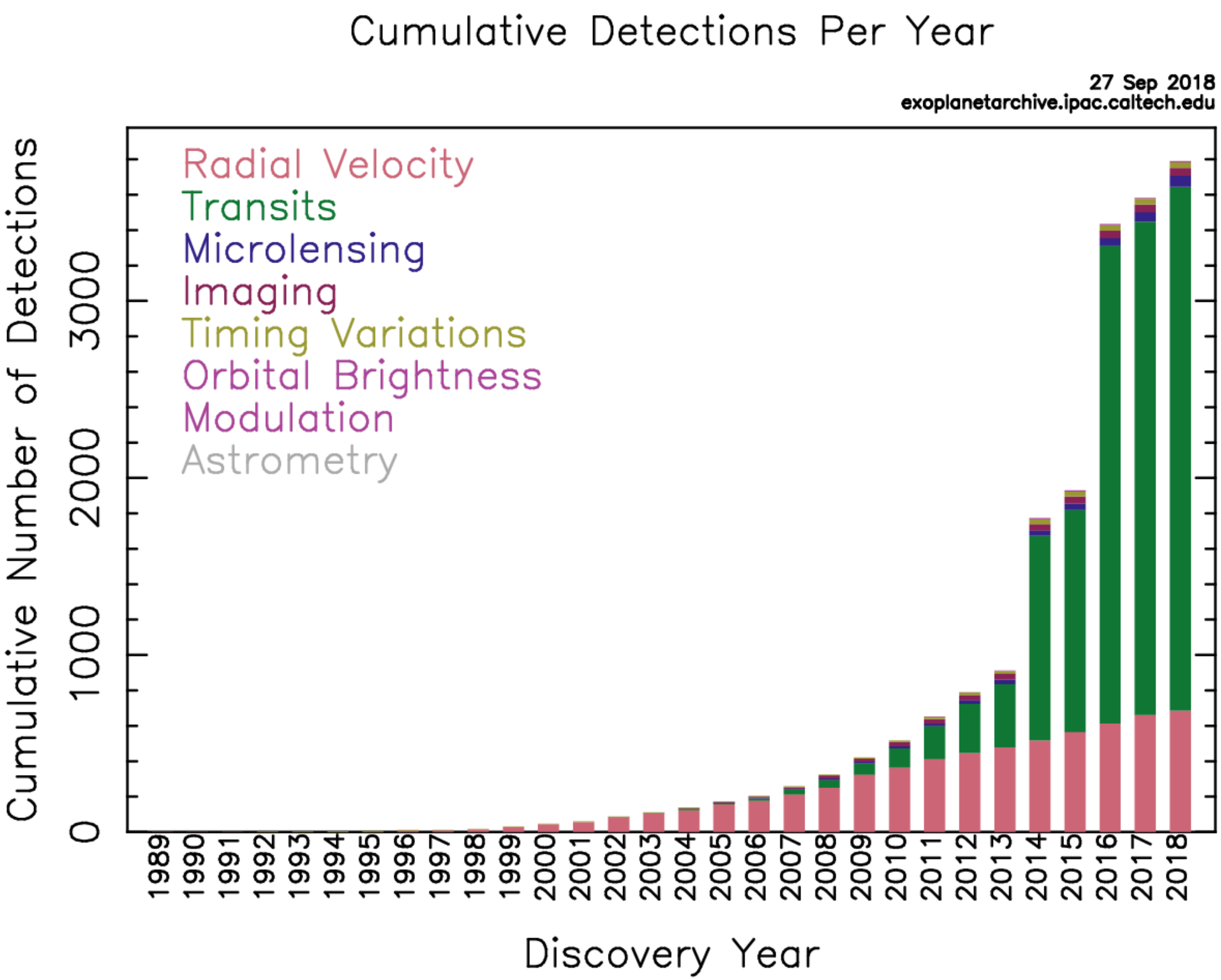

Exoplanet Hunter:HARPS
Tianjun Gan
2018.10.19
Supervised by Prof.Xuening Bai

# Outline

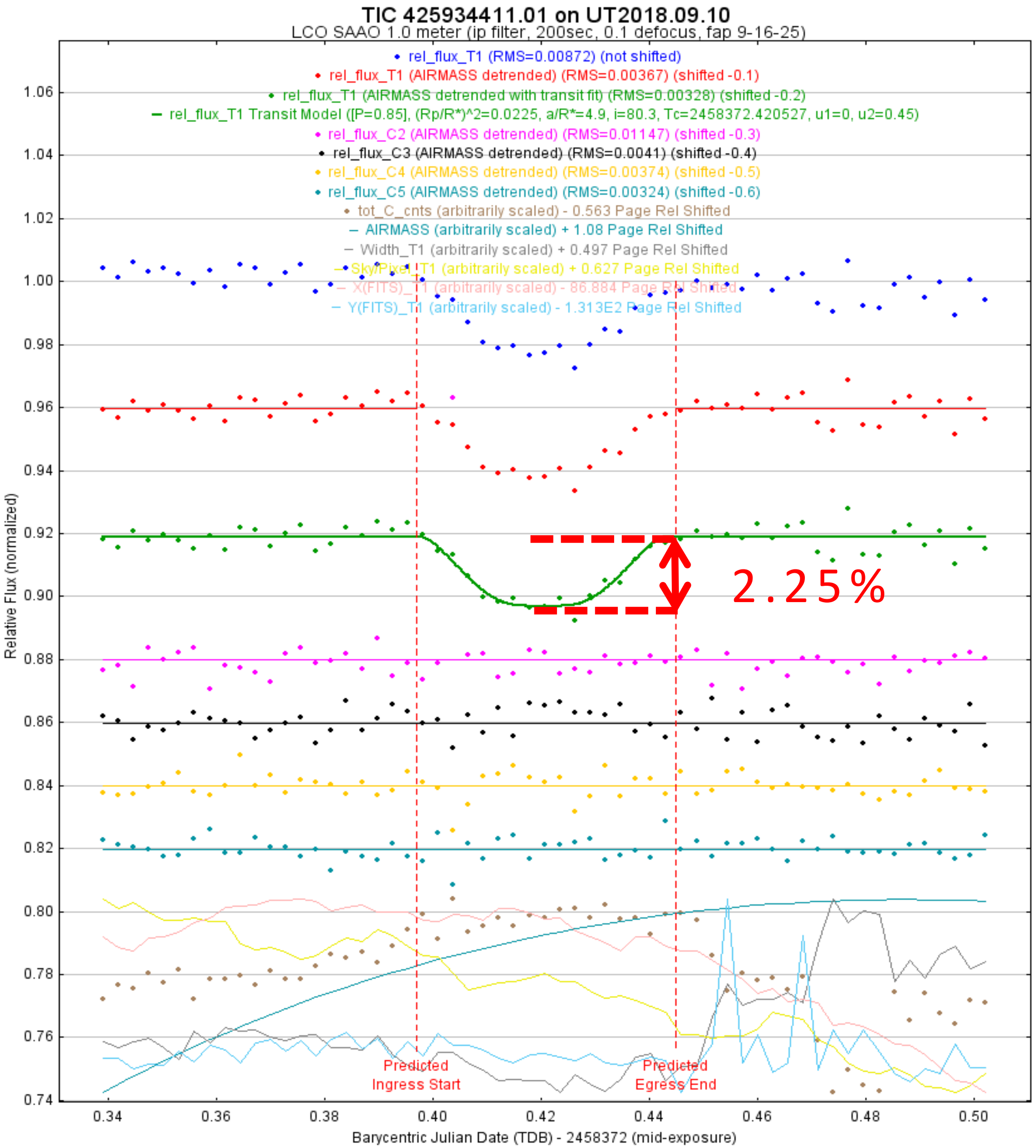
- Exoplanets and radial velocity method.
- What is HARPS?
- Recent contributions
- Summary




**3791**
**confirmed planets**

**Why we still need radial velocity?**

From: NASA Exoplanet Archive




Stellar Parameters:

$T_{eff}$~ 3658±162K

V~ 16.6

M dwarf

$R_S$: 0.698$R_\odot$

Planet Parameters (raw)

Period: 0.853 d

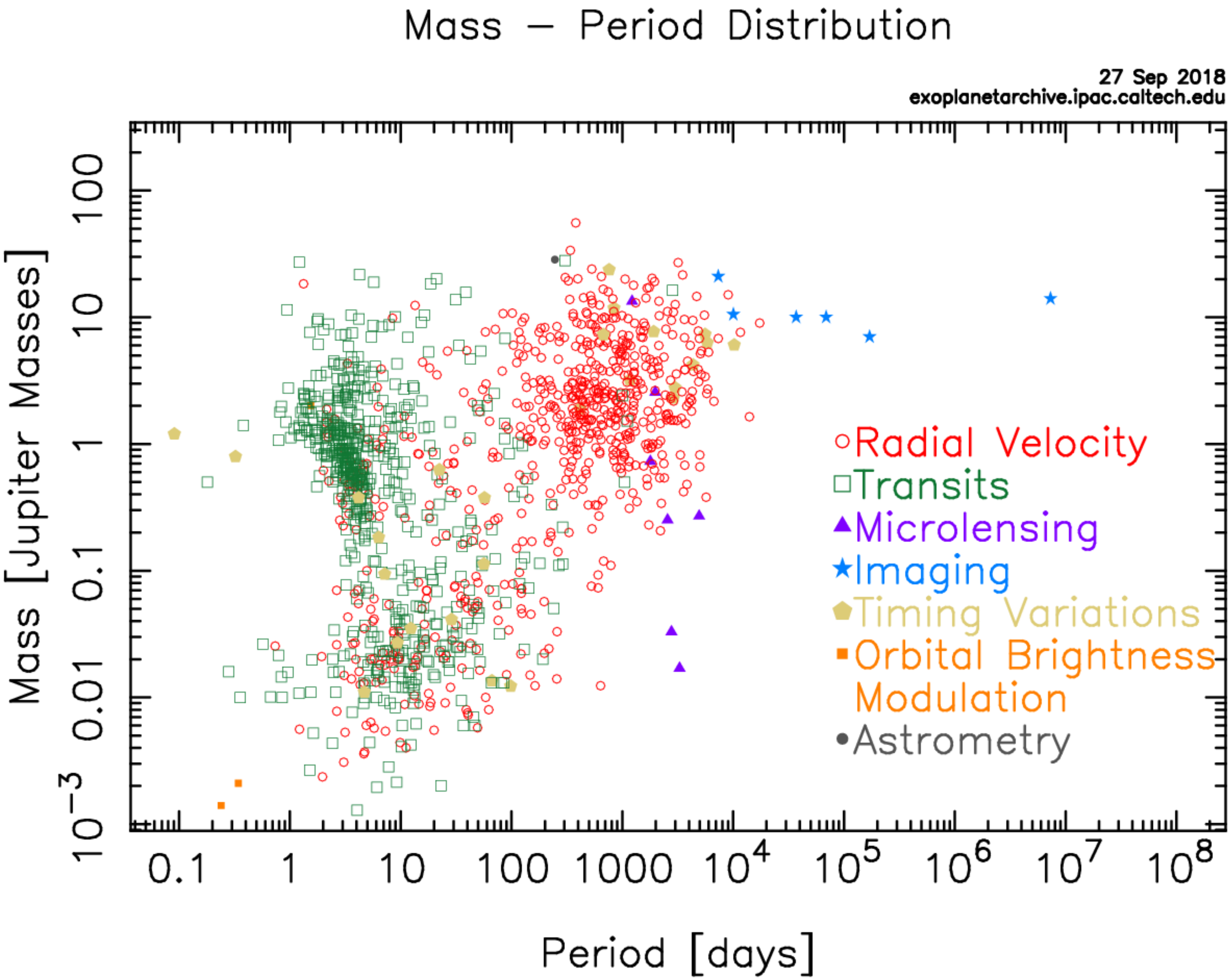
Duration time: 1.156±0.089 hrs

$R_P$~ 1.2$R_J$

$$\Delta F \simeq \left(\frac{R_p}{R_\star}\right)^2$$

A hot Jupiter?

A brown dwarf?



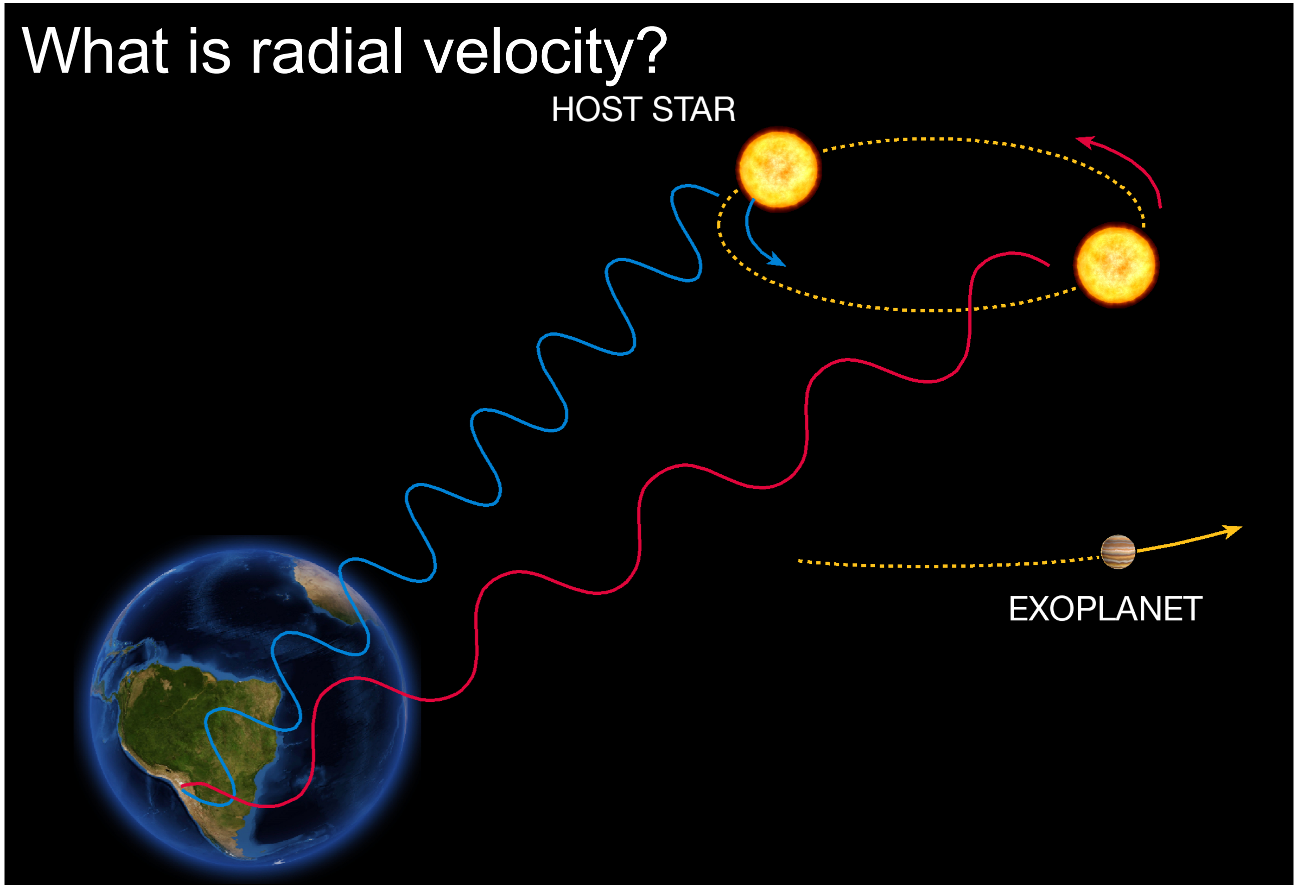

Transit Probability

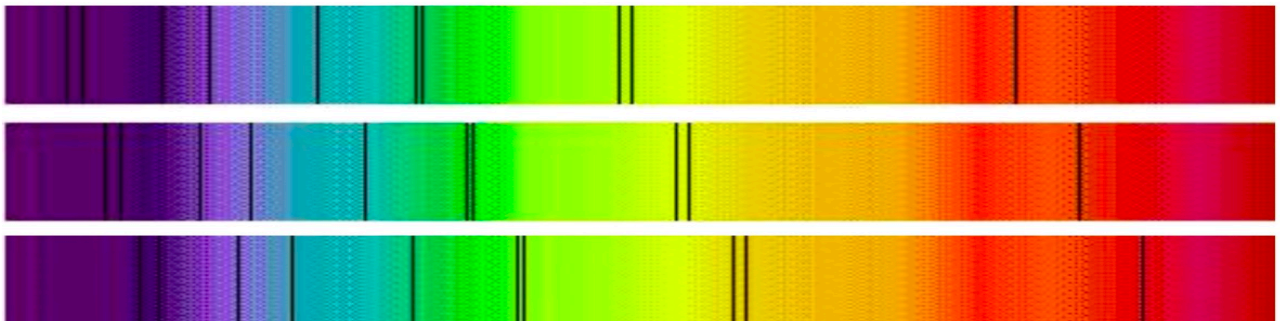
$$p = \left(\frac{R_\star \pm R_p}{a}\right)\left(\frac{1}{1-e^2}\right)$$

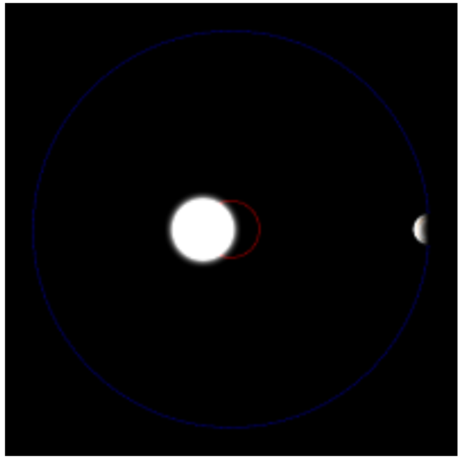
a: separation distance
e: eccentricity

Long period events

From: NASA Exoplanet Archive

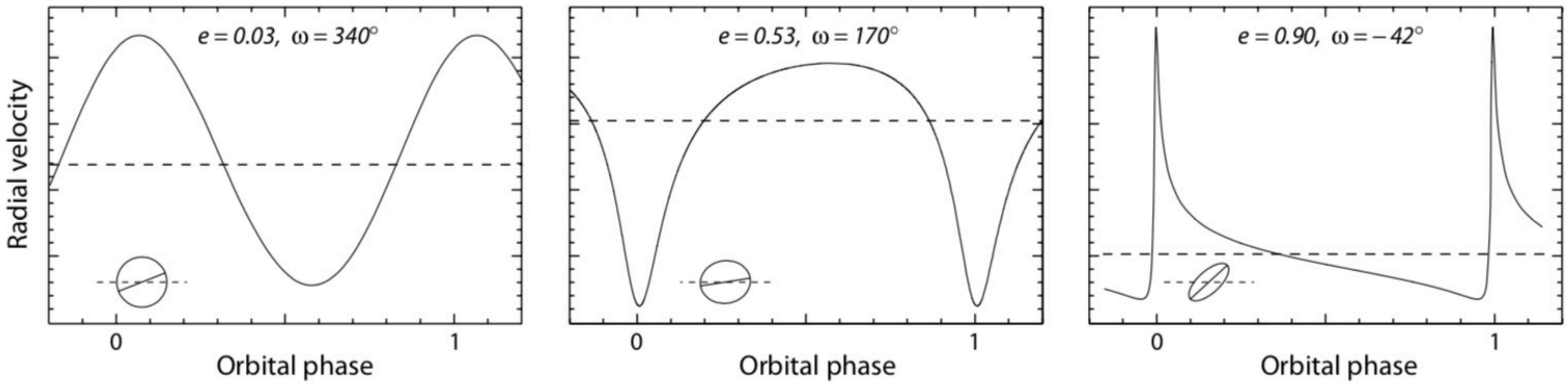




Radial velocity of Sun:

| | |
|---|---|
| 12 m/s | Jupiter |
| 9 cm/s | Earth |




$$K^2 = \frac{G}{(1-e^2)} \frac{1}{a_\star \sin i} \frac{M_p^3 \sin^3 i}{(M_\star + M_p)^2}$$

K : radial velocity semi-amplitude
e : eccentricity
i: orbit inclination
$a_*$: seperation distance
ω:argument of pericentre

$$\frac{M_p \sin i}{M_J} = 4.919 \times 10^{-3} \left(\frac{K}{\mathrm{km\,s^{-1}}}\right) (1-e^2)^{1/2} \left(\frac{P}{\mathrm{days}}\right)^{1/3} \left(\frac{M_\star + M_p}{M_\odot}\right)^{2/3}$$

if Circular Orbit, if Mp< < Ms :

$$K = 28.4\,\mathrm{m\,s^{-1}} \left(\frac{P}{1\,\mathrm{yr}}\right)^{-1/3} \left(\frac{M_p \sin i}{M_J}\right) \left(\frac{M_\star}{M_\odot}\right)^{-2/3}$$

European Southern Observatory

# HARPS

ESO — Reaching New Heights in Astronomy

## High Accuracy Radial velocity Planet Searcher

HARPS is a high-precision echelle planet finding spectrograph installed in 2002 on the ESO's 3.6m telescope at La Silla Observatory in Chile.

It has discovered over 130 exoplanets to date, with the first one in 2004.

# HARPS: Brief introduction

| Basic parameters | |
|---|---|
| Geographical Location | 70° 43' 54.1" W , -29° 15' 39.5" S |
| Spectral Range | 378nm-691nm |
| Zenith Distance | < 70° |
| Resolution | 115,000 |
| Guiding Accuracy | < 0.1 arcsec (rms) |
| Limit in hour angle HA | -5 h 30 m < HA < 5 h 30 m |
| Limiting magnitude | V< 16 |
| Limit in declination | δ<+29.5° |

## Why can HAPRS deliver such incredible high precision?

### ①Extra-ordinary instrumental stability

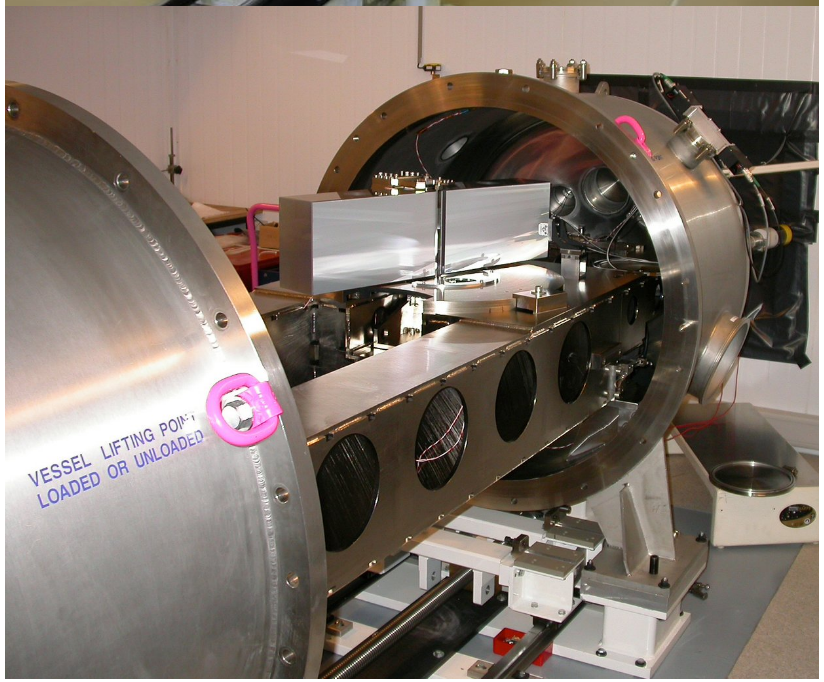
1. The instrument is operated in vacuum in order to avoid drifts of the spectrum on the CCD due to changes in atmospheric pressure.

2. The temperature of the spectrograph is kept stable.

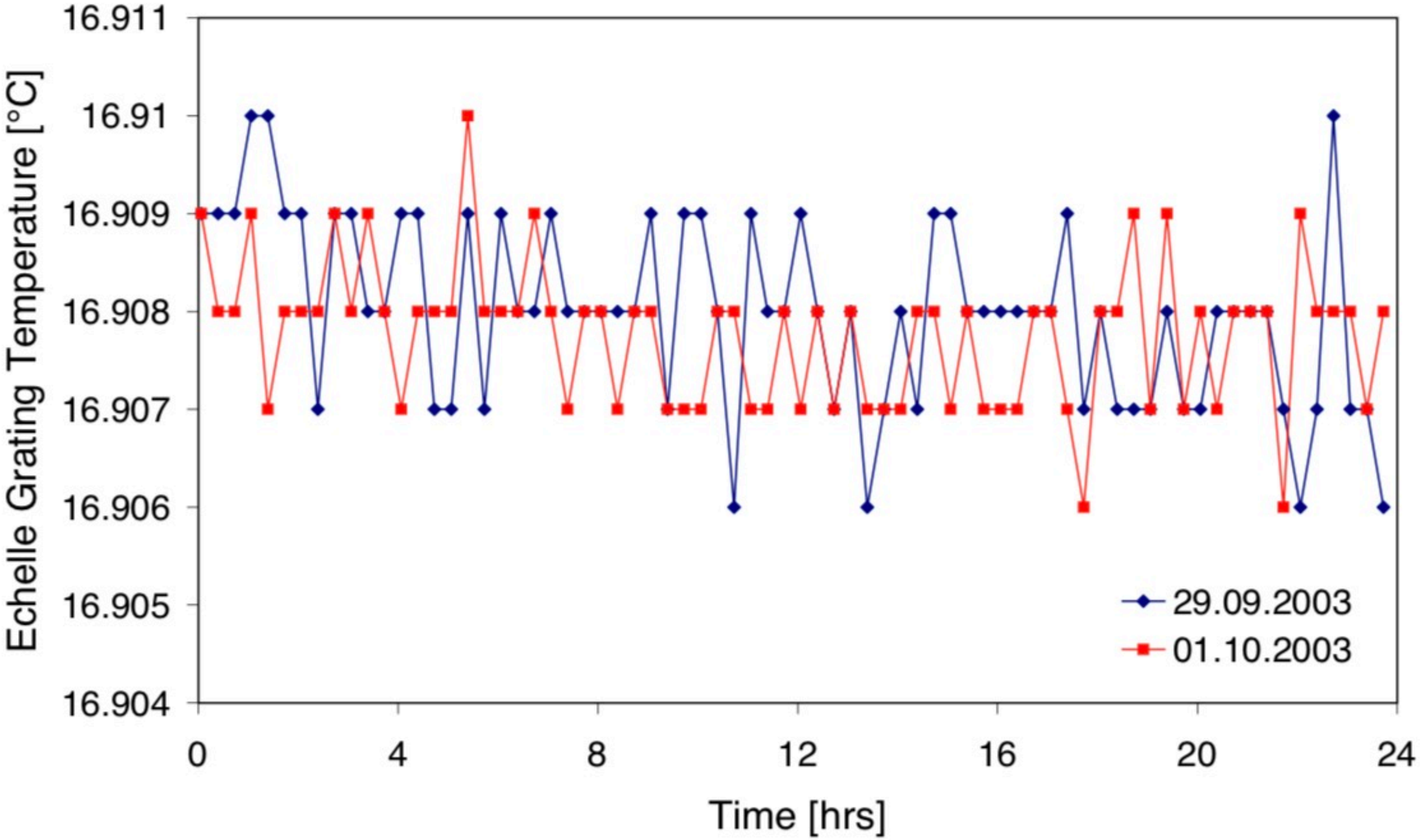
## atmospheric pressure

Ambient pressure variations would have produced huge drifts (typically 100 m/s per mbar).

The operating pressure is always kept below 0.01 mbar and the drifts will never exceed the equivalent of 1 m/s per day.



# Temperature




The stability during one day is of the order of 0.001 K, while the yearly stability is better than 0.01 K.

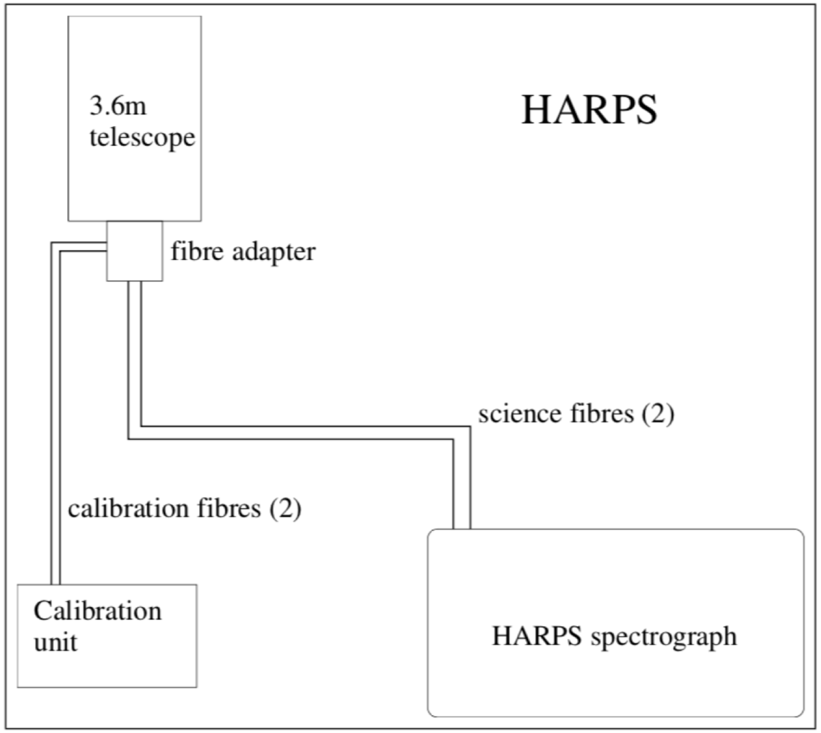
# ②New calibration method

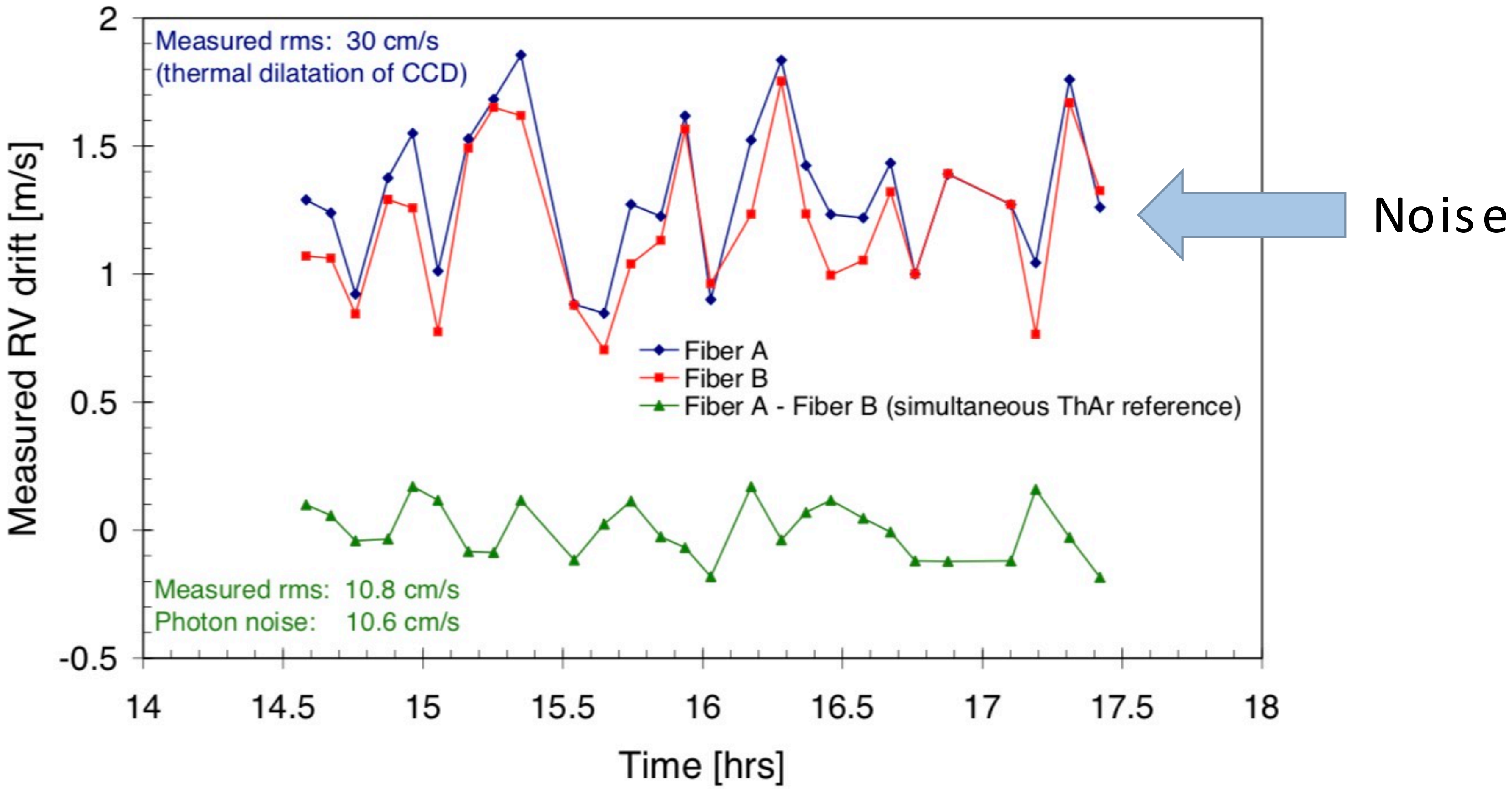
ThAr Reference Method

1.precise wavelength calibration
2.track instrumental drifts

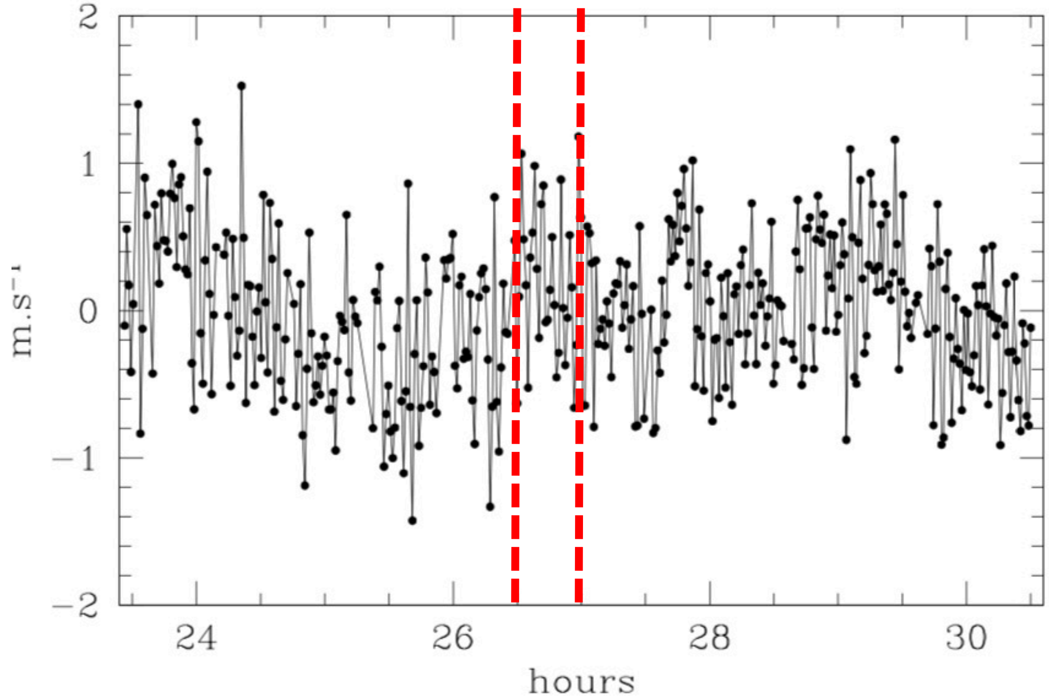
The iodine absorption cell

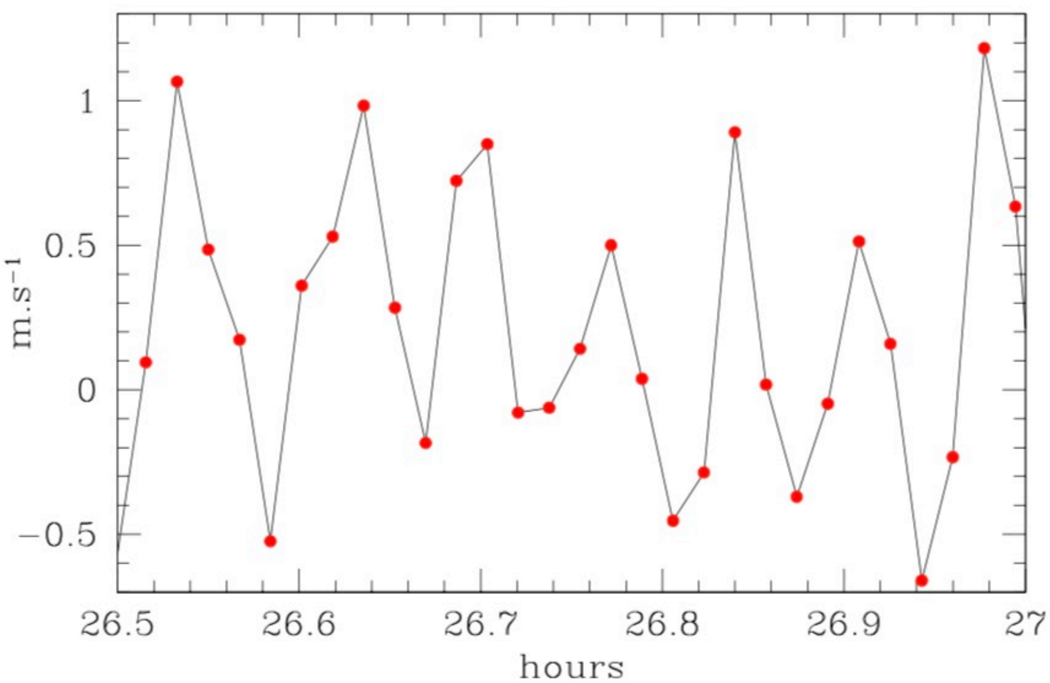
self calibration






This noise is introduced by the CCD whose temperature varies by ±0.02 K and produces microscopic dilatation of the chip.



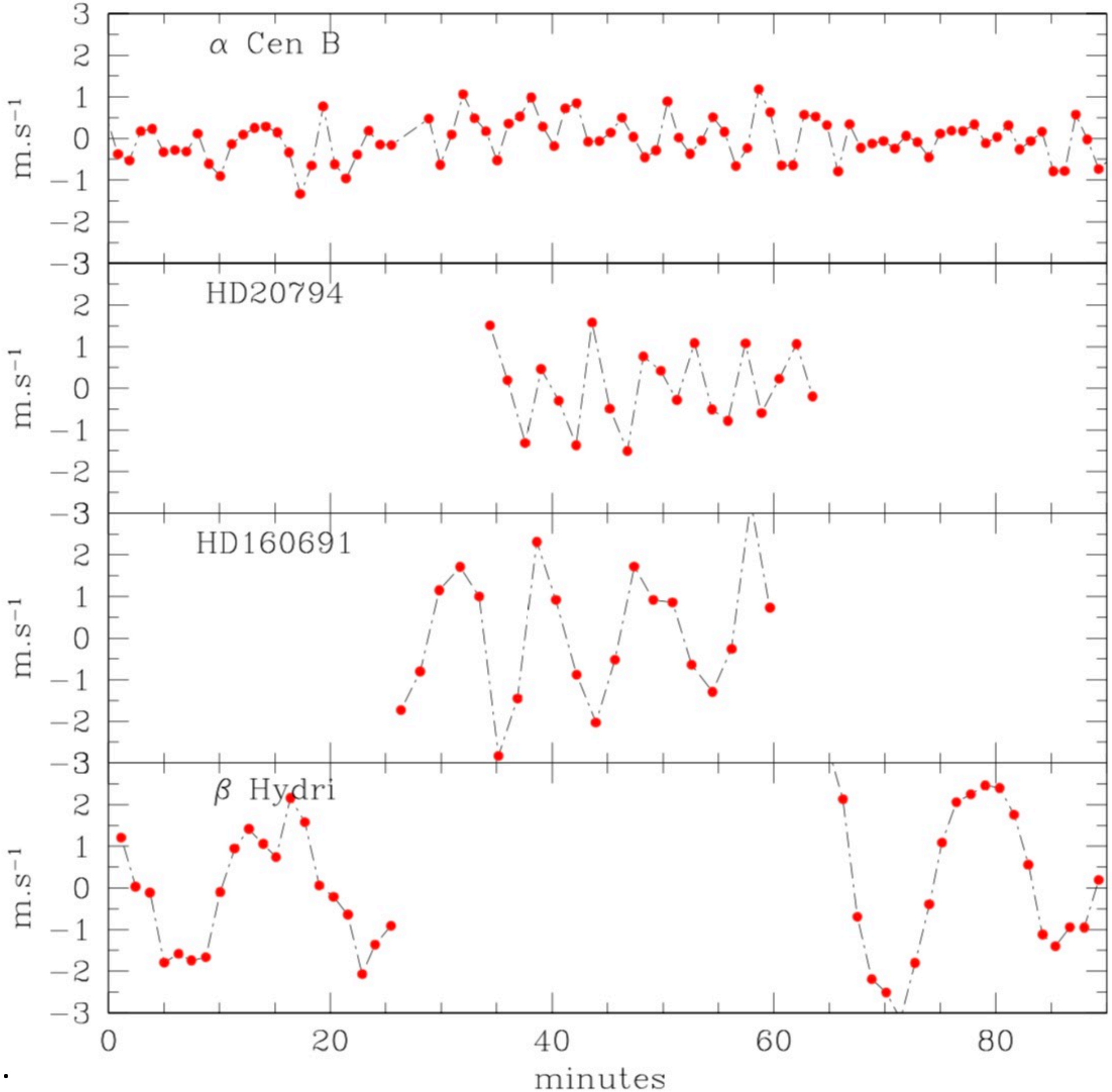




RV results of : α Centauri B

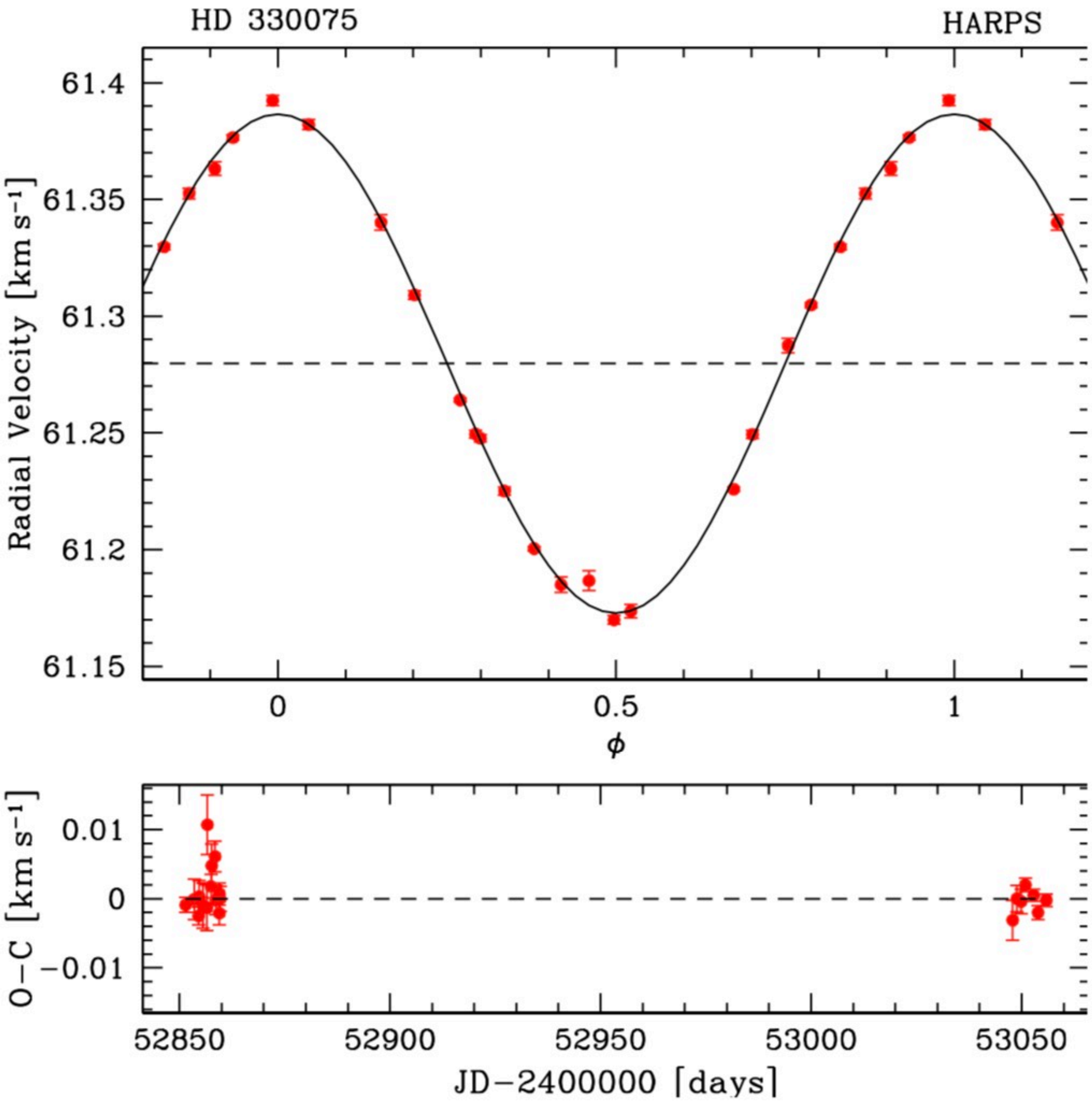

**Periodic signal produced by the star' s pulsation.**

Rupprecht, Mayor et al.

| Star | Dispersion |
| --- | --- |
| $\alpha$ Cen B | 5 $\mathrm{m\,s^{-1}}$ |
| HD20794 | 8 $\mathrm{m\,s^{-1}}$ |
| HD160691 | 7 $\mathrm{m\,s^{-1}}$ |
| $\beta$ Hydri | 7 $\mathrm{m\,s^{-1}}$ |




Rupprecht, Mayor et al.

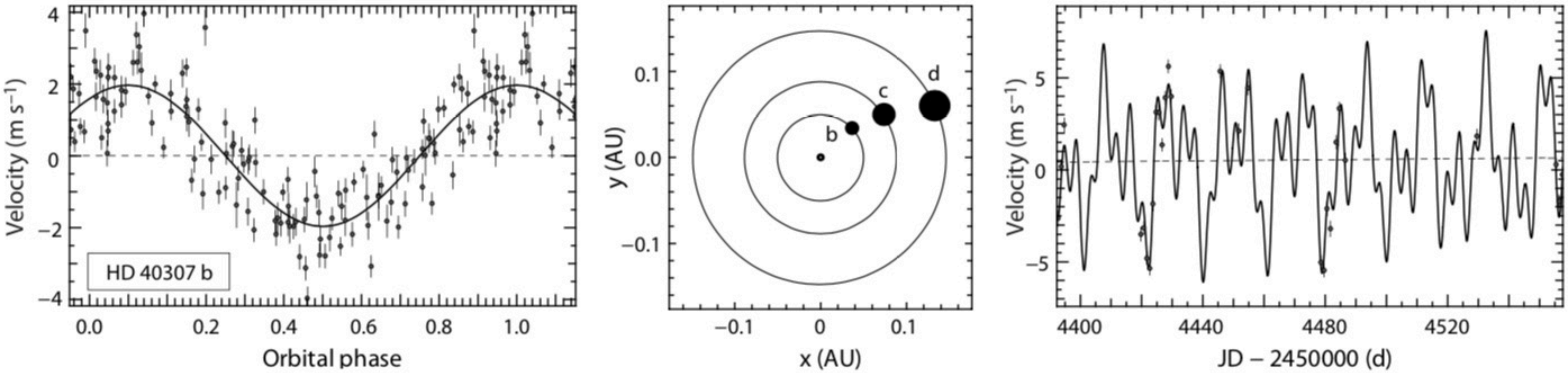



| Parameter | | HD 330075 b |
|---|---|---|
| $P$ | [days] | 3.38773 ± 0.00008 |
| $T$ | [JD] | 2452878.815 ± 0.003 |
| $\gamma$ | [km s$^{-1}$] | 61.2836 ± 0.0004 |
| offset between runs | [m s$^{-1}$] | 2.5 ± 0.8 |
| $e$ | | 0.0 ± fixed |
| $\omega$ | [deg] | 0.0 ± fixed |
| $K$ | [m s$^{-1}$] | 107.0 ± 0.7 |
| $N_{meas}$ | | 21 |
| $\sigma(O\text{-}C)$ | [m s$^{-1}$] | 2.0 |
| $a_1 \sin i$ | [Mm] | 4.983 |
| $f(m)$ | [$M_\odot$] | $4.297 \cdot 10^{-8}$ |
| $m_1$ | [$M_\odot$] | 0.7 |
| $m_2 \sin i$ | [$M_{Jup}$] | 0.62 |
| $a$ | [AU] | 0.039 |
| $T_{eq}$ | [K] | 990 |

## HD 330075b: A hot Jupiter

The first extra-solar planet discovered by HARPS in 2004.

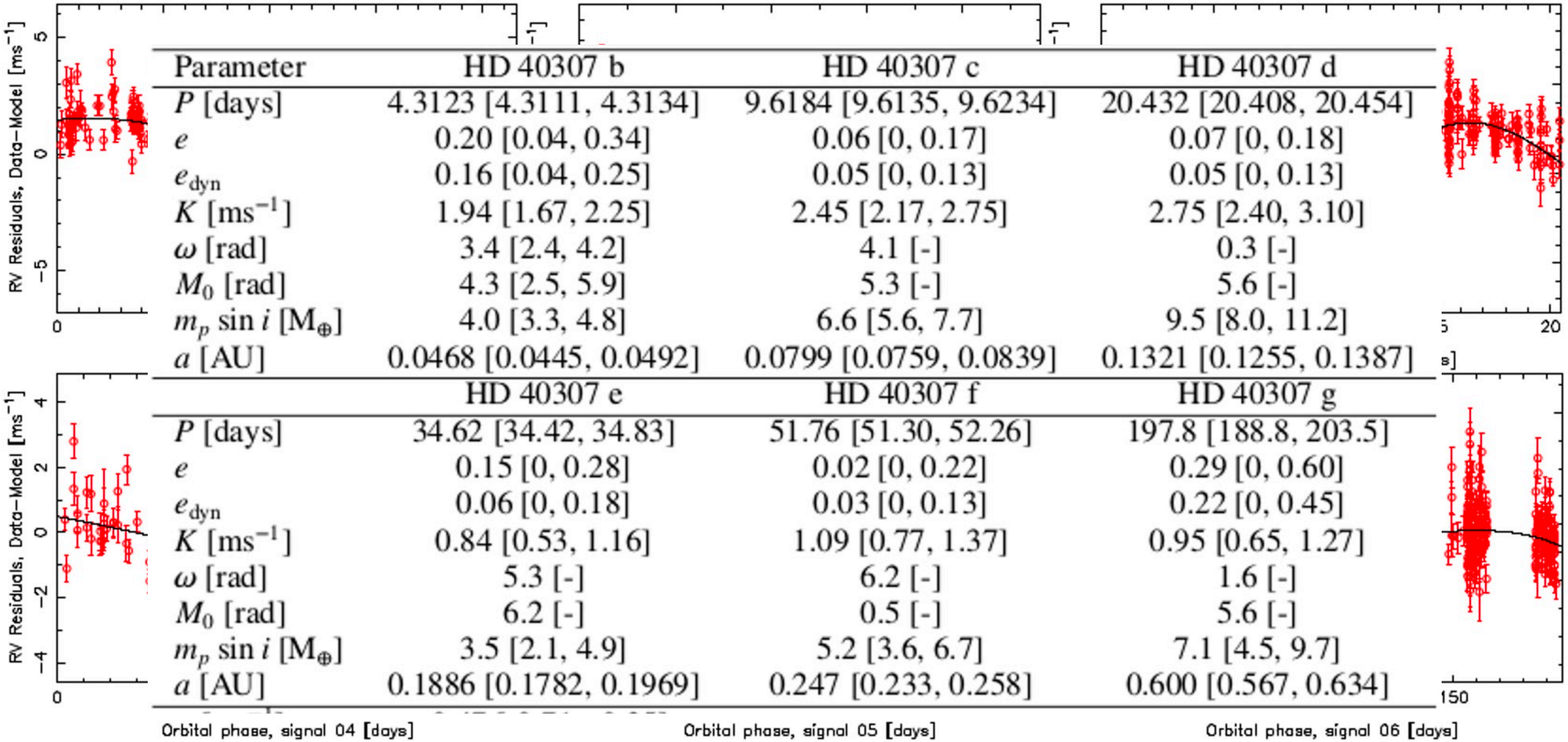
Pepe F. et al., 2004, A&A, 423, 385




Three super Earths orbit around low metallicity (-0.31±0.03) K dwarf star: HD 40307.

| Parameter | | HD 40307 b | HD 40307 c | HD 40307 d |
|---|---|---|---|---|
| $P$ | [days] | 4.3115 ± 0.0006 | 9.620 ± 0.002 | 20.46 ± 0.01 |
| $T$ | [JD-2400000] | 54562.77 ± 0.08 | 54551.53 ± 0.15 | 54532.42 ± 0.29 |
| $e$ | | 0.0 | 0.0 | 0.0 |
| $\omega$ | [deg] | 0.0 | 0.0 | 0.0 |
| $K$ | [m s$^{-1}$] | 1.97 ± 0.11 | 2.47 ± 0.11 | 4.55 ± 0.12 |
| $V$ | [km s$^{-1}$] | | 31.332 | |
| *drift* | [m s$^{-1}$/yr] | | 0.51 ± 0.10 | |
| $f(m)$ | [$10^{-14} M_\odot$] | 0.35 | 1.53 | 3.59 |
| $m_2 \sin i$ | [$M_\oplus$] | 4.2 | 6.8 | 9.2 |
| $a$ | [AU] | 0.047 | 0.081 | 0.134 |
| $N_{meas}$ | | | 135 | |
| *Span* | [days] | | 1628 | |
| $\sigma$ (O-C) | [ms$^{-1}$] | | 0.85 | |
| $\chi^2_{red}$ | | | 2.57 | |

Mayor, M., Udry, S., Lovis, C., et al. 2009a, A&A, 493, 639

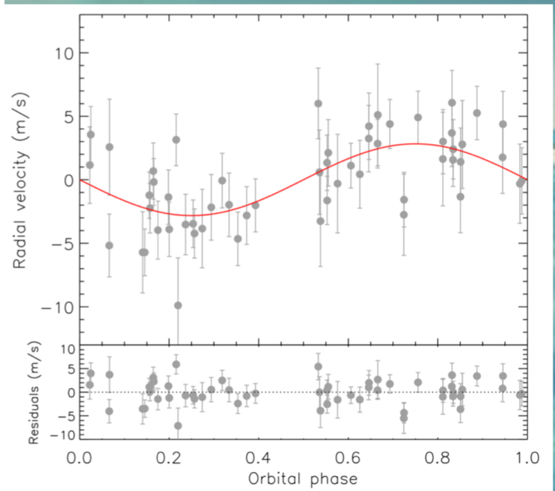




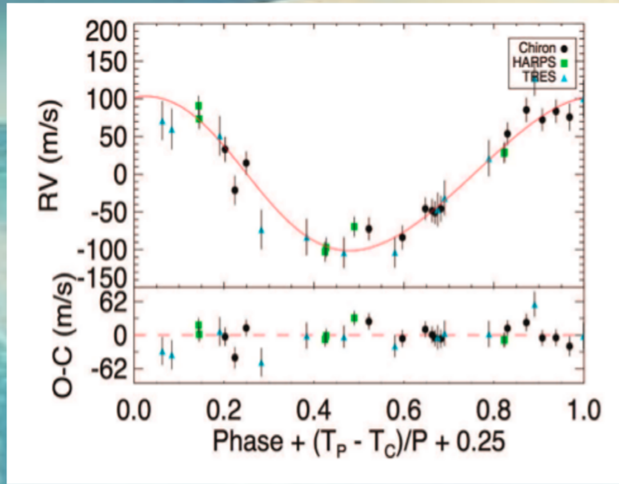
| Parameter | HD 40307 b | HD 40307 c | HD 40307 d |
|---|---|---|---|
| $P$ [days] | 4.3123 [4.3111, 4.3134] | 9.6184 [9.6135, 9.6234] | 20.432 [20.408, 20.454] |
| $e$ | 0.20 [0.04, 0.34] | 0.06 [0, 0.17] | 0.07 [0, 0.18] |
| $e_{dyn}$ | 0.16 [0.04, 0.25] | 0.05 [0, 0.13] | 0.05 [0, 0.13] |
| $K$ [ms$^{-1}$] | 1.94 [1.67, 2.25] | 2.45 [2.17, 2.75] | 2.75 [2.40, 3.10] |
| $\omega$ [rad] | 3.4 [2.4, 4.2] | 4.1 [-] | 0.3 [-] |
| $M_0$ [rad] | 4.3 [2.5, 5.9] | 5.3 [-] | 5.6 [-] |
| $m_p \sin i$ [$M_\oplus$] | 4.0 [3.3, 4.8] | 6.6 [5.6, 7.7] | 9.5 [8.0, 11.2] |
| $a$ [AU] | 0.0468 [0.0445, 0.0492] | 0.0799 [0.0759, 0.0839] | 0.1321 [0.1255, 0.1387] |
| | HD 40307 e | HD 40307 f | HD 40307 g |
| $P$ [days] | 34.62 [34.42, 34.83] | 51.76 [51.30, 52.26] | 197.8 [188.8, 203.5] |
| $e$ | 0.15 [0, 0.28] | 0.02 [0, 0.22] | 0.29 [0, 0.60] |
| $e_{dyn}$ | 0.06 [0, 0.18] | 0.03 [0, 0.13] | 0.22 [0, 0.45] |
| $K$ [ms$^{-1}$] | 0.84 [0.53, 1.16] | 1.09 [0.77, 1.37] | 0.95 [0.65, 1.27] |
| $\omega$ [rad] | 5.3 [-] | 6.2 [-] | 1.6 [-] |
| $M_0$ [rad] | 6.2 [-] | 0.5 [-] | 5.6 [-] |
| $m_p \sin i$ [$M_\oplus$] | 3.5 [2.1, 4.9] | 5.2 [3.6, 6.7] | 7.1 [4.5, 9.7] |
| $a$ [AU] | 0.1886 [0.1782, 0.1969] | 0.247 [0.233, 0.258] | 0.600 [0.567, 0.634] |

Tuomi, M., Anglada-Escudé, G., Gerlach, E., et al. 2013, A&A, 549, A48

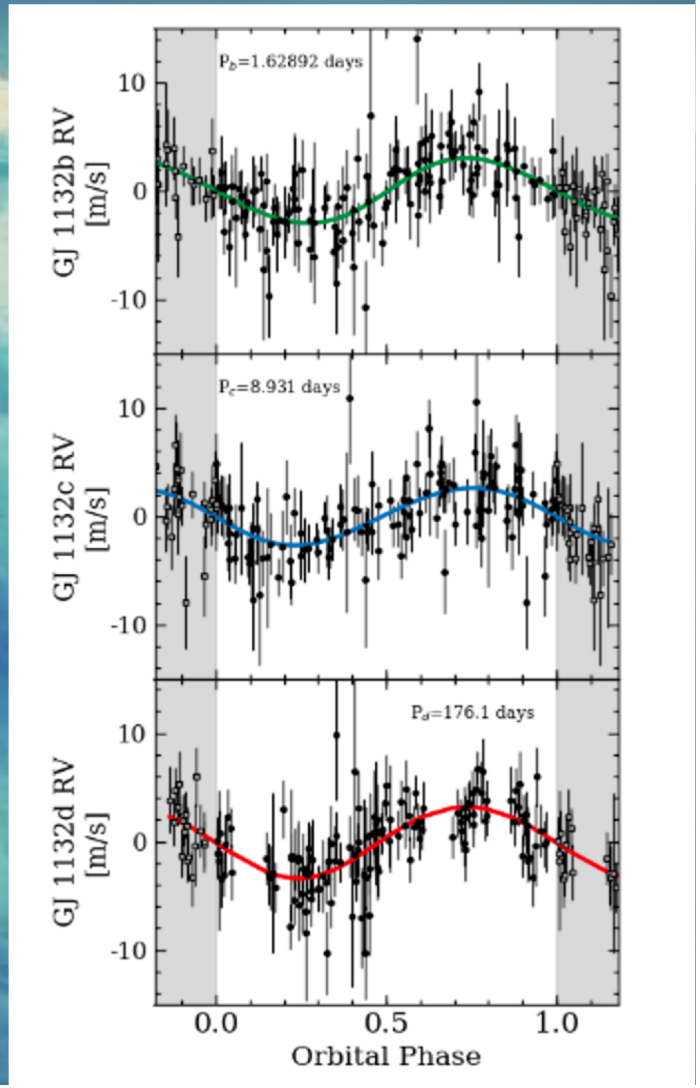
# A large planets' family is being built by HARPS

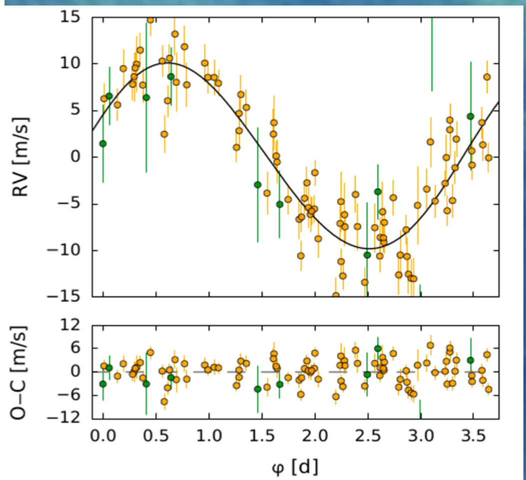



K2-263 b
Mortier et al. 2018




HD 202772A b
Wang et al. 2018




More and more in the future!

GJ1265b
Luque et al. 2018

GJ1132b, c, d
Bonfils et al. 2018

# Kinematics and chemical properties with HARPS?

850 FGK solar neighborhood long-lived dwarfs with :
log g ≥ 4 dex, 5000 ≤ Teff ≤ 6500 K, and -1.39 ≤ [Fe/H] ≤ 0.55

α : average abundance of Mg, Si and Ti.

black:
thick disk stars

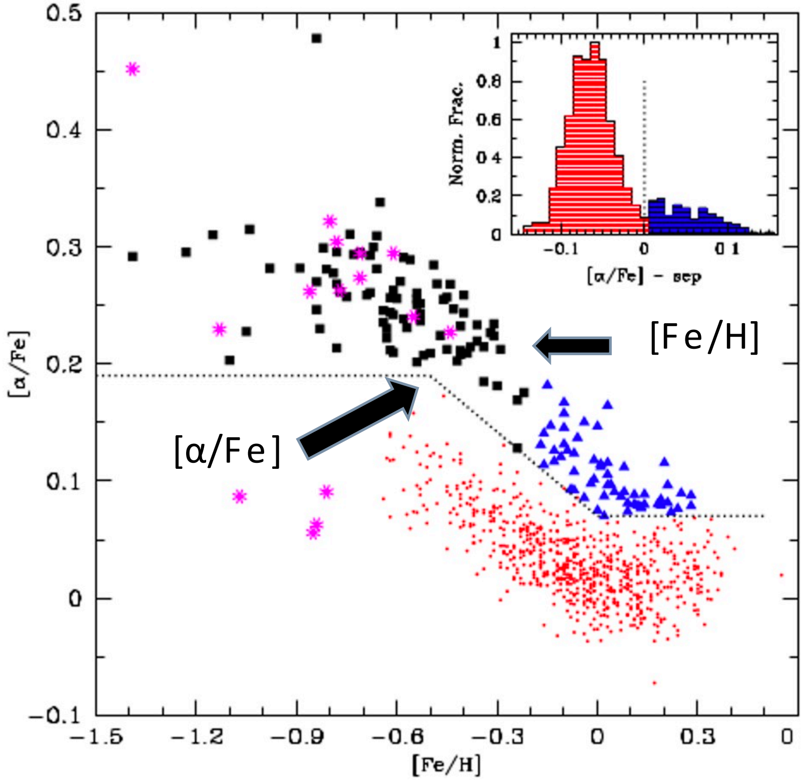
blue:
hαmr stars

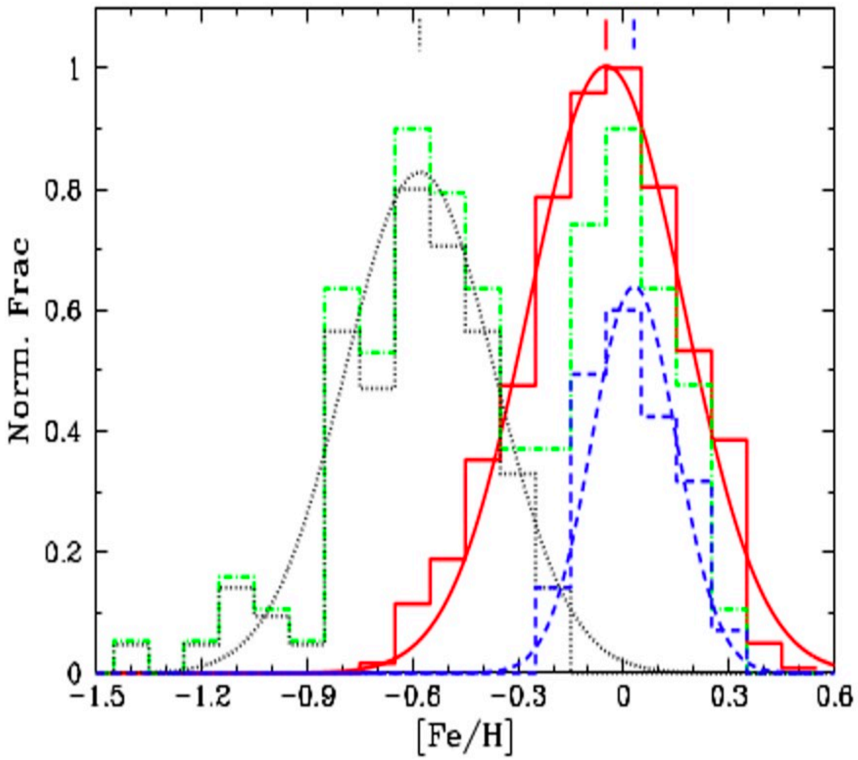
green:
thick+hαmr stars

red:
thin disk stars

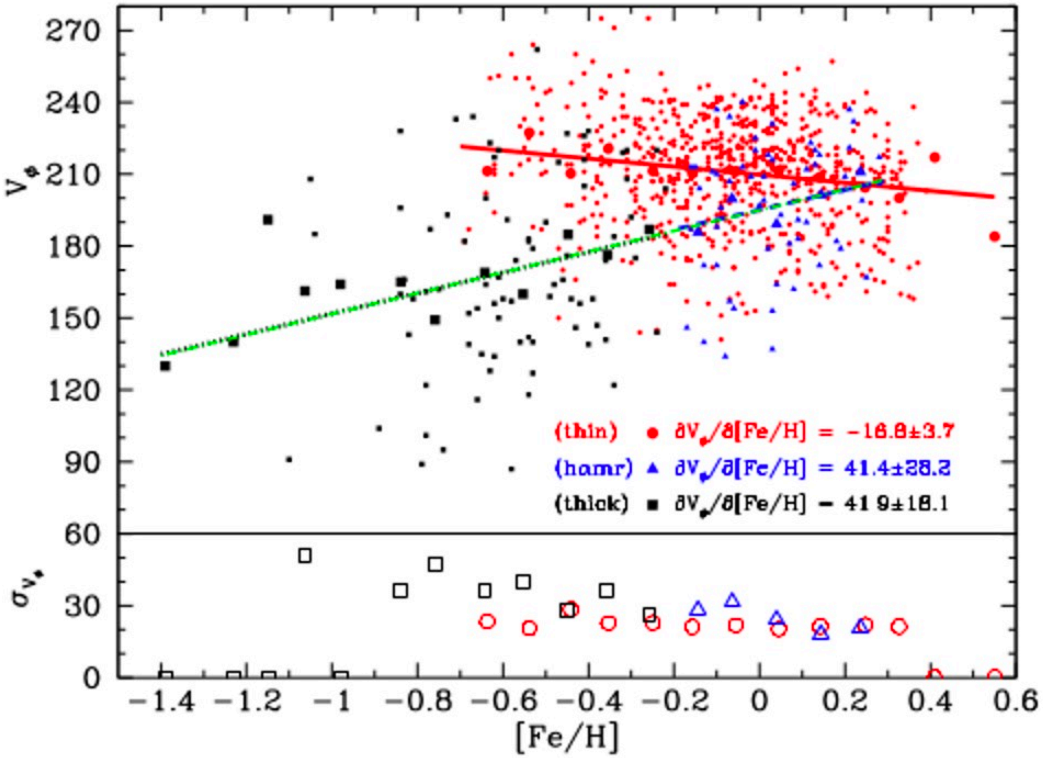
magenta:
halo stars

Adibekyan V. Z., et al., 2013, A&A, 554, A44



| Stellar groups | $\partial V_\phi/\partial$[Fe/H] (km s$^{-1}$ dex$^{-1}$) | $r_{\partial V_\phi/\partial[Fe/H]}$ | N($V_\phi$) | n$\sigma$($V_\phi$) | $\partial e/\partial$[Fe/H] (dex$^{-1}$) | $r_{\partial e/\partial[Fe/H]}$ | N($e$) | n$\sigma$($e$) |
|---|---|---|---|---|---|---|---|---|
| Thick | 41.9±18.1 | 0.247 | 84 | 2.24$\sigma$ | -0.184±0.078 | -0.266 | 73 | 2.24$\sigma$ |
| h$\alpha$mr | 41.4±28.2 | 0.190 | 58 | 1.43$\sigma$ | -0.185±0.138 | -0.212 | 40 | 1.30$\sigma$ |
| Thick+h$\alpha$mr | 43.9±7.6 | 0.435 | 142 | 5.19$\sigma$ | -0.208±0.036 | -0.475 | 113 | 5.27$\sigma$ |
| Thin | -16.8±3.7 | -0.164 | 692 | 4.43$\sigma$ | -0.023±0.015 | -0.212 | 515 | 4.81$\sigma$ |




Hαmr stars are more metal-rich than the thick disk stars and they are as metal-rich as the bulge stars.

Hαmr stellar family may have originated from the inner Galactic bulge and migrated up to solar neighborhood.

Adibekyan V. Z., et al., 2013, A&A, 554, A44

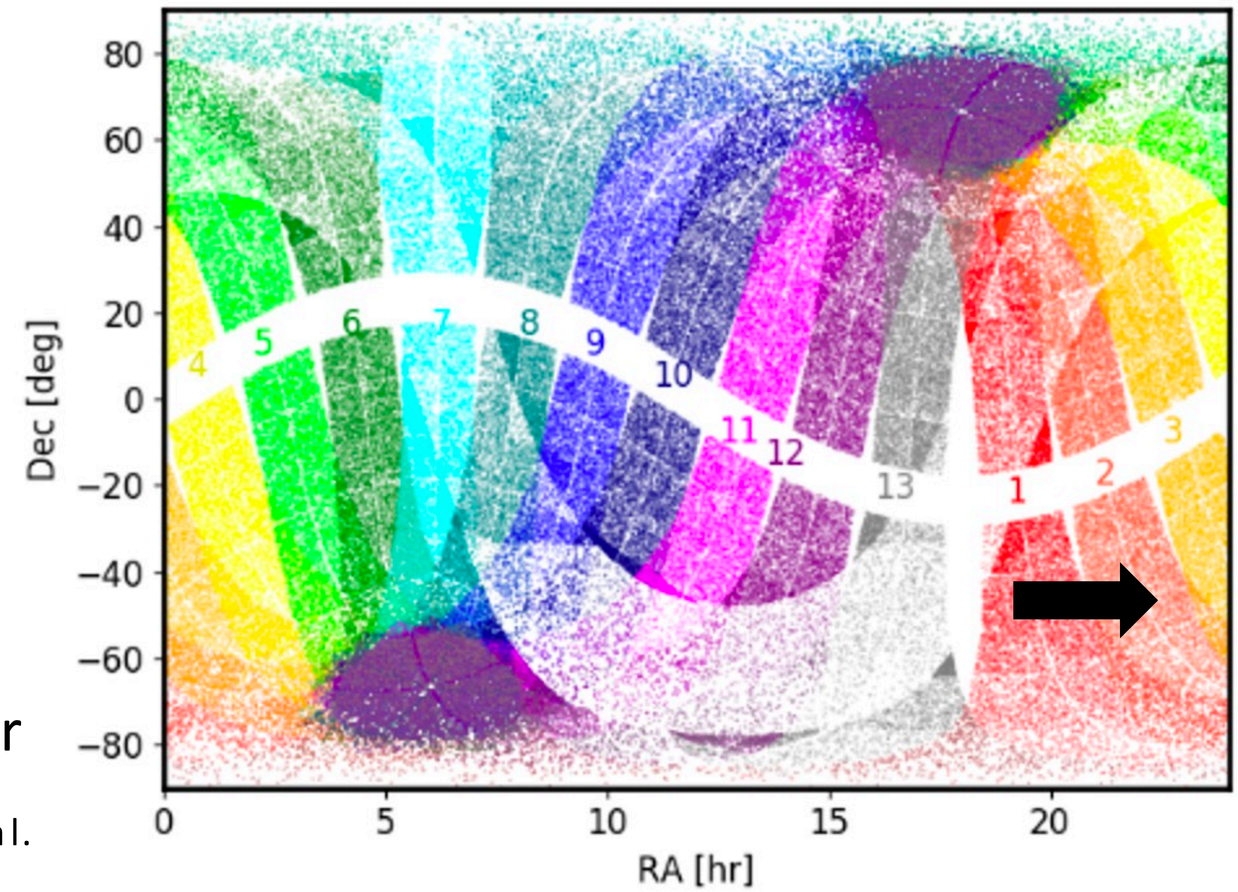
# Possible scientific researches

- TESS follow up (Transit Exoplanet Survey Satellite)

~ $10^4$ exoplanets orbiting around bright stars(V< 13)

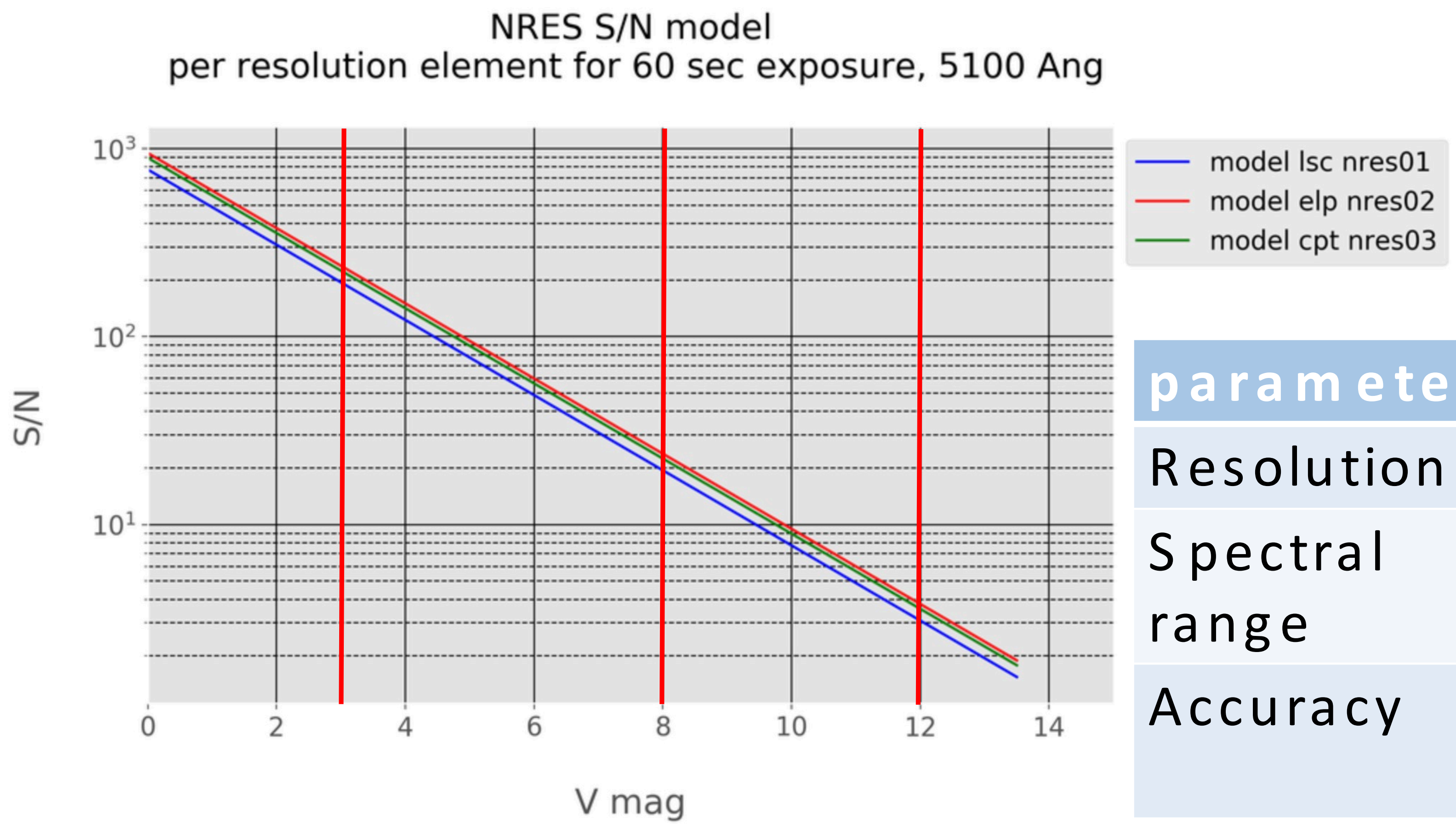
~ 3500 planets with Neptune size and smaller

Huang, C. X., Shporer, A., Dragomir, D., et al. 2018a, ArXiv e-prints, arXiv:1807.11129



Las Cumbres Observatory
MANY EYES - ONE VISION

# The Network of Robotic Echelle Spectrographs




| parameter | |
|---|---|
| Resolution | 53,000 |
| Spectral range | 380-860 nm |
| Accuracy | 3m/s(for V< 11) |

# Summary

- Combining transit with radial method, we can constrain the planet's properties better.
- HARPS has a radial velocity accuracy about 1m/s due to its extra-ordinary instrumental stability.
- HARPS has big contributions in planets hunting, kinematics and chemical properties.
- HARPS can play an important role in TESS follow-up.