Space Interferometry Mission

SIM

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Project Status Update & SIM Science Breadth Discussion for the Origins Subcommittee (OS)

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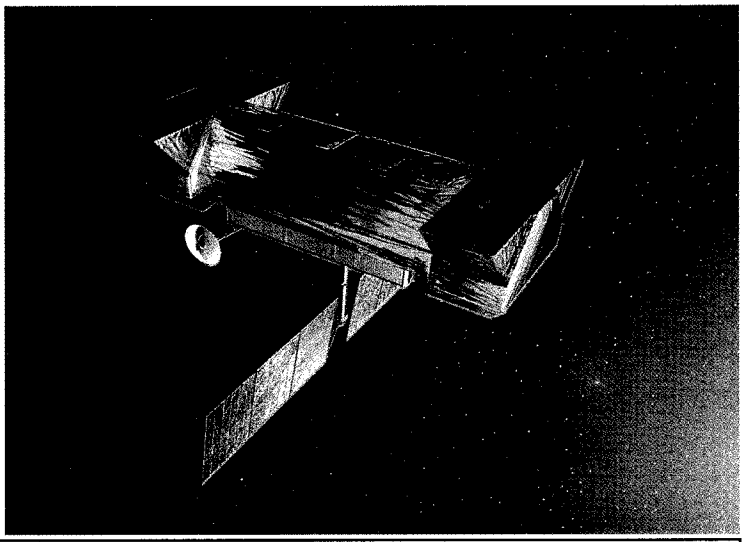
JPL

- **Salient Features**
- 3 parallel Michelson Stellar Interferometers
- 10 meter baseline
- Visible wavelength
- Launch Vehicle: Space Shuttle or EELV
- Earth-trailing solar orbit
- 5 year mission life with 10 year goal
- SIM is a JPL, Caltech, Lockheed Martin,
  - NGST, and SIM Science Team partnership



Science Goals

- Perform a search for other planetary systems by surveying 2000 nearby stars for astrometric signatures of planetary companions
- Survey a sample of 200 nearby stars for orbiting planets down to terrestrial-type masses
- Improve best current catalog of star positions by >100x and extend to fainter stars to allow extension of stellar knowledge to include our entire galaxy
- Study dynamics and evolution of stars and star clusters in our galaxy to understand how our galaxy was formed and how it will evolve.
- Calibrate luminosities of important stars and cosmological distance indicators to improve our understanding of stellar processes and to measure precise distance in the distant universe

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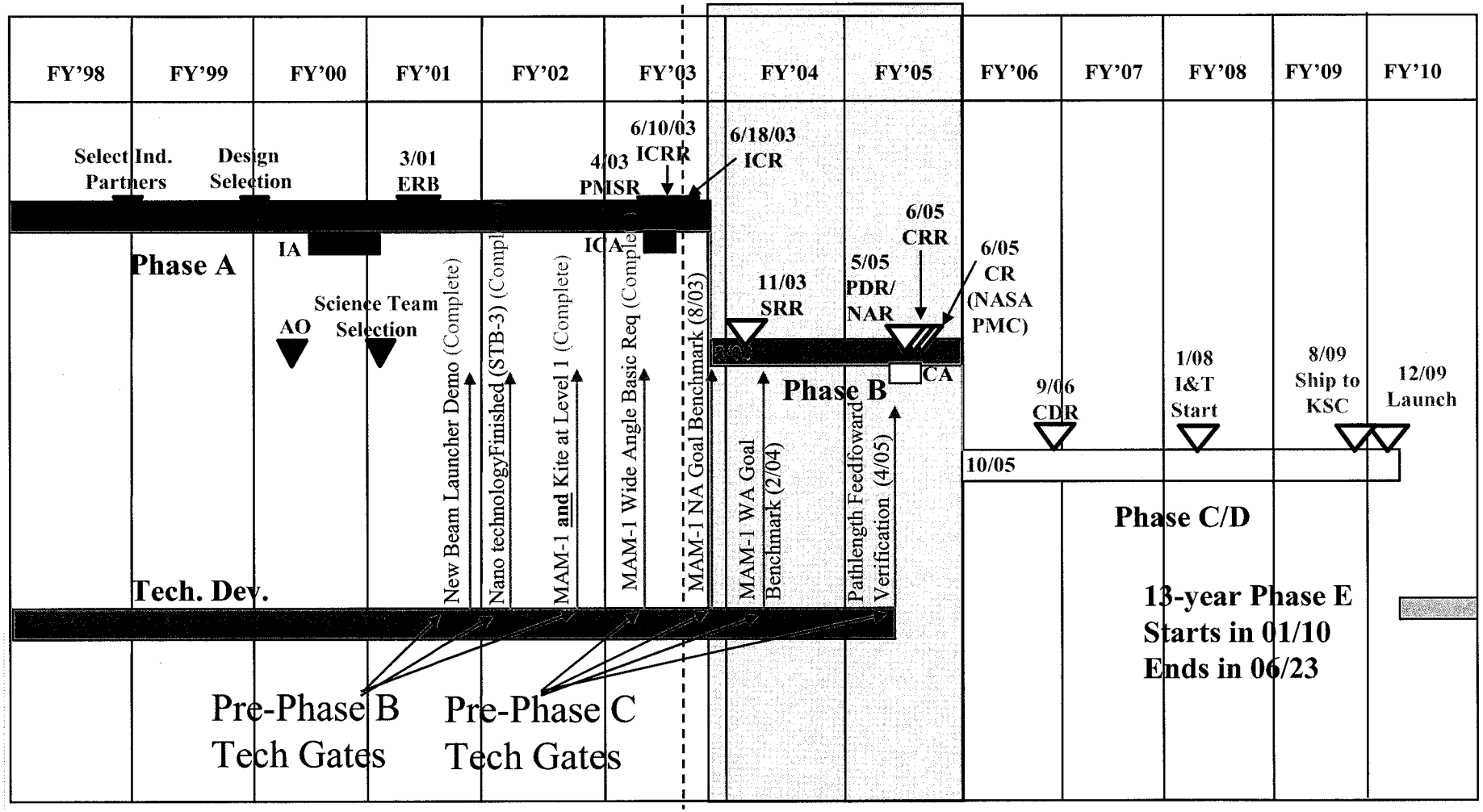
SIM Synoptic Schedule



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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

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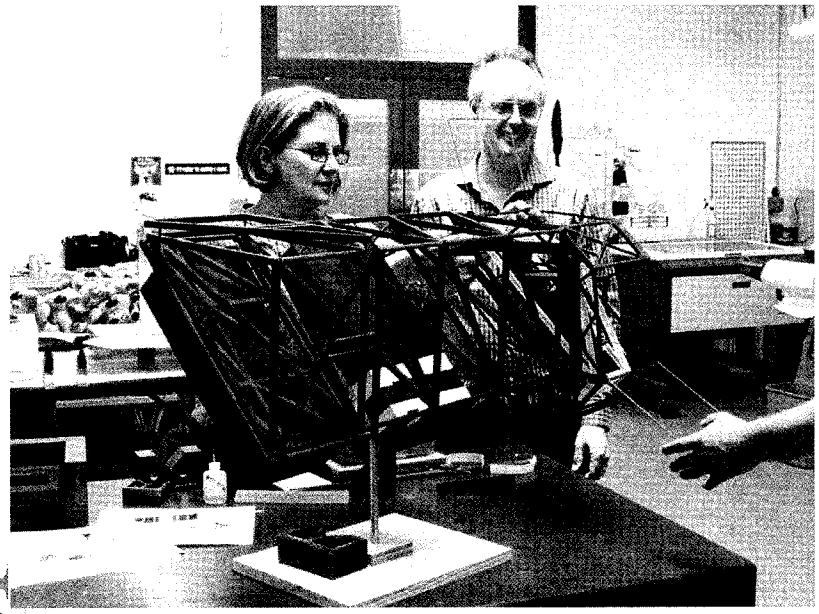
Accomplishments Since December 2002

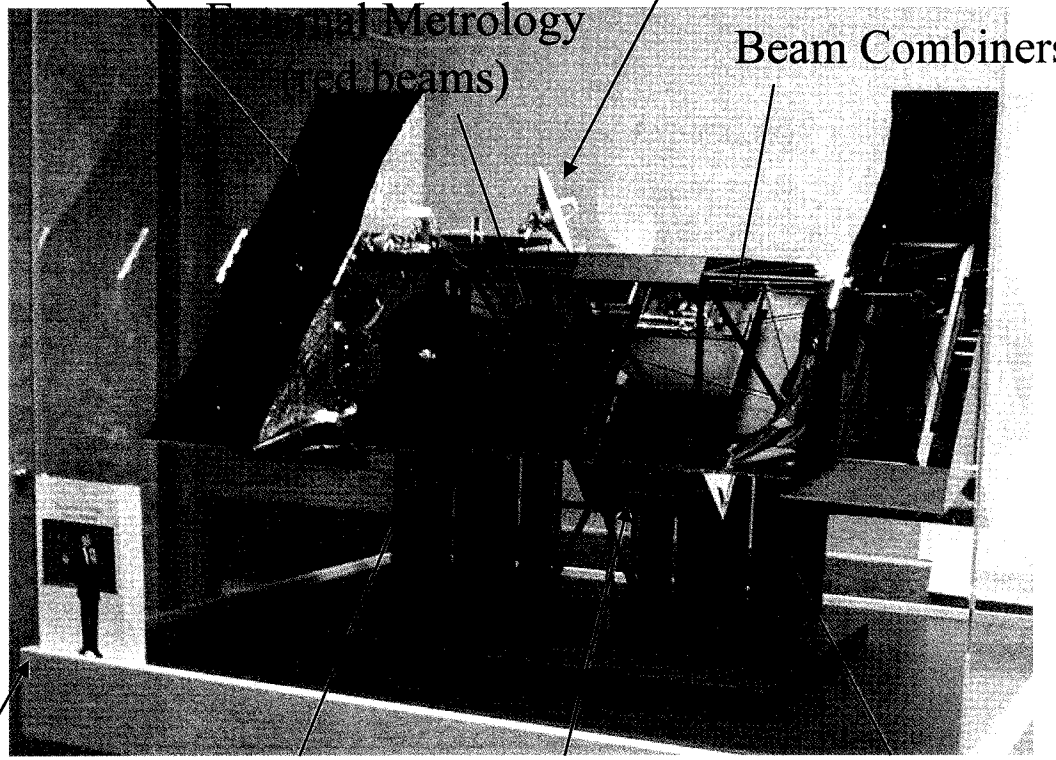
- NASA HQ has provided the funding profile needed to support a Dec 2009 launch (the alternate Apr 2010 launch schedule has been dropped)
- Preparation for Phase B (preliminary design) entry:
  - Prepared for and conducted the Preliminary Mission and System Review (PMSR)
    - Equivalent to the NASA Mission Definition Review (MDR) which is the gate review for Phase B entry
  - Supported Initial Confirmation Assessment (ICA) with Navigator Program Independent Review Team
  - Held an Initial Confirmation Readiness Review (ICRR) with the JPL Governing Program Management Council
    - Received their recommendation that SIM proceed to Phase B
  - Held an Initial Confirmation Review (ICR) with the Office of Space Science (OSS) Enterprise Program Management Council (EPMC)
    - Received their recommendation that SIM proceed to Phase B
  - Waiting for final Phase B direction letter from NASA
- Held SIM Science Team meetings #8 (Dec 12, 2002) and #9 (May 20, 2003)
- Published SIM Newsletter issues 24 through 28 to roughly 800 readers

Accomplishments Since December 2002

- Built a 1/10th scale model of SIM from current engineering drawings



Model Building Shop at DMI



Closeup Showing Scale (5' 9" Human)

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Kite & MAM Testbed Results Summary

- Technology milestone #5 (Micro-Arcsecond Metrology testbed demonstration of baseline wide angle measurement capability) completed (highlighted in pink)
  - First of phase C entry milestones
  - Vetted with the SIM Technical Advisory Committee and the Navigator Program Independent Review Team
- Bottom line: WA predict currently ~8.4 uas; NA predict currently ~1.8 uas

New

Parameter	Science Measurement Capability	Current SIM Error Budget Reqmt	Headquarters Milestone Value	Testbed Results
MAM (single B/L Interferometer):				
- Wide Angle "Minimum" (M/S#5)	30 uas	3,200 pm	3,200 pm	1,260 pm
- Wide Angle "Baseline" (M/S#7)	10 uas	1,000 pm	1,000 pm	(Feb'04)
- Wide Angle "Goal" (M/S#7)	4 uas	280 pm	"Benchmark"	(Feb'04)
- Narrow Angle "Baseline"	**3 uas**	**106 pm**	**150 pm**	**40 pm**
- Narrow Angle "Goal" (M/S#6)	1 uas	24 pm	"Benchmark"	(Aug'03)
Kite (external metrology):				
- Wide Angle "Minimum"	**30 uas**	**2,050 pm**	**300 pm**	**202 pm**
- Wide Angle "Baseline"	10 uas	650 pm	none	Met
- Wide Angle "Goal"	4 uas	140 pm	none	
- Narrrow Angle "Baseline"	**3 uas**	**28 pm**	**50 pm**	**27 pm**
- Narrrow Angle "Goal"	1 uas	8 pm	none	

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Accomplishments since December 2002

- Grid Star Observing Program RFP issued, proposals received and being evaluated
  - Radial velocity screening of binaries unsuitable for use as grid stars
- New SIM Observing Opportunities
  - Project is proposing to make time available for a large number (~20k?) of medium accuracy (~50 uas) parallax measurements to support the general astronomical community
    - Intent is to make SIM available to provide precision distances in support of a large number of other astronomical observing programs
    - Would use ~10% of SIM observing time
    - Time allocation via proposal process similar to a guest observer proposal process
  - Special session planned for the winter AAS meeting to obtain feedback from the community
    - Presently 6:00-7:30 PM on Jan 5th being proposed

Plans for next 6 months

- Complete Technology Milestone #6 (benchmark narrow angle performance against goal criteria)
  - Team has already identified and implemented fixes that prevented reaching goal level NA performance before & is already in test
- Launch Vehicle Trade by August 2003
  - Trade is between STS and EELV (Atlas V or Delta IV)
  - Current reference design is STS but, with Columbia loss, likely result will be shift to EELV
- Award Grid Star Observing Program contract(s)
- Address recommended actions from PMSR/ICRR/ICR
- Project-level System Requirements Review (SRR) in November 2003
- SIM Science Team meeting #10 Dec 16 & 17, 2003

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The Breadth of SIM Science

M. Shao

SIM Science in a Larger Context

- Planet Finding is a core goal for Origins
  - SIM astrometry complements other methods of planet detection
    - Determines mass, the most fundamental parameter of a planet
    - Is more sensitive than Radial Velocity (3 vs 30 M_{Earth}) with no sin(inclination) ambiguity
  - SIM targets stars within 25 pc that are suitable for follow-up by TPF
- SIM will determine the architecture of solar systems, telling us whether our solar system is rare or common
- At no extra hardware cost, SIM carries out an exciting program of fundamental galactic and extragalactic astrophysics
  - A key parameter for all Milky Way objects observed by HST, Chandra, SIRTF, JWST, GALEX, etc is an accurate distance from the Earth
    - A distance turns a flux into a luminosity or an angular motion into a physical motion
    - SIM turns phenomenology into physics
  - 10 μas wide angle astrometry gives 1% distances to any object in the galaxy and 10% proper motions in the local group of galaxies

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SIM Will Make Definitive Planet Census

What We *Don't* Know

- Are planetary systems like our own common?
- What is the distribution of planetary masses?
  - Only astrometry measures planet masses unambiguously
- Are there low-mass planets in 'habitable zone' ?

Deep Search for Earths

- Are there Earth-like (rocky) planets orbiting the nearest stars?
- Focus on ~250 stars like the Sun (F, G, K) within 10 pc
- Sensitivity limit of ~3 M_e at 10 pc requires 1 μas accuracy

Broad Survey for Planets

- Is our solar system unusual?
- What is the range of planetary system architectures?
- Sample 2000 stars within ~25 pc at 4 μas accuracy

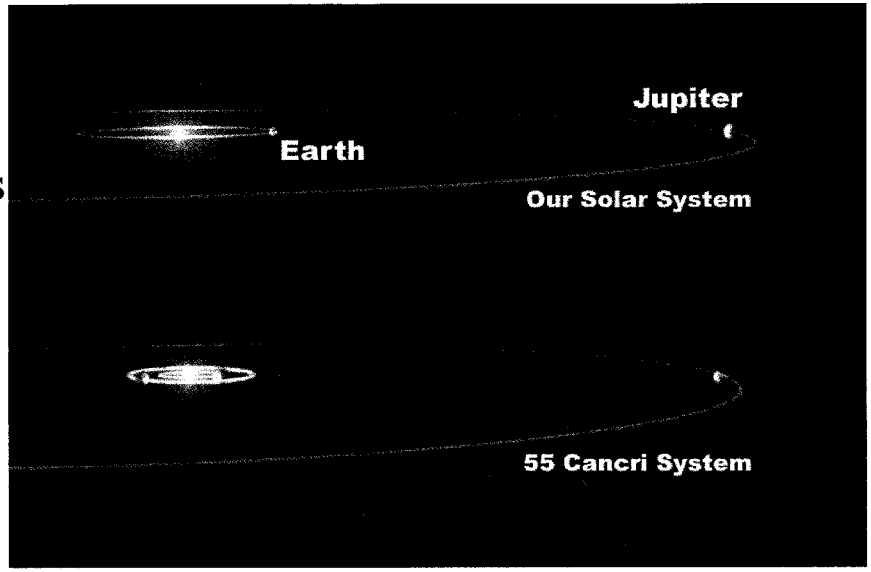
Evolution of Planets

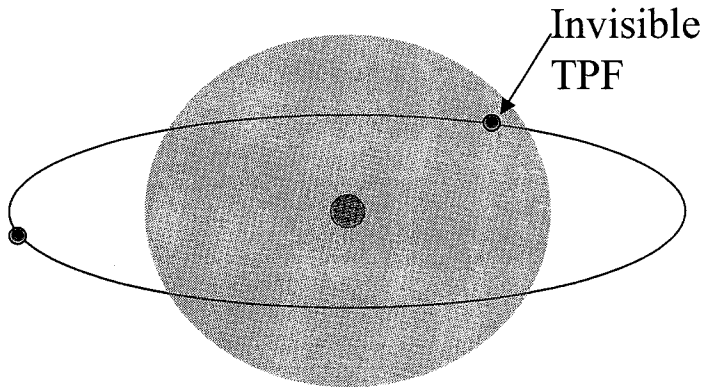
- How do systems evolve?
- Is the evolution conducive to the formation of Earth-like planets in stable orbits?
- Do multiple Jupiters form and only a few (or none) survive?

SIM Complements and Paves The Way for TPF

JPL

- SIM will tell TPF what stars are likely to be hospitable to terrestrial planets
  - Presence of Jovian planets in the wrong orbits will preclude stable orbits in the habitable zone
- SIM's orbital information will determine when planets in eccentric/inclined orbits will be at an elongation suitable for direct detection. (avoid false negatives)
- Combination of SIM masses with TPF spectroscopy of hundreds of planets will lead to new era in comparative planetology
- For stars where SIM doesn't detect a planet, and subsequently, TPF does detect a planet, SIM archival data can determine or constrain the mass of that planet with ~0.5 Earth mass accuracy.





TPF inner working R

False Positives and
False Negatives.

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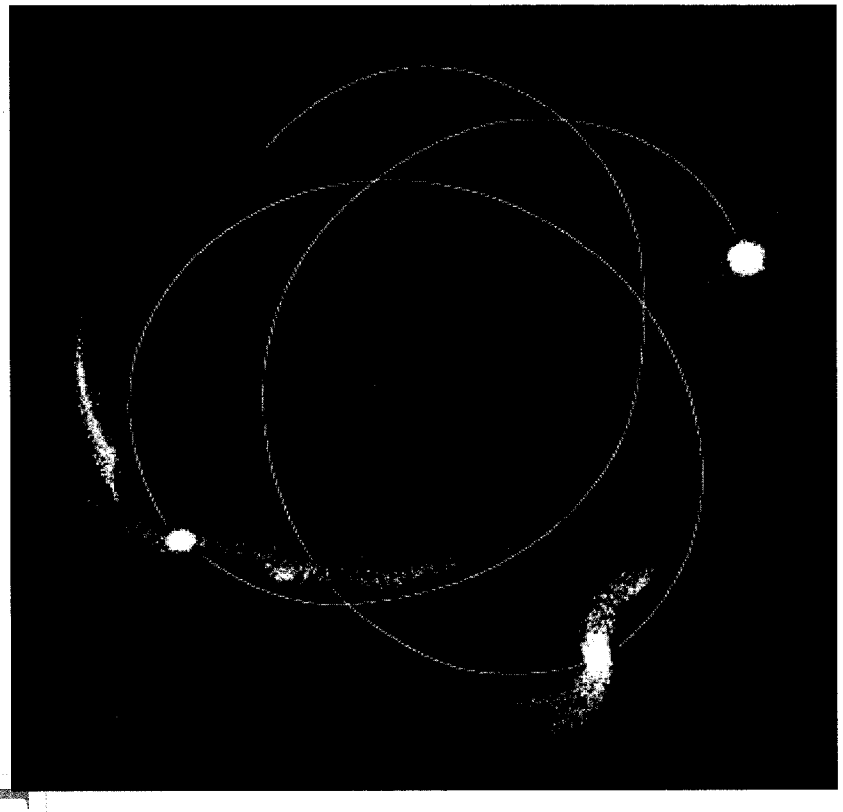
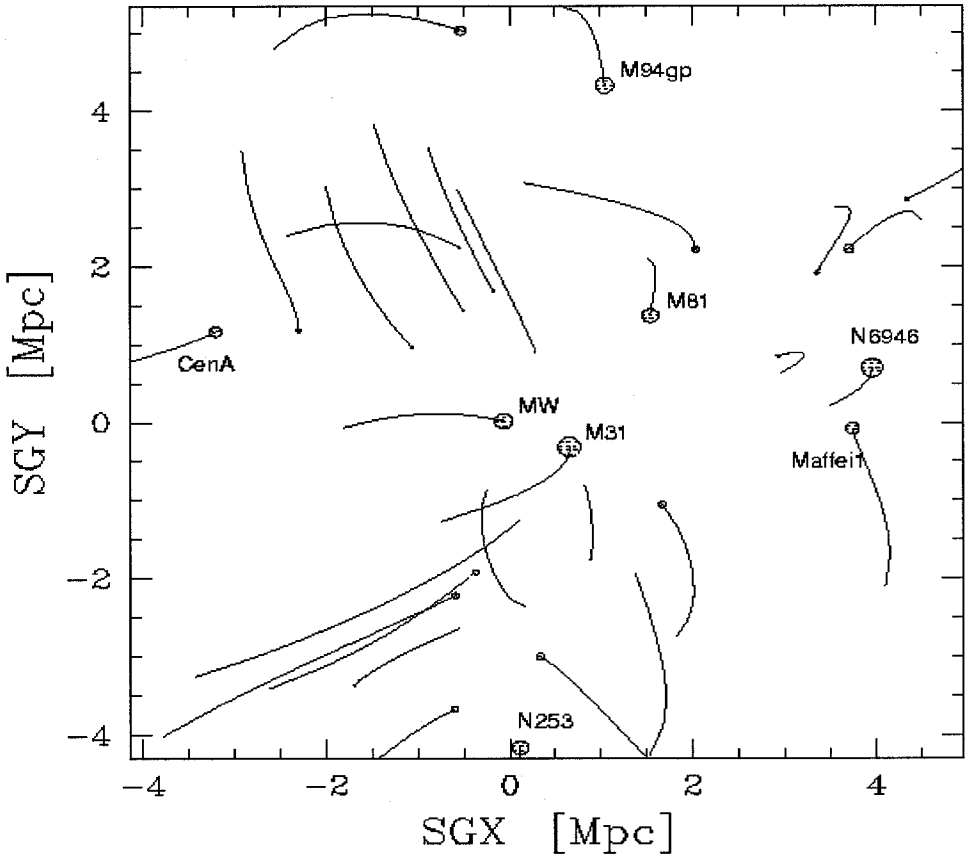
Cosmic Distance Scale and Mach's Principle

- In 1999, the Hubble Key Project led by W. Freedman concluded an 8 year effort to measure the age of the universe to 10%
  - The dominant uncertainty in this body of work is the zero point calibration of the Cepheid Period-Luminosity (vs. metallicity) relation.
  - SIM will directly measure, with 1% accuracy, all Cepheids in the Milky Way and with 3% accuracy for Cepheids in the LMC
  - SIM will thus greatly reduce this last remaining uncertainty.
- Mach's Principle postulates a linkage between the distant Universe and local inertial forces
  - Newton, Mach, Einstein asked whether inertia of an object is an intrinsic property of matter or the manifestation of the interaction of a moving (rotating) object with all other matter present in the rest of the universe.
  - The SIM astrometric grid is anchored to ~50 QSO's providing an *inertial* reference frame based on the most distant objects in the universe.
  - SIM also measures positions in the dynamical reference frame defined by the elliptical orbits of the planets around the Sun.
  - The radio positions of millisec pulsars will be measured at the ~10uas level by the time SIM flys. Their radio positions are measured in the ecliptic reference frame. Mach's principle is tested when their optical positions are measured by SIM with respect to the QSO's.

Dark Matter: In the Disk, in the Halo and Between Galaxies





- SIM observations of the motions of stars will tell us about the distribution of all gravitating mass (light plus dark matter) in the Galaxy
- SIM observations of the motions of dwarf galaxies around our own will determine the mass distribution (light plus dark matter) in the Halo.

SIM will measure the proper motion of ~28 nearby galaxies get the distribution of matter in the local group

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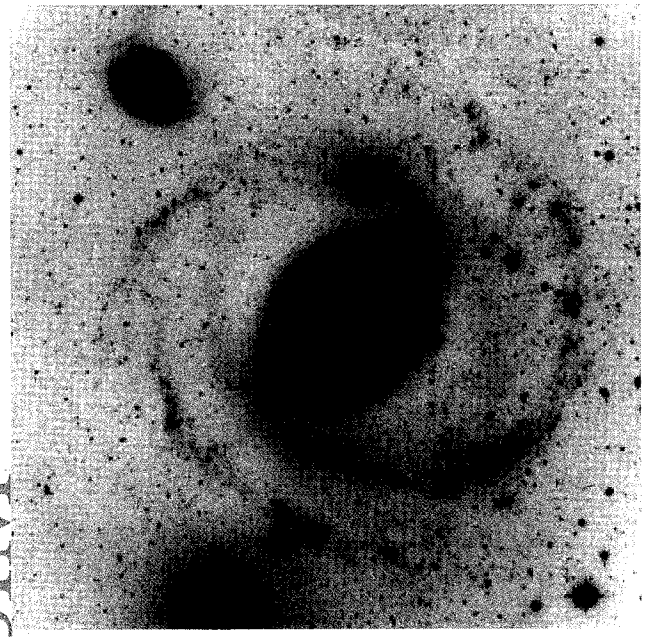
Imaging AGN's, Super massive Black Holes (From Keck to SIM)

Keck-I made the first interferometric measurement of the emission of an AGN, **NGC 4151**. SIM will greatly extend these observations to test the theories of accretion disks around super massive black holes.

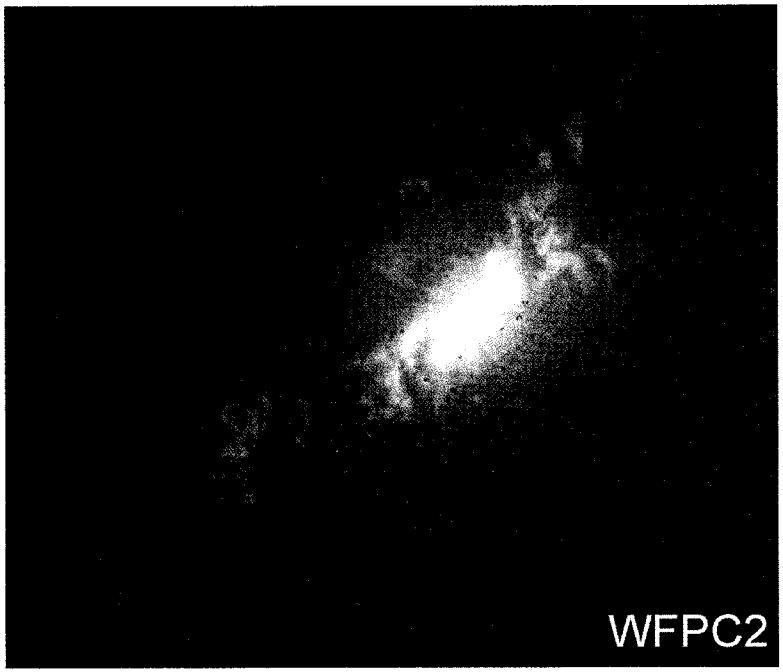


~30 kpc

Distance ~ 13 Mpc

Previous IR(2.2um) Images showed the core to be < ~ 1 arcsec.

Keck-Interf data has constrained the size to ~ 1 mas.



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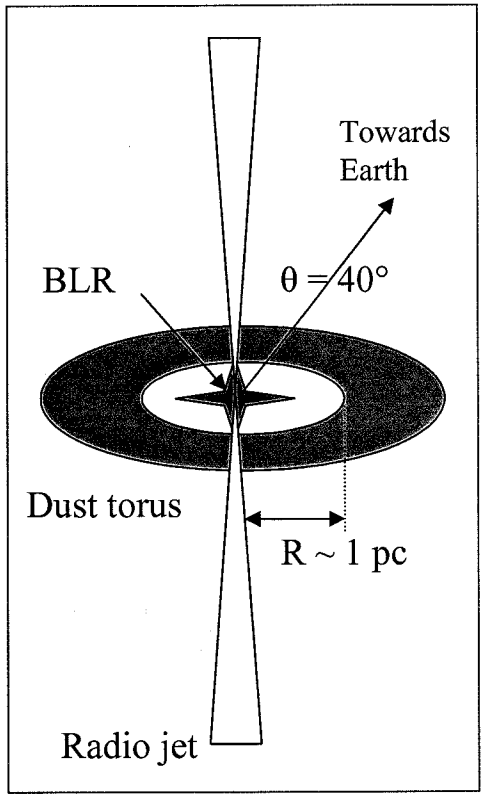
What is the Source of Compact Emission?

Stars ? ✗ Too big

Dust Torus ? ✗ Too big

Jet ? ✗ Too bright (>100x)

Accretion Disk ? Yes

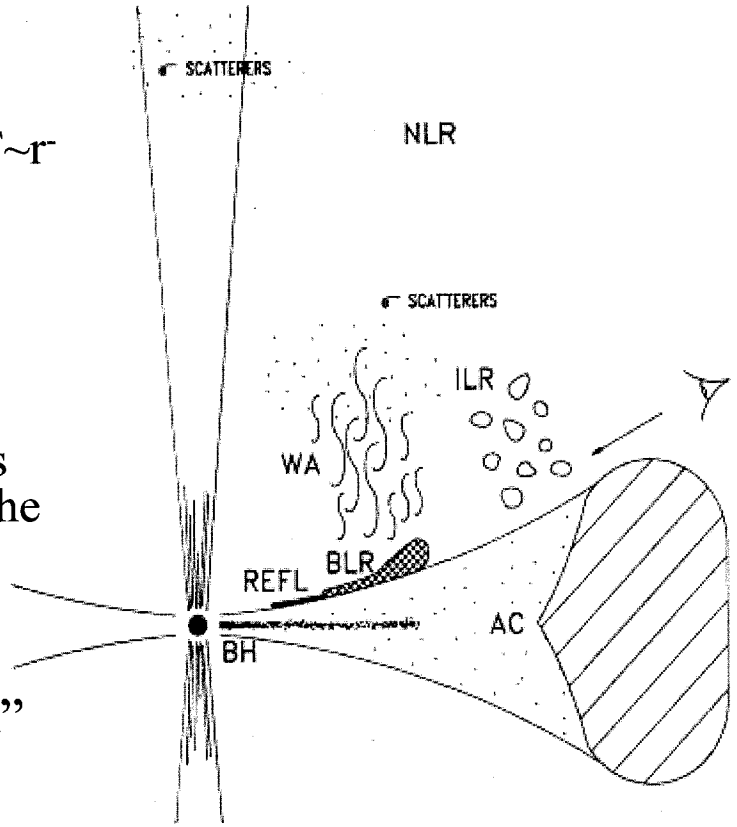


V^2 ~0.8 @2.2um, 85m baseline (λ/B ~5 mas)
Implies the emission comes from a region <~1 mas dia
radius < ~0.05 pc

Extrapolation of radio emission of the jet (synchrotron emission) to the IR would result in 100x fainter emission from this 0.05pc region

What Can SIM Add to This?

- Even though SIM is no longer optimized for general imaging, SIM has advantages for studying AGN and other very compact objects
  - Accurate visibility measurements in space
  - Extends wavelength range 0.45~0.9 um to within ~100 Schwarzschild radii (assuming $T \sim r^{-3/4}$)
  - Broad wavelength coverage and 180 deg baseline rotation for improved uv-plane coverage (to measure disk geometry)
  - Spectroscopic imaging to give the apparent diameter of the disk at ~80 temperature zones and a channel centered on OIII emission of the BLR to locate the BLR with respect to the accretion disk
- AGN's are near the limit of ground based interferometers, at 10.4 mag, this is a "bright" target for SIM.
  - SIM could probe dozens of AGN in this manner



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SIM Support for Other NASA Missions

- SIM offers a unique tool to enhance science return from other NASA missions
  - A key parameter for all Milky Way objects observed by HST, SIRTF, Chandra, JWST, GALEX, etc is their distance from the Earth.
  - SIM can uniquely determine distances and proper motions of sources brighter than ~20 mag with just a few observations spread out over 1-2 years.
    - Binary neutron stars (mass, radius, EOS), η carinae, Cepheids/RR Lyrae, star forming clusters for accurate evolutionary tracks
- SIM is planning an observing mode to determine distances and proper motions of 10's of thousands of objects throughout the Milky Way.
  - SIM can offer the community a valuable resource by providing low astrometric accuracy for relatively bright objects (>30 uas and/or <15 mag)
  - SIM will involve community in major effort to identify targets for this mode.
  - SIM can capture much of the science lost when FAME was not confirmed

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Project Manager's Summary Assessment

- SIM Science capability is broad and compelling
  - Design team is still designing to meet goal level performance objectives
    - 4 uas wide angle, 1 uas narrow angle
    - No show stoppers yet found
- The SIM team continues to make outstanding technology progress
  - All four milestones required for Phase B entry are complete, with margin
  - First of four milestones required for Phase C entry is complete
- SIM flight design is progressing well
- SIM has completed the initial confirmation review process for Phase B entry
  - Awaiting formal Phase B entry direction letter from NASA HQ
- SIM remains on schedule for a Dec 2009 launch
  - This has been the working schedule for ~3 years

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