Other Worlds in the Cosmos? The Search for Planets Similar to

Doppler cross-correlation spectroscopy + transit spectroscopy as a path to the detection of Earth-like planets and maybe life.

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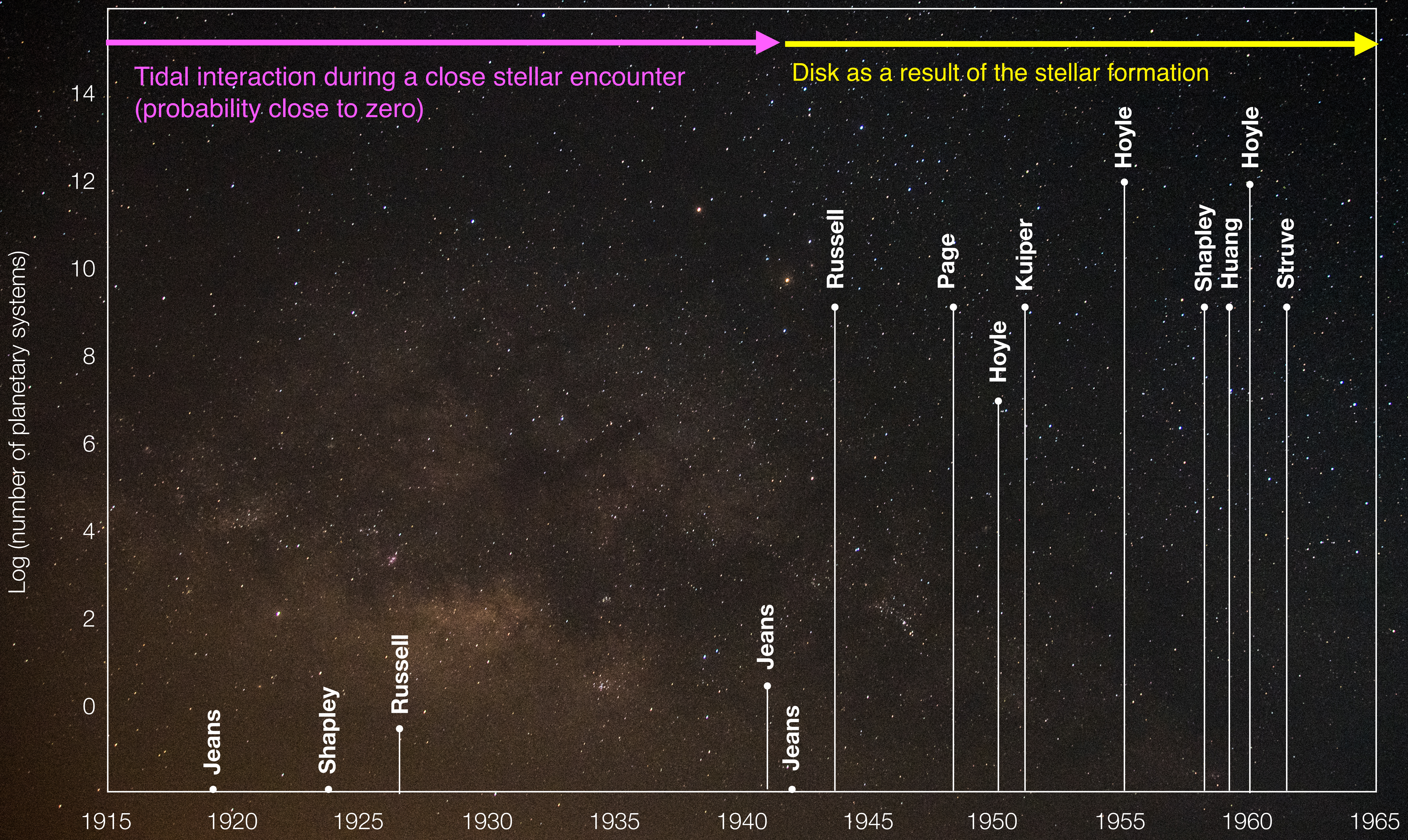
Université de Genève

Estimated number of planetary systems

in the Milky Way



Adapted from S. J. Dick

Observatory (1952) 72,199

PROPOSAL FOR A PROJECT OF HIGH-PRECISION STELLAR RADIAL VELOCITY WORK

By Otto Struve

"I have suggested elsewhere that the lack of rapid axial rotation of normal solar-type stars ... suggests that these stars have converted their angular momentum from axial rotation to angular momentum from the orbital motion of the planets. Therefore there can be many planet-like objects in the galaxy. "

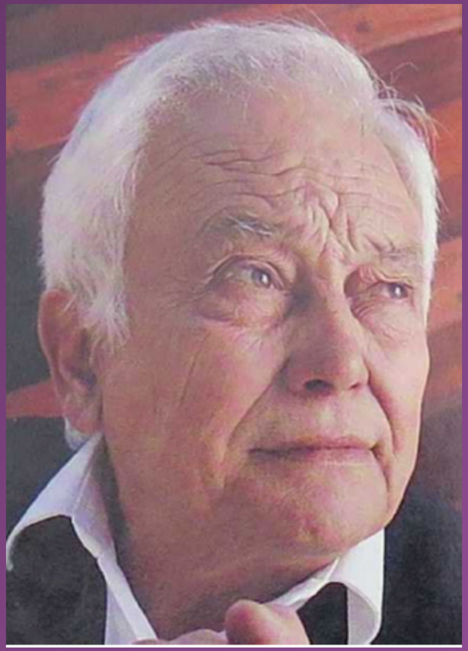
Fellgett 1955 : the cross-correlation idea
"A proposal for a radial velocity photometer,"
Opt. Acta 2, 9–15.

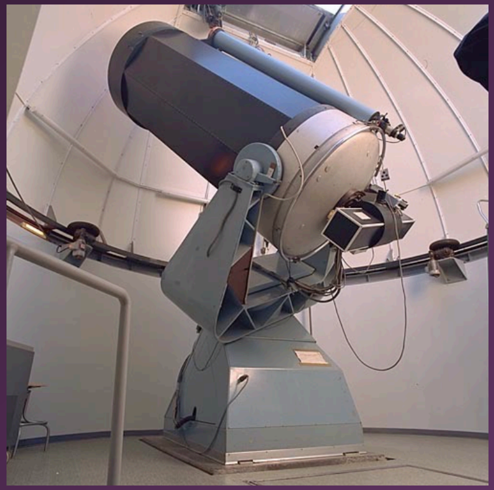
Griffin 1967 : A first instrument on the 1 m telescope
at Cambridge Obs. photomultiplier, 500 m/s
Efficiency relative to photographic plate
gain 1000 !

1967, "A photoelectric radial-velocity spectrometer."
Astrophys. J. 148, 465–476.

Baranne, Mayor, Poncet 1977,1979 :
CORAVEL at 1-meter telescope OHP.
Cross-dispersed optics,
white pupil, computer controlled.
300 m/s , optical cross-correlation,
efficiency gain 4000 !

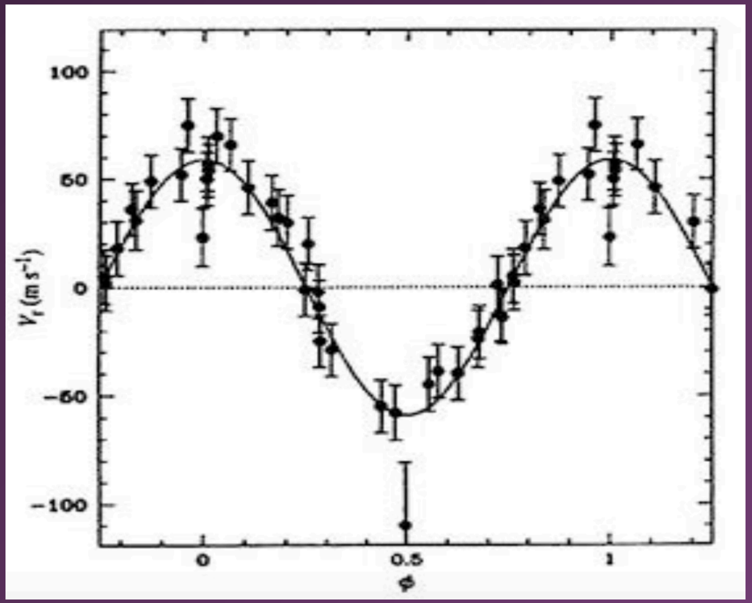
1979, "CORAVEL: A new tool for radial velocity measurements.
Vistas Astron. 23, 279–316.



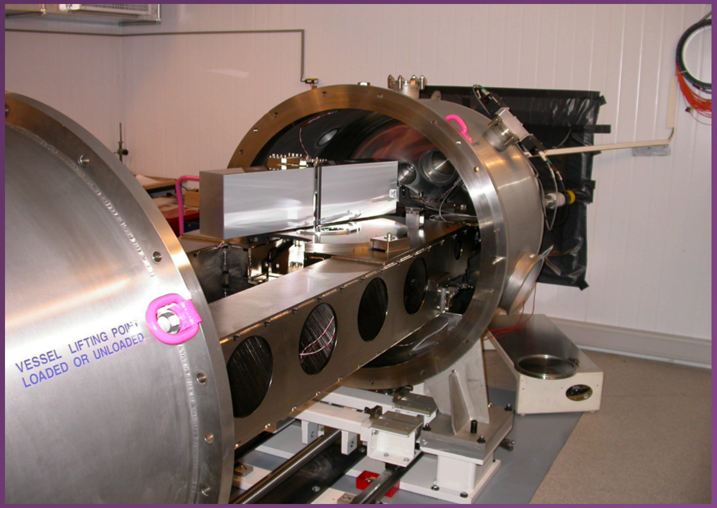


Baranne, Queloz, Mayor ,et al. 1996

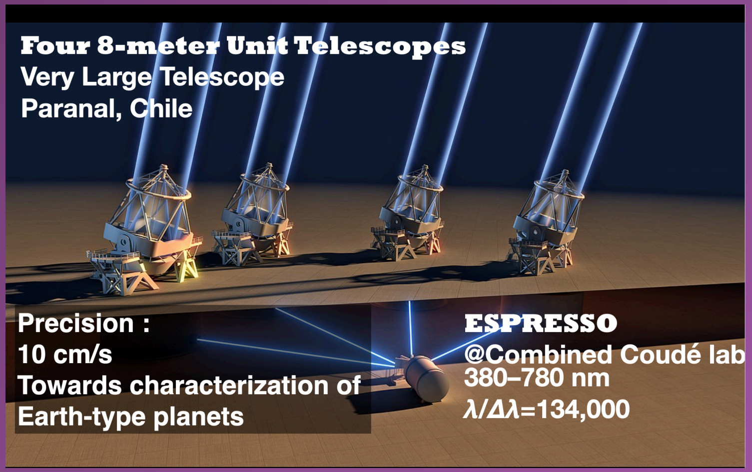
ELODIE , Haute -Provence Observatory ,
1.93 m-telescope, 2 optical fibers,
CCD >> numerical cross-cross-correlation (!!!)
13 m/s >>>>>>>> 51 Pegasi b (1995)

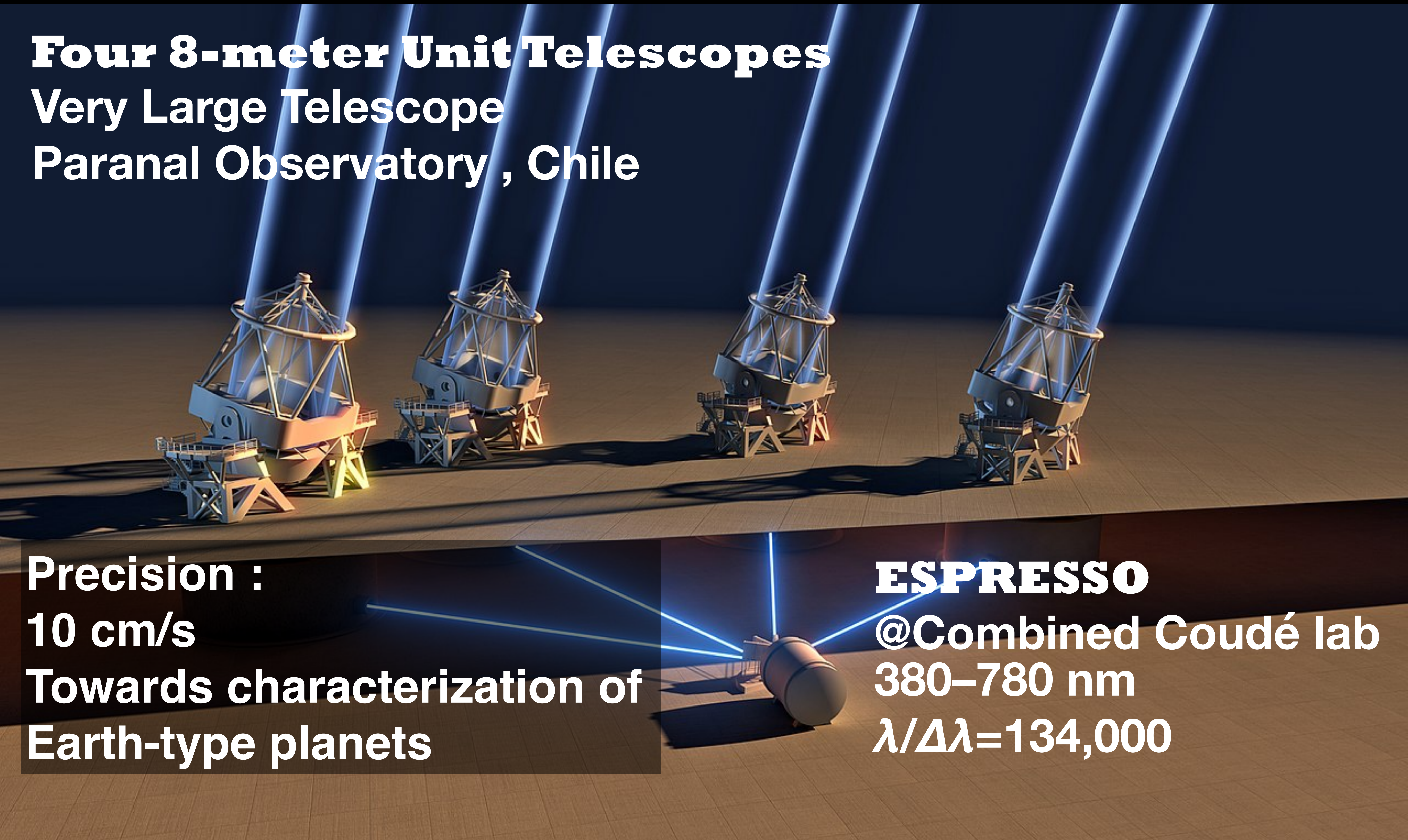


Mayor, Pepe, Queloz et al. 2003
HARPS , ESO-La Silla, 3.6-m telescope,
vacuum and temperature control, + a lot of software improvements (CCD stitching, better air mass correction, octogonal fibers for better scrambling, Perot-Fabry etalon, lasercomb…) 1 m/s



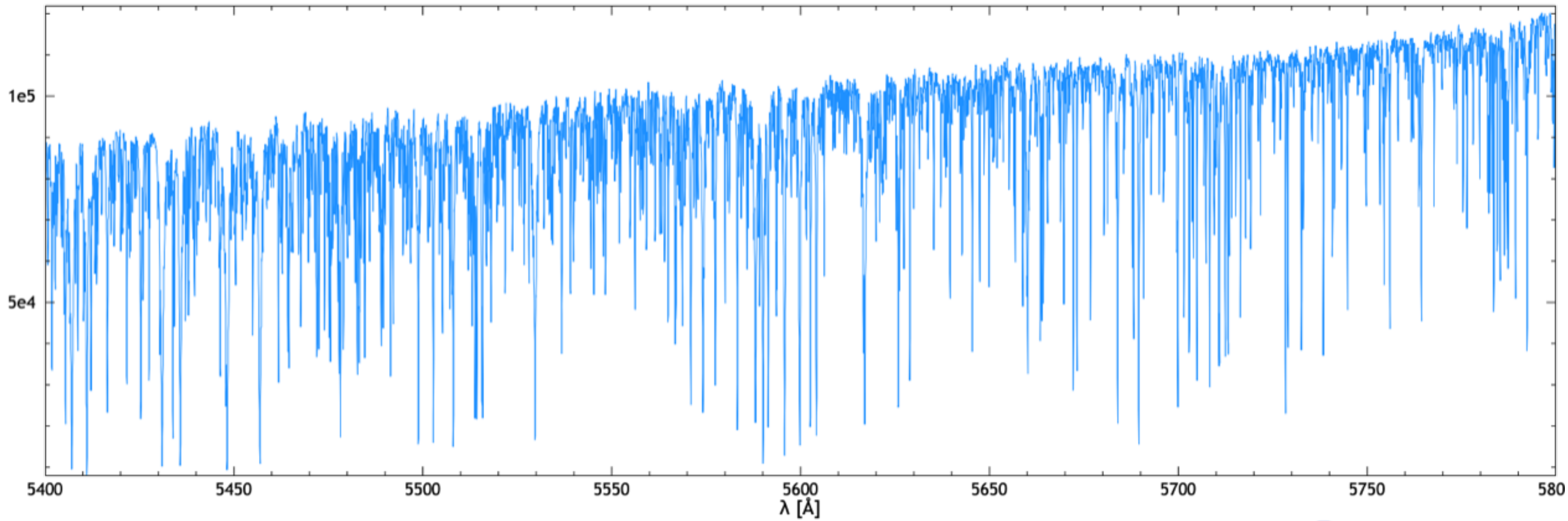
Pepe et al. 2018
ESPRESSO , ESO Paranal , 1 (or 4) x 8.2 m-telescope
0.1 m/s




Four 8-meter Unit Telescopes
Very Large Telescope
Paranal Observatory , Chile
Precision :
10 cm/s
Towards characterization of
Earth-type planets
ESPRESSO
@Combined Coudé lab
380–780 nm
λ/Δλ=134,000

The variation in stellar radial velocity induced by the influence of a planet analogous to our Earth.

Below: 1/10 of the spectral range used for the determination of the radial speed using the Doppler effect. (ESPRESSO Spectrograph , ESO Paranal Obs.)
The variation in the speed of a solar star due to an Earth-like planet (P = 1 year) is 8 cm / s therefore relative variation of 0.3 x 10 ** (- 4) of the width of the spectral lines. (about 1 nanometer)
>>>>>> the cross-correlation technique makes it possible to concentrate the Doppler information of several thousand spectral lines to achieve this precision.



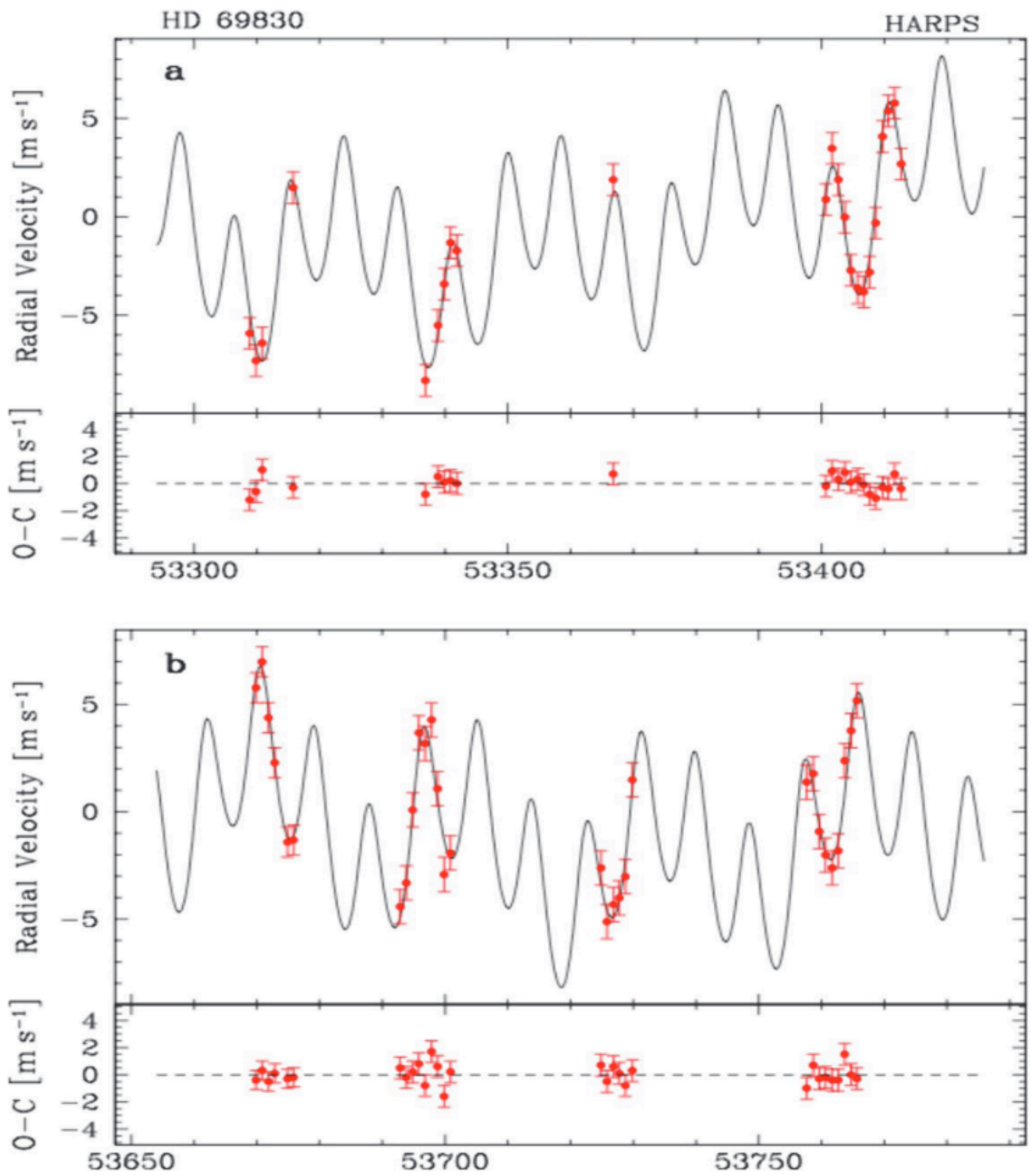
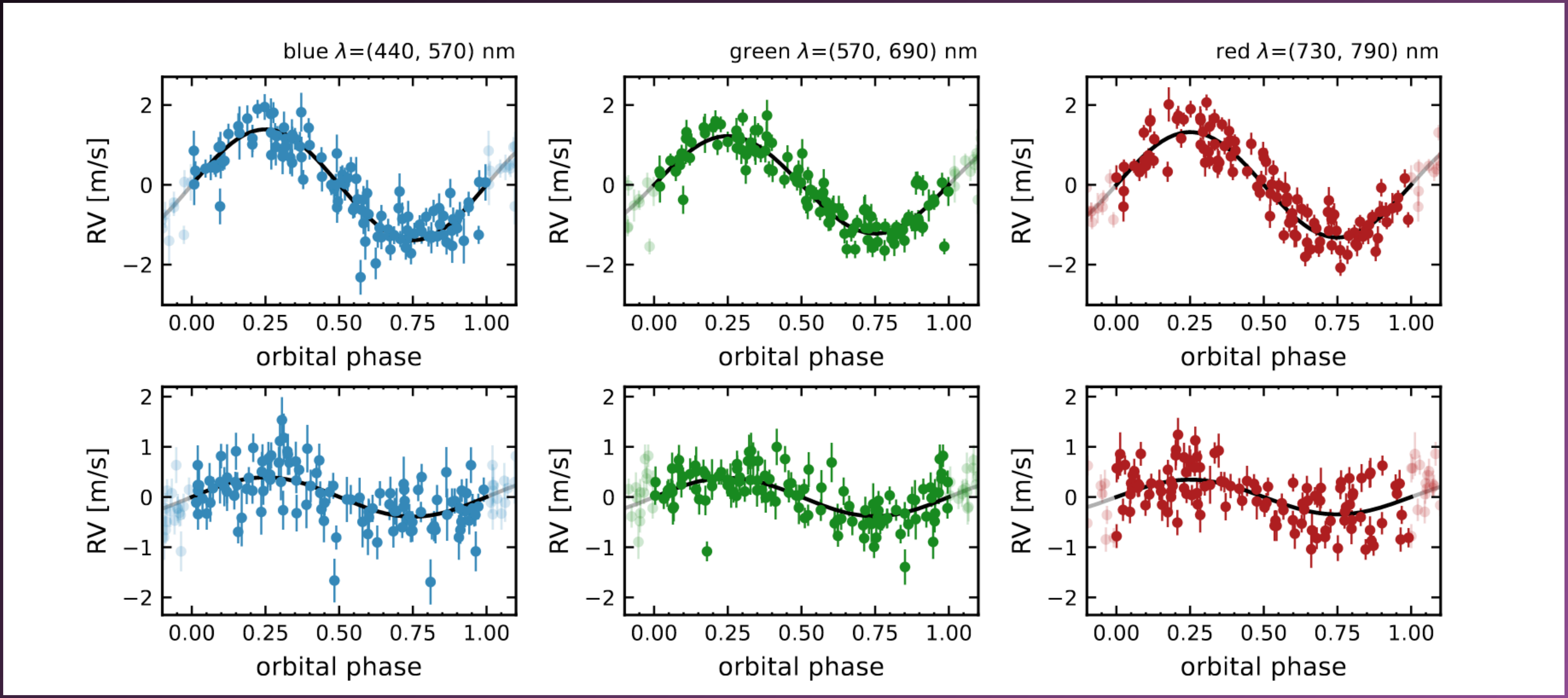


Fig. 4. A limited range of the velocity variation of HD 69830 giving an example of the complex curve resulting from the stellar reflex motion due to three planets (Lovis *et al.* 2006, *Nature* 441, 305).

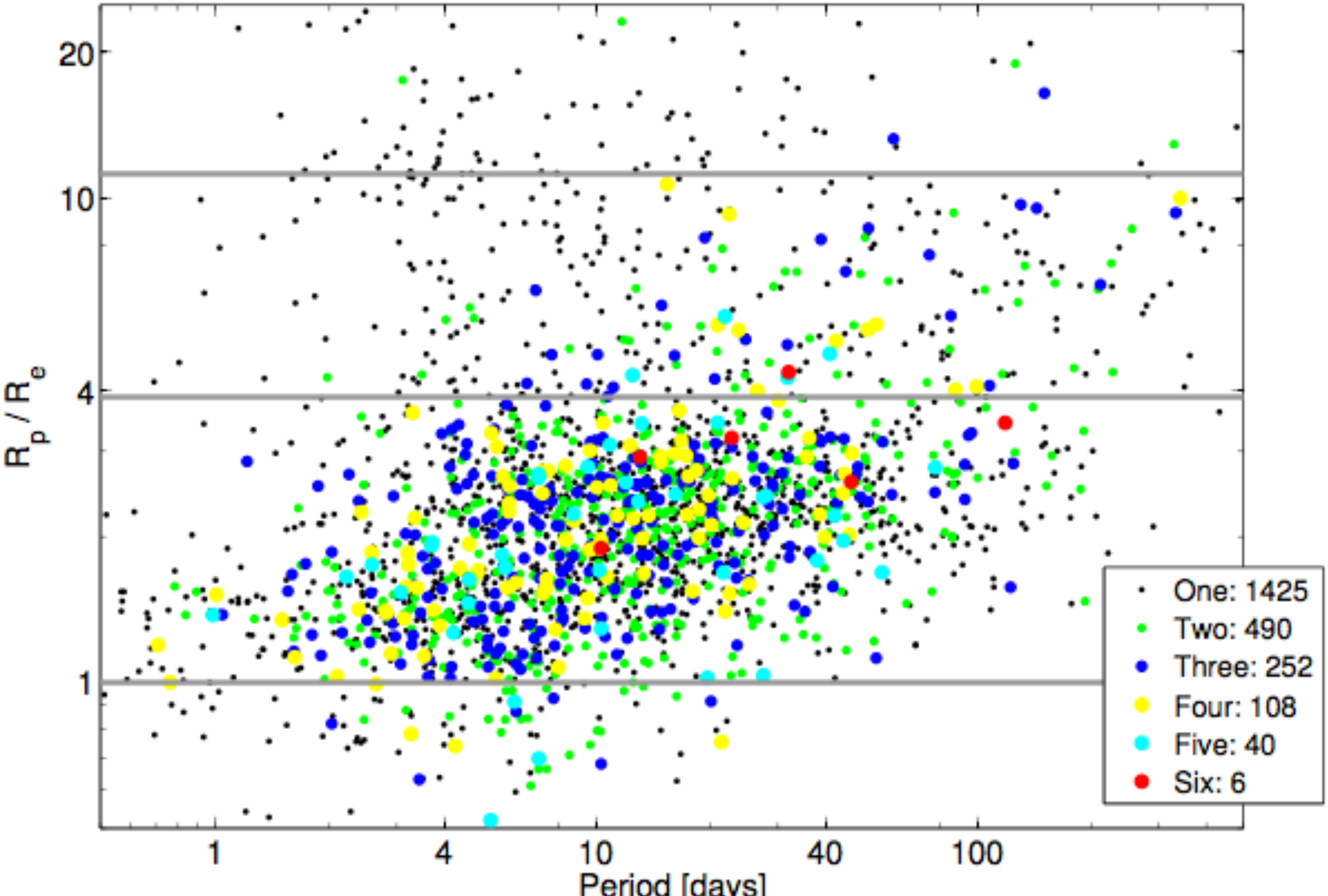
Proxima Centauri , ESPRESSO measurements of the 2 inner planets,

Proxima b P = 11 d Anglada-Escudé et al. 2016

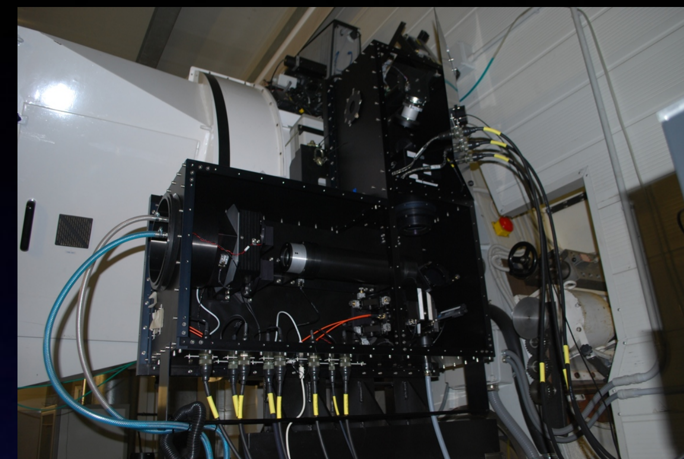
Proxima d P= 5.12 d Faria et al. 2022 Mass = 0.26 Earth.mass

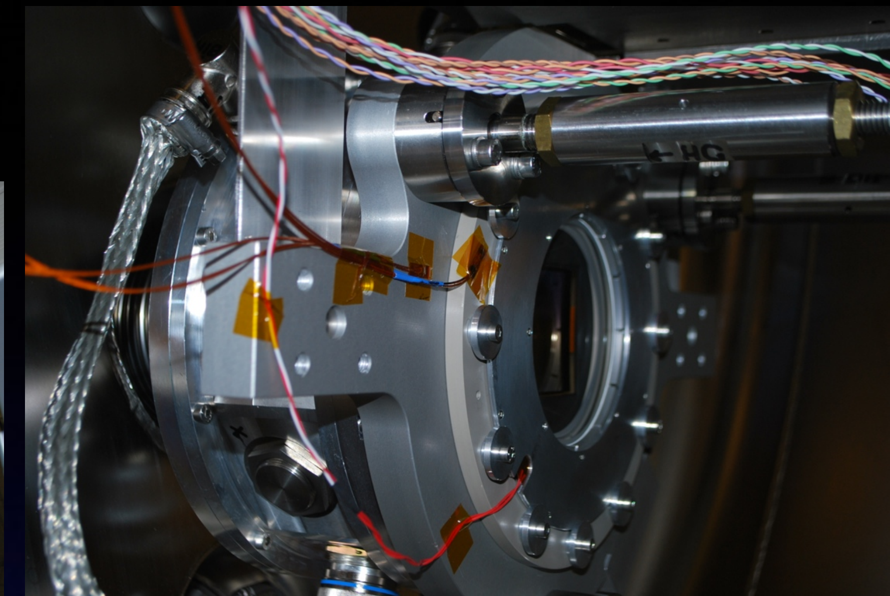


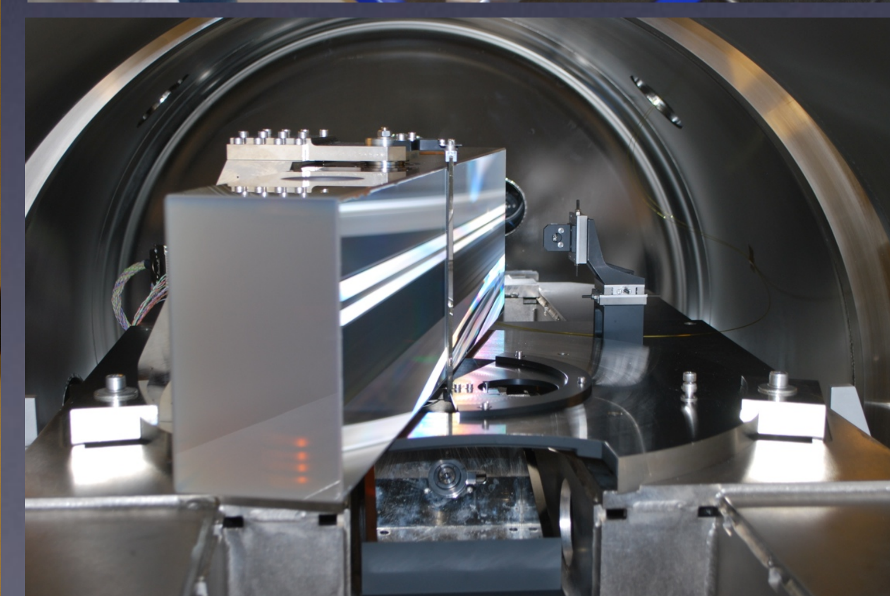
The harvest from the KEPLER space mission



HARPS-N @ Galileo telescope at La Palma Observatory







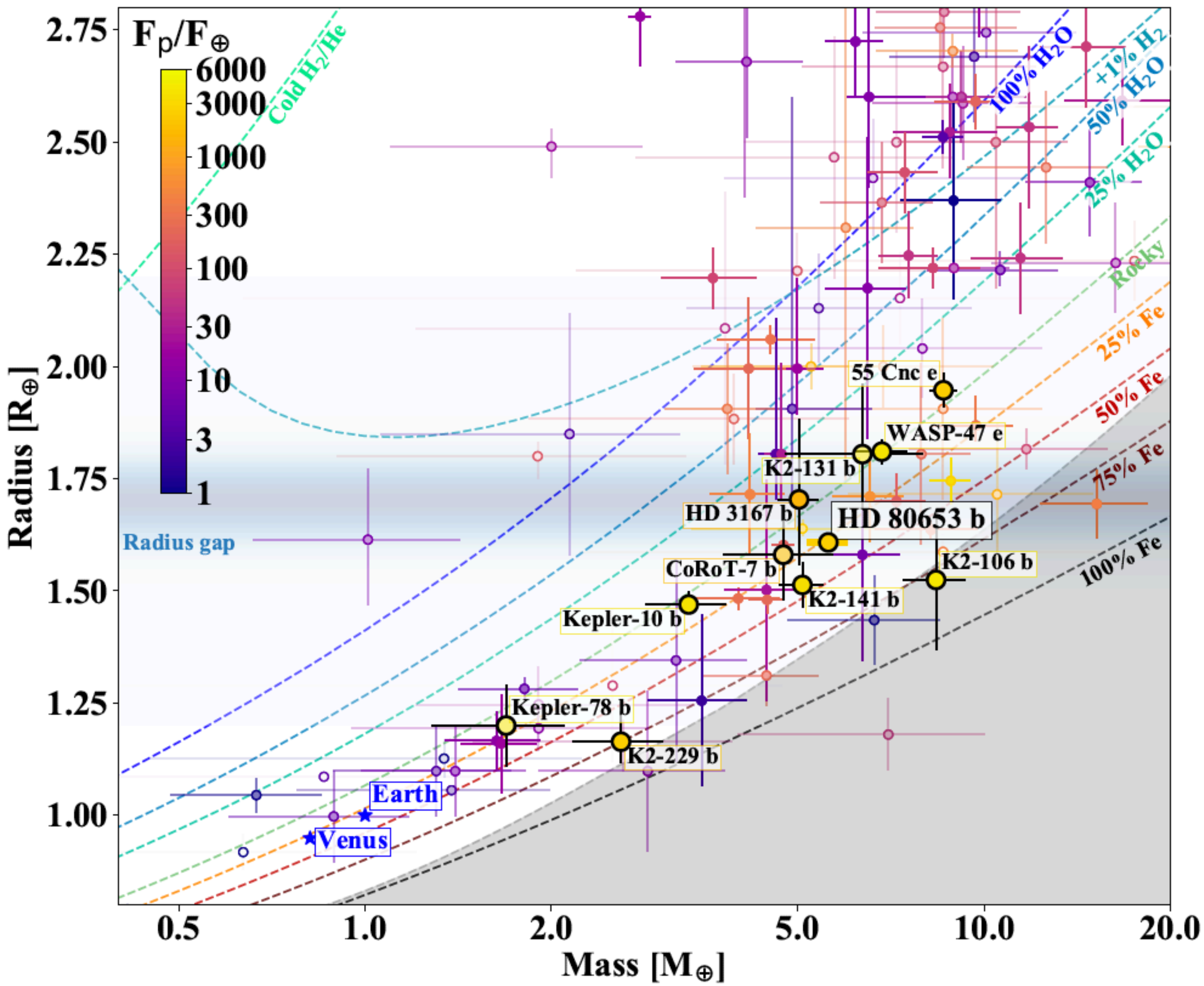
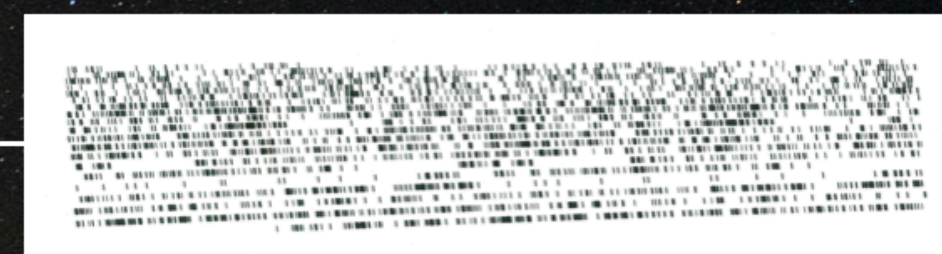


Fig. 11. Mass-radius diagram of planets smaller than ~2.8 $R_{\oplus}$. The data points are shaded according to the precision on the mass, with a full color indicating a value better than 20%. Earth and Venus are shown for comparison. The dashed lines show planetary interior models for different compositions as labelled (Zeng et al. 2019). Planets are color-coded according to the incident flux Fp, relative to the solar constant $F_{\odot}$ The horizontal light-blue shade centered on $R \sim 1.70\,R_{\oplus}$ shows the radius Gap. The shaded gray region marks the maximum value of iron content predicted by collisional stripping (Marcus et al. 2010).

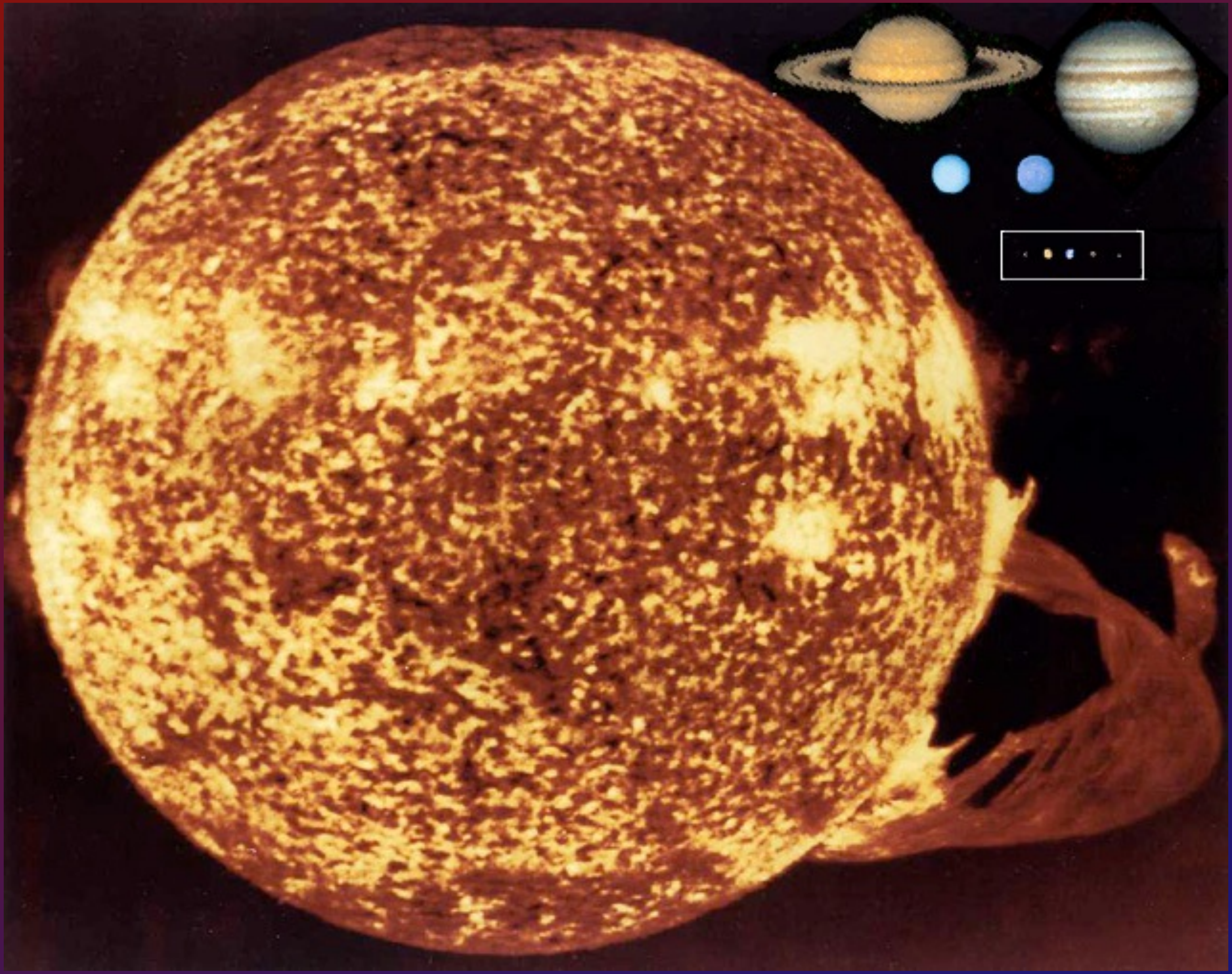
Increasing the precision

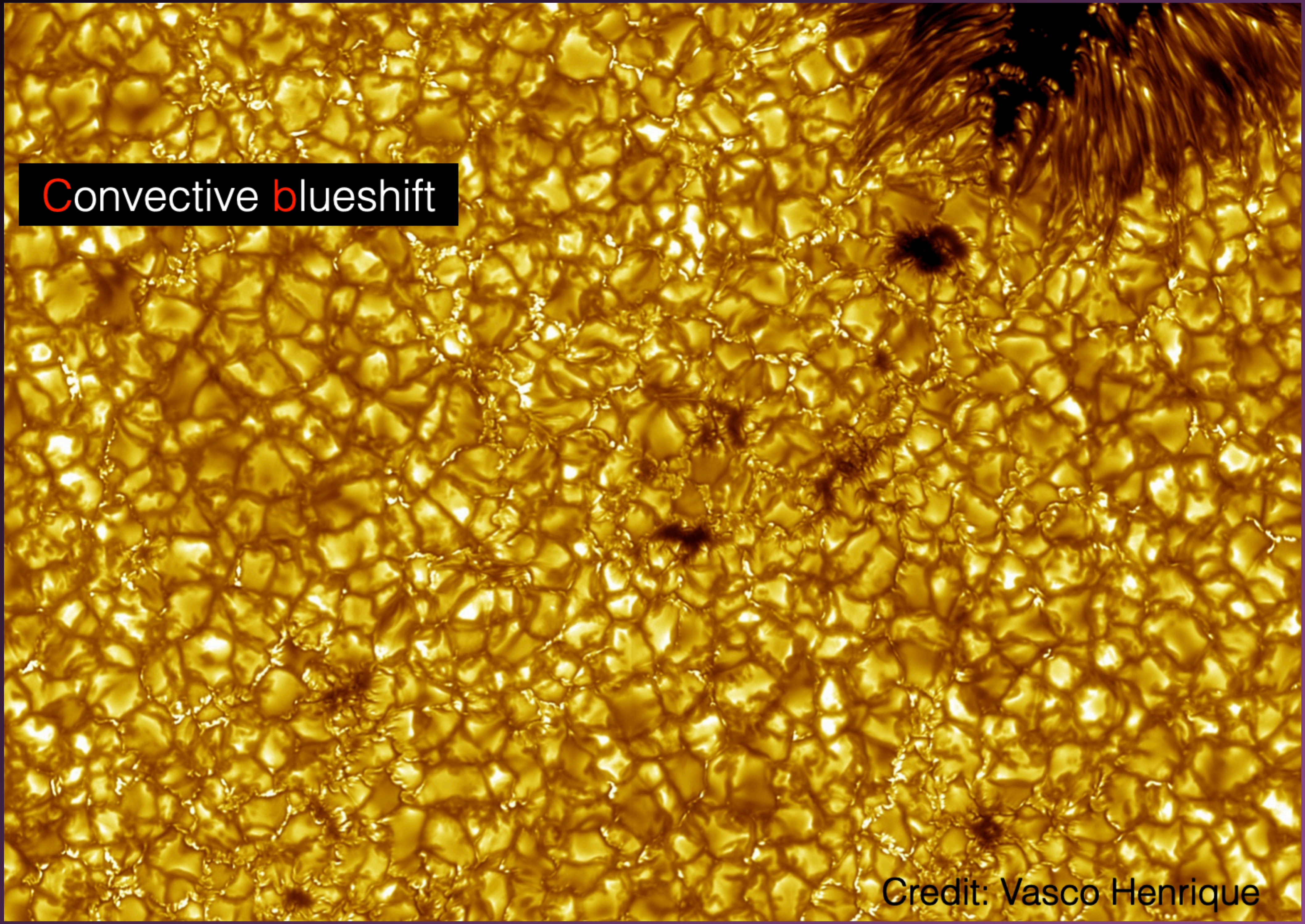
Radial velocity via cross-correlation spectroscopy:
A path to the detection of Earth-type planets

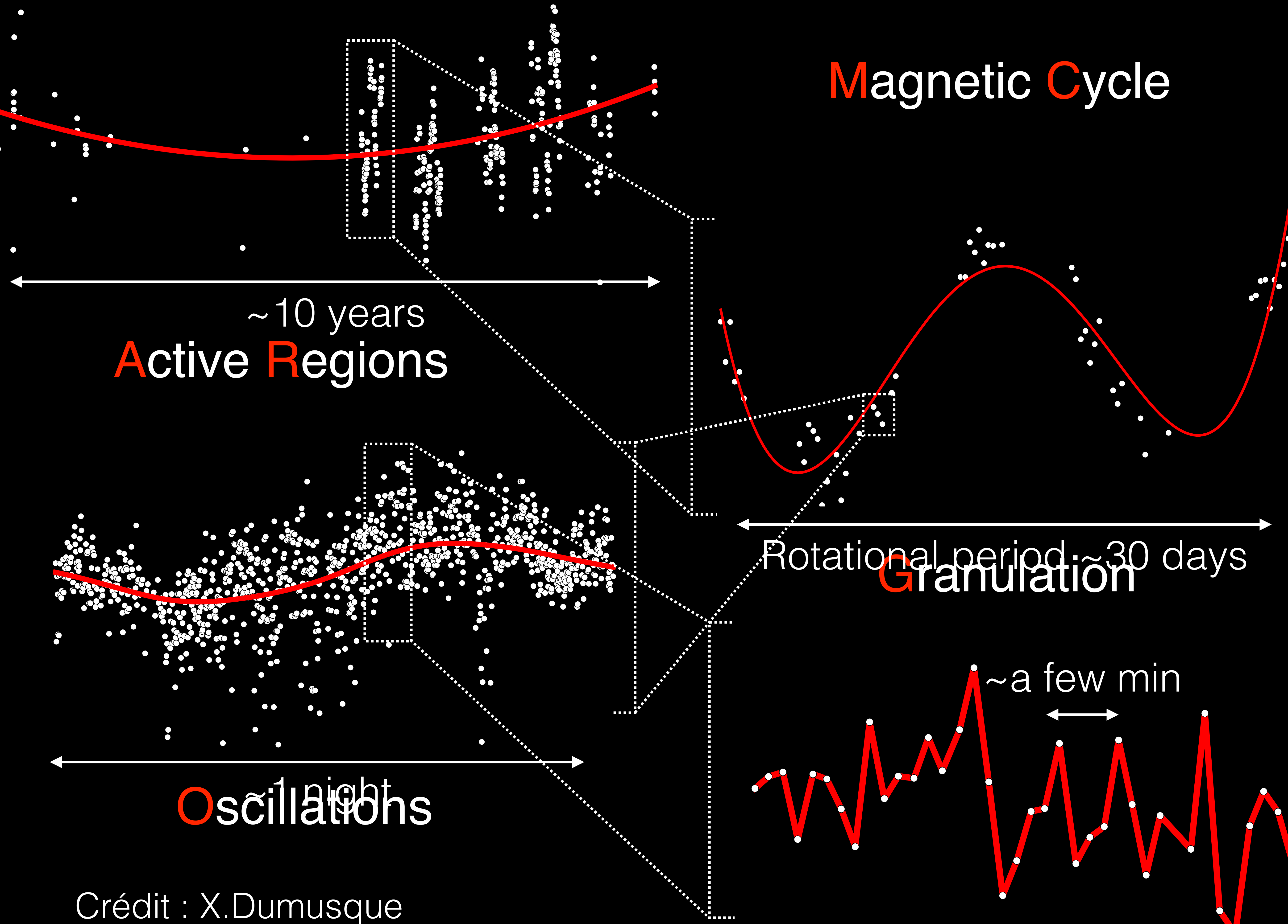
SPECTRO	year	precision	Telescope	
CORAVEL	1977	300 m/s	1 m	OHP
ELODIE	1994	13 m/s	1.9 m	OHP
CORALIE	1998	6 m/s	1 m	ESO Chile
HARPS	2003	1 m/s	3.6 m	ESO Chile
HARPS-N	2013	1 m/s	3.5 m	IAC La Palma
ESPRESSO	2018	0.1 m/s	8.2 m (x4)	ESO Chile



An increase of the sensibility by a factor 3000 during the last 40 years

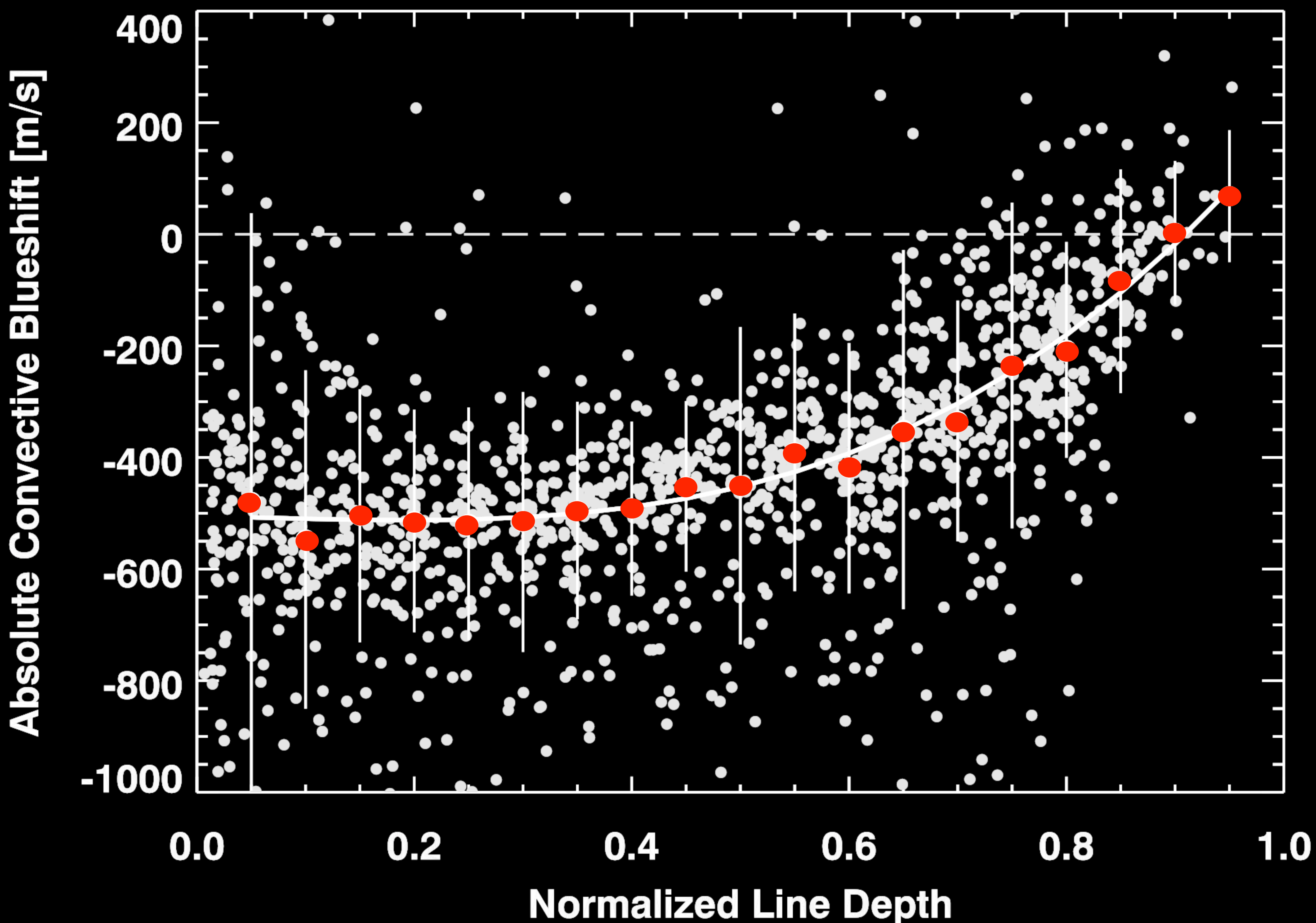



Convective blueshift
Credit: Vasco Henrique



Crédit : X.Dumusque

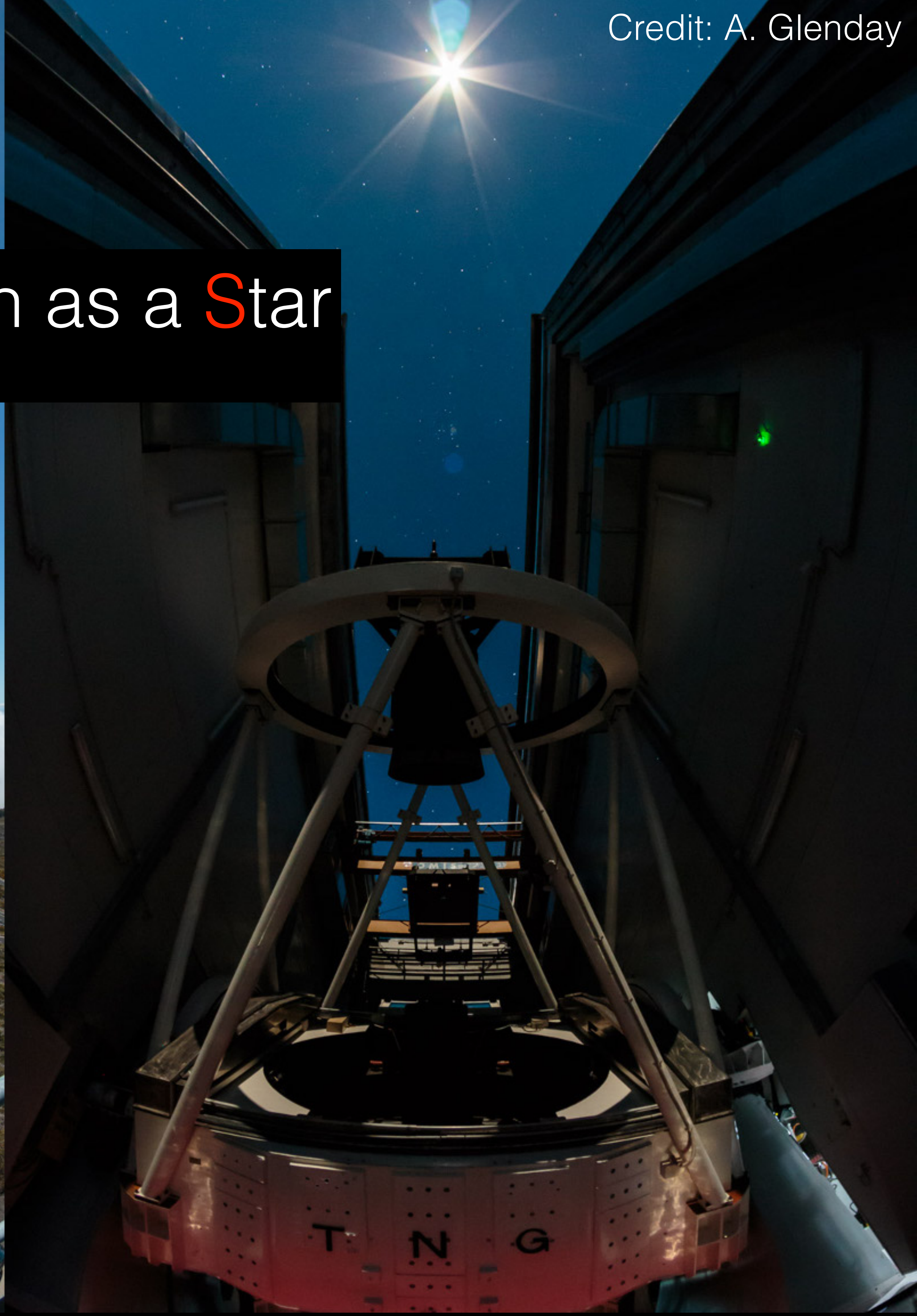
Convective blueshift



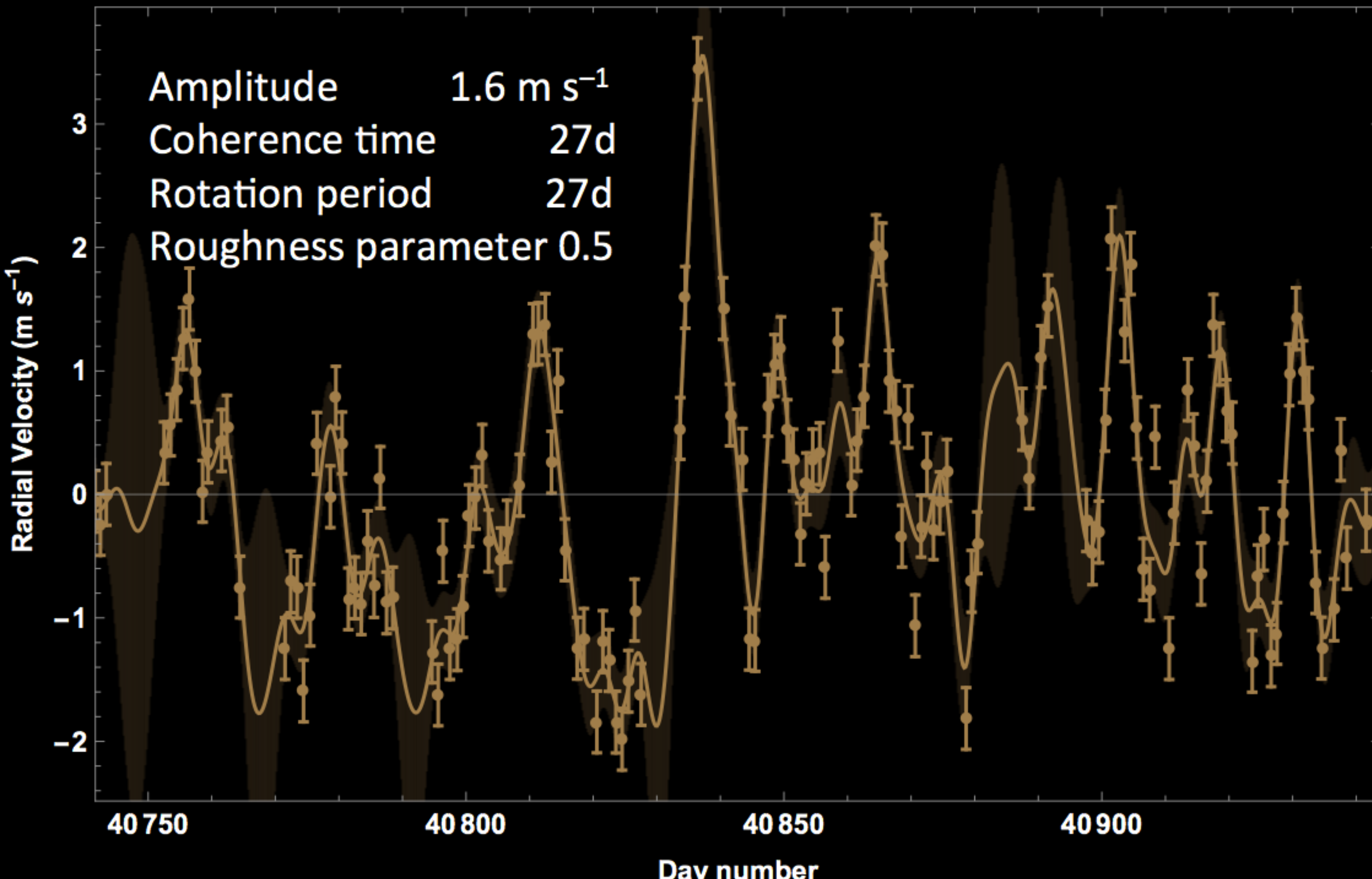
Reiners+ 15

HARPS-N Observes the Sun as a Star

X. Dumusque et al. 2017

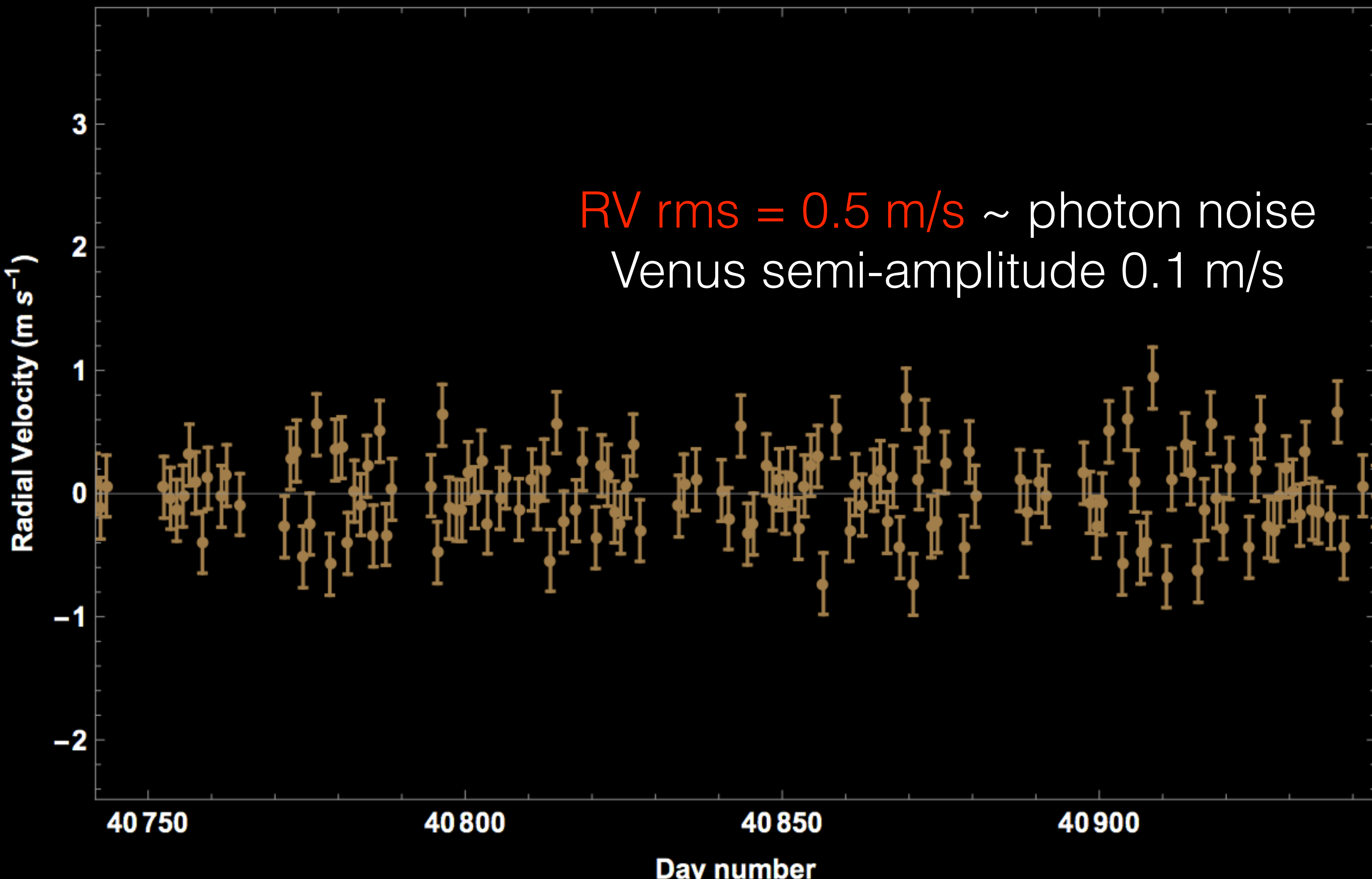


Gaussian Process Regression



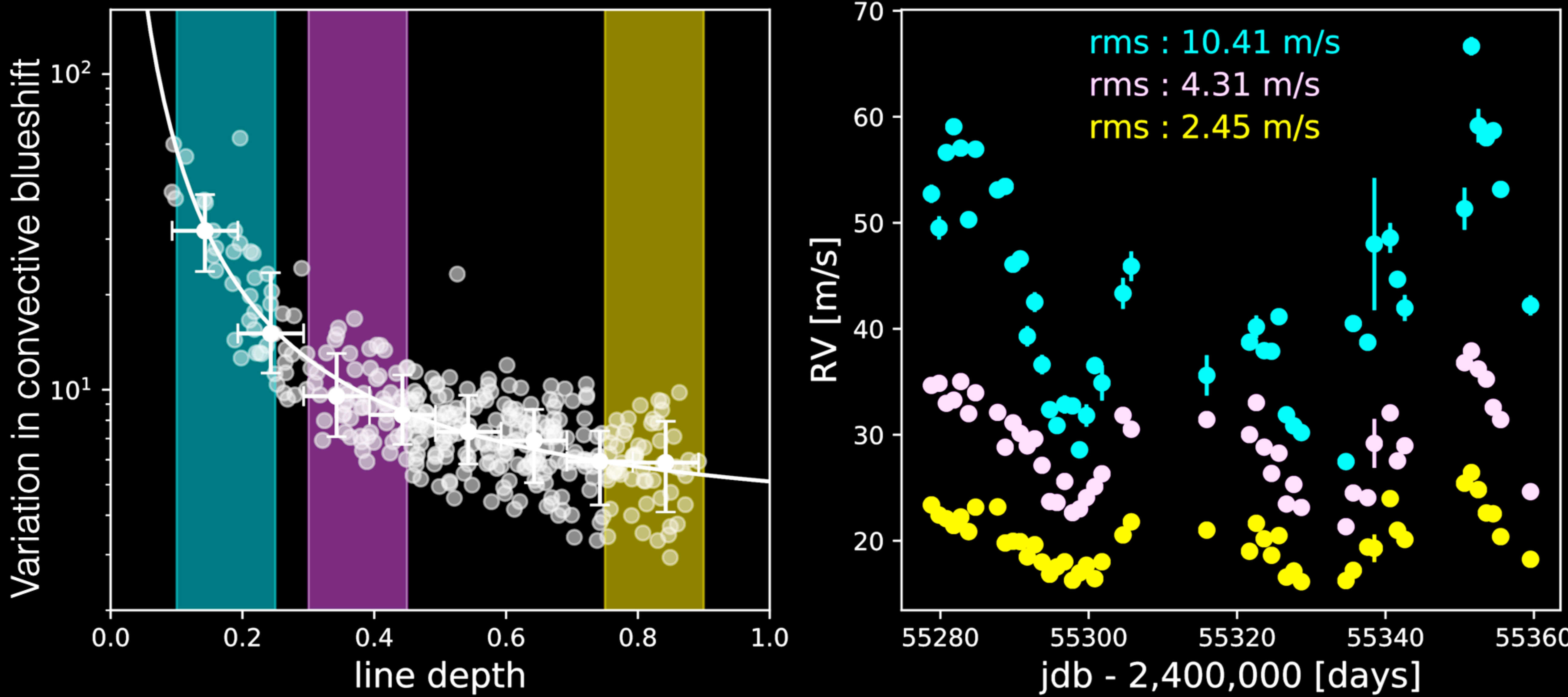
A. Collier Cameron

Residuals after Gaussian Process Regression

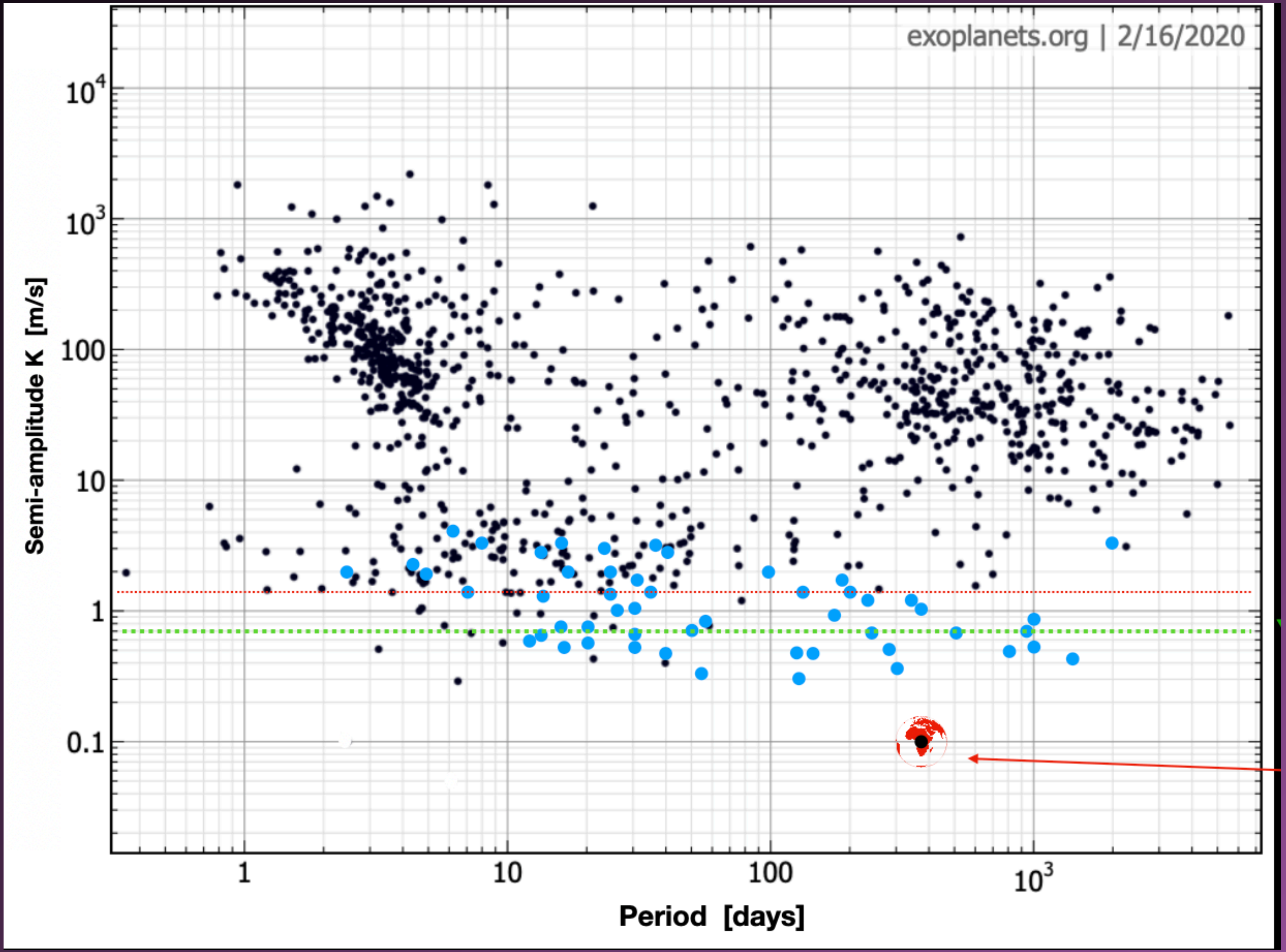


A. Collier Cameron

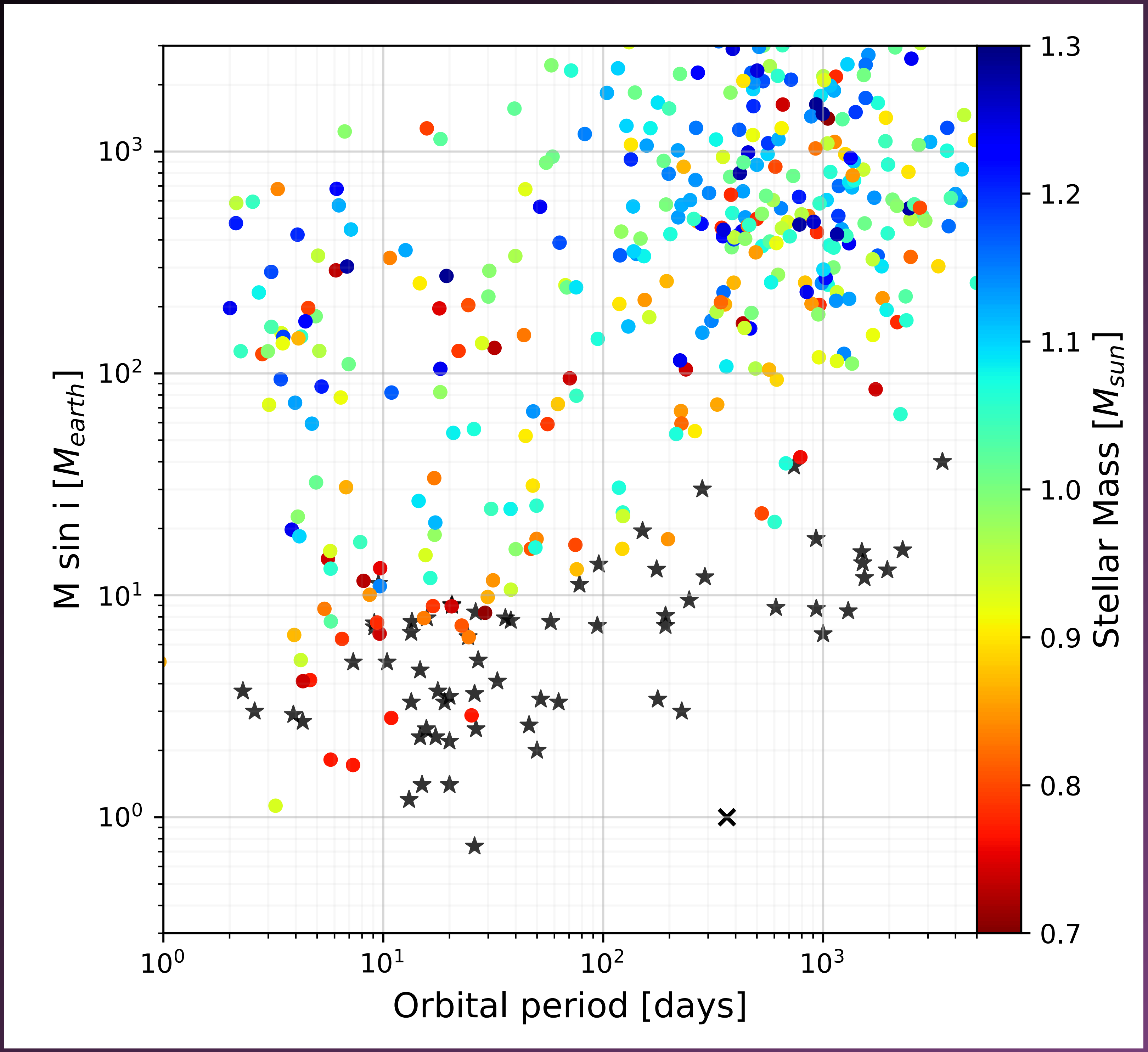
Stellar signal amplitude as a function of line depth



Cretignier+ 20

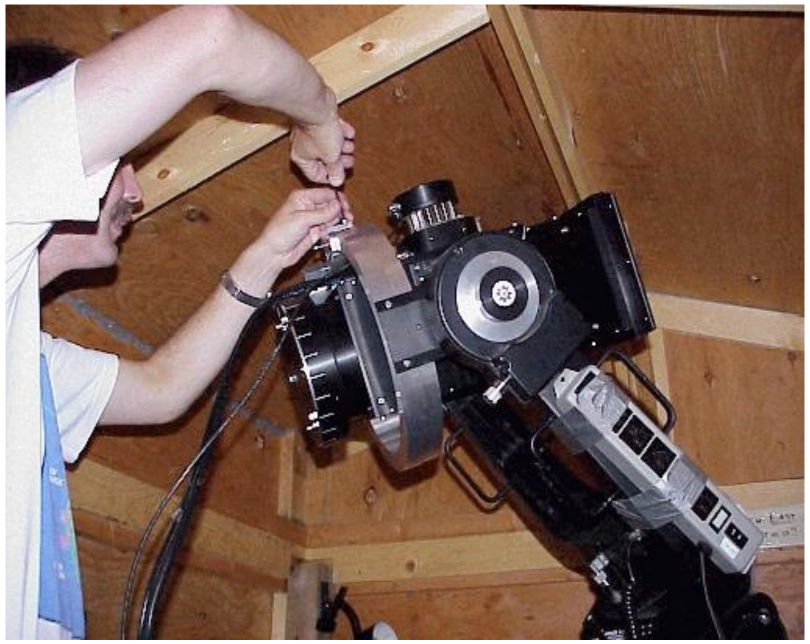


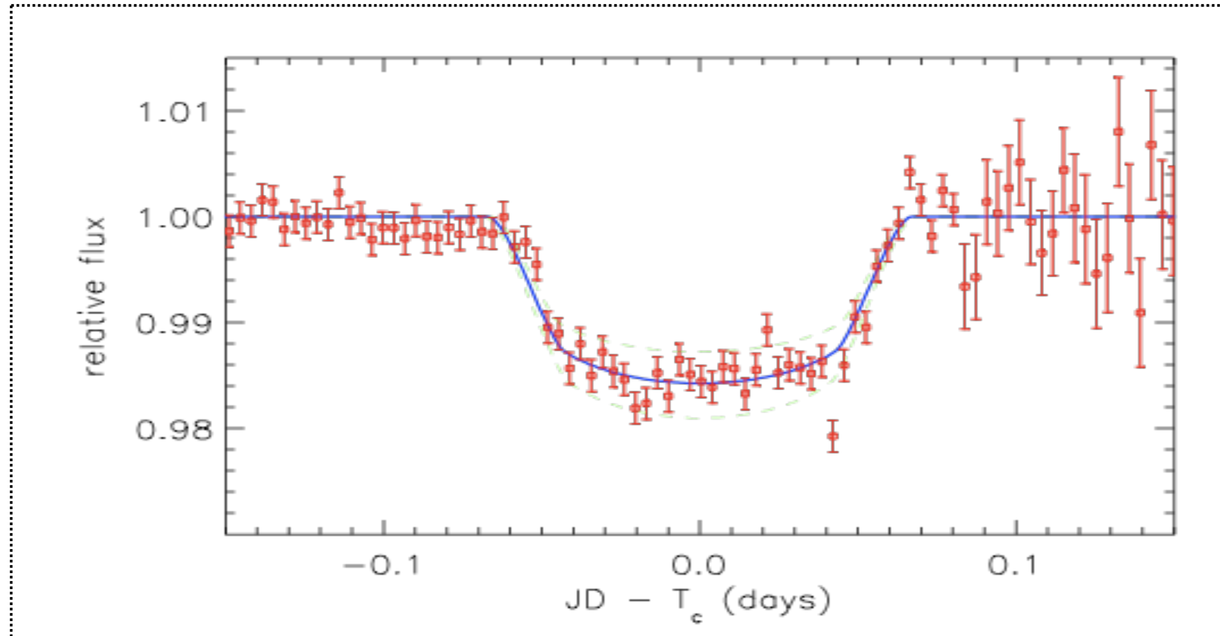
Cretignier 2022 (PhD)



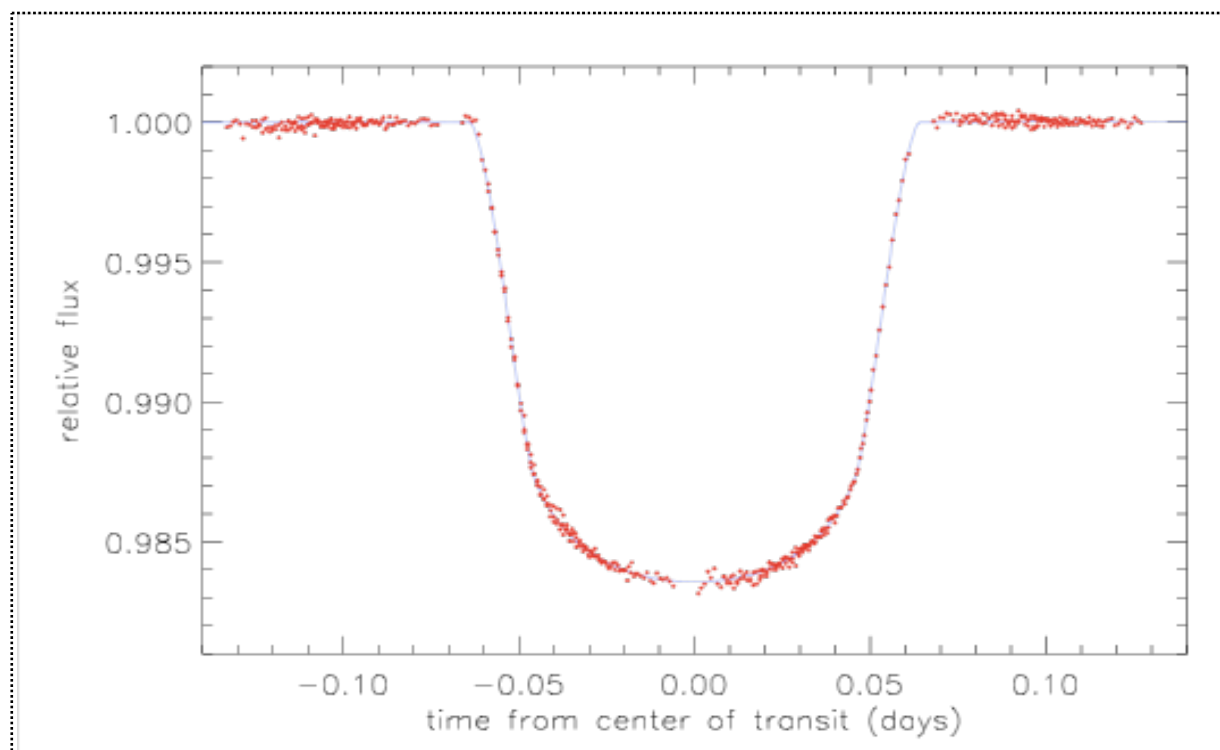
Cretignier 2022 , PhD (HARPS measurements , '*' New low mass candidates detected with the Yarara software)

9 and 16th Sept 1999: A first planetary transit





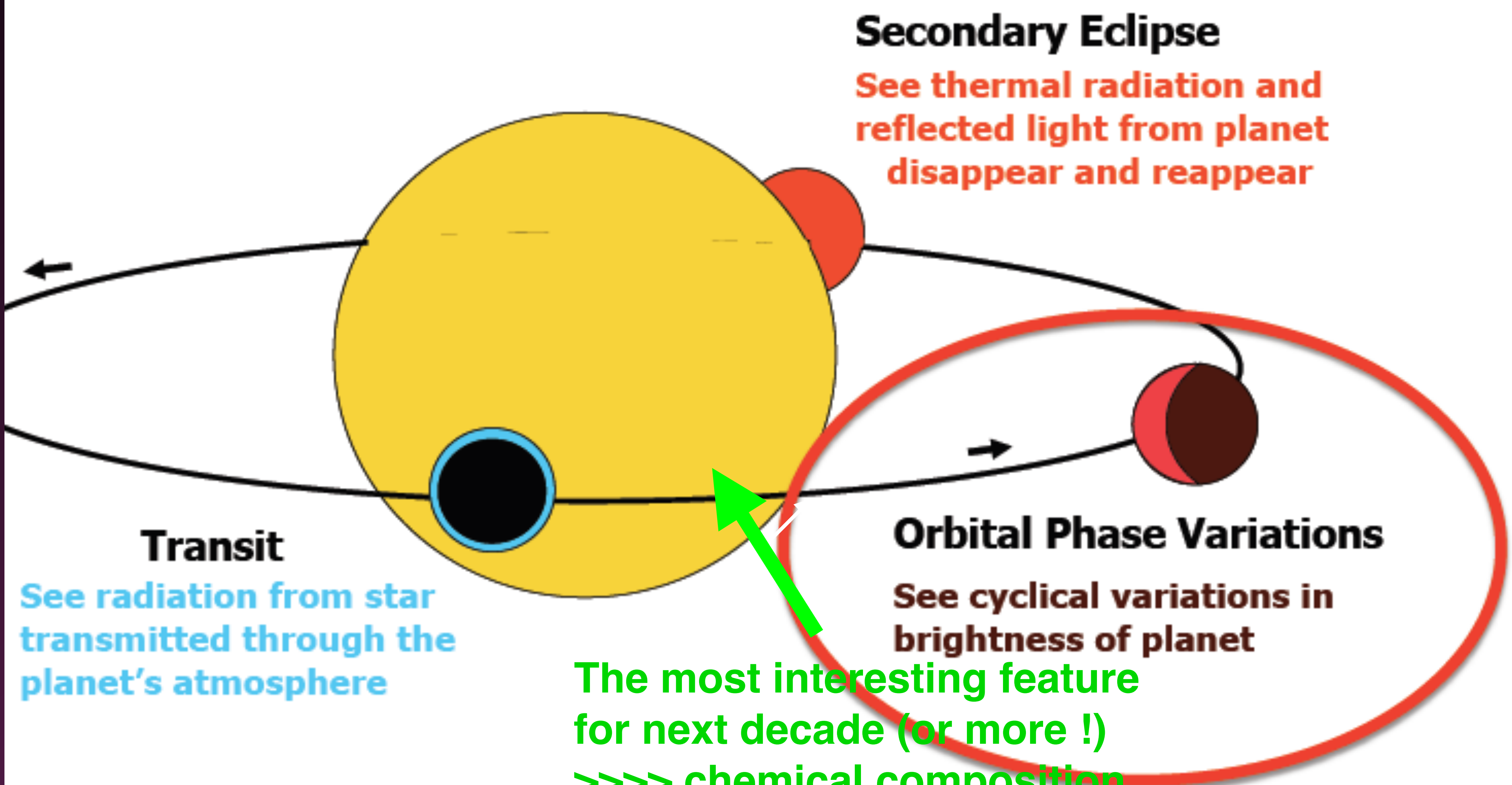
Charbonneau, Brown,Latham, Mayor 2000, ApJ,529



Brown, Charbonneau, Gilliland, Noyes, Burrows 2001,ApJ,552,699

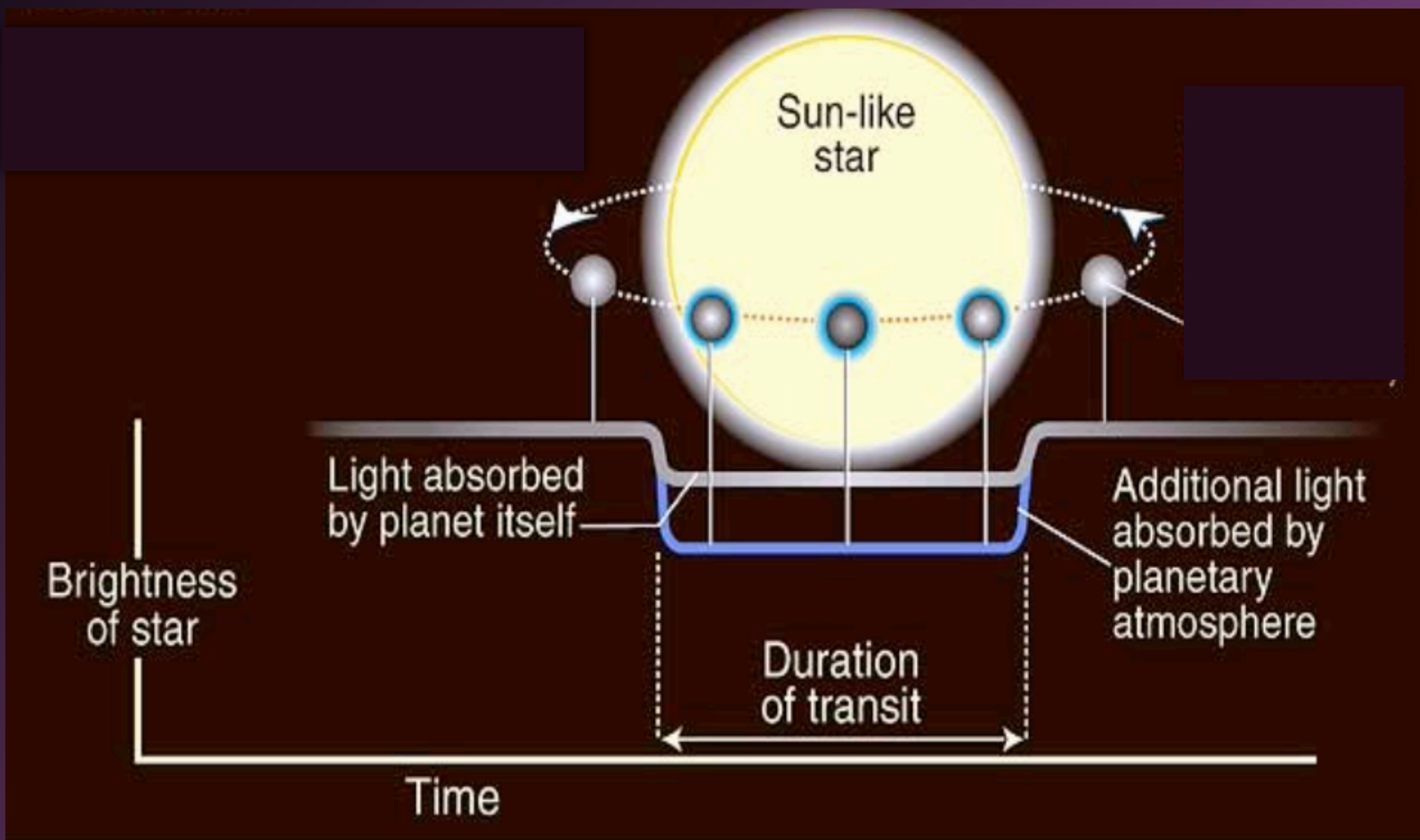
HOT JUPITERS are gaseous giant planets : density = 0.3 g/ cm**3

Transiting Planets as a Tool for Studying Exoplanetary Atmospheres



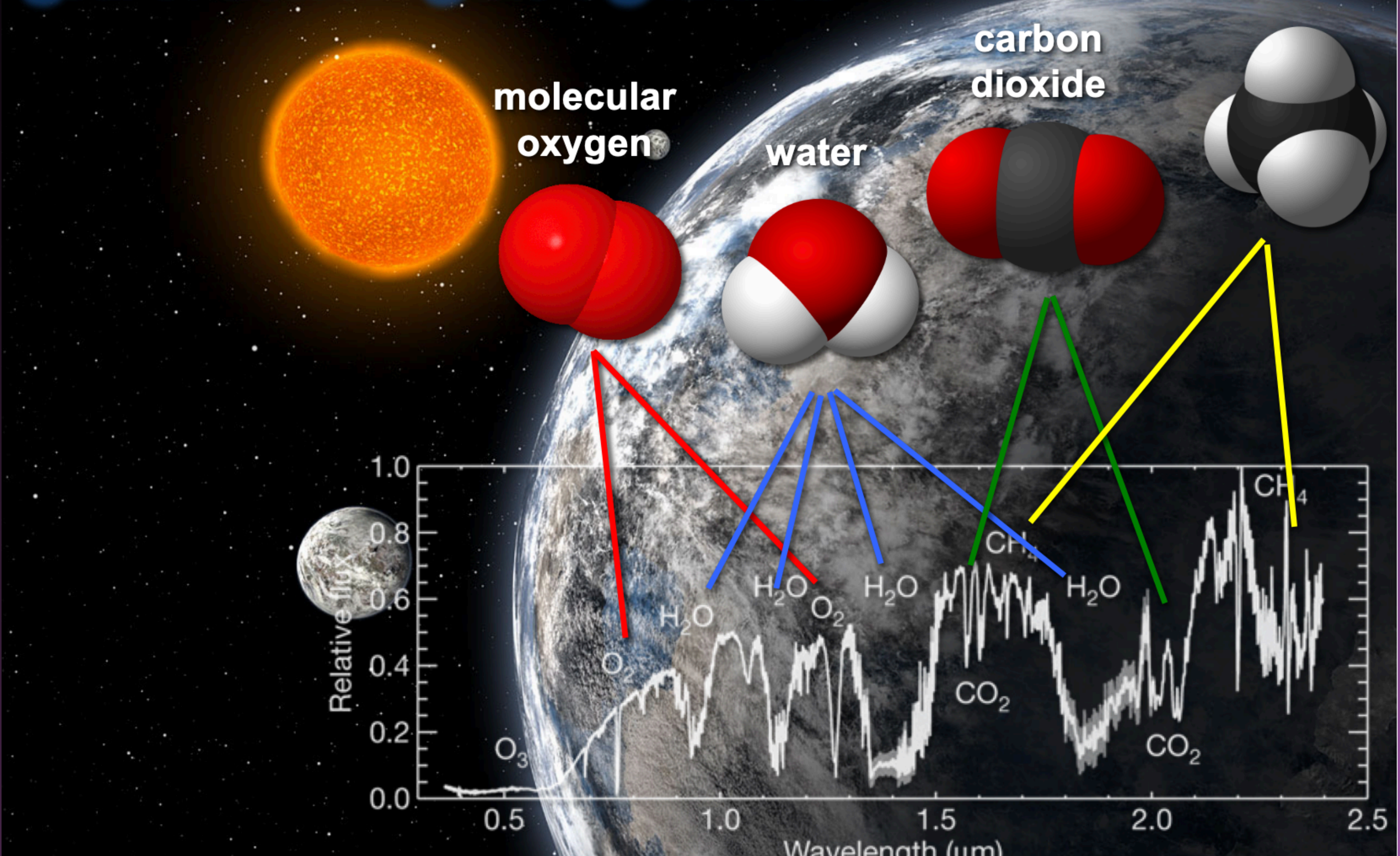
The most interesting feature for next decade (or more !)
>>>> chemical composition of planetary atmospheres
>>>> biomarkers

The apparent size of the planet depends on the opacity at a given wavelength >>>>>
The contrast of the transit as a function of wavelength gives access to the composition of the planetary atmosphere .



Life : a « cosmic imperative » ?

Exoplanets atmospheres, with the ultimate goal of detecting bio-signatures

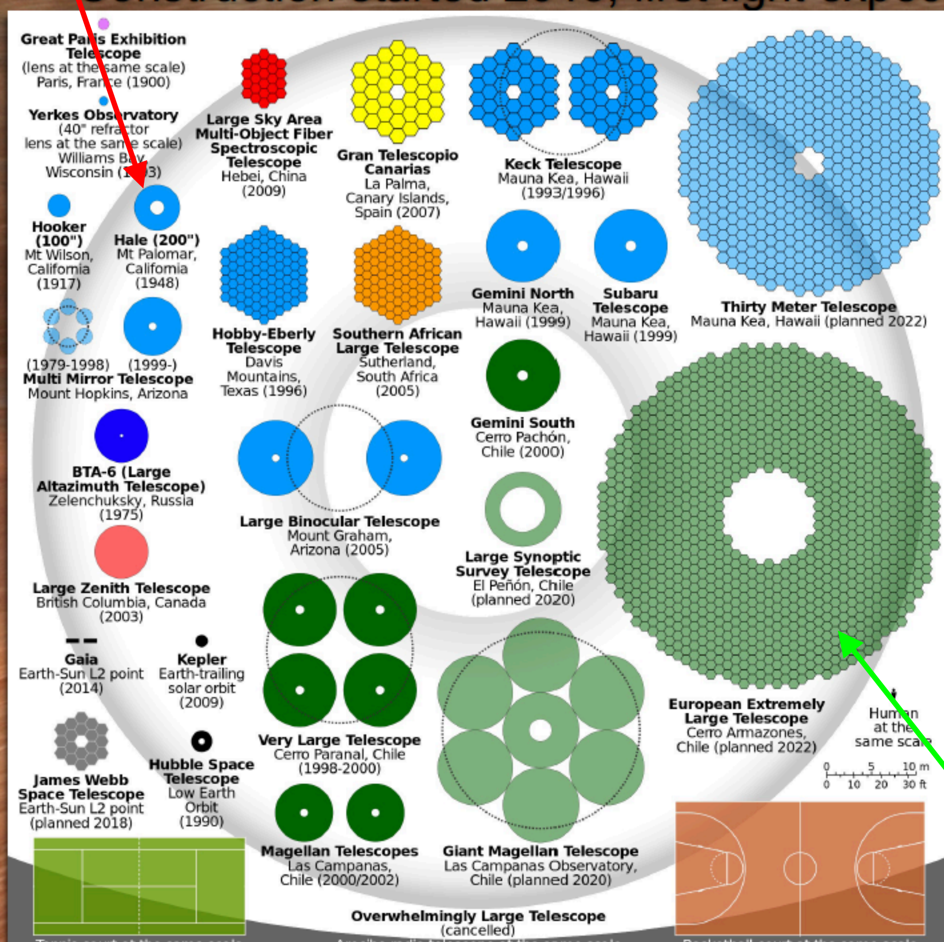


Palomar 5.08 m (1948)

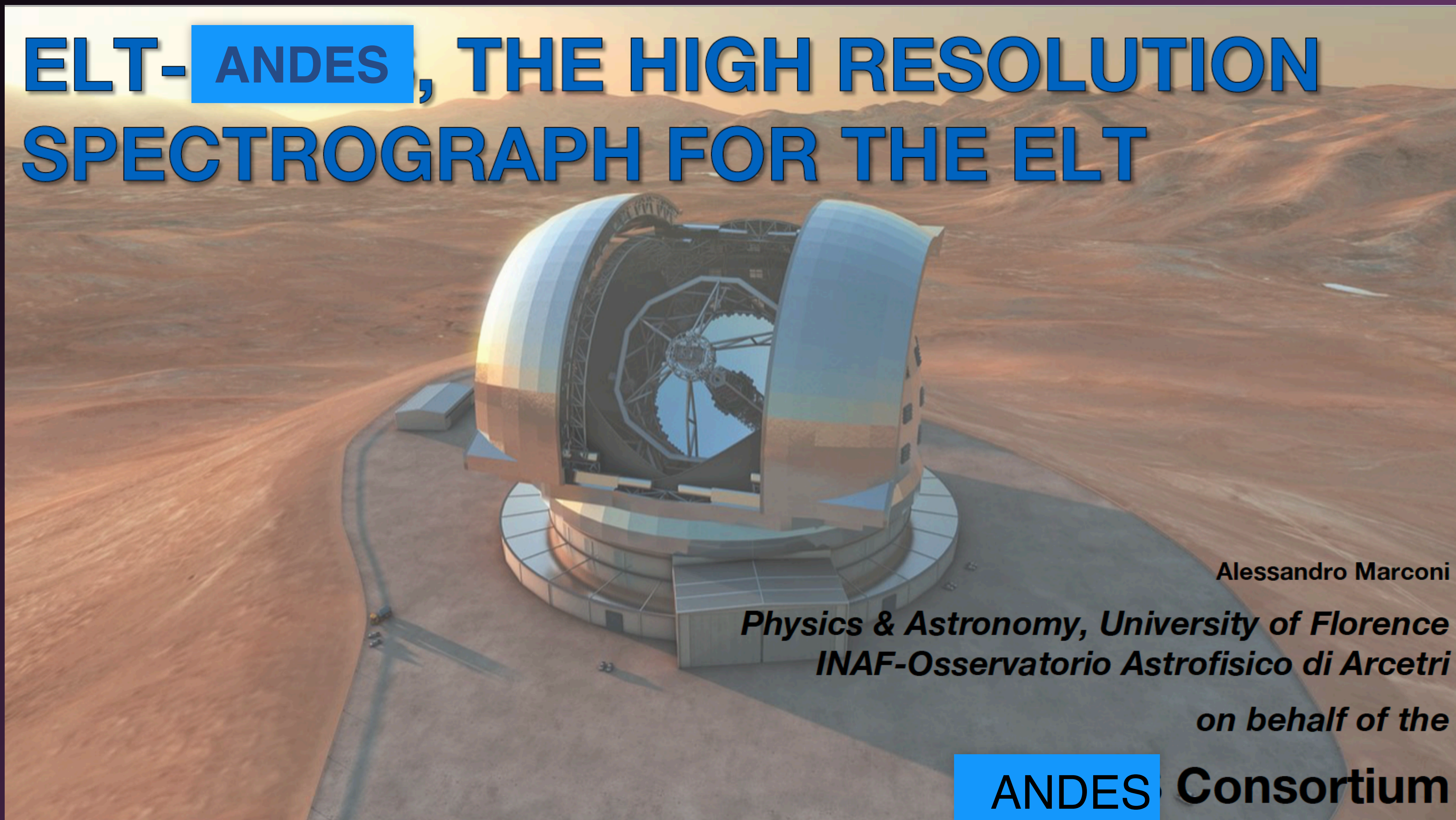
The European ELT

Largest optical/infrared telescope in the world

- 39-m segmented primary mirror
- fully AO assisted telescope
- On Cerro Armazones, integral part of the Paranal system
- Construction started 2015, first light expected end of 2025



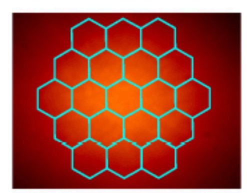
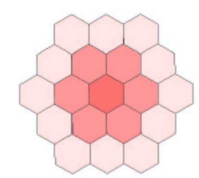
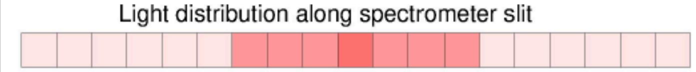
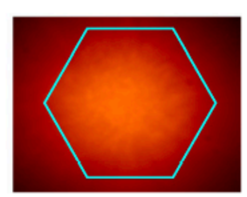
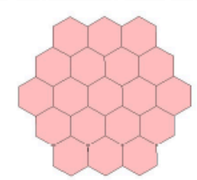
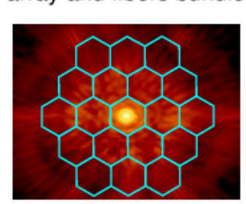
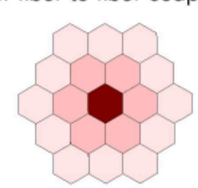
ESO ELT 39 m (2028)


ELT-ANDES, THE HIGH RESOLUTION SPECTROGRAPH FOR THE ELT
Alessandro Marconi
Physics & Astronomy, University of Florence
INAF-Osservatorio Astrofisico di Arcetri
on behalf of the
ANDES Consortium

Observing modes: the fibre feeding

IL = Imagination Limited

- Many different observing modes possible (IL)
- *Both* Seeing limited and Diffraction Limited observations possible
- Unique IFU capability: 0.5”×0.5” or 0.04”×0.04” FOV, R~100,000 1-1.8 μm sim. range

	Front–end	Fiber–to–fiber interface	Spectrometer
High throughput seeing limited observing mode	PSF on microlenses array and fibers bundle 	Light distribution on fibers bundle after fiber to fiber couplers 	Light distribution along spectrometer slit 
High accuracy seeing limited observing mode	PSF on single large fiber 	Light distribution on fibers bundle after scrambler and slicer 	Uniform light distribution along spectrometer slit 
IFU AO corrected observing mode	PSF on microlenses array and fibers bundle 	Light distribution on fibers bundle after fiber to fiber couplers 	Light distribution along spectrometer slit 

Thank you