KINEMATICS OF DISKS AROUND T TAURI STARS

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1. Introduction

The presence of circumstellar disks around T Tauri stars ('TTs') is strongly supported by narrow- and broad-band spectroscopic evidence at many wavelengths (cf. Sargent 1995). Spatially resolved observations of the associated velocity field are needed to establish whether or not the circumstellar material is centrifugally supported and available to planet formation. Past studies relied on averaged presentations of the data such as rotation curves or Position-Velocity diagrams and often led to ambiguous or conflicting interpretations. Synthetic spectral line maps generated by a kinematic model provide a more precise identification of the circumstellar velocity field, as illustrated by modeling of rotating disks around the TTs GM Aurigae (Koerner *et al.*, 1993) and the T-Tauri multiple system GG Tauri (Dutrey *et al.*, 1994). To adequately study younger stars, a radial velocity component must be added to such a model and parametrized in a physically appropriate way.

2, Synthetic Spectral Line Maps

Synthetic maps of a disk inclined 45° illustrate the expected contrast for Keplerian rotation and free fall in Fig. la and 1 b, respectively. Patterns are similar at velocities which differ by a factor of $\sqrt{2}$, with infall patterns at right angles to their rotational counterparts. Since the principal difference lies in the orientation of patterns with respect to the disk, the disk orientation must be well identified to distinguish between kinematic states. To potentially aid kinematic analysis of disk-like structures with rotation *and*

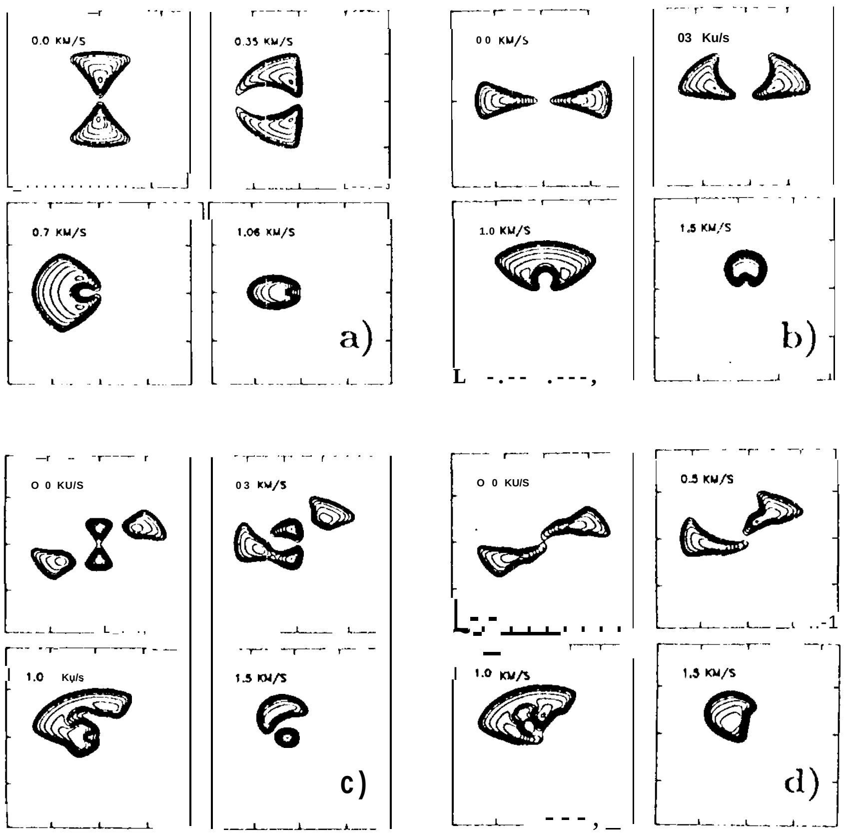

Figure 1. Synthetic Spectral **Line Maps from a disk of** gas with **velocity strut** tures **given by: (a) Keplerian rotation, (b) free** fall, **(c) combined disk/envelope, and (d)** an inviscid **outer region. Maps** are **at velocities which correspond to the c** enter, **inner** slope, **peak,** and **outer slope of one half of the corresponding** double-peaked **spectral** line.

infall, synthetic maps from two hybrid models are displayed in Fig. 1c and 1d. Fig. 1c illustrates a flat infall envelope surrounding a region of centrifugal support; a pattern discontinuity occurs at the radius where the infalling gas meets a shock boundary of the accretion disk. In Fig. 1d, the velocity field of the outer disk is that derived by Stabler *et al.*, (1994) for an inviscid disk formed during collapse of a uniformly rotating molecular cloud. The radial momentum of infalling gas is largely conserved in the outer disk and gradually decreases to zero with approach to a critical radius; no break occurs in the corresponding patterns.

3. Kinematic Evolution of T-Tauri Disks

The need to consider both radial and tangential velocity components in kinematic analyses of T-Tauri disks is reinforced by detection of a strong contribution from infalling gas to small-scale CO emission from HL Tauri (Hayashi *et* al., 1993; Sargent&Koerner,1995), although recent HST observations indicate it is embedded (Stapelfeldt *et* al., 1995). Images of circumstellar gas around the TTs RY Tau, DL Tau, DO Tau, and AS209 reveal smaller disks ($R \sim 100$ AU) which appear to be centrifugally supported (Koerner & Sargent, 1995) with some infall around the youngest object (Koerner, 1994). The older TTs, GM Aur, exhibits Keplerian rotation in a somewhat larger disk (Koerner *et* al., 1993). Consideration of this small sample suggests that young low-mass stars undergo the following stages in the transition from an embedded to T-Tauri phase: 1. "Flat spectrum" sources are surrounded by large (1 000 AU) disks dominated by an in falling velocity component with an inner circular Keplerian region. The outer disk is plausibly represented by Fig. 1d; R_C expands rapidly in the late stages of infall, since accreting material arrives with progessively greater angular momentum ($R_C \propto t^3$), but, this newly accreted material is not necessarily on *circular* Keplerian orbits. 11. Young T-Tauri stars have smaller disks dominated by Keplerian rotation, but are still surrounded by a remnant of dynamically accreting gas. 111, Dynamic infall ceases altogether, but viscous transport of angular momentum drives continued expansion of the disk. Although the stages suggested here are generally accepted in some form, the classification of late embedded objects and TTs within this scheme remains uncertain until detailed kinematic modeling of high-resolution observations can be carried out for a larger sample,

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