NIRPS: finding M dwarf exoplanets through near-infrared velocimetry

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INSTITUTE FOR RESEARCH ON EXOPLANETS

NIRPS overview

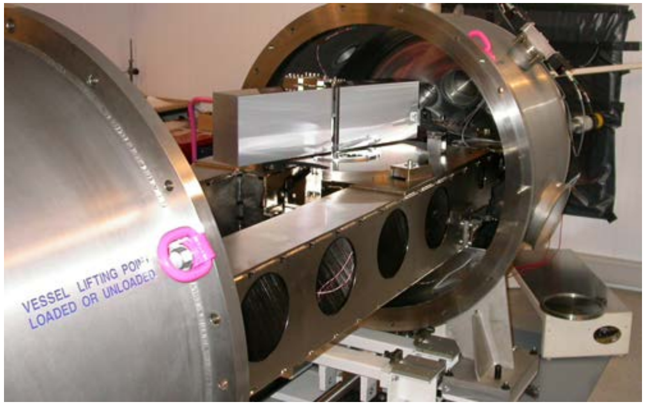
- Infrared channel to HARPS at the La Silla 3.6-m telescope
  - Optical+IR leverage to filter activity
- R=100 000 (80 000 high-efficiency fibre)
- 0.4″ (0.8″) fibre, AO-fed
  - Very compact instrument
  - >2 smaller than SPIRou
- 0.36-0.68μm + 0.98-1.80μm simultaneous coverage
  - Provision for a *K*-band upgrade
- Designed for <1 m/s repeatability
  - UrNe + Fabry-Pérot
  - Laser comb option being pursued
- H4RG science array

NIRPS who's who

- Partners: Canada, Switzerland, Spain, Portugal, Brazil, France
- Team
  - Co-PIs : **R. Doyon** (UdM), **F. Bouchy** (Geneva)
  - Co-Is : F. Pepe, N. Santos, R. Rebolo, X. Delfosse, J. De Medeiros, G. Wade
  - Proj. Scientist : E. Artigau (UdM)
  - Proj. Manager : O. Hernandez (UdM)
  - System Engineer : F. Wildi (Geneva)
- Strong overlap with the SPIRou
  - Science-wise (no spectropolarimetry)
  - >50% of NIRPS team is in SPIRou including the two co-Is
  - Technically, lots of design recycling

NIRPS timeline

- 2014 : Call for proposals for NTT instrument
- 2015 : No PRV instrument selected… but offer by ESO to recycle NIRPS design as an IR channel for HARPS
- Jan. 2016 : PDR
- May. 2017 : FDR
  - Construction rapidly progressing
- First-light in the lab : mid-2018
- Mid-2019 : First light
- 2020-2024+ : At least 5 year GTO

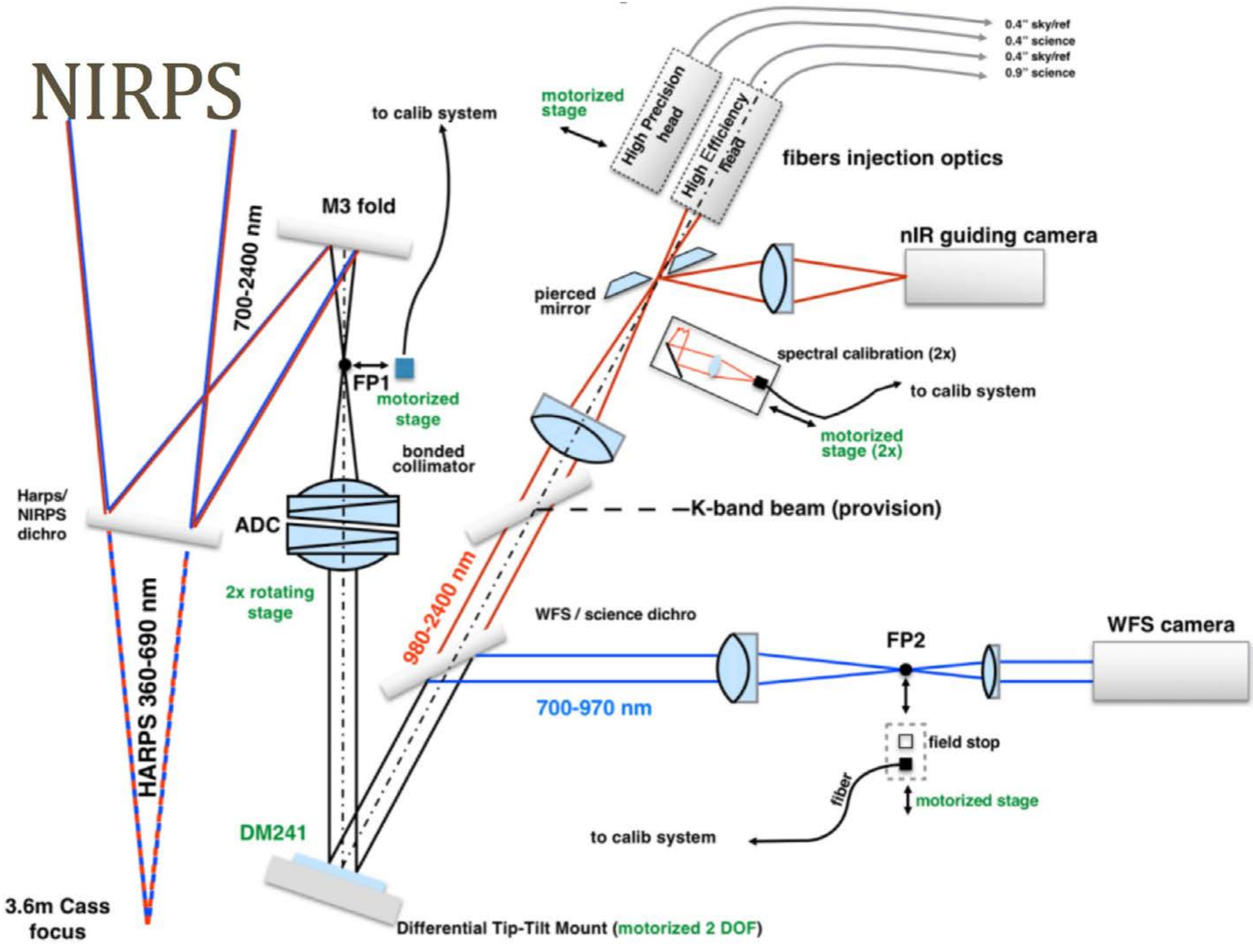


NIRPS : the deal

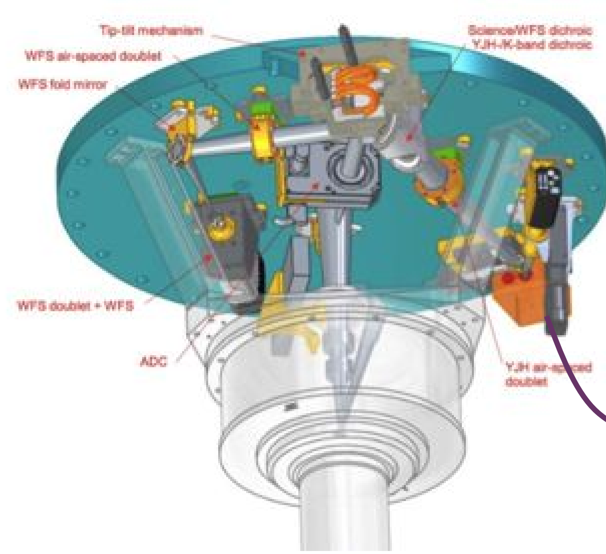
- Somewhat peculiar a non-ESO institution funding an instrument for La Silla!
  - Funds through the Canadian Foundation for Innovation
- **40%** of the first 5 years : **GTO for M dwarf exoplanets**
  - Yes, that’s 725 nights for the GTO team!
  - **More than all canadian time at CFHT** over the same period

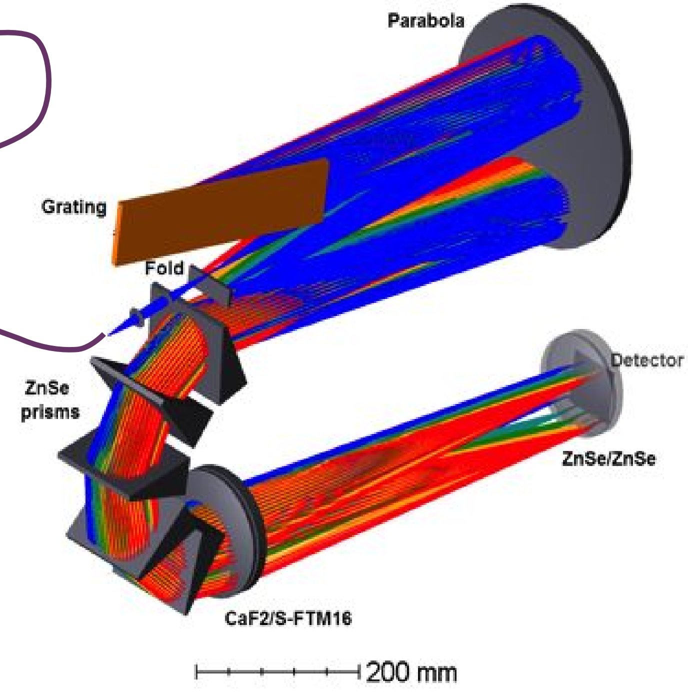
- Three GTO programs
  - **A survey for imagable planets around very nearby Ms (360 nights)**
    - Target finder for ELTs!
    - Determine η_{Earth} for mid to late M dwarfs
  - **Transit (mostly TESS) follow-ups (240 nights)**
  - **High-resolution transit spectroscopy (125 nights)**
    - Pathfinder for Earth-sized planet characterisation with ELTs

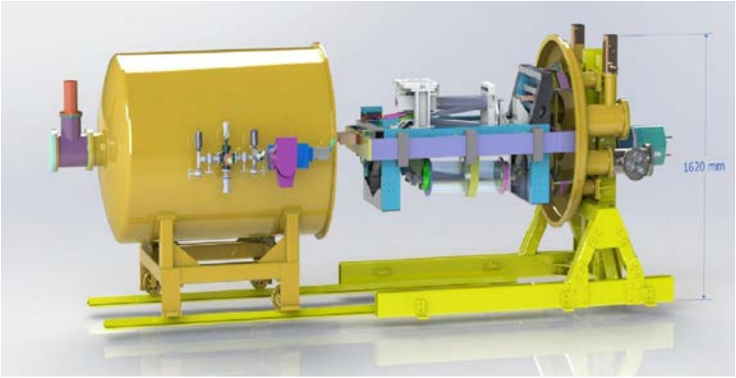
NIRPS


0.4" sky/ref
0.4" science
0.4" sky/ref
0.9" science
motorized stage
to calib system
High Precision head
High Efficiency head
fibers injection optics
M3 fold
700-2400 nm
nIR guiding camera
pierced mirror
spectral calibration (2x)
to calib system
FP1
motorized stage
motorized stage (2x)
bonded collimator
Harps/ NIRPS dichro
ADC
K-band beam (provision)
HARPS 360-690 nm
2x rotating stage
980-2400 nm
WFS / science dichro
WFS camera
FP2
700-970 nm
field stop
fiber
motorized stage
DM241
to calib system
3.6m Cass focus
Differential Tip-Tilt Mount (motorized 2 DOF)

NIRPS overview





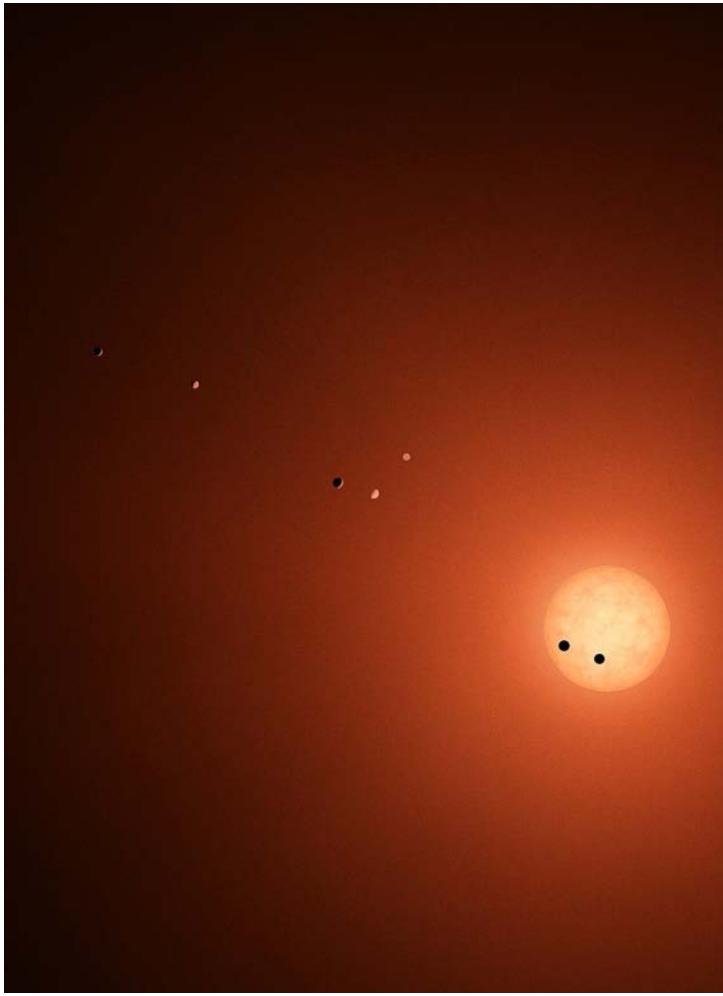


NIRPS : an instrumental pathfinder

- First AO-fed fibre HRS
  - Allows for much more compact instrument designs
- Grating-based HRS scale in size linearly with …
  - Fiber size on sky
  - Telescope diameter
  - … factor of 7.5 worse for TMT
- Not a monomode fibre…
  - Modal noise mitigation with the AO modes
- Fibre-based HRS transit spectroscopy
  - Much more stable PSF than for slit spectrographs

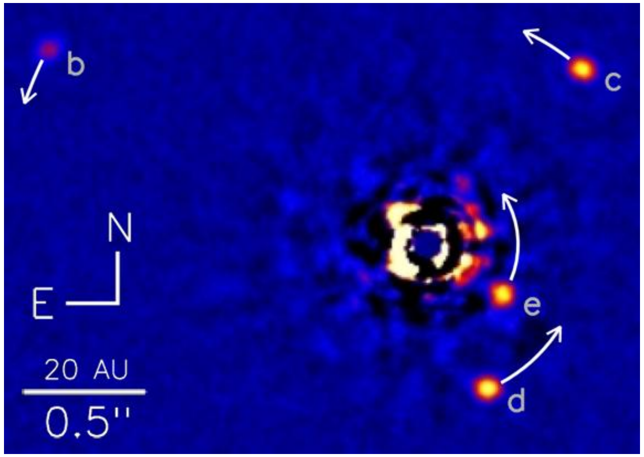
Why M dwarfs and near-infrared

- planet/star radius ratio as good as it gets for main sequence stars
  - Transit signal proportional to $(R_p/R_*)^2$
- M dwarfs are numerous
- Many Earth and super-Earths around M dwarfs
- Flux peaks in the nIR... best RV in that wavelength domain?
  - 0.7-1.0μm as good as nIR due to deeper lines
- True show-stopper : stellar activity
  - Lower activity signal in the nIR
  - Even better with simultaneous optical+nIR



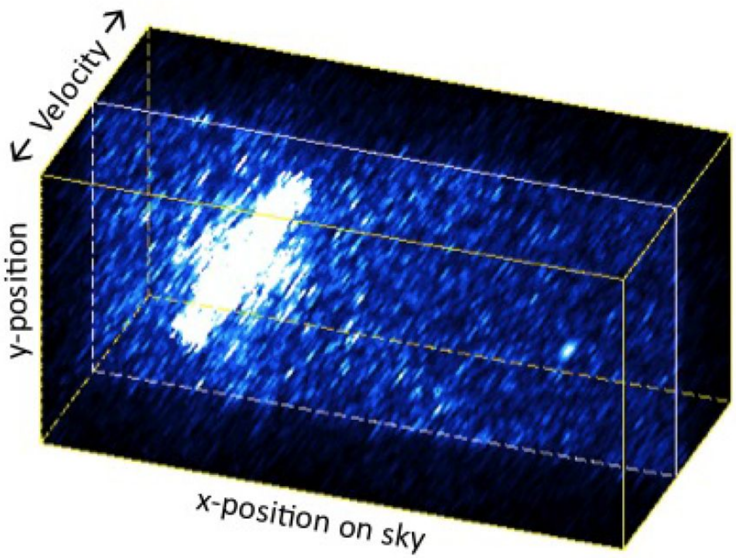
Finding imagable planets

- All directly imaged planets are self-luminous young, massive gas giants
- One of the biggest near-term (<20 years) goal : **direct imaging of Gyr-old planets in reflected light**
  - No age constraints
    - Many exciting targets within a few parsec
  - Contrast is much **less dependent on planet mass** (through radius)
  - Strong contrast dependence with orbital separation

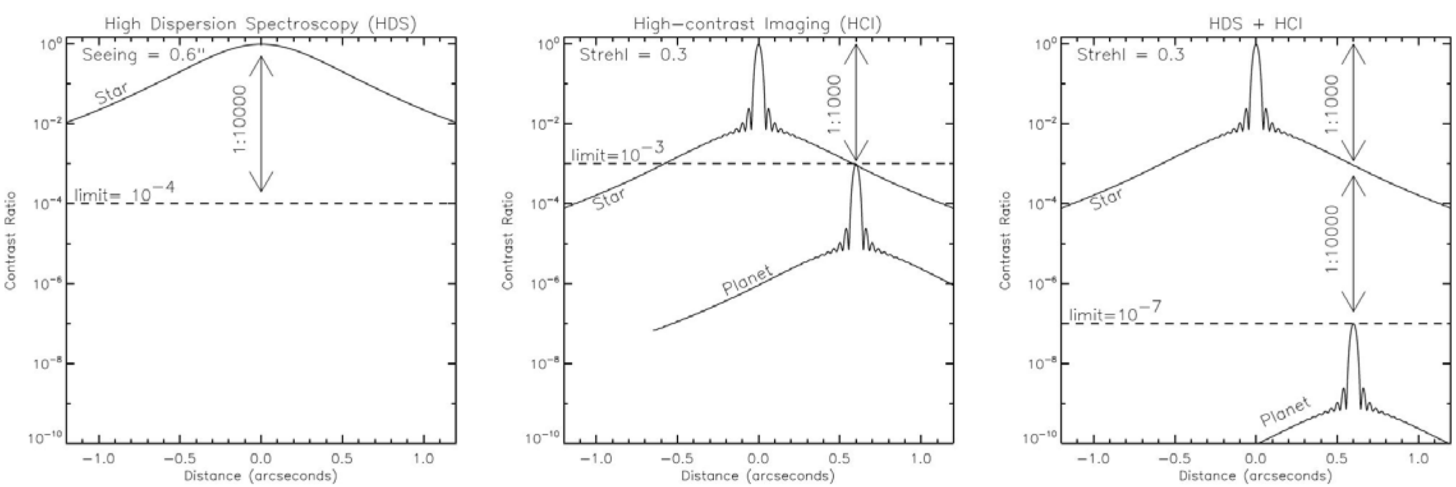


- Hybrid **high-contrast imager + high-resolution spectrograph** is arguably the best approach for ground-based characterisation
  - One planet is (maybe) observable with an 8-m
  - Tens of planets accessible with ELTs

Finding imagable planets



Snellen et al. 2015

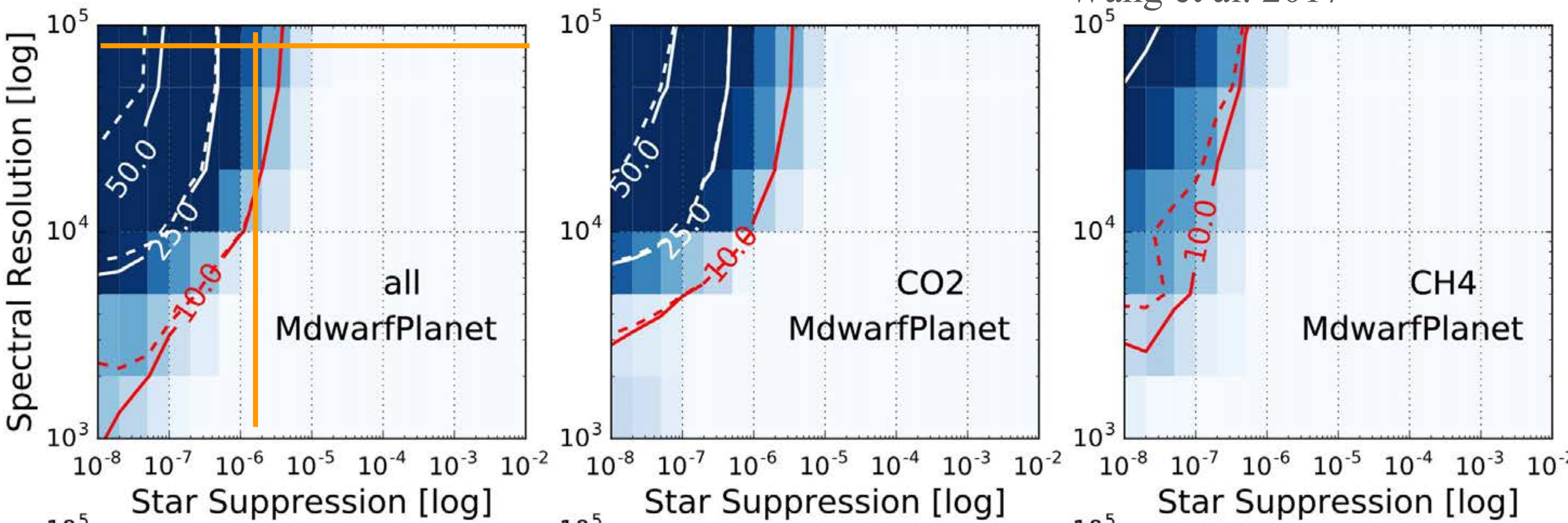


Finding imagable planets

- Star
  - 3500K
  - 5 pc
- Telescope
  - TMT
  - 100h

- Earth analog
  - 1 M⊕
  - 1 R⊕
  - Teq=300K
  - Separation : 20mas / 0.1 AU

Wang et al. 2017

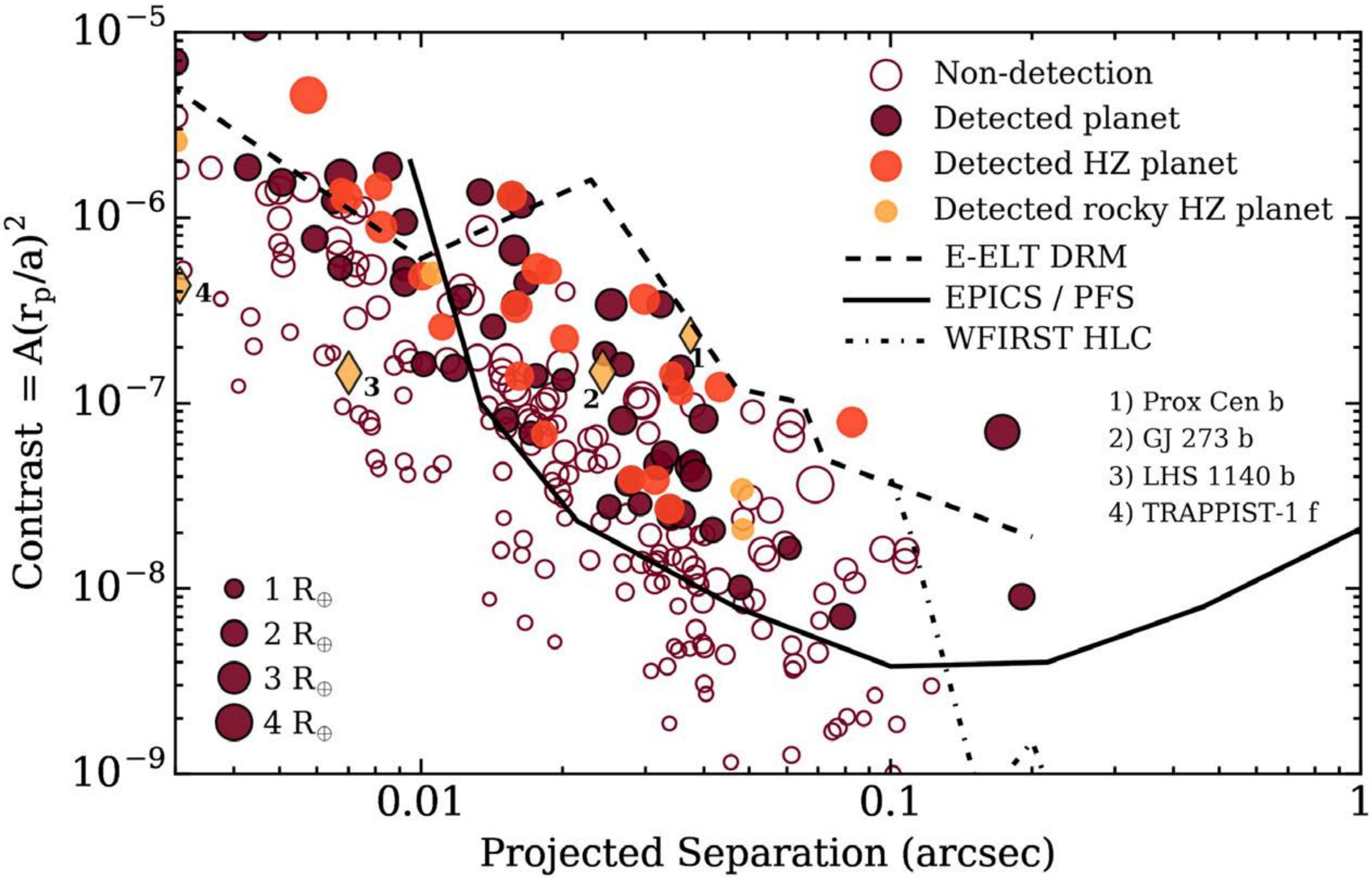


Finding imagable planets

- One cannot envision a fishing expedition *on any telescope* with ~100 h/target!
- Planets must be identified in advanced...
  - These planets can be identified now!
- Major boost for instrument builders to have an actual target list!

- Deep RV survey of nearby Ms
  - AJ paper submitted by R. Cloutier (UofT/UdeM PhD)
  - 109 targets
  - 190 visits per target
  - ~1.5 m/s RMS per visit
  - Very detailed error budget, activity/filtering, window function, etc
  - A handful planets may transit, most likely none that can be imaged with TMT

Finding imagable planets



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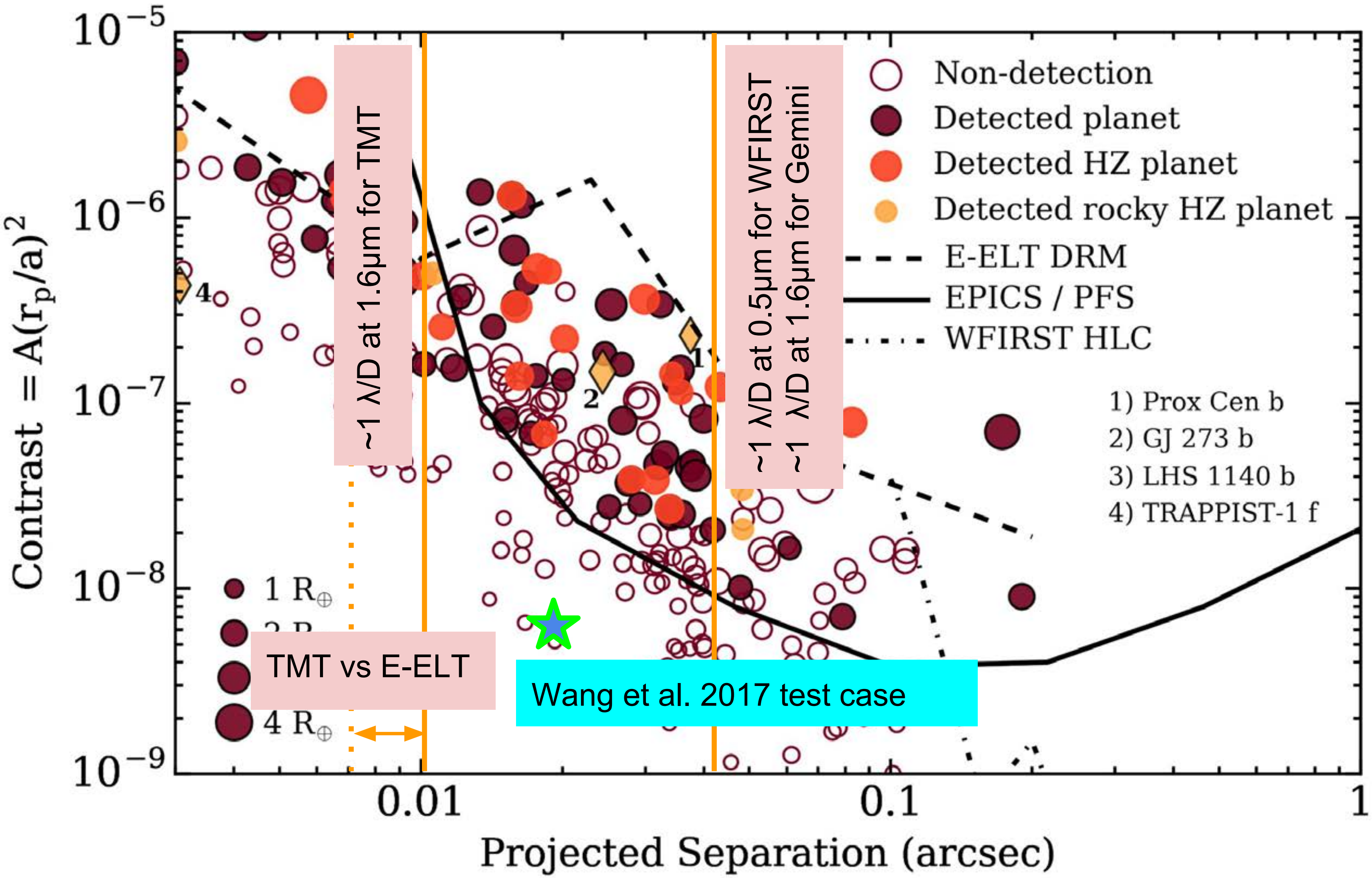
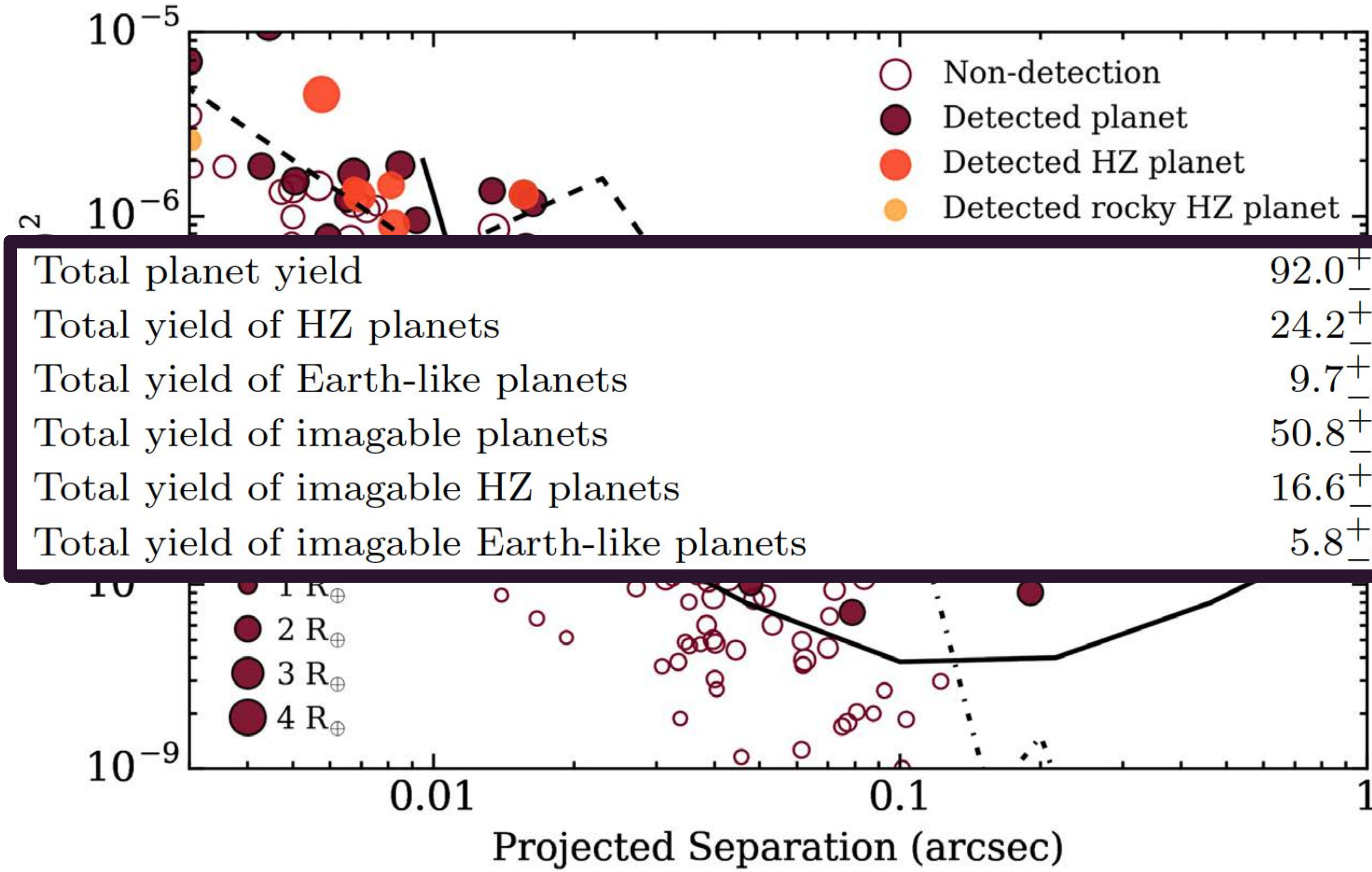
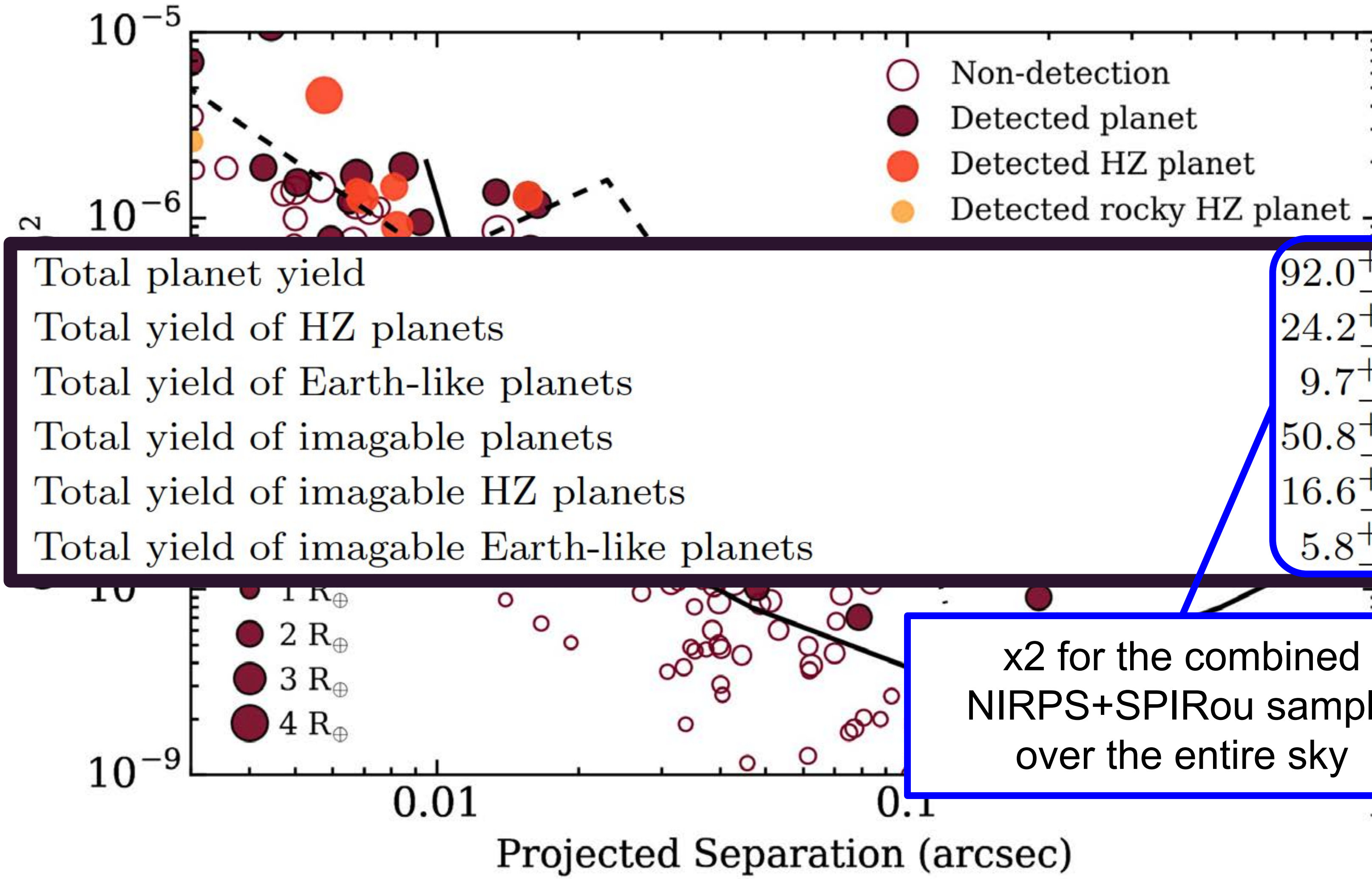


Finding imagable planets



Total planet yield	$92.0^{+25.7}_{-10.1}$ (1)
Total yield of HZ planets	$24.2^{+20.3}_{-8.7}$ (1)
Total yield of Earth-like planets	$9.7^{+9.3}_{-3.9}$ (1)
Total yield of imagable planets	$50.8^{+14.2}_{-4.9}$ (1)
Total yield of imagable HZ planets	$16.6^{+13.9}_{-5.9}$ (1)
Total yield of imagable Earth-like planets	$5.8^{+5.6}_{-2.3}$ (1)

Finding imagable planets



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x2 for the combined NIRPS+SPIRou sample over the entire sky

Transit follow-ups

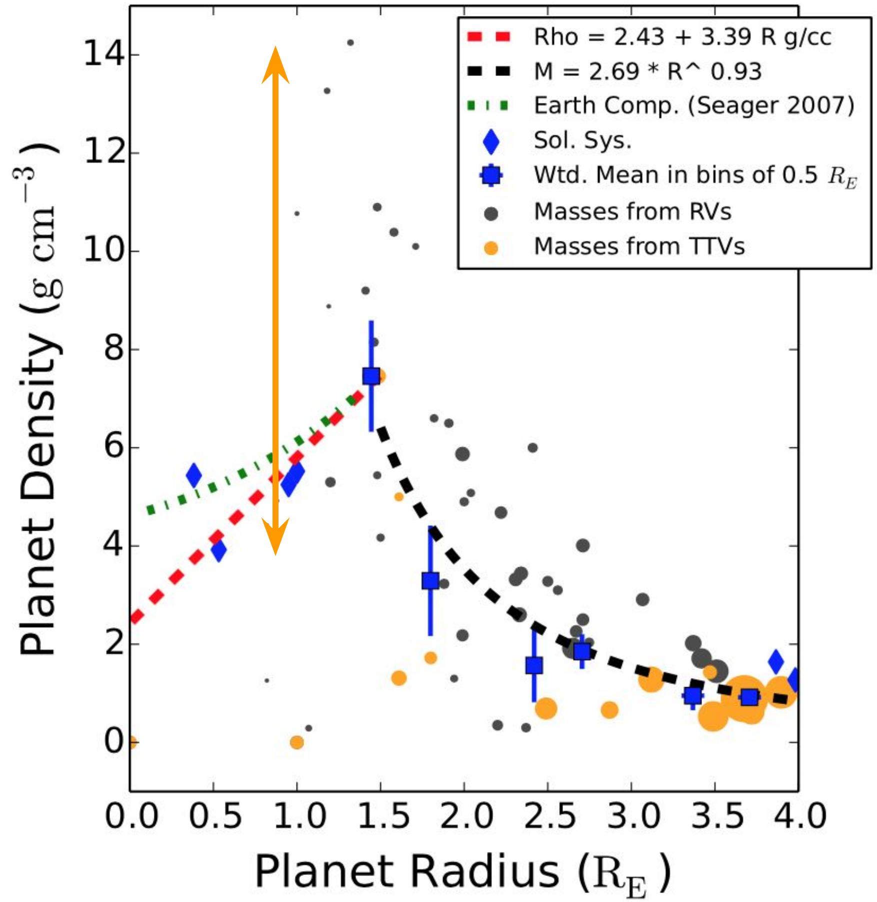
- Mostly TESS
  - AO system designed to enable observations of the median TESS target with high-resolution fibre
- Mass and density determination
  - Huge scatter in the radius/density diagram for Earth-sized planets and super-Earths
- Density is **key** for transit spectroscopy

$$A \sim 5 \times \left(\frac{2R_pH}{R_*^2}\right)$$

$$H = \frac{kT}{\mu g}$$

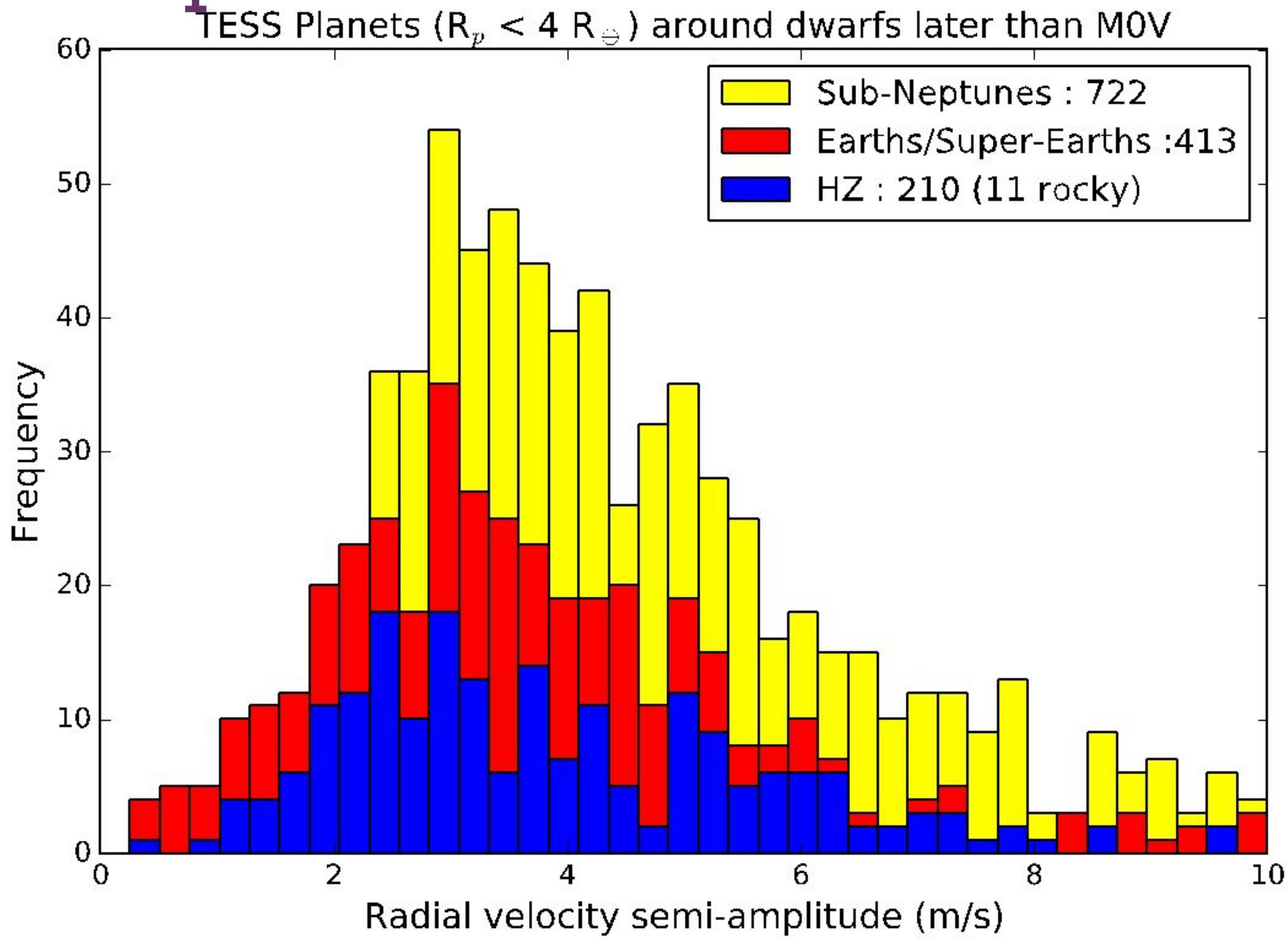
All other things being equal, transit spectroscopy signal scales as M_p^{-1}

A nitrogen vs hydrogen atmosphere μ of 28 vs 2



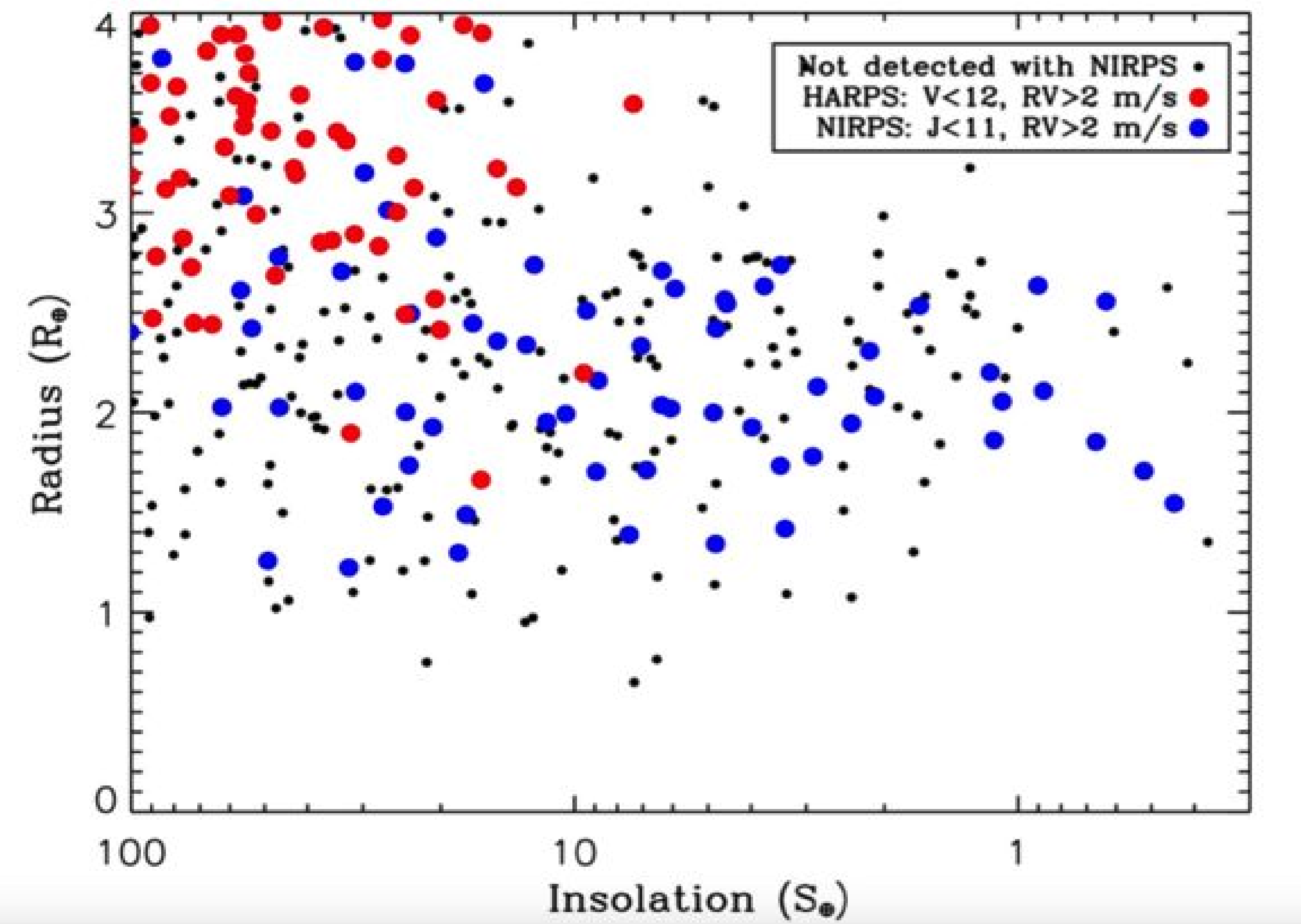
Weiss & Marley 2014

TESS targets well suited for RV follow-ups

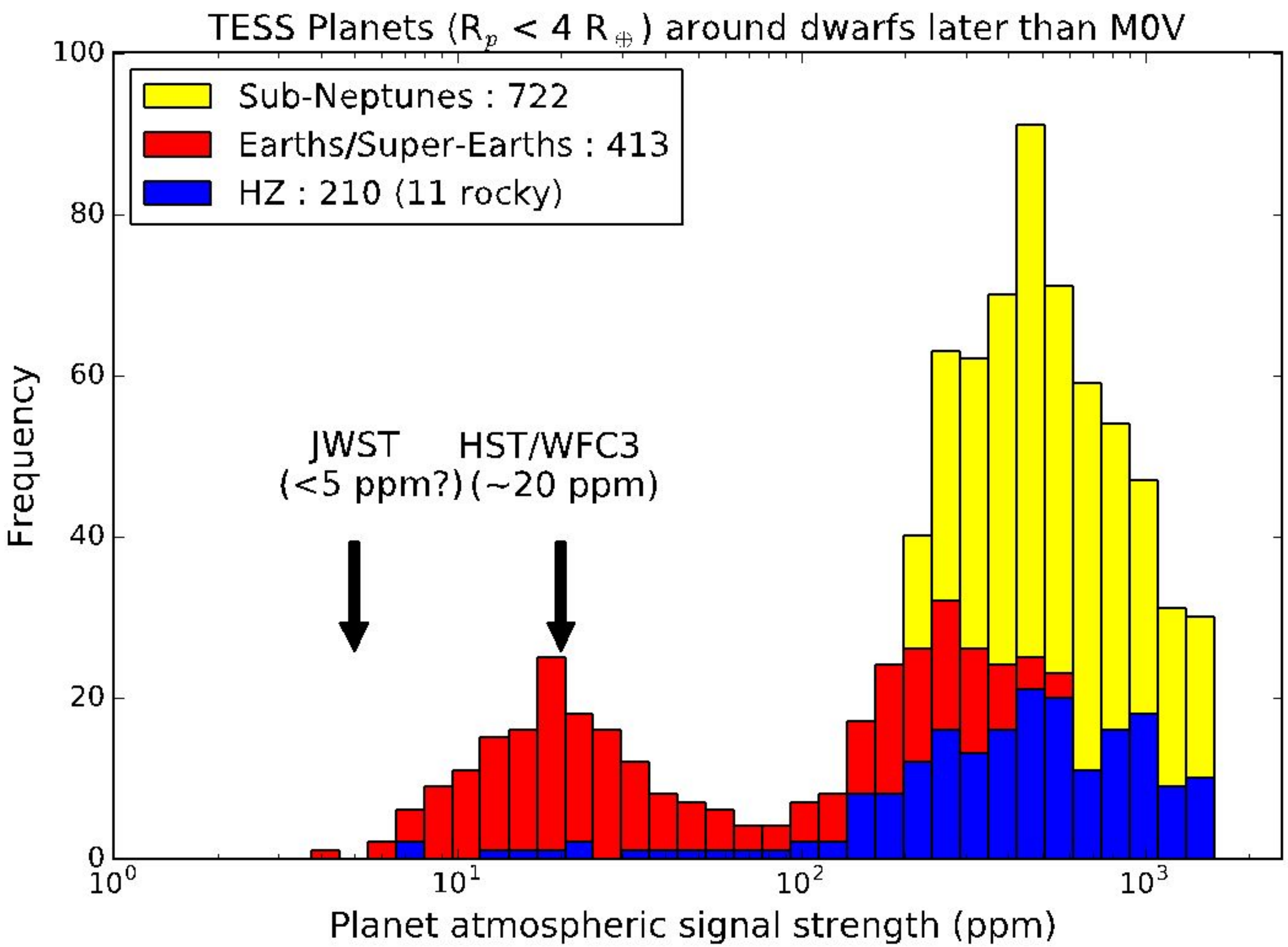


Data from the "targeted star" sample of Sullivan et al (2015)

+ Good complementarity between HARPS and NIRPS



The bulk of TESS targets should be amenable for atmospheric characterization with JWST



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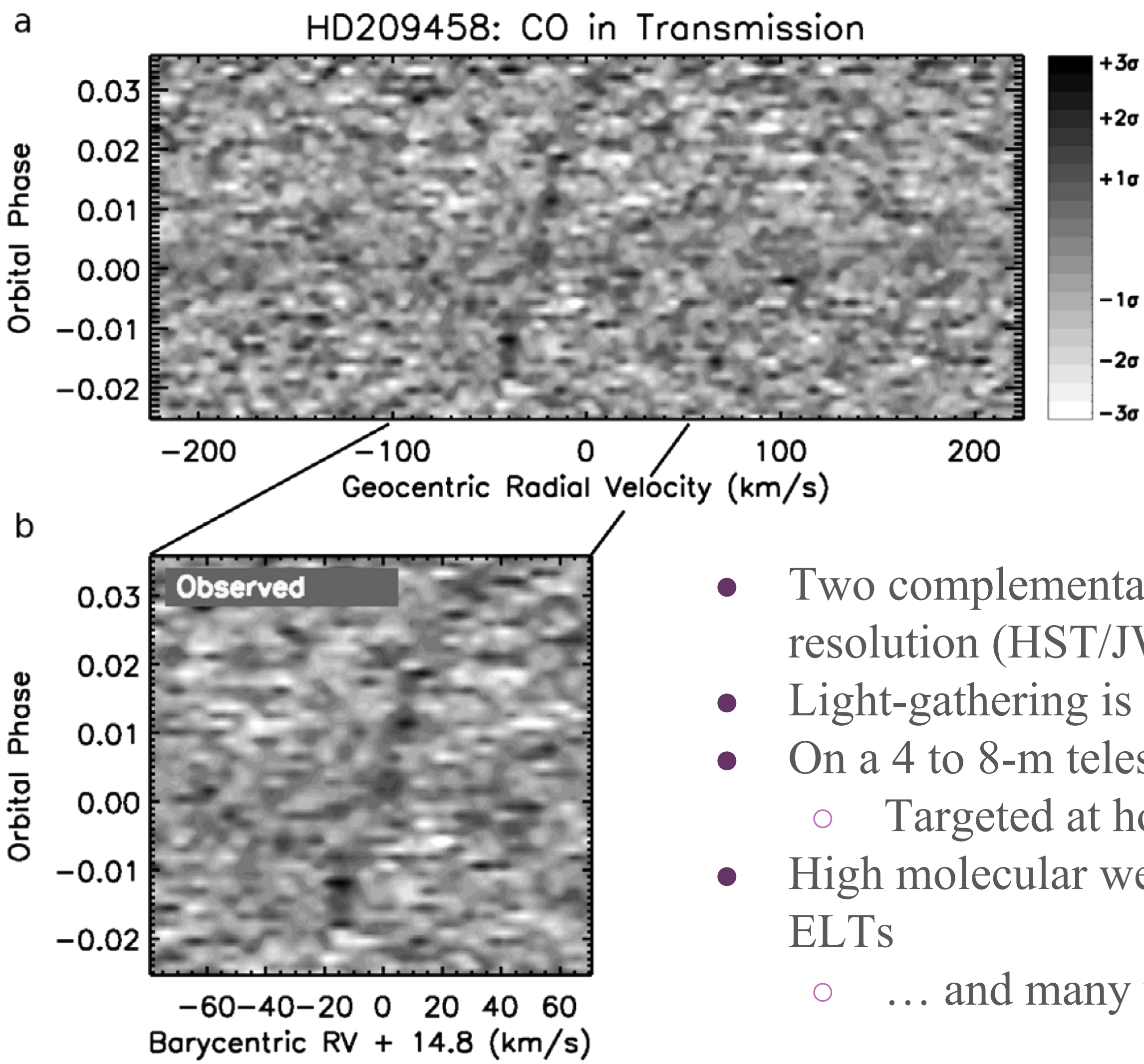
Transit spectroscopy at high-resolution

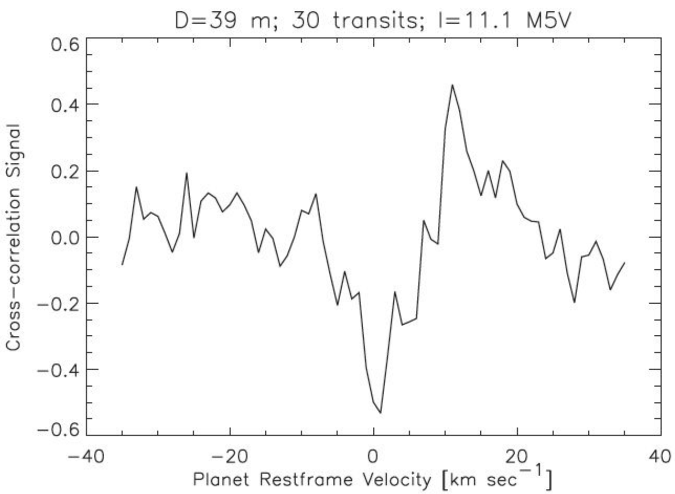


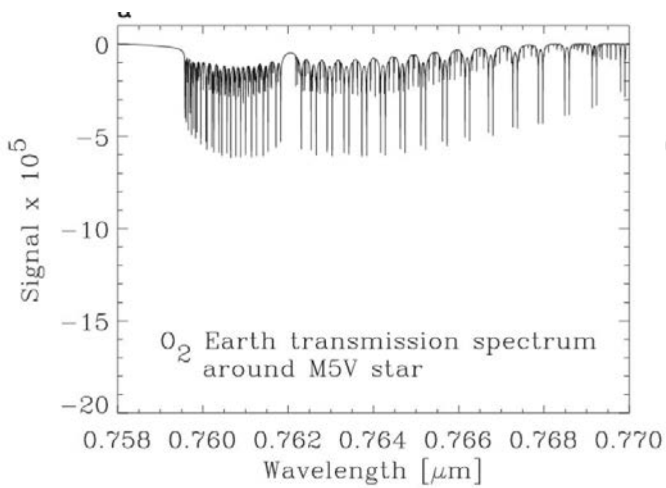
- Two complementary paths to low/intermediate resolution (HST/JWST)
- Light-gathering is key here
- On a 4 to 8-m telescope…
  - Targeted at hot Jupiters and a few super Earths
- High molecular weight atmospheres will require ELTs
  - … and many visits!

Transit spectroscopy at high-resolution

- Possibility to study an Earth analog with the TMT
  - … and detect oxygen on it!
- Median TESS planet host with T_{eff}<3800 at I=12.7
  - ~10 Earth-sized planets around stars brighter than I=11.1

~100h on TMT





Snellen et al 2013

Conclusion

- HARPS+NIRPS will be a prime facility for RV exoplanet searches in the Southern sky up to +30N
  - Impressive number of GTO nights will be as important as instrument performances
  - ⅔ of the sky area accessible to TMT is accessible to NIRPS
- NIRPS is paving the way for various exoplanet research avenues to be done with TMT
  - It is the sonar for the fishing expeditions!