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LUMINOUS M GIANTS IN THE BULGE OF M31

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ABSTRACT

We report on spectroscopy of luminous red stars in the central bulge of M31. A number of these are shown to be late-type M giants similar to those in the Baade's window field of the bulge of the Milky Way. Among the M31 stars, we serendipitously discovered an exceptionally luminous M0 Ie red supergiant which has brightened by more than 5 mag in the last 2 yr. At peak brightness, this star was the most luminous red supergiant in the local group, with $M_{bol} = -10$.

Subject headings: galaxies: stellar content — stars: supergiants — stars: stellar statistics

I. INTRODUCTION

The nearest stellar populations that in their integrated light resemble the metal-rich populations of giant elliptical galaxies are found in the bulges of the Milky Way galaxy and M31 (Whitford 1978). The bulge of the Milky Way has been under intensive study in recent years (cf. Frogel 1988). The stellar population in Baade's window, 500 pc from the nucleus of the Galaxy, has been shown to be metal-rich (Rich 1988) and have a giant branch dominated by luminous M giants (Blanco, McCarthy, and Blanco 1984; Frogel and Whitford 1987).

Mould (1986) resolved the nuclear bulge of M31 into individual stars ≈ 1 kpc from the nucleus; the brightest of these are ≈ 1 mag more luminous than the brightest in the halo of M31. Thus we have a second example of a bulge population in which individual stars may be studied. We have obtained spectra of the luminous stars in the M31 bulge to determine if they are similar to the M giants in the bulge of the Milky Way.

II. M GIANTS

Candidate resolved stars were chosen from a field in the M31 bulge adjacent to the location illustrated by Mould (1986), about 3′ SE of the nucleus (~ 700 pc, using Mould's 1988 distance modulus for M31 of 24.2). Many luminous M giants are found in a field of the nuclear bulge of the Milky Way at $\approx -6°$ (Blanco 1988), also 700 pc from the nucleus if we adopt Moran *et al.*'s (1987) value of R_0 of 7.1 kpc. However, these fields are not equivalent because of the different viewing geometry and the different structures of the M31 and Galactic bulges, a detailed comparison of which is beyond the scope of this *Letter*.

The stars for which we obtained spectra are indentified in Figure 1 (Plate L1), an image obtained with the 4-Shooter on the 5 m telescope (see § III). Table 1 gives the magnitudes and spectral classification (derived below) for the stars, most of which are fainter than $i = 19.5$ (Gunn system). The brightest stars, 1 and 9, are "anchor" stars, chosen to constrain the rotation of the slit mask. Spectra were obtained on 1988 September 5 (UT) using a photographic multislit mask and the 4-Shooter transmission grating spectrograph (Gunn *et al.* 1987) on the 5 m telescope of Palomar Observatory. Slits 1.″3 wide suppressed the M31 bulge background light. Since the stars are very red, a 1 hr exposure in the wavelength region from 6400 to 9500 Å yielded ≈ 1000 net counts with a resolution of 18 Å. The sky-subtracted stellar spectra were extracted from flattened (dome exposure), bias-subtracted frames. The spectra were wavelength calibrated, then divided by the spectrum of a B star obtained at identical air mass, which canceled the deep atmospheric absorption bands in this region of the spectrum. The spectra were smoothed with a 16 Å (4 pixel) wide Gaussian.

Figure 2 (Plate L2) illustrates the first spectra obtained of M giants in the nuclear bulge of M31; classification is based on the criteria of Nassau and Velghe (1964) and comparison with spectra of classified Galactic M giants. All of the stars have the prominent TiO band at 7054 Å; the appearance of TiO λ7600 sets apart M2 from M0. Significantly, Na I λ8183, 8195 is always absent; it is strong in dwarfs. The appearance of λ8430 signals M5; as this feature deepens, a later classification is assigned. A complex of TiO at λ8340 signifies a classification of M7 for stars 6 and 7. Giants later than M7 have VO bands at $\lambda\lambda$7400 and 7900, which cannot be seen in these spectra under any circumstances due to noise. Those giants with strong TiO resemble the late M giants found by Blanco, McCarthy, and Blanco (1984) in Baade's window.

On October 25 UT, a 240 s exposure with the SBRC IR imager at the prime focus of the 5 m reflector yielded K band photometry for five of the M giants, which is given in Table 1. Reduction of these data is described in Mould *et al.* (1989). If we use Frogel and Whitford's (1987) BC_K as a function of spectral type, these stars exceed by ≈ 0.5 mag the luminosity of brightest red giants found in Baade's window (Frogel and Whitford 1987).

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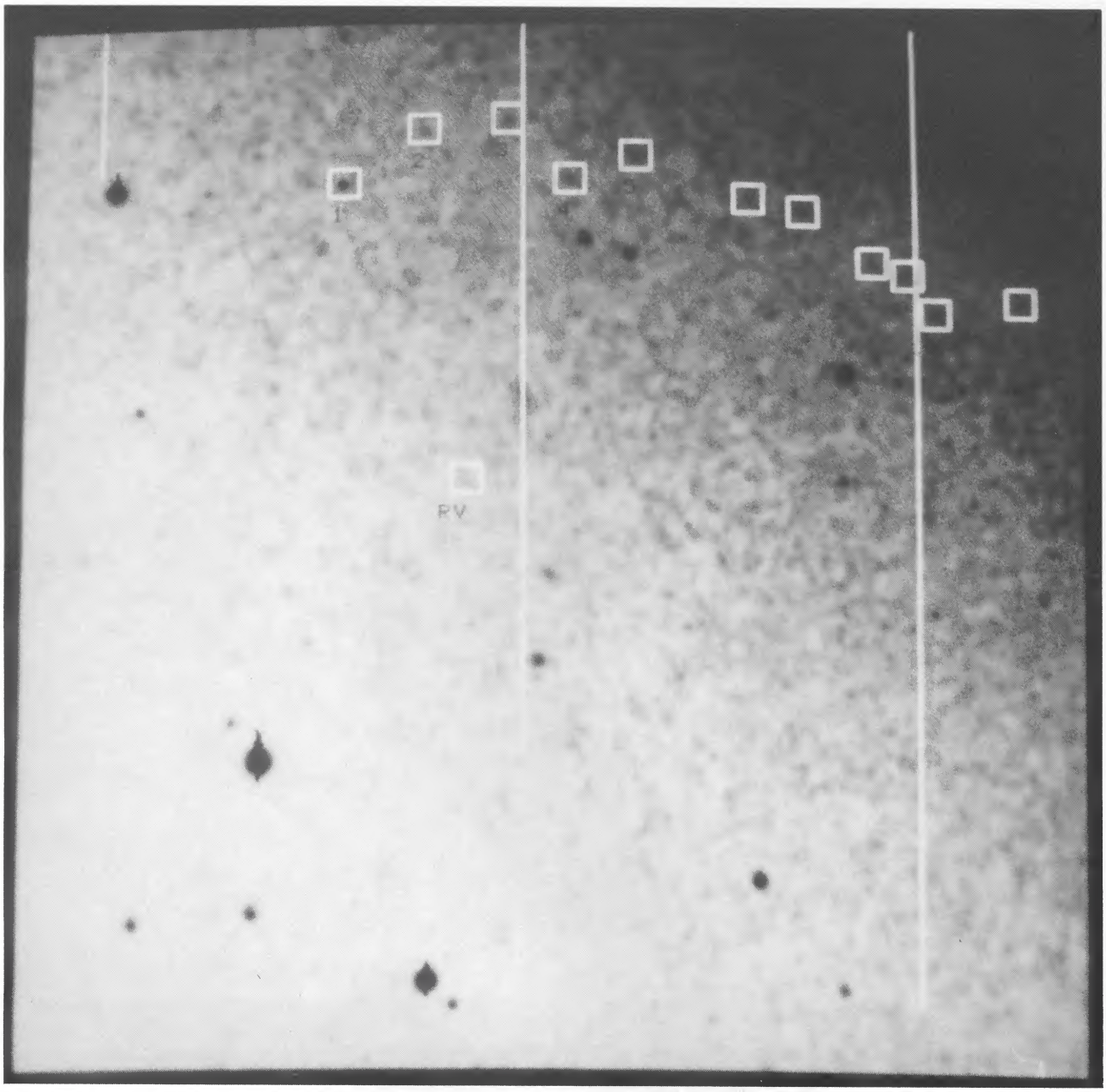

FIG. 1.—Field of the M31 bulge ≈3′ SE of the nucleus. Program stars are in the upper part of the field, enclosed in boxes labeled 1–11. A box encloses the position of the red variable (RV); north is up, east to the left.

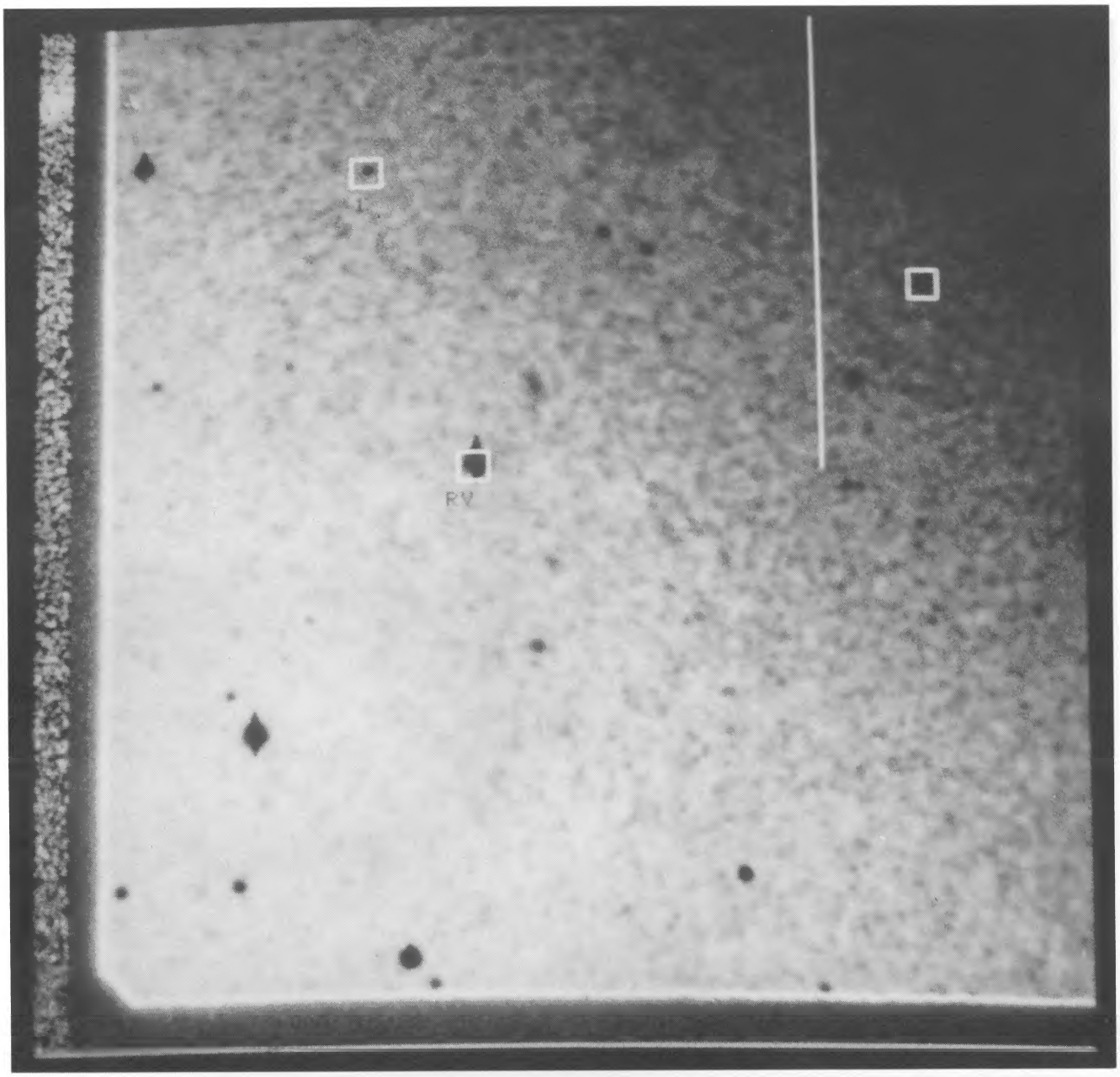

FIG. 2.—Discovery frame of star RV, illustrating the same field as Fig. 1

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TABLE 1

M31 BULGE FIELD

Object	Gunn i	K	M_{bol}	Sp
1	18.61	15.67	−5.87	M2
2	19.87	16.11	−5.49	M2
3	19.90	16.48	−4.83	M5
4	19.97	16.68	−5.02	M2
5	19.80	16.36	−5.34	M0
6	19.94	...	...	M7
7	19.90	...	...	M7
8	19.09	...	...	K:
9	...	...	...	A0?
10	19.75	...	...	M5
11	19.78	...	...	M6
12	19.93	...	...	?

NOTES.—Magnitudes and spectral classifications for stars identified in Fig. 1. Spectra of some of these stars are presented in Fig. 3. No magnitude could be obtained for star 9 because it lies too close to a dead column or the CCD chip. Bolometric magnitude based on BC_K appropriate for spectral type (Frogel and Whitford 1987) and modulus of 24.2 for M31 (Mould 1988).

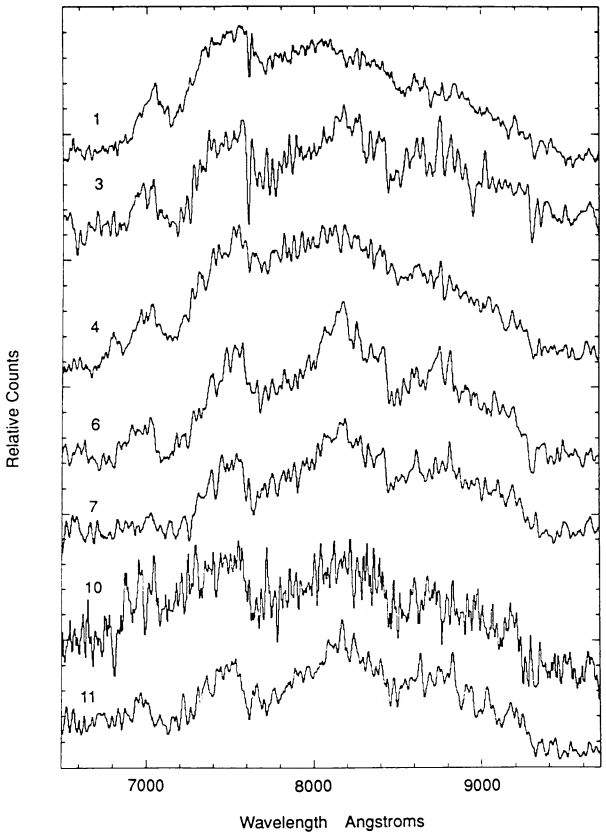

FIG. 3.—Spectra of M giants discovered in the M31 bulge field (Fig. 1), Note strong bands of TiO at 7054, 7598, and 8430 Å. Stars 6 and 7 are the latest giants, classified M7; magnitudes and spectral classes are reported in Table 1. The raw spectra were divided by a B star to remove atmospheric absorption.

III. A LUMINOUS RED SUPERGIANT

In the course of identifying the field in Figure 1, we noticed a relatively bright star (Fig. 2) that had not been present in images taken two years earlier. Figure 3 is the discovery image of the red variable (RV) obtained on 1988 September 3 in a 300 s exposure with the 4-Shooter through a Gunn i filter in 1″ seeing. RV is located 214″E and 196″S of the nucleus (±2″). Photometry on 1988 September 5 yielded $i = 14.9$ on the Gunn system (Schneider, Gunn, and Hoessel 1983), $g - r = 1.33$, and $r - i = 0.68$, which did not change the following night.

On 1988 September 5 (UT) the 4-Shooter spectrograph was used to obtain blue and red spectra of RV in two 600 s exposures with the 400 and 300 line gratings respectively, with slit widths of 2″ and 1.″3, at the same resolution as the M giant spectra. Figure 4 depicts these spectra, which show unresolved Hα and Hβ in emission, Na absorption, weak TiO bands, and a strong Ca triplet. The spectral type is M0 Ie; luminosity classification is based on the strength of the Ca triplet, the lack of CaH absorption, and the strength of the λ6500 blend. The latter feature is a combination of Ba II, Ca I, and Fe I at this resolution, and is strong in LMC supergiants (Reid and Mould 1985).

The amplitude of the observed variation of RV is extraordinary. Confusion makes accurate identification in Figure 1 difficult, but if we choose the most prominent of the blended images at the center of the box in Figure 1, we find a star of $i = 20.4$. This probably is a lower limit on the magnitude of RV on 1984 December 24, when the image shown in Figure 1 (also a 300 s i frame) was obtained. RV is no brighter in images obtained on 1984 September 20, or a later frame obtained on 1986 August 11. Therefore, star RV in Figure 2 has risen over 5 mag at λ8200 over a 2 yr time interval, remaining quiescent (or undetected) for at least 2 yr prior to its present rise. Rosino's surveys for novae in the M31 bulge (Rosino *et al.* 1988; Rosino 1964, 1973) could have detected RV, which at $B = 18.2$ (converted from the Gunn system; Hoessel and Danielson 1984; Kent 1985) would have been easily discovered. However, none of Rosino's novae, discovered over a three decade period, coincides with the position of RV.

After its extraordinary outburst, RV faded by 3 mag in 43 days to $i = 17.97$ on October 18 (UT); in the same interval, it faded only 0.8 mag at K (see below). As of 1989 February 8, RV has remained quiescent at its preoutburst i magnitude.

RV also varied dramatically in radial velocity. When the blue spectrum of September 5 (Fig. 4) was obtained, the radial velocity (based on Hα, Hβ, and NaD) was -610 ± 100 km s^{-1}. Eight hours later, however, the red spectrum of RV indicated that its radial velocity had *changed* by $+390 \pm 60$ km s^{-1} (based on cross-correlation); Hα emission changed in lockstep with the stellar absorption lines. This remarkable result was checked by confirming that the night sky emission lines were at their proper wavelengths, with no velocity shifts between the lines recorded in the portion of the spectrum covered by both the blue and red exposures. Unfortunately, the radial velocity variation of RV has only been discovered after the conclusion of its outburst.

CCD photometry shows that RV was extremely luminous at the time of discovery. RV had an apparent color excess ($E_{B-V} = 0.25$) over a normal M0 supergiant (Kent 1985; Johnson 1966). Converting to the Johnson system (Hoessel and Danielson 1984), we obtain $I_0 = 13.35$, corresponding to $m_{bol} = 14.35$ (Eggen 1972). For a distance modulus $(m - M)_0 = 24.2$ (Mould 1988) the bolometric magnitude on 1988 September 5 was ~ -9.8.

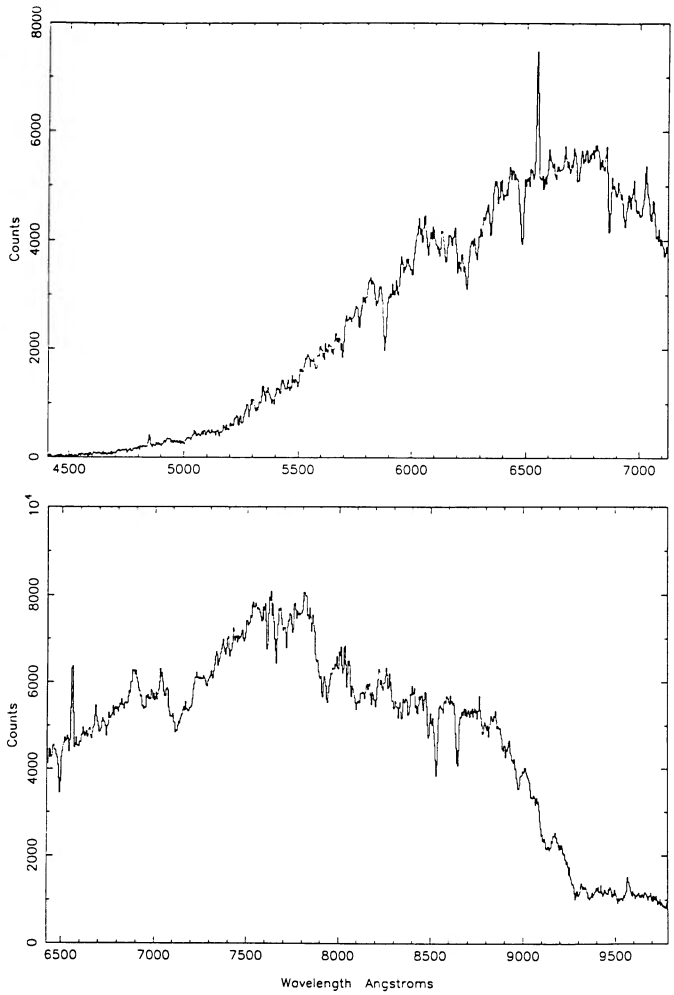

FIG. 4.—Blue and red spectra of the red variable (star RV in Fig. 2). Note emission of Hα and Hβ. Assignment of supergiant luminosity (M0 Ie) is based on the strength of the blend at 6540 Å and the Ca triplet at ≈8550 Å. Bands of TiO are also present at 6200 and 7054 Å. In the red spectrum, atmospheric absorption bands have been corrected by B star division.

On 1988 September 21 UT, images of a field 24″ square centered on star RV were obtained at J, H, and K with the KPNO Infrared imager (IRIM) at the f/7.5 focus on the KPNO 4 m telescope. FWHM of the image of RV was 1″.2 with 0″.4 pixels. Exposure time was 5 × 30 s in each filter. A dark frame of equal length was subtracted from the object frames. Flat-fielding was accomplished by division by a dark-subtracted sky frame in each color. The aperture magnitude of RV was determined with respect to 10 measurements of IR standards from Elias *et al.* (1982). Transformation to the standard system yields $K = 12.01$, $J-K = 0.86$, $H-K = 0.22$. We estimate a ± 0.05 mag uncertainty in these values due to corrections and the transformation; statistical errors were negligible.

If RV has $E_{B-V} = 0.25$, application of the reddening law of Elias, Frogel, and Humphreys (1985) yields $K_0 = 11.94$, $(J-K)_0 = 0.70$, and $(H-K)_0 = 0.19$. Applying $BC_K = 2.30$ for M giants (Frogel, Persson, and Cohen 1980), we find $m_{bol} = 14.24$. The modest value of $H-K$ gives no hint of any cool circumstellar dust shell in the object, although observations should be extended to 3.6 μm to confirm this. With the adopted distance modulus to M31 of 24.2, we calculate that on September 21, the red variable was $M_{bol} = -9.96$, making it the most luminous M supergiant in the local group at that time (cf. Humphreys *et al.* 1988).

IV. CONCLUSIONS

Spectroscopy of giants in the bulge of M31, 700 pc from the nucleus along the minor axis, has confirmed that they are K and M giants similar to those found in the bulge of the Milky Way. Out of 11 secure bulge members, two late M giants of classification M7 have been found, as well as three more giants M5 or later. In the K band, these stars are as bright as the brightest variables in Baade's window.

Near the bulge field, a red variable with an M0 Ie supergiant spectrum and a bolometric magnitude of ≈ -10 has been discovered. After increasing in brightness by at least 5 mag in the last 2 yr, this extraordinary star has faded in 2 months; further monitoring of it is urgent. Should the star brighten, it should be monitored for large radial velocity variations on time scales of a few hours.

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