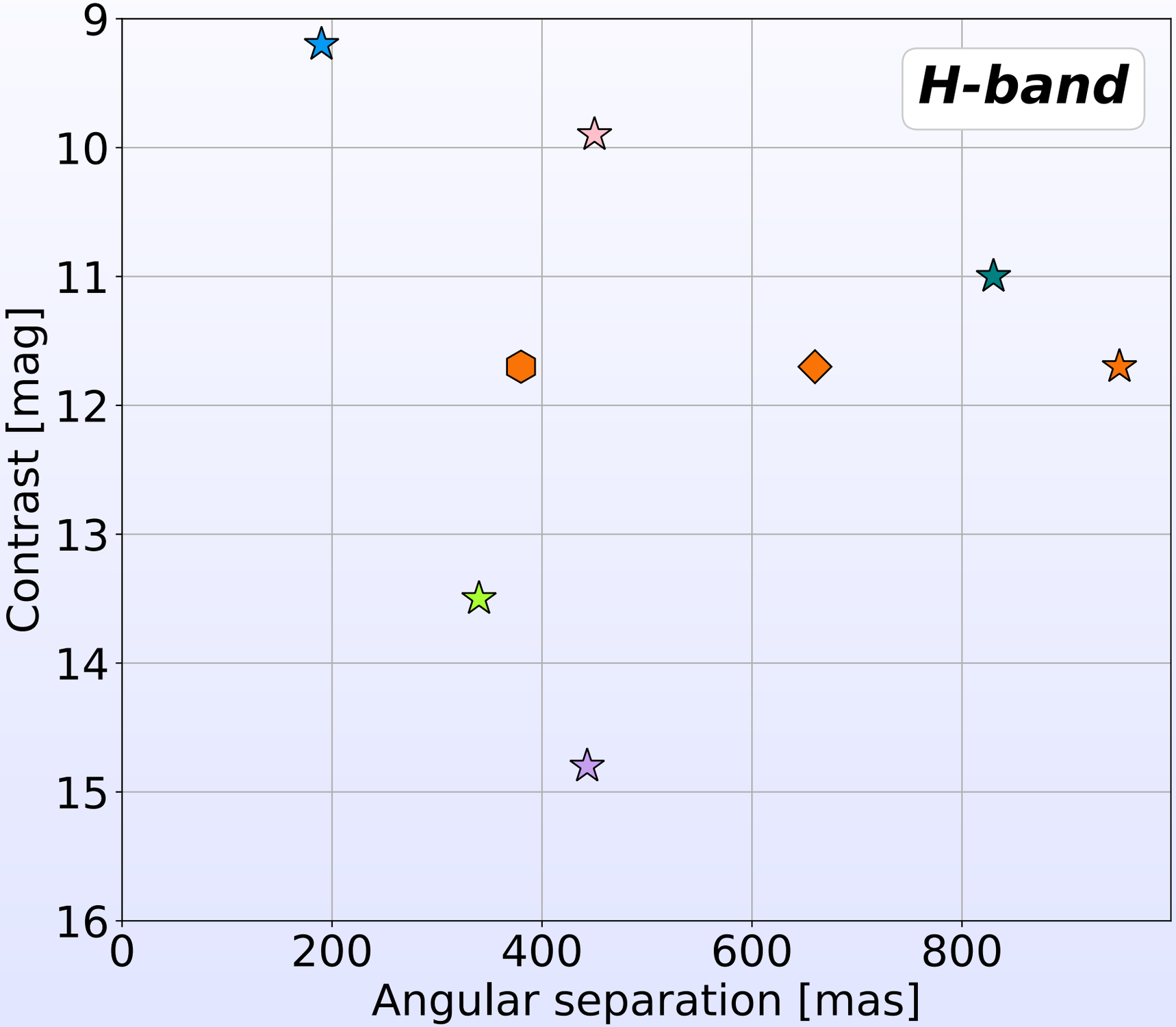
CRIRES+

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

Fiber coupling

HiRISE

Expected performance



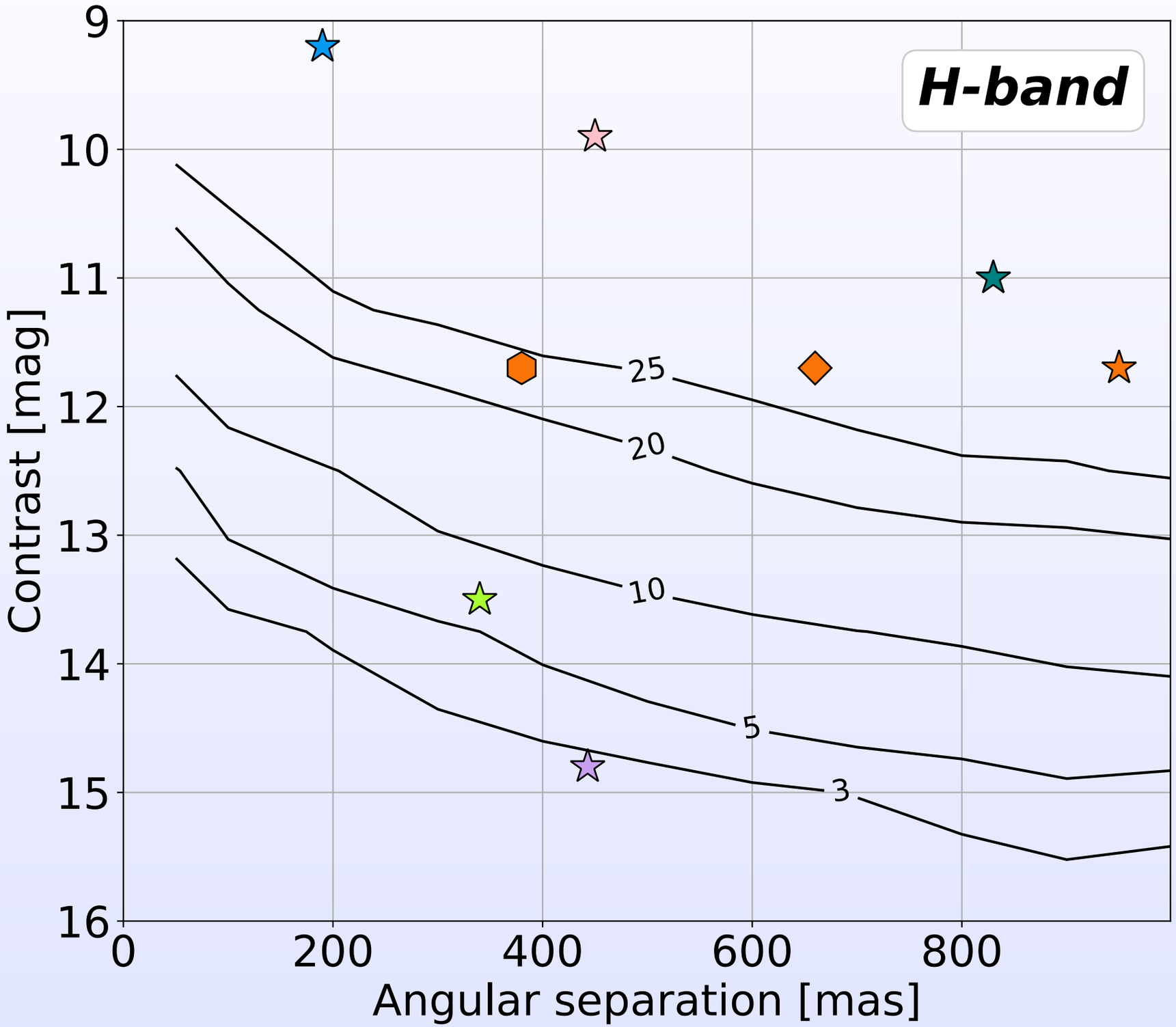
Star
A5V, 19.0 pc, 12.0 Myr
H = 3.5, K = 3.5

Companion
Teff = 1200K
log(g) = 4.0

Observation
Texp = 2.0 h
Test molecule → all12

- CRIRES+
- HiRISE
- β Pic b
- HIP 65426 b
- 51 Eri b
- PDS 70 b
- HR 8799 c
- HR 8799 d
- HR 8799 e
- HD 95086 b
- Mordasini+ 2017 10 Myr - hot start
- SPHERE/IFS, 5σ SHINE best 20%

Expected performance



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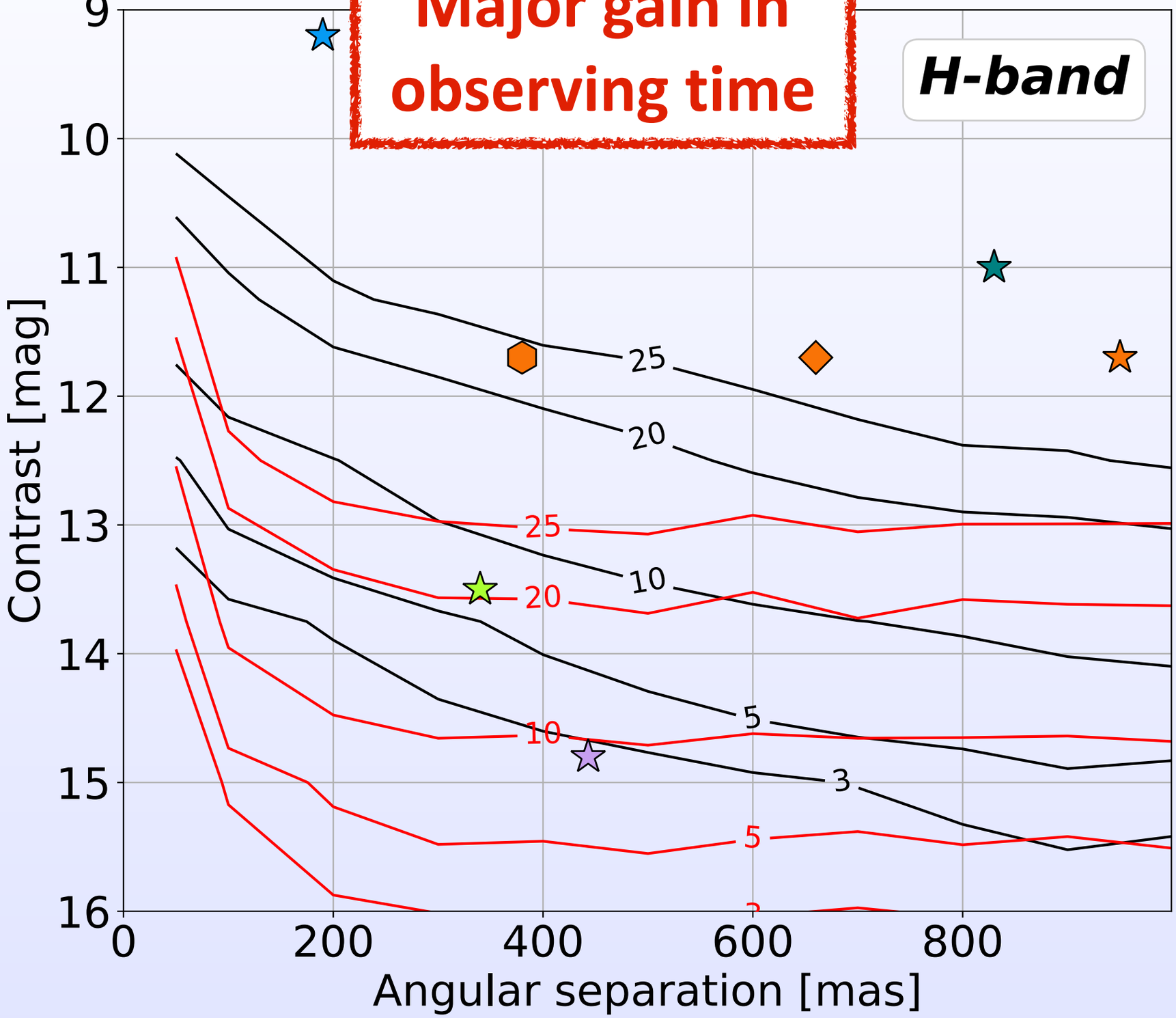
Expected performance

Major gain in observing time



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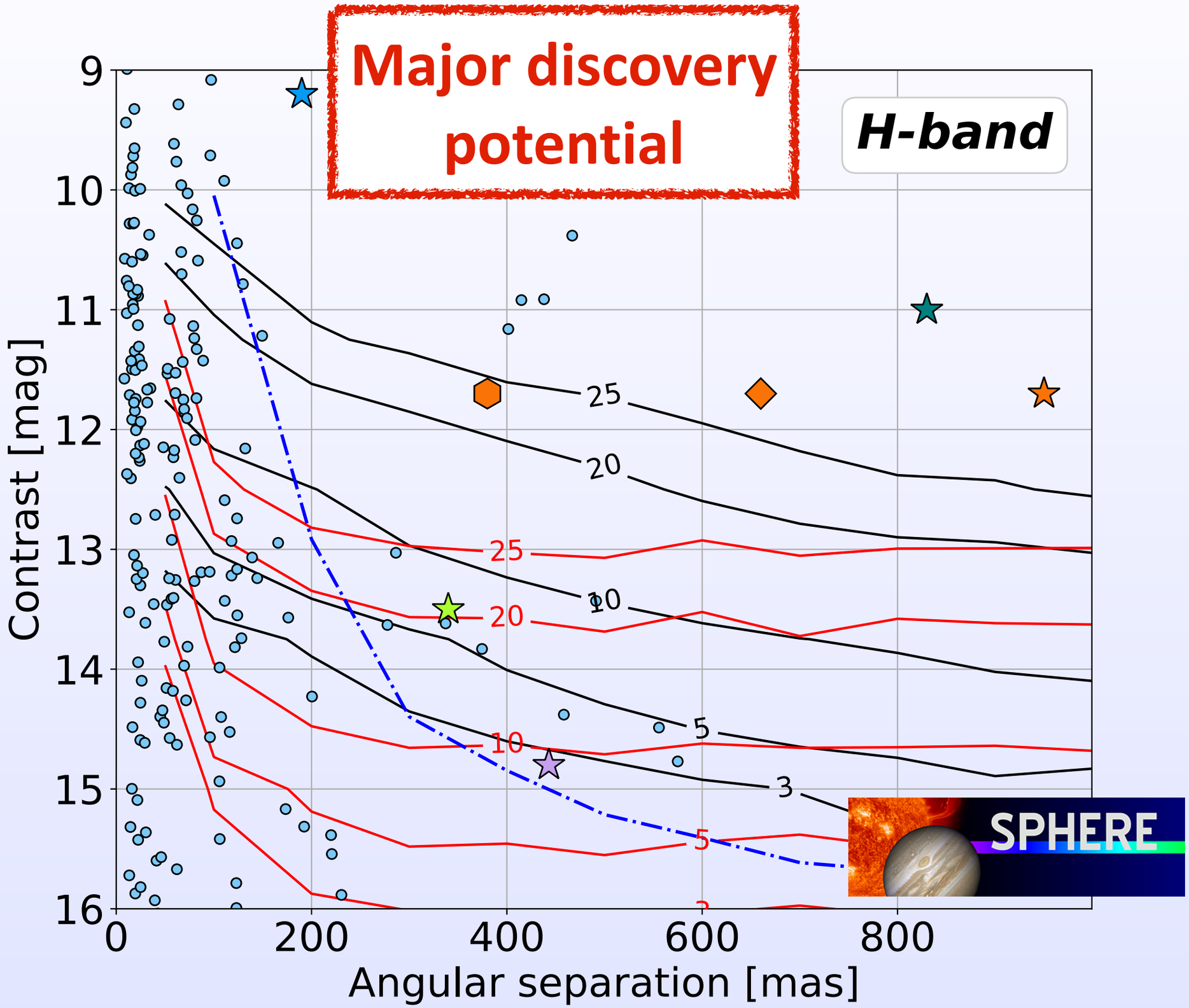
Expected performance



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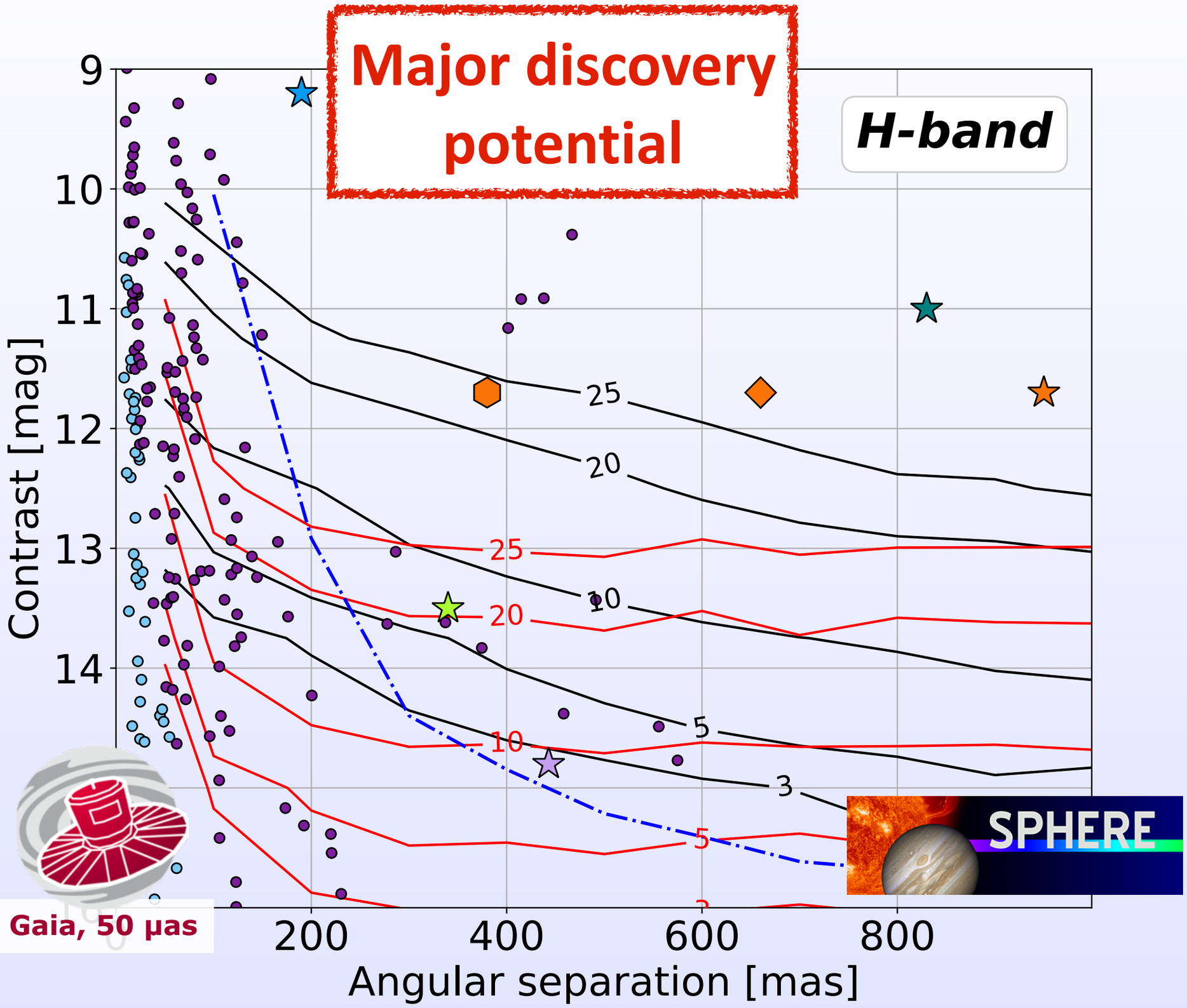
+ see G. Otten's presentation next

Expected performance



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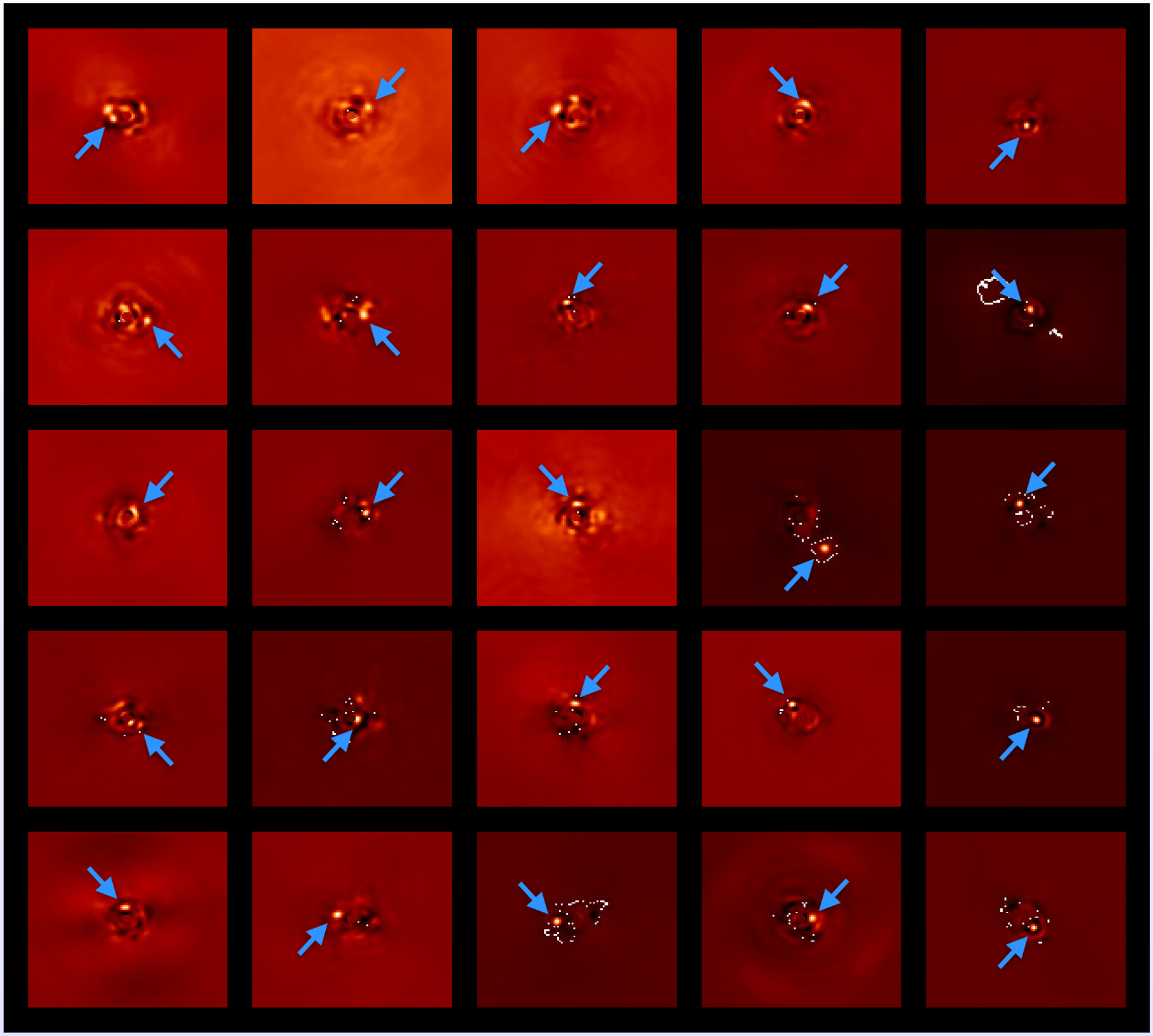
- Mordasini+ 2017 10 Myr - hot start
- SPHERE/IFS, 5σ SHINE best 20%

+ see G. Otten's presentation next

Confirming borderline candidates

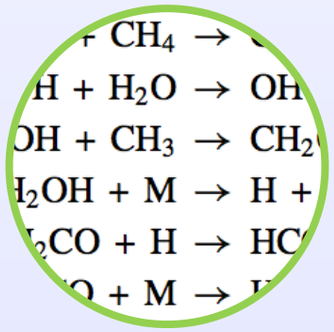


Planet confirmation + characterisation

Credit: A. Müller (MPIA)
SHINE data
RDI reprocessing

New science at high-spectral resolution

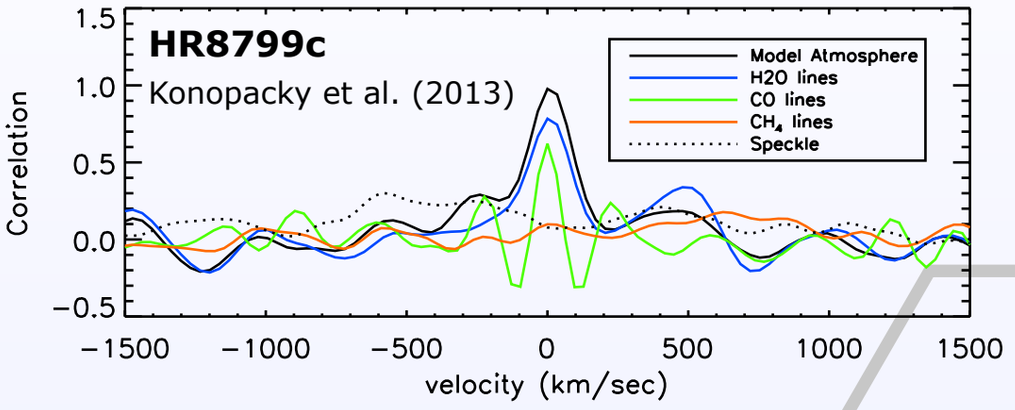
Formation, migration & evolution



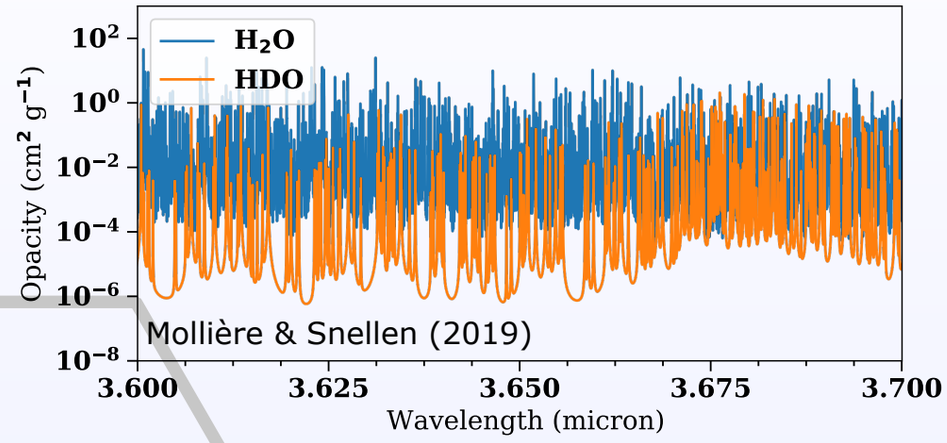
Atmospheric chemistry & dynamics

New science at high-spectral resolution

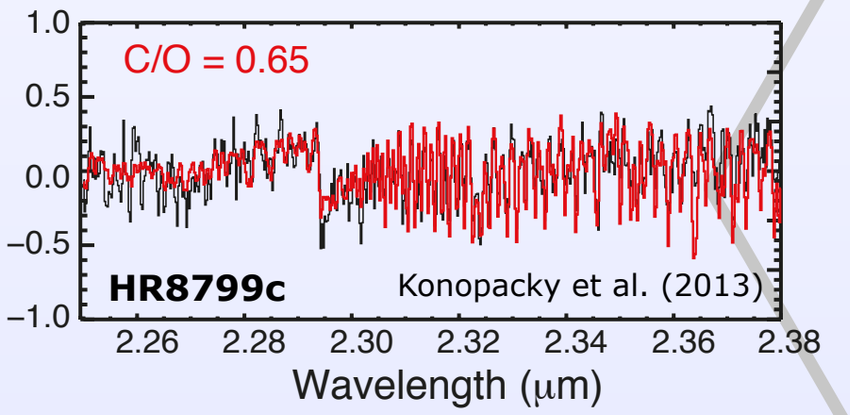
Molecules detection



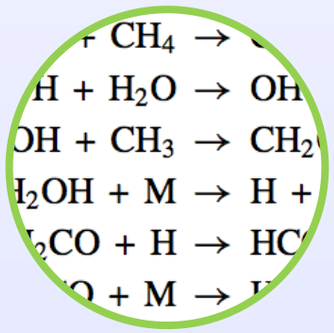
Isotopologues detection



Abundances determination

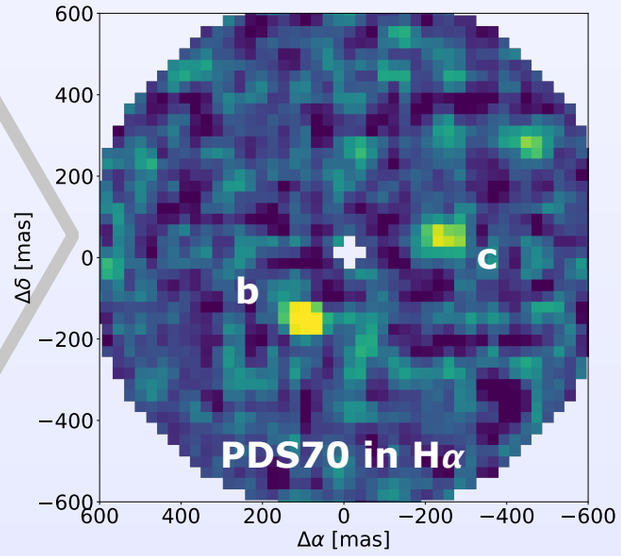


Formation, migration & evolution

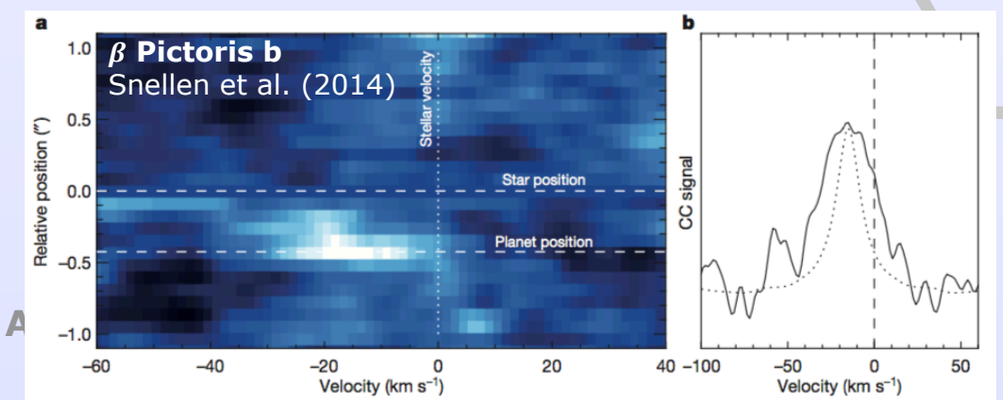


Atmospheric chemistry & dynamics

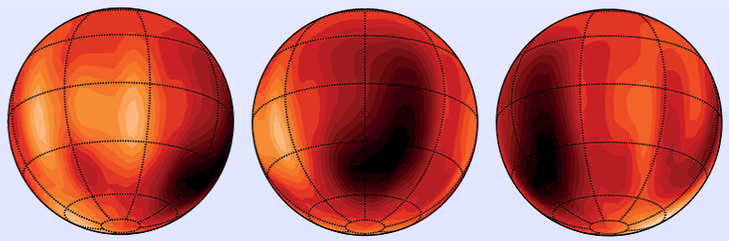
Accretion lines



Orbital and rotational velocity



Variability & Doppler imaging



Luhman 16B (Crossfield et al. 2014)

HiRISE partners and support

Laboratoire d'Astrophysique de Marseille
A. Vigan, G. Otten, E. Muslimov, Y. Charles, K. Dohlen, R. Pourcelot, J.-L. Beuzit, M. Houllé, E. Choquet, N. Tchoubaklian, J.-F. Sauvage, P. Cristofari, P. Tomlinson

University of Göttingen
U. Seemann, A. Reiners

European Southern Observatory
M. Kasper, R. Dorn, J. Milli, G. Zins, P. Figueira

University of Exeter
M. Phillips, I. Baraffe

Institut de Planétologie et d'Astrophysique de Grenoble
D. Mouillet, A. Carlotti

Laboratoire Lagrange
M. N'Diaye, R. Flamary, D. Mary

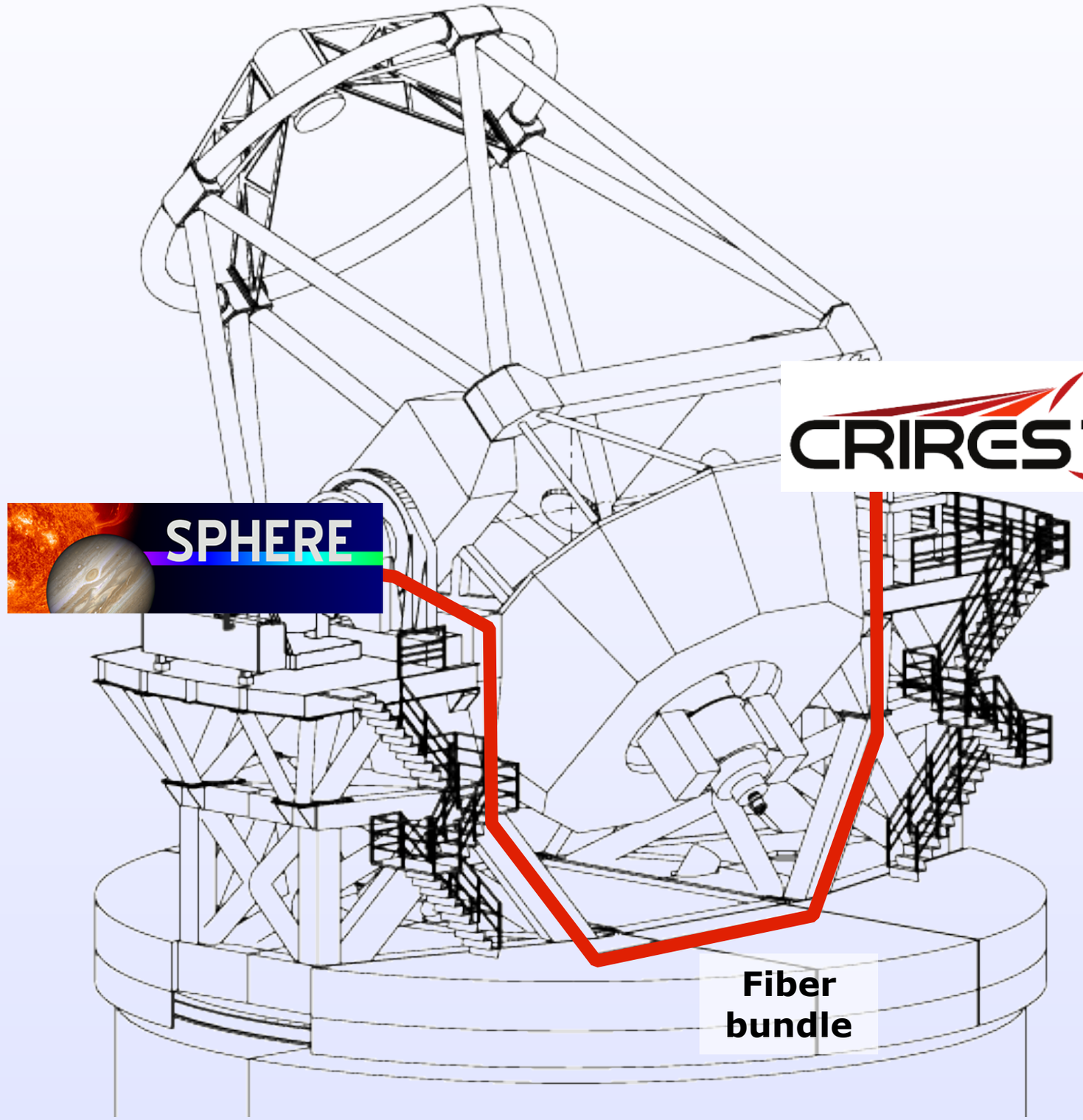
Observatoire de Paris - LESIA
A. Boccaletti, B. Charnay

Support from the SPHERE and CRIRES+ consortia

Financial support: European Research Council

Starting grant #757561
1.5 M€
2018-2022
PI: Vigan

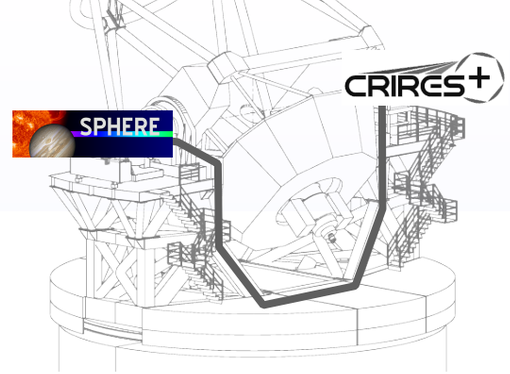
HiRISE general implementation



Fiber extraction module (FEM)

Fiber injection module (FIM)

Fiber injection module in SPHERE



High-quality optics

Stable instrument

Extreme AO

Coronagraph

IRDIS

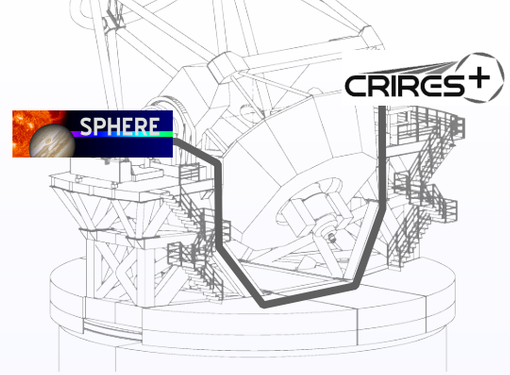
IFS

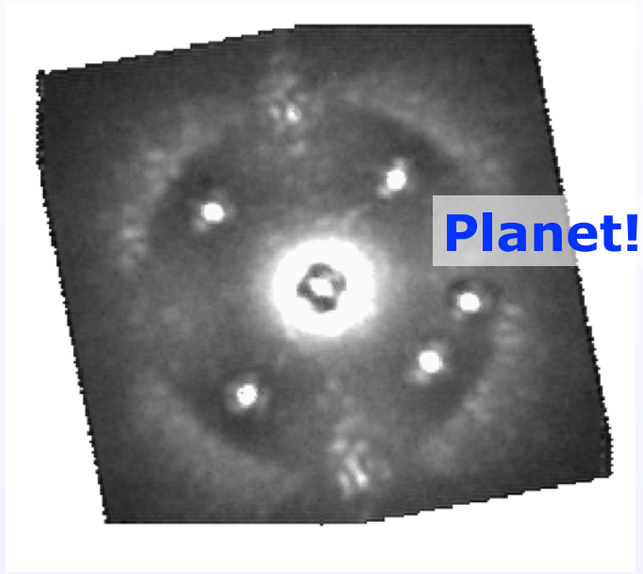
ZIMPOL

HiRISE

Fiber Injection Module

FIM conceptual design





Tracking camera

Tip-tilt mirror

J

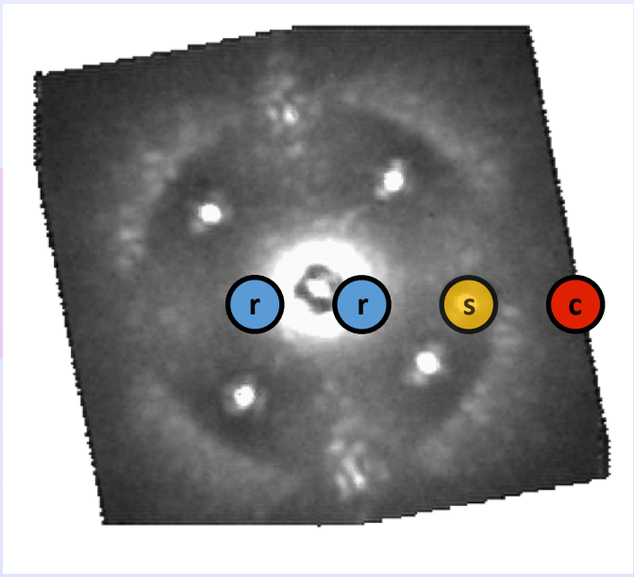
H+K

Dichroic

Fibre bundle

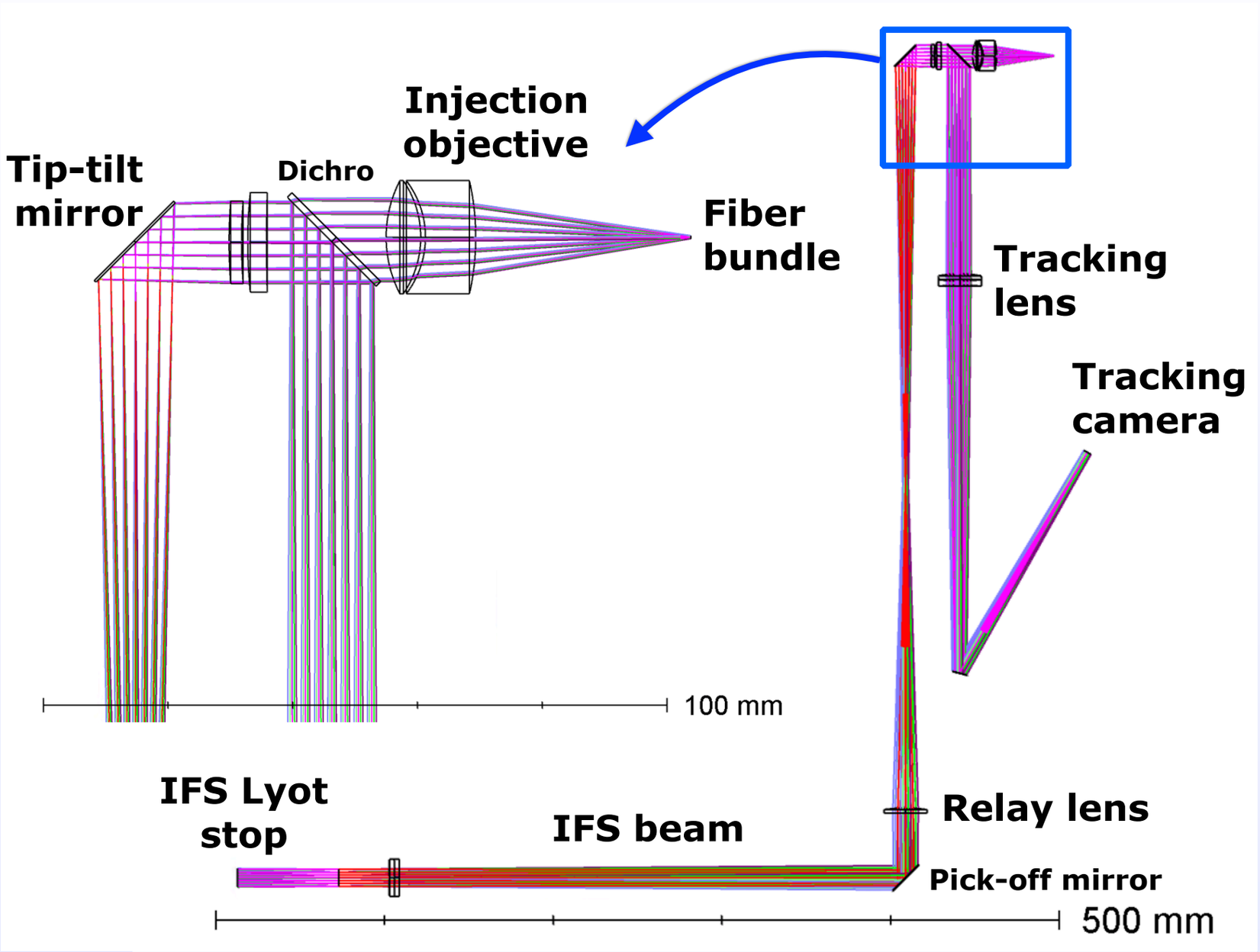
IFS beam

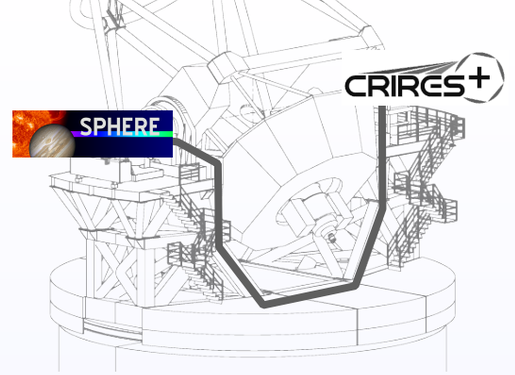
Retractable pick-off mirror



Inspired by Mawet et al. (2017)

FIM opto-mechanical design



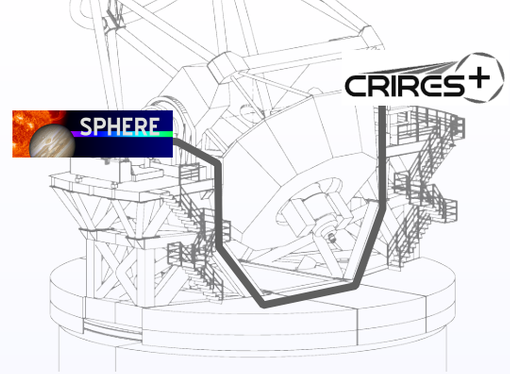


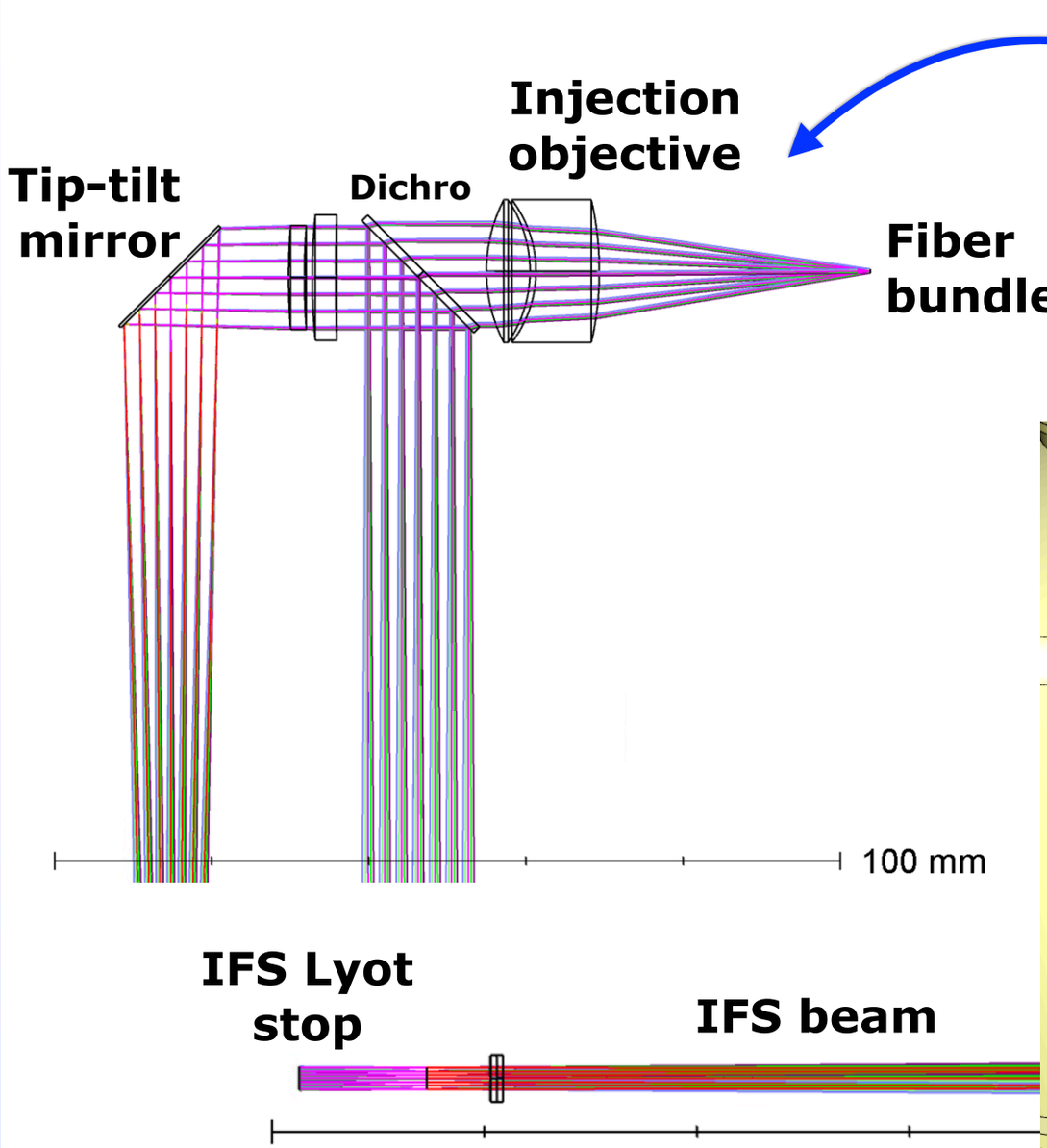
Preliminary designs

Optics: E. Muslimov

Mechanics: Y. Charles
N. Tchoubaklian

FIM opto-mechanical design





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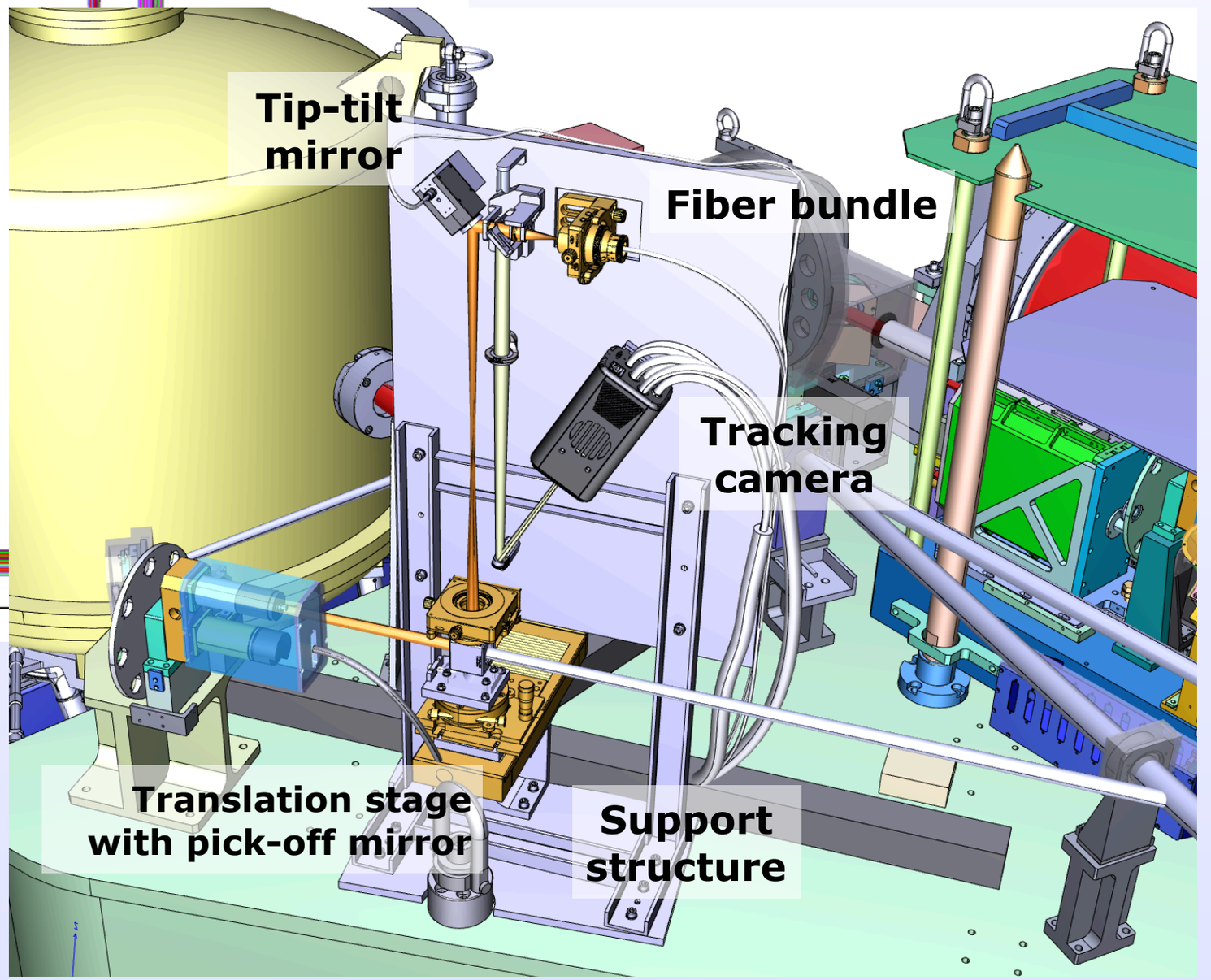
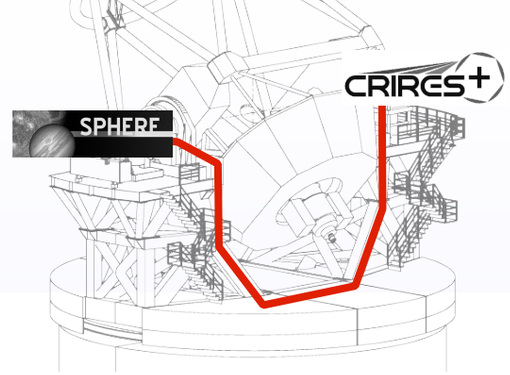
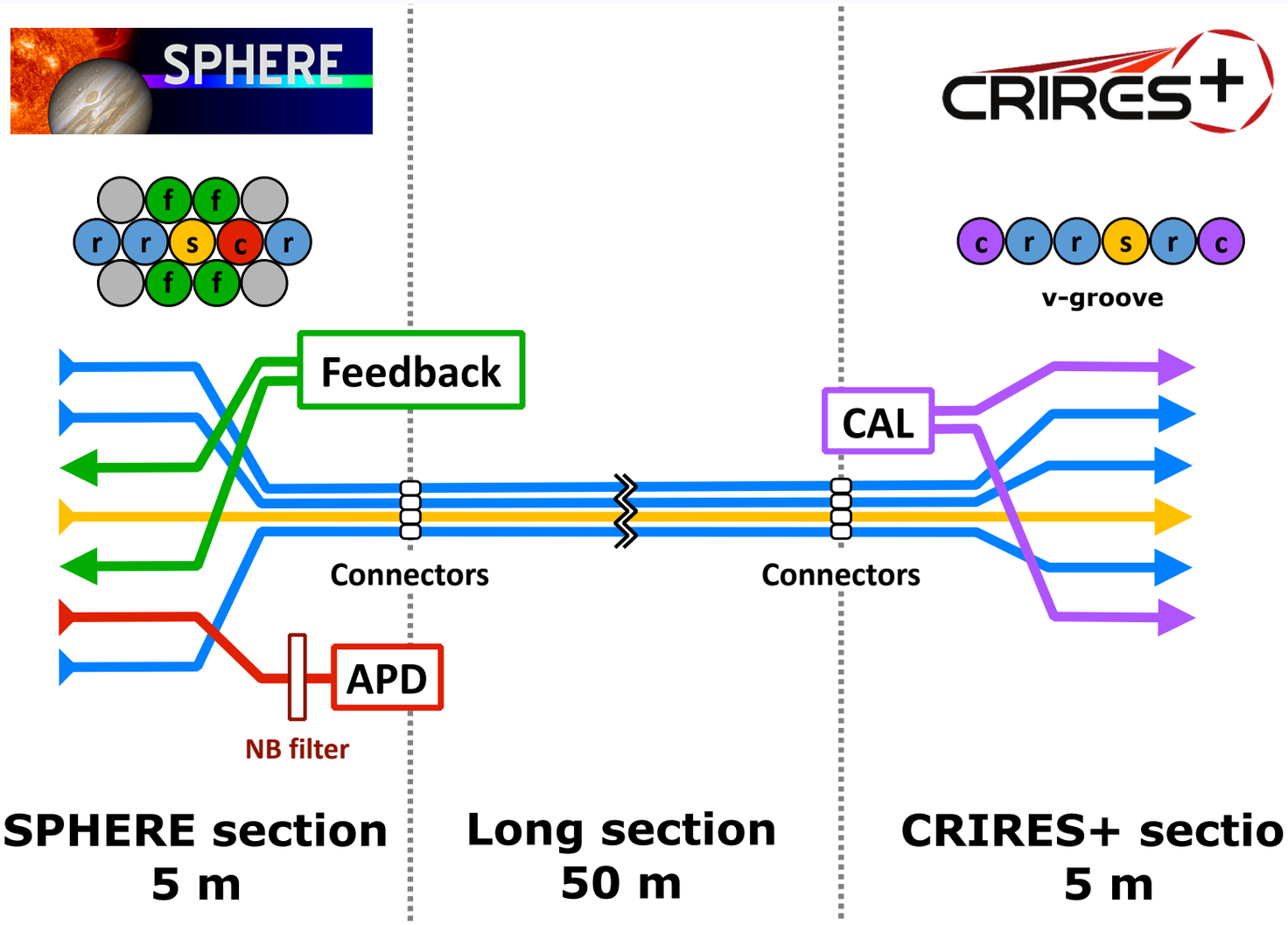
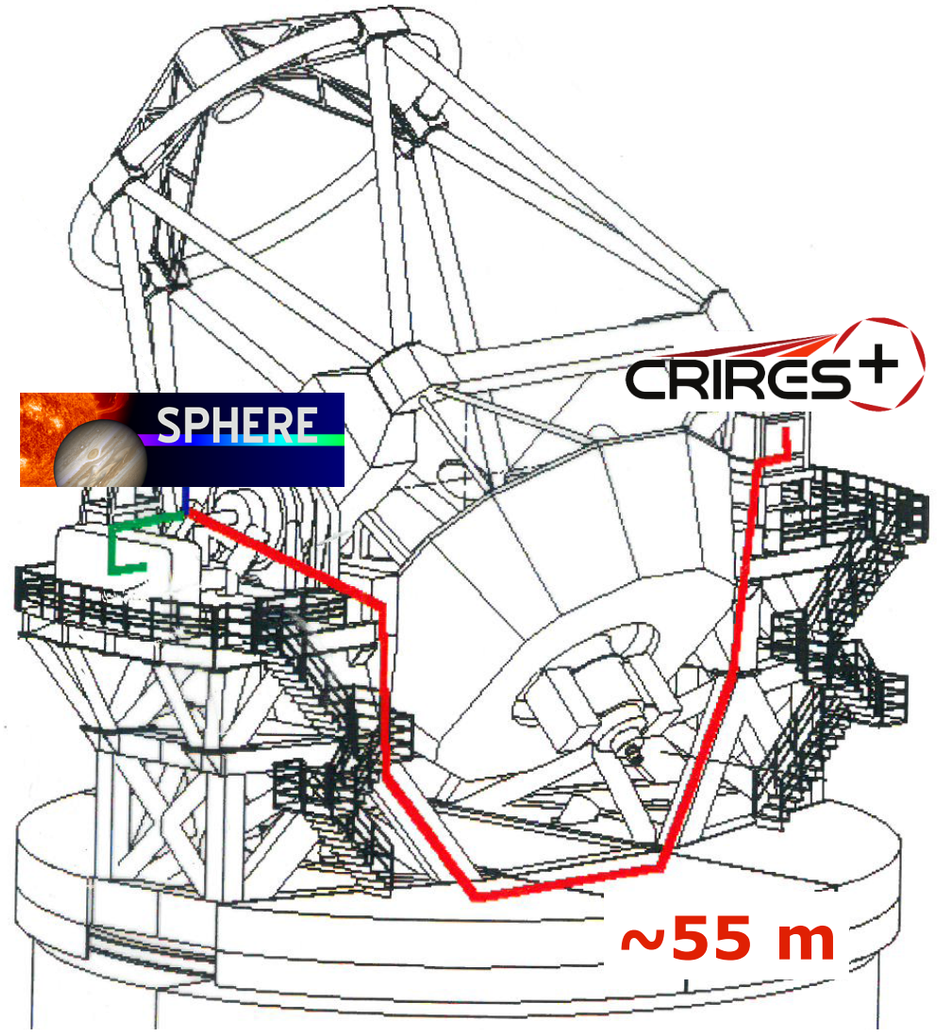


Plug & play!

Fiber bundle around UT3







ZBLAN single-mode fibers (LVF)

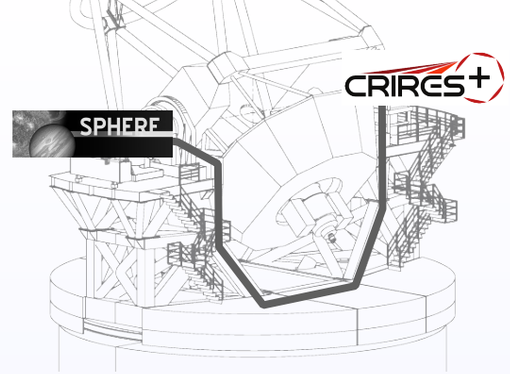
- s — Science fiber, planet, 1.4-2.5 µm
- r — Reference fiber, star, 1.4-2.5 µm

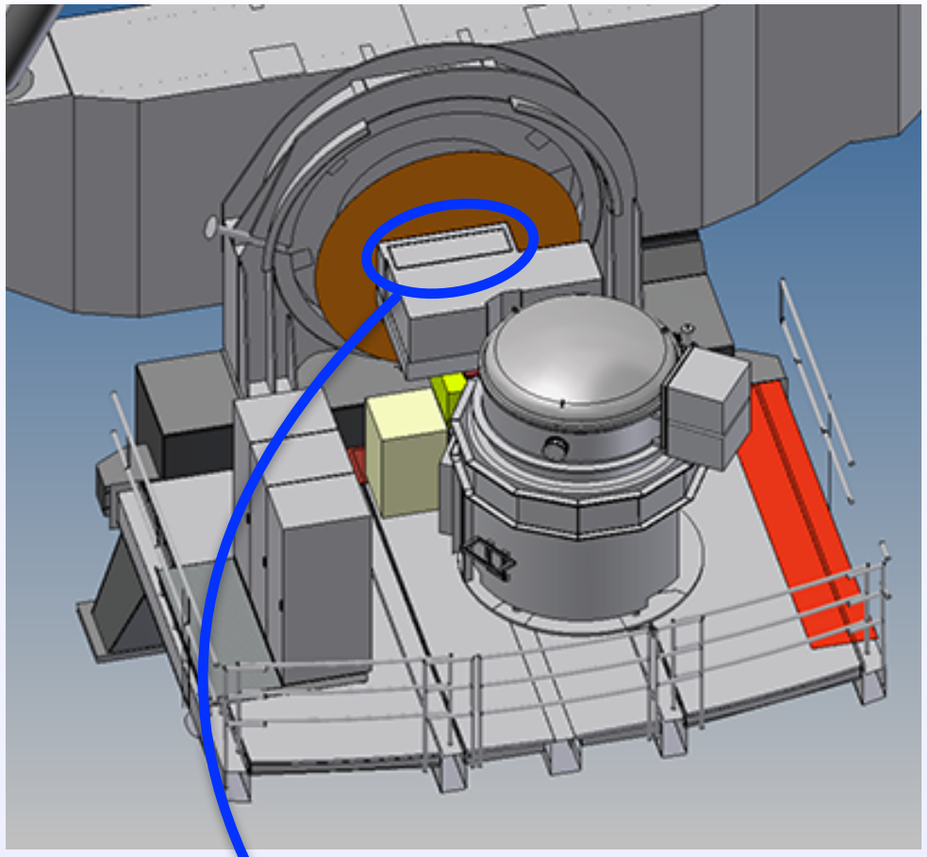
Standard telecom fibers

- f — SPHERE feedback fiber, max 1.4 µm
- c — CRIRES+ centering fiber, 0.8-1.6 µm
- c — SPHERE centering fiber, ~1.6 µm

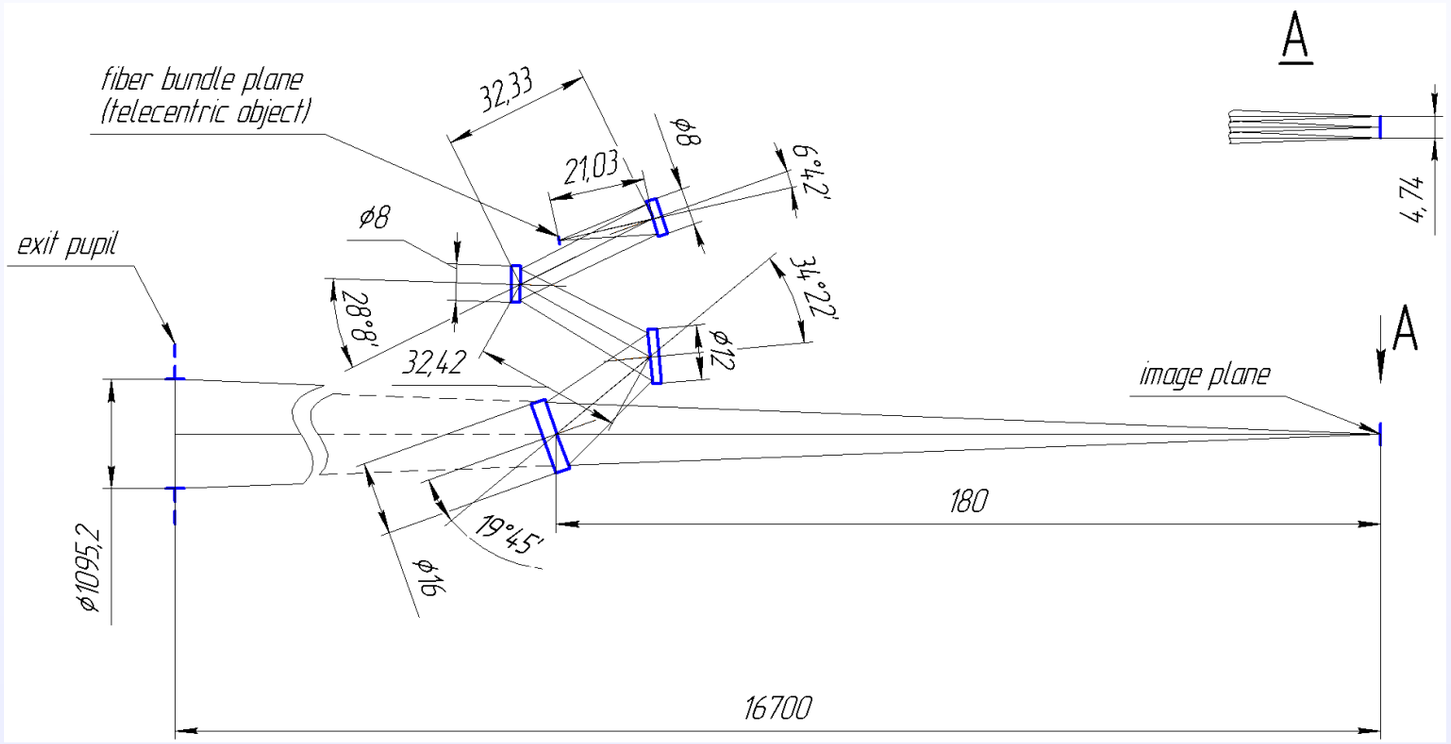
Plug & play… by definition!

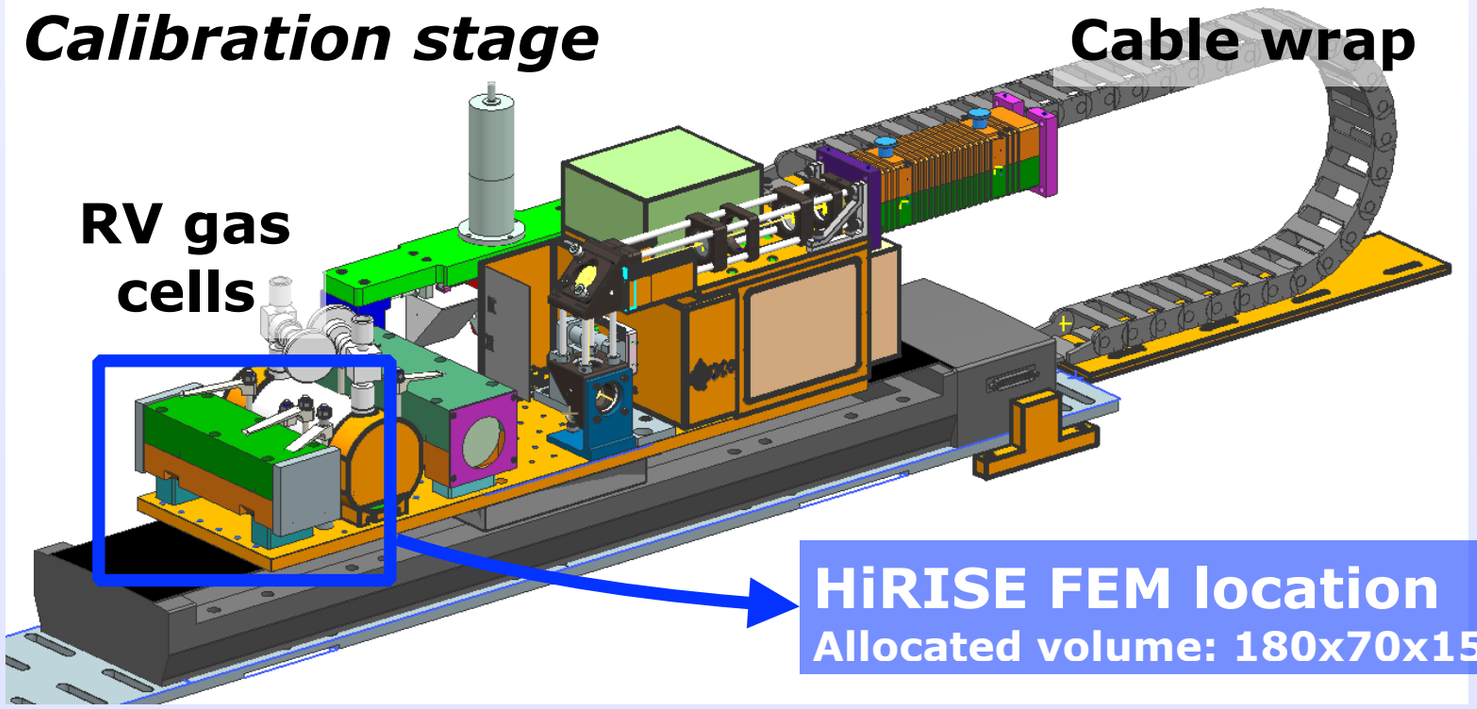
Fiber extraction module in CRIRES+





Fully reflective design





HiRISE FEM location
Allocated volume: 180x70x150 mm³

Plug & play!

HiRISE operations

HiRISE operations

Fully transparent

- Standard acq
- Standard AO mode

HiRISE operations

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CRIRES+

Almost transparent

- Derotator disabled
- AO + slit viewer

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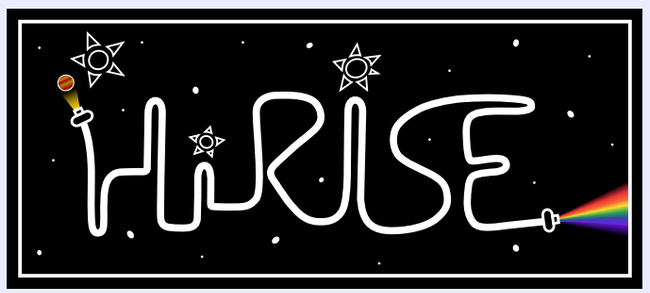
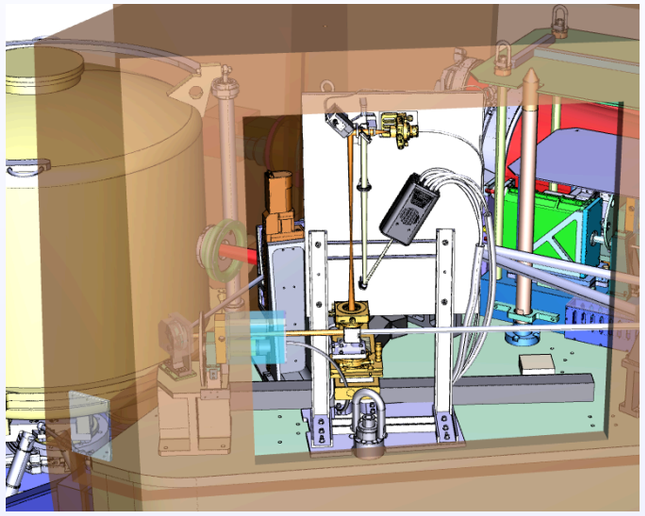


FIM	Bundle	FEM
Active	**Passive**	**Passive**

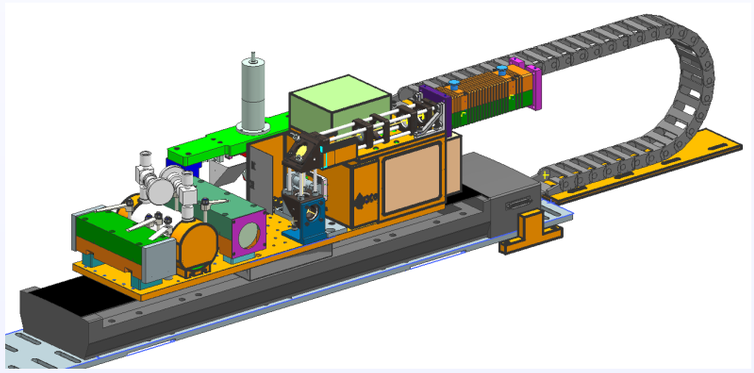
- Acquisition
- Planet centering & tracking

Risk assessment

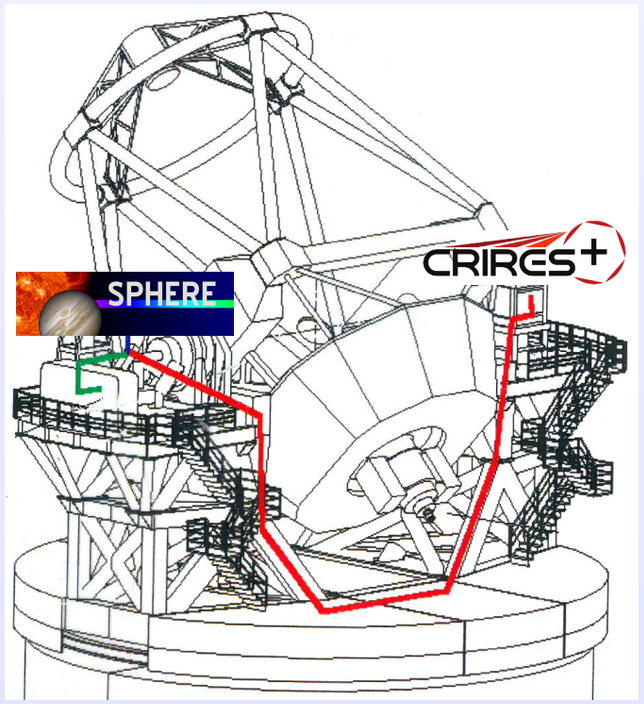
Installation in SPHERE



Installation in CRIRES+



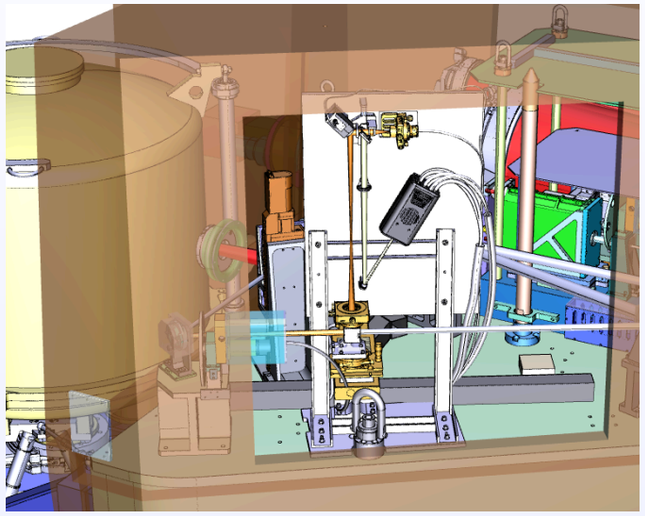
Installation of the fiber bundle



Operations & overall performance

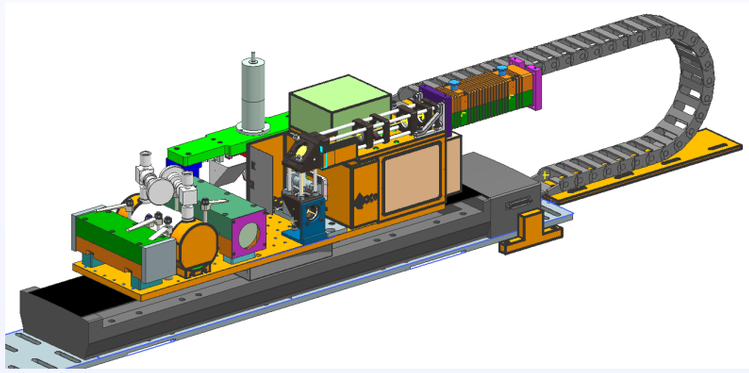
Risk assessment

Installation in SPHERE



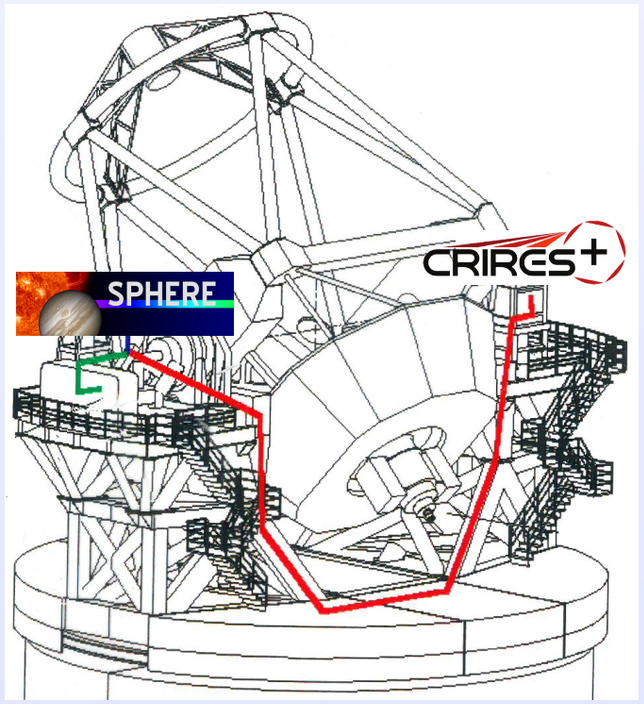
Low risk

Installation in CRIRES+



Low risk

Installation of the fiber bundle



Low risk

Operations & overall performance

Medium risk

- **HiRISE is a R&D project**
- **Development as a *visitor mode***
- **Totally new approach… uncertainty is inevitable!**

Low risk installation

Building HiRISE

Cost

Estimated: 150-170 k€

Dominated by fiber bundle, tracking camera, dichroic, custom optics, ...

Contingency: 20%

Hardware funding

Available (ERC): ~120 k€

Requested: 60 k€

Backup and co-funding under study

Manpower

AIT engineer: 2 years

PhD student: 3 years

Postdoc: 2 years

1 FTE margin

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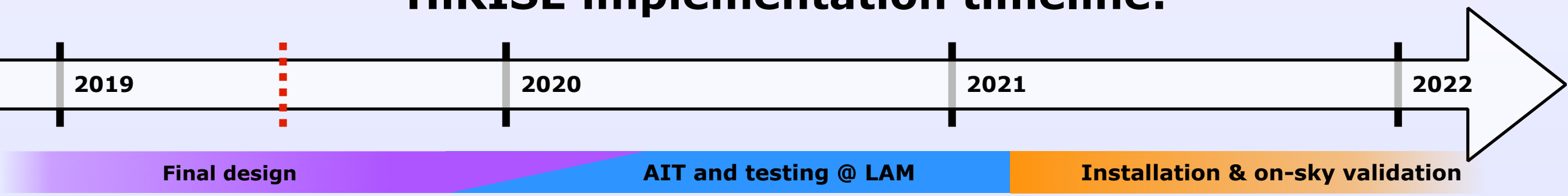
HiRISE implementation timeline:



Fast-track implementation as a visitor mode!

Coordination with SPHERE+

***Fully independent* from SPHERE+**

Coordination with SPHERE+

***Fully independent* from SPHERE+**

- HiRISE will benefit from an ExAO gain
- Full integration with SPHERE: software, operations, calibrations... → fully supported mode
- **Improved transmission**

Coordination with SPHERE+

***Fully independent* from SPHERE+**

- HiRISE will benefit from an ExAO gain
- Full integration with SPHERE: software, operations, calibrations... ➙ fully supported mode
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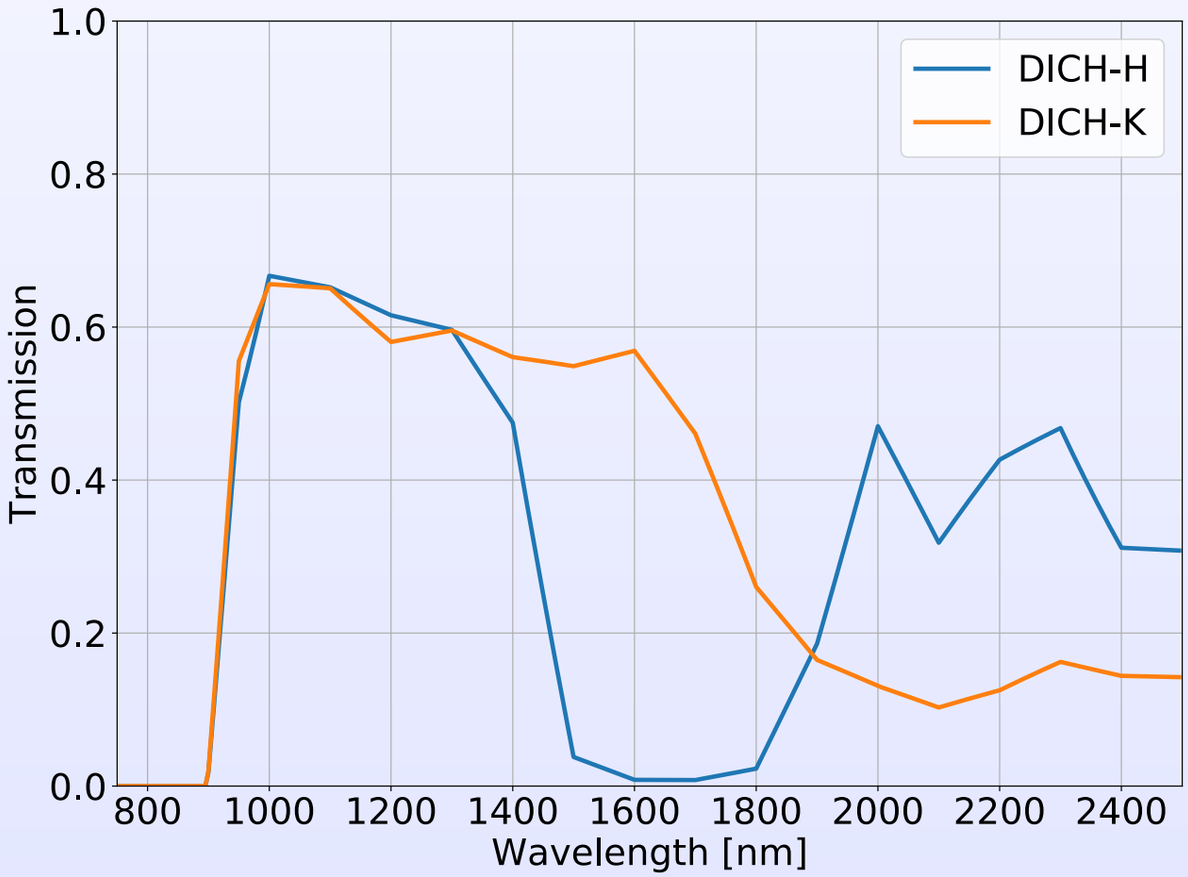

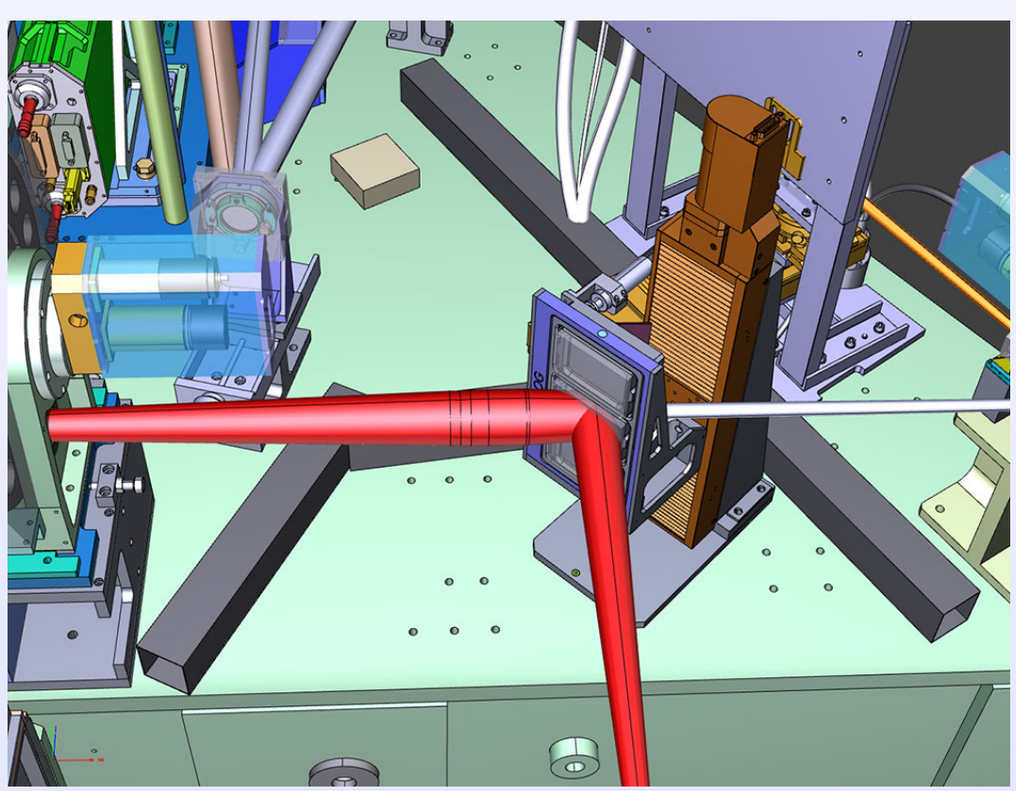

Coordination with SPHERE+

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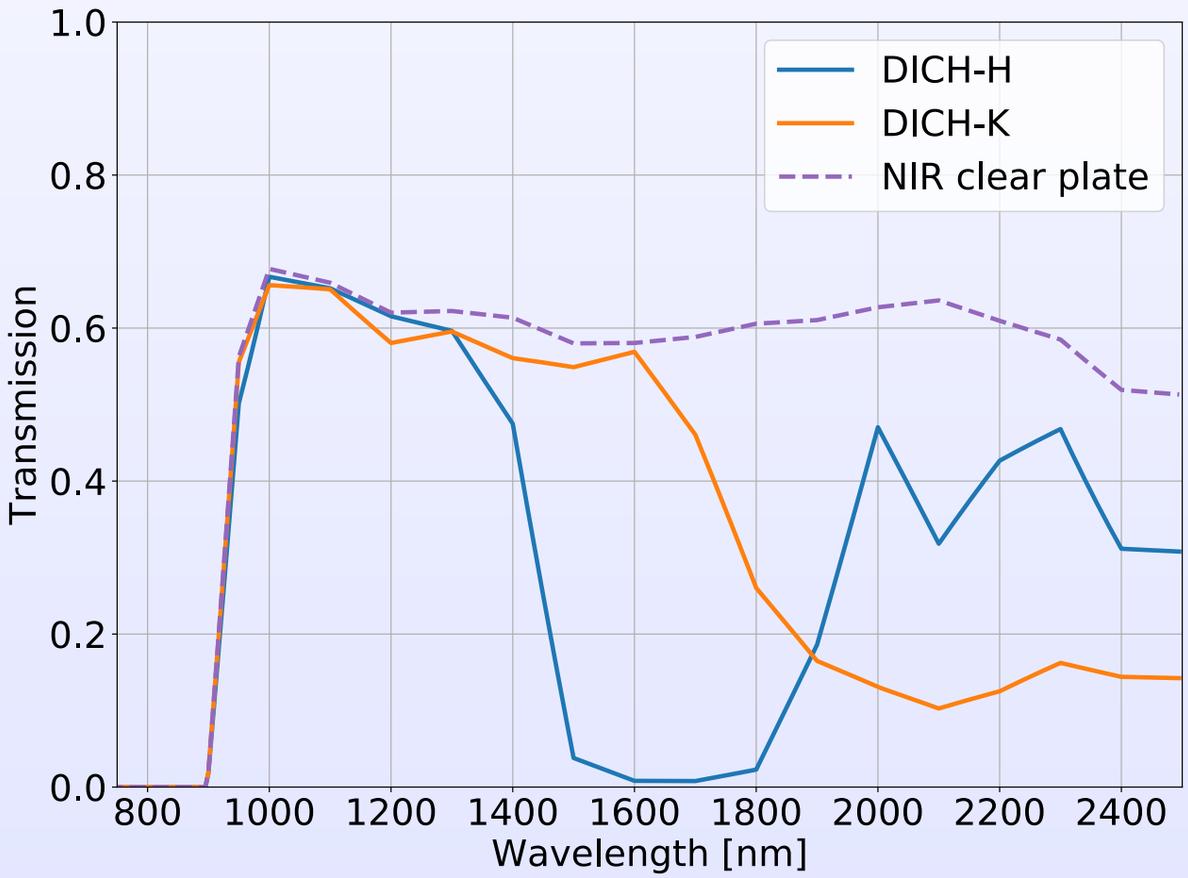
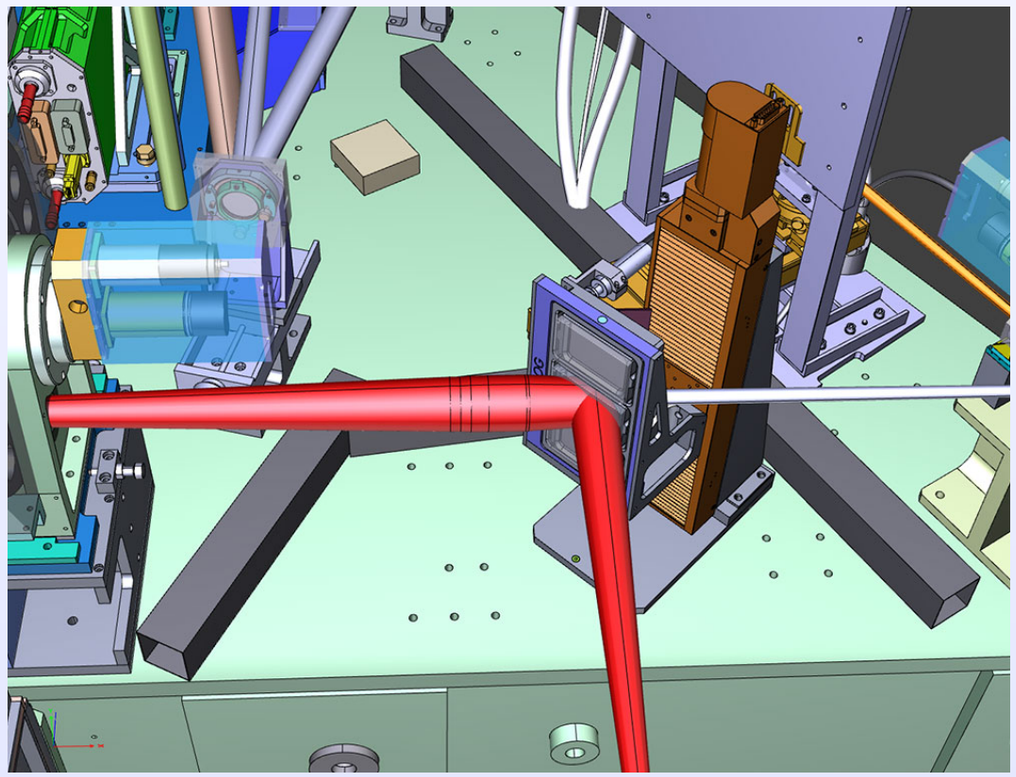




A European opportunity in the South

On-going projects on 8-10 m telescopes with ExAO:

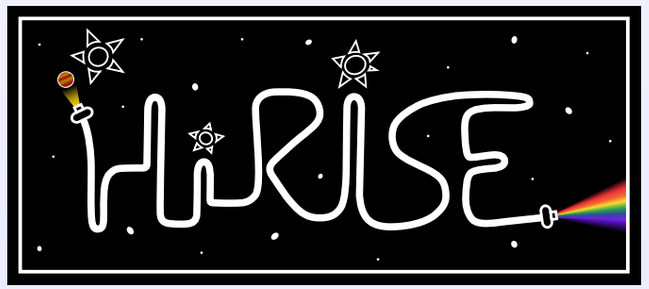
- ***Keck*/KPIC:** D. Mawet, Caltech ***[already on-sky!]***
- ***Subaru*/SCExAO:** O. Guyon, University of Arizona
- ***VLT*/HiRISE:** A. Vigan, CNRS/LAM

HiRISE

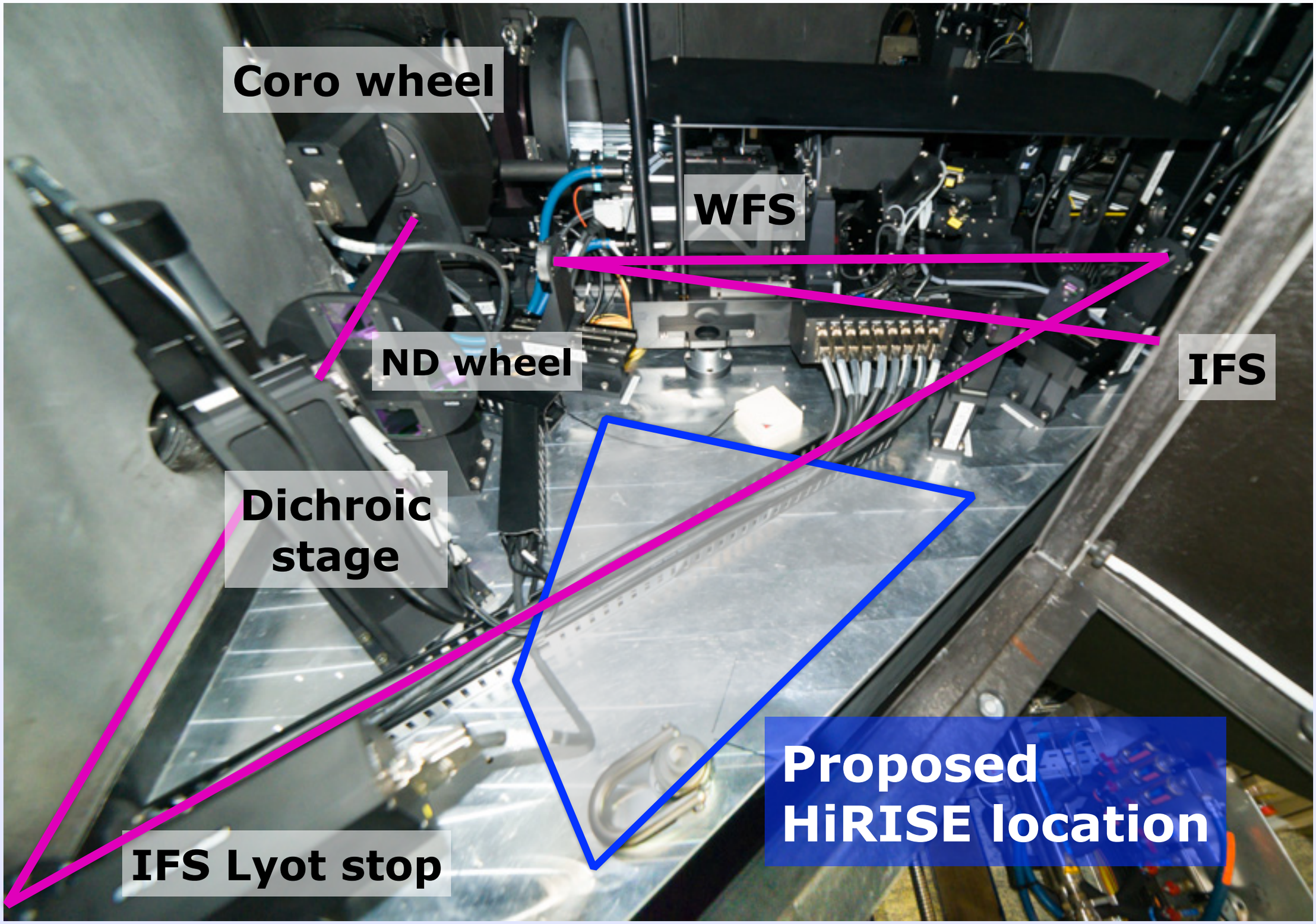
Unique European opportunity to **stay at the forefront!**

Conclusions

- **SPHERE is a powerful direct imaging instrument with limited characterisation capabilities**
  - Next step ➙ **high-spectral resolution!**
- **Opens new science opportunities for young giant exoplanets**
  - Atmospheric chemistry & physics
  - Orbital and rotational speed
  - Calibration of mass-luminosity relationships with Gaia planets
- **HiRISE: fiber optics coupling with CRIRES+**
  - **Doable TODAY**
  - Completely independent from SPHERE+
  - Design almost finalized
  - Funding mostly secured
  - We propose a **fast-track implementation as a visitor mode!**
- Pathfinder for ELT instrumentation: PCS, HARMONI

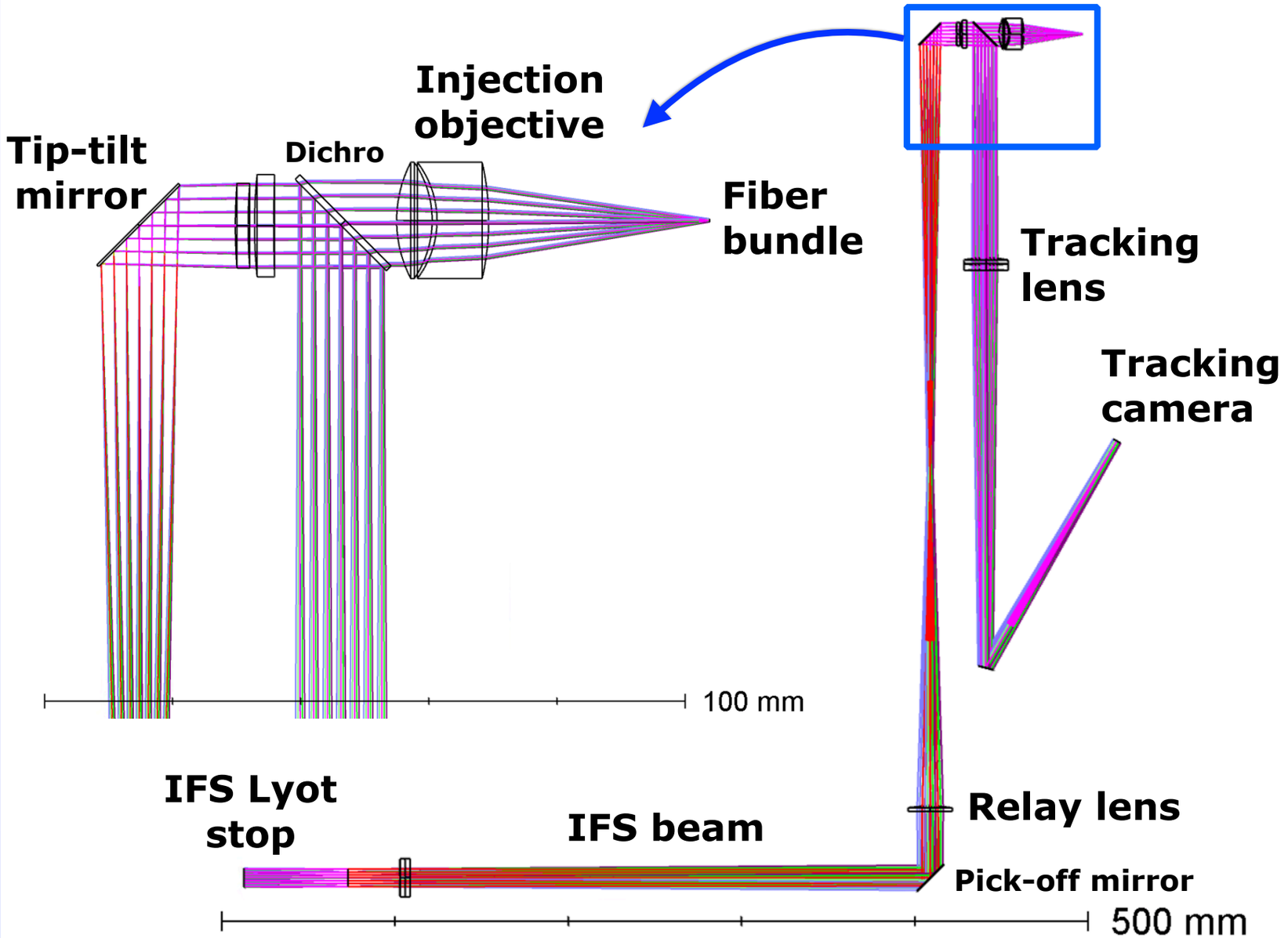


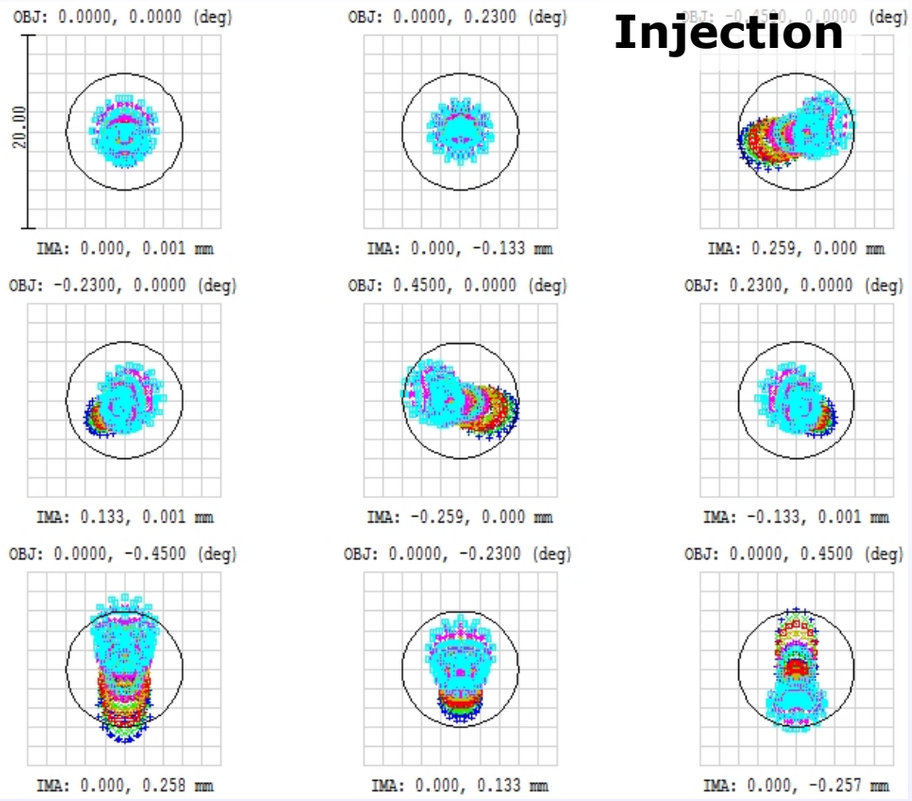
Fiber injection module (FIM) in SPHERE



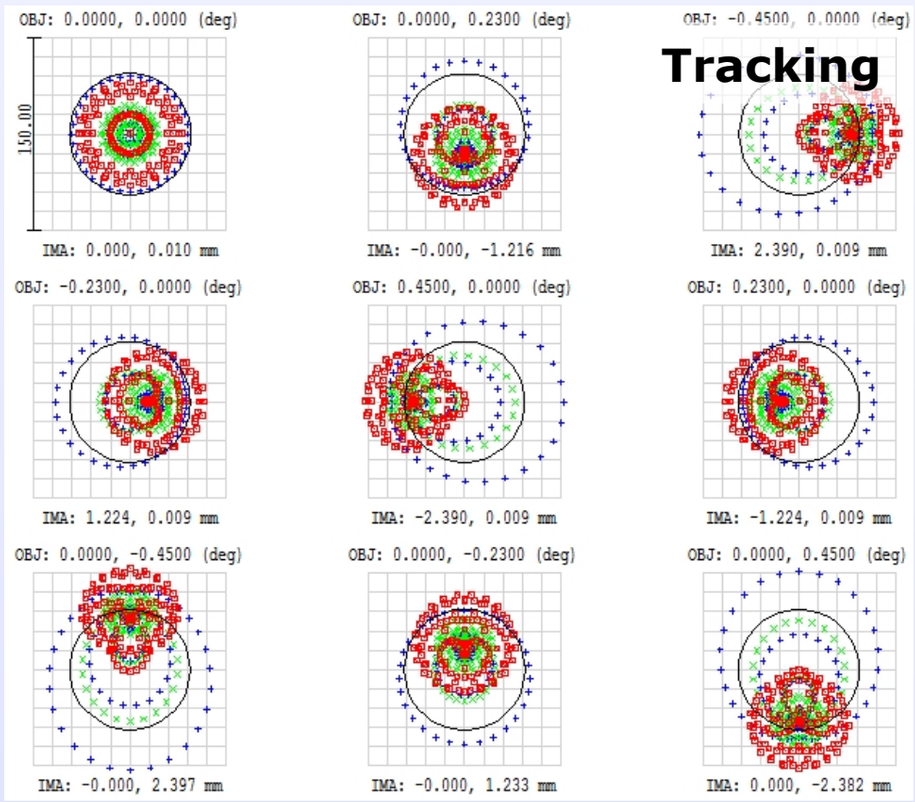
FIM optical design

Optical design: E. Muslimov





~30 nm rms on axis



~60 nm rms on axis

FIM mechanical design

Mechanical design: Y. Charles
N. Tchoubaklian

Enclosure main top

IRDIS

VIS/IR bench door (open)

Total weight < 50 kg

Tip-tilt mirror

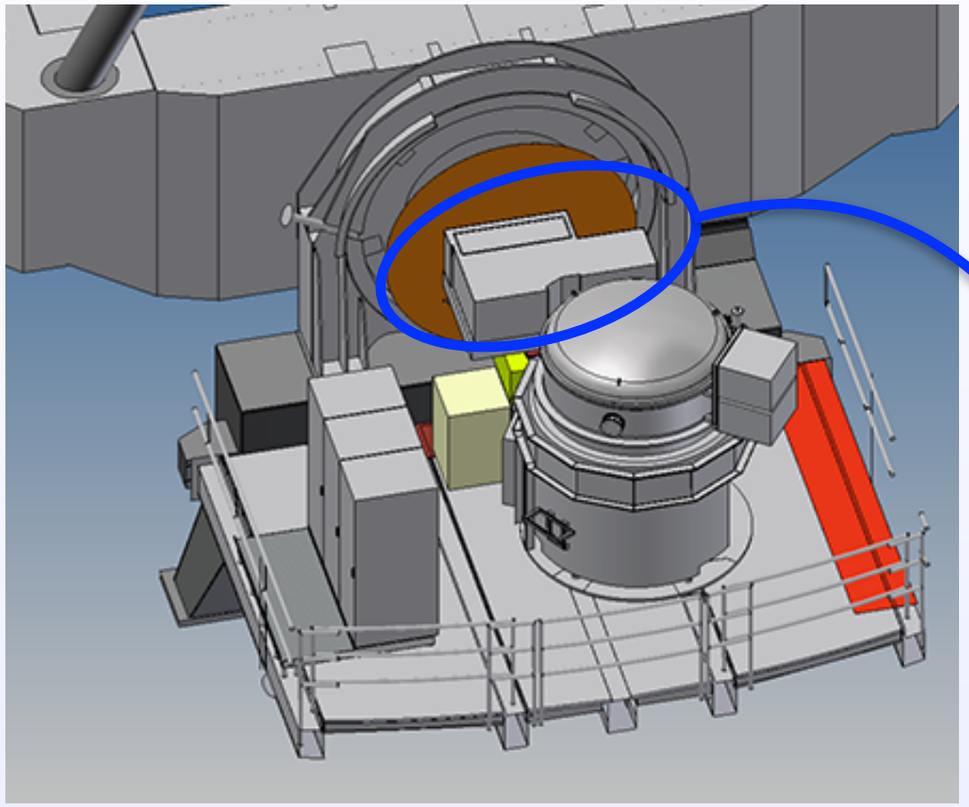
Fiber bundle

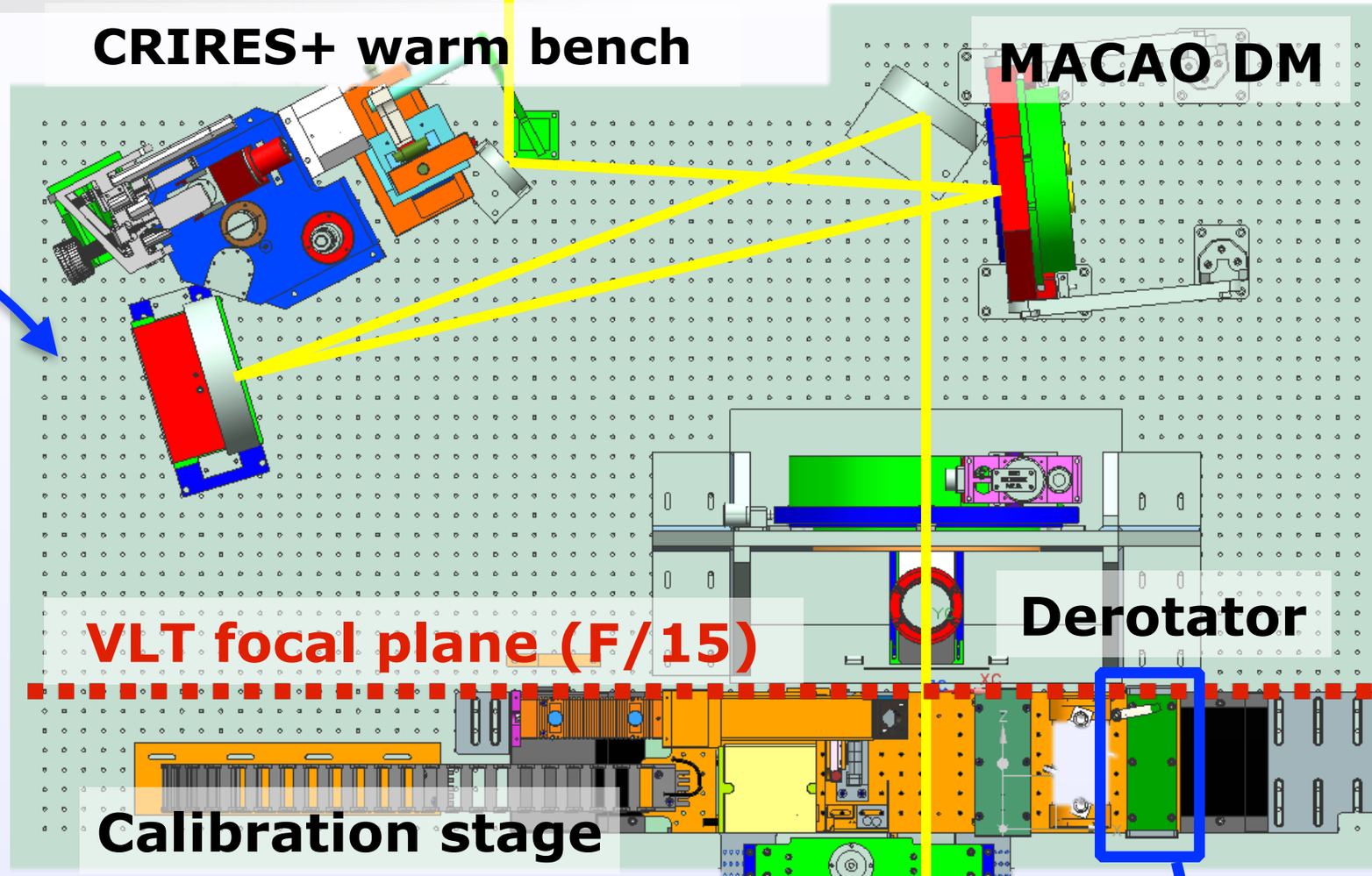
Tracking camera

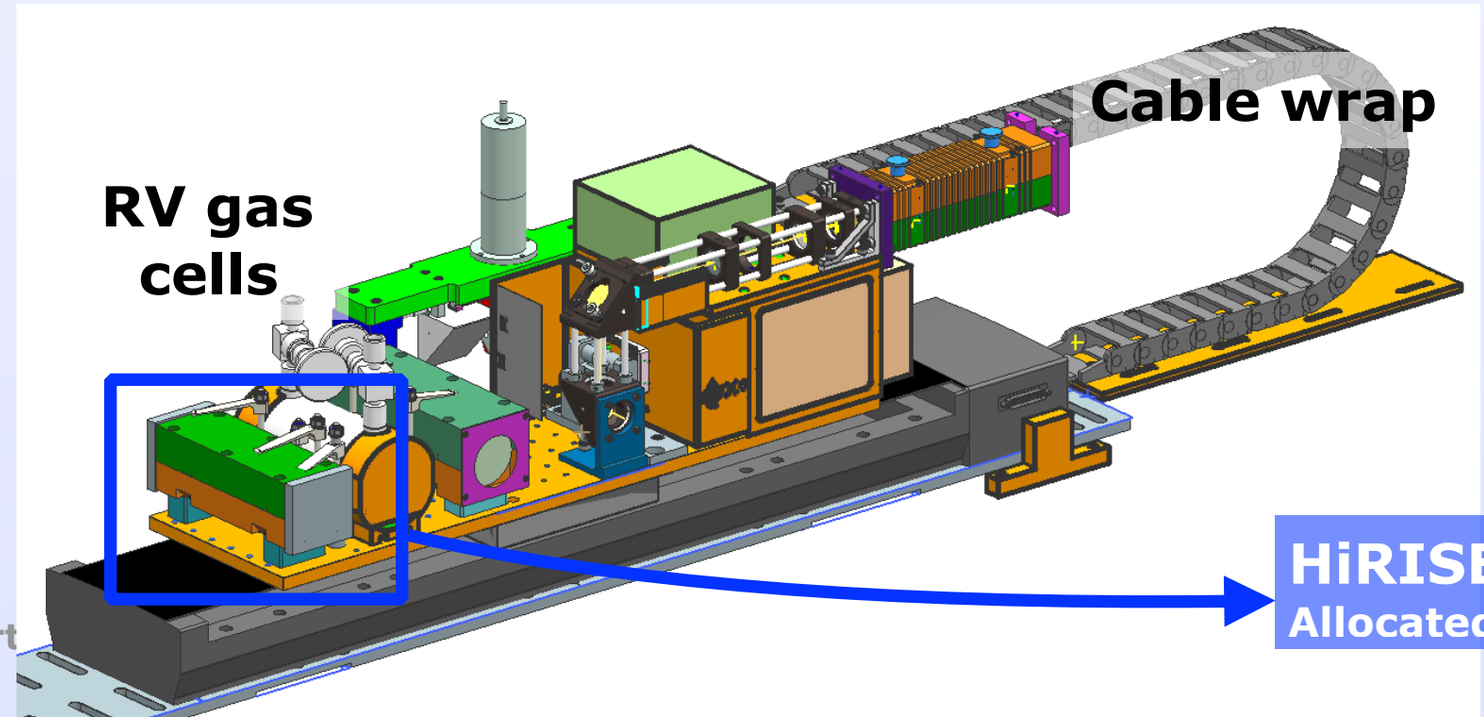
Translation stage with pick-off mirror

Support structure

Fiber extraction module (FEM) in CRIRES+



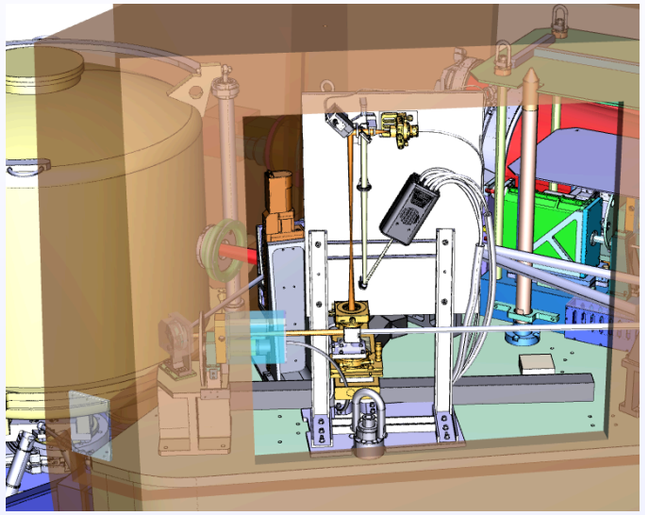




HiRISE FEM location
Allocated volume: 180x70x150 mm³

Technical risk assessment

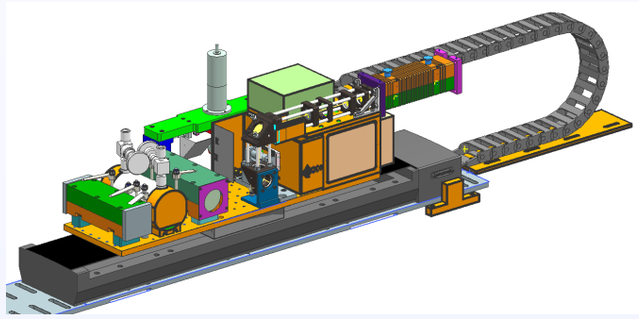
Installation in SPHERE



- <u>No upgrade required</u>
- No impact on AO
- No interference with other subsystems
- Easy access
- FIM can be removed at any time
- SPHERE team experience

Low risk

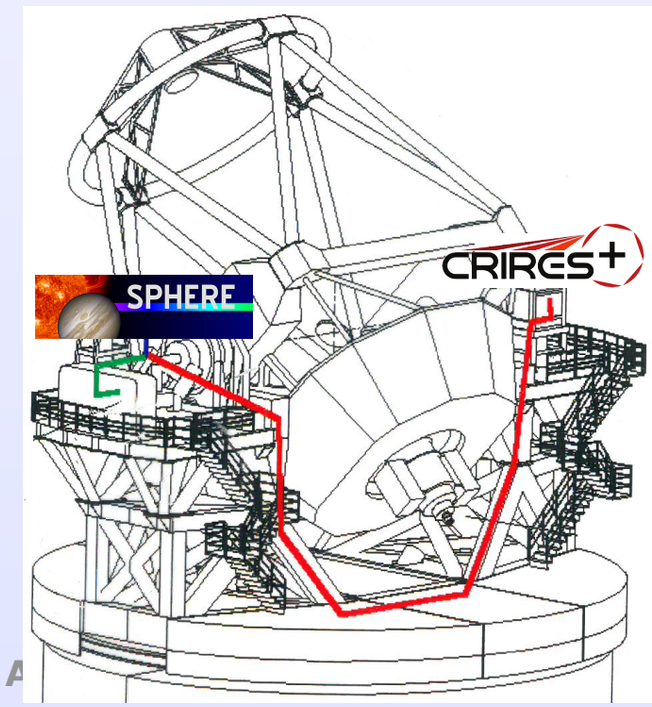
Installation in CRIRES+



- <u>No upgrade required</u>
- RV gas cells designed to be swapped
- Easy access
- FEM can be removed at any time
- CRIRES+ team experience

Low risk

Installation of the fiber bundle



- <u>No hardware required</u>
- FLAMES/UVES experience
- Existing cable duct

Low risk

Operations & overall performance

- Very low throughput
- Fiber injection is extremely sensitive
  - Centering of the planet is <u>critical</u>

Medium risk

Rotational velocity