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(NASA-CR-181387) OPTICAL SPECTROSCOPY OF IRAS SOURCES WITH INFRARED EMISSION BANDS. 1: IRAS 21282+5050 AND THE DIFFUSE INTERSTELLAR BANDS Semiannual Status Report, 31 May - 30 Nov. 1987 (California Univ.)

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CONTENTS

This 6 month period included two technical publications one in press for The Astrophysical Journal Letters, the second submitted to the same journal. The article in press deals with optical spectroscopy follow-in to an IRAS source studied with the Kuiper Airborne Observatory. The second treats the subject of the most recent KAO expedition to New Zealand, to observe Supernova 1987a.

ATTACHED 2 papers

OPTICAL SPECTROSCOPY OF IRAS[1] SOURCES WITH INFRARED EMISSION BANDS: I. IRAS 21282+5050 AND THE DIFFUSE INTERSTELLAR BANDS.

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Received............

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1 The Infrared Astronomical Satellite was developed and operated by the U.S. National Aeronautics and Space Administration (NASA), the Netherlands Agency for Aerospace Programs (NIVR), and the U.K. Science and Engineering Research Council (SERC).

ABSTRACT

Spectroscopy of the starlike optical counterpart to IRAS 21282+5050, a source with the "hydrocarbon" infrared emission band spectrum, shows an O7(f)-[WC11] planetary nebula nucleus suffering an extinction of 5.7 mag. Emission line widths in the WC spectrum are only $\sim$100 km s^{-1}, indicating a very slow stellar wind. Optical diffuse interstellar bands (DIBs) are prominent. Five DIBs are strongly enhanced, namely $\lambda\lambda$5797, 6196, 6203, 6283, and 6613. The presence of circumstellar hydrocarbon molecules may explain both the infrared emission bands and the enhanced DIBs.

Key words: nebulae:planetaries - infrared sources - stars:Wolf-Rayet - stars: Of - diffuse interstellar bands

I. INTRODUCTION

This letter represents the first in a series treating optical spectroscopy of selected IRAS sources from the sample of 20 objects described by Cohen, Tielens, and Allamandola (1985) that have IRAS low-resolution spectra showing the strong infrared emission bands at 7.7, 8.7, 11.3, and the weaker new feature at 12.7 μm. All these bands are attributed to emission from polycyclic aromatic hydrocarbon (PAH) molecules (e.g. Cohen et al. 1986).

The present paper treats the starlike optical counterpart of IRAS 21282+5050 (hereafter 21282). De Muizon et al. (1986) have found an emission plateau, extending the strong 3.3 μm feature to 3.6 μm, that Barker, Allamandola, and Tielens (1987) argue represents "hot bands", related to the 3.3 μm PAH feature but displaced to longer wavelengths due to molecular anharmonicity.

We describe low- and high-resolution spectra of 21282; determine radial velocities and line widths; find a hot photosphere and a slow stellar wind; and note a strong, optical, diffuse interstellar band (DIB) spectrum, several bands of which are selectively strongly enhanced. It is tempting to regard the circumstellar environment of 21282 as a "missing link" between the DIBs and the PAHs. A general connection between the spectra of ionized PAHs and the DIBs has already been suggested (e.g., Crawford, Tielens, and Allamandola 1985).

II. THE OBSERVATIONS

a) Cassegrain Spectroscopy

On 1985 December 12 we observed 21282 on the Shane 3 m telescope with a Cassegrain grism spectrograph having an 800x800 Texas Instruments CCD detector covering 4000-7500A at ~13A resolution. The slit was

2.5" wide. The spectrograph also yielded direct images by moving the grism out of the light path. On 1986 November 9 we reobserved 21282 in the blue with a UV grating spectrograph incorporating the same CCD chip and slit. We covered 3300-6500A with ~10A resolution. Both exposures were 10 min.

b) Echelle and Coude Spectra

On 1986 December 11 we used the new Hamilton Echelle Spectrograph (Vogt 1987) with the same CCD chip for a 60 min exposure of 21282 from ~4600-7600A. Instrumental resolution (the observed FWHM of lines from a Th-Ar calibration lamp) was 0.13 (in the blue) to 0.18A (red). Flatfields and Th-Ar exposures were taken for smooth images and wavelength calibration. Two 30 min exposures with 1.4A instrumental resolution between 6425 and 6818A were kindly obtained by Dr. G. Herbig on 1987 June 7 at the coude focus of the Shane telescope with the same CCD readout. We coadded these to check the accuracy of wavelengths from the echellogram, also to fill in data lost because the echelle image is larger than the CCD detector.

III. RESULTS

21282 appears starlike on the NGS-PO Sky Survey plates and with the Shane Telescope's CCD acquisition TV camera. The spatial profile of 21282, perpendicular to the dispersion direction, is 2.5" FWHM from a "mash" of the entire spectrum, compared with 2.2" for a neighboring star. Further, the spatial profile in 21282's strongest emission line (nebular [N II]) yields the same FWHM as the adjacent red continuum. 21282 is, therefore, no bigger than 1.2" FWHM.

Seeing conditions caused the red and blue Cassegrain spectra to yield flux density scales differing by 1.36 ± 0.04. We refer measurements to the brighter (red) scale for absolute quantities. Synthesized continuum magnitudes for 21282 from the low-resolution spectra (ignoring emission features) are U = 16.33, B = 15.98, V = 14.40, and R = 13.39.

Fig. 1 presents the two Cassegrain spectra. Fig. 2 combines these using the average of the red data and 1.36 times the blue where they overlap. Scales are chosen to emphasize absorption features in Fig. 1, and emission lines in Fig. 2. The spectrum is dominated by prominent emission lines of [NII] (λ6584 overpowers even Hα), H, [OII], and C II. Table 1 details the emission lines from high-dispersion data. The low-resolution blue spectrum also shows λ3727 [O II] 1F; 3754-9 O III 2; 3785 He I 64; 3813 He II 4; 3819 He I 22; 3923 He II 4; 4713 He I 12; 4861 Hβ; 5640/48/62 C II 15; 6095/99 C II 7/9; and 6300 [O I] 1F. The combination of powerful [N II] and the plethora of C II and C III emissions recalls late-WC planetary nebula nuclei like CPD-56° 8032 (Thackeray 1977). All lines identified in Table 1 are seen in planetaries or in cool WC stars.

Photospheric absorptions confirmed by the independent low-resolution spectra include: H11; H8; H7; 4009 He I 55; 4026 He I 19/He II 3; 4068-70 C III 16; 4089 Si IV 1; Hδ; 4116 Si IV 1; 4121 He I 16; 4200 He II 3; 4471 He I 14; 4542 He II 2; 4647-51 C III 1; 4922 He I 48; 5048 He I 47; 5412 He II 2; and 5592 of O III 5. The He II lines indicate an O-star; the ratio of EW(4471)/EW(4542) suggests O7-8 (cf. Conti 1973). We divided the blue low-dispersion spectrum of 21282 by reddened O-type photospheres from Jacoby, Hunter, and Christian (1984), seeking the flattest quotient spectrum and incrementing the extinction by 0.1 mag. The flattest spectrum and best overall line cancellation were achieved by dividing 21282's spectrum by that of HD 108 (O7f: Hutchings 1976), extinguished by 5.7 mag (Fig. 3). The λ4640 emission of N III (assumed stellar rather than a nebular fluorescent line) relates 21282 to the Of stars. The echellogram shows He II λ4686 is almost "neutralized" as Walborn (1971) terms the cancellation of envelope emission and photospheric absorption. The He II line shows an emission core within a much broader absorption so we designate 21282's spectrum as O7(f) following Walborn (1971). The absence of C IV $\lambda\lambda$5801,5812 emission supports this classification.

A_V is 5.7$\pm$0.1 mag from the flatness of the quotient spectrum although 21282 turns down below ~3800A (Fig. 3). This extinction agrees with that derived from the color excess ($(B-V)_{intrinsic}=-0.30$ for an O7 I, E(B−V)=1.88 and $A_V\sim5.8$).

Table 2 details the photospheric absorption lines beyond 4626A where the echellogram begins. We estimate velocity errors of $\pm$5 km s^{-1} in the blue and $\pm$2−3 km s^{-1} in the red. Excluding the He II 4686 structure and any P Cyg components, Table 2 yields an average velocity of −12.3$\pm$3.3 km s^{-1} from 10 absorption lines. We omitted four lines from Table 2 because their identifications seemed uncertain. These are 5380.96, Ti II 69 5381.02; 6077.89, A II 12 6077.43; 6468.04C, N III 14 6468.77; 6532.74C, N II 45 6533.0 ("C" denotes coude observed wavelength). Their inclusion, however, would not greatly influence the mean velocity of the absorption features.

Strong non-telluric, non-photospheric absorptions are also conspicuous, notably $\lambda\lambda$3933,3969 of Ca II 1, the Na I D-lines, and the DIBs at $\lambda\lambda$4428, 4882, 5362, 5780, 5797, 6178, 6203, 6283. We sought weaker DIBs in the echellogram but the mismatch between CCD dimensions and the echelle image meant that not all DIBs were covered at high dispersion. Table 3 summarizes these diffuse absorption features. EWs have been converted into color excesses, E(B−V), and hence A_Vs (for R=3.10), extrapolating from the relations given by Herbig (1975) for Cygnus. For the sodium lines we followed Bromage and Nandy (1973). Both sodium lines consist of at least two overlapping narrower components (Table 2) whose combined intrinsic widths are 27 (D1) and 25 (D2) km s^{-1}. Most of the DIBs show two absorption components and/or are very broad.

IV. DISCUSSION

a) The Emission Lines

We categorize 21282 as an unresolved planetary nebula with a modest-excitation spectrum. Photons ~30 eV are necessary to produce the [O III], [A III], and permitted C III and N III lines. There is no significant difference in width between three groups of lines, namely: 6 H, He I, or He II, 26±5 km s^{-1}; 2 NIII, 30±10; and all 9 forbidden lines, 22±1. However, the Wolf-Rayet-like lines are all much broader: 11 C II lines, 78±11 km s^{-1}; 4 C III, 89±24; and 3 O II, 122±28. The absence of C IV emission, the dominance of C II over C III emission, and the narrowness of the observed lines mark 21282 as [WC11] (cf. van de Hucht et al. (1981)). Yet the presence of stellar absorptions and of [O III] lines indicate a somewhat hotter environment than typifies some [WC11] planetary nebula nuclei. We therefore characterize 21282 as O7(f)-[WC11], noting that even the Of emission lines are "sharp" according to Heap's (1977) scheme.

The ratio of intensities of the 6717 and 6731A [S II] lines appears to be 0.95±0.07. However, the λ6731 line is seriously blended with C II emission so this ratio is strictly a lower bound, suggesting $N_e<500$ cm^{-3}. Assuming the [S II] lines suffer the same extinction as the stellar continuum, the observed limit on the combined strengths of the λλ4069+4076 blue lines ($<7.3\mathrm{x}10^{-16}$ erg cm^{-2} s^{-1}) implies an intensity ratio, I(6717+6731)/I(4069+4076), of >0.25, so N_e is only $\lesssim 10^5$ cm^{-3}. If the [O II] lines suffered the identical extinction, the intrinsic ratio of I(3726+3729) to I(7319−30) would be ~50, implying N_e=200 cm^{-3} for $T_e=10^4$K. N_e is therefore modest, around a few hundred.

b) Luminosity and Distance

If the photospheric reddening were purely interstellar (rather than circumstellar) then, from the studies of extinction by FitzGerald (1968) and Lucke (1978), 21282 would be more distant than 3 kpc. Alternatively, 21282 might lie much closer to the sun, reddened by a dusty circumstellar envelope. Conti, Garmany, and Hutchings (1977) have shown that, in Of stars in general, even the absorption line velocities do not represent the stellar systemic motion but are formed in a wind. Therefore, we can derive no reliable distance from velocities in 21282.

The IRAS fluxes in version 2 of the Point Source Catalog (1985) are 51, 74, 33, and 15 Jy, respectively, in the four bands. The total luminosity seen by IRAS if 21282 is at distance D pc is, therefore, $5.69\mathrm{x}10^{-4}D^2$ $L_\odot$ including allowance for luminosity beyond 100 μm (Cohen 1973). Estimating the optical luminosity and that between 0.75 and 12 μm rather crudely (using the 3−3.8 μm continuum data of de Muizon et al. 1986) increases the multiplier in the bolometric luminosity to $6.04\mathrm{x}10^{-4}$. Even if the reddening were entirely interstellar with A_V~1 mag kpc^{-1}, L_{bol} would be ~20000 $L_\odot$, entirely reasonable for a compact planetary nebula.

c) The Diffuse Bands

Krelowski and Walker (1987) have argued for three families of DIBs. Of the DIBs relevant to 21282, they group 4430 with 6177; 5780, 6196, 6203, 6269, and 6283; and 5797, 5850, and 6613. We converted EWs into A_Vs when possible and compared EWs in 21282 with those in HD 2905 (Krelowski and Walker's reference star). Some of the DIBs appear with normal strength in 21282 (Table 3) based on either their equivalent A_V values or their small increase in EW toward the much more heavily reddened 21282 (5.7 mag) compared with HD 2905 (1.0). Therefore, we assign these "normal" bands (4430, 5778+5780, 6269, and probably the D-lines [the latter are masked by night sky emission in the echellogram but the low-resolution spectra yield a combined EW of 1.1A, equivalent to $A_V \sim 4$]) to one family. Likewise we group 6196, 6203, and 6283 due to their appreciable enhancement in 21282. Our final family would be 5797 and 6613 which are very strongly enhanced, by factors of 2-4 (in either A_V or EW). The assignment of 5850 is in doubt (due perhaps to our inability to separate the sharp, strong 5849 feature from the much broader 5844 band); its A_V suggests modest enhancement but comparison with HD 2905 suggests none. Our groups resemble Krelowski and Walker's "families", notably in the association of 5797 with 6613, and the common behavior of 6196, 6203, and 6283. The decoupling of 5780 and 5797 apparent in 21282 supports a general suggestion by Westerlund and Krewloski (1987). Despite the differences between the spectrum of 21282 and the norm, the ratios of $A_c(4430)/E(B-V)$ and $A_c(5780)/A_c(5797)$ (A_c denotes central depth) fall on the trend presented by Krelowski et al. (1987) for slightly reddened stars (their Fig. 9).

Since the primary criterion for observing 21282 was its circumstellar PAH emission bands, it is tempting to ascribe the five strongly-enhanced DIBs also to the presence of circumstellar PAH-related molecules. Certainly 21282 is carbon rich, if the overabundance of carbon in the [WC11] object, CPD-56° 8032 (Houziaux and Heck 1982), is a guide, and Cohen et al. (1986) have shown a strong correlation for planetaries between nebular C/O and strength of the dominant PAH band. We note also that one obtains wavelengths near PAH features from the difference in wavenumbers between 5797 and 6283 (7.5 μm); 5797 and 6203 (8.9 μm); and 6283 and 6613 (12.6 μm).

d) Velocity Structure and Implications

We find the following average radial velocities for different groups of lines: 3 P Cyg absorptions, -39 ± 4 km s^{-1}; 3 N III and He II emissions, -20 ± 6; 10 pure absorptions (Table 2), -12 ± 3; all 12 forbidden lines, 7 ± 2; all 29 permitted lines, 10 ± 3. Hα is markedly asymmetric with red emission extending to +246 km s^{-1}. Although we cannot gauge 21282's systemic motion directly we expect the centroid of the C II and C III emission lines (+8 km s^{-1}) to provide a rough estimate of the stellar velocity since these lines should arise, and be observable, throughout the entire nebula. Combining this velocity with the emission line widths and P Cyg absorptions suggests that the wind velocity is only $\sim$50 km s^{-1}.

The coexistence of N III emission in the wind from 21282 with a carbon-rich envelope is puzzling but not without precedent among cool [WC] nuclei. IC418, O7fp or [WC7], shows N III 2 like 21282 (Aller and Kaler 1964); BD+30°3639, [WC9], N IV 1 and N V 1 (Smith and Aller 1971); and M4-18, [WC10], N III 3 (Sabbadin 1980). However, the velocity difference for 21282 between the O-star lines and the C II/III emissions could alternatively signify a binary nucleus.

The bluest velocities are shown by the DIBs, up to −120 km s^{-1} for some band edges, with distinct components at ∼−55 and even −90 (Table 3). Assuming the enhanced DIBs are circumstellar, we might expect them to show radial velocities distinct from the sodium lines. Therefore, we tentatively associate these enhanced DIBs with clouds at −3 km s^{-1} (6196 and 6613) and at substantially negative velocity, up to ∼−100 km s^{-1}, to match the highly blueshifted absorptions of 6203 and 6283. It is, therefore, plausible that the DIBs are associated with material both in the wind from 21282 (highly blueshifted, carbon-rich matter) and close to the systemic velocity of 21282 (the −3 km s^{-1} component) that has already been decelerated by the ambient medium.

We thank Gibor Basri for his valuable help in extracting the data from the Hamilton echellogram; George Herbig for permission to use his coude spectra; and Lou Allamandola, Peter Conti, George Herbig, Xander Tielens, and Nolan Walborn for useful discussions. The Cassegrain observations and reductions were partially supported by NSF grant AST 86-14510 to the University of California, Santa Cruz. MC thanks NASA-Ames Research Center for supporting this work through Cooperative Agreement NCC 2-142 with Berkeley.

FIGURE CAPTIONS

Fig. 1: Separate blue and red Cassegrain low-dispersion spectra of 21282. Ordinate is F_λ; units are 10^{-14} erg cm^{-2} A^{-1}. Scale is chosen to emphasize the absorption features.

Fig. 2: Combined spectrum of 21282; ordinate as for Fig. 1. Scale is chosen to show the emission lines.

Fig. 3: Ratio of the blue spectrum of 21282 to that of HD 108, an O7f star, after extinguishing the latter by 5.7 mag.

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Table 1. Emission lines in IRAS 21282+5050.

Observed [a] Wavelength (A)	Identification Wavelength (A)	Ion/M'plet [c]	V(heliocentric) ($km\ s^{-1}$)	Width [b] ($km\ s^{-1}$)
4640.72	4640.64	N III 2	-10	40
4641.66:	4641.90	N III 2	-31:	20:
4685.62	4685.68	He II 1	-19	-
4959.23	4958.91	[O III] 1F	4	29
5007.13	5006.84	[O III] 1F	2	26
5696.26	5695.9	C III 2	4	81
5875.99	5875.63	He I 11	3	21
5932.84	5932.2	He II -	17	15
5953.89	5953.0	He II -	30	19
6364.28	6363.81	[O I] 1F	7	19
6461.55C	6462.0	C II 5	7	78
6548.43	6548.06	[N II] 1F	2	20
6563.16	6562.82	$H\alpha$	0	27
6577.91C	6578.03	C II 2	9	53
6583.82	6583.39	[N II] 1F	4	20
6628.20C	6627.62	O II 85	41	126
6641.19C	6640.90	O II 4	28	71
6678.38C	6678.15	He I 46	25	49
6716.91	6716.4	[S II] 2F	7	26
6721.87C	6721.35	O II 4	38	168
6727.62C	6727.4	C III 6	25	2
6731.17	6730.8	[S II] 2F	1	20
blend	6731.1	C II 5	-12	
6738.34	6738.36	C II 21	14	-

6741.94C	{6742.2	C III 5	3	} 32
blend	{6742.4	C II 3	−6	}
6744.21C	6744.4	C III 3	6	75
6761.80C	6762.2	C III 3	−3	153
6780.32	6779.9	C II 8	3	94
6784.25	6783.9	C II 10	0	85
6787.58C	6787.2	C II 6	32	67
6791.35C	6791.5	C II 5	8	138
6797.64C	6798.1	C II 3	−6	67
6801.10	6800.7	C II 7	32	137
6952.46	6952.8	O III −?	−30	46
7037.92	7037.3	C III 7	11	56
7065.70	7065.19	He I 10	6	25
7136.26	7135.8	[A III] 1F	4	22
7231.73	7231.3	C II 18	3	57
7236.65	7236.4	C II 20	8	54
7319.45	7318.6	[O II] 2F	19	19
7320.41	7319.4	[O II] 2F	26	18
7330.07	7329.9	[O II] 2F	11	20
7331.13	7330.7	[O II] 2F	2	21

[a] geocentric; if a "C" follows, the observed wavelength is from the coude spectra; otherwise all are from the echellogram. The corrections to convert geocentric to heliocentric velocities were −15.3 (1986 Dec.) and +14.7 km s^{-1} (1987 Jun.).

[b] corrected for instrumental resolution

[c] C II and C III multiplet assignments follow Thackeray (1977)

Table 2. Photospheric features in 21282.

Wavelength (A)	Identification Ion	(A)	V(heliocentric) (km s^{-1})
4647.41	C III 1	4647.34	-10.8
4650.14	C III 1	4650.16	-16.6
4651.21	C III 1	4651.35	-24.3
4685.39	He II 1	4685.68	-34.0[a,b]
4686.19	He II 1	4685.68	17.2[a]
4783.56	O IV 9	4783.43	-7.1
4794.32	O IV 9	4794.22	-4.7
4798.49	O IV 9	4798.25	-0.3
4921.94	He I 48	4921.93	-14.9
5047.70	He I 47	5047.74	-17.7
5592.72	O III 5	5592.37	3.5
5811.85	C IV 1	5812.14	-30.3
5875.25	He I 11	5875.63	-34.7[b]
6676.75C	He I 46	6678.15	-48.2[b]

[a] absorptions flanking the He II emission core

[b] P Cyg absorption component

Table 3. Interstellar features in IRAS 21282+5050.

Observed Wavelength (A)	DIB (A)	EW (A)	Velocity (km s^{-1})	A_V mag.	Notes	EW cf. HD 2905
4430	4428	3.3		5.4	1	3.2
4881.48	4882	1.0	-32		2	
5368	5362	0.7				
5534.31,5534.90	5535	0.3	-53,-21			
5779	5778+80	2.0		6.1	3	4.4
5779.56,5780.46	5780.41		-59,-13			
5800	5795+97	1.4		19/33	4	15.1
5850	5844+50	0.3		8.3	3	3.0
5889.38,5889.52	5889.97 }	1.1	-30,-23	4:	5	1.1:
5895.29,5895.56	5895.94 }		-33,-19			
6178	6177	1.4				3.5
6195.93,6196.21	6195.95	0.25	-16,-3	12		6.8
6201.49,6202.88	6203.06	0.85	-91,-24	12	6	7.4
6206.17	6206.49	0.3	-31			
6269.76	6269.77	0.3	-16	5.7		4.7
6283.85	6283.91	2.4	-18	16	7	6.6
6314	6314	0.35				
6613.25C	6613.63	1.5	-3	18		

Notes

1: wavelengths given precisely are from echelle data, or from coude data if followed by a "C"

2: λ4882 extends from -96 to +6 km s^{-1}

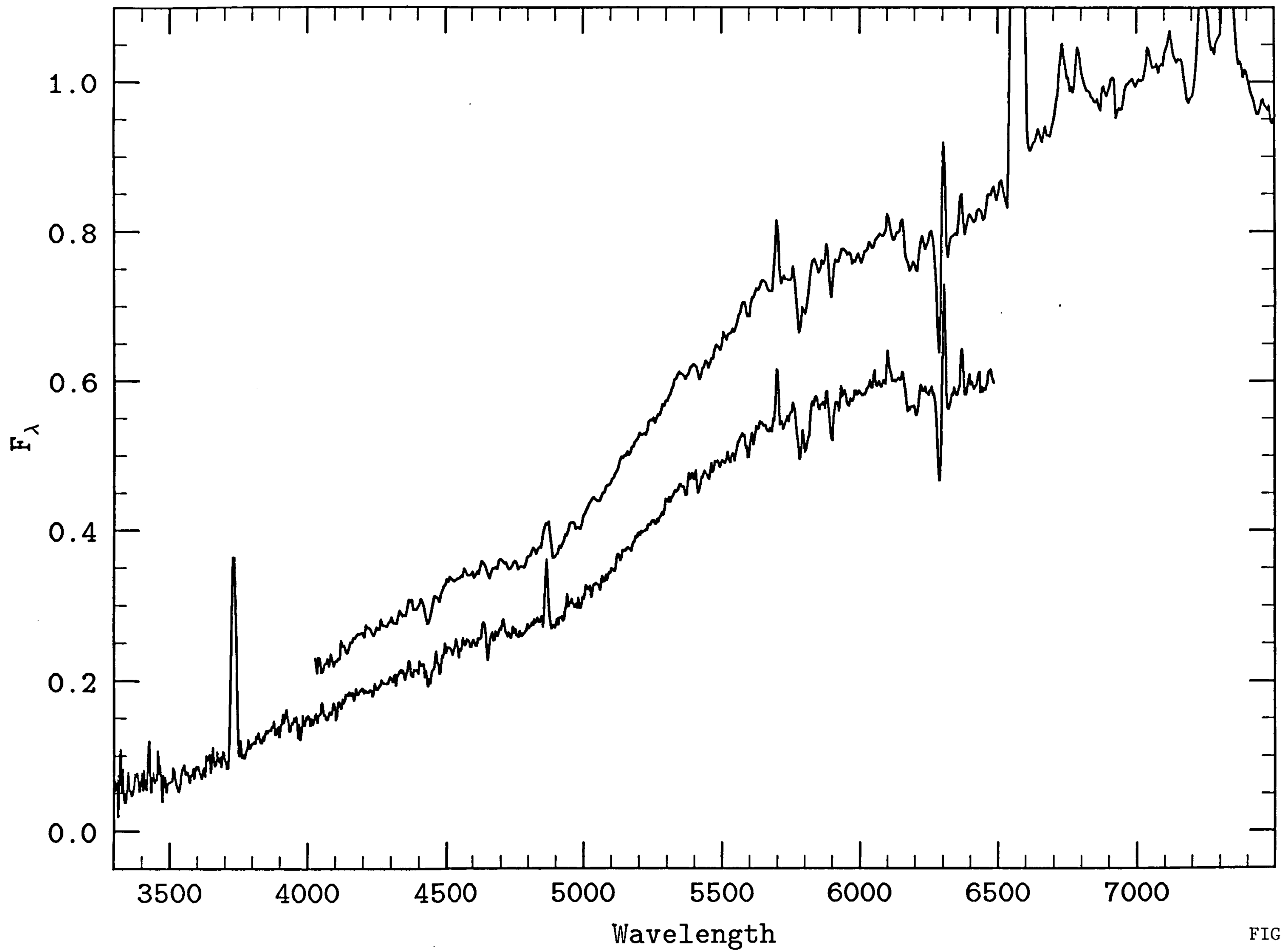
3: assuming EW is split equally between broad and sharp features

4: EW of λ5797 is corrected for the blend with C IV λλ 5801,12 absorption (C IV contributes 1.2 of the total 2.6A); A_V would be 19 from Herbig (1975) but 33 from Chlewicki et al. (1986)

5: redward emission to +19 km s^{-1} attends both D lines

6: λ6203 extends from −120 to +17 km s^{-1}

7: EW is corrected for O_2 λ6277 telluric absorption; absorption extends from at least −90 to +53 km s^{-1}.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0.6
0.4
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Wavelength
FIG. 1

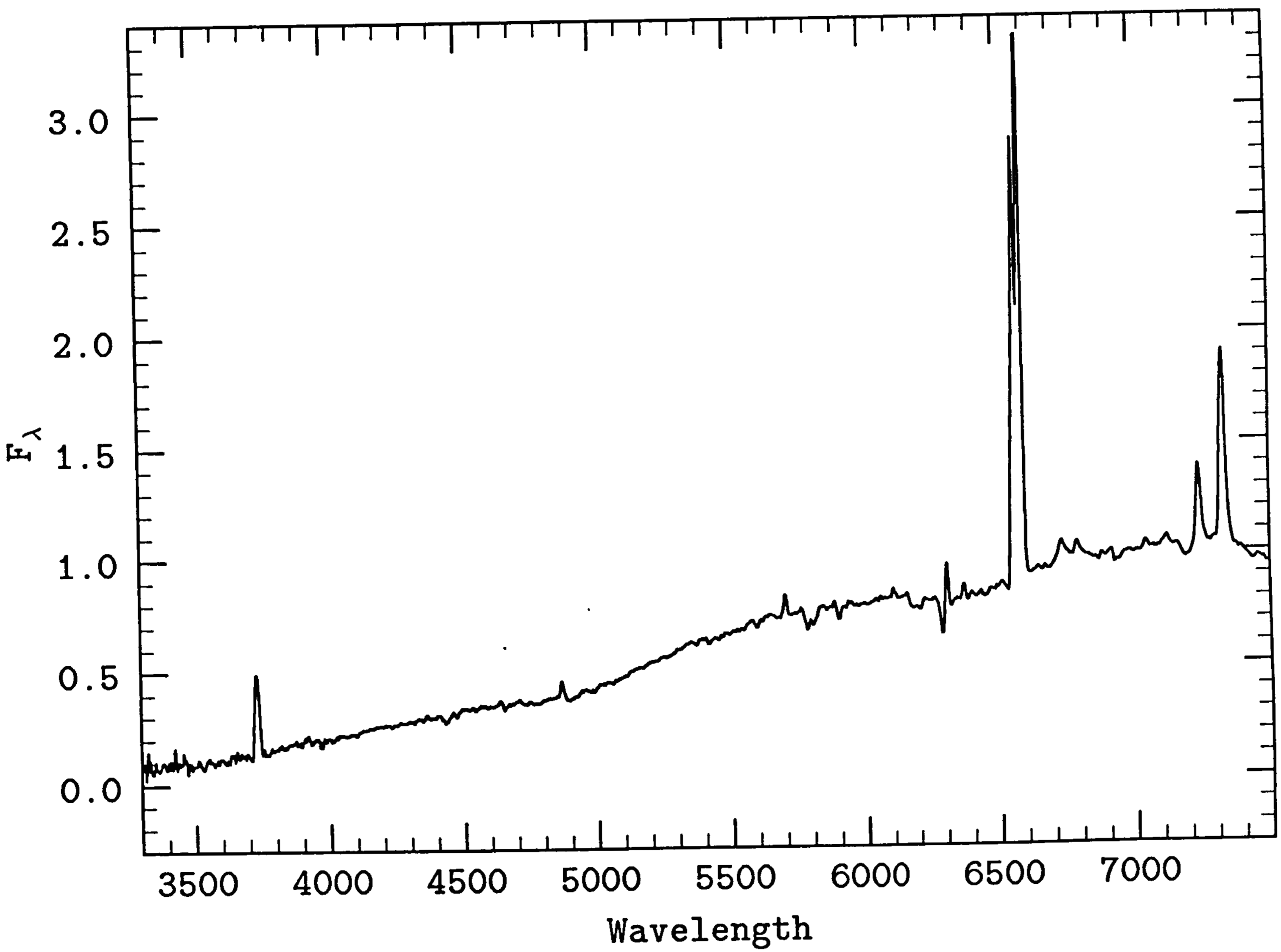
3.0
2.5
2.0
F_λ
1.5
1.0
0.5
0.0
3500
4000
4500
5000
5500
6000
6500
7000
Wavelength

FIG. 2

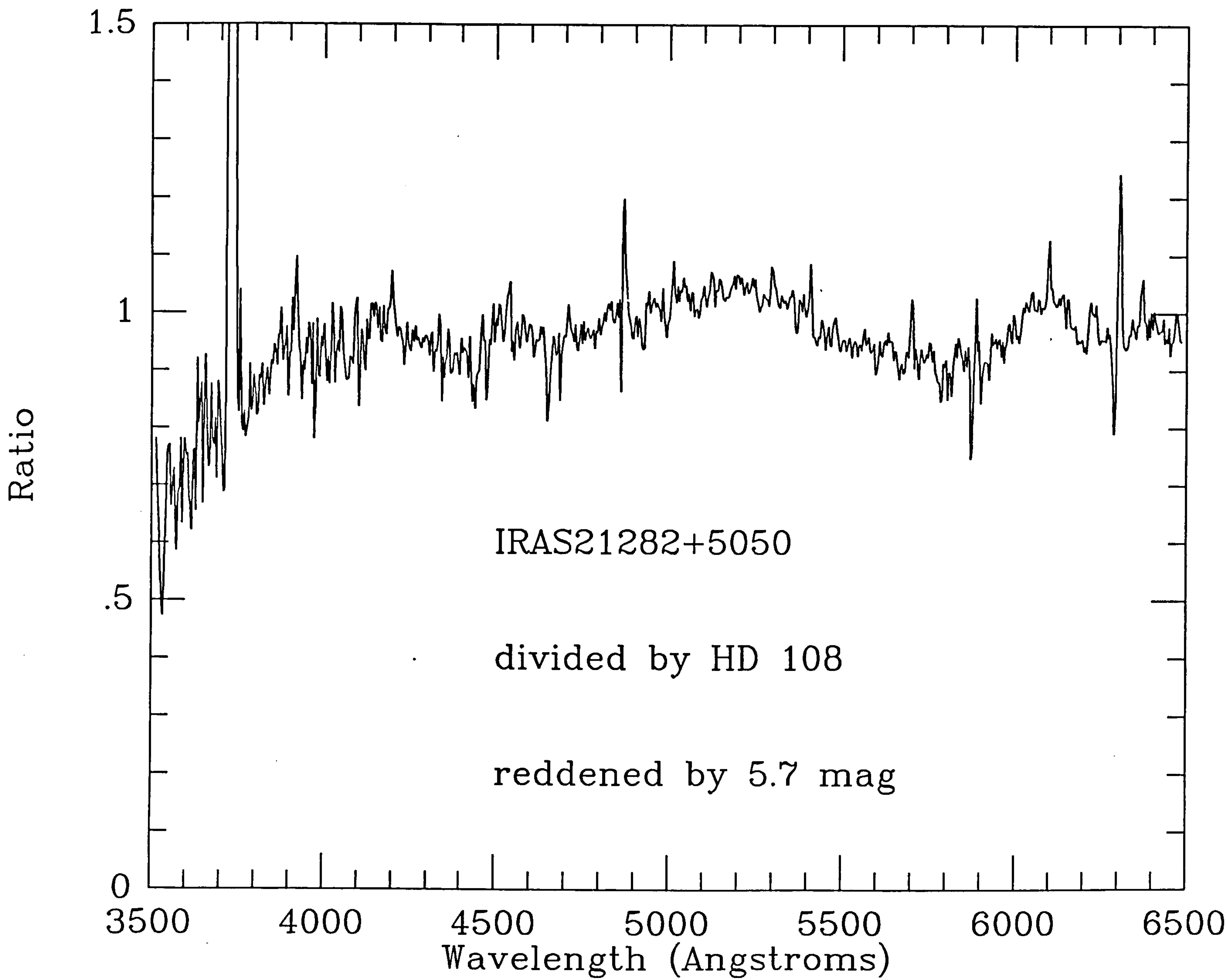
1.5
1
.5
0
Ratio
3500
4000
4500
5000
5500
6000
6500
Wavelength (Angstroms)
IRAS21282+5050
divided by HD 108
reddened by 5.7 mag

FIG. 3