Astrometry

A Precision Tool for the 21st Century

To many astronomers, astrometry is merely a necessary step toward other goals in astronomy. Only a minority really savor this important work and appreciate the fundamental nature of determining the positions of stars to higher and higher precision as the years pass. They glean parallaxes, yielding distances, and proper motions, which ultimately help define the general behavior of the stars in the Milky Way. A larger group of astronomers applies such measurements directly to the problems of astrophysics, a field recognized for only about 150 years, though its roots are much deeper. They determine the masses of binary stars' visible and invisible companions and reflect on their results in the context of theoretical predictions.

An astrometric observatory is a different "animal" than most astronomers are used to, and using one effectively requires a different mindset. There aren't going to be pretty pictures or high-resolution spectra for interpretation. There will be little instant gratification since many astrometric results require years (which could be the full duration of a space mission) to acquire the necessary data.

So many problems in astrophysics are addressed by the results from SIM Lite that anyone with an interest in planets, stars, star clusters, galaxies, quasars, or the Universe will find its investigations to be valuable. That includes just about everyone from professional astronomers to school children.

SIM Lite promises results that aren't just fundamental, but foundational. They will strengthen the whole edifice of astronomical science. In a different context but entirely appropriately, William Thompson (Lord Kelvin) expressed it well:

> "When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the state of science."

The technology necessary to make these measurements is impressive — control of the separation of optics at the nanometer level and knowledge at the picometer level. SIM Lite has demonstrated these measurements in the laboratory, and it has demonstrated all the technologies needed to make these precision measurements with SIM Lite in the space environment.

We know planets orbit other stars, and in a few cases we can actually see them directly or by silhouette. But we don't know their masses. We don't know if there are Earth-like planets. Do the planets we know about and the ones SIM Lite will find orbit in systems like the Sun's? Are there variations on this one scheme we are intimately familiar with? How do systems of planets change from formation to maturity? Do they survive the deaths of their parent stars?

Inside stars, nuclear reaction rates are dependent on the core temperature. The core temperature is dependent on the mass of the star. Except in a handful of cases, the masses of stars are known no better than to 10 percent, much too uncertain to distinguish between energy generation processes across the Hertzsprung-Russell diagram or to make the best use of the mass-luminosity relation, and in both of those the third dimension of metallicity lurks to confound results. How massive are the most massive O stars? How massive are the red dwarf stars that are just across the boundary from brown dwarfs? How massive are stellar remnants like white dwarfs, neutron stars, and black holes in the Milky Way? SIM Lite data will yield masses at the 1 percent level. And SIM Lite's measurements of the luminous centroid of microlensing events, impossible in any other way, can be combined with observations made from the ground to address the unknown population percentages of stars, planets, and stellar remnants orbiting the Milky Way between the Sun and the nucleus of the Galaxy.

Star clusters are interesting in themselves, and offer clues to broader questions. How do stars behave dynamically within a young open cluster compared to an old globular cluster? SIM Lite will measure the distances and proper motions of individual cluster members. What does this behavior tell us about the ages of those stars, and what do the ages of the clusters tell us about the age of the Galaxy?

The motions of the Galaxy's dwarf spheroidal companions and their star streams, its globular clusters, and its halo stars help address a pressing mystery: dark matter. What is its distribution in the Milky Way? How much is there? What hints are there to its actual composition? SIM Lite's measurements can be expanded to many other members of the Local Group to address dark matter and its effects on galaxy motions within the Group.

Looking further afield, the processes ongoing in the extreme environment of the cores of galaxies are sure to expand our understanding of physics and the life cycles of galaxies. SIM Lite's resolution and measurements of events around the black holes there will clarify the processes behind the optical- and radio-activity in these tiny volumes.

Finally, one of the most exciting prospects for SIM Lite is "opportunity." This is a flexibly scheduled instrument that can be pointed at targets as faint as V = 20, with astrometric precision of a few microarcseconds. This capability, as with any fundamentally new instrument, offers the opportunity for unexpected discovery. One Science Team member summed it up this way:

> "As an astronomer, if you can't think of something truly interesting to do with SIM Lite, you should go back and think harder, because the opportunities are out there."

Many of the questions posed in this book recapitulate questions asked when astrophysics was just beginning, and in the case of planets, by some shepherd on a hilltop lost in antiquity. We have the opportunity to be the first to answer these questions both to a depth and across a breadth that will test the best theoretical models and that will leave a lasting foundation and legacy for the researchers who follow us.

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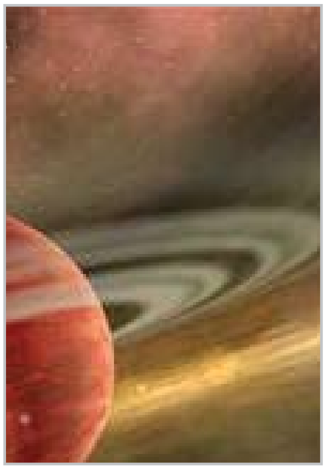
Acronyms and Abbreviations

ΛCDM	Lambda Cold Dark Matter
µas	microarcsecond
ABC	Astrometric Beam Combiner
ACS	Attitude Control System
AEB	Astrometric Error Budget
AGB	Asymptotic Giant Branch star
aMet	Angle Metrology
AO	Announcement of Opportunity
AOM	Acousto-Optic Modulator
ATC	Angle Tracking Camera
AU	Astronomical Unit
BB	Brassboard
BBB	Big Blue Bump
BD	Brown Dwarf
BDE	Brightness-Dependent Error
BH	Black Holes
BN	Becklin-Neugebauer star
CCD	Charge-Coupled Device
CFRP	Carbon-Fiber Reinforced Plastic
CMB	Cosmic Microwave Background
CMD	Color-Magnitude Diagrams
COMBO-17	Classifying Objects by Medium-Band Observations (a spectrophotometric 17-filter survey)
COPHI	Common Optical Path Heterodyne Interferometer
CSIRO	Commonwealth Scientific and Industrial Research Organization
CTE	Coefficient of Thermal Expansion
cTTs	Classical T Tauri stars



D	Distance
DCC	Double Corner Cube
DEBs	Detached Eclipsing Binaries
DETF	Dark Energy Task Force
DM	Dark Matter
DOR	Differential One-Way Ranging
DRM	Design Reference Mission
dSph	Dwarf Spheroidal galaxies
EB	Eclipsing Binary
EHZ	Earth Habitable Zone
EOS	Equation of State; Earth Observing System
FAP	False-Alarm Probability
FGLR	Flux-weighted Gravity Luminosity Relation
FOR	Field of Regard
FSM	Fine-Steering Mirror
FTC	Fringe Tracking Camera
G2T	Guide-2 Telescope
GEMS	Galaxy Evolution from Morphology and Spectra
GO	General Observer
GR	General Relativity
GTO	Guaranteed Time Observers
HB	Horizontal Branch
HMXB	High-Mass X-ray Binary
HRD	Hertzsprung-Russell Diagram
HST	Hubble Space Telescope
HVS	Hypervelocity Star
HZ	Habitable Zone
ICRF	International Celestial Reference Frame
IHZ	Inner Habitable Zone
IIPS	Inverse Interferometer Pseudo Star
IMF	Initial Mass Function
IMXB	Intermediate Mass X-ray Binary
IRU	Inertial Reference Unit
ISCO	Innermost Stable Circular Orbit
ISM	Interstellar Medium
JDEM	Joint Dark Energy Mission
JWST	James Webb Space Telescope
kpc	kiloparsec
LCROSS	Lunar Crater Observation and Sensing Satellite
LMXB	Low-Mass X-ray Binary
LOS	Line of Sight

MAM	Microarcsecond Metrology
mas	milliarcsecond
MASSIF	Masses and Stellar Systems with Interferometry
MLI	Multilayer Insulation
MLR	Mass-Luminosity Relation
MMR	Mean Motion Resonances
Mpc	Megaparsec
MS	Main Sequence
MSC	Michelson Science Center
MSTO	Main Sequence Turn Off

NA	Narrow Angle
NCVE	Non-Common Vertex Error
NExScI	NASA Exoplanet Science Institute
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPRO	Non-Planar Ring Oscillator
NS	Neutron Star
NYMG	Nearby Young Moving Groups

ODL	Optical Delay Line
ONC	Orion Nebula Cluster
OPD	Optical Pathlength Difference

pc	parsec
PFF	Pathlength Feed-Forward
PL	Period Luminosity
PMS	Pre-Main Sequence
PN	Planetary Nebula
POM	Pathlength Optic Mechanism
PPN	Parameterized Post-Newtonian
PSD	power spectral densities
PSF	point spread function
PSS	Precision Support Structure
PZT	Piezoelectric Transducer

RECONS	Research Consortium on Nearby Stars
RFP	Request for Proposal
RGB	Red Giant Branch
RLQ	Radio-Loud Quasars
RMS	Root-Mean-Square
RP	Rotational Parallax
RQQ	Radio-Quiet Quasars
RS	Schwarschild Radius
RV	Radial Velocity

SAVV	Sub-Aperture Vertex-To-Vertex
SB	Spectroscopic Binary
SCDU	Spectral Calibration Development Unit
sdO/B	Subdwarf O-type and B-type stars
SED	Spectral Energy Distribution
SIM	Space Interferometry Mission
SMA	Single-Measurement Accuracy

SMBH	Supermassive Black Hole
SME	Single-Measurement Error
SNR	Signal-to-Noise Ratio
SSTA	Single-Strut Test Article
STB-3	Three-Baseline System-Level testbed
TA	Test Article
TDI	Time Delay Integration
TOM	Thermo-Opto-Mechanical testbed
TOO	Target of Opportunity
VLBI	Very Long Baseline Interferometry
WA	Wide Angle
WD	White Dwarf
WIMP	Weakly Interacting Massive Particle
WLR	Wind-momentum Luminosity Relation
WR	Wolf-Rayet star
wTTs	Weak-lined T Tauri stars

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This book is a collection of white papers spanning the full range (as presently understood) of SIM Lite science and technology. At the outset, it was expected that the necessary editing would be minor, mainly consisting of supplying figures and checking punctuation and grammar. This expectation was short-lived. It was, in fact, a major editorial effort to weave 20 disparate manuscripts into an integrated fabric that presented the story of SIM Lite's remarkable science and technology in a way that was both rich in detail and accessible to anyone with a technical background.

The size of the editorial task, together with the need to reach our science audience in a timely manner, set a limit on the amount of polishing that could be done. The remarkable extent to which the book that you hold is complete, logically organized, and reads smoothly is due to the efforts of many capable professionals who lent their often unrecognized and uncompensated support. We acknowledge them here with great thanks for the service they performed.

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Search for Habitable Worlds

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For more information about the SIM Lite Astrometric Observatory, visit our Web page at — sim.jpl.nasa.gov

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