A New Approach to Micro-arcsecond Astrometry with SIM Allowing Early Mission Narrow Angle Measurements of Compelling Astronomical Targets

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The Space Interferometry Mission (SIM) is capable of detecting and measuring the mass of terrestrial planets around stars other than our own. It can measure the mass of black holes and the visual orbits of radio and x-ray binary sources. SIM makes possible a new level of understanding of complex astrophysical processes while bestowing a new perspective on our place in the Universe.

SIM achieves its high precision in the so-called "narrow-angle" regime. This is defined by a 1° diameter field in which the position of a target star is measured with respect to a set of reference stars. The observation is performed in two parts: first, SIM observes a grid of stars that spans the full sky. After a few years, repeated observations of the grid allow one to determine the orientation of the interferometer baseline. Second, throughout the mission, SIM periodically observes in the narrow-angle mode. Every narrow-angle observation is linked to the grid to determine the precise attitude and length of the baseline.

The narrow angle process demands patience. It is not until five years after launch that SIM achieves its ultimate accuracy of 1 microarcsecond (μas). The accuracy is degraded by a factor of ~ 2 at mid-mission.

Our work proposes a technique for narrow angle astrometry that does not rely on the measurement of grid stars. This technique, called Gridless Narrow Angle Astrometry (GNAA) can obtain μas accuracy and can detect extra-solar planets and other exciting objects with a few days of observation. It can be applied as early as during the first six months of in-orbit calibration (IOC).

The motivations for doing this are strong. First, and obviously, it is an insurance policy against a catastrophic mid-mission failure. Second, at the start of the mission, with several space-based interferometers in the planning or implementation phase, NASA will be eager to capture the public's imagination with interferometric science. Third, early results and a technique that can duplicate those results throughout the mission will give the analysts important experience in the proper use and calibration of SIM.

Gridless narrow angle astrometry (GNAA) with SIM is simply the application of traditional single-telescope narrow angle techniques to SIM's narrow angle optical path delay measurements. The technique allows one to perform micro-arcsecond astrometry without solving for baseline length, precise baseline orientation, or the metrology constant term. In GNAA, a set of reference stars and a target star are observed at several baseline orientations. A linearized model is used to solve for reference star positions and baseline orientations. The target star position is determined using the estimated baseline orientations. Then the process is repeated at a later time and a conformal transformation is applied to relate the reference target stars to a common reference frame.

As with narrow angle astrometry at a telescope, the conformal transformation absorbs SIM instrumental parameters. To first order, baseline length errors cause angular scale errors, baseline orientation errors cause rotational errors about the center of the reference frame, and the

metrology constant term is a translation along the direction of the baseline. The conformal transformation solves the scale, rotation, and translation of the observed reference frame without requiring the intermediate step of exact baseline determination. The absolute scale is lost, but it is estimated with a precision approximately given by the a priori scale knowledge of the field size.

Simulation results shows that GNAA can measure changes in the position of the target relative to the reference frame at the micro-arcsecond level. Even for extended periods in which the reference frame deforms by 10 mas, the noise level remains $\sim$ 1 micro-arcsecond.

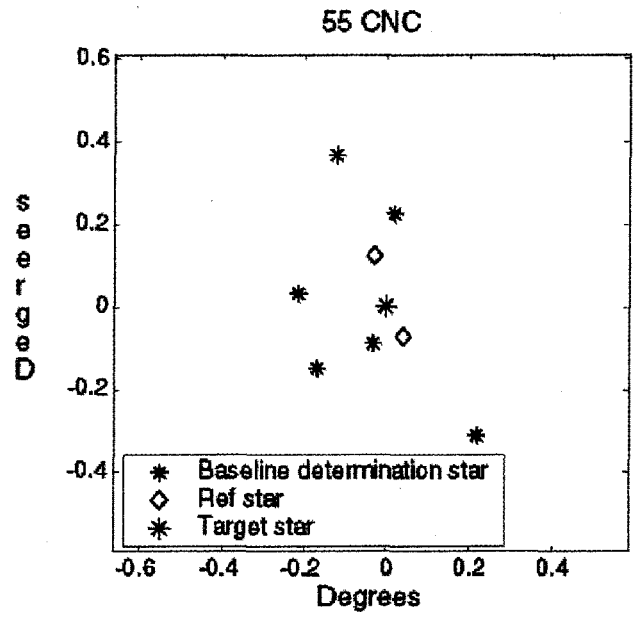

Figure 1: Figure shows the reference frame around a typical target, 55 Cnc. All stars shown in the 1° field have visual magnitude brighter than V=10.5. The figure indicates stars that are used to determine instrument parameters (blue symbols), stars that serve as independent reference stars (diamonds), and the target 55 Cnc (red symbol). 55 Cnc has a 14.7 day period, Msini = 0.84 Jupiter masses, and a semi-major axis of 8 micro-arcseconds corresponding to 0.11 AU.

We intend to use the GNAA technique to observe short-term periodic signals, including known and potential extra-solar planets, the black-hole Cyg X-1 (P = 5.6 d), as well as Radio and X-ray binary systems, e.g. the Be star LSI 61303 (P = 26.5 d), and similarly V725 Tau, X Per, V801 Cen, HD 63666, HD 91188, all with periods < 35 d.

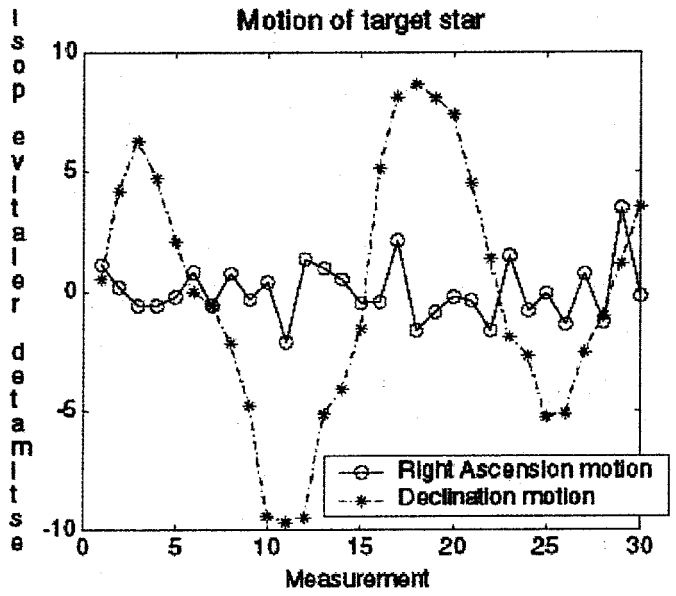

Figure 2: Estimated relative positions from 30 daily observations of 55 Cnc. Each day, the baseline is oriented to 3 positions rotated 120° about the line of sight to the target. For demonstration purposes, the 8 uas signal is assumed to be a pure N-S sine wave. The R.A. axis thus indicates the noise level. The simulation assumes 50 picometers delay measurement errors per star, and reasonable assumptions with respect to baseline positioning control and knowledge. The astrometric precision is 1.0 μas on each axis for each 3-baseline (3-hour long) observation.