Space Interferometry Mission Science Overview

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SIM Deputy Project Scientist

Astrometry in the Age of the Next Generation of Large Telescopes

October 18-20, 2004

SIM will:

- Search ~250 nearby stars for terrestrial planets
- Study the diversity of planetary systems around various types of stars
- Advance our understanding of planetary system evolution by studying planets around young stars
- Study the Astrophysics of
  - Stars of all types in our galaxy
  - The structure of our Galaxy
  - Distant Active Galactic Nuclei

A particular attraction of SIM is its ***dual capability:***

- "the detection of planets through narrow-angle astrometry and
- "the mapping of the structure of our galaxy and nearby galaxies through wide-angle astrometry."

"Astronomy and Astrophysics in the New Millennium"
2001 NRC Decade Report
C. McKee & J. Taylor, Editors

SIM Science Team

Key Science Projects

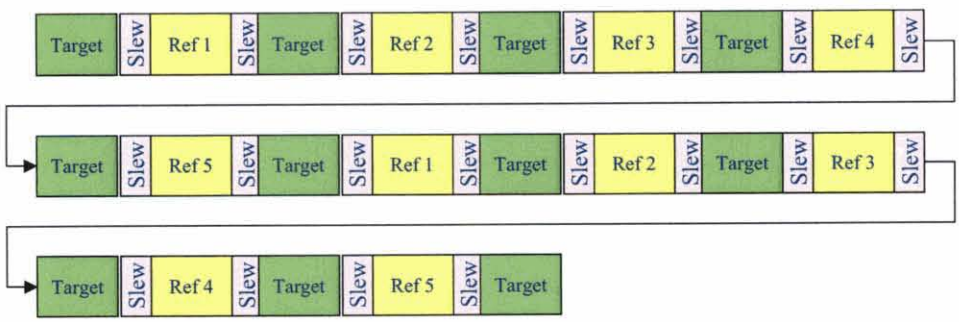
Dr. Geoffrey Marcy	U. California, Berkeley	Planetary Systems
Dr. Michael Shao	NASA/JPL	Extrasolar Planets
Dr. Charles Beichman	NASA/JPL	Young Planetary Systems and Stars
Dr. Andrew Gould	Ohio State University	Astrometric Micro-Lensing
Dr. Edward Shaya	Raytheon ITSS Corp.	Dynamic Observations of Galaxies
Dr. Kenneth Johnston	U.S. Naval Observatory	Reference Frame-Tie Objects
Dr. Brian Chaboyer	Dartmouth College	Population II Distances & Globular Clusters Ages
Dr. Todd Henry	Georgia State University	Stellar Mass-Luminosity Relation
Dr. Steven Majewski	University of Virginia	Measuring the Milky Way
Dr. Ann Wehrle	MSC/Caltech	Active Galactic Nuclei

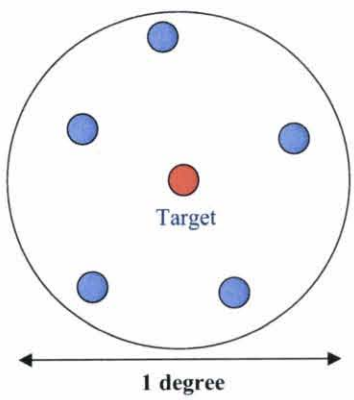
Mission Scientists

Dr. Guy Worthey	Washington State University	Education & Public Outreach Scientist
Dr. Andreas Quirrenbach	U. California, San Diego	Data Scientist
Dr. Stuart Shaklan	NASA/JPL	Instrument Scientist
Dr. Shrinivas Kulkarni	Caltech	Interdisciplinary Scientist
Dr. Ronald Allen	Space Telescope Science Inst.	Synthesis Imaging Scientist

Only Principal Investigators listed. Including co-investigators the SIM Science Team has 86 members.

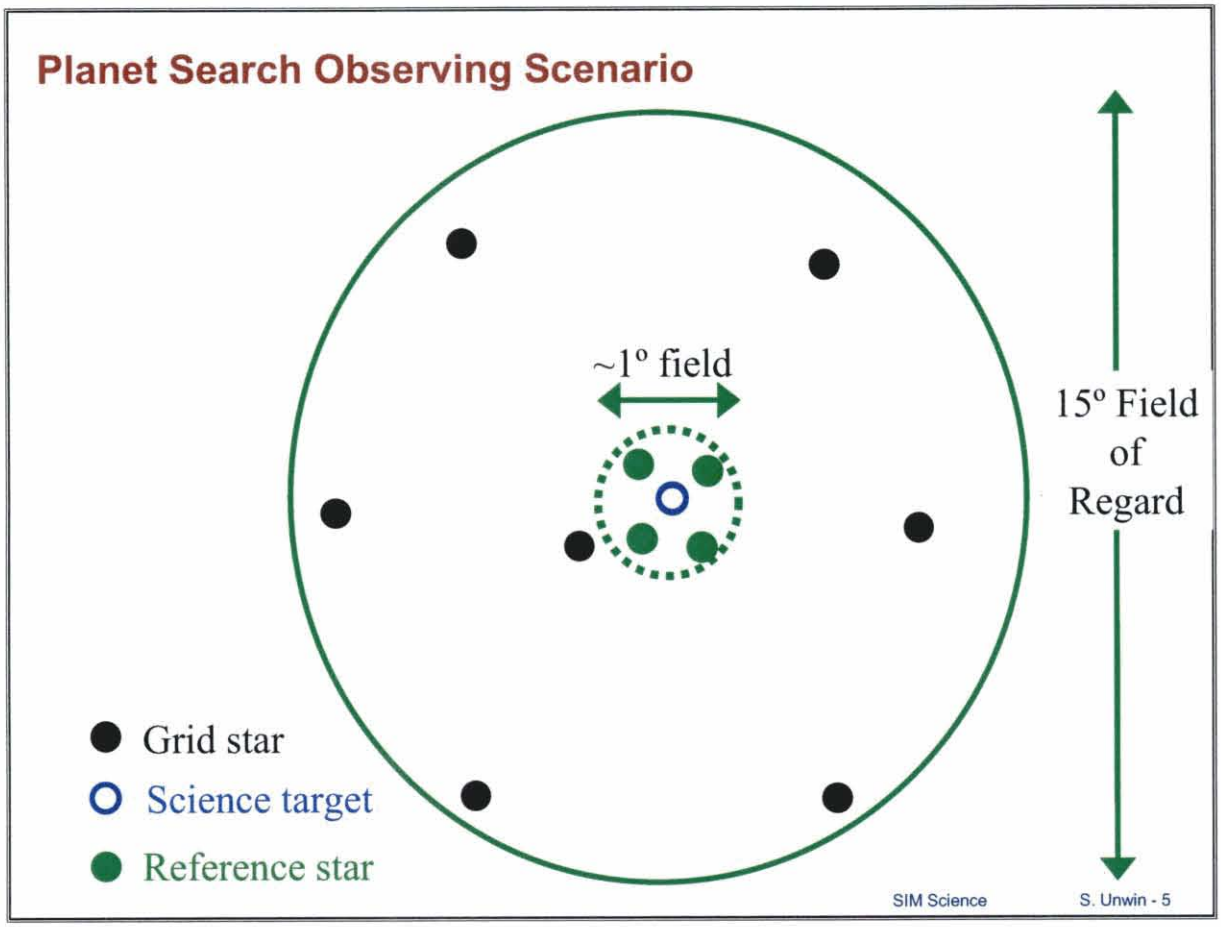
Narrow Angle Observing Scenario





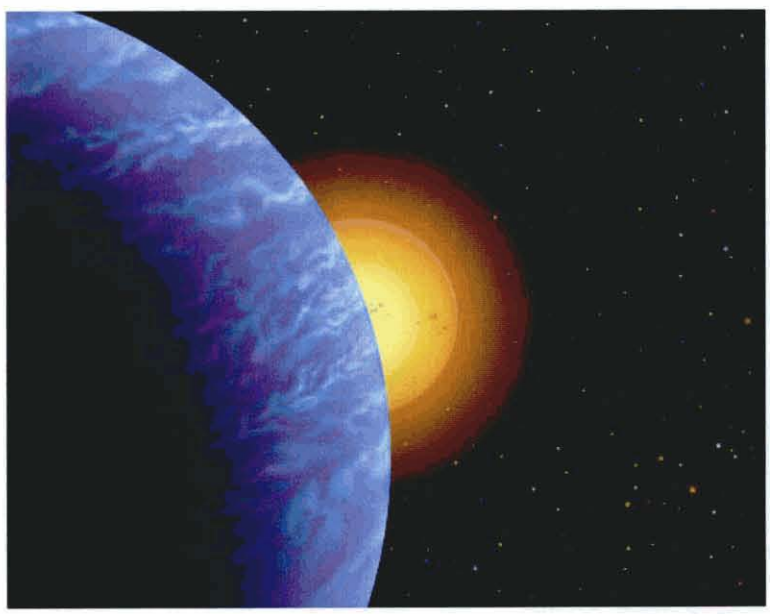
- Reference stars surround target star
- All observations are 30 seconds
- All optics slews are 15 seconds
- Nominal scenario is 10 target-reference pairs or **"chops"**

Planet Search Observing Scenario



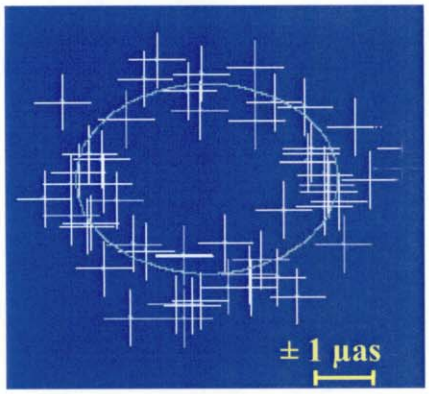
Planet Detection with SIM

- **Deep search** for terrestrial planets
- **Broad survey** of planetary system architectures
- Planetary systems Around **young stars**



Astrometric Planet Detection

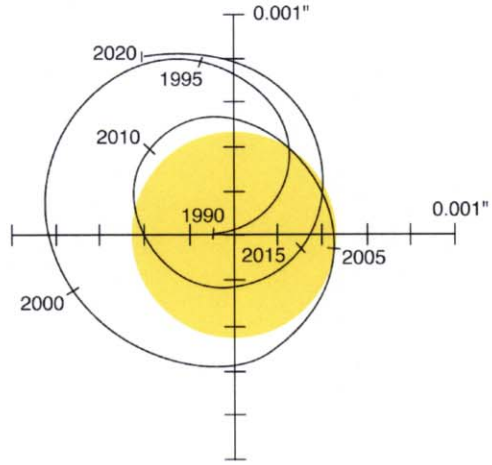
- A microarcsecond (1 μas) is SIM's goal accuracy in *a single measurement*
  - Equals the thickness of a nickel when viewed at the distance of the Moon !



SIM Simulation:

detecting a planetary orbit with a series of 2-D measurements, each 1 μas

(Ellipse represents the computed 'wobble' track of the parent star)



"The wobble effect": our Solar System as seen at 10 pc distance

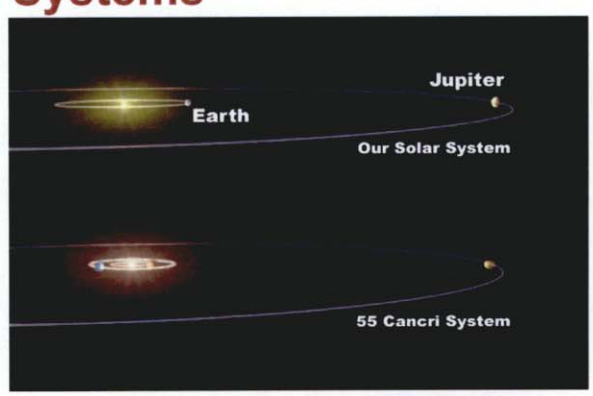
- 1 tickmark = 200 μas
- Sun-Jupiter wobble = 500 μas
- Sun-Earth wobble = 0.3 μas

Broad Survey of Planetary Systems

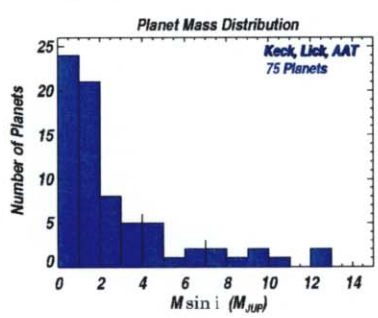
Out of ~120 planetary systems discovered to-date, only one resembles our Solar System

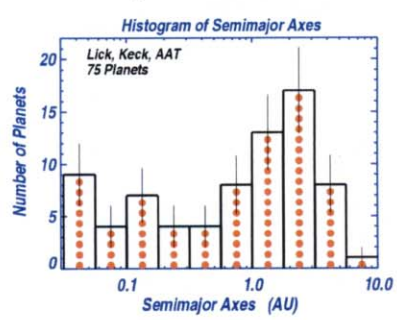
Questions:

- Is our solar system typical or unusual?
- Are planets more common around sun-like stars?
- What are the 'architectures' of other planetary systems



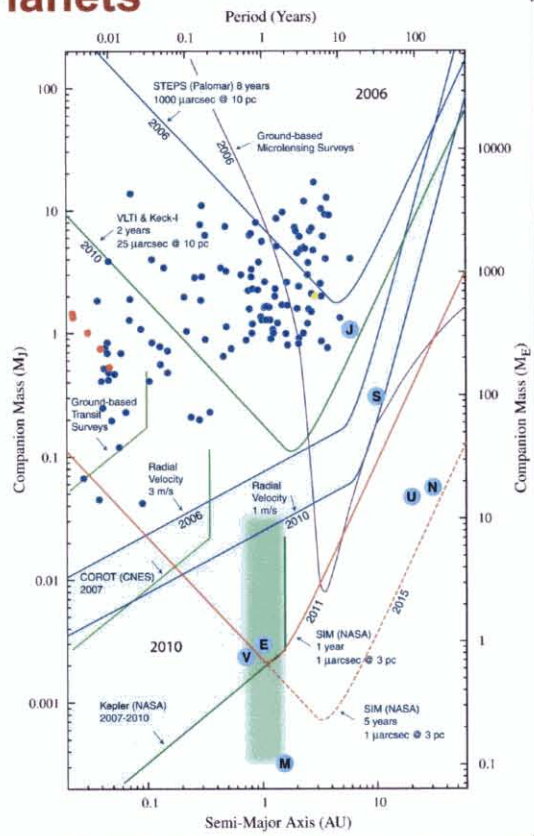
55 Cancri: a planetary system like our own?



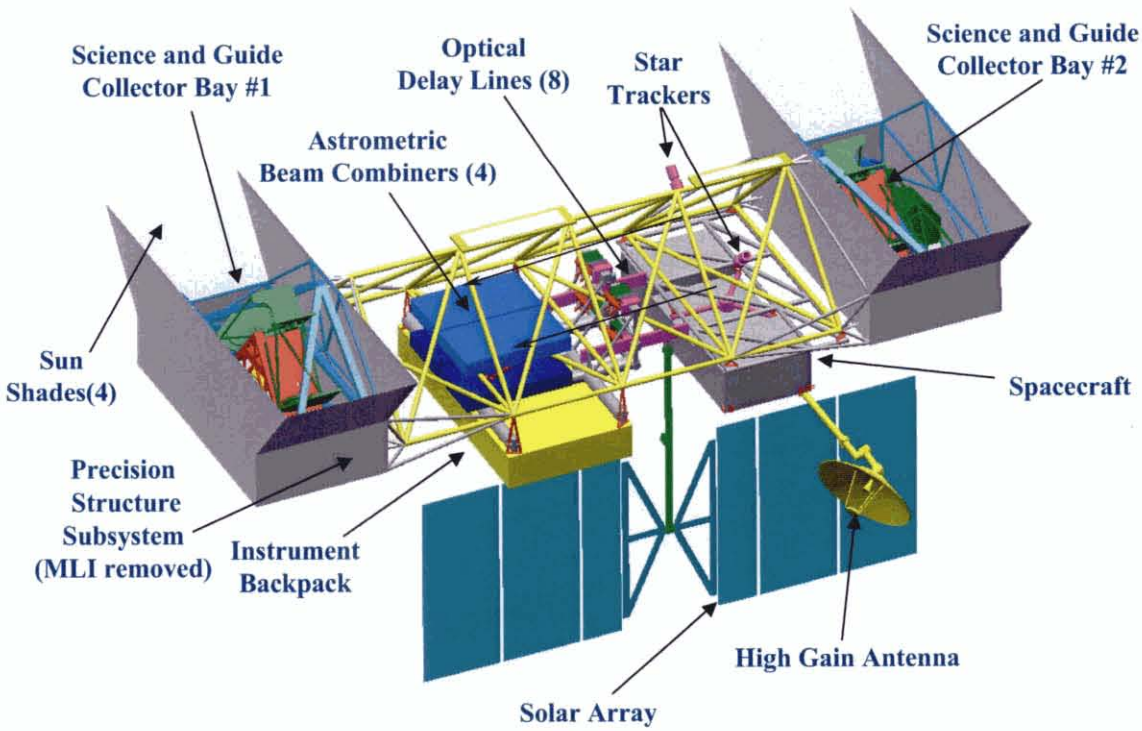


Deep Search for Terrestrial Planets

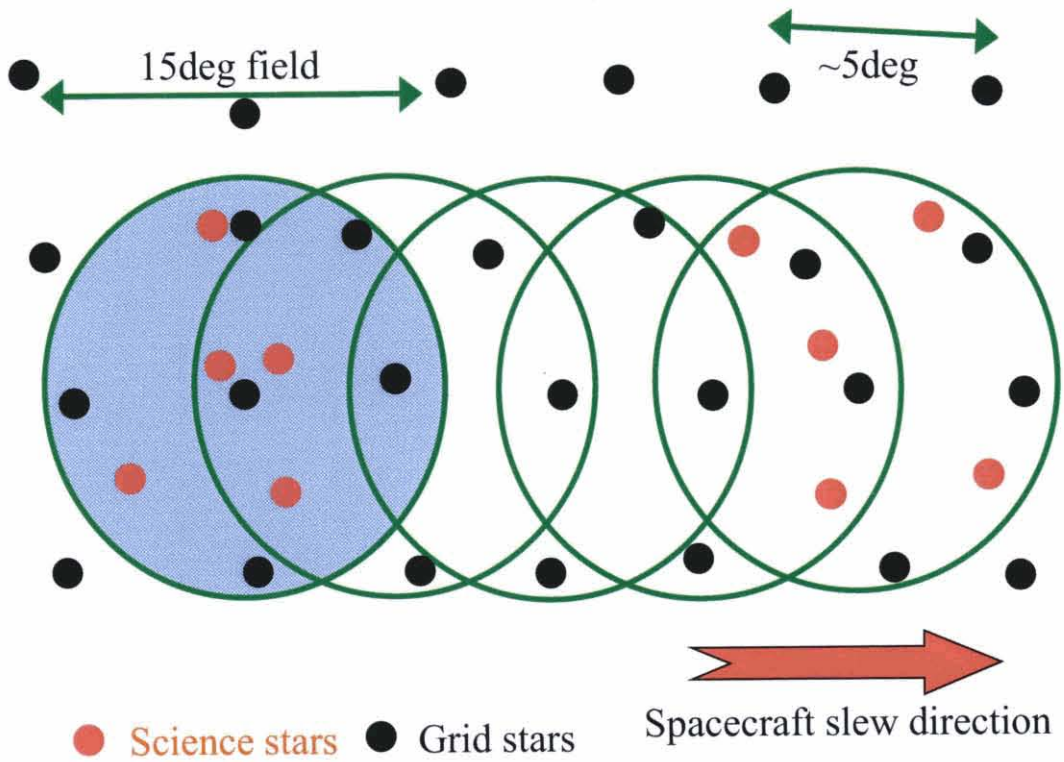
- Several Neptune-sized planets have been discovered recently
  - Planets with masses of 15-30 Earth-masses appear to be common
  - They all have short orbit periods (3 - 10 days) and orbit very close to the star
  - These are not Earth-like planets: they have very short periods and are more than 15 times as massive
- SIM will extend the search to Earth-mass planets, with a survey of 250 nearby stars
- Complete survey will reach ~3 Earth-masses in 5 years
- First detections of terrestrial planets could occur within the first year



Flight System Architecture

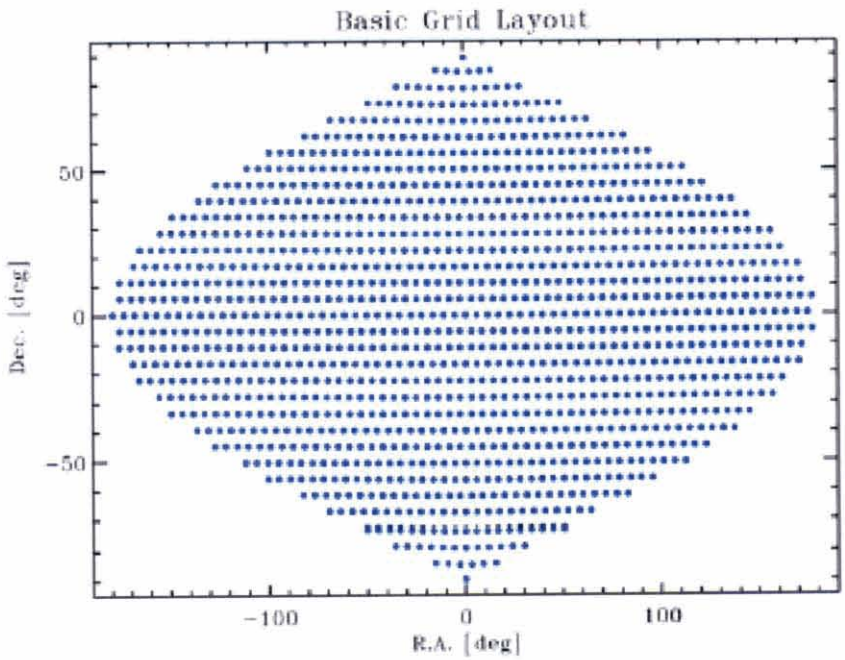


Combined grid star + science target observing scenario



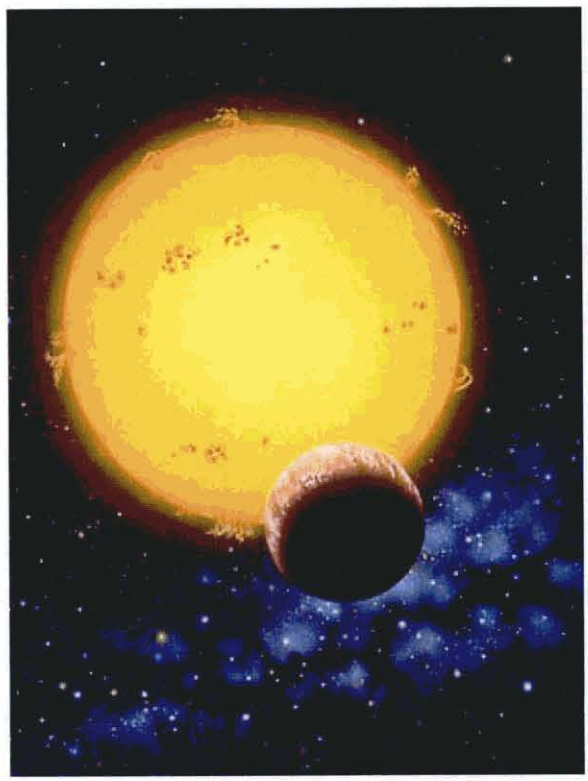
SIM astrometric grid: 1302 'bricks'

- Bricks are ~evenly spaced at ~ 5°
- SIM uses the best candidate star in each 'brick'



Planets around Young Stars

- How do planetary systems evolve?
- Is the evolution conducive to the formation of Earth-like planets in stable orbits?
- Do multiple Jupiters form and only a few (or none) survive?



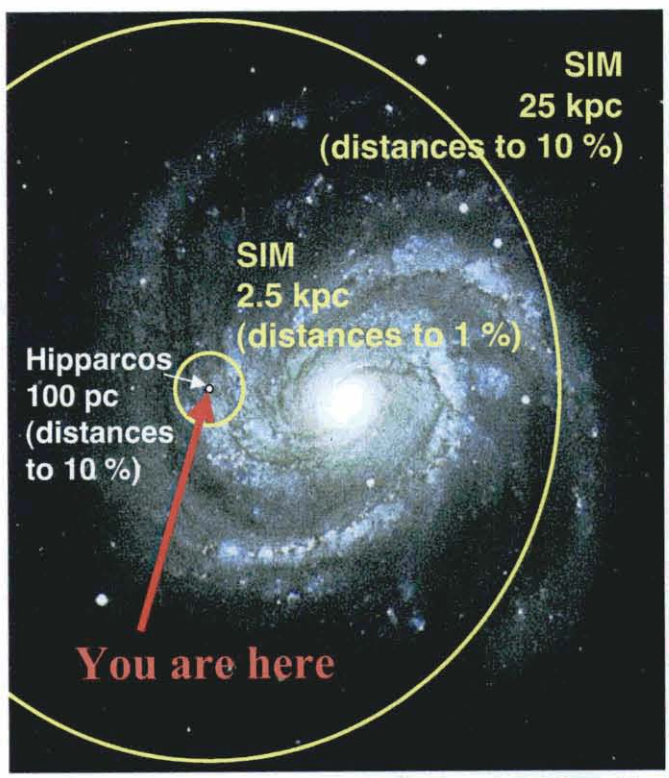
SIM will:

- Search for Jupiter-mass planets around young stars
  - Pick stars with a range of ages
- Measure the ages and 'evolutionary state' of young stars
  - Need precise distances and companion orbits

SIM's Reach Extends Across our Entire Galaxy

- What makes SIM unique?
- It is the *combination* of extreme astrometric precision ***and*** the ability to observe faint targets:
  - 4 μas (microarcsec) positions

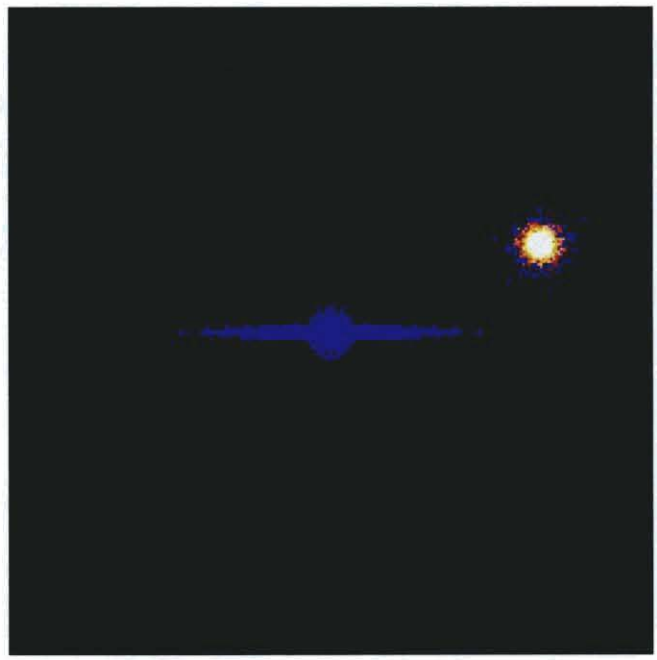
    and
  - Targets as faint as 20th mag
- This combination of capabilities lets SIM do "precision astrophysics" across our entire Galaxy, and beyond



Dark Halo of our Galaxy

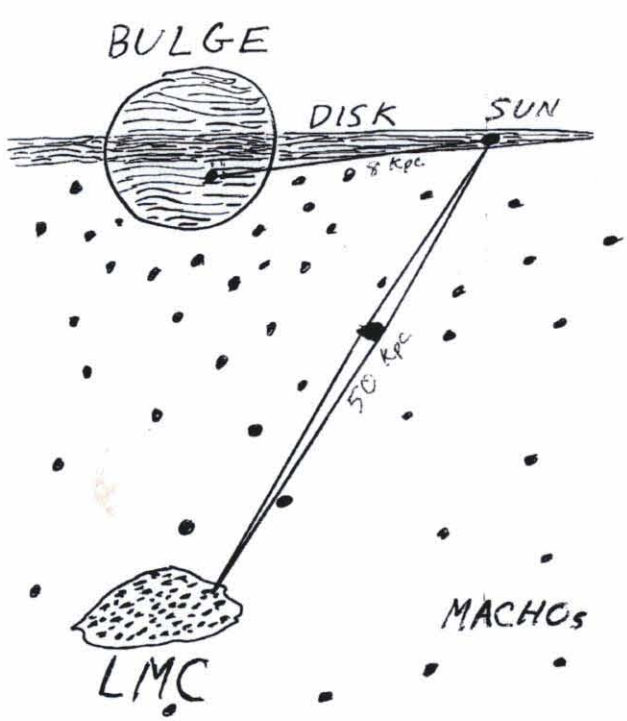
- 'Dwarf spheroidal' galaxy orbits the Milky Way
- Gravitational forces pull out 'tidal tails' of stars
- The orbits of these tails trace the past history of the dwarf
- They also trace the mass distribution of the Milky Way

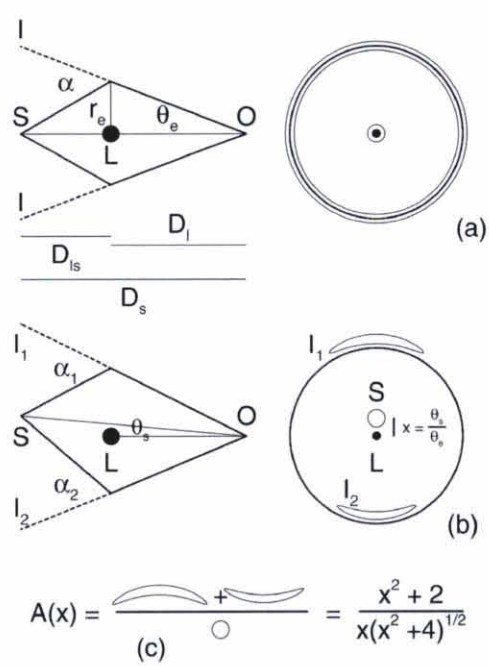
- SIM provides:
  - Astrometric motions of stars out to 20 kpc
- Why SIM?
  - Need astrometric accuracy
  - and sensitivity



Simulation by Kathryn Johnston (Wesleyan University)

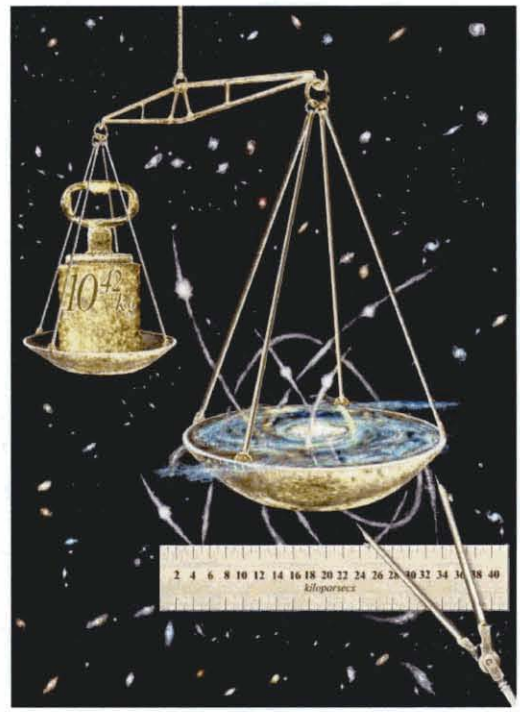
Galactic Structure from Microlensing



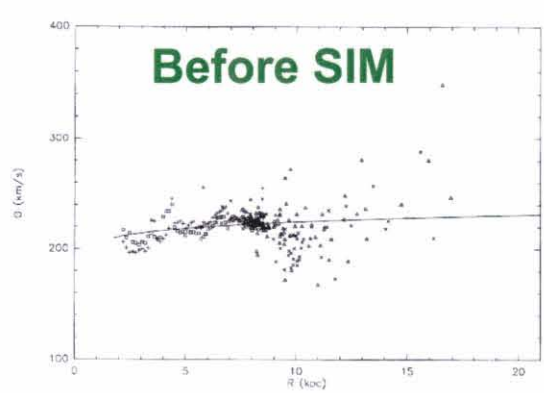


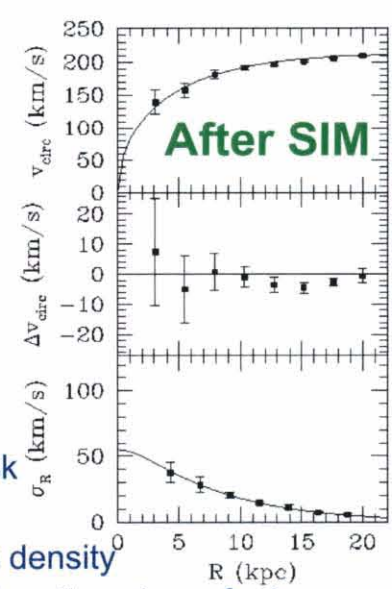
Taking the Measure of the Milky Way

- *Unique, legacy, measurements* of fundamental parameters of the Milky Way:
  - Mass scale → Total mass
  - Distance scale → Size
  - Dynamical scale → Rotation curve



Probe of Inner Galactic Potential

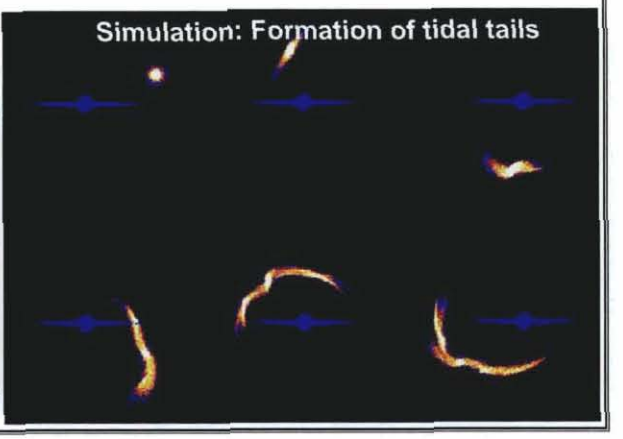




- SIM will measure:
  - Galactic rotation curve across entire disk
  - $V_{circ}(R)$ → disk potential to 2-3% ≤ $2R_o$
  - Local mass volume density and column density
  - Amplitude, pattern speed, shape, wavelengths, phase for large non-axisymmetries:
    - bars, warps, spiral arms

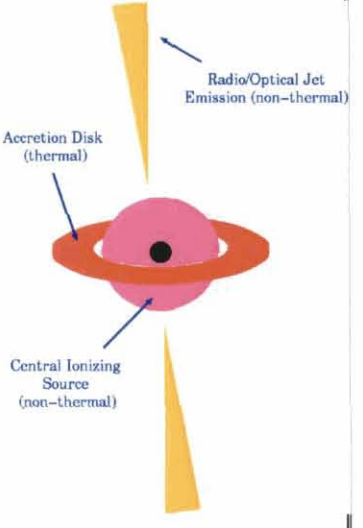
Mass of the Galaxy (Dark Halo)

- SIM is the only means for obtaining precision velocities in outer Galaxy
- SIM can determine mass vs. radius to $R > 200$ kpc via complementary methods:
  - **Jeans Equation**: ~1000 random field giants, Galactic globulars and satellite galaxies
  - Stars in **tidal streams** (e.g., Sagittarius): Milky Way potential from true 3-D orbits



Physics of Active Galactic Nuclei

- Does the most compact non-thermal optical emission from an AGN come from an *accretion disk* or from a *relativistic jet* ?
- Do the cores of galaxies harbor *binary supermassive black holes* remaining from galaxy mergers ?
- Can AGNs be used to 'anchor' the SIM astrometric reference frame (the grid) ?

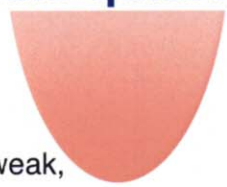


Location of the non-thermal emission

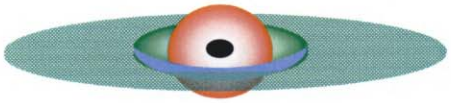
Expect no color shift,
(or small shift ~1-5 μas)
with no preferred axis;
no preferred variability direction

Expected
variability
direction:
along jet

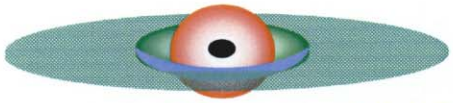
Radio-quiet AGN



(Jet is weak,
poorly
collimated,
or absent)



Radio-loud AGN

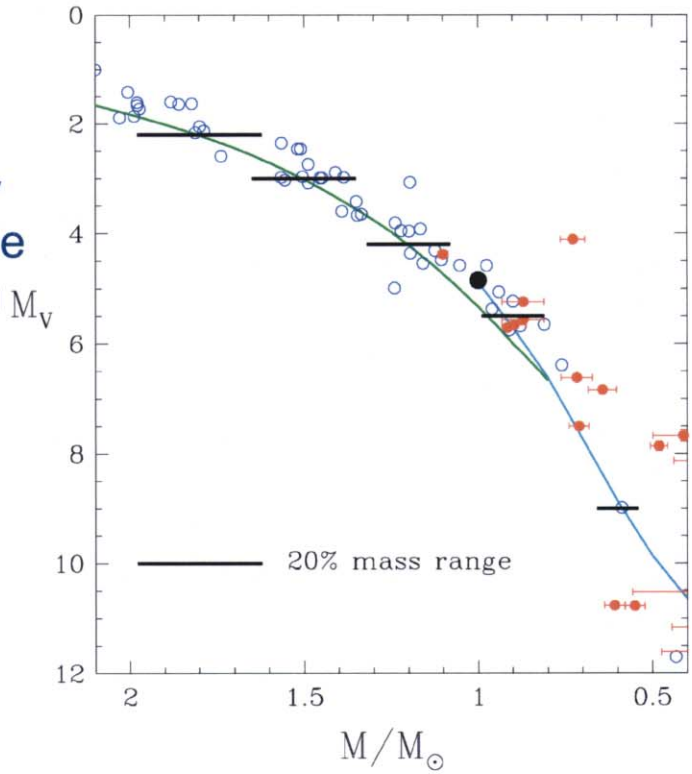


Stellar Astrophysics

- What is the mass of the largest star?
- What are the masses of black hole candidates?
- What are the masses of very young stars?
- What is the true dependence of the MLR on age?

Measuring Stellar Masses

- Masses are poorly known - even in the middle of the main sequence



Why Measure Precise (1%) Masses?

- **Individual stars:**
  - challenge stellar astrophysics models
    - location of true 'zero-age' main sequence
    - evolution within the main sequence
    - abundance effects
  - beginning and end of main sequence
    - what is the largest star?
    - boundary between stars and brown dwarfs
  - primary stars for planet detection
- **Populations of stars:**
  - mass-luminosity-age-metallicity relation
  - mass function of stars $dN / dM = f(M)$

State-of-the-art Masses for Binary System GL748AB

Masses — four parameters with HST:

P	2.4664 ± 0.0081	(0.3%)
a	0.1480 ± 0.0009	(0.6%)
π	0.0981 ± 0.0004	(0.4%)
f	0.3358 ± 0.0021	(0.6%)
M_A	0.3750 ± 0.0088	(2.4%)
M_B	0.1896 ± 0.0046	(2.4%)

The Need for SIM:

- *this is a relatively easy system*
- if P, a errors = 0 mass error still 1.3%
- if P, a errors = 0.1% and SIM determines π to 4 μas, f to 0.000014 (both 0.004%)

masses are known to 0.4%

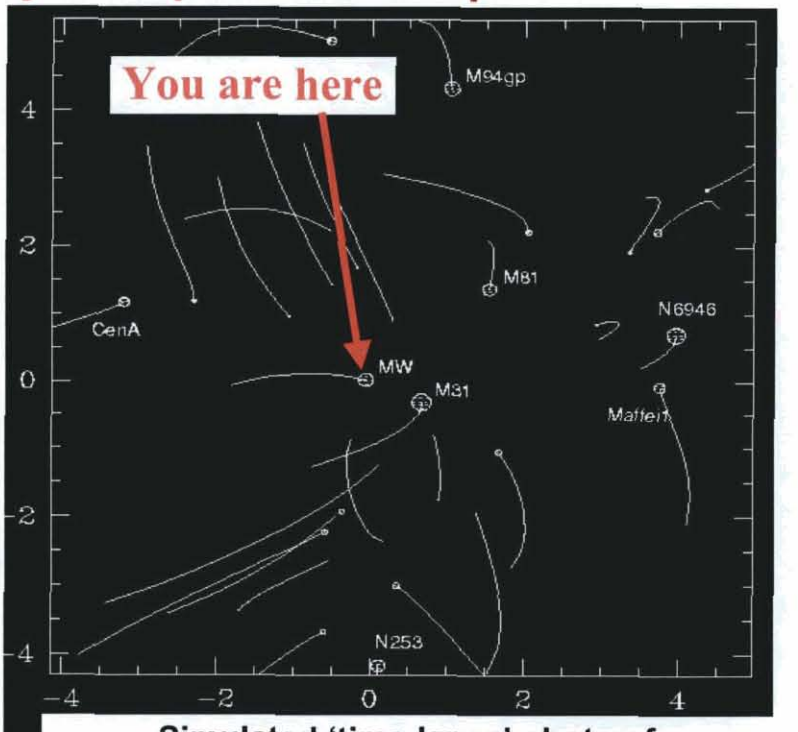
Dynamics of Galaxy Groups within 5 Mpc

Simulation from dynamical model

- Fidelity is limited because only 1-D velocity info is available (RV)

SIM will provide critical data for improving the models

- SIM will measure current 2-D velocities across the sky
- Models will then sample the full 6-D phase space



Simulated 'time-lapse' photo of 30 galaxies closest to our Milky Way (1-billion year exposure)

Proposal Opportunities: AO-2

- SIM Science Team (AO-1) - already awarded in 2000
  - 10 Key Projects; 5 Mission Scientists
- SIM Science Team (AO-2) - release in ~Oct 2005
  - Planet searches 1 - 2 Key Projects ?
  - Other large observing programs 1 - 2 Key Projects ?
  - Survey proposal in 'Snapshot Mode' mode 1 Key Project ?
  - Successful proposers (~2 - 3 teams) become members of the Science Team
  - Funding at $ 250 k /year for each Key Project selected
    - Covers preparatory science, analysis of SIM data, publication

Proposal Opportunities: General Observer

Proposals for 'Snapshot Mode'

- Small: ~1 - ~100 targets many proposals
  - Primarily parallax (or proper motions) for specific targets of interest to PI
  - PI just wants the astrometric parameters, with realistic error bars
  - PI needs *minimal interaction* with MSC for their science
- Medium: ~100 - ~1000 targets several proposals
- Large: ~1000 - ~10,000 targets one proposals
  - Large Projects should be proposed to AO-2 in 2005 as Key Projects
  - Key Project PIs are expected to *interact a lot* with MSC

Proposals for other modes, e.g.

- Targets fainter than V ~ 15 or parallaxes <~ 10μas
  - Require more than 10 visits, or more than 30s integrations
- Timed observations: interacting binaries, gravitational lenses
- Observations requiring a local reference frame

What is 'Snapshot' Mode ?

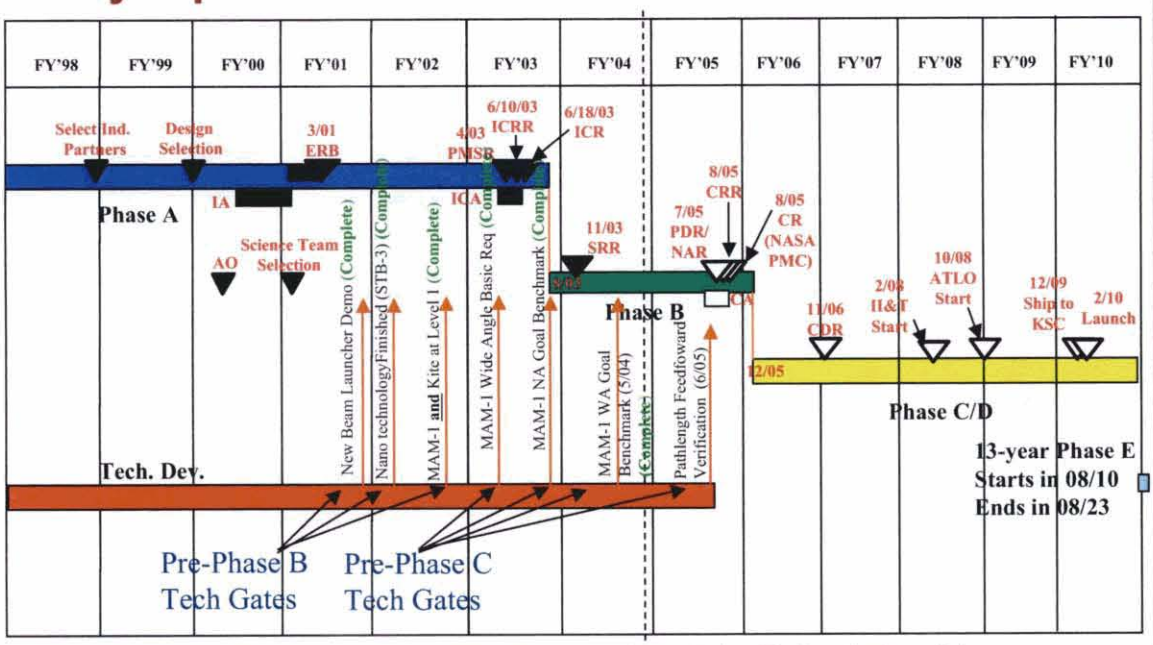
- 'Snapshot' Mode is a simplified SIM observing mode
  - Large number of targets (up to ~26,000)
  - Designed to yield *sub-milliarcsecond* positions, parallaxes, proper motions
  - Lower accuracy (~10-50 μas) than the ultimate possible
  - Brighter (V ~ 8-17) than the ultimate possible
  - *You don't need to be a black-belt astrometrist to use this mode*
- SIM 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.)

Allocation of Observing Time (nominal 5 years)

OBSERVING CATEGORY	% of years 0-2	% of years 2-5
Science observing time:		
Science Team (AO-1) (already awarded in 2000)*	36 %	36 %
Science Team AO-2 (more terrestrial planet searches)	9 %	9 %
Science Team AO-2 (other key science)	10 %	10 %
General Observer (GO-1) program (proposal call in 2007)	10 %	0 %
General Observer (GO)-2 program (proposal call in ~2011)	0 %	10 %
Director's Discretionary Time	4 %	4 %
Astrometric grid observation (excluding slews)	9 %	9 %
Spacecraft slews (~1 turn per hour)	12 %	12 %
Engineering time (including reserve)	10 %	10 %
Total	**100 %**	**100 %**

***Searches for terrestrial planets: 10.3%; other Key Projects 22.9%; Mission Scientists 2.9%**

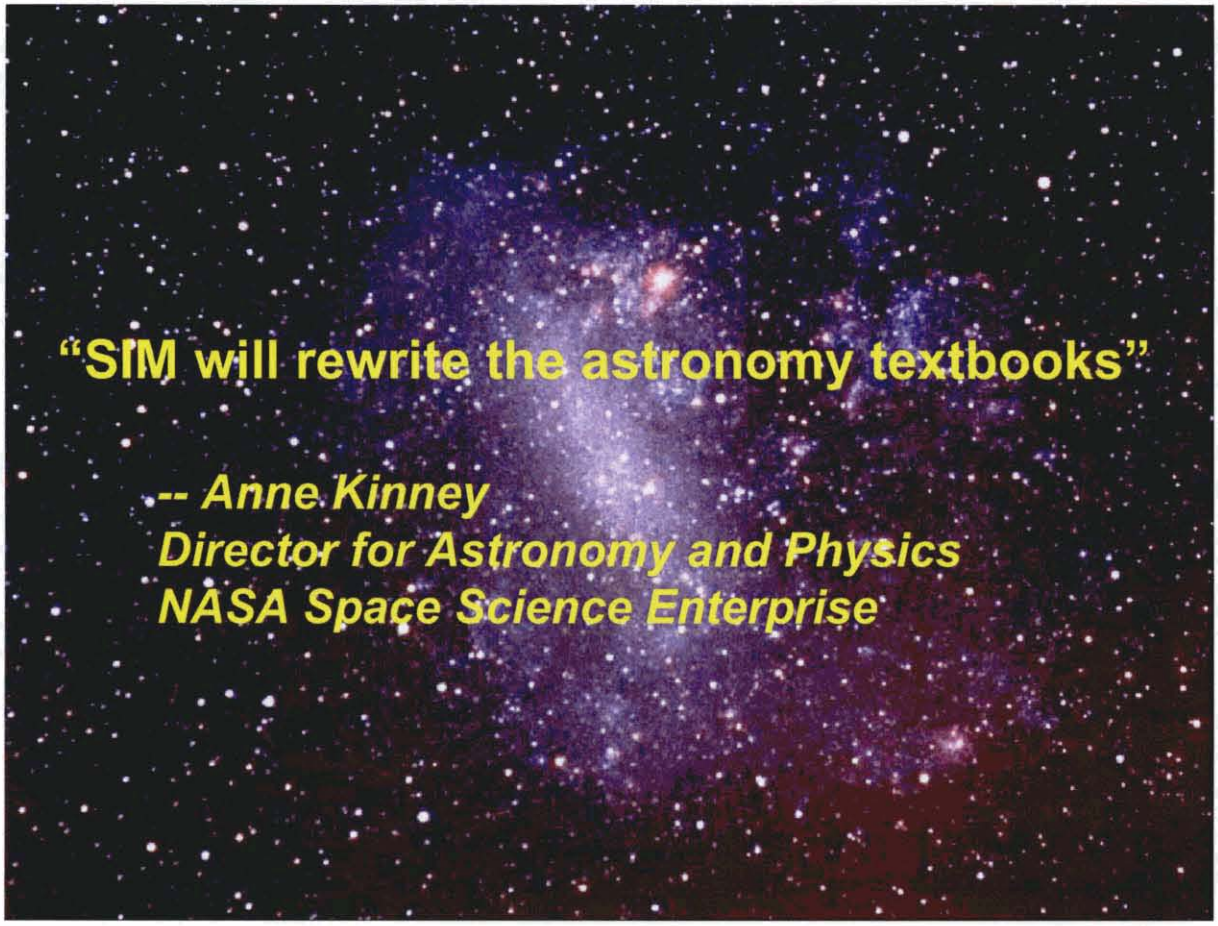
SIM Synoptic Baseline Schedule



ATLO = Assy, Test & Launch Ops
ERB = External Review Board
PMSR = Preliminary Mission & Systems Review
SRR = System Requirements Review
CA = Confirmation Assessment
IA = Independent Assessment
NAR = Non Advocate Review
ICRR = Initial Confirmation Readiness Review (JPL GPMC)
CDR = Critical Design Review
I&T = Integration & Test
PDR = Preliminary Design Review
ICR = Initial Confirmation Review (Code S EPMC)
CR = Confirmation Review (NASA PMC)
NASA PMC = Programmatic Management Council

Conclusions

- SIM is on track for a launch in 2010
- Project 'Phase C' start in October 2005
- SIM is a flexibly-pointed instrument
- Astrometric capability (wide angle)
  - 4 μas parallax precision on targets down to V = 20
    - Stellar and Galactic astrophysics
  - 1 μas *single measurement* accuracy
    - Sensitive to terrestrial-mass planets around the nearest stars
- New proposal opportunities
  - AO-2 for new (large) Key projects - 2005
  - General Observer program, for smaller proposals - 2006


"SIM will rewrite the astronomy textbooks"
-- Anne Kinney
Director for Astronomy and Physics
NASA Space Science Enterprise