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THE EXTENDED GIANT BRANCH OF THE ANDROMEDA II DWARF SPHEROIDAL GALAXY

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ABSTRACT

One, and possibly two, carbon stars and an M giant are reported in And II, a dwarf spheroidal companion of M31. Infrared photometry indicates an extended asymptotic giant branch in And II, reaching −4.5 bolometric magnitude for $m - M = 24.3$. These results can be understood in terms of the third dredge-up mechanism in asymptotic giant branch (AGB) stars, if And II has spent approximately half its life as a gas-rich star-forming irregular galaxy. But the alternative possibility that these luminous late-type stars could be a consequence of binary mass transfer cannot be ruled out. In either event, the presence of AGB carbon stars may be a general characteristic of dwarf spheroidal galaxies, as they are also found in most of the spheroidal systems that surround the Milky Way.

Subject headings: galaxies: Local Group — galaxies: stellar content — infrared: sources — stars: carbon — stars: evolution

I. INTRODUCTION AND OBSERVATIONS

Andromeda II is a dwarf spheroidal companion of M31 discovered by van den Bergh (1974). Its absolute visual magnitude of approximately −11 suggests comparison with the Leo I dwarf satellite of our own Galaxy (van den Bergh 1980). Like most of the dwarf spheroidals of the Milky Way, Leo I contains a number of asymptotic giant branch (AGB) carbon stars (Aaronson, Olszewski, and Hodge 1983; Azzopardi, Lequeux, and Westerlund 1985). The presence of these stars is prima facie evidence for star formation in these systems within the last several billion years (Aaronson and Mould 1985, hereafter AM85).

To see if this property of our own dwarf spheroidals extends to those of Andromeda, we recently obtained spectra of the reddest stars in And II. Spectra of four stars were secured on the nights of 1984 August 4, 5 with the double spectrograph (Oke and Gunn 1982) at the Cassegrain focus of the Hale telescope. For maximum sensitivity we worked without a dichroic and used the 158 lines mm^{-1} grating, 15 Å resolution configuration described by Aaronson, Mould, and Cook (1984). The best data were obtained in two half-hour exposures with the position angle of the spectrograph rotated so that Olszewski and Suntzeff (1985) stars 209, 210, and 211 fell on the slit at the same time.

II. THE SPECTRA

The spectra were reduced using the FIGARO software package on the DEIMOS VAX at Caltech. To properly correct fringes in the CCD response, projector lamp flat fields were employed at every telescope position. The spectra were rotated to lie exactly along rows of the resultant images, and sky subtraction was performed in a routine manner. Wavelength calibration was effected by means of He-Ar comparison spectra, but spectrograph flexure precludes useful radial velocities at this resolution.

Spectra of four stars are shown in Figures 1 and 2. The flux calibration is approximate (10% uncertainty): it was transferred from a flux standard observed the previous night. Mean continuum extinction coefficients were employed, and no attempt was made to correct for the O_2 A and B bands or water vapor depressions at 7200 Å or beyond 9000 Å. The effects of overlapping second order (4000 Å at 8000 Å) do not seem to be noticeable in either the program stars or the flux calibration, because of the insensitivity of the red CCD to $\lambda < 4500$ Å.

Andromeda II 211 is immediately recognizable as a carbon star in Figure 2. The C_2 Swan bands $\lambda\lambda 5165, 5635$ are clearly present, together with the red system of CN $\lambda\lambda 6927, 7876$. The 30 microjansky flux at 8000 Å corresponds to a Cousins I magnitude of ~ 19.8 (Bessell 1979), which places the star well above the M31 giant branch tip (Mould and Kristian 1985). Infrared photometry (see below) confirms that star 211 is an AGB carbon star.

Andromeda II 209 is readily identified as an early M giant from its weak TiO bandheads at 7054, $\gamma(0,0)$ and ~ 6200, $\gamma'(0,0)$. CaH and NaD are not visible which rules out the possibility that star 209 is a foreground dwarf. The existence of an M star on the And II giant branch suggests the presence of a population more metal-rich than one-tenth solar abundance by analogy with Galactic globular clusters (Johnson, Mould, and Bernat 1982). Note that this comparison ignores that star 209 is more luminous than the first giant branch tip, and that one is only drawing inferences about the metal-rich tail of the abundance distribution.

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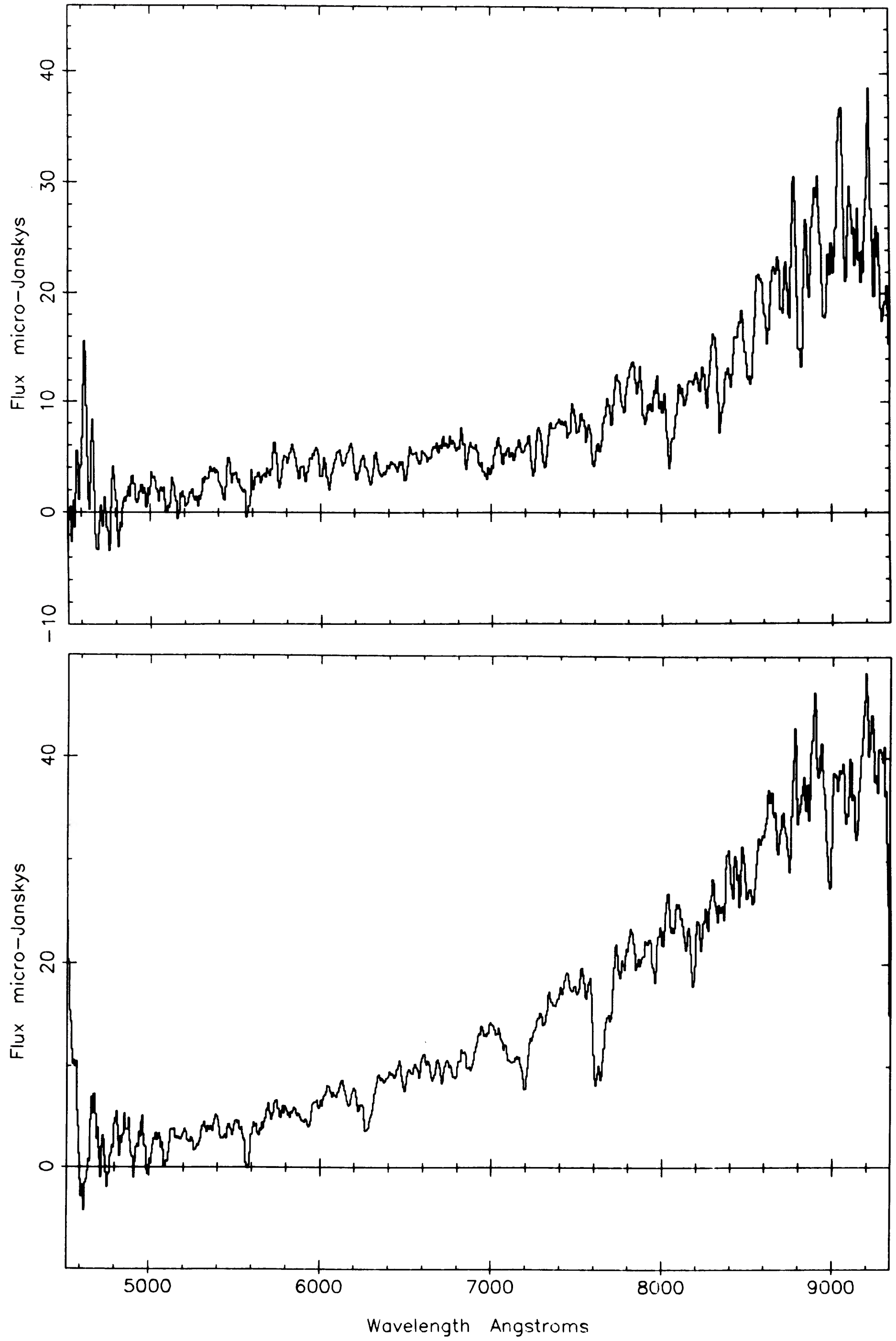

FIG. 1.—Spectra of And II 10 (*above*) and 209 (*below*)

The remaining two stars are harder to classify. Star 10 appears to be a marginal carbon star as indicated by weak CN bands; star 210 has a fairly smooth red continuum.

III. INFRARED PHOTOMETRY

Photometry was obtained of three of these stars with InSb detectors on the MMT and Hale telescopes. A 9″ aperture with a 15″ chopper throw was used on the MMT, and a 5″ aperture with a 10″ chopper throw was employed at Palomar. Integrations of 400–1000 s per filter yielded the results reported in Table 1. These magnitudes are on the system of Elias *et al.* (1982). For Palomar the color term reported by AM85 was adopted; the need for a color term with the MMT data has not yet been clearly established. These are limiting observations of potential variable stars in crowded fields, and do not agree within the estimated photometric errors for star 211. Completion of the Palomar observations was prevented

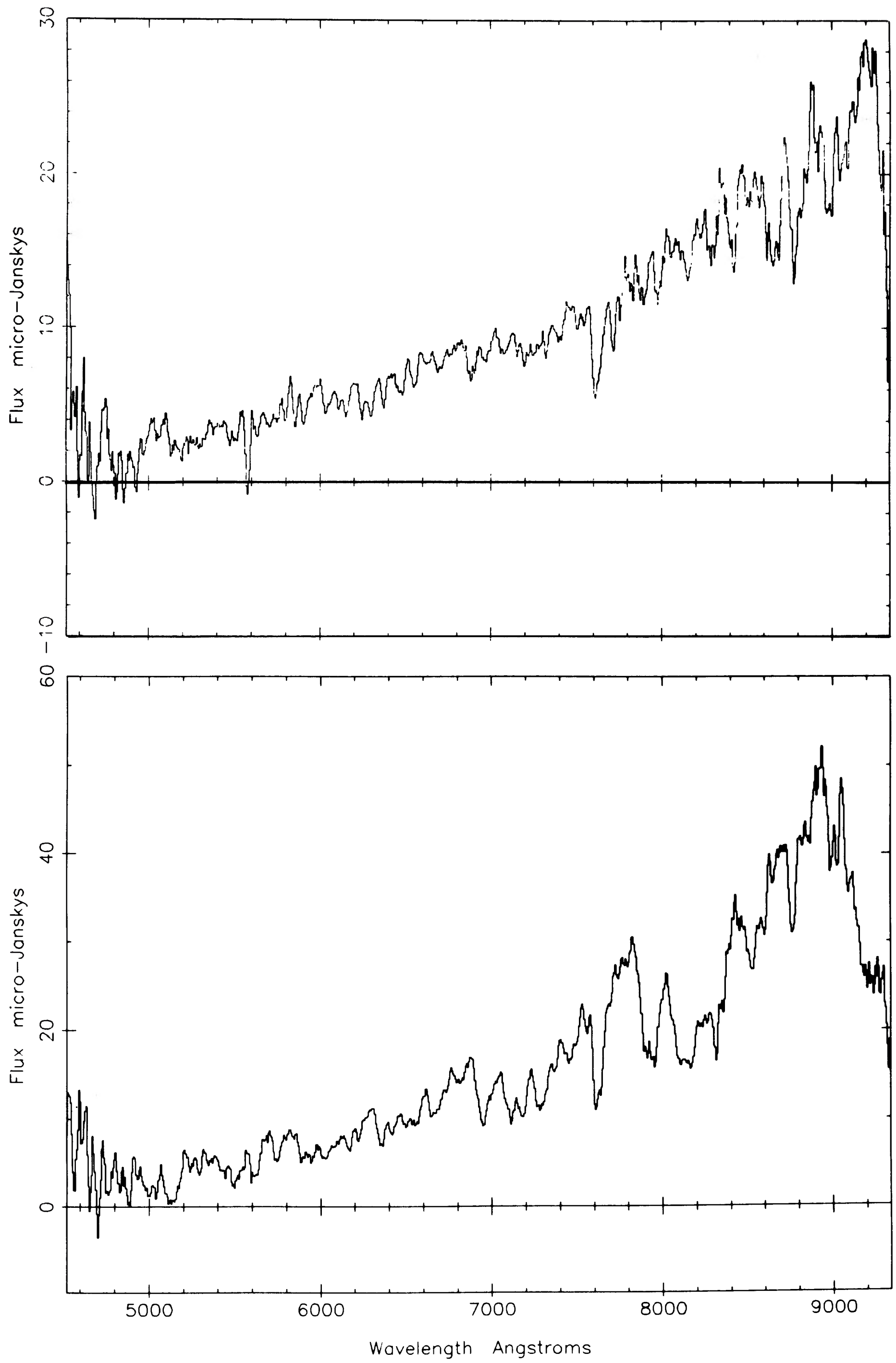

FIG. 2.—Spectra of And II 210 (*above*) and 211 (*below*)

by a rare failure of the drive system. Further measurements are clearly required.

The observed *JHK* colors of stars 10 and 211 are consistent with their classification as C stars. Bolometric magnitudes were calculated from the mean value of H for each star and the MMT measured $H - K$. The $J - H$ value of star 211 would be more consistent with a redder $H - K$ (cf. Mould and Aaronson 1980). Since $H - K$ for this star is poorly determined, we adopted $H - K = 0.5$, based on its $J - H$. We followed the standard procedure of applying the bolometric correction to the K magnitude tabulated by Frogel, Persson, and Cohen (1980). This correction is a function of $J - K$. For star 209 we adopted $J - K = 0.88$ and $H - K = 0.16$, which is appropriate for the spectral type. The reddening in this field is very low: $E(B - V) = 0.03$ according to Burstein and Heiles (1982). In spite of the large photometric errors, the

TABLE 1

PHOTOMETRY FOR ANDROMEDA II GIANTS

Star (1)	Telescope (2)	J^a (3)	H^a (4)	K^a (5)	Date (m/d/y) (6)	Type (7)	$M_{bol}{}^b$ (8)
10.......	MMT	18.15 (0.20)	17.35 (0.10)	16.85 (0.15)	11/20/83	...	−4.45
	5 m	...	17.50 (0.10)	...	8/6/84	C:	...
209.......	MMT	...	17.35 (0.20)	...	11/21/83	M0	−4.45
211.......	MMT	18.50 (0.15)	17.40 (0.15)	17.00 (0.25)	11/21/83	...	−4.10
	5 m	...	17.80 (0.15)	...	8/6/84	C	...

[a] Photometric errors given in parentheses.

[b] $(m - M)_0 = 24.3$ assumed; mean H magnitudes used.

uncertainty in the bolometric luminosities of the stars is dominated by the unknown distance of And II. Since it is 9° away from M31 on the sky, it is fair to assume that it lies within 100 kpc of the line-of-sight distance to M31. We adopt $(m - M)_0 = 24.3 \pm 0.3$ from the M31 moduli of Aaronson *et al.* (1985) and Mould and Kristian (1985).

Even with these uncertainties these stars are more luminous than the brightest red giants in Galactic globular clusters. This extended giant branch is a property which And II shares with most of the dwarf spheroidals of the Milky Way (Aaronson and Mould 1980; AM85). The carbon stars discussed here would fit comfortably on the bright side of the luminosity function for carbon stars in dwarf spheroidals presented by AM85 (their Fig. 11). In particular, the brightest carbon star in the analog system Leo I is at $M_{bol} = -4.46$.[5] That luminosity function excludes the Fornax dwarf which has carbon stars up to a magnitude brighter than And II.

IV. DISCUSSION AND SUMMARY

There are two possible explanations for the extended giant branch and the presence of carbon stars in And II.

1. Andromeda II may have spent the first part of its life as a dwarf irregular galaxy. If star formation ceased 10 Gyr ago, carbon stars would be expected to populate the AGB up to a luminosity $M_{bol} = -4.5$ (Mould and Aaronson 1982).

2. The additional fuel required to raise AGB stars to this luminosity could have been provided by mass transfer from evolved companions.

[5]A typographical error is present in Table 3 of AM85, where the brightest Leo I star is incorrectly listed as being at $M_{bol} = -4.76$.

The first mechanism has as its prototype the Fornax dwarf satellite of our own Galaxy. The Fornax AGB is more luminous than stellar envelope transfer between two 0.8 $M_\odot$ stars in a Population II system can realize. One would need to hypothesize coalescence of whole stars to fuel an AGB of this extent. In the case of Fornax, continuing star formation until 3 Gyr ago seems a more plausible hypothesis (Buonanno *et al.* 1985; AM85). Evidence has been discussed from surface photometry that dwarf ellipticals may generally have had a previous incarnation as dwarf irregulars (Kormendy 1985).

Envelope transfer cannot be ruled out for dwarfs such as And II and Leo I, whose AGB terminates at −4.5. One needs to suppress this mechanism in globular clusters, however, where upper AGB carbon stars are not observed. But this problem has been discussed by Renzini, Mengel, and Sweigart (1977) in the context of the anomalous Cepheids in dwarf spheroidal galaxies. We cannot at present choose between these explanations in the case of And II. Binarism in Galactic dwarf spheroidal galaxies should be detectable spectroscopically.

We are unable at present to discuss the completeness of our investigation of luminous giants in And II. It is worth remarking, however, that the transition luminosity from oxygen-rich to carbon-rich stars may be as bright as −4.45 in And II. The third dredge-up mechanism is capable of explaining carbon stars fainter than the transition luminosity. Star 211 might be experiencing the "interpulse dip" (Iben and Renzini 1982) under this hypothesis.

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REFERENCES

Aaronson, M., Bothun, G., Mould, J., Huchra, J., Schommer, R. A., and Cornell, M. E. 1985, *Ap. J.*, submitted.

Aaronson, M., and Mould, J. R. 1980, *Ap. J.*, **240**, 804.

______. 1985, *Ap. J.*, **290**, 191 (AM85).

Aaronson, M., Mould, J. R., and Cook, K. H. 1984, *Ap. J. (Letters)*, **291**, L41.

Aaronson, M., Olszewski, E., and Hodge, P. 1983, *Ap. J.*, **267**, 271.

Azzopardi, M., Lequeux, J., and Westerlund, B. E. 1985, *Astr Ap.*, **144**, 388.

Buonanno, R., Corsi, C. E., Fusi Pecci, F., Hardy, E., and Zinn, R. 1985, *Astr. Ap.*, in press.

Bessell, M. S. 1979, *Pub. A.S.P.*, **91**, 589.

Burstein, D., and Heiles, C. 1982, *A.J.*, **87**, 1165.
Elias, J. H., Frogel, J. A., Matthews, K., and Neugebauer, G. 1982, *A.J.*, **87**, 1029.
Frogel, J. A., Persson, S. E., and Cohen, J. G. 1980, *Ap. J.*, **239**, 495.
Iben, I., Jr., and Renzini, A. 1982, *Ap. J.* (*Letters*), **259**, L79.
Johnson, H. R., Mould, J. R., and Bernat, A. P. 1982, *Ap. J.*, **258**, 161.
Kormendy, J. 1985, preprint.
Mould, J. R., and Aaronson, M. 1980, *Ap. J.*, **240**, 464.
Mould, J. R., and Aaronson, M. 1982, *Ap. J.*, **263**, 629.
Mould, J. R., and Kristian, J. 1985, *Ap. J.*, submitted.
Oke, J. B., and Gunn, J. E. 1982, *Pub. A.S.P.*, **94**, 586.
Olszewski, E., and Suntzeff, N. 1985, in preparation.
Renzini, A., Mengel, J. G., and Sweigart, A. V. 1977, *Astr. Ap.*, **56**, 369.
van den Bergh, S. 1974, *Ap. J.*, **191**, 271.
———. 1980, in *Normal Galaxies*, ed. M. Fall (Cambridge: Cambridge University Press), p. 201.

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