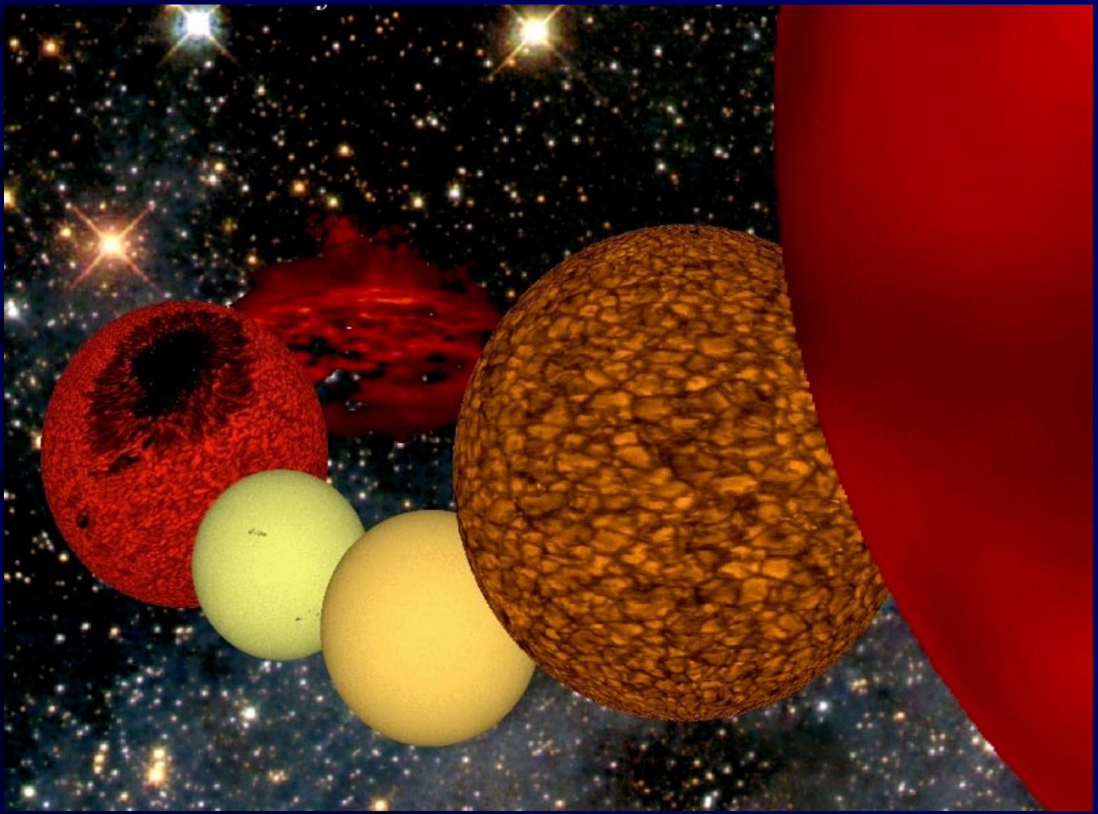
# The Stellar Imager (*SI*) Mission Concept

## Imaging the Surfaces of Distant Stars



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and the SI Mission Concept Development Team

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# Mission Concept Development Team

- Mission concept under development by NASA/GSFC in collaboration with LMATC, NRL/NPOI, STScI, UMD, CfA...
  - NASA-GSFC: Ken Carpenter (Study Lead), Rick Lyon , GregSolyar/UMBC, Joe Marzouk/ΣSpace, Lisa Mazzuca, Bill Danchi, Susan Neff
  - LMMS/ATC: Carolus Schrijver (Science Lead)
  - NRL/NPOI: Tom Armstrong, Dave Mozurkewich, Tom Pauls, Xiaolei Zhang
  - STScI: Ron Allen, Jay Rajagopal
  - UMD: Lee Mundy
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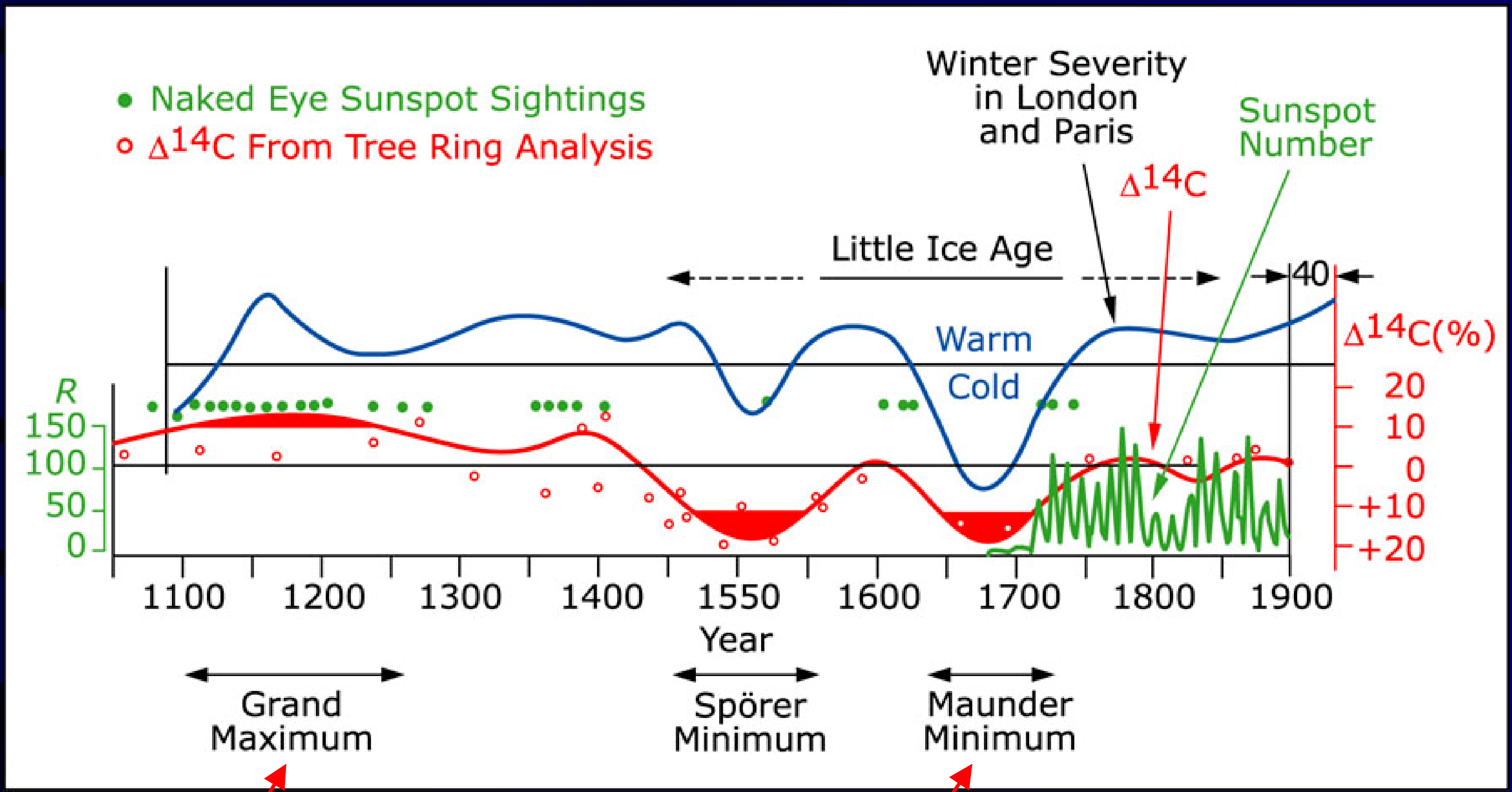
# Science Context for *SI*: The Importance of Understanding Stars and Stellar Dynamos

- The Sun is only one of many classes of stars, but our close-up view of the Sun 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". The Dynamo:
  - 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

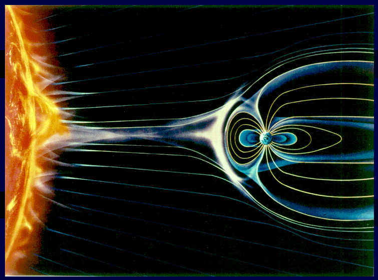



"global warming", aggravating greenhouse effect

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

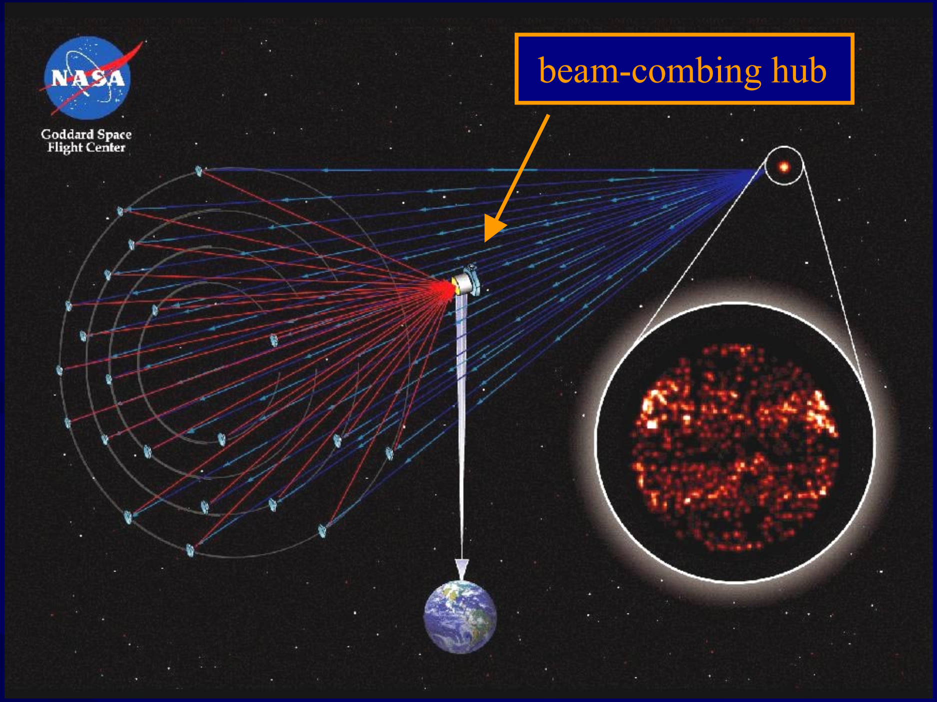
- a 0.5 km diameter space-based UV-optical Fizeau Interferometer
  - located near the sun-earth L2 point to enable precision formation flying

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

# Simulated Interferometric Stellar Images

\# rotations(step size): 0 (0) 24 (15deg)

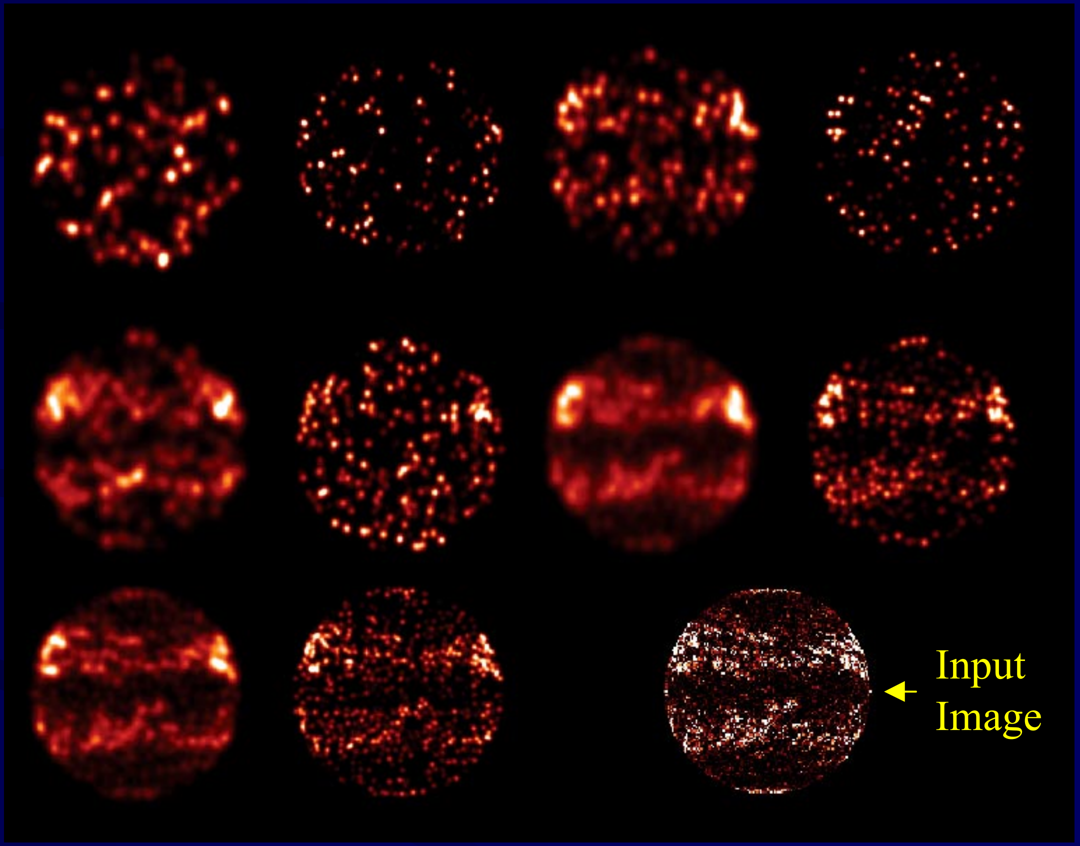
**# elements**

- simulations computed with SISIM (Allen & Rajagopal)
- computed in the light of CIV (1550 A), of solar star at 4pc
- first two rows: Y-configuration
- last row assume 30 elements arranged in a low-redundancy "Golomb rectangle" (Golomb & Taylor, IEEE Trans. Info. Theo., 28, #4, 600, 1982)

**6**

**12**

**30**



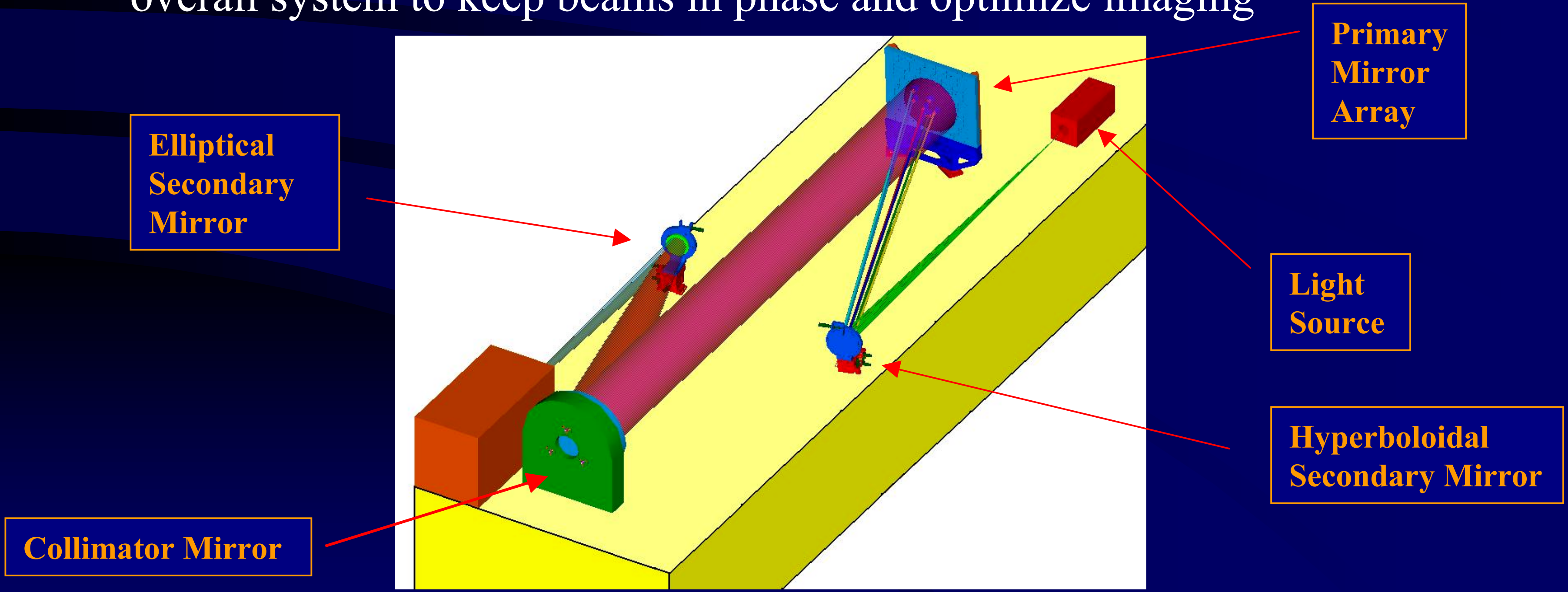

**Baselines:** **250 m** **500 m** **250 m** **500 m**

"Snapshots" (no rotations) (24 array rotations)

Conclusion: 30 static elements appear to be sufficient to adequately synthesize this stellar image. Alternatively, fewer elements can be used with a large number of rotations.

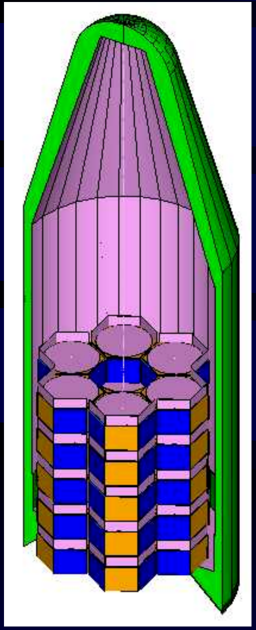
# The Fizeau Interferometer Testbed (FIT)

- A ground-based lab testbed at GSFC for UV-Optical Fizeau Interferometers
  – Designed to explore the principles of and requirements for the SI mission concept and other Fizeau Interferometers
  – Utilizes 7-30 separate apertures (each with 5 degrees of freedom: tip, tilt, piston, 2D translation of array elements) in a sparse distribution
  – Goal of demonstrating closed-loop control of articulated mirrors and the overall system to keep beams in phase and optimize imaging



# GSFC IMDC "Full SI" Mission Study

- Baseline concept studied by GSFC Integrated Mission Design Center (IMDC)
  - 30 "mirrorsats" formation flying with beam-combining hub
  - control satellites to 5 nm, rather than use optical delay lines for fine tuning
  - Fizeau interferometer: 0.5 km max. baseline, 4 km focal length (now 65 km)



## Moderate Challenges

dual launch of Delta IV + Delta III 3940-11

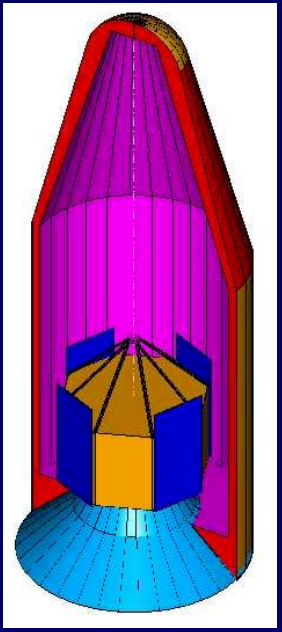
power systems: solar cells must be *body-mounted* to avoid unacceptable impact on precision formation-flying, battery life/storage a concern

propulsion: use Field Emission Electric Propulsion (FEEP's) for fine-control

operations concept: autonomous control except for command uploads and anomaly resolution

thermal: main concern is keeping mirrors isothermal

communications:
- mirrorsats talk to hub and each other, hub talks to earth
- contingency: mirrorsats can be commanded from earth
- enhancement: central communications hub at L2



# IMDC Results: The Technological "Tall Poles"

- 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
- long mission lifetime requirement
  - hub will have redundant components, but may need backup hub for launch-on-need or original deployment
  - need to fly additional backup mirrorsats to put into operating array as failures occur

- most important "enabling technologies" needing development
  - Deployment/initial positioning of elements in large formations
  - Metrology and autonomous nm-level control of many-element formations over kilometer scales
  - 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)

# Precursor/Pathfinder Mission

- The path to a large-baseline UV-optical interferometer in space is long - a pathfinder mission which takes smaller technological steps and produces science results sooner is desirable and would advance technologies needed for other missions in the 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

# "Strawman" Pathfinder Design

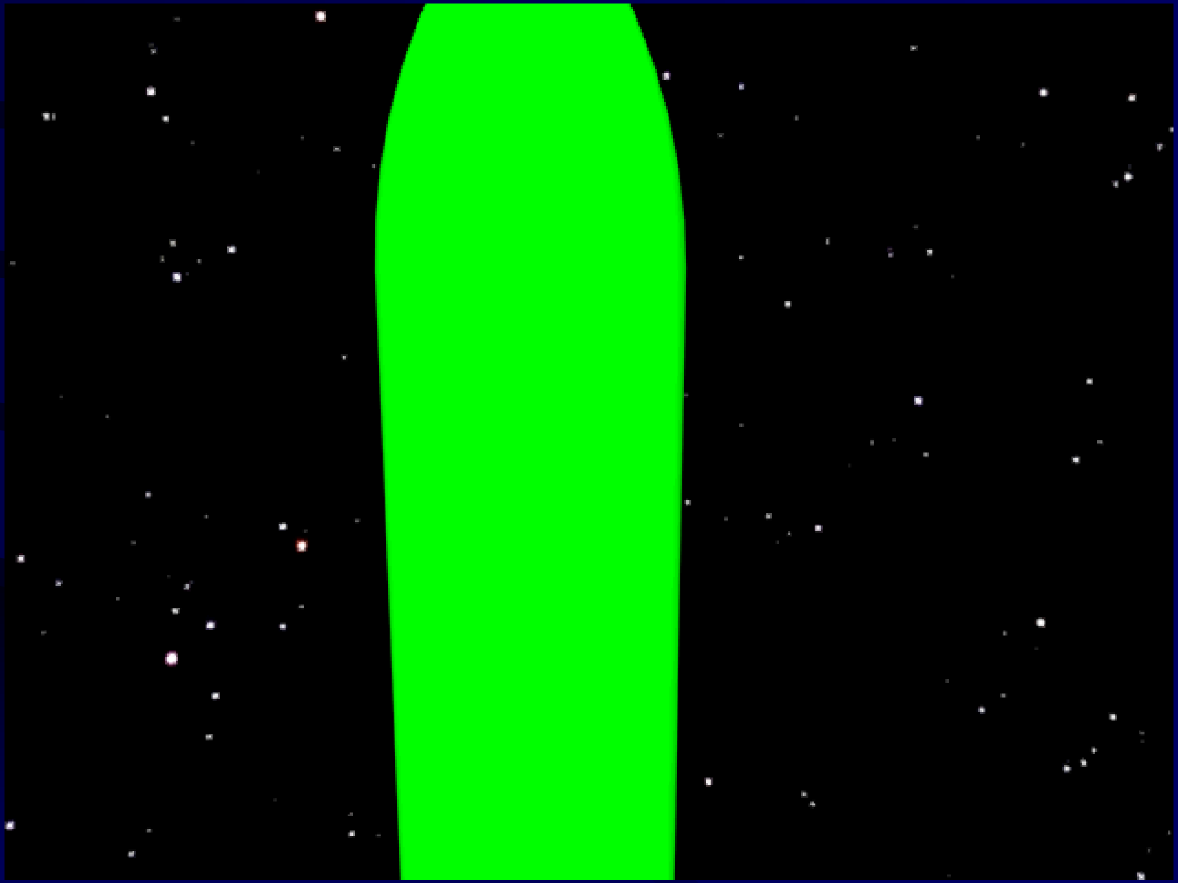
- GSFC Integrated Design Center (IMDC and ISAL) Studies
  - suggest a combination system using both a boom and a free-flyer

Boom

3 mirrors (sections of a parabola)

plus

an attached secondary mirror mast



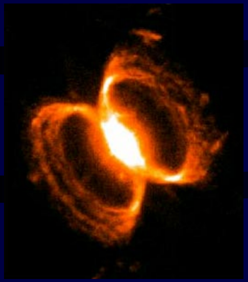
1 free-flyer

with a deformable spherical secondary mirror

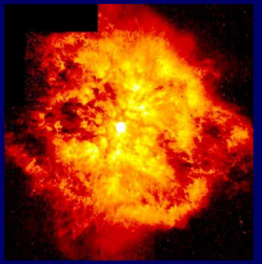
# Place in NASA/ESA Strategic Roadmaps

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



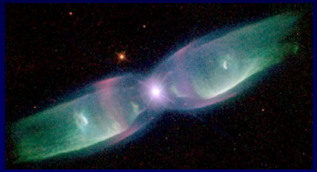
# *SI* and General Astrophysics



## 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

- Included in far-horizon NASA "Sun-Earth Connection" Roadmap
- Mission concept continues to be developed by NASA/GSFC in collaboration with LMATC, NRL/NPOI, STScI, UMD, CfA etc.
- Recent Events
  - Requirements defined, optical design completed, hardware procurements in progress for Laboratory Fizeau Interferometry Testbed (FIT) at GSFC
  - IMDC Studies performed for full and Pathfinder missions
  - 3 supporting ISAL studies performed
  - full-color brochure published, "whitepaper" submitted to Roadmap panels
- 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**