Fundamental Stellar Parameters of a Binary Blue Straggler (V6) in the Globular Cluster NGC 3201

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Abstract / Introduction: Blue stragglers trace the main sequence past the turn-off point toward the blue and luminous region in the color-magnitude diagram of globular clusters (GCs). Thus, they appear to be part of a younger population with initial masses higher than the turn-off mass of the globular cluster. However, practically no evidence exists for significant age spreads among stars in GCs. The nature and formation mechanisms of the blue straggler population in open and globular clusters is still not fully understood. Commonly proposed theories attempting to explain their high surface temperatures include mass transfer between binary components, the coalescence or merger of two stars in a high-density stellar environment, or a dredge-up of hot material from lower layers in a star's atmosphere due to the gravitational interaction between binary components. To date, only one direct mass determination of a binary blue straggler inside a GC exists (Kaluzny et al. 2007).

Photometry

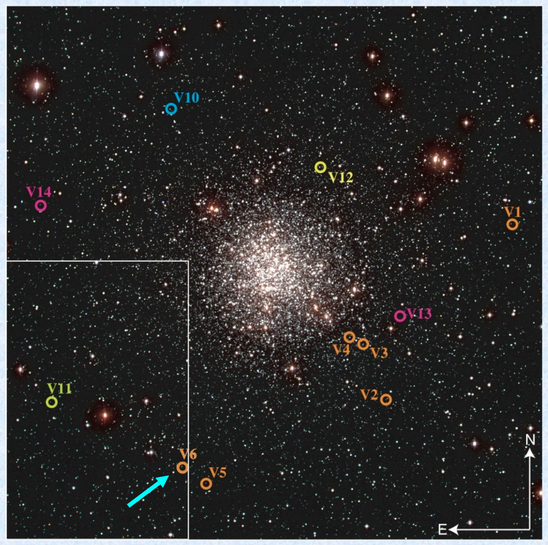

Fig. 1: V6 was discovered as one of the variables in the survey of von Braun & Mateo (2001, 2002) of the southern GC NGC 3201. This figure shows the location of the variable stars in the field. V6 is to the south east of the cluster center. The colors of the variable stars indicate their type (orange = EW contact binaries). The bulk of the photometry data was obtained using the Las Campanas 1m Telescope during 1996, 1997, and 1998, with additional coverage of an adjacent field using the CTIO 0.9m Telescope in 2001. The overlap between the LCO and CTIO fields is indicated by the white lines in the south east quadrant of the field.

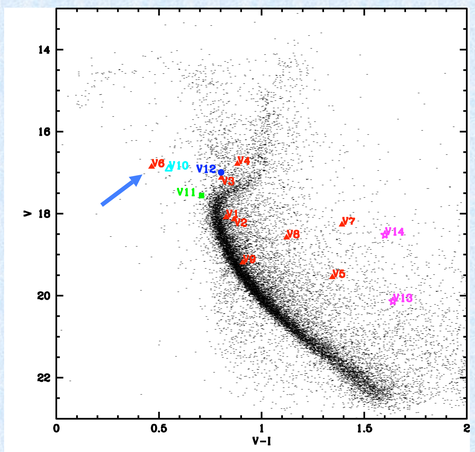

Fig. 2: The locations of the variables in the color-magnitude diagram of the cluster. V6 is in the blue straggler region (see arrow).

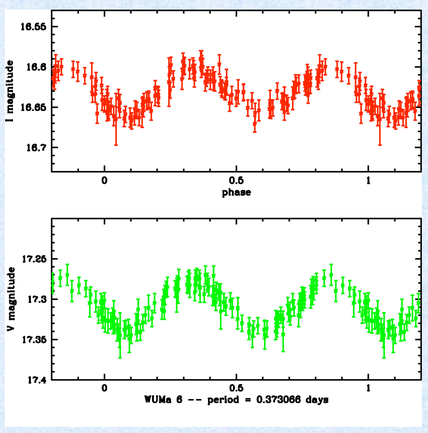

Fig. 3: The photometric light curve of V6 in the *V* (bottom) and *I* (top) bands. The period is 0.37307 days, phase is arbitrary.

Spectroscopy

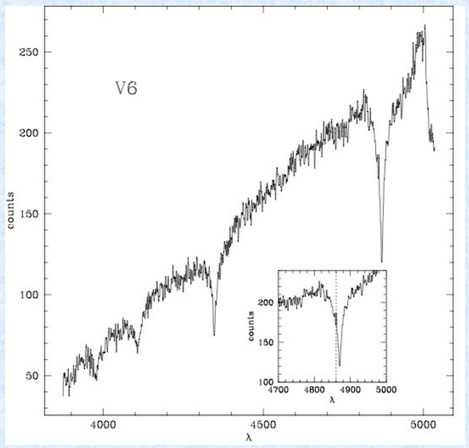

Fig. 4: Though estimates concerning cluster membership of variable stars can be made based on location in the field of view or color-magnitude diagram, the final verdict must be based on a comparison between systemic velocities of the cluster (NGC 3201: ~500 km/s) and the star. Of all the variables shown in **Figures 1 and 2**, only V6 proved to be associated with the cluster, based on Doppler redshift (shown here for Hβ).

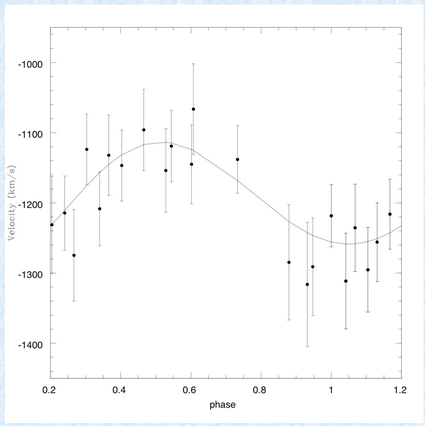

Fig. 5: Using the CTIO 4m Telescope, we obtained radial velocity (RV) data for V6 at moderate resolution (R~4000), fighting clouds and technical problems. These data allowed us to only extract velocities for only one of the two components, shown in this figure with an arbitrary velocity zero point. The overlain fit is a sine curve (i.e., not a physical fit), phased to V6's period of 0.37307 days. We estimate the semi-velocity amplitude to be ~75 km/s.

V6 Observables

- RA(2000) = 10:17:59.1
- Dec (2000) = -46:33:25.7
- systemic velocity = 500 km/s
- V_{bright} = 17.270(13)
- I_{bright} = 16.599(19)
- E_{V-I} = 0.366
- $(V-I)_o$ = 0.305
- period = 0.37307(39) days
- amplitude $\Delta V \sim \Delta I \sim 0.06$
- K1 ~ 75 km/s
- **[Fe/H] = -1.42 (NGC 3201)**
- **distance = 4.5 kpc (NGC 3201)**

Notes:
- Data from Gonzalez & Wallerstein (1998); von Braun & Mateo (2002).
- Values in parentheses indicate uncertainties in the last two digits.
- Parameters in **blue** are for NGC 3201.

V6 System Parameters

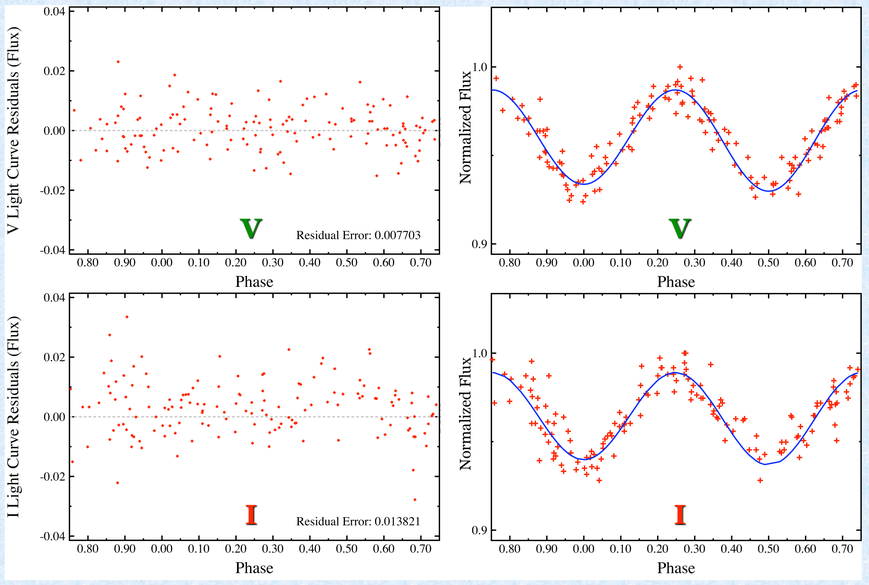

Fig. 6: Using Binary Maker 3 (Bradstreet 2003), we obtained simultaneous best fits to the *V* and *I* light curves as shown above (along with the residuals around the fit). The light curves are rescaled to normalized flux and phased such that the primary eclipse occurs at phase angle 0.0.

$q = M_1/M_2$	0.80	(fixed)
eccentricity	0.0	(fixed)
T1	7500 K	Worthey & Lee 2006
T2	8000 K	
inclination angle	27 deg	
L_1/L_2	0.97 (*V*) / 1.04 (*I*)	
Ω_1	3.304	
reflection coefficients	R1 = R2 = 0.5	L3 = 0 (no third light)
gravity coefficients	G1 = G2 = 1.0	
fillout factors	F1 = F2 = 0.25	
limb darkening (*V*)	X1 = 0.47 / X2 = 0.51	
limb darkening (*I*)	X1 = 0.29 / X2 = 0.35	
mean radii (solar units)	$R_1 \sim 1.15$ / $R_2 \sim 1.04$	from K1~75 km/s
masses (solar units)	$M_1 \sim 1.11$ / $M_2 \sim 0.89$	from K1~75 km/s
additionally set	no spots, no disk	synchronous rotation

Table 1: Preliminary results for V6 system parameters from the Binary Maker 3 fit to V6's light curves and the assumption that K1~75 km/s (**Fig. 5**). We will improve on these results by (1) performing a rigorous multiparameter X^2 minimization, and (2) taking into consideration the results from our ongoing analysis of Magellan high-resolution spectral data of V6's RV curve.

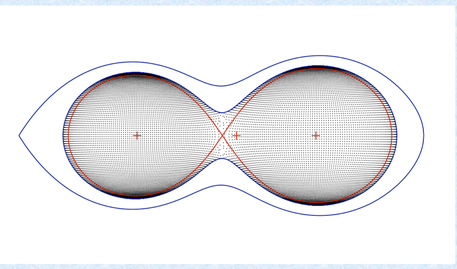

Fig. 7: This Figure shows the potential surfaces of the blue straggler system. The blue and red lines represent the outer and inner Roche lobe, respectively. The crosses indicate the locations of the centers of mass of the two components as well as the barycenter of the system. V6 is an overcontact system in which both components overfill their Roche lobes.

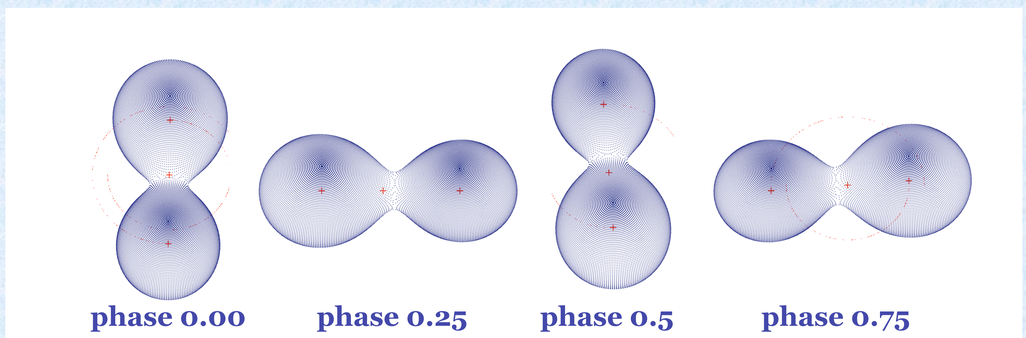

Fig. 8: This figure shows the system geometry seen along the line of sight at various phase angles. The crosses indicate the locations of the centers of mass of the two components as well as the barycenter of the system. Based on our fit, the photometric variations are not caused by eclipses, but instead are due to projection effects alone.

References

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