Massive binaries as seen with GAIA

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Introduction

GAIA is ESA's global astrometry mission that will be launched in August 2012. The goal of this mission is to measure the position, velocity and distance of about one billion stars, hence creating a 3-D map of the Milky Way. The satellite features two telescopes that use the same focal plane. The 3-in-1 instrument, placed in the unique focal plane, is composed of an assembly of 106 CCDs. This instrument has three channels: one for astrometry, one for spectro-photometry and a radial velocity spectrometer (RVS).

The very high precision of the astrometric instrument (down to 7 µas) will provide a tremendous breakthrough in several fields, including our knowledge of stellar parameters, the stellar populations distribution, the search for exoplanet systems, the galactic structure, minor bodies of the solar system,… The RVS is a medium-resolution (~11 500) spectrograph operated in the near infrared (847-874 nm). Its goal is to measure the radial velocity of stars and therefore complete the information of the astrometric instrument. The wavelength range was mainly chosen to be suited for late-type stars, featuring a strong Ca II triplet. Here, we investigate the capabilities of this instrument for studies of O-type stars.

Simulations

We have simulated the detection of binary systems containing at least one O-star with the RVS. The Monte Carlo simulations for 9 million binary systems were done with MATLAB®. The first step was to build synthetic spectra of binary systems in the RVS domain. For this purpose, we used a set of observed O-star spectra and a grid of synthetic spectra of cooler stars from Castelli & Munari (2001, A&A 366, 1003). The spectra were wavelength shifted according to the orbital elements of the fake binary system. The latter were generated following the distributions of mass ratios and semi-major axis given by Kobulnicky & Fryer (2007, ApJ 670, 747) and assuming a random orbital inclination in the range [0,π] radians. We further made the assumption of a circular orbit and considered the extreme values of the true anomaly. Finally, we added observational noise to the synthetic spectra. The resulting simulated spectra were then cross-correlated with two masks (one for the O-star and another one for its companion) and we consider that the binary nature is successfully detected if the cross correlation peak yields the right radial velocity within the resolution of the RVS (see Fig. 1).

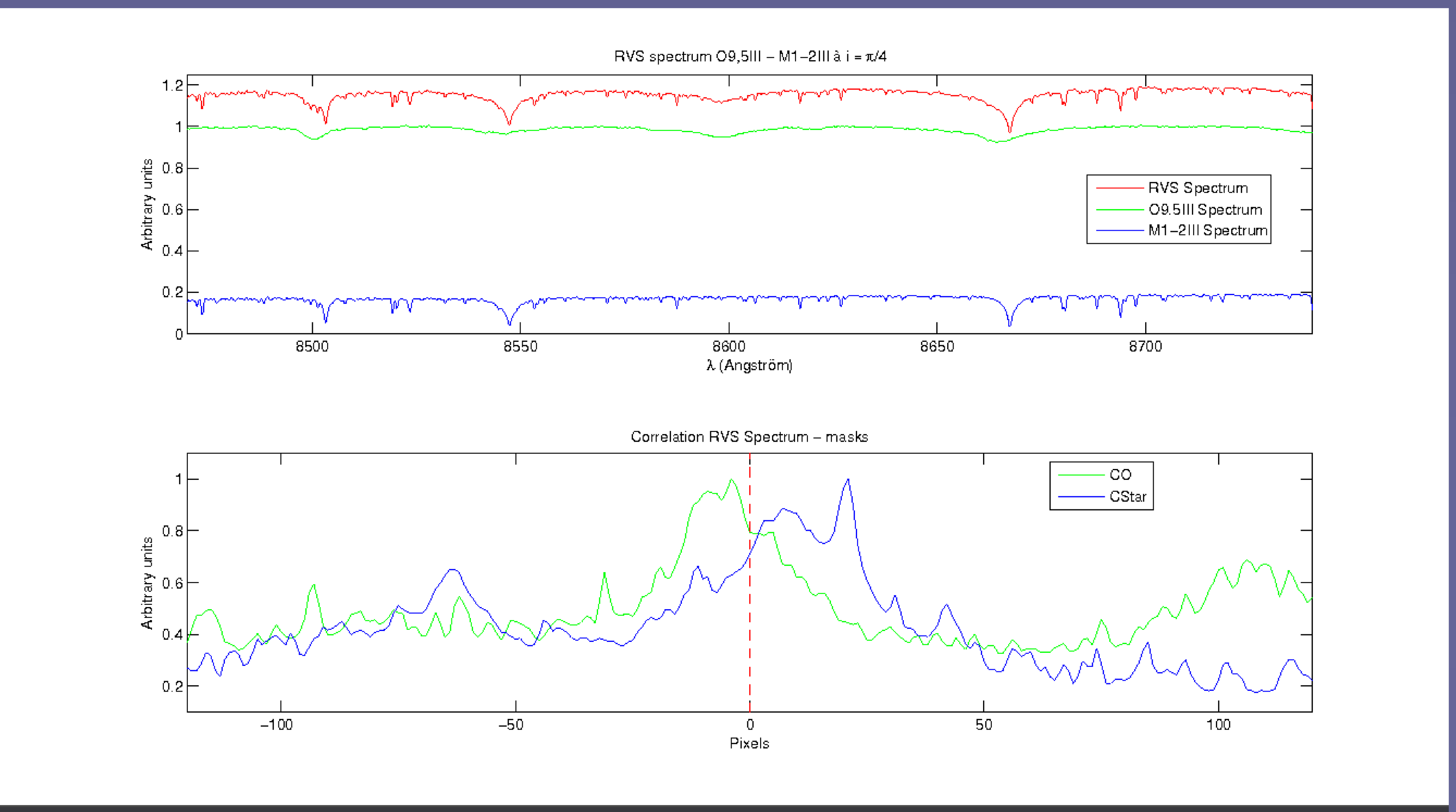

Fig. 1: Upper panel: Example of combining spectra of an O9.5 III and an M1-2 PMS star at $\pi/4$. Lower panel: Result of the cross correlation. The input radial velocities are recovered within the resolution of the RVS.

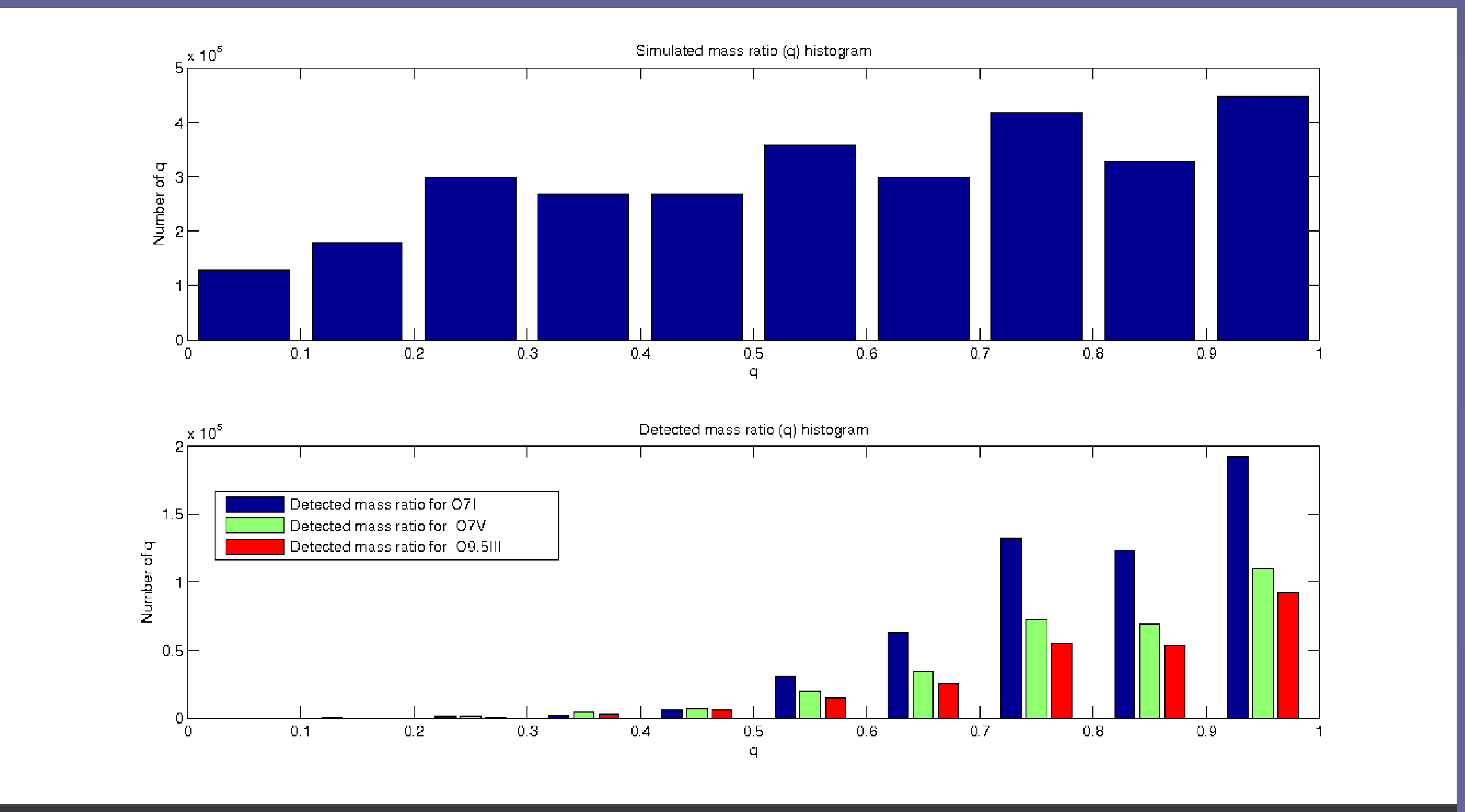

Fig. 2: Upper panel: histogram of the simulated mass ratios. Lower panel: histograms of the detected mass ratios for SB2 spectral signatures.

Results and conclusions

The first important result is that the RVS wavelength domain does not allow us to get rid of the common luminosity bias that affects the detection of the companion star. Indeed, binary systems with mass ratios ($M_{companion}/M_O$) below 0.4 will probably not be detected by the RVS (see Fig. 2). The percentages of detections of SB1 and SB2 spectral signatures are given in the table below for simulated O + O systems and O + non O systems. As can be seen, the total detection rate will be around 50%, which is not very good. We also simulated a smaller sample of O-star binaries without noise and a fixed orbital period of 10 days. This study showed that the detection rate depends on the luminosity classes of the O-star and its companion. The spectral signatures of O-stars in association with supergiant companions are usually more difficult to detect.

In conclusion, we find that the RVS is not well suited for the study of massive binaries. The wavelength range is not well adapted since it lacks strong spectral lines.

To finish on a positive note, we also simulated the capabilities of the astrometric instrument to quantify the impact of the Lutz-Kelker bias (Lutz & Kelker 1973, PASP 85, 573) that affected the Hipparcos parallaxes. The impact of the bias on the determination of the absolute magnitude calibration of O-stars was simulated using the catalogue of Humphreys (1978, ApJS 38, 309). We showed that the Lutz-Kelker bias will be negligible thanks to the unprecedented precision of the astrometric instrument.

Stars	SB1 signatures (%)		SB2 signatures (%)		SB1+SB2 signatures (%)	
	V_O	V_{Star}	V_O	V_{Star}	V_O	V_{Star}
O7I	11.7	40.1	35.5	17.3	47.2	57.4
O7V	21.0	42.1	26.3	16.4	47.3	58.5
O9.5III	19.9	42.3	20.2	14.5	40.1	56.8

Stars	SB1 signatures (%)		SB2 signatures (%)		SB1+SB2 signatures (%)	
	V_{O1}	V_{O2}	V_{O1}	V_{O2}	V_{O1}	V_{O2}
O7I	38.6	9.8	7.2	11.6	45.8	21.4
O7V	32.9	12.2	5.2	5.9	38.1	18.1
O9.5III	27.7	9.5	5.3	7.4	33.0	16.9

Percentages of detections of SB1 and SB2 spectral signatures for three O-star primaries of different luminosity classes.
Left: O + non O systems. Right: O + O systems.

Conclusions: The RVS instrument onboard GAIA is not well suited for the detection and characterization of massive binaries containing an O-type star. The near infrared spectral range, chosen for this instrument, contains only weak lines in the spectra of O-type stars and does not allow to overcome the detection bias for mass ratios below 0.4. The detection rate of SB1 & SB2 spectral signatures is predicted to be around 50% and depends on the luminosity classes of the O-star and its companion. The astrometric instrument will provide parallaxes with unprecedented accuracy that should allow us to obtain a bias-free absolute magnitude calibration for massive stars.