Some Investigations of Interstellar Clouds

by

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CERTIFICATE

This is to certify that the thesis entitled *"Some Investigations of Interstellar Clouds"* submitted by **Jayadev Rajagopal** for the award of the degree of DOCTOR OF PHILOSOPHY of Jawaharlal Nehru University is his original work. This has not been published or submitted to any other university for any other Degree of Diploma.

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DECLARATION

I hereby declare that this thesis is composed independently by me at the Raman Research Institute, Bangalore, under the supervision of Prof. G. Srinivasan. The subject matter presented in this thesis has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or any other similar title.

(Prof. G.Srinivasan) (Jayadev Rajagopal)

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Acknowledgement

As I write this, I can't seem to shake the lingering feeling that just the act of putting it down lessens the acnowledgement. Nevertheless, let me take the plunge. I have faith that the many people who have contributed to this effort in some way or the other and who do not find themselves here will indulge me.

Going by that adage of deeper the feeling the lesser need be said, my thesis advisor shouldn't figure here at all. So I will simply say, <u>for everything,</u> thank you Srini.

A major part of the thesis describes work done with the VLA. K.S. Dwarakanath's contribution to this has been considerable. The thesis also describes work done with T.K. Sridharan here at RRI and Harish Bhatt at the Indian Institute of Astrophysics. I would like to thank IIA for their support and the use of the facilities at Kavalur. I have learnt much working with TKS and continue to do so. B.Ramesh has also helped initiate me into mm wave astronomy.

What the thesis does not describe, is the 5 years I spent working on optical interferometry. I enjoyed working with my advisors, Udayashankar at RRI and Saxena at IIA. I owe much to both of them. The rest of the team, including Mani, Sampson and others I thank for the enormous effort and enthusiasm they put into the project. During those years, I benefitted from discussions with Rad and Rajaram, the frequency of which have greatly declined during the thesis work in the all consuming race to meet deadlines.

Needless to say, the astrophysics group at RRI figures prominently in this list. Dwaraka and Desh, I have collaborated with. The others have offered untiring support and help when needed.

As for my fellow students, I opt for the coward's way out and mention no names. Each of them know just how much I owe them. Thanks guys.

The staff at the mm wave observatory have been of invaluable help. A vital cog in the machinery are the computer folk. Thoroughly undeserving of the usual bad guy reputation of system managers, the RRI computer group is unique.

So is the RRI library and its staff. A big thank you to all of them. Raju in the photo lab has put in much work.

The canteen, transport and the workshops complete the RRI picture and I have been lucky to work in one of the nicest places you can imagine.

Now to the home front.

Hari and Nandana, in loco parentis. Quiet confidence in my abilities for what seemed an interminable period. More than I could say of myself! Pattabhi for inspiration on everything. Anil, Kiron and Reema. Everybody else at home for the love and support of a home away from home. My family in Trivandrum, Cochin and scattered around the globe.

Mom and Dad.

This list could go on and on. But that would be a bit like the endlessly scrolling credits in a theatre long since empty. Curtain time.

Thank you again.

A synopsis of the thesis

The thesis is concerned with the investigation of interstellar clouds, both atomic and molecular. In chapter **1** we study diffuse atomic hydrogen clouds, with particular emphasis on their random motions. Chapter **2** deals with molecular gas found in the ring-like structure called the IRAS Vela Shell in the region of the Gum Nebula. Chapters **3** and 4 are concerned with small dense molecular clouds called Cometary Globules found in the same region. Chapter **3** examines the magnetic field in these globules and in chapter 4 we study ionized gas found in them. A brief outline of each of these chapters, as well as a summary of the main results and conclusions is given below.

Chapter 1

In the first chapter we describe an observational effort to detect absorption in the 21 cm line radiation of neutral hydrogen from interstellar clouds which had earlier been detected through the absorption lines of Na and Ca^+. The major aim of this investigation was to establish a one-to-one correspondence between clouds seen in optical absorption towards bright stars and those seen in 21 cm absorption and emission in general Galactic surveys. A brief summary of the history of the problem and the motivation behind our experiment is as follows:

One of the first major efforts to understand the nature of interstellar "clouds" was the observation of interstellar absorption in the optical line of Ca^+ towards nearly **300** nearby bright (O and B) stars by Adams in 1949. This study revealed the presence of multiple absorption features at various velocities in each line of sight, presumably arising in interstellar "clouds". Such absorption features had been seen previously in observations of a less extensive nature and had led to the cloud model of the interstellar medium.

In 1952 Blaauw analysed the velocities of these absorption features to study the random motions of these clouds. One of the major results of the study was that it revealed the existence of a high velocity tail in the cloud population. A single gaussian could not account for the distribution of cloud velocities and

Blaauw found that an exponential function fitted the distribution better.

After the advent of radio astronomy and the 21 cm line, extensive observations of absorption and emission from neutral atomic hydrogen revealed a two phase ISM, with cool diffuse clouds existing in pressure equilibrium with a rarer and warmer intercloud medium. The velocity distribution of these clouds did not have any clearly defined tail at high velocities. Some of the basic questions we have addressed in the first chapter are:

- Do the optical absorption features arise in circumstellar gas ? This suggestion had been made very early on, in the context of the high velocity absorption. The gas in the vicinity of these bright stars could be accelerated away from the star through the effects of UV radiation (the rocket effect) and stellar winds.

- Do they arise in relic supernova remnants ? This was a scenario advocated by Siluk and Silk in 1974 to account for the observed distribution of the high velocities.

- Or, do the absorption features arise in truly interstellar gas in the form of "clouds" ?

- If they are interstellar clouds, **are they the same as seen in 21 cm absorption and emission** ?

The early attempts to answer these questions came to a large extent from the Dutch group of astronomers (van Woerden, Takakubo, Habing, *et al.)*. These consisted of looking for HI *emission* in the 21 cm line from direction of stars towards which optical absorption features had been seen. These observations threw up a big puzzle. The HI emission showed features which could be identified with the *low velocity* optical absorption. There was, however, *no* 21 *cm emission at velocities corresponding to the high velocity optical absorption features.*

Our experiment was to **measure** HI **absorption towards radio sources very close to the line of sight towards stars which show interstellar optical absorption features in their spectra.** This is the first time that such an absorption survey is being attempted and it allows us to directly compare optical absorption with 21 cm absorption from atomic hydrogen. The primary advantage of the absorption measurement is that it affords very high resolution. This aspect is one of the major criticisms of the earlier attempts to measure HI a degree. Comparison of the features from such a beam with those from the arc-second resolution achieved in optical absorption is difficult and the high velocity features might be missing in emission due to *beam dilution.* Another advantage of the absorption experiment is that in combination with the previous emission measurements, *the spin temperature* of any absorption feature that we detect can he determined which would help in establishing the correspondence between the clouds seen in optical and those seen in the radio.

The observations were carried out with the VLA in June 1996 and Feb-April, 1997. We identified a sample of stars with reasonably strong radio sources close to their line of sight, allowing us to probe parsec sized features. All the chosen stars show optical absorption features at both low and high velocities in their spectra, and a majority of these fields have already been examined for HI emission.

Chapter 2

In this chapter we describe a study of the molecular gas associated with a shell-like object in the Gum-Vela region delineated by its infrared emission. **The IRAS Vela Shell** is a ring-like structure seen in projection in the region of the Gum Nebula in the 25, 60 and 100 μm maps of the IRAS Sky Survey Atlas. The far infrared emission indicates the presence of dust and associated gas. The only previously known indicator of molecular gas in the region was the presence of a small set of comet shaped molecular clouds in the region called the cometary globules; but the association of the cometary globules with the IRAS Shell was tentative. The IRAS Point Sources in the region also clearly delineates the Shell. The Shell as seen in the IR envelopes the Vela OB2 association of stars. Two very bright stars γ^2 Velorum and ζ Puppis are also seen inside the Shell in projection. Morphologically, the dark clouds seen in the region as areas of obscuration also describe a ring like structure.

We describe observations in the 115 GHz line of the ^{12}CO molecule towards the Shell, targetting a selected sample of the IRAS point sources, *in order to detect and study the nature and kinematics of the molecular gas in the Shell.* Our aim was also to understand the relation between the Cometary Globules and the shell, as well as the dark clouds in the region. Using the positions and velocities of the dark clouds from a recent ^{12}CO survey of these objects from the Mopra

Chapter 3

In this chapter we report some measurements of linear polarisation of light from stars within, and seen through, the Cometary Globule CG 22. The aim of this experiment was to detect and determine the orientation of the magnetic field in this globule. If polarisation of the light from the stars is caused by dust grains aligned by the ambient magnetic field, the direction of polarisation gives the component of the field in the plane of the sky. Our motivation to do this experiment was to understand the possible role of the magnetic field in determining the peculiar head-tail morphology of these globules found in the vicinity of bright stars. The morphology and expansion of the Cometary Globules are attributed to the influence of nearby massive stars. The tail of the CG shows fine structure in the form of thin filaments which are difficult to explain on the basis of such arguments. The magnetic field could play a role in confining the gas in the tails of CGs, since the measured random velocities (of ^{12}CO) in the tail should have caused them to disperse in the absence of any confinement. CG 22 is known to harbour a young star and the CGs in general are recognized to be sites of star formation at enhanced rates. The magnetic field in these clouds could be important in the star formation process. The observations were done to explore some of these issues and were carried out with the 1 m telescope at the Kavalur observatory of the Indian Institute of Astrophysics.

Chapter 4

In chapter 4 we present a photometric observation of the Ha! emission from the bright rim of the Cometary Globule CG 22, carried out with the 2.3 m telescope at the Kavalur observatory of the Indian Institute of Astrophysics. The objective was to establish the physical conditions prevailing in the rim and in turn to shed light on the connection between the bright rims of the cometary globules in the Gum-Vela region and the two bright stars seen (in projection) in their vicinity, γ^2 Velorum and ζ Puppis. ζ Puppis is one of the most luminous stars. Its spectral type and surface temperature are ill determined leading to a large range of possible distances. Its association with the CGs is therefore not certain. To explain various features of the CG system (bright rims, expansion, tail structure to name a few), the influence of ζ Puppis has been invoked by previous investigators. The presence of the expanding IRAS Vela Shell (Ch. 2) has added a new dimension

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