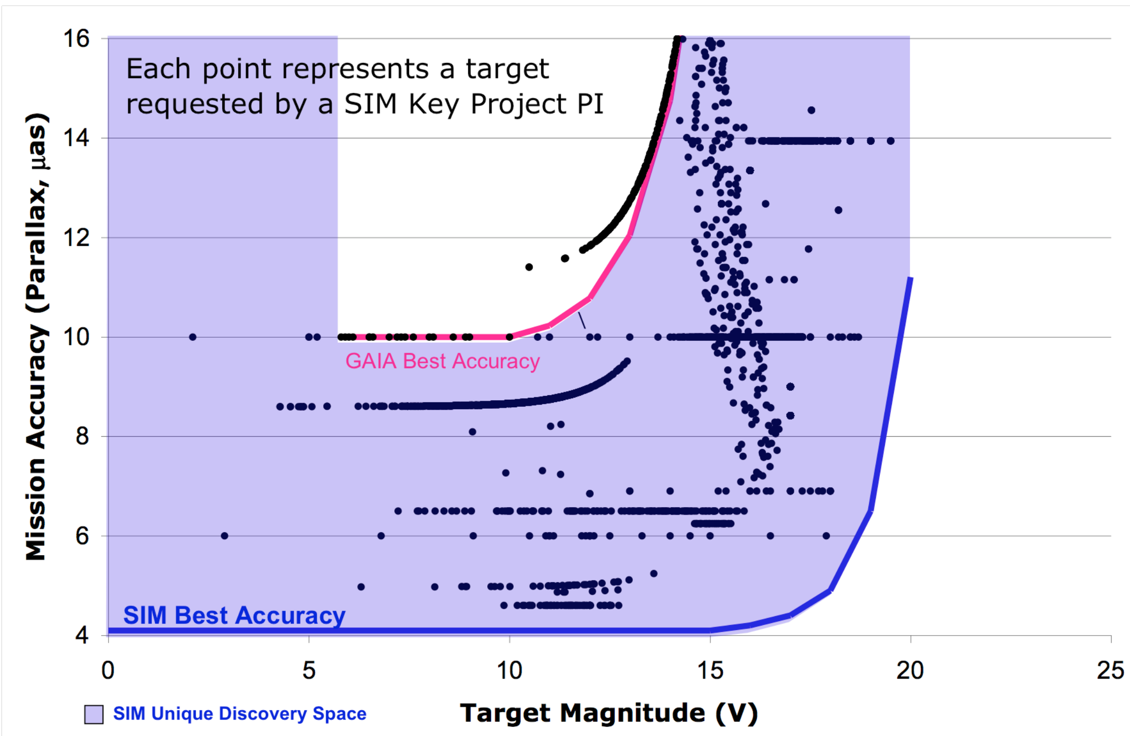
FAINT AND FAR WITH FINESSE:

ASTRONOMY WITH SIM PLANETQUEST

The SIM PlanetQuest key projects exploit the mission's unique capability in numerous ways. This document presents planned science programs that are unique to SIM.



This plot shows the expected parallax mission performance, above and left of the curves, for the SIM PlanetQuest (blue) and GAIA (pink) missions as a function of target magnitude. Black points represent specific science targets requested by SIM Key Project P.I.s

FAINT:

SIM PlanetQuest is the only mission, past or planned, that will achieve unmatched astrometric accuracy for targets as faint as V~20. Some projects that take advantage of SIM's high astrometric accuracy at faint magnitudes include:

- *SIM's Dynamical Observations of Galaxies* (Edward J. Shaya, P.I.) will obtain proper motions for a sample of 27 nearby galaxies within 5 Mpc from the Milky Way. These will be the first proper motion survey of galaxies, and, in conjunction with advanced gravitational flow models, will result in the first total mass measurements of individual galaxies. This SIM study will lead to determinations of galaxy halo sizes, and the overall spatial distribution of dark matter in the local vicinity.

- *Taking the Measure of the Milky Way* (Steven Majewski, P.I.) will determine fundamental quantities such as the mass density of (and the dark matter contribution to) the Galactic disk, the Sun's angular velocity around the Galactic Center, and the Sun's distance to the Galactic Center. These measurements require high accuracy (10 microarcseconds (μas)/year) proper motions for faint (V=17 to 20) stars, observations that only SIM can provide.

- *Binary Black Holes, Accretion Disks and Relativistic Jets: Photocenters of Nearby Active Galactic Nuclei (AGN) and Quasars* (Ann E. Wehrle, P. I.) will use SIM's ability to observe faint sources to determine if the most compact optical emission from an AGN comes from an accretion disk or from a relativistic jet. SIM will also measure the precise location of the photocenters of these systems (down to V=17) to discover if the cores of galaxies harbor binary supermassive black holes remaining from galaxy mergers.

- *Anchoring the Population II Distances and Ages of Globular Clusters* (Brian Chaboyer, P.I.) will significantly improve the Population II distance scale and significantly diminish the errors in the ages of metal-poor globular clusters. SIM will look at globular cluster stars as faint as V~15 with five μas parallax accuracy. These improved distance measurements translate into more accurate determination of globular cluster luminosities and, hence, the mass (and age) of stars in the cluster turning off of the main sequence, thereby significantly reducing the uncertainty in the derived ages of metal-poor stars. Determining the distance scale to globular clusters will allow us to determine the ages of globular clusters and field halo stars with unprecedented accuracy.

- *The Astrophysics of Reference Frame Tie Objects* (Kenneth L. Johnston, P. I.) will investigate the underlying physics of SIM global reference grid objects and improve the absolute reference frame of SIM beyond the solution obtainable from the K-giant grid constituent stars alone. SIM will observe 100 "bright" (15-16th mag) quasi-stellar objects (QSOs) at 10-20 μas single epoch positional accuracy. This is required to achieve the 4 μas or better SIM absolute reference frame, which in turn will enable the science of many other projects which depend on absolute proper motions, parallaxes, and small systematic errors in the SIM frame. SIM's high single source positional precision will allow SIM to examine the physics of QSOs and identify microarcsecond "anomalies" from source to source.

- *Masses and Luminosities of X-Ray Binaries* (Andreas Quirrenbach, P. I.) will use the wide angle mode of SIM to measure the distances and proper motions to a large number of X-ray binaries, providing reliable luminosities of many systems for the first time. The project has targeted twenty-seven targets for distance measurements; nineteen are 17^{th} magnitude or fainter.

- *Masses and Stellar Systems with Interferometry* (Todd Henry, P.I.) will determine accurate masses (with errors of 1%) for representative examples of nearly every type of star. In particular, only SIM will be capable of measuring high-precision masses for the ubiquitous M dwarfs in essential clusters of various ages out to 1 kpc. Knowledge of individual masses of binaries of known age and metallicity will allow us to map their descent onto the main sequence. SIM will deconvolve the binaries directly, thereby providing luminosities for both components.

FAR:

SIM's ability to observe faint objects at high accuracy allows the mission to perform high-accuracy measurements within a volume of space larger than for any other mission past or planned. For every factor of two in astrometric accuracy, SIM will reach a factor of two farther in distance and a factor of eight larger in volume, thereby opening up large swaths of the Galaxy for high-precision astrometric work. Some examples of SIM science that take advantage of SIM's ability to reach further into the Galaxy and beyond include:

- *SIM's Dynamical Observations of Galaxies* will reach beyond the immediate neighborhood of the Milky Way, LMC, and SMC out to 5 Mpc.

- Tidal streams drawn from globular clusters and dwarf spheroidal galaxy satellites of the Milky Way offer sensitive probes of the symmetry and uniformity of the dark matter halo. These systems will be observed as part of the *Taking the Measure of the Milky Way* project. The orbital motions are highly sensitive to sub-structure in the halo, and therefore test merger theories in cold dark matter cosmologies. SIM is the only instrument capable of obtaining the requisite observations: proper motions translating to better than 0.5 km/s accuracy in transverse velocities at 10 kpc for targets as faint as 20th magnitude.

- The most metal-poor globular clusters are among the first objects formed in the Milky Way, and an accurate determination of their age, coupled with the WMAP estimates of the age of the universe, will allow the *Population II/Globular Cluster* project to determine when the first stars were forming in the universe. SIM can obtain distances accurate to 5% (corresponding to age errors of 5-8%, and age difference errors of 5%) out to 10 kpc from the Sun, encompassing roughly 30 globular clusters with low reddening and of varying metallicity. The project will select the 20 most scientifically interesting globular clusters for SIM observations, including 6 globular clusters which are very metal-poor.

- *Masses and Stellar Systems with Interferometry* will make accurate measurements of stars in the Orion star formation complex and the M67 star cluster as part of the detailed mapping of the stellar mass-luminosity relationship. To reach 1% mass errors in these (and other) clusters, high astrometric accuracy is of paramount importance to map the orbits of binary stars.

FINESSE:

As a pointed rather than a survey instrument, SIM will maintain high astrometric accuracy to magnitude V=16 to18, opening up many opportunities for scientific breakthroughs. SIM is a targeted mission that can selectively schedule observations of varying duration for any target, limited by solar exclusion constraints. High-accuracy measurements for planets, stars, and exotic objects having short period or highly eccentric orbits, as well as for targets of opportunity, such as microlensing events, are all possible with SIM. Some examples of SIM science that take advantage of the mission's astrometric accuracy and scheduling advantages include:

- SIM is able to discover terrestrial planets within their stellar habitable zones and, uniquely, to obtain unambiguous planet masses. Two SIM projects—*Discovery of Planetary Systems* (Geoffrey Marcy, P.I.) and *Extrasolar Planets Interferometric Survey* (Michael Shao, P.I.)—will use ~1 μas astrometric precision to detect terrestrial planets. This extraordinary precision will reveal the complex architecture of multi-planet systems and enable unprecedented precision in the measurement of key orbital parameters. In addition, SIM's pointed capability allows scheduled observations that maximize detection efficiency. In a survey of the best 120 candidate stars for hosting such planets, SIM PlanetQuest can find planets in the habitable zone as light as one Earth mass or smaller at six stars. Within this same group of stars, SIM's sensitivity permits it to detect planets of twice Earth's mass (or smaller) around 30 stars. SIM has the sensitivity to find planets of roughly triple Earth's mass (or less) around every star in this group.

- By detecting Jupiter- and Saturn-mass planets orbiting young stars in the critical orbital range of 1 to 5 AU, the *Search for Young Planetary Systems and the Evolution of Young Stars* project (Charles Beichman, P. I.) will develop a dataset for comparison with the planetary systems found around mature stars discovered with other SIM projects and with planets in distant orbits (50-100 AU) found around young stars (<10 Myr) through AO imaging. Only astrometry with SIM can find these planets because (a) photospheric oscillations limit radial velocity measurements to ~100 times worse sensitivity than for mature stars; and (b) the distances to these stars (25-150 pc) makes direct imaging of the inner planetary system (< 5AU, or 30 milliarcsec at Taurus) impossible even for advanced AO systems.

- *A New Approach to Microarcsecond Astrometry with SIM Allowing Early Mission Narrow Angle Measurements of Compelling Astronomical Targets* (Stuart Shaklan, P. I.) demonstrates a technique for narrow angle astrometry that does not rely on the measurement of grid stars. This technique, called Gridless Narrow Angle Astrometry (GNAA) will obtain microarcsecond accuracy and can detect extra-solar planets, measure interacting binaries, and reveal other exciting objects with a few days of observation. The microarcsecond astrometry is processed within days of making the observations—there is no five year waiting period for a global grid to be finalized. This approach will return the first accurate mass measurements of known extrasolar planets and can be used to quickly measure relative astrometric motion of any time-critical target.

- The proposed observations in the *Masses and Stellar Systems with Interferometry* project will target 100 or more relatively close binary systems, separated by less than a few AU. In particular, SIM will be able to point at each binary at specified intervals to provide tailored orbital phase coverage.

- The primary goal of *Stellar, Remnant, Planetary, and Dark-Object Masses from Astrometric Microlensing* (Andrew P. Gould, P. I.) is to make a census of the stellar-mass objects of the Galaxy, in particular "dark" objects like brown dwarfs and black holes, which cannot be detected *and* characterized by any other method. Current microlensing experiments routinely detect such dark "lenses" by the magnification they induce on background stars ("sources"), but these experiments are unable to measure the lens mass and distance, and thus do not distinguish them from ordinary stars. By measuring the 100 μas astrometric deflection that the lens induces on the source (and by comparing its photometry with that obtained from Earth) SIM will break the mass/distance degeneracy of ground-based experiments, and permit individual identification and mass measurements of these dark populations for the first time.

- *Masses and Luminosities of X-Ray Binaries* will perform narrow-angle observations of several X-ray binaries to determine their orbits. Dynamical masses derived from these orbits provide fundamental information that cannot be obtained with any other mission. Precise mass determinations of neutron star systems such as Vela X-1 can address the question of whether neutron stars can be significantly more massive than 1.4 solar masses, which would eliminate soft models of the neutron star equations of state.

- *The Astrophysics of Reference Frame Tie Objects* will also use SIM's flexibility in time resolution to observe non-thermal and chromospherically active "radio" stars. These RS CVn and Algol-type binaries have orbital periods on the order of a few days. SIM will determine accurate orbits for these binaries, and in conjunction with ground-based radio observations, determine the location of the radio emission relative to the two stars.

- *Binary Black Holes, Accretion Disks and Relativistic Jets: Photocenters of Nearby Active Galactic Nuclei (AGN) and Quasars* will observe faint targets at high accuracy (12 μas single measurement accuracy). It will also examine if the optical photocenters of the quasars used for the reference frame tie shift on the timescales of their photometric variability at a level of a few microarcseconds.

- The goal of *Open and Globular Cluster Distances for Extragalactic, Galactic, and Stellar Astrophysics* (Guy Worthey, P.I.) is better than 1% distances to the "stellar population cluster network" at each point in age-metallicity space. GAIA can obtain this target precision for only three clusters, with little or no sampling of the metallicity axis. SIM will be able to measure an additional 8 clusters to the requisite accuracy, with much greater coverage of the age-metallicity space. This project also inherits key distance information for metal-poor globular clusters from the *Population II/Globular Cluster* project, whose science is also mostly beyond what GAIA can accomplish.

- As mentioned, the *SIM's Dynamical Observations of Galaxies* project will measure proper motions of 27 galaxies with SIM, an order of magnitude greater than can be done with any other past or planned mission. These results will provide a robust map of the dynamical environment of the Local Group. Once this additional information is in hand, the orbits of hundreds of nearby galaxies since their formation until now will be calculable and the history of the nearby groups, clouds, and the Local Supercluster plane will be revealed.

FUTURE OF ASTRONOMICAL IMAGING IN SPACE:

- SIM will demonstrate high-dynamic-range synthesis imaging at optical wavelengths in space, showing the viability of this approach for the next generation of UV/Optical/IR imaging telescopes. The demonstration will focus on targets of modest complexity but with a wide range of surface brightness. SIM's imaging P. I. (Ron Allen) will push this capability to the limit by imaging dense stellar systems, such as the cores of Galactic globular clusters and the nuclear regions of the nearest galaxies. By measuring positions, proper motions, and even accelerations of many individual stars in a crowded field (dozens of stars in the SIM aperture) over the mission lifetime, SIM will be able to detect massive dark objects in these regions.

- SIM is in a unique position to have a profound influence on the architecture of future UV/Optical/IR imaging space astrophysics missions. Imaging synthesis provides for the first time the possibility of separately choosing the resolution and the collecting area of space telescopes in order to provide a more cost-effective match to the specific astrophysical problems to be addressed. Such flexibility is essential for the future if instruments are to provide ever-increasing angular resolution and still be affordable. SIM will break new ground by demonstrating these imaging techniques at optical wavelengths in space.