Mission Design Workshop

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Solar Physics Summer School

Summary of the Workshop

- Present an overview of the space mission design process
- Identify some resources
- Explore some key issues for science mission development
  - In general
  - Specific to NASA's *Solar Sentinels*

Terminology

- Mission
- Spacecraft bus
- Instruments
- Trades
- Maturity & Risk
- REQUIREMENTS
  - Science questions

It all starts with requirements

From NASA's Science and Technology Definition Team (STDT) for Solar Sentinels

2.0 Science Objectives and Measurements

The goals of the Sentinels mission are

1) to understand and characterize the production and propagation of solar energetic particles (SEPs) and

2) 2) to understand and characterize the initiation of coronal mass ejections (CMEs) and their evolution (and that of their associated shocks) during transit to 1 AU. …

Required/Supporting Measurements and Models

Required

- ‡ High and low energy ions and electrons
- ‡ Energetic particle composition
- ‡ Energetic particle charge states
- ‡ Suprathermal ions and electrons
- ‡ Solar wind composition
- ‡ Neutron/gamma ray emissions
- ‡ Hard/soft x-rays
- ‡ Radio (type II and III)
- ‡ AC magnetic fields
- ‡ DC magnetic fields
- ‡ Solar wind plasma
- ‡ Coronal plasma conditions and composition

Supporting

- ‡ Photospheric magnetic field
- ‡ Plasma waves

Models

- ‡ SEP acceleration and transport
- ‡ Global heliospheric magnetic field
- ‡ Coronal dynamics

Mission/Instrument Trades

(example from COMPTEL on CGRO)

Science Questions	Measurement Capability	Instrument and Mission Requirements
Point sources of γ-rays in space? →	Develop detectors with fine spatial resolution (10× better than previous) →	Achieving this science sensitivity goal required: •Heavy detectors above atmosphere •Low background orbit (ideal=equatorial)

Shuttle has the required lift capability.

Need charged particle rejection capability >99.999% ← But… 28° minimum orbit inclination

Science Requirements as Design Drivers

(& a few flow-down examples from GLAST)

TABLE 1: Expected Performance of the Large Area Telescope

Parameter	*Baseline*	*Goal*
Energy Range	20 MeV – 300 GeV	10 MeV – >300 GeV
Energy Resolution [1]	10% (100 MeV – 10 GeV) 50% (20 – 100 MeV)	2% @ E > 10 GeV
Effective Area [2]	8000 cm^2	>10,000 cm^2
Single Photon Angular Resolution (68%; on-axis) [3]	< 3.5° @ 100 MeV < 0.15° @ E > 1 GeV	<2° @ 100 MeV <0.1° @ E>1GeV
Single Photon Angular Resolution (95%; on-axis) [3]	$< 3 \times \theta_{68\%}$	$2 \times \theta_{68\%}$
Single Photon Angular Resolution (off-axis at FWHM of FOV)	< 1.7 times on-axis	< 1.5 times on-axis
Field of View [4]	2 sr	>3 sr
Point Source Sensitivity [5] @ E > 100 MeV	4×10^{-9} cm^{-2} s^{-1}	$<2 \times 10^{-9}$ cm^{-2} s^{-1}
Time Accuracy[6]	10 μsec absolute	2 μsec absolute
Background Rejection	$> 10^5:1$	$> 10^6:1$
Dead Time	< 100 μs per event	< 20 μs per event and < 10% instrument average for event rates up to 10 kHz
Mission Life	5 years, with no more than 20% degradation of above parameters	10 years

[1] Equivalent Gaussian sigma, on-axis.
[2] Peak effective area, including inefficiencies necessary to achieve required background rejection.
[3] Space angle for 68% and 95% containment.
[4] Integral of effective area over solid angle divided by peak effective area.
[5] Sensitivity at high latitudes after a 2 year survey for a 5 sigma detection.
[6] Relative to Universal Time.

→
- •S/C pointing control and determination subsystem
- •alignment budget & plan for s/c and instrument

- •real-time UT sync. (S/C)
- •internal instrument clock to time stamp data

→
- •radiation tolerant parts & designs
- •redundant systems
- •in-flight calibration
- •quality standards

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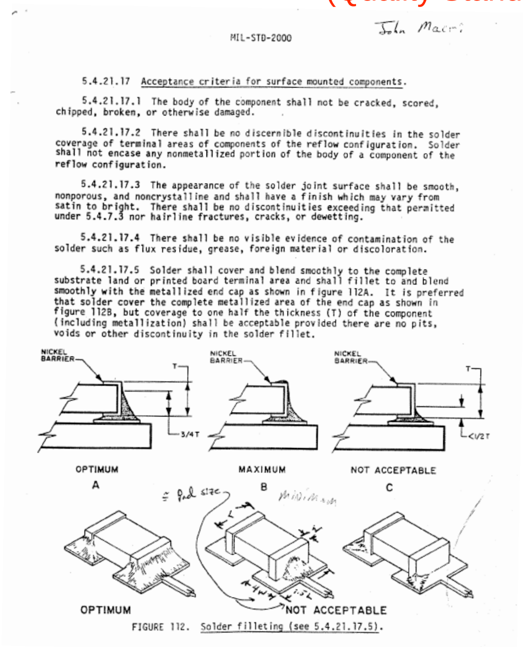
Program Requirements as Cost Drivers

(Quality Standards Example)



John Macri

MIL-STD-2000

5.4.21.17 Acceptance criteria for surface mounted components.

5.4.21.17.1 The body of the component shall not be cracked, scored, chipped, broken, or otherwise damaged.

5.4.21.17.2 There shall be no discernible discontinuities in the solder coverage of terminal areas of components of the reflow configuration. Solder shall not encase any nonmetallized portion of the body of a component of the reflow configuration.

5.4.21.17.3 The appearance of the solder joint surface shall be smooth, nonporous, and noncrystalline and shall have a finish which may vary from satin to bright. There shall be no discontinuities exceeding that permitted under 5.4.7.3 nor hairline fractures, cracks, or dewetting.

5.4.21.17.4 There shall be no visible evidence of contamination of the solder such as flux residue, grease, foreign material or discoloration.

5.4.21.17.5 Solder shall cover and blend smoothly to the complete substrate land or printed board terminal area and shall fillet to and blend smoothly with the metallized end cap as shown in figure 112A. It is preferred that solder cover the complete metallized area of the end cap as shown in figure 112B, but coverage to one half the thickness (T) of the component (including metallization) shall be acceptable provided there are no pits, voids or other discontinuity in the solder fillet.

FIGURE 112. Solder filleting (see 5.4.21.17.5).

- picky, picky, ...

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Instrument Design & Development Stages

- Pre-Phase A
  - Concepts, laboratory and simulation studies, literature searches, NASA SR&T funding, feasibility demonstration
- Phase A
  - Conceptual design
- Phase B
  - Preliminary design
- Phase C
  - Detailed design
- Phase D
  - Flight instrument development and test
- Phase E
  - Flight operations, data analysis, SCIENCE

Maturity

Technical Readiness

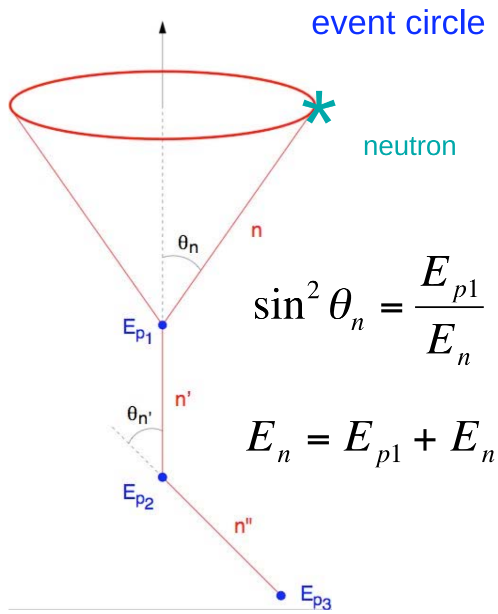
Technical Readiness Levels Summary	
TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 7	System prototype demonstration in a space environment
TRL 8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
TRL 9	Actual system "flight proven" through successful mission operations

UNH Measurement Concept for IH Sentinels: Detecting and Imaging Neutrons

- Use a detector material rich in hydrogen (protons)
- Detect and measure recoil protons from elastic n-p scattering
- Select double and triple scatters
- Apply the kinematics of elastic scattering

two recoil protons
+ neutron energy
= neutron event circle

multiple circles = image

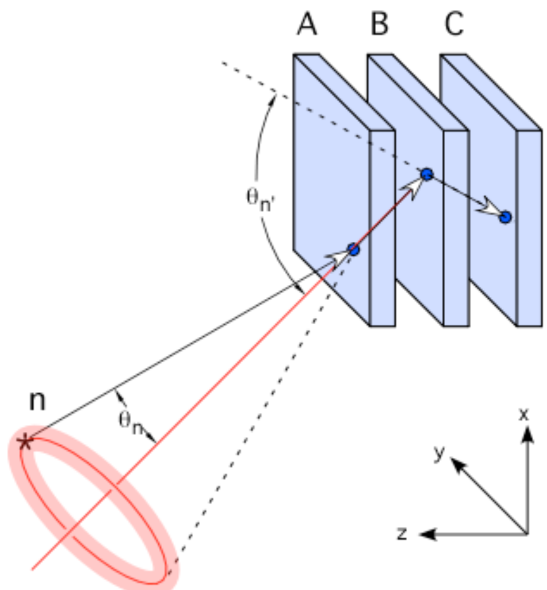


$$\sin^2\theta_n = \frac{E_{p1}}{E_n}$$

$$E_n = E_{p1} + E_{n'}$$

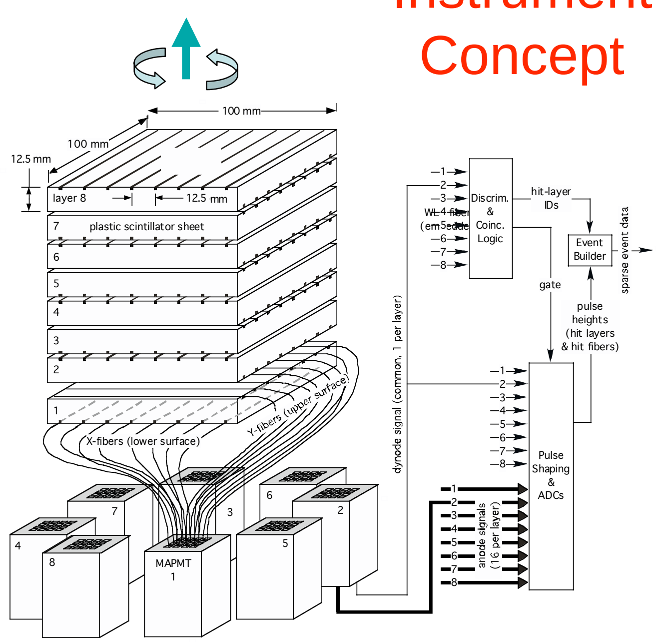
Detection Principle: Neutron Instrument for IH Sentinels

- Event circle width – *and source energy and location errors* –driven by detector plate resolutions
  - Energy (E_{p1}, E_{p2}, …)
  - Position (x_1,y_1,z_1; …)
  - Timing (time-of-flight)



Instrument Concept

- Pre-Phase A
  - Concepts
  - Laboratory studies
  - Literature searches
  - NASA SR&T funding

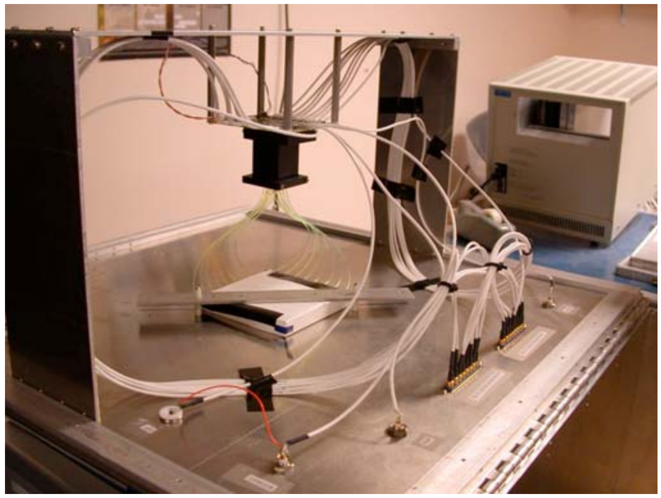


Instrument Concept: Fast Neutron Imaging Telescope (FNIT)

Neutron Spectrometer Instrument Concept for Sun axis spinning *Solar Sentinels*

NASA SR&T Laboratory Studies

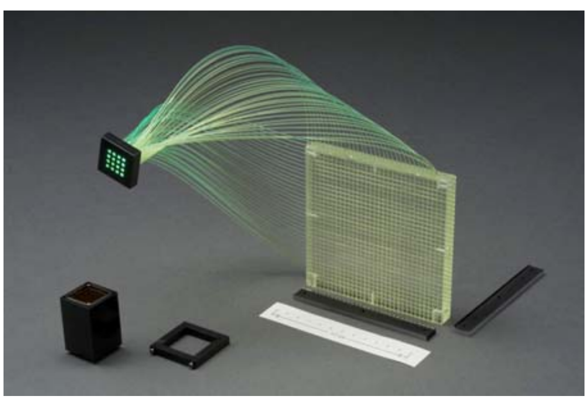
- Feasibility studies
- Element performance characterization
  - $\sigma_{x,y,z}$, σ_E , σ_t
- Instrument simulation



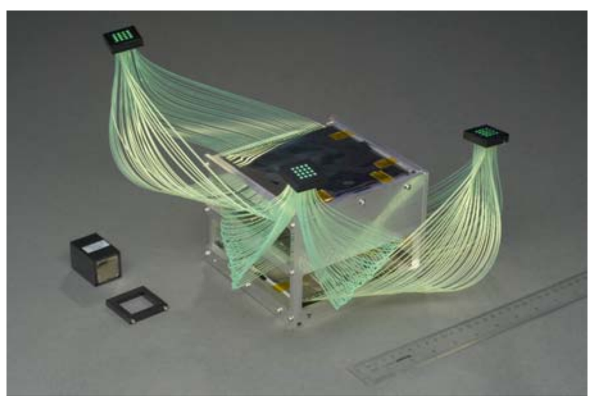
FNIT: Test of early prototype detector plate

Raising the TRL

FNIT Science Model 1



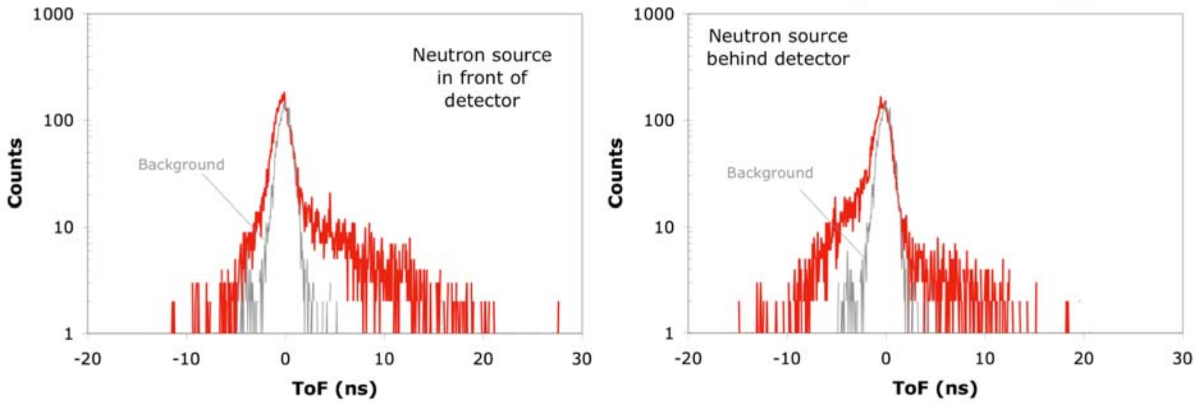
Detector plate



3-plate instrument

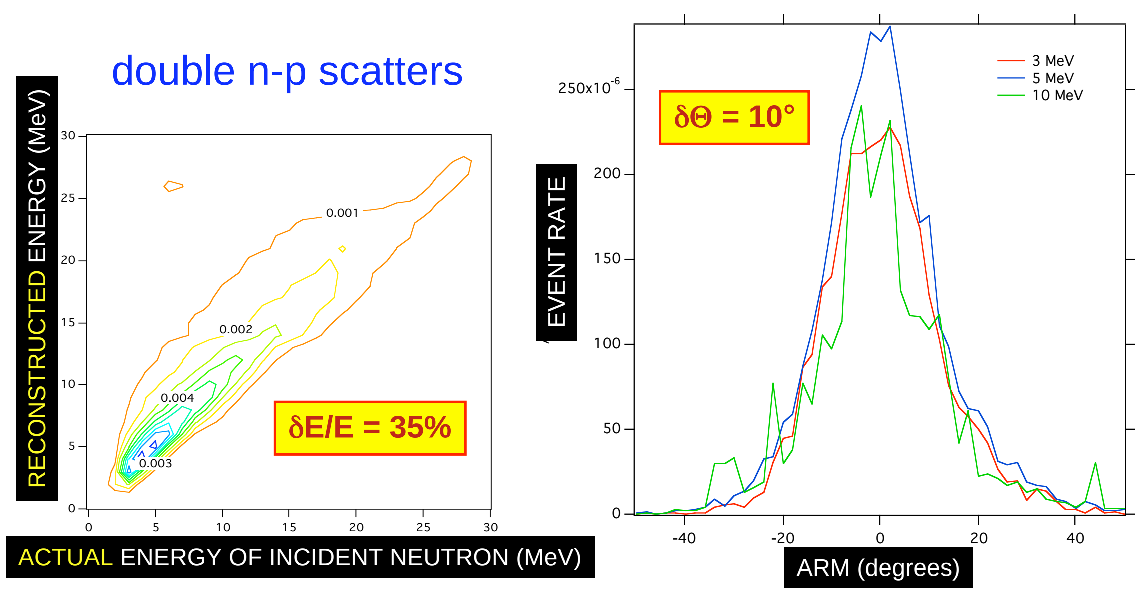
- Design optimization
- Instrument prototype studies

Measured Detector Performance (Feasibility)



- ToF plate A to plate C
- Am/Be neutron source (0-10 MeV neutrons). Compare with background, no source.
- Background: cosmic ray muons and Compton scattered gammas
- Encouraging preliminary result:
  - clear neutron signature emerges in the ToF distributions
  - Front-back direction discrimination

Simulated Instrument Performance (Feasibility)

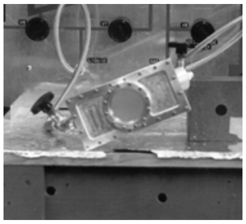


FNIT

- TRL 3 ⇒ 4
- Pre-Phase A

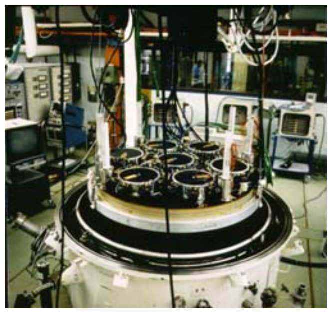
Instrument Design Stages & Maturity

FORMULATION		IMPLEMENTATION
Phase A	Phase B	Phase C
Conceptual Design (minimum for proposal)	Preliminary Design	Detailed Design
Present your case (strong science justification, credible instrument and plan)	“Design-to” specs Concepts ⇒ Concept	“Build-to” specs
Kickoff: AO Milestone: Selection	Milestone: PDR	Milestone: CDR



Instrument Development, Flight & Operations

IMPLEMENTATION	
Phase D	Phase E
Development	Operations
Build it; test it	Fly it; operate it; do science
Milestones: Instrument testing complete, integration with spacecraft, end-to end test, FRR	Milestones: Launch, activation, science operations, end of mission



Conceptual Design

(Proposal and Advanced Study Phase, Phase A)

Purpose: Further examine project feasibility before significant funding

Technical and Management Products (from NASA handbook)

- Mission goals
- Science requirements
- Mission & instrument concepts
- Operations concepts
- Life cycle estimates
- Design evaluation criteria.
- Preliminary trade study results and analyses
- Feasibility assessment
- Plans (many plans), co$t estimates and schedule

Instrument Technical Package* (example from FiberGLAST instrument proposal)

- Baseline instrument and subsystem description
- System and subsystem **requirements**
- **Logical block diagrams** identifying and describing all physical and functional interfaces (incl. spacecraft) and redundancies, data flow, and instrument control.
- Resources and margins (ample): mass, power, envelope, data volume, data rate estimates.
- Thermal requirements, identify hot & cold spots
- Descriptions of approach to: integration, test, calibration, operations, data reduction, distribution, analysis and archiving (credibility). **Flow charts**, **support equipment**.
- Prototype test results (demonstrate feasibility)
- Define trade studies. Show preliminary results.
- **Software** (flight and ground) **requirements** and development approach

Conceptual Design (cont.)

Instrument Technical and Management Package
(more stuff to include)

- Schedule baseline (show margins)
- Cost estimates and justifications (at least 25% margin at this stage)
- Descope options and criteria
- Lists of risks, issues and mitigation strategies
- Team definition, organization and management. Org chart, responsibility matrix.
- Plans: systems engineering, product assurance, quality assurance, safety, risk management, instrument integration, spacecraft integration, operations, data analysis distribution and archiving, ...
- Controlled documentation
- List of deliverables

Instrument Conceptual Design Approach

- Address (or define) the external instrument interface and constraints
- Partition the design (subsystems)
  – Group logical functions
  – Design for testability
  – Establish clean, sensible subsystem interfaces
  – Consider team capabilities and resources
- Consider Risks
- Establish a model philosophy
  – SM, EM, QM, PFM, FM, . . .

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Conceptual Design: Functional Block Diagram

Very handy for:

- team communication and coordination
- cost estimation
- division of responsibilities
- interface control development
- subsystem requirements definition
- allocation of important functions
- seeing the full picture

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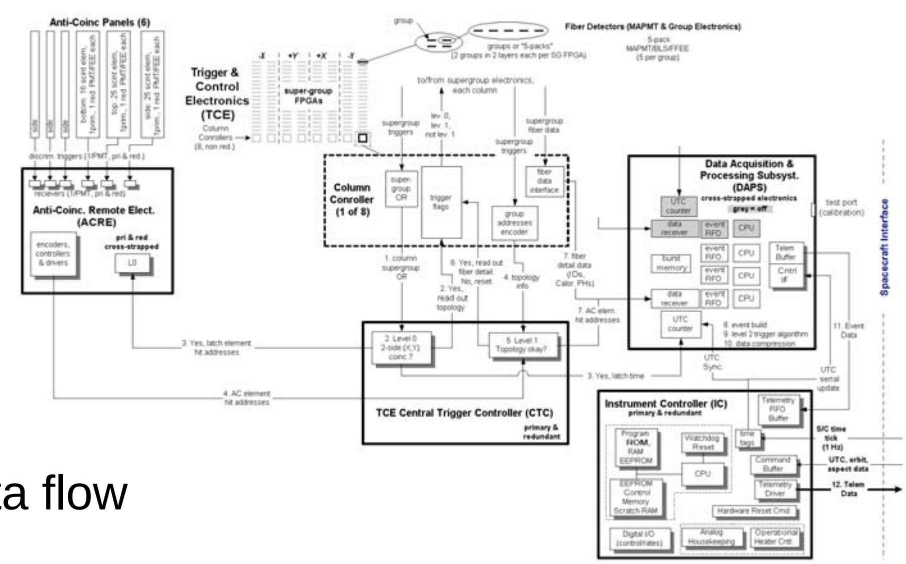
Instrument Conceptual Design: Block Diagram

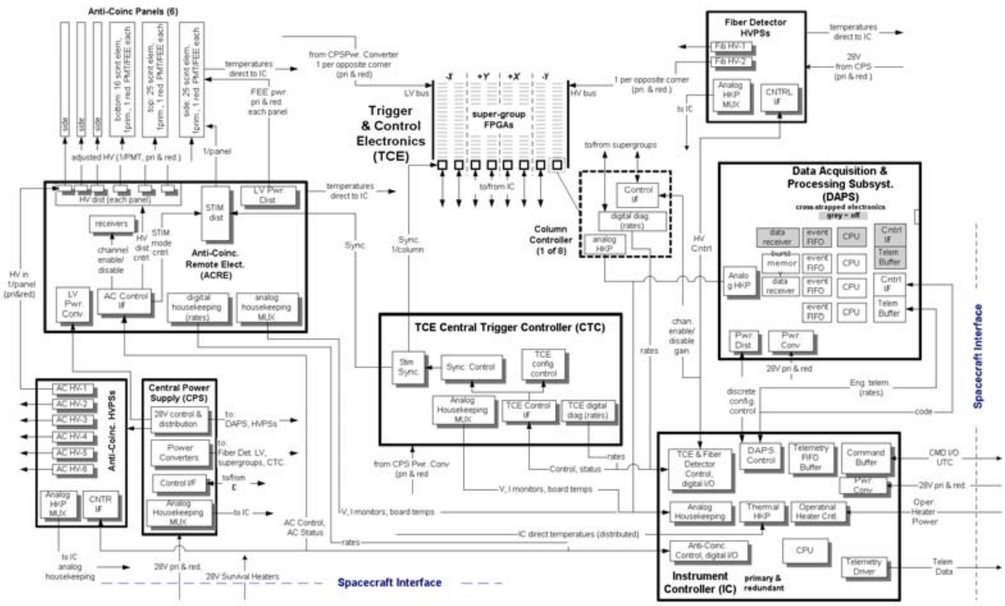
(example from FiberGLAST proposal)

Illustrate system components, functions, interfaces, redundancies



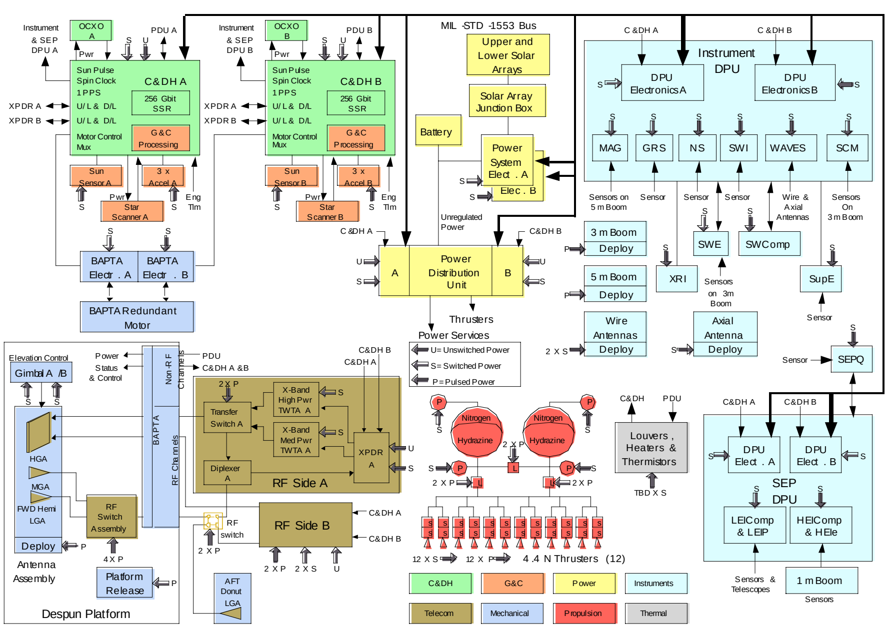
Data flow

Instrument Conceptual Design: Block Diagram



Instrument Control

Spacecraft Conceptual Design



Block diagram of the Inner Heliospheric Sentinels spacecraft

NASA Mission Design Resources

Integrated Design Capability (IDC)

- http://idconline.gsfc.nasa.gov/
- Integrated Mission Design Center
  - Mission conceptual designs http://imdc.gsfc.nasa.gov/
- Integrated Synthesis & Analysis Laboratory
  - Instrument conceptual designs http://isal.gsfc.nasa.gov/

- Rapid Spacecraft Development Office (RSDO)
  - http://rsdo.gsfc.nasa.gov/
  - Catalog of spacecraft, tables of spacecraft properties

RSDO ROM

- Can help you identify candidate busses from its catalog
- Can provide a Rough Order of Magnitude price range estimate

RSDO Rough Order of Magnitude (ROM) Request Form

Mission Name:

As of:

Mission Contact Name	
Mission Contact Phone	
Mission Contact Email	

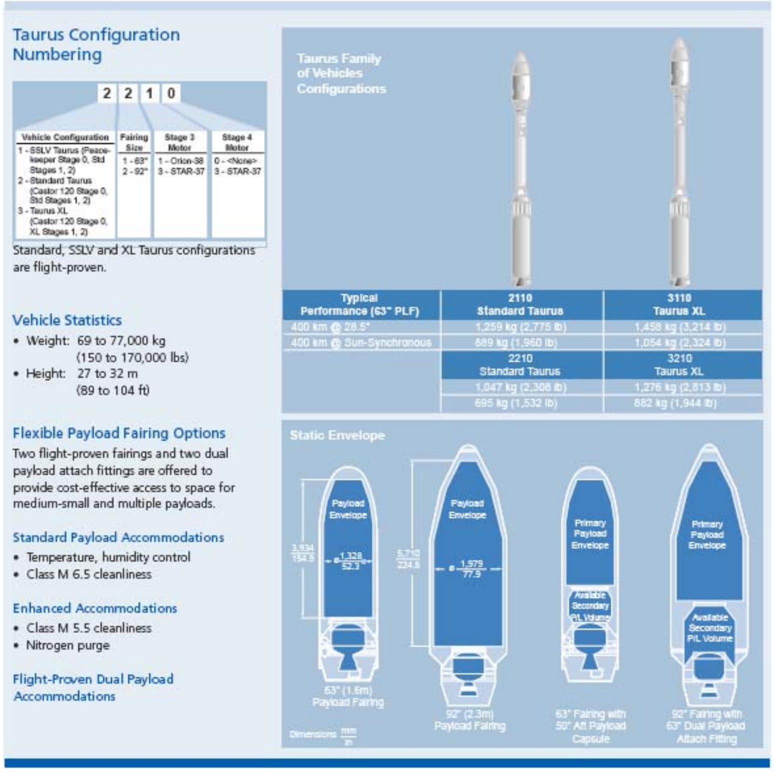
Mission Payload Accommodation Requirements:

Payload Mass kg	
Payload Power (EOL) Required W	
Science Data Downlink/Band kbps	
Science Data Storage Gbits	
Pointing Knowledge arcsecs	
Pointing Control arcsecs	
Pointing Stability (Jitter) arcsecs/sec	
Launch Date	
Acquisition Date	
Mission Life years	
Launch Vehicle	
Orbit km	
Orbit Knowledge	
Radiation Dosage kRads	
Propulsion requirement	
Other considerations	

Other Assumptions Used in the Estimate:

Downlink Communication Band	
Redundancy Needed	
Propulsion	
Star Trackers	
GPS Receivers	
Schedule Assumption	
No. of Spacecraft Types	
No. of Spacecraft	
Other	
Other	
Other	
Other	

Vendor Resources

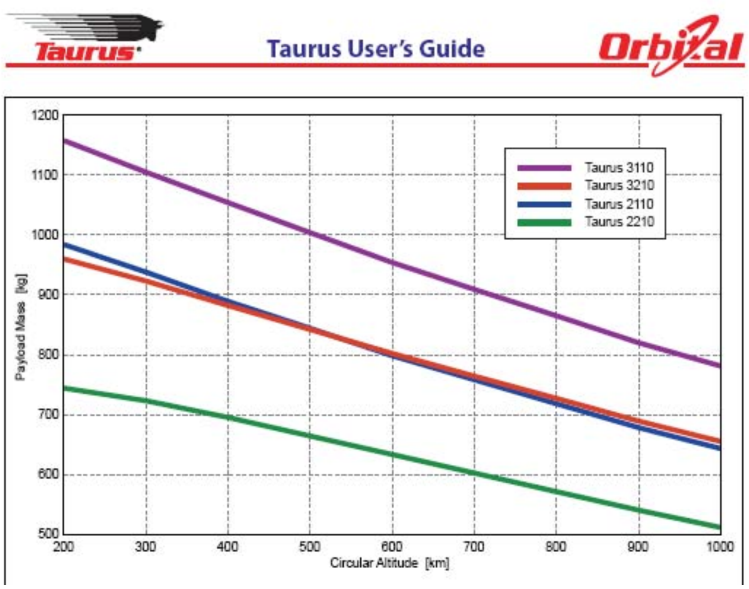


Example: Orbital Sciences Taurus launch vehicles

•http://www.orbital.com/SpaceLaunch/Taurus/index.html

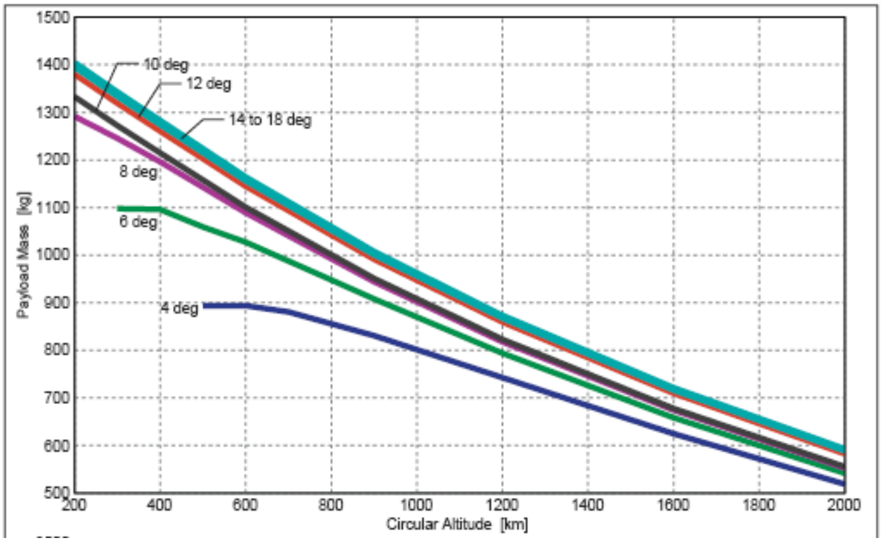
•Taurus User's Guide available

Vendor Resources



Taurus performance to Sun-synchronous orbits from North VAFB.

Orbit Inclination



Taurus 2110 LEO Performance from Reagan Test Site

Solar Mission Concepts

- Solar Sentinels (NASA)
  - http://lws.gsfc.nasa.gov/documents/mission_requir_ws_2_2000/sentinels.pdf
- Solar Orbiter (ESA)
  - http://sci.esa.int/science-e/www/area/index.cfm?fareaid=45

Mission Design Process

Reference: Wertz & Larson, *Space Mission Analysis and Design*

- Define the objectives
  - Define broad objectives and constraints
  - Estimate mission needs and requirements
- Characterize the mission
  - Define alternative mission concepts and architectures
  - Identify system drivers
  - Characterize concepts
- Evaluate the mission
  - Identify critical requirements
  - Conduct trade studies
  - Define baseline mission concept
- Define requirements
  - Define system requirements
  - Allocate requirements to system elements
- Iterate (and negotiate)

Mission Design Process

(Example: Sentinels, Pre-Phase A)

- Define the objectives
  - Define broad objectives and constraints
  - Estimate mission needs and requirements
- Characterize the mission
  - Define alternative mission concepts and architectures
  - Identify system drivers
  - Characterize concepts
- Evaluate the mission
  - Identify critical requirements
  - Define baseline mission concept
- Define requirements
  - Define system requirements
  - Allocate requirements to system elements
- Iterate

- Objectives, constraints, mission needs
  - Understand and characterize SMEs and CMEs
  - Improve forecast lead time for geospace disturbances
  - Constraints: cost
- Mission characteristics, concepts
  - multiple spacecraft, near Sun, near Earth
  - system drivers: orbits, instruments, mass,
  - L1 spacecraft concepts: Sun axis spinning or orbit axis spinning?
  - Instrument suite baseline: neutron spectrometer, gamma spectrometer, solar wind analyzer, magnetometer, . . .
  - Define instrument needs (resources)
- Evaluate the mission
  - Scope out single and multiple instrument concepts for Imaging Sentinels; conduct trade studies
  - Scope out Sun axis and orbit axis spin concepts for IH Sentinels
  - Define a baseline
- Requirements
  - Total mass, power, telemetry, . . .
  - Allocate resources to instruments, s/c, launch and ground segments

Imaging Sentinels Mission Study

Commissioned by NASA's Living With a Star (LWS) Program

Appendix D: Imaging Sentinels: Report of the Science and Technology Definition Team

Imaging Sentinels (IS) is designed to complement the Inner Heliospheric Sentinels (IHS) mission that is tasked with probing the characteristics of the solar environment to within 0.3 AU of the sun. While the four IHS spacecraft will conduct detailed in-situ investigations, the Imaging Sentinels spacecraft will provide a global context for these local measurements by studying the sun from near 1.0 AU in conjunction with observations from the Earth. Thus, the more comprehensive view provided by the IS mission will contribute to an improved understanding of the overall solar dynamics. Additionally, insight for the IS mission was provided from comparing three previous 1.0 AU solar orbiter missions, including Farside Sentinel, SHIELDS, and STEREO.

Baseline Sentinels Mission

The baseline Sentinels mission recommended by the STDT consists of three flight elements:

- Inner Heliospheric Sentinels (IHS)
  - four spin-stabilized spacecraft in elliptical heliocentric orbit with perihelia at ~0.25 AU and aphelia at ~0.75 AU; a three-axis stabilized
- Near-Earth Sentinel (NES, Imaging Sentinel)
  - in Sun-synchronous orbit at 1 AU;
- a small Farside Sentinel (FS)
  - drifts slowly away from Earth in a heliocentric orbit at 1 AU.

Imaging Sentinels Mission Study

D.1 Major Design Drivers

The Imaging Sentinels system design is driven by the science objectives, as identified by the STDT. In particular, the instrument payload and trajectory have a major impact on the design. Depending on the instrument suite, its development can be nearly as complex and labor intensive as the spacecraft bus. Part of this complexity is due to the addition of the guide telescope, which is required by several instruments and imposes a need for precise pointing knowledge. The other principal driver is the set of derived requirements from the trajectory. The trajectory design process endeavors to fulfill the viewing requirements, including overlap with IHS, while trading launch vehicle size, flight times, magnitude of delta-V, and type of propulsion. The requirements derived from this process drive the use of a redundant spacecraft design (due to a longer flight time) and a more capable launch vehicle. Combined, the instrument payload and trajectory design directly drive the majority of the mission budget.

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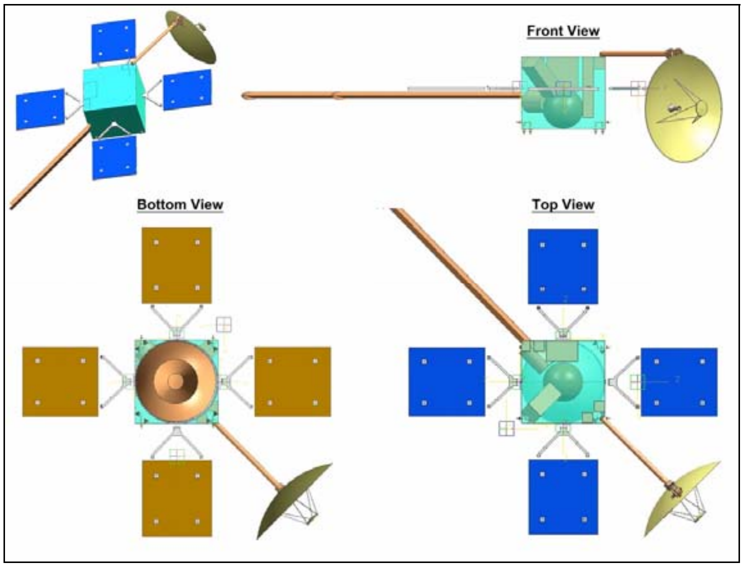
Imaging Sentinels Mission Study

D.4 Summary

There are several potential concepts for the Imaging Sentinels mission, defined primarily by the trajectory and instrument payload options. … All of these options require interplanetary trajectories and long mission durations that drive the ultimate cost of the mission. The instrument suite is the second principal driver, contributing nearly as much to the development effort as the flight system. Four payload options were considered that range from ….

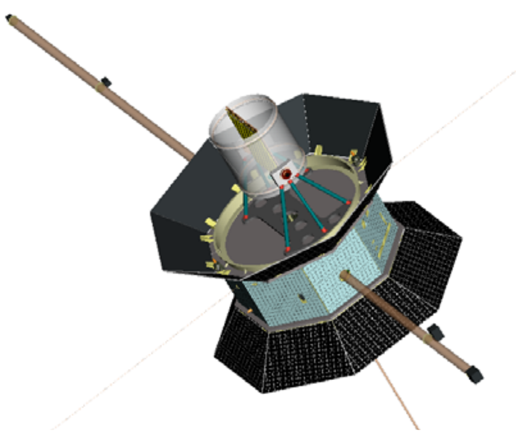
In parallel, three concepts were studied to support the mission trade space. These options included two complete instrument payloads, differentiated by their trajectories and launch vehicles (Delta II versus Taurus). The third concept emphasized a minimum cost option of a single instrument payload (using a suboptimal trajectory and Taurus launch vehicle). Of these point designs, the 6 Instrument Taurus Option was presented in this report. It is a 3-axis stabilized, redundant flight system. ….

Imaging Sentinel Spacecraft



Flight system configuration

IHS Spacecraft



One of the four Inner Heliospheric Sentinels spacecraft in deployed configuration.

Imaging Sentinels Mission Design Drivers

Table D-1. Summary of Major Design Drivers

Design Driver	STDT Report	Other Options	Type of Analysis
1. Instrument Payload	6 Instrument Suite: Magnetograph + Coronagraphs + In Situ	• Magnetograph Only • Helioseismology • Magnetograph and Coronagraphs	Point Designs Sys. Trade Studies
2. Trajectory	0 to 180 deg Drifting with Lunar Gravity Assists	• 120 deg Fixed • Optimal 60 to 180 deg • 0 to 180 deg Drifting (slow) • 0 to 180 deg Drifting (fast)	Trajectory Analysis Sys. Trade Studies
3. Science Data Collection Rate	115.6 kbps	• 37.3 to 500 kbps	Telecom Analysis Sys. Trade Studies

Imaging Sentinels Mission Design Overview

Table D-7. Mission Design Overview

Mission Design	Units	6 Instrument Taurus Option	*1 Instrument Taurus Option*
Destination		0 to 180 Drifting	*0 to 180 Drifting*
Lunar Gravity Assist	Yes/No	Yes (x 2)	*No*
Duration of IHS Overlap	years	1.5	*1.7*
Maximum Sun Range	AU	0.85	*0.8*
Maximum Earth Range	AU	2.0	*2.0*
C3	km^2/s^2	-1.9	*4.5*
Delta-V	m/s	85	*85*
Maneuvers	#	6	*2*
Launch Vehicle (LV)		Taurus 3113 / Star 37F	*Taurus 2130*
Fairing Size (inner diameter)	m	1.4	*1.4*
LV adapter (LV-side) Included	Yes/No	No	*Yes*
LV Performance	kg	445.0	*310.0*
LV Margin	kg	8.7	*67.3*

Definition of Elements

- Operations Concept
- Spacecraft bus
- Orbit selection
- Payload
- Budgets
- Communications
- Launch segment
- Ground segment

Operations Concept

- Define data delivery process
  - Space vs. ground processing
  - Level of autonomy
- Define scheduling and control
  - Central vs. distributed control
- Define communications architecture
  - Data rates, bandwidth, timeliness of communications
- Define preliminary mission timeline
  - Concept, development, operations, end of life

Spacecraft Bus

- Propulsion
  - Thrusters for orbit and attitude adjustments and control
- Attitude determination and control system (ADCS)
  - Determination and control of pointing of spacecraft and instruments
- Communication (Comm)
  - Communication with ground and other spacecraft
- Command and data handling (C&DH)
  - Processes and distributes commands
  - Processes, formats and stores data
- Thermal
  - Maintains equipment within allowed temperature ranges
- Power
  - Generates, stores, regulates and distributes electrical power
- Structures and mechanisms
  - Provides support structure, booster interface, moving parts

Orbit Selection

- Establish the required orbit types
  - Parking, transfer, space-referenced, earth referenced
- Determine orbit-related mission requirements
- Single satellite vs. constellation
  - Single large satellite vs. constellation of smaller simpler satellites
- Mission orbit design trades
  - How do orbit parameters affect mission requirements?
- Assess launch, retrieval or disposal options
  - Launch vehicle limits how much mass can be put into an orbit at a given altitude
- Document the options, assess, iterate

Imaging Sentinels Trajectory Options

Table D-4. Mission Trade Space

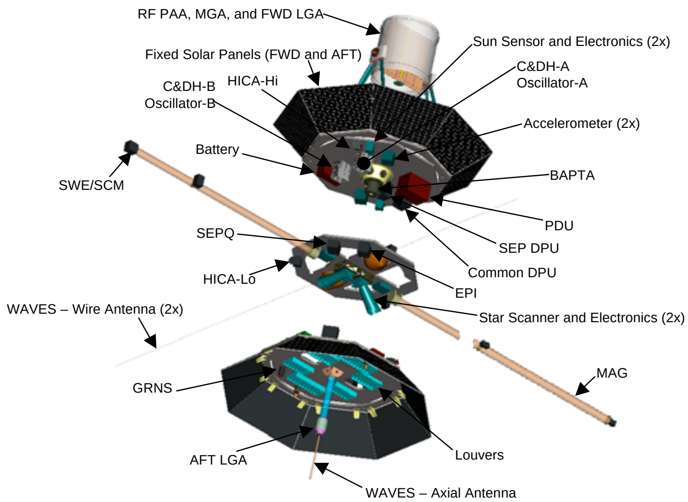
Total Launch Mass (kg)				
	Instrument Payload Options			
Trajectory Options	**Magneto-graph**	**Helio-seismology**	**Magnetograph + Coronagraphs**	**Magnetograph + Coronagraphs + In Situ**
120 deg Fixed	L: 510 kg	H: 580 kg	H: 737 kg	H: 765 kg
	VL: 458 kg	L: 517 kg	L: 674 kg	L: 742 kg
Optimal 60 to 180 deg Drifting	L: 479 kg	H: 545 kg	H: 693 kg	H: 719 kg
	VL: 429 kg	L: 485 kg	L: 633 kg	**L: 697 kg (3)**
0 to 180 deg Drifting (slow)	L: 273 kg	H: 328 kg	H: 357 kg	H: 429 kg
	VL: 243 kg	L: 276 kg	L: 349 kg	L: 370 kg
0 to 180 deg Drifting (fast)	L: 273 kg	H: 328 kg	H: 349 kg	H: 429 kg
	VL: 243 kg (1)	L: 276 kg	L: 349 kg	L: 394 kg
0 to 180 Drifting with Lunar Gravity Assist	L: 273 kg	H: 328 kg	H: 394 kg	H: 395 kg
	VL: 243 kg	L: 276 kg	L: 364 kg	**L: 402 kg (2)**

Validated Point Designs						
(1) 1 Instrument Taurus Option	**Mission Cost**	MIDEX Class		♉		Discovery Class
(2) 6 Instrument Taurus Option		VL	L	M	H	VH
(3) 6 Instrument Delta II Option	**Data Rate**	VL = 37.3 kbps		L = 115.6 kbps		H = 500 kbps

Payload (Instruments)

- One instrument mission or suite of instruments?
- Select instrument(s) to address the mission performance objectives
  - Conduct trades
    - Performance thresholds
- Develop instrument operations concept
  - End-to-end concept for all mission phases and operating modes
- Determine required instrument capabilities
- Identify candidate instruments
- Evaluate candidates, select a baseline
  - Resource requirements
- Identify and negotiate instrument-derived requirements
- Document and iterate

IHS Instrument and Subsystem Locations



Views of the Inner Heliospheric Sentinels spacecraft, showing the locations of the science instruments and the spacecraft subsystems.

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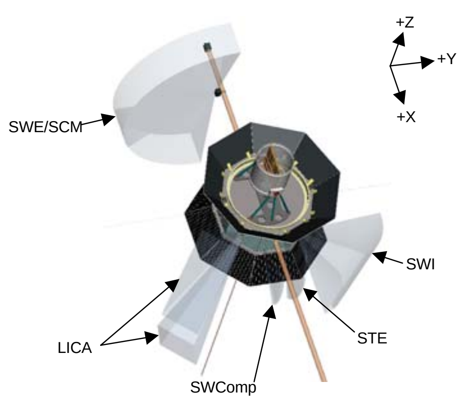
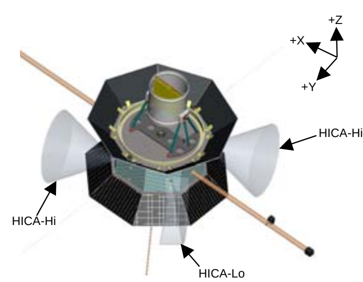
IHS Instrument Fields of View





Instrument fields-of-view.

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Budgets

- Size and mass
  - Estimate envelope and mass each instrument and spacecraft subsystem. Consider location on spacecraft and FoV requirements
- Power
  - Estimate operating power requirements of each instrument and spacecraft subsystem
  - Size the solar arrays and batteries
  - Charge-discharge cycles
- Telemetry
- Propellant
- Reliability
  - Follows from mission success criteria
- Consider margins

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Mass

example from IH Sentinel Study

Appendix B: Inner Heliospheric Sentinels Mass and Power I

Table B-1: **Mass estimates.**

Component	Mass (kg)
Instruments	
Dual Magnetometer	0.5
Dual Mag Boom	10.0
SW Electrons	1.5
Search Coil	0.5
SW/SC Boom	5.0
Protons/Alpha	4.0
Composition	6.0
Radio	4.7
Low Energy Ions	3.5
High Energy Ions and electrons and Boom	8.0
SEP Q-States and SEP DPU	10.5
Energetic Electrons & Suprathermals	2.0
Neutron Spectrometer	3.8
XR Imager	2.0
Gamma Spectrometer	2.2
Common DPU	3.0
DPU components	1.8
Purge system	0.1
Instrument harness	1.4
Instruments subtotal	70.5
Attitude Determination and Control	
Star scanner (2)	8.2
Accelerometers (2)	2.0
Sun sensors (2)	2.5
Attitude subtotal	12.7
Command & Data Handling	
IEM & OCXO - A	5.6
IEM & OCXO - B	5.6
Command subtotal	11.2

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Mass

example from IH Sentinel study, cont.

Structure	
Honeycomb decks and fasteners, average mass	57.7
Load-bearing structure, average mass	69.7
Despun platform	7.3
RF radiators with mounts	1.9
Secondary structure	9.7
Fasteners	2.3
Spin balance mass (no Cg offset)	13.0
Structure subtotal	161.6
Propulsion	
Propellant tank (2)	7.4
Thrusters 4.4N (12)	4.8
Latch and service valve	1.3
Propellant filter	0.4
Pressure transducer	0.8
Cabling and connectors	3.4
Tubing/fasteners/tube clamps/etc.	5.1
Propulsion subtotal	23.2
RF Communications	
HGA	4.9
RF support structure	4.6
BAPTA & Electronics Box	20.9
HGA Actuator	2.3
Forward LGA and MGA	0.9
Aft LGA and boom	11.1
Rotary joints (2)	3.5
TWTA (4)	9.2
Transponder (2)	6.0
Waveguide RF Transfer Switches (3)	2.0
Waveguide diplexer (2) and Isolators (4)	2.0
Radome, pressure baffle, support	3.4
Waveguide runs	1.2
Coax transfer switch, filters	1.2
RF subtotal	73.1

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Mass

example from IH Sentinel study, cont.

Thermal	
MLI blankets	5.0
Radiator	4.0
Thermal curtains	0.5
OSRs	5.2
OSR Panels	5.4
Louvers	5.0
Despun thermal spacer	0.3
Heaters and miscellaneous	0.1
Thermal subtotal	25.5
Harness	
S/C harness, 9% dry mass	45.3
Harness subtotal	45.3
Spacecraft dry mass total (average)	**503.7**
Launch	
Wet mass with margin (average)	697.8
Usable propellant	42.5
Trapped propellant and pressurant	0.5
Dry mass with margin (average)	654.8
Dry mass with margin (top spacecraft)	614.1
Dry mass with margin (bottom spacecraft)	695.9
Margin on dry mass (average), kg	151.1
Margin on dry mass %	30.0%
Bottom spacecraft wet with margin	738.9
Mid-Lo spacecraft wet with margin	709.2
Mid-Hi spacecraft wet with margin	686.3
Top spacecraft wet with margin	657.1
Mass of 4 observatories	2791.3
Jettisoned support cylinders w/ 30% margin	89.0
Separation and jettison systems w/ 30% margin	312.0
Total Launch Mass	**3192.4**

Solar Sentinels Mission Study

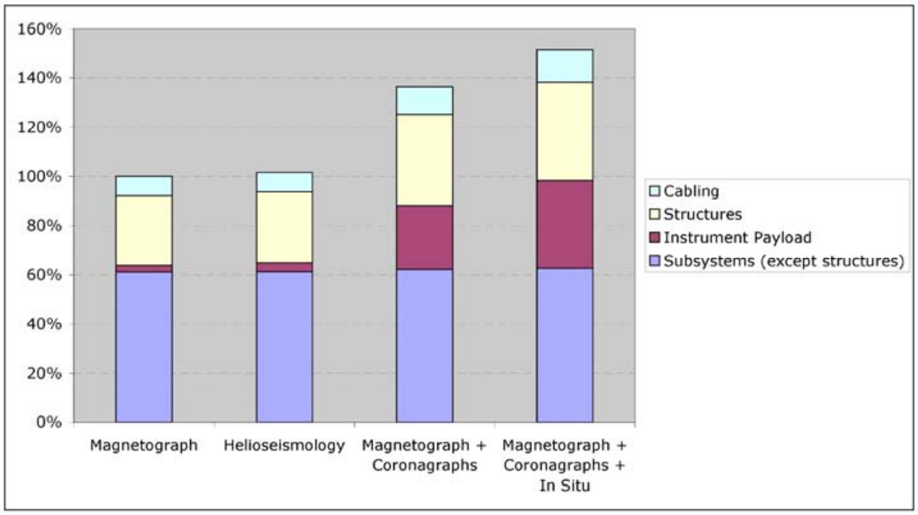


Figure D-3. **Impact of Instrument Options on Spacecraft Dry Mass**

Communications

- Identify communications requirements
  - Develop mission data flow diagram
  - Specify: data sources, end users, data rate, access time, transmission delay
- Specify alternate communication architectures
  - Links and ground station locations
  - Use relay satellites or ground relay stations?
  - Determine data processing location
  - Determine data rates and schedules for each link
- Evaluate options and select
  - Consider power, bandwidth, line of sight

Imaging Sentinels Communications Options and Trades

Table D-3. Summary of Data Rate Options

Science Data Rate Options	Telecom Subsystem Design & Ground Systems (optimized for design)			
	Transmitter Size	High Gain Antenna	Weekly Passes	DSN Coverage
37 to 500 kbps	25 to 250 W TWTA	0.85 to 1.5 m	4 to 8 hour duration 1 to 2 passes/week	36 to 100 12-m nodes (assumes new 200 node 12-m DSN array)

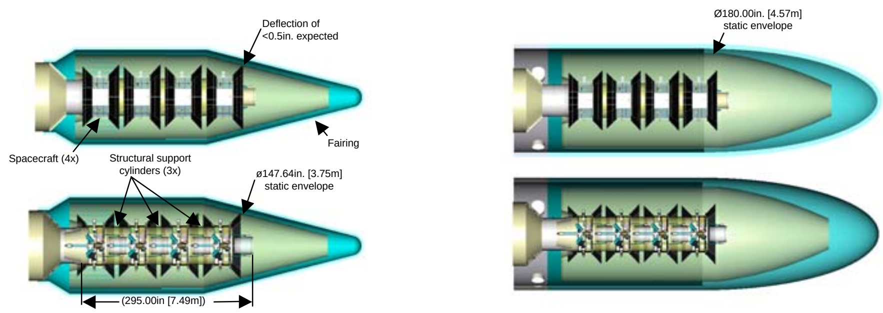
Table D-13. Telecom Subsystem Parameters

Telecom	Units	6 Instrument Taurus Option	*1 Instrument Taurus Option*
Band	S/X/Ka/etc.	X-band up Ka-band down	*X-band up* *Ka-band down*
Redundancy		Dual-string	*Dual-string*
High Gain Antenna Size	m	1.25	*1.25*
TWTA Power	W	90.0	*30.0*
Downlink Data Rate	Mbps	2.8	*0.9*
Pointing Accuracy	Deg	0.1	*0.1*
Margin	dB	3.02	*3.42*

Launch Segment

- Collect the requirements
  - Consider deployment strategy, number of spacecraft per launch, mission orbit, mission lifetime, cost, size and mass
- Identify and assess candidate launch vehicles
  - Payload weight capability and margin
  - Example: Taurus: http://www.orbital.com/NewsInfo/Publications/Taurus_fact.pdf
  - Consider environments dictated by the launch system

IHS Launch Configuration and Launcher Options



The four Inner Heliospheric Sentinels spacecraft stowed in (a) the 4-m fairing on an Atlas V-431 and (b) the 5m fairing of an Atlas V-541.

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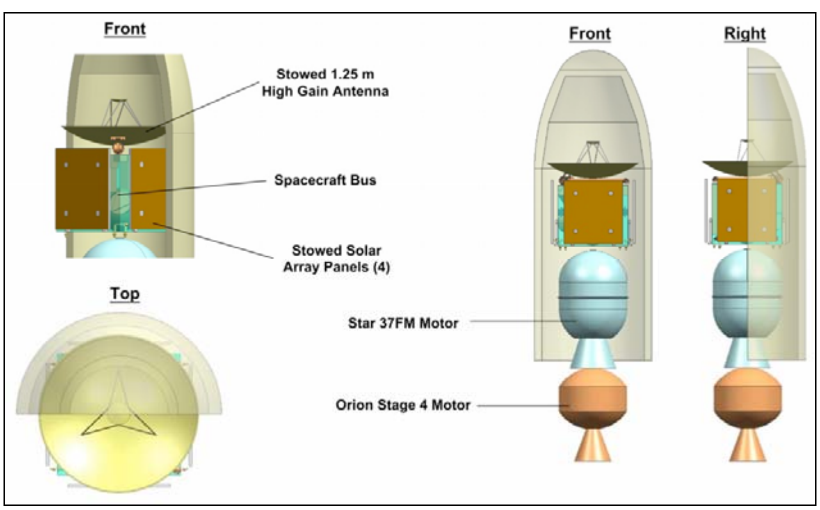
Launch Vehicle Accommodation



Imaging Sentinel spacecraft

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Ground Segment

- Establish number and locations of ground stations
- Establish space to ground data rates
- Determine receiver and transmitter requirements
- Determine data handling requirements and location
- Decide location of SOCC and POCC
- Dedicated custom system or partial use of service provider ground systems?

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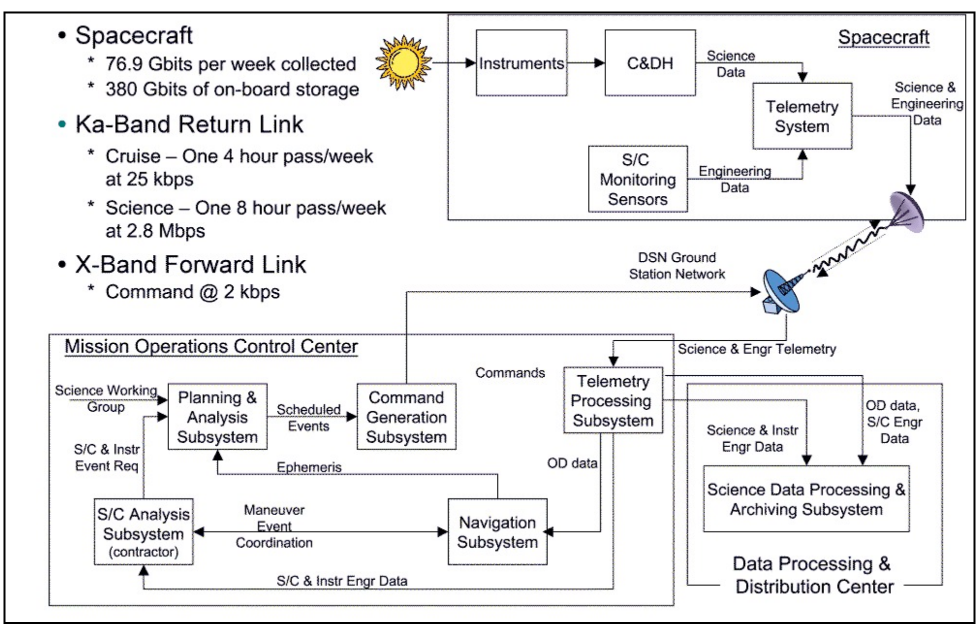
Sentinels Ground System



Imaging Sentinels Ground Segment Trades

Table D-18. Ground Systems Overview

Ground Systems	Units	6 Instrument Taurus Option	*1 Instrument Taurus Option*
Engineering Data Rate (uplink)	Kbps	0.5	*0.5*
Engineering Data Rate (downlink)	kbps	2.0	*2.0*
Data Return Overhead	kbps	15%	*15%*
Phase E: Cruise			
Link Duration	hours	4	4
Passes per Week	passes/wk	1	1
Number of 12-m Antennas	#	1	1
Downlink Data Rate	Mbps	0.025	0.025
Phase E: Operations			
Link Duration	hours	8	8
Passes per Week	passes/wk	1	1
Max Number of 12-m Antennas	#	36 (average of 33)	36 (average of 33)
Downlink Data Rate	Mbps	2.8	0.9

Summary (including some advice)

- The space mission design & development process attempts to cover all bases. It's a guideline; iterations and compromises are essential and unavoidable.
- Resources are becoming more readily available
- This is hard work but can be fun and rewarding. Not everyone is well-suited to it. You will need to wear many hats.
- Successful mission proposal preparation is hard work. Before you start be sure; the science is hot, the funding intentions are strong, the technology is mature, the team is up to the task, ...
- Small details can be very important.
- Time spent planning is well spent. Consider risks. Low level models are very helpful.
- You are doing R&D. This is time consuming. Don't build what you can buy.
- Most plans are success based. Retain margins (schedule, cost, power, mass, telemetry, ...) to deal with the unexpected.
- Good teamwork is essential. The people in this business, internationally, are a small community. Treat everyone like you will have to work with them again. You probably will.
- Thanks