Effects of stellar activity on RV measurements

and a way to disentangle stellar activity and planetary signals

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and
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Plan

Introduction

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How spots (and plages) creates RV fake variations

- CCF ≈ mean line of the spectra
- fitted with a Gaussian
- spots or plages deform the CCF

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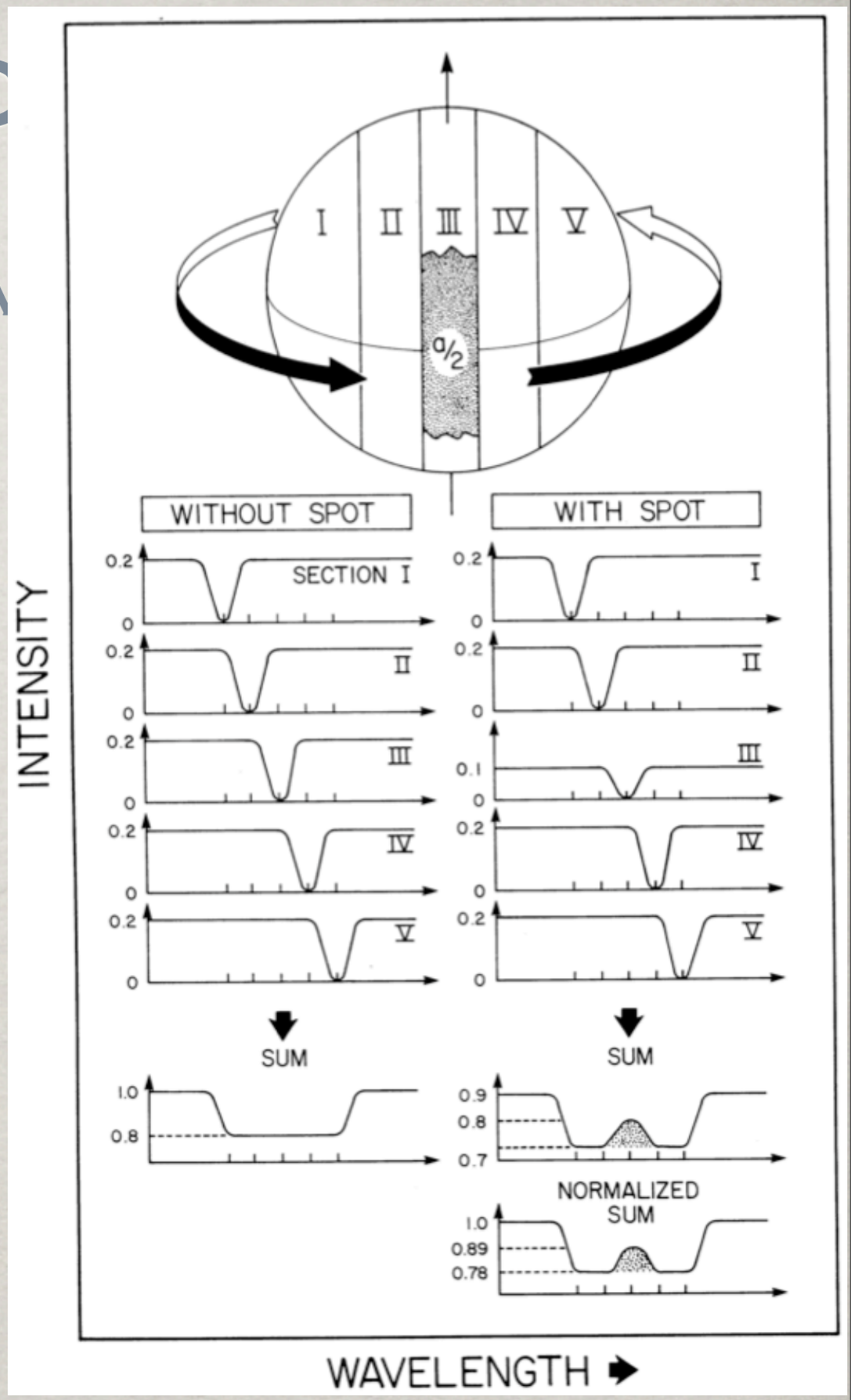

Vogt & Penrod 1983

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How spots (and plages) creates RV fake variations

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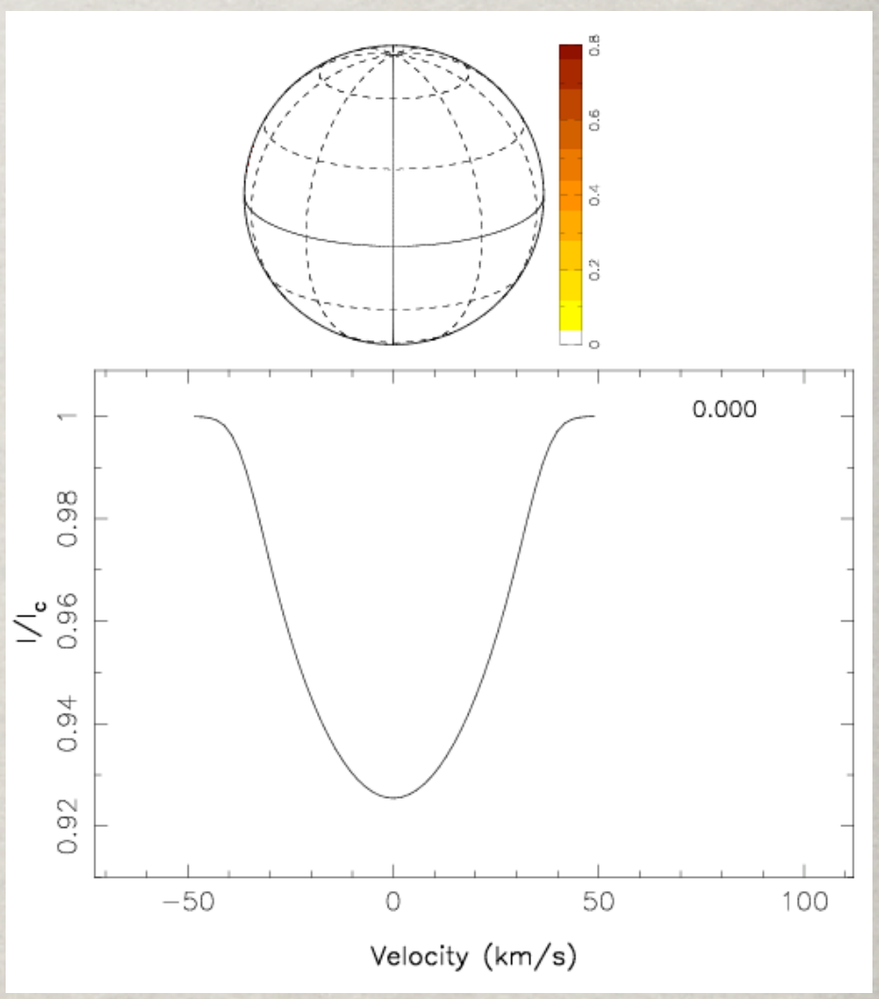
- fitted with a Gaussian
- spots or plages deform the CCF
- induced variations of the measured RV



@ Donati

Introduction

Consequences

- Young and active stars were removed from RV surveys

  RV follow-up (of transit detections) of active stars is difficult

- But:

  spots and plages exist on all stars, even low-activity stars

  planet detection around young stars needed for planet formation theory

  RV follow-up to establish the planetary nature of the transiting candidates and characterize the true mass

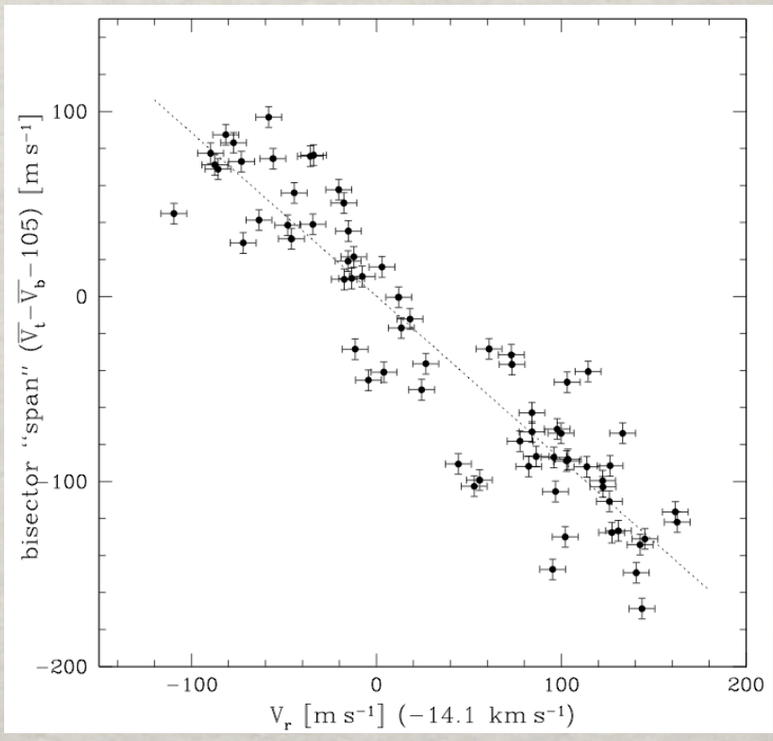
Introduction

- Diagnostics of stellar activity

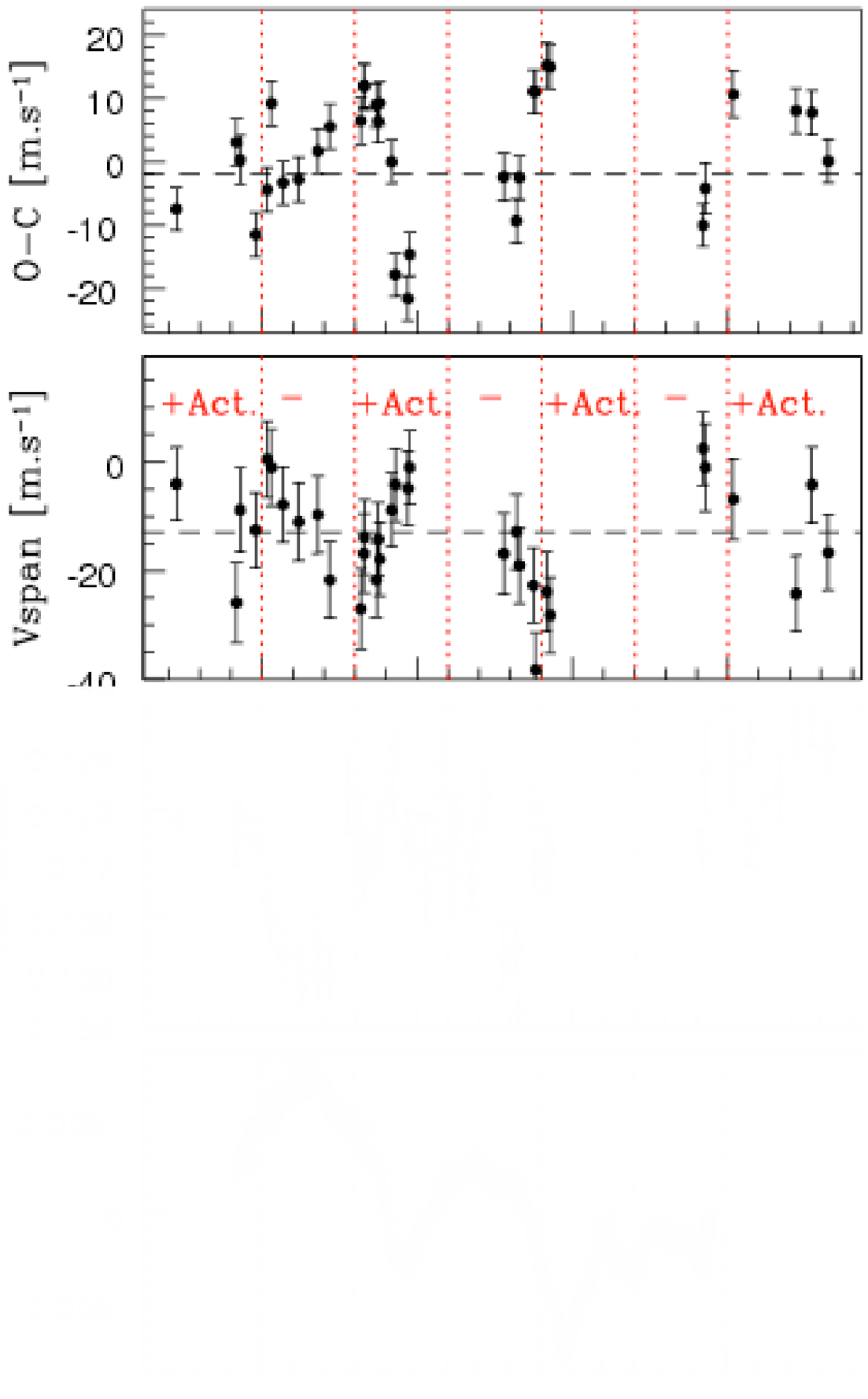
  line bisector variations spectroscopy

  active lines CaII H&K, Hα, HeI, Hβ spectroscopy

  stellar flux photometry



Queloz et al. A&A, 2001



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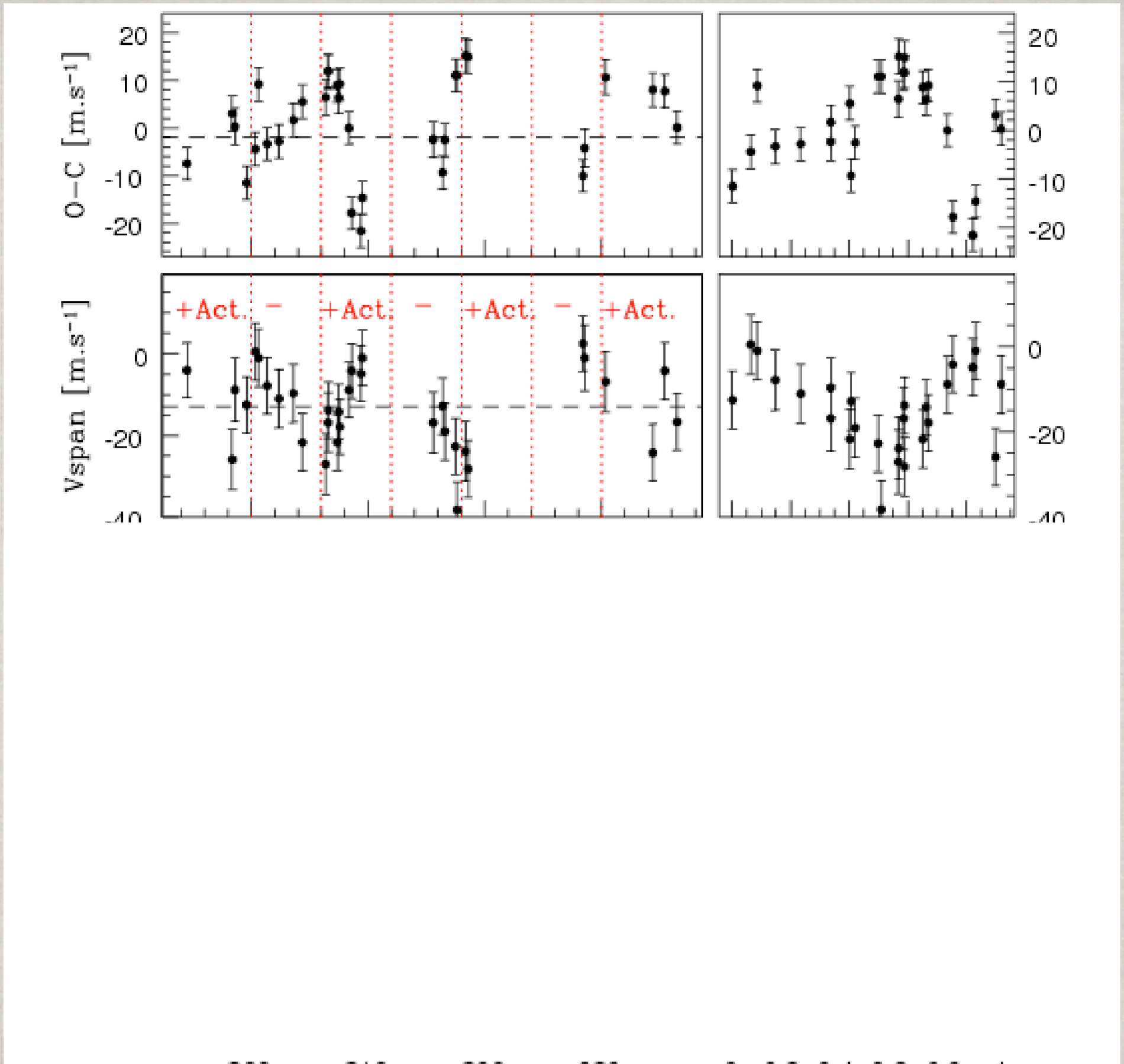

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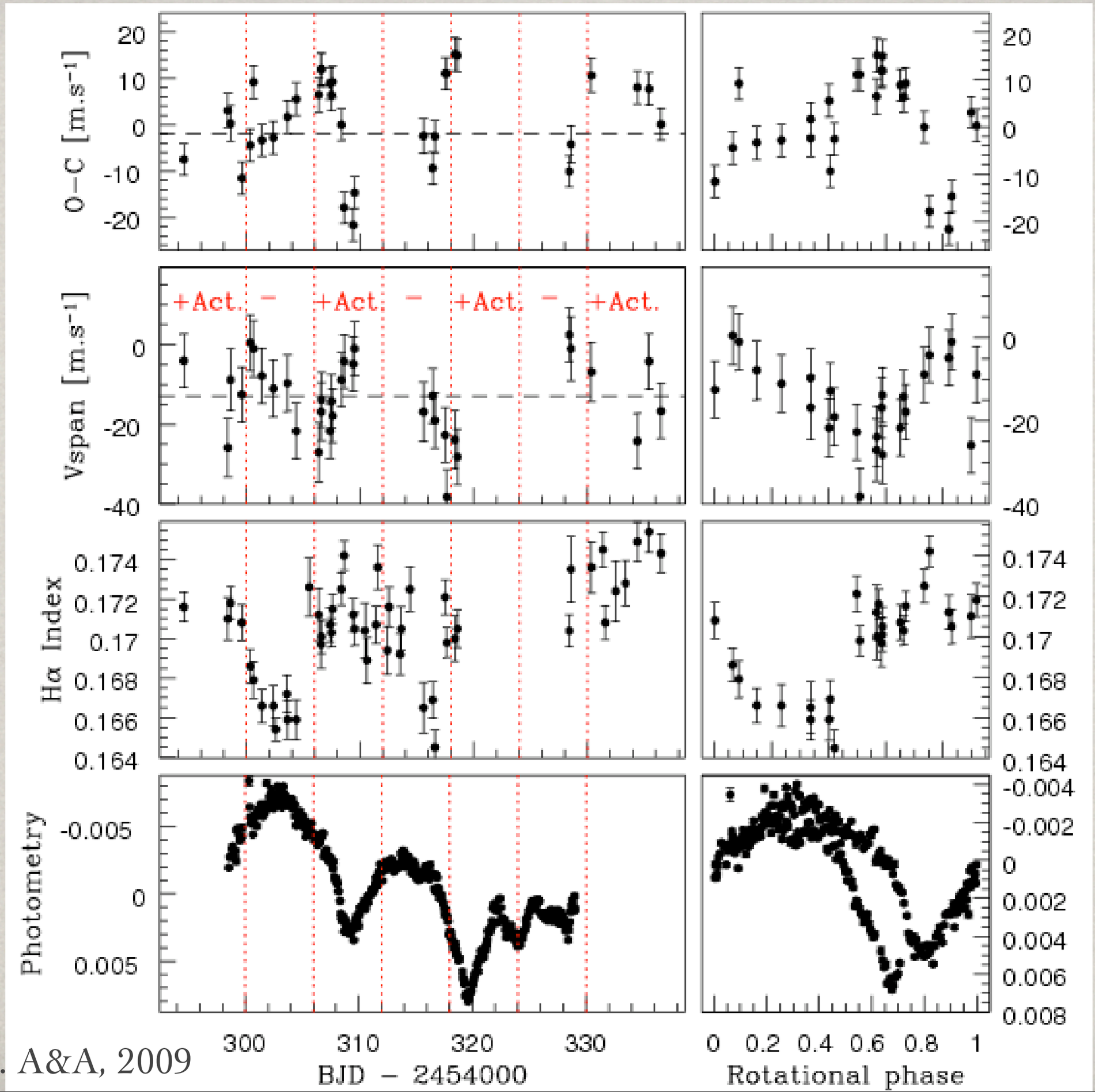

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Introduction

Several Attempts to remove active jitter

HD219828 Melo et al. 2007 ⟶ remove anti-correlation BIS / RV

GJ674 Bonfils et al. 2007 ⟶

Gl176 Forveille et al. 2008 ⟶

HD189733 Boisse et al. 2009 ⟶ remove anti-correlation BIS / RV

CoRoT-7 Queloz et al. 2009 ⟶

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CoRoT-7 Queloz et al. 2009 ⟶ harmonic decomposition of Prot

CoRoT-7 Hatzes et al. 2010 ⟶ Fourier analysis

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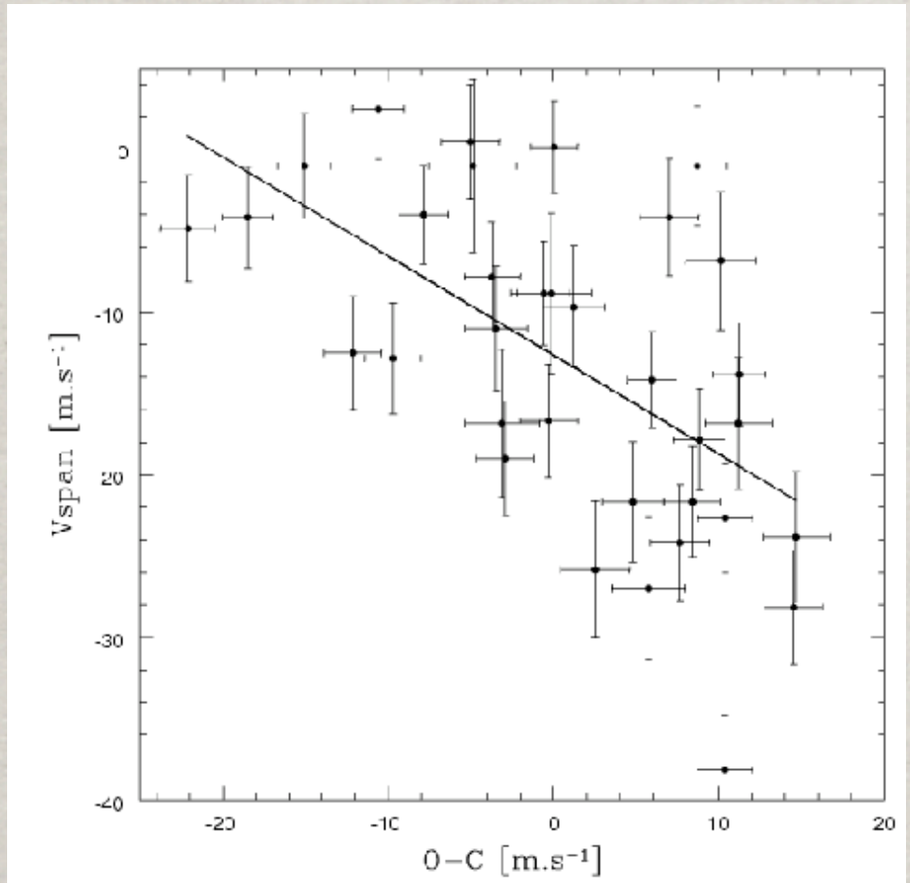
Attempts to remove active jitter

- Remove anti-correlation BIS / RV



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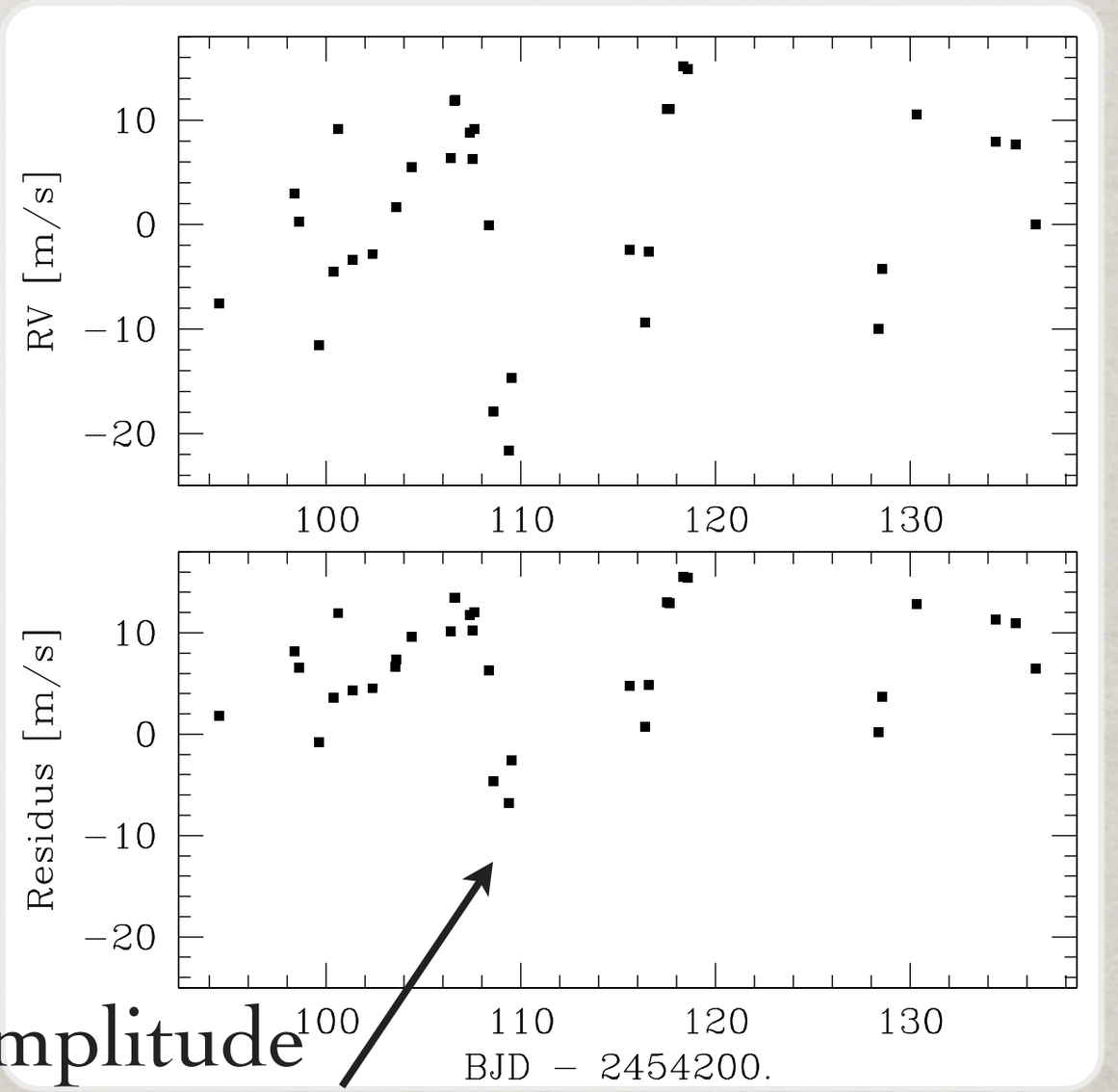
HD189733



Lower amplitude but same pattern !!!

Studies of Dark spots Simulations

Boisse et al. A&A, subm.

Simulations studies

Impact of stellar spots

Amplitude of the RV depends on:

- $v \sin i$, spot size and star age FeI line Saar & Donahue 1997
  up to few hundred m/s
  point out convective inhomogeneities

- up to few tens m/s CaI line Hatzes 2002

- spectrograph resolution and spot temperature
  Visible spectra Desort et al. 2007

Simulations studies

- Tool SOAP Bonfils & Santos, in prep.

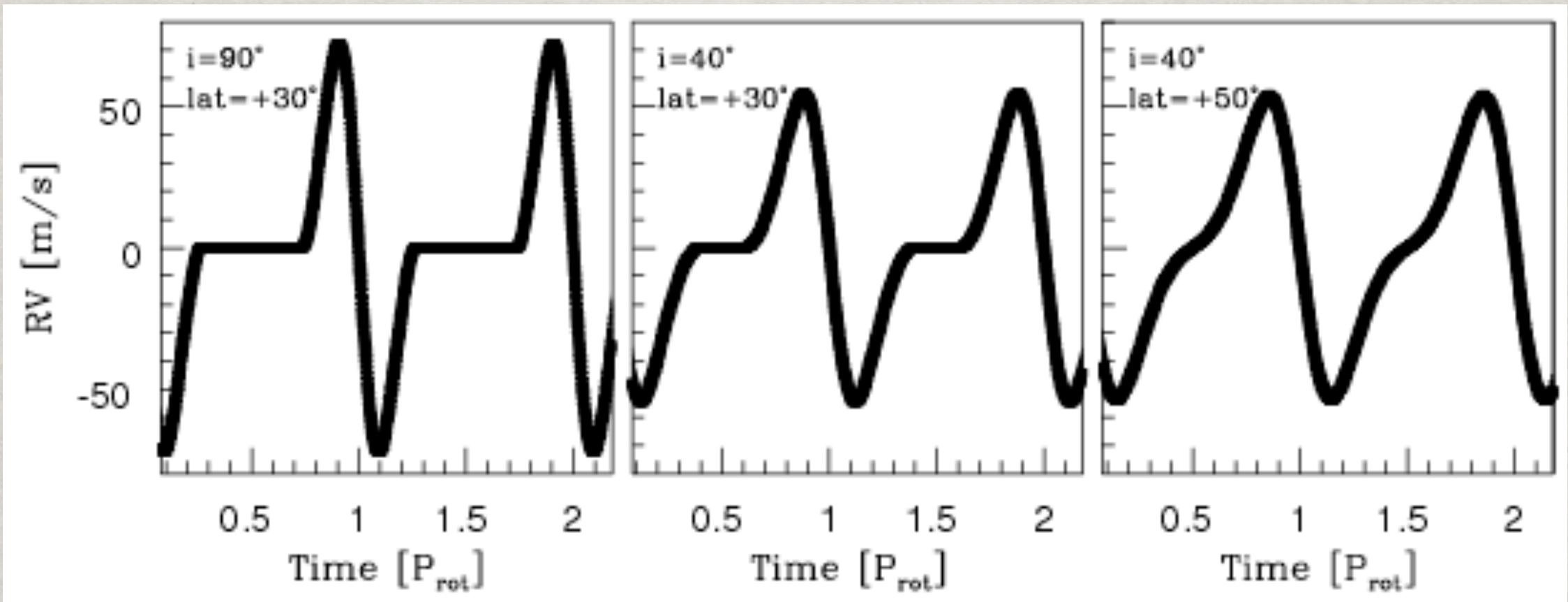
- Photometry and the mean spectral line (∝ CCF) fitted with a Gaussian: RV, BIS, FWHM and Contrast

- Parameters:

  $v$sin i -- R⋆ -- size and number of spots -- limb-darkening -- inclination of the star with the line of sight I -- width of the typical spectral line of non-rotating star (vary with instrumental resolution and stellar B-V) -- no differential rotation

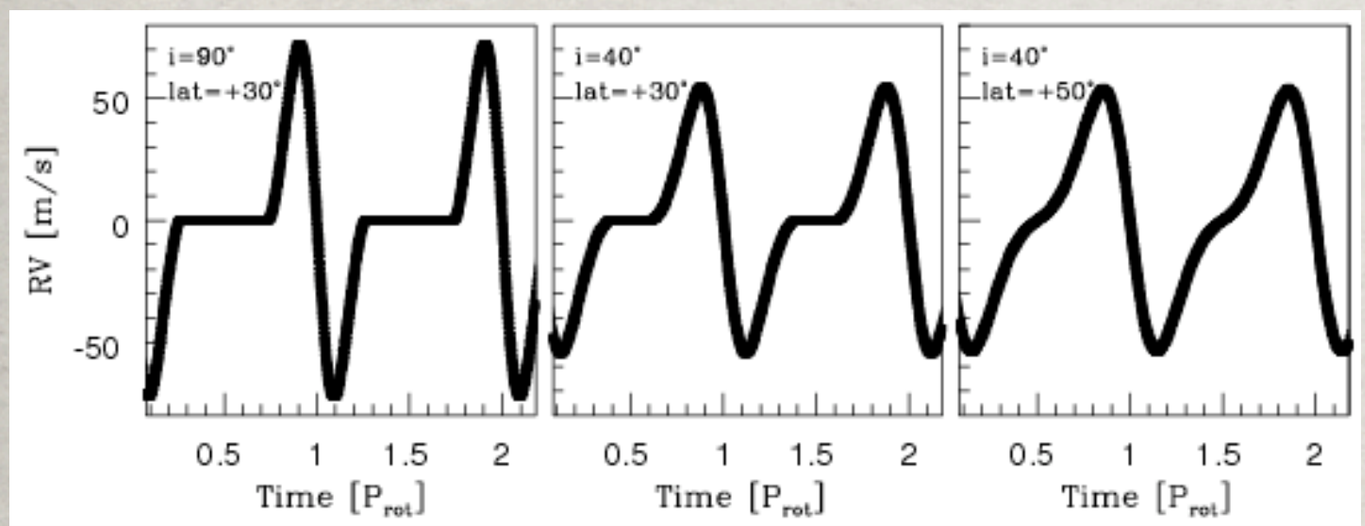
Simulations studies

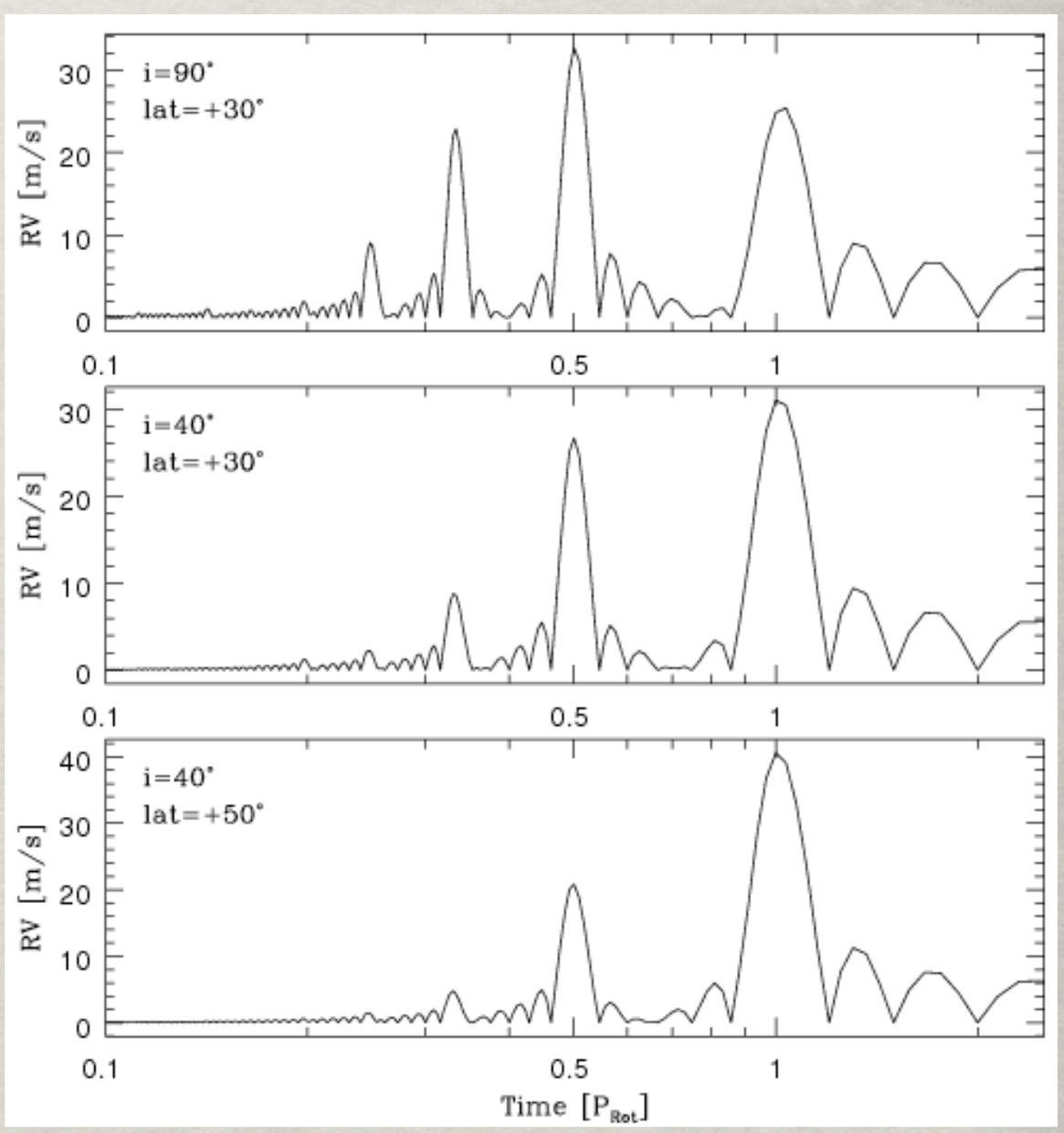
- Shape of active jitter: depends on stellar I and spot latitude δ
- Perfect sampling + Gaussian noise



Simulations studies

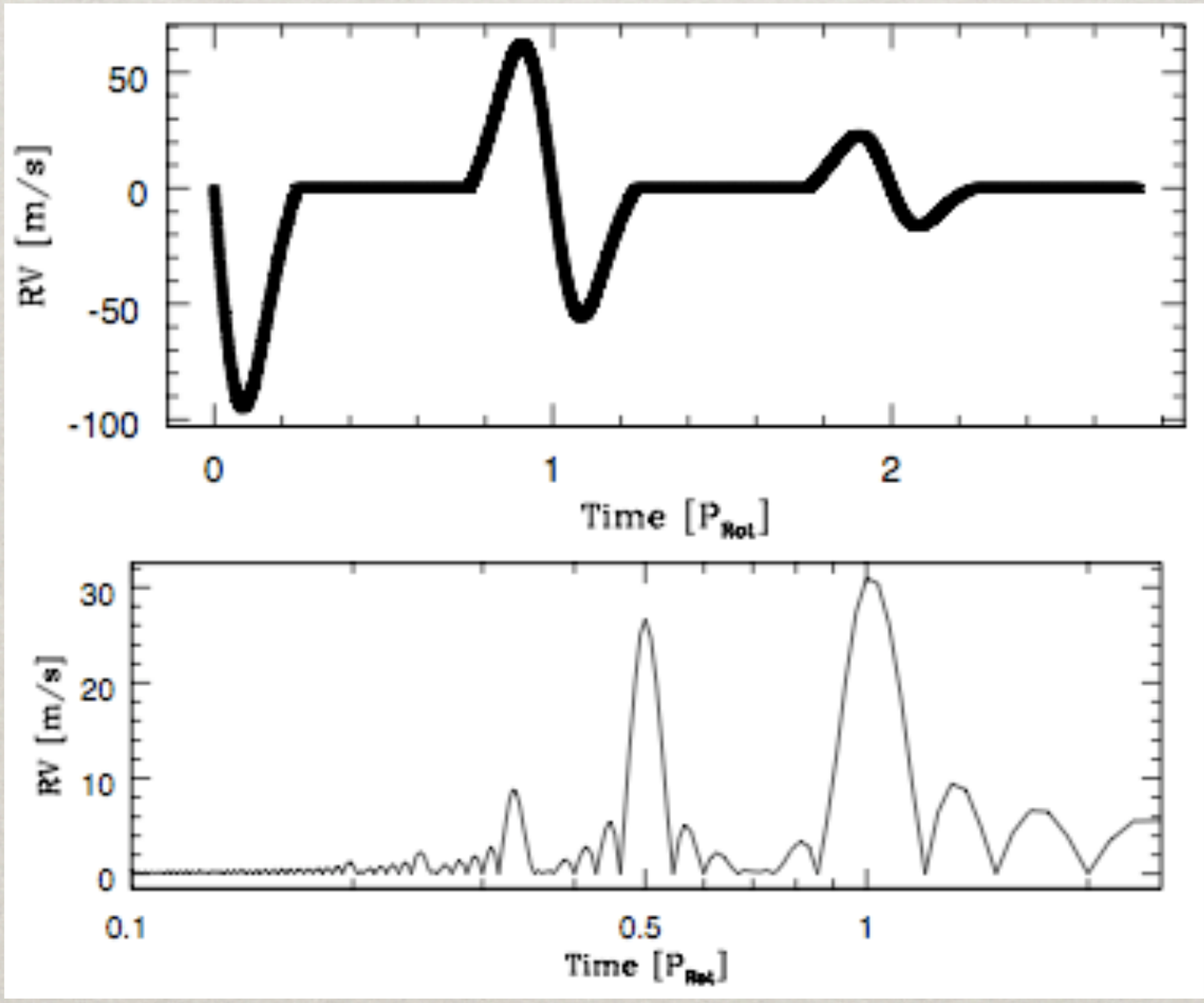
One Spot





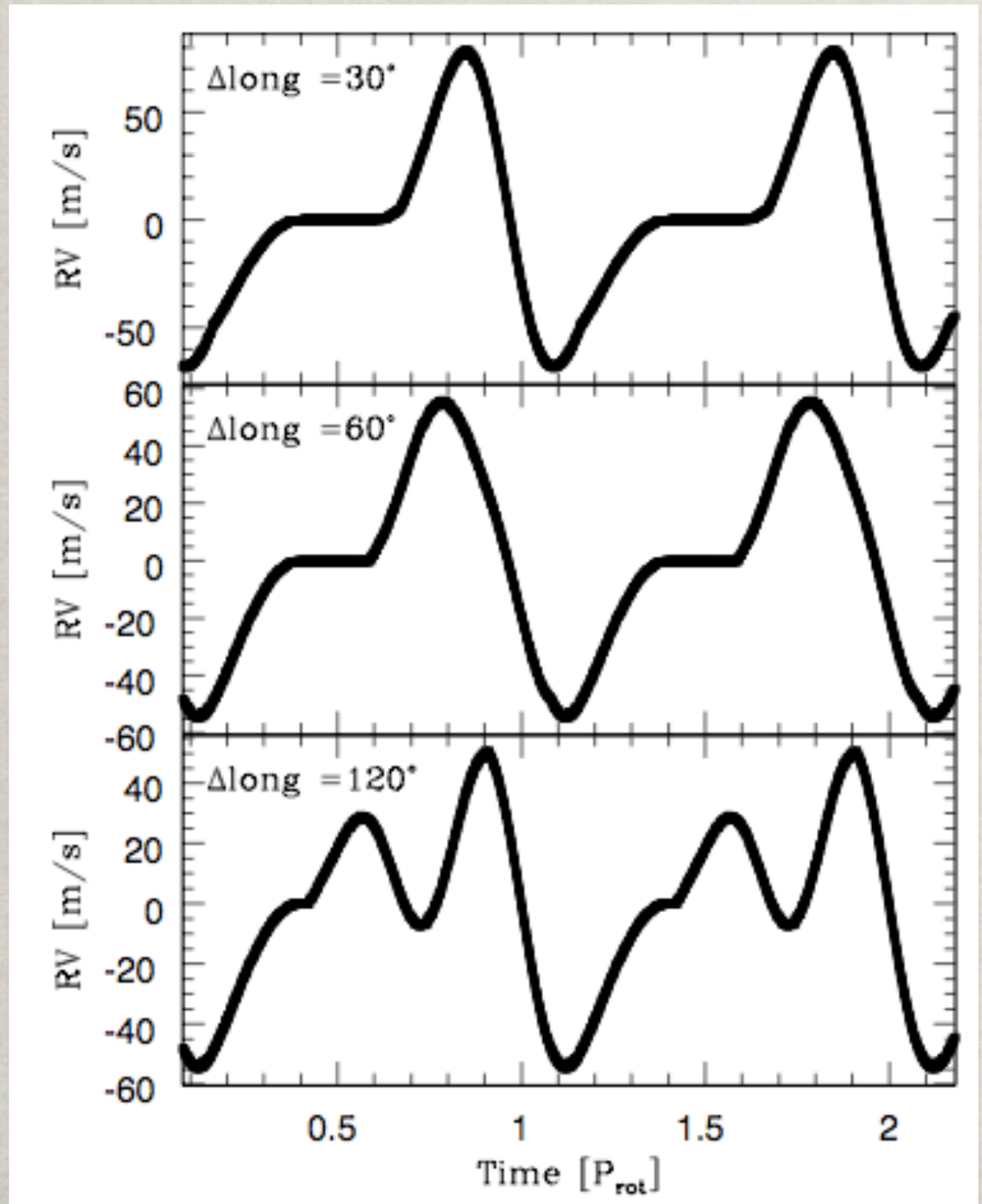
Simulations studies

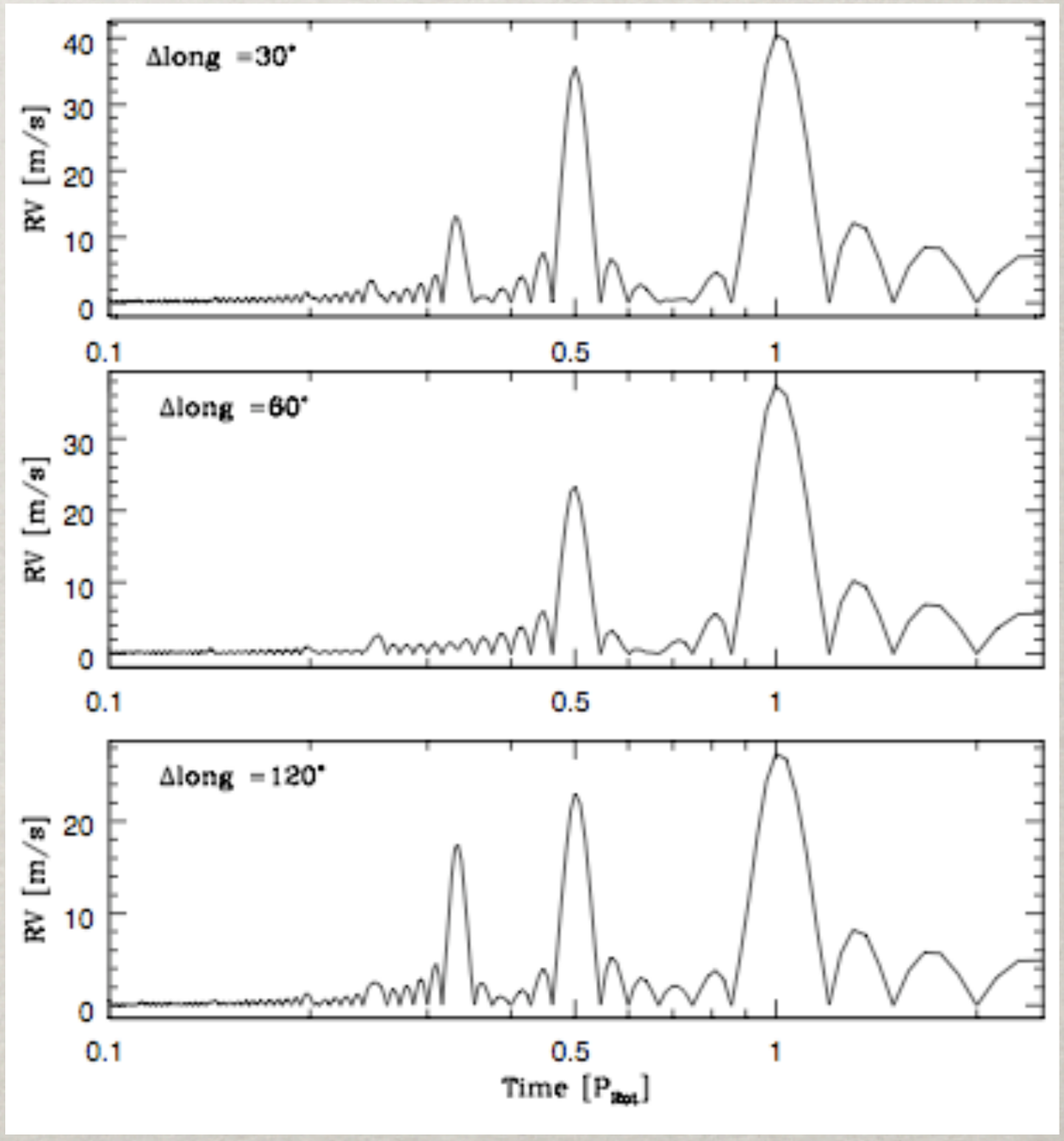
spot with amplitude variations



Simulations studies

Several spots





Simulations studies

Fit active jitter

- Fit activity jitter with 3 sinusoids with periods fixed at P_{rot}, $P_{rot}/2$, $P_{rot}/3$

- Removed 90% of the active jitter

Observations and Applications on real data

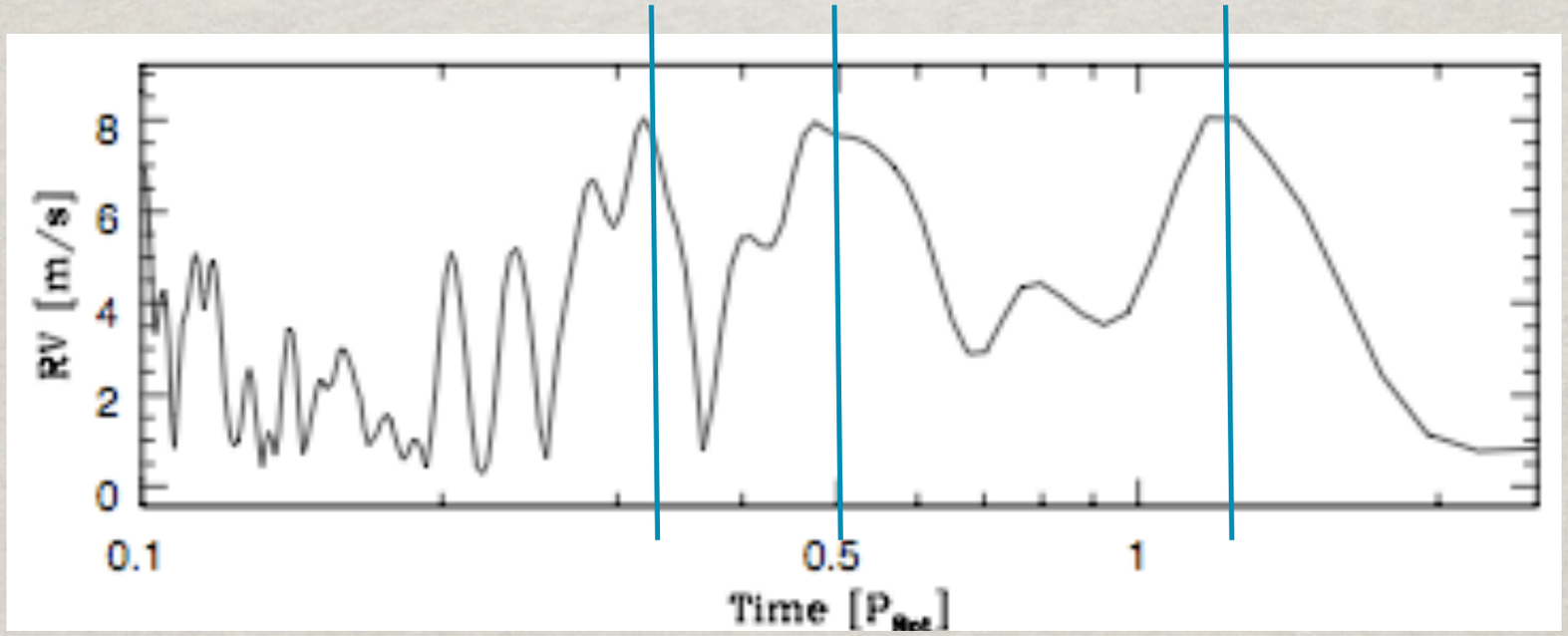
Boisse et al. A&A, subm.

Tests on real data

HD189733

- Active planet host star
- Periodogram of the RV after removed planetary signal

Prot /3 Prot/2 Prot



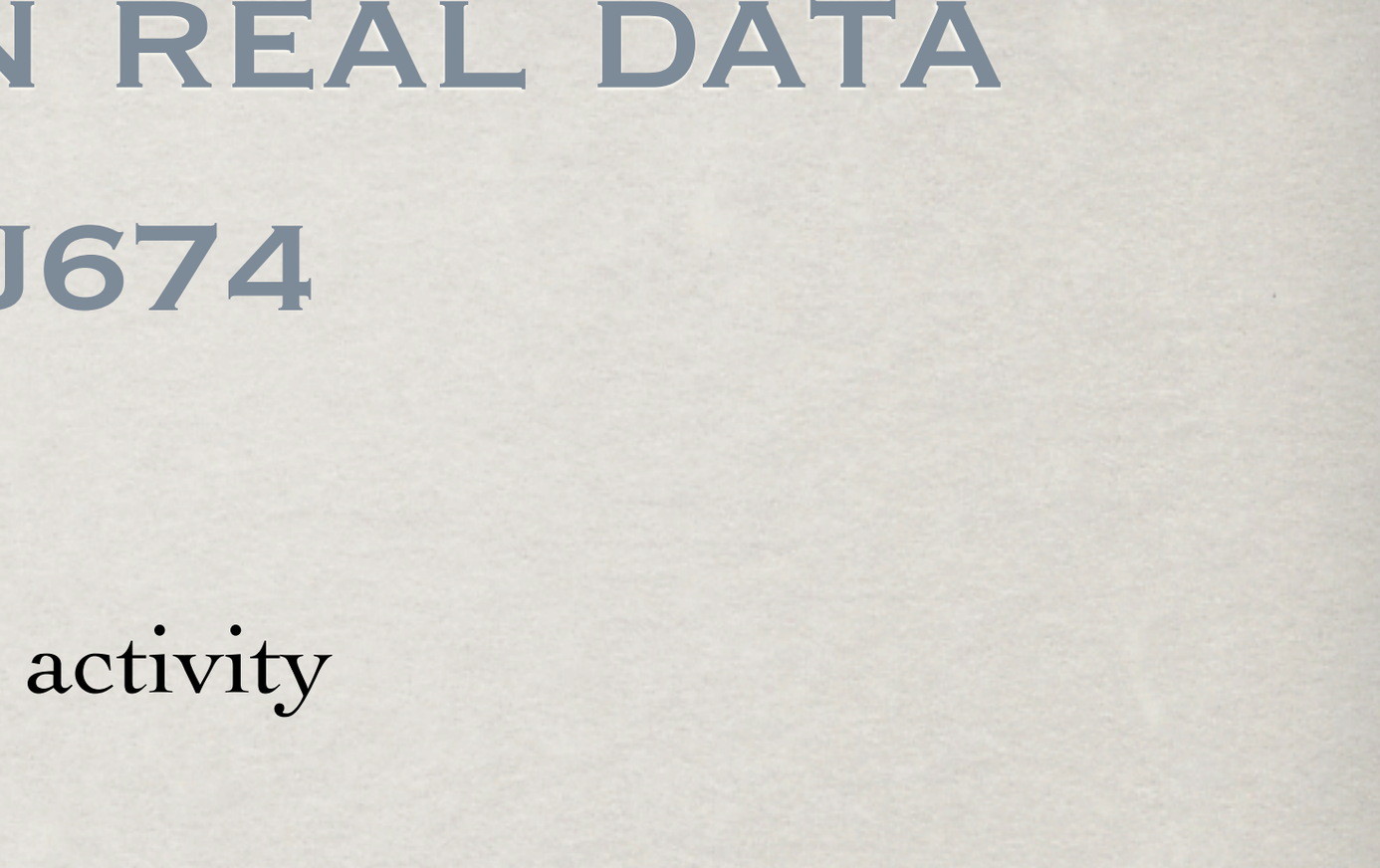
Tests on real data

GJ674

- Active M-dwarf
- Two signals: planet and activity

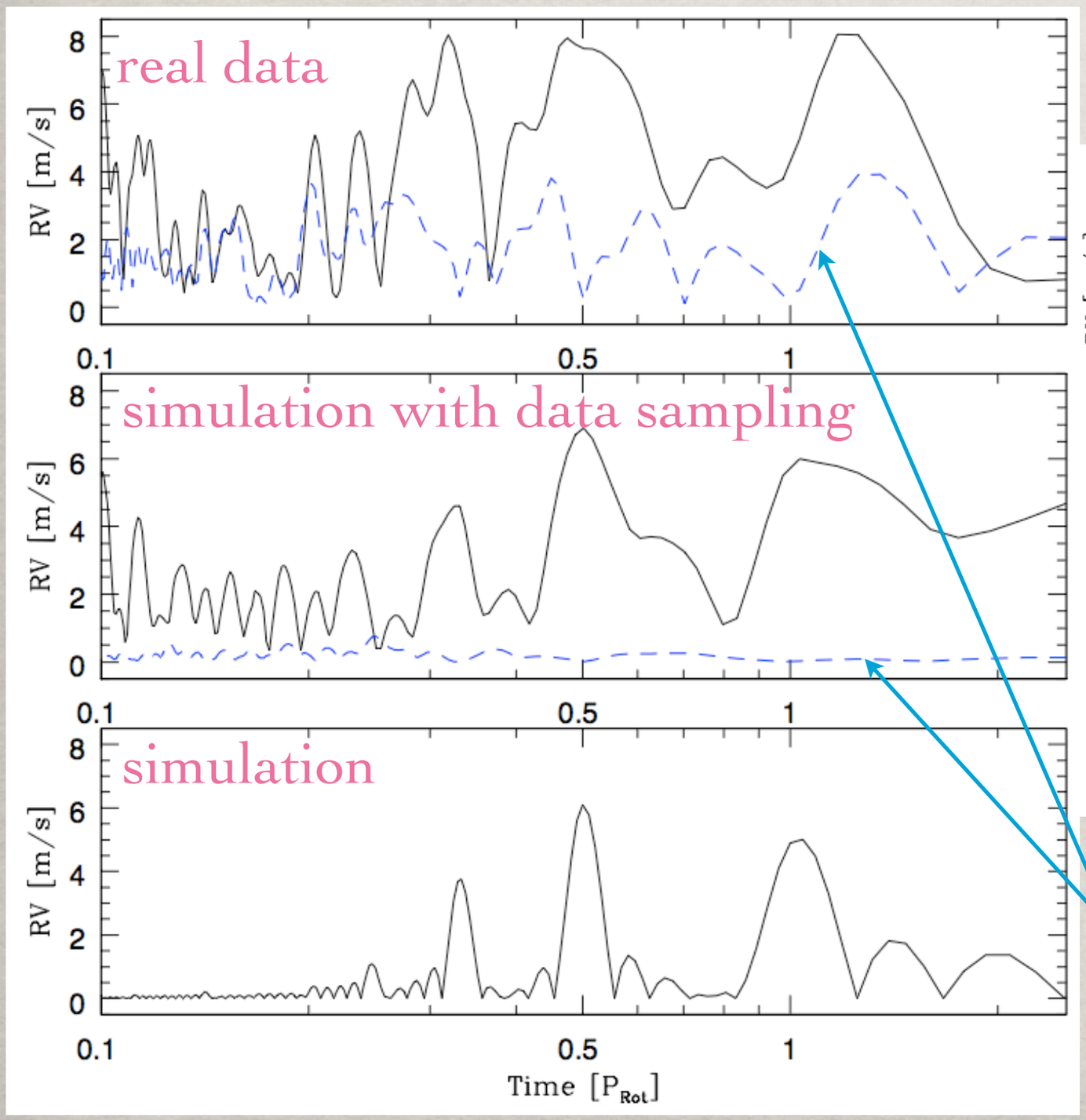
Planetary parameters	Bonfils et al. (2007)	This paper
P_P [days]	4.694 ± 0.007	4.694 ± 0.002
K [$m\,s^{-1}$]	8.70 ± 0.19	8.9 ± 0.3
e	0.20 ± 0.02	0.19 ± 0.03
ω [deg]	143 ± 6	159 ± 10
T_0 [JD]	53780.09 ± 0.08	53780.25 ± 0.12
$m_2 \sin i$[a] [$M_\oplus$]	11.09	11.39
$\sigma_{(O-C)}$[b] [$m\,s^{-1}$]	0.82	0.65
reduced χ^2	2.57	1.36 ± 0.27

[a] assuming $M_\star = 0.35\ M_\odot$ (Bonfils et al. 2007)
[b] $\sigma_{(O-C)}$ after the fit



Sampling effect

HD189733



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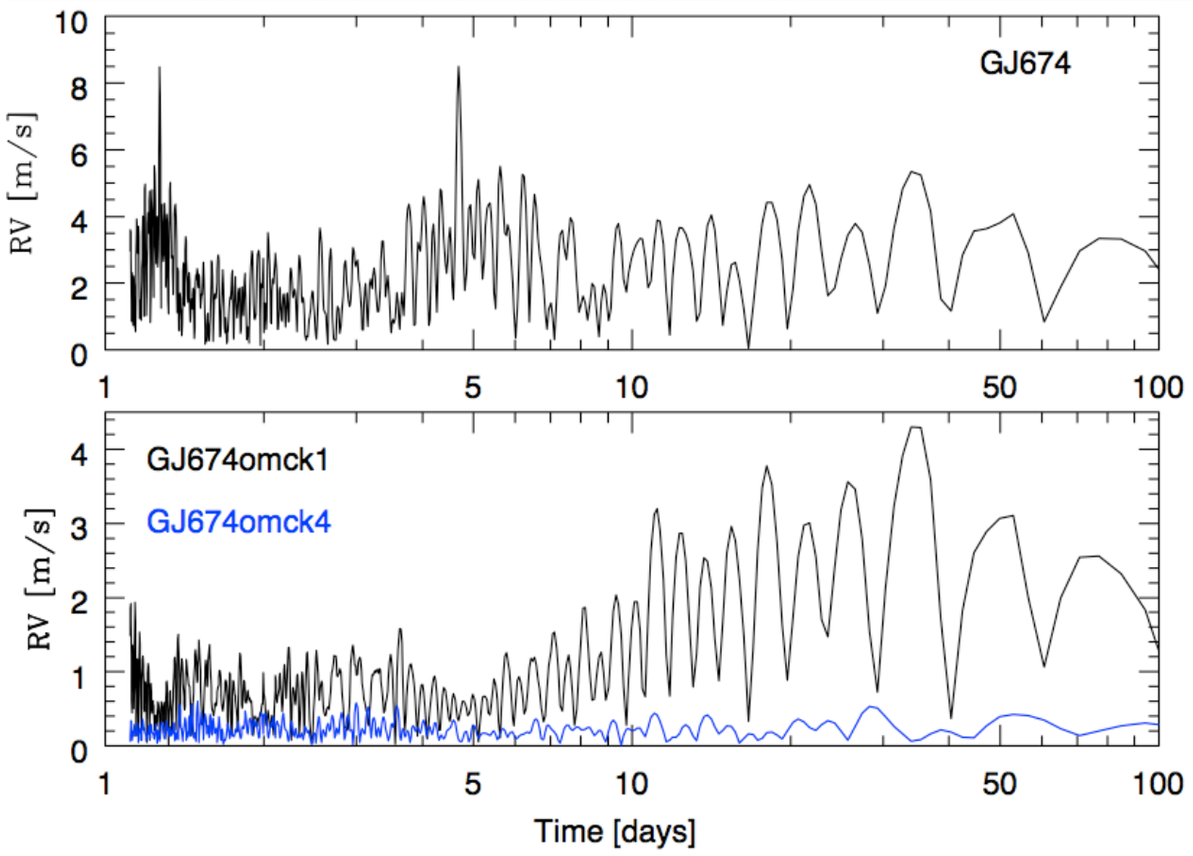


after activity subtraction with 3 sinusoids fixed at P_{rot}, $P_{rot}/2$ and $P_{rot}/3$.

Tests on real data

CoRoT 7

- Transiting planet CoRoT-7b Léger et al. 2009
- RV follow-up: masses and CoRoT-7c Queloz et al. 2009

→ Simultaneous fit of stellar activity and planetary parameters

Parameters					
P_P [days]	P_{rot}=23 (fixed)	$P_{rot}/2$=11.5 (fixed)	$P_{rot}/3$=7.66667 (fixed)	3.695 ± 0.02	0.8536 (fixed)
K [$m\,s^{-1}$]	14.3 ± 0.8	3.7 ± 0.8	1.2 ± 0.2	6.1 ± 0.6	4.5 ± 0.7
e				0 (fixed)	0 (fixed)
T_0 [JD]				54899.2 ± 0.7	54899.761 (fixed)
mp [$M_\oplus$]				14.4 ± 1.5	6.4 ± 1.1
$\sigma_{(O-C)}$ [$m\,s^{-1}$]		before the fit 10.	after the fit 3.1; reducedχ^2 = 2.		

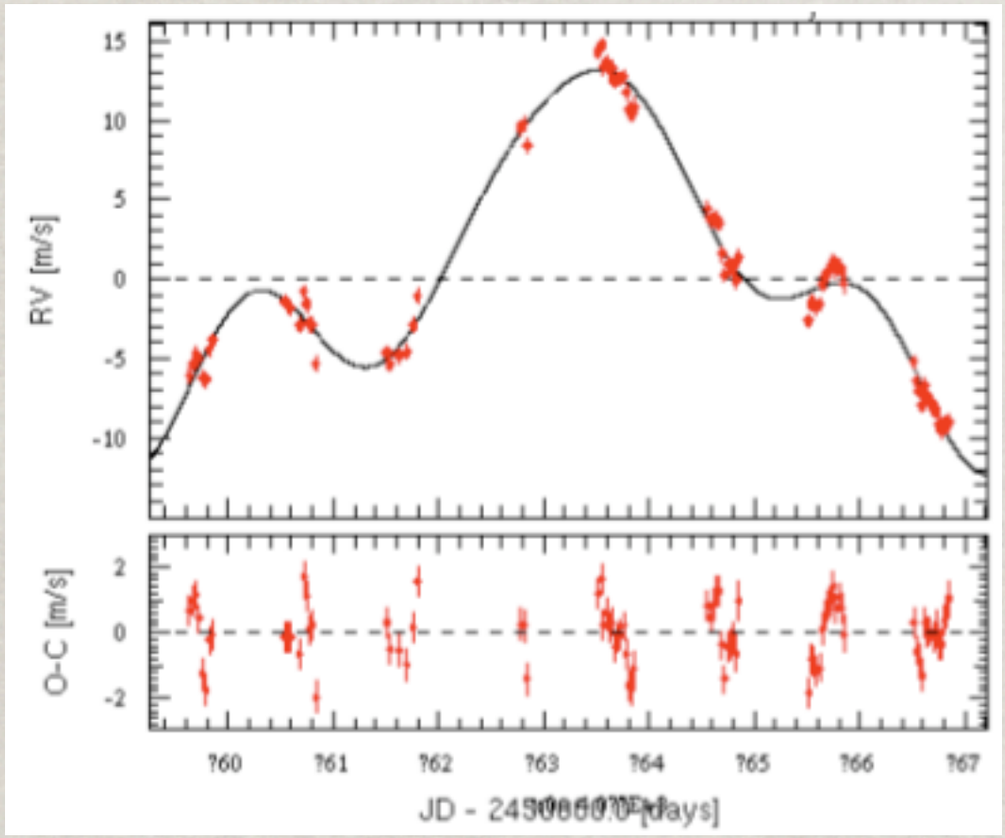
Tests on real data

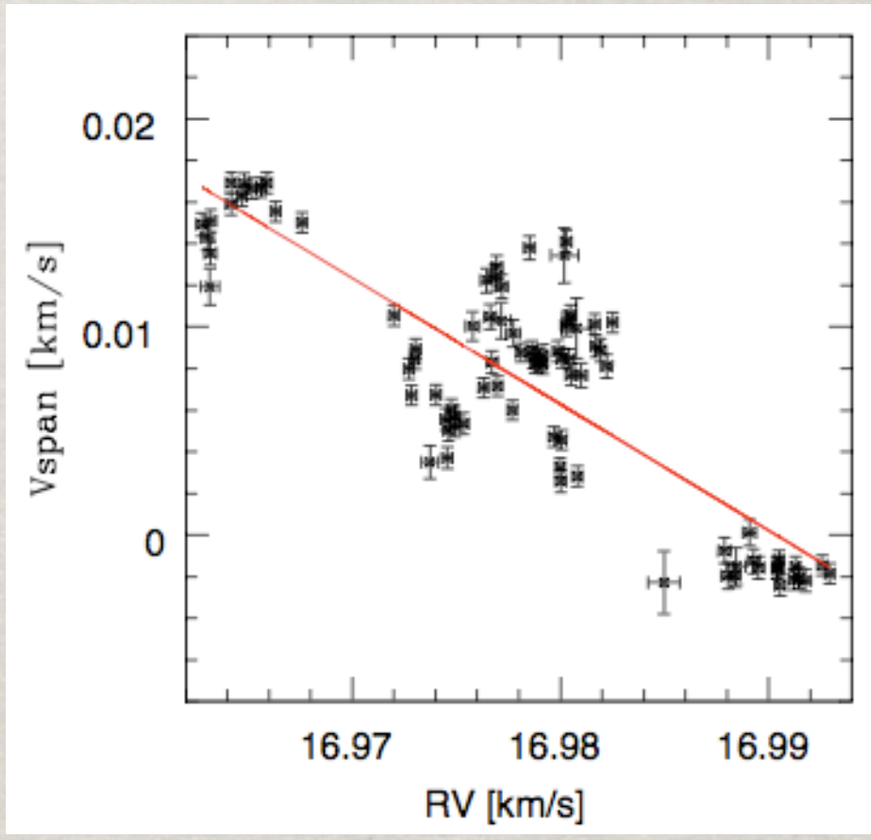
iotaHor

- Young active G0V star
- Long-period exoplanet (320.1d)
- 8-nights asteroseismologic run with HARPS Vauclair et al. 2008
- Stellar rotational period ≈ 8 days

Tests on real data

iotaHor





Tests on real data

iotaHor

- Simulations with fake planets to check which planets are fitted with the active signal

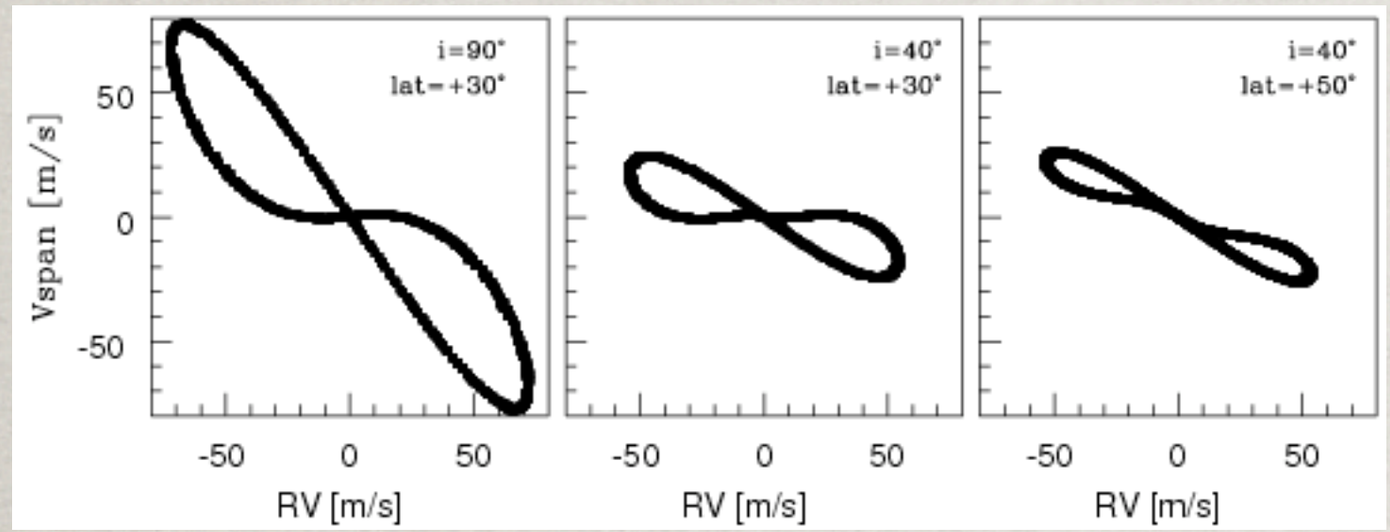
- No planets with period < 2.5 days and K > 3 m/s

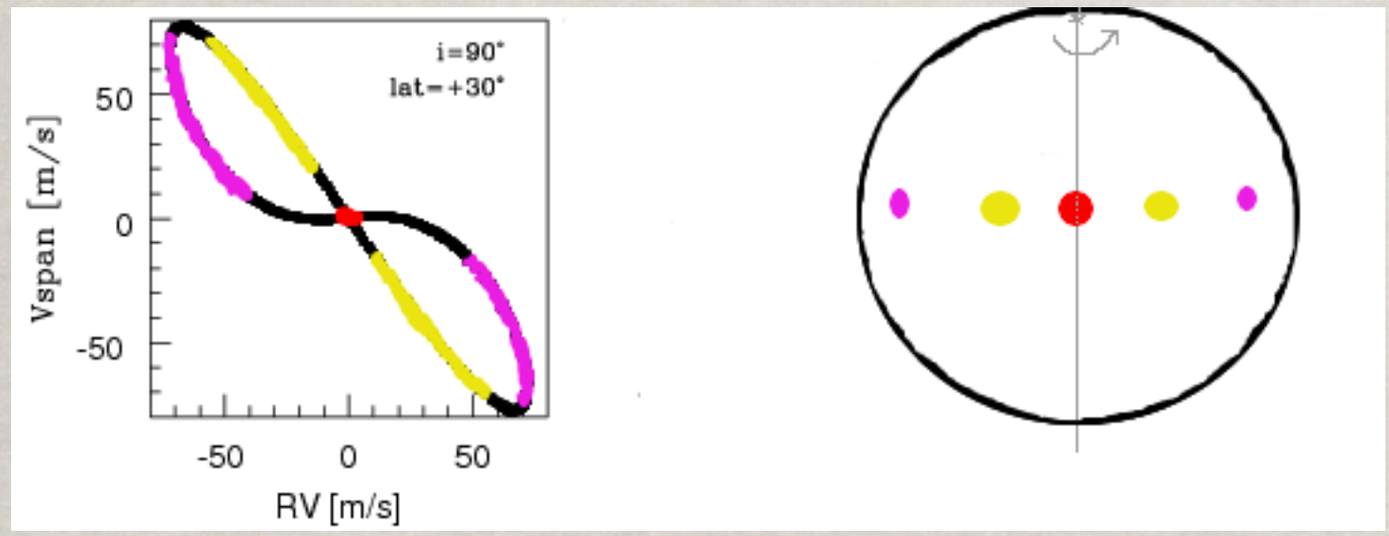
Other Parameters

Boisse et al. A&A, subm.

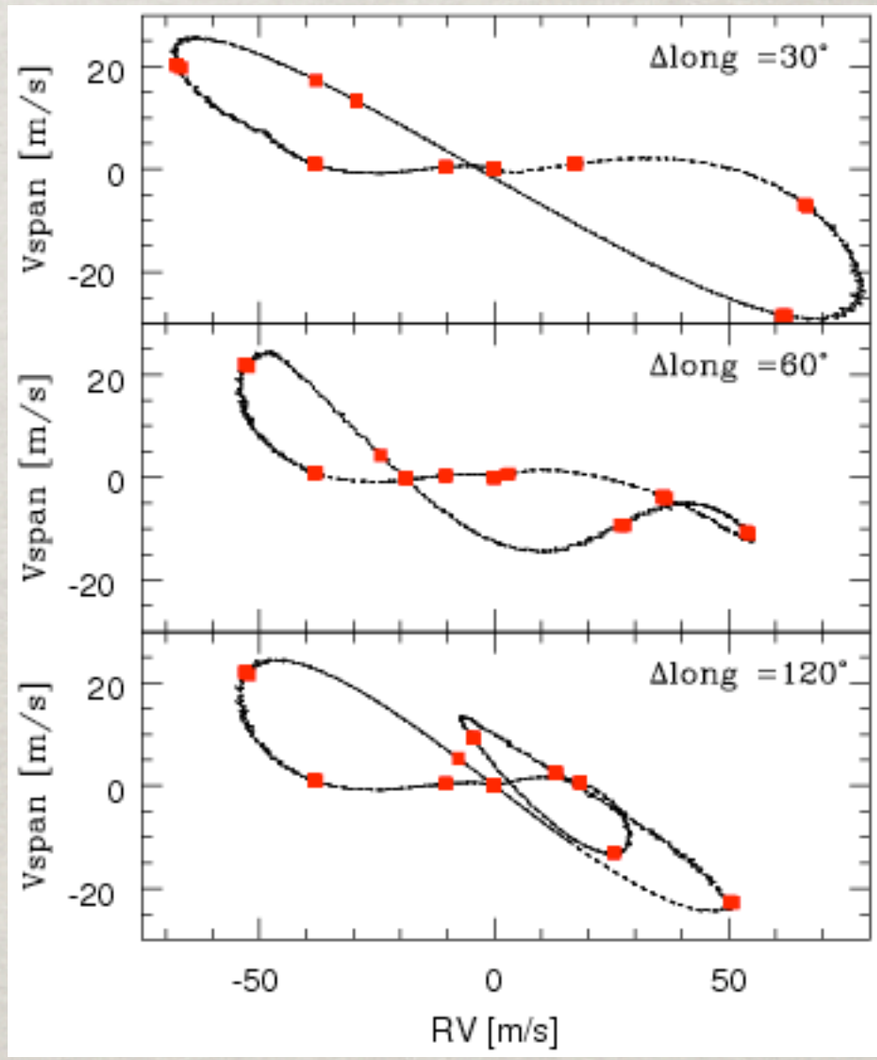
Anti-correlation Bis / RV

One spot



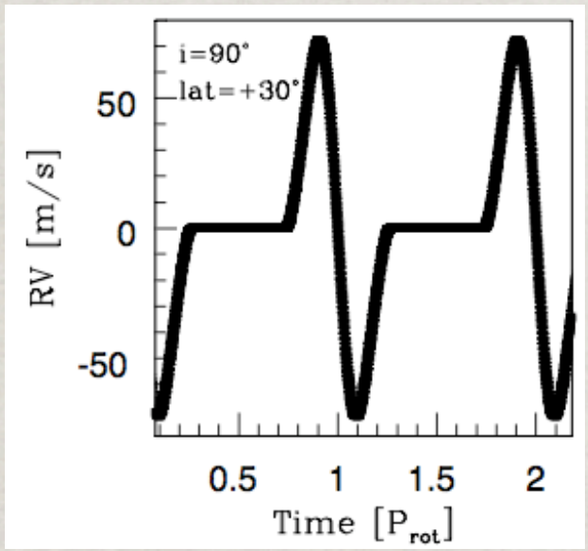


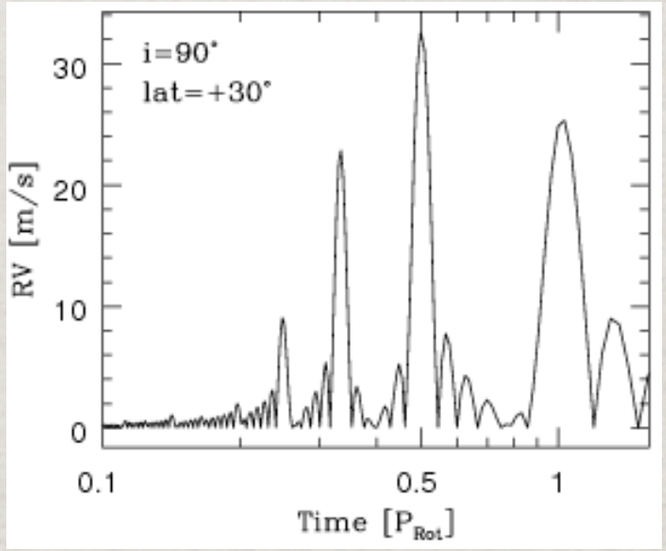
Two spots

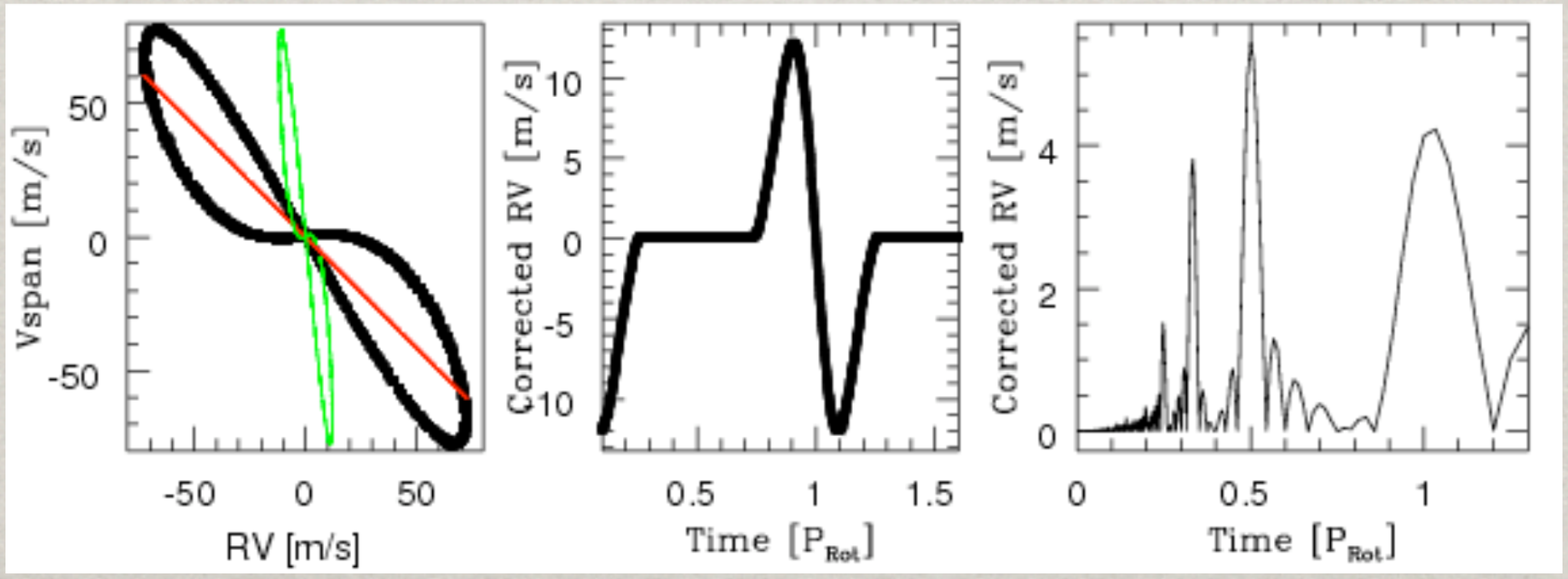


Anti-correlation BIS / RV

- Remove anti-correlation BIS / RV

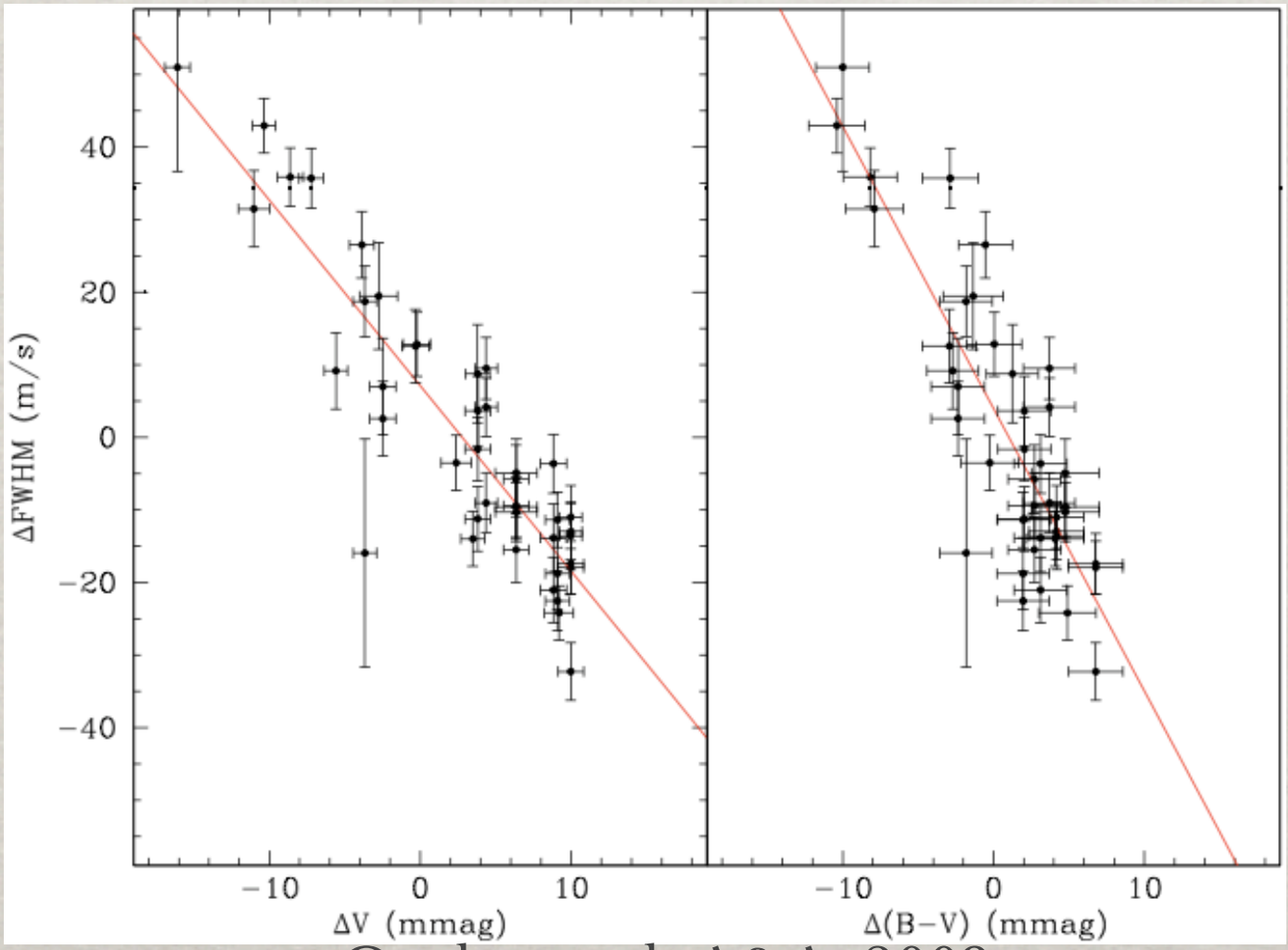






FWHM variations

- A better indicator than bisector ?
- Bisector variations are compared to those of RV that may be affected by a planetary signal !!



Queloz et al. A&A, 2009

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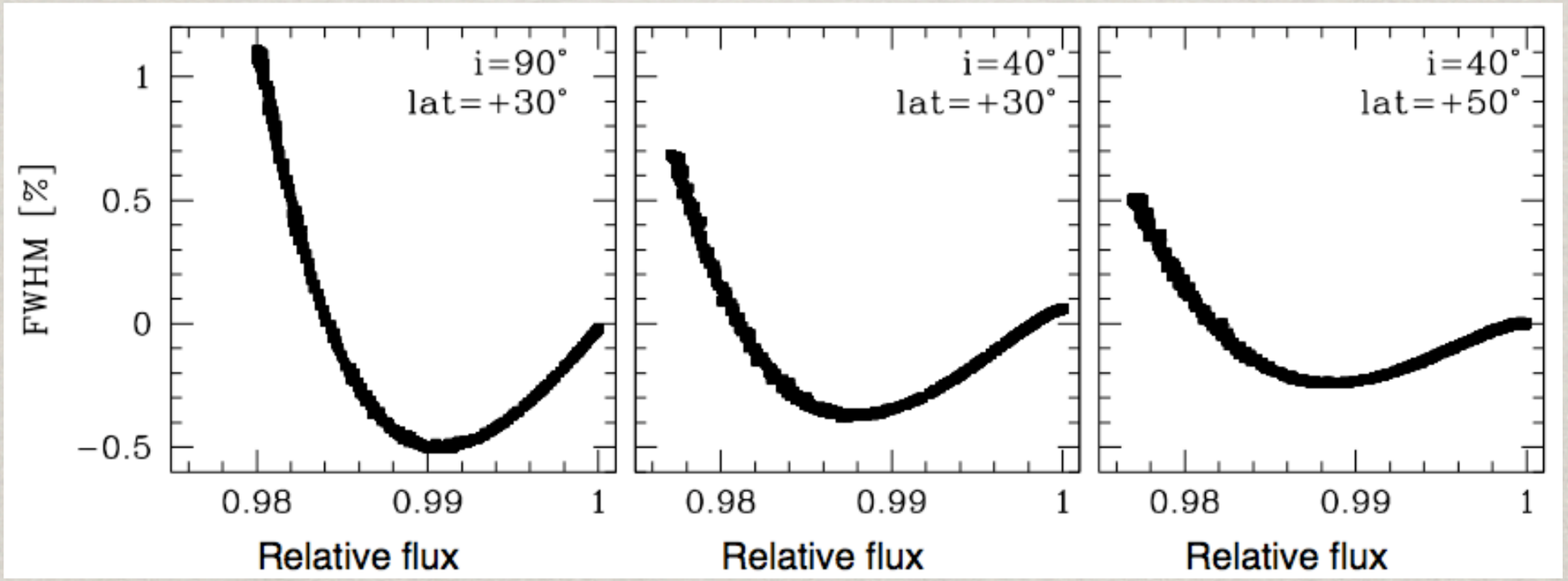
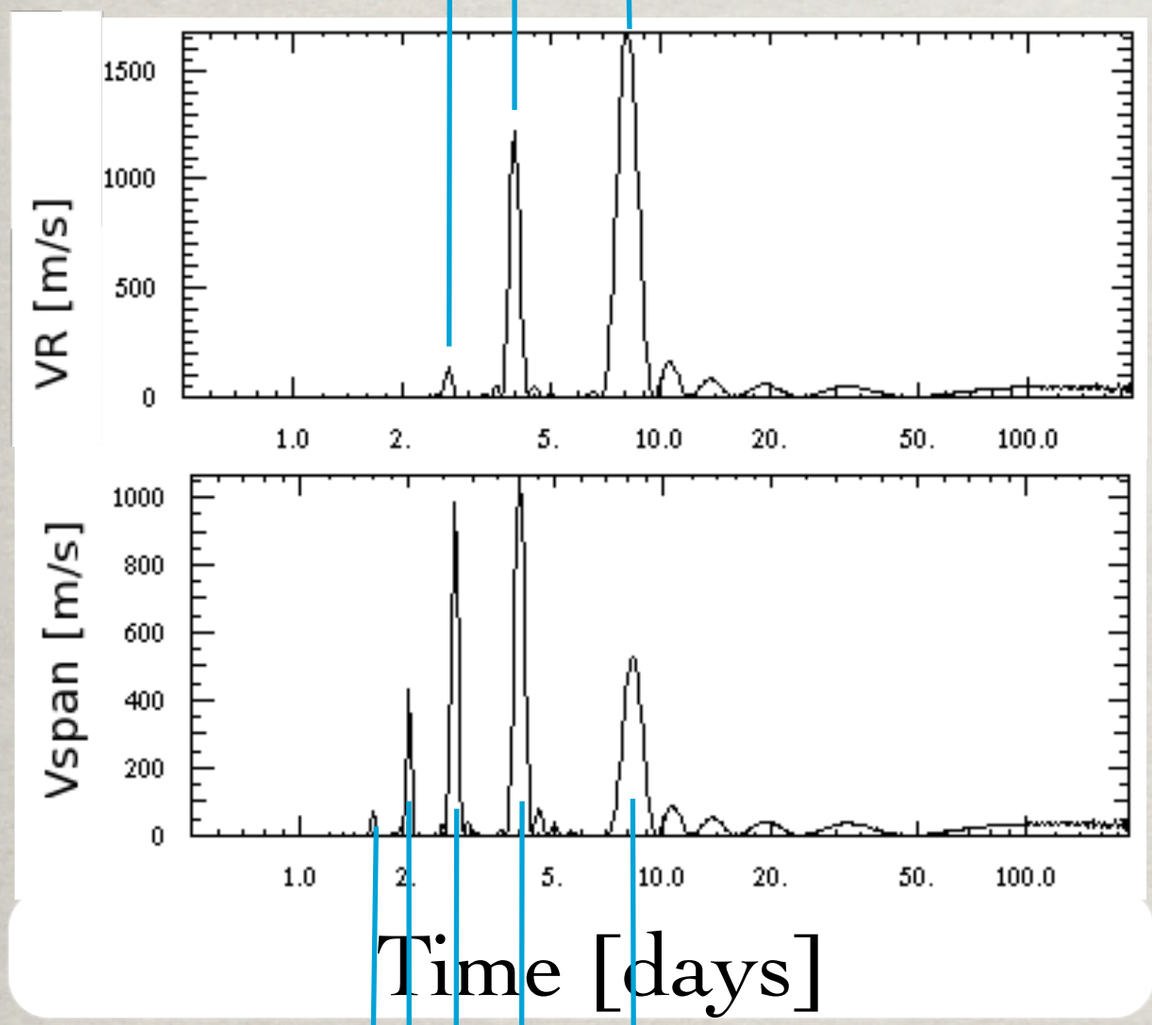
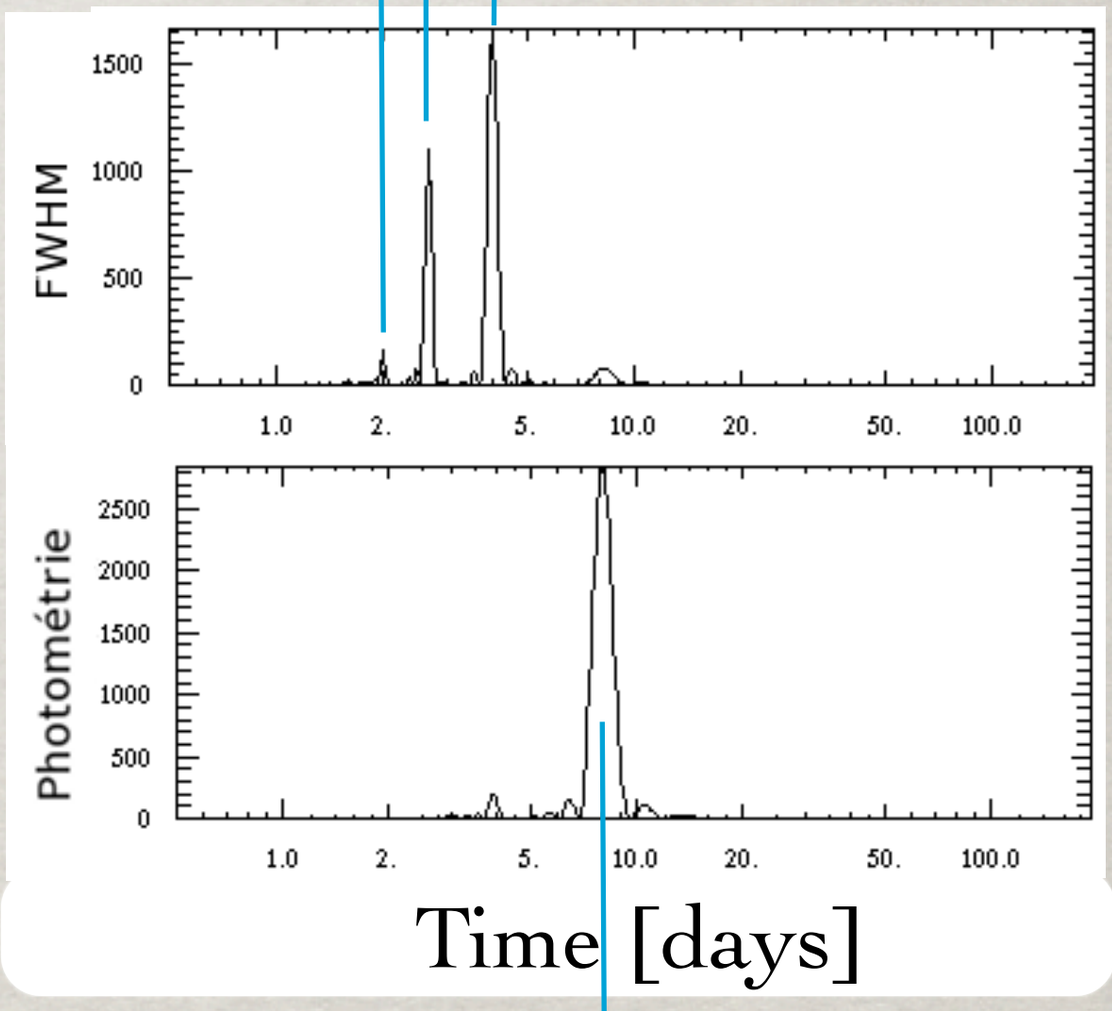


Other CCF parameters

One Spot





Simulations studies

Bright plages

- Lower amplitude impact than spots Saar 2003, Meunier et al. 2010
- Low-active stars are dominated by plages (Sun during its active phase), different from active stars Lockwood 2007

→ Shapes of all parameters are reversed

→ Anti-correlation BIS / RV and FWHM / Photometry remain indicators

Conclusions and Perspectives

Conclusions & Perspectives

- RV variations due to activity present periodicities at P_{rot} and its two first harmonics
- Three sinusoids fit removes 90% of the active jitter
- Need to know the P_{rot} of the star or data cover two P_{rot}
- Explore the FWHM / Photometry anti-correlation
- Find another way to measure the deformation of the CCF ?

  Cameron et al. 2009, 2010
- Find another way to measure the RV ?