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Density Distribution in Disks around Protostellar Objects

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Abstract. A new method to find the density distribution in disks around protostellar objects, based on linear polarization maps, is presented. This method uses the displacement of the polarization null points as a function of wavelength. Variations in optical depth are converted into density variations with opacity tables for dust grains. The method has been applied with five linear polarization maps obtained at different wavelengths of the classical T Tauri star HL Tau. The slope of the density as a function of radius in the disk is compatible with the model of the standard protosolar nebula. The total mass of the disk is compatible with values determined by other methods. Other objects have been analyzed, with similar results, although with a smaller number of wavelength bands.

1. Introduction

A key question in the study of star formation is the density distribution in protostellar disks. In particular, observations are needed for testing theoretical predictions. Some results are available from radio interferometry, but here we present a new method based on linear polarization maps obtained in the visible and near infrared.

Polarization in the visible and near IR in young stars is due to scattering of light by dust grains in the circumstellar material (see the review by Bastien 1996 for more details). Linear polarization maps usually show a region of aligned polarization vectors near the central source, and further out a centrosymmetric polarization pattern which is due to single scattering. The region with aligned vectors (sometimes called the "polarization disk") has been interpreted in terms of multiple scattering (Bastien & Ménard 1988, 1990). A consequence or prediction of this model is that the dimension of the disk should change with wavelength. This dimension is obtained by measuring the position of the polarization null points between the region of aligned vectors and the region with centrosymmetric vectors.

Observations of HL Tau are used to verify this prediction and to find out how density changes with radius in the disk.

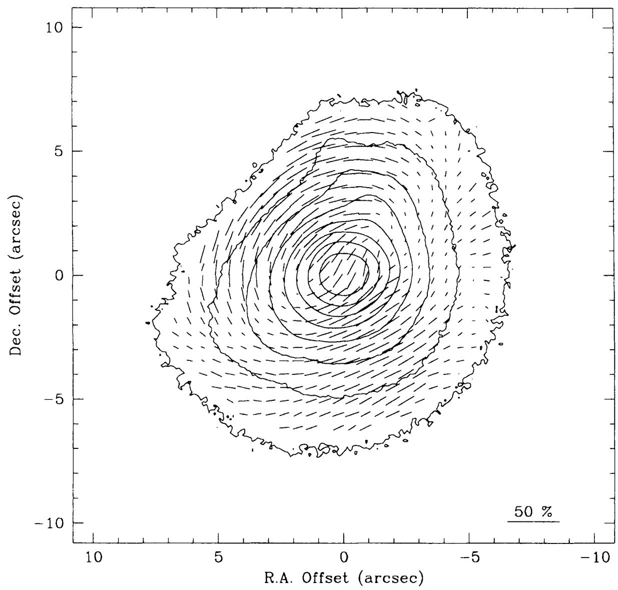

Figure 1. The I band polarimetric map of HL Tau superposed on intensity contours. The two null points are clearly visible on the map.

2. Observations and Analysis

A new polarization map in the I band has been obtained at the Canada-France-Hawaii telescope. The resolution is $0.11''$per pixel and the seeing was about $0.6''$during the observation (Figure 1). Published polarization maps were also used to get a good wavelength coverage.

The position of the null points has been determined as accurately as possible using contours of constant polarization position angles and also contours of constant $P \times I$ (Table 1).

Table 1. Size of the Polarimetric Disk at Different Wavelengths

Filter	Resolution ($''$)	Disk Size ($''$)	Ref.
7500 Å	1.25	6.7	1
I	0.6	4.5	2
J	0.7	4	3
H	0.7	2.2	3
K	0.7	≤ 1	3

References: 1) Gledhill & Scarrott 1989, 2) this work, 3) Weintraub et al. 1995.

One can show that an optical depth of ≈ 1 corresponds to (Hajjar 1998)

$$\sigma_c = \frac{1}{\kappa_\nu},$$

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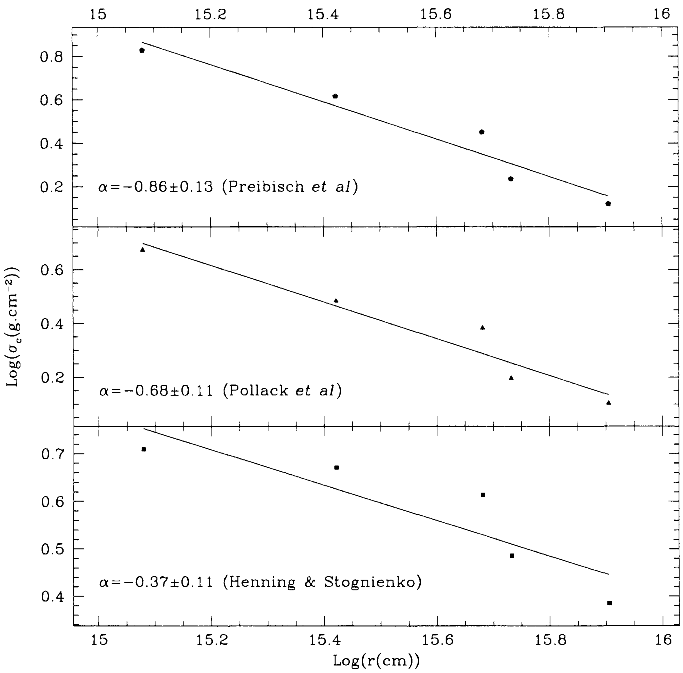

Figure 2. Logarithmic plots of the column density as function of radius for three different opacity models. Linear regression fits to the data are shown.

where σ_c is the column density along the line of sight, in g/cm^3, and κ_ν is the opacity per unit mass of the grains.

Then opacity models are used to compute the column densities which are plotted as a function of radius from the central star in Figure 2. Straight lines are fitted to obtain a slope. The slope of the density distribution is obtained from $\rho(r) \propto r^{(\alpha-1)}$. The values obtained from these fits, from -1.4 to -1.9, are compatible with the value for the density distribution of the standard solar nebula, -1.5. The total mass in the disk can be obtained by integrating the density distribution, to yield values of 0.09 to 0.14 $M_\odot$, compatible with other mass determinations.

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