CONSTRAINTS ON ACCRETION DISK LIFETIMES: METHODOLOGY AND RESULTS

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INTRODUCTION

It is common belief that circumstellar disks appear near-ubiquitously around stars at birth. These disks are the sites of planetary formation, and with detection of extra-solar planets now occurring routinely, understanding of the evolutionary link between young circumstellar disks and planets is more critical than ever. Dimunition of accretion disk activity and transition from optically thick accretion disks to optically thin post-planet-building disks occurs during the early pre-main sequence phase. Observationally, we have yet to place solid quantitative constraints on accretion disk lifetimes as a function of stellar mass.

METHODOLOGY

Constraining disk lifetimes means measuring infrared excesses and stellar ages and masses for large samples of young stellar objects.

Infrared excesses:

- A combination of stellar irradiative and viscous heating in circumstellar disks produces flux excesses at micro-meter $\rightarrow$ milli-meter wavelengths.
- The magnitude of the infrared excess depends on:
  - stellar parameters: M_* and R_*
  - disk parameters: $\dot{M}_{acc}$, inc, and $\mathrm{R}_{inner\ hole}$
- Measuring an infrared excess entails taking the observed flux and correcting it for:
  - interstellar/circumstellar extinction
  - contribution of the stellar photosphere

Stellar Ages/Masses:

- "Measuring" a stellar age/mass requires combining theory with observations
- Pre-main sequence evolutionary theory is uncertain due to our incomplete understanding of:
  - convection
  - opacities
  - stellar atmospheres
  - initial mass-radius relationship
- Deriving an age/mass from observations requires locating a star on the theoretical HR diagram, by converting a spectral type into an effective temperature and a color/magnitude into a reddening corrected luminosity.

Despite the uncertainties in calculating both infrared excesses and stellar ages/masses, if sample sizes are large enough, relative comparisons may be meaningful.

In this poster we attempt to identify any trends with stellar age or stellar mass in the presence/absence of circumstellar accretion disks using data from the literature.

SAMPLE

We consider star-forming regions closer than $\sim$800 pc with the following data for >20 stars:

- spectral types
  $\Rightarrow$ log $\mathrm{T}_{eff}/\mathrm{K}$
- optical/infrared photometry
  $\Rightarrow$ A_V and log $\mathrm{L}/\mathrm{L}_\odot$
- H- and K-band photometry
  $$\Rightarrow \Delta(H-K) = (H-K)_{observed}$$
  $$-(H-K)_{reddening} - (H-K)_{photosphere}$$

The parameters derived from the data are: stellar ages, stellar masses, and near-infrared excesses.

Our sample consists of ~ 2500 stars found in:

- Taurus
- Ophuichus
- Lupus
- Chamaeleon
- IC 348
- Orion Nebula Cluster
- L 1641
- NGC 2024
- Mon R2
- NGC 2264

and also contains young stars associated with:

- TW Hyd
- Upper Sco
- Alpha Per
- Pleiades

RESULTS

Correlations of near-infrared excess with stellar age and stellar mass are less tight than one might hope. This indicates perhaps that these data are not characterized by smooth functions, and hence that there are large dispersions in circumstellar disk lifetimes as a function of stellar mass.

However, one must be cautious about the sensitivity of an infrared excess diagnostic as a function of stellar age and mass: it is more difficult to detect infrared exesses around young stars and around lower-mass stars due to contrast effects.

We also note that our sample is wrought with selection effects:

- stars often are picked out as members of clusters *because* they show the observational signatures of having accretion disks
- cluster surveys are incomplete at the low-mass end
- we do not have good samples of 5-30 Myr old stars!!!

WHAT HAVE WE LEARNED?

It has been clear for some time (Strom et al., 1989; Skrutskie et al., 1990; Beckwith et al., 1990; Wolk & Walter, 1996; Allen, 1996) that there are rather young (<1 Myr) stars which already have lost their disks, and also rather old (∼10 Myr) stars which still retain their disks.

It also has been clear for some time that stars of the same age and/or mass have large ranges in accretion rate (Valenti et al., 1993; Hartigan et al., 1995; Gullbring et al., 1998; Hartmann et al., 1999).

Our analysis of near-infrared excess trends
with stellar age and stellar mass
supports a conclusion of large dispersions
in disk accretion rates and disk lifetimes.

Nevertheless, a declining trend
of disk fraction with age is suggested.

THE FUTURE

2MASS, SOFIA, and SIRTF have the potential to contribute greatly to the problem of circumstellar disk lifetimes as a function of stellar mass.

In order to make the best use of their capabilities, we need:

- HR diagram locations for large samples of stars in the 5-30 Myr age range.
- tests of the accuracy of pre-main sequence evolutionary tracks and isochrones

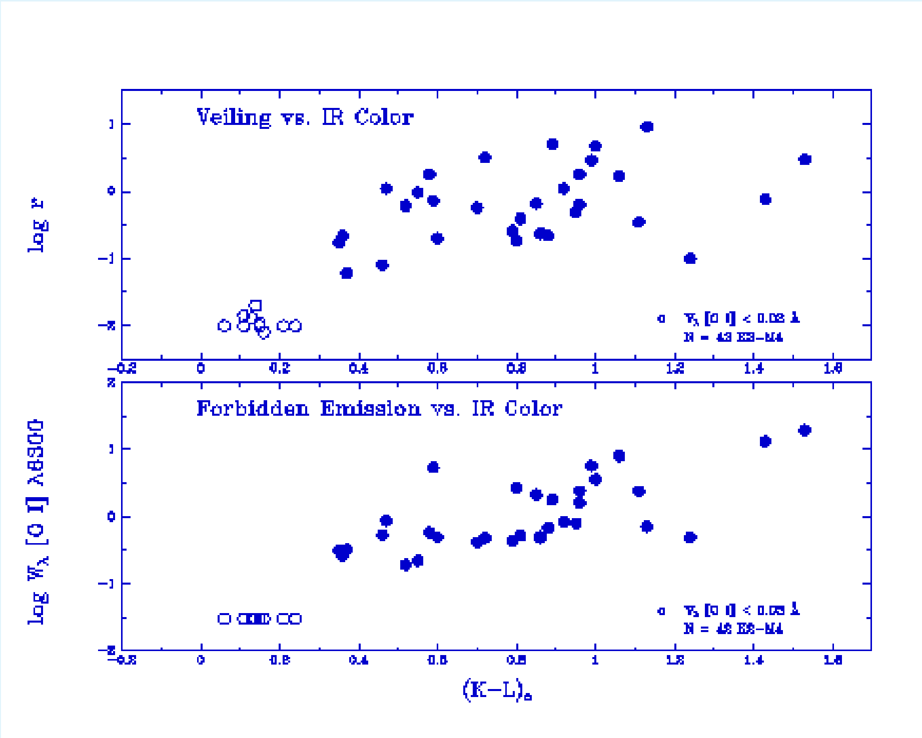

Fig. 1.— Correlation between presence of a near-infrared excess and presence of diagnostics of accretion directly onto the star. These plots show the optical continuum emission ("veiling", expressed as r, the ratio of veiling to photospheric flux at 5500 $\AA$) and equivalent width of the strongest forbidden emission line, [OI] 6300, against the reddening corrected (K - L) color index for 42 K and M T-Tauri stars, from Edwards (1995).

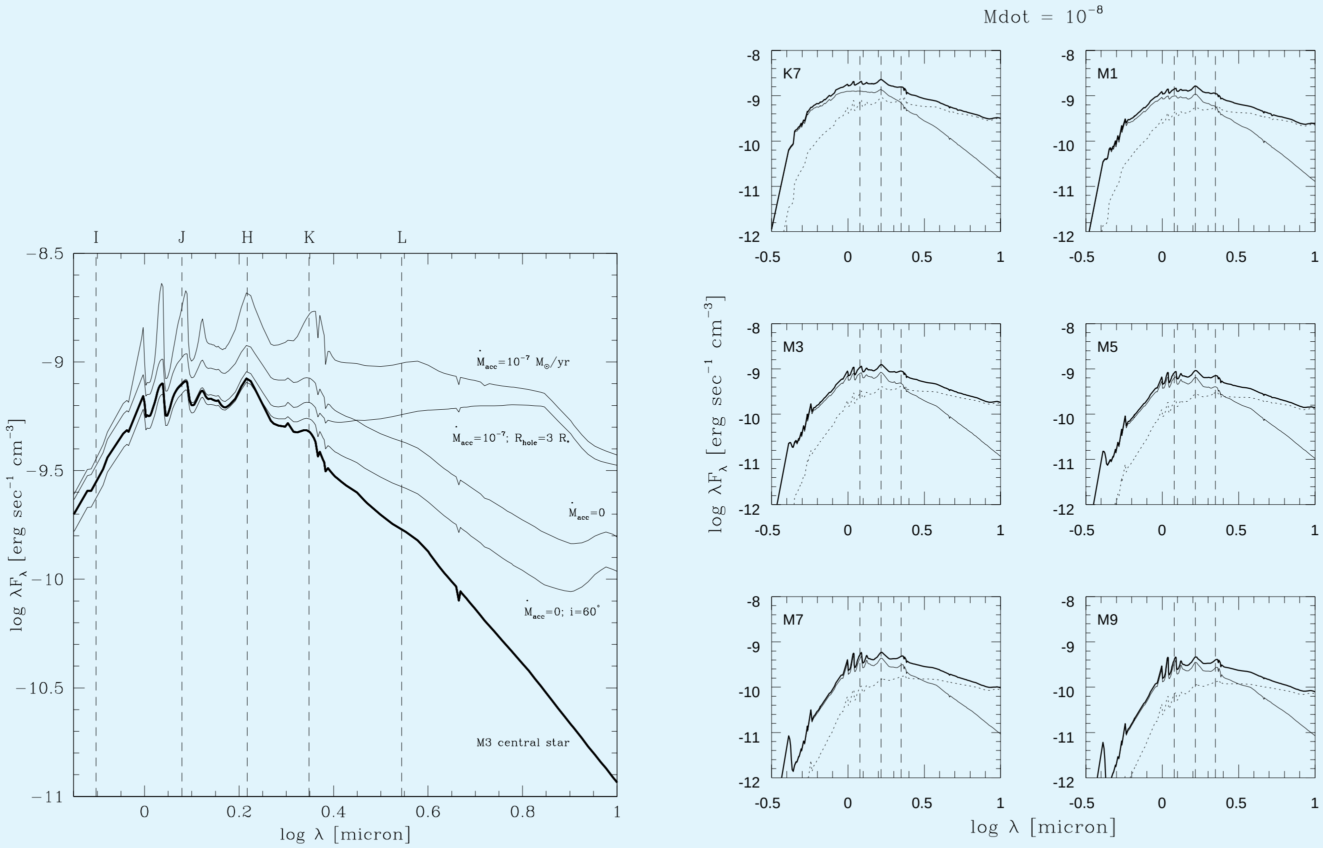

Fig. 2.— Spectral energy distributions for various star/disk combinations, using the models of Calvet et al. The heavy solid line represents the spectral energy distribution of an un-reddened star while the light solid lines indicate the total spectral energy distributions expected when the star is surrounded by an irradiation + accretion disk. *Left panel:* Disks of various accretion, inner disk hole, and inclination properties. Compared to the non-accreting no-hole pole-on disk, inclined disks reduce the magnitude of the infrared excess at all wavelengths, while inner disk holes reduce the infrared excess at short near-infrared wavelengths only, and accreting disks increase the magnitude of the infrared excess modulo the strong absorption bands which appear at higher accretion rates. *Right panel:* Stars of various spectral type, all surrounded by a $10^{-8}\ M_\odot\ yr^{-1}$, no-hole, pole-on disk. The magnitude of the infrared excess decreases with decreasing spectral type/temperature/mass. Not shown is a similar trend of decreasing infrared excess towards larger/younger stars of given mass. Deciding whether or not a near-infrared excess is present requires accounting for the temperature/mass and radius/age of the star. Even at fixed temperature/mass or radius/age, one must also account for sensitivity to disks of various accretion, inclination, and inner disk hole properties.

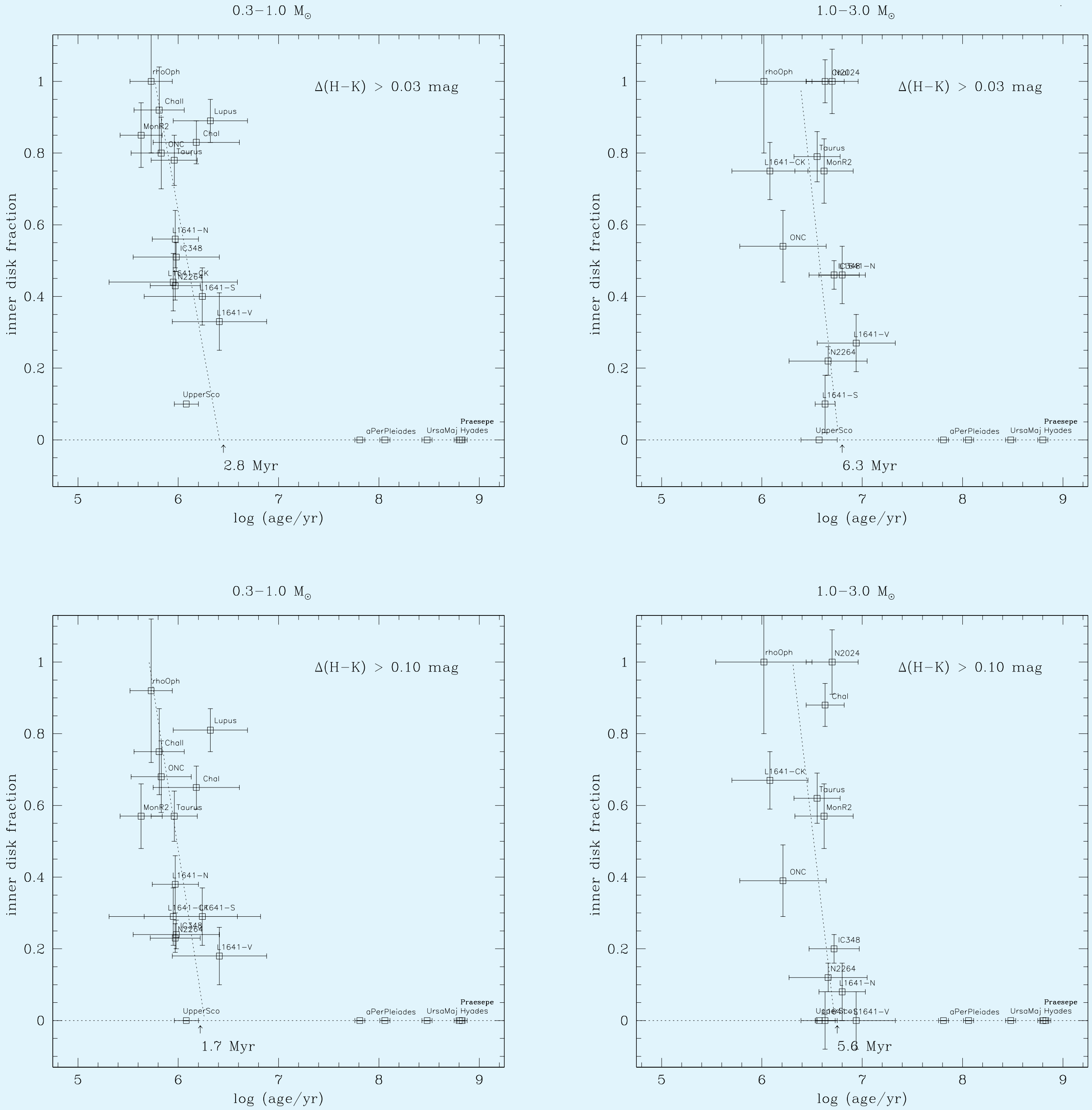

Fig. 3.— Fraction of stars in each cluster showing disks, as a function of cluster age. Top panels use a cut of Δ(H-K) > 0.03 mag to define a disk while bottom panels use Δ(H-K) > 0.1 mag. Left panels show stars 0.3-1.0$M_\odot$; right panels show stars 1.0-3.0$M_\odot$. The apparently longer disk lifetimes for higher mass stars probably reflects the fact that the tracks used in this analysis (D'Antona & Mazzitelli, 1997/1998) have not been corrected for the effects of the stellar birthline (Palla & Stahler, 1993). Note that different tracks (e.g. Baraffe et al. 1998, Burrows et al. 1997) may give different ages; thus the absolute ages are considered highly uncertain. Nevertheless, for low-mass stars disk lifetimes appear to be only a few Myr in the mean.

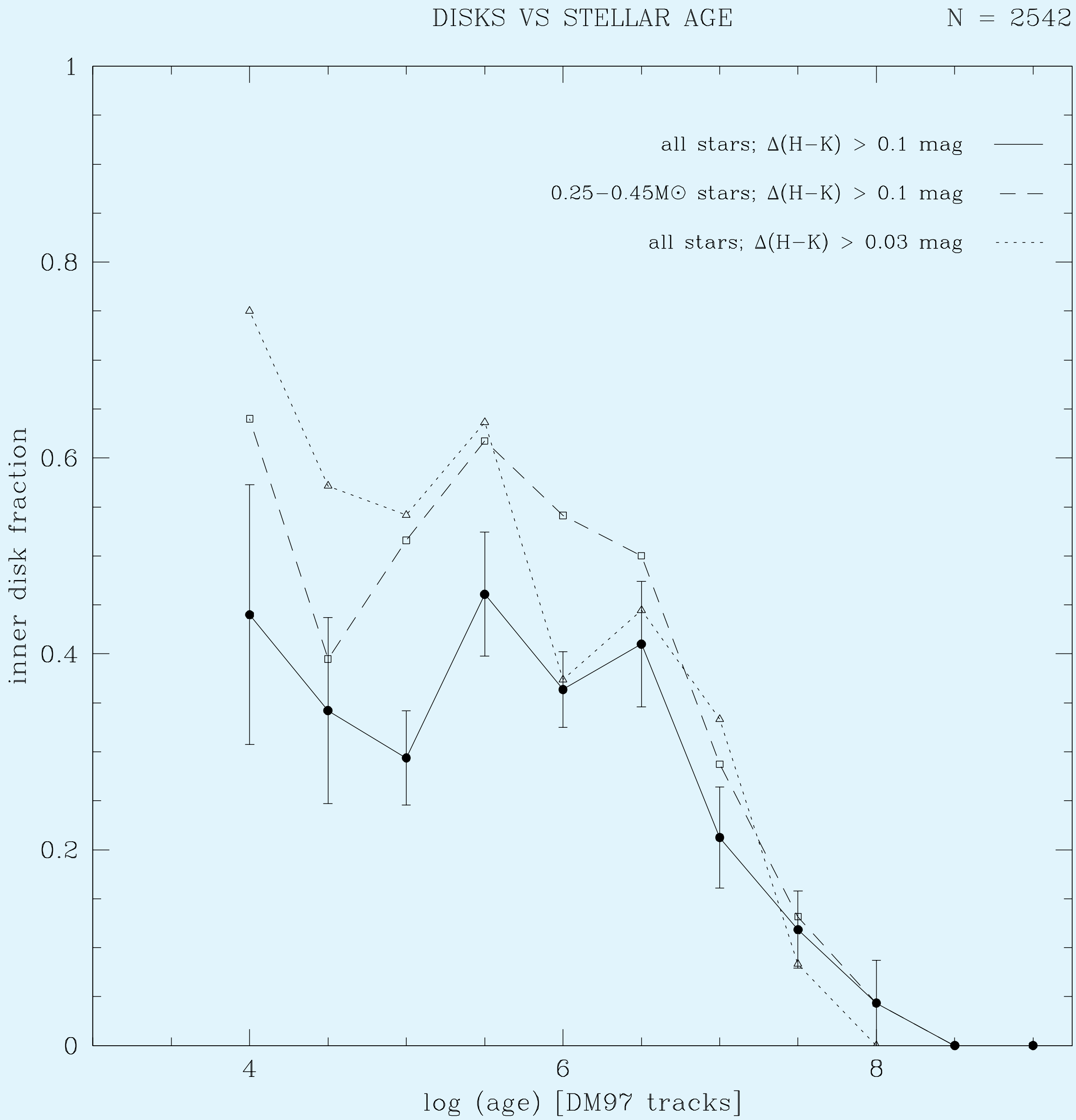

Fig. 4.— Inner disk fraction vs stellar age for all stars in near-by star-forming regions located on the HR diagram and having H-K photometry. The dashed line uses a cut of Δ(H-K) > 0.03 mag to define a disk while the solid line uses Δ(H-K) > 0.1 mag. Dotted line indicates a restricted range of masses around the peak of the mass function.