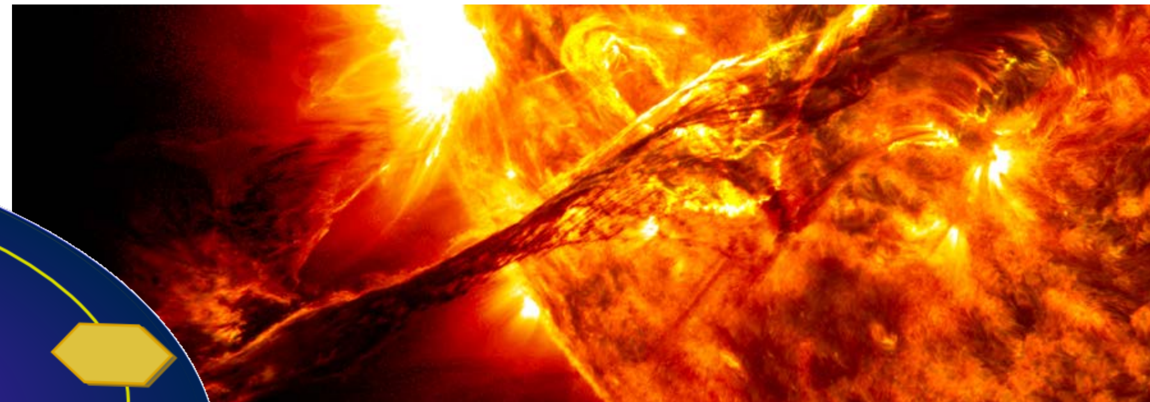
Summer School

Alpbach 2013



CARETAKER

Team blue

Summer School

Alpbach 2013

CARETAKER

- Steve:
  Introduction
- Arjan:
  Mission Definition
- Daniel:
  Instrumentation
- Peter:
  Technical
- Steve:
  Conclusion
- Arjan:
  Moderator for Q&A

CARETAKER

Coronal Mass Ejection

Analysis

Reporting to

Earth

To

Allow

Keeping

Everything

Running

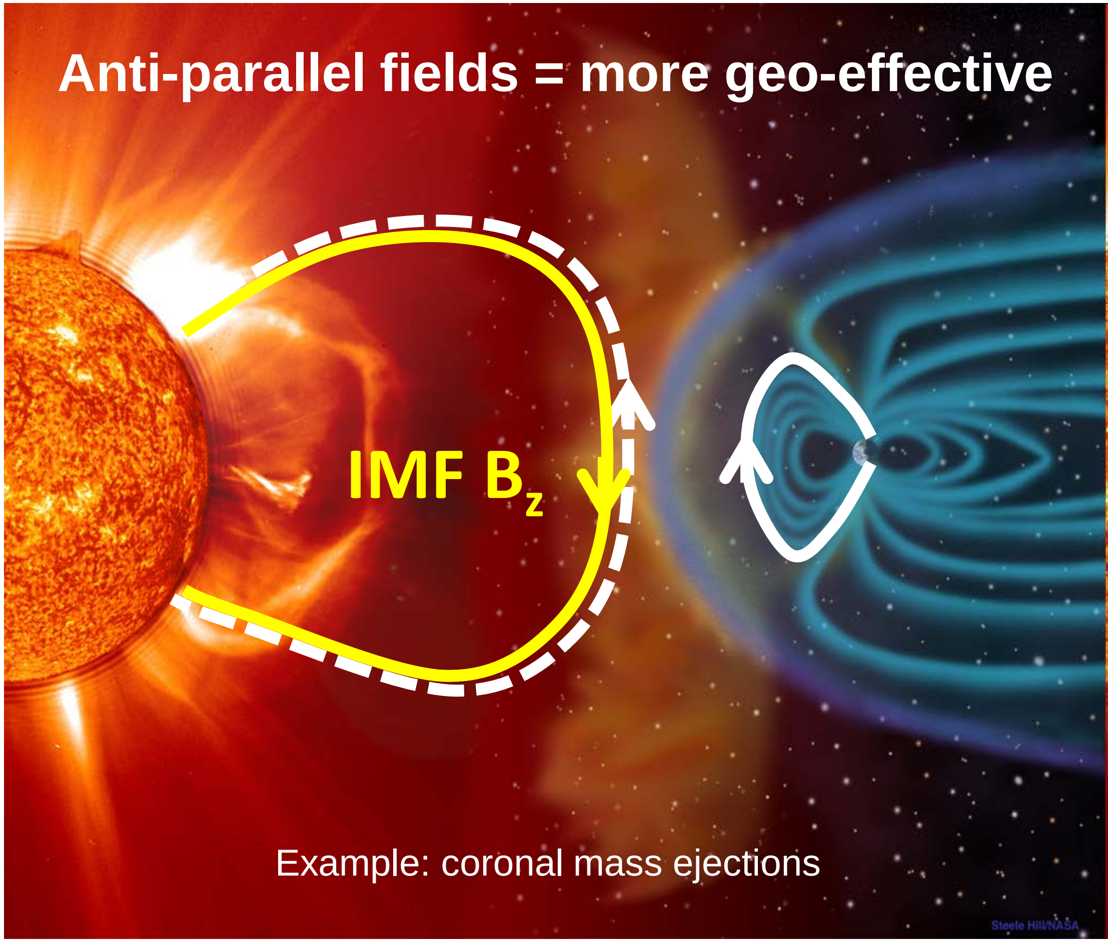
Space Weather

CME can impact

- Communications
- Navigation
- Power Plants
- Flight/Astronauts
- Economic

IMF

- B_z determines the geo-effectiveness of the magnetic storm



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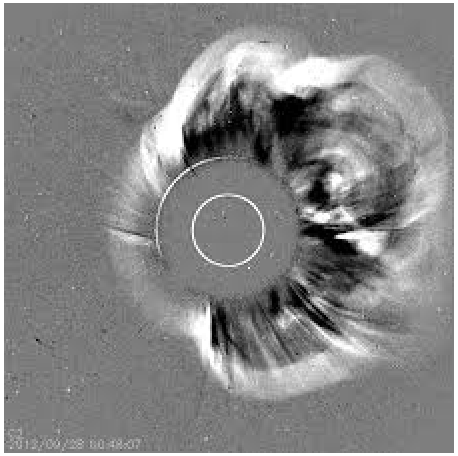
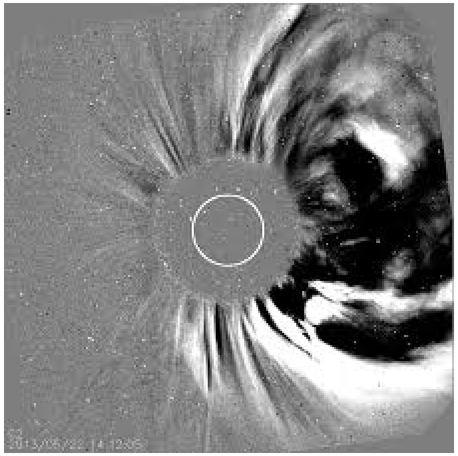
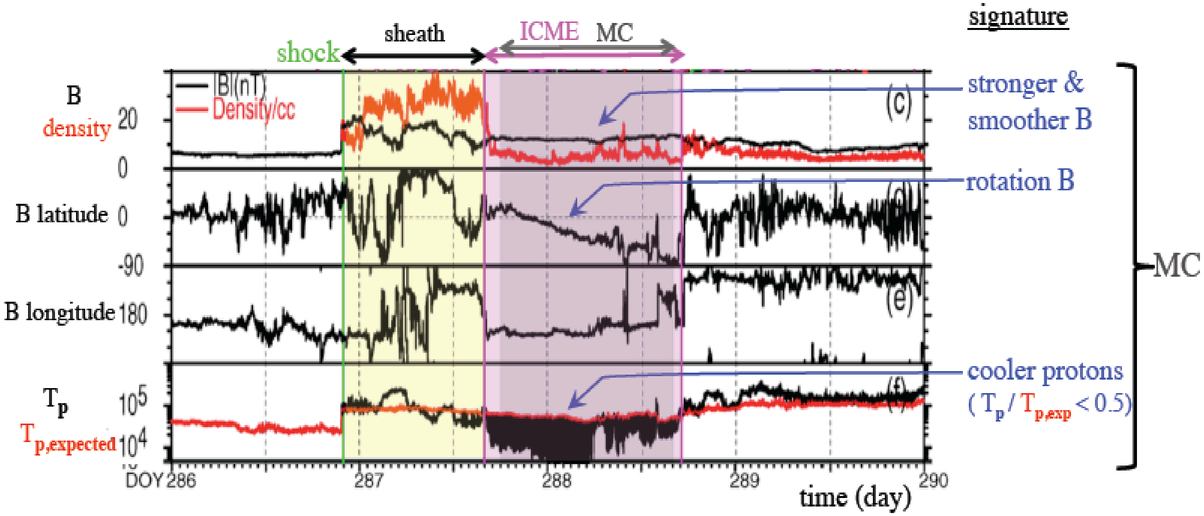
L1 observations





Single Coronagraph measurement
If there's a Halo – Earthbound

It is a very rough idea of trajectory, speed and strength.



In-situ CME measurement is at 1AU :

We need a set of signatures!
- Magnetic field
- Proton temperature, etc…

- This gives the B_z

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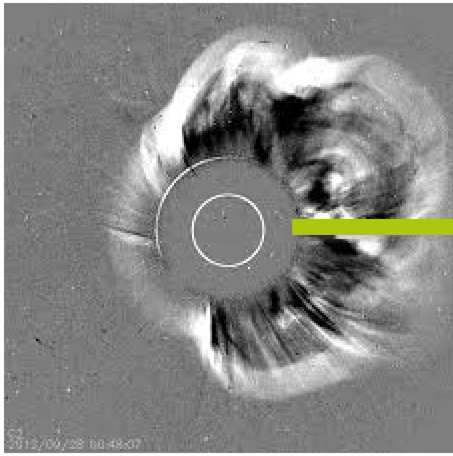
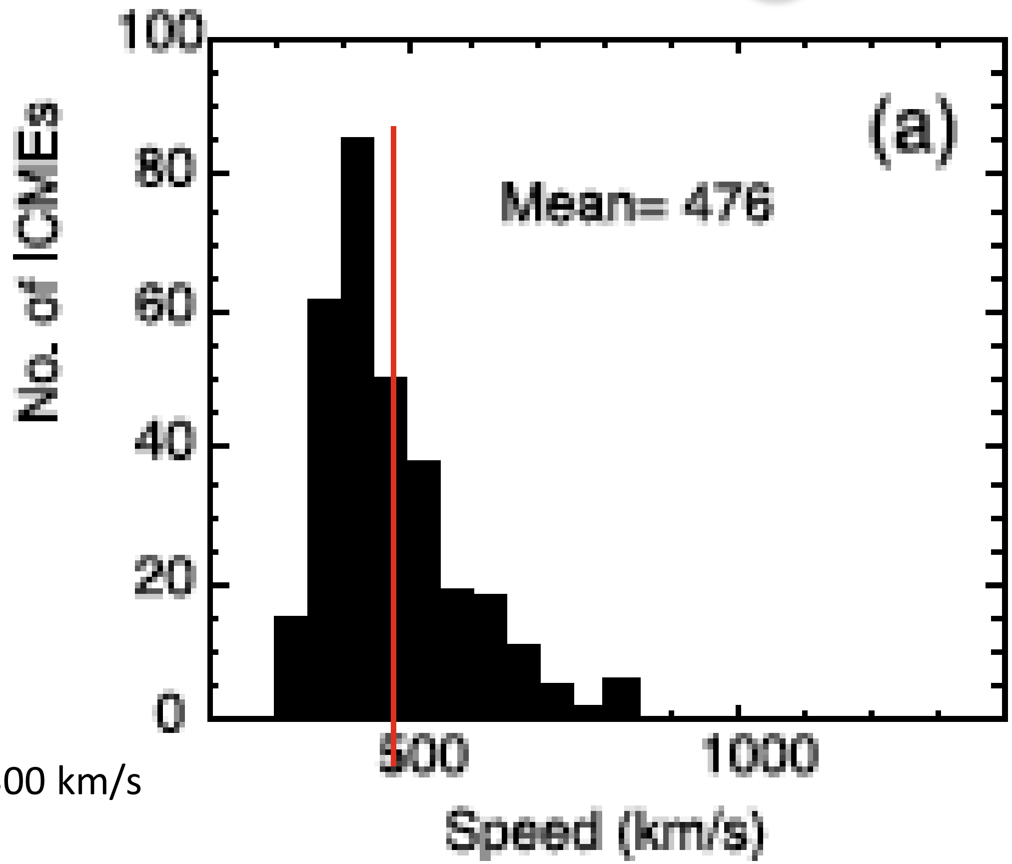


CME In-Situ Measurement

- Better than 4 hours
- Typically better than 9 hours



ICME speed measured at 1 AU : 290 - 1300 km/s
(Cane and Richardson, 2010)

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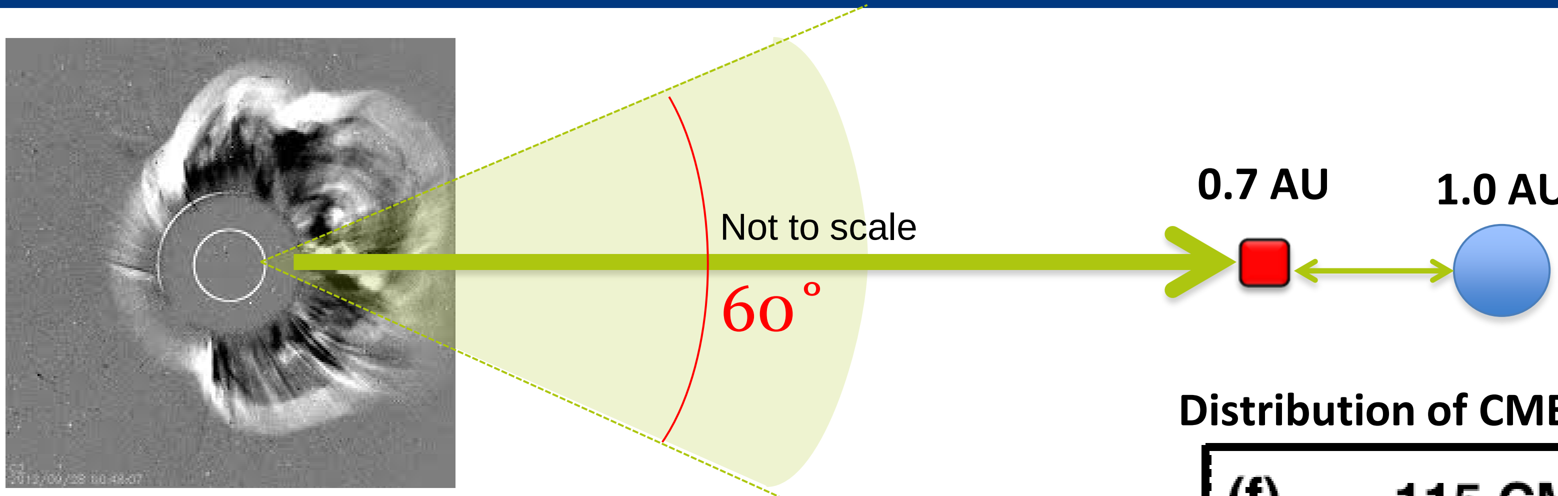
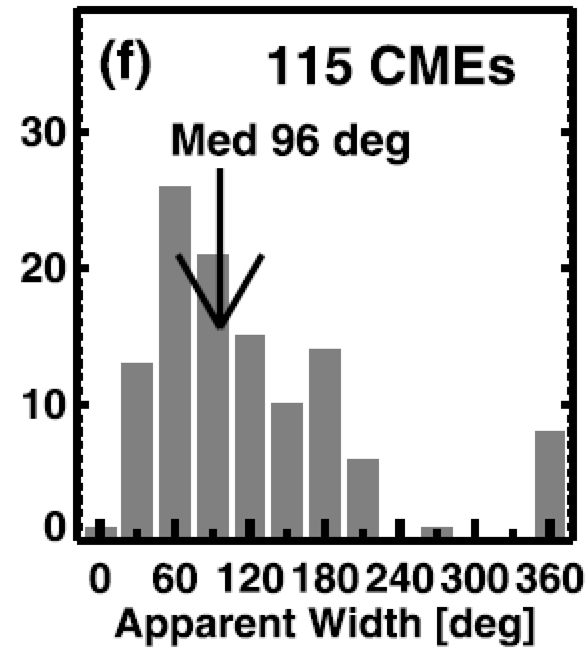


CME Width Distribution

Median of 96° for strong CMEs with a peak of 60°.

Distribution of CME Width



Yashiro et al., 2005

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Motivation: OECD report from 2011

"The international community **should improve** the current geomagnetic storm warning and alert system"

"The relative absence of **public awareness of space weather** phenomenon contributes to the lack of national-level strategic planning amongst OECD member states."

Mission statement & Operational concept

Mission statement

“The system consists of a near real-time information-service, based on the physical properties of solar Coronal Mass Ejections.”

Primary objective

“Develop a CME warning system for the Earth”

1. Measurement of trajectory of CMEs that are heading for Earth
2. Physical properties of CMEs

Secondary objective

“Improve CME models by in situ and remote multipoint measurements.”

Mission top level requirements

1. Determine the CME's propagation trajectory
2. CME plasma parameters:
   I. Protons
   II. Electrons
   III. Heavy ions
3. Measure a CME's magnetic field orientation and magnitude
4. Operational life time of 5 years with an optional 5 years extension

Mission lower level requirements

1. The trajectory of CMEs shall be to less than 4.3 arcmin
2. In situ measurements of heavy ions up to 56 amu/q shall be measured each minute
3. Low-energy ion particle flux in the range of 0.26 to 20keV/q shall be measured each minute.
4. Low-energy electron flux in the range of 1 eV to 5 keV shall be measured each minute.

Mission lower level requirements

5. CMEs will be remotely sensed from ~2 to 15 Rs

6. CMEs will be remotely sensed and in situ measured from at least two positions simultaneously >45° apart.

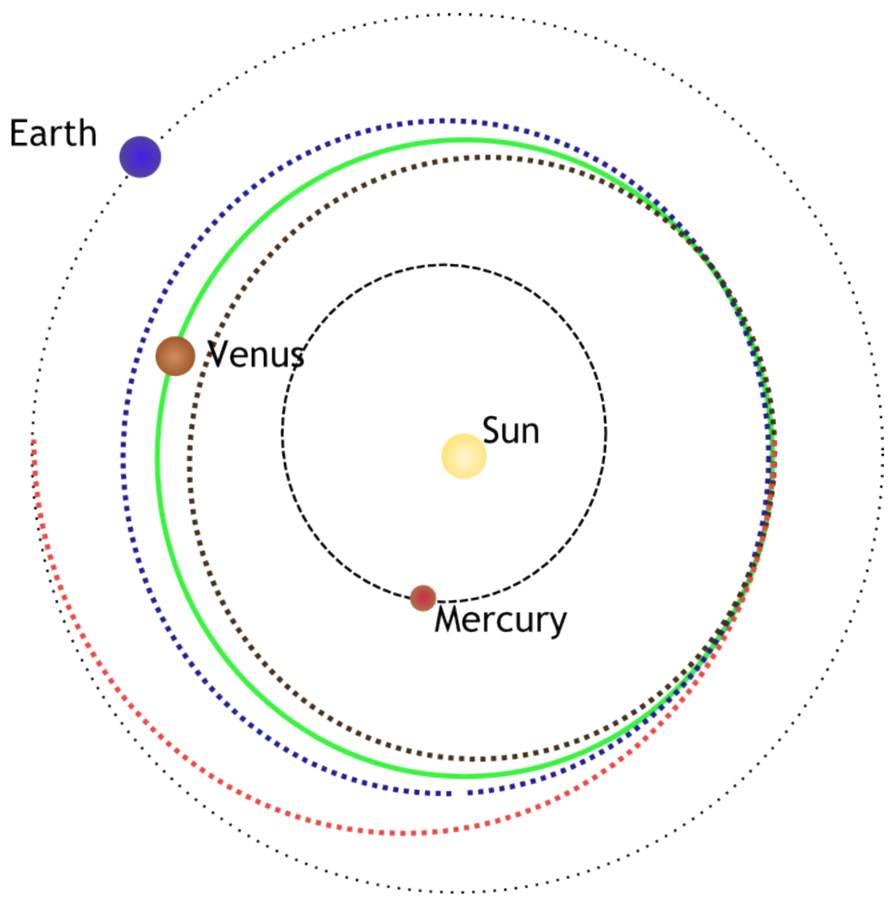
7. The magnetic field shall be measured with a resolution of 0.1nT and an amplitude from -200nT up to 200nT.

8. The data shall be processed according to the Space Weather Coordination Centre (SSCC) Standards and shall be made available to the SSCC.

Launch & orbit

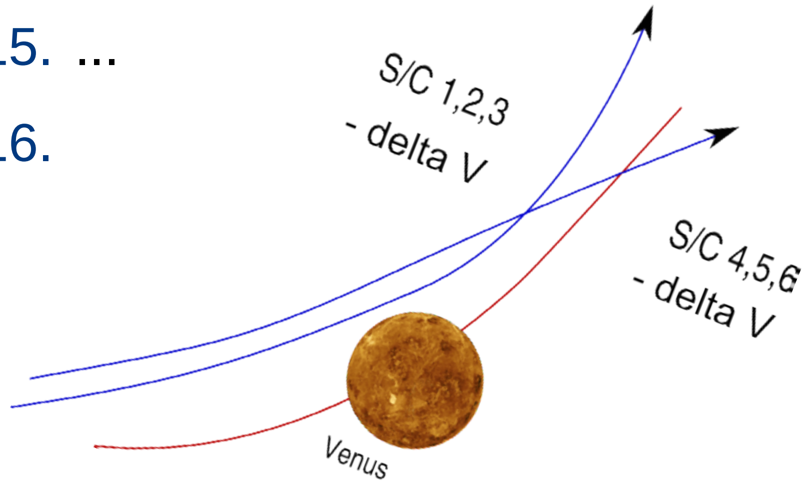
- six spacecrafts
- launcher: Ariane 5
- launch window: 3 weeks
- opportunity: every 19 months

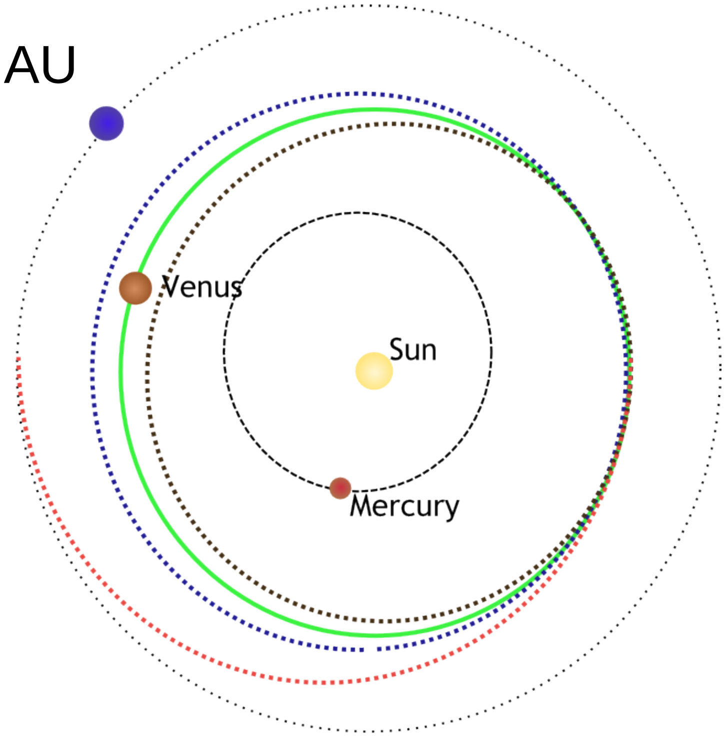
1. launch date: 25 July 2026
2. separation launcher
3. low gain antenna communication
4. stacked space crafts will be separated
5. solar panels will be opened
6. deployment of high gain antenna



Launch & orbit

10. cruising time to Venus: ~6 months
11. Gravity assist at Venus
12. Insertion S/C1, calibration, one month
13. S/C1 operational, 224day rotation, 0.7 AU
14. Insertion SC 4, calibration, one month
15. ...
16.





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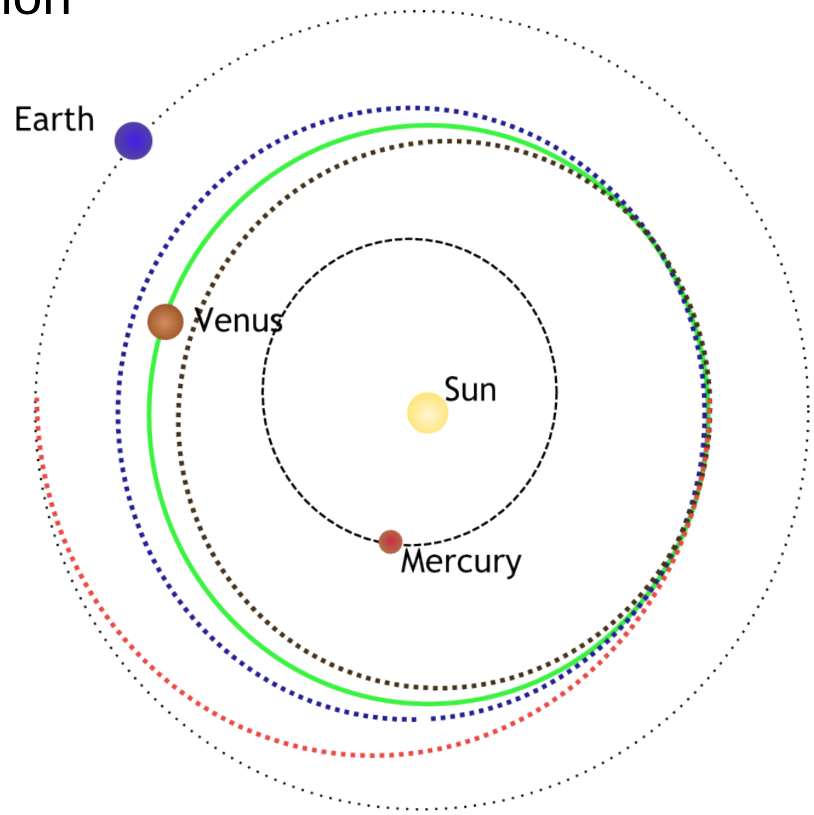
Launch & orbit

16. Mission fully operational, 15 may 2030
17. 15 may 2035, start mission extension
18. ...
19. 2040 decommissioning



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Communication

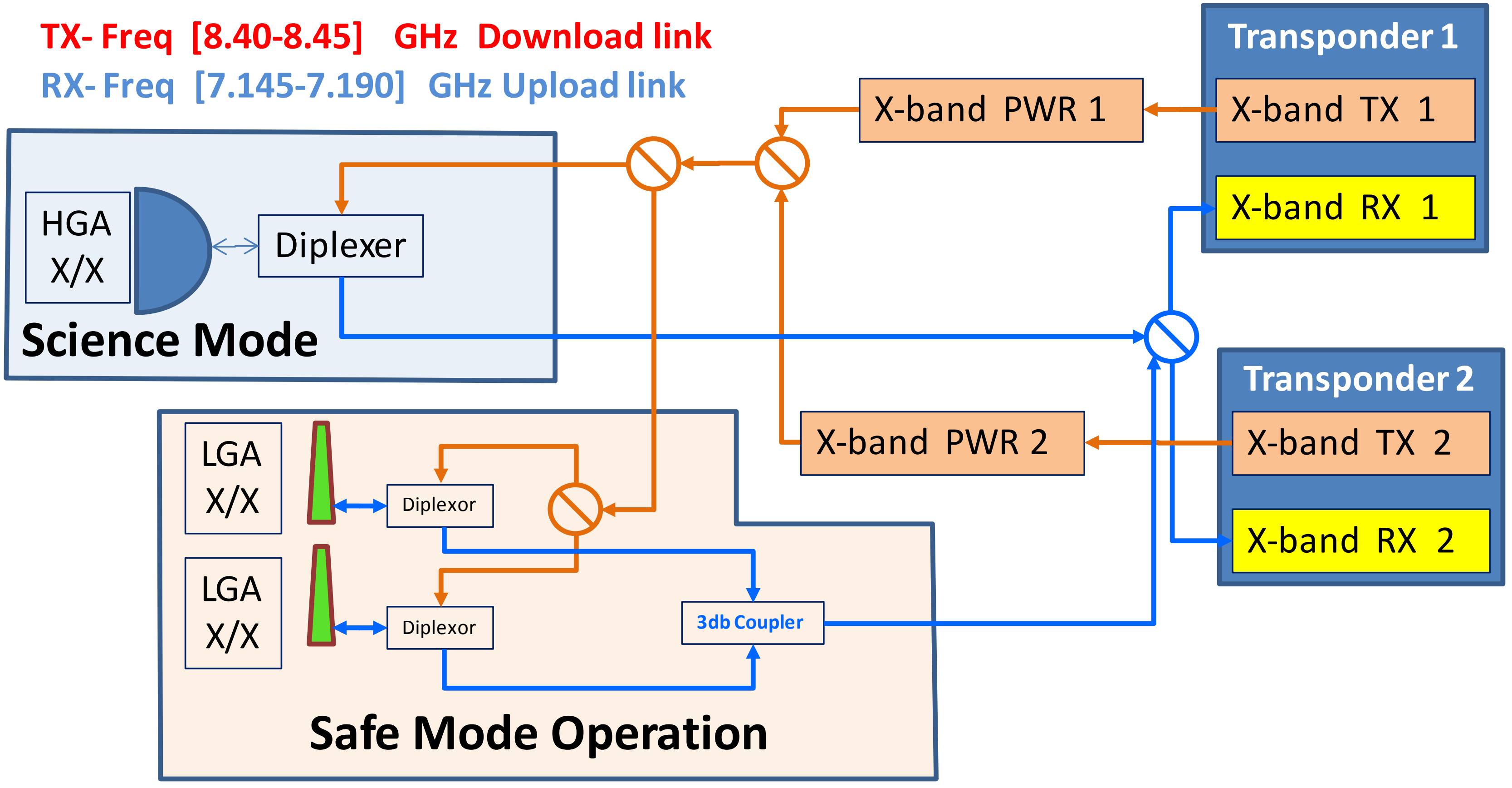
Antennas

- 1 x High Gain Antenna (HGA), Articulated, deployable, X-band, 1m dish, 1.75 deg Beamwidth
- 2 x Low Gain Antenna (LGA), Near omni-directional coverage

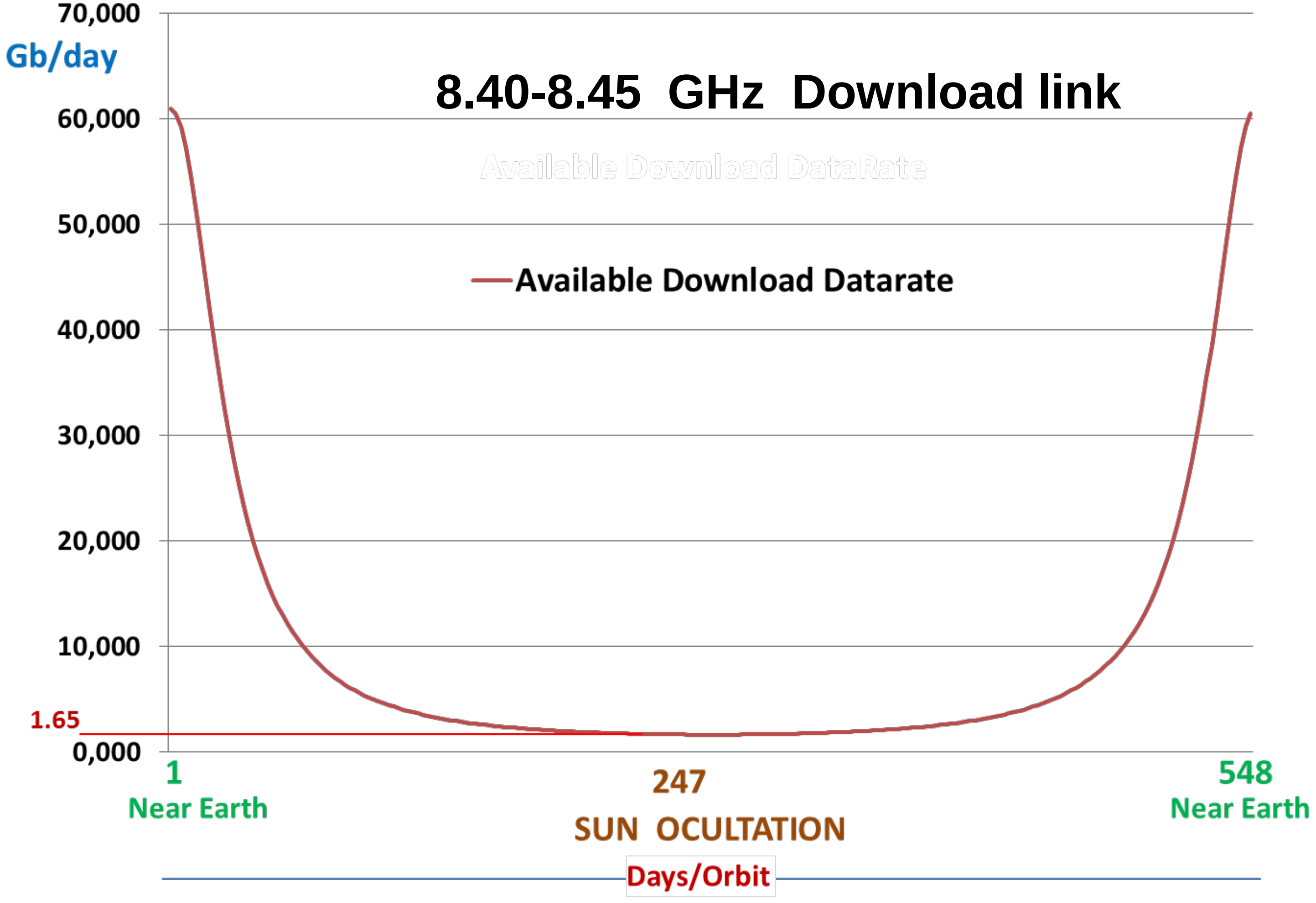
Radio Frequency Distribution Unit

- 8.40-8.45 GHz Download link
- 7.145-7.190 GHz Upload link
- 60 W travelling wave tube amplifiers

Communication



Communication



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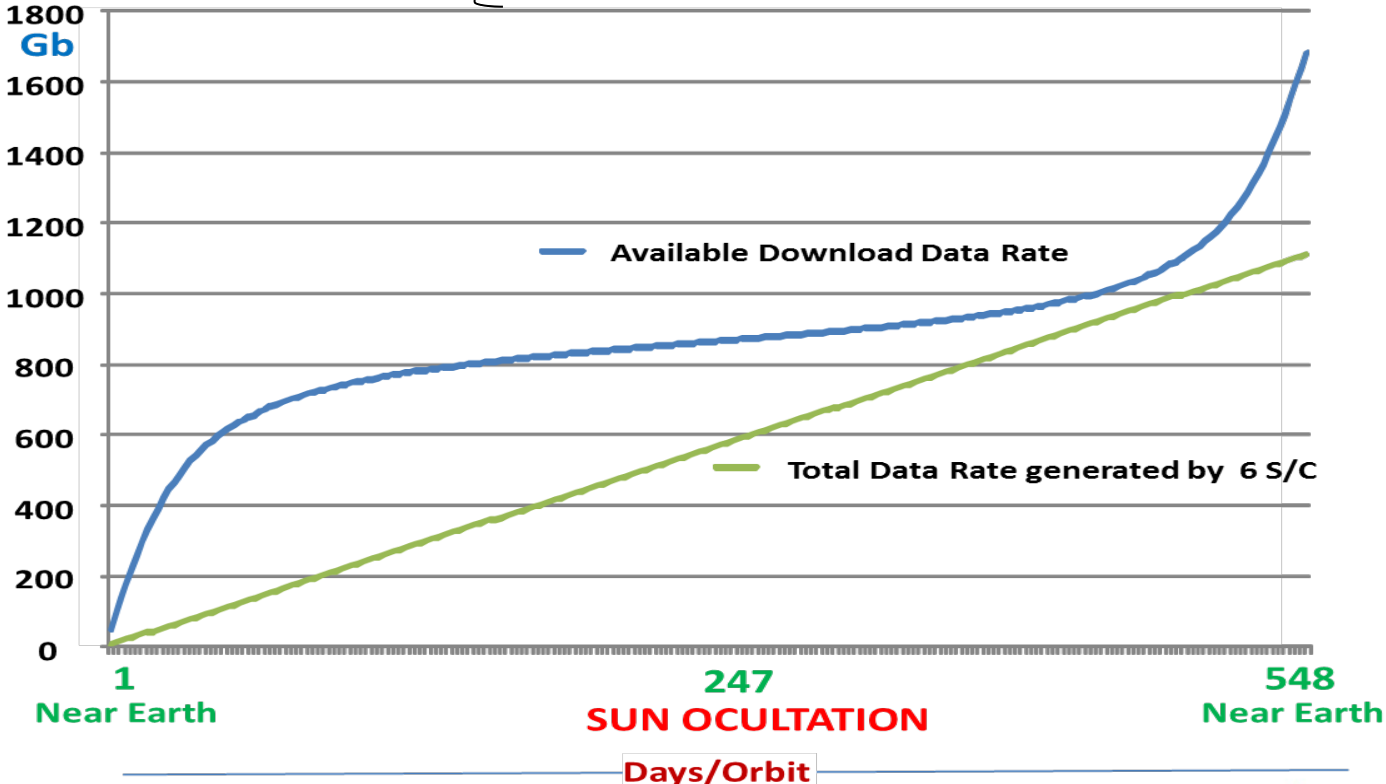
Communication

2-S/C with coronagraphs + insitu and 4-S/C only in situ

1112 Gb during orbit → 841 Gb with Earth Antenna A + 841 Gb with Earth Antenna B



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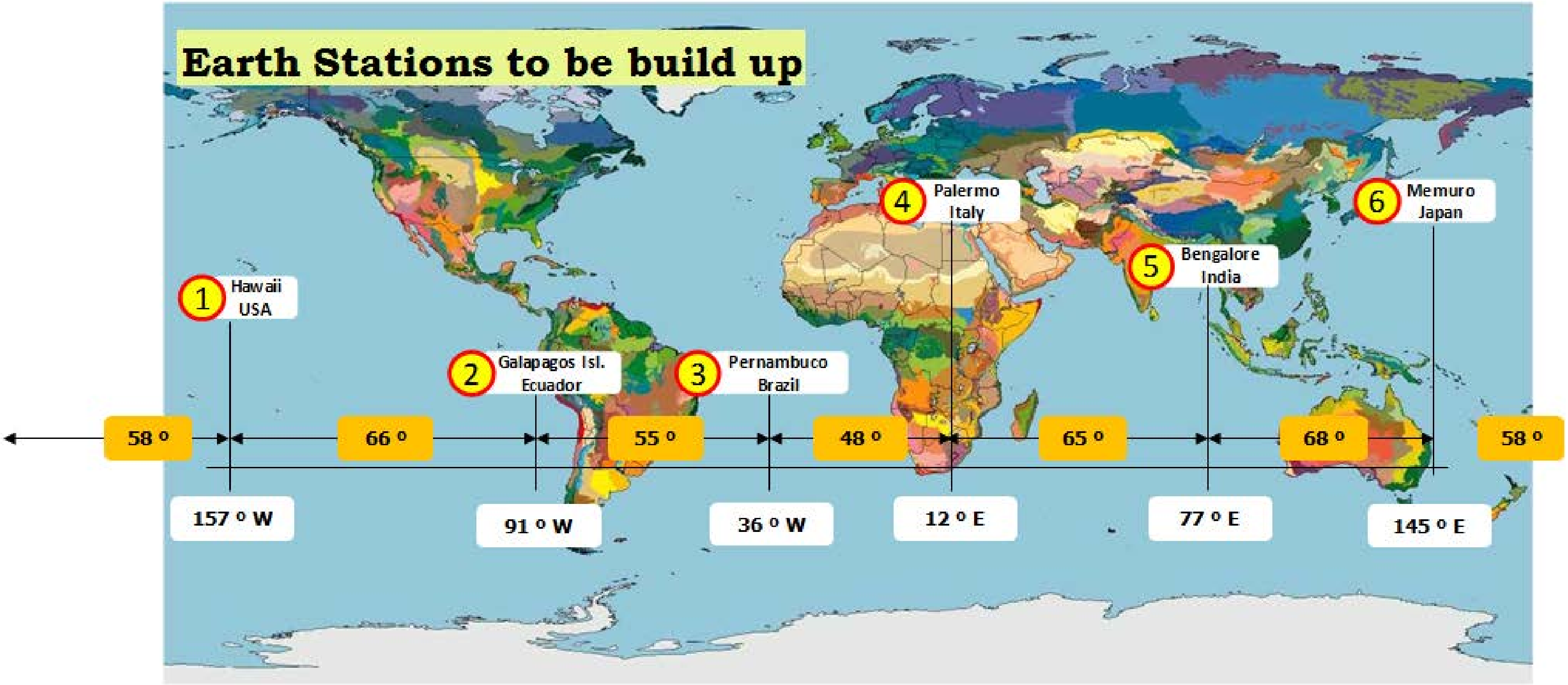
Communication

- 6 dedicated Earth antennas of 15 m during total operation



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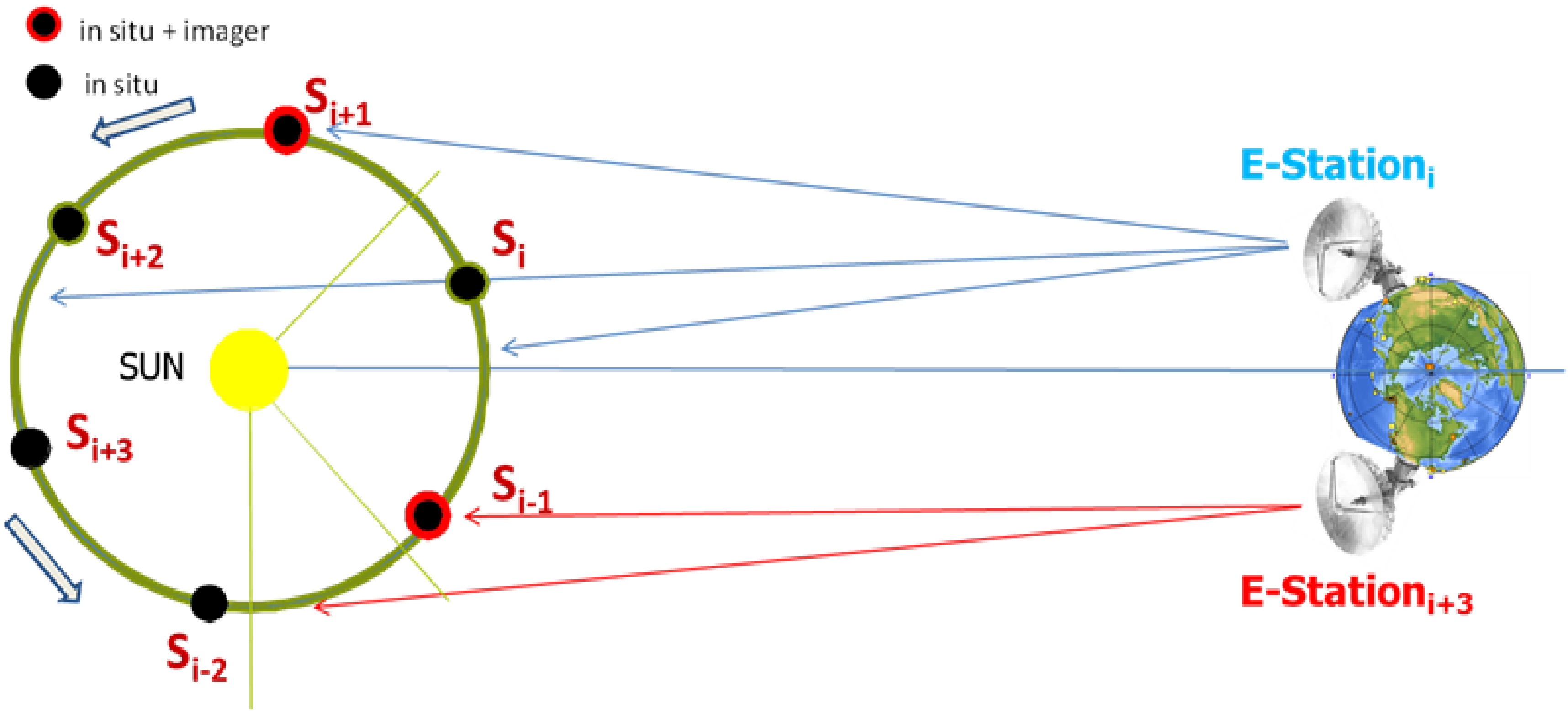
Communication



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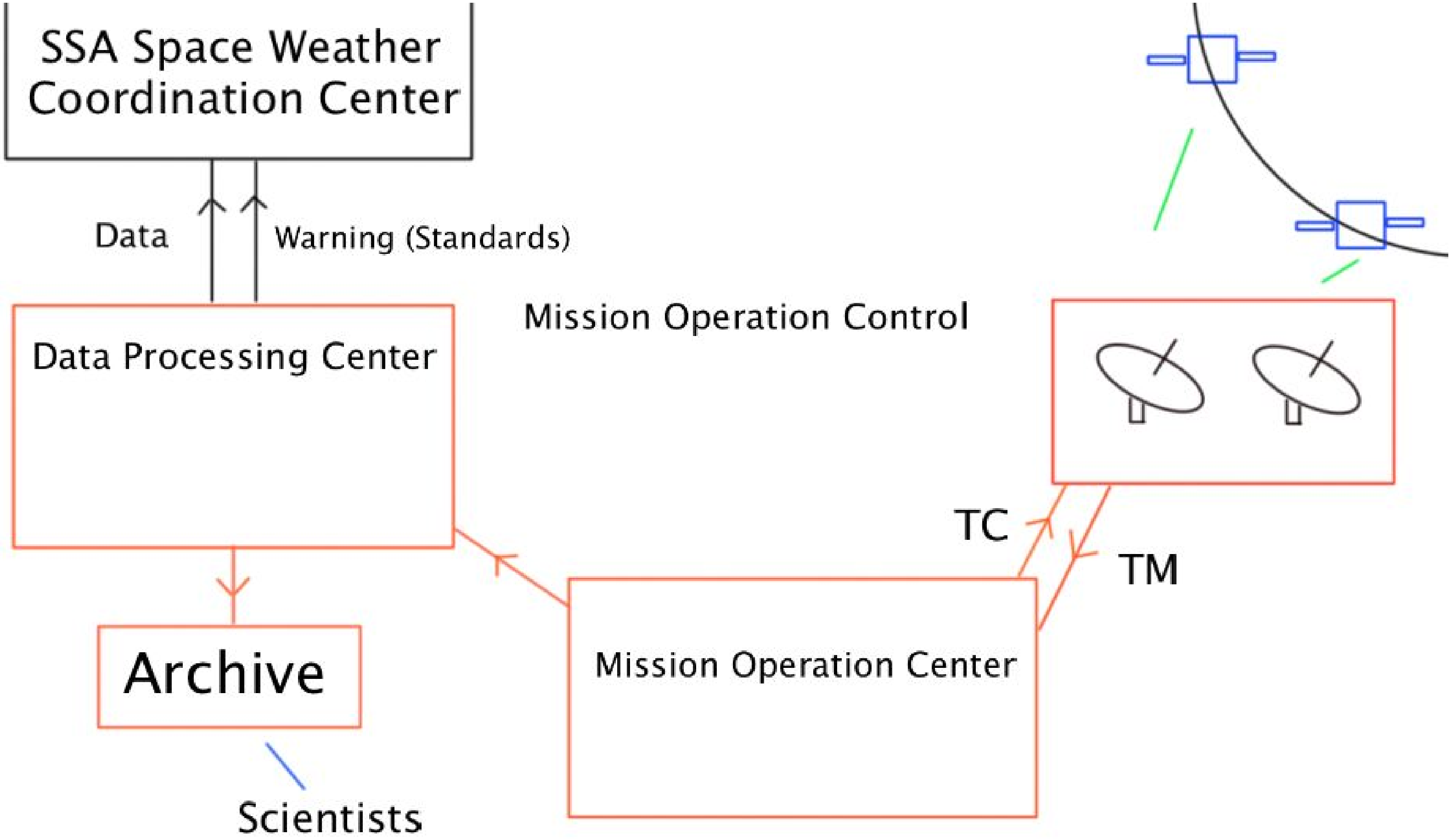
Ground segment



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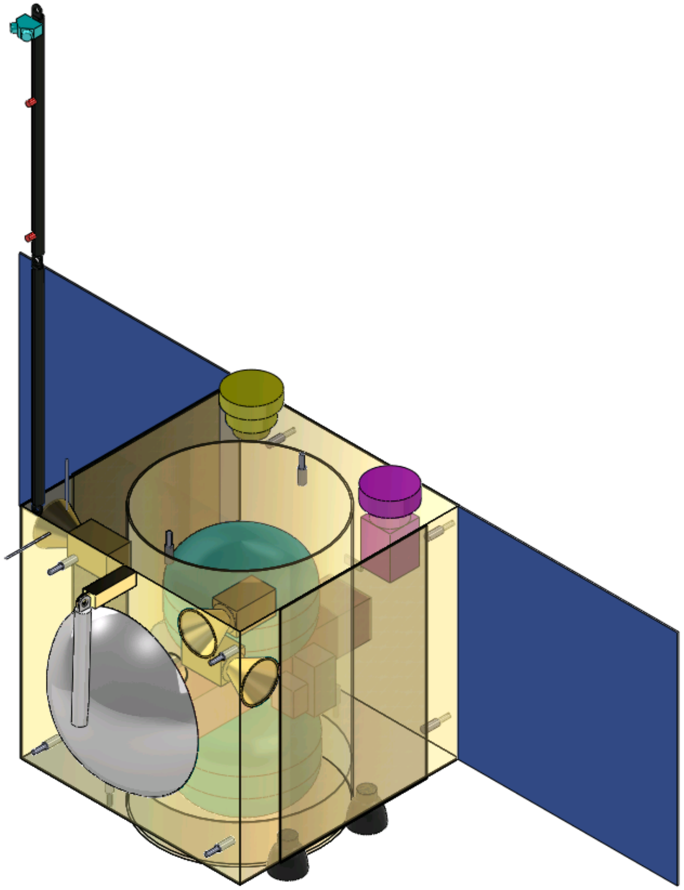
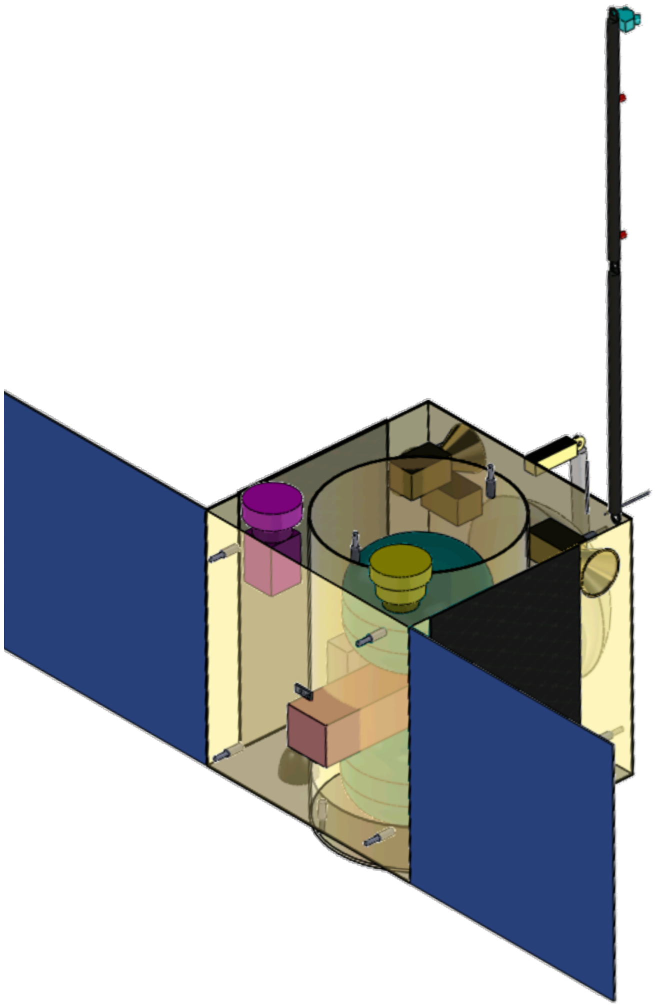
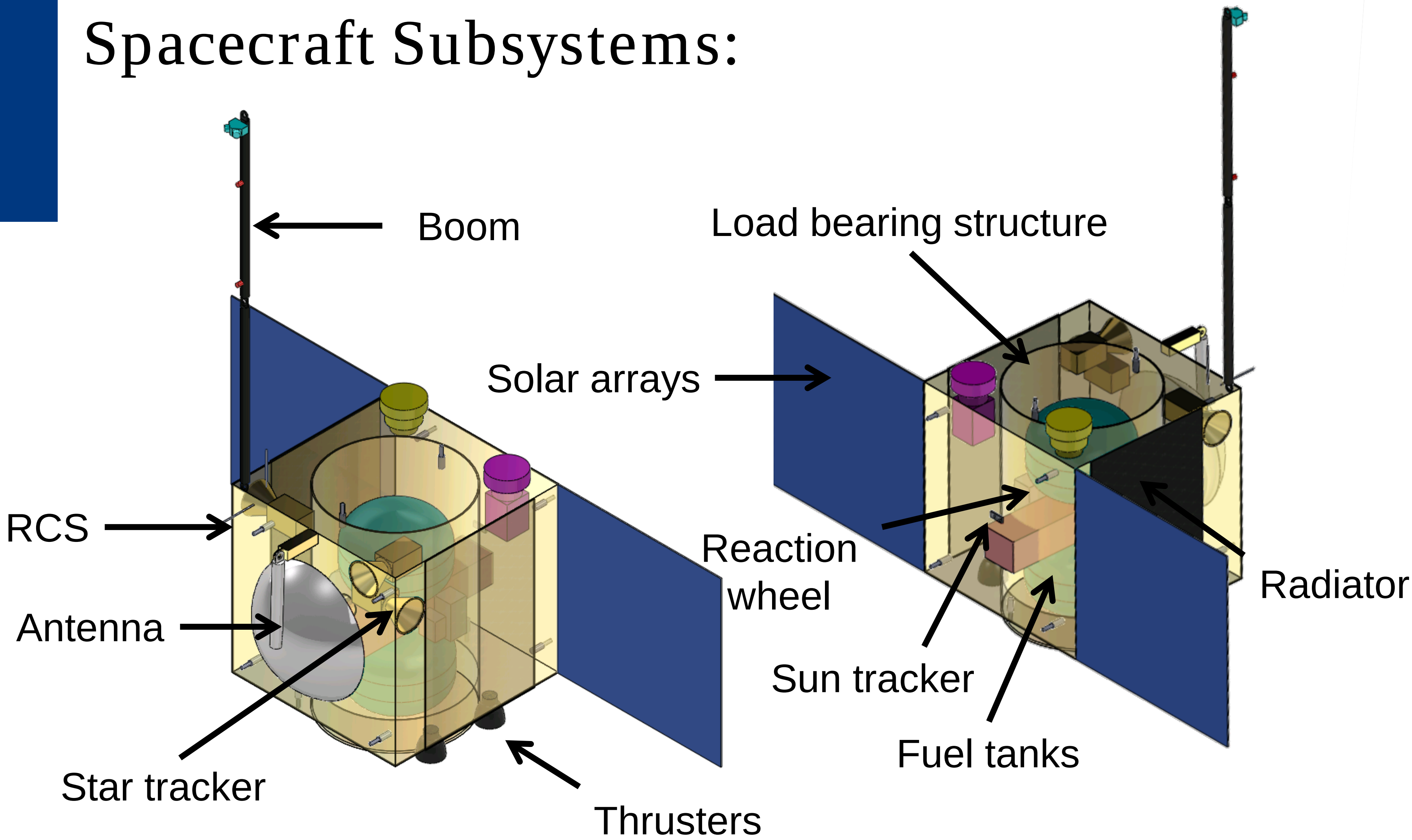
Spacecraft Subsystems

Spacecraft Subsystems:





Spacecraft Subsystems:



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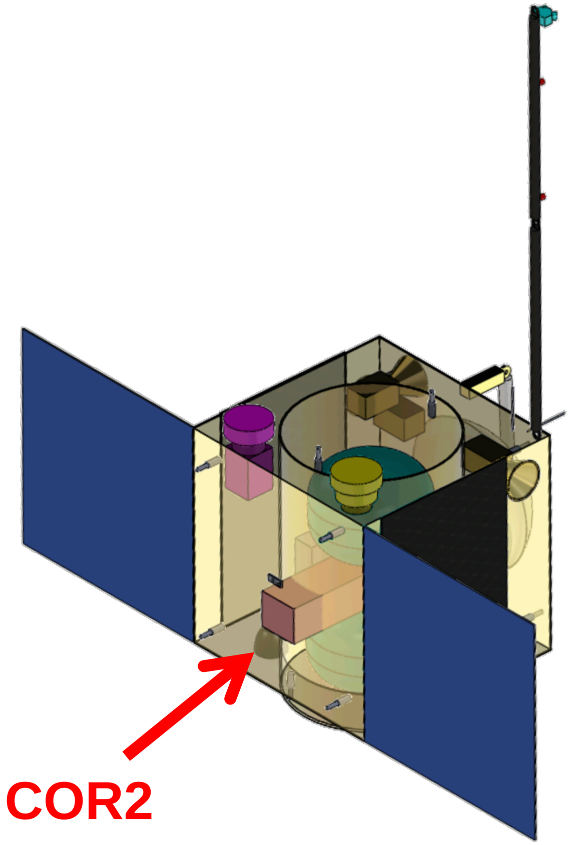
Payload

Payload

Instruments:

1. Coronagraph (*based on STEREO*)

   * SECCHI – COR2



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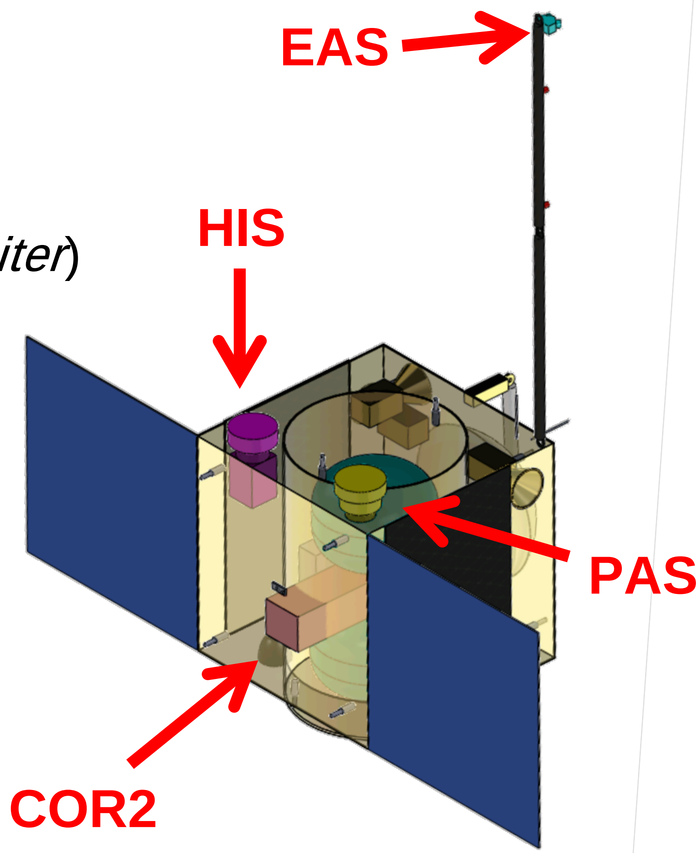
Payload

Instruments:

1. Coronagraph (*based on STEREO*)
   * SECCHI – COR2
2. Solar Wind Analyzer (*based on Solar Orbiter*)
   * Electron Analyzer System - EAS
   * Proton Alpha Sensor – PAS
   * Heavy Ion Sensor - HIS



Payload

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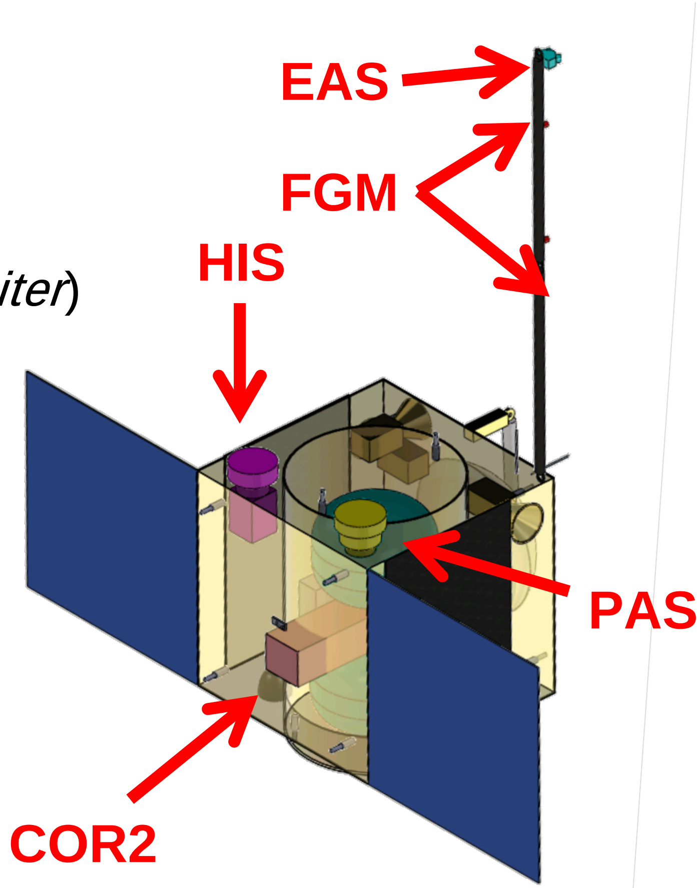
1. Coronagraph (*based on STEREO*)
   * SECCHI – COR2
2. Solar Wind Analyzer (*based on Solar Orbiter*)
   * Electron Analyzer System - EAS
   * Proton Alpha Sensor – PAS
   * Heavy Ion Sensor - HIS
3. Magnetometer (*based on Venus Express*)
   * Fluxgate Magnetometer



1. Coronagraph

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Measurement: remote sensing

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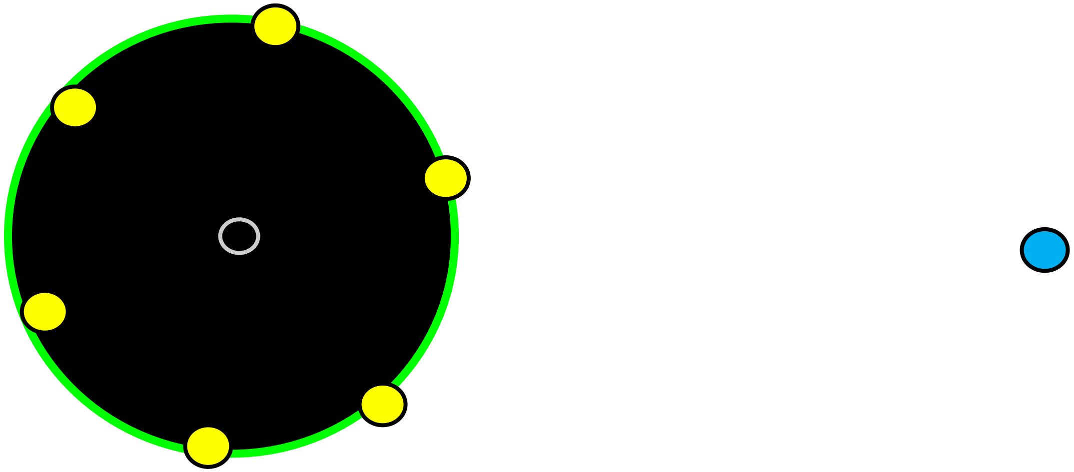
Measurement: remote sensing



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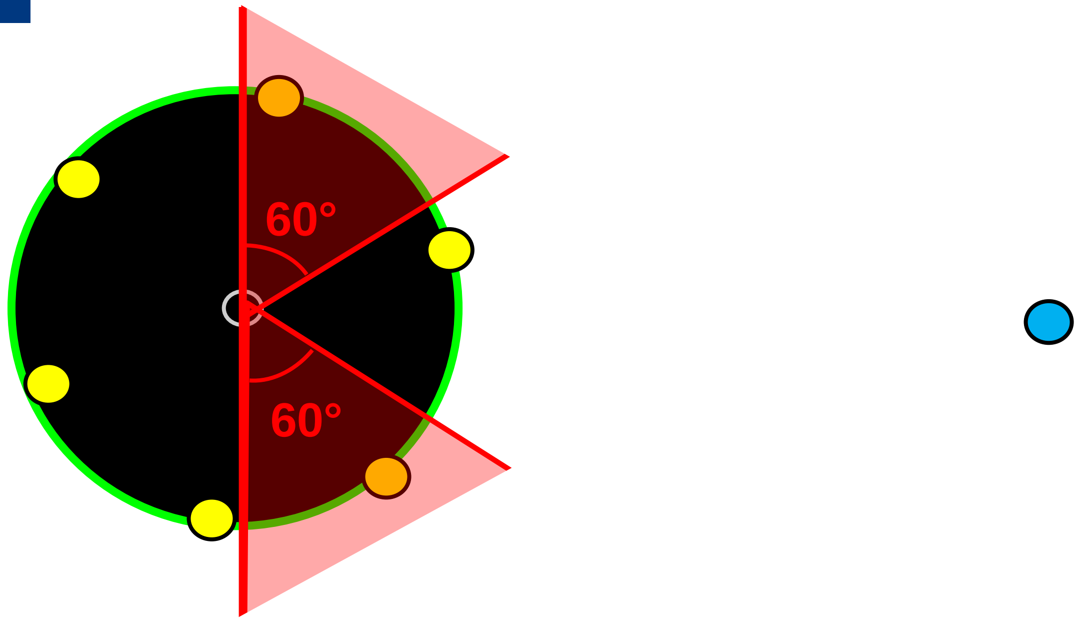
Measurement: remote sensing



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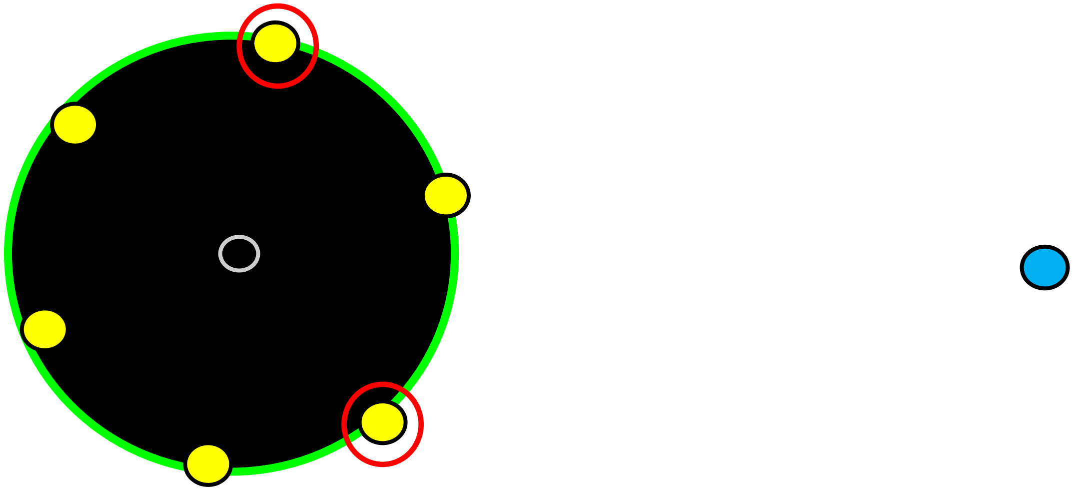
Measurement: remote sensing



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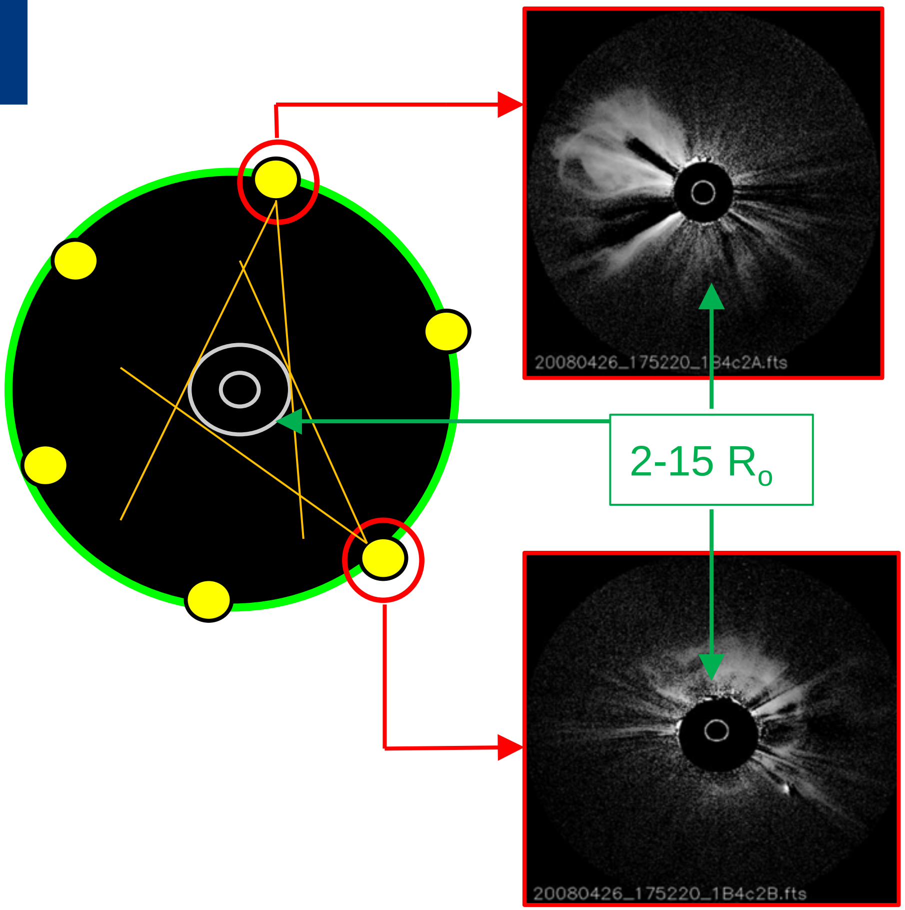
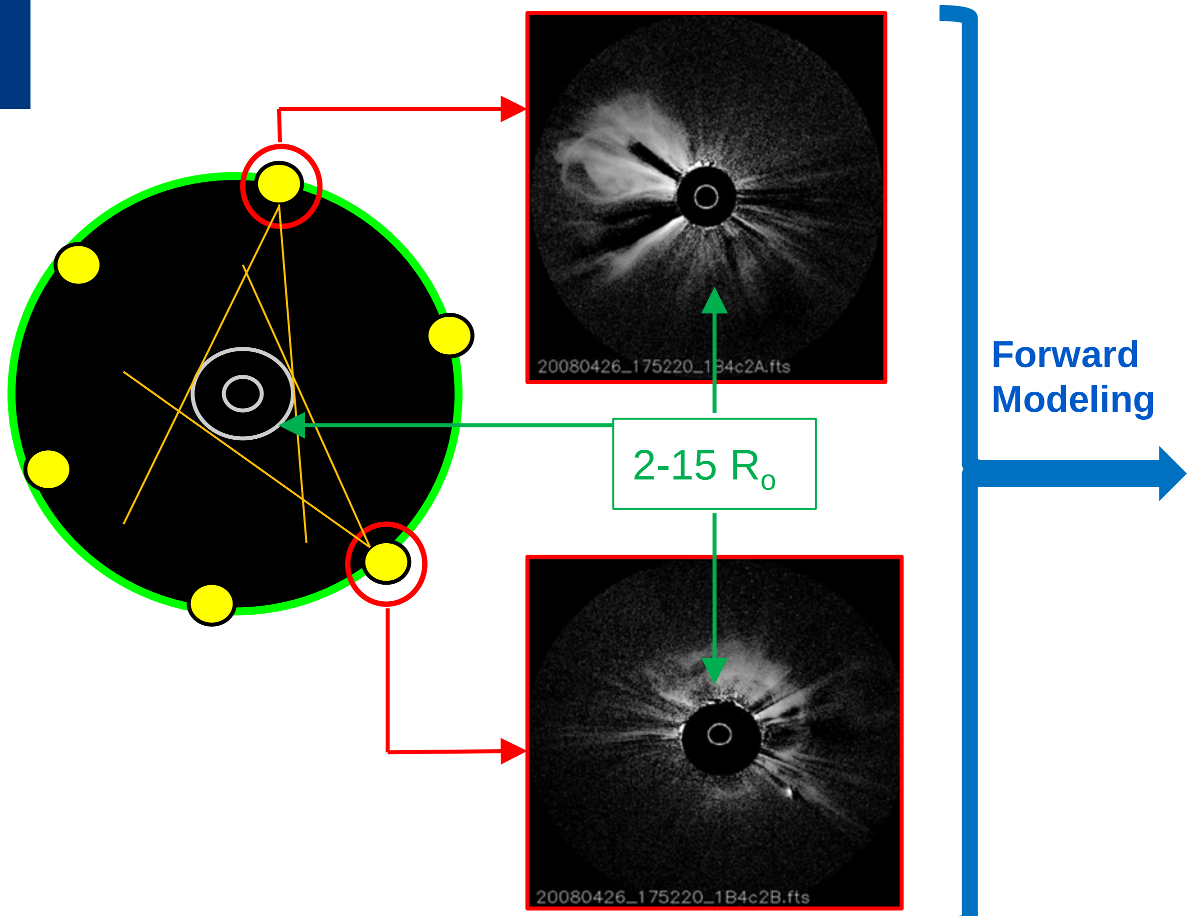
Measurement: remote sensing



Credit STEREO Mission

1. Coronagraph

Measurement: remote sensing

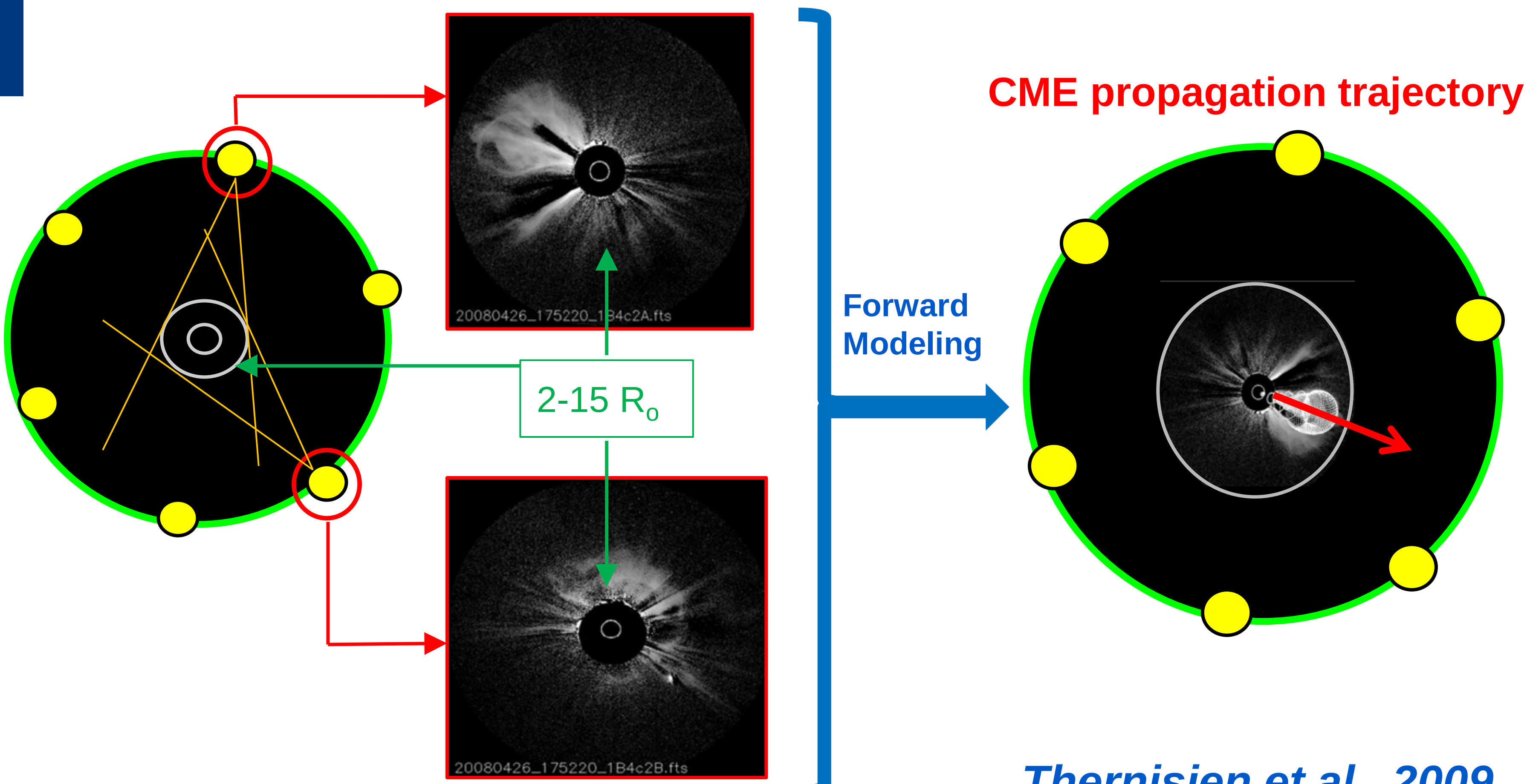


Credit STEREO Mission

Thernisien et al., 2009

1. Coronagraph

Measurement: remote sensing



Credit STEREO Mission

Thernisien et al., 2009

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1. Coronagraph

Instrument Properties:

Distances observed [Ro]	2 – 15
FOV [deg]	11.4
Wavelength [nm]	450 - 750
Compression factor	10
Pixel size (arcsec)	15
Images per hour	12

2. Solar Wind Analyzer (SWA)

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Measurement: in situ

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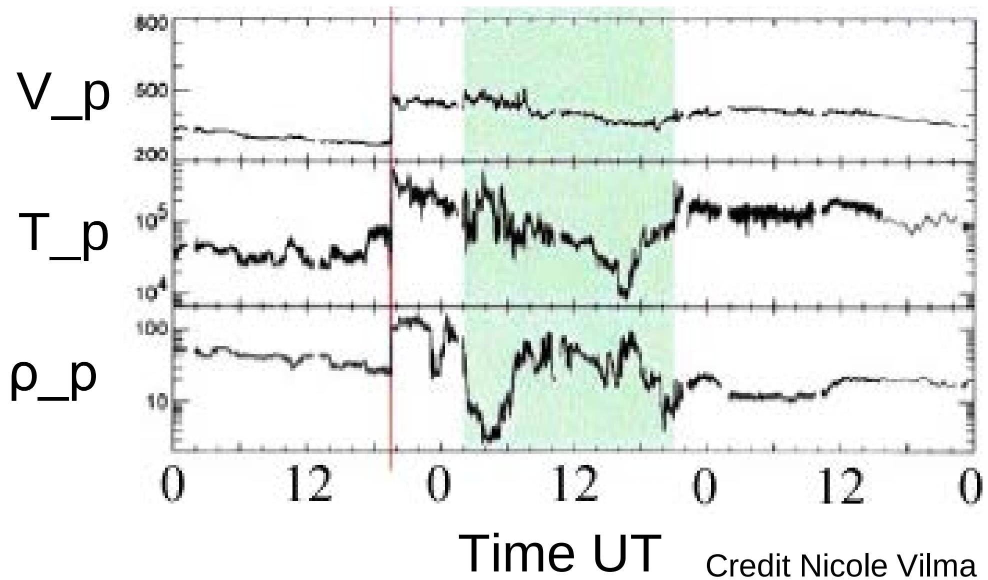
Measurement: in situ

Plasma Parameters (3D Distribution) of protons, electrons heavy ions:

- ion moments (density, velocity, temperature)
- electron pitch angle distribution
- charged state and composition



Credit Nicole Vilma

2. Solar Wind Analyzer (SWA)

Measurement: in situ

Plasma Parameters (3D Distribution) of protons, electrons heavy ions:

- ion moments (density, velocity, temperature)
- electron pitch angle distribution
- charged state and composition

Instrument properties:

	EAS	PAS	HIS
Particle Species	Electrons	H+,He++	3He - Fe
Energy Range	1 eV to 5 keV	0.2 to 20 keV/q	0.5 to 100 keV/q(Az) 0.5 to 16 keV/q(El)
Cadence	4 sec	4 sec	30 sec

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3. Fluxgate Magnetometer (MAG)

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Measurement: in situ

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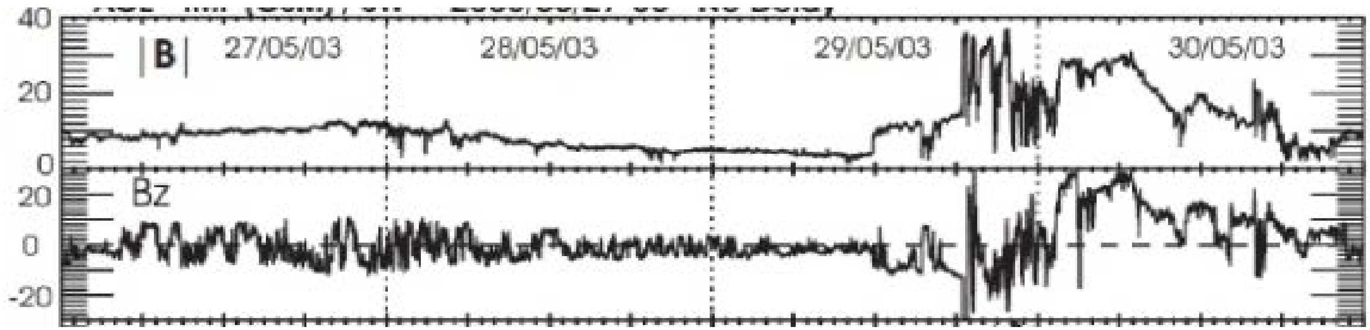
Measurement: in situ

3 Magnetic field components (Bx,By,Bz)

|B|

B_z



Time UT

Credit Nicole Vilma

3. Fluxgate Magnetometer (MAG)

Measurement: in situ

3 Magnetic field components (Bx,By,Bz)

Instrument properties:

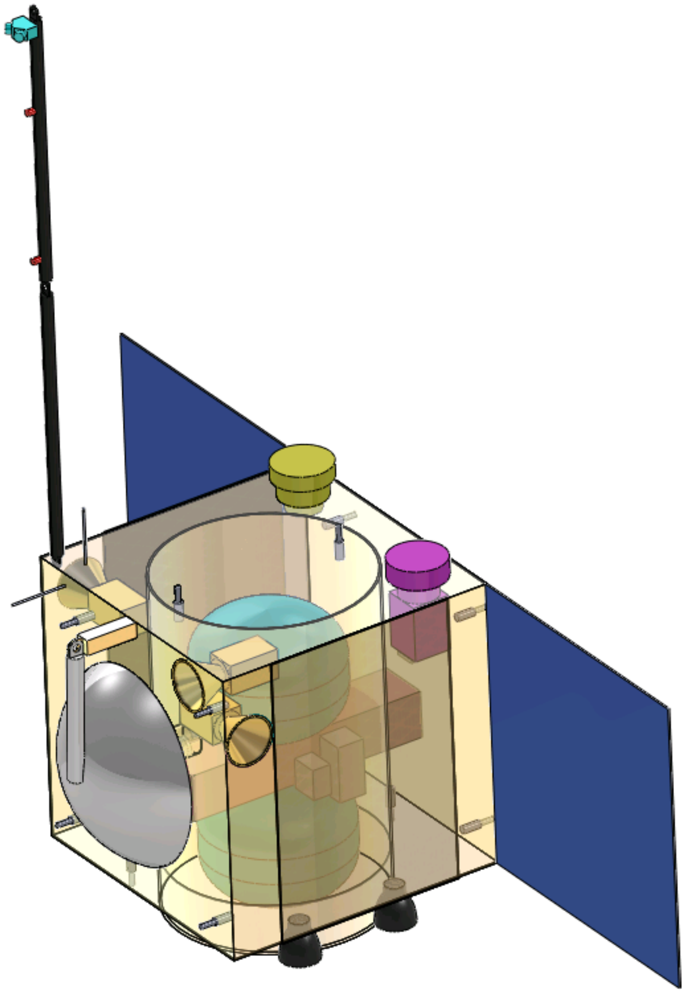
Operating Range	-160 to 120°C
Sensitivity	16 pT
Range	± 262 nT
Cadence	1 Hz

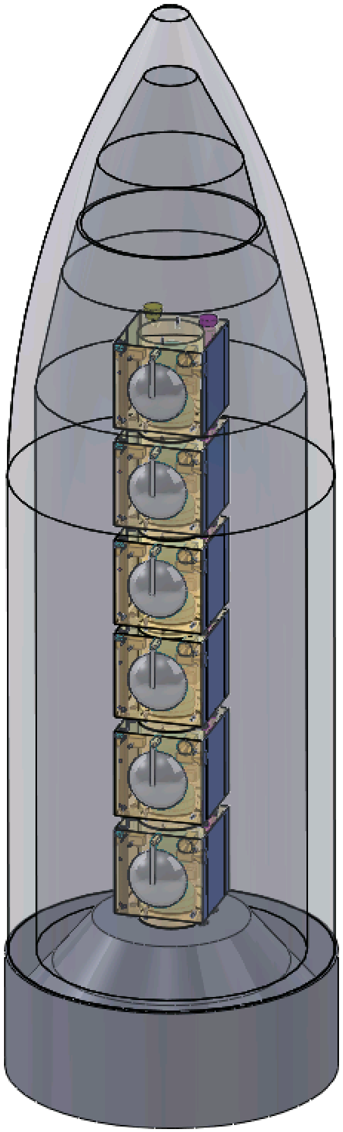
Subsystem - Payload

Budget:

Instrument	Mass [kg]	Power [W]	Telemetry Volume [kbph]
Coronagraph	11.0	5.5	150,995
SWA (ESA+PAS+HIS)	15.5	11.0	115
Magnetometer (+ Boom)	4.2	2.0	5
Total	**30.7**	**18.5**	**151,115**

Spacecraft Overview





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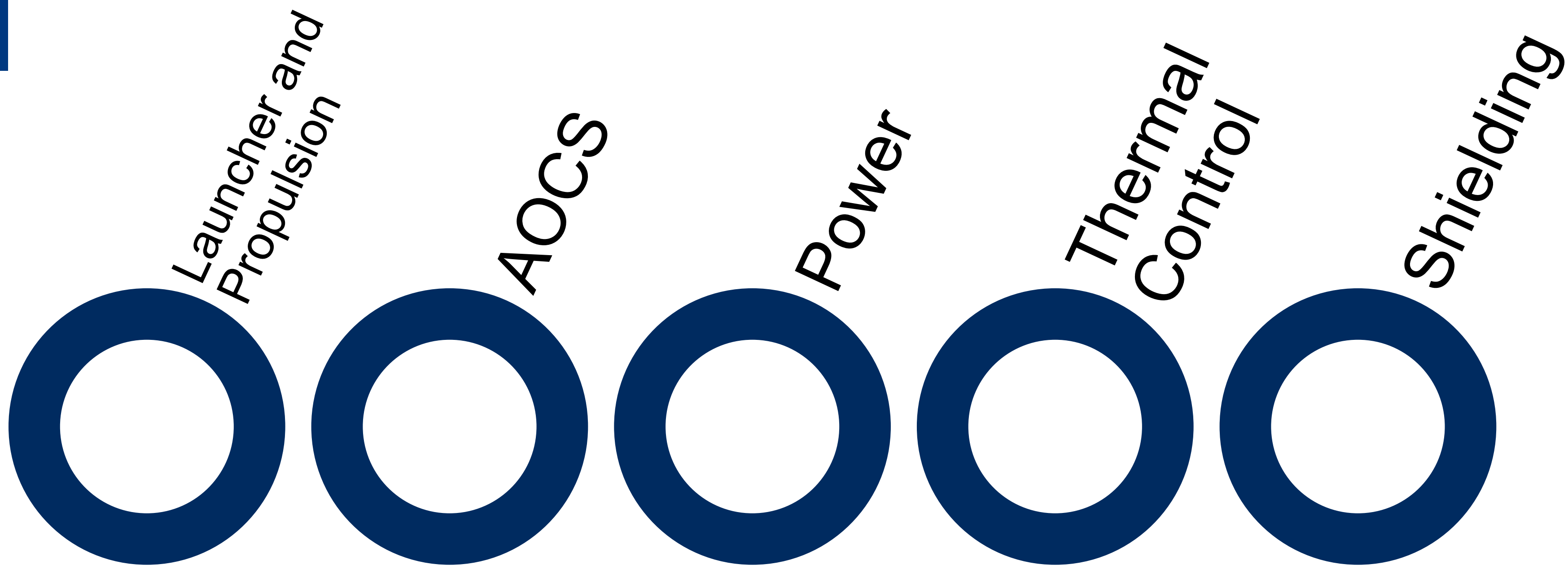
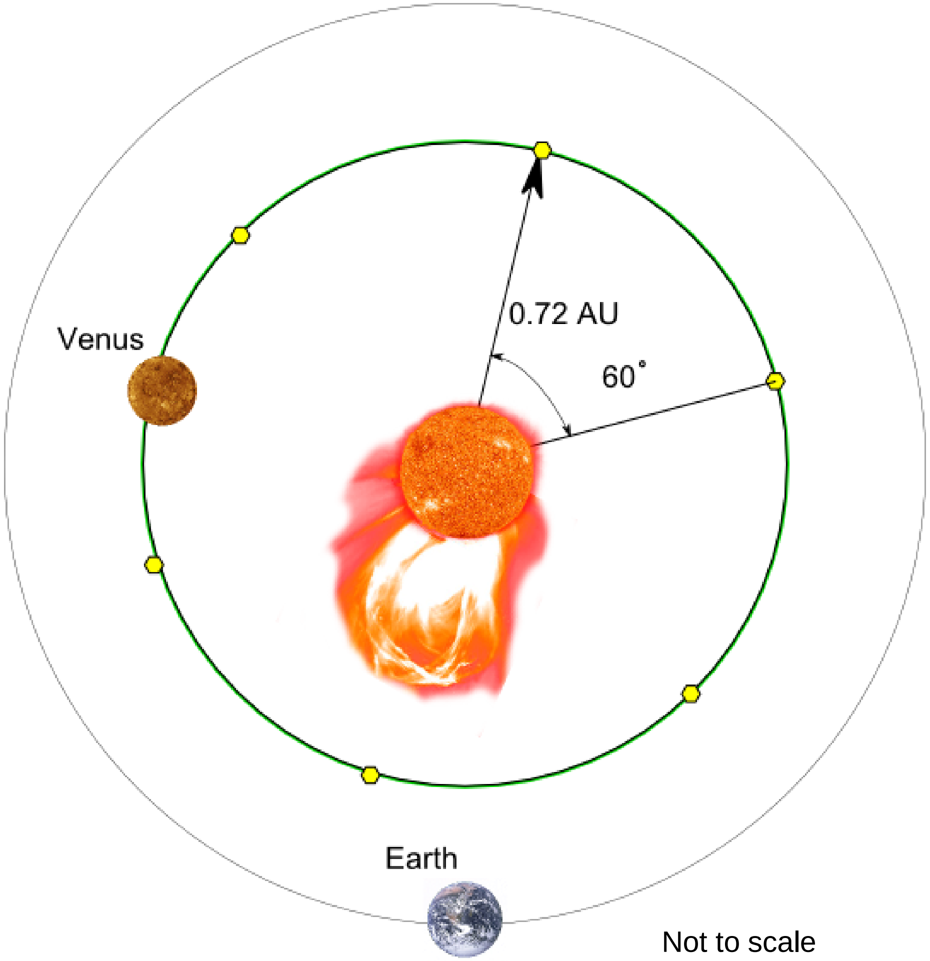
Spacecraft Subsystems



Launcher and Preliminary Transfer

Not to scale



Not to scale

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Launcher Trade Off

Parameter\Launcher	Soyuz	Ariane 5	Units
Performance at Required Escape Speed	1850	5255	[kg]
Cost per Launch	75	160	[M€]
Cylindrical Fairing Dimensions (height x diameter)	5060 x 3860	10039 x 4570	[mm^2]
Number of Launchers Required	3	1	N/A
Total Mass Delivered to Transfer Orbit	**5550**	**5255**	[kg]
Total Cost	**225**	**150**	[M€]

- Ariane 5

Propulsion

Types of propulsion considered:

Electrical

Chemical

Propulsion Trade Off

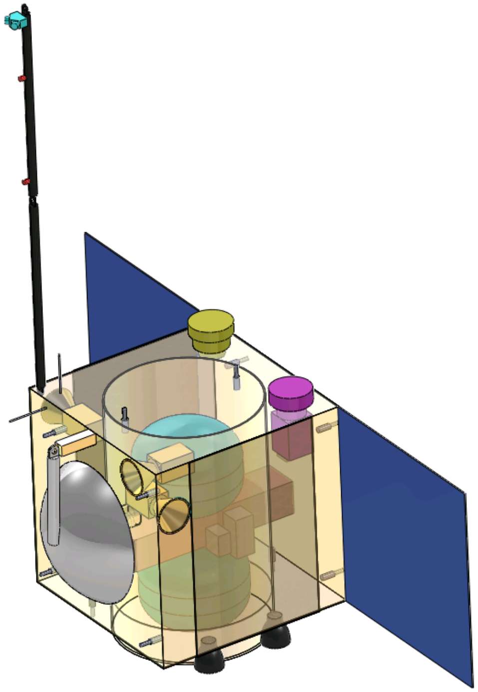
Parameter\Engine	Electric	Chemical	Units
Time to Reach Required Final State	~8	~4	[yrs]
Power Consumption	4320	2	[W]
Thrust	0.12	420	[N]
Fuel Mass	32	275	[kg]
Subsequent Mass	95	5	[kg]
Total wet mass of Satellite	670	800	[kg]

- Chemical Propulsion

Thruster Configuration

- 4 x 22 N Hydrazine Bi-propellant Engines
- Two 189l propellant tanks shared with RCS

Astrium OST 25/0

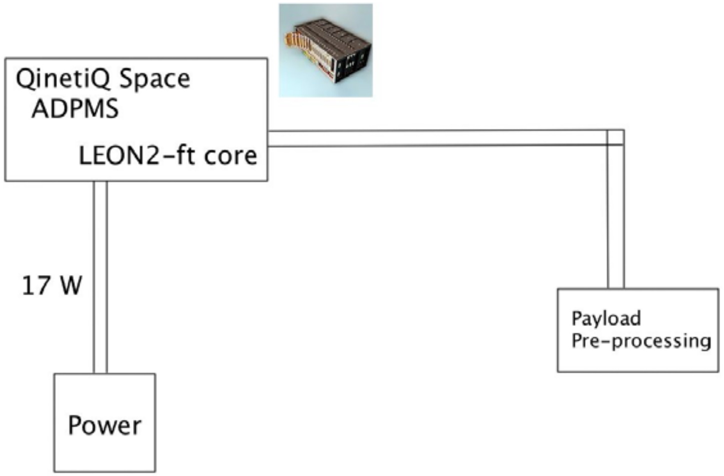


Attitude and Orbit Control System (AOCS)

Sub Components:

- Spacecraft Attitude Determination and Control (SADC)
- Reaction Control System (RCS)

Subsystems - AOCS: SADC

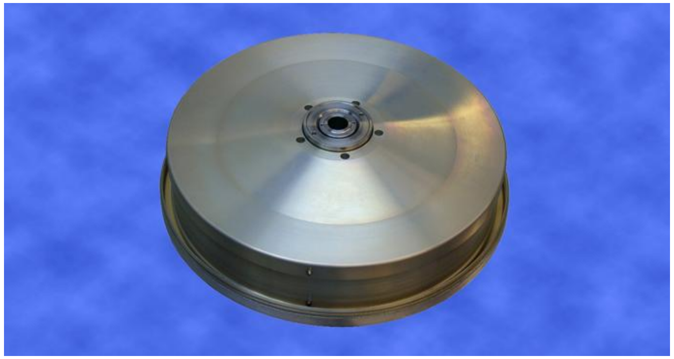


Control Algorithm Processing

- via Central CPU

Momentum Wheels

- 3+1 redundant (all running)
- Pointing accuracy
  - 4.5 arcsecs over the exposure time of 4s



Rockwell Collins Euro.: RSI 4-75/60

Subsystems - AOCS: SADC

IMU (Inertial Measurement Unit)

Safe Mode Pointing with Thrusters

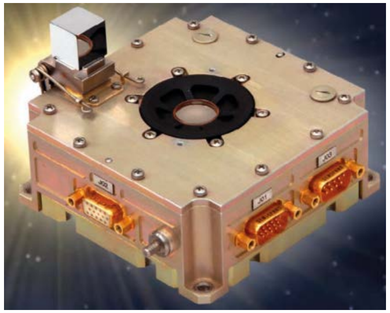
1+1 redundant

Sun Sensor

1+1 redundant

Star Tracker

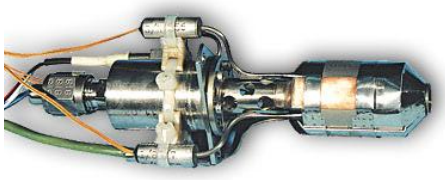
2+1 redundant



Selex S3

Selex AA-STR

Subsystems - AOCS: RCS



12 x 4N Hydrazine Thrusters

2 Propellant Tanks (Common with Main Thruster)

Propellant mass (Delta-V Corrections): 41.4 kg

Power

Solar Panels:

- 30% Triple Junction GaAs solar cell
- Required solar cell area: 3 m^2
- Generate up to 1000 W

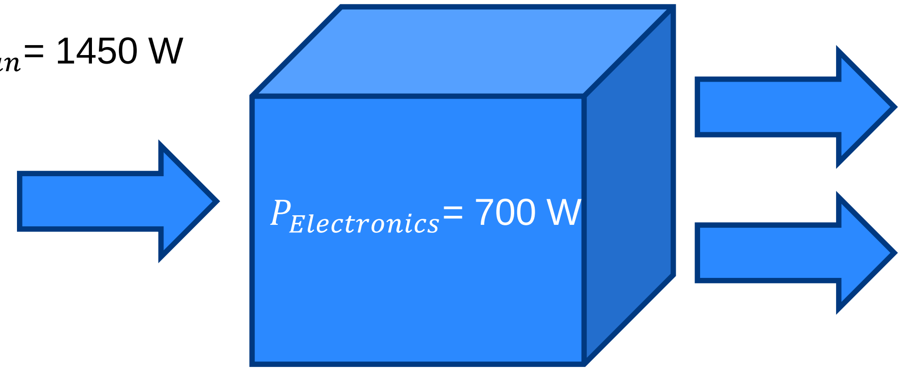
Batteries

- Nickel-Hydrogen Batteries
- 12 Cells deliver 28 V
- Discharge during launch: max. 4%
- During 24 hour safe mode: half of the charge is used
- Considering using a switching-mode power supply

Power

Sub-mission	Power required	Solar Panel	Batteries	Components
Trajectory to Orbit	2W 780W	✓		Propulsion Sub-systems except for instruments
Operation without propulsion	600W 20W 20W 110W	✓		AOCS Instrumentation CPU Communication
Orbit correction	7W 600W 15W	✓		Propulsion system AOCS CPU
Safe Mode	15W 2W		✓	CPU Sun tracker
Launch	15W 10W		✓	CPU Communication

Thermal Subsystem



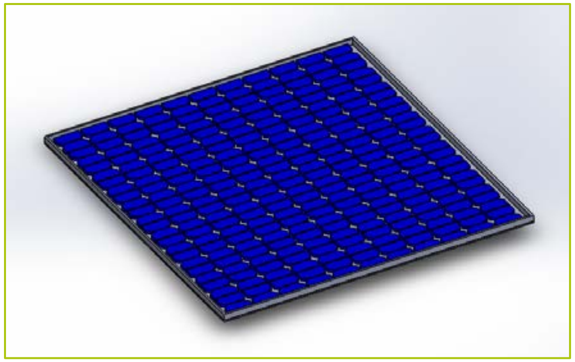
- Operational temperature of $20^{o}C$
- 10 layers MLI
- Radiator of ~4 m^2

Thermal balance of Solar Cells

Absorptivity – sun side	91.0%
Emissivity – sun side	82.5%

Maximum equilibrium temperature		177	deg, C

Panel Structural Mass	6.4 kg
Mass of single Cell	0.002 kg
Number of cells per panel	264
Panel Mass	0.685 kg
Number of Panels	2
Overall mass for solar Power	**14 kg**



30% Triple Junction GaAs Solar Cell
Type: TJ Solar Cell 3G30C

Spacecraft Subsystems - Shielding

Total Ionizing Dose (TID)

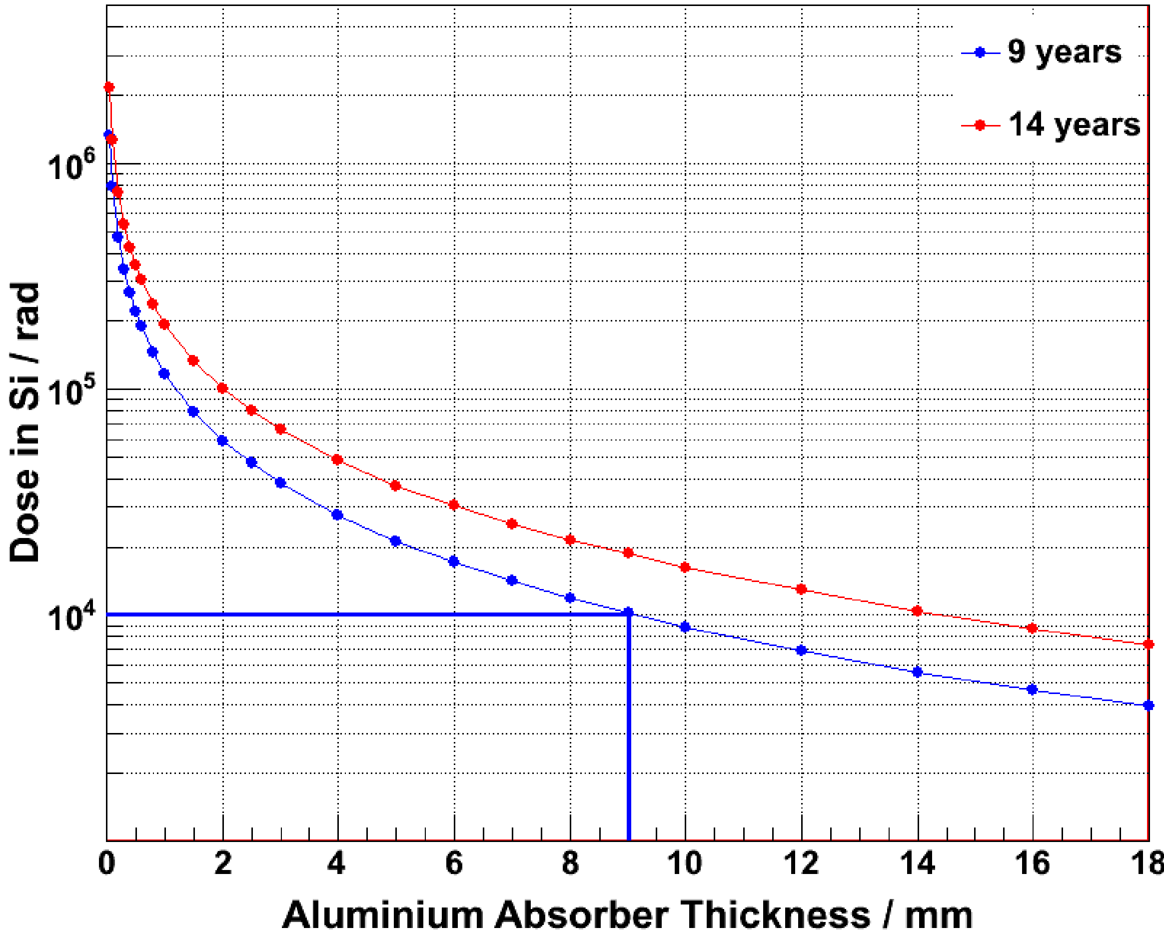
Mission requirements:

- 9 years exposure
- Orbit at 0.7 AU
- 20 krad TID tolerance for electronic components

Margin: factor of 2 (10 krad)
Minus 3 mm satellite structure

Estimated with SPENVIS*:

- 6 mm of additional shielding
- Shielding mass of 43 kg Aluminium



*Space Environment Information Service, www.spenvis.oma.be

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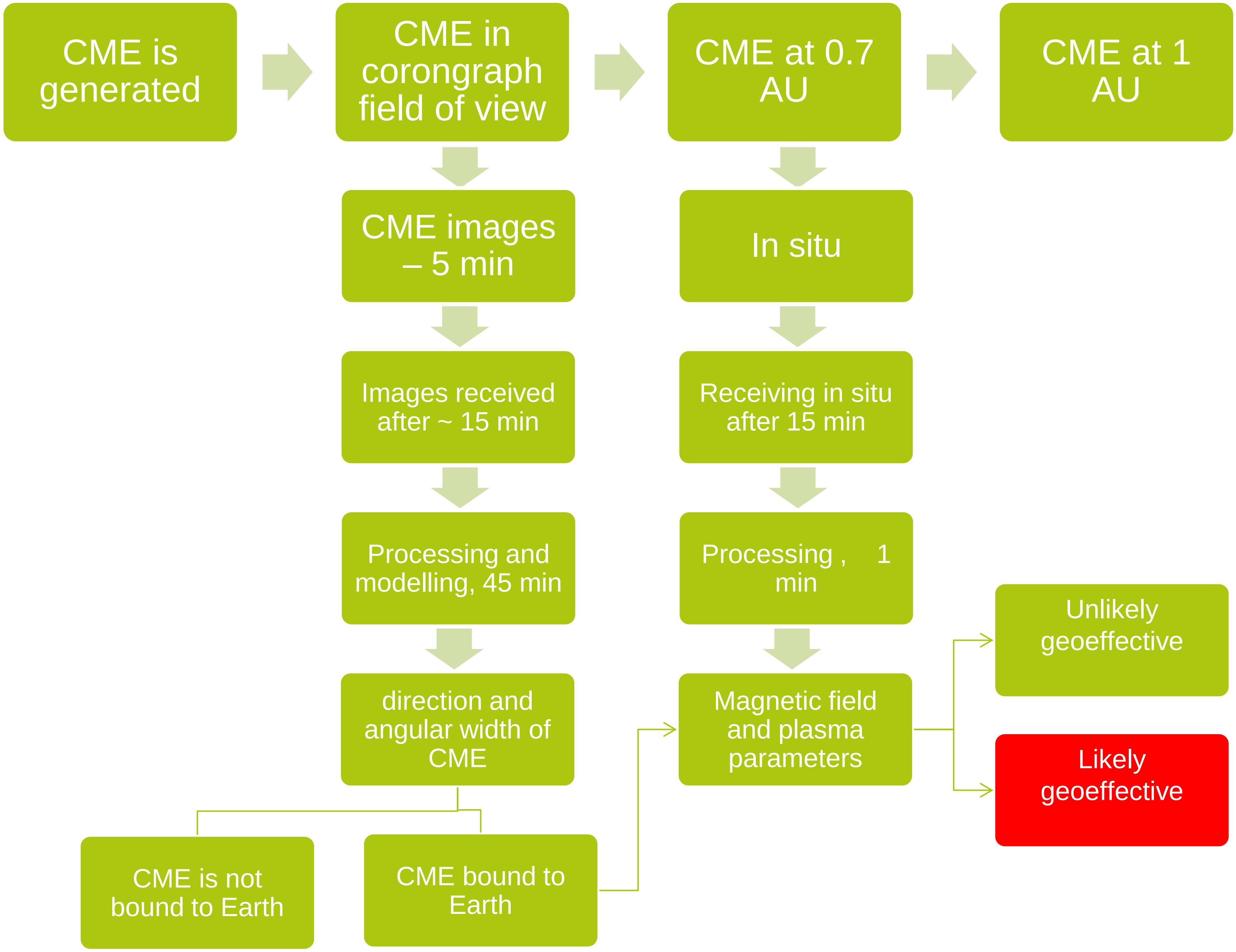
Warning System

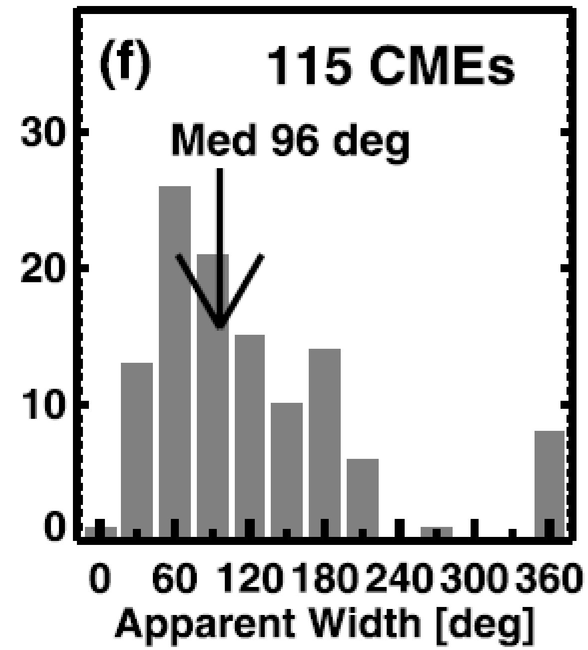

CME is generated
CME in corongraph field of view
CME at 0.7 AU
CME at 1 AU
CME images – 5 min
In situ
Images received after ~ 15 min
Receiving in situ after 15 min
Processing and modelling, 45 min
Processing , 1 min
Unlikely geoeffective
direction and angular width of CME
Magnetic field and plasma parameters
Likely geoeffective
CME is not bound to Earth
CME bound to Earth

Risks

Probability (P)	1	2	3	4	5
E	low	medium	high	very high	very high
D	low	low	medium	high	very high
C	very low	low	low	medium	high
B	very low	very low	low	low	medium
A	very low	very low	very low	very low	low
	Severity (S)				

There is really only 1 major risk – Loss of a spacecraft

Distribution of CME Width



Yashiro et al., 2005

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Cost Budgets

Item	Cost (b€)	#	Totals (b€)	%
Ariane 5 Launcher	0.150	1	0.150	10
Spacecraft	0.146	6	0.880	61
Platform	*0.133*		*0.800*	
Payload	*0.013*		*0.080*	
Ground Segment & Operations	0.410	1	0.410	29
Ground	*0.160*		*0.160*	
Operations	*0.100*		*0.100*	
Communications	*0.150*		*0.150*	
Total (±20%)			**1.440**	**100**

Mass Budget

Subsystem	Mass / kg	Margin / kg	Total / kg
Power	44.00	2.80	46.80
Payload	31.00	2.96	33.96
Communications	28.20	5.22	33.42
Onboard Data Handling / Avionics	15.00	0.75	15.75
AOCS	95.13	2.57	97.70
Thermal Control	32.00	3.20	35.20
Additional Shielding	42.67	0.00	42.67
Chemical Propulsion System (dry mass)	44.60	4.33	48.93
Harness (5%)	16.63	0.00	16.63
Structure (20% of dry mass)	69.85	0.00	69.85
TOTAL (dry, without system margin)	419.07	21.83	440.90
System Margin (20 %)	83.81		
TOTAL (dry, with margin)			524.71
Propellant			275.32
TOTAL (wet mass)			**800.03**

Power Budget

Subsystem	Power Consumption / W	Margin / W	Total / W
Power	48.0	0	48.0
Payload	18.5	1.8	20.3
Communications	165.0	5.3	110.3
Onboard Data Handling / Avionics	17.0	0.9	17.9
AOCS	211.2	105.6	316.8
Thermal Control	0	0	0
Chemical Propulsion System	5.0	1.0	6.0
TOTAL (without margin)	464.7	114.5	579.2
System Margin (20 %)	92.9		
TOTAL (with margin)			**683.1**

Power provided by solar panels: **1000 W**

Descoping

- Reduce the number of spacecraft
- Reduce number of spacecraft with Imagers/Coronagraphs
- Ground Segment
  - Reduce number of Earth Stations
  - Dedicated Array

Outlook / Possibilities

- Additional warning possibility for other satellite missions (e.g. on Mars, Jupiter)

- Continuous observational data sets on 360° of Sun’s activities. We can monitor all CME’s.

- Possible hitchhiking options for further scientific instruments.

Summary

- 1 Ariane-5 Launcher
- 6 Spacecraft @ 0.7AU
- Continuous In-Situ and Remote Measurement of CME's
- Warning System Providing
  - Timely Delivery and Processing of Data
  - Determination of Velocity and Severity of CME's
- Cost Budget b€1.44

Special thanks to all the tutors.

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