Astron. Astrophys. 177, L9–L12 (1987)

ASTRONOMY AND ASTROPHYSICS

LETTER

*Letter to the Editor*

# Infrared photometry of SN 1987 A

**P. Bouchet**[1], **R. Stanga**[2], **T. Le Bertre**[1], **N. Epchtein**[3], **W. R. Hamann**[4], **and D. Lorenzetti**[5]

[1] European Southern Observatory, Casilla 19001, Santiago 19, Chile
[2] European Southern Observator, Karl-Schwarzschild-Strasse 2, D-8046 Garching bei München, Federal Republic of Germany
[3] Observatoire de Meudon, DESPA, F-92195 Meudon Principal Cedex, France
[4] Institut für Theoretische Physik und Sternwarte der Universität, Olshausenstrasse 40, D-2300 Kiel, Federal Republic of Germany
[5] Istituto Fisica dello Spazio Interplanetario, Casella Postale 27, I-00044 Frascati, Italy

Received March 26, accepted March 30, 1987

SUMMARY

We present infrared (1µm-14µm) photometric and spectroscopic observations of SN 1987A obtained at ESO La Silla between February 28 and March 16, 1987. A preliminary interpretation of the photometry suggests an expanding photosphere with $T_{eff}$ decreasing from 5800 K on March 1, to 5200 K on March 11; adopting a distance of 55 kpc, the luminosity increased from 3.2 to $5.5\times10^7$ $L_\odot$, and the effective radius from 5600 to 9100 solar radii. No significant excess could yet be detected longward of the L band filter. The spectrum is dominated by hydrogen emission lines whose intensities and shapes vary on timescales as short as one day. Some of these lines show P-Cygni profiles, indicative of expansion velocities of 6000-10000 km/s.

Keywords: infrared radiation - photometry - spectroscopy - spectrophotometry - supernovae and supernova remnants: individual

1. INTRODUCTION

An infrared (1-14 µm) photometric monitoring programme of the LMC supernova SN 1987A has been initiated at ESO, La Silla, on February 28, 1987. It has also been possible to obtain, for the first time, low ($\lambda/\Delta\lambda$ ~ 80) and medium ($\lambda/\Delta\lambda$ ~ 1500) resolution spectroscopy of a SN in this range. The observations obtained during the first two weeks covering its brightening phase are presented here.

2. OBSERVATIONS

2.1. Photometry:

Broad-band photometry of SN 1987A has been carried out with the standard ESO infrared photometer attached to the 1 m telescope. The observations have been made through a 15" diaphragm and sky subtraction has been achieved by chopping at 8 Hz frequency in the east-west direction with a throw of 30" amplitude. The photometric standards and the absolute flux calibration are derived from Koornneef (1983). The standard star HR2015 is observed as a comparison star. The final errors include errors in the measurements as well as uncertainties arising from the colour transformations, extinction coefficients, and zero-point determinations.

Send offprint requests to P. Bouchet

Table 1. JHKLM photometry

| Date(*) (March) | J (±.02) | H (±.02) | K (±.02) | L (±.03) | M (±.04) |
|---|---|---|---|---|---|
| 01.020 | 3.49 | 3.31 | 3.05 | 2.61 | 2.57 |
| 01.028 | 3.51 | 3.33 | 3.05 | 2.61 | 2.58 |
| 01.153 | 3.49 | 3.28 | 3.05 | 2.61 | 2.68 |
| 01.775 | 3.52 | 3.27 | 3.01 | 2.54 | 2.54 |
| 02.126 | 3.51 | 3.36 | 2.99 | 2.56 | 2.59 |
| 02.135 | 3.40 | 3.19 | 2.96 | 2.53 | 2.58 |
| 02.144 | 3.41 | 3.21 | 2.98 | 2.53 | 2.58 |
| 03.849 | 3.24 | 3.02 | 2.82 | 2.44 | 2.47 |
| 03.860 | 3.31 | 3.03 | 2.80 | 2.46 | 2.46 |
| 04.049 | 3.25 | 3.03 | 2.80 | 2.42 | 2.36 |
| 04.147 | 3.26 | 3.03 | 2.81 | 2.43 | 2.40 |
| 04.808 | 3.30 | 3.07 | 2.81 | 2.41 | 2.44 |
| 05.075 | 3.22 | 2.99 | 2.77 | 2.38 | 2.41 |
| 05.809 | 3.18 | 2.94 | 2.75 | 2.37 | 2.43 |
| 05.820 | 3.20 | 2.92 | 2.75 | 2.38 | 2.44 |
| 07.805 | 3.10 | 2.80 | 2.61 | 2.28 | 2.35 |
| 07.811 | 3.07 | 2.81 | 2.65 | 2.28 | 2.36 |
| 09.793 | 3.03 | 2.79 | 2.53 | 2.21 | 2.39 |
| 10.785 | 2.98 | 2.70 | 2.56 | 2.13 | 2.21 |
| 10.792 | 3.02 | 2.71 | 2.50 | 2.12 | 2.24 |
| 11.789 | 3.00 | 2.63 | 2.49 | 2.10 | 2.28 |
| 11.796 | 3.01 | 2.63 | 2.51 | | |
| 13.167 | 2.85 | 2.58 | 2.40 | 2.10 | 2.20 |
| 13.182 | 2.86 | 2.57 | 2.38 | 2.09 | 2.19 |
| 14.795 | 2.78 | 2.47 | 2.28 | 1.94 | 2.00 |
| 14.802 | 2.76 | 2.48 | 2.27 | 1.94 | 1.97 |
| 15.782 | 2.74 | 2.45 | 2.26 | 1.89 | 1.74 |
| 15.790 | 2.73 | 2.47 | 2.24 | 1.90 | 1.94 |
| 15.993 | 2.67 | 2.43 | 2.22 | 1.85 | 1.82 |

(*): fraction of days (U.T.)

Table 2. Bolometer photometry

| Date(*) (March) | N | N1 | N2 | N3 |
|---|---|---|---|---|
| 04.176 | 1.77(.09) | | | |
| 10.134 | 1.71(.18) | 1.73(.20) | 1.96(.25) | 1.61(.35) |
| 11.008 | 1.67(.09) | 1.64(.09) | 1.74(.15) | 1.17(.24) |

(*): fraction of days (U.T.)

The journal of observations and the results are given in Tables 1-2. The light curves in bands J to M, and colours (J-H), (H-K), (K-L), (L-M) are displayed in Figure 1.

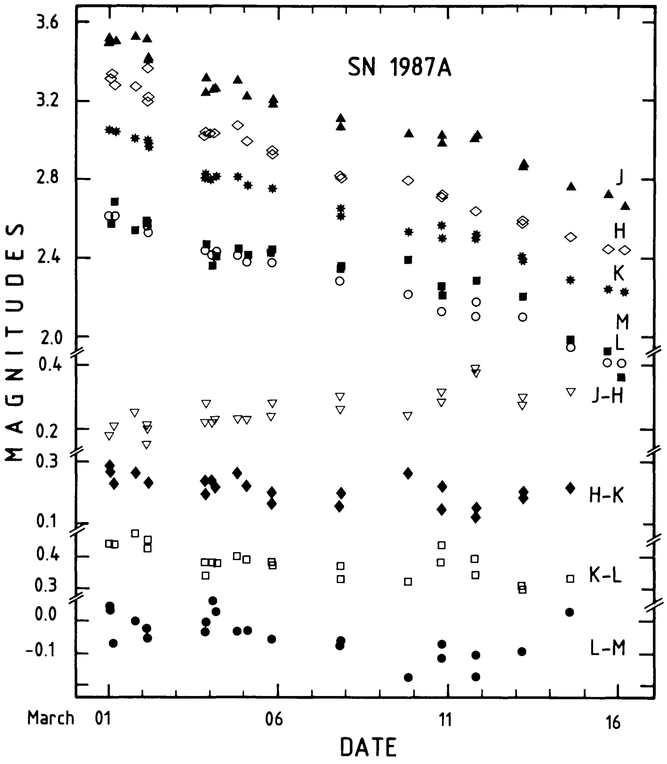


Fig. 1. Infrared light curve of SN 1987A. Symbols = ▲:J; ◇:H; *:K; ○:L; ■:M; ▽:(J-H); ◆:(H-K); □:(K-L); ●:(K-M).

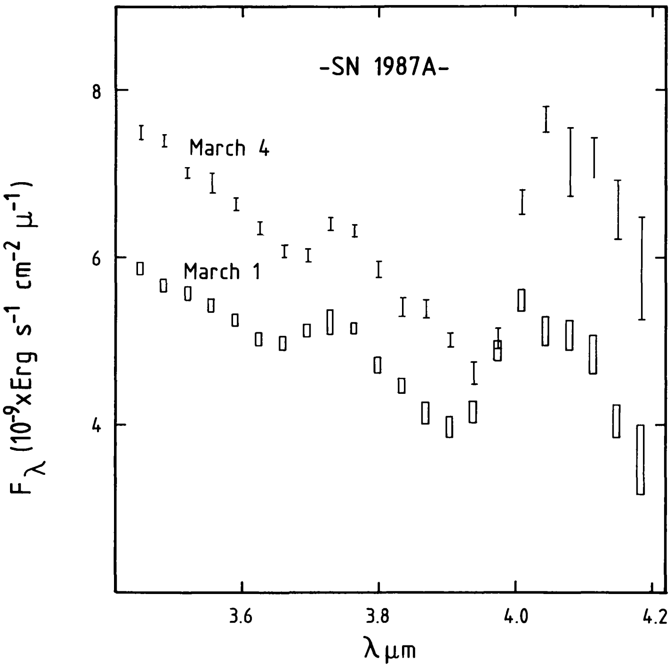


Fig. 3. Infrared CVF scans: note the variations of the two hydrogen recombination lines, Pfγ at 3.739 µm and Brα at 4.057 µm, from March 1 to March 4.

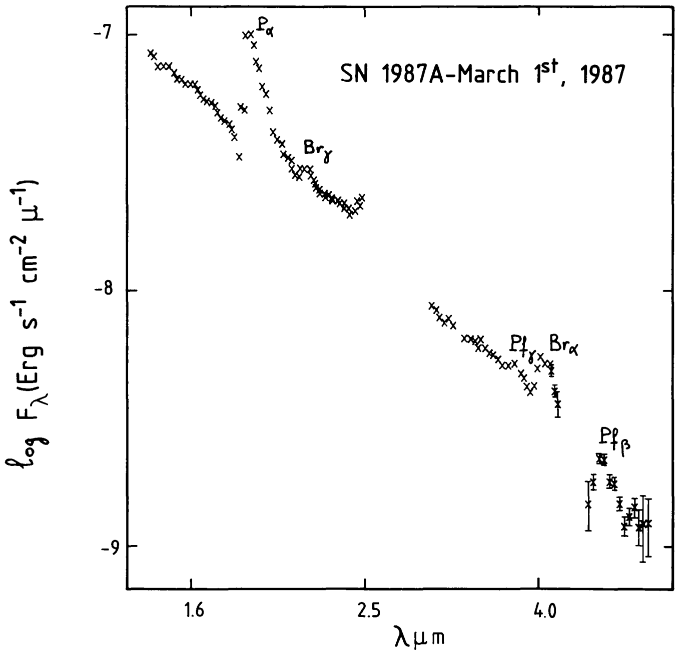


Fig. 2. Infrared CVF data scans obtained on the night February 28 to March 1. Hydrogen recombination lines dominate the spectrum. The prominent feature at 1.87 µm is due to Pα at 1.875 enhanced by a not completely subtracted atmospheric absorption, and contaminated by Brδ at 1.944 µm and Brε at 1.817 µm.

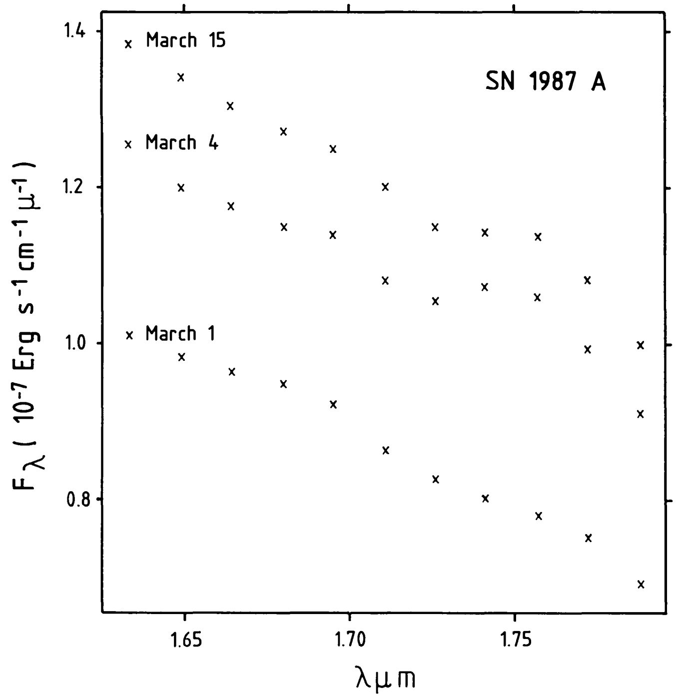


Fig. 4. Infrared CVF scans taken on March 1, March 4 and March 15 in the Brζ range (1.736 µm). The flux densities of the scans taken on March 1 and 4 have been multiplied by 1.75.

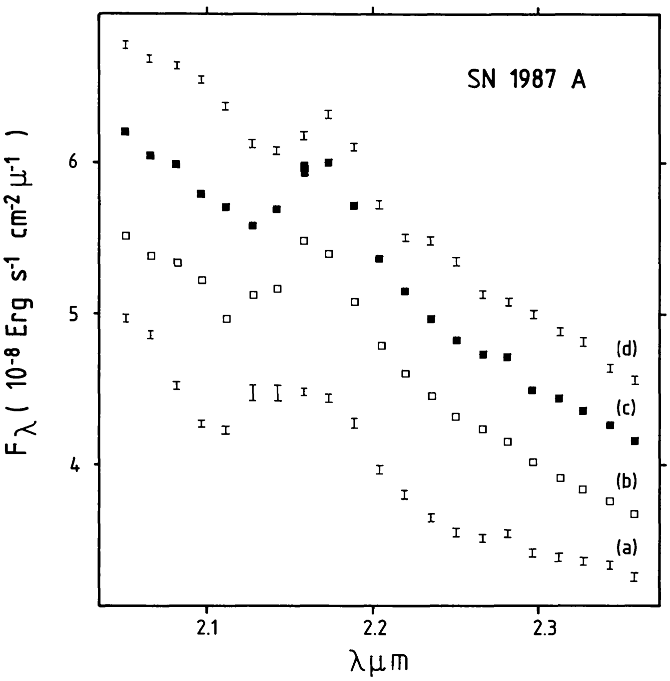


Fig. 5. Infrared CVF scans obtained on March 1 (a), March 3 (b), March 6 (c), and March 15 (d) showing the variations of the P-Cygni profile of the Brγ line (see text). The IRSPEC spectrum taken on March 6 (see Figure 8,(c)) shows a P-Cygni profile, which is not apparent in the CVF scan of the same date (c). The flux densities of scans (a), (b), (c) have been multiplied by 1.5.

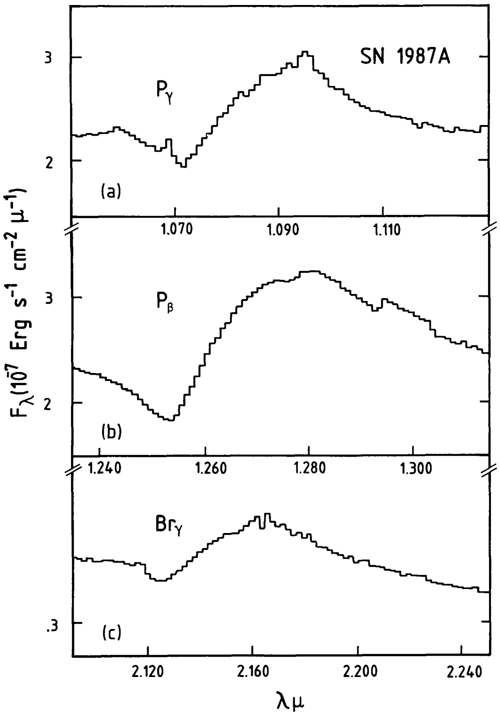


Fig. 7. Infrared spectra of SN 1987A obtained on March 6 at the ESO 3.6 m telescope equipped with IRSPEC, showing the Pγ (a), Pβ (b) and Brγ (c) lines. Flux calibration is accurate to ± 30%.

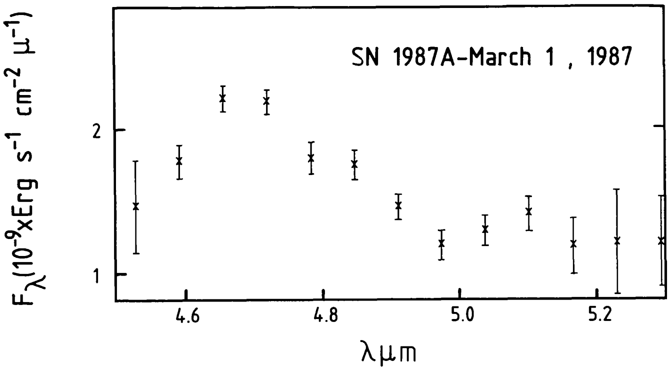


Fig. 6. Infrared CVF data scan; the two features can be attributed to hydrogen recombination lines: Pfβ at λ = 4.652 μm and Huδ (10-6) at 5.126 μm.

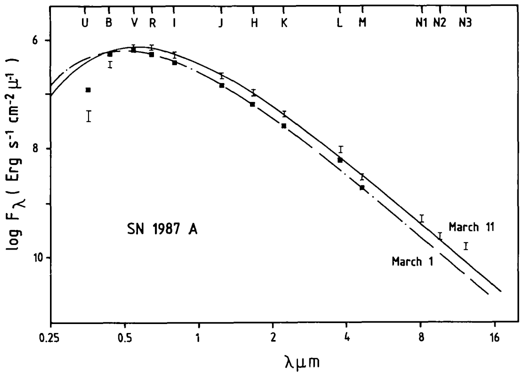


Fig. 8. UBVRI and infrared photometry. The continuous line is a black body curve at temperature T = 5800 K (March 1), and the dotted line, a black body at T = 5200 K (March 11).

## 2.2 Spectrophotometry:

Scans with three different CVF's (Circular Variable Filters), included in the 1 m telescope photometer, have been performed to cover the range 1.4μm-2.4μm, 2.4μm-4.2μm, 4.5μm-5.2μm, with the InSb detector. The calibrations of the observations are made using the star HR2015 (A7V) as reference star for the range 1.4μm-2.4μm and HR2326 (α Car; FOII) at the other wavelengths, on the assumption that they radiate as black bodies. The effective temperatures and absolute fluxes have been taken from Lamla (1965) for HR2015 and from Code et al. (1976) for HR2326. For each spectrum, the standard star is observed at least once at the same airmass as the SN, and with the same spectral sampling. The flux calibration of the CVF spectrophotometry is consistent with broad band photometry to better than 10%. Figures 2-6 show some results. Because of the high velocity of the ejecta, the lines are resolved, even at the low resolution of the CVF.

## 2.3. Spectroscopy:

Infrared spectroscopy was obtained at the 3.6 m telescope, using a cooled grating spectrometer, IRSPEC (Moorwood et al., 1986). The slit width was set to 3", and the spectral resolution (λ/Δλ) to 1500. Spectral regions around Paschen γ and β and Brackett γ were observed on March 6. The spectra (Figure 7) have been corrected for atmospheric absorption and flux calibrated using the star HR2015 as reference.

## 3. DISCUSSION

### 3.1. Photometry:

The light curves presented in Figure 1 show a remarkable scatter, particularly for the colours. This scatter seems to be real, and may correspond to the variations observed in spectrophotometry.

The spectral energy distribution of SN 1987A (deduced from UBVRI photometry from Cristiani et al. (1987) and our measurements) may be represented by a black body curve (see Figure 8), except for: - the blue part of the spectrum which is progressively deviating from the BB, the cut-off point moving redward with time; - a slight excess at L which can be partially due to the contribution of Pfund γ and Brackett α; - a clear excess in the N3 band (12.89 μm) which may be attributed to SiC emission. By fitting the spectrum (redward of the V filter), with a black body, we evaluate the effective temperatures, radii and luminosities of the supernova, from March 1 to March 11; results are given in Table 3. No correction for reddening has been applied.

### 3.2. Spectrophotometry:

The spectrum of SN 1987A is dominated by hydrogen recombination lines; at this early stage no other features have been detected. The line intensities have been calculated by the subtraction of a power law $\alpha\lambda^{\beta}$ fitted to the continuum. The results are insensitive to the values of α and β, within the accuracy of the data. In Table 4 are given for the period March 1-6 and for some clearly detected lines, the central wavelengths with intensities and related errors (Brackett (13-4) at 1.611 μm on March 1, and Brackett (20-4) at 1.519 μm on March 1 and March 5, were present but too weak to be measured). It is apparent that both the intensities and their ratios vary from day to day, by substantial amounts. In Figure 3 are presented two scans in the region of Brackett α and Pfund β, made on March 1 and March 4, that show the variations in the spectrum; in Figure 4, it can be seen that Brackett ζ, which was missing on March 1, was present on March 4 and March 15. Brackett γ shows on March 1 a P-Cygni profile which is not seen on the following nights (see Figure 5); the peak of the absorption component is at λ = 2.1 μm; from the separation of the two components, we calculate v = 9140 km/s. This velocity is in agreement with the velocity determined from the broadening of Brackett α (v = 9100 km/s), and is larger than the velocity determined from the broadening of Pfund γ (v = ~7000 km/s).

We detected also the Paschen α line at 1.8751 μm; but problems in the cancellation of atmospheric effects in that region, and contamination of this line by Brackett δ and ε at 1.944 μm and 1.817 μm make it difficult to determine its intensity.

### 3.3. Spectroscopy:

Figure 7 shows the three spectra obtained on March 6. On all spectra, the lines are clearly visible and exhibit P-Cygni profiles. Adjustment of these profiles has been performed using a two gaussian model to reproduce the P-Cygni profile; in all cases, the observational data were well fitted by the sum of these two gaussians. Relevant parameters are given in Table 5; for each profile, they indicate relative velocities of the order of ~ 5700 km/s. It is noteworthy that the P-Cygni absorption of Brackett γ, which is not detectable on the March 6 CVF spectrum, is well apparent on our higher resolution spectrum (Figure 7; Table 5).

Table 3. Physical parameters deduced from the photometry

| Date | Mar1 | Mar2 | Mar4 | Mar5 | Mar7 | Mar11 |
|---|---|---|---|---|---|---|
| $T_{BB}$ °K | 5800 | 5600 | 5600 | 5500 | 5400 | 5200 |
| $R/R_{\odot}$ | 5600 | 6200 | 6200 | 6700 | 7200 | 9100 |
| $L/10^7L_{\odot}$ | 3.2 | 3.4 | 3.5 | 3.8 | 4.0 | 5.5 |

Table 4. Intensities of lines observed in spectrophotometry

| Identification | λ | Mar1 | Mar4 | Mar5 | Mar6 |
|---|---|---|---|---|---|
| Br (12-4) | 1.641 | (<.5) | (<.4) | 2.25 | (<.5) |
| Brζ (10-4) | 1.736 | (<.5) | 1.39 | 1.48 | 2.10 |
| Brγ (7-4) | | | | | |
| emission | 2.166 | 1.10 | 1.00 | 2.87 | 2.59 |
| absorption | 2.100 | 0.79 | (<.5) | (<.4) | (<.5)(*) |
| Pfγ (8-5) | 3.739 | 0.71 | 0.71 | 0.95 | N.O. |
| Brα (5-4) | 4.057 | 2.90 | 5.60 | 5.60 | N.O. |
| Pfβ (7-5) | 4.653 | 2.70 | N.O. | N.O. | N.O. |

N.O. : "Not observed"; the line intensities are expressed in $10^{-10}$ × erg $s^{-1}$ $cm^{-2}$; the errors are lower than 10%.

(*) : A P-Cygni profile has been observed on the same day in spectroscopy, with IRSPEC (Figure 8; Table 5) with an absorption of $.43\times10^{-10}$ × Erg $s^{-1}$ $cm^{-2}$.

Table 5. Parameters of the line profiles observed in spectroscopy

| Line | $\lambda_0$ | emission $\lambda_c$ | emission FWHM | emission $I_c$ | absorption $\lambda_c$ | absorption FWHM | absorption $I_c$ |
|---|---|---|---|---|---|---|---|
| Pγ | 1.094 | 1.092 | .020 | .253 | 1.070 | .028 | .144 |
| Pβ | 1.282 | 1.277 | .042 | .354 | 1.254 | .018 | .347 |
| Brγ | 2.166 | 2.168 | .067 | .184 | 2.127 | .026 | .115 |

($\lambda_c$: central wavelength; $I_c$: intensity at $\lambda_c$ relative to the continuum; FWHM: full width half maximum of each gaussian - see text)


ACKNOWLEDGEMENTS

We thank the technical staff at La Silla for their permanent support, and especially Th. Bohl, J. Roucher and A. van Dijsseldonk. We are very grateful to R. Vega for performing with skill and enthusiasm daytime observations at the 1 m.


REFERENCES


Code, A.D., Davis, J., Bless, R.C., Hanbury Brown, R.: 1976, Astrophys. J., **203**, 417

Cristiani, S., et al.: 1987, Astron. Astrophys., this issue

Koornneef, J.: 1983, Astron. Astrophys., **128**, 84

Lamla, E.: 1965, Landolt-Bornstein vol. 1, H.H. Voigt editor, 393

Moorwood, A., Biereichel, P., Finger, G., Lizon, J.-L., Meyer, M., Nees, W., Paureau, J.: 1986, The Messenger, **44**, 19