A MULTI-WAVELENGTH STUDY OF SHARPLESS 185

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Abstract

The HII region S185 (nebulosity around γ Cas) has been observed with the DRAO synthesis telescope in continuum and line emission at 21 cm, and in continuum emission at 74 cm.

Continuum emission is clearly detected for IC63 and is barely above the detection limit for IC59. The emission of both clouds is thermal. A small amount (≈ 0.15 and 0.65 $M_\odot$ for IC63 and IC59 respectively) of atomic hydrogen is found to be associated with the nebulae at velocity ($LSR$) near 0 km s$^{-1}$. Infrared emission from the clouds is also detected from the IRAS survey. The infrared and radio luminosities of the clouds are consistent with heating and ionization being produced by the B0.5IV exciting star γ Cas. However, comparison of the amount of atomic material with the dissociation properties of γ Cas requires an age less than the main sequence life time by orders of magnitude. As a result, production of the extended atomic gas in the clouds by dissociation appears to have already ceased.

The geometry of the region is inferred from the assumption that the clouds are bounded to the ionizing radiation coming from γ Cas. Accordingly, the weak radio continuum emission of IC59 may be explained by one of the following hypothesis. The cloud is either farther away from the exciting star than the observed projected distance, or the Lyman continuum radiation from the exciting star is shielded by the postulated Be star envelope. In the former case, the line joining the cloud and the star would make an angle of 51° with the line of sight. The star-to-cloud distance would be about 3 pc. The strong infrared and weak continuum emissions would be due to the long extent (≈ 0.8 pc) of the cloud in the radial direction from the star. For the latter hypothesis, the envelope is shielding about 60% of the stellar ionizing luminosity.

IC63 appears to be composed of two main components: a series of dense filaments
on the side of the exciting star which have been compressed by the stellar winds or radiation pressure from the star, and a mixture of lower density dust and dissociated hydrogen mostly located farther away from the exciting star. It is suggested that the density increase on the edges facing the exciting star would have allowed molecules to form in these tiny regions. IC59, being farther away from the star, would only exhibit the low density component.

Atomic hydrogen is also detected at $V_{LSR} \approx -34\,\text{km}\,\text{s}^{-1}$ near the infrared source IRAS 00556+6048. The emission is very fragmented and exhibits a shell-like structure that appears to surround the infrared source. The source which is probably not associated with S185 would be located at a kinematic distance of $\approx 1.8\,\text{kpc}$ and may be a candidate for a dissociating star object.

Another source with flux density 114 mJy, is detected in the 21 cm Bonn continuum galactic plane survey. Surprisingly, the source is not detected in the NRAO survey performed at the same wavelength with a similar telescope. Moreover, it is not detected by the DRAO continuum observations while a coincident large ridge of HI emission at $V_{LSR} \approx -29\,\text{km}\,\text{s}^{-1}$ is observed.
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Chapter 1

Introduction: Original Motivations

Multi-wavelength studies of nebulae excited by neighbouring O-B stars are fundamental to understand the chemical and physical processes occurring in the interstellar medium. Detailed modeling of these processes is required to improve our understanding of various astronomical objects such as star forming regions. However, for most regions, accurate comparison between predictions from these models with observations is limited due to the lack of information about the exciting star, and due to the poorly determined geometry of the region. In fact, current astronomical data interpretation usually involves accepting current theories which are then used to infer the properties of the exciting star. In this work a precise comparison between observed cloud emissions and predictions from models describing the ionization of atomic hydrogen, dissociation of molecular hydrogen and heating of nebular dust grains due to stellar radiation is proposed. This may lead to constrain the modeling of the physical and chemical processes occurring in the clouds. On the other hand, given that the models are accurate, such comparison may allow to infer interesting properties of the clouds.

For this purpose, the region Sharpless 185 was observed through emission in the 21 cm line, in the radio continuum and in the infrared wavelengths. The region was chosen for three reasons: (i) The exciting star γ Cas has been studied extensively and direct observations of its spectrum are available. (ii) The geometry of S 185 is relatively simple. The region is close (≈ 230 pc) and the location of the clouds with respect to the exciting star is sufficiently well defined to provide accurate comparison between models.
and observations. (iii) The region has an overall angular extent of about 1.5° in diameter and can be mapped all at once by the wide field of view synthesis telescope (SST) of the Dominion Radio Astrophysical Observatory (DRAO).

Gamma Cassiopeia appears to be the exciting star of two clouds located 20″ away from the star in the northern and north-east directions (Figure 1.1 and 1.2). First listed as “IC63” and “IC59” in Dreyer’s supplement to the NGC catalogue (Index Catalogue), the nebulæ also appeared later in Sharpless’s catalogue (1953) as S185¹ [1]. On the prints, a larger ridge of fainter nebulosity is also barely seen and extends as far as 1° east of the star. As opposed to most HII regions, the nebulosity associated with γ Cas is quite inhomogeneous. No emission is seen on the southern and western sides of the star.

Given the spectral type of γ Cas (B0.5IV), ionized hydrogen and infrared emission from dust should be detectable from the neighbouring nebulosity. Moreover, strong molecular hydrogen fluorescent emission and extended red emission (ERE) were both detected recently in IC63 [2]. None of these features was observed in IC59 while both clouds were found to have similar emission spectra in the 600-700 nm region [2] indicating closely matched excitation conditions. The detection of fluorescent emission and ERE which are both stimulated by ultraviolet radiation from the exciting star is a striking signature of on-going H₂ photodissociation. As a result, there should be a detectable zone of atomic hydrogen in IC63. The latter can be compared with the recent dissociation model of Roger and Dewdney [3].

Other aspects of this region are interesting as well. First of all, the exciting star is one of the most famous Be stars which has experienced spectacular variations about 50 years ago. The star has been studied extensively since then and its nature still remains a mystery [4]. Moreover, it was soon noted (1957) that the two associated nebulæ exhibit

¹For this work, S185 is defined as the entire nebulosity surrounding γ Cas that is, IC63, IC59, and the other fainter emission seen on the prints.
marked differences among their colours and morphological structures [5, 6]. IC63 is characterized by the presence of strong filaments (Figure A.1 (a) and (b)) whose emission appears to be predominantly red. The emission from IC59 is bluer and no filamentary structure is observed.

This thesis contains five other Chapters. Chapter 2 summarizes background information about S185. The first section is devoted to γ Cas while the second section deals with the surrounding nebulosity. Chapter 3 presents all the observations used for this work. The data processing pertaining to the DRAO observations is described in greater details as they contain more important information. Chapter 4 presents basic results from the observations. In the first section, each object dealt with in this thesis is described individually in terms of all the observations where it is detected. The second section deals with flux integration from the provided maps. Finally, the last section of Chapter 4 presents the geometric parameters of the clouds which are used in Chapter 5 to compare the cloud emissions with the exciting star properties. In this Chapter, the emission from IC63 and IC59 are compared to the stellar parameters presented in Chapter 2. Some discrepancies are found and a possible explanation for these is discussed at the end of the Chapter. The last Chapter (Chapter 6) deals with unrelated objects discovered in the observations and summarizes results for S185. Directions for future work are also discussed.
Figure 1.1: E-band Print of the POSS survey. The brightest star is γ Cas which is exciting the surrounding nebulosity in the northern direction. The HII region appears to be very inhomogeneous as no nebulosity is seen in the southern direction, and between the star and the northern nebulosity. Scale: 7'/cm
Figure 1.2: O-band Print of the POSS survey. Visual comparison with Figure 1.1 clearly indicate an important colour and morphological structure difference between IC63 and IC59. The former is redder and has a prominent filamentary structure. Scale: 7'/cm
Chapter 2

Previous Studies of S185

This Chapter presents background information concerning S185. The first Section summarizes the enormous observations found throughout the literature for γ Cas. The Be phenomenon is briefly introduced to provide a clearer description of the star.

The second Section of this Chapter summarizes previous observations and work regarding the surrounding clouds IC 63 and IC 59. Early theories describing the evolution of the cometary shape of these nebulae are presented first. Next, more recent work concerning the chemical and physical structure of the clouds is summarized.

2.1 Gamma Cassiopeia

2.1.1 A Be Star

The Be phenomenon initially defined by optical observations was first discovered in 1867 when Secchi in Rome [7] observed an emission line in the spectrum of γ Cas superposed on the normal B-star shallow absorption line. A visual comparison with the spectrum of the neighboring star β Cas allowed him to identify the line with the β transition of atomic hydrogen. The presence of emission lines in stellar spectra is not particular to stars of spectral type B. Oe, Ae, Fe, etc. stars exist as well but Be stars are the most studied among them. Because the emission lines are not predicted by classical stellar atmosphere theory except for the case of supergiants, their occurrence remains an anomaly and justifies extensive studies of the phenomenon.
Emission lines in Be stars are of a wide variety and are commonly classified into two categories: The shell spectrum (Figure 2.1, 1935.94 to 1936.30 and 1939.68 to 1940.43) is characterized by a deep V-shaped absorption core with or without emission wings. The Be spectrum has no absorption core and exhibit emission lines with a single or a doubled peak profile (Figure 2.1, all except the shell spectra).

A first explanation of emission lines in the spectrum of non-supergiant stars was proposed by Struve [10] in 1931 and was improved in the following years [11]. Struve postulated the presence of a disk-like envelope in the equatorial plane of the rapidly rotating B star (Figure 2.2). The disk mostly composed of hydrogen would be ionized by the strong stellar UV radiation and a recombination spectrum blended with the stellar continuum emission would result. In Struve’s model, the double-peak lines are produced by Doppler shift of the emission coming from the edges of the rotating disk. The separation of the peaks is directly related to the rotation speed of the envelope and to the angle between the rotation axis of the star and the line of sight. Stars seen “pole-on” would exhibit a single-peak profile while stars seen “edge-on” would show doubled-peak lines with wider peak separation. In order to create and maintain the disk, Struve’s model required the star to be rotating at critical velocity when the centrifugal force exactly balances the gravitational attraction.

Although simple and elegant, his model had two major weaknesses. First there is no observational evidence for fast rotation of Be stars. Next, the model does not account for a very important characteristic of Be stars; their long term variability in the visible. The description of this phenomenon for γ Cas has been summarized by Doazan [8] and it is fascinating. During the 1927-1942 period γ Cas has shown spectacular variations of its magnitude and emission line spectrum (Figure 2.1 and 2.3).

From 1930 until now, the apparent magnitude of the star has varied between 1.5 and 2.7 which corresponds to a change of a factor of three in luminosity. The peak may
Chapter 2. Previous Studies of S 185

Figure 2.1: Hβ emission lines in the spectrum of γ Cas for the 1926-40 period (from [8]). Corresponding years are shown on the right hand side of the lines. The horizontal scale is wavelength in Angstrom.
occurred during the 1932-40 period. At present the star luminosity is still increasing at a slow rate.

Along with the luminosity variations, important changes also occurred in the line emission spectrum. These will be described briefly: Within thirty years, three types of spectrum were observed for \( \gamma \) Cas: Be, shell and that of a normal B type star\(^1\). From 1866 to 1915, the star exhibited a normal Be spectrum (emission lines with no strong absorption core) with no noticeable variations (Figure 2.3 (a)). In 1915, the intensity of the emission lines began to fluctuate slightly. However, spectacular changes occurred only 17 years later in 1932 when the peak emission rose quickly, while both lines started to merge together (Figure 2.1 1932.5 to 1934.8). Towards the end of 1934, the doubled-peak profile had completely disappeared and emission was at its maximum. Several lines such as FeII, HeII, MgII, SiII and CaII were seen in the spectrum, and the widths of the Balmer lines indicated very different velocities from one to another. The strength of

\(^1\)This quite significant in Be stars theory. Showing that the three spectra belong to the same class of object, it also suggests that the Be phenomena could simply be a normal period of stellar evolution; Be stars represent 20% of the B stars.
the emission lines then decreased until the appearance of a shell spectrum at the end of 1935. The latter lasted for 11 months.

In September 1936, a similar scenario was repeated but with much higher intensity. Emission was maximum a year later in September 1937. The lines of FeII, CaII, TiII, CrII, AlIII, MgII, SiII and HeII were seen in emission. Again a strong shell phase followed the peak emission, starting in 1940 and ending in 1942 after which γ Cas displayed the spectrum of a normal B star until 1948. From then, the emission lines slowly reappeared and their intensity is currently increasing at a constant rate (Figure 2.3 (a)).

The V/R ratio\(^2\), defined as the ratio of the line intensities in a doubled-peak profile, roughly followed the variations of the emission strength in the 1932-42 period (Figure 2.3 (c)). From 1942 to 1970, the line ratio was rather constant. Fluctuations began again in 1970 and surprisingly, no strong emission and shell phases followed. The V/R ratio now

\(^2\)In a double-peak profile, the red-shifted peak is commonly referred to as the Red line (R) and the blue-shifted peak is called the Violet (V) line.
currently undergoes variations with a typical period of 5 years.

It is extremely difficult to account for all these observations and only a few incomplete models are found in the literature [13, 14, 15]. One model is as follows: an optically thick disk responsible for the shell spectrum will gradually expand to a more spherical shape (Figure 2.4) and become optically thin because of the expansion. This accounts for the luminosity increase which is due to scattering of starlight in the expanded envelope. However, an extra component is required to explain the \( V/R \) fluctuations. The envelope would be deformed by the presence of a companion, possibly a neutron star [16]. However, if it exists, the mass of the companion must be quite low. The weak fluctuations in the radial velocity of \( \gamma \) Cas allowed to place an upper limit of 1 M\(_{\odot}\) for the orbiting star [17].

Along with long term variations in the optical spectrum of \( \gamma \) Cas, rapid changes (time scale of a few minutes) of the H\( \delta \) and H\( \alpha \) line profiles have also been detected [16, 18, 19]. These are very irregular and mostly affect the line profile rather than the absolute line intensity.

### 2.1.2 Infrared Observations

The infrared line emission spectrum of \( \gamma \) Cas is similar to the optical. The lines are doubled-peaked and variable. The continuous spectrum however reveals an important characteristic of Be stars: the occurrence of an excess of infrared radiation compared to normal B stars. This was first pointed out by Johnson [20] in 1967 from photometric measurements in the U, B, V, R, I, J, K and L bands. Later in 1970, measurements at 3.4, 5.0, 8.5 and 11.5 \( \mu \)m [21] suggested that the excess is due to free-free emission in the envelope. Four years later, the free-free nature of the emission was confirmed by a study of 33 classical Be stars showing that the IR excess varies slowly with wavelength (as expected for free-free emission in an optically thin envelope), and that no 10 or 20 \( \mu \)m silicate features suggestive of dust emission are present [22]. The excess of infrared
Figure 2.4: Two possible types of expanding envelopes to explain the long term variations of Be stars (from [13]). The magnitude increase is due to scattering in the expanding optically thin envelope. The shell spectrum is created by the contracted optically thick disk.

radiation for $\gamma$ Cas is about $300 \, L_\odot$ or $1.18 \times 10^{29} \, \text{W}$ for a distance of 230 pc [23].

The Infrared Astronomical Satellite (IRAS) launched in January 1983 provided observations of $\gamma$ Cas in four continuum bands centered on 12, 25, 60 and 100 $\mu$m (Figure A.3). Various interpretations of these results are found in the literature [24, 25, 26, 27]. The IRAS data are consistent with fluxes predicted by the free-free emission process invoked to explain the infrared excess [26]. However, the data is also in agreement with predictions from a model in which matter accreted onto a companion produces the infrared emission [24].
2.1.3 Ultraviolet Observations

Most ultraviolet observations of γ Cas were carried out after the launch of the Copernicus and International Ultraviolet Explorer (IUE) satellites in 1972 and 1978 respectively [29, 30]. All together, these data provided the following information:

(i) Superionized lines such as PV, NV, CIV, CIII, CII, SiIV etc. are detected and their amplitudes undergo strong variations on time scales of hours, weeks or months. Compared to the visual, the UV fluctuations are of a much greater intensity. The large Doppler shifts of these lines indicate the presence of strong stellar winds. The observed terminal velocities can be as high as 1700 km s\(^{-1}\) [31], implying that γ Cas is losing mass at a rate of \(10^{-9}\) to \(10^{-11}\) M\(_{\odot}\) year\(^{-1}\) [31, 29, 11].

(ii) There is a stellar wind zone in the Be star envelope. Since the larger Doppler shifts are observed for stars of lowest \(V \sin(i)\) (those seen pole-on) [32], the winds probably arise from the polar regions of the star.

(iii) A correlation exists between the presence of high velocity winds and the \(V/R\) ratio [33]. It was noticed that the winds are more often seen when the \(V/R\) ratio is greater than 1. Interpretation of this observation is difficult.

2.1.4 Radio Observations

Radio observations of γ Cas have been undertaken only in the last 10 to 15 years. Initially, no detection of the star at 2, 6 and 20 cm was reported with the Algonquin Radio Observatory (ARO) and the Very Large Array (VLA) [34, 35]. In 1985, the star was detected at 6 cm with the VLA [36] and a flux of 0.26 mJy was measured. A year later, an upper limit of 0.13 mJy was placed at the same wavelength [37]. The star is therefore variable at radio frequencies. In 1988, a flux of 0.46 mJy at 2 cm was measured from other VLA observations [38].
The radio emission of Be stars would arise from free-free emission in the ionized envelope. A correlation has been found between the radio 2 cm and the Hα luminosities of Be stars\(^3\) [38], suggesting that both arise from the same component of the envelope.

Carbon monoxide observations in the neighborhood of γ Cas have been carried out with the Kitt Peak telescope [39]. Five positions were observed in a radius of 2′ around the star. No emission was detected to an upper limit of 3 K.

2.1.5 X-ray Observations

The X-ray counterpart of γ Cas was discovered in 1976 [40]. A flux of \(3.5 \times 10^{-13} \text{ W m}^{-2}\) (2.21 \(\times 10^{26}\) W for a distance of 230 pc) was measured over the 2-11 keV band. Located within a radius of 1′ centered on a point 10″ away from the star, the source (designated MX 0053+60) could easily be identified with γ Cas.

However, the star had been detected much earlier by the Copernicus and UHURU satellites. Between November 1974 and January 1976, Copernicus measured an average flux of \(1.1 \times 10^{-13} \text{ W m}^{-2}\) (0.69 \(\times 10^{26}\) W) in the 3-8 keV band [41]. During the 1971-1973 period, the 2-6 keV band detector of the UHURU satellite measured an averaged flux of \(6.95 \times 10^{-14} \text{ W m}^{-2}\) (0.44 \(\times 10^{26}\) W) with maximum variation of a factor of three [42]. This and a flare-type event in 1977 [18] have shown that the X-ray emission of γ Cas is also variable.

Two well known mechanisms are invoked to explain the origin of the X-ray flux: In the first case, the emission would be produced in a very hot \((T > 2 \times 10^7 \text{ K})\) optically thin corona surrounding the star. The X-ray flux would originate in a maxwellian plasma with an electron density less than \(10^{11} \text{ cm}^{-3}\) [43]. The major difficulty with this model is that it cannot account for the observed variability.

In the second mechanism, the emission is generated by mass transfer onto a companion.

\(^3\) Gamma Cas is an exception to this correlation.
star; a neutron star [44] or a white dwarf [45]. The problem is that no periodicity has been found in the radial velocity or the X-ray emission of $\gamma$ Cas $^4$ that could indicate the presence of a $> 1 M_\odot$ companion [17]. Gamma Cas is known to have a visual companion (ADS 782B). However, it is located 2.2" away from the star and fainter by 8 magnitudes. At a distance of $\approx 230$ pc, the stars are separated by about $10^5 R_\odot$ and the absolute magnitude of ADS 782B is between 3 and 4. These facts hardly support the possibility of mass accretion onto the companion [43].

2.1.6 Polarization Measurements

The Be stars, along with Of, Wolf-Rayet and other stars exhibit intrinsic linear polarization of their spectrum, and so does $\gamma$ Cas. This observation is probably the strongest evidence for the disk-shaped envelope model. Polarization is supposed to arise from electron scattering in the asymmetric envelope. A correlation between the amount of polarization in the neighboring continuum of the H$\alpha$ line with $V \sin(i)$ $^5$ provides stronger support for the disk model [47]. Be stars with higher $V \sin(i)$ show a higher degree of polarization as would be expected if the latter is produced in an equatorial envelope.

The polarization of $\gamma$ Cas is about 0.6% and 0.3% at angles of 105° and 102° (measured counter clockwise from the north direction) in the continuum and line emissions respectively [47]. The disk which is perpendicular to the angle of polarization would be parallel to the $\gamma$ Cas-IC 59 line which suggests a possible explanation for the difference between IC 63 and IC 59 (see Section 2.2.2).

The amount of polarization in the H$\alpha$ and H$\gamma$ lines decreases towards the line center [48, 49]. This suggests that line emission occurs in an optically thin region of the envelope.

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$^4$Except for a short time scale periodicity of 6000 s in the X-ray emission [46].

$^5$The angle between the line of sight and the rotation axis of the star (i) can be estimated from measurements of the width of the absorption hydrogen lines. The measure yields a parameter called $V \sin(i)$. i can be inferred if the equatorial speed at the stellar surface $V$ is known.
A wavelength dependence in the polarization of the stellar continuum is also observed and is consistent with the disk model [48]. Short and long term changes are again observed in the polarization of $\gamma$ Cas [50, 51].

2.1.7 The Distance to $\gamma$ Cas

Considerable amount of scatter is found in the literature regarding the distance to $\gamma$ Cas (Table 2.1). Unfortunately, the star is too far away to show any stellar parallax, and less direct methods must be used to estimate its distance. Almost all the estimates found in the literature depend on two parameters such as the absolute visual magnitude $M_v \approx 4$ and intrinsic colour $(B - V)_0 \approx -0.25$ of the star. These values are compared with the apparent magnitude and colour to yield informations on the distance and interstellar reddening along the line of sight. The intrinsic stellar parameters are themselves estimated from the spectral type of the star, which is estimated from spectroscopic observations. Absolute calibrations between stellar classification and intrinsic parameters are used to provide $M_v$ and $(B - V)_0$.

The spectral type estimation can be quite inaccurate, especially in the case of Be stars since their apparent magnitude and colour are variable. Moreover, the underlying mechanism causing these variations is not well understood. Altogether, these uncertainties can account for the observed scatter in the distances quoted. Nevertheless, the reasonable estimate of Vakili et al. [52] is adopted for this work.

They assume that $\gamma$ Cas is a BO.5IV star surrounded by an envelope responsible for the increase of luminosity during the Be phase. From the calibrations of Balona and Crampton [53] and FitzGerald [54], the corresponding intrinsic absolute magnitude and colour are $M_v = -4.0 \pm 0.6$ and $(B - V)_0 = -0.28 \pm 0.01$. During the normal B phase of 1942-46 (when presumably no envelope was surrounding the star), the apparent magnitude and colour of $\gamma$ Cas were $B - V = -0.26 \pm 0.02$ and $m_v = 2.8$. This yields
a distance of $D = 230 \pm 70$ pc for the star, with most of the uncertainty coming from the uncertainty in the absolute magnitude. This distance will be adopted for this work. However, it should be kept in mind that this result mostly depends on the estimated spectral type and on the interpretation of the Be phenomenon.

It is of interest to present the results of Fabregat and Reglero [55]. They developed a method to obtain the underlying B-star characteristics of Be stars from photometry and Hα emission line width measurements. They obtained $M_v = -6$ and $(B - V)_0 = -0.13$ which together with $m_v = 2.23$ and $(B - V) = -0.04$ imply $D = 442$ pc for γ Cas. The disagreement between this result and the distance of Vakili et al. is mostly due to the difference between the absolute magnitudes estimates.

2.1.8 The Continuous Spectrum of γ Cas

The continuous energy distribution of γ Cas has been observed over a wide frequency band and peaks in the UV region\(^6\). Hence, if the distance to the star is known, a direct estimate of the non-ionizing stellar luminosity ($L_{\lambda>912}$) is available from these measurements. Moreover, stellar atmosphere model calculations such as those of Kurucz and Panagia [56, 58] allow one to infer the ionizing luminosity and number of ionizing photons for the star.

Two continuous energy distributions for γ Cas are available from the literature [28, 23]. The distribution of Waters et al. [28] is shown on Figure 2.5 with the best Kurucz model fit. The spectrum has been corrected for interstellar absorption assuming $E(B - V) = 0.03$. The Kurucz model fit yields $T_e = 25000$ K and $\log(g) = 3.0$, for a stellar radius of 10 $R_\odot$. The corresponding luminosity is thus $L_* = 4\pi R^2 \sigma T_e^4 = 1.35 \times 10^{31}$ W. If we integrate the distribution of Figure 2.5, a non-ionizing luminosity $L_{\lambda (\lambda>912)} = 1.40 \times$\(^6\)No measurements at $\lambda < 912$ Å is available because of strong absorption by the gas in the line of sight for these wavelengths.
Figure 2.5: The dereddened energy distribution of $\gamma$ Cas (data digitized from the Figures of Waters et al. [28]).

$10^{31}$ W is obtained for the distance of 230 pc. The fractional ionizing luminosity $P \equiv L_{*}(\lambda<912)/L_{*}$ is 0.0032 for the fitted distribution. Hence, the total luminosity of $\gamma$ Cas practically equals the non-ionizing luminosity. The difference between the luminosity directly integrated from the spectrum and the luminosity corresponding to the model is partly due to the excess of infrared emission observed for $\gamma$ Cas ($1.18 \times 10^{29}$ W). The latter is usually interpreted as an envelope effect.

These values compare reasonably well with the lower estimate of Jansen et al. [57] for the same distance. They quote $L_{*}(\lambda>912) = 1.11 \times 10^{31}$ W. The result for a B0.5IV star in Panagia is close ($L_{*} = 1.2 \times 10^{31}$ W), while the luminosity of the underlying B
star evaluated by Hamann et al. [23] is larger \((2.02 \times 10^{31} \text{ W})\). From these considerations, 
\(L_*= (1.4 \pm 0.5) \times 10^{31} \text{ W}\) is adopted for the rest of this work.

The fractional ionizing luminosity \(P = 0.0032\) with \(L_* = (1.4\pm0.5)\times10^{31}\ \text{W}\) translates into 
\(L_{\leq 912} = (4.5 \pm 1.5) \times 10^{28} \text{ W}\). Assuming an average energy per ionizing photon 
\(\langle E_{\leq 912} \rangle = 0.82 \times 10^{-18} \text{ J}\), a number of ionizing photons \(N_L = (5.5 \pm 1.5) \times 10^{46} \text{ s}^{-1}\)
is obtained for the star. This value is adopted for this work. The average energy per ionizing photons used to calculate this result was obtained from 
\(L_* = 1.4 \times 10^{31} \text{ W}\) and \(N_L = 4.7 \times 10^{46} \text{ s}^{-1}\) given in Panagia for a B0.5IV star, and with \(P = 0.0032\).

The fact that the star is variable requires further discussion. Most of the data used to derive the luminosities discussed above were collected during the 1960-80 years. Over this period, the apparent visual magnitude of \(\gamma\) Cas has experienced a maximum variation of 0.2 magnitudes (Figure 2.3 (b)) which corresponds to change by a factor of 1.2 in total luminosity.

2.1.9 The Age of \(\gamma\) Cas

Unfortunately, no information is found in the literature concerning the age of \(\gamma\) Cas. As a result, only an upper limit can be inferred given the nuclear energy available to the star and the star luminosity. The available nuclear energy is determined by the mass. For \(\gamma\) Cas which is a main sequence star with an absolute magnitude of \(\approx -4\), the mass is about \(16 M_\odot\), and the corresponding available energy is \(2.02 \times 10^{45} \text{ J}\) [59]. Given the luminosity of \(1.41 \times 10^{31} \text{ W}\), the longest main sequence evolution time is \(\approx 4.5 \times 10^6\ \text{years}\). From the quasi total absence of material around the star, it appears that the star is well established on the main sequence, as a minimum amount of time is required for the radiation and stellar wind to expulse the material from which the star was formed. However, it is difficult to estimate this time.

Table 2.1 lists parameters for \(\gamma\) Cas collected from the literature. These parameters
may not be consistent with one another in the sense that different distances may have been used to compute a distance-dependent parameter. Hence, the values listed below are crude estimates. One really need to check the listed reference carefully before any conclusion can be drawn from these results. The table however remains useful to point out appropriate references and to show the general values and uncertainty in the stellar parameters.

2.2 The $\gamma$ Cassiopeia Nebulosity

2.2.1 Morphology of the Clouds and Association with $\gamma$ Cas

The idea that galactic nebulae shine by re-emission and/or reflection of radiation coming from neighbouring stars may have risen from observations of cometary shaped nebulae such as IC 63 and IC 59. These nebulae would always point towards a common star or group of stars thus identifying a possible source of excitation. The verification of this idea is due to Edwin Hubble [84] who performed a statistical study of galactic nebulae. The analysis of Hubble included IC 63 and IC 59 and it is interesting to read his comment on the association of $\gamma$ Cas with the clouds:

"The star is obviously associated with, although not involved in, the nebulae. The very form of the nebulosity seems determined by radiation or repulsive action from the star which lies at a center of radial symmetry with respect to the fans."

Diffuse nebulae with a cometary shape are found frequently in the galaxy and often characterized by the presence of strong filaments or bright rims such as those seen in IC 63 (Figure A.1 (a) and (b)). Struve in 1937 [85] noted that bright rims are always associated with emission nebulae, and never with reflection nebulae. He also observed
<table>
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<th>HR 264</th>
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<td>SAO 11482</td>
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<td></td>
<td></td>
<td></td>
<td>00536+6026</td>
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<tr>
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<td>$0^h 53^m 40.323^s$</td>
<td>$l = 123.58^\circ$</td>
<td>$b = -2.15^\circ$</td>
<td></td>
</tr>
<tr>
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<td>($1950$)</td>
<td>(galactic)</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>205 [38]</td>
<td>220 [60, 61, 62]</td>
<td>230 [52]</td>
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<tr>
<td></td>
<td>300 [65]</td>
<td>194 [66]</td>
<td>40 [67]</td>
<td></td>
</tr>
<tr>
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<td>0.12 [55]</td>
<td>0.07 [60, 69, 21]</td>
<td>0.15 [26]</td>
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<td>0.02 [70]</td>
<td>0.10 [71]</td>
<td>0.20 [64]</td>
<td>0.08 [72]</td>
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<td></td>
<td>0.05 [65]</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>-4.00 [52, 65]</td>
<td>-4.10 [73]</td>
<td>-4.50 (B0IV) [58]</td>
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<td>-4.2 [58]</td>
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<td>BOIVe</td>
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<td>[74, 64, 66]</td>
<td>[75, 39]</td>
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<td>[79]</td>
<td>[80]</td>
<td>[22]</td>
<td>[58]</td>
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<tr>
<td></td>
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<tr>
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<td>[58]</td>
<td>[62]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radial Velocity Hel. (km s$^{-1}$)</td>
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<td>-7.0</td>
<td>-3.46</td>
<td>-6.8</td>
</tr>
<tr>
<td></td>
<td>[81]</td>
<td>[82]</td>
<td>[17]</td>
<td>[83]</td>
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</table>

Table 2.1: Stellar parameters for $\gamma$ Cas collected from the literature. Appropriate references are shown in square brackets.
that the brightest parts of the filaments were always seen on the side of the exciting star. More detailed studies of the structure and formation of cometary nebulae were performed in the 50's, and unfortunately, no more work appears to be done on this subject nowadays. The best discussions concerning diffuse cometary nebulae are found in the papers of Osterbrock [5], Pottasch [86] and Spitzer [87]. The papers outline the following conclusions:

(i) The structure of cometary nebulae evolves from a flat edge towards narrow broken spikes with only a dense roundish globule remaining at the latest evolutionary stage. Two mechanisms may be involved to explain the formation of these shapes, that is radiation pressure or shocks between media of different densities. The former would apply for IC63 and IC59 since no low density medium is observed between the star and the clouds. Both mechanism are equivalently described by a combination of two theories; the first order theory of Rayleigh-Taylor (which applies at the initial stage when the shape of the nebula is flatter) and a theory of finite displacements to explain the formation of long and thin spikes. As an analogy, consider the unstable configuration created by a layer of water superposed on top of a less dense layer of oil (Figure 2.6). The slightest mechanical perturbation will lead to the formation of an initial disturbance which amplitude will increase exponentially with time according to the former theory. According to the latter theory, thin spikes of dense material falling through the lighter material with bubbles of lighter material moving into the heavier fluid will then arise. Furthermore, the velocity discontinuity at the surface of the spikes would eventually causes the structure to fragment. As a result, broken structures would be observed. Such structures are observed in many nebulae such as IC63.

Broken cometary shapes can also be seen in water falls. These are due to the strong wind resulting from the rapid speed of the falling water, and also to the gravitational
acceleration which enhances the velocity discontinuity in the layer of water. The continuous layer of water at the top evolves into cometary shape and then to several drops from the top to the bottom of the fall.

(ii) Bright rims are always located on the side of the exciting star. They appear to consist in regions of higher density in the cloud. Furthermore, in the same region, the presence of bright rims is correlated with the angular distance between the nebula and the exciting star. Bright rims are more often seen for clouds with lower angular separation from the exciting star. Moreover, closer clouds have a more pronounced cometary shape thus suggesting their faster evolution towards the final roundish globule stage. Hence, the clouds with bright rims would have been compressed more rapidly by radiation pressure or expanding low density medium.

In this view, the structure difference between IC 63 and IC 59 may suggest that the latter is farther away from the exciting star. Consequently, the line joining IC 59 and $\gamma$
Cas may not be perpendicular to the line of sight.

2.2.2 Physical and Chemical Structure

The chemical content and physical conditions inside IC 63 and IC 59 have been studied in greater details by Poeckert and van den Berg (hereafter PvdB) [63], Witt et al. [2] and Jansen et al. [57]. The work of these three groups is summarized in this section.

The Work of Poeckert and van den Berg

PvdB present an interesting although incomplete study of S 185. They propose three hypotheses to explain the origin of the nebulosity: (i) The clouds could have resulted from the interface between the supersonic wind of γ Cas and the interstellar medium (ISM), (ii) they might be remnants of a dense stellar wind and (iii) they could have been compressed by the explosion of a supernovae that may have existed in the past. The latter would explain the presence of the hypothetical companion of γ Cas (Section 2.1.5).

The observations of PvdB consist of Palomar plates taken in 1967 and 1980 in the E, O and J bands (Figure A.1 (a) and (b)). Their intention was to look for structural changes in the cloud emission over a time period of 28 years. They could only set an upper limit of 2'' to any morphological variations. PvdB also used the Dominion Astrophysical Observatory (DAO) 1.8 m telescope to obtain a spectrum of IC 63 in the 5640-6890 Å wavelength region. From the line emission, they could infer a number of characteristics. The intensity of the SII doublet suggested that the cloud is shock excited, and the line ratio indicated an electron density $N_e < 10^3$ cm$^{-3}$. More importantly, PvdB were able to measure the Doppler shifts of the SII and NII lines to give a radial velocity of 26 km s$^{-1}$. They do not state whether the velocity is evaluated with respect to the sun or to the LSR.
PvdB interpret their observations in the following way: The colour difference seen on the POSS prints is due to the fact that IC 59 is a reflection nebula while the redder colour of IC 63 results from line emission within the cloud. The weakness of the emission lines in IC 59, would result from shielding of the stellar Lyman continuum radiation by the postulated equatorial disk surrounding the Be star. The observed intrinsic polarization angle of $\gamma$ Cas (Section 2.1.6) implies that IC 59 exactly lies in the equatorial plane of the star.

This conclusion is supported by the work of Osterbrock [5] who compared red and blue plates with plates taken in a spectral region where line emission is absent. He concluded that line emission is very weak in IC 59 while IC 63 and all the other fainter nebulosities in S 185 have emission line spectra with some continuum.

The possibility that IC 59 is a pure reflection nebula suggests a few interesting observations. In such a case, the spectrum of IC 59 should exhibit the same features as that of $\gamma$ Cas but with lower intensity. It should then be possible to observe the stellar emission lines in the cloud to provide a measure of $V \sin(i)$ viewed from a different angle. This extra information, together with the measurement from the earth should provide accurate determination of $V$ and $i$ separately. Furthermore, since the magnitude of $\gamma$ Cas has varied significantly in the past due to its envelope, a corresponding luminosity variation should also be seen in IC 59 and probably not in IC 63. In principle, observation of such a light echo should allow a direct determination of the distance between $\gamma$ Cas and the cloud. For a distance of 230 pc and an angle made by the line joining the cloud and the exciting star and a line perpendicular to the line of sight $\alpha \approx 0$, this echo should be visible about 5 years after the magnitude increase. Hence, the 0.8\" sudden change of 1937 should have been observed in 1942. Unfortunately, to our knowledge, no plates of S 185 are available at that epoch. However, we note that this estimate strongly depends on $\alpha$. For example if $\alpha = 70^\circ$ and if IC 59 is farther away from us than the star is, the
light echo should have been visible 33 years later, that is during the 70’s. If $\alpha = 70^\circ$ and the cloud is closer than the star, the light echo would have been seen almost at the same time as the sudden brightening of $\gamma$ Cas.

The Work of Witt et al.

Witt et al. [2] provide IUE observations of IC 63, IC 59 and $\gamma$ Cas. They obtained UV spectra in the 1150-1950 Å band at the tips of the clouds. Using the 1.3 m telescope of the McGraw-Hill Observatory, they also obtained spectra covering the 1150-9000 Å band at the same positions.

After subtraction of the scattered light continuum of $\gamma$ Cas from the UV spectrum of IC 63, Witt et al. obtained a residual spectrum which could be identified with fluorescence emission from molecular hydrogen. Such a spectrum is a striking sign of photodissociation: the absorption of a photon in the Lyman-Werner band ($91 \leq \lambda \leq 112$ nm) is quickly followed by fluorescent line emission and the molecule remains in some vibrational level. If the energy of the absorbed photon was sufficient, the remaining vibrational energy can cause the molecule to dissociate. The efficiency of this process is about 10-20% depending on the excitation conditions [88].

The optical spectrum of IC 63, after subtraction of the scattered light continuum exhibits three major components: two emission lines and a broad band red emission peaking near 6700 Å due to Extended Red Emission (ERE) (Figure 2.7). The lines are due to (i) blends of H$\alpha$ and the NII doublet and (ii) to the SII doublet.

ERE was first detected through photometric measurements [89, 90, 91] in the R and I bands. Emission greater than expected from light scattering on dust grains alone was detected. Duley [92] first suggested that ERE arises from excitation of Hydrogenated Amorphous Carbon grains (HAC) by the exciting star radiation. He compared a spectrum of the red rectangle with laboratory data from Watanabe et al. [93]. This suggestion
Chapter 2. Previous Studies of S185

Figure 2.7: The residual spectrum of the tip of IC63 in the 5000-9000 Å region (from [2]).

enabled Witt et al. [94] to understand their observations of NGC 2023 and NGC 7023 which consisted of a correlation between the wavelength of the peak of the broad emission and the distance from the exciting star. Hot dust in dissociation zones becomes rehydrogenated which stimulates ERE and shifts the peak of the broad band feature towards shorter wavelengths.

At the tip of IC59, no UV fluorescence or extended red emission spectrum was detected. Thus, the cloud appears to be of a nature totally different than IC63. However, the same optical lines mentioned above were detected with similar relative strength but smaller widths. This led the authors to conclude that ERE is the main agent causing the colour difference between IC59 and IC63, since the similarity of the line ratios in both nebulae suggests similar excitation conditions.

The work of Witt et al. showed that only the UV flux of γ Cas is sufficient to produce
the fluorescent luminosity. Among the three possibilities (X-ray flux, stellar wind and UV flux), the X-ray flux and the stellar winds appear to be fainter by orders of magnitude. Furthermore, Witt et al. predicted an H$_2$ column density of $3 \times 10^{16}$ cm$^{-2}$ from their molecular hydrogen luminosity.

**The Work of Jansen et al.**

A detailed physical and chemical study of IC63 has been initiated by Jansen et al. [57]. The $^{12}$CO $2 \rightarrow 1$, $^{12}$CO $3 \rightarrow 2$, $^{13}$CO, and CS $2 \rightarrow 1$ transitions have been observed along with other species such as HCO$^+$, HCN, CS and H$_2$CO. Submillimeter wavelength fluxes at 450, 800 and 1100 $\mu$m respectively, were also observed with the James Clerk Maxwell Telescope (JCMT).

A tiny (1' x 2') molecular cloud peaking at the observed position of Witt et al. was discovered (Figure 2.8). The cloud has a radial velocity ($LSR$) of about 0.6 km s$^{-1}$ and temperature $T_A^* = 14.2$ and 16.8 K for the respective 3$\rightarrow$2 and 2$\rightarrow$1 transitions of $^{12}$CO. The orientation of the cloud's axis pointing towards $\gamma$ Cas ensures its association with IC63. The lines of HCO$^+$, HCN, CS and H$_2$CO are observed at velocities consistent with the CO data and are detected only at the peak CO emission where higher density allows molecules to survive dissociating radiation from the exciting star. The authors suggest that the cloud is warm ($T \approx 50$ K) and dense with $N_{H_2} \approx 5 \times 10^4$ cm$^{-3}$, corresponding to a column density of $N_{H_2} = 5 \pm 2 \times 10^{21}$ cm$^{-2}$. The latter result compares badly with the estimate of $3 \times 10^{16}$ cm$^{-2}$ of Witt et al. Abundances of species such as CN and CS are similar to those found in cold dark clouds but other molecules such as HCN, HCO$^+$ and N$_2$H$^+$ are depleted by a factor of three, possibly due to the intense radiation field.

Limited observations were carried out for IC59, and only a widespread component

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$^7$This velocity is not consistent with the estimate of PvdB which according to the galactic rotation curve is obviously wrong.
Chapter 2. Previous Studies of S185

Figure 2.8: CO molecular cloud in IC63 (from [57]). The zero position of the map is at $0^h\,59^m\,1.38^s\,60^\circ\,53'\,17.46''$ (J2000).

of $^{12}$CO $2\rightarrow1$ is detected at $V_{LSR} = -20\,\text{km}\,\text{s}^{-1}$, and is probably not associated with the cloud.

Some infrared data analysis is presented in the paper, but integrated fluxes are given only for a single beam area which is not very meaningful because of the poor resolution of the analyzed IRAS maps. It is however surprising that their fluxes for $\gamma$ Cas are less than those of Smith et al. [24], Waters et al. [25] and Coe [27] by roughly a factor of two.
Chapter 3

Observations

This Chapter deals with all the observations used for this thesis: the Bonn and NRAO radio continuum surveys, the IRAS survey and the DRAO observations. The data reduction process for the DRAO observations is described in greater details.

3.1 Previous Observations of the Region

Several observations of S185 are already available from surveys covering a wide band of the spectrum. Those are: (i) The Palomar Observatory Sky Survey (POSS) observations and the prints of Poeckert and van den Berg [63] in the optical, (ii) the Bonn and NRAO surveys in the radio domain, and (iii) the IRAS survey in the infrared.

The POSS E and O band prints (Figure 1.1 (a) and (b)) were obtained in September 1952 and show a large ridge of diffuse emission extending as far as 1° east of γ Cas. The exciting star is obviously overexposed on the prints and unfortunately prevents seeing the neighboring stars. Another set of prints is available from the observations of Poeckert and van den Berg. The prints, (Figure A.1 (a) and (b)) were probably obtained in 1967 and observed with the E and J band filters. These prints are less exposed than the POSS prints and are best to show the filamentary structure of IC 63.

The Bonn surveys provide images of S185 at 11 [95] and 21 cm [96] in the continuum emission. Table 3.1 lists parameters for the observations. They were carried out with the Effelsberg single dish telescope. The quoted rms was measured on an area close to S185 and free from outstanding emission. Grey scale of the 21 and 11 cm maps are shown in
Chapter 3. Observations

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Table 3.1: Parameters for the Bonn surveys.

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</table>

Table 3.2: Parameters for the NRAO surveys.

Figure A.2 (b) and (c).

The NRAO surveys provide 6 cm [97] and 21 cm [98] maps (Figures A.2 (a) and (d)) of S185 observed with the late Greenbank 300 foot telescope. The resolution of the 6 cm map is slightly higher than the 11 cm map (Table 3.2). However, extended emission (more than 30') is slightly attenuated on this image due to subtraction of extended low atmospheric emission during the data processing. We immediately note that a source detected in the 21 cm Bonn map (hereafter MG) is not seen in the 21 cm NRAO data (Figures A.2 (c) and (d)). This will be discussed in Chapter 4 and 6. The rms for both NRAO maps was again measured on an area close to S185 and free from outstanding emission.
Chapter 3. Observations

Table 3.3: Parameters for the IRAS survey.

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<tr>
<td>Bandwidth (µm)</td>
<td>$\approx 7$</td>
<td>$\approx 13$</td>
<td>$\approx 35$</td>
<td>$\approx 35$</td>
</tr>
<tr>
<td>Measured rms (MJy sr$^{-1}$)</td>
<td>0.12</td>
<td>0.17</td>
<td>0.74 (1.8)</td>
<td>3.4</td>
</tr>
<tr>
<td>Calibrators</td>
<td>$\alpha$ Tau</td>
<td>Asteroids</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The IRAS observations [99] started in January 1983 (Table 2.3) and ended in November of the same year after 96% of the sky had been successfully surveyed. The satellite measured infrared emission within four wide bands centered on 12, 25, 60 and 100 µm. The satellite was also equipped with a low resolution spectrometer which covered the 8-22 µm band. Most regions have been observed four times by the satellite and individual maps for each scan are available, as well as images made from the entire database ("coadded images").

Low resolution maps for the four IRAS bands are shown in Figure A.3. Figure A.3 (d) shows the enhanced resolution map (1') processed by Waters [100]. The effective beam sizes of these maps are listed in Table 4.2. IC 63 and IC 59 are prominent on these images and their shapes generally correspond to the optical emission. Two extra features appear on the IRAS maps (labeled 1 and 2 on (b)). The first of them is an unresolved source located halfway between IC 63 and IC 59. Included in the IRAS point source catalogue (PSC) the source is designated IRAS 00556+6048. A second peculiar object (IRAS 00533+6030) shows up besides $\gamma$ Cas. Its spectrum seems to be similar to that of $\gamma$ Cas (the source is not detected for $\lambda > 60$ µm).
3.2 The Dominion Radio Astrophysical Observatory

The modern era of the observatory began with the synthesis telescope which has become the major instrument of the observatory [101]. The first interferometer had two paraboloids of 9 m diameter movable on a 300 m east-west precision track to stations spaced at 4.3 m interval. Later on, the number of antennae was brought to four on a twice longer baseline configuration, and was increased to seven in 1991. As for any east-west oriented synthesis telescope, the earth rotation is used to cover the UV plane. Twelve days of twelve hours observing are required for a complete survey consisting of data collected at 140 antenna spacings between 12.9 and 604.3 m.

The DRAO Super Synthesis Telescope (SST) operates simultaneously in continuum bandwidths of 30 and 4 MHz at 1420 (\( \lambda = 21 \text{ cm} \)) and 408 MHz (\( \lambda = 74 \text{ cm} \)) respectively [102], and in 128 channels of the HI line at 21 cm. For the latter, a choice of various spectrometer bandwidths is available: 0.125, 0.25, 0.5, 1, 2 and 4 MHz. In continuum, the system temperatures are typically 150 K (408 MHz) and 80 K (1420 MHz) with a corresponding rms noise level of 3.3 and 0.28 mJy/beam at the center of the field of view. The synthesis telescope receivers measure both left and right circular polarizations at 1420 MHz for which polarimetry is now available with the recent development of new software and calibration procedures. Only right circular polarization is detected at 408 MHz and in the 21 cm line emission. The 1' angular resolution of the instrument at 21 cm is ideal for comparing SST observations with those from other surveys such as IRAS (infrared) and ROSAT (X-rays). Observations at 74 cm, although of lower resolution, are useful to derive spectral indices of the detected emissions.

The relatively small diameter of the interferometer dishes (compared to other telescopes such as the VLA) makes the DRAO telescope unique, being a wide field of view instrument. Fairly large galactic structures (2° and 8° at 1420 and 408 MHz respectively)
can be mapped at once thus reducing the required observing time and need for field mosaics. Data quality and completeness is strongly emphasized by incorporating visibilities corresponding to spacings shorter than 13 m to the interferometer measurements. The data for short spacings are obtained from the existing Effelsberg survey database for the 1420 MHz continuum emission, and are observed with the DRAO 26 m diameter single dish for the hydrogen line. The 26 m telescope is equipped with a 128 channels digital spectrometer similar to that of the SST. The receiver has an overall system temperature of about 50 K and a 30' beam width.

3.3 DRAO Observations

The DRAO observations of S185 started in October 1992 and ended two weeks later in November (Table 2.4). As one of the first surveys after the array upgrade to seven antennae, the observing went quite smoothly with only a minor problem with the crosstalk calibration which was done at the wrong spectrometer bandwidth (2 instead of 0.5 MHz). The calibration parameters of the earliest survey at 0.5 MHz were used instead. The overall data quality is particularly good in line and continuum at 1420 MHz.

3.3.1 Continuum Data Reduction

During the observations, the raw data coming from the telescope is sampled at 5.26 seconds interval, and stored sequentially in computer disk memory. In order to reduce disk space, these data are later averaged every 90 seconds after which visual inspection of the uncalibrated visibilities is carried out by the observatory staff. The visibilities are then calibrated against standard calibrators at nearby declination (Table 2.4), from observations carried out before and after each 12 hour observing block.

A dirty map and dirty beam are next generated by Direct Fourier Transformation
### Table 3.4: Parameters for the DRAO SST observations.

<table>
<thead>
<tr>
<th>λ (cm)</th>
<th>Continuum</th>
<th>HI Line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>21</td>
</tr>
<tr>
<td>End of Observations</td>
<td>11 Nov. 1992</td>
<td></td>
</tr>
<tr>
<td>Observation Epoch</td>
<td>1992.85</td>
<td></td>
</tr>
<tr>
<td>Bandwidth (MHz)</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>Channel Width</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Channel Separation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Velocity of Central</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Channel (# 65)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Resolution (HPBW)</td>
<td>3' 57.67&quot;</td>
<td>1' 8.24&quot;</td>
</tr>
<tr>
<td></td>
<td>3' 25.04&quot;</td>
<td>58.8&quot;</td>
</tr>
<tr>
<td>Measured rms Noise (mJy/beam)</td>
<td>8.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Calibrators</td>
<td>3C295, 3C147</td>
<td>3C309.1, 3C147</td>
</tr>
</tbody>
</table>

(DFT), a method used because of its computation time efficiency. For an east-west baseline SST, the observed UV plane consists of elliptical rings sampled at constant hour angle interval. The DFT method requires the input UV plane to be computed on a rectangular grid structure with uniform U and V increment. To compute the grid, the input UV plane is first convolved with a gridding function to produce a continuous visibility distribution which is then re-sampled on the desired rectangular grid. At DRAO, the convolution function used is gaussian and spans about five sampled points of the original UV plane.

Next, the UV plane is multiplied by a weighting function giving more weight to points located in undersampled (due to constant sampling rate over longer elliptical UV tracks) UV plane areas to emulate a uniform sampling density. The UV data are also multiplied by a gaussian tapering function down to 20% of its peak at the longest spacing. This
Chapter 3. Observations

has the effect of smoothing the transition between observed and non-observed (assumed to be 0) visibilities at the longest spacing boundaries. As a result, the sidelobe level of the telescope point source response will be reduced at the cost of a subsequent loss in resolution. The inverse Fast Fourier Transform (FFT) of the resulting structure is then computed to generate the dirty map.

Continuum dirty maps are made on a $1024 \times 1024$ pixels grid with a $20''$ (1420 MHz) and $70''$ (408 MHz) interval. In this manner, the area covered by the map is about four times the field of view of the instrument so that grating artifacts are aliased outside the field of view. At 1420 MHz, data taken in the four bands (A, B, C and D) and four polarizations (RR, LL, RL and LR) were averaged into a single map in order to improve the dynamic range.

Dirty images at 21 and 74 cm are displayed on Figures 3.1 and 3.2 respectively. The S185 region is particularly well seen with great details at 1420 MHz where the resolution is higher. The peculiar fan-shape of IC63 is easy to recognize and closely corresponds to the optical nebula. IC 59 is rather weak. A strong point source at its tip is present and does not seem to be resolved by the instrument. Significant depressions are seen around point sources and around the central portion of the map. This indicates a lack of short spacings components. At 74 cm (Figure 3.2), S185 is still recognizable. IC 63 is represented by a tiny triangular shape sitting on a larger ring of faint emission. The shell structure on the north-east side of the field of view is the supernovae remnant R5 (G127.1+0.5 [103]) and the strong double peaked extended emission in the southern direction of the field center is S184. The map is covered with stripes and sidelobes artifacts which indicate that interference occurred during the observations. The 408 MHz data are particularly sensitive to these features due to the extremely wide field of view of the telescope at this frequency.

In order to eliminate the beam sidelobes, an algorithm first devised by Högbom
Figure 3.1: The 21 cm continuum dirty map. Note the sidelobes around point sources and the depressions around the whole region in the center of the field of view. Grey scale setting (white, black): 3 and -1 mJy beam\(^{-1}\).
Figure 3.2: The 74 cm continuum dirty map. The large stripe between $0^h 30^m$ and $0^h 45^m$ is due to interference from the supernovae remnant Cas A located outside the field of view of the telescope. Fainter stripes originating from the pole are due to ground based interference. The supernovae remnant R5 (G127.1+0.5) and HII region S184 are seen as a shell-like and strong double-peak structures at approximately $(1^h 30^m, 63^\circ)$ and $(0^h 52^m, 57^\circ)$ respectively. Grey scale setting (white, black): 50, -15 mJy beam$^{-1}$. 
Chapter 3. Observations

[104], successfully implemented by Barry Clark [105] and later improved by David Steer [106] called CLEAN is used. The earlier version of the algorithm (CLARK) is efficient in removing artifacts from strong point sources in the field while the improvement of STEER is designed for extended emission. The actual software in which CLEAN is implemented at DRAO permits usage of both algorithms in the same run by setting a switch from the CLARK to the STEER portion of the program.

The 21 cm map is already quite good and barely needs CLEANing. However, a quick CLEAN is necessary to remove the low level sidelobes on the faint emission of IC 59. At this stage of the process, CLEAN has to be applied with some precautions. Ideally, one wants to CLEAN only the point sources and the emission of small extension. A deep CLEAN will try to make up for the missing short spacings in the beam pattern by raising the extended emission and its surrounding depression. This is of course undesirable since the short spacings will be added later on. In fact, a better approach to this problem involves adding the short spacings to the dirty map first and then CLEANing with a beam computed on the combined visibility sets. This idea is currently under development in Australia and may eventually be used at DRAO.

For the reasons mentioned above, CLEAN was stopped early, when the rms of the residuals had reached 2.4 mJy beam\(^{-1}\). The CLEAN was performed with the CLARK algorithm until the rms of the residuals was comparable to the strength of the wings of IC 63, after which the STEER portion of the program was used.

The short spacings data were then extracted from the Bonn survey database by selecting a field of 6° × 6° which is larger than the SST field of view. The SST polar diagram was applied to this map. Other than making the angular attenuation of both images equal, this also has the advantage of tapering the edges of the single dish map which can be useful if a large slope in the emission across the field is present.
The low resolution map was then converted to UV plane by taking its Fourier transform. In the UV representation, interferometer and single dish data overlap and a decision has to be made on how to match the redundant spacings. For the single dish, visibilities at distances longer than 54 m in both U and V directions were not used and data corresponding to spacings between 14 and 54 m were attenuated with 0% and 100% weight at 54 and 14 m respectively. The weighting function is cubic, and has zero slope at the boundaries with 50% attenuation half way between 54 and 14 m. Since the resolution of a map made from single dish observations is limited in long spacings due to the size of the beam, its response over the UV plane is not constant and a correction has to be applied. The response is basically shaped as a gaussian decreasing to 50% of its maximum value at a distance given by:

$$D_t = 15.4 \lambda / R$$

(3.1)

where $\lambda$ has units of cm and $R$ is the resolution of the map in minutes of arc. For the Effelsberg 100 m diameter telescope, $D_t = 34$ m.

After this correction had been applied, the UV plane was transformed back to sky brightness distribution and the filtered map was made on the same grid as the SST image.

The visibilities of the high resolution map were edited in a similar manner. The map was first transformed to UV plane where spacings between 14 and 54 m were cut with cubic weighting function and the UV plane was converted back to brightness distribution. Note that for an interferometer, no correction for primary UV pattern is needed since all the spacings are measured with equal weight.

Figure 3.3 shows a contour plot of the low resolution image superposed on a grey scale of the interferometer map just before combining them. Note the positional correspondence between the point sources on both displays. Being narrow spikes surrounded by dark regions on the interferometer map, they are rather faint and extended on the
Figure 3.3: Overlay of filtered interferometer data (grey scale) and single dish data (contours). Note the correspondence between point sources that are more extended on the low resolution map with the corresponding narrow spikes on the filtered high resolution data. Contours start at 0.1 K with a 0.2 K increment. Grey scale setting (white, black): 3, -1 K.
Figure 3.4: The 21 cm continuum map after addition of the short spacings. One quarter of the field of view is shown. No depressions around extended emission remains after the process. Comparison with Figure 3.3 shows that the extended emission of S185 and other emission at approximately 1$^h$ 5$^m$, 61° 15' is uniquely due to the short spacings data. Grey scale setting (white, black): 2.1, 1.0 K.
single dish image. The interferometer single dish beam pattern that was applied to the low resolution map is clearly seen. Note that MG (the source detected in the 21 cm Bonn survey and not in the NRAO data at the same wavelength) is seen as a deformation of the fourth highest contour in the north-east direction of IC 63, and is not detected in the SST data.

The map resulting from adding both images after correction for the interferometer dishes beam pattern is displayed on Figure 3.4. One quarter of the actual field of view is shown. The process appears to be successful since no depressions are left in the neighborhood of strong emission. Note that the point source detected only in the Bonn survey now appears as a weak, roughly circular and flatter extended emission due to filtering of the longer spacings of the Bonn map. The latter is not compensated for by the SST data. The final map has a rms noise level of 0.06 K (0.4 mJy beam\(^{-1}\)) at the field center.

At 408 MHz, no short spacings are added to the SST data since no corresponding low resolution survey exists. On the dirty map (Figure 3.2), many grating rings or artifacts seem to originate from sources located outside the field of view. East of S185 there is a strong and large stripe going through the map in the north-south direction. On average, the peak intensity of the stripe is about 40 mJy beam\(^{-1}\) along the ring. This feature is due to interference from the supernova remnant Cas A which is strong enough to make a significant contribution to the map through a weak telescope sidelobe. Several large and fainter stripes having their origin towards the north pole are also present. Their intensity is about 20 mJy beam\(^{-1}\). However, they cover a major part of the field of view. These artifacts are probably due to ground based interference. This can be understood from the fact that the pole is the only point in the sky that will appear to move in the field of view of the antennae as they track the observed region. Hence, non celestial interference which is fixed with respect to the earth, is moving in the field of view, and can only be
mapped at the pole.

Obviously, a CLEAN will not remove these artifacts. A special treatment is therefore necessary. A first step in this process is to remake a dirty map that will have its phase centre shifted to the position of the source of interference. Figure 3.5 shows these maps for the north pole (upper display) and Cas A (lower display). Cas A is the strong source on the right edge of the map. The point sources on the left hand side are included in the field of view. The polar interference has a more complex structure and its origin is unknown.

A visibility model is needed to remove interference due to sources outside the field of view. The model is created by CLEANing the shifted maps within the source area and by creating visibilities corresponding to the generated clean components. For this method to be successful, the number of components used must be properly chosen. A reasonable number of components are required to model the source accurately. On the other hand it is important that unreal information taken on unrelated noise or artifacts is not included. A choice of 127 components gave satisfactory results for Cas A, while 719 of them were needed to model accurately the more complex polar structure.

Once the model visibilities were subtracted from the original data, another dirty map was made and CLEANed inside an area including all strong sources. The CLEAN procedure was stopped when a peak residual of $\approx 12 \text{ mJy beam}^{-1}$ was reached. This level corresponds to the strength of the polar interference residuals and sets a limit to further CLEANing. Figure 3.6 presents the final 74 cm CLEANed map. About one quarter of the field of view is shown. Both interference removal processes worked reasonably well. The intensity of the polar stripes has been reduced and the Cas A feature is now barely detectable. The 408 MHz has an rms noise level of $\approx 1.2 \text{ K (8.2 mJy beam}^{-1}$ at the center of the field.
Figure 3.5: Maps shifted to the sources of interference.
Figure 3.6: The 74 cm continuum map after interference removal and CLEANing. One quarter of the field of view is shown. The sidelobe due to Cas A is barely perceptible and the polar stripes have been significantly reduced. Corrupted data however still remain.
3.3.2 Line Data Reduction

The spectrometer data consist of a family of 128 maps (one per spectrometer channel) needing to be processed as a whole. As a result, line data reduction requires considerably more disk space. Because of the limited dynamic range of the HI emission and since the individual members of the map family have a very narrow bandwidth (0.006 MHz), it is no longer necessary to make the extent of the maps twice the field of view (as is the case for the continuum image). A size of 256×256 pixels with a 30” grid interval is adequate. Combined with good UV coverage, the low dynamic range of the emission reduces the sidelobe level (<4%) so that CLEANing of the line maps is not required.

The telescope receivers are equipped with an Automatic Gain Control system (AGC) that maintains constant input signal for better correlator function. In general, atomic hydrogen in the observed field will raise the system temperature above what it is when pointing at the calibrator so that the line receiver gain may not be equal to the continuum gain. The attenuation factor of the AGC system is not yet recorded automatically by the system and a first step in line data reduction is to recover this value. Various methods can be used for this purpose. They are discussed in the following paragraphs.

In the direction of S185 (l = 124° and b = −2°), the velocity of the atomic hydrogen gas is less than 13 km s\(^{-1}\) as can be seen on the spectra of Weaver and Williams [107]. All the material along the line of sight is located farther away from the galactic center than the sun. As a result, the differential rotation of the Galaxy causes most of the gas to move towards the observer (V_{LSR} < 0). The little amount of gas at V_{LSR} > 0 is mostly due to local motions in the solar system neighborhood, and partly due to the fact that the sun itself is moving at a velocity of ≈1 km s\(^{-1}\) with respect to the LSR along the line of sight direction, and towards the galactic center.

The result of this is that the first 25 channels of the spectrometer (for which V_{LSR} =
Chapter 3. Observations

31.94 to 12.98 km s\(^{-1}\)) should not contain any emission other than the continuum. Taking the average of these first channels yields a 0.00 MHz bandwidth continuum map at 1420 MHz with lower noise than the individual channels. This averaged map can then be compared with the calibrated continuum 1420 MHz data to provide an estimate of the AGC correction factor.

The strongest point source in the field of view (located about 45′ south of the map centre) was used for that purpose. The averaged map was successively multiplied by factors ranging from 1.0 to 1.6 in increments of 0.1. Each of the resulting images was then subtracted from the wide band continuum map and stripcharts of the residual source were plotted. After visual inspection of the residuals, the correction factor was found to lie somewhere between 1.3 and 1.4. The noise of the residuals prevented more precise determination of the correction factor. For comparison, the same method was applied to a fainter source in the field. However, the precision was even less due to the lower signal to noise ratio. Nevertheless, results from both sources were consistent with each other.

Another estimate of $F$ is provided by integrating the spectrum of Weaver and Williams (hereafter W&W) nearest to the observed SST field. This allows one to predict by how much the SST antenna temperature should have been raised by the HI emission. Taking into account the different telescope beam sizes and the SST aperture efficiency, the integrated W&W antenna temperature of 19.6 K translated into a 9 m interferometer single dish temperature of 16.7 K. For a SST system temperature of 65 K, the predicted $F$ is 1.26 [108]. This however remains a crude estimate since the fields observed by the two instruments are not the same. Moreover, comparison with results from other surveys seems to indicate a systematic discrepancy between corrections predicted by the spectra of W&W and those obtained from the ratio of the continuum emission in the wide band map and in the averaged empty HI channels. The continuum ratio method yields systematically higher AGC gains. Considering this, $F = 1.35 \pm 0.05$ was adopted.
The rest of the line data reduction can be described briefly. The HI maps are first corrected for the AGC system gain, and the continuum emission is subtracted from each of the spectrometer maps in order to retain only the atomic gas component. Next, the 26m dish HI spectra are compared with those of W&W and are calibrated in brightness temperature against the standard S7 profile of the same authors. A baseline level computed from the empty channels is then removed and the single dish observations are ready to be combined with the SST data. The procedure is basically the same as for the continuum observations except for the fact that the visibilities need to be matched at shorter distances in the UV plane (7 and 15m) since the DRAO single dish is smaller than the Effelsberg telescope. As mentioned earlier, no CLEAN is required.

Some of the HI maps are shown in Figure A.4 (grey scales with darkest areas indicating strongest HI emission). A mean galactic profile computed on the entire field of view has been subtracted from the maps and is shown at the end of the plot series. Several fascinating and unexpected features such as sharp extended ridges are detected. IC63 and IC59 are detected at $V_{LSR} \approx 0 \text{km s}^{-1}$. 
Chapter 4

Preliminary Results

This Chapter presents basic results from the observations described in the previous Chapter. The first section discuss the identification of each object of interest on the available observations. This identification is then used to determine the edges of the clouds as accurately as possible in order to perform accurate flux density integration. The latter is presented in Section 4.2. Finally, geometric parameters for the clouds are presented in the last Section of this Chapter. Altogether, these preliminary results will be used in Chapter 5 to compare the cloud emissions with the stellar properties.

4.1 Sources Identification

4.1.1 IC 63

Among all the observations presented in Chapter 3, the prints of PvdB (Figure A.1 (a) and (b)) have by far the highest resolution and show the cloud with the greatest details. As mentioned earlier, the nebula has a cometary shape pointing almost exactly towards $\gamma$ Cas and has several sharp and intense filaments seen mostly on the side of the exciting star. Except for an intriguing straight ridge observed in front of the tip of the cloud on the blue print, the bright rims of IC 63 are observed only on the red print. As a result, the filamentary emission of IC 63 appears to be being dominated by line emission.

No filamentary structure is seen on the DRAO continuum 21 cm image (Figure A.1 (a)). The resolution of the DRAO observations is too low to show such structures.
However, the broken shape of the cloud is very well detected and fits the optical emission nicely. On the DRAO map, IC63 is surrounded by a faint background extended emission which probably traces a very low density ionized gas.

The other radio continuum maps at 6, 11 and 74 cm do not show the cloud so well due to lower resolution (Figure A.2). The cometary shape of the cloud is roughly reproduced at 6 and 11 cm. At 74 cm, the nebula is poorly resolved and is barely recognizable as a triangular cloud sitting on top of a larger ridge of background emission. Since IC63 and its neighboring point sources are embedded in the background, it is not obvious to determine the edges of the cloud on these maps.

The infrared emission of IC63 is best seen on the 60 μm high resolution map (Figures A.1 (b) and A.3 (d)). The cometary shape fits the radio continuum and optical emission quite nicely. The dust cloud appears to have a more filled triangular structure than the red and radio continuum emissions. In average, the difference in strength of the emission between the edges facing the exciting star and the centroid of the nebula is less. On the set of low resolution IRAS maps (Figure A.3 (a), (b), (c) and (e)), IC63 has a smoother shape and appears to be partially resolved.

IC63 was barely detected by the HI observations (Figure A.4, Channels 36 to 43). Positive identification of the HI component of the cloud is provided by recognizing the cometary shape at radial velocities of 0.61 and 1.44 km s\(^{-1}\) with respect to the LSR. Other emission is also detected at lower and higher velocities and probably belongs to the cloud. Globally, the spectrometer data indicate that emission at the centre of the cloud appears first at 3.08 km s\(^{-1}\) and persists until −1.04 km s\(^{-1}\). This is a velocity interval of 5.44 km s\(^{-1}\) (from the lowest velocity of one map to the highest in the other) centered on \(V_{LSR} = 1.02\) km s\(^{-1}\). A map made by averaging these data is displayed in Figure A.5 (a) with overlaying contours of the 21 cm continuum emission. The shape of the HI cloud is mostly triangular with peaks behind and at the tip of the ionized
component. Atomic gas is detected behind the fans as well.

It is also of interest to look at the spectrometer data displayed in spectral form (Figure A.5 (c)). From the individual channel maps, four HI spectra were obtained at the positions indicated on Figure A.5 (b). A galactic profile computed on a 75' × 25' rectangular area centered on the southern edge of the field of view was subtracted from these spectra. Altogether, the emission lines of the nebula have an average peak temperature of 20.8 K, an average peak half width of 3.8 km s\(^{-1}\), and a peak velocity of \(\approx -0.21\) km s\(^{-1}\).

4.1.2 IC 59

IC 59 is defined by its optical and infrared emissions only. The nebula has a cometary shape but is free of filamentary structures on either prints (Figure A.1). The apex of the cloud does not exactly point towards \(\gamma\) Cas but rather a few degrees to the east of it. The bluer colour of IC 59 on the prints suggest that it shines mostly by scattering of starlight upon dust grains.

At 21 cm in the continuum, only a very faint extended emission is detected (Figures A.1 (a) and 3.4). However, the emission fits the cloud on the optical red print closely, especially on the eastern edge. If there were no strong point source in the neighborhood, it is likely that the entire cometary shape of the nebula would be reproduced by the radio emission contours. At 11 and 6 cm, a similar structure is barely detected (Figure A.2 (a) and (b)) due to background confusion.

The IRAS observations clearly detect IC 59. Close coincidence is observed between the high resolution IRAS data and the optical blue emission (Figure A.1 (b)).

IC 59 has weak and extended HI line emission embedded in a noisy background (Figure A.4 channels 36 to 43). The association of this component with the nebula is confirmed by a close morphological fit to the POSS blue print and IRAS high resolution 60 \(\mu\)m
shapes. Such a precise fit is very unlikely to occur unless the sources are physically related. The velocity extent of the HI gas in IC 59 is similar to that of IC 63. The northern region of the cloud is detected first at $V_{LSR} \approx 3.91 \text{ km s}^{-1}$ while the southern part is first detected at $2.26 \text{ km s}^{-1}$. At $-1.86 \text{ km s}^{-1}$, the cloud has disappeared almost completely. A velocity range of $7.09 \text{ km s}^{-1}$ centered on $1.03 \text{ km s}^{-1}$ is adopted for IC 59. Figure A.6 (a) shows a grey scale image of IC 59 made by averaging the channel maps within this interval. Contours show the high resolution 60$\mu$m associated emission.

A few spectra were computed at various locations within the HI cloud (Figure A.6 (b) and (c)). The subtracted background is the same as for IC 63. The spectra have an average peak temperature of 25 K and an average half width of $4.2 \text{ km s}^{-1}$. It is interesting to note the variation of the peak velocity within the nebula. The spectrum of position 3 appears to peak at a lower velocity.

4.1.3 Infrared Source Between IC 63 and IC 59 (IRAS 00556+6048)

The unresolved infrared source located midway between IC 63 and IC 59 is possibly detected on the POSS prints, at 74 cm, and in the HI line emission. Nothing is observed at any other radio continuum frequency. The POSS prints show a very weak and small nebulosity partly surrounding a star almost coincident with the peak of the infrared source (Figure A.1 (b)). At 408 MHz, a continuum source is detected (Figure A.2 (c)) but its peak emission is separated by more than two minutes of arc from the peak of the IR source.

The shell-like HI nebulosity near IRAS 00556+6048 may be an associated component. A partial shell of HI is observed around the IR source (Figure A.4, channel 75 to 85 incl.). The shell is seen on six channels of the spectrometer. A fragmented ridge is observed first at $-30.72 \text{ km s}^{-1}$ and is detected until $-35.66 \text{ km s}^{-1}$. From then, the shell becomes fragmented and only small bits of HI remain. The emission has entirely disappeared by
-38.14 km s\(^{-1}\). A velocity interval of 7.91 km s\(^{-1}\) centered on -34.01 km s\(^{-1}\) is adopted for IRAS 00556+6048. The average map computed on these data is displayed in Figure A.7 (a) with superimposed contours of the 60 \(\mu\)m high resolution map. The resulting structure is quite inhomogeneous. It is however interesting to note that the spike of HI emission in the north-east direction lines up with the end of the northern edge of stronger shell emission and with the peak of the infrared source.

4.1.4 Point Source at the Edge of IC 59 (Tip Source)

On the edge of the tip of IC 59 (Figure A.1 (a) and A.2), a point source (hereafter “Tip Source”) is obviously detected at all four radio continuum wavelengths, although it is more embedded in background emission at 6 and 11 cm (Figure A.2 (a) and (b)). Before the DRAO observations were performed, it was not obvious weather this feature was associated with IC 59 or not. The fact that the source appears to be much stronger at 74 cm than at any other wavelength now suggests that it is an extragalactic object. However, we are unable to detect any 21 cm line absorption to a limit of 20 K (peak) towards the source.

4.1.5 Emission Near \(\gamma\) Cas (IRAS 00533+6030)

An infrared source is detected on the north-west side of \(\gamma\) Cas (labeled 2 in Figure A.3 (b)). This object does not seem to have any radio or optical counterpart. Like \(\gamma\) Cas, the infrared emission of IRAS 00533+6030 is stronger at 12 \(\mu\)m and is not detected at 100 \(\mu\)m. On the other hand, it is significantly weaker than the star. In the optical, no nebulosity is present within the area covered by IRAS 00533+6030. It is interesting to look at the source on the high resolution 60 \(\mu\)m map where it appears to be resolved into two components. The emission is however weak at this wavelength and high resolution
images at 12 and 25μm would be more useful. Gamma Cas is very well detected as a tiny point source on the 60 μm image (Figure A.1 (b) and A.3 (d)).

The γ Cas region has been mapped a number of times in radio continuum emission with the VLA in order to detect the postulated envelope of the Be star [109]. Some neighboring continuum sources were detected as well and are shown as asterisks on Figure A.3 (d). No correspondence is seen with the infrared emission. However, one of the VLA sources coincides with a continuum 21 and 74 cm point source (hereafter MN) on the DRAO maps. Coincident HI emission is also detected (Figure A.4, channels 73 to 78).

Atomic hydrogen emission coincident with IRAS 00533+6030 is detected and appears at $V_{LSR} \approx -22.5 \text{ km s}^{-1}$ (Figure A.4, channel 68 and following) and evolves into two stronger peaks as velocity decreases. The two HI peaks suddenly disappear at $-26.6 \text{ km s}^{-1}$ (channel 73) after which a larger elongated structure is observed.

Since no morphological connection can be clearly established between the IR, the continuum and the HI emissions, association of these components is quite uncertain. For this reason, no average map of the HI data is presented here. The best display is still provided by the individual maps of Figure A.4.

4.1.6 Point Source East of S185 (MG)

On the east side of IC 63, a point source (hereafter MG) of 114 mJy was detected in 1974 by the Bonn 21 cm continuum observations (Figure A.2 (c), and not in the DRAO (1992, A.2 (e) and 2.3), NRAO 21 cm (1983, A.2 (d)), NRAO 6 cm (1987, A.2 (a)), Bonn 11 cm (1982-83, A.2 (b)) or infrared observations (1983, A.3). As mentioned earlier in Chapter 3 (Section 3.3), the weak extended emission on the DRAO map is due to the Bonn data alone. On the POSS blue and red prints, (1952) there is a faint star with no surrounding nebulosity coincident with the centroid position of MG.
Chapter 4. Preliminary Results

The position of the continuum source is coincident with a depression in a larger structure of HI emission which appears to be associated (Figure A.4 Channel 73 and following). The structure is present between velocities of $-26.60$ and $-31.54$ km s$^{-1}$; that is a velocity range of 6.26 km s$^{-1}$ centered on $-29.07$ km s$^{-1}$. Figure A.8 (a) displays the average map generated from these data with contours of the Bonn 21 cm continuum emission. An HI spectrum computed over the area delimited by the rectangular box shown in Figure A.8 (b) is displayed in (c). It has a peak of 38.2 K at $V_{LSR} = -28.2$ km s$^{-1}$, and a half width of 7.7 km s$^{-1}$. Further discussion of this object is found in Chapter 6.

4.2 Flux Density Integration

4.2.1 Methods

Unresolved Sources

The flux integration of unresolved sources is best performed by fitting the telescope beam pattern to the map emission profile. The accurate knowledge of the instrument response is used to eliminate the inaccuracies inherent to the digitization of the source. For a synthesis telescope, the beam without sidelobes is well represented by an elliptical two-dimensional gaussian function that can be fitted to the map.

In practice, a conventional least square fit procedure is performed on the data and yields a gaussian amplitude and size from which the flux density is calculated. Initially, a box including the source is defined on the map and an initial guess for the amplitude of the gaussian to be fitted is provided by the actual peak in the area. A background emission component is calculated and subtracted from the map before the fit is performed. The background consists of a twisted plane defined by the map values at the edges or corners points of the selected box.
Two important sources of uncertainty arise when measuring the flux of an astronomical object. The first of them comes from the noise of the map being analyzed, and the second one is mainly due to the inability to locate the edges of the emission precisely. In order to account for both of these, several fits on the same source, defined on slightly different boxes, are performed and the variance of these results is used to provide an estimate of the uncertainty.

Extended and Irregular Emission

It is not possible to fit a single gaussian to extended emission. Instead, the source brightness distribution must be integrated directly. The pixel values inside a carefully selected boundary are summed, and the result is multiplied by the size of the selected area. Again, a background emission level consisting of a twisted plane defined by the edges of the polygon delimiting the integration area is removed, and the uncertainty is estimated from the variations of the flux density computed on slightly different areas.

4.2.2 IRAS Flux Densities

IRAS fluxes for the objects studied in this thesis are listed in Table 4.1. The integration method for extended sources was used to estimate the flux density of IC63 and IC59, since they are partially resolved. Flux densities of IRAS 00556+6048 and IRAS 00533+6030 are respectively taken from the IRAS PSC and from Smith et al. [24]. The flux of γ Cas is taken from Smith et al. [24]. As indicated previously, the uncertainties derive from the standard deviations of the flux densities computed on approximately five slightly different boundaries for the same source. The uncertainties of IRAS 00556+6048 were given in the PSC. They are generally higher since other sources of error due to various problems are included [99]. For comparison, the flux densities measured on the high resolution 60 μm map are given. They are in general agreement with the low resolution
data. The high resolution flux densities and peak surface brightnesses for $\gamma$ Cas and IRAS 00556+6048 were obtained by fitting a gaussian to the emission.

The 100 $\mu$m flux densities of IC 63 and IC 59 obtained by integrating the extended emission on the IRAS maps are between 5 to 6 times higher than the values listed in the PSC. This is to be expected since an important fraction of the emission arises from the cloud extensions. Furthermore, the background subtracted for the PSC fluxes might have been defined on the source extension and would therefore be overestimated. The upper limits on the flux of MG have been computed on the maps over the extent of the continuum source.

Table 4.2 lists peak surface brightnesses for the sources with their corresponding positions. These have been background subtracted. The listed beam sizes were obtained by fitting a gaussian to IRAS 00556+6048. It is seen that the beam sizes for the 12, 25 and 60 $\mu$m measurements are the same within the uncertainty while that for the 100 $\mu$m is significantly lower. Results from the high resolution data are listed for comparison and are generally quite higher. The low resolution 60 $\mu$m peak surface brightness normalized for the high resolution beam size is 903 MJy sr$^{-1}$ which is in good agreement with the measurement on the map. IC 63 and IC 59 are partially resolved on the low resolution data set so that such comparison is not relevant for these sources.

4.2.3 Radio Flux Densities

Continuum

Table 4.3 lists radio continuum fluxes for IC 63, IC 59, the Tip Source, and upper limits for IRAS 00556+6048 and MG. The upper limits are computed for a sensitivity of 3$\sigma$ (Tables 3.1 to 3.4). In the case of MG, the source size listed in Table 4.7 was used to compute the upper limits for maps having a higher resolution than the Bonn 21 cm map.
### Chapter 4. Preliminary Results

<table>
<thead>
<tr>
<th>λ (μm)</th>
<th>Integrated Fluxes (Jy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>(Low Resolution)</td>
</tr>
<tr>
<td>IC 63</td>
<td>19.0 ± 0.4</td>
</tr>
<tr>
<td>IC 59</td>
<td>20.3 ± 0.5</td>
</tr>
<tr>
<td>IRAS 00556+6048</td>
<td>4.7 ± 0.4</td>
</tr>
<tr>
<td>IRAS 00533+6030</td>
<td>4.24</td>
</tr>
<tr>
<td>γ Cas</td>
<td>19.2</td>
</tr>
<tr>
<td>MG</td>
<td>&lt; 1.9</td>
</tr>
</tbody>
</table>

Table 4.1: IRAS integrated fluxes.

<table>
<thead>
<tr>
<th>λ (μm)</th>
<th>Peak Surface Brightnesses (MJy sr⁻¹) and Positions (J2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>(Low Resolution)</td>
</tr>
<tr>
<td>IC 63</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>00h 59m 15.5s</td>
</tr>
<tr>
<td></td>
<td>60° 53' 42.6&quot;</td>
</tr>
<tr>
<td>IC 59</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>00h 57m 26.2s</td>
</tr>
<tr>
<td></td>
<td>61° 07' 41.6&quot;</td>
</tr>
<tr>
<td>IRAS 00556+6048</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>00h 58m 32.0s</td>
</tr>
<tr>
<td></td>
<td>61° 03' 49.2&quot;</td>
</tr>
<tr>
<td>Beam Sizes (10⁻⁶ sr)</td>
<td>1.8 ± 0.1</td>
</tr>
</tbody>
</table>

Table 4.2: IRAS peak surface brightnesses and corresponding positions.
Table 4.3: Radio continuum fluxes.

Fluxes at 21 cm are the most reliable while those at the three other wavelengths are less precise because of inaccurate determination of the source edges due to lack of resolution. The large errors quoted for these flux densities were obtained by integrating over very large and small boundaries. In order to see how resolution affects the flux integration results, the 21 cm continuum map was convolved to the resolution of the 11 cm image and the flux of IC 63 was re-estimated. The fluxes of the largest and smallest boundaries are 146 and 110 mJy respectively, with an average flux density of 128 mJy which compares reasonably well with the high resolution result. Generally, a large integration boundary placed at the limits where the emission still delineates the cometary-like shape yields an overestimated flux since the estimated background is generally less than what it is at the true source boundary. On the other hand, choosing a smaller boundary to include only the emission well separated from the background results in underestimating the true flux since emission diluted in the beam is not included. Altogether, these systematic effects partially cancel each other.

Table 4.4 lists peak flux densities for IC 63, the tip source, MG, MN and the 408 MHz
source near IRAS 00556+6048. The emission of IC 59 is so weak that peak flux density is not relevant for this object. For IC 63, the peak emission at 21 cm is significantly higher due to better resolution. It is interesting to note that the position of the peak of IC 63 varies with wavelength. This may result from the convolution of the irregular intrinsic source brightness distribution with different beam sizes and sampling grids on which the region was observed.

Table 4.4: Peak radio continuum fluxes and corresponding positions.

<table>
<thead>
<tr>
<th>( \lambda ) (cm)</th>
<th>Peak Flux Density (MJy/sr) and Positions (J2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>21</td>
</tr>
<tr>
<td>IC63 Positions (J2000)</td>
<td>0.031</td>
</tr>
<tr>
<td>00(^{h}) 59(^{m}) 28.8(^{s})</td>
<td>00(^{h}) 59(^{m}) 41.1(^{s})</td>
</tr>
<tr>
<td>60(^{o}) 53(') 29.2('')</td>
<td>60(^{o}) 52(') 58.8('')</td>
</tr>
<tr>
<td>Tip Source Position (J2000)</td>
<td>2.1</td>
</tr>
<tr>
<td>00(^{h}) 57(^{m}) 45.6(^{s})</td>
<td></td>
</tr>
<tr>
<td>61(^{o}) 03(') 46.7('')</td>
<td></td>
</tr>
<tr>
<td>MN Position (J2000)</td>
<td>0.031</td>
</tr>
<tr>
<td>00(^{h}) 56(^{m}) 12.7(^{s})</td>
<td></td>
</tr>
<tr>
<td>60(^{o}) 41(') 44.9('')</td>
<td></td>
</tr>
<tr>
<td>MG Position (J2000)</td>
<td>-</td>
</tr>
<tr>
<td>01(^{h}) 04(^{m}) 28.7(^{s})</td>
<td></td>
</tr>
<tr>
<td>61(^{o}) 14(') 41.3('')</td>
<td></td>
</tr>
<tr>
<td>74 cm Source Position (J2000)</td>
<td>0.043</td>
</tr>
<tr>
<td>00(^{h}) 58(^{m}) 52.0(^{s})</td>
<td></td>
</tr>
<tr>
<td>61(^{o}) 03(') 17.4('')</td>
<td></td>
</tr>
<tr>
<td>Beam Sizes (10^{-6}) sr</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Line

The results concerning the atomic gas observations will be given in terms of column densities rather than brightness temperatures or integrated fluxes. For a spin temperature
Chapter 4. Preliminary Results

$T_s$ and an optical depth $\tau$, the column density of HI in units of cm$^{-2}$ is given by [110]:

$$N_{HI} = 1.823 \times 10^{18} \int_{v_1}^{v_2} T_s \tau dv$$

(4.1)

where $v$ is the velocity in km s$^{-1}$, and $v_1$ and $v_2$ define the velocity interval of the associated emission. For optically thin gas we have

$$T_B = \tau T_s$$

(4.2)

where $T_B$ is the brightness temperature in K. Hence,

$$N_{HI} = 1.823 \times 10^{18} \int_{v_1}^{v_2} T_B dv$$

(4.3)

In the optically thick case we must use the exact relationship between $T_B$ and $T_s$, that is

$$T_B = T_s (1 - e^{-\tau})$$

(4.4)

and we have

$$N_{HI} = 1.823 \times 10^{18} \int_{v_1}^{v_2} \frac{T_B \tau dv}{1 - e^{-\tau}}$$

(4.5)

Column densities reported here were derived using (4.3) i.e. $\tau << 1$. By assuming that the source is optically thin, the resulting column densities are lower limits of the true column density, since:

$$\frac{\tau}{1 - \exp(-\tau)} \geq 1 \quad (\tau \geq 0)$$

(4.6)

The column density is integrated by summing the pixel values on the average map multiplied by the velocity interval over which it was made. Table 4.5 lists the summed (before conversion to total number of atoms) and peak column densities for each source.

4.3 Geometry

The geometry of the objects studied is another important aspect. The distance between the observer and the source ($D$) is one of the most critical parameters on which subsequent
Table 4.5: Summed and peak HI column densities.

<table>
<thead>
<tr>
<th></th>
<th>Summed Column Density $(10^{20} \text{ atoms cm}^{-2})$</th>
<th>Peak $(10^{20} \text{ atoms cm}^{-2})$</th>
<th>Peak Position (J2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC 63</td>
<td>1500±200</td>
<td>1.8</td>
<td>00$^h$ 59$^m$ 47.8$^s$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60° 55' 49.9&quot;</td>
</tr>
<tr>
<td>IC 59</td>
<td>6400±600</td>
<td>2.8</td>
<td>00$^h$ 58$^m$ 07.4$^s$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>61° 13' 19.0&quot;</td>
</tr>
<tr>
<td>IRAS 00556+6048</td>
<td>7000±1000</td>
<td>4.1</td>
<td>00$^h$ 59$^m$ 20.7$^s$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>61° 06' 09.9&quot;</td>
</tr>
</tbody>
</table>

astronomical data interpretation greatly depends. In the case of S185, other parameters such as the solid angle sustained by the nebulae ($\Omega$) and the distance between the cloud and the exciting star ($d$), are also important, and are directly related to $D$. The adopted distance for S185 is 230±70 pcs as seen in Section 2.1.7. For the other objects not related with S185 and for which HI emission was detected, an estimate of the distance is available from the velocity of the associated gas. The results of Jan Brand [111] are used to evaluate the kinematic distance of IRAS 00556+6048, IRAS 00533+6030 and the HI gas surrounding MG.

Table 4.6 and 4.7 list these parameters and a few related quantities. The angles ($\theta$) sustained by the nebulae are estimated from the red and blue prints of PvdB for IC 63 and IC 59 respectively, and from the IRAS high resolution 60 $\mu$m map for IRAS 00556+6048. All three angles represent the angular extent spanned by the entire emission associated with the clouds. For now, it is assumed that the sources all lie in the plane perpendicular to the line of sight at the distance between the observer and the exciting star. This assumption also holds for the computed distances between the nebulae and the star $d_{tip}$ (distance between the star and the closer edge of the cloud) and $d_{out}$ (distance from the star to the farthest edge). The solid angle $\Omega = 2\pi(1 - \cos(\theta/2))$ and cloud volume
Table 4.6: Geometric parameters assumed for S185.

<table>
<thead>
<tr>
<th></th>
<th>$d_{\text{tip}}$ (pc)</th>
<th>$d_{\text{out}}$ (pc)</th>
<th>$\theta$ (°)</th>
<th>$\Omega$ (sr)</th>
<th>Centroid (J2000)</th>
<th>$V$ ($10^{64}$ cm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC63</td>
<td>1.29</td>
<td>1.78</td>
<td>23.4</td>
<td>0.13</td>
<td>00$^h$ 59$^m$ 29.2$^s$ 61° 54' 11.8&quot;</td>
<td>4.61</td>
</tr>
<tr>
<td>IC59</td>
<td>1.58</td>
<td>2.05</td>
<td>26.6</td>
<td>0.17</td>
<td>00$^h$ 57$^m$ 20.2$^s$ 61° 10' 49.9&quot;</td>
<td>8.03</td>
</tr>
<tr>
<td>S185 (whole)</td>
<td>1.1</td>
<td>2.1</td>
<td>81.4</td>
<td>2.0</td>
<td>00$^h$ 59$^m$ 15.0$^s$ 61° 04' 35.7&quot;</td>
<td>-</td>
</tr>
<tr>
<td>IRAS 00556+6048</td>
<td>1.6</td>
<td>1.8</td>
<td>9.7</td>
<td>0.029</td>
<td>00$^h$ 58$^m$ 39.5$^s$ 61° 05' 06.9&quot;</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4.7: Geometric parameters for unrelated objects.

\[ V = \frac{2}{3} \tan^2(\theta/2)(d_{\text{out}} - d_{\text{tip}}) \] are calculated by assuming a conical source volume. The opening angle of the cone is then equal to the projected opening angle. The assumption of equal depth along the line of sight may be inadequate for IC63. Such a possibility will be considered in the next chapter where the cloud emissions and the exciting star radiation are compared.
This Chapter proposes a detailed comparison between the cloud parameters inferred from the results of Chapter 4 and the properties of $\gamma$ Cas described in Chapter 2. This is done for cloud components traced by infrared, radio continuum and HI emissions.

The first Section presents the IRAS results. The correction required to obtain the flux density at the effective frequencies given the IRAS wide band measurements is first described. Next, the cloud and stellar luminosities are compared according to the geometry given in Chapter 4. A similar comparison for the continuum and HI data is presented in the next two sections. A major discrepancy is found for the continuum results of IC 59, and for the HI results from both clouds, and a possible explanation for these disagreements is discussed in the last Section of this Chapter.

5.1 Infrared Analysis

5.1.1 Colour Correction and Dust Temperature

Since the IRAS detectors are sensitive to the energy emitted within a relatively wide band ($\approx 20 \mu m$ [99]), accurate flux densities at the four effective frequencies can only be obtained if the shape of the source distribution within the band is already known. While the flux densities from most radio observations are calculated assuming that the spectrum of the emission is flat within the band, the IRAS catalogues and map fluxes are computed for a source distribution having constant energy per logarithmic frequency
interval \((f_\nu \propto \nu^{-1})\). In absence of any information regarding the true spectrum, this assumption is probably as good as any. However, when the spectral shape of the source is known, a correction can be applied to the IRAS flux densities \(f_{\nu 0}\) (quoted) to obtain the actual or true flux \(f_{\nu 0}\) (true) at the effective frequency \(\nu_0\). This process is called the colour correction and is significant mostly at 12 and 25 \(\mu\)m.

In principle, the far infrared emission of dust in HII regions is mostly thermal and should be reasonably well fitted by a distribution \(f_{\nu\text{(true)}}\) consisting in the product of a source size \(\Omega_s\), an emissivity law \(Q_\nu = 1 - e^{-\tau}\) and a blackbody spectrum \(B(\nu, T_D)\) with dust temperature \(T_D\). In the far infrared domain, the grain radius is much less than the wavelength and \(Q_\nu\) follows a power law \((Q_\nu = \varepsilon \nu^\beta)\) with \(\beta = 2\) for metals and crystalline and \(\beta = 1\) for amorphous material [113]. A priori, it is reasonable to assume that such a distribution is suitable for IC63 and IC 59, and perhaps also for IRAS 00556+6048.

When a value for \(\beta\) is assumed, the shape of \(f_{\nu\text{(true)}}\) is uniquely determined by the dust temperature \(T_D\). Moreover, only the ratio between two flux densities at two different frequencies is needed to determine \(T_D\). The problem is that only the wide band IRAS measurements are available for S185. However, a good estimate of the temperature can still be obtained if the bands for which the colour correction would be minimal are used. This will occur if any or some of the following conditions are satisfied: (i) the bands are sufficiently narrow, (ii) thermal emission is flat enough within these bands and (iii) more importantly, emission within these bands is strong enough so that the variations due to the shape of the distribution are negligible compared to the total power received.

Thermal emission from most HII regions is strongest at 60 and 100 \(\mu\)m. This is also the case for IC63, IC59 and IRAS 00556+6048. As a result, the colour correction factor \(K \equiv f_{\nu\text{(quoted)}}/f_{\nu\text{(true)}}\) are close to unity for these bands. Given individual black body and power law \((f_\nu = \nu^\beta)\) energy distributions with dust temperature between 40 and 200 K and \(0 \leq \beta \leq 2\), we have \(|K - 1| \leq 0.25\) [99]. For these reasons, the dust temperature
will be estimated from the power received in the 100 and 60 \( \mu \text{m} \) bands.

The power received in a band of the IRAS detector \( F_{\nu_0} \) at the effective frequency \( \nu_0 \) can be computed from the band shape \( R_{\nu_0} \),\(^1\) the quoted flux density \( f_{\nu_0} \) (Table 4.1) and the normalized spectral distribution for which the quoted flux densities were computed \((f_{\nu}/f_{\nu_0})_{\text{quoted}}\). These quantities are related by [99]:

\[
F_{\nu_0} = f_{\nu_0(\text{quoted})} \int_0^\infty (f_{\nu}/f_{\nu_0})_{\text{quoted}} R_{\nu_0} d\nu = f_{\nu_0(\text{true})} \int_0^\infty (f_{\nu}/f_{\nu_0})_{\text{true}} R_{\nu_0} d\nu
\]

(5.1)

However, the so-computed powers must be corrected to take into account the different band shapes at 60 and 100 \( \mu \text{m} \). We have:

\[
F'_{\nu_0} = \frac{F_{\nu_0}}{\int_0^\infty R_{\nu_0} d\nu}
\]

(5.2)

Given \( f_{\nu(\text{true})} = \Omega_s \nu^\beta B(\nu, T_D) \) and from the approximation discussed above, it is easy to show that the dust temperature is related to the power received in the bands at the effective frequencies \( \nu_1 \) and \( \nu_2 \) by:

\[
T_D = \frac{h \frac{\nu_2}{k} (\nu_2 - \nu_1)}{(3 + \beta) \ln(\frac{\nu_2}{\nu_1}) + \ln(\frac{r_{\nu_1}}{r_{\nu_2}})}
\]

(5.3)

where \( e^{\frac{h \nu_2}{kT_D}} >> 1 \) is assumed to hold for both \( \nu_1 \) and \( \nu_2 \). Once a temperature is estimated, the color correction factors can be calculated using (5.1). We have:

\[
K = \frac{f_{\nu_0(\text{quoted})}}{f_{\nu_0(\text{true})}} = \frac{\int_0^\infty (f_{\nu}/f_{\nu_0})_{\text{true}} R_{\nu_0} d\nu}{\int_0^\infty (f_{\nu}/f_{\nu_0})_{\text{quoted}} R_{\nu_0} d\nu} = \frac{\int_0^\infty \frac{e\nu^\beta B(\nu, T_D)}{e\nu_0^\beta B(\nu_0, T_D)} R_{\nu_0} d\nu}{\int_0^\infty (\frac{\nu}{\nu_0})^{-1} R_{\nu_0} d\nu}
\]

(5.4)

and finally,

\[
f_{\nu_0(\text{true})} = \frac{f_{\nu_0(\text{quoted})}}{K}
\]

(5.5)

which yields the desired colour corrected flux densities.

\(^1\)The band shapes are given in the IRAS Explanatory Supplement [99]
After colour correction of the IRAS flux densities, the dust temperature and emissivity constant ε need to be re-evaluated according to the colour corrected 60 and 100 μm. This will make the whole set of infrared parameters consistent with each other.

The flux in the bands (F_{\nu}), the colour corrected flux densities (for \( \beta = 1, 1.5 \) and 2) and the dust temperatures computed from the 60 and 100 μm points are listed in Table 5.1 with the corresponding emissivity constants ε. The source size listed in Table 4.6 was used to calculate the emissivity constant. The uncertainties for these parameters directly derive from the non-corrected flux uncertainties. Figure 5.1 shows the color corrected spectra of IC63, IC59 and IRAS 00556+6048 for \( \beta = 1 \). The solid line is the fitted emissivity and blackbody product distribution. Generally speaking, the colour correction reduces the 12 μm flux densities by a factor of approximately fifteen and has very little effect at the three other wavelengths. Variations of \( \beta \) change the dust temperature, the emissivity constant and the 12 and 25 μm points only. The 12 μm flux is closer to the fitted spectrum after colour correction but still remains about 100 times larger than the black body spectrum.

The difference between the measurements and the fit at 12 and 25 μm is usually attributed to line emission within the band or to temperature gradients within the cloud.

---

This process can be iterated: new colour corrected fluxes are computed according to this temperature, and a new temperature is calculated again from the corrected fluxes and so on. Fluxes for IC63, IC59 and IRAS 00556+6048 were corrected in this manner for \( \beta = 1, 1.5 \) and 2. For all three sources and three values of \( \beta \), it is found that the colour corrected fluxes (and their correction factors) converge. To test the validity of this method, flux densities that would be measured by IRAS for a source having a spectral distribution \( f_{\nu(true)} = \varepsilon \nu^\beta B(\nu, T_D) \) with known \( \beta \) and \( T_D \) were computed. These simulated flux densities were then colour corrected as described above to see how close the resulting flux and dust temperature would be from the true values. When the true \( \beta \) is assumed, the resulting flux densities and temperature are the same (to 5 significant figures) as the theoretical ones thus showing that the method is adequate even if the temperature is approximated in the first step. A change of 0.5 in the assumed value for \( \beta \) yields errors of \( \approx 10\%, \leq 55\% \) and \( \leq 0.04\% \) on the dust temperature, the 12 and the 100 μm colour corrected fluxes respectively. The aim for doing this analysis was to verify the convergence of the process and to see if the so color corrected flux densities would differ significantly. Such is not the case and for this reason, the following data interpretation will be based on results obtained as discussed above.
However, the line contribution to the 25 μm IRAS band is about 20% and may be larger than 50% in the 12 μm band [114]. This does not appear sufficient to account for the observed discrepancy. It is also difficult to invoke temperature gradients. Since the clouds are relatively small compared to their distance from the exciting star, the geometrical dilution of the oncoming stellar flux alone (if the cloud is optically thin to stellar radiation) implies reduction of the temperature at the farthest edge of the nebula by 20% at most. Moreover, the emission of IC 59 which does not appear to have strong gradients over the observed surface (Figure A.3) still exhibits the discrepancy at 25 and 12 μm. Hence, there must be another unknown effect causing the difference at 12 and 25 μm.

It is interesting to note that for IC 63, an emissivity index $\beta = -1.55$ and an unrealistic dust temperature of 101 K are required to fit all 100, 60 and 25 μm flux densities, while the 12 μm flux still remains larger than the fitted spectrum. At constant $\beta$, IRAS 00556+6048 and IC 59 have the highest and lowest dust temperatures respectively. The 25 and 60 μm flux of IRAS 00556+6048 imply a temperature of 73 K for $\beta = 1$, which is about 1.6 times the dust temperature derived from the 100 and 60 μm flux densities.

The dust emissivity plays an important role in the infrared emission of clouds. A spherical grain emitting as a perfect black body at the tip of IC 63 would have a temperature much lower ($\approx 15$ K) than values listed in Table 5.1. Hence, the dust is obviously a better absorber and emitter in the UV than in the infrared.

Major differences between the far infrared spectra of IC 63, IC 59, IRAS 00556+6048, IRAS 00533+6030 and γ Cas are apparent from the maps and integrated fluxes. To compare the distributions accurately it is useful to normalize the flux densities in order to account for differences in strength due to size, density or distance. For this purpose, the flux densities of each object was normalized to one at 12 μm. Figure 5.2 shows a plot of the resulting spectra colour corrected for $\beta = 1$ (the flux densities of γ Cas and IRAS 00533+6030 taken from the literature [24] were already colour corrected).
<table>
<thead>
<tr>
<th></th>
<th>( \beta )</th>
<th>( \lambda ) (( \mu )m)</th>
<th>( T_D ) (K)</th>
<th>( \varepsilon ) (Hz(^{-\beta}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12</td>
<td>25</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td>IC 63 ( F_{\nu} ) ( (10^{-12} \text{ W m}^{-2}) )</td>
<td>-</td>
<td>2.57</td>
<td>1.18</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>( \pm 0.05 )</td>
<td>( \pm 0.05 )</td>
<td>( \pm 0.2 )</td>
</tr>
<tr>
<td>( f_\lambda ) (Jy)</td>
<td>1</td>
<td>1.40</td>
<td>22</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>0.89</td>
<td>21</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.57</td>
<td>19</td>
<td>260</td>
</tr>
<tr>
<td></td>
<td>all</td>
<td>( \pm 0.03 )</td>
<td>( \pm 1 )</td>
<td>( \pm 10 )</td>
</tr>
<tr>
<td>IC 59 ( F_{\nu} ) ( (10^{-12} \text{ W m}^{-2}) )</td>
<td>-</td>
<td>2.75</td>
<td>0.93</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>( \pm 0.07 )</td>
<td>( \pm 0.05 )</td>
<td>( \pm 0.3 )</td>
</tr>
<tr>
<td>( f_\lambda ) (Jy)</td>
<td>1</td>
<td>0.64</td>
<td>14.4</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>0.41</td>
<td>13.1</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.26</td>
<td>11.9</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>all</td>
<td>( \pm 0.02 )</td>
<td>( \pm 0.8 )</td>
<td>( \pm 10 )</td>
</tr>
<tr>
<td>IRAS 00556+6048 ( F_{\nu} ) ( (10^{-12} \text{ W m}^{-2}) )</td>
<td>-</td>
<td>0.64</td>
<td>1.5</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>( \pm 0.05 )</td>
<td>( \pm 0.1 )</td>
<td>( \pm 0.5 )</td>
</tr>
<tr>
<td>( f_\lambda ) (Jy)</td>
<td>1</td>
<td>0.52</td>
<td>30</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>0.33</td>
<td>28</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.21</td>
<td>26</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>all</td>
<td>( \pm 0.04 )</td>
<td>( \pm 2 )</td>
<td>( \pm 20 )</td>
</tr>
</tbody>
</table>

Table 5.1: Colour corrected flux densities and flux in the bands.
Figure 5.1: Thermal fits to the Infrared Emission
Figure 5.1: Thermal fits to the infrared emission of IC 63, IC 59 and IRAS 00556+6048. The crosses and squares show the colour corrected and the non colour corrected IRAS flux densities respectively. The solid line shows the spectrum of a black body with emissivity $Q_\nu = \varepsilon \nu$ fitted on the 60 and 100 $\mu$m fluxes.

IRAS 00556+6048 has a distinct spectral shape compared to IC 63 and IC 59 which are pretty similar. This is consistent with the higher dust temperature of the cloud and the significantly higher 25 $\mu$m flux density. Gamma Cas and IRAS 00533+6030 are much hotter objects and their spectra appear to peak at a significantly lower wavelength.

5.1.2 Luminosity Balance

Since the star exciting IC 63, IC 59 is very well known (Chapter 2), it is of interest to compare its properties with what can be inferred from the source emissions. Such
Figure 5.2: A comparison of the infrared spectra for the five IRAS sources. The flux densities (colour corrected with $\beta = 1$ for IC 63, IC 59 and IRAS 00556+6048) were normalized to one at 12 $\mu$m in order to compare the spectral shapes. Note the distinct spectrum of IRAS 00556+6048 compared to IC 63 and IC 59. Gamma Cas and IRAS 00533+6030 appear to be much hotter objects.

comparison is also of interest for IRAS 00556+6048 to confirm that the source is unrelated to S 185. Since nearly all the luminosity of galactic nebulae is emitted in the far infrared domain, the most obvious parameters to consider in this section is the cloud total and infrared luminosities which are nearly equal. The latter can be compared to the incident energy from the exciting star which has been estimated from direct stellar observations (Section 2.1.8).

There is a number of ways in which the luminosity of a cloud can be inferred from the

\[^{3}\text{The radio and optical luminosities are less than the infrared one by orders of magnitudes.}\]
Table 5.2: Cloud luminosities and their $4\pi$ steradians equivalent. The fraction of the stellar luminosity captured by the clouds ($f = L'/L_*$) is also listed.

IRAS data. The most conservative approach consists into summing the power measured in each receiver band. However, this method systematically underestimates the luminosity since the spectrum is not entirely covered by the IRAS bands. A more accurate and method is based on a linear approximation between the colour corrected IRAS flux densities. This method yields the following formula for the far infrared flux $F_{IR}$ (W m$^{-2}$), given the four IRAS fluxes $f_\lambda$ (Jy):

$$F_{IR} = (2.5f_{100} + 4.5f_{60} + 10.0f_{25} + 6.5f_{12}) \times 10^{-14}$$  \hspace{1cm} (5.6)

If the spectrum of the source is thermal, the flux between 100 and 60 $\mu$m is underestimated by this method since this is where the peak emission resides. However, the flux between 60 and 25 $\mu$m where the true distribution has a concave curvature will be overestimated. The other spectral regions ($\lambda > 100$ $\mu$m and $\lambda < 25$ $\mu$m) are well approximated by straight lines. Nevertheless, if the source distribution is mostly thermal, the error associated with this approximation is limited.

Under the assumption that the cloud luminosity ($L$) is almost entirely emitted in the infrared domain and that the cloud is optically thin in all directions we have:

$$L = 4\pi D^2 F_{IR}$$  \hspace{1cm} (5.7)

Table 5.2 lists the luminosities of IC 63, IC 59 and IRAS 00556+6048 at the adopted distance of 230±70 pc. The luminosity in the IRAS bands ($L_B$) is significantly lower
than results computed from the colour corrected flux densities \( L_{\beta=1}, L_{\beta=1.5} \) and \( L_{\beta=2} \) using (5.6) and (5.7). For comparison, luminosities calculated from the non-corrected flux densities \( L_{nc} \) are also presented. The effect of the colour correction on these results is clearly negligible (<5%). Also listed is the luminosity normalized to the entire 4\(\pi\) steradians sphere \( L' = \frac{4\pi}{\Omega} L_{\beta=1} \), assuming the solid angle \( \Omega \) listed in Table 4.6. The quoted uncertainties on these luminosities do not include the distance uncertainty which translates into a 60% uncertainty (from one end of the interval to the other). The luminosity adopted for \( \gamma \) Cas is \( L_* = (1.4 \pm 0.5) \times 10^{31} \) W (Section 2.1.8). It is largely sufficient to maintain the cloud emissions. Moreover, these results imply that approximately 10%, 6% and 24% of the incoming energy is intercepted by IC63, IC59 and IRAS 00556+6048 (if the latter is excited by \( \gamma \) Cas). These fractions are independent of the distance between S185 and the observer, provided that the nebulae and the star are at the same distance from the observer.

5.2 Radio Continuum Analysis

Radio continuum emission mainly arises from two important processes. Free-free (or thermal) emission occurs when electrons in a hot plasma of ionized gas are accelerated (or decelerated) due to bremsstrahlung and particle collisions. At radio frequencies, the plasma is optically thin and the spectrum follows a power law \( S_\nu \propto \nu^{-\alpha} \) with spectral index (\( \alpha \)) less than 0.1. Synchrotron emission is the result of relativistic electrons moving in a strong magnetic field. The emission is again optically thin at radio frequencies and also follows a power law with typically \( \alpha \approx 0.75 \). Figure 5.3 shows the continuum emission spectra of IC63, IC59 and the tip source with straight line fits performed on the data (the derived spectral index is shown in the plot key). It is obvious that the emission from IC63 and IC59 is of thermal origin (although the spectral index of IC59 is a little low).
Figure 5.3: Radio continuum spectra for IC63, IC59 and the Tip Source. The point source emission is definitely not thermal. Spectral indices are shown in the plot key.

while that of the tip source is due to synchrotron process.

5.2.1 Ionization Balance

It is simple to relate the radio flux at frequency $\nu$ emitted by a hydrogen plasma to the number of ionizing photons ($N_L$) required to maintain the emission. This depends on the recombination coefficient to excited atomic levels ($\beta_{ex}$) which is a function of the electron temperature ($T_e$). For hydrogen, it is well approximated by [115]:

$$\beta_{ex} = 4.10 \times 10^{-10} T_e^{-0.8}$$ (5.8)
where \( \beta_{ex} \) and \( T_e \) have units of \( \text{cm}^3 \text{s}^{-1} \) and K respectively. From the definition of the recombination coefficient, the number of ionizing photons for the whole plasma is then:

\[
N_L = \int_{\text{vol}} n_e^2 \beta_{ex} dV
\]

(5.9)

where \( n_e \) is the local electron density. The flux density can be related to \( n_e, T_e \) and \( D \) using the relation of Mezger and Henderson [116]:

\[
S_\nu = 8.61 \times 10^{-53} D^{-2} \nu^{-0.1} \int_{\text{vol}} n_e^2 T_e^{-0.35} dV
\]

(5.10)

where \( S_\nu, \nu, \) and \( D \) have units of Jy, GHz and pc respectively. Combining (5.8), (5.9) and (5.10), and assuming that the electron temperature and density are constant over the entire plasma we have:

\[
N_L = 4.76 \times 10^{42} \nu^{0.1} T_e^{-0.45} D^2 S_\nu
\]

(5.11)

where \( N_L^4 \) has units of \( \text{s}^{-1} \).

From (5.10), it is possible to derive a relationship between the electron density and the radio emission, given a source volume \( V \) (Table 4.6). Assuming again that the density is constant over the source volume, we have:

\[
n_e = \left( \frac{S_\nu D^2 \nu^{0.1} T_e^{0.35}}{8.61 \times 10^{-53} V} \right)^{1/2}
\]

(5.12)

The excitation parameter is defined as the capability of a star to ionize a plasma having a recombination rate coefficient corresponding to an electron temperature of 7000 K. It is given by:

\[
U_* = 2.01 \times 10^{-19} \left( \frac{N_L^*}{\beta_{ex}} \right)^{1/3}
\]

(5.13)

\(^4\text{Note that in order to make (5.11) independent of the frequency at which the radio flux density is measured, the exponent of } \nu \text{ needs to be equal to the spectral index of the spectrum (}\alpha\text{). Nevertheless, using } \alpha = 0.03 \text{ instead of 0.1 for IC 63 reduces } N_L \text{ by less than 2%.}\)
Table 5.3: Number of ionizing photons, electron densities, exciting parameters and $U^3/L$ from the cloud radio flux densities. Values for the peak sector emission are listed under "(peak)".

<table>
<thead>
<tr>
<th></th>
<th>$N_L$ (10$^{44}$ s$^{-1}$)</th>
<th>$N_{L*}^I$ (10$^{46}$ s$^{-1}$)</th>
<th>$n_e$ (cm$^{-3}$)</th>
<th>$U_e^I$ (pc-cm$^{-2}$)</th>
<th>$U_e^{33}/L_e^I$ (10$^{-28}$ pc$^3$ cm$^{-6}$ W$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC 63 (peak)</td>
<td>5.9±0.8</td>
<td>5.7±0.8</td>
<td>20.4</td>
<td>11.1±0.5</td>
<td>10±2</td>
</tr>
<tr>
<td>IC 59</td>
<td>2.9±0.5</td>
<td>2.2±0.3</td>
<td>10.9</td>
<td>8.0±0.4</td>
<td>6±1</td>
</tr>
</tbody>
</table>

Table 5.3 lists parameters calculated using the above equations. The 21 cm continuum flux densities and the geometric parameters of Table 4.6 were used. The quoted uncertainties include uncertainties associated with both flux densities and electron temperature. The number of ionizing photons normalized to the equivalent 4π steradians sphere ($N_{L*}^I$) is also listed for comparison with γ Cas. Under the geometrical assumptions of Chapter 4, IC 63 requires a number of ionizing photons consistent with the value adopted for γ Cas ($N_L = (5.5 ± 1.5) \times 10^{46}$ s$^{-1}$, Section 2.1.8). Hence, the nebula could be radiation bounded considering the uncertainty. This is consistent with the detection of atomic gas. On the other hand, the required ionization for IC 59 is less. This will be
discussed in Section 5.4. Results computed for the entire emission of S185 and assuming again a depth along the line of sight equal to the observed extent basically yield the same value for $N'_L_{\ast}$ as for IC 63 alone.

The ionization balance analysis can also be done for the areas of stronger emission in the clouds. In this case only IC 63 is considered since the emission of IC 59 is too weak to obtain significant results. Figure 5.4 shows the atomic (grey scale) and continuum (contours) data for the cloud with sectors for which the emission was integrated. The
sector for which maximum integrated flux occurs is indicated by filled triangles placed at the integration boundaries. The filled circle and square show the sectors where peak infrared and HI emission occur respectively. The number of ionizing photons from the peak integrated flux $N'_{LP}$ is about 1.5 the value obtained when the entire nebula is considered (Table 5.3). The value is almost consistent with the adopted number of ionizing photons for $\gamma$ Cas.

### 5.3 HI Analysis

When the distance to the region is known, the summed column densities of Table 4.5 can be converted to the number of hydrogen atoms in the cloud ($N_{HI}$). Furthermore, the density of atomic hydrogen atoms ($n_{HI}$) can be computed from the cloud volume listed in Table 4.6. The total mass of hydrogen in the cloud ($M_{HI}$) and the $4\pi$ spherical equivalent masses $M'_{HI} = M_{HI} \frac{4\pi}{4\pi}$ directly follow from these parameters. These results are presented in Table 5.4. The atomic densities appear to be much higher than the ionized densities. This is probably due to the fact that the volume occupied by the ionized material is significantly smaller than the volume assumed in Chapter 4.

### 5.3.1 Dissociation Balance

The $4\pi$ steradians equivalent mass estimates can be compared with predictions from the dissociation model of Roger and Dewdney [3]. The model simulates the time-development
of HI photo-dissociation zones in an homogeneous spherically symmetric cloud around a central O-B main sequence star. The location of the boundary between dissociated and molecular gas (dissociation front) is calculated from the condition that the dissociation and molecule formation rates must be equal at this position. The model assumes that the Strömgren sphere and the main sequence star are in place at time $t = 0$. This is justified by fact that the time required to form the HII region is negligible compared to the dissociation rate.

Due to the particular geometry of S185, the model was modified to remove any extinction due to dust between the exciting star and the tips of the clouds. Computations were performed for the following parameters:\textsuperscript{a}

\begin{enumerate}
  \item $T_{\text{eff}} = 27000 \text{ K}, n_{HI} = 100 \text{ cm}^{-3}$ and $d_{\text{tip}} = 1.0 \text{ pc}$
  \item $T_{\text{eff}} = 27000 \text{ K}, n_{HI} = 300 \text{ cm}^{-3}$ and $d_{\text{tip}} = 1.0 \text{ pc}$
  \item $T_{\text{eff}} = 25600 \text{ K}, n_{HI} = 100 \text{ cm}^{-3}$ and $d_{\text{tip}} = 1.3 \text{ pc}$
  \item $T_{\text{eff}} = 25600 \text{ K}, n_{HI} = 300 \text{ cm}^{-3}$ and $d_{\text{tip}} = 1.3 \text{ pc}$
  \item $T_{\text{eff}} = 25000 \text{ K}, n_{HI} = 50 \text{ cm}^{-3}$ and $d_{\text{tip}} = 3.0 \text{ pc}$
\end{enumerate}

The primary results from the model consist in plots of the amount of dissociated material as a function of time, and density of molecular hydrogen as a function of distance from the exciting star for various times. These results were scaled to match the actual numbers of Table 5.4.

According to the model computations, $\approx 725$ years are required to dissociate the spherical equivalent mass $M_{HI} = 14.5 \text{ M}_\odot$ of atomic hydrogen in IC63. This is quite low considering that $\gamma$ Cas is probably well established on the main sequence as very little material is observed around it. In 725 years, the boundary between dissociated and molecular material (dissociation front) would have reached an outer radius $< 1.38 \text{ pc}$. This is clearly inconsistent with the observed $d_{\text{out}} = 1.78 \text{ pc}$ for IC63.

\textsuperscript{5}$d_{\text{tip}}$ is the distance between the star and the tip of the cloud.
Approximately 2900 years are required to dissociate the $\approx 50 \, \text{M}_\odot$ in IC 59. Again, this time is rather short. However, the predicted $d_{\text{out}} = 1.9 \, \text{pc}$ is closer to the observed value (2.0 pc). Hence, the dissociation time is the main discrepancy between the model computations and the observations. An explanation for this is suggested in the following section.

5.4 A Model for IC 63 and IC 59

So far, the spectrum of $\gamma$ Cas is in good agreement with the observed infrared and radio continuum emissions from IC 63. However, an important discrepancy remains for the atomic gas component of IC 63 and IC 59, and for the radio continuum emission of IC 59. Moreover, several differences between the two clouds were noted and are yet unexplained. Those were the colour difference on the POSS prints, the presence of bright rims and the more broken structure of one cloud and finally, the fact that ERE and molecular material are detected in IC 63 only. In this section, a possible explanation for these observations is suggested. The knowledge about the structure of cometary nebulae presented in Section 2.2.1 is used to provide reasonable assumptions on the actual geometry of the region. The hypothesis that the postulated Be envelope is shielding the ionizing radiation from $\gamma$ Cas in the direction of IC 59 (Section 2.2.2) is also examined. The model is based on the following assumptions:

(i) As a first order approximation, the fraction of stellar ionizing photons that are absorbed directly by dust grains is assumed to be negligible$^6$.

(ii) The nebulae are ionization bounded. In other words, all of the stellar ionizing

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$^6$ According to the model of Mezger et al. [112], this fraction is almost 30% for IC 63, given its "infrared excess" of $\approx 9$. However, a deeper analysis is required to verify this result which intuitively appears too large.
photons are used to maintain the radio continuum emission from the clouds. This assumption is justified by the detection of atomic gas in the nebulae. The gas must be shielded from the ionizing photons in order to survive in atomic form.

(iii) The line joining IC 63 and the exciting star is assumed to be perpendicular to the line of sight. This is justified from the observation of bright rims in the nebula and from the very cometary shape of the cloud. As mentioned in Section 2.2.1, such structures are detected only for nebula that are close to the exciting star. The distance between IC 59 and γ Cas may be larger than the projected distance. This is also suggested by the apparent shape of the cloud: the apparent extent of the nebula in the radial direction is significantly smaller than the size in the tangent direction. Due to its homogeneous apparent structure, the shape of IC 59 will be assumed to be the same as in Section 4.3, that is a cone having a circular section and pointing towards γ Cas.

The geometric parameters that were assumed in Section 4.3 will be updated according to these assumptions. In order to balance the number of ionizing photons required to maintain the cloud emissions with the number of incident photons from the star, the effective solid angle ($\Omega_{eff}$) of both clouds will be re-evaluated. For IC 63, the resulting $\Omega_{eff}$ will be used to evaluate the depth along the line of sight ($\alpha_{eff}$), given the apparent angle sustained by the nebula ($\theta$). For IC 59, the resulting $\Omega_{eff}$ will be used to estimate the true star-to-cloud distances $d_{tip}$ and $d_{out}$ and the angle between the line of sight and the line joining the star with the cloud ($\phi$).

In order to estimate the uncertainty resulting from uncertainties in the exciting star properties, computations were performed for two different types of exciting star: for a B0.5 IV and a B0 IV star. Table 5.5 lists the adopted stellar parameters for each spectral type. The absolute magnitudes $M_v$ are taken from the calibration of Balona and Cramp ton [53], the intrinsic colours $(B-V)_0$ are from FitzGerald [54], the fractional ionizing luminosity ($P$) for a B0.5 IV star is from Kurucz [56] for $\log(g) = 4$, and the effective
temperatures $T_e$ and fractional ionizing luminosity for a B0IV star are from Panagia [58]. The average energy of a single ionizing photon $\langle E_{\lambda<912} \rangle$ has been calculated from the stellar luminosity and number of ionizing photons of Panagia, using values of $P$ mentioned above. The distances $D$ are computed using the apparent colour and magnitude assumed by Vakili et al. [52]. It should be noted that for B0 and B0.5 stars, the stellar ionization parameters are very sensitive to the spectral type. This is due to the fact that the Lyman limit lies in the rapid fall-off region of the stellar spectrum.

Table 5.6 shows the cloud parameters calculated and re-evaluated assuming (i) to (iii) for two spectral types. Assuming a B0.5 star, the parameters of IC63 basically remain the same. The depth along the line of sight of is slightly higher than the projected size due to the fact that $N_L$ is a little larger than $N'_{L*}$. As a result, the volume of the nebula is slightly increased, and the resulting densities are lowered\(^7\). If $\gamma$ Cas is a B0 star, the distance to the region, the stellar number of ionizing photons and the stellar luminosities are increased (Table 5.5). As a result, the computed effective solid angle of the nebula is reduced by a factor of 5. Hence, the cloud is rather thin along the line

\(^7\)Note that the electron density ($n_e$) is not significant since the volume of the ionized component is smaller.
Table 5.6: Parameters for IC63 and IC59 from the model geometry. Computations for two spectral types are presented. For IC59, two set of parameters are shown; for a star-to-cloud distance larger than the projected distance ($\phi \neq 0$) and for a situation where the ionizing photons from the star are shielded by the Be star envelope and $\phi = 0$. 

\[
\begin{array}{|c|c|c|c|c|c|}
\hline
\text{Spectral Type:} & \text{B0.5IV} & & \text{B0IV} & & \\
\text{Cloud:} & IC63 & IC59 & IC63 & IC59 & \\
\hline
\text{Geometric Parameters:} & & & & & \\
\phi (\degree) & 0 & 0 & 51 & 0 & 0 & 74 \\
\Omega_{\text{eff}} (\text{sr}) & 0.14 & 0.17 & 0.067 & 0.026 & 0.17 & 0.013 \\
d_{\text{tip}} (\text{pc}) & 1.31 & 1.60 & 2.57 & 1.46 & 1.78 & 6.62 \\
d_{\text{out}} (\text{pc}) & 1.80 & 2.08 & 3.33 & 2.01 & 2.31 & 8.59 \\
\theta_{\text{eff}} (\degree) & 23.4 & 26.6 & 16.7 & 23.4 & 26.6 & 7.36 \\
\alpha_{\text{eff}} (\degree) & 25.0 & 26.6 & 16.7 & 3.6 & 26.6 & 7.36 \\
V_{\text{eff}} (10^{54} \text{ cm}^{-3}) & 4.86 & 8.3 & 13.3 & 1.26 & 11.5 & 43.7 \\
\hline
\text{Infrared Parameters:} & & & & & \\
T_{\text{D} (\beta=1)} & 40.7 & 34.2 & 34.2 & 40.7 & 34.2 & 34.2 \\
L \left(10^{28} \text{ W}\right) & 1.46 & 1.27 & 1.30 & 1.81 & 1.60 & 1.67 \\
L_{\text{\prime}} \left(10^{30} \text{ W}\right) & 1.33 & 0.94 & 2.44 & 8.85 & 1.18 & 16.3 \\
f (\%) & 9.4 & 6.7 & 17.1 & 47 & 6.4 & 87 \\
\hline
\text{Ionization Parameters:} & & & & & \\
N_L \left(10^{44} \text{ s}^{-1}\right) & 6.09 & 3.00 & 3.05 & 7.57 & 3.73 & 3.94 \\
n_e \left(\text{cm}^{-3}\right) & 20.1 & 10.8 & 8.63 & 44.2 & 10.2 & 5.40 \\
\hline
\text{HI Parameters:} & & & & & \\
N_{HI} \left(10^{56} \text{ atoms}\right) & 1.82 & 7.78 & 7.93 & 2.27 & 9.66 & 10.2 \\
n_{HI} \left(\text{cm}^{-3}\right) & 37.5 & 93.5 & 59.6 & 180 & 84 & 23.4 \\
M_{HI} (\text{M}_\odot) & 0.15 & 0.65 & 0.67 & 0.19 & 0.81 & 0.86 \\
M_{HI}' (\text{M}_\odot) & 13.7 & 48.7 & 125 & 91 & 61 & 831 \\
\hline
\end{array}
\]
of sight and has the shape of a piece of pie. The volume of the nebula is considerably reduced and densities of atomic and ionized material are larger. The luminosity, number of ionizing photons and number of dissociated hydrogen atoms are larger due to the increased distance to the observer. Mostly due to the smaller solid angle of the cloud, the $4\pi$ steradians equivalent parameters are considerably increased. IC 63 would then retain nearly 50% of the incident stellar luminosity. Moreover, the mass of dissociated gas is close to $100\,M_\odot$. The corresponding dissociation time is then $\approx 4500$ years for the updated HI density and distance from the exciting star. This time remains low compared to the main sequence life time ($\approx 10^6 - 10^7$ years).

For IC 59 and a B0.5IV star, assuming $\phi = 0$ and $\Omega_{eff} = 0.17$ imply that the Be star envelope would shield 60% of the stellar ionizing photons. On the other hand, ignoring the postulated envelope shows that the line joining the cloud and the star makes an angle of 51° with the line of sight. The true star-to-cloud distance is then about 3 pc and the stellar radiation is considerably diluted. The volume of the cloud is increased by a factor of 1.6. The cloud would then retain 17% of the incident stellar luminosity, which is almost twice the value of IC 63. This is consistent with the fact that the cloud has a larger radial thickness. The resulting density of atomic gas is then $60\,cm^{-3}$, and the $4\pi$ steradians mass of HI is $125\,M_\odot$. The corresponding dissociation time is $\approx 6500$ years and is again quite low compared to the main sequence time.

Similarly, if $\gamma$ Cas is a B0 star, the surrounding disk retain 93% of the ionizing stellar photons. If the effect of the envelope is ignored, the line joining IC 59 and the star would make an angle of 74° with the line of sight. The true star-to-cloud distance is then about 7.5 pc. The cloud would retain as much as 87% of the incident stellar luminosity. The extent of IC 59 in the radial direction would be close to 2 pc which explain the high optical depth along the same direction. The $4\pi$ equivalent mass of HI is considerably larger. The corresponding dissociation time is $\approx 10^3$ years which is getting close to the
main sequence life time. Note however that the latter estimation is very crude as no runs of the dissociation model were performed for such a large distance between the star and the cloud.

The parameters presented in Table 5.6 were computed assuming that IC 59 is farther from the observer than the exciting star. However, calculations for a cloud closer than the star would yield approximately the same results. This is due to the fact that the difference between the distance to γ Cas and to IC 59 is small compared to the stellar distance.

5.4.1 Discussion

From these results, it appears that the model is quite sensitive to the spectral type assumed for γ Cas. However, a major result is that the infrared and radio continuum observations for IC 59 may be explained by geometrical arguments. The cloud which is optically thick to the ionizing radiation would face a very diluted radiation field and radio continuum emission would be faint. However, the large extent along the radial direction from the star would explain the relatively large amount of observed infrared luminosity. The lower dust temperature for the cloud is also in agreement with this hypothesis. However, the computed radial distances do not match. Assuming a dust temperature of 40.7 K (for $\beta = 1$) at the distance of IC 63 and a temperature of 34.2 K for IC 59 requires distances of 1.8 pc (B0.5) and 2.1 pc (B0) for IC 59 if only the geometric $1/d^2$ dilution of stellar radiation is considered. Hence, the distance between IC 59 and the exciting star appears to be overestimated.

This geometry also requires a longer dissociation time. However, a major discrepancy remains for IC 63 and maybe for IC 59. This is interpreted as a density effect. It is probable that beyond the outer edge of the clouds, no molecular material is present. This is indicated by the FCRAO CO observations of the region which basically do not
show any molecular emission in the cloud surroundings at velocity near $0 \text{ km s}^{-1}$. As a result, dissociation of the gas in the nebulae may have ceased long time ago and most of the dissociating photons would directly go through the nebula with very little interaction with the gas. The derived densities for the atomic gas are generally low ($< 200 \text{ cm}^{-3}$) and the molecule formation rate is probably also low. Moreover, for a density of $300 \text{ cm}^{-3}$ and an effective temperature of $30000 \text{ K}$, the thickness of the dissociated gas along the radial direction may be as high as $1.5 \text{ pc}$ [3]. Consequently, it is not surprising that a lot of the dissociation photons would go through the nebulae with little interaction, given the lower density and radial thickness of the clouds.

The dissociation model considers cases where a large amount of material still surrounds the exciting star and is being expelled by the stellar winds and radiation. The HII region is expanding into the dissociated material thus creating a zone of shocked HI. It is obvious that $\gamma$ Cas is an evolved star from the fact that most of the surrounding material has already been dissipated. As a consequence, it is difficult to compare the model predictions with the amount of HI in the clouds. In this view, the presence of IC63 and IC59 at this later stellar age may result from inhomogeneities in the parent cloud.

The hypothesis that the difference between IC63 and IC59 is due to a disk surrounding the Be star $\gamma$ Cas needs further discussion. Although it has been shown that the difference in radio continuum emission between the clouds can be explained by geometrical arguments, the presence of a disk may be required to reduce the derived distance between IC59 and $\gamma$ Cas. A smaller distance is suggested by the dust temperature of IC59 which appears too high. Hence, both effects may have an important role. However, the observations of Witt et al. [2] suggest that there cannot be an important fraction of ionizing luminosity absorbed by the envelope. The ratio of the two lines due to blend of the H$\alpha$ and NII lines, and of the SII doublet are similar in both clouds thus suggesting
little absorption of Hα in the envelope.

In fact, the overestimated distance of IC 59 may be explained if a substantial fraction of the incident ionizing luminosity is directly absorbed by dust. This would have an effect equivalent to reducing the number of available ionizing photons from the star and the resulting distance would be less.

**Molecular Content of the Clouds**

The farther distance of IC 59 from the exciting star also provides a natural explanation for the difference in the molecular content of both nebulae. As mentioned in Chapter 2, the evolution of the cometary shape of IC 63 would have been faster due to its proximity to the exciting star. In this view, IC 63 can be described as a cloud with two components. One is a dense component directly exposed to the stellar radiation that has been compressed with time thus causing the increase of density. Such densities would have allowed molecules to form again and CO emission and UV fluorescence due to dissociation would occur. This is consistent with the observations of Jansen et al. who detected molecules at the tip of IC 63 only.

The second component of IC 63 would consist in a more diluted mixture of atomic gas and dust mainly located behind the zones of higher density. The material of this component would be in a relatively quiescent state.

The fact that Extended Red Emission (ERE) is detected only in IC 63 and not in IC 59 is significant. The absence of ERE in IC 59 can result either from the fact that the UV stellar radiation is too diluted at the position of the cloud, or from insufficiently high density of the nebular material. The latter hypothesis appears more plausible. The dissociation rate in IC 59 is probably low and as a result, ERE which appears to be strongly enhanced in regions where amorphous carbon grains are re-hydrogenated due to nearby on-going photodissociation would not be observed. Re-hydrogenation of carbon
dust probably also requires a minimum density which may not be met in IC 59. Thus ERE may not occur anywhere else in S 185 other than in the bright filaments of IC 63.
Chapter 6

Conclusion: Summary and Future Work

This Chapter provides a brief summary of the results from Chapter 5 for S185. Unrelated objects discovered in these observations are also briefly analyzed.

6.1 S185

Major discrepancies between model predictions and observations were found for the continuum emission of IC59 and the HI emission of IC59 and IC63, while infrared emission for both clouds and continuum emission for IC63 are consistent with the exciting star properties. The inconsistency of the HI results suggests that the dissociation model is inadequate for this particular region. The absence of molecular material over the whole clouds imply that dissociation of the detected atomic gas has already ceased.

Moreover, the inconsistency in the continuum emission of IC59 provides an explanation for the differences between IC63 and IC59. These would be due to different geometries for the clouds. IC59 is farther away from γ Cas than it appears to be. As a result, the radiation field at the position of IC59 is considerably more diluted than for IC63, which explains the weaker continuum emission of IC59. Moreover, the cloud has a larger extent along the radial direction than IC63. Since most of the stellar luminosity responsible for heating of dust penetrates the cloud with little interaction, substantial infrared and weak continuum emissions can be detected simultaneously.

Moreover, the proximity of IC63 from the exciting star suggest that the cloud is composed of two distinct regions: a first component observed as bright filaments on the
POSS prints would consist of regions of higher density. Observed mostly on the side of the exciting star, these structures would have been compressed by the radiation pressure and/or stellar winds coming from the exciting star $\gamma$ Cas. As a result, a number of complex molecules would be allowed to form due to the increased density. Photodissociation of molecules such as $\text{H}_2$ by the stellar radiation then leads to the observed fluorescent and ERE spectra at the dense tip of IC63. Such component is absent in IC59 mostly due to its larger distance from the exciting star.

A second component consists of diluted atomic hydrogen and dust shielded by the bright rims. This component would be less active, as photodissociation of the observed HI would have occurred at the beginning of the main sequence stage of $\gamma$ Cas, and ceased after a time shorter than the main sequence period by orders of magnitude. As a result, most of the dissociating photons would travel across the nebula with little interaction with the gas. IC59 would be primarily composed of this diluted component.

However, quite a few of these suggestions require further investigation. The cometary shapes of the clouds definitely indicate a morphological evolution. Detailed modeling of these shapes is needed to understand this evolution and perhaps to estimate a time scale for the formation of these structures. Given adequate modeling, a lower limit could be set on the age of the exciting star.

Clearly, more accurate stellar properties are needed. The determination of the stellar properties of $\gamma$ Cas is complicated by the fact that it is a Be star whose behaviour is not yet fully understood. The postulated disk may have interfered with observations of the spectrum of the star thus leading to inaccurate stellar parameters.

The analysis presented here was performed for average properties of the whole clouds. Given sufficient resolution, the same analysis could be performed on the individual filaments of IC63 to infer the conditions inside these compact clouds. High resolution mapping of all the bright rims in IC63 would be of interest since these regions would
Chapter 6. Conclusion: Summary and Future Work

consist in a dynamic environment. High resolution CO mapping of the entire nebula is required to verify the hypothesis that molecular material is only present in the bright rims.

6.2 Other Unrelated Objects

The last subject to discuss regards the objects discovered in this survey which are not related to S185. For most of them further observations need to be carried-out and are discussed in the next paragraphs.

6.2.1 Infrared Source Between IC 63 and IC 59 (IRAS 00556+6048)

This source is a strong infrared emitter with a distinct spectrum. The emission peaks at a lower wavelength than IC 63 and IC 59, suggesting that it is a hotter object which may have an internal source of heating. The source has recently been observed in $^{12}\text{CO} \ 1 \rightarrow 0$ and $^{13}\text{CO}$ at the Five College Radio Astrophysical Observatory (FCRAO) and a coincident source was detected in both lines. Detection of both atomic and CO components at nearby velocities ($LSR$) of $-34$ (HI) and $-32.5\ km\ s^{-1}$ (CO), and the radiation balance analysis of the previous chapter suggest that the source is probably not related to S185. At a kinematic distance of $1.8\ kpc$, the entire atomic gas emission surrounding IRAS 00556+6048 translates into a total mass of $4.3\pm0.6\ M_\odot$.

The strong infrared and atomic hydrogen emissions together with the absence of weak continuum suggest that IRAS 00556+6048 could be a dissociating star similar to IRAS 23545+6508 recently discovered by Dewdney et al. [117]. Such objects are excited by B1-B5 type stars for which the radiation is insufficient to ionize the surrounding gas, but can account for the dissociated hydrogen and dust components.

In order to test this hypothesis, further observations are required. At the position
of IRAS 00556+6048 two or three stars surrounded by a ring of faint nebulosity are seen in the POSS prints. It would be useful to obtain spectral types for these stars in order to compare their spectra with the HI and IR emissions. Observation of the weak surrounding optical nebulosity would also be of interest, as well as VLA observations at different frequencies to determine the nature (thermal or synchrotron) of the weak continuum emission if there is any.

6.2.2 Emission Near γ Cas (IRAS 00533+6030)

From the IRAS data alone, IRAS 00533+6030 appears to be a stellar object because of its infrared spectrum similar to γ Cas. However, no strong stars are seen in the area covered by IRAS 00533+6030. The source integrated infrared flux is \( F_{IR} = 5.28 \times 10^{-13} \text{ W m}^{-2} \) (from the 12 and 25\( \mu \text{m} \) points only) which is 20% of that of γ Cas (\( F_{IR} = 2.50 \times 10^{-12} \text{ W m}^{-2} \)). However, the distance to the source is unknown and it is difficult to compare the emissions.

As pointed out earlier in Chapter 4, the 60\( \mu \text{m} \) high resolution map shows two extremely weak sources at the position of IRAS 00533+6030 and perhaps the infrared emission is due to a number of weaker stars. High resolution maps at 12 and 25\( \mu \text{m} \) would be useful for IRAS 00533+6030. HI nebulosity is also present around γ Cas, and two small areas of stronger emission appear to coincide with the two weak infrared sources on the high resolution map (Figure A.4, channels 70 to 71). The association of HI with these objects would be rather intriguing if these are stars.

Some other HI nebulosity is seen around γ Cas but no coincident infrared emission is detected. However, a coincident continuum point source MN, see Table 4.4, is clearly seen at both 21 and 74 cm (Figure A.2 (e), 3.4 and A.4, channels 73 to 78). Its flux densities of 59 and 17 mJy beam\(^{-1} \) at 21 and 74 cm respectively imply a spectral index \( \alpha = -1.0 \) which clearly indicate the non-thermal nature of the emission. The source
may be extragalactic and the coincident HI would not be associated. MN has also been observed with the VLA observations by Dougherty et al. [109]. They detected flux densities in the range of 0.2 to 0.9 mJy at 8.3 GHz.

6.2.3 Point Source East of S185 (MG)

This source is particularly interesting because of its apparent variability, and because of the close coincidence with the surrounding HI emission. MG is detected only in the Bonn 21 cm survey, while assuming thermal emission, it should have been detected by all other radio continuum observations except at 74 cm (Table 4.3) where sensitivity is reduced due to corrupted data.

It is difficult to interpret the non detection of MG by any observations other than those made in the 21 cm Bonn survey. A first and obvious thing to do would be to repeat the 21 cm Bonn observations to the same or even higher sensitivity. Next, the DRAO 74 cm map which still needs improvement could be self-calibrated in order to improve the signal to noise ratio.

At a kinematic distance of 1.6 kpc, assuming thermal emission from a plasma with an electron temperature of 8000 K, the flux of 114 mJy implies a number of ionizing photons \( N_L = 2.52 \times 10^{46} \text{s}^{-1} \) to maintain the cloud radio emission. This corresponds to a B0.5-B1 star [58]. For a radius of 2 pc, the corresponding electron density is \( \approx 20 \text{ cm}^{-3} \).
Appendix A

Figures of Chapter 4
Figure A.1: E-band Print of PvdB ([63]). The overlayed contours (at 1.3, 1.5, 1.7, 2.0, 2.5 and 3.0 K) show the DRAO 21 cm continuum emission. Note the correspondence between both optical and radio emissions, also seen for IC 59.
Figure A.1: J-band Print of PvdB ([63]). The overlayed contours (at 9, 13, 17, 30, 40, 50 and 60 MJy sr$^{-1}$) are from the high resolution 60 μm IRAS map [100]. Note again the close correspondence of both emissions, and the faint shell-like nebulosity surrounding a star almost coincident with the peak infrared emission of IRAS 00556+6048. IRAS 00533+6030 appears to be resolved into two weak components while γ Cas is clearly seen as a tiny point source on the infrared contours.
Appendix A. Figures of Chapter 4

(a) 6 cm Continuum (NRAO)

(b) 11 cm Continuum (Bonn)

Figure A.2: Radio Continuum Maps
Figure A.2: Radio Continuum Maps (continued)
Appendix A. Figures of Chapter 4

Figure A.2: The low resolution continuum maps from the Bonn, NRAO and DRAO surveys (grey scale) with contours (at 1.4 and 1.7 K) of the high resolution 21 cm continuum map from DRAO. (c) and (d) show the same field observed by two similar telescopes at different epochs. The white contour around MG is the result of the Bonn data alone used to provide the short spacings for the DRAO high resolution image (Chapter 3). Note that MG is not detected at any other wavelength. A point source is seen at 74 cm near IRAS 00556+6048. Grey scale setting (white, black): (a): 0.04, -0.006 (b): 0.17, 0.0 (c): 1.6, 1.1 (d): 0.32, -0.06 and (e): 0.065, -0.005 (K)
Appendix A. Figures of Chapter 4

Figure A.3: IRAS Maps
Figure A.3: IRAS Maps (continued)
Appendix A. Figures of Chapter 4

Figure A.3: The low ((a), (b), (c) and (e)) and high (d) resolution maps from the IRAS survey (grey scale). IRAS 00556+6048 and IRAS 00553+6030 are labeled 1 and 2 on the 25 μm map. IRAS 00553+6030 appears to be resolved into two weak components on the high resolution map. Asterisks on (d) show the positions of the continuum sources detected in the VLA observations of γ Cas. The star coincides with the strongest infrared point source in this neighborhood. Note that MG and MN are not detected by the infrared observations. Grey scale setting (white, black): (a) 5.5, 1.4, (b) 10.0, 3.7, (c) 55, 5, (d) 50, -5 and (e) 110, 35 (MJy sr⁻¹).
Figure A.4: HI Line Maps
Figure A.4: HI Line Maps (continued)
Figure A.4: HI Line Maps (continued)
Figure A.4: HI Line Maps (continued)
Appendix A. Figures of Chapter 4

Figure A.4: HI Line Maps (continued)
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Figure A.4: HI Line Maps (continued)
Appendix A. Figures of Chapter 4

Figure A.4: HI Line Maps (continued)
Appendix A. Figures of Chapter 4

Figure A.4: Maps of the atomic hydrogen emission (grey scale). A galactic spectrum (shown above) was removed from the line maps. The bottom figure shows contours at 1.4 and 1.7 K of the radio 21 cm continuum emission from DRAO, while the top display has overlayed contours of the high resolution IRAS data starting at 7 MJy/sr with 5 MJy/sr interval. The five points stars indicate positions of strongest stars in the field. Continuum sources detected by the VLA observations of γ Cas are represented by asterisks. The HI emission of IC 63 and IC 59 is visible from channels 37 to 42 incl. HI emission possibly associated with IRAS 00533+6030 appears from channels 68 to 76 incl., and from channels 72-73 to 80-81 for MN. The HI shell structure around IRAS 00554+6048 is present between channels 78 to 85 incl., and the hole in background atomic emission at the position of MG is seen from channel 72 to 79 incl.. Grey scale setting (black, white): (ch. 36 to 43 incl.) 20, 2 (K) and (ch. 67 to 88 incl.) 36, 0.0 (K)
Figure A.5: HI Column Density Map and Spectra for IC 63.
Figure A.5: HI column density map (grey scale of (a)) and spectra (c) for IC 63. Contours at 1.4 and 1.7 K are from the 21 cm continuum DRAO map. Spectra computed at the positions shown on (b), over an area of approximately 3' × 3' are displayed above in (c). Note the wing on the right hand side. Grey scale setting (black, white): 7.0, 5.5 \((10^{20}\text{ atoms cm}^{-2})\).
Figure A.6: HI Column Density Map and Spectra for IC 59.
Figure A.6: HI column density map (grey scale of (a)) and spectra (c) for IC 59. Contours represent the high resolution IRAS data at 60 μm, starting at 5 in steps of 5 MJy/sr. Positions for HI spectra computed on areas of 3'×3' are indicated in (b). Note the peak velocity difference with IC 63. Grey scale setting (black, white): 9.0, 7.1 (10^{20} \text{ atoms cm}^{-2}).
Figure A.7: HI Column density map for IRAS 00556+6048. Contours of the 60 μm high resolution map at 15, 100, 400 and 700 MJy/sr are shown. The stripes surrounding IRAS 00556+6048 are artifacts from the high resolution data processing. The fragmented HI emission at different velocities does not combine very well into a single cloud. However, note that the extraneous spike on the north east side of the map lines up with the end of the northern edge of the strong shell and the infrared source. Grey scale setting (black, white): 8.9, 4.3 (10^{20} \text{ atoms cm}^{-2}).
Figure A.8: HI Column Density Map and Spectrum for MG.
Figure A.8: HI column density map (grey scale of (a)) and spectrum for MG. Contours are from the Bonn 21 cm survey starting at 1.3 in steps of 0.1 K. The spectrum shown on (c) has been computed within the area delimited by the box on (b). Note the large width of the line. Grey scale setting (black, white): 7.0, 3.0 ($10^{20}$ atoms cm$^{-2}$).
Bibliography

Bibliography

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