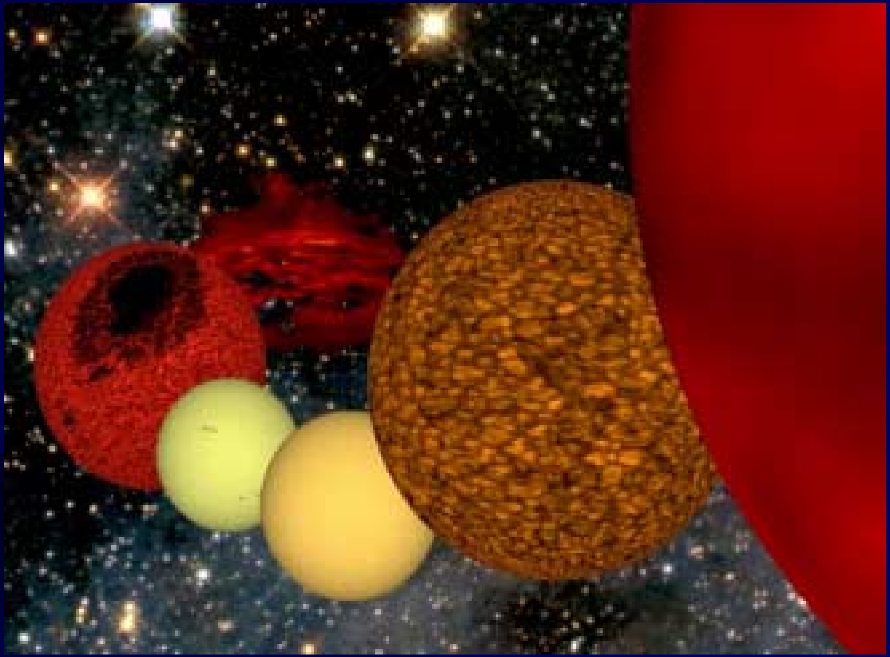
The *Stellar Imager* (*SI*) Mission Concept

A voyage of exploration to understand the stars, the formation of planetary systems, and the existence of life



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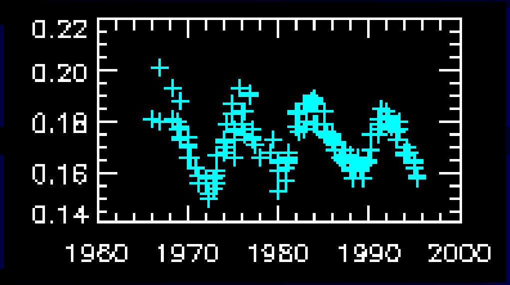
Presented at the January 2001 meeting of the American Astronomical Society in San Diego, CA

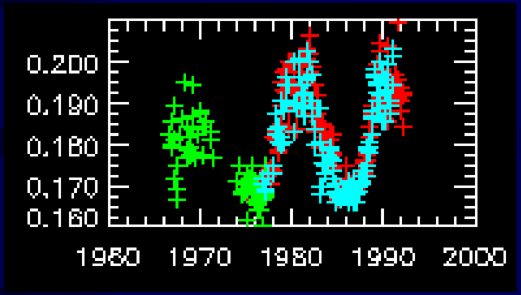
Primary Science Goals

- Study spatial and temporal stellar magnetic activity patterns in a sample of stars covering a broad range of activity level, in order to understand the underlying dynamo process(es) and thereby
  - enable improved forecasting of solar activity on time scales of days to centuries, including Maunder-like minima and “grand maxima” that significantly affect geospace and earth’s weather
  - understand the impact of stellar magnetic activity on astrobiology & life
- Enable asteroseismology (acoustic imaging) to measure internal stellar structure and rotation and their relationship to the dynamo
- Complete the assessment of external solar systems
  - image the central stars of systems for which the Origins IR-interferometry missions find and image planets, and determine the impact of the activity of those stars on the habitability of the surrounding planets

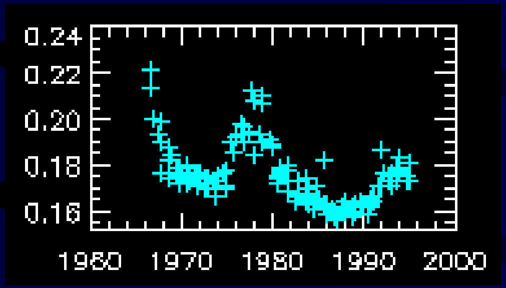
Manifestations of Magnetic Activity



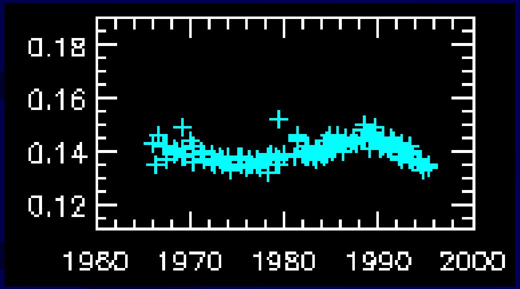
HD 81809: 8.2 yrs



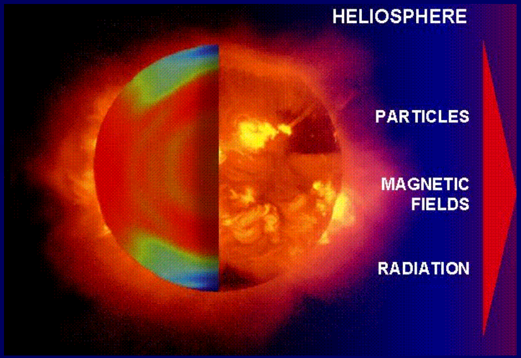
The Sun: 11 yrs

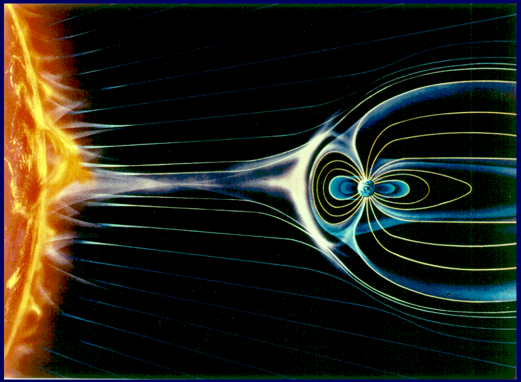


HD 3651: 13.8 yrs



HD 136202: 23 yrs





- stellar luminosities show cyclic changes (e.g. Mt. Wilson Ca II disk-integrated flux)
- long-term solar variations have induced climate changes on Earth, such as the 17th-Century Little Ice Age during the Maunder (low-activity) minimum

- In solar/stellar atmospheres:
  - magnetic regions & star spots;
  - very hot outer atmospheres;
  - explosive flares & high-energy particles and radiation;
  - stellar wind & coronal mass ejections

Value to Society: Space-Weather & Earth-Climate Forecasting

- We must develop & validate a dynamo model in order to
  - understand past solar activity
  - enable forecasting of solar and heliospheric activity days to decades in advance
  - anticipate the impact of those changes on the earth's biosphere and society from
    - long-term changes which effect climate, such as Maunder minima and grand maxima, can lower/raise overall global temperatures
    - short-term changes, e.g. enhanced activity/flares, have the potential to
      - disable communication satellites
      - knock out power grids
      - increase the speed of corrosion of oil pipelines
      - place astronauts at risk from particle radiation

Science Driver: Stellar activity is key to understanding life in the Universe and Earth's habitability

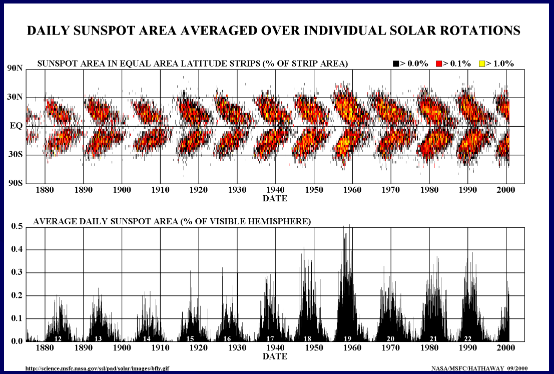
The stellar magnetic field

- 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 planetary climate through luminosity, wind, magnetic fields, and radiation

- Problem: there is no comprehensive model of solar/stellar magnetic activity

Science Requirement:
Population Study of Cool Stars

- To understand the dynamo, we need to know how magnetic fields are generated & behave in different circumstances
- The sun is only one example
  - provides insufficient constraints on theories of dynamos, turbulence, structure, and internal mixing
  - must observe other stars to *establish how mass, rotation, brightness and age affect the patterns of activity* & determine:
    - What determines cycle strength and duration?
    - How common is solar-like activity?
    - Can multiple cycles exist at the surface?
    - What are Maunder-minimum states like?
    - How do polar spots form?
    - What are extremely (in)active stars like?



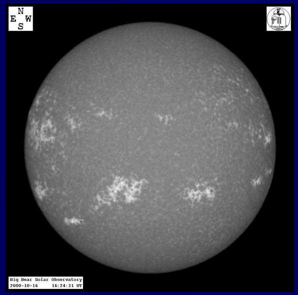
Science Requirement: Asteroseismology

- Although its clearest manifestations are visible on the stellar surface, a full understanding of the dynamo requires a knowledge of the subsurface layers of the star in which it resides
- Asteroseismology (acoustic imaging) of the star enables us to address questions related to the stellar interior
  - Where is the seat of the dynamo?
  - What determines differential rotation and meridional circulation, and what role do they play in the dynamo?
  - What is the impact of magnetic deceleration on internal rotation and stellar evolution?
  - How are stellar interiors modified in extremely active stars?

Primary Performance Goals

- Image different stars of different activity
  - for a substantial sample of nearby dwarf and giant stars, obtain a resolution of order 1000 total pixels (33x33) (~50,000 km on a Sun-like star)
  - study a sample in detail, revisiting over many years
  - measure:
    - sizes, lifetimes, and emergence patterns of stellar active regions
    - surface differential rotation, field dispersal by convective motions, and meridional circulation
    - directly image the entire convection spectrum on giant stars, and the supergranulation on, e.g., the solar counterpart α Cen
- Enable asteroseismology, using low to intermediate degree non-radial modes to measure internal stellar structure and rotation.

Design Requirements

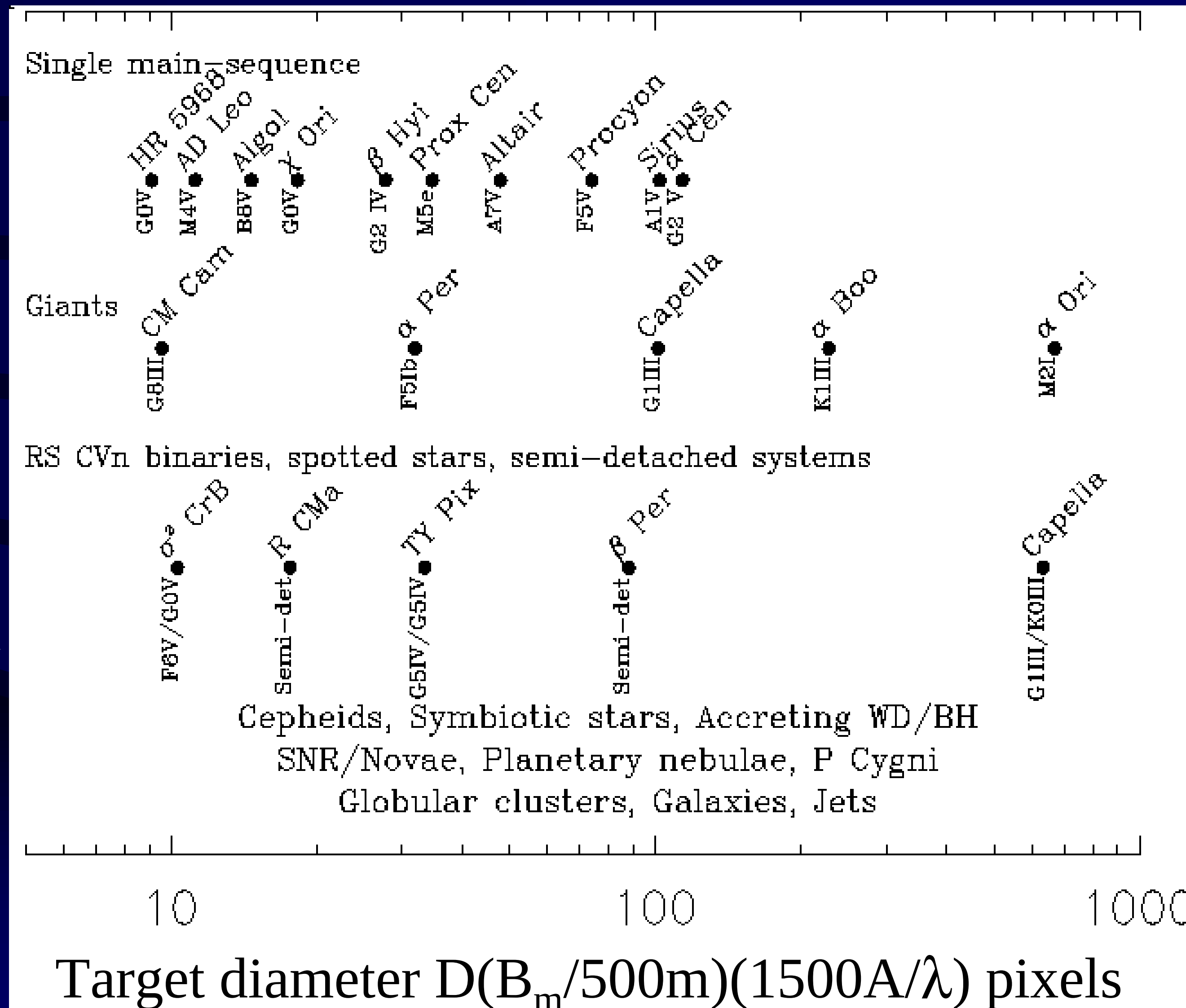


- Imaging of stellar activity requires
  - High contrast, therefore UV wavelengths (chromospheric plages better than photospheric spots)
  - Obtain a stellar image as fast as possible to avoid rotational smearing and activity evolution
- Imaging of stellar interiors requires
  - Short integration times for seismology (minutes for dwarf stars to hours for giant stars)
  - Low-resolution imaging to measure non-radial resonant waves (30-100 resolution elements)
  - Flexible interferometer configuration

Sample Targets

Sample target categories:

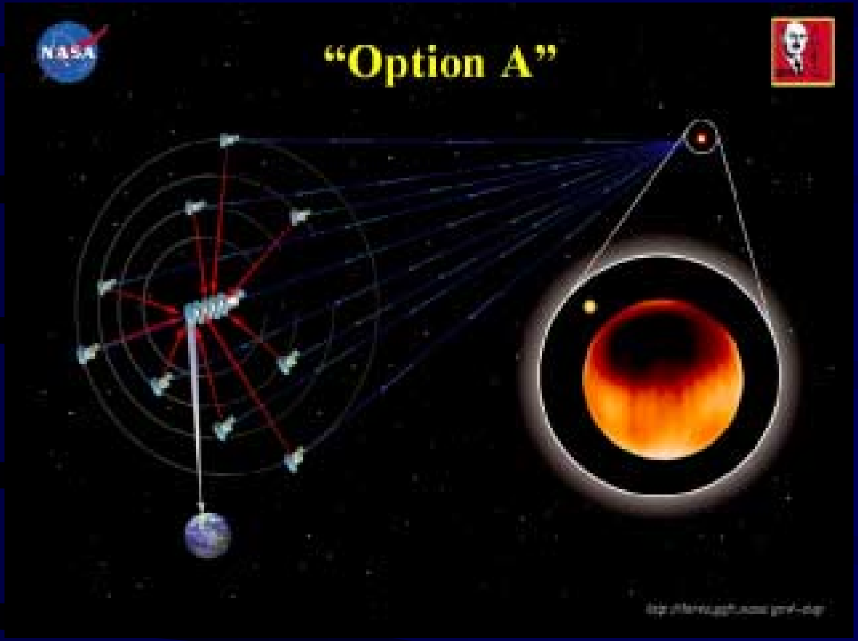
χ Ori	"Young Sun"
β Hyi, α Cen	Solar analogs
HR 5968	Maunder-minimum star
α Boo	"Ancient Sun"
Altair, Procyon, α Per	Onset activity
AD Leo, Prox Cen	Flare star; deep convection
CM Cam	Giant polar spot
Capella , σ CrB	Magnetically interact. binary
TY Pyx	Compact binary
R CMa, β Per	Semi-detached binary
α Ori	Supergiant star
Algol	Mass transfer
Sirius	Hot star

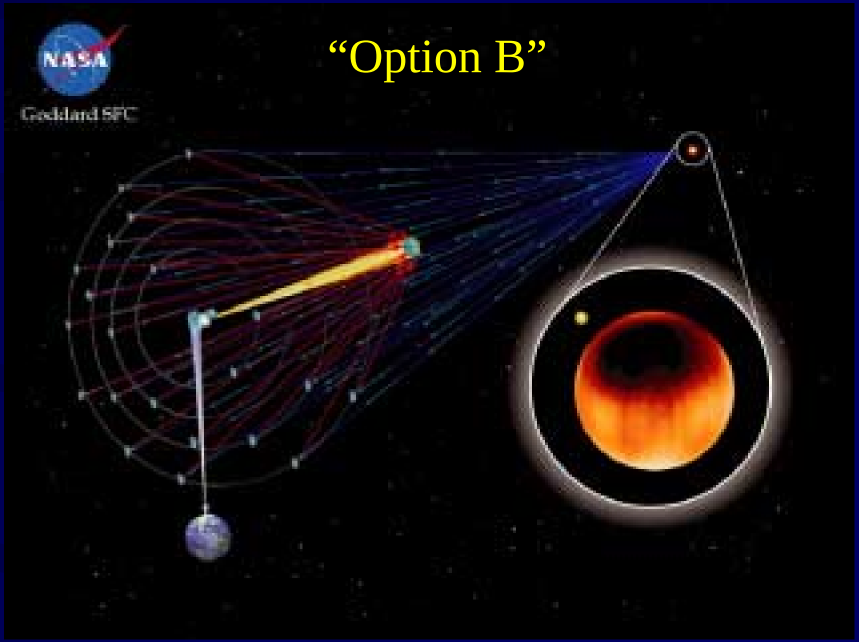


Basic Strawman Design Elements

- The Stellar Imager is a large space-based UV-optical interferometer, that provides a tool to astrophysicists of the same fundamental nature as the microscope to biologists, yielding
  - an angular resolution of 60 and 120 micro-arcsec at 1550 Å and 2800 Å
  - ~ 1000 pixels of resolution over the surface of nearby dwarf stars
  - largest telescope-pair baseline at least 500 meters
  - observes in
    - ~10-Ångstrom UV pass bands (C^{3+} (100,000 K), Mg^{+} h&k (10,000 K))
    - broadband, near-UV or optical continuum (3,000-10,000 K)
  - telescope formation reconfigurable for synthesis imaging
  - 5-10 year mission to study stellar activity/magnetic cycles:
    - individual telescopes/central hub can be refurbished or replaced as needed
  - 10 - 30 one-meter-class array elements, plus central hub

Early Concepts





- ~10 1-meter class telescopes
- likely Michelson design
- central hub: optics to combine and interfere beams
- requires many reconfigurations of array to obtain synthesized image, but fewer nodes

- ~30 one-meter class flat mirrors
- Fizeau design
- "secondary" mirror + central hub
- requires fewer reconfigurations of array to obtain synthesized image, but more nodes

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 the ***Planet Imager****:* ***SI*** resolution is ~40x less demanding than ultimate NASA goal
  - … 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, especially radiation from accretion processes

Supernovae
close-in spatial structure

Stellar interiors
internal structure, including, e.g., opacities, in stars outside solar parameters

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

Spectroscopic binary stars / apparently single 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

Cool, Evolved Giant & Supergiant Stars, LPV/SRV's
spatiotemporal structure of extended atmospheres/winds, shocks

Current Status

- Included in far-horizon SEC Roadmap (summer 1999)
- Mission concept further developed by
  - C.J. Schrijver (Stanford-Lockheed Institute for Space Research)
  - K.G. Carpenter (LASP - NASA/GSFC)
  - in consultation with informal Concept Development Group
- Presentations of mission concept
  - October, 1999 Cool Stars, Stellar Systems, & the Sun Conference
  - NASA GSFC/HQ on March 6 & 14 and October 18, 2000
  - June, 2000 AAS and SPD meetings
  - September, 2000 NEVEC Summer School
- Web site created: **http://hires.gsfc.nasa.gov/~sisp**
- "white paper" written to describe science goals/technology req'ts
- Included in SEC "State of the Theme" report (May, 2000)
- next steps
  - Architecture/Feasibility Studies
  - ground-based Testbed Development Program

Concept Development Group

- NASA-GSFC: Ken Carpenter (GSFC Science Lead), Dick Fisher, Joe Davila, Bill Danchi
- LMMS/ATC: Carolus Schrijver (LMMS Science Lead), Domenick Tenerelli
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- U. Aarhus: Jörgen Christensen-Dalsgaard
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- Catholic Univ.: Fred Bruhweiler
- U. Colorado: Alex Brown, Jeff Linsky, Jon Morse
- Ball Aerospace: Steve Kilston
- STScI: Ron Allen
- CFA: Andrea Dupree, Lee Hartmann
- Mt.Wilson Obs.: Sallie Baliunas
- SUNY: Fred Walter
- Yale: Pierre Demarque