Discovery of Planetary Systems With SIM

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We are witnessing the birth of a new observational science: the discovery and characterization of extrasolar planetary systems. In the past five years, over 70 extrasolar planets have been discovered by precision Doppler surveys, most by members of this SIM team. We are using the data base of information gleaned from our Doppler survey to choose the best targets for a new SIM planet search.

In the same way that our Doppler database now serves SIM, our team will return a reconnaissance database to focus Terresrial Planet Finder (TPF) into a more productive, efficient mission.

Goals

1. Detect terrestrial planets of 1–3 M_{Earth} around stars closer than 8 pc.

2. Detect 3–20 M_{Earth} planets around stars at a distance of 8–30 pc.

3. Determine absolute masses of Doppler-detected planets and search for additional planets

4. Determine the degree of coplanarity in known multiple systems

5. Reconnaissance for TPF

While our proposed science projects assume 1 μas precision, in every case, we have inherent flexibility to select different targets that will accommodate the ultimate operating precision of SIM.

Current Knowledge About Extrasolar Planets

- The level of giant-planet occurrence (0–2 AU): 7%

- The rising nature of the mass function down to current detection threshold (1 M_{SAT})

- Eccentric orbits are common (due to scattering?).
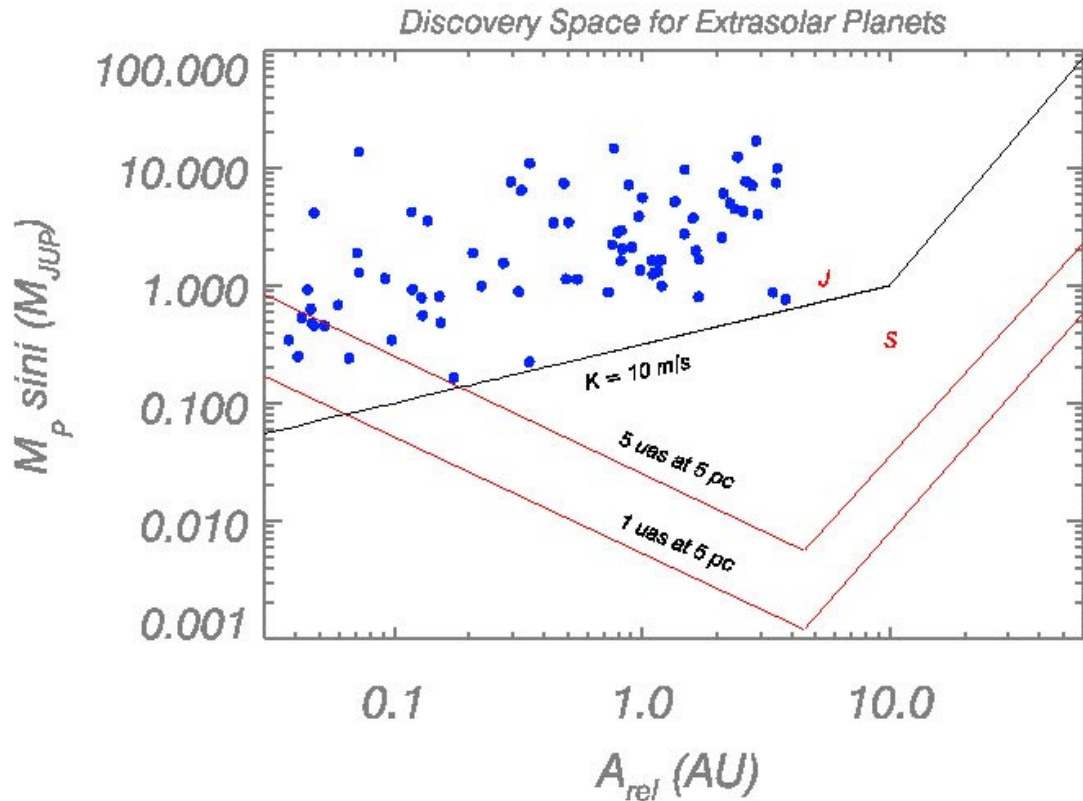
- There exist multiple systems of giant planets.

Figure 1: Detectable Parameters: SIM will detect planets that are 3 M_{Earth} or more massive in the habitable zone around nearby stars. High-precision Doppler work will be used to identify the best SIM targets: stars with habitable zones that could harbor dynamically stable Earths.
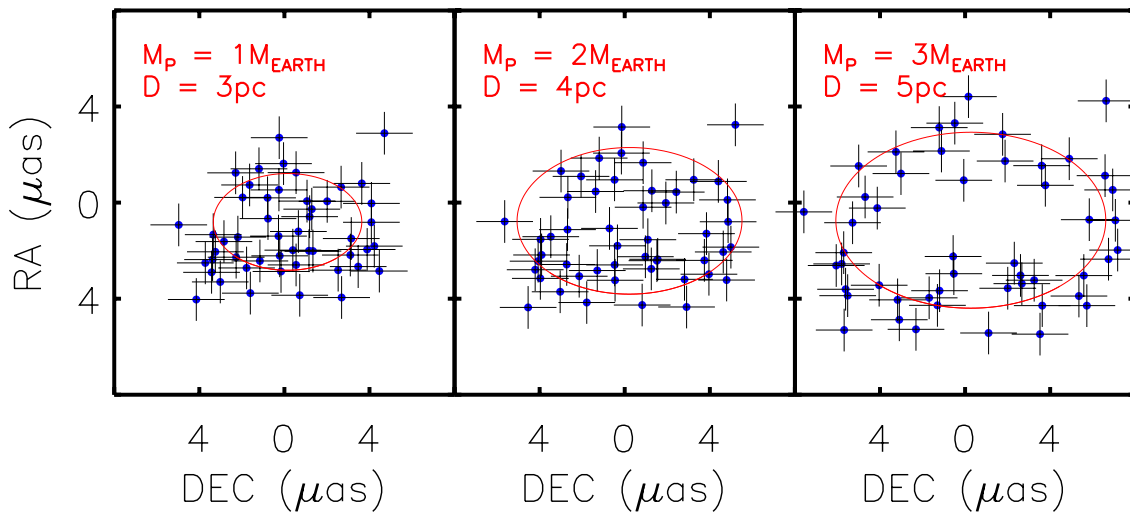

Figure 2: Ultraprecise Planet Search: 1 μas Precision. High-cadence SIM observations of a few well studied, nearby stars could reveal planets of a few earth masses.

Current Ignorance About Extrasolar Planets

- The occurrence rate and mass distribution of terrestrial planets

- The architecture of planetary systems

- Eccentricities of low-mass planets

- The occupancy rate of the habitable zone

Our SIM planet search is designed to answer key questions about the cosmic properties of planets in general. What fraction of stars have planetary systems? How many planets are there in a typical system? What is their distribution of masses and semimajor axes? How common are circular orbits? How commonly do planetary systems have an architecture similar to that of our Solar System?

Properties of planets below 1 M_{SAT} may be estimated speculatively from known higher mass planets by extrapolation, the only estimate available. The rising mass function implies that a significant fraction, perhaps 30–50% of all single stars, will harbor planets of mass, $M = 10$ $M_{Earth} - 1\ M_{SAT}$, detectable by SIM. Indeed, many (most?) will harbor multiple planets in that mass range. Our SIM planet search must be designed to anticipate the astrometric confusion stemming from multiple planets.

In addition, orbital eccentricities are ubiquitous within 2 AU for Jupiter-mass planets. It remains unknown whether terrestrial planets will also exhibit eccentric orbits. Clearly, therefore, a SIM planet search must obtain enough observations per star to adequately assess the often subtle eccentricity parameters.

We are compiling years-long plots of precision Doppler measurements for each SIM target star. This Doppler reconnaissance of all SIM target stars establishes the saturns and jupiters within 3 AU, and provides Doppler suggestions of 10–30 M_{Earth} planets. We consider this Doppler reconnaissance of SIM targets to be a prerequisite of a SIM planet search. Many planets with Neptune-Saturn-Jupiter mass will be anticipated and included in SIM astrometric models.

We are currently surveying the nearest 900 G,K, and M main sequence stars in the northern hemisphere with the Lick 3-m and the Keck 10-m telescopes. We are also surveying the nearest 200 GK southern hemisphere stars with the Anglo-Australian 3.9-m telescope. Moreover, with the 6.5-m Magellan telescope, we will extend our Doppler reconnaissance to another 600 GKM stars in the southern hemisphere. From the Doppler reconnaissance (both detections and nondetections), ideal SIM targets will be chosen, as described in section 4. Indeed, by the time of the SIM launch, we project that 200 jupiter–saturn planets will be known, with hints of dozens of planets from 10-30 M_{Earth} within 1 AU.

Narrow Angle Reference Stars

To maximize SIM's astrometric accuracy, we are employing Doppler techniques to compile a network of reference stars. These reference stars must be:

- astrometrically stable to 1 μas

- located within a 0.5 degree radius in order to achieve 1 μas precision

- brighter than V = 12 to minimize the exposure times.

The existence of a sufficient number of reference stars must be one of the selection criteria for science target stars. Hence the focus of studies before SIM's launch date will be the identification of a reference grid around each of the targets selected from the Doppler program.

The optimal stars to serve as local reference stars are K giants. Because of their bright intrinsic luminosity, K giants can be found at greater distances than almost any other star of the same apparent magnitude. Hence, they offer the smallest astrometric jitter from dynamical effects (e.g., planets and stellar companions) compared to other stars of the same apparent magnitude. With a typical brightness of $V = 11.5$ at 2 kpc, K giants are plentiful enough to provide several candidate reference stars for most science targets. Indeed, we consider K giants to be the only objects suitable to serve as narrow angle reference stars.

Every known star closer than 5 pc of F,G,K,M spectral type is already being observed in our surveys. Since these stars constitute targets for which the highest astrometric precision is desired, we will increase our ground-based monitoring (both sampling frequency and S/N) in order to obtain the highest precision Doppler reconnaissance for planetary companions. The candidate reference stars to the 5 pc sample should also be observed at the higher Doppler precision.

A detection of a terrestrial planet will be extremely challenging because the amplitude of the signal is so low. Figure 2 shows simulations of astrometric data for a 1 M_{Earth} planet at 3 pc, a 2 M_{Earth} planet at 4 pc, and a 3 M_{Earth} at 5 pc. In these simulations, as in all other simulations shown in this proposal, the data are plotted as if the parallax and proper motion were known and cleanly removed. In fact, absolute parallaxes may not be known for these stars unless the reference stars are modeled as grid stars, so the astrometric perturbations due to orbital motion will actually be tiny wobbles on top of enormous signals.