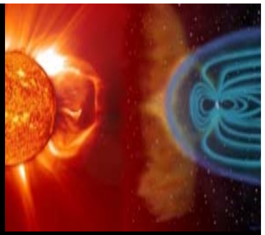


XSOLARA

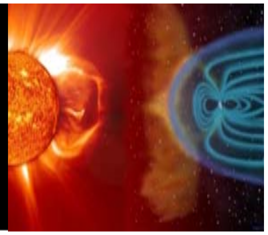
ExtraSolar Observing Low-Frequency Array for Radio Astronomy

Workshop for CubeSat-Based Low Frequency Radio Astronomy
Keck Institute For Space Studies
July 10,2012

Payam Banazadeh
(payam.banazadeh@gmail.com)
or
(pbanazadeh@utexas.edu)

The University of Texas at Austin

Team



JPL Mentors

Dayton Jones   Joseph Lazio   Daniel Scharf   Courtney Duncan

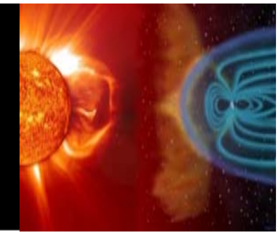
Study Lead

Payam Banazadeh

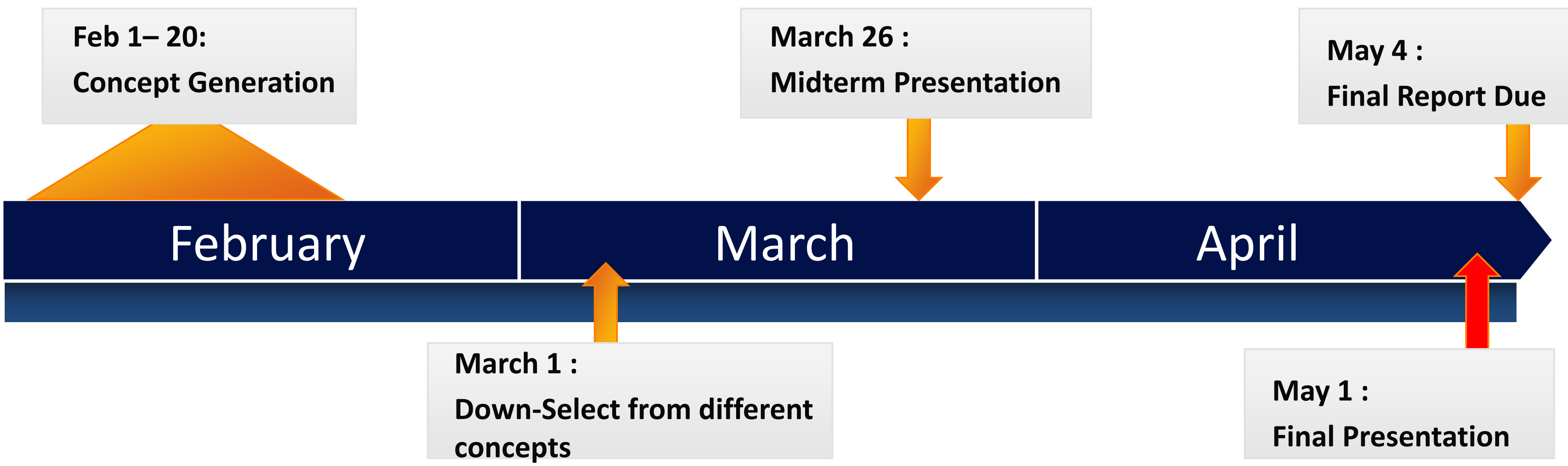
Team Members

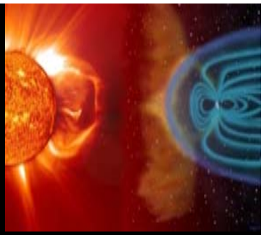
Chinmay Aladangady
Michelle Bolduc
Bryse Ed
Sarah Hand
Kyle Olson
Rebekah Sosland

Timeline

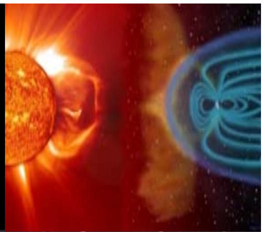


- XSOLARA team primary objective:
  - Feasible mission
  - High science return
  - Low cost
  - Student designed/built mission
- XSOLARA team constraints:
  - Only 3 months to work on
  - Team of 7 “full time” students
  - Limited resources





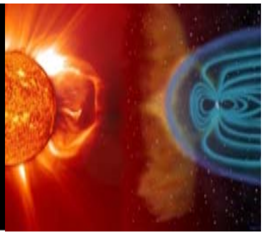
Science



"A time will come when men will stretch out their eyes. They should see planets like our Earth."

-Christopher Wren , 1702

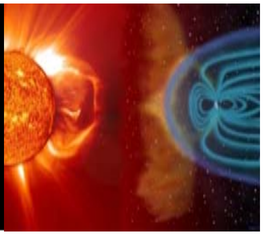
XSOLARA Goals



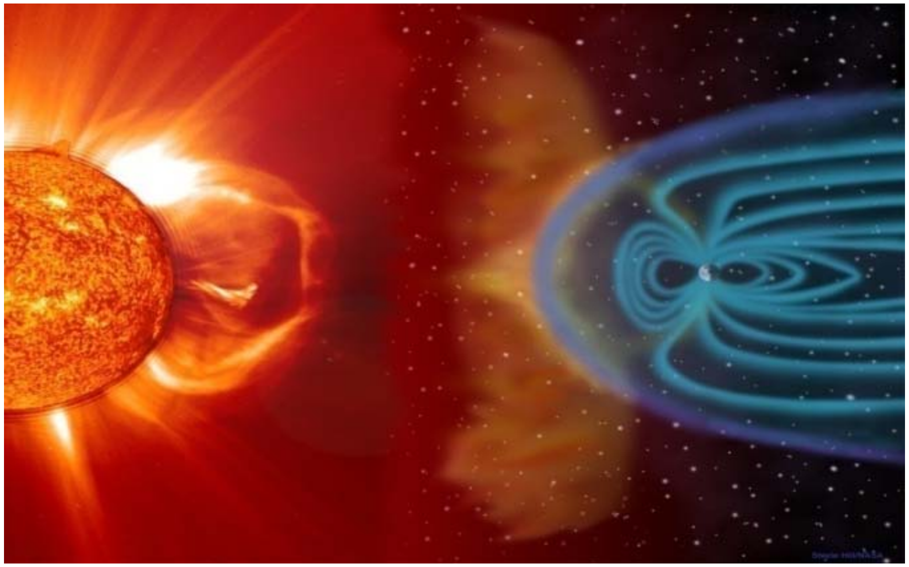
- **Science Goal:**
  - Detect extrasolar planets
  - Prove the concept that exoplanets can be detected with this method
  - Path finder mission

- **Education Public Outreach (EPO) Goal:**
  - Inspire and motivate students to do STEM
  - Provide hands on experience for college students

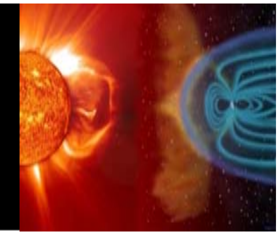
Science Background



- Earth and gas giants of our solar system are “magnetic planets”
  - The interaction between solar wind and their “magnetospheres” generate radio-wavelength masers
  - In the case of Earth, its magnetic field contributes to its habitability

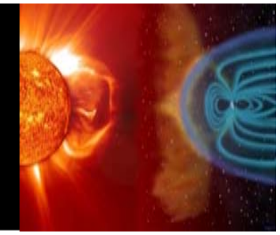


Science Background



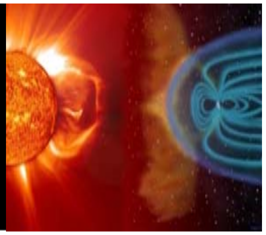
- In 2004, an exoplanet orbiting HD 179949 located 90 light-years in Sagittarius was identified to have magnetic properties
  - Hot spot that rotates around the star every 3 days (period of the planet)
    - Cause: Interaction between planet’s magnetic field and the star’s lower atmosphere
  - Analogous to magnetic connections between Jupiter and its moons

Science background



- It’s likely that most or all giant exoplanets possess magnetic fields
- One could use this discovery to “detect” exoplanets
  - Extrasolar giant planets should emit at radio wavelength allowing for their direct detection
- Current searches:
  - Very Large Array (VLA)
    - 74 MHz/ 135-200 mJy
  - Metrewave Radio Telescope(GMRT)
    - 150 MHz/0.3-2mJy

Science Priority

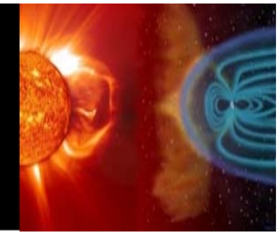


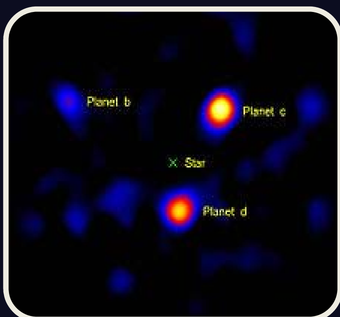
- Huge limitation for all the ground-based telescopes:
  - Earth's ionosphere
    - Cut off frequency of 10 MHz

- Need for a space-based radio telescope

XSOLARA

Science Objectives





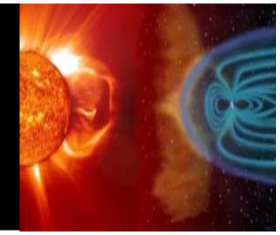
Primary

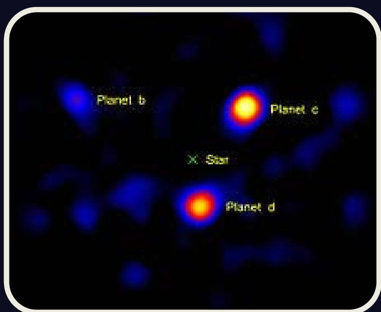
- Detect known exoplanets in order to prove the concept that exoplanets can be detected by looking for magnetospheric emissions in low-frequency range.

Secondary

- Image and track transient solar disturbances. Observe Earth's magnetospheric response to these coronal mass ejections (CMEs) and accurately predict geomagnetic storms days in advance.

Primary Objective





Primary

- Detect known exoplanets in order to prove the concept that exoplanets can be detected by looking for magnetospheric emissions in low-frequency range.

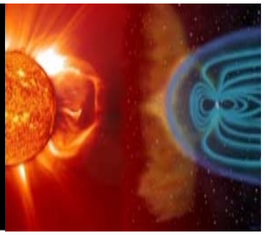
Scientific Investigations

- Observe pre-determined stars in 0.1-10 MHz frequency range
- Achieve sensitivities in order of mJy

Science Return Areas

- Enhancement of radio emission at the location of the target star
- Demonstrating that there is radio emission coming from the direction of the pre-determined star
- Prove the concept

Secondary Objective



Secondary

- Image and track transient solar disturbances. Observe Earth's magnetospheric response to these coronal mass ejections (CMEs) and accurately predict geomagnetic storms days in advance.

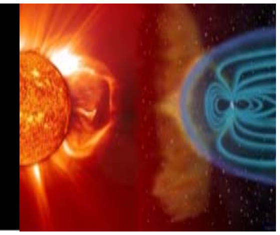
Scientific Investigations

- Little to no modification to the system
- Observe solar disturbances in the low frequency range

Science Return Areas

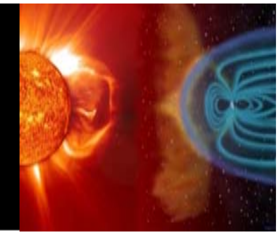
- Image and track solar disturbances with spatial resolution

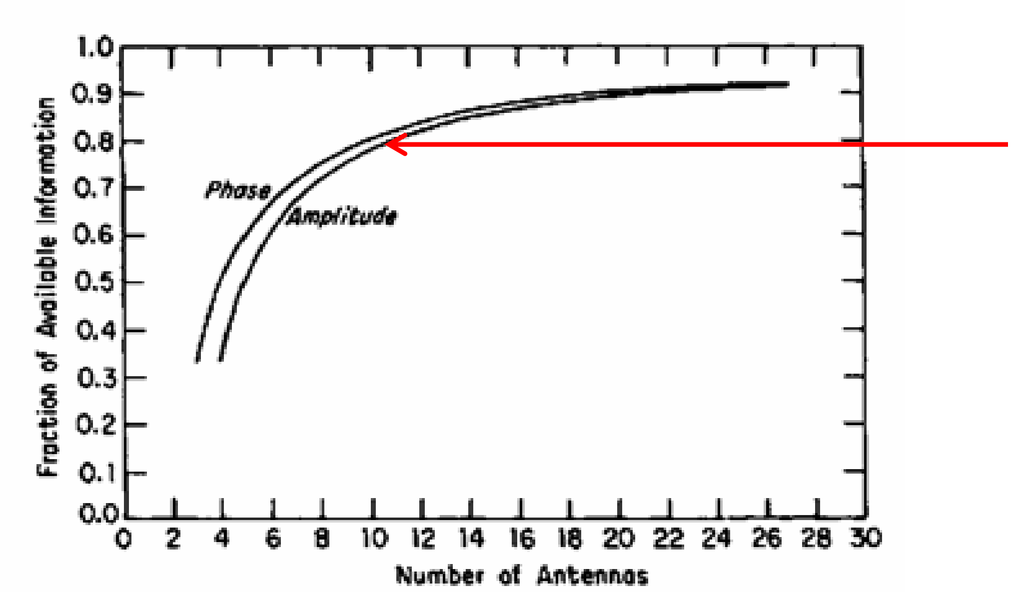
Science Traceability



XSOLARA						
Exploration Priorities			**Science Objectives**	**Science Investigations**	**Specification**	**Parameter Criteria**
Decadal Survey	**Goal I:**	**<u>Science Goal 1c</u>**: Search for and exploit extrasolar planet	search for an extrasolar planetary magnetospheric emissions as a means of directly detecting and characterizing those planets.	Observe the sky below Earth's ionosphere cutoff freq.	Frequency	0.1-10 MHz
					Instantaneous aperture plane	91
					Bandwidth	1 MHz
				Use Aperture Synthesis techniques	Sensitivity	120 mJy
	Goal II:	**<u>Science Goal 2c</u>**: Characterize the structure of extrasolar planets			Number of Antennas	14
					Relative time Knowledge	500 nanosecond
					Relative Position Knowledge	30 m

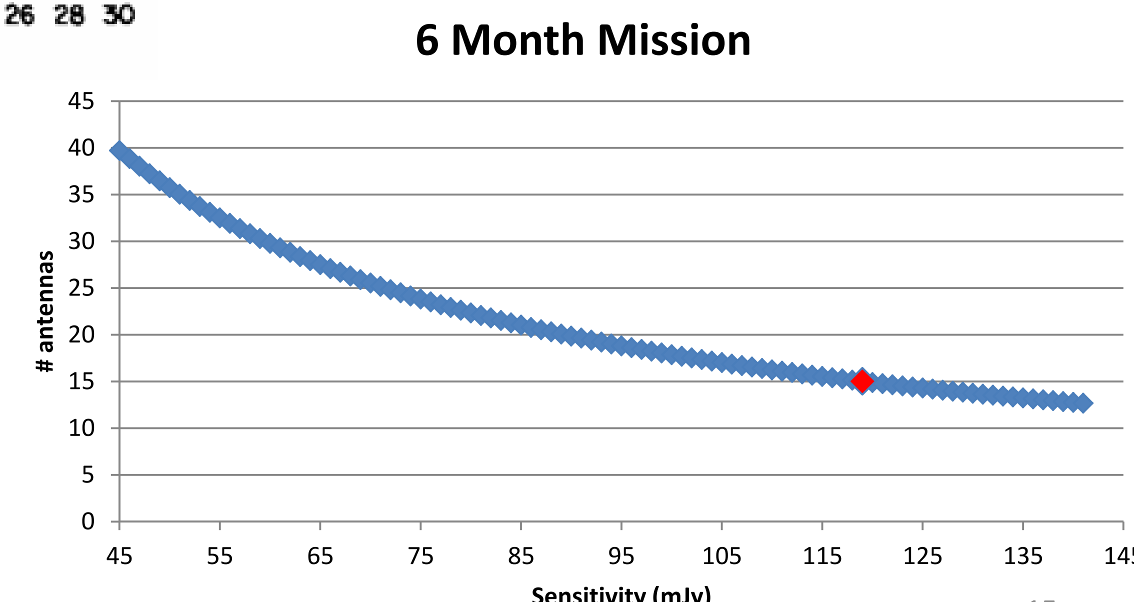
Sensitivity vs. # Antennas



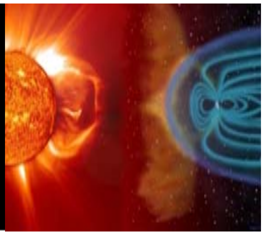


Bare minimum number of antennas needed for a synthesis array. Can get 80% of the possible phase data and 78% of the amplitude data.

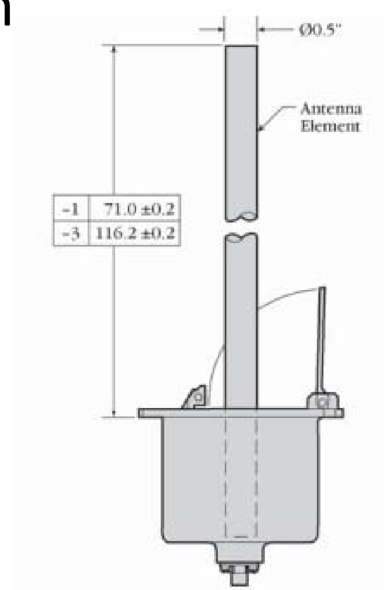
- 180 days of mission, 10 antennas
  - 125 mJy
- 180 days of mission, 14 antennas
  - 120 mJy
- 365 days of mission, 10 antennas
  - 90 mJy
- 365 days of mission, 40 antennas
  - 24 mJy

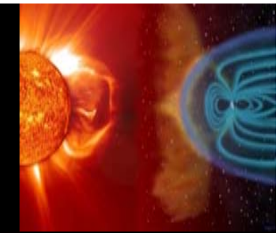


Science Instrument



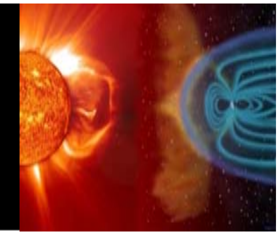
- Simple dipole antenna
- "STEM" technology
  - Storable Tubular Extendable Member
  - Manufactured in beryllium copper
  - 11 meter in length
  - Flight heritage:
    - Voyager
    - Hubble
    - Many more
- Modified MF/HF receiver
  - Capable of frequency range 0.1-10 MHz
  - Proven technology





Mission Design

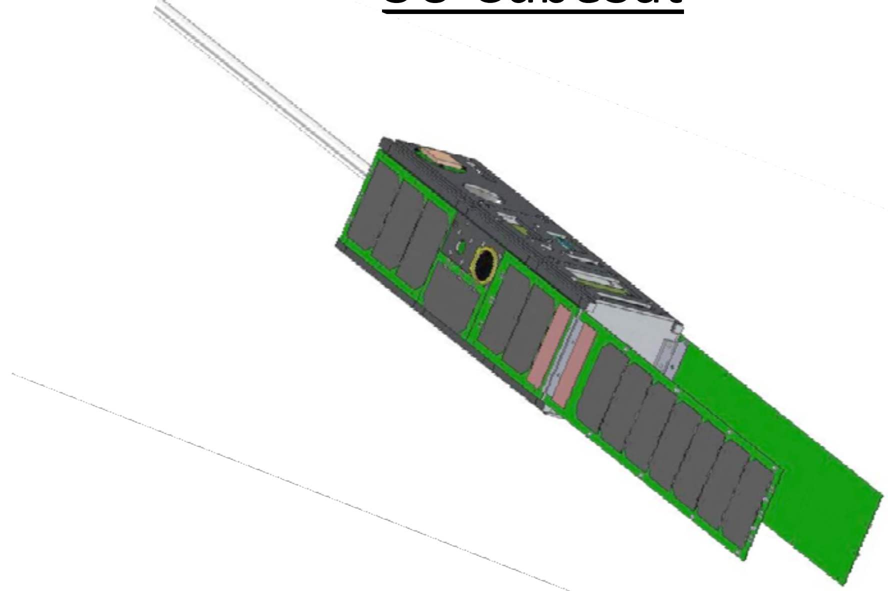
Mothership/CubeSat Platform



Mothership

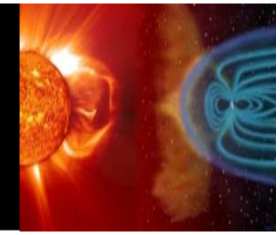
- Modified ESPA ring

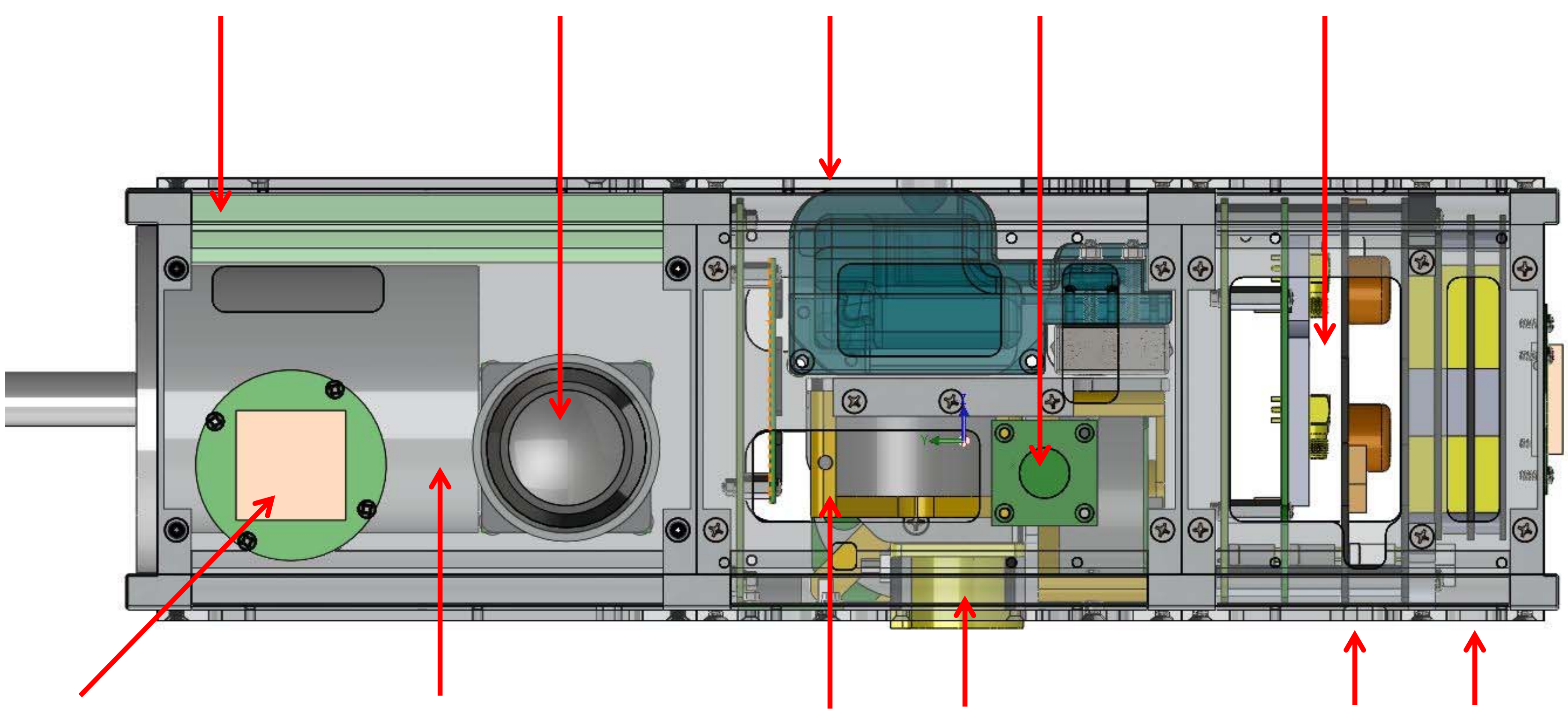
3U CubeSat



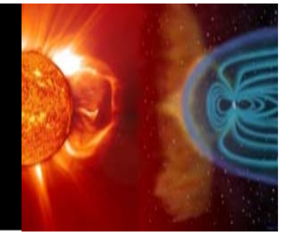
- CubeSats
  - 34x10x10 cm
  - 4 kg
  - Low-cost
  - Student built

CubeSat Components





Orbit design

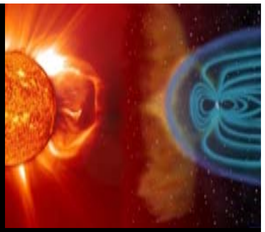


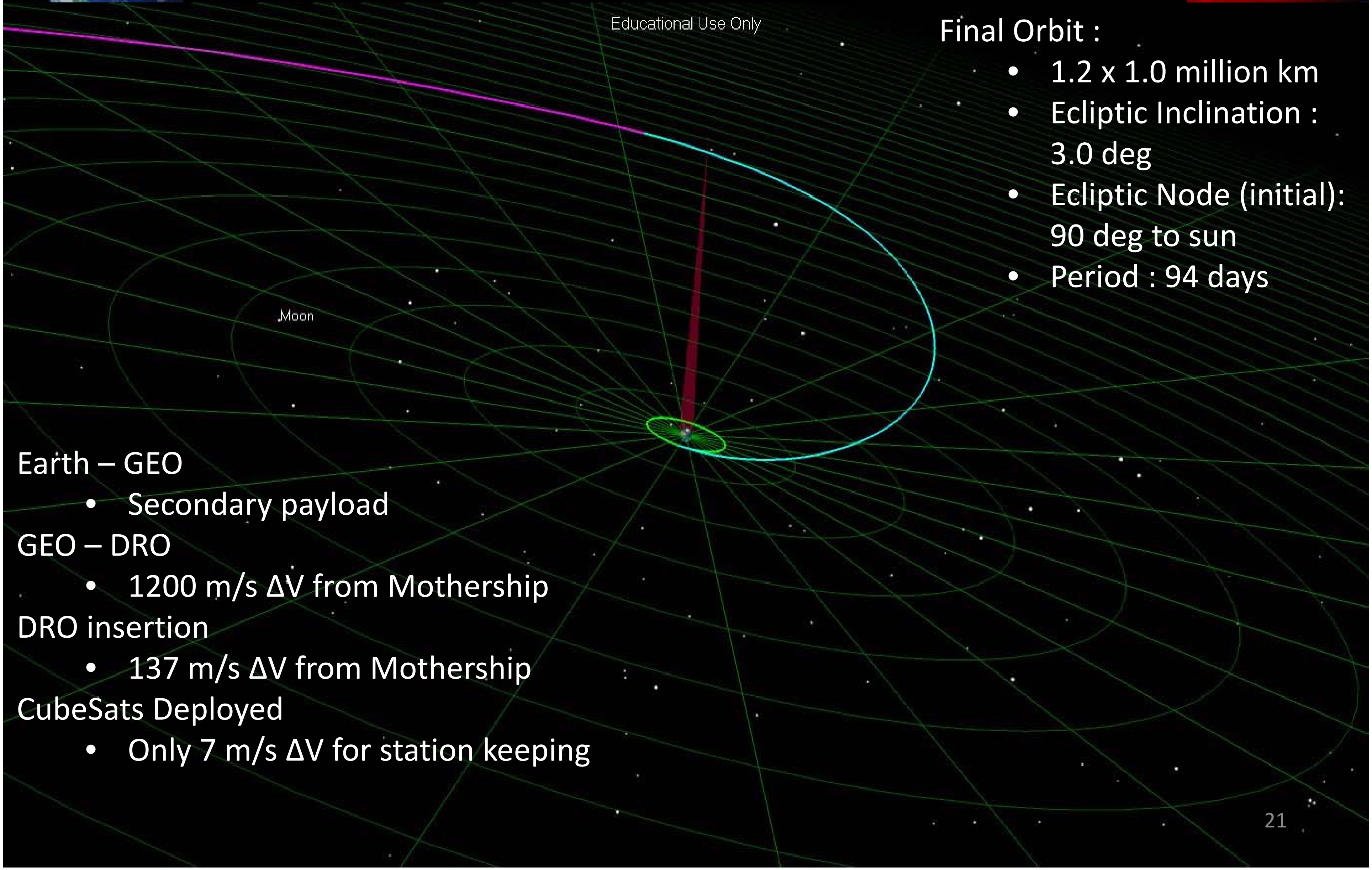
Criteria

- Minimize terrestrial radio interference
  - Heavy use of the radio spectrum in the relevant frequency (AM radio band)
- Avoid “break-out” of terrestrial signals
- Largest accessible fraction of sky at any given time
- Stable orbit to minimize station keeping

→ Distant Retrograde Orbit (DRO) at 1.2 million km from Earth

Trajectory





Final Orbit :

- 1.2 x 1.0 million km
- Ecliptic Inclination : 3.0 deg
- Ecliptic Node (initial): 90 deg to sun
- Period : 94 days

Earth – GEO

- Secondary payload

GEO – DRO

- 1200 m/s ΔV from Mothership

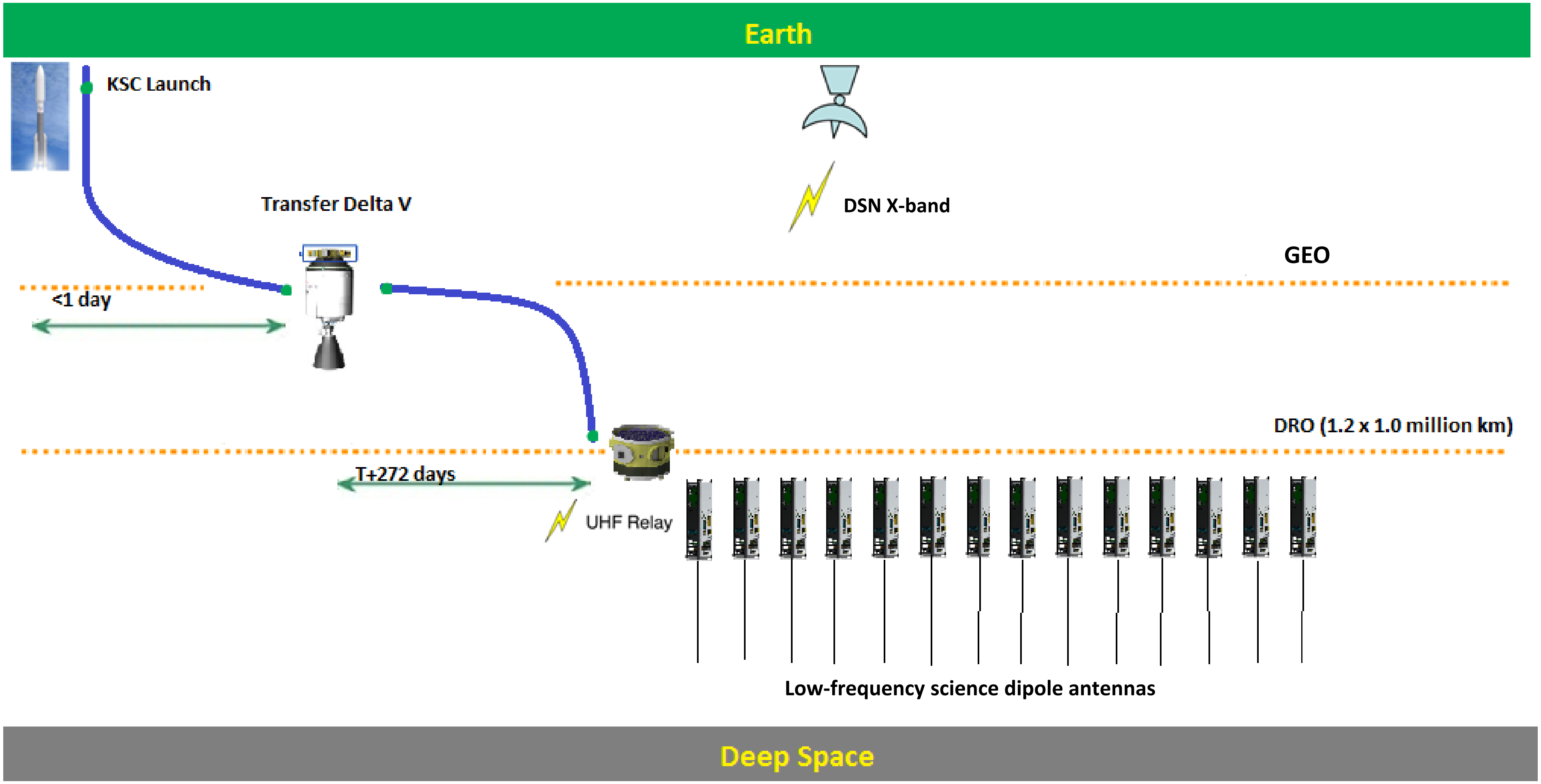
DRO insertion

- 137 m/s ΔV from Mothership

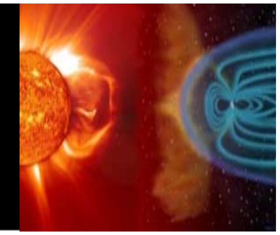
CubeSats Deployed

- Only 7 m/s ΔV for station keeping

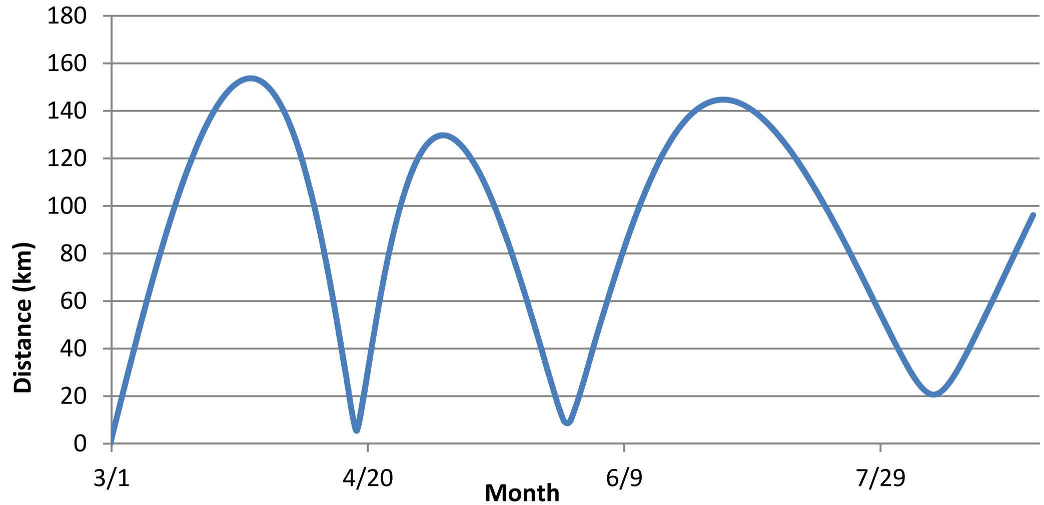
Mission Design



CubeSat Deployment/Configuration

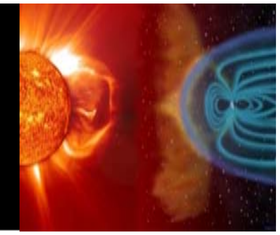


- No particular configuration will be followed
- CubeSat deployment timing
  - $t = t_o + 10$ minutes
- CubeSat deployment ΔV
  - 0.1 m/s



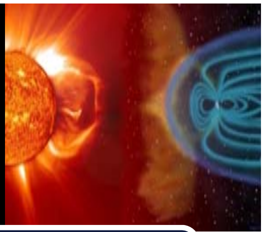
- Need to have position knowledge of each CubeSat
- No need to control the position of each CubeSat
- No need to point the science antenna
- Can use the drift rate in our advantage to change angular resolution over time

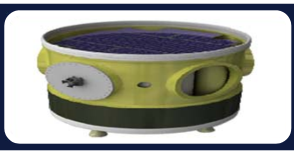
Current Design Status

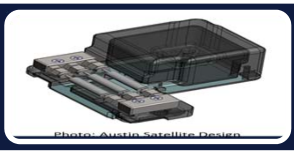


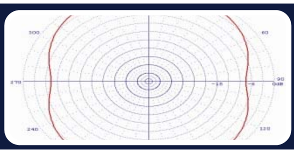
- Design Maturity
  - Currently XSOLARA is a feasibility study
  - Components and data shown are to demonstrate the design is reasonable and achievable
- Technical Margins
  - Resource margins meet JPL design principles for Concept Review
  - Resource margins will be continuously monitored
- Cost
  - University and hardware costs will be shown

XSOLARA Subsystems Overview

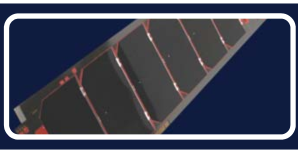



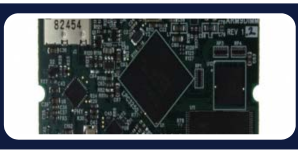

Mothership


Propulsion

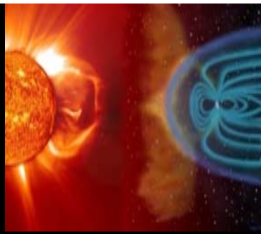

Communication


ADCS


Power

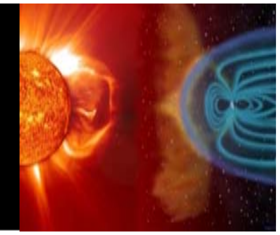

C&DH


Structure



Mothership

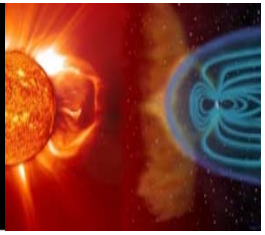
Hardware



Mothership: SHERPA 2200

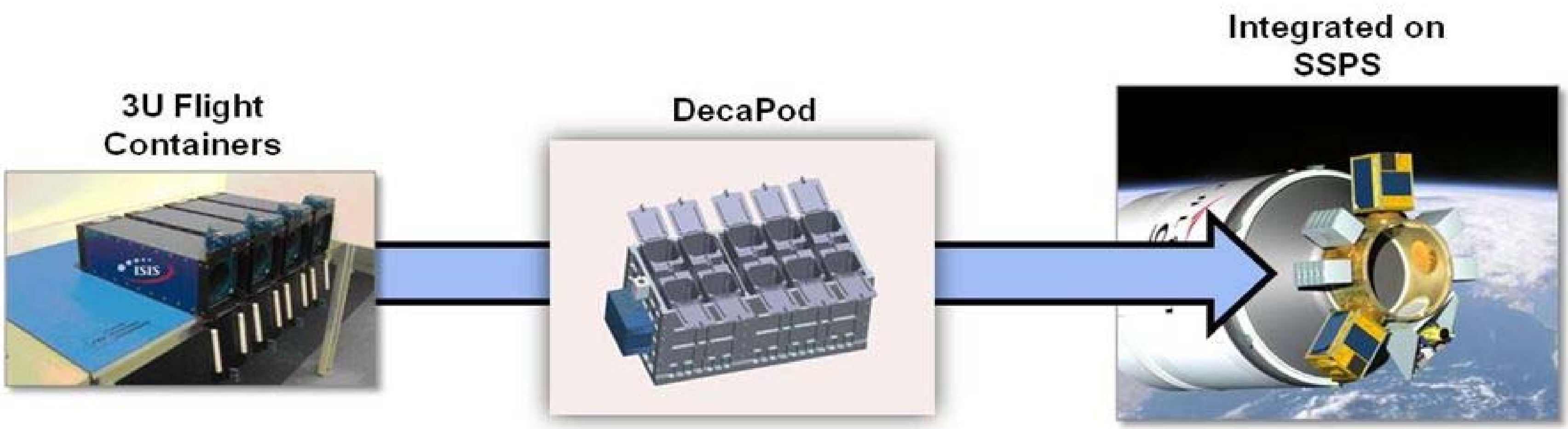
- Gross Mass: 2000 kg
- Capable of 2200 m/s of ΔV
- Size/Volume: Standard ESPA ring (1575 mm) interface
- Currently rated for Cis-Lunar environments, can be modified for DRO
- All subsystems are compatible with XSOLARA's mission with slight modifications in the communication and attitude control subsystems

Hardware

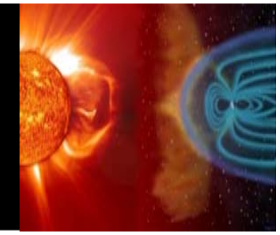


Andrews CubeSat Launcher

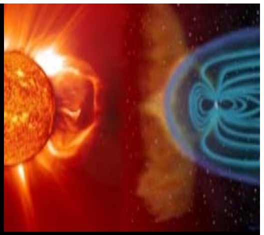
- 2 launchers attach directly to SHERPA
- Each launcher holds 10 3U CubeSats
- Uses the ISIS-POD launcher
- Contains a sequencer that automatically dispenses the CubeSats in a collision-free environment
- Capable of recording data from and photographing separation



Launch Services

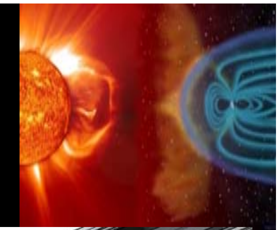


- Launch opportunities:
  - Falcon 9
  - Falcon Heavy
  - Delta IV
  - Atlas V
  - Minotaur IV SLV
- Andrews Space will be providing the launch vehicle, SHERPA, and CubeSat launcher for XSOLARA
- First flight scheduled for 2014



Propulsion

Baseline

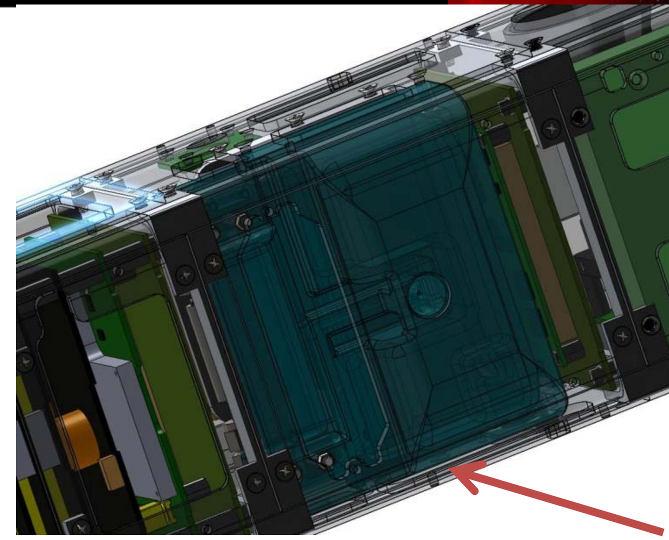


- CubeSat propulsion system:
  - Cold Gas system
  - Must provide at least 7 m/s ΔV

- CubeSat propulsion system can hold up to 0.09 kg of propellant providing up to 15 m/s ΔV

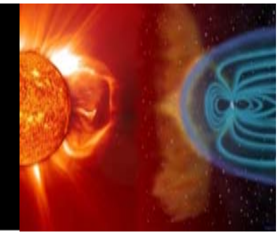
CubeSat Cold Gas Mass		
Mass of 1 CubeSat (kg)	4.00	4.00
ΔV (m/s)	15.20	7.00
ISP (s)	70	70
Propellant mass (kg)	0.09	0.04

- CubeSat can provide more than double XSOLARA's station keeping needs



Thruster in CubeSat CAD model

Hardware



- CubeSat propulsion system:
  - Austin Satellite Design
  - R-236fa cold gas refrigerant
  - 1 thruster per CubeSat for station keeping

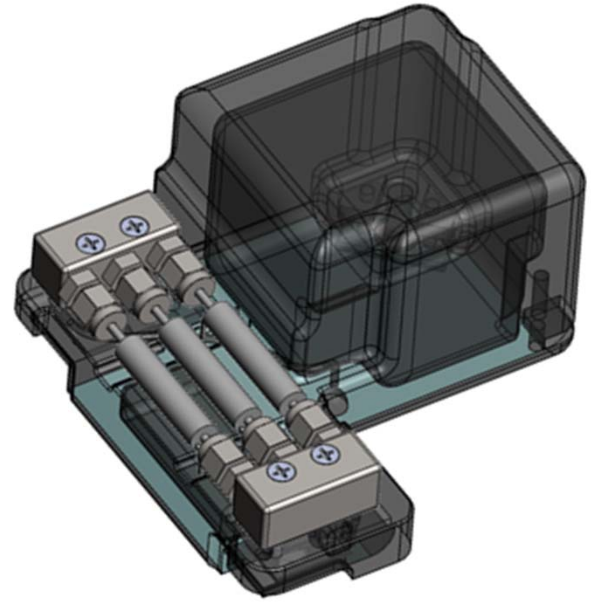
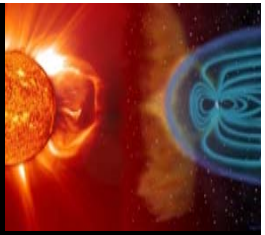


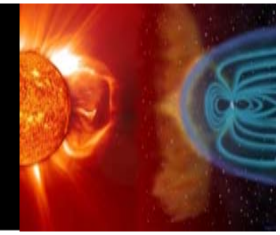
Photo: Austin Satellite Design

- Complete module
  - Tanks and plumbing built into one piece made from solid stereolithography plastic



Communication

Constraints



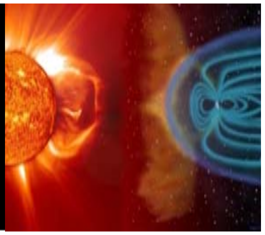
Mothership

- Power is limited by SHERPA's capabilities
  - 150 W allotted to the Communication Subsystem
  - 140 W only includes transmit power
  - Maximize bit rate within this limitation
- Minimum downlink data rate is determined by Nyquist Sampling Rate

CubeSats

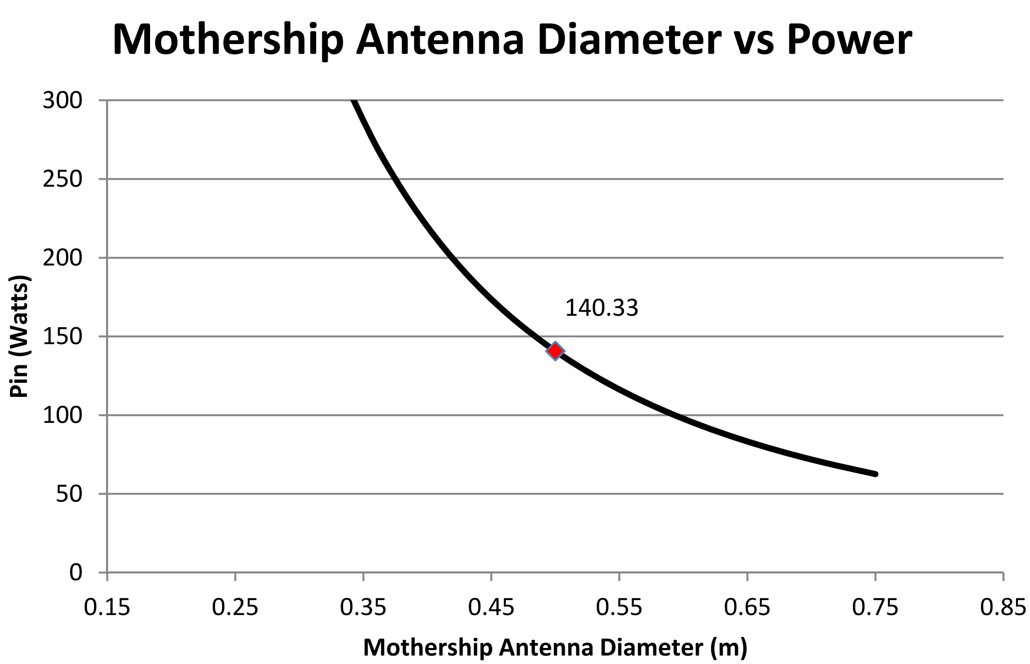
- Data rate is limited by the Mothership's data rate
- Determined by modulation and Eb/No requirements
- 0.1 to 10 MHz frequency range
  - Determines minimum bit rate via Nyquist Sampling
  - Limits hardware possibilities and selection
- Transmit power will be rounded up to 0.5 W to account for any errors that may be experienced throughout the mission

Baseline

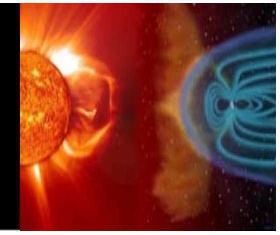


Mothership

- The Mothership will have nearly constant uplink and downlink communication with the Deep Space Network's 34m antennas via X Band frequency
- Equipped with a 0.5m High Gain Antenna (~30dB), multiple receivers and patch antennas
- Receivers will be unique to XSOLARA's requirements
- SHERPA shall allocate ~150 W to the communication subsystem
  - Approximately 140 Watts will be used in transmit/receiving power



Downlink-Mothership

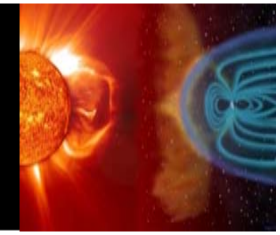


- 37.7 Mbps (Maximum performance)
  - Minimum set by Nyquist Sampling
    - Bit Rate=N*2*df*b
  - Constrained by available power
- PM-BPSK Modulation
  - Binary Phase Shift Keying
  - Converts to binary: robust and compact
- Transmit Power: 140.33 W
  - Worst Case Scenario
  - Highest Performance

Mothership to Earth

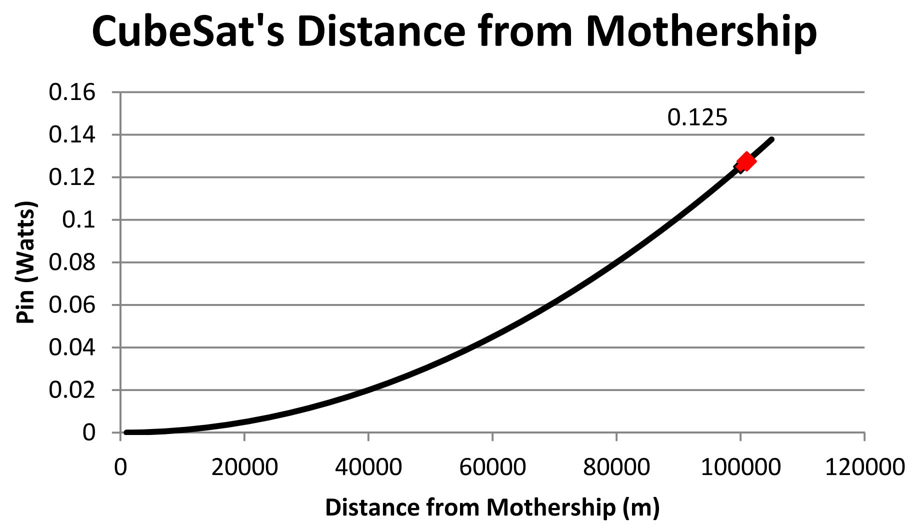
Downlink	**Linear**	**dB**
η-comm	0.3	
η-mother	0.6	
η-DSN	0.7	
D-DSN	34	
D-mother	0.5	
Frequency	8.40E+09	
Speed of Light	2.98E+08	
λ	0.04	
Distance	1.20E+09	
Gtrans	1176.30	30.71
Grec	6.35E+06	68.02
Ls	5.53E-24	
La	0.45	-3.5
Lϴ	1	0
k	1.38E-23	
Ts	100	
B	3.77E+07	
I	2.00	3
Eb/No req	1.82	2.6
Link Margin	3.16	5
Eb/No des	11.48	10.6
Pin	107.95	
Margin	32.38	
Pin Total	140.33	
Prec	5.98E-13	

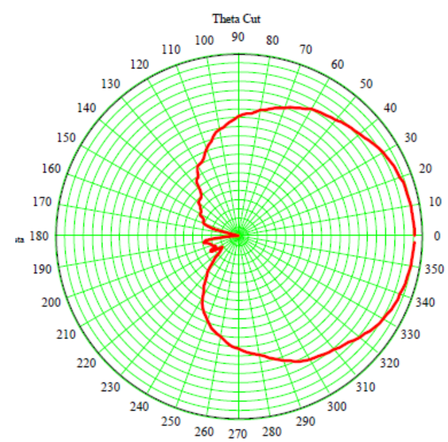
Baseline



CubeSats

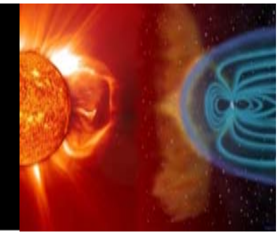
- Power was calculated at maximum distance from Mothership
- Equipped with a Low Gain antenna (~6dB), patch antennas, receivers, and a science antenna





Patch Antenna Coverage

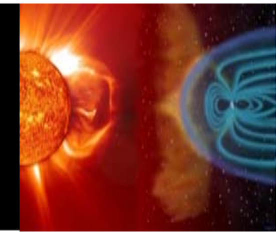
Downlink-CubeSat



- 2.67 Mbps (Maximum Performance)
  - Minimum set by Nyquist Sampling
    - Bit Rate=N*2*df*b
  - Constrained by Mothership's data rate
- Transmit Power: 0.125 W
  - Round to 0.5 W
  - Worst Case Scenario
  - Highest Performance

CubeSat to Mothership		
Downlink	**Linear**	**dB**
η-comm	0.3	
η-cube	0.6	
η-mother	0.6	
D-mother	0.5	
D-cube	0.50	
Frequency	5.00E+08	
Speed of Light	2.98E+08	
λ	0.60	
Distance	1.00E+05	
Gtrans	3.98	6
Grec	1.64	2.15
Ls	2.25E-13	
La	1	0
LΘ	1	0
k	1.38E-23	
Ts	100	
B	2.67E+06	
l	2.00	3
Eb/No req	1.82	2.6
Link Margin	3.16	5
Eb/No des	11.48	10.6
Pin	0.096	
Margin	0.029	
Pin Total	0.125	
Prec	4.2372E-14	

Hardware

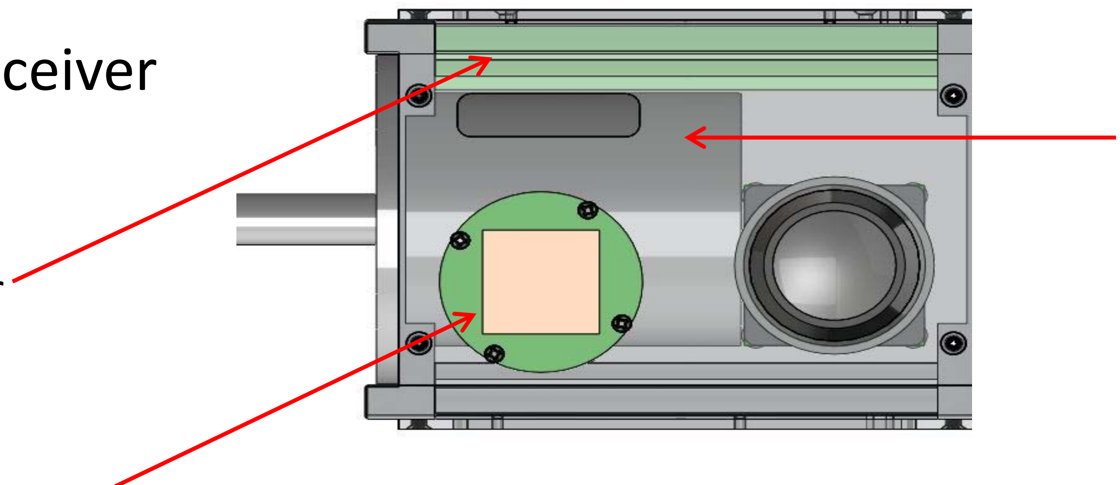


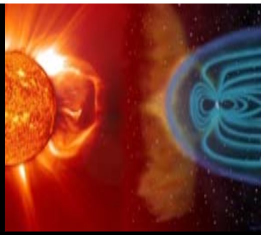
Mothership

- High Gain Antenna
  - 0.5 m
  - Gain on ~30 dB
  - Efficiency of 60%
- UHF Receiver
- Patch Antennas
- X-Band Receiver

CubeSat

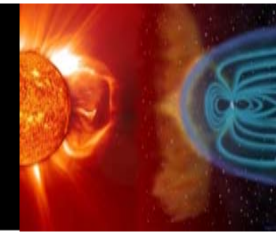
- 3 Patch Antennas
- 1 Science Dipole Antenna
  - STEM JIB Antenna (11m)
- 1 MF/HF Receiver
- UHF Receiver





ADCS

Constraints



CubeSat

- Power Constraint:
  - Keep solar panels facing toward the Sun at ±5.5°
- Volume/ Mass Constraint:
  - 1U dedicated to ADC
- Propulsion Constraint:
  - The CubeSats have a limited amount of propellant onboard

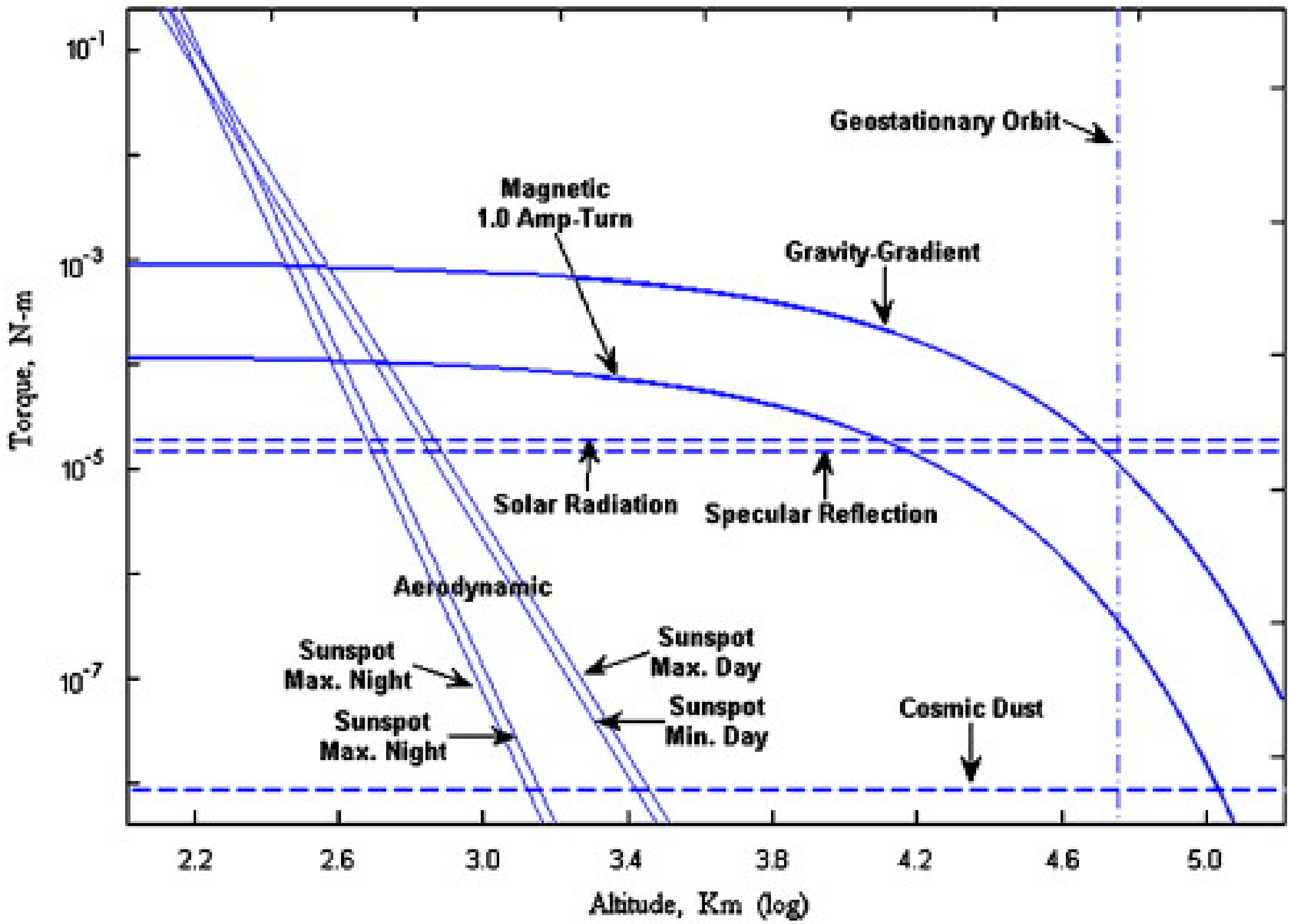
Mothership

- Pointing Constraint:
  - The Mothership's HGA must be pointed at Earth at ±1.75° at all times

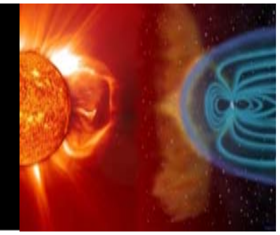
Subsystem	Instrument	Control Requirement	Determination Capability
Mothership COM	HGA	±1.75 °	Not Given
CubeSat EPS	Solar Array	±5.5°	±0.1°

Baseline

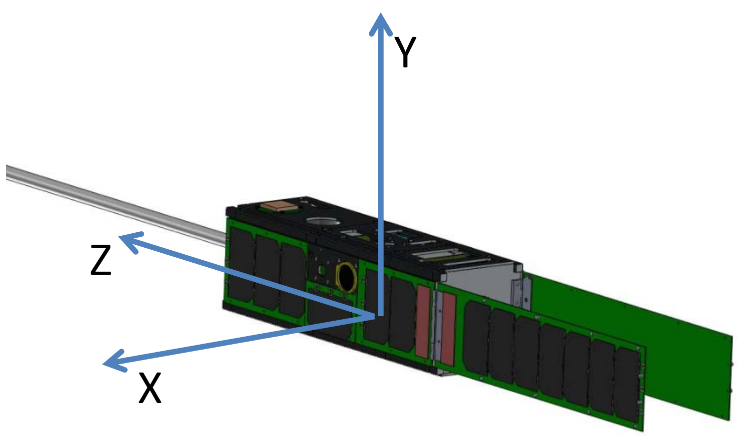
Disturbance Torques



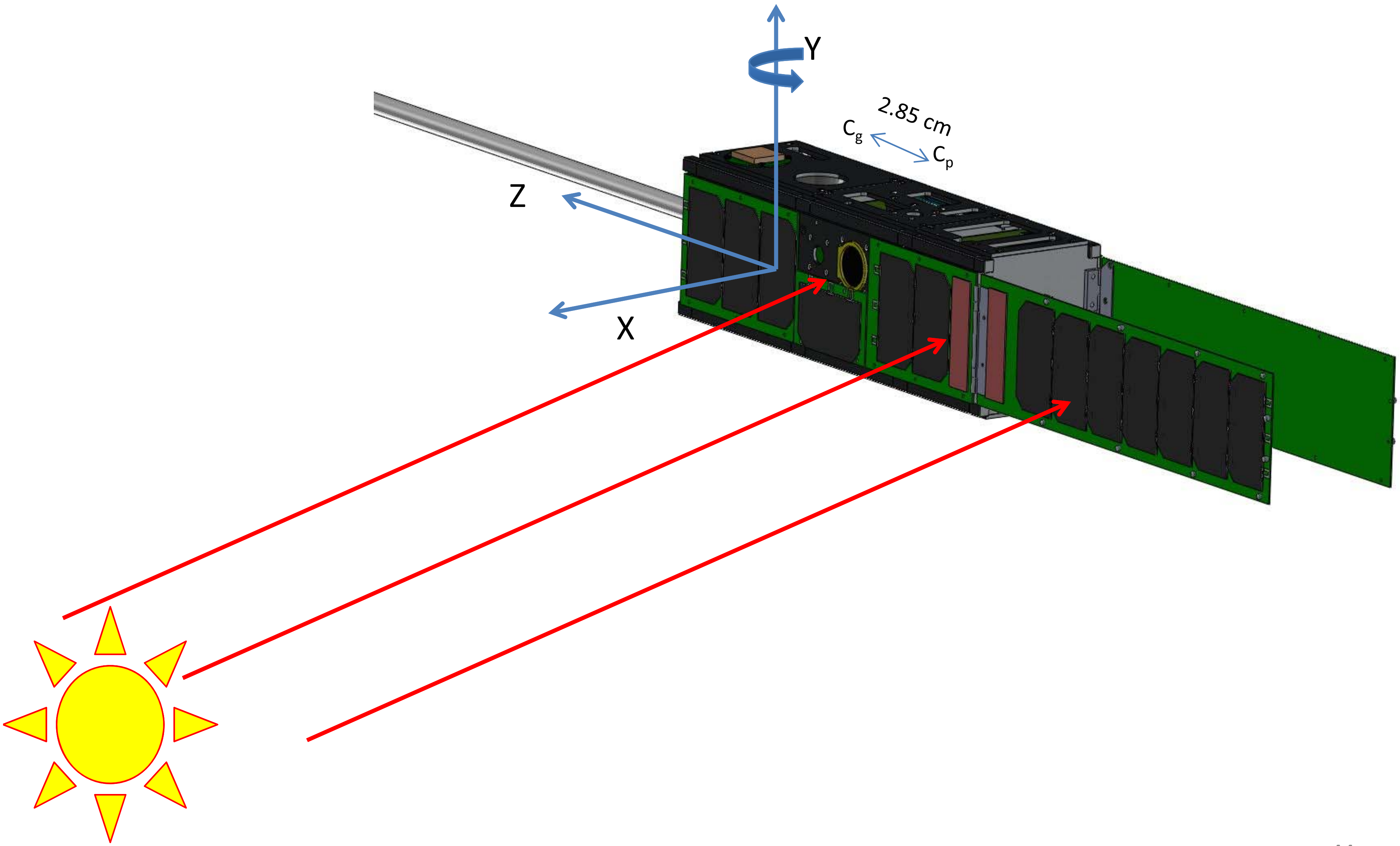
Baseline



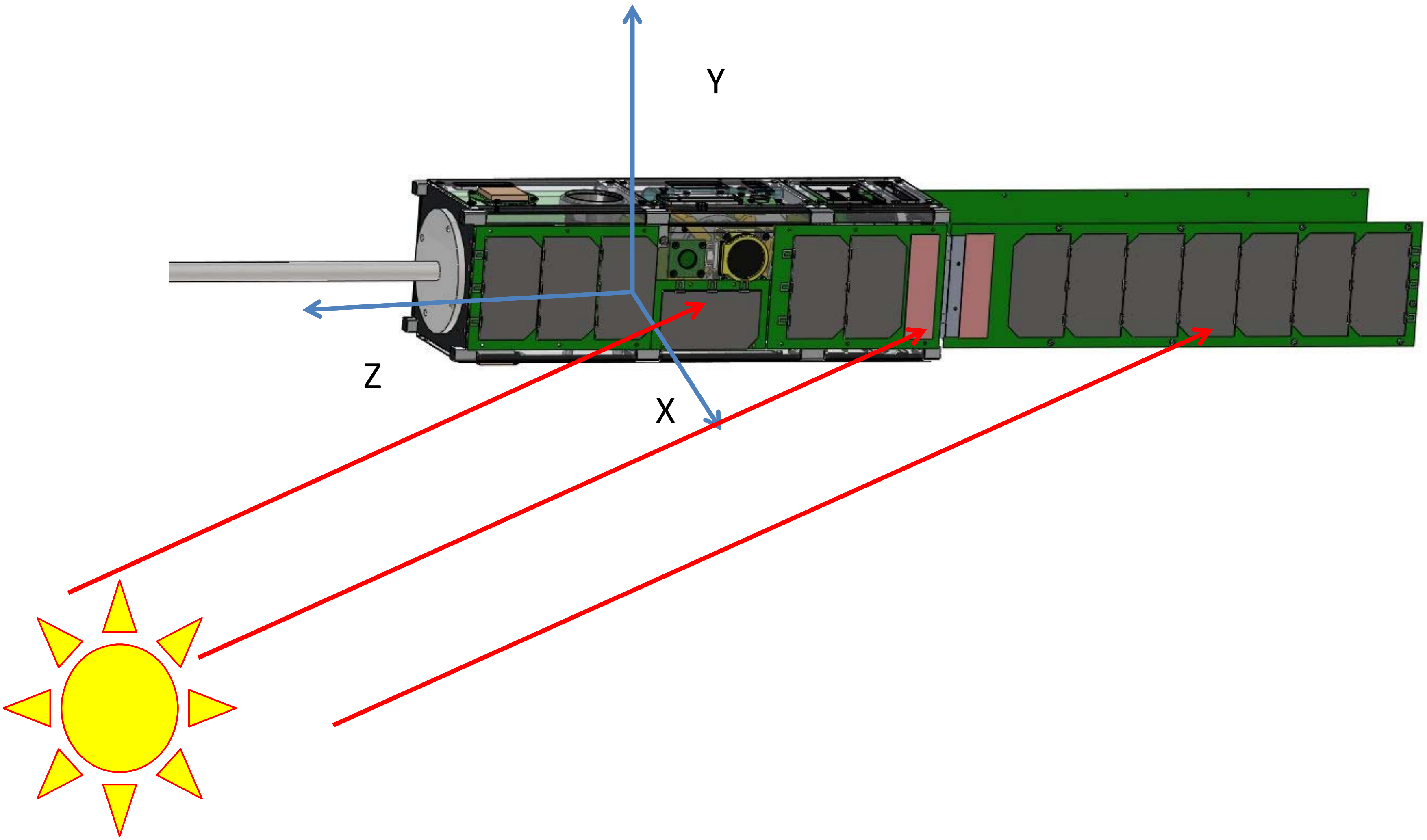
Analysis of Reaction Wheels for a 3U CubeSat	
Period of DRO (Days)	94
Distance Between Cg and Cp (m)	0.029
Solar Radiation Pressure at DRO – Tps (N*m)	7.12E-9
Sinclair Reaction Wheel Capability (Nms)	7.00E-3
Momentum Storage in Momentum Wheels (Nms)	5.79E-2
Days Between Unloading (days)	8.27



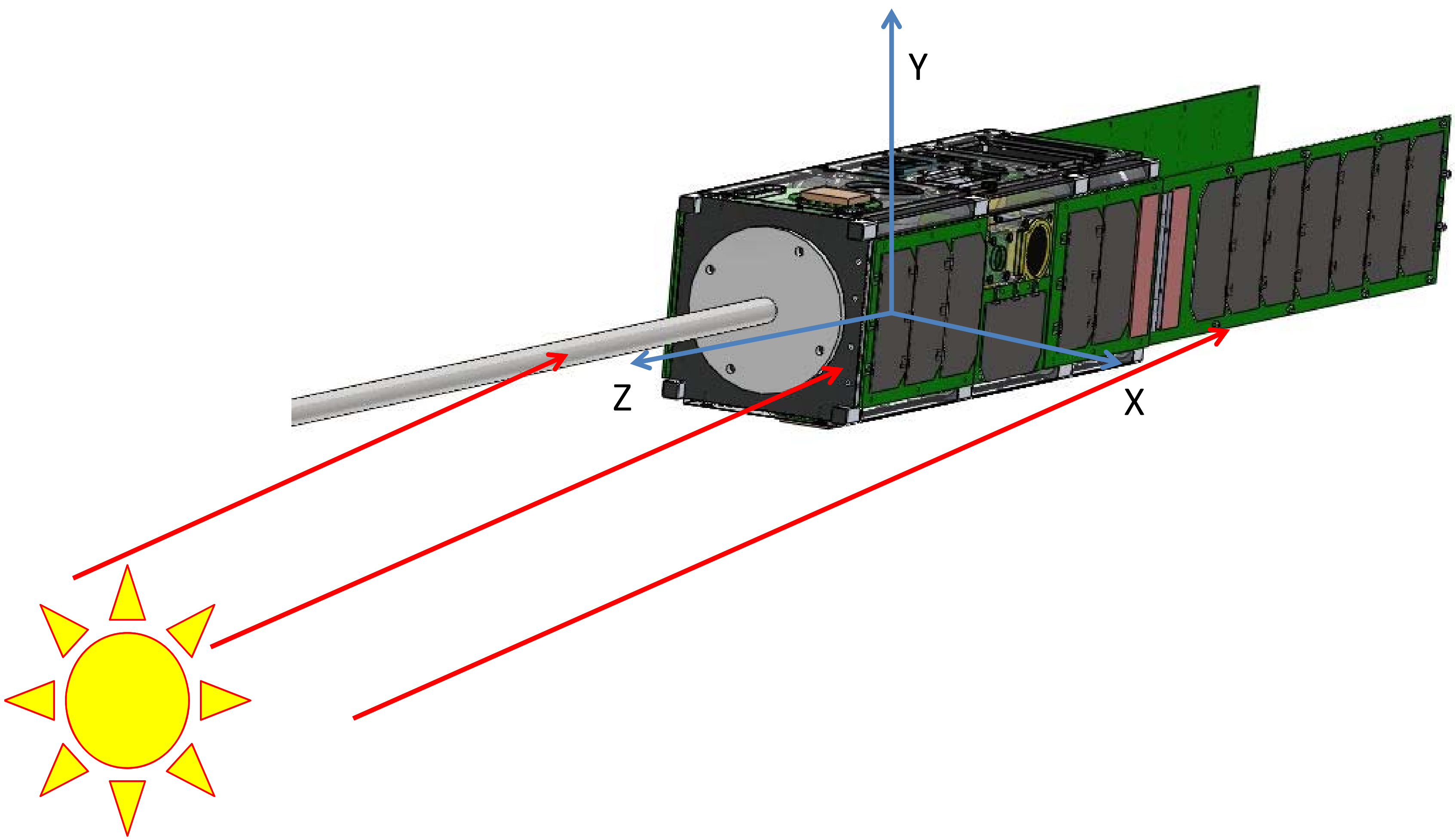
Baseline



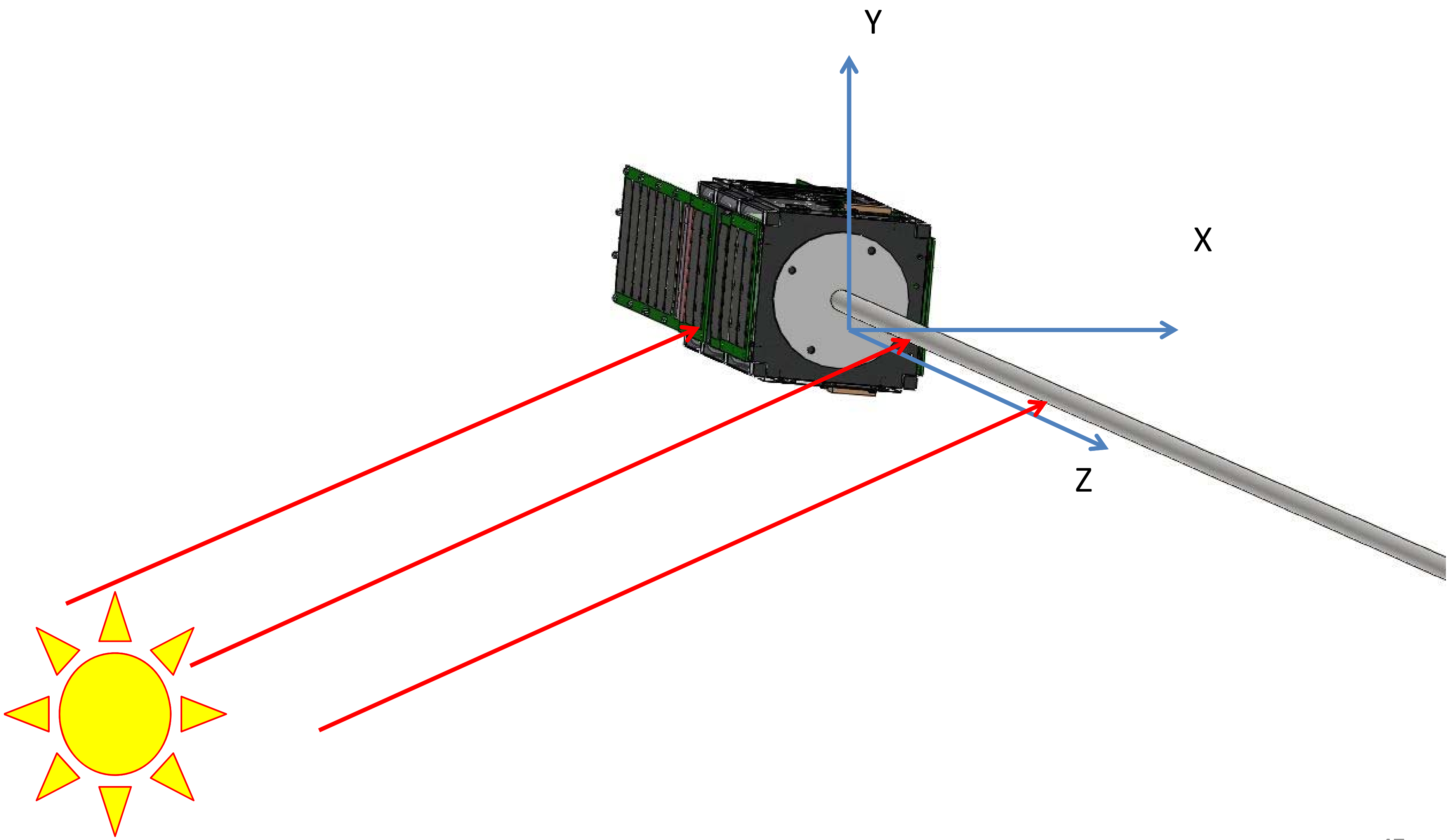
Baseline



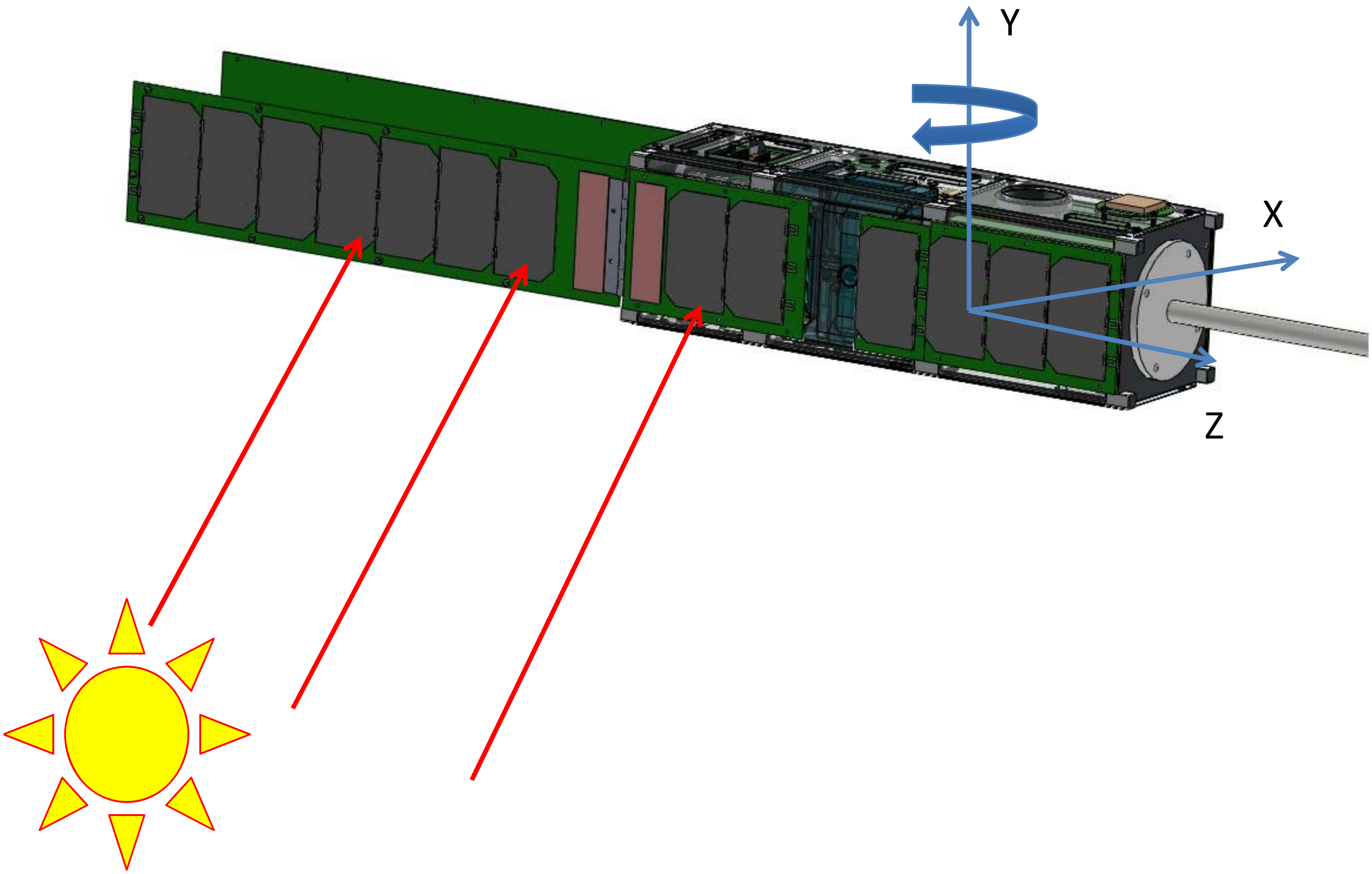
Baseline



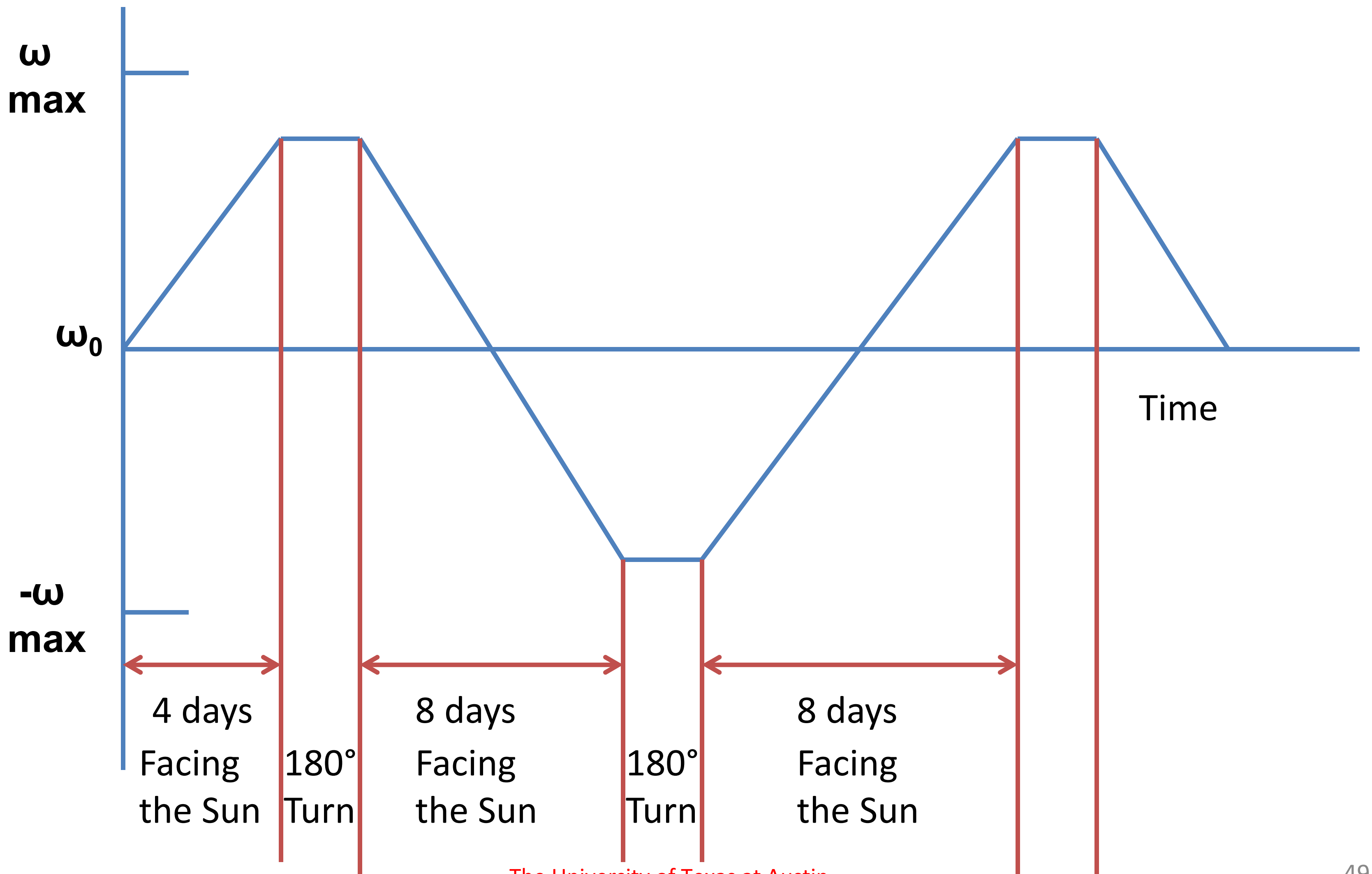
Baseline



Baseline

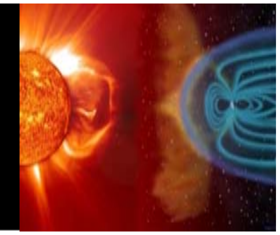


Baseline



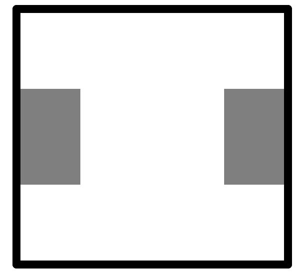
ω max
ω0
-ω max
Time
4 days
Facing the Sun
180°
Turn
8 days
Facing the Sun
180°
Turn
8 days
Facing the Sun

Baseline



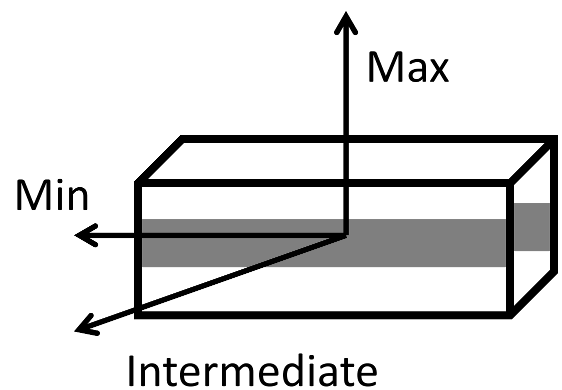
How to Maintain Max Moment of Inertia:

Top View

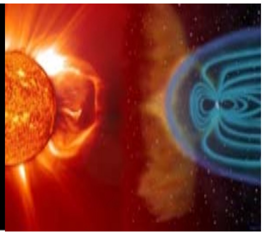


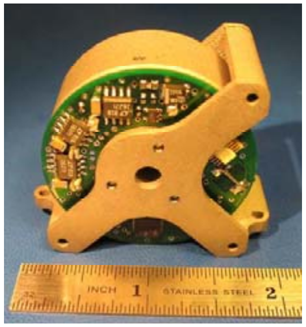
Side View

Front View



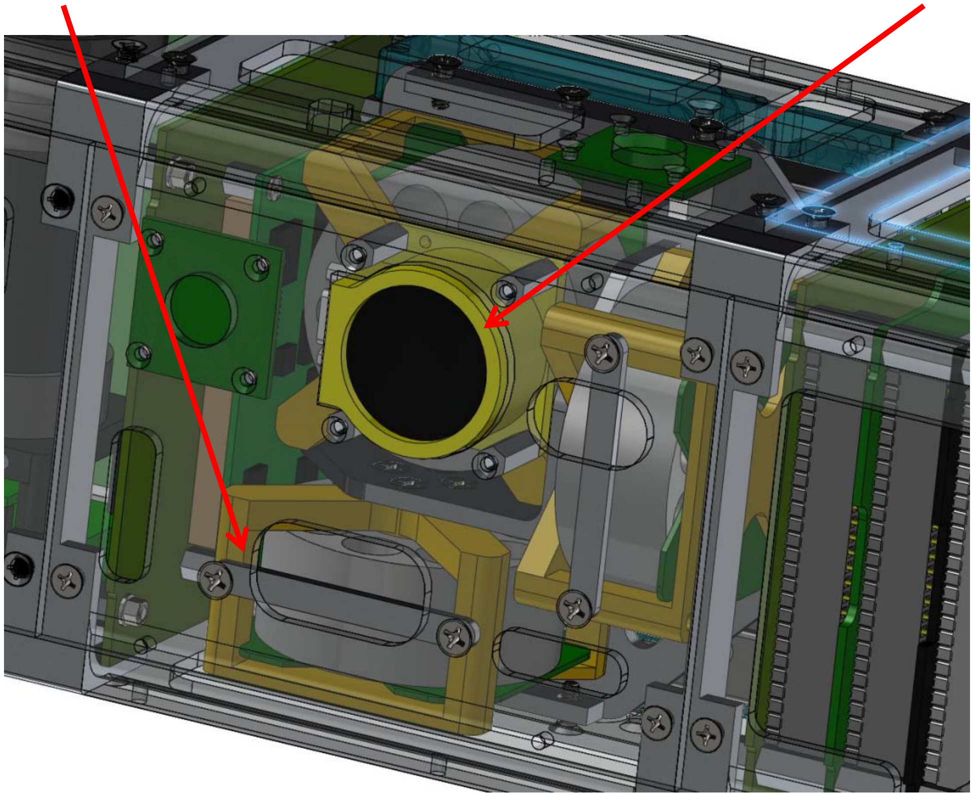
Hardware



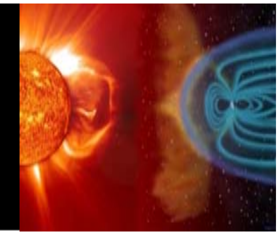


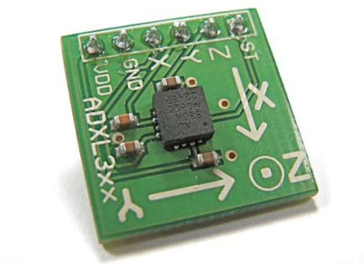
Reaction Wheels: Sinclair Interplanetary

Sun Sensor: Space and Ground Systems UK



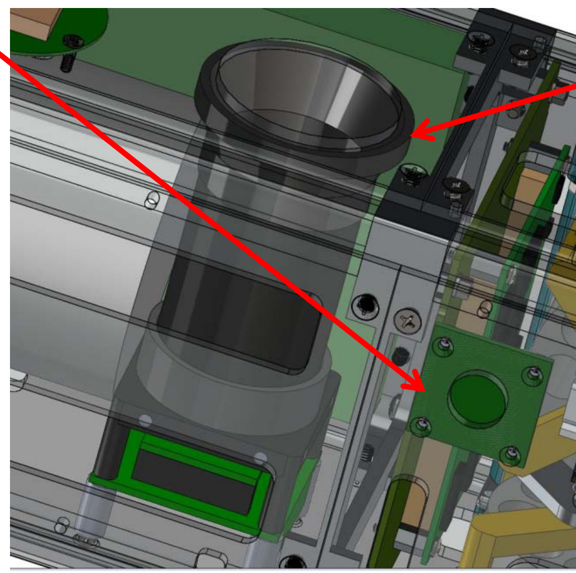
Hardware

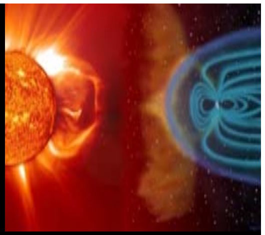




3-axis Accelerometer: Analog Devices
3-axis Gyroscope: Honeywell

Star Camera: Computer-Matrix Vision,
Lens-Schneider Optics
Designed By: Chris McBryde



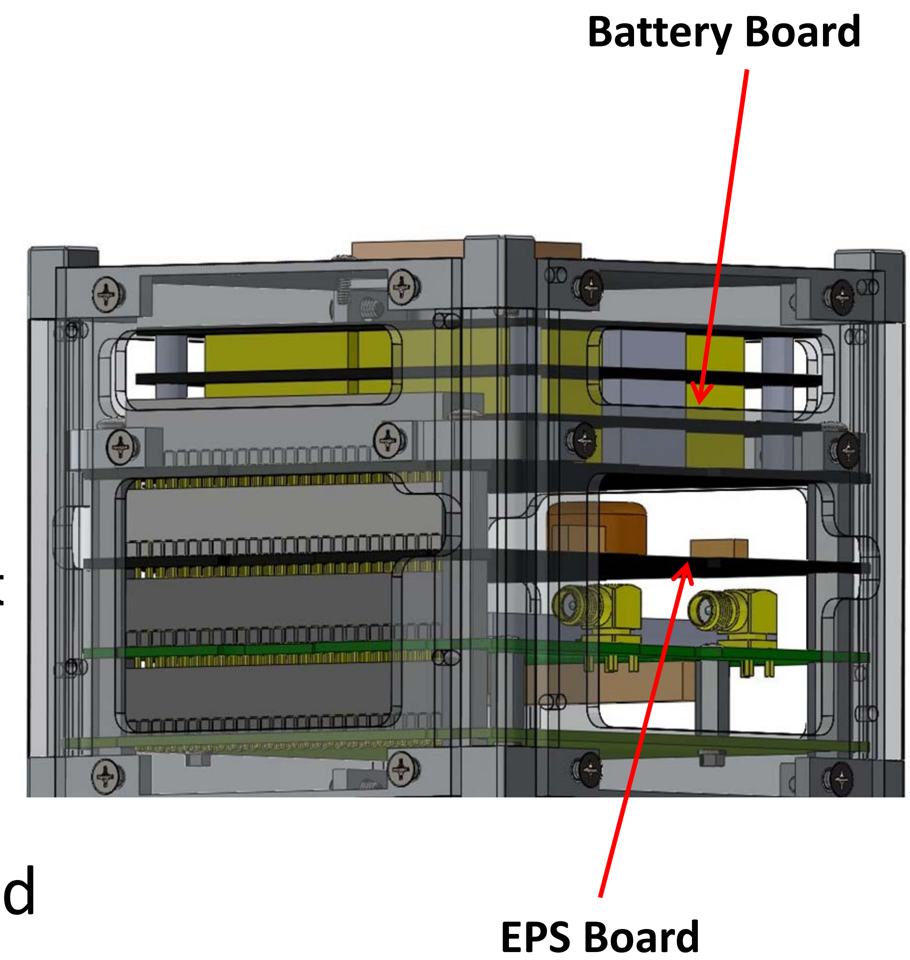


Power

Constraints

<u>CubeSat</u>

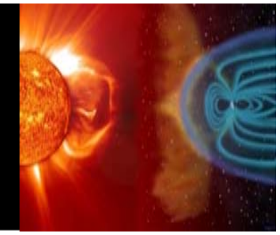
- Provide power to all subsystems
- Volume/Mass:
  - Stay under a 1U in size
  - Minimize mass
- Cost:
  - Find components that are capable of the requirement but minimize cost



<u>Mothership</u>

- Use the SHERPA as designed

CubeSat Power Budget

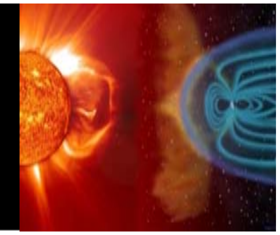


Maximum Case

Subsystem	Power (W)	30 % Contingency	Total Power (W)
Attitude Determination & Control	3.04W	0.91	3.95 W
Command & Data Handling	0.97 W	0.29	1.26 W
Communication	3.50 W	1.05	4.55 W
Power	0.01 W	0.00	0.01 W
Propulsion	0.80 W	0.24	1.04 W
Total Power			**10.81 W**

Other Power Modes: Slewing, Uplink, Downlink, and Safe

CubeSat Batteries



On Board Batteries

- Provide the spacecraft with power in the case of:
  - Eclipse
  - $\beta > 5.5°$

Lithium-Polymer Batteries (30 W-hr)

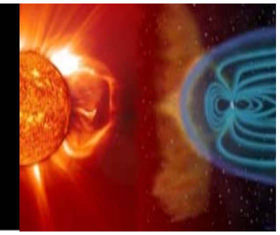
- 3.3V and 5V regulated buses
- Built in inhibits to protect from shorts

Electrical Power System

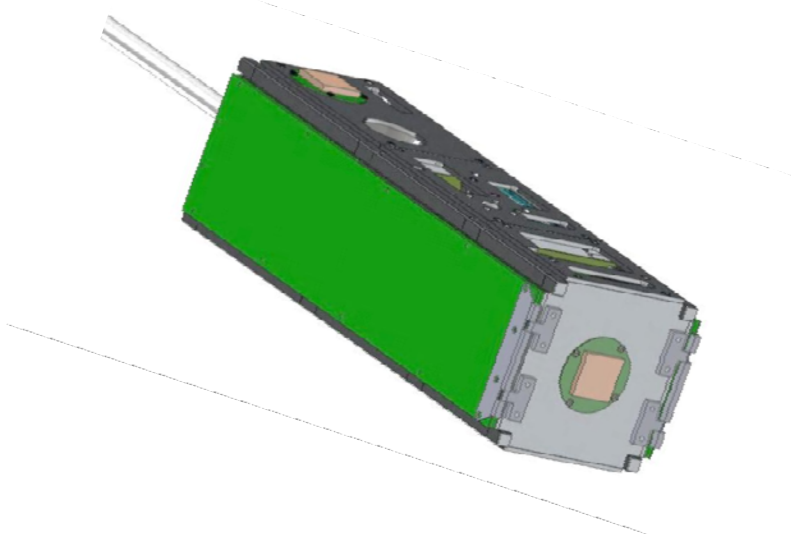
- Built in inhibits

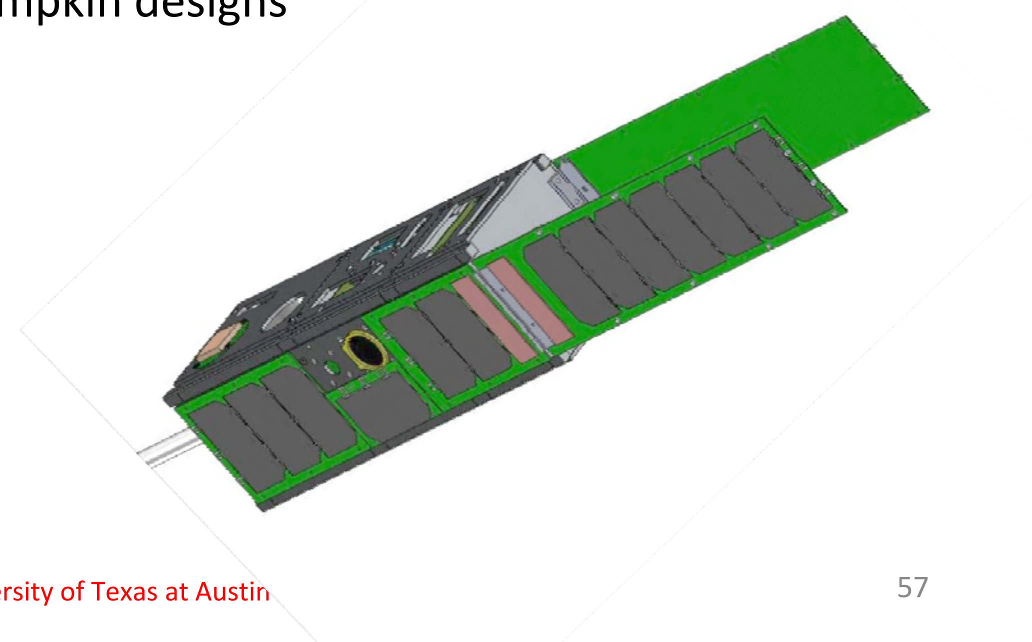
Slewing Power Mode	
Subsystem	Total Power (W)
Attitude Determination & Control	3.00 W
Command & Data Handling	1.26 W
Communication	0.00 W
Power	0.01 W
Propulsion	0.00 W
Total Power	**4.27 W**

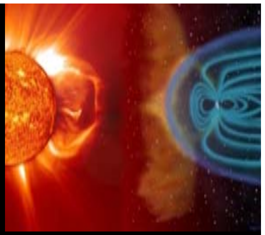
CubeSat Solar Panel Design



- **Deployable Solar Panels**
  - Need a maximum of 10.81 W for all subsystems
  - Non-deployable solar panels allow for up to 5.2 W
  - Allows for up to 11.27 W when deployed
  - 7 solar panels built with Ultra Triple Junction CICs solar cells on each deployable section
  - Thermal knife used for deployment after separation from ISIS-Pod
  - Based on Clyde Space and Pumpkin designs

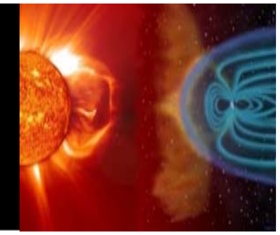






C&DH

Constraints



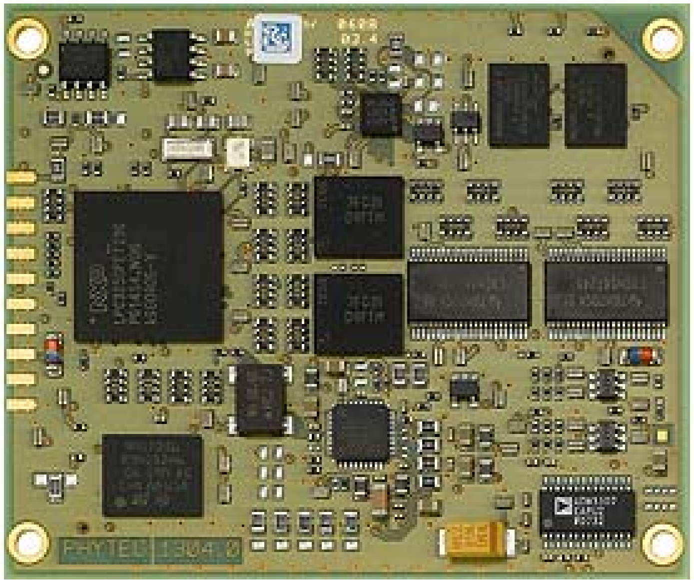
Mothership

- Receive and handle commands from the ground station
- Transfer science data from the CubeSats to the ground station
- Interpret ranging data

CubeSat

- Receive and execute commands from Mothership
- Perform ranging functions
- Handle science data to be sent to the Mothership

Hardware

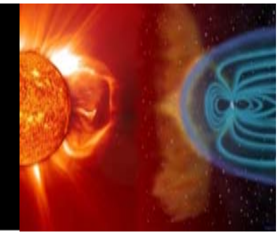


<u>CubeSat system</u>

- phyCore-LPC3250
  - 208 MHz CPU
  - 256 KB SRAM on-chip
  - 128 MB NAND Flash
  - Vector Floating Point (VFP)
  - Built on Linux OS framework
  - Coding will be in C ++

- Oscillator:
  - Chip Scale Atomic Clock (CSAC) with 100 nanosecond accuracy
  - On board every CubeSat and Mothership
  - Synchronized upon release from the Mothership

Baseline

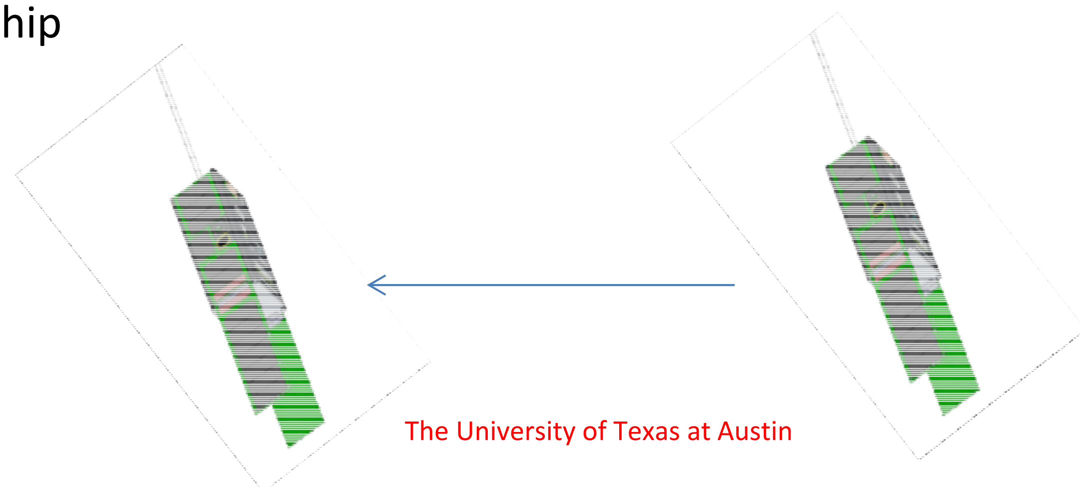


CubeSat

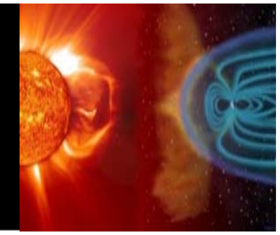
- Each CubeSat will transmit a timestamp-encoded signal
- The other CubeSats will listen for the signal and timestamp this upon receipt
  - The CubeSat will determine the Δt between the timestamps
- After obtaining 13 ranges, ranging data will be transmitted to the Mothership

Mothership

- The data sets will then be interpolated to determine:
  - CubeSat geometry
  - Instantaneous position, velocity, and acceleration
- With this knowledge, the science objective can be met and station keeping may be performed



Time Division Multiple Access (TDMA)



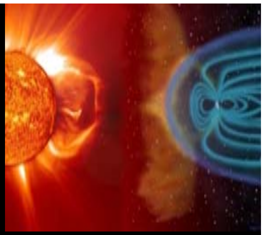
- Each satellite will transmit in sequence while the other 13 listen
- This technique requires minimal power to run and allows ranging on one frequency

<u>Sequence</u>

- CubeSat will transmit for 30 seconds
- Next 30 seconds “silent”

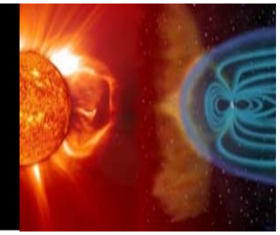
<u>Total rotation</u>

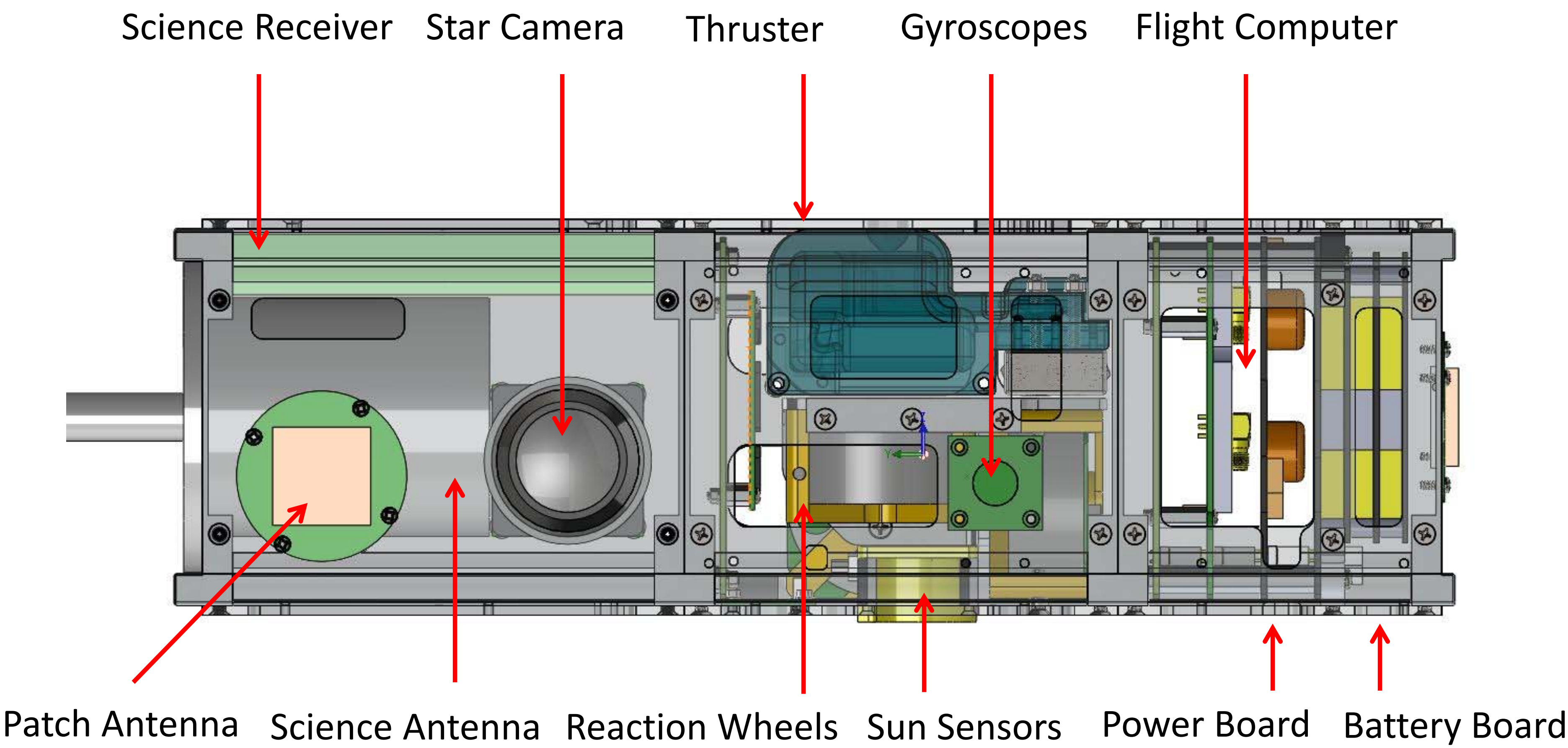
- Lasts 14 minutes
- Each CubeSat only broadcasting for 1/28th of total time



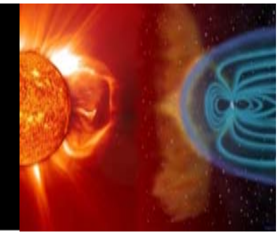
Structure

CubeSat Components

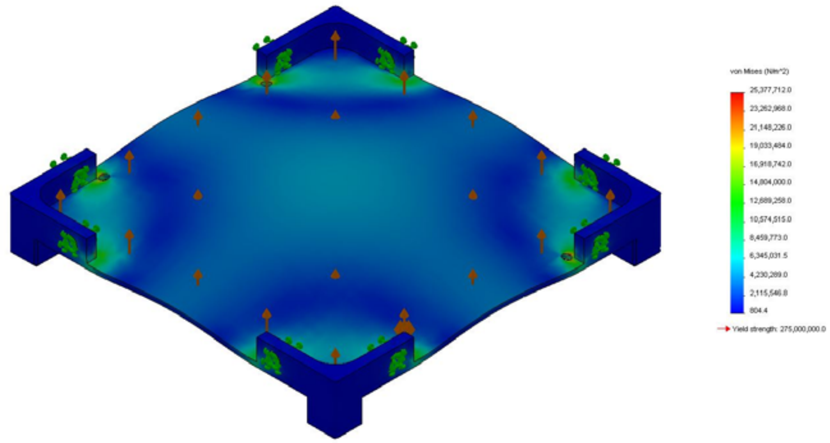


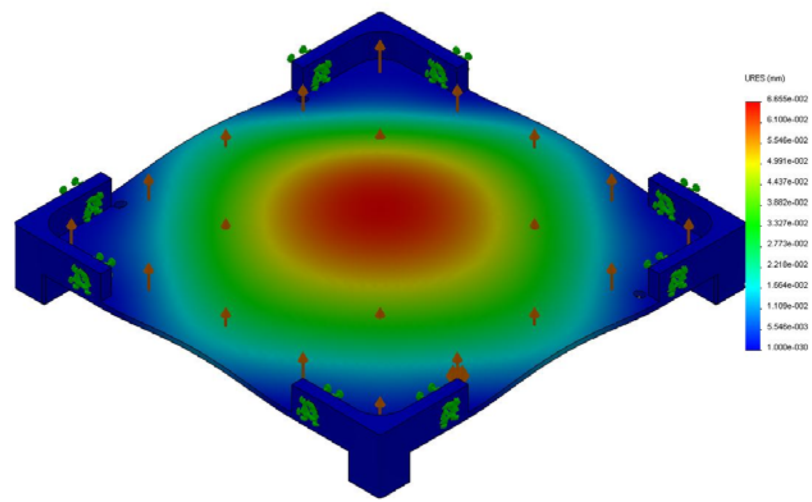


Structural Analysis

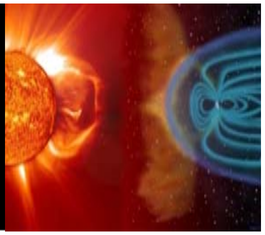


- Analyzed stresses and displacements of CubeSat shell components (FEA)
- FOS > 4 for all pressurized containers
- Estimated Launch Loads
  - Lateral load of 11 g’s
  - Axial load of 6 g’s

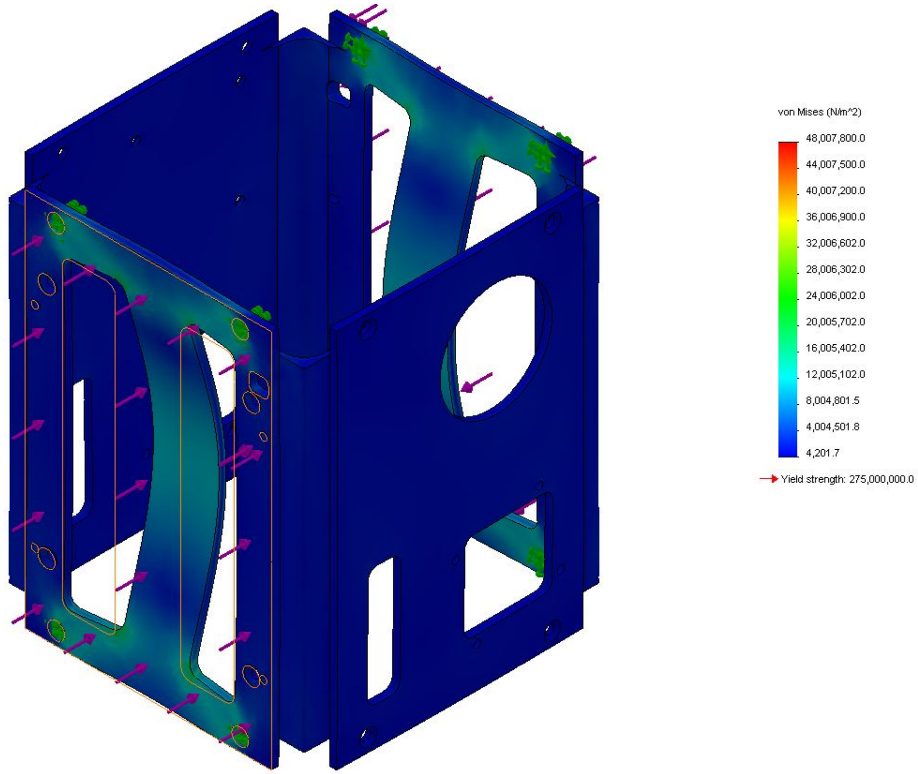


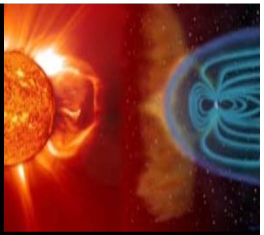


Structural Analysis



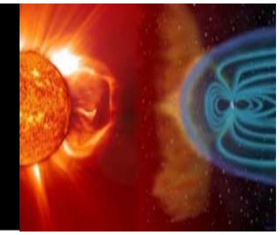
- Weakest Piece:
  - Payload Shell on ± X face
- FOS: 5
- Solutions:
  - Smaller cutouts
  - Thicker walls
  - Reinforce metal strip in middle



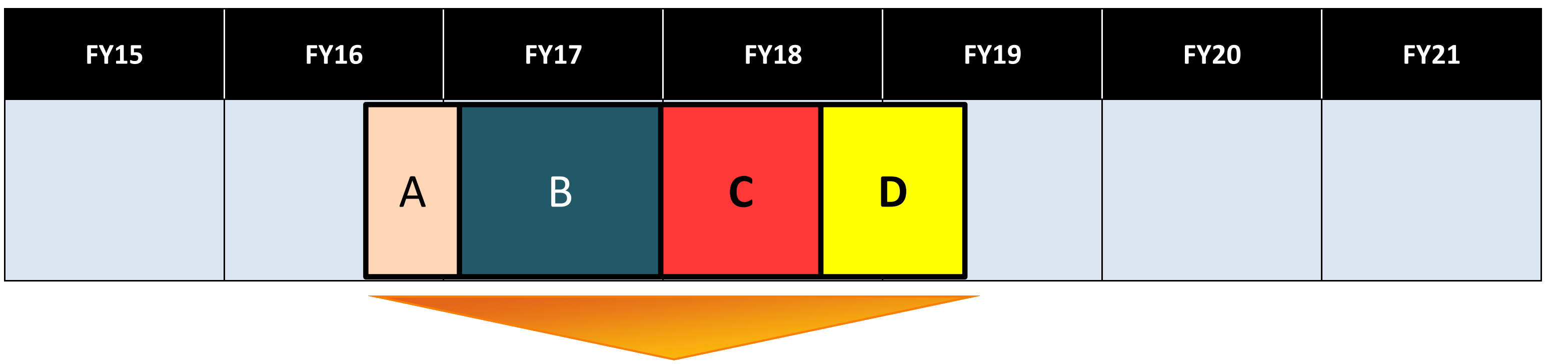


Management and Cost

Timeline

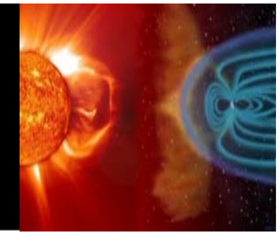


Phase	Duration (months)
A	4
B	11
C	9
D	6



30 months formulation and Implementation

Costing Tool



- No cost model will accurately work for CubeSats
- Cost analysis is based on current CubeSat programs in different universities

<u>Small Satellite Cost Model (SSCM)</u>

- Used to compare the integration, testing, and program costs

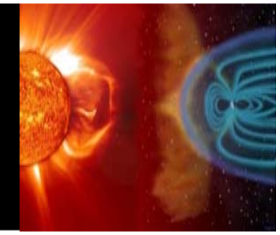
<u>Quotes</u>

- “Quotes” for material components

<u>University Grassroots</u>

- Student labor cost

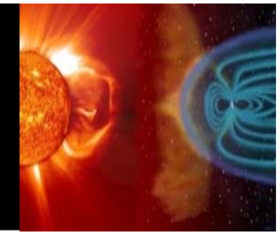
Hardware Cost (CubeSat)



Hardware Cost(CubeSat)	
Component	Cost
Propulsion	$19,500
ADC	$75,660
Communications	$13,000
Power	$35,600
Structure/Thermal	$12,000
Payload	$7,000
Total (per CubeSat)	$163,000
Total (14 CubeSat)	$2.27 M

- All costs include a 30% contingency

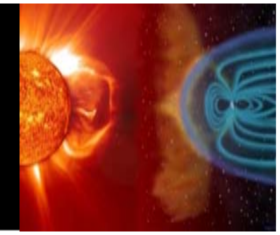
Integration, Assembly, Test Cost(CubeSat)



- Assume two universities will be involved
  - Each university will be in charge of 7 CubeSats

Labor Cost			
	Approximate Number	Annual Cost for Single Student	Total Cost Per Year
PhD	5	$55k	$275k
Masters	6	$38k	$228k
Undergraduate	60	$0	$0k
Total cost per year per University			$503k
Total cost per University	2.5 work years to Integrate, assemble and test		$1.25 M
Total cost	2 universities involved(30% Contin)		$3.25 M

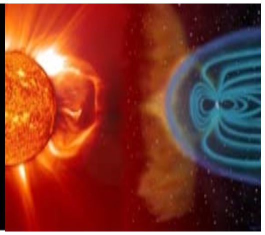
Mothership/Program Level



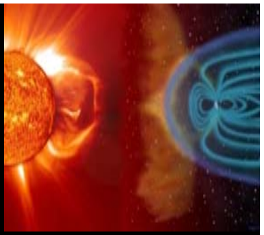
Launch Vehicle/Mothership	
Component	Cost
Launch Vehicle to GEO	
SHERPA to DRO	
SHERPA	
IA&T	
Program Level	
Ground Support	
Total	$38 M

Program Level Cost	
Component	Cost
Systems Engineering	
Program Management	
Reliability	
Planning	
Requirements flow down	
Quality assurance	
Project Control	
Total	$0.5 M

Total Cost

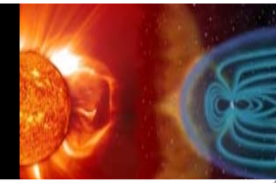


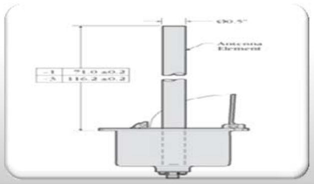
Component	Cost
CubeSat Hardware	$2.27 M
IA&T	$3.25M
Program Level	$0.5 M
Launch Vehicle & SHERPA	$38.0 M
Total	$44.02 M



XSOLARA Conclusion

Overview of XSOLARA subsystems





Payload

- The only payload for XSOLARA is its 11 meter dipole antenna . Simple, reliable and proven technology

Communication

- All the data can be sent back to Earth with ample link margin
- High bandwidth will ensure data quality

Power

- Even in the worst case scenario, the system does not exceed available power.

ADCS

- No pointing requirement for the science payload but XSOLARA's ADCS can control the CubeSat to a very good accuracy

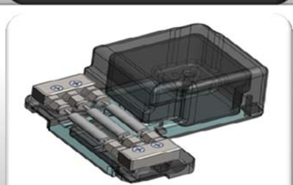


Photo: Austin Satellite Design

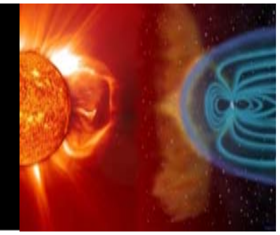
Propulsion

- Propulsion system can provide up to 15 m/s for each CubeSat.
- Only 7 m/s is needed for the entire mission duration

Structures

- CubeSat structure is well known and proven
- CubeSat can stand all the stresses and vibrations throughout its lifetime

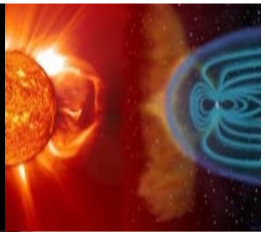
Mass Budget-System Summery



Mass Budget	
Component	**Mass**
Payload	300 g
Propulsion	379.1 g
ADC	611.6 g
Communications	465.3 g
Power	83.4 g
Structure	676.5 g
Thermal	165 g
Spacecraft Dry Mass	3542.2 g
Propellant	147.7 g
Loaded Mass	3689.6 g
Margin	310.4 g

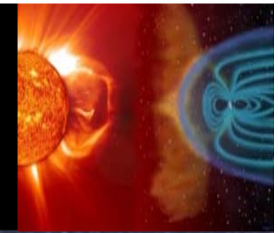
XSOLARA capability		
Component	**Required**	**Capability**
No. of Satellites	10	14
Pointing (deg)	5.5	0.1
Propellant (kg)	0.04	0.09
Data rate (Mbps)	28	37.37
Power (W)	10.81	11.27
Mass (kg)	3.698	4

What has been done…



- Ground-based arrays with tens of antennas have been built
- None of them can observe in 0.1-10MHz frequency

What we can contribute…

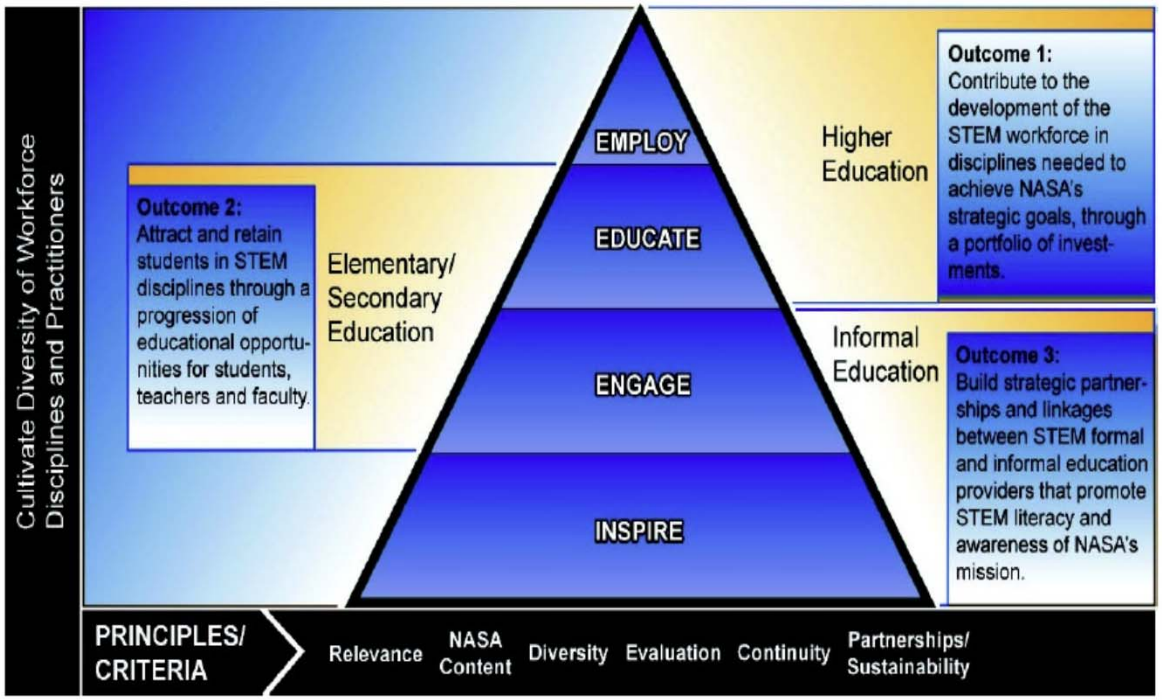


- XSOLARA can provide science not obtainable from Earth Observing platforms
- Observation in low frequency with a sensitivity enough to detect exoplanets
- Path way to larger scale missions to follow up
- Create a whole new category of missions with CubeSats

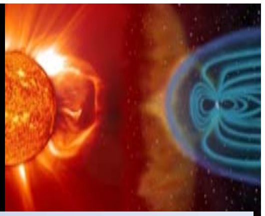
Education Public Outreach

- Top universities will be designing and building XSOLARA

- **INSPIRE:** XSOLARA will inspire K-12 students to do STEM
- **ENGAGE:** Involved universities will commit to engage K-12 students by having tours, conference, etc.
- **EDUCATE:** College students will be directly involved
- **EMPLOY:** Involved students are best candidates for NASA employment

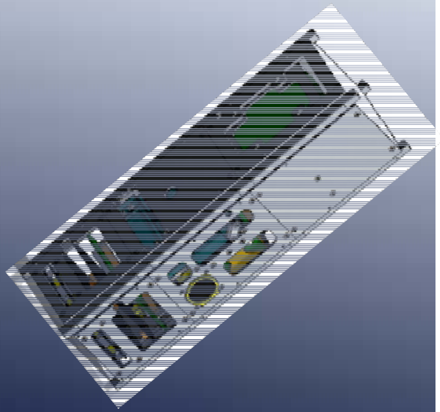


XSOLARA Conclusion



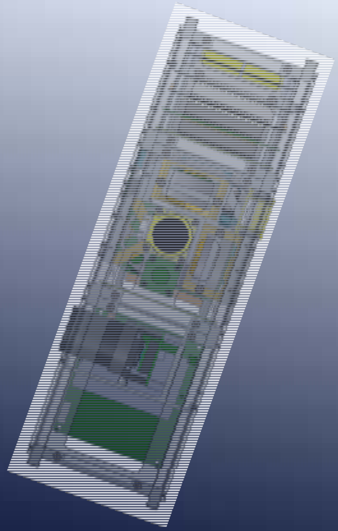
Exoplanets are among the top priorities for NASA

Valuable Science



XSOLARA will have direct impact to many college students and indirect impact to thousands of k-12 students

High EPO Value

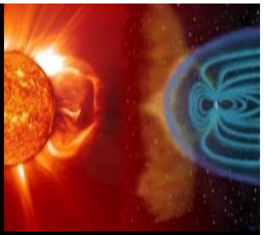


CubeSats are simple, cheap and low risk

Low Risk, Simple

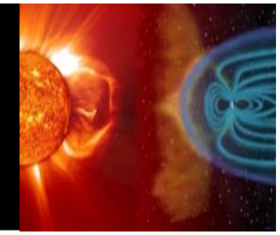
XSOLARA will cost only 43 million dollars

Low Cost



Backup slides

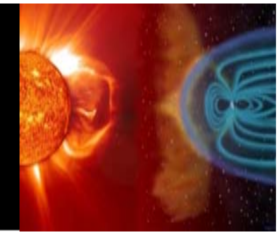
Thermal



- Operating Temp (0-45°C)
- Star tracker defines boundaries

Components	Coldest Temperature (°C)	Hottest Temperature (°C)
Star Camera	0	45
Reaction Wheels	-40	70
Gyros	-45	85
LPC 3250	-40	85
Sun Sensors	-25	50
Battery Board + EPS	-40	85

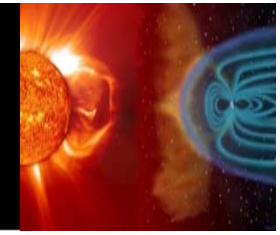
Single Node Analysis

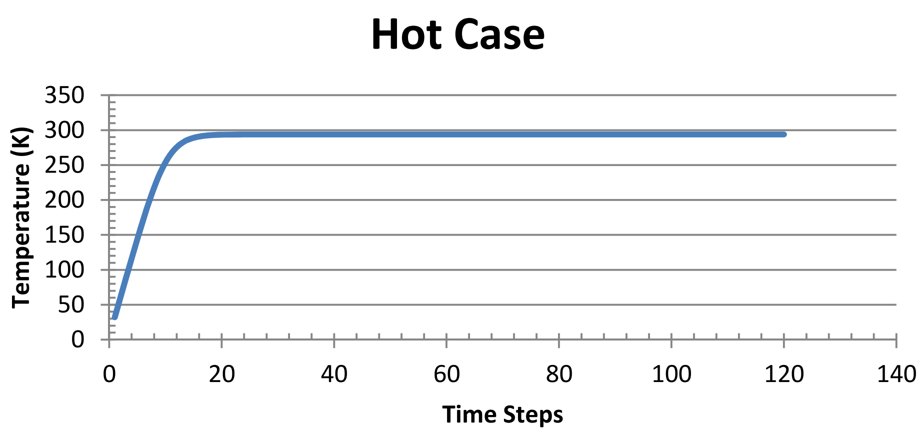


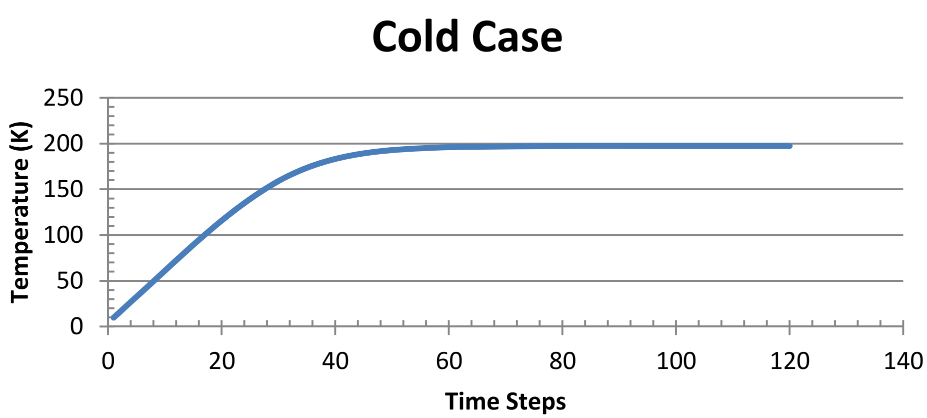
- Spreadsheet Calculation
- Assumptions:
  - Spherical Satellite
  - No Conduction or Internal Radiation
  - Outer Planet Albedo/IR
  - Only Solar Cells
- Average Spacecraft Temperature:
  - 293 K

External Constants (W/m^2)	
Solar Heat Flux	1345
Albedo	387
Planetary IR	235

Thermal Environment

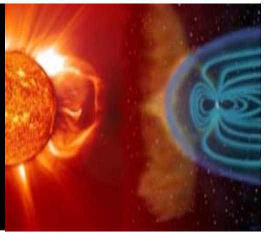


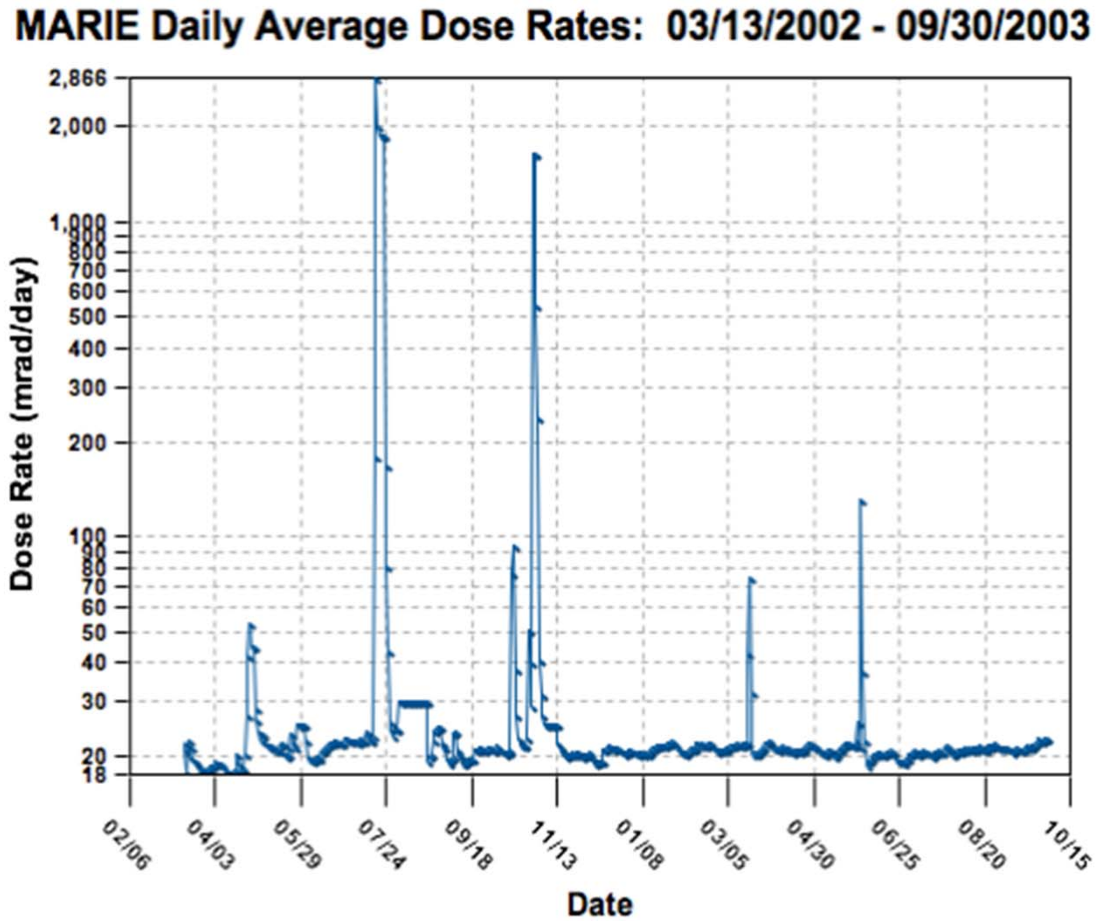




- Temperature Gradient
  - Hot Case: 295 K
  - Cold Case: 197 K
- Typical Range for Satellite is 125 K (~30% Margin)
- Multi-Layer Insulation (MLI) – Kapton Tape to be used

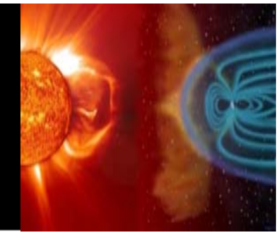
Radiation Mitigation





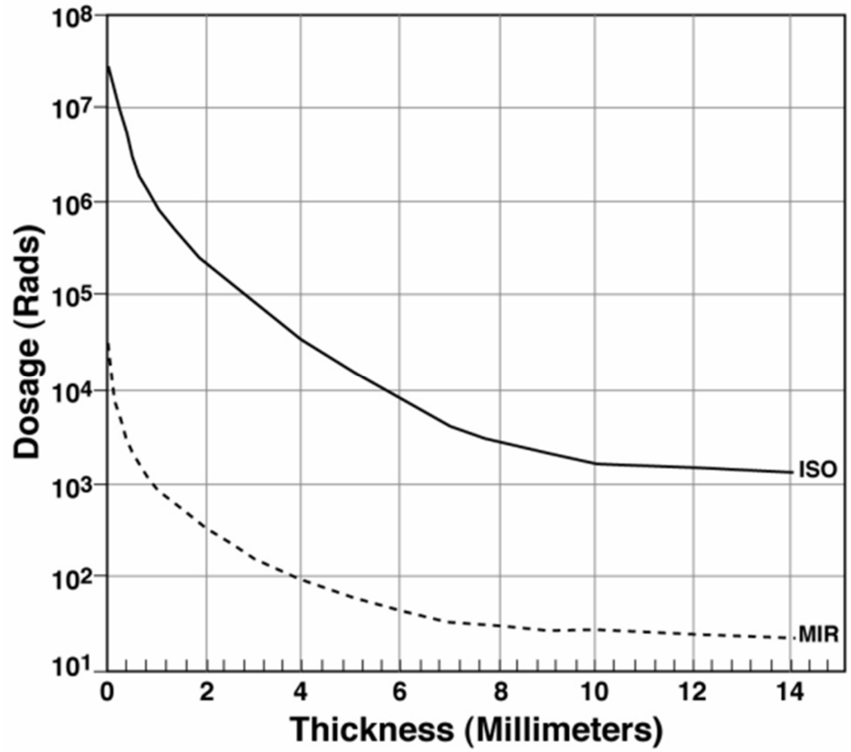
- Assume 6 month mission life in deep space
- Including Solar Events lasting 3 days each
  - Total dosage results in 17-22 rads over 6 month period

Radiation Mitigation

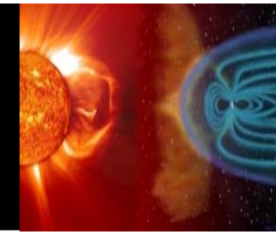


- 2.5mm CubeSat wall thickness
- ~110,000 rads max dosage (for glass instruments)
- Well below dangerous levels

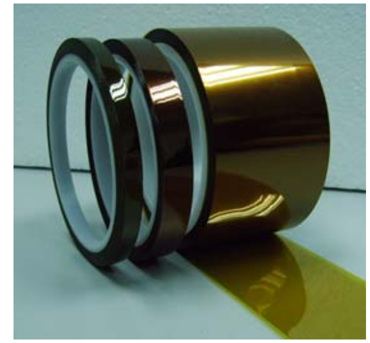
Aluminum Radiation Absorption



Radiation Mitigation

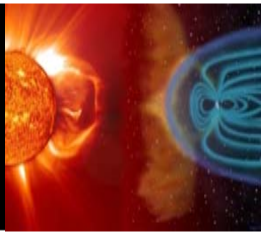


- MLI – Kapton Tape



	Kapton Tape on Aluminum Shell	Polyethylene/RXF 1
Description	Aluminum shell of spacecraft coated with reflective Kapton Tape	Rigid plastic material derived from polyethylene
Cost	Tape: $1.61 per sq ft	Unknown since product still under development
	Sheet: $9.00 per sq ft	
Pros	Cheaper	Light, flexible, durable
	Tested through heritage	Superior radiation shielding (could potentially protect humans)
	Feasible/Sturdy	
Cons	Heavy	Projected to be costly
	Not good at dealing with micrometeorite impacts	Sensitive to thermal activity
	Mediocre radiation shielding (needs to be coupled with Rad-Hard equipment)	No heritage

Baseline



<u>CubeSat-Mothership Relay</u>

- 14 CubeSats will communicate to the Mothership via UHF relay
- CubeSat to Mothership frequency will be within the authorized space to space link
  - 0.4 GHz to 0.6 GHz
  - XSOLARA will utilize 0.5 GHz until authorized frequency is specified