CINEMA

CubeSat for Ions, Neutrals, Electrons, MAgnetic fields

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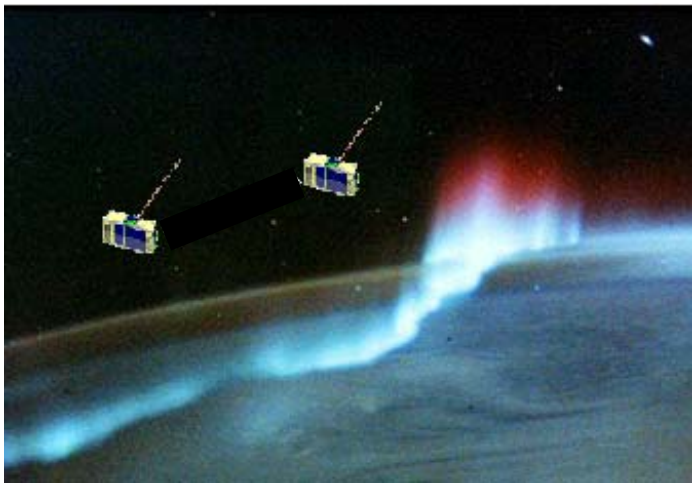
Overview

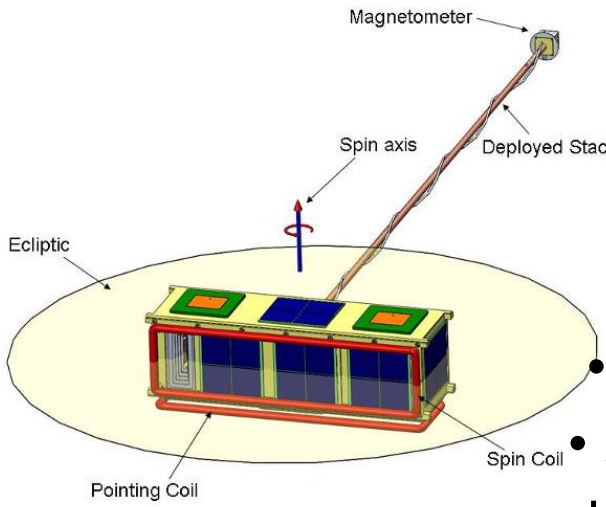
- Collaborating Institutions
- Mission Highlights
- Science Summary
- CINEMA Spacecraft System Design
  - Communication
  - Mechanical/Bus
  - Science Instruments (2)
  - ACS
- Mission Plan
- Final Thoughts

Collaborating Institutions

- **UC Berkeley/SSL** (Lead Institution)
  - A World Leader in Space Weather Research
  - Developing Compact Suprathermal Particle Instruments
  - Experienced in Spinning Spacecraft ACS
  - Formal (NASA) and “Informal” (Sounding Rockets) Flight Experience
- **Imperial College London, Space Magnetometer Laboratory**
  - Fluxgate Magnetometers on Cassini, Cluster
  - Developing Small, Low-mass Magnetometers for CubeSats
- **NASA Ames**
  - Cubesat Experience (GeneSat, PharmaSat, O/OREOs)
  - Possible Contribution of GeneSat Avionics
- **Kyung Hee University (S. Korea)**
  - World Class University project
  - Space Weather Research

Mission Highlights





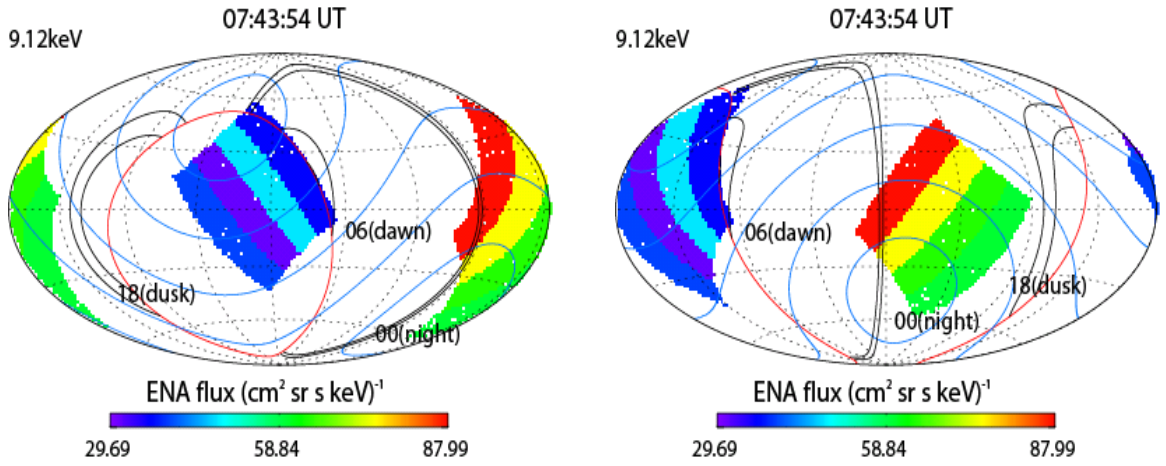
- 3U CubeSat (2008-9 NSF Proposal)
- 1 Additional CubeSat (Kyung Hee U.)
- Balance of Heritage and Innovation
- Mix of Student and Professional Labor
- Purpose: Space Weather Research
  - SupraThermal Particle Detector
  - Boom-mounted 3-Axis Magnetometer
- Spinning Ecliptic-Normal Attitude
- High Inclination Orbit
- ~1 Year Mission Duration

Technological Impacts

- New Sensors and Spacecraft Systems
- Active ACS
- High Data Throughput (~900 Mbit/day)

CINEMA Science

- Magnetic Storms and Ring Current
  - Image ring current particles in local time
  - Observation of approximately equatorial ring current fluxes
- High Latitude Charged Particle Precipitation
  - Will measure ~4-100 KeV ion precipitation in-situ and remotely sense ion precipitation with Energetic Neutral Atoms (ENAs)

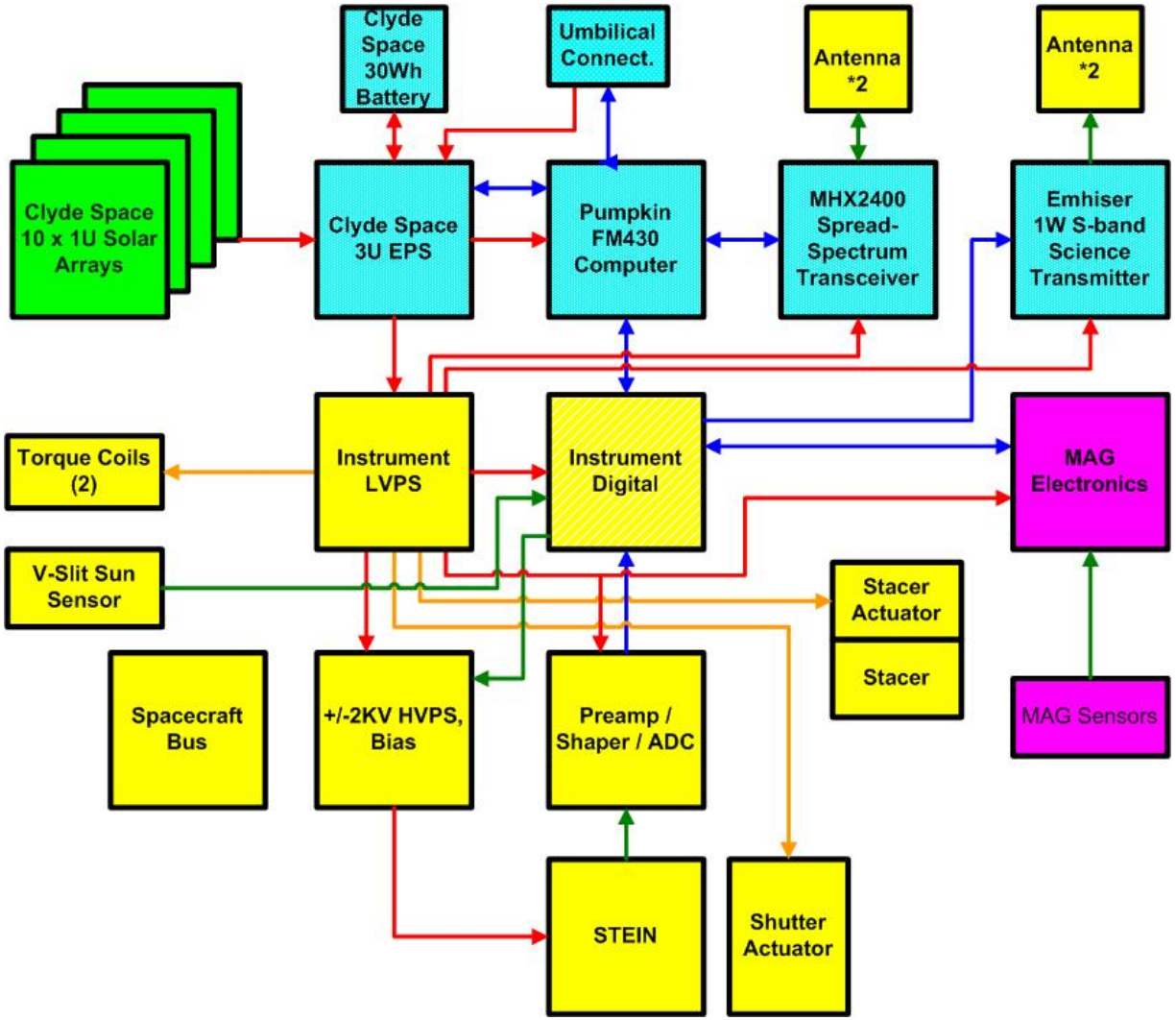


ENA map from STE instrument on STEREO

CINEMA Science

- Electron Microbursts (0.10 – 0.25 sec)
  - Measure precipitated electrons and ions with a single detector
  - Used to study microbursts, pulsations and other precipitation structures
- Magnetic Field
  - For interpreting particle detector measurements
  - Waves and Currents
  - Track Phase Fronts of
    - Ultra-low Frequency waves (0.1 Hz or lower)
    - Flux Transfer Events (FTEs) - quasi-periodic reconnection events at the Earth's magnetopause
- Multi-Satellite Science
  - Multi-Point Measurements
  - Stereo Observations

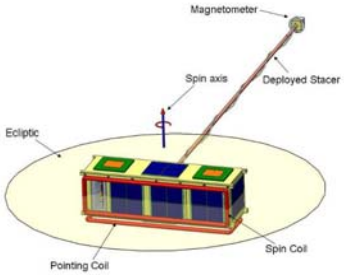
CINEMA Spacecraft Design



- Yellow – SSL/Kyung Hee
- Magenta – Imperial
- Blue – NASA Ames or COTS
- Green - COTS

Communications

- On board
  - µHard MHX2400
  - 3-dB power splitter
  - Four circular polarized patch antennas
  - Emhiser 1 W S-band transmitter
- Ground
  - 11-m Berkeley Ground Station
  - Secondary feed containing a short helix antenna and a uHard WiFi transceiver that is identical to the unit on the spacecraft



CINEMA

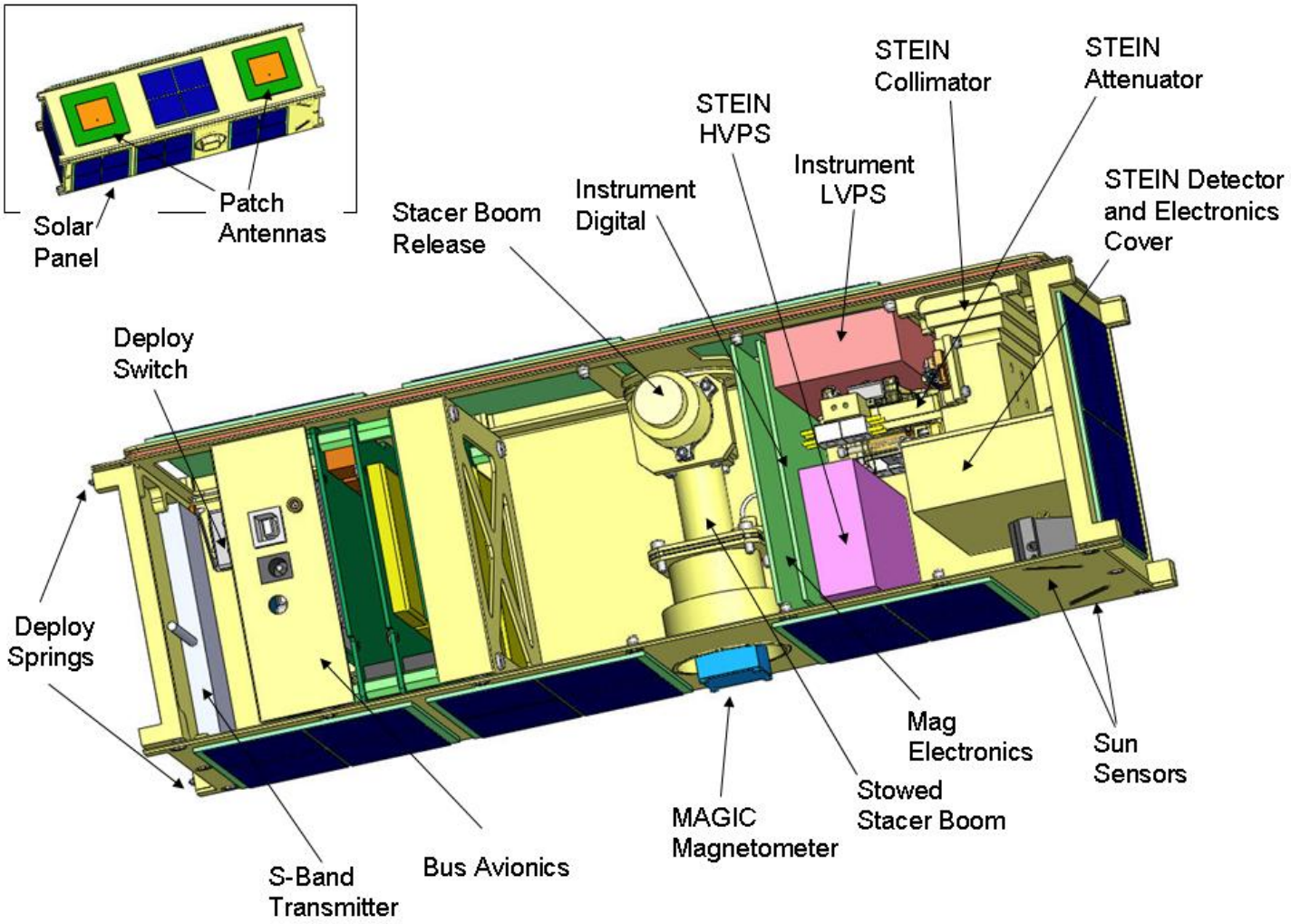
Science TLM
2200-2300 MHz

Eng TLM/CMD
2400-2450 MHz

BGS 11m
at UCB/SSL

MOC at UCB/SSL

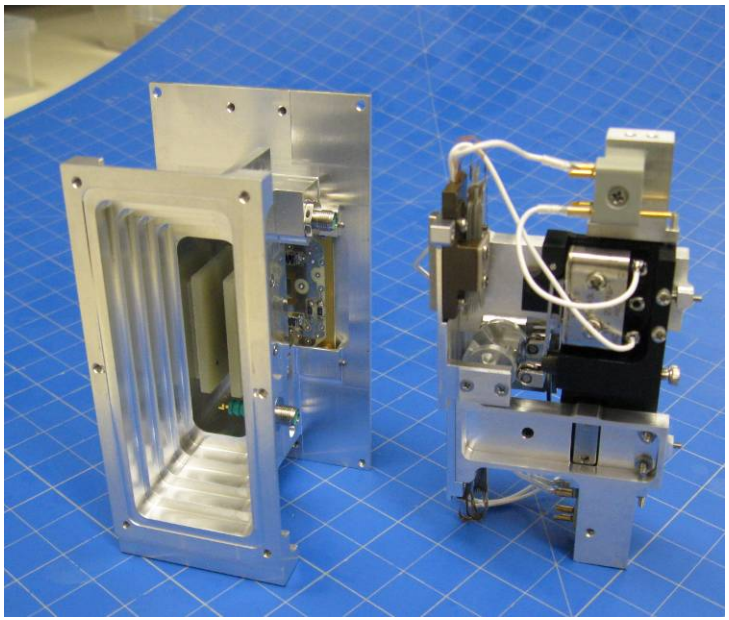
CINEMA Bus

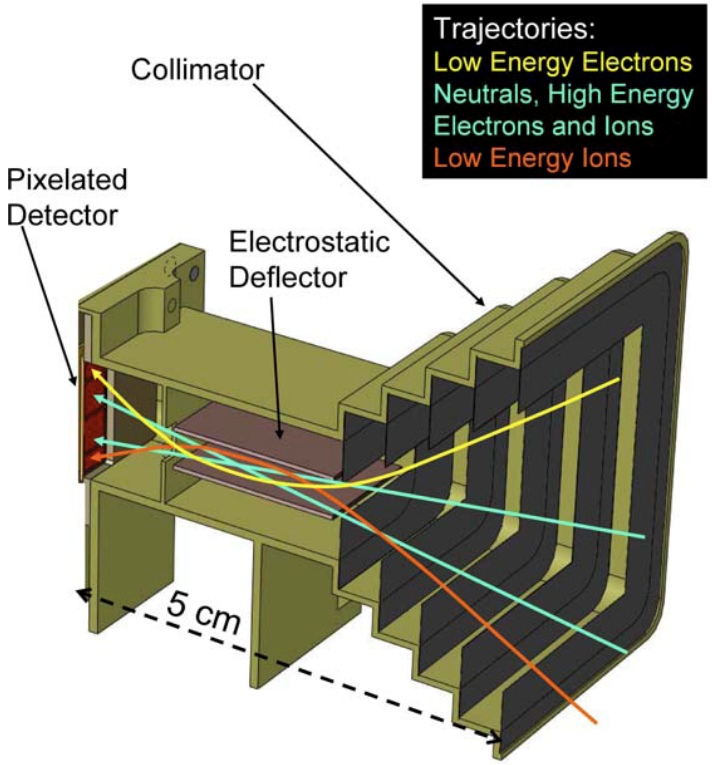

Solar Panel
Patch Antennas
Stacer Boom Release
Instrument Digital
STEIN HVPS
Instrument LVPS
STEIN Collimator
STEIN Attenuator
STEIN Detector and Electronics Cover
Deploy Switch
Deploy Springs
S-Band Transmitter
Bus Avionics
MAGIC Magnetometer
Stowed Stacer Boom
Mag Electronics
Sun Sensors

STEIN Instrument

SupraThermal Electrons Ions & Neutrals

- Heritage: STEREO STE Sensor
- with Electrostatic Deflection
- Heritage: Mechanical Attenuator Reduces Particle Count by 10^2
- Prototype Built and Being Tested





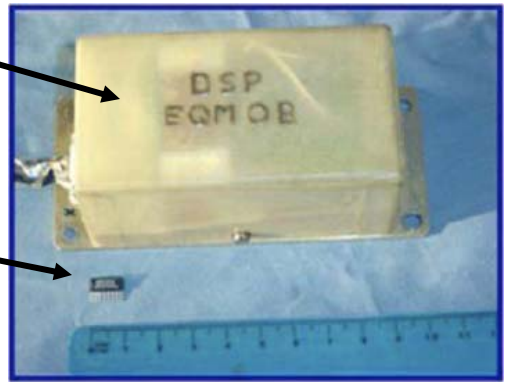
Resolution: ~1KeV FWHM
Range: few to 100KeV

MAGIC Instrument

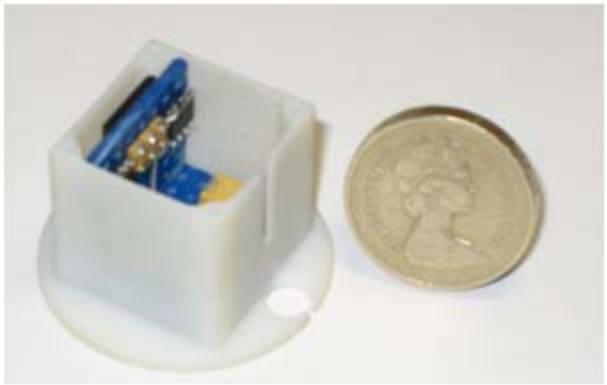
MAGnetometer from Imperial College

Fluxgate Mag

MR Mag (1 axis)

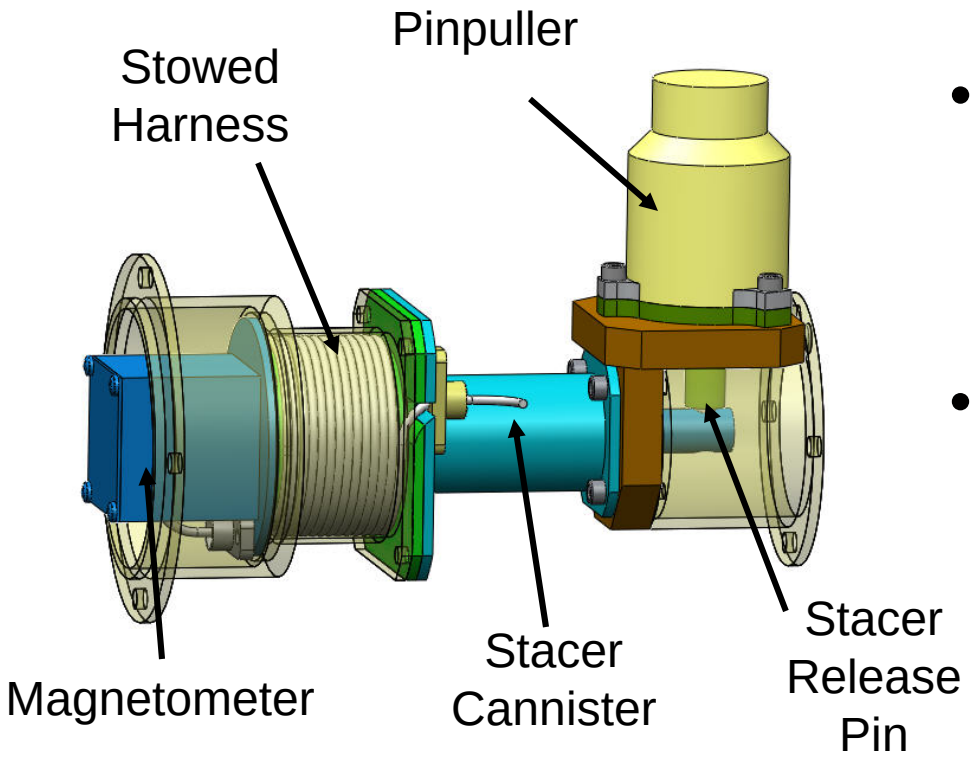


3-axis MR Mag

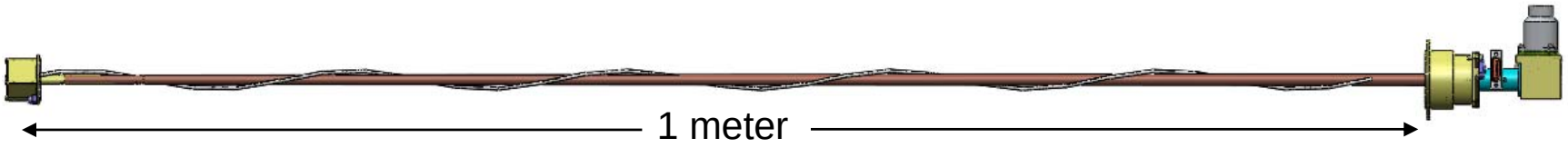


- Magnetoresistive Technology
- Inboard + Boom Deployed
  - Calibration
  - Spacecraft Induced Field Meas.
- Sensitivity 0.25nT
- Resolution
  - 2n-10nT Science Mode (200 mW)
  - 25nT ACS mode (~100 mW)

Mag Boom



- Heritage: Self-deploying Stacer Element
  - •50 mm stowed length
  - • 1 m deployed length
- Heritage: TiNi Aerospace SMA Pinpuller



ACS Overview

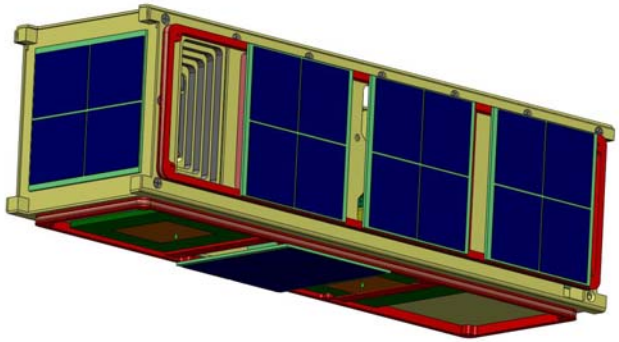
- Requirements
  - Ecliptic normal spinner
  - Maintain spin axis in a 10° cone
  - Maintain a spin rate of 2 RPM

- ACS Initial Acquisition/Attitude Goals
  - Without ground intervention
  - Capable of detumble, spin-up and precession maneuvers after MAGIC calibration
  - Establishing the nominal spin rate from any orientation with tip-off rates not exceeding 5 deg/sec in the transverse

ACS Hardware

Actuators

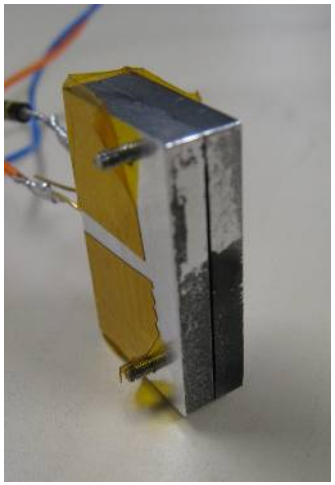
- Torque coils:
  - 1.16 Am^2 (62 turns copper wire 26 AWG)
  - perpendicular (precession) and parallel (spin) to spin axis



Torque Coils (Red)

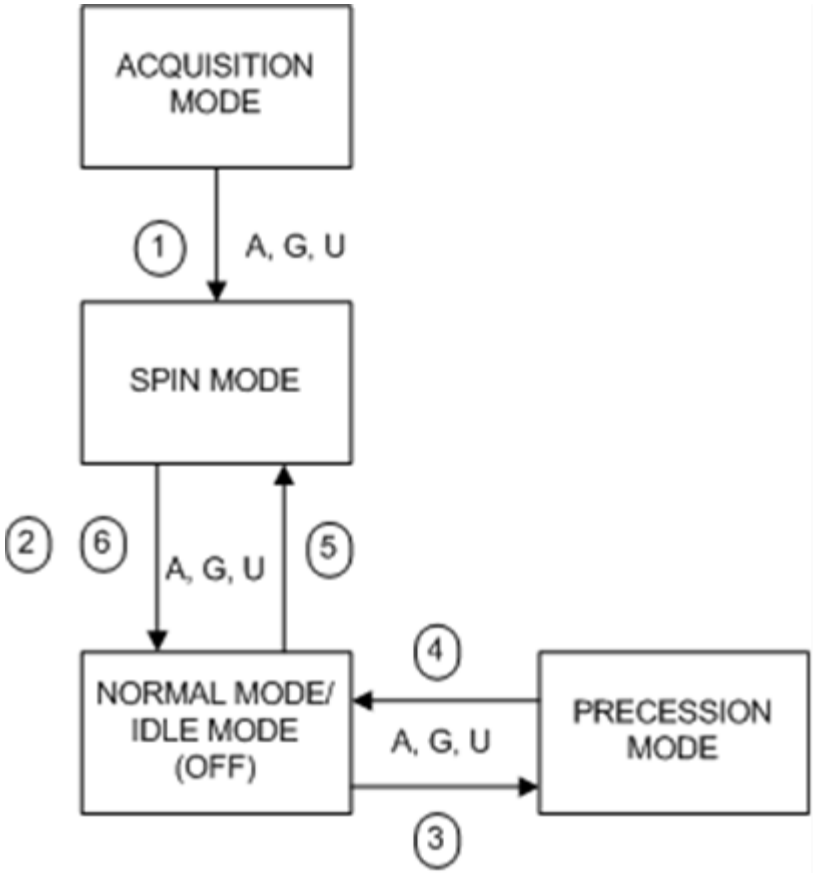
Sensors

- Sun sensors
  - V-slit sun sensor oriented looking out at the spin plane
    - 4° x 90° fan-shaped field of view (FOV)
    - Heritage from the UCB Rocket program
  - Solar panels
- Magnetometer
  - In-board and out-board



Sun sensor prototype

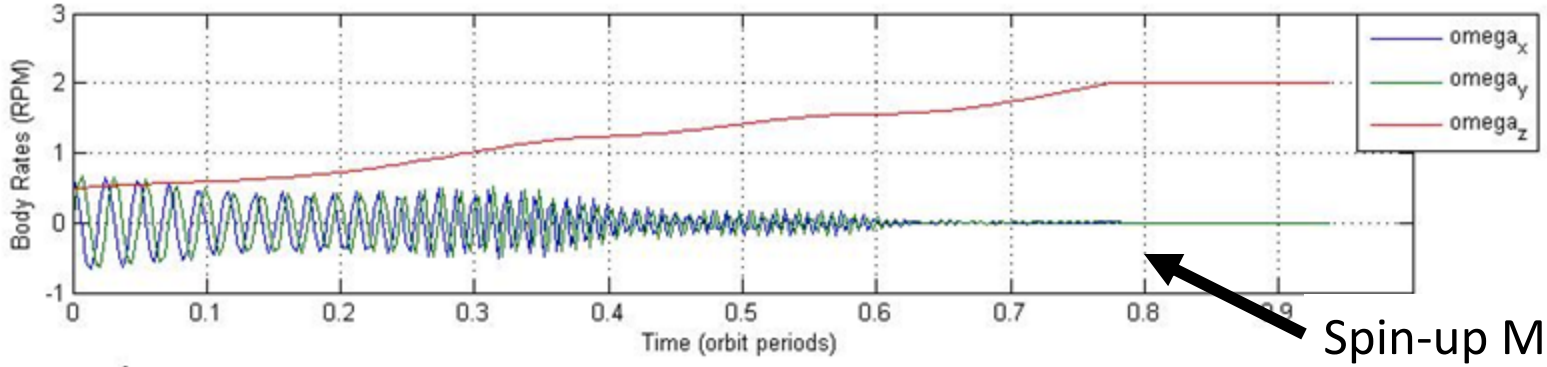
ACS Software

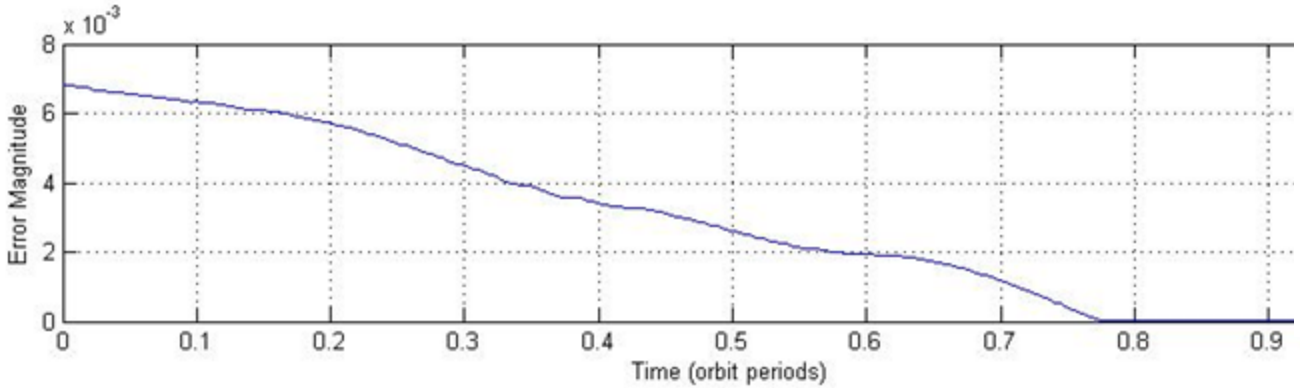


A - Autonomous
G - Ground
U - Unresolved Error (autonomous)
(#) - Sequence of events

- Initial Acquisition Mode
  - Detumble maneuver using B-dot Control
  - Initial attitude acquisition using solar panels
  - Initialize sun sensor by inducing spin
- Spin/Precession Mode
  - ACS initial phase
  - Ground Bias
  - Attitude Maintenance
- Nominal Mode
  - Idle Mode (OFF)

ACS Modeling Results





Spin-up Maneuver
- 10% duty cycle of spin coil
- 5 deg/sec tip-off rate
- ~0.8 orbit period required to spin up

Other results
- ~ 5.5 orbit periods to preccess 90°
- ~ 3 orbit periods to detumble
- ~ 22 orbit periods to drift-off 10° cone
- ~ 1.2 orbit periods to complete maintenance maneuver

Mission Plan

- Launch and Early Operations
  - –Launched in passive mode
  - –MAG boom deployed after PPOD separation
  - –Safe mode (power positive in any orientation) until communication with MOC
  - –Initialization includes
    - Entering ACS mode (STEIN is OFF)
    - System Checkout
    - MAG calibration using torque coils
- Normal Operations
  - –STEIN, MAG On and collecting data in high rate mode
  - –s/c contacted at least once per day

Final Thoughts

- CINEMA will perform important space weather research
- CINEMA uses a combination of flight heritage and innovation that balances risk and safety
- The CINEMA project emphasizes student labor with guidance by experienced engineers and scientists
- CINEMA will pave the way for Magnetospheric Constellations with many satellites making multi-point observations

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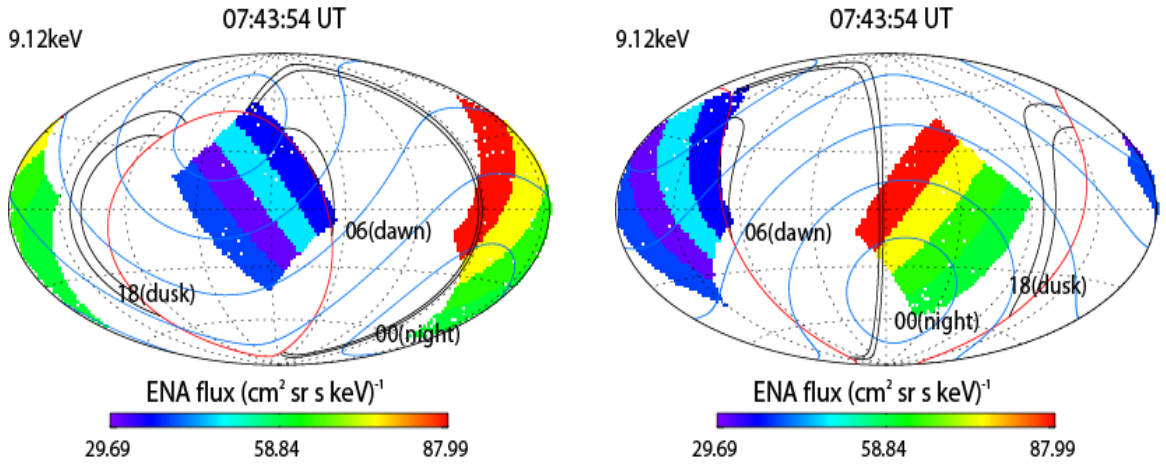
Science Questions:

John Sample – jsample(at)ssl.berkeley.edu

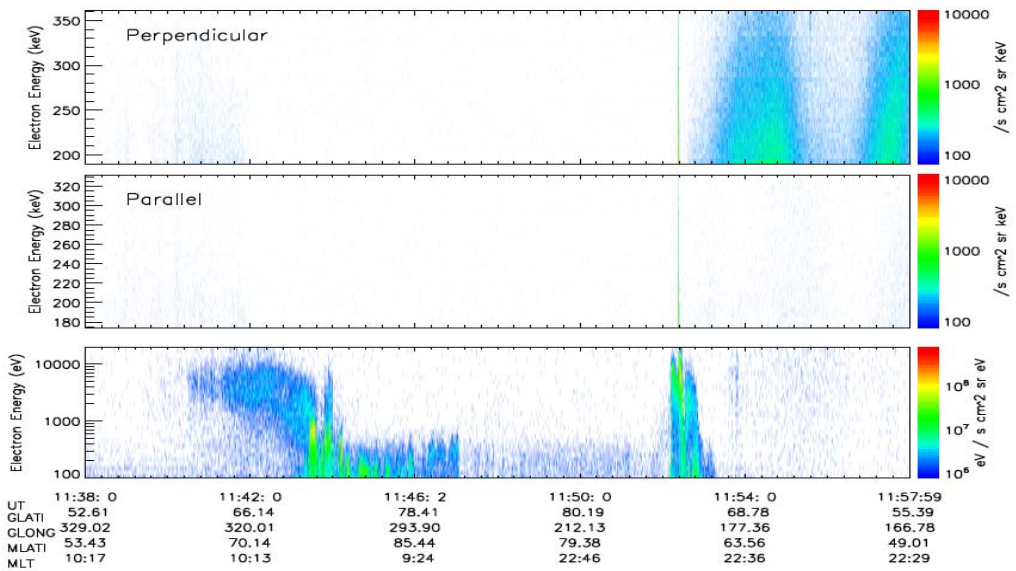
Back-up slides

STE ENA Map



Angular distribution as a function of source direction centered at noon (left) and midnight (right) on Nov. 6, 2006. STE downstream sensors looked in the magnetotail direction close to midnight and detected larger fluxes than upstream sensors looking towards the Earth (the Earth's horizon is indicated by red curve). The blue curves show the iso-pitch-angle contours of the local magnetic field. The black curves show the magnetic field lines at dusk, midnight and dawn.

Multi-Satellite Science



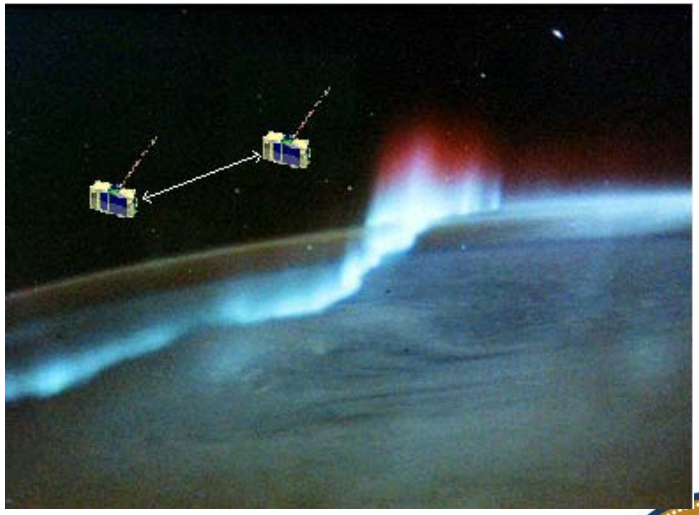
Separation Speed: 1m/min

1 d: 1.4 km

10 d: 14 km

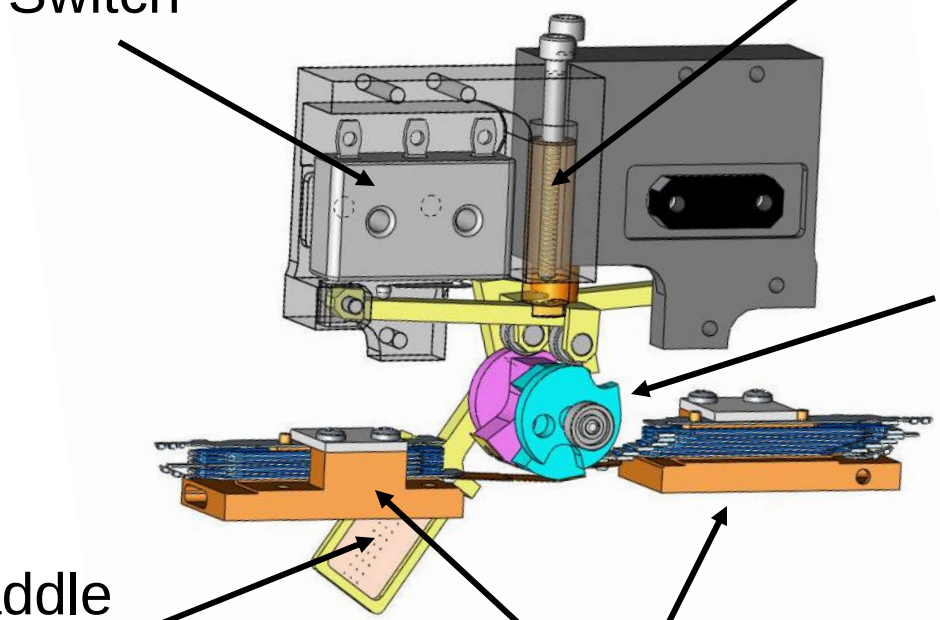
1 m: 42 km

1y: 504 km



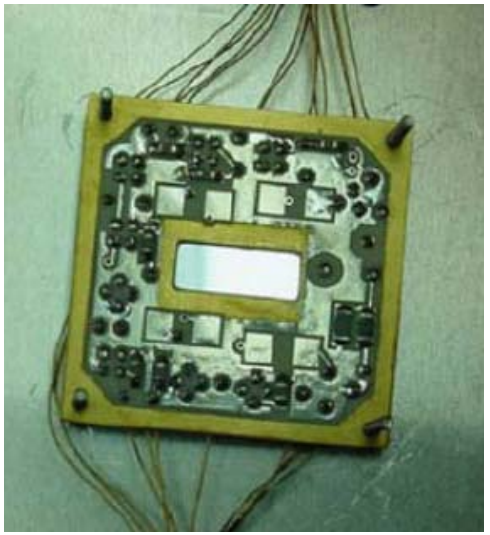
Spatial or Time Variation
“Is it local acceleration?”

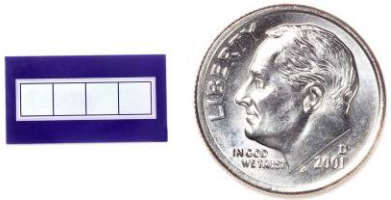
STEIN Attenuator



SSD Detector

- Low Capaciance
- Thin Window Dead Layer
- Passively Cooled
- Pulse-Height Detection Electronics





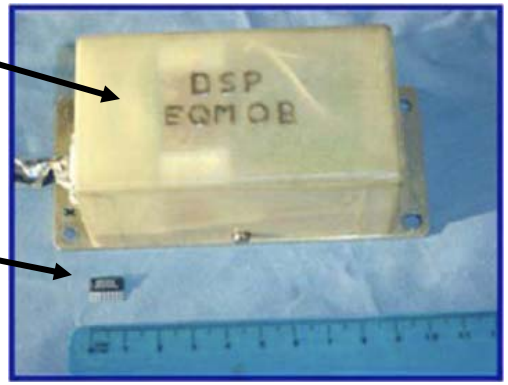
- Detector Area: 4 x 0.1 cm^2
- Electrons: ~2-40 keV
- Ions: ~4-40 keV
- Neutrals: ~4-20 keV
- Resolution: ~<1 keV FWHM

MAGIC Instrument

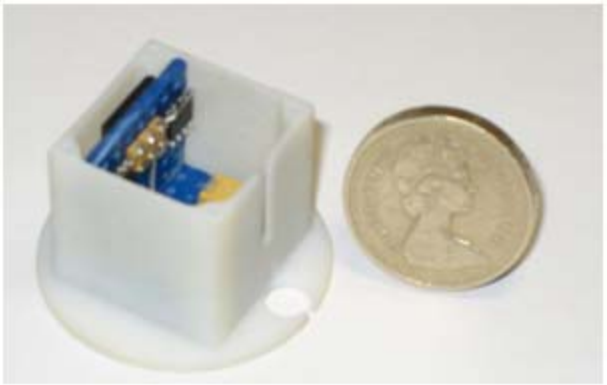
MAGnetometer from Imperial College

Flux Gate Mag

MR Mag (1 axis)



3-axis MR Mag



Credit: Imperial College London

- Measure vector DC field from 0-10Hz for both ACS and Science
- Two 3-axis sensors based on Anisotropic Magnetoresistance
- Mass: 20g and Volume: 15cm^3
- Delivers ambient MAG fields, plus temperature
- Sensitivity ≤ 2nT
- Resolution: <10nT science mode, 25nT ACS mode.
- Noise Spectral Density (NSD) ≤ 100pT/√Hz above 1Hz

Power Generation

1U solar array

Size	0.00532	2*ATJ, m2	Emcore
Solar Visible	1353	W/m2	
Earth IR	237	W/m2	
Earth Albedo	406	W/m2	
Efficiency	27.5%	ATJ GaAs	Emcore
Power	1.78	W/1U	Sun only
	0.31	W/1U	Albedo only
	0.53	W/1U	IR Only
	2.63	W/1U	Sun, Albedo, & IR

Solar Array Power Transfer Efficiency

Clyde Space 3U converter

BCR 90%

Bus average power generation

Assume Ecliptic Normal Spin, MAG boom deployed:

Side 1	1U Array
Side 2	3U Array
Side 3	1U Array
Side 4	1U + 2U array (one or the other shadowed by the boom)

Spin Avg Illuminated Arrays **2.07** U

Battery charge/discharge Efficiency 99% Lion

Orbit	Period	98.8 minutes	
	Shadow	35.5 minutes	Worst Case
	Albedo Illum	49.4 minutes	(incl top/bottom arrays)
	IR Illum	98.8 minutes	(incl top/bottom arrays)

Orbit Average Power Available (assume full load in shadow)

3.78 W

Worst Case Orientation

1U towards the sun, no spin, 2U towards the Earth

Orbit Average Power Available

2.51 W

Power Usage

CINEMA Power Usage Spreadsheet
2/6/2009 Dave Curtis

MAG	150	mW	IC, PDR	Low rate; 1 sample/sec, ~25nT resolution
	500	mW	IC, PDR	High Rate; 10 samples.sec, <10nT resolution
STEIN				
Analog	287	mW	McBride PDR	
HVPS, Bias	250	mW	Berg 5/21/2008	
Instrument Digital				
	100	mW	Based on STEREO SWEA/STE	
Sun Sensors				
	20	mW	Diode, camparator, FPGA timing	
Instrument Power Conversion				
	345.86	mW	70% Efficiency	
Inst Total	1152.86	mW	(MAG low power mode)	
Bus Power (excluding COM, Battery charging, Torquing)				
C&DH	20	mW	FM430	
EPS	100	mW	ClydeSpace	
Bus Total	120	mW		
Torque Rods	8,000	mW	each	

Modes:		**SAFE MODE**		**ACS Mode**		**Normal Mode**	
	Base, mW	**Duty**	**Power, mW**	**Duty**	**Power, mW**	**Duty**	**Power, mW**
SAFE							
Bus	120	100.0%	120	100.0%	120	100.0%	120
COM Rx	1,167	100.0%	1167	3.4%	40	3.4%	40
COM Tx	1,889	0.0%	0	0.6%	12	0.6%	12
Science Tx	9,750	0.0%	0	0.0%	0	2.8%	273
Instrument, LR	796	0.0%	0	100.0%	796	0.0%	0
Instrument, HR	1,653	0.0%	0	0.0%	0	100.0%	1,653
ACS	8,000	0.0%	0	10.0%	800	0.0%	0
		Total:	**1,287**		**1,768**		**2,097**
		Margin	49%		30%		44%
		Available	2,513		2,513		3,776

MHX2400 Transciever		Power
Rx mode	210 mA	1.68 W
Tx mode	550 mA	4.4 W

Emhiser EDTC01-DEA 1W Transmitter		
	650 mA	9.75 W

4.43	Passes a day
7	minutes/pass
2	minutes/pass margin
98.8	minutes/orbit
99%	Battery charge/discharge efficiency
100%	Antenna view factor (transmitter on through antenna switchover)

Mass Budget

Subsystem/Part	Mass (g)
Chassis	463
Solar Arrays	375
MAG Boom System	160
Sun Sensors	10
Antennas	140
Genesat Avionics	950
COTS Avionics	500
Transmitter	57
Torque Coils	85
STEIN Detector Head	261
STEIN Electronics	90
STEIN HVPS	150
MAG Electronics	45
Instrument Digital	90
Instrument LVPS	150
Harnessing	60
Thermal	50
Total	**2730/3180 g**