# 8-meter UV/Optical Space Telescope

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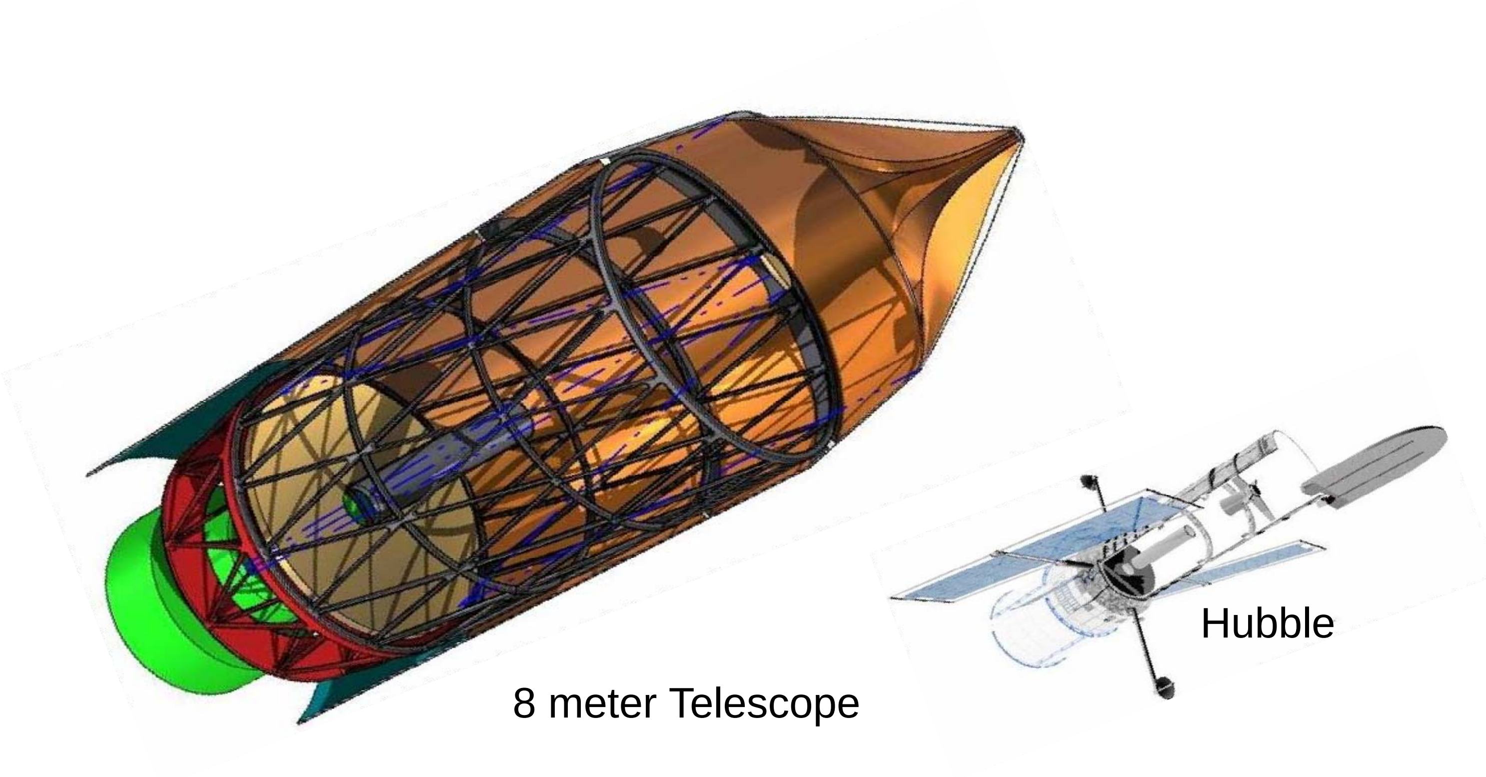
NASA MSFC



# Executive Summary

The unprecedented volume capability of an Ares V enables the launch of 8 meter class monolithic space telescopes to the Earth-Sun L2 point.

The unprecedented mass capability of an Ares V enables an entirely new design paradigm – Simplicity.

Simple high TRL technology offers lower cost and risk.

NASA MSFC has determined that a 6 to 8 meter class telescope using a massive high-TRL ground observatory class monolithic primary mirror is feasible.

# Design Concept

8 meter Monolithic Telescope & tube can fit inside Ares V 10 m envelop.

Minimize Cost (& Risk) by using existing ground telescope mirror technology – optics & structure.

8-meter diameter is State of Art

9 existing: VLT, Gemini, Subaru, LBT

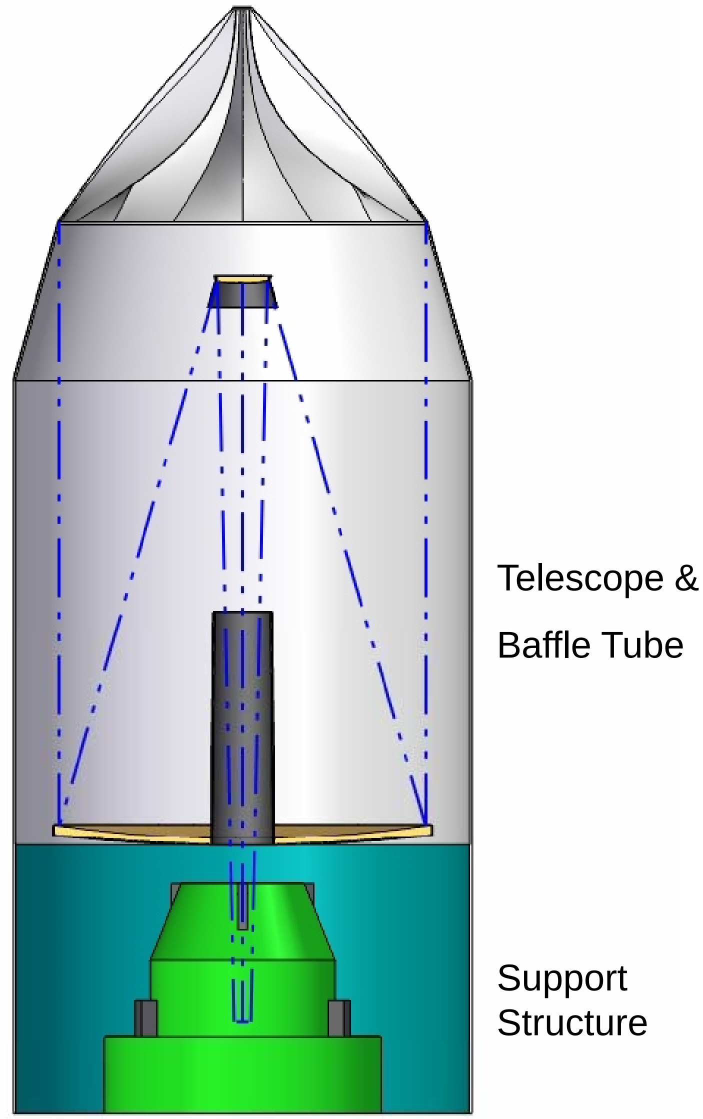
23,000 kg (6 m would be ~13,000 kg)

~$40M (JWST PM cost ~$150M)

7.8 nm rms surface figure (~TPF spec)

(DM in Instrument may achieve TPF spec)

Expect similar savings for structure



# Simplicity = Cost Reduction

More Massive Missions do not need to be More Expensive.

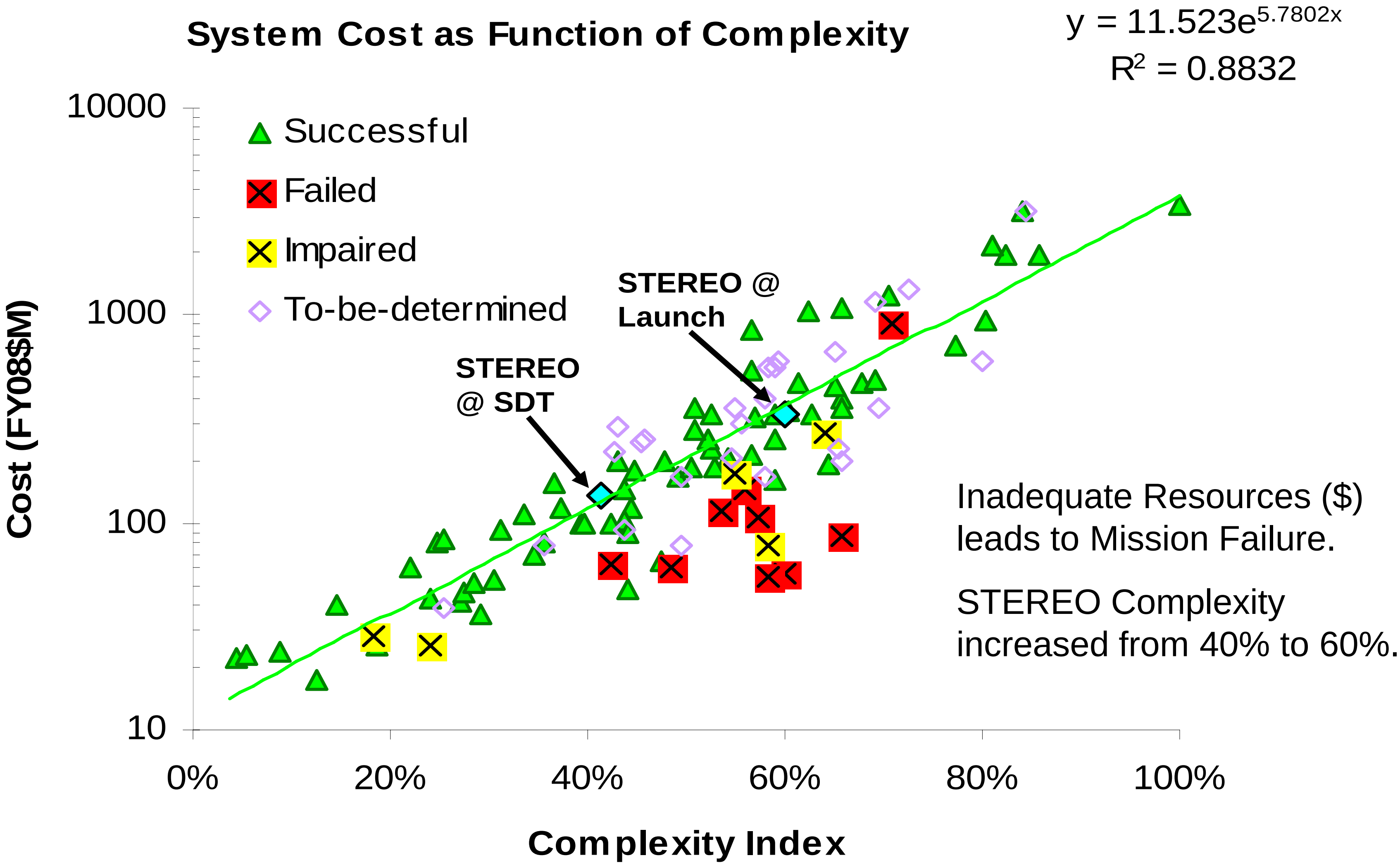
Simple, robust, low-risk, high-TRL mission is likely to be low cost.

It is also likely to be more massive than a complex, high-risk, low TRL mission.

The challenge will be to overcome human nature.

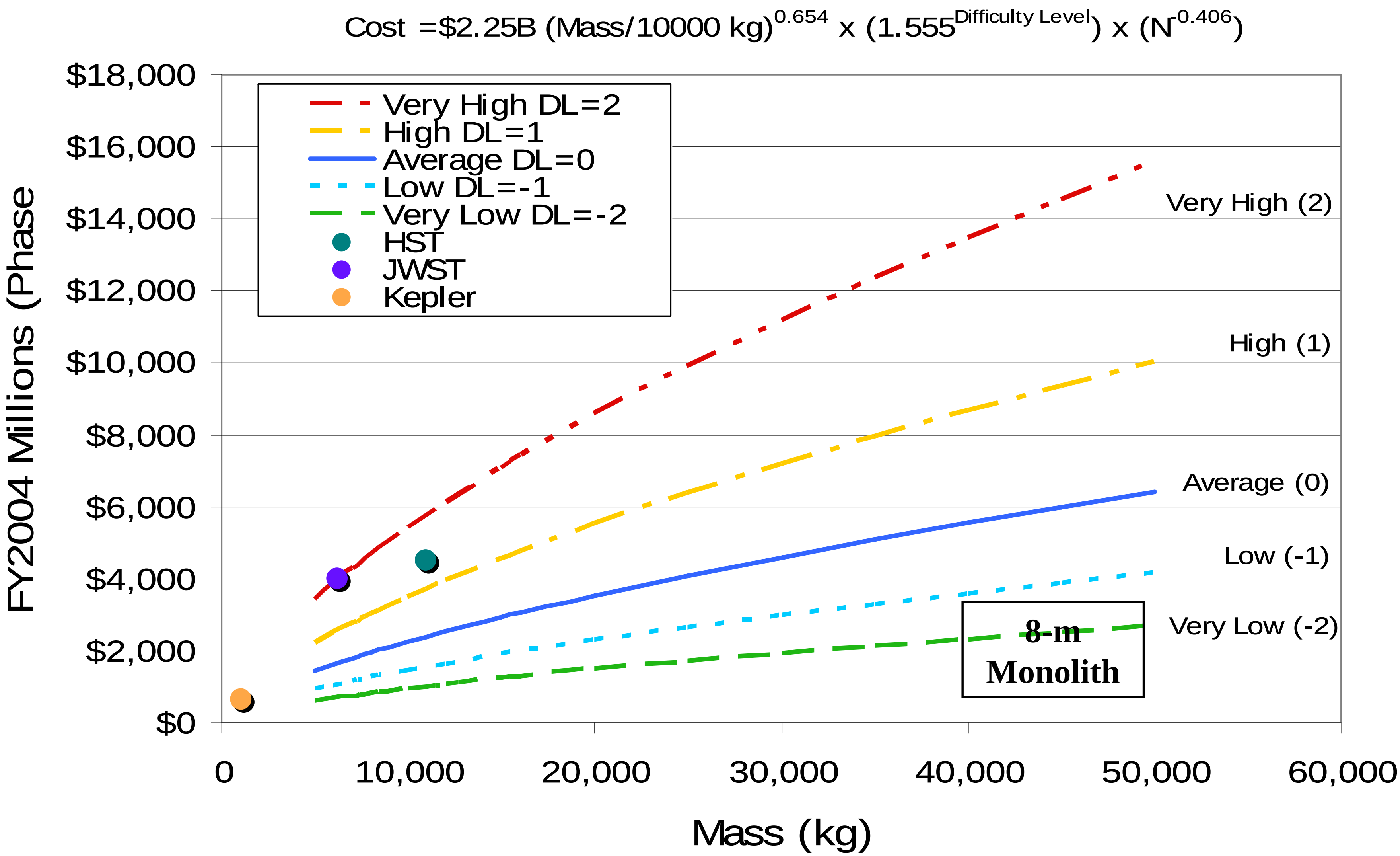
- Launch Date Constrained Missions Cost Less

# Effect of Increased Complexity on Flight System Cost and Mission Success




Bearden, David, "Perspectives on NASA Mission Cost and Schedule Performance Trends", copyright Aerospace Corp., GSFC Symposium, 3 June 2008.

Cost is driven more by Complexity than Mass




NASA JSC COST MODEL

# Simplicity = Cost Reduction

Cost models typically estimate that engineering design, AI&T, management, fees and program reserve is 2.5X to 3X the component costs.

Thus, every $1 spent at the component level = $3.5 to $4 at the program level.

Consider an 8 meter (50 m2) 500 nm diffraction limited primary mirror

HST's $10M/m2 areal cost yields a $500M 8-m primary mirror

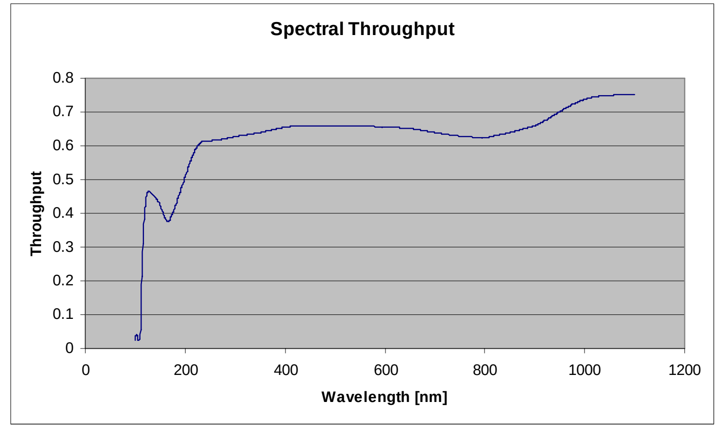
JWST's $6M/m2 (2 μm DL) areal cost yields a $300M PM

8-m Ground Telescope mirrors cost $20M to $40M.

A $250M to $450M savings in the cost of a primary mirror translates into a $800M to $1.8B potential total program cost savings.

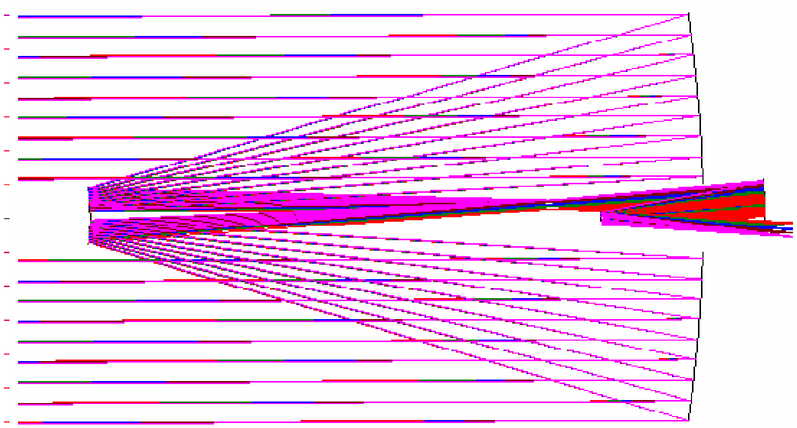
The total cost for an 8-meter observatory (excluding science instruments and operations is estimated to be $1B to $1.5B.

# 6 meter Optical Design




Ritchey-Chretién optical configuration

- F/15
- Diffraction Limited Performance at <500 nm
- Diffraction Limited FOV of 1.22 arc minute
  - (10 arc minute FOV with Corrector Group)
- Coating: Aluminum with Mg F2 overcoat
  - Average transmission > 63% for wave lengths of 200 to 1,000 nm
- Primary to secondary mirror vertex: 9089.5 mm
- Primary mirror vertex to focal plane: 3,000 mm



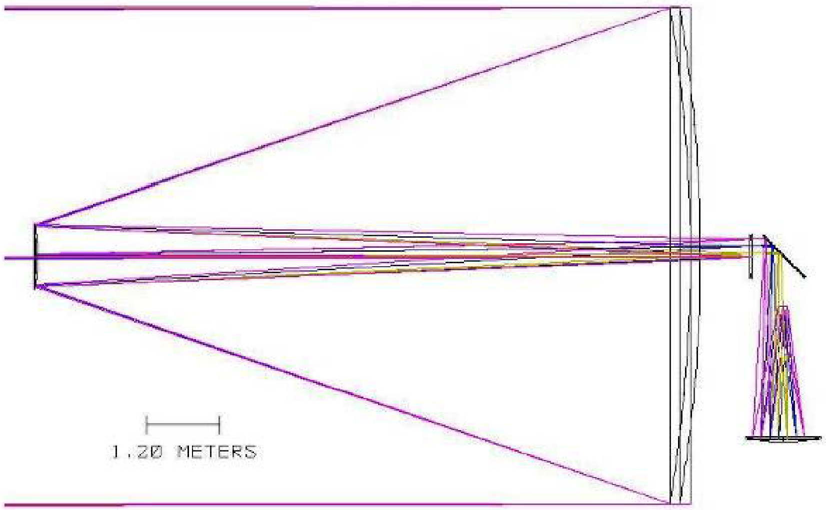
All Reflective Design

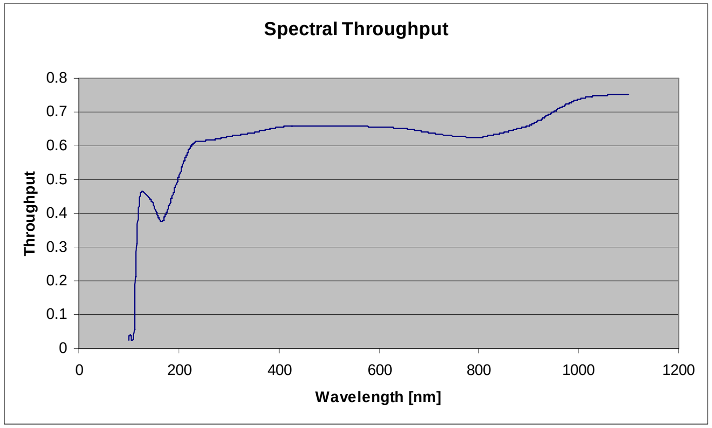
- Three Mirror Anastigmatic
- With Fine Steering Mirror
- Multi-Spectral 10 arc min FOV
- Reduced Throughput

# 8 meter Optical Design

Dual Pupil Optical Configuration

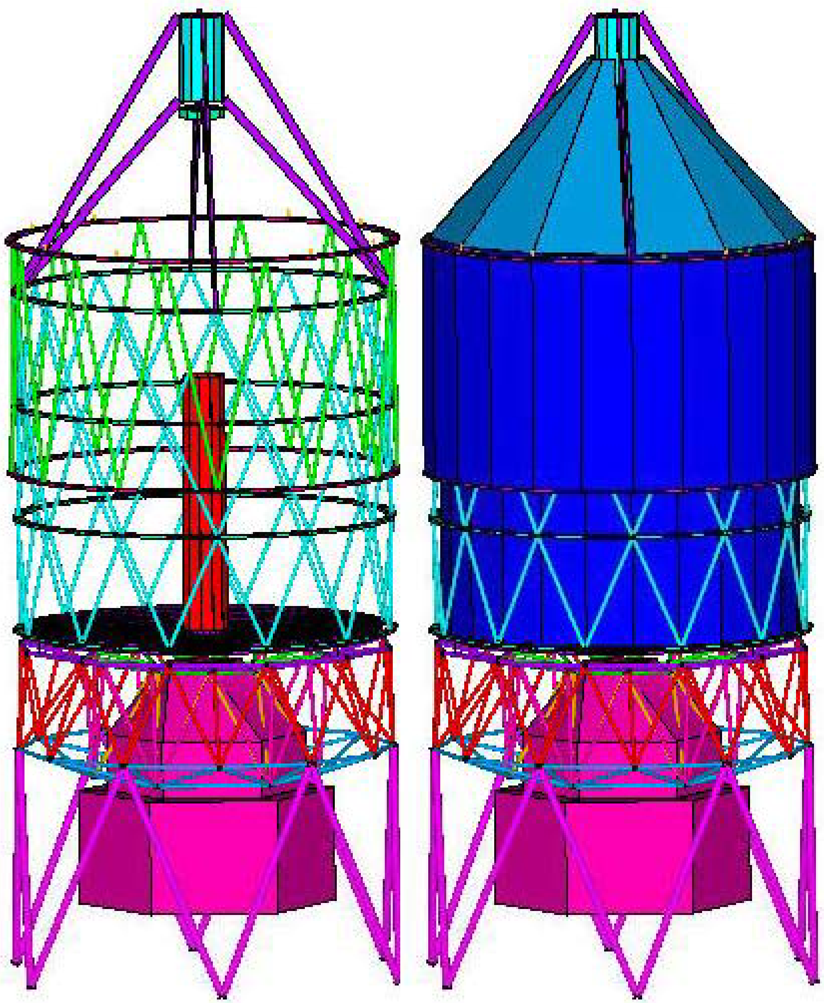
- Narrow 1 arc minute FOV at Cass Focus
- Wide 16 x 10 arc minute FOV at TMA Focus
- Diffraction Limited Performance at <500 nm
- Coating: Aluminum with Mg F2 overcoat
  - Average transmission > 63% for wave lengths of 200 to 1,000 nm



# Structural Design

Launch Configuration



Tube is split and slides forward on-orbit.

- Faster PM or taller shroud may allow for one piece tube.

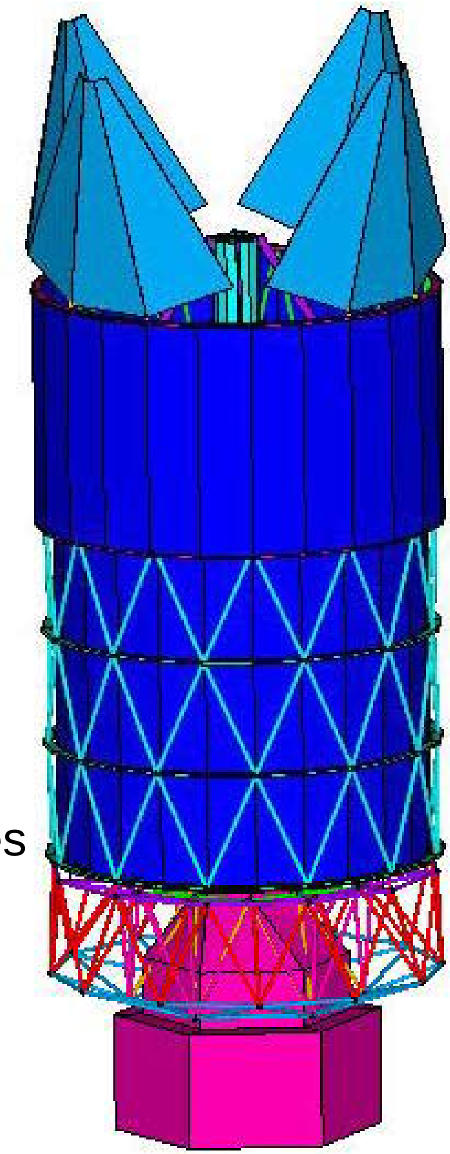
Doors can open/close

Forward Structure is hybrid of Hubble style and four-legged spider

Truss Structure interfaces with 66 mirror support attachment locations

Launch Structure attaches Truss to Ares V

Operational



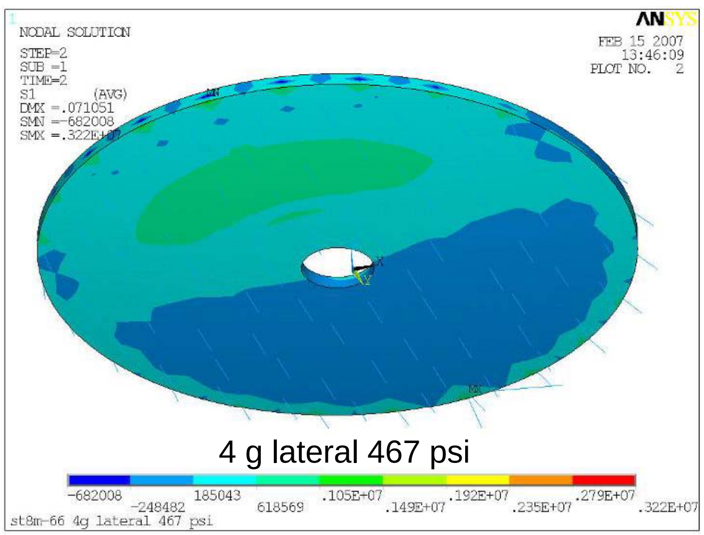
# Structural Analysis

Launch loads: *maximum* values from POST3D (not concurrent)

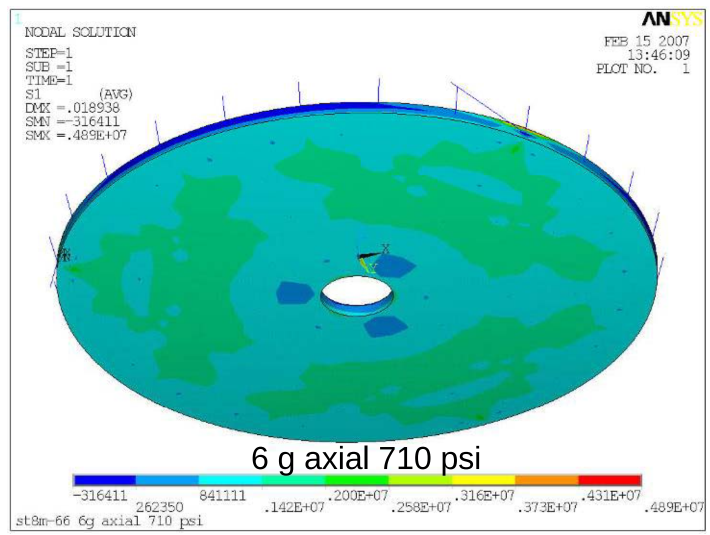
| | |
|---|---|
| Axial: | 4 g's |
| Lateral-y: | $7 \times 10^{-6}$ g's |
| Lateral-z: | $6 \times 10^{-4}$ g's |

8.2 meter 175 mm thick meniscus primary mirror <u>can survive launch</u>.

66 axial supports keep stress levels below 1000 psi



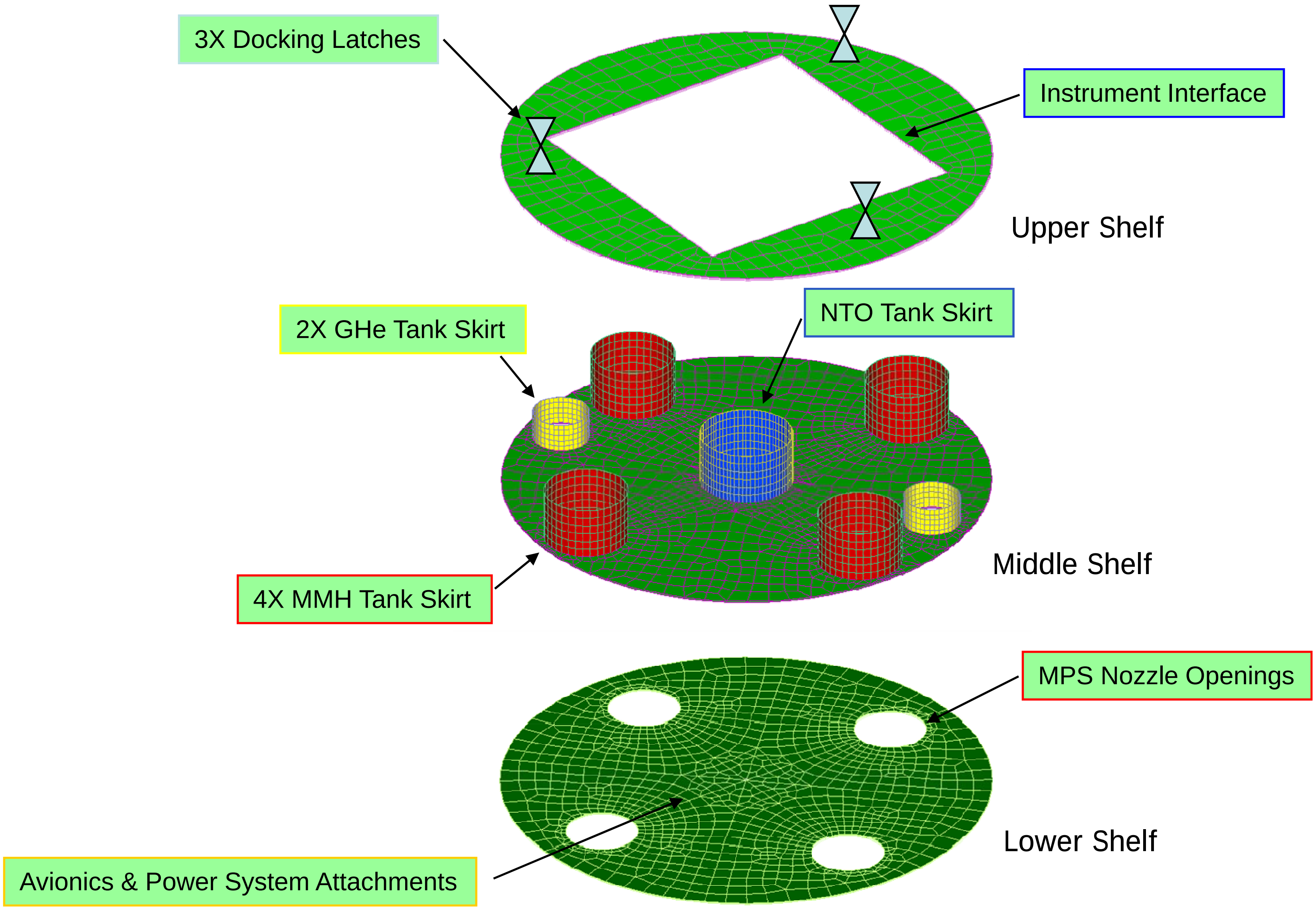
4 g lateral 467 psi



6 g axial 710 psi

# Spacecraft Structural Modeling

**Instrument Frame & Outer Skin Not Shown**

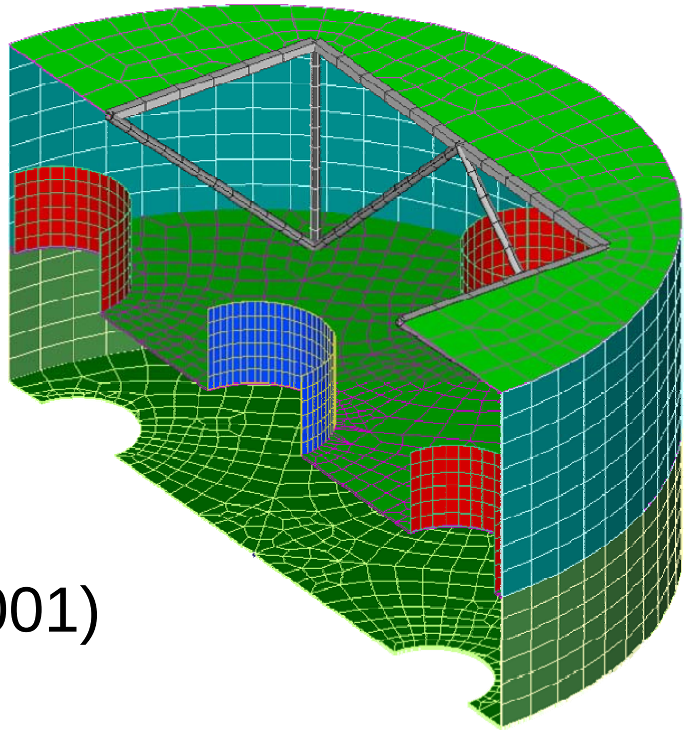


# Spacecraft Structural Analysis Assumptions

Launch Load Case: 4.0g Axial + 2.0g Lateral

Materials: Metallic Structure Only

- AA 2219 for plate elements
- AL 7075 for Beam Elements



Factors of Safety: (per NASA-STD-5001)

- Yield Factor of Safety:  1.1
- Ultimate Factor of Safety:  1.4

Cross-Sectional View of Spacecraft

# Structural Model Results

Upper Shelf:

- Shelf: Isogrid Panel 0.090”
- (minimum pocket thickness)

Middle Shelf:

- Shelf: Isogrid Panel 0.060”
- (minimum pocket thickness)
- MMH Skirts: 0.064” thk
- NTO Skirt: 0.088” thk
- GHe Skirt: 0.040” thk

Lower Shelf:

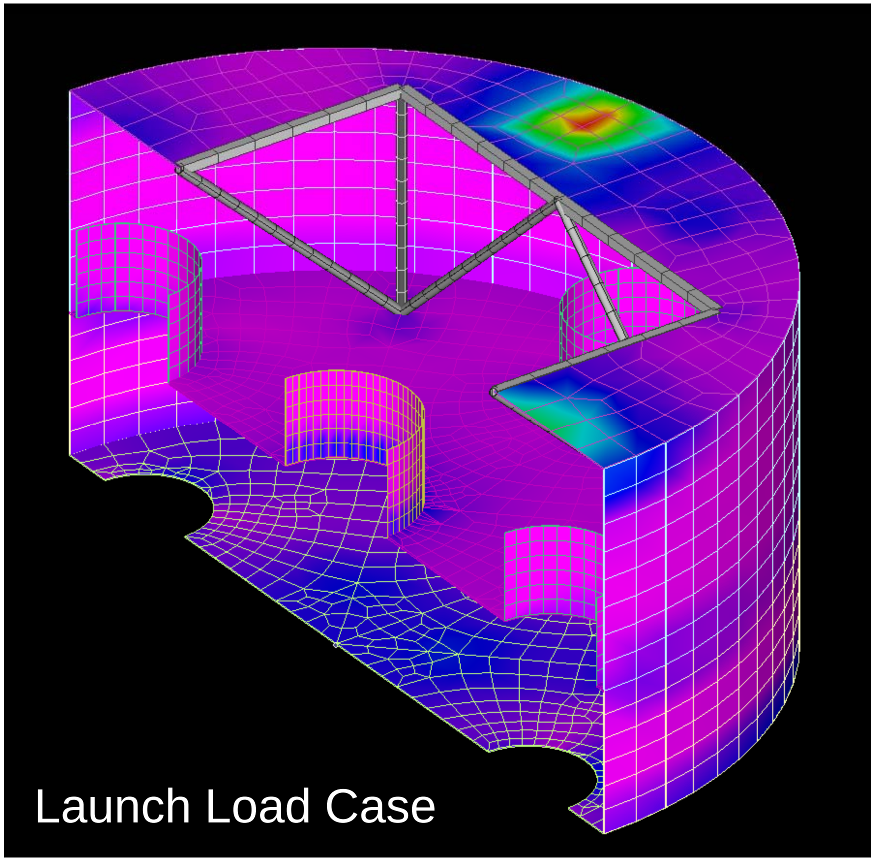
- Shelf: Isogrid Panel 0.060”
- (minimum (pocket thickness)

Instrument Support Frame:

- Upper Support: “T” Beam, 0.095” thk
- Uprights: 2” diameter, 0.030” thk
- Angled Supports: 1.75” diameter, 0.030” thk

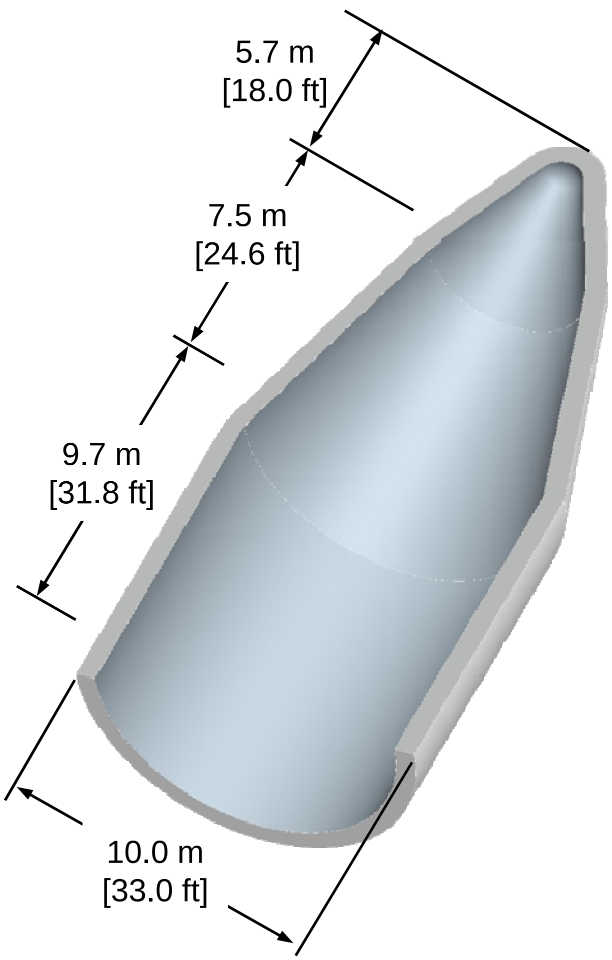
Outer Skin:

- Upper Outer Skin: 0.26” thk
- Lower Outer Skin: 0.21” thk

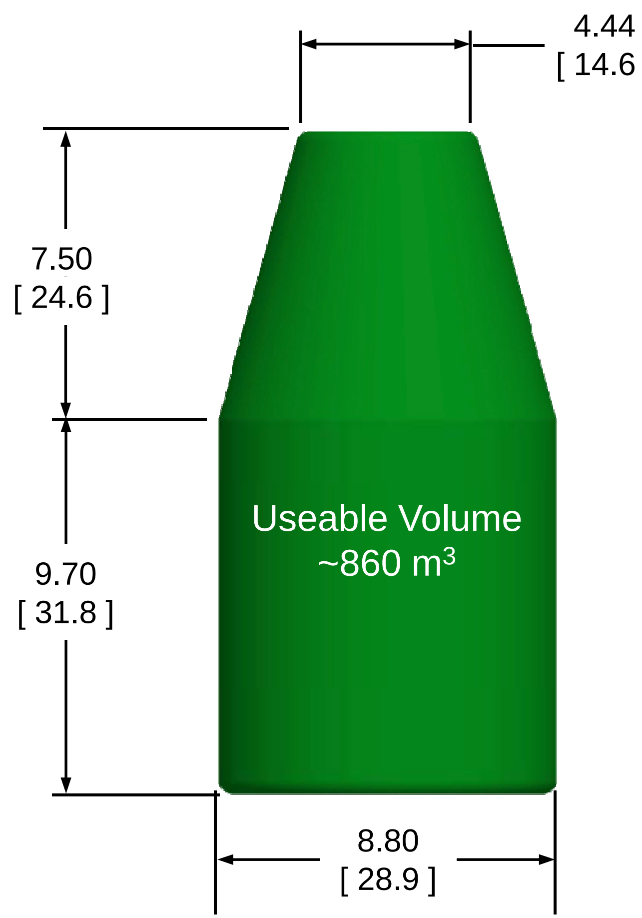


# Current Ares V 10 meter Shroud - Biconic

## Shroud Dimensions




## Usable Dynamic Envelope

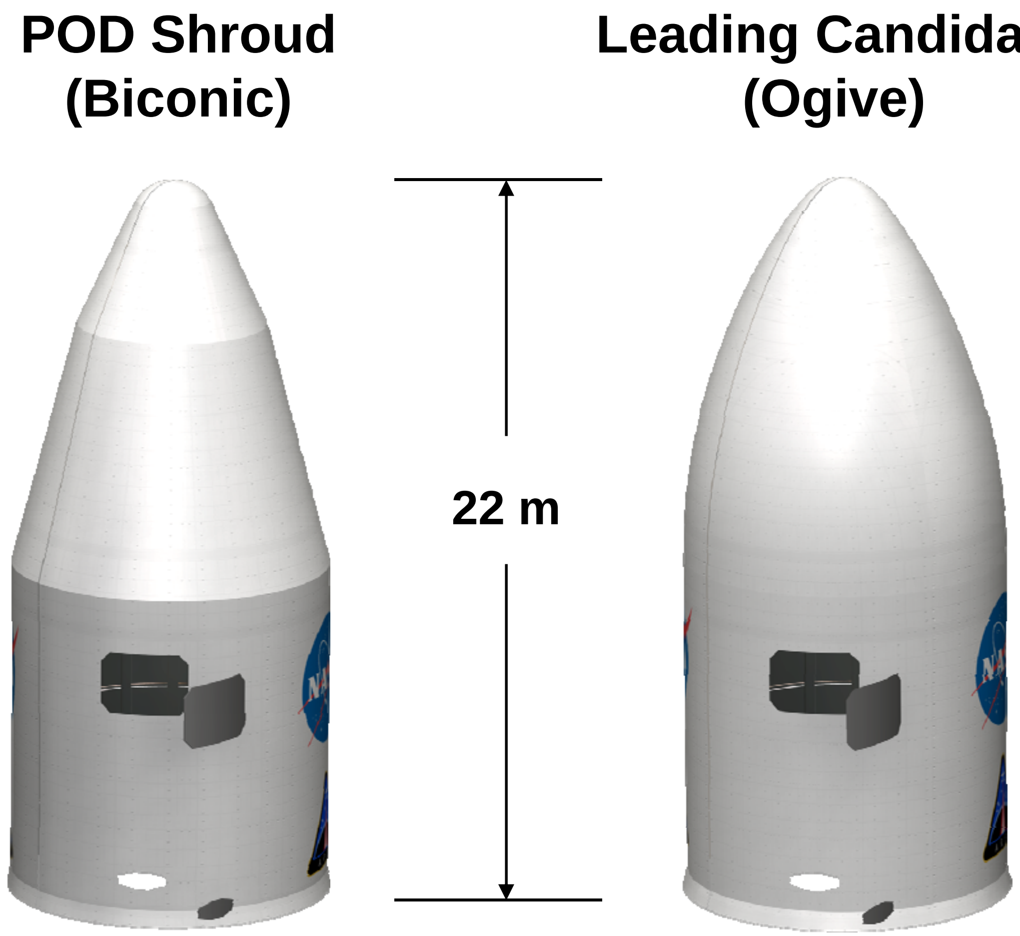



**Mass:** 9.1 mT (20.0k lbm)

**Total Height:** 22 m (72 ft)

**meters [feet]**

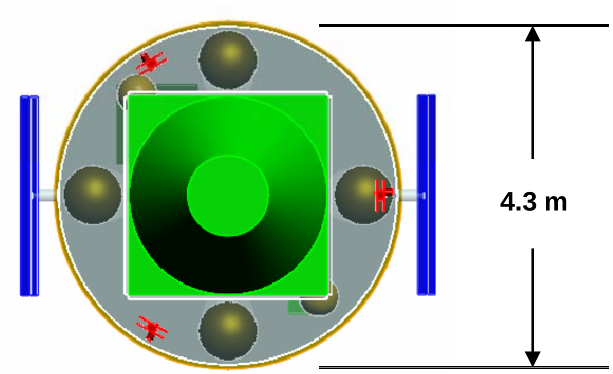
# Alternative Payload Shroud Design Concept



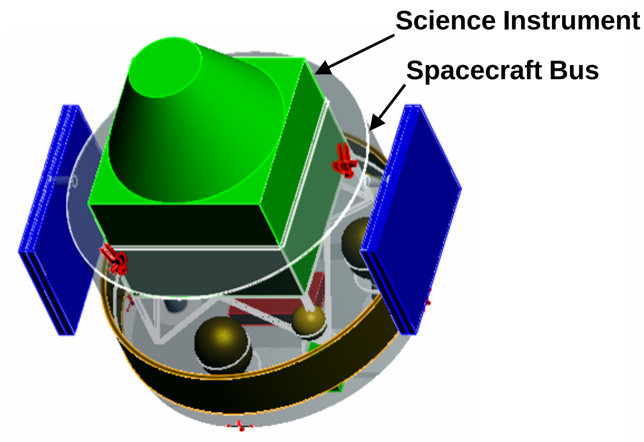

Ogive Shroud provides ~ 2.4 m more 8.8 m dia vertical payload height than Biconic

Both have ~2.3 m extra space below official volume ‘Reserved’ for Interface Adapter

# Spacecraft Design Detail & Shroud Integration



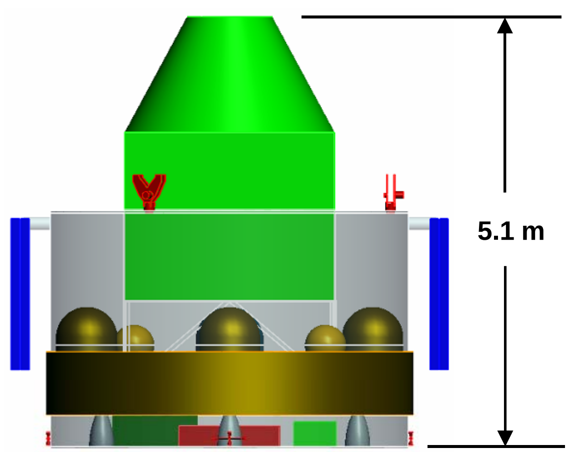

Top View



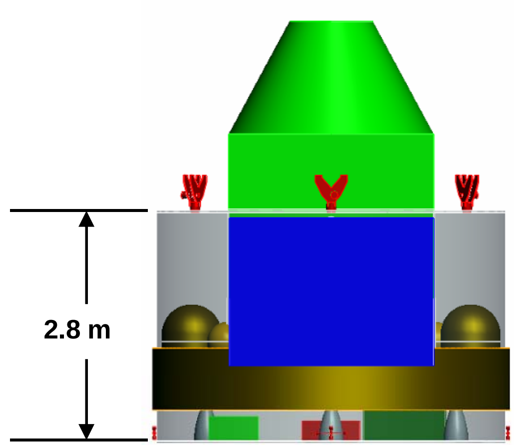

Iso View

**Science Instrument Envelope = 2.5 m x 2.5 m x 2.0 m**

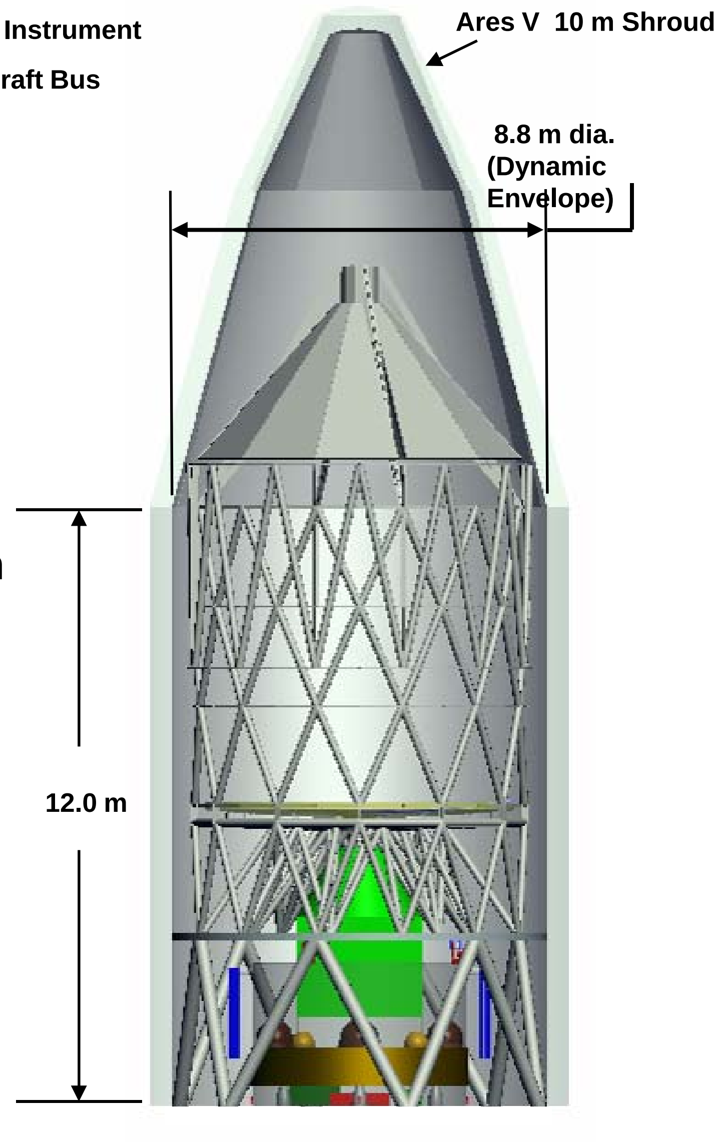
(Green Cube – does not include Cone)




Front View




Side View




Front View

**NOTE: All dimensions are in meters.**

# 6 meter Preliminary Mass Budget

| | Mass (Kg) | Heritage | Notes |
|---|---|---|---|
| Primary mirror assembly | 20000 | | |
| Primary mirror | 13,000 | calculated | Zerodur 175 mm thk. meniscus |
| Primary mirror support structure | 6,750 | estimate | Structural Model |
| Primary mirror center baffel | 250 | estimate | Structural Model |
| Secondary mirror assembly | 680 | | |
| Secondary mirror | 100 | calculated | Zerodur 50% light weight |
| Secondary mirror support & drive | 150 | estimate | Structual Model |
| Secondary mirror baffle | 30 | estimate | Structual Model |
| Secondary mirror spider | 400 | estimate | Structual Model |
| Telescope enclosure | 3,600 | | |
| Metering structure with internal baffels | 2,800 | estimate | Marcel Bluth |
| Rear cover | 300 | estimate | WAG |
| Head ring | 200 | estimate | WAG |
| Front cover & actuator | 300 | estimate | WAG |
| Attitude Determination and Control System | 150 | JWST | estimate plus JWST scaled |
| Communications | 76 | EI63 | |
| Command And Data Handling System | 54 | JWST | |
| Power | 380 | EI63 | |
| Thermal Management System | 1090 | JWST | 400% of JWST |
| Structures | 920 | estimate | WAG |
| Guidance and Navigation | 50 | estimate | 50% WAG |
| Propulsion | 20 | JWST | |
| Computer Systems | 50 | estimate | WAG |
| Propellant | 50 | Ei63 | |
| Docking station | 1,000 | estimate | WAG |
| | | | |
| OTE W / Bus mass | 28,120 | | |
| | | | |
| Science Instrument | 1500 | JWST | ISIM, contains Fine Guidance Sensor |
| Attitude Determination and Control System | 150 | JWST | estimate plus JWST scaled |
| Communications | 76 | EI63 | |
| Command And Data Handling System | 54 | JWST | |
| Power | 380 | EI63 | |
| Thermal Management System | 480 | EI63 | |
| Structures | 755 | estimate | WAG |
| Guidance and Navigation | 50 | estimate | 50% WAG |
| Propulsion | 250 | EI63 | |
| Computer Systems | 50 | estimate | WAG |
| Propellant | 1530 | EI63 | |
| Docking station | 1,000 | estimate | WAG |
| | | | |
| Science Instrument W / Bus mass | 6,275 | | |
| | | | |
| Total mass = OTE W / Bus + Science Instrument W / Bus = | | | 34,395 |

**38% Mass Reserve**

**8 meter Preliminary Budget is 45,000 kg (~20% Reserve)**

# Ares V Performance for Selected Missions

| Mission Profile | Target | Payload Mass (kg) |
|---|---|---|
| **Sun-Earth L2** | **C3 of -0.7 $km^2/s^2$ @ 29.0 degs** | **55,800** |
| **GTO Injection** | **Transfer DV 8,200 ft/s Final Orbit: 185 km X 35,786 km @ 27 deg** | **70,300*** |
| **GEO** | **Transfer DV 14,100 ft/s Final Orbit: 35,786 km Circular @ 0 degrees** | **36,200** |
| **Cargo Lunar Outpost (TLI Direct)** | **C3 of -1.8 $km^2/s^2$ @ 29.0 degs** | **56,800** |

* Performance impacts from structural increases due to larger payloads has not been assessed

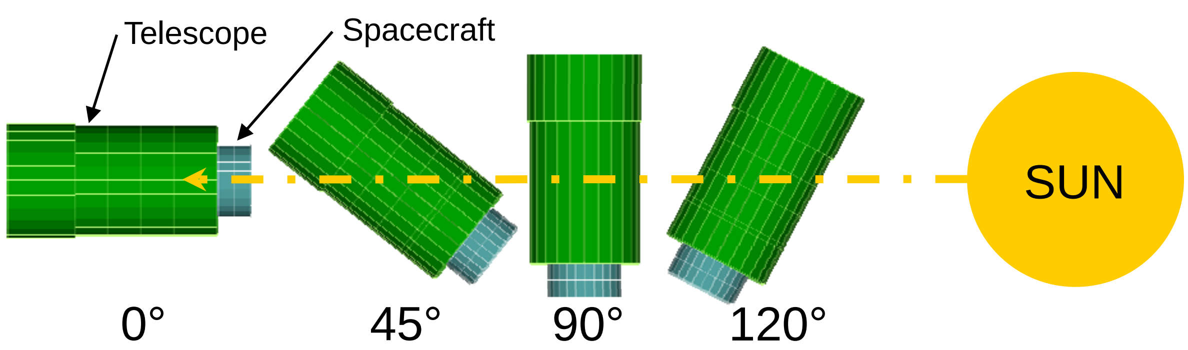
# Thermal Analysis

Spacecraft wrapped with 10 layer MLI blankets

16.0 $m^2$ thermal radiators

Load Cases

- 0° (base)
- 45°
- 90° (broadside)
- 120°



# Spacecraft Thermal Analysis

Solar Flux at L2 = 1296 W/m$^2$ applied to base

Instrument Heat Output = 750 W

Avionics Heat Output = 850 W

Propellant tanks modeled as

single nodes with heat leaks

from the spacecraft walls

Steady-state operational

temperatures determined

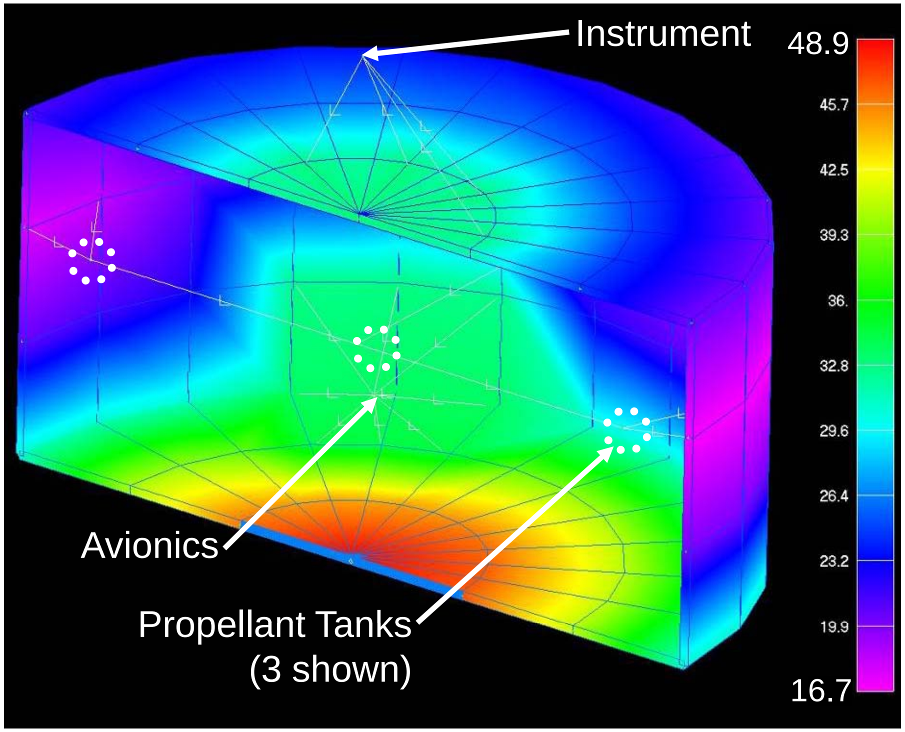
Spacecraft wrapped with

50 layer MLI blankets

16.0 m$^2$ thermal radiators

Propellant tanks maintained with MLI and heaters

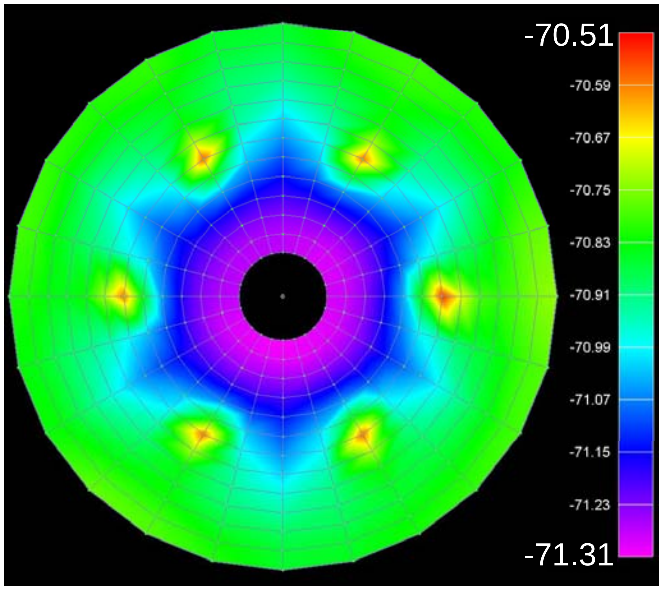
Heaters required to keep propellant from freezing



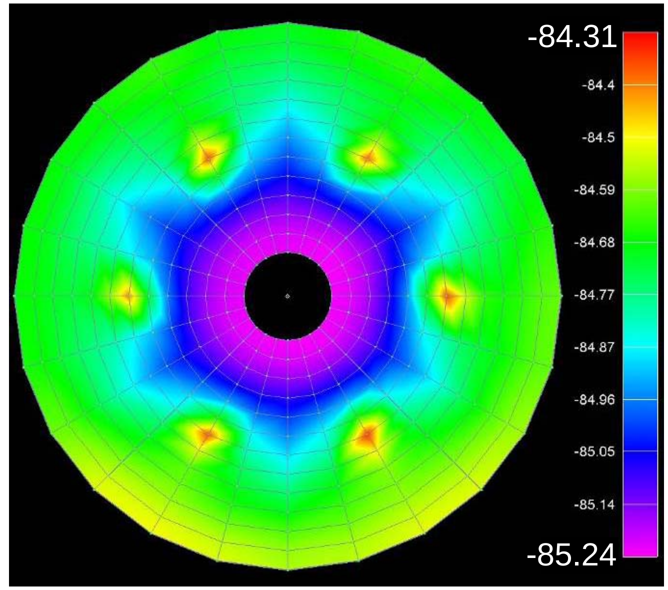

Temp in °C

# Primary Mirror Thermal Analysis Results

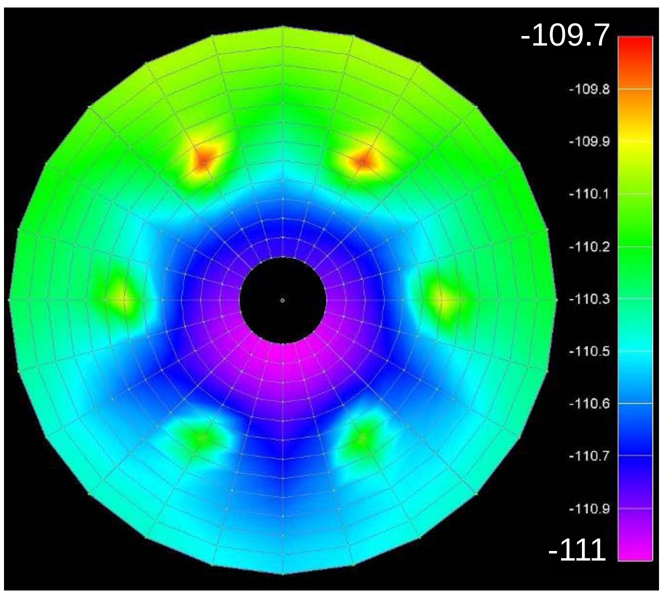
Sun = 0°



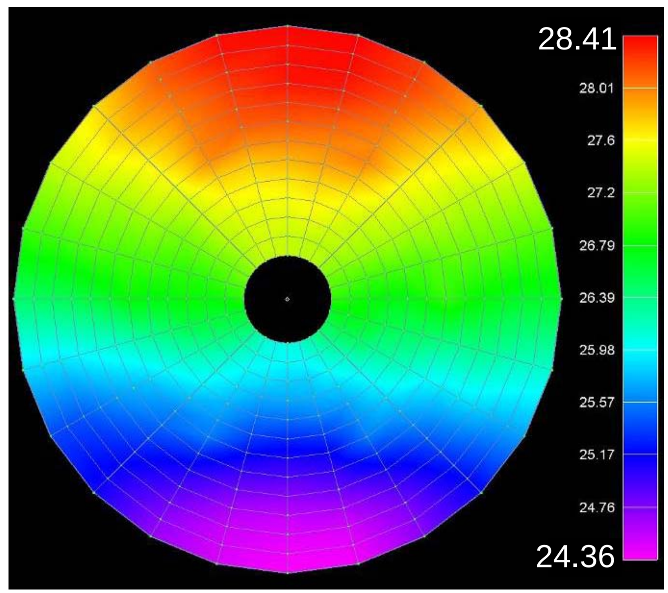

45°




90°



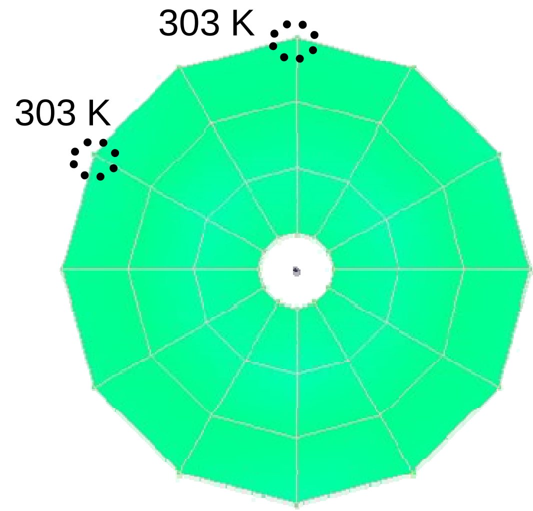

120°




* Temperatures are in °C. Note varied temperature scale for each load case.

# Primary Mirror Thermal Analysis

Active Thermal Management via 14 Heat Pipes yields a Primary Mirror with less than 1K Thermal Variation.




No Thermal Management yields a Cold PM

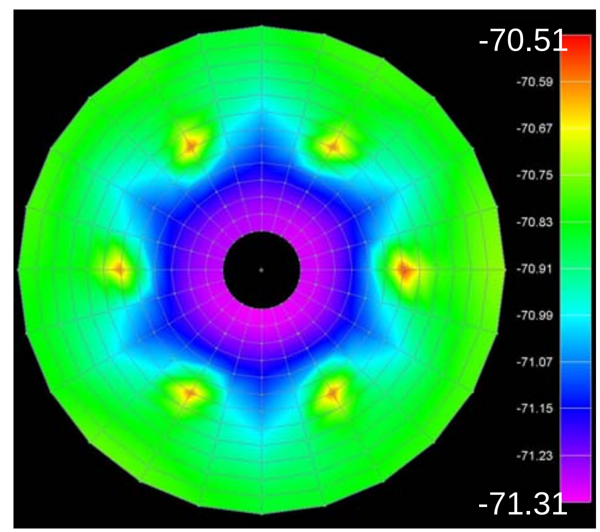
| Sun Angle | Temp |
|---|---|
| 0 deg | 200K |
| 90 deg | 160K |
| 120 deg | 300K |

with 1K Thermal Variation

Thus, possible End of Life use as a NIR/Mid-IR Observatory.

Figure Change will be driven by CTE Change from 300K to 150K

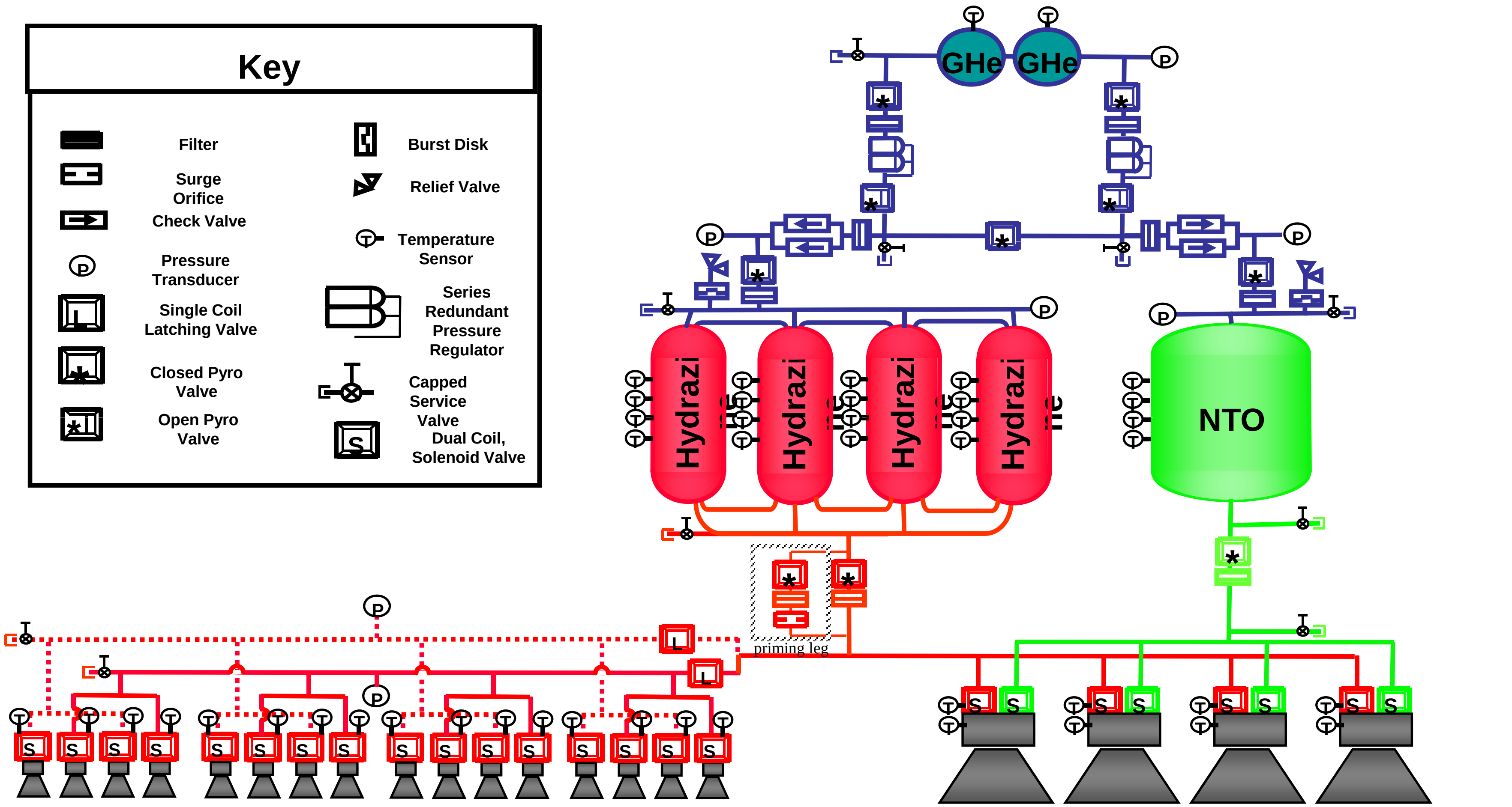
- Zerodur CTE is approximately 0.2 ppm.
- SiO2 CTE is approx 0.6 ppm.



# Notional Spacecraft Propulsion System

Dual Mode: Hydrazine-NTP Bi-Prop / Hydrazine Mono-Prop

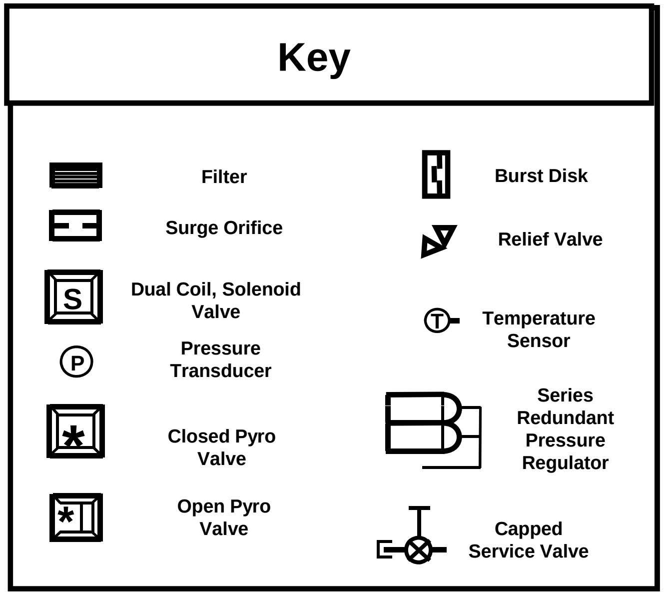
Propellant for 5 yr mission with redundant Thrusters




Hydrazine Mono-Prop with RCS 20/5 lbf Thrusters (Aerojet) for Station Keeping

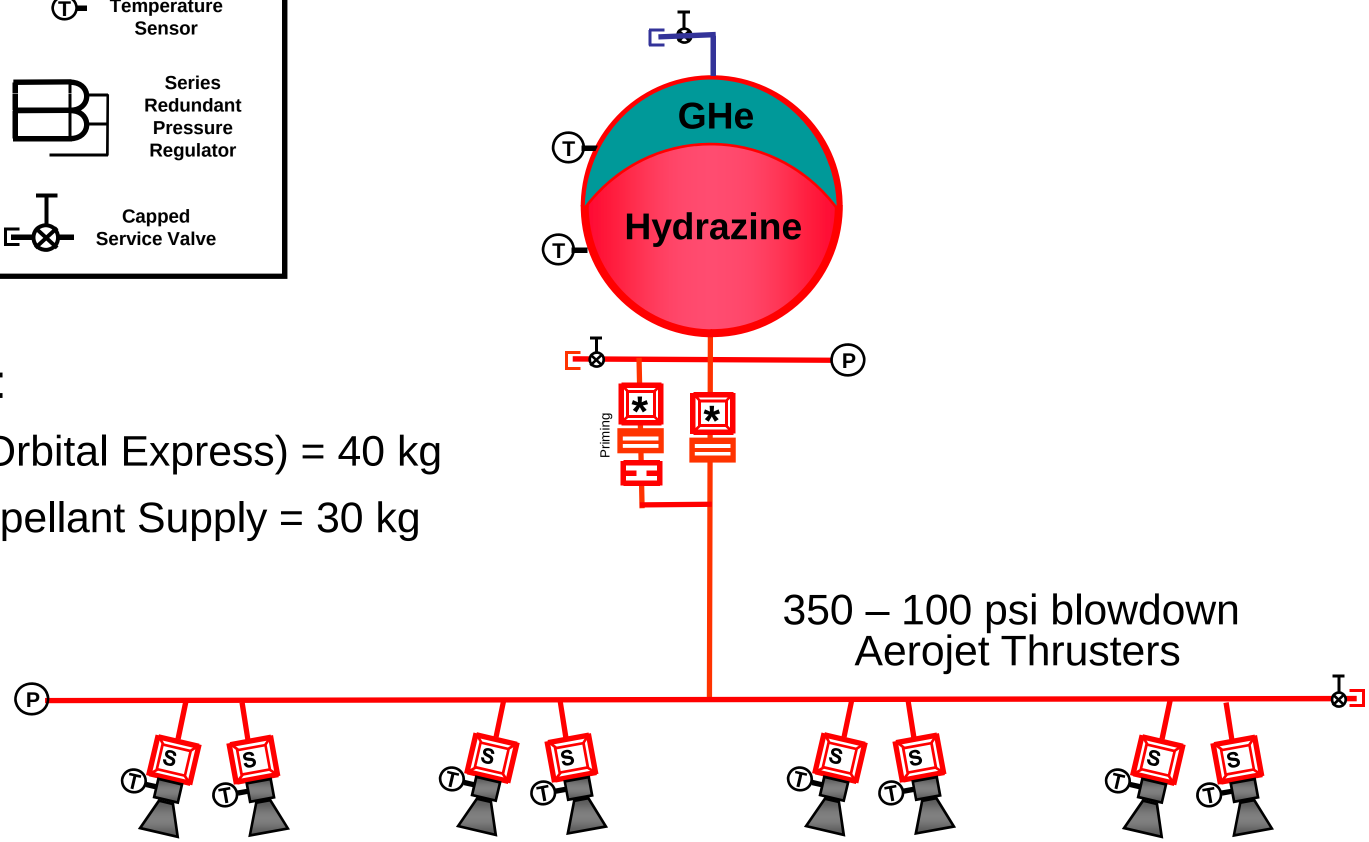
Hydrazine-NTP Bi-Prop with four 125 lbf Thrusters (Northrop) for trip to L2

# Notional Telescope Propulsion System




Telescope has Independent Control System

Mono-Propellant Hydrazine




Trade Analysis:

Refueling (Orbital Express) = 40 kg

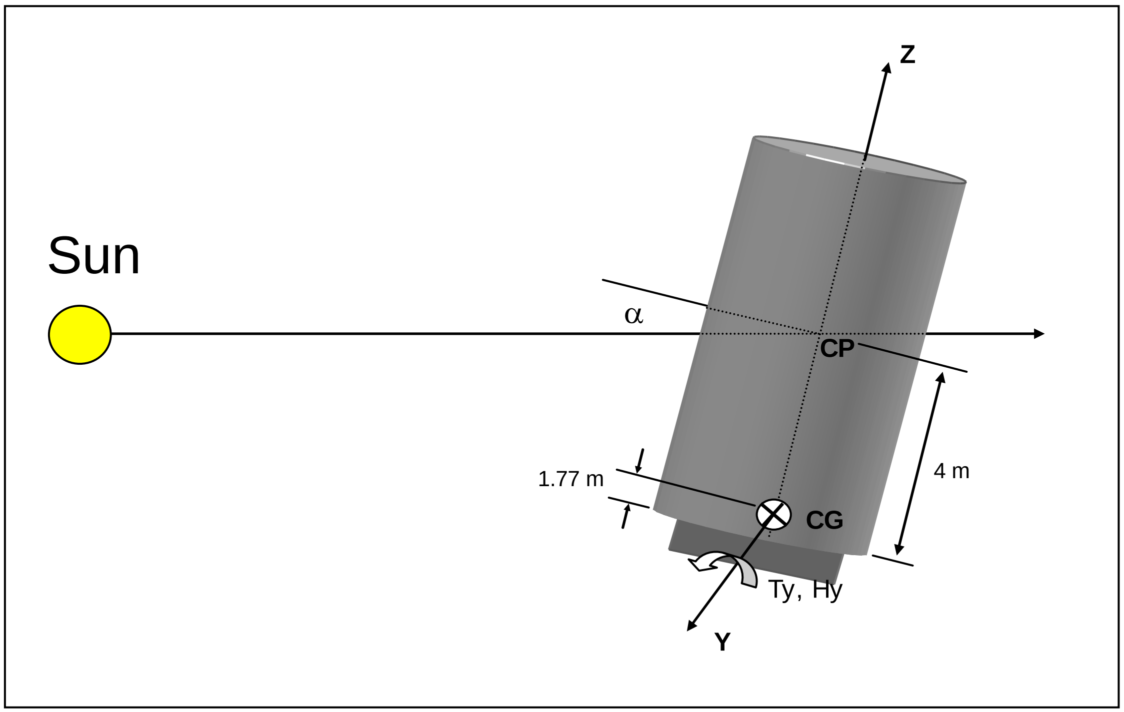
30 Year Propellant Supply = 30 kg

# Guidance Navigation and Pointing Control

Spacecraft Reaction Wheels provide all GNC

Worst condition for solar radiation pressure torque is at sun angle = 90.

Momentum buildup occurs in one axis (y-axis)



# GN&C Analysis

Two performance Parameters were analyzed and plotted against each other:

- Hours that Telescope can stare at a fixed point (remain at an inertial hold) before needing to perform a momentum dump due to solar radiation pressure torque
- How fast in minutes the Telescope can perform a 60 degree slew

6 wheel and 4 wheel configurations were analyzed along with the worst case single wheel failure for each configuration.

Each configuration was analysis for three different TELDIX reaction wheel versions with different (Torque : Momentum Storage)

Analysis

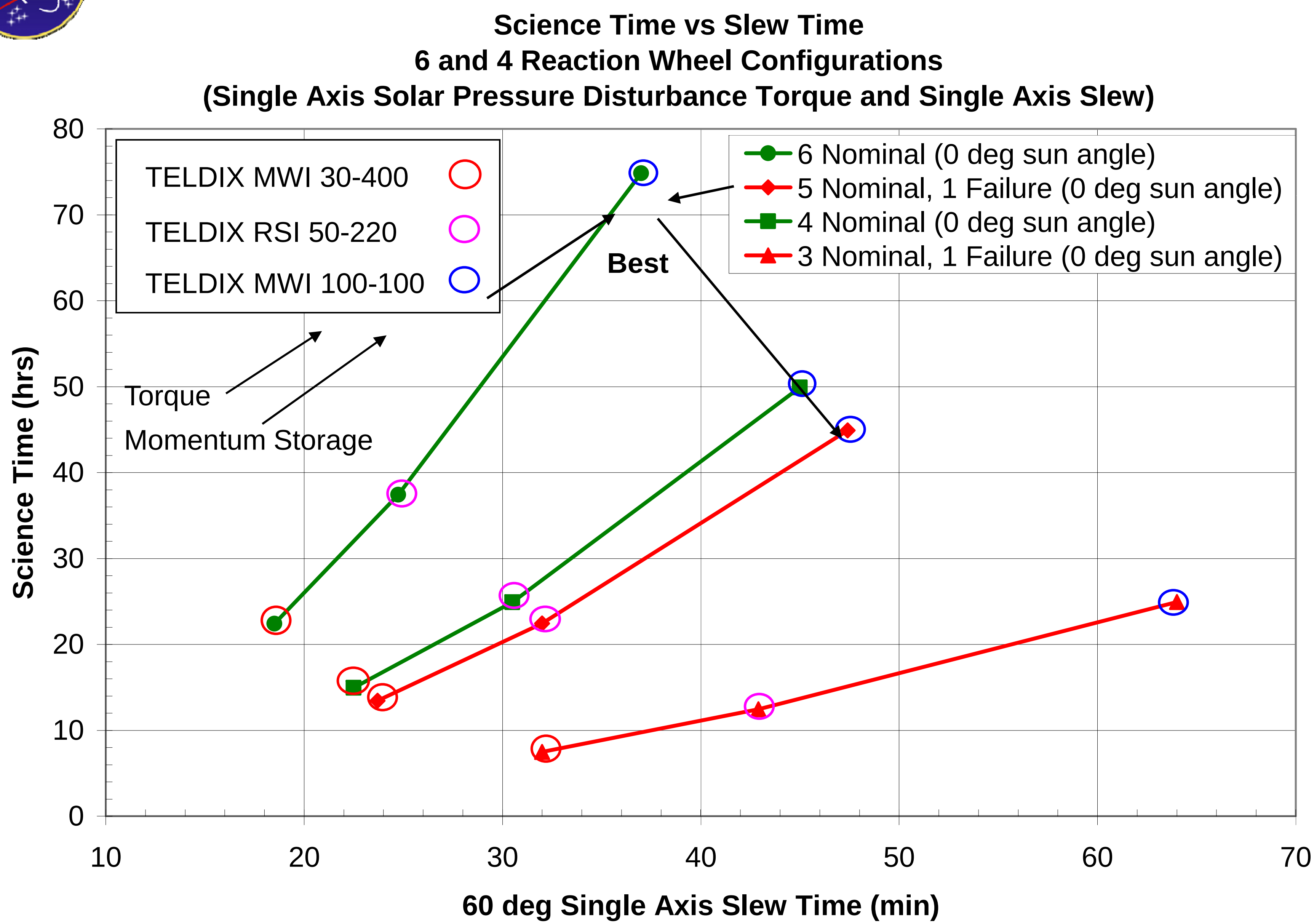
is only for the worst case sun angle = 0

As the sun angle increases so does the available science time.

did not account for any solar panel contribution to solar pressure cp location.

This is worst case since accounting for the solar panels would move the cp location closer to the cg. Also, Telescope geometry is preliminary and may change due refinement in design

# GNC: Reaction Wheels



# Avionics and Power Systems Assumptions

## Spacecraft

### Avionics

- Spacecraft avionics systems are 1-fault tolerant for 5 year life
- Guidance and navigation system includes star trackers, sun sensors, and IMUs
- AR&D consists of a LIDAR long range system, and an optical short range system
- Computers handle all normal station keeping, maneuvers, data management, and ground communications
- Communication systems consist of Ka-band HGA for ground, and s-band for local comm and backup capability

### Power

- Spacecraft power systems are 1-fault tolerant for 5 year life
- Power generation from two 9 m^2 deployable solar array wings with pointing ability
- Batteries are sized for 2 hours of power for midcourse and rendezvous operations (with arrays retracted)
- Spacecraft power system includes 800 w for mirror thermal control, and 750 w for telescope instrument package

# Avionics and Power Systems Assumptions

## Telescope

### Avionics

- Telescope avionics systems are 3-fault tolerant for 30 year life
- Minimal guidance and navigation system, used only for station keeping during spacecraft exchange
- Minimal computer capability, used mainly for station keeping during spacecraft exchange
- All health and status data sent directly to spacecraft avionics system
- Low gain communications capability with the servicing spacecraft only

### Power

- Telescope power systems are 3-fault tolerant for 30 year life
- 18 m^2 body mounted solar array around light tube, used for station keeping during spacecraft exchange
- Batteries sized for 0.5 hour attitude control contingency
- No active mirror thermal control during spacecraft exchange

# Spacecraft Astrionics & Power Systems

## 6m Telescope - Spacecraft Astrionics and Power Systems

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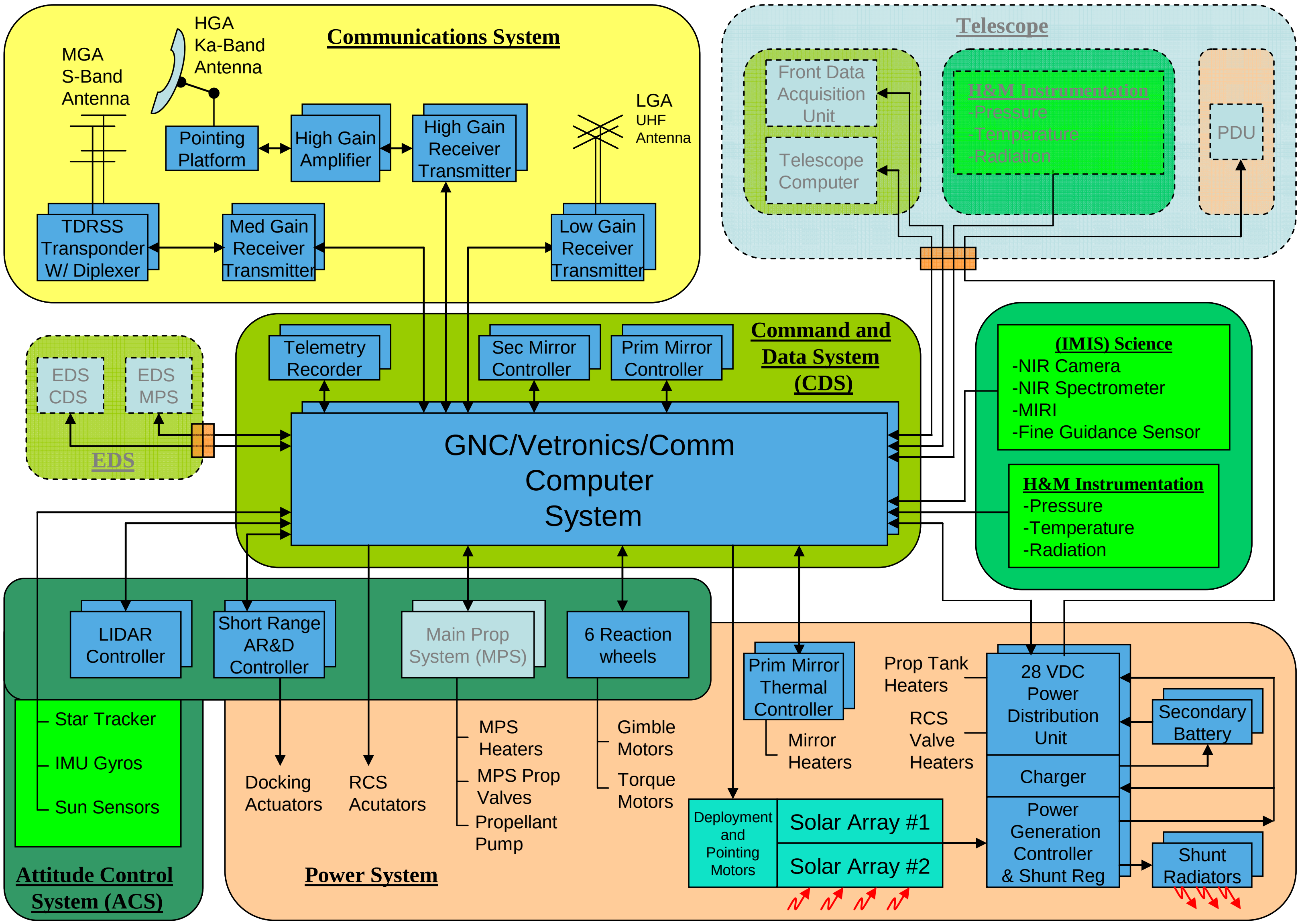
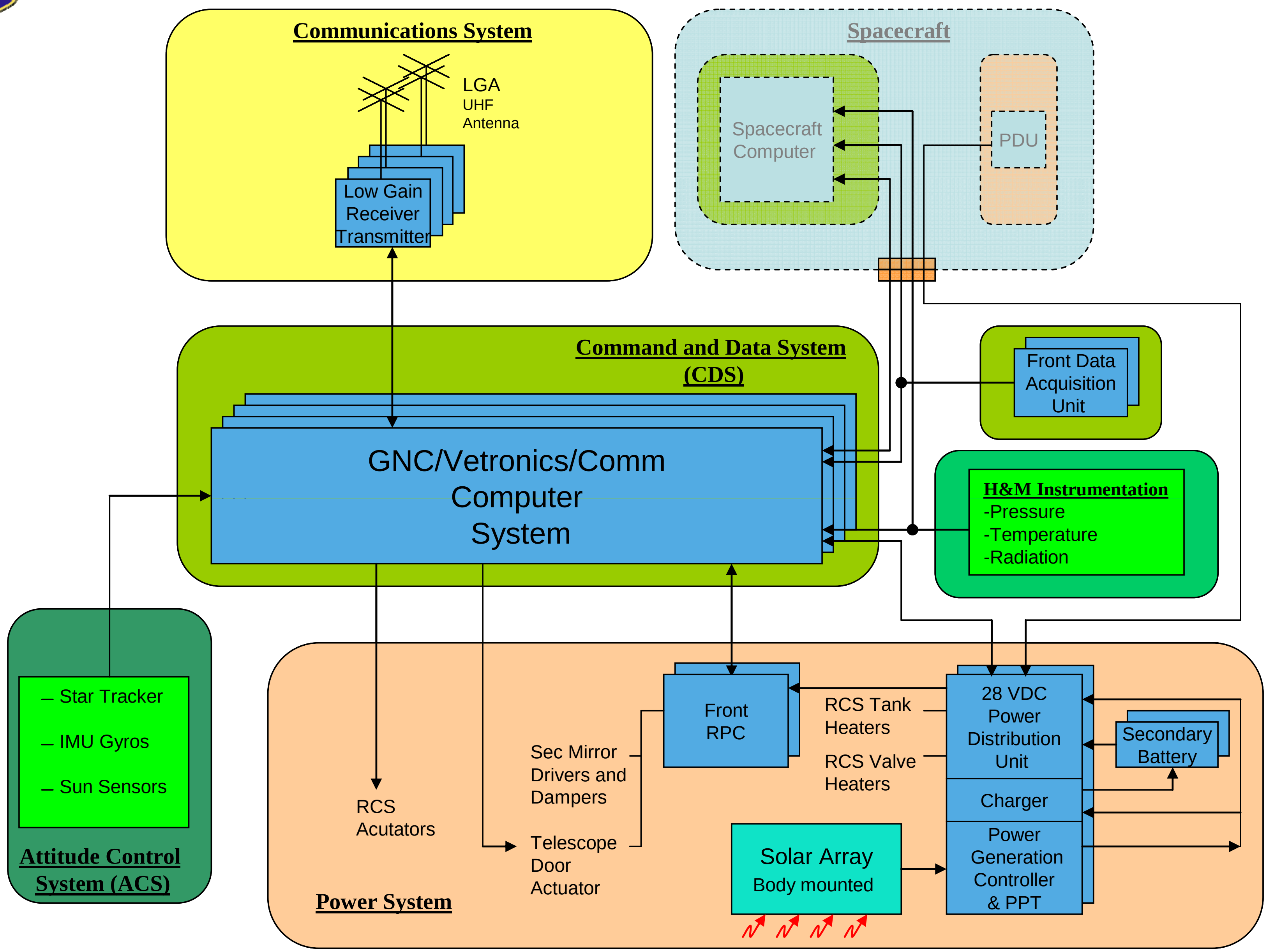


# Telescope Astrionics & Power Systems



# Mission Life

Initial Mission designed for a 5 yr mission life (10 yr goal) should produce compelling science results well worth the modest mission cost.

But, there is no reason why the mission should end after 5 or even 10 years.

Hubble has demonstrated the value of on-orbit servicing

The telescope itself could last 30 or even 50 years.

# 30 to 50 year Mission Life

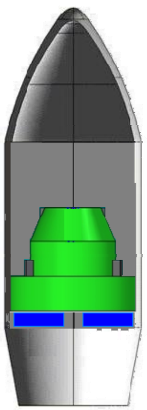
Copy Ground Observatory Model – L2 Virtual Mountain

Design the observatory to be serviceable

- Telescope has no inherent life limits
- Replace Science Instruments every 3-5 yrs (or even 10 yrs)

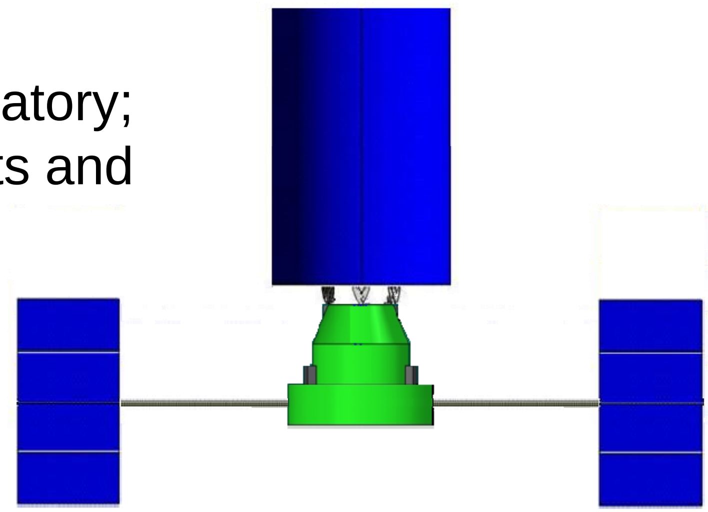
Replacement Spacecraft in ELV

Observatory has split bus with on-board attitude control and propulsion during servicing. (already in mass budget)

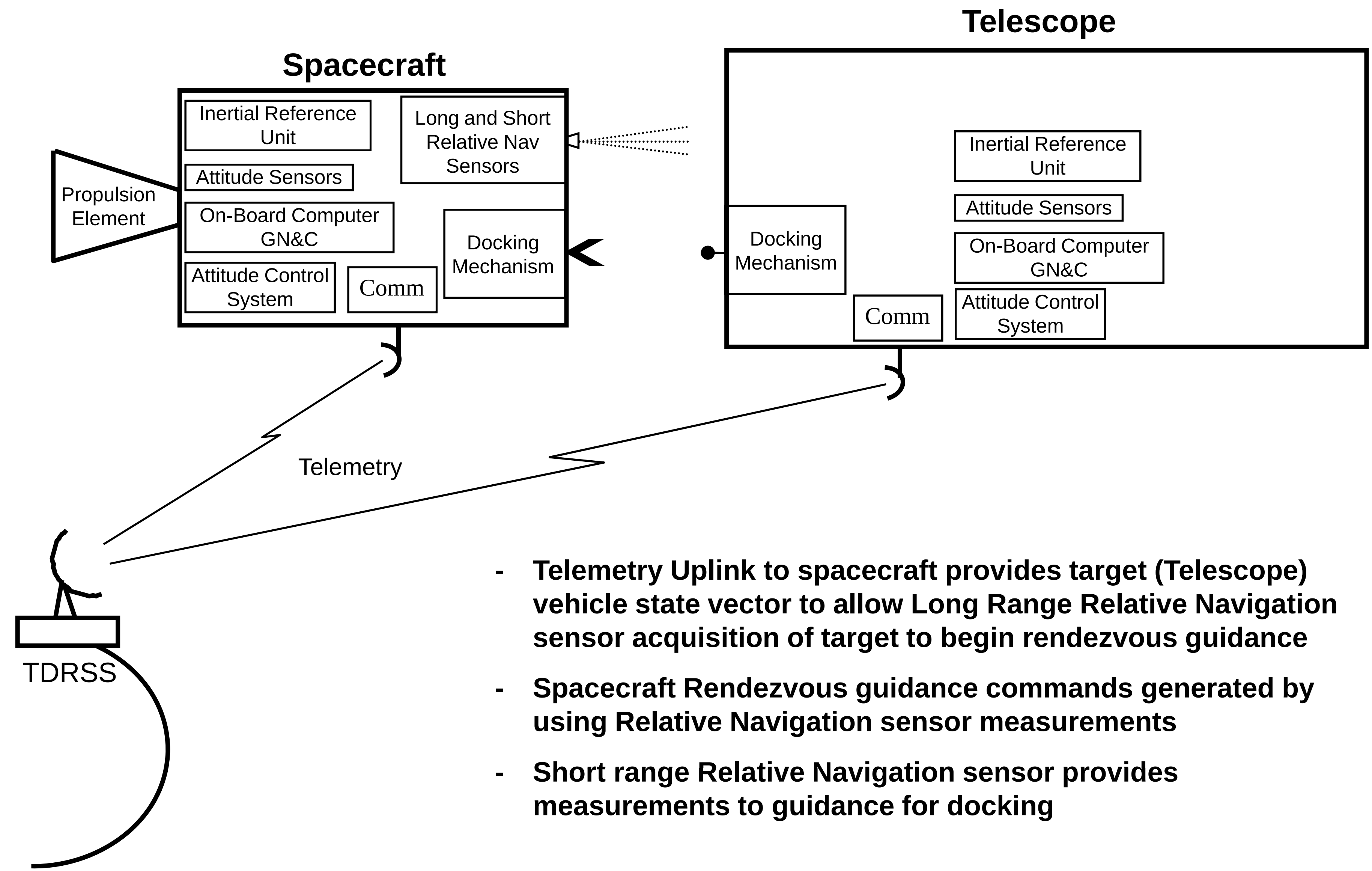


Spacecraft in
4.5 meter Payload Fairing

Autonomously docks to observatory; replaces all science instruments and ALL expendable components.



# AR&D System Elements




- Telemetry Uplink to spacecraft provides target (Telescope) vehicle state vector to allow Long Range Relative Navigation sensor acquisition of target to begin rendezvous guidance
- Spacecraft Rendezvous guidance commands generated by using Relative Navigation sensor measurements
- Short range Relative Navigation sensor provides measurements to guidance for docking

# Additional Thoughts on Servicing

Servicing can be achieved by humans or AR&D.

- I expect that the best approach is AR&D at SE-L2
- SE-L2 is not a nice place for Humans

8-m telescope can be returned from SE-L2 to L2TO with only approximately 200 kg of propellant.

Spacecraft with science instrument could be returned to L2TO for much less.

Servicing at L2TO requires an existing infrastructure.

# Conclusions

Unprecedented volume capability of an Ares V enables the launch of 8 meter class monolithic space telescopes to the Earth-Sun L2 point.

Unprecedented mass capability of an Ares V enables an entirely new design paradigm – Simplicity.

Simple high TRL technology offers lower cost and risk.

NASA MSFC has determined that a 6 to 8 meter class telescope using a massive high-TRL ground observatory class monolithic primary mirror is feasible.

Mature, High-TRL design enables early deployment.

Science Instruments, Expendables and Limited Life Components can be replace periodically via Spacecraft Autonomous Rendezvous and Docking.

# Any Question?