Massive Stars as Cosmic Engines
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LBT Discovery of a Yellow Supergiant Eclipsing Binary in the Dwarf Galaxy Holmberg IX

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Abstract. In a variability survey of M81 using the Large Binocular Telescope we have discovered a peculiar eclipsing binary ($M_V \simeq -7.1$) in the field of the dwarf galaxy Holmberg IX. It has a period of 271 days and the light curve is well-fit by an overcontact model in which both stars are overflowing their Roche lobes. It is composed of two yellow supergiants ($V - I \simeq 1$ mag, $T_{\rm eff} = 4800$ K), rather than the far more common red or blue supergiants. Such systems must be rare. While we failed to find any similar systems in the literature, we did, however note a second example. The SMC F0 supergiant R47 is a bright ($M_V \simeq -7.5$) periodic variable whose All Sky Automated Survey (ASAS) light curve is well-fit as a contact binary with a 181 day period. We propose that these massive systems are the progenitors of supernovae like SN 2004et and SN 2006ov, which appeared to have yellow progenitors. The binary interactions (mass transfer, mass loss) limit the size of the supergiant to give it a higher surface temperature than an isolated star at the same core evolutionary stage.

Keywords. galaxies: individual (Holmberg IX) – binaries: eclipsing

1. Introduction

Although small in number, massive stars are critical to the formation and evolution of galaxies. They shape the ISM of galaxies through their strong winds and high UV fluxes, and are a major source of the heavy elements enriching the ISM (Massey 2003; Zinnecker & Yorke 2007). A large fraction of massive stars are found in binaries (e.g., Kiminki *et al.* 2007). Eclipsing binaries are of particular use because they allow us to determine the masses and radii of the components and the distance to the system. Many young, massive eclipsing binaries have been found and studied in our Galaxy, the LMC, and the SMC, primarily in OB associations and young star clusters (e.g., Bonanos *et al.* 2004; Peeples *et al.* 2007; Gonzalez *et al.* 2005; Hilditch *et al.* 2005). The study of massive eclipsing binaries beyond the Magellanic clouds has been limited until very recently, when variability searches using medium-sized telescopes with wide-field CCD cameras, coupled with spectroscopy using 8-meter class telescopes, have yielded the first systems with accurately measured masses in M31 (Ribas *et al.* 2005) and M33 (Bonanos *et al.* 2006).

We conducted a deep variability survey of M81 (distance ~ 3.6 Mpc; Freedman *et al.* 2001) and its dwarf irregular companion, Holmberg IX, using the Large Binocular Camera (LBC) mounted on the Large Binocular Telescope (LBT). Holmberg IX is a young dwarf galaxy (age $\leqslant 200$ Myr), with a stellar population dominated by blue and red supergiants with no signs of old stars in the red giant branch (Makarova *et al.* 2002). The dwarf may have formed during a recent tidal interaction between M81 and NGC 2976 (e.g.,

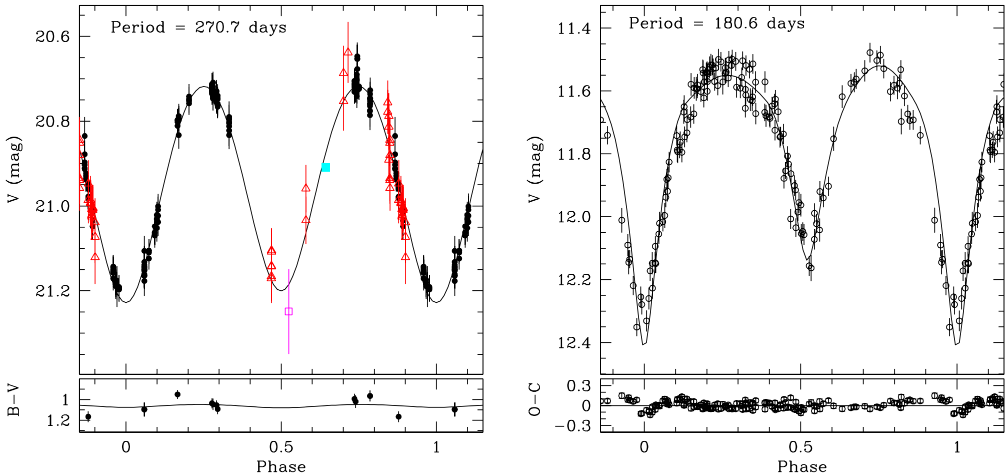

Figure 1. *Left:* V-band light curve (*top*) and $B-V$ color (*bottom*) of Holmberg IX V1. The data are from LBT (*filled bcircles*), MDM (*triangles*), SDSS (*square*) and HST ACS (*filled square*). The solid line is best-fit eclipsing binary model. *Right:* ASAS V-band light curve of the eclipsing binary SMC R47. The solid line shows the best-fit eclipsing binary model.

Boyce *et al.* 2001). The gas-phase metal abundance of Holmberg IX of between 1/8 and 1/3 solar (e.g., Miller 1995; Makarova *et al.* 2002) is consistent with this hypothesis (e.g., Weilbacher *et al.* 2003). A normal, isolated dwarf on the luminosity-metallicity relationship would have a metallicity of $\sim 1/20$ solar (Lee *et al.* 2006).

Here we report on the discovery of a 271 day period, evolved, massive eclipsing binary in Holmberg IX using data from the LBT. The overcontact system is the brightest periodic variable discovered in our LBT variability survey. It has an out-of-eclipse magnitude of $V_{max} = 20.7$ mag and is located at $\alpha = 09^{\rm h}57^{\rm m}37.14$, $\delta = +69°02'11''$ (J2000.0).

2. Observations

Holmberg IX was observed as part of a variability survey of the entire M81 galaxy conducted between January and October 2007 with the LBT 8.4-meter telescope, using the LBC-Blue CCD camera during Science Demonstration Time. The survey cadence and depth were optimized to detect and follow-up Cepheid variables with periods between 10-100 days (10% photometry at $V = 24$ mag). We discovered ~ 20 periodic variables in the dwarf, most of them Cepheids with periods between $10-60$ days. The light curve of the brightest periodic variable (hereafter V1) is well-fit by an eclipsing binary model with both stars overflowing their Roche lobes. Figure 1 shows the phased V-band light curve and $B-V$ color curve of the eclipsing binary system V1. We include LBT photometry, as well as contemporaneous photometry obtained with the MDM 2.4-meter telescope, and archival data obtained from SDSS and HST.

3. Massive Yellow Supergiant Binaries

The discovery of a 271 day period, luminous ($M_V \sim -7.1$), overcontact eclipsing binary system in our LBT survey of the dwarf galaxy Holmberg IX was unexpected. The colors of the binary V1 are consistent with an effective temperature of $T_{\rm eff} = 4800$ K. Given

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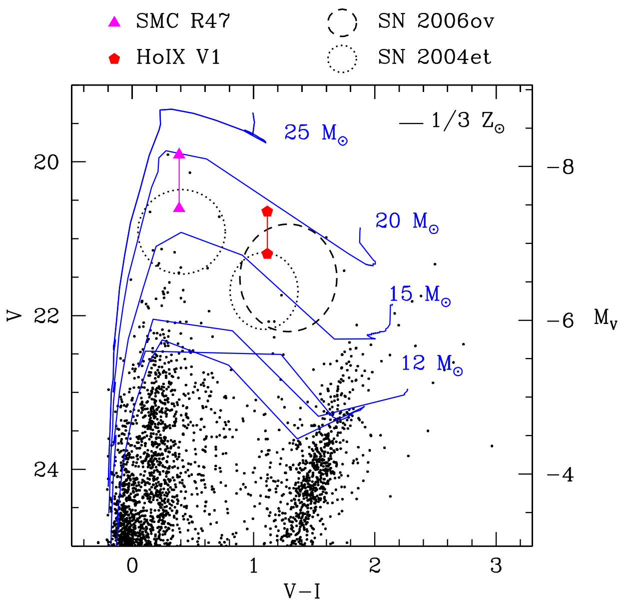

Figure 2. CMD with HST ACS photometry of Holmberg IX (*dots*) and the position at maximum and minimum of the yellow supergiant binaries: Holmberg IX V1 (*pentagons*) and SMC R47 (*triangles*) . The blue lines are Geneva evolutionary tracks for single stars (Lejeune & Schaerer 2001). The ellipses show error circles with the location of the progenitors of the type IIP supernovae 2004et (*dotted*) and 2006ov (*dashed*).

Table 1. Best-fit Binary Model Parameters.

Parameter	Holmberg IX V1	SMC R47
Period, P	270.7 ± 2.3 days	181.58 ± 0.16 days
Time of primary eclipse, $T_{\rm prim}$	2454186.0 ± 0.6	2452073.1 ± 0.2
Inclination, i	$55.7° \pm 0.6°$	$82.2° \pm 0.2°$
Primary temperature, T_1	4800 ± 150 K	7500 ± 100 K
Temperature ratio, T_2/T_1	1.05 ± 0.05	1.17 ± 0.02
Eccentricity, e	0.00	0.039 ± 0.002
Roche Lobe Filling factors	1.23 ± 0.02	1.02 ± 0.02

the absence of color variations and equal depths of the eclipses, both stars in the binary system are yellow supergiants.

We expected that such systems were rare†, but were surprised to find none in the literature. However, we found in the ASAS catalog of periodic variables (Pojmanski 2002) a luminous ($M_V \sim -7.5$ mag), 181 day period, contact eclipsing binary in the SMC (see Fig. 1). The star, SMC R47, had been spectroscopically classified as an F0 supergiant (Humphreys 1983). Table 1 gives the main parameters of the two long-period, yellow supergiant binaries, Holmberg IX V1 and SMC R47. From their position in the CMD (see Fig. 2), we estimate that at least one of the stars in each binary is $15-20\,{\rm M}_\odot$ (main sequence age $\sim 10-15$ Myr).

† While the relative numbers of eclipsing binaries is a much more complicated problem, we note that the relative abundances of red, blue and yellow supergiants is 4:13:1 for the Geneva evolutionary track of a single, non-rotating star with $M = 15\,{\rm M}_\odot$ and $Z = 0.004$.

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4. Supernova Progenitors?

The stellar evolutionary path of stars of a given mass in binary systems can differ significantly from their evolution in isolation (Paczynski 1971). In particular, binary interactions through mass loss, mass accretion, or common-envelope evolution, play a very important role in the pre-supernova evolution (e.g., Podsiadlowski *et al.* 1992). Most of the massive stars with masses $30\,\mathrm{M}_{\odot} \geqslant M \geqslant 8\,\mathrm{M}_{\odot}$ are expected to explode as supernova when they are in the red supergiant phase, with a small contribution from blue supergiants (e.g., 1987A; West *et al.* 1987). Surprisingly, Li *et al.* (2005) identified the progenitor of the Type IIP supernova 2004et in pre-explosion archival images and determined that it was a yellow supergiant with a main-sequence mass of $\sim 15\,\mathrm{M}_{\odot}$. Also, the position in the CMD of the likely progenitor of the Type IIP supernova 2006ov (Li *et al.* 2007) is remarkably similar to the position of the eclipsing binary in Holmberg IX.

We propose that the binaries we discovered in Holmberg IX and the binary found in the SMC are possible progenitors for these supernovae. A close binary provides a natural means of slowing the transition from blue to red, allowing the star to evolve and then explode as a yellow supergiant. As the more massive star evolves and expands, the Roche lobe limits the size of the star, forcing it to have a surface temperature set by the uncoupled core luminosity and the size of the Roche lobe. It can expand further and have a cooler envelope only by becoming a common envelope system, which should only occur as the secondary evolves to fill its Roche lobe. This delayed temperature evolution allows the core to reach SN II conditions without a red envelope.

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References

Bonanos, A. Z., Stanek, K. Z., Udalski, A. *et al.* 2004, *ApJ*, 611, L33
Bonanos, A. Z., Stanek, K. Z., Kudritzki, R.-P. *et al.* 2006, *ApJ*, 652, 313
Boyce, P. J., Minchin R. F., Kilborn, V. A. *et al.* 2001, *ApJ*, 560, L127
Freedman, W. L., Madore, B. F., Gibson, B. K. *et al.* 2001, *ApJ*, 553, 47
González, J. F., Ostriov, P., Morrell, N., & Minnitim, D. 2005, *ApJ*, 624, 946
Hilditch, R. W., Howarth, I. D., & Harries, T. J. 2005, *MNRAS*, 357, 304
Humphreys, R. M. 1983, *ApJ*, 265, 176
Kiminki, D. C., Kobulnicky, H. A., Kinemuchi, K. *et al.* 2007, *ApJ*, 664, 1102
Lee, H., Skillman, E. D., Cannon, J. M. *et al.* 2006, *ApJ*, 647, 970
Lejeune, T., & Schaerer, D. 2001, *A&A*, 366, 538
Li, W., Van Dyk, S. D., Filippenko, A. V. & Cuillandre, J.-C., 2005, *PASP*, 117, 121
Li, W., Wang, X., Van Dyk, S. D. *et al.* 2007, *ApJ*, 661, 1013
Makarova, L. N., Grebel, E. K., Karachentsev, I. D. *et al.* 2002, *A&A*, 396, 473
Massey, P. 2003, *ARA&A*, 41, 15
Miller, B. W. 1995, *ApJ*, 446, L75
Paczyński, B. 1971, *ARA&A*, 9, 183
Peeples, M. S., Bonanos, A. Z., DePoy, D. L. *et al.* 2007, *ApJ*, 654, L61
Podsiadlowski, P., Joss, P. C., & Hsu, J. J. L. 1992, *ApJ*, 391, 246
Pojmanski, G. 2002, *AcA*, 52, 397
Ribas, I., Jordi, C., Vilardell, F. *et al.* 2005, *ApJ*, 635, L37
Weilbacher, P. M., Duc, P.-A. & Fritze-v. Alvensleben, U. 2003, *A&A*, 397, 545
West, R. M., Lauberts, A., Schuster, H.-E. & Jorgensen, H. E. 1987, *A&A*, 177, L1
Zinnecker, H. & Yorke, H. W. 2007, *ARA&A*, 45, 481

Jose Prieto (right) with Kris Stanek (left).

Lucy Hadfield.

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From left to right: Miguel Urbaneja, Norbert Przybilla, Artemio Herrero, Ignacio Negueruela and Cesar Esteban.

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