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ASTRONOMICAL POLARIMETRY: NEW OPPORTUNITIES

BIMAN J. MEDHI
Aryabhatta Research Institute of Observational Sciences, Govt. of India, Manora Peak,
Nainital-263 129, India
(**E-mail**: biman@aries.res.in)

ABSTRACT

The information about any astronomical object is derived only from their radiation. The polarized state of radiation yields much more astrophysical information than the intensity of radiation alone. Astronomical polarimetry has been playing a very important role in our understanding about the universe since 1949, after the major discovery made by J. S. Hall and W. A. Hiltner that the light coming from the majority of stars are partially plane polarized. The polarimetric study of any astronomical object provides information about the physical processes occurring in the system and about the interstellar medium in that particular direction. The new generation of large optical and infrared telescopes equipped with adaptive optics, and new technology space telescopes geared up the polarimetric research from the nearby universe to very high redshifts.

Key words : *Polarization-astronomy, Dust, Extinction.*

INTRODUCTION

The polarization, in general yields information about the asymmetry carried out by the electromagnetic waves emanated from any astronomical object. The asymmetry may be intrinsic (within the source itself) or in the interstellar medium (medium between the source and the observer), or both. The common asymmetries are magnetic fields or the geometric asymmetries in the distribution of scattered radiation. In the sky most of the sources of radiation are polarized and the polarization is produced in various ways e.g.; directly from some radiation processes like cyclotron or synchrotron emission, selective absorption (dichroism) of radiation by interstellar medium, scattering of radiation by dust particles etc. Multiwavelength polarimetric study of any astronomical object may be used to observe the asymmetry in different parts of the object. Astronomers are interested to measure the polarization ranges from several tens of percent to very very small fraction like parts per million according to their different scientific programmes. The new generation of 8 to 10m class telescopes equipped with adaptive optics is providing very high spatial resolution, exceeding 0.1 arcsec in near-infrared, which is very important for polarimetry.

Recently, the near-infrared polarimetric study of SgrA*, using the 8m European Southern Observatory's Very Large Telescope, equipped with adaptive optics has shown high degrees of variable polarization (several tens of percent), which confirms that the source of near-infrared radiation is non-thermal, and provides evidence for a massive black hole of mass few million solar masses, at the centre of our Milky Way galaxy [1].

The coming sections of this article will cover briefly about some of the important contributions of the astronomical polarimetry in different areas like, interstellar polarization, extrasolar planet, and origins of life, galaxies and active galactic nuclei and finally conclude with a summary.

Interstellar polarization

The light coming from the majority of the distant stars is partially plane polarized. It is independent of the physical properties of the stars but correlated with the interstellar absorption lines and bands in the stellar spectra. The interstellar medium is mainly responsible for the partial plane polarized starlight [2,3]. In low galactic latitudes and perpendicular to the galactic spiral arm, starlight shows largest polarization where the planes of vibration of the electric vector deviates slightly off from the galactic plane. On the other hand the starlight shows very small polarization in the directions parallel to the galactic spiral arm and the planes of vibration are distributed at random directions. The accepted model for the interstellar polarization is linear dichroism (directional extinction) resulting from the presence of nonspherical dust grains which are aligned by the galactic magnetic field. The interstellar medium is also producing a component of circularly polarized light, if the direction of alignment changes along the line of sight. Although the identity of the dominant grain alignment mechanism has proved to be an intriguing problem in grain dynamics, it is generally believed that asymmetric grains tend to become aligned to the local magnetic field with their shortest axis parallel to the field [4]. The linear dichroism of starlight can be used to map the direction of the magnetic field. In the different lines of sight to the all stars the wavelength dependence of interstellar polarization $P(\lambda)$, appears to be the same, which can be described by using the maximum wavelength λ_{max} and maximum polarization P_{max}. These two parameters, the wavelength at which polarization is maximum λ_{max}, ranging from 0.3 to 0.8 μm with a mean value of 0.55μm and the maximum polarization P_{max}, which depends on the number of dust grains along the line of sight to the star and the grain alignment efficiency. $P(\lambda)$ is given by the famous Serkowski polarization law and adopting the parameter $k = 1.15$ [5]

$$P\lambda / P_{mm\,ax} = exp\ [- k\ ln2\ (\lambda_{max}/\lambda)\ ] \qquad (1)$$

Figure 1 shows a typical interstellar polarization and extinction curve along the line of sight of the star HD 161056. It is very important to note how the very large extinction peak at 4.6 μm-1 has no feature in the polarization curve, which implies that graphitic carbon particles are responsible only for the extinction feature do not contribute to the polarization.

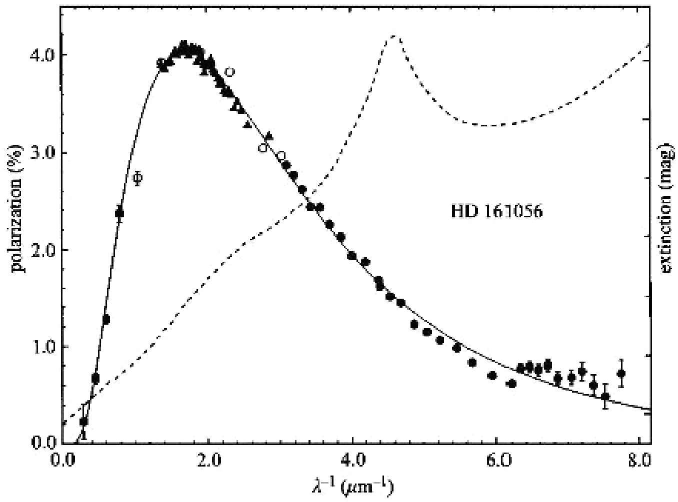

Figure 1: Linear dichroism of the interstellar medium in the direction of the star HD 161056.

The shape of the curve (solid line, from Somerville et al. 1994 [6]) is more or less the same for all stars ('Serkowski curve [5]) when the degree of polarization and the wavelength are both normalized at the peak of the curve. For reference, the extinction curve for this star has also been sketched (broken line, arbitrary zero-point).

Millimetre, sub-millimetre and mid-infrared polarimetric measurement has become increasingly important over past 10 years. At these longer wavelengths the aligned dust grains produce polarization in emission rather than absorption with the E-vector perpendicular to the local magnetic field. The polarization map of the dusty molecular clouds where the star formation initiates can give us a better understanding about the different phases of star formation including the initial collapse of the clouds as well as the simultaneous outflows.

Extrasolar planet

In the past decade, extrasolar planet (exoplanet) detection has drawn a lot of attention. Since the discovery of the first exoplanet by Mayor and Queloz [7], more than two hundred planets have been detected. However, direct detection of Earth-like exoplanets remains very challenging, mainly because of the huge brightness contrast between the star and the planet and their small angular separation. Polarimetry has been recognized as a powerful tool for enhancing the contrast between a star and an exoplanet. The direct light of a solar type star, which can be considered as unpolarized [8], has been reflected by a planet will usually be polarized, because it has been scattered within the planetary atmosphere and/or because it has been reflected by the surface (if there is any). The degree of polarization of the reflected starlight (the ratio of the polarized to the total flux) is expected to be especially large around a planet's quadrature (i.e. when the planet is seen at a phase angle of 900). Polarimetry can also be used for characterizing exoplanets, because the planet's degree of polarization as a function of wavelength and/or planetary phase angle is sensitive to the structure and composition of the planetary atmosphere and surface, which is used for remote sensing of solar system planets, in particular, Venus [9], Hubble Space Telescope polarization observations of Mars [10-11] etc. Venus is very much important for Earth-based polarimetric study than the outer solar system planets, because as an inner planet, Venus can be observed from small to large phase angles (including quadrature), whereas the outer planets are always seen at small phase angles, where the observed light is mostly back-scattered light and degrees of polarization are thus usually small [12]. The physical parameters derived from polarimetric data include orbital inclination, mass, atmospheric dust grain properties, albedo, planetary radius and temperature. Polarimetric technique is considered as an important technique for future exoplanet discovery and improving the planetary atmosphere models.

Origins of life

Studies of circular polarization in regions of active star formation can potentially lead to information on the origins of homochirality in terrestrial biology. Amino acids extracted from primitive meteorites have been shown to contain an excess of the L-enantiomer, and it is hypothesized that organic matter accreting to early Earth carried this imbalance and drove bio-chemical evolution toward homochirality. The high circular polarization observed at near-infrared wavelengths (Figure 2) in the regions where stars and planets are forming (Bailey et al. 1998), may be responsible for the origin of enantiomeric excesses, this may provide a possible explanation for the homochirality on earth.

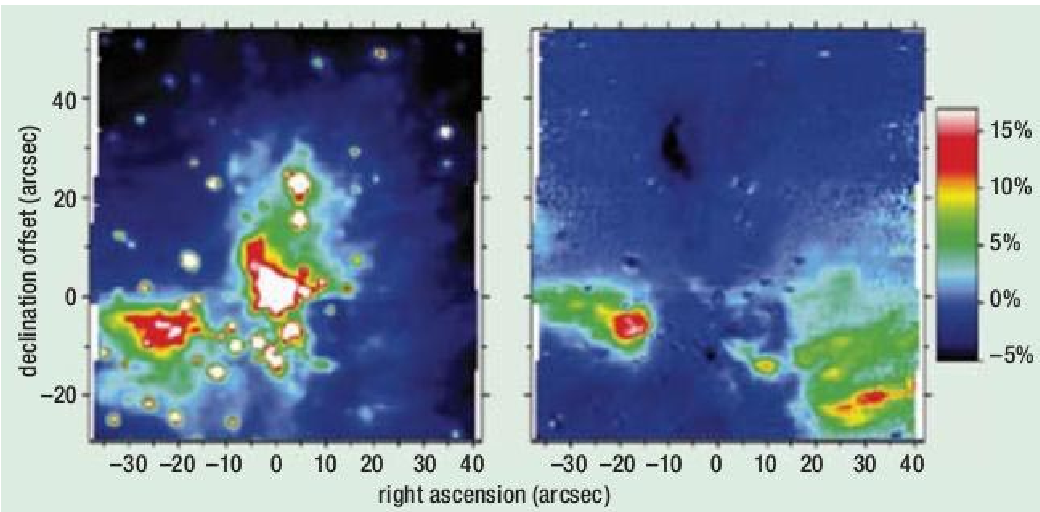

Figure 2: Circular polarization image of the OMC-1 star-formation region in Orion at 2.2 micron. Percentage circular polarization is shown on right ranging from -5% (black) to +17% (white). The total IR intensity is shown on the left with the bright Becklin-Neugebauer object at co-ordinate (0, 0) [13,14].

Homochirality has remained unexplained since Louis Pasteur discovered in 1848, that biological molecules have a preferred handedness which is believed to be a fundamental ingredient to the evolution of life. The influence of the circularly-polarized radiation on photochemical reactions in the star-forming environment is proposed as a viable mechanism for causing the excess of one enantiomer in prebiotic molecules, delivered to Earth during the early heavy bombardment period of the Earth, and acted as seeds for the development of life. Observations and modeling of circularly-polarized radiation in star-forming regions are critical to determining to prevalence of high levels of circular polarization in these environments. The discovery of life elsewhere in the Universe has become one of the key objectives of present-day scientific endeavour, and establishing robust biomarkers is an essential element in that programme.

Galaxies and active galactic nuclei (AGN)

Polarimetry has played a very important role in the advancement of the unified scheme of active galactic nuclei, AGNs. It is enhancing our fundamental physical understanding of the properties of the various types of AGN, which has helped to remodels the interior regions and torus, and finally leading toward a single coherent model. The high spatial resolution polarimetry provides a unique insight into the near-nuclear environments, which helps us in investigating the interaction of the AGN with the host galaxy. Polarimetry will play a decisive role in answering questions about the nuclear activity in such galaxies. In the near future, the focus will be on AGN at higher redshifts in order to explore evolutionary and environmental effects. Optical and near infrared spectro-polarimetry (spectroscopic application of polarimetry), can make a very significant contributions to determining the geometry of structures and velocity-resolved spectro-polarimetry gives the velocity of scatterers, which provides a unique tool for determining the geometry and speed of outflows associated with accretion disks in AGN and young stellar objects.

CONCLUSION

This article attempted to show very briefly the importance of polarimetric study in many important areas of astronomy. Polarimetry is an added application over photometry and spectroscopy which gives us many more information than the intensity/flux alone. New technology large telescopes, back-end instruments and detectors make this branch as a very important and challenging branch of astronomy, which gives us many more probable clues for long-standing unsolved problems and many more discoveries yet to come. It would be a significant loss for the community if astronomers are not able to extract the maximum information from the electromagnetic radiation incident on our telescopes, but this can only be achieved through polarimetry.

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