Hierarchical triple star systems towards the Galactic Bulge through the OGLE's eye

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Introduction

Hierarchical triples

The Optical Gravitational Lensing Experiment (OGLE)

System selection

Most light curves do not contain enough data points.
$\sim$450 000 EB $\rightarrow$ $\sim$80 000 EB

Determination of times of minima

- Automatic method to detect phases of beginning and ending of eclipses
- 12-th order polynomial template functions for the primary and secondary eclipses
- 1 normal minimum for every 17 consecutive binary cycles

$$f_{ecl}(p) = a_0 + a_1 \cdot f_{temp}(p + a_2) \tag{1}$$

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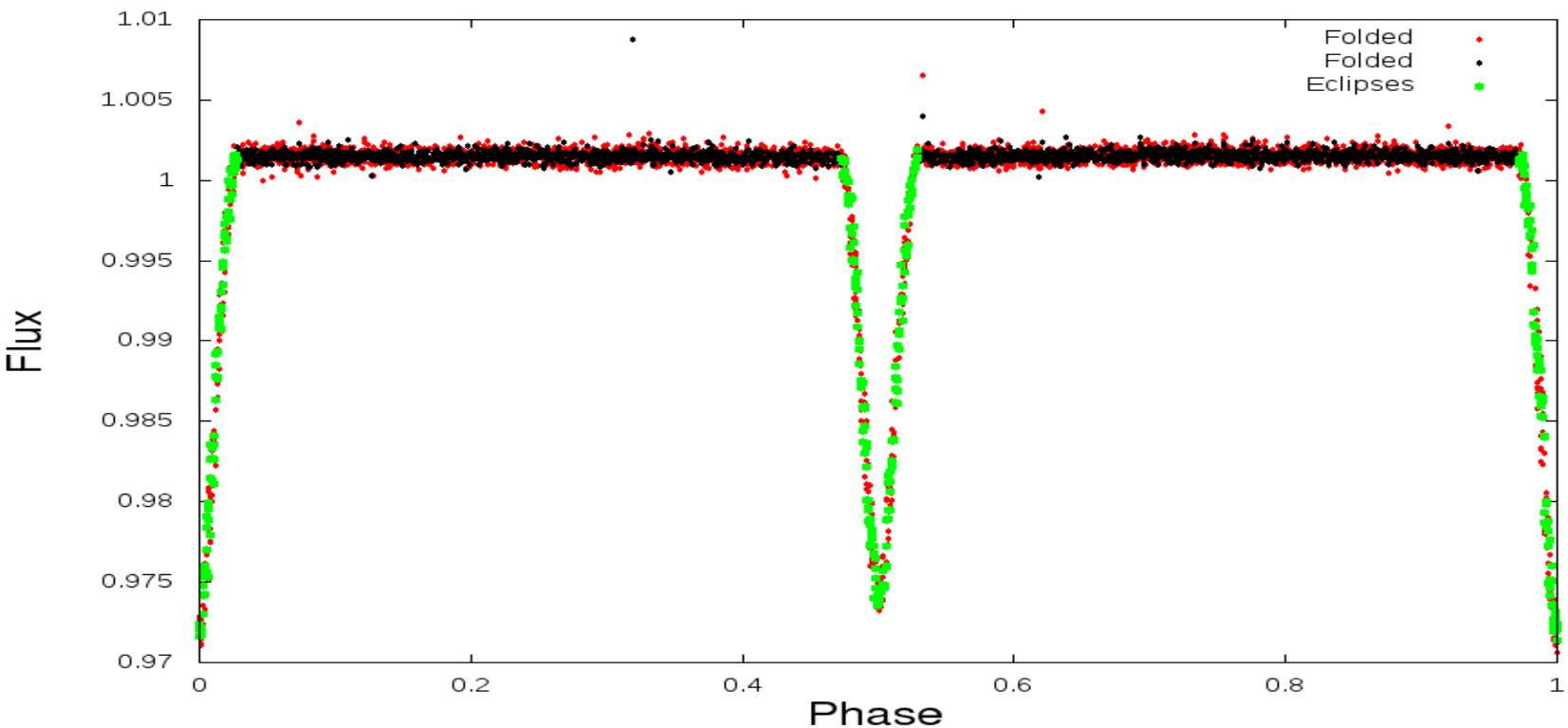
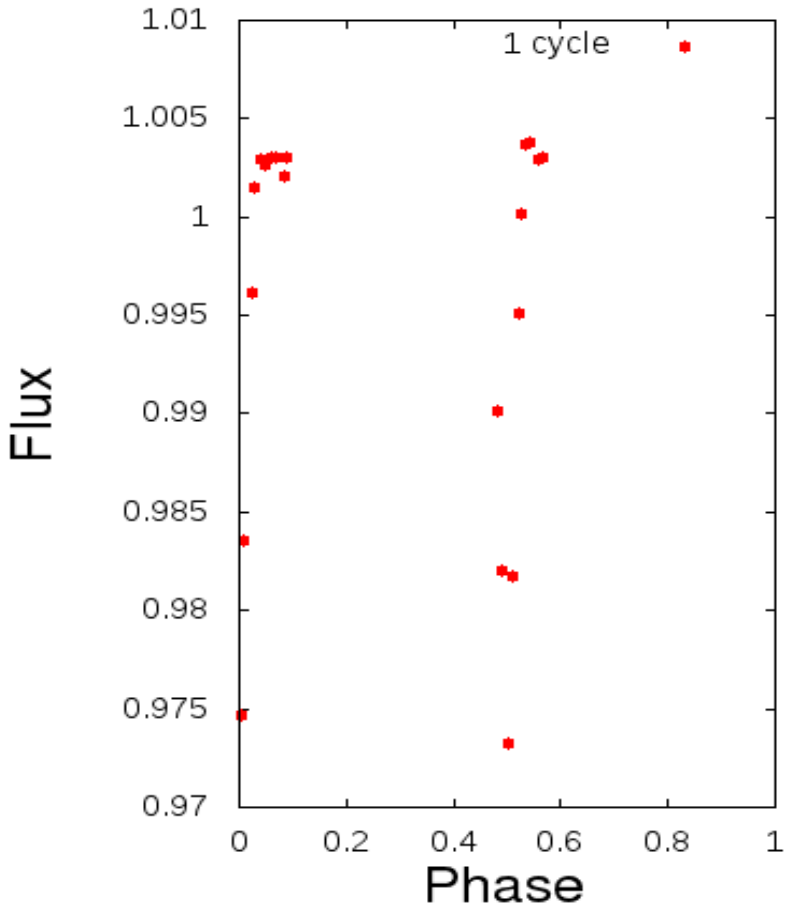
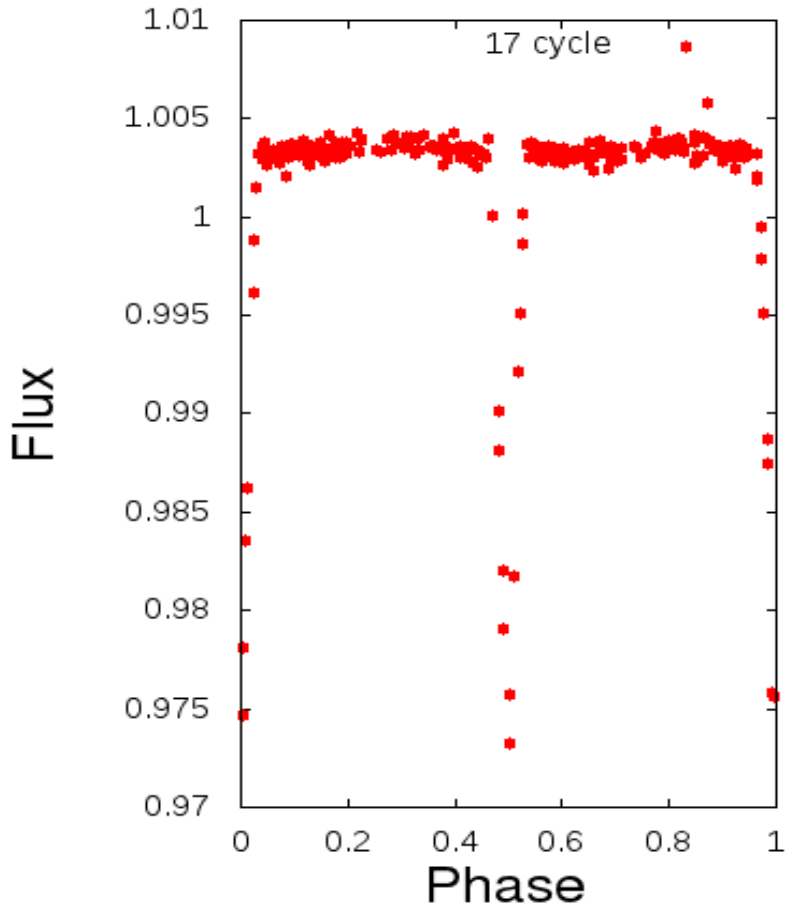


Determination of times of minima

- 1 normal minimum for every 17 consecutive binary cycles

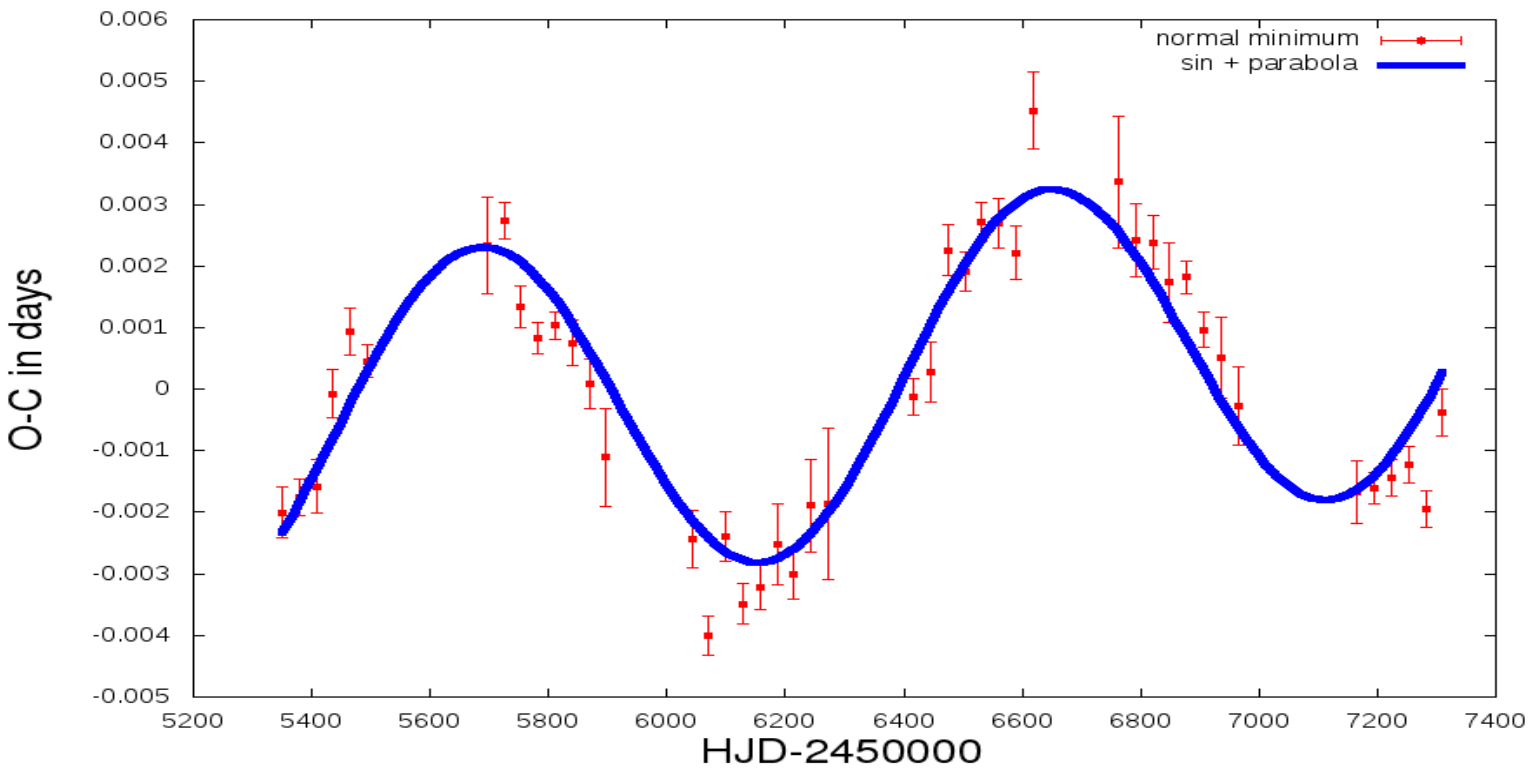
$$f_{ecl}(p) = a_0 + a_1 \cdot f_{temp}(p + a_2) \tag{2}$$





ETV analyses

- Simple sinusoidal curve + a parabolic function (6 parametersa) with grid + Levenberg-Marquardt $\rightarrow P_2$
- LTTE fit
- Checking the result



Another way

Only one parameter (a_2)

- All possible eclipse minima
- For short period triples
- Conditions: Eclipses do not change

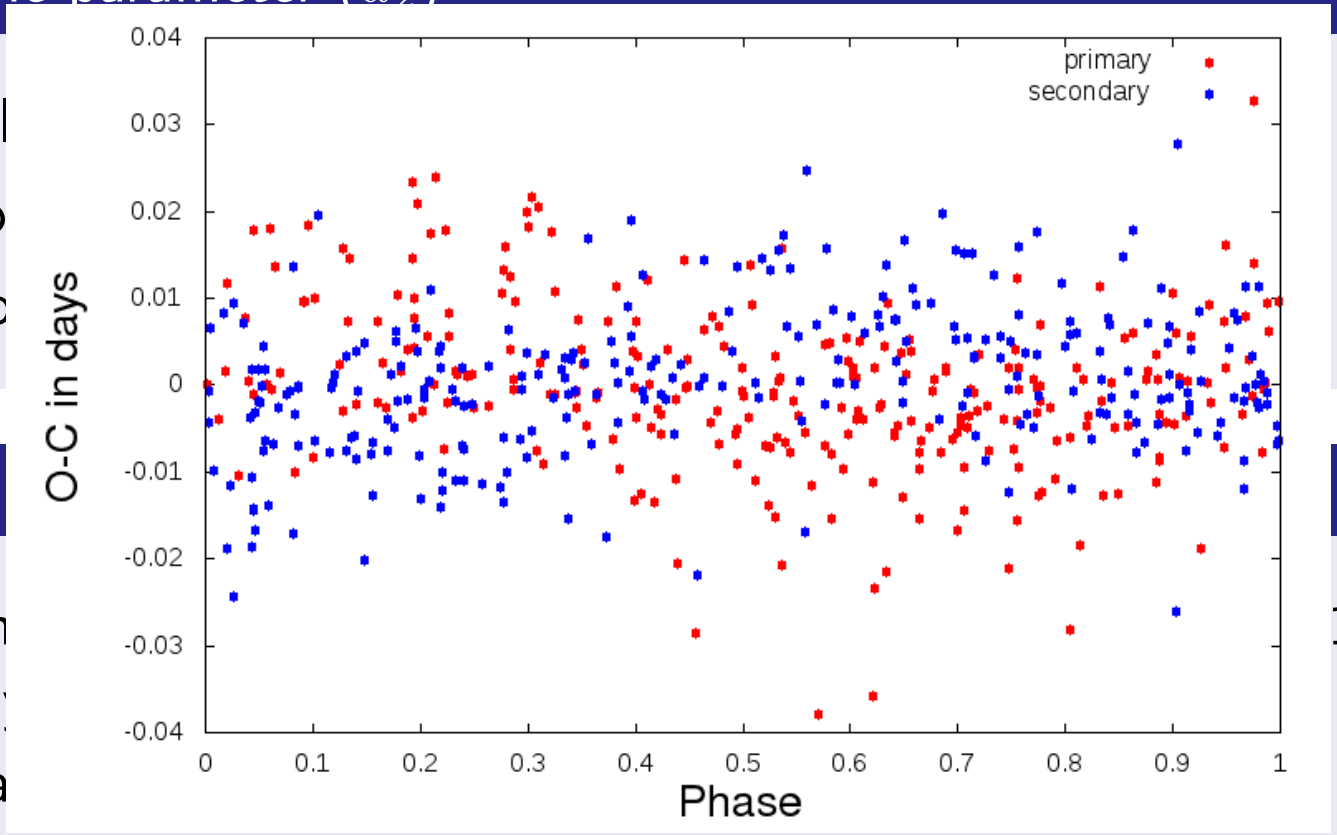
Search for short periodic triples

- Phase dispersion minimization (PDM) from 10 days to 1000 days with 0.1 day steps
- Candidates:
  - P_2 for primary and P_2 for the secondary is almost the same
  - $P_2 < 300$ days
  - Phases are the same (to avoid spotted binaries)

Another way

Only one parameter (a_2)

- All
- Fo
- Co



Search

- Ph
  da
  1000
- Ca
  - P_2 for primary and P_2 for the secondary is almost the same
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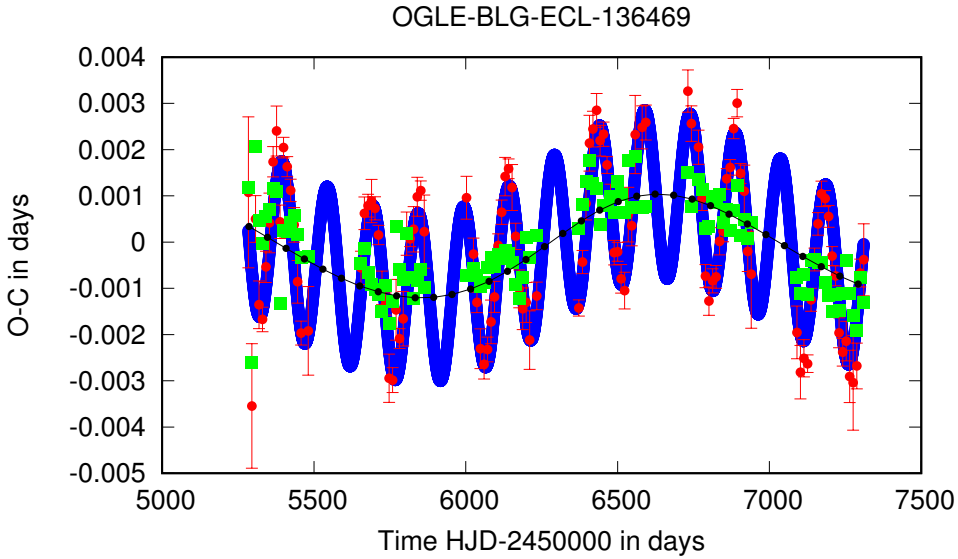
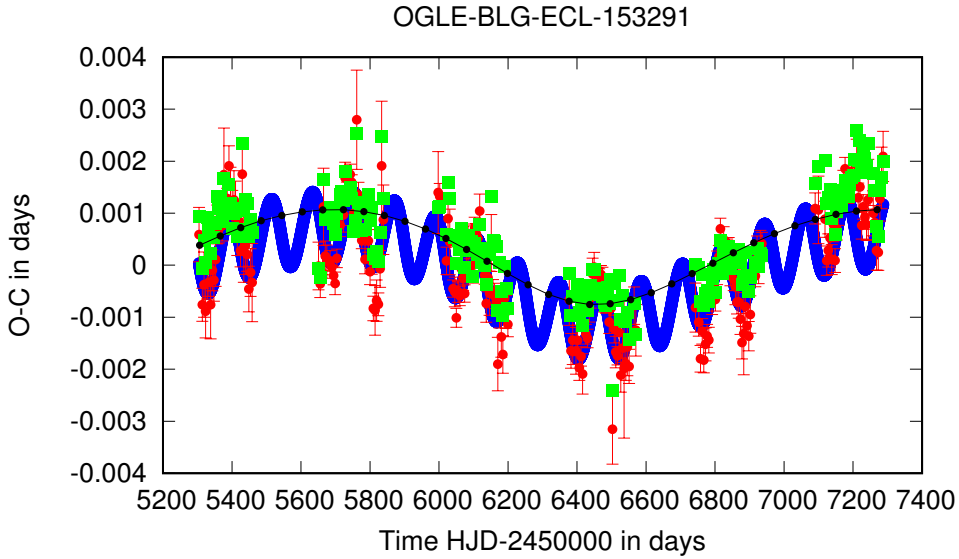
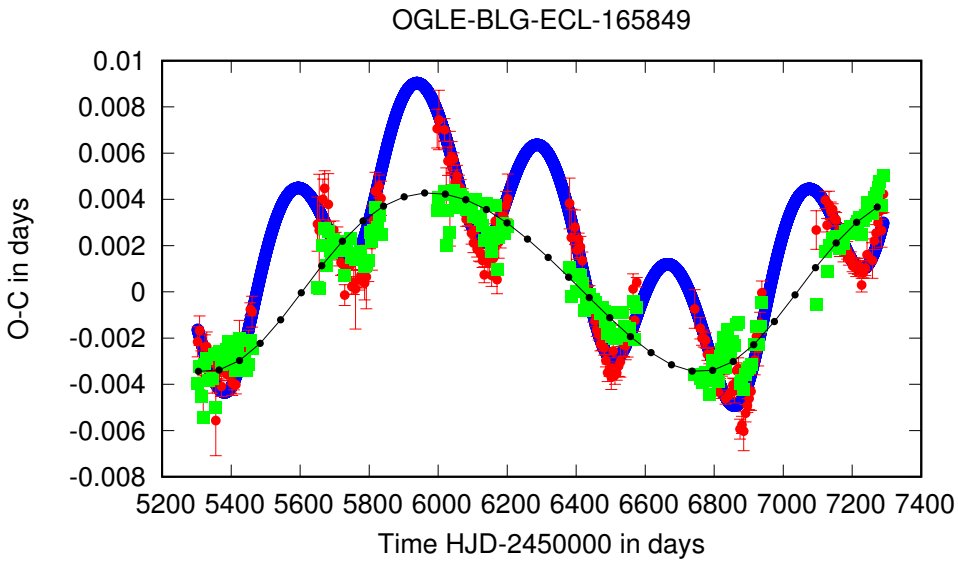
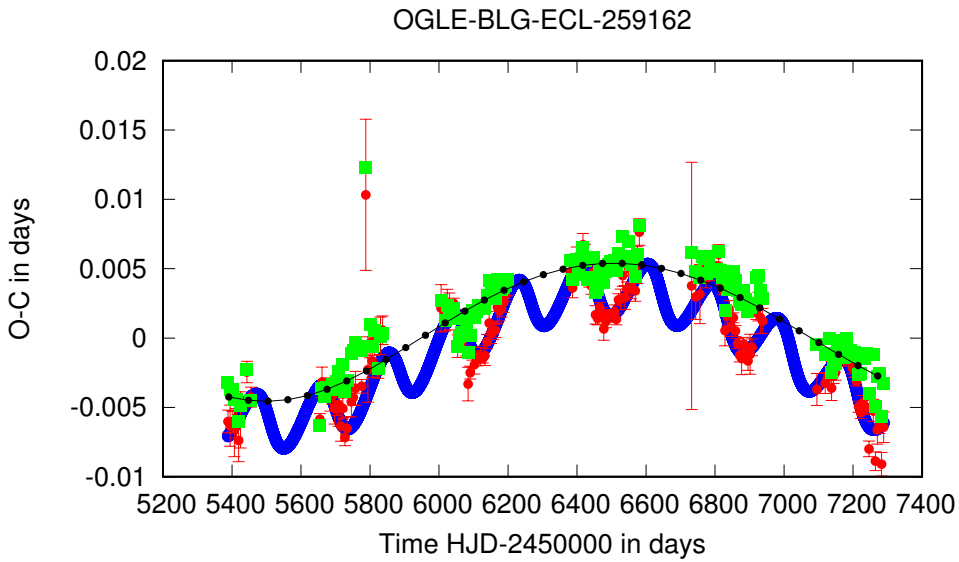
Systems with double periodic ETVs

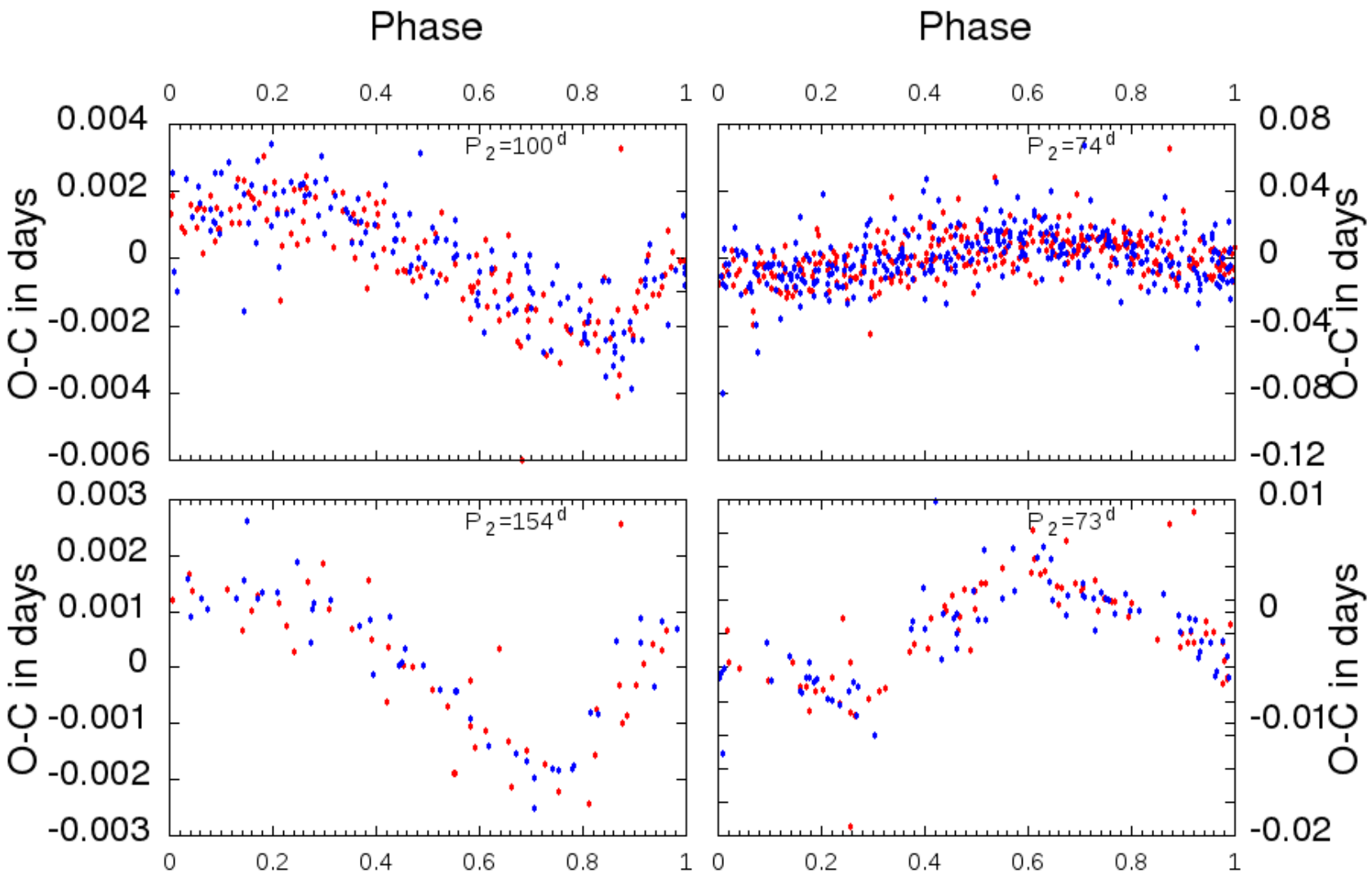




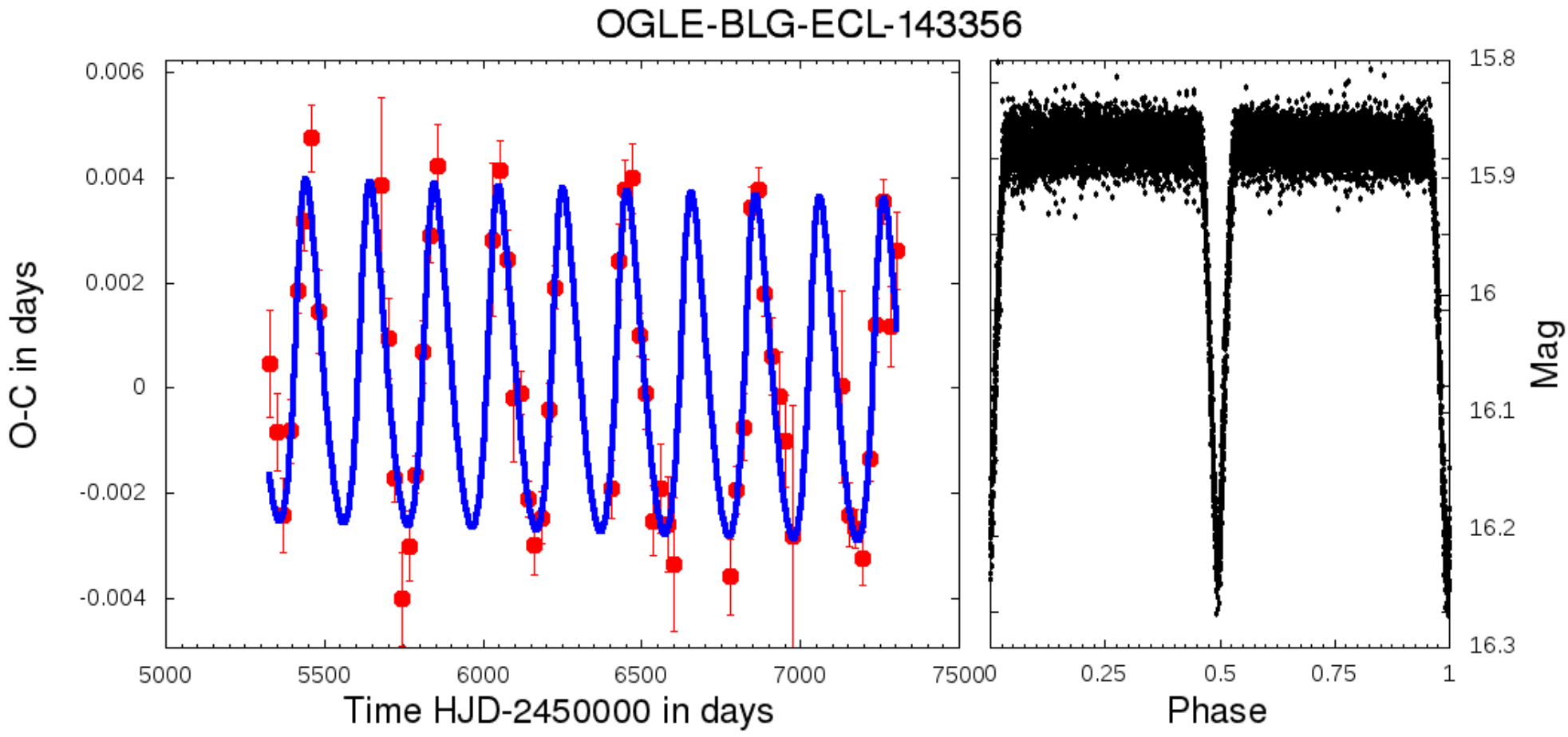




Systems with significant dynamical effect



red : O-C of the primary eclipses; blue : O-C of the secondary

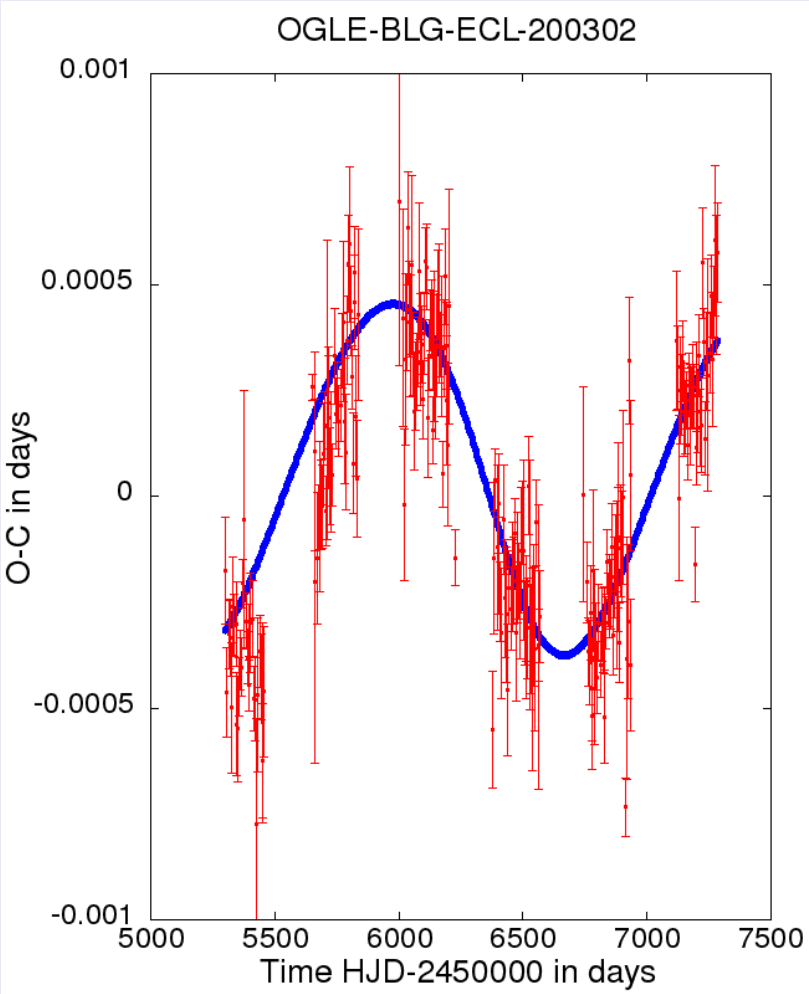


red : O-C of the normal minima;

System with possible substellar companion

OGLE-BLG-ECL-200302

- $P_1 = 0.24^d$ W UMa type
- $M(P)_{AB} = 1.29 M_\odot$ (Dimitrov, D. P.; Kjurkchieva, D. P. 2015)
- $f(m_C) = 0.00002 \pm 0.00003$
- $m_{Cmin} = 0.034 \pm 0.044 M_\odot$



Outer eccentricity

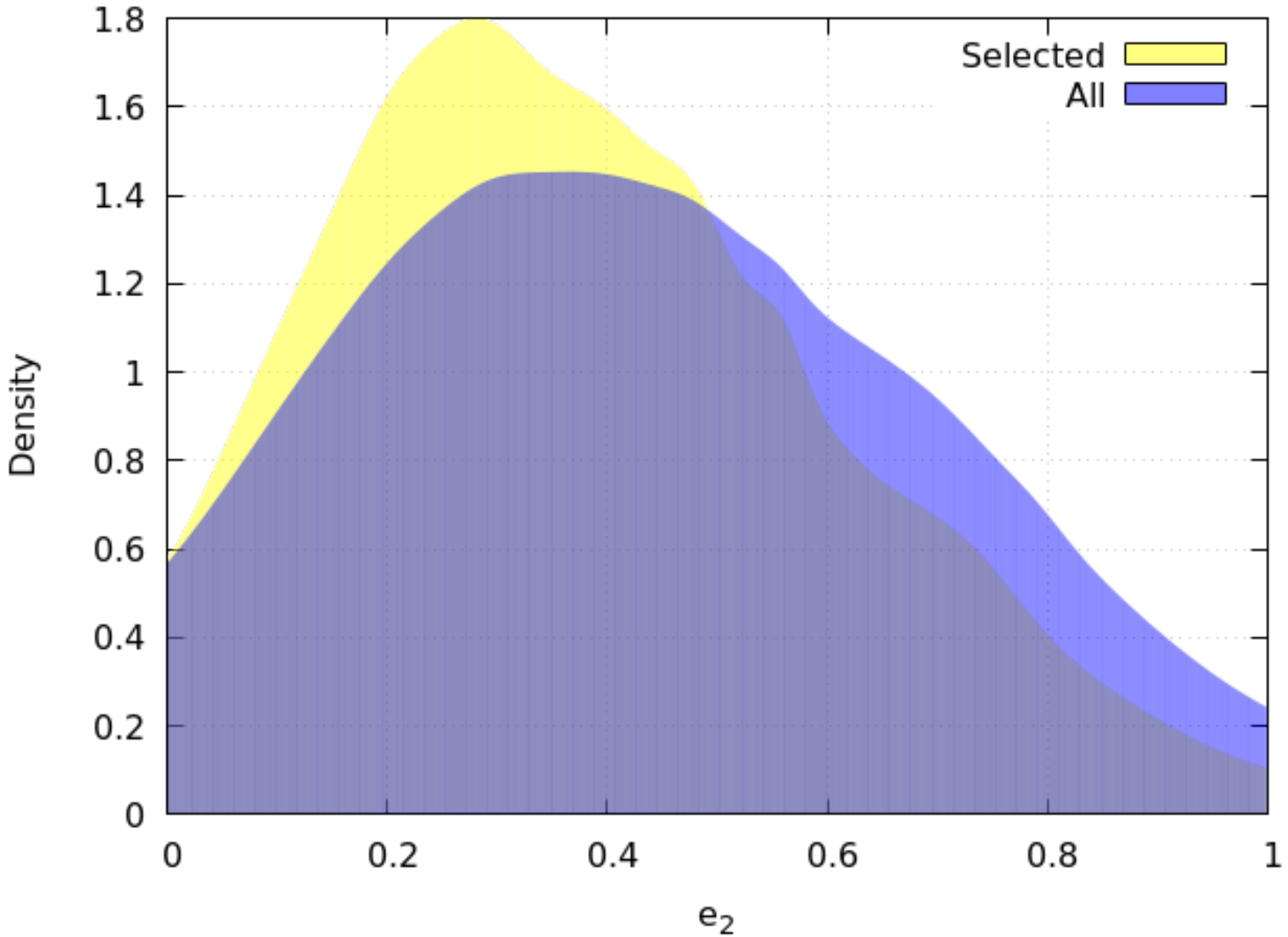
Selection

- $P_2 < 1500^d$ and the amplitude is at least 3 times higher than the variance of the residual
- or $P_2 < 1000^d$

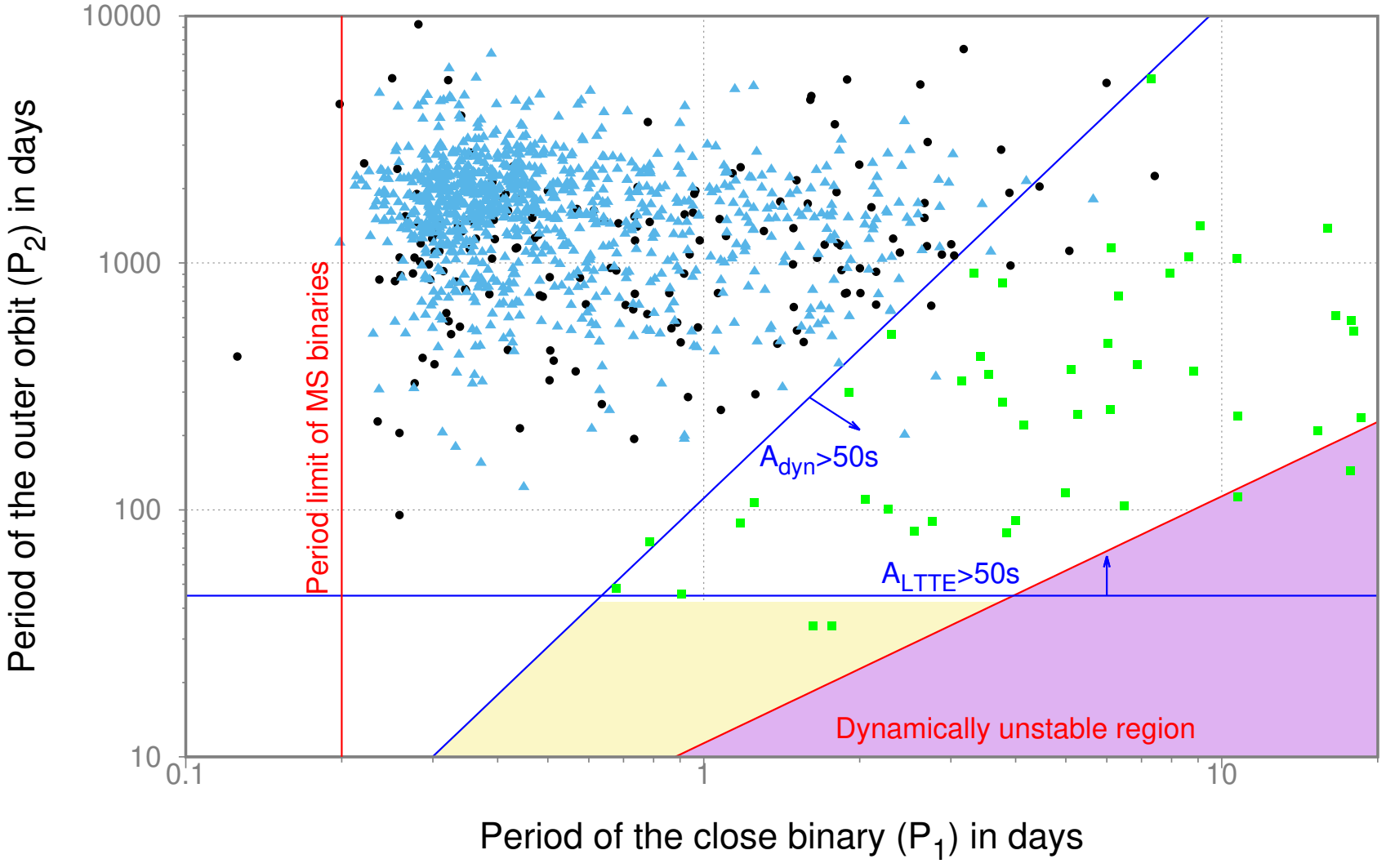
Kernel Density Estimation (KDE)

$$f(e) = \frac{1}{N} \sum_{i=1}^{N} \frac{1}{\sigma_i \sqrt{2\pi}} \exp\left(-\frac{(e - e_i)^2}{2\sigma_i^2} \right) \tag{3}$$

Outer eccentricity

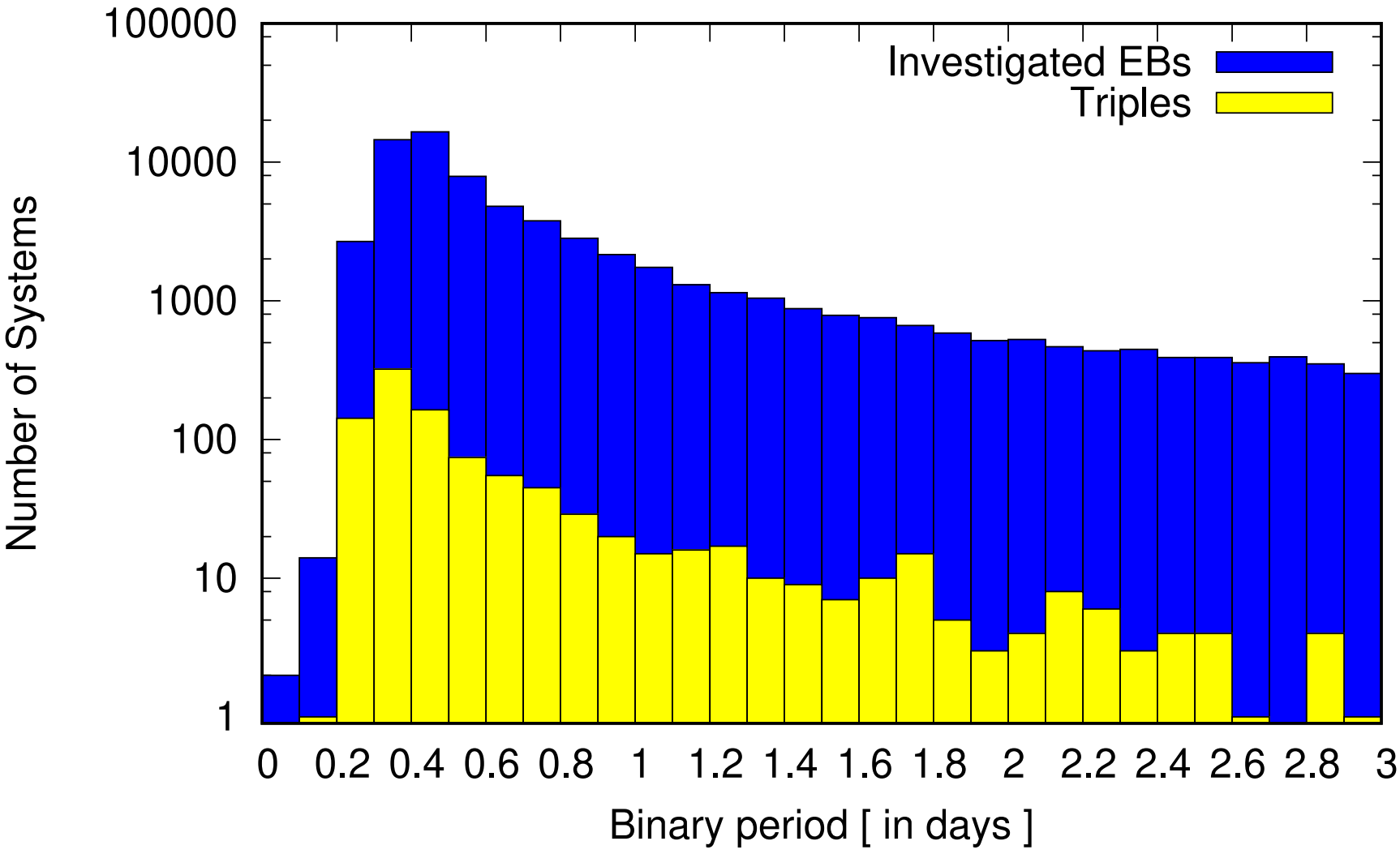


P_1 vs P_2

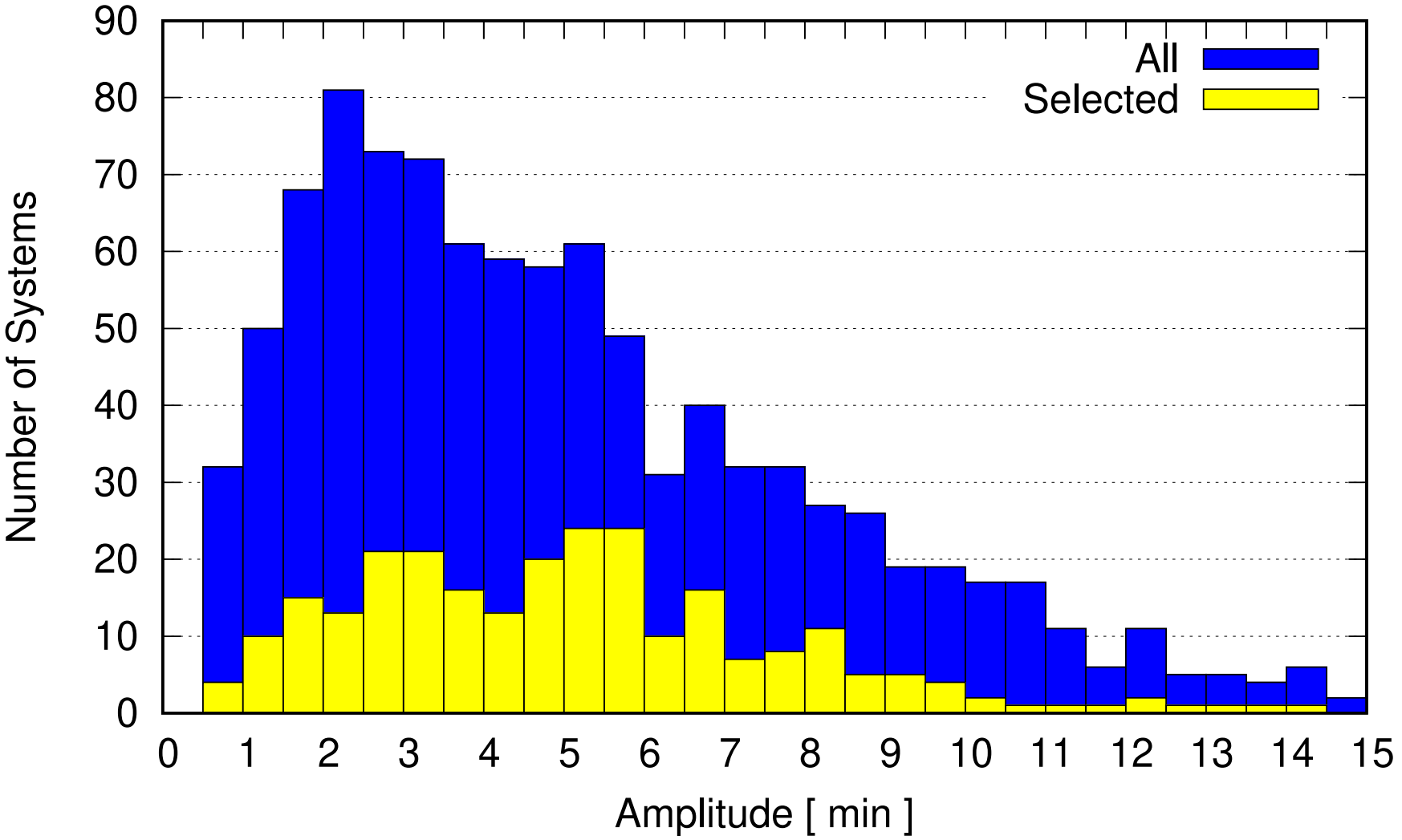


OGLE triples, Kepler triples (LTTE), OGLE triples (LTTE + dyn),

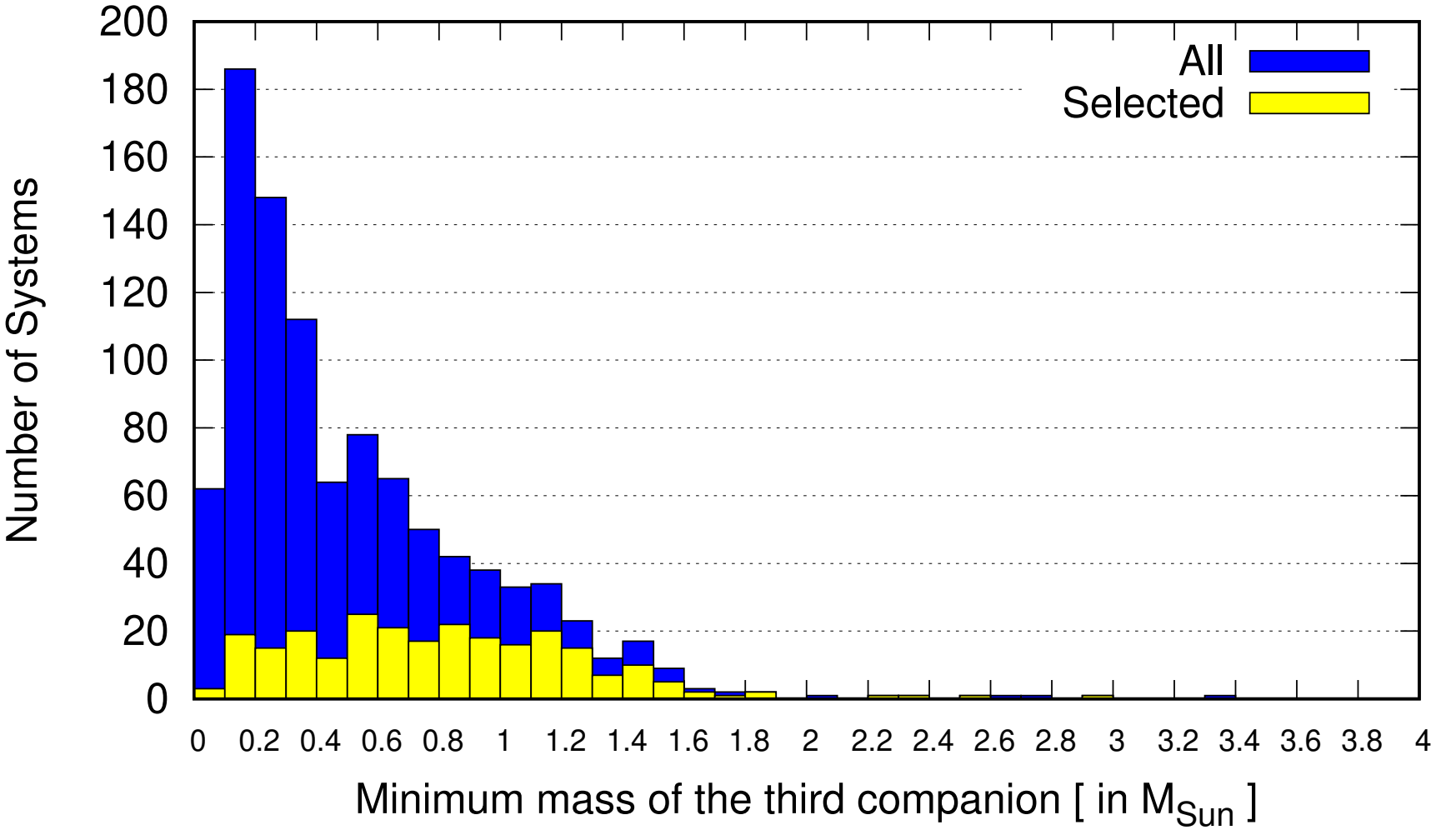
EBs-Triples ratio



Amplitude distribution



Minimum mass distribution



Summary and conclusion

Results

- More than 1000 hierarchical system candidates
  - Quadruple systems
  - Systems with significant dynamical amplitude
  - Triple with a substellar third component
- Statistical analyses
  - Peak in the eccentricity around $e_2 \approx 0.3$
  - Period $\sim$ probability of triplicity
  - $q_{2min} < 0.5$ in most cases

Next steps

- ETV analyses of the new short periodic systems