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Identification of New CeO Features in the S Star Pi Gruis

P. S. MURTY† *Indian Institute of Astrophysics, Kodaikanal*

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Spectrograms in the 6040–7300 Å wavelength region of the S star Pi Gruis reveal the presence of new molecular features attributable to CeO. Measures of band heads compare reasonably well with the laboratory spectrum. The proposed identifications are supported by the recent high resolution spectral studies of CeO in R Gem and R And.

A discussion based on the identified molecular features is included on the classification of Pi Gruis as a pure S-type star.

INTRODUCTION

The optical spectra of pure S stars are known to be very rich in molecular features due predominantly to the oxides of the *s*-process elements. Although the ZrO molecule has for long been known to exist in the atmospheres of cool S stars, it is only very recently that the existence of CeO has been established. Wyckoff and Wehinger (1977) discovered CeO molecule in the pure S star R Cyg near minimum light. Their tentative identifications, based upon the band head coincidences with laboratory spectra, of more than 15 bands in the 4500–8200 Å region of the spectra of R Cyg were supported from the molecular column density estimates by Wyckoff and Clegg (1978). Subsequently, Clegg and Lambert (1978) using high resolution (0.2 Å) spectrograms of the stars R Gem and R And have fully confirmed the existence of CeO in S stars.

We report in this communication, a tentative identification of more than 30 molecular features attributable to CeO in the 6040–7300 Å region of the spectrum of S star π^1 Gru. All the identified bands are seen to be red degraded. Both the structure and the measured band head positions match fairly well with the laboratory spectrum.

EXPERIMENTAL

The laboratory spectrum of CeO molecule is very complex, consisting of numerous bands degraded in either direction. Very recently Barrow *et al.* (1979) reported the identification of more than 300 bands in the absorption spectrum of CeO between 3600 to 8600 Å. In view of the complex nature of the bands structure, even the vibrational analyses are not obvious and many of the observed bands remain unassigned. The assigned band systems are characterized by the presence of strong (0, 0)

† Postal address: P. S. Murty, Indian Institute of Astrophysics, Kodaikanal, 624 103, India

bands of the $\Delta v = 0$ sequence. The rotational constants of the upper and lower states are almost the same and consequently the head-origin separations are large.

OBSERVATIONAL

The southern hemisphere S star π^1 Gru (a slightly varying, irregular variable of from 5.8 to 6.4 visual magnitude and of −5.2 bolometric absolute magnitude [Feast 1953; Feast, Catchpole, and Glass 1976)] is sufficiently bright that intense spectrograms may readily be obtained. Moderate dispersion spectra (~5800–7300 Å 46 Å mm^{-1} at Hα) used in the present investigation were obtained (by Mr. M. Mekkaden for Dr. M. K. V. Bappu, during the course of an investigation of atomic lines in cool stars) on 1978 November 14, with an image-tube system using the 7-inch camera of the Cassegrain spectrograph attached to the 40-inch (1 m) reflector at the Kavalur Observatory.

CeO IN PI GRUIS

In Figure 1, relevant portions of the spectrograms are illustrated. The strong molecular features identified with ZrO and YO are labeled at the bottom of each spectrum, while the newly identified strong features of CeO molecule are indicated at the top of the spectra. Table I gives the measured band head positions of CeO together with their assignments in the 6045–7280 Å region. Measured positions of the CeO stellar features are given in column (1). The observed wavelengths are corrected for a radial velocity of −20 km s^{-1} and have mean errors of the order of ~ ±0.4 Å with the exception of bands in the 7200–7280 Å region. The errors in this region are ~ ±2 Å due both to blending with atmospheric water vapor absorption features and image-tube distortions near the edge of the spectrograph field. In column (2) is listed the rough visual intensity estimate (on a scale of 0–10) of the identified molecular features. The measured band positions are compared with those

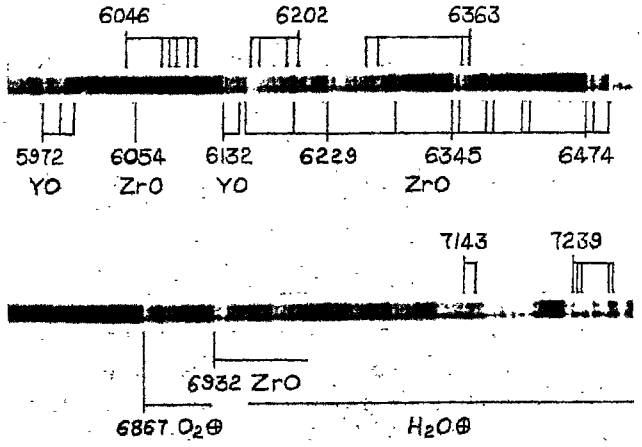

FIGURE 1 Image-tube spectra (original dispersion 46 Å mm^{-1} at Hα) of π^1 Gru. Intense band features identified with CeO are labeled at the top of each spectrum.

TABLE I

Measured band heads and assignments of CeO in the spectrum of π^1 Gru

Wavelength λ(Å) π^1 Gru (1)	Intensity (visual est.) (2)	Wavelength λ(Å) R Cyg (3)	Wavelength λ(Å) lab (4)	Transition (5)	Assignment v', v'' (6)	Masking source (7)
6046.2	2	6045.5	6045.8	B_1–X_1	0, 0	
6079.5	2	6080.6	6080.3	E_2–X_2	0, 0	
6084.3	2	—	6083.9	—	—	
6090.1	1	6091.1	6090.2	E_2–X_2	0, 0	
6102.2	3	—	6102.7	—	—	
6108.0	1	—	6107.4	—	—	
6161.2	2	—	6161.1	—	—	
6168.1	2	—	6167.9	—	—	
6191.6	1	—	6192.3	—	—	
6201.5	3	—	6202.0	—	—	ZrO e–X
6267.6	2	—	6268.3	—	—	
6275.9	2	—	6276.4	—	—	
6343.1	1	6343.9	6344.0	C_2–X_2	0, 0	ZrO γ
6353.8	3	—	6354.2	C_2–X_2	0, 0	ZrO γ
6363.0	2	—	6362.6	C_2–X_2	1, 1	ZrO
6429.0	1	—	6430.3	—	—	ZrO $^1\Sigma^+ - X^1\Sigma^+$
6866.5	8	6867.2	6867.0	—	—	atm. O_2
6900.8	1	—	6901.4	—	—	atm. O_2
6903.5	2	—	6903.4	B_2–X_2	2, 1	atm. O_2
6980.8	6	—	6981.4	—	—	atm. H_2O; ZrO e–X
6998.4	5	—	6998.3	—	—	atm. H_2O
7039.4	1	—	7039.5	—	—	atm. H_2O
7043.1	1	—	7043.0	—	—	atm. H_2O; ZrO γ
7057.2	2	—	7057.5	—	—	atm. H_2O
7143.0	3	—	7143.9	—	—	atm. H_2O; ZrO γ
7152.8	4	—	7153.5	—	—	atm. H_2O
7235	1	7237	7235.7	B_2–X_2	0, 0	atm. H_2O
7239	5	7239	7241.6	n	0, 0	+ ?
7243	3	—	7242.6	B_2–X_2	0, 0	atm. H_2O
7249	4	7246	7249.9	n	0, 0	atm. H_2O
7275	4	7274	7275.5	B_2–X_2	1, 1	atm. H_2O
7278	4	—	7277.9	—	—	atm. H_2O

observed in R Cyg by Wyckoff and Wehinger and Wyckoff and Clegg [column (3)] and with the laboratory wavelengths identified by Barrow *et al.* [column (4)]. The identified transition, band head assignment and the masking sources are presented respectively in columns (5), (6) and (7).

It may be seen from Table I that the identified band head positions in π^1 Gru match reasonably well with those of the laboratory spectrum. The bands lying in the 7200–7280 Å region are the strongest features identified both in the stellar and laboratory spectra. However the bands at 6866.5 and 6980.8 Å are seen (Figure 1) to be very strong because of their blending with the atmospheric absorption features. It may thus be noted that the atmospheric O_2 band (B-band) is the main contributor to the 6866.5 Å band, while the 6980.8 Å band is contaminated with the atmospheric H_2O and ZrO features. The identifications in this region and beyond are complicated due to the inaccuracies of band head positions coupled with the blending of terrestrial O_2 and H_2O (see Moore, Minnaert, and Houtgast 1966). Notwithstanding this difficulty, it is now well established that the identifications in

the region longward of 7200 Å are correct following Clegg and Lambert, who confirm the presence of CeO in S stars by resolving the rotational structure of the bands in the regions 7200–7295 Å of R Gem and 7500–7590 Å of R And.

Of the 32 stellar features identified in the present investigation, we find that the bands lying between 6046 to 6276 Å region are relatively free from blends. The features identified in the region of 6343–7278 Å are severely masked by ZrO, terrestrial O_2 and H_2O molecular features. In addition to the 9 bands already observed in R Cyg, in the present study 23 more new bands, 9 in the 6084–6276 Å and 14 in the 6353–7278 Å regions are tentatively identified. Although the stellar band head positions compare well with those of the laboratory spectrum, it is unfortunate that for only four bands at 6354, 6363, 6903 and 7243 Å, the assignments are available. Even though the identification of CeO is tentative, it is noteworthy that the present study shows up the need for further laboratory investigations of the CeO spectrum in the visible region, in addition to the observational studies of π^1 Gru under high resolution.

PURE S STAR CHARACTER OF π^1 GRU

The spectrum of π^1 Gru is seen to closely resemble the appearance of R Cyg, a well-known pure S star. Pure S stars are characterized by having very strong molecular features of ZrO, YO, LaO and the bands of TiO are either absent or only weakly present at moderate dispersion (Keenan 1966). The presence of strong ZrO and YO bands and the absence of the TiO γ' (0, 0) band at 6158 Å and γ (0, 0) band at 7054 Å, as seen from Figure 1, indicates that π^1 Gru is also a pure S star. Furthermore, molecular features due to CeO are also identified. The identification of CeO alone however, does not support the pure S star character of π^1 Gru, because CeO is also identified in R And, an S star with TiO. Nevertheless, the identification of CeO strongly suggests the possible presence of LaO also, since both Ce and La are chemically equivalent. It is thus evident that π^1 Gru warrants further study in order to confirm its pure S star character.

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