Chapter 1

INTRODUCTION

In this chapter, a brief account of the interstellar dust is discussed. Concept of dark clouds and how do stars form out of interstellar medium, are discussed. The polarimetry and photometry in dark clouds are then discussed. Finally, the objective and the layout of the thesis are presented.

1.1 A brief account of Interstellar dust

Mankind has often thought the space between the stars (Interstellar space) is essentially clear and empty. Astronomers were, therefore, surprised in the last century when they found the first evidences of material in the interstellar space. It was all the more surprising to learn that this material consisted not only of gas atoms or molecules. but also grains of dust. The vast region of space between the stars is not completely devoid of matter. Ionised and neutral gas. both atomic and molecular, mingled with minute particles (Interstellar dust or grains). with varying concentrations. pervade the entire interstellar space which has been called Interstellar matter (Spitzer 1978. 1982). By dust grains. one means solid gains of matter. mostly graphites and silicates of sizes ranging between 0.005-10μ (1μ=10^{-6}m). Some observations also seem to require the presence of dirty ice (H_2O containing impurities) and ammonia. There are also indications of the existence of organic benzene ring-like molecules which are called polycyclic aromatic hydrocarbons (PAHs).

Interstellar dust plays at least two vital roles. Firstly. they polarize the starlight. Secondly. they extinct and redden the starlight. Even with different experimental results and theoretical speculations, the controversy regarding the nature and composition of interstellar dust still persists.

1.2 Dark clouds and formation of stars

The isolated regions of dense concentration of interstellar matter. in the vast interstellar space. appear as dark obscuring clouds or bright clouds with varying amounts of surface brightness. Such local concentrations of gas and dust have been known as Interstellar clouds or nebulae. Barnard (1927) prepared a list of such dark clouds in the sky.

Stars form out of gravitational collapse of gaseous clouds. If the cloud is hot. then the thermal pressure of the gaseous particles (arising from their random motions) would try to balance the gravitational force directed inward. Gravitational collapse can only occur when the gas has cooled down so that gravity wins. (Later, of course, the contraction due to gravitation would fire thermonuclear reactions in the core, lighting up the star).

Dust grains are, therefore, essential in the process of star formation. The energy generated during collapse is absorbed by the dust particles inside the star forming clouds, mostly in nearby regions at visual and ultraviolet wavelengths and is reradiated away in infrared and other low frequency radiations (Mathis 1994). The dust grains, thus, take part in energy-balance mechanism in star formation process allowing star formation to occur. Incidentally it is also the stars that produce the dust grains in the first place (Hecht et al. 1984, Hecht 1986, 1987, 1991). According to astronomers, relatively cool surfaces of cool stars are where most of the dust grains are formed. Lot of such stars show infrared emission in excess of expectations, which is thought to be due to nascent dust grains (Evans 1993).

The formation process of low mass stars can be divided into three phases. The first phase involves massive interstellar clouds or cloud fragments, which have cooled to the point where they are detectable in molecular lines (such as CO), but which are unable to collapse because of an excess of thermal, turbulent, rotational and magnetic energy over gravitational (de Jong et al 1980). The second phase, the protostellar collapse phase starts when fragments of ~1Mo become gravitationally unstable and it lasts 10^5 years. The most of the observable radiation produced during this phase fall in the mid-infrared at 30-100μm. A protostar is a star that has already formed but which is not yet in hydrostatic equilibrium. Observing protostars is difficult because the collapse phase is relatively short and because the star forming regions are highly obscured by dusts (Ladd et al. 1991). At the end, the cloud reaches the point where gas pressure can support it in equilibrium against gravity, it has star-like properties, and it begins a slow contraction in near hydrostatic equilibrium. A general discussion on star formation may be referred to (Dey 2000).

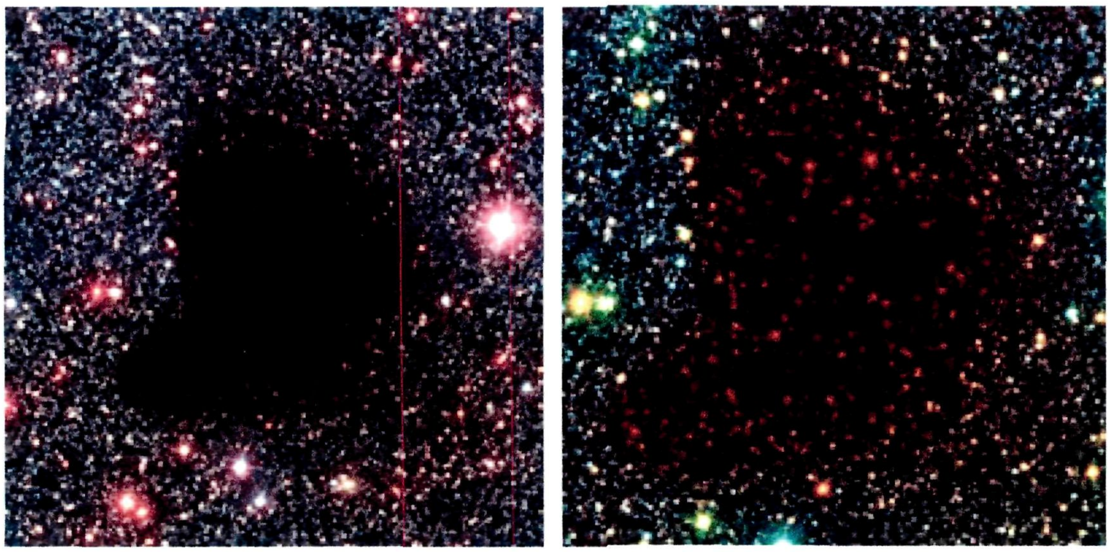
(Bok & Reilly 1947) suggested that small, compact and isolated dark regions or cloud in the sky (also known as 'Bok globules') were undergoing gravitational collapse on their way to form stars. Lynds (1962) published a catalogue of such dark objects. Bok (1956) himself studied many such dark regions or clouds. Clemens and Bervainis (1988) (hereafter, CB) compiled a list of 248 dark clouds. Bok's assertion, that the globules are a strongly star forming population, got firmly established through infrared (IRAS survey) and millimeter studies (^{12}CO map) on these clouds (Goldsmith et al. 1984, Yun & Clemens 1990, Keene et al. 1983, Clemens et al. 1991, Yun & Clemens 1992).

Fig. 1.1a shows a 'hole' in space which is a molecular cloud (Bok globule). Barnard 68 and blocks the passage of starlight at optical wavelengths that might be behind them. An infrared image of Barnard 68 (Fig1.1b) reveals the presence of stars behind the Bok globule. Infrared wavelengths, which are a little longer than visible light merely, wiggle through the dust in the cloud. Because of their small sizes, regularity and isolation, globules can be convenient objects to study the formation of individual stars. The small globule are especially well suited, as they are the simplest clouds, with single, central condensations and little supersonic gas motion (Dickman & Clemens 1983). Thus, Bok globules provide a more accurate picture of the physical conditions existing in small molecular clouds prior to, during and just after the onset of star formation. So, Bok globules are still a subject of intense research.

1.3 Polarimetry in dark clouds

When light from the stars background to a cloud passes through the cloud. it gets linearly polarized due to forward scattering by the magnetically aligned dichroic grains in the cloud. The interstellar polarization discovered by Hall(1949) and Hiltner (1949) and others gives clues to the understanding of the shape and orientation of the dust grains. Polarization cannot be produced by spherical grains. Furthermore: even non-spherical particles cannot produce polarization if they are oriented at random. Davis and Greenstein (1951) theorised that observed polarization is caused by dust grains oriented by interstellar magnetic field and worked out for the first time. the detailed process by which grains become aligned. In principle. polarization is a diagnostic that provides another integral of a grain property over the size distribution. However. it involves an additional function that is poorly understood - the alignment of grains of various sizes. Even so. polarization measurement is important. because it provides information regarding the optical properties of grains and the conditions under which grains can be aligned.

The magnetic field plays an important role in star formation dynamics in the clouds by mediating accretion. directing the outflows and collimating the jets. In order to understand the ambient magnetic field and study the star formation dynamics in the cloud. background star polarimetry are usually used. Different types of polarimeters are used for polarimetric study. The simplest type of polarimeter is a Polaroid rotated in discrete steps in front of a detector. The most widely used polarimeter without rapid modulation of the signal is called Wollaston polarimeter. The polarimeters. commonly



(a) (b)

Fig. 1.1 (a),(b) Image of Barnard 68, at optical wavelengths (left) and infrared wavelengths (right)

used in background star polarimetry, are CCD imaging polarimeter. photoelectric polarimeter. infrared polarimter etc. There have been many studies. on background star polarimetry to investigate the ambient magnetic field and star formation dynamics in the clouds (Verba et al. 1981; Joshi et al. 1985; Goodman et al. 1989; Kane et al. 1995; Sen et al. 2000. to mention a few).

1.4 Photometry in dark clouds

The dust grains play a vital role in dimming the starlight on its way to the observer. This dimming is due to absorption or scattering of starlight by the grains and is called Interstellar extinction (Trumpler 1930). Interstellar extinction is wavelength dependent. It was found that distant stars are apparently reddened as opposed to nearby stars of the same type. which is called Interstellar reddening (Whitford 1958). This reddening of star light is due to the fact that the dust grains scatter more light for red in the forward direction as compared to blue. It scatters more in blue light when looked at a scattering angle of 90^0 (Hulst 1957).

When light from the background stars pass through a cloud. there is dimming or extinction of starlight due to absorption and scattering of starlight by the dust particles inside the cloud. The extinction depends on the size as well as composition and internal distribution of the dust grains in a cloud. The measurement of extinction of starlight yields clues to properties of dust grains which play a vital role in star formation mechanism. Colour excess. which is the amount of colour change produced by the dust particles. is a measure of extinction and it is generally denoted by E (B-V). E (V-R) etc.

As star forming clouds, themselves do not radiate in the optical regions, photometric study of the stars background to the cloud is a powerful tool to investigate these clouds and to understand different physical properties (dust size, composition and internal distribution of the dust grains) associated with these clouds.

The basic goal of astronomical photometry is to measure light flux from a celestial object. The photometric observation of celestial objects (galaxies, stars, comets etc.) involves a light detector with filters transmitting only a limited wavelength, placed at the focus of a telescope. Because of the use of different light detectors, filters and telescopes, the observation of the same star at exactly the same time, will not give the same result. A calibration process is necessary to enable the detection instrument to yield the same results (Henden & Kaitchuck, 1982). However, charge coupled device (CCD) cameras are used as a detector in most of the photometric observations and measurements.

In practice, a star is not measured in flux units. The detector produces an output that is directly proportional to the observed stellar flux. The stellar fluxes are very difficult to measure accurately. But the determination of a star's magnitude is comparatively simple and, furthermore, the magnitude can be related to the star's light flux. The magnitude is related to brightness or flux by the following

$$m_\lambda = q_\lambda - 2.5\log F_\lambda \qquad \ldots \qquad (1)$$

where, m_λ = instrumental magnitude, q_λ= instrumental zero point constant and F_λ = flux.

1.5 The objective and layout of the present work

The objective of the present work is to study different star forming clouds photopolarimetrically to investigate ongoing physical processes in the clouds. Starlight passing through a dark cloud can be affected in a couple of ways. The light can be totally blocked if the dust in the cloud is thick enough or it can be partially scattered by an amount that depends on the colour of the light and the thickness of the dust cloud. All wavelengths of light passing through a dark dust cloud will be dimmed somewhat. But all wavelengths are not scattered equally. Just as our air scatters the bluer colors in sunlight more efficiently than the redder colors. the amount of extinction by the interstellar dust depends on the wavelength. The amount of extinction is proportional to $1/\lambda$. Bluer wavelengths are scattered more than redder wavelengths. The $1/\lambda$ behavior of the scattering indicates that the dust size must be about the wavelength of light (on the order of 10^{-5} centimeters). Less blue light reaches us. so the object appears redder than it should. If the dust particles were much larger (say. the size of grains of sand). reddening would not be observed. At near-infrared (slightly longer than visible light) the dust is transparent. At longer wavelengths one can see the dust itself glowing and probe the structure of the dust clouds themselves as well as the stars forming in them (young stars that are hidden from us in the visible band). The clouds (Bok globules) themselves do not radiate in the optical region. It obscures all visible light emitted from within it. So it is very difficult to understand what is happening inside a dark cloud. The obscuring dust may be the means to understand the cloud's structure. Interstellar dust absorbs and reddens light in a way that can be understood very well. The dust grains inside a cloud also cause polarization of starlight passing through the cloud. The photopolarimetric study of the stars background to the clouds is important to investigate the clouds and to understand the star formation dynamics inside the cloud.

The present study aims to estimate extinction of background star light and to find any possible relationship between polarization and extinction of the starlight background to the clouds under consideration. An attempt is made to interprete the result in terms of different physical conditions in the clouds.

The layout of the thesis include following chapters:

1. Introduction
2. Review of literature
3. Observation and Data collection
4. Data reduction, analysis and results
5. Error analysis
6. Discussion and conclusions

As already discussed, the first chapter contains an overview of interstellar dust. The concept of interstellar clouds and star formation processes in the dark clouds are discussed. The polarimetry and photometry in dark clouds are then discussed.

The second chapter will contain survey of literature which will include different works on dark clouds, photometric and polarimetric study in dark clouds, by different authors.

The third chapter will deal with a discussion on CCD imaging, CCD aperture photometry, observation of the clouds under consideration and collection of data.

The fourth chapter will contain a brief discussion of the image processing software IRAF, the reduction and analysis of photometric data using IRAF, the methods followed and the calculations and results.

The fifth chapter will deal with the errors, how errors from different sources propagate through the calculations to the final result.

The sixth chapter will deal with the discussions on observed extinction of background starlight of different field stars for each of the clouds under consideration and conclusions are drawn from the present study.