VENUS TRANSIT OF 6 JUNE 2012:

Detection of the Rossiter-McLaughlin effect a test bench for the study of other Earths with HIRES@E-ELT

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Detection of the Rossiter–McLaughlin effect in the 2012 June 6 Venus transit★

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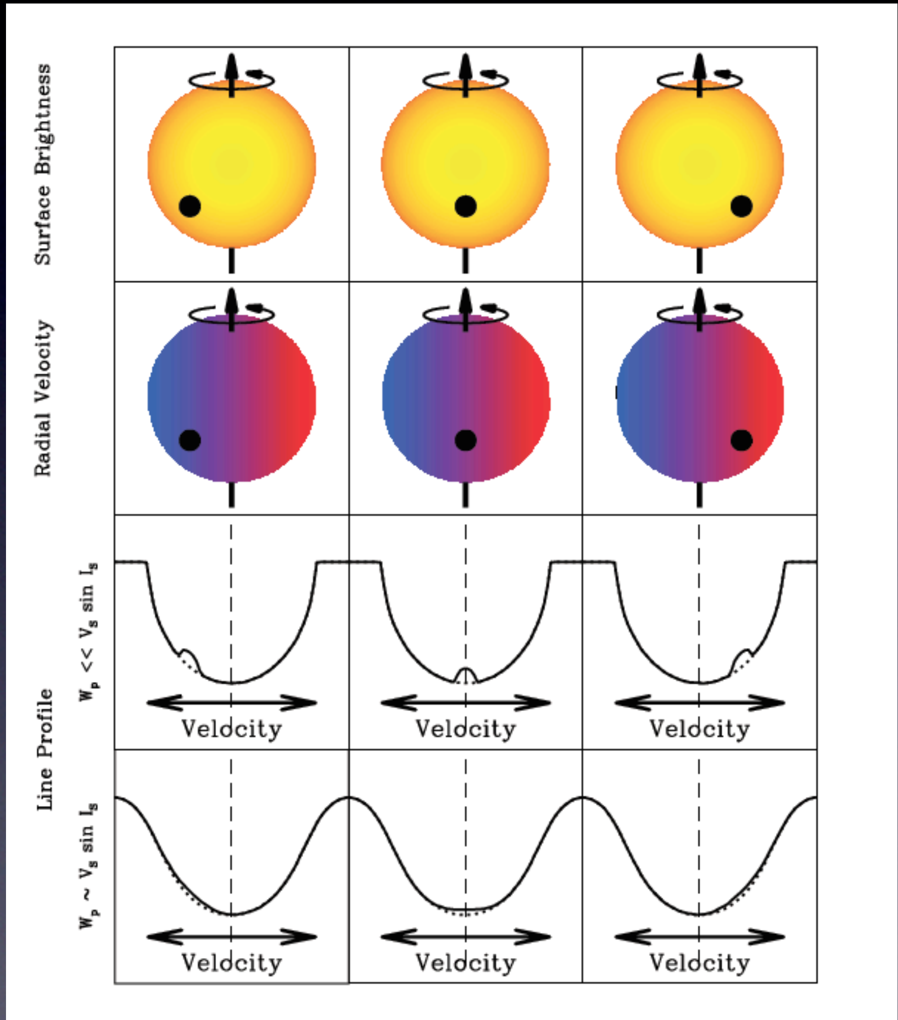
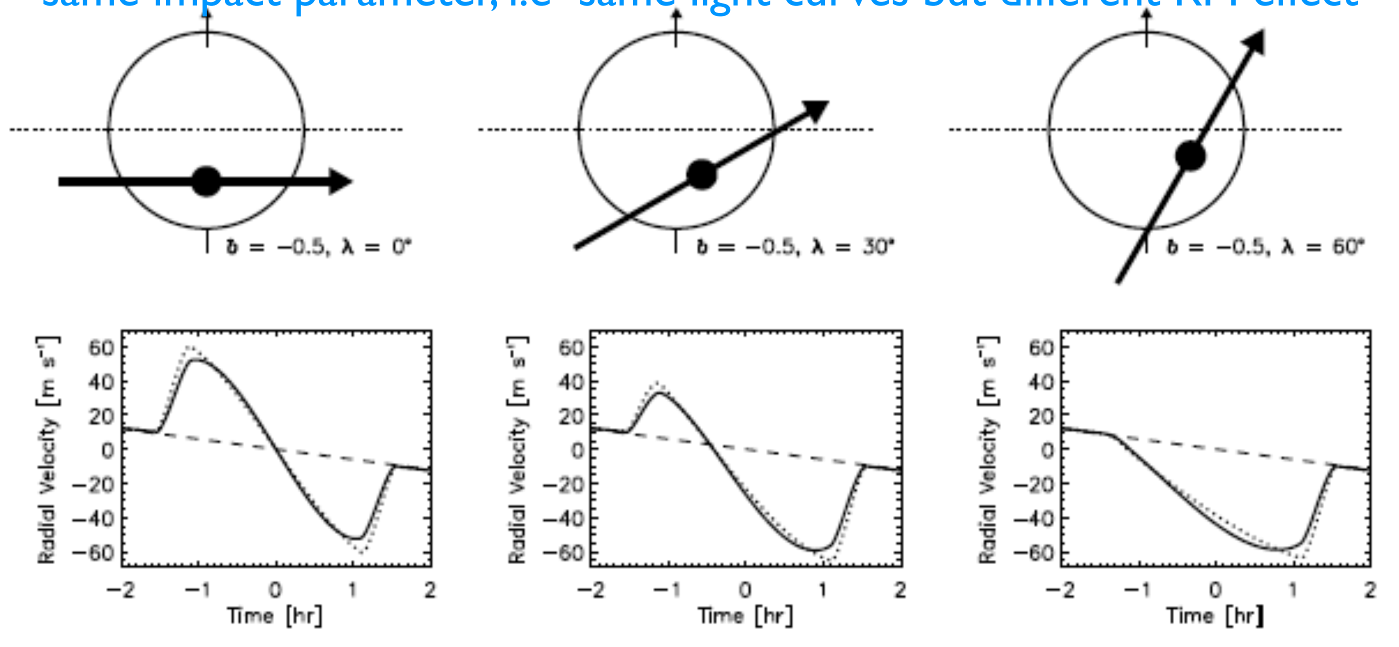
The Rossiter-McLaughlin effect

Rossiter 1924 in Algol
McLaughlin 1924 in Beta Lyrae

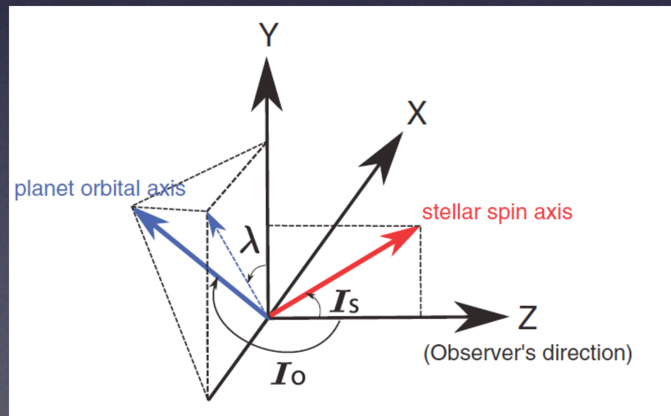


from Gaudi Winn 2007

same impact parameter, i.e same light curves but different RM effect

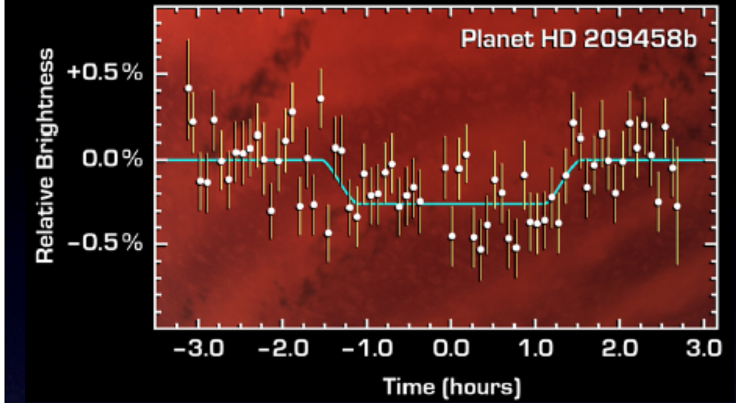


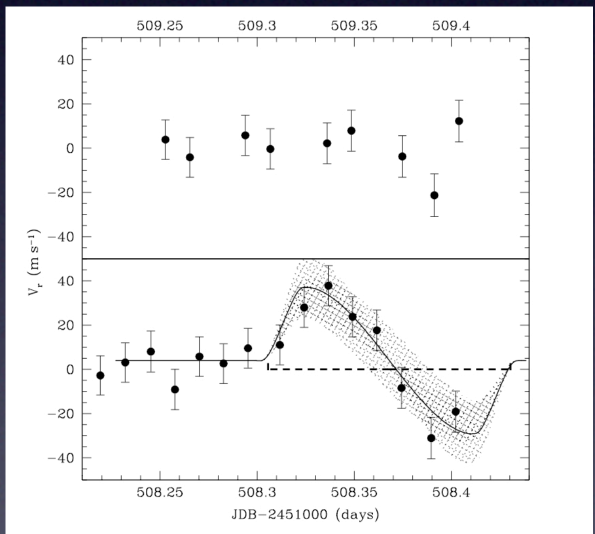
- Planet orbit stellar spin angle
- Corotation or retrograde orbit
- Planet confirmation in few hours (false positives up to 90%)



$$\Delta V_s = \frac{k^2}{1-k^2}\,\Omega_s \delta_p \sin I_s$$

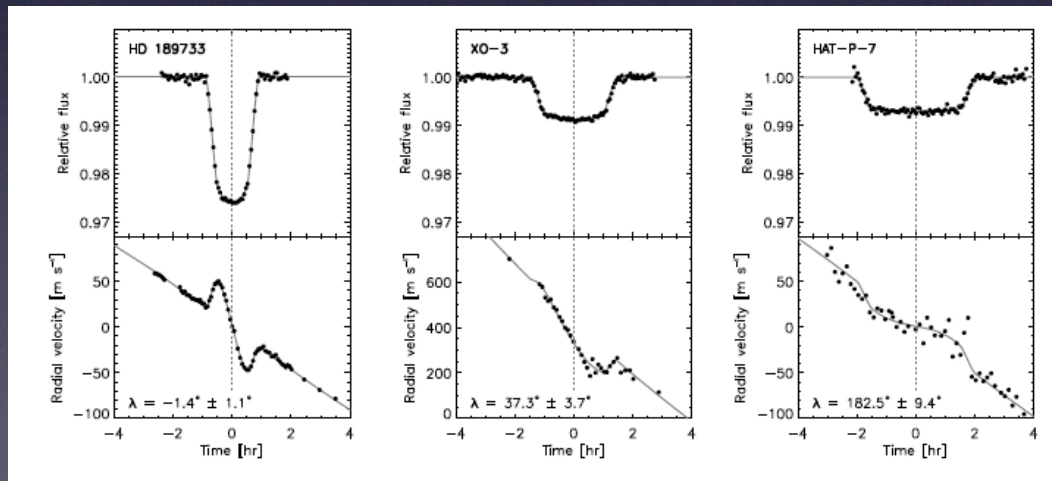
K= Rp/Rs





co-aligned rotation

- First detection of the RM due to an extrasolar planet Queloz et al 2000
- ~ 60 RME studied due to hot Jupiters
- Hirano et al 2012 studied a sample of Kepler Transit and RV with Subaru 40% substantial misalignments
- hot-Neptune:HAT-P-11b (Hirano el 2011)
- How small can be the planet?



Hirano et al 2012

SDO -NASA

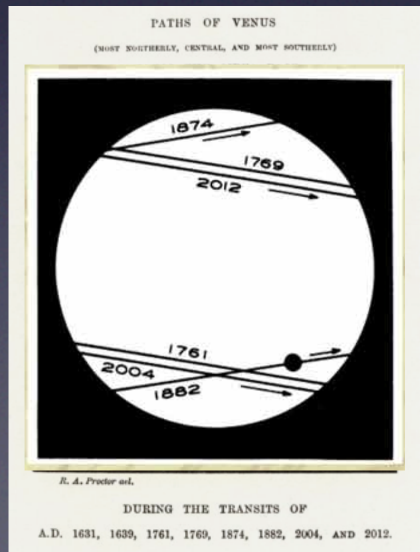
orange sun is filtered visible light

golden sun is 171 A

red sun 304 A

magenta 1700 A

1874 Proctor Richard Anthony



every 105 or 121 years

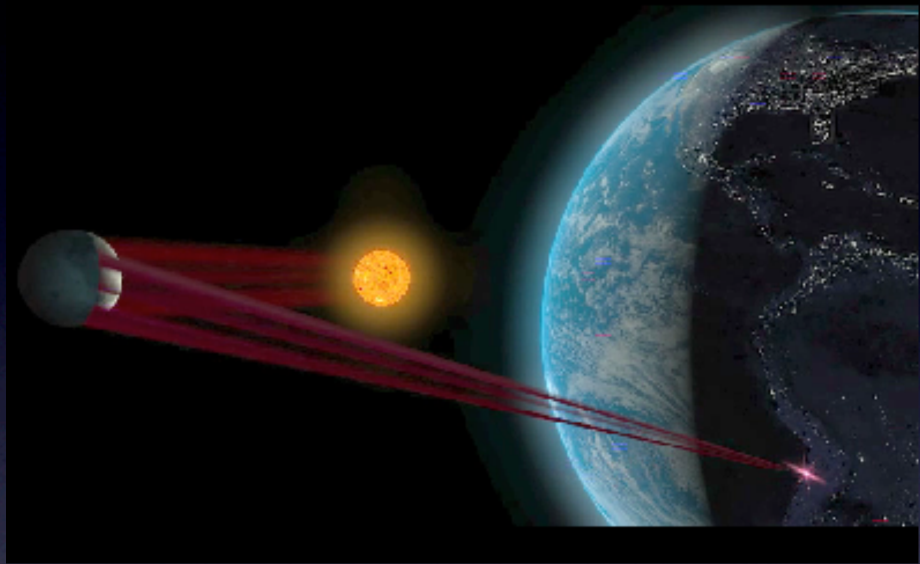
The signal is small:

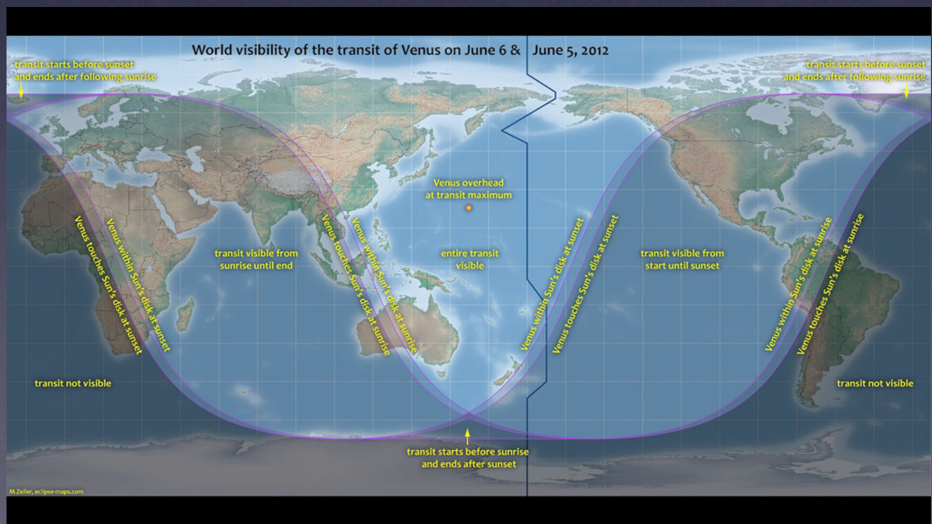
$$\Delta V_s = \frac{k^2}{1-k^2}\,\Omega_s \delta_p \sin I_s$$

K= Rp/Rs =1/33

$$\Delta V_s \sim 1 \text{ m s}^{-1}$$

Strategy





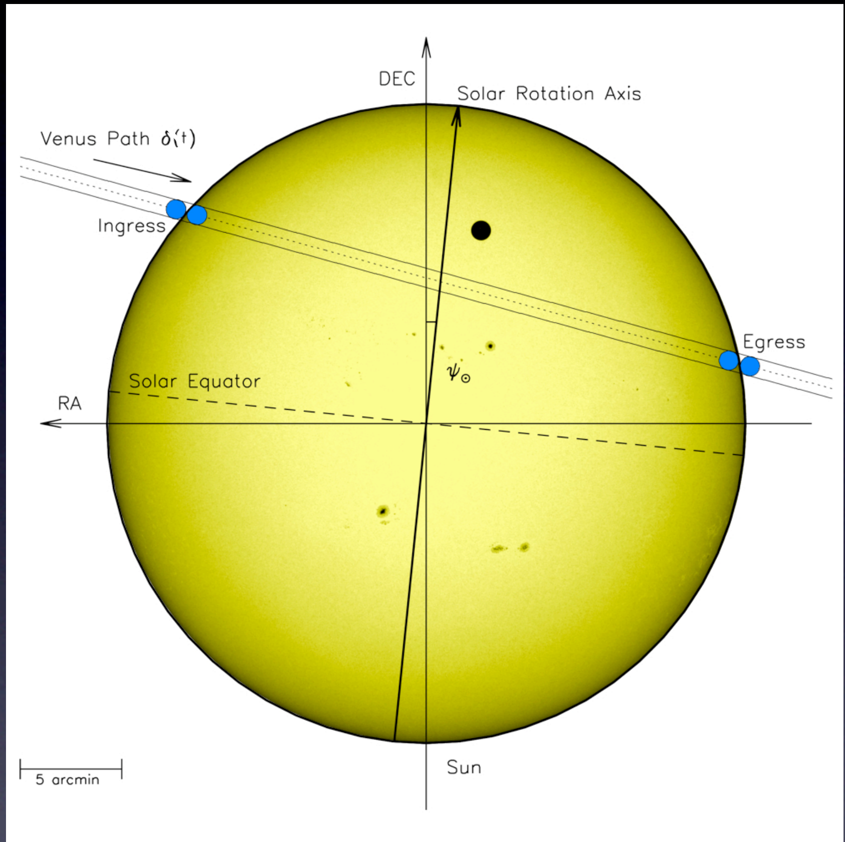
- Need of solar integrated light & HR

➡ Moon as a mirror ~ Full Moon (97%) => pointing the Moon center to avoid Moon rotation

- Unfortunately the Moon rise at La Silla happened at mid-Transit

- Unfortunately HARPS-N not operational

Venus Path From the Moon



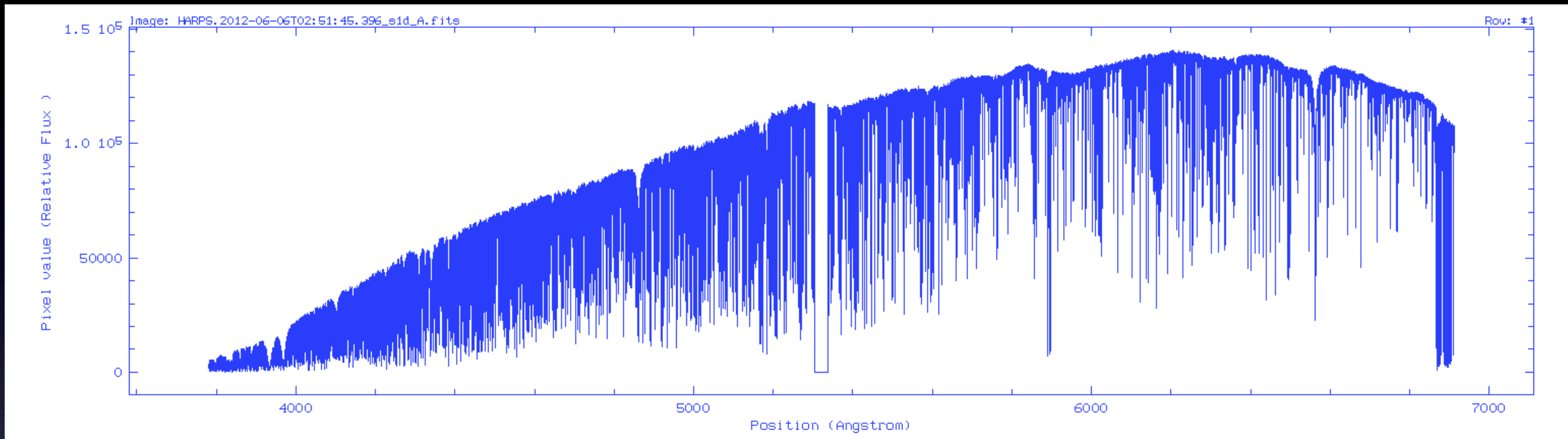
The Moon was ~ 8 degrees ahead the Earth

- ➡ Venus reached the Sun-Moon alignment with a delay of ~ 2 hours. First contact at 23h:46m UT
- ➡ The Transit was of ~ 8h, i.e. longer than from Earth (Moon was above the Earth-Sun rotation plane).

SDO image

in principle one can use the Halley's method to compute the AU.....

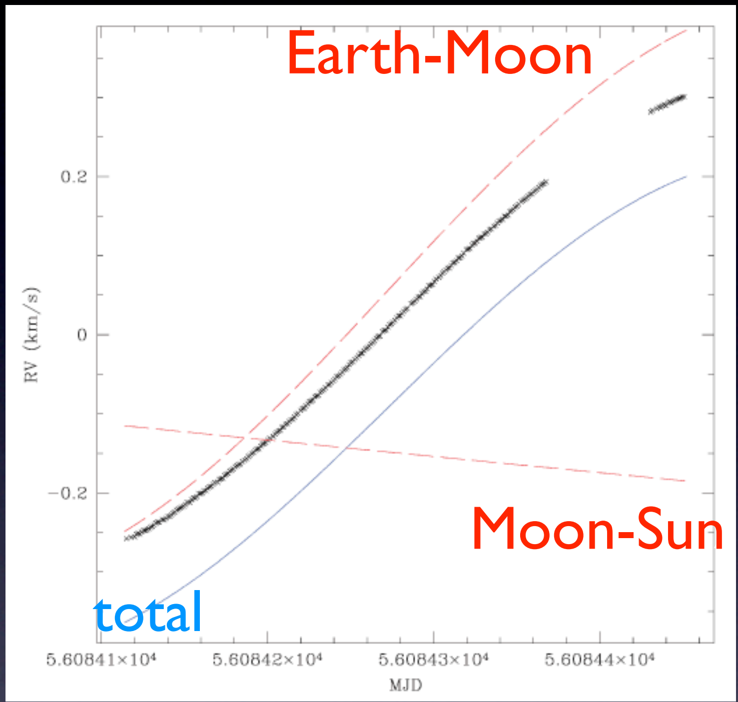
Observations

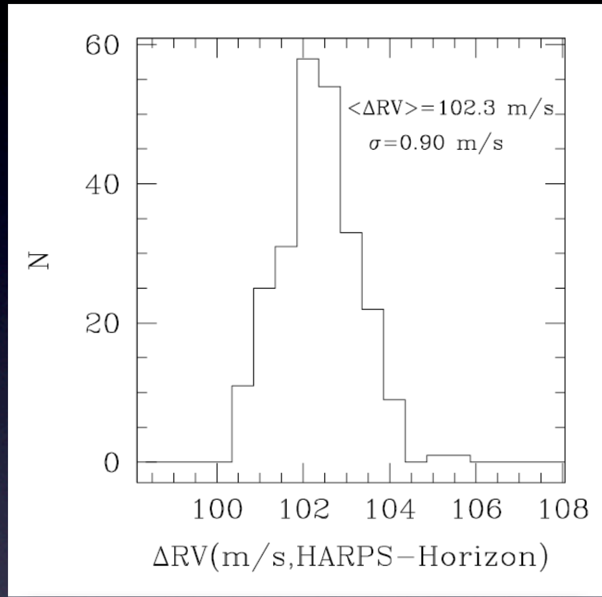


- DDT proposal on May the 14th *Observing the Rossiter-Mclaughlin effect in the Sun due to Venus Transit* got 6 hours of HARPS (+ twilight)
- Observations started when the Moon was at > 30 deg over horizon (~ half Transit)
- 245 "moon" observations of exposure times of 1 minute + 22 s overheads
- S/N ~ 400 @ 550nm, R~ 115000
- RV HARPS pipeline: X-Corr with a G2V mask (Kurucz solar spectrum)

motion corrections

Observed uncorrected RV



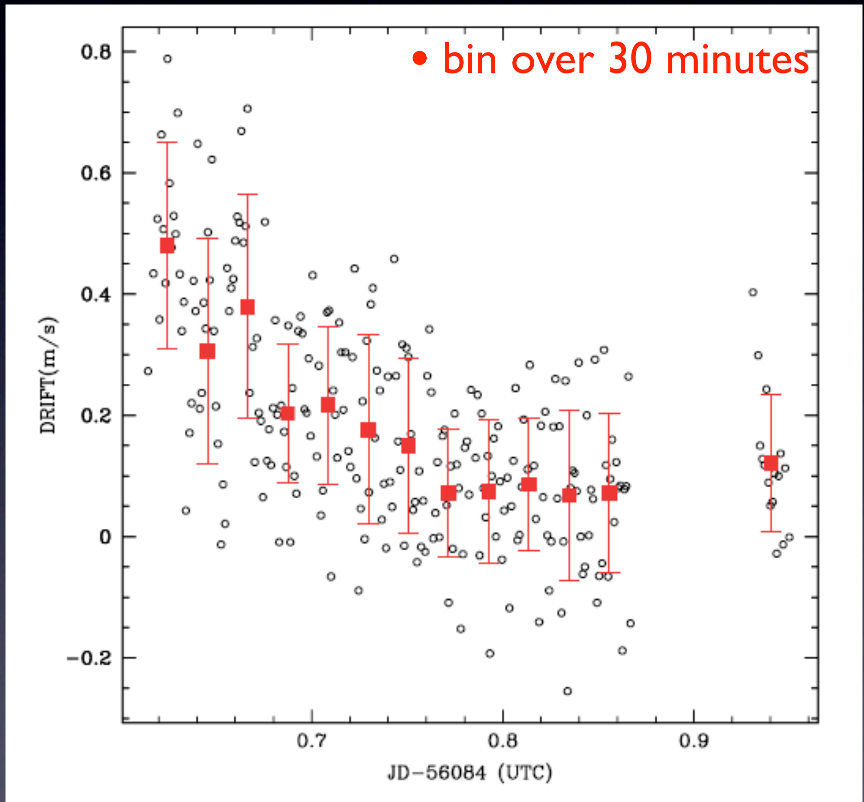


Offset= 102.3 ± 0.9 m s^{-1}

- Offset origin: HARPS mask for the sun i.e. Kurucz spectrum + temporal effects (Solar activity on June the 6th)

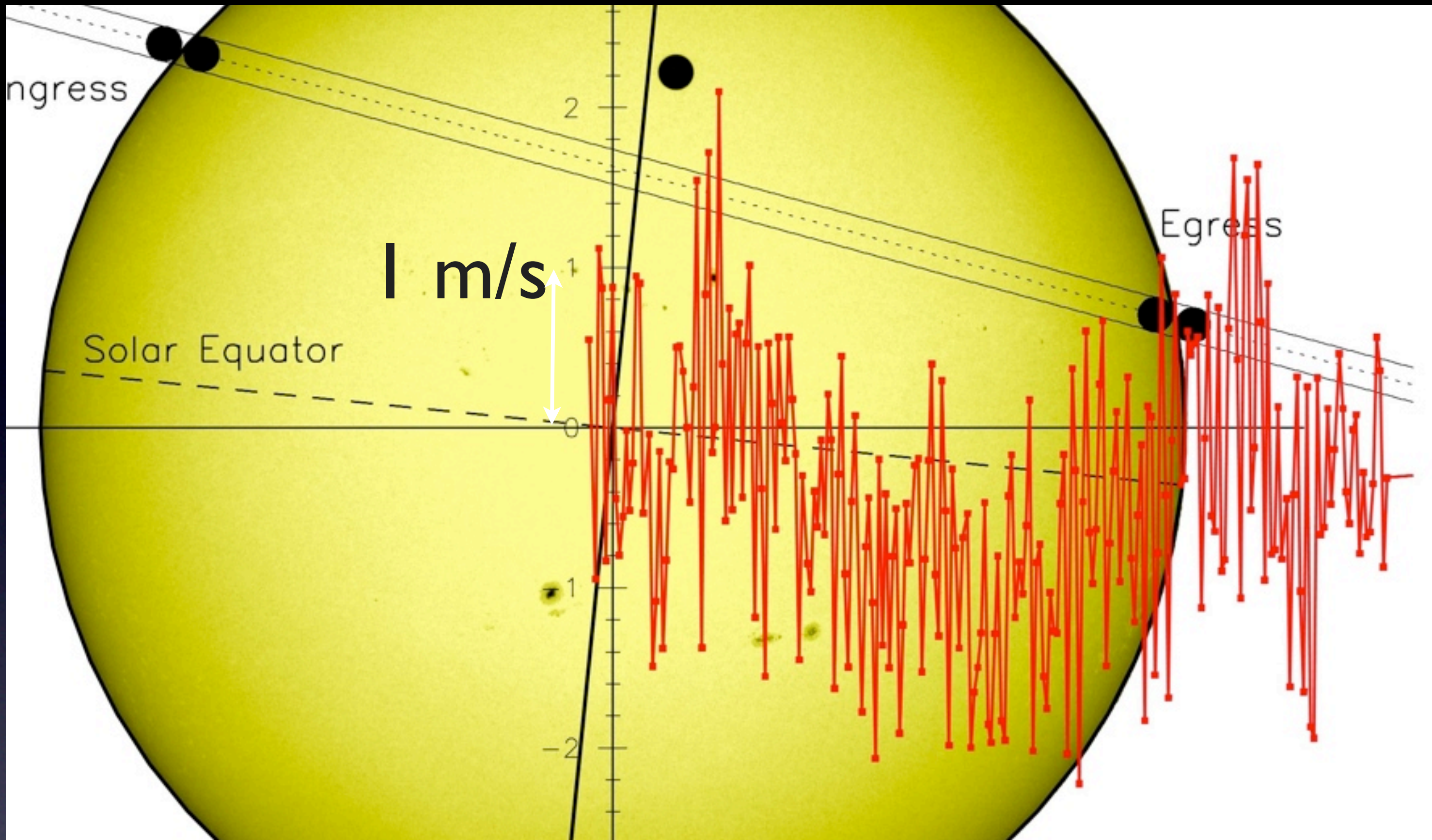
- Normalization with mean RV after Transit (60 datapoints): 102.53 ± 0.1 m s^{-1}

INSTRUMENTAL DRIFT



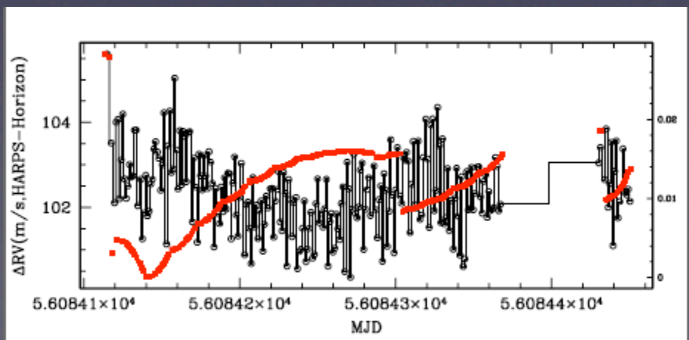
- HARPS fiber-B simultaneous ThAr to measure instrumental drifts along the night
- Drift of ~ 40 cm s^{-1} at the beginning of the night
- Not critical!!

Vr



Time

RME?



moon rotation 30 cm/s arcmin

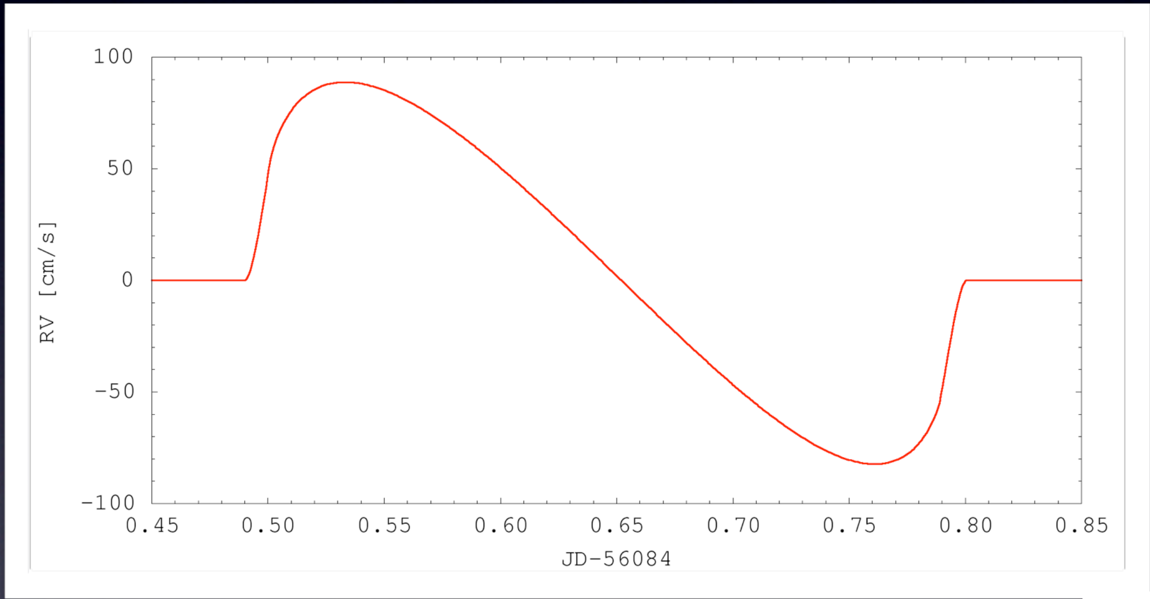
The model

Gimenez 2007

$$\delta V = \frac{\int_S V' J \cos\gamma \, d\sigma}{\int_S J \cos\gamma \, d\sigma}$$

$$\delta V = \frac{V^*}{\delta} \frac{\sum_{n=0}^{N} C_n \alpha_n^1}{1 - \sum_{n=0}^{N} C_n \alpha_n^0},$$

$$\alpha_n^1(b,c) = \frac{cb^2(1-b)\Gamma(\nu)(1-c^2)^{\nu+1}}{\Gamma(\nu+2)\Gamma(\nu+2)} \sum_{j=0}^{\infty} (-1)^j (2j+\nu+3) \times \frac{\Gamma(\nu+j+3)}{\Gamma(j+1)} \left[G_j(\nu+3,\nu+2;1-b)\right]^2 \times G_j(\nu+3,2;c^2) \quad (11)$$



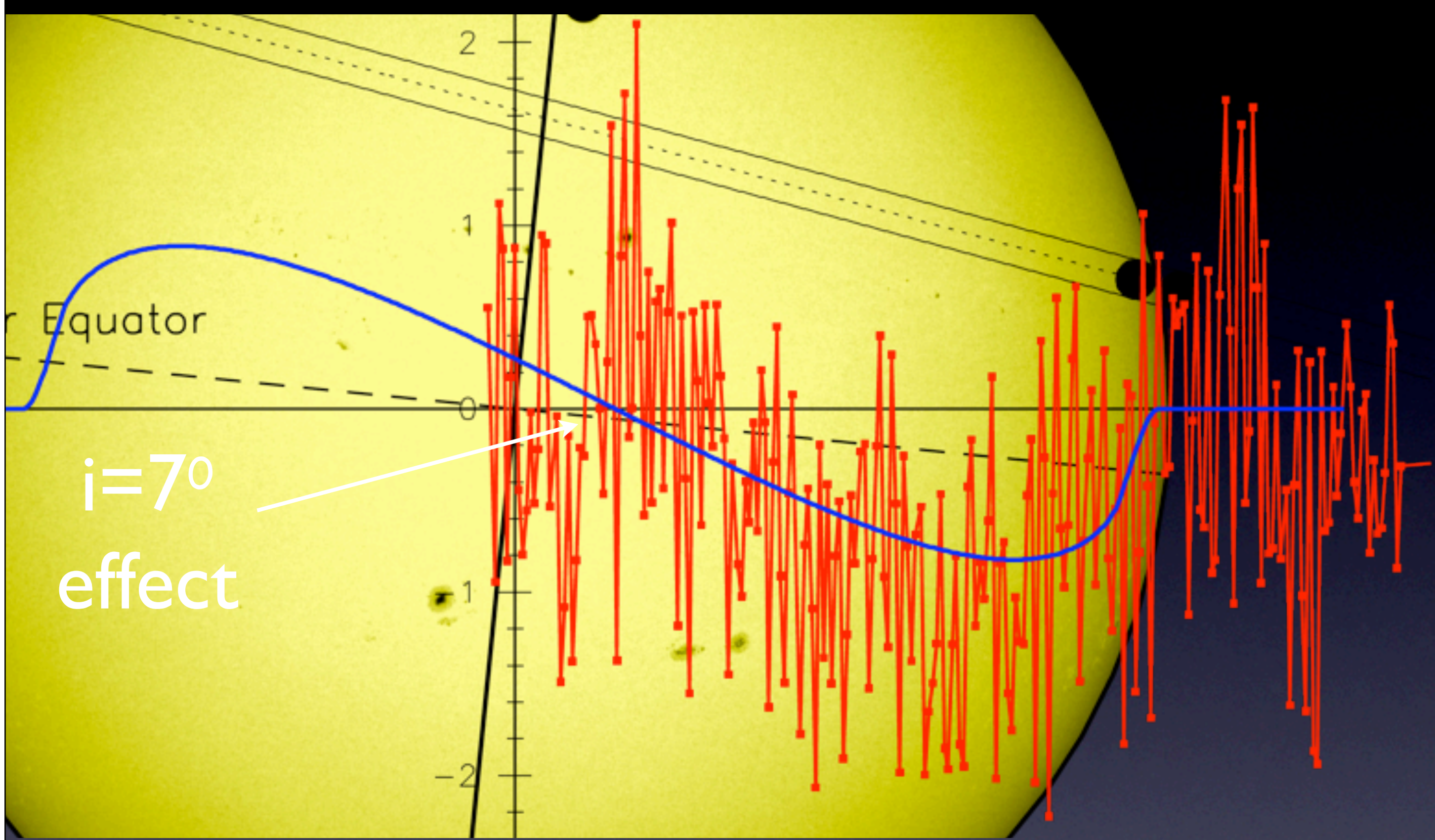
$$J(\mu) = J(1)\left[1 - \sum_{n=1}^{N} u_n (1-\mu^n)\right]$$

- Solar differential rotation

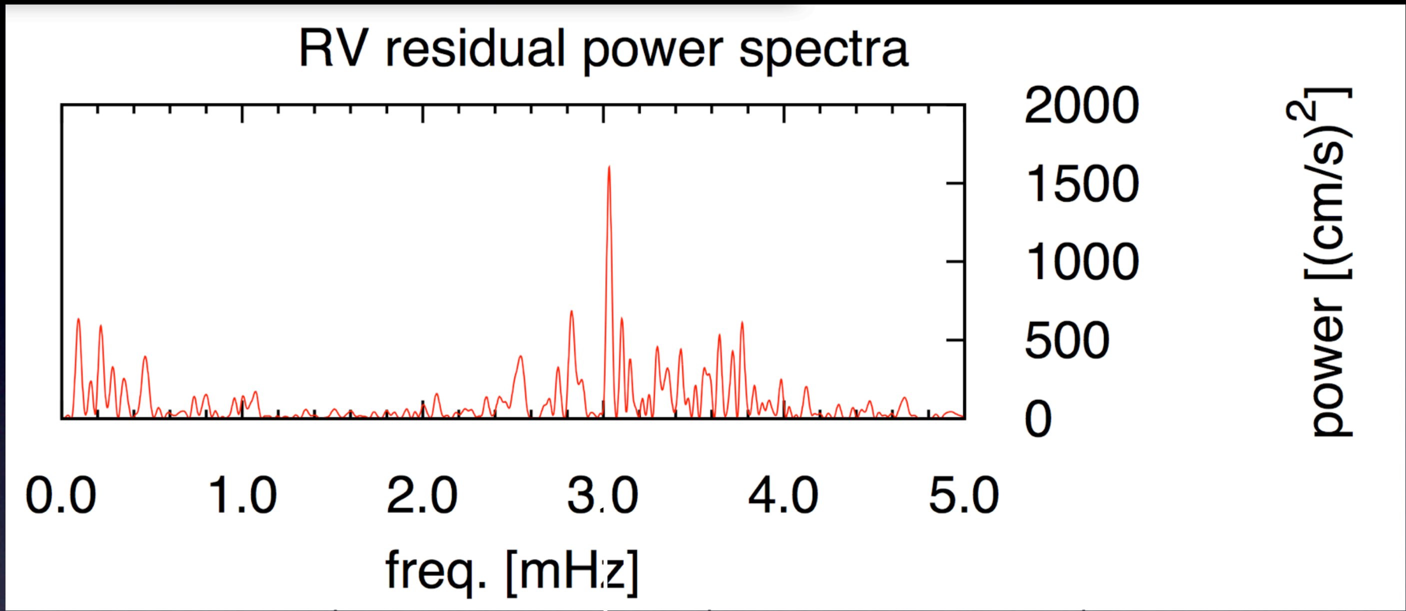
- Limb darkening, coefficients: Ua=0.5524, Ub=0.3637 (Claret 2004)

- Solar inclination: ~ 7.25 deg, pointing direction RA= 286.13, DEC =63.87, on 6th June at ~ 90 deg with the l.o.s

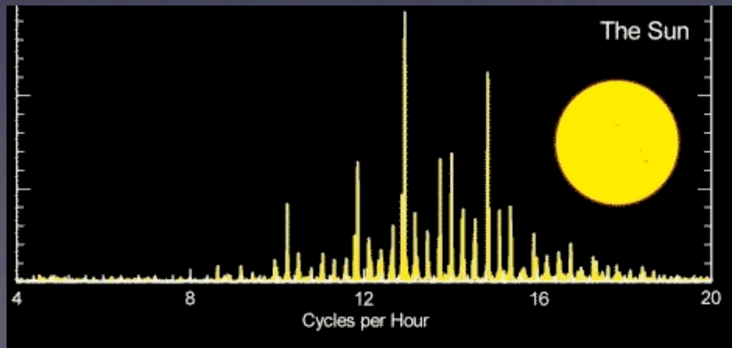
NOT a Fit!



- r.m.s =0.68 cm s^{-1} (with solar oscillation)
- <ΔVr> = -1.7 cm s^{-1}
- the RM effect due to ~ Earth-size planets could be detected against "stellar Jitter"

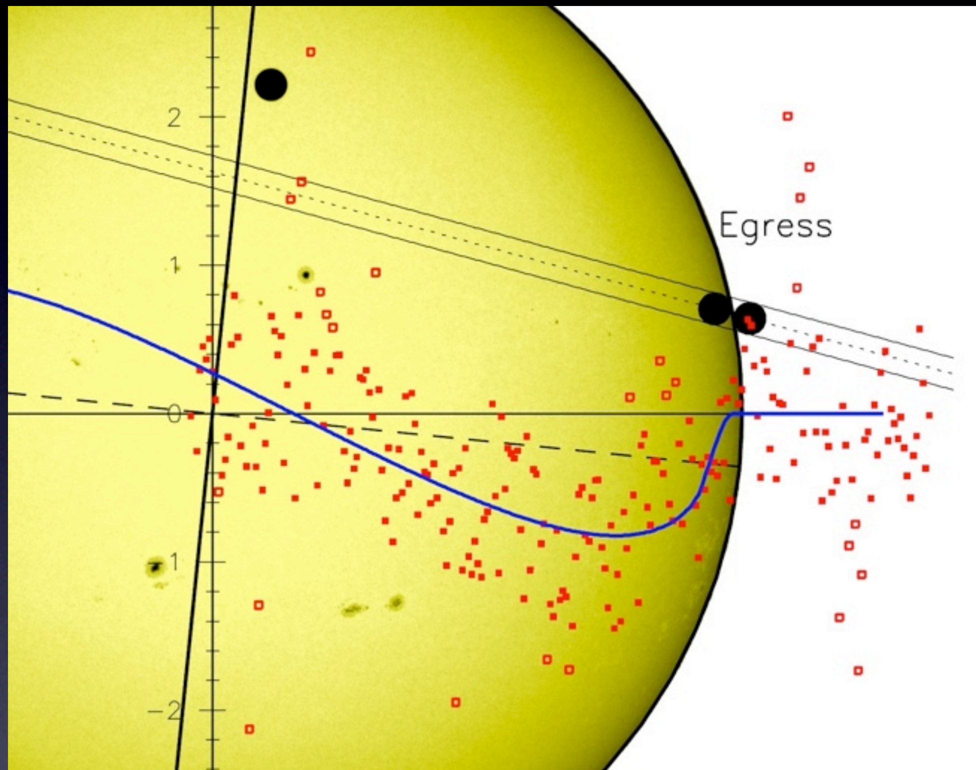


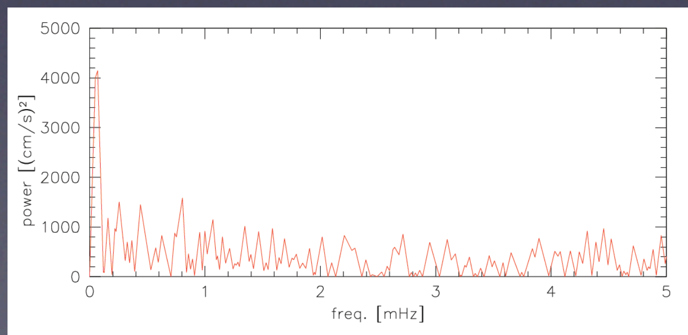
3.03227 mHz ~ 5m 30s p-modes solar oscillation



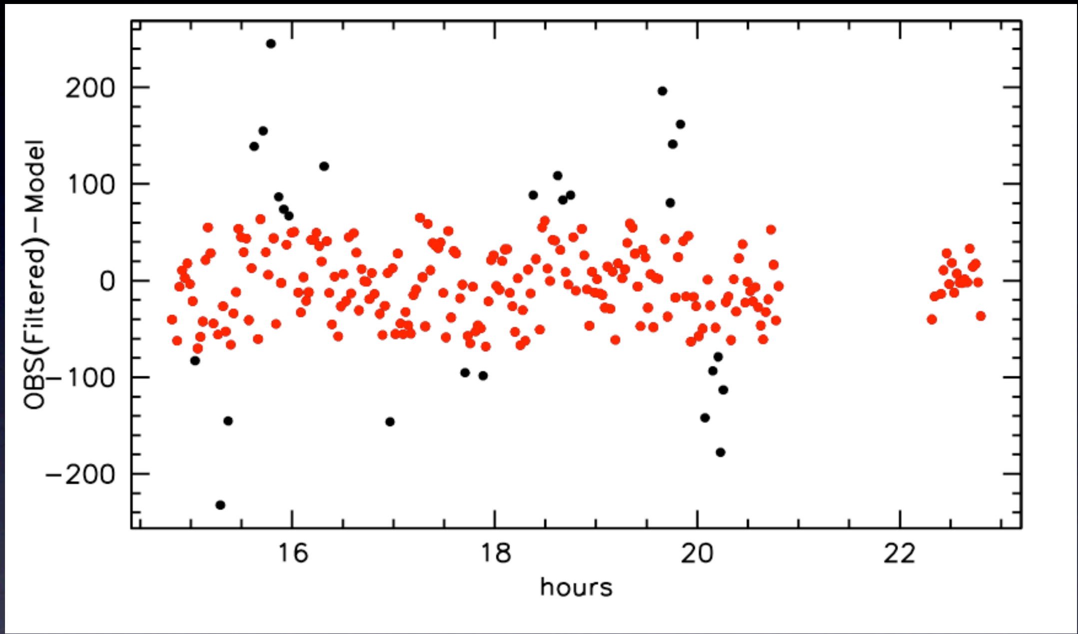
amplitude: 0.41 m/s

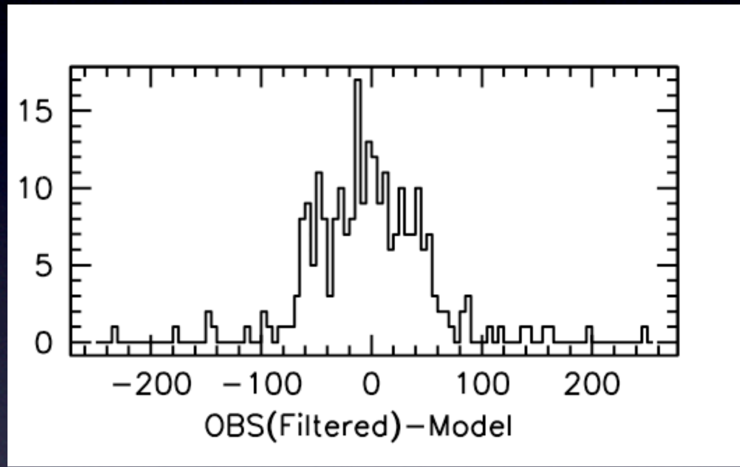
filtering of solar oscillation known frequencies





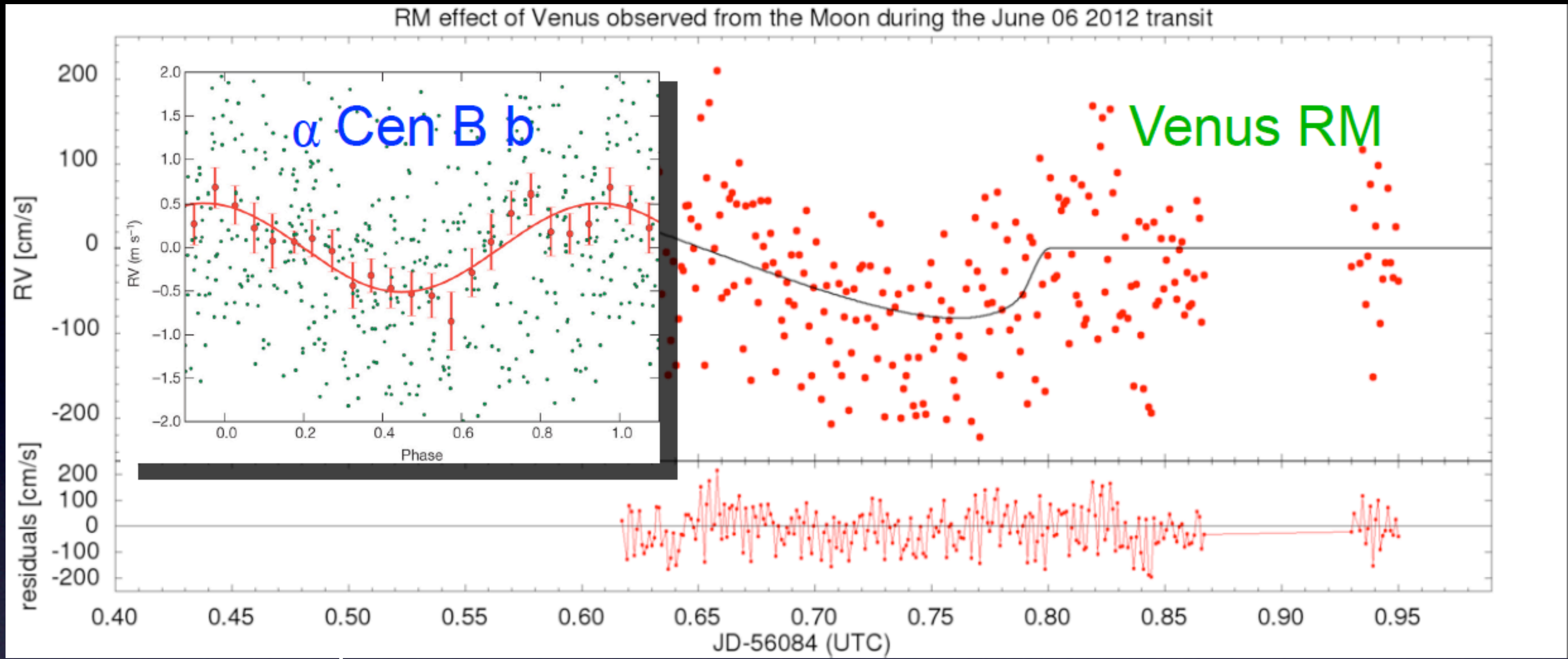
residuals (Observations - RME model)





all data r.m.s = 55 cm s^{-1} <ΔVr>= -2 cm/s

2 sigma outlayers r.m.s = 35 cm s^{-1} <ΔVr>= -4 cm/s



Dumusque et al Nature 2012

459 observations 2008-2011 (3 obs/night) rms =1.2 m/s , 0.2 binned

6 hours 245 observations

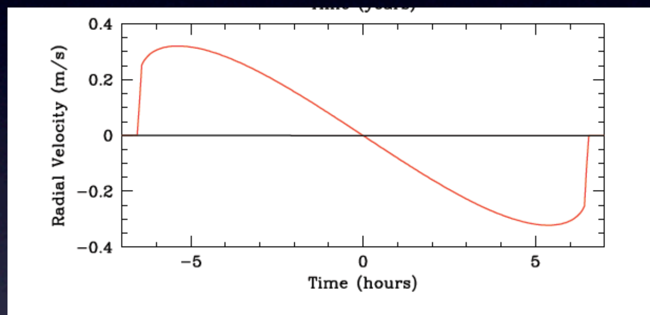
Rossiter versus Orbital

$$\frac{K_R}{K_O} \sim 0.3 \left(\frac{M}{M_{\rm Jup}}\right)^{-1/3} \left(\frac{P}{3\ {\rm days}}\right)^{1/3} \left(\frac{v \sin i}{5\ {\rm km\ s^{-1}}}\right).$$

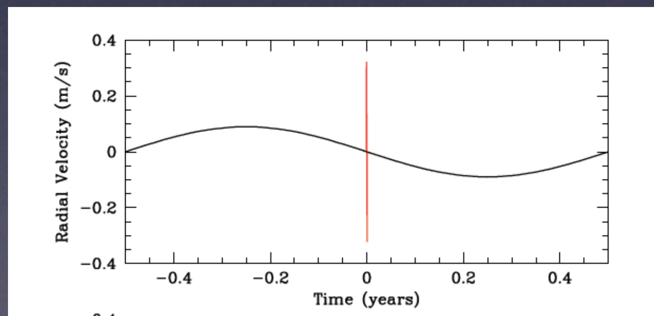
vinn

for an Earth

star Vsini=5 km/s

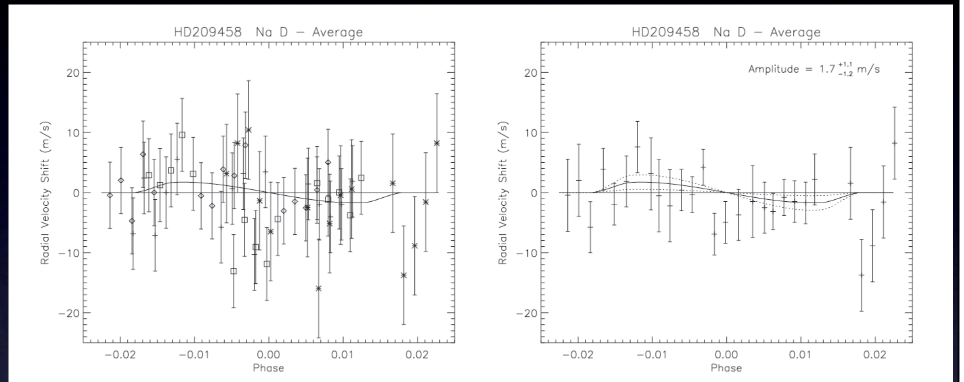


Kr/Ko ~ 3 and



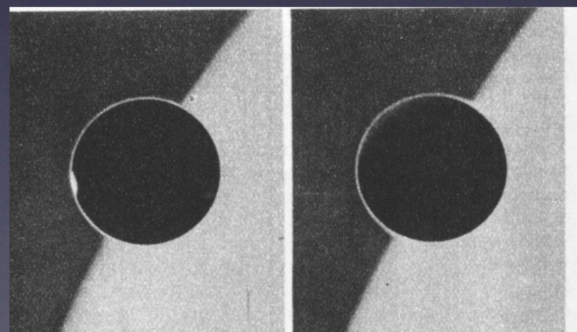
RME & atmospheres

- Planet atmospheres: the amplitude of RM is proportional to the effective size of the planet
  - found larger in NaI D in HD 209485 (Snellen 2004)
  - WASP-17b (Wood et al 2011)
- Stellar chromosphere: larger in CaII H&K in CoRoT-2b (Czesla et al 2012)



but no NaI is expected in Venus's atmosphere !

Mikhail Lomonosov, June 5, 1761 suggests that Venus has an atmosphere

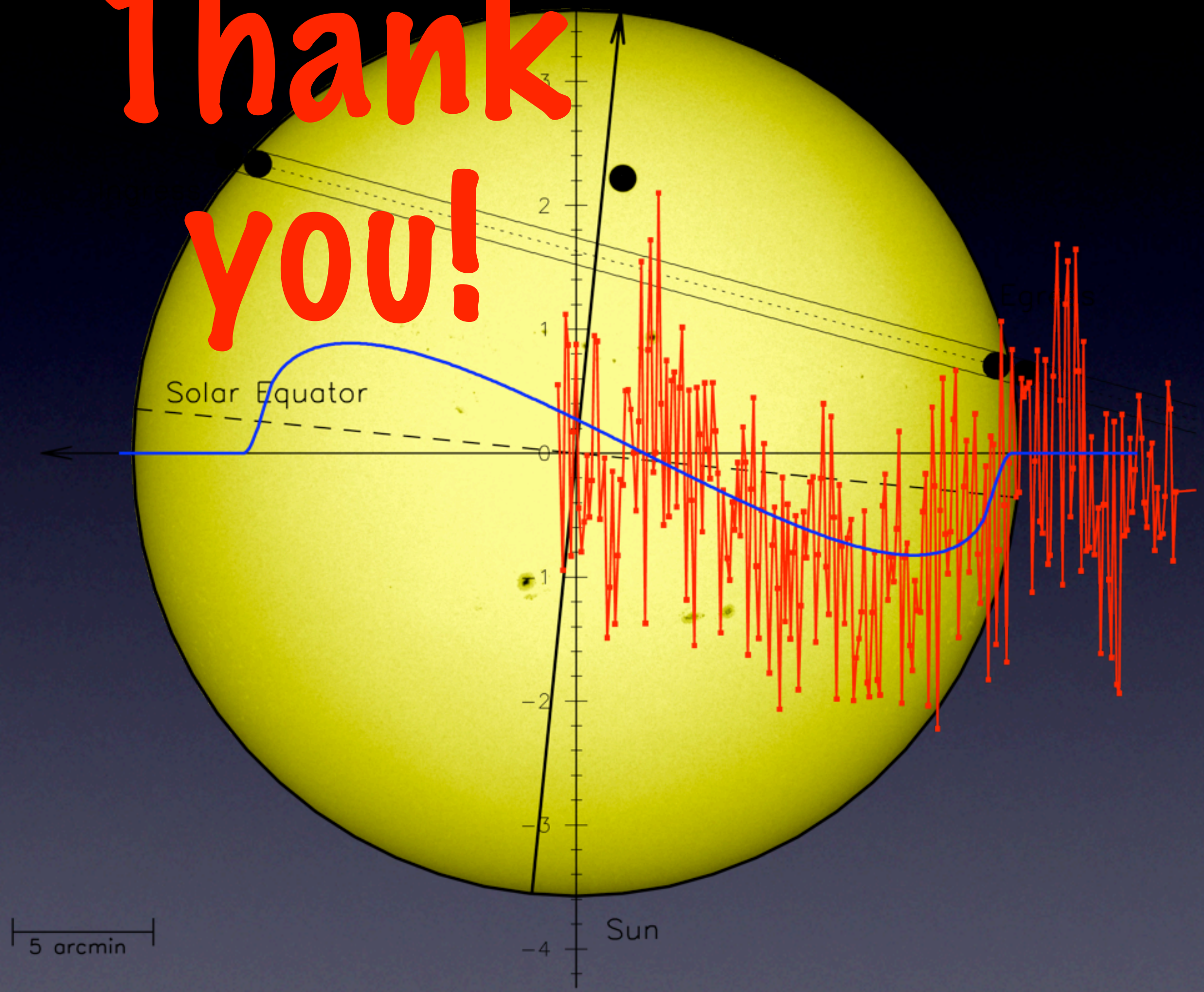


Vidal-Madjar et al project to observe the Venus Transit with the HST to characterize the Venus atmosphere

Summary

- Detection of RME in the Venus Transit 2012 shows that the RM effect due to Earth-size planets could be detected against "stellar Jitter"
- RME provides a cheap way to confirm photometric Transits
- RME provides fundamental observables for exoplanetary systems (not only the degree of alignement but others depending on the precision of observations)
- RME is likely to grow of importance in the future possibly also for transmission spectroscopy
- Mercury Transit 2016 May 9 but UT start 11:12 end 18:42. entire transit in S. America, western Europe...

Thank you!



Good bye to 2117