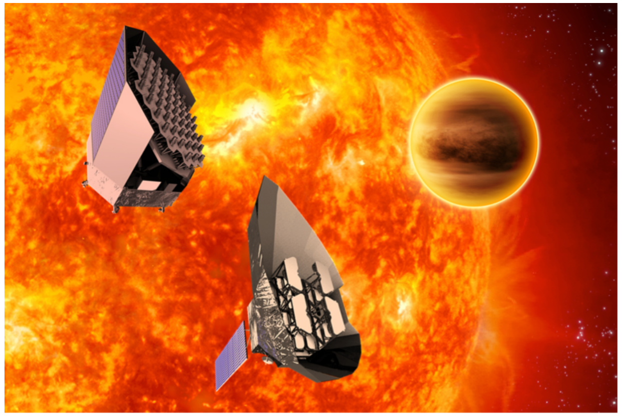
Screening PLATO targets with High-resolution spectroscopy



Why PLATO?

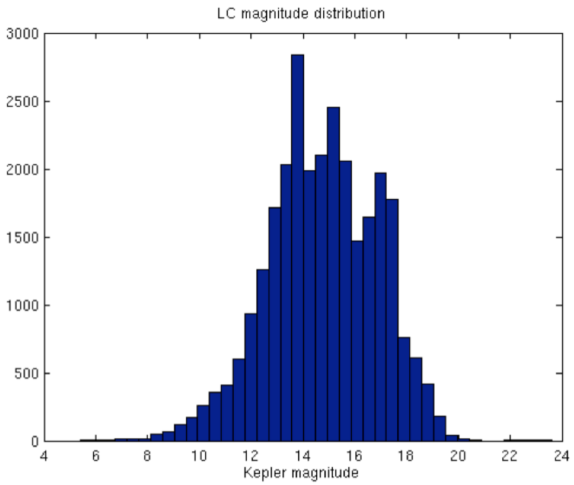
PLATO (PLAnetary Transits and Oscillation of stars) will increase the yield of characterized Earth to super-Earth planets (1-2 R_{Earth})

-- by a factor 10 above Kepler for planets with 90 d < P < 500 d periods

-- by 1000 above TESS for planets with 90 d < P < 500 d periods.

Amongst these PLATO will be detect transit signals of about 40-70 super-Earths in the HZ of G-type stars. The main hunting ground of PLATO will be 85,000 FGK-stars in the brightness range from 4 to 11 mag.

Kepler sample

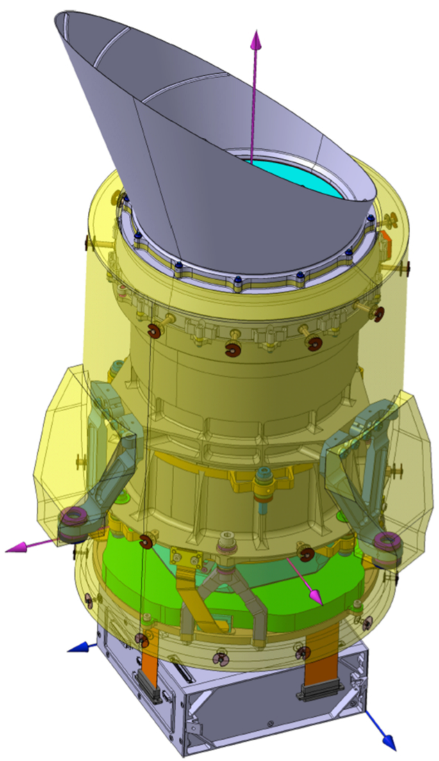


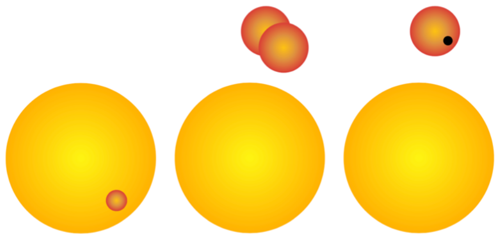
PLATO sample

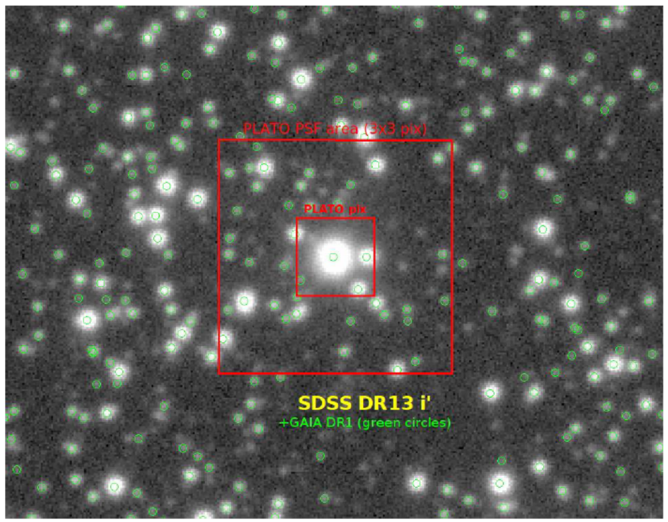
	Sample 1 (P1)	Sample 2 (P2)[5]	Sample 4 (P4)	Sample 5 (P5)
Stars	≥ 15 000 (goal 20 000)	≥ 1000	≥ 5000	≥ 245 000
Spectral type	Dwarf and subgiants F5-K7	Dwarf and subgiants F5-K7	M dwarfs	Dwarf and subgiants F5-K7
Limit *V*	11	8.2	16	13
Random noise (ppm in 1 hour)	34	34	800	
Observation phase	LOP	LOP	LOP	LOP

The camera of PLATO

The payload consists of 24 'normal' cameras with CCD-based focal planes, operating in white light. They will be read out with a cadence of 25 s and will monitor stars with m_V > 8. Two additional 'fast' cameras with high read-out cadence (2.5 s) will be used for stars with m_V ~4 to 8. The 'normal' cameras are arranged in four groups of six. The survey a total field of about **2250 deg^2** per pointing, but with different sensitivities over the field. The image scale is 12.5 arcsec/pixel --> We need a large program to remove false positives and to determine the contamination factor.







The sample:

1.) 22000 FGK-stars with mv<11 mag, noise 34 ppm/h in the long pointing.

2.) 85000 FGK-stars with mv<11 mag including step and stare.

Planets with R<2 R_{Earth} can only be detected on stars brighter than mv=11 mag.

Background information:

1.) Transit depth of 2(1) R_{Earth} planet orbiting solar-like star: 334(84) ppm.

2.) RV-amplitude of 10 M_{Earth}-planet @ 1.0 AU of 1 Msun-star: 1.8 m/s.

3.) RV-amplitude of 10 M_{Earth}-planet @ 0.6 AU of 0.7 Msun-star (K-star): 2.7 m/s.

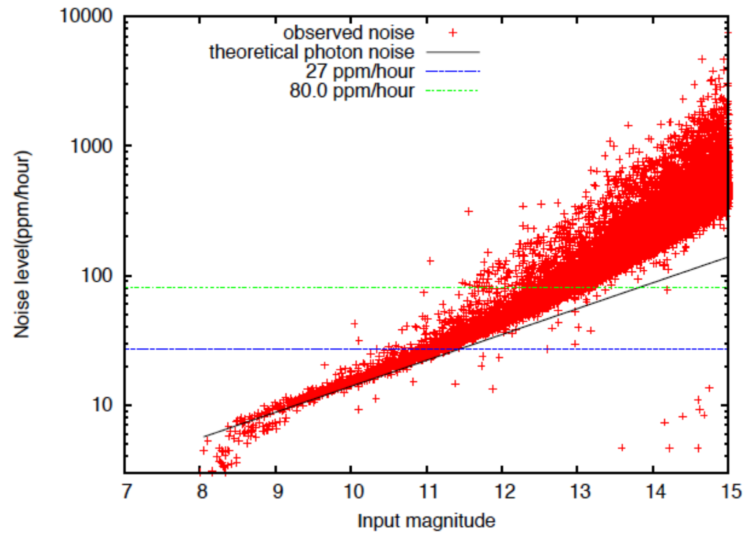


Fig. 3 Expected noise level in ppm/h for observations with 40 telescopes using realistic noise modelling without jitter in the sub-field and a PSF at the optical axis. Each red cross represents the noise of a star using aperture photometry. The dark blue line is the median of the noise in bins of 0.5 mag. The theoretical photon noise is indicated as green line. Measurements that fall below this value are affected by smearing from saturated stars. The two relevant noise levels for PLATO at 27 and 80 ppm/h are marked. It can be seen that the limit for a precision of 27 ppm/h is at approximately $m_V = 11$. Towards faint magnitudes, the noise increases rapidly due to the confusion issue.

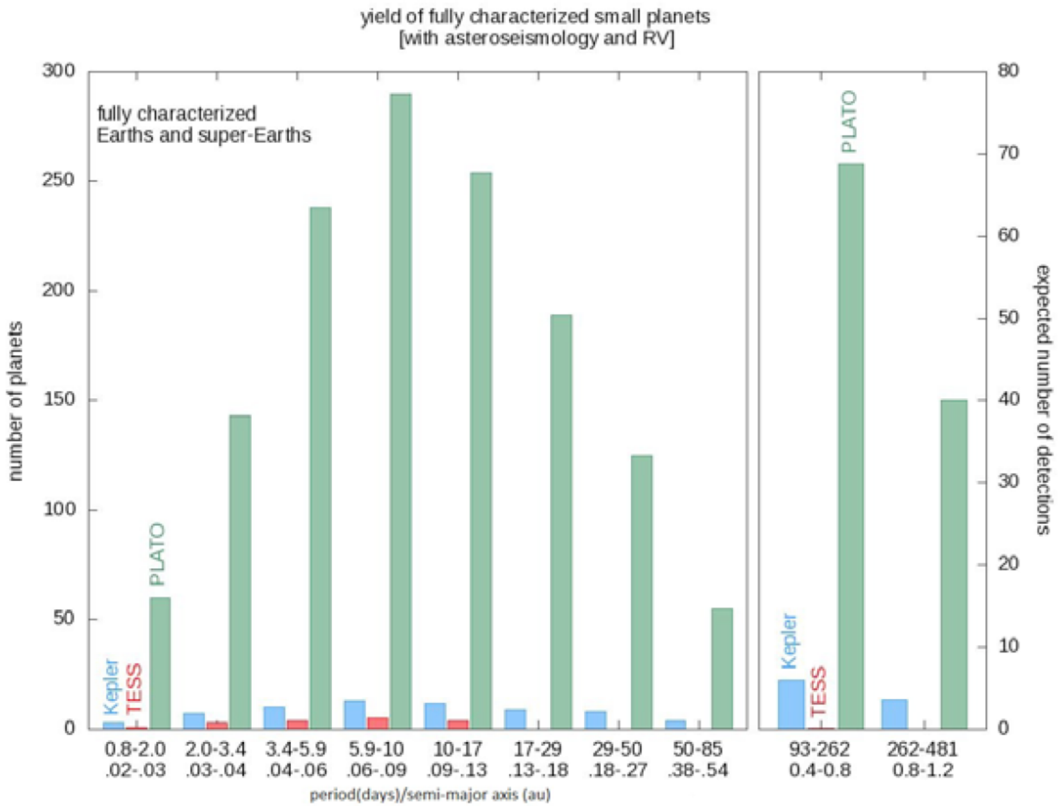
The Expectation:

Transit signals from about 4000 super-Earth planets around stars with mv<11 mag.

Transit signals of up to 280 super-Earths in the HZ of G-type stars.

---> We will get 4000 super-Earths.

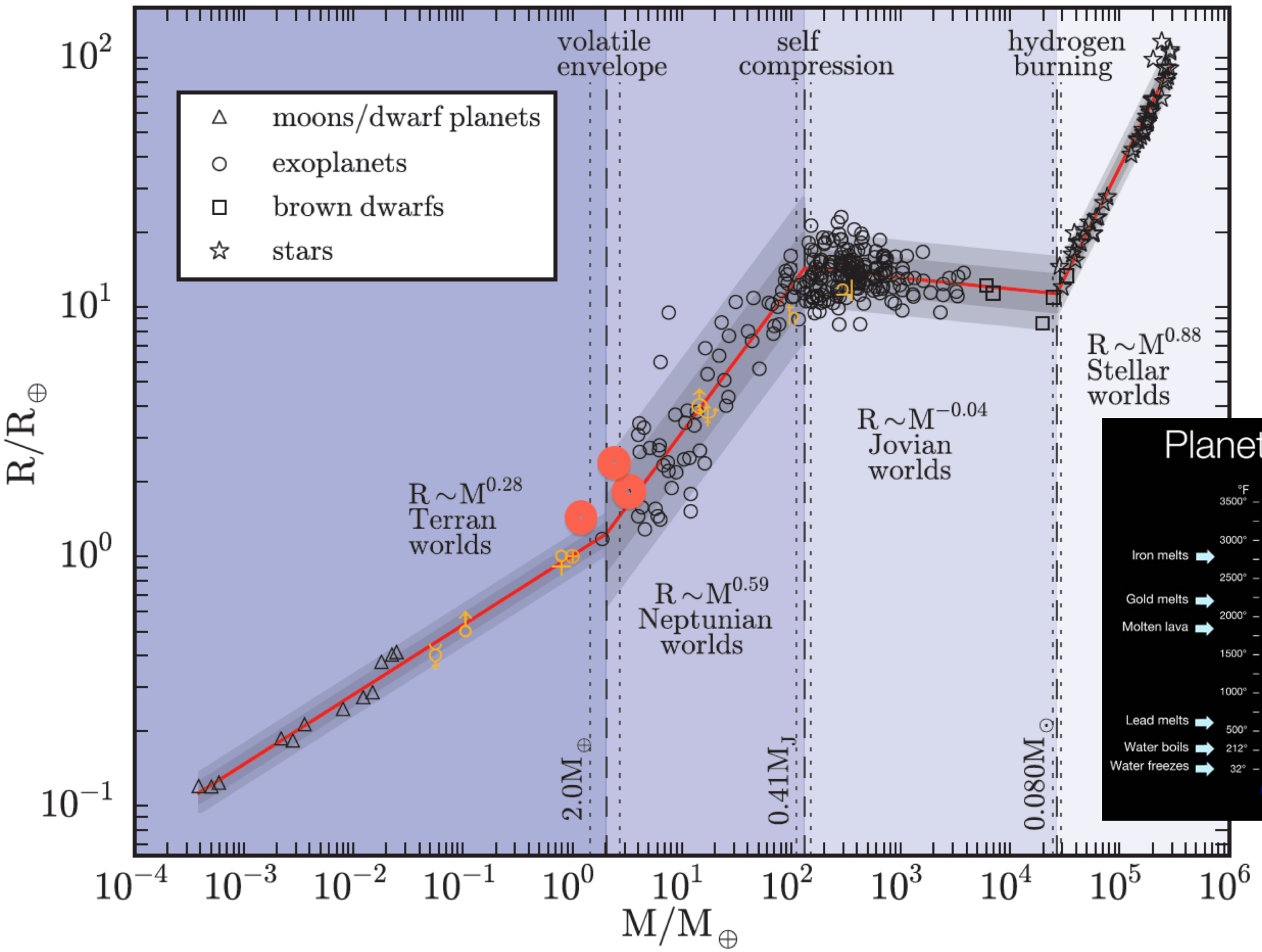
How do we find out which stars are best for obtaining the masses of the planets?

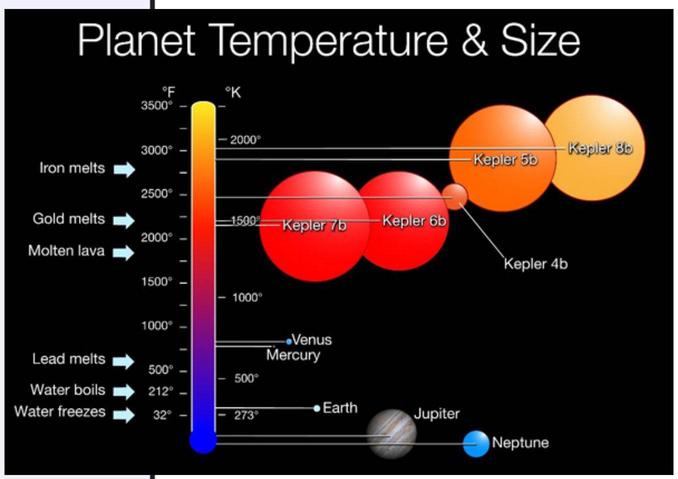


Fraction of stars hosting Earth-like planets in their habitable zones (J. Cabrera)

reference	Planet frequency	Host star type
Catanzarite & Shao 2011	1%-3%	Sun-like stars
Traub 2012	20%-58% (34%)	FGK stars
Silurt et al. 2015	5.3%-9.8%	FGK stars
Petgura et al. 2013	7%-15%	GK stars
Batalha et al. 2014	11%-22%	GK star
Foreman-Mackey et al. 2014	0.8%-2.5% (1.7%)	G stars
Traub 2016	90%-110%	G stars
Gaidos 2013	31%-64%	Dwarf stars
Bonfis et al. 2013	28%-95%	M stars
Dressing & Charbonneau 2013	9%-28% (15%)	M stars
Kopparapu 2013	24%-60% (48%)	M stars

Probabilistic mass-radius relation conditioned on a sample of 316 well-constrained objects





Strategy to determine masses of super-Earths

a.) Estimate RV-signal of planet based on R_{planet}/R_{star} and P_{orbit} as derived from PLATO-data, combined with R_{star} as derived from GAIA-data and HR-spectra.

a1.) Get with M_{star} combining this with HR-spectra.

b.) Estimate the RV-jitter of star using CaII HK-index and vsini as derived from the HR-spectra (vsini can also be estimated from rotation period as derived using PLATO photometry).

c.) Calculate how many spectra are needed to detect planet with HARPS, or ESPRESSO taking the activity jitter and the measurement error in to account.

--> Select targets to be observed with 2m-class telescopes, HARPS, ESPRESSO.

The role of HR-spectroscopy for stars with low mass planet candidates:

Remove false positives? Possibly not relevant, because GAIA data allows to remove giants, grazing transit should also not be a problem and background eclipsing binaries can not be detected with HR-optical spectroscopy.

a.) Determine that stellar parameters mass and radius and metallicity.

b.) Determine the stellar activity level from the CaIIH&K lines.

Stars have to have R'_{HK}<-4.86 so that the RV-jitter is less than 1 m/s.

c.) Take a few RV-measurements to exclude binaries and to get some statistics on the activity.

→ **Minimum requirement 4 spectra per star:**

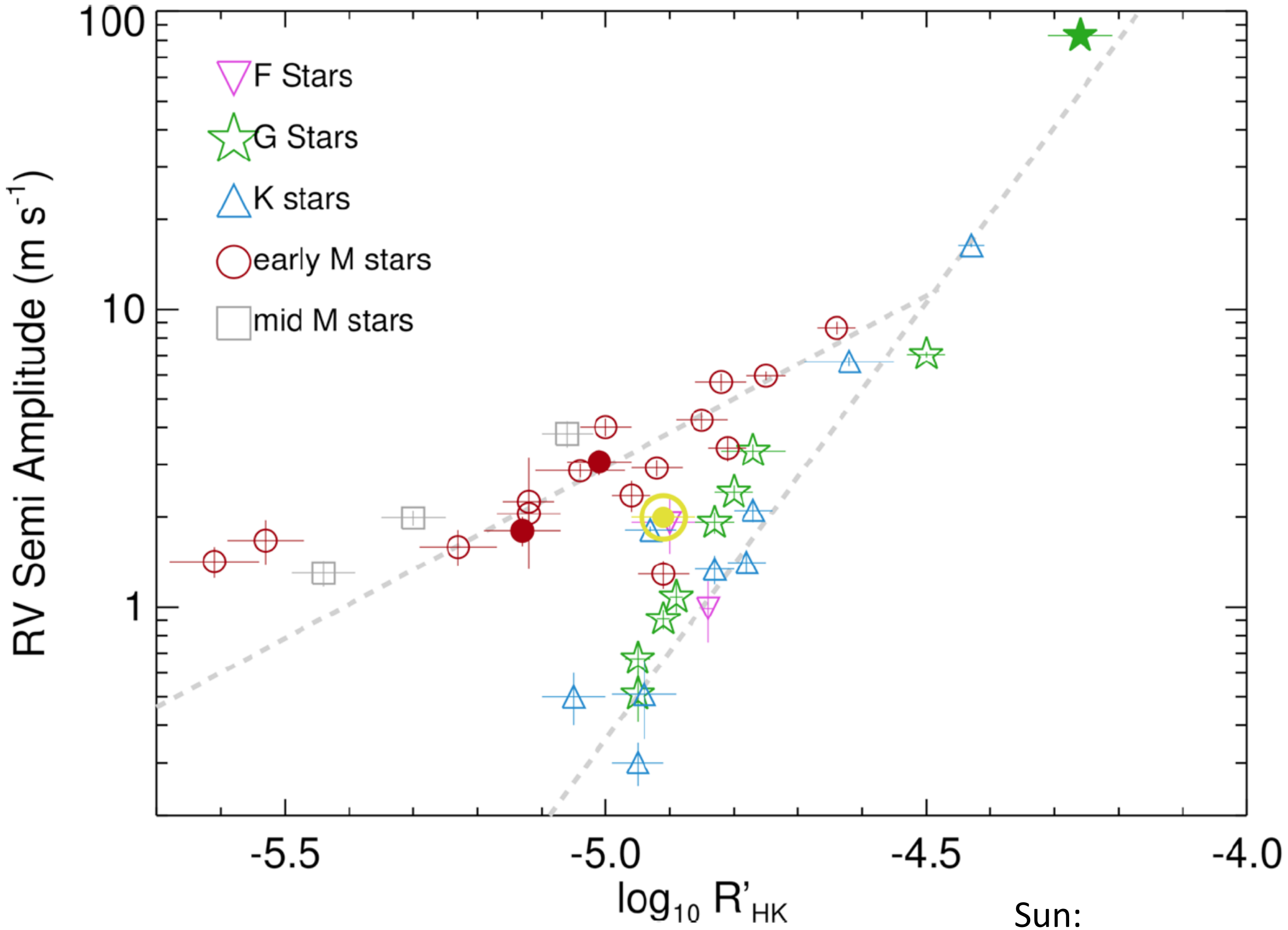
4 x 4000 stars x 0.5 hours --> 8000 hours → 1000 nights

d.) Determine the vsini. This is only to remove the rapid rotators. The resolution of the spectrograph is 4.2 km/s and the Sun rotates with 1.997 km/s. For slow rotators we have to determine rotation periods using PLATO photometry and using CaIIH,K monitoring. That requires more efford.

Requirement 50 spectra per star:

50 x 300 stars x 0.5 hours --> 15000 hours → 1875 nights

Defenitly more than 50 nights



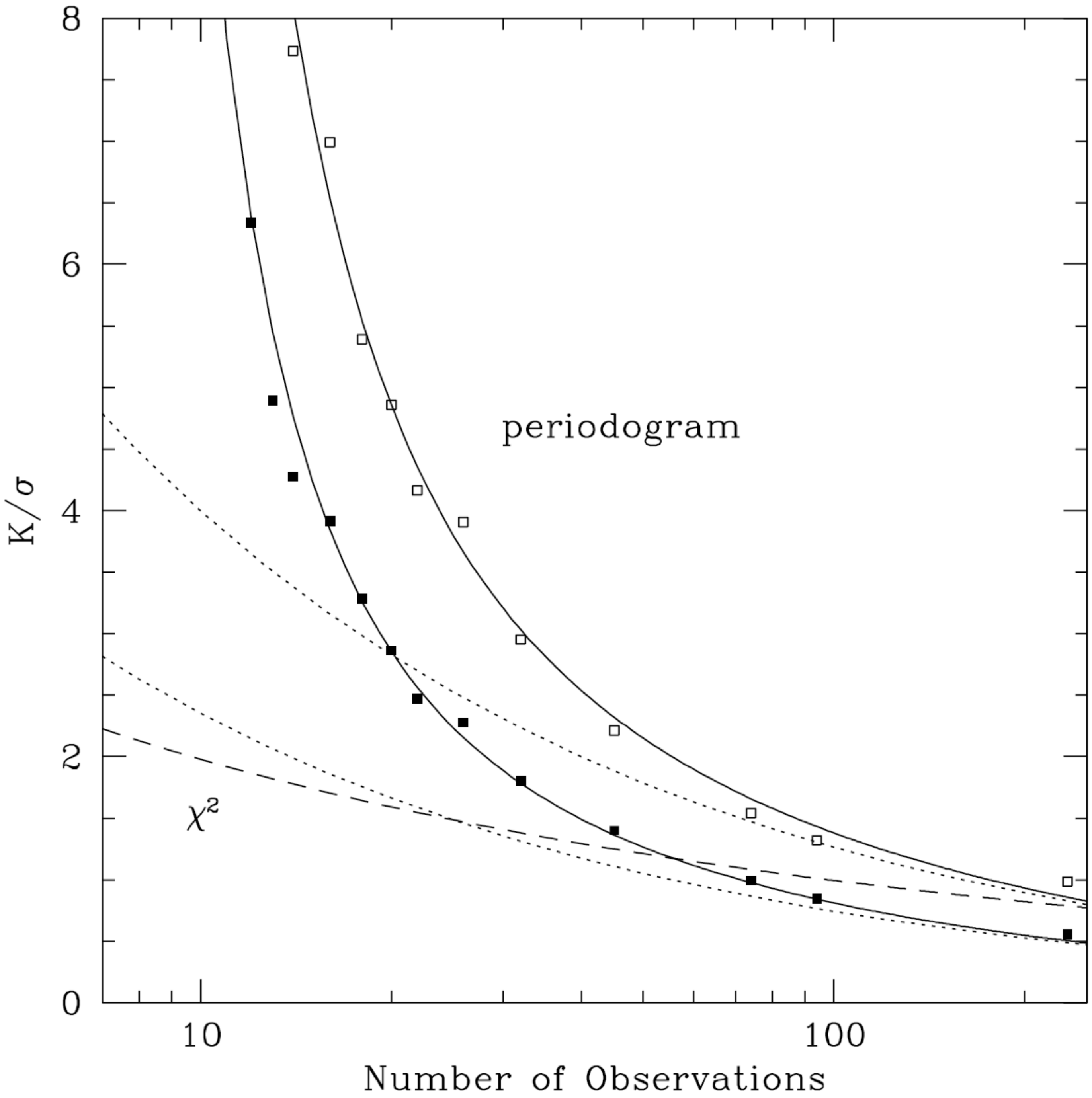
Sun:

. RV rms (in m/s) for specific components.

	Spots	Plages	sp+pl	Conv.	Total
All	0.34	0.31	0.33	2.38	2.40
Low	0.09	0.10	0.08	0.44	0.44
High	0.48	0.44	0.42	1.39	1.42

$\log_{10}(K)=2.93*\log_{10}(R'_{HK})+14.23$ for GK-stars

Suarez Mascare˜no et al. 2017



Full lines: Probability 50% (99%) to detect planet using a periodogram analysis (Cumming 2004).

--> 100 RVs needed for K/Sigma=1 (1.5).

Limiting factor: Activity level of G-stars

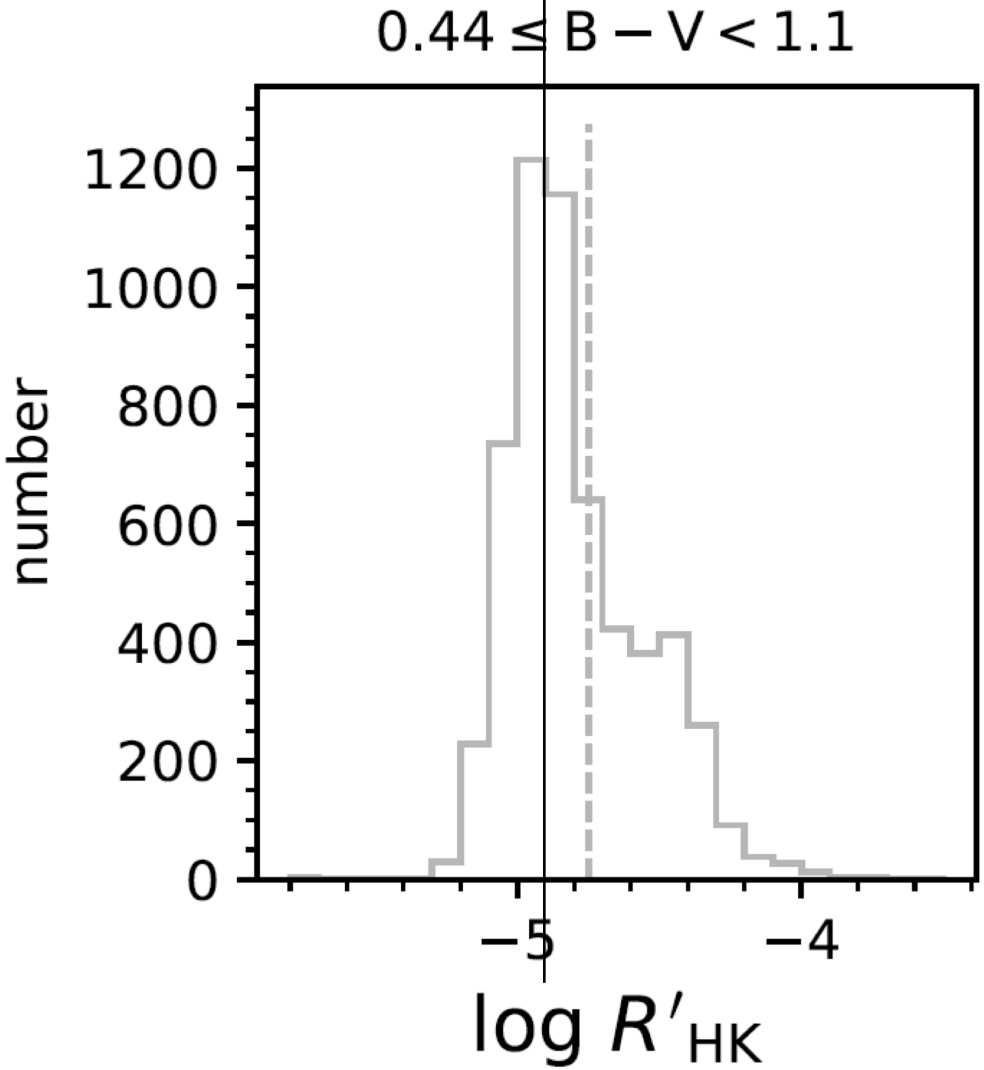
40% of the G-stars have R'_{HK}<-4.9. These stars are inactive enough to limit the stellar jitter to 1 m/s.

20% of the G-stars have R'_{HK}<-5.0.

Stars R'_{HK}<-5.0 are inactive enough to achieve 0.5 m/s by taking 100 RVs.

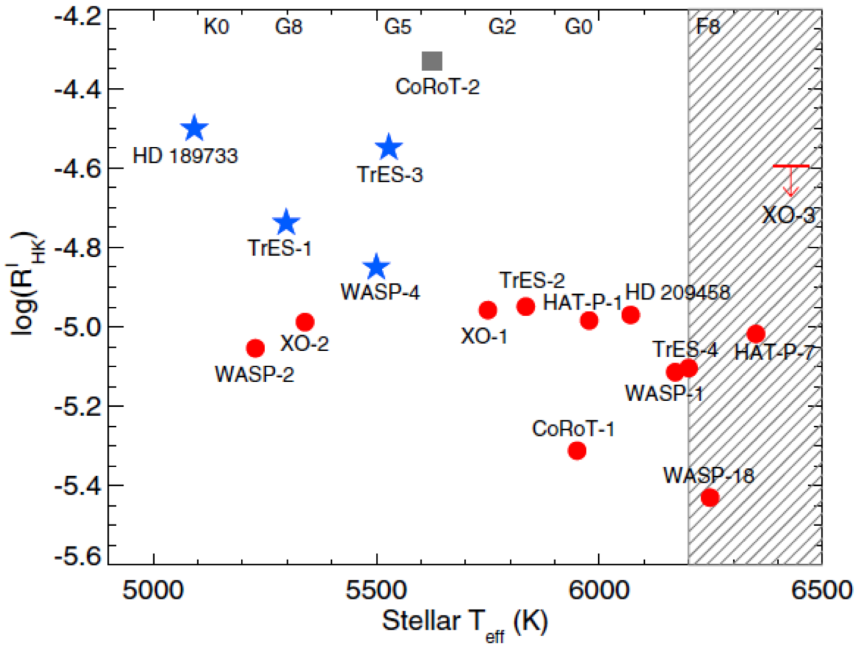
This allows the detection of

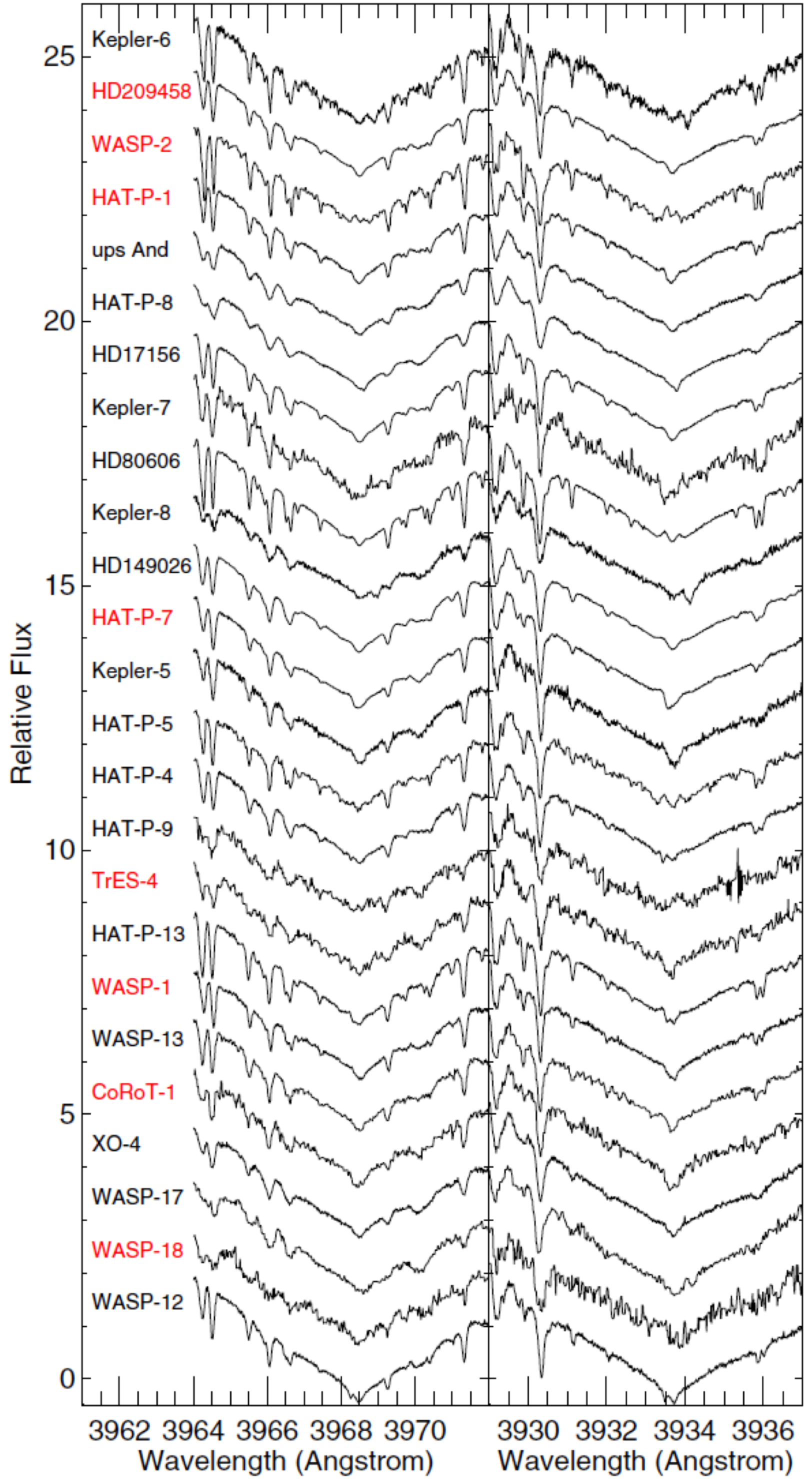
4 M_{Earth} planet in HZ of G-star, or 2 M_{Earth} of K-star.

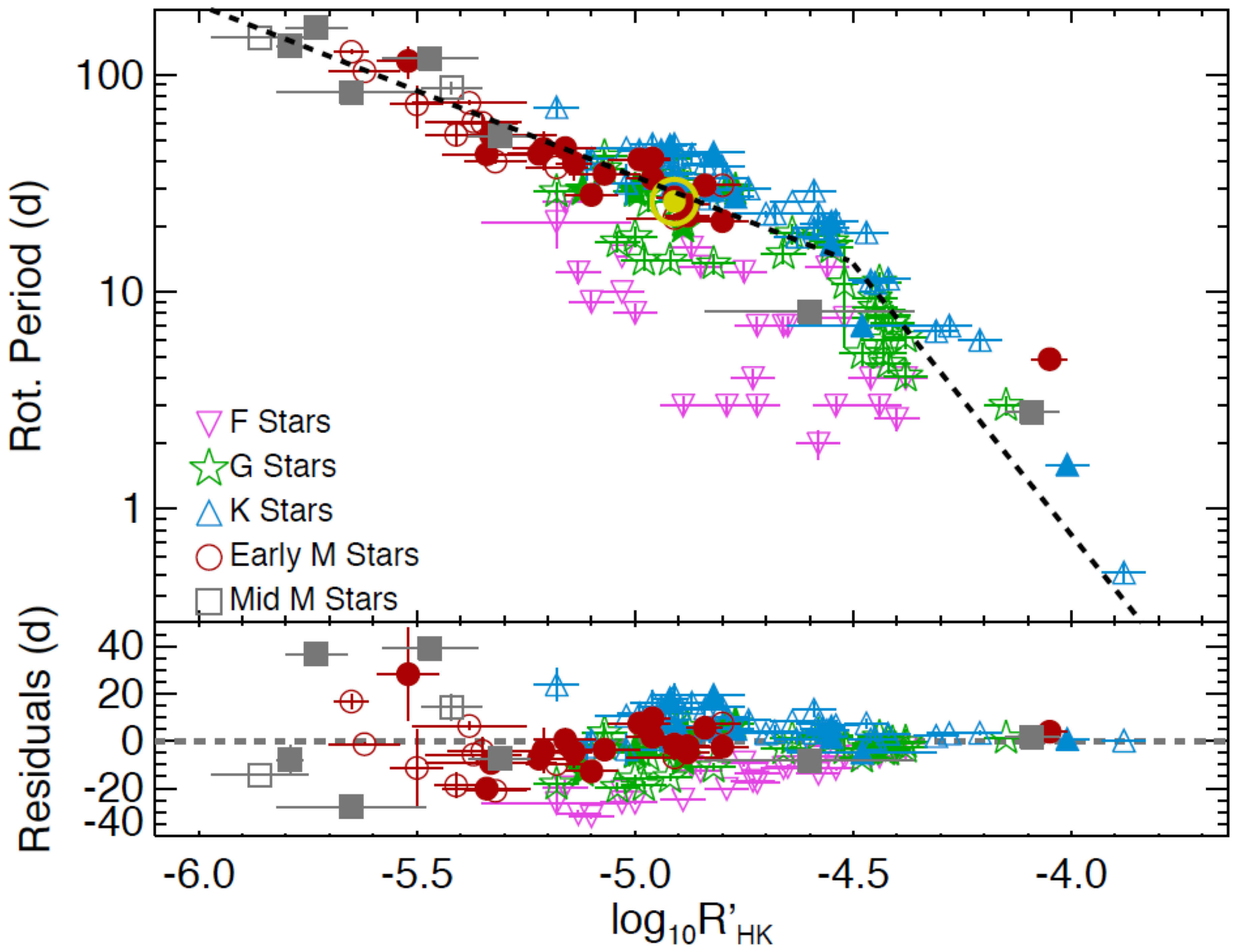


CaII H&K lines of planet host stars

Many planet host stars have R'_{HK}<-5.0. The spectra on the left show the CaIIH,K lines. Note that they don't have an emission core. We thus need a good S/N-ratio.







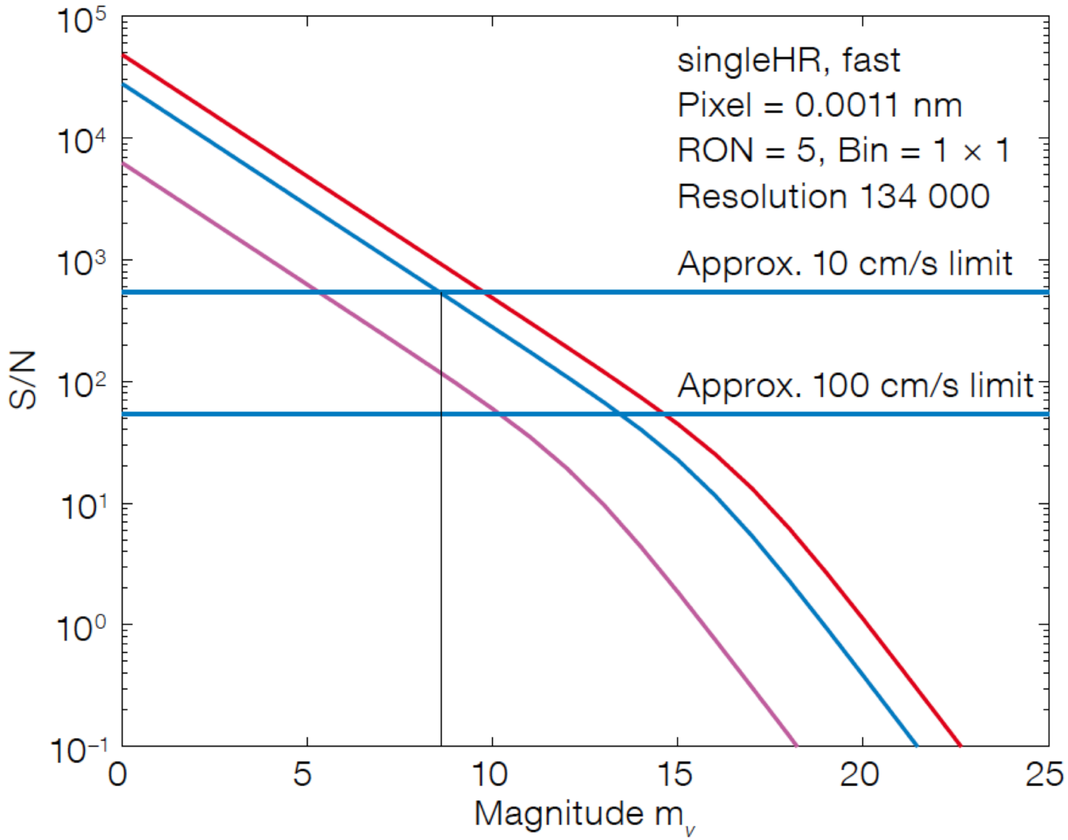
100
10
1
Rot. Period (d)
F Stars
G Stars
K Stars
Early M Stars
Mid M Stars
40
20
0
-20
-40
Residuals (d)
-6.0
-5.5
-5.0
-4.5
-4.0
$\log_{10}R'_{HK}$

How much observing time is needed if all stars with low mass-planets were to be observed with ESPRESSO?

Red, blue and magenta curves indicate expo sure times of 3600 s, 1200 s and 60 s, respectively.

We need 1200s +120s (overheads) per target. 4000 targetsx3 spectra = 1500 hours (190nights) if which 80% are wasted, because the stars are not that stable.

Wavelength range 380–780 nm



ESO 1.5-m @PLATOspec

Wavelength range: 360-680nm

Resolution: 70000 (4.2 km/s)

Sampling: >2 pix

Fibre-fed Echelle-spectrograph

Iodine-cell

CCD: Andor ikon XL 231 BEX2 DD

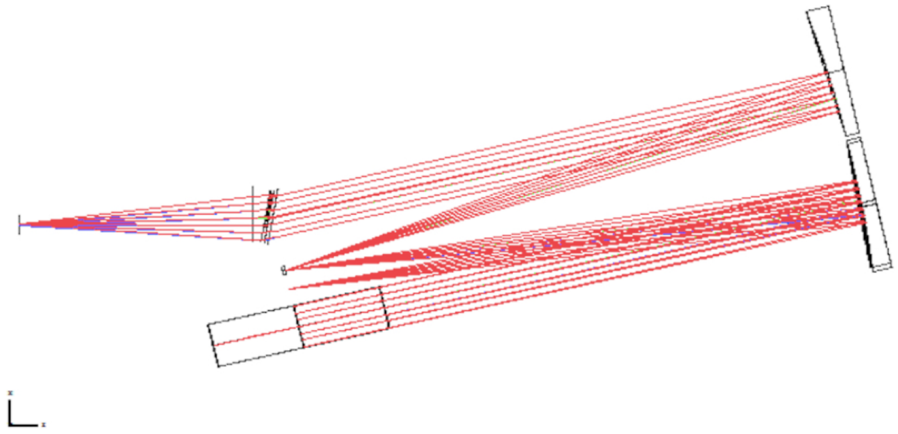
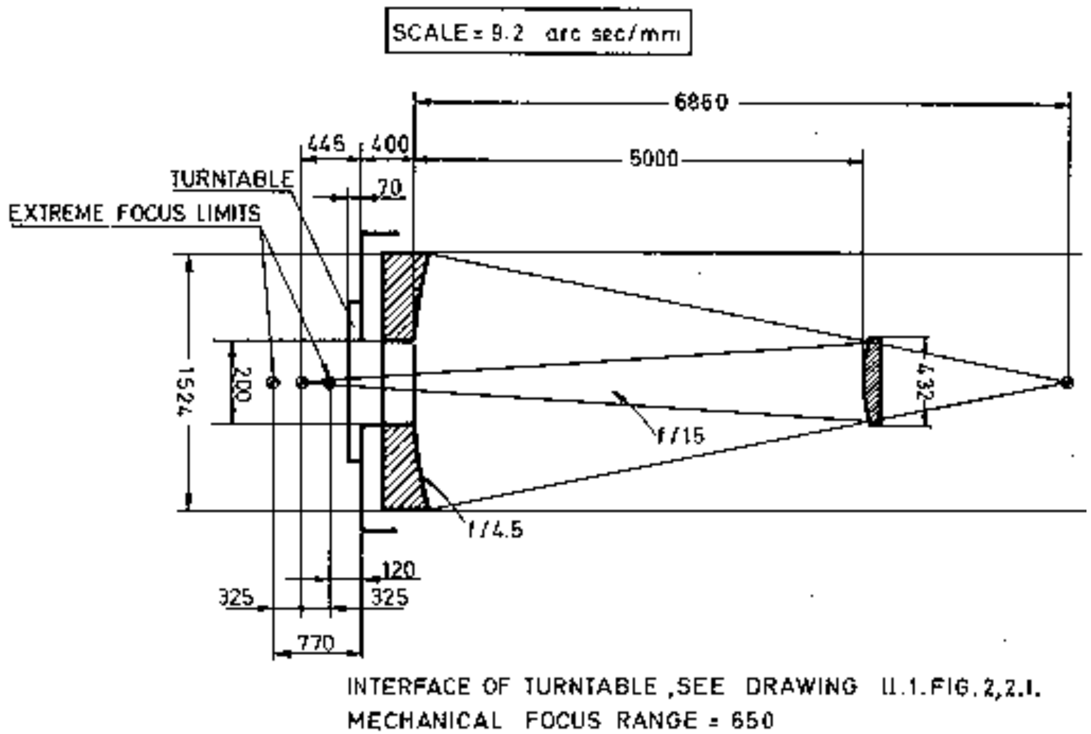


Fig. 2 Spectrograph optical lay out in white pupil configuration with two collimating mirrors both of 1280 mm focal length

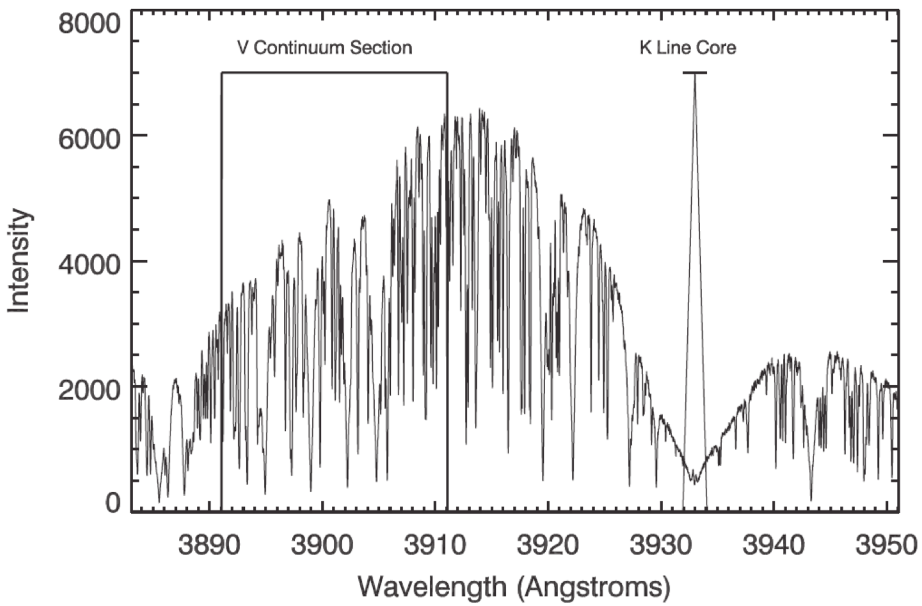
Key parameters of the ESO 1.52-meter telescope

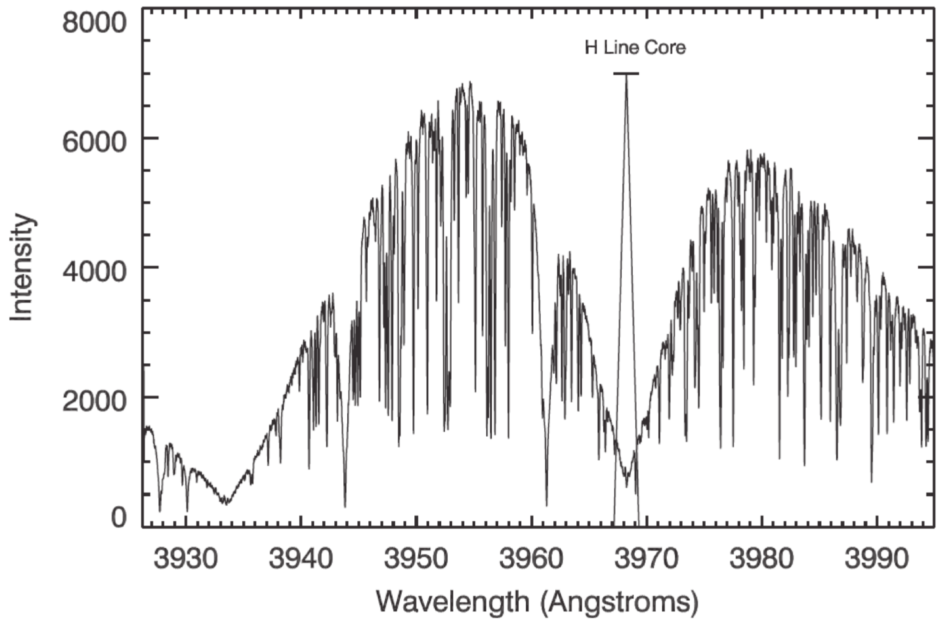
Observatory: La Silla
Altitude: 2374m
Cassegrain: f 14.9
Primary mirror: 1.52m
Secondary mirror: 0.43m
Mirror material: Borosilicate
Mount: English yoke mount
First light: 7 July 1968
Decomissioned: 2002



S/N>20 better 30 in the CaII H,K lines needed

CaIIK: 3933.666 AA, CaIIH: 3968.468 AA





Width of line core: 2 AA → 151-152 km/s → 70 pixel with PLATOspec
(spectrograph R>2000 required)

Can we do it with PLATOspec?

Exposure time: 11 mag star G2V, exposure time 1800s.

Note 10 (9) mag: increase the S/N by factor 1.6 (2.5) but decreases sample by factor 2.7 (7.4). (Average density of stars per square degree: 8 mag:1.2, 9 mag:3.4, 10mag:9.3,11 mag: 25.4). At 9th mag we have only 140 super Earths of which 5-10 are in the HZ.

HARPS-like: (R=115k 3.4 pixel sampling)

Eff. at 390nm: 0.6% S/N=4 --> S/N=7 (PLATOspec) at 9 mag S/N=18

Eff. at 656nm: 2.9% S/N=21.5 --> S/N=36 (PLATOspec)

UVES-like: (R=80k, R=110k, 2 pixel sampling)

Eff. at 390nm: 3.7% S/N=17 --> S/N=18 (PLATOspec)

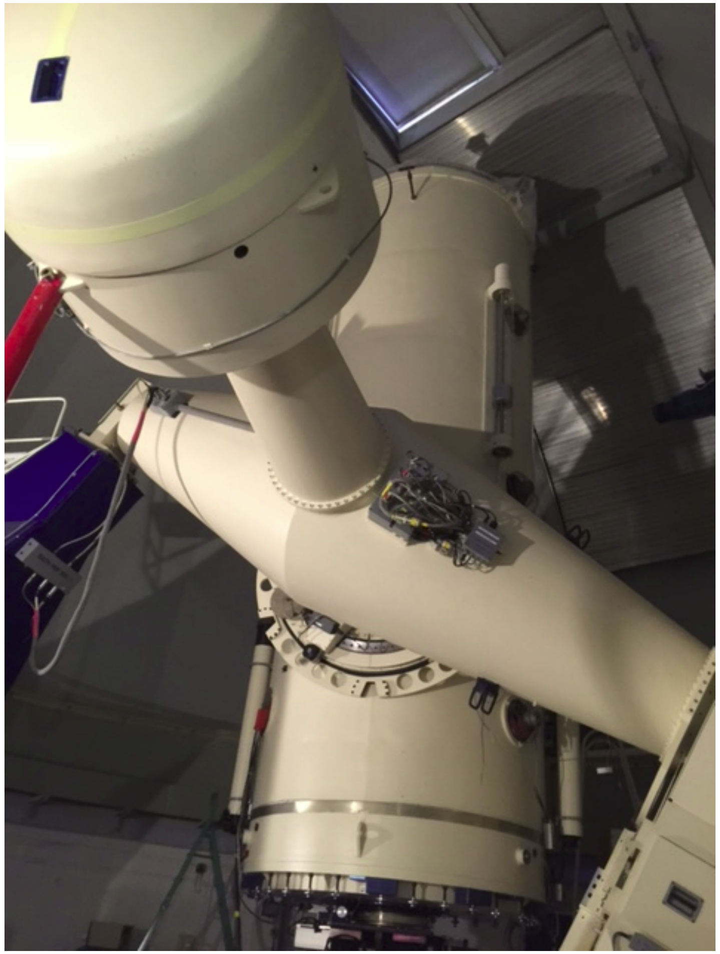
Eff. at 656nm: 8.1% S/N=45 --> S/N=56 (PLATOspec)

FEROS-like: (R=48k, 2-pixel sampling)

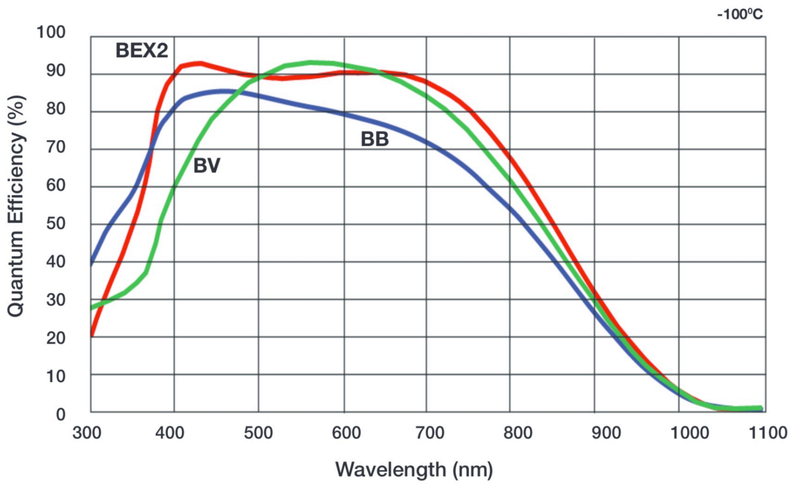
1.52-m telescope, a spectrum of a 12.5th magnitude star can be taken in two hours with a S/N=100 per wavelength bin in V.

Eff. at 390nm: 5.2% S/N=28 --> S/N=23 (PLATOspec)

Eff. at 656nm: 13.4% S/N=92 --> S/N=76 (PLATOspec)

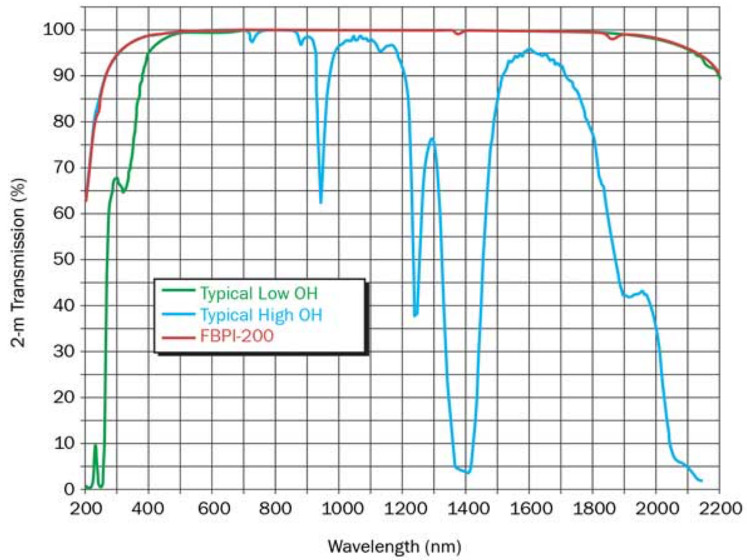


Fibers and detector need to be optimized for the UV



Standard Silicon Sensor Options

- **BV:** mid band AR coating
- **BB:** broad band AR coating (blue optimized)
- **BEX2:** dual AR coating (sensitivity extends to both the blue and NIR wavelength regions)



Observing time required to determine masses of hot Jupiters/BDs

→ One hot Jupiter per 2100 stars --> 40 hot Jupiters.

→ Mass determination of hot Jupiters (1 M_{Jup}, 0.1 AU)

to better than 10%: --> K-amplitude 100 m/s.

→ Requirement more 15 RVs with sigma RV<10 m/s per star.

→ A spectrum with S/N>50 gives 5 m/s.

→ 600 RVs with S/N>50; ca 30 min exposure time.

→ **300 hours observing time**