THE ASTROPHYSICAL JOURNAL, **291**:L41–L44, 1985 April 15

DISCOVERY OF THE FIRST S STAR IN NGC 6822

MARC AARONSON[1]
Steward Observatory, University of Arizona

JEREMY MOULD
Palomar Observatory, California Institute of Technology

AND

KEM H. COOK
Steward Observatory, University of Arizona
Received 1984 October 26; accepted 1985 January 7

ABSTRACT

A spectroscopic survey of the red giants located in a 1'.5 × 2'.5 patch of NGC 6822 has led to the discovery of an S star, the first to be identified in a system lying beyond the Milky Way's outer halo. Seven M stars and eight carbon stars have also been spectroscopically confirmed. The S star spectrum shows prominent ZrO and LaO features, while TiO, C_2, and CN bands are weak or absent. Infrared photometry yields $M_{\text{bol}} \approx -5.15$ mag, a value similar to that of the only known pure S star in the Magellanic Clouds.

The results of the spectroscopic survey also confirm the reliability of a new technique for finding very distant C and M stars from intermediate-band filter photometry.

Subject headings: stars: evolution — stars: S-type

I. INTRODUCTION

S stars are generally believed to be double-shell burning giants related to carbon and M stars via the evolutionary scheme M → S → C. As such, they perhaps hold the key for unraveling nucleosynthetic patterns on the asymptotic giant branch (AGB). Unfortunately, this task has been made difficult by the comparative rareness of galactic S stars and an uncertain knowledge of their absolute bolometric magnitudes.

There were remarkably enough no extragalactic S stars known until this decade, when Richer and Frogel (1980) identified an SC star in the Large Magellanic Cloud. This fact is a testament to the difficulty of locating S stars with conventional objective prism methods. In the past few years, largely through spectroscopic programs, numerous MS stars have been identified in both Clouds in the intermediate-age clusters (e.g., Lloyd Evans 1983) and among the long-period variables (LPVs) (Wood, Bessell, and Fox 1983), and two SC stars have now been found in the SMC (Lloyd Evans 1984). Curiously, the only case of a pure S-type star in the Clouds is the one reported in the SMC by Blanco, Frogel, and McCarthy (1981), although in the Galaxy they are much more common than SC stars. One MS star has also been discovered in the Fornax dwarf spheroidal (Westerlund 1983). Through all of this work, our knowledge of intrinsic S star luminosities and their relative locations in the H-R diagram has been placed on a much sounder footing.

In this *Letter* we present the discovery of the first S star in NGC 6822—a galaxy lying well beyond the Milky Way's halo. The discovery of the first carbon star in this system was recently made by Aaronson *et al.* (1984). These results are part of a long-term effort to study the red stellar content of nearby galaxies in order to learn about both AGB evolution and galaxian star formation history. Using the new filter-band method described by Aaronson *et al.* (1984), supplemented by additional spectroscopic observations, we have been surveying selected fields in Local Group systems to locate C and M stars and determine the C-to-M star ratio and C star luminosity function.

[1]Visiting Astronomer, Palomar Observatory.

II. SPECTROSCOPIC SURVEY IN NGC 6822

In 1984 August we used the Palomar 5 m telescope to survey spectroscopically red AGB candidates in a 1'.5 N–S × 2'.5 E–W patch positioned about 20" E and 100" S of the center of NGC 6822. Candidate stars were selected on the basis of an imaging study of this region (to be reported by Cook, Aaronson, and Norris 1985) using the aforementioned filter technique. The spectroscopic sampling was 100% complete in the magnitude range $-6.6 \leq M_I \leq -5.4$, but only ~ 20% complete in the range $-5.4 < M_I \leq -4.7$ [adopting a reddening and distance modulus of $E(B-V) = 0.3$ mag and $(m-M)_0 = 23.5$ mag after McAlary *et al.* 1983].

The results are summarized in Figure 1, where observed $V - I$ color is plotted against instrumental "77-81" color (see Aaronson *et al.* 1984). (The actual spectra will be presented in a future article.) The figure provides striking confirmation of the validity of the filter-band method. Redder than $V - I =$ 2.2 mag, every star predicted from the 77-81 color to be a carbon or M star turned out to be just that, with the exception of the S star reported here. Bluer than $V - I = 2.2$ mag, there is clearly a transition region in which K and C stars may be difficult to disentangle solely via the filter-band method. It is interesting to note that the S star falls on the leftward edge of

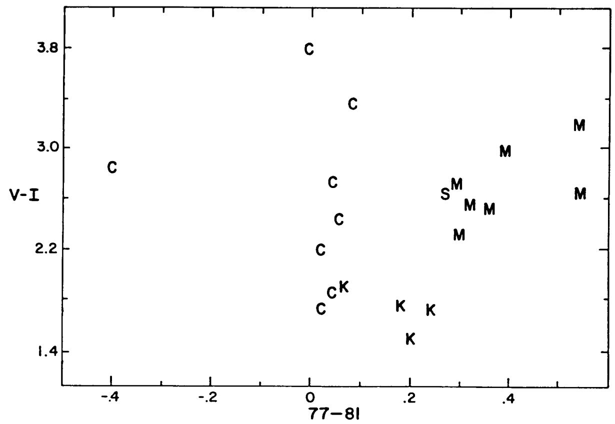

FIG. 1.—Observed $V-I$ color plotted against instrumental 77-81 index for stars spectroscopically surveyed in NGC 6822. Symbols represent the resulting spectral types. The abscissa is a measure of the relative flux in two intermediate-band ($\Delta\lambda \approx 300$ Å) filters centered at 7750 Å and 8100 Å (see Aaronson *et al.* 1984).

the M star track. Locating red stars with weak band strengths in the ($V-I$, 77-81) diagram may provide an effective means of selecting future S star candidates for spectroscopic investigation.

The reader may be struck by how large the C-to-M star ratio in NGC 6822 is in comparison with the Galaxy—a result also found for the Magellanic Clouds (e.g., Blanco and McCarthy 1983). It is also clear from Figure 1 that as for both the Milky Way and the Magellanic Clouds, the C-to-S and M-to-S star ratios are large. Incompleteness in the magnitude sampling does not affect these conclusions. Further discussion of the C-to-M star ratio and its variation with galaxy morphology is given in Cook, Aaronson, and Norris (1985).

III. SPECTROSCOPY AND PHOTOMETRY

In Figure 2*a* we show a spectrum of the NGC 6822 S star obtained from a 30 minute exposure in good seeing and bright moonlight on 1984 August 6 (UT). We used the red camera of the Double Spectrograph (Oke and Gunn 1982) but discarded (for the entire observing run) the dichroic and order separating filters in the interests of high throughput. The 158 line mm^{-1} grating employed gave a pixel spacing of 6 Å on the TI CCD detector and a resolution of approximately 15 Å with the 1″ slit.

The data were flattened, sky subtracted, and extinction corrected with a smooth function containing no absorption bands. Flux calibration was secured from observations of BD +25°3941 (Stone 1977), a standard chosen for its red energy distribution, which minimized second-order contribution at 9000 Å from residual sensitivity at 4500 Å. Unfortunately, spectrophotometry of this star has not been obtained beyond 8370 Å. We therefore made a constant flux extrapolation, which is approximately correct but makes the stellar flux calibration over the reddest 1000 Å correspondingly uncertain. For comparison purposes, we show in Figure 2*b* a 1 s exposure of the galactic S star R Cyg observed with half the telescope aperture. The absolute flux calibration of this star is therefore approximate. Note also that second-order contamination appeared negligible for the very red stars we were in general observing.

The spectra in Figure 1 have not been corrected for atmospheric molecular absorption, and the terrestrial A and B bands are apparent in them. Visible stellar features include the λ6474 (0, 0) band head of the γ system of ZrO, which is a key signature of S stars, and $\lambda\lambda$7877, 7910 (0, 0) band heads of the $A-X$ system of LaO, although the band strengths of these features in the NGC 6822 star are somewhat weaker than in R Cyg. However, the reverse is true for the strongest lines of the calcium triplet at $\lambda\lambda$8542, 8662, seen very prominently in the NGC 6822 star. Both objects show a feature at 9300 Å, a ZrO band in S stars (Bessell 1984). However, this is located at the edge of the CCD, at the onset of strong terrestrial water vapor absorption, and we do not claim a detection, especially since the feature is visible in many of our spectra. The continuum energy distributions of the two stars are also similar, and TiO, C_2, and CN are weak or absent in both. This is a characteristic of pure S stars. R Cyg, a long-period variable, also has Hα emission. Our spectrum of R Cyg was obtained close to maximum light (phase 0.15).

Available photometry of the NGC 6822 S star is summarized in Table 1. The $V-I$ data were obtained on 1982 September 19 (UT) with the Steward Observatory 2.3 m telescope and CCD camera, while the *JHK* photometry was measured 1984 August 7 (UT) with the Palomar 5 m and D-68 InSb detector. The variability characteristics of the NGC 6822 S star are unknown and will be assumed to be unimportant in what follows. The position of the S star (1950 epoch, $\pm 1''$ accuracy) is $19^h42^m11^s.5$ and $-14°56'50''$, and a finding chart is provided in Figure 3 (Plate L2).

In comparison with the LPV S stars that have been measured in the Galaxy (Mendoza and Johnson 1965; Mendoza 1967; Feast, Catchpole, and Glass 1976) and the various types of Magellanic Cloud S stars referenced earlier, the colors of the NGC 6822 star are rather blue. This may be a reflection of an abundance effect. In particular, the NGC 6822 S star matches most closely in color the Cloud cluster MS stars identified by Lloyd Evans (1983), and it may be an analog to these stars that is simply too metal poor to show TiO. Of course, pure S stars are believed to have C ≈ O, a condition for which the molecular equilibrium favors the formation of ZrO over TiO if there is residual oxygen (e.g., Scalo and Ross 1976).

The bolometric magnitude may shed further light on this point. Because there appears to be no reliable S star calibration available, we have estimated M_{bol} in five different ways. The first three are from the ($J-K$, BC_K) and ($V-K$, BC_K) relations for M giants, and the ($J-K$, BC_K) relation for C stars (details of these procedures are given in Aaronson and Mould 1985). The last two estimates come from extrapolation of the very crude ($J-K$, BC_K) and ($V-K$, BC_K) relations constructed from the nine observations of five S stars presented by Mendoza and Johnson (1965) and Mendoza (1967). The resulting range in m_{bol} varied from only 18.24 to 18.46 mag. We adopt $m_{bol} = 18.35$ mag, which with our earlier assumed distance yields $M_{bol} = -5.15$ mag. The Mendoza and Johnson results can also be used to extrapolate a color temperature for the star, yielding $T = 3200$ K, to which a large uncertainty must be attached.

The M_{bol} value for the NGC 6822 S star is similar to that for the pure S star in the SMC found by Blanco, Frogel, and McCarthy (1981), and also falls within the range of -4.3

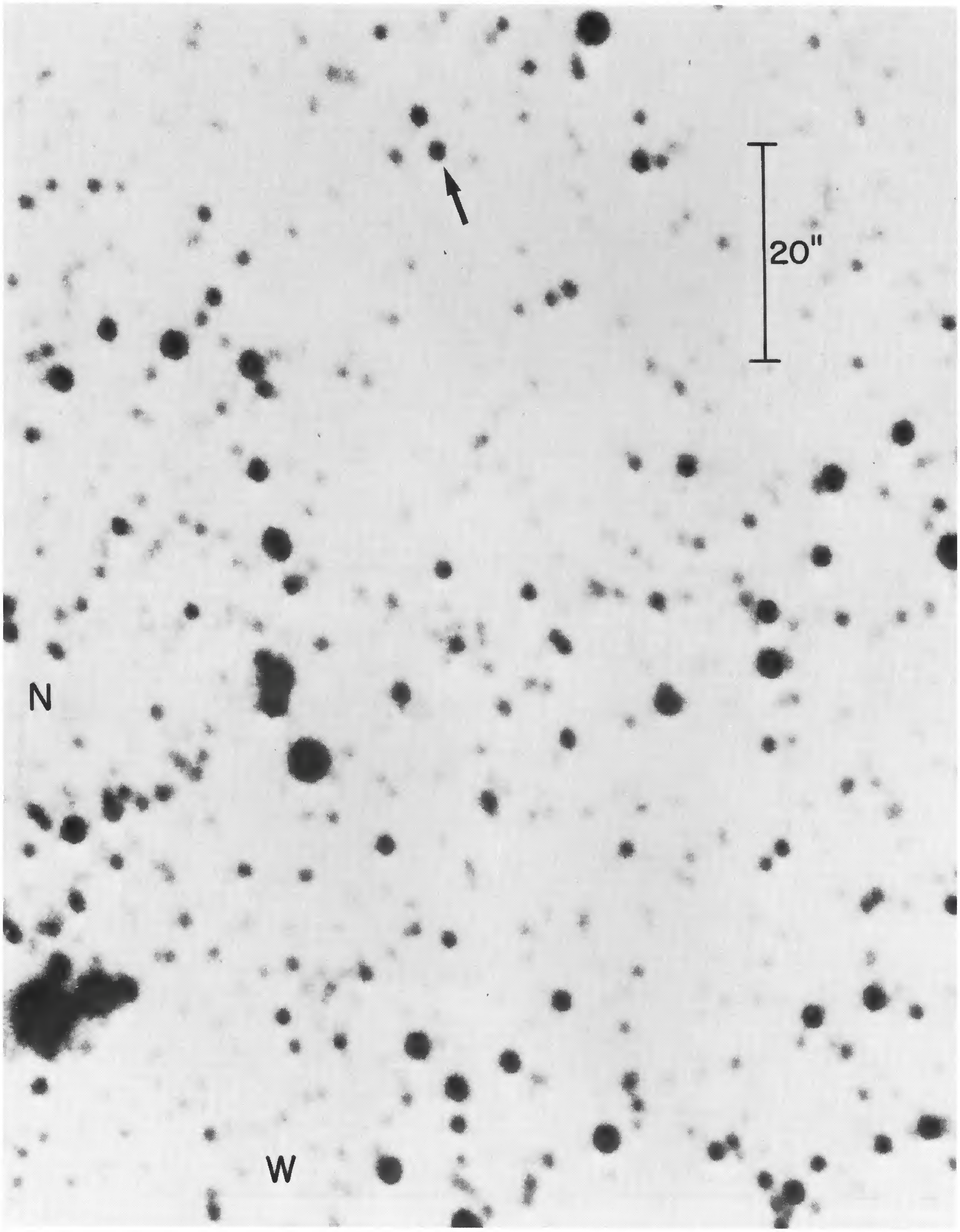

FIG. 3.—Finding chart for the NGC 6822 S star, produced from the median of three 4 minute *I* exposures obtained with the Steward Observatory 2.3 m telescope and CCD camera.

AARONSON, MOULD, AND COOK (*see* page L42)

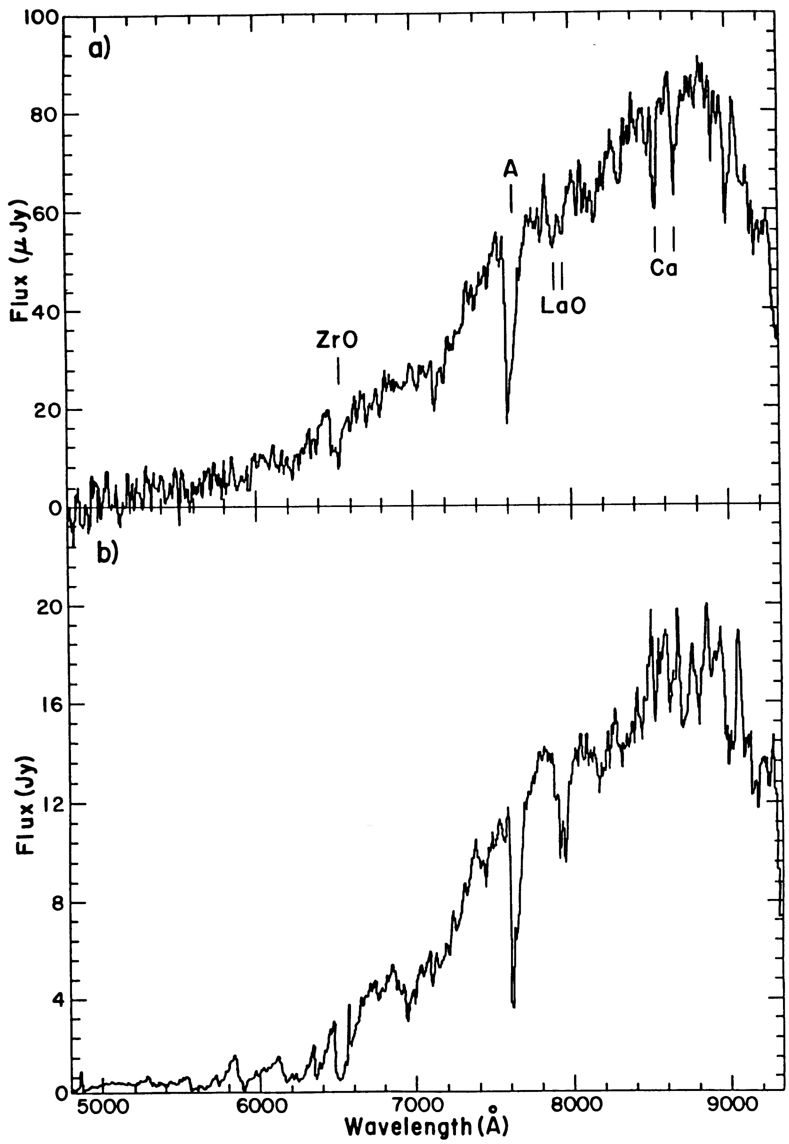

FIG. 2.—Palomar 5 m spectra of (*a*) the newly discovered NGC 6822 S star, and (*b*) the galactic S star R Cyg. The spectrum in (*a*) has been smoothed by Gaussian convolution using a half-width of 2 pixels and full truncation at 4 pixels. Prominent stellar features in these spectra include λ6474 ZrO; λλ7877, 7910 LaO; and in (*a*) λλ8542, 8662 calcium triplet lines.

TABLE 1

NGC 6822 S STAR PHOTOMETRY[a]

Parameter	V	$V-I$[b]	H[c]	$J-H$[c]	$H-K$[c]	$V-K$
Observed	21.15(5)	2.65(6)	15.81(3)	1.01(5)	0.22(7)	5.56(8)
Reddening corrected[d] ...	20.22	2.26	15.67	0.92	0.16	4.71

[a] Errors in hundredths of a magnitude are given in parentheses.
[b] Kron-Cousins system.
[c] CIT system.
[d] $E(B-V) = 0.3$ assumed.

to -5.2 mag covered by the cluster MS stars discussed by Lloyd Evans (1983). In contrast, the field SC stars of Richer and Frogel (1980) and Lloyd Evans (1984) range in $M_{\rm bol}$ from -5.5 to -6.1 mag, while the Cloud LPV S stars are generally brighter still, ranging from -5 mag up to the theoretical AGB limit at -7 mag (Wood, Bessell, and Fox 1983). Sorting out the interrelationships among these various types of stars and between them and the other peculiar red giants will continue to provide a challenge for our understanding of the advanced stages of stellar evolution.

It is a pleasure to thank Pete Stockman and John Norris for assistance with the CCD observations at Steward Observatory, and Juan Carrasco, Keith Matthews, and Gabrielle Gordon for various types of aid in California. This work was partially supported with funds with NSF grants AST 83-06139 and AST 83-16629.

REFERENCES

Aaronson, M., Da Costa, G. S., Hartigan, P., Mould, J. R., Norris, J., and Stockman, H. S. 1984, *Ap. J. (Letters)*, **277**, L9.
Aaronson, M., and Mould, J. 1985, *Ap. J.*, **290**, 191.
Bessell, M. S. 1984, in *IAU Symposium 108, Structure and Evolution of the Magellanic Clouds*, ed. S. van den Bergh and K. S. de Boer (Dordrecht: Reidel), p. 171.
Blanco, V. M., Frogel, J. A., and McCarthy, M. F. 1981, *Pub. A.S.P.*, **93**, 532.
Blanco, V. M., and McCarthy, M. F. 1983, *A.J.*, **88**, 1442.
Cook, K. H., Aaronson, M., and Norris, J. 1985, in preparation.
Feast, M. W., Catchpole, R. M., and Glass, I. S. 1976, *M.N.R.A.S.*, **174**, 81P.
Lloyd Evans, T. 1983, *M.N.R.A.S.*, **204**, 985.
______. 1984, preprint.
McAlary, C. W., Madore, B. F., McGonegal, R., McLaren, R. A., and Welch, D. L. 1983, *Ap. J.*, **273**, 539.
Mendoza V., E. E. 1967, *Bol. Obs. Tonantzintla y Tacubaya*, **4**, 114.
Mendoza V., E. E., and Johnson, H. L. 1965, *Ap. J.*, **141**, 161.
Oke, J. B., and Gunn, J. E. 1982, *Pub. A.S.P.*, **94**, 586.
Richer, H. B., and Frogel, J. A. 1980, *Ap. J. (Letters)*, **242**, L9.
Scalo, J. M., and Ross, J. E. 1976, *Astr. Ap.*, **48**, 219.
Stone, R. P. S. 1977, *Ap. J.*, **218**, 767.
Westerlund, B. E. 1983, *Astr. Ap.*, **118**, L5.
Wood, P. R., Bessell, M. S., and Fox, M. W. 1983, *Ap. J.*, **272**, 99.

M. Aaronson and K. H. Cook: Steward Observatory, University of Arizona, Tucson, AZ 85721

J. Mould: Robinson Laboratory, California Institute of Technology, 1201 East California Boulevard, Pasadena, CA 91125