MILLIMAGNITUDE PHOTOMETRY FOR TRANSITING EXTRASOLAR PLANETARY CANDIDATES. IV. SOLUTION TO THE PUZZLE OF THE EXTREMELY RED OGLE-TR-82 PRIMARY

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ABSTRACT

We present precise new $V$, $I$, and $K_s$-band photometry for the planetary-transit candidate star OGLE-TR-82. $V$-band images acquired in good seeing with the VIMOS instrument at the Very Large Telescope allowed us to measure $V = 20.61 \pm 0.03$ mag for this star despite the presence of a brighter neighbor about 1' away. This faint magnitude answers the question why it has not been possible to measure radial velocities for this object. One transit of this star has been observed with the GMOS-S instrument on Gemini South in the $i$ and $g$ bands, which allowed us to verify that this is not a false positive, to confirm the transit amplitude measured by OGLE, and to improve the ephemeris. The transit is better defined in the $i$-band light curve (with a depth of $A_i = 0.034$ mag), than in the $g$ band ($A_g = 0.1$ mag), in which the star is significantly fainter. Near-IR photometry obtained with the SOFI array at the ESO New Technology Telescope yields $K = 12.20 \pm 0.10$ and $V-K = 8.40 \pm 0.10$, so red that it is unlike any transit candidate studied before. With the new data, we consider two possible configurations for the system: (1) a nearby M7 V star or (2) a blend with a very reddened, distant red giant. The first hypothesis would give a radius for the companion of $R_p = 0.3 \pm 0.1 R_J$, i.e., the size of Neptune. Quantitative analysis of near-IR spectroscopy finally shows that OGLE-TR-82 is a distant, reddened, metal-poor early K giant, confirmed by direct comparison with stellar templates, which gives as a best match a K3 III star. Therefore, we rule out a planetary nature for the companion, and conclude that this system is a main-sequence binary blended with a background red giant. As a case study, a system that can so mimic a planetary transit presents a lesson for future transit surveys.

Subject headings: planets and satellites: formation — stars: individual (OGLE-TR-82)

Online material: color figures

1. INTRODUCTION

Because low-mass stars are the most numerous in our Galaxy, they provide, despite their dimness, an exciting possibility to detect transits of planets much smaller than Jupiter. This has been pointed out by many authors (e.g., Pepper & Gaudi 2006). The known planets in the solar neighborhood exhibit a very steep mass function: low-mass planets are much more common around solar-type stars than are high-mass planets (Butler et al. 2006). Even though low-mass planets are more difficult to detect than Jupiters, there have been a few recent discoveries of “Neptunes” or “super-Earths” around low-mass stars (McArthur et al. 2004; Butler et al. 2004; Santos et al. 2004; Bonfils et al. 2005; Lovis et al. 2006; Beaulieu et al. 2006; Gould et al. 2006).

More recently, Sahu et al. (2006) found a number of planetary candidates around low-mass stars in a bulge field. The search for planets is being extended into a new realm: M dwarfs are the most numerous stars in the Galaxy, and transiting planets around such stars open a wealth of new possibilities for ground- and space-based planet searches. The transit candidate OGLE-TR-82 (Udalski et al. 2002a) appears to be an extreme case that is important to study in the context of future transit discoveries made by space missions such as Kepler and COROT. We note that there has been progress on the models triggered by these observational discoveries as well. For example, the formation of Neptunes and super-Earths has been studied recently by Baraffe et al. (2005, 2006), Kennedy et al. (2006), and Alibert et al. (2006).

The search by the Optical Gravitational Lensing Experiment (OGLE) has provided the largest list of transit candidates (Udalski et al. 2002a, 2002b, 2002c, 2003). In particular, Udalski et al. (2002a) discovered very low amplitude transits in the $I = 16.30$ mag star OGLE-TR-82, located in the Carina region of the Milky Way disk, at R.A. = $10^\text{h}58^\text{m}03.07^\text{s}$, decl. = $-61^\circ34'25.8''$ (J2000). They monitored 22 individual transits of this star, measuring an amplitude $A_I = 0.034$ mag and a period $P = 0.76416$ days. They listed $R_p = 1.09 R_J$, making this a prime hot-Jupiter candidate. Recently, Silva & Cruz (2006) obtained $M_p = 0.65 M_J$ and $R_p = 1.10 R_J$, also singling out OGLE-TR-82b as a possible planetary companion. We have followed up OGLE candidates with infrared and optical photometry, with the aim of identifying and characterizing planetary companions to low-mass stars (Gallardo et al. 2005; Fernández et al. 2006; Díaz et al. 2007).
M dwarfs with hot Jupiters should stand out in a diagram of period versus color as objects with short periods and very red colors. Early in our program, it was recognized that OGLE-TR-82 is a very interesting candidate. For example, Figure 1 shows the OGLE periods versus $I-K$ colors for several candidates observed in the Carina fields. OGLE-TR-82 is clearly unique in this sample: it is a very red and faint object, according to both the Two Micron All Sky Survey (2MASS) and our own photometry. The colors are consistent with those of a very late M dwarf, for which the low-amplitude transits would imply a very small companion. We then intensively followed up this candidate. However, acquiring the complementary data to characterize OGLE-TR-82 and its companion has proved difficult, as a result of the extreme nature of this object.

Pont et al. (2004) observed this candidate with UVES and FLAMES at the ESO Very Large Telescope (VLT), arguing that it was possibly a K7–M0 V star. They obtained precise velocity measurements for several OGLE targets, discovering three planets in their sample, but they could find no cross-correlation function (CCF) signal for OGLE-TR-82, concluding that this was an unsolved case. Why is there no signal for this object? In this paper, we answer this question using optical and infrared photometric data acquired at Gemini Observatory, the VLT, and the ESO New Technology Telescope (NTT).

Future space missions such as COROT and Kepler should discover many faint transit candidates, which will need to be followed up and confirmed. The most fundamental follow-up observation is echelle spectroscopy, in order to measure radial velocities and derive the companion masses. However, in some special cases optical echelle spectroscopy will not work. OGLE-TR-82 is one example, and it provides an interesting case study.

After a thorough follow-up study, in this paper we rule out the planetary nature of OGLE-TR-82, concluding that it is a blend with a reddened, distant giant. Section 2 describes the observations and reductions for all the data: optical and infrared photometry, and infrared spectroscopy. Section 3 presents the results and discussion. The conclusions are listed in § 4.

![Diagram](image.png)

**Fig. 1.** — Period vs. $I-K$ color for OGLE transit candidates in the Carina region. The reddest object is OGLE-TR-82, marked with the crosses. The left cross on top of the circle is our $I-K$, and the right cross is from 2MASS.

## Table 1

| Instrument                  | Date     | Type                     |
|-----------------------------|----------|--------------------------|
| VLT + VIMOS                | 2005 Apr  | $I$-band photometry      |
| NTT + SOFI                 | 2005 May  | $K_s$-band photometry    |
| Gemini South + GMOS        | 2006 Jan  | $g$- and $i$-band photometry |

The paper uses data obtained at various facilities, as listed in Table 1, which we discuss in turn.

### 2.1. Infrared Observations: Photometry and Spectroscopy

OGLE-TR-82 was observed during the nights of 2006 May 4 and 5 using the SOFI (Son of ISAAC; Moorwood et al. 1998) infrared camera and spectrograph at the NTT. SOFI is equipped with a $1024 \times 1024$ HgCdTe HAWAII detector, characterized by a $5.4 \text{e}^- \text{ADU}^{-1}$ gain, readout noise of 2.1 ADU, and dark current of less than 0.1 $\text{e}^- \text{s}^{-1}$. We used it in the large-field camera mode, obtaining a $4.9' \times 4.9'$ field. All measurements were made through the $K_s$-band filter (center = 2.162 µm and width = 0.275 µm).

The reductions were carried out using IRAF tasks. First of all, a correction for cross talk was applied, taking into account the difference in detector sensitivity between the upper and lower halves. Then sky subtraction was applied by subtracting an appropriately scaled mean sky, which was obtained by combining all the offset images (two per target using "dither 5" mode) but rejecting outlying pixels. Finally, we applied flat-field corrections to all the images and aligned them. For the flat fields, we used correction images provided by the NTT Science Operations team, and the alignment was performed with LINTRAN and IMSHIFT.

OGLE-TR-82 is listed as 2MASS source J10580297–6134263, with $J=13.48 \pm 0.06$, $H=12.08 \pm 0.04$, and $K_s=11.54 \pm 0.03$. The 2MASS values yield a very red color for this star, $J-K_s=1.94$. OGLE-TR-82 is located in Carina, in the Galactic plane at $(l,b)=(289.8638', -1.6131')$. This region is relatively crowded, and hence we find that for some OGLE candidates, the 2MASS photometry differs from ours. The 2MASS photometry may be contaminated by nearby neighbors, as a consequence of the pixel scale of 2MASS. We obtained the $K$-band magnitude by using deeper and better sampled SOFI images. Our infrared photometry was calibrated using 2MASS. The zero point of the $K$-band photometry should be good to 0.1 mag, which is accurate enough for our purposes.

Using aperture photometry with an aperture small enough to exclude nearby neighbors, we find $K=12.20 \pm 0.10$ for this star. Even though this is more than half a magnitude fainter than the 2MASS value, in what follows we adopt this as the final $K$ magnitude for OGLE-TR-82. This allows us to plot OGLE-TR-82 in Figure 1, which shows period versus $I-K$ color for several OGLE transit candidates observed in the Carina fields. OGLE-TR-82 is clearly unique in this sample as a very red object, with a short-period companion, that warranted further study.

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12 IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

13 See http://www.la.eso.org/lasilla/sciops/ntt/sofi/reduction/flat-fielding.html.
Therefore, we also acquired a near-IR spectrum with SOFI, covering the region from 1 to 2.5 \( \mu \text{m} \). The low-resolution blue and red grisms delivered spectral resolution of \( R \approx 700 \) with a 1\( '' \) slit. This is adequate for spectral classification. The total integration was 480 s in the blue and 720 s in the red, split into individual integrations of 240 and 180 s, respectively. The usual observing technique of nodding along two slit positions was used. The data reduction included cross-talk removal, flat-fielding, subtraction of the sky emission, extraction of a one-dimensional spectrum from each individual image, wavelength calibration, and combination into a final spectrum for each mode separately. Finally, we removed the telluric absorption with observations of a solar analog, HIP 54715 (for details, see Maiolino et al. 1996). The two SOFI spectra were joined together by scaling the overlapping regions from 1.51 to 1.645 \( \mu \text{m} \), and the spectra were not flux-calibrated.

2.2. VLT Optical Observations and Photometry

The \( V \)-band VLT observations and photometry are described in Fernández et al. (2006). Briefly, the photometric observations were taken with VIMOS (the Visible Multi-Object Spectrograph).
at Unit Telescope 4 of the VLT at Paranal Observatory during the nights of 2005 April 9–12. The VIMOS field of view consists of four CCDs, each covering 7′ × 8′, with a separation gap of 2′ and a scale of 0.205″ pixel⁻¹. We used the Bessell V filter of VIMOS, with ω₀ = 5460 Å and FWHM = 890 Å.

A number of OGLE transit candidates were monitored simultaneously. OGLE-TR-82 was located in one of the four monitored fields, and it was scheduled to have a transit during the first night of our run. However, a later revised ephemeris provided by OGLE (A. Udalski et al. 2005, private communication) showed that the transit occurred after the night was over. Nonetheless, some of the VIMOS images had exquisite seeing and we can use them for precise astrometry and to measure the magnitude of OGLE-TR-82 in the presence of a brighter optical neighbor located 1″ away. It was necessary to perform point-spread function photometry using DAOPHOT in IRAF in order to account for this brighter nearby neighbor.

The images with the best seeing (FWHM = 0.5″) taken near the zenith were selected, and a master optical image was made. The images of OGLE-TR-82 analyzed here are 400 × 400 pixels, or 80″ on a side. This small image contains about 500 stars with 15 < V < 24. Figure 2a shows a 20″ × 20″ portion of this V-band master image, showing OGLE-TR-82 with a larger circle and its neighbor, located 1″ north, with a smaller circle. We measure \( V = 20.61 \pm 0.03 \) for OGLE-TR-82 and \( V = 17.39 \pm 0.01 \) for the neighbor. The OGLE I-band image is shown in Figure 2b for comparison; both stars have similar magnitudes in this image. Taking I = 16.30 ± 0.10 from Udalski et al. (2002a), we obtain a very red color of \( V − I = 4.31 \pm 0.10 \) for OGLE-TR-82. This color indicates that the target is a very late M dwarf or an early brown dwarf. The \( K_s \)-band image of Figure 3 shows that the relative brightness of the two stars is reversed: OGLE-TR-82 is much brighter than its neighbor in the near-infrared.

2.3. Gemini South Optical Observations and Photometry

The object is so faint in the optical passbands that it takes an 8 m telescope to measure the transit accurately. Therefore, a full transit of this target was observed with the GMOS instrument at the Gemini South telescope. The observations were acquired in queue mode on 2006 January 27. The GMOS field of view is 5.5′ × 5.5′, with a scale of 0.0727″ pixel⁻¹. This scale is finer than that of VIMOS, but the seeing during the observations was worse than the VIMOS run, which complicates the transit photometry in the presence of the brighter neighbor 1″ away. The beginning of the transit was noisier because of weather problems, but the night stabilized after the ingress, resulting in a relatively good light curve.

We used the \( g \)- and \( i \)-band filters (Gemini filters \( g_\text{G0325} \) and \( i_\text{G0327} \), respectively), alternating three consecutive exposures of each filter in turn. This observation sequence was repeated without interruption for a period of 5.3 hr. There were 117 images for each of the two filters. The seeing and image quality were not optimal, but they were good enough for difference-image photometry. Figures 2c and 2d show the best Gemini South single images of the OGLE-TR-82 field for comparison with the previous Figures 2a and 2b. The stellar images are elongated, but obviously of higher resolution than the VLT and OGLE images. It can be appreciated that the source has a faint unresolved companion 1−2 pixels away to the east.

The transit light curves were measured following the procedure described for the VLT transits (see Fernández et al. 2006). The \( g \)-band transit was very difficult to measure, because the star becomes very faint and is overwhelmed by the nearby neighbor. There is a factor of 10 difference in counts in each individual image for this star between the \( g \) and \( i \) bands. Figure 4 shows the full \( g \)- and \( i \)-band light curve for the Gemini South observations, when the OGLE-TR-82 transit was monitored. There are about 30 points in each of the light curves during our single transit shown in Figure 4, and the minimum is well sampled, allowing us to measure accurate amplitudes. The resulting light curves (which were not corrected for a linear trend) yield \( \text{rms}_g = 0.005 \) and \( \text{rms}_i = 0.002 \) mag in the flat portion at the end of the night. Figure 4 also shows the phased light curve of the OGLE \( I \)-band photometry (on a similar scale) for comparison. The transit is well sampled in our \( i \)-band observations, and the scatter appears smaller. We confirm the amplitude of the transit measured by OGLE in the \( I \) band, \( A_I = 0.034 \) mag, but find that the amplitude in the \( g \) band is larger, \( A_g = 0.10 \) mag. Already the Gemini South data cast doubts on the planetary-transit scenario, because of the amplitude difference between the \( g \)- and \( i \)-band transits. Also, the \( g \)-band light curve exhibits a more triangular eclipse shape, which is more characteristic of a grazing binary. However, the \( g \)-band light curve was hard to measure, and we cannot rule out residual contamination from the neighbors or fluxing problems with the difference-image photometry.

2.4. Previous Spectroscopy

As noted in § 1, Pont et al. (2004) observed OGLE-TR-82 with UVES and FLAMES at the VLT, but they could find no CCF signal, concluding that this was an unsolved case. They pointed out that the object could be too red and suggested further observations. They suggest a K7/M0 dwarf, less extreme than the spectral type found in the next section.

We conclude that there was no signal for this object in the spectroscopic observations because they were made in the \( V \)-band portion of the spectrum, where the target is simply too faint, with \( V = 20.61 \) mag. Using the setup of Pont et al. (2004), this target cannot provide useful signal to measure velocities with an accuracy of \( \sim 30 \) m s⁻¹ in any reasonable amount of integration time, according to the UVES+FLAMES exposure time calculator. Having solved the mystery about the absence of a spectroscopic
signal for OGLE-TR-82, we raise a more important question: Is this star a giant or a dwarf?

3. A PLANETARY TRANSIT?

With the present optical and infrared photometry, one can estimate some of the stellar parameters: the spectral type, luminosity, mass, radius, and distance.

3.1. Period of OGLE-TR-82b

The VLT observations did not show a transit, which was scheduled for the end of the night according to the original OGLE ephemeris. A. Udalski et al. (2005, private communication) revised the ephemeris for this object, giving mean transit times of

\[ \text{JD} = 2,452,323.84747 + 0.764244t. \]

This puts the transit beyond the end of the VIMOS observing night, explaining its absence. At the same time, this is a minor revision that allowed us to recover the transit for the Gemini observations. With the transit observed at Gemini South, the ephemeris is improved. We obtain a period similar to that from OGLE: \( P = 0.7643813 \pm 0.0000010 \) days.

3.2. Spectral Type of OGLE-TR-82

In a previous work, we used optical and infrared photometry to characterize OGLE extrasolar planetary companions (Gallardo et al. 2005). We can estimate the spectral type of OGLE-TR-82 first using the multicolor photometry. The stellar parameters from OGLE and the present photometry are listed in Table 2.

The optical-infrared color-magnitude diagrams are shown in Figure 5 for all stars in a Carina field of about 1' x 1'. The disk main sequence is very well defined. The target star OGLE-TR-82 is located away from this main sequence, indicating that it is either a nearby late-M dwarf or a very reddened, distant giant. Because both alternatives are very different from the spectral type of K7–M0 V adopted by Pont et al. (2004), we consider these two possibilities that arise from the photometry.

Figure 6 shows the loci of giants and dwarfs of different spectral types in a \( V-I \) versus \( I-K \) color-color diagram. The position of OGLE-TR-82 in this diagram is consistent with an unreddened spectral type of M7 V, with an error of about 1 subtype (between M6 V and M8 V). For this spectral type, the mass and radius are \( M_\ast = 0.10 \pm 0.02 \, M_\odot \) and \( R_\ast = 0.15 \pm 0.02 \, R_\odot \). This star lies at
the boundary between M dwarfs and brown dwarfs. In fact, adopting the 2MASS photometry ($V-K = 9.1$) instead of our values ($V-K = 8.4$) results in an L-type brown dwarf. The spectral type of M7 V would yield an absolute magnitude of $M_v = 18.60$ (Bessell 1991). The resulting distance modulus of $m - M = 2.01$ gives a distance of 25 pc and would make this the nearest OGLE transiting-planet candidate. Most other OGLE transit candidates are located at distances between a few hundred parsecs and a few kiloparsecs (Gallardo et al. 2005). However, Figure 6 also shows that if the reddening is severe, $E(B-V) \approx 2$ mag, the location of OGLE-TR-82 could also be consistent with that of a distant red giant.

### 3.3. Radius of OGLE-TR-82b

If we consider the case of an M7 V dwarf, the OGLE I-band transit light curve amplitude yields $R_p/R_\ast = 0.18$. This is a small planetary radius, similar to that of Neptune, $R_p = 0.3 \, R_J$.

| Parameter | Value       | Ref. |
|-----------|-------------|------|
| Period (days) | 0.764244 | 1    |
| JD_0        | 2,452,323.84747 | 1    |
| $A_1$        | 0.034     | 2    |
| $A_2$        | 0.034     | 3    |
| $A_3$        | 0.1       | 3    |
| $V$            | 20.61 ± 0.03 | 2    |
| $I$            | 16.30 ± 0.10 | 2    |
| $K$            | 12.20 ± 0.10 | 3    |
| $V - I$         | 4.31 ± 0.10 | 2    |
| $I - K$         | 4.10 ± 0.10 | 3    |
| $V - K$         | 8.41 ± 0.10 | 3    |
| $t_r$ (days)    | 0.063     | 3    |

**Fig. 5.— Optical-infrared color-magnitude diagrams of all stellar objects in a $1' \times 1'$ field in Carina. In both panels, the large square to the right is OGLE-TR-82, while the one on the left is OGLE-TR-113, shown for comparison. The reddening vector, corresponding to $A_V = 6$ mag, is shown for OGLE-TR-82. [See the electronic edition of the Journal for a color version of this figure.]**

**Fig. 6.— Color-color diagram indicating the fiducial loci of giants (circles) and dwarfs (triangles) of different spectral types. The observed position of OGLE-TR-82 is marked by the crosses. The top one comes from the 2MASS colors, and the bottom one comes from our photometry. This position is consistent with a late main-sequence star, next to the location of a typical M7 V star. The direction of the reddening vector is indicated by the straight line; its length gives the vector corresponding to a total $A_V = 6.0$ mag. Considering this reddening, the star would lie closer to the location of K-type red giants.**

This is very different from the two previously published values for the radius of the OGLE-TR-82 companion, both based on the OGLE photometry. Udalski et al. (2002a) obtained $R_p = 1.1 \, R_J$, and Silva & Cruz (2006) assumed a star with $M = 0.65 \, M_\odot$ and obtained a radius $R_p = 1.10 \, R_J$. Both values are much larger than the radius implied for an M7 V star, indicating the dramatic change due to the new spectral type obtained for OGLE-TR-82 based on the $V-K$ color of this source, if it is indeed a main-sequence star.

The present photometry shows that the previous attempts to measure the radial velocities of OGLE-TR-82 failed because this object is much too faint in the optical. It is now clear that with $V = 20.61$ it would have been impossible to measure. However, velocities in the near-infrared are within reach of the largest telescopes, because the target is very red, $K = 12.20$. If this were a low-mass star with a planet in a tight orbit, these velocity measurements would not need to approach the accuracy of a few meters per second usually needed for radial velocity planet searches. In this case, a Jupiter-mass planet would yield a radial velocity semi-amplitude of about 1.1 km s$^{-1}$, well within reach of near-IR spectrographs at large m class telescopes. A Saturn-mass planet would give a smaller radial velocity semi-amplitude of 300 m s$^{-1}$.

The smallest extrasolar planet currently known is HD 149206b, with $R_p = 0.7 \, R_J$ (Sato et al. 2005), a Saturn-mass planet with a large, dense core. The smallest companions so far have been detected in a bulge field by Sahu et al. (2006) around stars of 0.5 $M_\odot$. If OGLE-TR-82 were a K7–M0 V star (Pont et al. 2004), it would be an extreme case because of its low mass, small size, and short-period companion. The planetary option would be still open for this target if we could confirm it as an M dwarf of later type.

In the absence of spectroscopic velocities, we cannot estimate the mass of the companion. However, in order to give an idea of the possibilities, we note that a companion with $M = 1 \, M_J$ would yield an orbital semimajor axis of $a = 10.8$ and $R_p = 0.0076$ AU.
There is, however, a problem with this interpretation: the total transit time observed is $t_T \approx 0.06$ days, while the stellar and orbital parameters would predict a shorter transit of $t_T = 0.027$ days. Though interesting as a good planetary candidate at this stage, a deeper study shows that the interpretation is not so simple, as discussed below.

3.4. A Triple System?

We have explored different possibilities for the nature of the OGLE-TR-82 companion: a planetary companion to an M dwarf, a white dwarf transiting in front of an M dwarf, a brown dwarf transiting in front of an M dwarf, a grazing M dwarf tight binary of similar masses, variability such as spots, a main-sequence star transiting in front of a red giant, and a blend with a reddened background giant star. The last possibility is the only one that agrees with all the available data, as discussed below.

3.5. Blend with a Background Star

An eclipsing binary blended with a background star yields low-amplitude transits because the light from the contaminating star dilutes the eclipse. Similarly, the eclipses of a distant binary would be diluted by a blend with a foreground star. It is now well known that transit searches are plagued by blends and that in order to confirm the planetary nature of a transit candidate, a radial velocity orbit must be obtained. In the present case, the blend possibility appears the most likely.

The best-seeing optical images from Gemini South (Figs. 2c and 2d) show an elongated shape even for the faint OGLE-TR-82 star. This is obvious in the $g$ band (Fig. 2c) but less evident in the $i$ band (Fig. 2d). The elongation is in the east-west direction, but the pair is faint and unresolved; we estimate the separation to be approximately 1–2 pixels in the Gemini South images. One of the sources appears to be the very red source (to the north), while the other (to the south) has normal color for a typical main-sequence field star. Note that spectroscopic fiber sizes (e.g., HARPS, FLAMES) would not be able to resolve the light from both stars; the spectra would necessarily be the composite spectrum of the blend.

We conclude that the red source is a reddened background giant, while the other source is a normal main-sequence binary. The blend reduces the amplitudes of the eclipses of the binary as seen in the $I$ band, mimicking the light curve of a planetary transit.

It is usually not possible to distinguish between the case of a foreground binary blended with a background star and that of a background binary blended with a foreground star. In the present case, while a late main-sequence star transiting in front of a red giant can produce an eclipse of the measured depth ($A = 0.034$ mag), a blend of a foreground main-sequence star with a background binary red giant does not work, because the measured transit time of 1.5 hr is too short compared with typical red giant sizes, even taking into account the short period of OGLE-TR-82. It would have to be a grazing eclipse with a markedly triangular shape.

The final solution to the dilemma comes from the near-IR spectroscopy obtained with SOFI at the NTT. The first question that our near-IR spectra allow us to address is whether the star is a giant or a dwarf. The two-dimensional spectral classification is discussed in detail by Ivanov et al. (2004; see § 5.2). First, we used their equations (2) and (4) to determine the effective temperature and then placed the object on the plots shown in their Figure 12 (left; Fig. 7 here). We measured Mg i 1.50 $\mu$m, Si i 1.58 $\mu$m, CO 1.62 $\mu$m, and Mg i 1.71 $\mu$m indices as defined in that paper on the extinction-corrected spectrum to obtain $0.11 \pm 0.04$, $0.03 \pm 0.01$, $0.04 \pm 0.02$, and $0.06 \pm 0.02$ mag, respectively. Note that here and below in this section, the uncertainties should be treated with caution because they include only the Poisson errors from the spectra and not any systematic errors that might arise from the sky subtraction or the telluric corrections, for example. Also, we did not correct for any differences due to the lower resolution of our spectra with respect to the library of Ivanov et al. (2004). The derived stellar effective temperatures were 4077 and 5101 K. We averaged them to obtain $T_{\text{eff}} \sim 4600$ K, suggesting the star...
has a K0 spectral type. The CO $1.62 - (\text{Mg}+1.50 + \text{Mg}+1.71)/2$ versus log $T_{\text{eff}}$ plot (Fig. 7, top) firmly places the target among the giants, while the plot of CO $2.29 - (\text{Na}+2.20 + \text{Ca}+2.26)/2$ versus log $T_{\text{eff}}$ (Fig. 7, bottom) is inconclusive.

Finally, we applied the metallicity calibration technique of Frogel et al. (2001; see their eq. [3]) based on the strength of Na $i$ 2.20 μm, Ca $i$ 2.26 μm, and the 2.3 μm CO band. We preferred the spectroscopic method rather than the combination of spectroscopic and photometric indices because our target suffers strong extinction and even a small uncertainty in the extinction would cause significant error in the metallicity estimate. Following the prescriptions of Frogel et al. (2001) and Ramirez et al. (1997), we measured equivalent widths of 1.5 ± 0.1, 1.6 ± 0.1, and 10.2 ± 2.0 Å, respectively, for the Na, Ca, and CO features. For the metallicity estimates we tentatively doubled the errors. This yields [Fe/H]$_{\text{ZW}} = -1.0 ± 0.1$ on the Zinn & West (1984) metallicity scale. The transformation from Frogel et al. (2001; their eq. [6]) gives [Fe/H]$_{\text{CG}} = -0.86$ on the Carretta & Gratton (1997) scale. Frogel et al. also give a metallicity calibration based on the CO strength alone. It yields [Fe/H]$_{\text{ZW}} = -1.06 ± 0.13$, in agreement with the first estimate.

Of course, the classification criteria of Ivanov et al. (2004) and the calibrations of Frogel et al. (2001) were derived for disks or globular cluster stars, with ages, chemical enrichment history, abundance ratios, etc., different from Milky Way halo stars. Therefore, our results should be treated with caution, and we can only conclude that the OGLE-TR-82 primary is consistent with being a metal-poor red giant.

In addition, we used the library of Pickles (1985) to carry out empirical spectral classification by comparing template spectra of dwarfs and giants with the near-IR spectrum of our target. From this method, this spectrum first confirms the extremely red nature of this object, as deduced from the infrared photometry. Second, and most importantly, the spectral type obtained is consistent with a K3 III, with an estimated absorption $A_V = 7$ mag.

The strong CO band at 2.3 μm makes it impossible to match the host star with the spectrum of any red dwarf from the spectral library of Pickles (1985) except for the latest spectral types, M6–M7. However, the specific shape of the continuum for these stars does not match the shape of the continuum of our star (Fig. 8). Dwarfs earlier than M5 are also inconsistent with the observed colors, unless one assumes an unrealistically larger absorption of $A_V > 12–15$ mag, which appears impossible for a nearby star.

This leaves us only with the possibility of a distant giant star, supported by the shape of the continuum. The comparison with the giants’ template spectra shown in Figure 9 illustrates that the best fits are found with a K3 III giant and $A_V = 7$ mag, as expected for a distant giant star located in the Galactic plane. Stars of later type provide poor matches because of the strong water vapor features. We caution that some contamination from the nearby blue star is expected in the blue part of the spectra at 1 μm.

This spectral type finally rules out a planetary-size companion. Even though the mass of the secondary is unconstrained because of the lack of radial velocities, we conclude that this companion is most probably a late-type main-sequence star. Thus, the OGLE-TR-82 system is an eclipsing binary, blended with a background, reddened K giant.

4. CONCLUSIONS

Udalski et al. (2002a) discovered low-amplitude transits in the main-sequence star OGLE-TR-82, which was considered to be a prime planetary candidate orbiting an M-type dwarf (Pont et al. 2004; Silva & Cruz 2006). We find that this object has an extremely red color, $V-K = 8.4$, making it unique among the OGLE transit candidates in Carina. Future space-based missions such as COROT and Kepler may discover low-amplitude transits in a few faint red objects, which may turn out to be difficult to observe with echelle spectrographs. OGLE-TR-82 is one example, a difficult but interesting case that we have followed up here.

We acquired images with good seeing in the $V$ band with VIMOS at the VLT and in the $K$ band with SOFI at the NTT. We also observed a single transit of this star in the $g$ and $i$ bands with Gemini South. Our data are complemented by $I$-band data from Udalski et al. (2003), who observed 22 transits but with few points per transit. We conclude that it was not possible to measure velocities for this star in the past, and thus to estimate the mass of the companion, because the star is too faint in the optical ($V = 20.61$).

The transit amplitudes are well measured, with 30 points in transit for each of the two optical bands. We confirm the amplitude of the transit measured by OGLE in the $I$ band, $A_I = 0.034$, but find that the amplitude in the $g$ band is larger, $A_g = 0.10$ mag.

We explored different possibilities for this system. First, the hypothesis of an M7 V primary leads to a possible planetary size for the transit candidate. In this case, based on the new photometric data and assuming an M7 V primary, the radius for the companion would be $R_p = 0.3 ± 0.1 \ R_J$, that is, the size of Neptune. This scenario has the problems that the measured transit time is too long and that the amplitudes seem to be different in the $g$ and $i$ bands. Second, an alternative explanation consists of a triple system composed of an eclipsing binary blended with a background red giant. In this case the red giant has to be very reddened and very distant.

Clearly, spectroscopic measurements were still needed for this interesting target. These are more efficiently carried out in the near-infrared, given the extremely red color of this object. Quantitative analysis of the near-IR spectrum obtained at the NTT finally proves that OGLE-TR-82 is a distant, reddened, metal-poor
early giant. This result is confirmed by direct comparison with stellar templates, which gives the best fit with a K3 III star with an absorption of $A_V = 7$ mag. This rules out a planetary-size companion. We conclude that this system is a main-sequence binary blended with a background red giant.

Based on the $J$-band photometry, the OGLE-TR-82 system perfectly mimics an M dwarf with a Neptune-size companion. After long follow-up effort, we have found that the system is composed of an eclipsing binary blended with a background K giant. There is a lesson to be learned for future transit surveys searching for hot Neptunes and super-Earths around late-type stars.

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