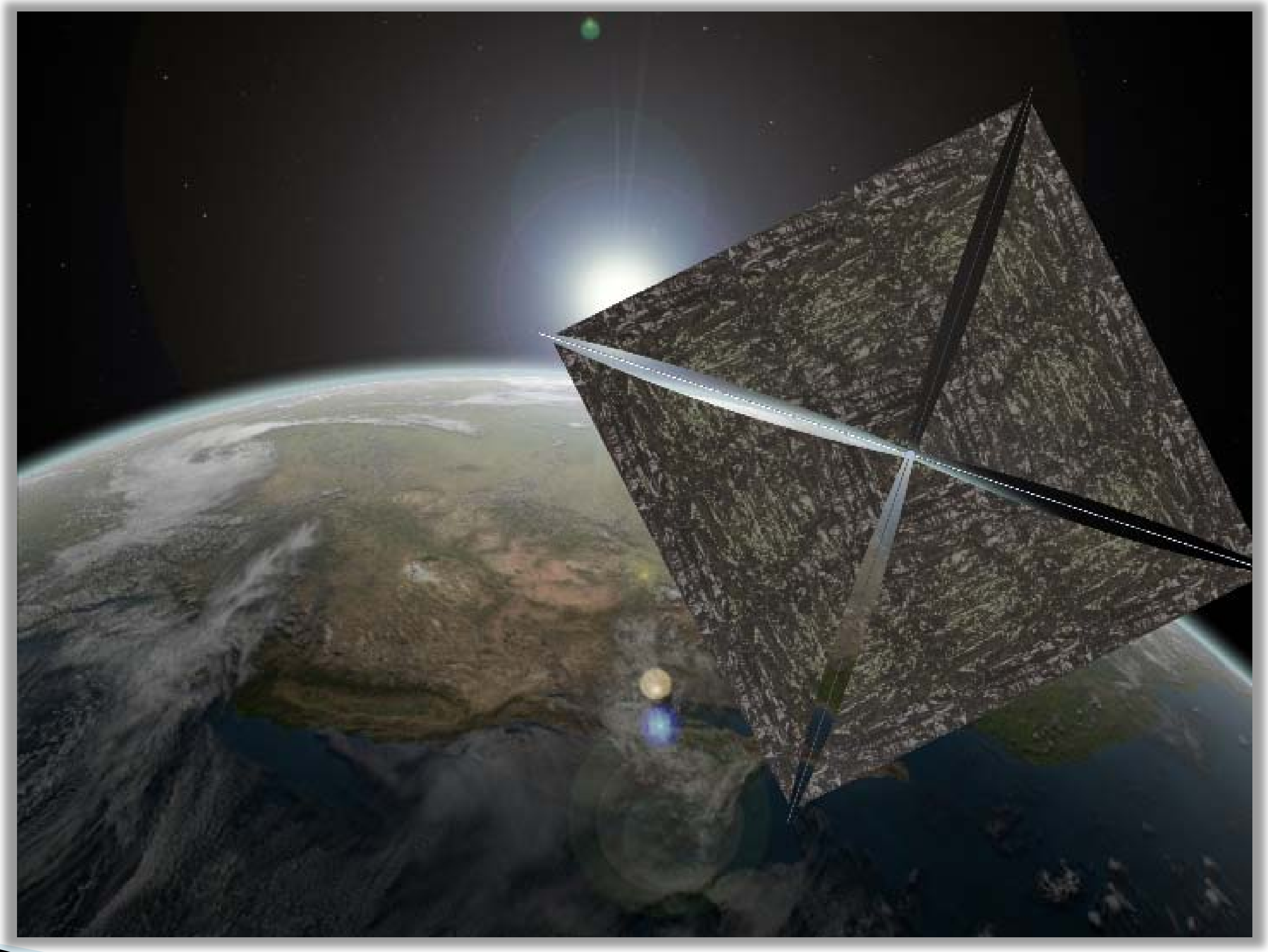
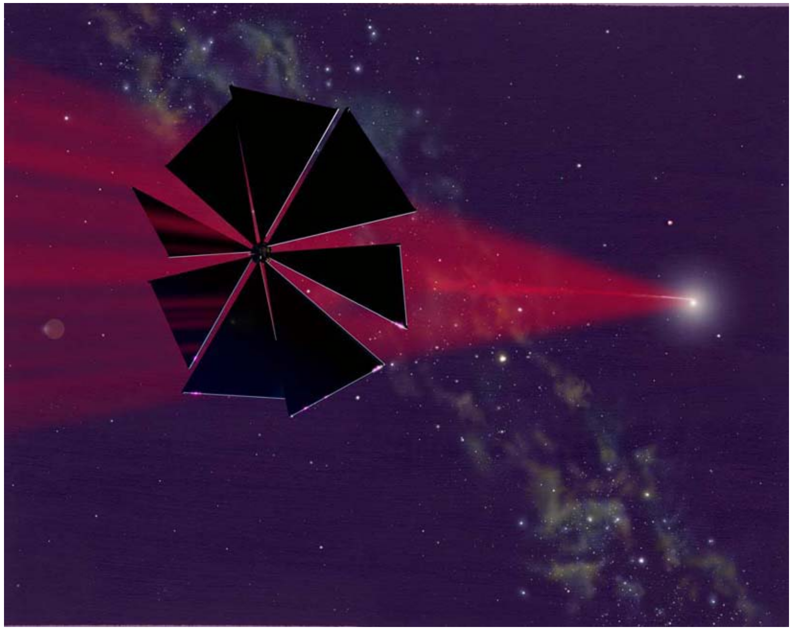
LightSail
The Solar Sail Project of The Planetary Society



Chris Biddy and Matt Nehrenz

Why Solar Sailing?

- Pathway to the Stars – the only known technology able to visit an extra-solar planet
- Interplanetary travel without fuel
- Monitoring the solar system
- Gossamer technology



"We have lingered for too long on the shores of the cosmic ocean; it's time to set sail for the stars." Carl Sagan

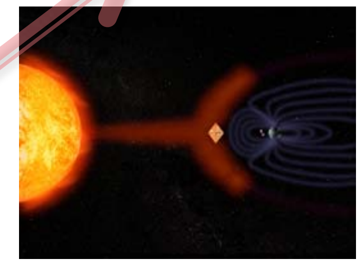
STELLAR EXPLORATION

LightSail Program

1,000,000

Km

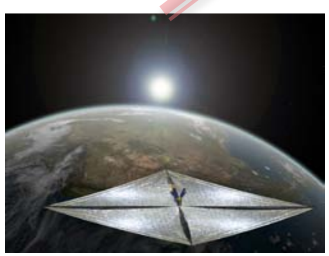
LightSail-3 escapes Earth orbit and flies toward L1



10,000

LightSail-2 flies further, longer to raise orbit energy

1,000



LightSail-1 demonstrates controlled flight by light

2010 **2013** **2015**

LightSail Objectives

- Demonstrate viability of Solar Sails
  - Ability to alter orbit energy in positive direction
  - Ability to manage orbital energy
  - Ability to control spacecraft under solar sail power
- Develop and demonstrate key technologies
  - Sail deployment
  - Sail material management during flight
  - Gossamer structure dynamics
- Demonstrate pathway to deep space with solar sails
  - Lightweight spacecraft
  - Compact and lightweight booms

STELLAR EXPLORATION

Success Criteria

- LightSail-1
  - Deploy and control sail
  - Demonstrate controlled flight with solar pressure force
- LightSail-2
  - Demonstrate controlled solar sail flight over moderate duration
  - Provide notable increase in orbit energy and altitude
  - Demonstrate key technologies required for sustained sail flight
- LightSail-3
  - Demonstrate key solar sail technologies for deep space flight
  - Leave Earth's gravity influence under solar sail power
  - Head toward L1, the locale of a possible a solar weather station

LightSail-1 Mission Requirements

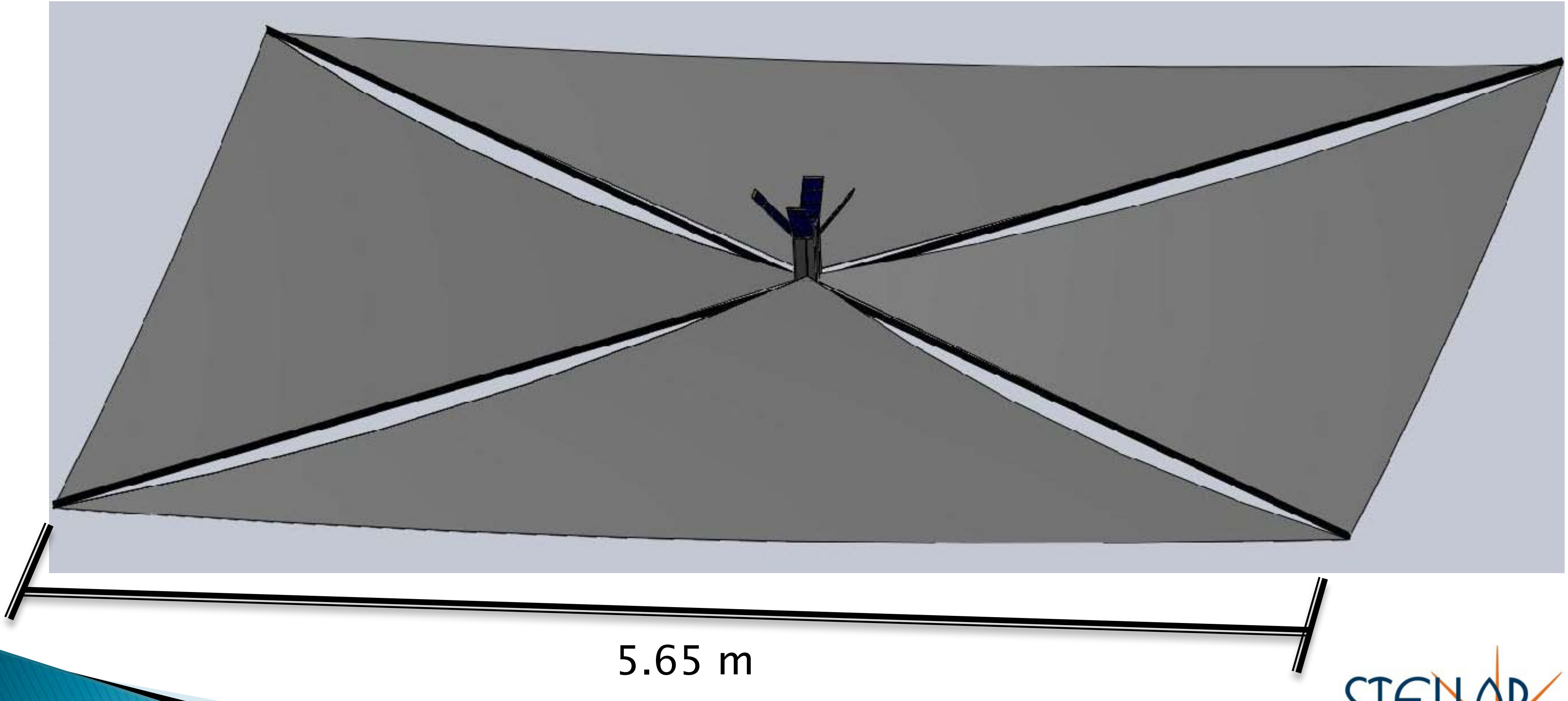
PARAMETER	REQUIREMENT	COMMENTS
System mass	< 5 kg	Cubesats each 1-2 kg leaves 2-4 kg for sail module
Lifetime	3-4 weeks	Long enough to prove feasibility
Orbit altitude	> 800 km	High enough to avoid atmosphere
Communications	Command uplink – 435 Mhz Data downlink – 435Mhz	Compatible with many ground station options
Sail Area	Large enough to accelerate sail > 0.06 m/s^2	Exceeds Cosmos 1 and other performance
Attitude control	Point toward sun with rough accuracy ~ 10°	Necessary to achieve thrust and orbit raising
Camera	As much as possible to see full sail	Minimum one camera to imaging sail deployment and deployed sail
Other sensors	What is necessary to verify flight goal	Accelerometer, GPS, doppler tracking, sun sensors, rate gyros

STELLAR EXPLORATION

LightSail-1 Configuration

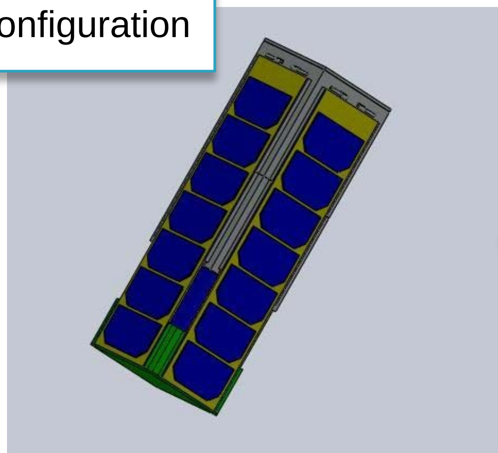
- 3U CubeSat
  - Avionics section, sail storage section, boom deployer section and payload section
- TRAC (Triangular Rollable and Collapsible) booms developed by AFRL
- Custom boom deployer and satellite structure designed by Stellar Exploration Inc.
- Avionics developed by Cal Poly
- 32 m^2 Solar Sail made from Aluminized Mylar

Deployed Configuration

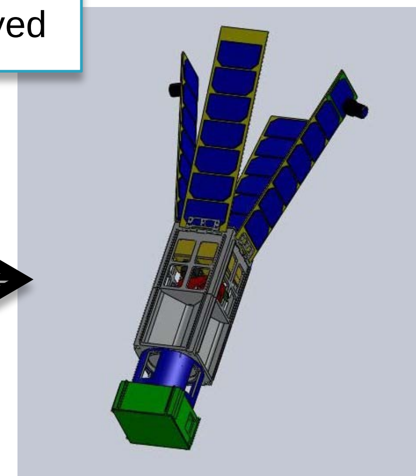


Deployment Sequence

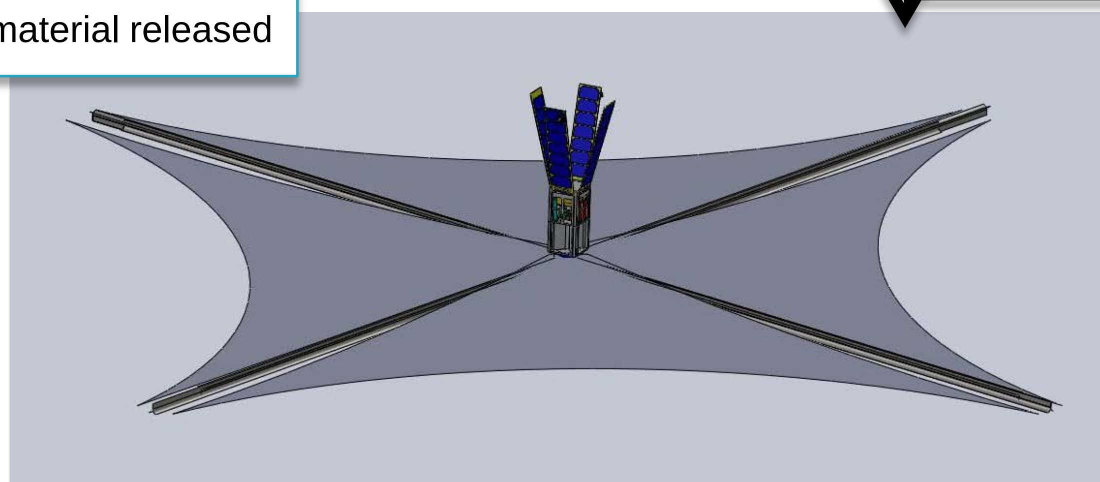
Stowed Configuration



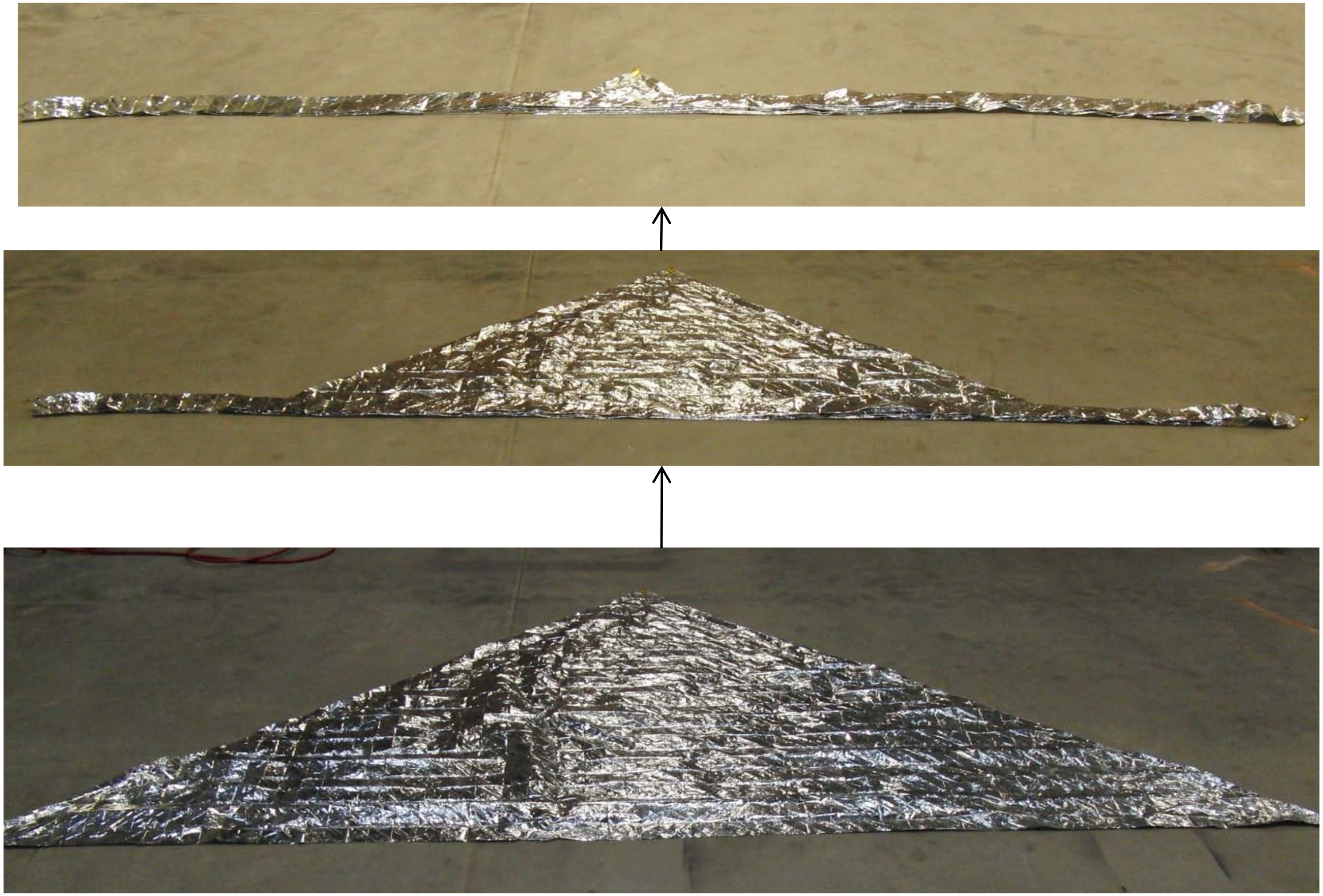
Panels Deployed



Boom and sail material released

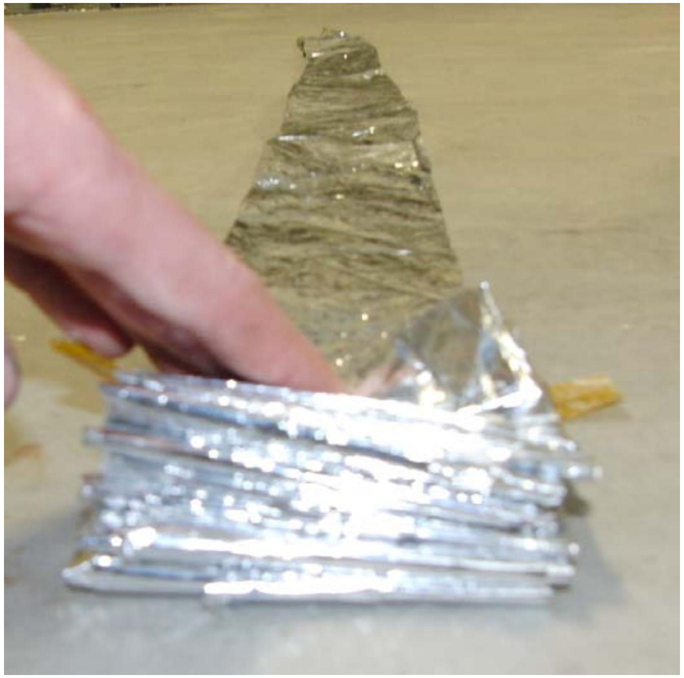


Sail Deployment



Folding Technique

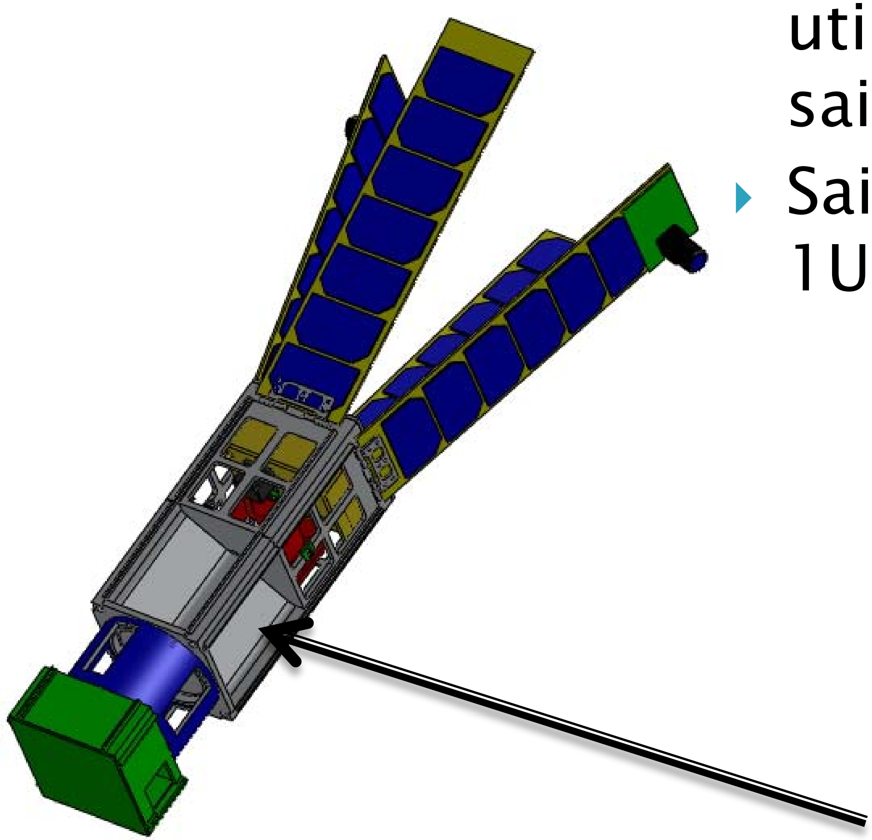
- Similar “accordion” type folds



Folds start at ends and move towards the center of the sail

Wedge shaped folded sail

Sail Stowage



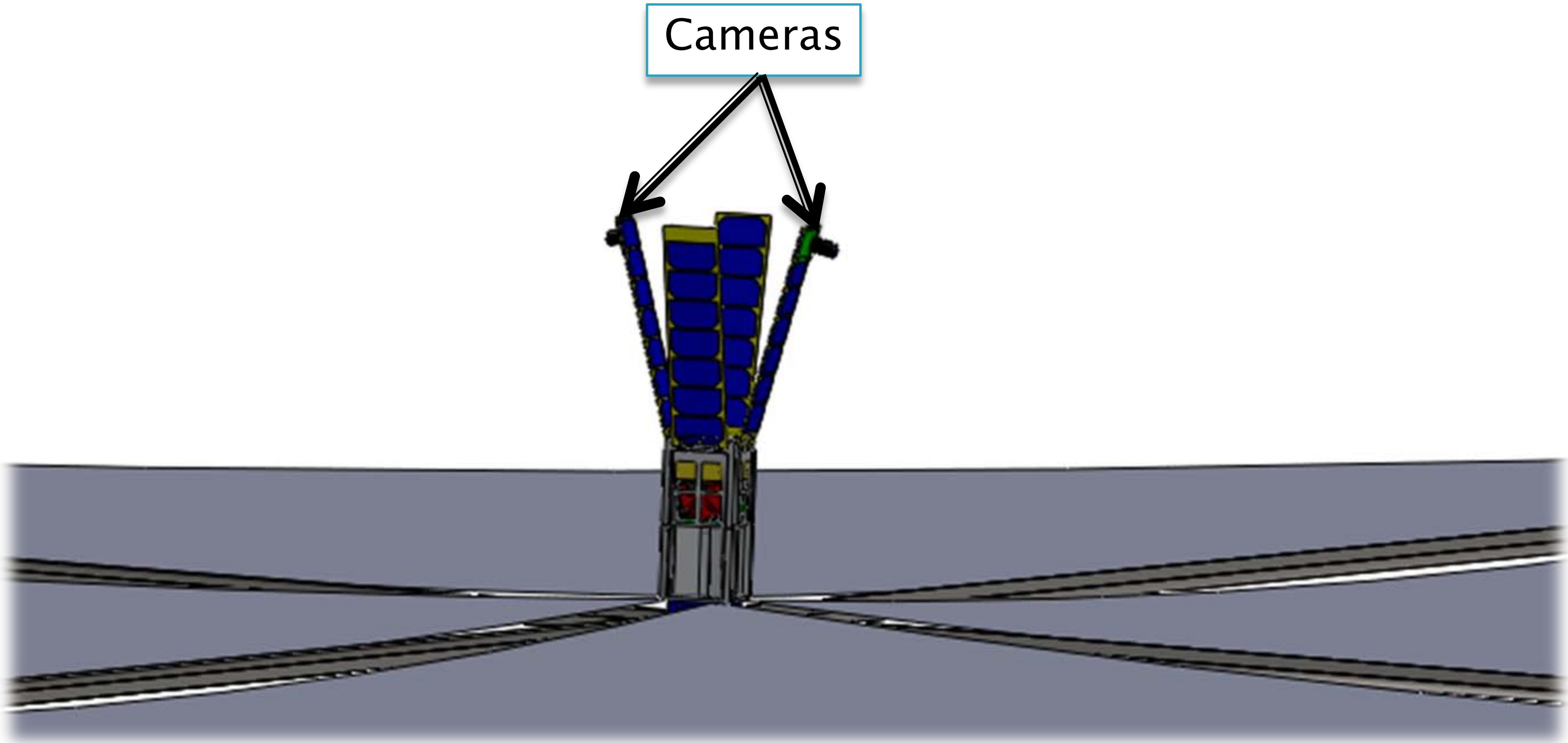
- Wedge shape folded sail utilizes all volume for initial sail cavity design
- Sail cavity may only require 1U

Wedge shaped folded sail to fit in sail cavity shown

LightSail-1 Cameras

- Imaging on LightSail-1 will:
  - Provide verification of sail deployment and state.
  - Provide the most important PR products The Planetary Society will have.
- We require onboard camera to image the sail and the Earth in the background
- Total data amounts per day are adequate for high quality imaging assuming one uses
  - 10 kbps => 11.5 Mbit/day ~=> 1.4 Mbytes/day
  - Camera – 1.2 Mpixel can compress to 100 Kbytes ~=> 14 images per day
- Have fiducial marks on boom, and consider on sail

Lightsail-1 Cameras



Cameras mounted to the ends of the solar cell panels

ADCS modes

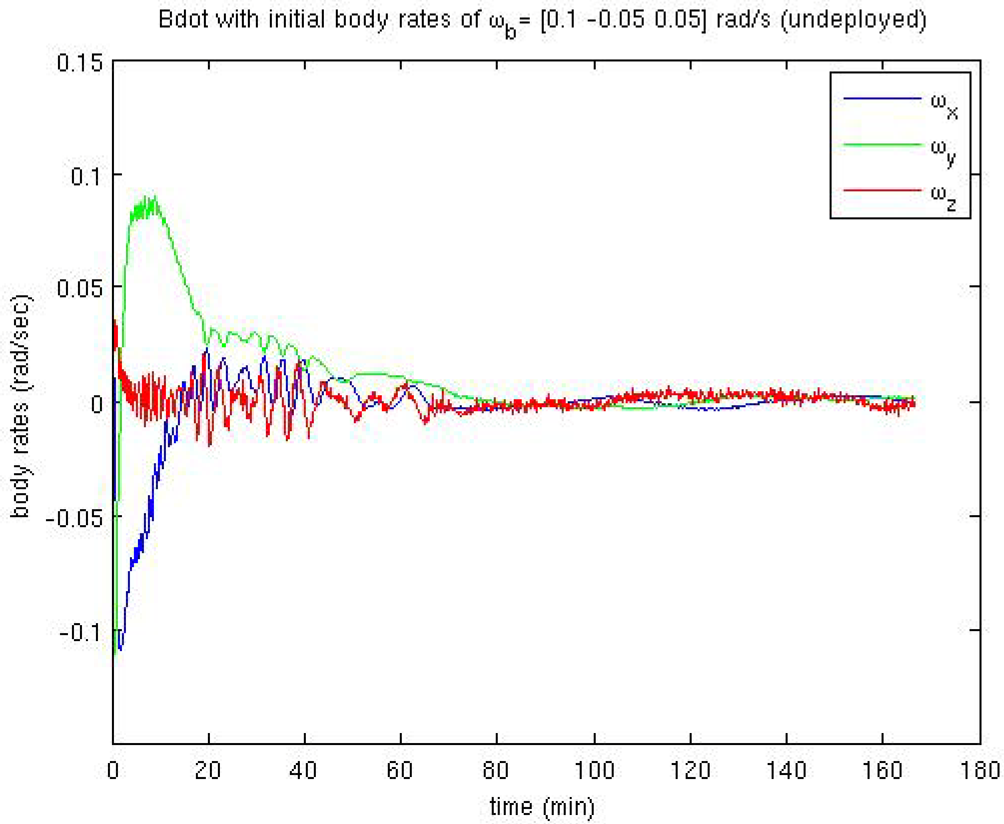
- B-dot detumble
- Momentum wheel turn-on
- Sun-pointing
- Orbit raising (thrust on/thrust off)

- Assumptions for MatLab simulations:
  - Rigid body
  - Body axes are the principal axes
  - IGRF-10 magnetic field model
  - Disturbance torques: gravity gradient and solar torque
  - Aerodynamic torque ignored (950 km orbit)
  - Sensor noise included, but sensor misalignment excluded
  - Momentum wheel spins at constant rate

B-dot Detumble Mode

- Only sensors used are magnetometers
- B-dot algorithm applies a magnetic dipole that minimizes the change in the magnetic field

$$M = -K \cdot \dot{\vec{B}}$$

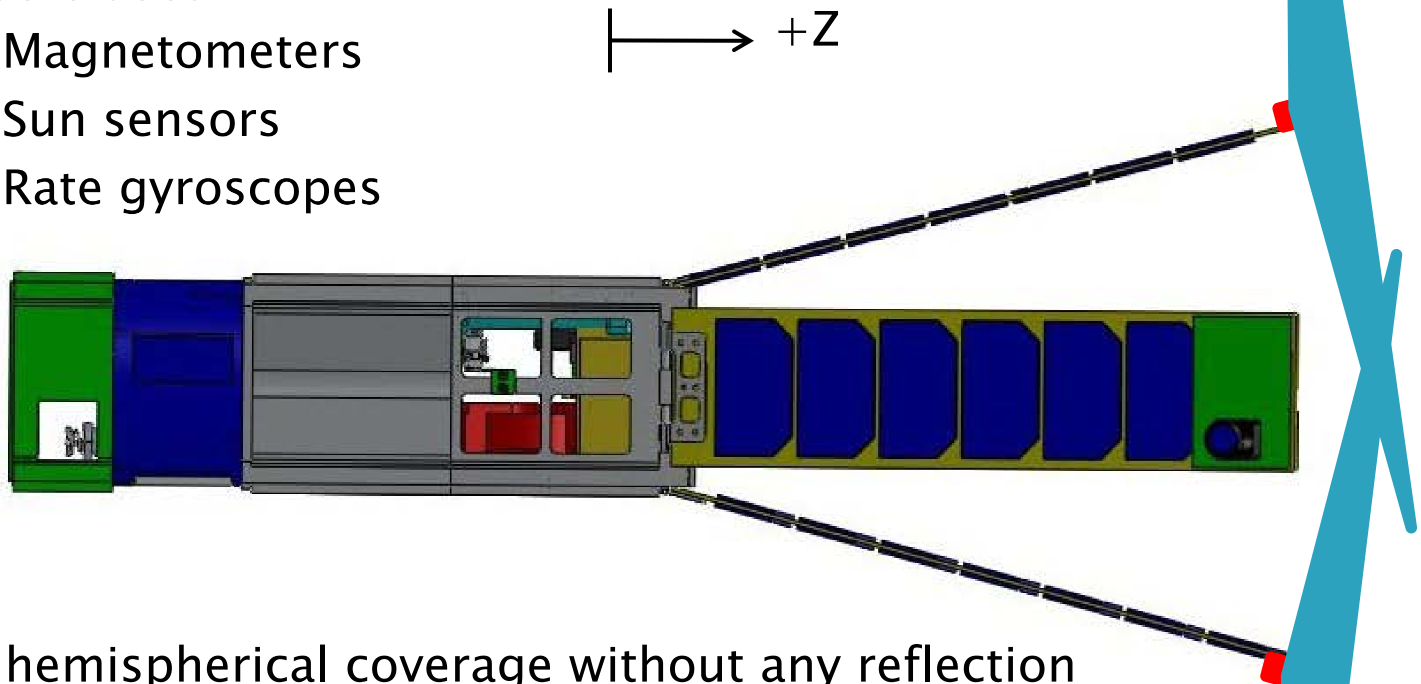


Momentum Wheel

- Sinclair microsatellite reaction wheel
- Nominal momentum: 0.060 Nms
- When spun up, an angular velocity of 2.5 deg/sec will be imparted on the spacecraft which will require a second detumble mode.
- Wheel is needed for orbit raising mode

Sun-Pointing Mode

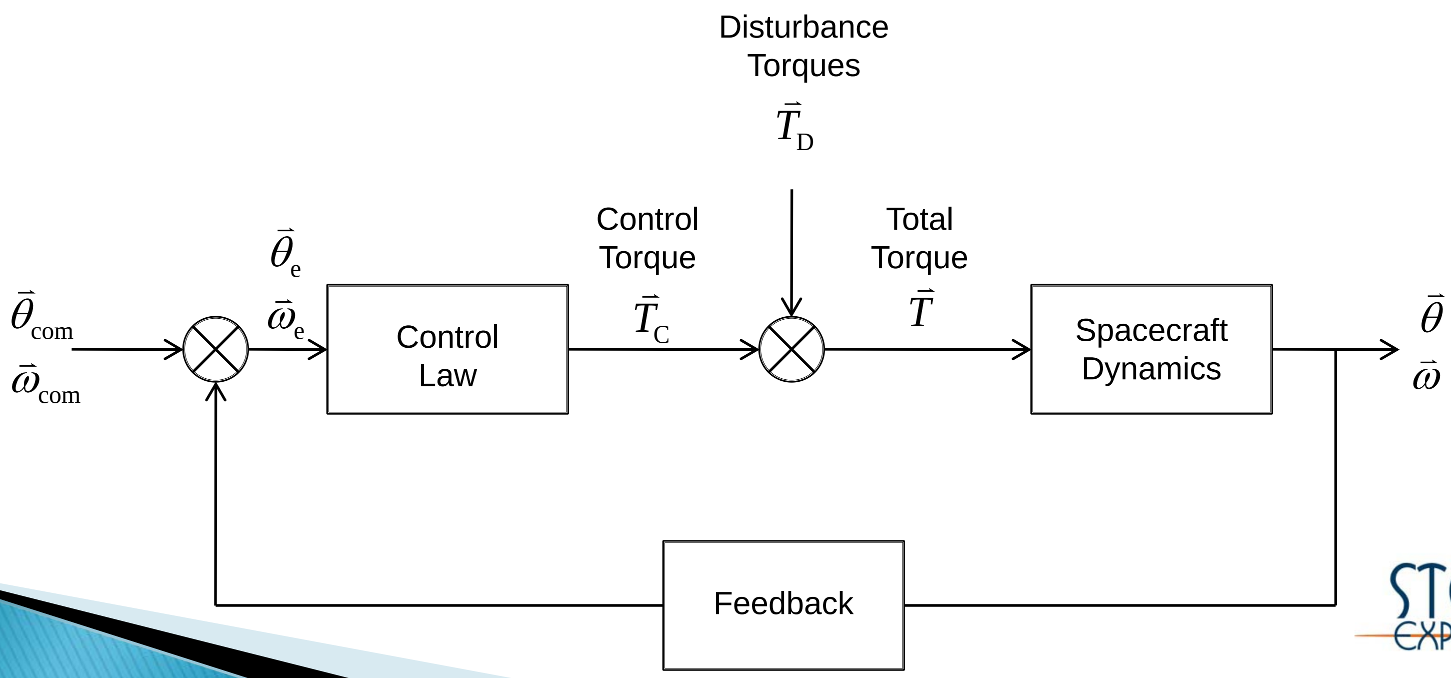
- +Z axis points towards sun
- Sensors used:
  - Magnetometers
  - Sun sensors
  - Rate gyroscopes



- Full hemispherical coverage without any reflection off the solar panels or solar sail

Sun-Pointing Mode

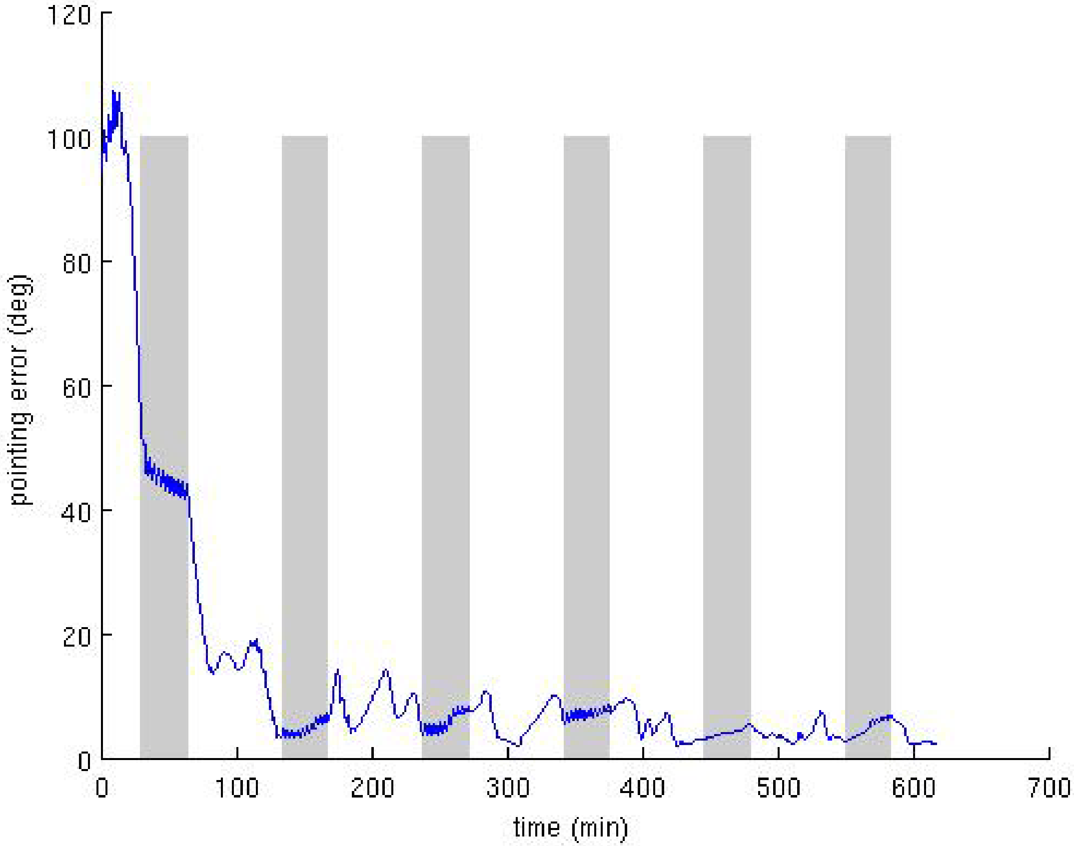
- Calculate a requested torque from Control Law $T_{\mathrm{req}} = -K_{\mathrm{P}}\theta_{\mathrm{e}} - K_{\mathrm{D}}\omega_{\mathrm{e}}$
- θ – a vector of angles that is a function of the sun vector in body coordinates and the desired sun-pointing axis (+Z)
- Solve for magnetic dipole needed to achieve requested torque $\vec{M}_{\mathrm{req}} = \dfrac{\vec{B} \times \vec{T}_{\mathrm{req}}}{\left|\vec{B}\right|^2}$



Sun-Pointing Mode

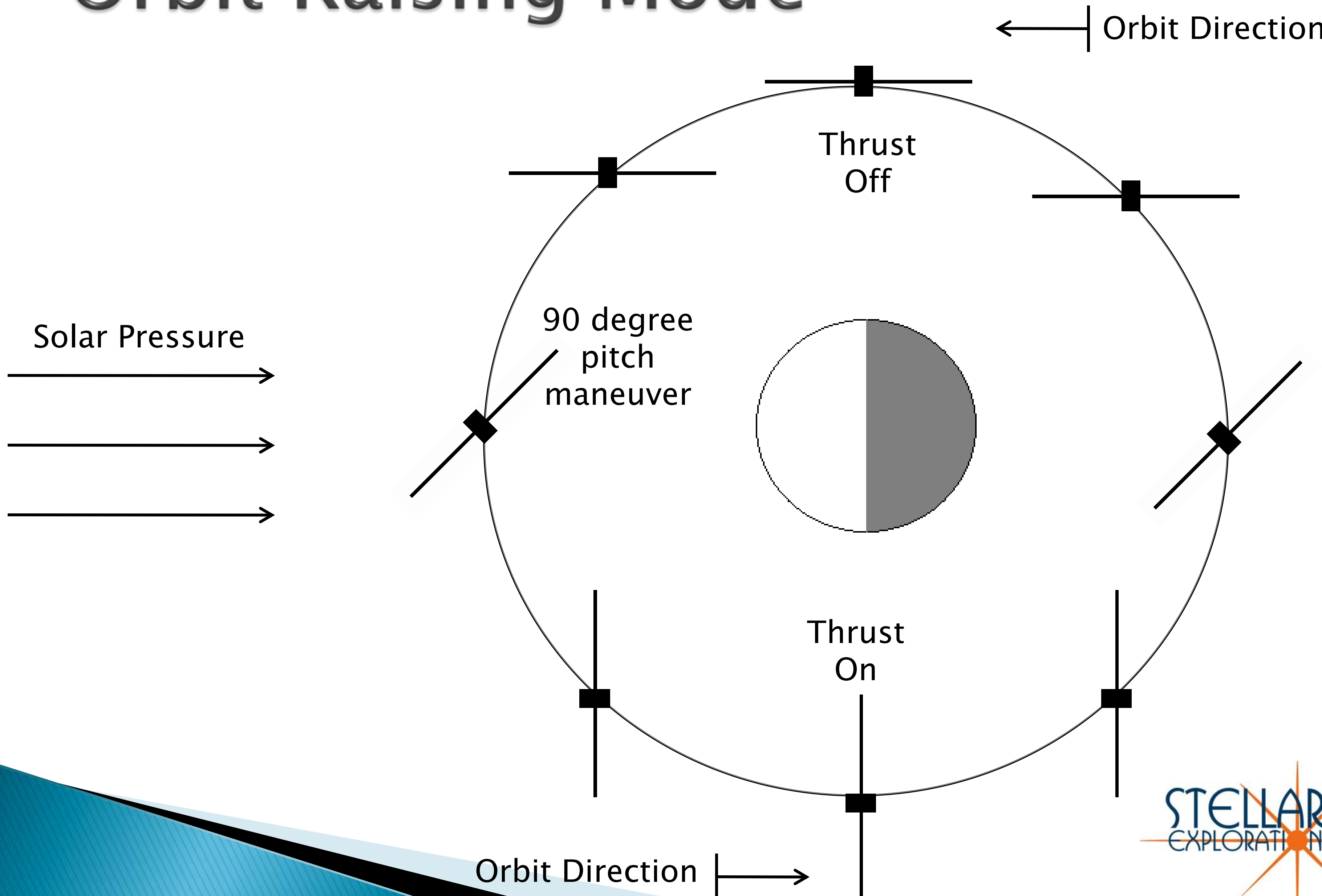
Parameter	Value
Spacecraft mass	5 kg
Deployed inertias ($kg \cdot m^2$)	$I_{xx} = 1.4$ $I_{yy} = 1.4$ $I_{zz} = 2.8$
Orbit	950 km sun-sync
System cycle	10 sec
Wheel momentum	0.060 $N \cdot m \cdot sec$
Max magnetic dipole	1 $A \cdot m^2$
Max power consumption	< 1 watt

Sun-pointing error over ~7 orbits



(shaded areas are eclipses)

Orbit Raising Mode



¿Questions?