PSPM WP 123 500

Tools to measure rotational modulation

HH exercises on rotation measurements:

Methods and preliminary results

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Aims

- To test our ability to measure rotation periods and surface differential rotation from the PLATO photometric time series.

Method

- Periodogram analysis (Lomb-Scargle, GLS, CLEAN) of *simulated* PLATO L0 light curves.

Simulated PLATO light curves

We take advantage of the experience gained with the periodogram analysis of Kepler targets.

Aigrain et al. (2015) have generated **1000** non-variable light curves:

- **770** are light curves Kepler-based, that is of non-variable Kepler targets (PDC-MAP curves)
  These contain the photon shot-noise and residuals of systematics removal
- **230** are light curves completely simulated (noise free)

They injected *variability ingredients* into these light curves in order to mimic the real behavior of solar-like stars :

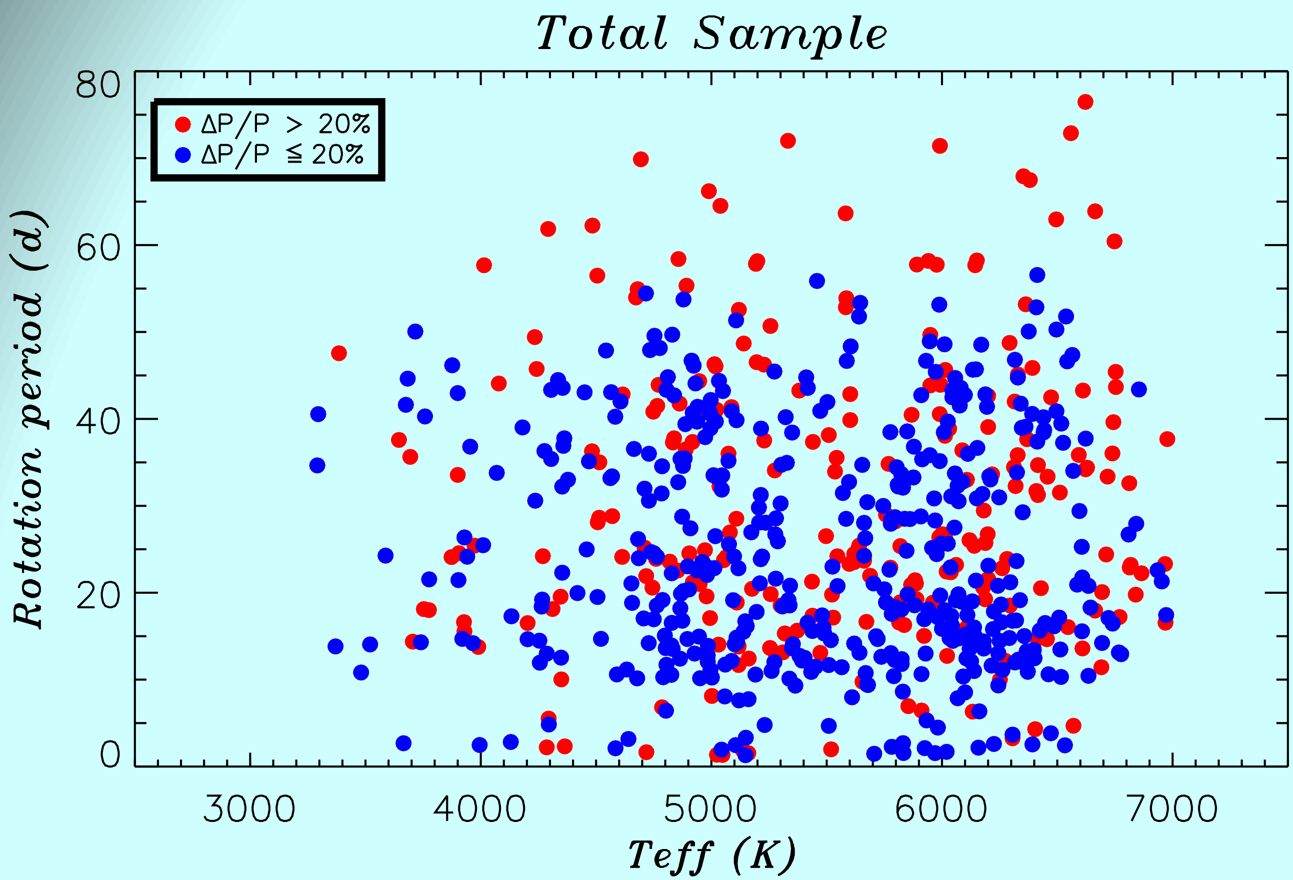
Variability ingredients are:

- Spots with rotation period in the 1--50 days range;
- Surface Differential Rotation in the 0--100% range;
- Spot cycles (1--10 yr); active region decay time (1-10)P_{eq}; activity lev. 0.3--3 x solar;
- Butterfly-like diagrams.

Initial sample: 1000 curves

Working sample: 498 curves with DP/P < 0.2

(374 Kepler-based + 124 noise-free)



Light curves have:

- **1100-d time span**
- **2.5-h cadence**
- **10800 points**

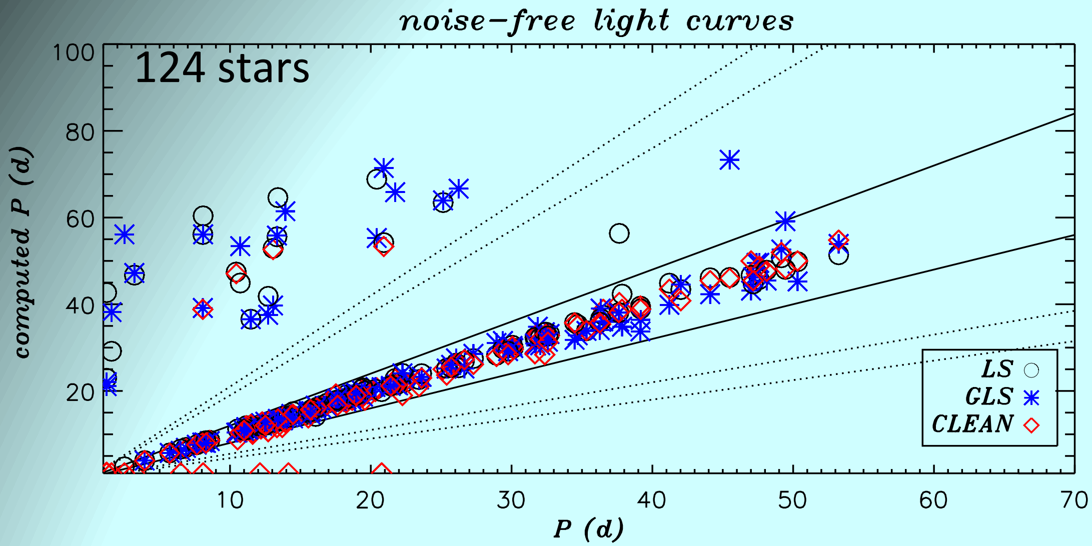
Rotation period search

- Lomb-Scargle (Scargle 1982; Horne & Baliunas 1986)
- Generalized Lomb-Scargle (Zechmeister & Kuerster, 2009)
- CLEAN (Roberts et al. 1987)

Case 1: periodogram analysis of simulated Kepler-based and noise free curves

Case 2: periodogram analysis as in Case 1 + instrumental effects by PSLS (PLATO Solar-like light curve Simulator; **Samadi et al. 2019**)

Results for Case 1

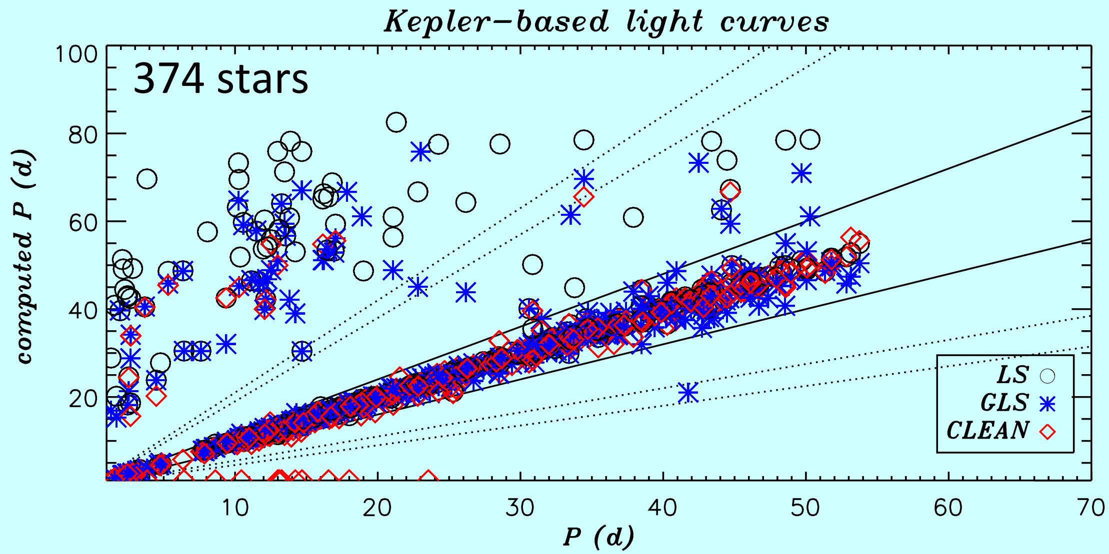


Period detection rate: Scargle 86%, GLS 85%, CLEAN 91%

We get comparable results in noise-free and Kepler -based light curves → intrinsic stellar variability dominates over residuals systematics in PDC-MAP Kepler curves.

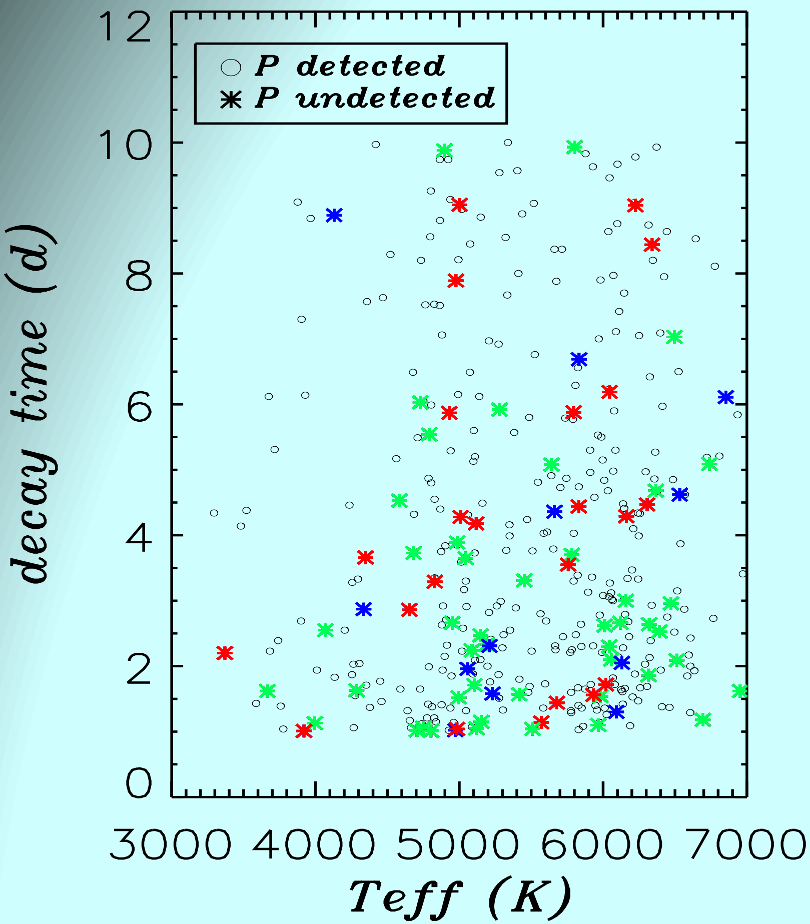
It makes sense their use in our tests

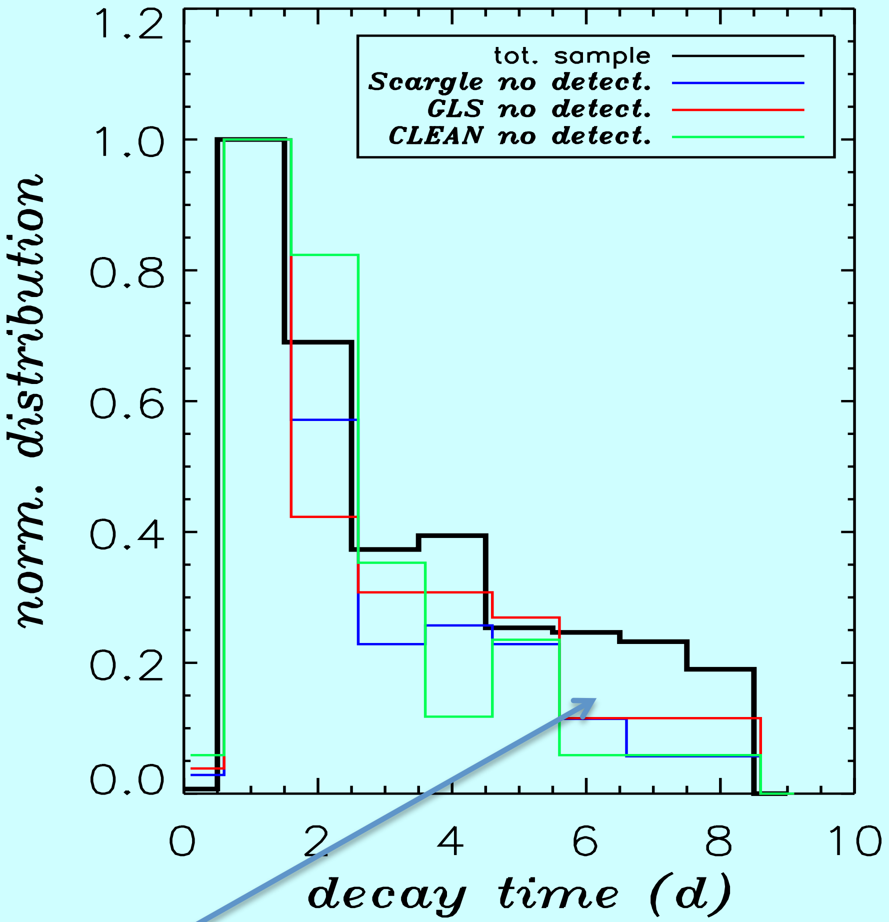
Since our periodogram tools provide detection rates comparable to those obtained on the same set of light curves by independent groups (see paper by Aigrain et al. 2015), we are confident we can trust our tools.



Period detection rate: Scargle 80%, GLS 85%, CLEAN 90%

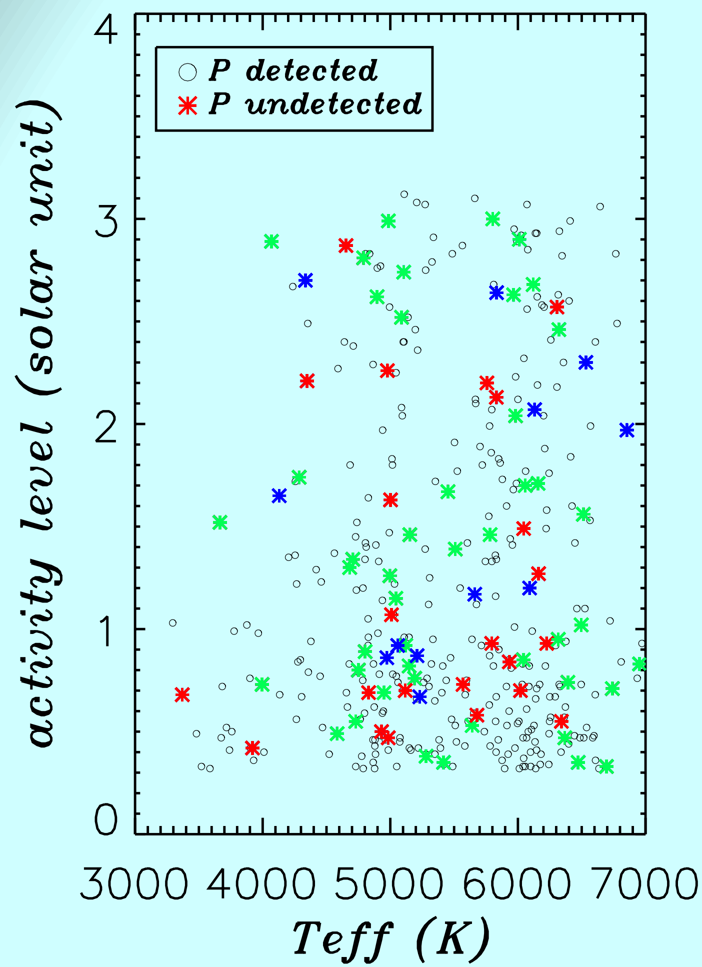
Dependence of non-detection rate on variability ingredients: <u>active regions decay time</u>

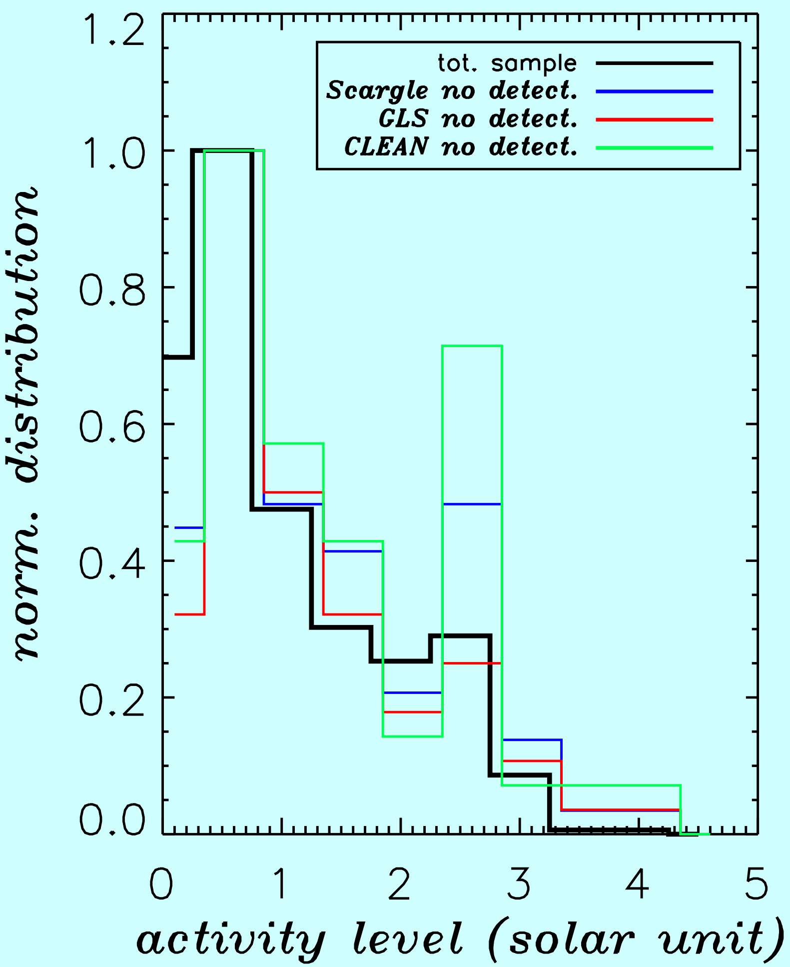




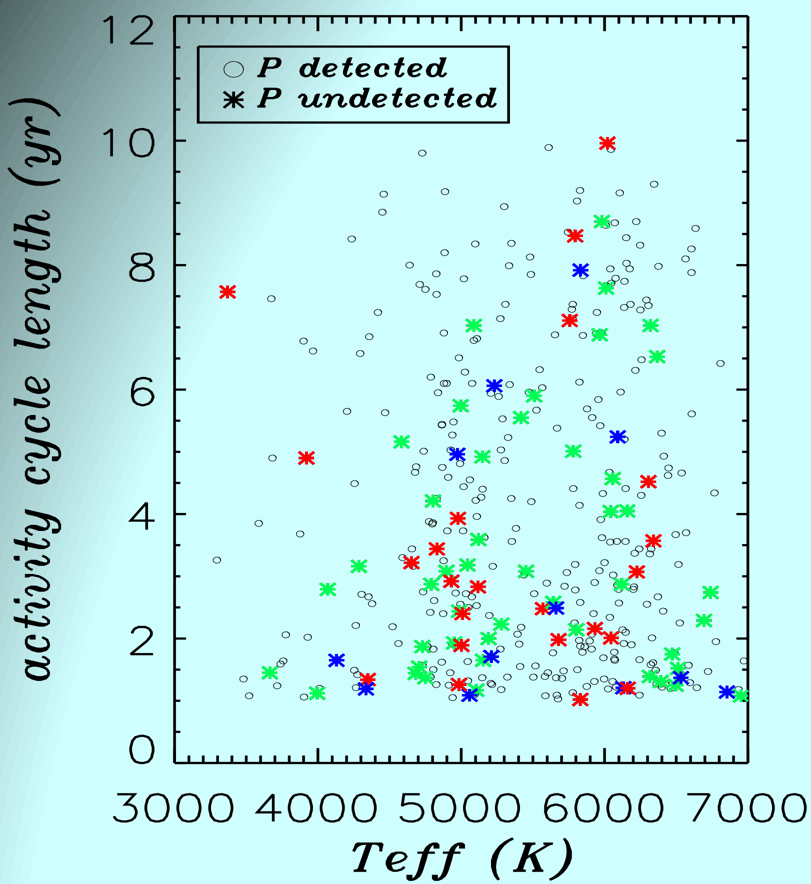
The longer the active region decay time the higher the rotation period detection rate

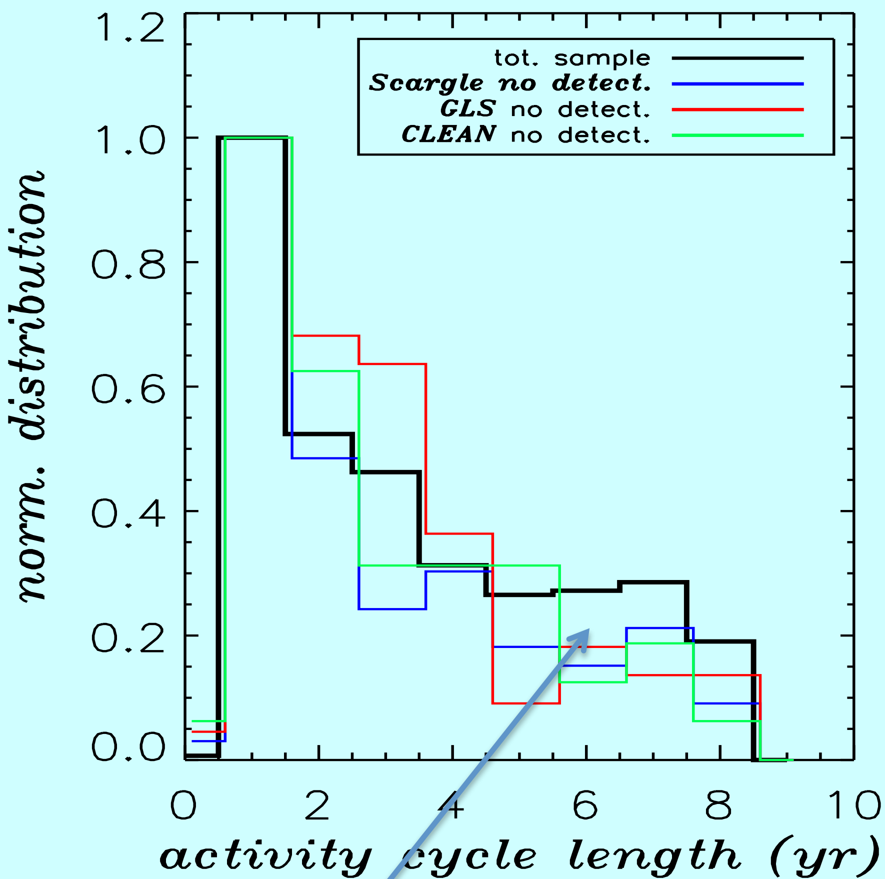
Dependence of non-detection rate on variability ingredients: activity level





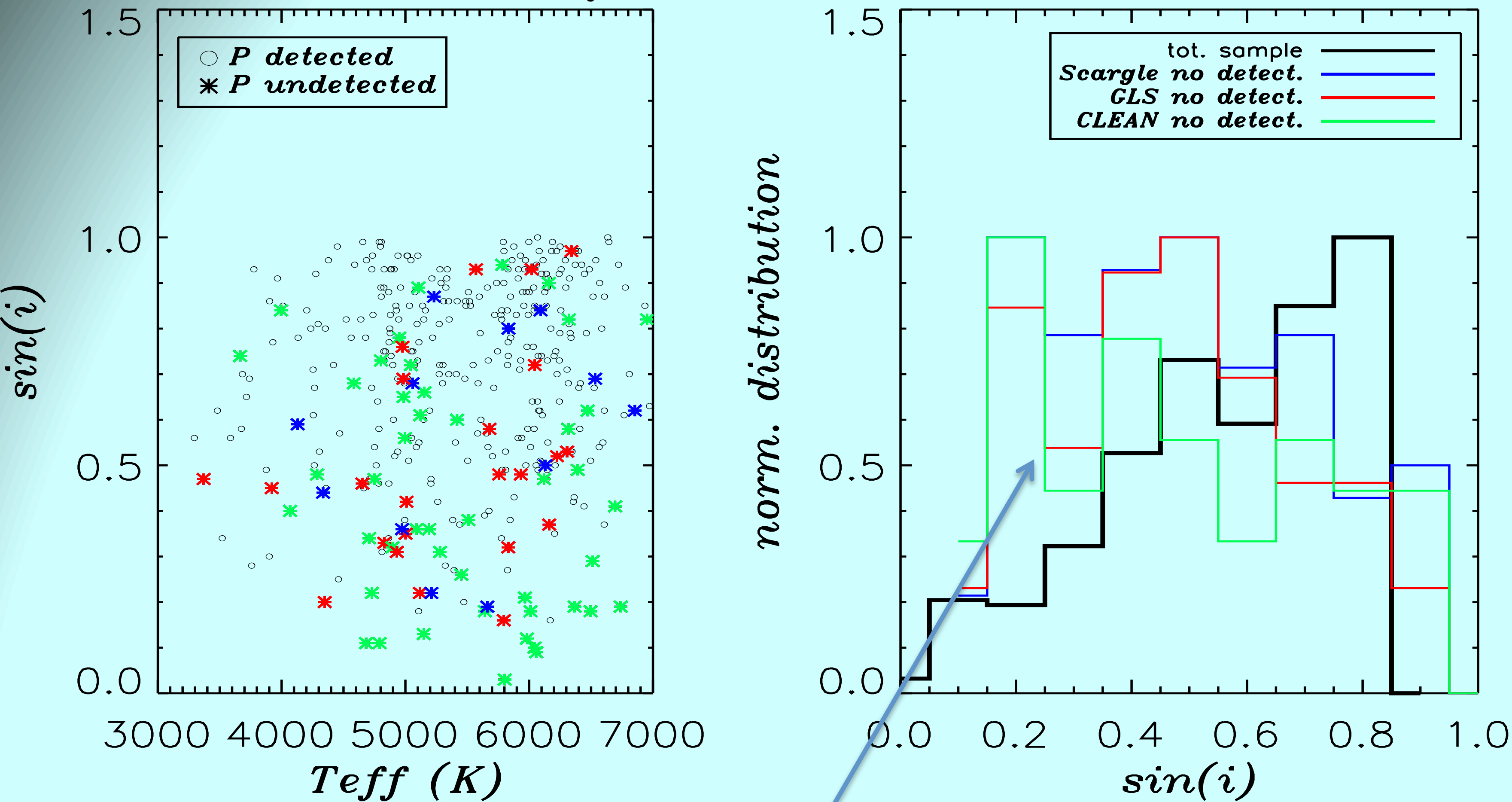
Dependence of non-detection rate on variability ingredients: activity cycle length





The longer the activity cycle the higher the rotation period detection rate (though marginal)

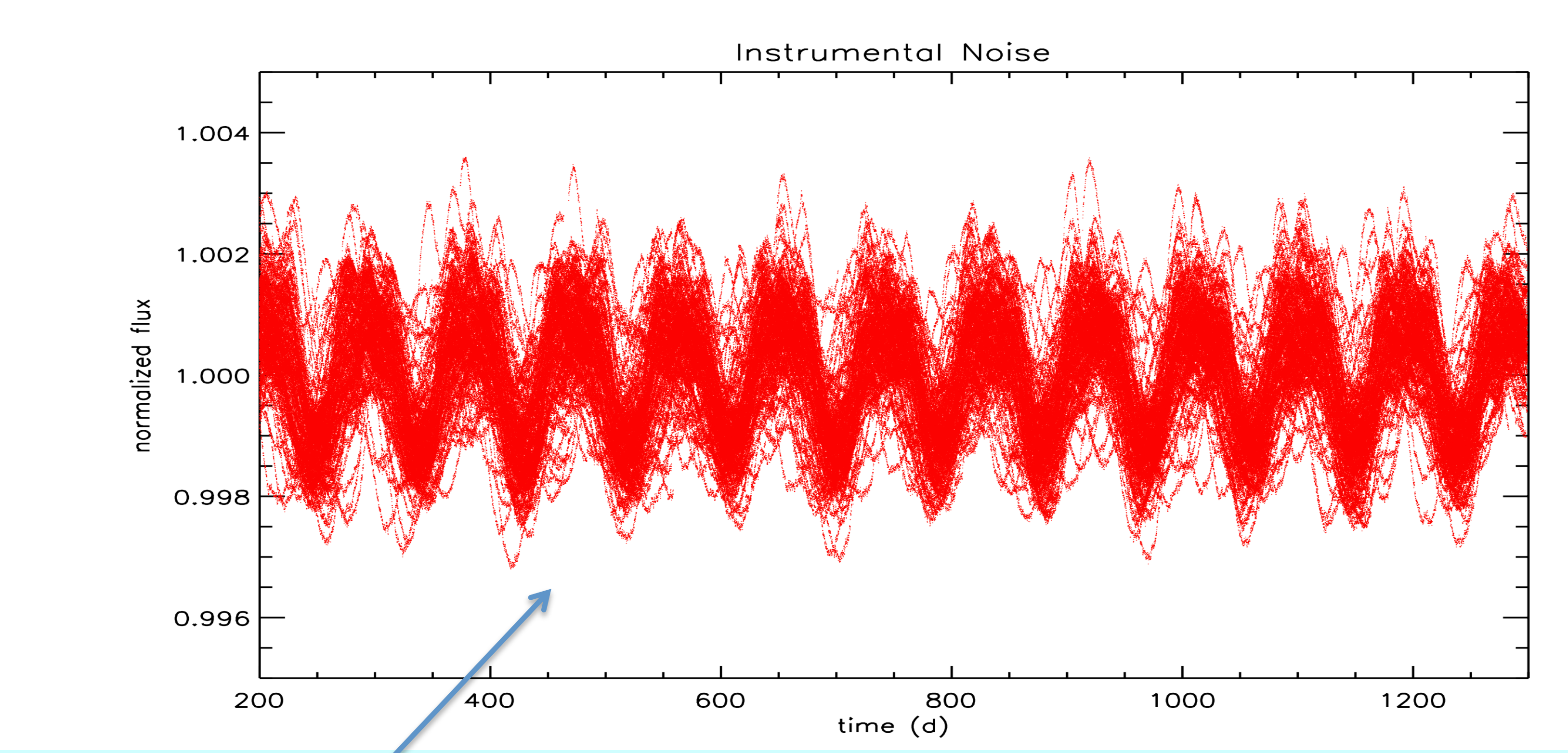
Dependence of non-detection rate on variability ingredients: spin axis inclination



Highest non-detection rate among pole-on stars: sin(i) <0.4

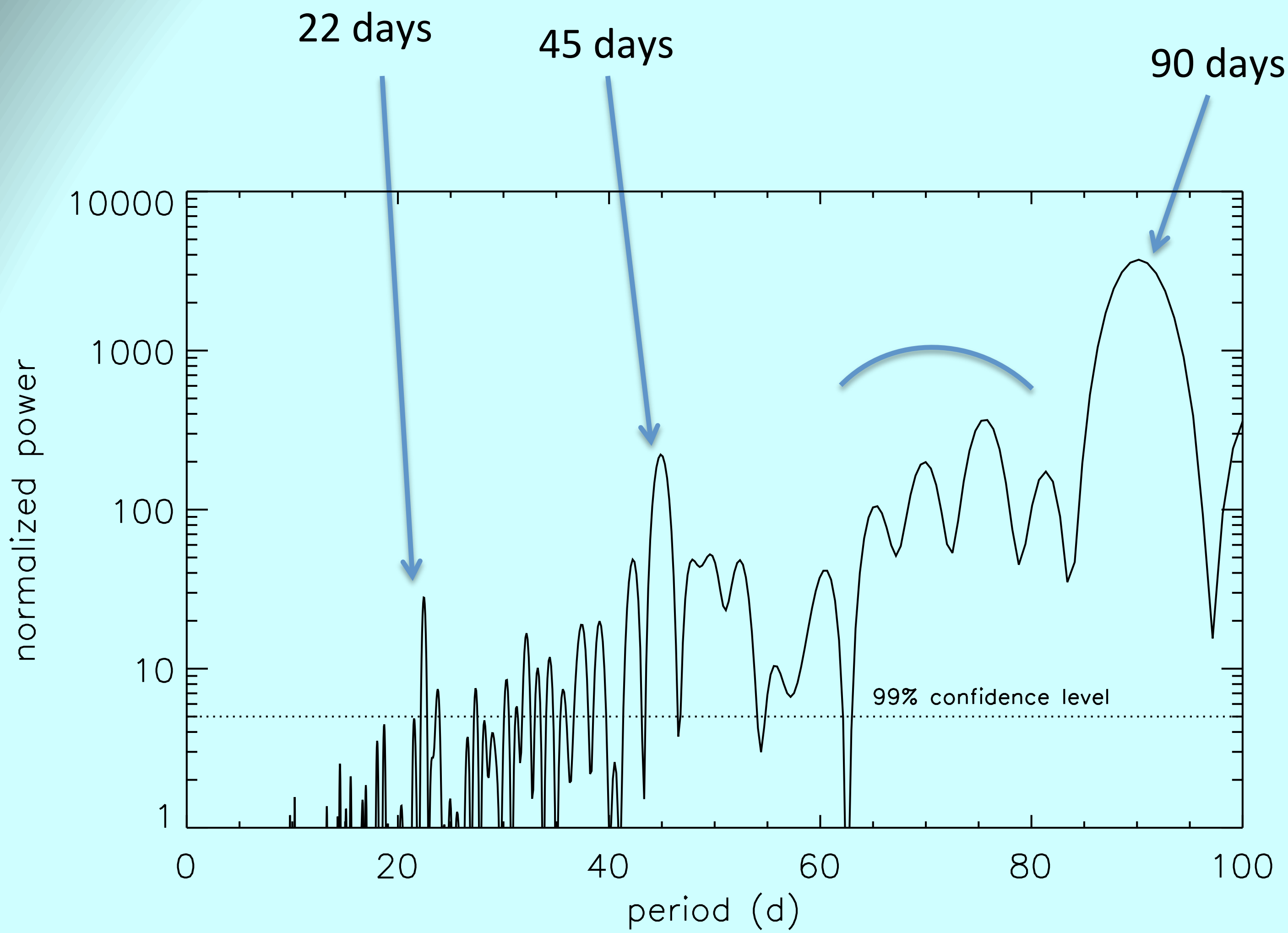
Adding instrumental noise from PLATO Solar-like lightcurve Simulator (PSLS)

We generated 498 instrumental-noise lightcurves with PSLS to be added to the 498 simulated light curves in our working sample maintaining same duration and binning (1100d; 2.5h; 10800 points)



Full sample of 498 instrumental-noise PSLS curves

Instrumental-noise light curves are periodic: primary period at P=90 d and secondary periods at P=45d, 60d, 80d, …



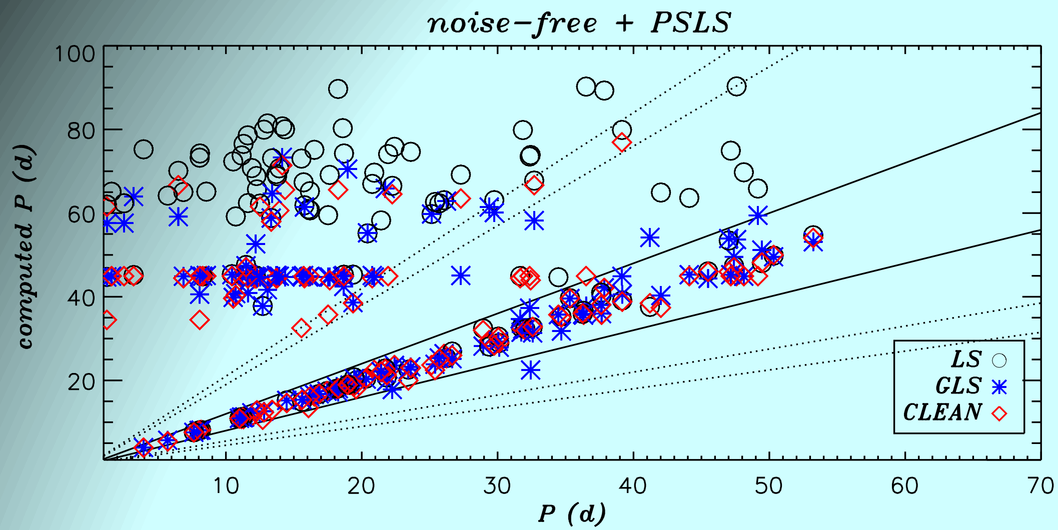
Instrumental noise has an average standard deviation $\sigma = 0.001$

Important notice!

- PSLS simulates effects on L0 level light curves;
- It takes into account a number (but not all, yet) instrumental effects;
- The results of our tests on rotation period recovery are, therefore, preliminary and must be considered valid for L0 light curves.
- WP123 500 will finally work on L1 curves (calibrated light curves, corrected for instrumental effects such as temperature sensitivity, jitter, differential aberration, pixel sensitivity dropout (talk by A.F. Lanza))
- WP 123 000 expects to further remove discontinuities, residual instrumental effects, gaps, (so-called L2 curves) that will all help WP123 500 to improve the period detection rate.

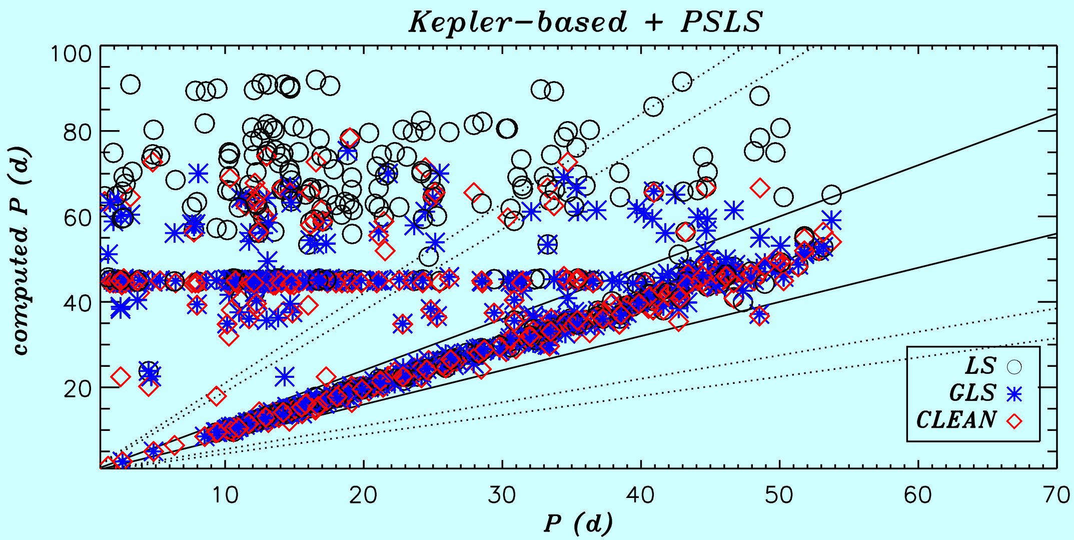
In other words, our preliminary results refer to the worst (most noisy) case.

Results for Case 2



We get comparable results in noise-free and Kepler-noise light curves → residuals systematics in PDC Kepler curves are dominated by intrinsic variability.

Period detection rate: Scargle 34%, GLS 54%, CLEAN 60%



A significant fraction of spurious periods is introduced by the instrumental systematics

Excluding only P ≈ 45d

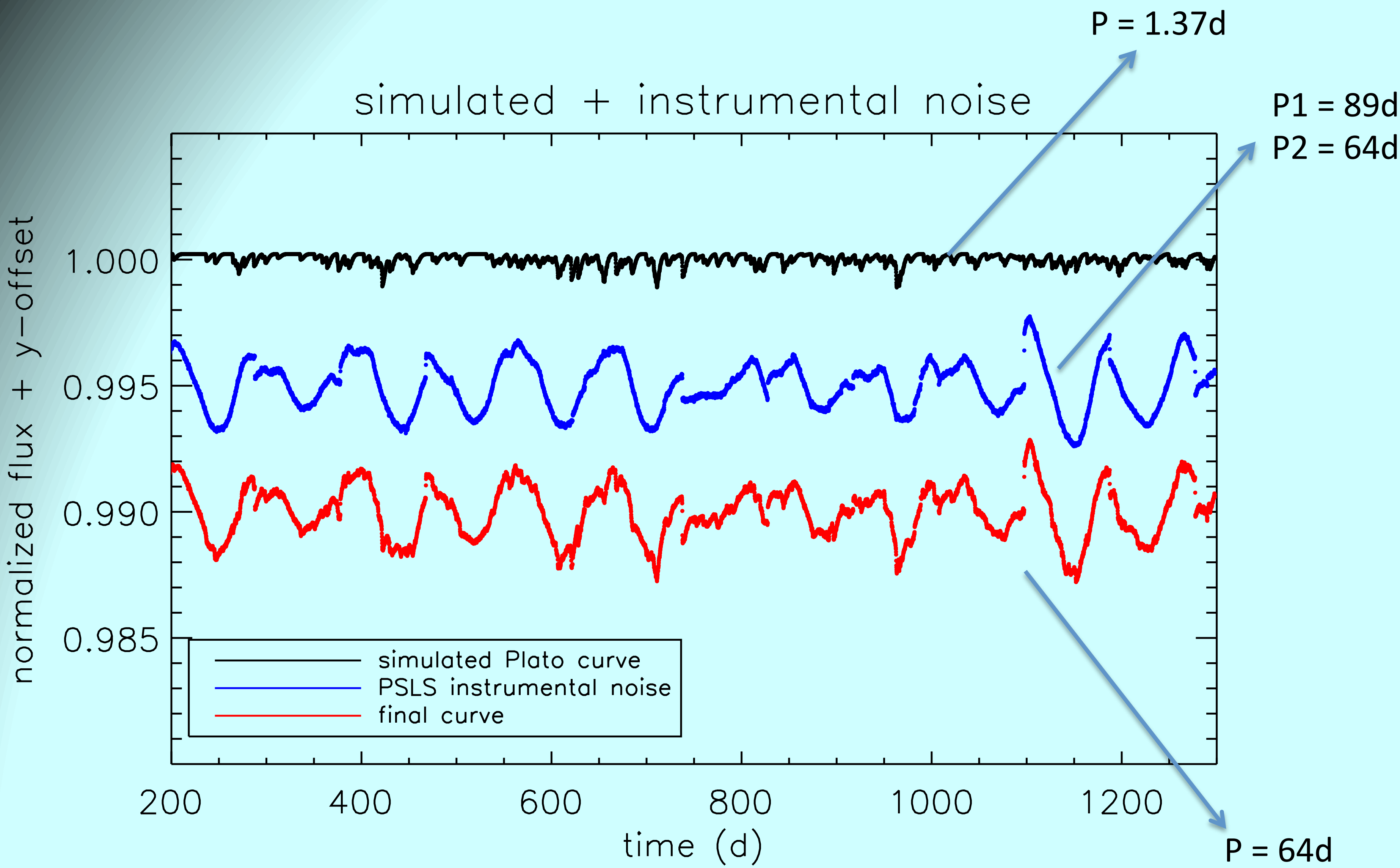
51% Scargle

84% GLS

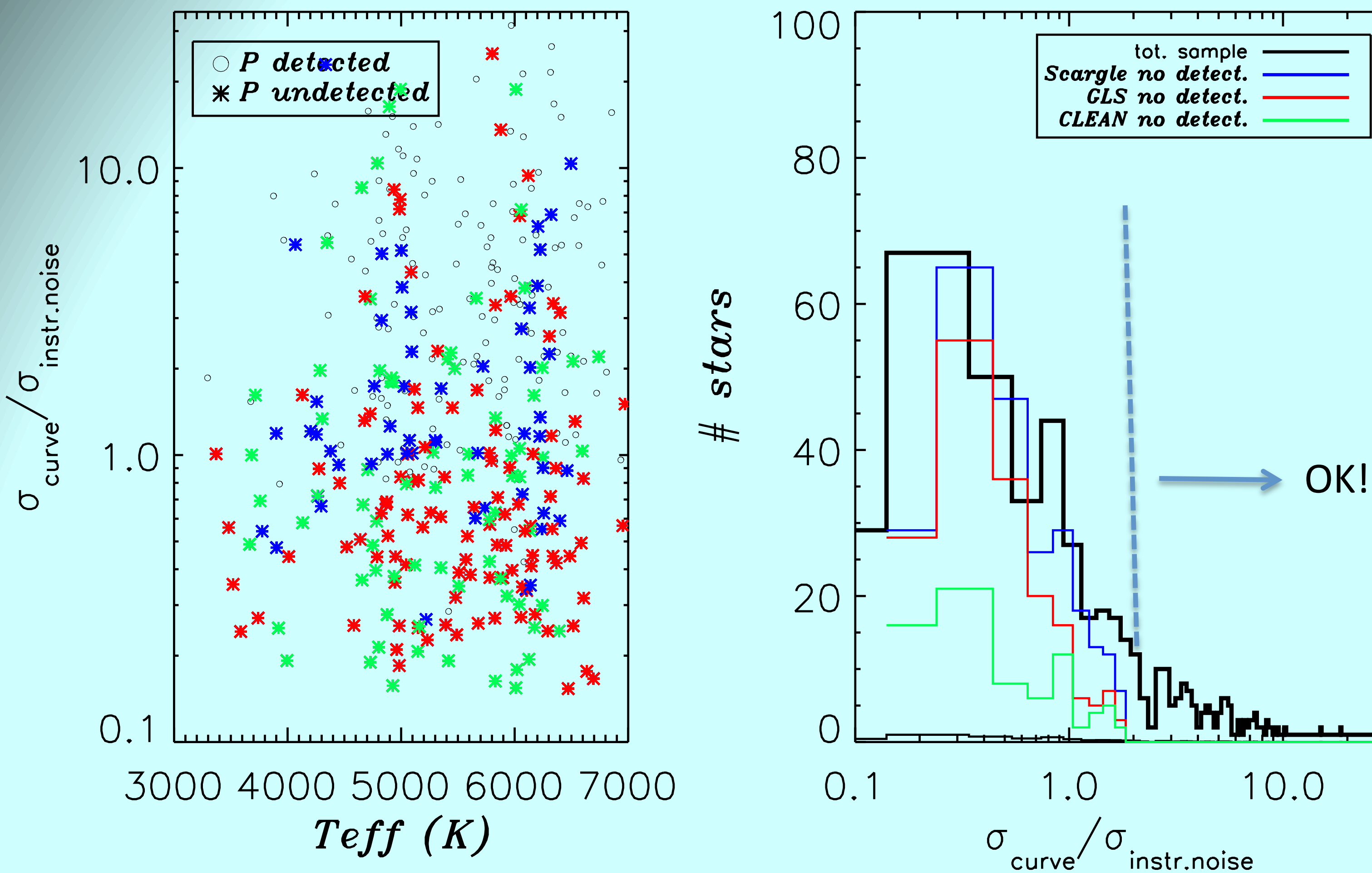
88% CLEAN

Period detection rate: Scargle 42%, GLS 58%, CLEAN 61%

Example of variability dominated by instrumental noise



Dependence of non-detection rate on variability ratio $\sigma_{simul.curve}/\sigma_{instr.noise}$



Despite the analysis of L0 curves, we could detect correct rotation periods in about 50% of curves. We expect a much higher percentage in L1 light curves (and even more in L2).

Next action

- ✓ Test additional methods for rotation period detection: autocorrelation, …
- ✓ Implement detection and measurement of Surface Differential Rotation

We invite other research groups to join us in our tests.

They can significantly improve the WP123 500 activity with their own period detection techniques and new ideas.

Many Thanks
for
your kind attention