Spectroscopic monitoring of Southern Galactic O and WN-type stars:

Some highlights of the OWN Survey

Presented by: **Roberto Gamen**

Massive stars

- The O-type and Wolf-Rayet stars are the major source of ionizing and UV radiation.
- They play a crucial role in the chemical evolution of galaxies.
- They end their lives as core-collapse supernovae, producing black holes and neutron stars.
- They seem to prefer living in binary o multiple systems, which in turn originate intriguing phenomena such as HMXRB and gravitational waves.

The rate of such events, and their properties, strongly depends on the frequency of binaries and stellar parameters of components.

Massive binary systems

Studying massive binary systems is very important by many reasons:

- To determine some stellar properties, as mass, radius, etc.
- (But) Stars in binary systems do not evolve as single ones (if any). Mass and angular momentum exchange between them at different evolutionary stages.
- Multiplicity can provide evidence for understanding the origin of massive stars. For instance, mass ratios depend on the phenomena acting during formation. Star migration or competitive accretion tend to unify masses, but RLOF during the early pre-MS phase makes to diverge the masses.

In this context, O+O and WR+O binaries are key objects.

The OWN Survey:

We are conducting a spectroscopic monitoring of O- and WN-type stars for which there is no indication of multiplicity in the Galactic O Stars, GOS, Catalogue (Maiz Apellaniz et al. 2004) or in the VIIth Catalogue of Galactic Wolf-Rayet Stars (van der Hucht 2001).

Team: **Rodolfo Barbá – Nidia Morrell – Julia Arias – Nolan Walborn† – Jesús Maíz Apellániz – Alfredo Sota – Emilio Alfaro**

Fellows: Abdo Campillay – Gabriel Ferrero – Gonzalo Holgado – Cristina Putkuri – Guillermo Retamales – Cinthya Rodriguez – Carolina Sabín San Julián – Natalie Ulloa

Collaborations with: Sergio Simón Díaz – Fabrice Martins – Yael Nazé – Ignacio Negueruela – Gregg Wade

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Major goals:

- To determine multiplicity among massive stars.
- To characterize orbital parameters (e.g. P, and e).
- To infer stellar parameters (e.g. minimum masses).

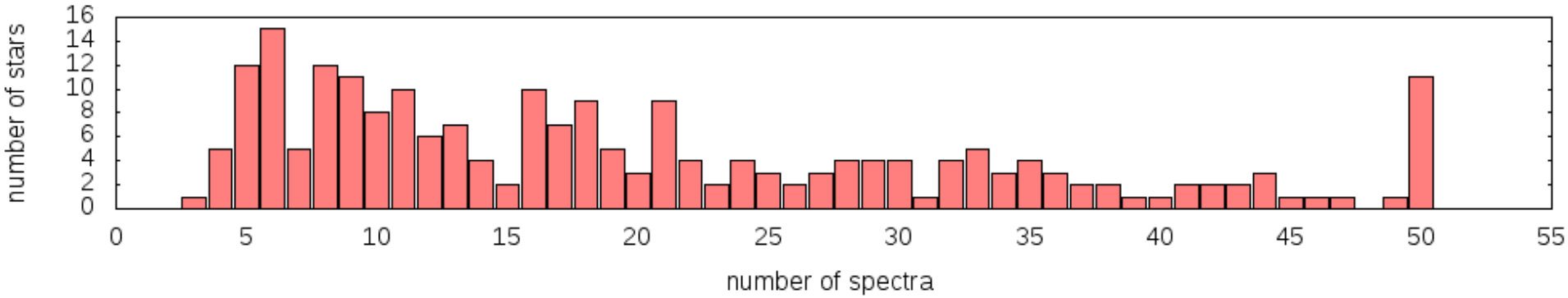
The OWN Survey:

Observations:

7 200 spectra with échelle spectrographs at:

- El Leoncito, Argentina (CASLEO): Sahade, 2.15 m (n=3100).
- Las Campanas, Chile (LCO): du Pont, 2.5 m; Clay, 6.5 m (n=2700).
- La Silla/ESO, Chile (ESO): 2.2 m (n=1300).
- Cerro Tololo, Chile (CTIO): 1.5 m (n=100).

obtained since 2005.

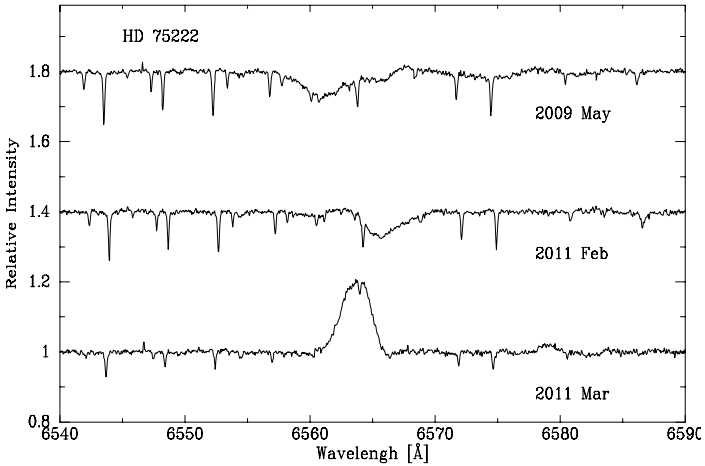


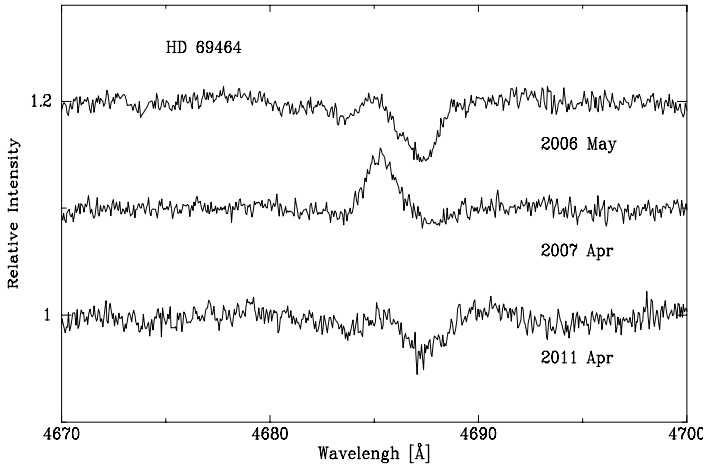
The sample is increased with other high-res spectra obtained at CASLEO between 1997–1999.

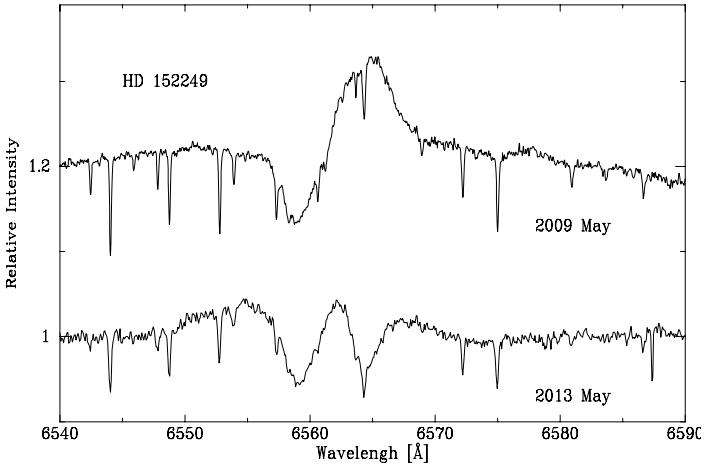
Observing runs with Nidia at CASLEO were seeds of the OWN Survey.

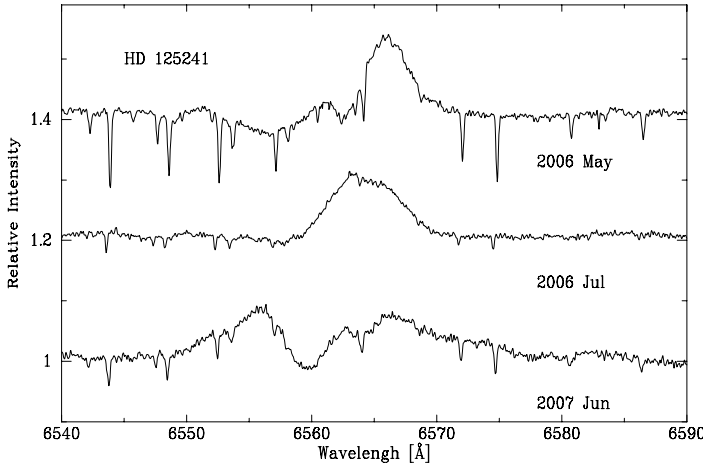
Spectral variability

We discovered about ten spectral variables.









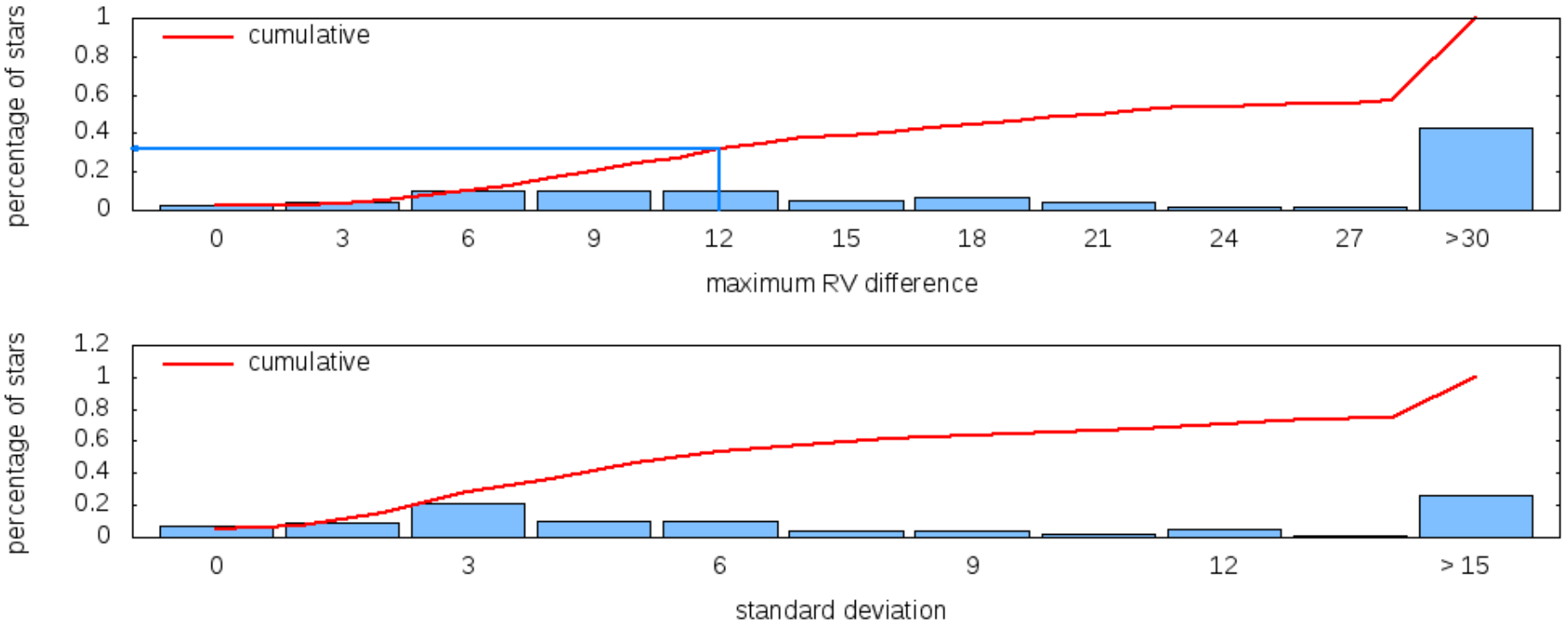
About multiplicity

¿Por qué la tierra es mi casa?
¿Por qué la noche es oscura?
¿Por qué la luna es blancura
que engorda como adelgaza?
¿Por qué una estrella se enlaza
con otra, como un dibujo?
Y ¿por qué el escaramujo
es de la rosa y el mar?
Yo vivo de preguntar:
saber no puede ser lujo.

(Silvio Rodríguez)

Multiplicity

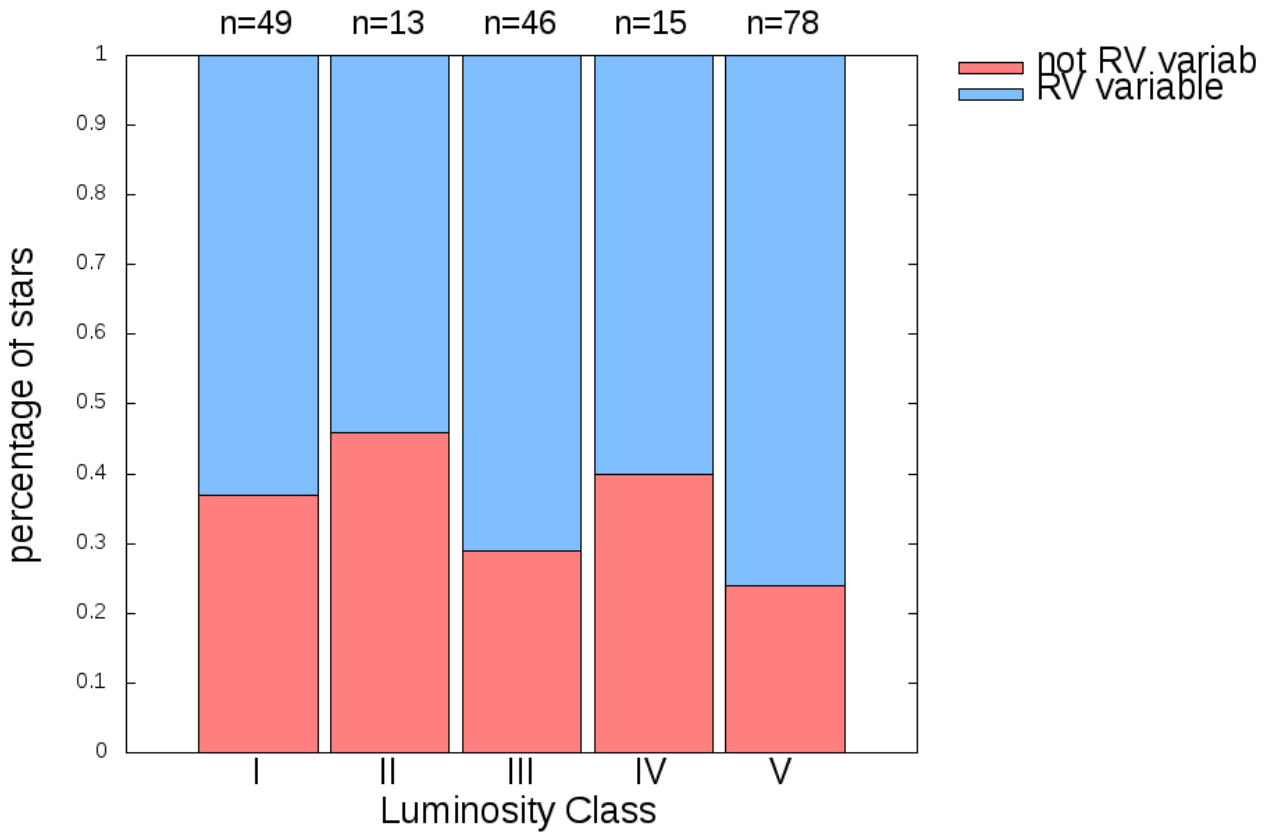
Radial velocity variations as indicative of orbital motion. Confusion by other phenomena, as pulsation, wind instabilities, etc.



About 68 % showing RV variations greater than 12 km $^{-1}$, i.e. candidates to be binary/multiple systems.

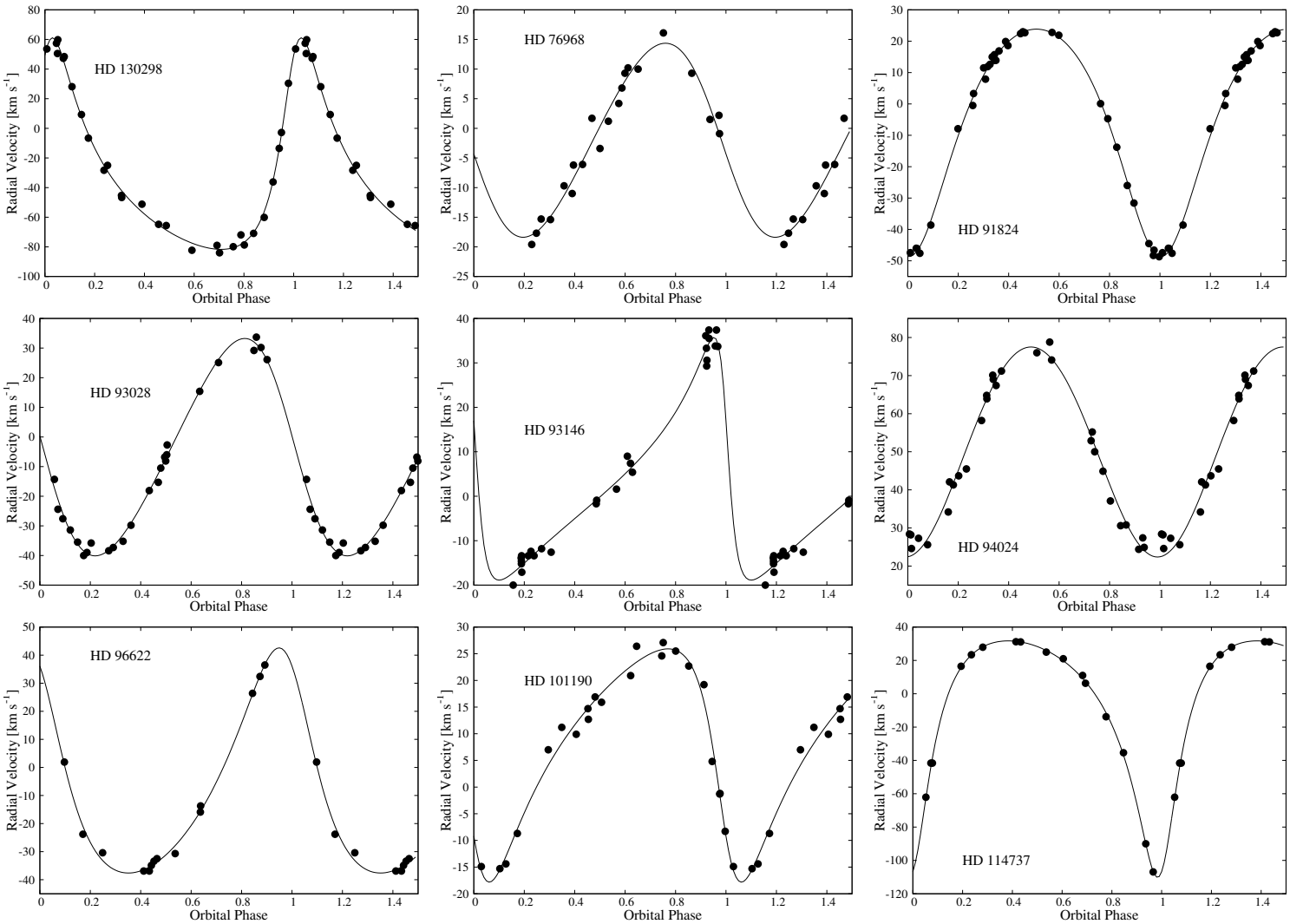
Multiplicity

Does multiplicity correlate with the luminosity class? Evolution effect?

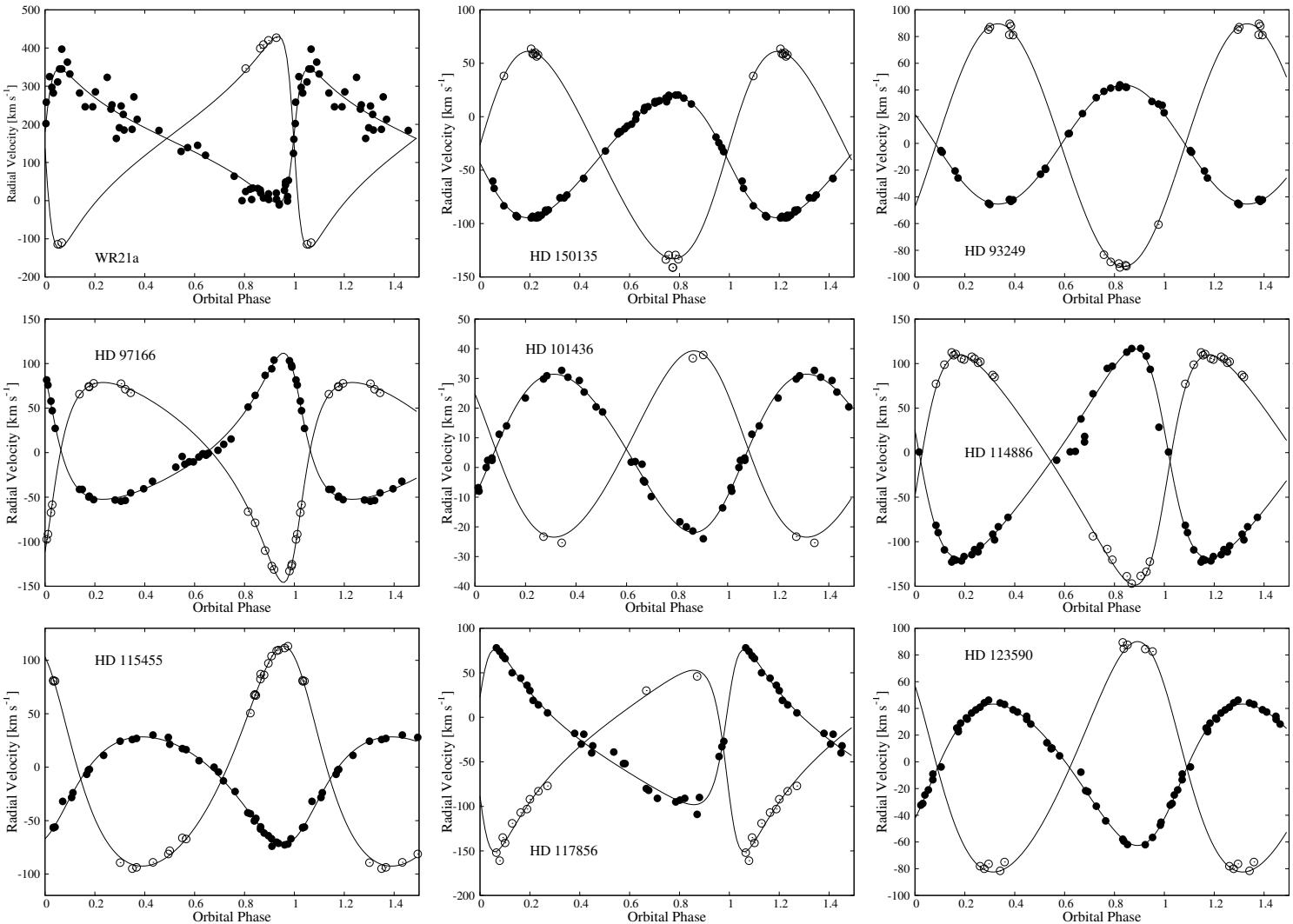


The number of stars in II and IV classes in the sample is low.

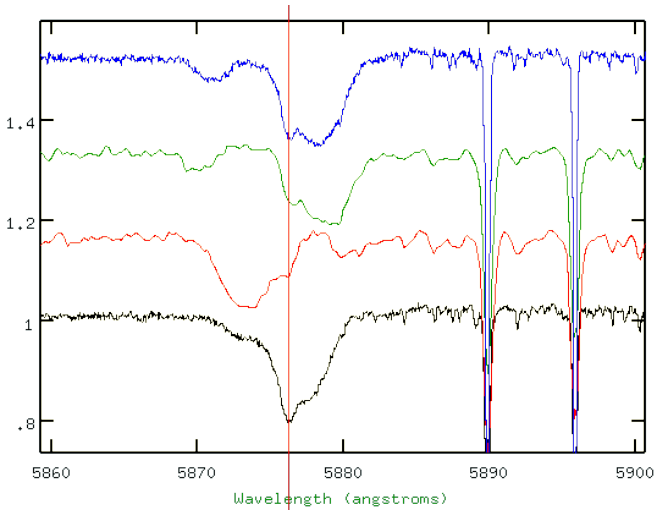
25 new SB1 with orbits

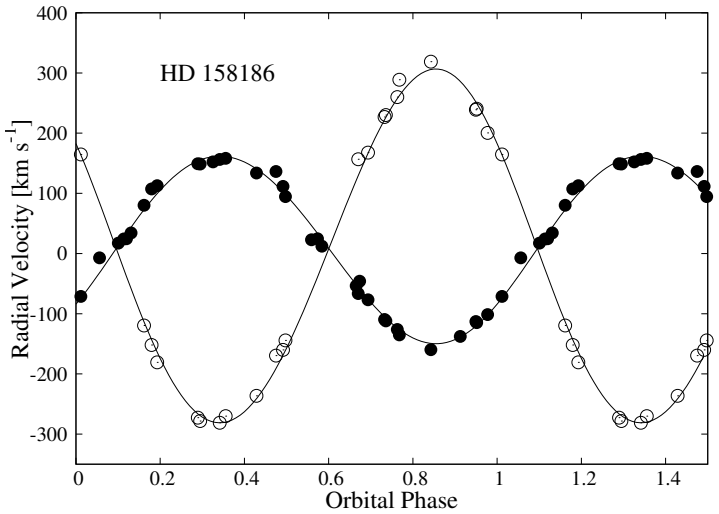


26 new SB2 with orbits



9 new SB3 (not all) with orbits

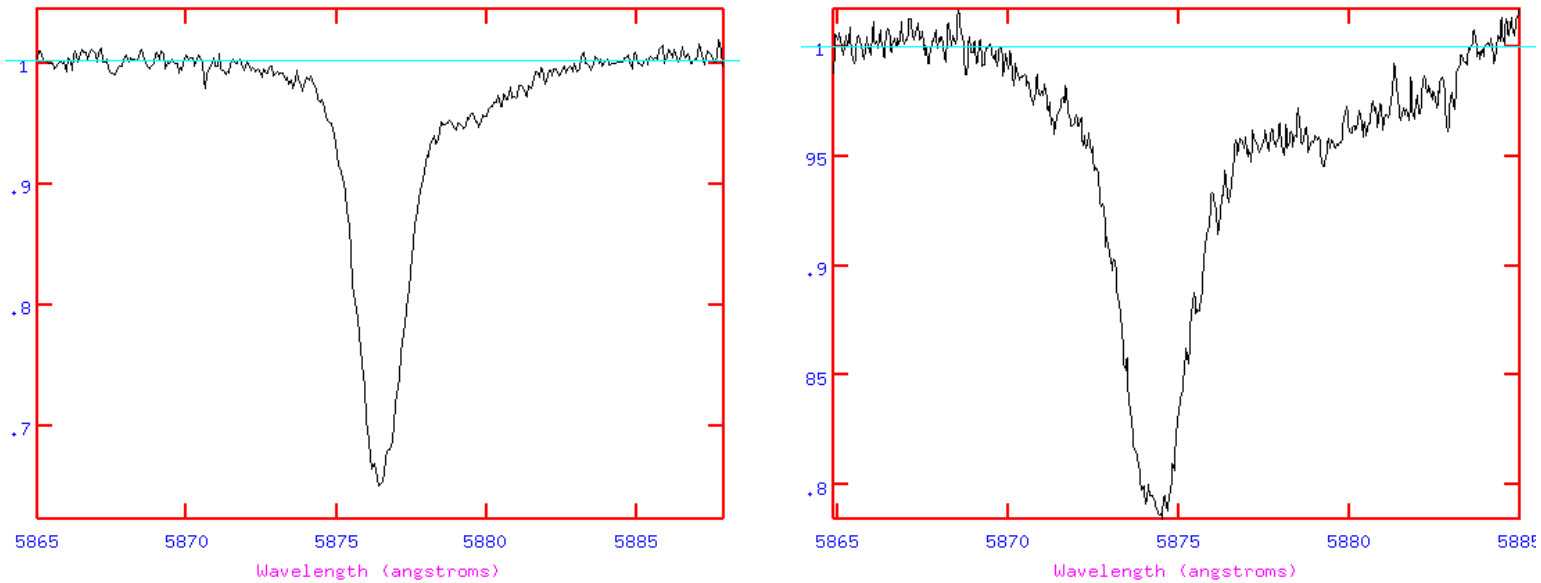




+ Her36A (see Julia Arias's poster).

Miscellaneous

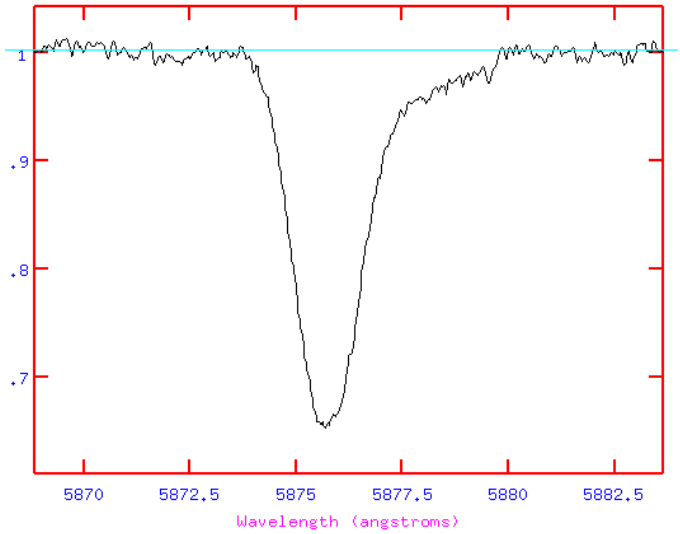
Some stars showing composite spectra with narrow and broad lines (C. Putkuri).

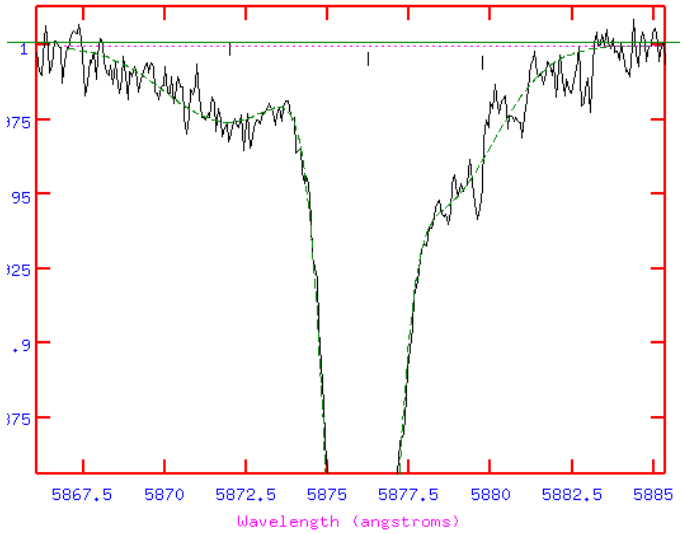


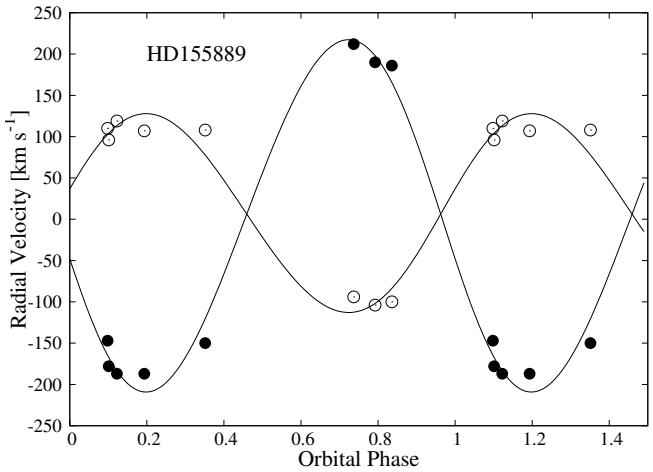
This may be related to strong differences in their rotational velocities or in the inclination of their rotation axis relative to the orbital plane.
In these cases, the first step was to demonstrate that the composite spectrum is a SB2.

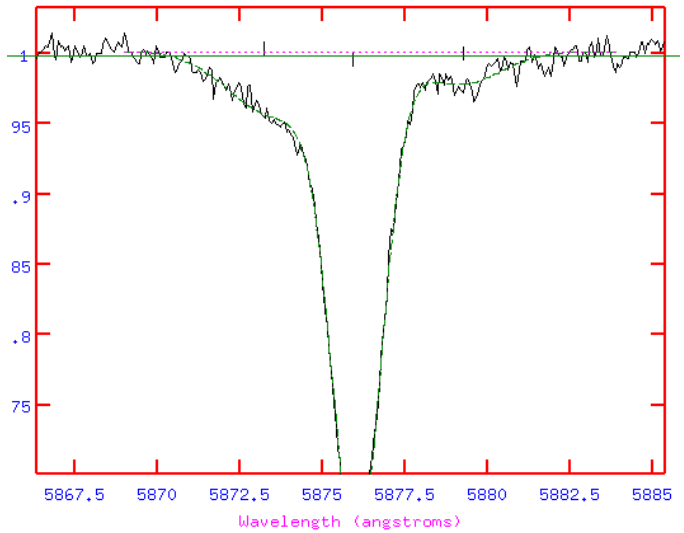
Miscellaneous

In one case the “broadened line” was, in fact, another binary.



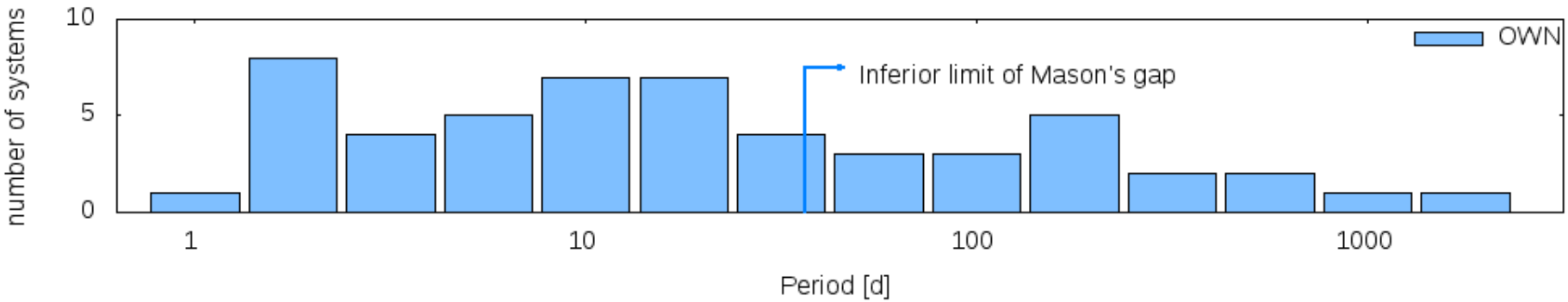


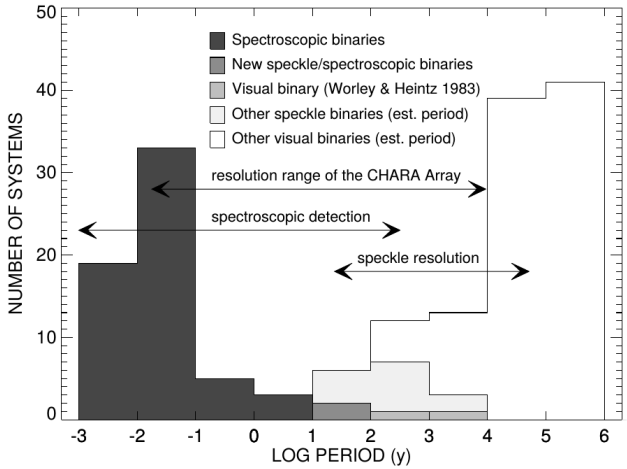


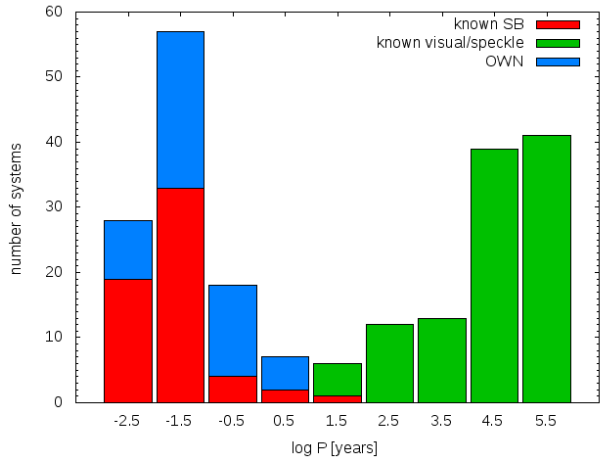


About periods

We add 19 new binaries with periods larger than 0.1 years. Filling the Mason et al (1998)'s gap.

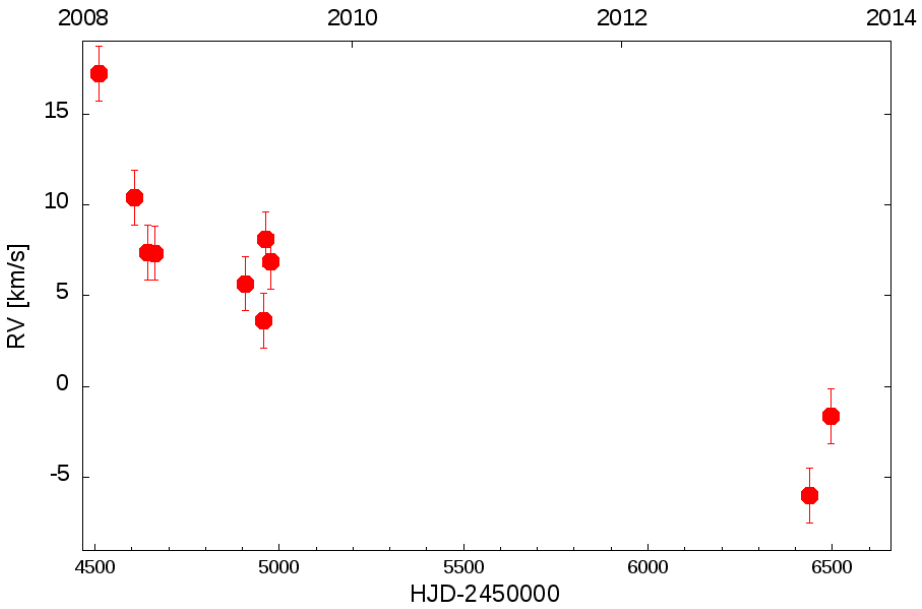


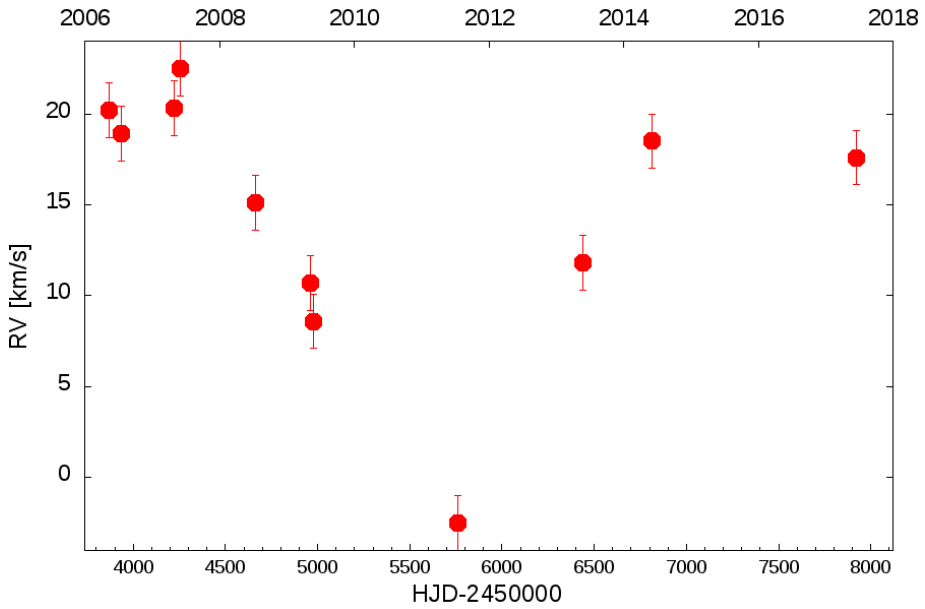




High-res spectra and longer time coverage bring to new synergy with interferometric surveys (e.g. 3-D orbit of HD 54662).

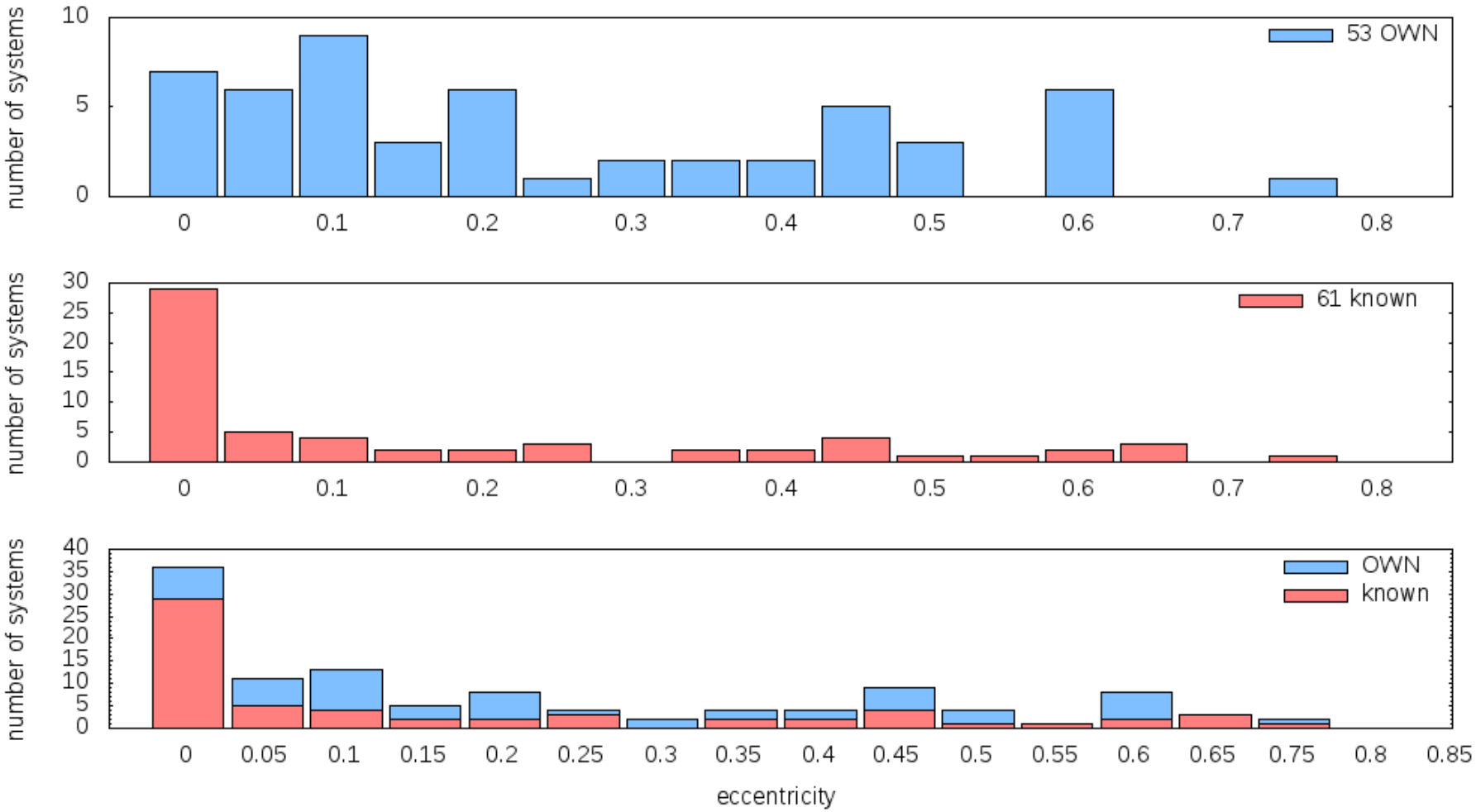
Rarities





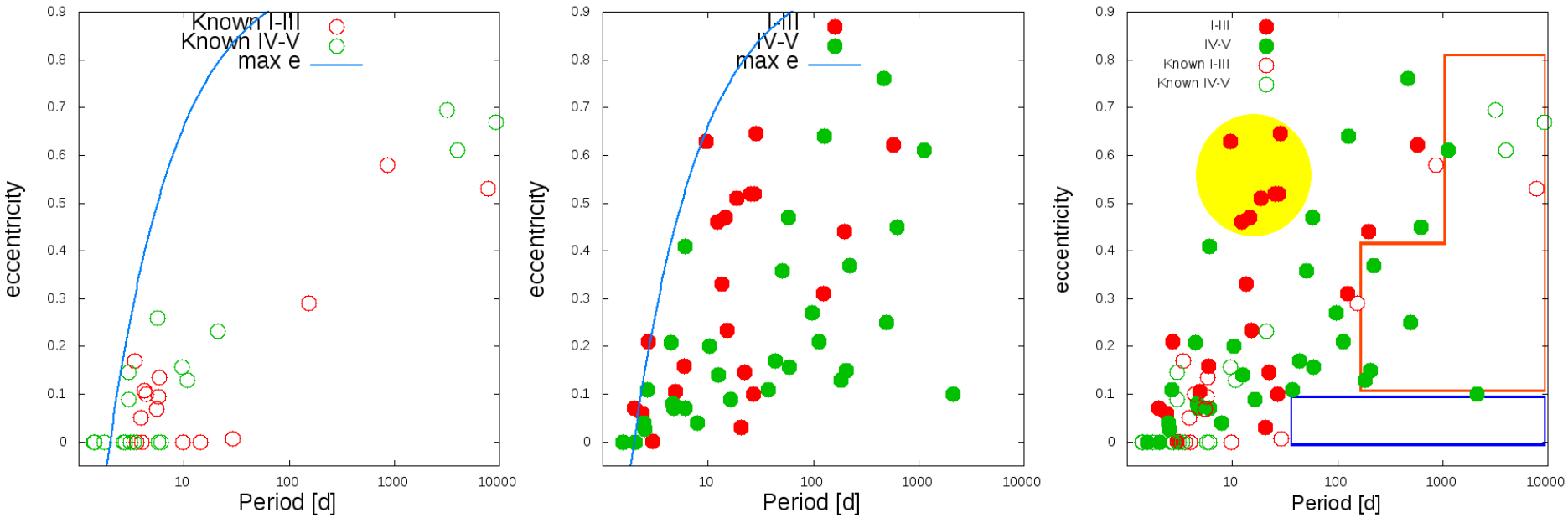
Some stars present RV variations which seem to indicate very large periods.

About eccentricities



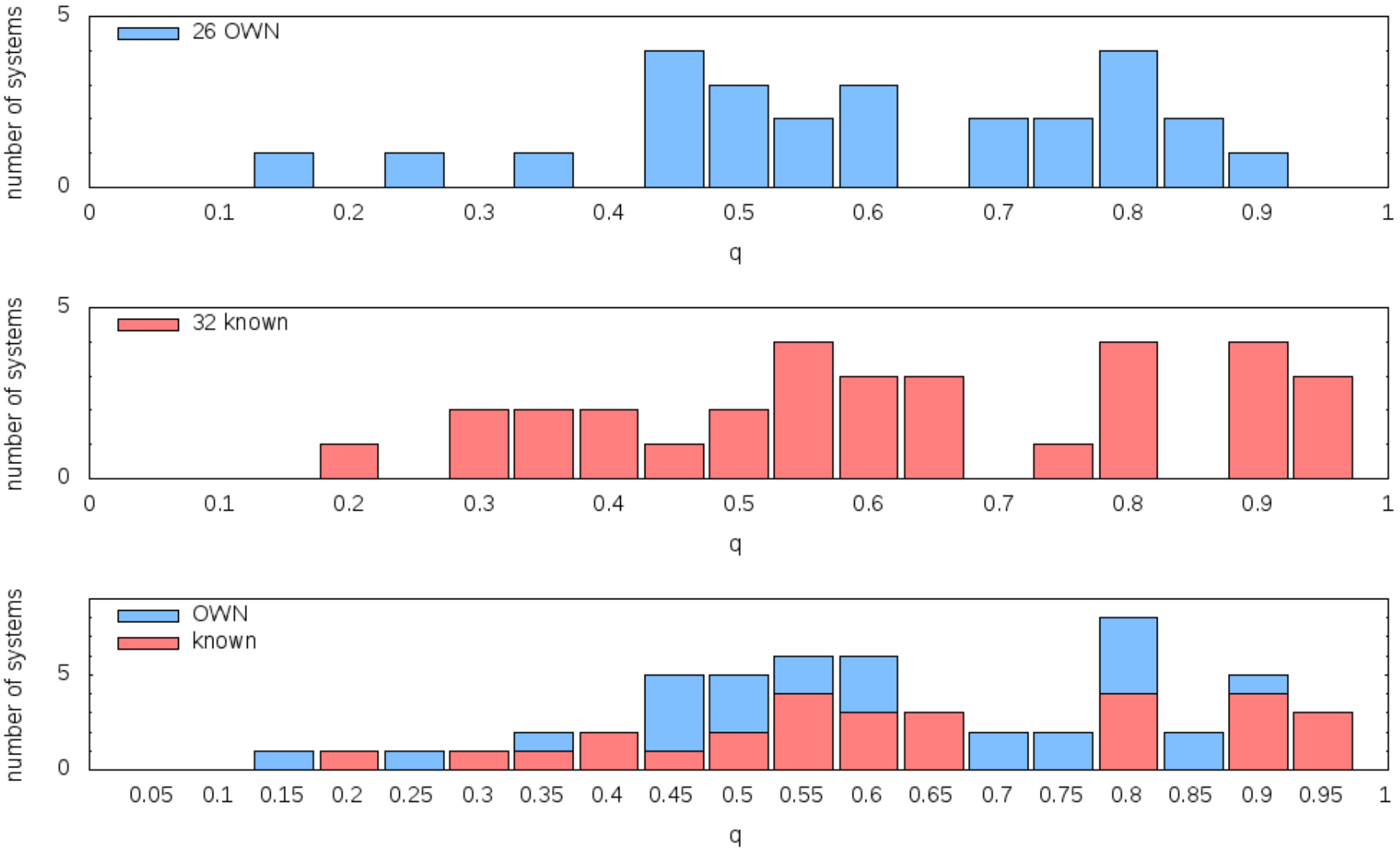
57 % of binaries have $e < 0.15$.

About eccentricities vs. periods



- There are no circular orbits ($e < 0.1$) with $P > 20$ d.
- No giants–supergiants in the red zone. Exception: HD 167971 (astrometrical orbit, Le Bouquin et al, 2017)
- Group (in yellow) of I–III with low P and large e. 6 SB1. One of them is the SFXT HD 74194, but only 1 is a X-ray source.

About mass ratios



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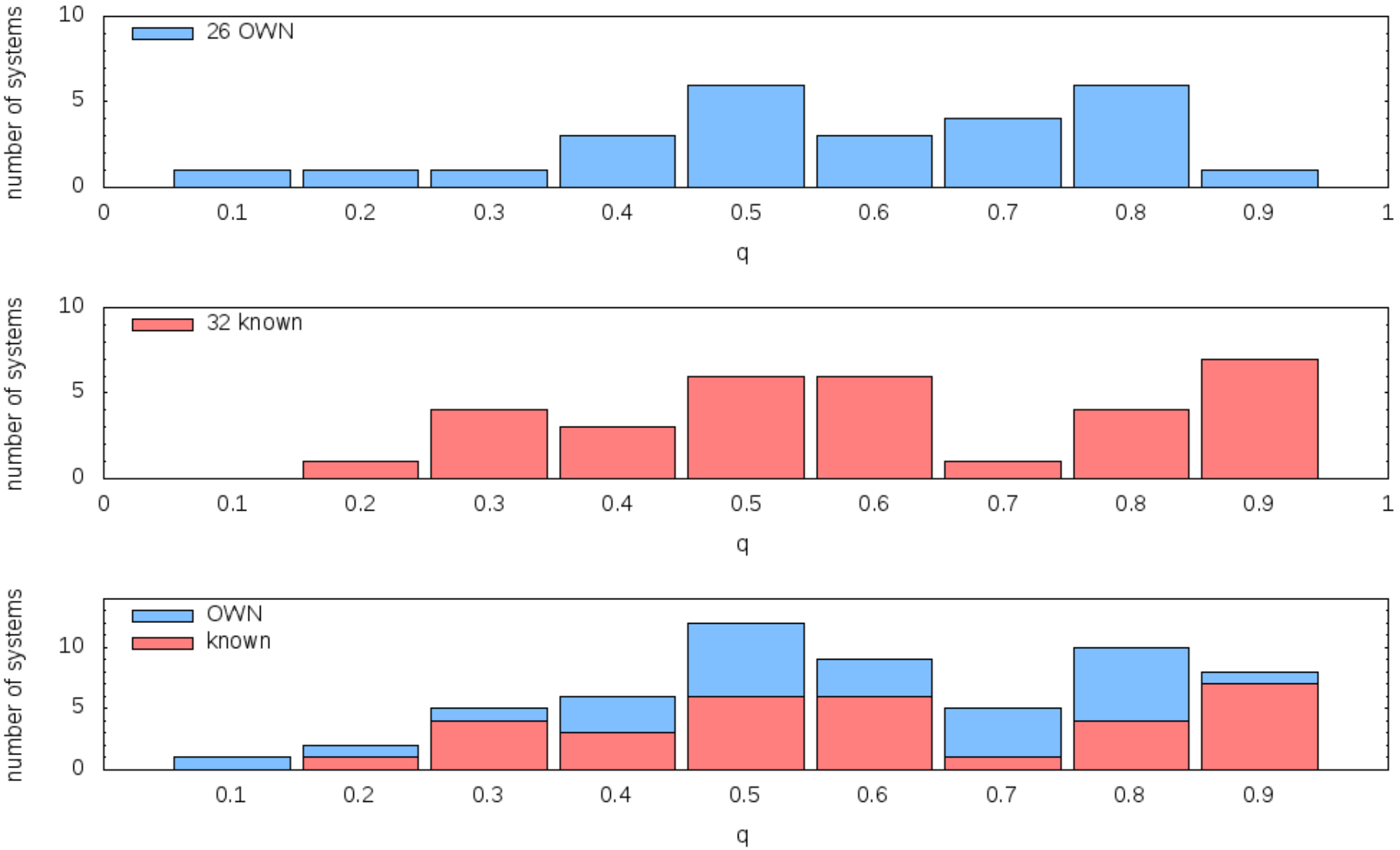
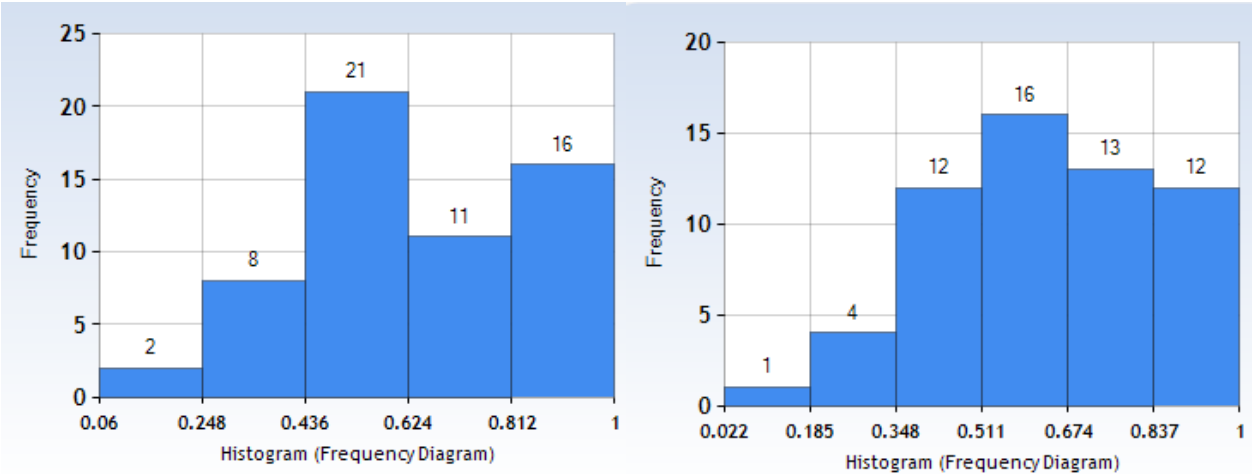


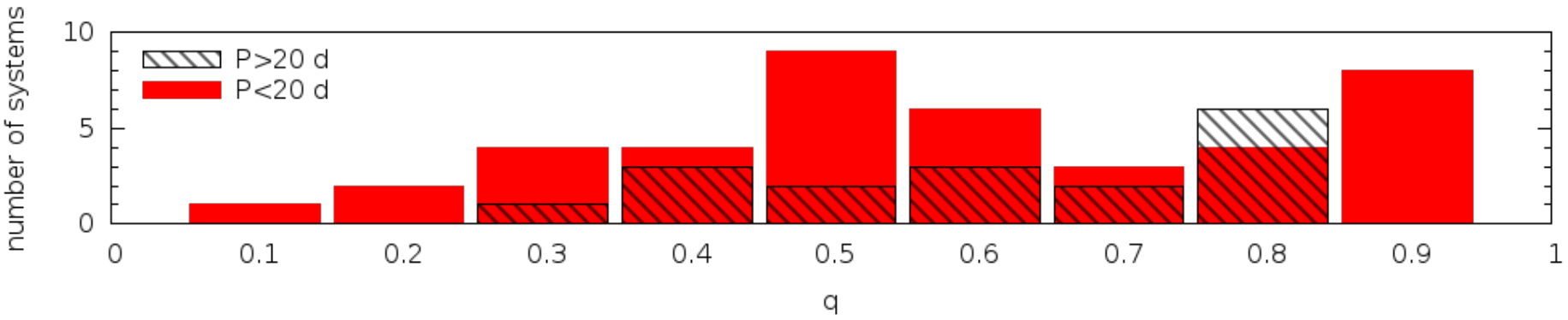
About mass ratios

Assuming the optimal binning as $W = 3.49 \times \sigma \times n^{-1/3}$(Scott, 1979) or $W = 2 \times IQR \times n^{-1/3}$(Inzenman, 1991) where IQR is the interquartile range (the 75th percentile minus the 25th percentile), $W = 0.188$ or $W = 0.163$ is obtained.

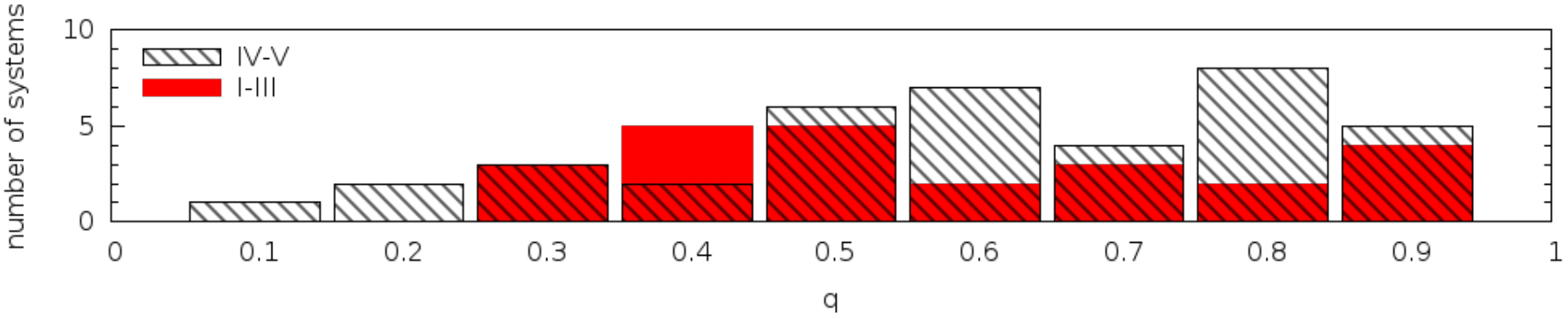


It seems a maximum around $q = 0.5$ should be analysed. More SB2 are needed!

About mass ratios

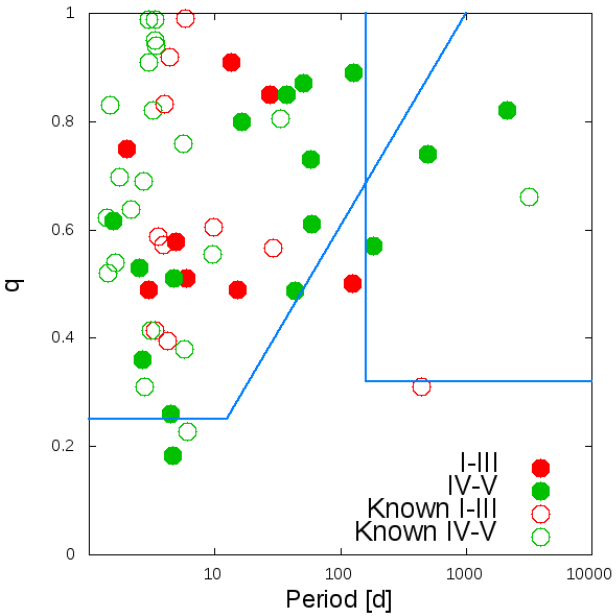


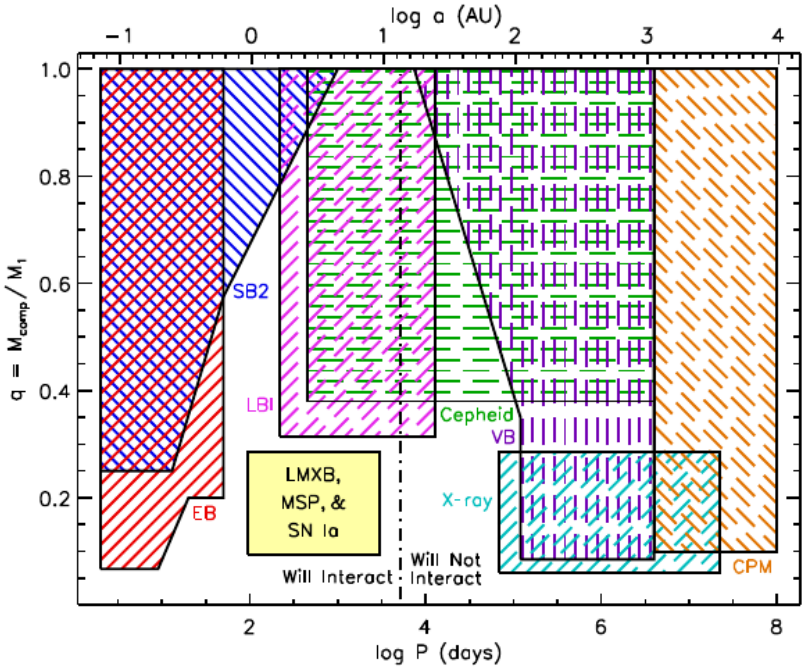
No $0.9 < q < 1.0$ among periods longer than 20 days!
The maximum at q=0.5 is not seen in long period binaries.
KS-test determines datasets differ significantly.



KS-test determines datasets do not differ.

About mass ratios vs. periods



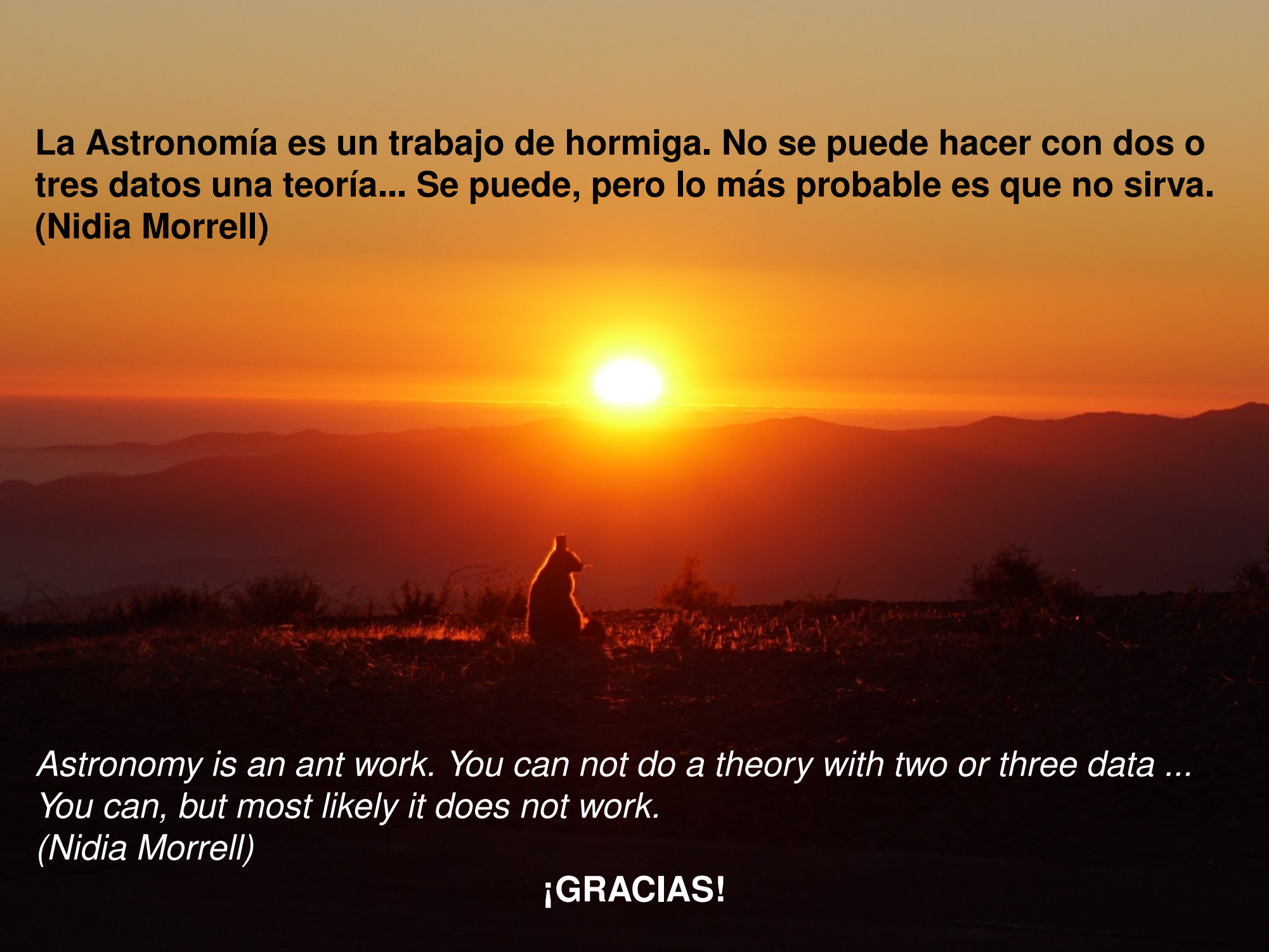


The new binaries cover very well the zone where SB2 should be detected (Moe & Di Stefano, 2017), and even exceed toward lower q.

Besides, three new binaries fall in the long-baseline interferometry zone.

Summary

- Collection of 7 200 high-resolution spectra of 221 O- and WN-type stars since 2005 (1997).
- $\sim$10 spectral variables were discovered.
- $\sim$**68 % of the sample are candidates or confirmed binary/multiple systems**. Value between the 56 % of Sana (2012) and the 82 % of Chini et al (2012).
  - 25 SB1.
  - 26 SB2.
  - 9 SB3.
  - 19 new binaries with $P > 0.1$ years.
- **Distribution of periods**: Over-density of low-P: $\sim$51 % with $P < 10$ d.
- **Distribution of eccentricity**: 57 % of systems have $e < 0.15$.
- **Distribution of mass ratio**: maximum at q=0.5. It depends on P.
- **Binary frequency is different among luminosity classes!**



La Astronomía es un trabajo de hormiga. No se puede hacer con dos o tres datos una teoría... Se puede, pero lo más probable es que no sirva. (Nidia Morrell)

Astronomy is an ant work. You can not do a theory with two or three data ... You can, but most likely it does not work.
(Nidia Morrell)

¡GRACIAS!