With this instrument, M. Dennefeld has obtained at the ESO 3.6 m telescope the spectra of 4 O stars (Fig. 3).

The corrections for atmospheric absorption have been achieved by standard photometric procedures (observations of a standard star at different heights above the horizon), but they are imperfect because these observations have been performed during the early phase of putting the instrument into service.

We do not detect any intense C III λλ 9701–9715 emissions in the 2 hot stars (O3 and O4) we have observed. These lines are also absent in the O7.5 IIIe star, but they appear as a strong emission only in HD 152408 (O8 If) which is one of the most "extreme" O stars with a very important extended envelope (Fig. 3).

Our results, deduced from a very limited sample (only four O stars) do not confirm the predictions of H. Nussbaumer (1971, *Astrophys. J.*, **170,** 93) that λλ 9701–9715 should be in emission in hot stars (T_{eff} = 40,000–50,000 K) without taking into consideration an extended atmosphere. On the contrary, our observations show that the presence of λλ 9701–9715 emissions depends essentially on the importance of the atmosphere, in better agreement with the theory recently developed by N. A. Sakhibullen, L. H. Auer and K. A. Van der Hucht who conclude that there is a temperature and a luminosity effect.

The Paschen Series Lines

P8 and P9 are very well visible on all our spectra: they are in absorption: strong in the classical B9 star which is normal, faint in the Of stars. These latter observations are compatible with the theoretical predictions. Klein and Castor have computed the contribution of the stellar envelope of O stars to the intensities of Paschen lines. In most cases, they obtain a strong emission contribution at Pα but a weak one at P6. If we extrapolate, it is normal to observe P8 and P9 in absorption.

Only the Oe star (HD 155806) exhibits P8 and P9 in emission but this star is related to Be stars which often present the Paschen series in emission.

Oe Stars

In the blue region, the spectra of Oe stars are similar to Be stars. So far, no Oe star has been observed up to 1,1 μ. It was interesting to fill this gap and to compare the spectra of Oe and Be stars in the near infrared (Y. Andrillat, J. M. Vreux, M. Dennefeld 1982, IAU Symp. No. 98 p. 229, Eds. M. Jaschek, A. G. Groth).

M. Dennefeld has observed HD 155806 (O 7.5 IIIe) with the Boller and Chivens spectrograph + Reticon at the ESO 3.6 m telescope in the spectral range λλ5900–11000.

The spectrum is very rich (Fig. 4) exhibiting many emissions: Hα is very strong and the Paschen series is visible up to P18. He I lines are present: λ 10830, not visible in Fig. 4, is intense; He II λ 10123 is absent; O I λλ 7772, 8446, Ca II infrared triplet, Fe II λλ 7515, 7712, 9997 are very well visible.

We have found all the elements identified in the Be stars. It appears that HD 155806 is related to Be stars of early type with

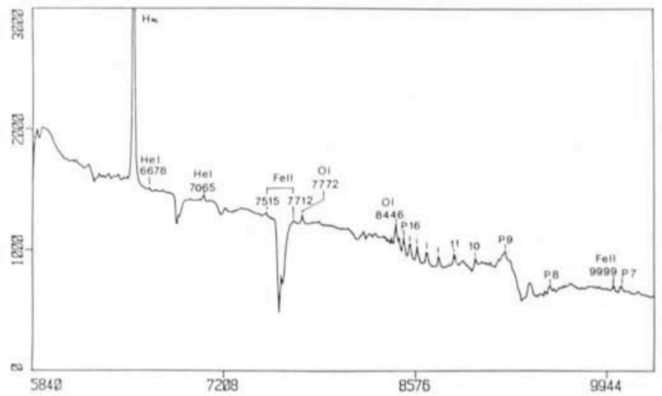

Fig. 4: *Spectrum of an Oe star in the near infrared: HD 155806 (O7.5 IIIe). (ESO 3.6 m telescope; Boller and Chivens spectrograph + Reticon; dispersion 228 Å mm^{-1}).*

a strong metallic envelope revealed by O I λ 7772 and Fe II λ 7712 both in emission and an Hα line very strong and without structure.

Moreover, a study concerning 68 Be stars (Y. Andrillat, L. Houziaux 1967, *Journal Obs.* **50,** 107 = Publ. OHP 9 n° 11) shows that the Paschen series and O I λ 8446 appear in emission in B0e, B1e, B2e . . . B5e stars but principally in B2e stars. He I λ 6678, visible in HD 155806, is present only in the B0e . . . B3e classes.

In conclusion, our observation confirms that HD 155806 initially classified as an O 7.5 IIIe is actually a Be star and very likely B2e or B3e star with strong metallic envelope.

Conclusion

In the evolutive scenario proposed by P.S. Conti, a link exists between the late-type O stars and the transition Wolf-Rayet stars. Some authors think that these WN7-WN8 stars have probably been formed from massive Of stars ($M > 35 M_{\odot}$), binary or not, having lost their mass by stellar wind effect.

It is therefore important to complete our knowledge of physical conditions in the atmospheres and evelopes of O stars. So it was desirable to extend the observations to a larger spectral range, in particular to the near infrared region for which observational data were very scarce.

This has been possible owing to the development of modern receivers, principally the ones with a linear response.

Our first observations in the near infrared have specified the behaviour of helium lines in terms of spectral types and luminosity classes in order to help the elaboration of theoretical models. In this spectral interval we have reached the important lines of C III and we could bring observational data to the studies of the processus of line formation. Finally the similitude between the Oe and Be stars are confirmed by their infrared spectrum. Especially the observations we have performed at the ESO Observatory using a Reticon receiver have already brought important results which are only a first approach of a further study of O stars which appears as a very promising one.

White Dwarfs—the Dying Stars

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Introduction

White dwarfs are one of the possible end products of stellar evolution—perhaps not as exciting as neutron stars or black holes, but certainly much more numerous: more than 90% of all single stars end their life as a white dwarf.

A study of these objects can thus provide information on the mass budget of the galaxy as a whole as well as on the evolution of normal stars—e. g. the amount of mass given back to the interstellar medium during the stellar lifetime compared to that locked forever in the interior of the final remnant. Aside from these statistical considerations many white dwarfs are of great interest also individually. Some of them have large magnetic fields of the order of 10^8 G, some are members of X-ray emitting binary systems. The great advantage in the study of white dwarfs compared to neutron stars is that we are able to look directly at the surface and analyse the atmospheres with the methods of model atmospheres, determining effective temperatures, chemical abundances, masses, etc.

The current picture of stellar evolution towards the final stages for a star of solar mass is the following: On the asymptotic giant branch the star consists of a small, dense core of about 0.5 to 0.6 solar masses and a very extended envelope, where the nuclear energy generation takes place in two shell sources, burning hydrogen respectively helium. At the top of the giant branch the star somehow manages to get rid of its envelope, which after some time becomes visible as a planetary nebula with the former core of the giant as the exciting central star at effective temperatures of 50,000 to 100,000 K. About 20,000 years later the nebula is dispersed and invisible and the central star has now become a hot white dwarf. It has no possibility for further nuclear energy generation, the only available sources being gravitational and thermal energies. Under the physical conditions prevailing in white dwarfs the final evolution must be a cooling down at almost constant radius until the star becomes invisible after 5 to 10 billion years.

What are these physical conditions? White dwarfs are objects of the size of the earth with masses half that of the sun ($0.5\ M_\odot$); the density is around 10^6 g/cm^3. In the interior the atoms are completely ionized and the free electrons are compressed to such a small volume that according to the Pauli principle many are forced to have high momenta. The pressure of these "degenerate" electrons stabilizes the star against its own gravity—independent of temperature. Therefore nothing will happen to the white dwarf if it cools down to very low temperatures: it is really a final state!

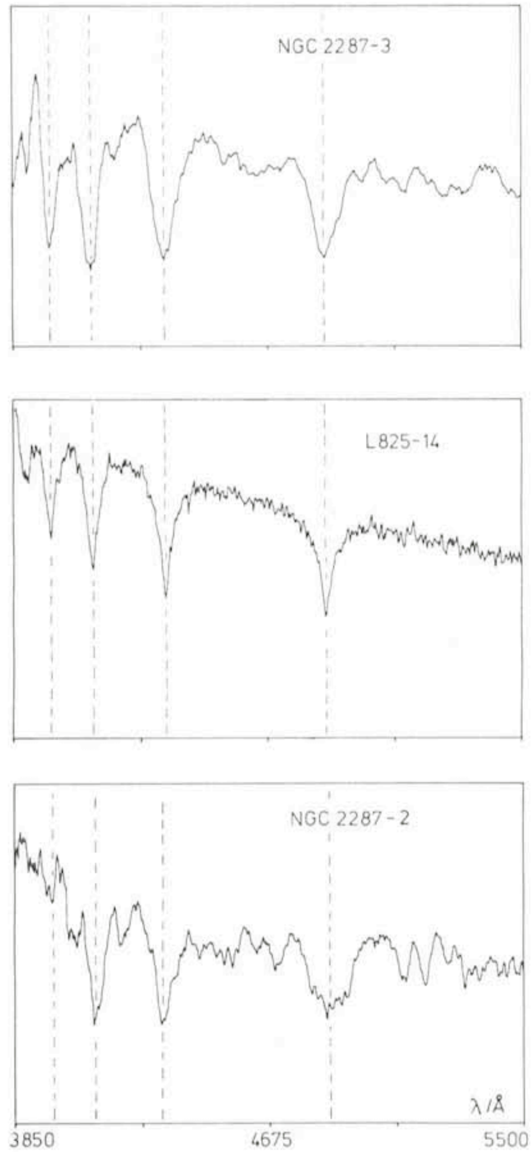

Fig. 1: *IDS spectra of white dwarfs No. 3 and No. 2 in the direction of NGC 2287. L825-14, a normal DA white dwarf in the field, is included for comparison.*

Which Stars Become White Dwarfs and which Not?

The largest mass for which stabilization by the degenerate electron pressure is possible is $1.4\ M_\odot$. However, also stars much more massive initially on the main sequence may loose enough mass during their evolution, especially in the giant phase, to get finally below this limit. Direct evidence is provided by the Hyades cluster with at least 6 white dwarf members. Since only main-sequence stars more massive than $2.1\ M_\odot$ (turnoff mass) can have evolved at all in the cluster lifetime, the parent masses of the white dwarfs must have been larger than this value.

At present we assume that it is only the initial mass, which decides about the final fate of the star, although this picture might be oversimplified (Weidemann 1980, IAU Coll. **59,** 339): stars with main-sequence masses below a critical value M_{wd} will become white dwarfs, those above M_{wd} supernovae and neutron stars (or black holes).

Several attempts have been made to determine the important parameter M_{wd}. Estimates from supernova statistics yield —with large uncertainties—$M_{wd} \gtrsim 5\ M_\odot$ (Tinsley 1975, *PASP* **87,** 837). Stellar evolution calculations including a semi-empirical mass-loss formula (Reimers 1975, *Mem. Roy. Sci. Liège* **8,** 369, Kudritzki and Reimers 1978, *Astron. Astrophys.* **70,** 227) also give $M_{wd} \approx 5\ M_\odot$ (Mengel 1976, *Astron. Astrophys.* **48,** 83; Fusi-Pecci and Renzini 1976, *Astron. Astrophys.* **46,** 417). Mass-loss rates have, however, not yet been determined for stars in the evolutionary phases near the top of the second giant branch most relevant for the total amount of mass loss.

Thus the only safe method to determine M_{wd} seems to be the identification of white dwarfs as members of galactic clusters in which stars around or slightly below M_{wd} are dying at the present time. The Hyades cluster is not particularly suited, since the turnoff mass is only about $2.1\ M_\odot$. Up to now, the only conclusive case seemed to be LB1497, a Pleiades member, with a progenitor mass $\gtrsim 6\ M_\odot$.

In order to improve the statistics Romanishin and Angel (1980, *Ap. J.* **235,** 992 = RA) conducted a search for a statistical excess of faint blue objects in galactic clusters compared to a nearby comparison field. They used a photographic method and confined the search to clusters in the galactic plane, where the blue extragalactic objects expected at faint magnitudes are obscured by the galactic dust layer. They found indeed several white dwarf candidates and, applying some statistics, concluded that $M_{wd} \approx 7\ M_\odot$.

Observations at La Silla

The main disadvantage of RA's method is that the identification of white dwarfs and cluster membership rests solely on blue colour and statistical considerations. I therefore decided—in collaboration with D. Reimers (Hamburg)—as a first step to continue the programme of RA with an attempt to make spectroscopic observations of the candidates identified by RA in the clusters NGC 2287 and NGC 2422 (Koester and Reimers 1981, *Astron. Astrophys.* **99**, L8). White dwarfs in these clusters are expected at magnitudes between $19\overset{m}{.}0$ and $21\overset{m}{.}0$, which means that a large telescope like the ESO 3.6 m is certainly required. The Image Dissector Scanner (IDS) is an ideal instrument for this kind of work, since it allows the subtraction of the sky background (much larger than the stellar signal!) and because high resolution is not necessary: most white dwarfs show only the Balmer lines of hydrogen broadened to $\approx$ 50 Å width by the high pressure in the atmospheres. These lines are easily identified even at a resolution of 10 Å.

For an observer not accustomed to such faint magnitudes it takes time to get used to some problems and the help of the staff astronomer and night assistant was gratefully accepted. The stars are so faint on the field of the television screen that integration times of the order of one minute are required to make them visible. If a brighter star is nearby its image may get so large that it completely hides the white dwarf. Also the guiding demands some skill if it takes a minute to see the result of the operation! When the object is finally in the aperture, the excitement is of course large, if after 10 min integration time—as was the case with exceptionally good seeing—the Balmer lines can already be seen in the raw spectrum, confirming that the object is indeed a white dwarf!

Fig. 1 shows two of the objects observed in the direction of NGC 2287 after 4 hours integration time. These are clearly white dwarfs of spectral type DA, as documented by the broad lines and a comparison with the field DA L825-14.

However, besides this information, what can the spectra tell us about cluster membership?

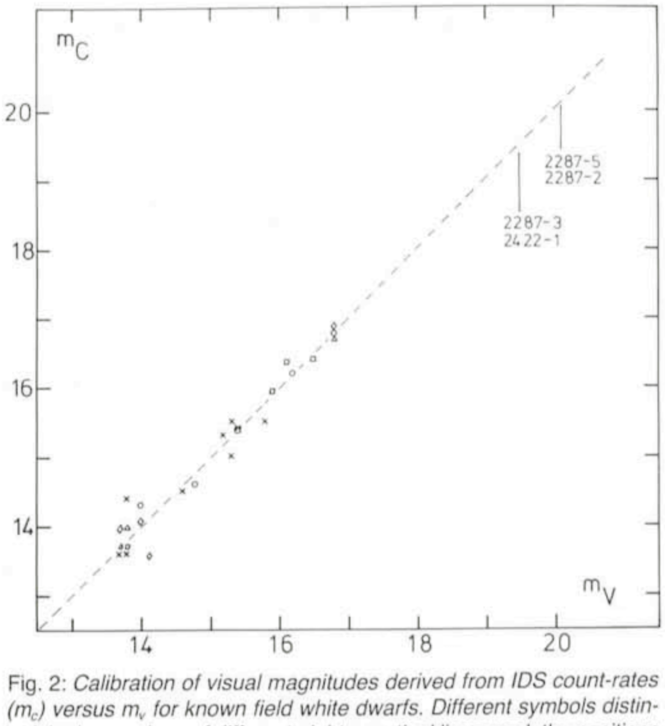

Fig. 2: *Calibration of visual magnitudes derived from IDS count-rates (m_c) versus m_v for known field white dwarfs. Different symbols distinguish observations of different nights; vertical lines mark the positions of the cluster candidates.*

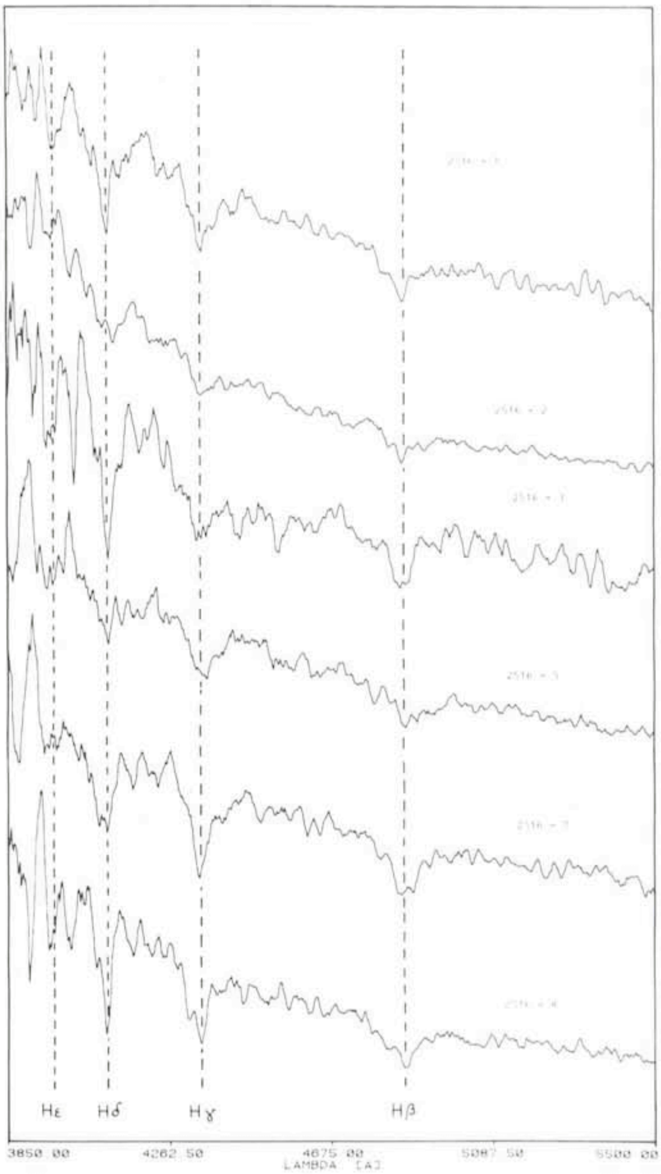

Fig. 3: *Six DA white dwarfs in the direction of NGC 2516. Nos. 1, 2, and 3 are close to the cluster centre.*

From the comparison of line equivalent widths with theoretical calculations a rough estimate of effective temperature is possible, which together with the fact that the DA seem to be confined to a narrow range of radii (Koester, Schulz, Weidemann 1979, *Astron. Astrophys.* **76,** 262) leads to an absolute magnitude for the objects. With the known distance modulus ($9\overset{m}{.}4$) for NGC 2287 the expected V magnitudes are $21\overset{m}{.}1$ for No. 3 (with an admissible range, including all uncertainties, of 20.1-23.2) and $19\overset{m}{.}9$ (range 18.9-22.0) for No. 2. Unfortunately the V magnitude is not known and would be difficult to obtain photometrically. To overcome this problem we made an effort to use the IDS itself as a photometer. The wavelength region used (4000-6000 Å) roughly covers that of the Johnson V band. We therefore just added all net counts (sky subtracted) of the IDS system, derived a magnitude from this number (≈ -2.5 log N) and calibrated this against the known V magnitudes of brighter DA white dwarfs observed during the same nights at similar zenith distance. The scatter around a linear relation with slope 1 turns out to be surprisingly small and gives us confidence in an extrapolation to V $\approx$ 20 (Fig. 2) which, however, relies heavily on the assumed linearity of the IDS at low count-rates. The derived magnitudes are 19.5 ± 0.5 (No. 3), respectively 20.1 ± 0.5 (No. 2). A comparision of this observed V with the expected value, together with a thorough discussion of error margins, cooling ages of the white dwarfs, and cluster ages led us to the conclusion that 2 of the 3 white dwarfs identified in the direction of NGC 2287 (including No. 2) are most probably cluster members, whereas No. 3 is probably a foreground object. From the turnoff mass of NGC 2287 we thus find that M_{wd} is definitely larger than 3.9 $M_\odot$.

The next step in our project was the extension of RA's photographic search to clusters accessible only from the southern hemisphere. H. E. Schuster (ESO) took excellent Schmidt plates of several clusters in the red and blue spectral regions, which allowed us to find many blue candidates. For NGC 2516 the spectroscopic observations have been completed by D. Reimers in March 1982. Fig. 3 shows 6 white dwarfs identified, three of which lie very close to the cluster centre. An analysis like that for NGC 2287 has not yet been completed; we are quite sure, however, that at least some of them are cluster members. This will bring the lower limit on M_{wd} up to 5 $M_\odot$, without using any statistical considerations.

Conclusions

The 3.6 m ESO telescope and the IDS are an ideal combination to identify extremely faint white dwarfs in open clusters. We have now set by purely observational methods the lower limit of the critical mass M_{wd} that determines the final fate of single stars (white dwarf vs. supernova) at ≈ 5 $M_\odot$. In the case of NGC 2516 one of the original candidates turned out to be probably a QSO. The extragalactic background is obviously not completely obscured even at low galactic latitudes, and spectroscopic observations are necessary to distinguish white dwarfs.

In the future we plan to extend our search to clusters with even higher turnoff masses, and a number of candidates have already been detected on the Schmidt plates.

High Spectral Resolution Observations of [S II] Lines in the Planetary Nebula IC 418 at the CES Spectrograph

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Summary

Preliminary observations of [S II] lines at 6717 and 6731 Å of the planetary nebula IC 418 are presented. Observations are made with the ESO Coudé Echelle Spectrometer (CES) and the Coudé Auxiliary Telescope (CAT); the resolving power is 10^5, corresponding to a dispersion of 1.87 Å mm^{-1} or a spectral resolution of 0.067 Å. Both [S II] lines present two well separated components corresponding to a shell expanding at the velocity of 30.3 km s^{-1}. It is shown that density and thickness of this shell, as observed on the line of sight at two diametrically opposite points, are similar, whereas the S^+ concentration suggests a non-symmetrical ionization structure.

Introduction

The low-excitation planetary nebula IC 418 is a small, nearly round (14 × 11″) ring-shaped nebula. Because of its apparently simple structure it has been carefully studied both observationally and theoretically. Wilson and Aller (1951), Aller (1956) and Reay and Worswick (1979) have published isophotes for several emission lines. Osterbrock (1970) has made high resolution spectral observations at the coudé spectrograph of the 100 inch Mount Wilson telescope: the dispersion was 4.1 Å mm^{-1} in the green spectral region and 6.5 Å mm^{-1} in the red. Whereas the [N II] lines showed double, the [O III] and hydrogen line profiles showed no central dips, in good agreement with Wilson's pioneering work (1950, 1953). This is explained by the fact that O^{++} ions are concentrated near the centre of the nebula, where the expansion is lower, while N^+ is present in the outer layers where the expansion is larger. Simple hydrogen line profiles can be explained partly by the fact that thermal Doppler width is larger and also by the fact that these lines are formed throughout the nebula.

High resolution spectrographic observations of the [S II] doublet at 6717–6731 Å allow the measurement of the expansion velocity of the nebular shell and the determination of the density of this shell (Pradhan, 1978; Cantó et al., 1980; Czyzak and Aller, 1979). On the other hand, from previous observations, it is expected that low-excitation lines, such as the [S II] doublet, will present the most evident splitting effect. These are the reasons why we decided to observe IC 418 at these wavelengths in order to check the feasibility of spectrographic observations of (southern) planetary nebulae with a resolving power of 10^5 with the CES at the coudé focus of the 1.4 m CAT. This first test is quite promising.

The Observations

The integrated magnitude of this planetary nebula is given as 12; we used a slit of 1.3 × 5 arcsec which corresponds, at face value, to a magnitude of nearly 15. The slit was kept aside the central star (m ~ 10.5). Observing conditions (seeing, transparency) were good. The detector was the presently used Reticon Chip cooled to 136°K, the central wavelength 6723 Å and the spectrum length 52 Å. The resolving power was 10^5, corresponding to a spectral resolution of 0.067 Å or a linear dispersion of 1.87 Å mm^{-1}, the channel width being 0.028 Å. The

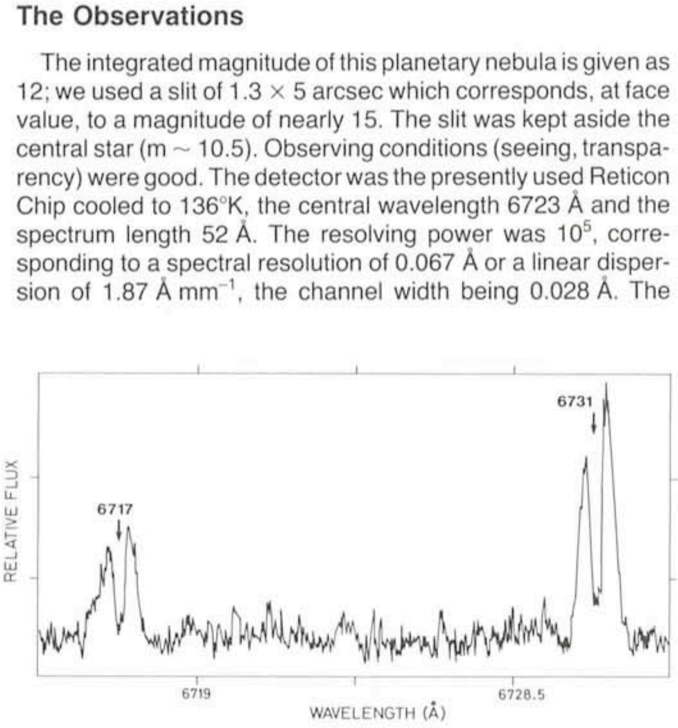

Fig. 1: *Spectrum of IC 418 showing the [S II] emission lines. This spectrum was obtained on 7 December 1981; the exposure time was 5400 s.*