Stellar Imager (SI): Observing the Universe in High Definition

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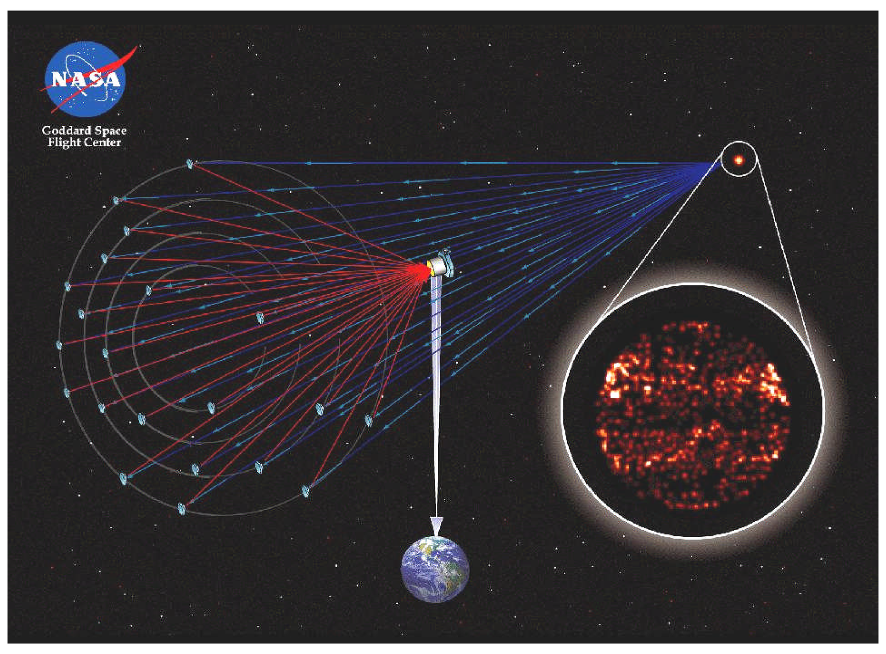
and the SI Development Team*



Artist's Concept of SI, operating at Sun-Earth L2

Summary

SI is a space-based, UV/Optical Interferometer (UVOI) with *over 200x the resolution of HST.*

- It will enable 0.1 milli-arcsec (mas) spectral imaging of stellar surfaces and of the Universe in general and open an enormous new "discovery space" for Astrophysics with its combination of high angular resolution, dynamic imaging, and spectral energy resolution.
- SI will provide heretofore unattainable views of the surfaces and interiors of other solar-type stars, of the interior regions and winds of Active Galactic Nuclei, and of the dynamics of many systems and processes throughout the universe.

Capabilities:

- angular resolution of 0.1 milli-arcsec at ~2000 Å
- ~1000 pixels of resolution over the surface of nearby dwarf stars:
- ~10-Å UV pass bands to enabling imaging in spectral lines (e.g., C IV [10^5 K], Mg II h&k [10^4K])
- broadband, near-UV or optical continuum (3,000-10,000 K)
- spectroscopic imaging

High Level Science Goals

High Level Science Goals

Understand by high angular resolution spectral imaging the details and dynamics of heretofore unresolved objects and processes:

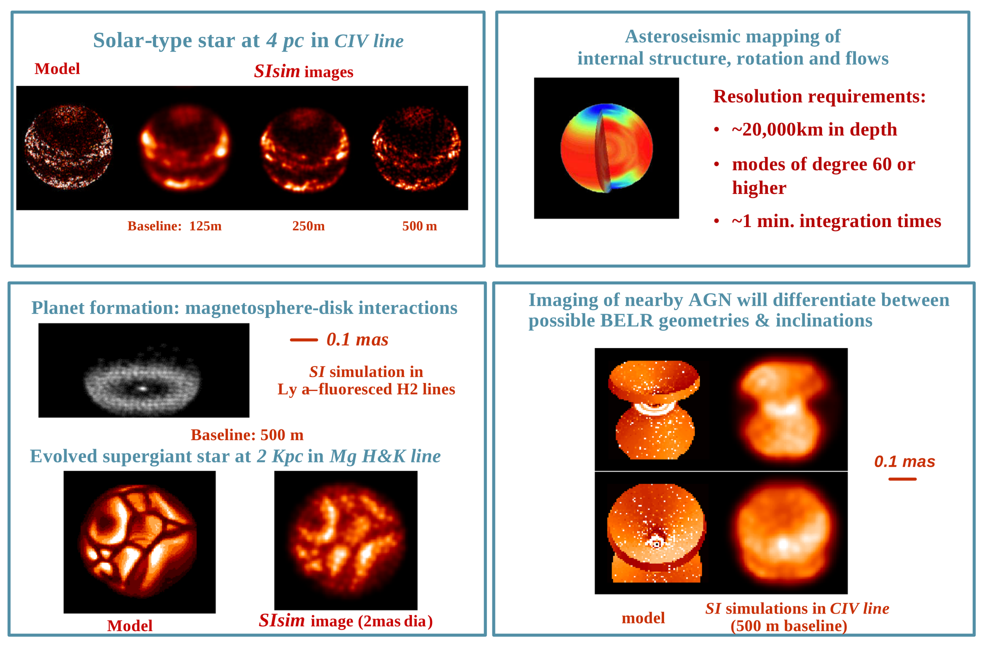
- Solar/Stellar Magnetic Activity and their impact on Planetary Climates and Life
- Magnetic & Accretion Processes and their roles in the Evolution of Structure and in the Transport of Matter throughout the Universe
- The close-in structure of AGN and their winds

Detailed Science Goals

- Support development and validation of a predictive stellar dynamo model, by resolving patterns of surface activity and by determining internal structure and flows for a diverse sample of stars
  - to understand the origins of variability in the Sun-Earth system
  - to enable improved long-term forecasting of solar/stellar magnetic activity and understand the impact of that activity on planetary climates and on the origin and maintenance of life
- Study dynamics of systems/processes enabled by sub-milliarcsec resolution

  SI's resolution brings the study of the dynamical evolution of many astrophysical objects into reach – hours to weeks between successive images will detect dramatic changes which are important clues to understanding:
  - jet formation and propagation in young planet-forming systems
  - accretion and magnetic field structure and star/disk interaction in young stellar systems
  - mass-transfer in binaries
  - pulsation-driven surface brightness variations and convective cell structure in giant and supergiant stars
  - non-radial pulsations, rotation and structure of, e.g., envelopes and shells of Be and Wolf Rayet stars
  - flows in black-hole environments, supernovae, planetary nebulae and their core structure
  - reverberating AGN
- Observe & understand close-in AGN structure and winds
  - Resolve the transition zone between Broad and Narrow Line Emitting Regions
  - Image inner accretion disk where synchrotron jet emerges
  - Determine origin and orientation of their jets
  - Determine nature and geometry of their winds
  - Precisely measure average opening angle of AGN reflection cones at pc scales to test the AGN Unification Picture
- Study internal transport processes in stars at different evolutionary phases, their impact on stellar evolution, and their consequences for the chemical evolution of galaxies
- Study exo-planets by resolving transits across stellar disks

The Science Potential of SI



SI is a cross-theme mission addressing Science Goals of both the NASA Heliophysics and Astronomy/Physics Divisions:

SI:

- is included as a "Flagship and Landmark Discovery Mission" in the 2005 Heliophysics Roadmap
- is a candidate implementation of the UVOI in the 2006 Science Program for the Astronomy/Physics Division
- was the subject of a NASA/HQ Vision Mission Study (see the anthology "NASA Space Science Vision Missions" 2008, ed. M. Allen)
- has been recommended in the 2008 NRC Report for further study as a mission potentially enhanced by launch on an Ares V (enables larger primary mirrors), though an incrementally-deployed version could be launched using smaller rockets

SI and the Decadal Survey

The SI mission is targeted for the mid-to-late 2020's, the decade after the one under consideration now.

However, significant technology development is needed to enable SI and other space-based sparse aperture telescopes and interferometers:

- Precision (~cm-level) formation flying of numerous (up to ~30) spacecraft
- Precision metrology (nm-level) at distances up to 1 km
- Closed-loop control of sparse optical arrays with many elements (nm-level accuracy in mirror surface placement)
- Staged-control systems covering 12-orders of magnitude, from the nm-level of the mirror surfaces, to the cm-level placement of spacecraft in formation-flying, to the management of km-sized formations

All of these technologies are being worked on at some level, but *it is critically important that the importance of these capabilities are called out in the current decadal survey, to enable the flight of such missions in the following decade.*

Feasibility of Interferometry from Space

- SI is part of a natural evolution from current ground-based interferometers and testbeds to a space-based system
- Feasibility of interferometry demonstrated by large variety of successful ground-based interferometers (e.g., CHARA, COAST, NPOI, and VLTI)
- Space provides a better environment
  - Not looking through an atmosphere, which on the ground limits spatial and temporal coherence (aperture size and integration time) of incoming wavefront
  - No need for large and complicated delay lines for off-axis obs.
  - Wavelengths not available from ground can be accessed
- A simple imaging interferometer, like SI, is a logical first "large baseline, space-based" interferometer
  - it is easier than an astrometric mission like SIM, since its light-path delay tolerance is ~2 orders of mag less than SIM's λ/1000 level
  - It is easier than TPF-I-like missions aimed at planet detection via nulling the central star and requiring a fringe contrast ~0.99999 and having error requirements ~10000x more severe than SI with its 0.9 fringe contrast requirement
- A small-baseline space interferometer with just a few primary mirrors (e.g., FKSI or Pegase) would be an ideal bridge from the ground-based to large baseline space-based interferometers

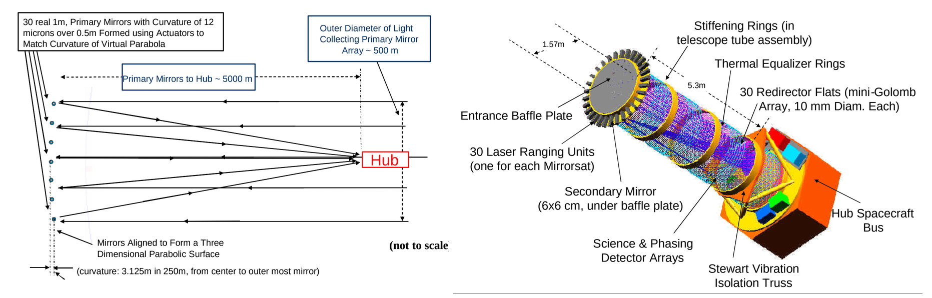
Technology updates

- Major Partnerships established between GSFC, LMATC, BATC, NGST, MIT, SAO, CU and international partners to develop concept and technology
- Fizeau Interferometry Testbed in operation at GSFC to develop closed-loop optical control
- SPHERES experiments run at MIT and MSFC to develop and test formation flying algorithms

For more information, see:
http://hires.gsfc.nasa.gov/si/

Mission Concept

SI Cross-Sectional Schematic — Principal Elements of SI Hub



Baseline Design:

- a 0.5 km diameter space-based UV-optical Fizeau Interferometer
- ~Sun-Earth L2 to enable precision formation flying
- 30 primary (>1m) mirror elements focusing on beam-combining hub
- more than 1 hub provides critical-path redundancy and strongly improved observing efficiency because of reduced slew requirement
- long-term (> 10 year) mission to study stellar activity cycles:
  - individual telescopes/hub(s) can be refurbished or replaced by human or robotic servicing

Mission and Performance Parameters

Parameter	Value	Notes
Maximum Baseline (B)	100 – 1000 m (500 m typical)	Outer array diameter
Effective Focal Length	1 – 10 km (5 km typical)	Scales linearly with B
Diameter of Mirrors	1 - 2 m (1 m currently)	Up to 30 mirrors total
λ-Coverage	UV: 1200 – 3200 Å Optical: 3200 – 5000 Å	Wavefront Sensing in optical only
Spectral Resolution	UV: 10 Å (emission lines) UV/Opt: 100 Å (continuum)	
Operational Orbit	Sun-Earth L2 Lissajous, 180 d	200,000x800,000 km
Operational Lifetime	5 yrs (req.) – 10 yrs (goal)	
Accessible Sky	Sun angle: $70^{\circ} \leq \beta \leq 110^{\circ}$	Entire sky in 180 d
Hub Dry Mass	1455 kg	For each of 2
Mirrorsat Dry Mass	65 kg (BATC) - 120 kg (IMDC)	For each of 30
Ref. Platform Mass	200 kg	
Total Propellant Mass	750 kg	For operational phase
Angular Resolution	0.05 mas – 0.2 mas (@1200–5000Å)	Scales linearly ~ λ/B
Typical total time to image stellar surface	< 5 hours for solar type < 1 day for supergiant	
Imaging time resolution	10 – 30 min (10 min typical)	Surface imaging
Asteroseismology time resol.	1 min cadence	Internal structure
# res. pixels on star	~1000 total over disk	Solar type at 4 pc
Minimum FOV	> 4 mas	
Minimum flux detectable at 1550 Å	5.0×10^{-14} ergs/cm^2/s integrated over C IV lines	10 Å bandpass
Precision Formation Fly.	s/c control to mm-cm level	
Optical Surfaces Control	Actuated mirrors to micron-nm level	
Phase Corrections	to λ/10 Optical Path Difference	
Aspect Control/Correct.	3 μas for up to 1000 sec	Line of sight maintenance

SI and the Constellation Architecture

- Ares V (its larger fairing volume) enables inclusion of larger primary array elements:
  - VM design has 30 mirrors, each 1m in diameter
    - Larger diameters may be desirable for improved sensitivity, but do not fit in 1-2 Delta IV launches
  - With Ares V: 30 x 2m (and larger!) are feasible
    - dramatically increases the sensitivity and science productivity of the observatory, especially for the fainter, extra-galactic sources
    - provides equivalent of an 11m diameter monolith in "light-bucket" mode (4x more light than 1m mirrors, nearly 20x light gathering capability of HST)
- Ares V may enable launch on a single vehicle of designs which include:
  - more than 1 hub (strongly desired for operational efficiency and redundancy)
  - a reference metrology/pointing control spacecraft

* The SI Development Team

Mission concept under development by NASA/GSFC in collaboration with experts from industry, universities, and astronomical institutes:

Arizona State University
Ball Aerospace & Technologies Corp.
Marshall Space Flight Center
Northrop-Grumman Space Tech.
Sigma Space Corporation
Space Telescope Science Institute
Stanford University
University of Maryland
Catholic University of America
Lockheed Martin Adv. Tech. Center
Massachusetts Inst. of Technology
Seabrook Engineering
Smithsonian Astrophysical Observatory
State Univ. of New York/Stonybrook
University of Colorado at Boulder
University of Texas/Arlington&SanAn.

European Space Agency
Astrophysical Institute Potsdam
College de France
University of Aarhus

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