

Terrestrial Planet Finder Mission

# Terrestrial Planet Finder Interferometer System Design Studies 14 October 2003

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# Acknowledgement



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- The research described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.

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# Interferometer Design Team Charge **JPL**

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- **By 2006 deliver a viable Structurally Connected Interferometer mission that meets or exceeds the minimum TPF science ( $\geq 30$  star survey)**
- **By 2006 deliver a viable Formation Flying Interferometer mission that meets or exceeds the minimum TPF science ( $\geq 150$  star survey)**

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# First Order Design Constraints



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- **Single Launch (self-imposed)**
- **U.S. launch vehicle (U.S. policy)**
- **No on-orbit assembly (self-imposed)**
- **Fit in 5 m x 22.4 m launch vehicle fairing (derived)**
  - largest for Delta IV Heavy
- **Launch mass < 9400 kg (derived)**
  - Delta IV Heavy capability to L2
- **Avoid use of radioisotope power if possible (NASA policy)**
- **Capable of launch in 2015**
- **5 year primary mission lifetime (consumables for 10)**

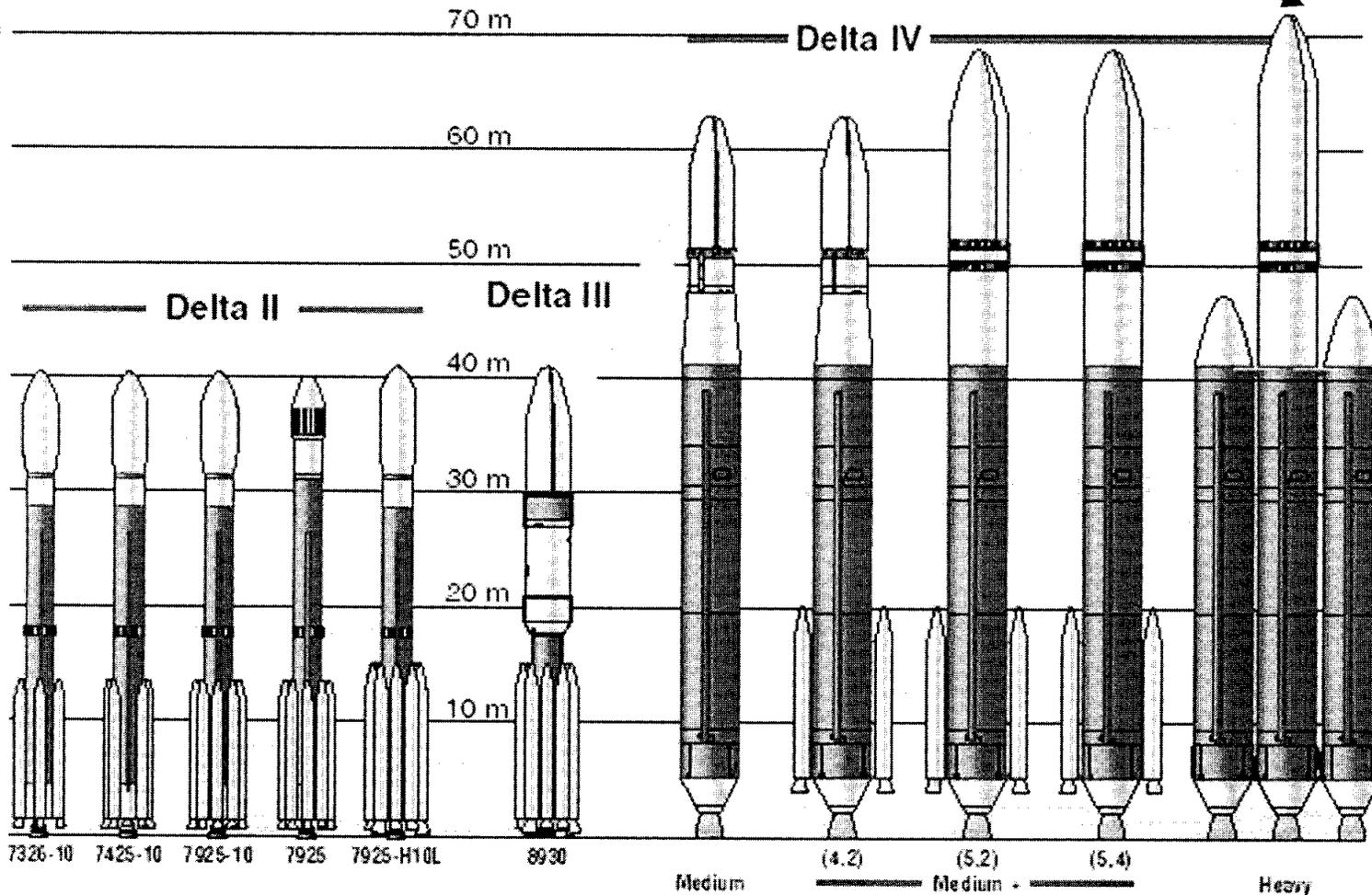
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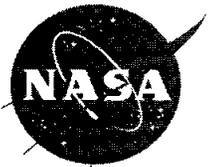
TPF needs this one



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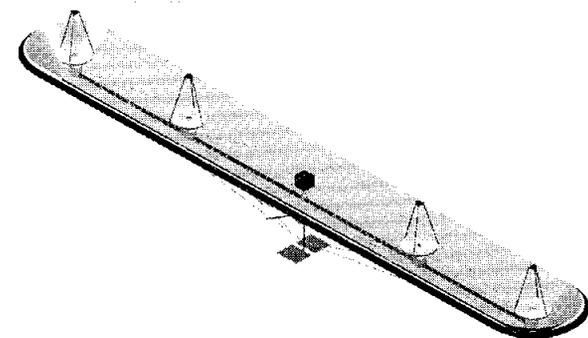
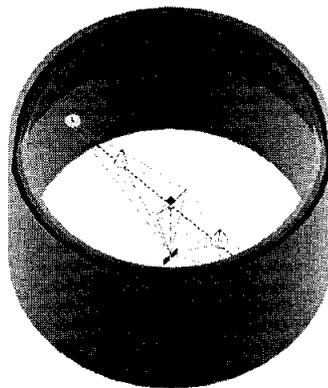
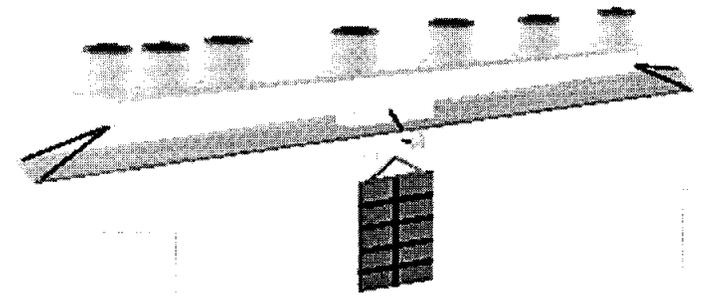
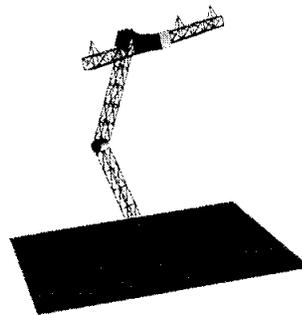
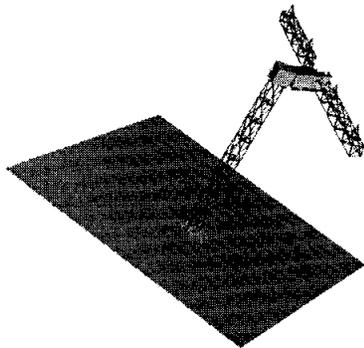
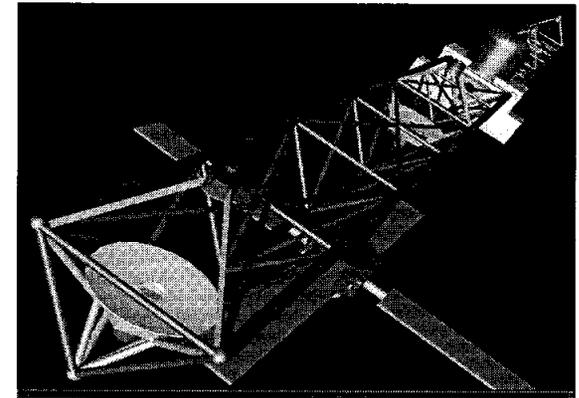
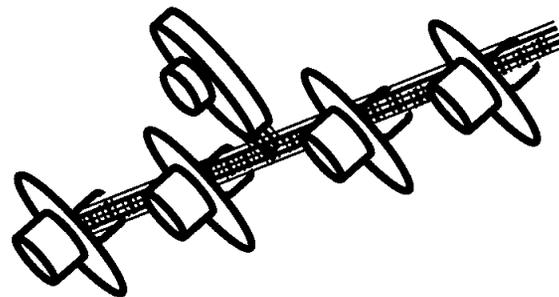
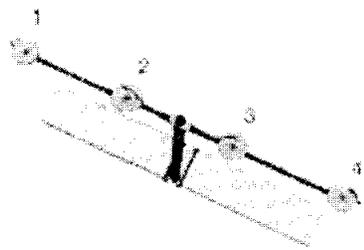
	7326-10	7425-10	7925-10	7925	7925-H10L	8930	Medium	(4.2)	(5.2)	(5.4)	Heavy
	2731	3094	4971	5139	5815	8292	8120	10,430	7980	11,475	23,840
	(6020)	(6820)	(10,960)	(11,330)	(12,820)	(18,280)	(17,900)	(23,000)	(17,600)	(25,300)	(50,800)
A NASA Origins Mission	898	1102	1799	1869	2064	3810	4210	5845	4640	6565	13,130
	(1980)	(2,430)	(3965)	(4120)	(4550)	(8400)	(9285)	(12,890)	(10,230)	(14,475)	(28,950)



# SCI, The Past – Thank You



Terrestrial Planet Finder Mission



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# SCI Mission Summary

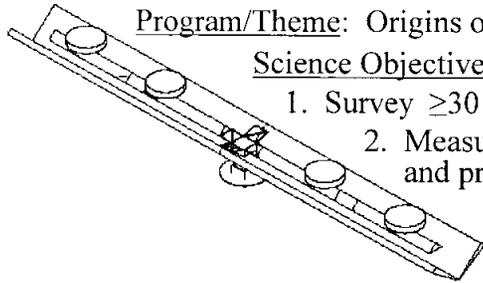


## A Search for Earth-Like Planets In the Habitable Zone Around Nearby Stars

Program/Theme: Origins of Stars, Planets, and Life

### Science Objectives:

1. Survey  $\geq 30$  stars for terrestrial planets
2. Measure planets' orbit, mass, and presence of biomarkers in the atmosphere ( $H_2O$ ,  $O_3$ ,  $CO_2$ ,  $CH_4$ )
3. Observe astrophysical sources (active galaxies, etc.)



**Mission Description:**

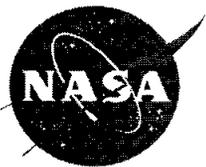
1. Structurally Connected Interferometer--consisting of 4 telescopes supported on a linear truss
2. Infrared Nulling Interferometer operating at cryogenic temps
3. Observatory flies in L2 Halo orbit for low disturbance enviro.

Key Enabling Technologies	TRL	Type
Precision Pathlength Control	5	Enabling
Precision Wavefront Control	4	Enabling
Adaptive nuller	2	Enabling
Cyro-actuators	5-6	Enabling
Large Deployable Sunshield	5-6	Enabling
Nulling Beam Combination	3	Enabling
Metrology	3	Enabling
Detectors	5-6	Enabling
Thrusters	4-6	Enabling
Primary Mirror	4-6	Enabling
Cyrocooler	3-4	Enabling

Instrument		Observatory	
Telescopes	4	# of Collectors	4
Aperture Diameter	3.2 m	Design Life	10 years
Array Length	36	Attitude Control	3-axis
Angular Resolution	50-75 milli-arcsec	Pointing Accuracy	15 as
Stellar Light Rejection	$> 10^6$	Pointing Knowledge	10 as
Field of View	1 arcsec @ $12\mu$	HGA Pointing	3-axis
Sky Coverage	+/- 45 deg anti-sun	Solar Array Pointing	3-axis
Wavelength Range	7-17 $\mu$	Data Downlink Rate	2.0 Mbps
Spectral Res.	$\lambda/\Delta\lambda = 100$	Downlink Frequency	Ka-band
Telescope Temp	$< 40$ K	Onboard Data Storage	TBD
Detector Temp	$< 6$ K	Uplink Data Rate	2000 bps
<b>DC Power</b>		Uplink Frequency	Ka-band
Predicted Max	1495 W	Mission $\Delta V$	650 m/s
Margin	30%		

Trajectory	
C3	-0.69
$\Delta V$ (TCM's)	105 m/s
Launch Vehicle	Delta 4050H
Duration	100 days
Mission Orbit	L2 Halo

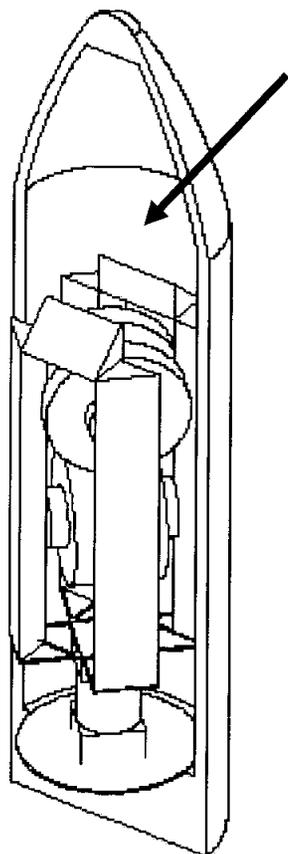
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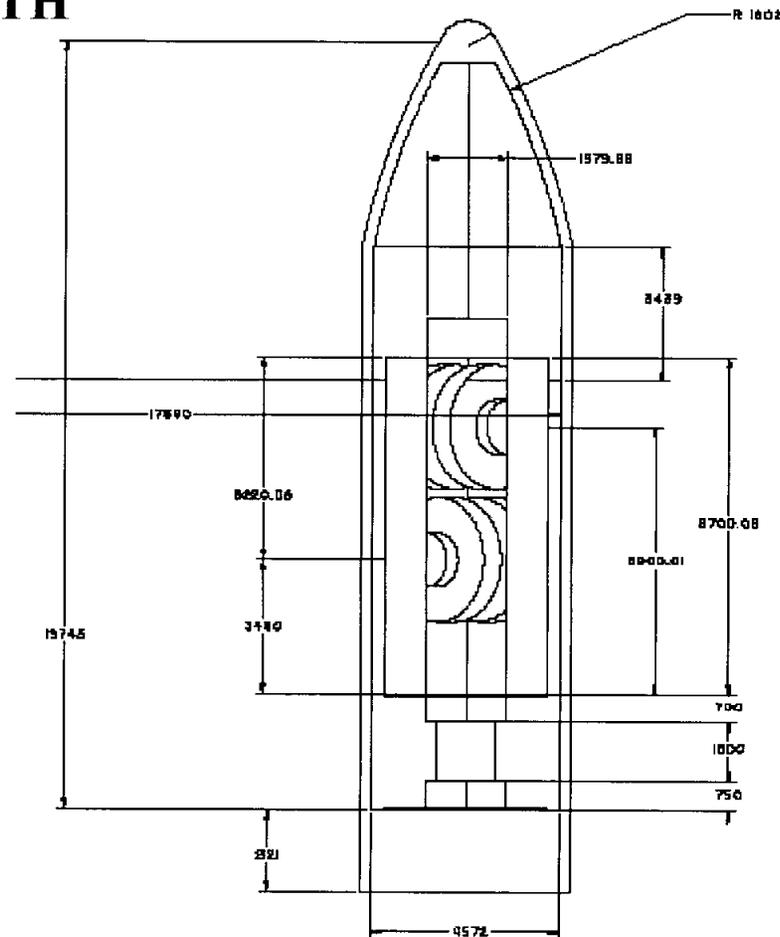
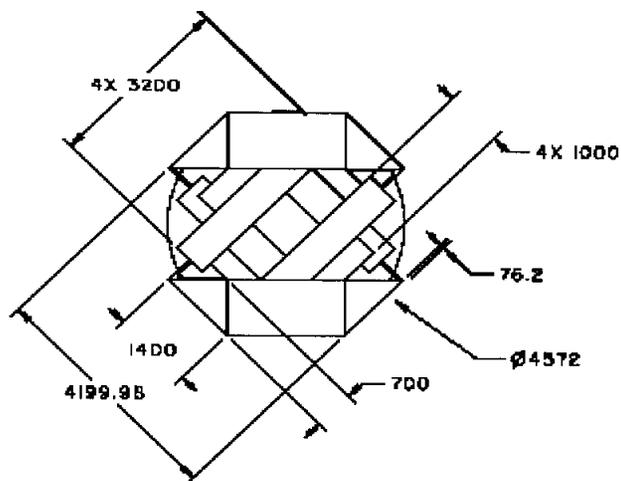
# 6-Fold Oblique Stowed Configuration



Terrestrial Planet Finder Mission

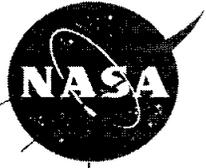


**ROOM TO GROW LENGTH**



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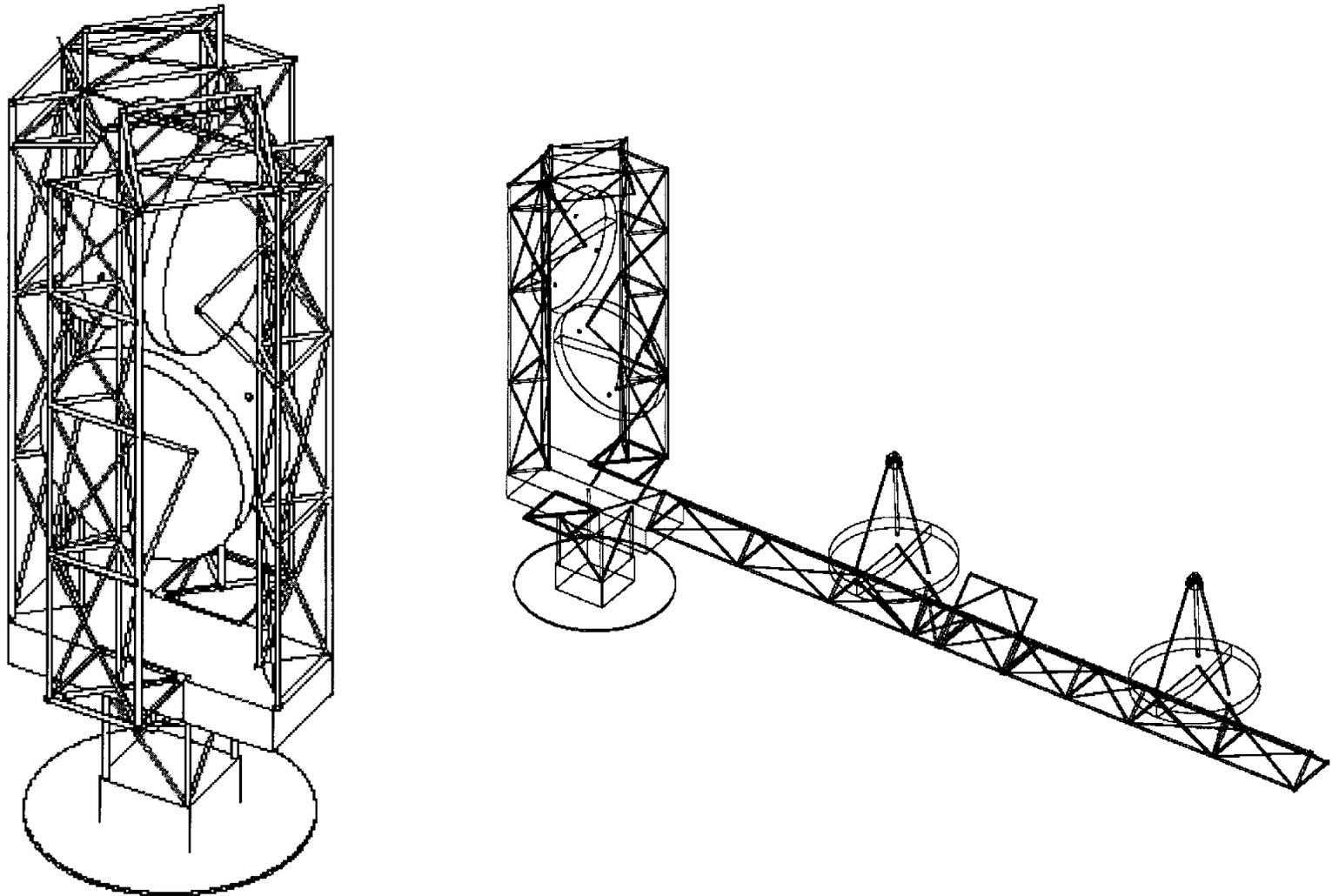
ARRAY LENGTH 36000 MM.



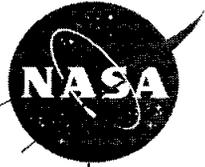
# 6-Fold Oblique



Terrestrial Planet Finder Mission



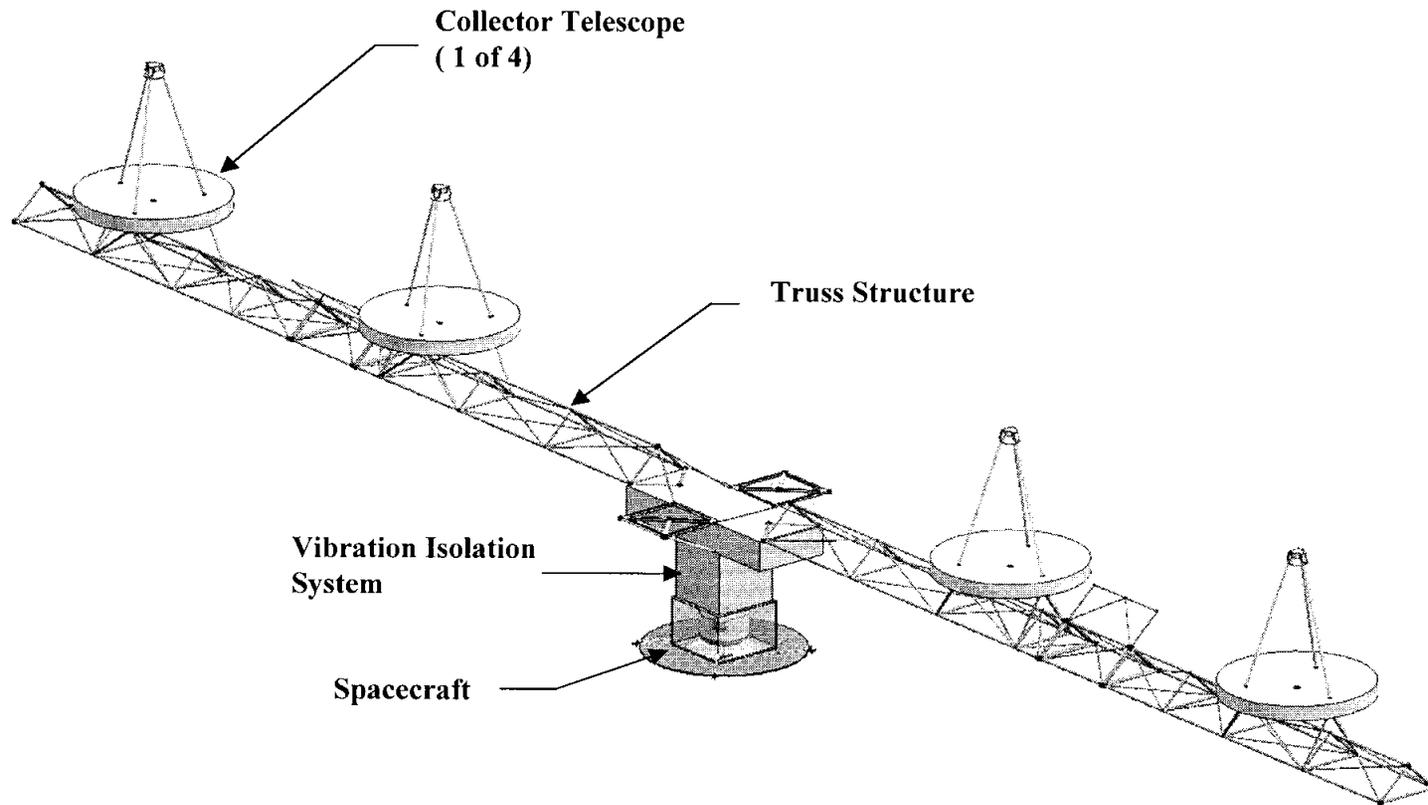
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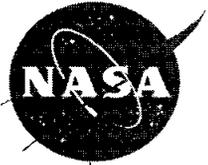
# 6-Fold Oblique



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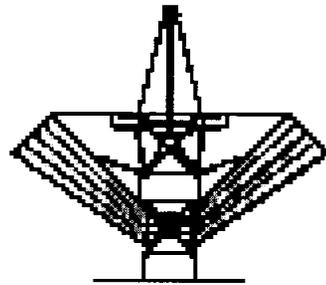
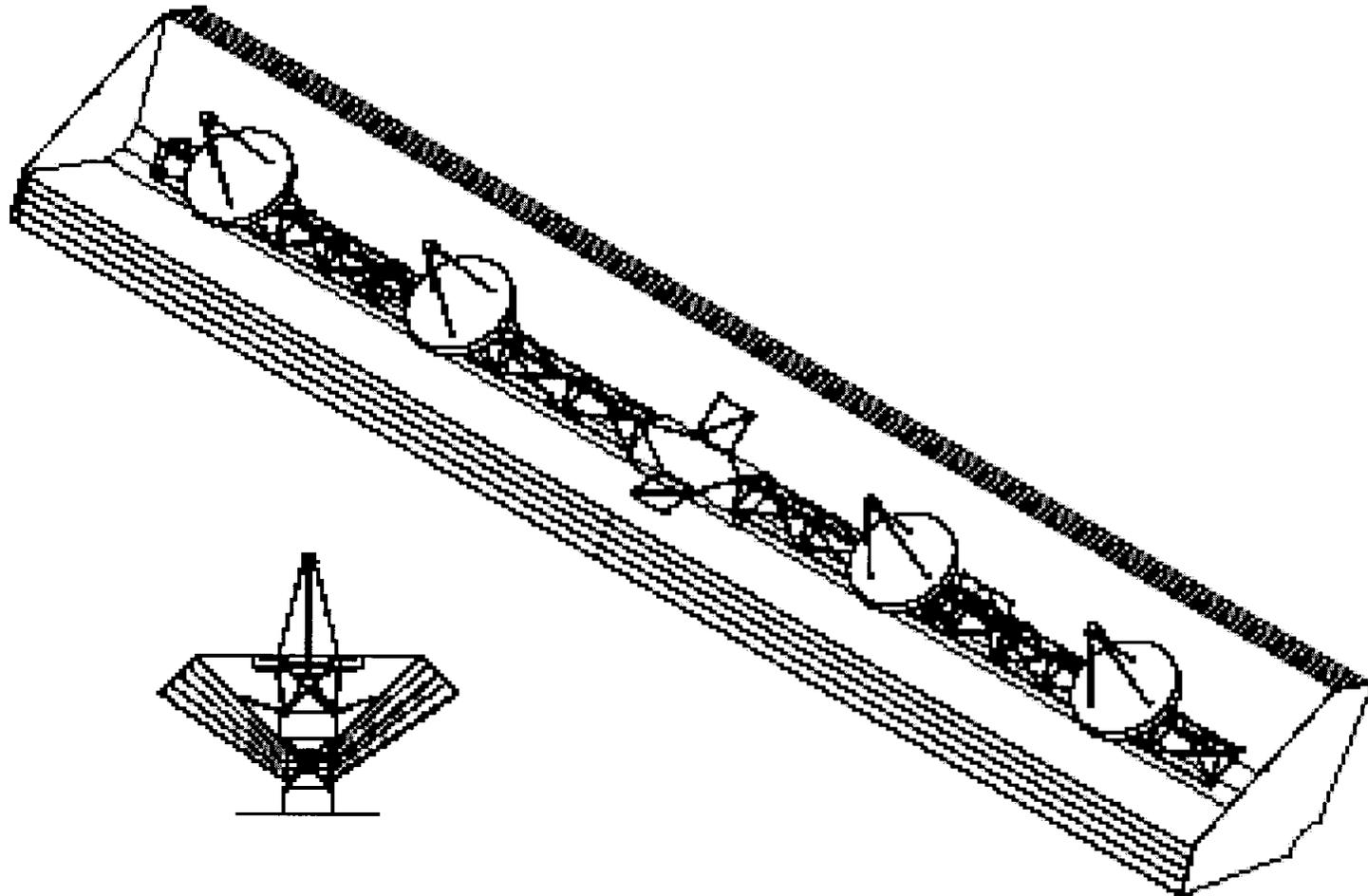
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# Sunshield Concept for 6-Fold Oblique

**JPL**

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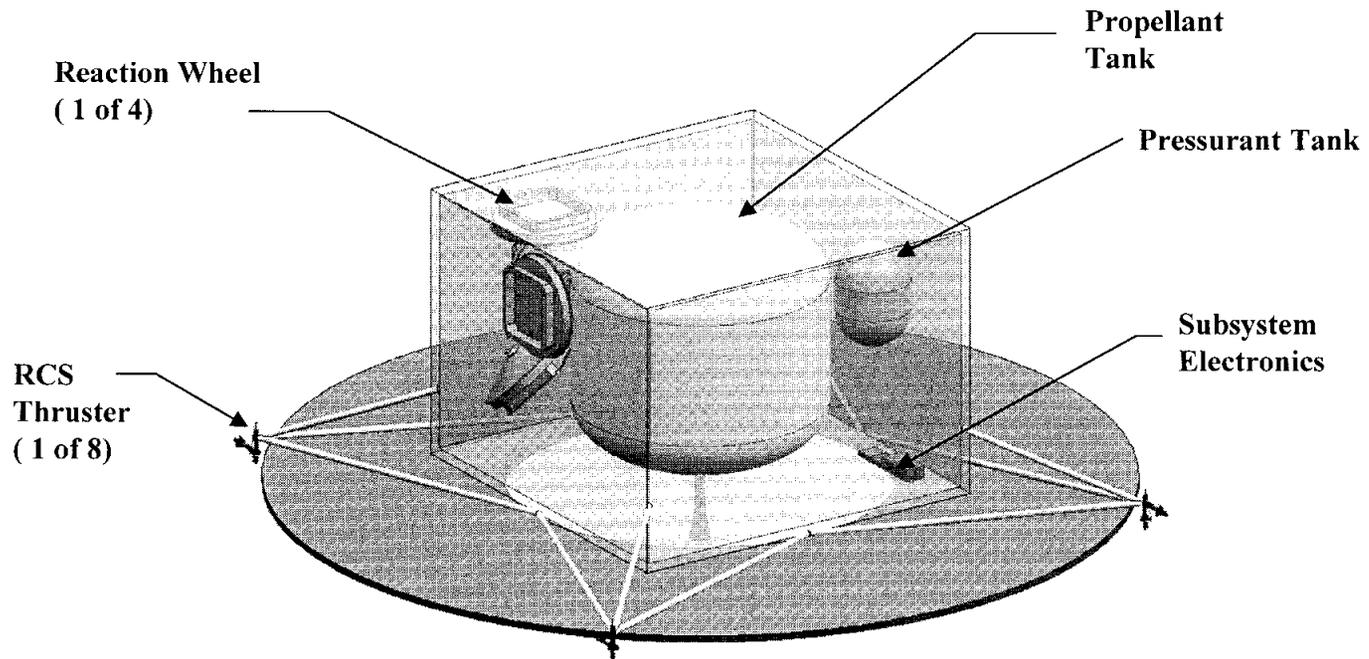
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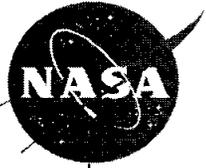
# SCI Engineering Bus



Terrestrial Planet Finder Mission



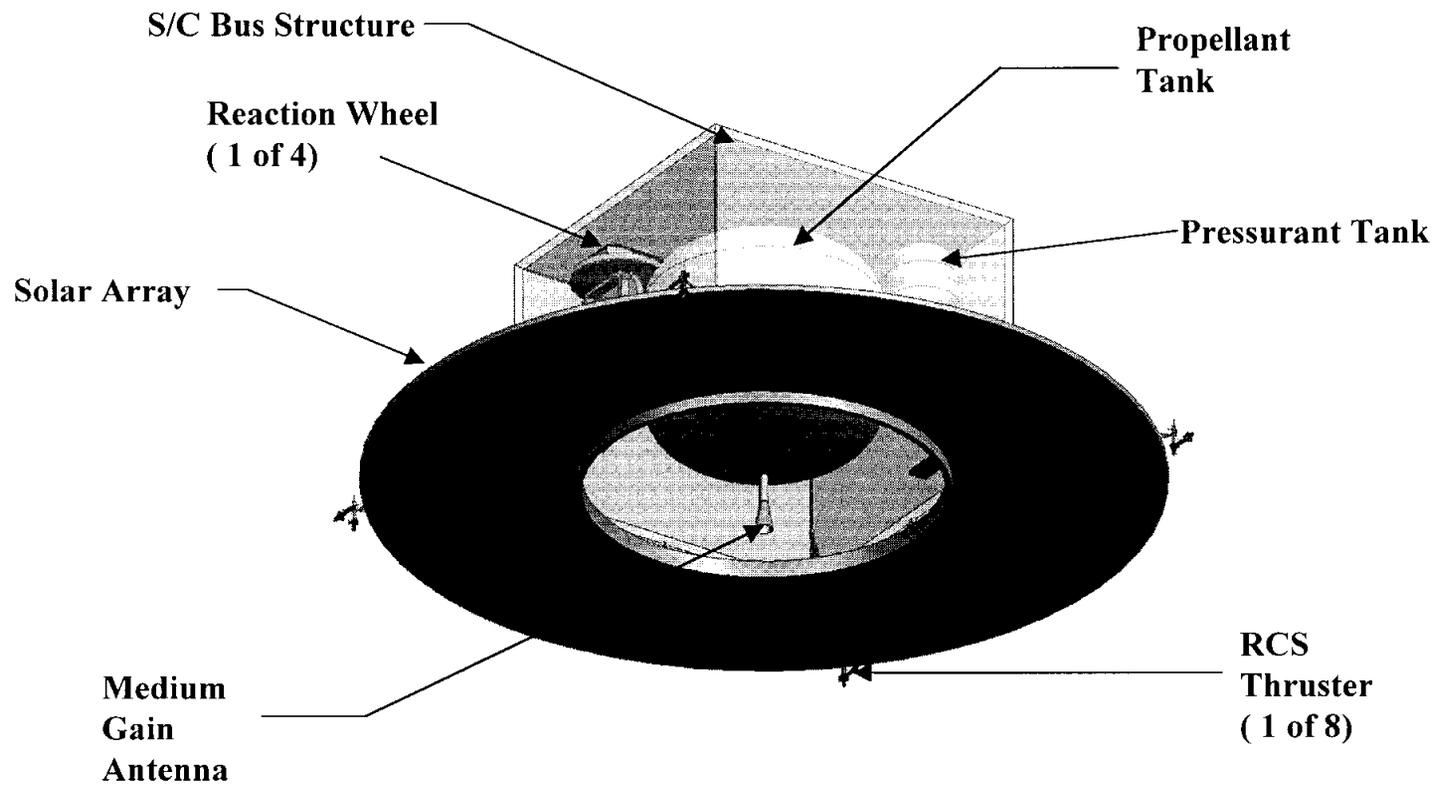
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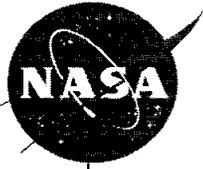
# SCI Engineering Bus



Terrestrial Planet Finder Mission



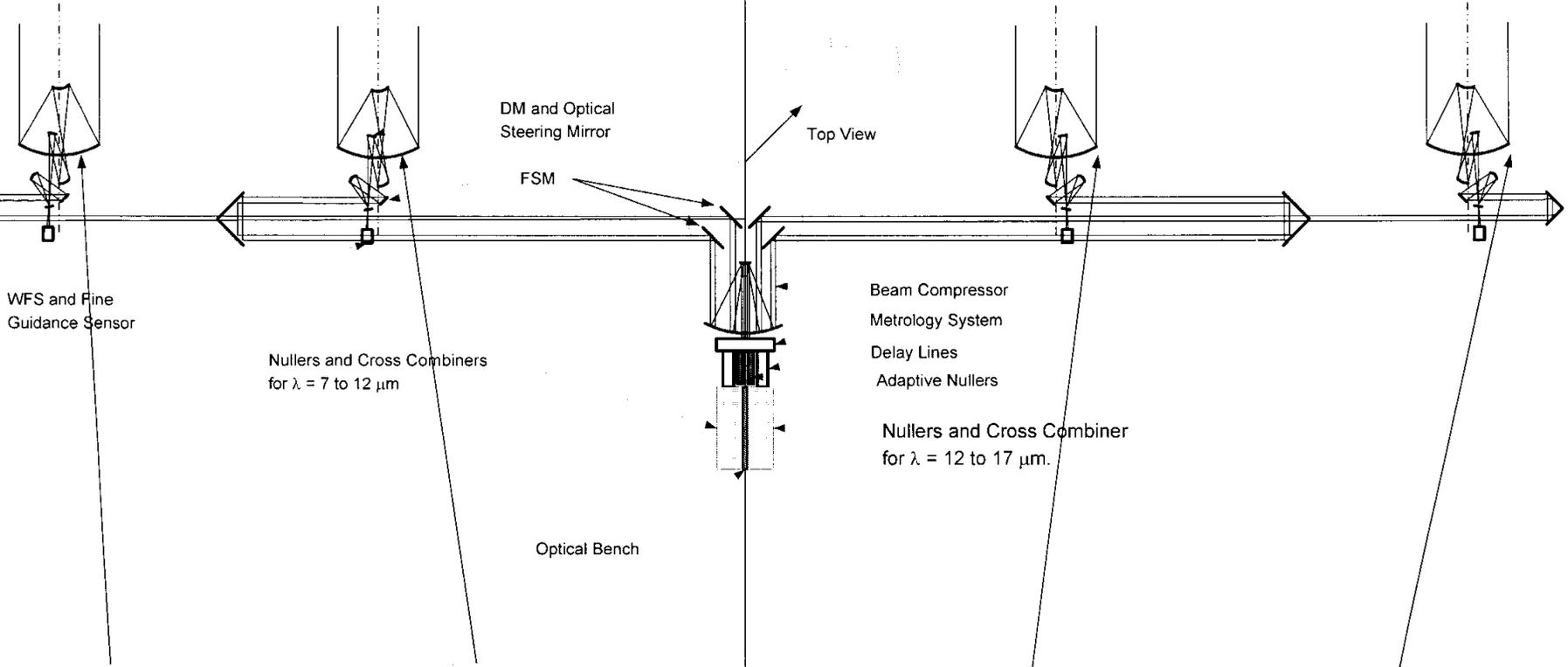
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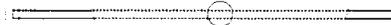
# SCI Optical Schematic



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Top View



Top View

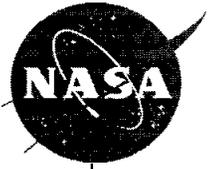


Top View



Top View

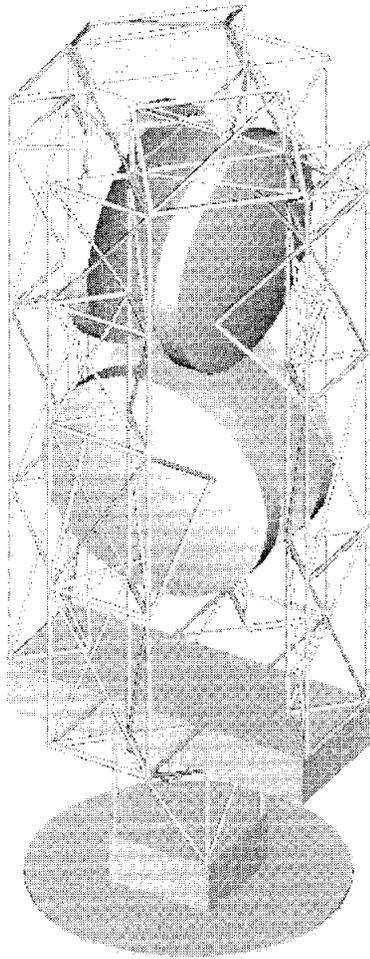
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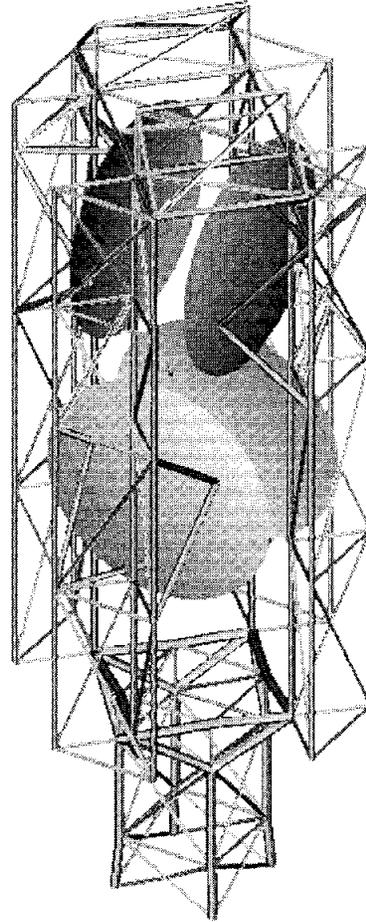
# SCI FY04 - Structures Modeling



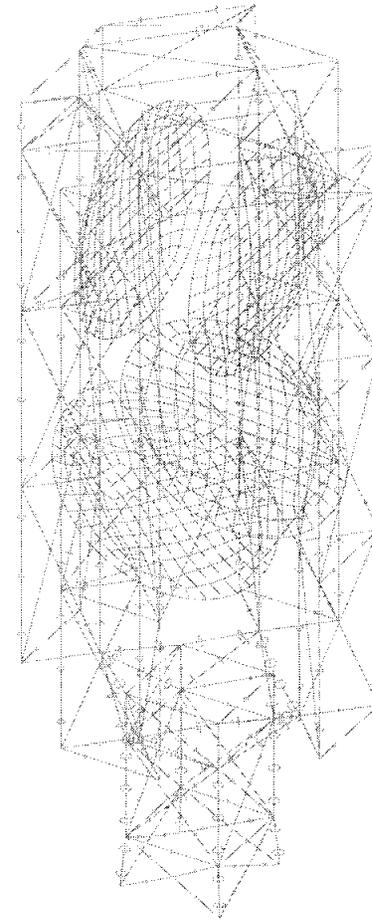
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**Original STEP File**

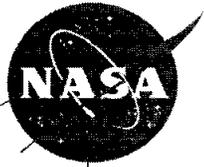


**Shaded FEM  
(Original)**



**Wireframe FEM  
(Original)**

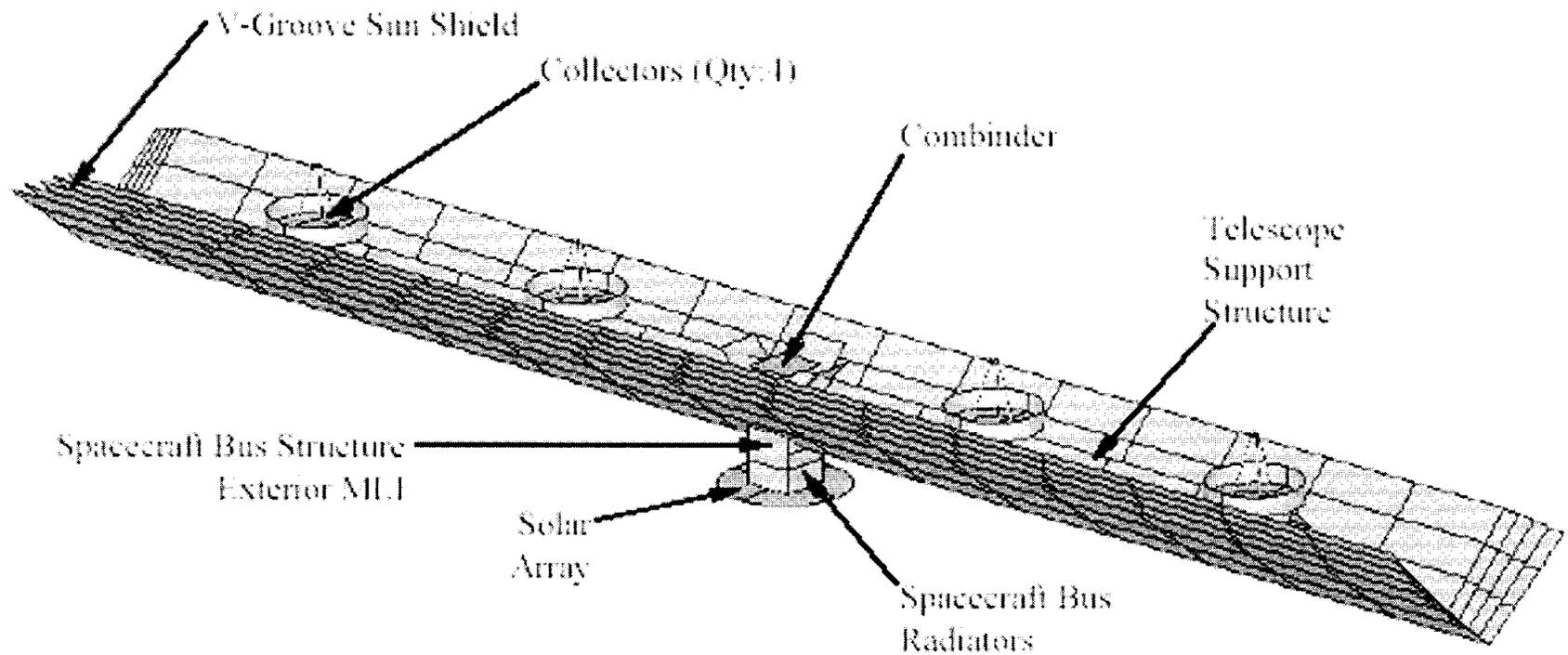
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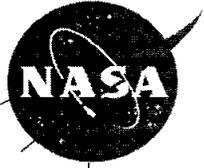
# SCI, FY04 – Thermal Modeling



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## SCI FY04 – Other Plans



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- **First analytical estimate of the ability to meet the proposed error budget**
- **Models**
  - **Optics Stand-Alone**
  - **Instrument Control Systems**
  - **Integrated Observatory Simulation**
- **Trades**
  - **Sunshield Deployment**
  - **Increased Sky Coverage**
  - **Telescope Configuration**
    - **F#**
    - **Secondary Mirror Packaging & Positioning**
    - **Tertiary Mirror Packaging & Positioning**
    - **Material/ Areal Density**

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# SCI Posters and Exhibits



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- **Posters**
  1. **Mechanical Configuration**
  2. **System Characteristics**
  3. **Optical Schematic**
  4. **Observatory Simulation**
- **L2 Orbit Animation**
- **“Secret Display” – Full Scale Line Drawing of a Telescope**

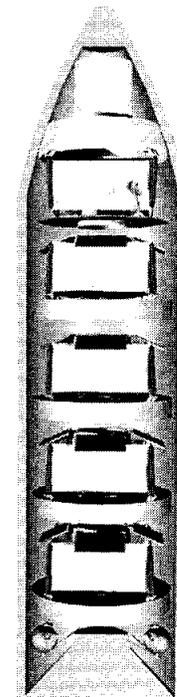
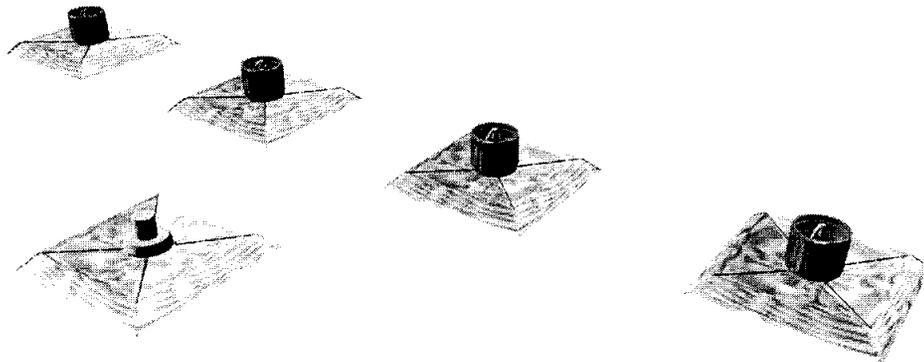
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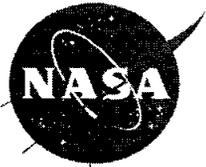
# Formation Flying Interferometer Design Team Status

Daniel Miller  
October 15, 2003



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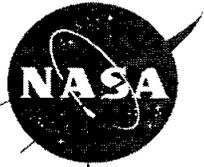
# FFI Design Team Goals for FY2003 **JPL**

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- **Develop a revised baseline requirements set for the FFI approach**
- **Conduct trade studies to investigate system technical, cost, and risk issues**
- **Develop a revised baseline FFI design concept satisfying the updated requirements**
- **Generate models and analytical tools to enable initial assessments of FFI's performance and facilitate trades in follow-on study phases**
  - **Mechanical Configuration CAD**
  - **Structural FEM**
  - **Thermal**
  - **Stray Light**
- **Document evolving requirements and design in updated Requirements and Baseline Design Definition packages**

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# FFI Major System Trade Summary



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Trade	Resulting Selection	System Benefit/Impact
Mission Orbit (Drift Away, L2 halo, Inclined, Elliptical Deep Space, etc.)	L2 Halo	Good sky coverage, low C3, simple flight ops, short transit time to mission orbit, adequate solar power available
Launch Vehicle (Delta IV vs. Atlas V vs. Ariane V)	Delta IV 4050H-22	Maximum available lift mass and envelope for 2015 launch
Number of Launch Vehicles (1vs. 2)	Single Launch	Minimum LV cost, minimum flight ops cost
Interferometer Architecture (Dual Bracewell vs. DAC vs. Lurance)	Dual Chopping Bracewell (Architecture Team Selection)	Maximizes number of observable stars
Aperture Size (3.0 m vs. 3.5 m vs. 4.0 m)	4.0 meter	Maximizes number of observable stars
Timing of Formation Deployment (Final Mission Orbit vs. LV Separation)	Final Mission Orbit	Minimizes flight ops complexity (one S/C transit to L2 vs. 5), simplifies S/C propulsion (no high thrust maneuvers required), requires cruise stage for 100-day transit

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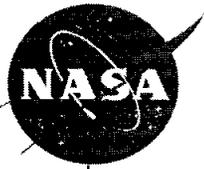




# FFI Major Spacecraft Trade Summary **JPL**

Terrestrial Planet Finder Mission       A NASA Origins Mission	Trade	Resulting Selection	System Benefit/Impact
	Sunshade Configuration (Separate Free-Flying Shade vs. Individual S/C Sunshades)	Individual S/C sunshades (each S/C with a shade)	Lower total system mass, minimum electrical power system complexity, minimum control system complexity
	Power System Selection (PV vs. RPG's vs. Fuel Cells)	Photovoltaic array and Li-ion battery	Lowest cost, lowest development risk, lowest safety/environmental risks
	Propulsion System Selection (Monoprop vs. Biprop vs. PPT vs. XIPS vs. FEEP vs. Colloid)	Pulsed Plasma Thrusters (PPT's)	Low propellant mass, moderate power requirements, variable thrust capability for coarse and fine maneuvers
	Formation Flying Sensor Configuration (# and location of receivers and transmitters)	4 transmitters and 12 receivers located on sunshade booms and S/C bus	Optimized for maximum field of view (4-pi coverage goal), avoid power dissipation on cryogenic instrument
	S/C-To-Ground Communications (through Combiner or each S/C)	Nominally through Combiner, but each S/C has DTE system	Minimizes risk of constellation evaporation
	HGA Configuration (Gimballed or Body-pointed)	Gimballed	Allows data downlink without changing constellation config, minimizes ops complexity

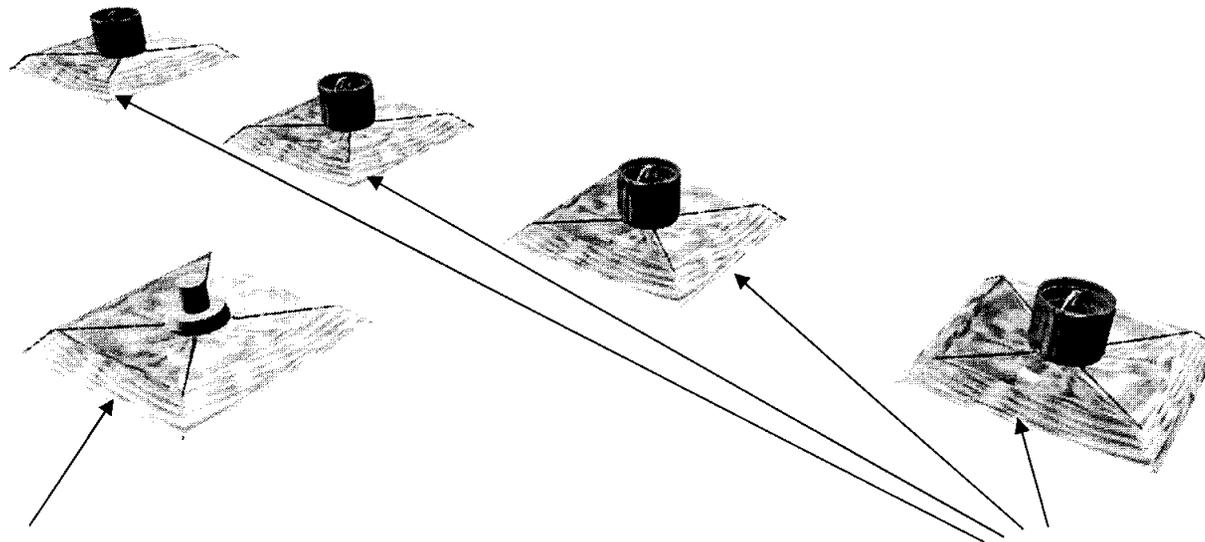




# Formation Flying Interferometer Concept--2003



Terrestrial Planet Finder Mission



## •Role of Nulling Beam Combiner-Master Control Element

- Combine collimated light beams from Collectors
- Sense nulled combiner outputs for signatures of planets
- Store science data for downlink to ground
- Constellation Command and Control architecture directed by the Master S/C
- Constellation guidance controlled through Master S/C
- Metrology sensors installed throughout the constellation
- Metrology data centralized and processed by the Master S/C

## •Role of Collector Elements

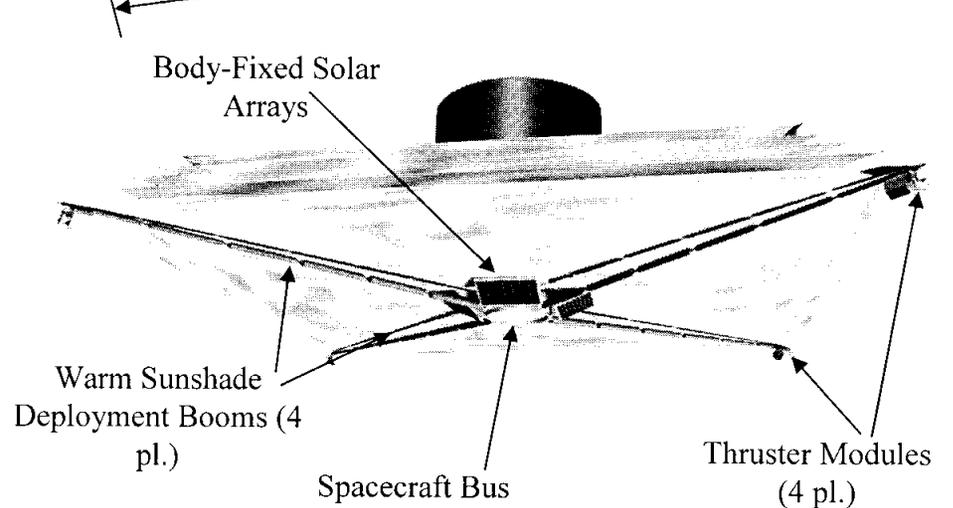
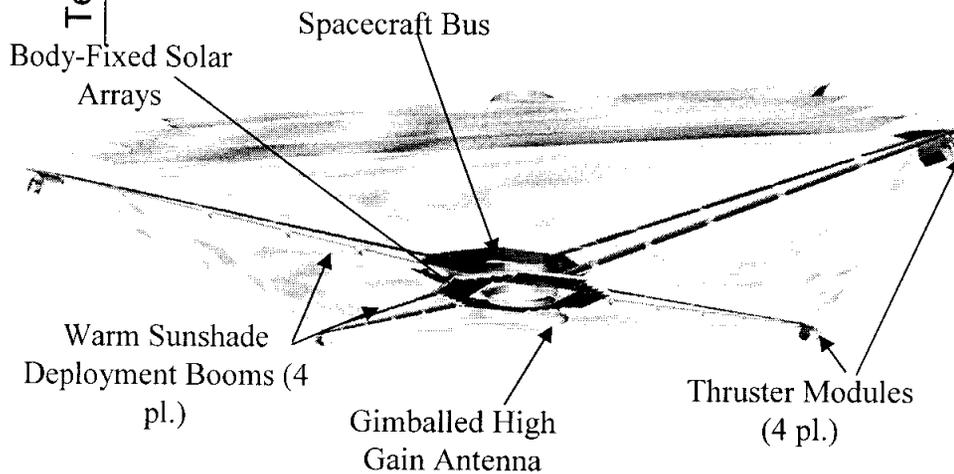
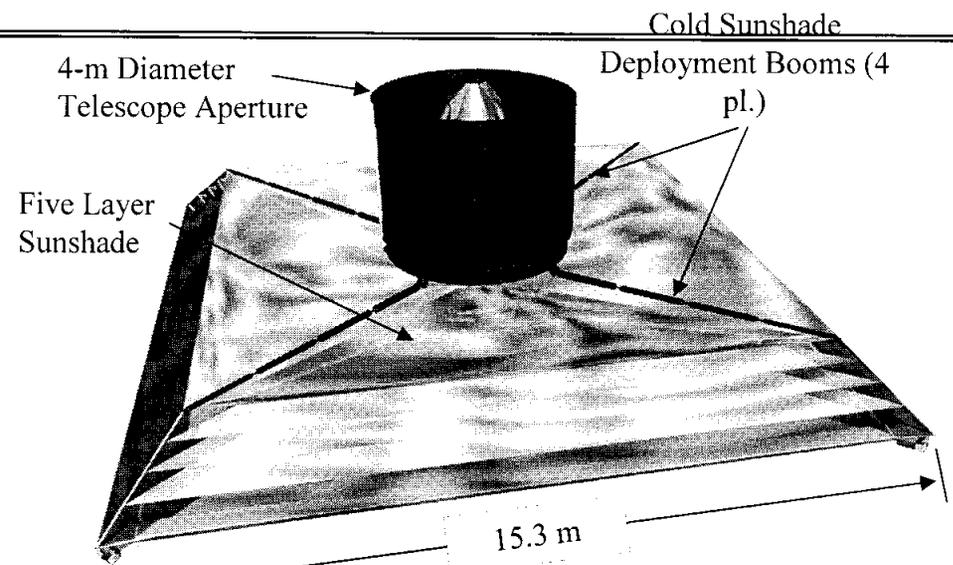
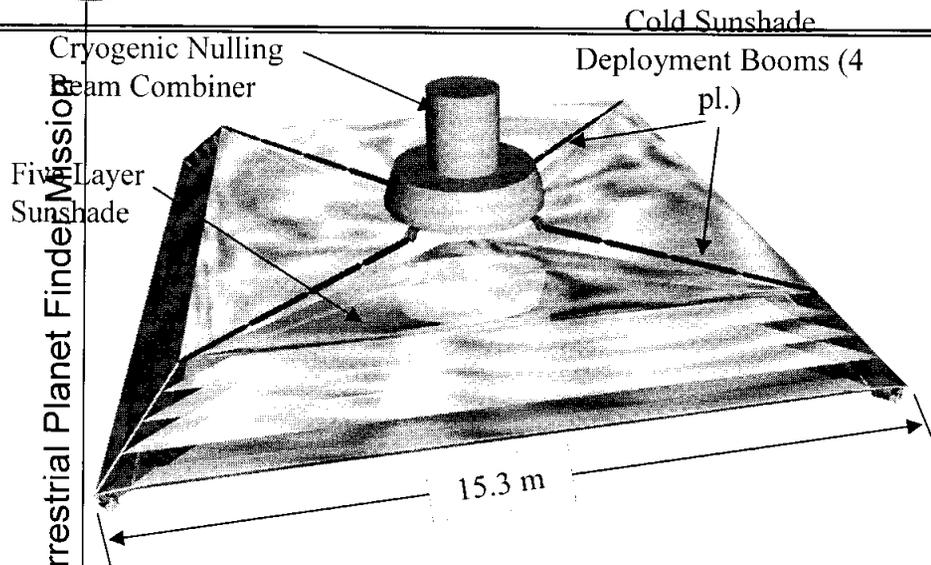
- Gather light from target star
- Generate collimated beams and route to nulling beam combiner on Master S/C
- Respond to Master Control S/C commands for Collector S/C formation flying and light path adjustment
- Provide autonomous fault and collision avoidance protection

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# FFI Collector and Combiner Elements Overview

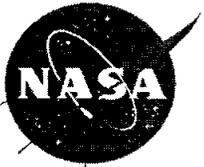


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**Combiner / Master control S/C  
with sunshield deployed**

**Collector S/C with sunshade  
deployed**





# FFI Launch Concept



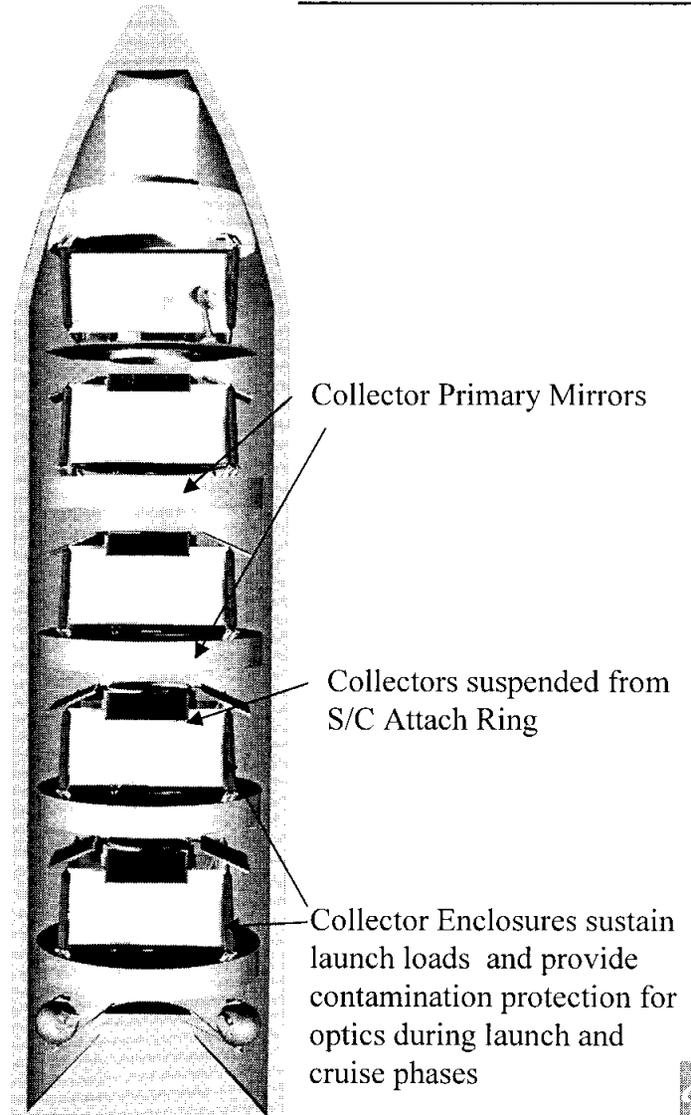
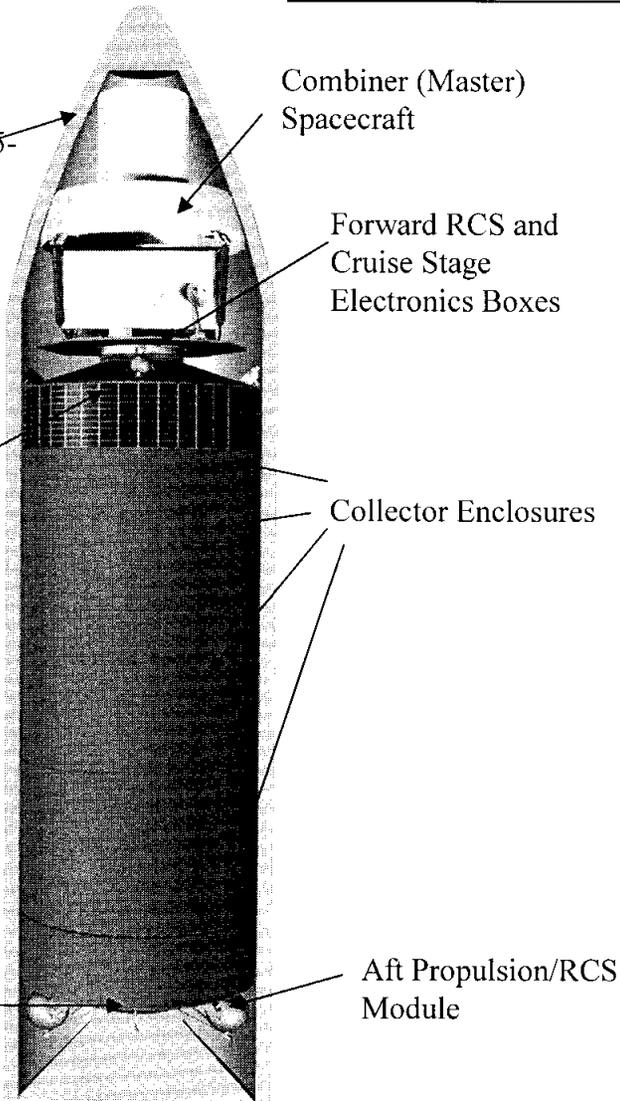
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Delta 4050H 5-m dia X 22.4 m length fairing

Cylindrical Cruise Stage Solar Array

LV Separation Plane

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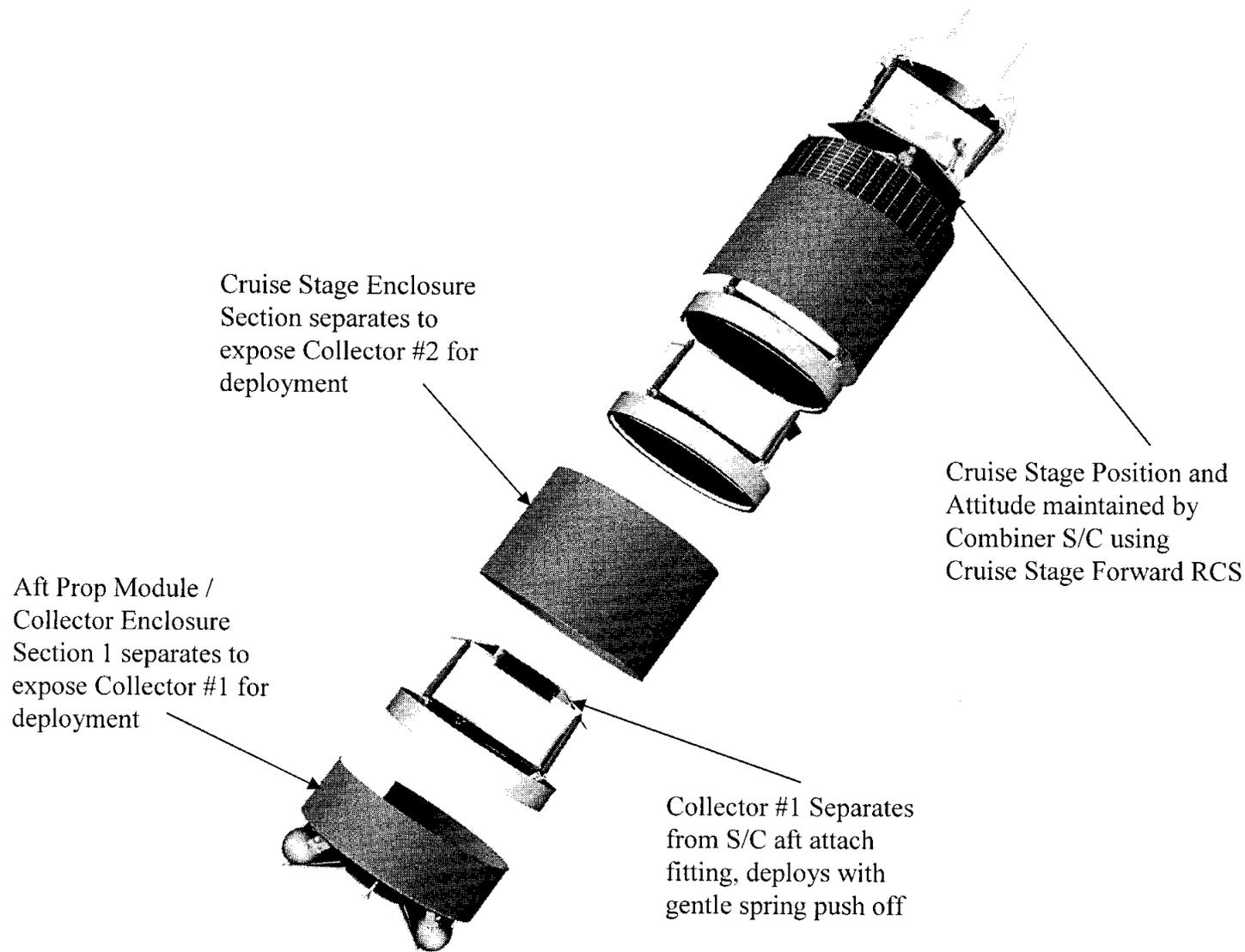




# FFI Deployment Approach



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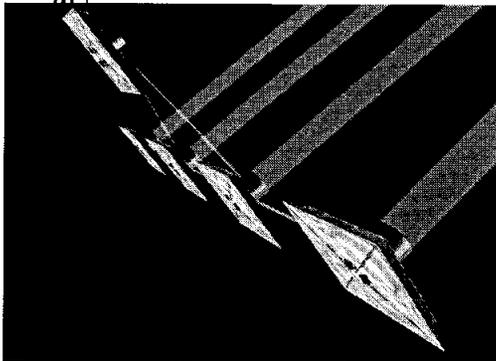




# FFI Design/Performance Summary



## A Search for Earth-Like Planets In the Habitable Zone Around Nearby Stars



**Program/Theme: Origins of Stars, Planets, and Life**

**Science Objectives:**

1. Survey  $\geq 150$  stars for terrestrial planets
2. Measure planets' orbit, mass, and presence of biomarkers in the atmosphere ( $H_2O$ ,  $O_3$ ,  $CO_2$ ,  $CH_4$ )
3. Observe astrophysical sources (active galaxies, etc.)

Instrument	
Telescope f#	~1.0
Aperture Dia.	4.0 m
Baseline	60-100 m
Angular Res	50-75 milli-arcsec
Stellar Light Rejection	$> 10^6$
Field of View	1 arcsec @ $12\mu$
Field of Regard	+/- 45 deg anti-sun
Wavelength Range	7-13 $\mu$ req. 7-17 $\mu$ goal
Spectral Resolution	$\lambda/\Delta\lambda = 3-20$
Sensitivity	0.35 $\mu$ Jy @ $12\mu$
Interferometer Arch.	Dual Chop. Bracewell
Peak Data Rate	< 1 Mbps
Telescope Temp.	< 40 K
Detector Temp.	< 6 K

Spacecraft	
# of Collector S/C	4
# of Combiner S/C	1
Design Life	5 years
Attitude Control	3-axis
Pointing Accuracy	15 arcsec
Pointing Knowledge	10 arcsec
Relative Position Control (S/C-S/C)	2 cm
Relative Bearing Angle Ctrl. (S/C-S/C)	60 arcsec
Retargeting Agility	45 deg/hr
Inter-S/C Data Rate	< 2Mbps
Inter-S/C Frequency	UHF
Data Downlink Rate	1 Mbps
Downlink Frequency	Ka-band
Onboard Data Storage	9 GB
Uplink Data Rate	2 kbps
Uplink Frequency	X-band
Mission $\Delta V$	750 m/s

**Mission Description:**

1. Formation Flying Interferometer--consisting of multiple (4-6) telescopes on separate Collector spacecraft flying in closely coordinated constellation with separate Combiner spacecraft
2. Instrument is an Infrared Nulling Interferometer operating at cryogenic temperatures that employs destructive interference to cancel light from a target star and enable direct observation of the star's planets
3. Spacecraft separation distance is adjusted to vary the interferometer baseline for optimum viewing of each target
4. Constellation flies in L2 Halo orbit for low disturbance environment relative to Earth orbit

DC Power	Collector	Combiner
Payload	75 W	475 W
Downlink	58 W	78W
Housekeeping	537 W	557 W
Reserve	192 W	335 W
Total	862W	1445 W

Mass	Collector	Combiner
Payload (ea.)	550 kg	461 kg
S/C (ea.)	605 kg	684 kg
Reserve	276 kg	268 kg
Total (ea.)	1431 kg	1413 kg
Launch Mass	5724 kg	1413 kg

Trajectory	
C3	-0.69
$\Delta V$ (TCM's)	105 m/s
Launch Vehicle	Delta 4050H
Cruise Propulsion	Mono-Prop
Cruise Duration	100 days
Launch Window	21 days
Mission Orbit	L2 Halo
Total Launch Mass	8071 kg
LV Launch Cap.	9408 kg
Reserve/Margin	16.6%

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# FFI Key Focus Areas/Trades for 2004 **JPL**

Terrestrial Planet Finder Mission

Task	Priority	Rationale
Telescope Optical Design and Stowage Approach	High	Drives launch vehicle packaging, total system mass
Stray Light Mitigation	High	Impacts instrument sensitivity and total system performance
Sunshield Design	High	Drives mass, propulsion system and formation flying sensor configurations
S/C and Cruise Stage Structural Design	High	Drives total system mass, margins
Vibration Assessment and Mitigation	High	Impacts total system performance
Redundancy and Reliability Trade	Medium	Optimize mass, cost, performance
Propulsion System Selection	Medium	Drives total system mass (Isp), system performance (contamination)
Contamination Assessment and Control	Medium	Impacts launch vehicle packaging, total system mass, and system performance
Metrology Design	Medium	Drives system performance

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# FFI Posters and Exhibits



Terrestrial Planet Finder Mission

- **Posters are on display to provide additional details:**
  - **System Configuration Overview Poster**
    - Details about FFI baseline configuration and performance
  - **Inter-Spacecraft Communications Poster**
    - Details of Inter-spacecraft operations and communications approach
  - **Fault Modes and Mitigation Poster**
    - Details of FFI fault modes and mitigation approaches
- **Formation Flying Interferometer Animation illustrates:**
  - **Constellation Deployment Sequence**
  - **Sunshade Deployments**
  - **Constellation Acquisition Phase**
  - **Formation Flying Science Observations**

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# Backup Charts

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# Comparison Of Launch Vehicle Fairings

