Global Observations and Alerts from Lagrange-point, Pole-sitter, and Geosynchronous Orbits (GOAL&GO)

a revolutionary measurement concept that will provide a new capability for humankind to monitor the Earth as it responds to anthropogenically–induced global climate change

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The GOAL&GO Architecture Meets Many Requirements

The GOAL&GO study investigates the application of near-term technology to

- Unmet needs for disaster monitoring and relief assistance
- Curiosity-driven applications
  - Science
  - Infotainment

Why “near-term”?

- The idea was to use the NIAC study as a springboard for Instrument Incubator or New Millenium Program
  - How do you take the first step?
- There is no current technology investment program that is applicable to system-wide problems in disaster-monitoring and relief assistance.

Longer term sensor-web concepts have not yet been addressed in this study.

GOAL&GO is Designed as an Evolutionary System

Most Earth observing missions fall into either of two categories:

- Large monolithic spacecraft with very expensive high-value sensors
  - Failure of a sensor means either replacing the spacecraft or losing the data
    - In the current EOS architecture, data continuity is lost
  - Large systems are inflexible and resistant to evolution
    - Landsat users have as a principle concern that the same "colors" be used in all data sets.
- Small spacecraft are produced by small companies that provide a unique service
  - Low-cost access to space
    - Function and flexibility are often secondary considerations

Disaster Monitoring and Relief Assistance Begins With Avoidance

Hazard mitigation is the first step

- Can the scope of a disaster be reduced by providing timely, accurate, and adequate warning?
  - What are the features that must be monitored?
- Can planning information be provided and disseminated?
  - Escape routes
  - Avoidance of threatened areas

Disaster monitoring provides hazard warnings for areas not yet affected.

Relief assistance may require data that has not been heretofore available or that may have recently changed.

- Some applications (e.g. trafficability) may require very high resolution imagery

GOAL&GO is Revolutionary

- The GOAL&GO study is intended to look at ways in which we can change the way that most of the human race sees the world.
  - Time frame is 10 – 20 years
- The majority of the Earth's population and governments still have a very limited view of the world and how what happens in one part of the world effects another.
- Many nations seek a space presence.
  - How can the cost be kept low?
  - How can success be assured and risk reduced?
  - How can a valuable service be provided?
    - Can information be revolutionary?

The GOAL&GO Architecture Uses Simple Elements to Respond to System-wide Requirements

The "full-up" constellation is shown with the major external drivers and functional requirements.

Functional Requirements

Performance

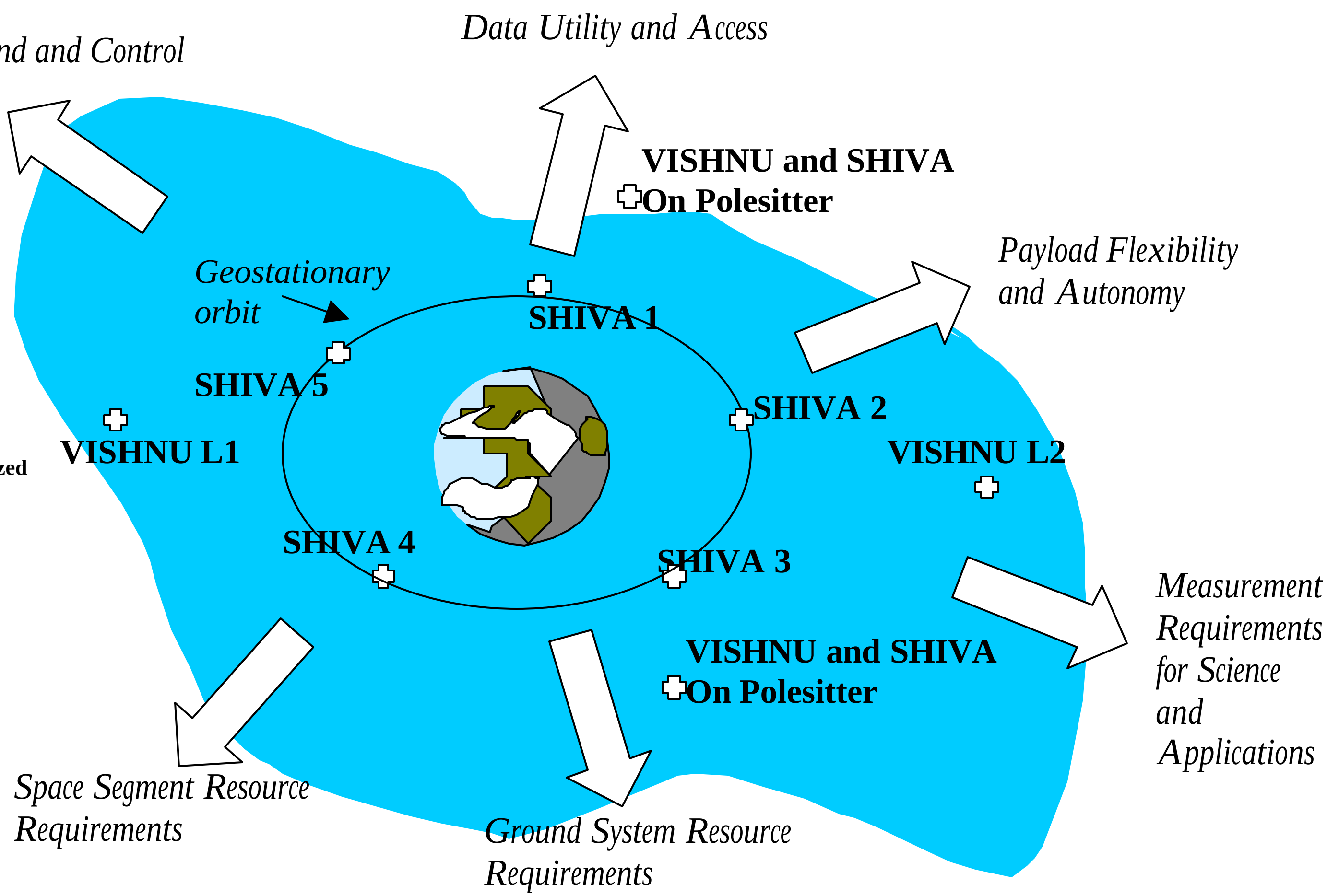
- **Resolution**
  - **Coverage: Temporal, Spatial, Spectral**
  - **Data Availability**
- **Data Distribution**
  - **Maximize Utility**
    - **Data Content Maximized**

Operational

- **Data Downlink Minimized**
- **Minimize Data Latency**
- **Autonomy Maximized**

Constraints

- **Minimize Cost**
- **Minimize Impact on Host Spacecraft**



GOAL&GO Can Address ESE Key Areas

Natural Hazards and Solid Earth	Volcanic ash detection and tracking, severe storm studies and tracking, fire and flood forecast, extent and progress, volcanic eruption detection and plume forecast
Land Cover and Land Use	Vegetation index, biomass burning, fire occurrence and frequency, urbanization via city lights
Ocean and Polar Science	Ocean and land albedo and ocean productivity mapping and change detection
Atmospheric Climate and Water Cycle	Water vapor, cloud heights, aerosols, albedo
Ozone/Atmospheric Chemistry	Tropospheric plume transport on scales from 250 m to 100s of km, total ozone

[1] These thrust areas are delineated in the ESE Strategic Plan (2000) see also www.earth.nasa.gov/science/index.html.

GOAL&GO Sensor-web Requirements are Manageable

"Overarching" drivers for the design are

- Design an expandable architecture
- Use simple subsystems
- Reuse "heritage" technology as much as possible
- Design to minimize the impact of the sensors on the bus
  - Reduce power
  - Reduce mass
  - Reduce pointing requirements
  - Reduce downlink requirements
  - Manage uplink requirements
- Enable system elements to be controlled by the "user"
  - Reduce complexity at all levels
  - Reuse software

Enabling Technologies

System Driver	Enabling Technology to be Evaluated[1]	Impact
Realtime hazard monitoring and detection	Science feature extraction	Enables scene selection for cueing of SHIVA by VISHNU (or other means) and adjustment of SHIVA FOV
Pole-sitter orbit maintenance	Solar sail technology	Enables SHIVA and VISHNU sensors to continuously obtain undistorted, high resolution views of polar regions
Scene selection and real–time hazard warning	Onboard Engineering Data Summarization and Beacon (hazard “pager”)	Reduces requirement for data review by indicating when hazard has been detected – designed for S/C could be applied to data stream
Capture and use of custom data sets by remote user	Science from a Laptop	Enables remote users to configure SHIVA and collect data over their site
Coordination with EOS/ESSP missions (and follow-ons)	Virtual platform	Enhanced science synergy by adding to effective instrument complement of existing platforms by simultaneous sampling of the common volume
Pointing of the SHIVA system	High–displacement piezoelectric actuators	Allows improved performance by enabling pointing of FOV over large angular range

[1] These categories map to the general categories and themes in the New Millenium Program

Enabling Technologies

System Driver	Enabling Technology to be Evaluated[1]	Impact
Stability of fast high angular resolution optics	Silicon Carbide Mirrors and Structures	Improves performance of backend of system and enables ground resolution requirements to be met
Maximize collecting aperture for high spectral resolution measurements	Deployable, large diameter, high precision optical elements	Enables the SHIVA high spatial resolution Fabry-Perot cloud height sensor by minimizing integration period and maximizing SNR
Data rate reduction	High performance data compression (HPDC)	Reduces downlink requirements enabling lower transmitter power and/or receiver dish diameter
Spacecraft stability –Jitter requirement reduction	High precision pointing and stabilization of mirrors	Allows use on off–the–shelf spacecraft
Large aperture precision mirror	Deployable mirror	Reduces package size while meeting science driver for resolution and collecting area
Data rate reduction	High rate channel coding	Reduces downlink requirements
RF communications from HEO while minimizing package size	Deployable comm antenna	Enables implementation on a wider range of buses and potentially decreases requirements on ground segment

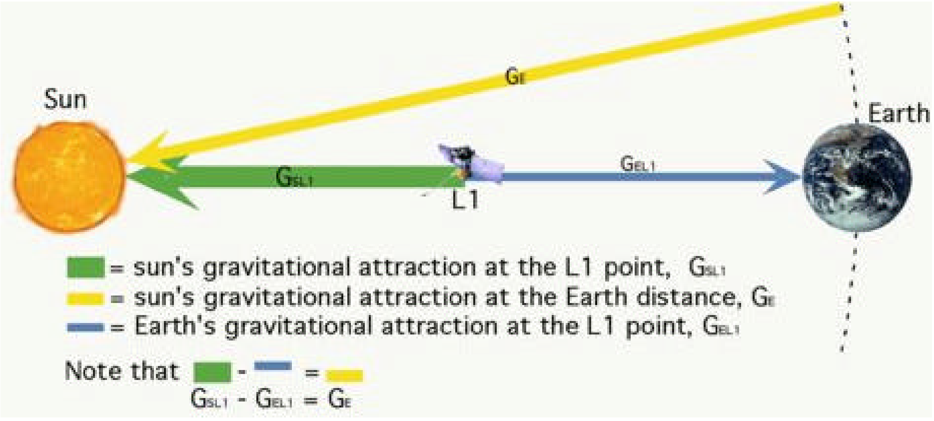
Enabling Technologies

System Driver	**Enabling Technology to be Evaluated**[1]	**Impact**
On–board image processing	Spaceborne fiber optic data bus (SFODB) Rad-hard Pentium-class CPU	Transports large amounts of data for image processing in space required to reduce downlink volume and produces products
Low temperature IR focal planes	Low T Long–life Cryocoolers – solid state?	Provides cooling for SHIVA fire detection array
Minimizing camera size	Chip–on–board Camera	Reduces power requirement and volume for star camera for pointing knowledge and CCD for science
Selectable bandpass for imager	Liquid crystal tunable filter	Provides science flexibility and meets SNR requirements for images while reducing jitter spec by allowing longer effective integration period than spectrographs or other scanning or rastering systems
Imaging of thermal radiation	Large format SWIR/MWIR InSb arrays	Enables fire detection mission for SHIVA with accurate cloud removal

L1 Orbit is Well-suited to Context-Setting Earth Observations

L1 provides a more complete image of the disk of the Earth (about 8 deg more than geosynch) but

- the principle advantage is that it always samples near local noon
- The globe equatorward of 60 deg can be imaged, continuously.



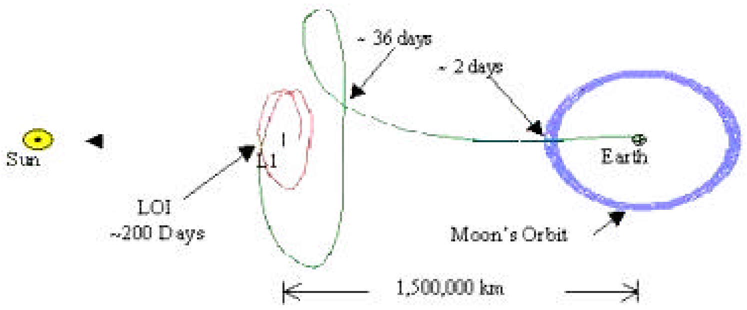


Figure from http://triana.gsfc.nasa.gov/instruments/lagrange.htm

Full Disk Imagery from L1 Would Provide Context Imagery

An “true color” image of the Earth from the equivalent of the L1 vantage point.

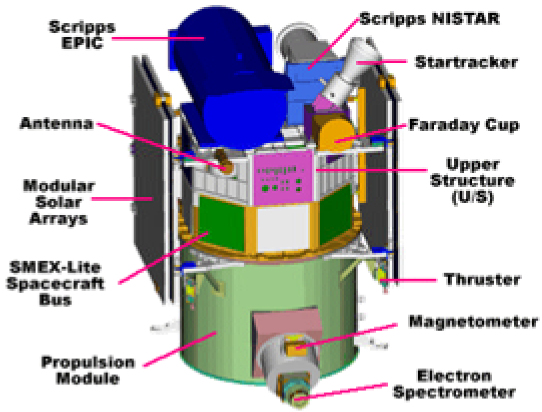
This image was produced by AstroVision.

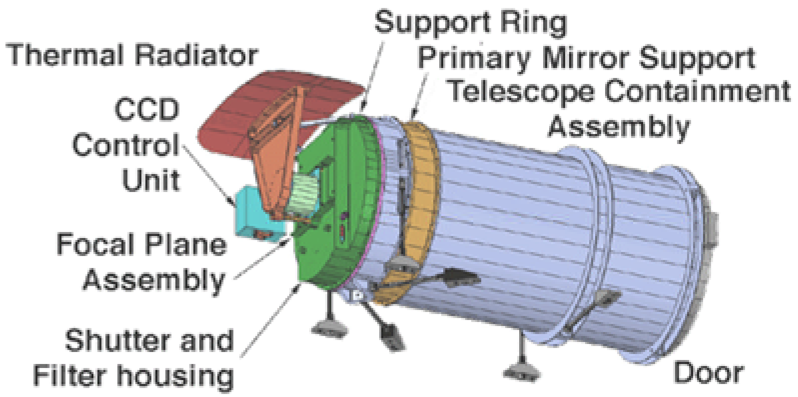
- ARC Science Simulations synthesized and colored this image using NOAA GOES 8 and 9 imagery for August 2, 1996.
- Image is as though viewed from geosynch.
- Used by permission
  - Dr. M.A. LeCompte

L1 Provides Continuous Near-Noon Viewing Geometry

The TRIANA mission was intended to take advantage of this viewing geometry to obtain images of the Earth

- in 10 wavelength intervals
- at 8 km resolution
- required 1.3 m antenna on s/c with 13 m antenna on the ground
- 100 to 200 kbps downlink rate or 10 min/image refresh rate





TRIANA was a Low-cost Mission – Less Than $100M

TRIANA had a very limited wavelength coverage

- Originally the instrument was to have an IR capability
- IR is currently not available on global scales at the resolution and wavelengths required for many applications
  - NISTAR was to measure the Earth's flux

Wavelengths	Bandwidth	Purpose	Spatial resolution
nm	nm		km
317.5	1	Ozone	8
325	1	Ozone, SO_2	8
340	5	Aerosols	8
388	5	Aerosols, Clouds	8
393.5	1	Cloud Height	8
443	10	Blue, Aerosols	8
551	10	Green, Aerosols	8
645	10	Red, Aerosols	8
869.5	15	Clouds	8
905	15	Water Vapor	8

L2 Point Provides Nightside Monitoring

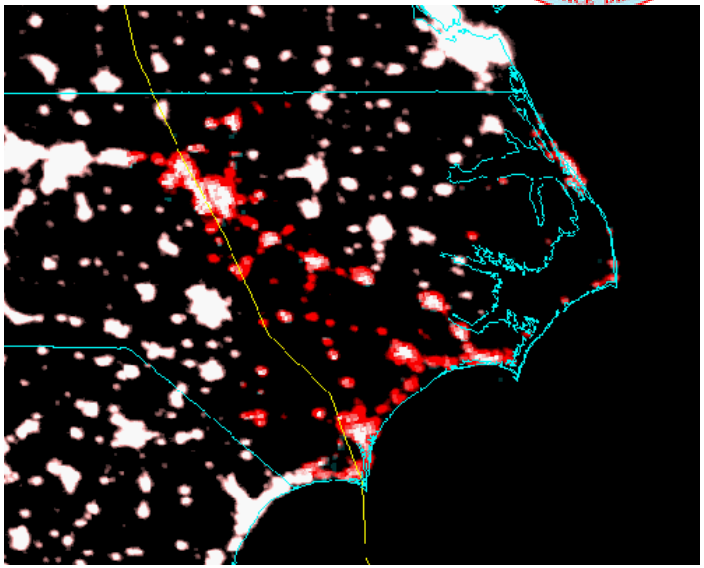
Light sources on the nightside provide a surprising amount of information that is not as readily accessible from sunlit observations.

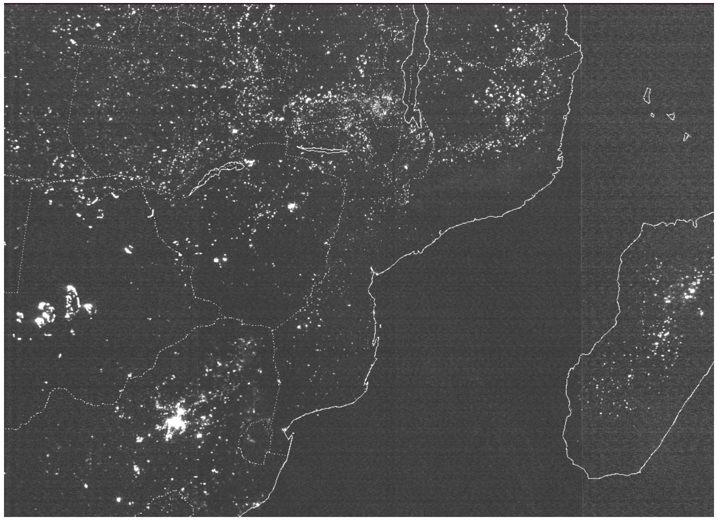
Artificial lights

- Fishing and territorial incursions
- Urbanization and economic productivity
- Infrastructure impact after fire or earthquake

Fires

- Biomass burning
  - Most fires are started in the early morning but they do persist and little is known about the diurnal variation in their output.





Images of night lights in South Carolina and fires in Southern Africa and Madagascar from: http://dmsp.ngdc.noaa.gov/html/projects.html

Geosynchronous Orbit is Very Accessible

- Geosynchronous orbit gives nearly the same coverage as from L1 but it is tied to a single location.
  - The advantage is that you have continuous coverage at all local times.
  - Important for applications driven by the desire to see a particular area at all times.
- Dedicated spacecraft at geosynch are very expensive (of the order of $100M) but
  - Many spacecraft vendors have space available for payloads that do not impose a significant burden on the host.
  - Vendors have proliferated even though business forecasts for comm usage appear down from previous years.
    - Ground infrastructure is taking up some of the “bandwidth”.

Satellite Users Have New Resources Available to Them

The old paradigm is that a user had to be tied closely to the spacecraft vendor now commercial or scientific users can look at “catalogs” of vendors

- GSFC Rapid Spacecraft Development Office
- http://rsdo.gsfc.nasa.gov/

Small venture-capital funded firms are able to consider a presence at geosynch with the latest application being optical imaging

- Astrovision, Inc. is looking at the “infotainment” value of geosynch images as well as their scientific application
- http://www.astrovision.com/

Geosynch Provides the Nearly Ideal Platform for Observations Tied to a Particular Location

Geosynch provides the opportunity to monitor the time dependent behavior of a physical phenomena

- Low-Earth orbits tend to have issues with aliasing of time-periodic phenomena
- We need extended datasets to build up data climatologies for inaccessible or less developed regions.

New Technologies Enable New Locations for Observatories

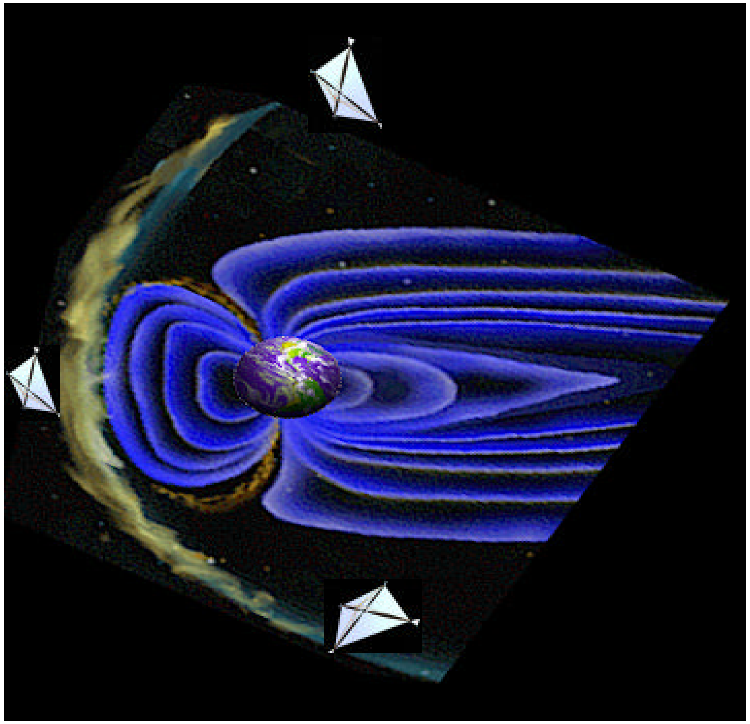
Solar sail technologies rely on solar photon pressure to enable non-Keplerian orbits.

The key technology that needs development is the reduction in the mass/area ratio.

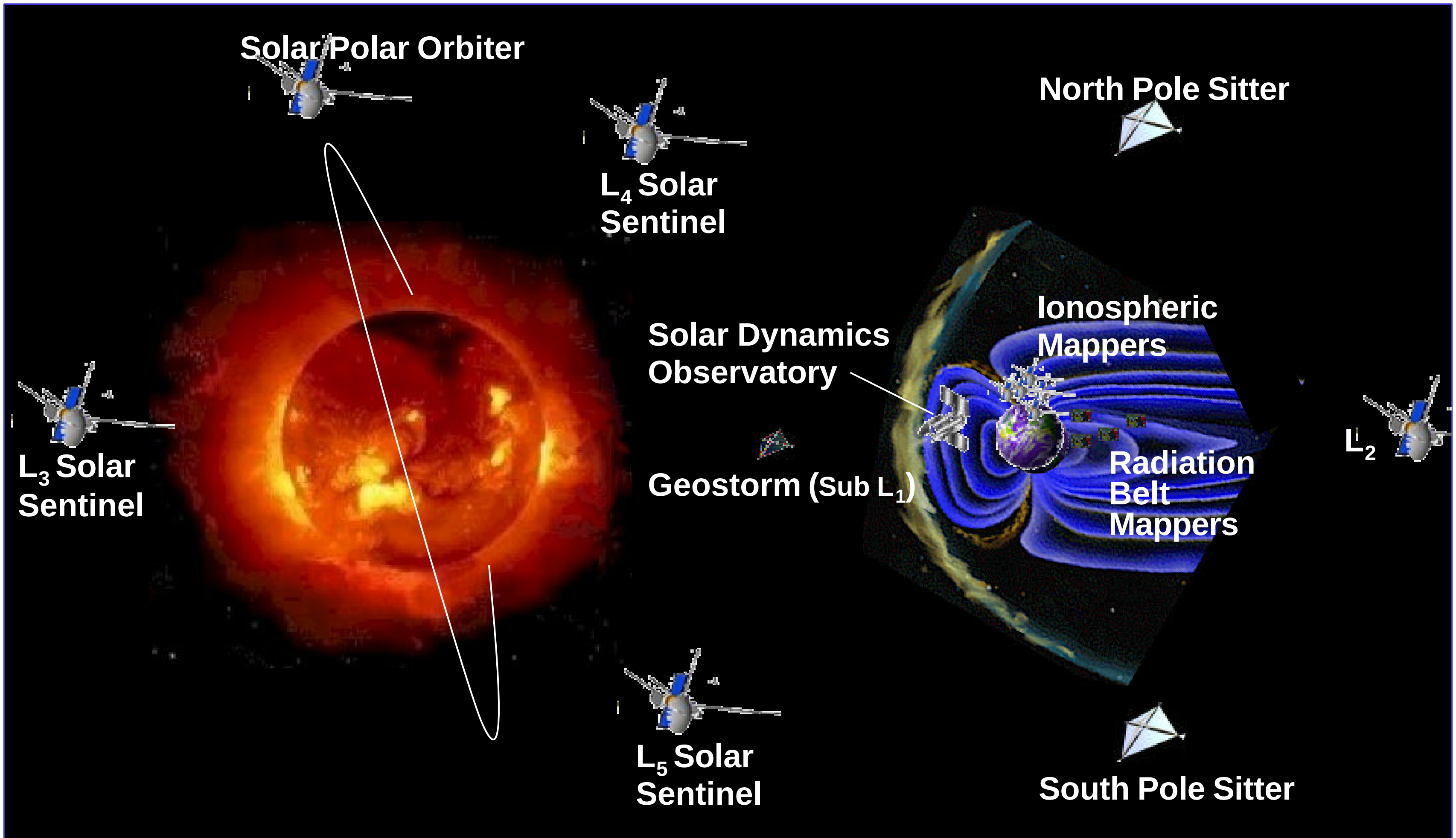
- Current technology support a ratio of about 66 g/m^2
- Required for station keeping and maneuvering is about 6 g/m^2
- Pole-sitter would prefer about 1 g/m^2

This technology would enable a sub-L1 view point

- Studied for the Geostorm mission



NASA's Living With A Star Program Takes Advantage of "Novel" Orbits



Slide courtesy George Withbroe

We Live in Interesting Times

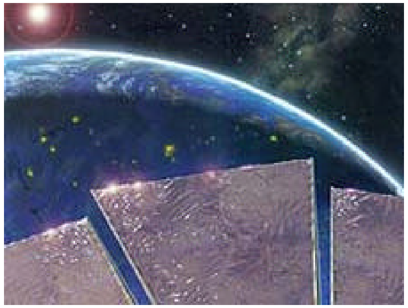
The first demonstration of a solar sail is planned for this year

- http://www.planetary.org/solarsail describes the project

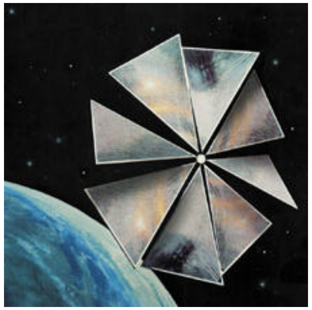
This is interesting because it shows the entry of a private entity (The Planetary Society) into collaboration with the Babakin Space Center using a commercialized SLBM.

Presence in space is dictated by

- Launch cost and availability
- Lifetime on orbit
- Market for products



Painting: Michael Carroll, The Planetary Society (c).

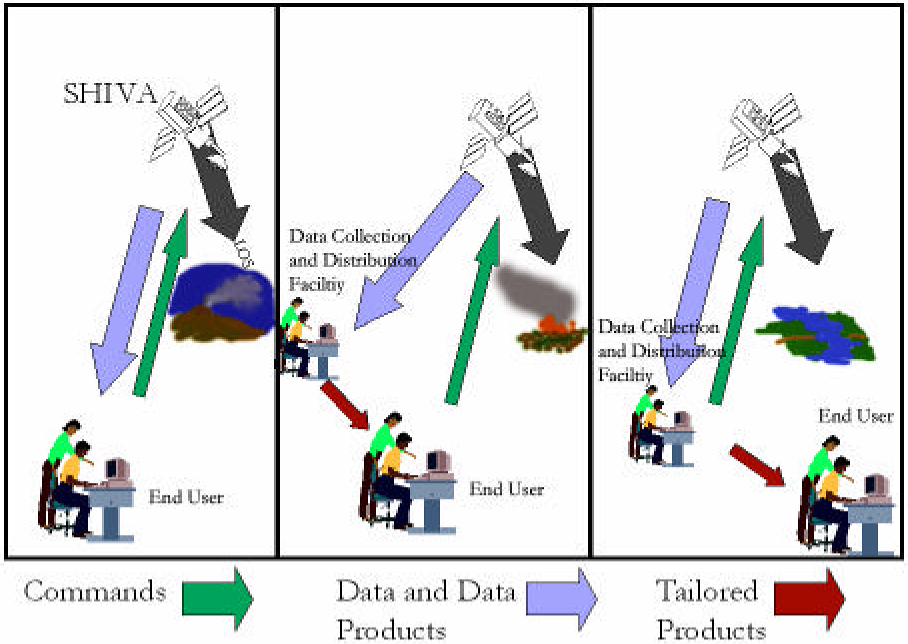


Babakin Space Center, The Planetary Society (c).

GOAL&GO Will Use a Steerable Imaging System and On-board Processing to Deliver Tailored Products to Users

Just three of the possible ways in which regional-scale (1000 km x 1000 km) data products could be delivered to an end-user.

- The GOAL&GO constellation would be designed to maximize flexibility and utility while minimizing the requirements placed on the end user and the overall system cost.
- End-user requirements are minimized by enabling generation of data products on the spacecraft and direct broadcast of the data to inexpensive widely distributed ground stations that are integrated with an organic display, processing and geographic information system (GIS) system.



The SHIVA system uses multiple, selectable bands as commanded by remotely located users to search for, identify, and report geophysical events. A pointed telemetry system reduces the ground system requirements.

The "Bits-to-Parameters" Problem is Well in Hand

Operational software can and does represent a substantial investment

- In the past, algorithms were usually uniquely generated and tied to a specific platform and operating system.

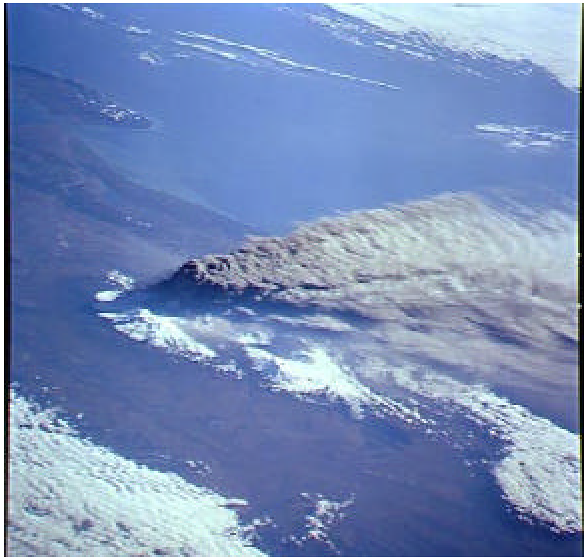
Can costs be reduced by "re-using" algorithms?

Applications include:

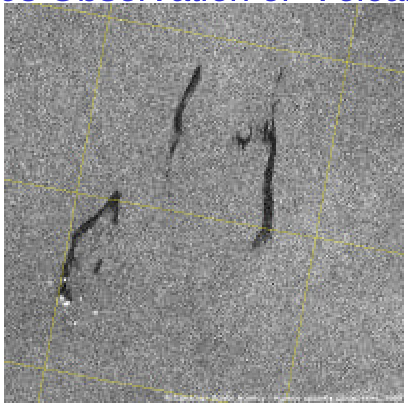
- Pollution compliance monitoring
- Volcanic ash advisory
- Severe storm evolution

Many applications require only limited spectral resolution

- Can be achieved in a number of ways



STS-68 Observation of Volcanic Plume



Oil Slick

VISHNU
***V**isible/IR/UV **I**maging **S**ystem **H**ardware for **N**ew **U**ses*

Weight	20 kg
Power	20 W
Volume (Optics)	35×80×30 cm
Data Rate	1 Mbps (X band downlink at 6W w/1.3 m dish) or 500 kbps (S band downlink at 5W w/1.3 m dish) both into 10–m ground system from L1 or L2
Pointing Requirement	0.05°, each axis, 3 sigma at L1,L2
Jitter Requirement	<0.06 arc sec /sec
Field of View	0.5° x 0.5° for L1, L2 system, 16°x16° from pole-sitter
Aperture Size	64 cm
Optical Design	*ƒ*/10 Cassegrain , *ƒ*/3 Burch-type Cassegrain on pole-sitter
Spatial Resolution	5 km/pixel, 3 km/pixel on pole sitter
CCD	4096×4096 pixels at 12 bits
Signal to Noise Ratio (SNR) Range	150<SNR<450
CCD Temperature	–35°C

[1] VISHNU at L1 and L2 requirements are the design drivers. VISHNU on the polesitters will have a smaller aperture and lower downlink power requirements.

SHIVA
Supporting High–resolution IR Visible Applications (SHIVA)

Weight	20 kg
Power	20 W
Volume (Optics)	35×80×30 cm
Data Rate	1Mbps (S band into 0.5 m receiver)
Pointing Requirement	0.05°, each axis, 3 sigma
Jitter Requirement	<0.4 arc sec /sec
Field of View	1.5° x 1.5°
Field of Regard	20°
Aperture Size	100 cm
Optical Design	*f* /2.2 Cassegrain (with electro–optical shutter)
Spatial Resolution	250 meters/pixel
CCD	4096×4096 pixels at 12 bits
CCD Signal to Noise Ratio (SNR) range	500<SNR<4000
CCD Temperature	–35° C
InSb Array	4096×4096 pixels[1] at 12 bits
InSb Array Temperature	70 K
InSb Fire Detection SNR range	160<SNR<2040

[1]Array size could be decreased resulting in smaller sampled fire detection area

Table 1.

VISHNU and SHIVA Bands (Example LCTF Band Identifications[1,2])

317 nm	UV/B, Ozone – TOMS wavelength
340 nm	Aerosols and Ozone –TOMS wavelength
395 nm	Raman scattering cloud height
400 nm	UV/A, aerosols, ocean color, clouds – TOMS wavelengths
412 nm	ocean color – SeaWiFS band 1
443 nm	ocean color – SeaWiFS band 2
465 nm	vegetation, albedo – MODIS band 3
490 nm	ocean color – SeaWiFS band 3
510 nm	ocean color – SeaWiFS band 4
555 nm	vegetation, ocean color, albedo – MODIS band 4, SeaWiFS band 5
645 nm	vegetation, albedo, and clouds – MODIS band 1, AVHRR
670 nm	ocean color – SeaWiFS band 6
765 nm	ocean color – SeaWiFS band 7
774 nm	Lightning – nightside observations with SHIVA only (dayside requires high rejection filter)
855 nm	water vapor, albedo – MODIS band 2
865 nm	ocean color – SeaWIFS band 8
935 nm	water vapor, albedo – MODIS band 19, AVHRR

[1] 5 nm bandwidth gives the required spectral resolution – many uses (AVHRR, MODIS, SeaWiFS) require only 10 to 40 nm resolution

[2] EOS instrument acronym definitions, descriptions and bands found in 1997 MTPE EOS Data Products Handbook, 1997 and EOS Reference Handbook, 1999

Light Path Can Accommodate Additional Detectors and Filter Assemblies

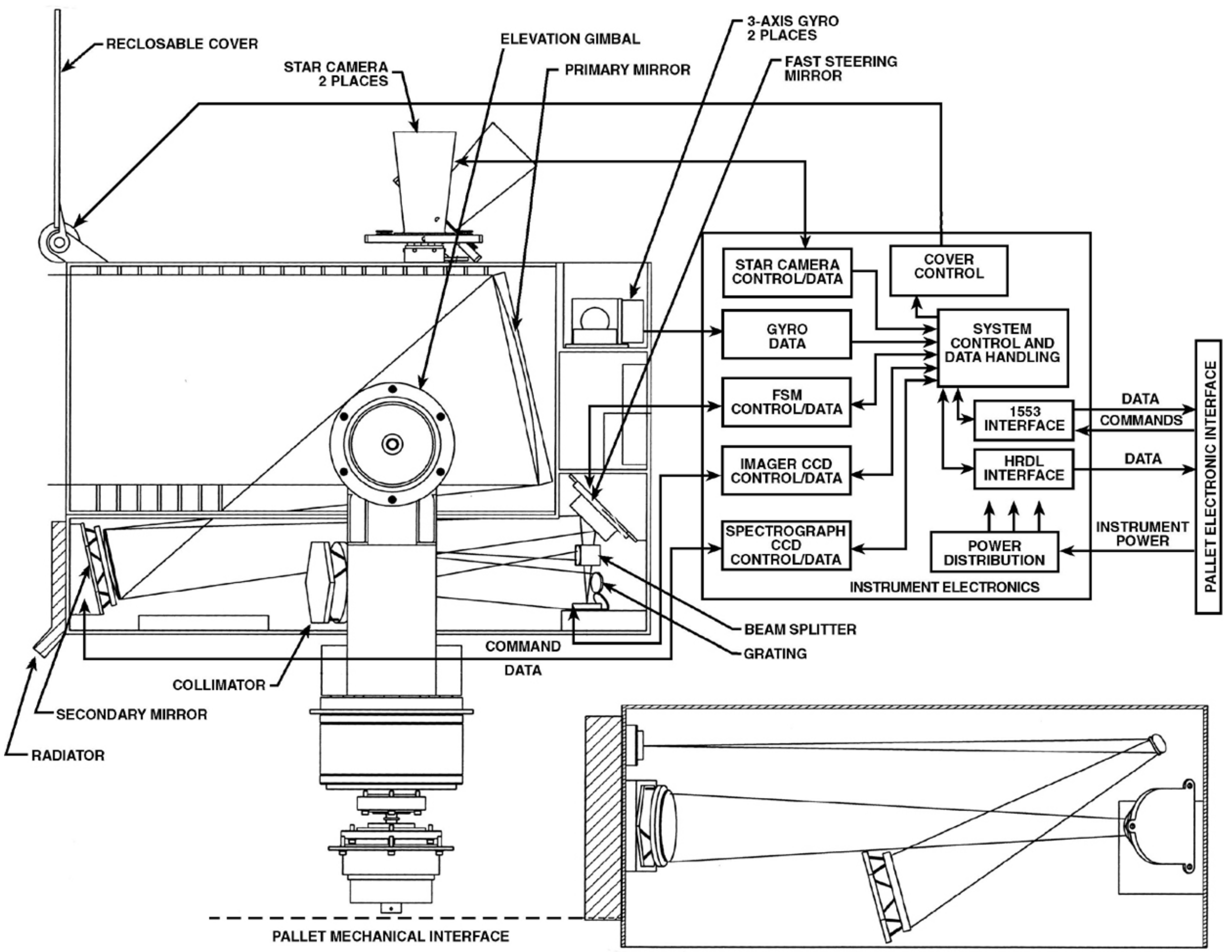
VISHNU Dedicated Filters for Second Camera

393.3 nm	Raman scattering infill for cloud height (0.5 nm width)
762.0 nm	cloud height determination from O_2 Atmospheric band (0.2 nm width)
760.7 nm	albedo for cloud height algorithm (0.2 nm width)
777.4 nm	dayside lightning sensor (0.2nm width)

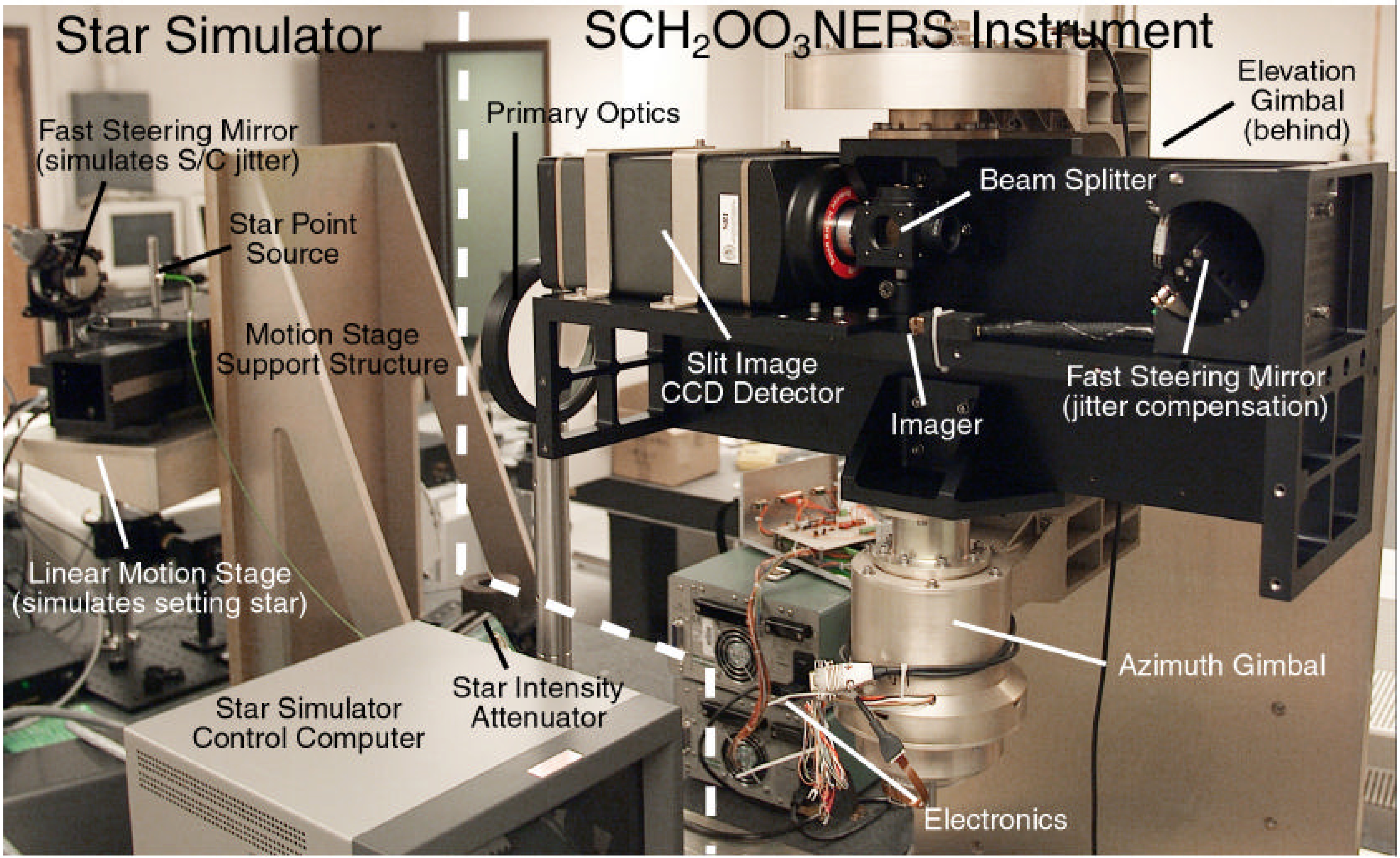
SHIVA Fire Detection Bands and Uses for Second Camera

1.38 µm	cirrus cloud detection – MODIS Band 26
1.7 µm	aerosol optical depth, vegetation stress – MODIS Band 6
2.2 µm	vegetation stress, burn scars (differentiated from water) – MODIS Band 7
2.5 µm	burn scars, active fires
3.7 µm	active fires, burn scars – MODIS band 20

Imager Steering and Stabilization Design Leverages SCHOONERS IIP



SCHOONERS Demonstrated a Practical Jitter Correcting System



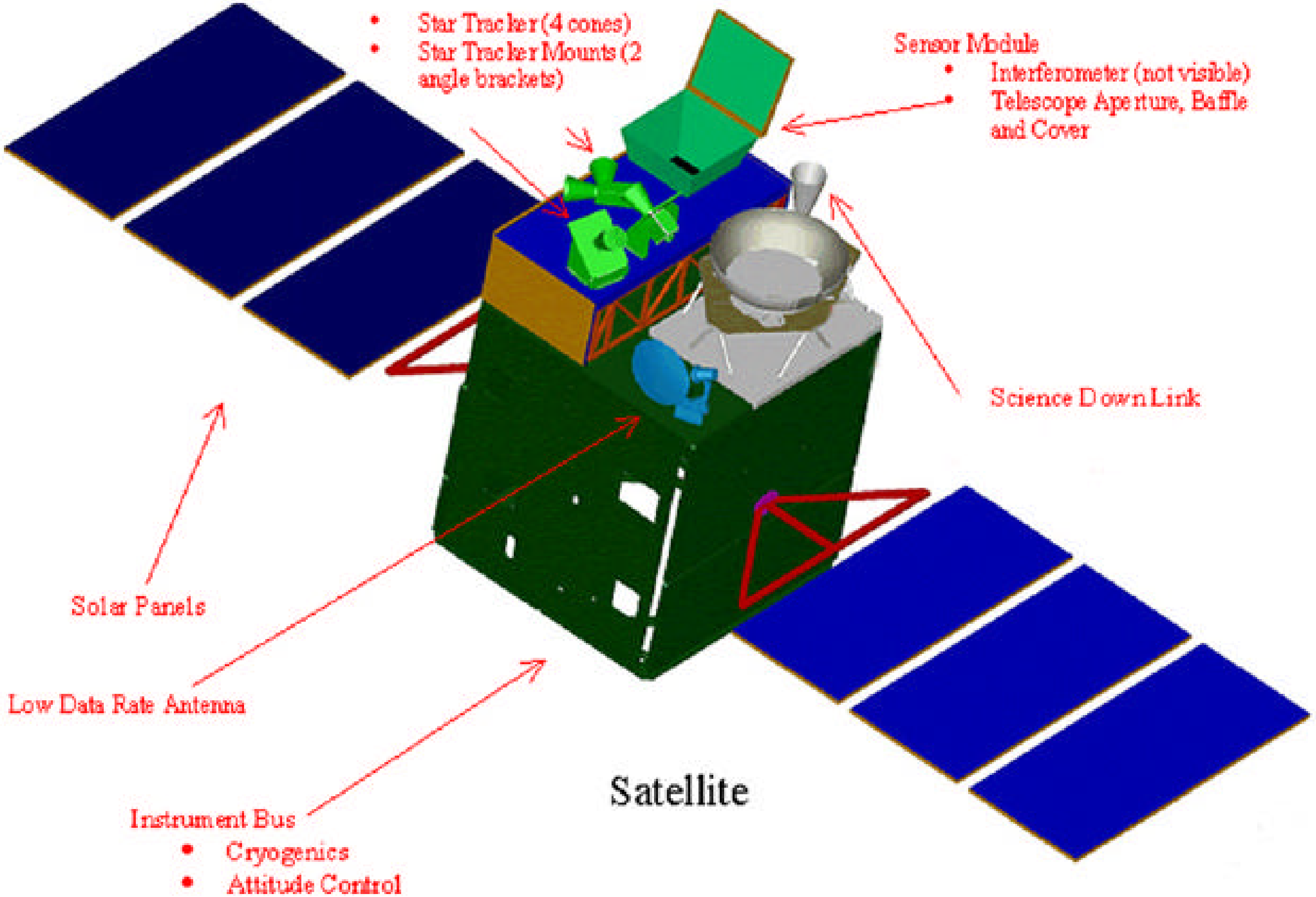
SCHOONERS Demonstrates Key GOAL&GO Pointing and Control Technologies

The SCHOONERS systems is designed to obtain spectral images of stars, from the Space Station, as the star sets through the atmosphere.

SCHOONERS demonstrated

- 100 Hz tracking correction
- Azimuth and elevation slew control to 0.1 arcsec over ±15°
- Control algorithms
  - Running on a Pentium III
- System could be isolated from larger and small scale motions of the platform

GIFTS-IOMI Will Demonstrate the Concept of a Self-Pointed Imager Operated at Geo



See: http://nmp.jpl.nasa.gov/eo3/tech/gifts.html

The Next Step

The “ideal” systems for basic research and disaster monitoring diverge on the issue of resolution:

- Basic research is often concerned with increasing spectral resolution
  – Variations in the radiance with optical depth give you the means to retrieve vertical information in the atmosphere
- Image-based applications are concerned with spatial resolution where individual physical features need to be detected.
  – Is synthetic aperture imaging from geo the next step?

These “ideal” systems will have very high data rates to handle and will require very fast rad-hard processors and bus architectures.

Data Rate is not a Constraint for the Basic System

In the ideal, intelligent, reconfigurable system, the data rate will be very high.

A globe-spanning sensor web could be formed that includes the GOAL&GO architecture and augments this with

- Long-duration high altitude UAV providing high resolution local data
- Distributed networks of tropospheric weather sensors, in space and on the ground, driving mesoscale forecast models
- Active remote sensing platforms providing “ancillary” information
  - SAR for soil moisture and biomass
  - Laser-sounding for winds, trace constituents, altimetry, and aerosols

Data Usage for an Integrated System Will Eventually Drive the Technology

Data rates and volumes are probably more easily addressed (i.e. more technology) than

- Cultural differences
  - Formatting and platform differences
  - Visualization and maping
- Knowledge extraction
  - Metadata access
  - Data mining and information harvesting
  - Archiving baseline datasets for comparison
- Establishing a robust and flexible system
  - Standards “need” to be defined

    Products that are generated: how, when, and whose
  - How do you exchange data?

Careful Choices Allow You to Build a System That Can be Built

The revolutionary idea behind GOAL&GO is that it can be built.

- Can we put the pieces together?
- Can we change the way that the Earth system is monitored?

The key technologies are nearly at hand.

- All are at TRL of 4 and above
- Most will be demonstrated in space by 2010.

Clearly a lot of work needs to be done to work out the details of the system and its accommodation within an evolving framework.

- Many of the driving elements within the system are being developed in response to commercial forces.
- Information management may shape the face of the market.