The Stellar Pulsation Timing Detection Method for Substellar Companions

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Abstract

We want to make use of the rapid pulsations in subdwarf B stars (sdBs) to detect substellar companions from periodic variations in the expected arrival times of the pulsations. This timing method is particularly sensitive to planets at large distances and complementary to other exoplanet detection methods because they are not as efficient for stars with small radii and high gravities. Thus, the timing method opens up a new parameter range in terms of the host stars. To date, substellar candidates in sdB systems are for example V391 Peg b (Silvotti et al., 2007), HW Vir b, c (Lee et al., 2009), HS 0705+67003 b (Qian et al., 2009) and Kepler-429 b, c, d (Silvotti et al., 2014).

sdB Stars

Subdwarf B stars are located at the extreme horizontal branch in the Hertzsprung-Russel diagram. They have a helium-fusion core but no hydrogen-shell fusion in their thin hydrogen shells. The mass-loss leading to such thin shells can be well explained in close binary systems but is difficult for single sdBs. Planets have been proposed to be responsible for the formation of single sdBs.

Some subdwarf B stars exhibit pulsation instabilities driving acoustic modes of a few minutes period. They can be used as a clock signal to detect periodic changes in the arrival time caused by a substellar companion.

Light Travel Time Effect

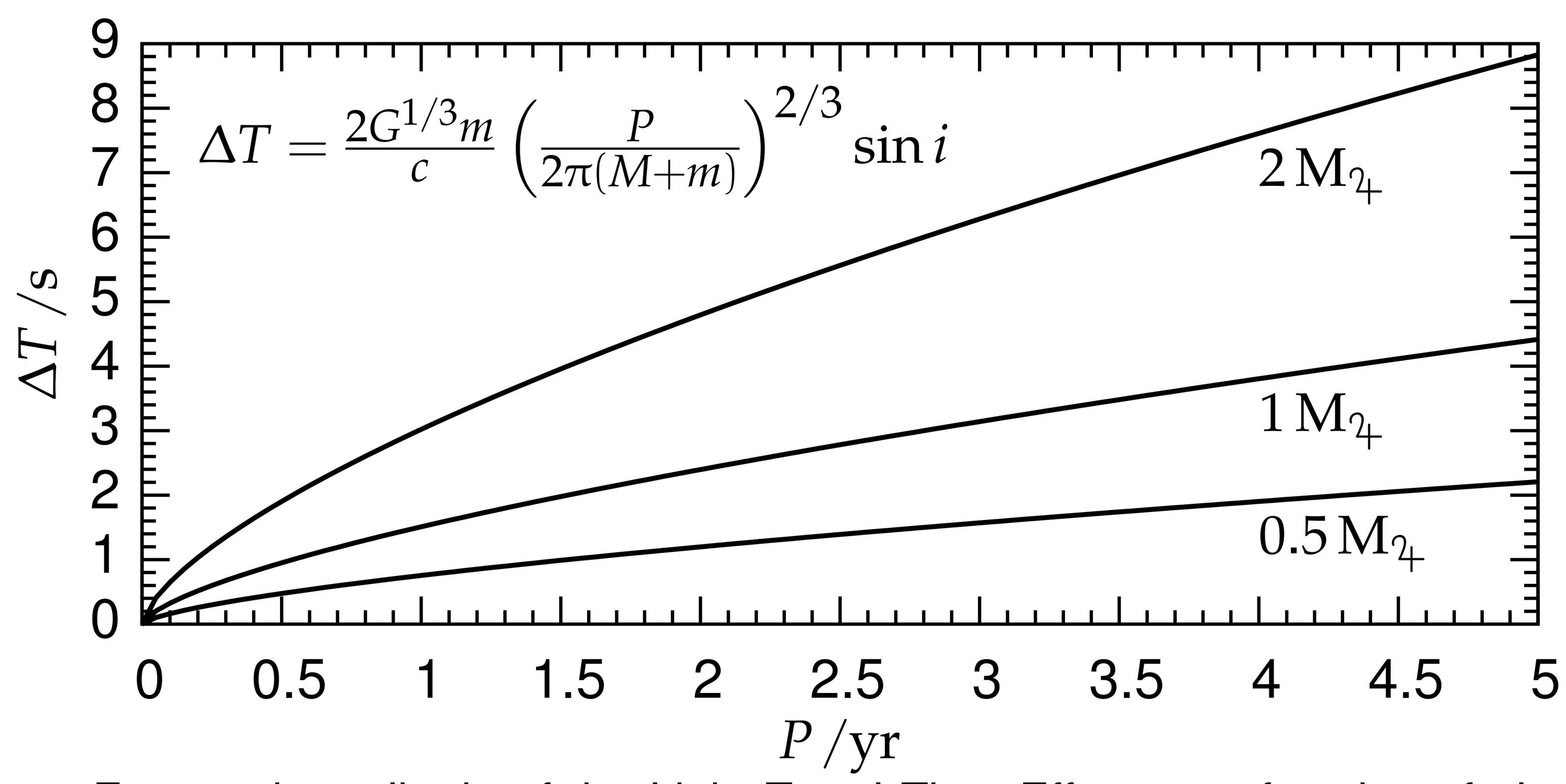
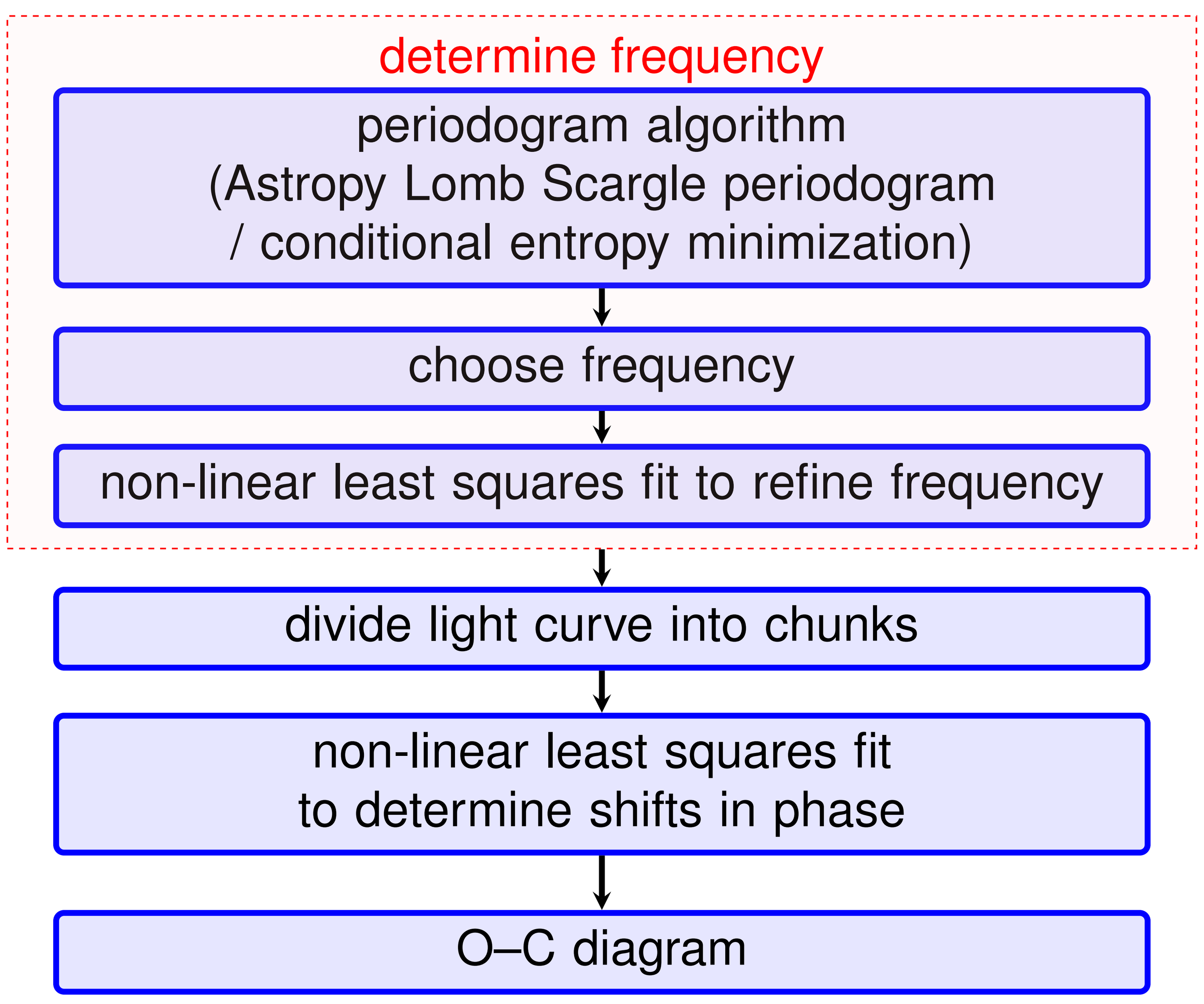


Figure: Expected amplitude of the Light Travel Time Effect as a function of planetary orbital period P for a host star of mass $M = 0.5\,M_{\odot}$, $\sin i = 1$ and different planetary masses m.

Python Pipeline



Simulated Data

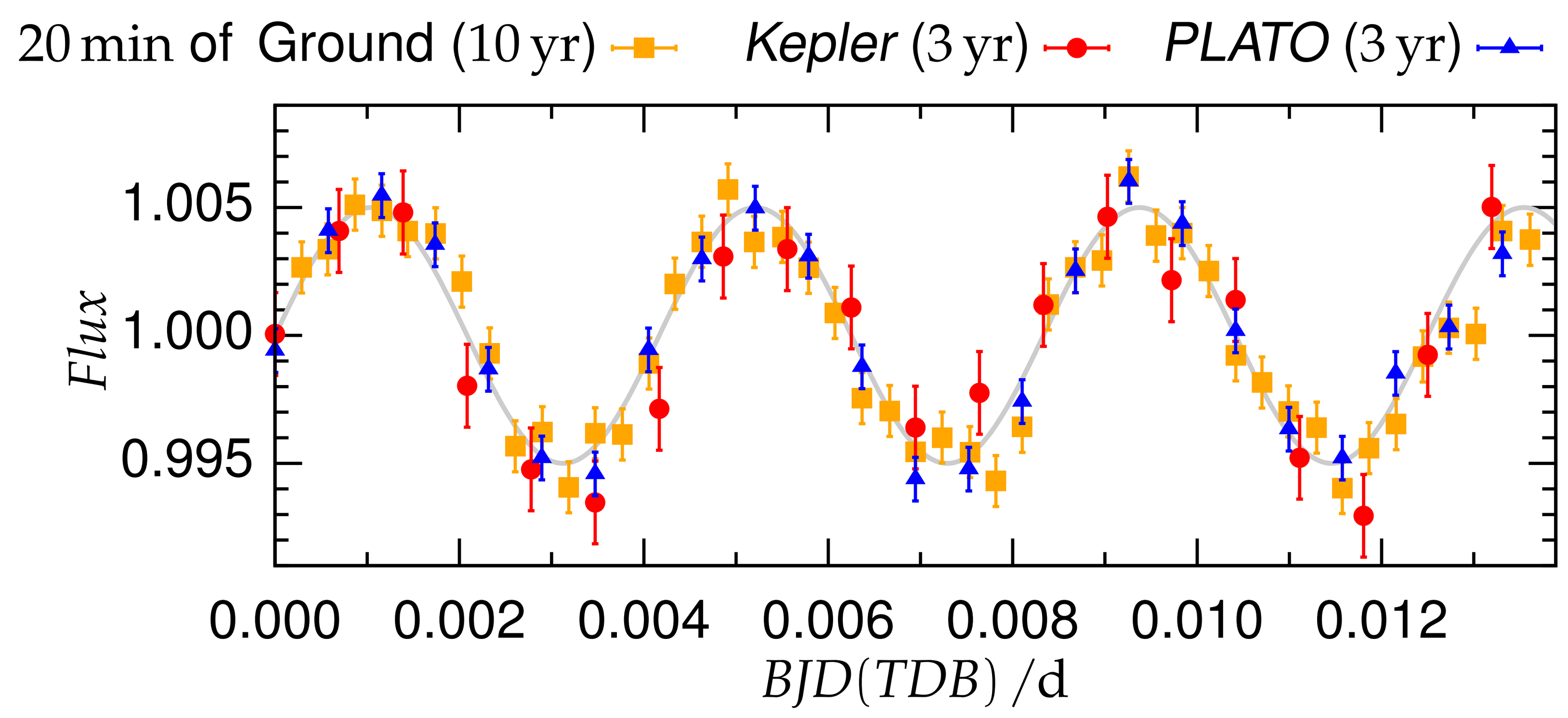


Figure: Excerpt of the artificial observations for ground-based-like, *Kepler*-like and *PLATO*-like noise and timing. Fast pulsating host star ($\sim 14\,\mathrm{mag}$) with a period of $6\,\mathrm{min}$ and amplitude of $5000\,\mathrm{ppm}$. Ground-based observations for three consecutive nights per month, cadence $25\,\mathrm{s}$ and noise level of $1000\,\mathrm{ppm}$. *Kepler-* / *PLATO*-like observations with a cadence of $60\,\mathrm{s}\,/\,50\,\mathrm{s}$ and noise level of $1620\,\mathrm{ppm}\,/\,850\,\mathrm{ppm}$, respectively.

Linear drifting Period

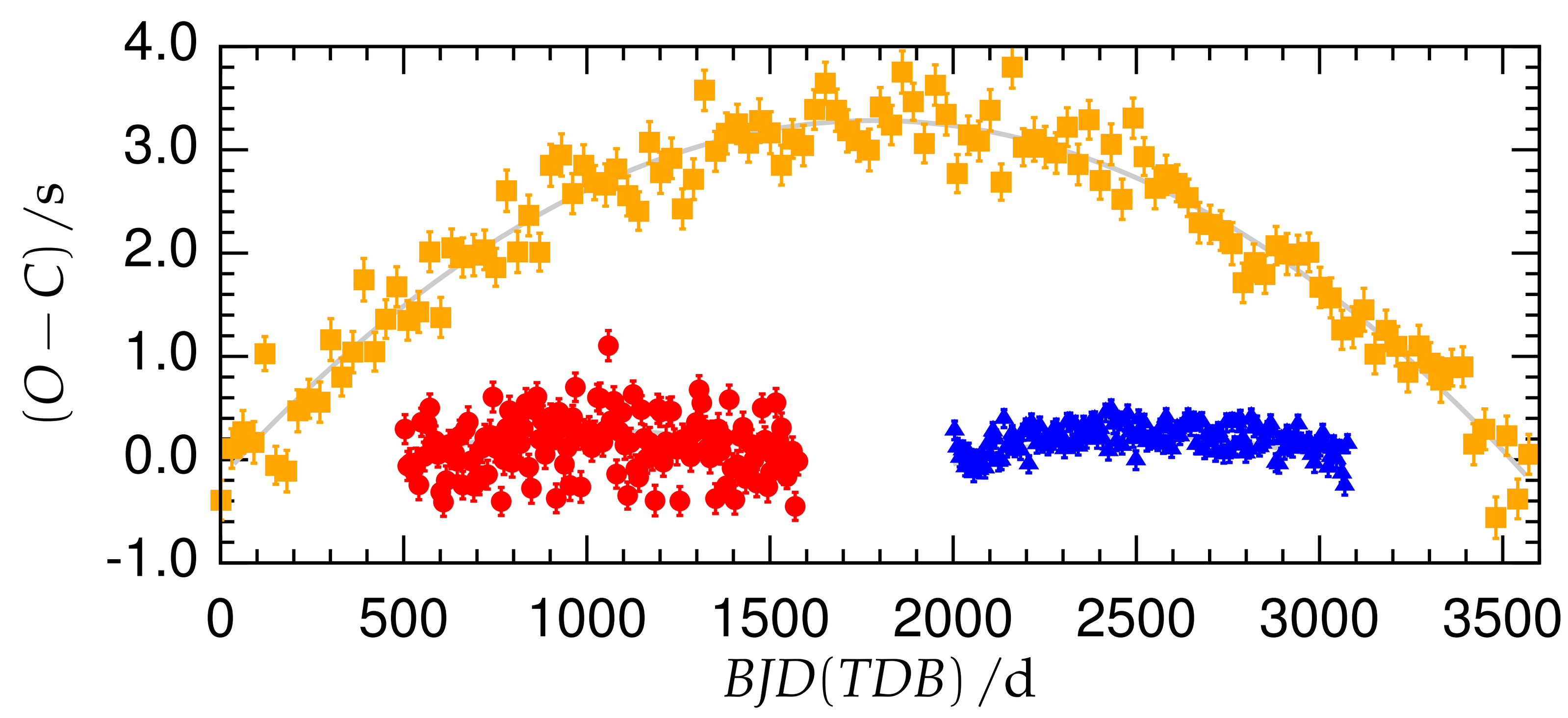


Figure: $O-C$ diagram for an injected linear change in stellar pulsation period $\dot{P} = 10^{-13}\,\mathrm{d\,d^{-1}}$, hence $\dot{P}/P = 2.4 \times 10^{-11}\mathrm{d}^{-1}$. Fitted parameters for ground-based: $\dot{P}/P = (2.5 \pm 0.5) \times 10^{-11}\mathrm{d}^{-1}$, *Kepler*-like: $\dot{P}/P = (2.3 \pm 0.3) \times 10^{-11}\mathrm{d}^{-1}$, *PLATO*-like: $\dot{P}/P = (2.2 \pm 0.2) \times 10^{-11}\mathrm{d}^{-1}$.

Planetary Signal

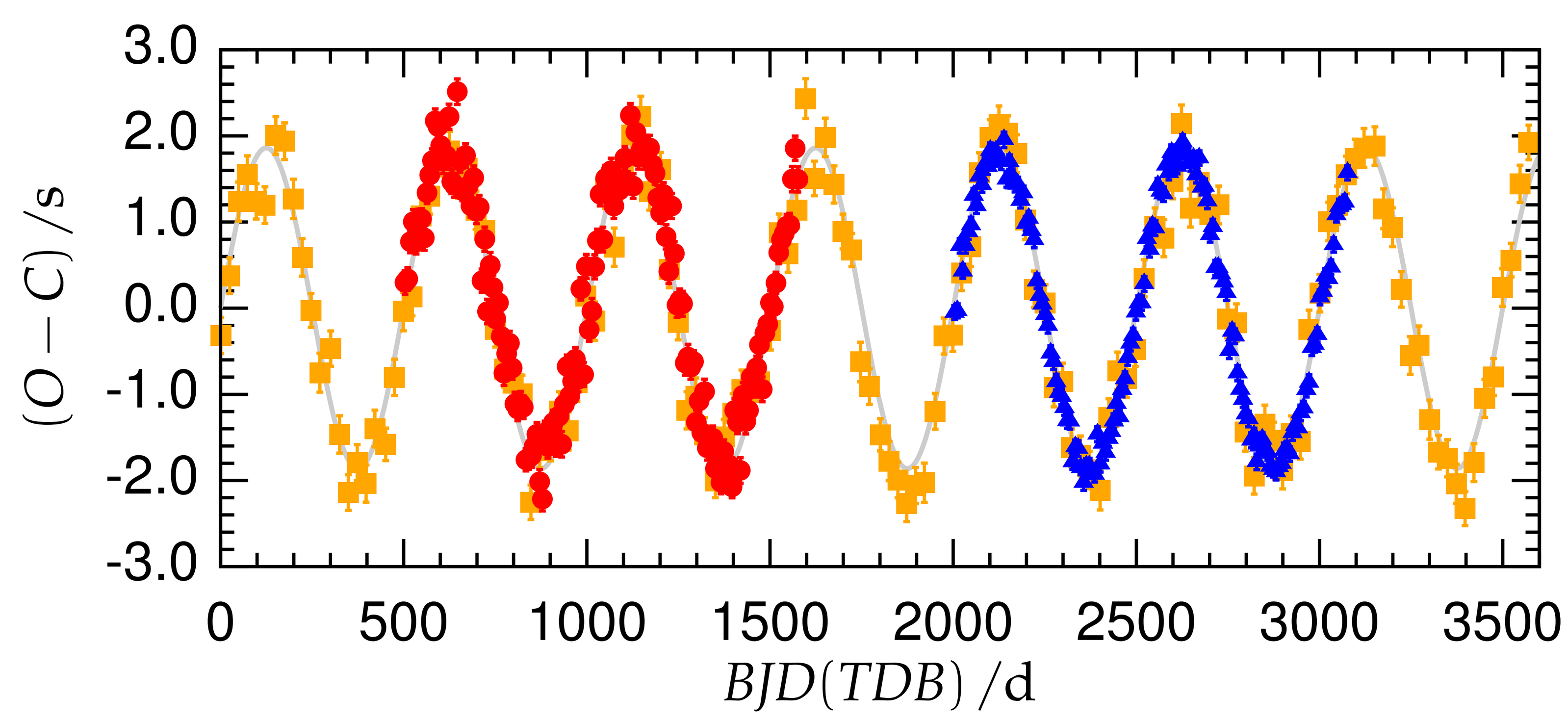


Figure: $O-C$ diagram for an injected planet with $P = 500\,\mathrm{d}$ and $m = 1\,M_{♃}$, hence $\Delta T = 1.862\,\mathrm{s}$. Fitted parameters for ground-based: $P = (499.839 \pm 0.007)\,\mathrm{d}$, $\Delta T = (1.87 \pm 0.03)\,\mathrm{s}$, *Kepler*-like: $P = (500.76 \pm 0.02)\,\mathrm{d}$, $\Delta T = (1.84 \pm 0.02)\,\mathrm{s}$, *PLATO*-like: $P = (500.46 \pm 0.01)\,\mathrm{d}$, $\Delta T = (1.85 \pm 0.01)\,\mathrm{s}$.

Outlook

Our target catalogue will consist of re-analysed *EXOTIME* objects (Lutz, 2011; `http://www.oato.inaf.it//silvotti/exotime/`) and selected *Kepler* stars. The *Kepler* field contains only few rapid pulsating sdB variables but the oscillations of slow pulsating sdBs and δ Scuti stars can be investigated with our pipeline.

In consideration of future photometric space missions like *TESS* and *PLATO* it is essential to enhance the diversity of potential exoplanet host stars that can be probed.

References

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