Viability of using photometric period variations as a proxy for stellar surface differential rotation

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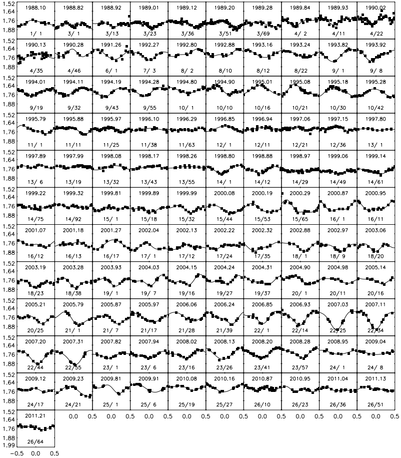
Photometry of active stars

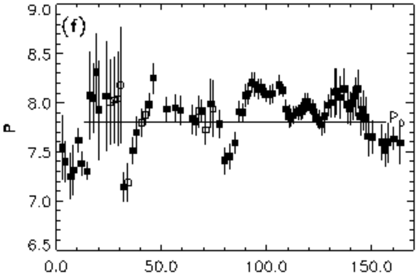
- There are different approaches for doing photometric studies of active stars (ground vs. space based, different modelling approaches).
- I will concentrate here on analysing ground based photometry using simple periodic piecewise or sliding fits.

- Analysing light curves of active spotted stars means essentially fitting models into the data to infer properties of the spot structure.
- One of the fitted parameters is the period P of the light curve, i.e. the *photometric rotation period of the star*.



Fitting light curves

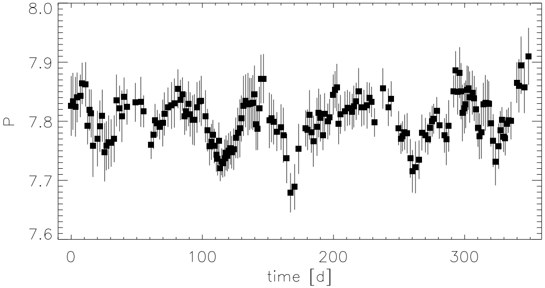
- On a differentially rotating star we expect spots on different latitudes to produce different values for the observable P.
- If we monitor a star long enough, we should see signatures of the rotation period at different stellar latitudes as variations of estimated "instantaneous" values of P.



Estimating differential rotation

- Eventually the spots will explore all of their possible configurations and the variation of the estimated P should give a measure of the surface differential rotation.
- Measures for differential rotation:
  - Hall (1991): $k \propto \frac{\delta P}{P} = \frac{P_{max} - P_{min}}{P}$
  - Jetsu (1993): $k \propto Z = \frac{6 \Delta P_w}{P_w}$
    (where $P_w = \sum w_i P_i / \sum w_i$, $\Delta P = \sqrt{\sum w_i (P_i - P_w)^2} / \sqrt{\sum w_i}$ and $w_i = \sigma_{P,i}^{-2}$)
- Note that all of these estimates also depend on the actual latitude extent of the spot activity.

- Unfortunately the periods estimated from light curve fits can be quite unstable.
- Bellow are sliding period estimates from a *constant* moderately noisy sinusoid with $P = 7.8$ d using time points of real observations.

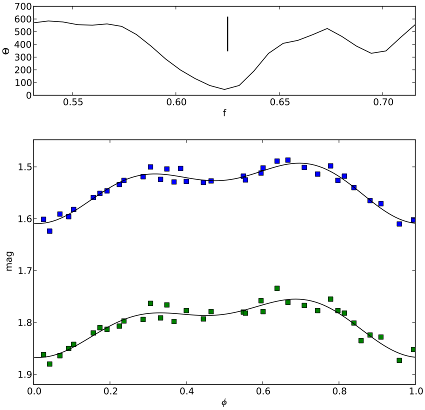


Things to take into account

- In order to get robust estimates for P, we need to optimise at least the following parameters:
  - Relative noise level ϵ of the data, i.e. the ratio of light curve amplitude to the observational errors
  - Number of data points n_{data} within the modelled data sets
  - Number of period cycles n_{per} within the modelled data sets
- Photometric errors ϵ are dependent on the observational setup but n_{data} and n_{per} can be tuned at the stage of modelling.
- Tuning these parameters typically involves compromising with other aspects of the analysis.

Combining multiple bands

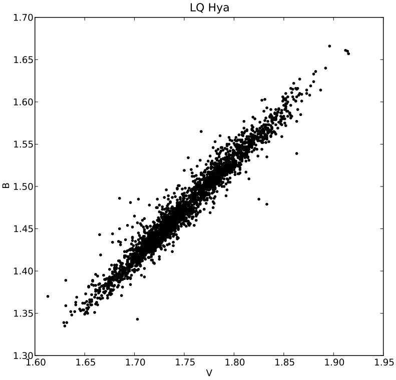
- If there is simultaneous data from multiple photometric bands, they can be used together to further stabilise the estimation of P.
- Eg. combining B- and V-band photometry can effectively double n_{data}.



Combining multiple bands

- Multiple photometric bands can be combined together in various ways.
- In practice we observe a linear relation between B- and V-band photometry of spotted stars.

⇒ Simple rescaling and combining data will work OK.



(24 yrs of LQ Hya B- and V-band photometry)

Testing with simple data

- To get a better feeling of the matters affecting the period estimation we need to do tests with simplified data sets.
- Let's first assume completely stationary sinusoidal data.
  - The simple shape of the data is justified by looking at data from real stars but it also gets rid of unwanted complications of comparing different data shapes.

Testing with simple data

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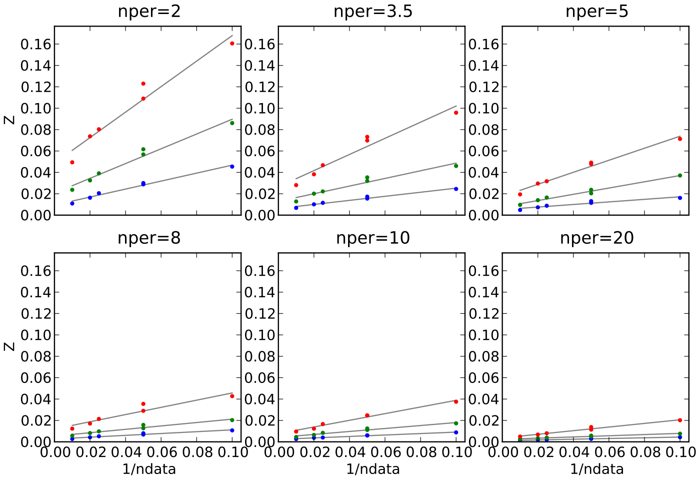
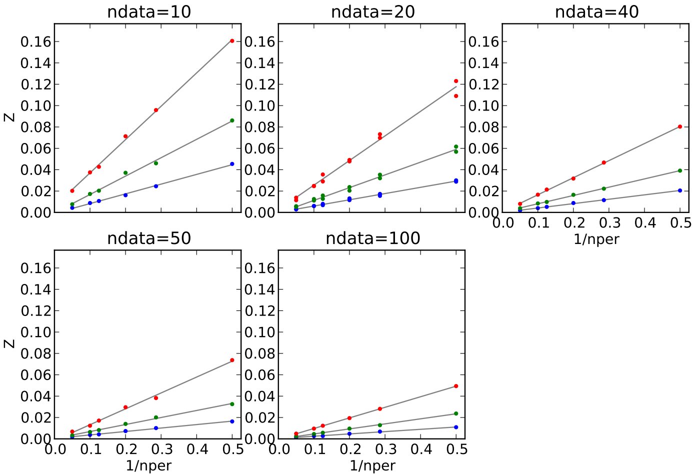
- Let's first assume completely stationary sinusoidal data.
  - The simple shape of the data is justified by looking at data from real stars but it also gets rid of unwanted complications of comparing different data shapes.
- Run period estimation for test data varying the data parameters within $n_{data} \in [10, 50]$, $n_{per} \in [2, 20]$, $\epsilon \in [0.02, 0.5]$ and $n_{channel} \in \{1, 2\}$.
- Do the test of each set of parameter values 200 times with independently generated random errors and time points.
- Extract the relative fluctuation of the period estimates to get the value of the "spurious differential rotation", $P_w \pm \Delta P_w \Rightarrow Z_{spu}$.

Z_{spu} vs. number of data points



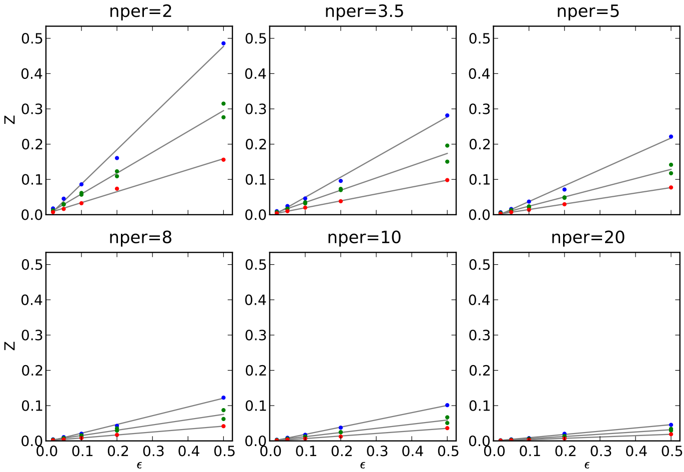
Relative errors of data, $\epsilon \in [0.05,\ 0.1,\ 0.2]$

Z_{spu} vs. number of periods included



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

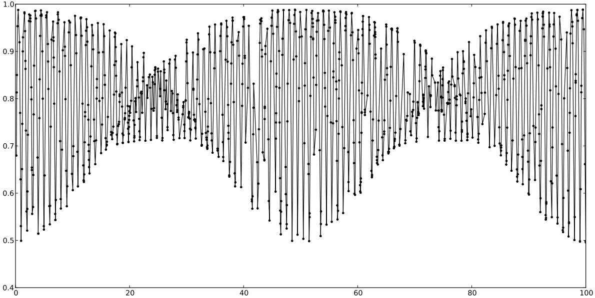
Z_{spu} vs. relative errors of data



Number of data points, $n_{data} \in [10,\ 20,\ 50]$

Changing light curves

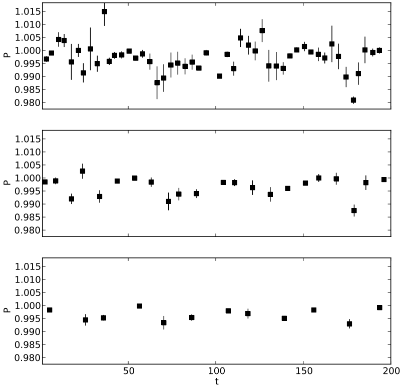
- In reality the light curves of active stars are not stationary.
- Potential problems created by this can be demonstrated with test data from a two spot star and running sliding period estimation for it with a time window of ΔT.
- Use $P_{spot,1} = 0.98$, $P_{spot,2} = 1.02$, $T = 200$ and 2000 data points with random times (but zero errors).



- We end up with values:

ΔT	2.0	5.0	10.0
n_{per}	2	5	10
$\overline{n}_{data}$	20	50	100
P_w	0.9969	0.9983	0.9981
ΔP_w	0.0043	0.0015	0.0016
Z	0.0259	0.0091	0.0094

- Z depends on ΔT, but how much of this is due to non-stationarity of the light curve shape within data sets and how much to the change of n_{per} and n_{data}?



Changing light curves

- Moreover, variations of P may be induced just by the growth and decay of spot areas affecting the light curve shape even if no differential rotation is present.
- It's also possible that spots created by a large scale dynamo field are not in fact following the surface differential rotation of the star (Korhonen & Elstner 2011).

Conclusions

- Determining stellar differential rotation from photometry is not straight forward.
- Estimates of low differential rotation from high quality data are likely reliable while very high values ($k > 0.30$) derived from noisy low amplitude data are almost certainly spurious.
- But what about estimates in the between ($k \approx 0.10$)?

Conclusions

Think twice when you encounter estimates of stellar differential rotation!