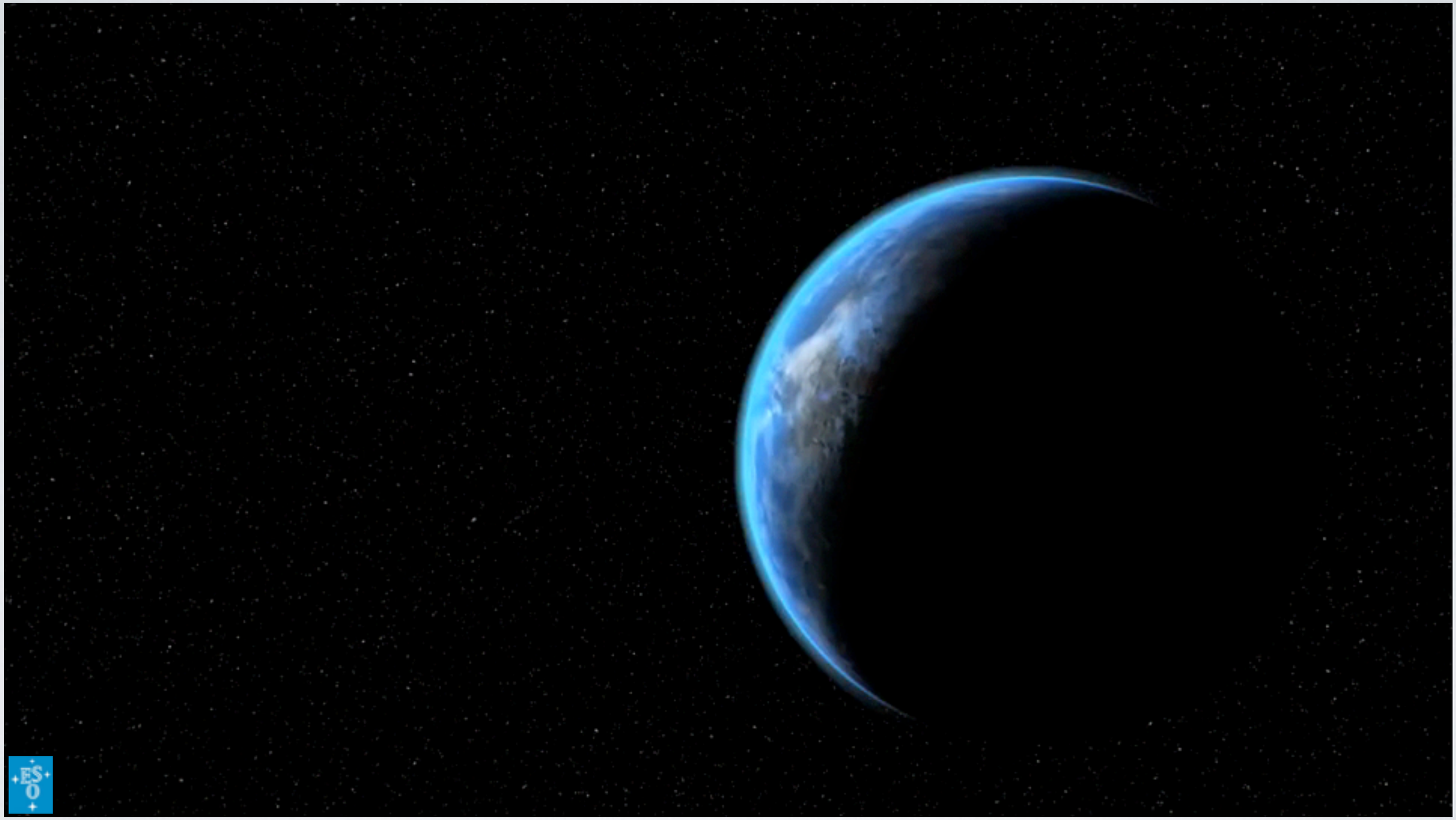
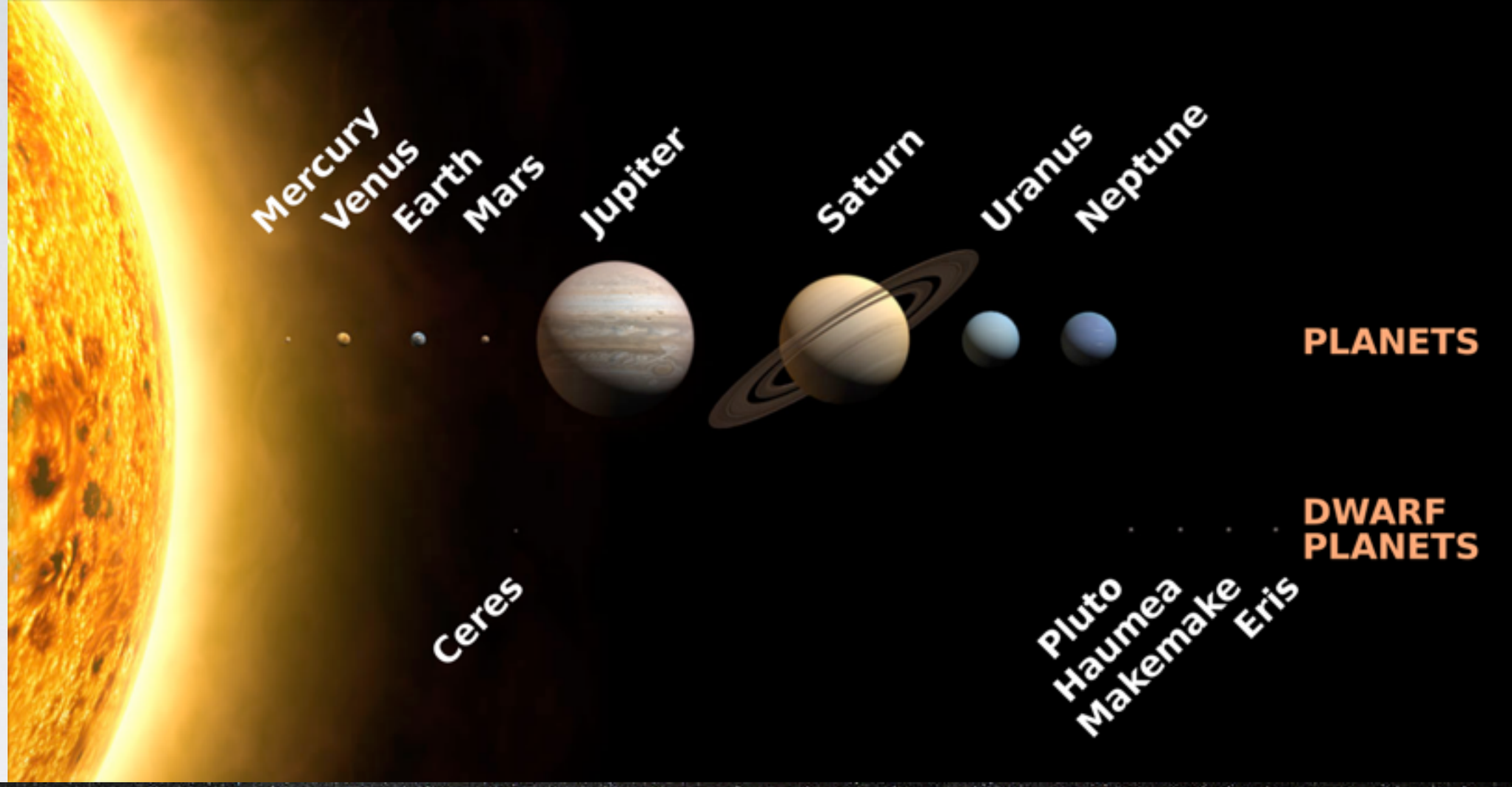
LA RECHERCHE D'EXOTERRES

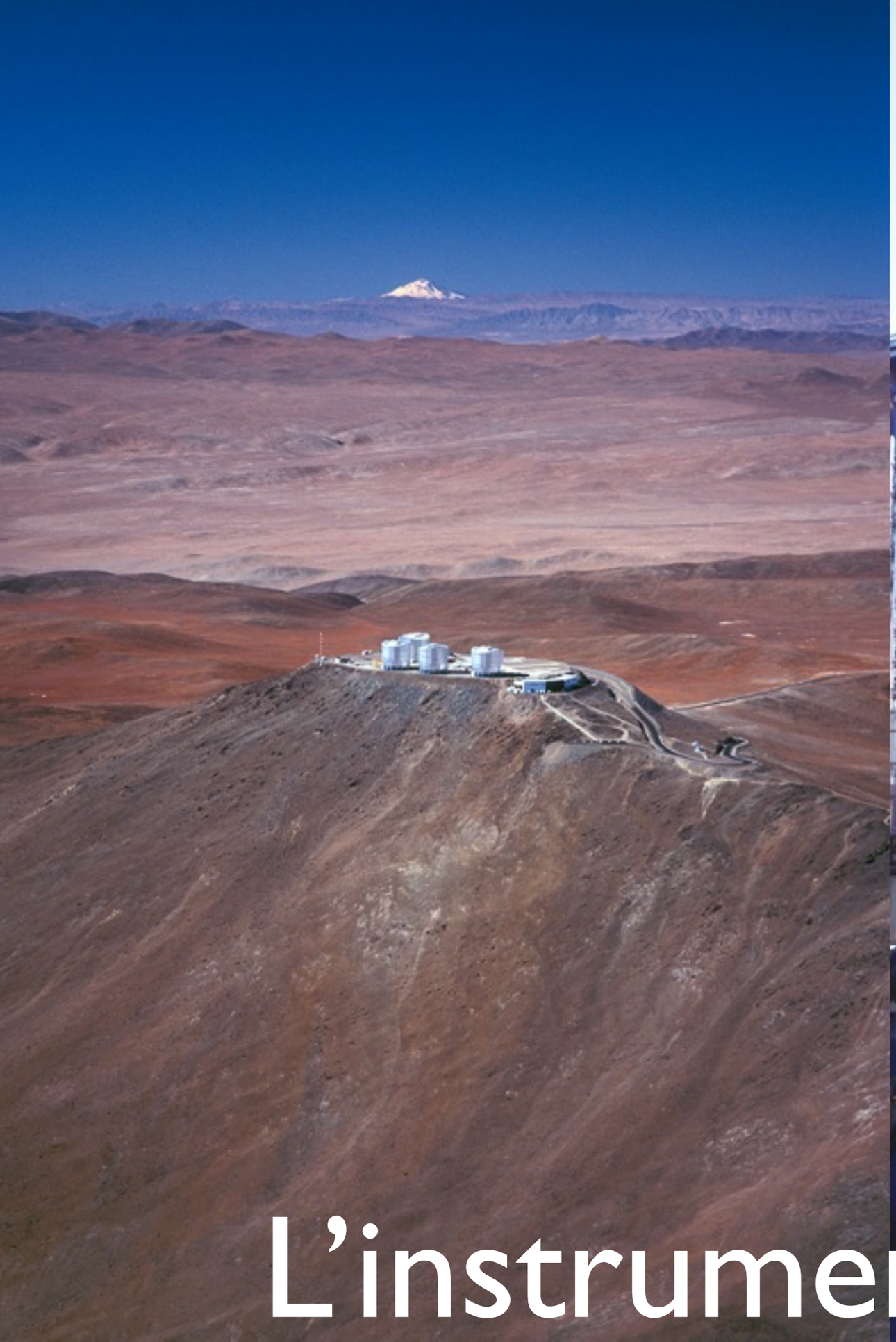


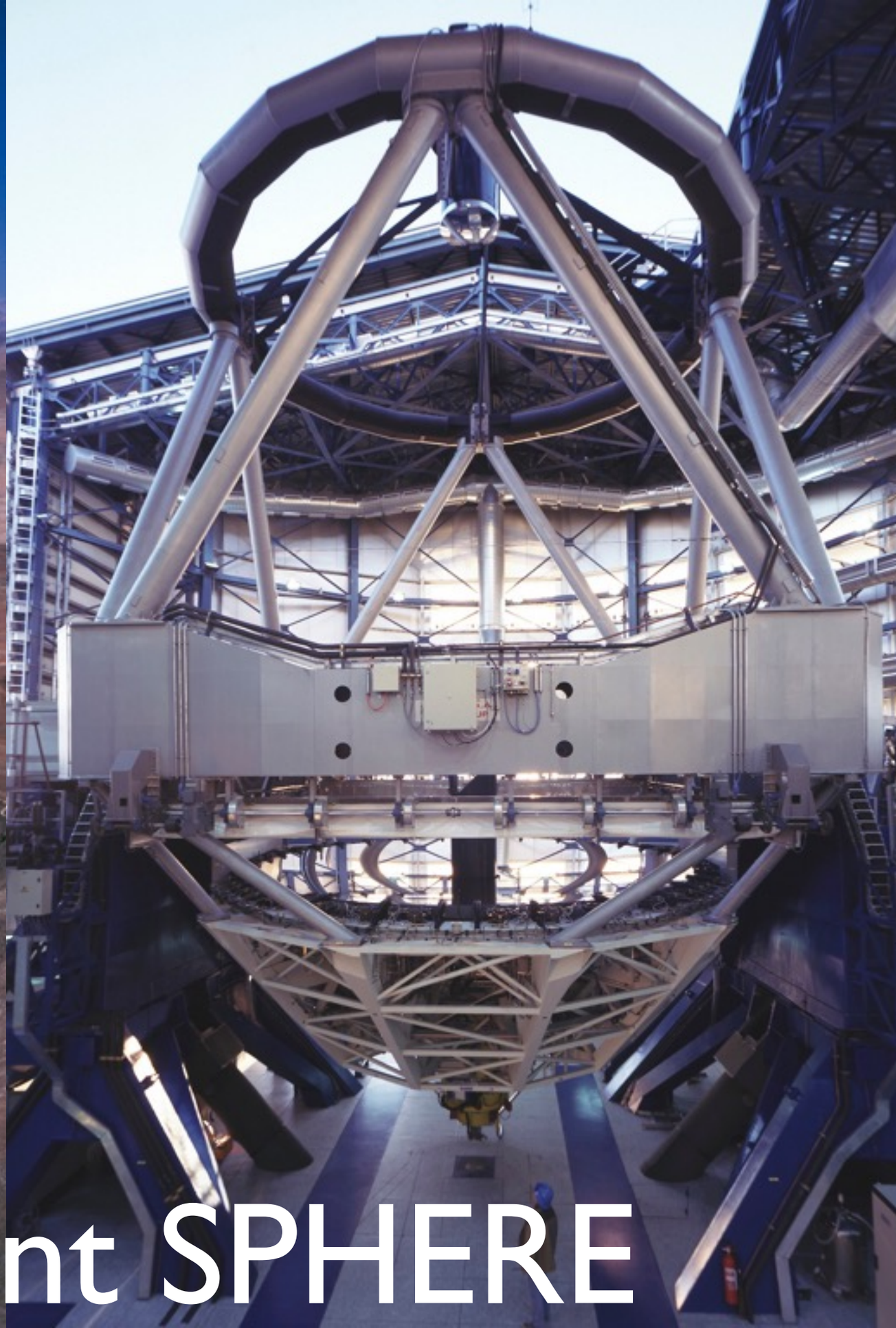
Présentateur : Xavier Bonfils **IPAG (CNRS, Grenoble)**

(Exo-) Planète ?

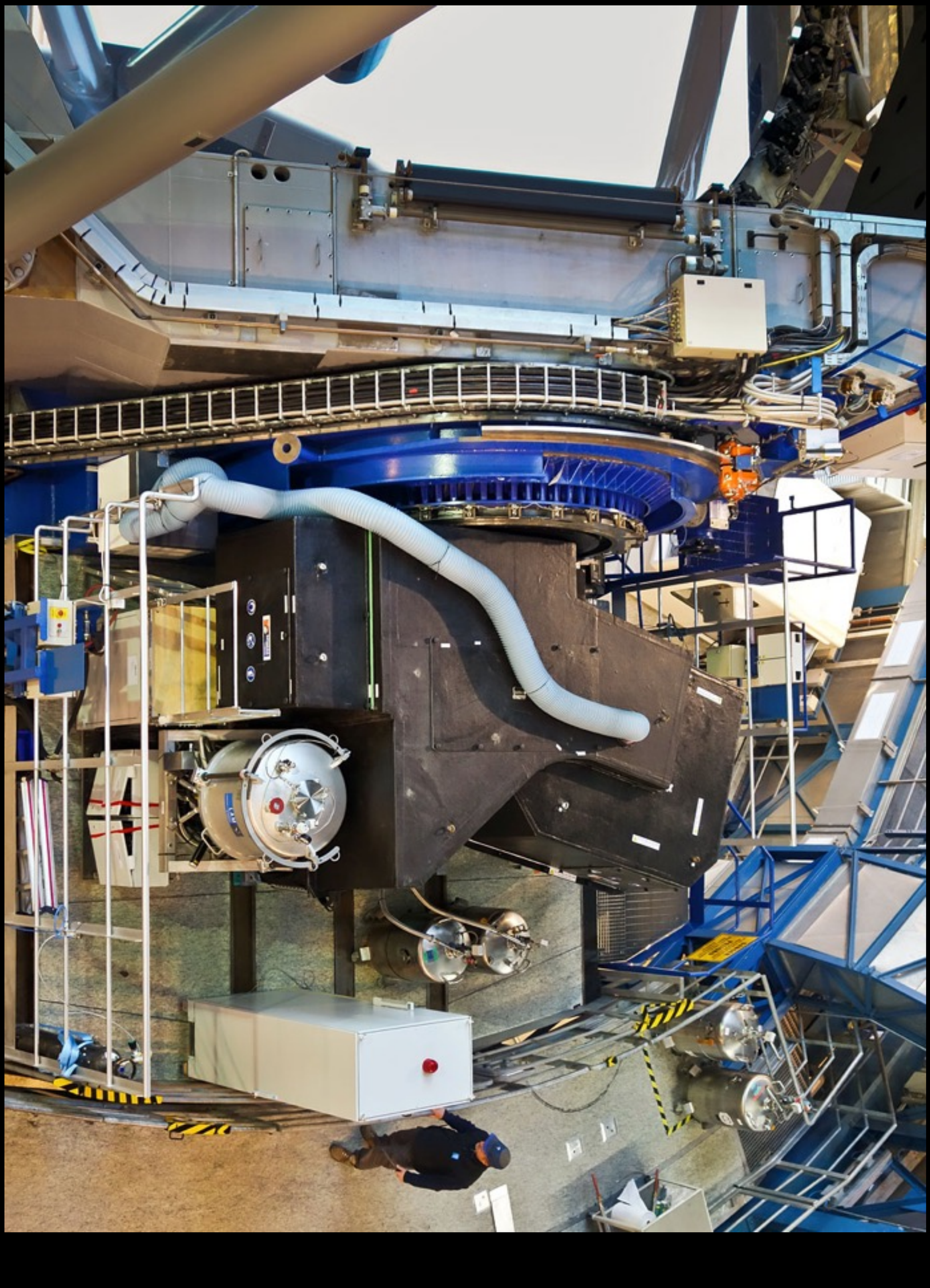

Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
PLANETS
DWARF PLANETS
Ceres
Pluto
Haumea
Makemake
Eris

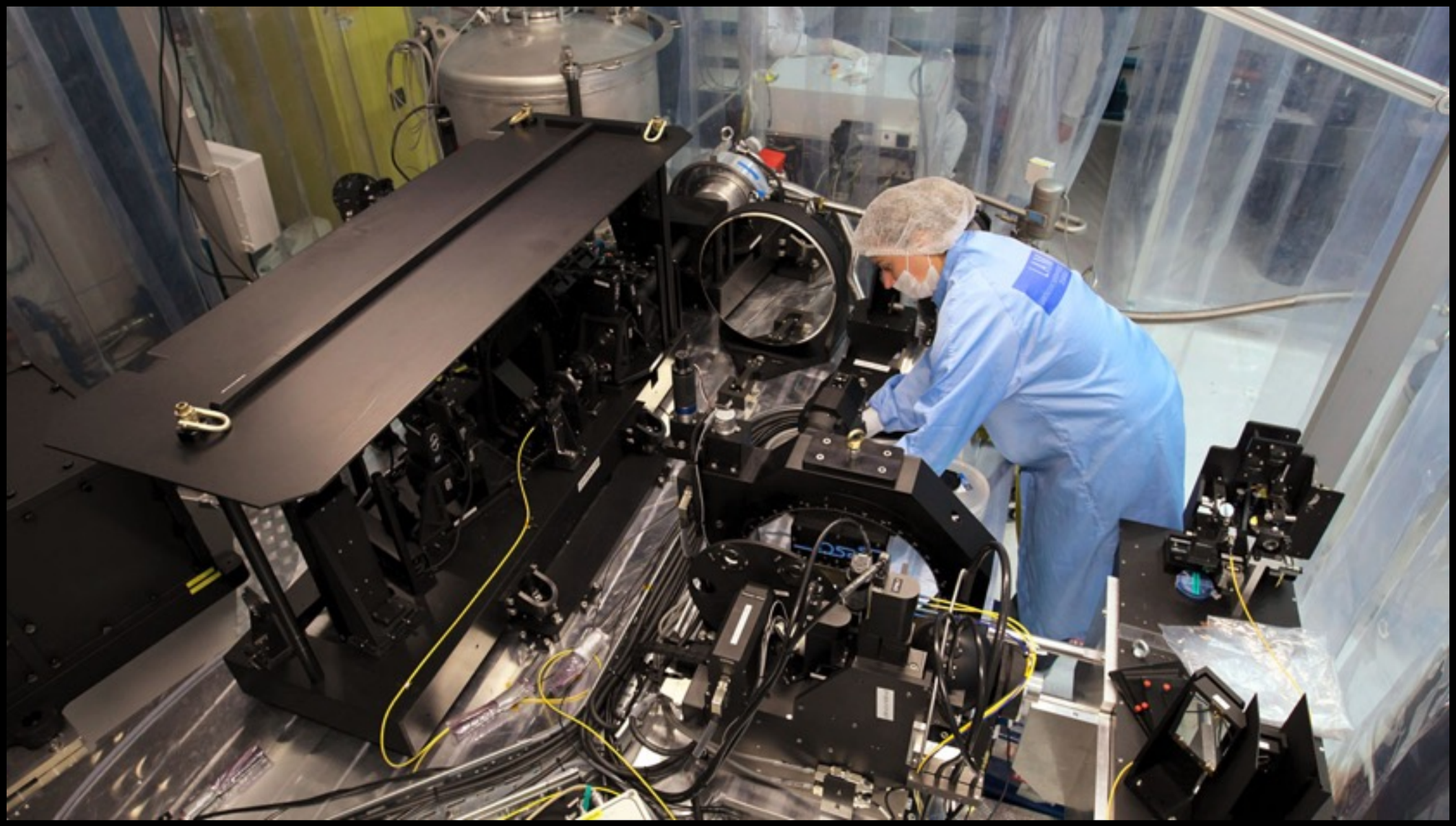
ici



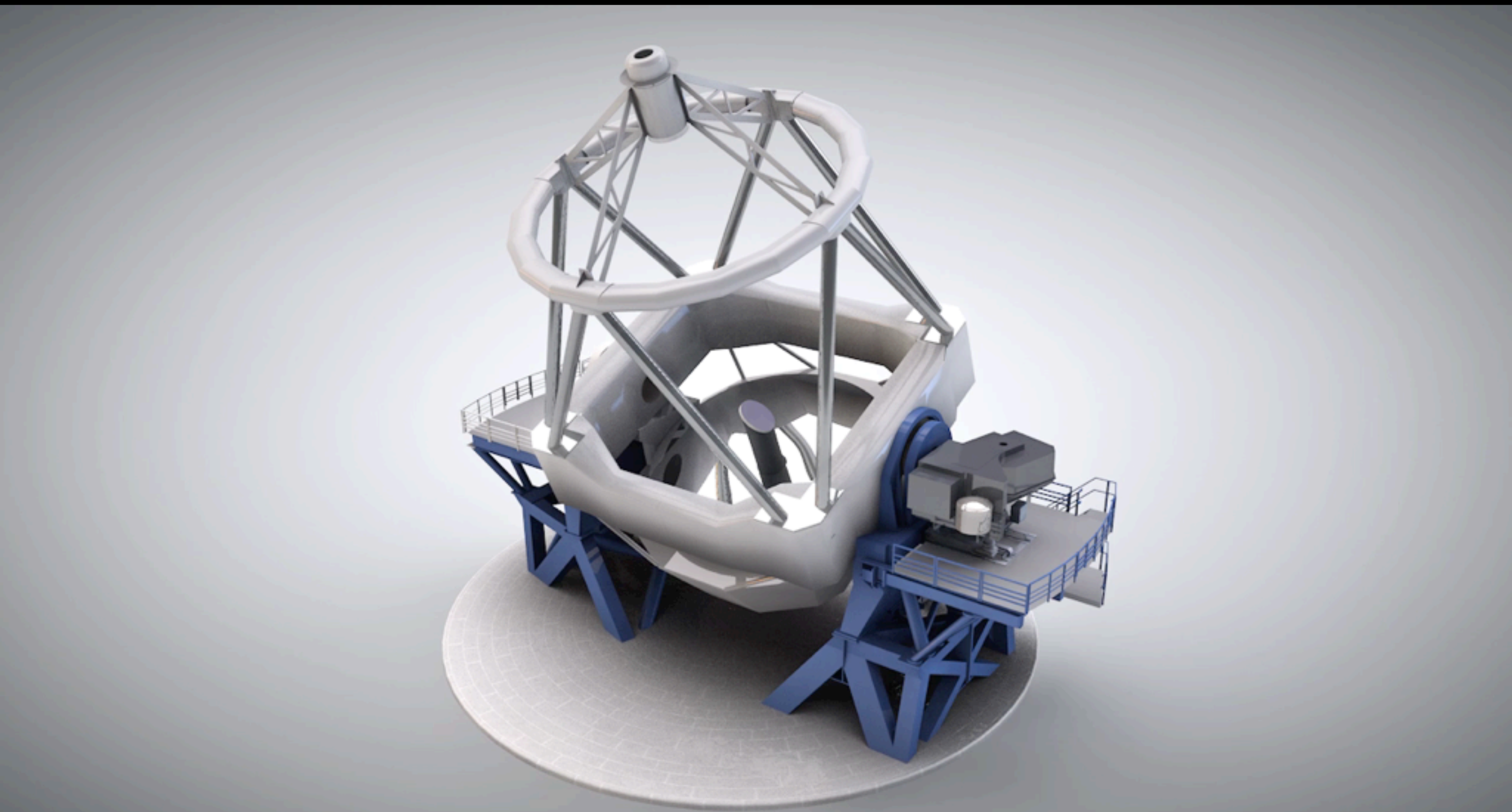


L’instrument SPHERE

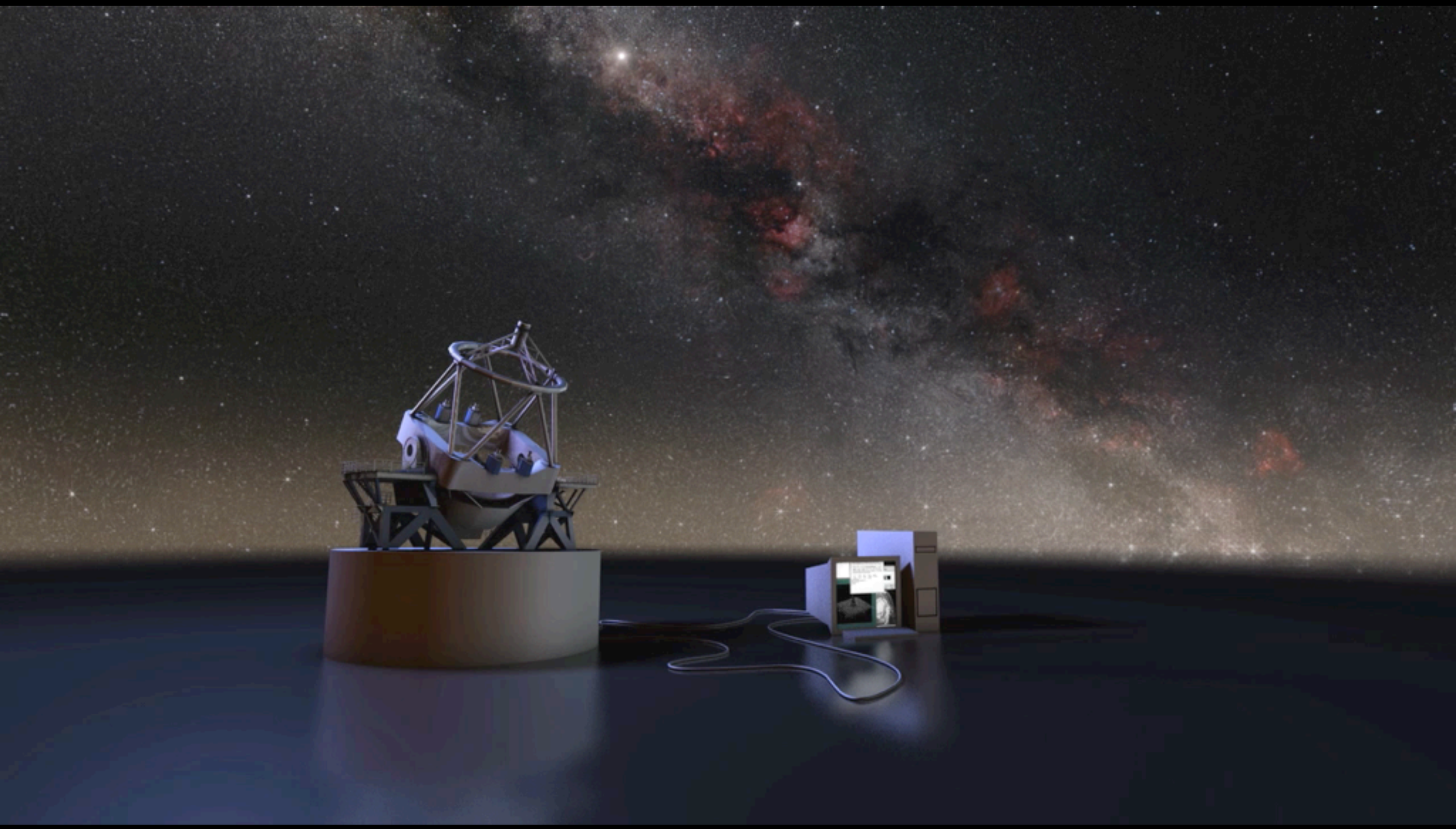




L’instrument SPHERE

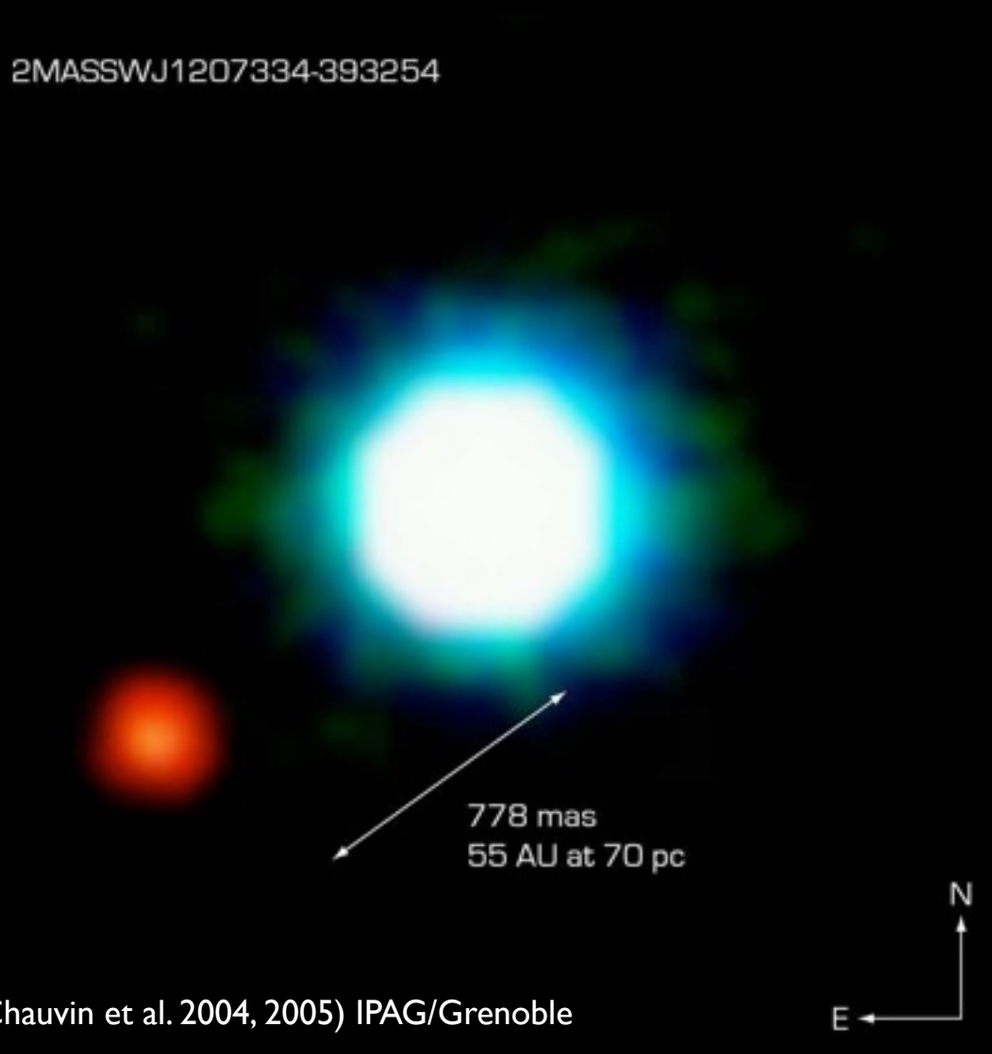


L’instrument SPHERE

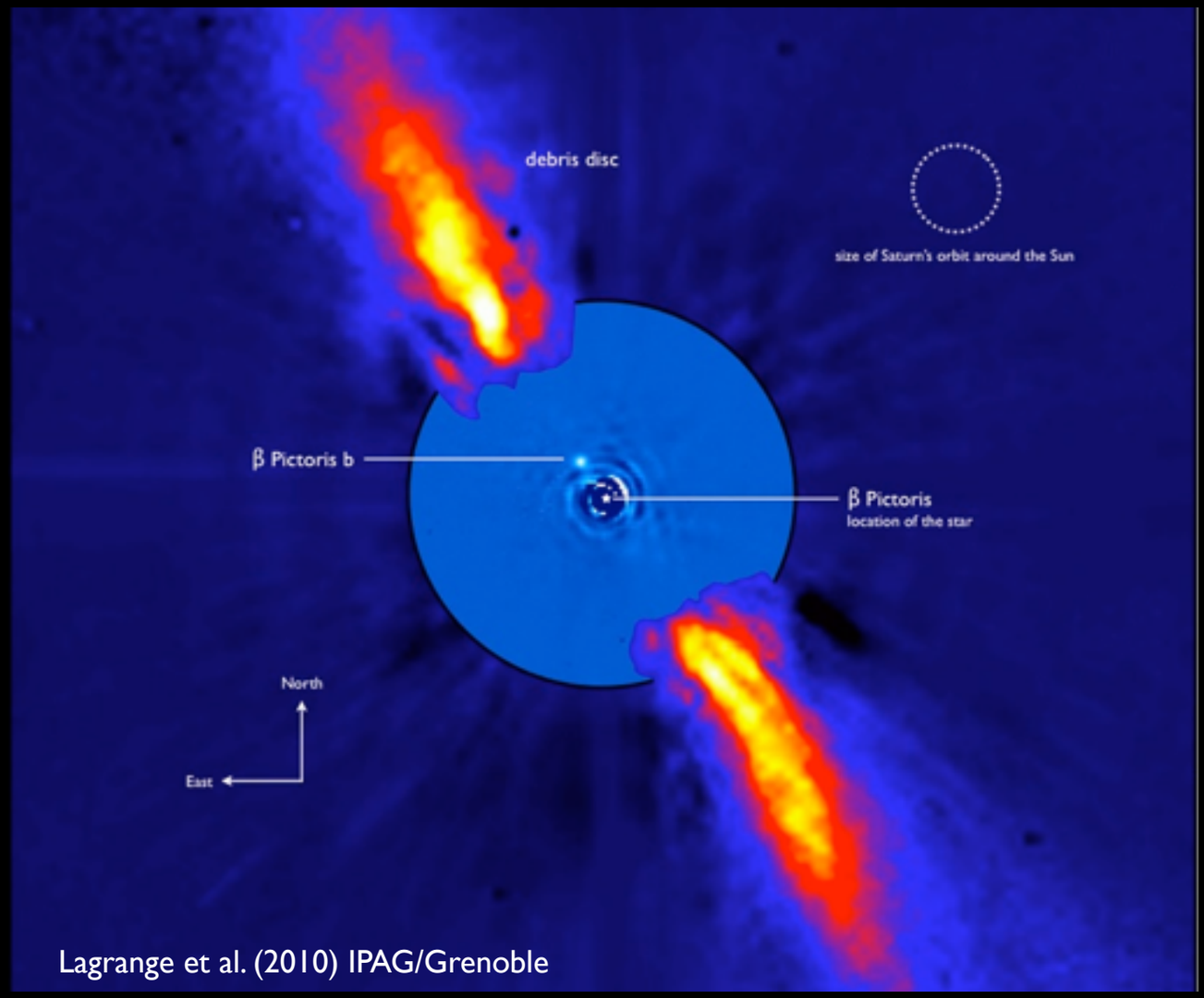


L’instrument SPHERE

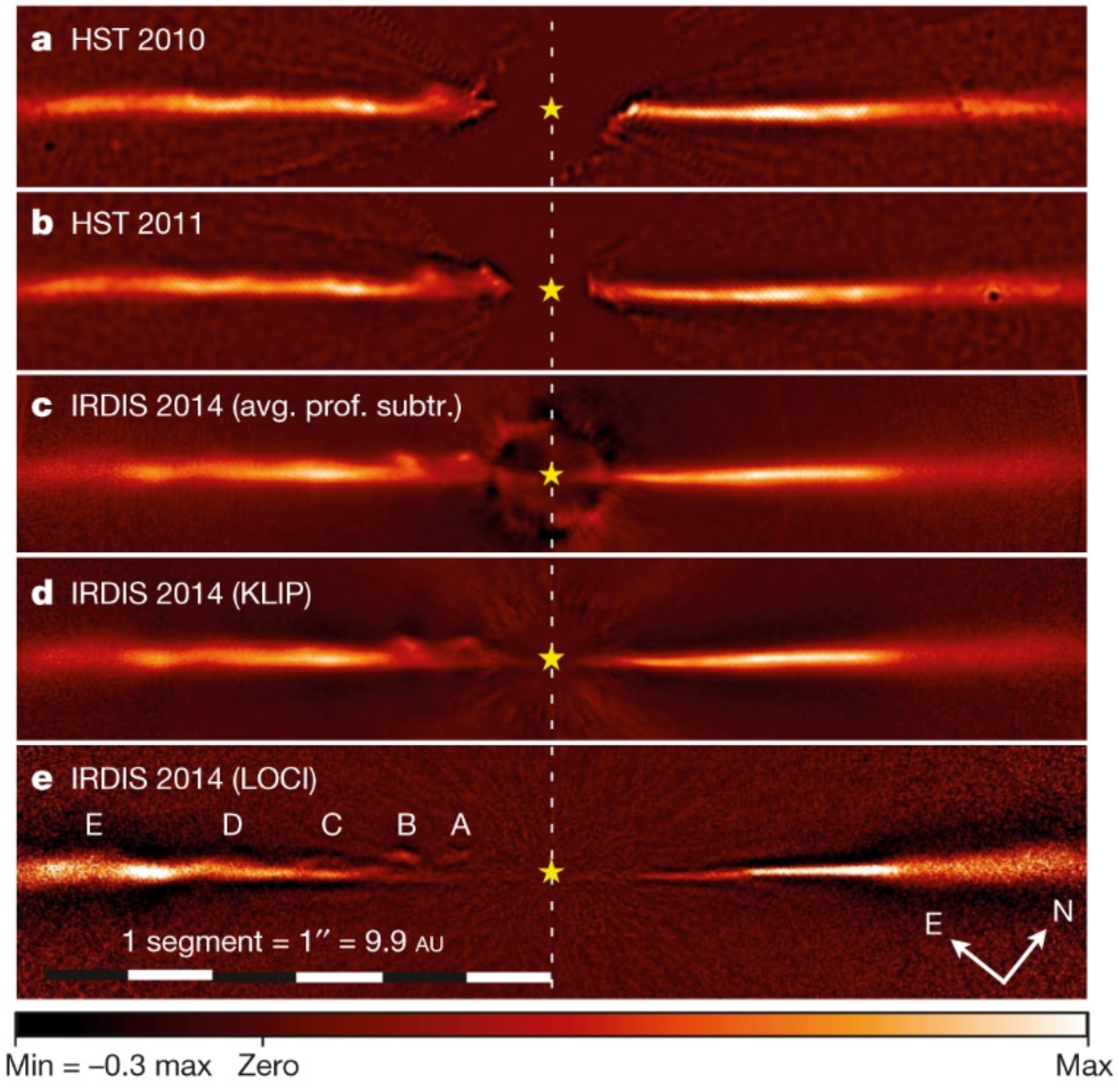
Prendre une photo



(Chauvin et al. 2004, 2005) IPAG/Grenoble

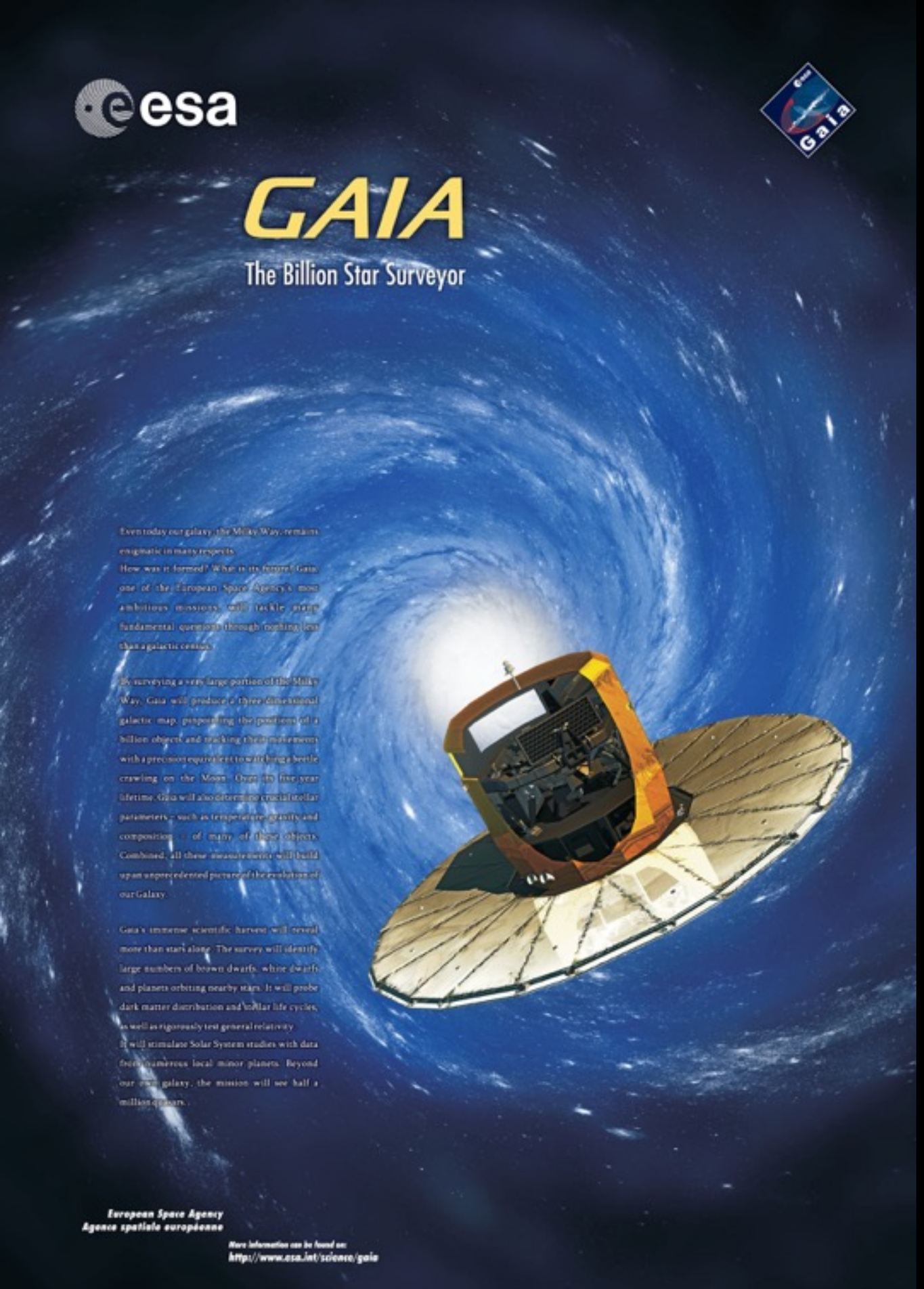


Lagrange et al. (2010) IPAG/Grenoble


a HST 2010
b HST 2011
c IRDIS 2014 (avg. prof. subtr.)
d IRDIS 2014 (KLIP)
e IRDIS 2014 (LOCI)
E
D
C
B
A
1 segment = 1″ = 9.9 AU
E
N
Min = –0.3 max
Zero
Max

Observer
le mouvement réflexe

astrométrie

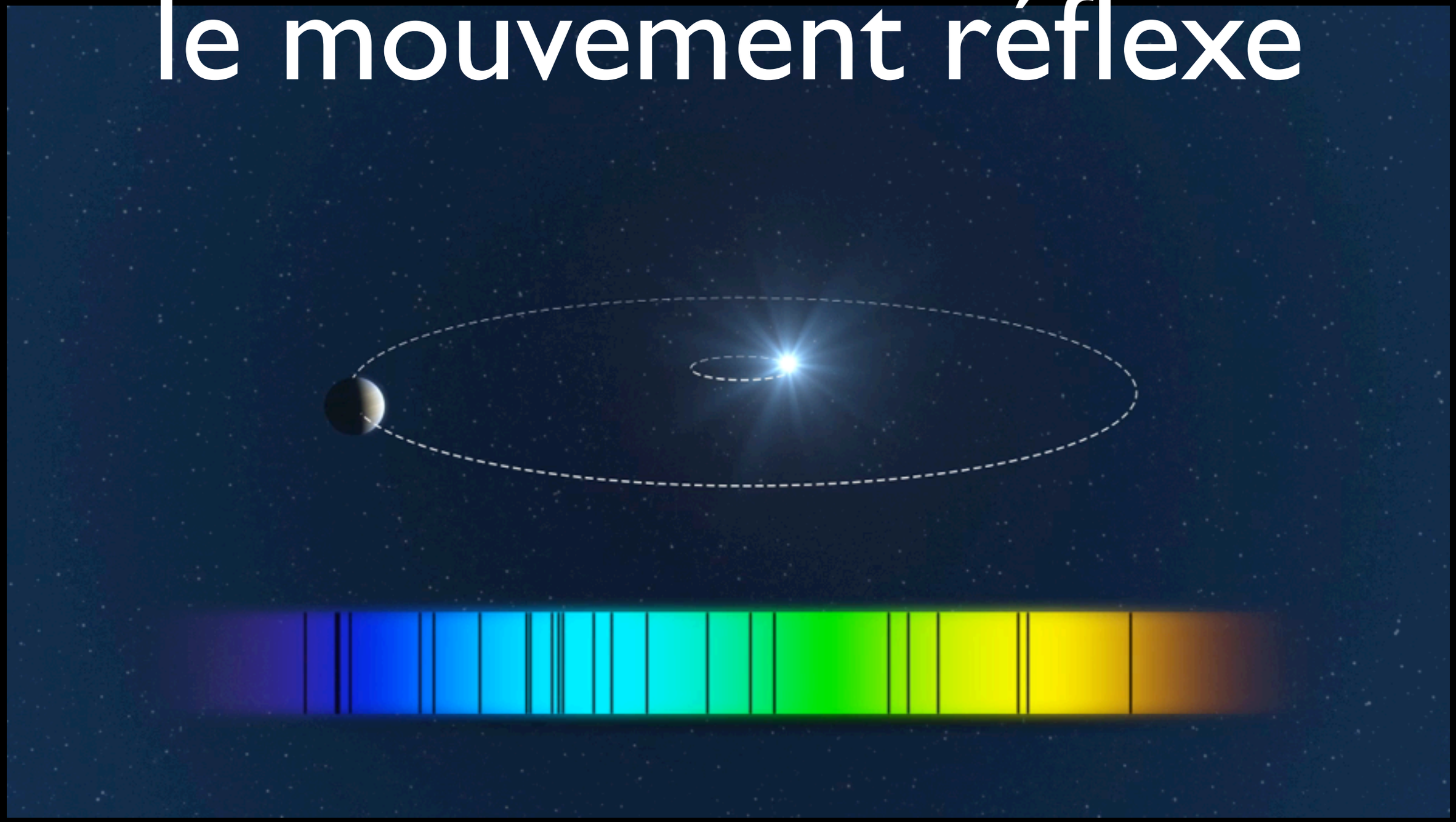


GAIA

lancer il y a 1 an

on espère la détection
de >20 000 exoplanète

Observer
le mouvement réflexe



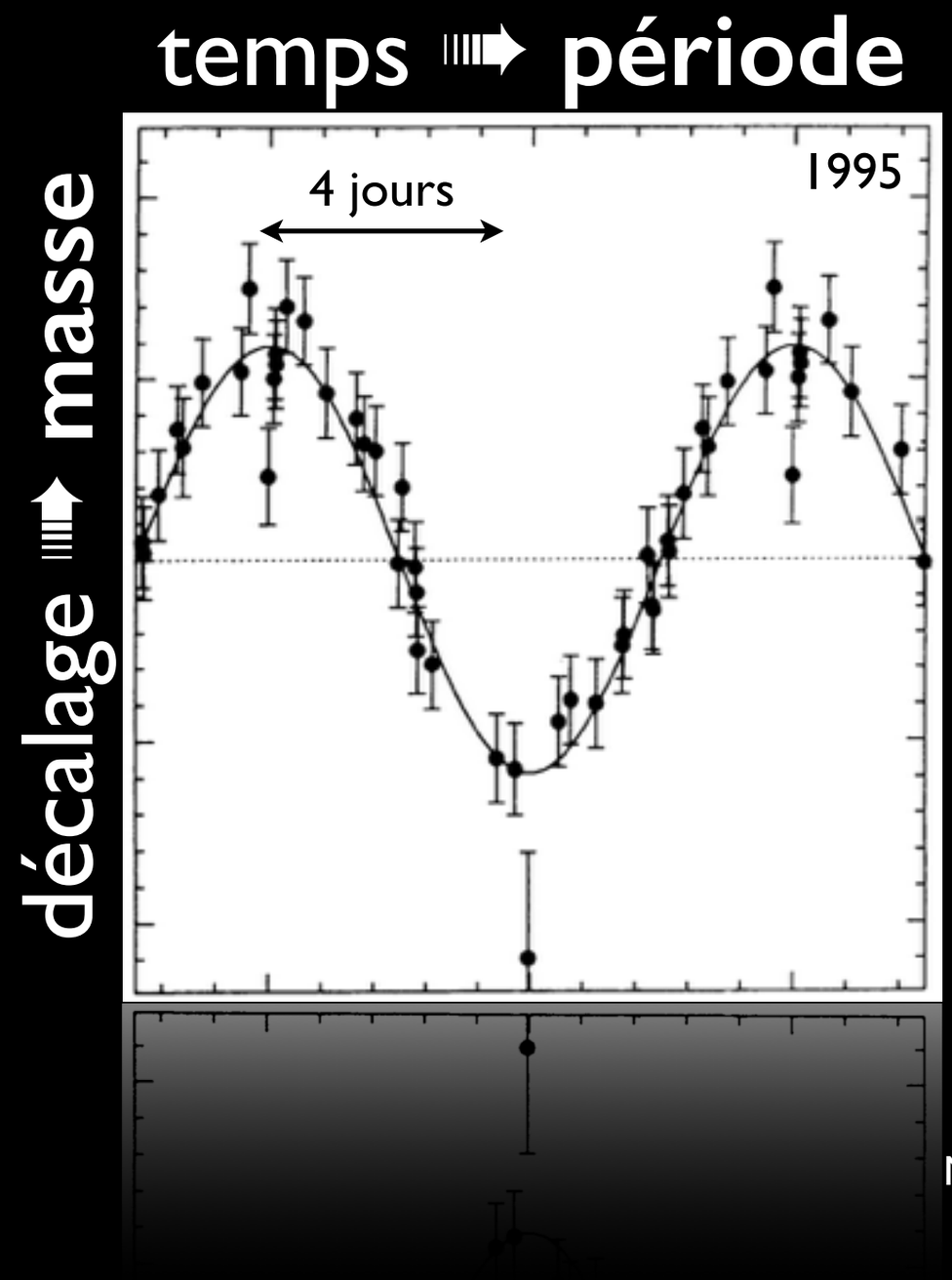
vitesse radiale / vélocimétrie

Un ballet stellaire

décalage vers le rouge

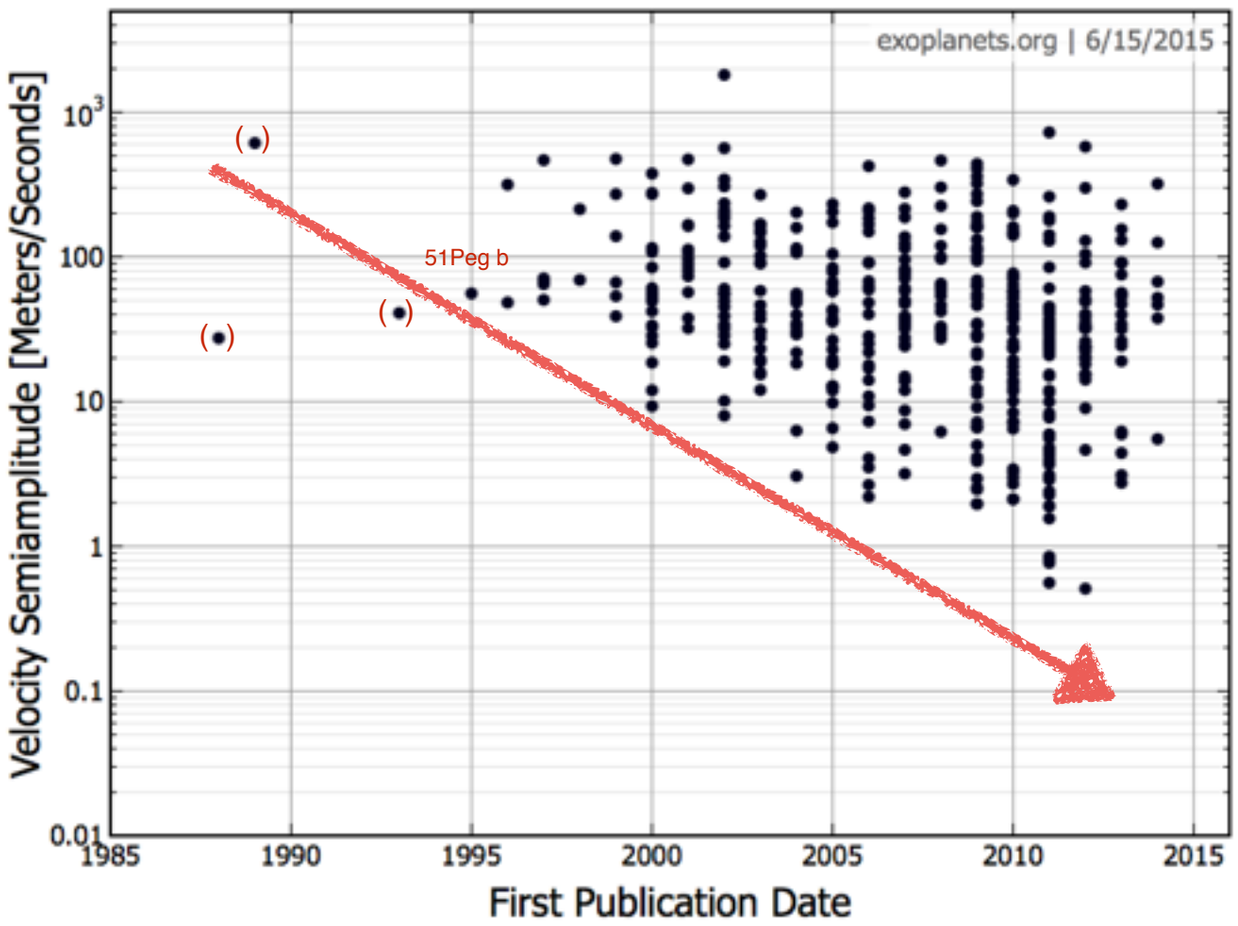
décalage vers le bleu

La première exoplanète



Michel Mayor & Didier Queloz (Genève)

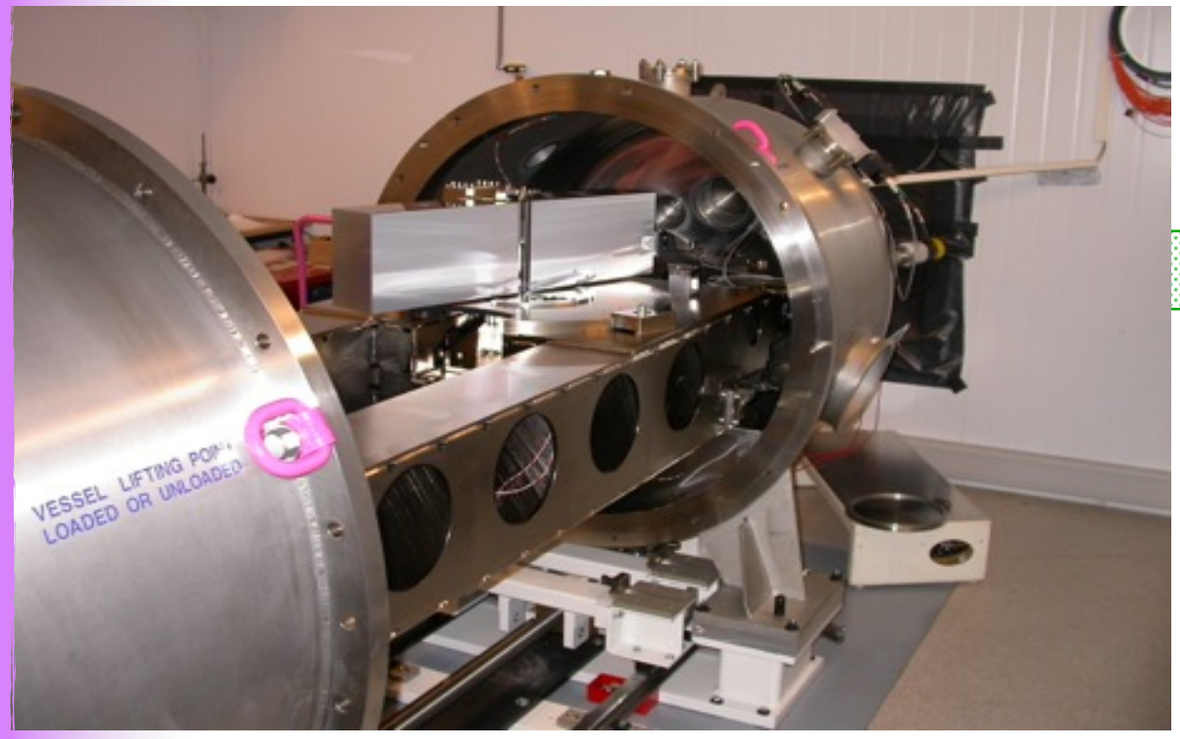
The Staknovist improvement in RV precisions



- RV semi-amplitude decreased by ~3 order of magnitudes in 20 years

HARPS

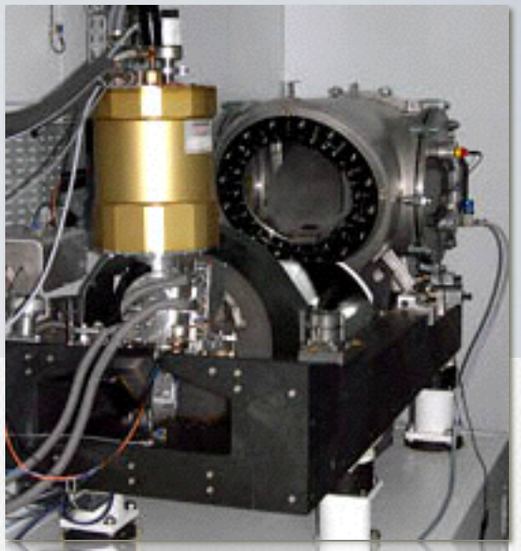
Fibres



~50 m

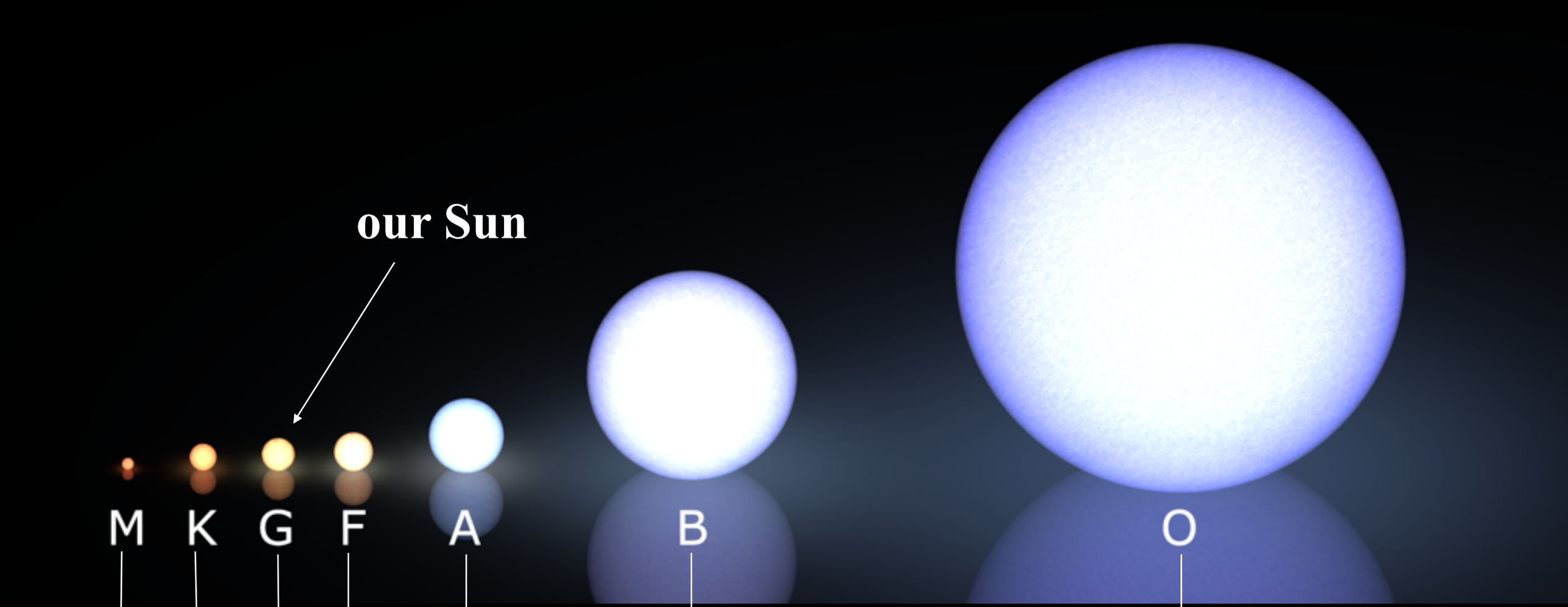
Sophie/1.93m - CNRS/OHP

- R=75000
- precision ~ 10 m/s
- N ~ 200 naines M



Harps/3.60m - ESO/La Silla

- R=115000
- precision < 1 m/s
- N = 100 + 300 M dwarfs



@ Grenoble, we have specialized in the search for exoplanets around M dwarfs

- dominant stellar population
- low-mass stars
- low temperature
- small
- intrinsically faint

Gliese 581

e

2x Terre

b

16x Terre

c

5x Terre

~~d~~

~~7x Terre~~

2005-2009

Michel Mayor (Genève), Xavier Bonfils (Grenoble) et collaborateurs

Sun

Gliese 581

e b c

1

0.1

Mass of star (in solar masses)

0.1

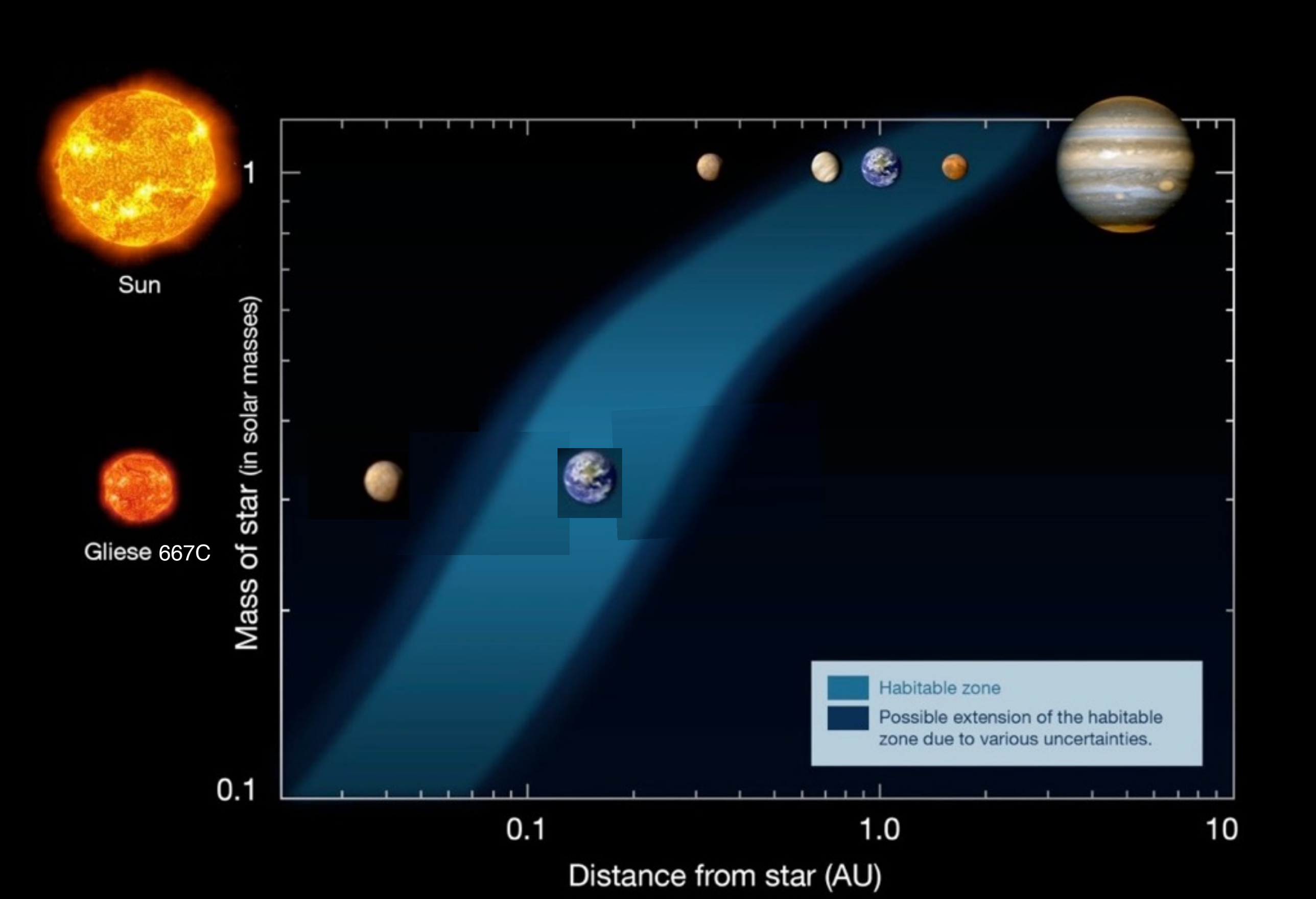
1.0

10

Distance from star (AU)

Habitable zone

Possible extension of the habitable zone due to various uncertainties.


Sun
Gliese 667C
1
0.1
Mass of star (in solar masses)
0.1
1.0
10
Distance from star (AU)
Habitable zone
Possible extension of the habitable zone due to various uncertainties.

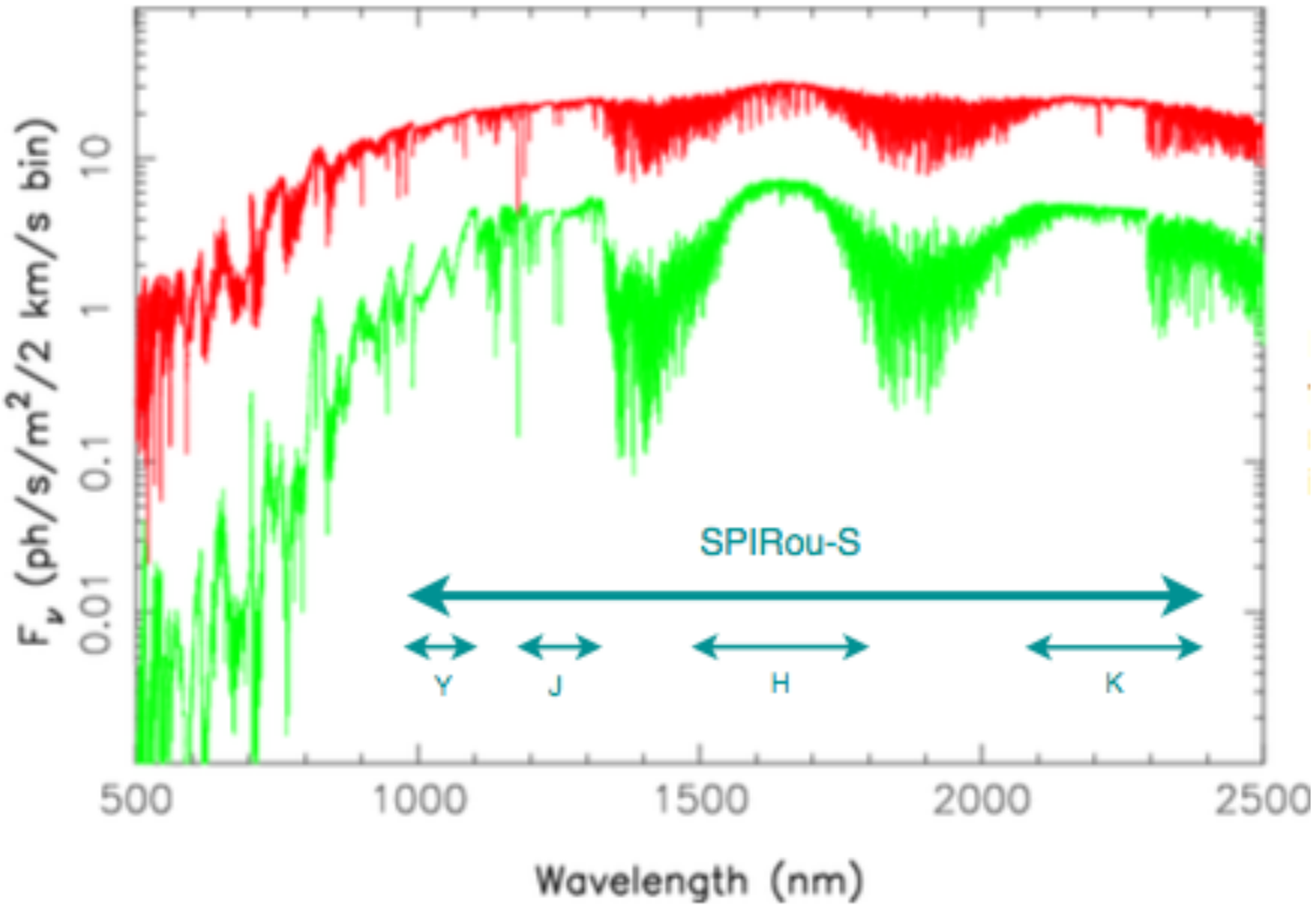
22 Potentially Habitable Worlds

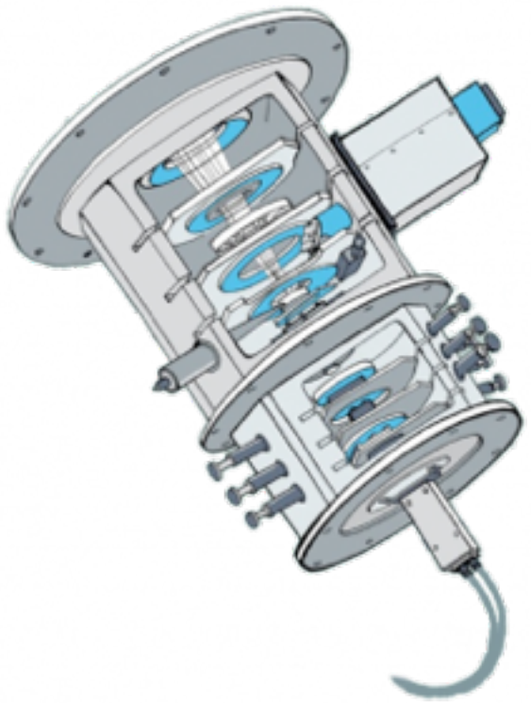
PHL
MAPPING THE HABITABLE UNIVERSE
UNIVERSITY OF PUERTO RICO AT ARECIBO
PHL.UPR.EDU

[12 ly] Tau Ceti e*
[13 ly] Kapteyn b
[16 ly] Gliese 832 c
[17 ly] Gliese 682 c*
[24 ly] Gliese 667C c
[24 ly] Gliese 667C e*
[24 ly] Gliese 667C f*
[38 ly] Gliese 180 b*
[38 ly] Gliese 180 c*
[41 ly] Gliese 422 b*
[42 ly] HD 40307 g
[49 ly] Gliese 163 c

[59 ly] Gliese 3293 c*
[492 ly] Kepler-186 f
[619 ly] Kepler-22 b
[1063 ly] Kepler-61 b
[1174 ly] Kepler-174 d
[1200 ly] Kepler-62 e
[1200 ly] Kepler-62 f
[1545 ly] Kepler-298 d
[1692 ly] Kepler-296 f
[1741 ly] Kepler-283 c
Earth
Mars

* Unconfirmed. Distance from Earth (light years) between brackets.

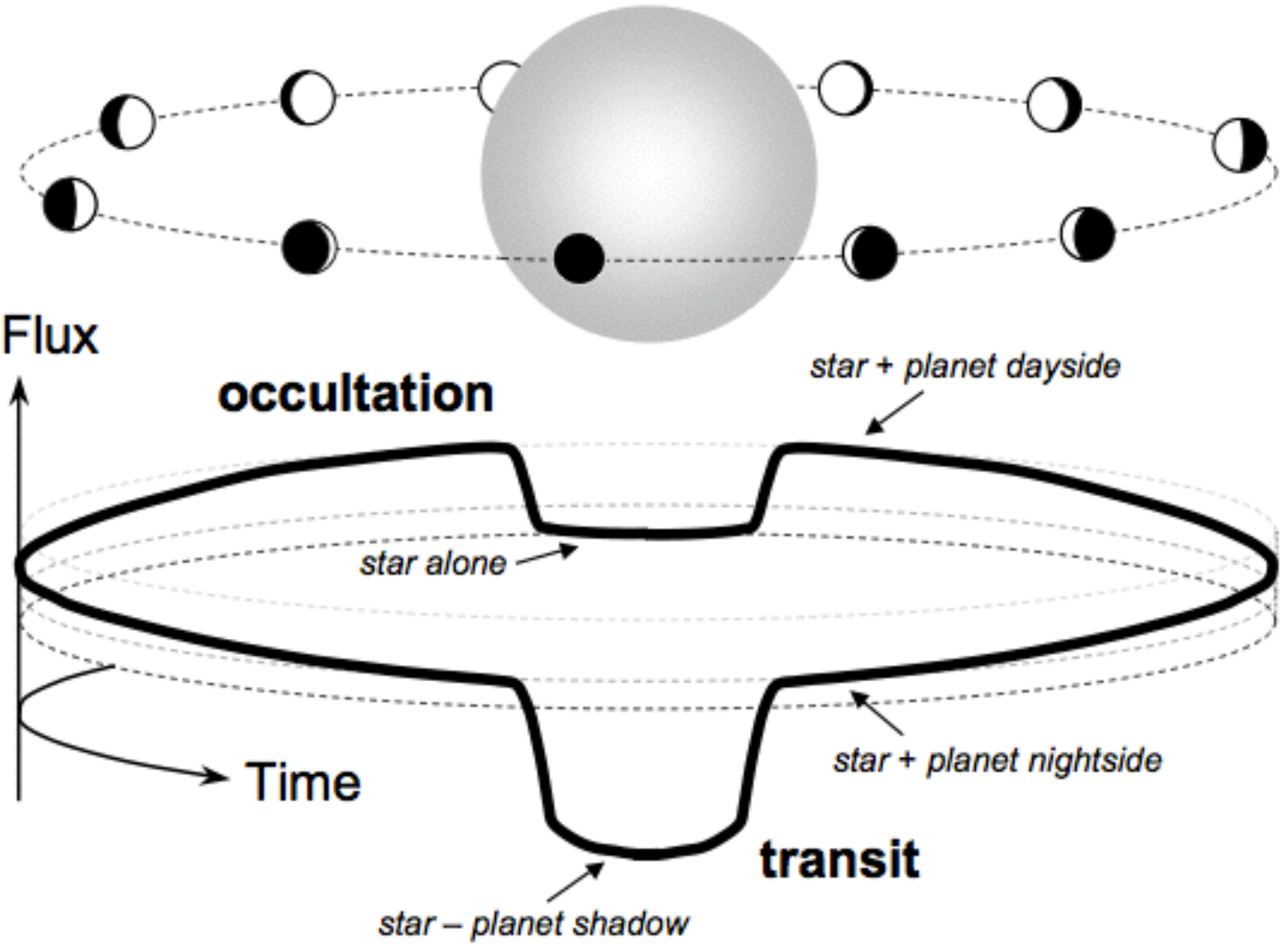

F_ν (ph/s/m^2/2 km/s bin)
0.01
0.1
1
10
SPIRou-S
Y
J
H
K
500
1000
1500
2000
2500
Wavelength (nm)

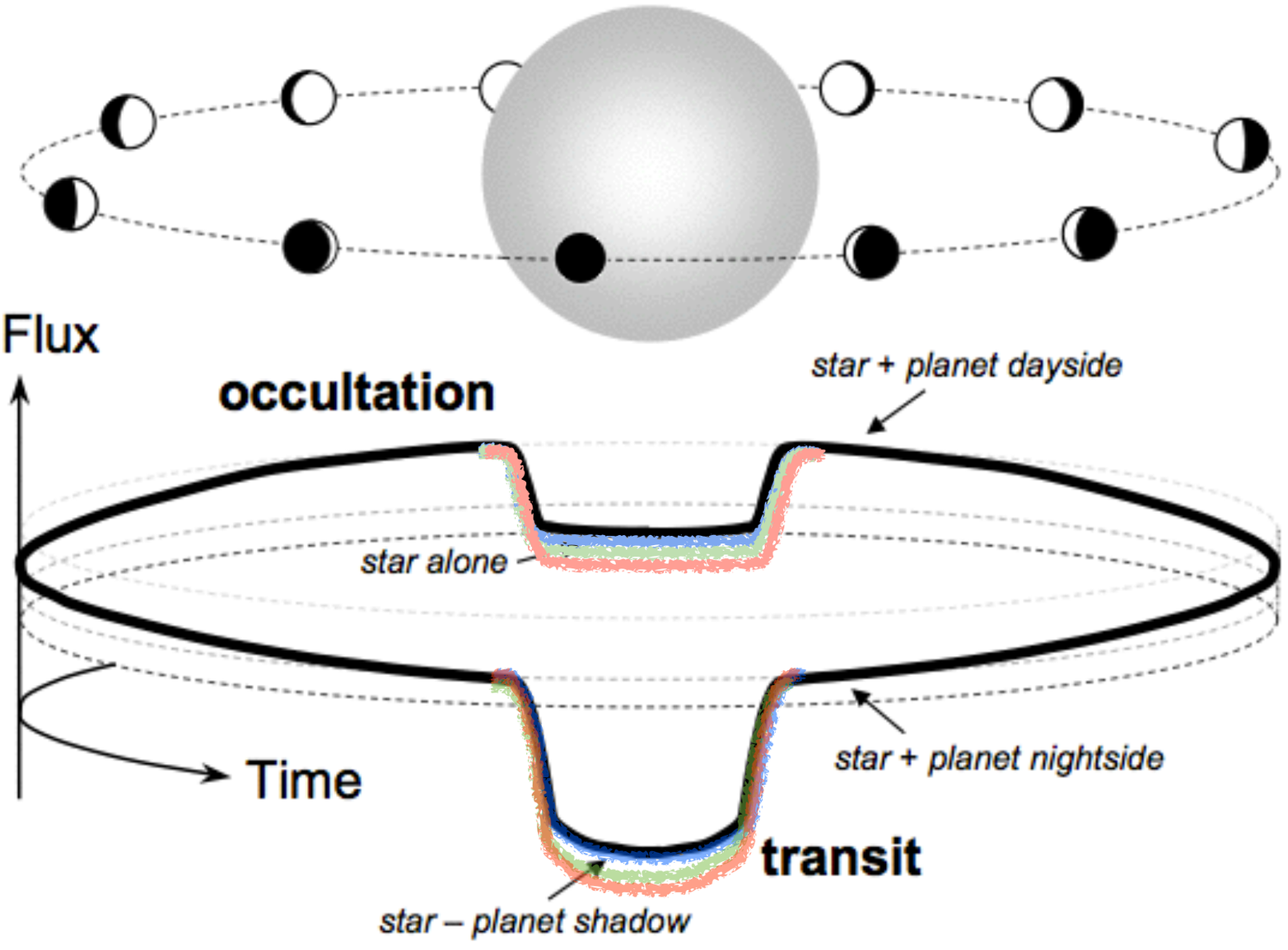


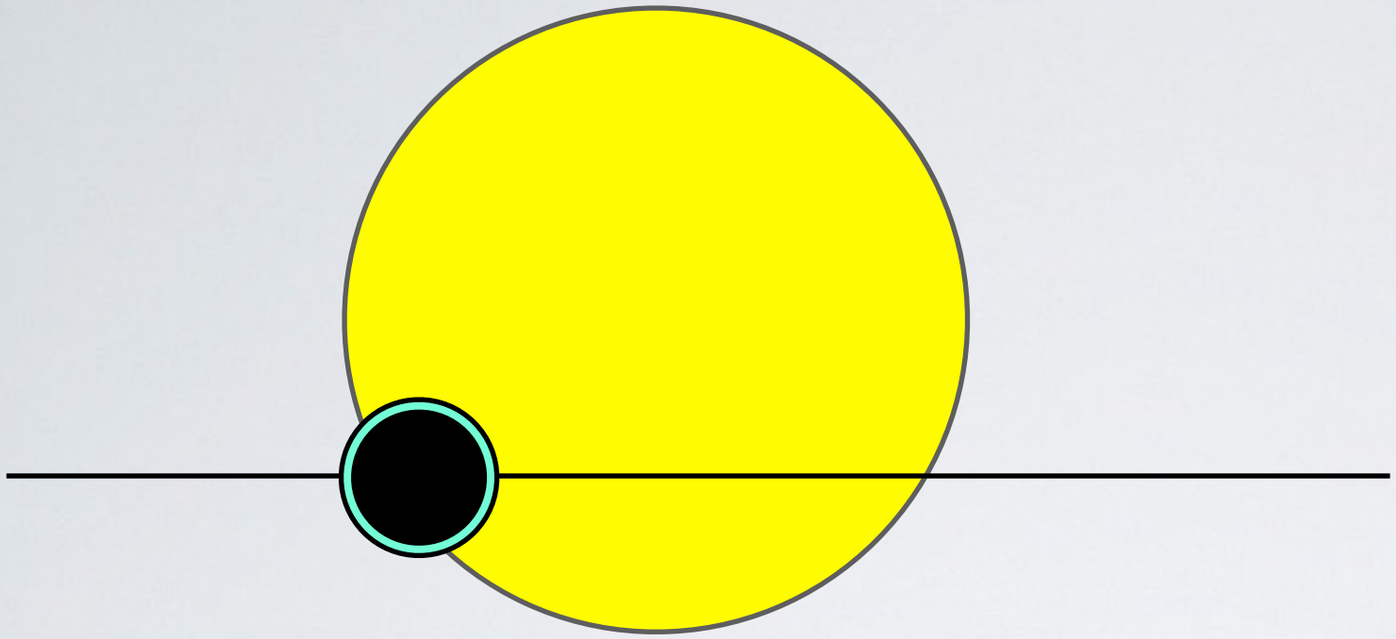
SPiRou

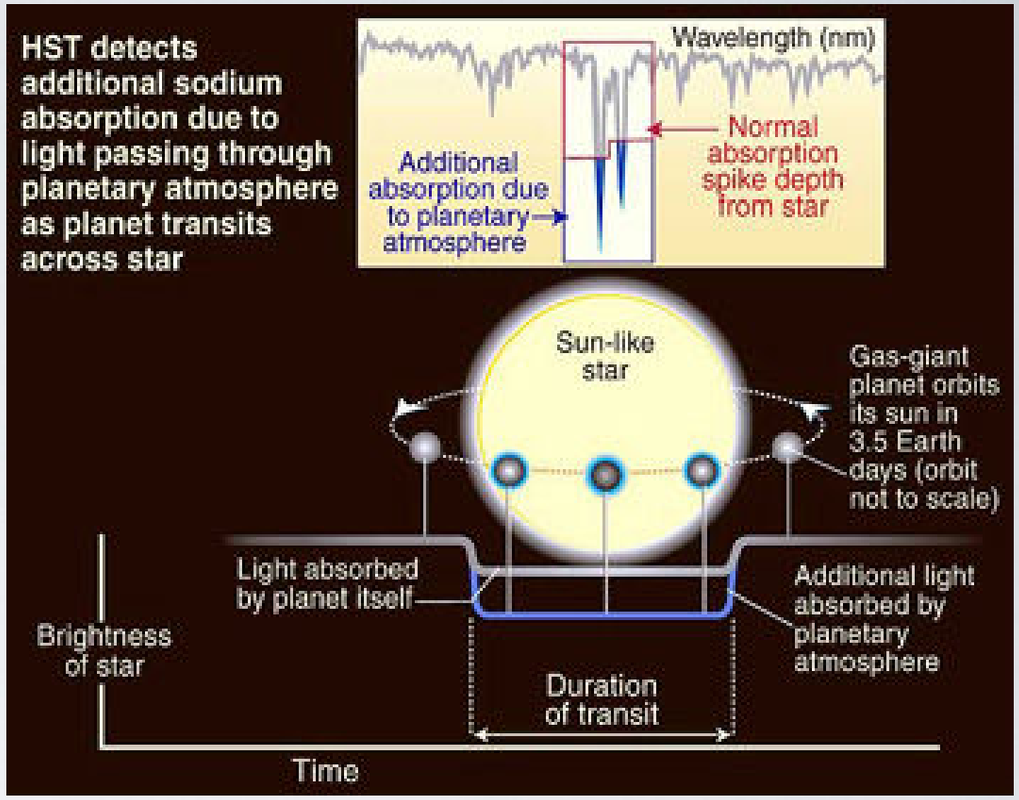
-200° !
cuve cryostat
miroir parabolique
caméra-détecteur
injection + miroirs plan
cassette
support + rails

Les transits

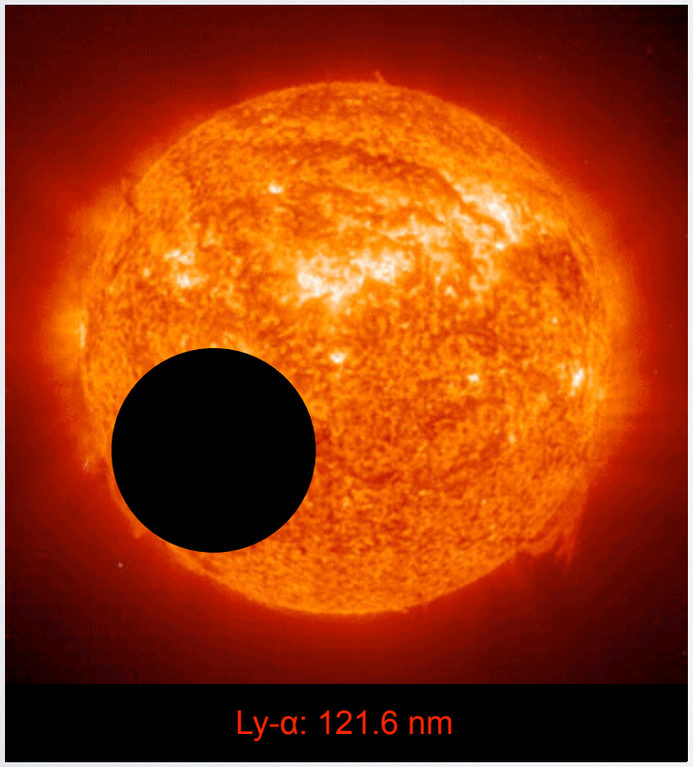

Flux
occultation
star + planet dayside
star alone
Time
star + planet nightside
transit
star – planet shadow


Flux
occultation
star + planet dayside
star alone
star + planet nightside
Time
transit
star – planet shadow

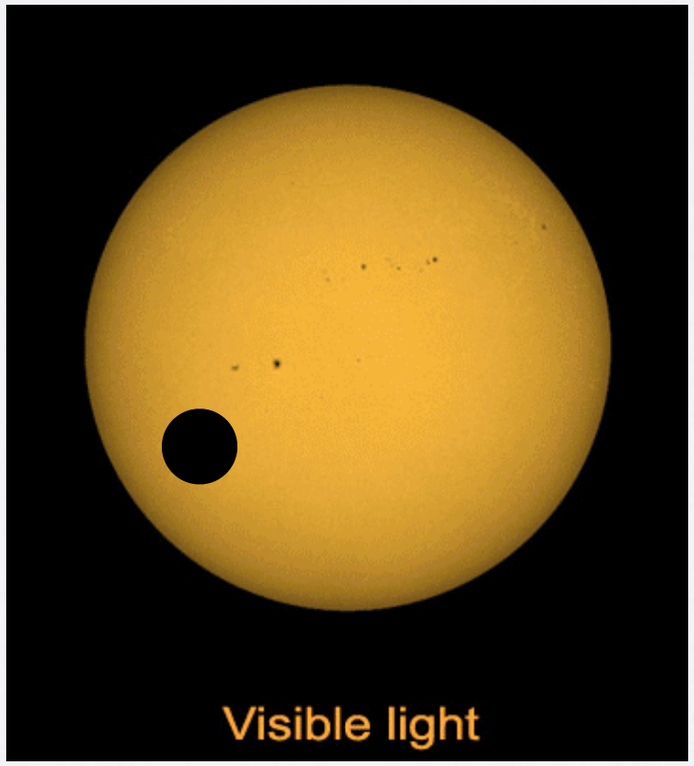




HD 209458



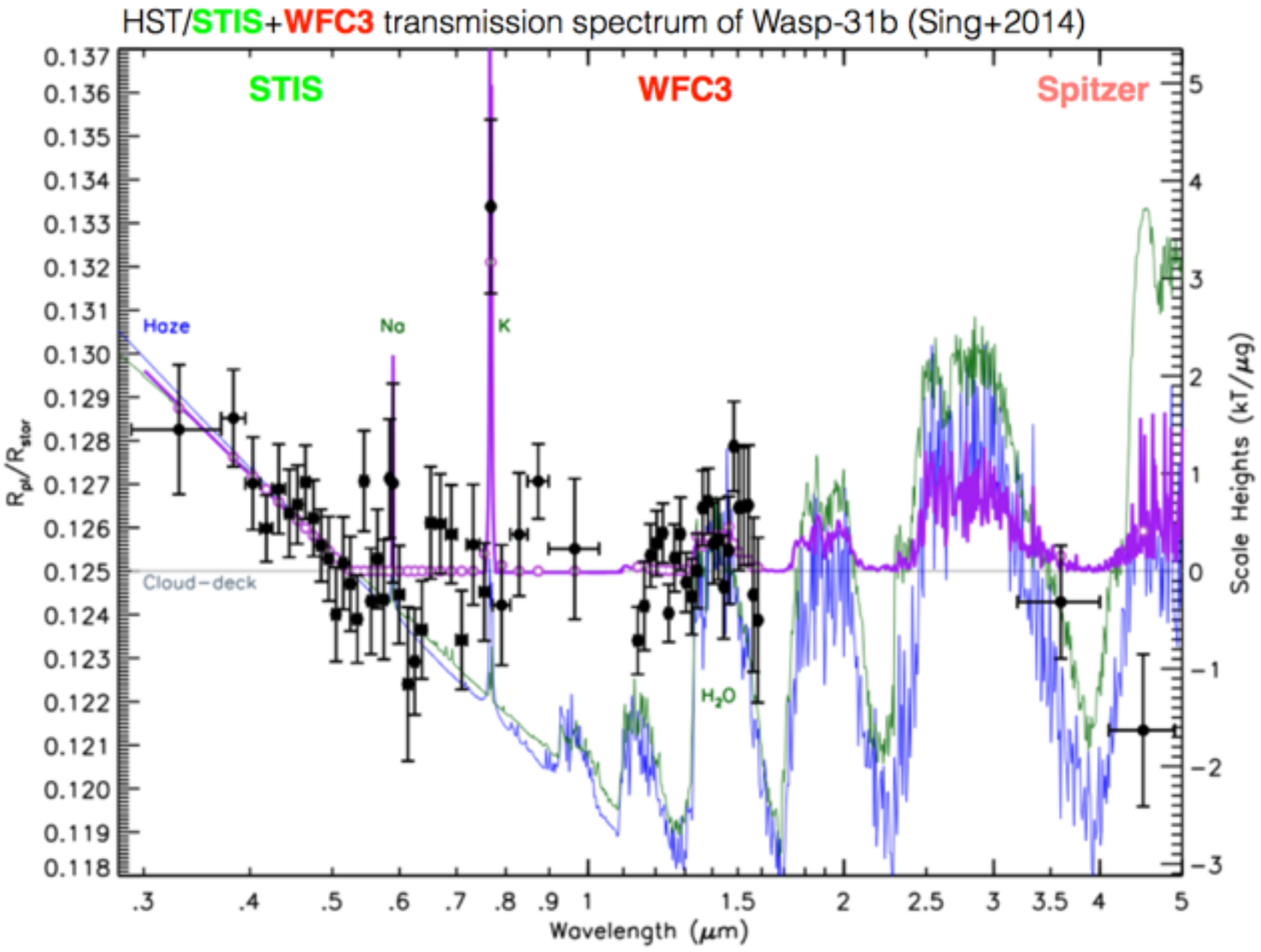
Vidal-Madjar et al. (2003)



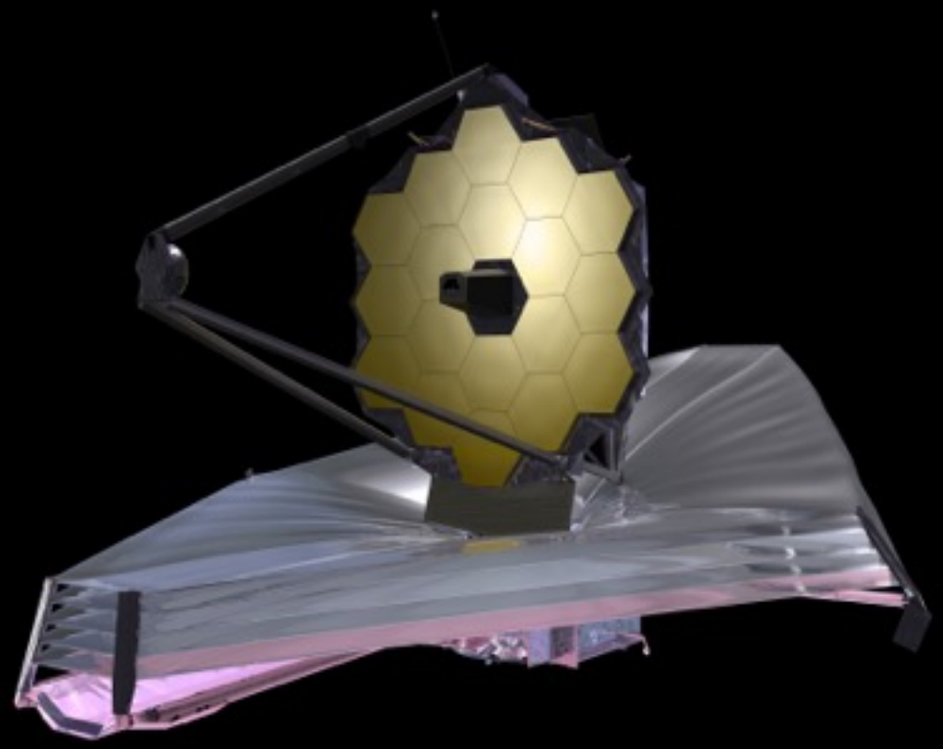
Charbonneau et al. (2000)

Richardson et al. (2006)

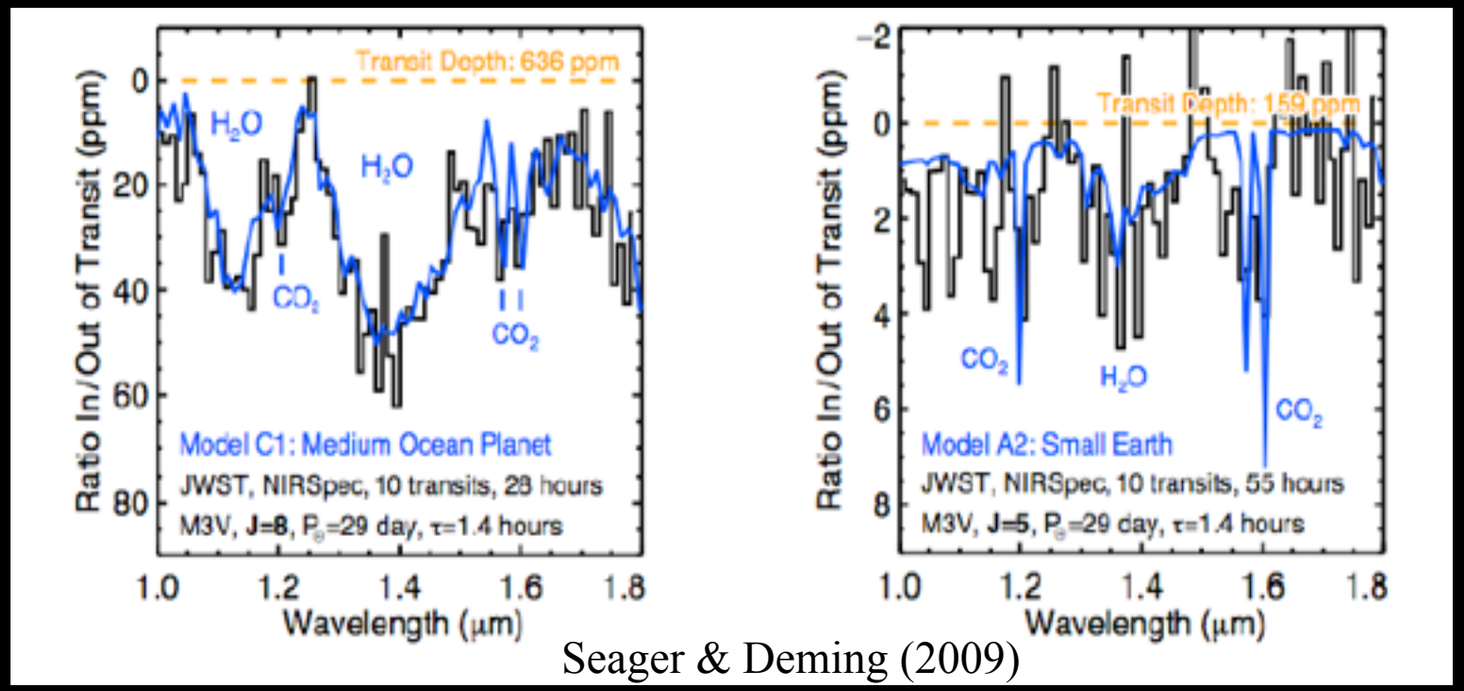
Visible+NIR transit spectroscopy



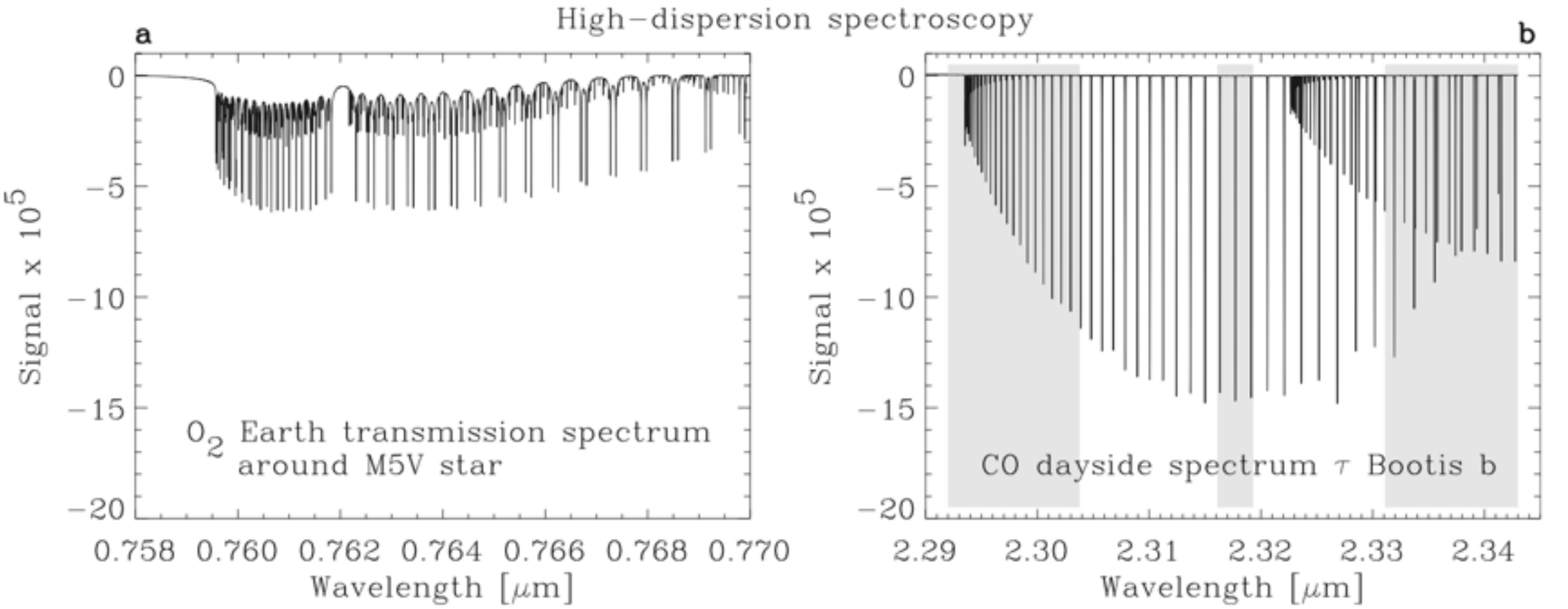
- Smog
- Na, K, H2O…
- Nuages



2019

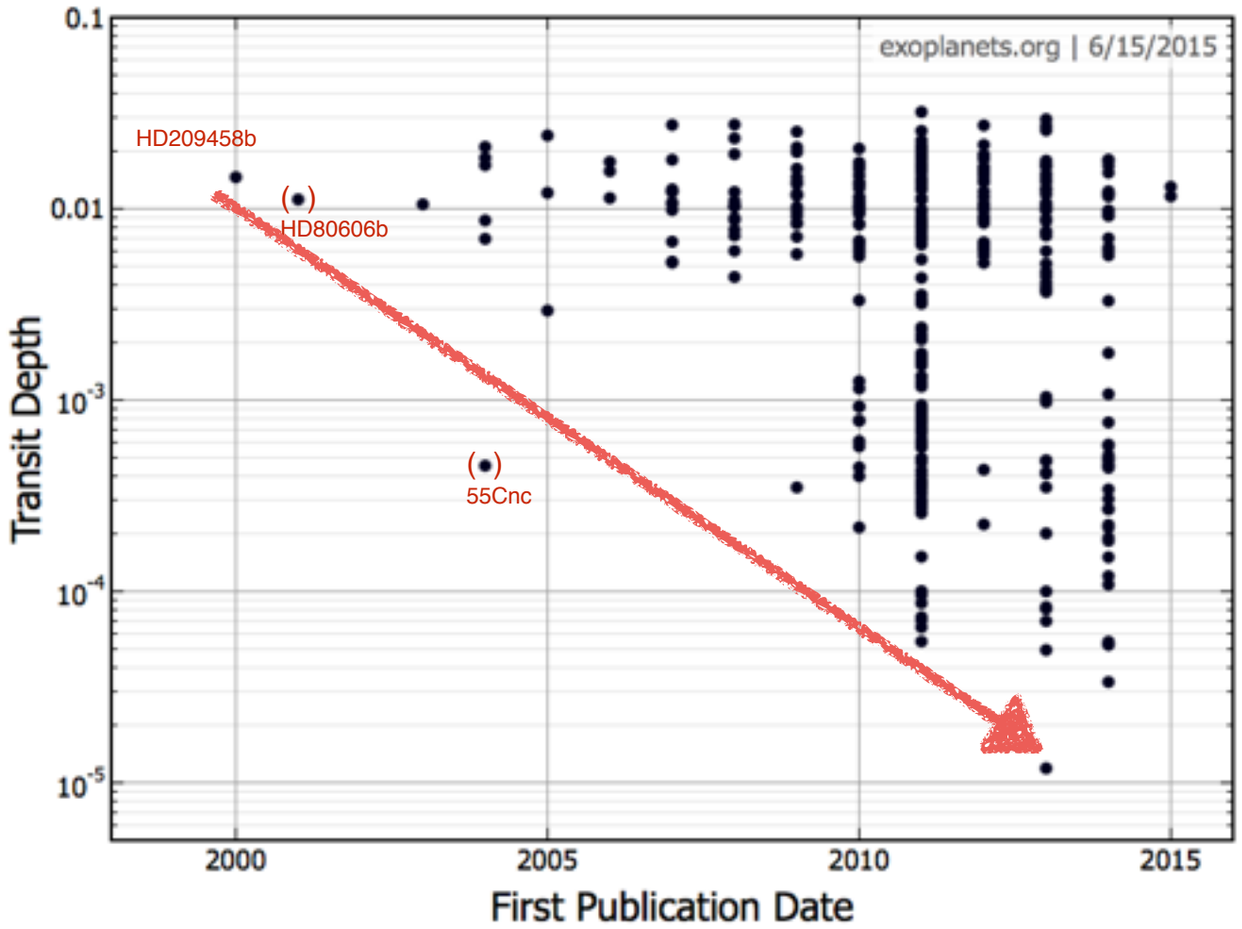


Seager & Deming (2009)

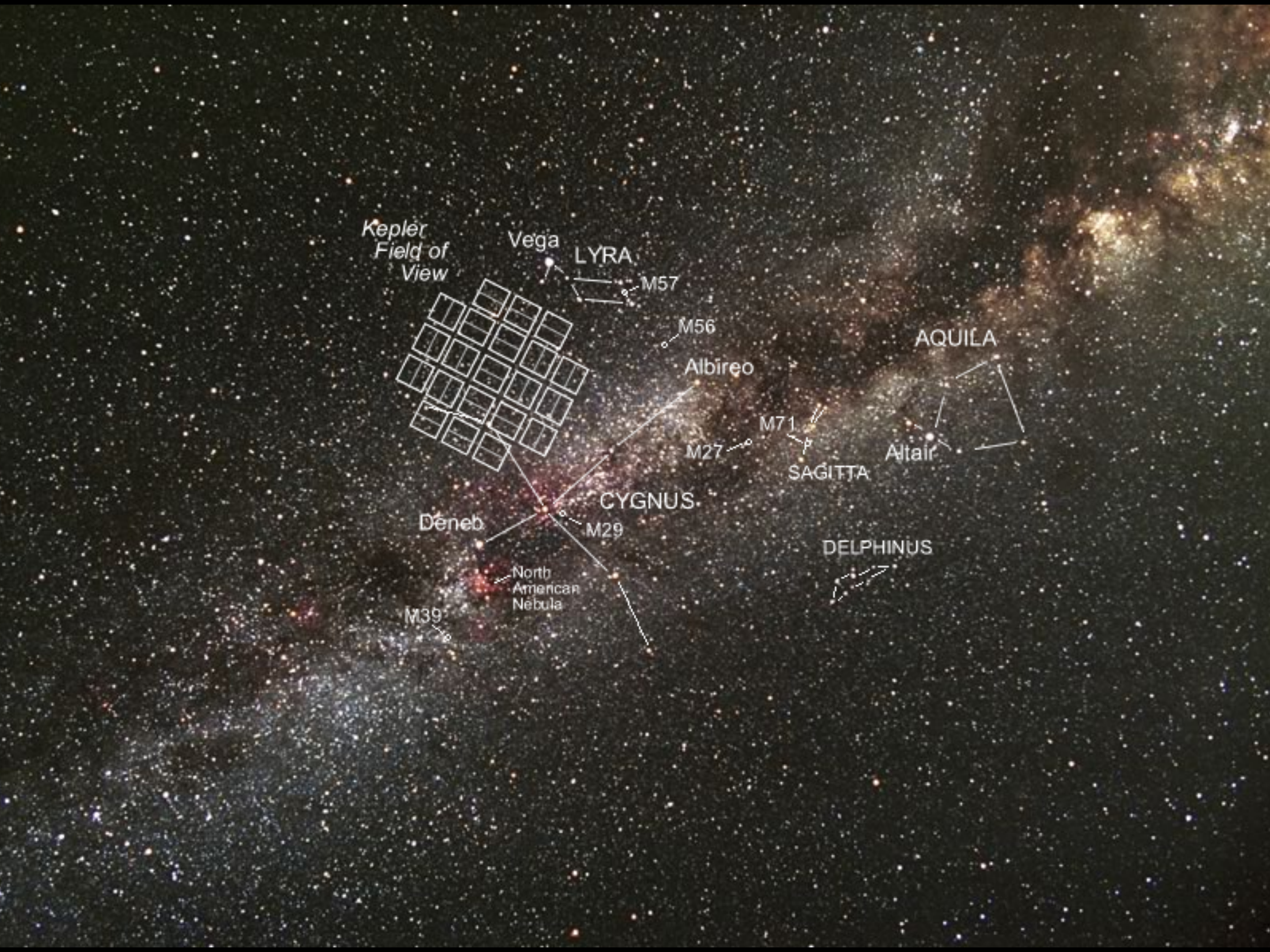

High−dispersion spectroscopy
a
b
Signal x 10^5
0
−5
−10
−15
−20
O_2 Earth transmission spectrum around M5V star
0.758 0.760 0.762 0.764 0.766 0.768 0.770
Wavelength [μm]
CO dayside spectrum τ Bootis b
2.29 2.30 2.31 2.32 2.33 2.34
Wavelength [μm]


140 м
120 м
100 м
80 м
60 м
40 м
20 м
2024

The Staknovist improvement in LC precisions

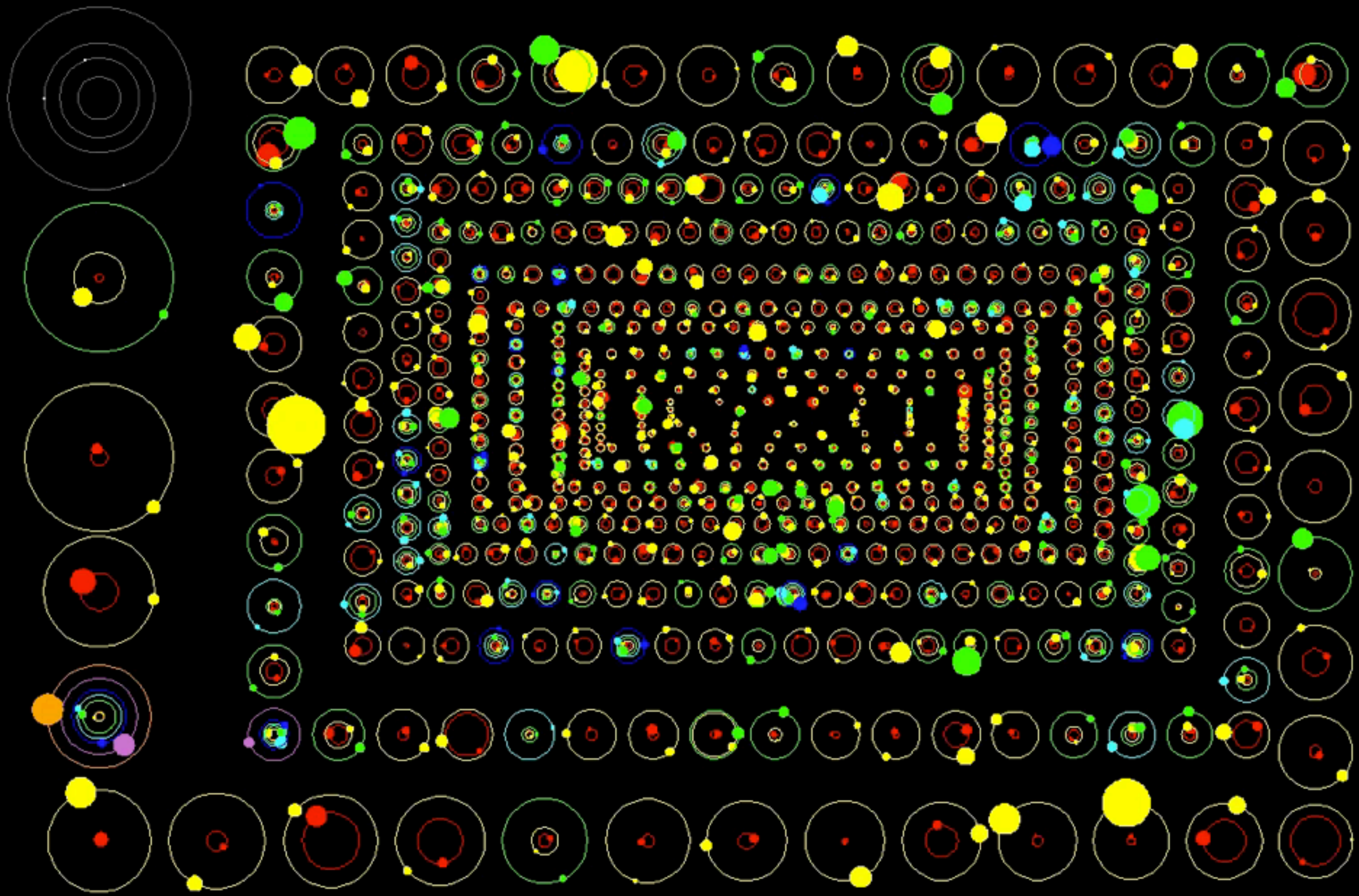


- Transit depths decreased by ~3 order of magnitude in 15 years


Kepler
Field of
View
Vega
LYRA
M57
M56
Albireo
AQUILA
M71
M27
SAGITTA
Altair
CYGNUS
Deneb
M29
DELPHINUS
North
American
Nebula
M39

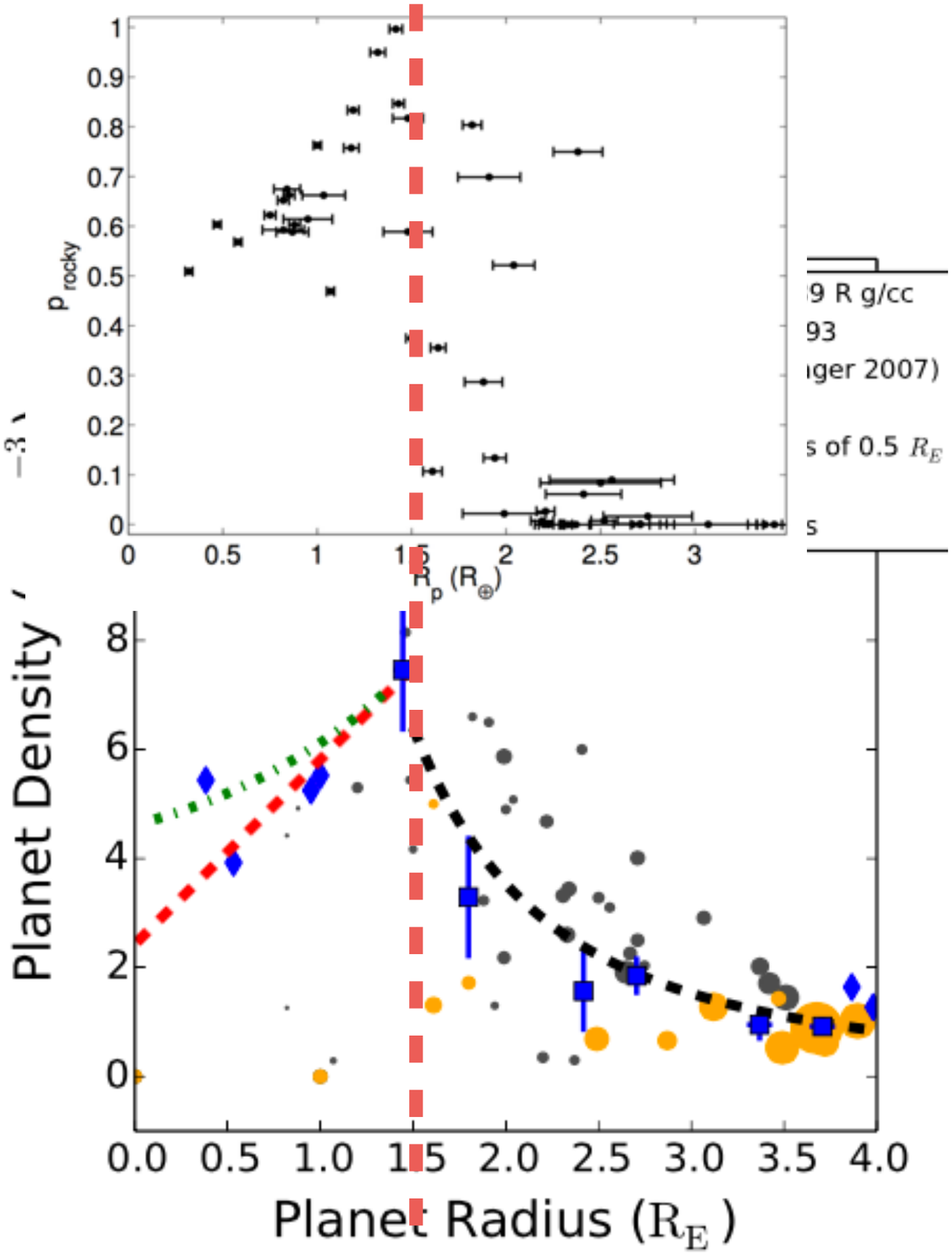
The Kepler Orrery III

t[BJD] = 2455215



Combination : Mass-radius relations

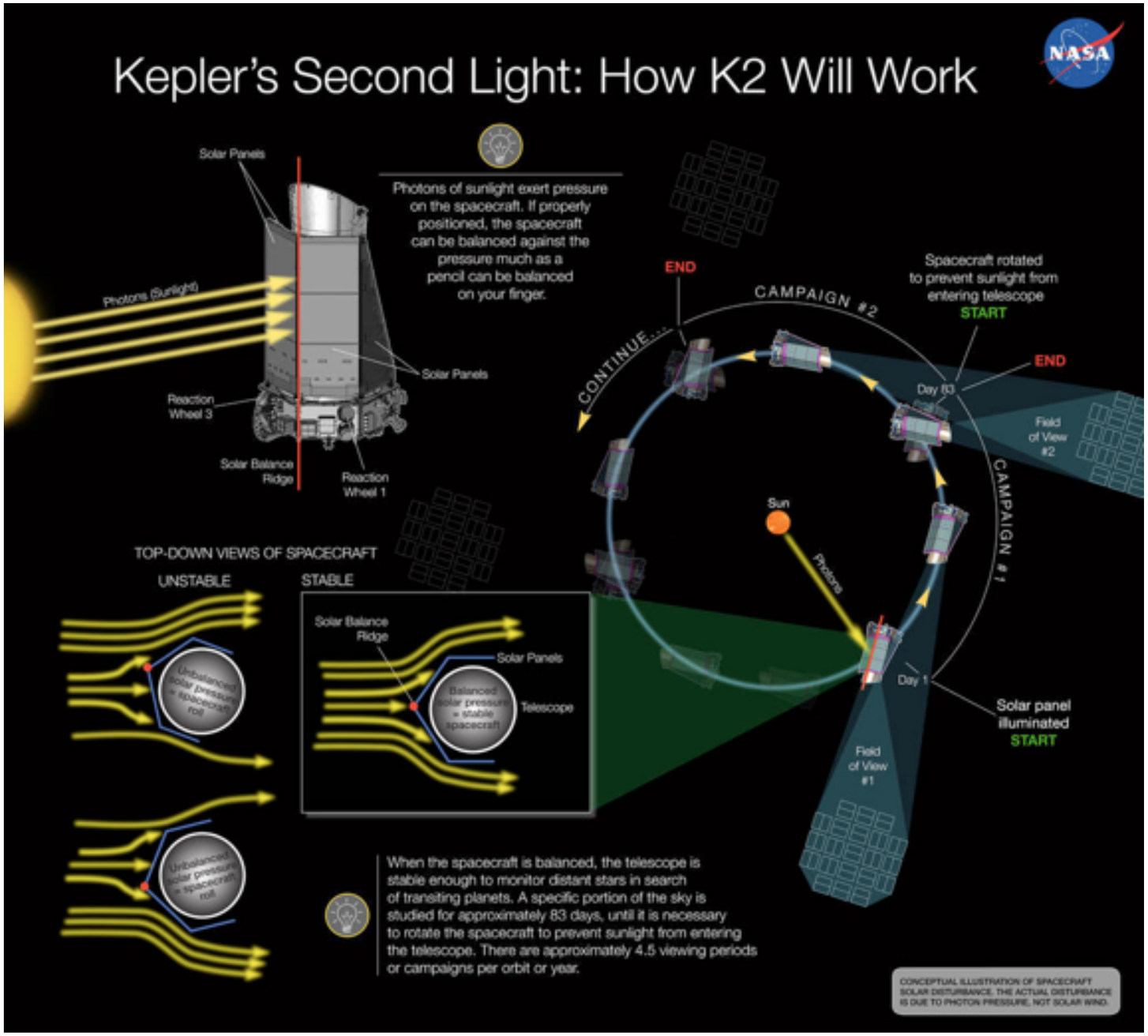
Rogers (2014)

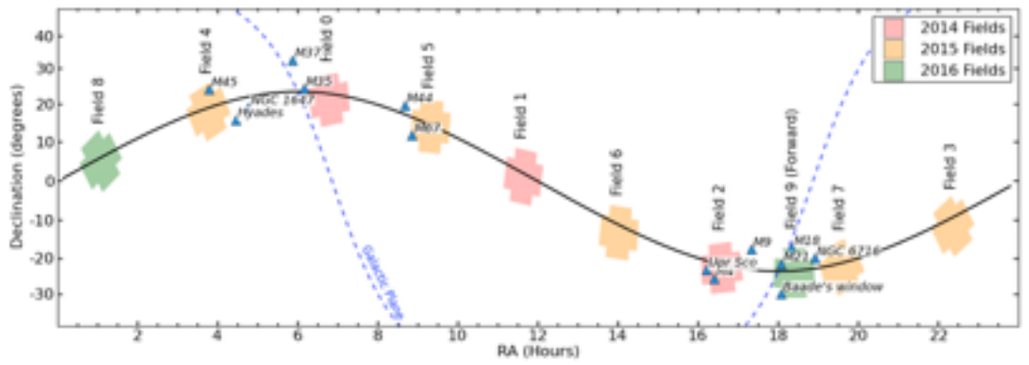


Weiss & Marcy (2015)

- Rogers (2014); Weiss & Marcy (2015)
- rocky transition @ 1.5-1.8 Rearth
- important consideration for HZ planet searches

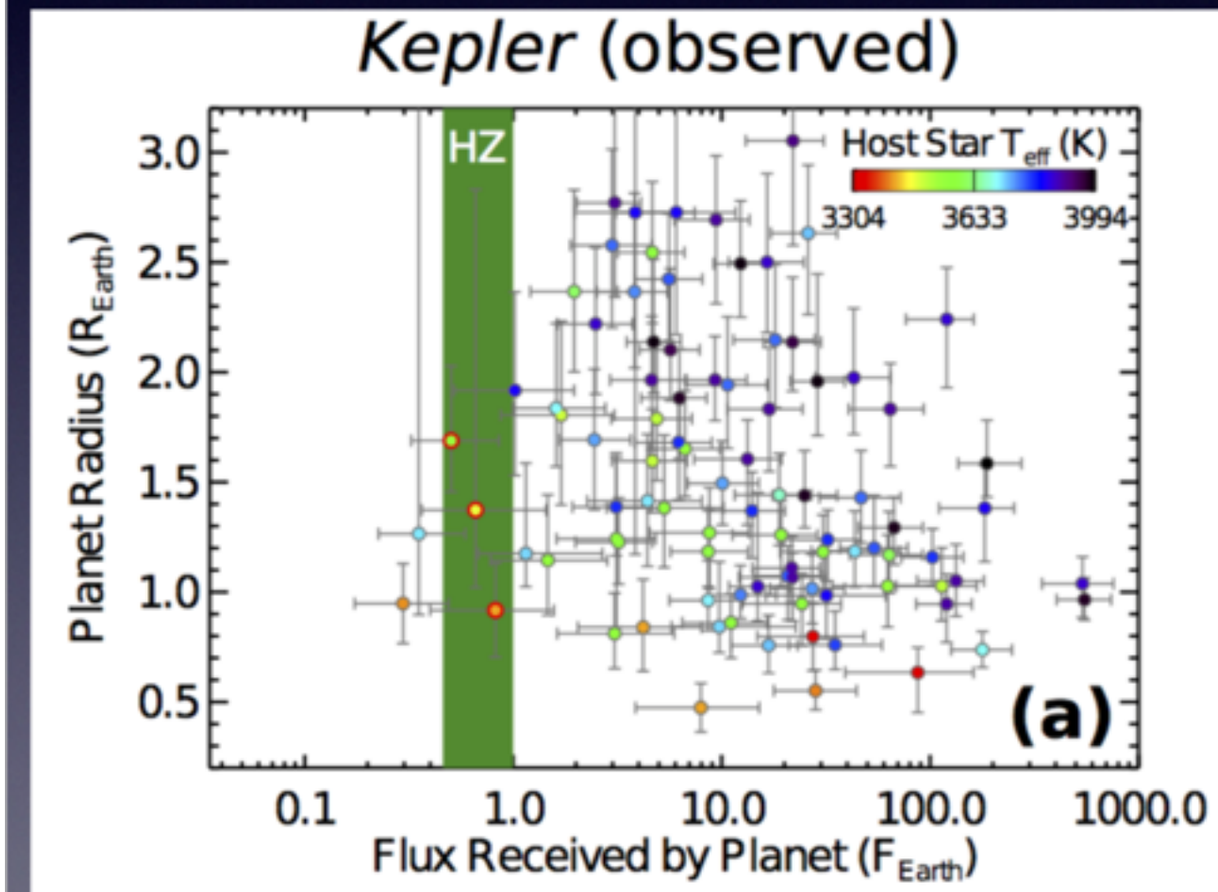
K2 = refurbished Kepler mission

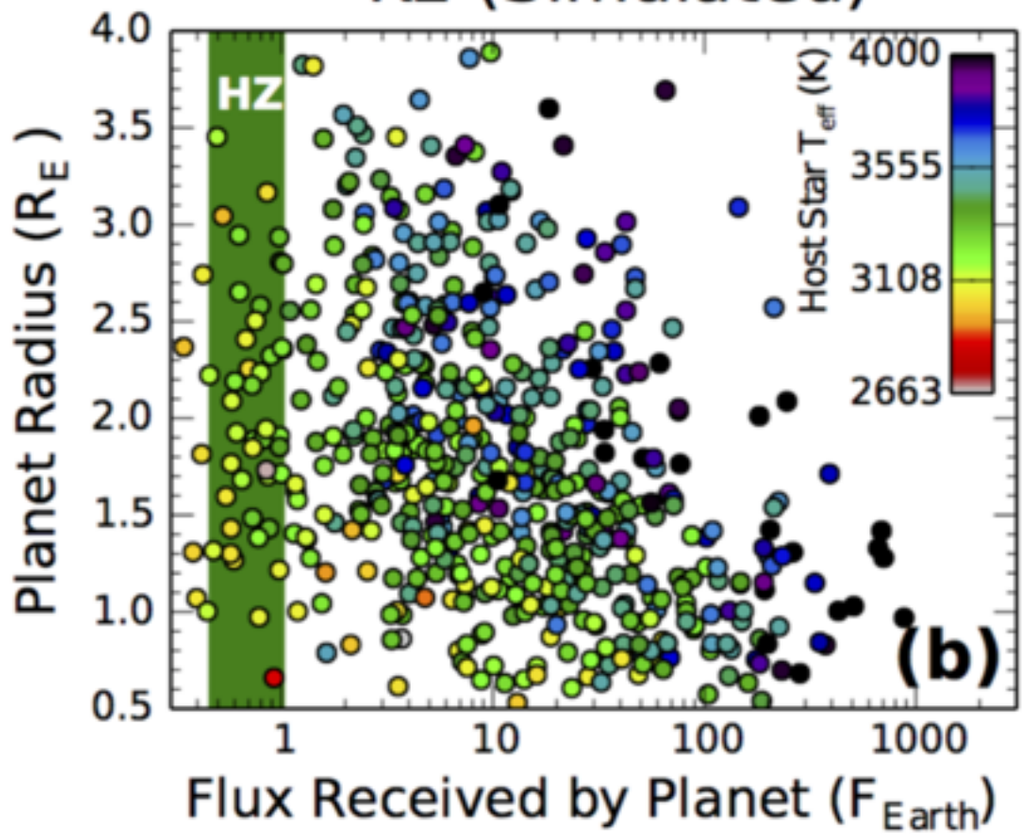




K2 M Dwarf Planet Yield

- K2 will observe ~60000 M dwarfs, 400 planets predicted
  - Nearby Stars
  - HZ planets and Transit Spectroscopy Targets





slide courtesy of Ian Crossfield

K2-3 could become the 1st system with a HZ planet candidate w/ both mass and radius

Kepler photometry

Crossfield et al. (2015)

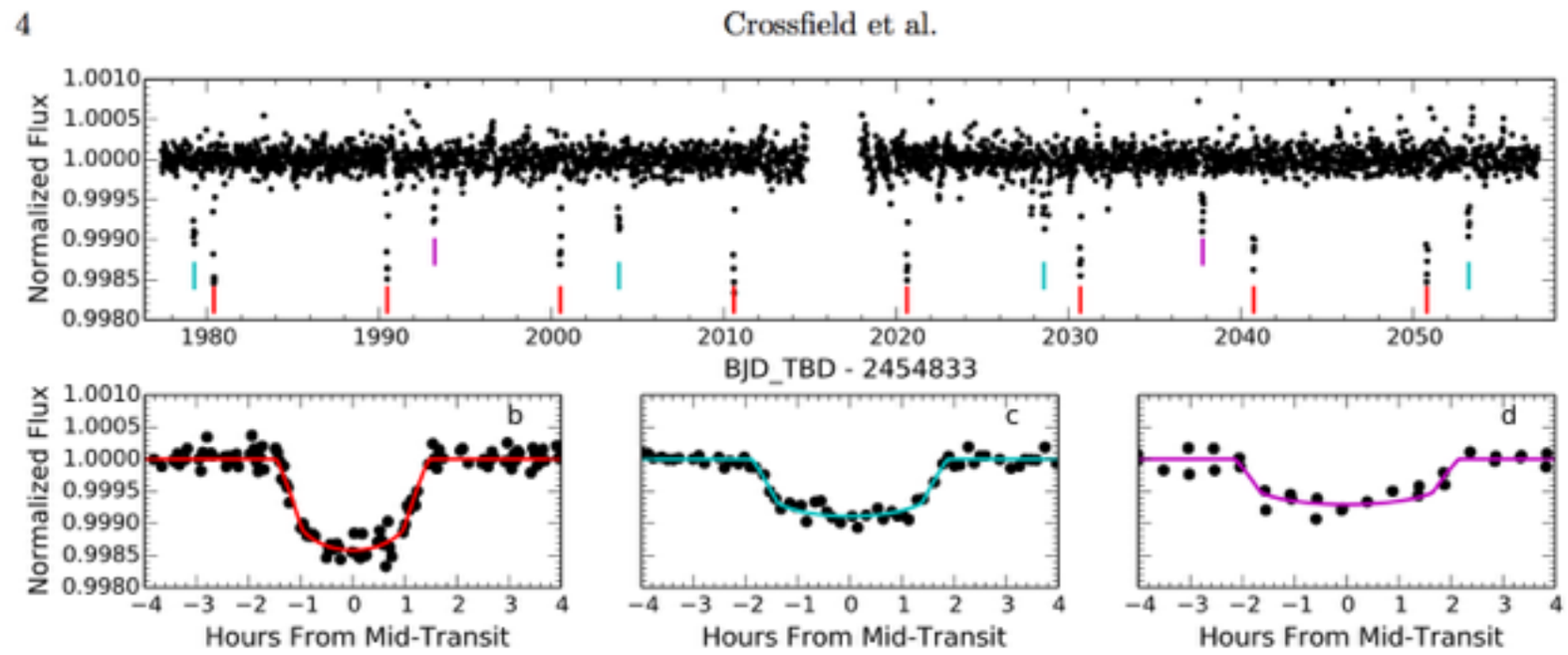
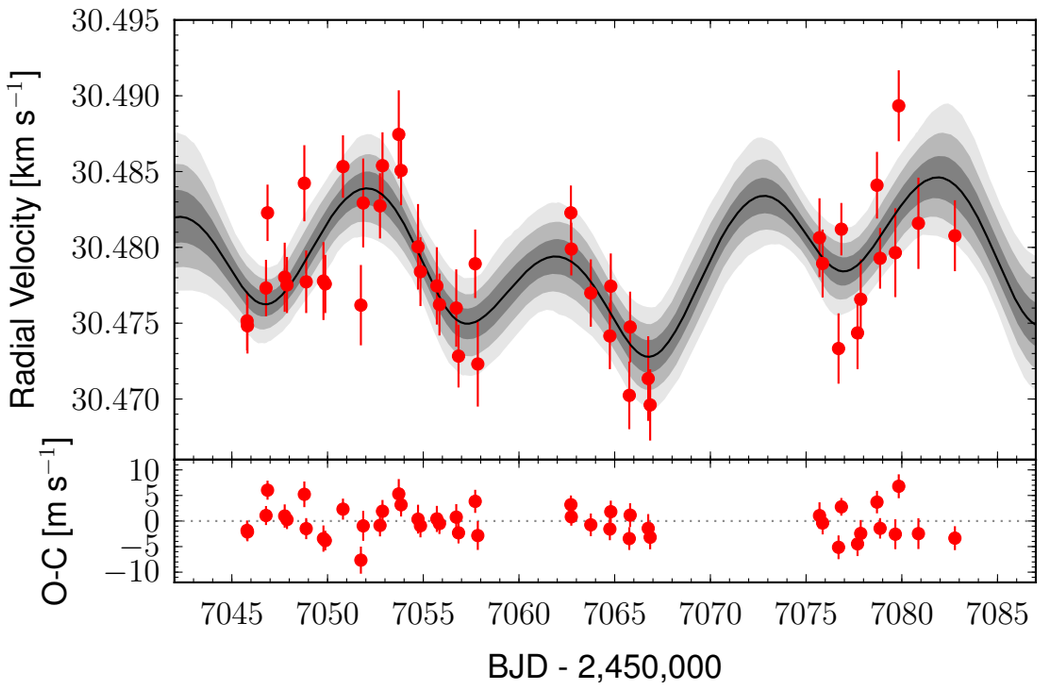
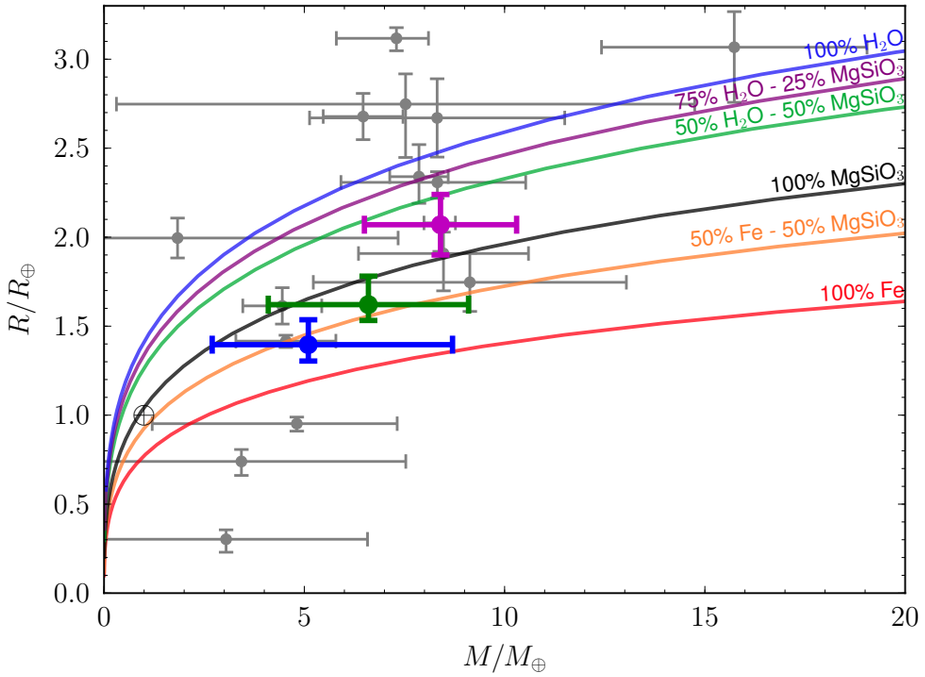


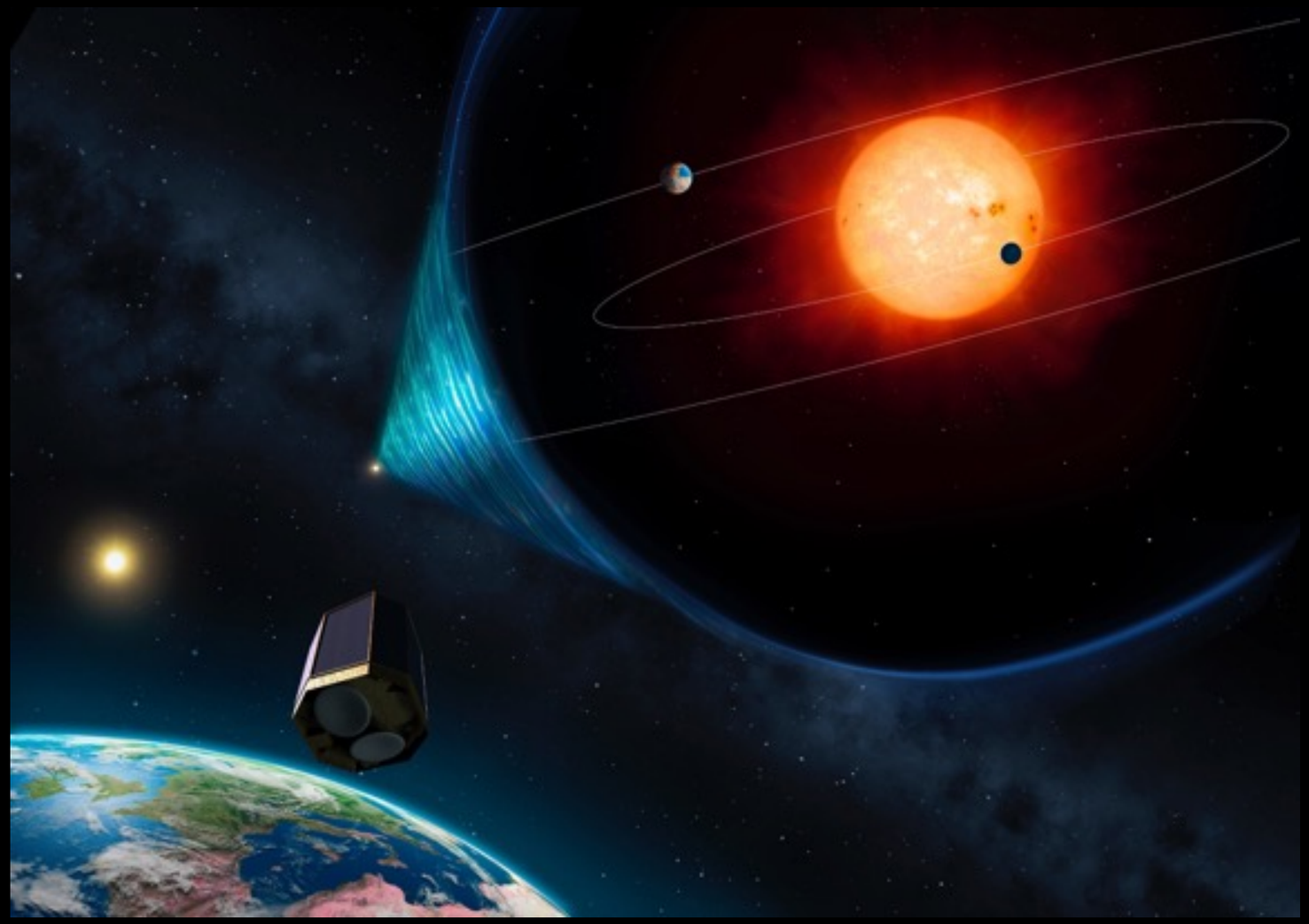
FIG. 1.— *Top*: Calibrated K2 photometry for EPIC 201367065. Vertical ticks indicate the locations of each planets' transits. *Bottom*: Phase-folded photometry and best-fit light curves for each planet.

HARPS RV

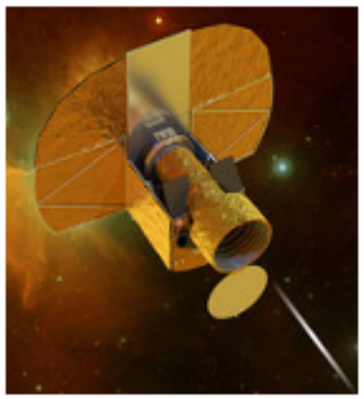
Almenara, Astudillo-Defru, Bonfils et al. 2015, A&A







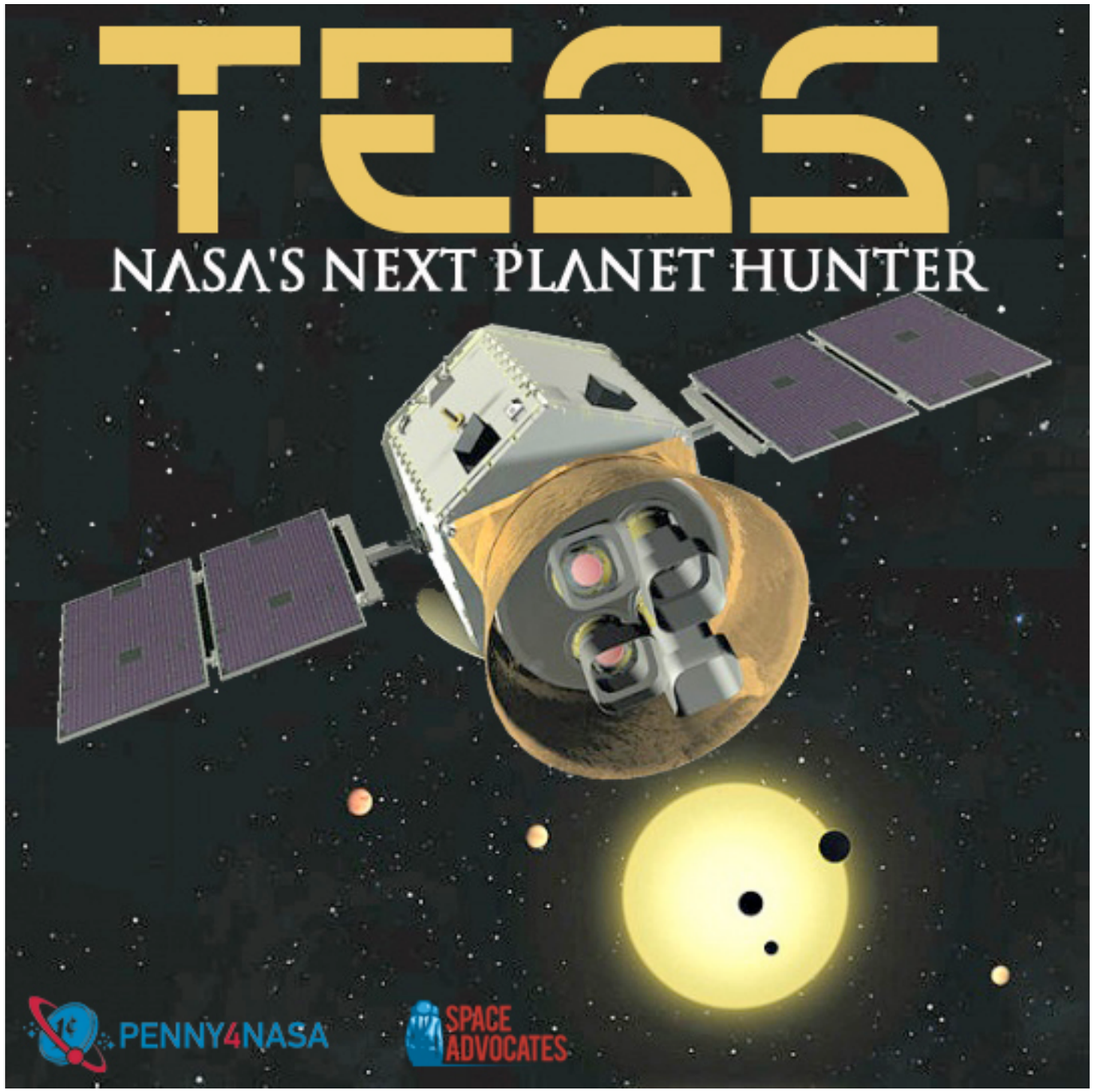
ExTrA

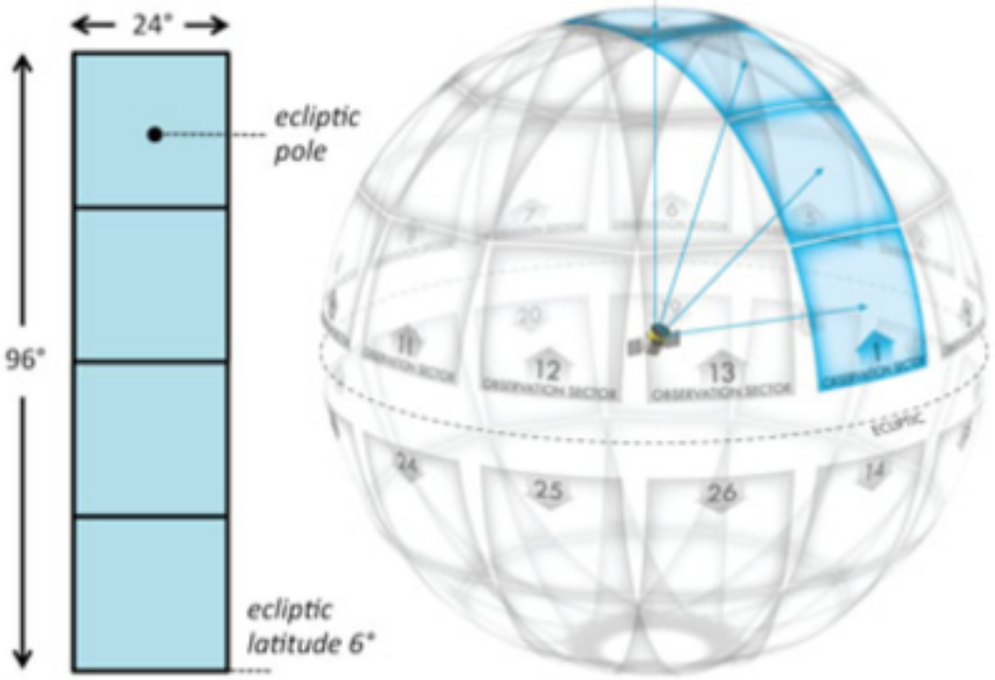


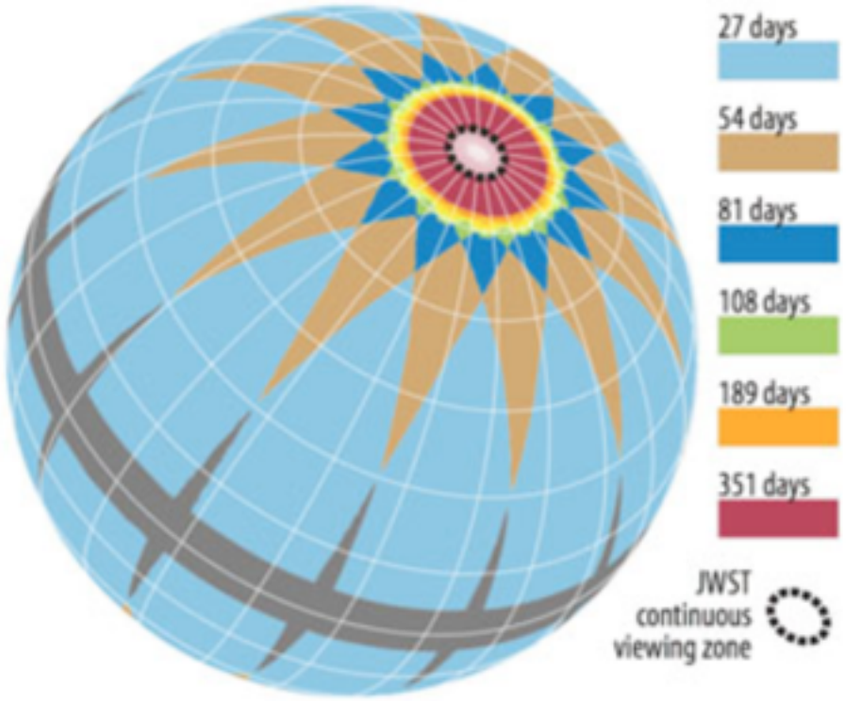
CHEOPS

CHARACTERISING EXOPLANET SATELLITE

TESS


TESS
NASA'S NEXT PLANET HUNTER
PENNY4NASA
SPACE ADVOCATES


24°
96°
ecliptic pole
ecliptic latitude 6°
ECLIPTIC POLE
12
13
25
26
ECLIPTIC


27 days
54 days
81 days
108 days
189 days
351 days
JWST continuous viewing zone

Sullivan et al. (2015)
http://arxiv.org/abs/1506.03845

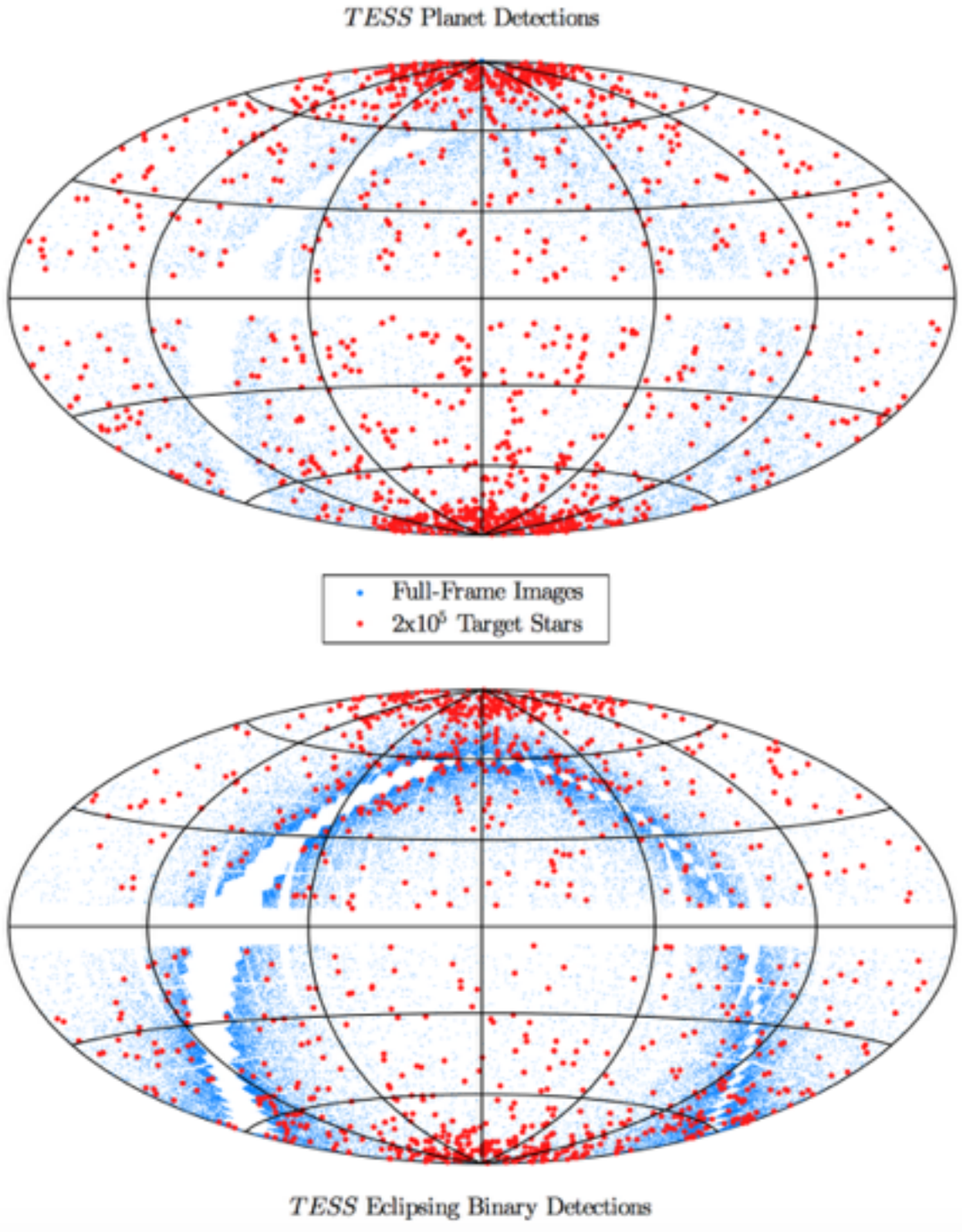
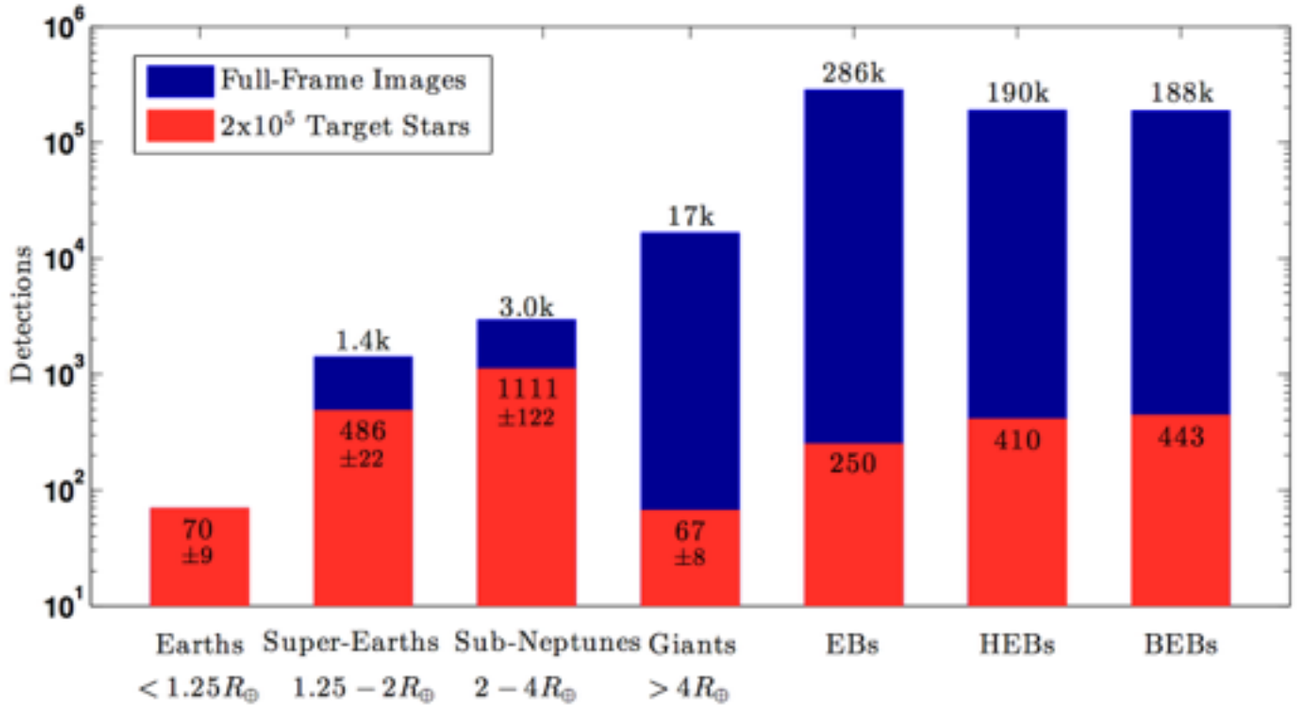
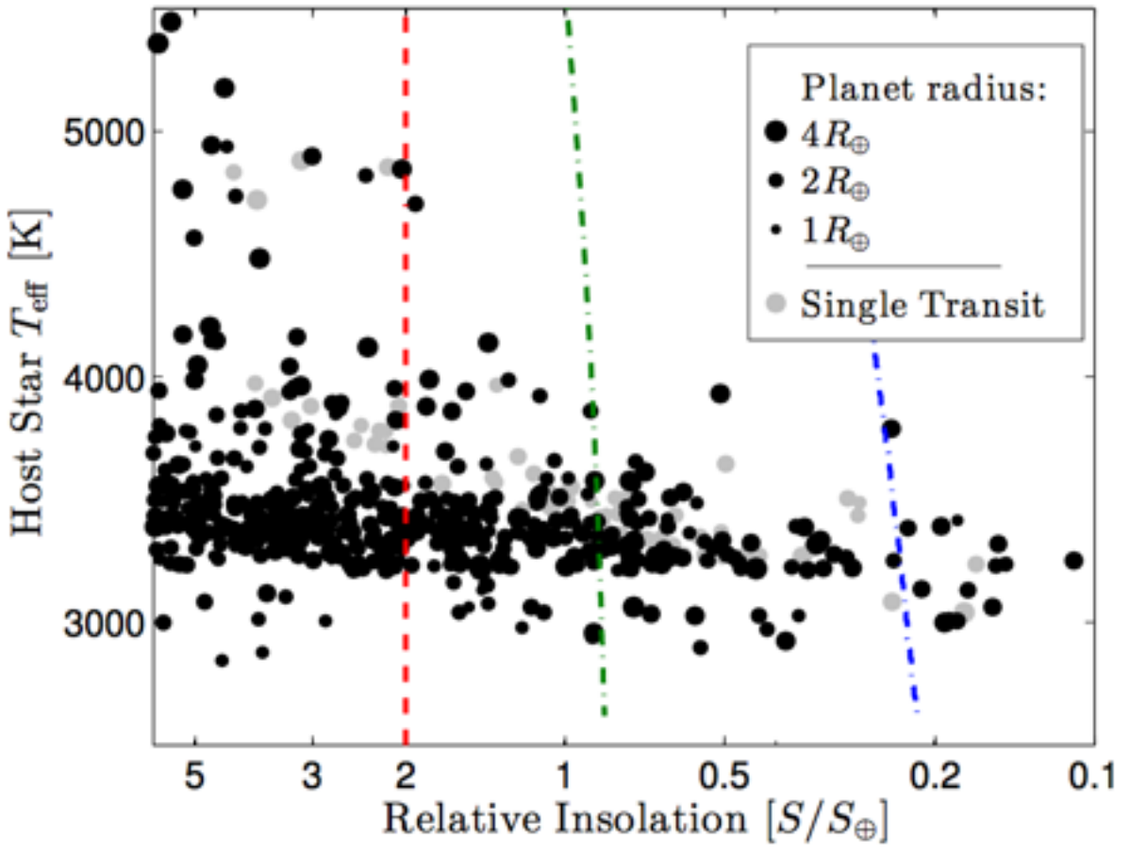


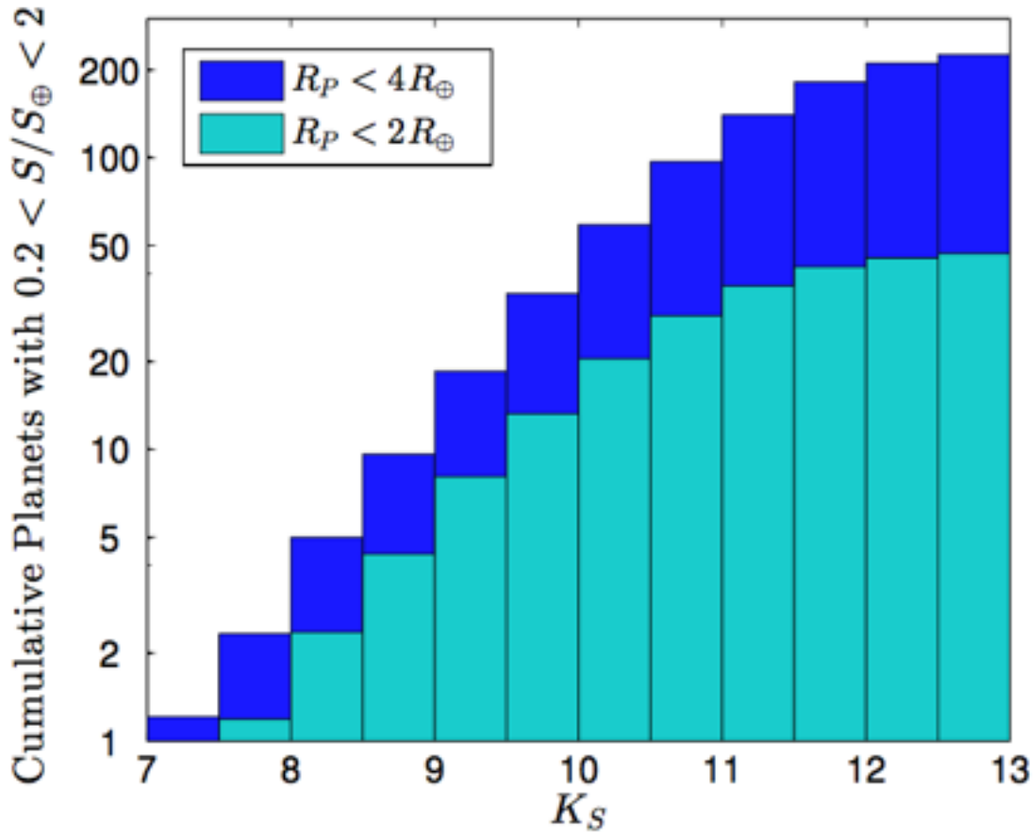
FIG. 19.— Sky maps of the simulated *TESS* detections in equal-area projections of ecliptic coordinates. The lines of latitude are spaced by 30°, and the lines of longitude are spaced by 60°. *Top.*—Planet detections. Red points represent planets detected around target stars (2 min cadence). Blue points represent planets detected around stars that are only observed in the full-frame images (30 min cadence). Note the enhancement in the planet yield near the ecliptic poles, which *TESS* observes for the longest duration. Note also that the inner 6° of the ecliptic is not observed. *Bottom.*—Astrophysical false positive detections, using the same color scheme. For clarity, only 10% of the false positives detected in the full-frame images are shown. (All other categories show 100% of the detections from one trial.) Note the enhancement in the detection rate near the galactic plane, which is stronger for false positives than for planets.

TESS

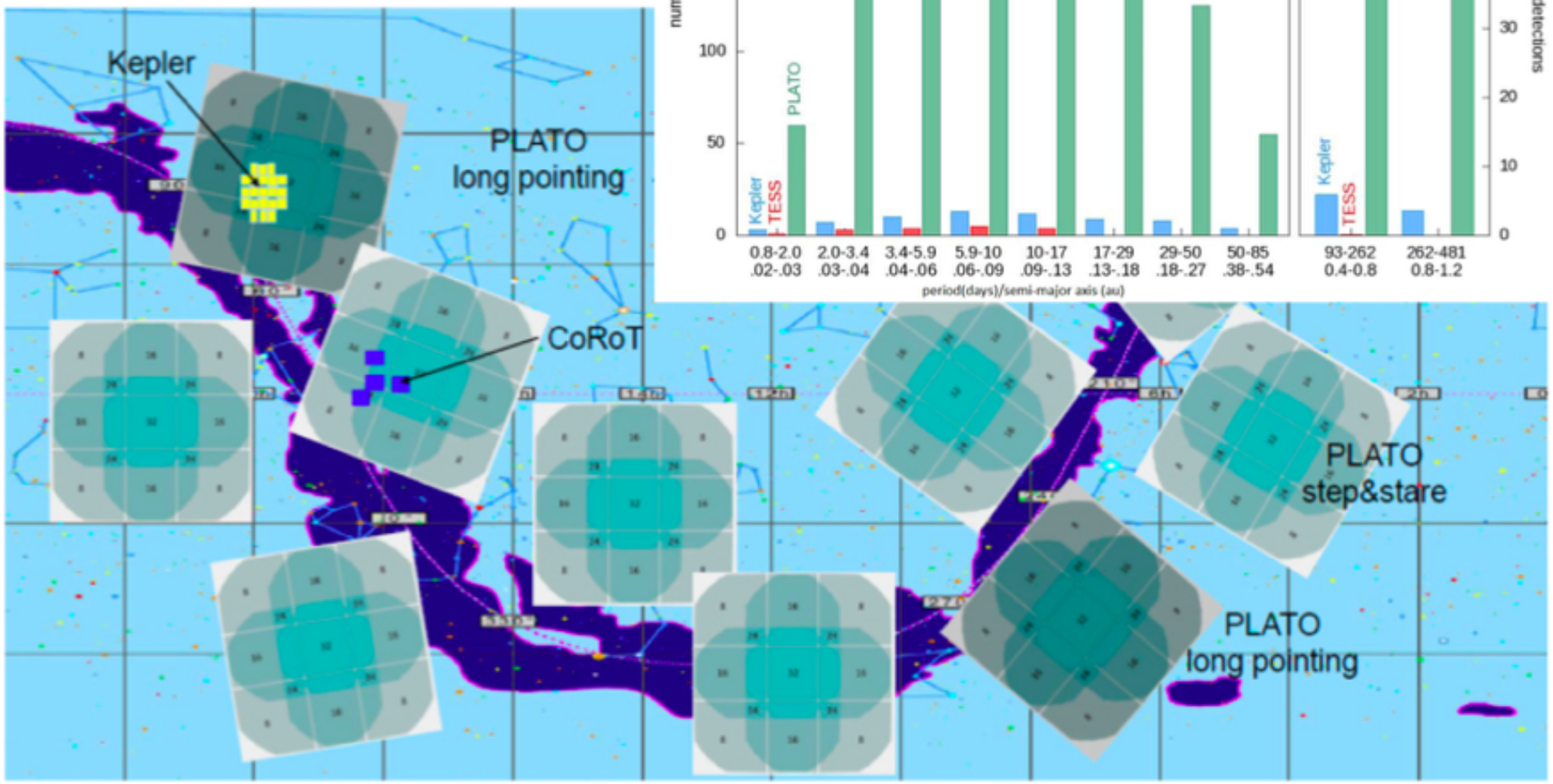
Sullivan et al. (2015)
http://arxiv.org/abs/1506.03845

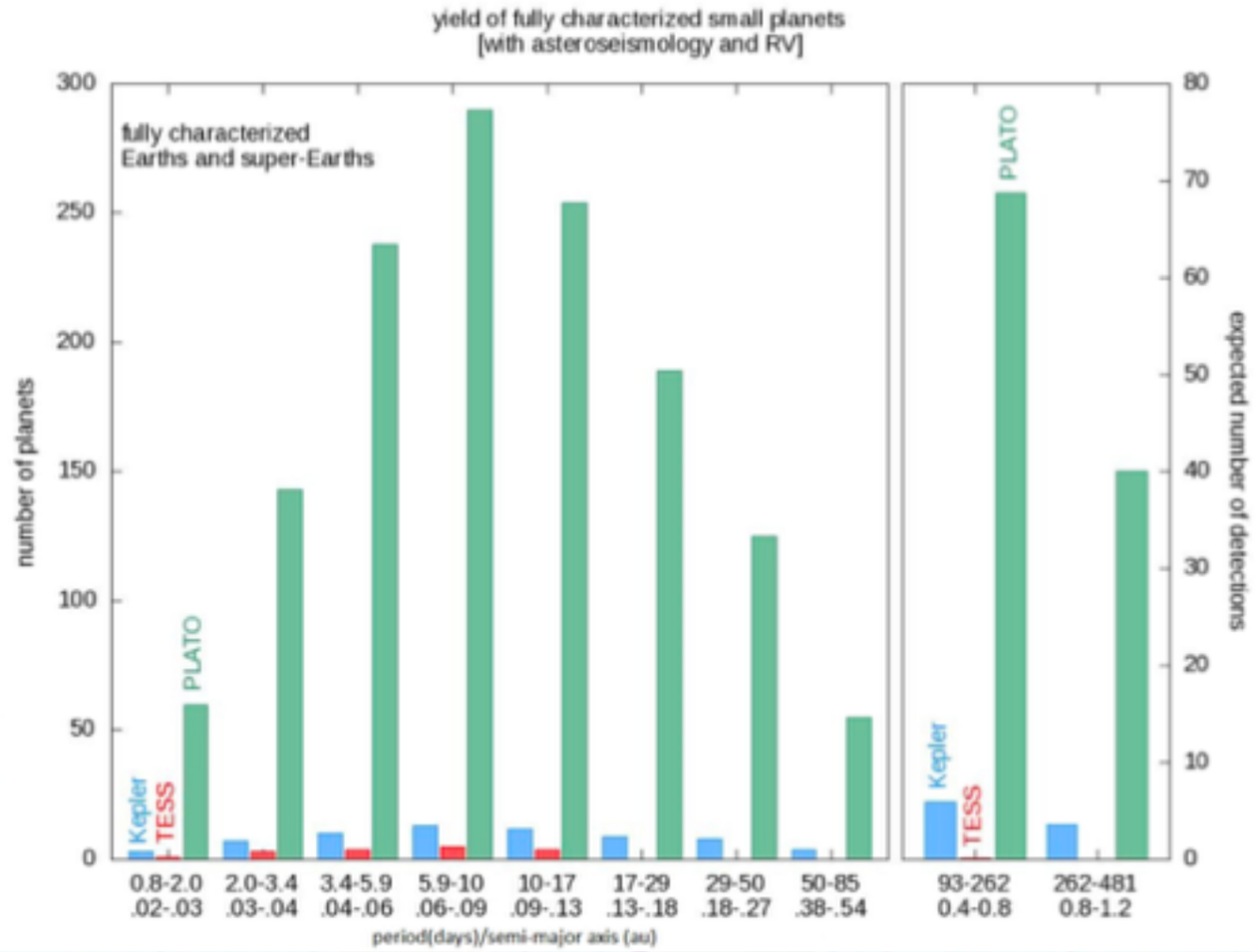






PLATO:
Radii, Masses, & Asteroseismology
$4 < m_V < 11$

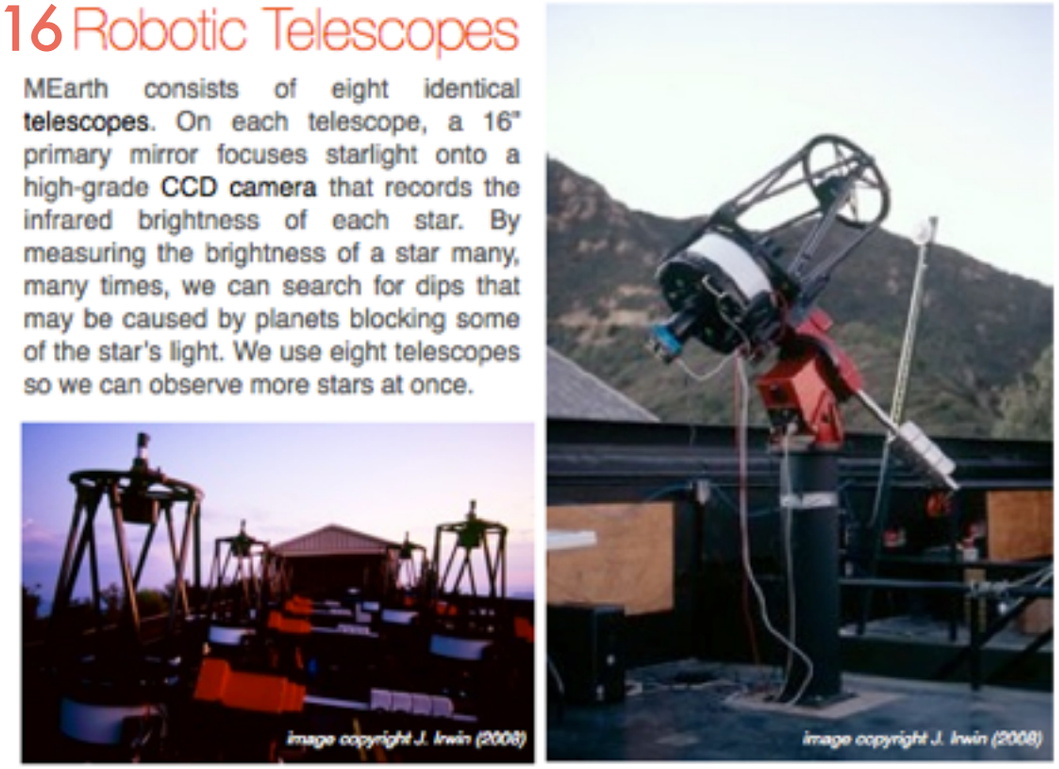


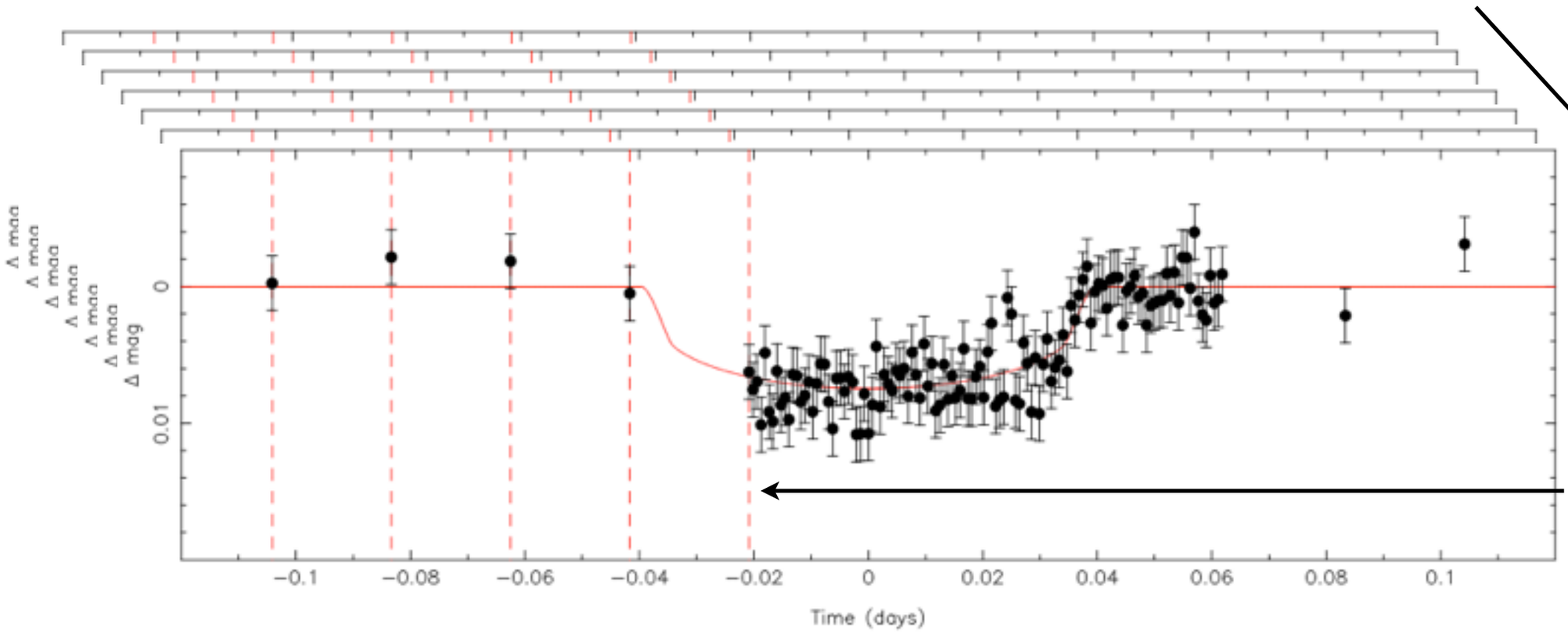


The MEarth Survey

P.I. D. Charbonneau (Harvard)

- 8 (+8) telescopes (⌀=40cm, fov=25'x25')
- CCD cameras 2048x2048 15μm
- 1 M dwarf per field
- each telescope cycles on ~10 fields
- effectively observing 16x10=160 stars at a time





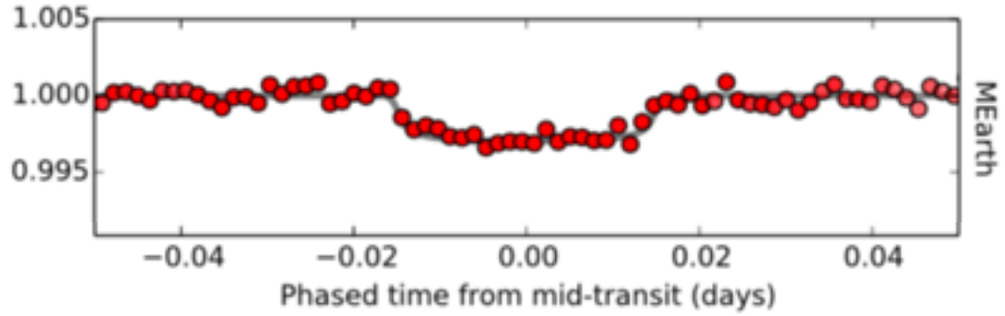


Figure 1a | Photometric measurements of GJ1132 in 2 min-bins of phased-folded time relative to mid-transit.

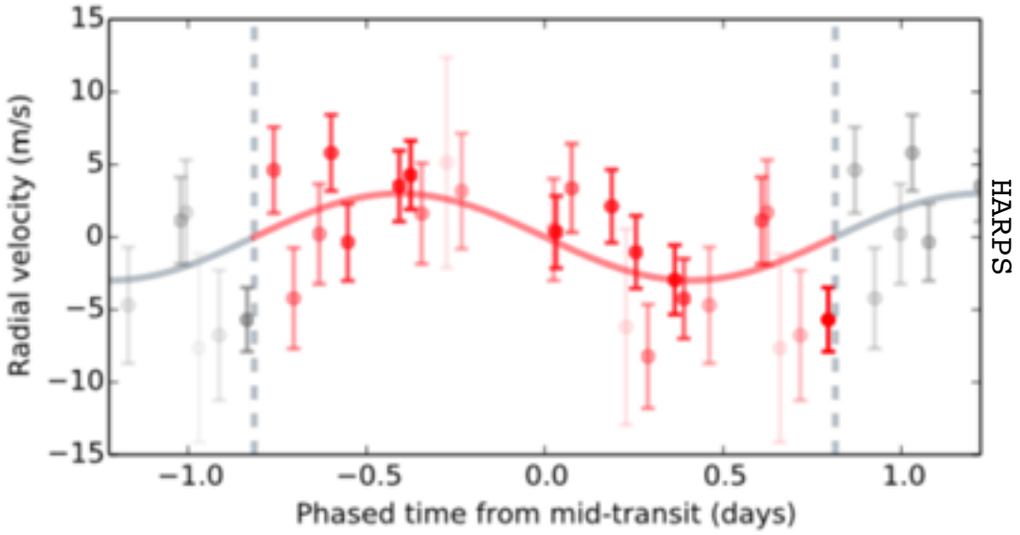


Figure 1b | Radial-velocity change over the orbit of GJ1132b.

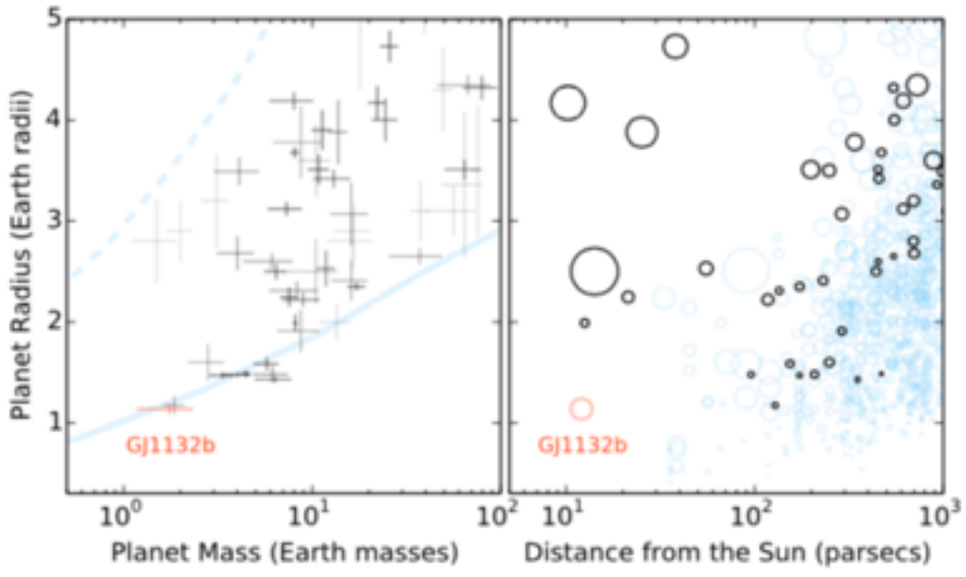
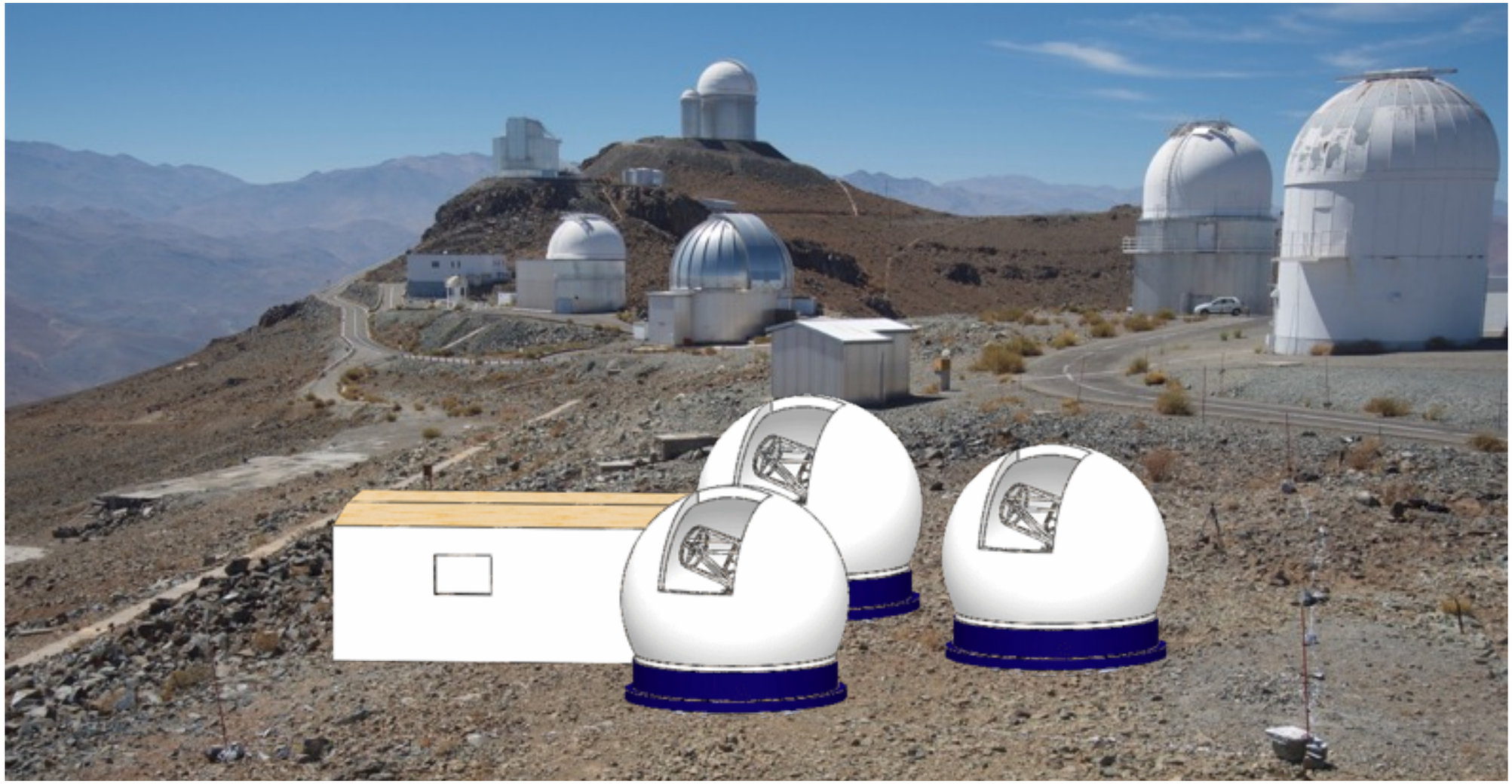


Figure 1c | GJ1132b in context. Masses, radii and distances of known transiting planets.

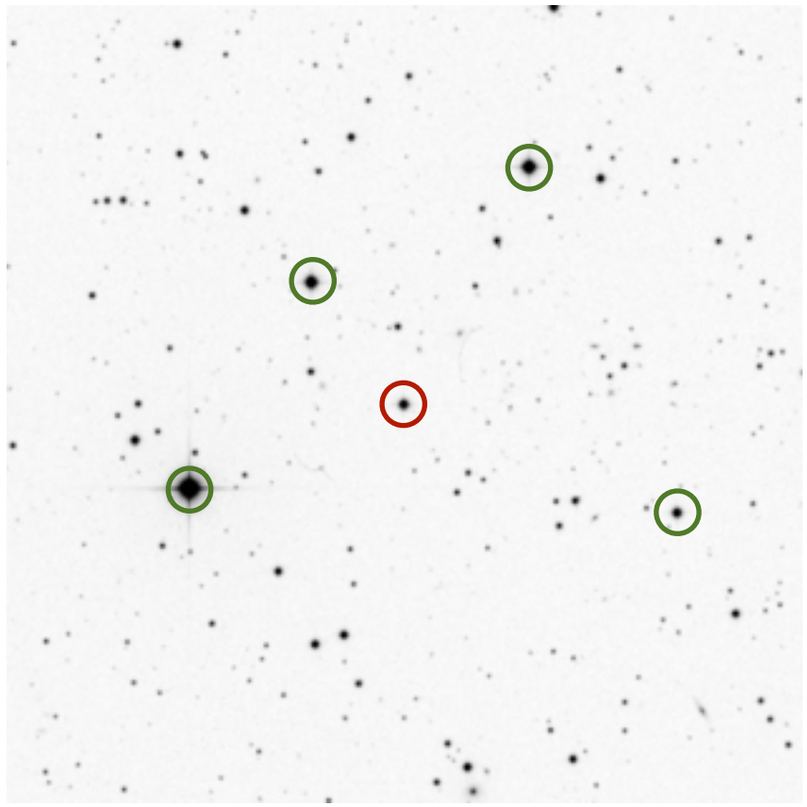
A rocky planet transiting a nearby low-mass star

ExTrA

Exoplanets in Transit and their Atmospheres



Differential photometry



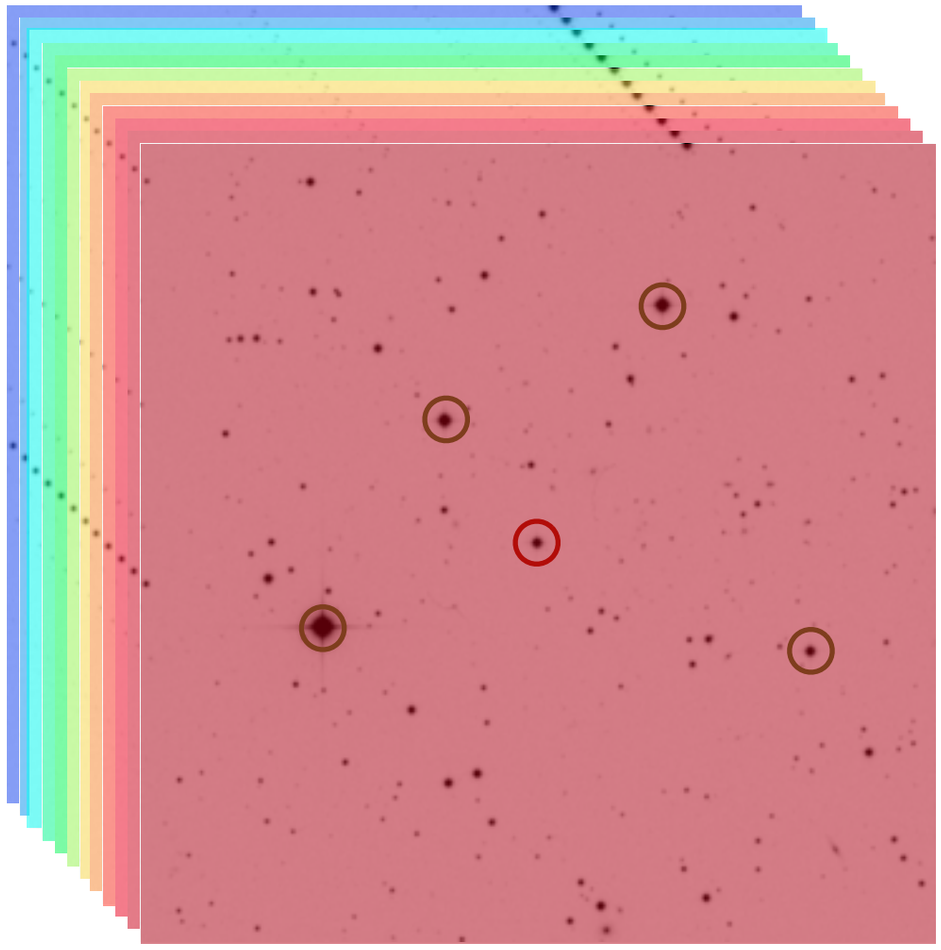
Method

- integrate flux in aperture
- normalize w/ comparison stars
- de-trend

Limitations

- atmosphere (imperfect comparisons)
- photon noise (small telescopes)
- detector (imperfect flat field)

An extra method



Differential spectro-photometry
with a Multi-Object Spectrograph

Correction of atmospheric variation

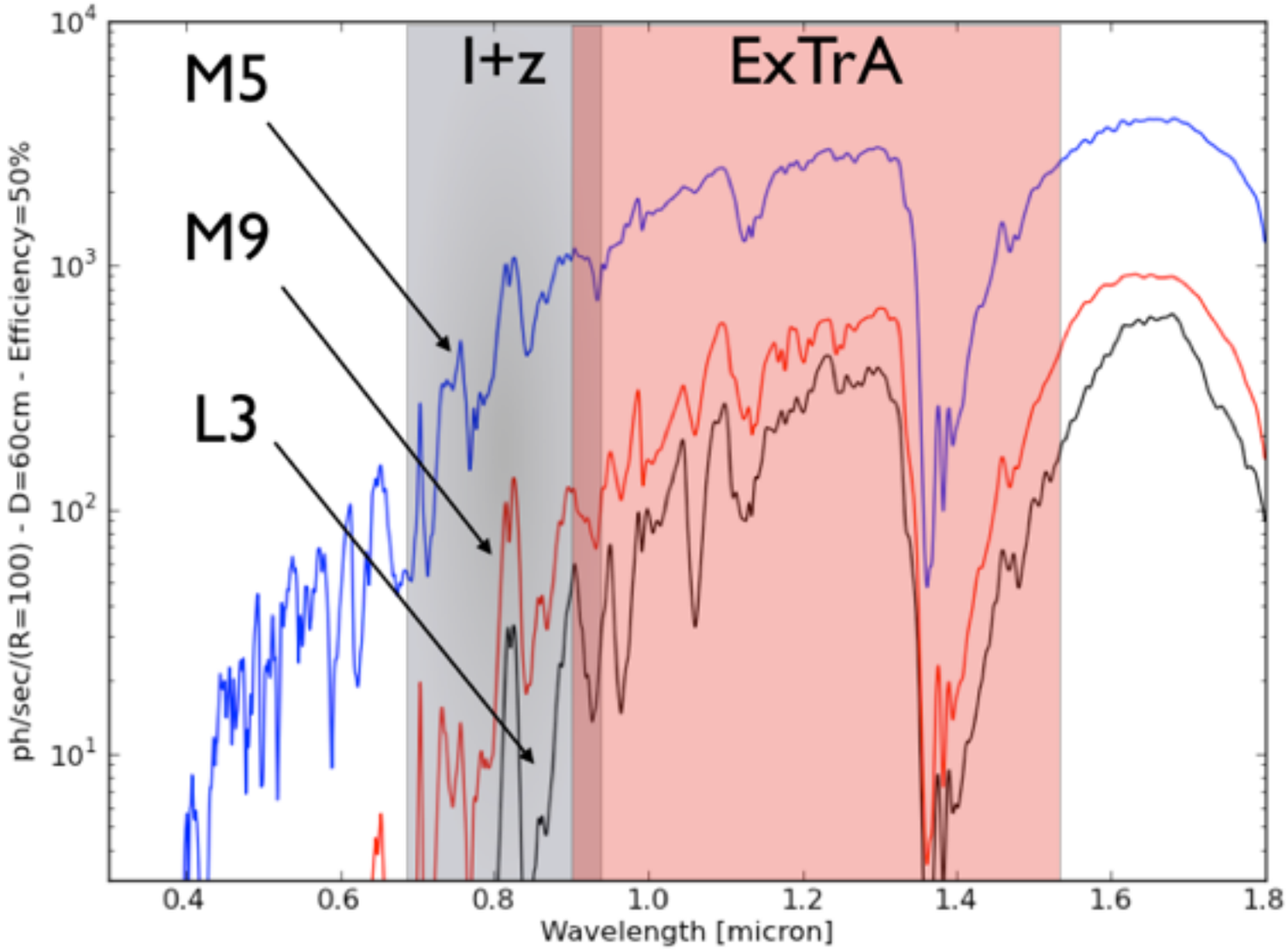
- small Δλ => perfect comparisons
- after correction, resolution is degraded to boost the S/N

More photons

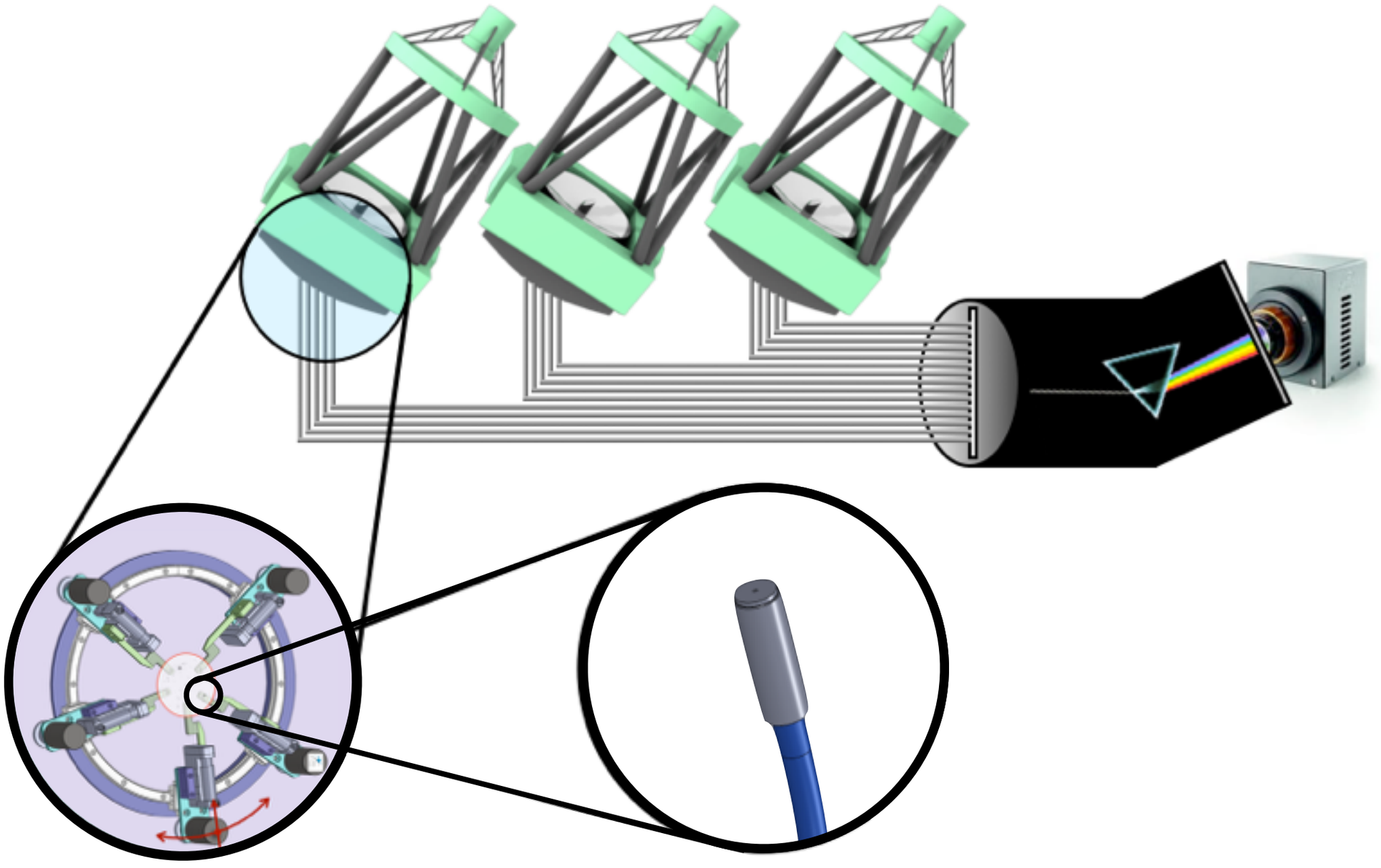
- larger spectral window
- infrared
- decrease detector systematics

An extra method

Spectral Energy Distribution



- 9-40 times more flux for M5-L3 dwarfs

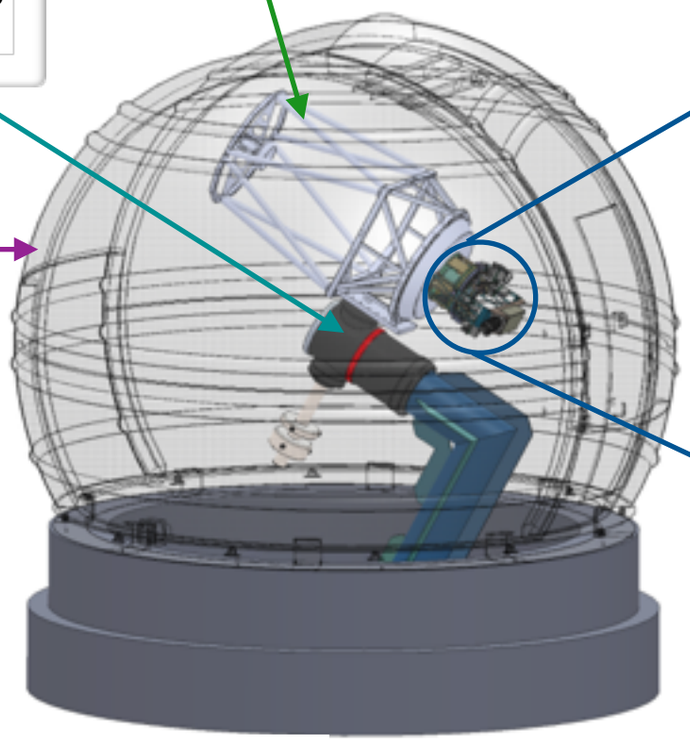


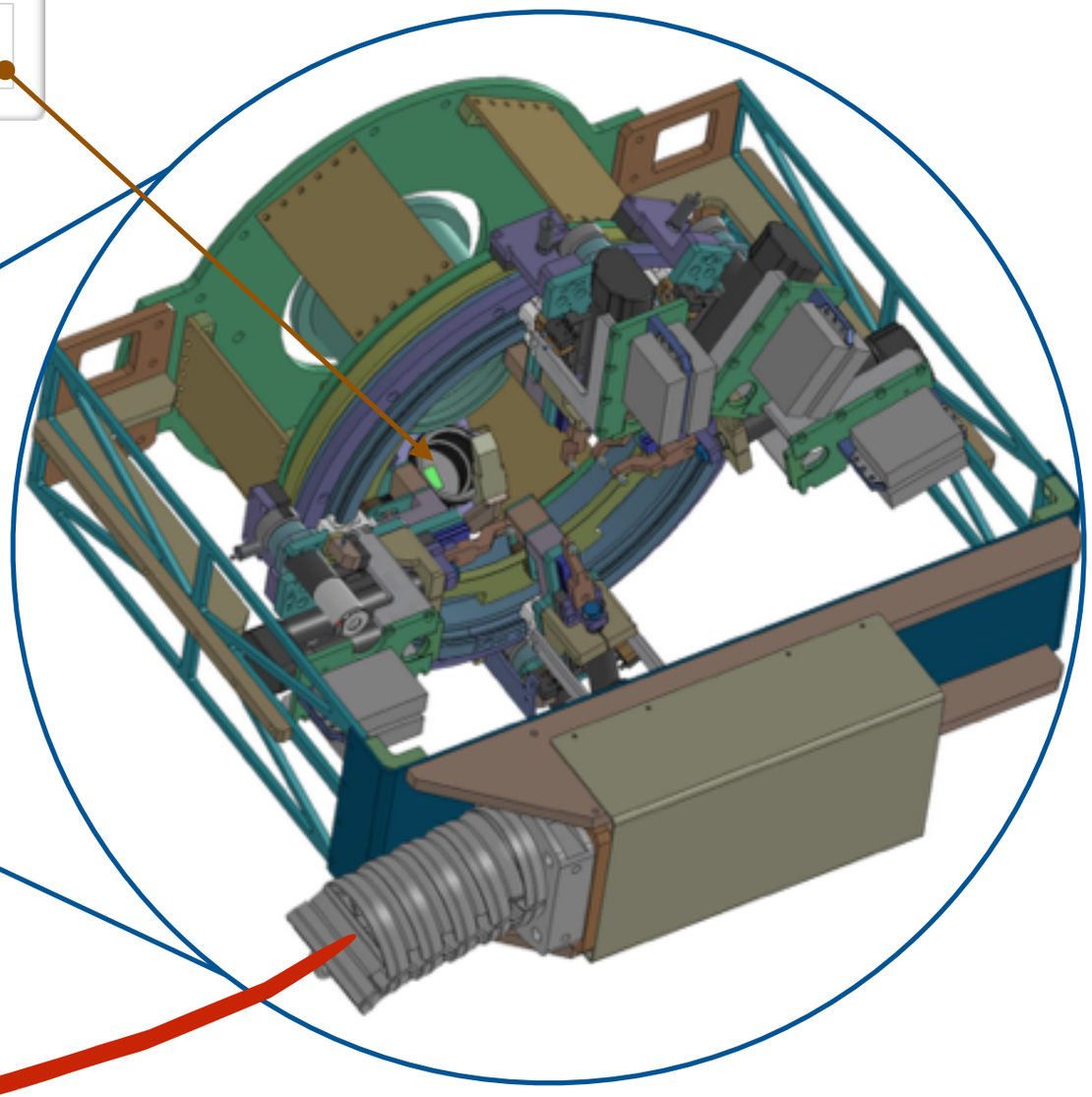
ASA 600 RC

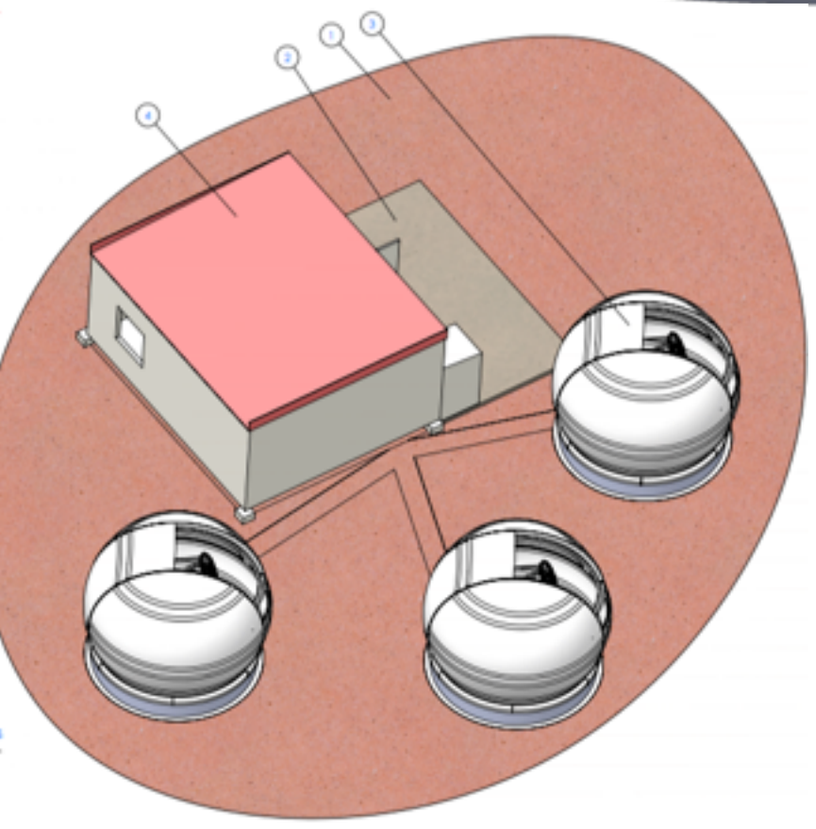
Off-axis Guiding Camera
Trius H16

ASA DDM160
Direct Drive

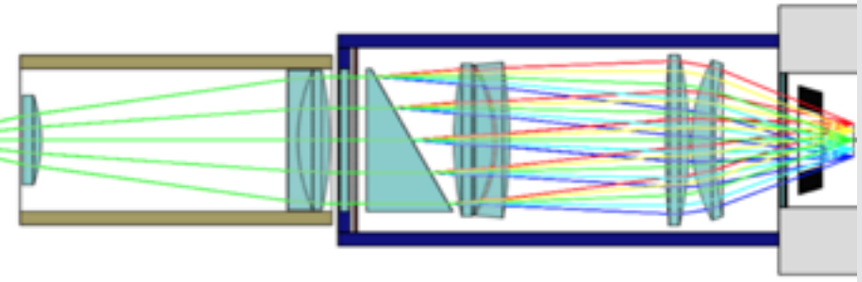
4m Dome
Scopedome







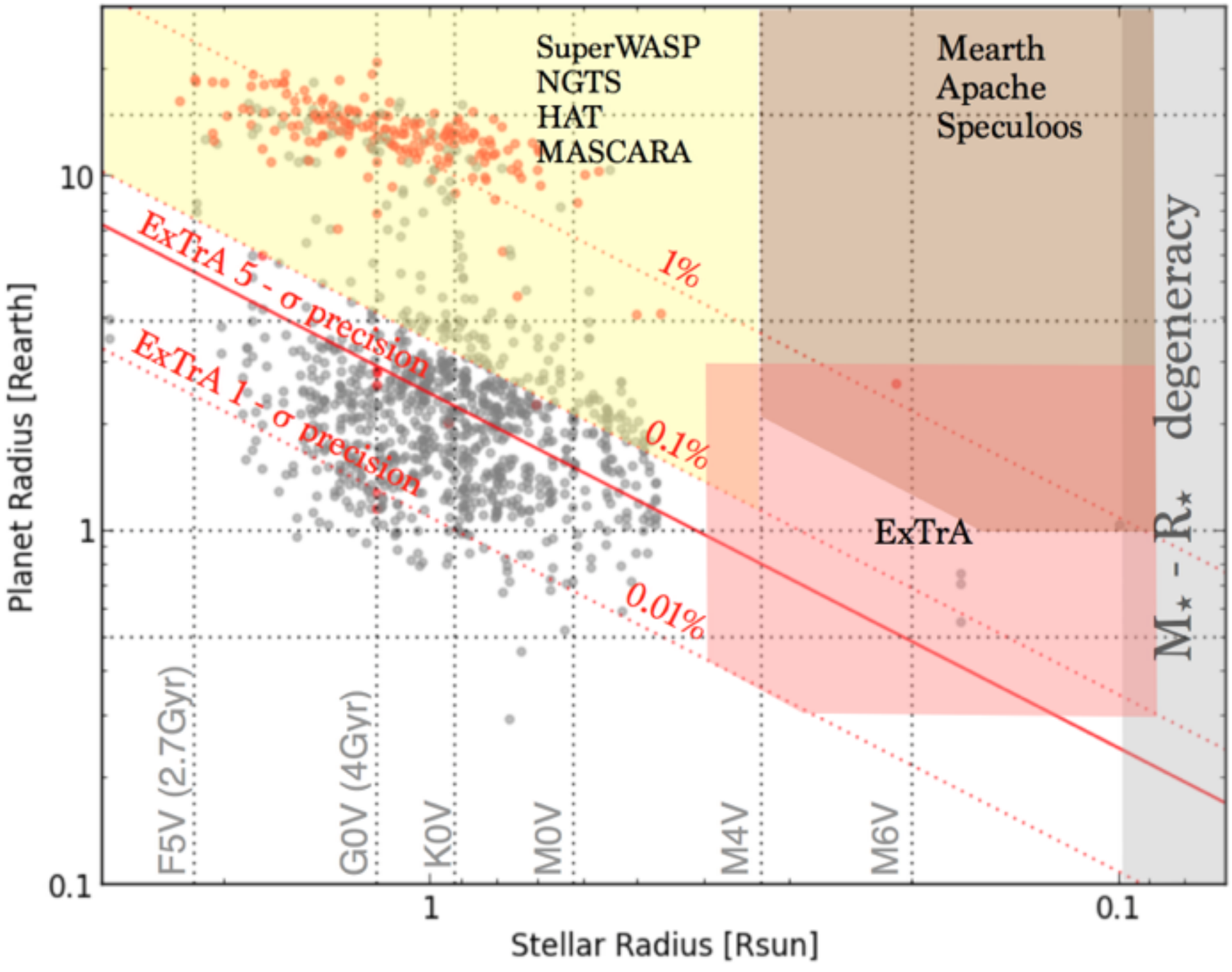
Fiber link

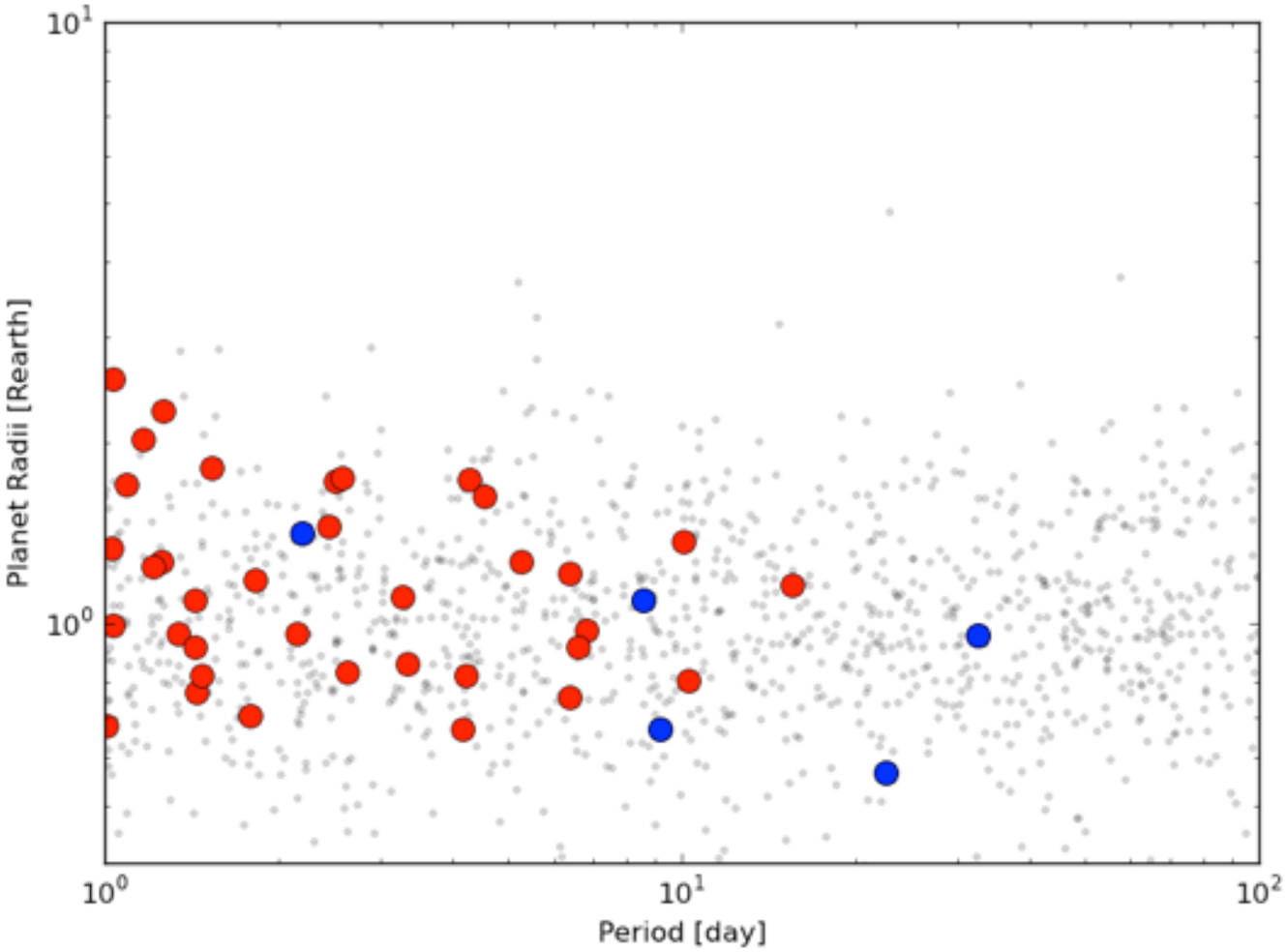


Spectrograph
0.8-1.55 μm
R = 200

Princeton / Xenics
InGaAs 640x512
LN2 cooled (-190C)

Parameter space of transit surveys




10^1
10^0
Planet Radii [Rearth]
10^0
10^1
10^2
Period [day]

Conclusion

- on est proche de détecter des exo-Terres
  (taille, masse et température proches de celles de la Terre)
- autant avec des observatoires spatiaux que sols
  (et avec leur synergie)
- les nouveaux télescopes géants (JWST & ELTs) pourraient y détecter des bio-marqueurs