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The Search for Young Planetary Systems

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Abstract. The Space Interferometer Mission (SIM) will provide a census of planetary systems by conducting a broad survey of 2,000 stars that will be sensitive to the presence of planets with masses as small as ∼15 Earth masses (1 Uranus mass) and a deep survey of ∼250 of the nearest stars with a mass limit of ∼3 Earth masses. The broad survey will include stars spanning a wide range of ages, spectral types, metallicity, and other important parameters. Within this larger context, the Young Stars and Planets Key Project will study ∼200 stars with ages from 1 Myr to 100 Myr to understand the formation and dynamical evolution of gas giant planets.

1. Introduction

More than 50 objects of apparently Jovian mass have been located via radial velocity (RV) studies orbiting within a few AU of a significant fraction (5-7%) of solar type stars (Marcy and Butler 2000). While the unknown inclination affects the RV determination of the true mass in all but a few cases, the most likely interpretation of these results is that most of these objects are gas giant planets. Are such systems rare or common? How did these massive planets get to their close-in orbital locations if they formed, as theory suggests, at or beyond the snow-ice condensation line? What is the origin of the large eccentricities seen in most of the planets found to date? What is the true distribution of orbital parameters and how do these evolve with age? What are the processes of planetary formation and dynamical evolution that lead to these distributions? Do planets of a few Earth masses exist around the closest stars? These are some of the basic questions that the Space Interferometer Mission (SIM) will address when it is launched around 2009. In this talk I briefly describe SIM's goals for planet detection with a more detailed focus on the Key Project to search for planets around young stars.

2. A Comprehensive Search for Planets

In its narrow-angle observing mode SIM will be able to detect astrometric signals with a Single Measurement Accuracy of 1 μas (1σ) in a "deep" integration and 4 μas in a quick "survey" mode (Unwin, Turyshev, and Shao 1998). For reference, a Jupiter orbiting 5.2 AU away from a solar type star 10 pc away produces an astrometric signal of 500 μas, an Earth orbiting the same star at 1 AU a 0.3

μas signal, and a Jupiter in a 5.2 AU orbit around a star 140 pc away a 35 μas signal. Simulations by Brown, Sozzetti, and Casertano (1999) suggest that the reliable detection of one or more planets of unknown orbital parameters requires approximately 50 measurements on each of two orthogonal axes spread over a mission duration of 5 years. The planetary signal must be detected at the 2σ level in each measurement for reliable characterization.

With these measurement capabilities and requirements in mind, the three SIM Key Project Science Teams chosen by NASA to search for planets (Tables 1 and 2) have developed an integrated plan to advance our understanding of formation and evolution of planets as well as to make a detailed examination of our closest neighbors for Earth-like planets.

Table 1. *Planet Detection Key Projects*

Key Project	Principal Investigator	Institution
Young Stars and Planets	C. Beichman	JPL
Discovery of Planetary Systems	G. Marcy	UC, Berkeley
Extrasolar Planets Interferometric Survey	M. Shao	JPL

Table 2. *Young Stars and Planets Science Team*

Name	Institution	Name	Institution
Beichman, C.	JPL	Mathieu, R.	U. Wisc.
Baraffe, I.	U. Nancy	Norman, D.	SUNY
Boden, A.	JPL/IPAC	Prato, L.	UCLA
Carpenter, J.	CIT	Shao, M.	JPL
Ghez, A.	UCLA	Simon, M.	SUNY
Hartmann, L.	CfA	Stapelfeldt, K.	JPL
Herbst, W.	Weslyan	Stauffer, J.	IPAC
Hillenbrand, L.	CIT	Strom, S.	NOAO
Kulkarni, S.	CIT	Velusamy, T.	JPL
Lin, D.	UCSC	Yorke, H.	JPL
Lunine, J.	LPL		

2.1. A Broad Survey of Planets

Are planetary systems like our own, with gas giants on stately circular orbits beyond the condensation line and rocky planets located cozily near to the central star, the rule (Pollack *et al.* 1996) or the exception to the rule? What is the prevalence of planets around stars not like the Sun? To address these questions SIM will conduct an exhaustive census of planetary systems at the 4 μas level, examining the full variety of spectral types, ages and metallicity. By carrying out a broad survey of approximately 2,000 stars to levels of a Uranus mass (15 Earth masses) over a wide range of stellar properties (age, metallicity, spectral type) and orbital locations, SIM will enable detailed theoretical investigations of the formation, migration and evolution of planets (Lin and Papaloizou 1986;

Lin *et al.* 2000) from ages of 1 Myr to over 5 Gyr. As described below, the SIM Young Stars and Planets program will focus on observations of about 200 T Tauri and other young stars with ages from 1 Myr (Taurus) to over 70 Myr (Pleiades).

2.2. The Search for Earth-like Planets

The second major goal for SIM's planet detection program is to characterize the solar systems that may exist around the closest ~250 stars, i.e. within 5-10 pc. By observing down to SIM's limiting astrometric sensitivity and by concentrating on the closest stars, SIM will be able to find planets with masses as small as a few (3-10) Earth masses. Achieving this mass limit is important for two reasons. First, it is thought that planets smaller than about 10 Earth masses are rocky objects that form in a different manner than the gas giants. SIM's measurement of the number and distribution of orbital parameters of "terrestrial" planets will advance our understanding of their origin and subsequent evolution. Second, the direct detection and physical characterization of terrestrial planets, and ultimately of habitable planets, is a fundamental goal of NASA's Origins program in general and of the Terrestrial Planter Finder (TPF) mission in particular (Beichman *et al.* 1999). SIM's observations will help identify which systems TPF should look at and which it might avoid in a search for habitable planets. Further, SIM data will be usable in determining the masses of planets detected by TPF to the level of an Earth mass or less for planets whose existence and preliminary orbital parameters are determined independently by TPF.

For both the broad survey and the deep search it must be emphasized that only SIM's dynamical measurements will yield unambiguously that most fundamental property of a planet, *its mass.*

3. The SIM Young Stars and Planets Project

The SIM Young Stars and Planets Project will investigate both the frequency of giant planet formation and the early dynamical history of planetary systems. We will gain a deep insight into how common is the basic architecture of our solar system compared with recently discovered systems with close-in giant planets. This project has two main goals. The bulk of the program is a planet search around 200 of the nearest (<150 pc) and youngest (1-100 Myr) solar-type stars. The sensitivity of the survey for stars located 140 pc away is shown in the planet mass-separation plane (Figure 1).

We expect to find anywhere from 10 (assuming that only the presently known fraction of stars, 5-7%, has planets) to 200 (all young stars have planets) planetary systems. We have set our sensitivity threshold to ensure the detection of Jupiter-mass planets in the critical orbital range of 1 to 5 AU. These observations, when combined with the results of planetary searches of mature stars, will allow us to test theories of planetary formation and early solar system evolution. A secondary goal of the program is put our knowledge of stellar evolution on a firmer footing by measuring the distances and orbital properties of ~100 stars precisely enough to determine the masses of single and binary stars to an accuracy of 1%. This information is required to calibrate the pre-main sequence

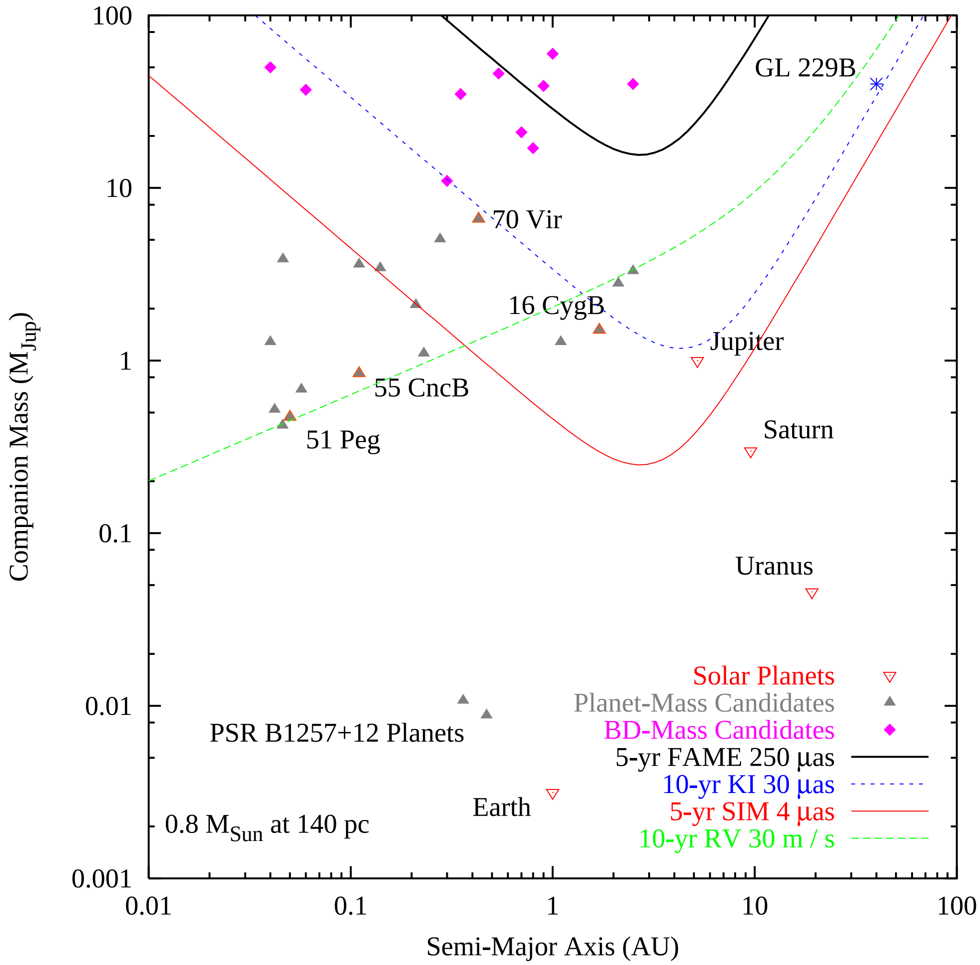

Figure 1. Comparison of our SIM survey, FAME, and the Keck Interferometer for the detection of planets around young stellar objects at a distance of 140 pc. We adopt single measurement accuracies of 4 μas for SIM, 250 μas for FAME (both for 5 yr missions), and 30 μas for the Keck-Interferometer (10 yr mission). We also show the sensitivity to planets for 30 m s^{-1} radial velocity measurements appropriate for young stars (10 yr survey).

Figure 2. Photometric variability due to sunspots can induce shifts in the stellar photocenter that becomes an astrometric noise source. Simulations show that stars more stable than ∼5% will have negligible astrometric jitter compared to the survey limits.

tracks that serve as a chronometer ordering the events that occur during the evolution of young stars and planetary systems.

By searching for planets around pre-main sequence stars carefully selected to span an age range from 1 to 100 Myr, we will learn at what epoch and with what frequency giant planets are found at the water-ice "snowline" where they are expected to form. This will provide insight into the physical mechanisms by which planets form and migrate from their place of birth, and about their survival rate. With these data in hand, we will provide data, for the first time, on such important questions as: What processes affect the formation and dynamical evolution of planets? When and where do planets form? What is initial mass distribution of planetary systems around young stars? How might planets be destroyed? What is the origin of the eccentricity of planetary orbits? What is the origin of the apparent dearth of companion objects between planets and brown dwarfs seen in mature stars?

The observational strategy is a compromise between the desire to extend the planetary mass function as low as possible and the essential need to build up sufficient statistics on planetary occurrence. About half of the sample will be used to address the "where" and "when" of planet formation. We will study classical T Tauri stars (cTTs) which have massive accretion disks and post-accretion, weak-lined T Tauri stars (wTTs). Preliminary estimates suggest the sample will consist of ∼30% cTTs and ∼70% wTTs, driven in part by the difficulty of making accurate astrometric measurements toward objects with strong variability or prominent disks. The second half of the sample will be drawn from the closest, young clusters with ages starting around 5 Myr, to the 10 Myr thought to mark the end of prominent disks, and ending around the 100

Myr age at which theory suggests that the properties of young planetary systems should become indistinguishable from those of mature stars. The properties of the planetary systems found around stars in these later age bins will be used to address the effects of dynamical evolution and planet destruction (Lin et al. 2000).

The sample will consist mostly of stars in well known star- forming regions 125-140 pc away but will also include some stars such as those in the TW Hydrae Association which is only 50 pc away. Only single stars meeting stringent requirements on photospheric stability, lack of nebulosity, and absence of a strong gas disk will be included in the sample. Such stars offer the stable photocenter needed for accurate astrometry (Figure 2). With proper selection, the effect of various astrophysical disturbances can be kept to less than a few μas.

4. Conclusion

SIM's census of planetary systems will address fundamental questions about the properties of planetary systems and the existence of terrestrial planets around the closest stars. The Young Star Key Project will provide the data needed to understand the formation and evolution of solar systems and address whether systems like our own, including at least inhabited planet, are common or rare in the solar neighborhood.

5. Acknowledgements

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