NEAR INFRARED POLARIMETRY OF DARK CLOUDS AND STAR FORMING REGIONS - TWO MICRON POLARIZATION SURVEY OF T TAURI STARS

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1 INTRODUCTION

Infrared polarimetry is one of the most useful methods to delineate the magnetic field structure in dark clouds and star-forming regions, where the intracloud extinction is so large that optical polarimetry is inaccessible. We have been conducting a near-infrared polarization survey of background field stars and embedded sources toward nearby dark clouds and star-forming regions (Tamura 1988). Particularly, the magnetic field structure in the denser regions of the clouds are well revealed in Heiles Cloud 2 in Taurus, ρ Oph core, and NGC1333 region in Perseus (Tamura *et al.* 1987; Sato *et al.* 1988; Tamura *et al.* 1988). This survey also suggests an interesting geometrical relationship between magnetic field and star-formation: the IR polarization of young stellar sources associated with mass outflow phenomena is perpendicular to the magnetic fields. This relationship suggests a presence of circumstellar matter (probably dust disk) with its plane perpendicular to the ambient magnetic field. Combining with another geometrical relationship that the elongation of the denser regions of the cloud is perpendicular to the magnetic field, the geometry suggests that the cloud contraction and subsequent star-formation have been strongly affected by the magnetic fields. Thus, it is important to study the universality of such geometrical relationship between IR polarization of young stellar sources and magnetic fields. In this paper, we report the results on a 2 micron polarization survey of 39 T Tauri stars, 8 young stellar objects and 11 background field stars in Taurus dark cloud complex.

2 RESULTS and DISCUSSION

About 60 % of the sample T Tauri stars are linearly polarized with relatively small degrees of polarization up to about 3 %. This is in contrast to the prevalence of large values of polarization in molecular outflow sources (Hodapp 1984; Sato *et al.* 1985) and *IRAS* sources other than optical T Tauri stars in the same region.

2.1 The origin of infrared polarization

Positive correlations between infrared polarization, optical polarization, and infrared color excess, together with the observed degrees of polarization which are too large to be interstellar or intracloud polarization, suggest that the infrared polarization is caused by circumstellar dust grains around the T Tauri stars. There is a positive correlation between polarization ($P(K)$) and color excess ($K-L$ color), while no correlation is found between polarization and reddening (A_V). This constrains the distribution of circumstellar dust to be in a disk-like structure, as has been previously suggested by other observations. The infrared polarization is therefore due to a circumstellar dust disk around the T Tauri stars, and is an indicator of the geometry of the disk.

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2.2 The geometrical relationship between dust disks and magnetic fields

A possible geometrical relationship between the circumstellar dust disk and the surrounding magnetic field in the cloud has been sought by comparing infrared polarization of T Tauri stars/young stellar objects with the nearby optical/infrared polarization vectors of field stars.

The distribution of the difference in angle between the P.A. of infrared polarization of TTSs/YSOs and the direction of the surrounding magnetic fields shows the following tendencies.

- Those targets which show polarization *perpendicular* to the magnetic field are mainly T Tauri stars known to be associated with extreme mass outflow phenomena such as molecular outflows and optical/radio jets (T Tauri itself, HL/XZ Tau, DG Tau and Haro6-13). They are also situated in the *redder/cooler* part of the region occupied by T Tauri stars in the *IRAS* far-infrared color-color diagram. These results suggest that the objects which show infrared polarization perpendicular to the magnetic field belong to a younger class of T Tauri stars, still surrounded by a thick circumstellar dust disk. The origin of the polarization might be infrared reflection nebulae extending above and below the disk surrounding cavities which are evacuated by the outflows.
- A tendency towards *parallelism* between the infrared polarization of the other "less active" T Tauri stars and the magnetic field is seen. This is naturally interpreted that the scattering *in the disk*, not in the reflection nebula, is the origin of polarization (see next subsection).

In both cases, the planes of the circumstellar dust disks are perpendicular to the magnetic field, indicating that the magnetic field has controlled the formation of circumstellar disks. The disks might have formed in a fragmentation process controlled by magnetic fields.

2.3 A model of the evolution of infrared polarization of TTSs/YSOs

At least three evolutionary stages of low mass stars can be recognized from the changes of infrared polarization.

(i) The objects at the earliest stages of evolution with extreme mass outflow phenomena show a large polarization parallel to the disk plane, because of heavy obscuration of the central source.

(ii) The objects at the earliest T Tauri phase– which are older than the objects (i) but still associated with outflow phenomena– show a small polarization parallel to the disk plane, because of dilution by direct radiation from the central source.

(iii) The "less active" T Tauri stars show a small polarization perpendicular to the disk plane, because of the scattering in the disk. The bipolar reflection nebulae seen in cases (i) and (ii) may be no longer present.

These changes of appearance in infrared polarization are attributed here to evolutionary changes in the optical thickness of the disks and bipolar reflection nebulae. The scheme proposed is a straightforward and intuitive description of the dissipation of the originally dense circumstellar dust cloud.

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