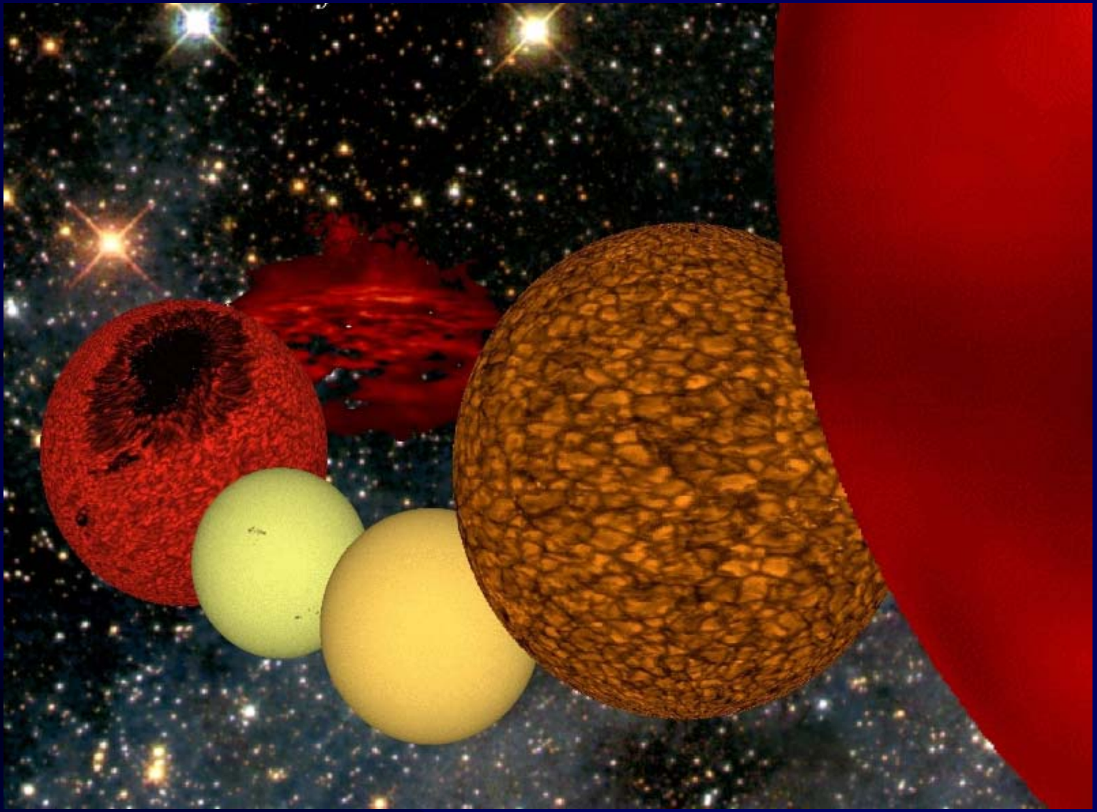
The Stellar Imager (*SI*):

A Large-Baseline Imaging Interferometer at the Sun-Earth L2 Point



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and the SI Mission Concept Development Team

Presented at the June, 2004 SPIE Meeting in Glasgow, Scotland

Mission Concept Development Team

- Mission concept under development by NASA/GSFC in collaboration with LMATC, BATC, JPL, NRL/NPOI, STScI, UMD, SAO, SUNY, Seabrook Engineering, and Sigma Space, Inc.
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  - NRL/NPOI: T. Armstrong, X. Zhang
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  - SAO: M. Karovska, J. Phillips, P. Nisenson, S. Baliunas, S. Korzennik, W. Soon
  - SUNY: F. Walter
  - UCO: A. Brown, G. Harper

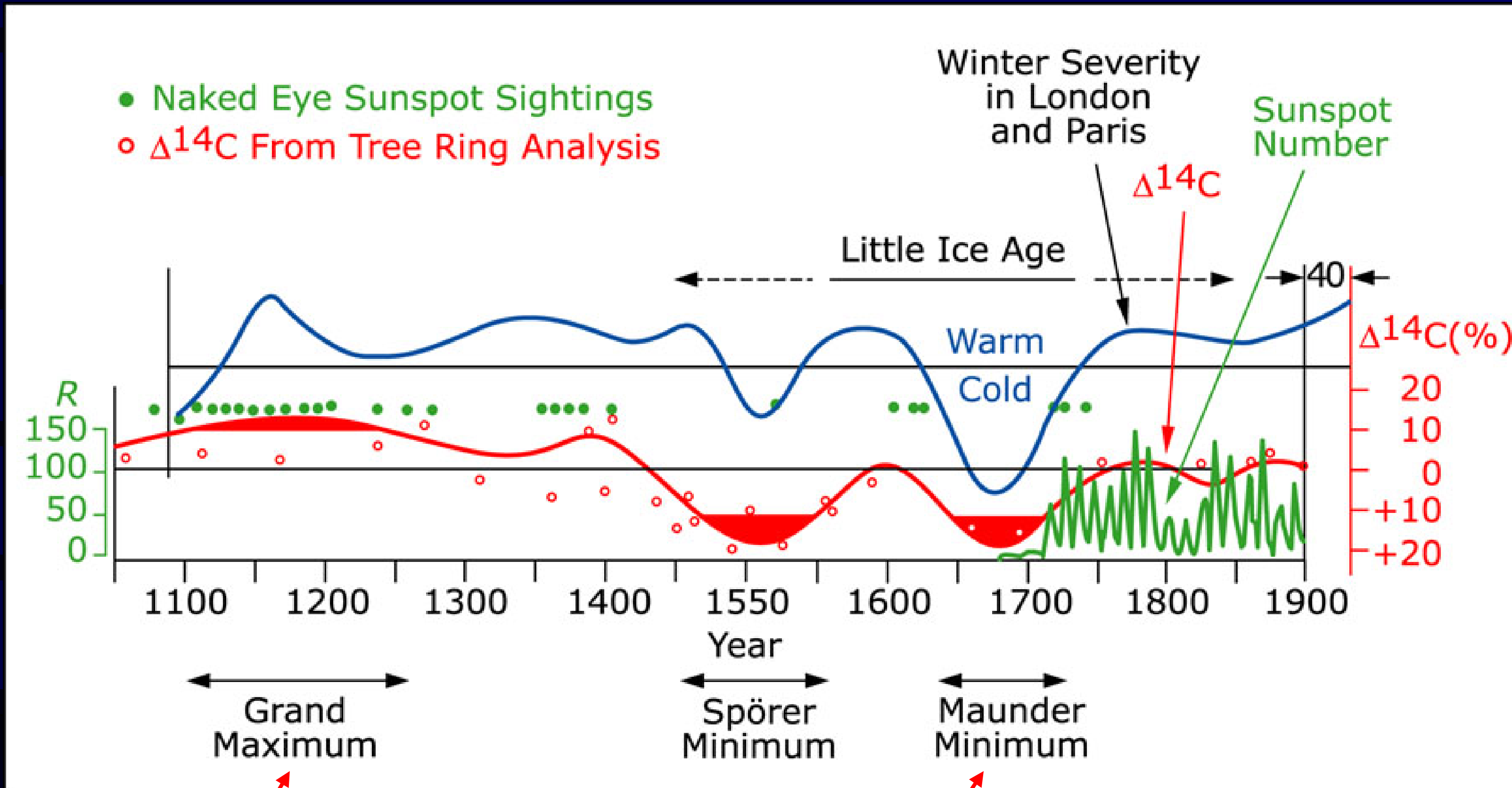
Science Context for *SI*: The Importance of Understanding Stars and Stellar Dynamos

- Our Sun represents only one of many types of stars, but our close-up view of it has enabled discoveries that have repeatedly revolutionized physics and astrophysics
  - existence of helium, role of nuclear fusion, convective envelopes, neutrino deficit
  - importance of non-linear, non-local processes (magnetic dynamo, convection, global circulation)

- The Dynamo is an ensemble of electric currents flowing in the subsurface layers of a star. It produces a complex magnetic field topology and induces associated activity which makes stars ever-changing and "dynamic". It:
  - slows the rotation of the collapsing cloud, enabling star formation
  - couples evolution of star and pre-planetary disk
  - results in energetic radiation conducive to the formation (& destruction) of complex molecules
  - governs the habitability of the biosphere through space weather and its effect on planetary climate by the high-energy particle winds, magnetic fields, and radiation which it controls

Understanding stars and the dynamo process in general is the foundation for understanding the Universe and the origin and continued existence of life within it

Effects of Solar Variations

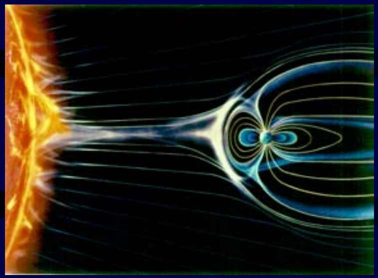


"global warming", aggravating greenhouse effect

crop failures,
July skating on the Thames

short-term effects:
disable satellites & power grids,
increase pipeline corrosion,
endanger astronauts

Stellar Activity is Key to Understanding Life in the Universe and Earth's habitability
BUT



There is no model of solar & stellar magnetic activity that predicts the level of stellar activity!

- Major progress requires a detailed understanding of the stellar dynamo and its behavior in time and with stellar parameters

The *Stellar Imager (SI)*
is a large space-based, UV-optical Sparse Aperture Telescope / Fizeau Interferometer designed to address this problem by

enabling the high angular resolution surface and sub-surface imaging
of a broad sample of stars
needed to constrain & refine dynamo/activity models

Primary Science Goals

- Study spatial and temporal stellar magnetic activity patterns in a sample of stars covering a broad range of activity level
  - Enable improved forecasting of solar activity on time scales of days to centuries
  - Understand the impact of stellar magnetic activity on planetary climates and astrobiology
- Measure internal stellar structure and rotation
- Complete the assessment of external solar systems
  - image the central stars and determine the impact of the activity of those stars on the habitability of the surrounding planets

Design Requirements

Requirements for imaging of stellar surface activity

- UV images: for visibility of surface manifestations of dynamo
  - visible-light dark starspots small/low contrast in most stars - poor choice
  - plages are high-contrast bright spots seen in Mg II h&k 2800 A, C IV 1550 A UV emission ==> ideal activity diagnostics
  - 1000 total resolution elements
- modest integration times (~ hours for dwarfs to days for giants)
  - avoid smearing of images due to rotation, activity evolution, proper motions

Requirements for imaging of stellar interiors by seismology

- Short integration times (minutes for dwarf stars to hours for giant stars)
  - requires broadband optical wavelengths to get sufficiently high fluxes
- Low-resolution imaging to measure non-radial resonant waves
  - 30-100 total resolution elements

Flexible interferometer configuration required for image synthesis

“Strawman” Full-SI Mission Concept

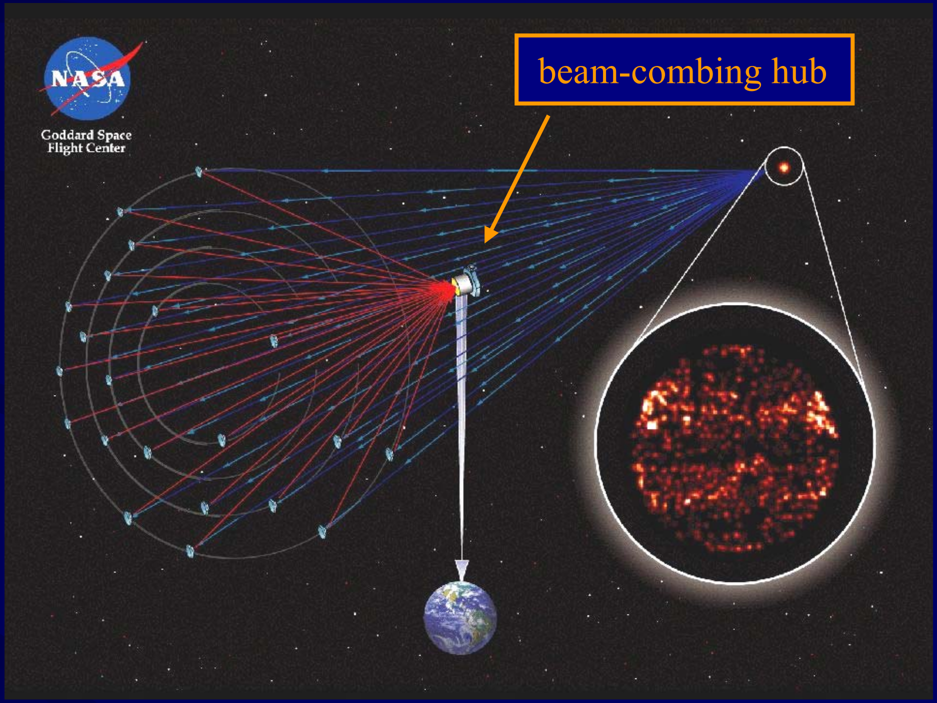
- a 0.5 km diameter space-based UV-optical Fizeau Interferometer
  - located near the sun-earth L2 point to enable precision formation flying

10 - 30 primary mirrors fly on “virtual” spherical surface with 130 km ROC

Capabilities Provided

- an angular resolution of 60 & 120 micro-arcsec at 1550 & 2800 Å
- ~ 1000 pixels of resolution over the surface of nearby dwarf stars
- observations in
  - ~10-Ångstrom UV pass bands
    - C IV (100,000 K)
    - Mg II h&k (10,000 K)
  - broadband, near-UV or optical continuum (3,000-10,000 K)
- a long-term (> 10 year) mission to study stellar activity cycles:
  - individual telescopes/central hub can be refurbished or replaced

hub and primary mirrors formation fly with ~ cm precision, mirror actuators maintain optical path lengths to within 5 nm



approximate distance to hub from center of array is 65 km

Top Technological Challenges/Enabling Technologies

- precision metrology and formation-flying
  - 3-level approach envisioned
    - rough formation control via radio frequency (RF) ranging and thrusters (to m's)
    - intermediate control (to cm's) via modulated laser ranging
    - fine control (to nm's) via feedback from science data system/phase diversity
- wavefront sensing and closed-loop control of many-element optical systems
- deployment/initial positioning of elements in large formations
- metrology/autonomous nm-level control of many-element formations over km's
- aspect control to 10's of μarcsecs
- variable, non-condensing, continuous μ-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)
- long mission lifetime requirement
- methodologies for ground-based integration and test of distributed s/c systems
- mass-production of "mirrorsat" spacecraft

Precursor/Pathfinder Mission

- Challenges suggest: a pathfinder mission which takes smaller technological steps and produces science results sooner is desirable
  - would advance technologies needed for other missions in NASA strategic plans

Desirable characteristics of such a mission

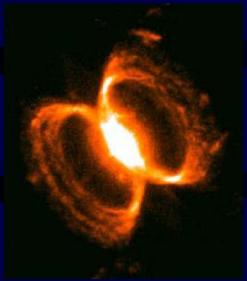
- possible within the current decade
- uses booms and/or a modest number of free-flying spacecraft
- operates with modest baselines
- performs beam combination with ultraviolet light
- produces UV images via imaging interferometry

- Such a mission with a small # of spacecraft
  - would require frequent reconfigurations and limit observations to targets whose variability does not preclude long integrations
  - would test most of the technologies needed for the full-size array

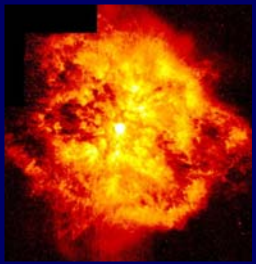
Place in NASA/ESA Strategic Roadmaps

- ***SI*** is on strategic path of NASA Origins interferometry missions
  - it is a stepping stone towards crucial technology…
    - ***SI*** is comparable in complexity to the ***Terrestrial Planet Finder***, and it may serve as a useful technological and operational pathfinder for ***Planet Imager***
  - … while addressing science goals of 3 NASA/OSS research Themes
    - understand why the sun varies (SEC)
    - understand the origin of stars, planetary systems, and life (Origins)
    - understand the structure and evolution of stars (SEU)
  - it is complementary to the planetary imaging interferometers
    - ***Terrestrial Planet Finder/Darwin***, and ***Planet Imager*** null the stellar light to find and image planets
    - ***Stellar Imager*** images the central star to study the effects of that star on the habitability of planets and the formation of life on them.

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



SI and General Astrophysics



A long-baseline interferometer in space benefits many fields of astrophysics

Active Galactic Nuclei
transition zone between BLR & NLR,
origin/orientation of jets

Quasi-stellar Objects & Black Holes
close-in structure,
radiation from accretion processes

Supernovae
close-in spatial structure

Stellar interiors
internal structure in stars outside
solar parameters

Hot Stars
hot polar winds, non-radial pulsations,
envelopes and shells of Be-stars

Spectroscopic binary stars
observe companions & orbits,
determine stellar properties,
perform key tests of stellar evolution

Interacting Binary Stars
resolve mass-exchange, dynamical
evolution/accretion,
study more efficient dynamos

Forming Stars/Disk systems: accretion
foot-points & magnetic field structure

Cool, Evolved Giant & Supergiant Stars, and Long-Period/Semi-Regular Variables
spatiotemporal structure of extended
atmospheres/winds, shocks

Current Status of SI

- SI included in far-horizon NASA SEC Roadmap
- SI selected for further concept development by the NASA HQ 2003 Vision Mission NRA review
- Major Partnerships established with LMATC, BATC, JPL, SAO, UCO to carry out further concept/technology development
- Phase I (7 primary elements) of the Fizeau Interferometry Testbed (FIT) has begun operation to develop closed-loop optical control of a multi-element array
- Next Steps
  - Continue Architecture Trade/Feasibility Studies
  - Test/demonstrate design concepts with ground-based testbed (the FIT)
  - Gather & utilize additional community input
  - Produce book summarizing science/societal motivations for mission, technology roadmap, and most promising architecture options

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