Period search from light curves with changing shapes

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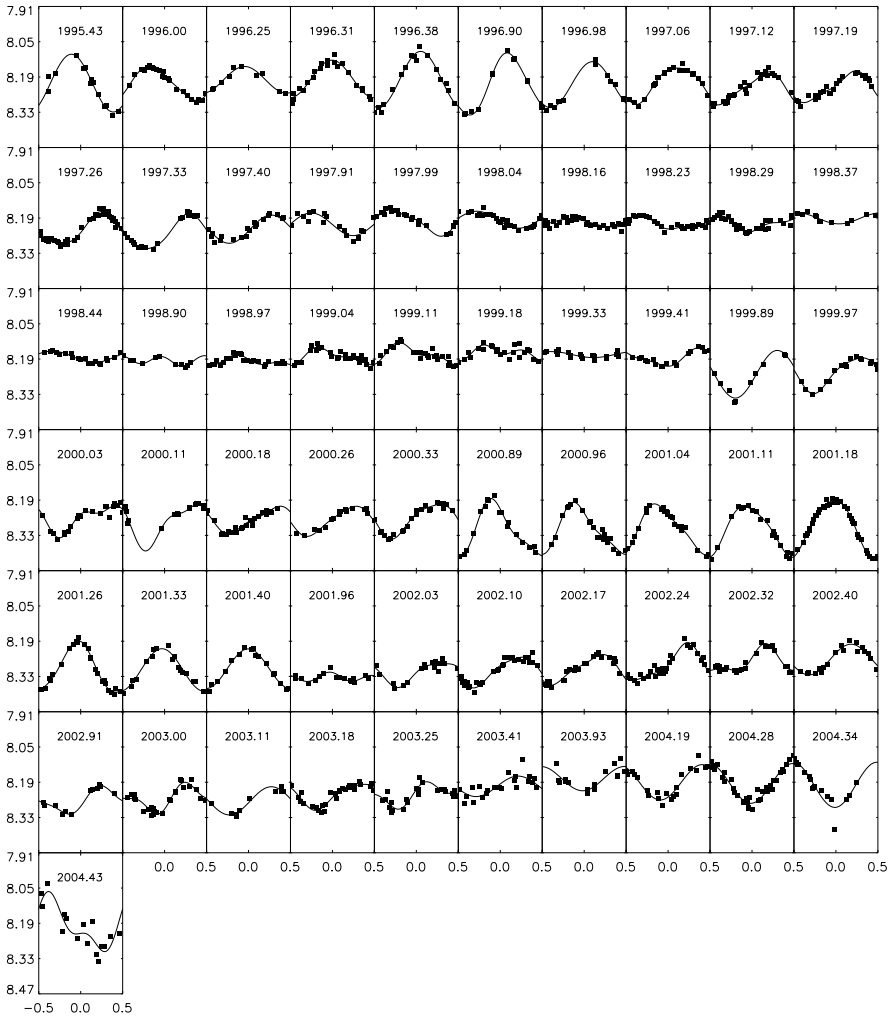
Many kinds of periodicity

- The sky is full of periodic phenomena inluding a large fraction of variable stars.
- While some periodic variable stars show nice stable light curves, this is not at all the case for all of them.
- The light curves can be unstable is a variety of ways, eg.
  - Variable period of eclipsing binaries $\Rightarrow$ changing eclipse timings
  - Changing light curve profiles of semiregulars and Miras
- The more carefully you observe the periodic variables, the more of them turn out not to have totally stable light curves.

Changing light curves

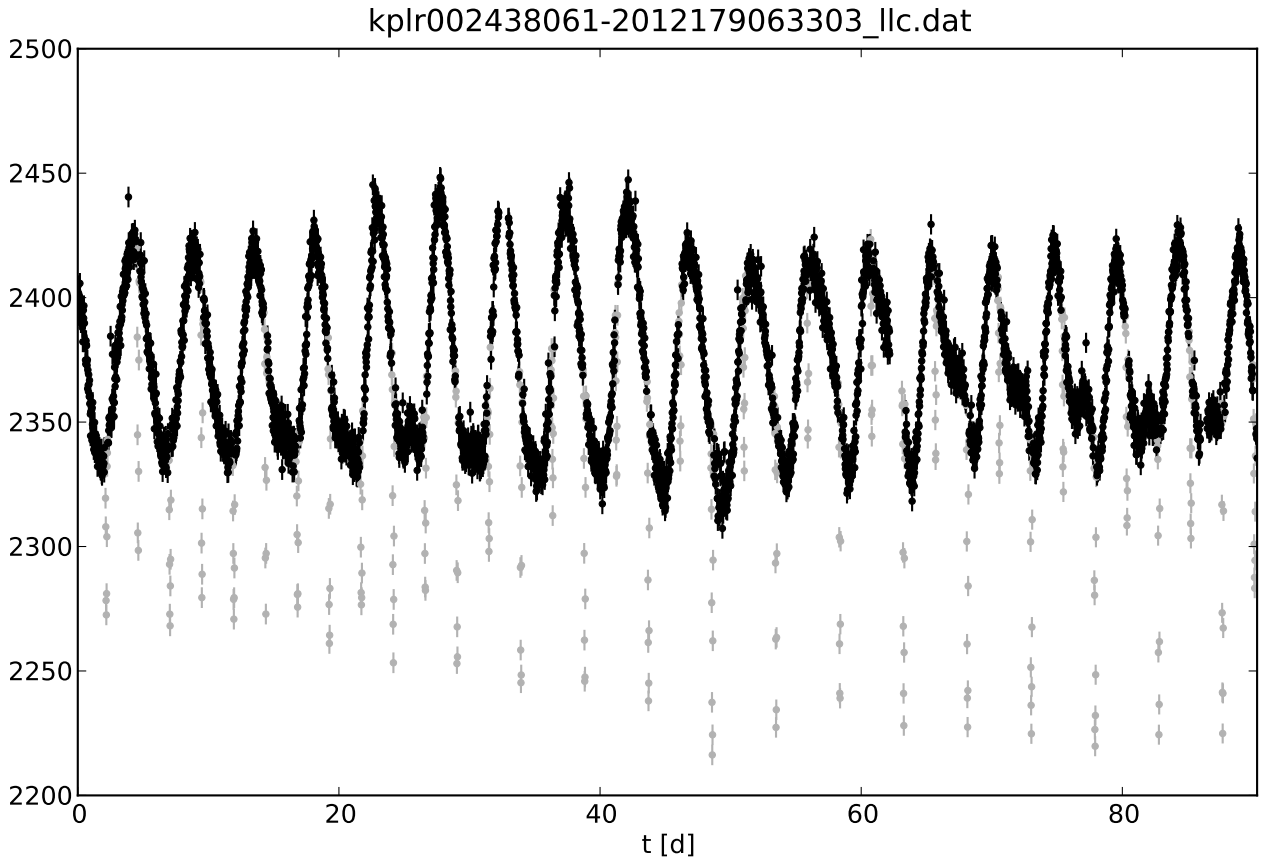
- A particularly involving case are the light curves of stars that have photospheric spots.
- Here we observe variations of both light curve shape and period and the variability can even disappear at times.



FK Com – Hackman et al. (2012)

Changing light curves

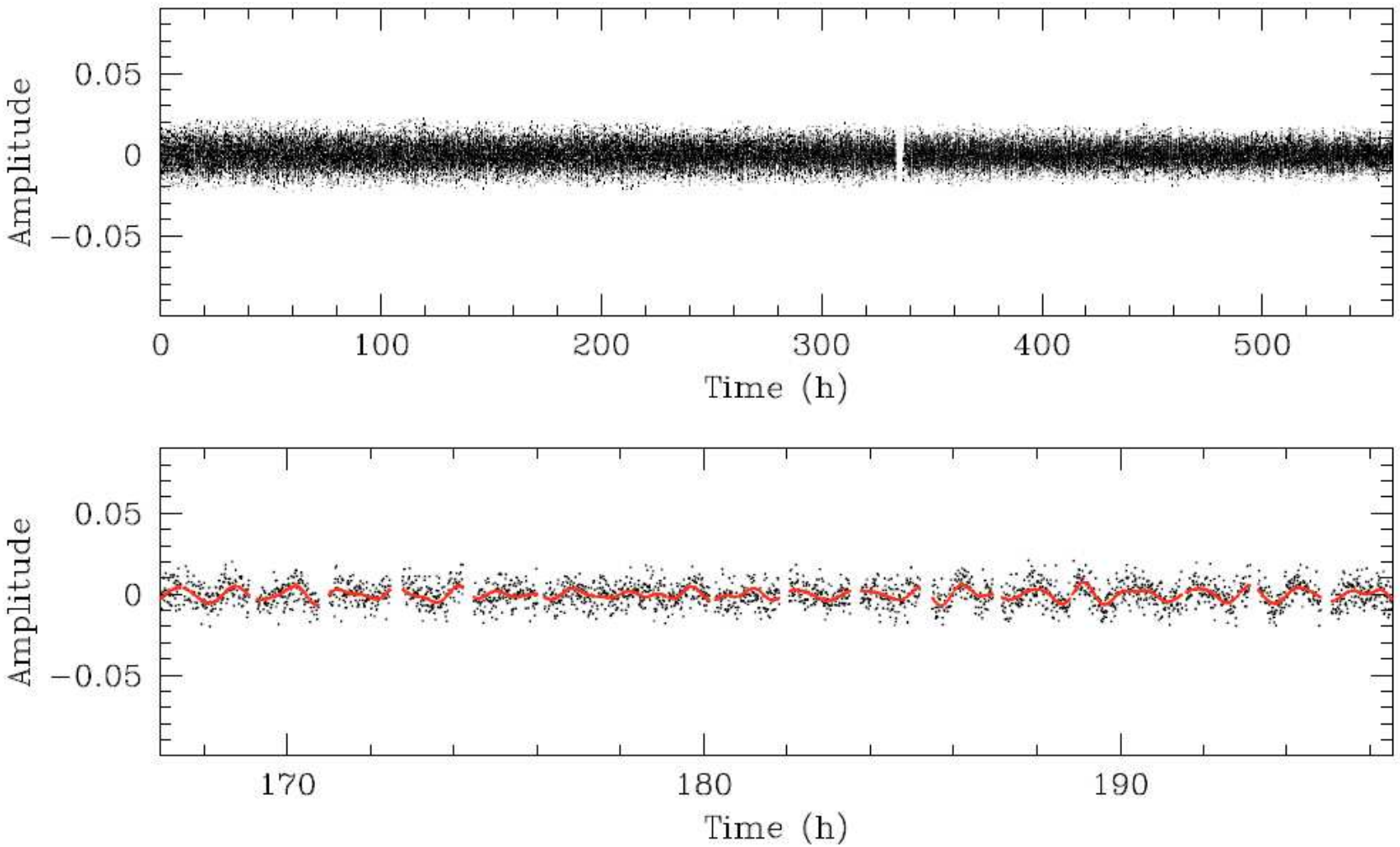
- With good enough data we see that the light curves of these spotted stars are constantly evolving and don't repeat any single period cycle.



Power spectrum

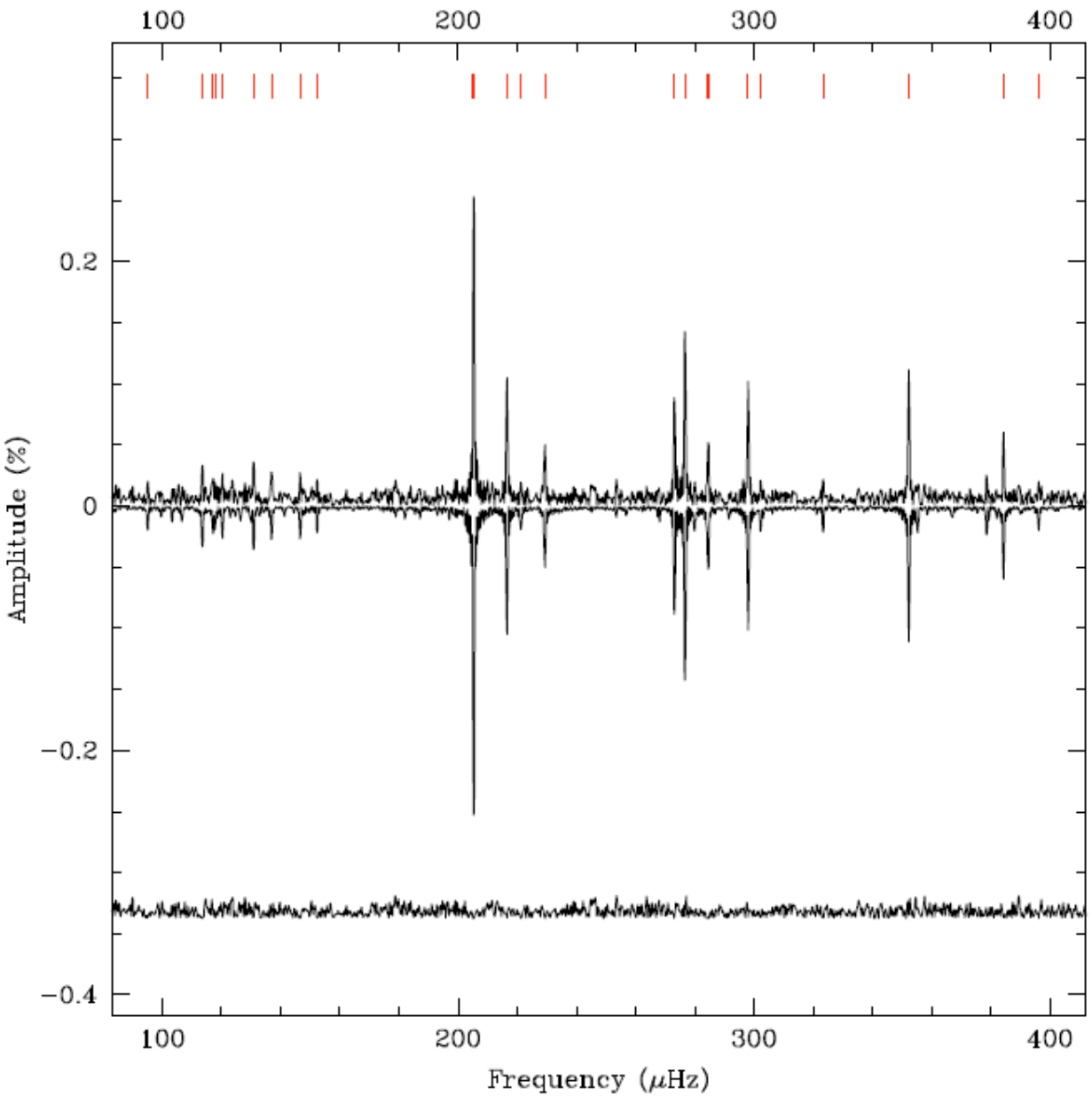
- A simple and commonly used way to search for periodicity is to compute the *power spectrum* of the data.
  - Lomb-Scargle periodogram for unevenly spaced observations (Scargle 1982)
- This assumes that the data consists of sinusoidal waves with stable frequencies.
  - Stationary waves or growing and decaying waves at specified frequencies
- Works well for stars with "non-violent" pulsations (δ Sct, asteroseismic targets).

Power spectrum



Charpinet et al. (2010)

Power spectrum



Piecewise modelling

- In many cases we don't want to make the assumptions that using the power spectrum forces us to do.
- An alternative is to select shorter pieces of the data and to do modelling of those.
- The optimal length of the analysed datasets has to be determined based on the data.
  - Short enough for excluding variations of the profile but long enough to include enough data for reliable modelling

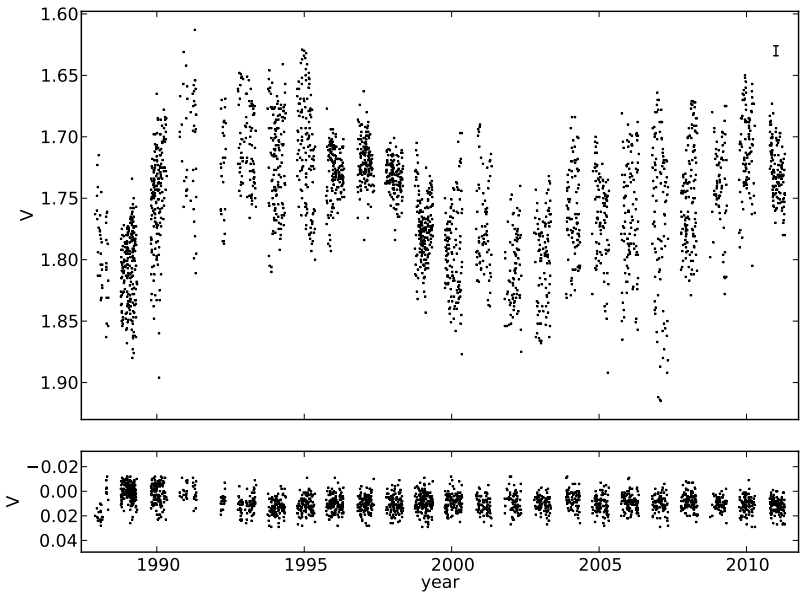
Piecewise modelling

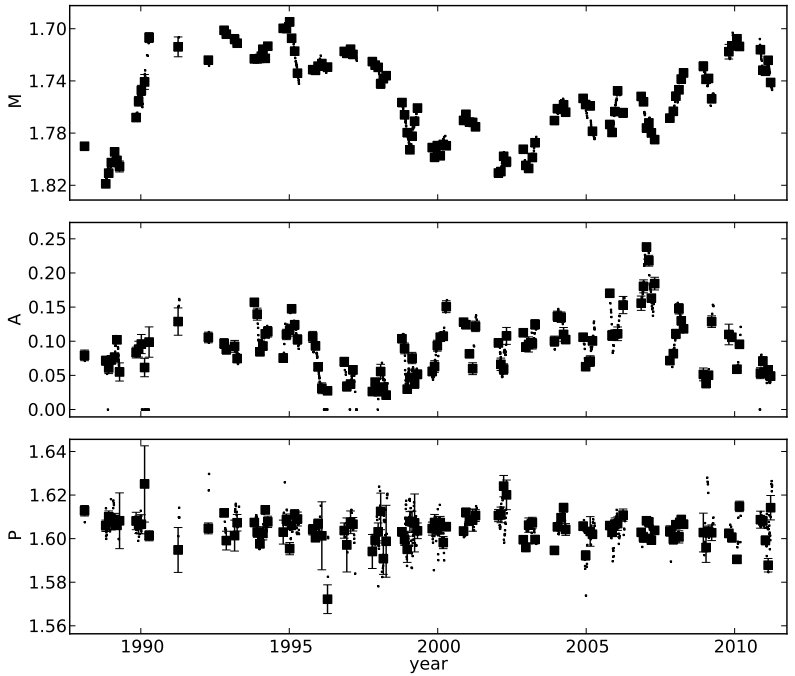
- The most obvious approach is to fit a low order Fourier-series into the short dataset,

$$\hat{y}(t_i) = M + \sum_{k=1}^{K} \left[B_k \cos\left(k 2\pi f t_i\right) + C_k \sin\left(k 2\pi f t_i\right) \right]$$

  (Continuous Period Search – Lehtinen et al. 2011)
- From the fit we estimate the mean M, amplitude A and period $P = 1/f$ of the dataset as well as minimum or maximum times of the light curve.
- By changing the model order K we can control how detailed modelling we want.

Piecewise modelling

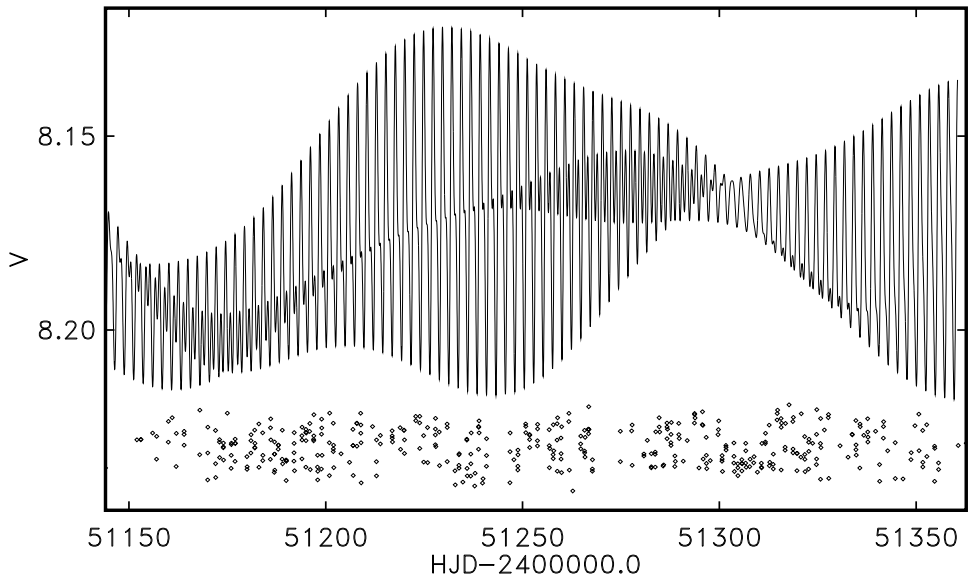




LQ Hya – Lehtinen et al. (2012)

Carrier wave modelling

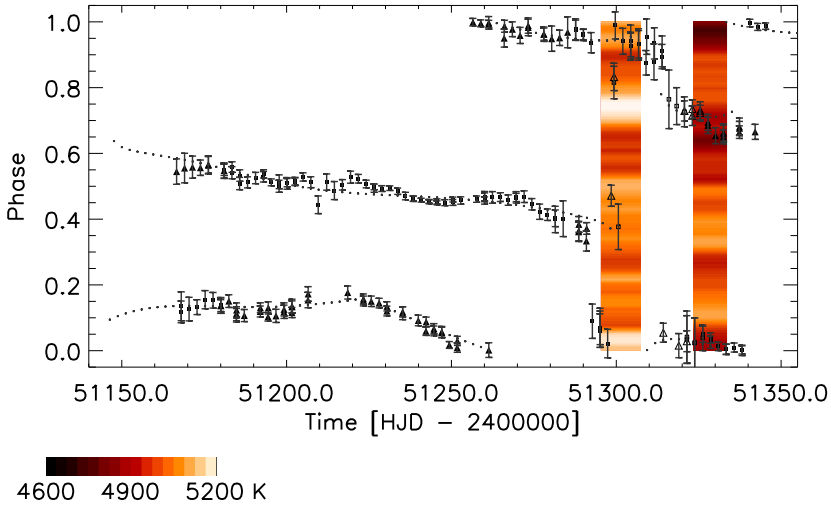
- Another approach is to model all the data on one go but to allow smooth variability of all the model parameters in time.
- This means fitting models for the parameters $M(t), B_k(t), C_k(t), f(t)$,
  (Carrier Fit Method – Pelt et al. 2011)

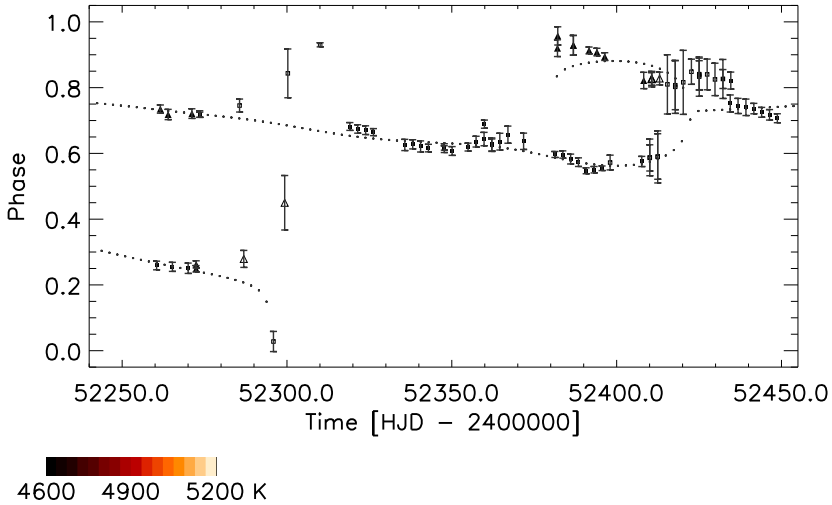


FK Com – Hackman et al. (2012)

Comparing the methods

- In reality the two approaches work well and give similar results for real photometry
- This is shown in phase diagrams of light curve minima of FK Com derived from the fits done with both of the methods:

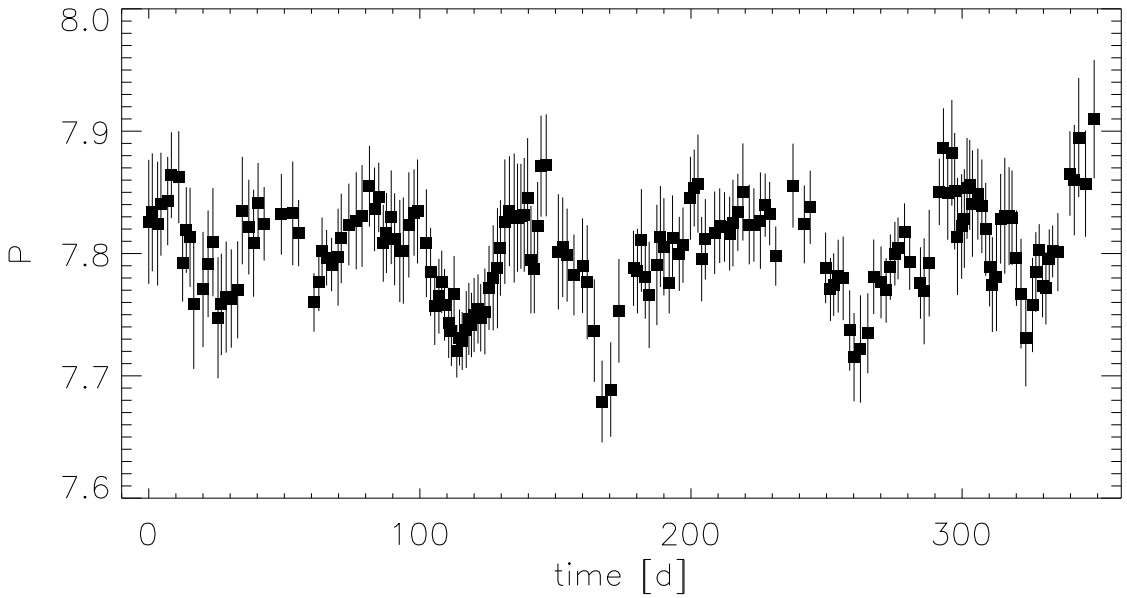




Hackman et al. (2012)

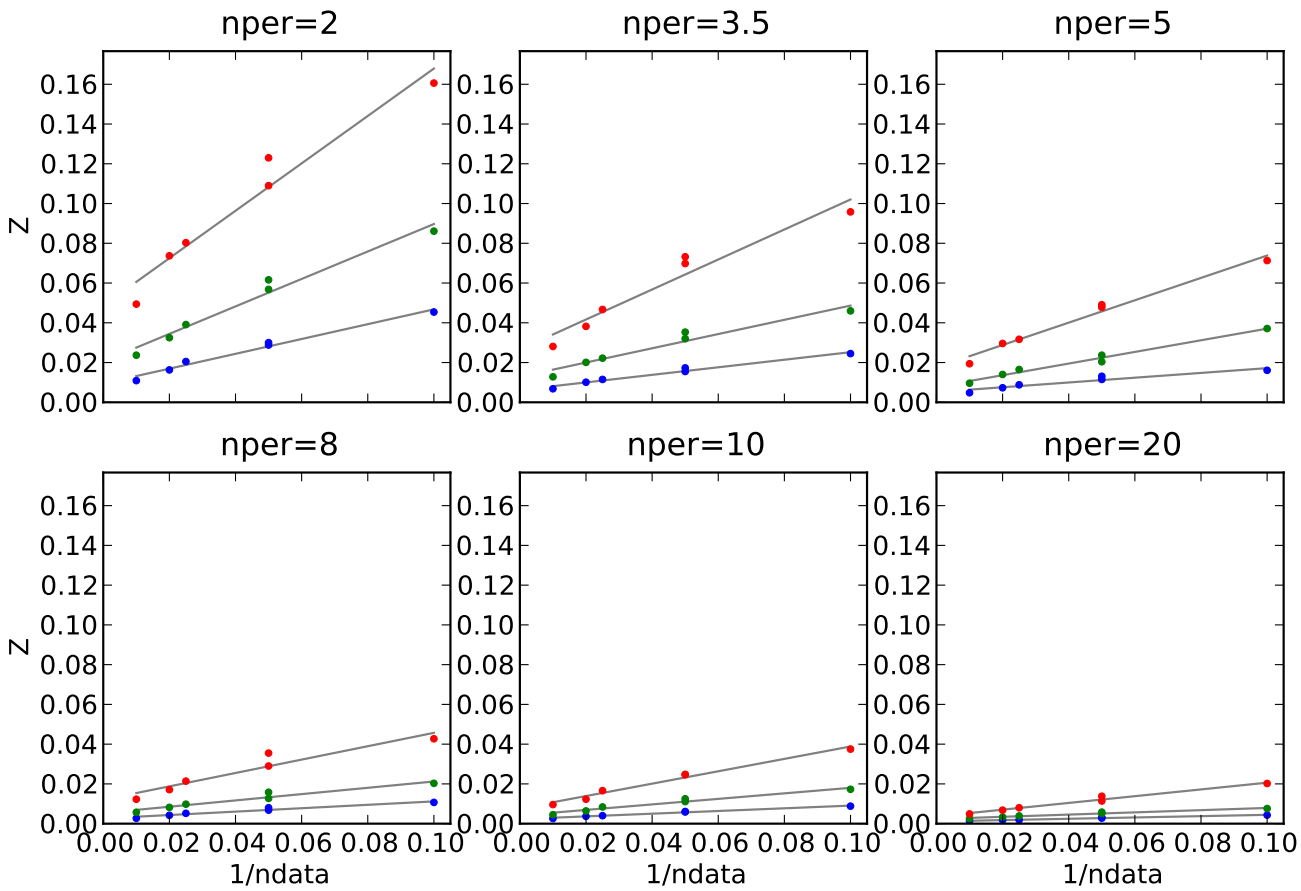
Errors of period estimation

- Unfortunately having to cut down the data used for modelling introduces errors in the period estimation.
- With a small amount of data, short time span of observations or large observational errors the uncertainties of the period estimation can far exceed real period variations.
- Below are period estimates of a *stable* sinusoid made to mimick real photometry and modelled with a sliding window.



Errors of period estimation

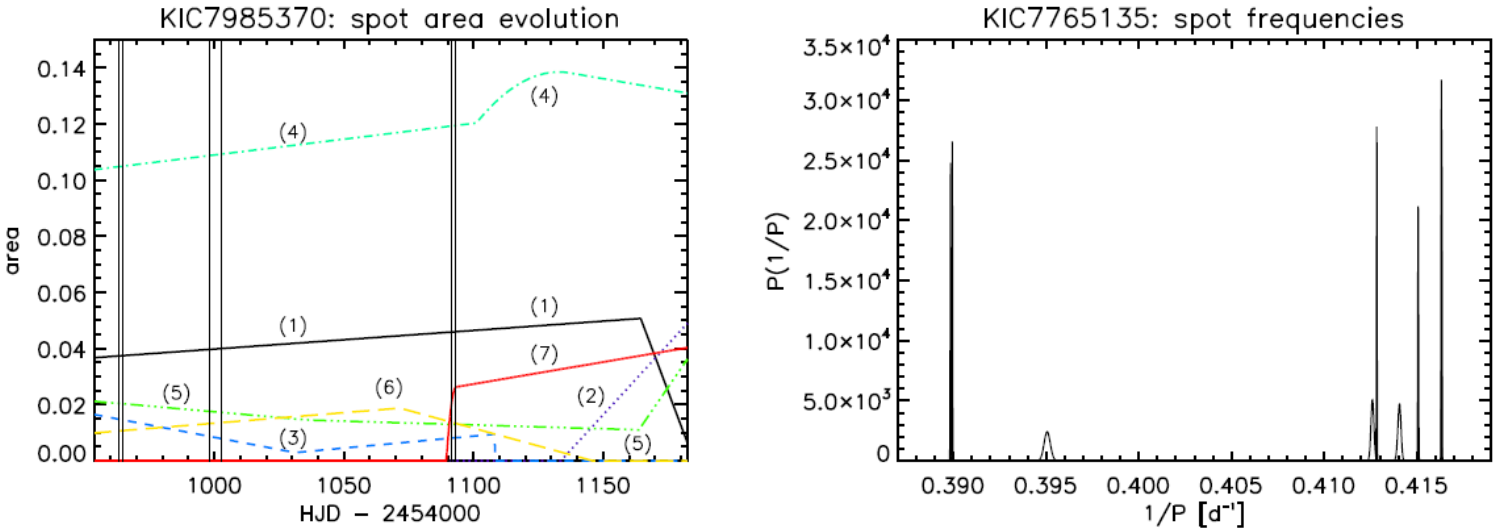
Relative uncertainty in period estimation:



Relative errors of data, $\epsilon \in [0.05,\ 0.1,\ 0.2]$

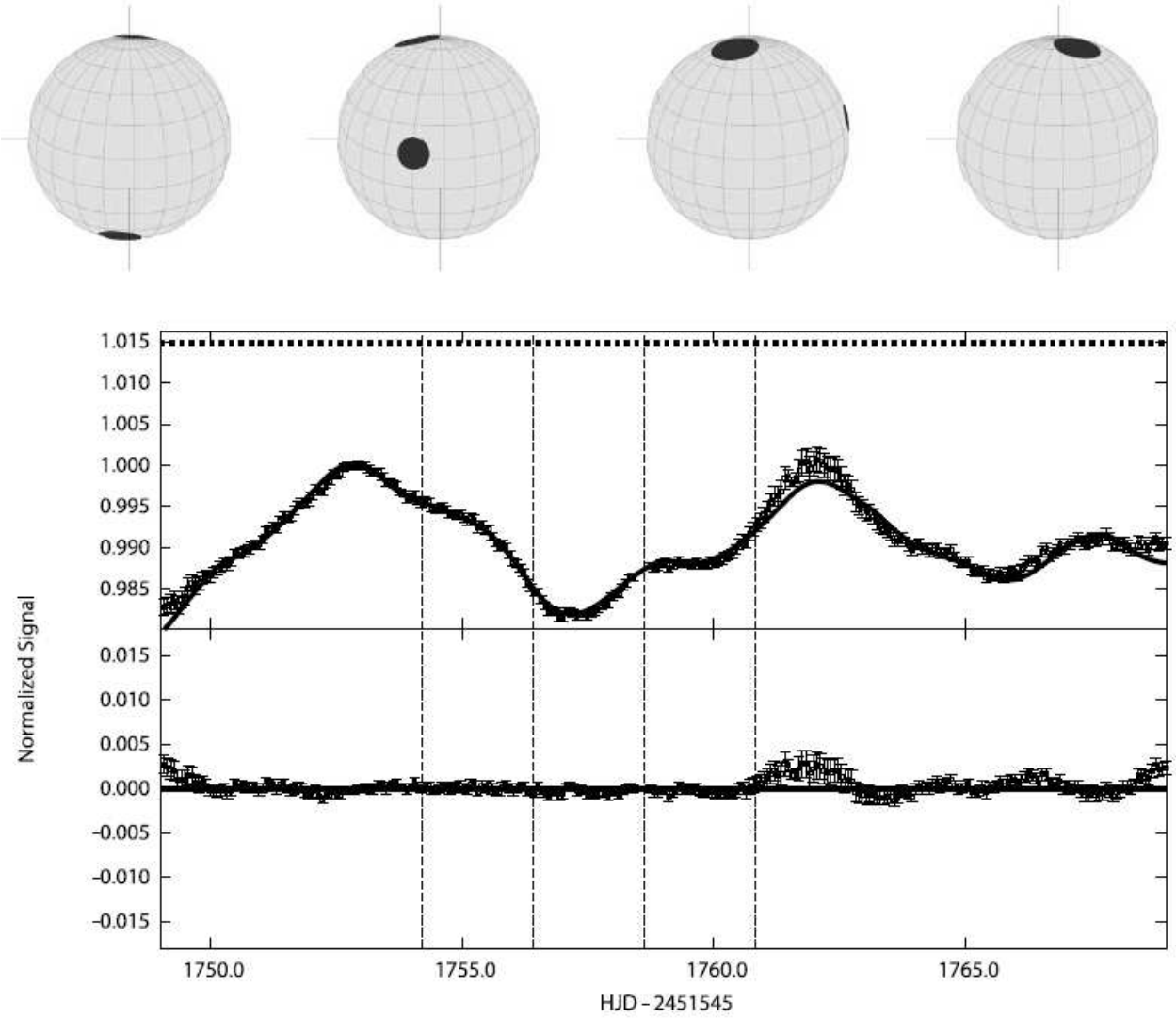
More physical modelling

- If we know more about the physics of the observed system, we can try to make our modelling reflect the actual reality of the system more closely.
- An example is modelling spotted stars by placing evolving spots on a rotating model star.



Frölich et al. (2012)

Power spectrum



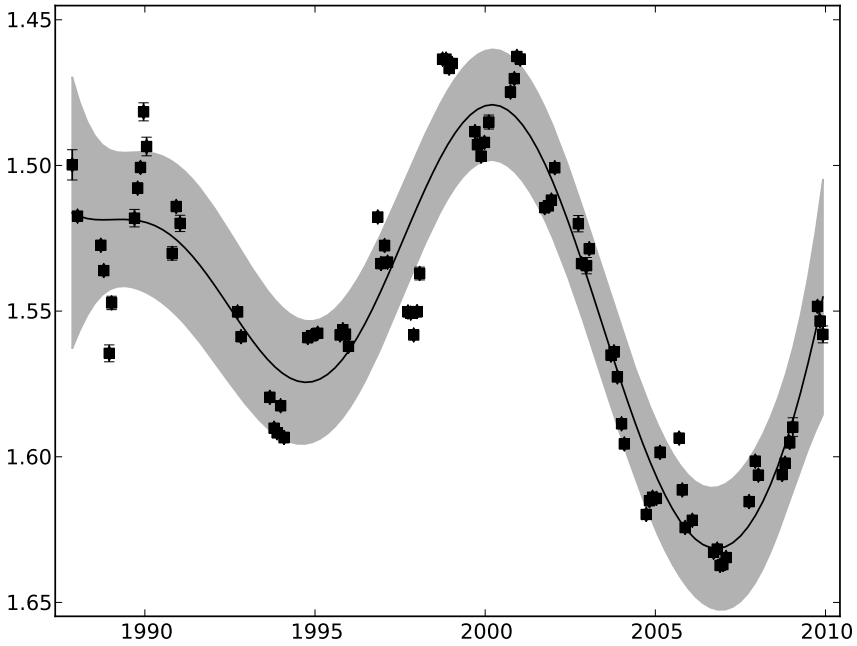
Walker et al. (2007)

More physical modelling

- However, the results can only be as good as the physical model you used to get them.
- Too complex models can also make it impossible to get well defined and unique solutions based on the available data.
- Results from such modelling can be misleading.

Further ideas

- Only barely periodic data might need special approaches to get good estimates of the periodicity.
- We need to pay attention for allowing enough variability in the light curve profile.



V711 Tau mean brightness

Concluding remarks

- For modelling periodic data succesfully we need to know how the data behaves as well as what assumptions or models force us to make.
- Bad choice of modelling approach can lead to misleading results.
- On the other hand, succesful analysis can be done using very simple ideas.