The Most Massive Stars in the Local Group: Measuring Accurate Masses of Stars in Eclipsing Binaries

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Abstract.

Accurate masses and, in general, all fundamental parameters of distant stars can only be measured in eclipsing binaries. Several massive star candidates with masses near 200$M_{\odot}$ exist, however they have large uncertainties associated with them. The most massive binary ever measured accurately is WR 20a, for which we present the light curve. Measuring the period and inclination, we derive masses greater than 80$M_{\odot}$ for each component. Massive binaries are bound to exist in Local Group galaxies, such as M31 and M33. These can be selected from their light curves, obtained by variability studies, such as the DIRECT project. We present photometry and spectroscopy of the detached system M33A, for which we are obtaining a direct distance determination. The DIRECT project has detected several candidate massive binaries which are brighter but non-detached systems, perhaps similar to WR 20a. We plan to obtain spectra for them and measure their masses.

Introduction

Measuring accurate masses for the most massive stars in our Galaxy and beyond is important for constraining star formation and stellar evolution theories, which have indirect implications for many objects that are not well understood, such as supernovae, gamma-ray bursts and Population III stars. Some of the most massive candidates in the Milky Way are LBV 1806-20 (Eikenberry et al. 2004; Najarro 2004), the Pistol Star (Figer et al. 1998), and η Carinae (Davidson & Humphreys 1997), which have inferred masses up to $\sim 200$ $M_{\odot}$. However, the masses of these stars are only indirect estimates and thus have large uncertainties associated with them. The only direct way of measuring accurate masses of distant stars is in eclipsing binaries.

Until recently, the most massive stars ever weighed in binaries were: R136-38 (O3V+O6V) in the LMC with a primary mass of $56.9\pm0.6$ $M_{\odot}$ (Massey et al. 2002), WR 22 (WN7+abs + O), with a minimum primary mass of $55.3\pm7.3$ $M_{\odot}$ (Rauw et al. 1996; Schweickhardt et al. 1998), and Plaskett’s star with a minimum primary mass of $51$ $M_{\odot}$ (Baganulo et al. 1992). We present the light curve for WR 20a, the most massive binary measured accurately, and propose to measure fundamental parameters of similar massive binaries in the Local Group.
The New Heavyweight Champion WR 20a

The current champion of the most massive star competition is WR 20a, a Wolf-Rayet (WR) binary in the compact cluster Westerlund 2, which is located at the center of the HII region RCW 49. Rauw et al. (2004) obtained spectroscopy for WR 20a and measured extremely large minimum masses of $70.7 \pm 4.0$ and $68.8 \pm 3.8 \, M_\odot$ for the components. The final masses strongly depend on both the period and inclination of the binary, which can only be measured from the light curve. In May 2004, Bonanos et al. (2004) obtained $\textit{I}$–band observations of WR 20a with the OGLE team’s 1.3 m Warsaw telescope at Las Campanas Observatory, Chile, which is operated by the Carnegie Institute of Washington.

![Figure 1. Wilson-Devinney model fit of a near contact binary to the $\textit{I}$-band light curve of WR 20a. The period is 3.686 days, the eccentricity is 0 and the inclination angle $i = 74.5^\circ$.](image)

The first goal of our observations was to confirm the $\sim 4$ day spectroscopic period of the WR 20a binary and refine its value to 3.686 days, thus confirming the remarkable masses of its components. Next, we derived an inclination angle $i$ for the system from our well-sampled light curve. We fit the curve with the Wilson-Devinney (WD) code (Wilson & Devinney [1971], Wilson [1979], van Hamme & Wilson [2003]) for modeling distorted stars and derived a best fit inclination angle of $i = 74.5 \pm 2.0^\circ$. In Figure 1 we show the result of the $\textit{I}$–band light curve model fit for WR 20a. The uneven eclipse depths suggest slightly different effective temperatures and, thus, different spectral types for the components.

Armed with the refined period and the exact value of the inclination angle, we re-analyzed the radial velocity data of Rauw et al. (2004). Fixing the eccentricity to 0, as the light curve confirms, and the period to 3.686 days, we fit the radial velocity data applying equal weights and rejecting points with radial velocity measurements smaller than 80 km s$^{-1}$. We derive slightly larger velocity semi-amplitudes than Rauw et al. (2004), which in turn yield larger minimum masses and final masses of the components of $83.0 \pm 5.0 \, M_\odot$ and $82.0 \pm 5.0 \, M_\odot$. 


Massive Binaries in the Local Group

The DIRECT Project (e.g., Stanek et al. 1998, Bonanos et al. 2003) has found \( \sim 1000 \) variables in each of the galaxies M31 and M33, which include about 100 eclipsing binary systems. Follow up photometry was done with the 2.1m KPNO telescope in 1999 and 2001 on the best system, M33A, and the light curve is shown on the left panel of Figure 2 (A.Z. Bonanos et al. 2004, in preparation). We have obtained spectra with ESI on Keck II in November 2002 and September 2003 and the radial velocity curve is shown on the right panel of Figure 2.

![Figure 2](image)

Figure 2. Phased light curve and radial velocity curve of the detached binary M33A. Photometry was obtained by the 2.1 m at KPNO and spectroscopy with ESI on Keck II.

Analogs of WR 20a, possibly with even higher mass components, are bound to exist in M31 and M33. We have selected the brightest eclipsing binaries as massive binary candidates and plan to obtain spectroscopy to derive their radial velocity curves and, hence, masses. In addition to measuring their fundamental parameters, we will obtain a direct distance estimate. The advantage of studying eclipsing binaries in these galaxies would be their well known distances and low reddening.

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