SIM PlanetQuest

This **Space Interferometry Mission, PlanetQuest**, scheduled for launch in 2010, will determine the positions and distances of stars several hundred times more accurately than any previous program. This accuracy will allow it to determine the distances to stars throughout the Galaxy and to probe nearby stars for orbiting Earth-sized planets. The mission will open a new world of discoveries.

This breakthrough in capabilities is possible because the spacecraft will use optical interferometry. It is designed as a space-based 10-m baseline optical Michelson interferometer operating in the visible waveband. Over a narrow field of view (1°), it aims to achieve an accuracy of 1 microarcsecond (μas) in a single measurement. In this mode, the spacecraft will search for planetary companions to nearby stars by detecting the astrometric 'wobble' relative to nearby reference stars. For targets separated by larger angles, the mission has the goal to reach 4 μas precision in absolute position measurements at the end of the five year mission. These wide-angle measurements will be made relative to an astrometric grid of reference stars covering the entire sky. The grid is constructed from repeated relative measurements of the separations of stars within overlapping "tiles." Each tile has a diameter of 15 degrees and represents the area of the sky accessible by re-pointing the optics without changing its baseline orientation.

Interferometer Baseline	10 m
Wavelength range	0.4 – 1.0 μm
Telescope Aperture	0.35 m diameter
Astrometric Field of Regard	15 degrees
Astrometric Narrow Angle Field of Regard	1 degree
Detector	Si CCD
Orbit	Earth-trailing solar orbit
Science Mission Duration	5 years (launch in 2010)
Wide Angle Astrometry	4 μas mission accuracy (goal)
Narrow Angle Astrometry	1 μas single measurement accuracy (goal)
Limiting Magnitude	20 mag (goal)

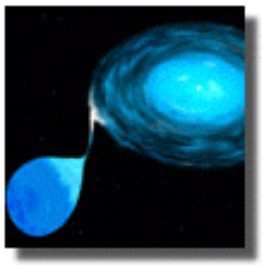
Visit http://planetquest.jpl.nasa.gov/SIM/sim_index.html and http://planetquest.jpl.nasa.gov/Navigator/sim_nav.html for more information on the mission and its science.

PLANET DETECTION

Presently, the planet search program consists of three main scientific areas:

- **Deep search**, a search for terrestrial planets around the nearest ~250 stars. “Deep Search” will use the full capability of the spacecraft to make relative positional measurements accurate to 1 μas.
- **Broad survey**, a second planet search program, is aimed at a much larger ~2000 star sample, albeit at lower positional accuracy (~3 μas). The goal of this program is to explore the prevalence of Neptune- and larger-mass planets in all stellar types in our part of the Galaxy.
- **Planets around young stars**, the third component of the planet search program, is the search for Jupiter-mass planets around young stars. This search is aimed at studying planetary systems with one or more Jupiter-mass planets before the system has reached long term equilibrium.

STELLAR ASTROPHYSICS

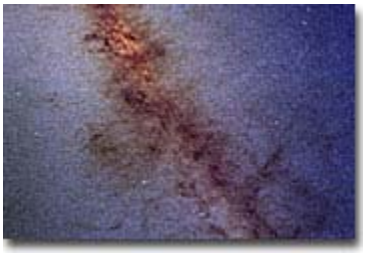


SIM PlanetQuest will investigate the mass distribution and mass content of the Galaxy --- from massive stars to brown dwarfs and from white dwarfs to black holes. It will target various samples of the Galactic population to determine and relate the fundamental characteristics of mass, luminosity, age, composition, and multiplicity -- attributes that together yield an extensive understanding of all stellar populations.

SIM PlanetQuest will measure the distances and orbital properties of ~ 200 stars precisely enough to determine the masses of single and binary stars to an accuracy of 1%. The mission will (1) define the mass-luminosity relation for main sequence stars in five fundamental clusters and associations (Trapezium, TW Hydrae, Pleiades, Hyades, and M67) so that effects of age and metallicity can be mapped, and (2) determine accurate masses for representative examples of nearly every type of occupant of the Galaxy, including X-ray binaries. The spacecraft can also probe the Galactic distribution of X-ray binaries by measuring the parallaxes and proper motions of about 50 X-ray binaries (yielding luminosities as well).

Microlensing will permit census of both ordinary stars and "dark" stars (old brown dwarfs, black holes, old white dwarfs, neutron stars, and perhaps exotic objects such as mirror matter stars or primordial black holes which can only be studied by their gravitational effects) in the field (rather than in binaries). The lensing effect can be detected by measuring the shift in the centroid of the background star. SIM PlanetQuest photometry (a byproduct of its astrometric observations) can be used to determine the geometric parameter needed to compute the lens' mass.

GALACTIC ASTRONOMY



SIM PlanetQuest will make definitive measurements of fundamental structural and dynamical parameters of the Milky Way. By selecting suitable "test particles" a – such as subsets of the mission's astrometric grid stars and samples of the major components (bulge, disk, halo, satellite system) of the Galaxy – SIM PlanetQuest will perform a definitive characterization of the mass distribution within the Milky Way. The mission will:

- Determine R_o (the Sun-Galactic Center distance) by measuring the parallax of the Galactic Center.
- Measure the rotation speed of the Sun around the Galaxy.
- Establish the rotation curve of the Milky Way, which is unknown outside the solar circle (making the Milky Way a poorly understood galaxy from a Tully-Fisher sense).
- Measure the proper motions for orbits of every Milky Way globular cluster and dwarf satellite galaxies and a large number of open clusters.
- Measure the mass and mass distribution of the Milky Way.

Age determinations for metal-poor Milky Way halo stars allow us (1) to set a firm lower limit to the age of the universe and constrain cosmological models and (2) to probe the early formation history of the Milky Way. SIM PlanetQuest will obtain accurate parallaxes to a number of Population II objects (globular clusters and field stars in the halo) improving the Population II distance scale and reducing the uncertainty in the estimated ages of the oldest stars.

SIM PlanetQuest will observe about two dozen globular and open star clusters in order to obtain accurate determinations of their chemical abundances, ages, and the amount of foreground interstellar reddening. Results from these clusters illuminate the behavior of different evolutionary stages with star age and metal abundance, applicable to other clusters and galaxies.

EXTRAGALACTIC ASTROPHYSICS

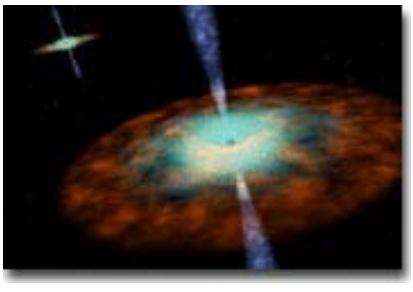
SIM PlanetQuest will obtain proper motions for a sample of 27 galaxies, the first proper motion measurements of galaxies beyond the satellite system of the Milky Way. These measurements lead to knowledge of the full six-dimensional position and velocity vector of each galaxy. Results will include the first total mass measurements of individual

galaxies. Mission measurements will strongly constrain galaxy total masses and make a locally determined estimate of the global mass density of the Universe. There will be sufficient information to measure dark matter mass to the outermost edges of galaxies and to discern the sizes of any halos that may extend far beyond the stars and gas of the observable galaxies.

Observations of extragalactic objects with the spacecraft will allow the study of parsec-scale structures in the optical waveband for the first time. Are the optical photo-centers of quasars compact and positionally stable on the microarcsecond level? There are many theoretical reasons to expect that the most variable quasars and AGN will show motion at several tens of microarcseconds. Changes in their optical positions will be resolvable by SIM PlanetQuest. In the standard theory, emission from quasars and AGN is assumed to be powered by a central engine (presumably a black hole). The origin of the optical wavelength radiation from AGN identified with compact radio sources is not well established. There are several possibilities: 1) the optical radiation is thermal emission from an accretion disk; 2) the optical radiation is non-thermal emission from a magnetized corona or wind emanating from the central region of the accretion disk; or 3) the optical radiation is emission from a relativistic jet beamed toward the observer. Spacecraft observations will determine which source dominates by looking at positional shifts across the spectrum.

The mission will also search for direct evidence of binary black hole systems buried within a host galaxy. Rough estimates, based on the circumstantial evidence currently available, indicate that displacements of 10 μas or more (readily detectable with SIM PlanetQuest) may be present in a number of AGN.

ROTATIONAL SYNTHESIS IMAGING

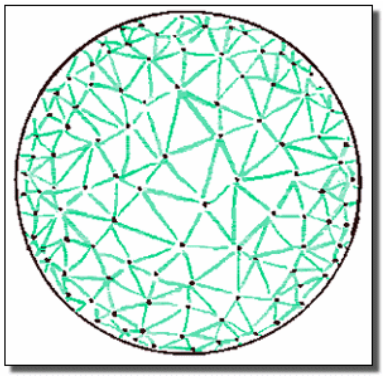


SIM PlanetQuest will be the first phase-stable optical interferometer ever built. Fringes will be stable to better than 1/100 of a wavelength over time scales of many minutes. The instrument will provide complex fringe visibility data (fringe amplitude and phase) of a quality to rival the best ground-based radio interferometers such as the Very Large Array, and do so at wavelengths that are a factor of >14,000 smaller. This feature of the instrument permits use of these data to image astronomical objects using the techniques of synthesis imaging that are well known from radio astronomy.

SIM PlanetQuest will image high surface brightness, low-complexity targets with more than four times the best resolution attainable with the Advanced Camera on the Hubble Space Telescope. The present design includes science interferometers (10 m baselines) and guide interferometers (8 m baselines). With data from both baselines and combined observations taken at many small increments in roll angle, the instrument can image simple, relatively bright targets over a field of view of ~1" with a resolution (FWHM) of ~0.008" at 500 nm wavelength.

The practical difficulties of doing synthesis imaging of faint targets of arbitrary complexity demand large collectors and a range of interferometer baselines from very short to very long, characteristics that the instrument unfortunately does not have in its current configuration. The limitations of the available collector area and interferometer baselines in the current design dictate that the targets chosen for this demonstration be relatively bright and simple in structure.

REFERENCE FRAMES & ASTROMETRIC GRID



SIM PlanetQuest will yield 4 μas absolute position measurements. In order to accomplish this, it will define a new astrometric reference frame, using a grid of approximately 1300 stars with positions accurate to 4 μas. The astrometric grid is a model of the positions and motions of a collection of astronomical objects: mostly stars, but some will be quasi-stellar objects (or quasars) that provide an extragalactic anchor for the grid. Grid objects will be chosen to uniformly cover the entire sky. A significant side benefit of the grid program is establishing a precision frame tie between optical and radio frames via observations of optical (radio-loud) quasars.

Observing and Proposing Opportunities in 2005-2010

SIM PlanetQuest will have several proposing opportunities before and after its 2010 launch:
September 2005: General Observer proposals ("GO-1") in which 5%-10% of the mission time will be allocated.
January 2007: An Announcement of Opportunity to select additional Science Team members, allocating 10-15% of mission time, will be issued by NASA Headquarters (36% was allocated to the Science Team members appointed in 2000).
June 2011: another call for General Observer proposals ("GO-2") may be made.

- **General Observer proposals** responding to the GO-1 call may fall into these general categories:
  - Proposals for 'Snapshot Mode', either (1) Small: ~ 1 - 100 targets, (2) Medium: ~ 100 - 1000 targets, or (3) Large: ~ 1000 - 10,000 targets
  - Proposals for fainter targets or higher accuracy required, e.g., targets fainter than V ~ 15 or parallaxes <~ 10μas
  - Proposals to combine data with other missions/databases, e.g., extend and enhance the entire 118,000-star Hipparcos catalog
  - Proposals with special observing requirements, e.g., (1) timed observations - interacting binaries, gravitational lenses, or (2) observations requiring a local reference frame

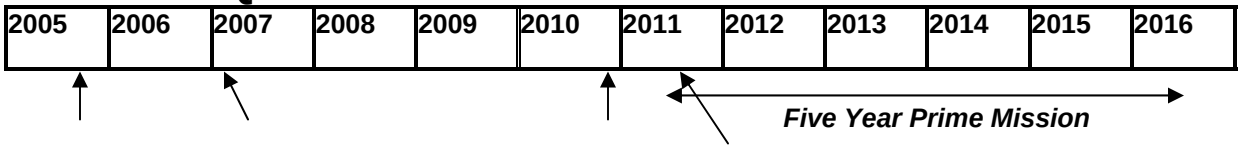
  Selected GO proposals may receive some funding for target selection before launch, and post-launch analysis and publication

- **Proposals for Key Projects** in response to the second Announcement of Opportunity ("AO-2") may include planet searches or other large observing programs, or may augment already-approved programs
  - Successful proposers (~2-3 teams) may become members of the Science Team.
  - Funding will cover preparatory science such as target selection as well as post-launch analysis and publication.

Using "Snapshot" Mode

- "Snapshot" Mode is a simplified SIM PlanetQuest observing mode
  - Large number of targets (up to ~24,000)
  - Designed to yield sub-milliarcsec positions, parallaxes, proper motions
  - Lower accuracy (~10-50 μas) than the ultimate possible
  - Brighter (V ~ 8-17) than the ultimate possible
  - *You don't need to be a black-belt astrometrist to use this mode*
- SIM PlanetQuest will deliver the "5 standard astrometric parameters":
  - Position (RA, dec), parallax, proper motion (RA, dec)
  - Astrometric accuracy scales with measurement errors, typically:
    - Position (each axis) ~11 μas (1-sigma)
    - Parallax ~14 μas
    - Proper motion (for a 2-year baseline) ~17 μas
- Scheduling
  - Observations spread over ~1.5 - 2 years
  - Observer need not be concerned about scheduling details
    - Schedule will be efficiently timed to optimize parallax and proper motion
  - Limited customization permitted (for binary orbits; asterisms, etc.)

SIM PlanetQuest Science Timeline



First Call for General Observer Proposals (Sept. 2005)

2nd Announcement of Opportunity (Key Projects) (Jan. 2007)

Launch (Dec. 2010)

2nd Call for General Observer Proposals (June 2011)