Spectroscopic binary processing within Gaia DPAC
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(with contributions from P. Geurts & L. Delchambre)

Plan

- DU434 work package as part of Gaia DPAC / CU4.
- Algorithms used in DU434.
- Performances of the implemented algorithms.
- Current development.
- Outlook.

Presentation of Gaia DPAC / DU434 work package

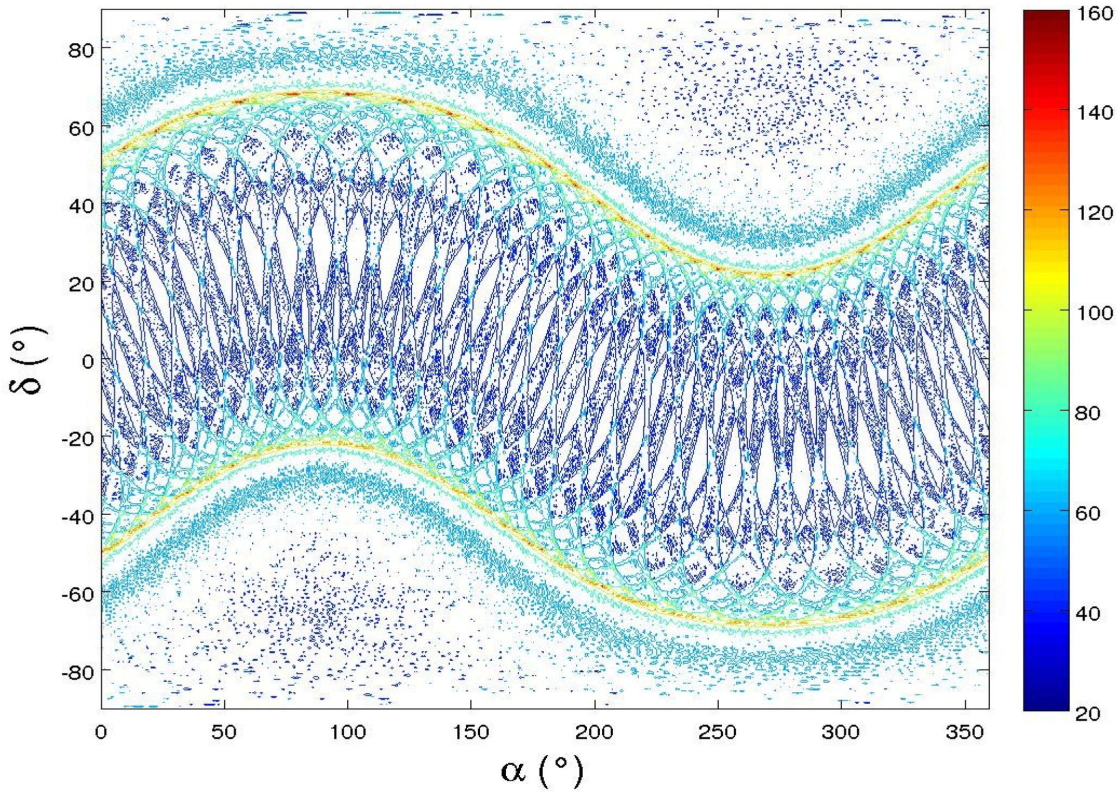
- **DU434 : part of CU4 in Gaia Data Processing and Analysis Consortium**

- **DU434 : spectroscopic binary work package.**

- **DU434 receives time series of radial velocities and observed RVS spectra from DPAC / CU6 of all suspected spectroscopic variable stars.**

- **DU434 derives orbital elements (period, center of mass velocity, semi amplitude, eccentricity, longitude of periastron and time of periastron passage) for SB1 and SB2 stars.**

Presentation of Gaia DPAC / DU434 work package



RVS transits
Median value is 50 transits – Mean value is 51.8 transits

Spectral type	$V = 6$	$V = 9$	$V = 12$	$V = 14$
G5 V	0.4	2	5	15
B5 V	3	10	30	-

Radial velocity precision (1σ) for single stars within CU6 / Single Transit analysis
Viala Y., Blomme R., Frémat Y., et al
WP650 STR document
GAIA-C6-SP-OPM-YV-007-1

Used algorithms in DU434 Gaia package

- Spectroscopic binary processing is a blind processing : no human intervention.
- Pre-selection of bona fide spectroscopic variable stars done “en amont” (see Dimitri's talk)
- For each input time series of radial velocities and observed spectra we :
  - Clean the inputs from erroneous data
  - Search for the orbital period using time series of radial velocities.
  - Search for an approached orbital solution using time series of radial velocities.
  - Refine the orbital solution using time series of radial velocities.
  - Test the significance of the found eccentricity by comparing it with a circular orbit.
  - Compare the spectroscopic solution with the trend (polynomial) solution.
  - Refine the spectroscopic binary solution using time series of observed spectra.

Used algorithms in DU434 Gaia package
Period search : the hardest task

Many methods tested : combination of 2 methods :

- Preselection of best local maxima in the periodogram using HMM method:

  Heck, A., Manfroid, J., Mersch, G. 1985, A&AS, 59, 63

  Fit of a simple sin function to the phase diagram (arbitrary t_0).

  Applied to Vr_1 for SB1 and $(|Vr_2 - Vr_1|, Vr_1)$ for SB2

- Selection of the best period and derivation of the approached solution using :

  Zechmeister & Kürster, 2009, A&A, 577

  Based on HMM : fit of a simple sin function to the true anomaly (v = f(e,Tp)).

  – $Vr_1 = [V_{01} + K_1 e \cos(\omega_1)] + [K_1 \cos(\omega_1)] \cos(v) + [-K_1 \sin(\omega_1)] \sin(v)$
  – $Vr_2 = [V_{02} + K_2 e \cos(\omega_2)] + [K_2 \cos(\omega_2)] \cos(v) + [-K_2 \sin(\omega_2)] \sin(v)$
  – Problem : $V_{02} != V_{01}$ and $\omega_2 != \pi + \omega_1$ => consider the average mean ?

Used algorithms in DU434 Gaia package

- The approached orbital solution determination : some alternative methods :
  - Commonly used methods : Lehmann-Filhès, Wilsing Russell.
  - Genetic algorithm coupled with Zechmeister & Kürster periodogram.
  - Pattern recognition algorithm (discussed in current development section).
- The approached orbital solution refined using :
  - Sterne algorithm for very small eccentricities ($e < 0.03$)
  - Schlesinger method for larger eccentricities ($e > 0.03$)
  - Levenberg-Marquardt minimisation

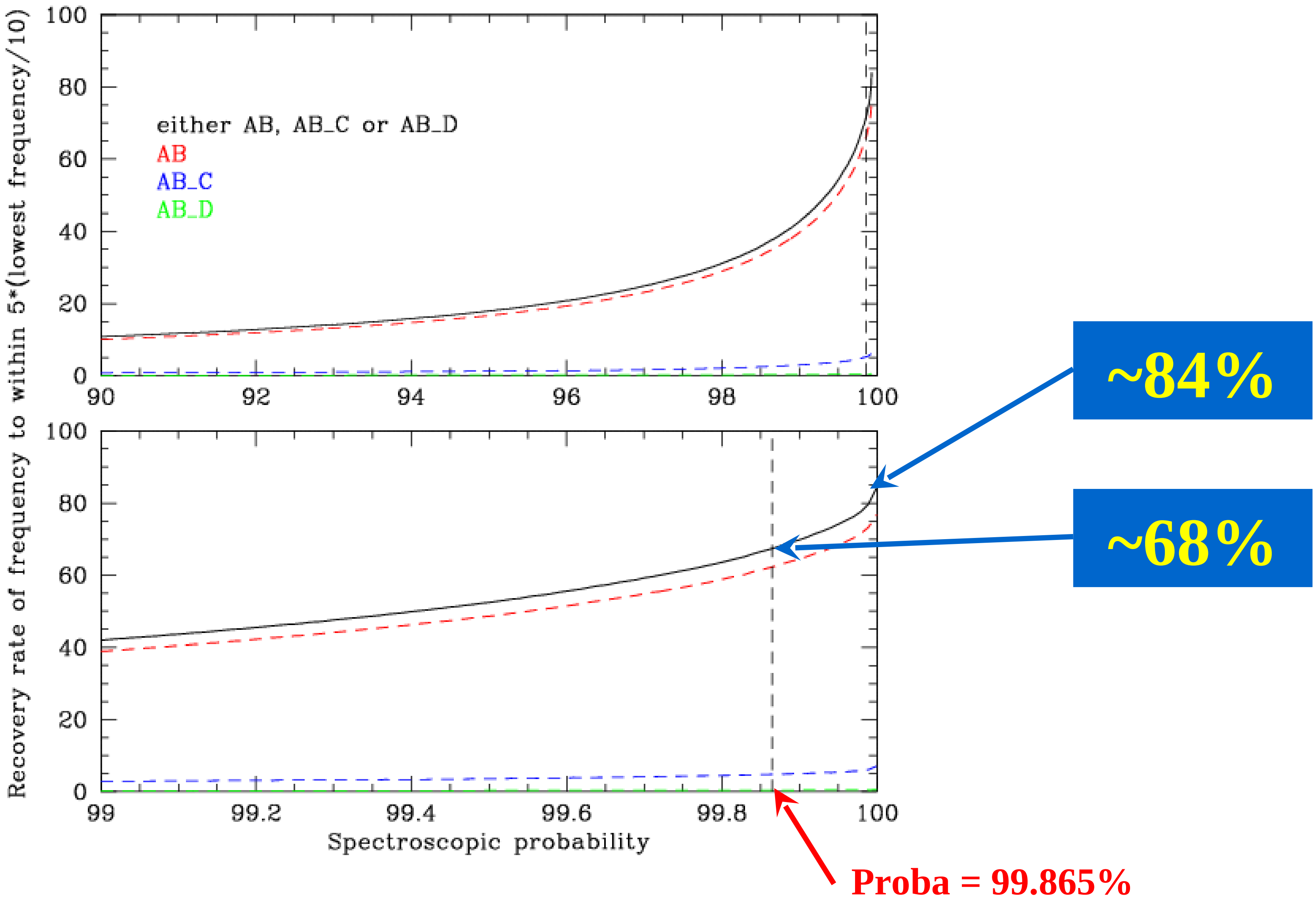
Current performances

The simulations are based on :

- Gaia simulator (Gaia Object Generator) : 10 million stars containing 80 000 and 10 000 of SB1 and SB2 respectively having a variability probability > 0.99865.

- Internal DU434 simulated curve using the Gaia satellite scanning law to generate the RVS transit dates.

Recovery of orbital period – SB1



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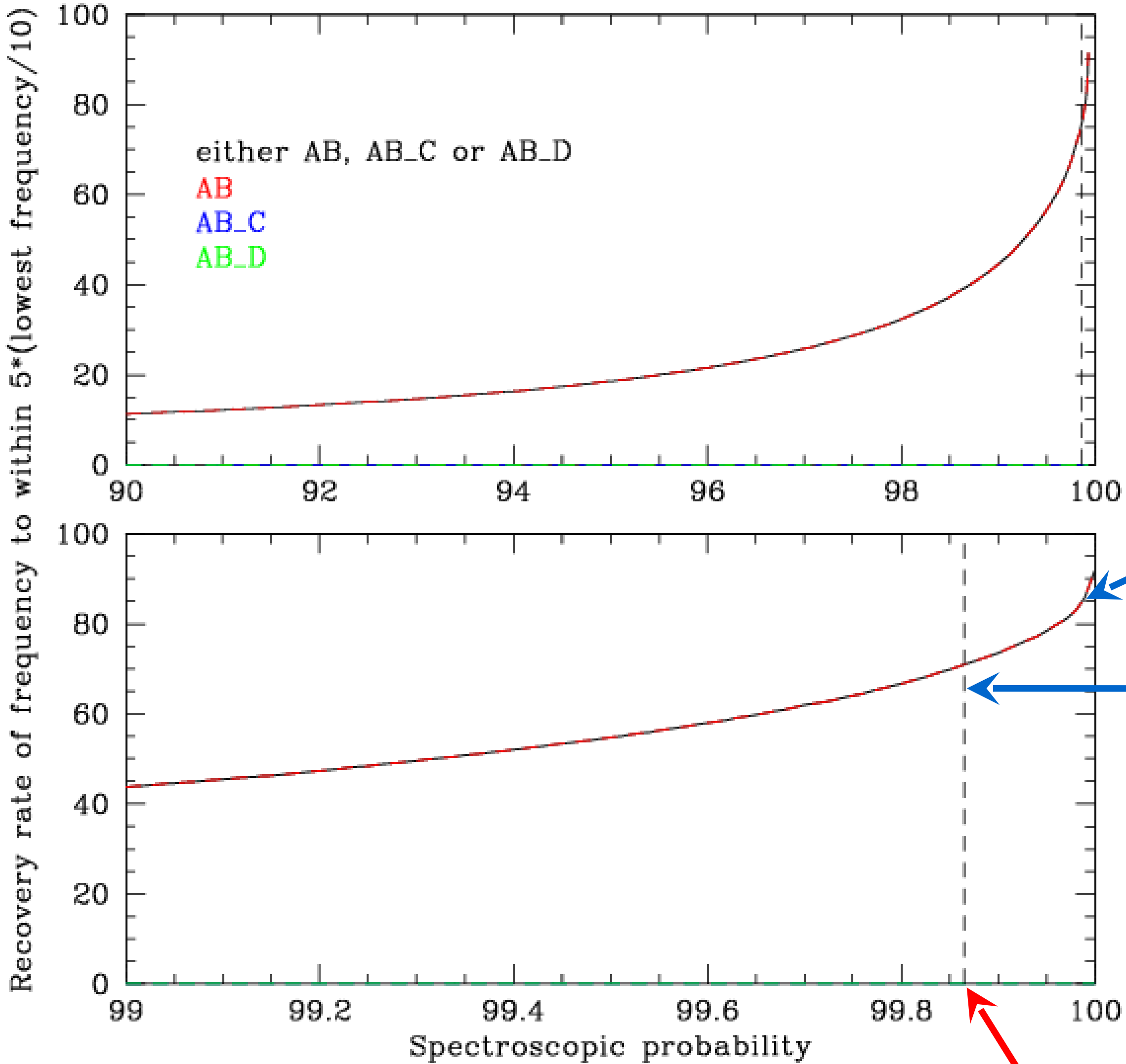
Recovery of orbital period – SB1



Systems with only two components and not intrinsically variable

~92%

~71%

Proba = 99.865%

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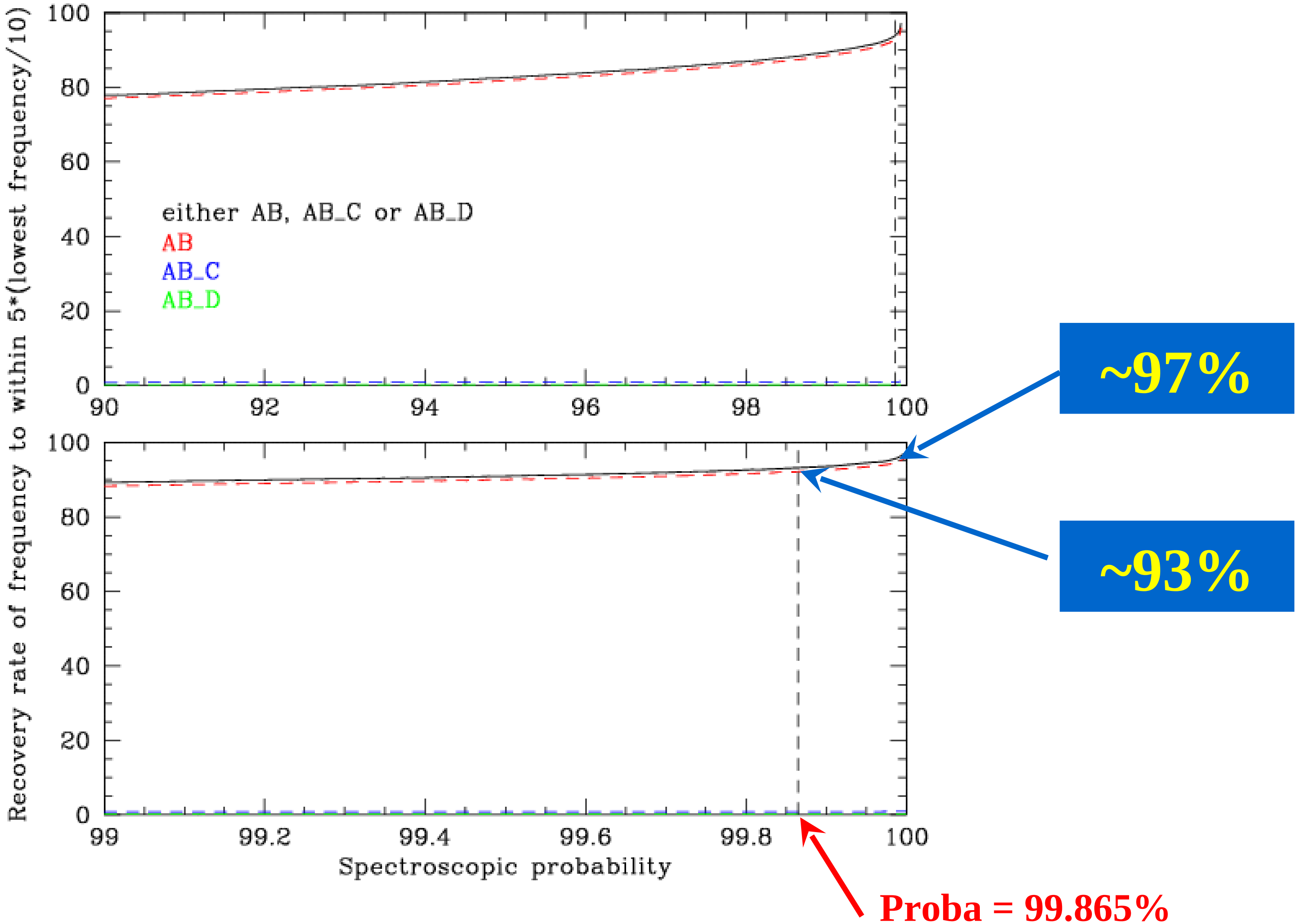
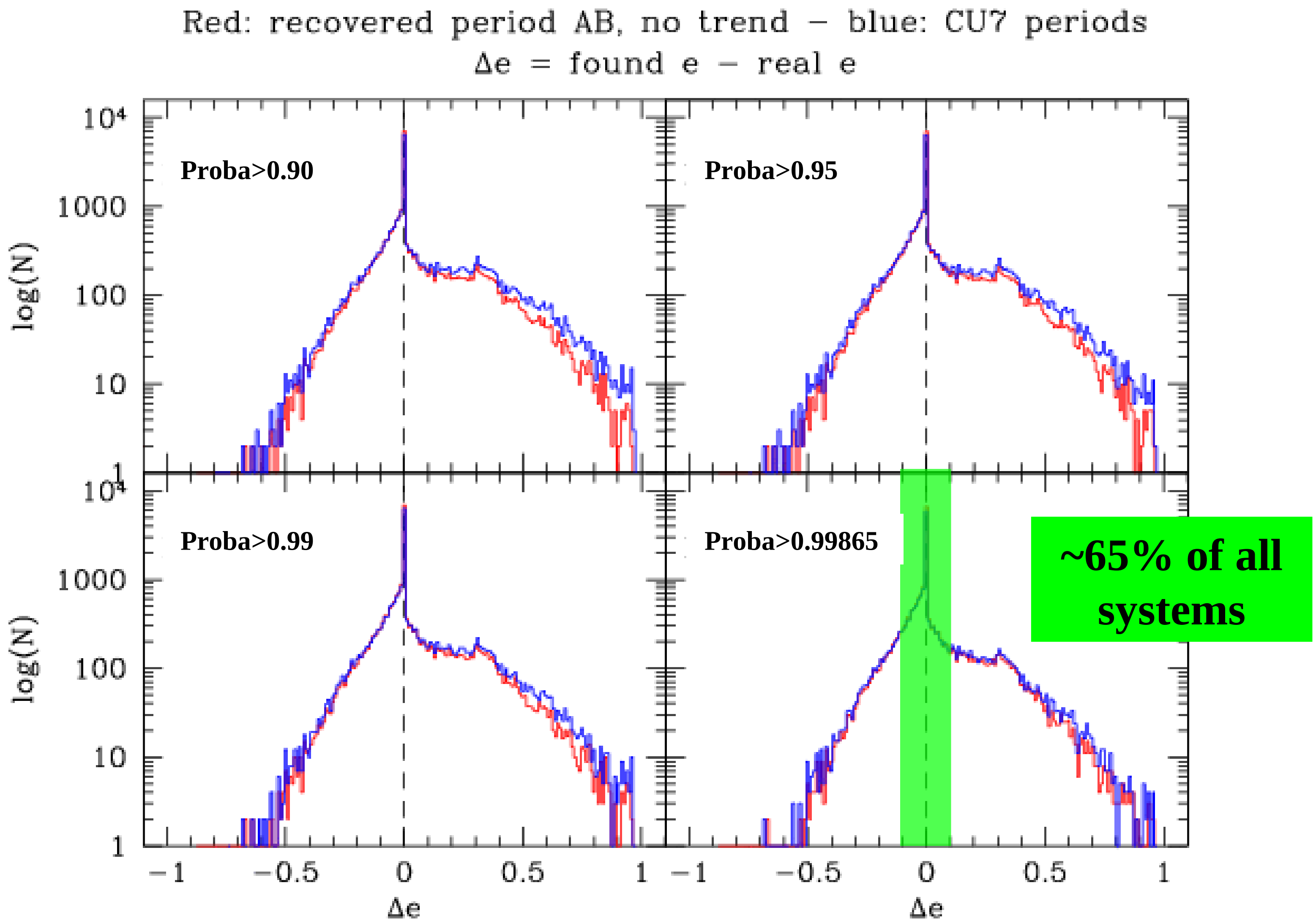
Recovery of orbital period – SB2



Recovery of eccentricity – SB1



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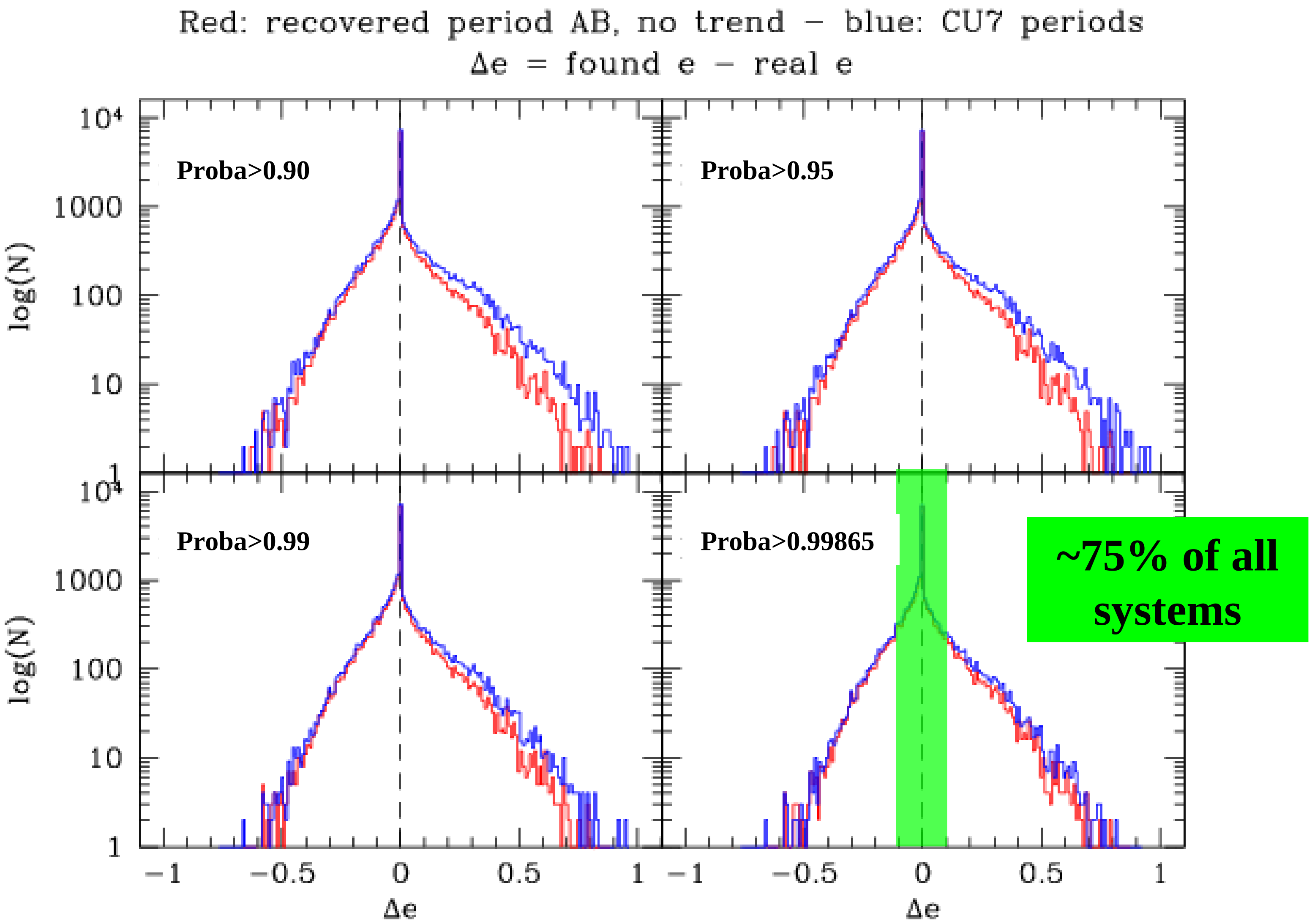
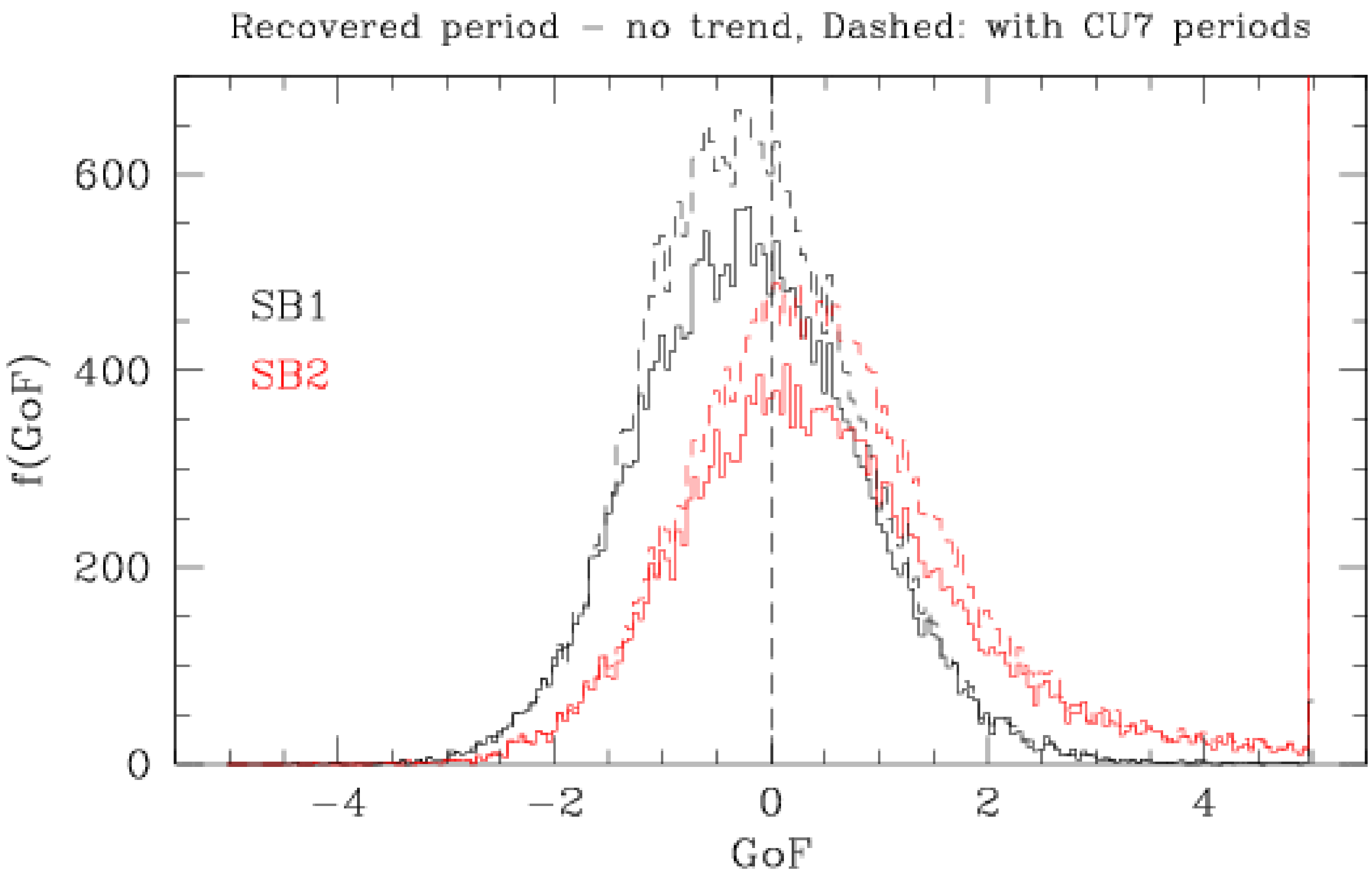
Recovery of eccentricity – SB2

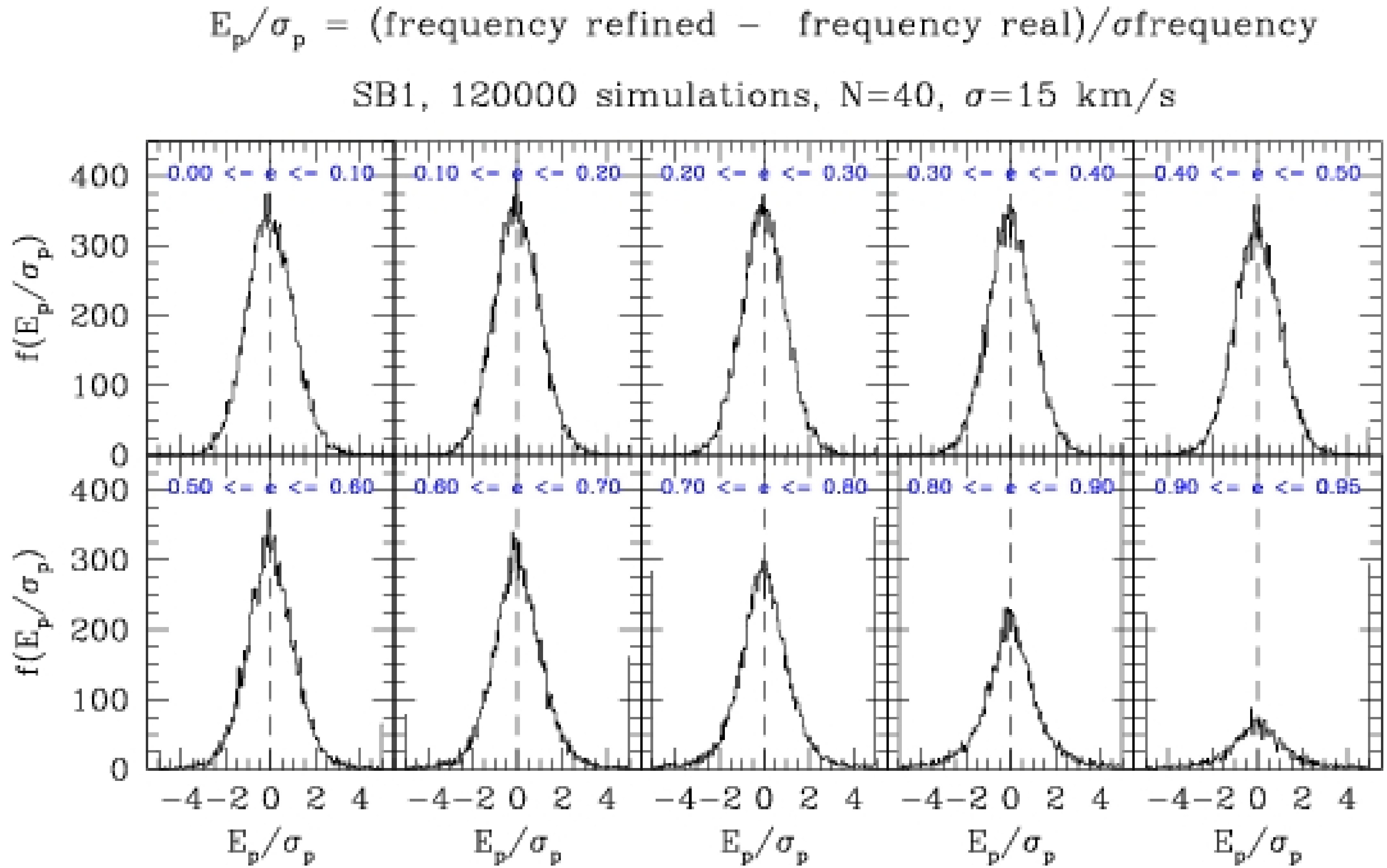


GoF



Recovered period – no trend, Dashed: with CU7 periods
SB1
SB2
f(GoF)
GoF
600
400
200
0
−4
−2
0
2
4

Orbital frequencies – SB1



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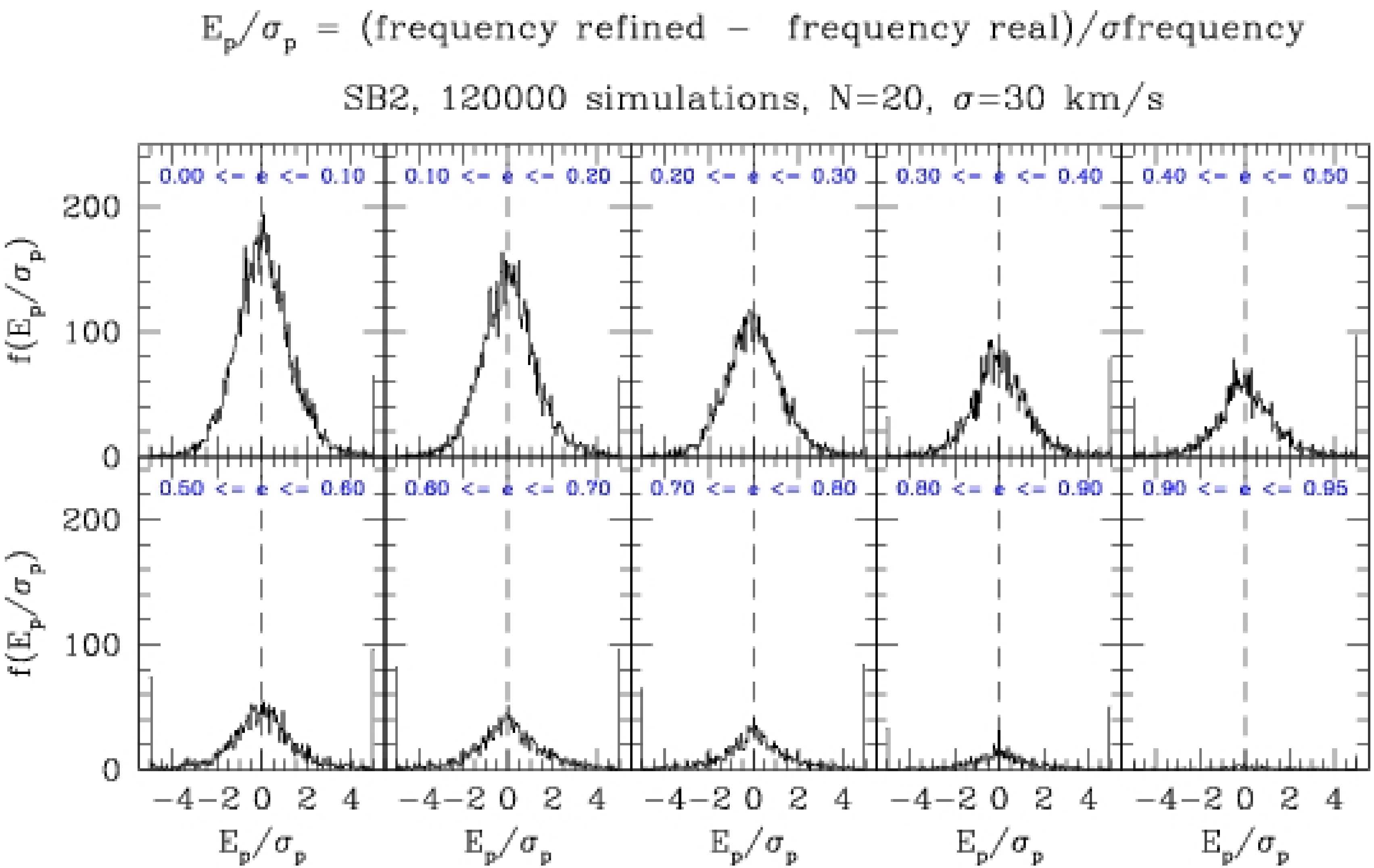
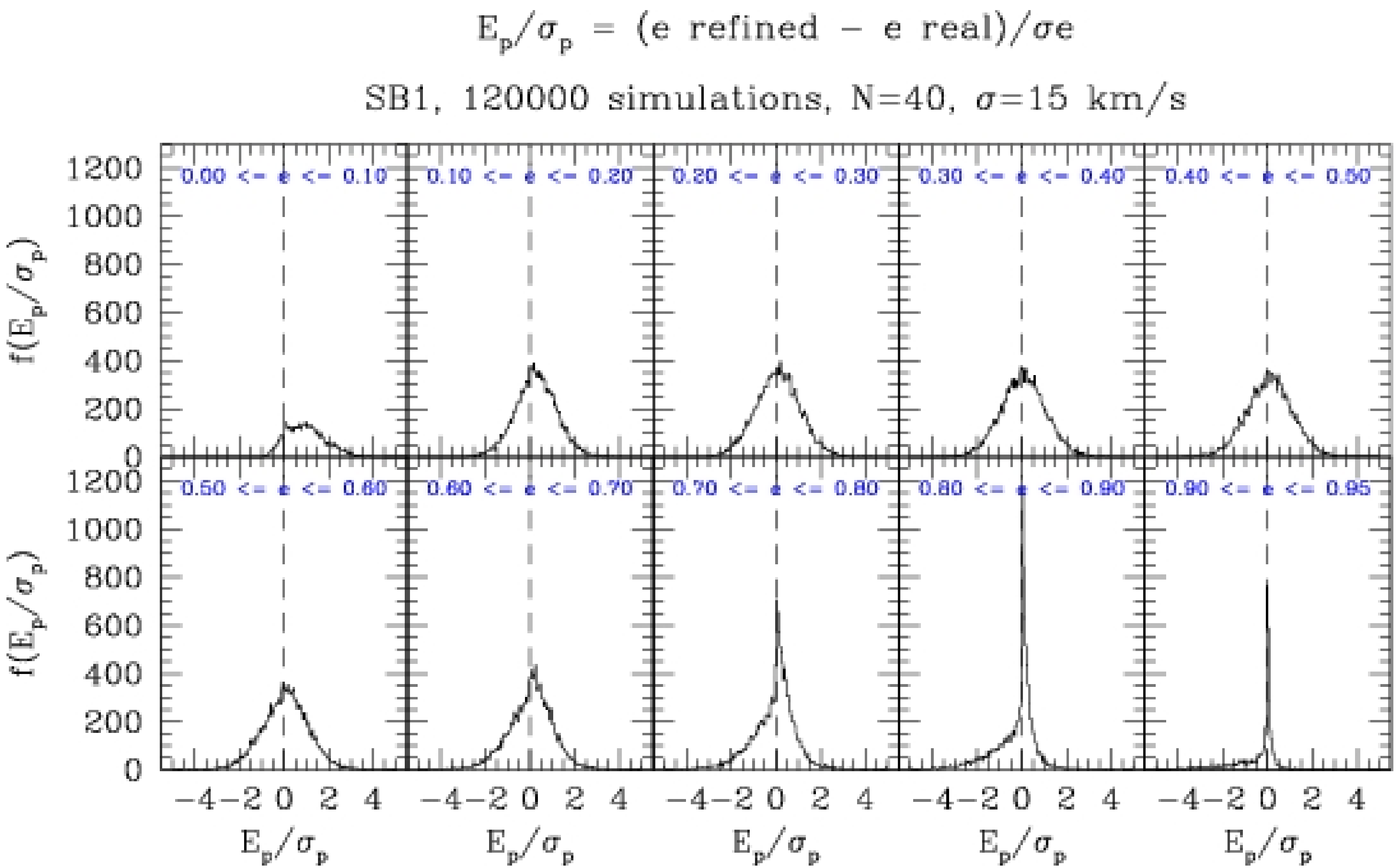
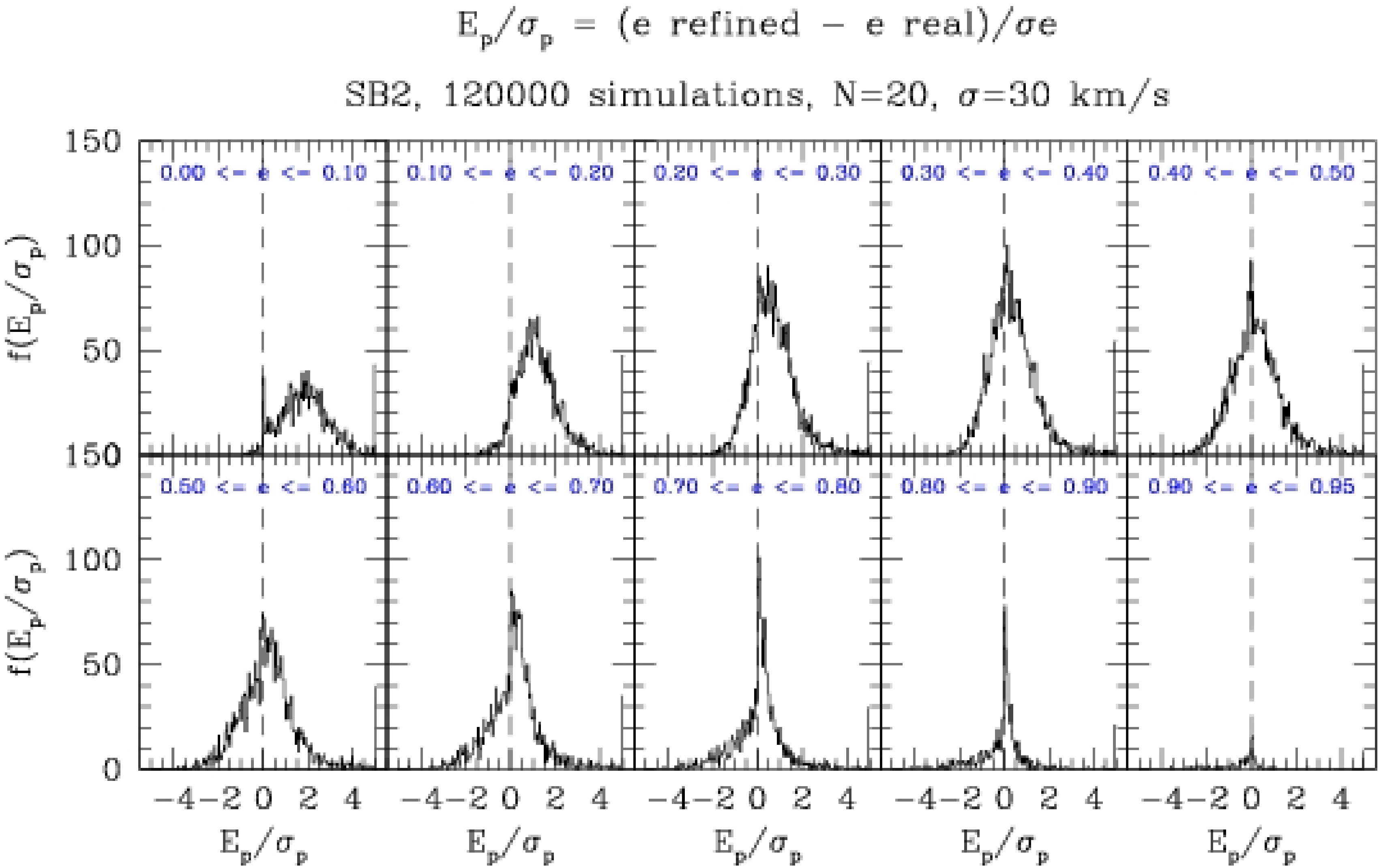
Orbital frequencies – SB2



Eccentricity – SB1



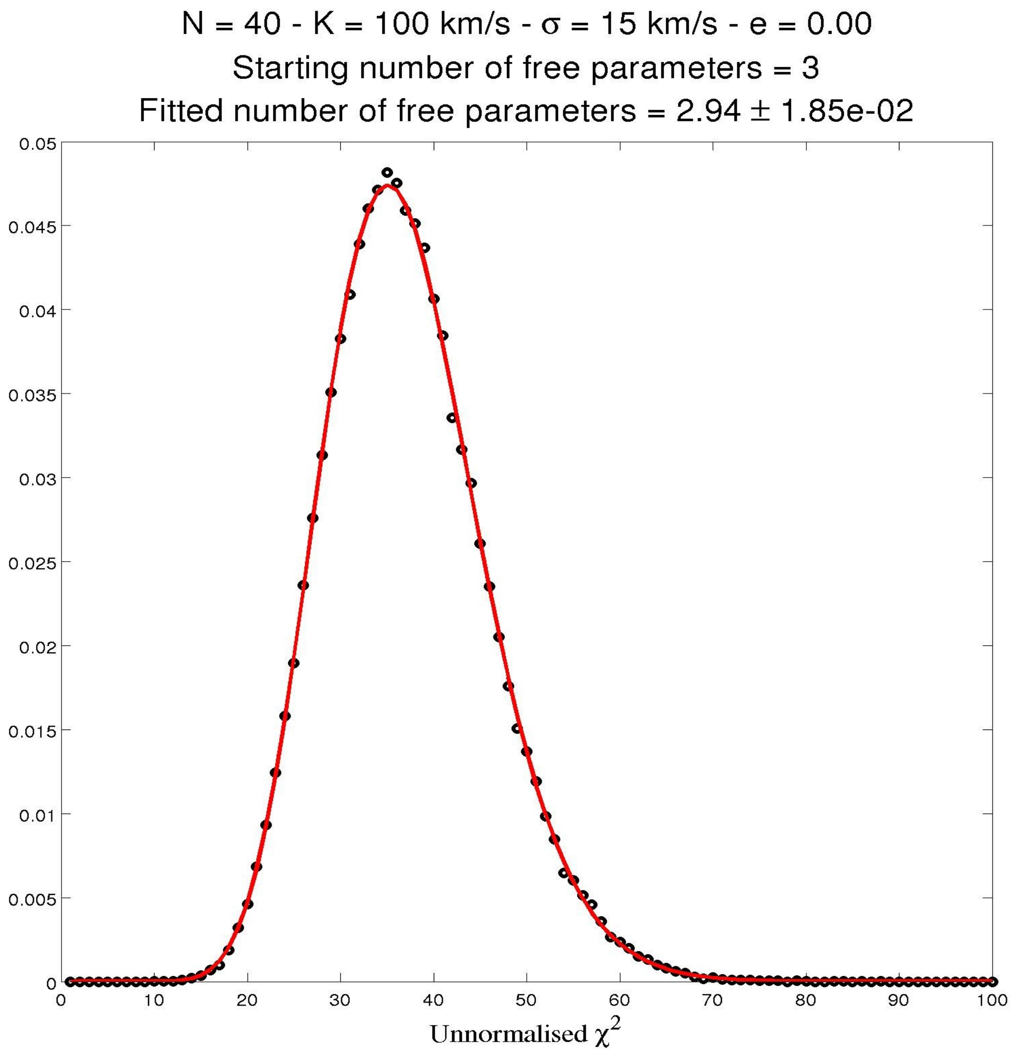
Eccentricity – SB2

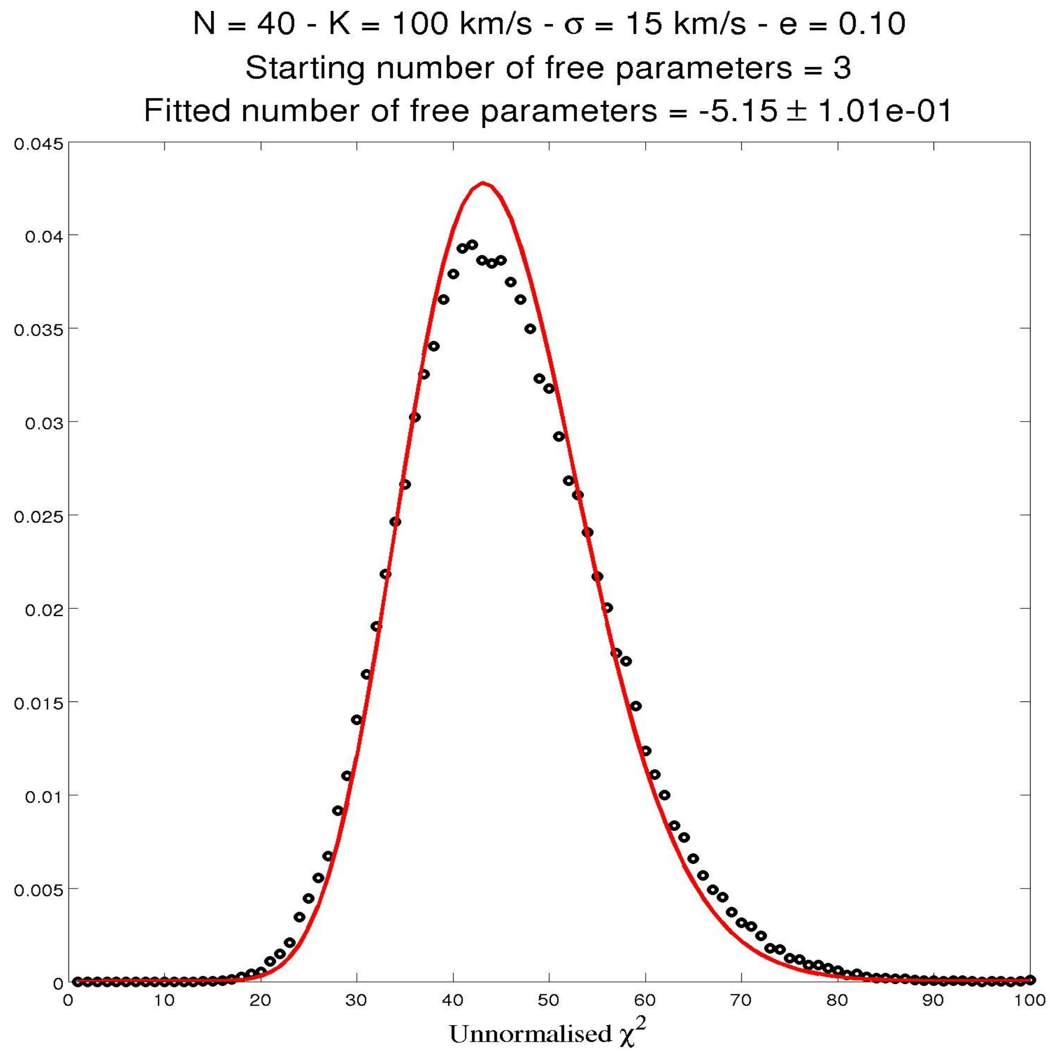


Current developments

- Test of eccentricity significance
- Period significance level.
- SB2 ambiguity : sorting velocities
- Pattern recognition for radial velocity curves.

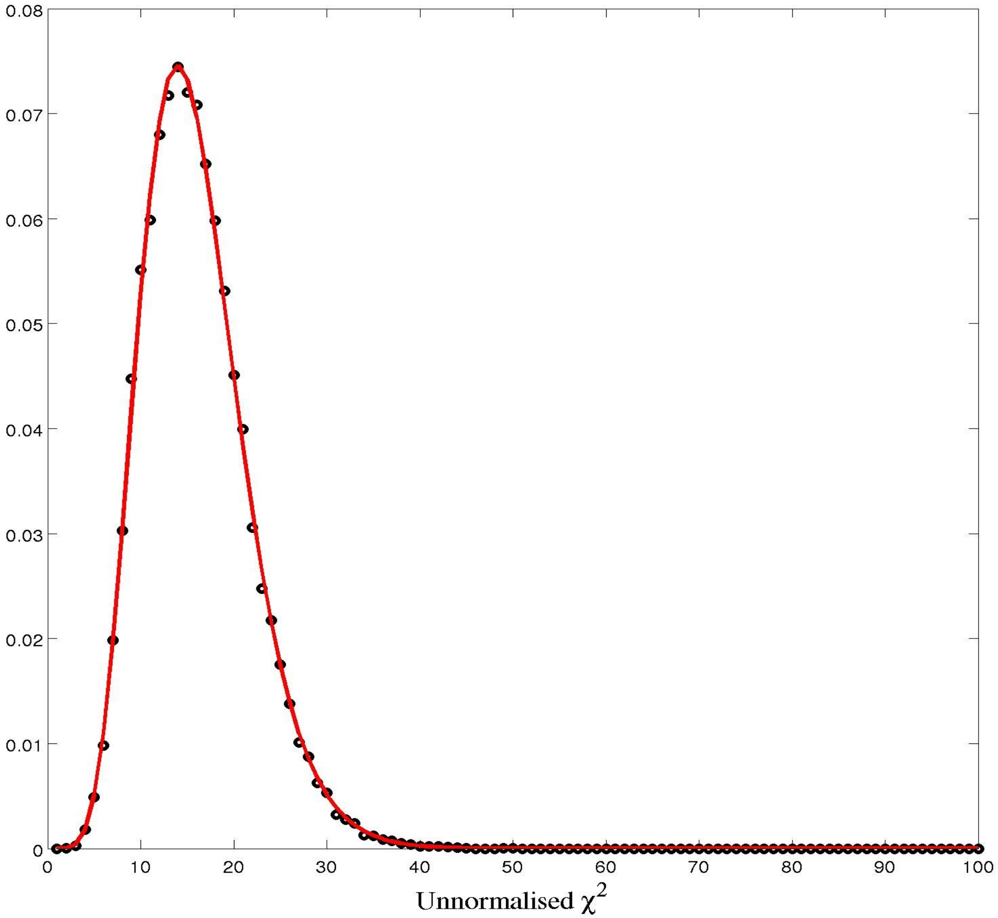
Test of eccentricity significance
Circular orbits with known periods



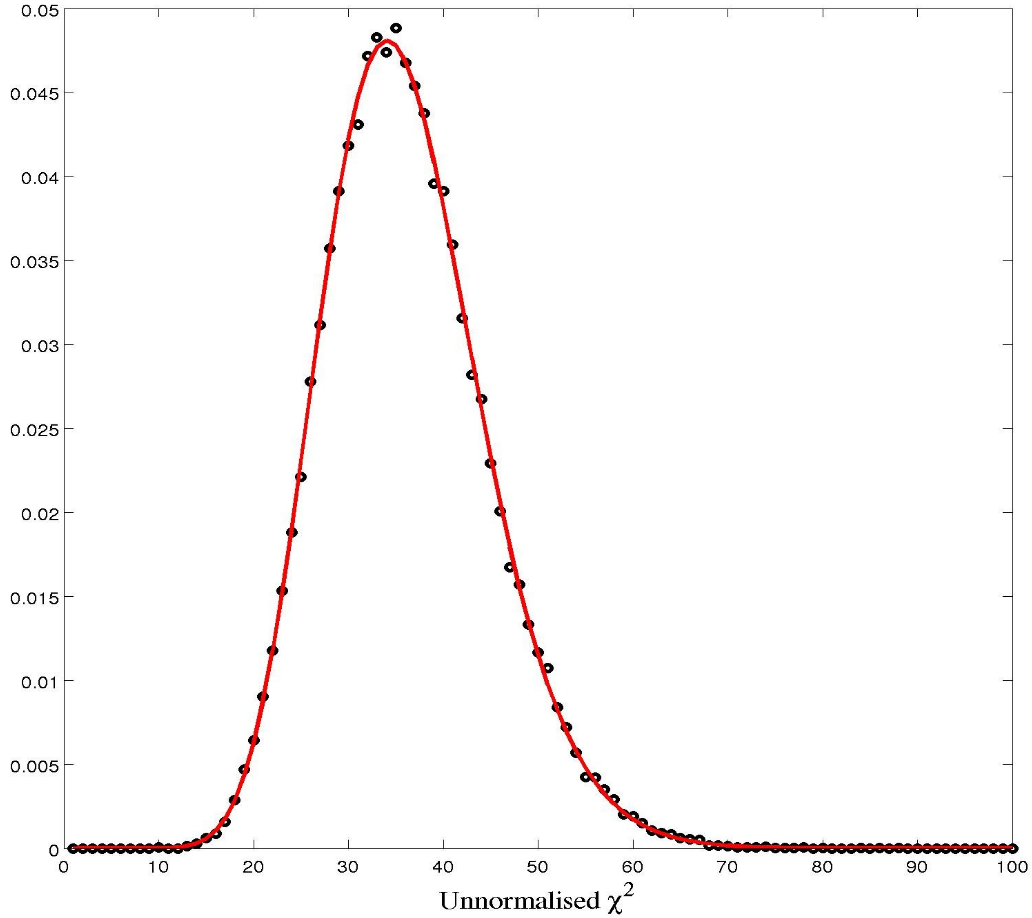


Test of eccentricity significance
Circular orbits with unknown periods

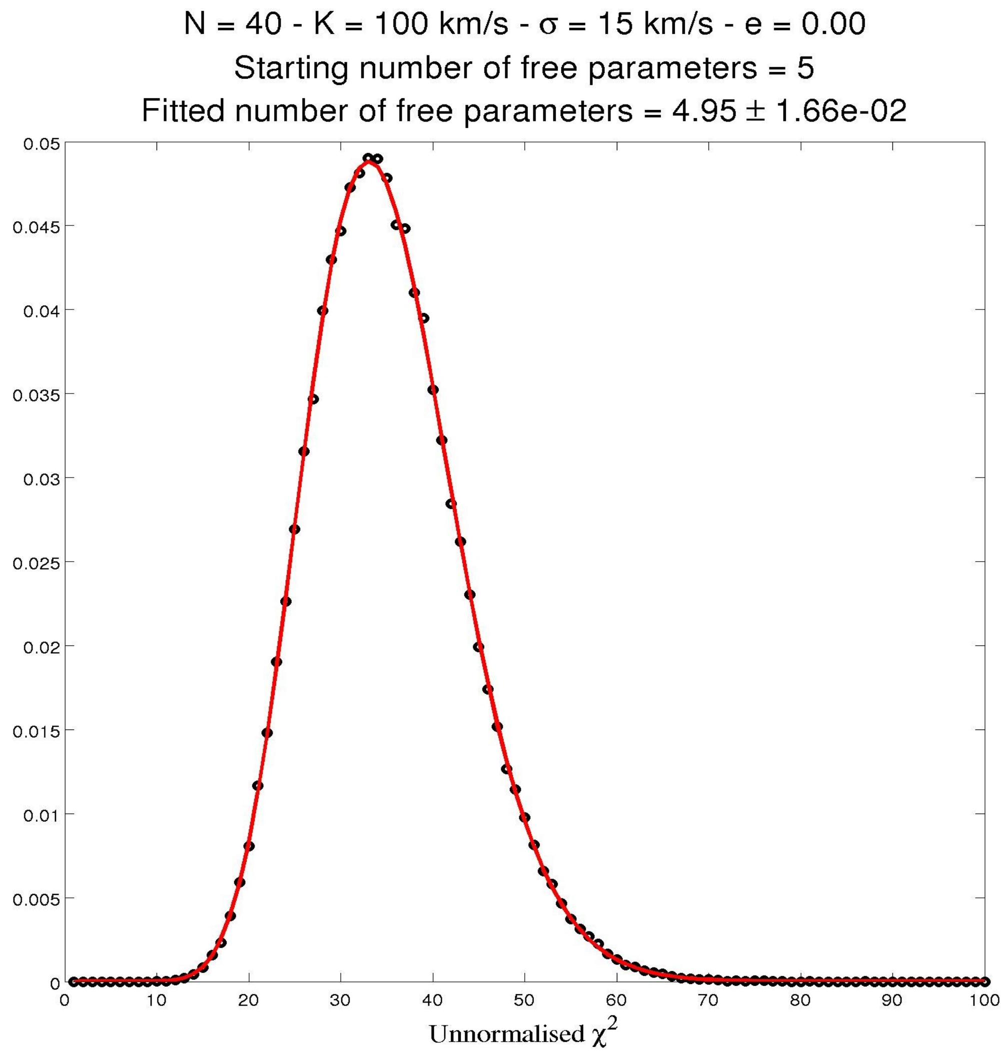
N = 20 - K = 100 km/s - σ = 15 km/s - e = 0.00
Starting number of free parameters = 4
Fitted number of free parameters = 4.04 ± 2.19e-02

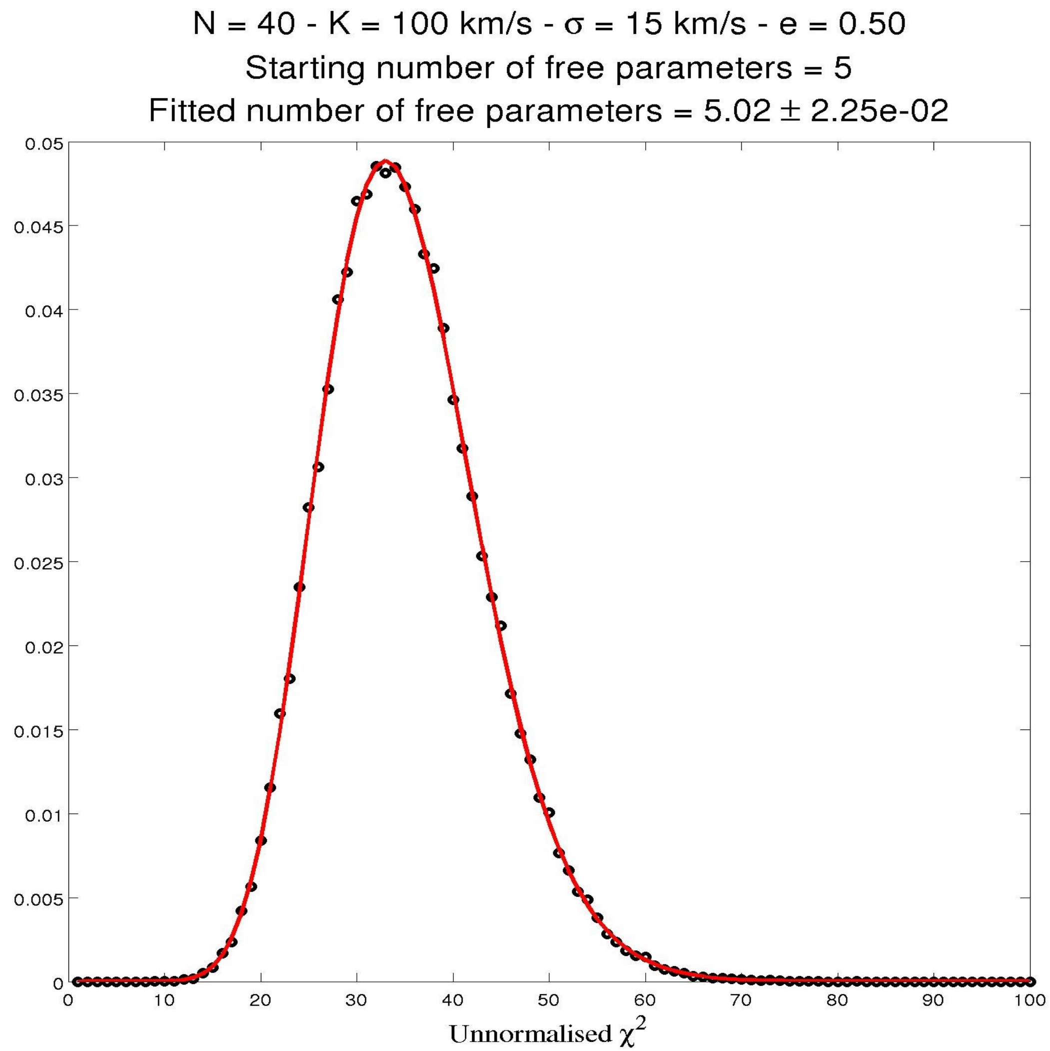


N = 40 - K = 100 km/s - σ = 15 km/s - e = 0.00
Starting number of free parameters = 4
Fitted number of free parameters = 3.94 ± 2.51e-02



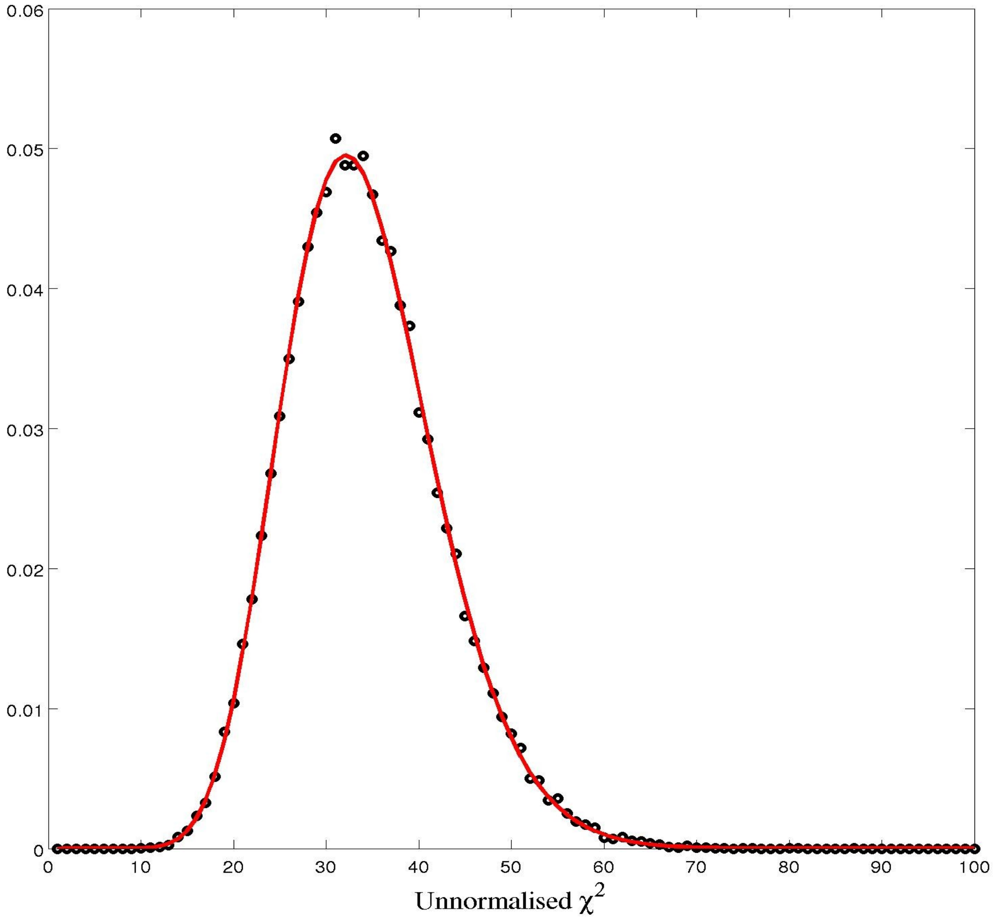
Test of eccentricity significance
Elliptical orbits with known periods



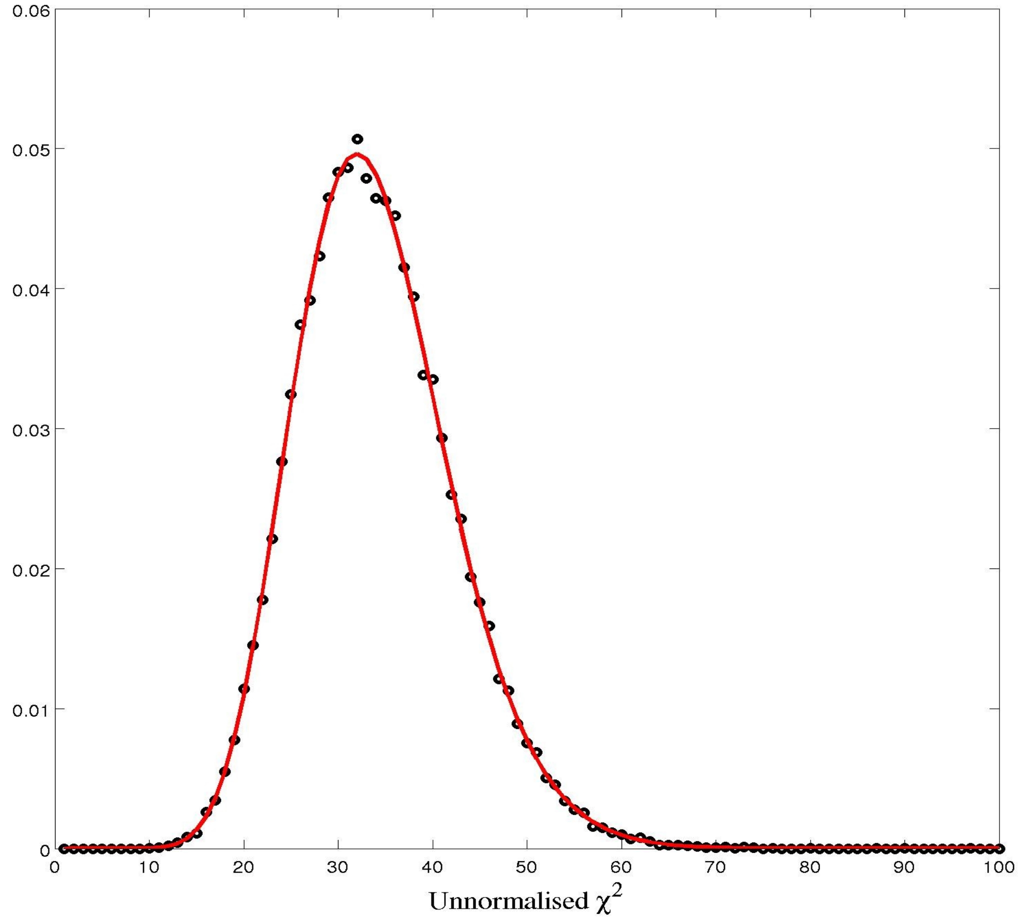


Test of eccentricity significance
Elliptical orbits with unknown periods

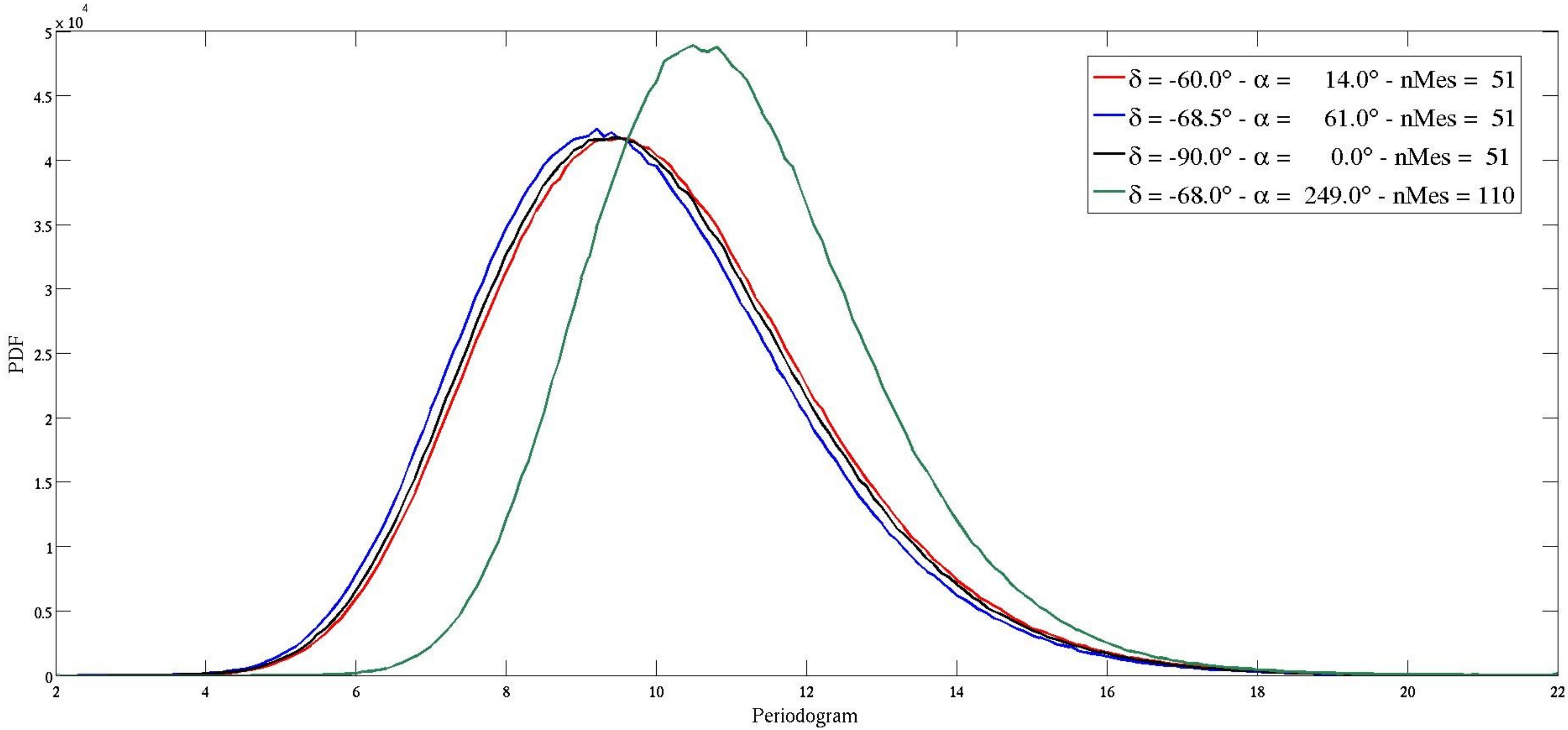
N = 40 - K = 100 km/s - σ = 15 km/s - e = 0.00
Starting number of free parameters = 6
Fitted number of free parameters = 5.90 ± 2.59e-02



N = 40 - K = 100 km/s - σ = 15 km/s - e = 0.20
Starting number of free parameters = 6
Fitted number of free parameters = 6.02 ± 2.83e-02

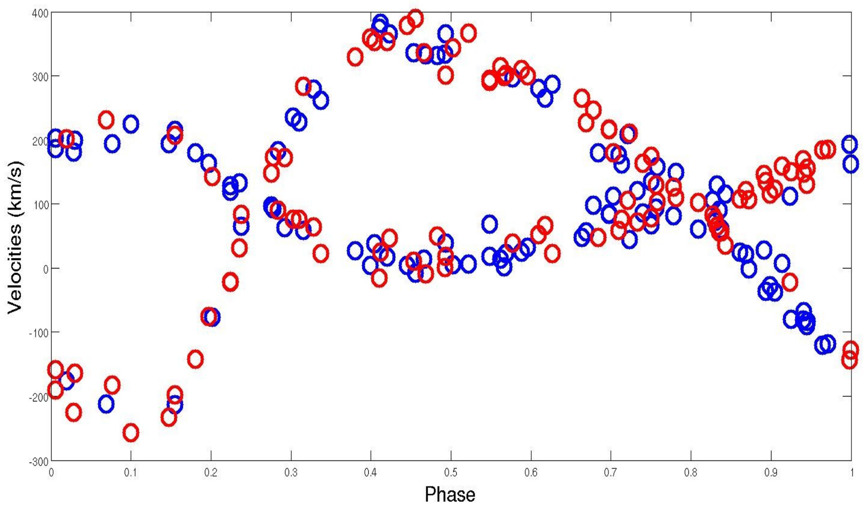


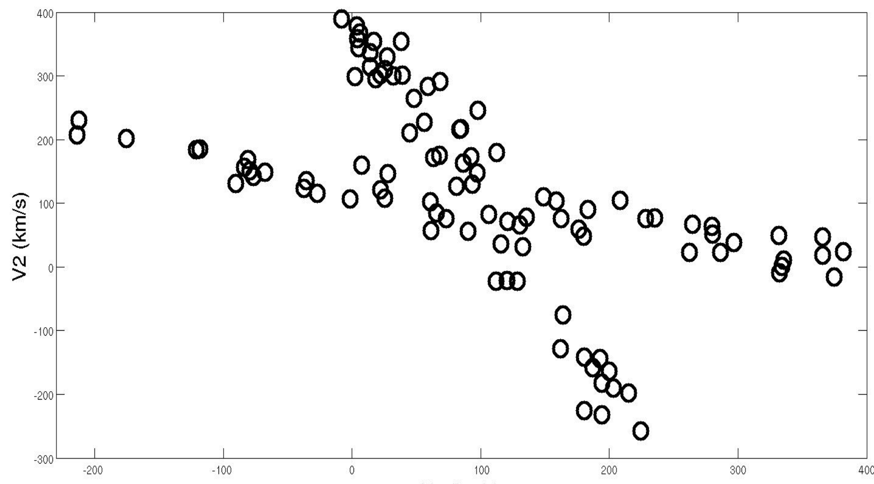
Period significance level

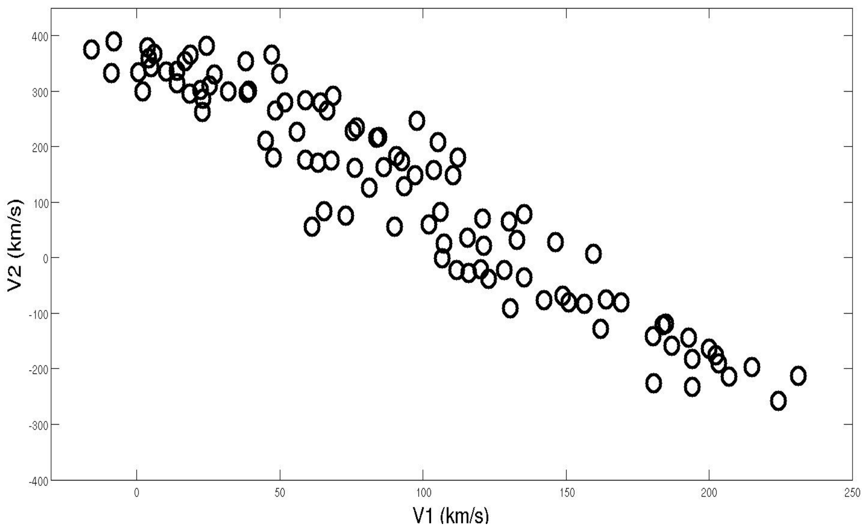


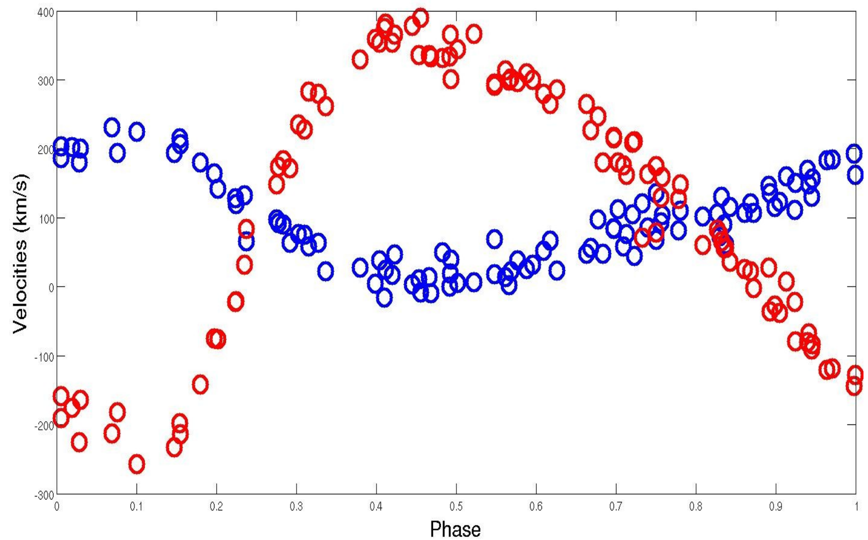
Sorting SB2 velocities

K1=100 km s-1, K2 = 300 km s-1, e = 0.3, σ = 20 km s-1



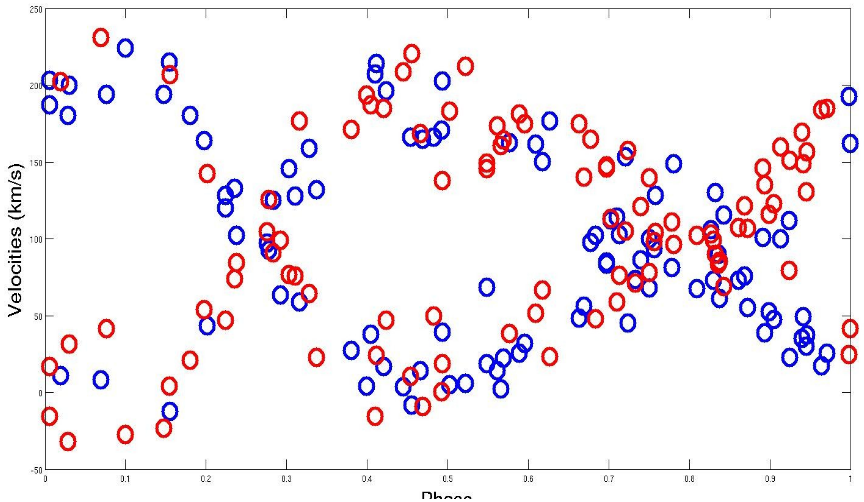


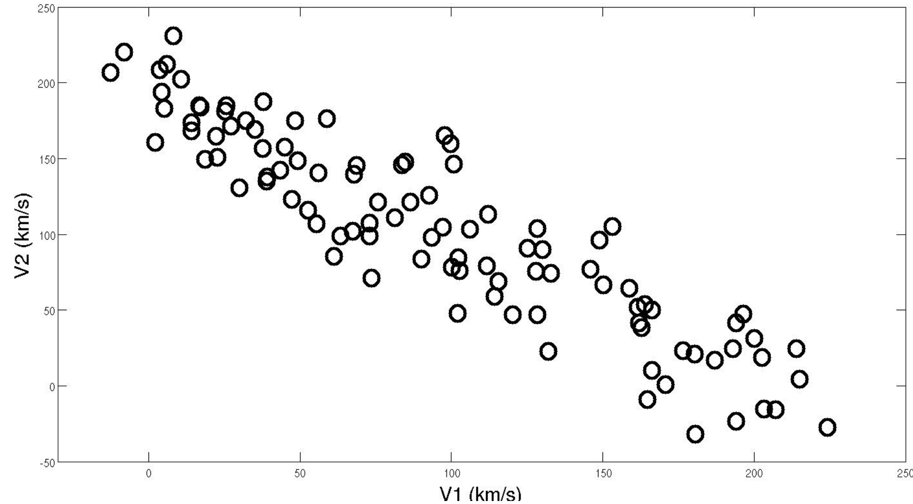


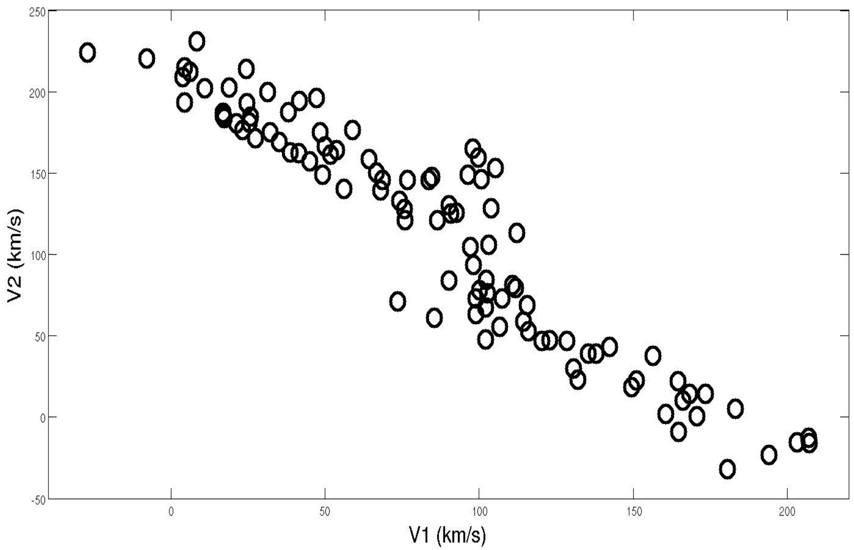


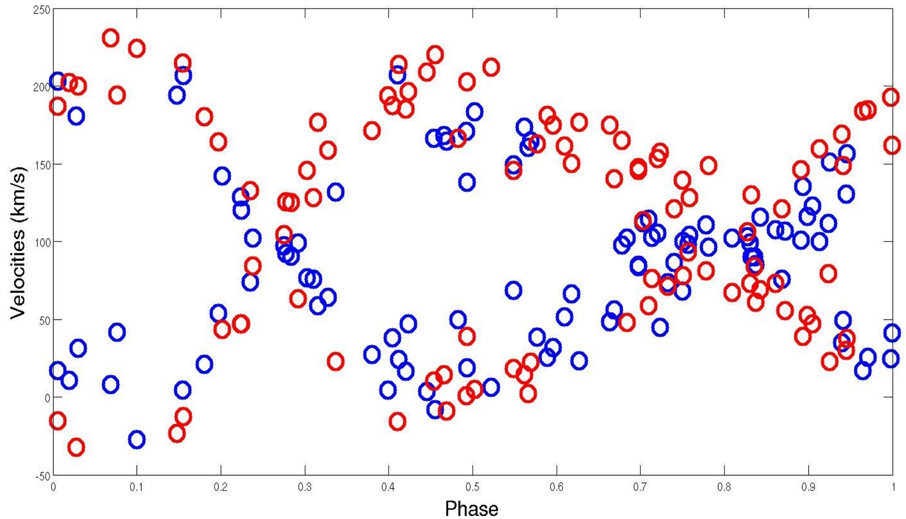
Sorting SB2 velocities

K_1=100 km s^{-1}, K_2 = 100 km s^{-1}, e = 0.3, σ = 20 km s^{-1}

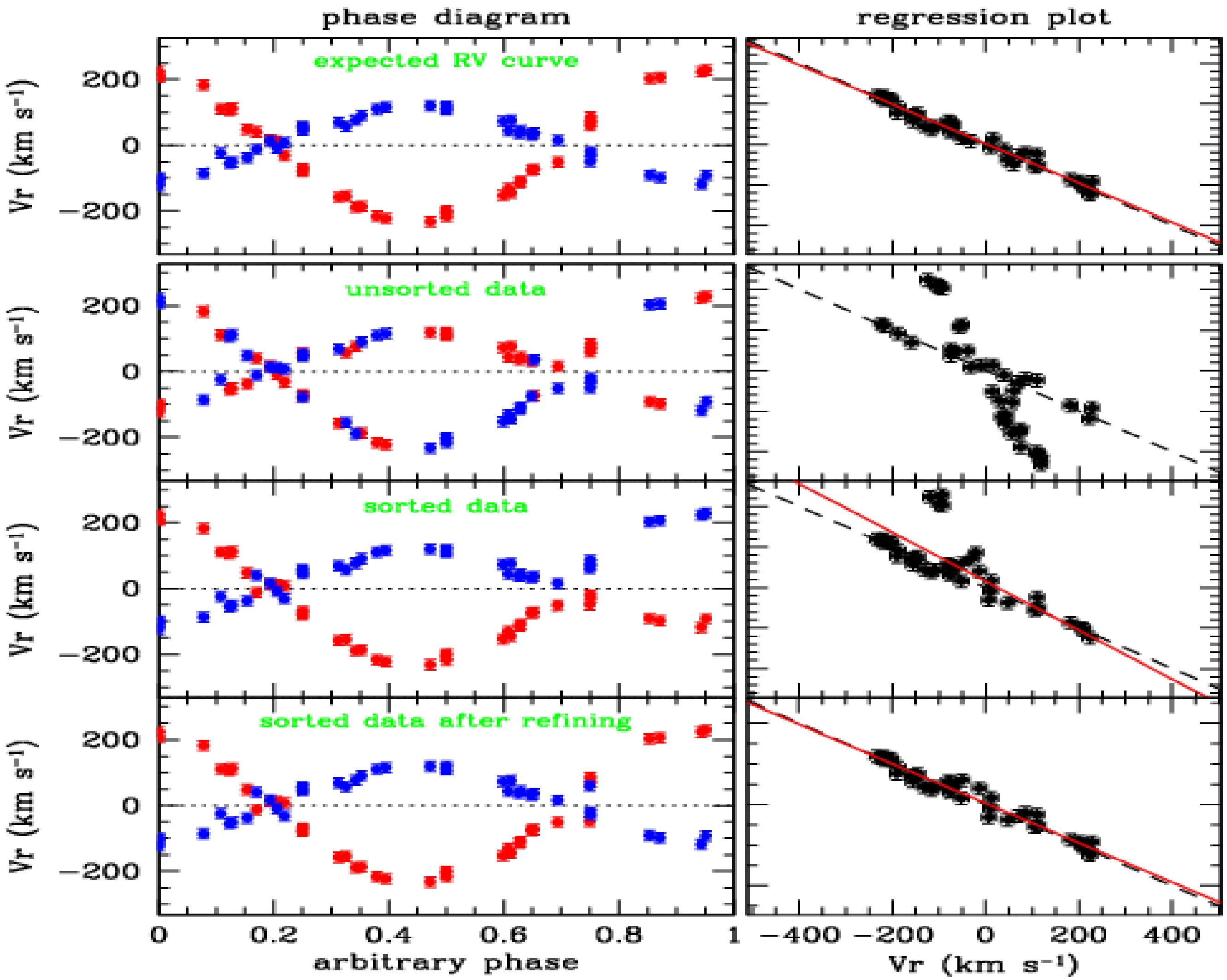








Sorting SB2 velocities



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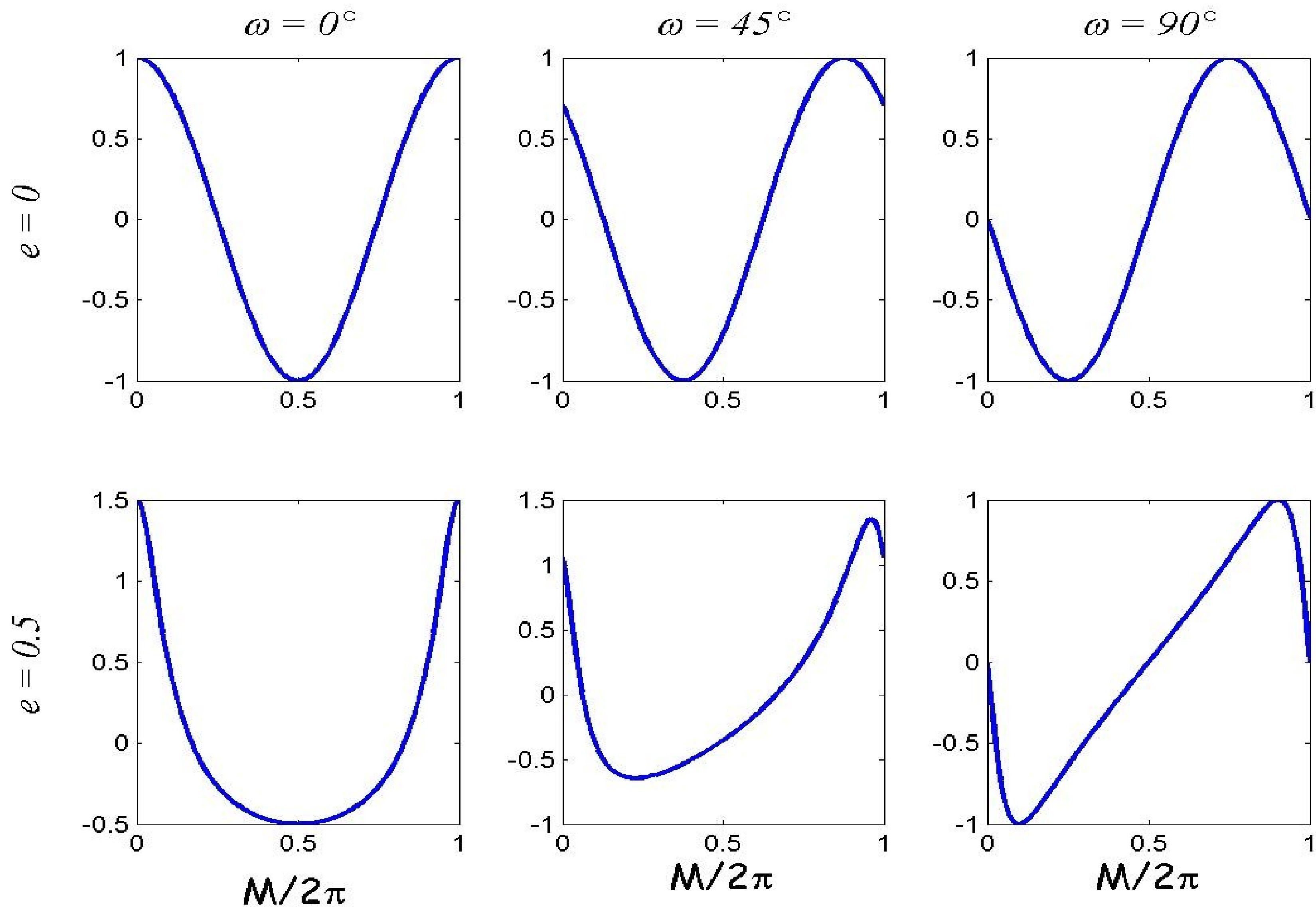
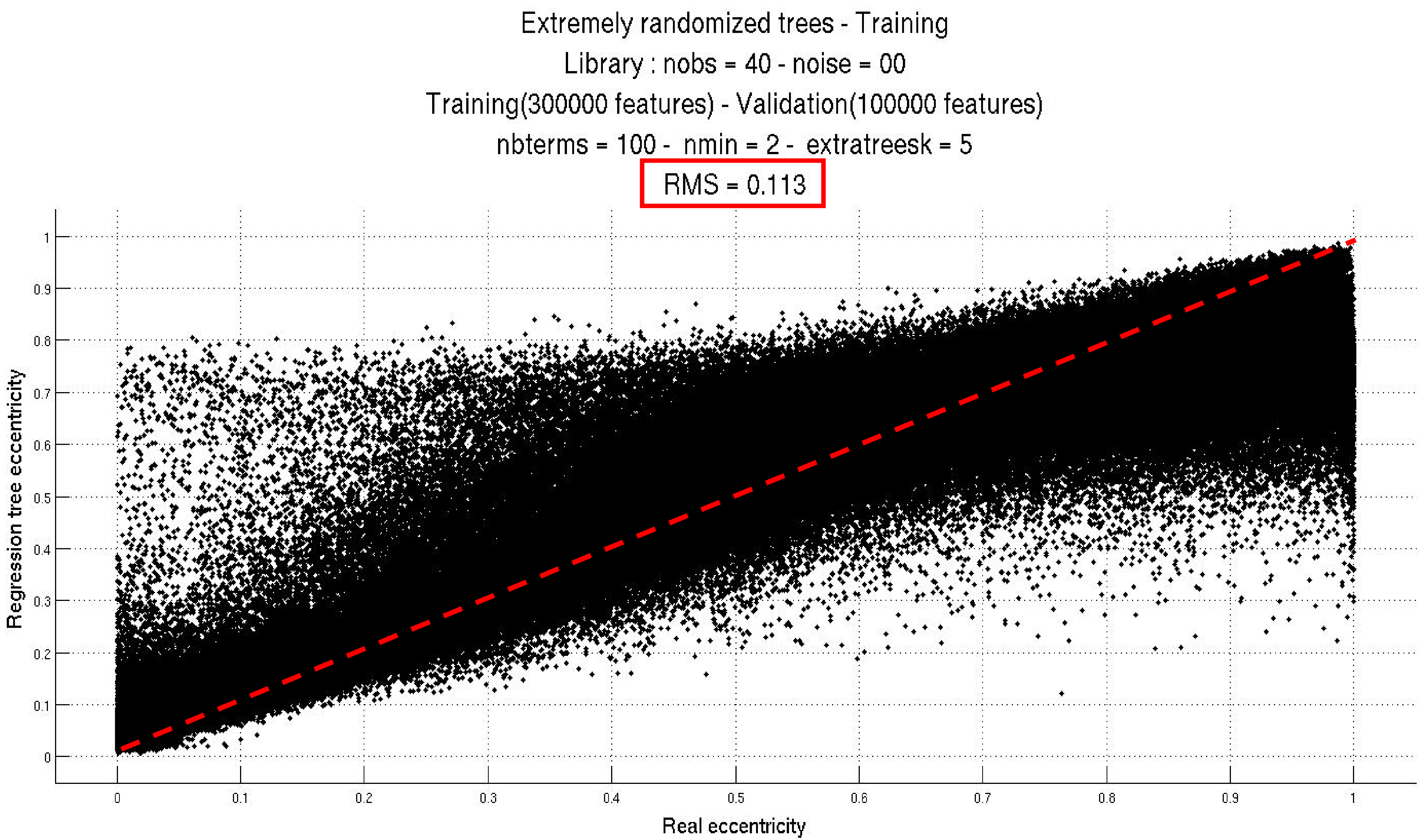
Pattern recognition SB1



Pattern recognition SB1

Extremely randomised trees by P. Geurts et al.



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