Characterizing exoplanets with infrared interferometry

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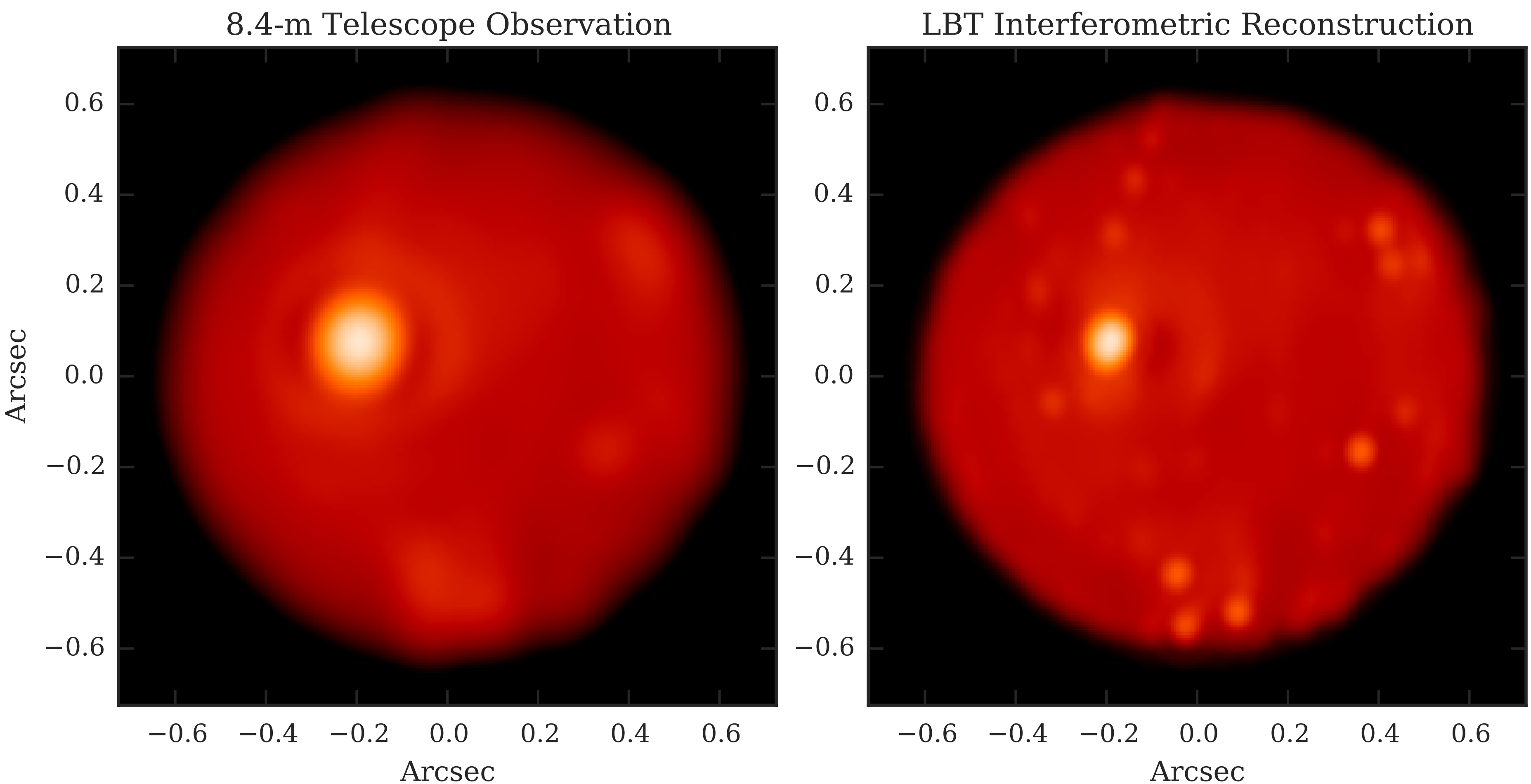
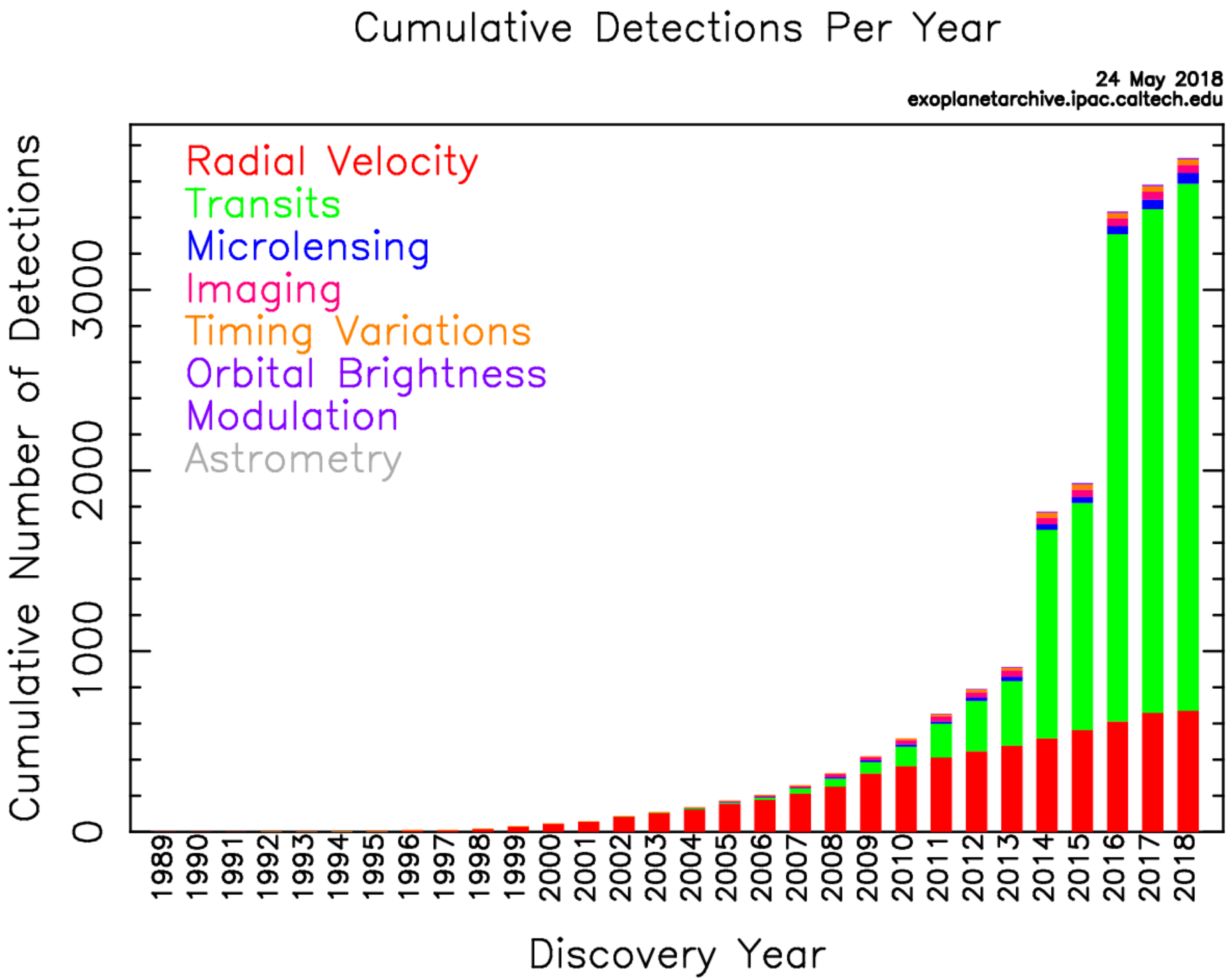
June 4th 2018 -- FNRS contact group – Bruxelles

Foreword

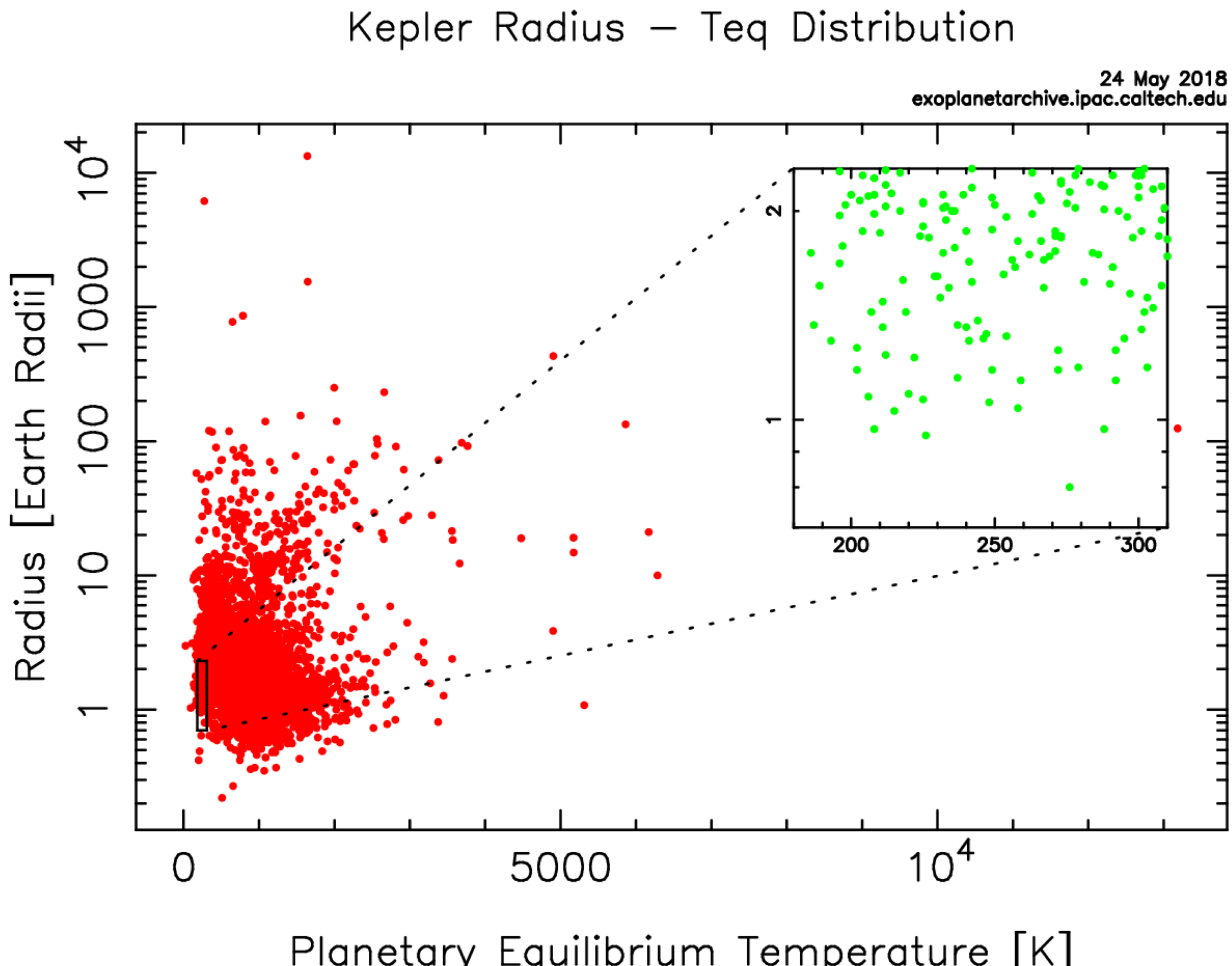


Conrad et al. 2015

Exoplanet detection



Many are rocky and in the HZ



Prevalence of HZ rocky exoplanets (2/2)

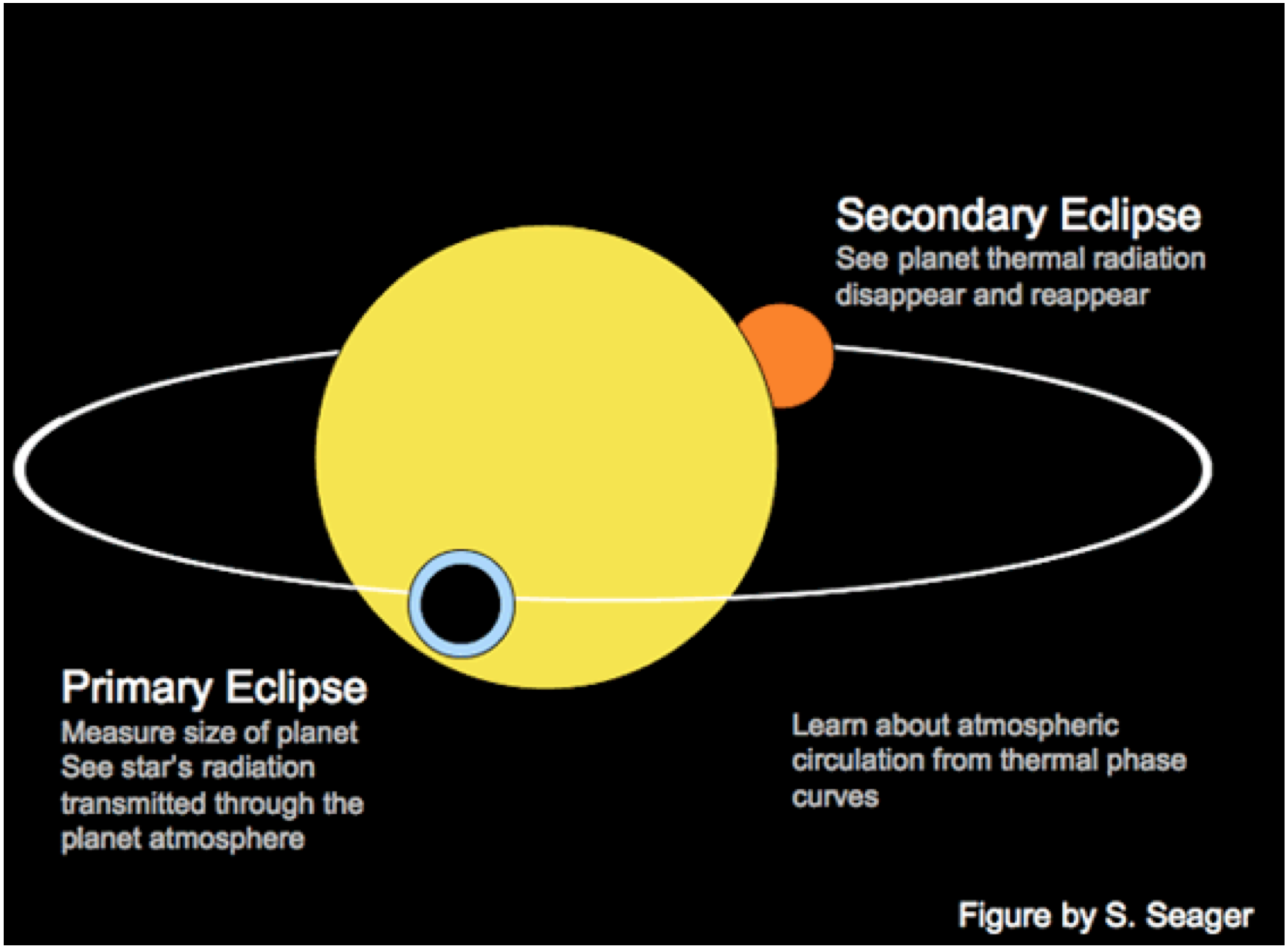
- HZ limits are debated (see table)
- Rocky planets: $R < 1.6\ R_{Earth}$ (Rogers et al. 2015)
- Prevalence of HZ rocky exoplanets:

Winn et al. 2015

Type of star	Type of planet	Approximate HZ boundaries[a] $[S/S_{\oplus}]$[b]	Occurrence rate [%]	Reference
M	$1–10\ M_{\oplus}$	0.75–2.0	41^{+54}_{-13}	Bonfils et al. (2013)
FGK	$0.8–2.0\ R_{\oplus}$	0.3–1.8	$2.8^{+1.9}_{-0.9}$	Catanzarite & Shao (2011)
FGK	$0.5–2.0\ R_{\oplus}$	0.8–1.8	34 ± 14	Traub (2012)
M	$0.5–1.4\ R_{\oplus}$	0.46–1.0	15^{+13}_{-6}	Dressing & Charbonneau (2013)
M	$0.5–1.4\ R_{\oplus}$	0.22–0.80	48^{+12}_{-24}	Kopparapu (2013)
GK	$1–2\ R_{\oplus}$	0.25–4.0	11 ± 4	Petigura et al. (2013)
FGK	$1–2\ R_{\oplus}$	0.25–4.0[c]	~0.01[c]	Schlaufman (2014)
FGK	$1–4\ R_{\oplus}$	0.35–1.0	$6.4^{+3.4}_{-1.1}$	Silburt et al. (2015)
G	$0.6–1.7\ R_{\oplus}$	0.51–1.95	$1.7^{+1.8}_{-0.9}$	Foreman-Mackey et al. (2014)

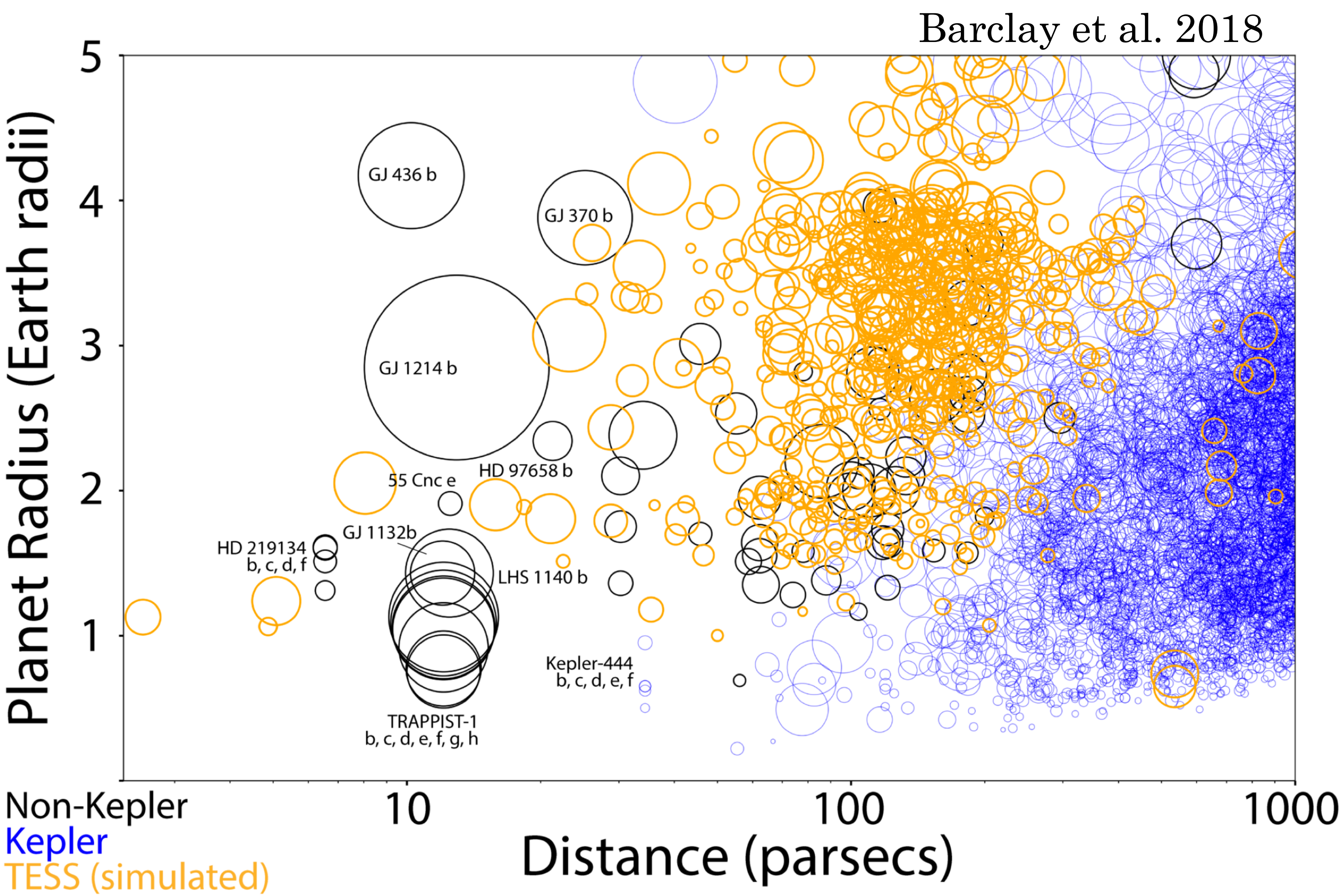
How to characterize them?

TRANSIT



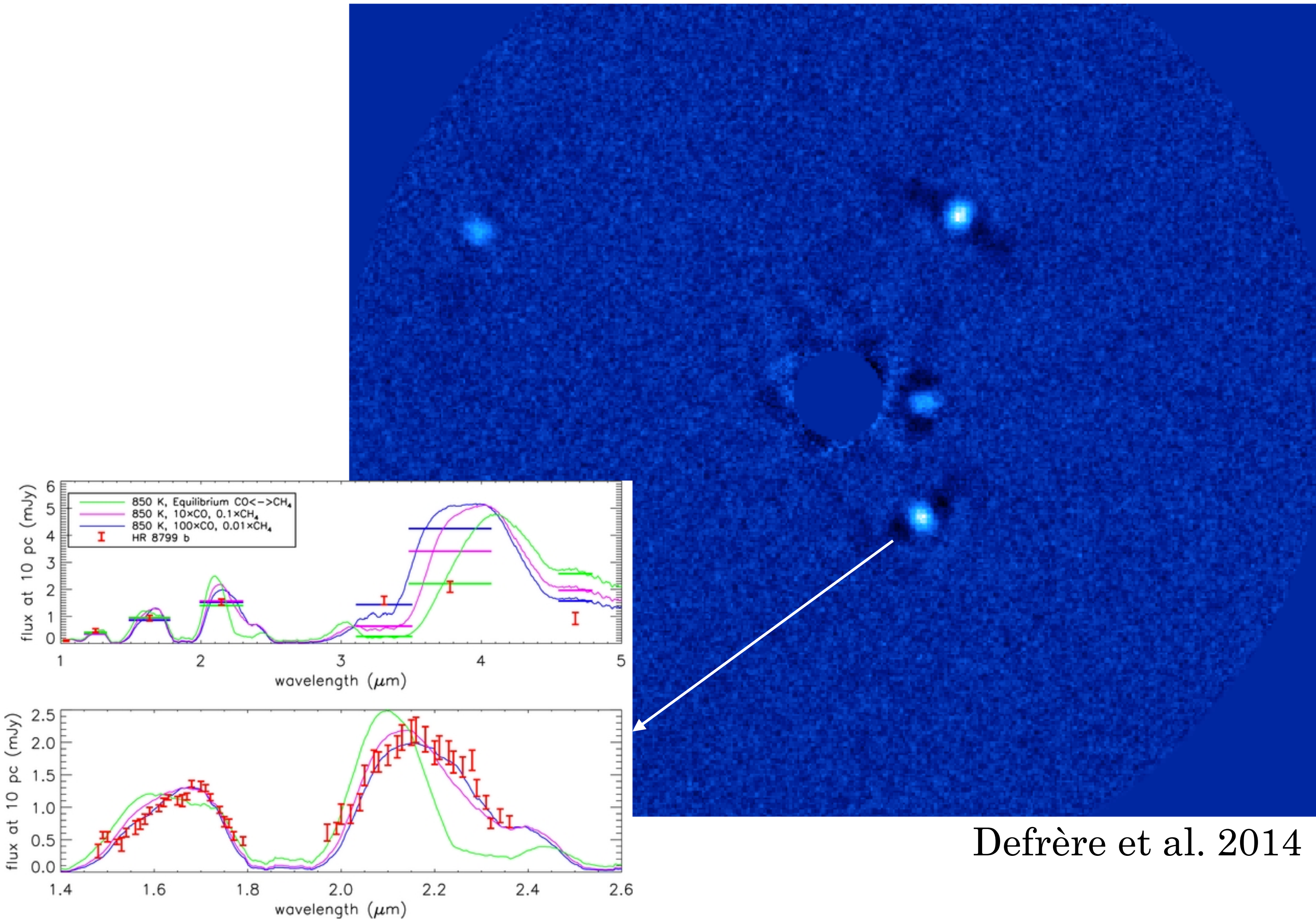
How to characterize them?

TRANSIT



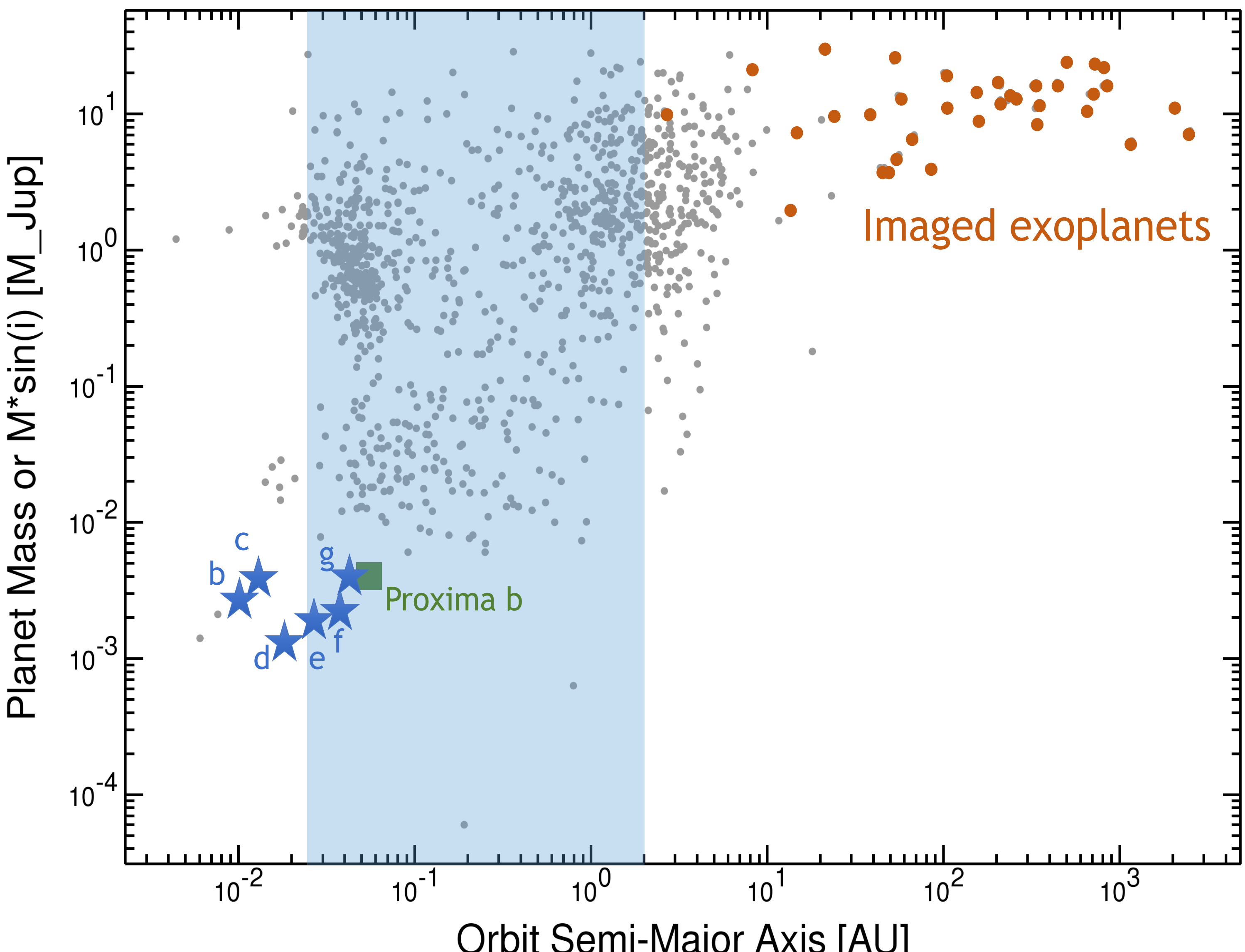
How to characterize them?

DIRECT IMAGING



Defrère et al. 2014

Direct imaging: context



Challenges for direct imaging

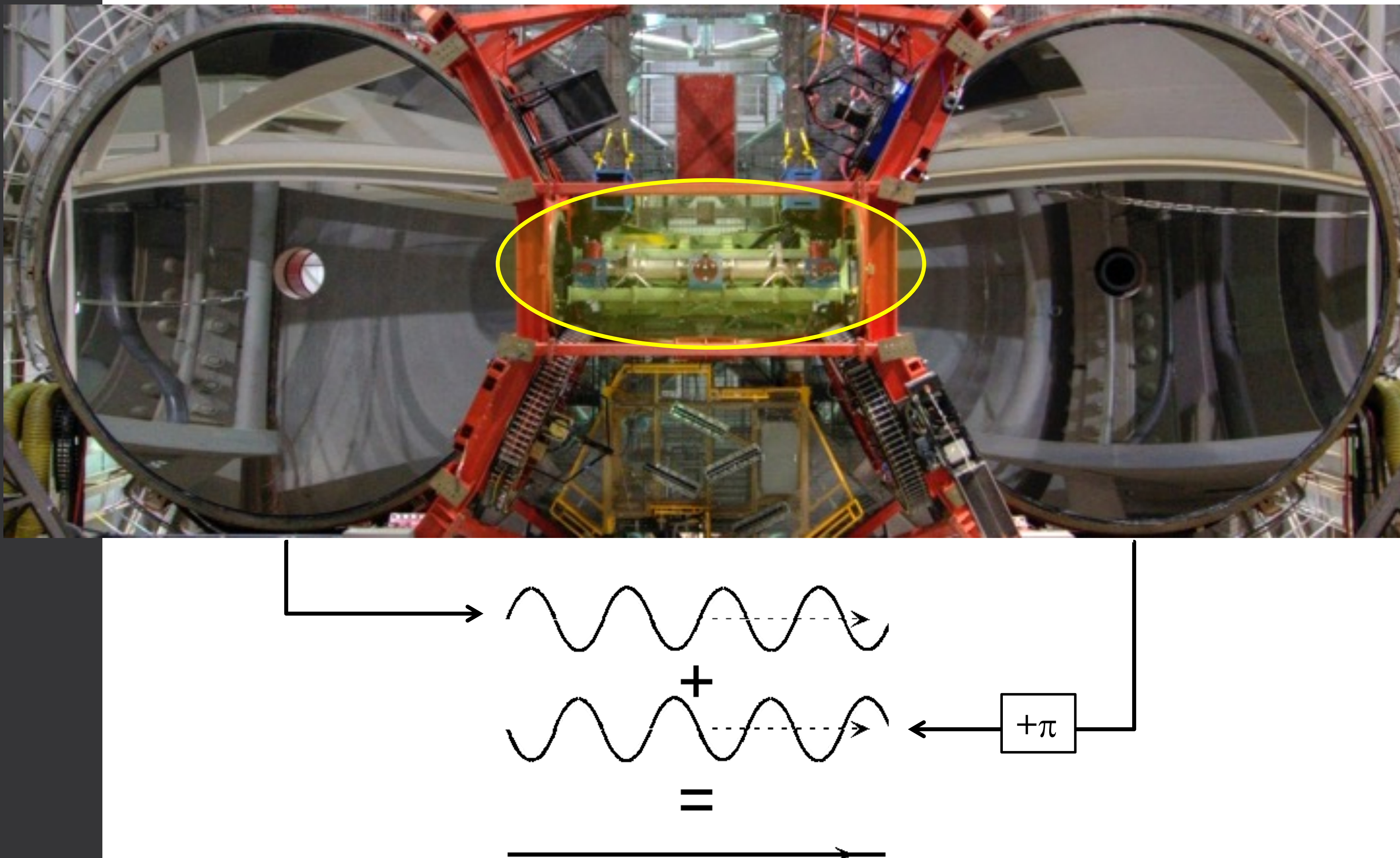
1. Contrast: need advanced wavefront and/or phase control techniques
2. Angular resolution: need large telescopes (or baselines)
3. Sensitivity: need large collecting area

VLTI (Cerro Paranal, Chile)

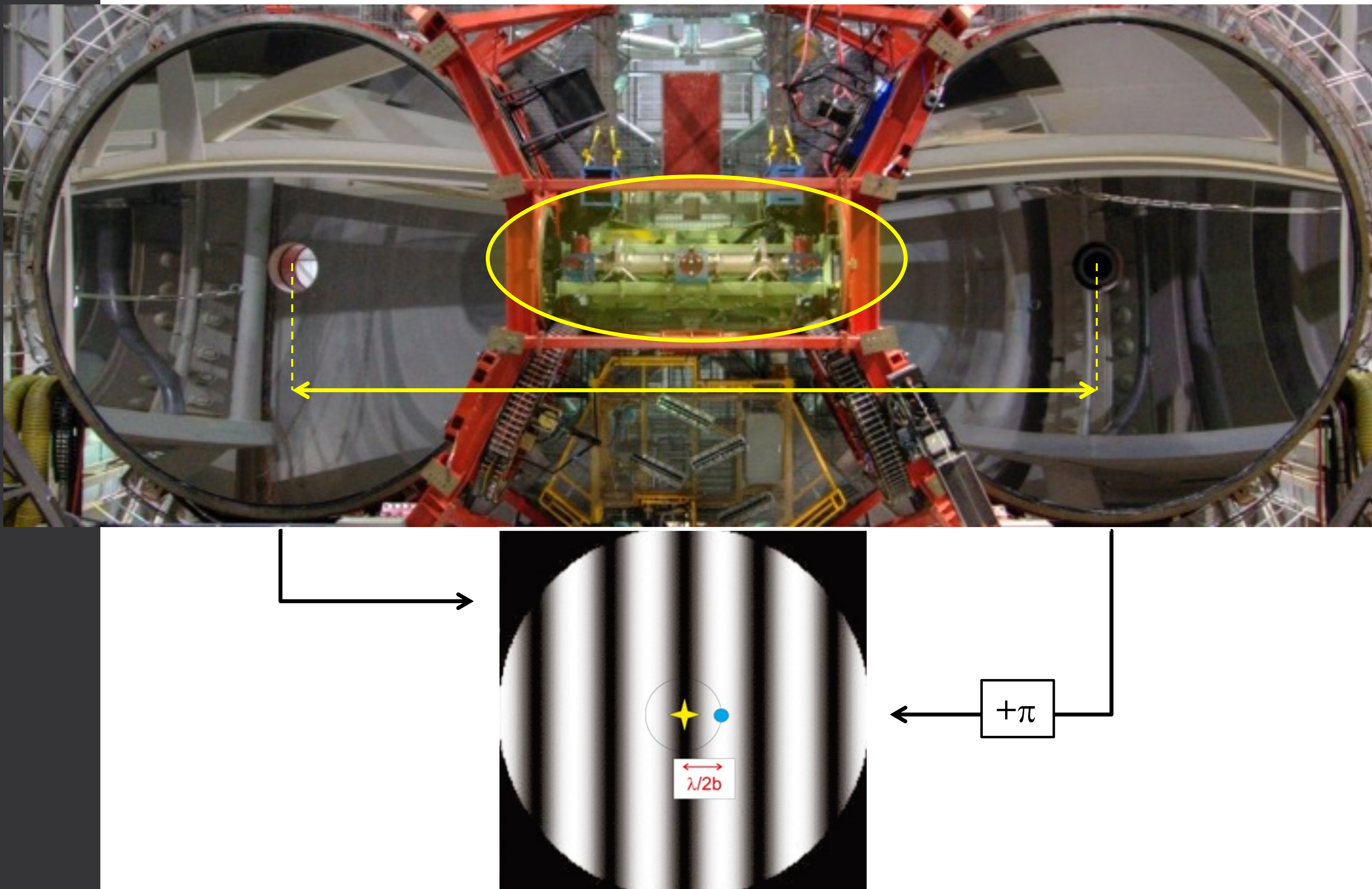
One solution: nulling interferometry

- Key advantages:
  - Interferometry provides the required **angular resolution**
  - Nulling provides the required **contrast** (~10^{-4} already demonstrated from the ground, Mennesson et al. 2011, Defrère et al. 2016)
- Must be space-based to get **reasonable integration times**

Nulling interferometry

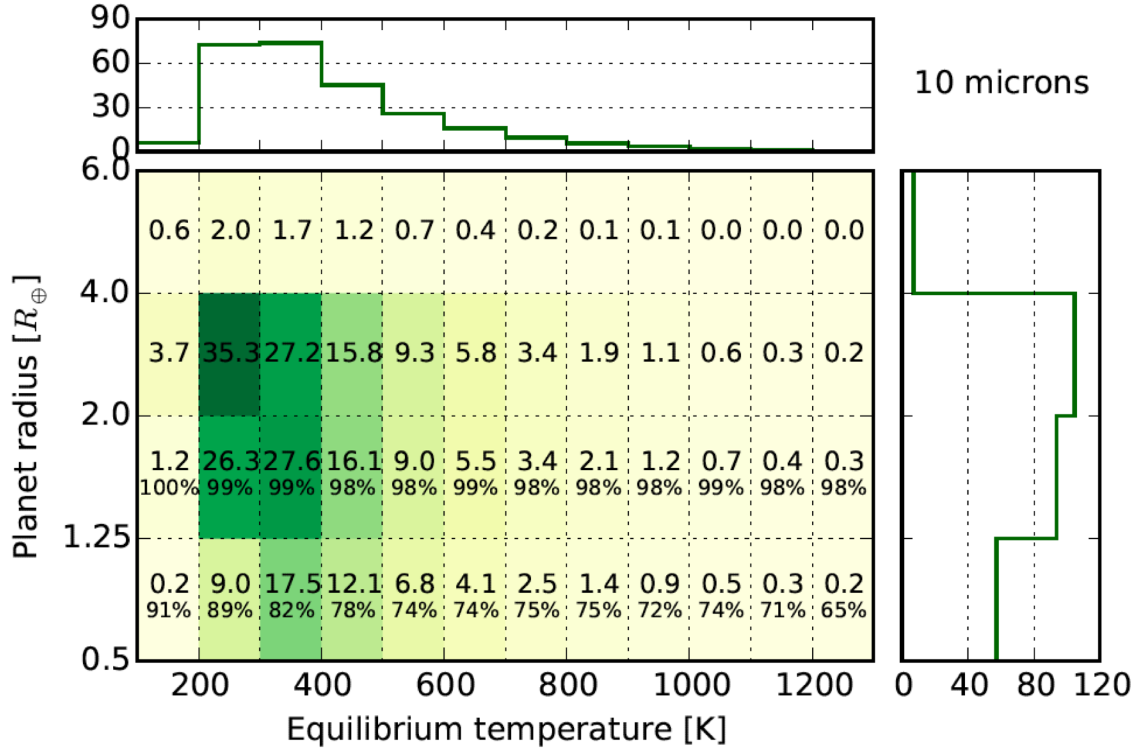


Nulling interferometry



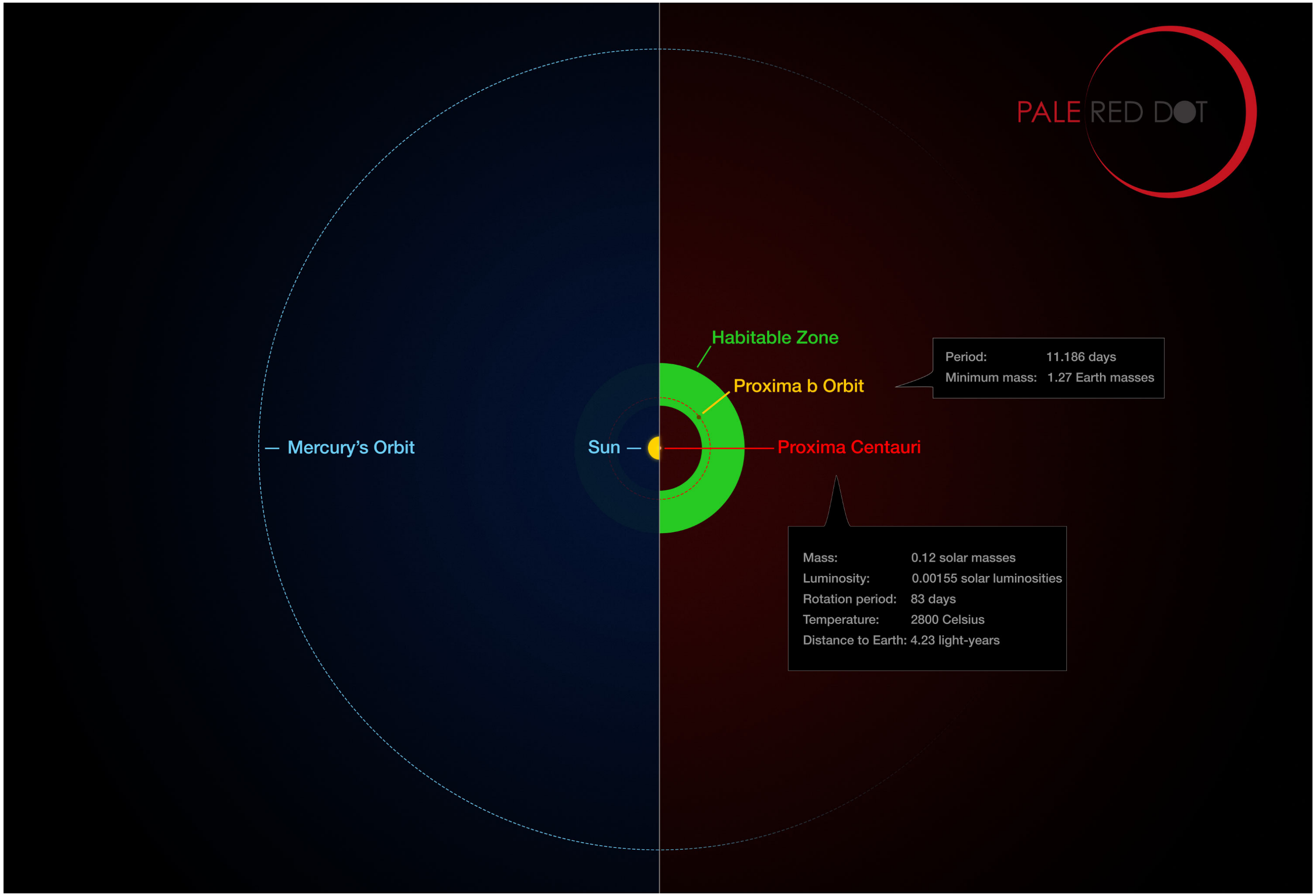
What can be done with a space nuller?

- Exoplanet yield based on Kepler stats (Kammerer and Quanz 2018)
- 4x 2-m, Darwin-like with 5 mas IWA:
  - For 200 and 450 K and radii between 0.5 and 1.75 R_{Earth} : **85 planets can be characterized**
  - 50% of observed planets are **around M stars**



Example: Proxima b

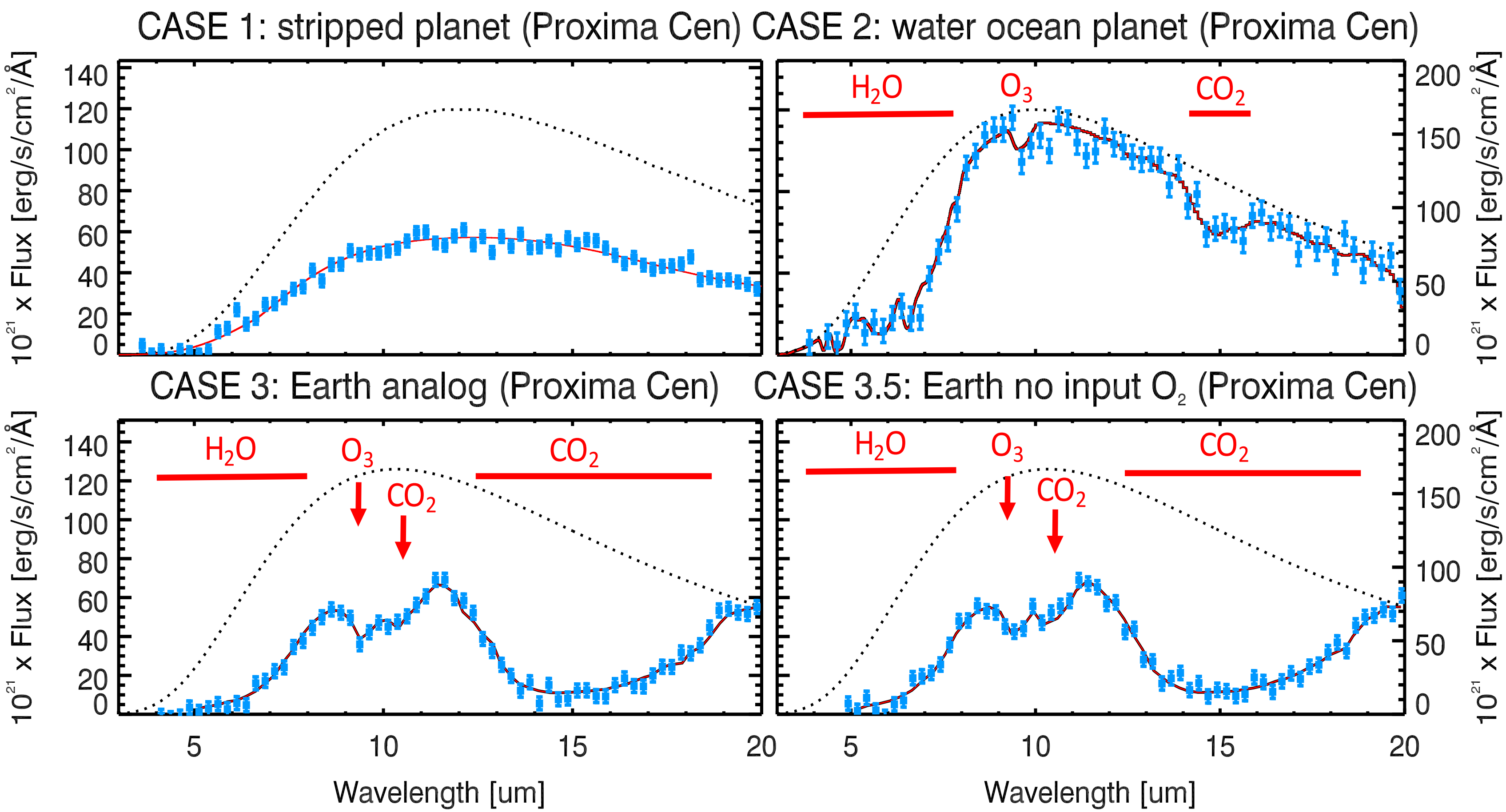
- Proxima Cen: M6V, 1.3 pc (4.2 ly, 270000 UA)
- 1.2 Earth-mass planet at 11.2 days (Anglada-Escudé *et al.*, 2016).



Example: Proxima b

- Simulated observations (R=40, blue points) imposing a S/N of 20 on continuum detection at 10 μm (Defrère et al. in press).

- All spectral features detected in a single visit (besides O_3):



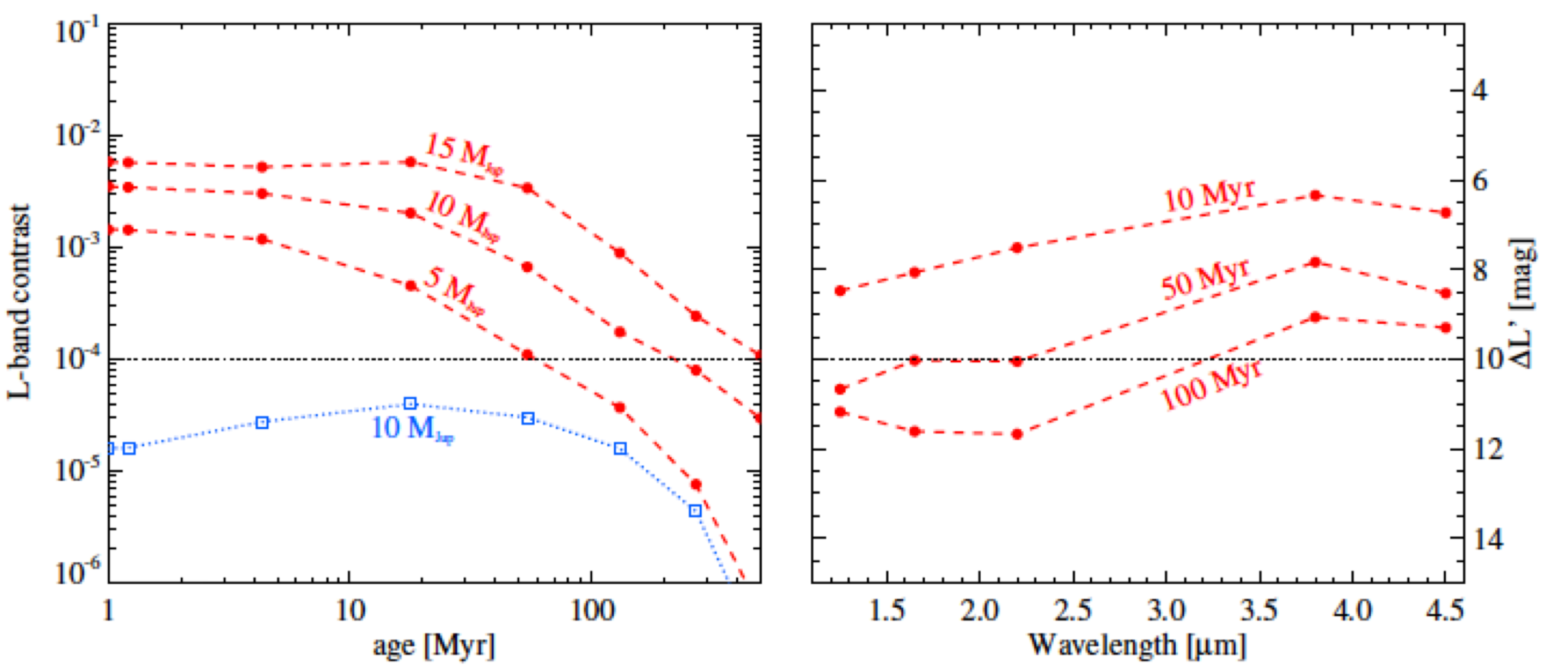
Technology preparation

- Technology is now mature :
    - Formation flying demonstrated (PRISMA mission, PROBA-3 soon)
    - Deep/stable nulling demonstrated (Martin et al. 2012)
    - Lot of expertise acquired from ground-based nulling interferometers (Mennesson et al. 2011, Mennesson et al. 2014, Defrère et al. 2016) and VLTI (integrated optics, fringe tracking).
- Next step, high-contrast interferometer on the VLTI: **the Hi-5 project**
    - Push key technologies like integrated optics, and fringe tracking
    - Push advanced beam combination strategies (e.g. Martinache and Ireland 2018)
    - Push advanced data reduction techniques

The Hi-5 project

- H2020-funded project for a new high-contrast VTLI instrument;
- Lead by ULiège;
- Strong exoplanet science case (young exoplanets, exozodiacal disks, planet formation);
- Also stellar physics and AGNs

Defrère et al. 2018



Hi-5 kickoff meeting

- Hi-5 kickoff meeting held in Liège in October 2017;
- Meeting website with presentations: http://www.biosignatures.ulg.ac.be/hi-5/index.html

A couple of pictures taken during the meeting. Left, the team in the beautiful "Horloge" room of our downtown campus. From left to right around the table, J. Surdej, T. Boulet, M. Ireland, G. Martin, S. Minardi, J.-P. Berger, B. Norris, P. Bendjoya, A. Matter, E. Serabyn , W.C. Danchi, O. Absil, A. Gallene, and K. Tristram. Right, picture taken in front of the building on the second day. From left to right, E. Pedretti, A. Mérand, J.-P. Berger, G. Martin, S. Minardi, E. Huby, O. Absil, M. Ireland, T. Boulet, E. Serabyn, D. Defrère, W.C. Danchi, B. Norris, F. Henault, K. Tristram, L. Labadie, A. Gallenne, G. Orban, M. Reggiani, J.-U. Pott, and S. Kraus.

VLTI expertise center

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VLTI Expertise Centres Network

A structured development of optical interferometry requires leaping towards a European network of VLTI Expertise Centres. These centres will be the backbone of dissemination activities to new VLTI users, by organising observing preparation and data reduction schools, by co-organising with ESO the VLTI community days, and being the end-points of the Fizeau staff exchange programme.

The leap aims at bringing the impact and return of the programme in spreading know-how in Europe to a new level. It follows at a smaller scale the successful experience of the ALMA Regional Centres, where researchers travel to the expertise centres to reduce their data. The centres will be the visible first contact point for astronomers interested in using VLTI.

The planned network of VLTI Expertise Centres includes the three partners from the OPTICON H2020 networking activity:

- Jean-Marie Mariotti Centre - Service aux Utilisateurs du VLTI, France,
- Portuguese VLTI Expertise Centre, Portugal,
- University of Exeter, United Kingdom,

as well as the three interferometry JRA (WP8) lead partners:

- Max Planck Institute for Astronomy, Germany,
- Observatoire de la Cote d'Azur, France,
- Université de Liége, Belgium.

Subpages (1): JMMC - Service aux Utilisateurs du VLTI

Comments

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Take away messages

- New era of exoplanet characterization
- Transit for short period exoplanets and direct imaging for exoplanets at wider separation (e.g. HZ around Sun-like star)
- Nulling interferometry provides both the contrast and angular resolution to directly image nearby exoplanets
- New VLTI project
- VLTI expertise center. Contact us: ddefrere@uliege.be