ESO 60 years

Planetary systems at ESO

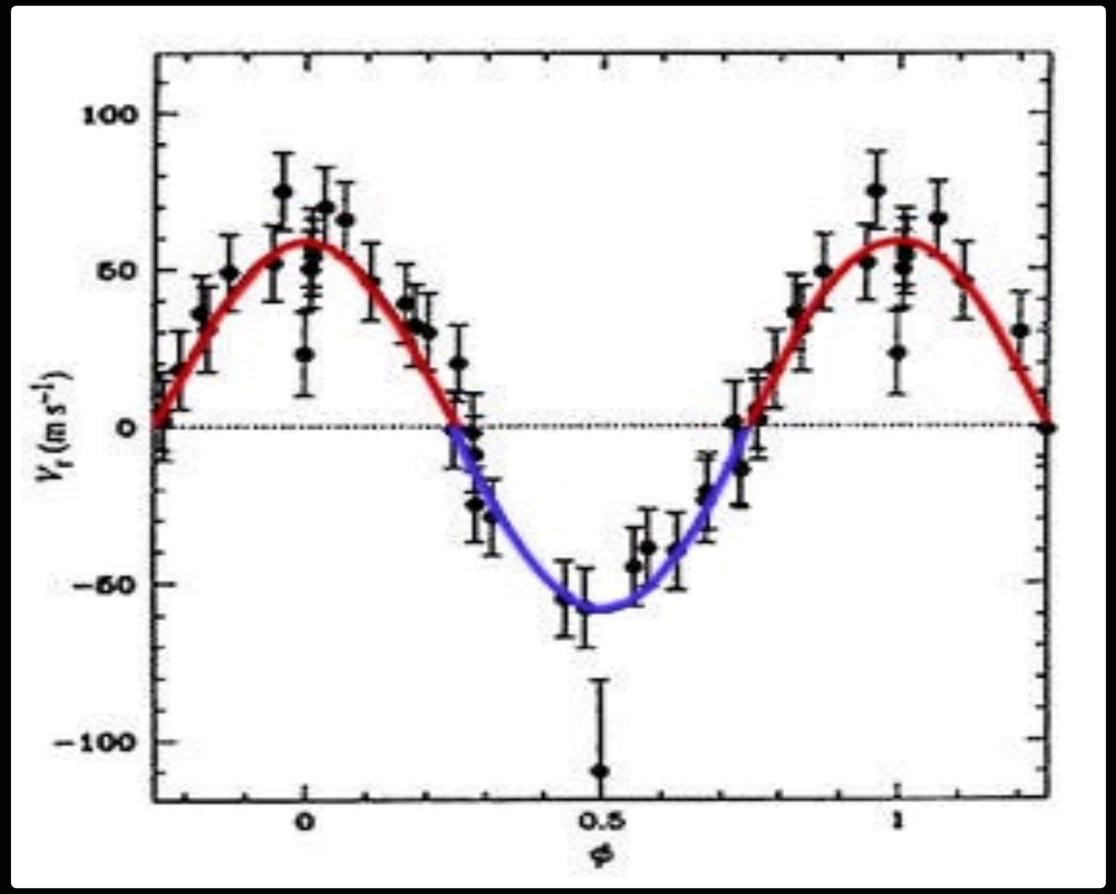
Anne-Marie Lagrange

FEET ON THE GROUND EYES ON THE SKY

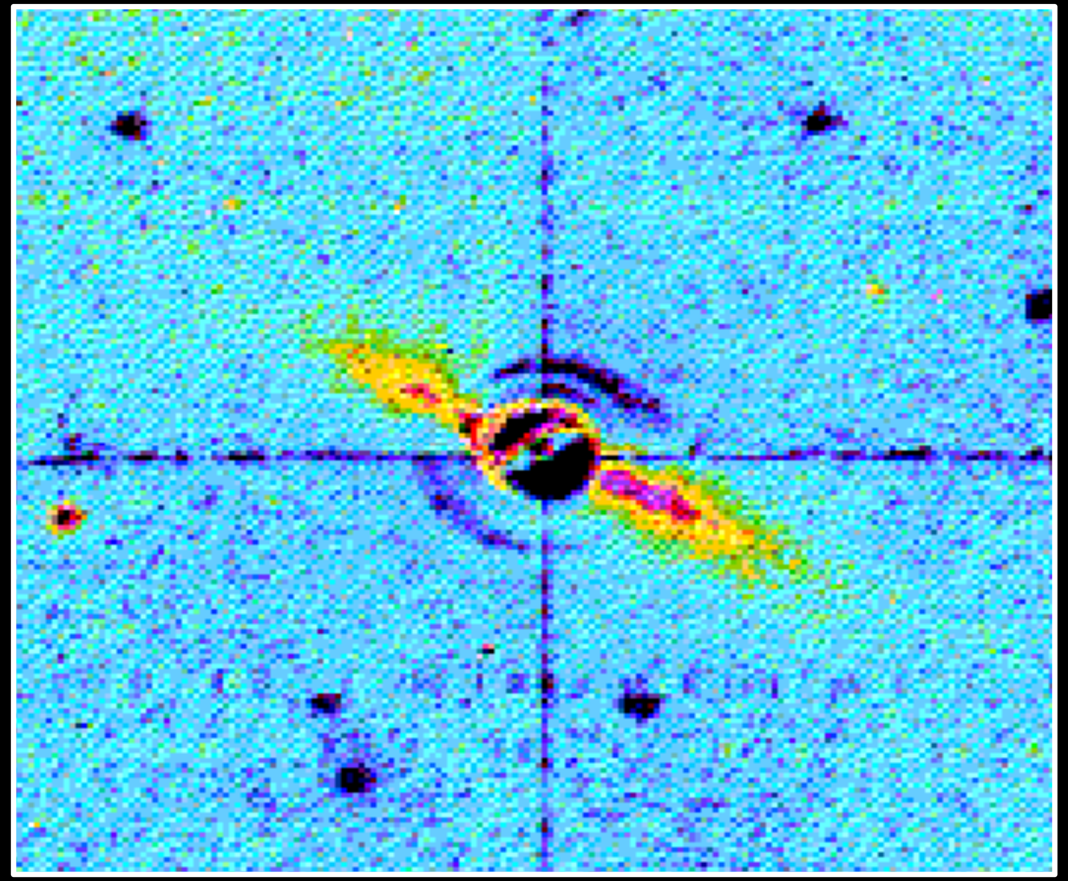
CNRS LESIA l'Observatoire de Paris | PSL OCAV PSL erc European Research Council


Early days

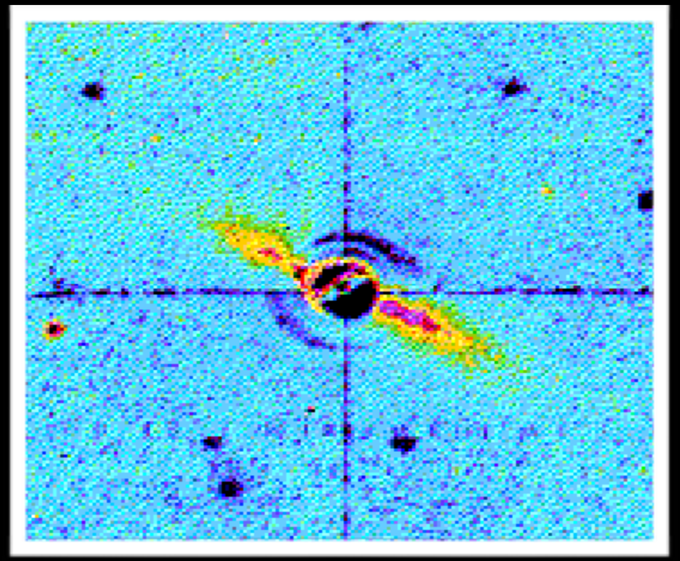
- Methods of exoplanet detection (1960-1990)
- First exoplanets (indirect) detections
  - Radial velocity low mass companions to stars:
    - 51 Peg b *Mayor & Queloz, 1995*
  - Earth-mass planets around a pulsar *Wolszczan, 1993*
  - Transiting planet HD209458 b *Charbonneau et al, 2000*
  - Micro-lensing event OGLE 2003-BLG-235/MOA 2003-BLG-53 *Bond et al, 2004*
- First image of a planetary system (1984) at Las Campanas Observatory



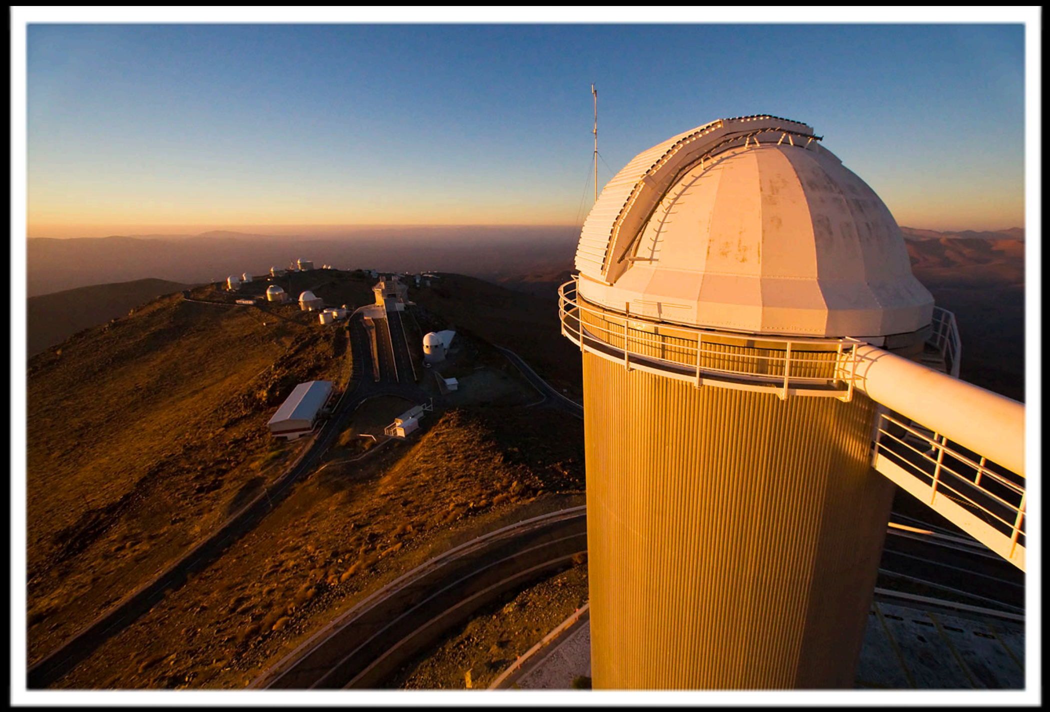
51 Peg b
Msin(i)~0.5 MJ
Mayor & Queloz, 1995
Nobel Prize 2019



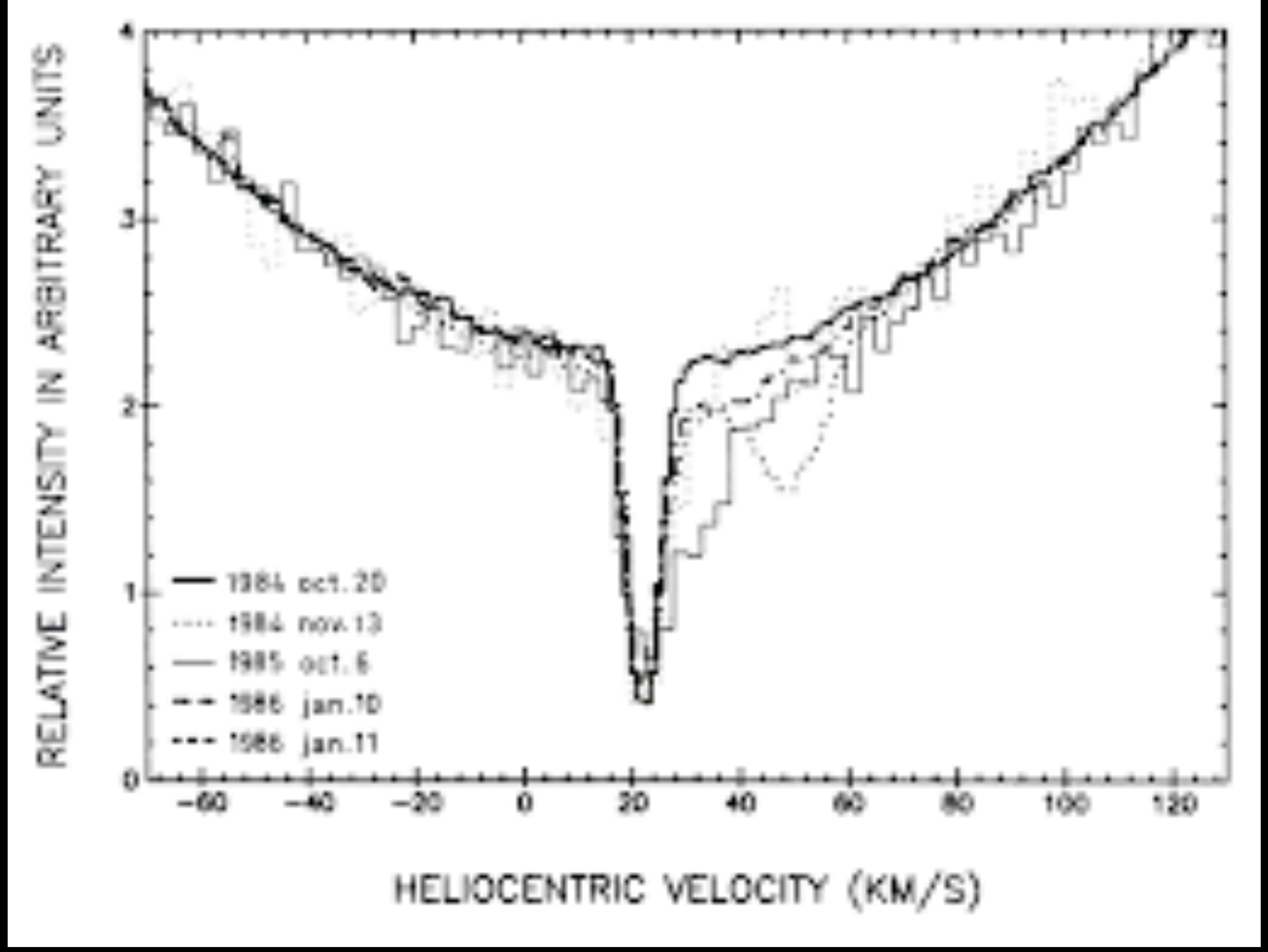
Smith & Terrile, 1984



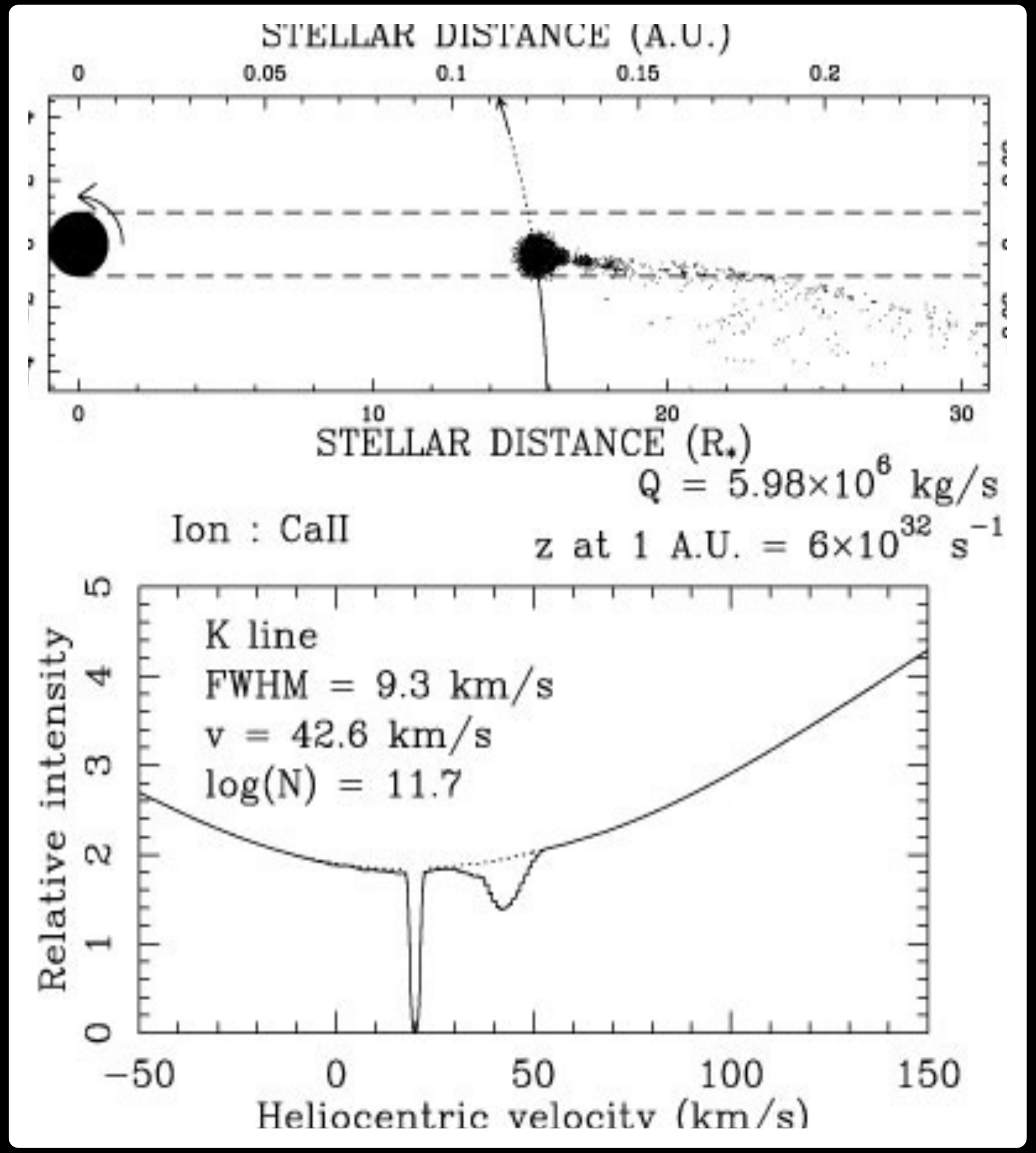
1986. Exocomets on Beta Pictoris



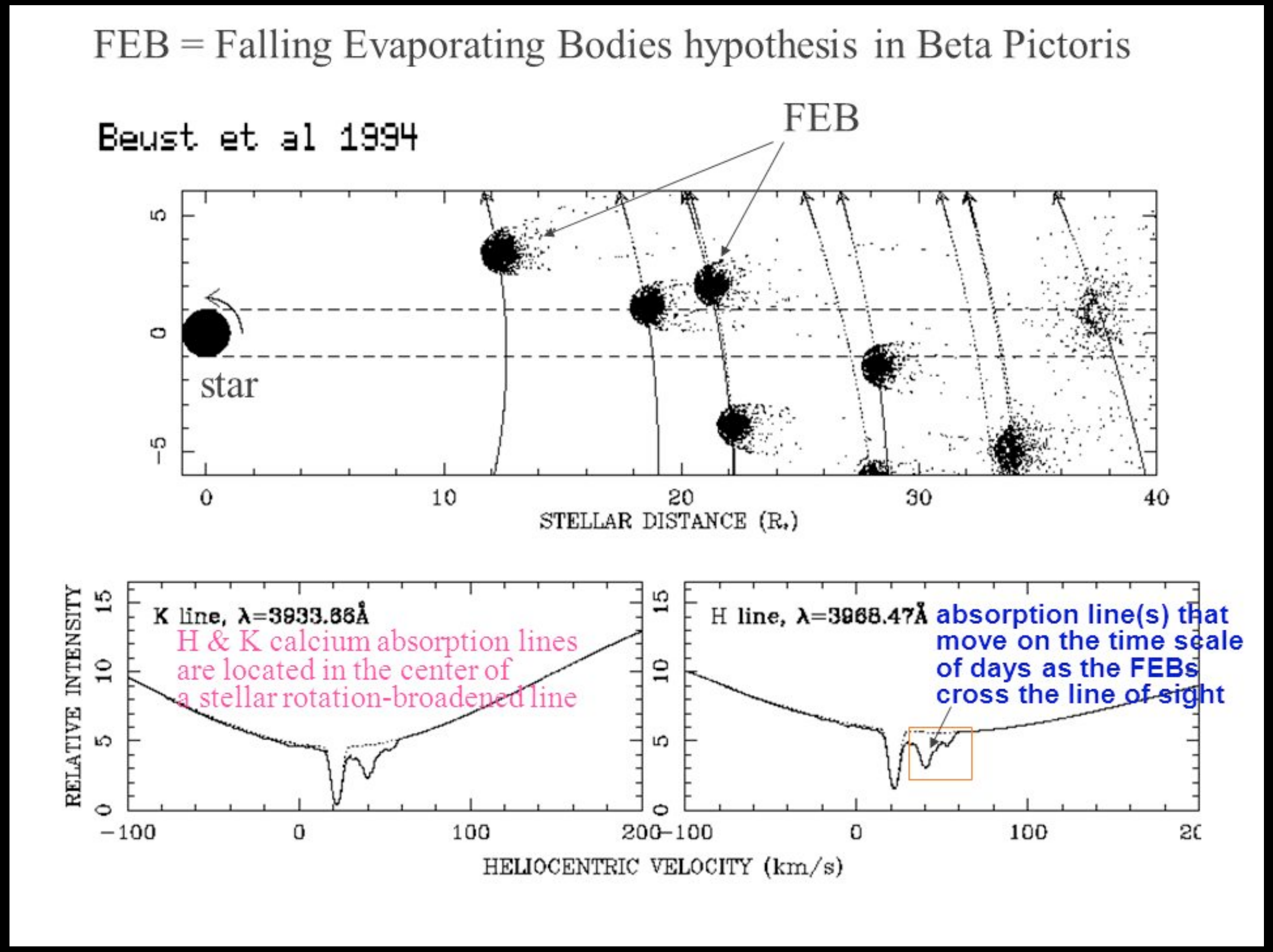
CAT/CES



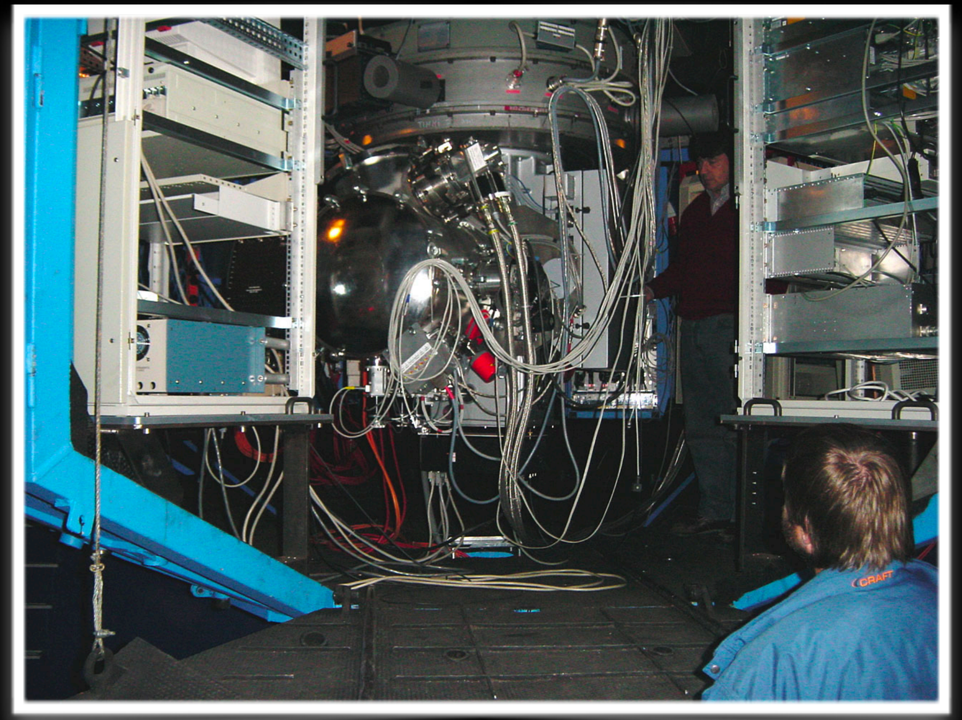
Vidal-Madjar, Ferlet, Lagrange, Lecavelier, Beust 1987,88,89,90 etc…



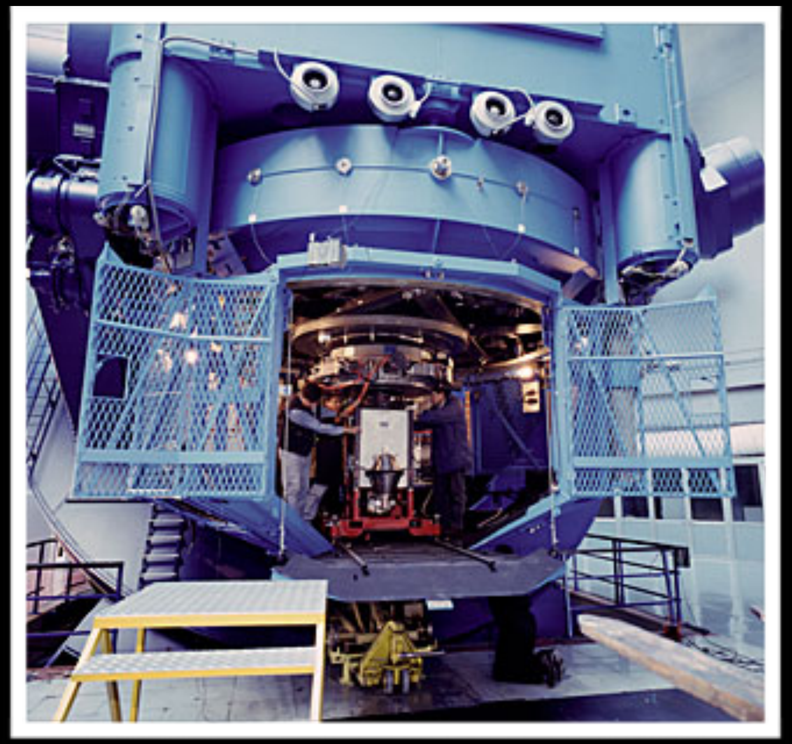
Beust et al, 1994



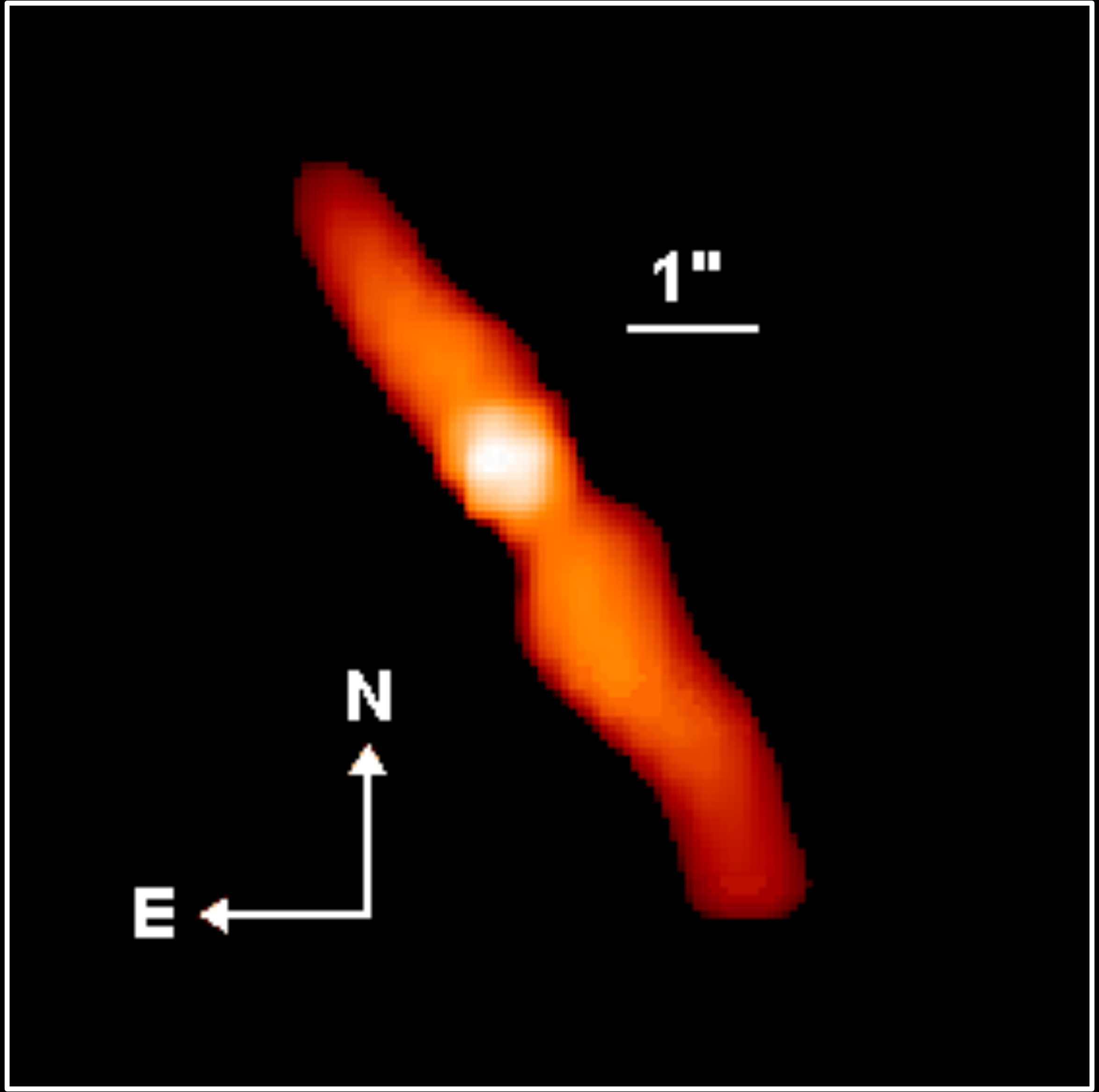
See also Kiefer et al, 2016
ESO PR1432



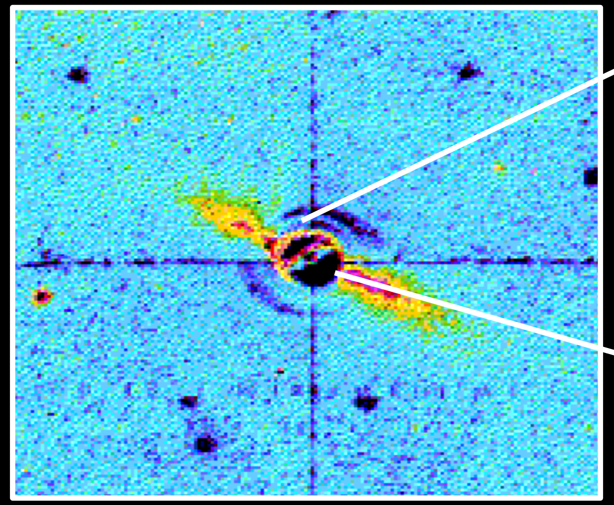
Beta Pic disk imaged at ESO
A planet is present

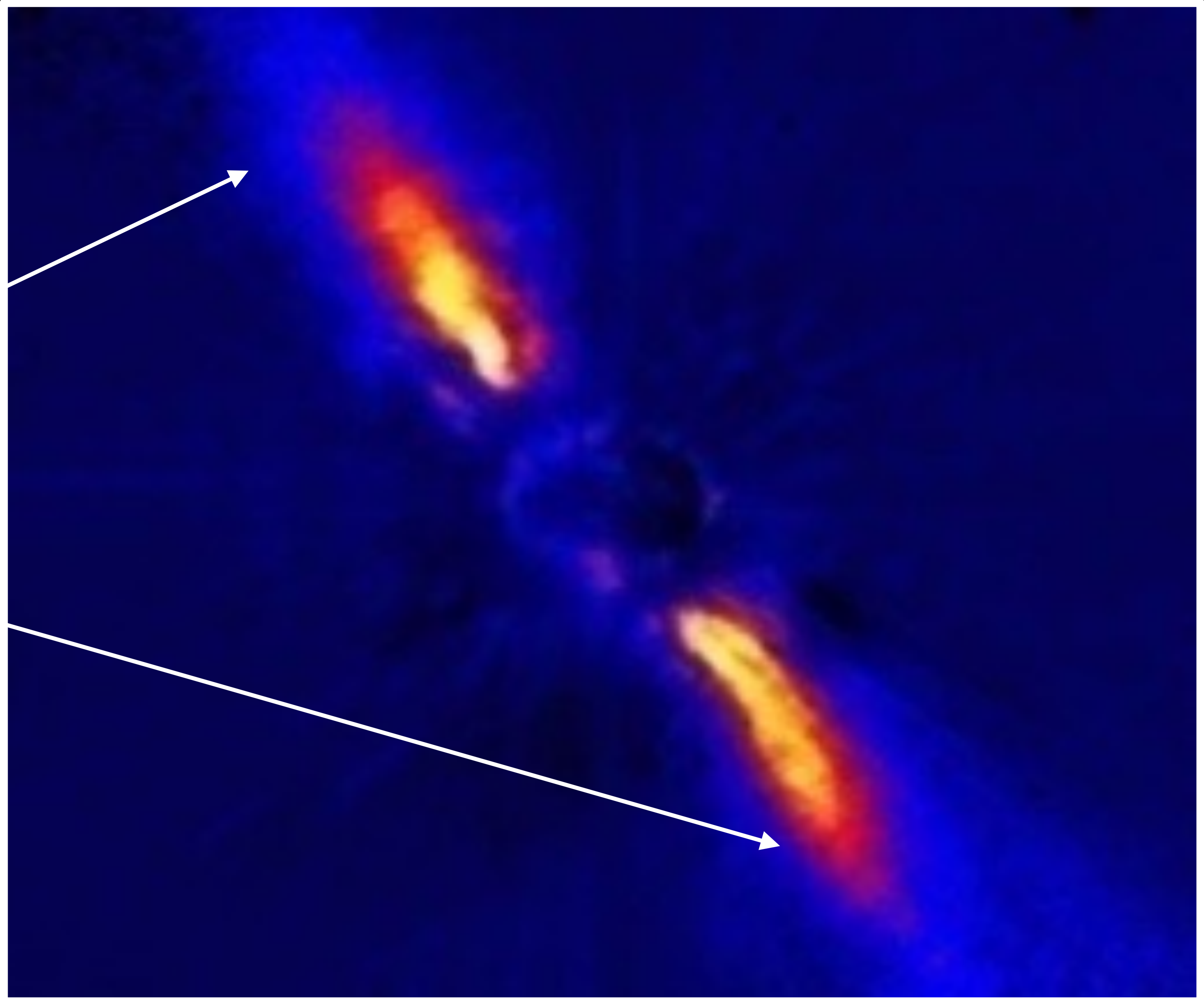


3.6m/TIMMI



3.6m/Adonis

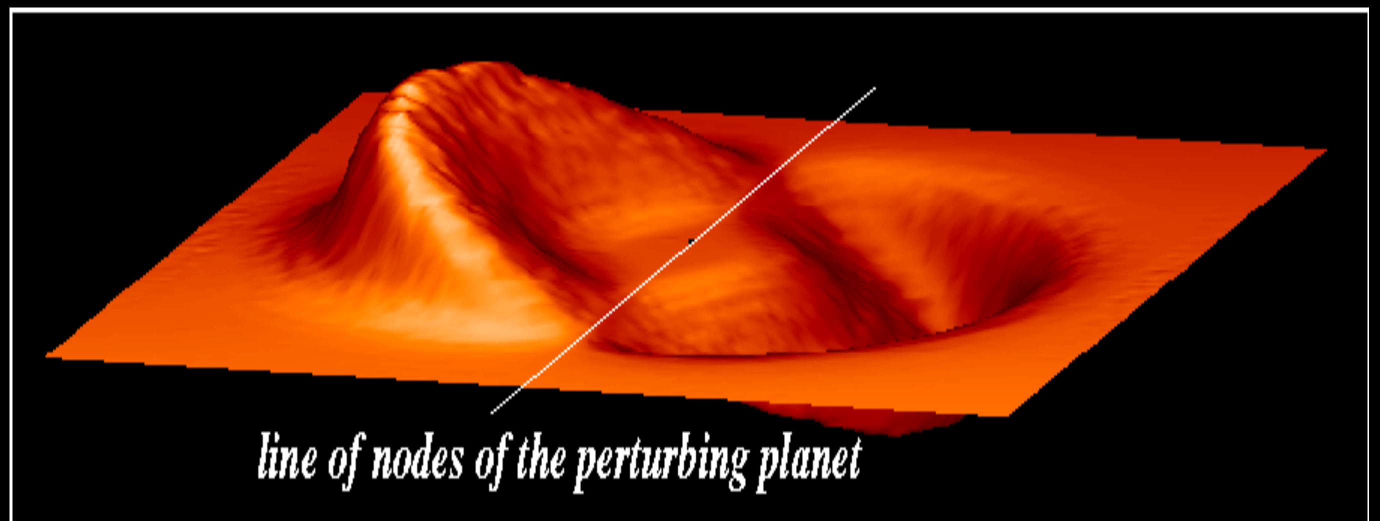




Mouillet et al., 1997; Augereau et al, 2000

Inner depletion => planet ?

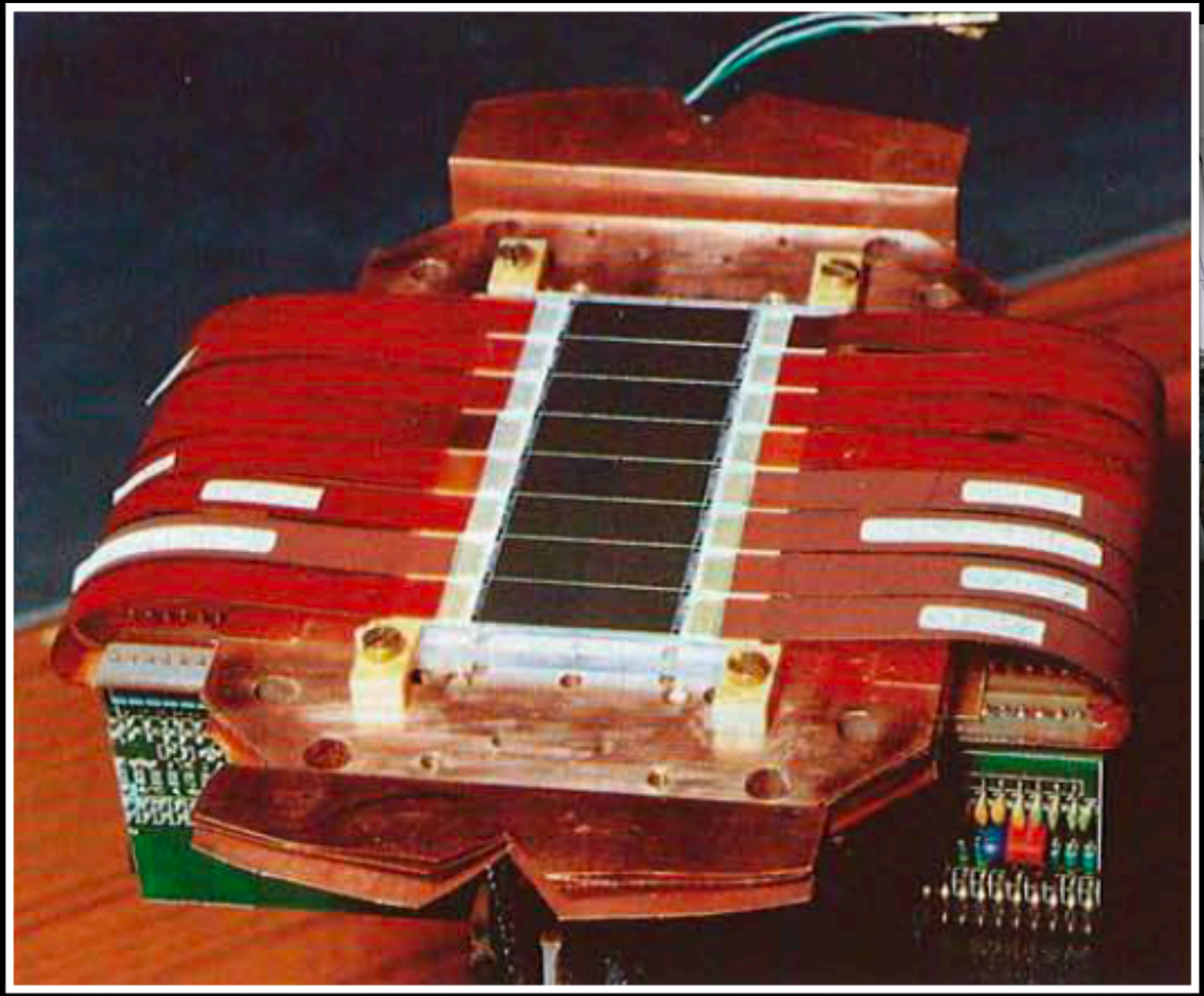
Lagage et Pantin, 1994



First survey for « dark objects »
Micro-lensing

EROS-1 (1990-1995)
EROS-2 (1996-2003)

40 cm GPO, La Silla
Aubourg et al, 1993 ESO Messenger 72



676 x 405 Thomson CCD chip (1 x 0.5 deg)

SCIENCE WITH THE VLT/VLTI

The Search for Extrasolar Planets at ESO

FINAL REPORT OF THE ESO WORKING GROUP ON THE DETECTION OF EXTRASOLAR PLANETS[1]

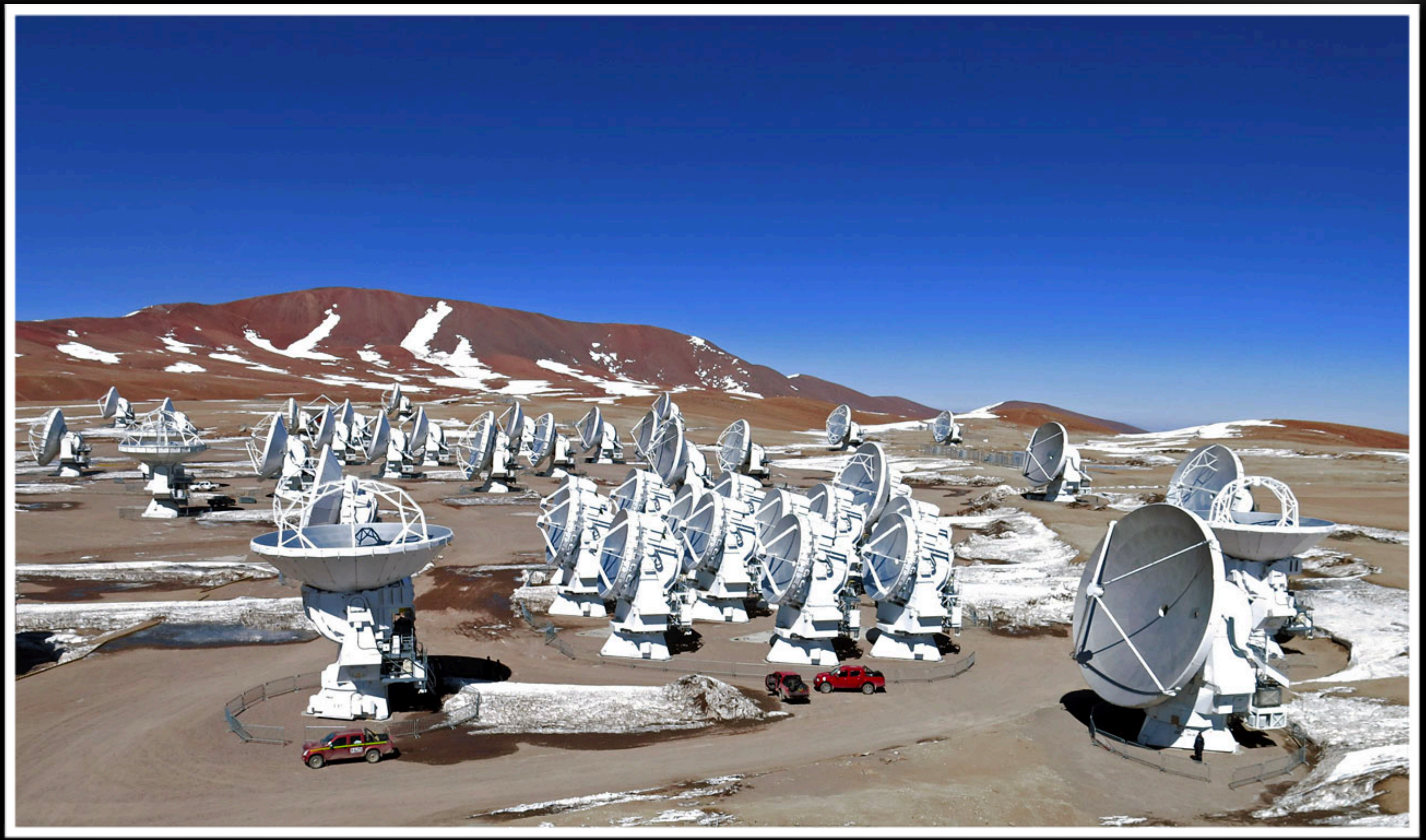
Prepared by F. PARESCE and A. RENZINI

ESO has great potential in the search for exoplanets. With the La Silla telescopes, the VLT, the VLTI, the special characteristics of the Paranal site, and the variety of professional expertise widely spread within the European astronomical community, ESO should be able to play a leading role in the search for exoplanets. For this to happen, however, a serious effort has to be made now to develop a global strategy and to allocate adequate resources. The WG

- A high precision spectrograph at the 3.6m is recommended
- Design the VLTI for narrow angle astrometry capabilities is highly recommended; most of AT time
- A 2.5m telescope dedicated (1/3) to micro-lensing to search for Earth mass planets is recommended
- High order AO system with modern coronagraphs and dark hole technics should be tried
- A high resolution spectrograph (CRIRES) is highly desirable
- Dedicate a 1m or part of a 100deg^2 Schmidt for transit is recommended

A new dynamics

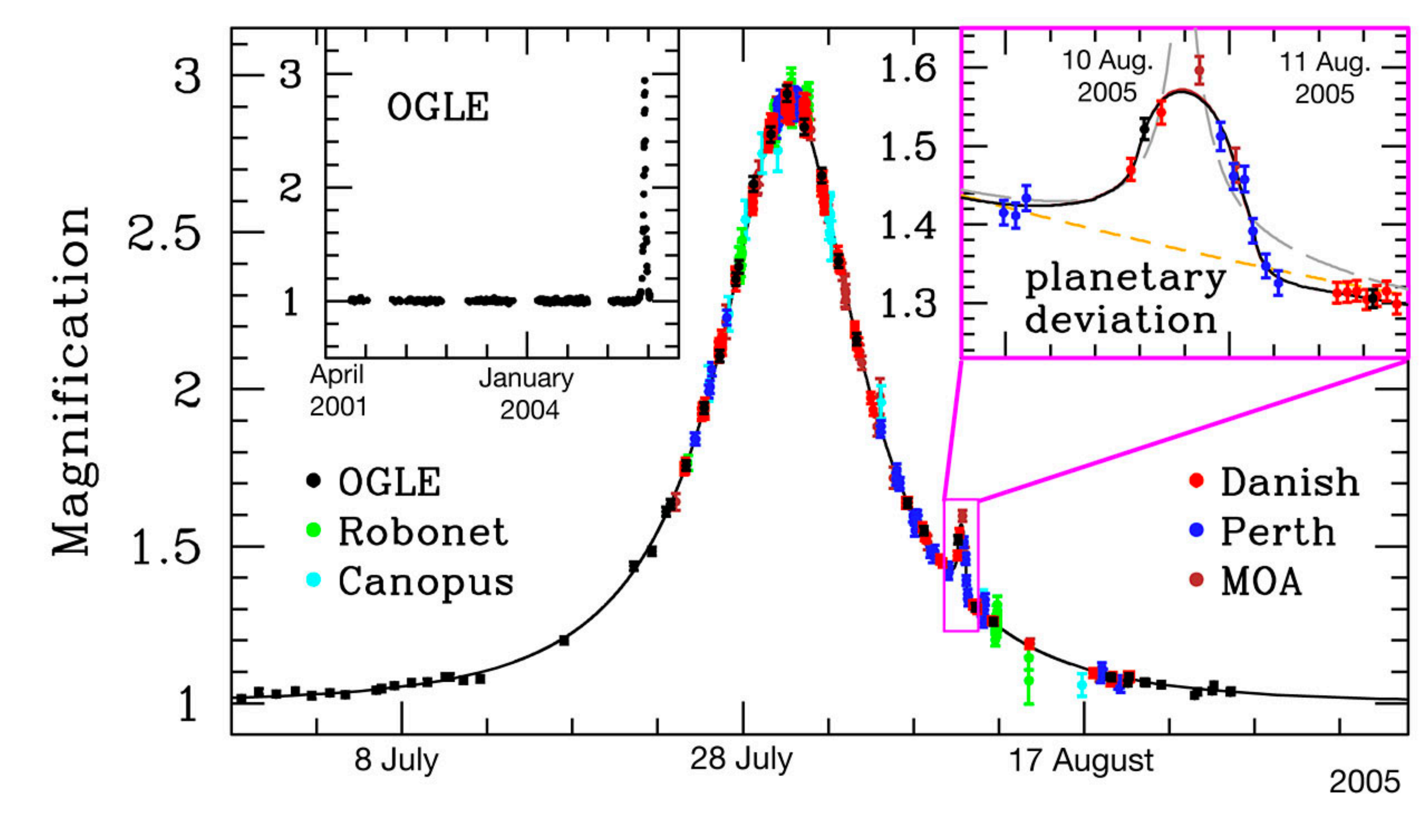
- Developed a few unique/game-changing facilities
  - High precision spectrograph *
  - Adaptive Optics & High Contrast Imaging
  - High precision astrometry Interferometry*
- Hosted dedicated infrastructures (e.g. for transit photometry) :
  - TRAPPIST, SPECULOOS, EXTRA, NGTS, etc
- Developed synergies with :
  - other ground facilities for micro-lensing & transits surveys
  - space missions (Corot, Kepler, TESS, Gaia, follow-ups)

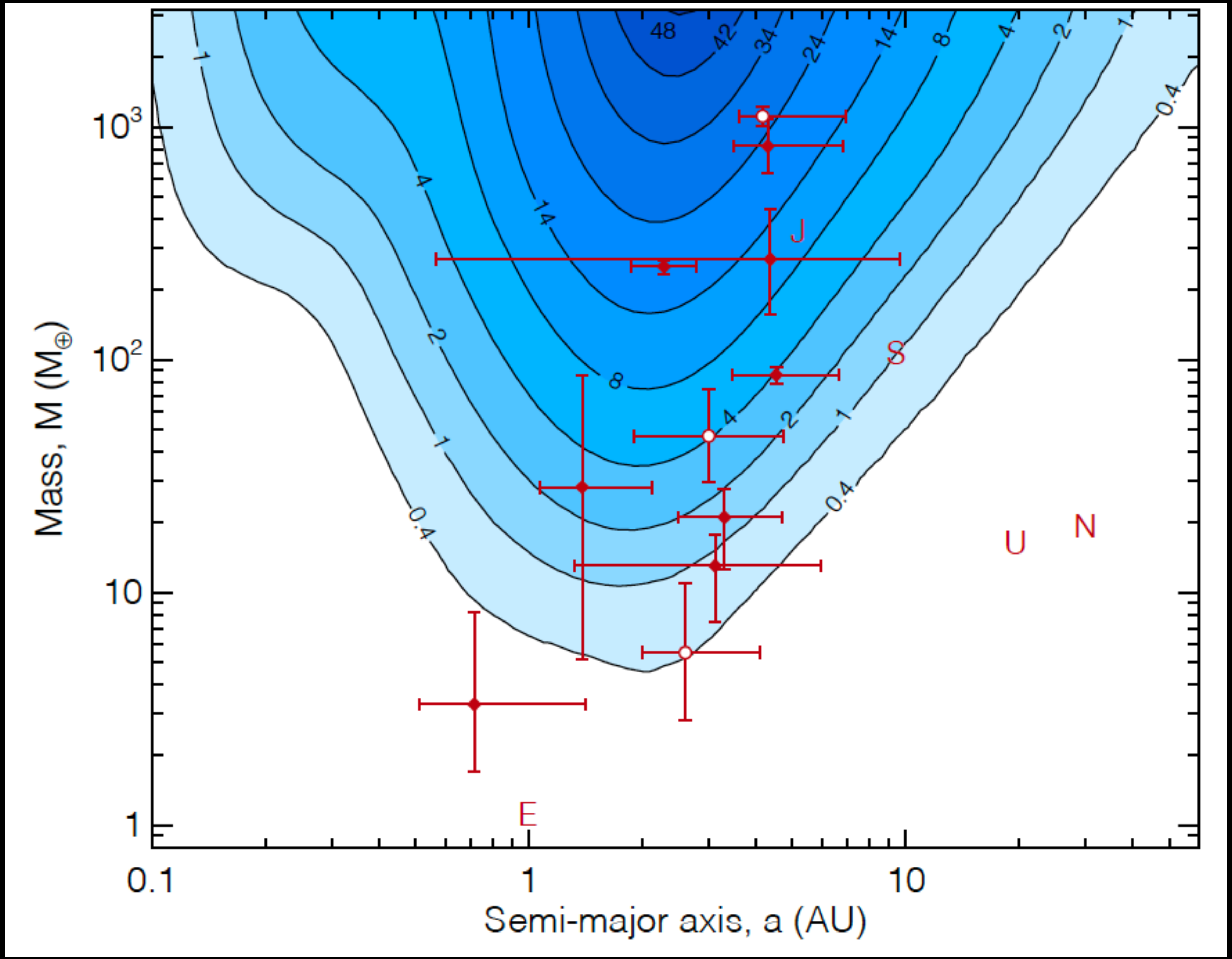


Planet population is plentiful

At least one planet per star

First detection of a remote (P=10d) 5 Earth-mass planet





Beaulieu et al. 2006

ESO PR0603

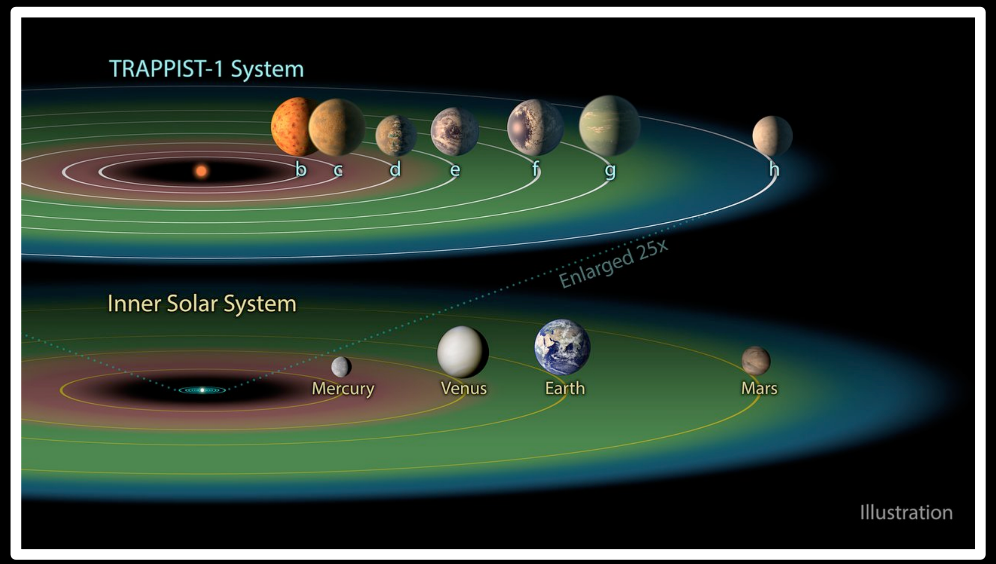
PLANET network

Cassan et al. 2014

ESO PR1204

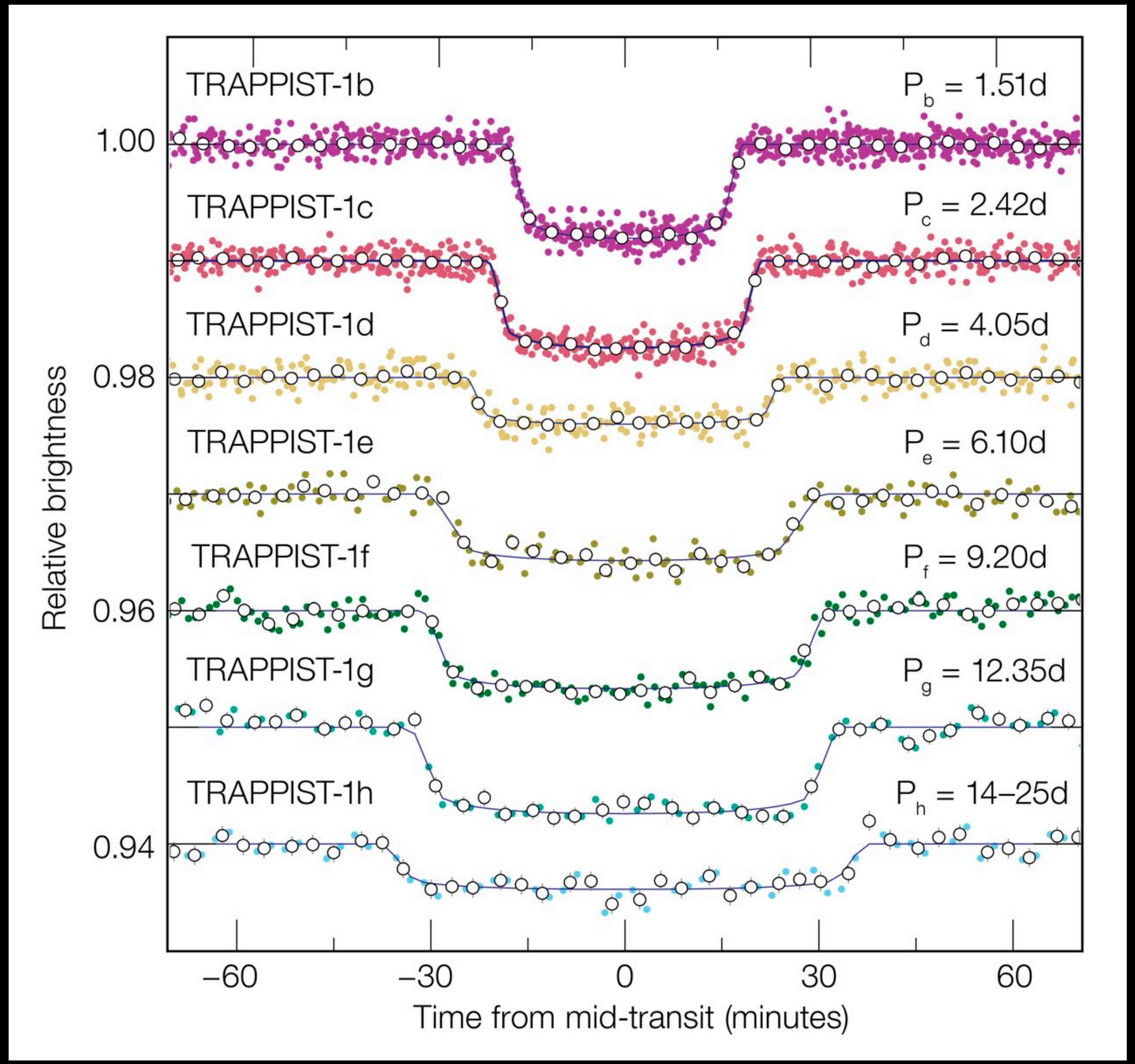
Hosting transit-team projects

Trappist-1bcdefg

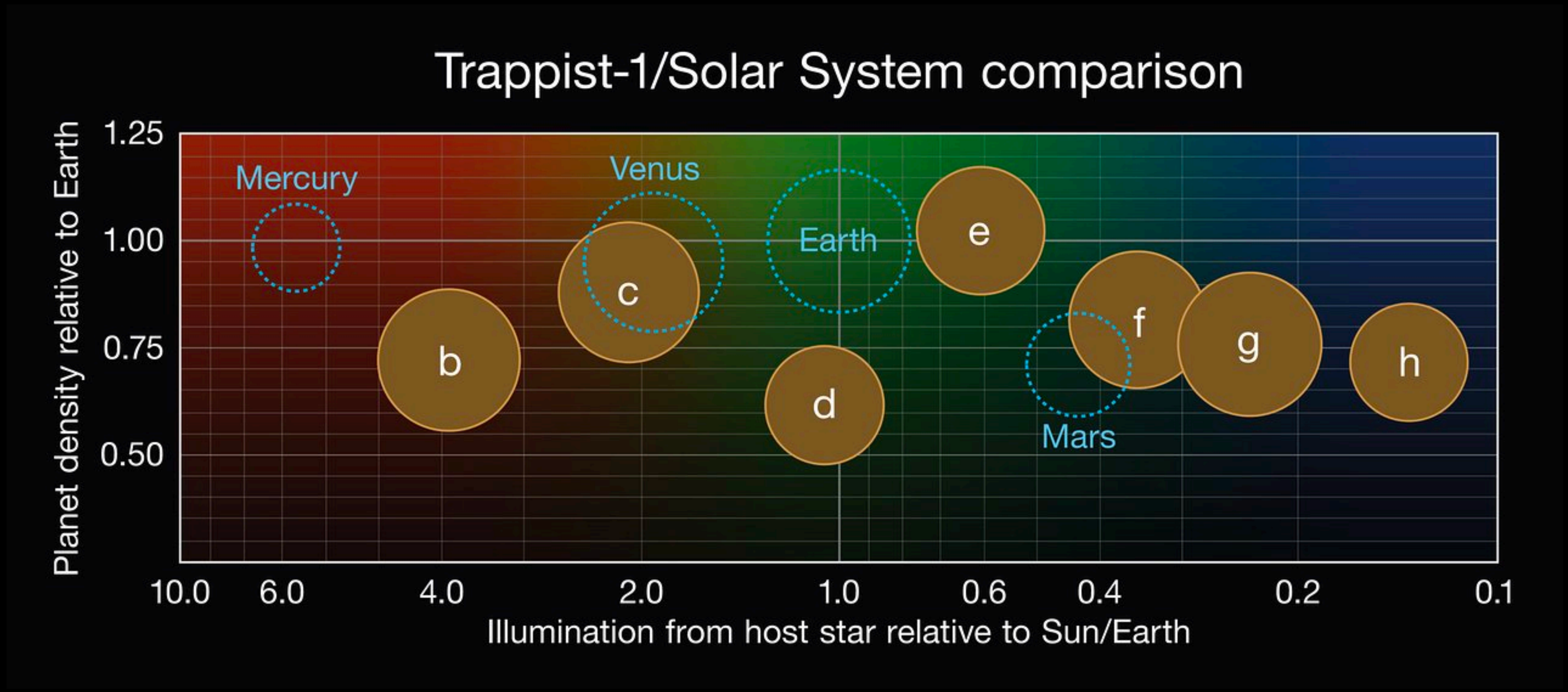


Trappist

Trappist + Speculoos



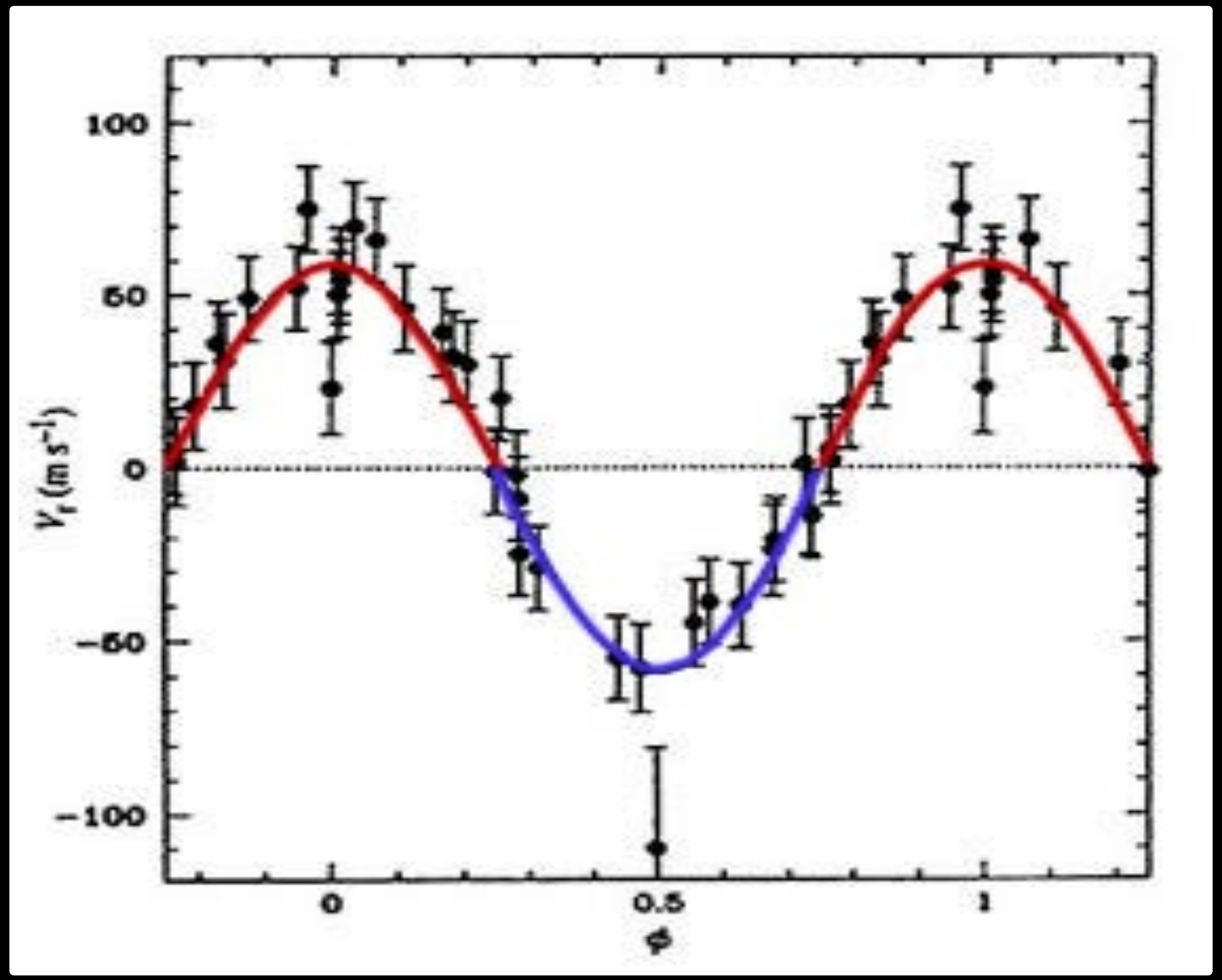
Guillon et al 2017 PR1706



Grimm et al, 2018 ESO PR1805

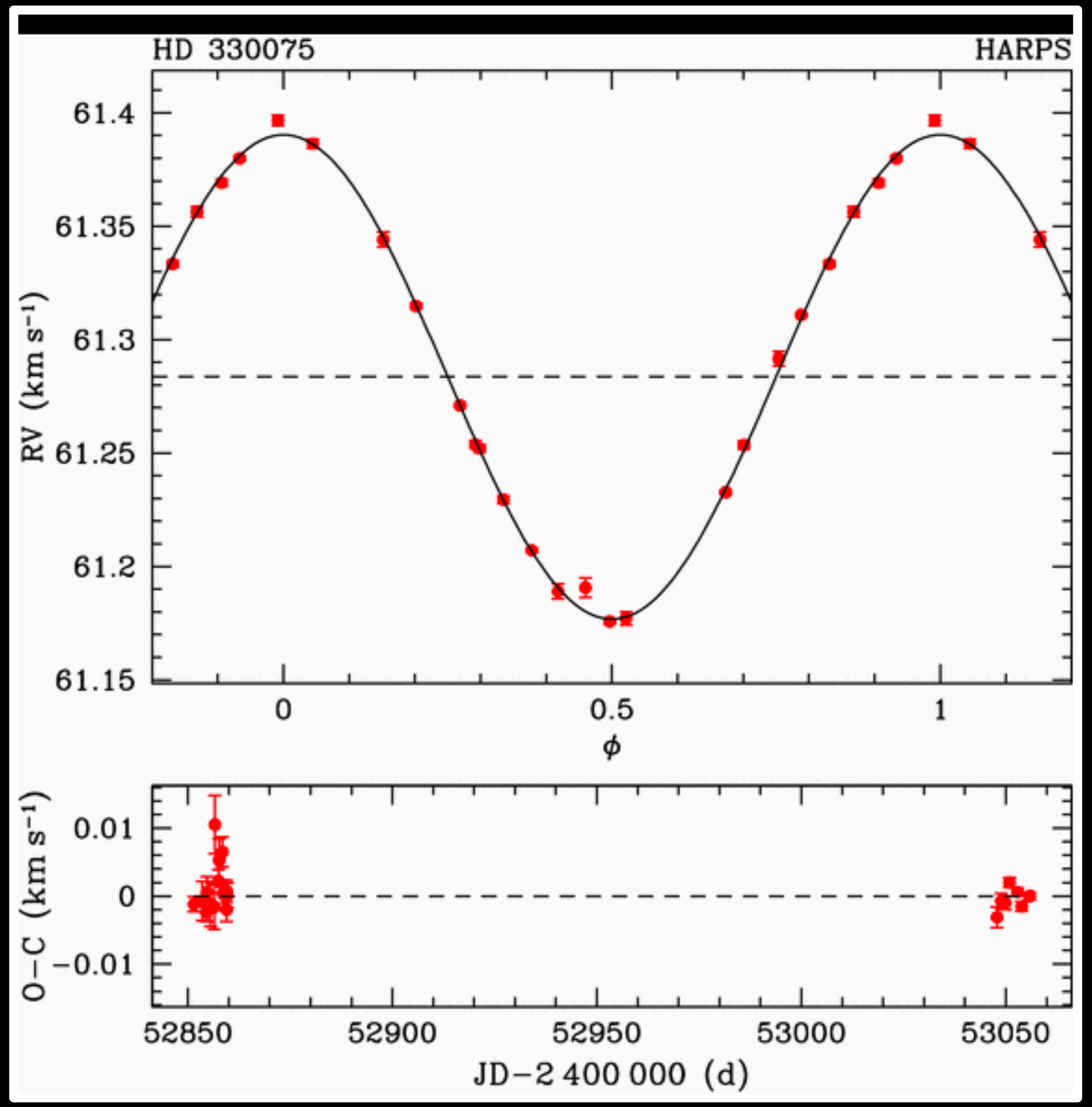
2003. HARPS Revolution

1.9m/Elodie (10m/s)



51 Pegase b
Mayor et Queloz, 1995
Nobel Prize 2019

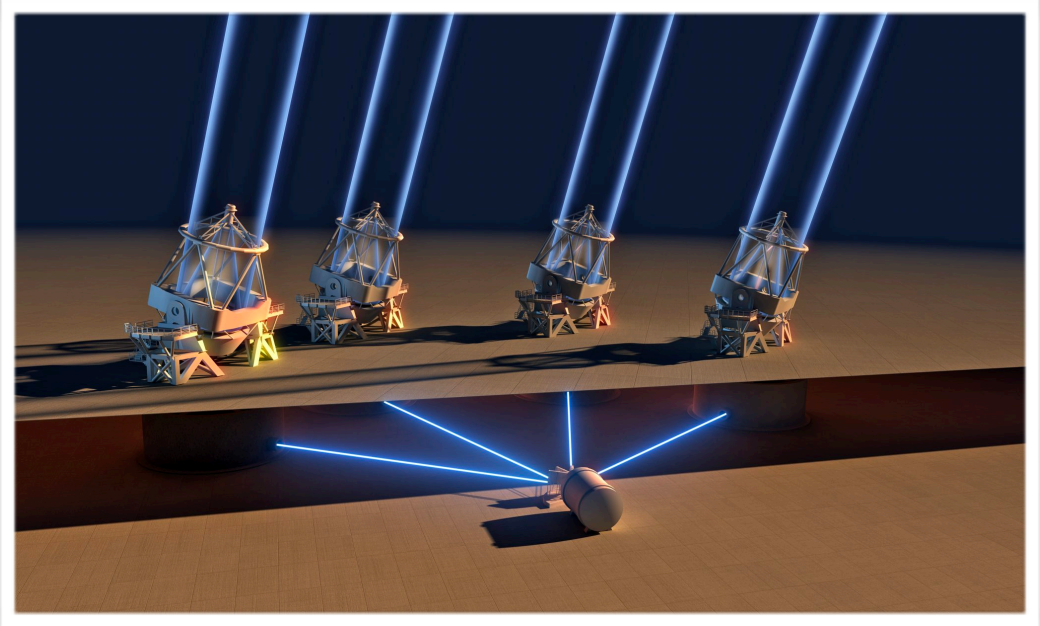
3.6m/HARPS (1m/s)



HD330075 b: 1st HARPS planet
Pepe et al, 2004

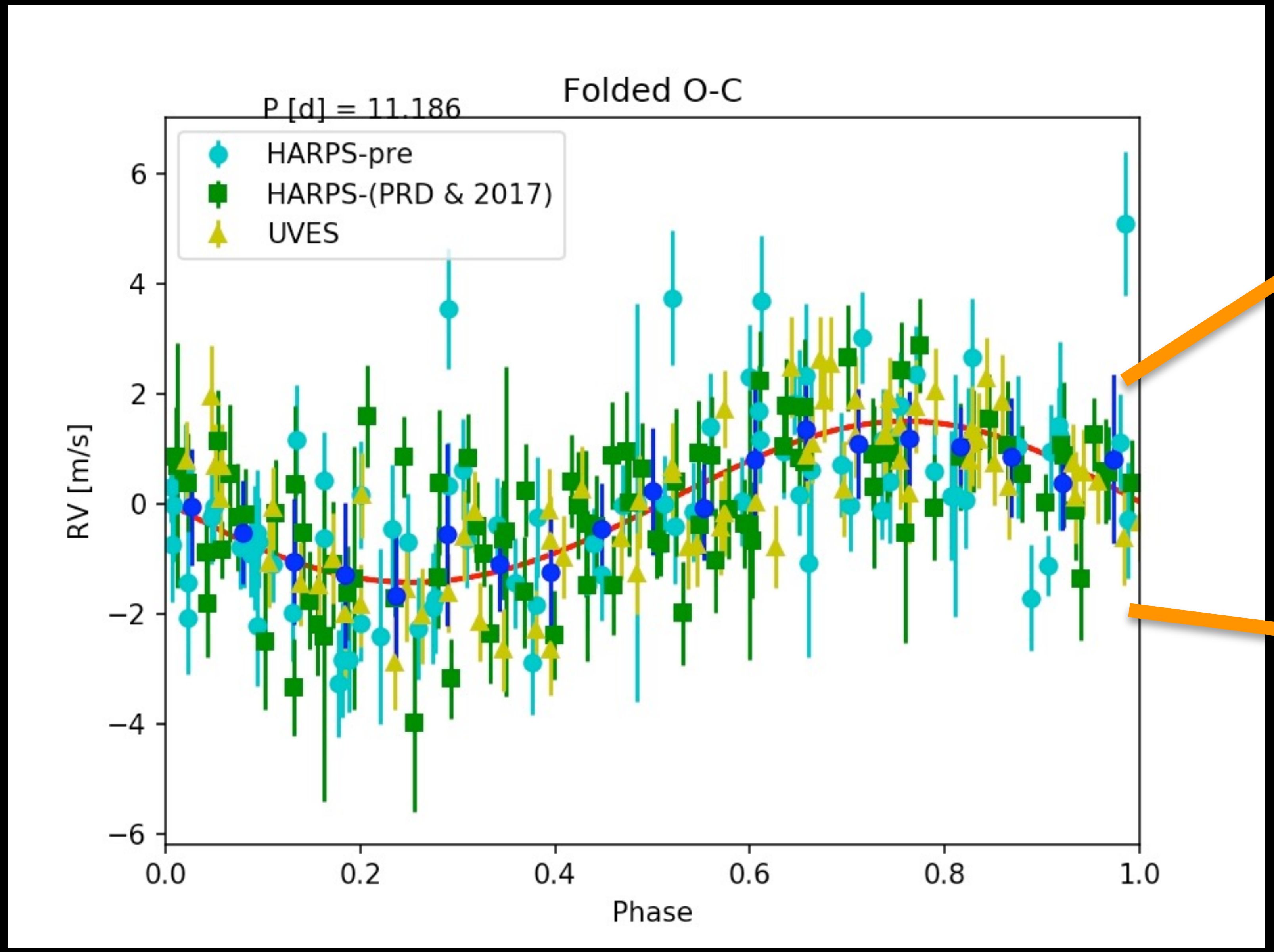
Ideal survey instrument. Hundreds of planets, from giants to super-Earths (Msini = 1 - 10 $M_\oplus$)
Super-Earths are super abundant: (50% for P = 10 - 100 d, HZ) around M dwarfs *Bonfils et al, 2014*. ESO PR1214.
Conclusion shared with *Cassan et al, 2014*

Proxima Cen planetary system



2016

3.6m/HARPS (1m/s)

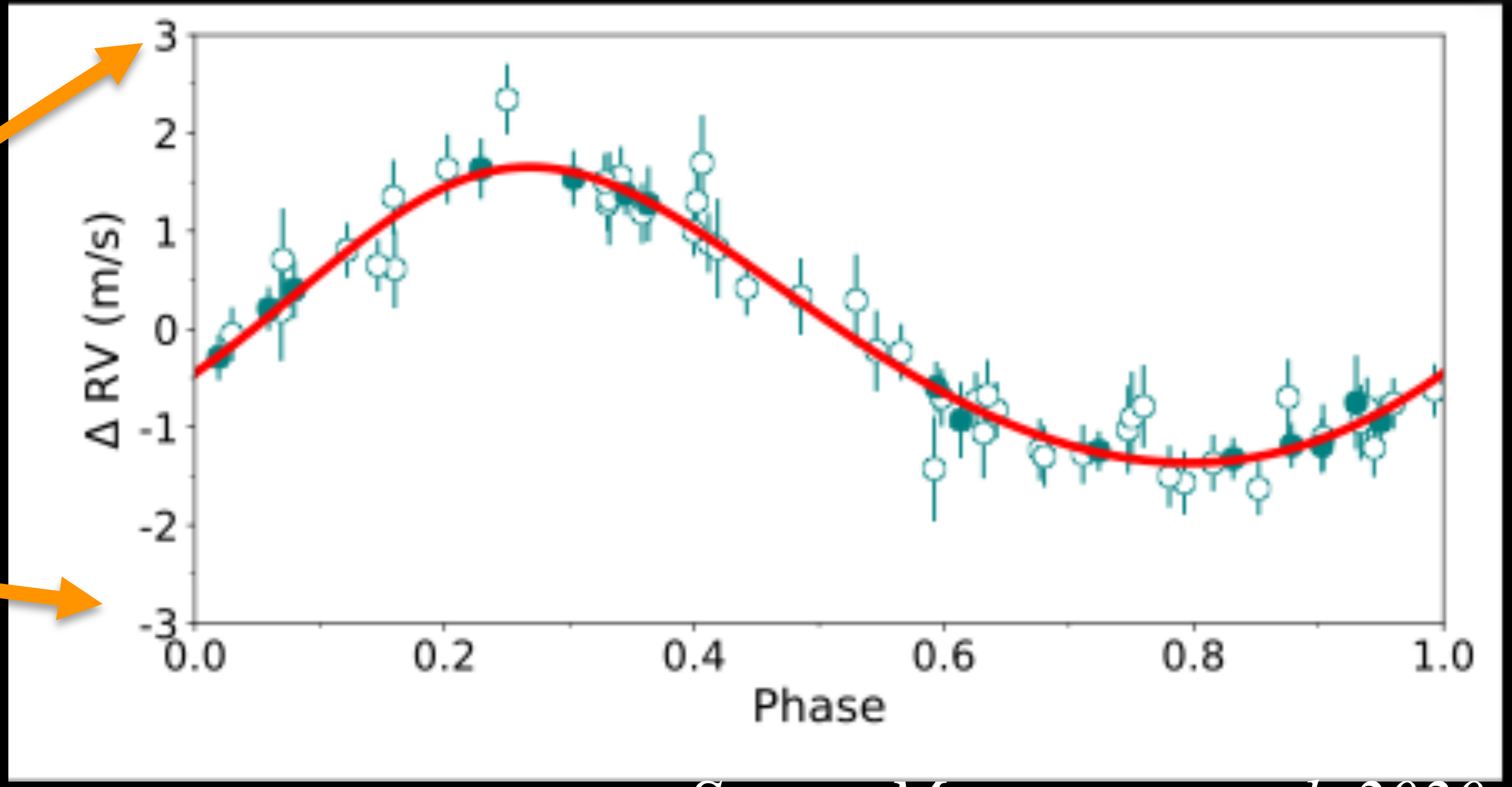


Anglada-Escude et al, 2016

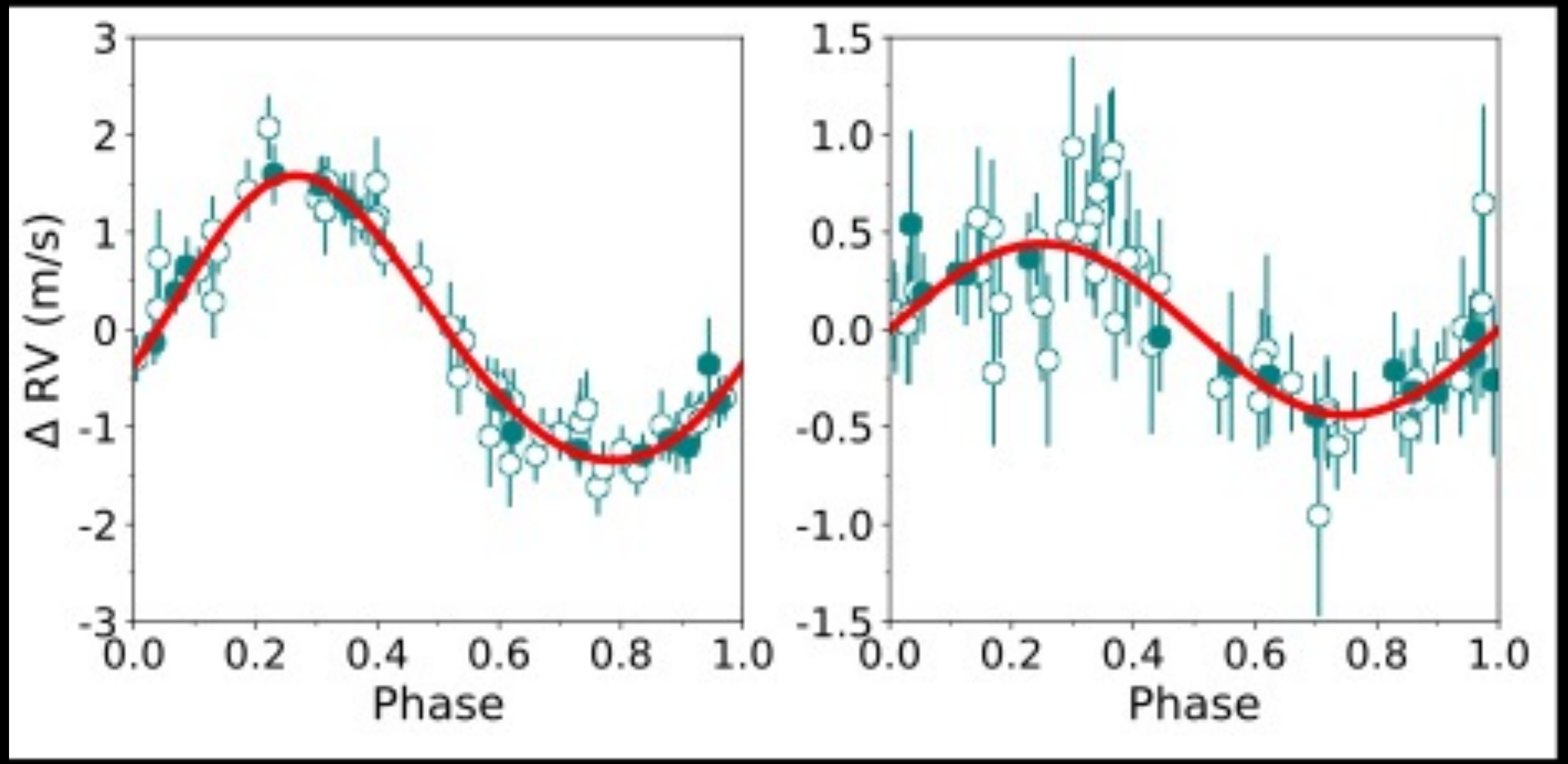
ESO PR1629

2020

VLT/ESPRESSO (25cm/s)



Suarez Mascareno et al, 2020



M= 1.3 ME
P = 11.2 d

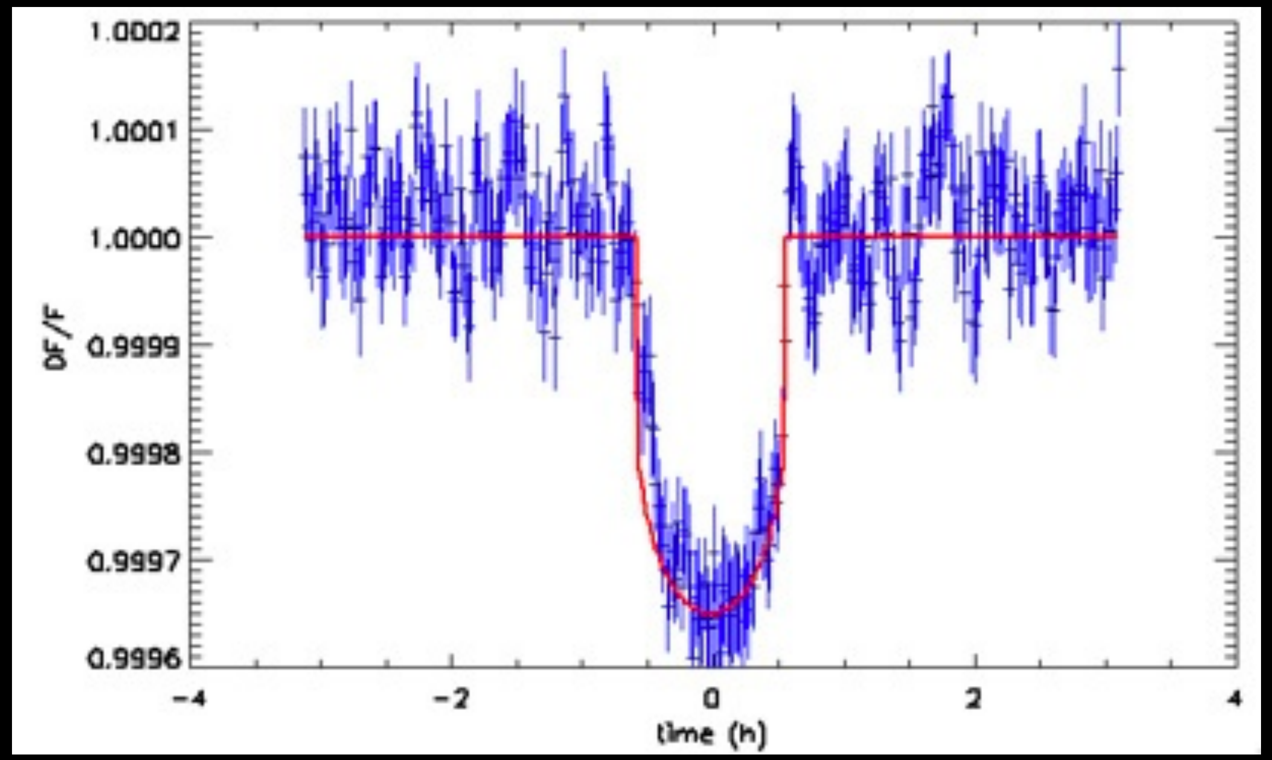
M= 0.3 ME
P = 5 d

Faria et al, 2022

ESO PR 2202

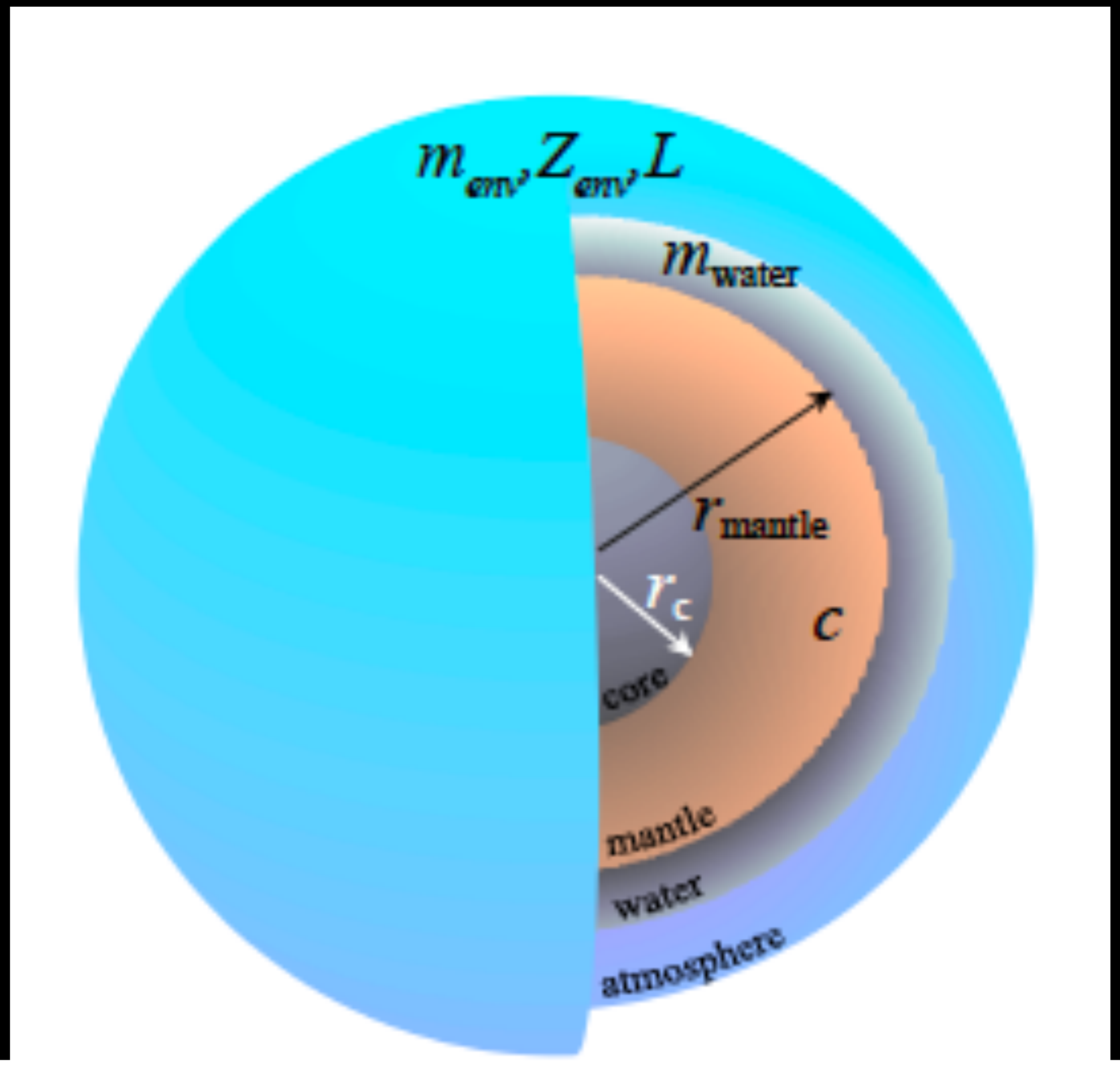
Characterization of transiting planets with HARPS

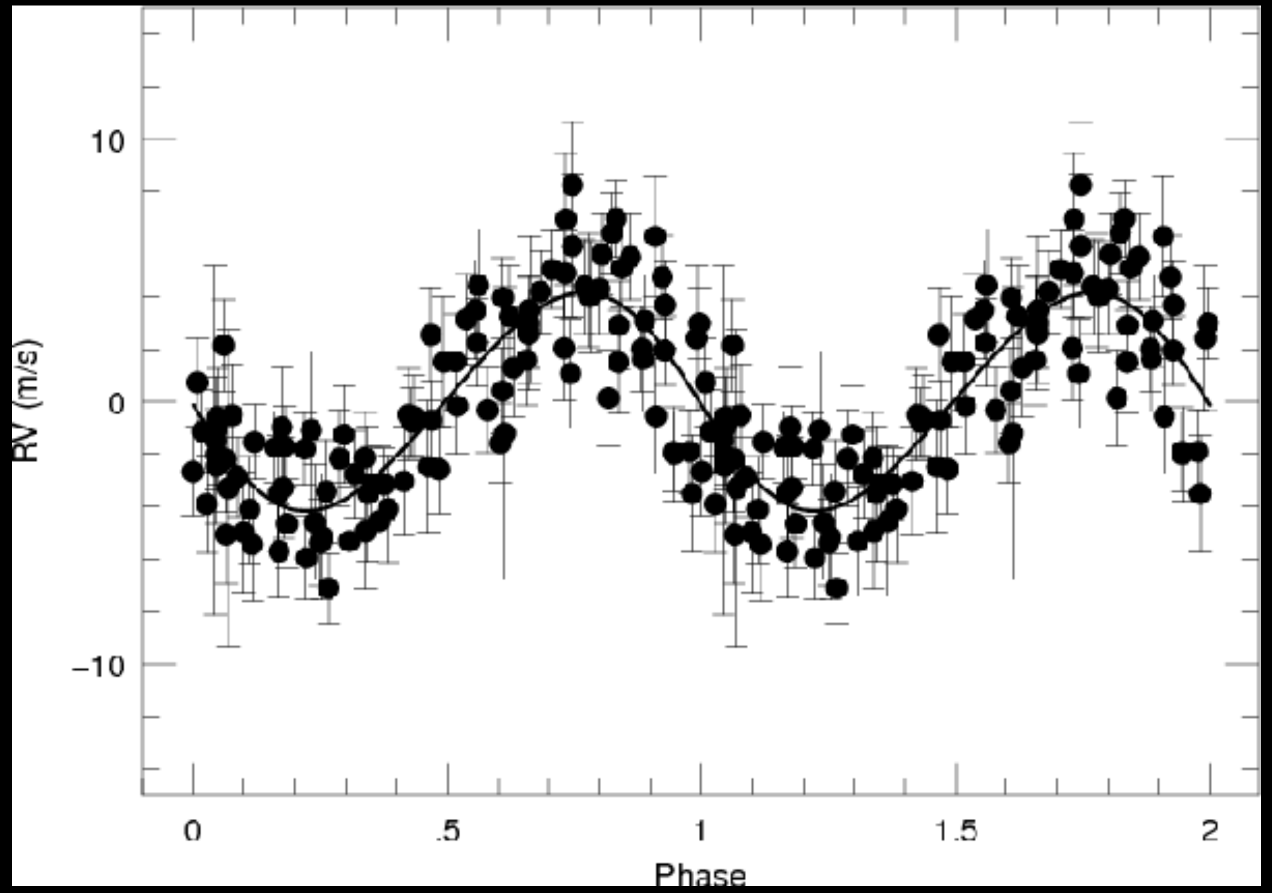
- Test Corot candidates *Moutou et al, 2009*
- Characterize the planets structures



Leger et al, 2009

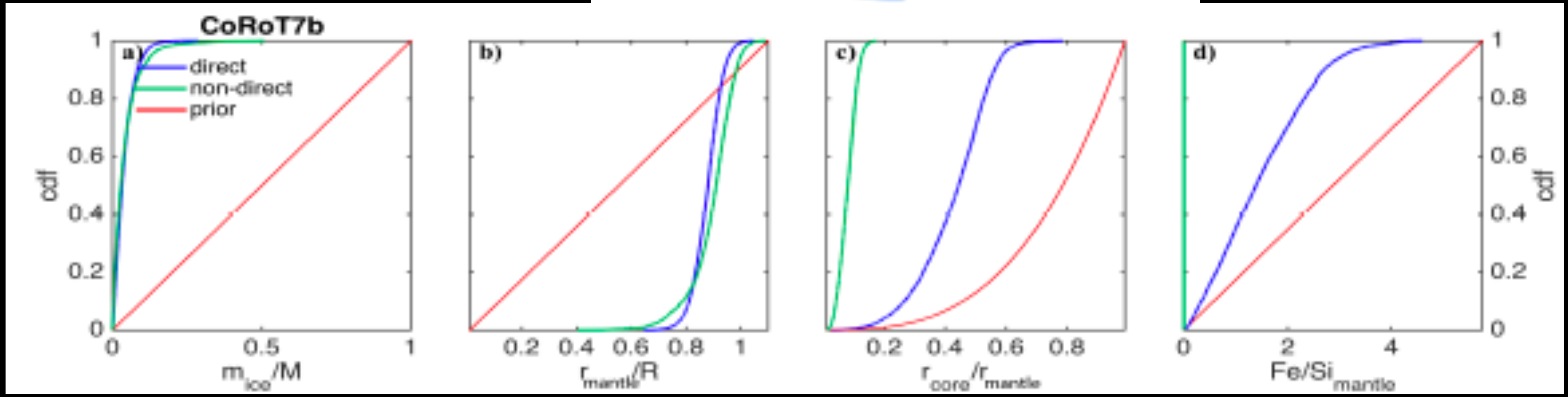
Corot-7 b (5ME)





Queloz et al, 2009

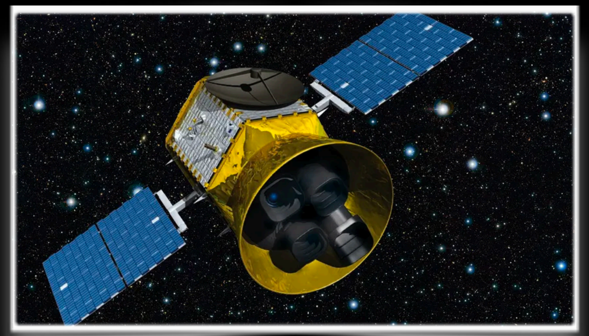
ESO PR0933



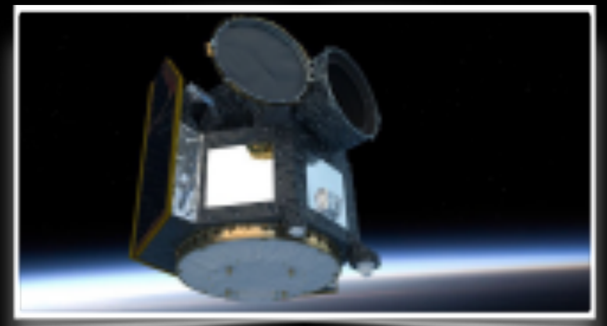
Dorn et al, 2017

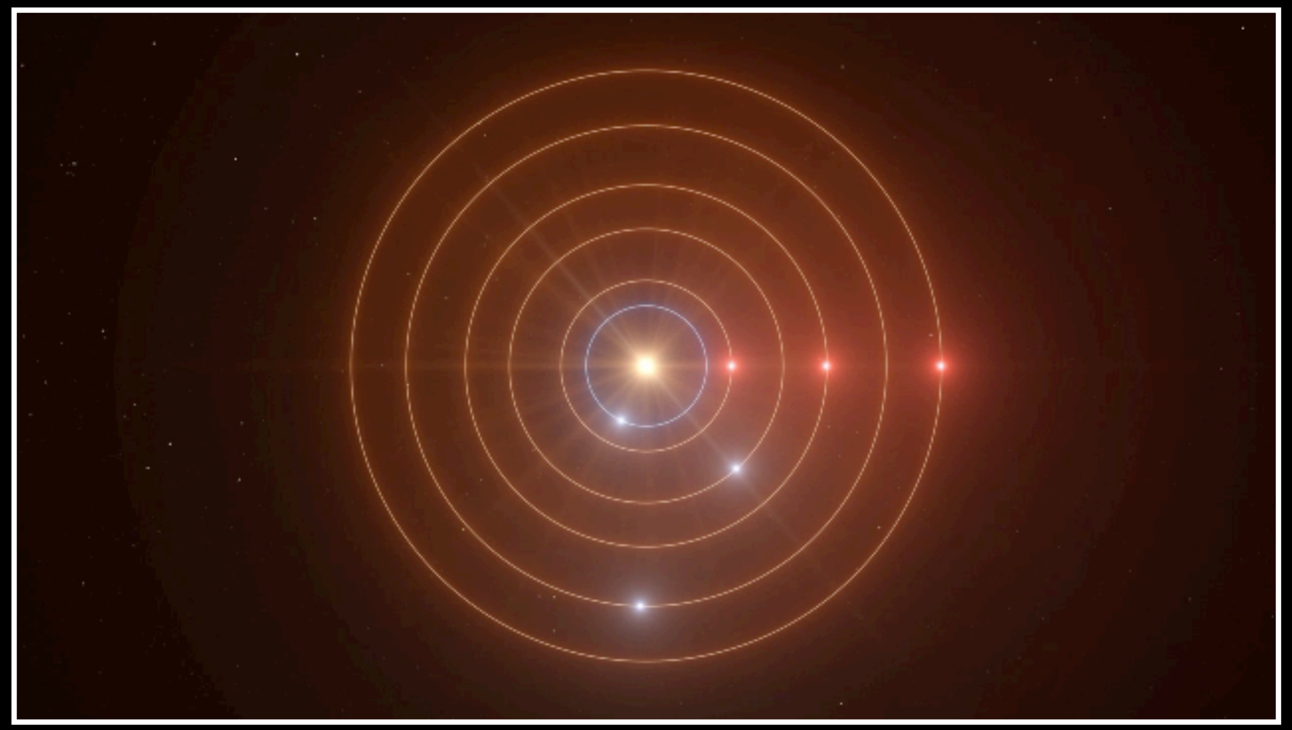
Characterization of complex systems with ESPRESSO

Combining TESS, SPECULOOS, NGTS, ESPRESSO, and CHEOPS

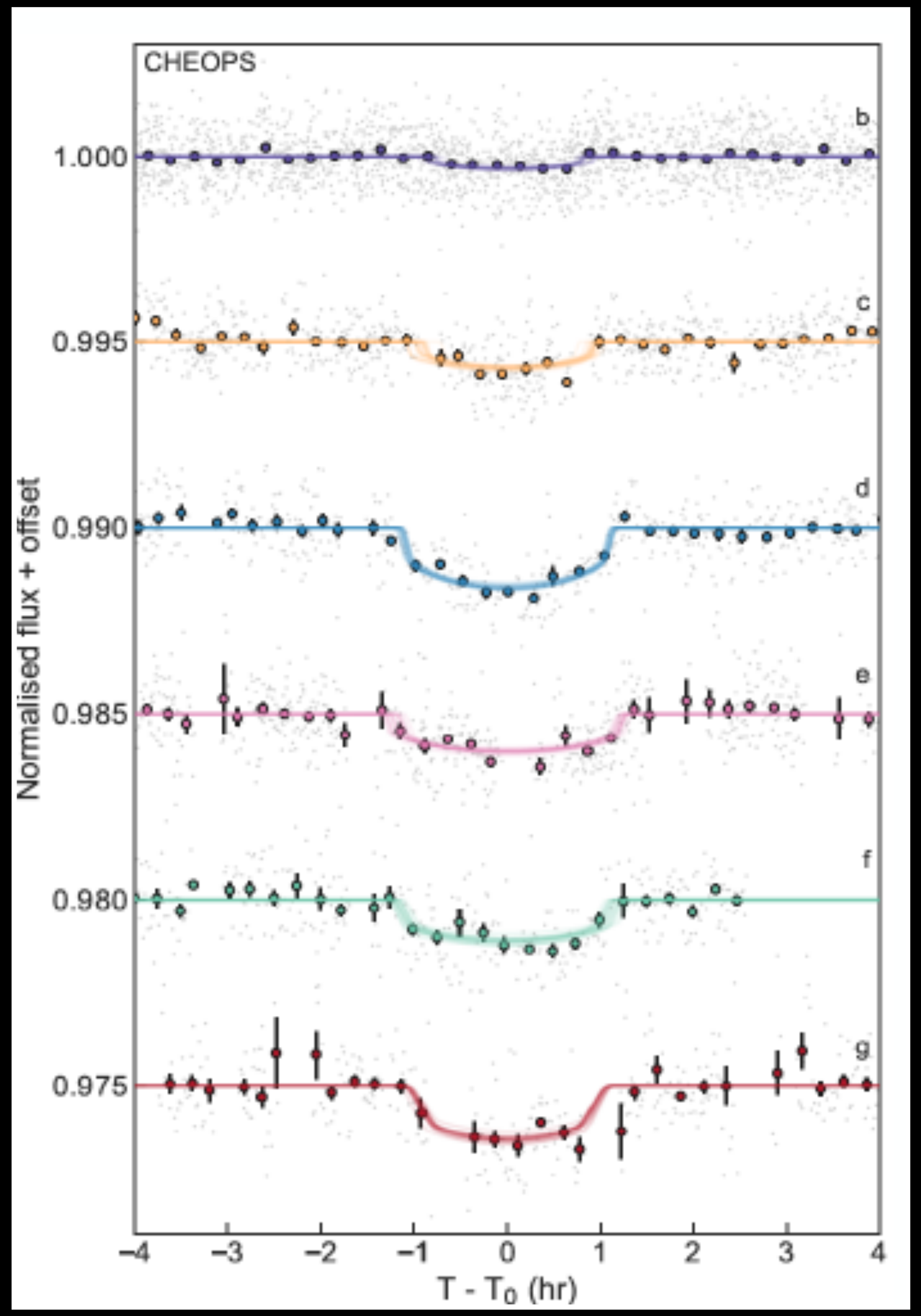


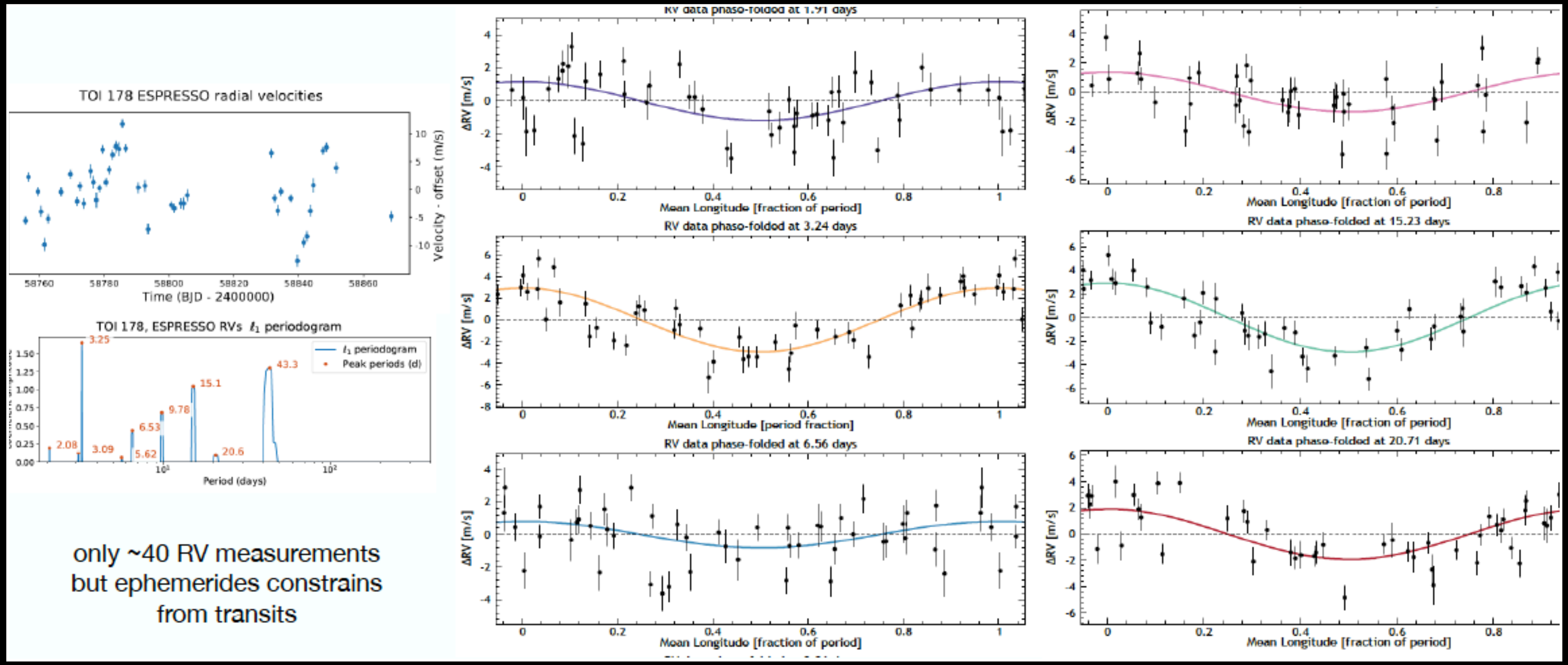






TOI 178



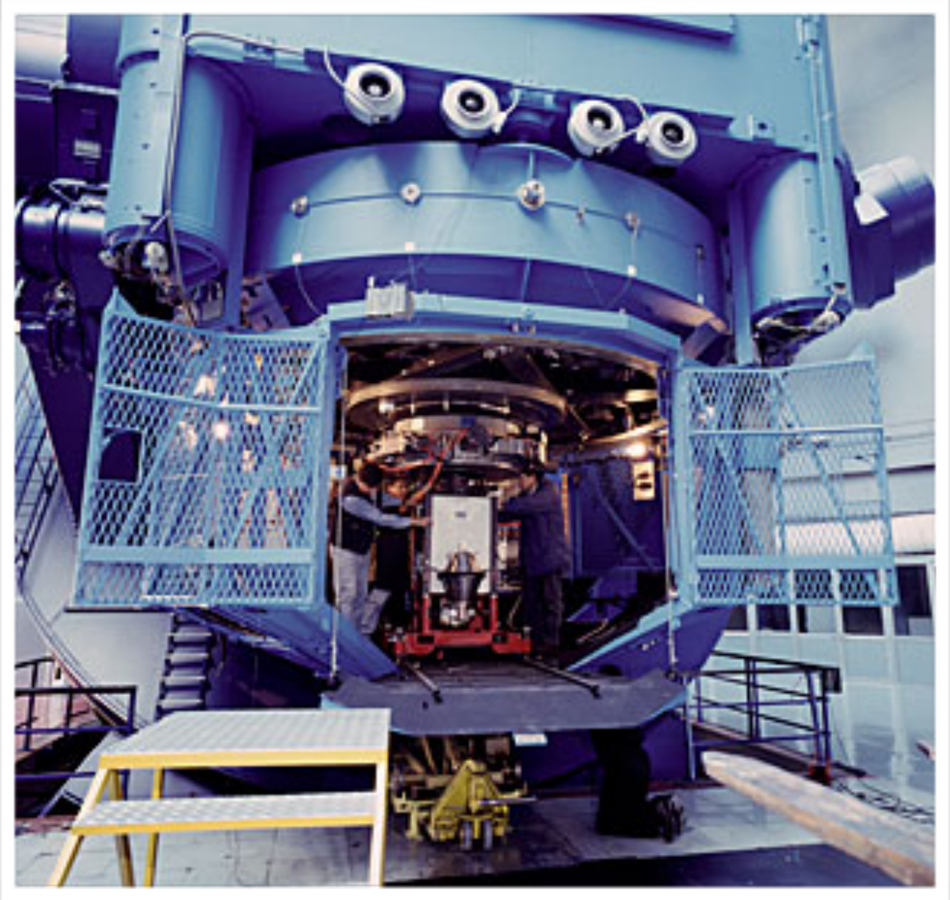


Leleu et al, 2021

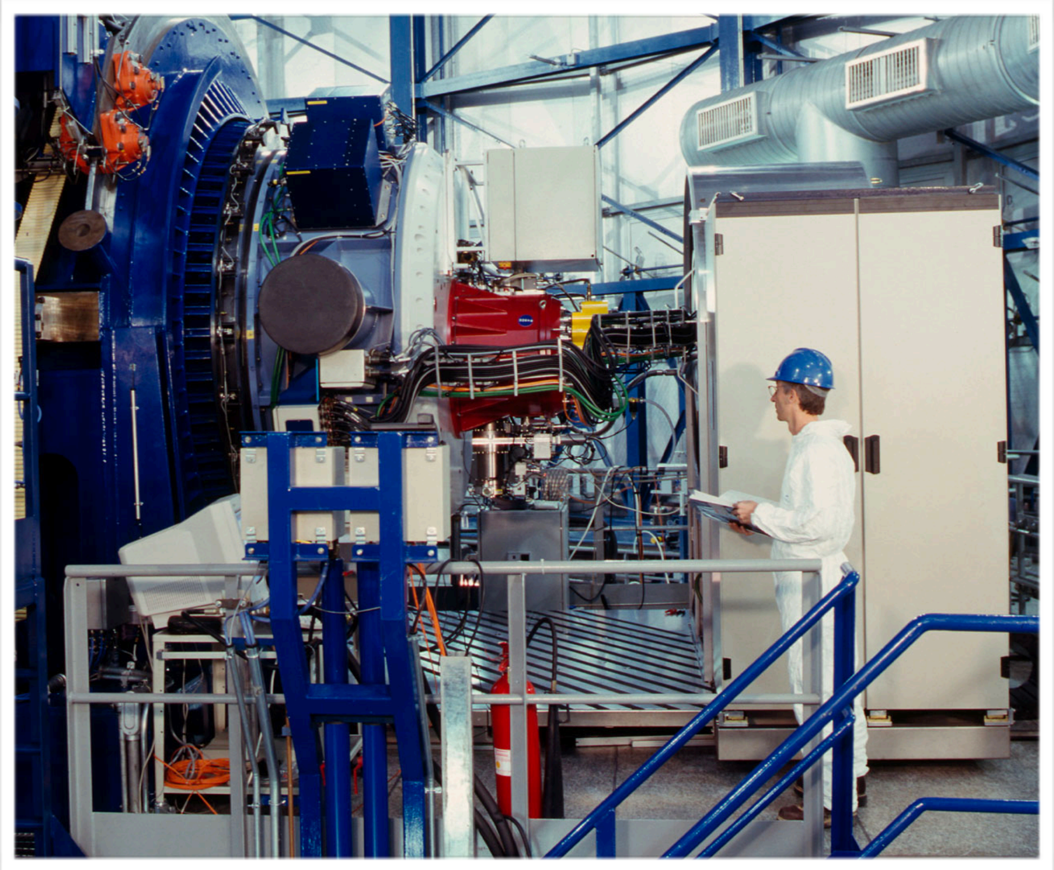
ESO PR2102

Imaging brown dwarfs with high contrast imagers at ESO

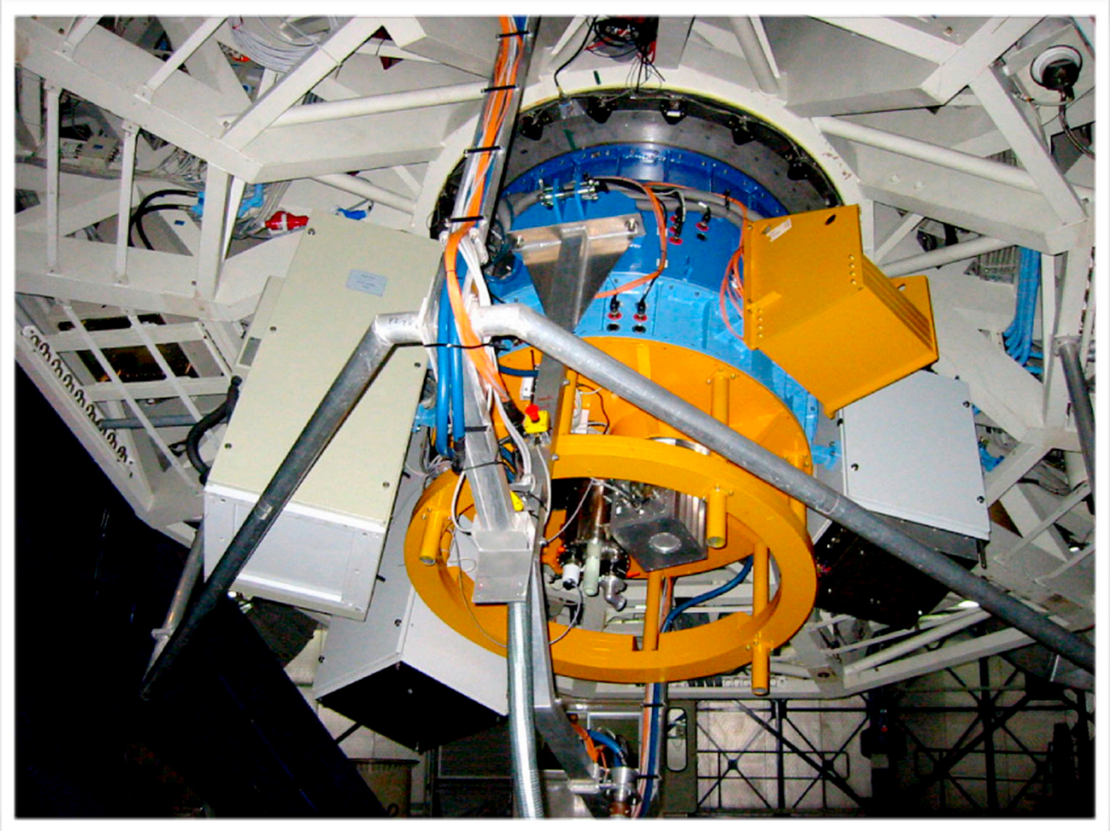
3.6m/Adonis (1993)



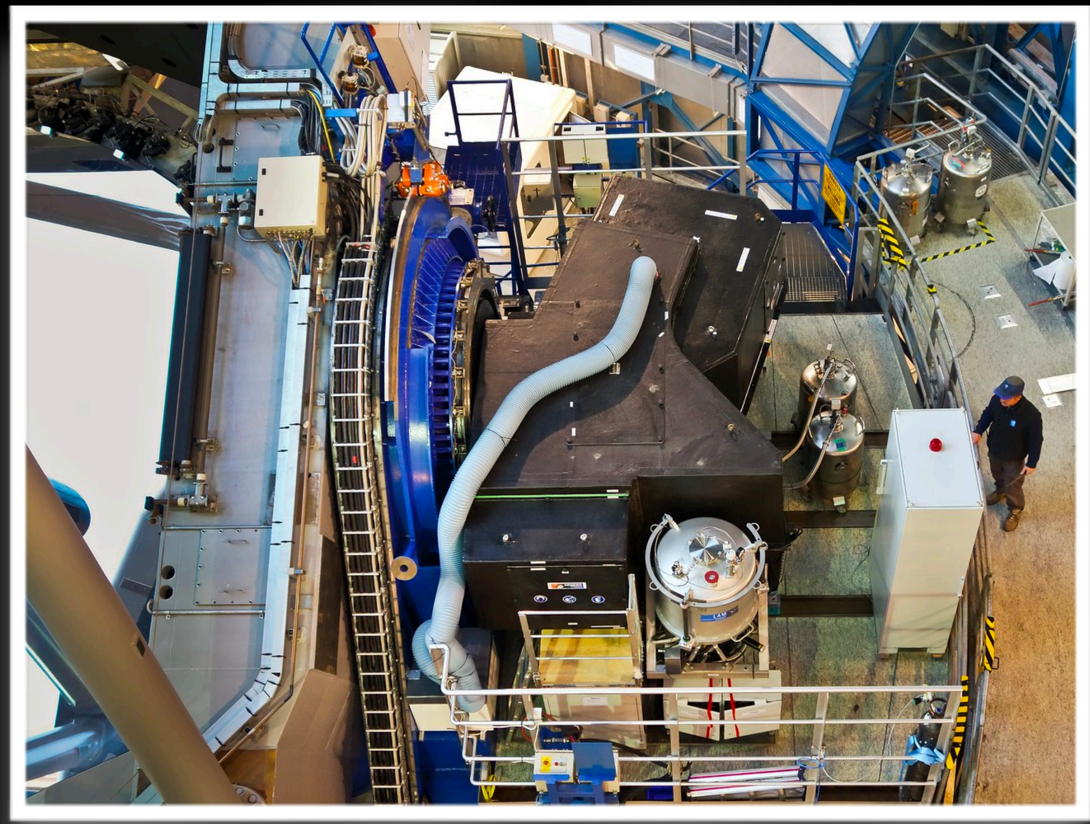
VLT/NACO (2001)

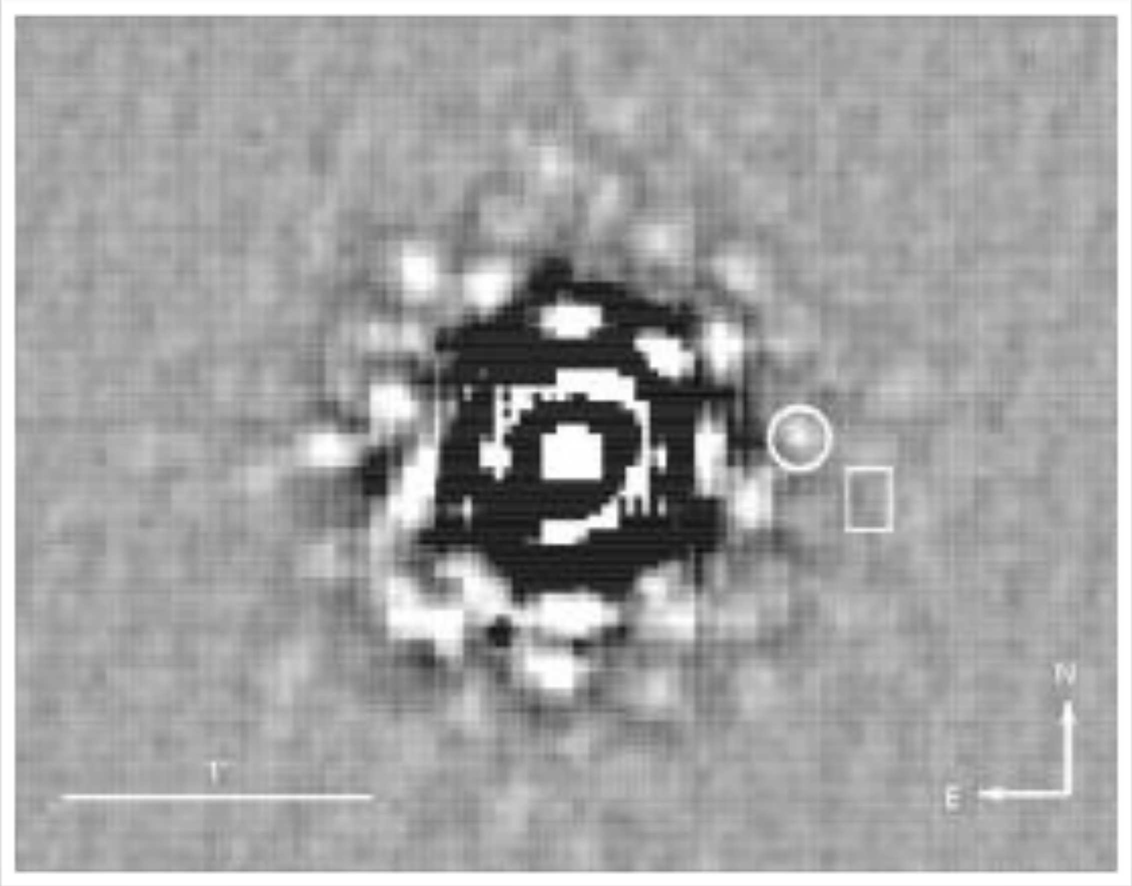


VLT/SINFONI (2004)

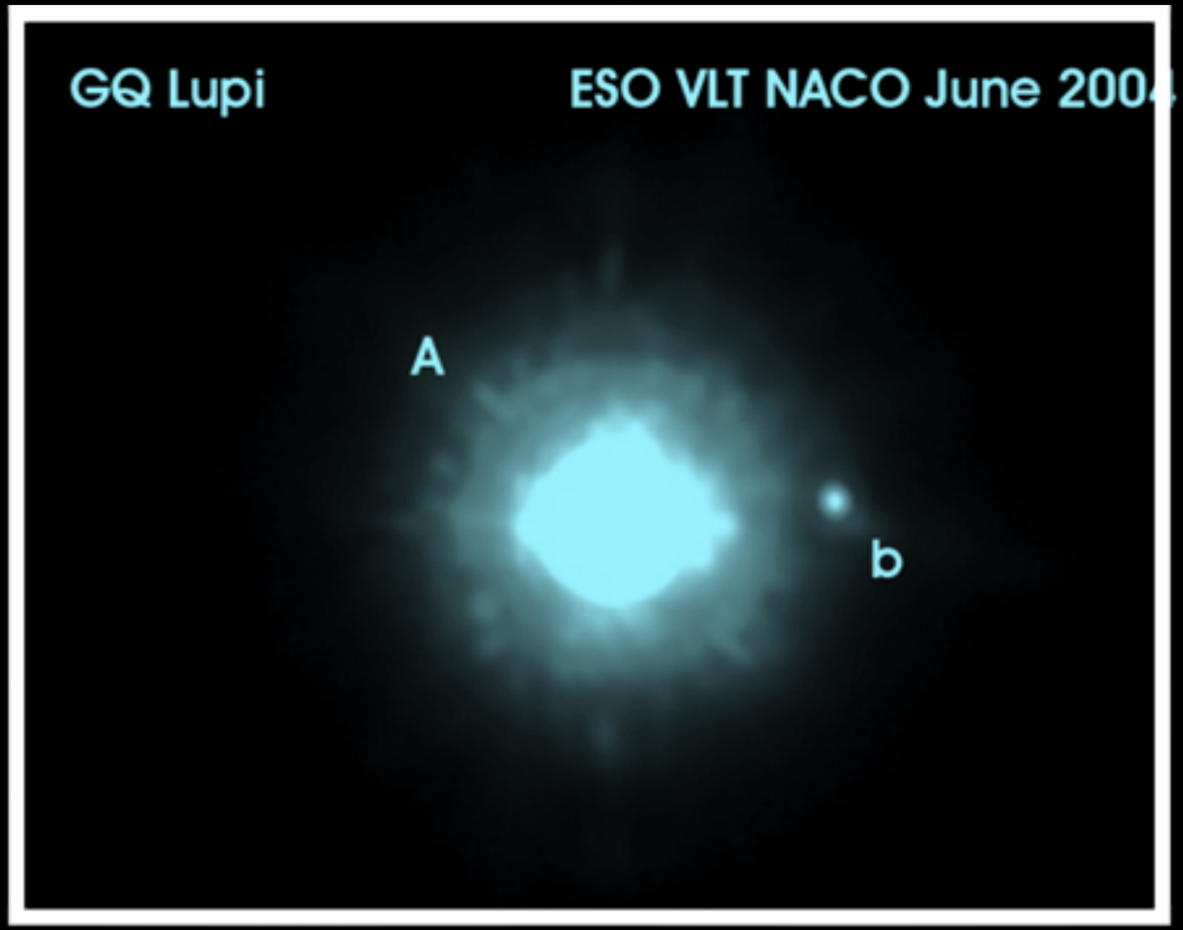


VLT/SPHERE (2014)

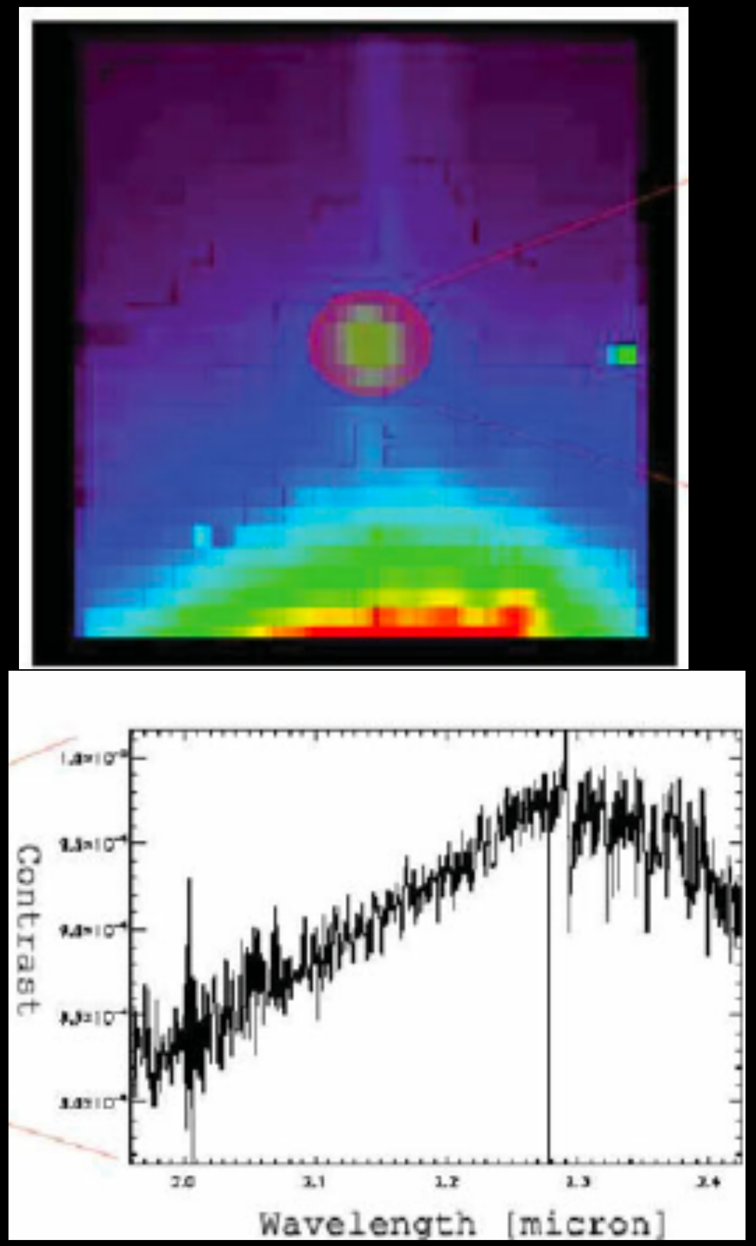




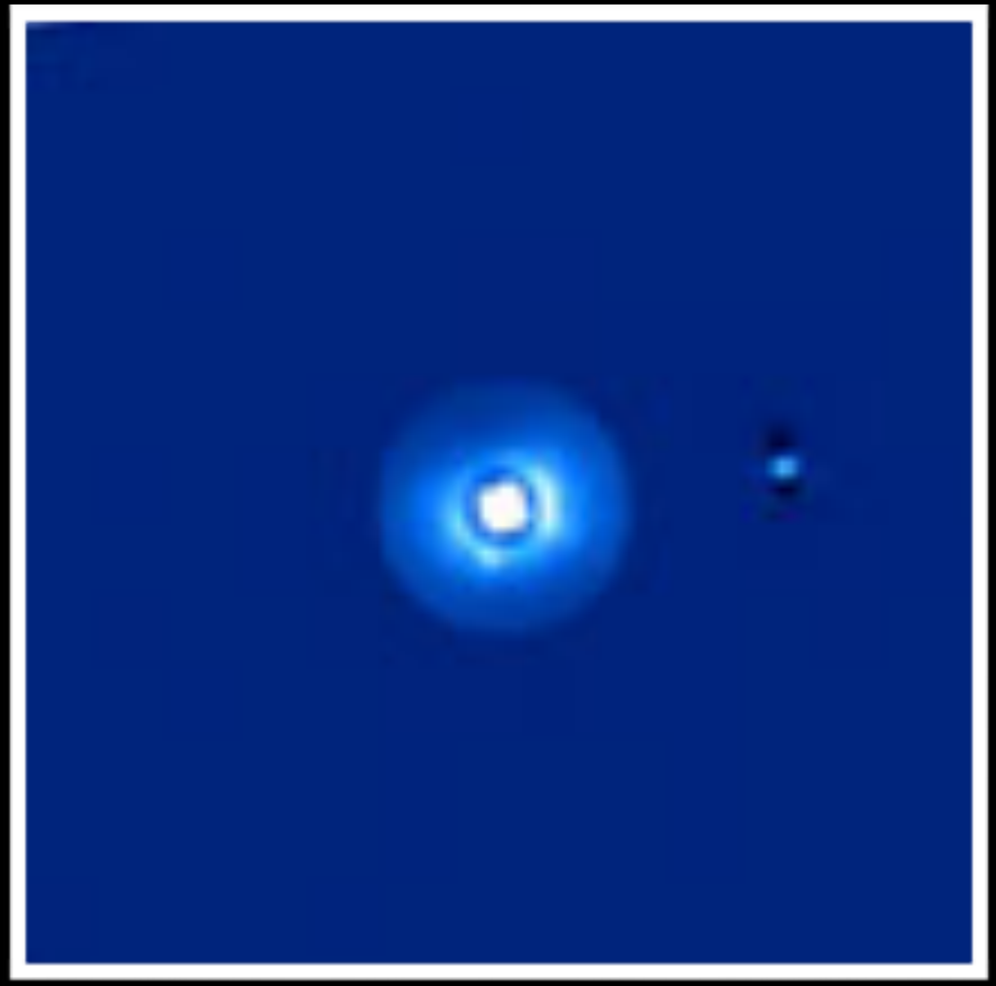
Neuhaueser et al,1995



Neuhaueser et al, 2005

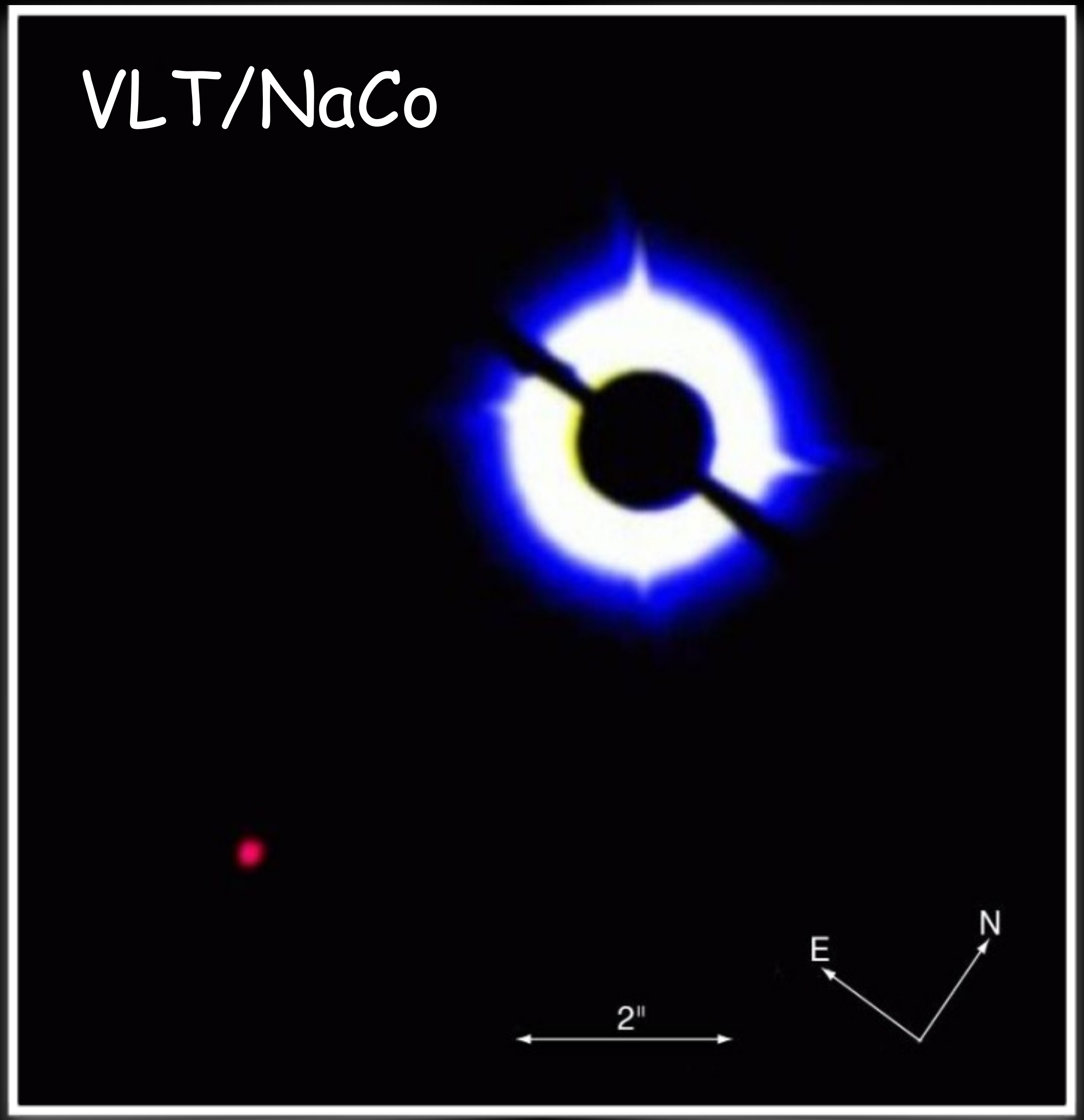


Angerhausen, 2008



Beuzit et al, 2015

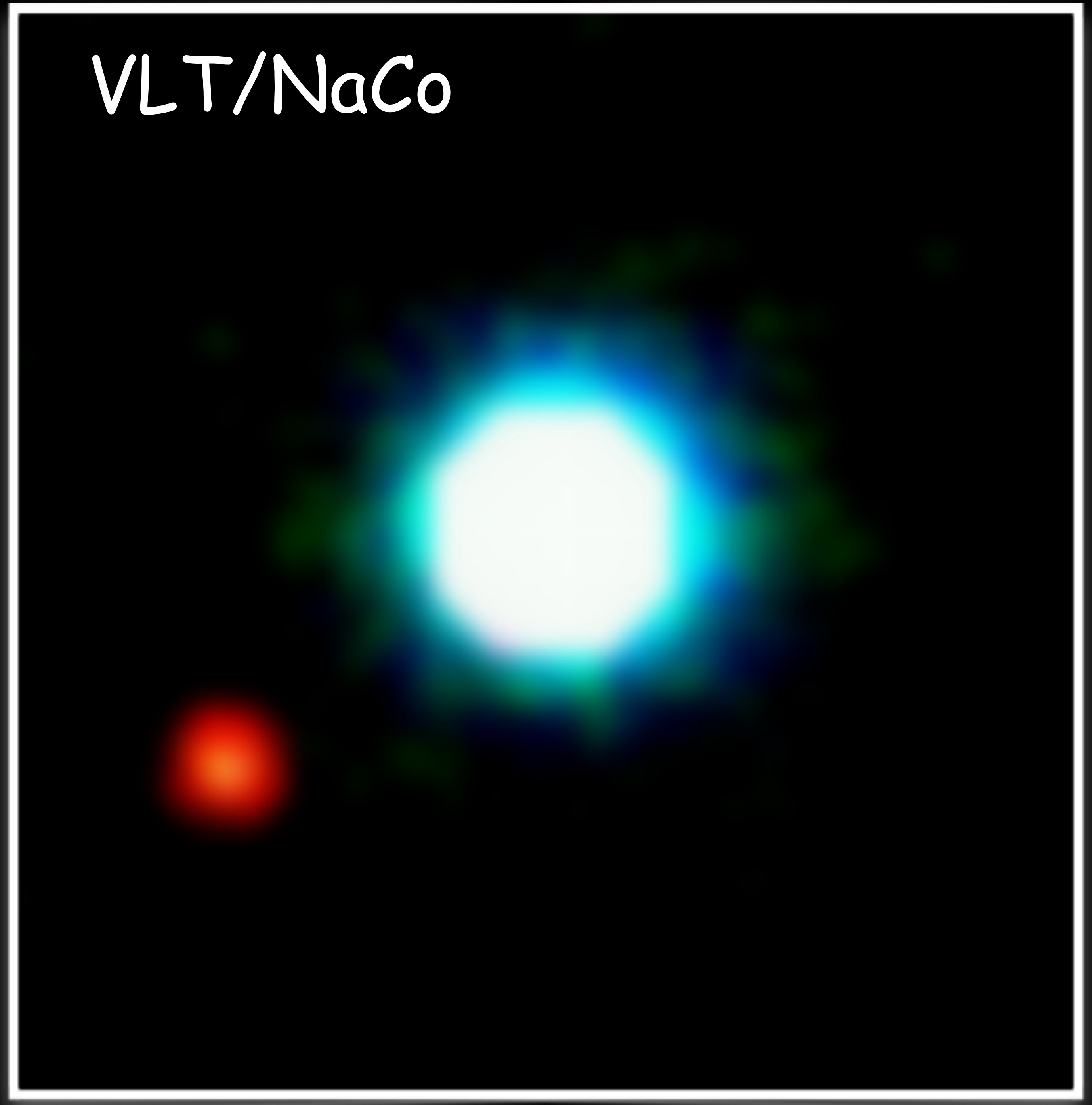
2004 : First images of exoplanets



ESO PR0515

AB Pic b
M ~ 13 M_{jup}
Sep = 260 AU (proj.)
30 Myr

Chauvin et al. 2005a

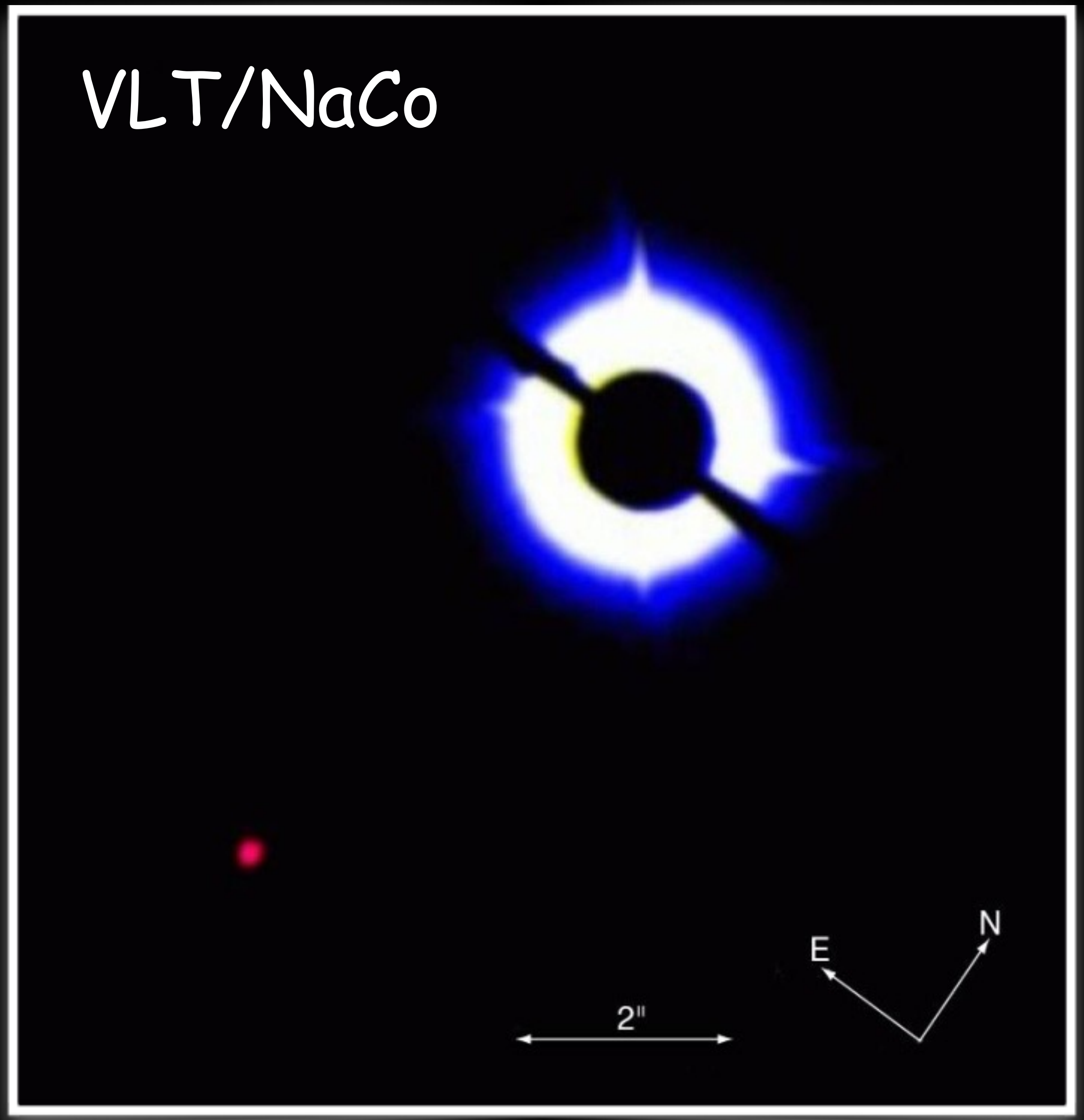


ESO PR0428

2Mass1207 b
M ~ 5-8 M_{jup}
Sep = 50 AU (proj.)
5 Myr

Chauvin et al. 2004, 2005b

2004 : First images of exoplanets

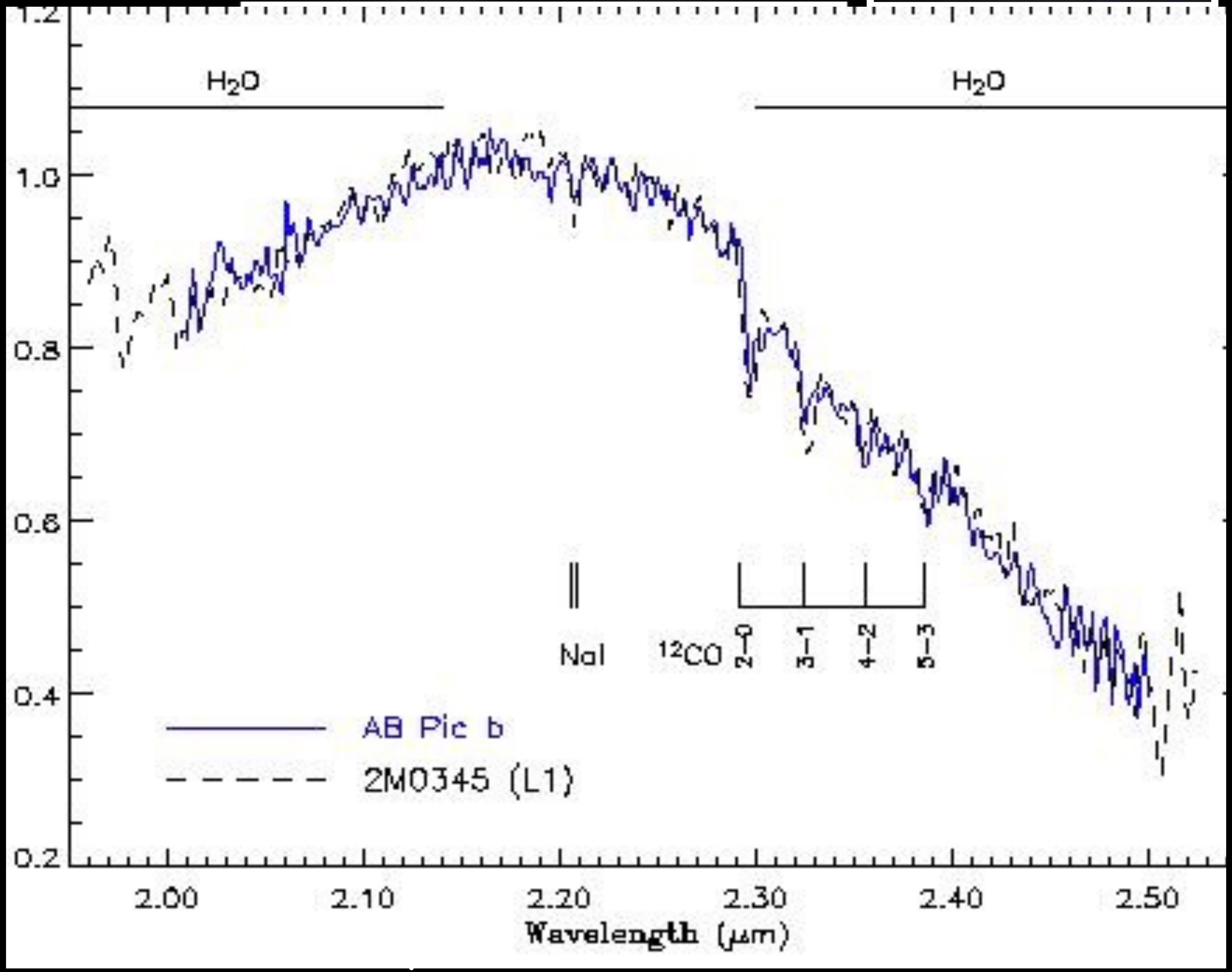


ESO PR0515

AB Pic b
M ~ 13 M_{jup}
Sep = 260 AU (proj.)
30 Myr

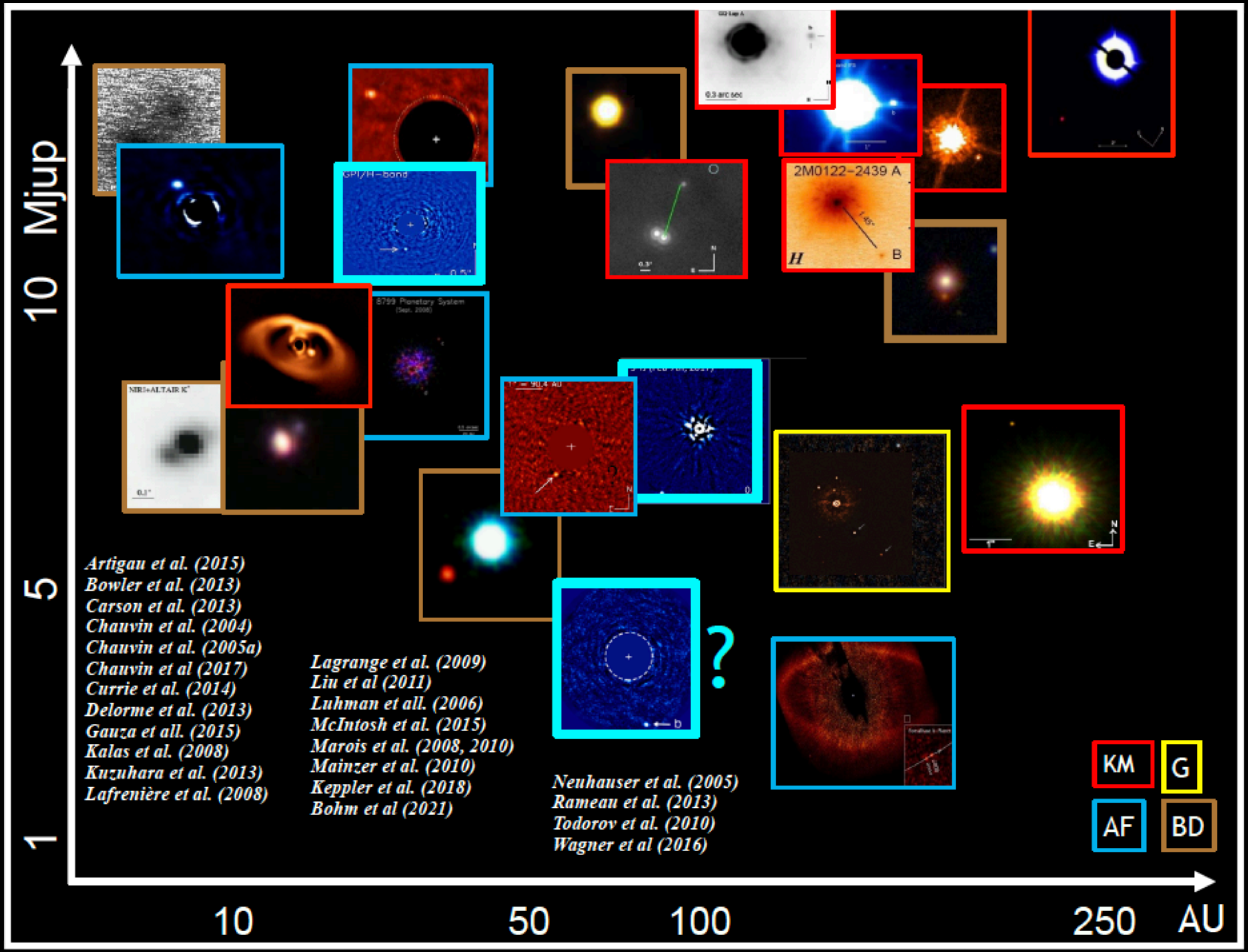
Chauvin et al. 2005a

CO, H2O



Chauvin et al. 2004, 2005b

Planets detected with M < 20 MJ

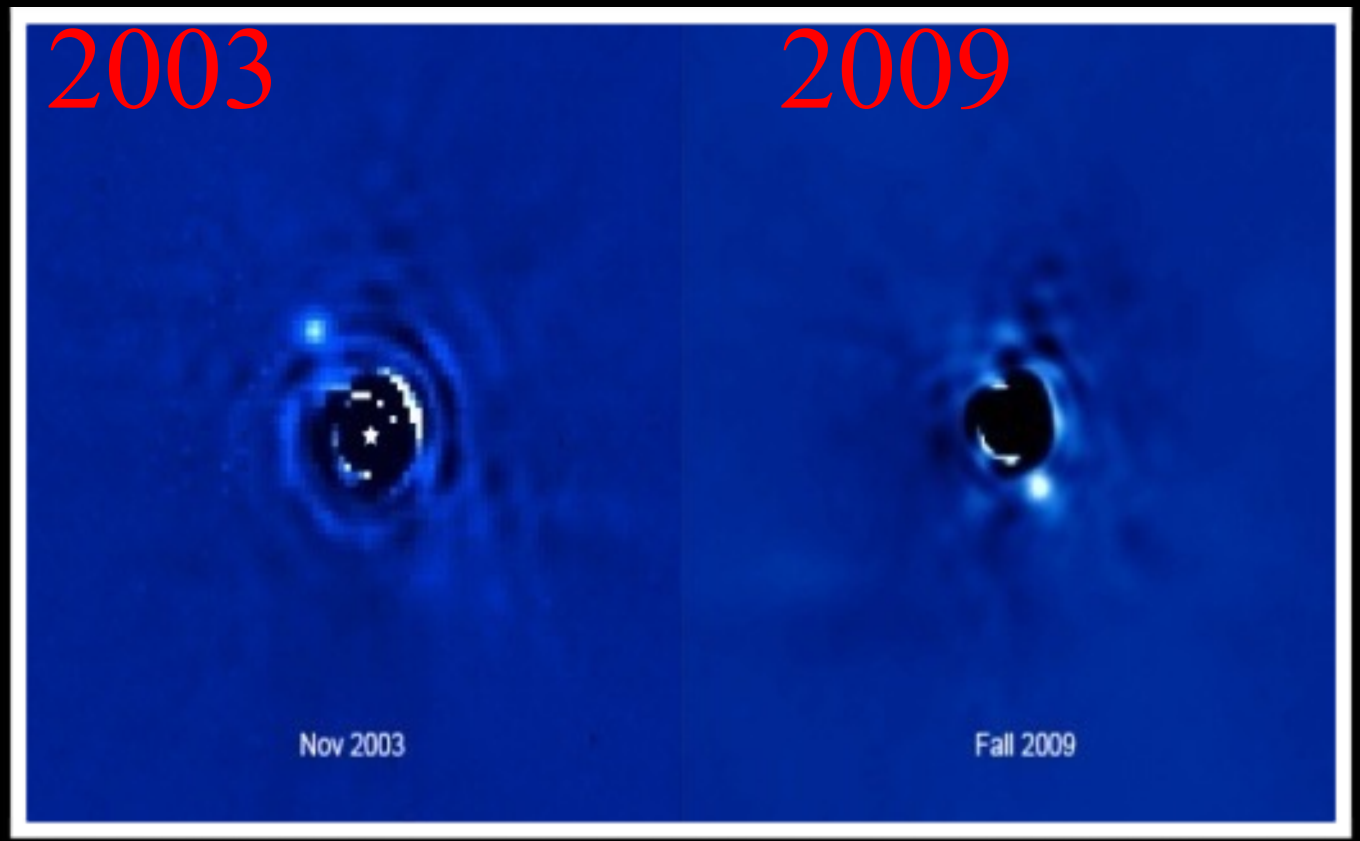


Most discoveries made at ESO (surveys)

A giant planet imaged at Saturn distance

β Pictoris b

VLT/NACO



Lagrange+ 2009, 2010

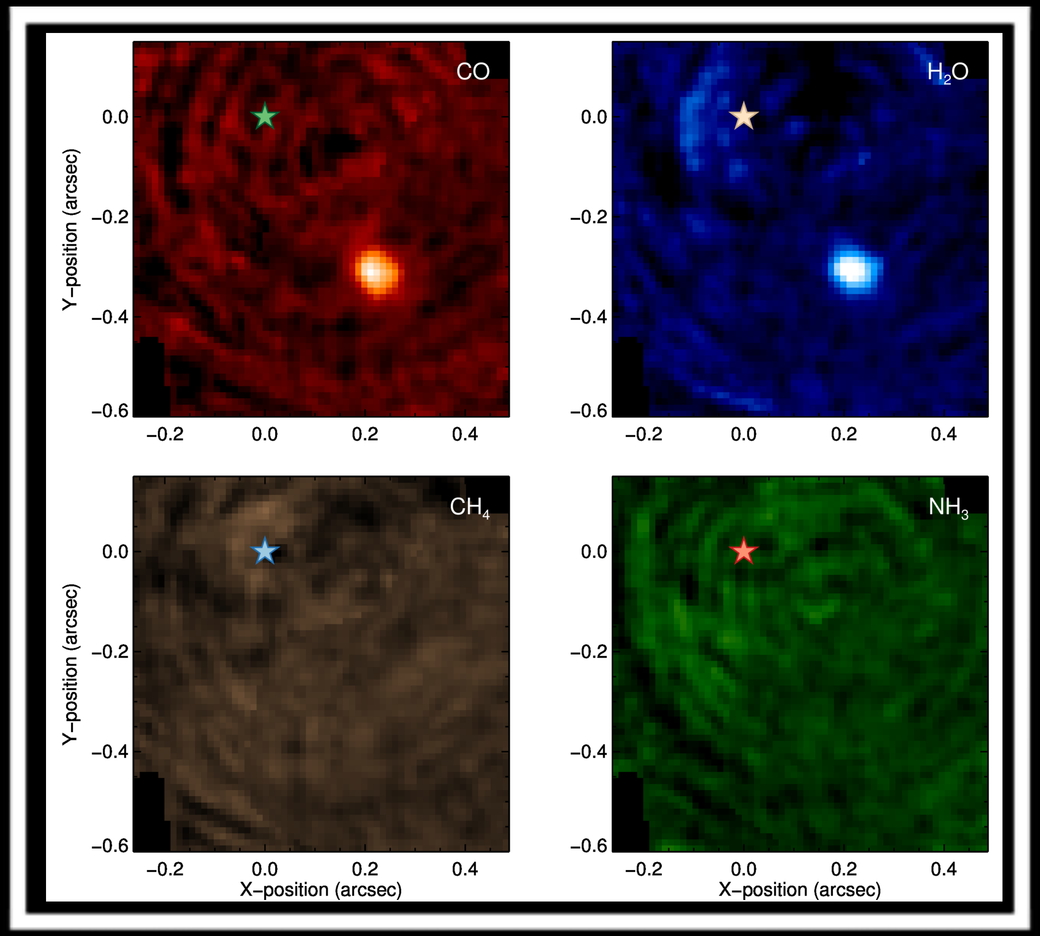
ESO PR0842

ESO PR1024

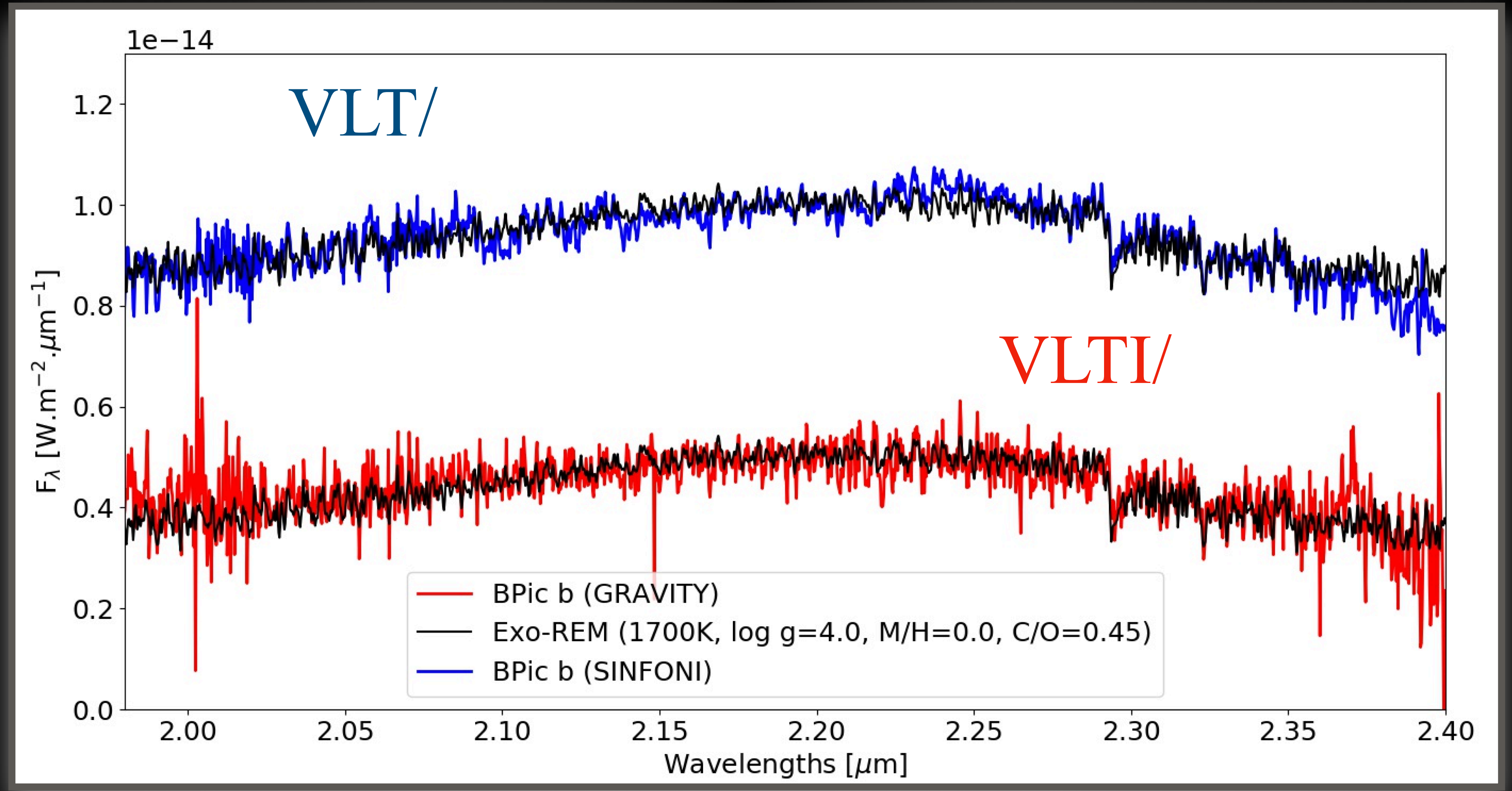
Lagrange/Boccaletti/Chomez

VLT/SINFONI

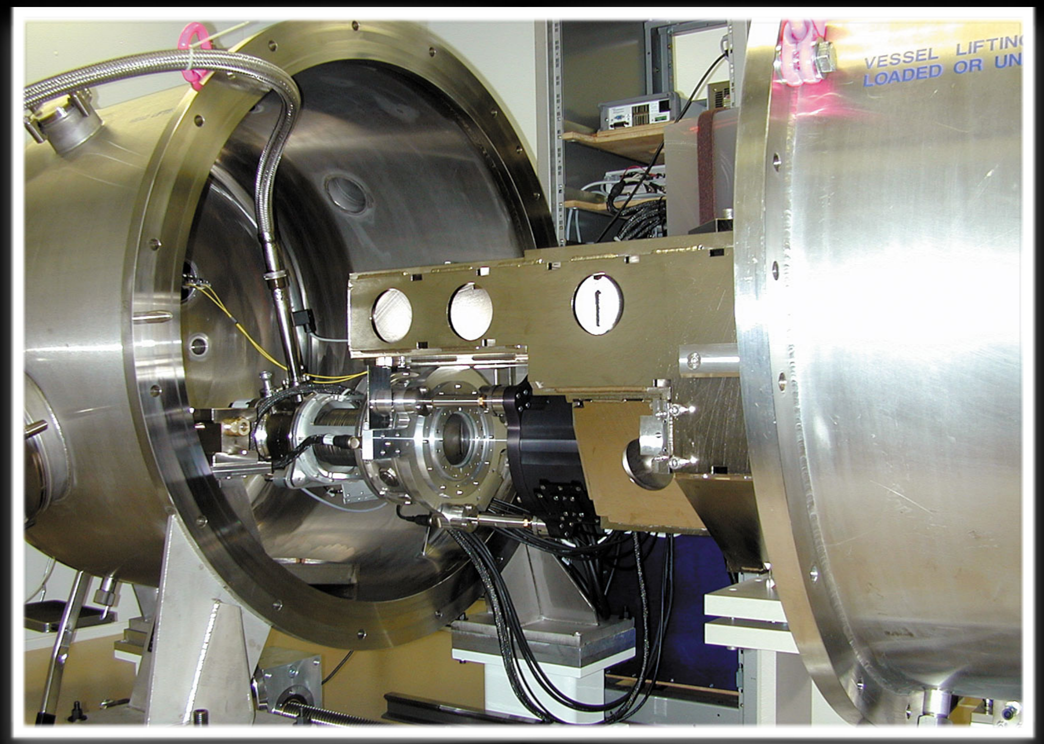
Correlation techniques



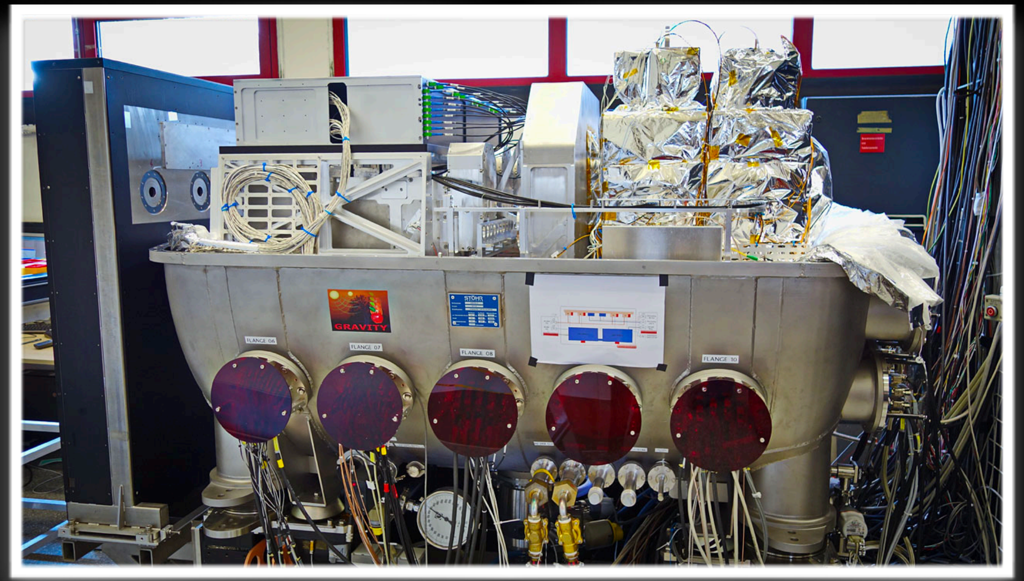
Hoeijmaker+, 2018



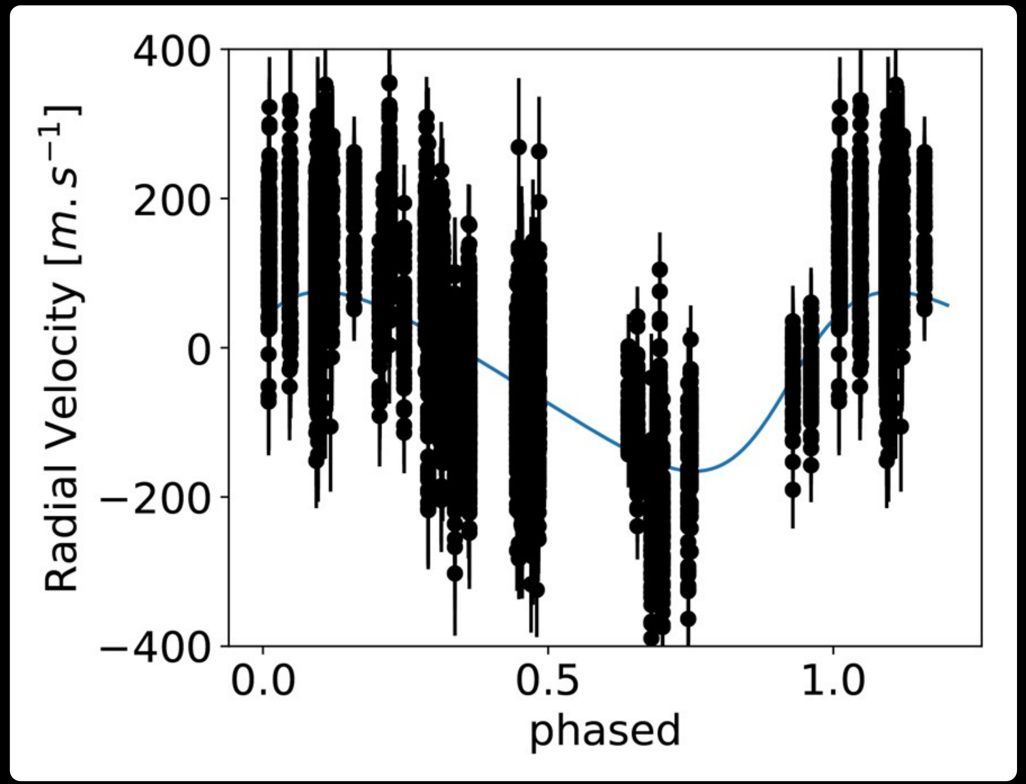
Bonnefoy et al, in prep. Nowak et al, 2020



Beta Pictoris bc



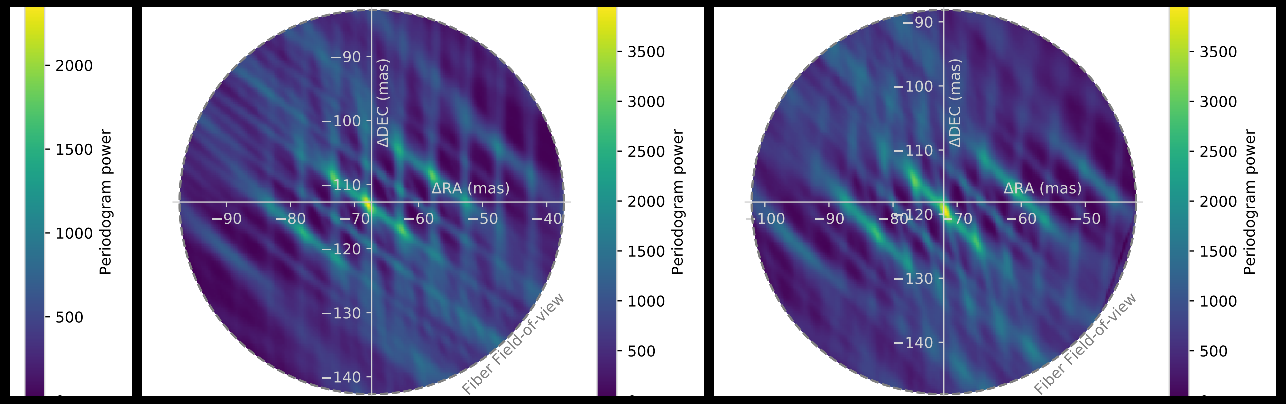
HARPS



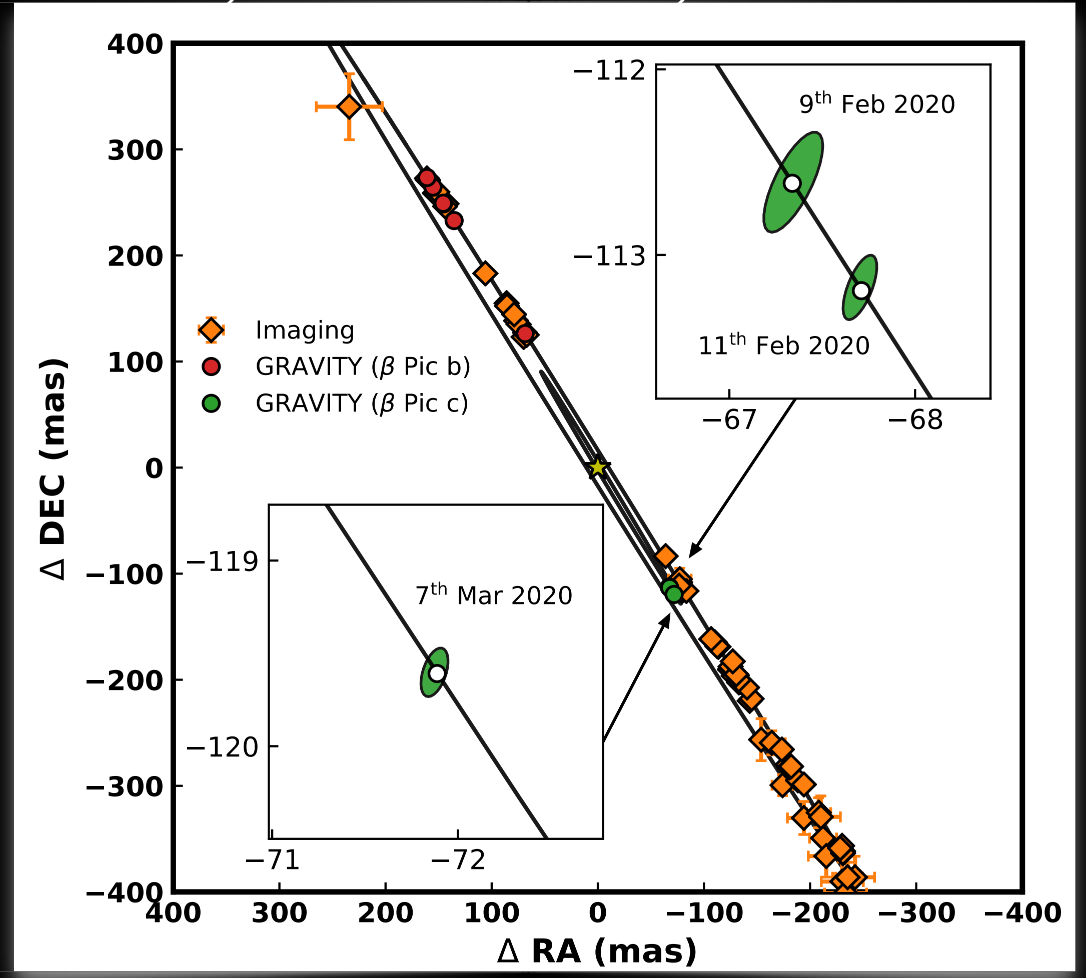
B Pic c
M ~ 9 M_{jup}
Sep = 2.7 AU
20 Myr

Lagrange et al, 2019

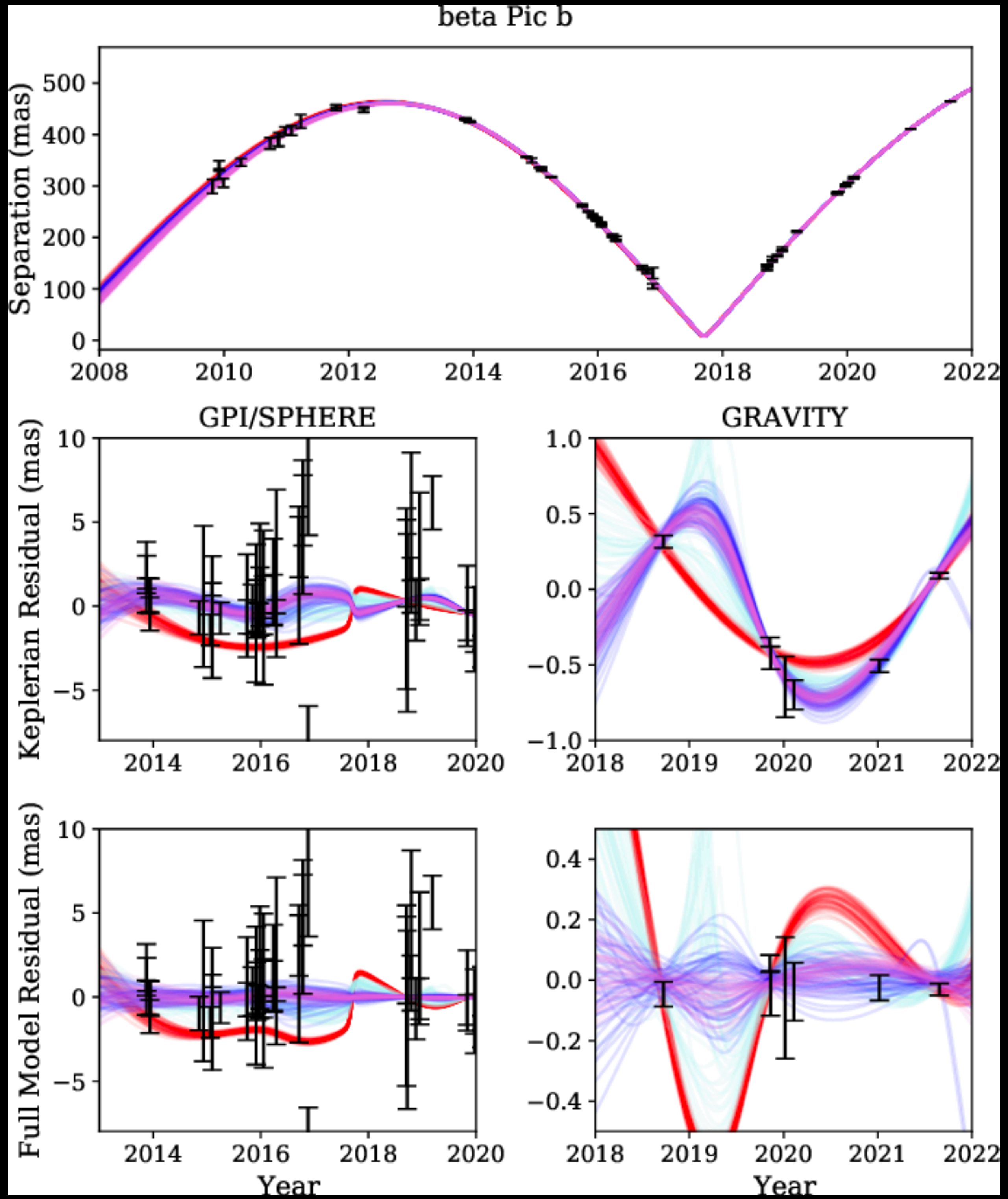
VLTI/GRAVITY



Full modeling:
HARPS, NACO, SPHERE, GRAVITY, Gaia



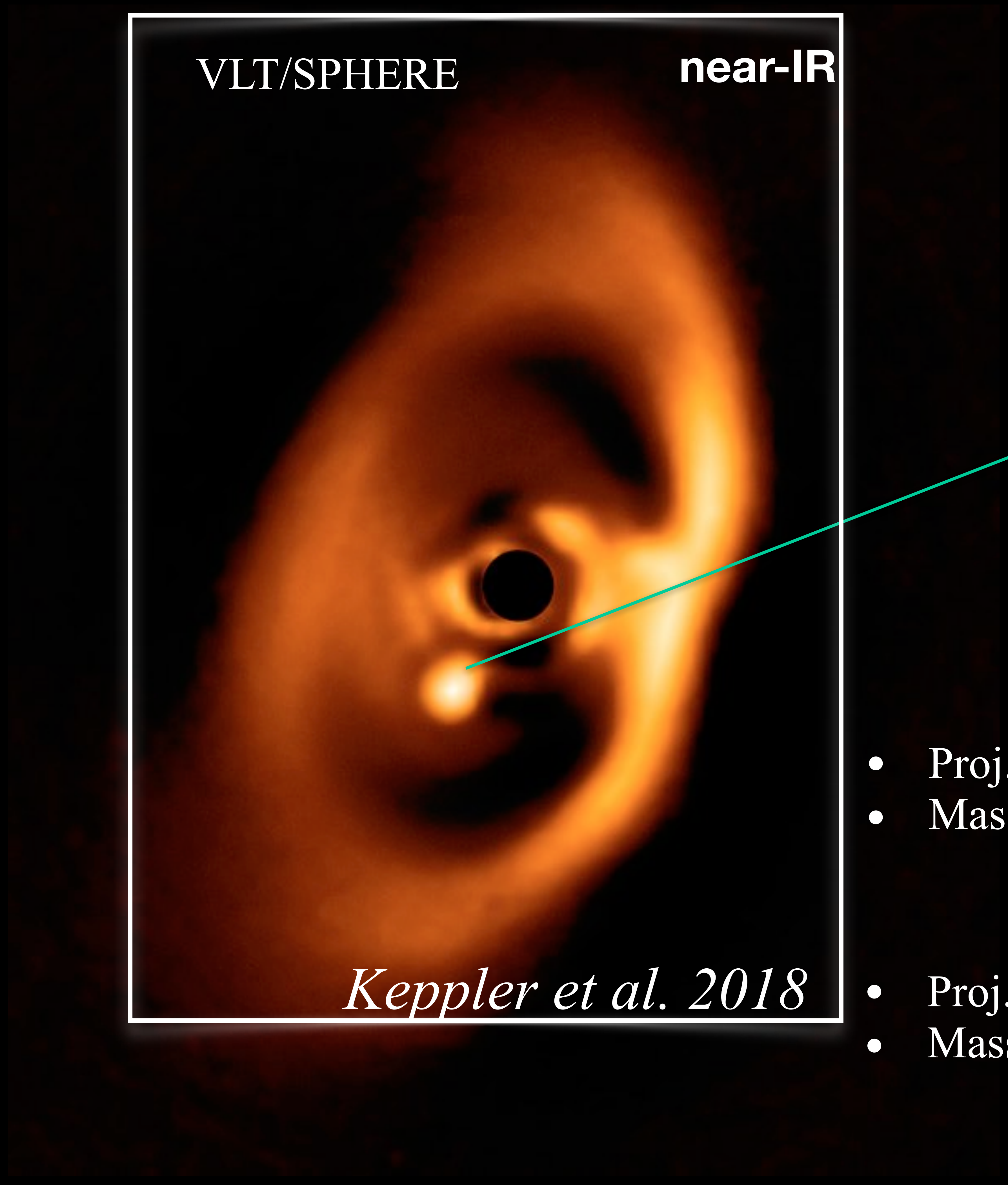
Nowak et al, 2020
Lagrange et al, 2020



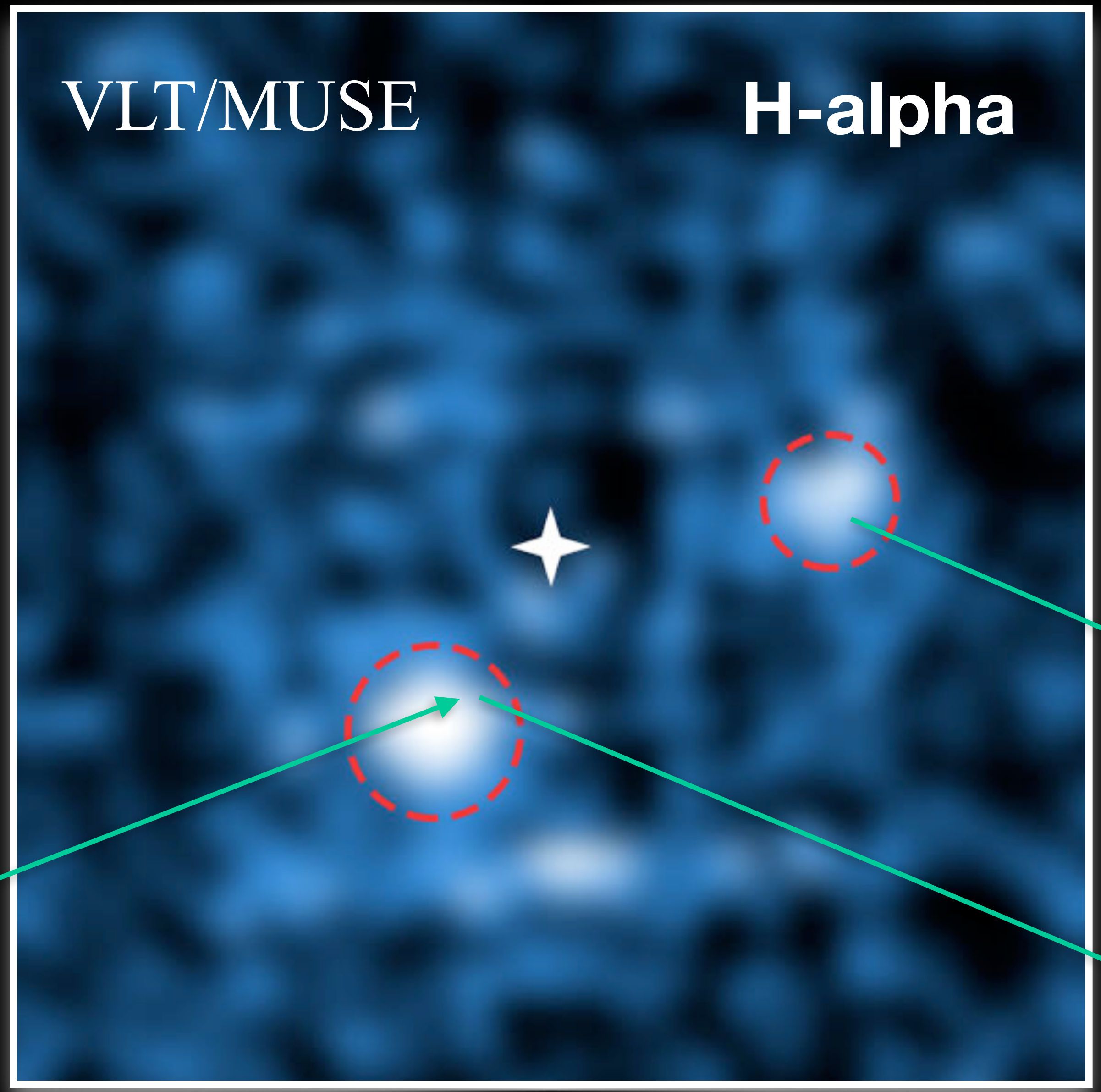
Dynamical mass of bPic c

Lacour et al, 2021

PDS 70 : a young (5Myr) forming planetary system



Keppler et al. 2018



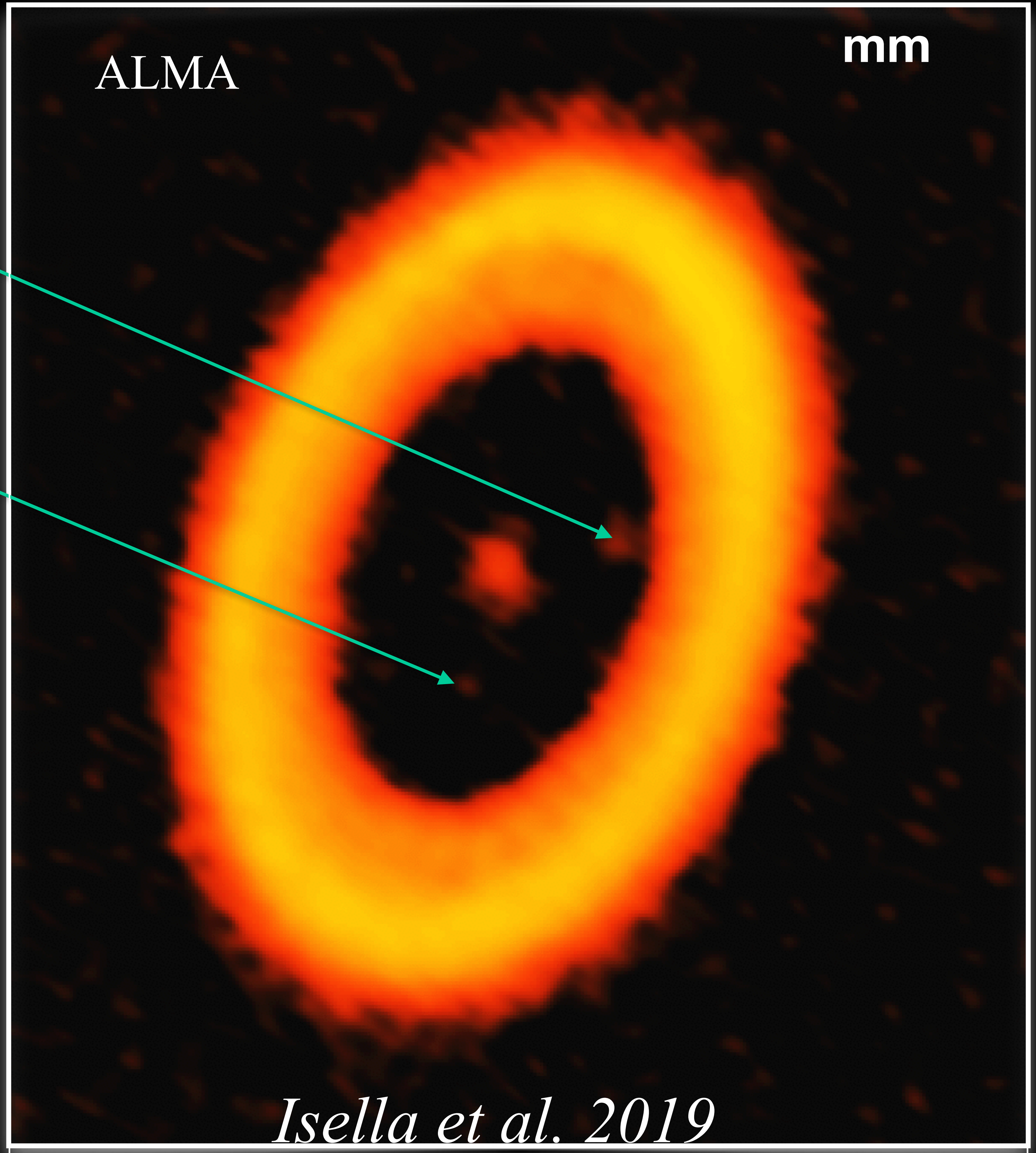
Haffert et al. 2019

PDS 70b

- Proj.sep. ~ 25 au
- Mass = 5-10 M_{Jup}

PDS 70c

- Proj. sep. : ~30 au
- Mass = 3-5 M_{Jup}



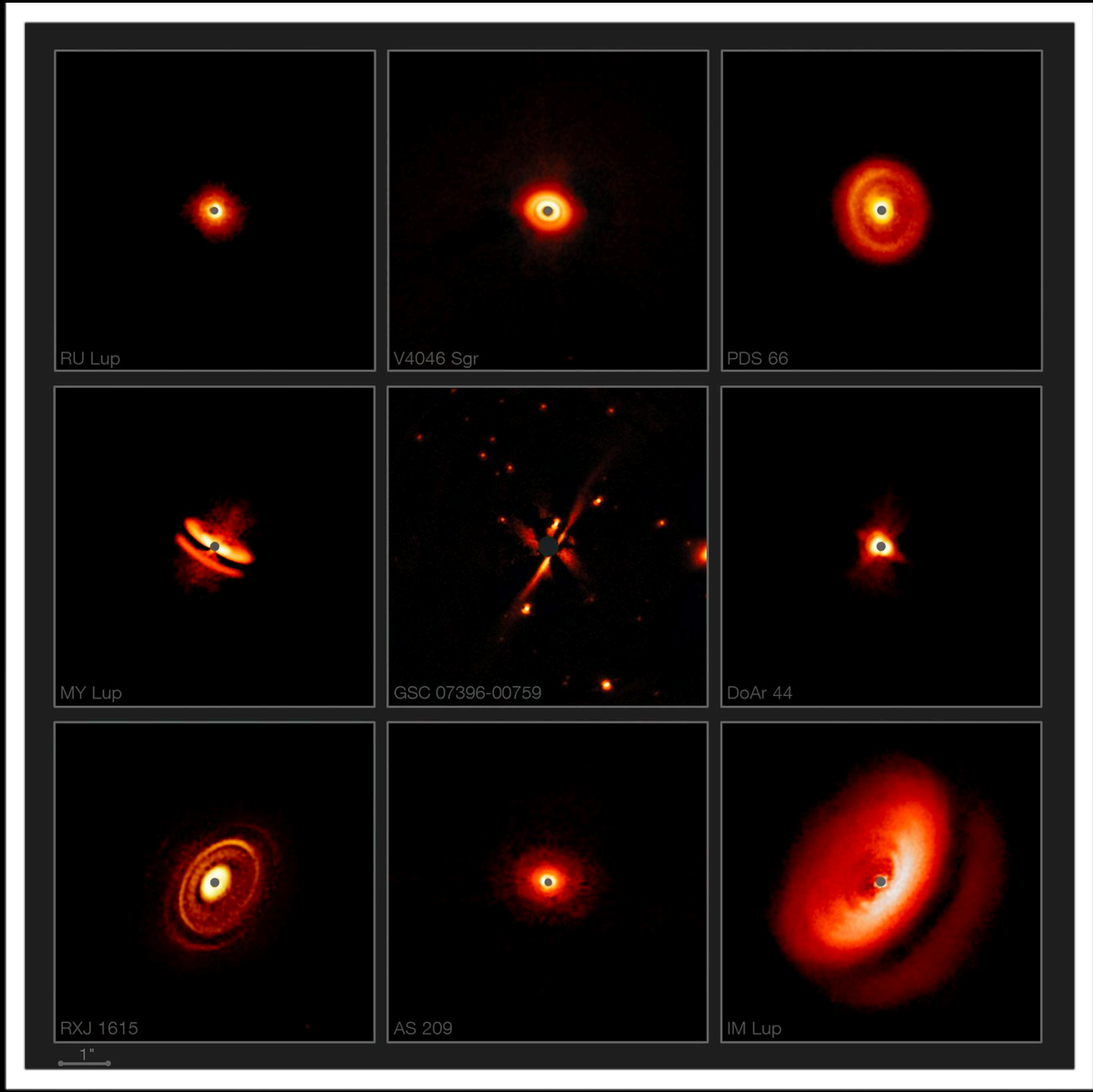
Isella et al. 2019

See also Benisty et al, 2021 ESO PR 2111

- Orbital configuration consistent with the planets in a 2:1MMR (GRAVITY, Wang et al, 2021)

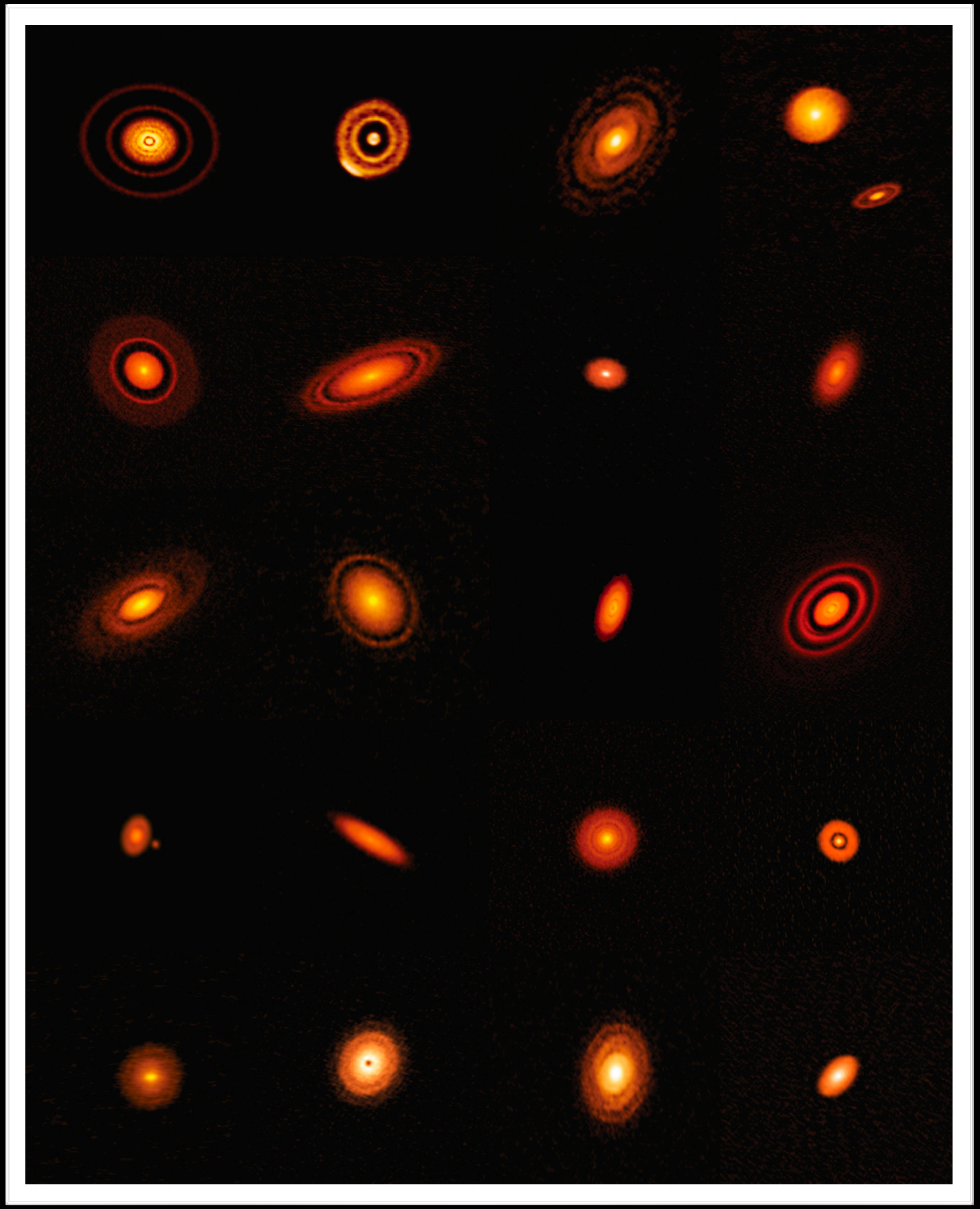
Structures of proto-planetary disks

SPHERE



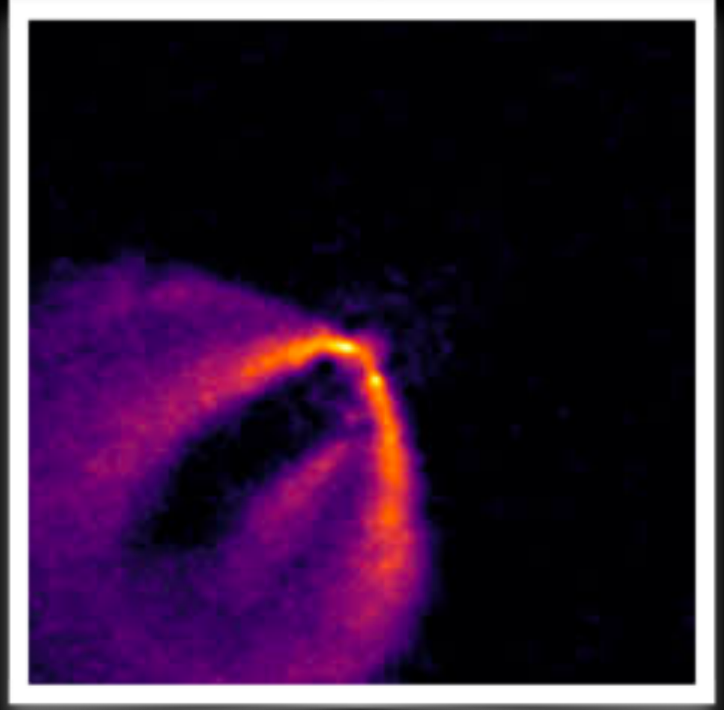
Avenhaus et al, 2018
Sissa et al, 2018 ESO PR1811

ALMA



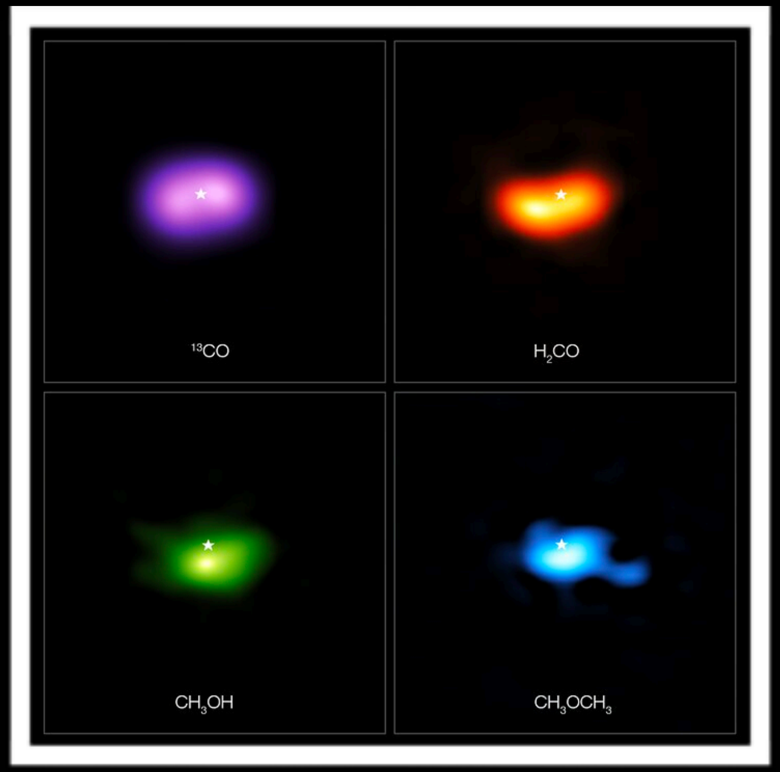
Andrews et al, 2018

Signposts of planets



Pinte et al, 2019, 2020

Complex organic molecules



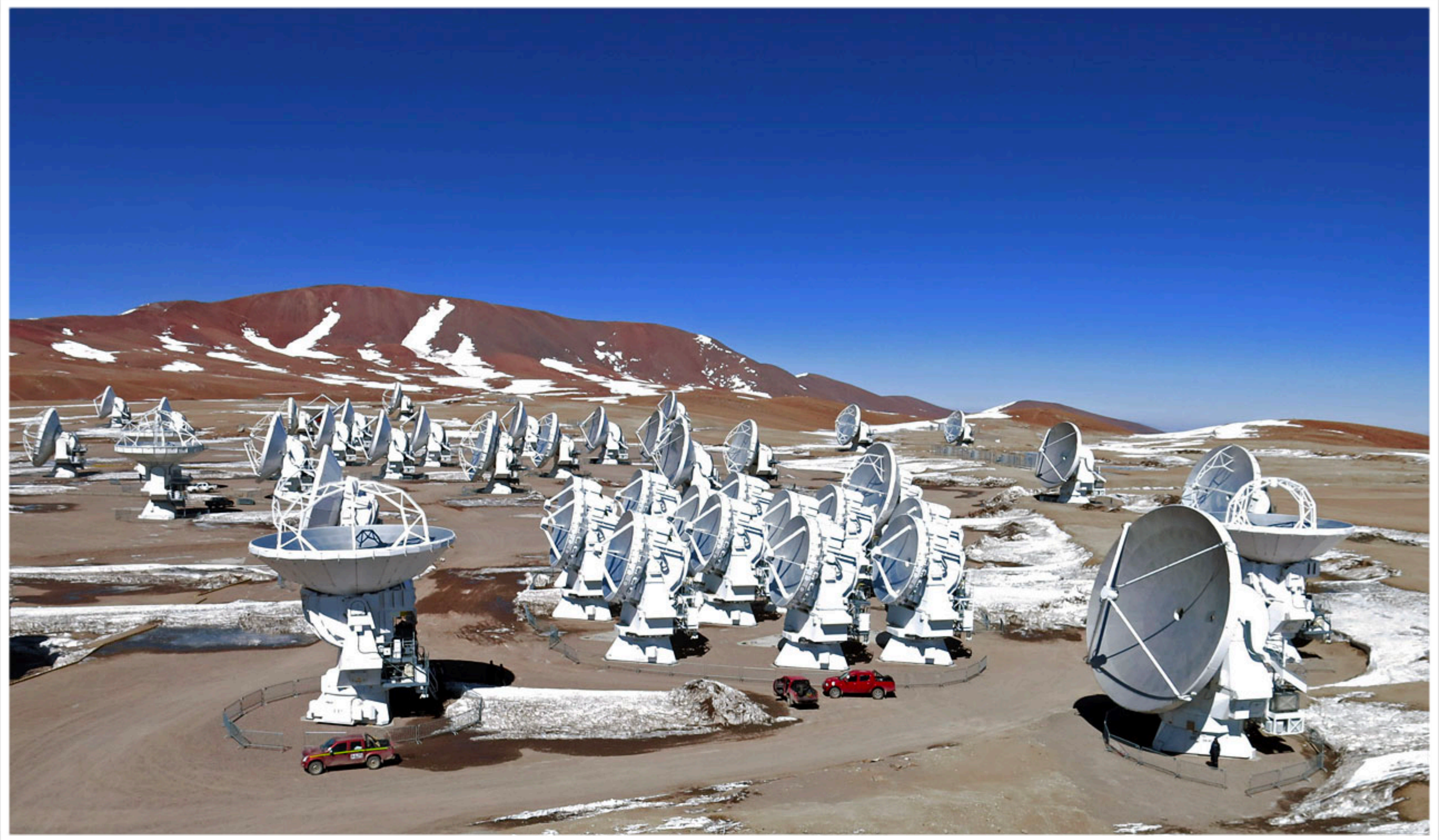
Brunken et al. 2022 ESO PR2205

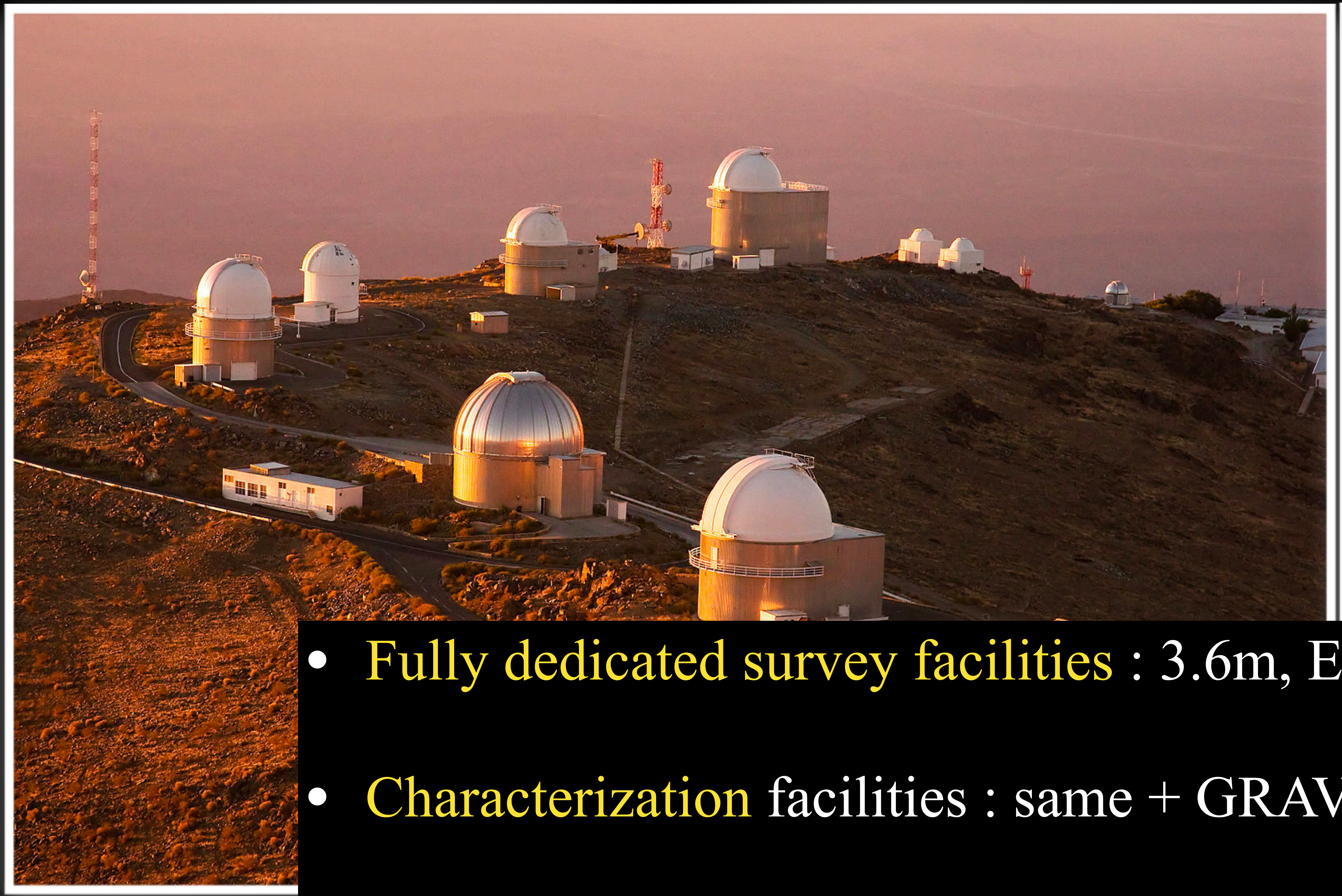
Exoplanetary systems
The future

ESO is now at the forefront of exoplanetology

Many questions remains

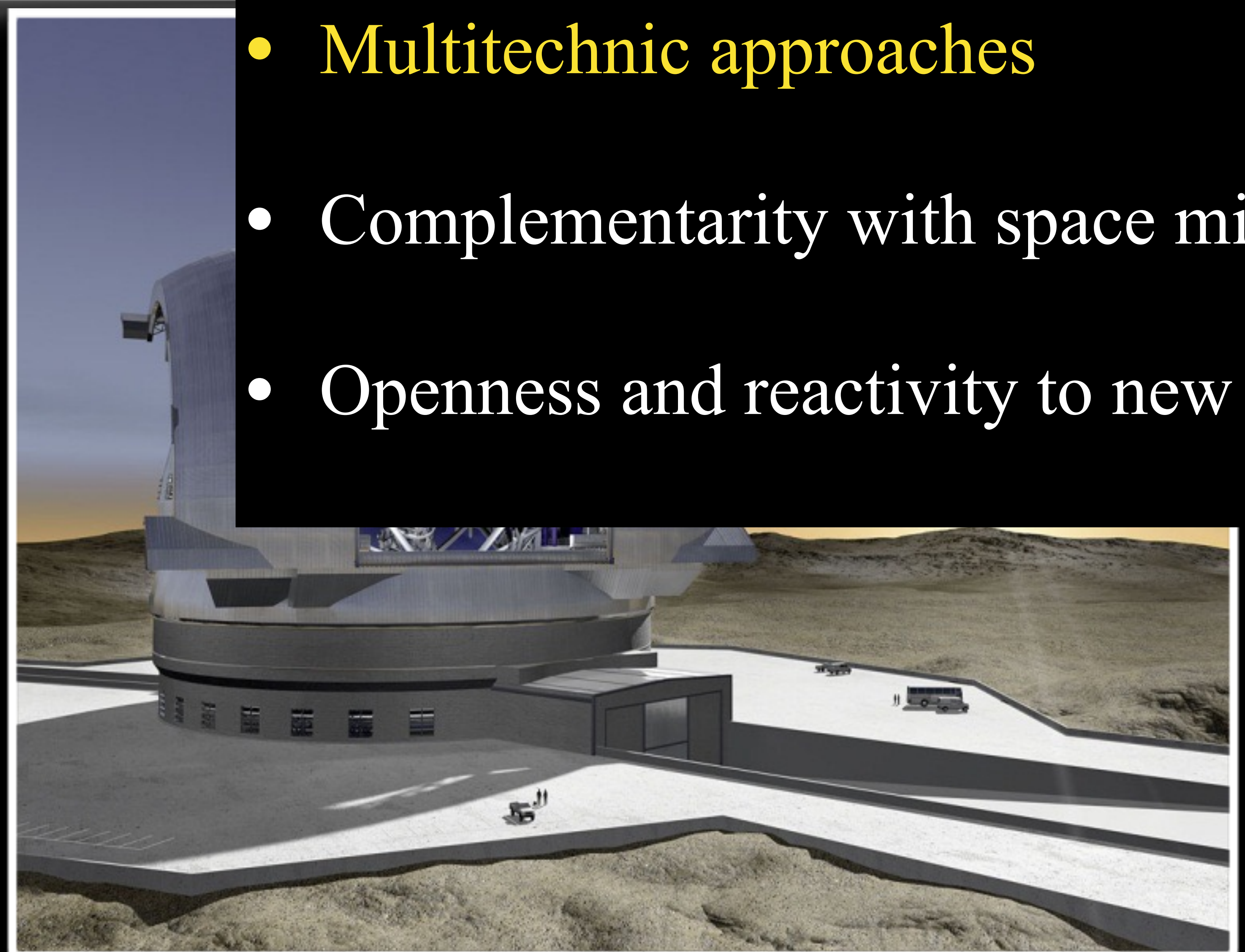
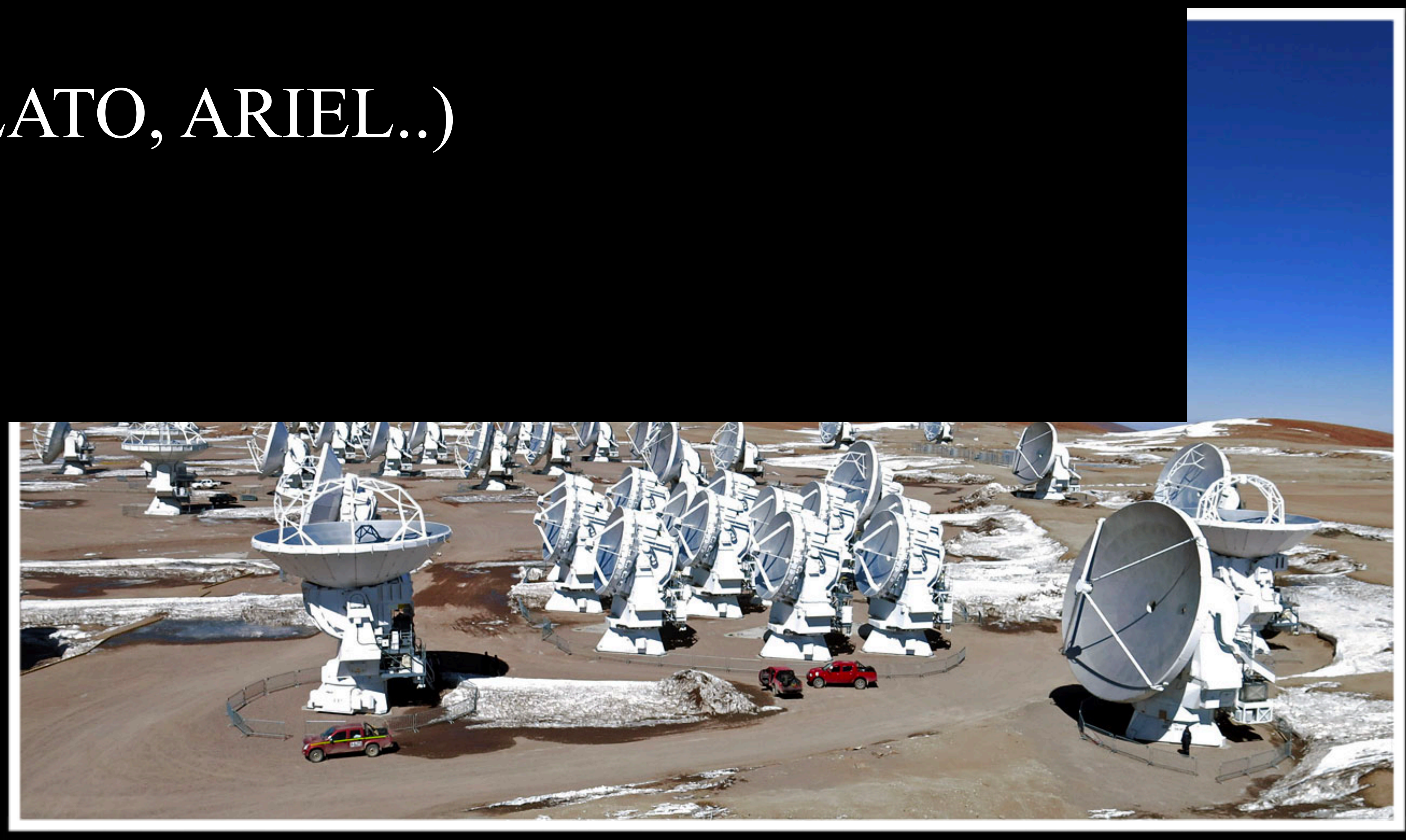
- Detail of planetary formation processes
- Diversity of extrasolar systems. Is the Solar System unique/rare ?
- How to find Earth twins ? Signatures of life ?

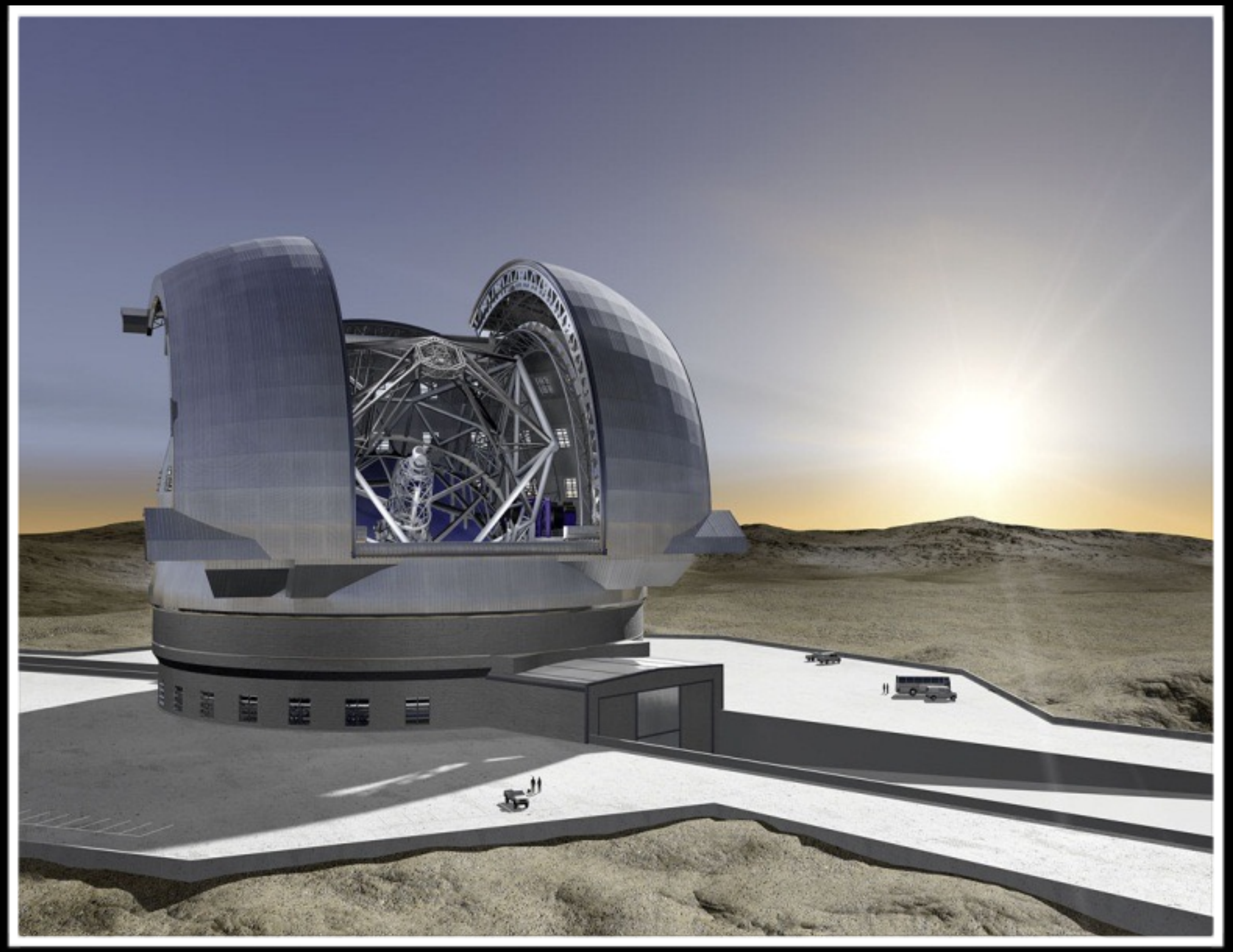





A way forward

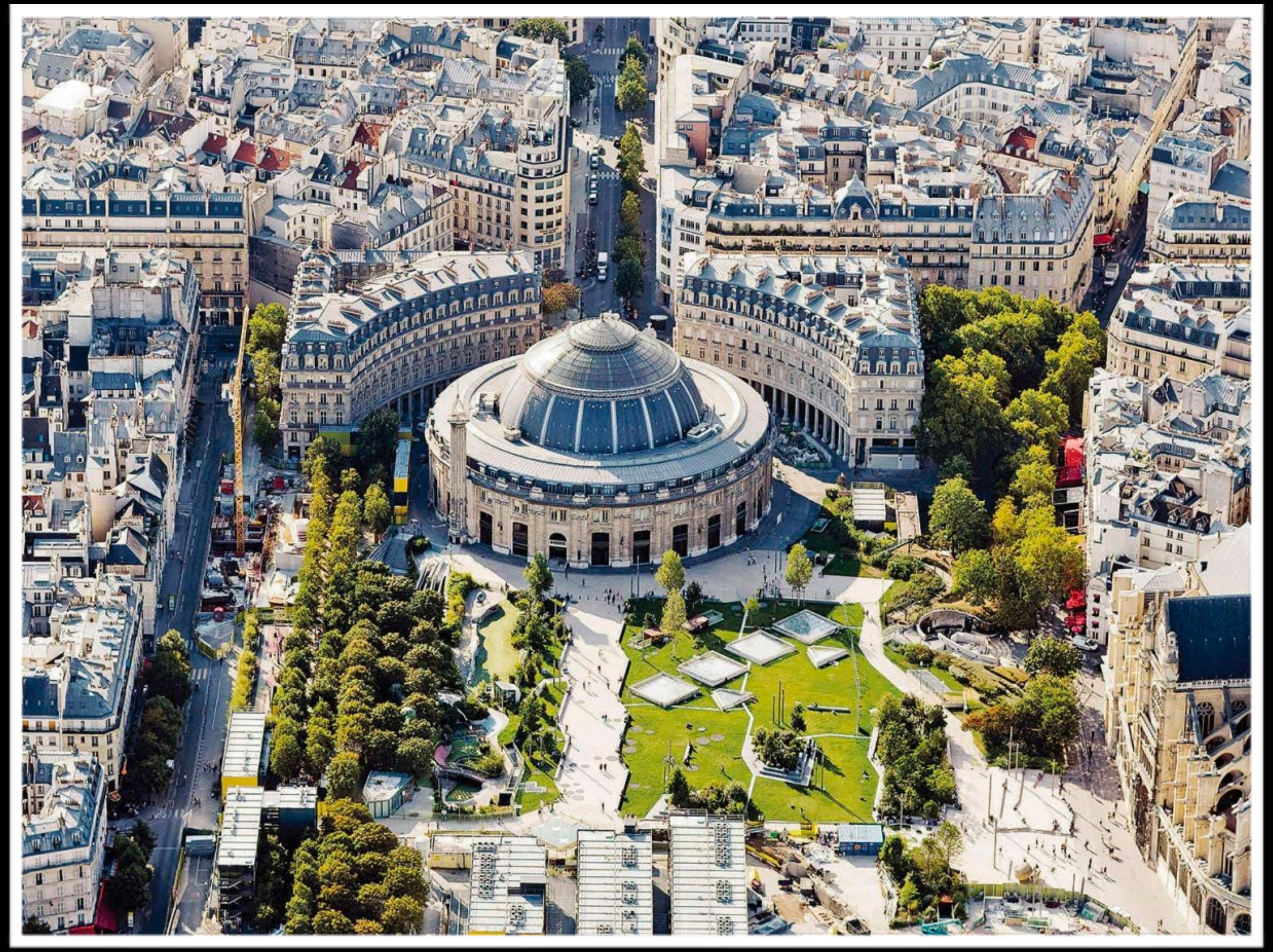
- Fully dedicated survey facilities : 3.6m, ESPRESSO, SPHERE(+), ERIS (?)
- Characterization facilities : same + GRAVITY(+), CRIRES+, + ELT (MICADO, HARMONI, METIS)
- Multitechnic approaches
- Complementarity with space missions (Gaia, TESS, JWST, PLATO, ARIEL..)
- Openness and reactivity to new ideas



ELT (39 m)

MICADO, HARMONI,METIS, PCS



Bourse du commerce, Paris (38m)