SI – The Stellar Imager: Results from the Vision Mission Study

SI **is a UV/optical deep-space telescope to image stars and observe the Universe with 0.1 milli-arcsec angular resolution.**

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Science Drivers for the Mission

Magnetic fields affect the evolution of structure in the Universe and drive stellar activity which is key to life's origin and survival

BUT

Our understanding of how magnetic fields form and evolve is currently very limited, even for the nearest star, our Sun.

Achieving an understanding of solar/stellar magnetism is key to deciphering magnetic fields and their roles in more exotic and distant objects.

Our close-up look at the Sun has enabled the creation of approximate dynamo models – but none predict the level of magnetic activity of the Sun or any other star. Despite detailed solar and stellar studies, we do not know

- **what sets the dynamo strength and pattern**
- **how active stars can form polar spots**
- **what to expect from the Sun on time scales up to centuries**
- **what causes solar-type 'Maunder minima' or 'grand maxima'**
- **why 2 in 3 Sun-like stars show no cycles**

No current dynamo model can reliably forecast the Sun's activity or reproduce its historical changes:
- will the next cycle be 8 or 15 years long?
- will it be half or double the strength?
- will there be one at all?

Major progress in understanding stellar magnetism requires a population study: we need maps of the evolving patterns of magnetic activity, and of subsurface flows, for stars with a broad range of masses, radii, and activity levels.

SI will address the critical questions on solar/stellar magnetism and activity by imaging surface structures on stars as they rotate and by using asteroseismology to map their internal structure and flows.

Primary Science Goals

- **Support development and testing of a dynamo model, by resolving patterns of surface activity and 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 activity and understand the impact of stellar magnetic activity on planetary climates and on the origin and maintenance of life
- **Determine the role of the central star in other 'solar systems'**
  - understand stellar dynamos to better determine the impact of stellar activity on the habitability of the planets orbiting them
- **Study the Universe at ultra-high angular resolution to understand**
  - the consequences of magnetic fields for the formation of stars and planetary systems as the cradles of life
  - internal transport processes in stars at different evolutionary phases, their impact on stellar evolution, and their consequences for the chemical evolution of galaxies
  - dynamo and accretion processes, mass exchange in binaries, and flows in AGNs, black-hole environments, supernovae,…

Design Requirements & Key Technologies

Science Goals	Data Required	Measurement Capabilities	Key Technologies
Understand the dynamo process responsible for magnetic activity in stars Enable improved forecasting of solar/stellar magnetic activity on time scales of days to centuries Understand the impact of stellar magnetic activity on planetary climates and on the origin and continued existence of life Complete the assessment of external solar systems begun with the Planet Finding and Imaging missions, by imaging the central stars and determining the impact of the activity of those stars on the habitability of the surrounding planets Study the Universe (AGN's, QSO's, black holes, supernovae, interacting binary stars, hot stellar winds/non-radial pulsations, forming-stars and disks, cool evolved and long-period variable stars) at high angular/spatial resolution	Empirical constraints to refine dynamo models. Specifically, for a solar-type star at 4 pc: Observations of spatial and temporal stellar surface magnetic activity patterns in a sample of stars covering a broad range of activity level: UV (1550 Å, 2800 Å) images with 1000 total resolution elements taken with modest integration times (~hours for dwarfs to days for giants) Measurement of internal stellar structure and rotation: Asteroseismology via optical images with 30-100 total resolution elements over a stellar disk to measure non-radial resonant waves with short integration times - minutes (dwarfs) to hours (giants) Long-mission lifetime (>10 years) needed to provide observations over significant fraction of stellar activity cycles	Angular Resolution 0.1 mas at 1550 Å Spectral Range 1200 – 5000 Å Field of View ~ 4 mas Flux Threshold at 1550 Å $5x10^{-14}$ ergs/cm^2/s Observations several dozen solar-type stars observed repeatedly over mission lifetime; month-long seismology campaigns on select targets **Engineering Implications** Baselines: 100 to 1000m >20 UV quality primary mirrors > 1 m in diameter Fizeau Beam combination Path Length Control to 3 nm Aspect Control to 0.030 mas Orientation +/-20deg to Sun orthogonal	precision metrology and formation-flying wavefront sensing and closed-loop control of many-element optical systems deployment/initial positioning of elements in large arrays metrology/autonomous nm-level control of many-element formations over kilometers variable, non-condensing, continuous micro-Newton thrusters light-weight UV quality spherical mirrors with km-long radii of curvature larger format energy resolving detectors with finer energy resolution (R=100) methodologies for ground-based integration and test of distributed s/c systems mass-production of "mirrorsat" spacecraft

Quick Facts: Stellar Imager Vision Mission

Science Goals

To understand:

- Solar and Stellar Magnetic Activity and their impact on Space Weather, Planetary Climates, and Life

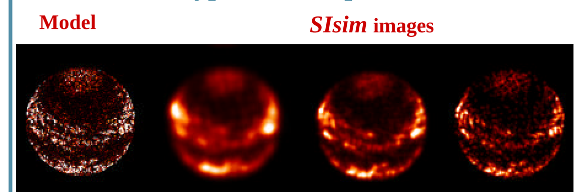
- Magnetic Processes and their roles in the Origin and Evolution of Structure and in the Transport of Matter throughout the Universe

Mission and Performance Parameters

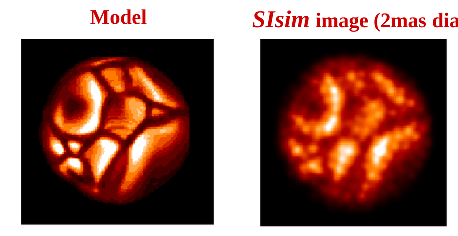
Parameter	Value	Notes
Maximum Baseline (B)	100 – 1000 m (500 m typical)	Outer array diameter
Effective Focal Length	1 – 10 km (5 km typical)	Scales linearly with B
Diameter of Mirrors	1 - 2 m (1 m currently)	Up to 30 mirrors total
λ-Coverage	UV: 1200 – 3200 Å Optical: 3200 – 5000 Å	Wavefront Sensing 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: $70° \leq \beta \leq 110°$	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	50 mas – 208 μas (@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.	spacecraft 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

The Science Potential of the Stellar Imager

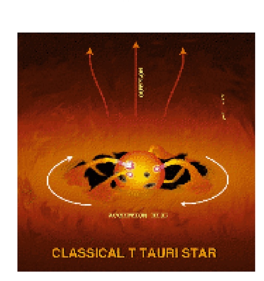
Solar-type star at *4 pc* in *CIV line*

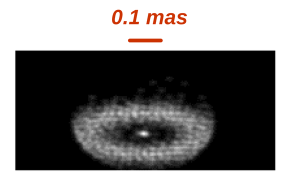


Evolved supergiant star at *2 Kpc* in *Mg H&K line*



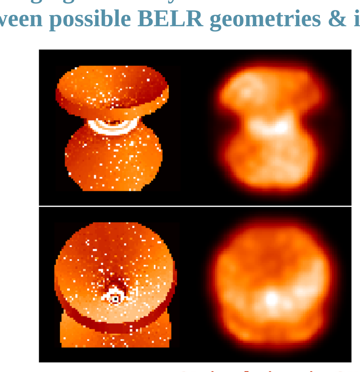
***SI* imaging of planet forming environments: magnetosphere-disk interaction region**





***SI* simulation in Ly a–fluoresced H2 lines**
Baseline: 500 m

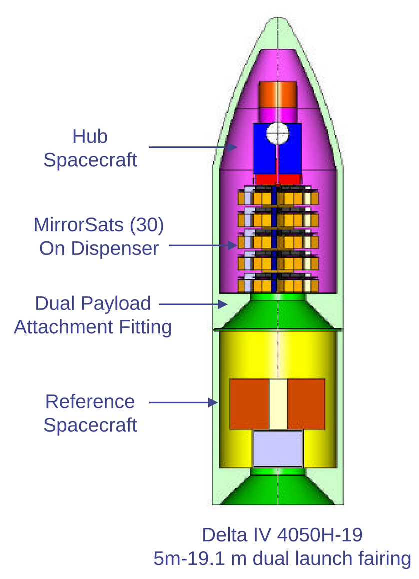
***SI* imaging of nearby AGN will differentiate between possible BELR geometries & inclinations**



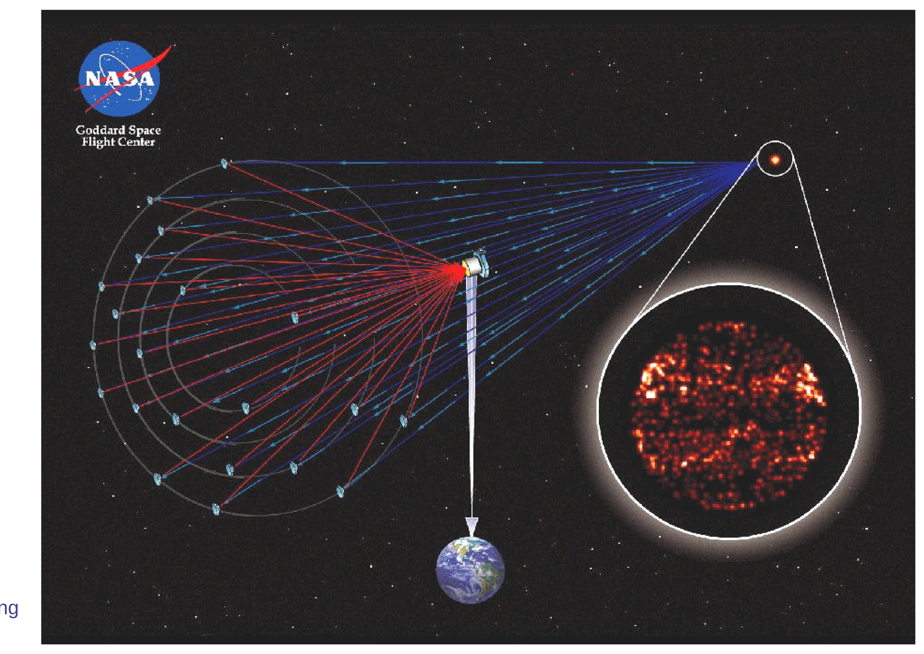
Status

- **SI included as a "Flagship and Landmark Discovery Mission" in the 2005 SSSC Roadmap and as a candidate for a "Pathways to Life Observatory" in the EUD Roadmap (5/05)**
  SI is a multi-theme, cross-division mission.
- **SI previously in NASA SEC (now SSSC) roadmaps for 2000 and 2003**
- **SI selected in 2003 by NASA HQ for further concept development as a Vision Mission**
  - **Major Partnerships established between GSFC, LMATC, BATC, NGST, JPL, SAO, CU and international partners to develop concept/technology and execute Vision Study**
  - **Vision Mission Report delivered to NASA HQ on 15 September 2005**
- **The related Fizeau Interferometry Testbed (FIT) is in operation at GSFC to develop closed-loop optical control of a many-element, sparse aperture system**

Mission Concept

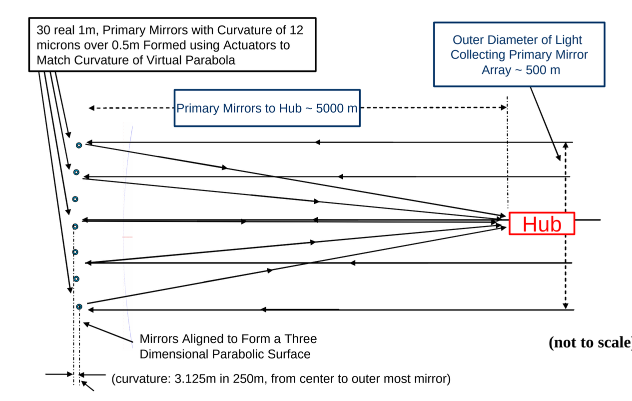


One possible launch concept

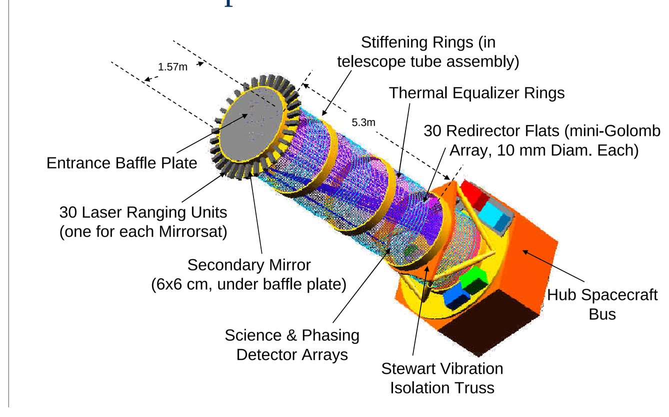


An artist's drawing of the current baseline design concept. A simulated interferometric image, in the light of CIV (1550 Å), of a sun-like star at 4pc is shown in the lower right.

SI Cross-Sectional Schematic



Principal Elements of SI Hub



Baseline Design:

- a 0.5 km diameter space-based UV-optical Fizeau Interferometer
- located near Sun-Earth L2 to enable precision formation flying
- 20-30 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

Capabilities:

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

Design Options:

- Classical Fizeau with large focal-plane detector (baseline design)
- Hybrid Hypertelescope which accepts partial pupil densification in order to maintain use of non-redundant array
- Fizeau with remapping of beams from 2D to 1D non-redundant array

SI and the NASA-ESA Strategies

SI **addresses science goals of 3 research Themes in NASA Science Mission Directorate:**

- ***learn how galaxies, stars, planetary systems form & evolve (Origins/EUD)***
- ***understand development of structure/flows of magnetic fields (SEU/EUD)***
- ***understand origins & societal impacts of variability in SEC (SSSC/SEED)***

TPF/Darwin, SI, and PI together provide complete views of other solar systems.

SI and the Exploration Initiative

SI is a key to developing models for long-term solar-system space weather forecasts

- *SI's population study aids development of dynamo models by exploring the manifestations of magnetic activity as a function of stellar properties and time*
- *SI's multi-star data base allows model validation within 10 y rather than 100 y or more*
- *Multi-year space-weather forecasts throughout the heliosphere guide vehicle design and mission planning and enable forecasts of extended periods for safe construction at Moon, Mars, Earth-Moon L1, Sun-Earth L2, and LEO staging orbits.*

SI is a "deep-space observatory" essential to the mandate of search and exploration of habitable planets around other stars (see NASA's "The Vision for Space Exploration", Feb. 2004 and the Exploration Level 0 Req. 1.7 ("NASA shall conduct advanced telescope searches for Earth-like planets and habitable environments around other stars"):

- *SI will explore the impact of stellar magnetic activity and radiation on the habitability of planets found by planet-search projects such as Kepler and the Terrestrial Planet Finder*
- *SI will investigate in detail how magnetic fields control formation of planetary systems (transport of mass and angular momentum, star-disk coupling, disk-clearance zones, …)*
- *SI technology & science are milestones towards the development of Planet Imager*

** The SI Vision Mission Team*

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

Ball Aerospace & Technologies Corp.
NASA's Jet Propulsion Laboratory
Northrop-Grumman Space Tech.
Sigma Space Corporation
Space Telescope Science Institute
Stanford University
University of Maryland
Lockheed Martin Adv. Tech. Center
Naval Research Laboratory/NPOI
Seabrook Engineering
Smithsonian Astrophysical Observatory
State Univ. of New York/Stonybrook
University of Colorado at Boulder
University of Texas/Arlington

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