Observing Protostellar Disks via Infrared Polarimetry

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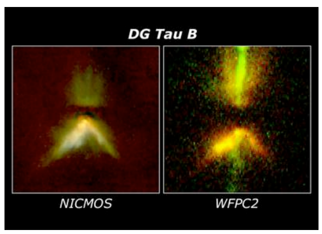
Abstract

Polarimetry of protostellar disks is still a relatively new field, with limited measurements in the Near-IR and only one detection of polarization at submillimeter wavelengths. As advancements in these wavelength regimes continue, observations in the Mid- to Far-infrared will be necessary to fill in the gaps of understanding for these disks, which are considered to be sites of early planet formation. Multiwavelength infrared polarimetry obtained via new instrumentation for SOFIA will complement existing polarimetry data. In this poster, we discuss previous measurements of polarization for protostellar disks. We will present the current model for polarization by dust grains in T Tauri Star disks, and show how data collected using SOFIA can help constrain these models.

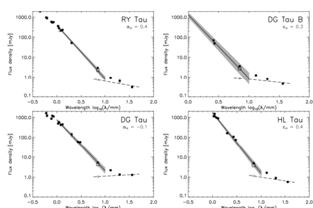
Introduction

T Tauri Stars (TTSs) are Class II low-mass protostars with masses similar to that of our sun. SED curve fitting (see below) and disk modeling suggest that dust grains in the surrounding circumstellar disks are coagulating up to ~ 1mm in size, making these disks the sites of very early planet formation.

We wish to learn about the role of the magnetic field in planet formation by observing the field geometry in the disk. Also, looking at the polarization spectrum of the disk may provide information about the size distribution of the dust grains.



HST images in the near-IR and optical of the disk surrounding TTS DG Tau B

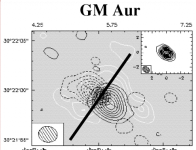


SEDs of selected TTSs from Rodmann et al. 2006. Measuring the slope can tell us the mass opacity index, β. For the ISM, β ~ 2, but for TTSs, β < 2, which indicates grain growth.

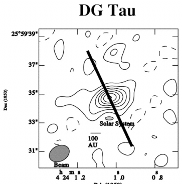
Polarization measurements and mapping of protoplanetary disks have been obtained in the optical and NIR; however, the polarized light observed at these wavelengths typically come from scattered light; thus, we cannot make inferences about the magnetic field from any polarization we may see. Light at longer wavelengths, ie, the mid-IR through submillimeter, comes from thermal emission of the aligned dust grains, which is directly related to the magnetic field. Thus we pursue observations at these wavelengths.

First Measurements and Model

GM Aur



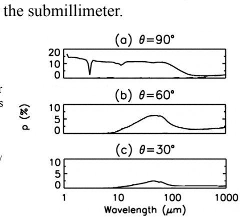
DG Tau



First detection of submillimeter polarization in TTS disks by Tamura et al. (1999). For both disks they measured 3% polarization orthogonal to the plane of the disk.

The first detection of submillimeter polarization for a TTS disk was made by Tamura et al. (1999). They measured a polarization of ~3% for both DG Tau and GM Aur. The polarization vectors were orthogonal to the planes of the disk, suggesting a toroidal magnetic field.

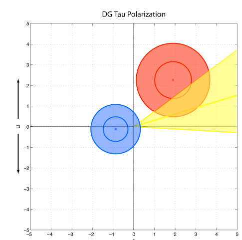
Cho & Lazarian (2007) have made the only existing model to predict polarization of these objects. They used a flared, layered disk in hydrostatic equilibrium. Grains ranged in size from 0.1μm to 1mm, and were aligned by radiative torques. The model predicts polarization peaks in the Mid/Far-IR (for some disk inclinations) and a relatively flat spectrum across the submillimeter.



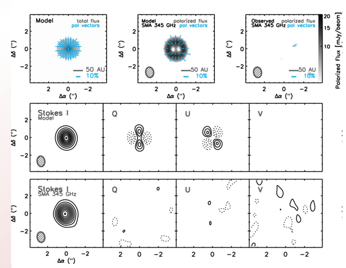
Predictions by Cho & Lazarian (2007) model for unresolved polarization for a TTS disk at various inclinations. For θ=60☒, which most closely matches DG Tau, only a slight change in polarization is predicted between 350 and 850 μm. Polarization peaks are predicted in the mid/far-IR regime.

Contradictions with Previous Work

Krejny et al. (2009) observed DG Tau at 350 μm using the SHARP polarimeter. They did not detect polarization within 3σ. Comparing with the Tamura result, this suggests that there is a drop in the polarization from 850 to 350 μm. This was not predicted by the Cho & Lazarian model. However, using information obtained from the model, they suggest that the drop could be caused by optical depth effects; increasing the mass of the model disk to match that of DG Tau may result in a significant drop.



Comparison in Stokes space of Tamura et al. (1999) 850μm measurement (red) with Krejny et al. (2009) 350μm measurement (blue). Circles show 1 and 2σ errorbars. The yellow region denotes the locus of points that correspond to polarization orientated orthogonally to the plane of the disk (within PA errors). The 350μm measurement is consistent with zero, suggesting that there is a drop in polarization from 850 to 350 μm.



Comparison on Cho & Lazarian model with SMA 340 GHz observations of TW Hya (Hughes et al. 2009). Top row: left, model prediction, center, simulated model observation using SMA, right, actual SMA observation. Middle row is model predictions for Stokes I,Q,U and V, while bottom row is corresponding SMA observations.

Hughes et al. (2009) obtained resolved polarimetric images of a TTS disk. However, the polarization observed did not match that predicted by the Cho & Lazarian model. Numerous explanations were made to explain the discrepancy, including a random magnetic field, contributions to polarization from scattered light, a change in the grain size distribution, and a non-perfect alignment efficiency.

Polarimetry with SOFIA

Mid/Far-IR polarimetry using SOFIA can be used to answer the following questions:

- Are TTS disks polarized? What about Class 0 and Class 1 young stellar objects?
- If the disks are polarized, what is the orientation of the magnetic field?
- What corrections need to be made to the model?
- Can the Mid/Far-IR polarization spectrum tell us about the grain size distribution, and how large the grains grow?

References

Cho & Lazarian 2007, ApJ, 669, 1085

Hughes et al. 2009, ApJ, 704, 1204

Krejny et al. 2009, ApJ, 705, 717

Rodmann et al. 2006, A&A 446, 211–221

Tamura et al. 1999, ApJ, 525, 832