SPHERE planet imager: instrument presentation and main results

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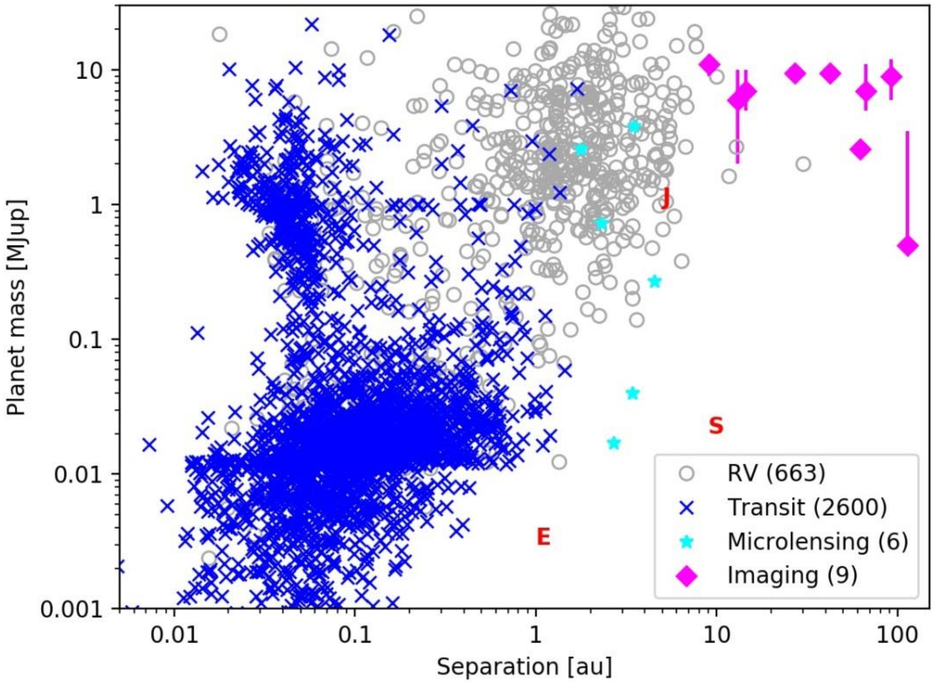
The field of extrasolar planets today

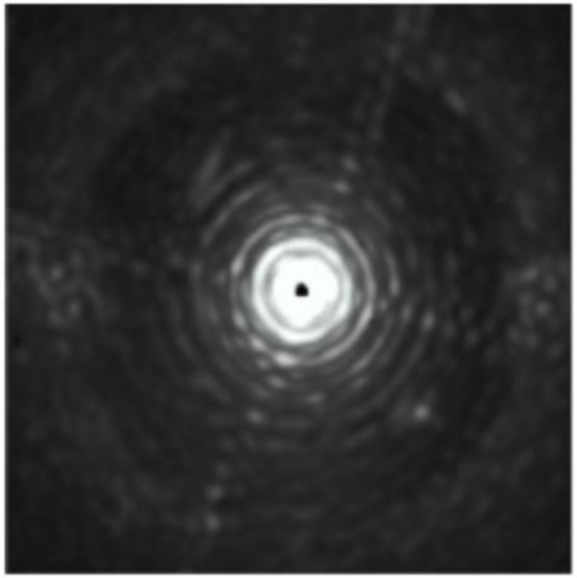


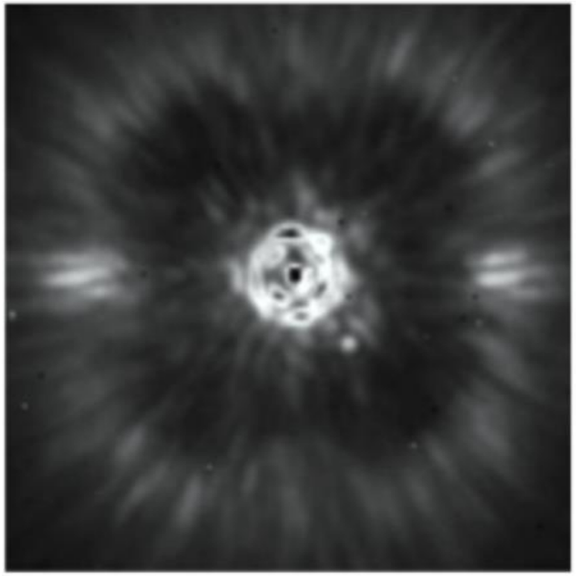
- **Thousands of exoplanet detected**
- **Just a few tens with direct imaging**
- **Challenging technique due to small angular separation and high luminosity contrast**

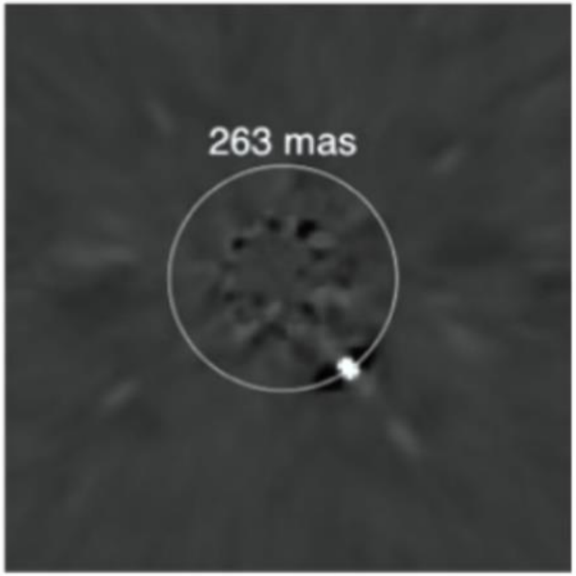
Why direct imaging?

1. **Allows to determine the substellar object orbit.**
2. **Spectro-photometry of the companion.**
3. **Probe the interaction substellar object – disk.**
4. **Precise characterization of the objects (in conjunction with indirect techniques).**
5. **High contrast spectroscopy (informations about presence of clouds and gravity.**

High contrast imaging pillars





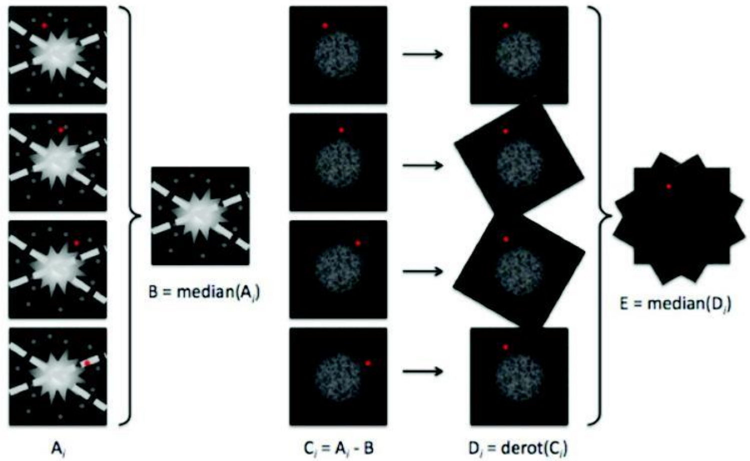


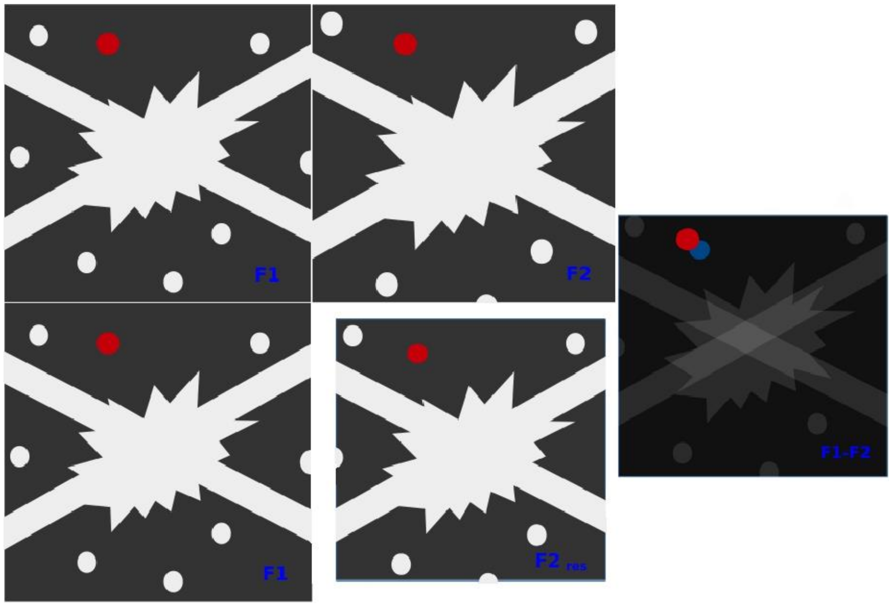
High order AO: Contrast ~ 10^{-3}

High efficiency coronagraphy: Contrast ~ 10^{-4}

Differential imaging techniques: Contrast ~ 10^{-6}

High contrast differential imaging techniques

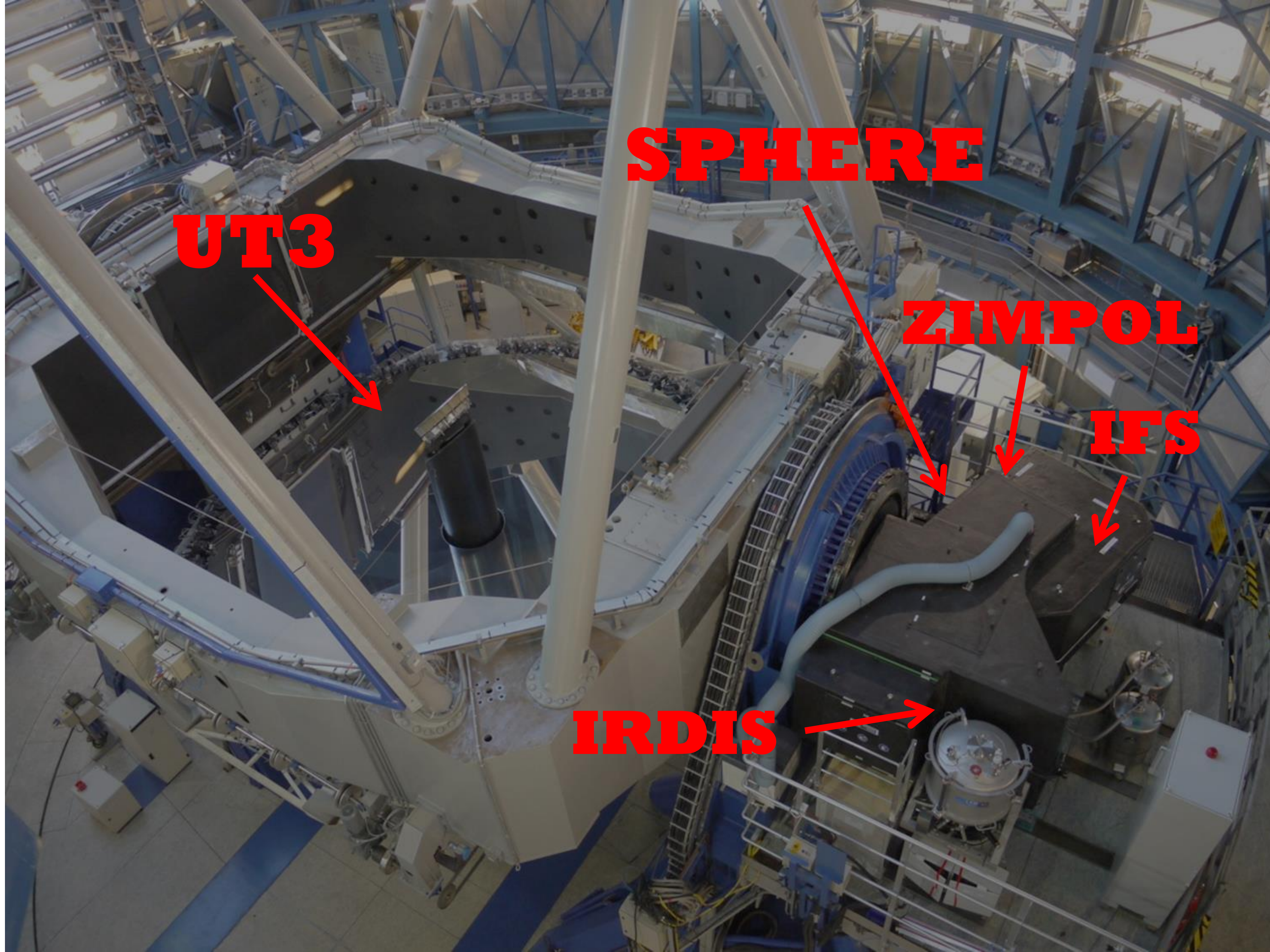




Angular differential imaging (ADI)

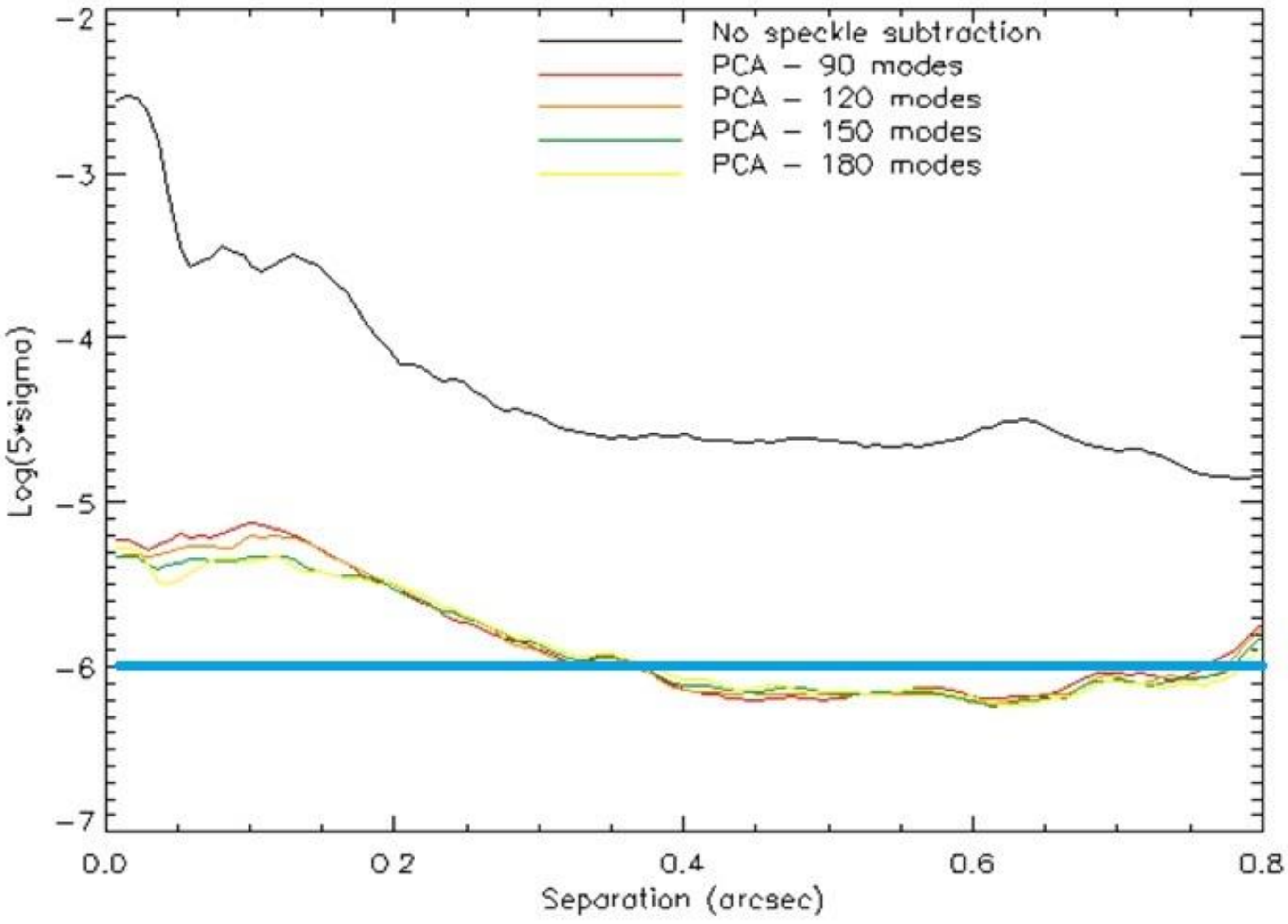
Spectral differential imaging (SDI)

- **Both the techniques can be implemented with SPHERE**
- **Different possible algorithms (e.g. TLOCI, PCA, NMF, PACO)**



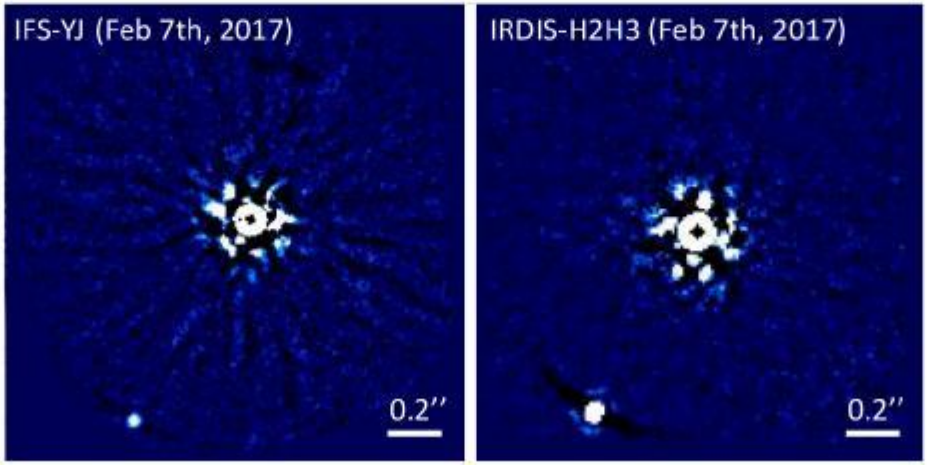
SPHERE
UT3
ZIMPOL
IFS
IRDIS

Results with SPHERE: contrast



IFS 5σ contrast at 0.3 arcsec ~10^{-6} for Tau Ceti (R=2.88)

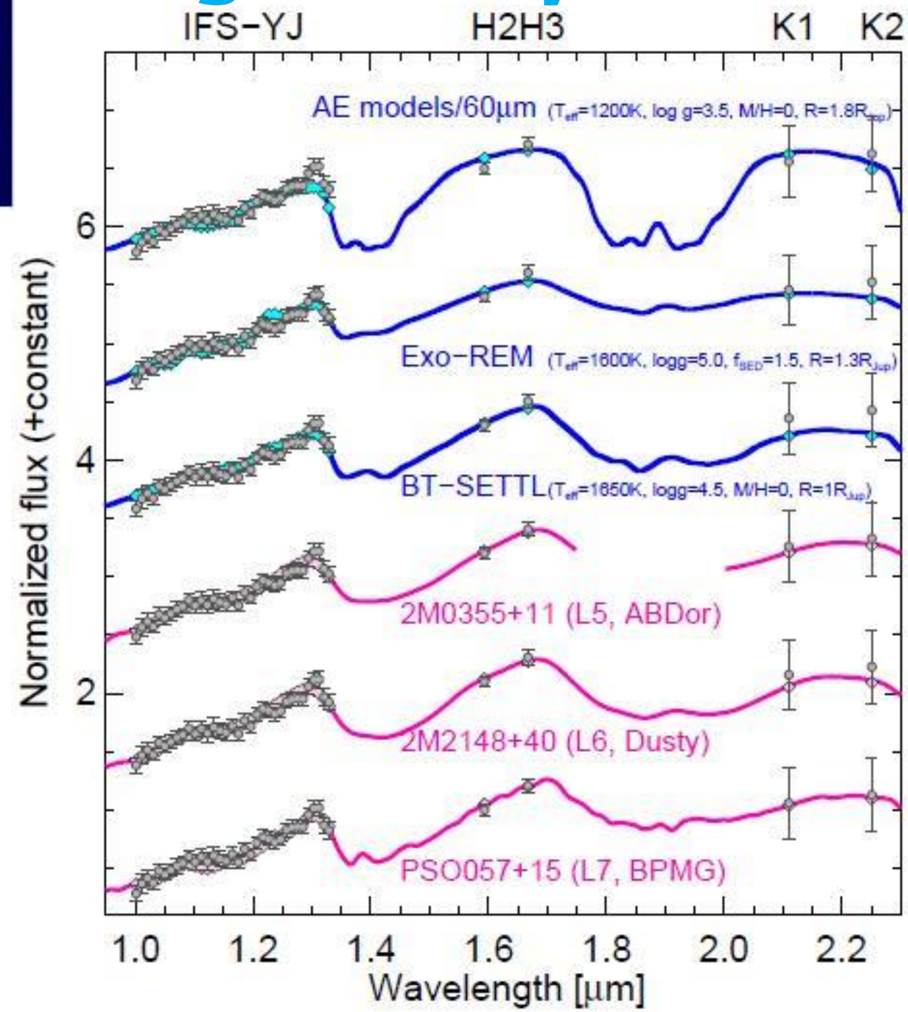
First planet detected: HIP65426



Chauvin et al. 2017

HIP65426:

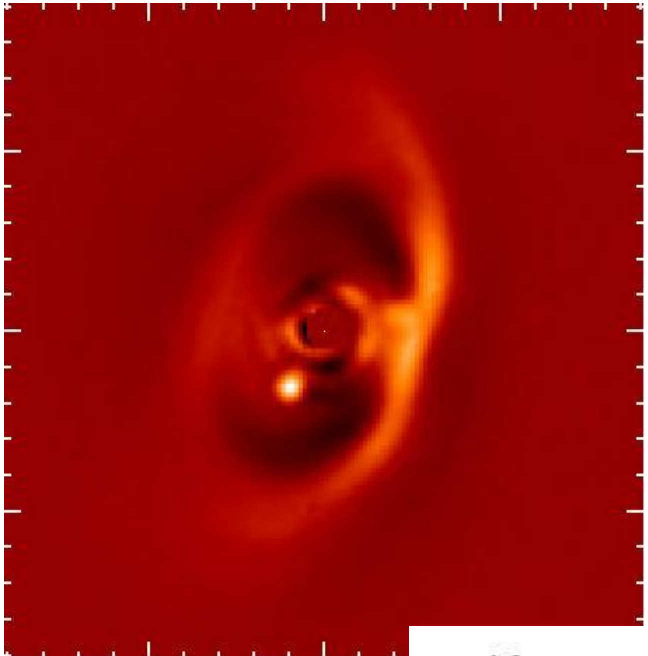
- A2 spectral type
- d ~ 114 pc
- Age ~ 14 Myr



Companion:

- Spectral type: L7
- $M \sim 7\ M_{jup}$
- $T_{eff} \sim 1500$ K

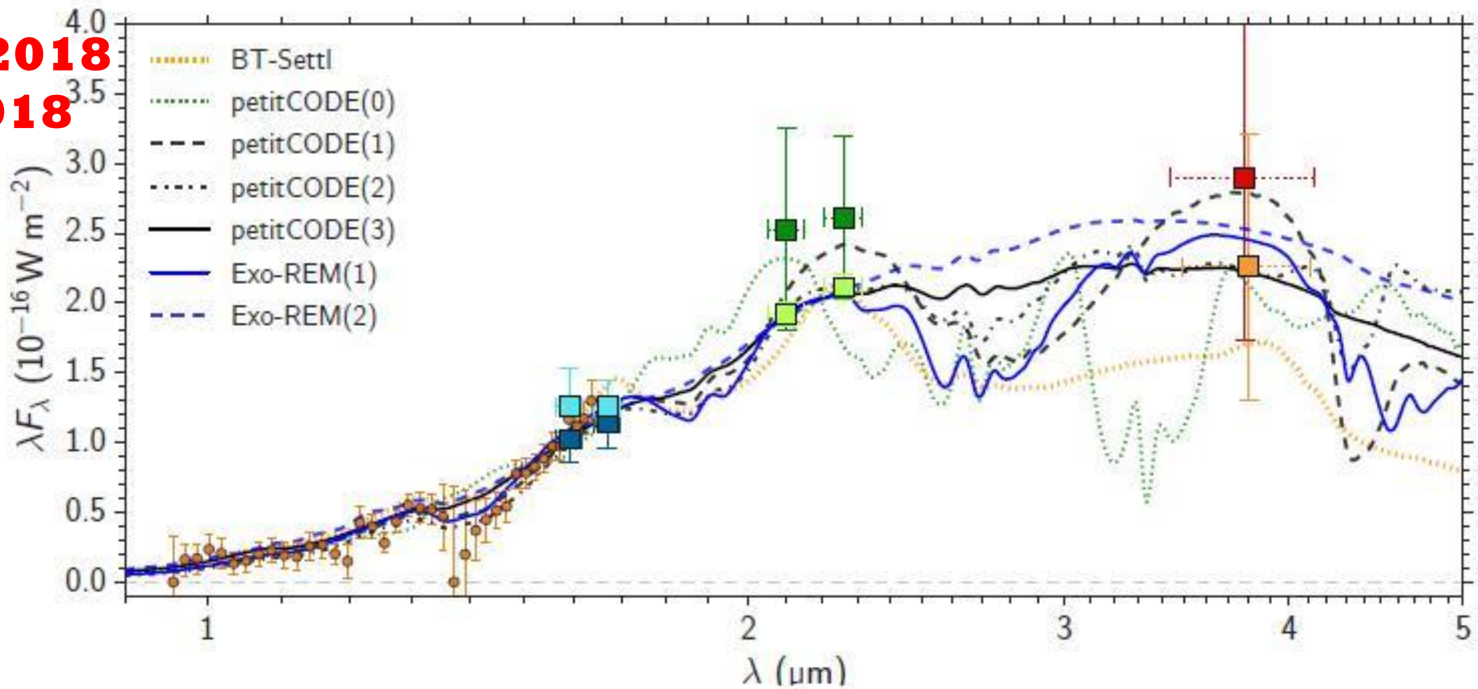
Second planet detected: PDS70



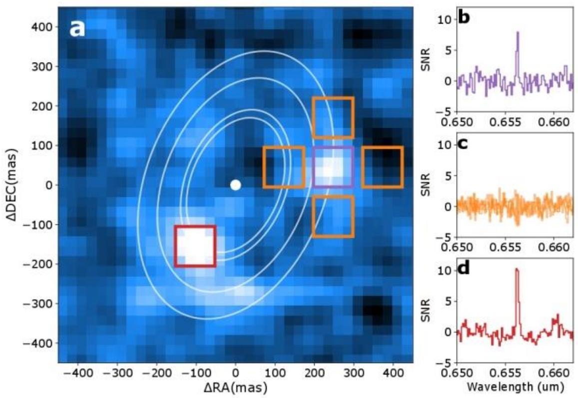
PDS 70:
- Spectral type: K7
- d ~ 113 pc
- Age = 5.4 Myr

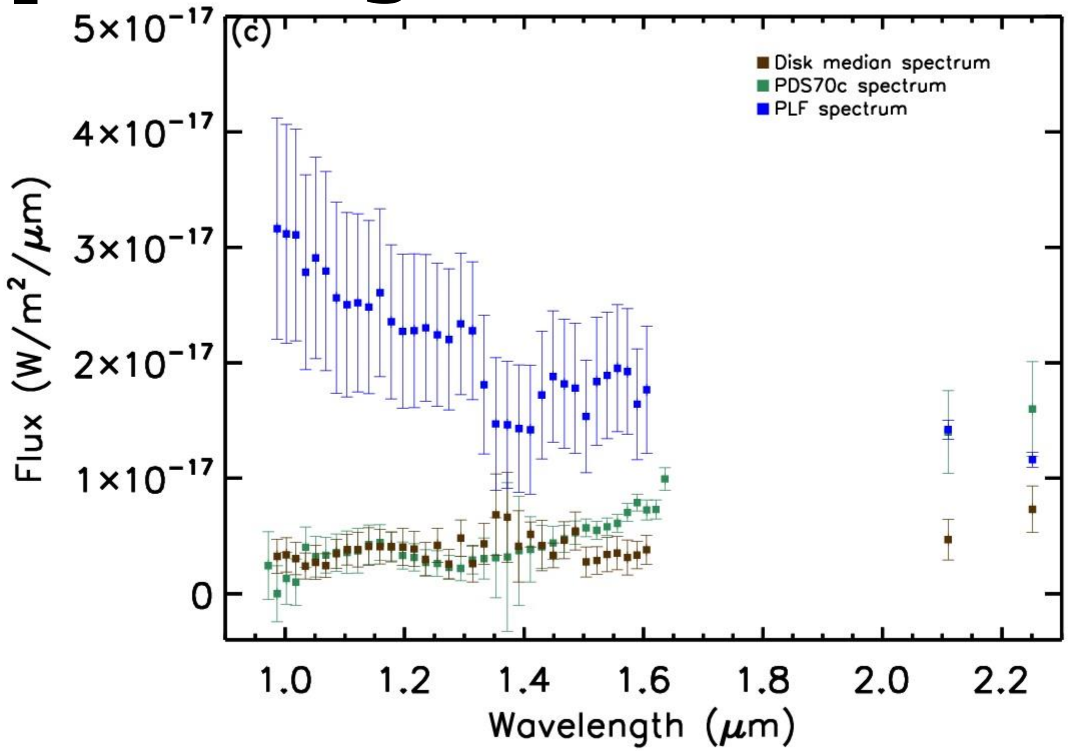
PDS 70 b:
- Separation ~ 22 au (into the gap of the protoplanetary disk)
- Mass: 5-9 M_{jup}
- T_{eff}: 1000-1600 K

Keppler et al. 2018
Muller et al. 2018



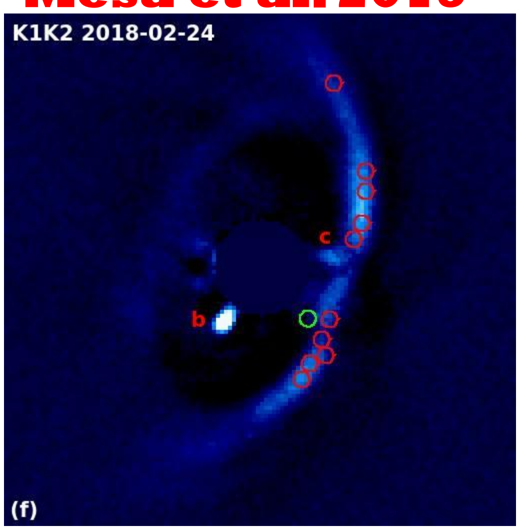
Third (fourth?) planet: again PDS70!!!

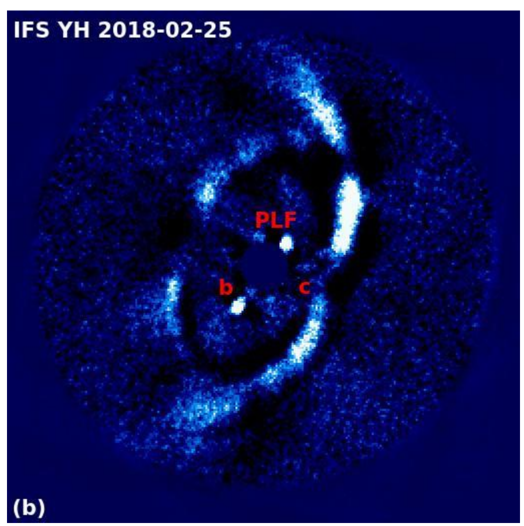




Detection of a second point source in H_α with MUSE (Haffert et al. 2019). Probable accretion.

Mesa et al. 2019



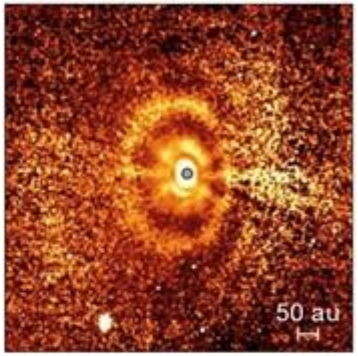


PDS 70 c:

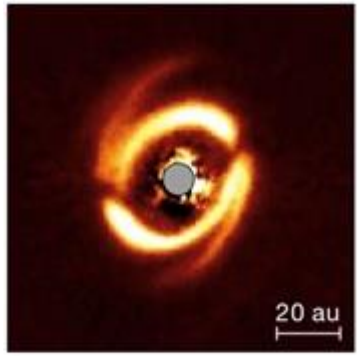
- **Separation: ~30 au (also in the gap of the disk)**
- **Mass less than 5 M_{Jup}**
- **T_{eff} ~ 900 K**
- **log(g) ~ 3.5 dex**

Possible a further object (only IFS). Part of the disk or in-formation planet?

Beyond planets: circumstellar disks

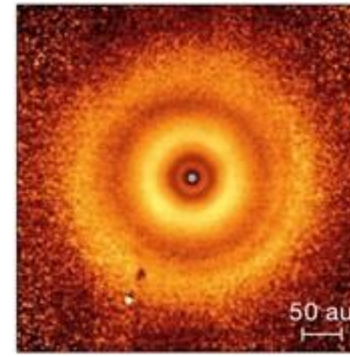


HD97048
Ginski et al. 2016

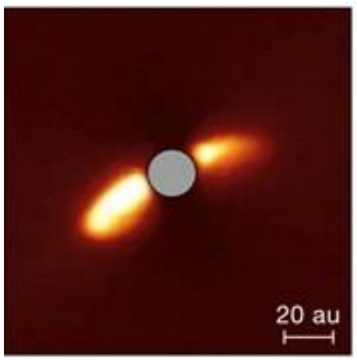


HD100453
Benisty et al. 2017

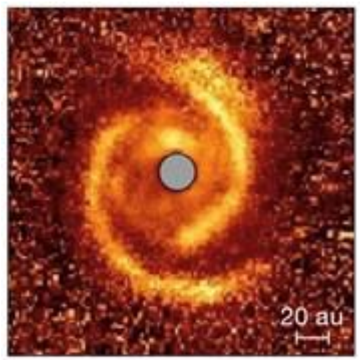
HD142527
Avenhaus et al. 2017



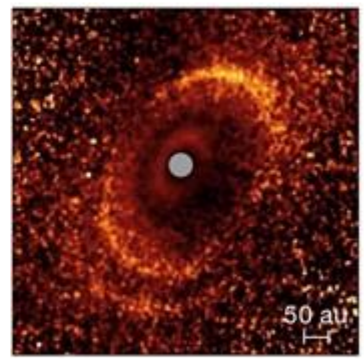
TW Hya
Van Boekel et al. 2017



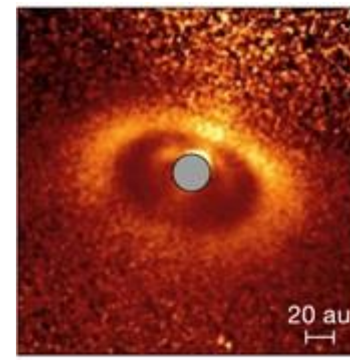
T Cha
Pohl et al. 2017



MWC 758
Benisty et al. 2015



RX J1615-3255
De Boer et al. 2016



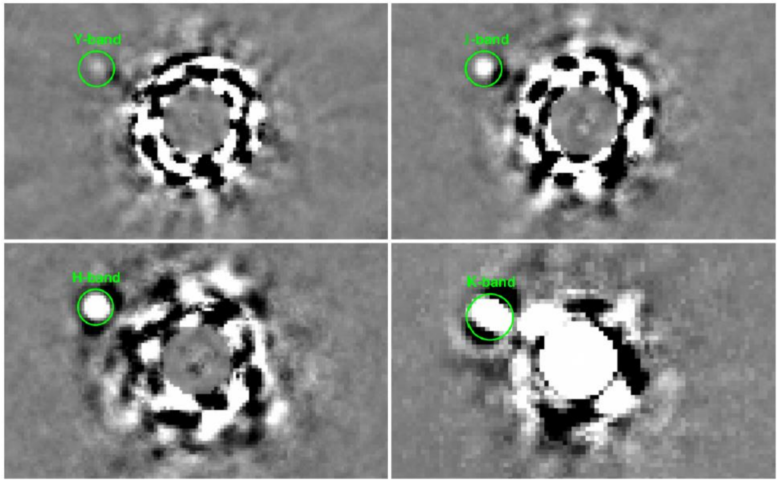
LkCa15
Thalmann et al. 2016

Huge contribution by SPHERE both in polarized and in scattered light: first detection of 11 debris disk out of the 45 known and of 39 protoplanetary disk out of 200 known.

Beyond planets: brown dwarfs

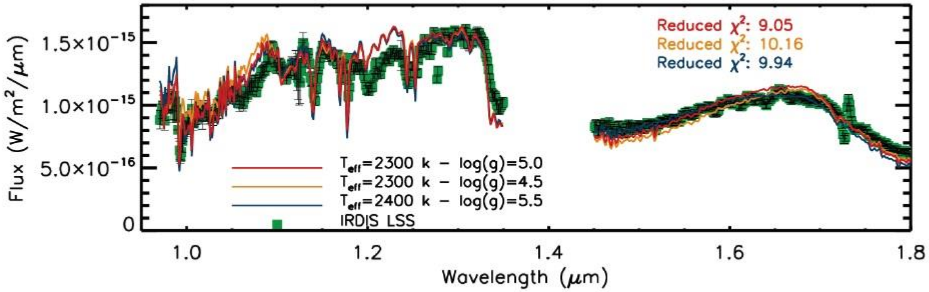
Two new detections:

- HD206893B (Milli et al. 2017)
- HIP64892 (Cheetham et al. 2018)



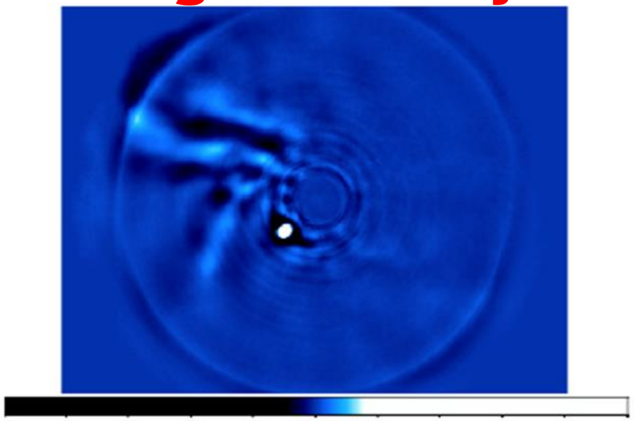
More precise characterization of known objects:

- HR3549 (Mesa et al. 2016)
- HR2562 (Mesa et al. 2018)
- GJ504 (Bonnefoy et al. 2018)



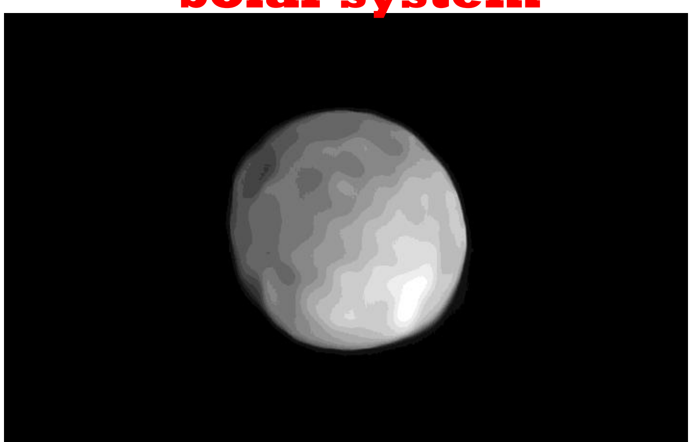
Beyond planets: other science

Young stellar objects



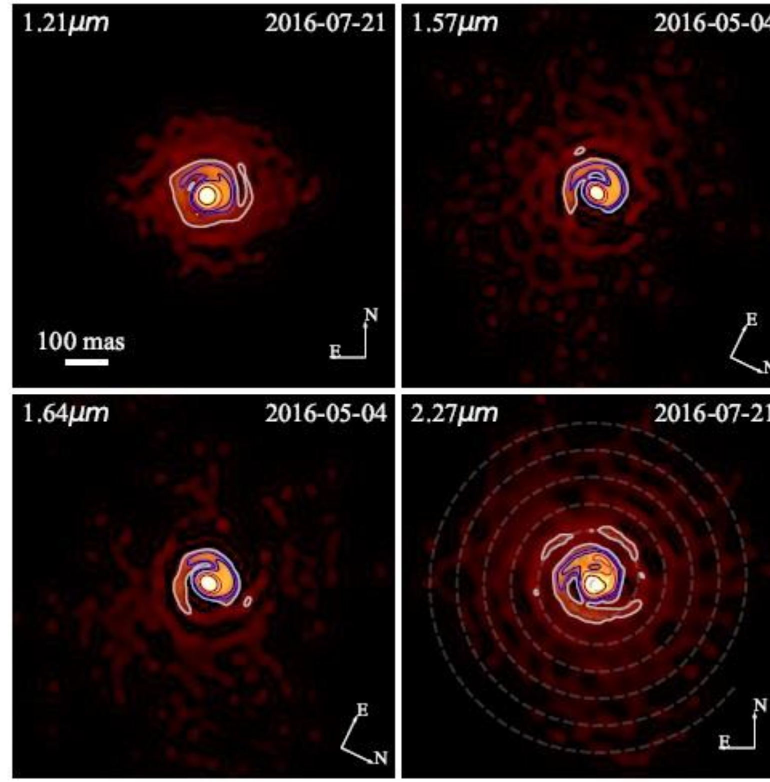
R CrA: stellar companion + jet + counterjet + extended structures (Mesa te al. 2019, Sissa et al. 2019, Rigliaco et al. 2019

Solar system



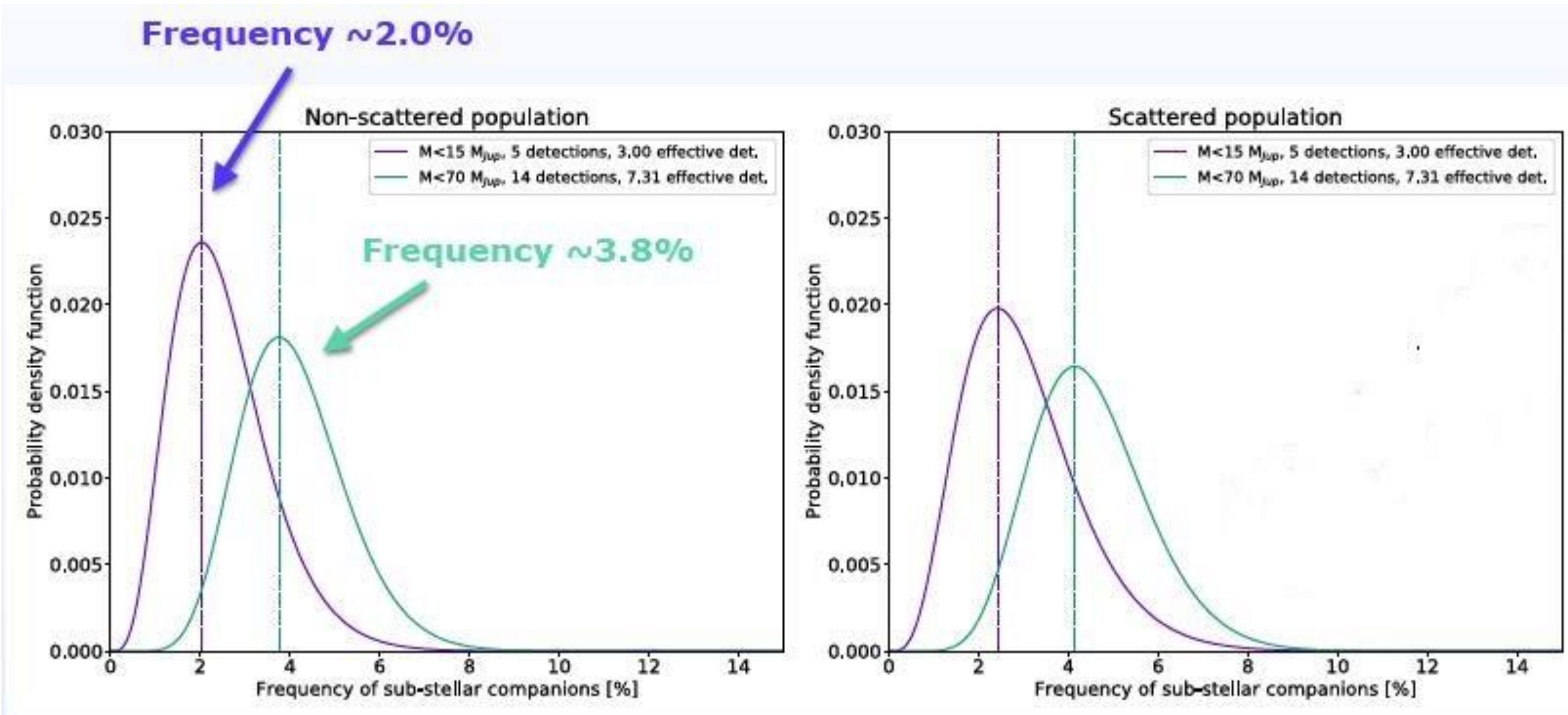
Hygiea: the smallest dwarf planet (Vernazza et al. 2019)

Evolved stars



Wolf-Rayet 104: first detection of dust spiral around this interacting binary at the end of its life (Soulain et al. 2018).

Back to planets: statistical analysis



- **Intermediate sample (167 targets) paper almost ready.**
- **The inclusion of scattering do not alterate the results.**
- **Full analysis for 2020-2021**

Future

Peak of the distribution of giant exoplanets at separations less than 10 au from the host stars (outside the possibility of present high-contrast imagers.

How to improve?

New instrumentation:

- **Updates of present instruments (SPHERE+, GPI, etc.**
- **ELTs (first light instrument probably not dedicated to planet imaging.**
- **Far future (10 years or more) → dedicated instruments at ELT (e.g. PCS).**
- **Space instruments: e.g. JWST, WFIRST, LUVOIR, HabEX**

New high-contrast imaging post processing techniques:

- **Working on the mathematical tools (PCA, NMF, ICA)**
- **Development of new and more effective pipelines**

SPHERE+

Three main keywords: closer, deeper and fainter.

How to get there?

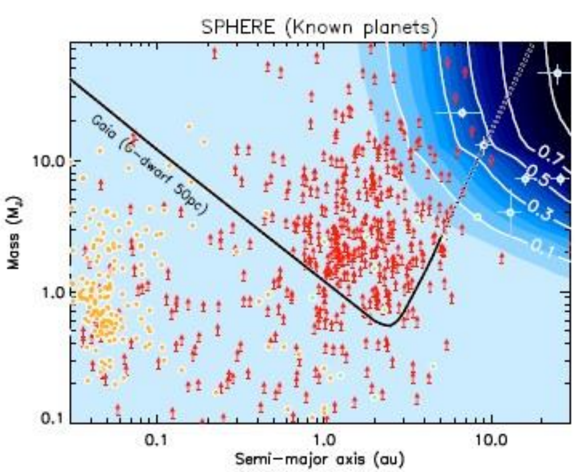
1. **AO secondary stage**
2. **New instrumentation**

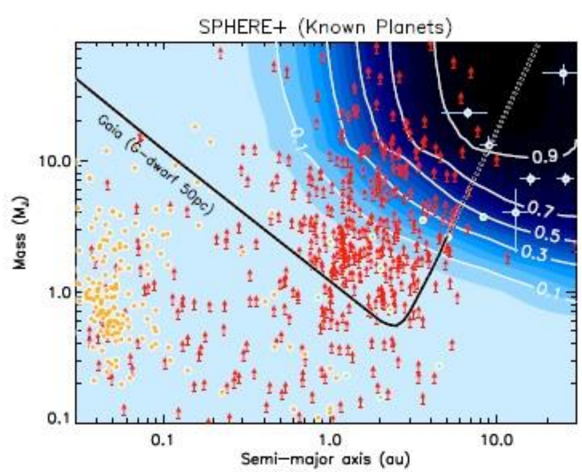
Which science we can do with this?

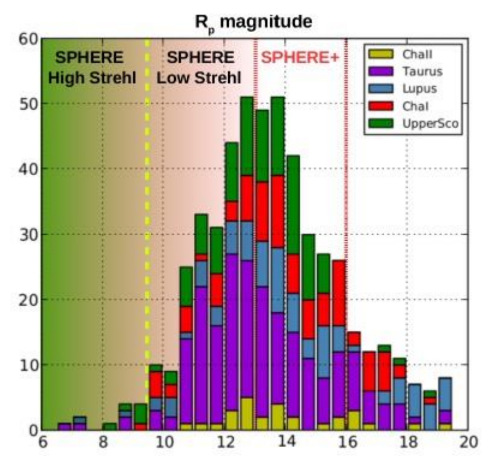
1. **Exoplanets: towards the snow line**
2. **Planet-disk interactions**

But also

Solar system | **Birth and death of stars** | **AGN**







Next deadlines and italian contribution

Deadlines (very temptative):

- **February 20th: White book preparation**
- **Autumn 2020-autumn 2021: Phase A**
- **Until 2024-2025: implementation of the SPHERE modifications**

Italian participation:

- **INAF-OAPD: development of new NIR instrumentation (e.g. high or medium resolution IFS)**
- **INAF-OARM: fast camere (SLOTS)**
- **INAF-Arcetri**