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VARIABLE STARS IN THE SMC STAR CLUSTER BRÜCK 50

SCHMIDTKE, P.C.[1]; UDALSKI, A.[2]

[1] School of Earth and Space Exploration, Arizona State University, Box 871404, Tempe, Arizona 85287 USA
E-mail: Paul.Schmidtke@asu.edu

[2] Warsaw University Observatory, Aleje Ujazdowskie 4, 00-478 Warsaw, Poland
E-mail: Udalski@astrouw.edu.pl

Brück 50 (RA $00^{\rm h}49^{\rm m}02^{\rm s}$, DEC $-73°21'44''$, J2000) is a young, compact star cluster in the Small Magellanic Cloud (Brück 1976). The blue supergiant HD 4862 lies 5.2″ from the cluster's center and is likely to be a cluster member. Lennon (1997) classified this star as B5 Ia, taking into account the low metallicity of the SMC. Bica & Schmitt (1995) determined the cluster's position and angular size ($r_{\rm cls}$=16.5″) that we adopt. This size, which corresponds to a radius of ∼5 pc at the SMC's distance, is comparable to many cluster candidates (e.g. Pietrzyński et al. 1998). Brück 50 is one of a close triplet of SMC clusters (de Oliveira et al. 2000), the other clusters being BS 41 (which lies 38″ away) and L39 (77″ away). Some authors question whether Brück 50 should be considered an individual cluster or simply a portion of a more extensive grouping. For example, Oey, King, & Parker (2004), in a study of the clustering of OB stars, include several early-type stars associated with Brück 50 into a much larger structure (see their OB group #73). From a color-magnitude diagram (CMD) analysis of OGLE-II photometry, de Oliveira et al. (2000) estimated the age of Brück 50 to be <30 Myr. Using a low-resolution integrated spectrum, Talavera et al. (2007) derived a cluster age of 4±2 Myr, a result that is likely influenced by the brightness of HD 4862. Glatt, Grebel, & Koch (2010), fitting Padova and Geneva isochrone models to CMD data from the Magellanic Cloud Photometric Survey, determined an age of ∼10 Myr.

Young SMC star clusters like Brück 50 often contain a high proportion of hot stars that are photometrically variable. Schmidtke, Chobanian, & Cowley (2008) found low-amplitude short-period pulsations in OGLE-II photometry for >20% of hot stars in NGC 330, a cluster noted for its large population of Be stars. The percentage of pulsators in NGC 330 was even greater for previously known Be stars. Similarly, in a study of MACHO observations for a sample of spectroscopically selected stars in the SMC, Diago et al. (2008) found that 4.9% (9 out of 183) of B stars and 25.3% (32 out of 126) of Be stars were pulsating variables.

We present here an analysis of 12 seasons of OGLE photometry (Udalski, A., Kubiak, M., & Szymański 1997; Udalski et al. 2008a) for Brück 50, obtained between 1997 and 2009. The cluster is in field SMC_SC5 of Phase II and field SMC100.8 of Phase III. An I-band finding chart is shown in Fig. 1. The small change in background sky level for the bottom 1/3 of this reference image corresponds to a boundary between subframes of OGLE-III data processing. The inner circle marks the cluster radius from Bica & Schmitt

(1995), while the outer circle ($r_{\rm lim}$=30″) encloses all stars that we examined in detail. HD 4862 is too bright for inclusion in OGLE data bases, and its brightness masks other nearby stars. For example, the star that lies ∼2″ southeast of HD 4862 is not included, despite being resolved on the chart. In the OGLE-III photometric maps (Udalski et al. 2008b), data are available for 118 stars with $r<r_{\rm cls}$ and an additional 224 stars with $r_{\rm cls}<r<r_{\rm lim}$. The OGLE-II maps (Udalski et al. 1998) are not as deep and have poorer spatial resolution. Hence, the corresponding numbers are 72 and 194 stars, respectively.

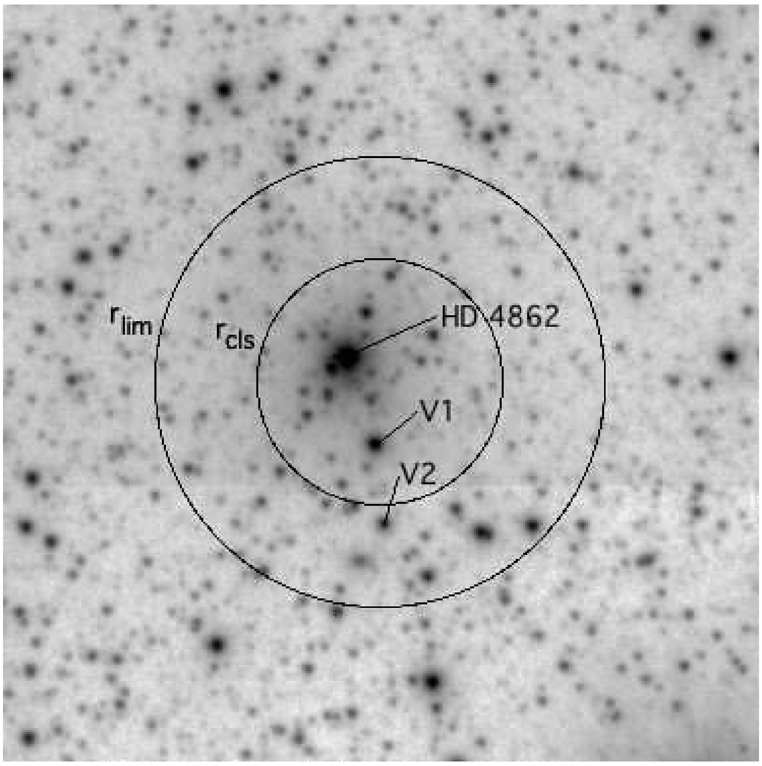

Figure 1. *I*-band finding chart for Brück 50. The field of view is 100″×100″, with north up and east to the left. The inner and outer circles identify $r_{\rm cls}$=16.5″ and $r_{\rm lim}$=30″, respectively. The blue supergiant HD 4862 and variable stars V1 and V2 are marked.

The stellar density (unweighted by brightness) of background stars in the direction of Brück 50 is high, complicating the assessment of membership for individual stars. Using a measurement of stellar density in an annulus surrounding $r_{\rm cls}$, we estimated the surplus of stars within the cluster radius. Only 17.8% (21 out of 118) of stars in the OGLE-III photometric maps with $r<r_{\rm cls}$ are expected to be true members of the cluster. Fitting a Gaussian profile to the spatial distribution of stars, we determined the FWHM to be 17.2″, which is consistent with the cluster size found by Bica and Schmitt (1995).

A CMD of V and I data for Brück 50 from the OGLE-III photometric maps is shown in Fig. 2. Stars in the upper left portion of the diagram often exhibit short-period, low-amplitude pulsations (e.g. see Balona 2010; Kołaczkowski et al. 2006; Moffat 2012). The dashed line at I=18.2 corresponds to the expected brightness of a B5 V star at the distance of and with an extinction appropriate for the SMC. None of the bright, cool stars in the figure can be a member of this young cluster.

A plot of σ_I vs. I from OGLE-III data for Brück 50 is shown in Fig. 3. At faint magnitudes there is an excess of stars with larger-than-expected photometric dispersion.

However, most stars with high σ_I lie within the cluster radius, while only a few are found outside $r_{\rm cls}$. This implies that a lack of consistent spatial resolution of stars near the cluster's core, rather than photometric variability, produces most of the scatter for faint stars in the diagram. Even among bright stars there are some with moderately large σ_I that turned out to be photometric blends.

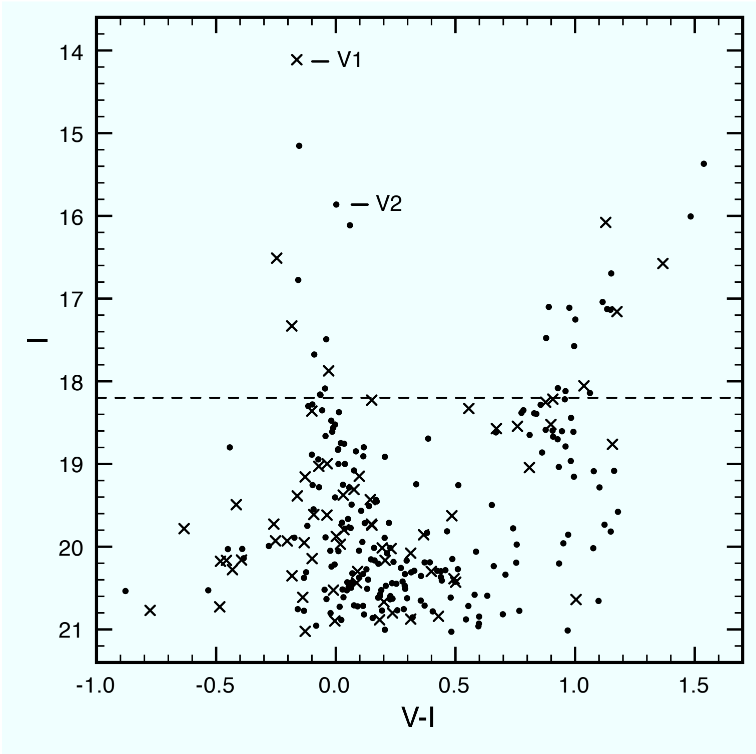

Figure 2. I vs. $V-I$ CMD from OGLE-III data for stars in Brück 50. Stars brighter than I=18.2 (the dashed line) were analyzed for photometric variability. Two variable stars were found. Crosses (×) represent stars within the cluster radius ($r_{\rm cls}$=16.5″), while filled circles (•) denote stars lying outside this boundary.

Table 1. Variable Stars in Brück 50

ID	RA[a] (J2000)	DEC[a] (J2000)	I^a (mag)	$V-I^a$ (mag)	GCVS Type	P (days)	Other IDs
V1	0:49:02.10	−73:21:52.3	14.112	−0.163	ELL	7.28417	SMC100.8 #45085 (OGLE-III) SMC_SC5 #16232 (OGLE-II)
V2	0:49:01.82	−73:22:02.8	15.863	0.002	BE	...	SMC100.8 #14736 (OGLE-III) SMC_SC5 #16286 (OGLE-II) [MA93] #277[b]

[a]From OGLE-III photometric maps of the SMC (Udalski et al. 2008)
[b]From Meyssonnier & Azzopardi (1993)

We selected all stars brighter than I=18.2 in the OGLE-III photometry maps, regardless of color, for further study. These stars were matched with their corresponding OGLE-II entries by position and magnitude. There are ∼340 and ∼720 I measurements for each star in the OGLE-II and -III data bases, respectively. After elimination of obviously discordant data points, spurious periodic signals were removed by subtracting low-order polynomial fits from short segments of data, typically on a season by season basis. These pre-whitened observations are hereafter identified by the notation I^*.

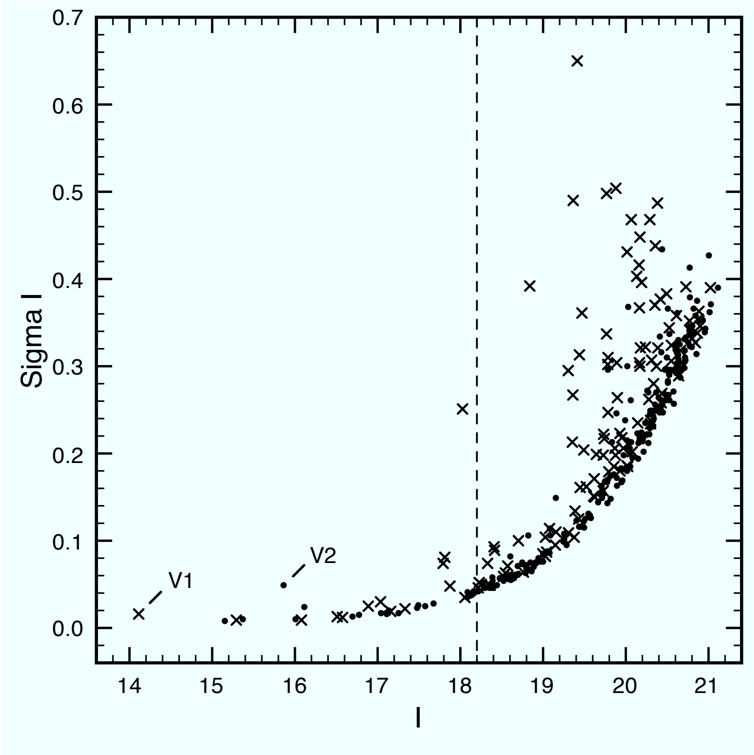

Figure 3. σ_I vs. I from OGLE-III data for stars in Brück 50. Stars brighter than I=18.2 (the dashed line) were analyzed for photometric variability. Two variable stars were found. Crosses (×) represent stars within the cluster radius ($r_{\rm cls}$=16.5″), while filled circles (•) denote stars lying outside this boundary.

The search for periodicities in I^* data used two techniques: periodogram analysis (Horne & Baliunas 1986) and, in the case of non-sinusoidal signals, phase dispersion minimization (Stellingwerf 1978). The period search covered frequencies in the range 0-20 day^{-1}, which is appropriate for the identification of orbital systems as well as pulsating B/Be stars. OGLE-II and -III data were analyzed separately and then combined if a common signal was present. An upper limit to a full-amplitude sine wave was estimated if no relevant signal could be identified. These limits depend on mean brightness, with typical values near 0.006, 0.012, and 0.018 mag for unblended OGLE-III stars with I ∼16, 17, and 18, respectively. The limits are slightly higher for OGLE-II data.

Only two stars in the direction of Brück 50 show meaningful photometric variations. The results are summarized in Table 1, and individual sources are discussed below. We note that no short-period pulsating variables are present in the cluster, a result that may be related to age. Other SMC clusters with a large population of pulsating variables (e.g. NGC 330) are thought to be slightly older.

Comments on individual sources.

V1: Except for HD 4862, for which no OGLE data are available, V1 is the brightest star in the sample. It lies well inside $r_{\rm cls}$ and is likely to be a member of the cluster. Periodogram analysis of OGLE-II and -III data revealed a very strong signal with P ∼3.64

days. However, when folded on this period, it was obvious that two minima with different depths were present. A revised period of 7.28417±0.00012 days, approximately double the original value, was determined using phase dispersion minimization. The folded I^* light curve, with an overall amplitude of ∼0.08 mag, is shown in Fig. 4. In addition to unequal depths of minima, the curve has two maxima of different heights and widths, which are not symmetrically spaced in phase. The adopted value of T_0 is HJD 2453000.97±0.07 and comes from the best-fit sine wave of the initial periodogram analysis. Hence, in the figure there is a small offset between phase zero and the phase of deepest minimum.

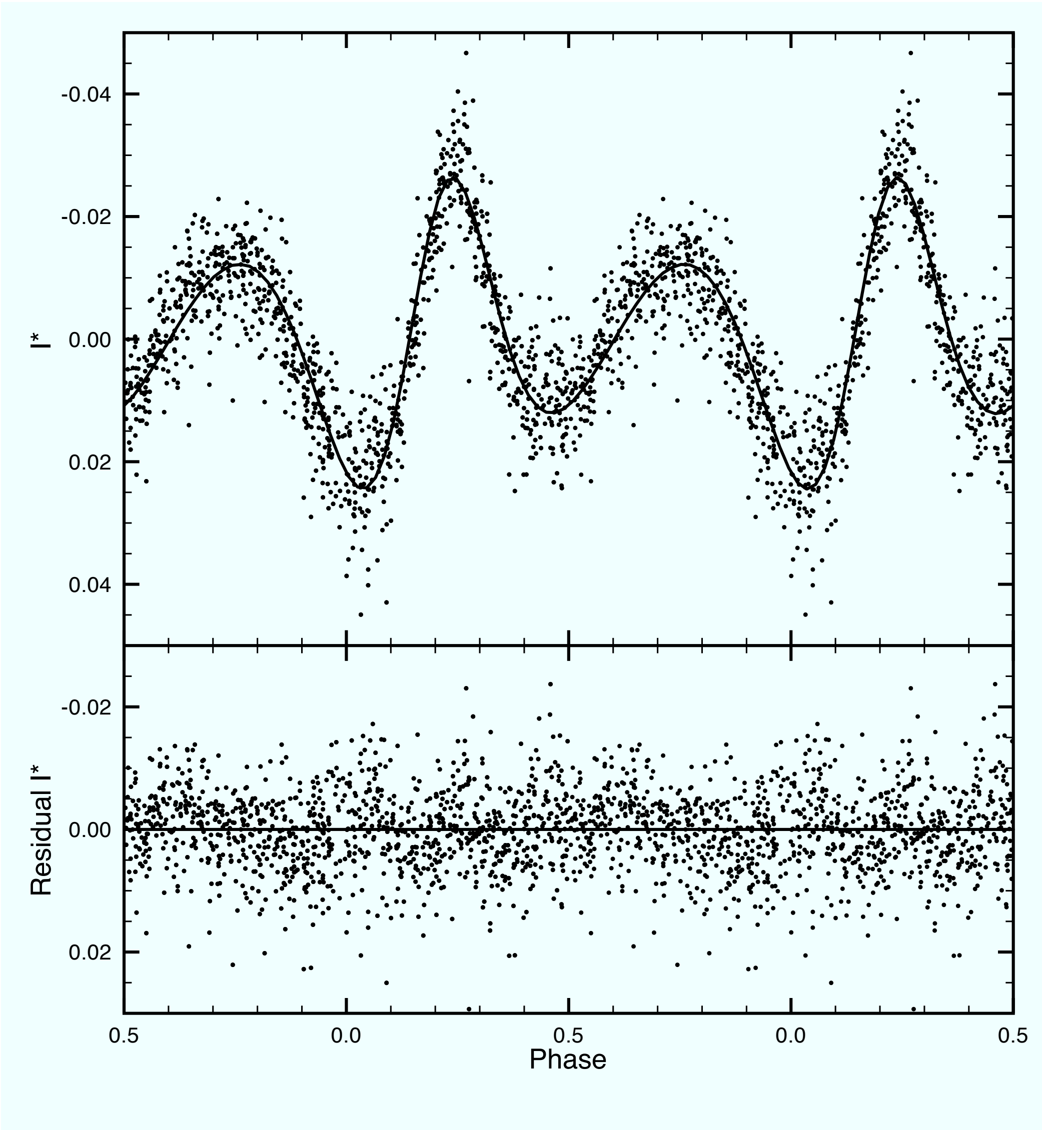

Figure 4. *I* light curve from OGLE-II and -III observations for star V1 of Brück 50. Top: Detrended data folded on the 7.28417-day photometric period, with the fitted model superimposed. Two cycles are shown for clarity. Bottom panel: Residuals between the observed light curve and fitted model. See text.

The light curve for V1 was modeled using version 0.31a of PHOEBE (Prša & Zwitter 2005), a convenient interface to the Wilson-Devinney code (Wilson & Devinney 1971). There are, however, only a few constraints from which to start the modeling process. Our working hypothesis is that of a detached binary system composed of a pair of early-type (OB) stars, but little is known about the temperature of either component. The observed color is not a good discriminant for a combination of hot stars, and no spectrum is available to define the spectral type(s). The adopted temperature of the primary star was set at T_1=26000 K. The gravity darkening and albedo coefficients were fixed at values appropriate for radiative envelopes, i.e., g=1.0 and A=1.0. Limb darkening coefficients were estimated via interpolation of the van Hamme (1993) tables.

The orbital inclination must be great enough to reveal ellipsoidal variations of the tidally distorted components but not so large as to produce eclipses. In initial models, both i and the mass ratio q (=M_2/M_1) were adjusted until the depths of minimum matched the observed light curve. These parameters were then fixed at i=51.5° and q=1.175 for all subsequent calculations. Spectroscopic observations are needed to confirm the value for q. At this stage of the modeling process, fitted values were obtained for the semimajor axis (a), temperature of the secondary star (T_2), and surface potential of each component (ψ_1, ψ_2).

In the remaining step, the model was expanded to include the orbital eccentricity (e) and longitude of periastron (ω). These two parameters are needed to account for the observed heights, widths, and phasing of maxima. Because e and ω are highly correlated, one of them must be fixed in the final solution. We tested a set of models with a range of values for e. Satisfactory fits were produced for $0.07 \leq e \leq 0.10$. No stable solution was found for an eccentricity >0.10. We note that these values for e are consistent with those found in many short-period B-type spectroscopic binaries (see the summary by Abt 2005). Adopting e=0.10, a final solution with five fitting parameters was obtained. Our provisional results are listed in Table 2 and plotted in Fig. 4. The stellar sizes and gravities given in the table are calculated quantities that represent the equivalent values for spherical stars that have the same volume as the tidally distorted ones.

The modeled light curve is a good match to the observations at both minima and near the fainter maximum, but there are systematic errors at other phases. For example, neither the height of the narrow sharp peak of brighter maximum nor the rise to fainter maximum is well matched. These deficiencies likely occur due to changing shapes of the Roche potentials in an eccentric orbit. At periastron, the primary star must be close to filling its lobe, resulting in a temporary state of mass transfer and accounting for $M_2 > M_1$. Hence, there is a limiting value for e in stable solutions. The alternation between detached and semi-detached condition is a very difficult configuration to model, since lobe-filling binaries normally require the assumption of circular orbits. A series of spectra taken near periastron may help clarify our interpretation of this interesting binary system.

Table 2. Provisional Light Curve Parameters for Star V1

Fixed Parameters		Fitted Parameters		Calculated Parameters	
P	7.28417 d	a	48.34±0.03 $R_\odot$	M_1	13.17 $M_\odot$
T_1	26000 K	T_2	20040±120 K	M_2	15.48 $M_\odot$
$q=M_2/M_1$	1.175	ψ_1	5.13±0.04	R_1	12.84 $R_\odot$
i	51.5°	ψ_2	7.31±0.03	R_2	9.07 $R_\odot$
e	0.10	ω	2.80±0.01 rad	$\log g_1$	3.34
				$\log g_2$	3.71

V2: This is a known emission-line star, [MA93] #277 (Meyssonnier & Azzopardi 1993). Because it lies just outside of $r_{\rm cls}$, cluster membership is uncertain. The OGLE light curve, spanning 12 years of observations, is shown in Fig. 5. The erratic variations are consistent with those of Type-1 Be stars described by Mennickent et al. (2002). The smoothest data segments were detrended and searched for periodicities. No coherent signal was found.

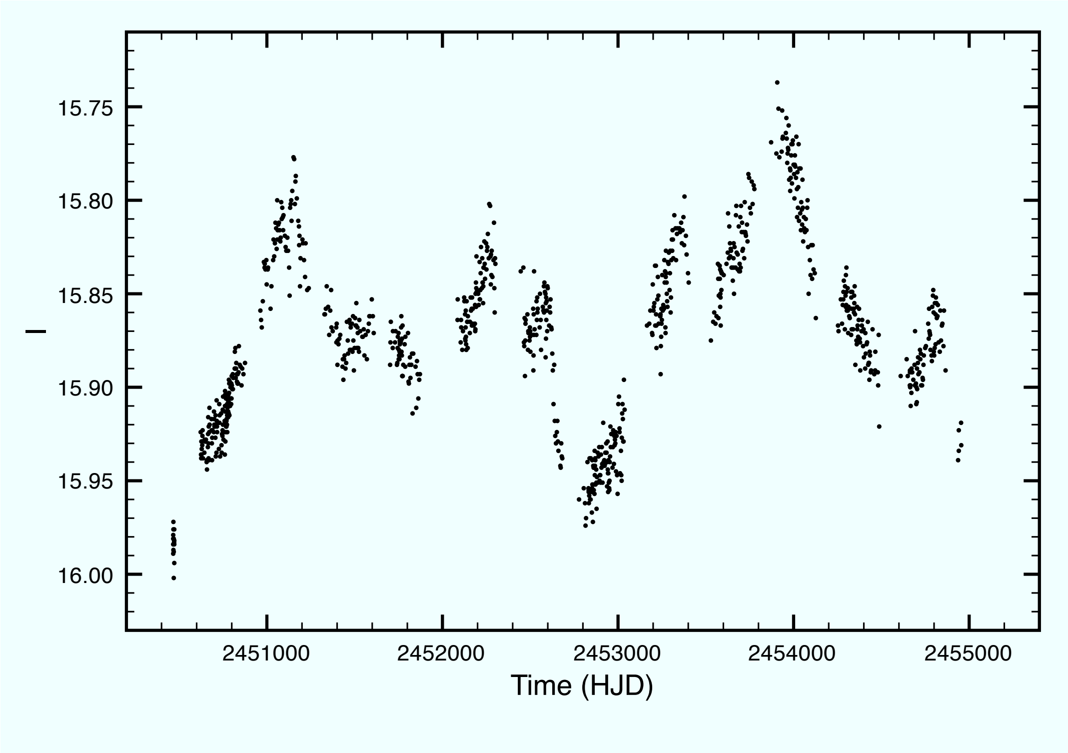

Figure 5. *I* light curve from OGLE-II and -III observations for star V2 of Brück 50.

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