Space Interferometry Mission
SIM PlanetQuest

S. Kulkarni
SIM Interdisciplinary Scientist
California Institute of Technology

SIM: Philosophy

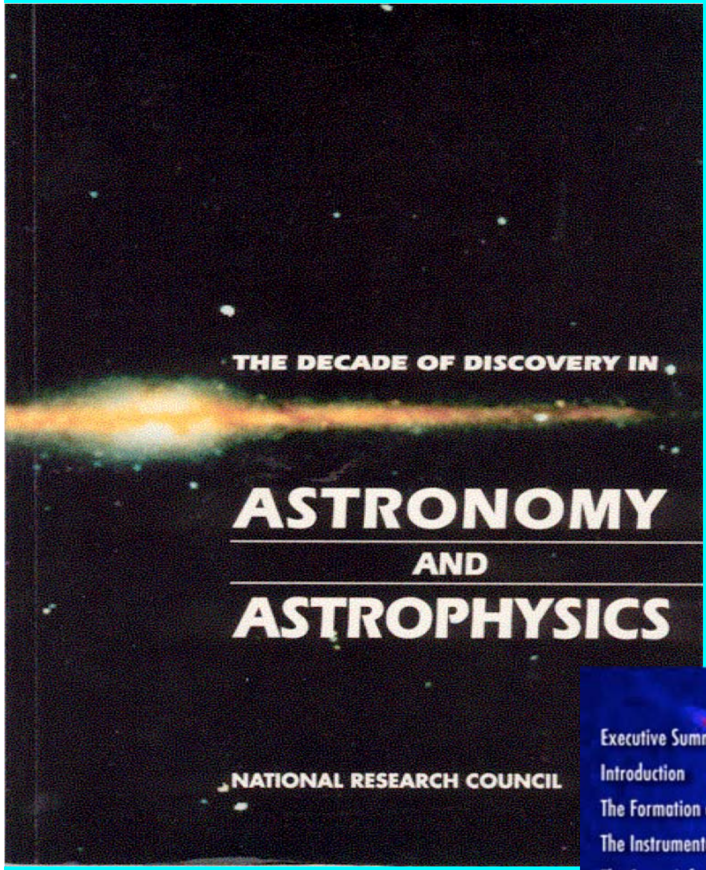
- "*You understand something truly only when you can measure it precisely*." Lord Kelvin
- *Confucius says "One excellent measurement is better than many mediocre measurements."*

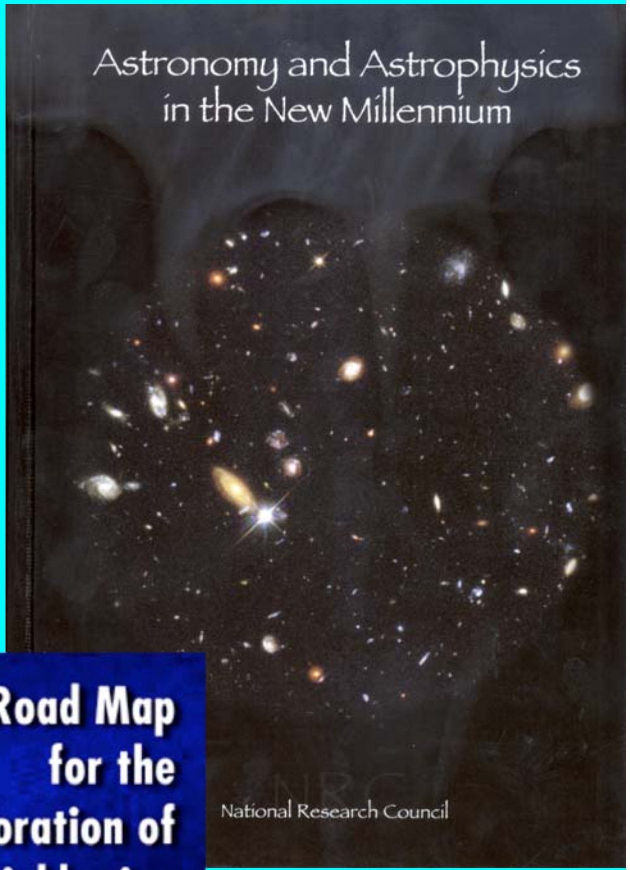
SIM in a nutshell

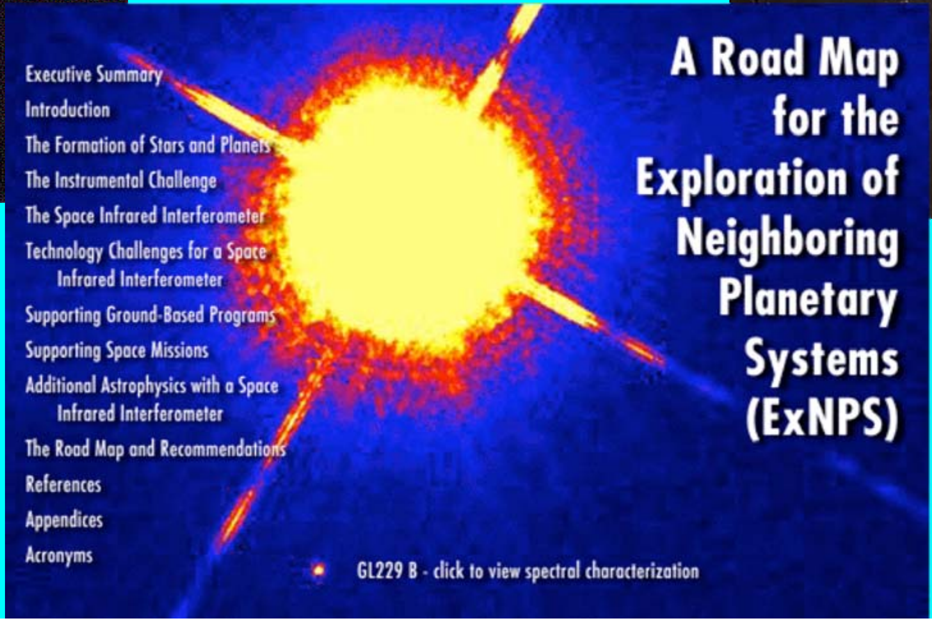
- Measure precise distances -- the basis to physics of stars and physics of the Universe
- Determine the mass makeup of our Galaxy and the Local Group

- *Detect earth mass planets in the habitable zone of nearby Sun-like stars*
- *Obtain insight into the formation & diversity of other planetary systems though orbit measurements*

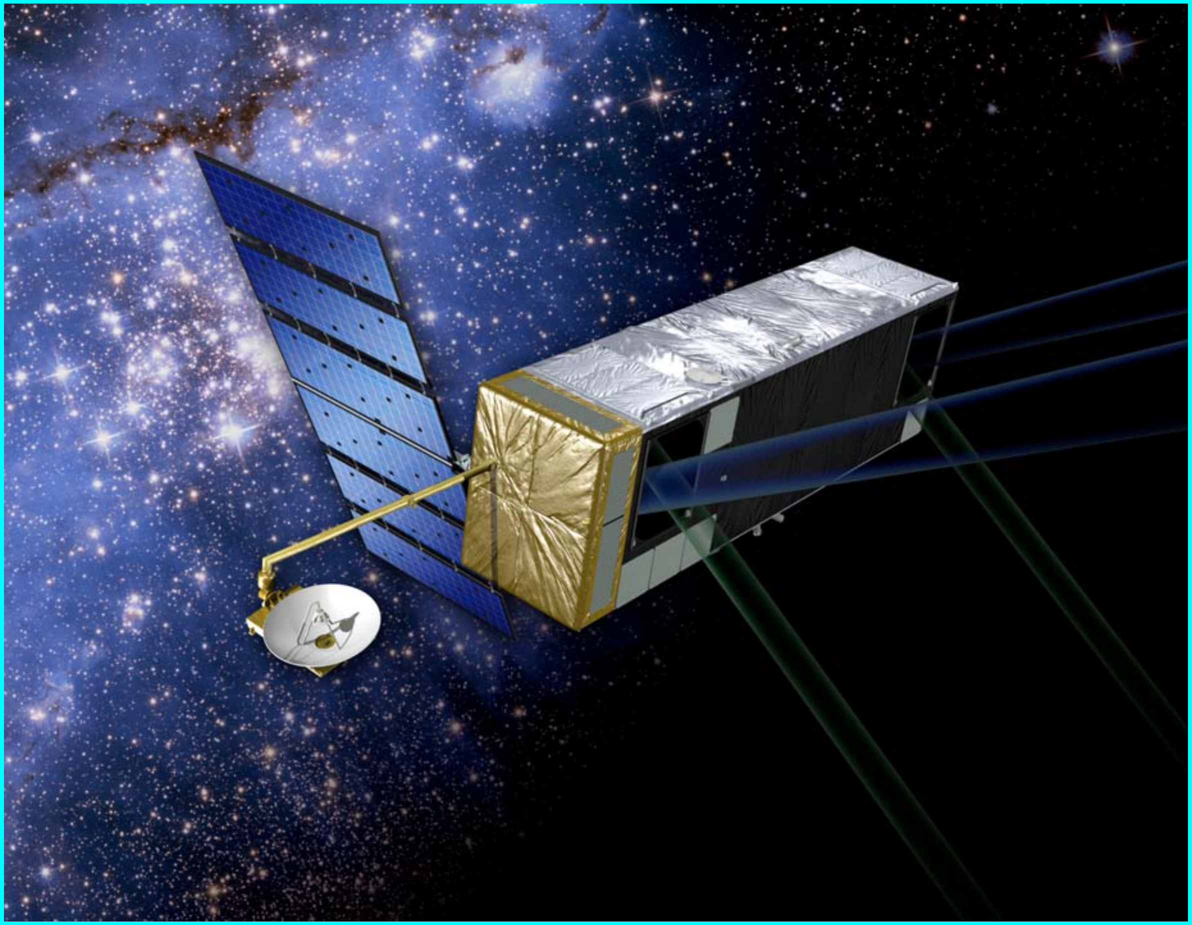
1990 & 2000 Decadal Reviews Endorse SIM







SIM: An Optical Michelson Interferometer



Global astrometry (5yr mission)

- 4 μas position (inertial)
- **<u>2.5 μas/yr</u>** proper motion
- **<u>4 μas</u>** parallax

Narrow angle astrometry, **<u>1 μas</u>**

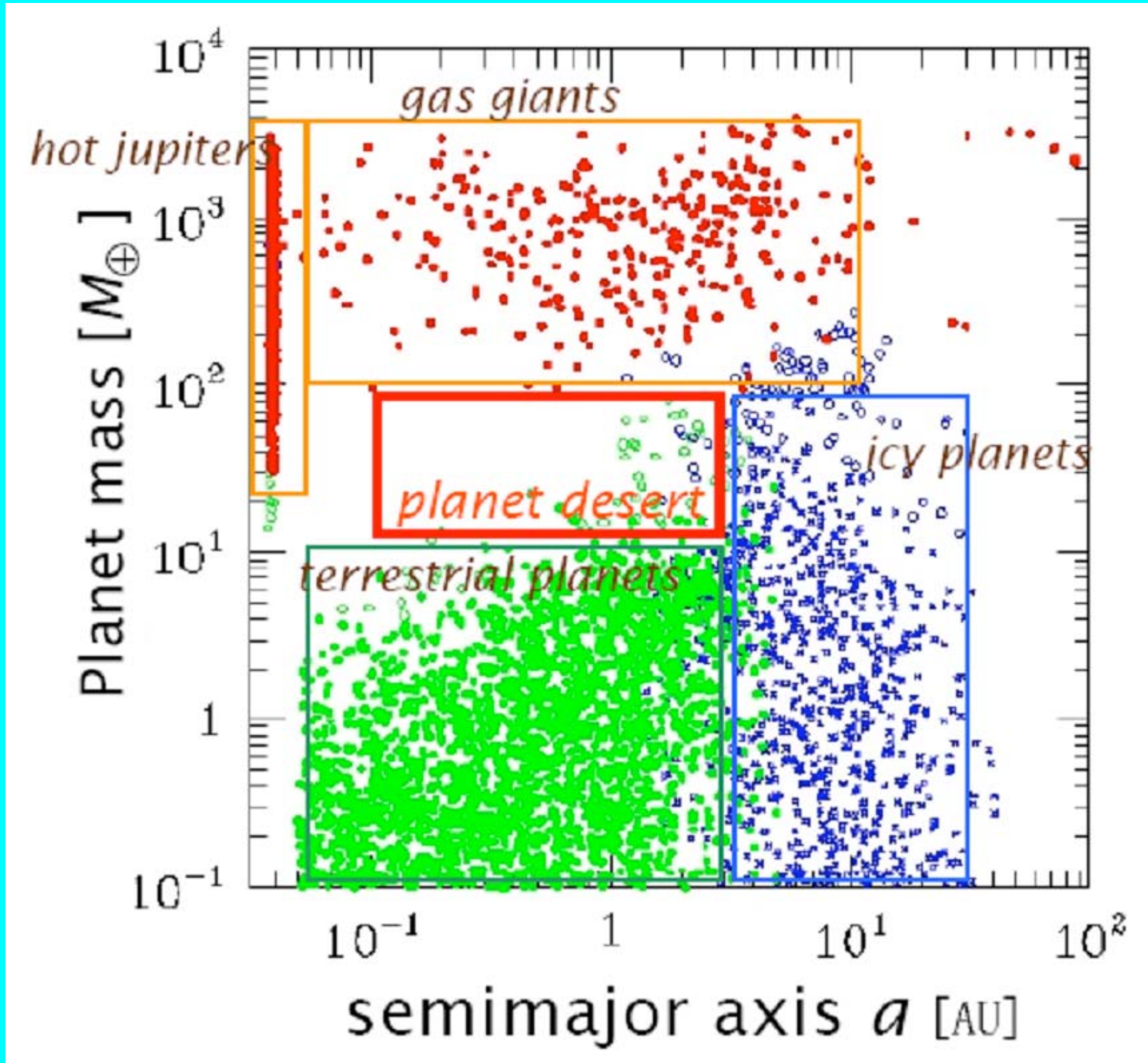
Extra-solar Planets Continues to be a Frontier Area

- Is our solar system rare or common?
- Are there earth-like planets around nearby stars?
- What sorts of planets exist around stars different from our Sun?

Extrasolar Planet Phase Space

Current harvest of 200 planets (RV): empirical constraints to planetary system formation.

Jupiter & Neptune appear to be the tip of the "planetary iceberg"



Simulations from Ida & Lin

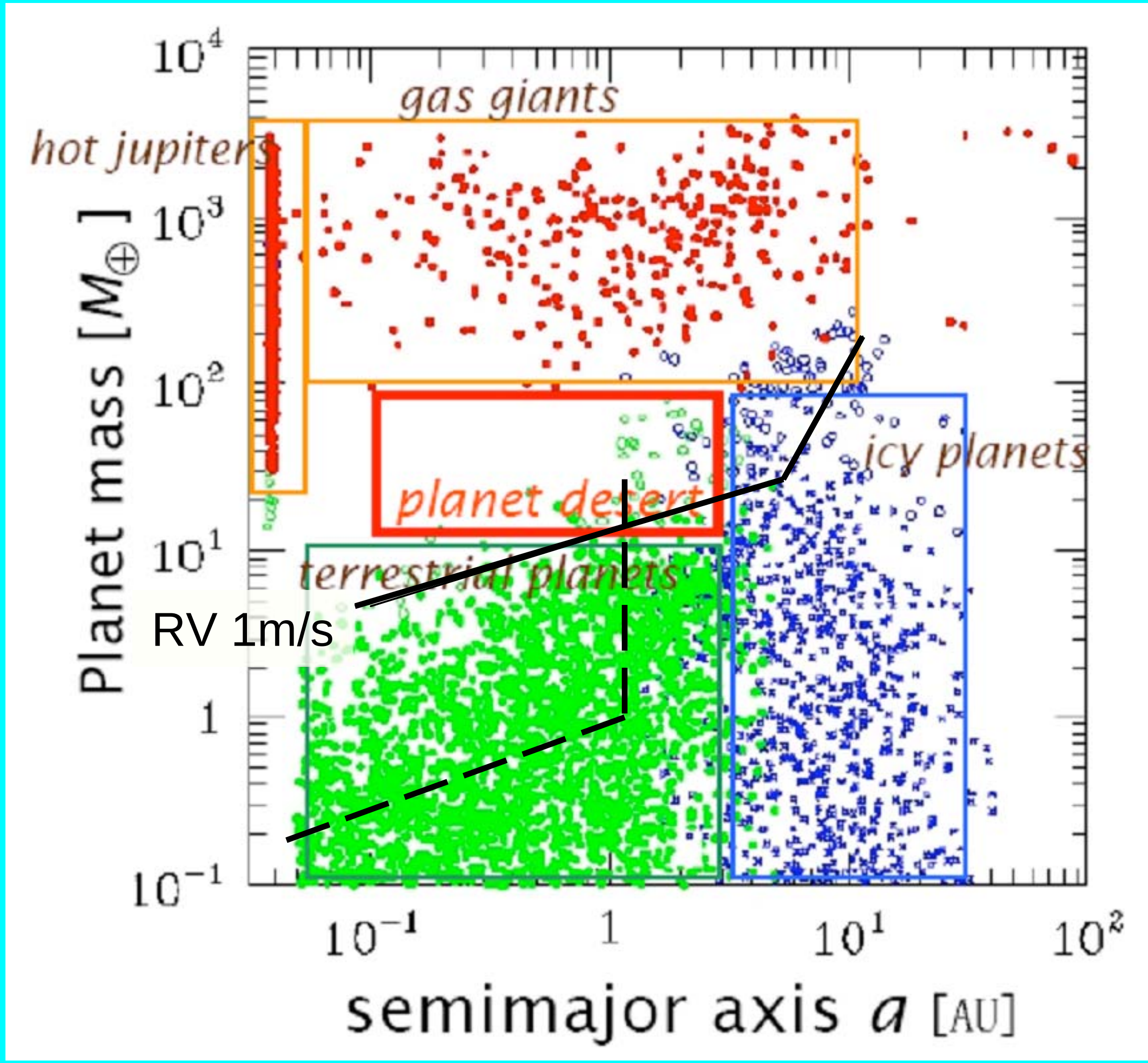
Discovery Space

RV will press on icy planets and close-in planets

Transit & Microlensing will provide statistical census of rocky planets

eg. Kepler, 1 kpc

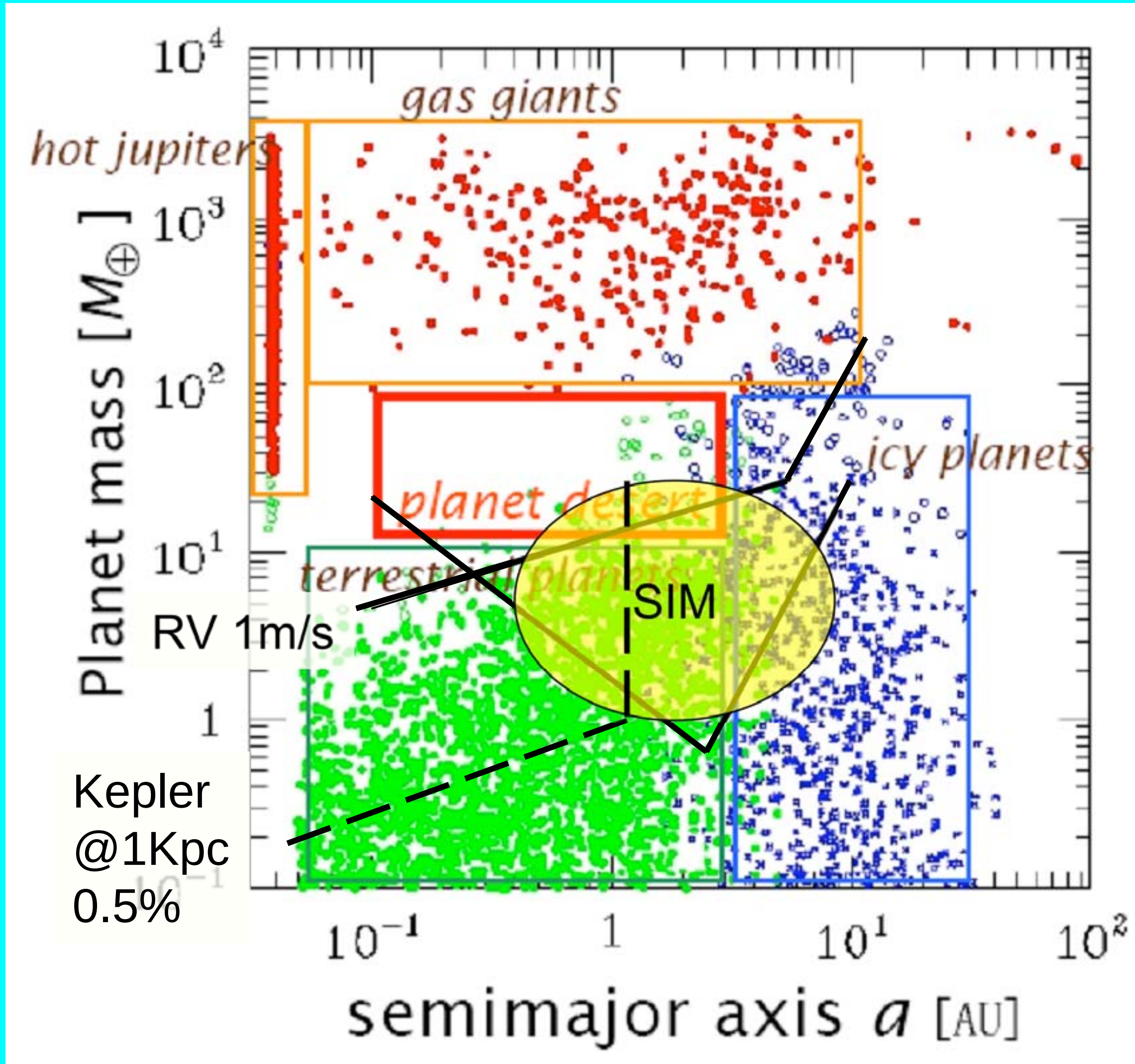
eg. Microlensing, 5 kpc



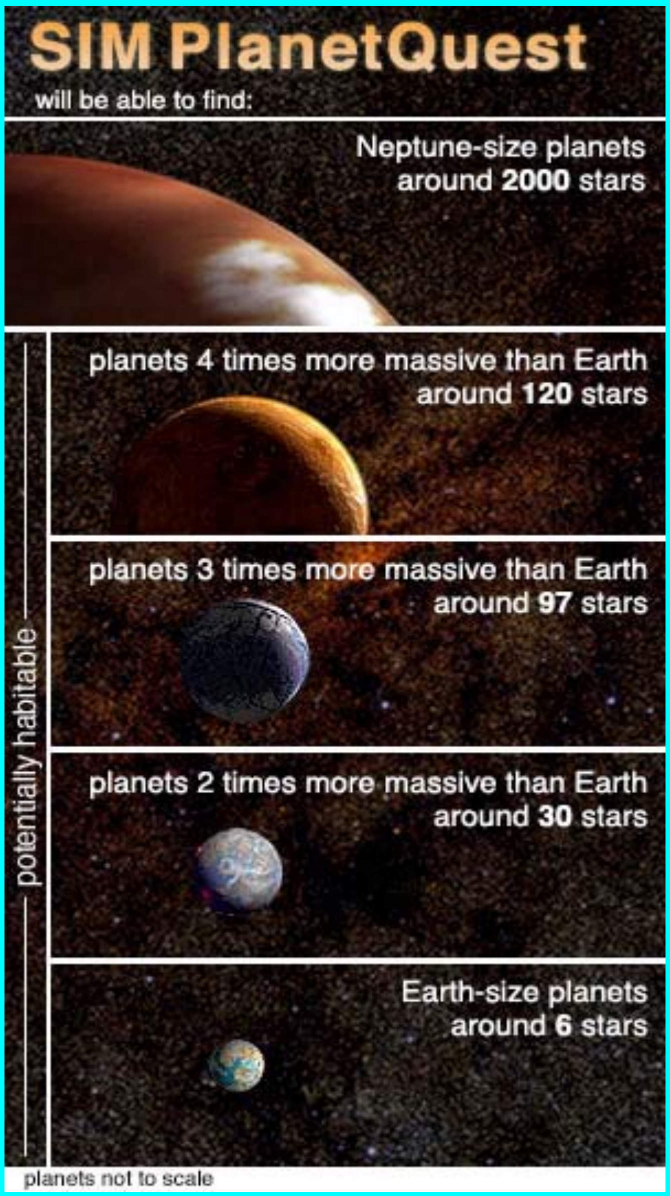
SIM Discovery Space

SIM: uniquely probes
1~10 M_{earth} (0.4~6.0AU)
(for nearby stars)

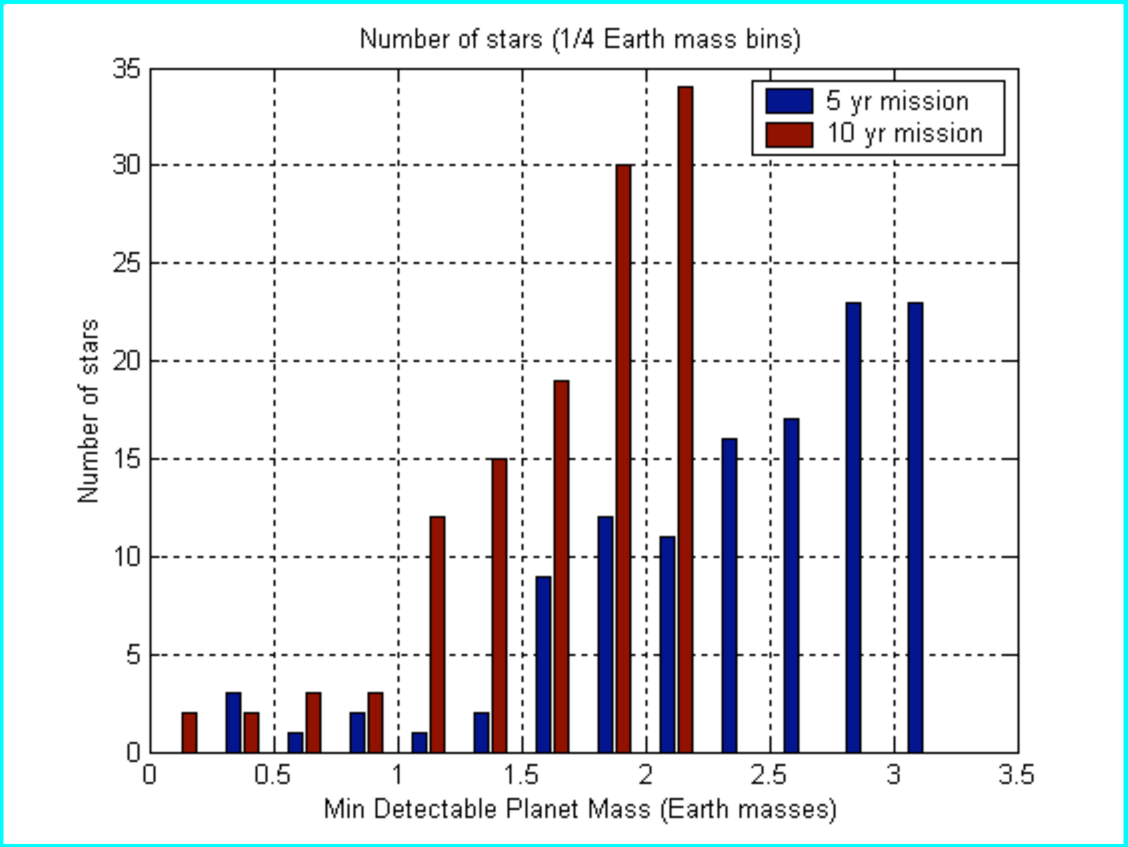
Orbital parameters and mass for RV planets



Deep Search of 120 nearby stars

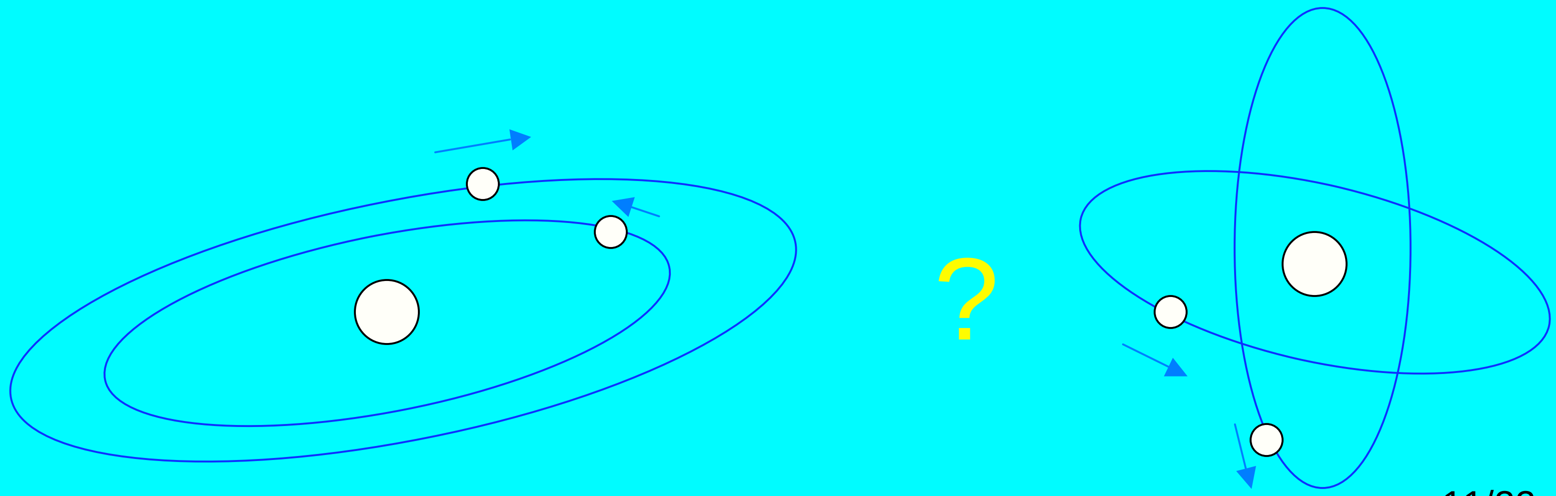


For the nearest solar-type stars hundred stars SIM has the capacity to detect earth mass planets in the Habitable zone

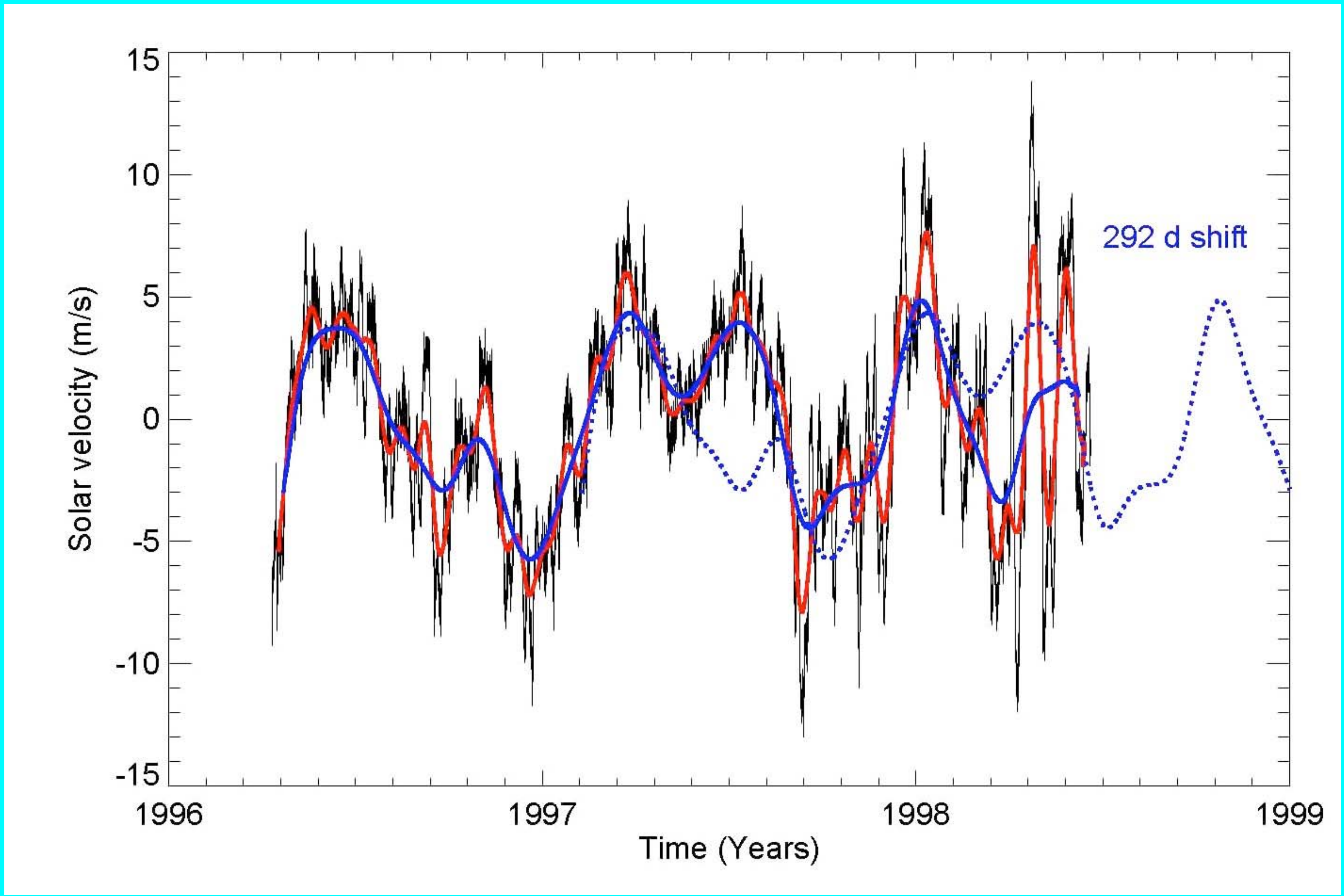


Planetary System Architectures & Diversity

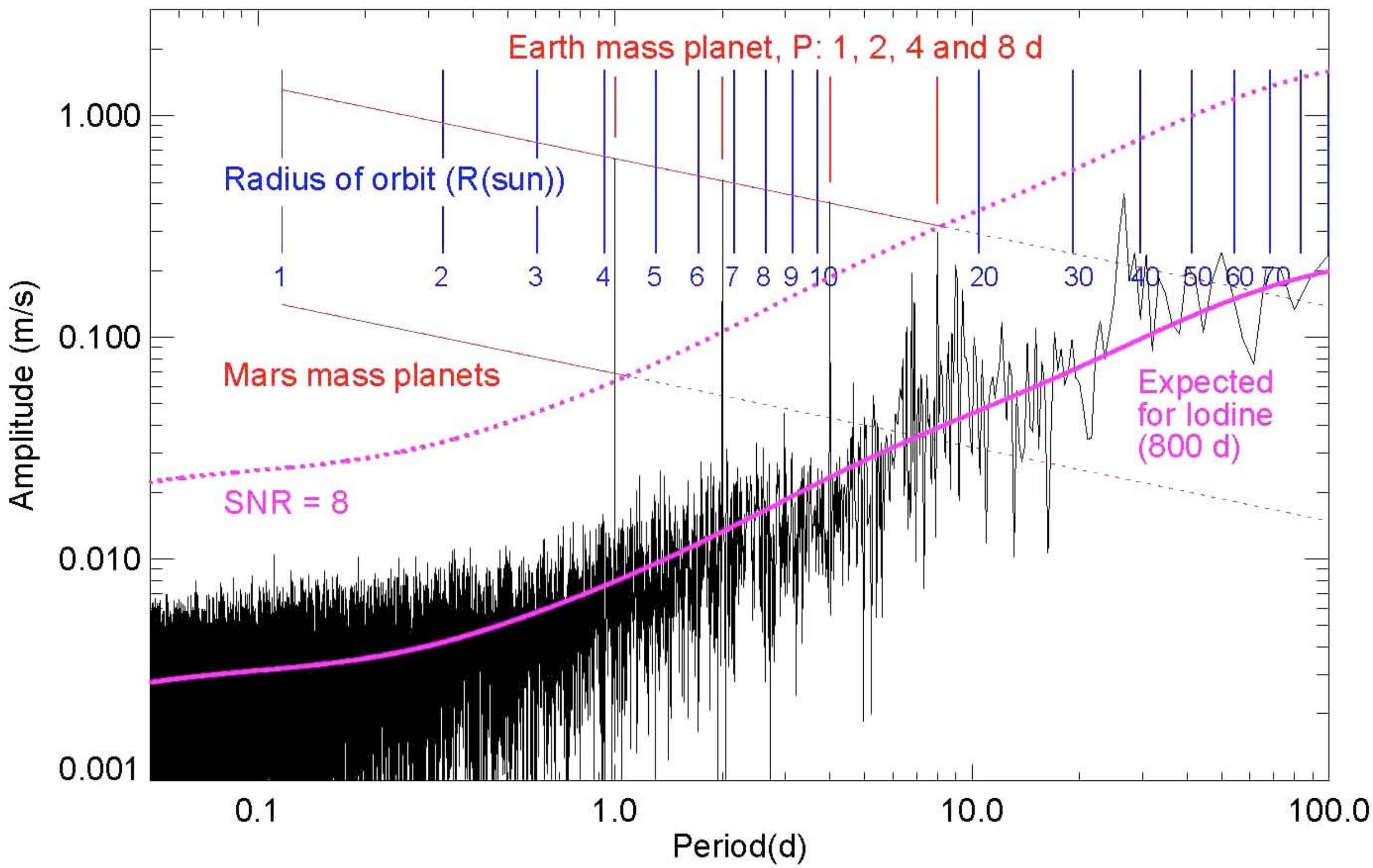
- Comprehensive survey of 2000 stars to probe Jovian/Neptunian planets (metalicity, debris disks, binary systems)
- Search for planets around stars not probed by any other technique (O, B, A, early F, white dwarfs).
- Uniquely probe for planets around young stars and thus provide insight into evolution of planetary systems
- Measure planet masses, eccentricities, orbital direction and mutual orbital inclinations of multiple planet systems



Full disk velocity of the Sun (800 d)

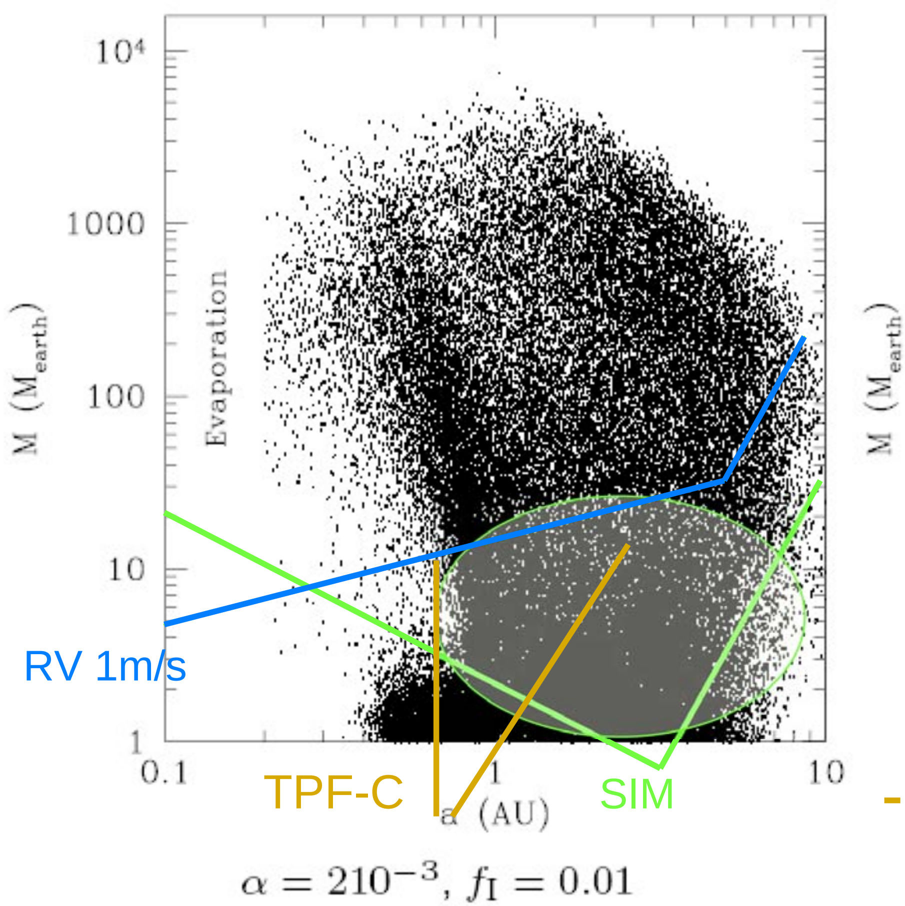


SoHo data (Kjeldsen)



Earth mass planet, P: 1, 2, 4 and 8 d
Radius of orbit (R(sun))
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
Mars mass planets
SNR = 8
Expected
for Iodine
(800 d)
Amplitude (m/s)
1.000
0.100
0.010
0.001
0.1
1.0
10.0
100.0
Period(d)

SIM provides targets to TPF



⟹ the majority of embryos do not become giants

Benz, et al. IAU Coll 200, 2005, p 1.

“No Distance, (mostly) no physics”

The history of astronomy is entwined with the determination of reliable distances

- Size of the Galaxy
- Size of the Local Group
- Size of the Universe
- Origin of Gamma-ray bursts

- SIM is a “distance measuring” machine
  - Poorly understood objects
  - New classes of objects, transients (e.g. PanSTARRS, LSST)
  - Rare objects (Neutron Star Systems, Black Hole Systems)

A true legacy: Distances to classes of stars

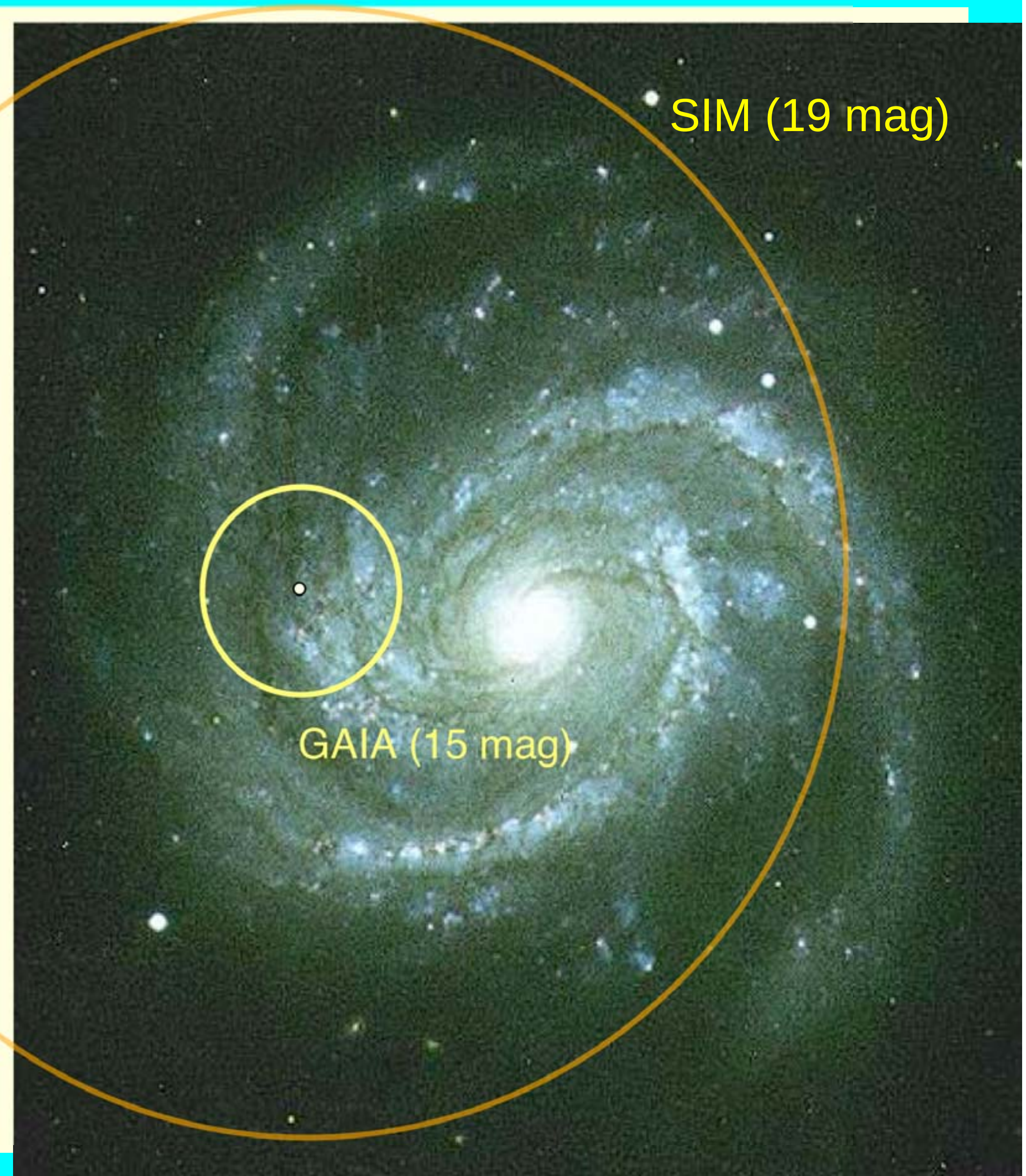
- Wolf Rayet Stars
- FK Comae Stars
- FG Saggitae
- SV Cen
- V838 Mon
- SX Phe
- High latitude B stars

…………

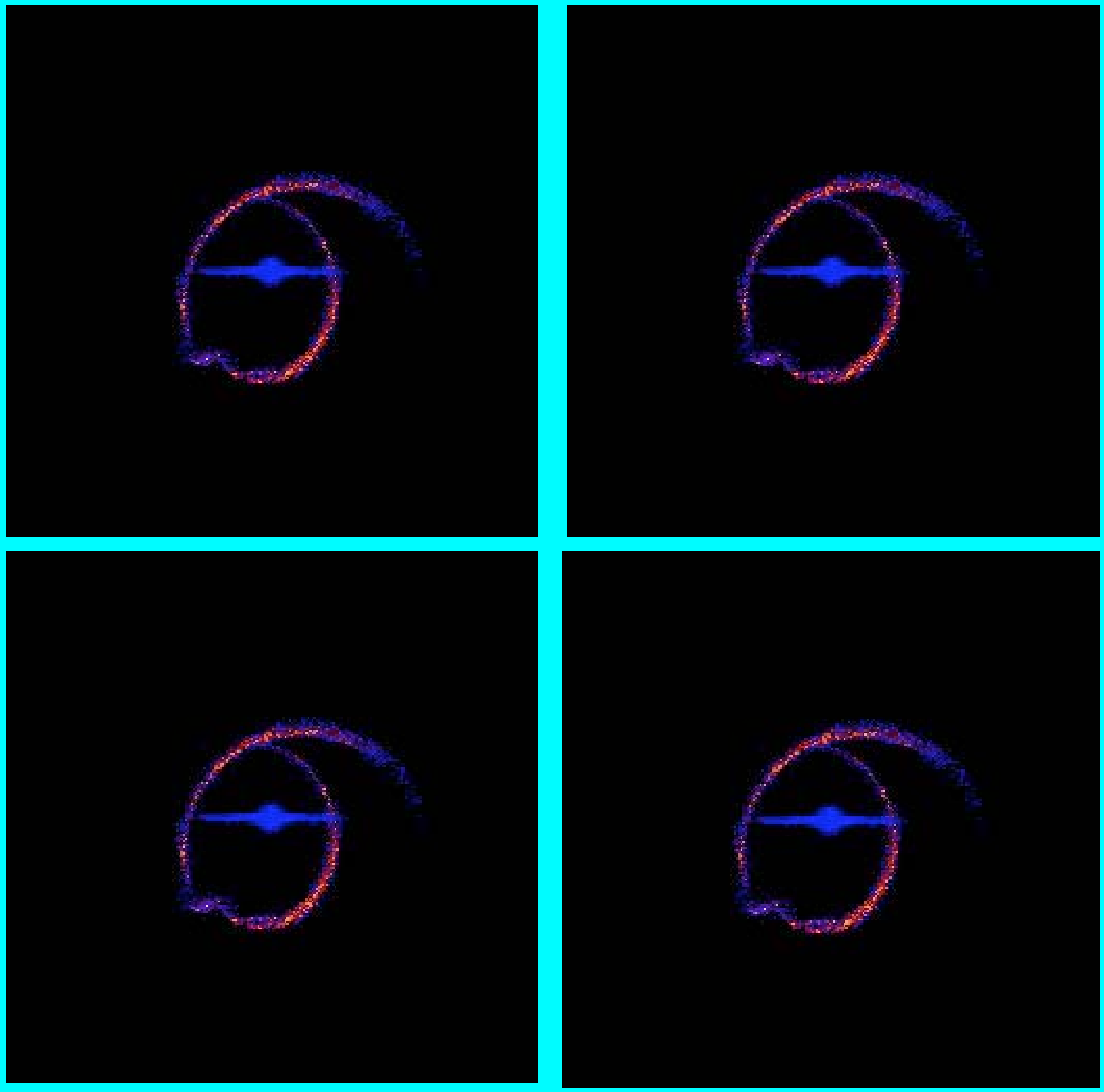
Trimble

SIM has a Galactic Reach

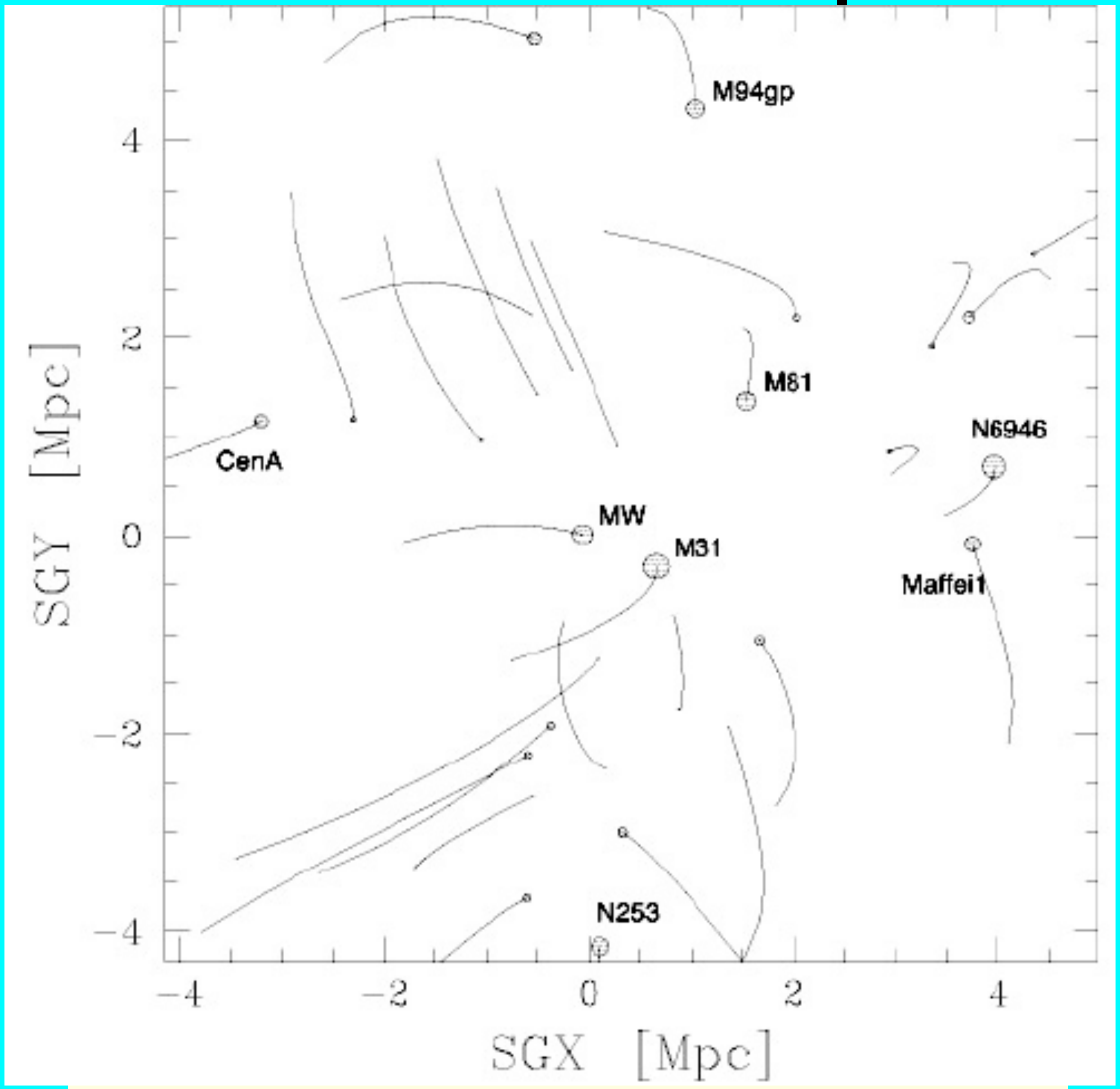
	1%	10%
SIM	2.5 kpc	25 kpc
GAIA	0.4 kpc	4 kpc
Hipparcos	0.010 kpc	0.1 kpc



Shape of our Galaxy



Matter Distribution of the Local Group



Simulated 1 Gyr trajectories of our neighbours

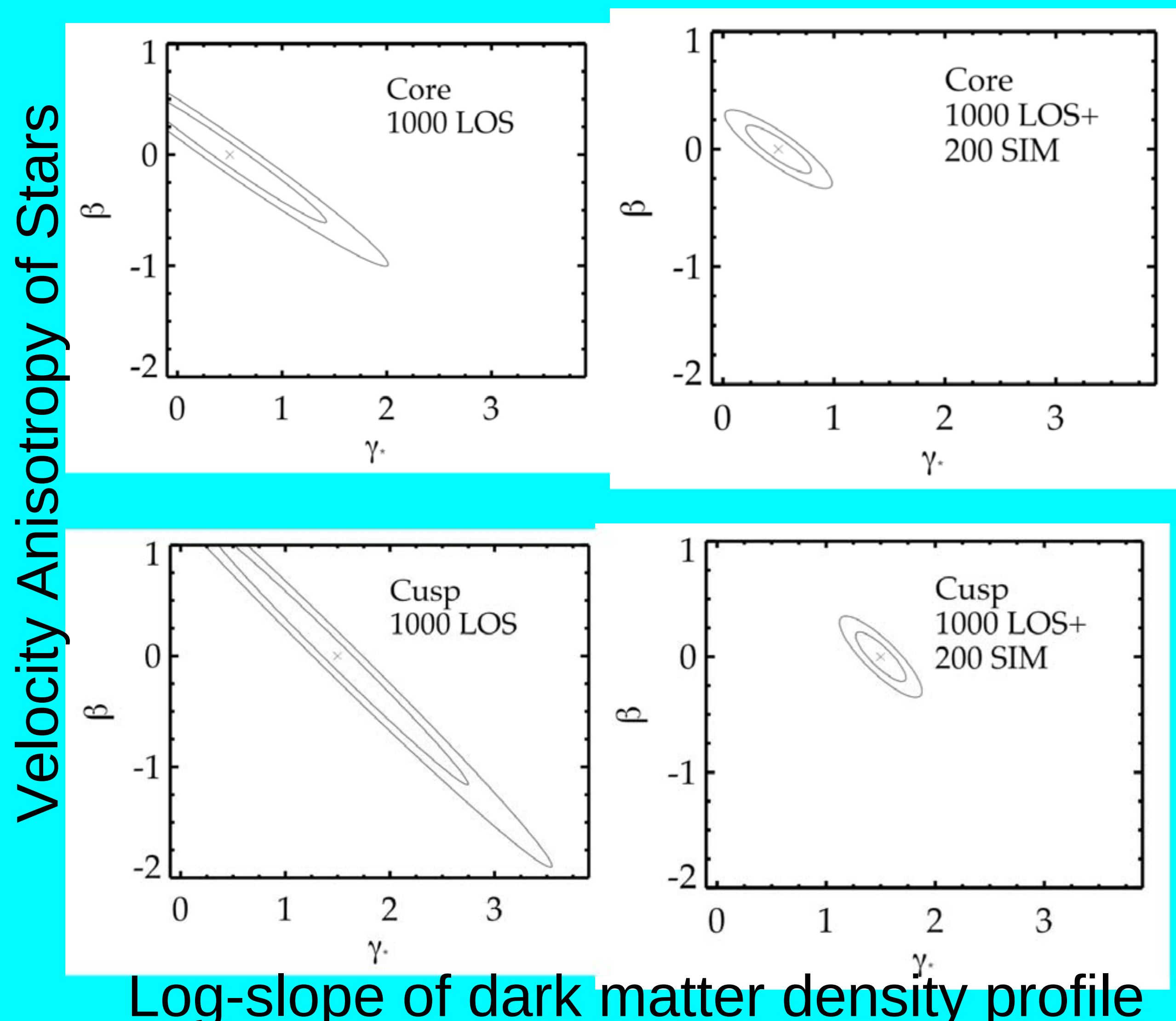
Determining the Nature of Dark Matter with SIM

Predictions:

- Cold Dark Matter: central density cusps
- Warm Dark Matter: central density cores

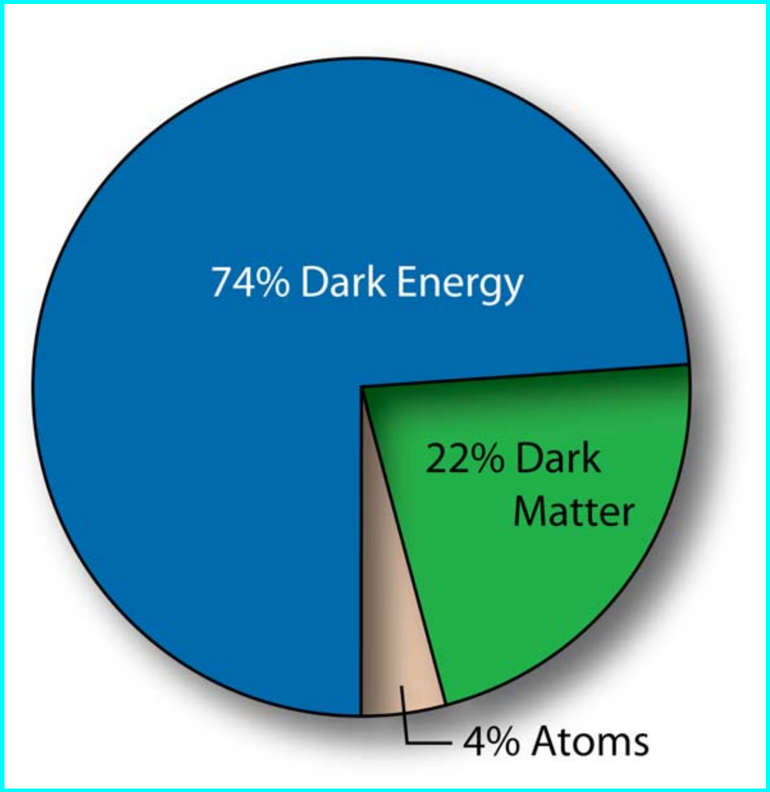
Tests:

- **dSph's**: DM dominated and low mass.
- Current:Strong degeneracy between central density slope and velocity anisotropy
- Future: 200 proper motions with SIM will break this degeneracy.



Strigari, Bullock, Kaplinghat, Kazantzidis, Majewski, & Munoz (2006)

A COSMIC PROBLEM: The Ghost of Hubble (7% is not good enough)



Precision cosmology is limited by precision (and accuracy) of Hubble's constant

•SIM can undertake a thorough calibration of Galactic Cepheids

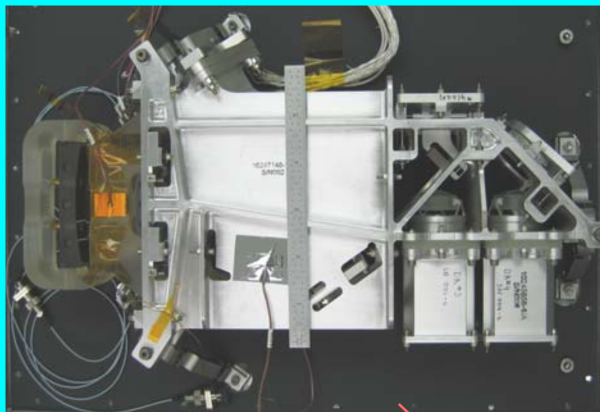
•SIM can measure the distances to M31 and M33 (rotational parallax)

•SIM can provide an independent determination of the age of the globular clusters

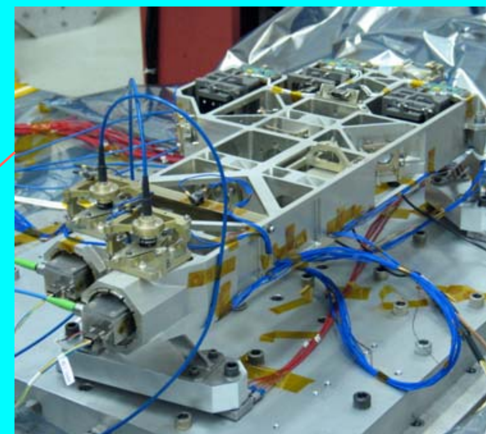
Fundamental Astronomy & Fundamental Physics

- SIM is uniquely suited to probe the true mass spectrum of our Galaxy
  - Microlensing+SIM = mass spectrum
- SIM has the ability to determine masses of neutron stars and black holes
  - Stellar black holes .. Lab for strong gravity and lab for jet formation
  - Neutron stars … Lab for dense matter (e.g. Vela X-1 and equation of state)

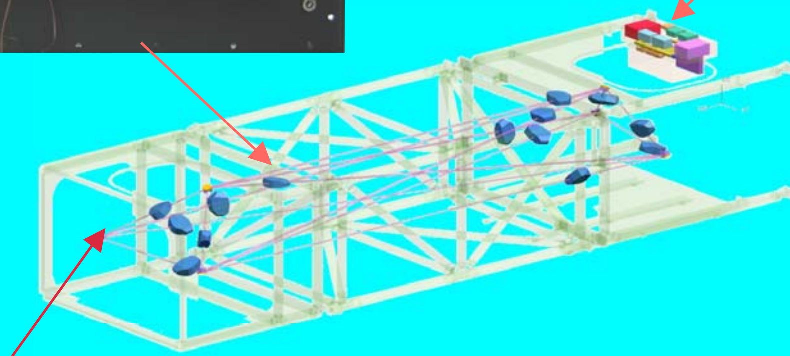
We are ready!

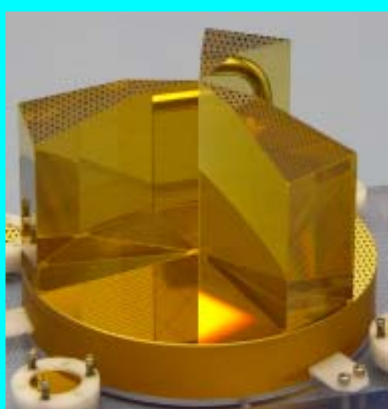


External Metrology Launcher



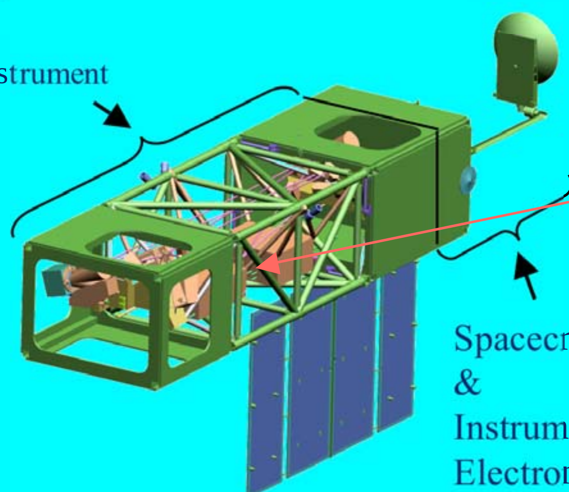
Metrology Source



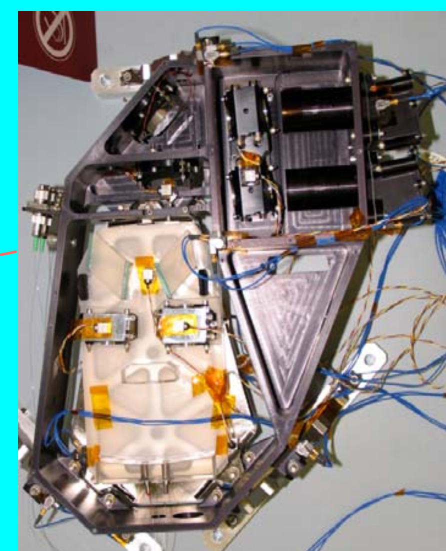


Double Corner Cube

Instrument



Spacecraft & Instrument Electronics



Internal Metrology Launcher

Nanometer Control & Picometer Knowledge: Flight Ready Hardware (TRL6)

SIM: Mature, Robust & Now

- SIM is technically ready to launch in 2012
  - Result of $500M (over a 10-year period) technology and design investment
- Run out cost meets NASA target for a 2012 launch
  - Through launch $1,560M (FY06)
  - Operations $ 370M (FY06) [5.5-yr ops + 1.5-yr archive)
- Development plans extraordinarily robust
  - Conservative Phase C/D budget reserves (43%) with appropriate schedule and technical margins

New Ideas

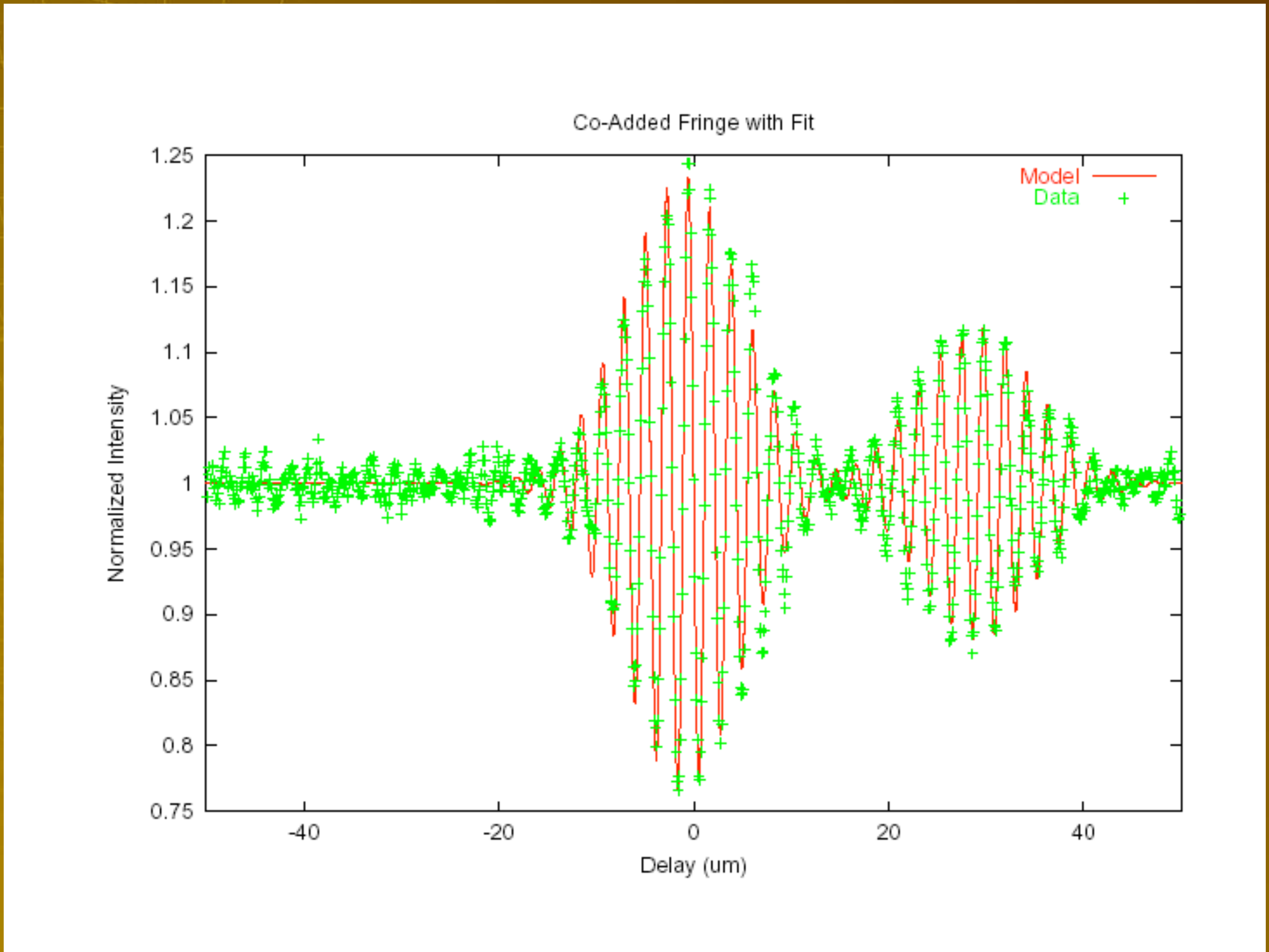
- 50% of SIM time is yet to be allocated
- Start thinking of key projects and innovative projects

PHASES:

Palomar High-precision
AStrometric Exoplanet Search

Caltech, MSC, JPL, MIT
(with Lane, Muterspaugh)

Scanning the Fringe

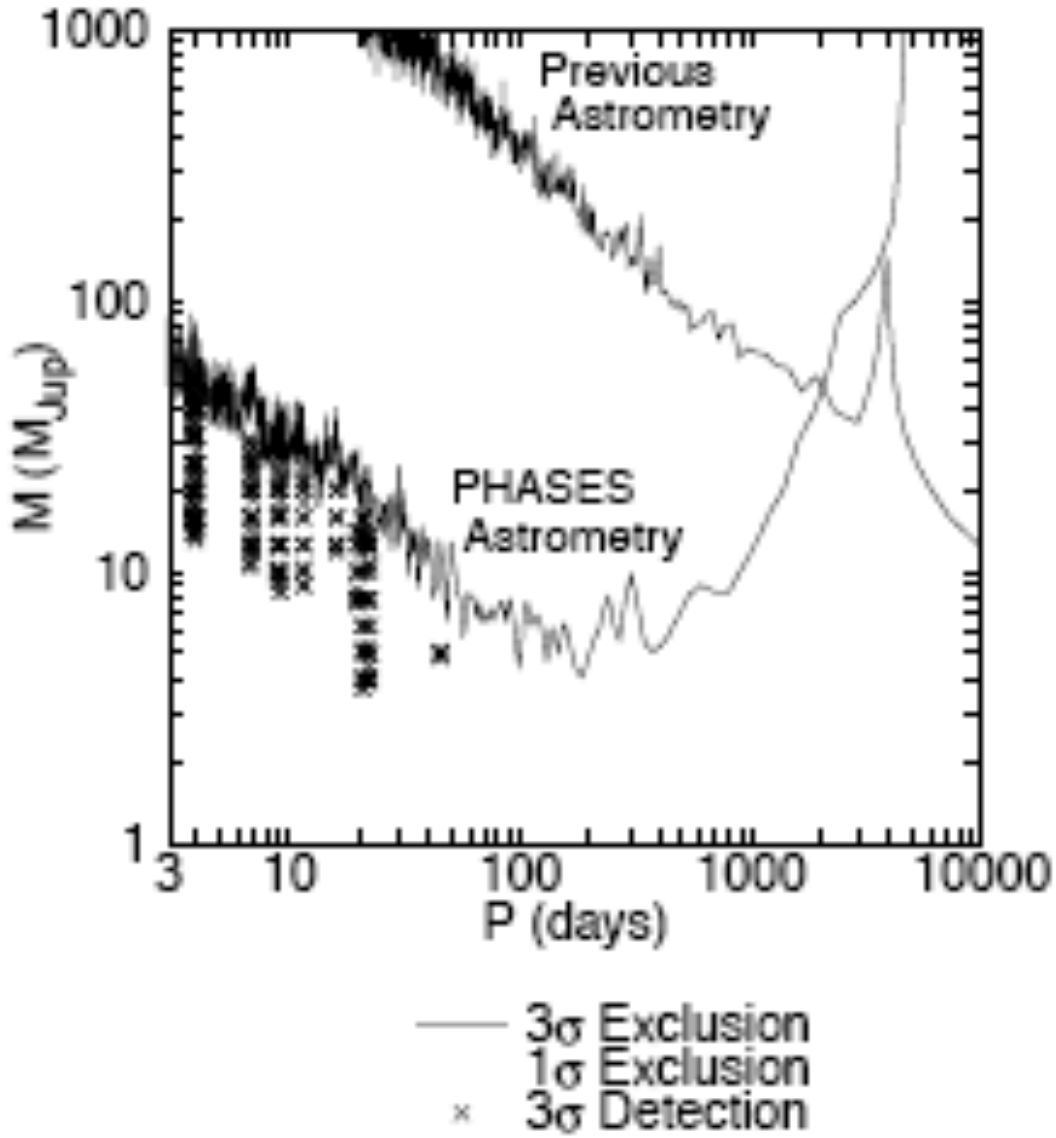


del Equulei

	Söderhjelm (1999)	Pourbaix (2000)	RV	PHASES	PHASES + RV	PHASES + Pre. + RV
P (yr)	5.713	5.703 $\pm$0.0070	5.706 $\pm$0.003	5.40 $\pm$0.11	5.7059 $\pm$0.0003	5.7058 $\pm$0.0003
P (days)			2084.08 $\pm$0.92	1974 $\pm$39	2084.07 $\pm$0.12	2084.05 $\pm$0.11
T_0 (yr)	1992.85	1981.47 $\pm$0.012	2004.285 $\pm$0.015	2004.299 $\pm$0.002	2004.2954 $\pm$0.001	2004.2950 $\pm$0.001
T_0 (MJD)			53109.9 $\pm$5.5	53114.53 $\pm$0.75	53112.90 $\pm$0.45	53112.76 $\pm$0.42
e	0.44	0.440 $\pm$0.0046	0.4519 $\pm$0.0029	0.415 $\pm$0.008	0.437001 $\pm$0.000076	0.436983 $\pm$0.000072
a (mas)	231	232 $\pm$1.8		222.8 $\pm$3.2	231.85 $\pm$0.11	231.88 $\pm$0.11
$V_{0,Lick}$ (km s^{-1})			-15.398 $\pm$0.097		-15.40 $\pm$0.10	-15.40 $\pm$0.11
$V_{0,DAO}$ (km s^{-1})			-15.876 $\pm$0.074		-15.875 $\pm$0.078	-15.875 $\pm$0.081
$V_{0,C}$ (km s^{-1})		-15.85 $\pm$0.074	-15.728 $\pm$0.095		-15.73 $\pm$0.10	-15.73 $\pm$0.10
$V_{0,Keck}$ (km s^{-1})						
M_1 ($M_\odot$)		1.19 $\pm$0.034			1.192 $\pm$0.012	1.193 $\pm$0.012
M_2 ($M_\odot$)		1.12 $\pm$0.032			1.187 $\pm$0.011	1.188 $\pm$0.012
$M_1 + M_2$ ($M_\odot$)	2.35				2.380 $\pm$0.018	2.380 $\pm$0.019
M_1/M_2	1.06 $\pm$0.03	1.06 $\pm$0.018	1.004 $\pm$0.011		1.004 $\pm$0.012	1.004 $\pm$0.012
i (deg)	99	99.0 $\pm$0.43		99.520 $\pm$0.052	99.394 $\pm$0.020	99.396 $\pm$0.019
ω (deg)	3	8.0 $\pm$1.0	187.01 $\pm$0.91	188.53 $\pm$0.25	187.96 $\pm$0.12	187.92 $\pm$0.11
Ω (deg)	203	203.8 $\pm$0.29		203.292 $\pm$0.044	203.301 $\pm$0.046	203.312 $\pm$0.043
π (mas)	54.32 $\pm$0.90	55.0 $\pm$0.67			54.38 $\pm$0.14	54.39 $\pm$0.15
d (pc)					18.388 $\pm$0.048	18.386 $\pm$0.050
a (AU)					4.263 (Derived)	4.263 (Derived)
$a \sin i$ (AU)			4.186 $\pm$0.011		4.206 (Derived)	4.206 (Derived)
K_1 (km s^{-1})			12.224 $\pm$0.074		12.181 (Derived)	12.182 (Derived)
K_2 (km s^{-1})			12.272 $\pm$0.074		12.229 (Derived)	12.230 (Derived)

Table 1: Orbit models for δ Equulei. Pre.: Previous differential astrometry measurements, listed in Tables 3, 4, and 5.

Beta Corona Borealis



Muterspaugh et al.

0 2005|doi:10.1038/nature03856 nature

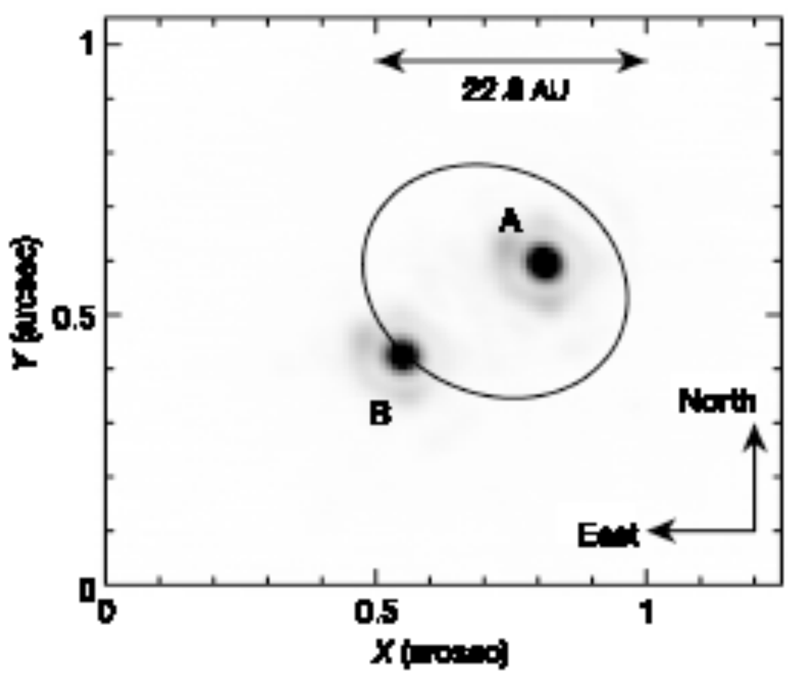
LETTERS

An extrasolar giant planet in a close triple-star system

Q1

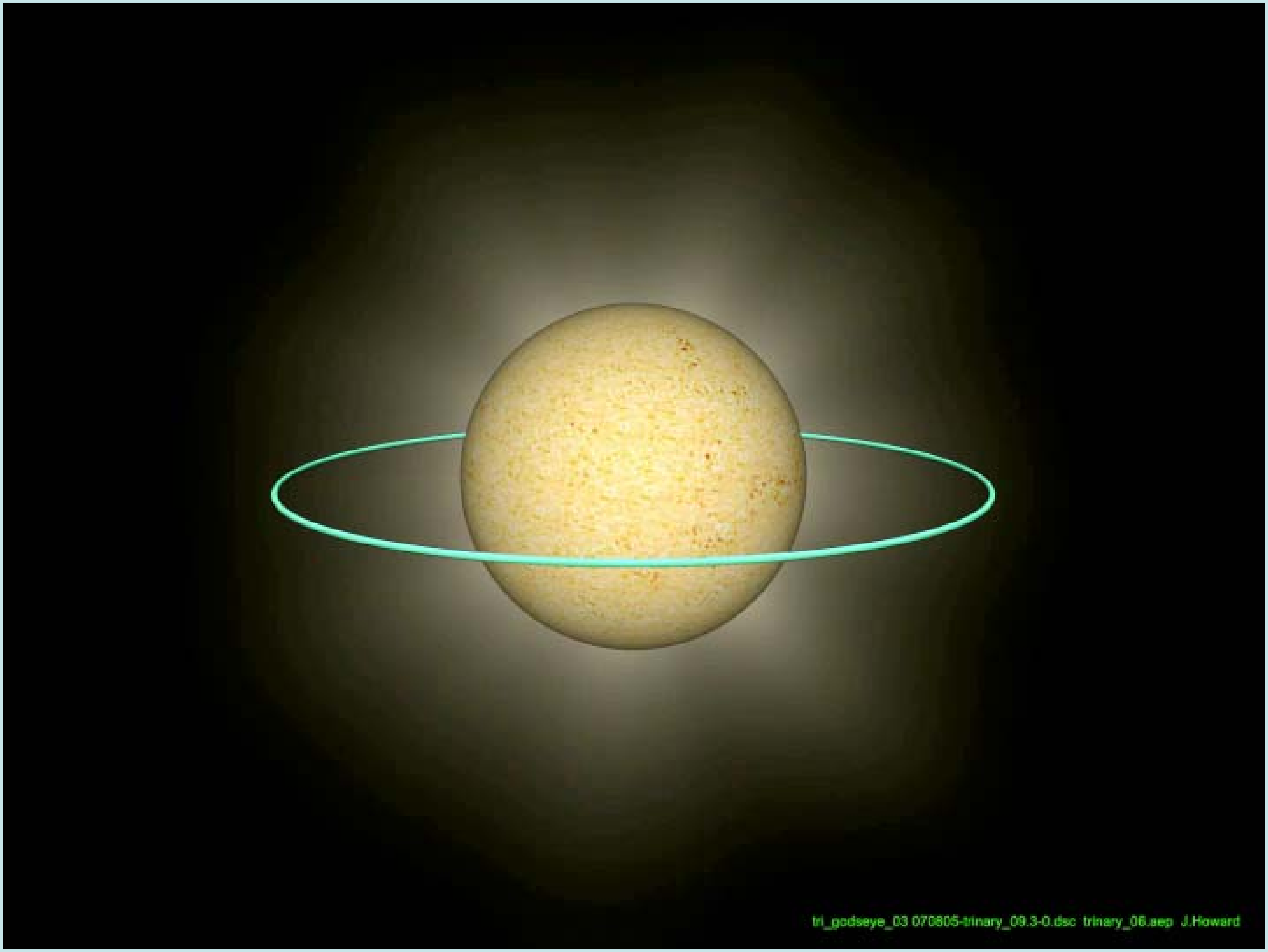
Maciej Konacki[1]

HD 188753A

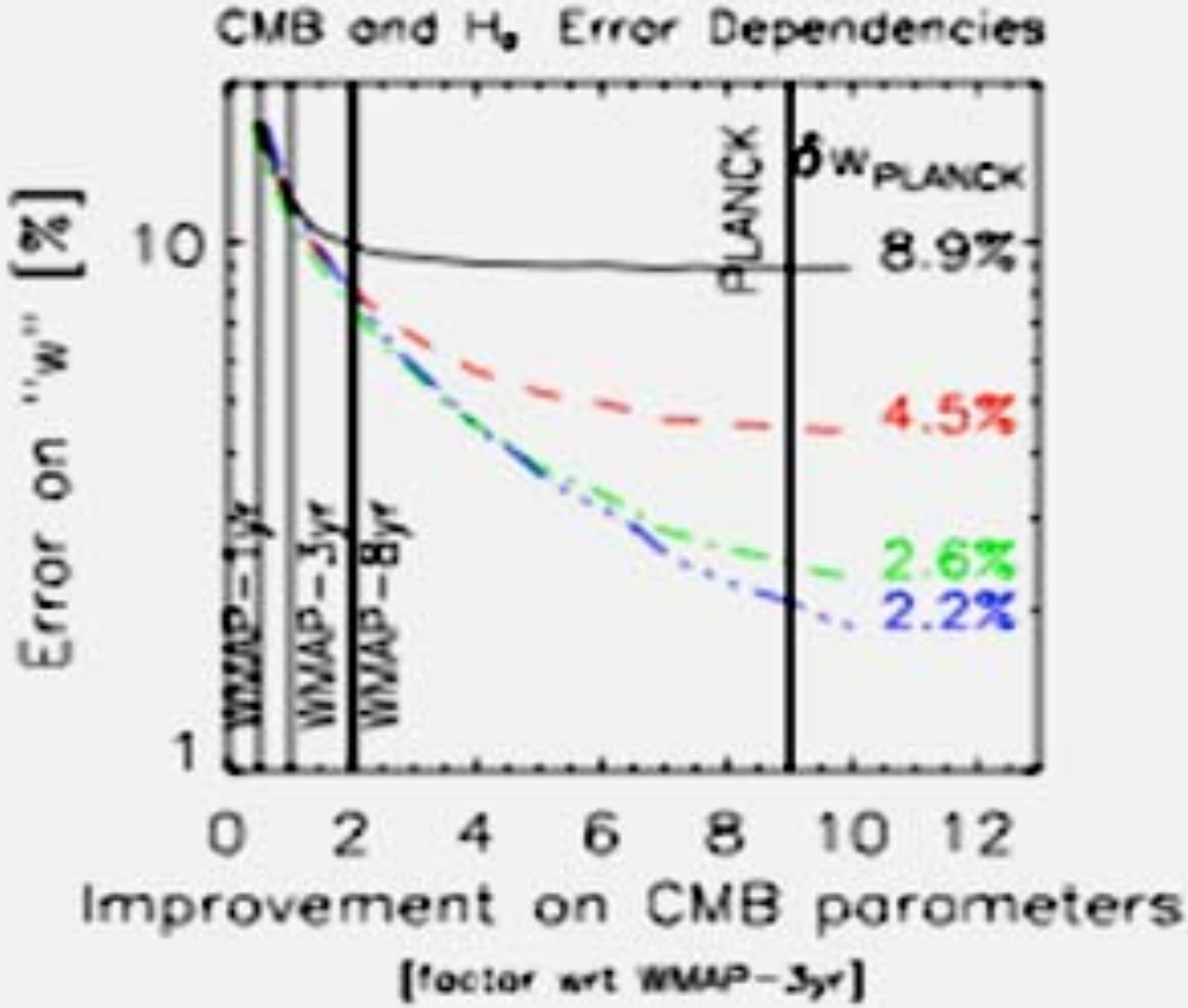


Keck/NIRC2

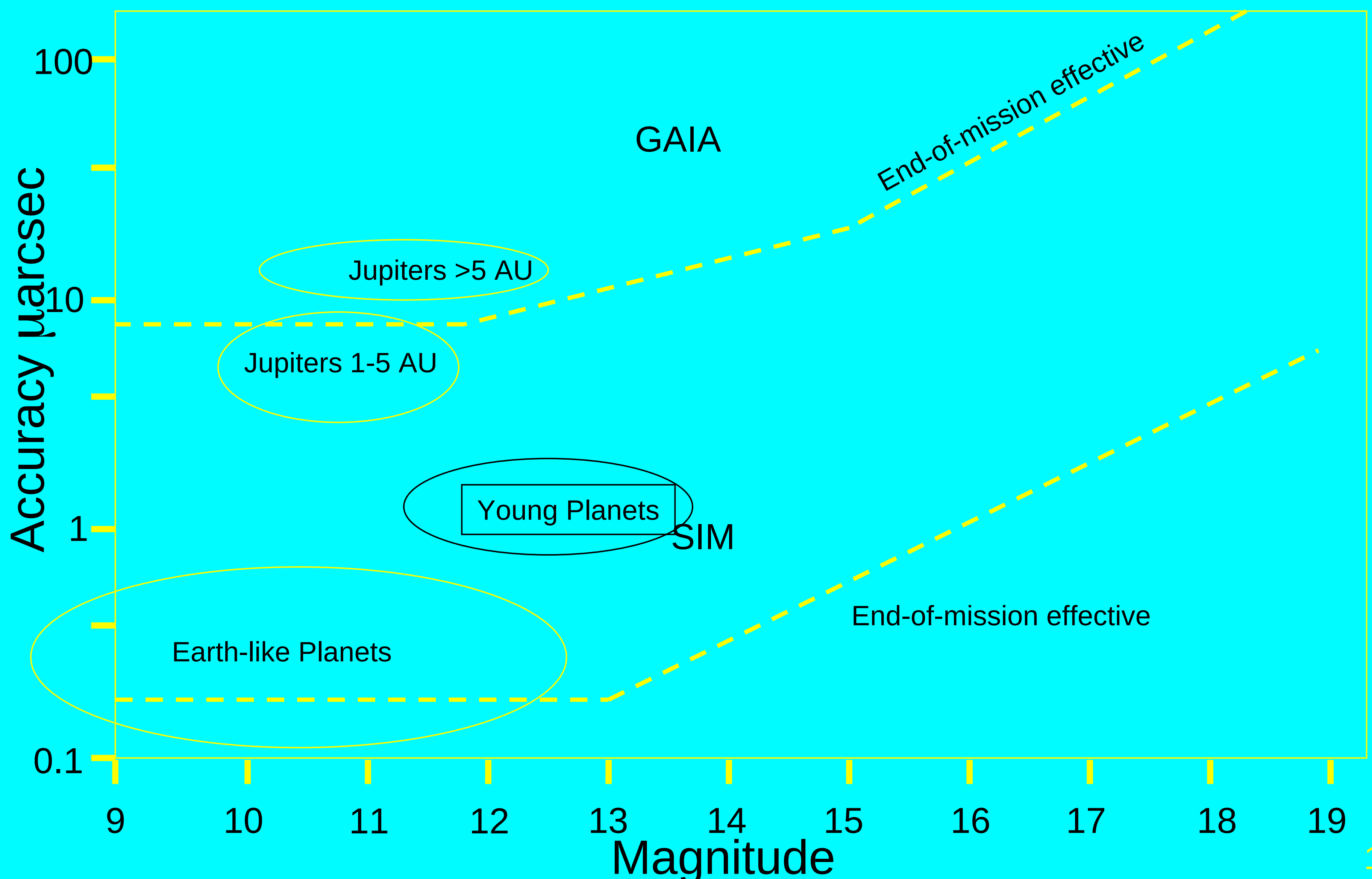
Planet in a triple star system



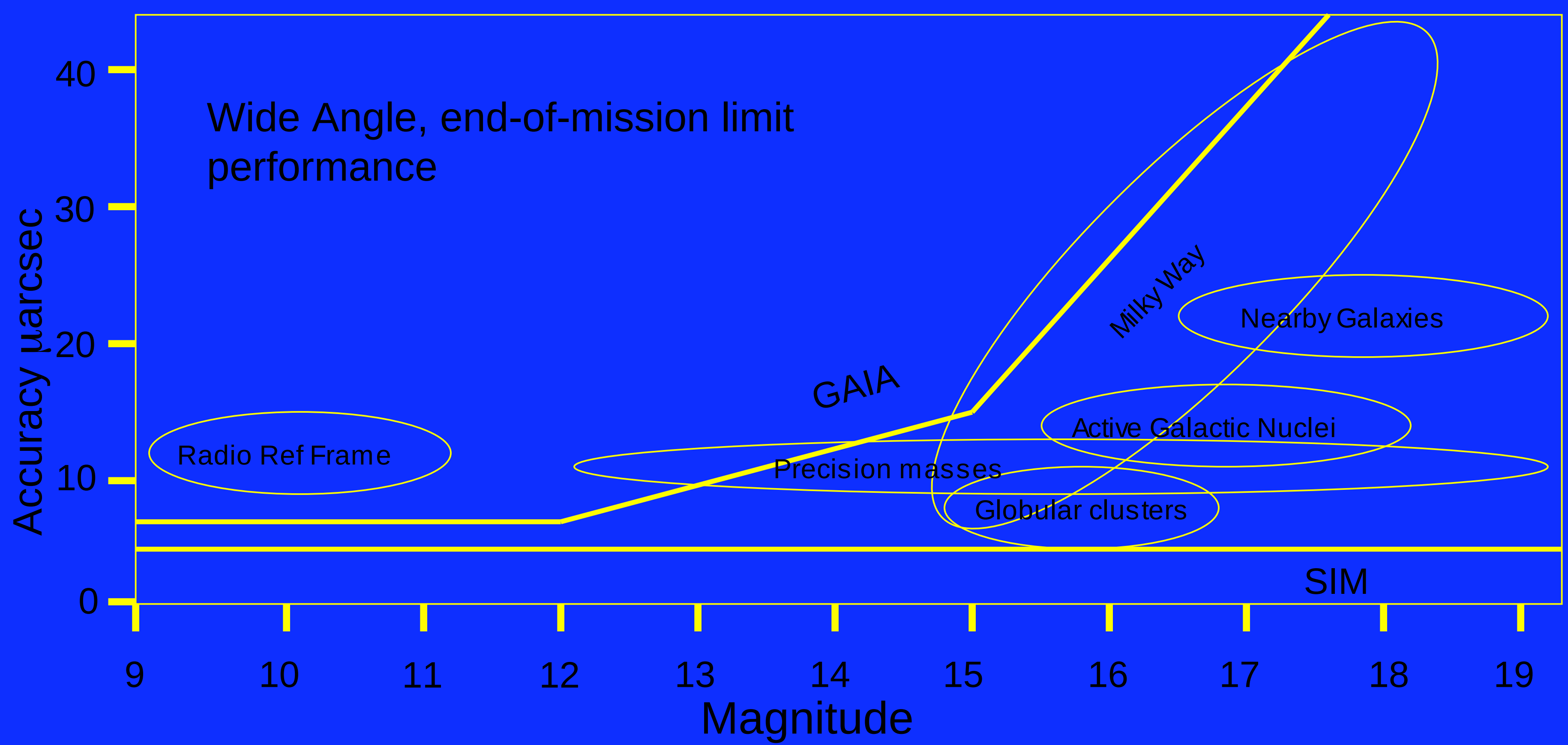
Dark Energy Equation of State:

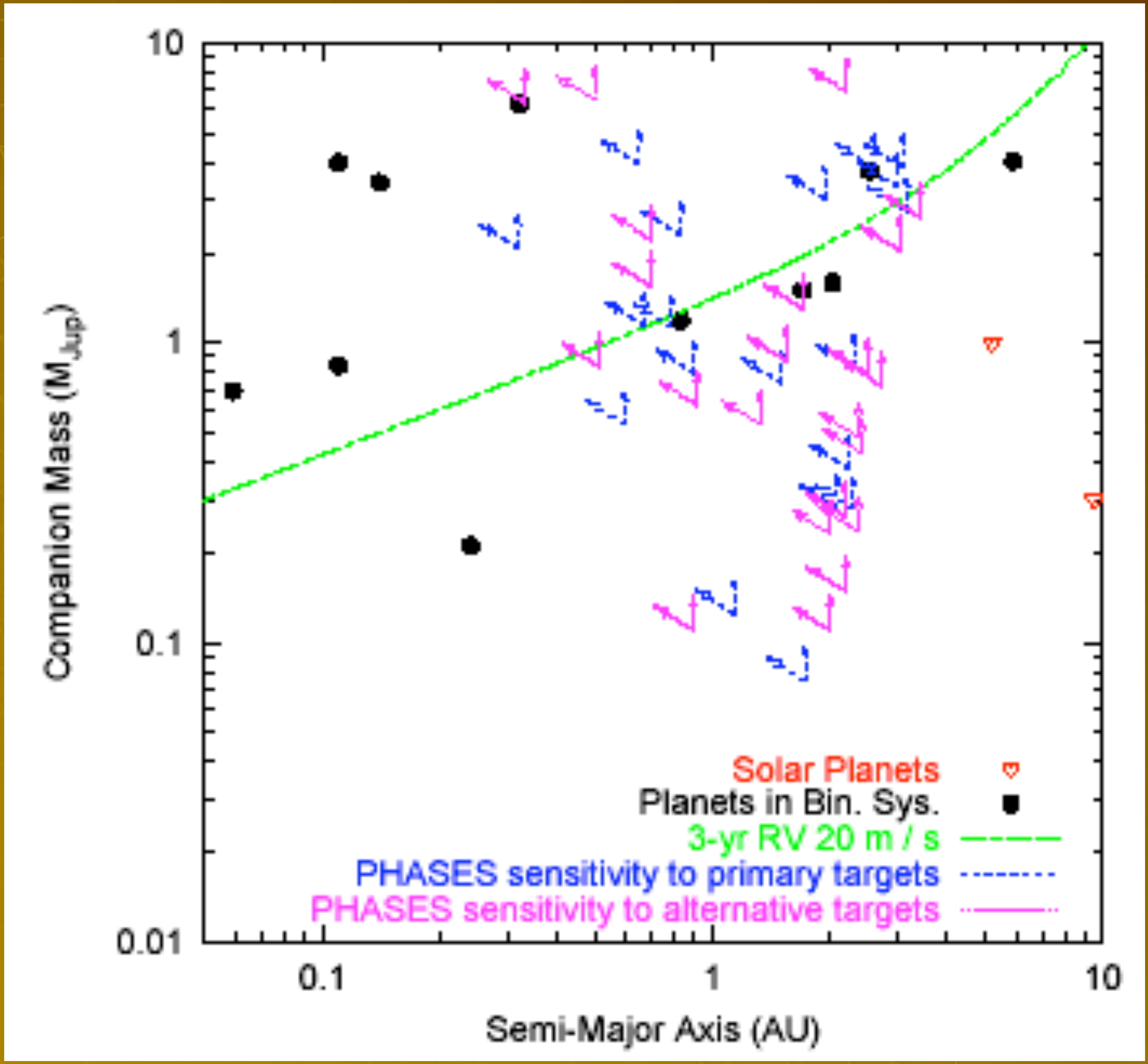


SIM and GAIA - Exo-Planet Detection Capability



SIM and GAIA –
Wide Angle Astrometry Science Targets

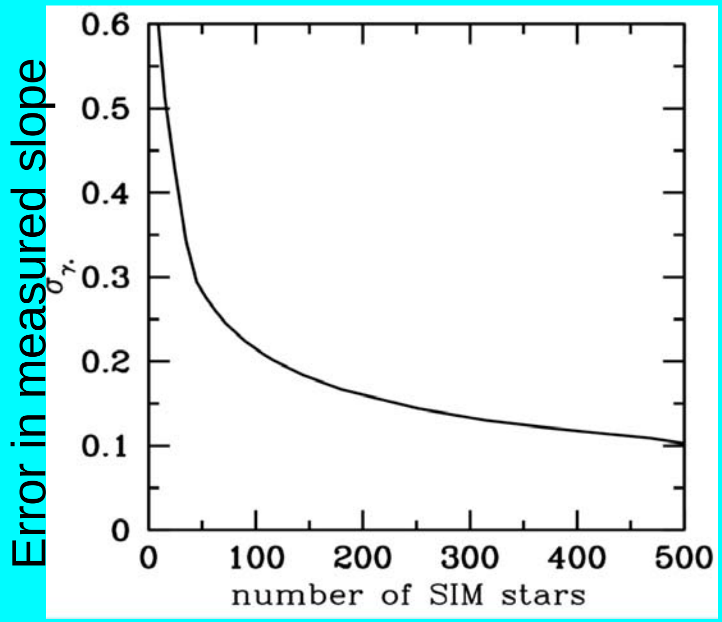


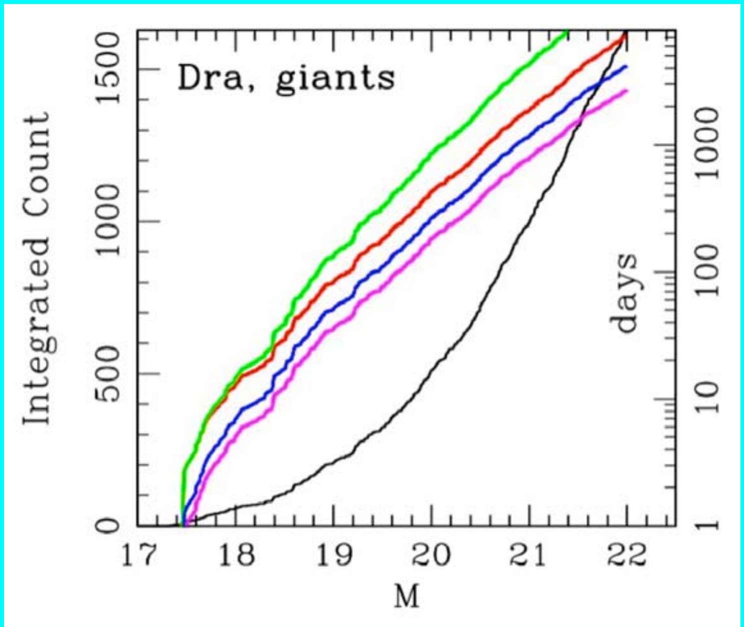


10
1
0.1
0.01
Companion Mass (M_{Jup})
0.1
1
10
Semi-Major Axis (AU)
Solar Planets
Planets in Bin. Sys.
3-yr RV 20 m / s
PHASES sensitivity to primary targets
PHASES sensitivity to alternative targets

Determining the Nature of Dark Matter with SIM

Strigari et al. (2006)





- Observations of transverse velocities with SIM provide a 2-sigma distinction between cored and cusped dark matter central density profiles

- 100 days of SIM observation time divided evenly will provide approximately 200 and 100 stars in Draco and Ursa Minor respectively.

Notes to explain the slides:

•Ongoing controversy over central slopes of DM-dominated galaxy rotation curves -- some suggestions that systematic errors in rotation curve analysis can drive these problems.

•Dark Matter dominated Local Group galaxies such as Draco and Ursa Minor are the ideal galaxies to study the density profiles of dark matter. In these cases baryons do not alter the density profiles.

• Current data on the central densities comes from the line of sight velocities of ~200 stars. However, due to a degeneracy with the velocity anisotropy of the stars, these measurements cannot distinguish between cores (WDM) and cusps (CDM) even with 1000 or more LOS velocities.

• SIM will measure the transverse velocities of stars out to ~ 80 kpc (the distance of Draco). Adding these to the current line of sight observations will break the degeneracy with the velocity anisotropy.

• Getting the transverse velocities from SIM is the key. Adding an order of magnitude more line-of-sight stars will not help, since the measurements are systematic limited.

•This has important implications for the nature of dark matter. Cold dark matter models predict cusps in the centers of galaxies. While well-motivated warm dark matter models, such as some **sterile neutrino** and **gravitino LSP** models, predict central density cores. Thus SIM is in a unique position to test the CDM paradigm, study dark matter halo properties and constrain particle physics theories that make detailed predictions for the dark matter particle.

To Conclude

- SIM addresses two timely major areas in astronomy & physics:
  - Planets
  - Universe
- SIM - the first true interferometer in space - is ready to be built
- SIM has unrivaled precision

- The team is ready to build for a 2012 launch
- Delay merely adds cost and delays timely science
- Not launching SIM will lead to a gap of a major space mission

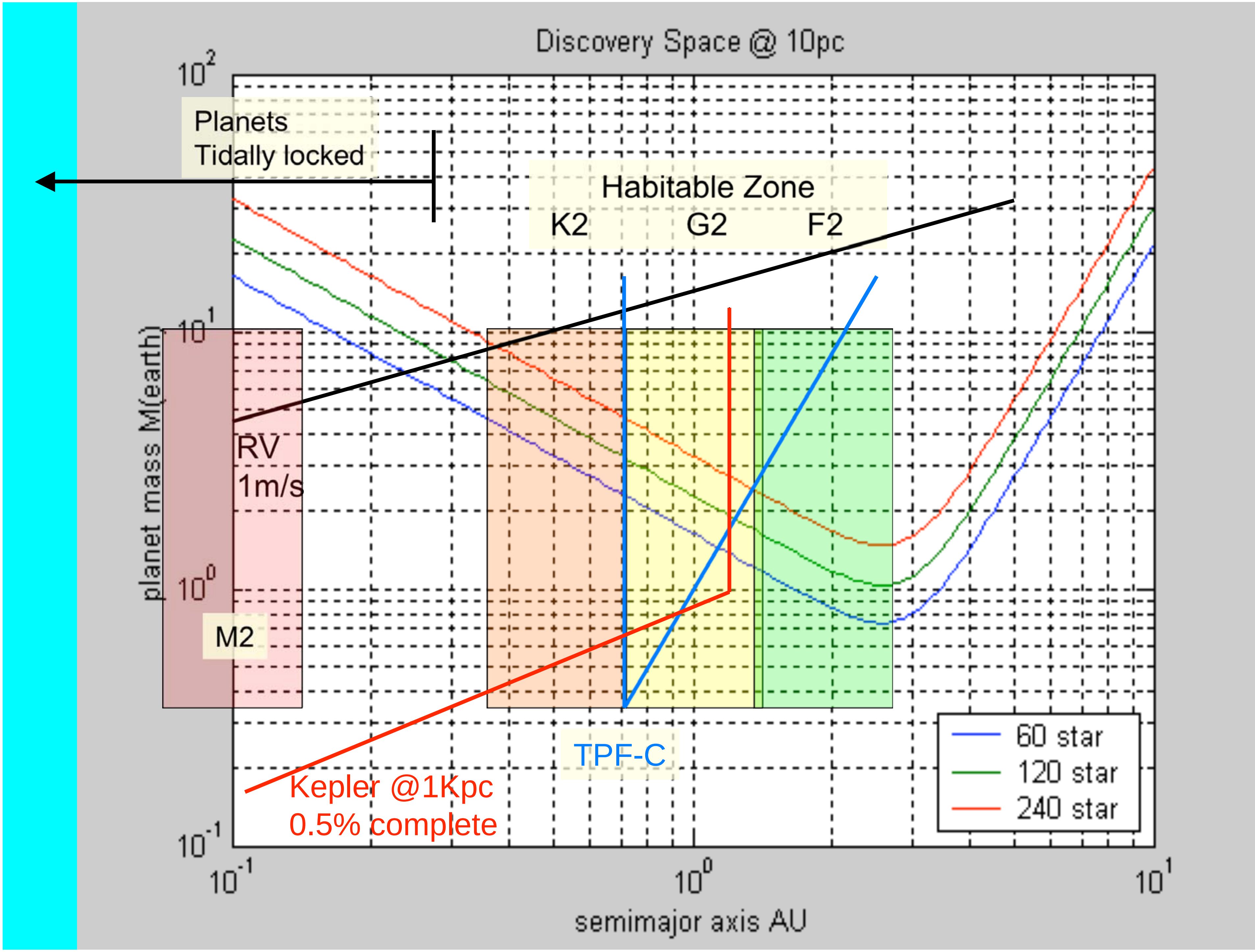
- 50% of SIM time is available for community (along with adequate funding)

- McKee-Taylor in preface to Major Mission recommendations

  "… assumed that the Space Interferometry Mission (SIM), one of the initiatives recommended in the 1991 survey report, will be flown …"

SIM Science (and fraction accomplished by GAIA)

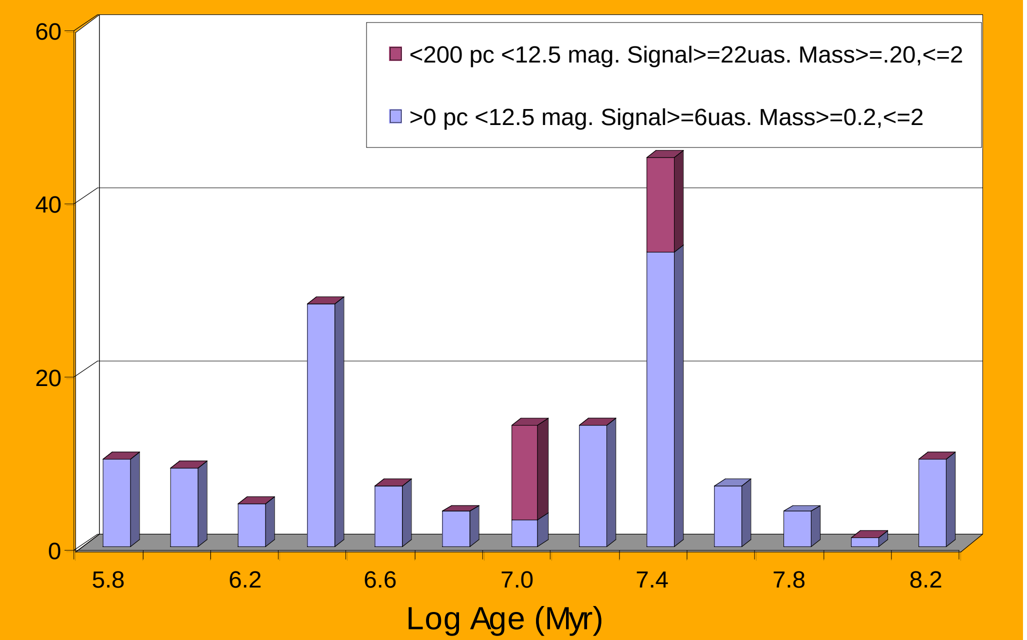
Key SIM Science Project Objectives	GAIA %
Find Earth-sized planets in Habitable Zone	0%
Reconnaissance of young planetary systems	~0%
Unbiased galactic mass function (from microlensing)	0%
Star masses to 1% (SIM program emphasizes difficult types)	~0%
Motion in/of QSO's, AGN's	0%
Exo-Planetary system contents census	>Jupiter
Local Galaxy group mass distribution (from motions)	8%
Age of galaxy (from globular clusters and stellar models)	20%
Structure of Galaxy (size, spiral arms, tidal streams, bulge, halo)	~50%
Coordinate frame tie to cosmological standard of rest (QSO's)	~50%



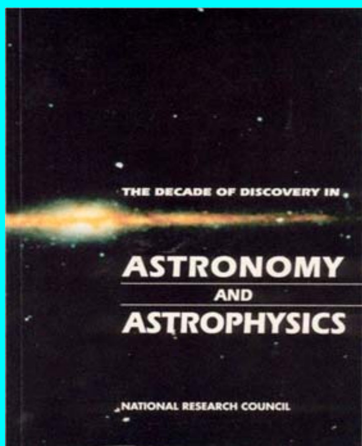
Discovery Space @ 10pc
Planets
Tidally locked
Habitable Zone
K2
G2
F2
RV
1m/s
M2
TPF-C
Kepler @1Kpc
0.5% complete
60 star
120 star
240 star
planet mass M(earth)
semimajor axis AU
10^2
10^1
10^0
10^{-1}
10^{-1}
10^0
10^1

How Do Planetary Systems Form & Evolve?

- What fraction of young stars have gas-giant planets?
  - Only SIM astrometry can find planets around young stars since active stellar atmospheres and rapid rotation preclude radial velocity or transit searches
- Do gas-giant planets form at the “water-condensation” line?
  - SIM will survey ~200 stars to a level adequate to find Jovian or smaller planets on orbits <1 AU to >5 AU around stars from 25-150 pc
- Does the incidence, distribution, and orbital parameters of planets change with age and protostellar disk mass?
  - Study of clusters with ages spanning 1-100 Myr to test orbital migration theories
  - Correlate with Spitzer results on disks (4-24 μm)
- Where, when, and how do terrestrial planets form ?
  - Understand the formation and orbital migration mechanisms of the giant planets
- *No other technique can find planets down to Saturn-Jupiter mass within 1-10 AU of parent stars at 25-150 pc*



1990 & 2000 NRC Decadal Reviews



"…emphasized the dual capability of SIM, noting that this capability would enable *"…both… detecting planets and … mapping the structure of the Milky Way and other nearby galaxies."*

THE NATIONAL ACADEMIES PRESS

Read more than 3,600 books online FREE! More than 1000 PDFs now available for sale

THE N

Advisers to t

HOME ABOUT NAP CONTACT NAP HELP NEW RELEASES ORDERING INFO

TRY OUR SPECIAL **DISCOVERY ENGINE:** FIND

Astronomy and Astrophysics in the New Millennium: Panel Reports (2001)

Commission on Physical Sciences, Mathematics, and Applications (CPSMA)

Board on Physics and Astronomy (BPA)

SUMMARY

Pg 328

The following missions are the priority recommendations of the Astronomy and Astrophysics Survey Committee's Panel on Ultraviolet, Optical, and Infrared Astronomy from Space. All recommendations are a consensus of the panel.

MAJOR MISSIONS

When it prioritized major missions, the panel assumed that the Space Interferometry Mission (SIM), one of the initiatives recommended in the 1991 survey committee report,[1] will be flown and that the Hubble Space Telescope (HST) will operate until 2010.

NEXT GENERATION SPACE TELESCOPE

NGST, ranked by the panel as the top-priority major mission for the decade, will reveal the onset of star and galaxy formation in the early universe. Its combination of scientific breadth and depth make it a compelling successor to the Hubble Space Telescope. It is the first of two logical paths to improved image resolution and sensitivity in space: increase overall aperture size. It should be technologically ready to be launched before 2010.

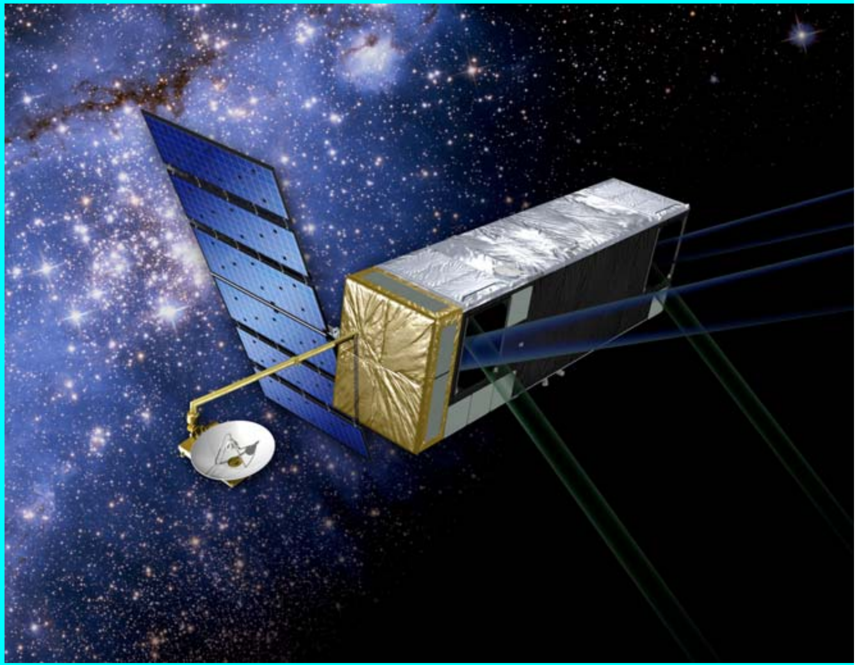
The panel considered extensions of the core mission, currently 1 to 5 μm, and favors an extension to longer wavelengths, beyond 20 μm, for example, as scientifically more useful than extension to shorter wavelengths.

TERRESTRIAL PLANET FINDER

TPF was ranked as the second-priority major mission for the decade. Designed to

Space Astrometric Interferometer

- 3 stellar interferometers connected by a laser optical truss (picometer accurate)
- 2 Guide interferometers hold the spacecraft attitude (in knowledge) stable at the uas level, while the Science interferometer measures the position of targets within its 15 deg field of regard (1 target at a time)
  - Narrow angle measurements are made over a ~1deg radius field of regard.
- 0.45~0.95 um in 80 spectral channels (wavelength synthesis imaging of simple objects)
- Technology development complete July 2005



- Global astrometry (5yr mission)
  - **4 uas** position (ref to QSO)
  - **2.5uas/yr** proper motion
  - **4 uas** parallax
- **1uas** Narrow angle astrometry (1 epoch 1100 s integ)
- Mag limit, -1 to 19 mag