

# The Association of Dust Disks and Planets

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## Abstract

We propose to continue a successful search for planetary-mass companions to stars younger than the Sun. Planet searches to date typically have targetted older stars which are expected to have lower photospheric activity. Recent work, however, has demonstrated that it is possible to monitor activity-induced “velocity jitter” via the Ca II H&K emission lines and specific absorption line profiles, and correct for the “jitter” in order to derive radial velocity curves sensitive to Jupiter- and Saturn-mass planetary companions. Our targets are drawn from a sample of stars being observed with Spitzer from 3.5-70  $\mu\text{m}$  and for which detailed information on dust disks will be available within 1 year. The young stars in our sample could have dusty disks that may have recently spawned planets, and the older stars could have dust disks that are caused by, and shaped by, existing planets. The evolution of disks and planets are inexorably connected. Our proposed observations will, in concert with the Spitzer data, provide the first direct assessment of the association of dust disks and planets.

## Science Case

### Disks and Planets

Raw material for building planetary embryos, earth-like rocks, and even gas giant planets is abundant in circumstellar disks surrounding newborn stars. At older ages, observations of rejuvenated “debris” disks around nearby main sequence stars, along with studies of the zodiacal dust and Kuiper belt in our own Solar System, have suggested a close relationship between disks and planetary systems. The FEPS Spitzer/Legacy program (Meyer et al., 2002) will carry out sensitive observations from 3.5-70  $\mu\text{m}$  of nearby solar-type stars. We target the 3 Myr—3 Gyr age range and will measure the properties and time scales of both primordial planet-building disks and secondary debris disks, establishing an evolutionary sequence to ages just younger than the Sun. We will detect dust masses as low as that inferred for our own present-day Kuiper Belt ( $6 \times 10^{22}$  g), surrounding stars within 30 pc, with sensitivity decreasing to the most distant targets at 150 pc.

The few disks for which spatially resolved information exists are asymmetric – radially, azimuthally, or both. Such intriguing morphology is often attributed to dynamical response of the disk to an embedded planet. Holes, gaps, truncated edges, and warps are consistent with planet-disk interactions (e.g., Calvet et al. 2002; Wolf et al. 2002; Ozernoy et al. 2001; Telesco et al. 2001). Indeed, our zodiacal dust disk exhibits clear signatures in IRAS and COBE data of gravitational effects induced by the planets, including: (1) a warp in the zodiacal cloud caused by differing orbital tilts of the planets; (2) displacement of the Sun from the center of the zodiacal disk, due to planetary orbital eccentricities; (3) bands of dust caused by collisions between large asteroids, stirred from circular orbits by gravitational interactions with planets; and (4) localized regions of dust produced by trapping of particles in resonances (e.g. Reach et al. 1995; Wyatt et al. 1999; Liou & Zook, 1999). Our Spitzer/Legacy team is currently developing a suite of models for comparison with our data that simulate observable effects of planets on disks (see, e.g. Moro-Martin & Malhotra, 2004, 2003, 2002; Backman et al. 2004; Wolf & Hillenbrand, 2003).

Our goal with this proposal is to continue a recently initiated observing program to test these forthcoming predictions based on Spitzer data by searching for the planets themselves. More than 120 extrasolar planets have been discovered to date. Measured masses and orbits constrain the physics of the disks in which they formed and the dynamical evolution (i.e. orbital migration and planet-disk interactions; e.g., Lin et al., 2000; Kley, 2000; and Ward & Hahn, 2000) at early stages. Important emerging properties of known extrasolar planets include: (1) near-uniform distribution with orbital distance ( $dN/d\log a \sim \text{const}$ ); (2) rising mass distribution ( $dN/dM \propto M^{-0.7}$ ); (3) prevalence of eccentric orbits ( $\langle e \rangle = 0.34$ , for  $a=0.2-3.5$  AU); (4) “hot jupiters” (giant planets within  $<0.1$  AU of 0.8% of all FGKM stars); (5) giant planets in a range of more distant orbits around 8-15% of all FGKM stars; and (6) commonality of multiple planets, often in resonances.

To date however, there has not been any empirical study of dust disks *and* planets around the same stars. We initiated just such a systematic investigation during 2002B and propose to continue it here. Our Spitzer/Legacy observations will be sensitive to gaps and holes in the disks located between 0.3–40 AU, likely caused by planets at those orbital radii.

### A Planet Search around Young Stars

The existing Doppler planet surveys (e.g. Marcy, Cochran, & Mayor 2000, Marcy & Butler 2000) have, thusfar, specifically targetted stars (see source list in Nidever et al., 2002) that are *older* than 3 Gyr. The only exception is a survey of 0.6 Gyr Hyades members (Cochran et al. 2002). The

younger stars can pose a challenge to precision Doppler work due to the enhanced starspot and plage magnetic activity of their photospheres that causes a velocity “jitter”, acting as noise in the Doppler measurements. For FGK stars there is decreasing jitter towards later spectral types (e.g. Santos et al. 2000) with amplitude 10–30 m s<sup>-1</sup> for stars of age 0.1–1 Gyr (e.g. Figure 2 of Paulson et al. 2004). Recall that our Spitzer/Legacy sample is 0.03–3 Gyr.

However, corrections for velocity jitter are possible. As demonstrated by Saar et al. (1998, 2000) velocity shifts can be correlated with spectroscopic activity indicators. At least 3 previously announced planets (HD 166435b, HD 192263b, and HD 19632b, all by the Swiss group) have been retracted due to later discovery of unaccounted for radial velocity and activity correlations (Queloz et al. 2001, Henry et al. 2002; Butler et al. 2004). Simultaneous monitoring of the chromospheric CaII H&K emission lines is the key, enabling jitter reduction to  $\sim 5$  m s<sup>-1</sup>. This precision allows detection of Jupiter-mass planets at 5 AU, and Saturn-mass planets within 1 AU, making planet detection nearly as robust for these middle-age 0.1–3 Gyr stars as it is for the older  $> 3$  Gyr stars.

### Proposed Measurements and Source List

We have adopted the Doppler technique used by Marcy et al. that is proven successful with Keck/HIRES. In addition to the radial velocity measurement itself, we obtain simultaneous measures of the CaII H&K core emission and monitor asymmetries and ratios of absorption lines (Hamilton & Lester 1999), both for velocity jitter correction. The jitter de-correlation algorithms have been under development for some time and are reaching a stage of maturity. Our data are their first major application. With them we will obtain precision of 5 m s<sup>-1</sup> for all stars, thus rendering our Doppler measurements photon-limited in precision.

We are searching for planets around 100 of the targets from our Spitzer/Legacy program (see age distribution in Figure 1). These stars have masses 0.7 - 1.4 M<sub>⊙</sub>, and V = 7 - 12 mag, ideal for Doppler planet searches with Keck. We have chosen stars  $> -30^\circ$  declination, d < 50 pc, SpT > F6, age > 80 Myr, and no companions within 2” based on our Palomar/PALAO survey (Metchev et al.). For our average star (V = 10), a 10 min exposure is needed; simultaneous CCD readout and telescope slewing takes 70 sec. Since initiation of this program we have obtained with HIRES over 10 observing nights, 5-8 spectra of each star and also “template” (no iodine cell in the beam) spectra for some portion of the sample which serve as the reference against which Doppler shifts are measured and the data on which spectral synthesis is performed (leading to accurate values of T<sub>eff</sub>, log g, vsini, [Fe/H] and other abundances). Figure 2 shows radial velocity curves obtained to date for a representative sample of our targets. At present the most critical need is for the remaining template spectra (December/January visibility). With them, at any given time *t* the presence of planets with periods < *t* can be assessed. Longer baseline observations are needed to sense planets orbiting farther from their host star, with a 10-year baseline required to detect planets at  $\sim 5$  AU.

From the known occurrence of giant planets, we expect to discover 10–15 planets from among the 100 “Spitzer” target stars. At least 3 are suspected from the data in hand thusfar. Their masses and orbits will feed directly into disk models designed to explain the Spitzer spectrophotometry.

### Project Plan

This is a semi-long term effort. To achieve maximum efficiency we have recently classified each star based upon our early observations (5-8 Doppler points over  $\sim 1$  year) into one of three categories (see Table below) which then merit different frequencies of continued observation. This strategy ensures efficient use of the Keck telescope.

Early Doppler Classification	Observing Cadence
no variation seen at $\pm 3 \text{ m s}^{-1}$	$\Rightarrow$ once per year
trend, having long time scale ( $\tau > 2 \text{ yr}$ )	$\Rightarrow$ twice per year, to establish long-period orbit
short time scale ( $\tau < 2 \text{ yr}$ ) variations	$\Rightarrow$ as often as possible, until orbit established

We will continue to work closely with Marcy and adopt the Marcy/Butler/Vogt observing technique and reduction pipeline. With that pipeline, we reduce all Doppler results during the morning, immediately after each Keck night. All velocities are available within 24 hours of the acquisition of the observations. We also adopt the Marcy et al. software for sensing the emergent Keplerian velocity variations and performing the Keplerian fitting, as well as the Fischer & Valenti spectral synthesis analysis.

The P.I. of the Spitzer/Legacy project is Michael Meyer. Pasadena-based members of this Spitzer/Legacy team include John Carpenter, John Stauffer, and Deborah Padgett.

**SUMMARY: To continue our survey of  $\sim 100$  young stars for Jupiter- and Saturn-mass analogs within 5 AU we request 2-4 nights on Keck I with HIRES.**

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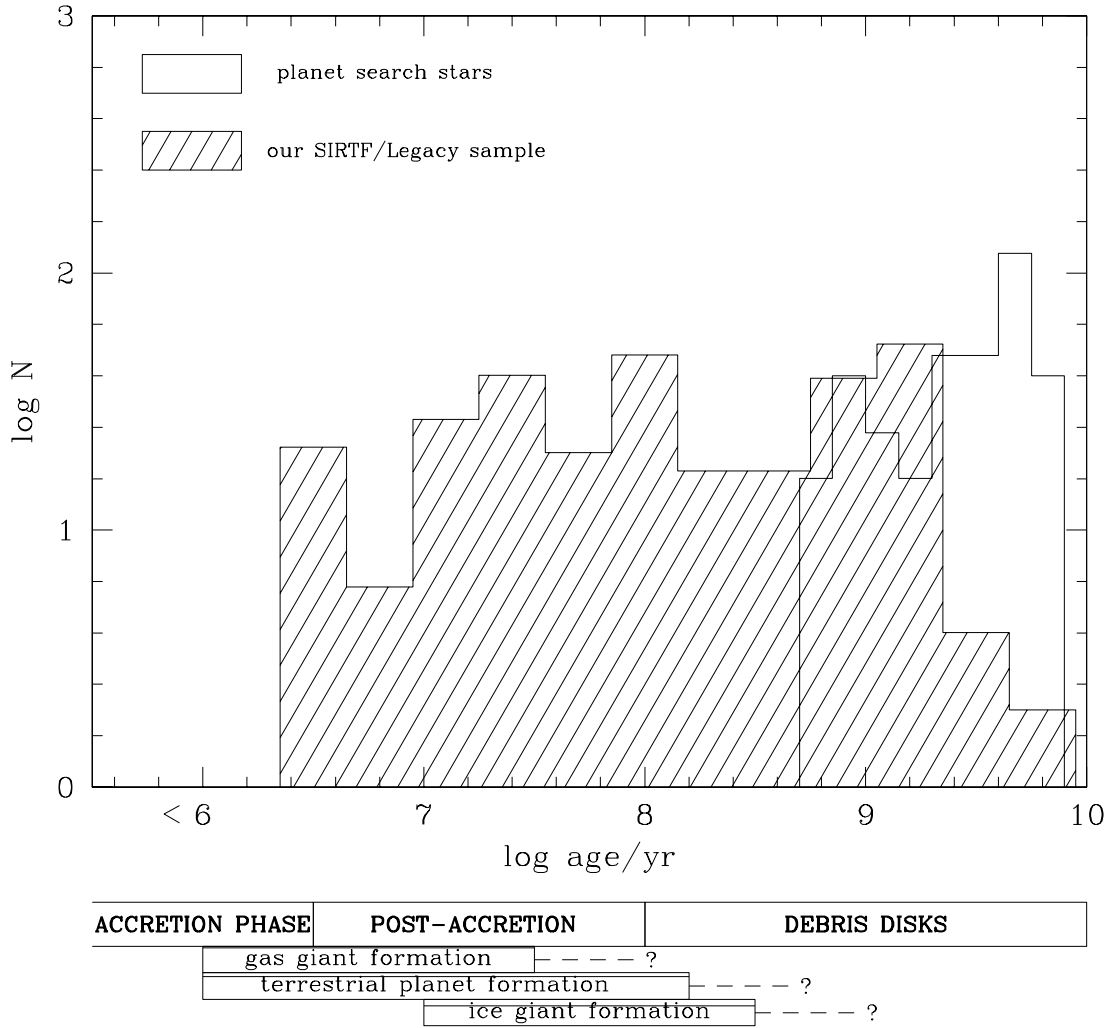
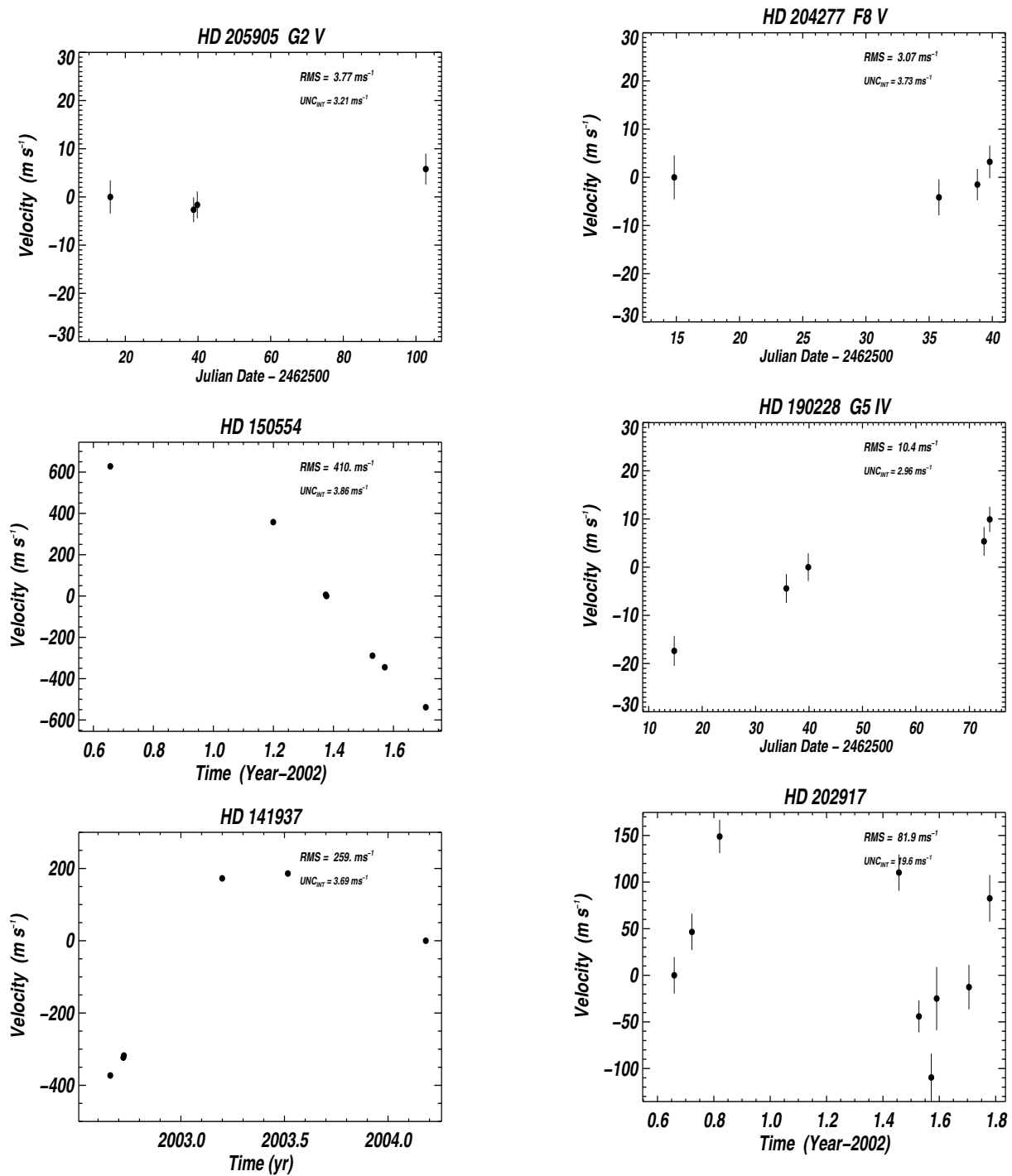


Figure 1: Distribution of ages for the FEPS Spitzer/Legacy sample (hatched histogram) compared to current planet search targets (open histogram), whose mean age is 4.5 Gyr with a  $1\sigma$  spread of 2 Gyr. The search conducted under the auspices of this proposal focusses on those objects from the FEPS sample with ages  $>80$  Myr. Recent work has demonstrated that it is possible to correct for activity-induced “velocity jitter” in these younger stars and hence derive radial velocity curves sensitive to planetary-mass companions as have been found surrounding 8-15% of the older stars.



**Figure 2:** Data for representative stars from the FEPS planet search illustrating the various types of radial velocity signatures seen thusfar. *Top panels:* Constant or very low-amplitude variables, constituting approximately 75% of the sample. *Middle panels:* A steady decline and a steady rise, both with potential flattening. *Bottom panels:* Likely planetary companions. The latter two categories of radial velocity variables constitute about 25% of the sample.