POPSF2026 - June 22nd-26th, 2026 - MPIA/Heidelberg

Imaging New Worlds: SPHERE, SPHERE+, and the PCS Pathway to the ELT

Gaël Chauvin

(MPIA/Exo-Worlds Imaging Group)

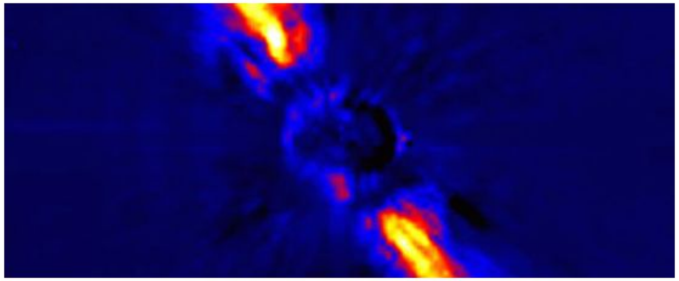
EXOWORLDS IMAGING GROUP

A Thomas Henning's Legacy

Press Release

New Detailed Image of the Disk around Beta Pictoris

11 June 1997



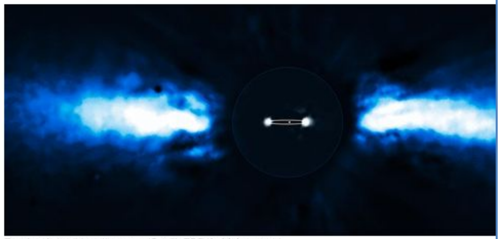
Disc around Beta Pictoris (Credit: ESO)

This new and very detailed image of the famous circumstellar disk around the southern star Beta Pictoris was obtained with the ESO ADONIS adaptive optics system at the 3.6-m telescope and the Observatoire de Grenoble coronograph. It shows (in false colours) the scattered light at wavelength 1.25 micron (J band) and is one of the best images of this interesting feature obtained so far.

Press Release

Exoplanet Caught on the Move

10 June 2010



Exoplanet caught on the move (Credit: ESO/A.-M. Lagrange)

For the first time, astronomers have been able to directly follow the motion of an exoplanet as it mov
side of its host star to the other. The planet has the smallest orbit so far of all directly imaged exopla
almost as close to its parent star as Saturn is to the Sun. Scientists believe that it may have formed i
to the giant planets in the Solar System. Because the star is so young, this discovery proves that ga
can form within discs in only a few million years, a short time in cosmic terms.

Only 12 million years old, or less than three-thousandths of the age of the Sun, Beta Pictoris is 75% more m

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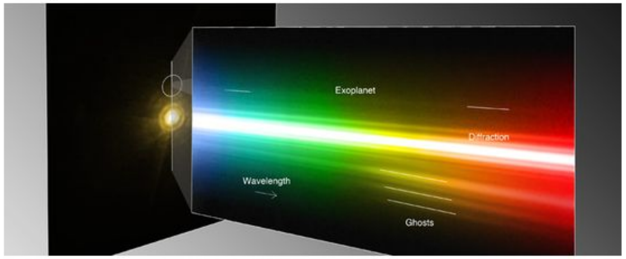
VLT Captures First Direct Spectrum of an Exoplanet

13 January 2010



Spectrum of the planet around HR 8799 (annotated) (Credit: ESO/M. Janson)

By studying a triple planetary system that resembles a scaled-up version of our own Sun's family of planets, astronomers have been able to obtain the first direct spectrum — the "chemical fingerprint" [1] — of a planet orbiting a distant star [2], thus bringing new insights into the planet's formation and composition. The result represents a milestone in the search for life elsewhere in the Universe.

Press Release

Yes, it is the Image of an Exoplanet

Astronomers Confirm the First Image of a Planet Outside of Our Solar System

30 April 2005

The brown dwarf 2M1207 and its planetary companion (Credit: ESO)

An international team of astronomers reports today confirmation of the discovery of a giant planet, approximately five times the mass of Jupiter, that is gravitationally bound to a young brown dwarf. This puts an end to a year long discussion on the nature of this object, which started with the detection of a red object close to the brown dwarf.

A Thomas Henning's Legacy

VLT-PF/CHEOPS concept for SPHERE (2003 meeting!)

Press Release

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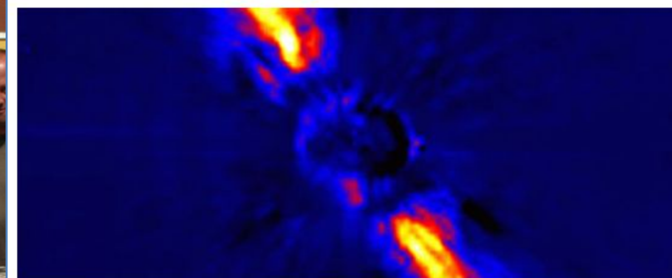

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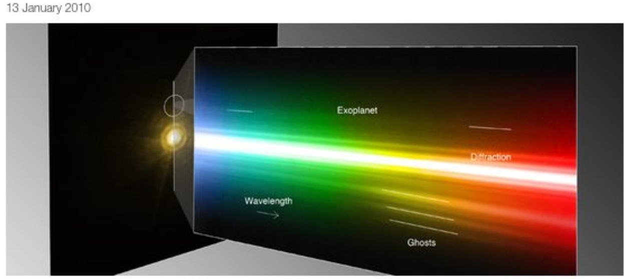

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SPHERE, a human endeavor

Consortium

INSU/IPAG: J.-L. Beuzit (PI), D. Mouillet/G. Chauvin* (PS), P. Puget (PM), A.-M. Lagrange*, P. Delorme, M. Benisty, F. Ménard, J. Milli, H. Beust, M. Bonnefoy, C. Dougados, J.-C. Augereau, A.-L. Maire, C. Desgrange, G. van der Plas*, M. Villenave*, L. Rodet*. **MPIA:** M. Feldt (Co-PI), **T. Henning,** R. van Boekel, M. Keppler*, M. Samland, A. Pohl*, W. Brandner, J. Olofsson*, S. Brown, N. Pawellek. **INSU/LAM:** K. Dohlen (SE), M. Langlois*, A. Vigan, H. Le Coroller, F. Cantalloube, E. Choquet, A. Zurlo*, G. Salter*, P. Vernazza. **INSU/LESIA:** A. Boccaletti, D. Rouan, Y. Clénet, P. Baudoz, R. Galicher, D. Gratadour, P. Kervella, C. Perrot, G. Singh*, T. Schmidt*. **INAF/OAPD:** M. Turratto, R. Gratton, S. Desidera, A. Baruffolo, V. D'Orazi, R. Claudi, D. Mesa, A. Garuffi*, E. Sissa*, S. Antoniucci, M. Bonavita*, C. Lazzoni*. **INSU/Lagrange:** E. Lagadec, M. Carbillet, R. Ligi, Z. Khorrami*, M. N'Diaye. **ETH-Z:** H.-M. Schmid, S. Quanz, N. Engler, C. Thalmann*, C. Tschudi, H. Avenhaus*, M. Meyer*, G. Cugno*. **ONERA:** J. Sauvage, A. Costille, T. Fusco, L. Munier, **UvA/ASTRON:** C. Dominik, C., Ginski, M. Kenworthy, G. Muro-Arena*, T. Stolker, R. van Holstein*, J. de Boer*, A. Bohn*. **Geneva Obs.:** S. Udry, D. Segransan, F. Wildi, J. Hagelberg, A. Cheetham*, S. Perretti*, E. Buenzli*. **ESO:** M. Kasper, Z. Wahhaj, C. Romero, G. Zins … (non exhaustive…)

& Collaborations…

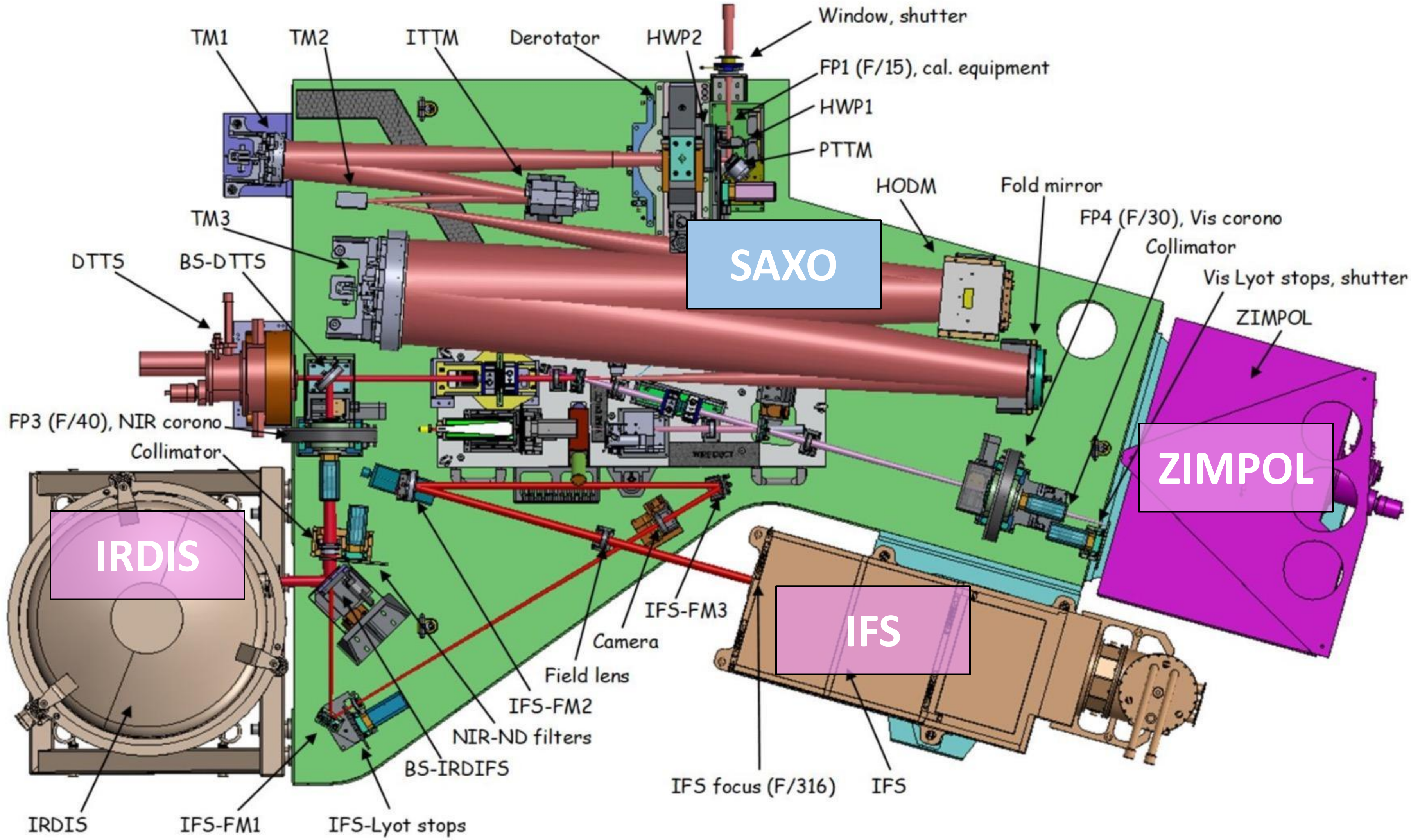
Steward Observatory: S. Ertel, V. Faramaz, **Univ. Stockholm:** M. Janson, G. Viswanath, Eriksson, S. Ringqvist. **Univ. Heidelberg:** S. Haffert, L. Stock. **Exeter:** S. Hinkley, C. Lazzoni, I. Baraffe, **INSU/CRAL-ENS:** O. Flasseur, J. Dalland, C. Graf, M. Langlois, G. Chabrier, F. Soulez, M. Tallon, M. Loupias, D. Homeier, **Univ. Edinburgh:** B. Biller, K. Rice, Forgan. **Univ. Bern:** C. Mordasini, C. Fontanive, G. Marleau, A. Emsenhuber, **CEA**: E. Pantin, P.O. Lagage, P. Tremblin, **STScI:** J. Girard, E. Rickman, **JPL/Caltech:** A. Potier, D. Mawet, **Leiden Univ.:** I. Snellen, R. Landman, Y. Miguel, J.-M. Désert, **U. Chile:** L. Perez, P. Rojo, S. Jorquera, M. Lombart, A. Gallenne, R. Mendez, M. Videla, **Univ. Valparaiso:** A. Bayo, N. Godoy, S. Petrus, **Univ. Santiago:** P. Weber, S. Perez **Univ. Cambridge:** M. Wyatt, S. Marino, **Univ. Bordeaux:** H. Bouy, E. di Folco, A. Dutrey, V. Pietu, S. Guilloteau, **Monash Univ:** D. Price, I. Hammond, C. Pinte … (non exhaustive…)


VLT/Paranal
UT3

SPHERE@UT3

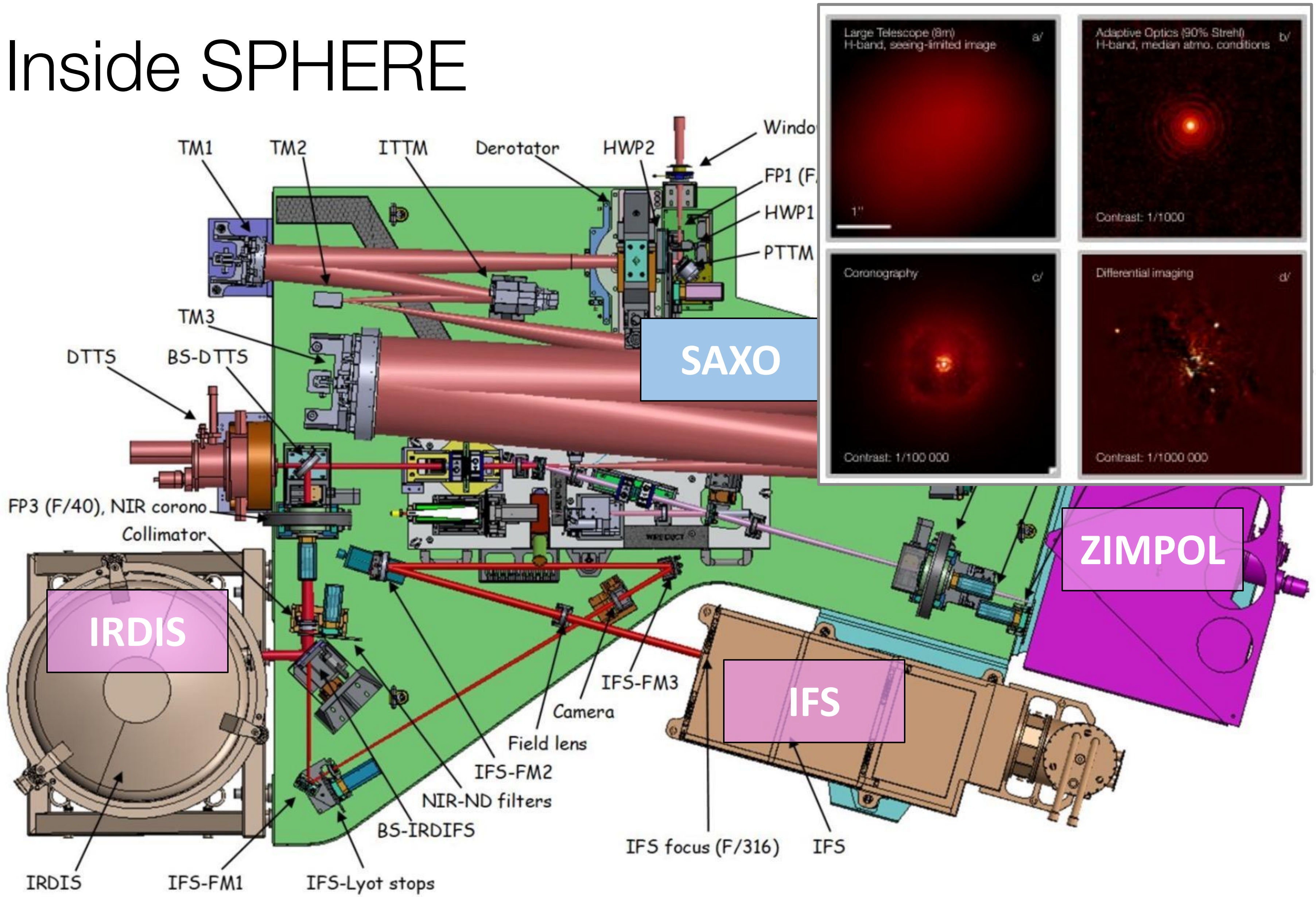
First light: May, 2014

Inside SPHERE



Beuzit et al. 2019

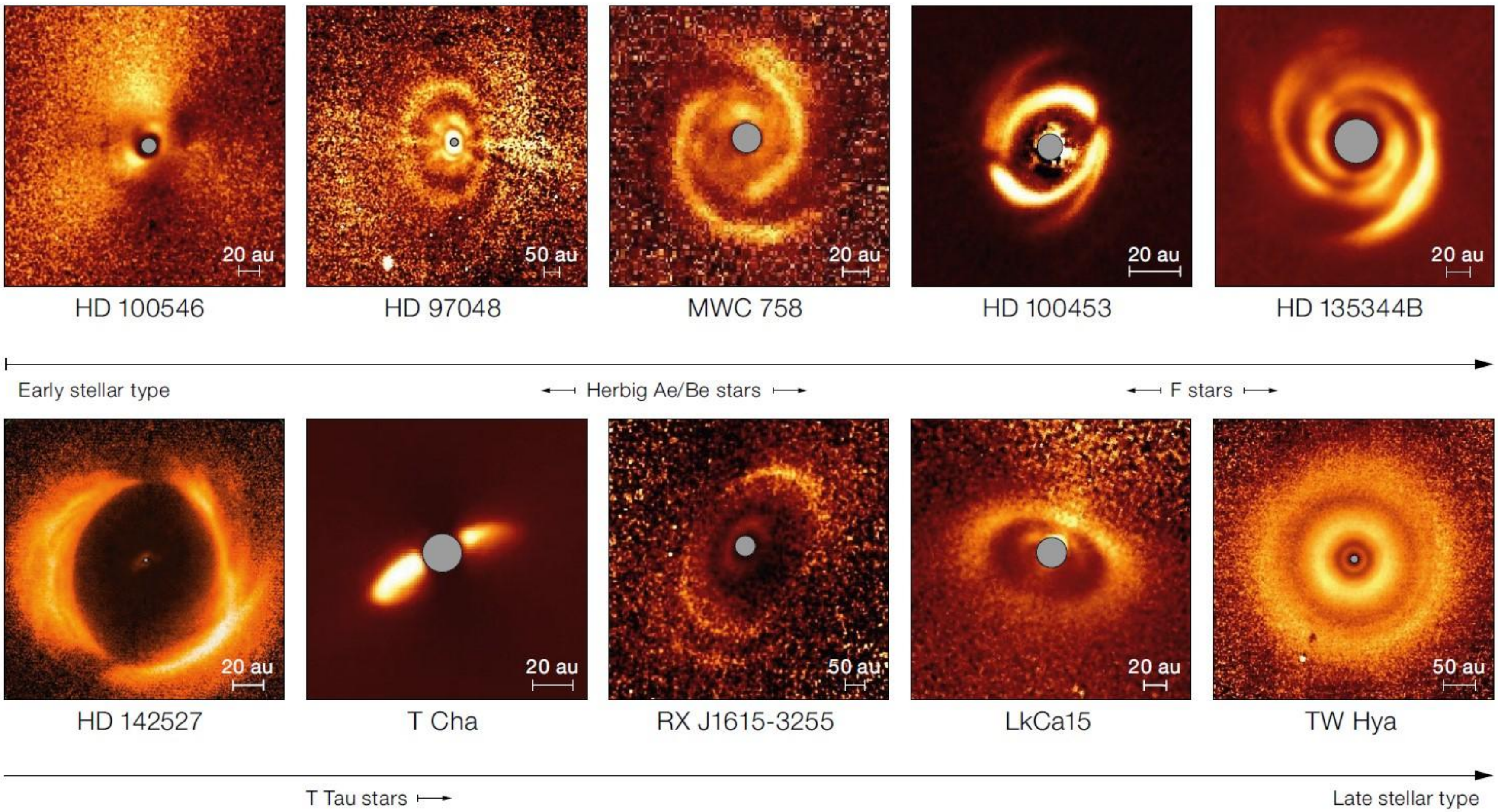
Inside SPHERE



Beuzit et al. 2019

Transformational for disks

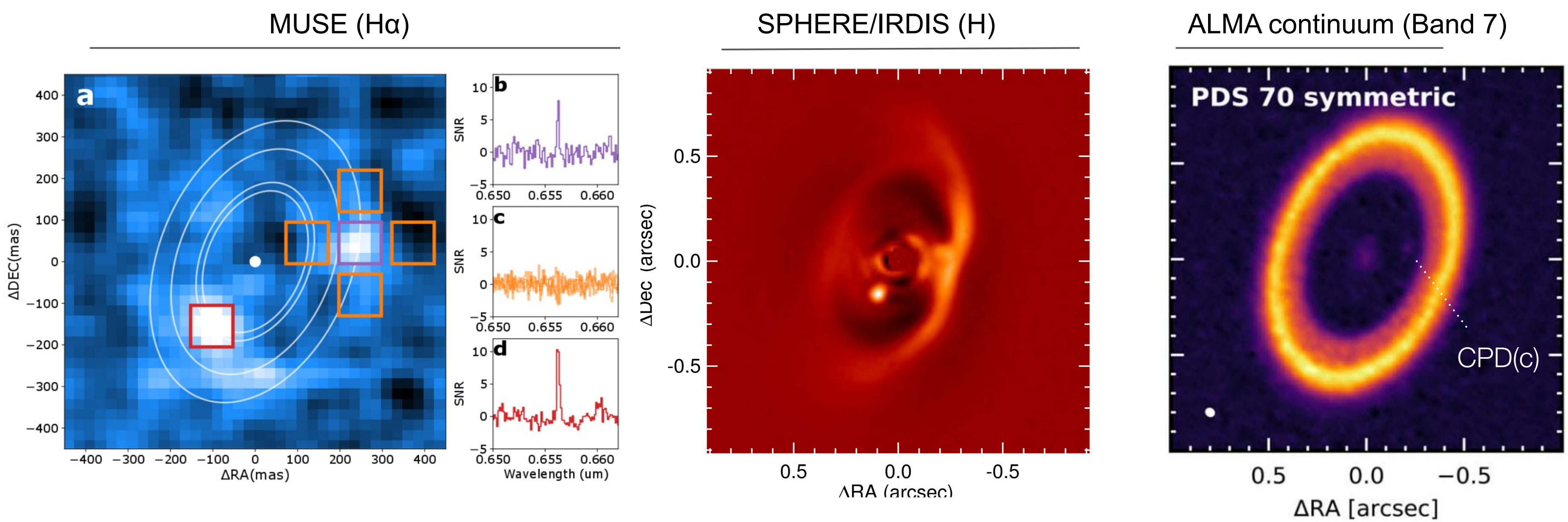
Spirals, shadows, gaps & ring in circumstellar disks



Garuffi et al. (2021)

First protoplanets!

PDS70 b & c: Planet(s) caught in formation



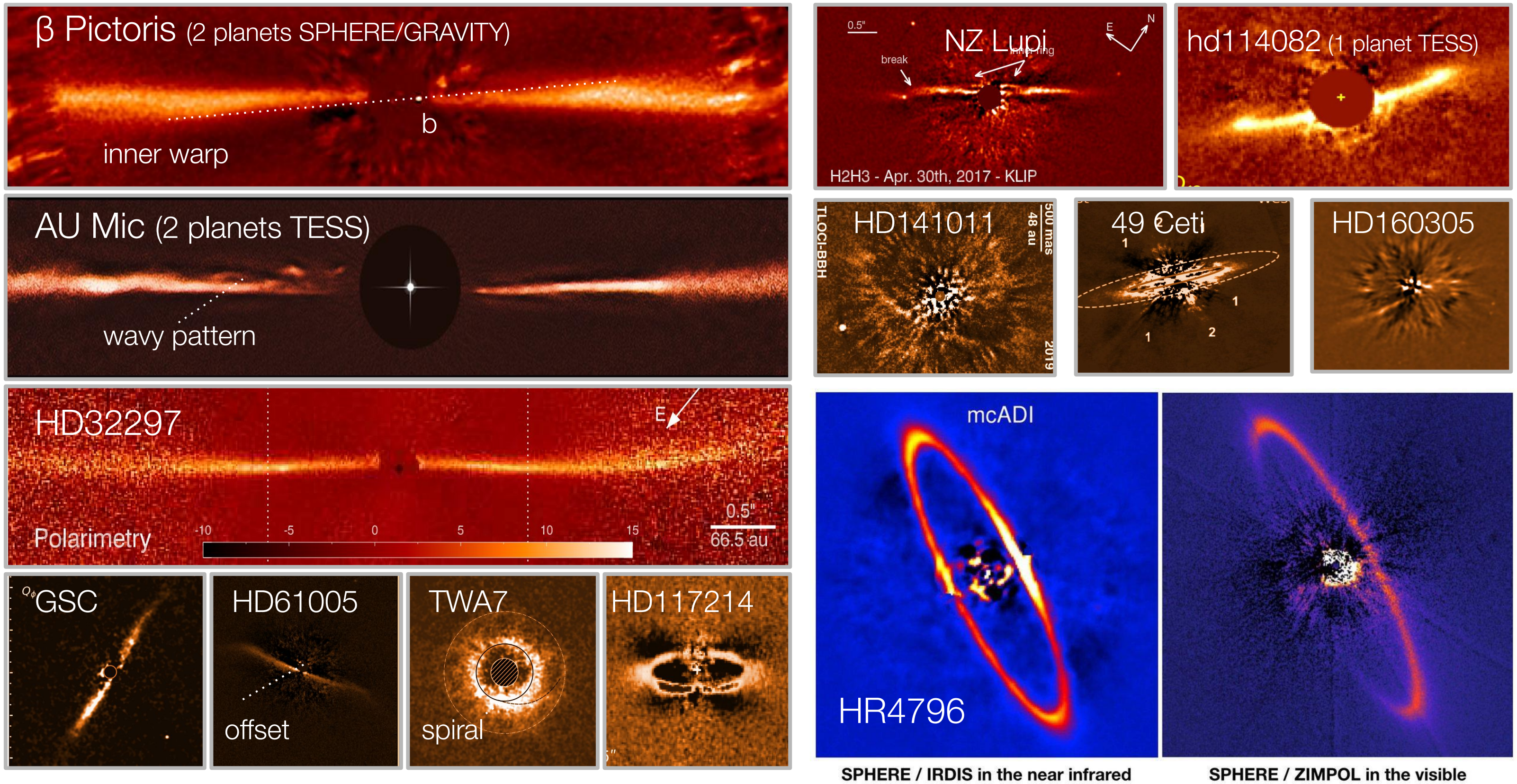
- Direct insights on protoplanet(s): giant planet formation, planet/disk interactions, architectures & stability, multiple planetary systems, circumplanetary disks, physics of accretion ($L_{H\alpha}$, accretion shocks on CPD versus planet's surface) & exomoons.

Synergies: ALMA, MUSE, CRIRES+, JWST, *ERIS, MAVIS SKA & ELT*

Keppler et al. 2018, 2019, Müller et al. 2018, Christiaens et al. (2018), Mesa et al. 2019, Haffert et al. 2019, Cugno et al. 2019, Gratton et al. 2019, Sissa et al. 2019, Thanathibodee et al. (2019), Xie et al. (2020), Wang et al. 2021, Benisty et al. 2021, Ayoma et al. (2021), Marleau et al. (2022), Currie et al. (2022)

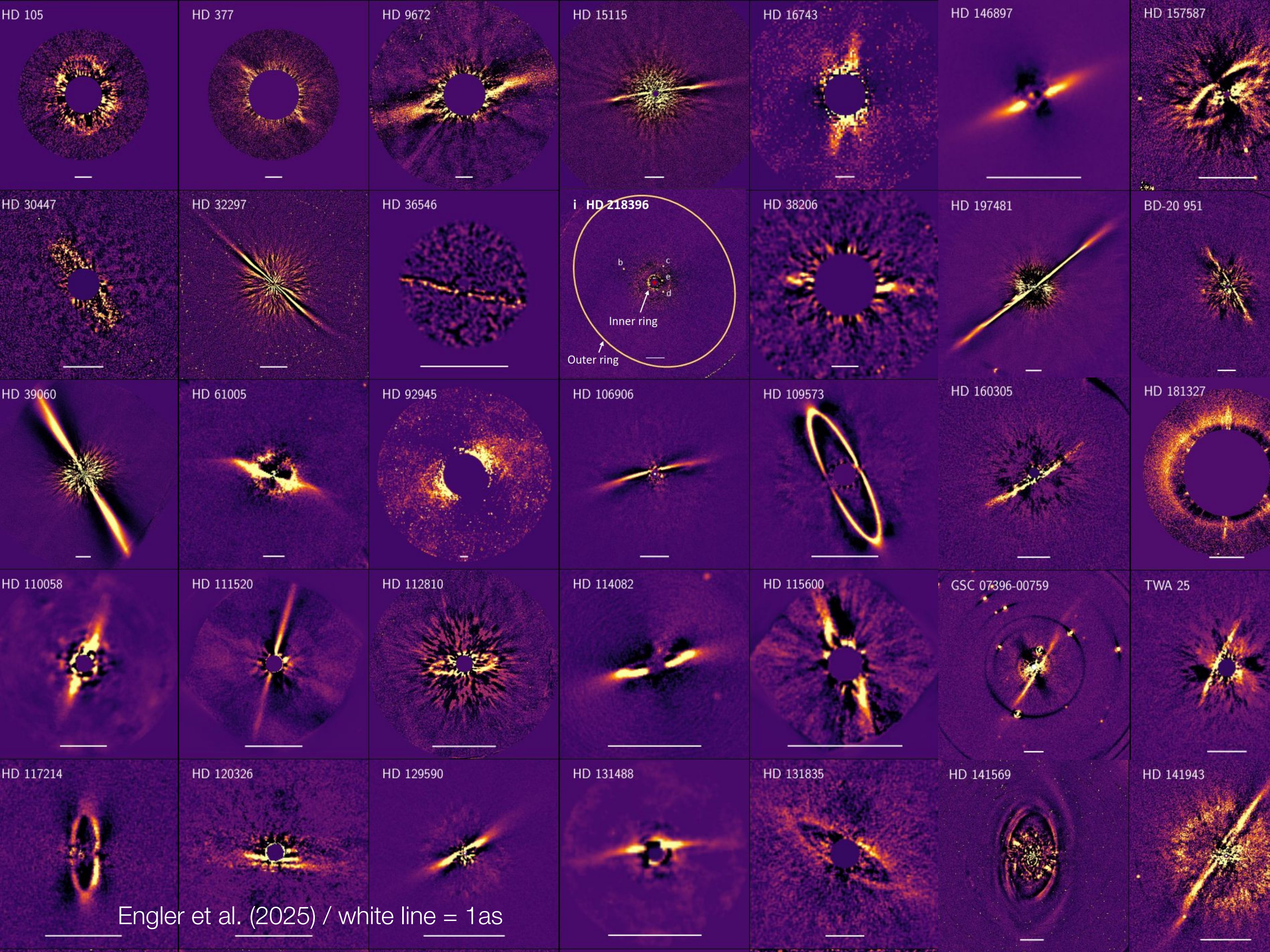
Orbits & Architectures

Planet(s) & Debris Belt(s)



- Morphologies: exoplanetary orbits & debris disk belt(s) location, sub-structures (warp, cavities, spiral, wavy pattern, eccentricity, offset…), exo-cometary activity, exo-zodi dust,
- Dust properties: polarized flux, phase function, grain size, structure & composition,

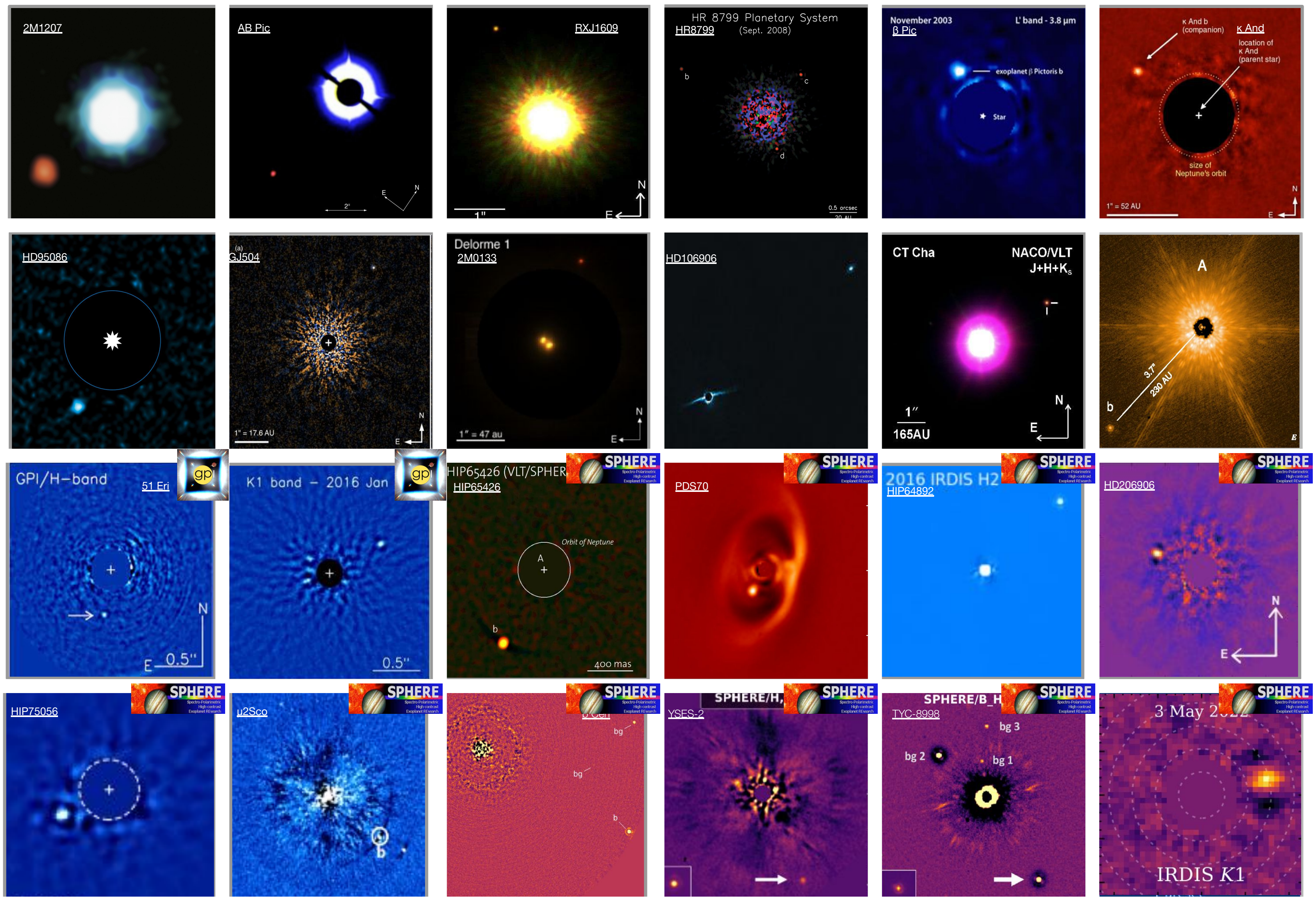
Boccaletti et al. (2015, 2019), Sissa et al (2017), Adam et al. (2019), Bowmhik et al. (2019), Lagrange et al. (2019), Engler et al. (2021, 2022), Milli et al. (2017, 2019), Perrot et al. (2019), Olofsson et al. (2016, 2018, 2019, 2020, 2022), Pawellek et al. (2019)


HD 105
HD 377
HD 9672
HD 15115
HD 16743
HD 146897
HD 157587
HD 30447
HD 32297
HD 36546
i HD 218396
b
c
e
d
Inner ring
Outer ring
HD 38206
HD 197481
BD-20 951
HD 39060
HD 61005
HD 92945
HD 106906
HD 109573
HD 160305
HD 181327
HD 110058
HD 111520
HD 112810
HD 114082
HD 115600
GSC 07396-00759
TWA 25
HD 117214
HD 120326
HD 129590
HD 131488
HD 131835
HD 141569
HD 141943
Engler et al. (2025) / white line = 1as

(*) AO imaged companions with $M < 25\ M_{Jup}$

New Exoplanets Discoveries

Chauvin et al. (2017), Keppler et al. (2018), Cheetham et al. (2018), Milli et al. (2017), Wagner et al. (2021), Squicciarini et al. (2022),Janson et al. (2019, 2021), Bohn et al. (2020, 2021a, 2021b), Bonavita et al. (2022)

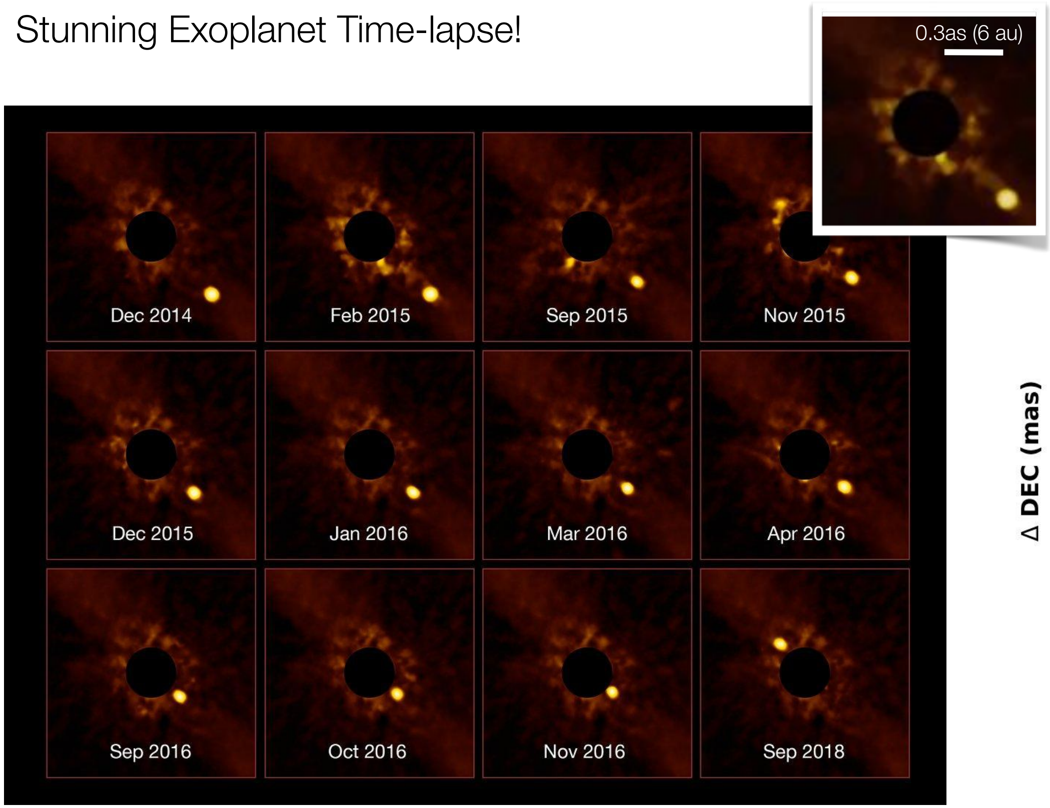


- April 2026: 14 new exoplanets with SPHERE, first protoplanet, three new multiple systems, two new circumbinary planets (SHINE, BEAST, SCORPION, YSES surveys)

Orbits & Architectures

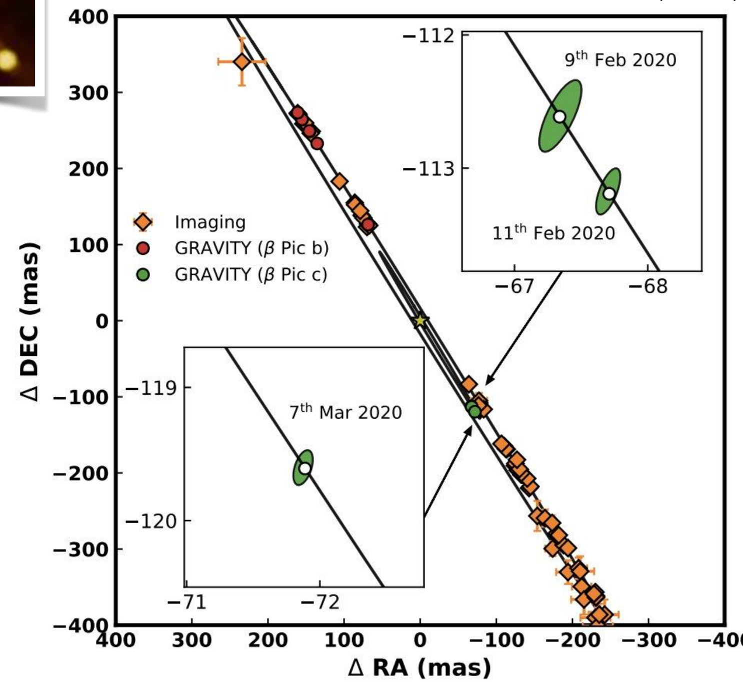
β Pic b, Witnessing a Giant Planet in Revolution!

Stunning Exoplanet Time-lapse!



Lagrange et al. (2019)

Nowak et al. (2020)



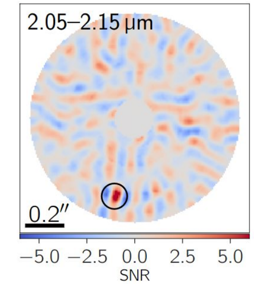
- Accessing mas-astrometry: for monitoring of exoplanetary orbits, disk sub-structures (blobs, shadows, spirals) & planet-disk interactions/signal unmixing

Synergies: VLT/GRAVITY, RV, Gaia & *ELT*

Vigan et al. (2016), Zurlo et al. (2017), Maire et al. (2018, 2020), Chauvin et al. (2018), Bonnefoy et al. (2018), Mesa et al. (2019), Lagrange et al. (2019), D'Orazi et al. (2019), Nowak et al. (2020), Lacour et al. (2022), Zurlo et al. (2022), Desgrange et al. (2022)

Exoplanetary atmospheres

Spectral Characterization of 51 Eridani b

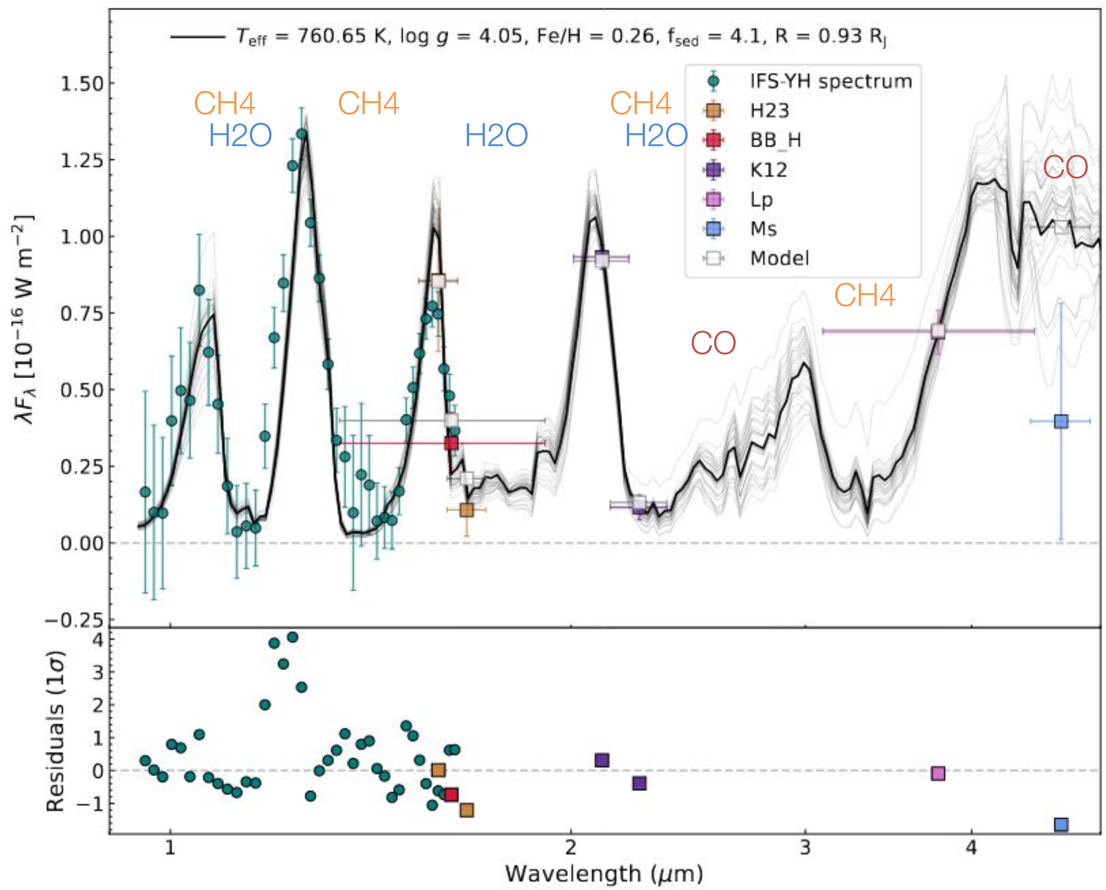


From color-magnitude diagram to low-resolution spectra of young giant planets,

51 Peg, F0V star, 29.4pc, 23Myr, Pictoris Moving Group

51 Eri b, 2.6 M_{Jup} exoplanet
a = 11.1au , e = 0.53, i = 136deg
T3-SpT, Teff = 760K, log(g) = 4.05 , Fe/H = 0.26, fsed =4.1 (large particles, thin clouds)

Synergies: SINFONI, VLTI/Gravity (K-band), CRIRES+, ERIS, JWST (NIRSpec, MIRI…)

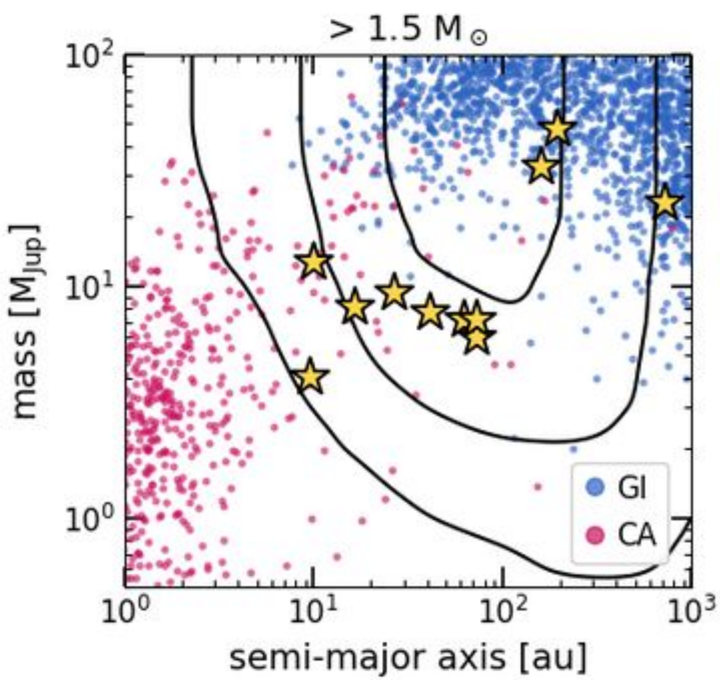


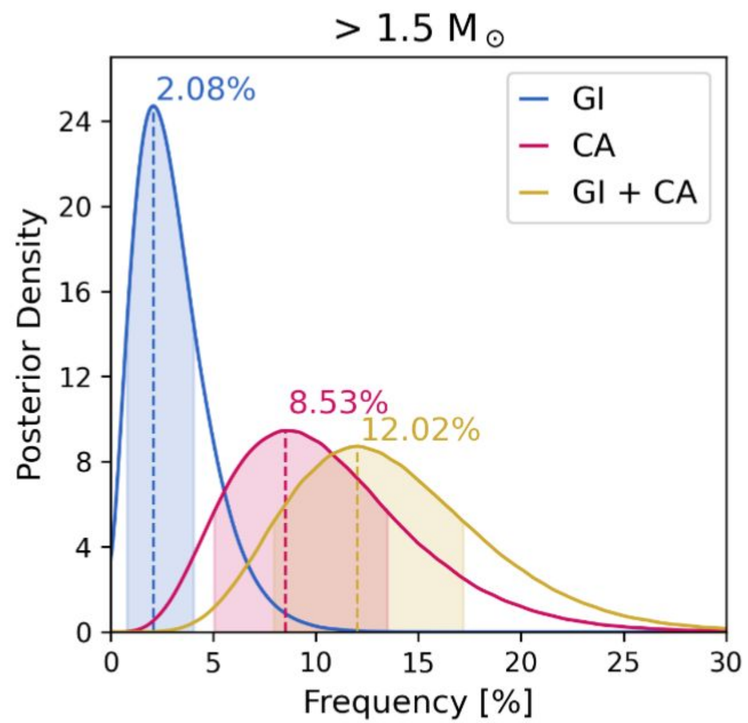
Brown et al. (2022)

Macintosh et al. (2015), Chilcote et al. (2015), Bonnefoy et al. (2016), de Rosa et al. (2016), Samland et al. (2017), Chauvin et al. (2017, 2018), Delorme et al. (2017), Cheetham et al. (2018, 2020), Hoeijmakers et al. (2018), Mesa et al. (2019), Novak et al. (2020), Wang et al. (2021), Petrus et al. (2021), Ruffio et al. 2022, Desgrange et al. (2022), Brown et al. (2022), Hinkley et al. (2022)

Demographics

Occurrence of Giant Planets beyond 5 au (SHINE F400, 340 stars)





- Planetary system hosting at least one giant planet (5 - 500 ua, 1-75 M_{Jup}):
  - > 1.5 $M_{\odot}$: 12.0±5.1%
  - 0.8-1.5 $M_{\odot}$: 4.0±2.1%
  - < 0.8 $M_{\odot}$: 2.7±2.3%
- Overlap of 2 populations (planets/BDs) - NGPPS & DISPY Bern's group models (e.g. Schib et al. 2025)
- Clear dependency on the stellar mass considering intermediate-mass to low-mass stars

Chauvin, Fontanive et al. (2026, in prep), Delorme et al. (2025), Squicciarini et al. (2025), Vigan et al. (2021), Nielsen et al. (2019), …

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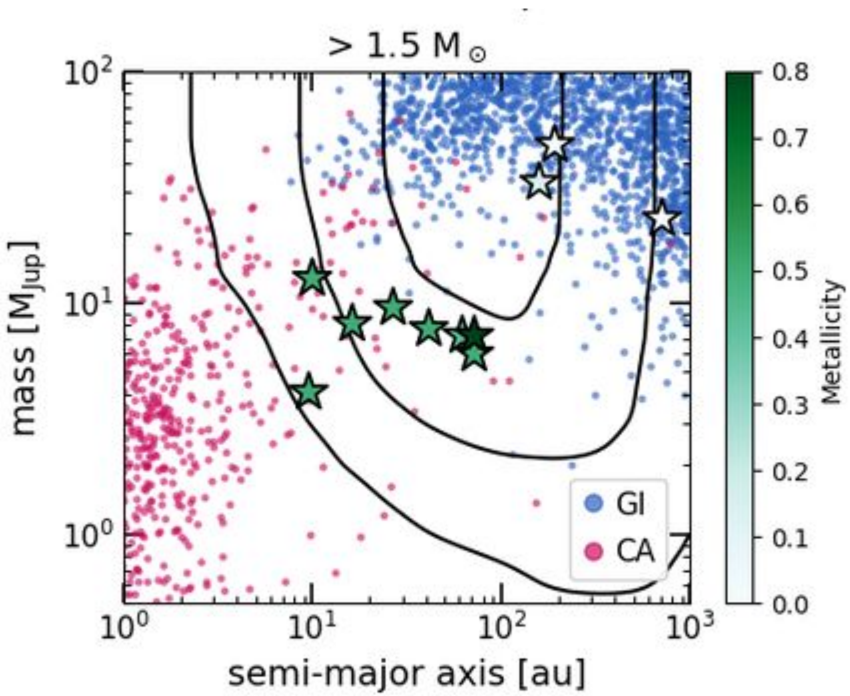

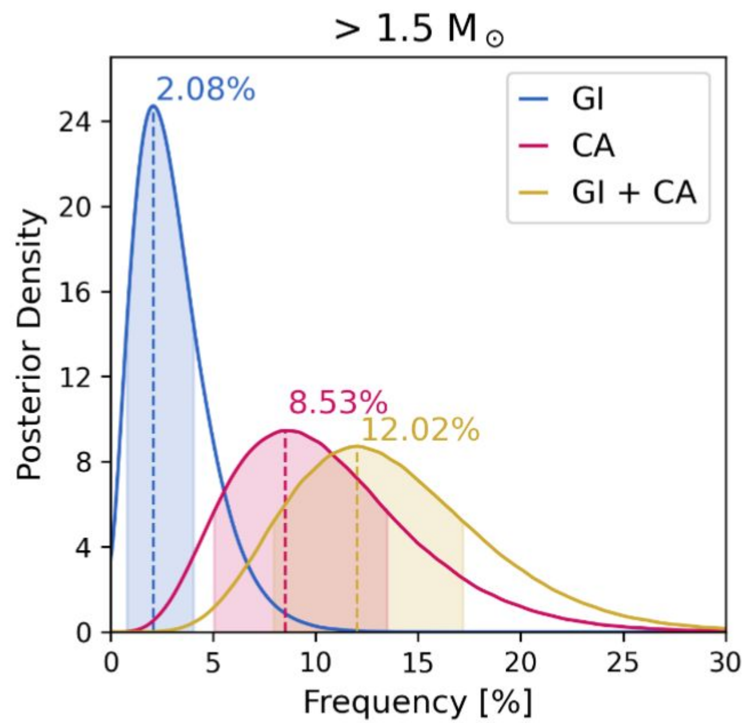

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SPHERE Lessons learned

SPHERE+
Spectro Polarimetric High contrast Exoplanet REsearch uPgrade

** 11 years of operation*
& 500+ publications (incl. 150+ from GTO)

Astrophysical success thanks to:

- Well identified science cases, tight specifications & trade-off analysis
- SAXO: xAO high-performances, stability, robustness in terms of operation (< 3% downtime),
- Versatile instrumentation: ZIMPOL, IRDIS and IFS in terms of wavelengths, spectral resolution, field of view & observing modes (ADI, SDI, DPI, RDI),

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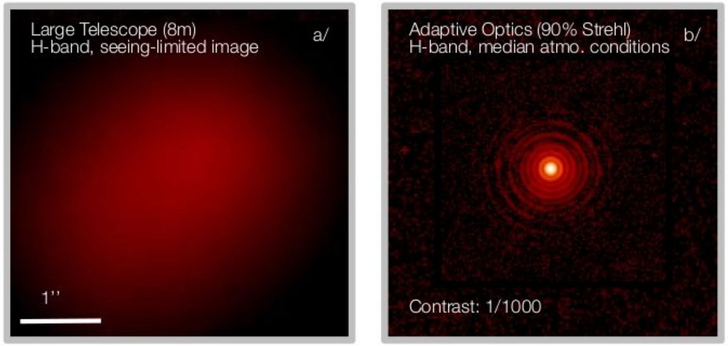
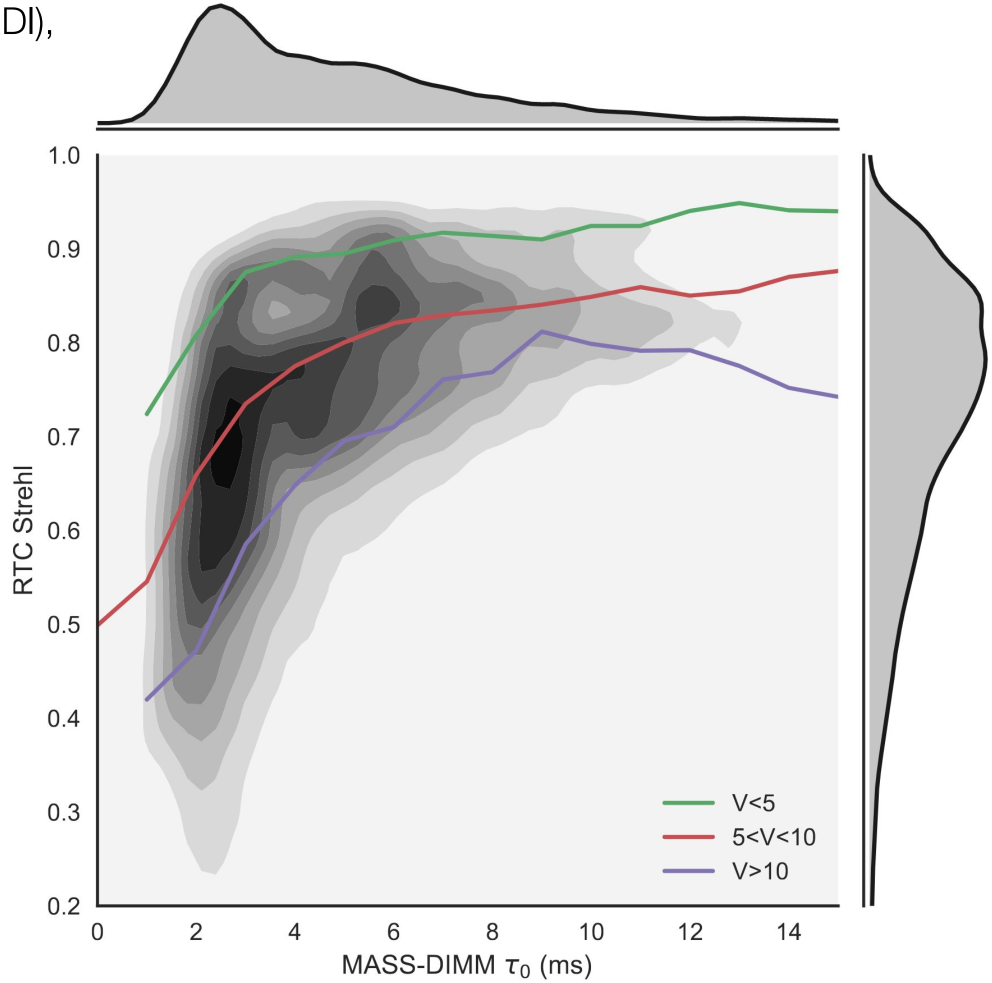
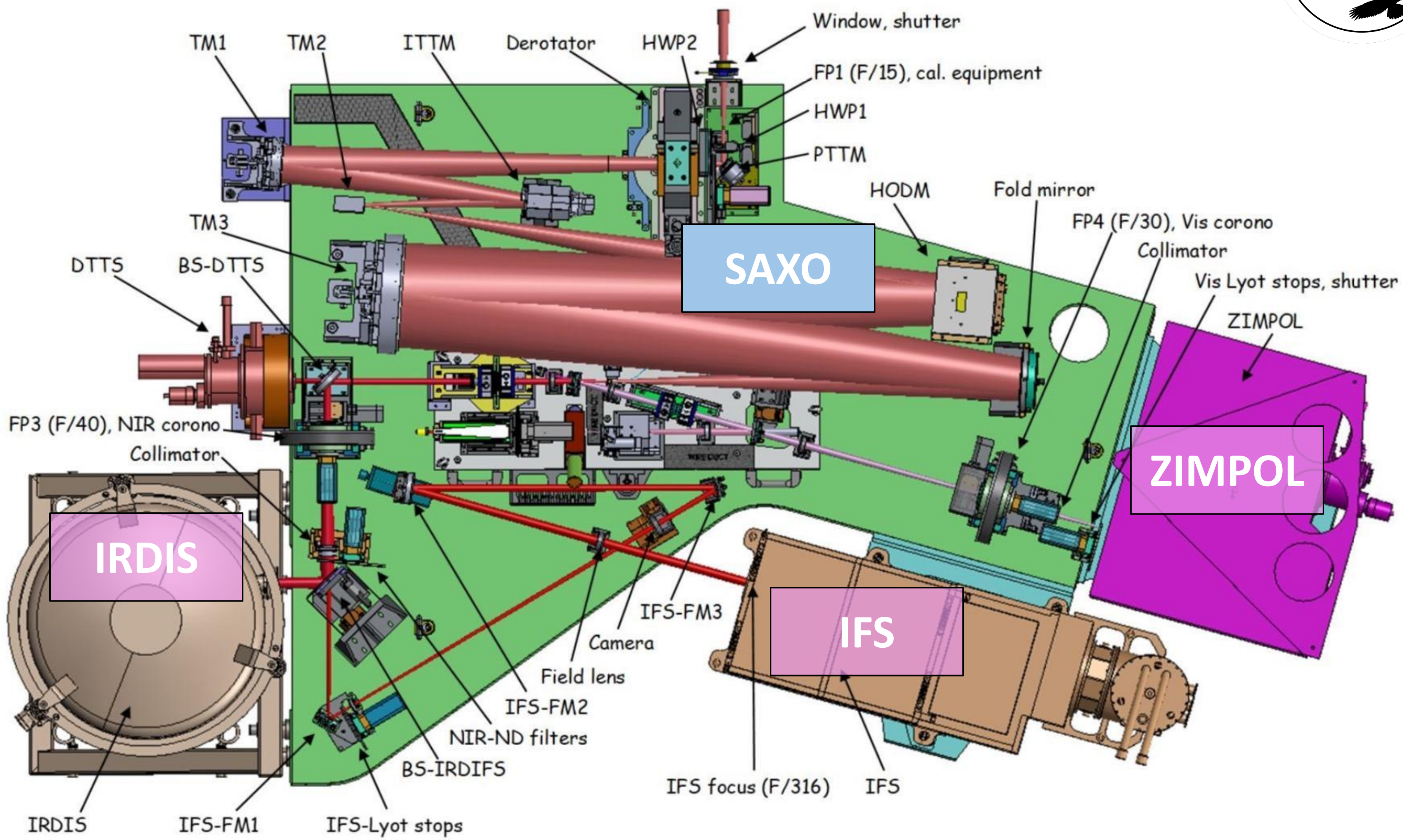
SAXO Strehl as a function of the coherence time - e.g. Milli et al. (2017)

200 000 telemetry data points, with each point corresponding to an average of 20 seconds. These data points are spread over 465 different nights and more than a thousand different stars.





Implementation



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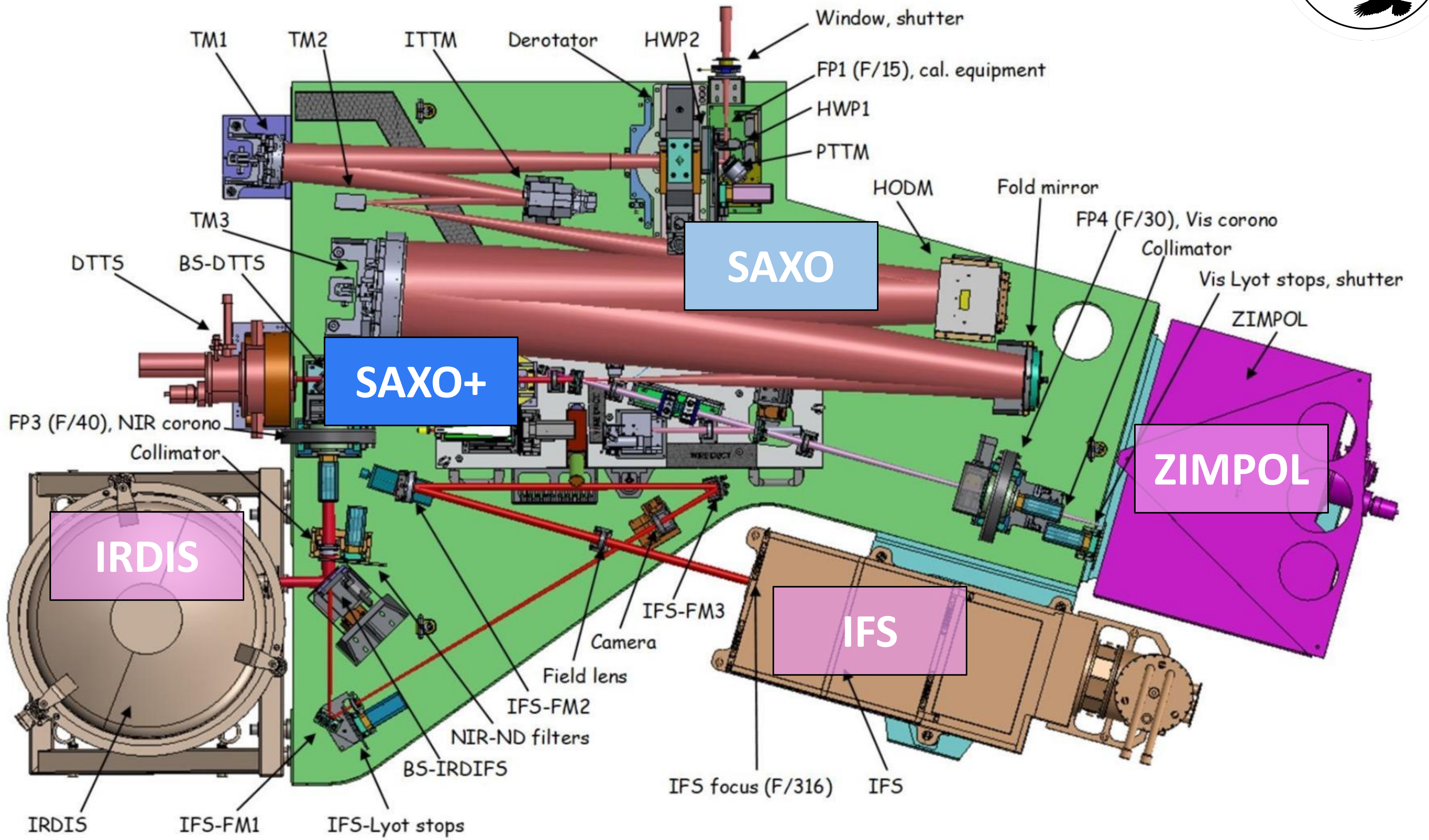
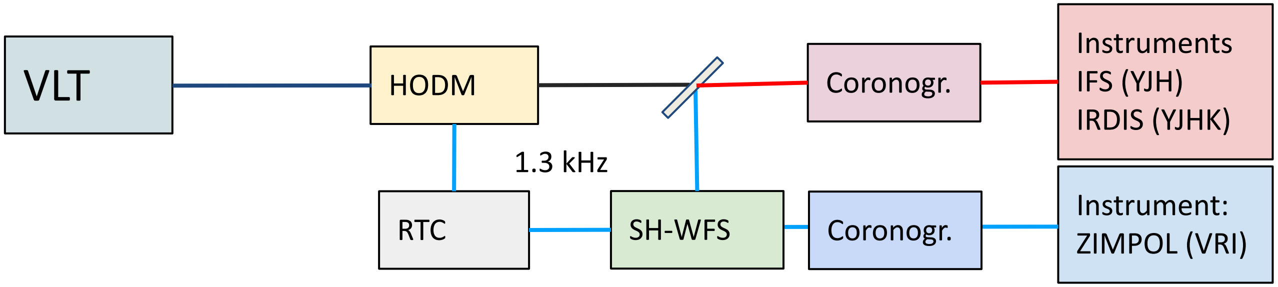


SPHERE+, a second-stage XAO

Concept:

- Do not break SPHERE!
- SAXO+ optics installed on top of the main NIR beam
- HODM2 (34x34) + IR pyramid WFS at 2.7kHz
- Real Time Computer (Cosmic-arch.), Stand-alone(+) & Predictive control
- Keep polarimetric performances
- Dichroics: DIC-Y & DIC-YJ
- New Apodizer
- NCPA control (Dark Hole)



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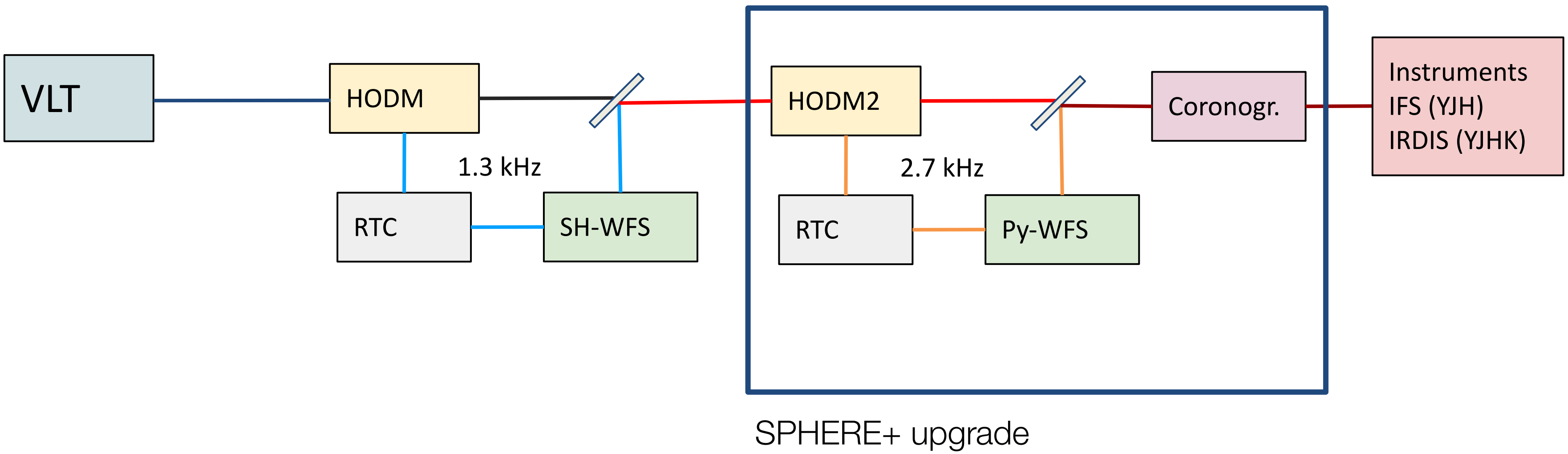

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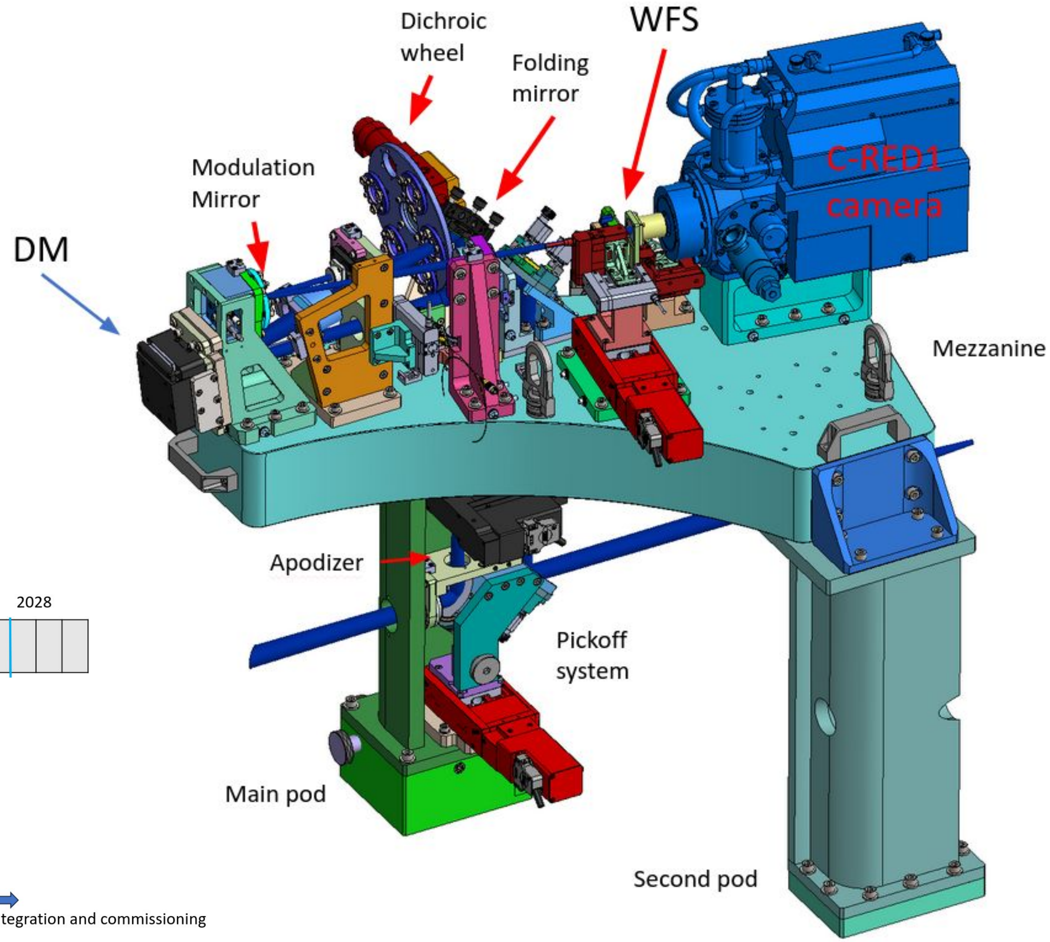
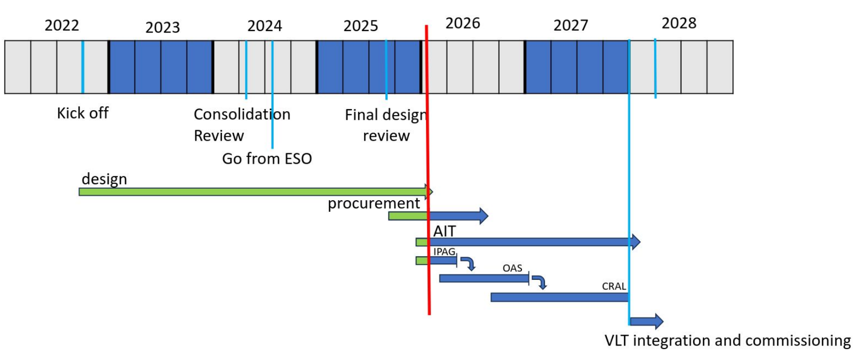
Mechanical Design

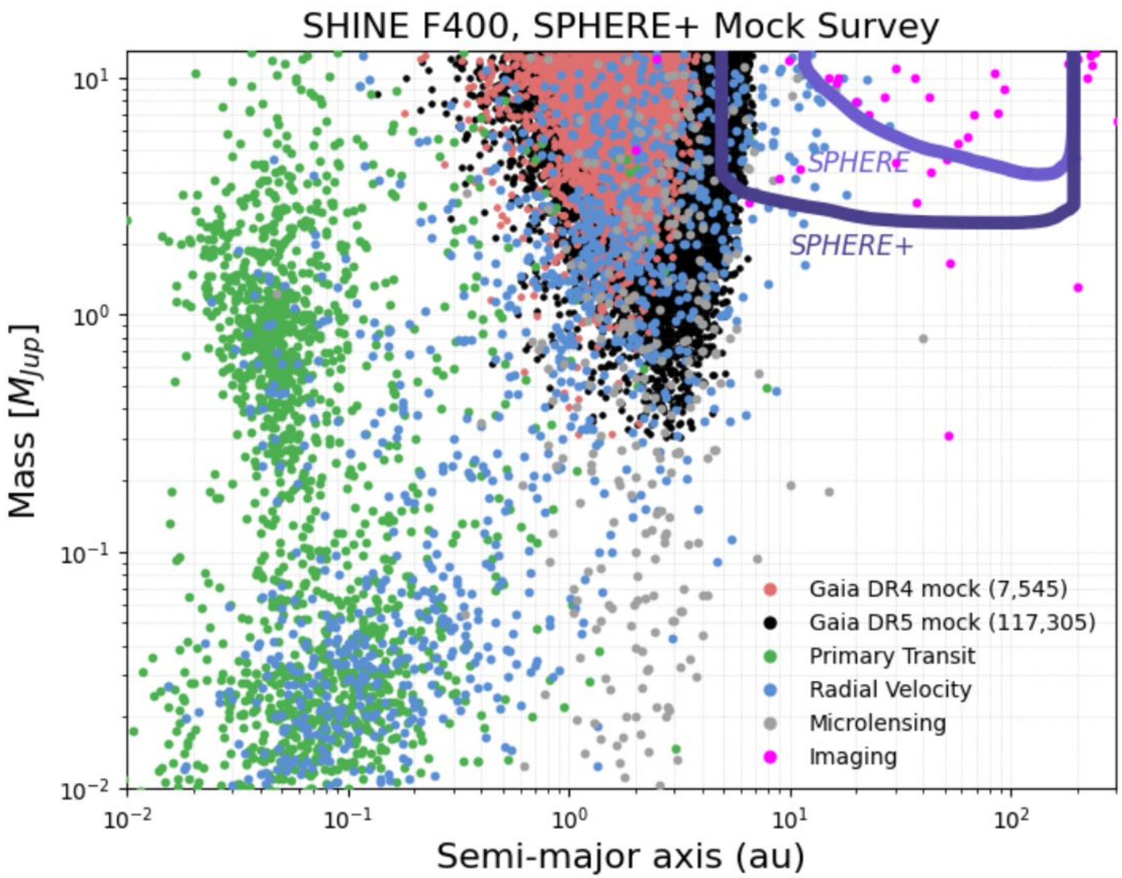




SPHERE+ Science Drivers

(*) Gaia will observe 450 (and 1200), young (≤ 500 Myr) stars at distances closer than 50 pc (and 150 pc, respectively)

1. Demographics of young Jupiters down to the snow line



Known exoplanets to date
exoplanets.eu

Sample: Young (< 500 Myr), nearby (< 150 pc) stars
Synergies: RV & Gaia (DR3/DR4)

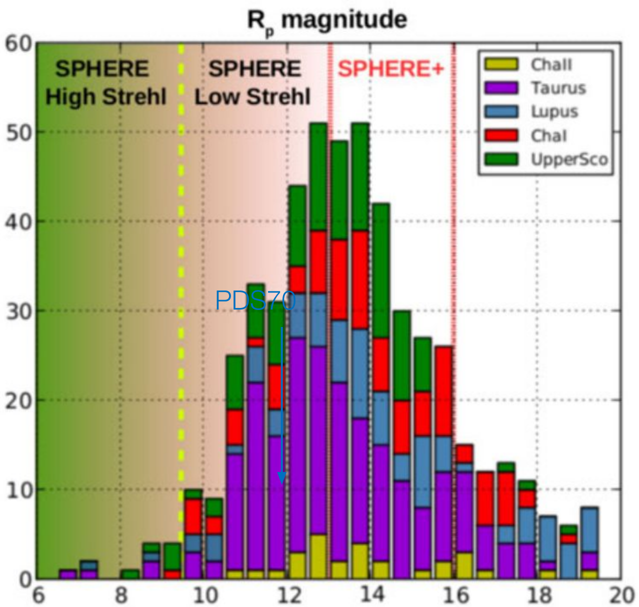
Trade-off-1 (SAXO+):
2nd stage AO (2.7 kHz)
IR path (IR WFS)

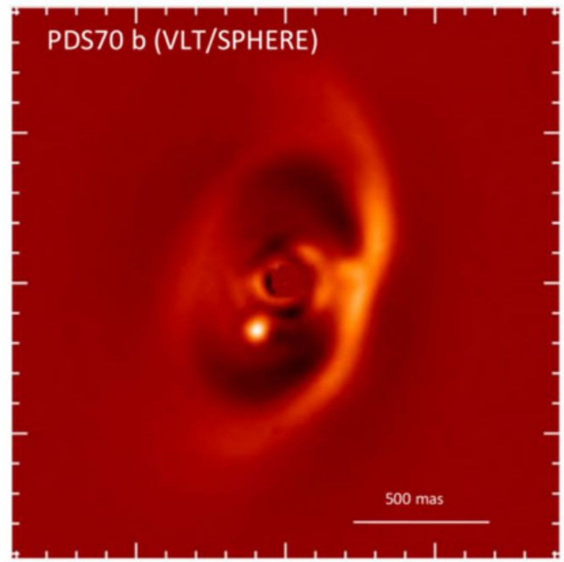
Sc. Req. 1: Deeper/Closer in contrast (10-5 at 100mas, 5σ) on bright (R < 9.5) targets at H-band

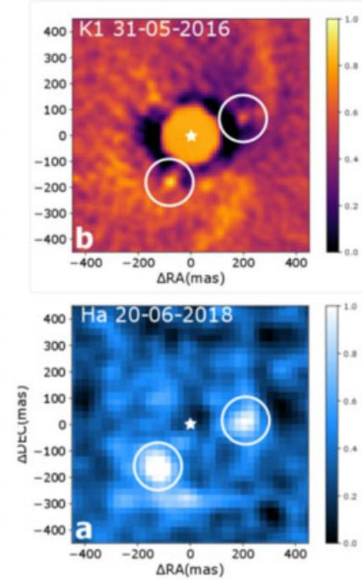
SPHERE+ Science Drivers

2. Discovering protoplanets & planet-forming disk diversity

Keppler et al. (2018), Haffert et al. (2019)





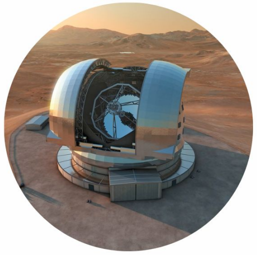


Trade-off-2 (SAXO+): photons sharing btw science and 2nd stage AO, Pyramid-WFS (more sensitive)

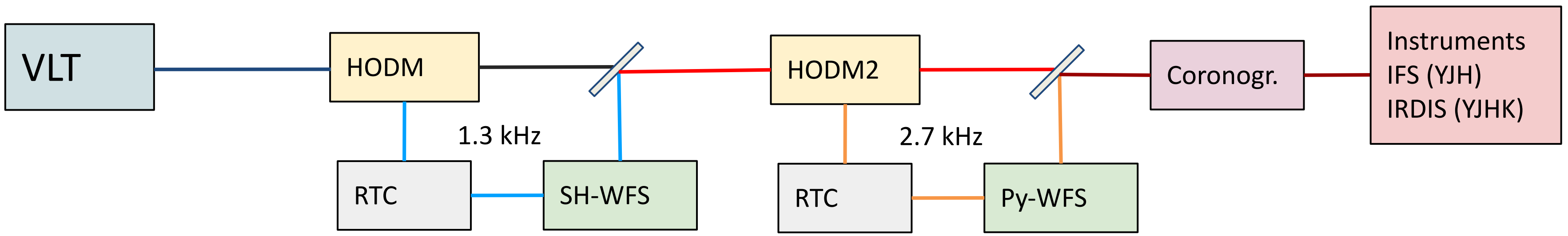
Sample: Faint members from SFRs (400+)
Synergies: ALMA, Gravity, ERIS(+)

Sc. Req. 2: Accessing fainter/redder targets (R < 14 mag, R - J = 2 - 5 mag)

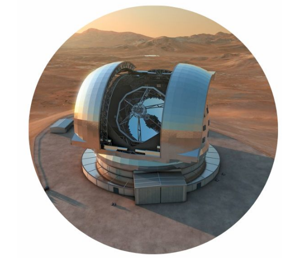
SPHERE+ Science Drivers



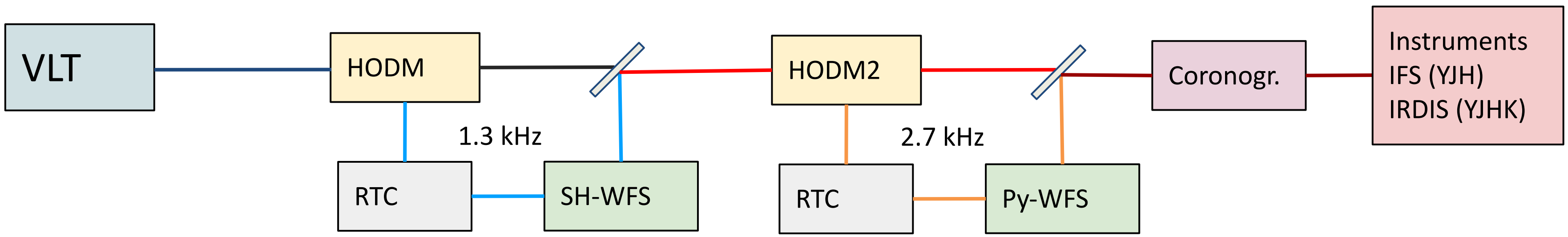
3. Proof of concept for PCS at ELT

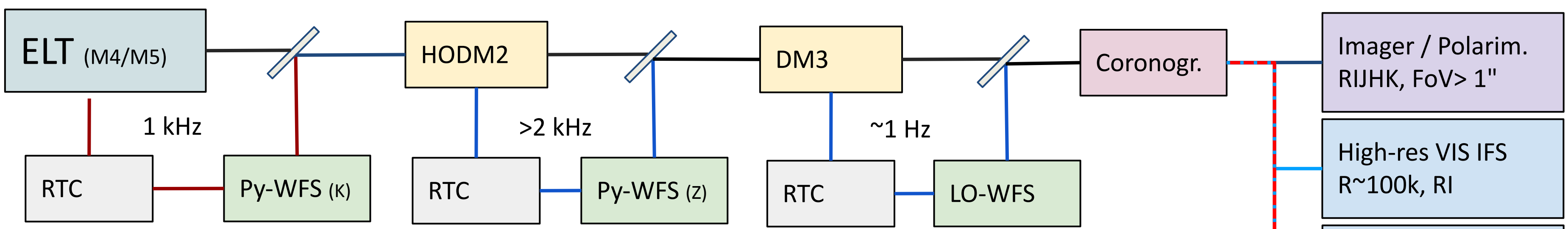


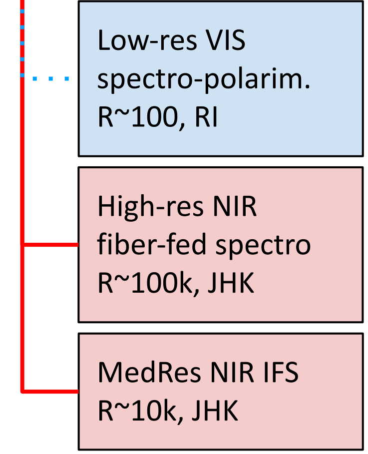
SPHERE+ Science Drivers

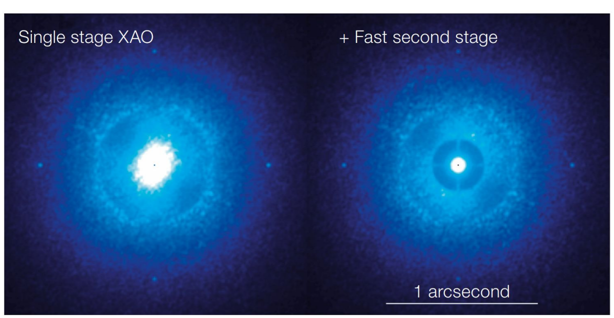


3. Proof of concept for PCS at ELT









Kasper et al. (2021)

ANDES

Possible connection to ANDES? RIZ, YJH and K-band spectrographs

PCS R&D Roadmap

Imaging & characterizing rocky worlds

Validate Science Drivers & Instrument Concept for a kick-off in 2029