Hα Observations of the Rosette Nebula and the Distribution of Interstellar Dust

W. E. Celnik, Astronomisches Institut, Ruhr-Universität Bochum

Introduction

The Rosette nebula is a well-known H II region in the constellation of Monoceros with a diameter of more than 2°. The nebula has a nearly circular shape forming a ring around a deep local intensity minimum (Fig. 1). The open star cluster NGC 2244 is visible within the H II region, containing early-type stars which emit enough hard UV radiation to ionize the nebula. Adjacent to the north-eastern border of the Rosette nebula there is the large supernova remnant of the Monoceros Loop.

Looking at the prints of the Palomar Sky Survey it is obvious that many dust clouds are directly related to the Rosette nebula. In order to state this more quantitatively it is useful to compare optical and radio frequency measurements of the nebula. Observations in the radio domain are not affected by interstellar dust grains along the line of sight. But optical Hα emission line radiation emitted from the H II gas will be partially absorbed by interstellar dust. Now both the intensities of the optically thin radio continuum and that of the Hα recombination line emitted from the H II region depend on the same physical parameters of the nebula, the electron temperature and the emission measure $E = \int n_e^2 \cdot ds$ of the electron density n_e and the effective path length s in the nebular gas. Therefore it is possible to calculate theoretical values for the Hα emission line intensity from the radio continuum intensity and the electron temperature. Oster (1961, *Ap. J.* **134,** 1010) gives the theoretical continuum emission coefficient needed for this.Comparing the theoretical values of the intensities in the Hα line with the measured ones the distribution of interstellar dust across the Rosette nebula can be determined.

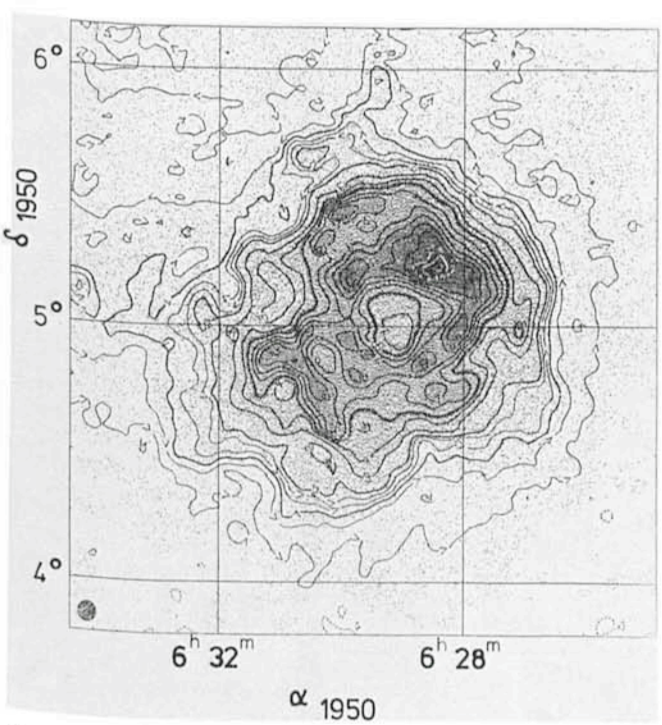

Fig. 1: *Distribution of the intensity in the Hα line across the Rosette nebula. Lowest contour line at O, thick (numbered) isophotes at 3·10¹², thin isophotes at 1, 2, 4 and 5·10¹², line with tick-marks at 15·10¹² i.f.u./beam; the angular resolution is 4'.75.*

The Hα Emission Line Intensity Distribution

The Rosette nebula was observed in the Hα emission line with the Bochum 61 cm Cassegrain telescope at La Silla during December 1979 and January 1981 using a photoelectric photometer with a cooled multiplier (EMI 9558 A) and interference filter (ESO 28) which has a full width at half transmission $\Delta\lambda = 10.2$ Å around $\lambda_0 = 6564.8$ Å. Such a small bandwidth was necessary because only then both the emission lines of [N II] at λλ 6548, 6584 on both sides of the Hα line could be excluded. The angular resolution was set to 4'.75 by a diaphragm. Scanning the nebula with resting telescope using earth rotation permitted an integration time of 4 sec per point, while the length of each scan reached 30 minutes. Subtracting background radiation and correcting for atmospheric extinction, a complete map of the Hα line intensity distribution could be constructed from 76 scans with an extension of 2°.4 × 2°.4 (Fig. 1). But the intensity scale was arbitrary, it still had to be tied into sources with absolutely known flux.

The Calibration of Hα Line Intensity

The calibration of the Hα line intensities in absolute units follows a rather complicated way. Two stars (α Car, β Cen) whose spectral continua had been calibrated absolutely by Tüg (1978, thesis, Ruhr-Universität Bochum) were measured before and after scanning the nebula. Thus the count rates from the nebula scaled to 100% filter transmission could be calibrated by the count rates I_o obtained from the stellar continuum spectrum I(λ multiplied with the transmission curve T(λ) of the interference filter. A special problem in this calibration resulted from the fact that Tüg's absolute values referred to such wavelengths where the stellar continuum is reasonably unperturbed by stellar lines, but the Hα measurements are strongly affected by the stellar Hα line. In order to determine how much the stellar continuum is depressed in the line, coudé spectra of the Hα region with a dispersion of 12.5 Å/mm for α Car and β Cen were taken by D. Reimers in January 1981. These plates were evaluated with the Grant machine and the IHAP system at ESO Garching, the linearity of the resulting intensity scale was checked by photoelectric low-resolution scanner spectra of the same stars obtained by D. Kaiser with the Bochum 61 cm telescope at La Silla in December 1981. In this way the shape of the stellar Hα line could be determined and the Hα nebular intensities could be calibrated in units of $W \cdot m^{-2} \cdot beam^{-1}$.

The nebula is ring-shaped, surrounding a deep central intensity minimum. But the map contains the contribution of many stars besides the line radiation of the gas, so stars with $m_v \leq 9.1$ had to be identified and subtracted from the map by Gaussian fitting. After this the maximum value of Hα flux densities is $S_{max} = 39.9 \cdot 10^{12}$ i.f.u./beam (1 i.f.u. = 1 integrated flux unit = 10^{-26} W · m^{-2}). In Fig. 1 some weak filaments of the Monoceros Loop are visible near the northern and eastern border of the map, but their intensities are not higher than 8% of the maximum intensity of the Rosette nebula. The mean error of the intensity at a single point is 1.1%, including the errors of the calibration in i.f.u./beam this increases to 5.0%. The rms noise in the map is $0.12 \cdot 10^{12}$ i.f.u./beam.

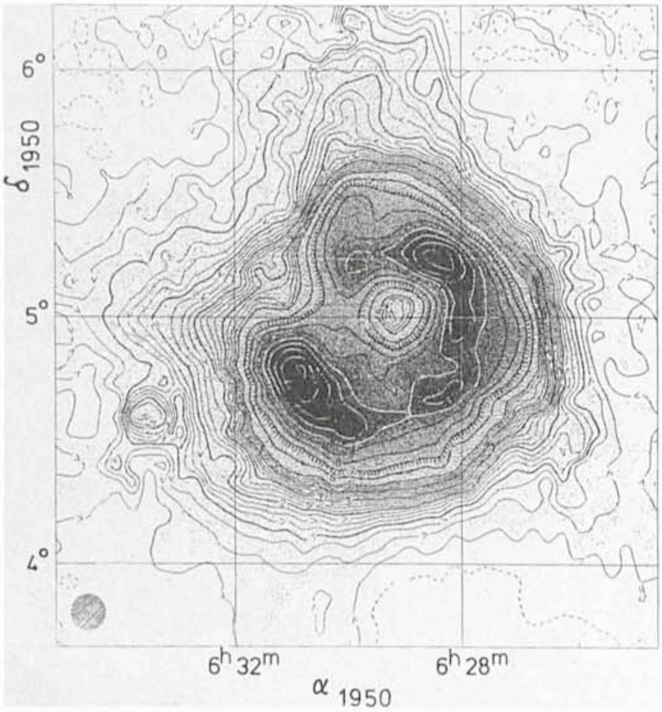

Fig. 2: *Distribution of the brightness temperature at 1410 MHz across the Rosette nebula. Lowest contour line at 0, thick (numbered) isophotes give brightness temperature in units of K, thin isophotes at 0.25, 0.5, 0.75 . . . 4.75 K, line with tick-marks at 7 K; the resolution is 9'.24.*

The Radio Continuum Observations

Two radio continuum maps of the Rosette nebula were obtained at 1410 MHz and 4750 MHz respectively. The intensity distribution at 1410 MHz (21.3 cm) was mapped with the 100 m telescope at Effelsberg in August 1980. 40 scans in right ascension and declination fully sampled with 4′ point separation were connected to a map of 2°.7 × 2°.7 (Fig. 2). The angular resolution is 9'.24 and the intensity calibration was made using the point source 3C147. The maximum brightness of the nebula is T_b=14.1 K, the rms noise in the map is less than 0.1 K.

A map of the continuum intensity at 4750 MHz (6.3 cm) was obtained with the same telescope in June 1981. 180 scans in right ascension and declination with a sampling distance of 1′ resulted in a map of 3° × 3° extension. The angular resolution is 2'.43 and the intensity scale was determined by observing the sources 3C48, 3C138, 3C147 and 3C249.1. The maximum brightness of the nebula at 4750 MHz is 1.7 K, the rms noise in the map is nearly 0.03 K. The map represented here (Fig. 3) is only a 1°.65 × 1°.65 section from the complete map. The radio data also show the Rosette nebula to be ring-shaped.

The Radio Recombination Line Observations

As discussed above, the electron temperature in the HII region is needed in order to compute the theoretical Hα line intensity from radio continuum measurements. The electron temperature can be estimated from measurements of radio recombination lines. Mezger and Henderson (1967, *Ap. J.* **147,** 471) gave a formula for this under conditions of local thermodynamic equilibrium (LTE), but effects of deviations from LTE can be taken into account using correction factors given by Brocklehurst (1970, *MNRAS* **148,** 417). The helium abundance was obtained from the ratio of the total line intensities of the He 112α and the H112α lines resulting in $<N_{He}+/N_H+> = 0.116 \pm 0.032$, the mean electron temperature derived was $T_e = (5790 \pm 1070)$K. Due to the low brightness temperature of the radio recombination lines (T_b(He112α)= 0.01 K) integration times of more than 4.5 hours were needed for a single position in these investigations.

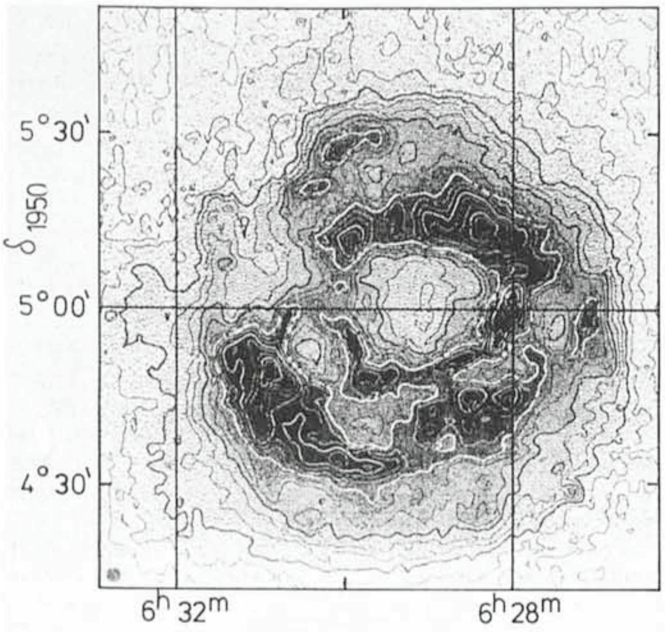

Fig. 3: *Distribution of the brightness temperature at 4750 MHz across the Rosette nebula. Lowest contour line at 0, thick isophotes at 0.3, 0.6, 0.9 . . . K, thin isophotes at 0.1, 0.2, 0.4, 0.5, 0.7 . . . K; the resolution is 2'.43.*

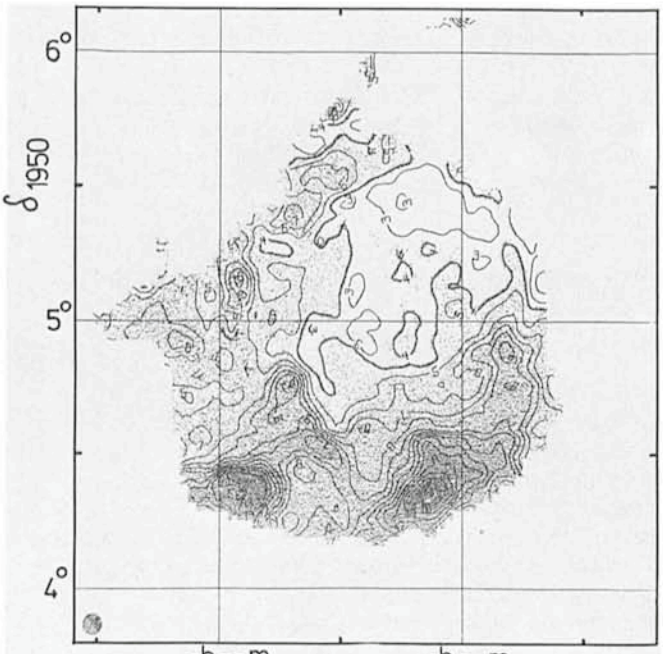

Fig. 4: *Distribution of the local absorption at Hα across the Rosette nebula from the comparison of the intensities in Hα and in the continuum at 4750 MHz, contour line 3 at 1.27 mag, contour line 4 at 1.47 mag and contour line 5 at 1.67 mag absorption; the resolution is 4'.75.*

The Distribution of Interstellar Dust

Comparing the distribution of the observed Hα line intensity in Fig. 1 with the distribution of continuum emission across the Rosette nebula (Fig. 2, 3) it turns out that the features in the north-western region are very similar on both maps, but that strong differences are visible in the southern region. Fig. 4 shows the comparison of the observed and the expected Hα emission estimated from the 4750 MHz continuum emission quantitatively. Only points at which both the Hα and radio continuum intensities are greater than 2.5 times the rms noise were used. The mean value of interstellar extinction between the nebula and earth at 6563 Å is A(Hα)=(1.21±0.04)mag. This value results from UBV photometry data of NGC 2244 by Ogura and Ishida (1981, *Publ. Astron. Soc. Japan* **33,** 149) who obtained a reddening of E(B–V)=0.47 mag, and from the mean interstellar extinction law A(1/λ) reviewed by Schmidt-Kaler (1982, in: Landolt-Börnstein, Gr. VI, Bd. 2b, 449). After subtracting this value of the "interstellar" A(Hα) from the absorption map the remaining absorption must be "local", that is must occur in the direct neighbourhood of the H II gas in front of the Rosette nebula. Its mean value in Fig. 4 is (1.9±0.5) mag. In the north-western region A(Hα)=(1.3±0.1) mag is nearly constant down to the noise limit at the nebula edge. In southern condensations it increases up to (4.3±0.1) mag, but varies around a mean value of (2.5±0.2) mag. The mean error of a single value is 0.3 mag.

A Model of the Rosette Nebula and Its Neighbourhood

The measured radio continuum intensities of Fig. 2 and Fig. 3 integrated in rings of 1 and 4 arcmin width around the nebula centre could be reproduced by a spherical symmetrical radial distribution of electron density with a central cavity and a hole in the shell pointing approximately to the direction of the line of sight. The mean value of the electron density in the shell is N_e=(15.0±1.5) cm^{-3}. This model results in a total mass of ionized material in the nebula of M_{ion}=(29,700±3,800) $M_\odot$.

Interstellar dust clouds and molecular cloud complexes are frequently correlated. Blitz and Thaddeus (1980, *Ap. J.* **241,** 676) have observed CO molecules in the Mon OB2 molecular cloud complex in the Rosette nebula region with angular resolutions very similar to that of the A(Hα) map. Both the shape of CO cloud structures and their distribution correspond quite well to that of the absorption by interstellar dust. Using the assumption that all CO molecular clouds within the considered region contain dust grains, it is possible to distinguish between CO clouds lying in front of and those lying behind the H II region, because dust absorption is only visible from dust clouds in front of the nebula.

Indeed the CO clouds are distributed behind as well as in front of the nebula. This suggests that the H II region is embedded in the molecular cloud complex. The centre and the greatest part of the nebula are visible within a region of relative small dust absorption (Fig. 4). Thus we suppose that the H II region is lying at the border of the complex. A more detailed model of the complex (Celnik, 1982, thesis, Ruhr-Universität Bochum) could be established using the velocity field within the complex. Radial velocity information had been given by Fountain, Gary and O'Dell (1979, *Ap. J.* **229,** 971) and by Blitz and Thaddeus. Assuming a spherical shape of the complex we find for the total mass of the dust M_d = 5,400 $M_\odot$. The total mass of the whole cloud complex consists of the masses of neutral hydrogen, molecules, stars, ionized matter and dust grains. Different authors have previously estimated the masses of neutral hydrogen (1.5·10^5 $M_\odot$, Raimond, 1964, thesis, Leiden), molecules (1.3·10^5 $M_\odot$, Blitz and Thaddeus) and stars (5,000 $M_\odot$ for NGC 2244, Ogura and Ishida). For the total mass we derive M_{tot} = 3.2·10^5 $M_\odot$, which corresponds to a density of about 0.5 $M_\odot$ /pc^3. 82 % of the total mass is in the form of neutral hydrogen and molecules.

Conclusions

From the comparison of the photoelectrically measured distribution of the Hα emission line intensity across the Rosette nebula with the distribution of the radio continuum intensity it was possible to construct the distribution of interstellar dust in front of the nebula. The comparison of this dust distribution with measurements of molecular spectral lines from other authors resulted in a model of the molecular cloud complex Mon OB2 in three dimensions. The Rosette nebula is embedded in this complex near the border, on the side turned to the direction of the Sun. No evidence could be found that the Monoceros Loop has any connection to the Rosette nebula or the molecular cloud complex.

The Copenhagen Binary Project

J. V. Clausen, Copenhagen University Observatory

While this short contribution is written and the rain has been pouring down in Denmark, surely setting up new records, we strongly hope for an unbroken long series of clear, stable photometric nights at La Silla. The last long-term (40 nights) photometric observing run for our eclipsing binary project at the Danish 50 cm telescope began a few nights ago. Last – at least with the characteristically shaped, well-known *uvby* photometer mounted at the manually operated telescope, a combination which through the years has demonstrated its accuracy and reliability in a large number of projects in different fields of galactic research.

Besides these important features, we have benefitted from a remarkably stable photometric instrumental system (E. H. Olsen, 1977, *Astron. Astrophys.* **58,** 217). A discontinuity will now be introduced. A most welcome one, since much faster Strömgren photometers of the type known from the Danish 1.5 m telescope are now available. A year from now – according to the schedule – the observer will find a renovated microcomputer-controlled, fast-moving 50 cm telescope, equipped with a new efficient 6-channel *uvby-beta* photometer in the dome.

So it might be opportune to give a brief status report at this stage of the project even though more spectroscopic observations are still needed.

More Than 500 Nights

The first observations for the Copenhagen binary project were made at the Danish 50 cm telescope at La Silla in 1971. Since then more than 500 nights have been allocated, and well-