Pathways towards habitable planets

Bern - 15 July 2015

Towards the detection of nearby exo-Earths

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Key Question 6:

"What can we expect from approved projects ?"

- Which are the approved projects with the capability to detect (massively) small planets in HZ ?

- What are the astrophysical limitations that might not allow those projects to detect (massively) small planets in HZ ?

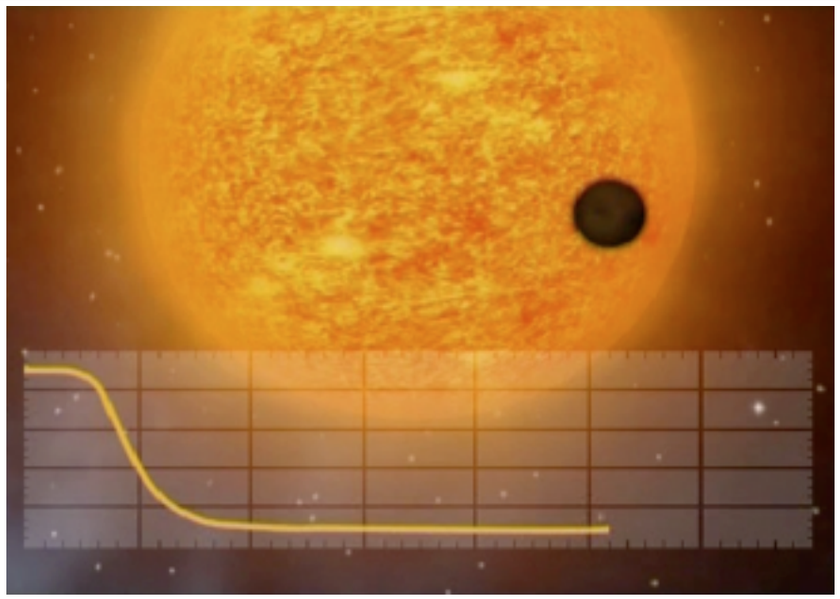
⚠ Disclaimer ⚠

This review is not an *exhaustive* catalog of approved projects !

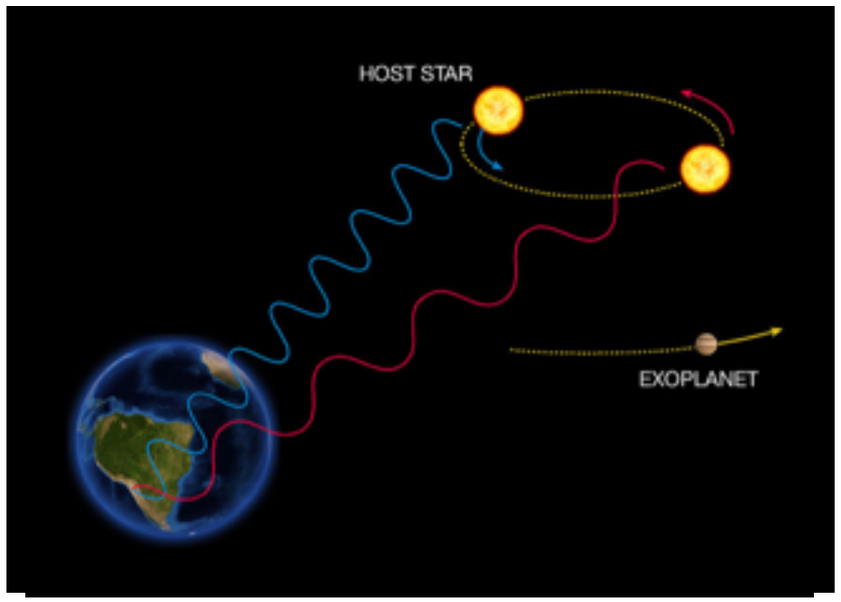
might be biased towards European projects

- For CHEOPS: see talk by Andrea Fortier
- For JWST: see talks by Mark Clampin & Pierre-Olivier Lagage (tomorrow)
- For LBT: see talk by Philip Hinz (tomorrow)

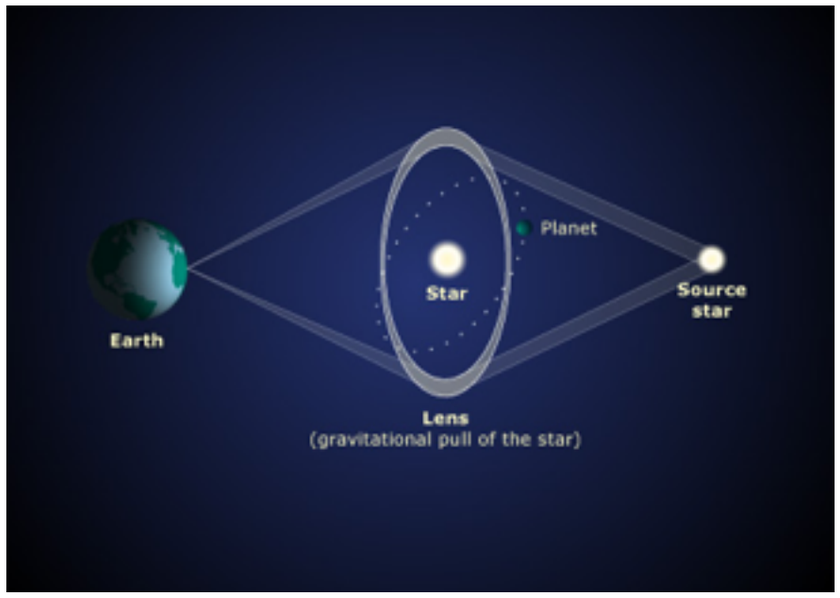
Different techniques …



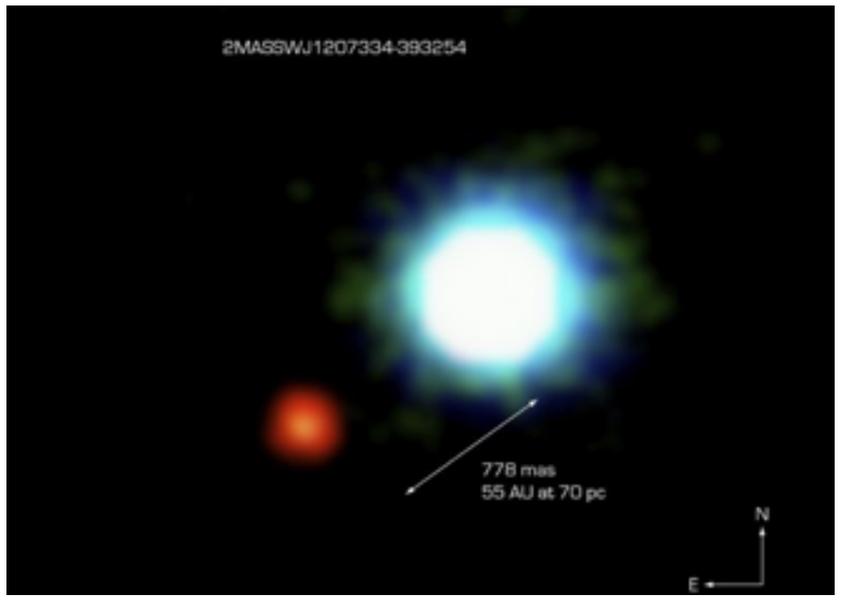
Transit



Radial velocity

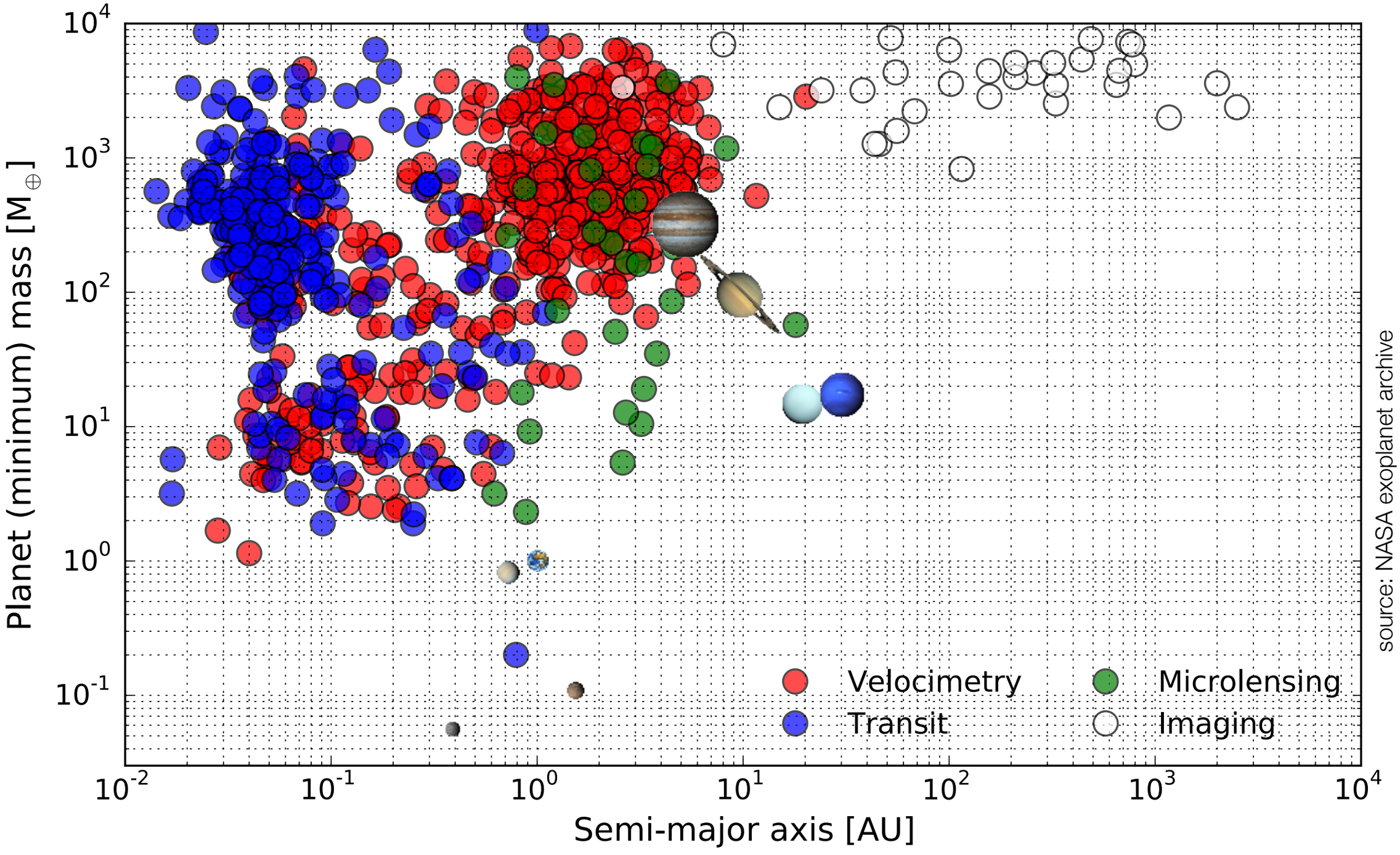


Microlensing

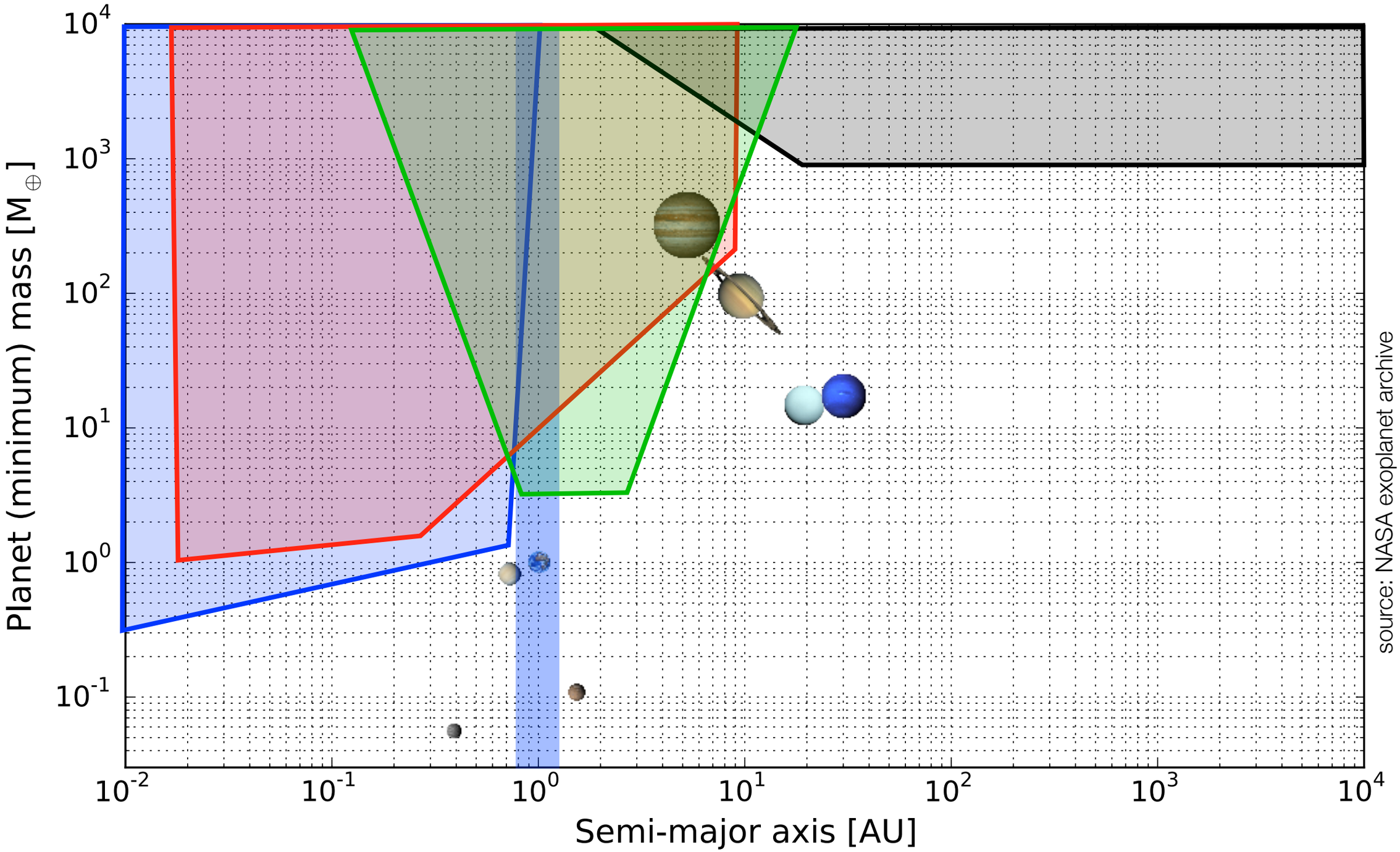


Direct imaging

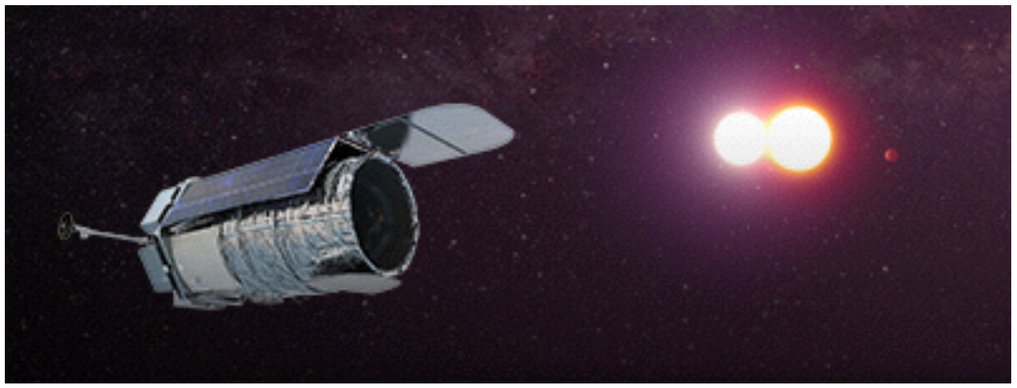
Different techniques … different sensitivities



Different techniques … different sensitivities

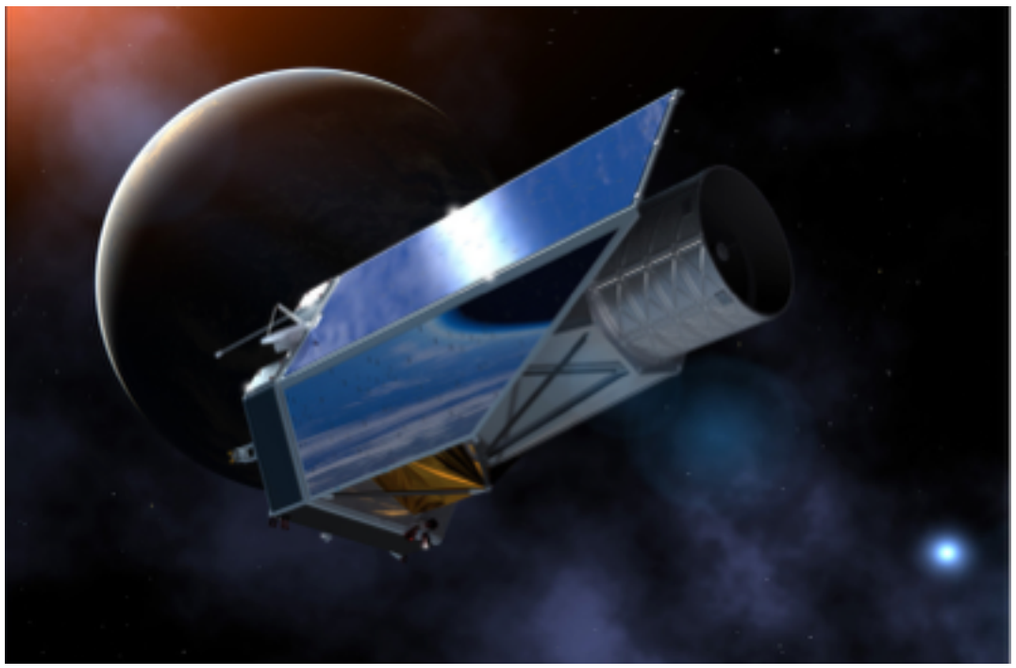


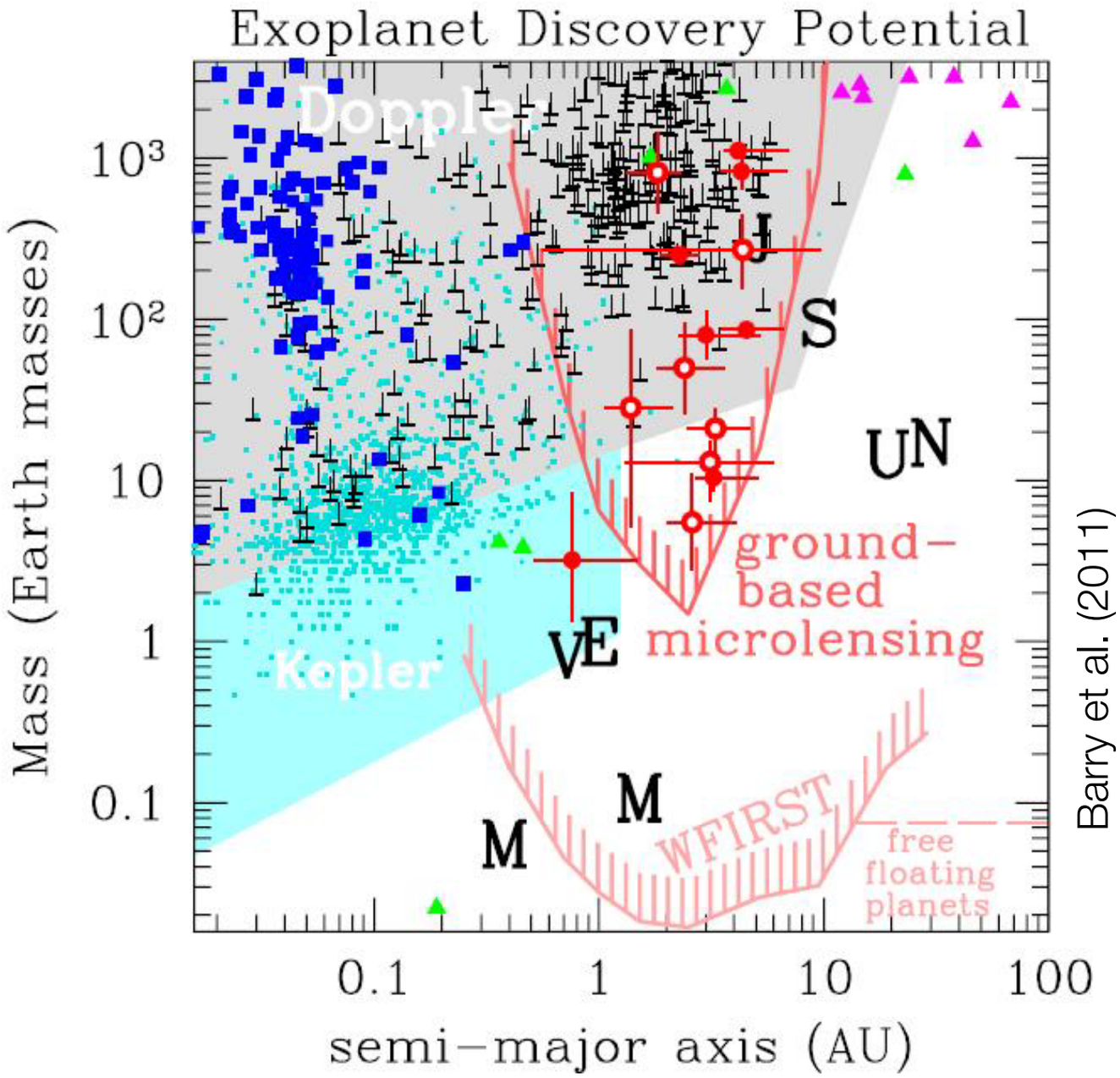
Microlensing exoplanets with WFIRST & EUCLID



WFIRST - NASA (2018+)

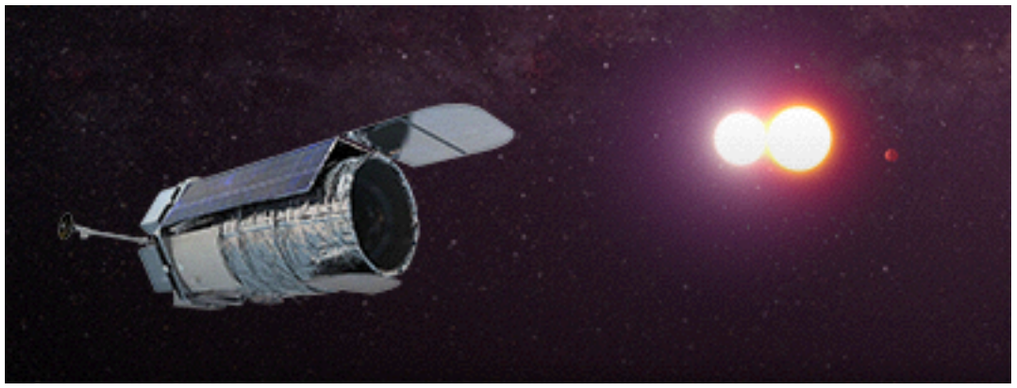
Euclid - ESA (2020+)





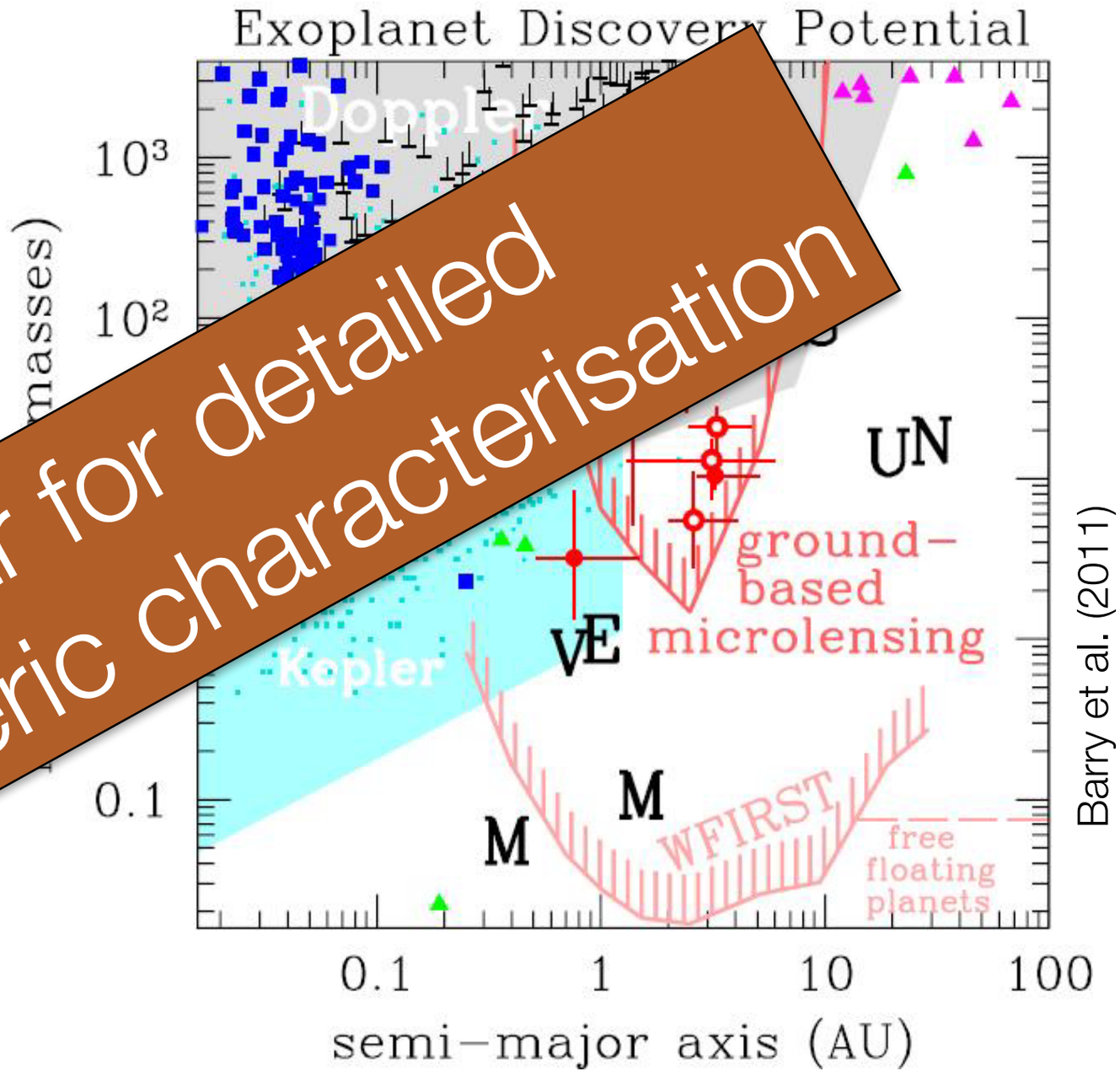
see also Beaulieu et al. (2011)

Microlensing exoplanets with WFIRST & EUCLID



WFIRST - NASA (2018+)

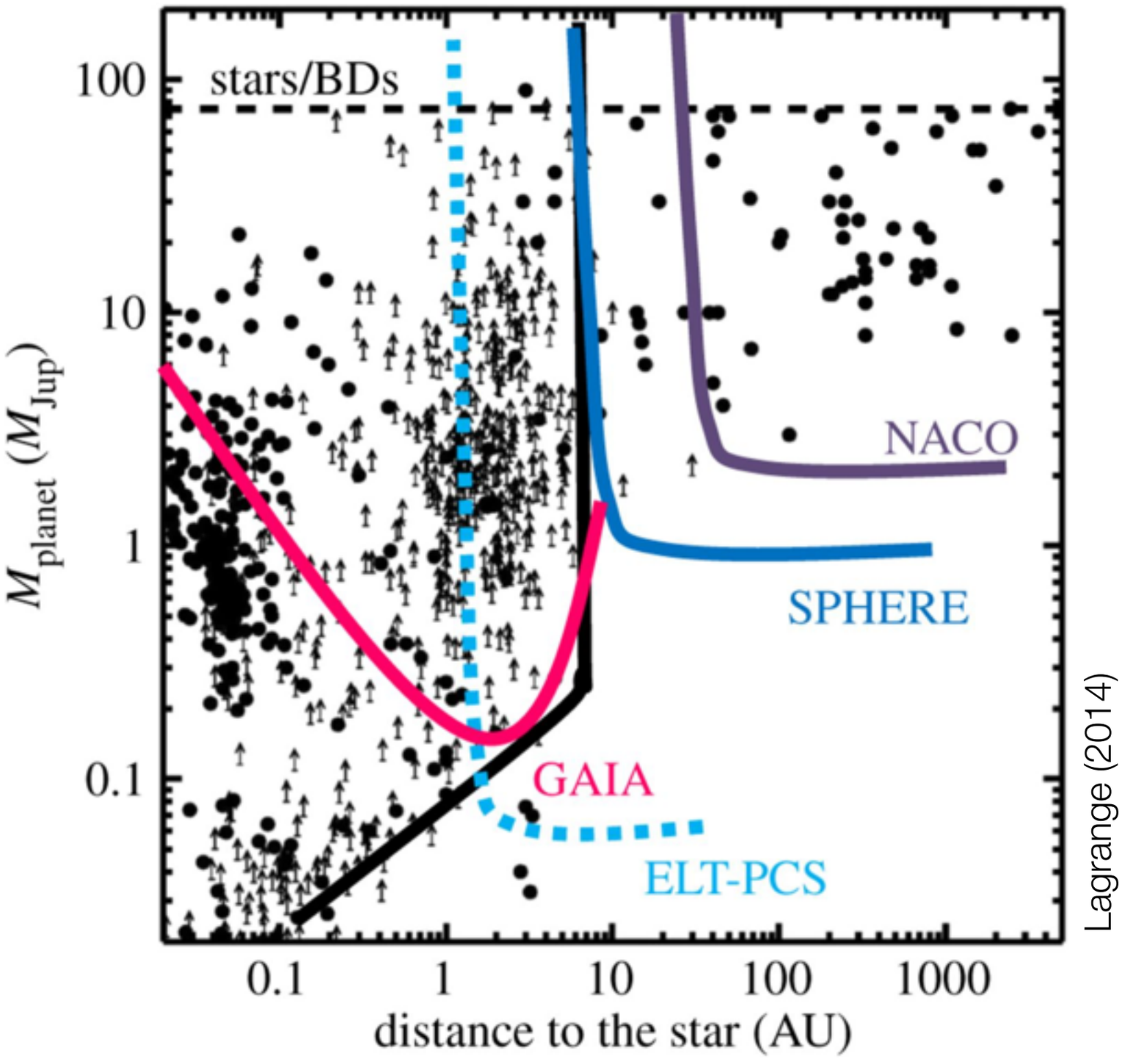
Euclid - ESA (20



Too far for detailed atmospheric characterisation

see also Beaulieu et al. (2011)

Direct imaging from the ground

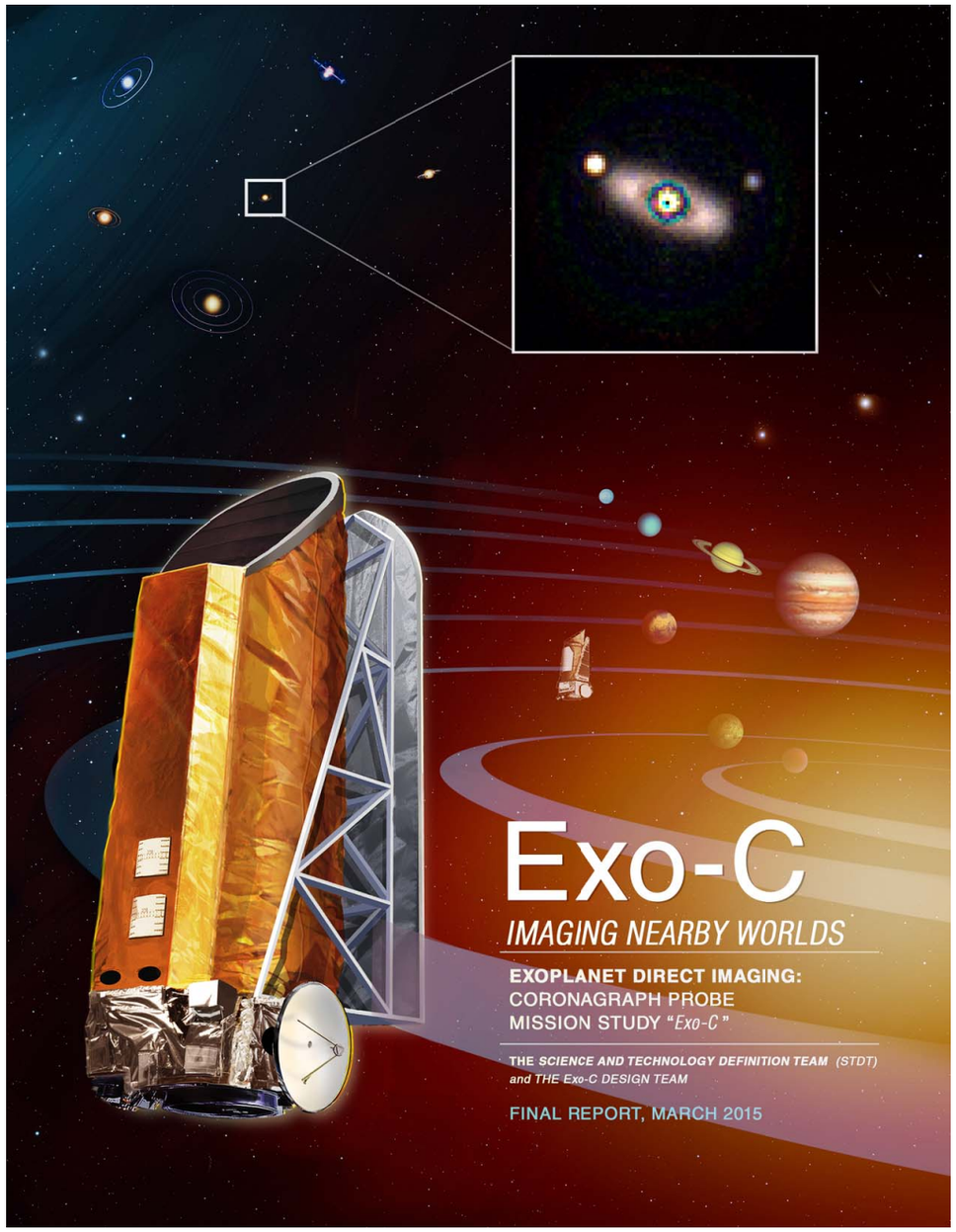


Lagrange (2014)

HZ planets will be imaged directly with ELTs - but only (sub-)giant planets

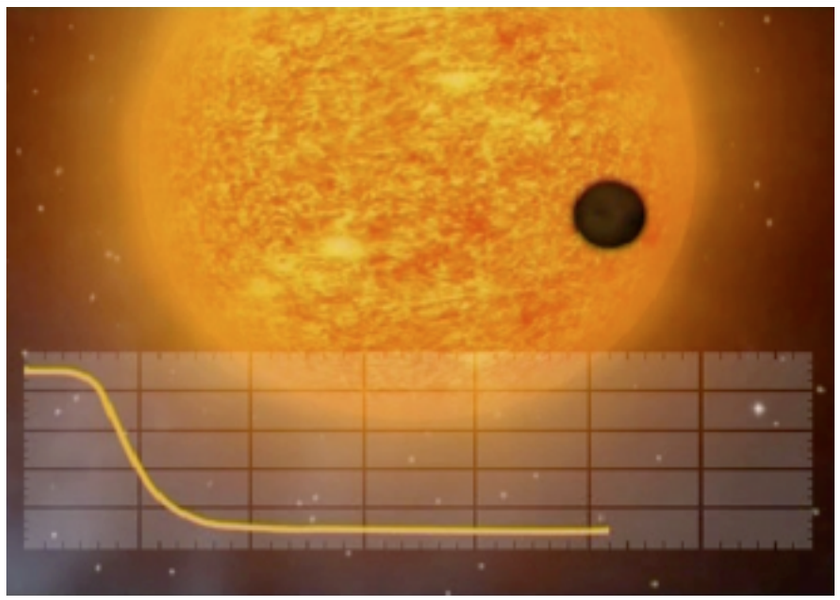
Same for GAIA

Direct imaging from space (2025+)

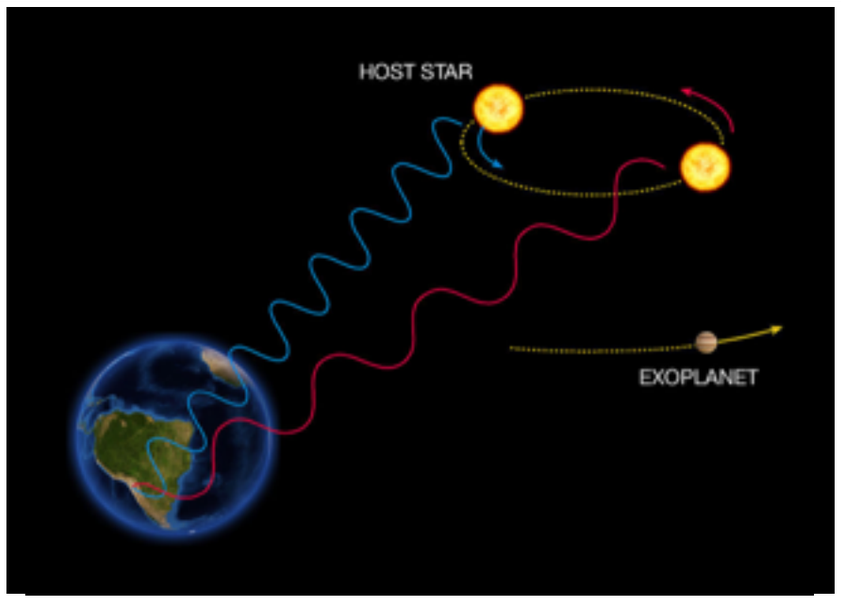


Small planets in HZ around very close stars (e.g. α Cen)

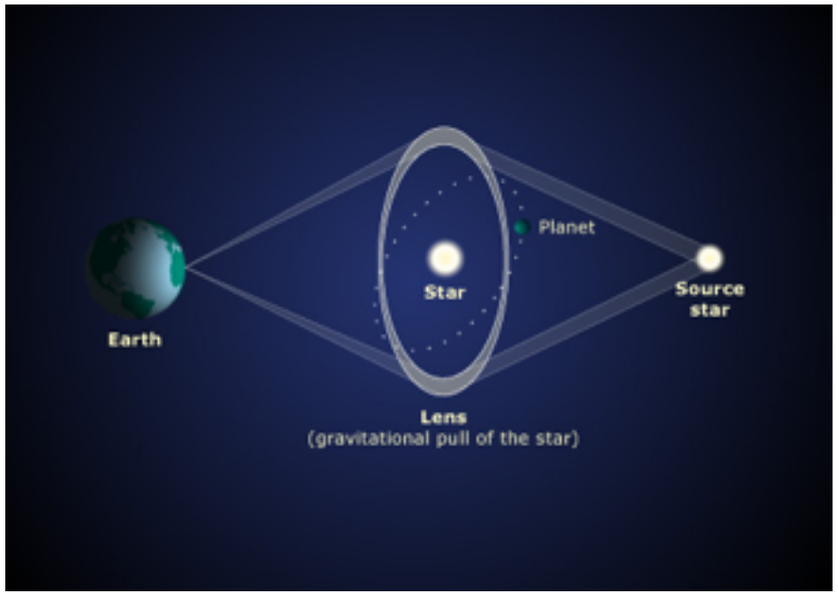
Detecting planets in HZ



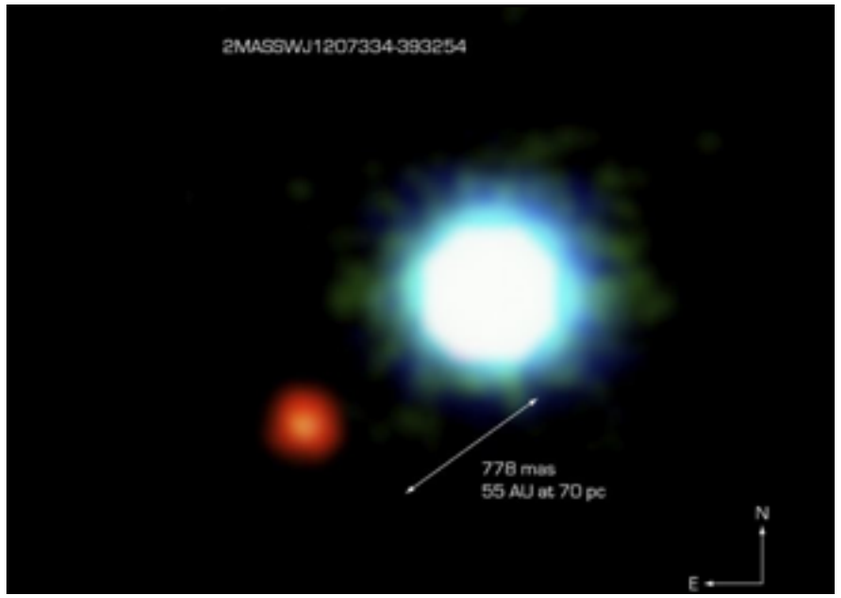
Transit



Radial velocity

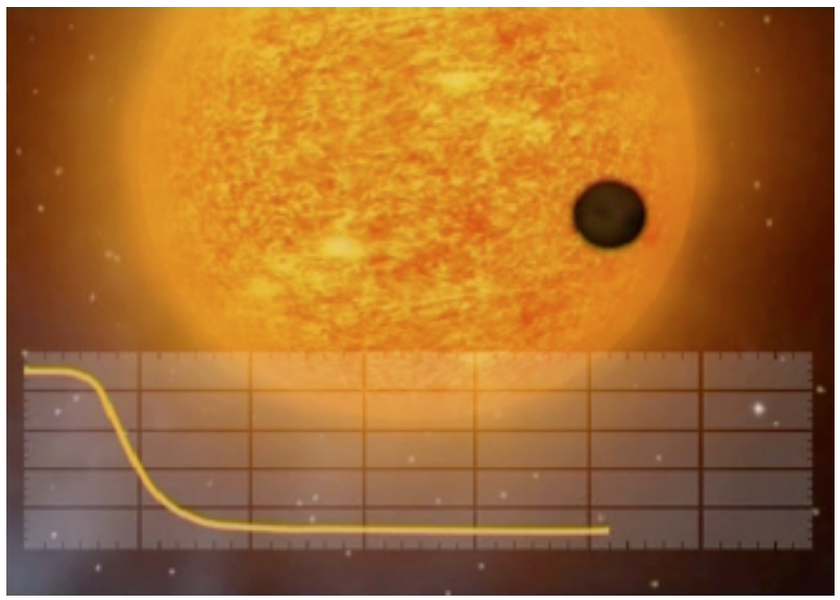


Microlensing



Direct imaging

Detecting planets in HZ



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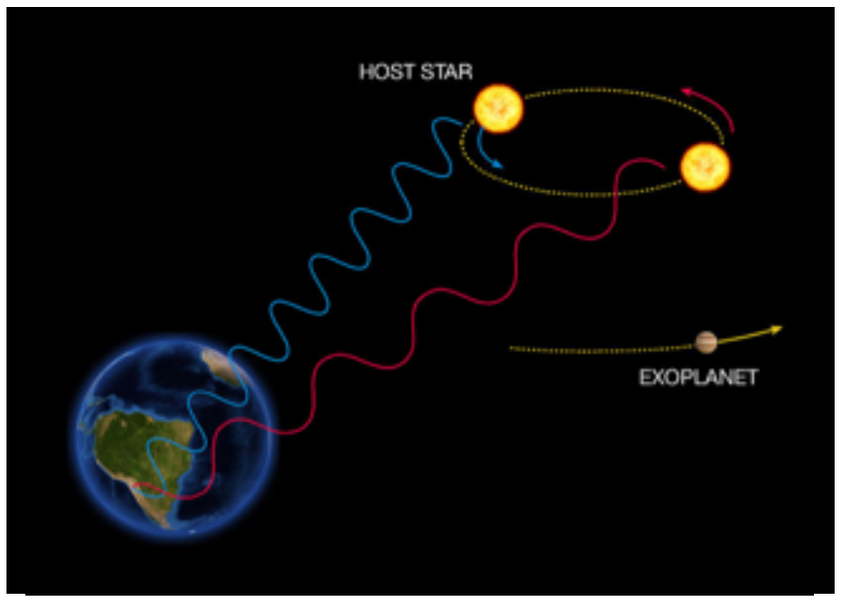

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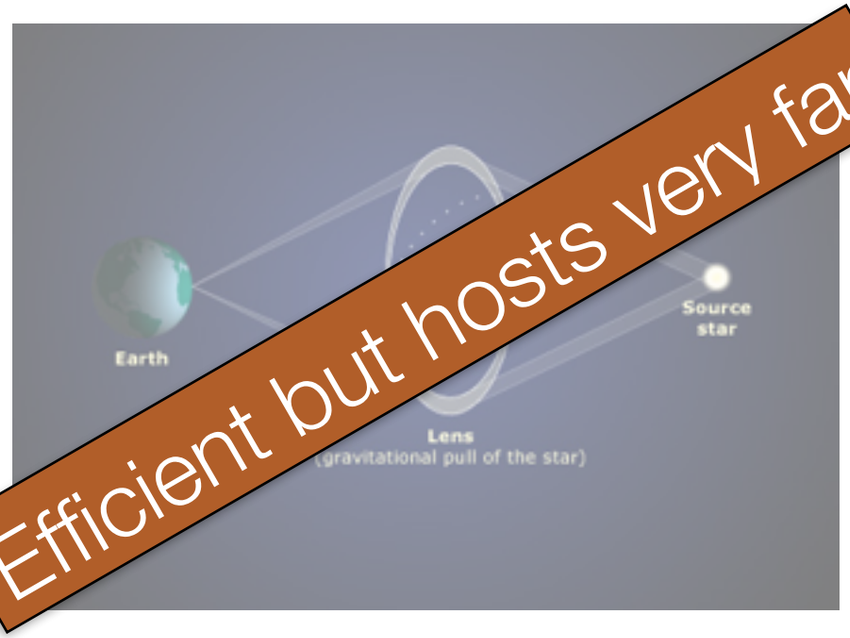


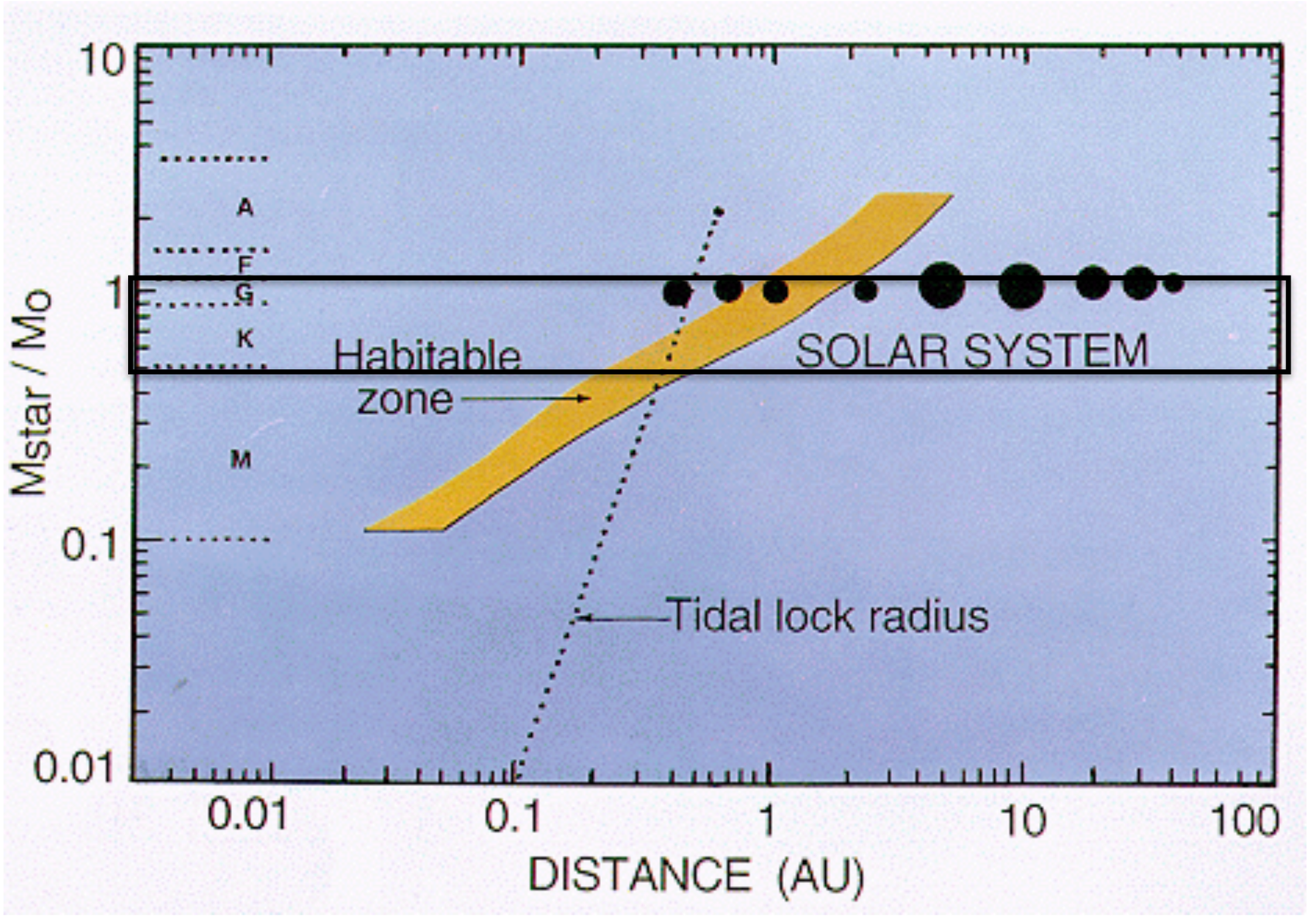
Efficient but hosts very far

Microlensing

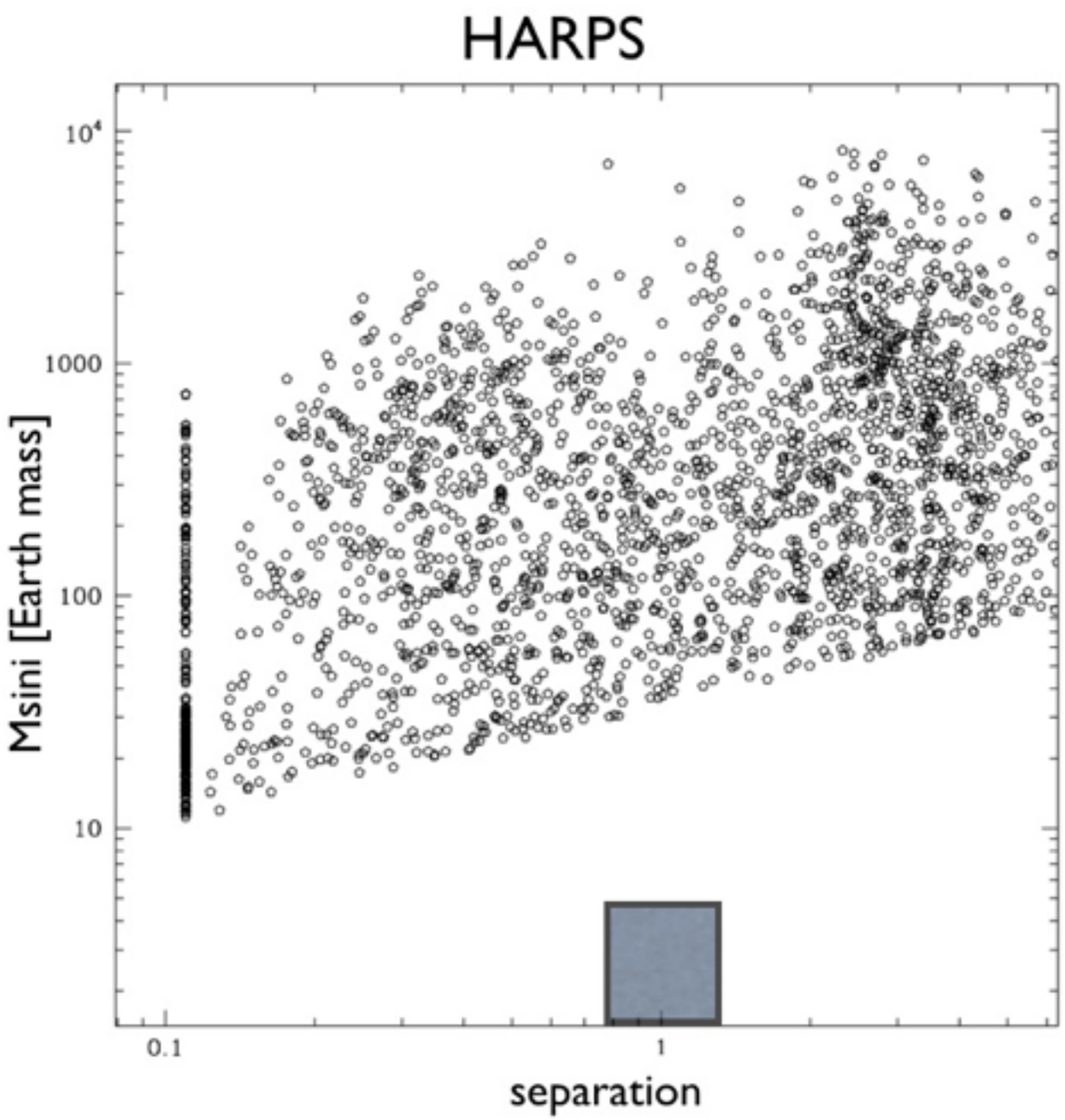
OK for GPs with ELTs, challenging for Earth-size

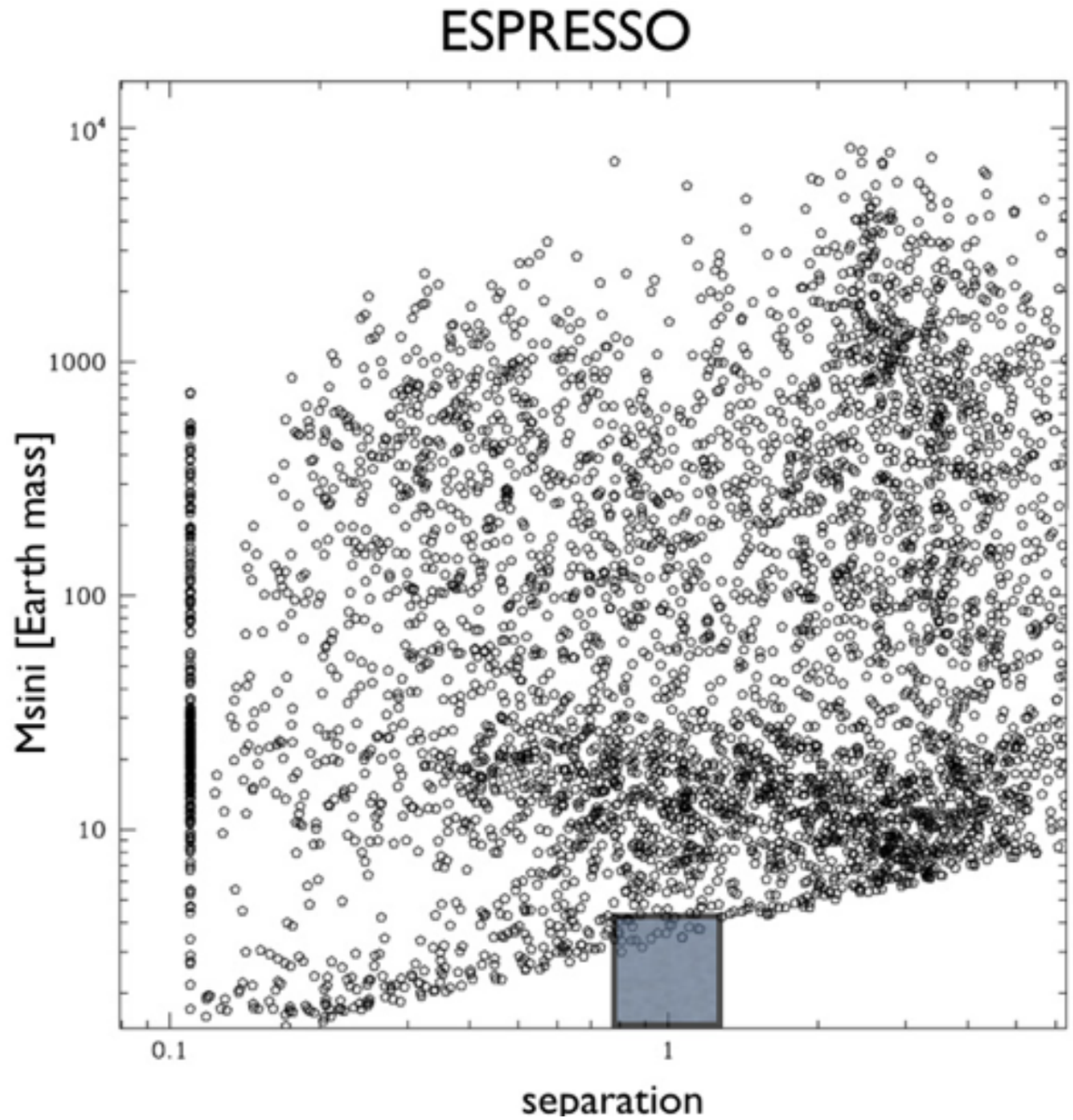
Direct imaging

The habitable zone



Radial velocity projects (I)
ESPRESSO: towards <10cm/s precision

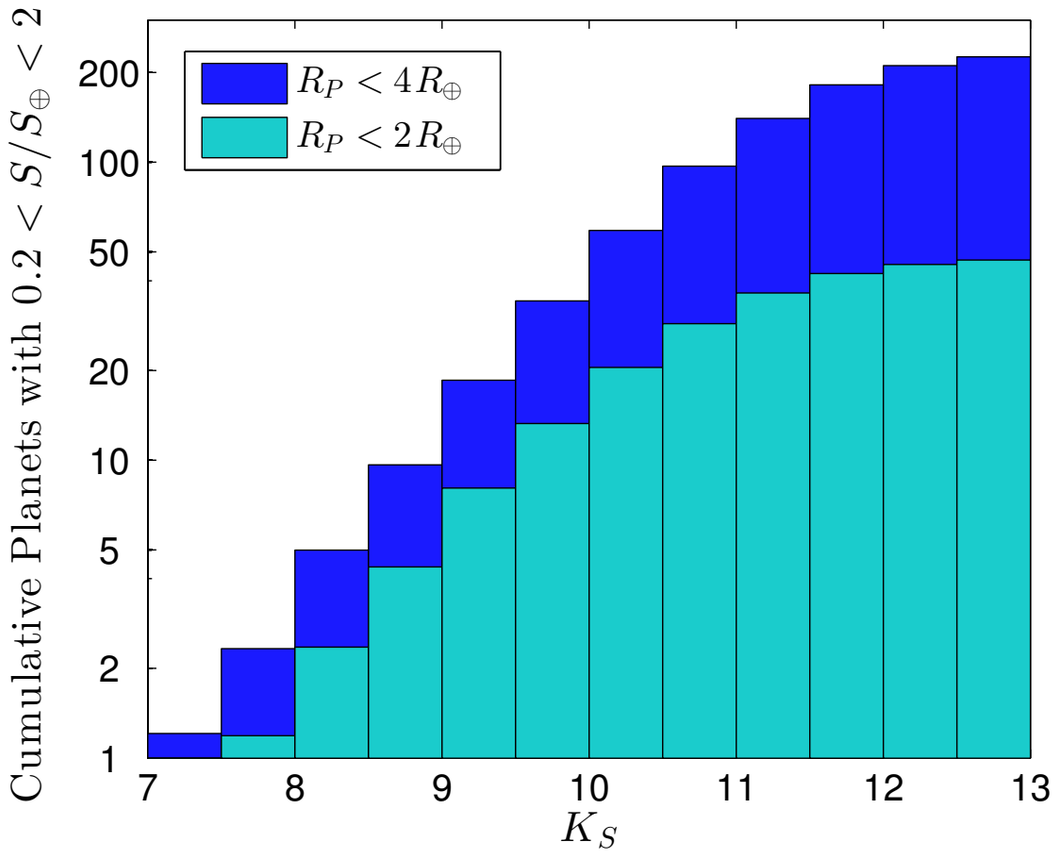




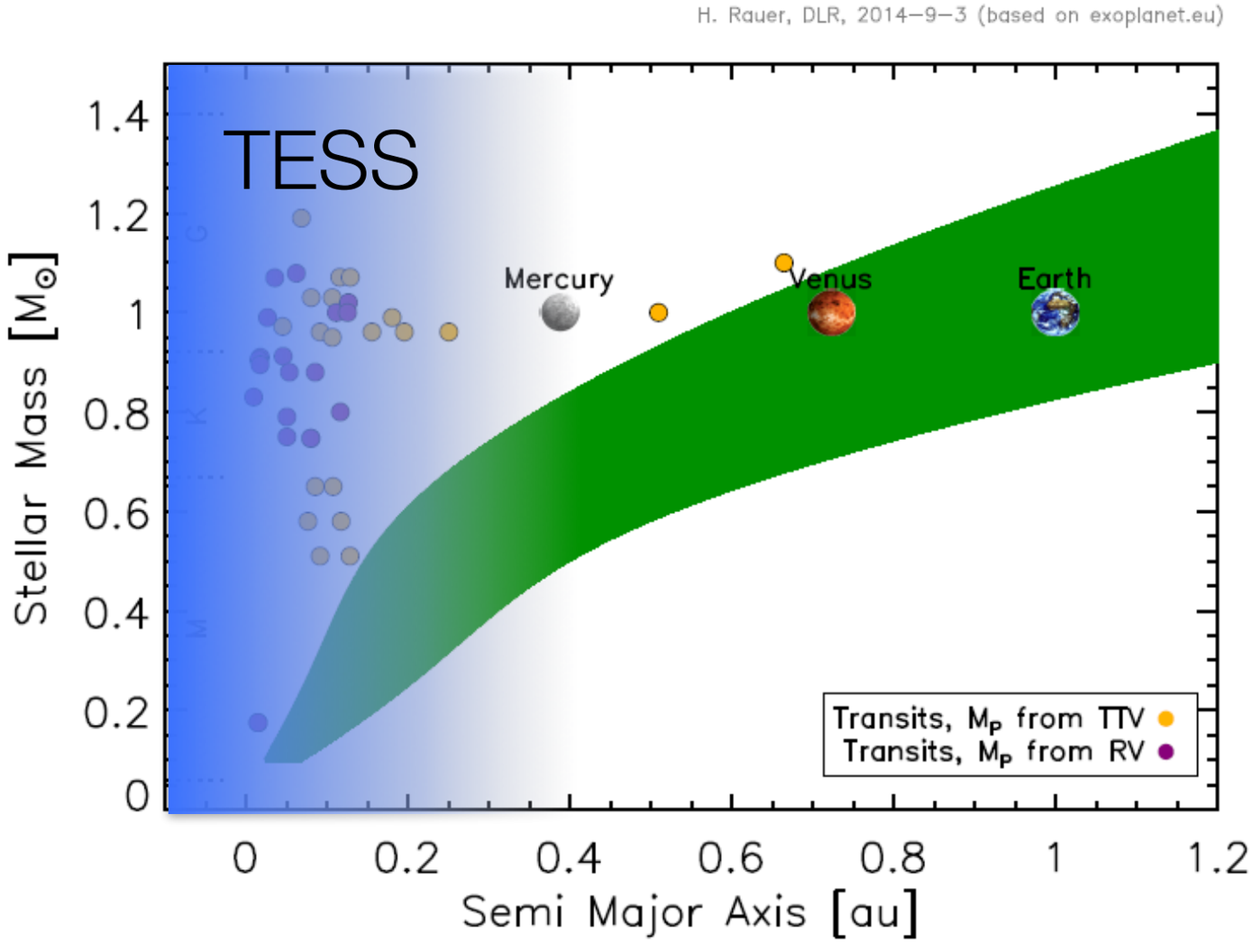
Credits: S. Udry. Adapted from Mordasini et al. (2009)

ESO-VLT (2016+)

Transit surveys (I)
TESS & PLATO: towards bright stars

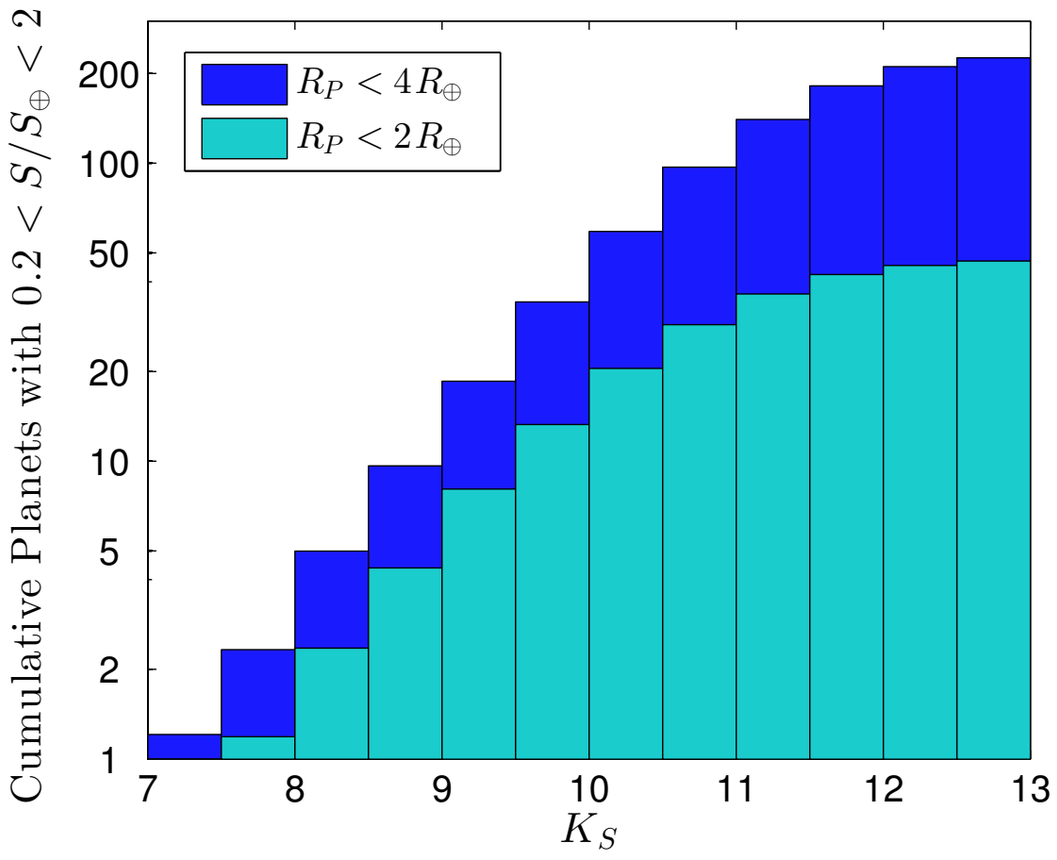


Sullivan et al. (2015)

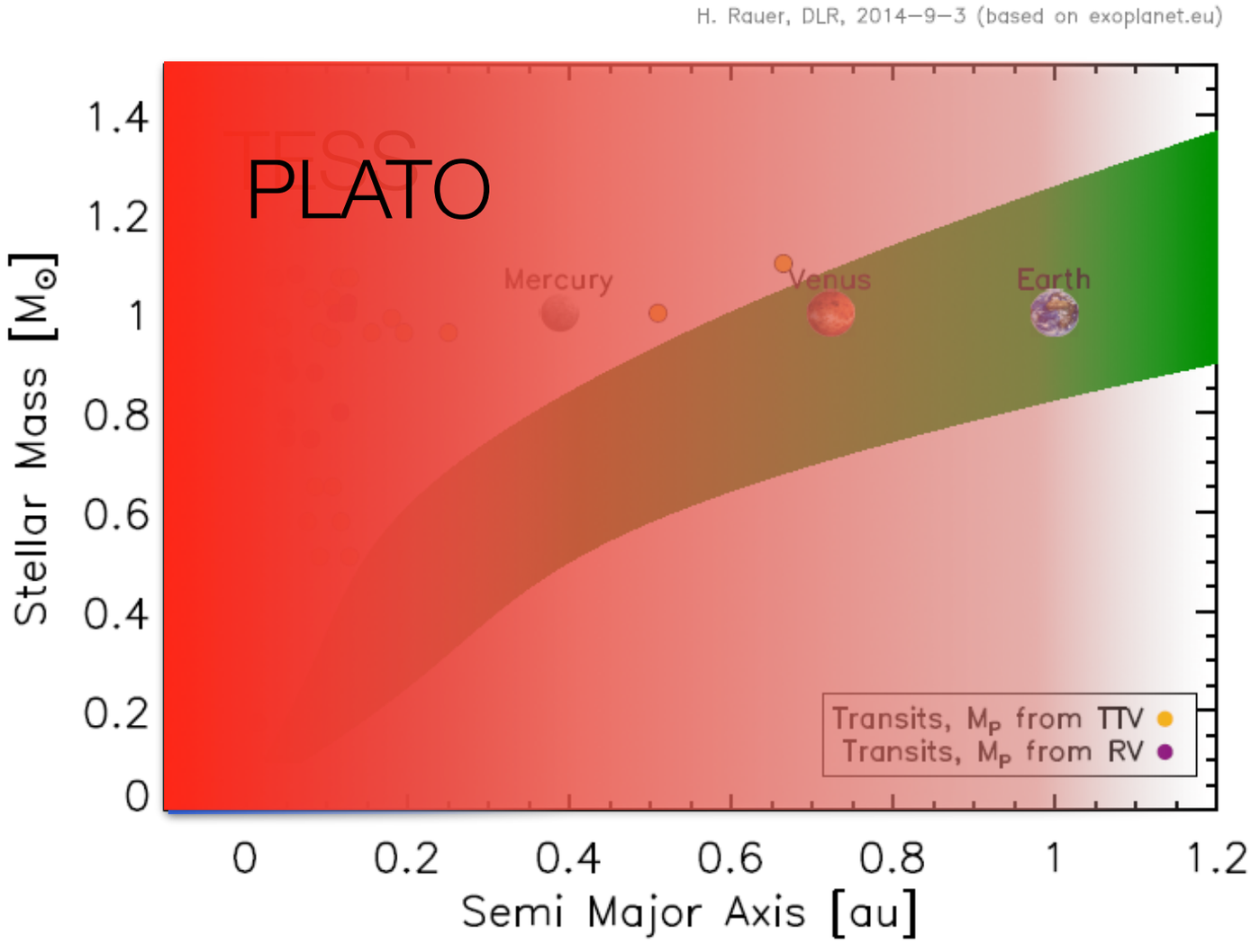


TESS (NASA): 2017+
PLATO (ESA - M3): 2024+

Transit surveys (I)
TESS & PLATO: towards bright stars



Sullivan et al. (2015)



TESS (NASA): 2017+
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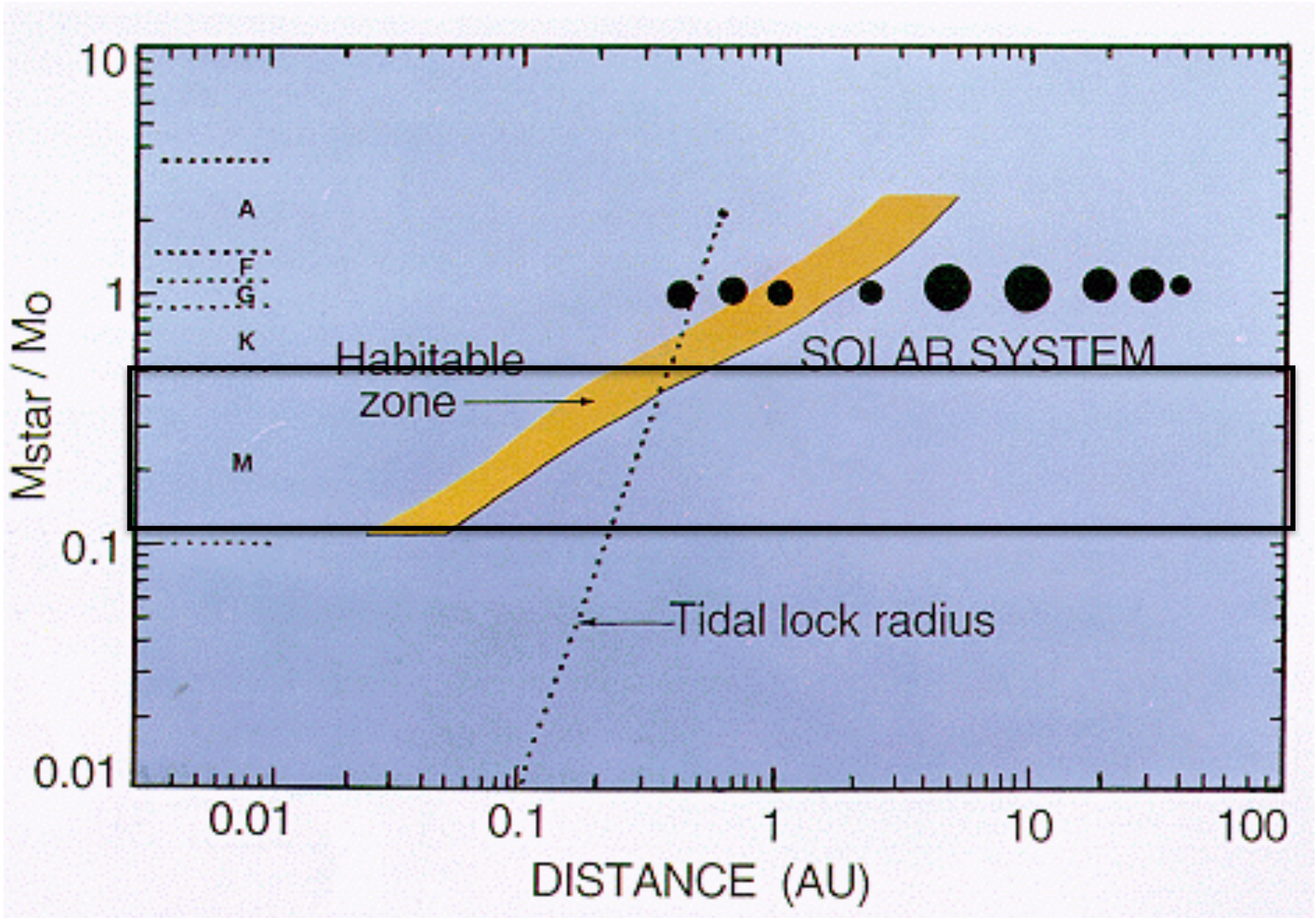
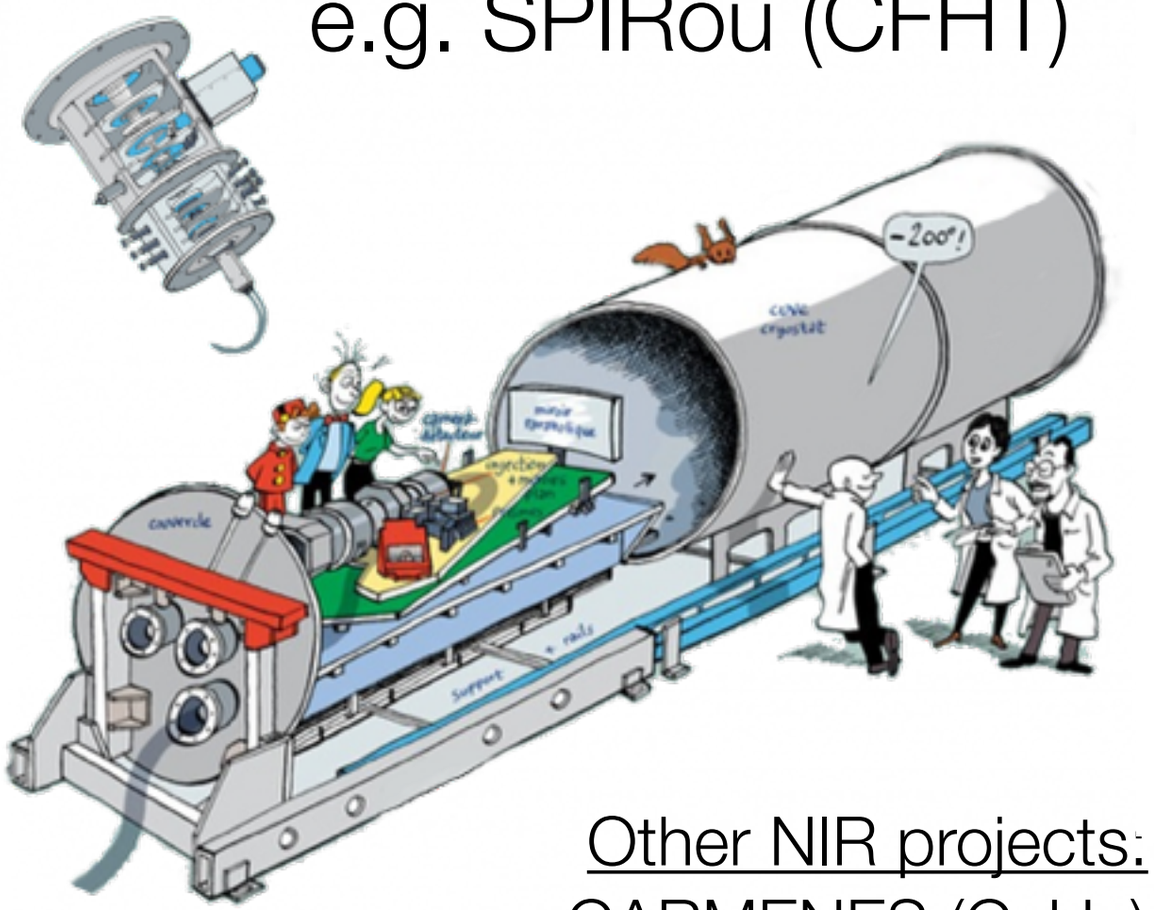
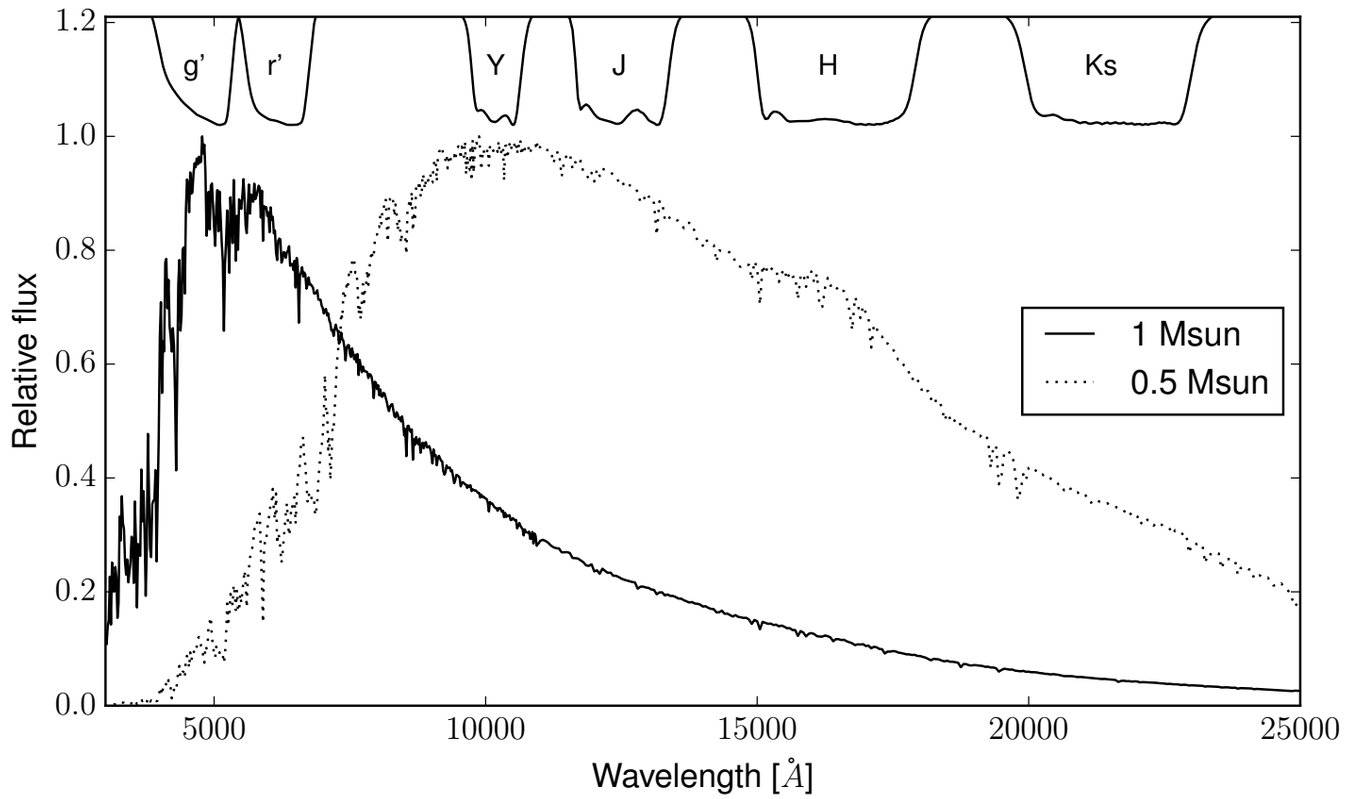
The habitable zone



Radial velocity projects (II)
Towards near-infrared wavelengths

e.g. SPIRou (CFHT)



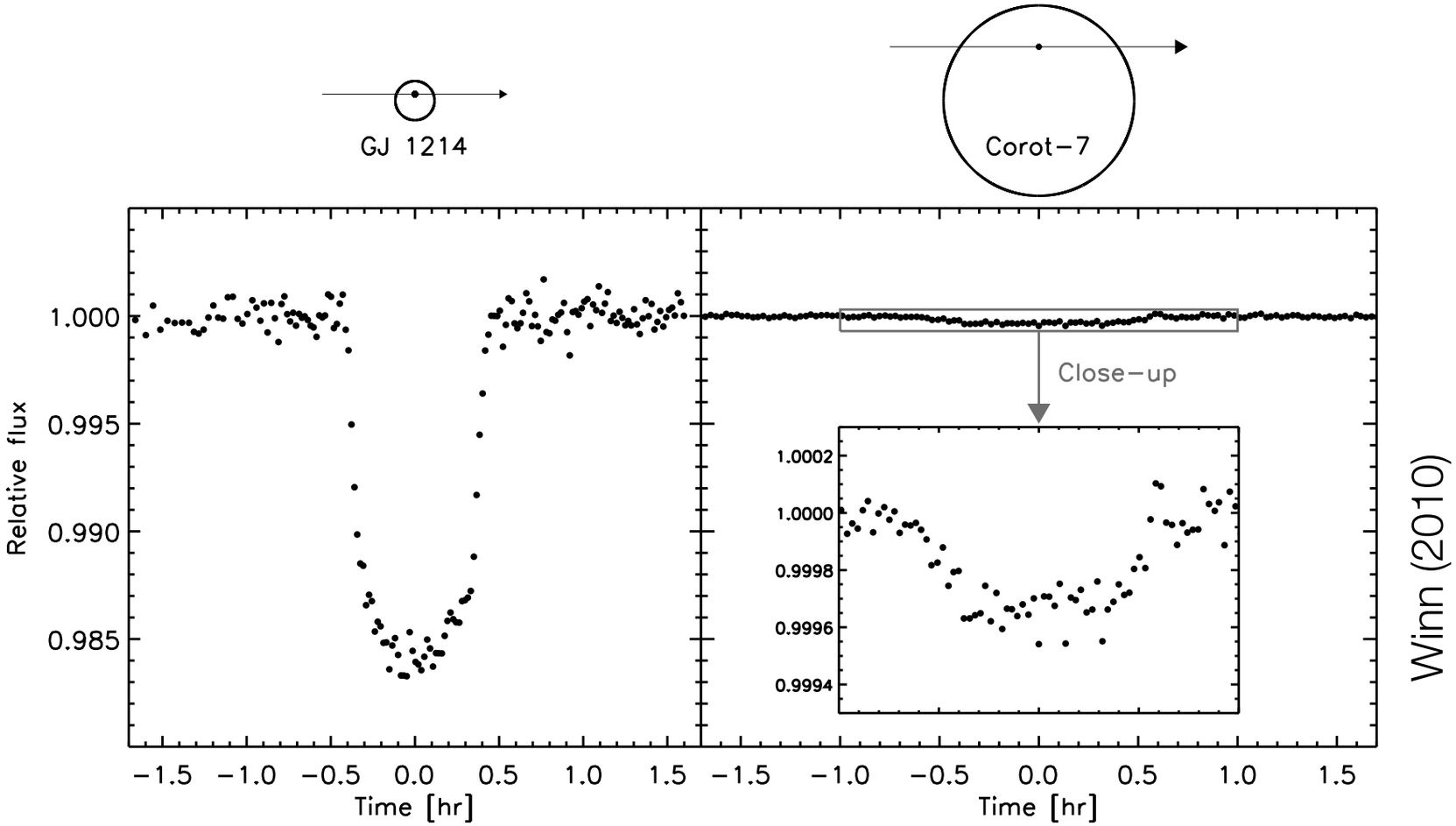


Other NIR projects:

- CARMENES (CaHa)
- IRD (Subaru)
- HPF (HET)
- CRIRES+ (ESO-VLT)
- HiReS (ESO-ELT)

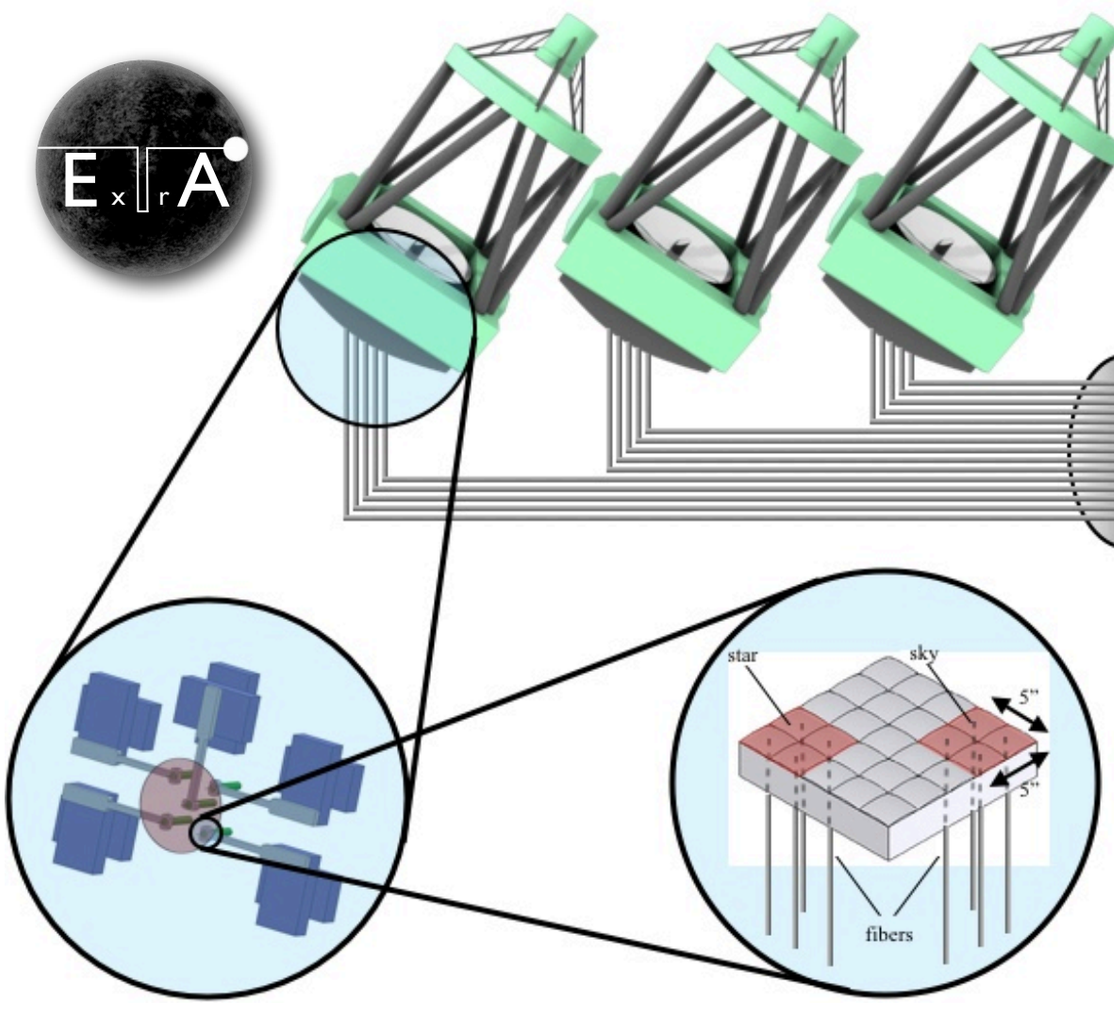
Planet in HZ of M dwarf
= RV signal 7x - 9x larger
than for a G dwarf

Transit surveys (II)
Towards near-infrared wavelengths



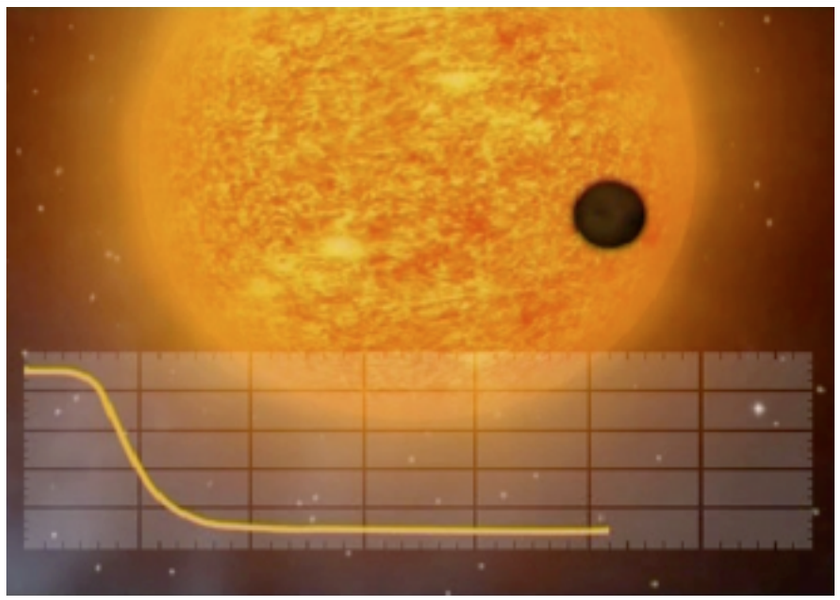
Winn (2010)

Transit surveys (II)
Towards near-infrared wavelengths

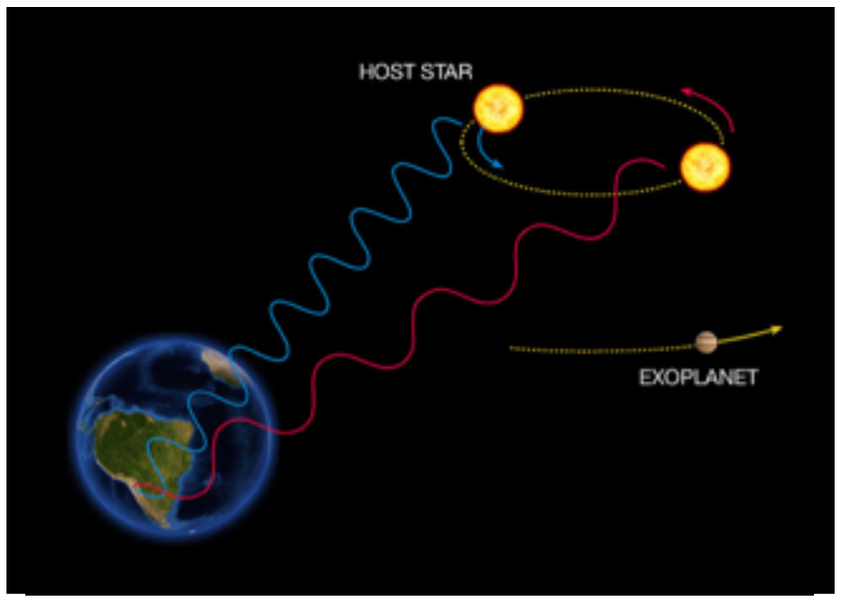


Courtesy: X. Bonfils (2016+)

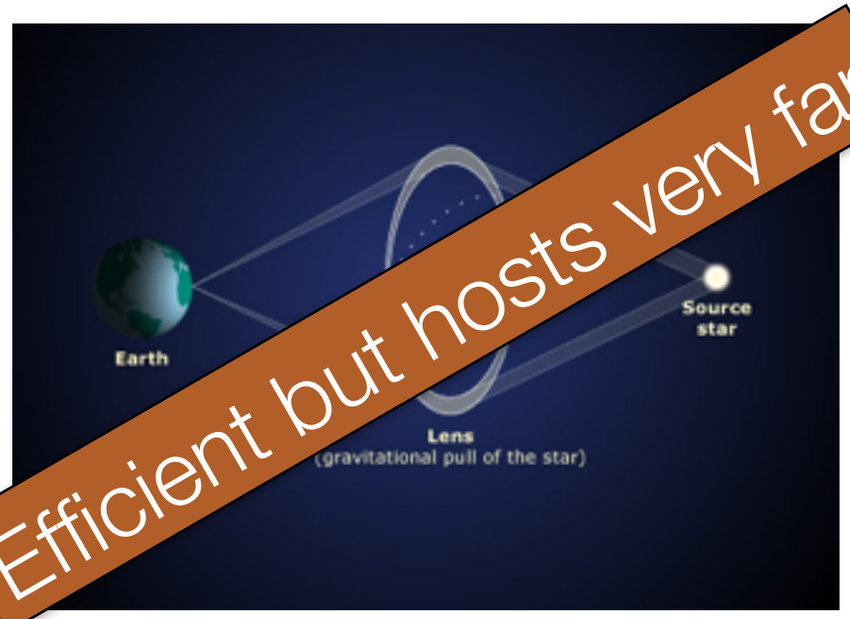
Detecting HZ planets



Transit



Radial velocity



Efficient but hosts very far

Microlensing

OK for GPs with ELTs, challenging for Earth-size

Direct imaging

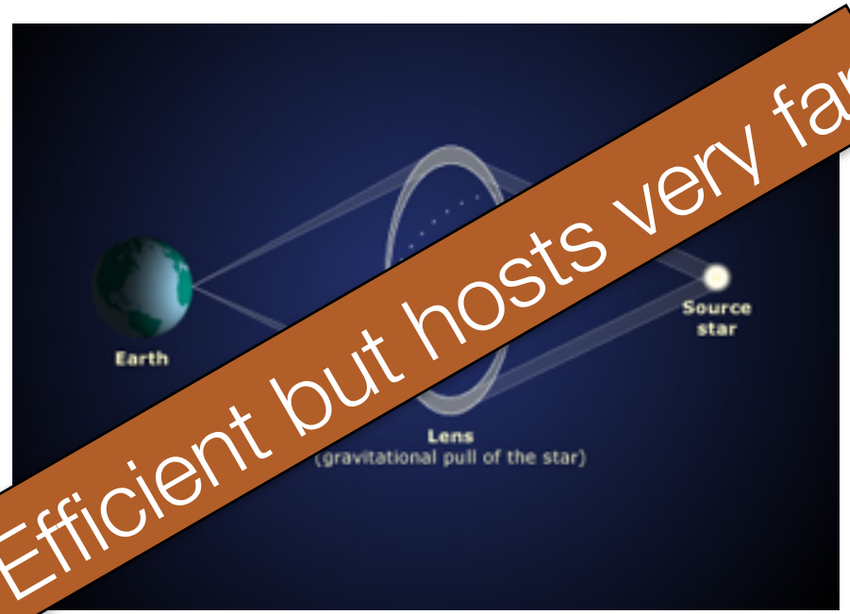
Detecting HZ planets

GK dwarfs: PLATO
M dwarfs: TESS, ExTrA

Transit

GK dwarfs: ESPRESSO
M dwarfs: SPIRou, etc…

Radial velocity



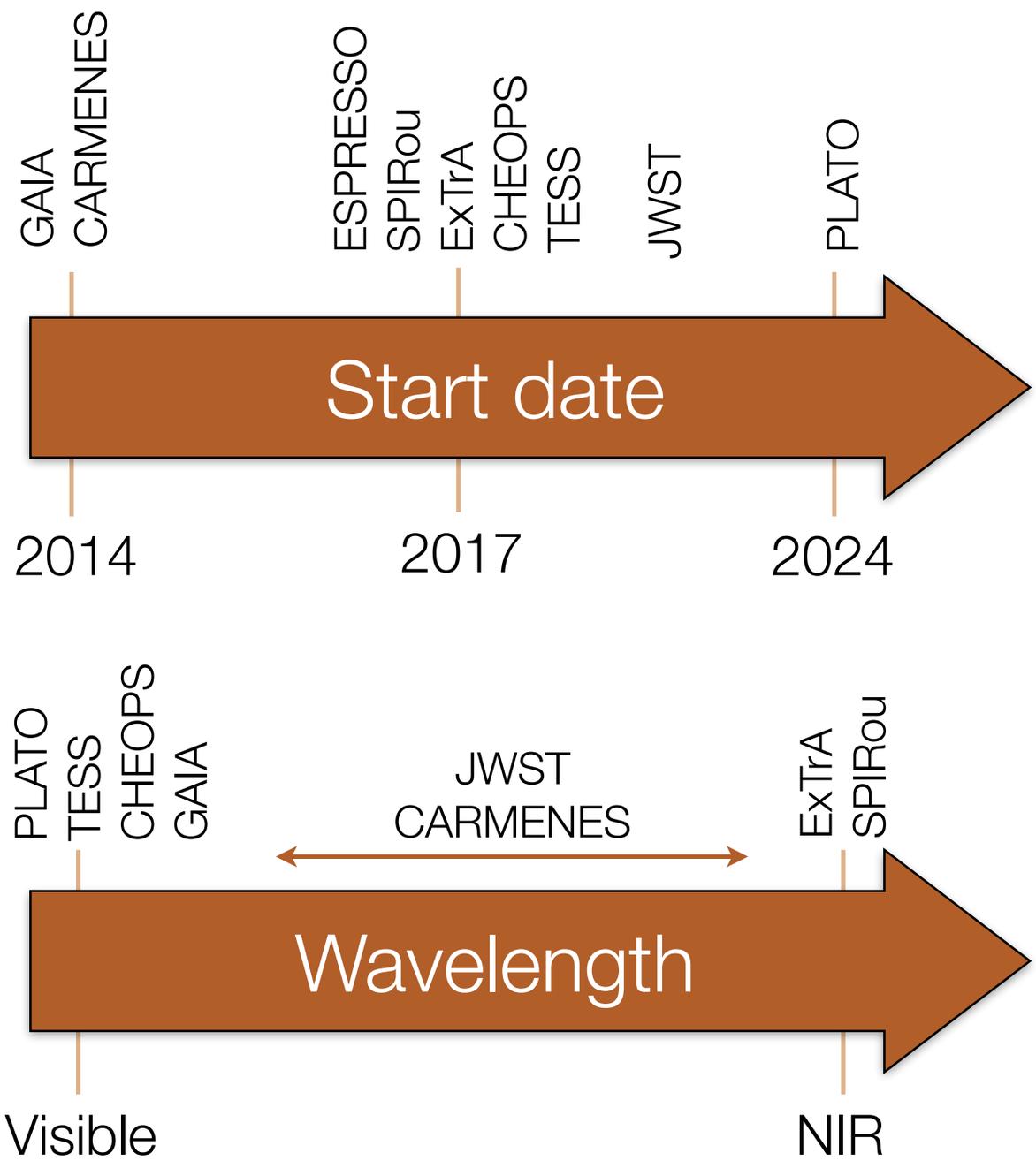
Efficient but hosts very far

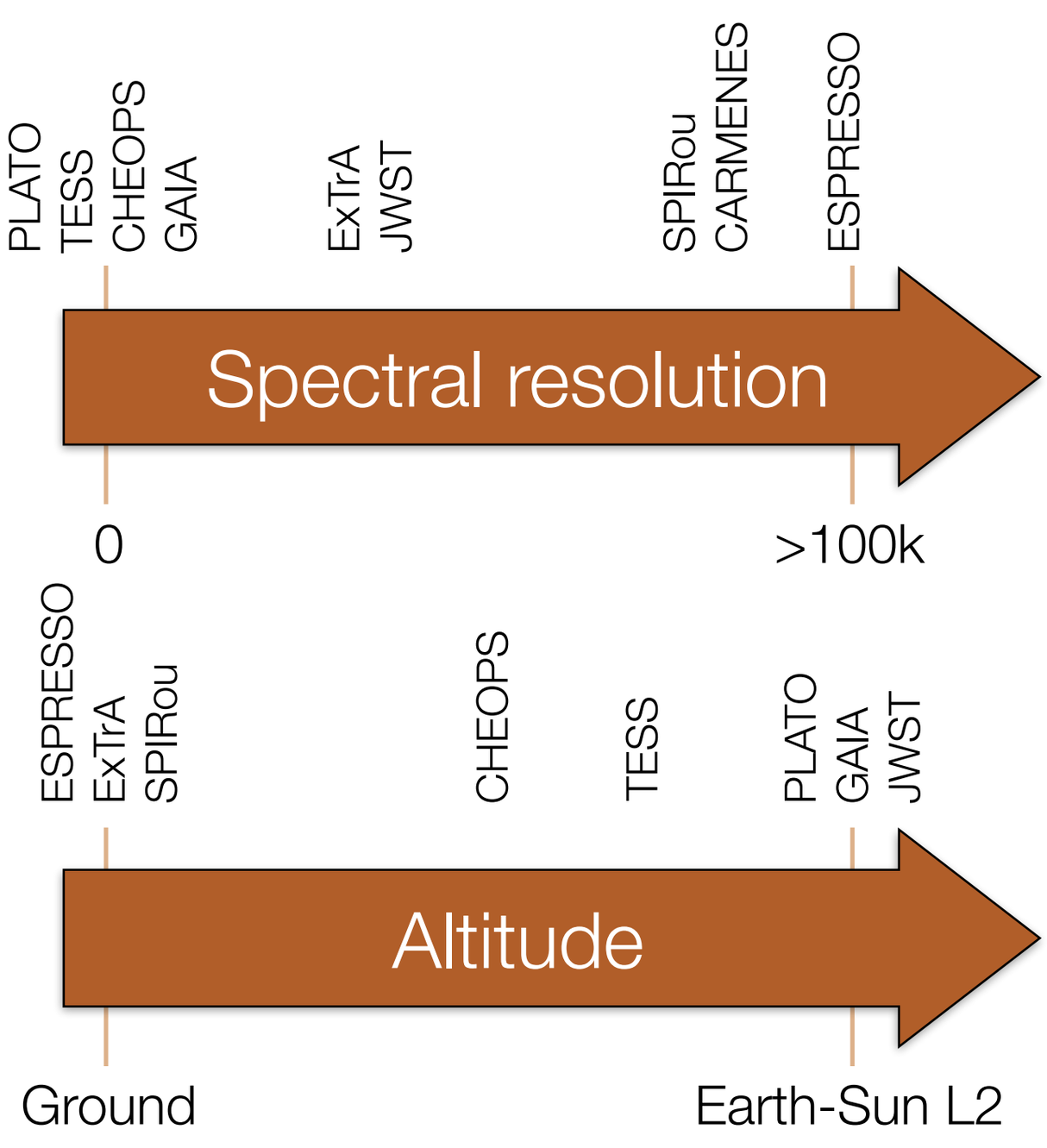
Microlensing

OK for GPs with ELTs,
challenging for Earth-size

Direct imaging

All projects in one slide

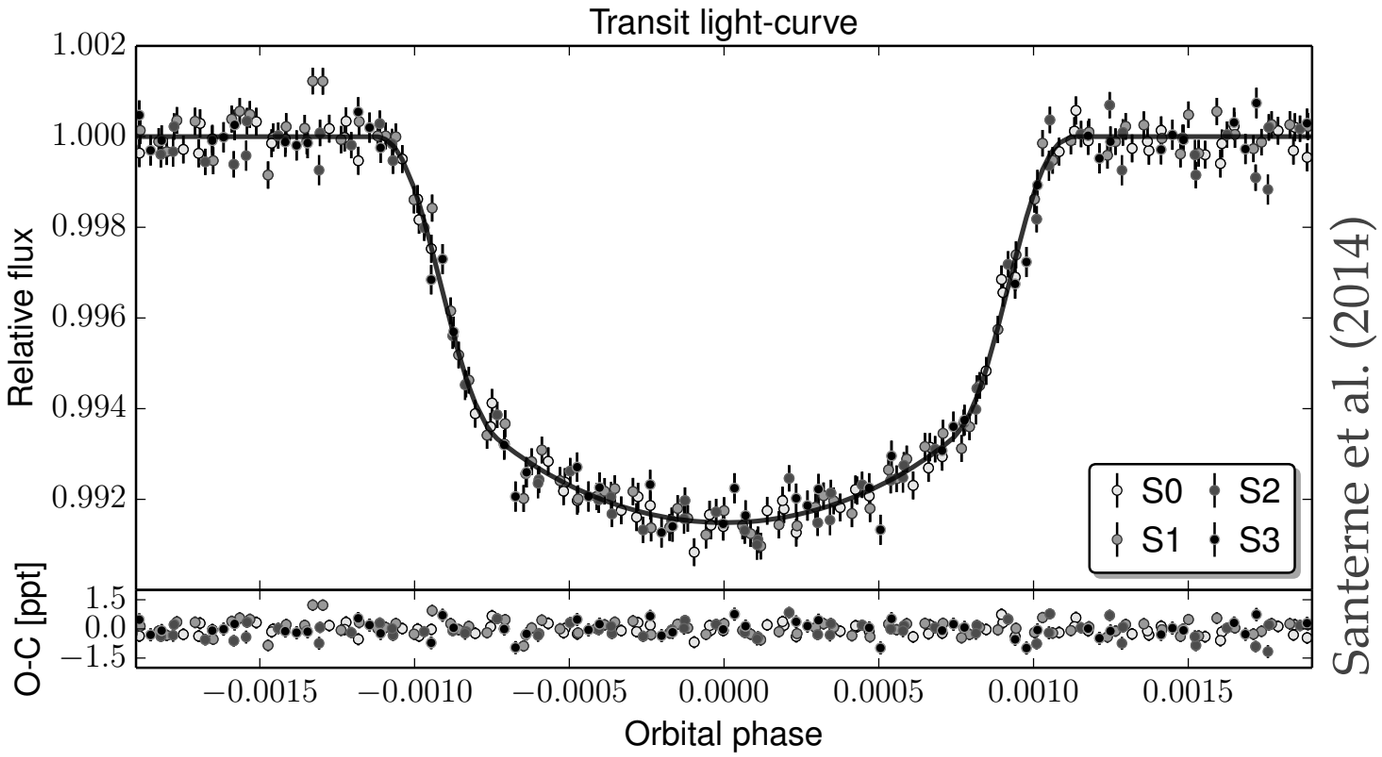


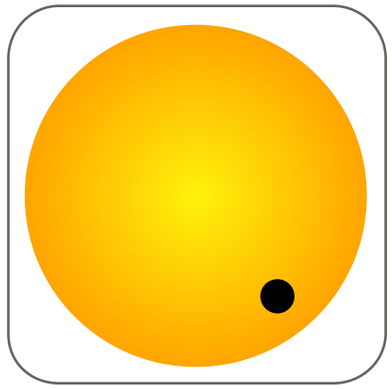


Astrophysical limitations

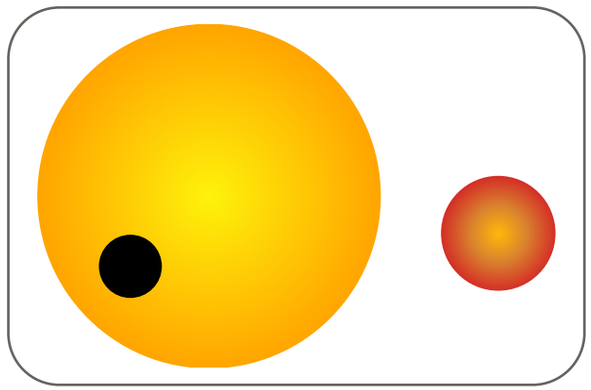
A small and periodic signal is not necessarily produced by a planet …

Stellar contamination

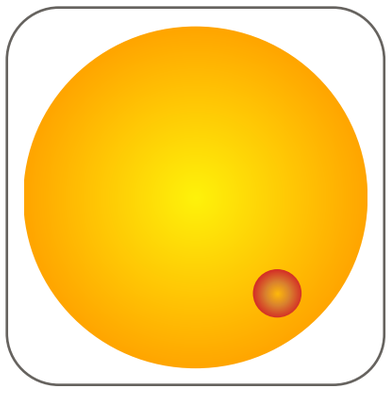




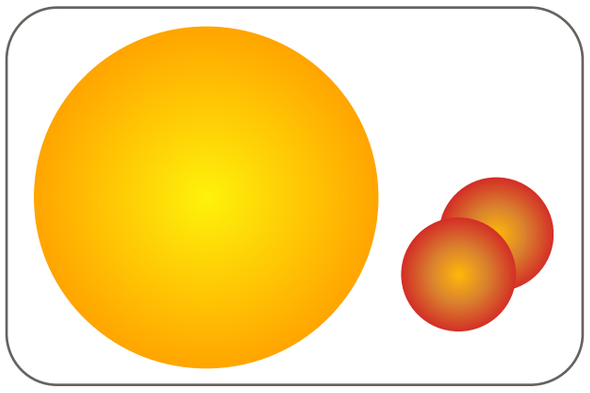
planet



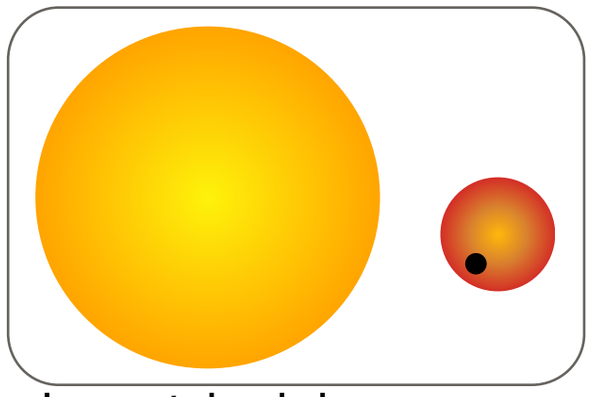
planet in binary



Binary



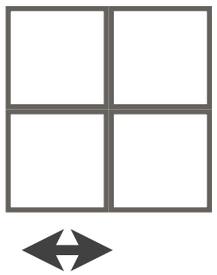
Triple or BEB



planet in binary or background transiting planet

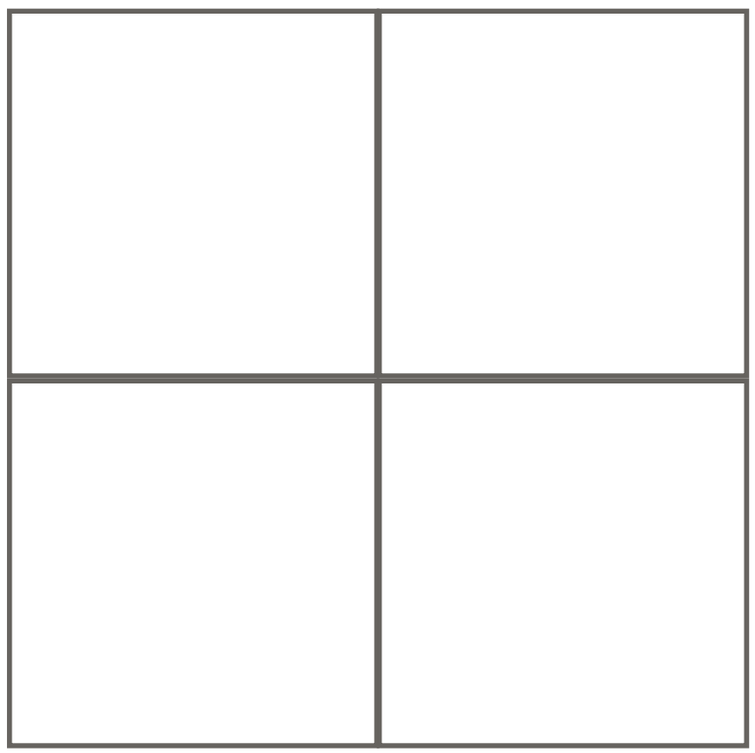
⚠ Pixel size ⚠

Kepler



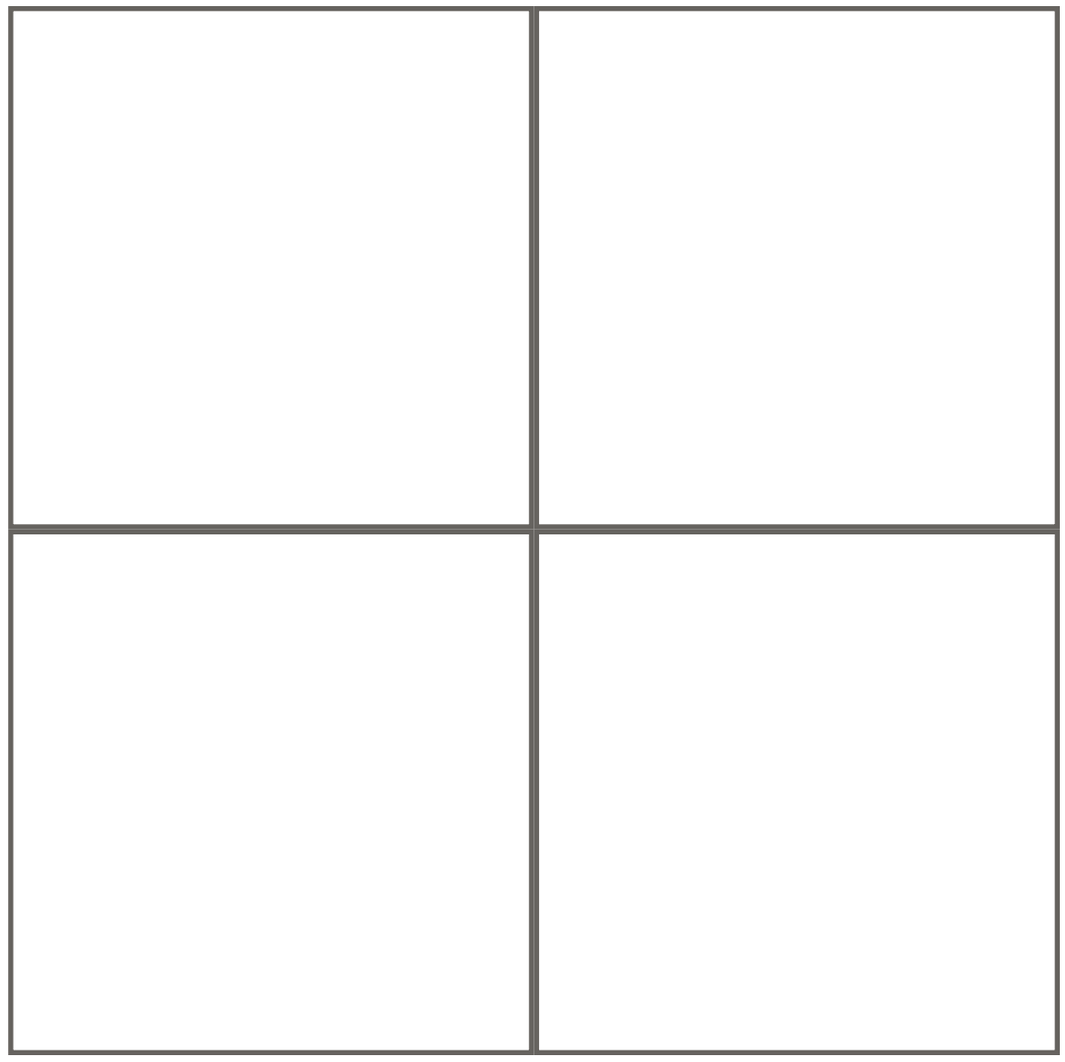
~4″

PLATO



~15″

TESS



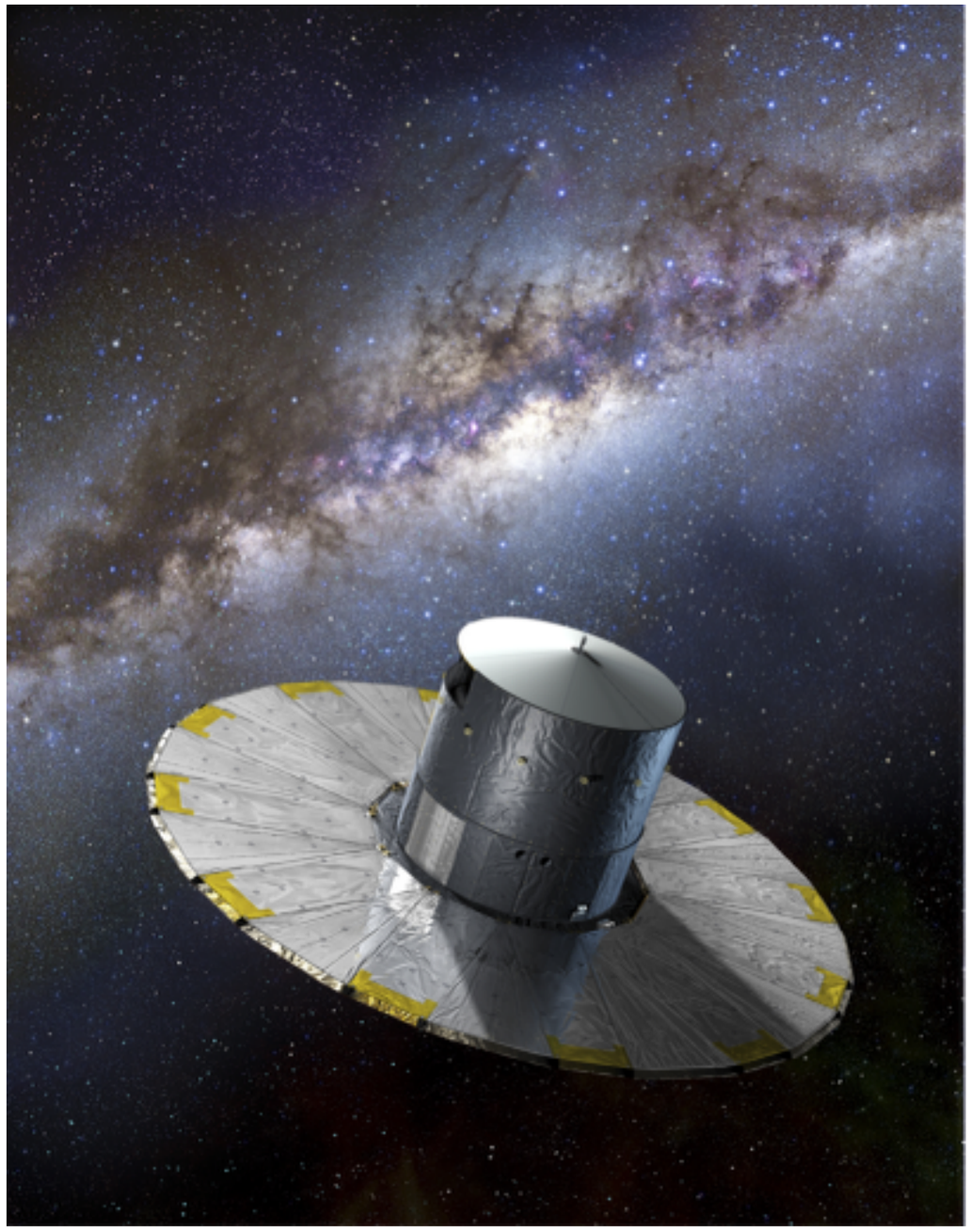
~21″

FOV
IRDIS /
Sphere

- fiber HARPS

A lot of background contamination expected…

To the rescue (I): GAIA



- Complete catalog of stars down to magnitude ~19 - 20
- High-angular resolution (<1”)
- Thanks to the targets PM + parallax = *all* background stars will be known ?

To the rescue (II): Planet-validation technique

1. Model all astrophysical scenarios (planet + false positives)
2. Constrain those scenarios using available data
3. Evaluate each scenario probability

Two main softwares:

BLENDER

Torres et al. (2011), Fressin et al. (2011,12a,b)

PASTIS

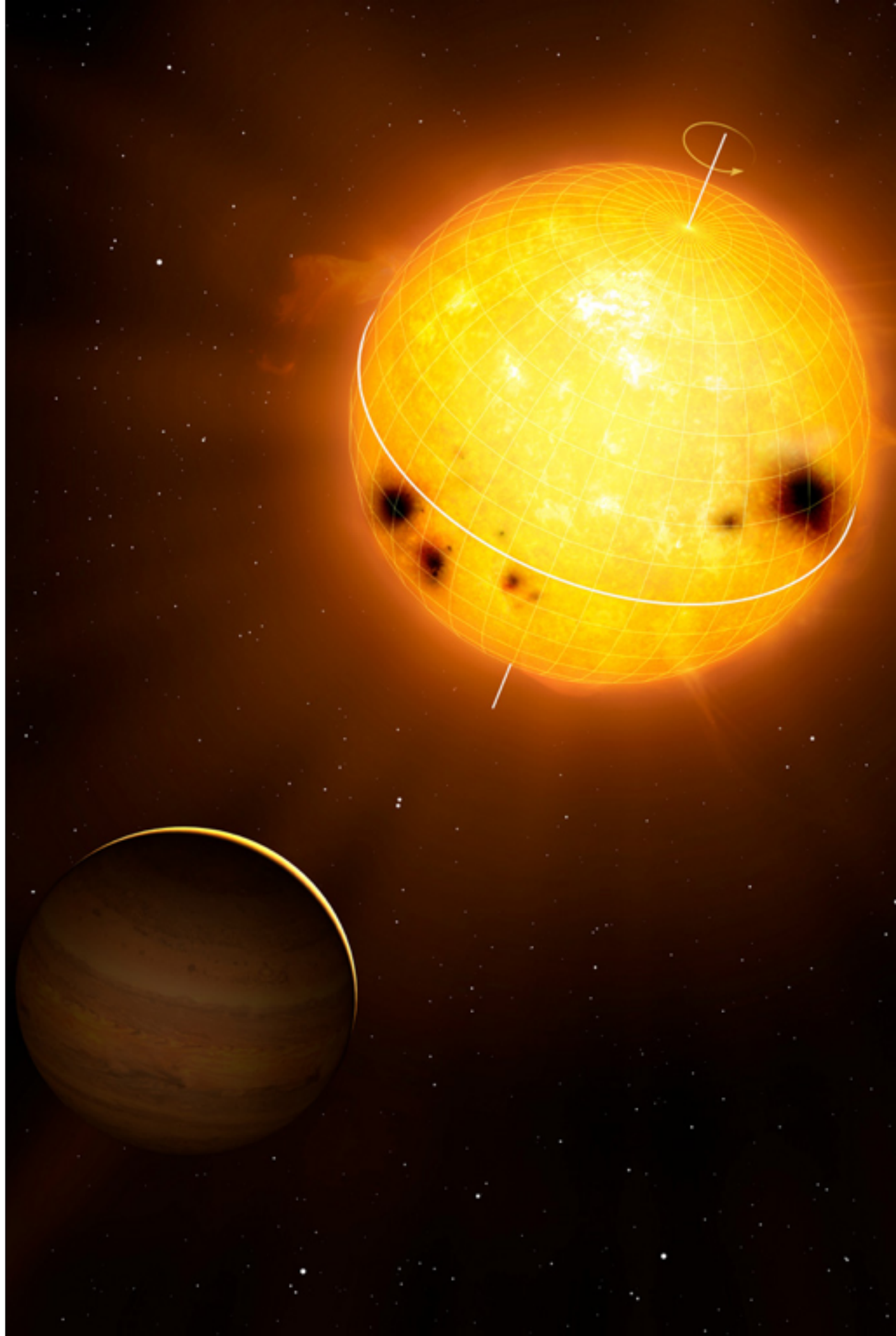
Díaz et al. (2014), Santerne et al. (2015)

computationally intensive:
a few 10k hours / planet

Radial velocity limitations

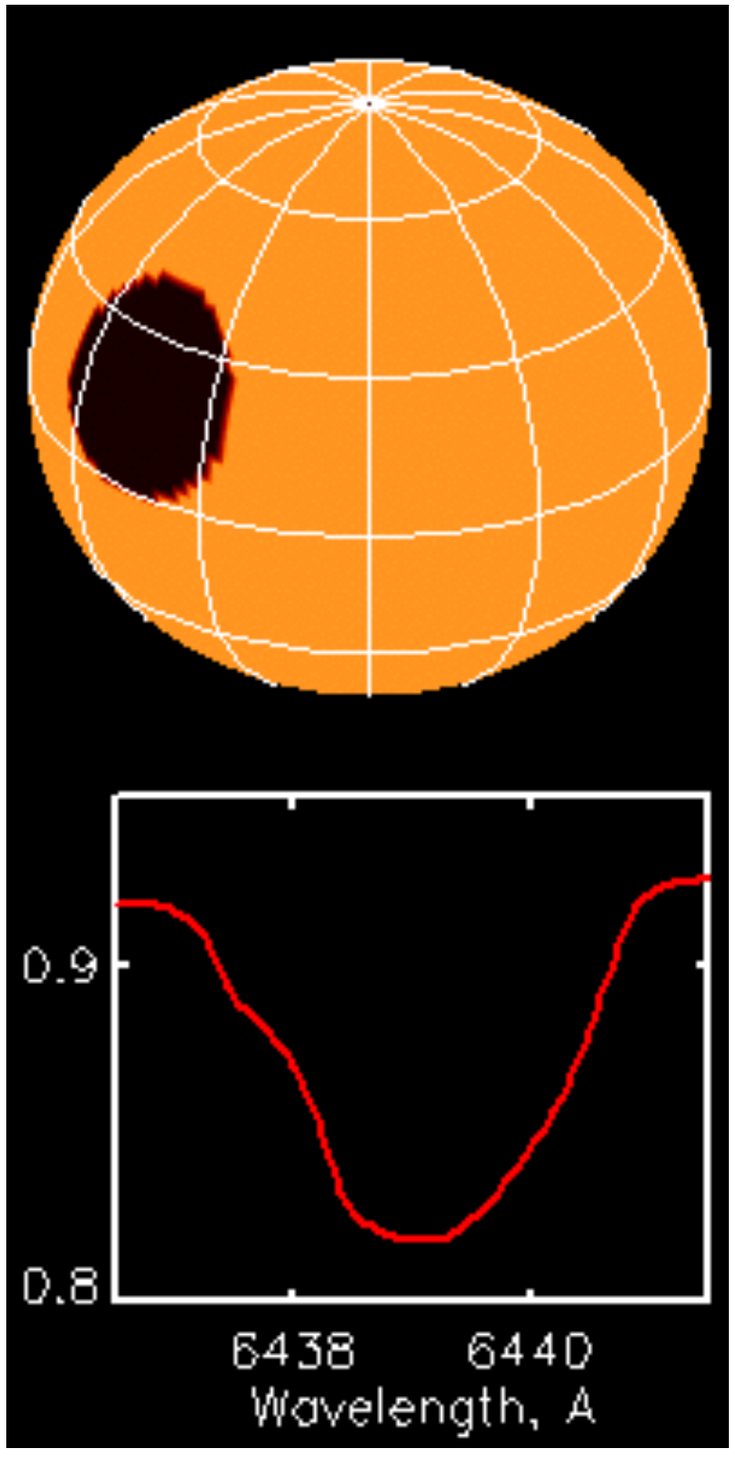
Stellar disk are not uniformly distributed:

- Acoustic (& gravity) modes
- Granulation
- Spots
- Faculae
- Plages
- Magnetic cycle

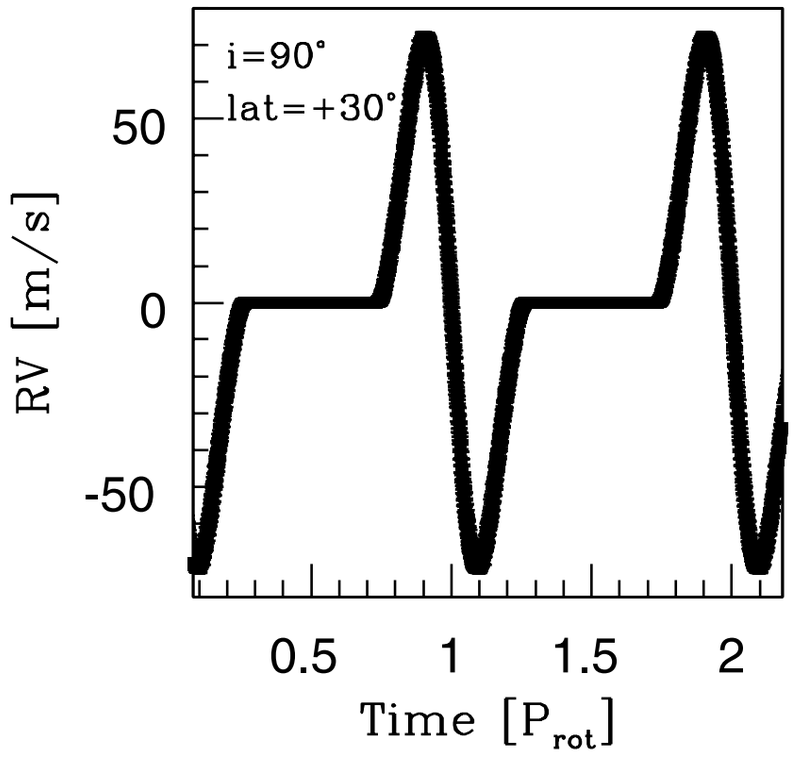


See talk by Mahmoudreza Oshagh

Impact of stellar spots on radial velocities

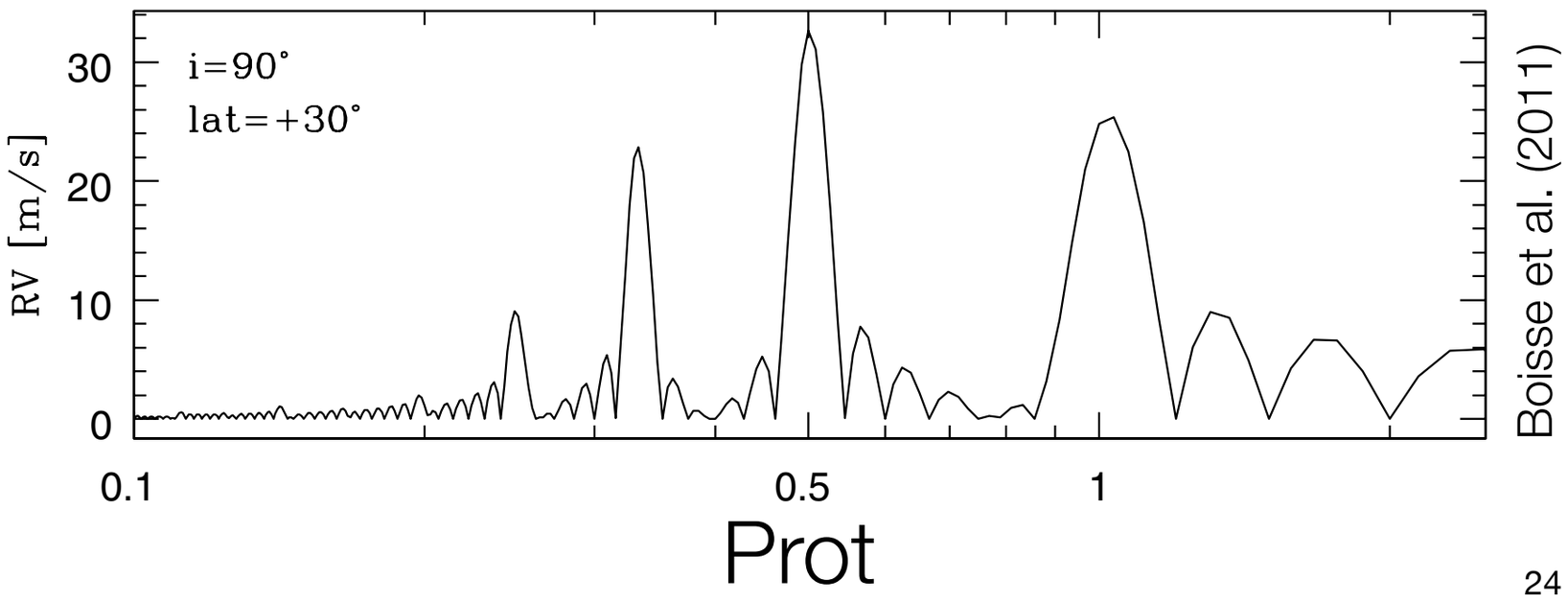


Svetlana Berdyugina

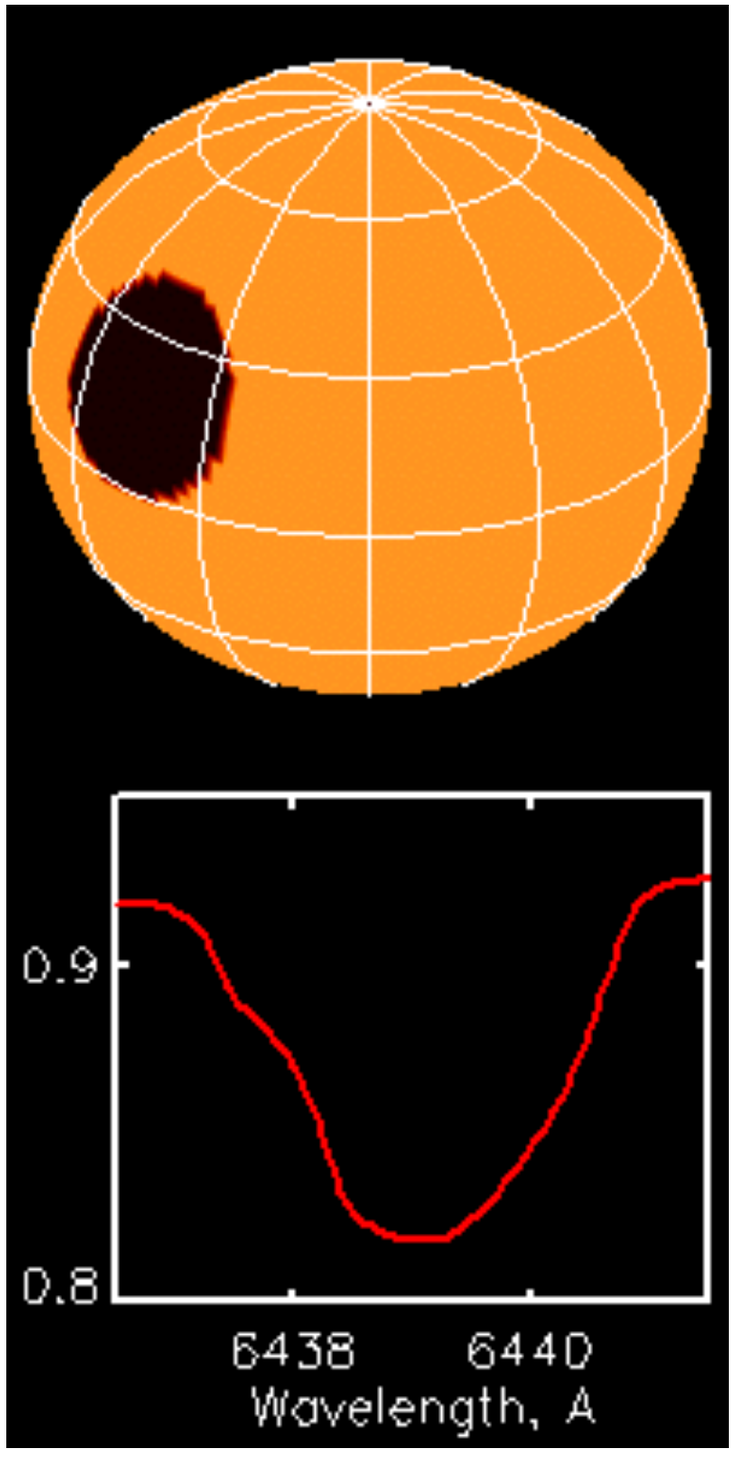


Diagnoses:

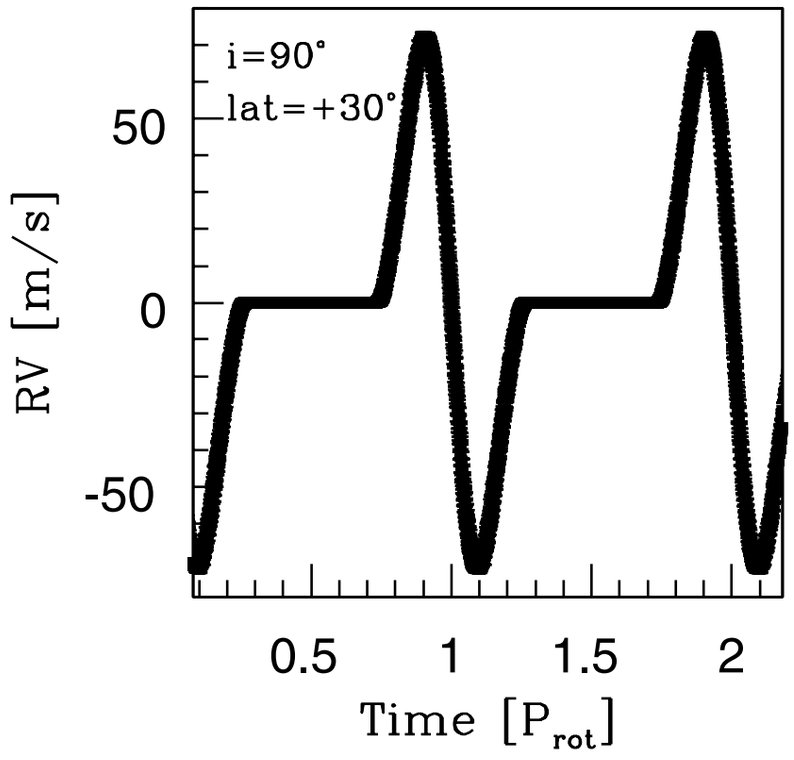
- Line-profile shape
- Photometry
- Activity indices (e.g. Ca II, Hα, Na I)



Impact of stellar spots on radial velocities

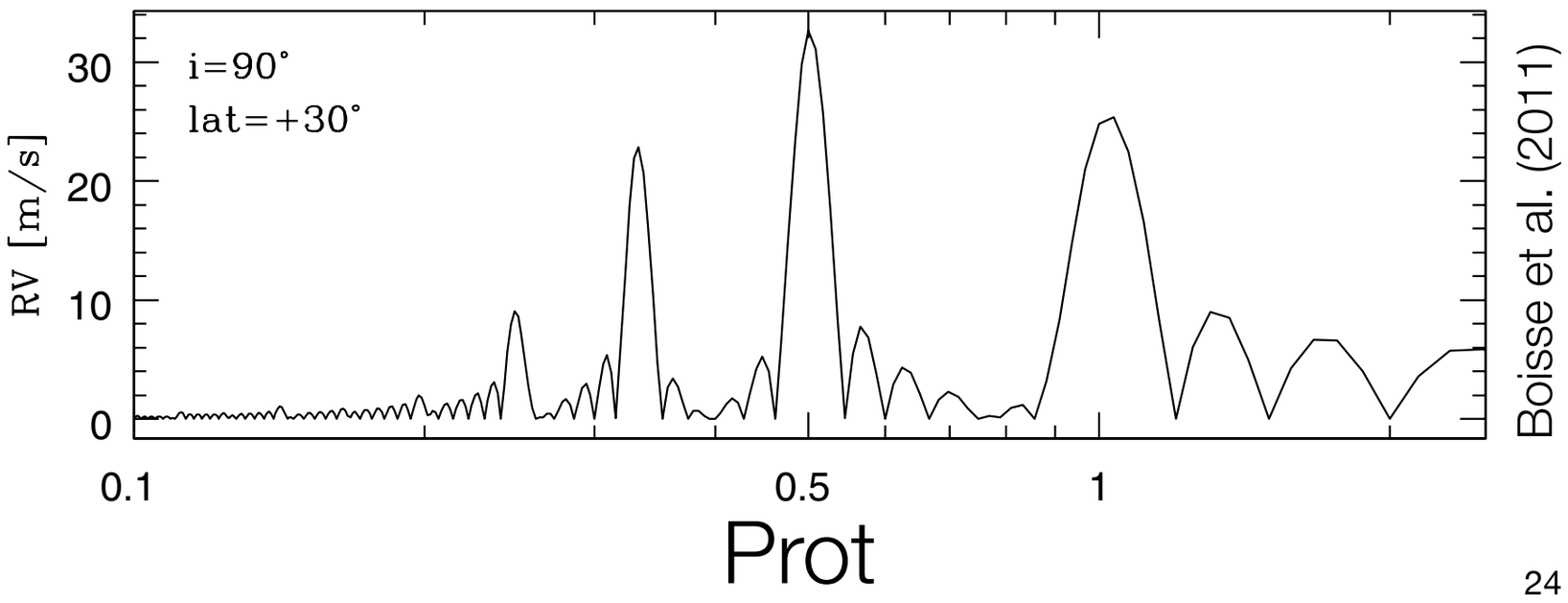


Svetlana Berdyugina



Diagnoses:

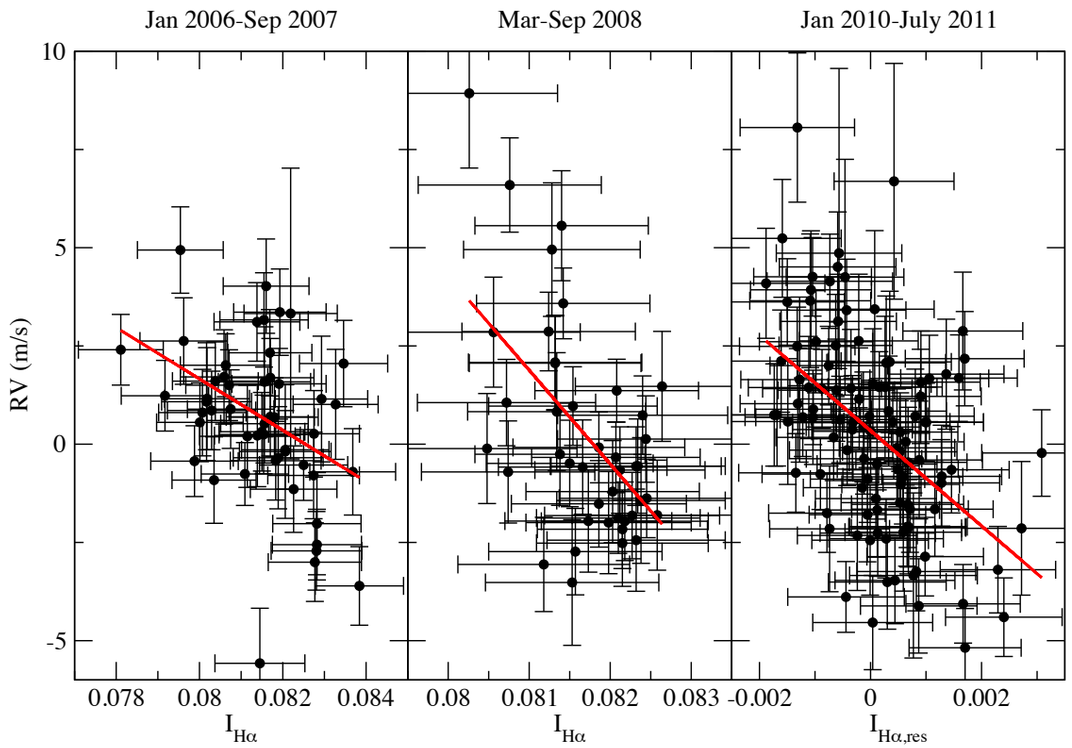
- Line-profile shape
- Photometry
- Activity indices (e.g. Ca II, Hα, Na I)



Correcting radial velocities

Mathematical filters:

e.g. decorrelation techniques, Gaussian Processes

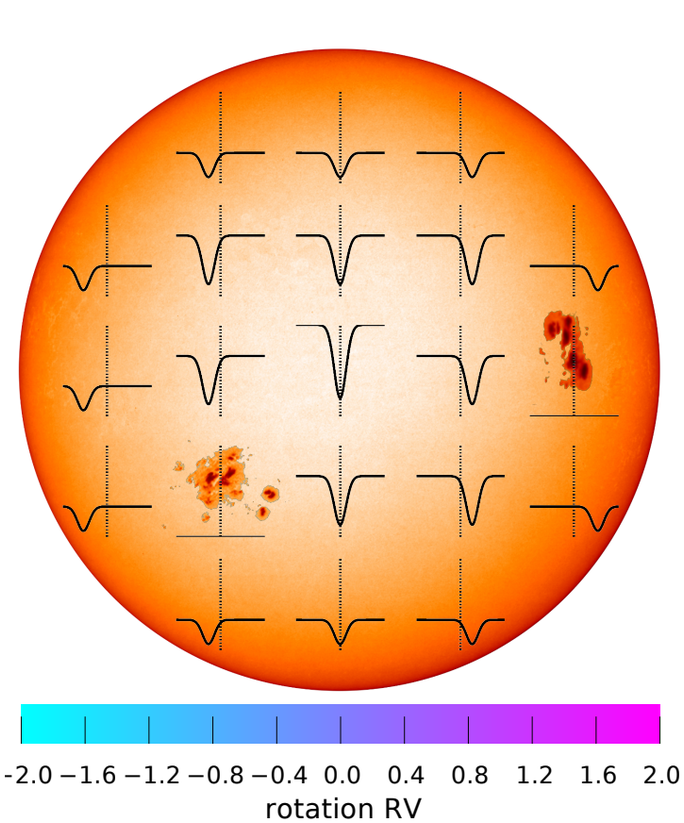


Robertson et al. (2014)

Residuals ?
Linearity ?

Physical models:

e.g. SOAP 2.0



Dumusque, Boisse & Santos (2014)

Missing physics ?

What we don’t want …

Exemple of GJ 581 d:

- Mayor et al. (2005): planet in HZ !
- Robertson et al. (2014): Activity signal in Hα ➙ no planet
- Anglada-Escudé & Tuomi (2015): HZ planet + activity is better fitted
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Question for ourself:
What is the probability that the detected signal is produced by a planet ?

What we need …

- We need to validate statistically the detected signals, using the same planet-validation technique as for transiting planets.

- We need an accurate (and fast to compute) model for stellar activity

- We need to compare the probability of
having a non-active star with N planets against the one of
having an active star with N-M planets
(M=number of planets mimicked by stellar activity)

Conclusions & Take home messages

- Armada of new projects to start in the next decade (2017 is a cornerstone) have the potential to detect small planets in the HZ

- Great complementarity between projects: from G to M dwarfs, transiting planet or not

- Improvement of instrumental capabilities, but the astrophysical limitations remain

- For transit surveys, analysis tools are ready

- For the interpretation of radial velocity data, need to develop a “good” model of stellar activity with a high priority

- A small and periodic signal is not necessarily produced by a planet

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- Thanks for your attention -

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