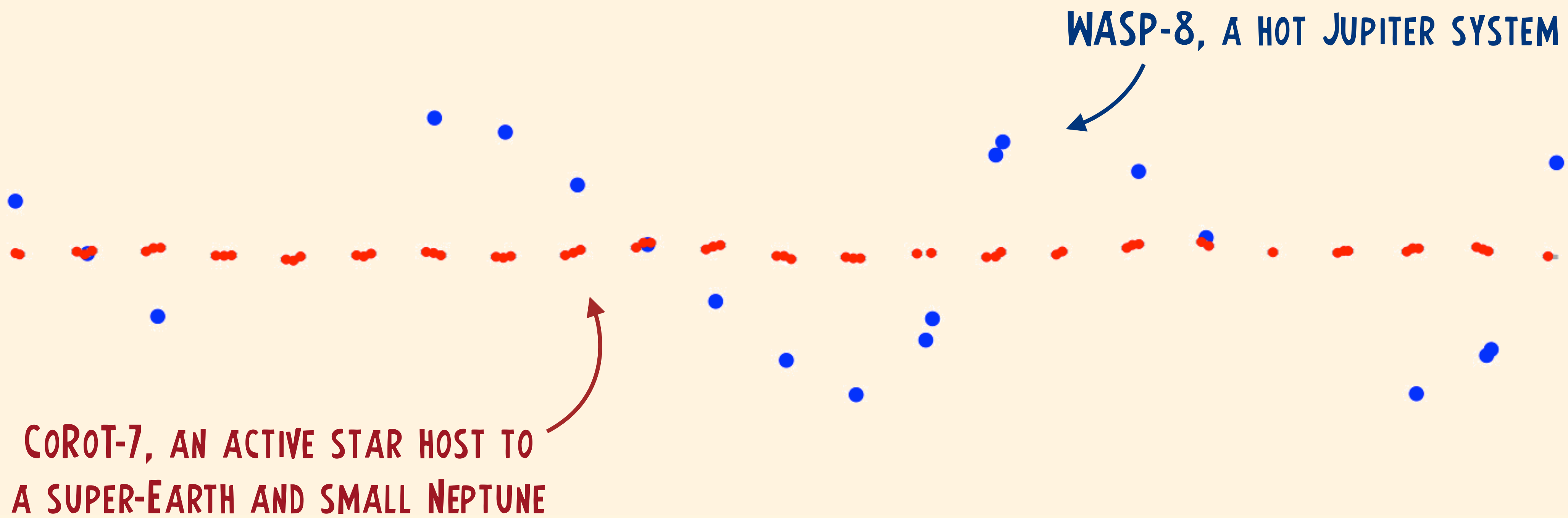
Accounting for stellar activity in exoplanet radial-velocity data using Gaussian processes



University of St Andrews

Raphaëlle D. Haywood

A. C. Cameron, D. Queloz, S.C.C. Barros, M. Deleuil, R. Fares, M. Gillon, A. Hatzes, A. F. Lanza, C. Lovis, C. Moutou, F. Pepe, D. Pollacco, A. Santerne, D. Ségransan, Y. Unruh

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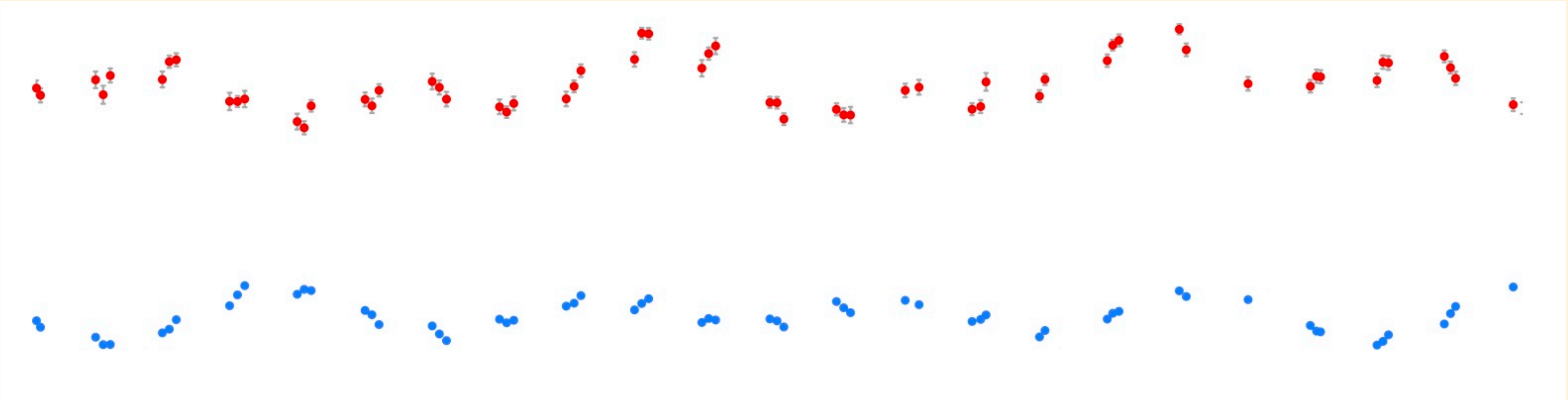

CoRoT-7, an active star host to a super-Earth and small Neptune

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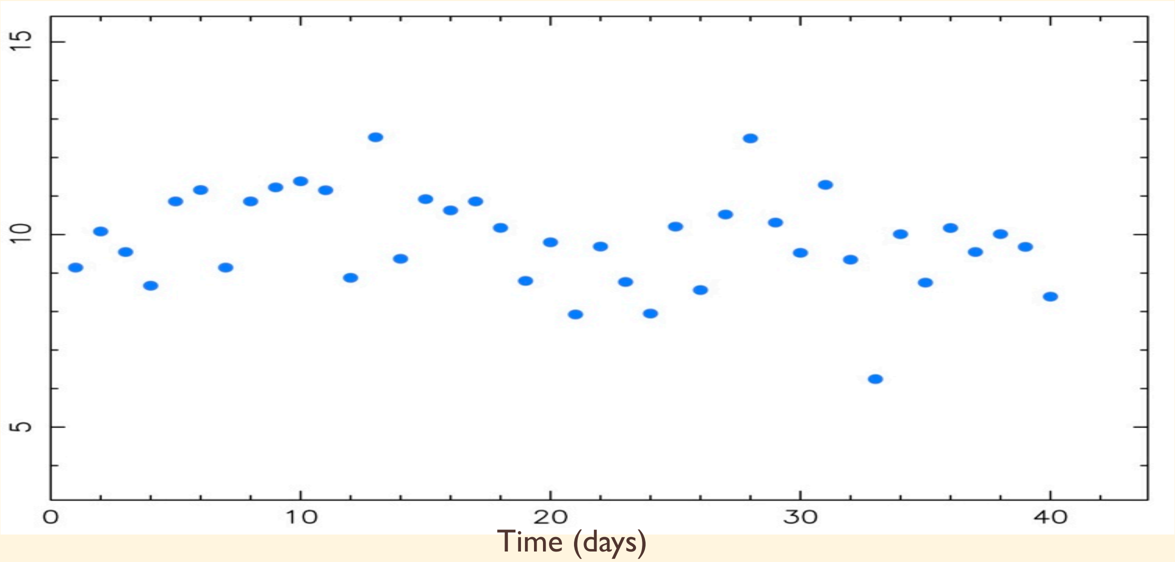
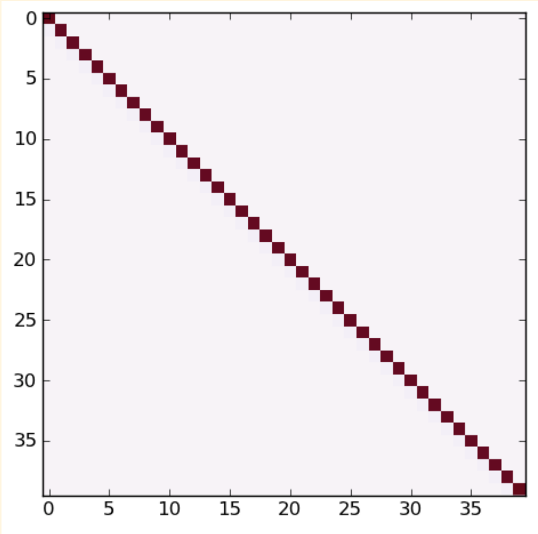
White and red noise

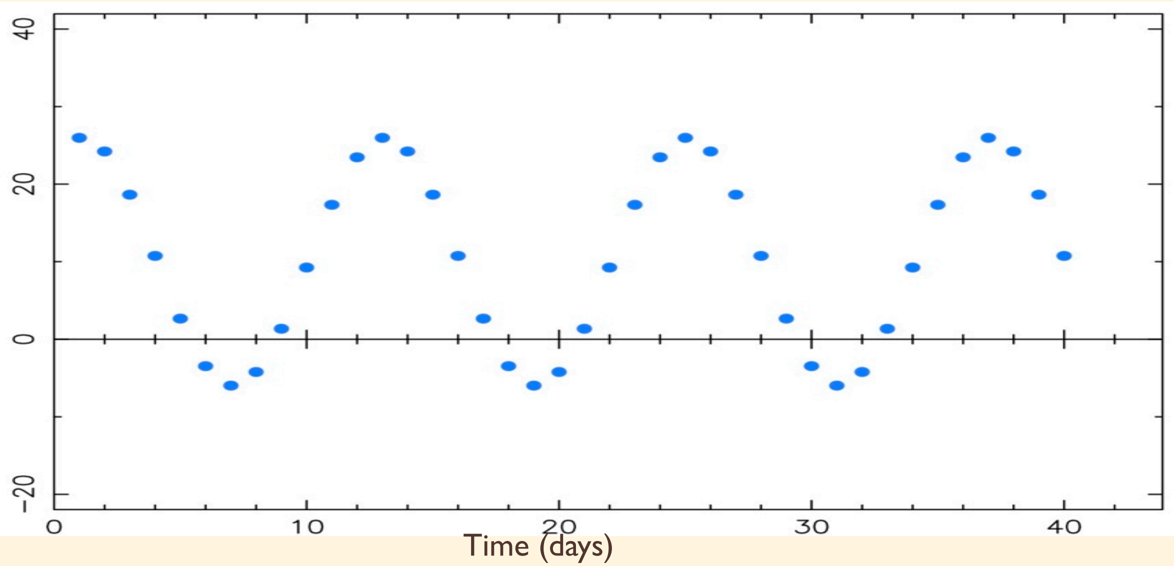
White noise: All data points are completely independent of each other

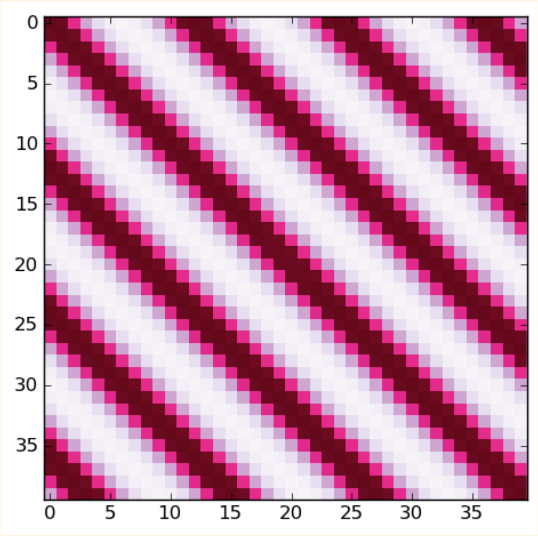




Covariance matrix

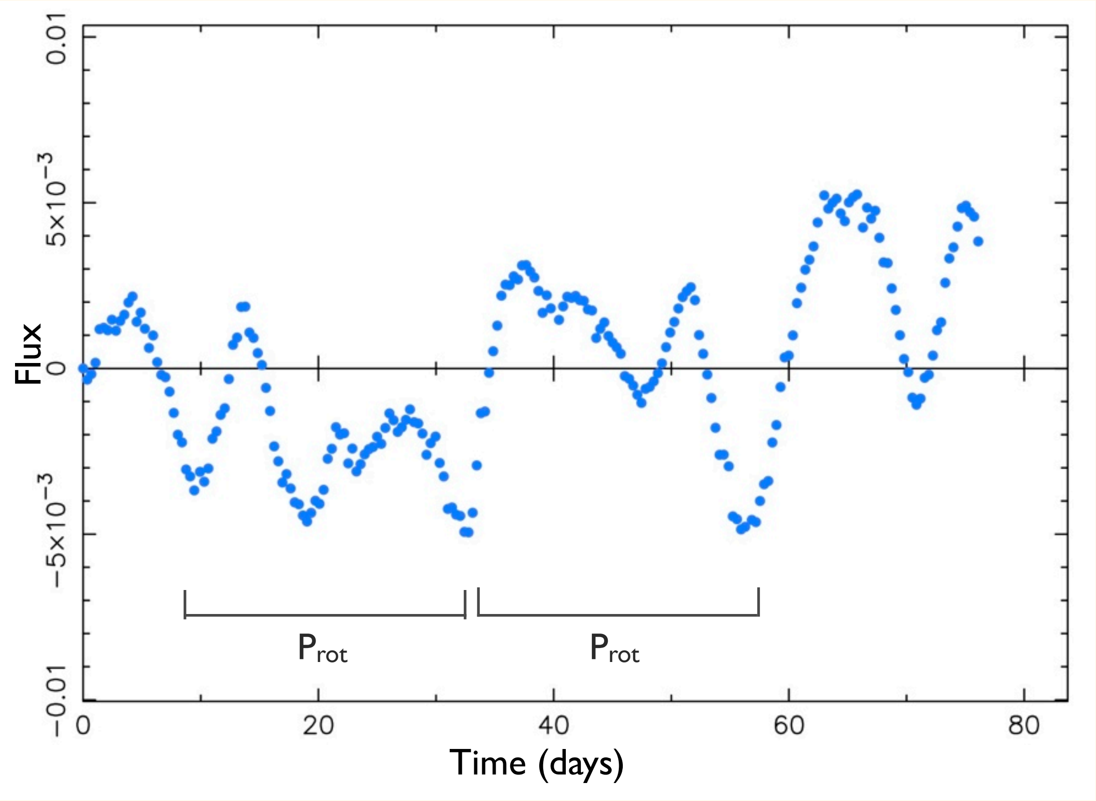
Red noise: Data points are correlated with each other



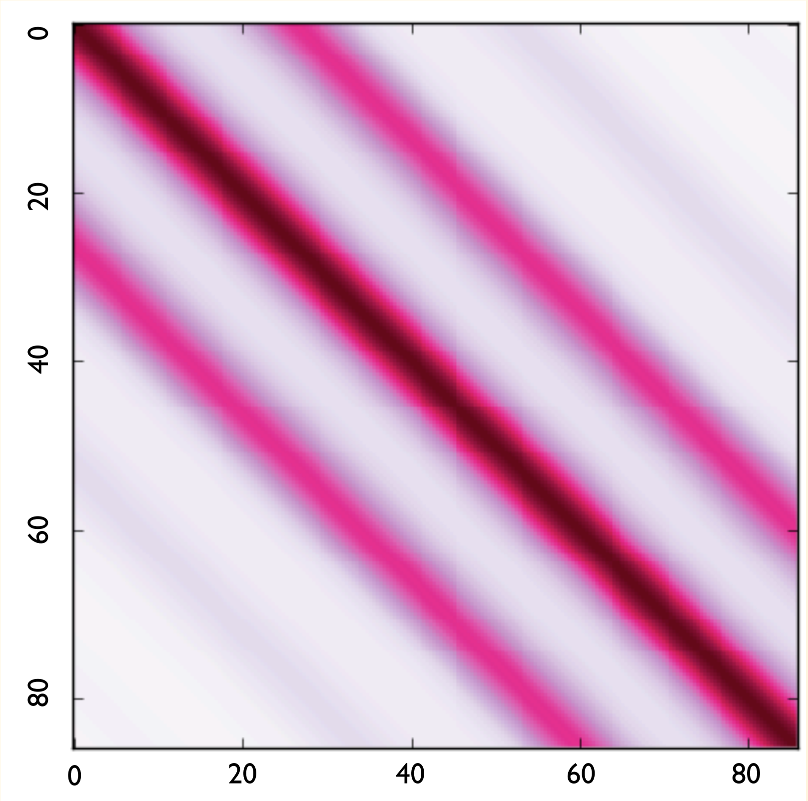


Example with real data: CoRoT-7 lightcurve

Lightcurve

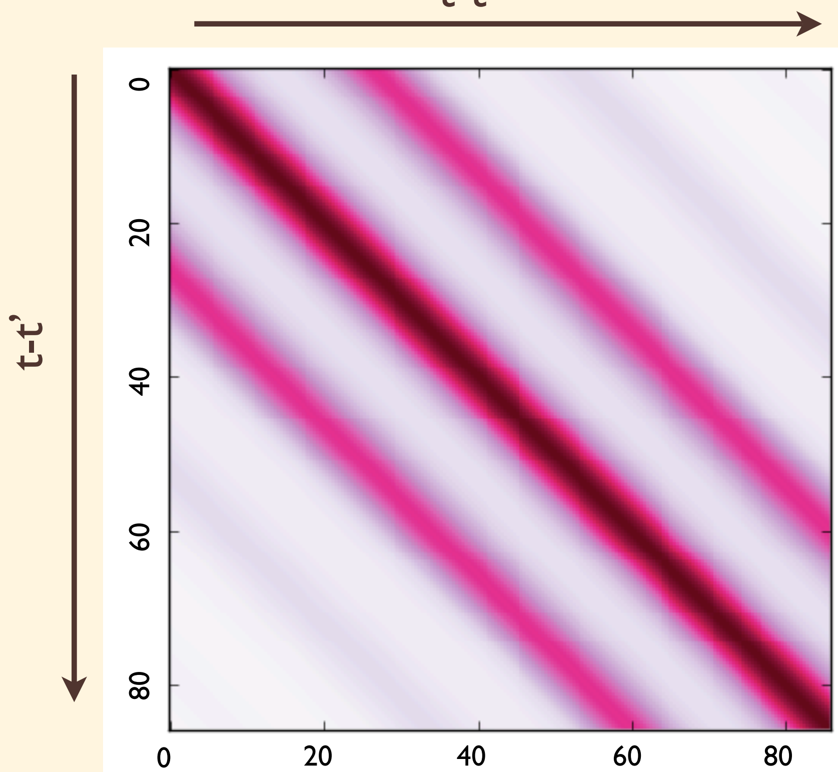


Covariance matrix

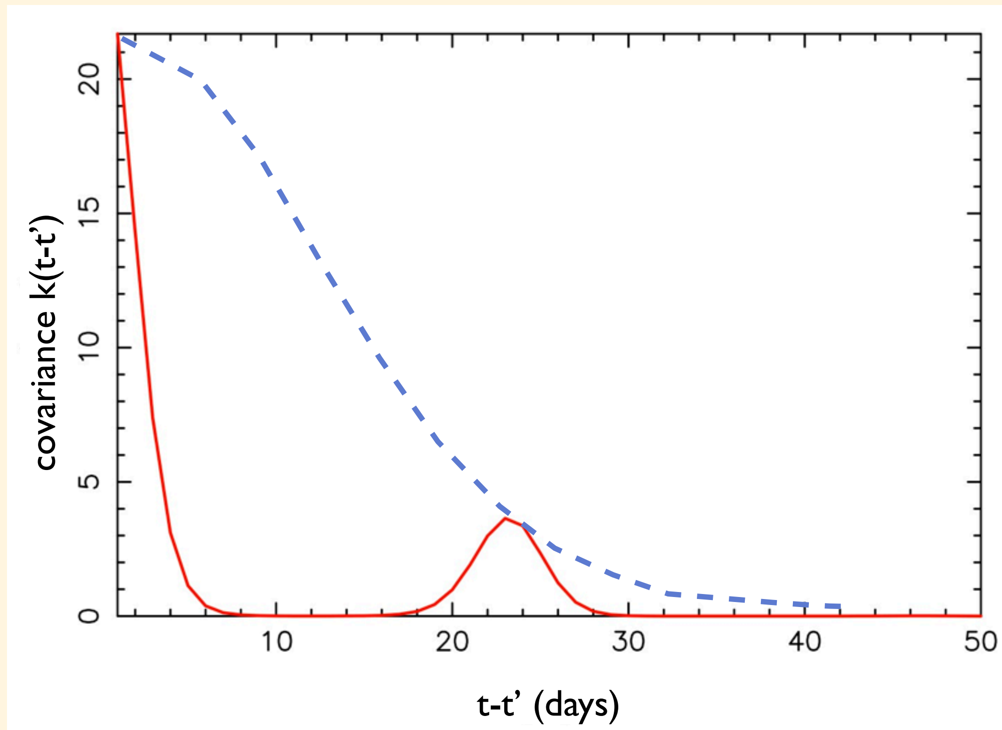


A Gaussian process is encoded by a **covariance function**

Covariance matrix



Covariance function



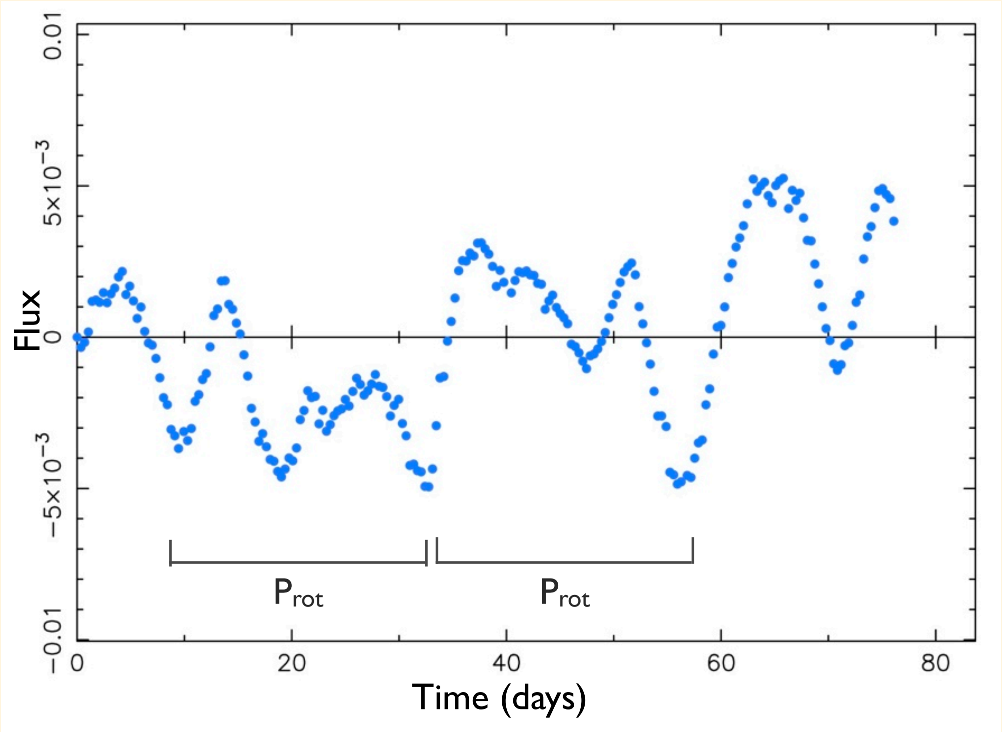
Quasi-periodic form:

$$k(t,t') = \theta_1^2 \, . \, exp\left(-\frac{(t-t')^2}{2\theta_2^2} - \frac{2\sin^2(\frac{\pi(t-t')}{\theta_3})}{\theta_4^2}\right)$$

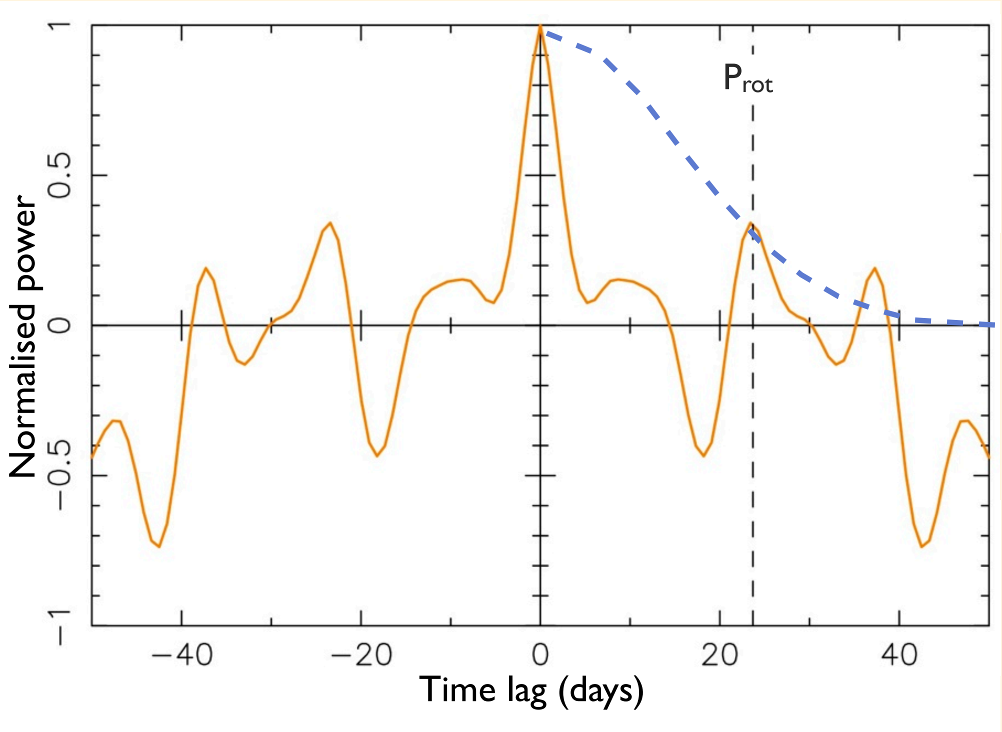
See Rassmussen & Williams (2006), Gibson et al. (2011), Haywood et al. (2014)

Frequency structure of a dataset

Lightcurve

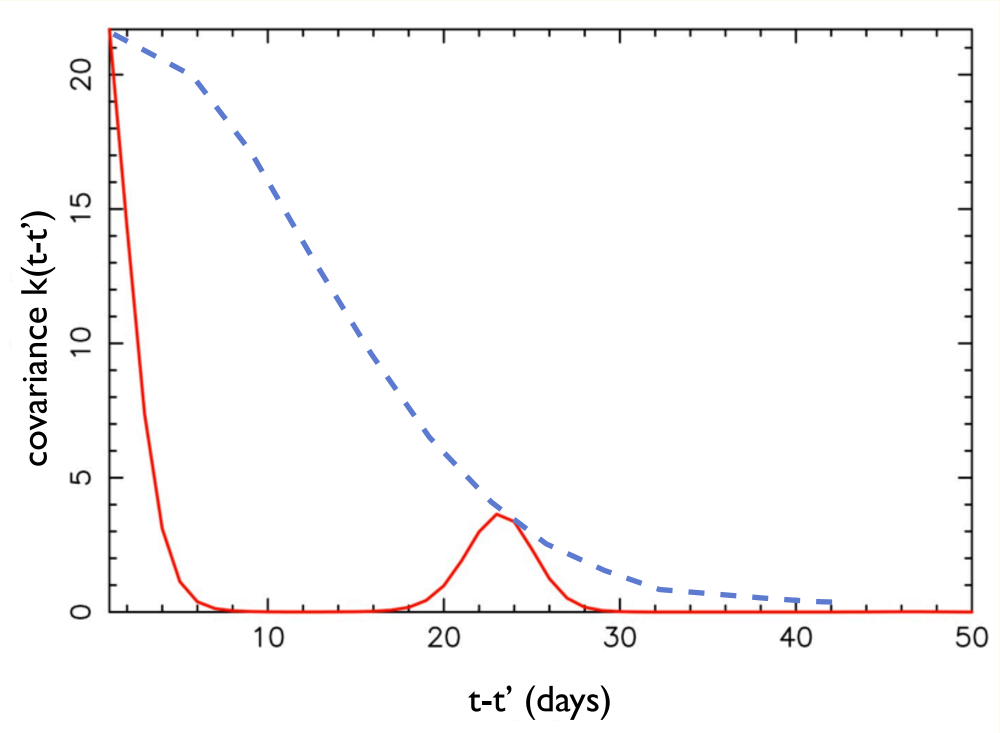


Autocorrelation function

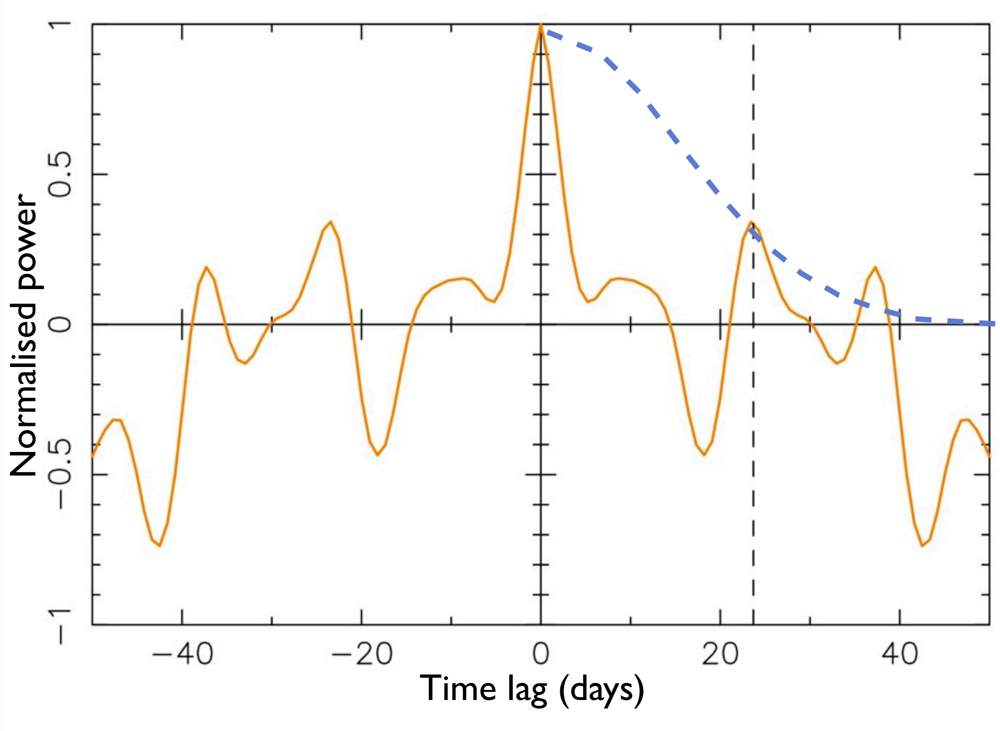


Covariance function = frequency structure

Covariance function



Autocorrelation function

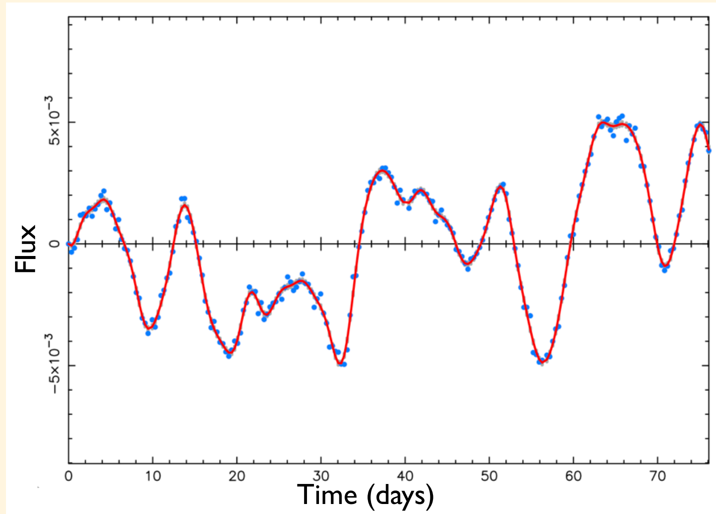


$$k(t,t') = \theta_1^2 \, . \, exp\left(-\frac{(t-t')^2}{2\theta_2^2} - \frac{2\sin^2\left(\frac{\pi(t-t')}{\theta_3}\right)}{\theta_4^2}\right)$$

- θ_1: amplitude
- θ_2: decay timescale
- θ_4: smoothing factor
- θ_3: reccurence timescale

Use a GP trained on the star's lightcurve to model $RV_{activity}$

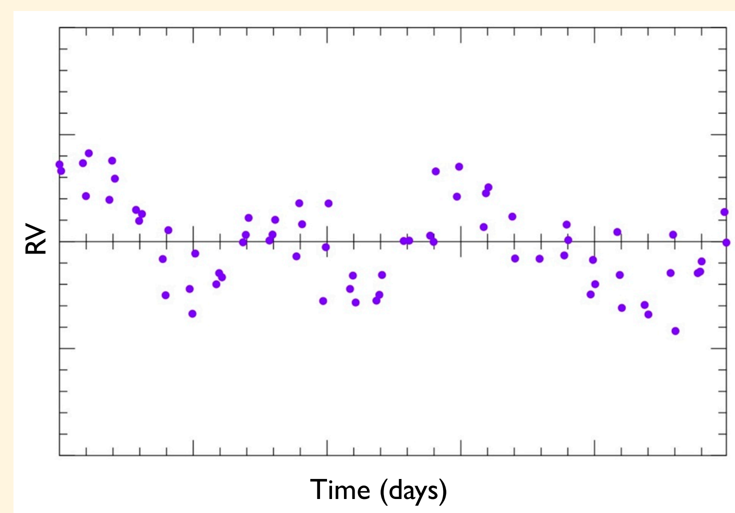
Lightcurve:
naturally has covariance properties of star's magnetic activity



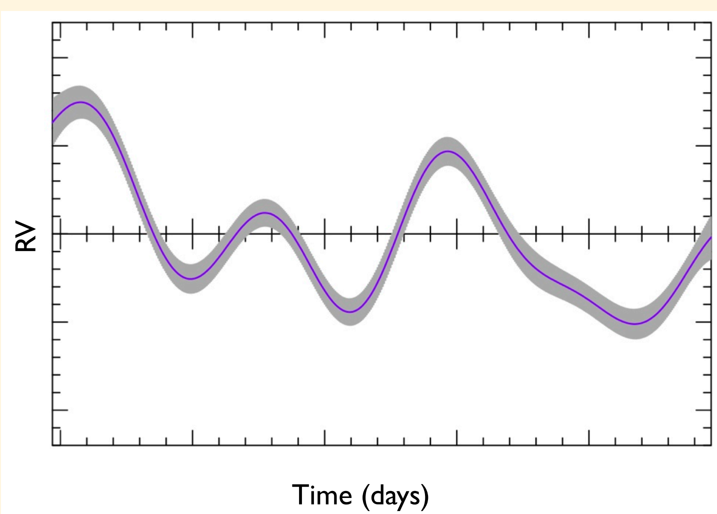
train GP: determine $\theta_1, \theta_2, \theta_3, \theta_4$ of covariance function through MCMC simulation

Determine covariance function $k\ (t, t')$

+



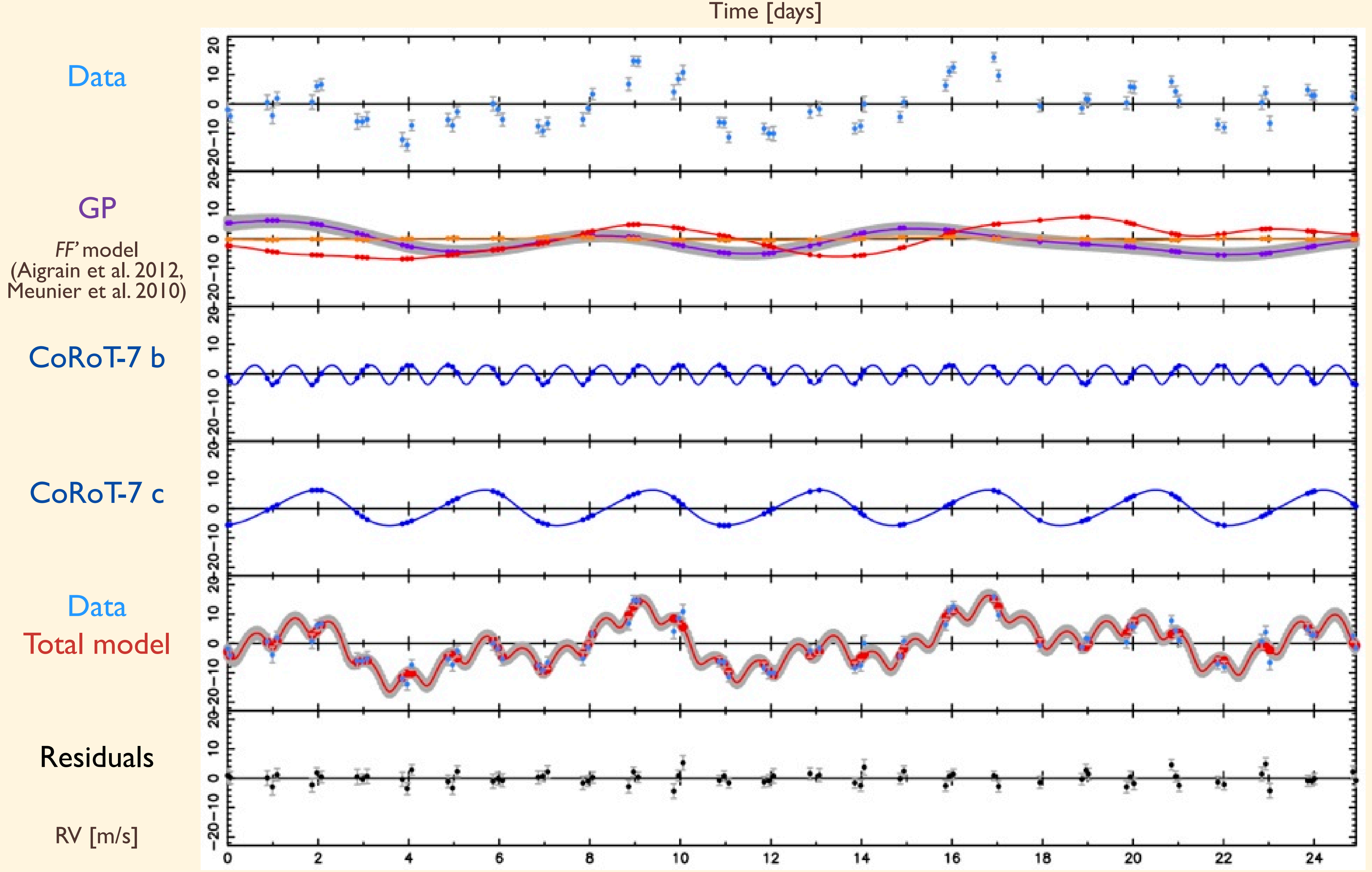
predict GP: compute covariance matrix using $k\ (t, t')$



$RV_{activity}$: basis function with covariance properties of lightcurve

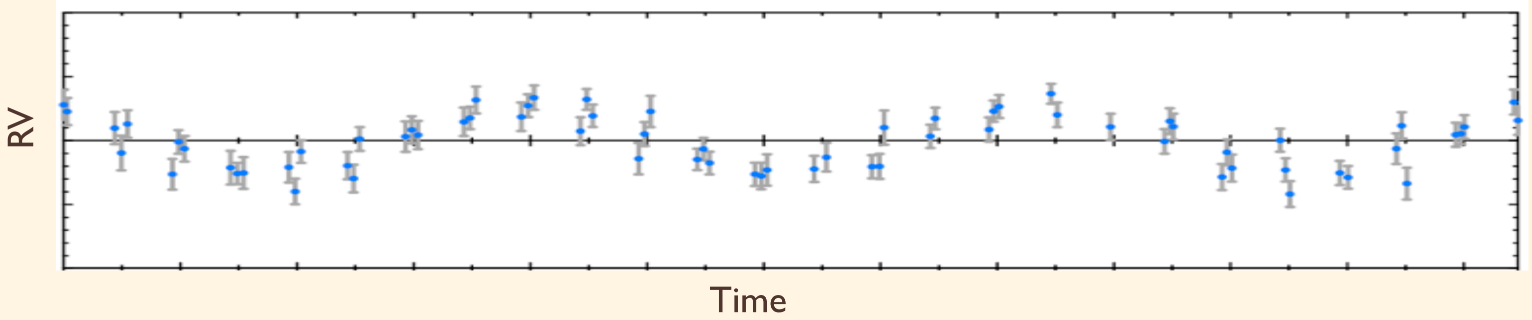
Application to CoRoT-7

Haywood et al. 2014



Will a Gaussian process absorb a planet's signal?

Data:
periodic signal
+
white noise



Will a Gaussian process absorb a planet's signal?

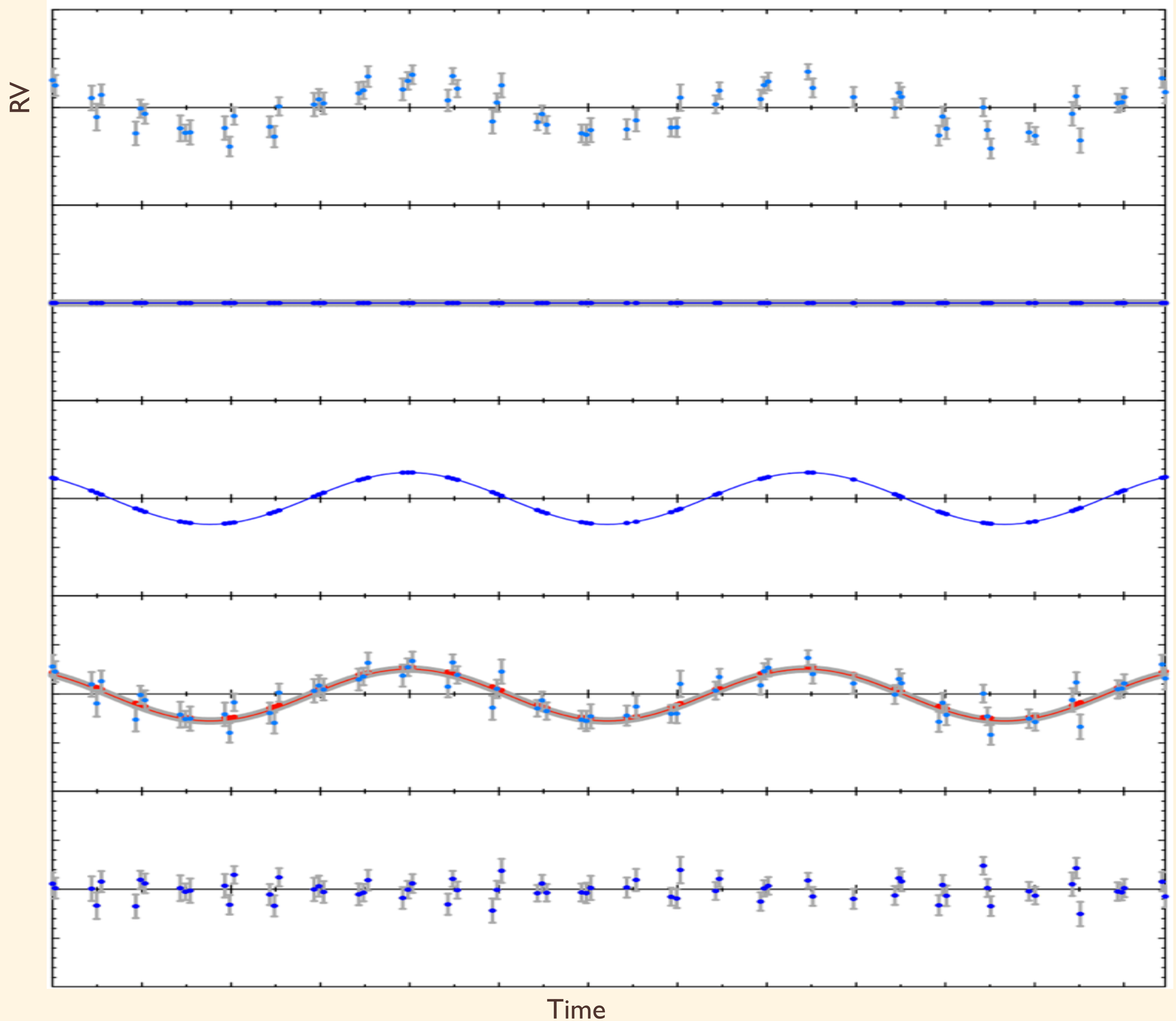
Data:
periodic signal
+
white noise

GP

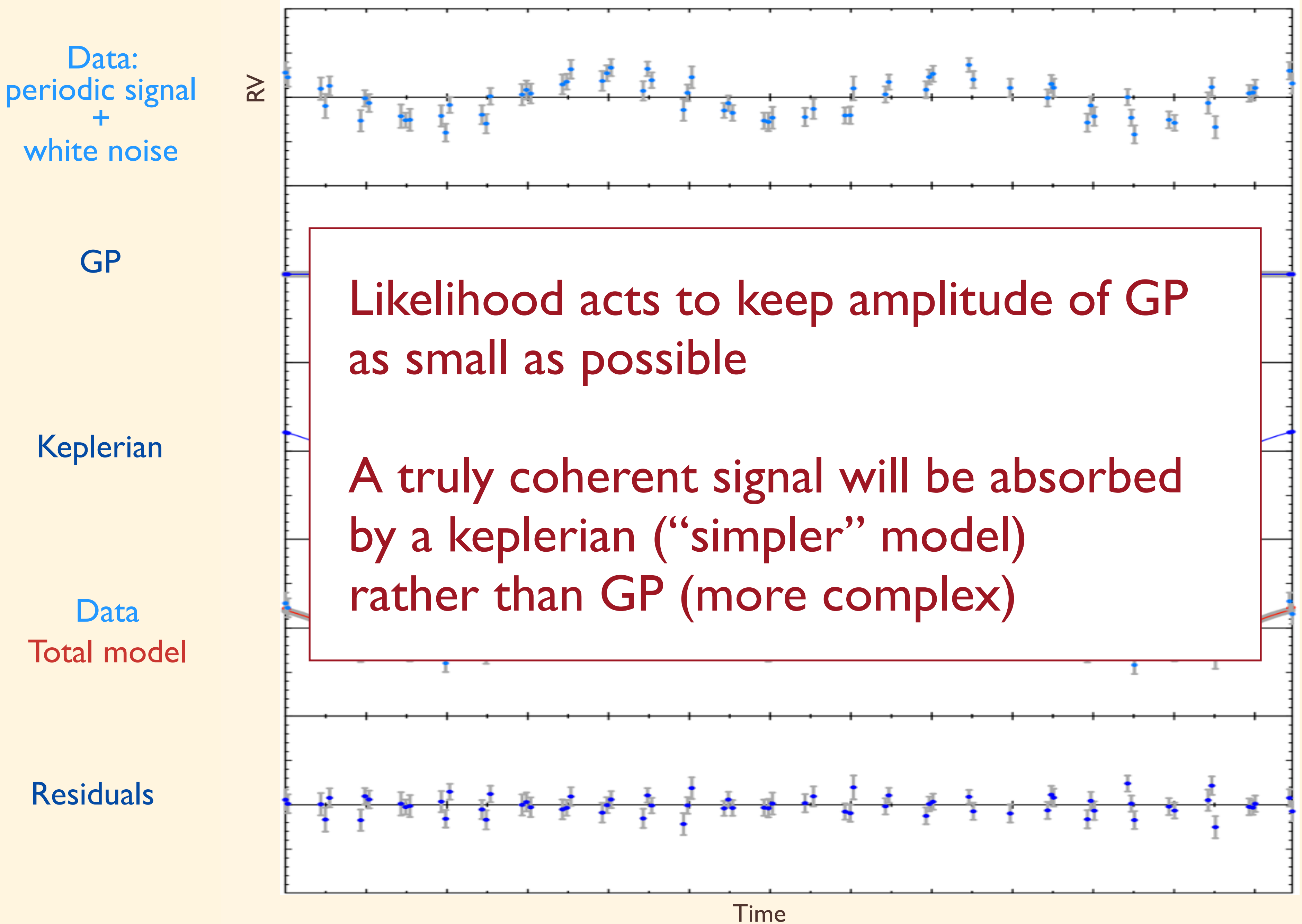
Keplerian

Data
Total model

Residuals



Why modelling $RV_{activity}$ with a GP lets us find planets



Likelihood acts to keep amplitude of GP as small as possible

A truly coherent signal will be absorbed by a keplerian ("simpler" model) rather than GP (more complex)

Summary

- Accounting for activity-induced radial-velocity signals is key to detecting low-mass planets and determining their masses
- Gaussian process: ideal tool to model activity-induced RV variations
- In case of CoRoT-7, signal at 9 days best explained as activity rather than a planet (Haywood et al. 2014)
- Next: apply Gaussian process method to Kepler systems observed with HARPS-N!