# Massive binaries in Magellanic star clusters

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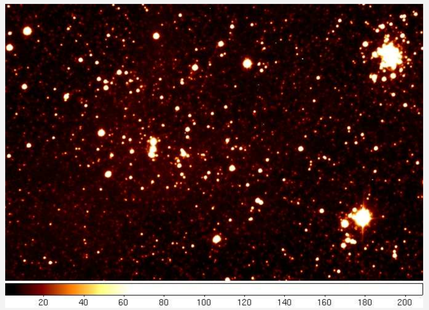
## Abstract

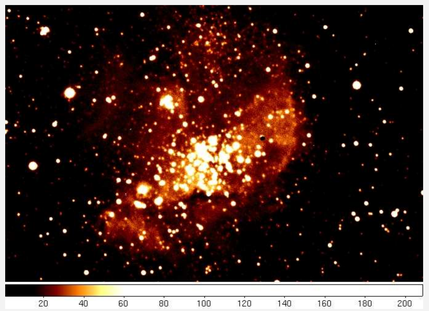
We are conducting a long term project aimed to tackle the "mass discrepancy" for massive stars on the basis of direct measurement of masses in eclipsing binary systems.
In order to define a suitable sample, we searched for eclipsing binaries in several massive star clusters in both Magellanic Clouds, and the Milky Way. From direct CCD imaging obtained at the 1-m CTIO/Yale (SMARTS) and LCO/Swope telescopes, we have found dozens of new eclipsing binaries, some of them still lacking a spectral classification, although their magnitudes and colors suggest they are hot massive stars.
Spectral types and radial velocity determinations are presently in course, using the spectrographs available at the Magellan and du Pont telescopes at LCO.
We present here partial results from our search for massive binaries in the star clusters R136, NGC 1910, NGC 2044 and NGC 2074, in the LMC; and the SMC clusters NGC 346 and NGC 602c.

## Introduction

Early O-type stars are among the brightest and most massive stars known, though accurate estimates of their fundamental parameters are still scarce. Although they form in small numbers and live shorter lives than less massive stars, they dramatically influence their surroundings with the effects of their ionizing radiation and strong stellar winds, and contribute to the chemical enrichment of the interstellar medium through supernova explosions.
It has not yet been determined how massive early O-stars can be, and moreover the masses predicted by evolutinary models are often in disagreement with those derived from model stellar atmospheres applied to their spectra, a problem often referred to as the "mass discrepancy" (Herrero et al. 1992 [3], Massey et al. 2005 [4]).
There is only one empirical method to determine stellar masses, and it is the combined light and radial velocity study of double lined eclipsing binaries. The most massive stars recently weighted in such a way are the components of NGC3603-A1, with $116 \pm 31$ and $89 \pm 16$ $M_\odot$, respectively (Schnurr et al. 2008 [6]); and those of WR20a ($\sim$ 83 $M_\odot$ each; Bonanos et al. 2004 [1]); all of them belonging to the spectral type WN6ha. Those measurements are close, but still below, the expected mass cutoff of 150 $M_\odot$ (Oey & Clarke 2005 [5]; Figer 2005 [2]).
In order to define an observational sample which is suitable to empirically study the "mass discrepancy" and other related problems, we have searched for eclipsing binaries in 11 massive star clusters and associations located in the Milky Way and the Magellanic Clouds.

## Observations and Results




### Imaging

Multiple V-band images of the selected targets were obtained between 2003 and 2007 using the LCO-Swope and CTIO-Yale 1-m telescopes. Our Magellanic Clouds dataset consists of about 15,000 V-band images of 6 clusters and associations which are rich in O-type stars. Photometric analysis revealed that all 6 clusters were not equally rich in eclipsing binaries. The number of eclipsing binaries (including new and previously known) for which V-light curves were obtained, are as follows:

LMC: 22 (R136), 12 (NGC 1910), 23 (NGC 2044), and 20 (NGC 2074)

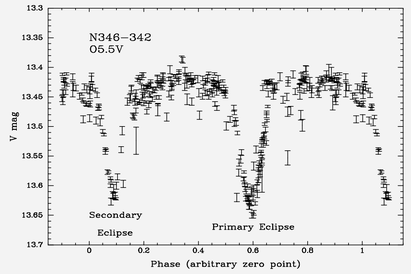
SMC: 12 (NGC 346), and 0 (NGC 602c).

The relation between binary frequency and other cluster characteristics will be addressed in a separate study.

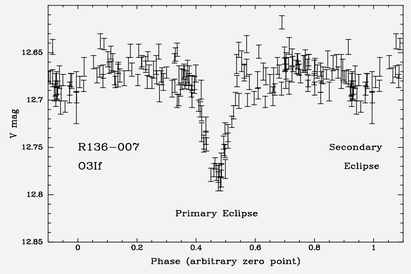
The figure shows Swope V-band images of NGC 1910 (top) and NGC 346 (bottom). N is up and E is left.

### Sample light curves

Light curve for one of our targets in the SMC cluster NGC 346. The spectral type is O5.5 V. The light curve suggests minimal interaction, but the period is only 2.355 days. Both components seem to be very similar. Magellan and du Pont spectroscopy obtained in May/June 2008, revealed a third component in the spectrum, very similar in spectral type to those previously known. This will complicate, but hopefully not preclude, further analysis of this massive multiple system.



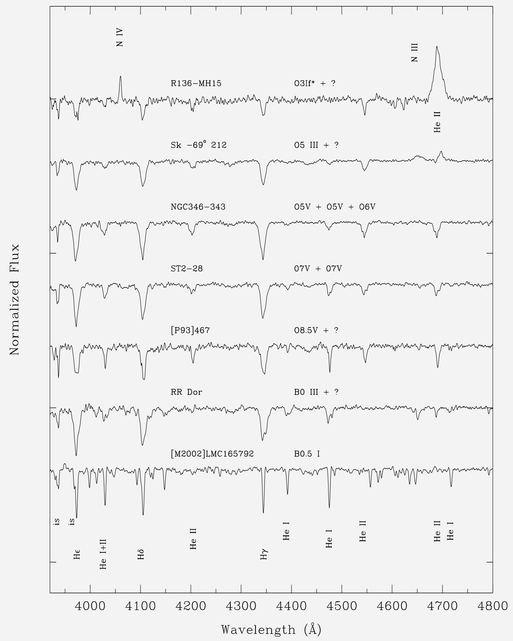

Light curve of one O3 supergiant in the R136 cluster in LMC. The period is 6.8283 days. The top of the light curve is flat, indicative of non interacting binary components. The secondary eclipse is well defined, but only 0.02 mag. in depth. High signal-to-noise spectroscopy ($\sim$ 250-300) will be needed in order to detect the secondary spectrum.




### Spectral types

We used the Boller & Chivens spectrograph attached to the du Pont telescope to obtain intermediate resolution (1.6 Å) observations suitable to determine accurate spectral types for the selected targets. This information was lacking for many of the newly found eclipsing binaries, and so absolutely needed before deciding to launch a radial velocity follow-up.

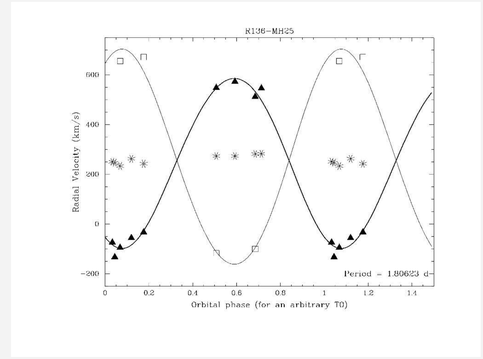
Following is a sample of our Boller & Chivens spectra with new and revised spectral types:



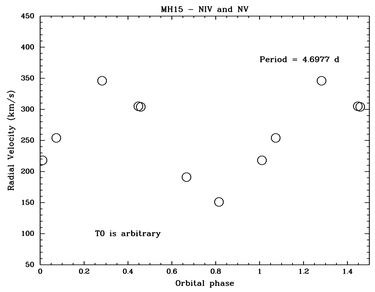

### Radial Velocities

High resolution spectra of several among the brightest targets have been obtained with the MIKE spectrograph at Magellan II (Clay) 6.5-m telescope, and the echelle spectrograph at the du Pont 2.5-m telescope, at Las Campanas Observatory. All our high resolution spectroscopic observations have been measured for radial velocities.

The plot below shows the observed radial velocities of an O3 V system in the R136 cluster folded with the period of the light variations. The light curve shows 2 narrow, similar eclipses approx. 0.3 mag. deep. However, the spectrum shows 3 sets of He II lines: the strongest component (stars) does not follow the orbital motion, while the 2 fainter components (filled triangles and open squares, respectively) show large radial velocity variations in good agreement with the photometric period. A very preliminary orbital solution is described by the continuous lines, yielding minimum masses of $48 \pm 10$ $M_\odot$ and $38 \pm 7$ $M_\odot$, respectively.




Observed radial velocities for the 4058 N IV emission line of a massive supergiant in the R136 cluster, folded with the photometric period. No features arising in the secondary component have been identified in our echelle spectra.




## Upcoming Magellan observations

Six consecuitve nights have been scheduled to this project in December 2008, with the IMACS instrument at the Magellan I (Baade) 6.5-m telescope. Then, we hope to obtain the spectroscopic observations needed to derive radial velocity orbits for 23 among the most massive systems in 4 Magellanic Clouds associations.

## References

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