Chapter 5

VELOCITY FIELD STRUCTURE IN THE TRIFID NEBULA

5.1 Introduction

The Trifid nebula (NGC 6514, M20), said to be the photogenic example of a 'classical' galactic nebula, is situated in the Sagittarius arm (α (1950) = $17^h58^m9^s$ and δ (1950) = $23^o02'$). It measures about 15 arc min in diameter (Allen, 1973). It is supposed to be first observed by Le Gentil in 1747. It seemed to be a spherical nebula with a central exciting star in the photographs. Initially, due to the presence of three prominent dark lanes observed, the nebulosity was catalogued as four separate objects , the central bright spot (including the multiple stellar system) and the three luminuous lobes surrounding it (Sir William Herschel). Eventually, it was found to be composed of three bright and irregularly formed nebulous masses excited by the central multiple system of stars and was termed as *trifid* by John Herschel. Fig 5.1 shows a photograph of the Trifid Nebula.

The 'trifid' pattern is found in the bright southern portion of the nebula where the three dark rifts radiate out from the central triple star HN 40 (Fig 5.1). The star HD 164492 is the primary of the HN 40 system, and is identified to be the chief ionizing source of the nebula. The main/primary component is an O7V type star (Abt, 1983). A cooler star is supposed to be situated towards the north surrounded by a blue reflection nebula. There is a strong continuum exhibited by the emission zone in the visible region arising from dust-scattered starlight. A distance of 1600 pc for the Trifid was derived by Buscomb (1963) from a study of the star cluster in NGC 6514.

5.2 Earlier studies

Observations on Trifid in the past were mainly concentrated on the study of characteristics of dust (O'Dell et al, 1966; Lynds et al, 1985) responsible for the continuum emission from the reflection nebular regions and models developed for the same (Mathis, 1972). A study on the kinematics of the nebula were made mainly by O'Dell et al(1987). The radial velocities were found to show a general circular symmetry about 2 arc minutes around the multiple star complex HN 40. The velocities of the flow components were found to be quite low ($\sim$ 5 km/s), indicating probably that the nebula is a

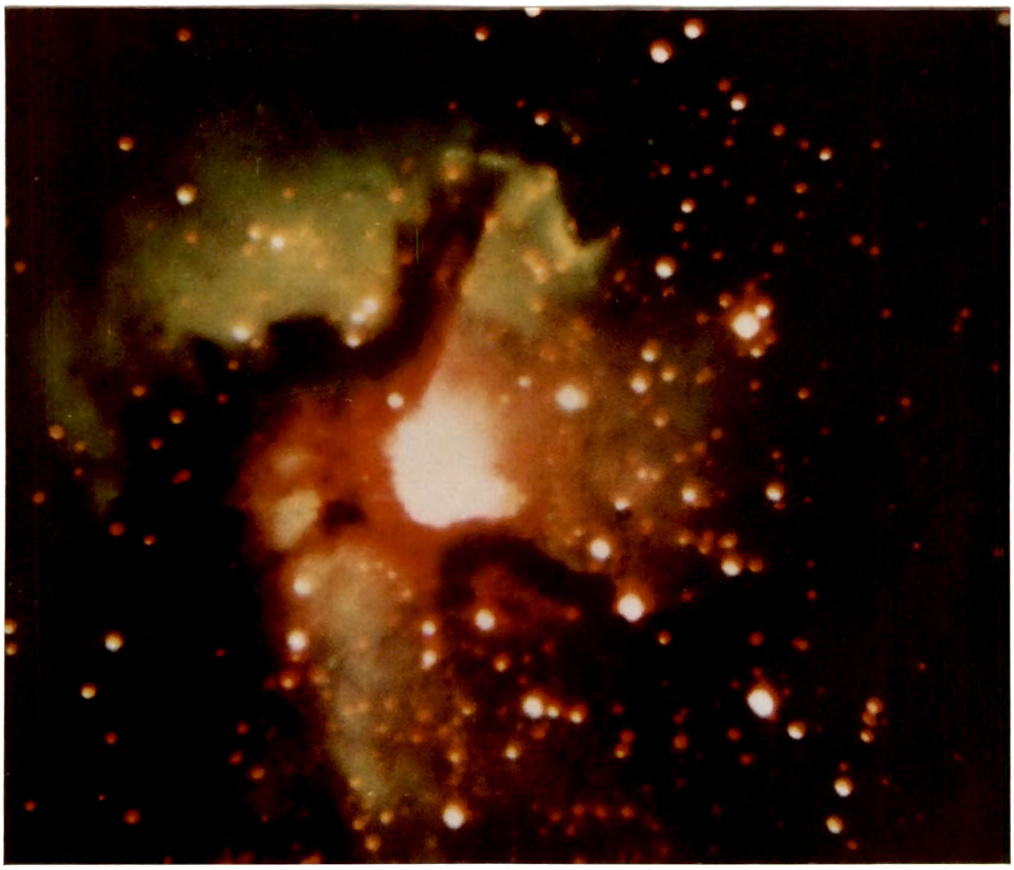

Figure 5.1: A photograph of Trifid nebula made by combining the blue, green, red, and near-infrared CCD images(Rudolph, 1988).

quiescent object. The symmetric flow was interpreted to be possibly due to the surrounding neutral shells with no open champagne flow situation as in the case of Orion nebula. The optical depth towards the central star in the nebula was found to be $\sim$ 1.5 at 4693 Å (Lynds et al, 1985) implying that all the extinction occurs within the nebula proper with the ratio of selective to total extinction $\sim$ 5.1 (similar to Orion) which is greater than the value found normally (3.0) in other nebulae. This shows that there is anomalous extinction in Trifid nebula.

5.3 Present studies

The velocity field across the Trifid nebula is studied by us over a much more extended region in order to have a more comprehensive picture than in the earlier observations and to have a comparative study with Orion nebula to put constraints on the models proposed for HII regions. An interferogram of Trifid nebula is obtained in [OIII] 5007 Å line with an integration time of 20 minutes. The field of view covered was 24 $'$. Each pixel corresponds to 4.6$''$ on the sky giving a spatial resolution of$\sim$ 9$''$. An optically contacted etalon having a FSR $\sim$ 1.25 Å (corresponds to 75 km/s at 5007 Å), with a velocity resolution of $\sim$ 7 km/s, was used. Our study provides the first wide field spectroscopic image of the nebula. The details of the observations and data analysis are discussed in chapter 3.

Line profiles were obtained for about 48 positions on the nebula. Firstly, the proper centre of the interferogram is found. Since the signal to noise ratio is small in this case, photon counts were added in a sector of 10° and velocity values were obtained for about 48 positions. Eventhough the number of positions at which the velocity is obtained is not large, because of their symmetric distribution, reasonably good (though a little coarse) picture of the velocity flows can be constructed. The calibration interferogram was taken with cadmium source at 5086 Å. But it was found to be bad due to some sky contamination. Therefore, the radii of the standard fringes were obtained theoretically from equation (3.1) ,

$$R_s = f\sqrt{2(1 - n\lambda/2\mu t)} \tag{5.1}$$

The centre of the observed interferogram is matched to that of the theoretical one. The use of theoretical fringe radii will not contribute to any uncertainties in the relative radial velocities. Then the doppler shifted velocities were obtained as discussed in section 3.2

Each profile is found to be fitted well with a single gaussian with FWHM of about 20 ± 5 km/s. Fig. 5.2 shows a typical profile. An isovelocity contour map is generated from the data and is shown in Fig. 5.3. The main results obtained are discussed in the following section.

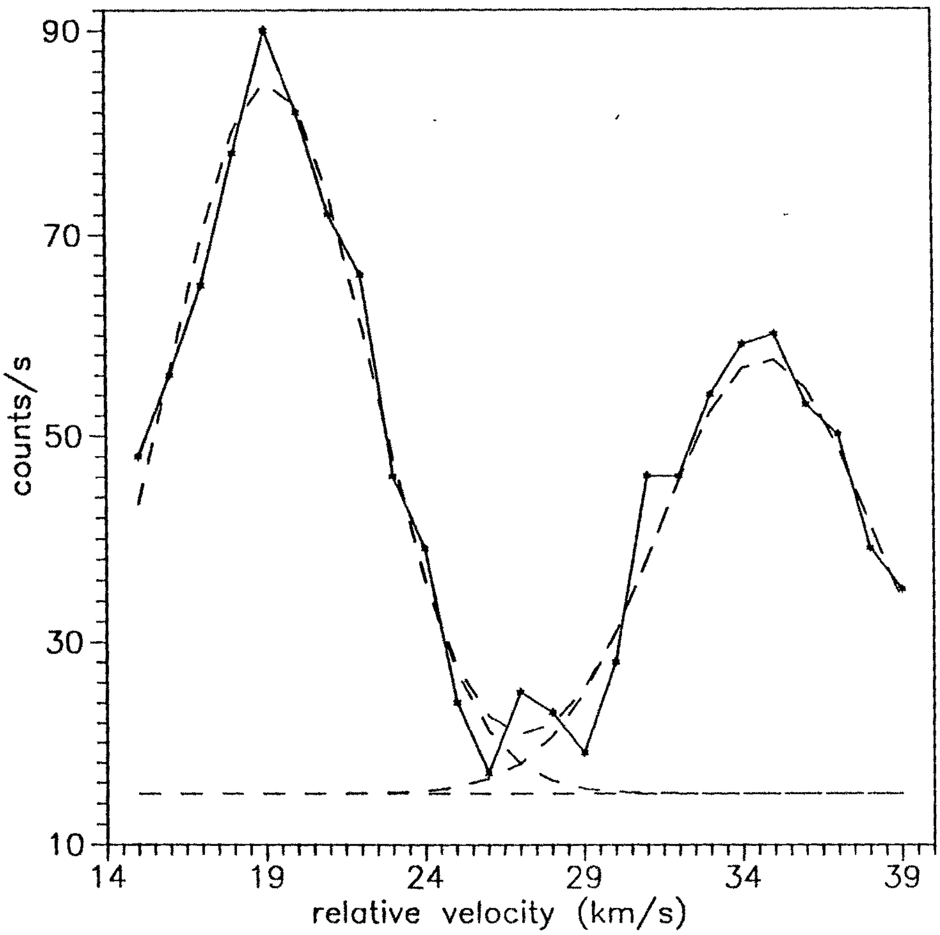

Figure 5.2: Typical line profile in [OIII] 5007 Å in Trifid nebula (solid line with asterisks). The dashed curve going through the asterisks is the composite gaussian fit with the individual gaussians shown by the small dashed curves. The dashed line at the bottom is the continuum level. The two peaks represent two adjacent fringes separated by a distance corresponding to 1 FSR.

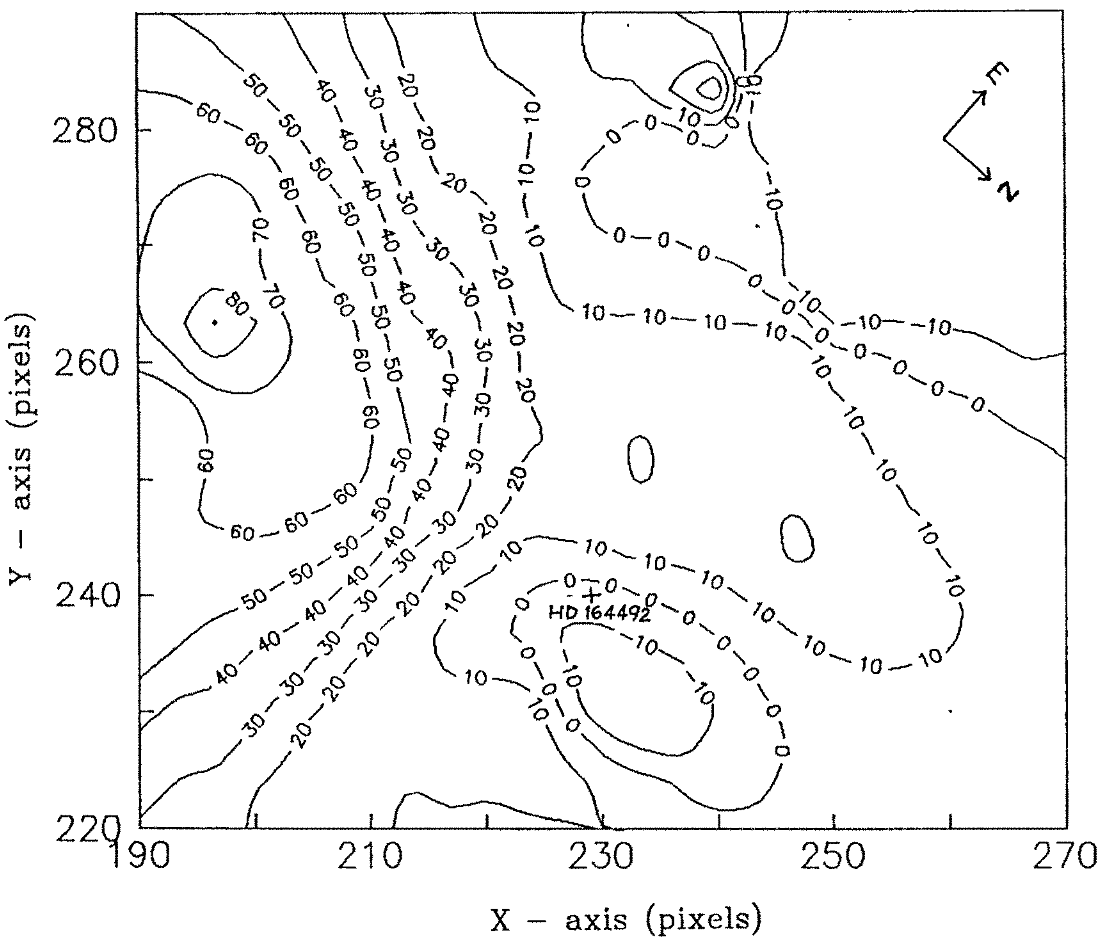

Figure 5.3: Iso-velocity contour map in [OIII] 5007 Å line in Trifid nebula. One pixel corresponds to about ~ 4.6 ″ on the sky.

5.4 General velocity field

5.4.1 About two arc minutes around the central star HD 164492

The radial velocities are found to be increasing from the centre rather symmetrically outwards implying a general expansion of HII region (Fig. 5.3). This indicates that there could possibly be a neutral shell surrounding the ionized region around the central star and therefore the flow is uniform in all directions. The star being a O type star, there should be associated stellar wind from the star and the shell could be driven by it. These observations are in corroboration with earlier observations of O'Dell et al (1987). There are no high velocity flows observed in this region indicating the absence of any jets or HH objects. The region seems to be quite quiescent.

Large scale red-shifted flow

There is a general red-shift in the radial velocities in the south west direction about 2 arc min from the central star HD 164492 with a velocity change of about 50 km/s (Fig. 5.3). Such a flow has so far not been reported, as the earlier kinematic observations were all confined to a small region surrounding the central star. This shows that the cloud is red-shifted along the line of sight, moving away from the observer. Since there are no other stellar sources in this region, the flow should possibly be associated with HD 164492. This suggests that the red-shifted region represents a champagne-like flow going away from the observer.

5.4.2 Peculiar velocity flow

One more important finding of the present study is the discovery of a localized velocity flow with maximum relative velocities around 40 km/s from a position about 2.3 arc minutes south east of the star HD 164492. There seems to be an indication of splitting in the line profile at this position as shown in Fig. 5.4.

Studies in the past (Dyson, 1973a; Dyson, 1975) have established that there are neutral condensations or globules distributed across the nebula which are being ionized by the Lyman continuum photons from the hot stars called partially ionized globule (PIGs). Further the stellar wind when passing around these globules leads to the formation of bow shocks (Dyson, 1975). A bow shock feature, adjoining a condensation of bright emission, is seen in the photograph shown in Fig. 5.1. However, in the case of Trifid, we find these condensations to be, in general, quite irregular and very extended. Our velocity contour map shows a rather symmetric localized flow with a relatively red-shifted velocity of a maximum of 40 km/s around the condensation. On the other hand, the bow-shaped feature seems to have relatively blue-shifted velocities. The line splitting, if true, should then indicate the expansion of the partially ionized condensation. From our observations it appears that

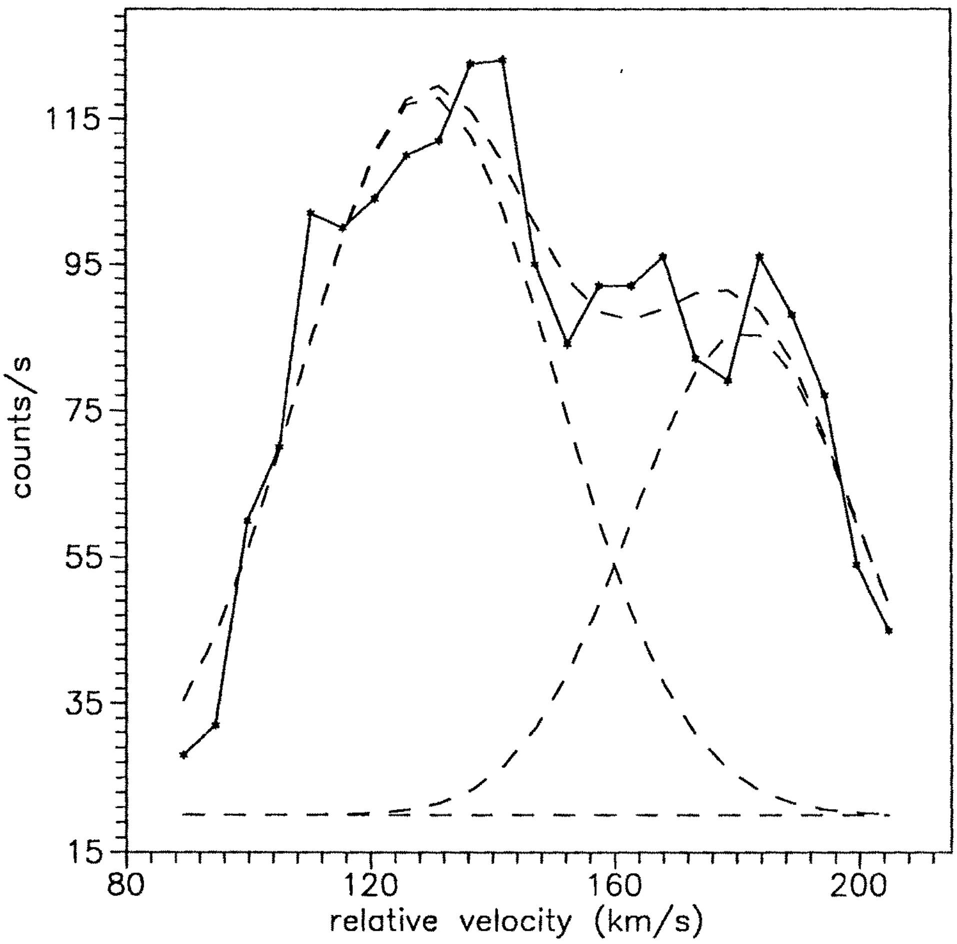

Figure 5.4: Profile across a feature 2.3 arc min SE of HD 164492 showing splitting in the line (solid line with asterisks). The dashed curve going through the asterisks is the composite gaussian fit with the individual gaussians shown by the small dashed curves. The dashed line at the bottom is the continuum level.

the HII region is surrounded by neutral clouds of complex structure.

5.5 Comparison of the velocity field structures of the Trifid and the Orion nebulae

A close scrutiny of the velocity fields of the Orion and the Trifid nebulae shows the following differences. (i) The line profiles in the case of Trifid nebula, in general, do not show two velocity components. This could probably be due to the fact that there is no interaction of the stellar winds giving rise to multiple velocity components along the line of sight as observed in the Orion nebula.

(ii) The general velocity flow pattern within 2 arc min of the central star in Trifid does not seem to follow the champagne flow proposed for the Orion HII region. In Orion nebula, the molecular cloud is situated behind the main ionizing stars (Trapezium), which obstructs the flow in that direction, but the Trifid nebula geometry does not show the presence of molecular cloud behind the star cluster HN40 and therefore the flow seems to be uniform in all directions. However, our observations on Trifid do show a red-shifted flow south west of the central star indicative of the champagne flow partly masked by the dust lane.