MODELING STELLAR VARIABILITY WITH GAUSSIAN PROCESSES

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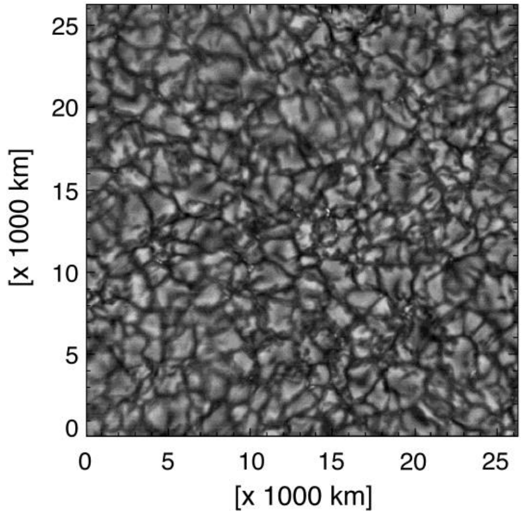
Outline

- Stellar Variability/Activity
- Gaussian Processes
- Granulation and Transits
- Activity and phase curves

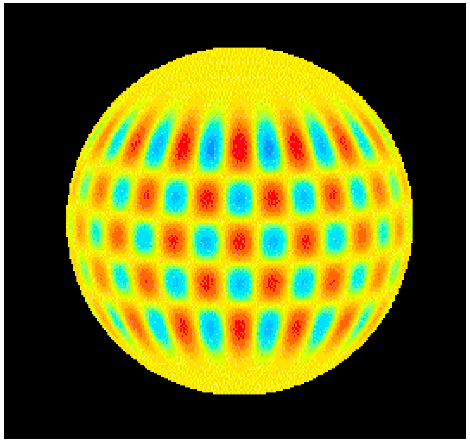
Stellar variability

Granulation



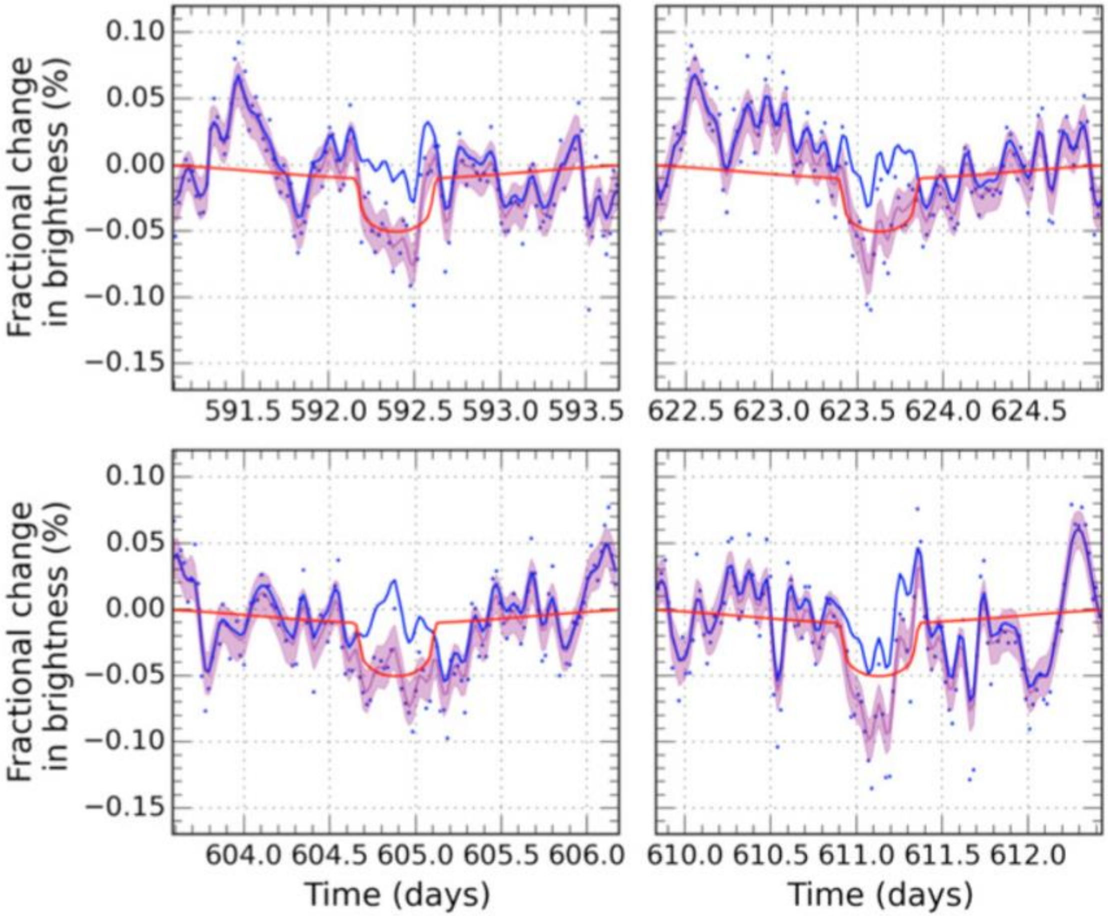
Convection of plasma
timescales ~20 minutes
Amplitudes 50-500 ppm
Stochastic

Oscillations



p-mode oscillations
timescales 5-15 minutes
Amplitudes 100-300 ppm
Quasi-periodic

Kepler-91 red giant

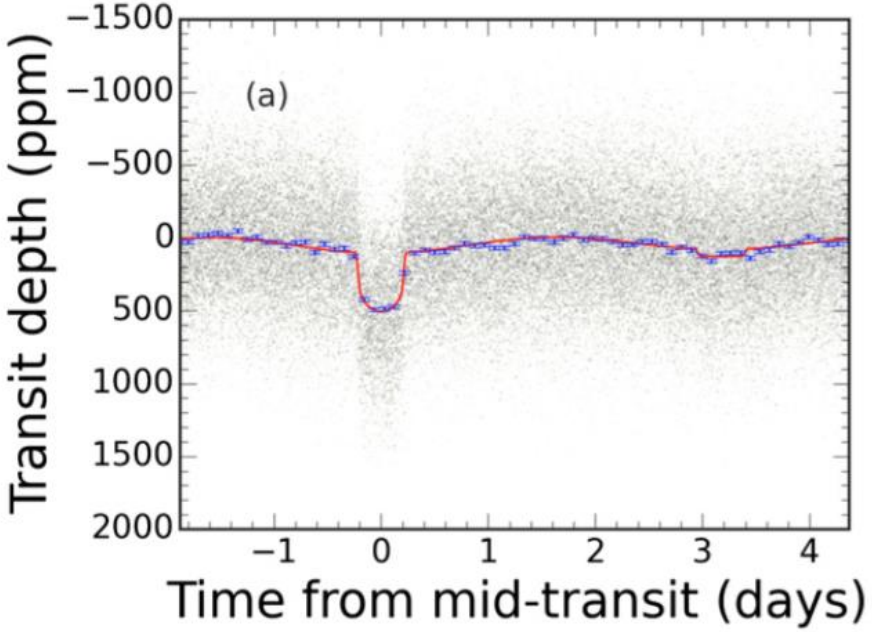


Amp = 302 ppm
Tau = 53 minutes

P_b = 6.3 days

Barclay et al, 2015, ApJ, 800,46

Phase fold



Barclay et al, 2015, ApJ, 800,46

BIAS single transits
detection?
parameters?

Gaussian Processes

- Multivariate Gaussian distributions with infinite dimension characterized by their covariance structure (Kernel)
- Can be used to preform non linear regression non parametrically
- Flexible
- Used to model noise in transmission spectroscopy (Gibson et al. 2011), stellar activity in radial velocity observations (Haywood et al. 2014), decoupling stellar activity systematic noise in K2 (Aigrain et al. 2016) and to estimate stellar rotation (Angus et al. 2017)
- More information: Rasmussen & Williams 2006.

Simulated light curves

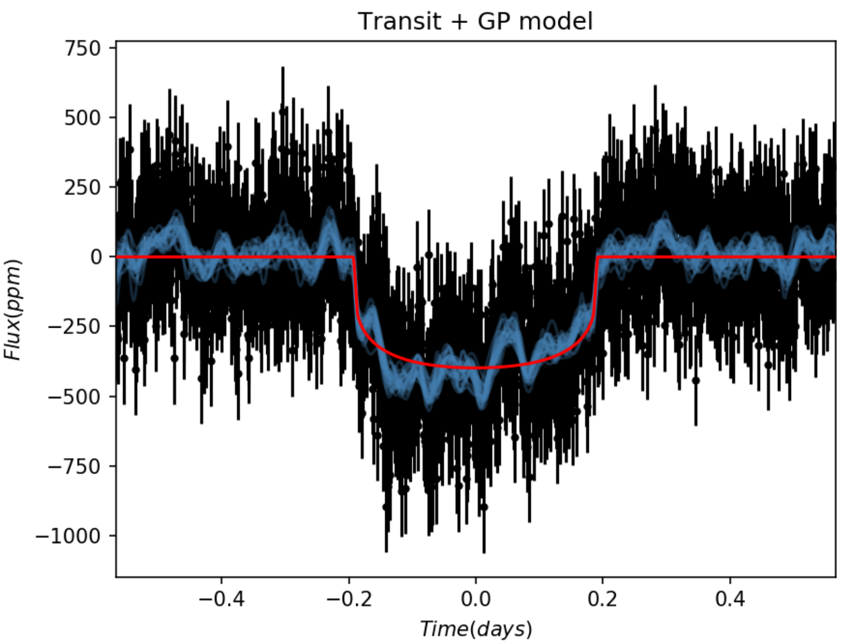
$$PSD(\nu) = \frac{2\sigma_{gran}^2 \tau_{gran}}{1 + (2\pi\nu\tau_{gran})^4};$$

$$\sigma_{gran} = 75 \left(\frac{M}{M_\odot}\right)^{-0.5} \left(\frac{R}{R_\odot}\right) \left(\frac{T_{eff}}{T_{eff,\odot}}\right)^{0.25} \quad ppm;$$

$$\tau_{gran} = 220 \left(\frac{M}{M_\odot}\right)^{-1} \left(\frac{R}{R_\odot}\right)^{2} \left(\frac{T_{eff}}{T_{eff,\odot}}\right)^{0.5} \quad seconds.$$

Kallinger et al. 2014 A&A, 570,41

Biasing transit parameters



4 R_{Earth} planet with a period of 19.14 days around a star with M = 1.3 M_{Sun} , R = 2 R_{Sun}, Teff =6000 K.

Simulated transits and granulation Hot Jupiter – Super Earths and instrumental noise of 30 ppm per 30 minutes

Concluded that granulation can bias the transit parameters (systematics of 2σ).

GPs allow a better determination of the uncertainties and to derive unbiased transit parameters.

Lendl, M.; Oshagh M. et al in prep.

Granulation sample

- Bright stars, high cadence ➔CoRoT seismology channel
- 32 second sampling

Star	Spetral type	V mag	P rot	comment
HD 49933	F3 V	5.8	3.4	
HD 52265	G0 V	6.3	12.3	non transiting Jupiter
HD 43587	G0 V	5.7	long	
HD 42618	G3 V	6.8		non transiting Neptune
HD 179079	G5 IV	8.0		non transiting warm Neptune

J. Cabrera, R. Diaz and ISSI team

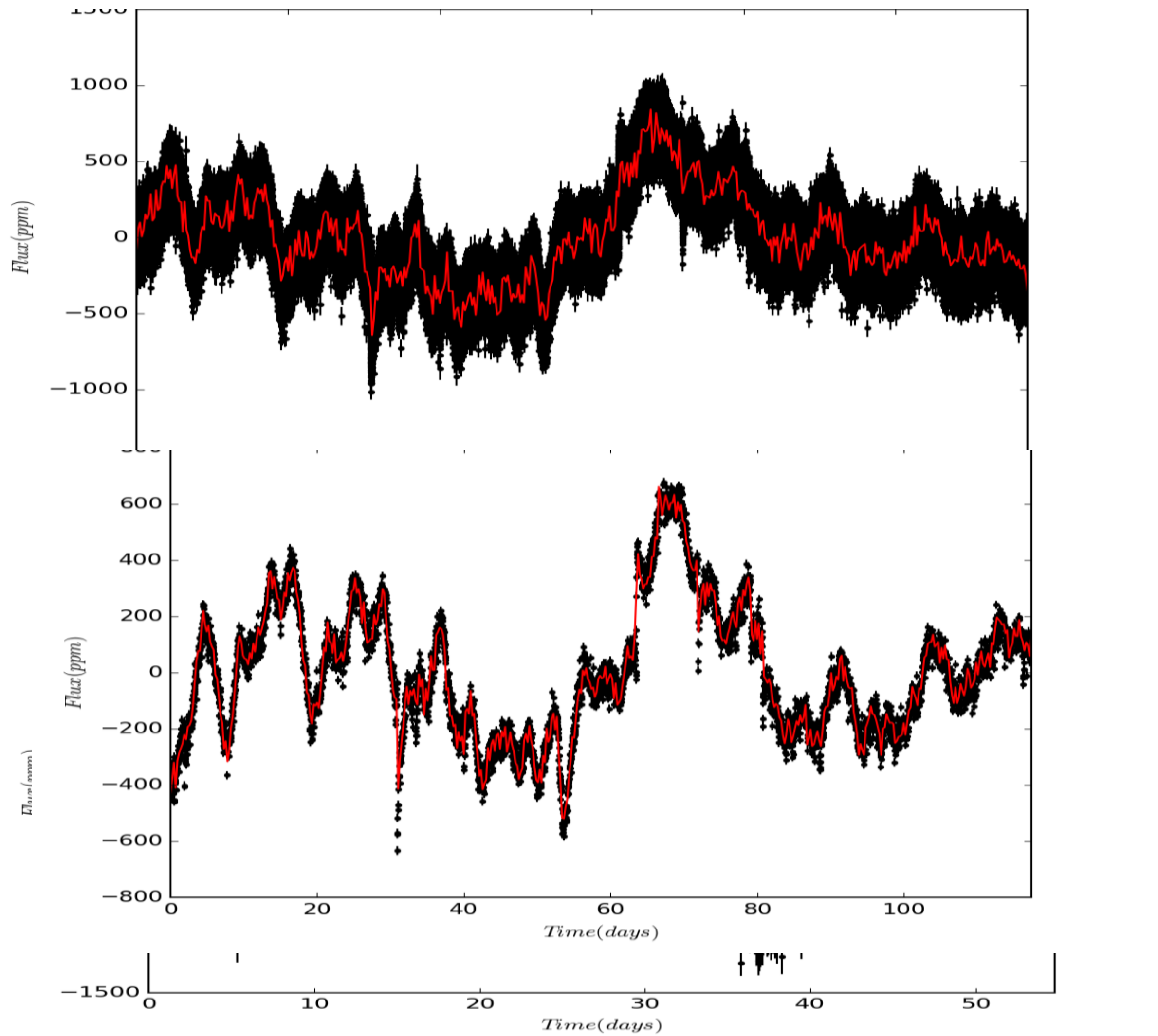
3 exponential squared kernels

Star	Spetral type	1^{st} component amp (ppm)	τ (min)	2^{nd} component amp (ppm)	τ (hours)	3^{rd} component amp (ppm)	τ (days)
HD 49933	F3 V	43	6.7	49	0.6	522	0.53
HD 52265	G0 V	42	5.5	30	1.2	309	1.4
HD 43587	G0 V	40	5.7	30	1.7	171	0.76
HD 42618	G3 V	57	4.9	50	2.3	84	1.17
HD 179079	G5 IV	94	4.9	60	1.5	190	1.46

Kepler -91
Amp = 302 ppm
Tau = 53 minutes
Barclay et al, 2015

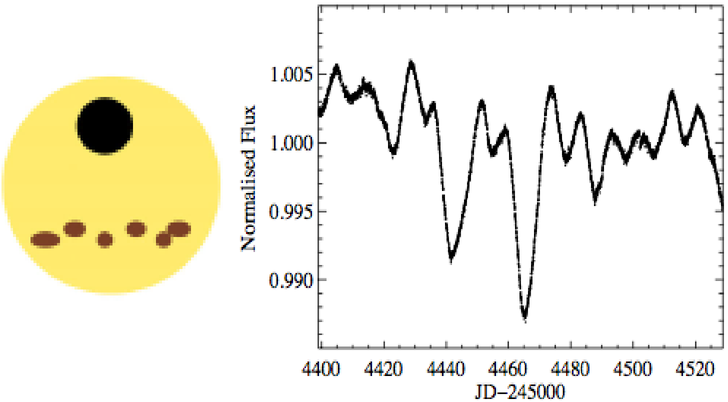
HD 52265

HD 179079

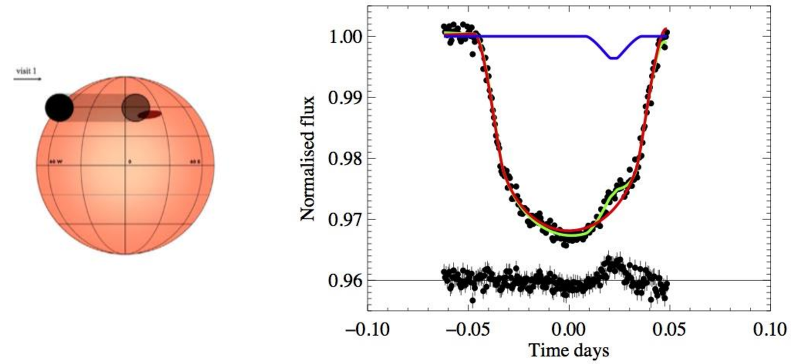


GPs model well stellar granulation and oscillations.
Further work is needed determine the number of components

Stellar activity effects on transits



CoRoT-7 Barros et al 2014, A&A.



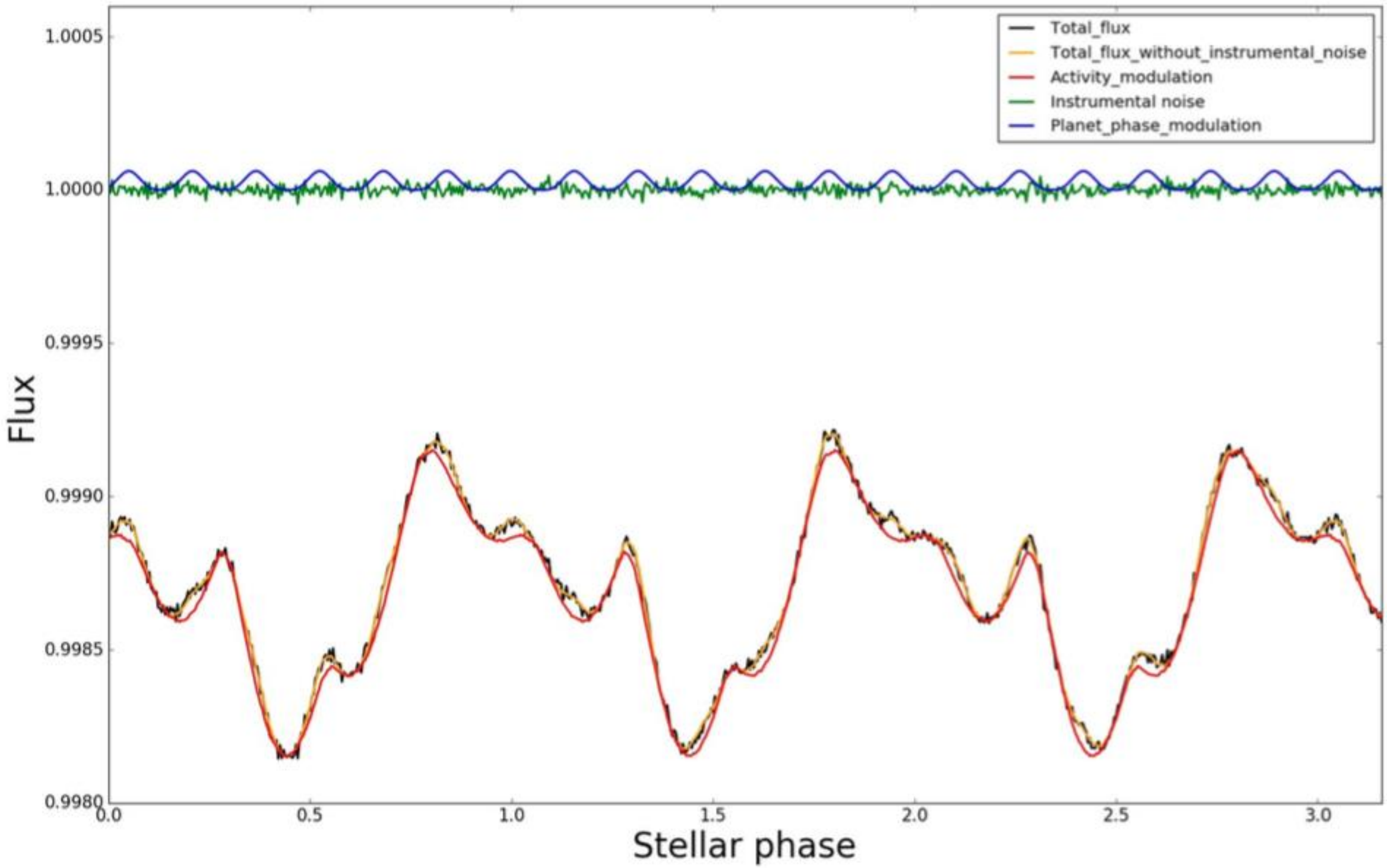
WASP-10b (Barros et al, MNRAS 2013)

The 2% out of transit variability affects transit depth:
0.6% error on stellar density
1% error on planetary radius

TTVs (WASP-10b Barros et al 2013, Oshagh et al 2013,)
Radius estimates (CoRoT-2, Silva-Valio 2010, Czesla et al 2009)
Transmission spectroscopy (HD189733b Pont 2007)

Effect on phase curves ?

Activity and phase curves



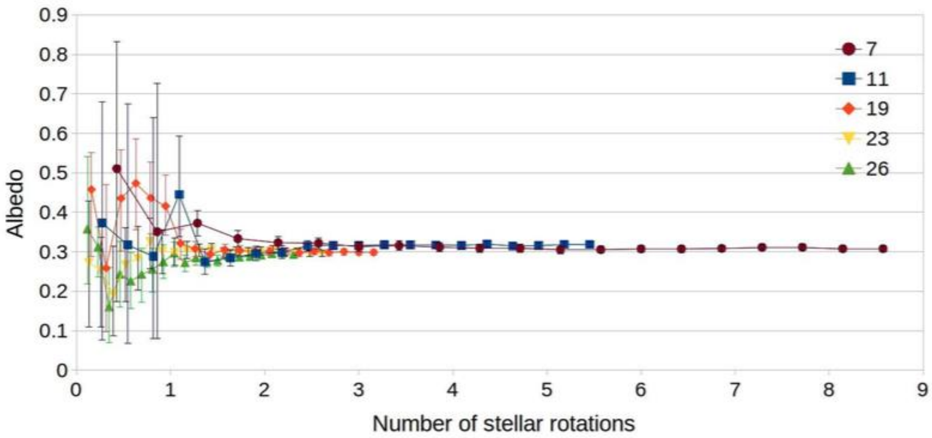
Luisa Maria Serrano, Nuno Santos, Mahmoudreza Oshagh

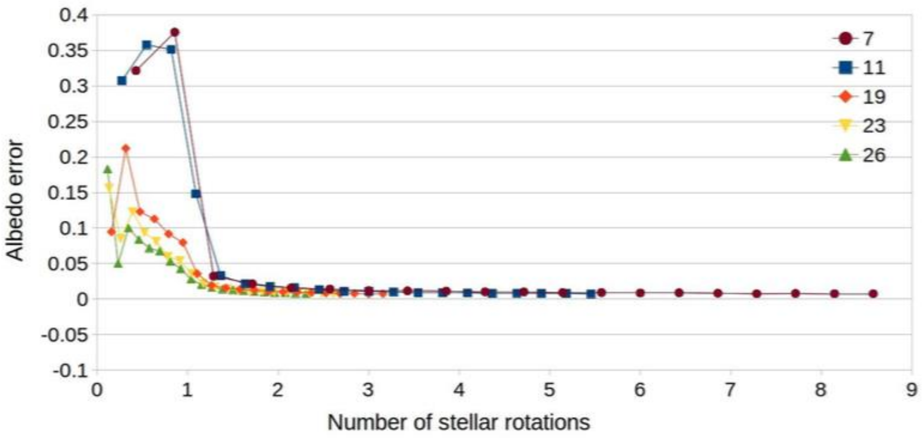
Method

- Model of the reflected light – albedo as free parameter
- GP with a periodic kernel to model the stellar activity
- Coupled with an MCMC for parameter inference

Will it work?
How long do we need to observe?

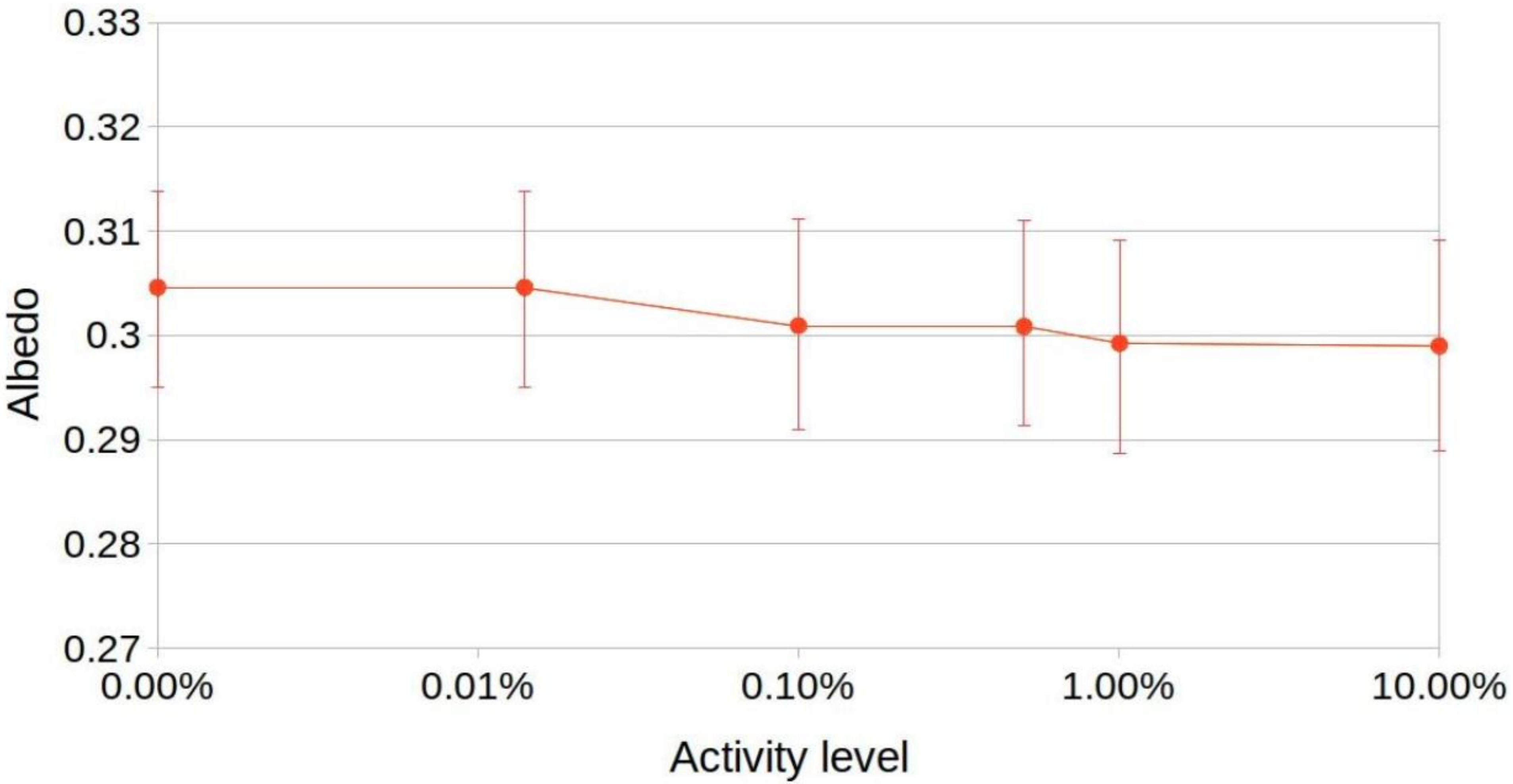
Main result





Need more than 1 stellar rotation to estimate albedo

Activity level



Conclusions

- For high signal-to-noise light curves stellar granulation can limit the accuracy of the transit parameters and decrease planet detectability

- Gaussian processes can model well stellar granulation in light curves and help unbias the transit parameters

- Gaussian processes can also be used to model stellar activity in light curves and help derive accurate albedos

THANKS