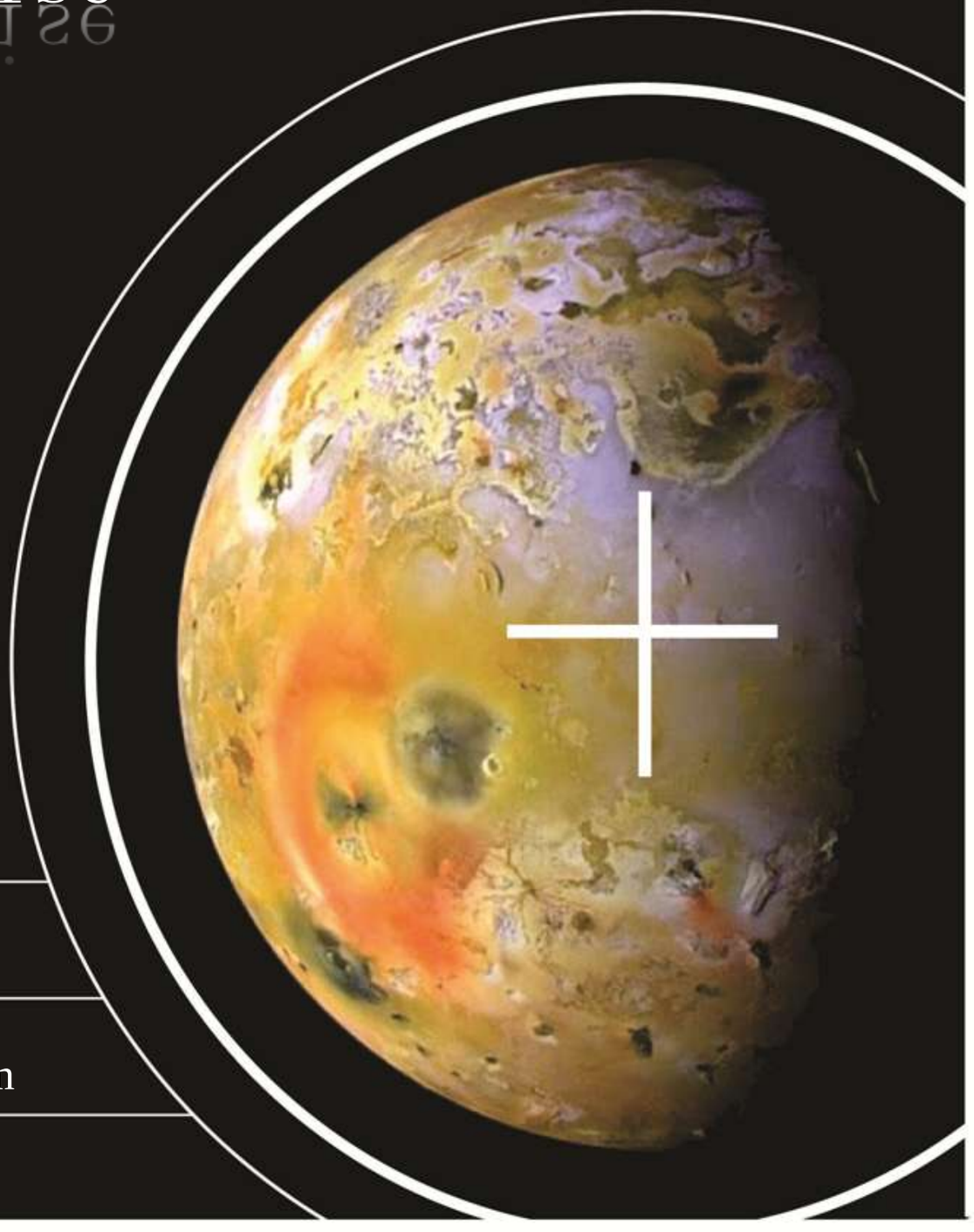
Radial Velocity Stellar Noise and Impact for the Detection of Exo-Earths



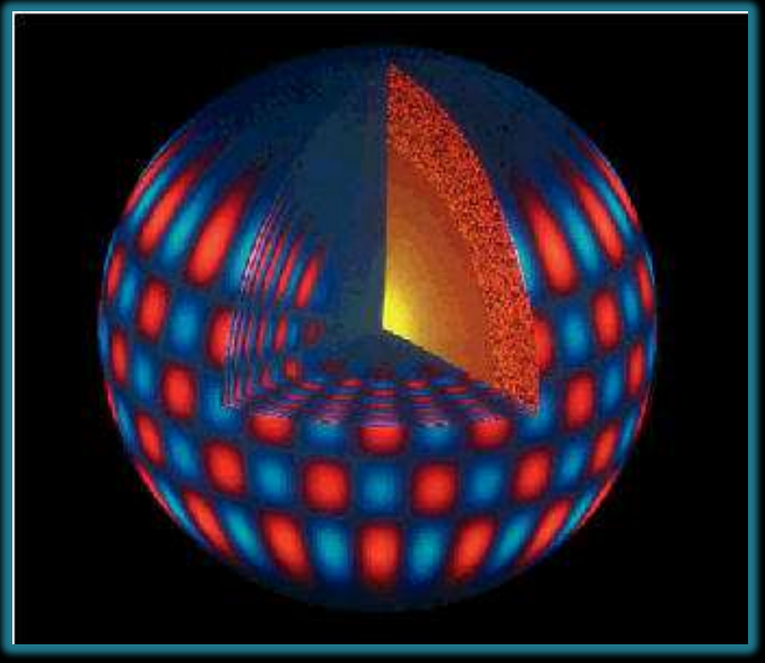
Stephane Udry, Nuno Santos, Christophe Lovis & Geneva planet team

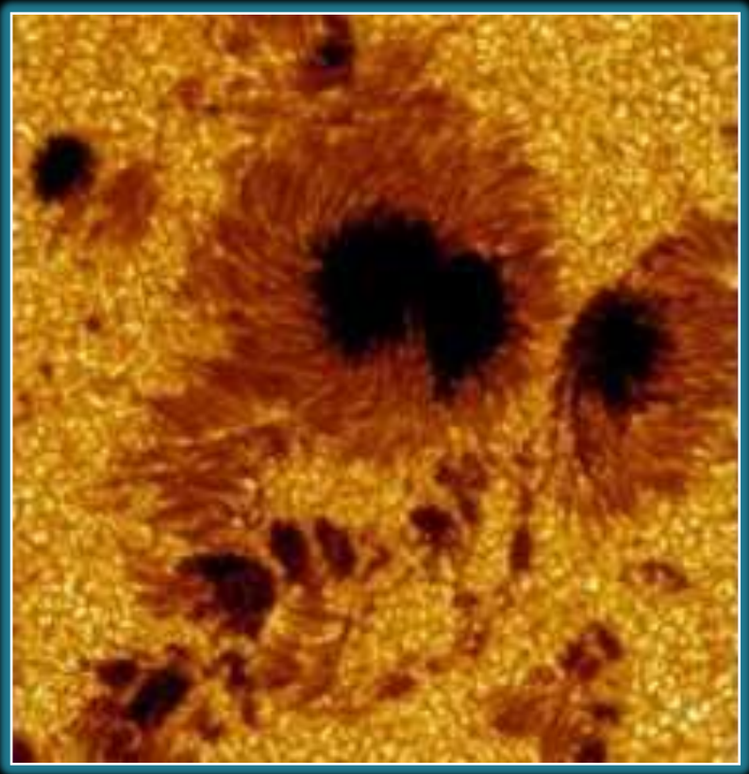
UNIVERSITÉ DE GENÈVE

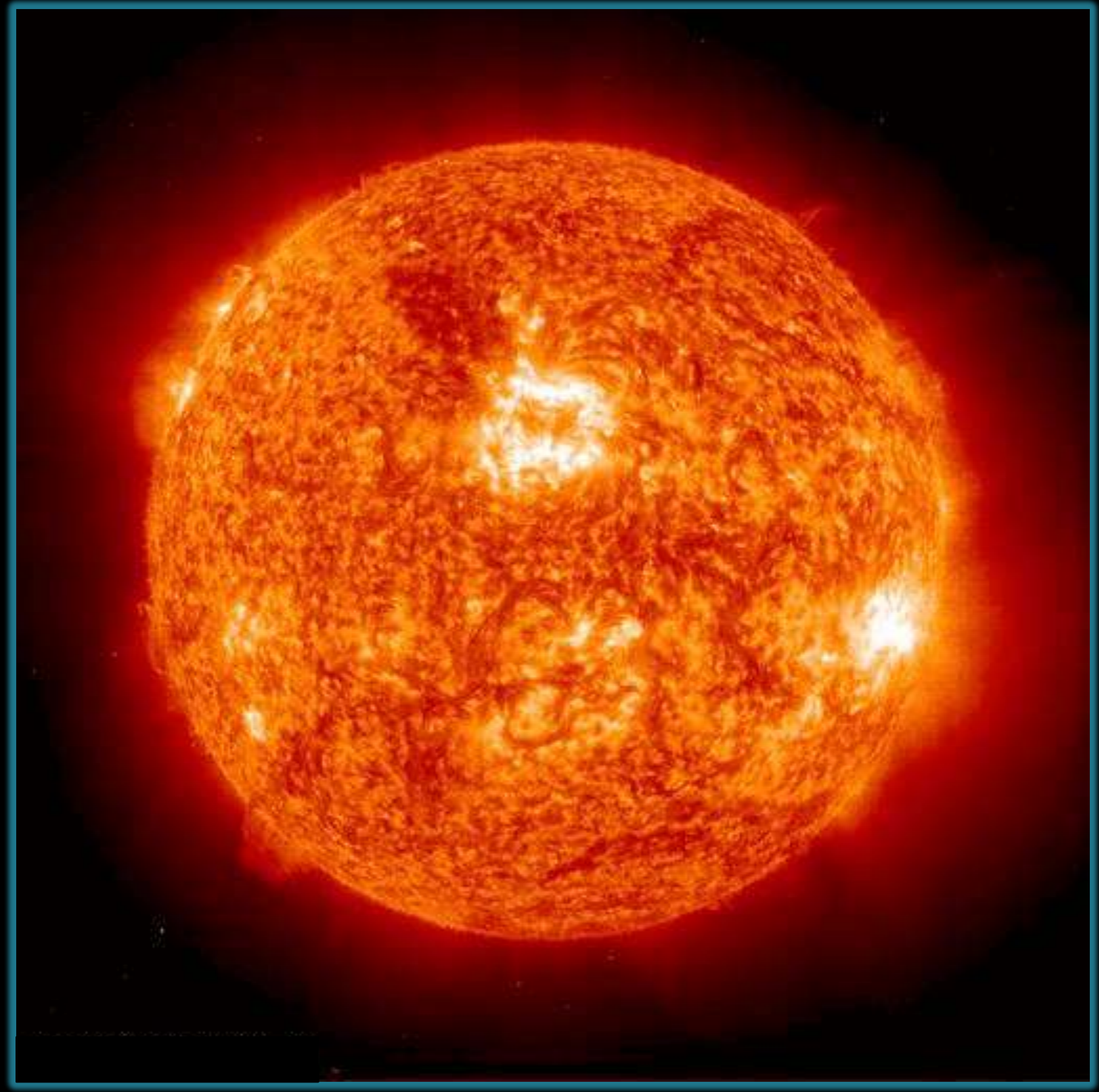
X. Dumusque

Centro de Astrofísica da Universidade do Porto

Stellar intrinsic limitations







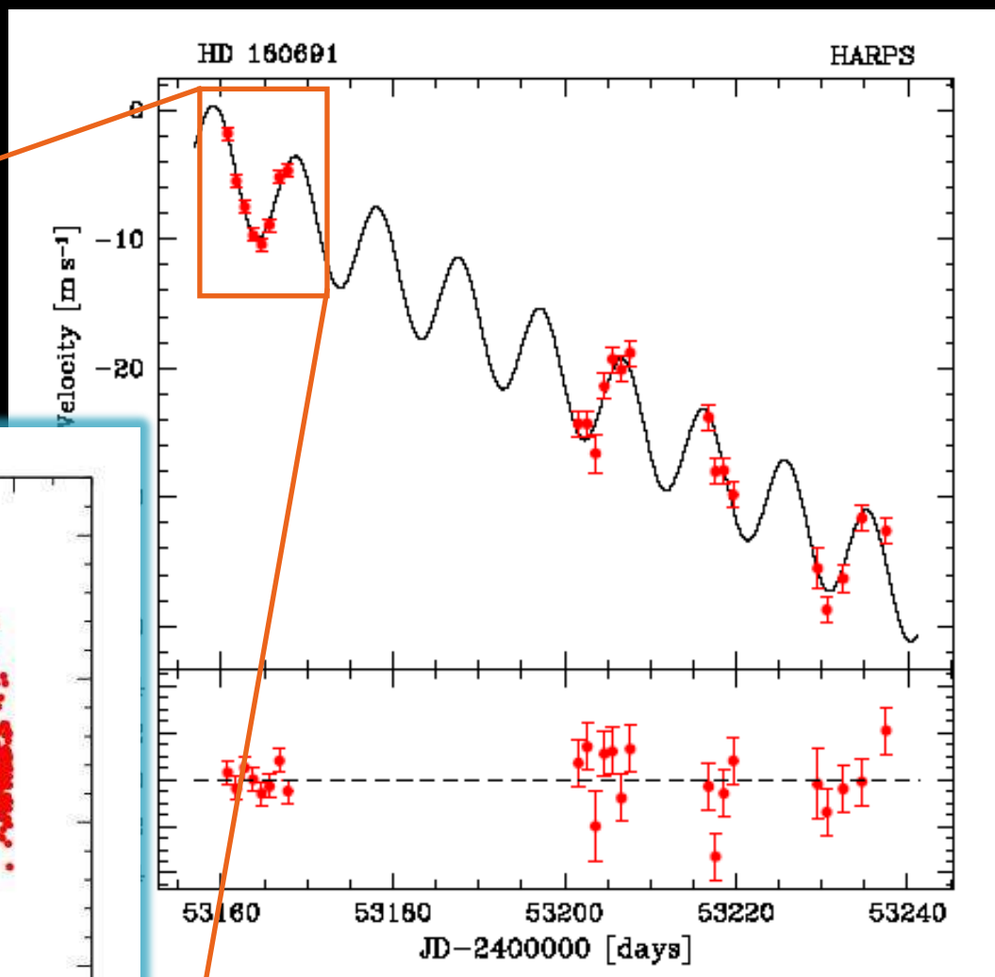
Stellar oscillation : The μ Ara example

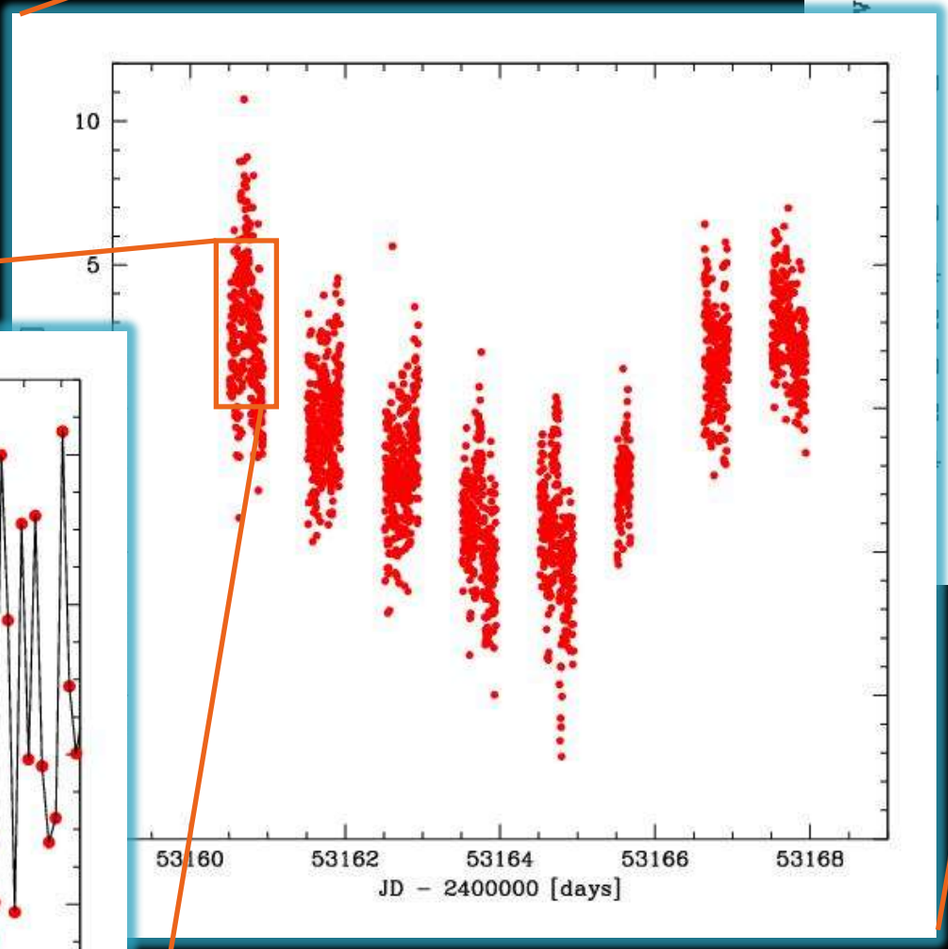
8 nights
250 measures/night
Photon noise < 20 cm/s

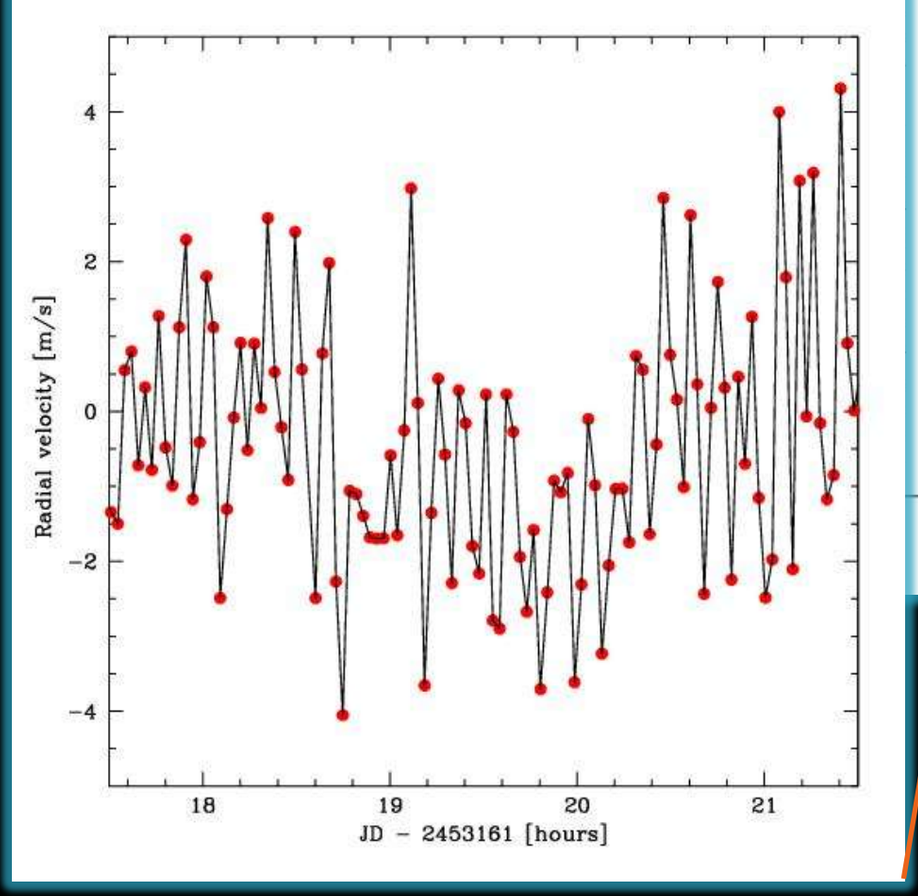
Santos et al. 2004

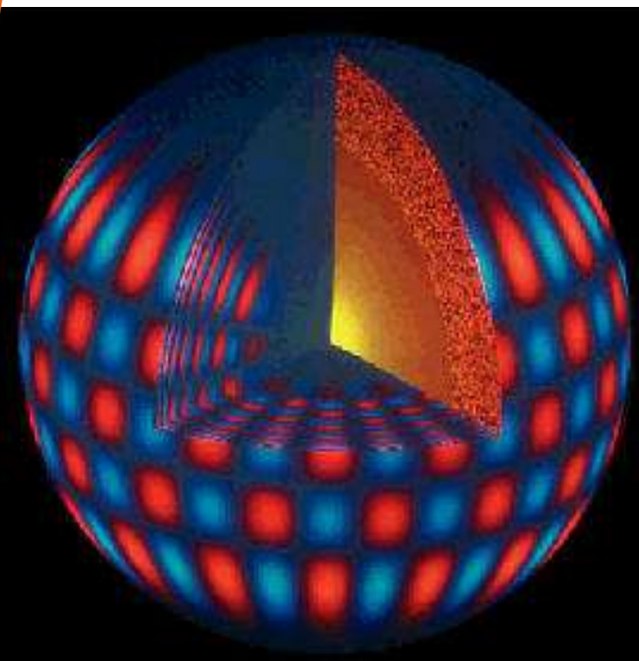
Bouchy et al. 2005

Bazot et al. 2005

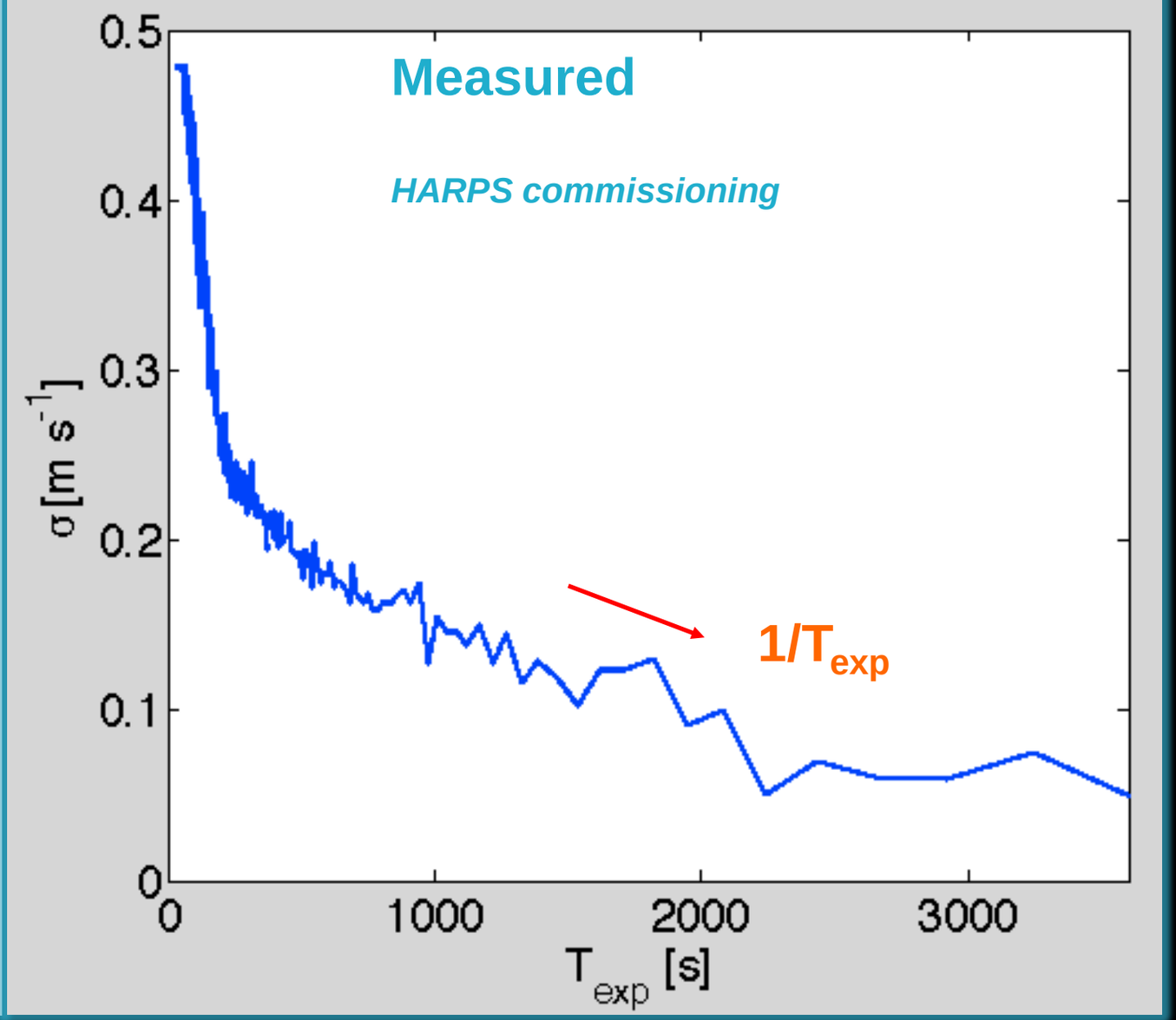






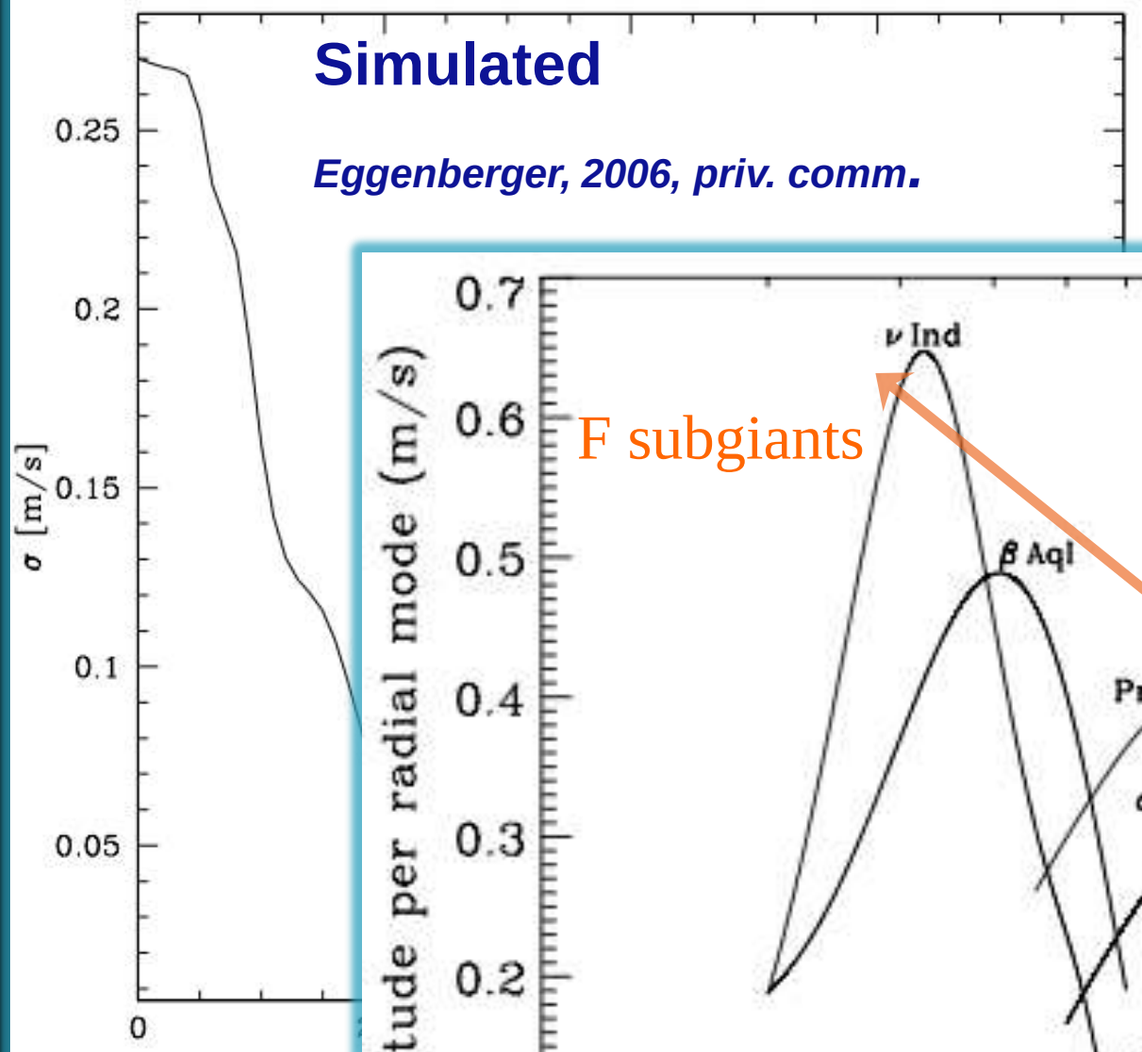


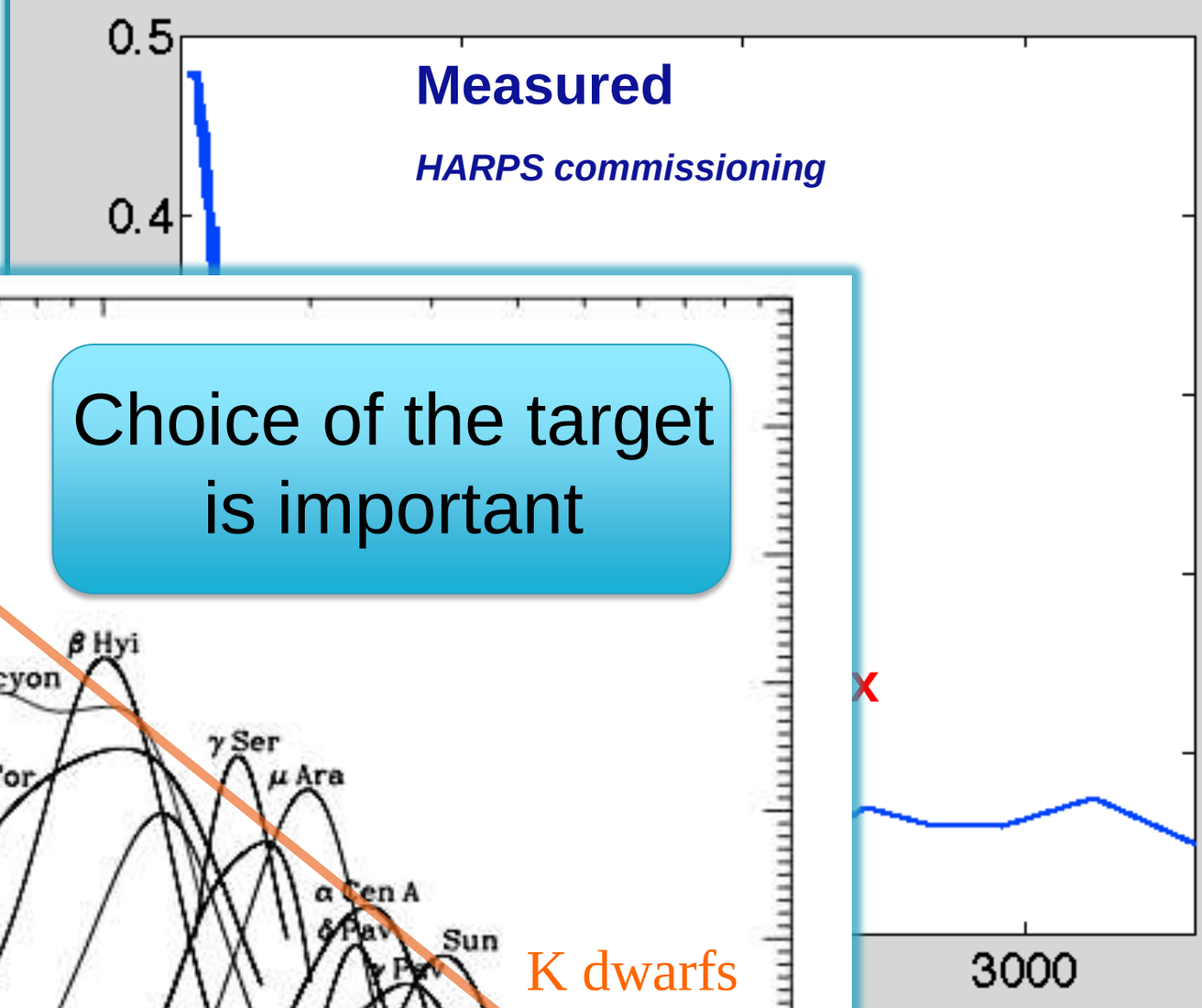
Stellar oscillations



- p-modes average well on time > ~1 characteristic timescale

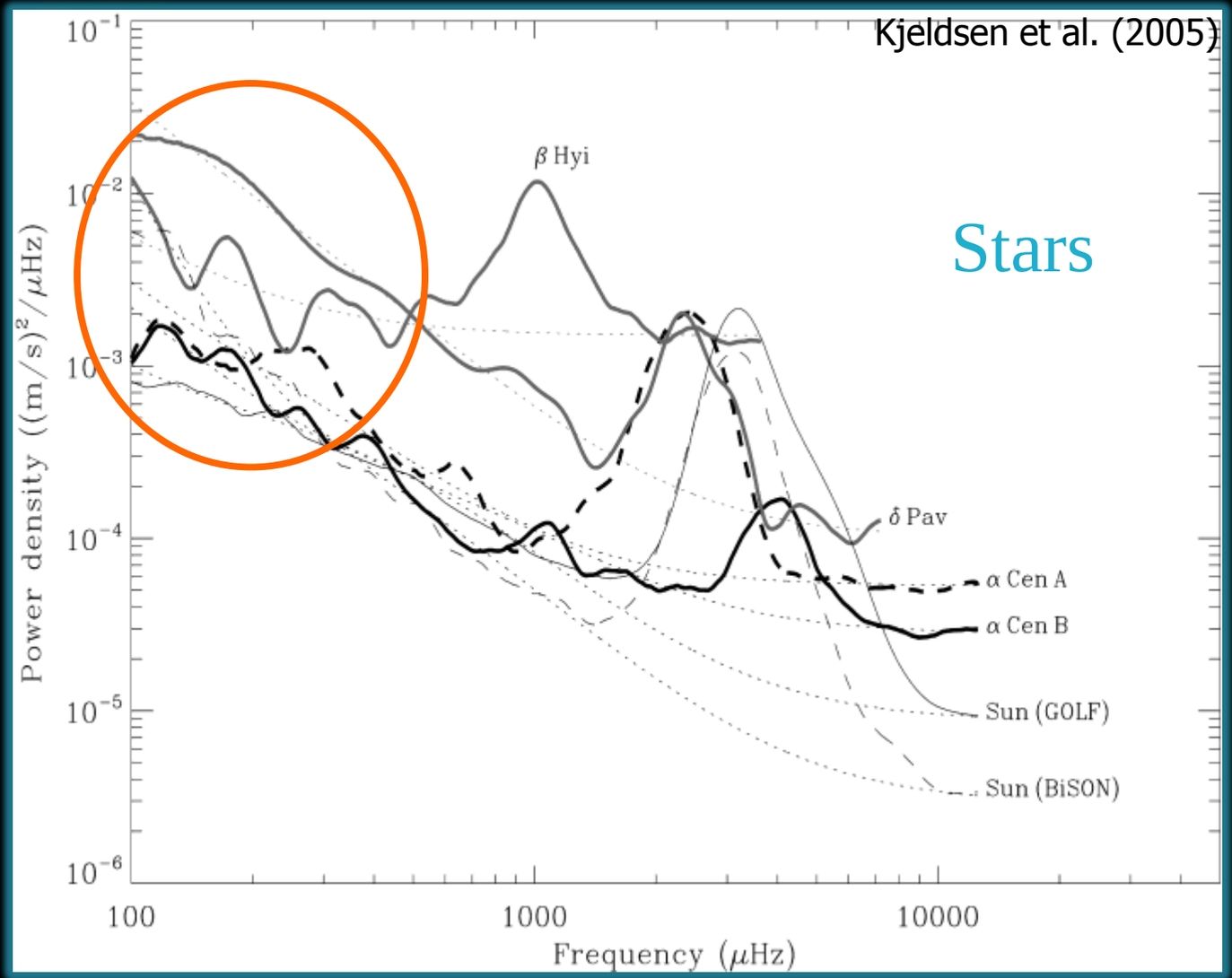
Stellar oscillations



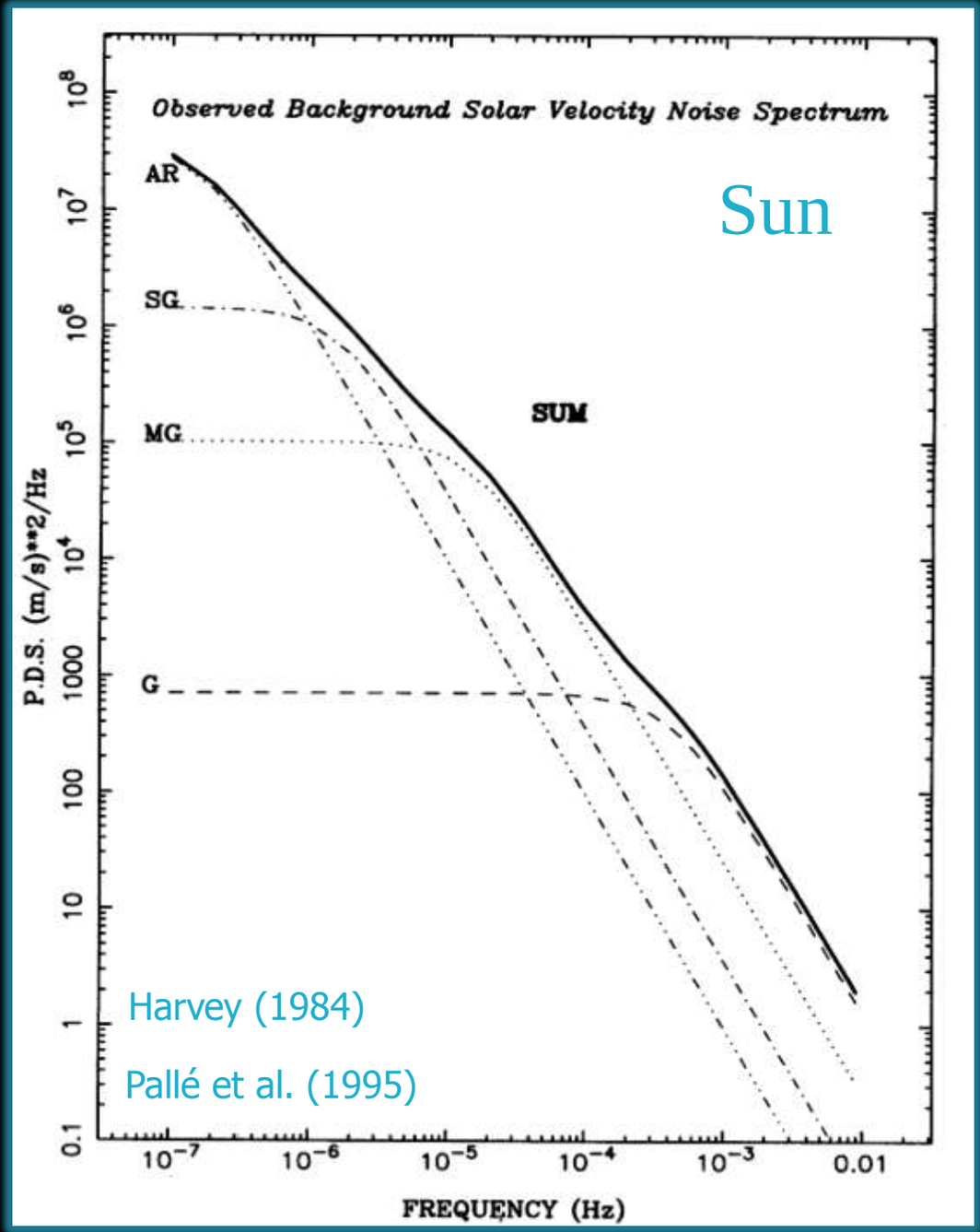


➢p- le

Granulation ?



- Granulation (| ~ 15 min)
- Mesogranulation (| ~ 3h)
- Supergranulation (| ~ 1 day)



- Other sources of noise at lower frequencies
- requires simulations

Simulations

- real asteroseismology observations
  -> noise model => synthetic observations

Observational strategy :
1 m/night 15 min
1 m/night 30 min
2 m/night, 2 x 15 min
3 m/night, 3 x 10 min

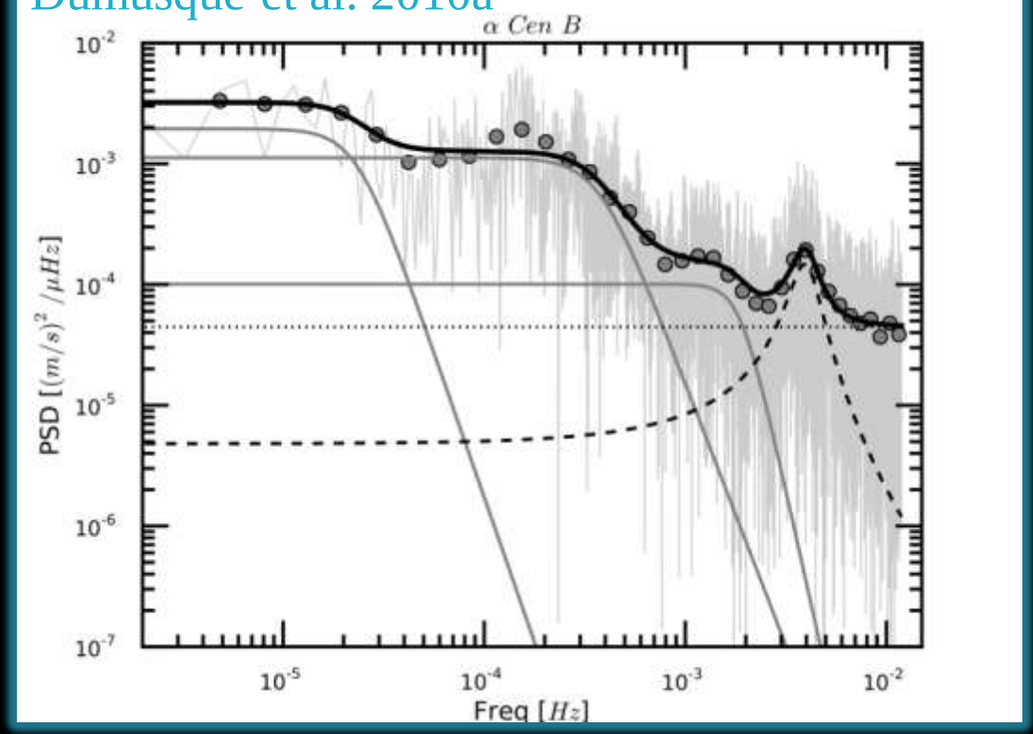
] Same T_{obs}

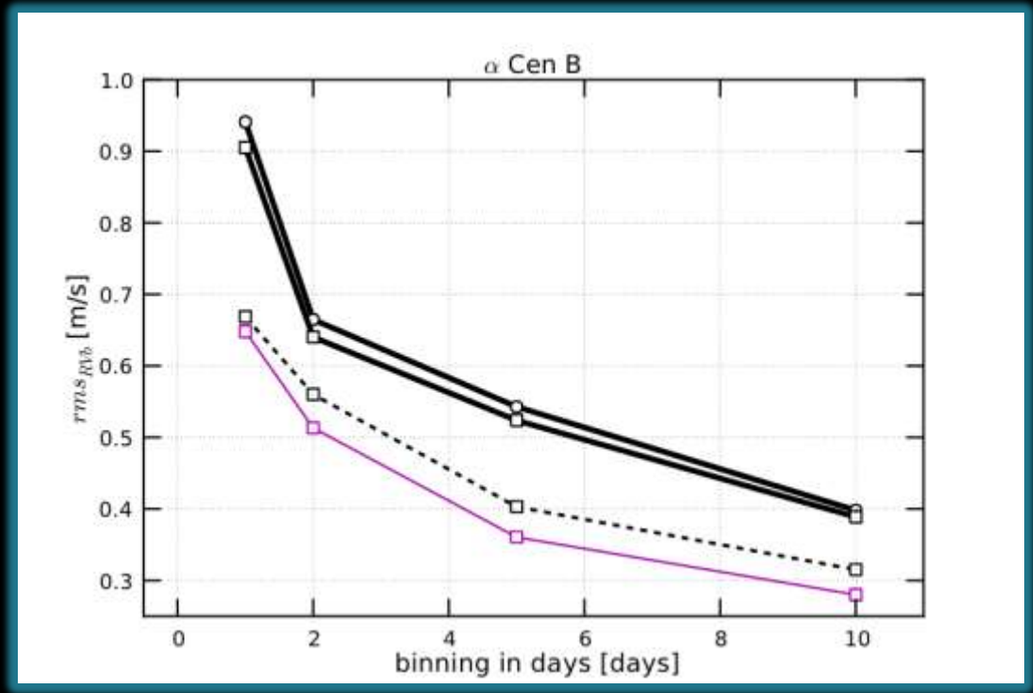
$$RV(t_i) = \sum_{\nu} \sqrt{\mathrm{VPSD}(\nu)}(\sin(2\pi\nu t_i + phase(\nu)))$$

RV rms

Beat the stellar limitations with
- good target selection
- clever observational strategy

Dumusque et al. 2010a





Simulations

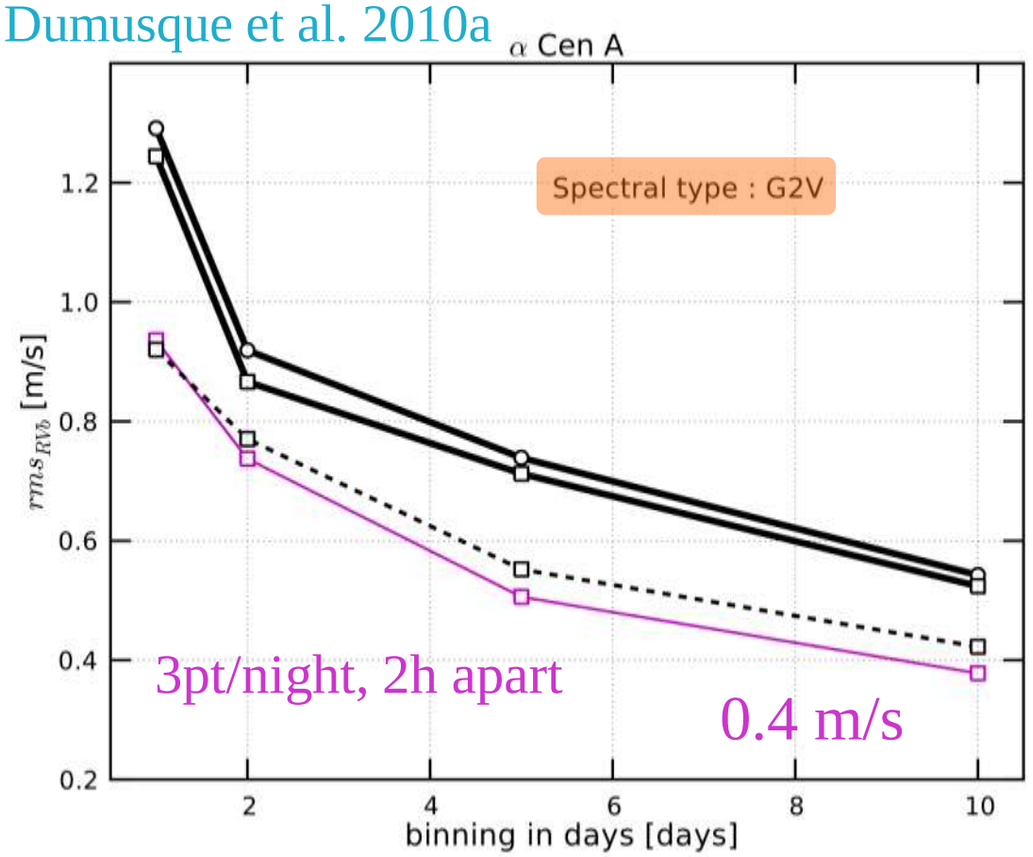
From p-modes+granulation point of view

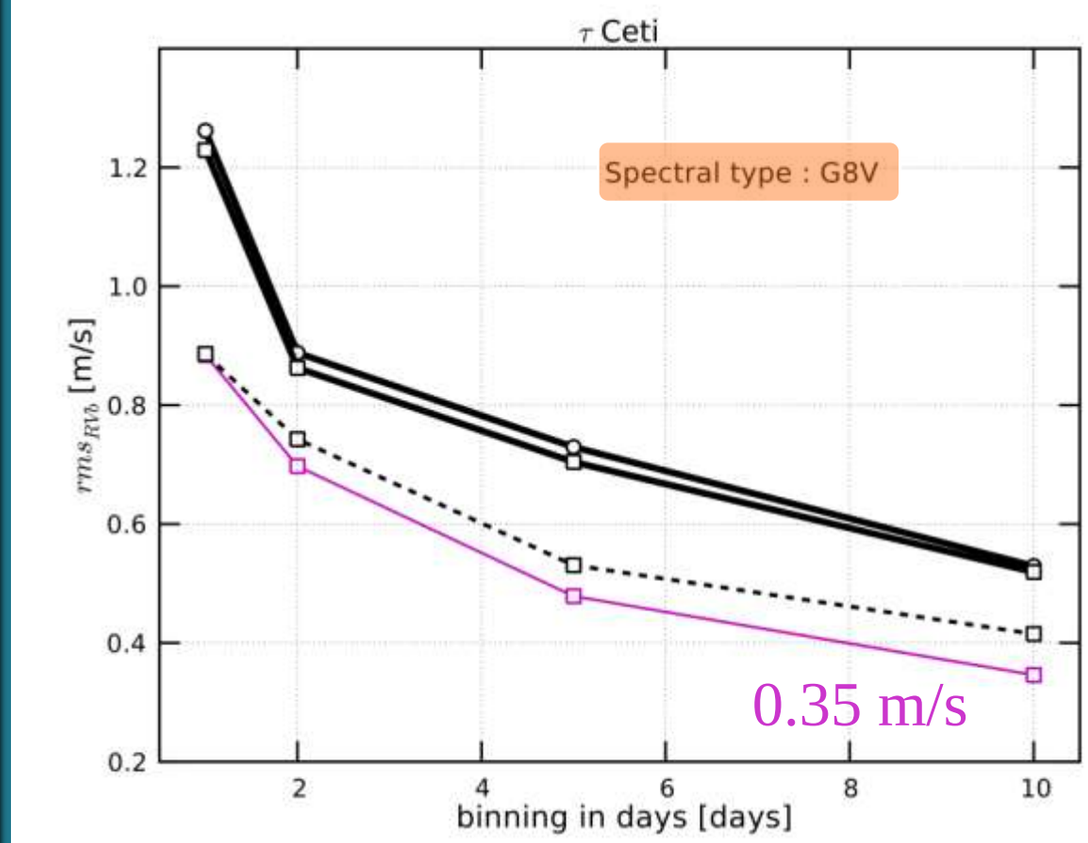
Detection capability depends on

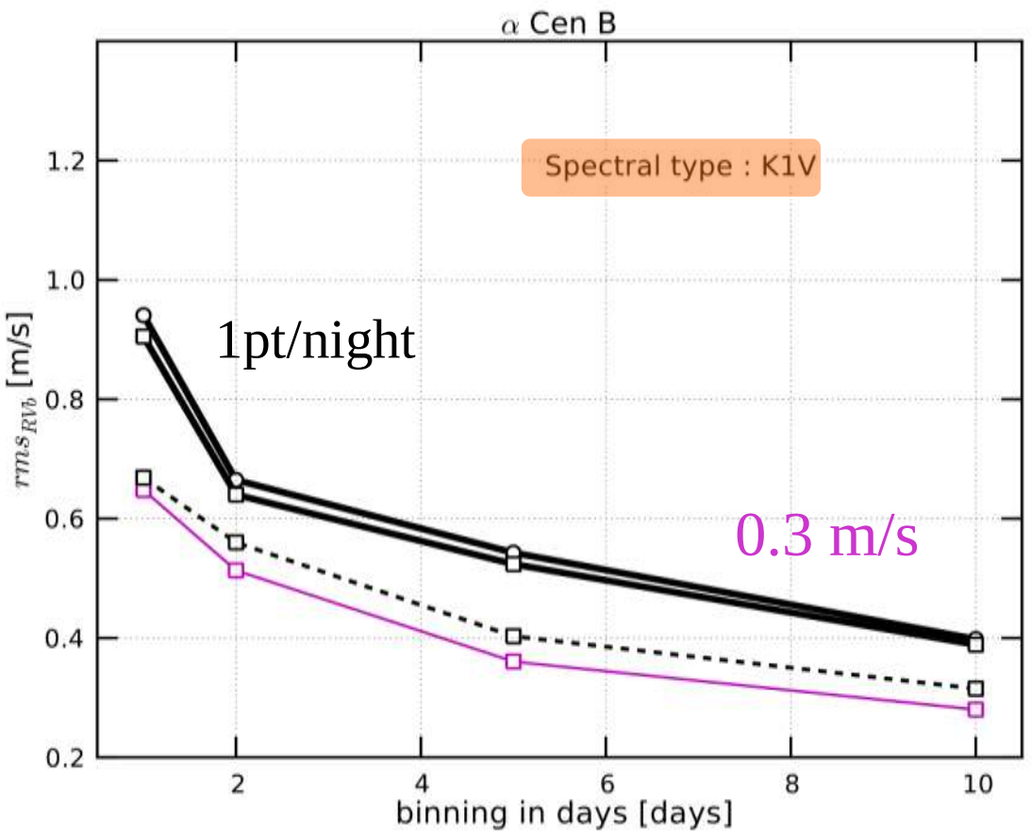
- spectral type
- luminosity class (evolution)

Choice of the target is important

Dumusque et al. 2010a



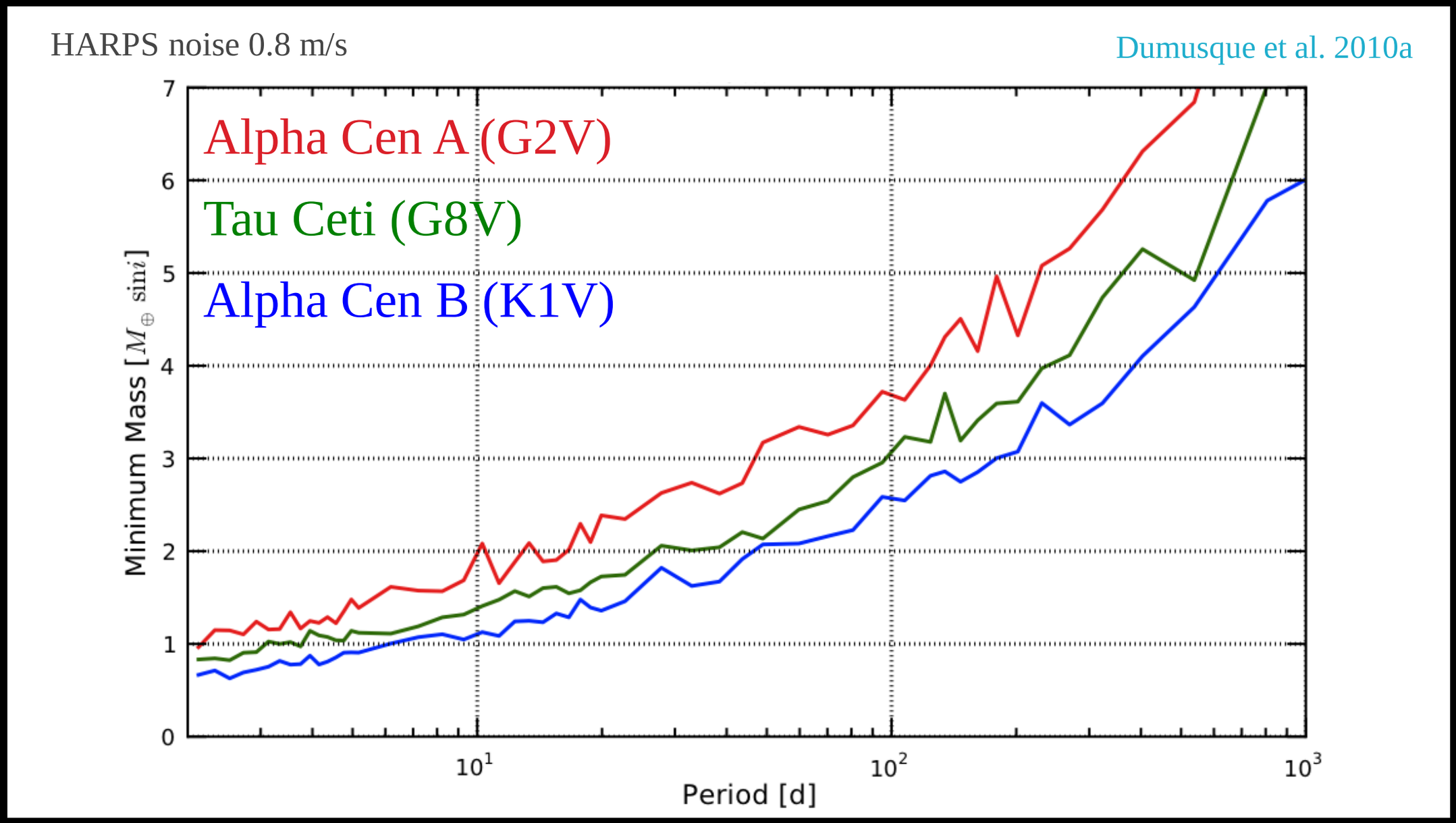




Detection limits (simulAtions)

Actual calender of HD69830 (3-Neptune system)

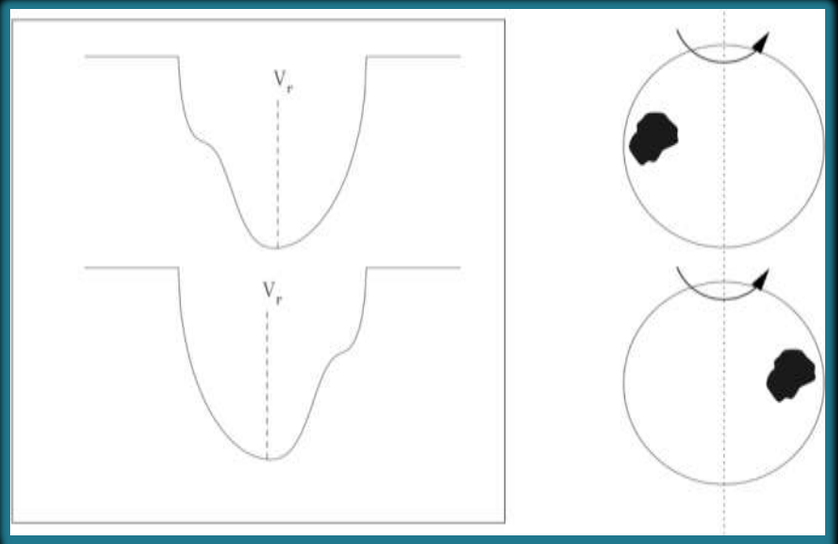
- This case = "no spot" phase (~3 years for the Sun)

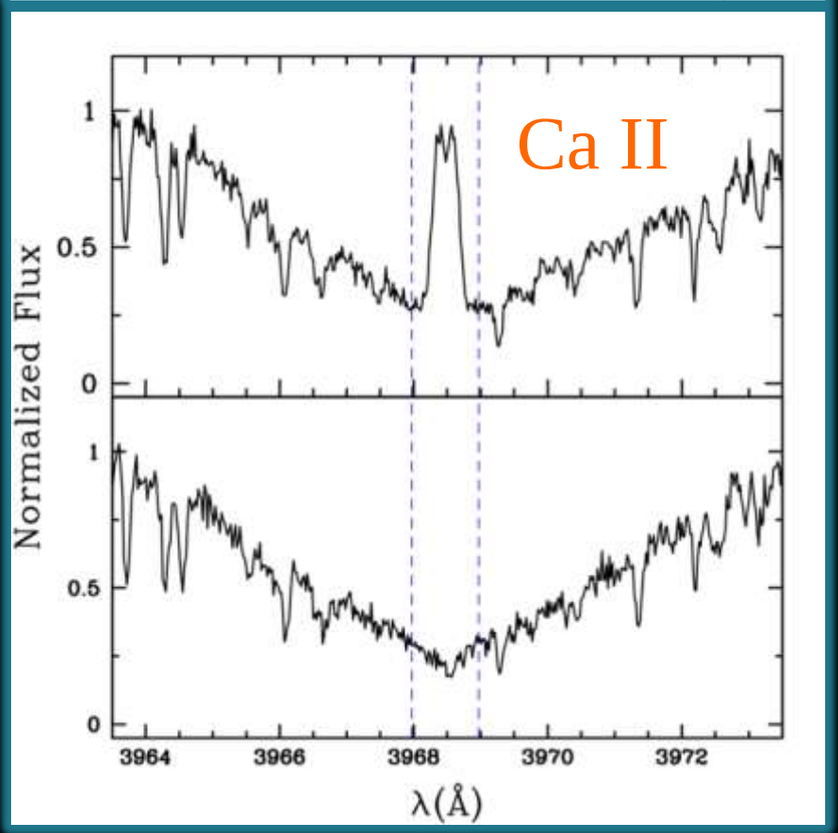


- Spot simulations to introduce activity effect still missing the longer timescales

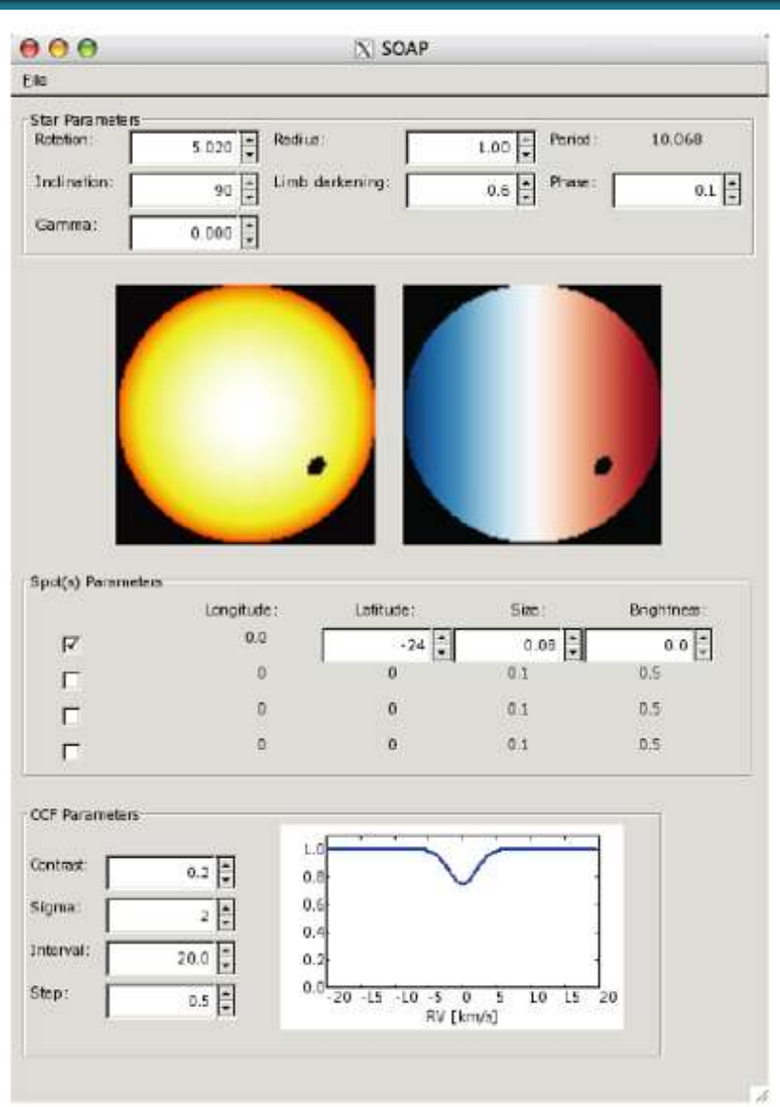
Simulations of spot effects on radial velocities

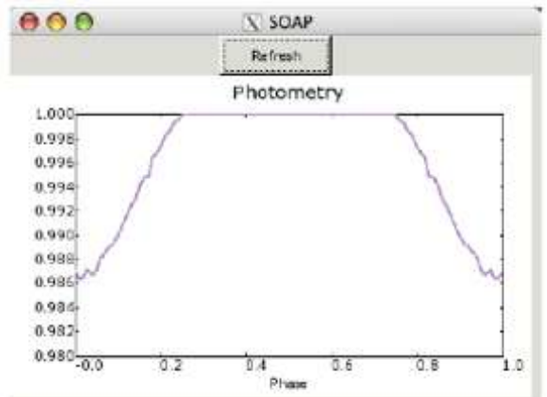
Activity index : Log(R'$_{HK}$)

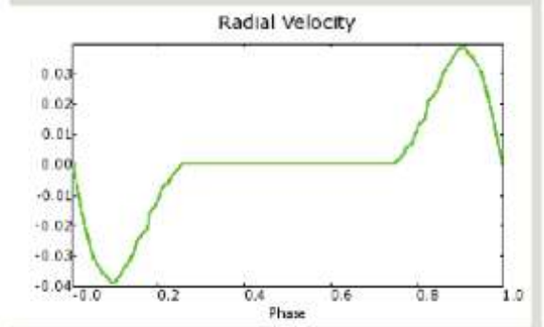


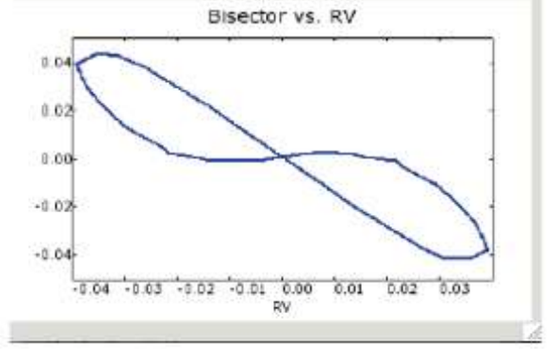


1) SOAP: effect of 1 spot (Bonfils et al. in prep)









Simulations of spot effects on radial velocities

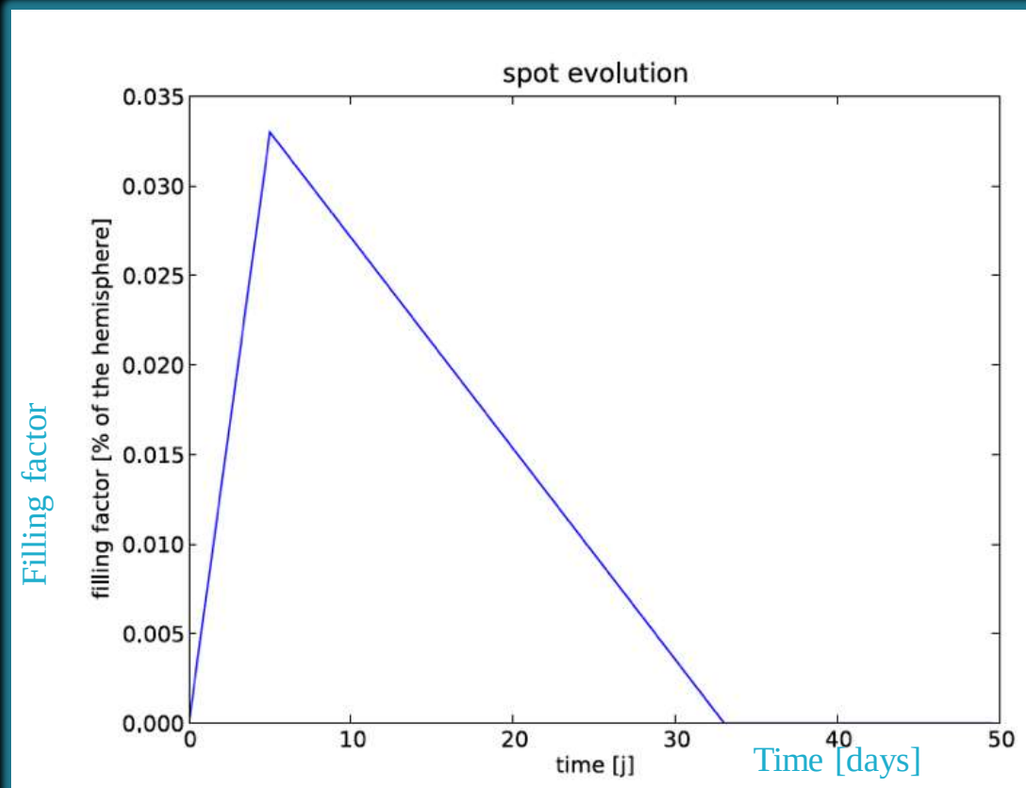
Takes into account (from observation of the Sun)

- Evolution of spots: growth, filling factor, lifetime
- # of spots = f(log[R'$_{HK}$])

Law of appearance of spots : (Poisson)

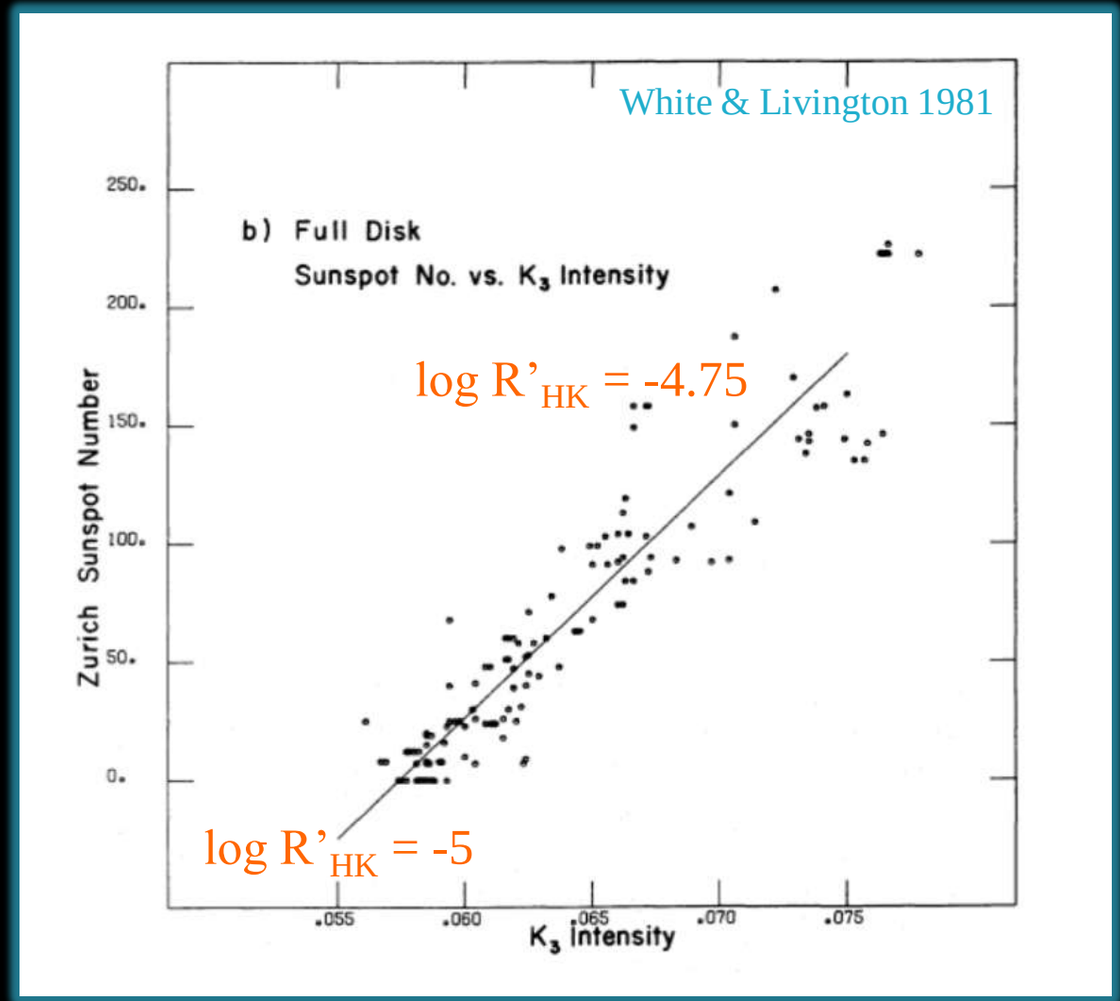
$$P[(N(t+\tau)-N(t))=k]=\frac{e^{-\lambda\tau}(\lambda\tau)^k}{k!} \qquad k=0,1,\ldots$$

Spot life



Filling factor

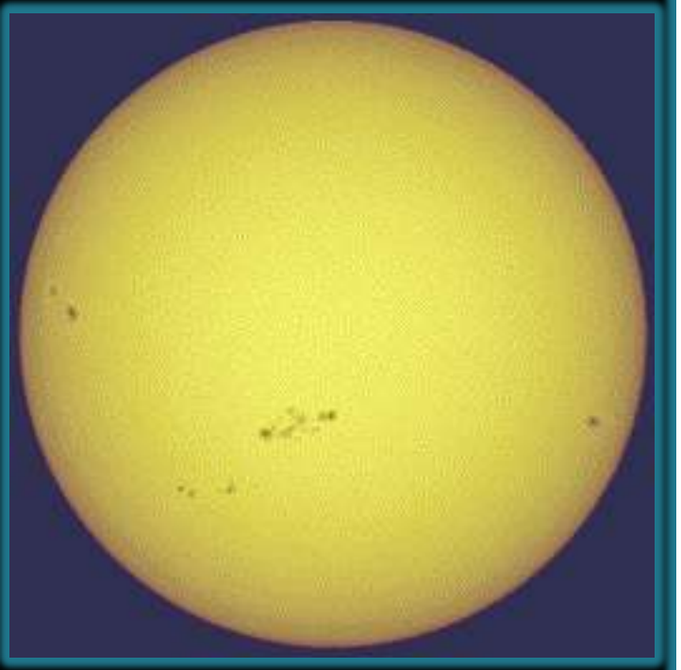
Time [days]

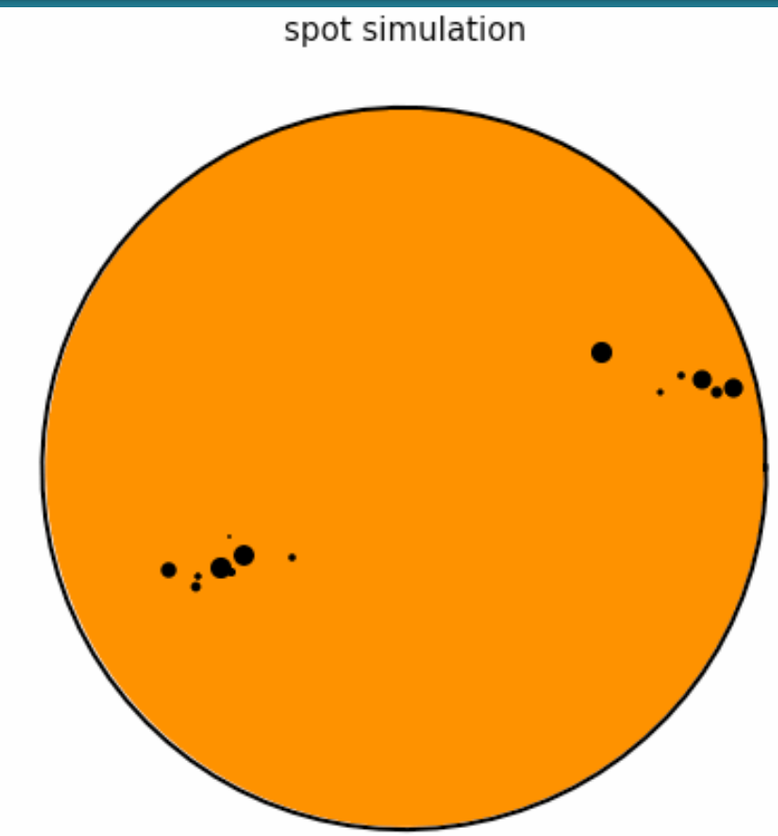


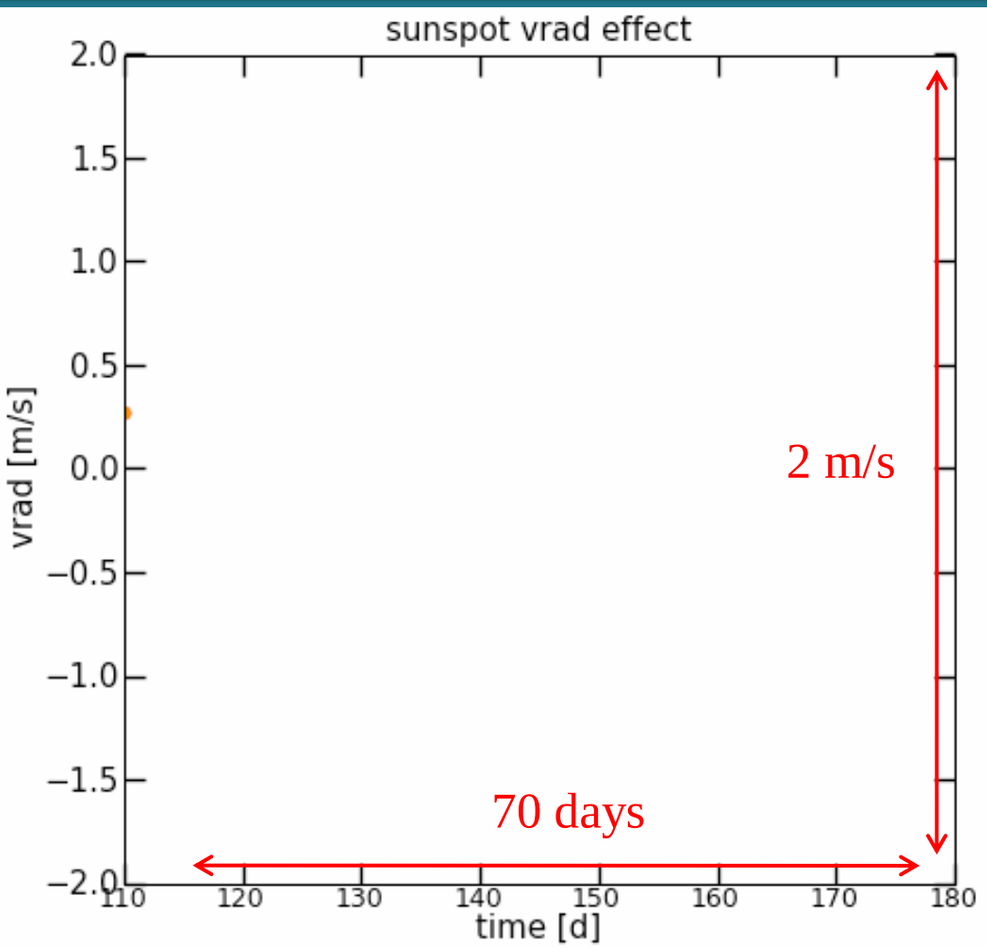
Number of spots depends on activity level

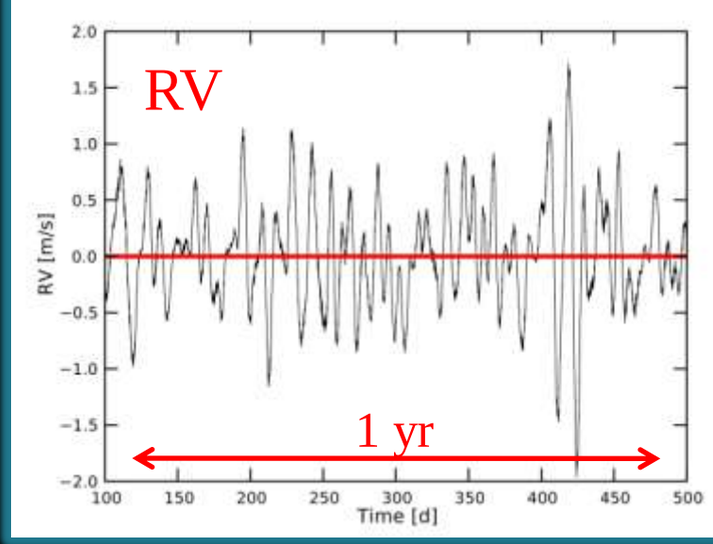
Simulations of spot effects on radial velocities

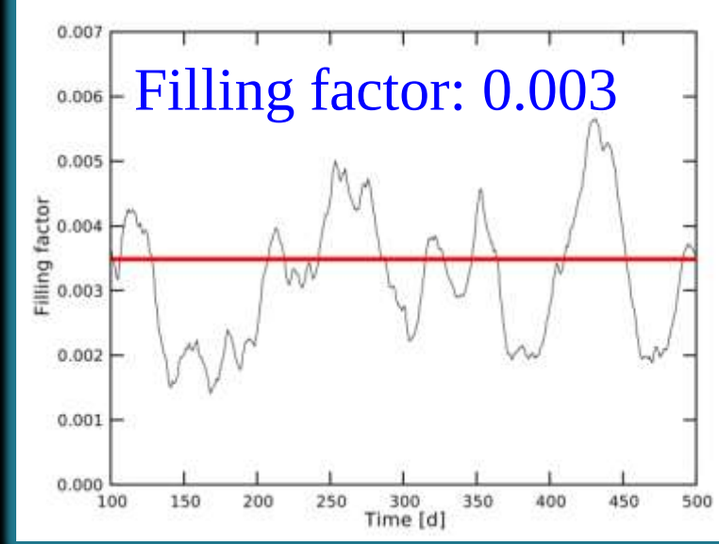
$\log(R'_{HK}) = -4.75$

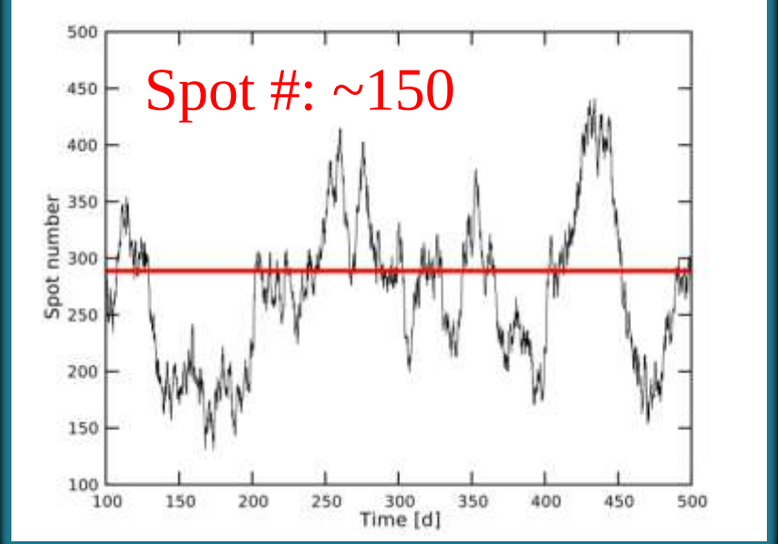






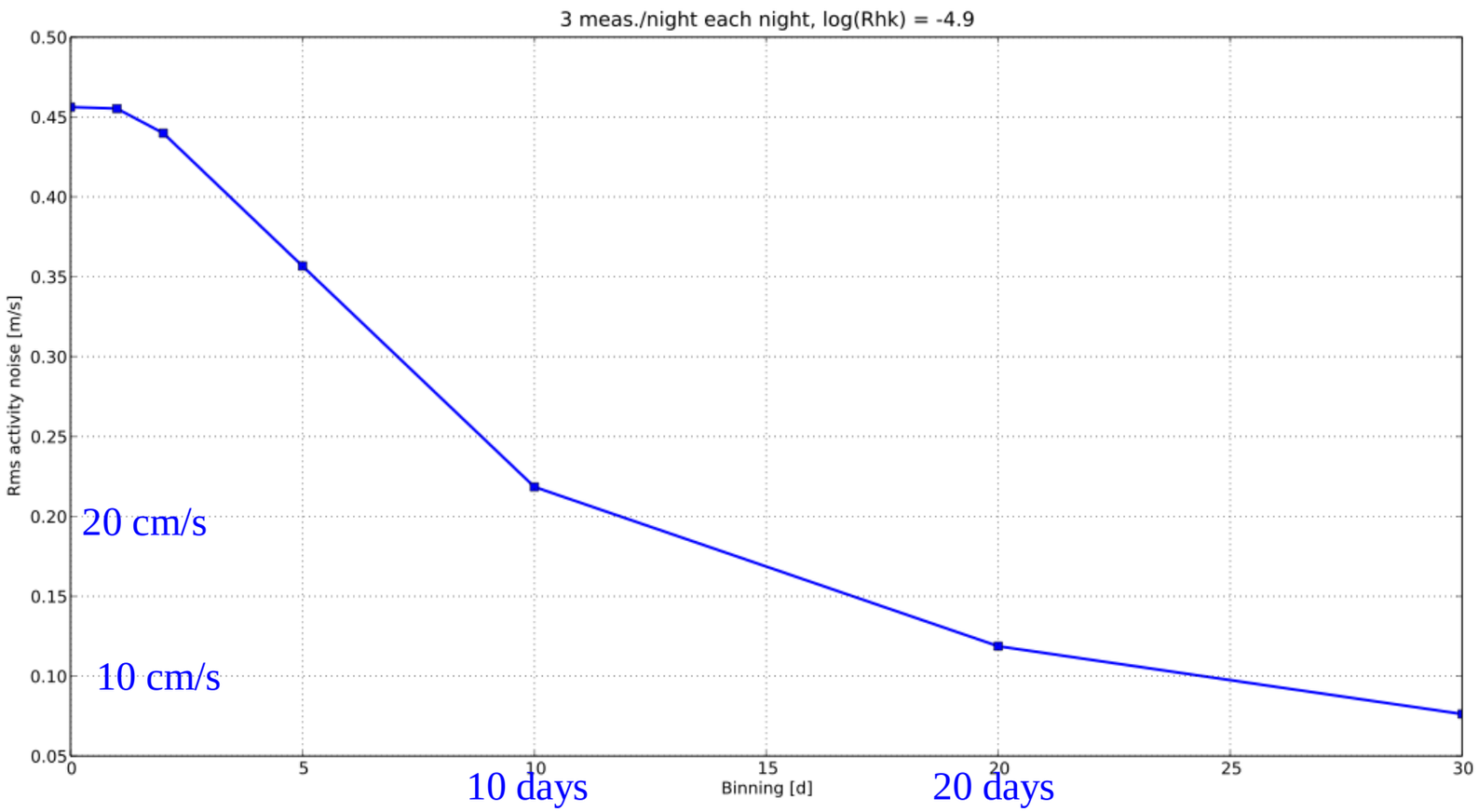






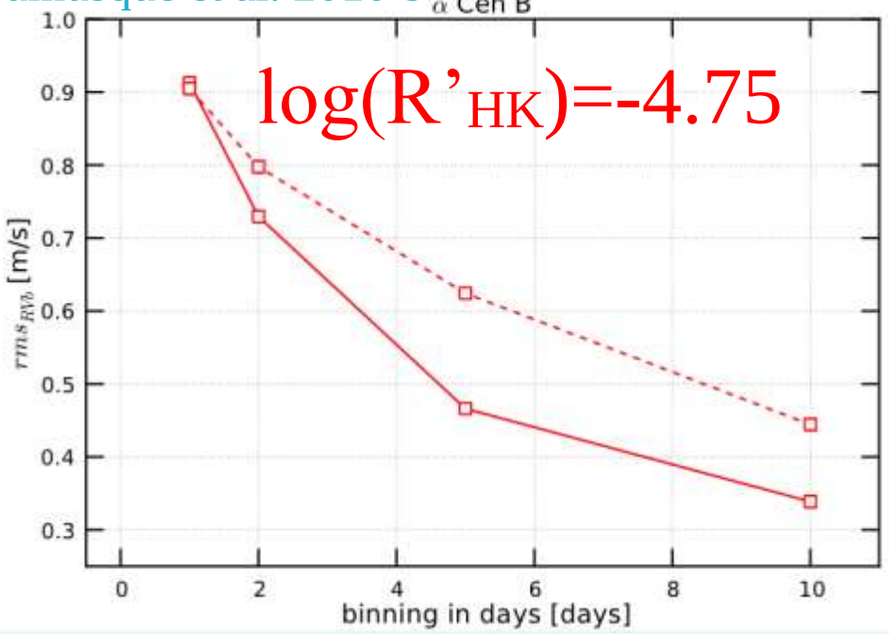
Simulations of spot effects on radial velocities

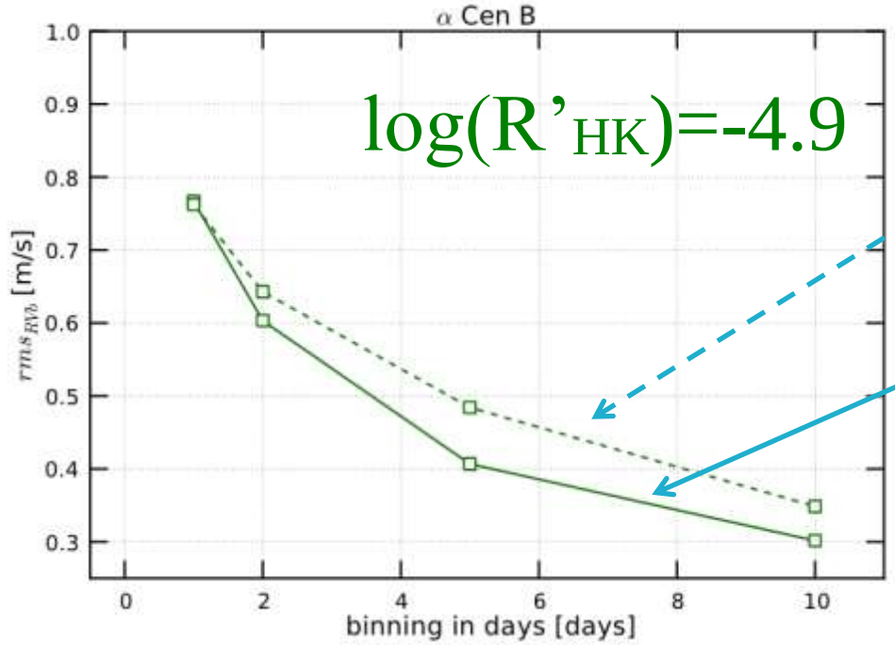
$\log(R'_{HK})$=-4.9 -> RMS < 1m/s



Simulations of spot + granulation + p-mode effects on radial velocities

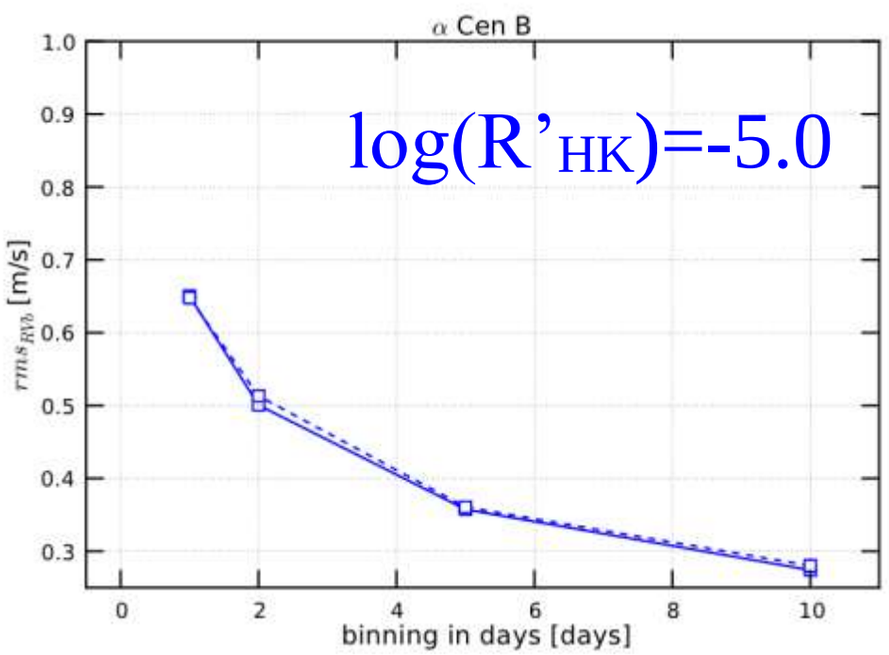
Dumusque et al. 2010 b

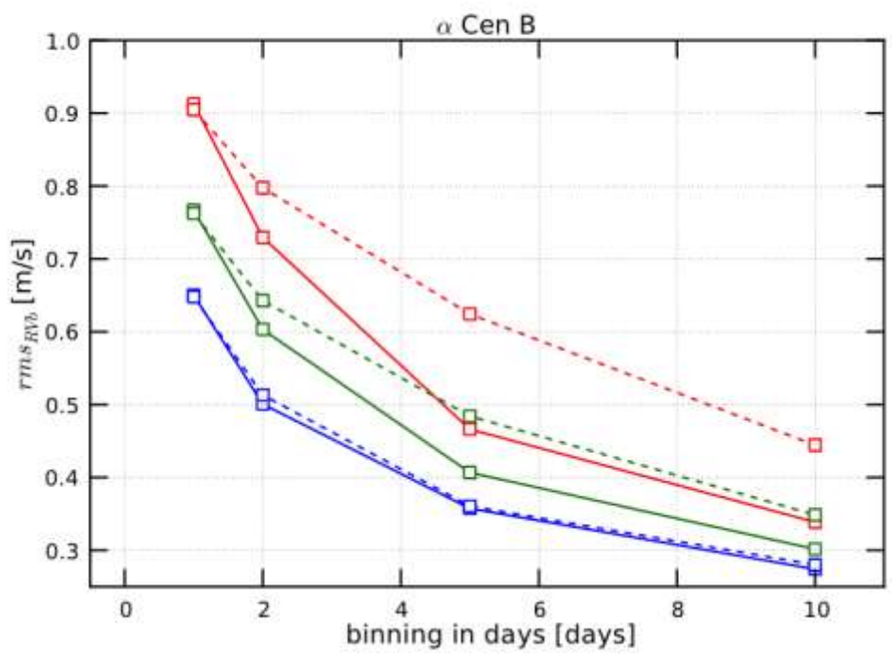




3x10 min each night

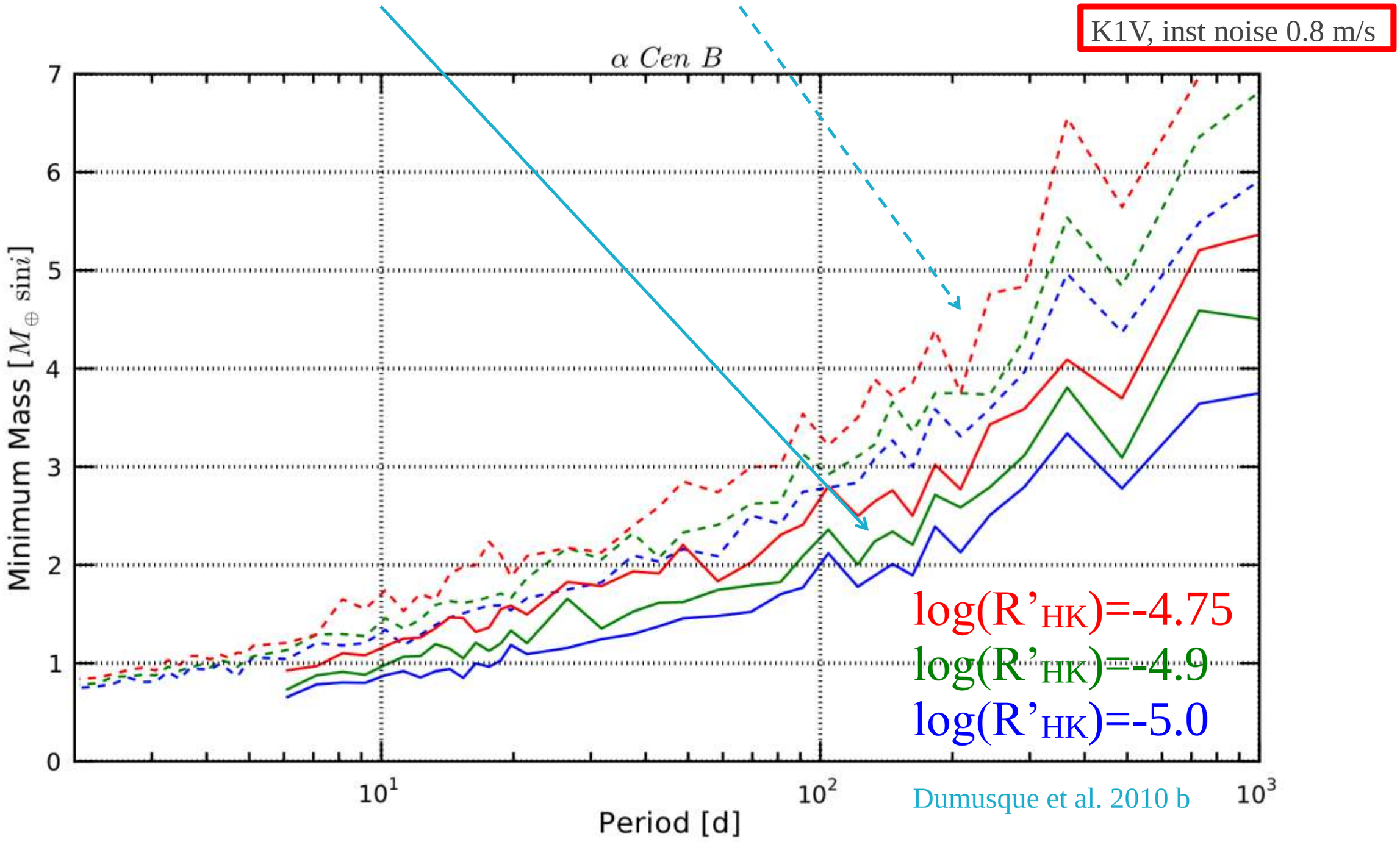
3x10 min each 3 nights





detection limits through Monte Carlo simulations

3x10 min each 3 nights 1x30 min each night



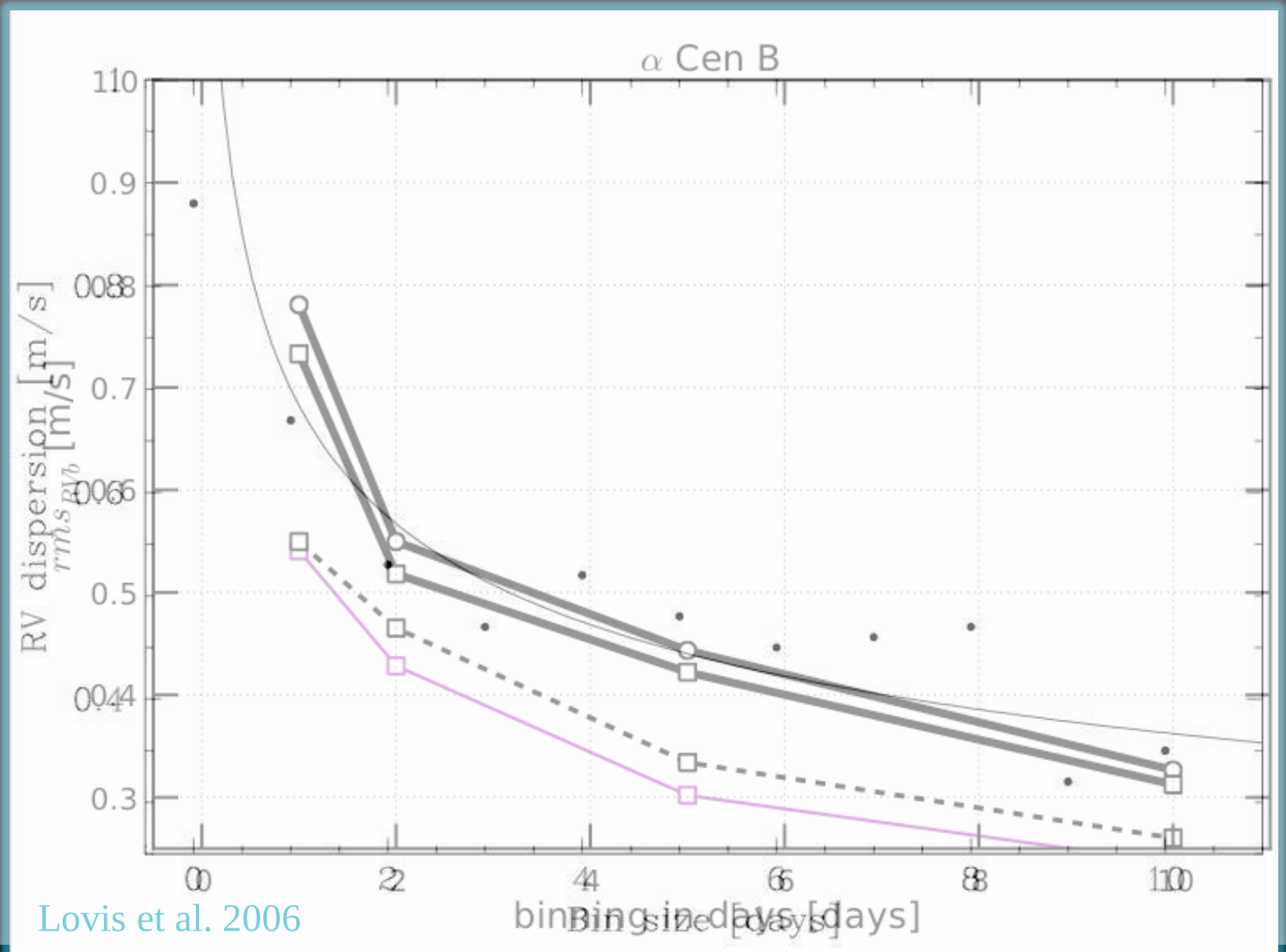
=> small effect of the period on detection capability

HD 69830 >>>>> 0.35 m/s

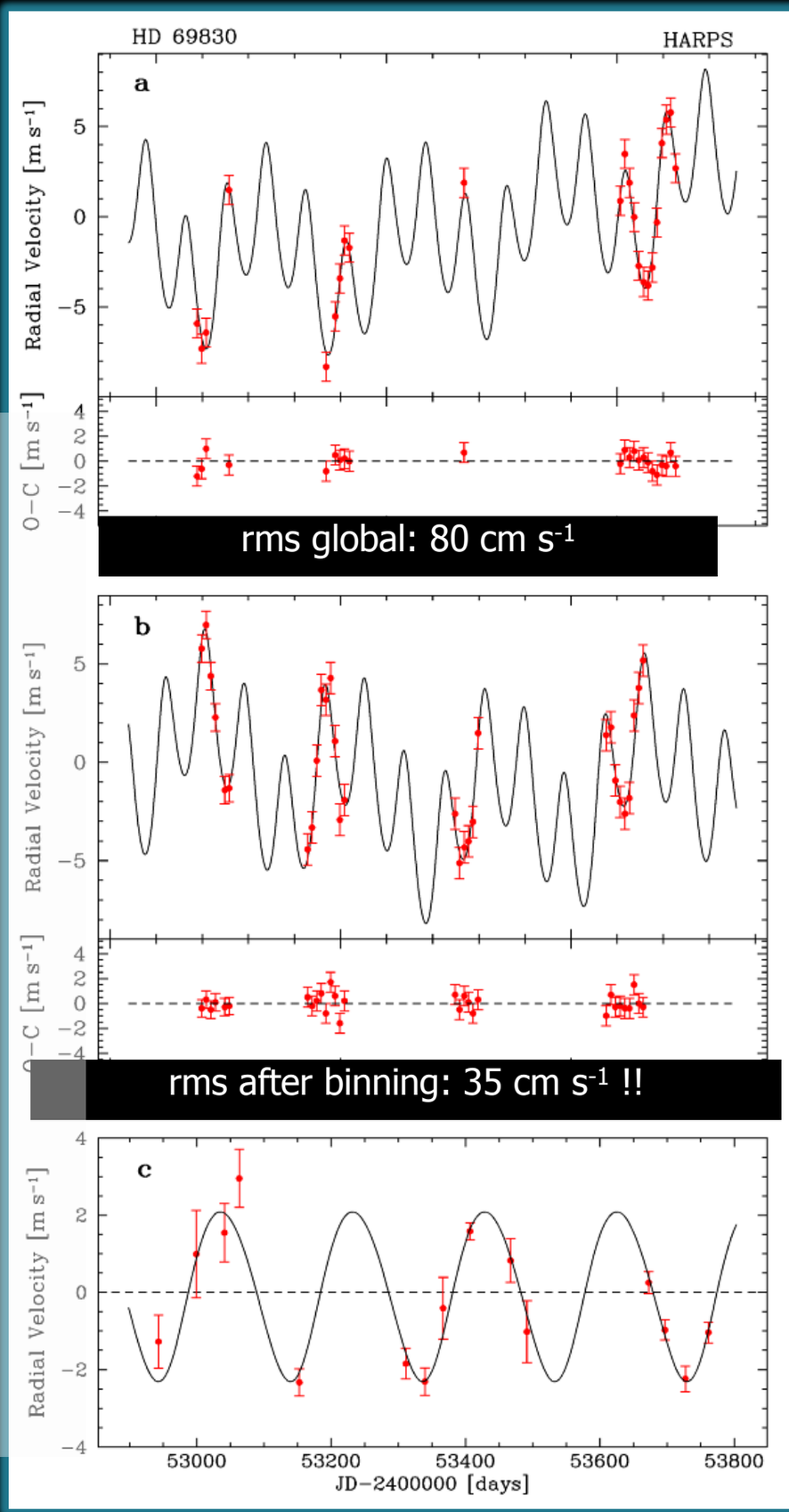
$Log(R'_{HK}) = -5$, Spec type K0V

On 5 seasons ...

- Residuals as function of the binning on .... days



Lovis et al. 2006



rms global: 80 cm s^{-1}

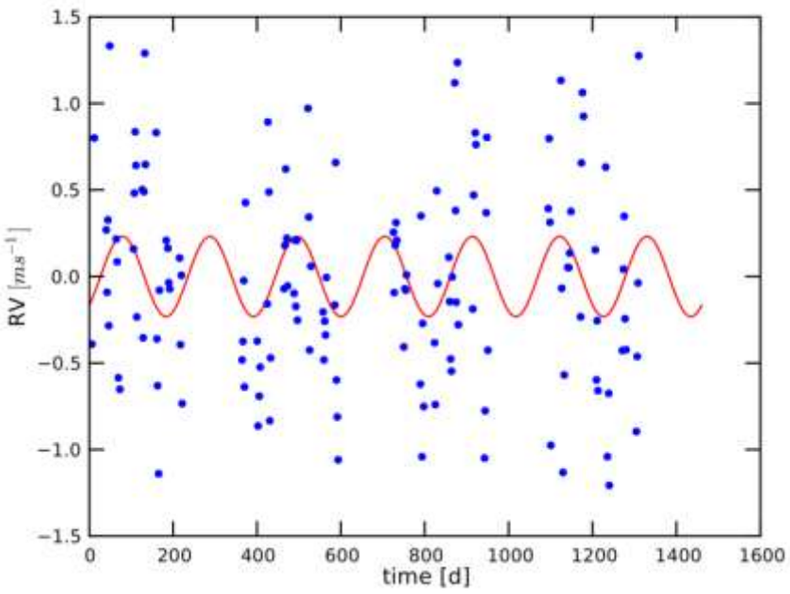
rms after binning: 35 cm s^{-1} !!

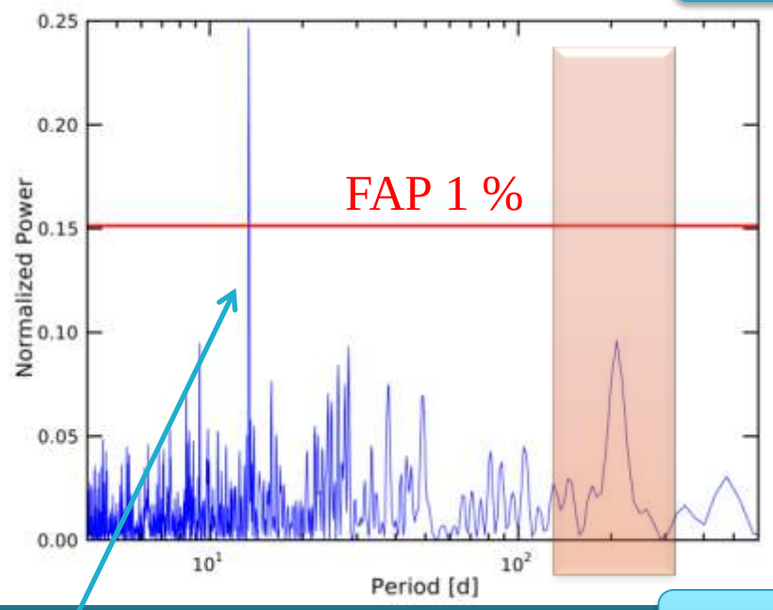
Simulations of stellar noise applied to ...

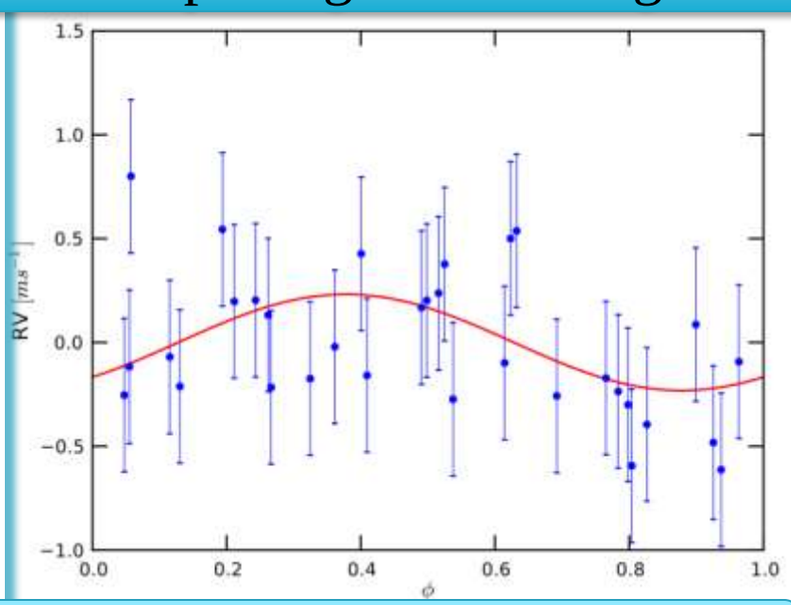
...ESPRESSO @ VLT

A 2 Earth-mass planet in the habitable zone of a quiet K star (P=200 days), Log(R'$_{HK}$) = -4.9

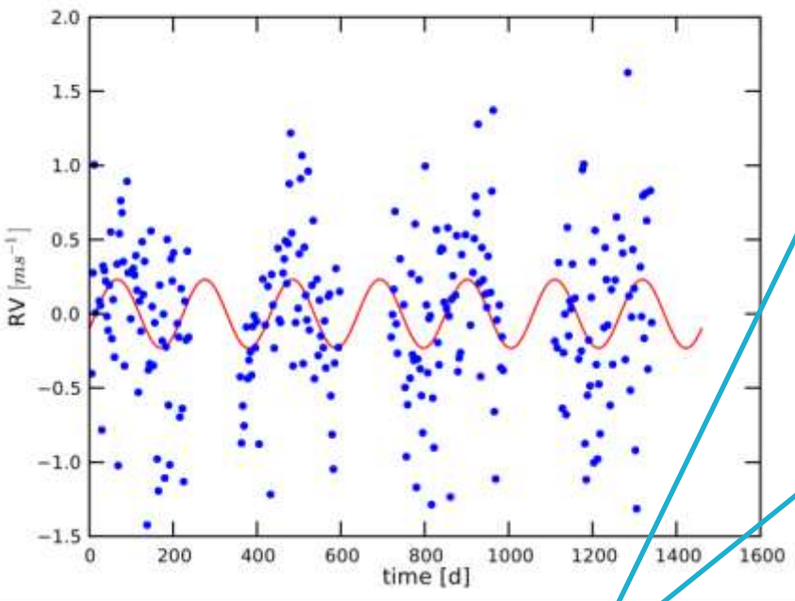
1x30 min per night each 1 night

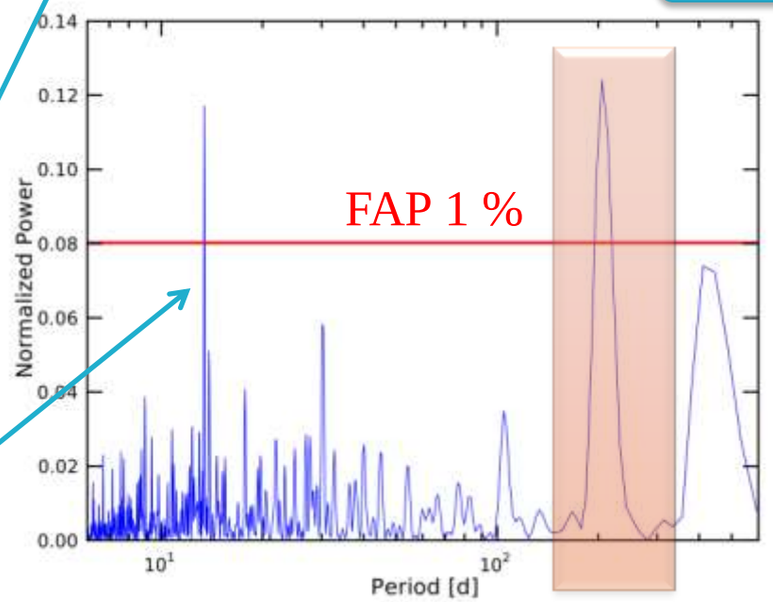


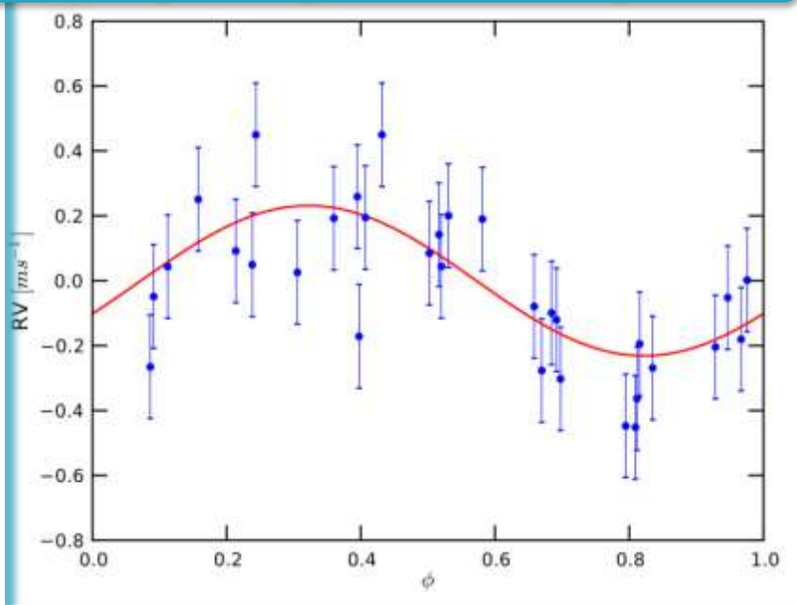




3x10 min per night each 3 nights







Alias

Dumusque et al., 2010b

END

Stephane Udry, Nuno Santos, Christophe Lovis & Geneva planet team

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Planet Detectability with radial velocities

HARPS : ~ 1 m/s

Super-Earth (5 $M_{\oplus}$)	@ 1 AU	: 0.45 m s^{-1}
Earth	@ 1 AU	: 9 cm s^{-1}

Required an order of magnitude improvement

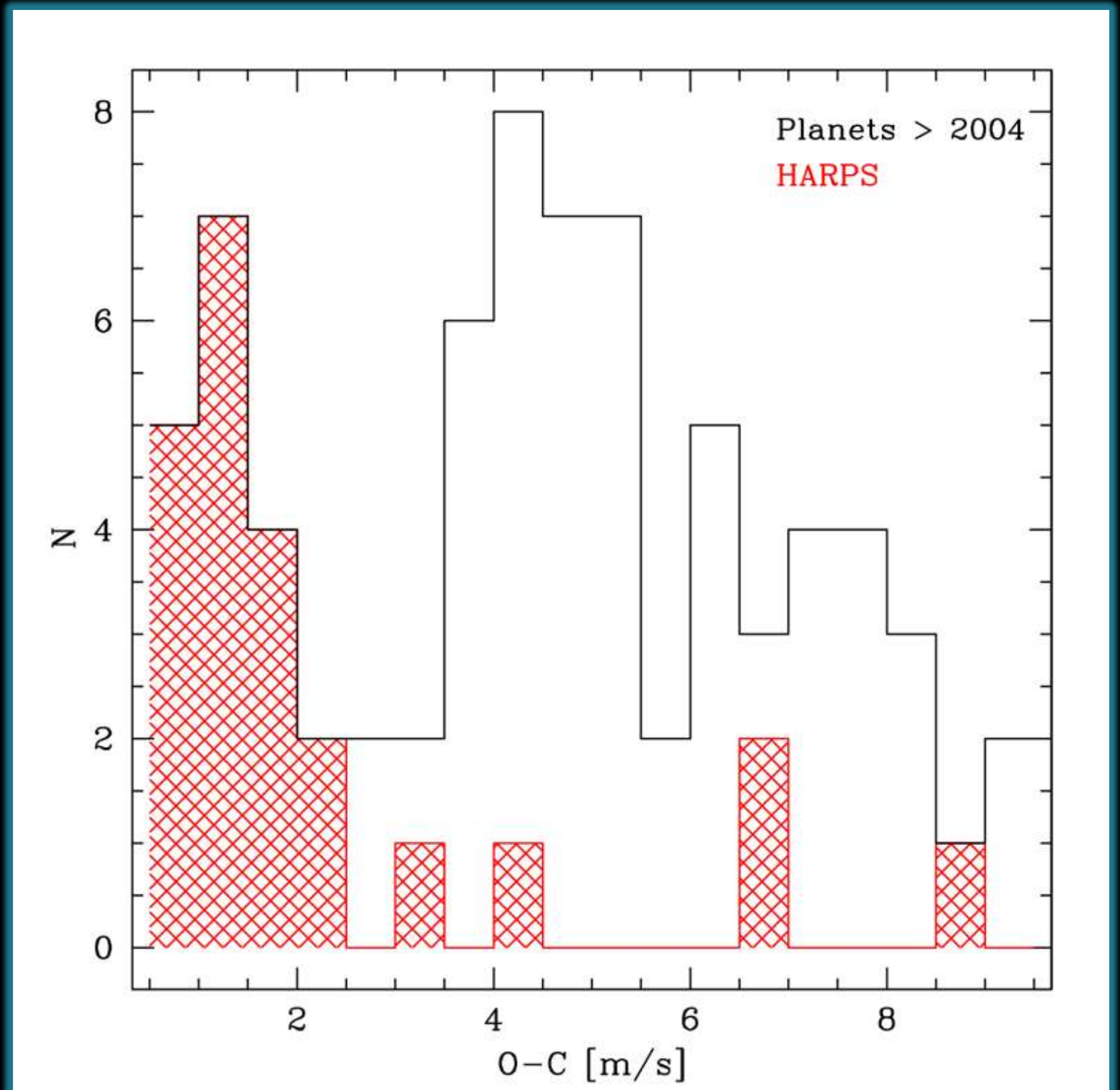
⟶ ESPRESSO @ VLT : 0.1 m/s (2012)

Harps: exploration of small-mass domain

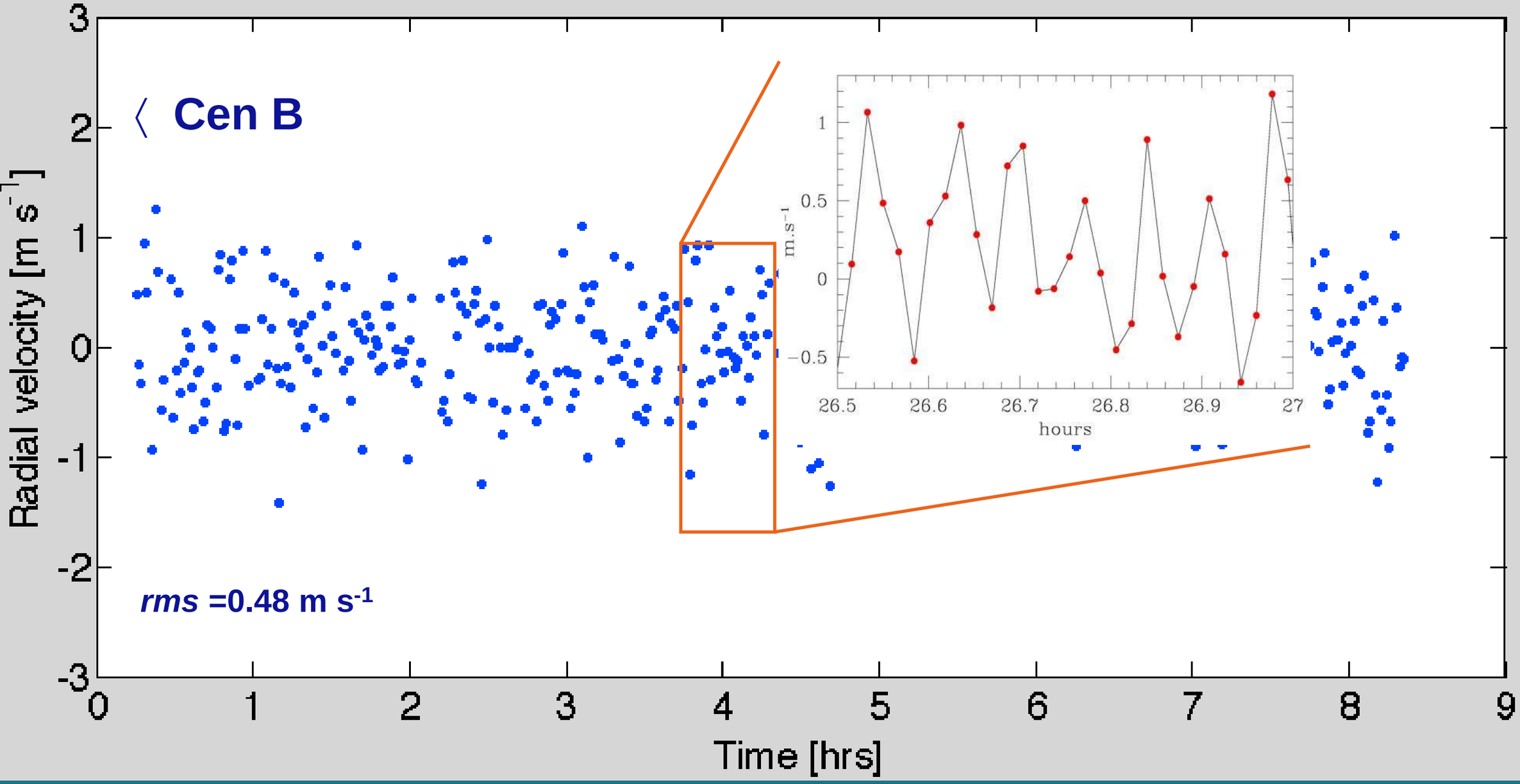
All published orbits with residuals < 2.5 m/s between 2004 and 2008 are from HARPS

Before HARPS, limit in precision was not set by the star but by the instrument

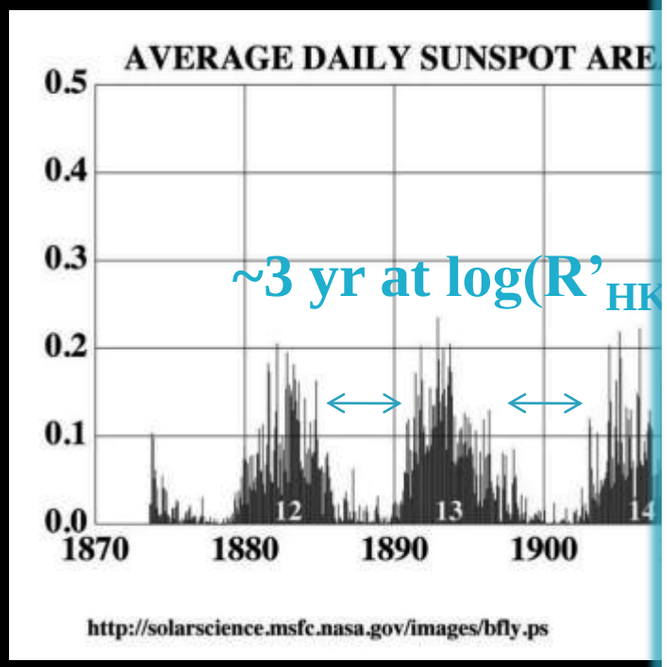
Still true with HARPS?

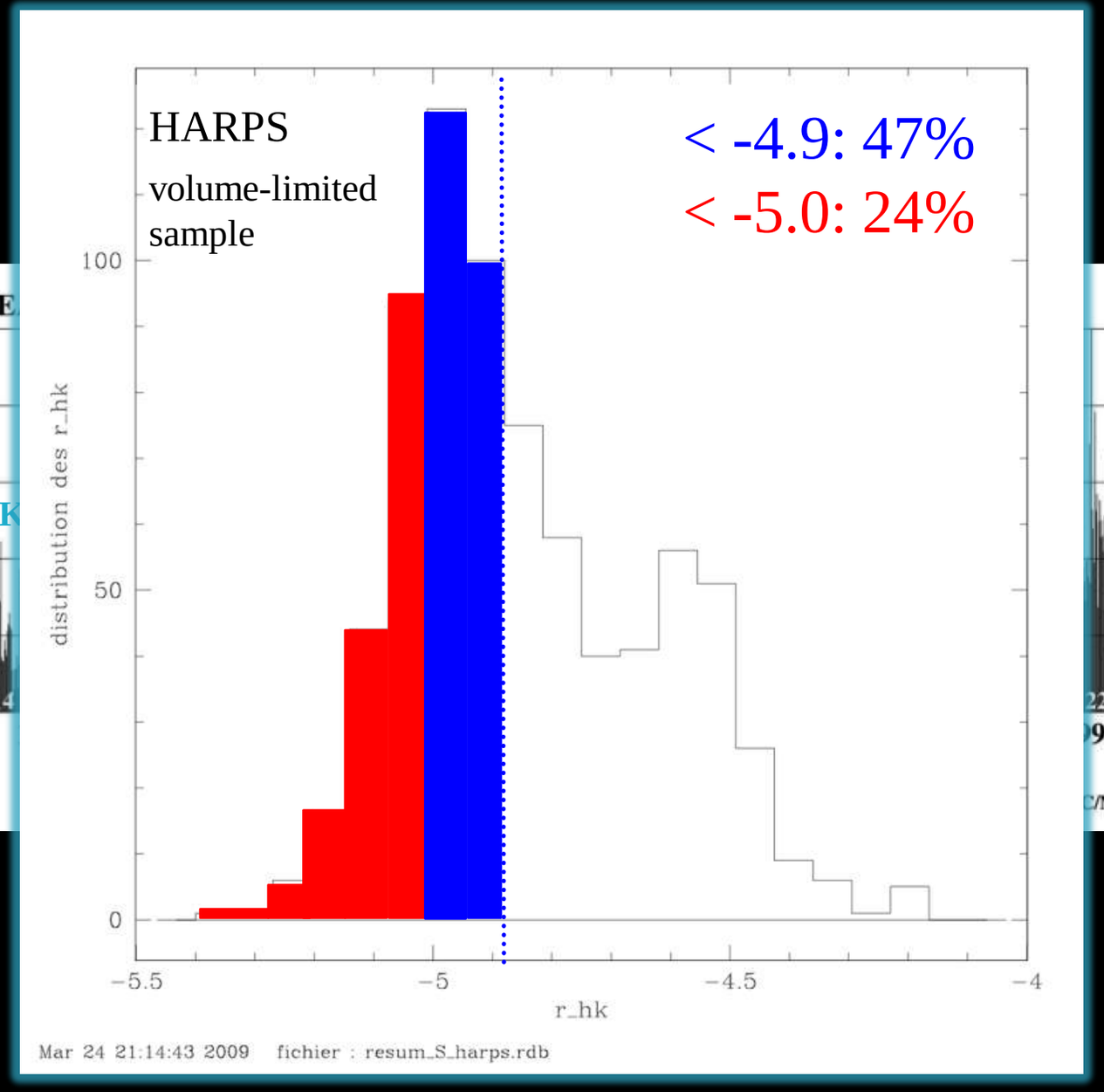


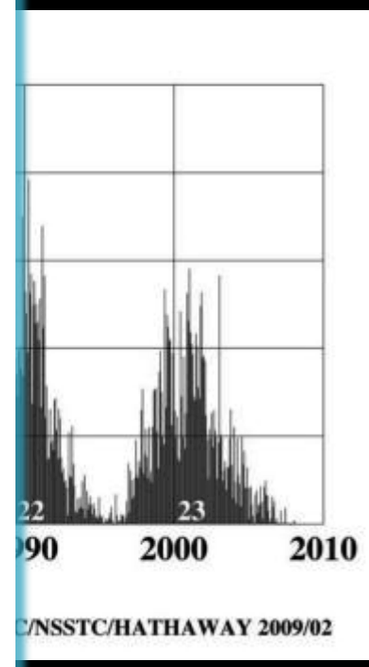
Stellar oscillations



Sun Activity







Log(R'HK)

-4.75

-4.9

-5.0