L5 mission concept for the ESA-China S2 small mission opportunity

INSTANT

INvestigation of Solar-Terrestrial Activity aNd Transients

The team

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Outline

- Motivations
- Limitations of current missions
- Scientific objectives
- Requirements
- Mission profile
- Model payload
- Spacecraft
- Science operations and archiving
- Conclusions

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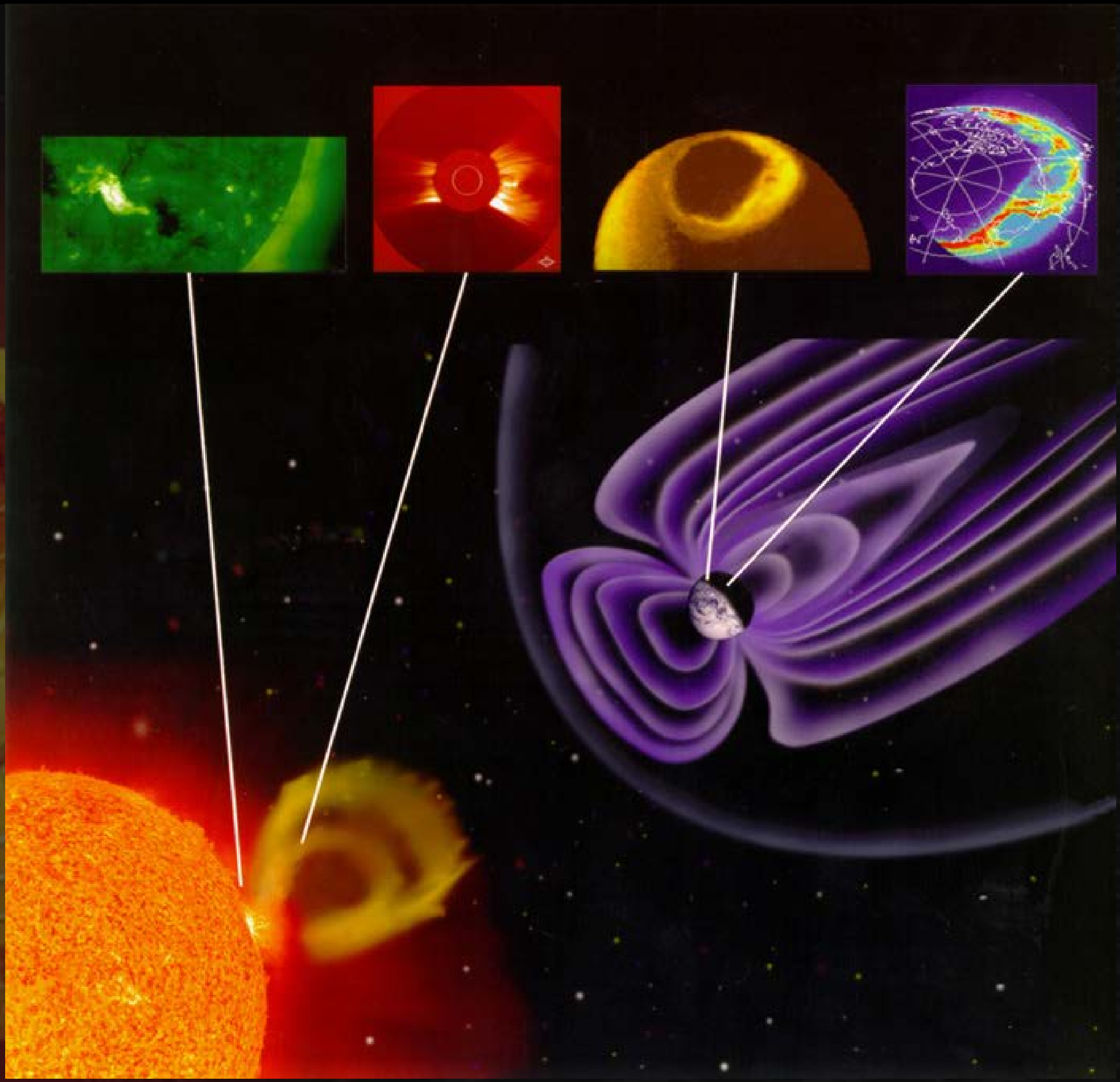
Motivation: the science of Sun-Earth connection

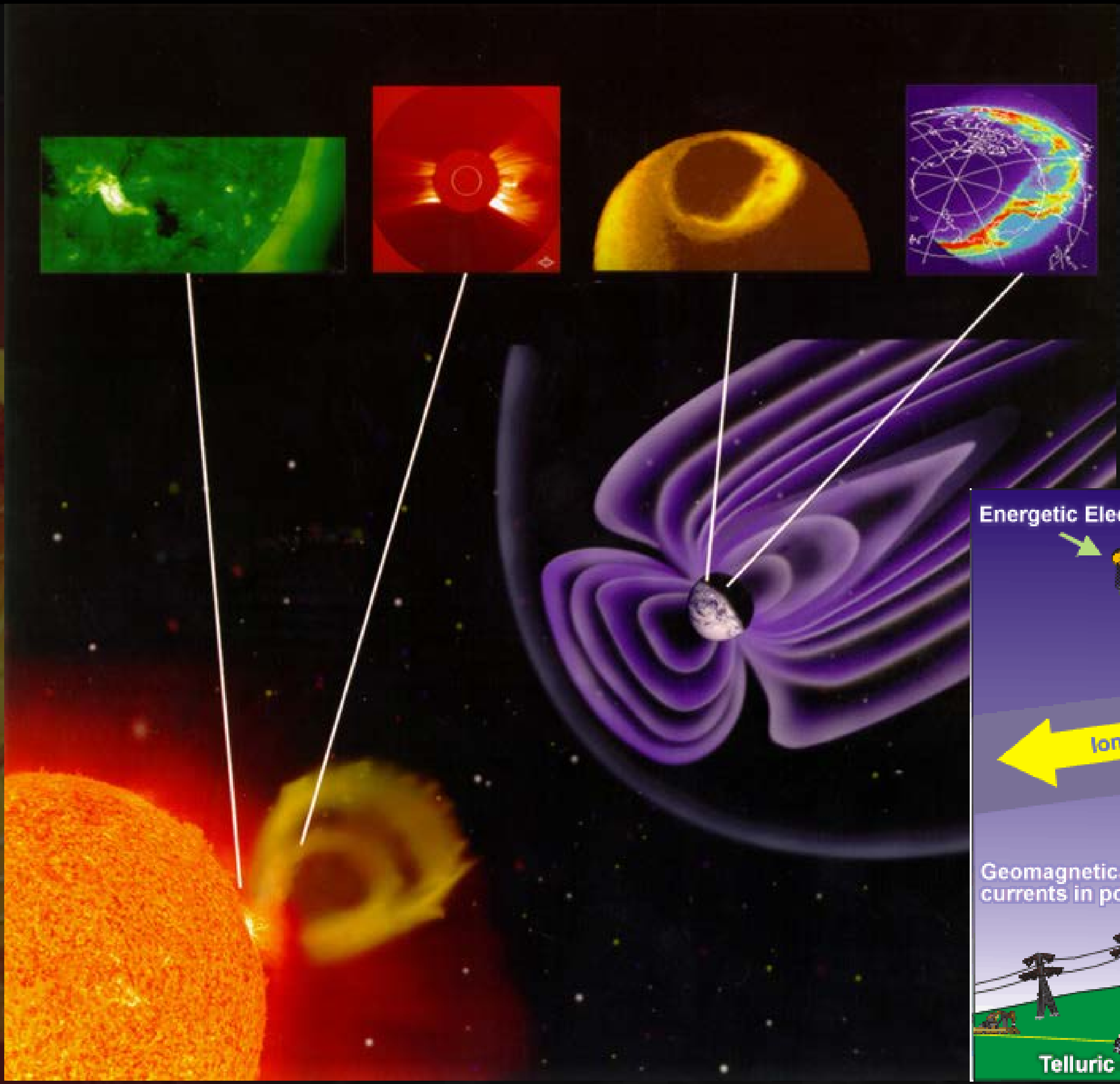


A chain of fundamental processes

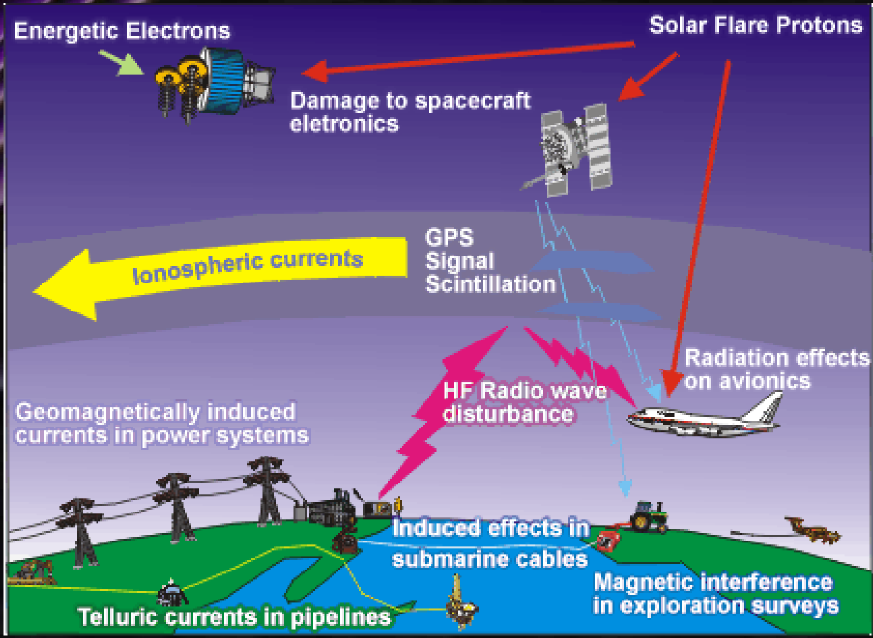
- Dynamo processes;
- Corona magnetic structure;
- Solar wind acceleration;
- Initiation of CMEs;
- CMEs propagation and evolution in heliosphere;
- Shocks, turbulence, magnetic reconnection;
- Solar energetic particles;
- Geomagnetic storms…

Fundamental plasma physics processes at hand

Motivation: the impacts of Sun-Earth connection

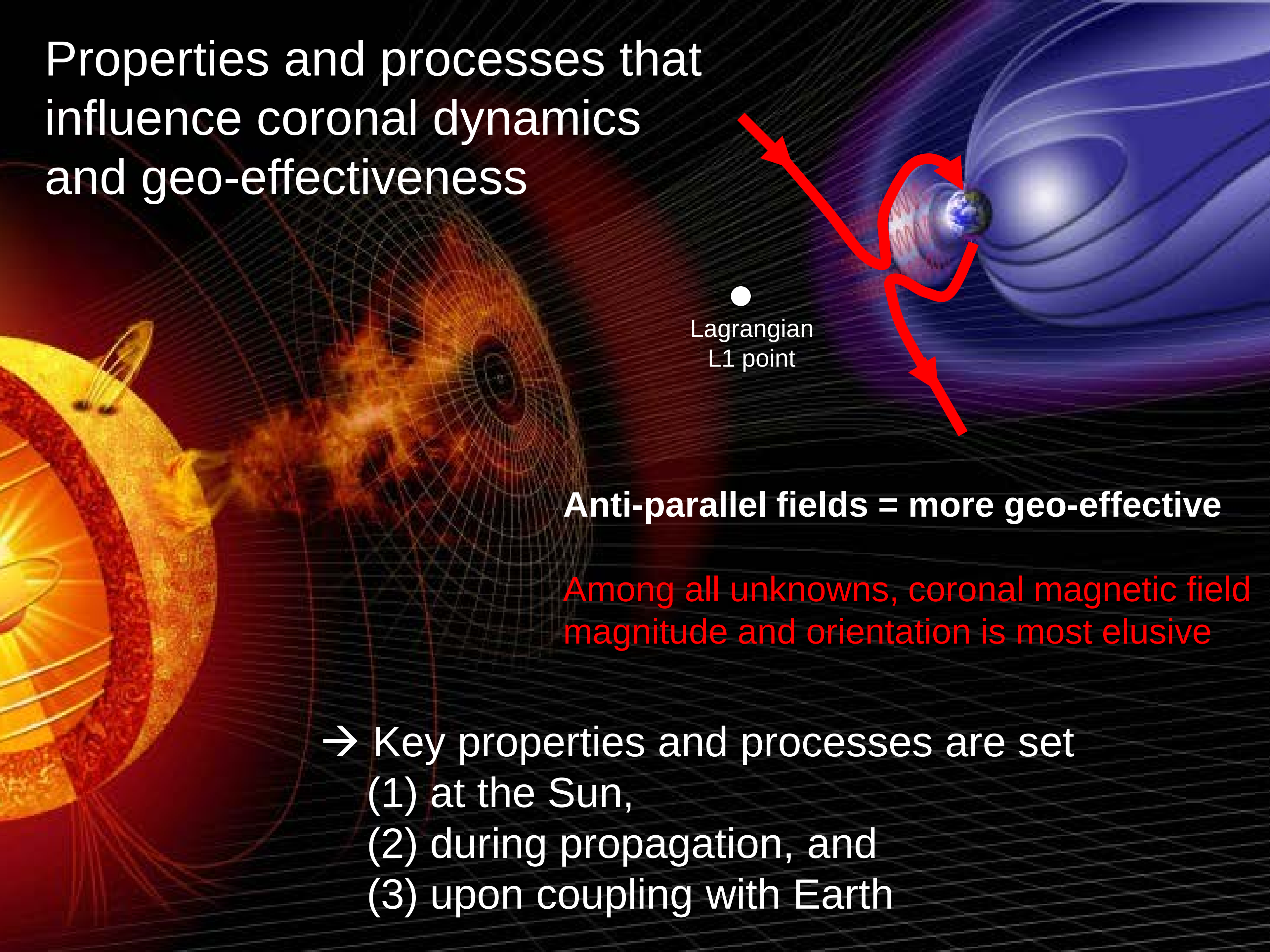


A chain of fundamental processes



Strong economic and societal impact: Space Weather as bonus

Properties and processes that influence coronal dynamics and geo-effectiveness



Anti-parallel fields = more geo-effective

Among all unknowns, coronal magnetic field magnitude and orientation is most elusive

→ Key properties and processes are set
(1) at the Sun,
(2) during propagation, and
(3) upon coupling with Earth

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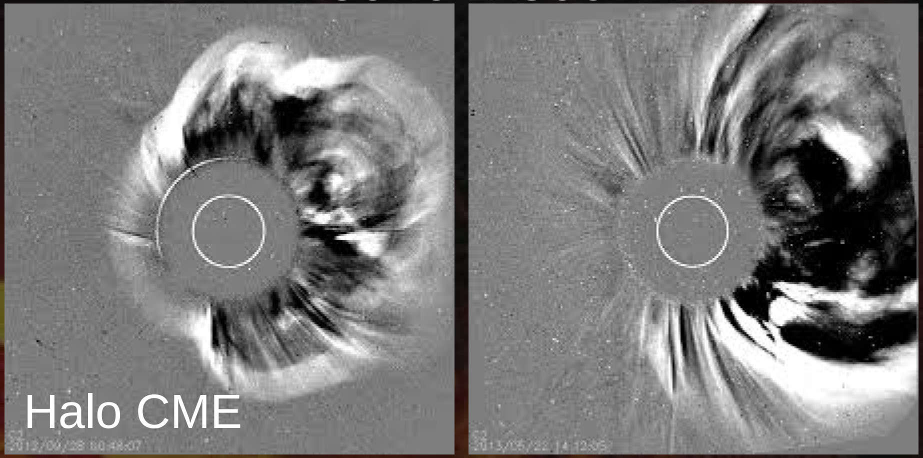
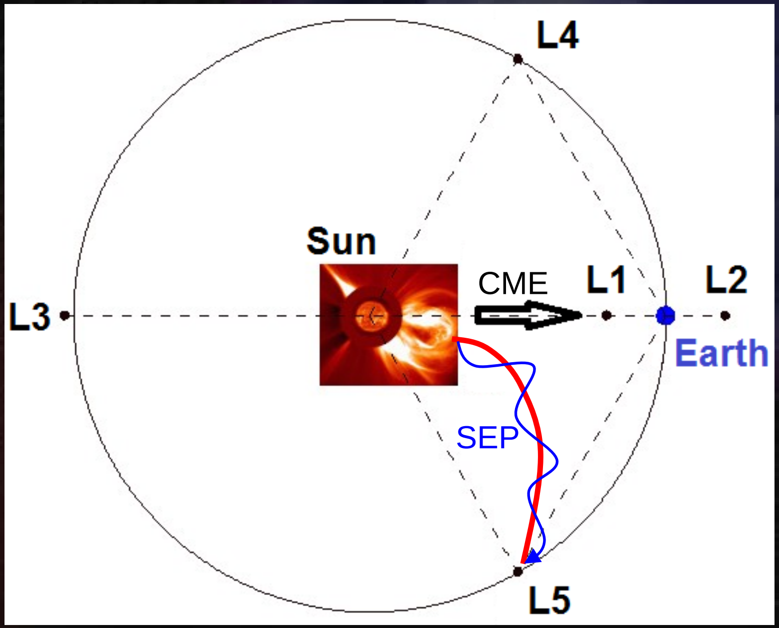
Limitations of Lagrangian L1 point observations

SOHO LASCO



L1 (i.e, Earth) **coronagraph** observations



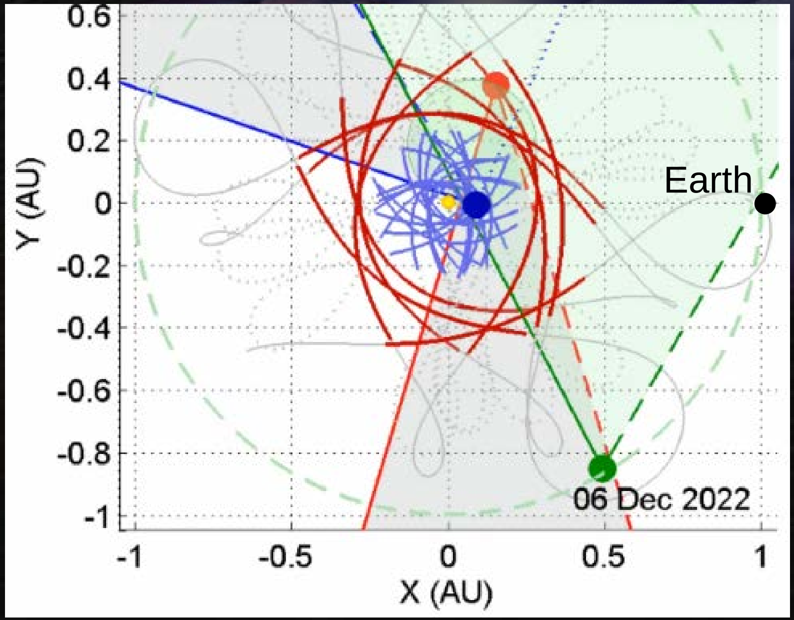
Imaging: only **very rough** idea of CME shape, trajectory, speed & strength
In situ: optimal knowledge of geo-effective parameters, **but late…**

→ Position off-Sun-Earth line is essential

Early properties of Earth-directed CMEs, continuous tracking, multi-point and SEP measurements, & impact at Earth

Limitations of past and future off-Sun-Earth line missions

Solar Orbiter Solar Probe+ INSTANT



Limitations of STEREO:

- During solar minimum (low CME statistics)
- Drifted through L5: no continuous "Sun-Earth" vantage point

Limitations of Solar Orbiter and Solar Probe +:

- Solar Orbiter imagers off at aphelion
- No broader context – orbits rarely in proper location for study of Sun-Earth connections

INSTANT will provide:

→ Novel coronal/heliospheric imaging and *in situ* data, during solar maximum, **at a key off-Sun-earth line vantage point**

→ Synergy with observations at Earth and inner heliosphere missions (Solar Orbiter, Solar Probe + and Bepi-Colombo)

→ Unprecedented space weather capabilities as bonus

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INSTANT
Science objectives

The proposed mission will tackle the following key objectives:

1. What is the magnetic field magnitude and topology in the corona?
2. How does the magnetic field reconfigure itself during CME eruptions?
3. How do CMEs accelerate and interact in the interplanetary medium?
4. What are the sources of and links between slow and fast solar winds?
5. Where do shocks form and how do they accelerate particles?

It will further provide the following crucial space weather capabilities:

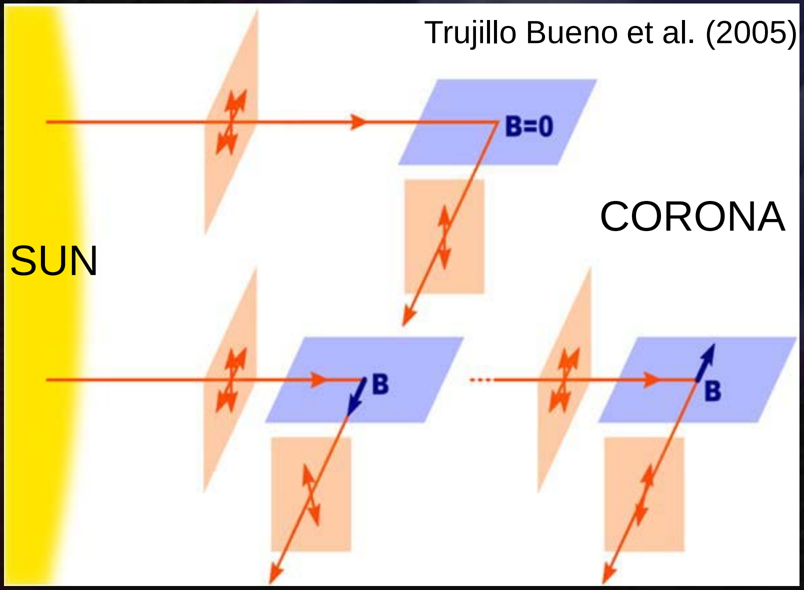
6. 3-days advance knowledge of CIR properties that reach Earth
7. Twelve hours to 2 days advance warning of Earth-directed CMEs
8. Twelve hours to 2 days advance warning of CME-driven SEPs
9. ***Unprecedented ability*** to reconstruct the magnetic field magnitude and orientation of Earth-bound CMEs early in the corona

1. What is the magnetic field magnitude and topology in the corona?

Dynamics is driven by magnetic fields in the low-beta corona

But elusive owing to the lack of proper measurements of coronal magnetic field

(except at photosphere using Zeeman effect and low corona with Hanle effect from ground)

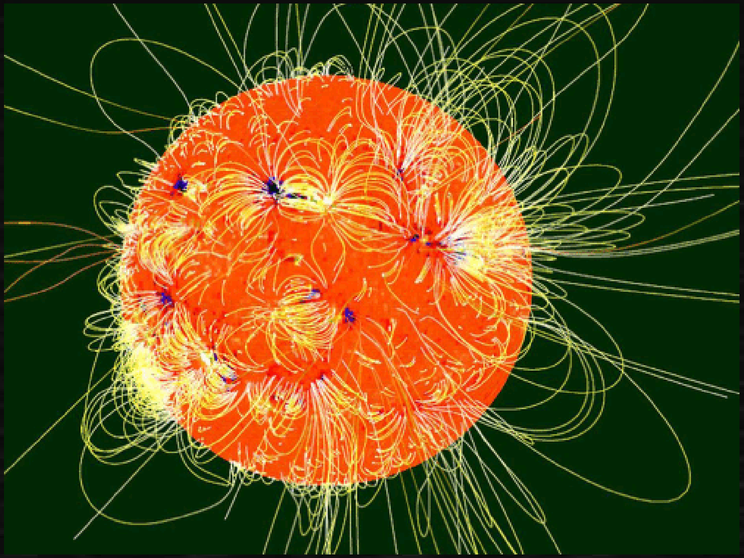


Sub-objectives:

1.1 Measure of the radial and latitudinal profiles of horizontal coronal magnetic field

1.2 Direct coronal magnetic field data to reconstruct coronal topology

1.3. Distribution of coronal Alfvén speed for reconnection and acceleration processes



Wiegelmann and Solanki (2004)

2. How does the magnetic field reconfigure itself during CME eruptions?

Coronal magnetic fields are also critical to constrain and test CME initiation models

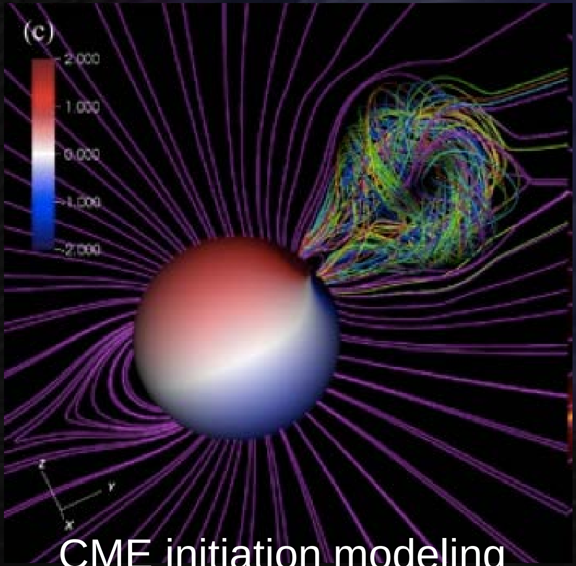
But CME magnetic field, and its geo-effective Bz component in particular, remains elusive to observations

<u>Sub-objectives:</u>

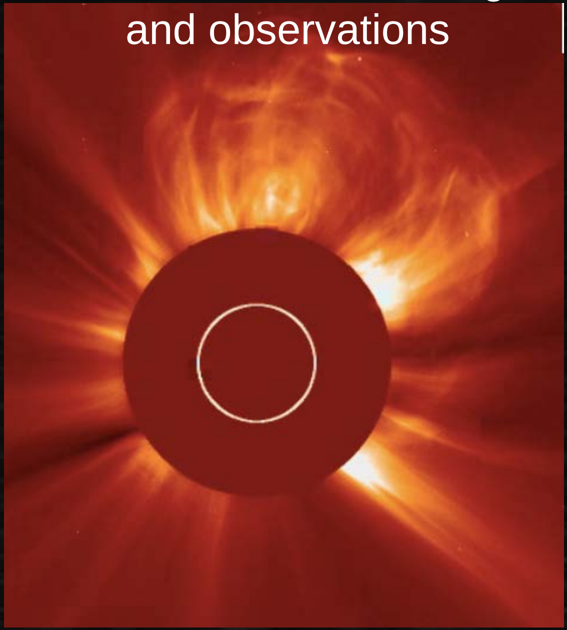
2.1 Direct measurement of horizontal coronal magnetic field above source active region

2.2. Constraints on coronal magnetic field reconfiguration during CME eruption

2.3. Benchmarking of actual CME properties, in combination with multipoint in situ data at Earth and elsewhere



CME initiation modeling and observations



3. How do CMEs accelerate and interact in the interplanetary medium?

CME flux rope formation induces large magnetic forces and pressure gradients

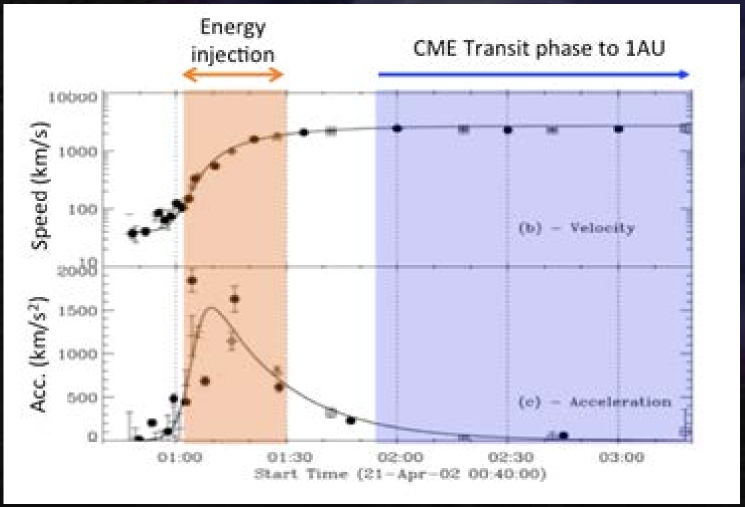
Yet CME dynamics and evolution in corona and solar wind are poorly understood owing to limited observations

<u>Sub-objectives:</u>

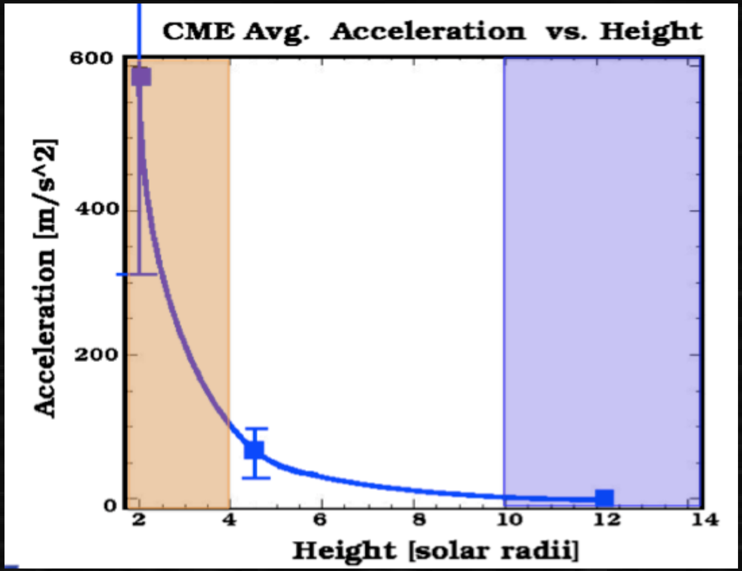
3.1 Simultaneous measurement of CME acceleration and magnetic field down to 1.15 Rs

3.2. Disentangling of projection effects to accurately determine CME dynamics and interaction in the inner heliosphere

3.3. Benchmarking of CME kinematics with multipoint in situ data at Earth and elsewhere



Gallagher et al., 2001



Burkepile (2004)

4. What are the sources of and links between slow and fast solar winds?

The processes that produce the slow and fast winds remain highly debated.

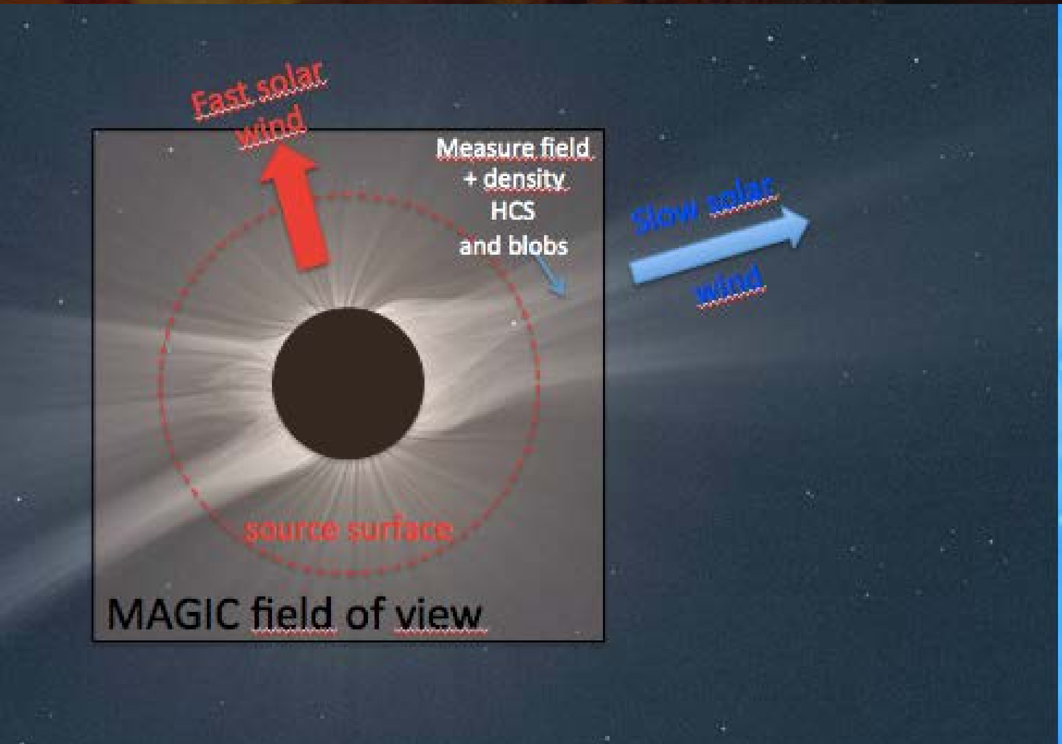
Combined plasma and magnetic field imaging in the upper corona will provide unprecedented diagnostics

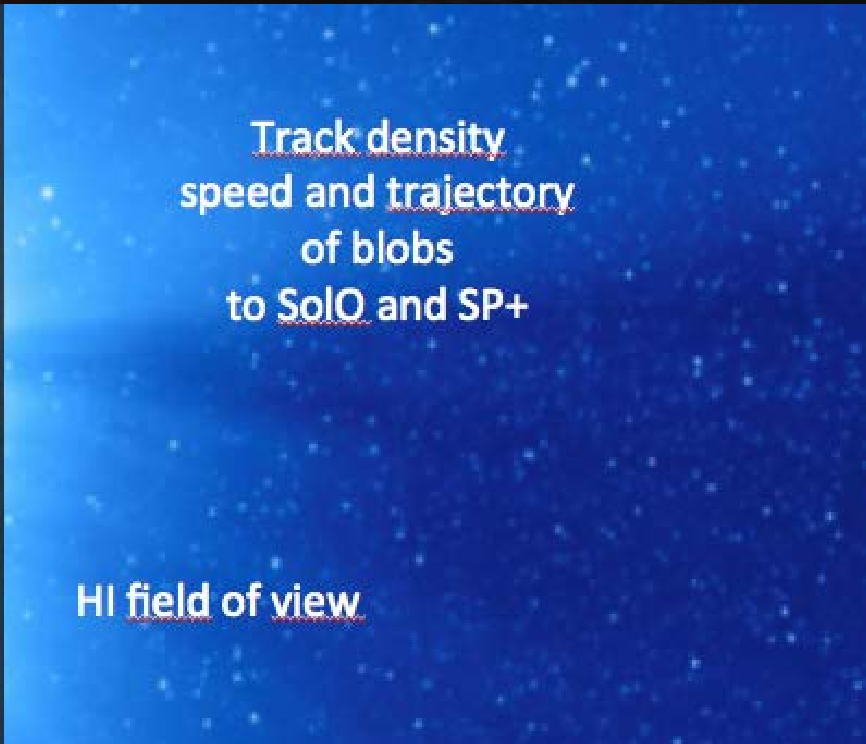
Sub-objectives:

4.1 Measure plasma and magnetic field profiles in the regions of slow and fast wind acceleration

4.2. Observe dynamic magnetic field reconfigurations (e.g., reconnection-driven)

4.3. Determine where the transient slow wind originates and how it evolves in the heliosphere





5. Where do shocks form and how do they accelerate particles?

The formation of shocks is critical to understanding solar energetic particle acceleration and impact in heliosphere

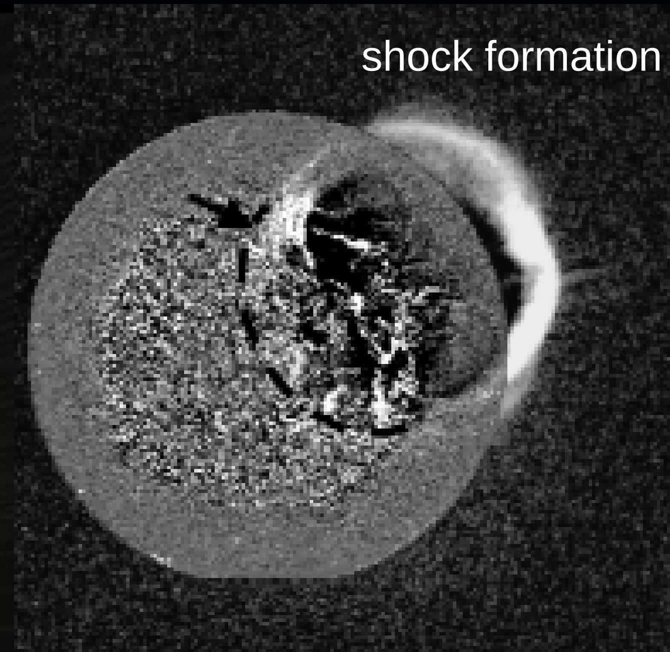
Yet their early formation is elusive, owing to a lack of appropriate measurements

Sub-objectives:

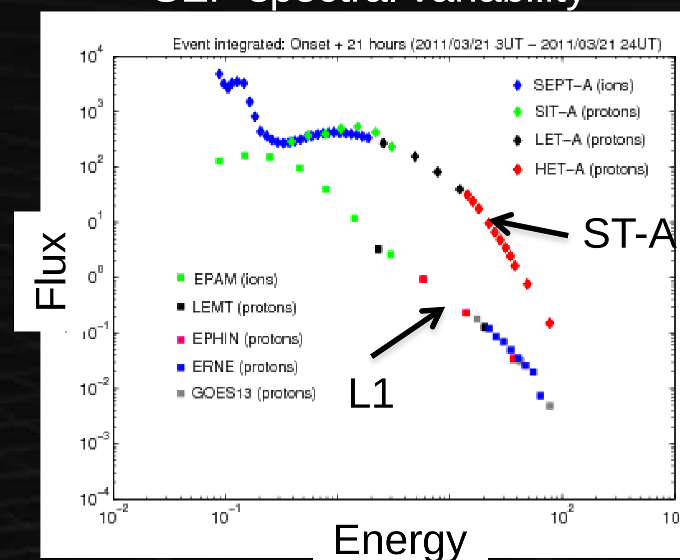
5.1 Early detection and determination of shock properties (B-field) in corona

5.2. Tracking and reconstruction of shocks in the heliosphere

5.3. Determine the spatial and temporal properties of solar energetic particle (SEP) acceleration for Earth-bound CMEs



SEP spectral variability



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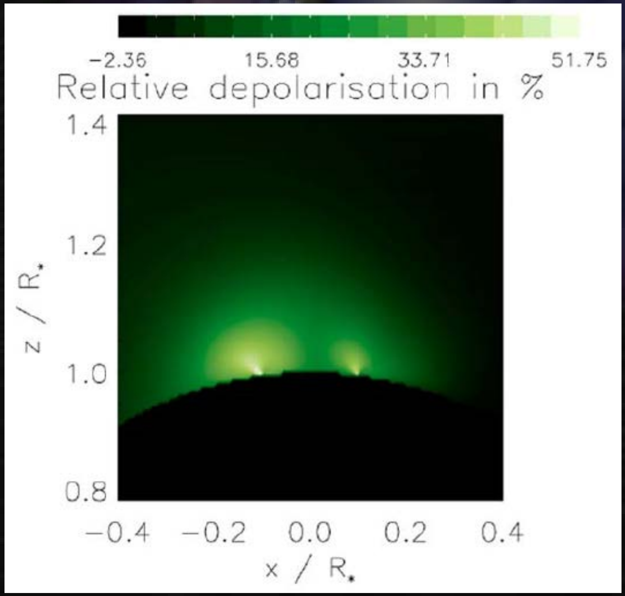
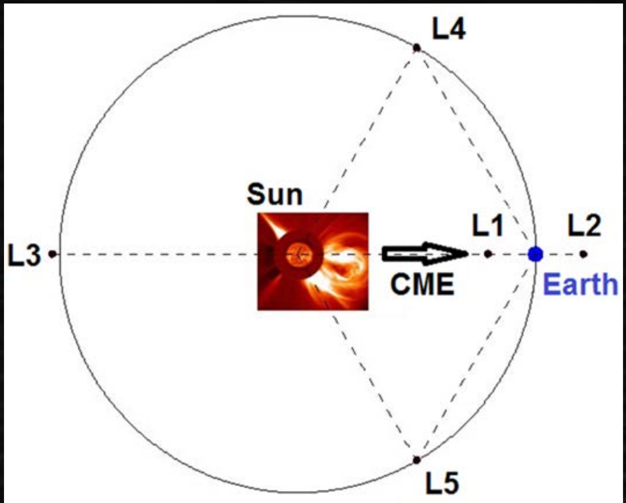
Requirements for objectives 1 and 2

→ What is the magnetic field magnitude and topology in the corona?
→ How does the magnetic field reconfigure itself during CME eruptions?

- Novel Lyman-α measurements to determine line-of-sight magnetic field through the **Hanle** effect
- Measurement in low corona (1.15 – 4 Rs) for reconstruction of magnetic field topology
- Off-Sun-Earth line location for early determination of magnetic structure of Earth-bound CME and comparison with *in situ* data in heliosphere

→ Also key measurements to address objectives 3, 5, 7, 9

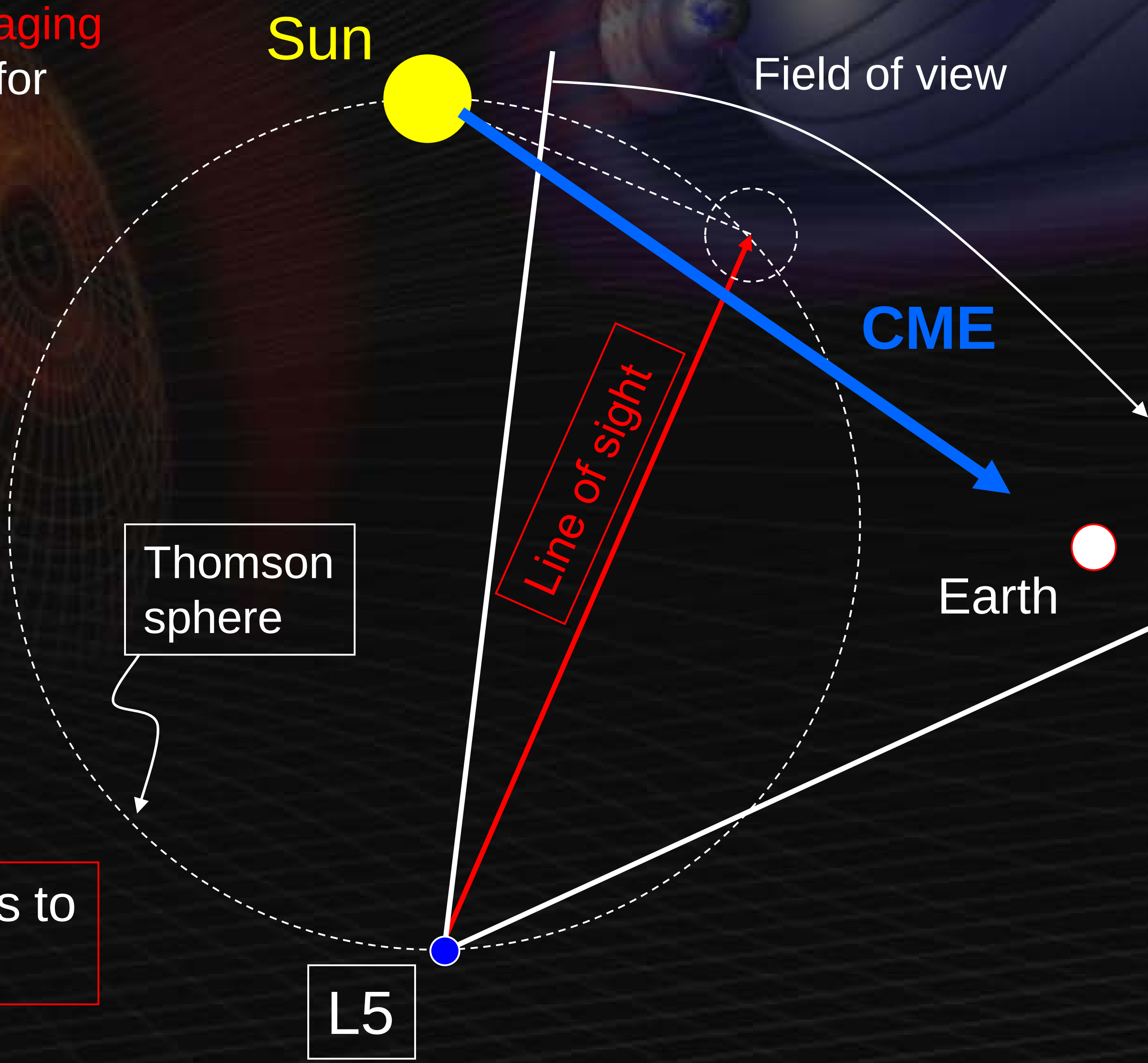




Requirements for objective 3

→ How do CMEs accelerate and interact in the interplanetary medium?

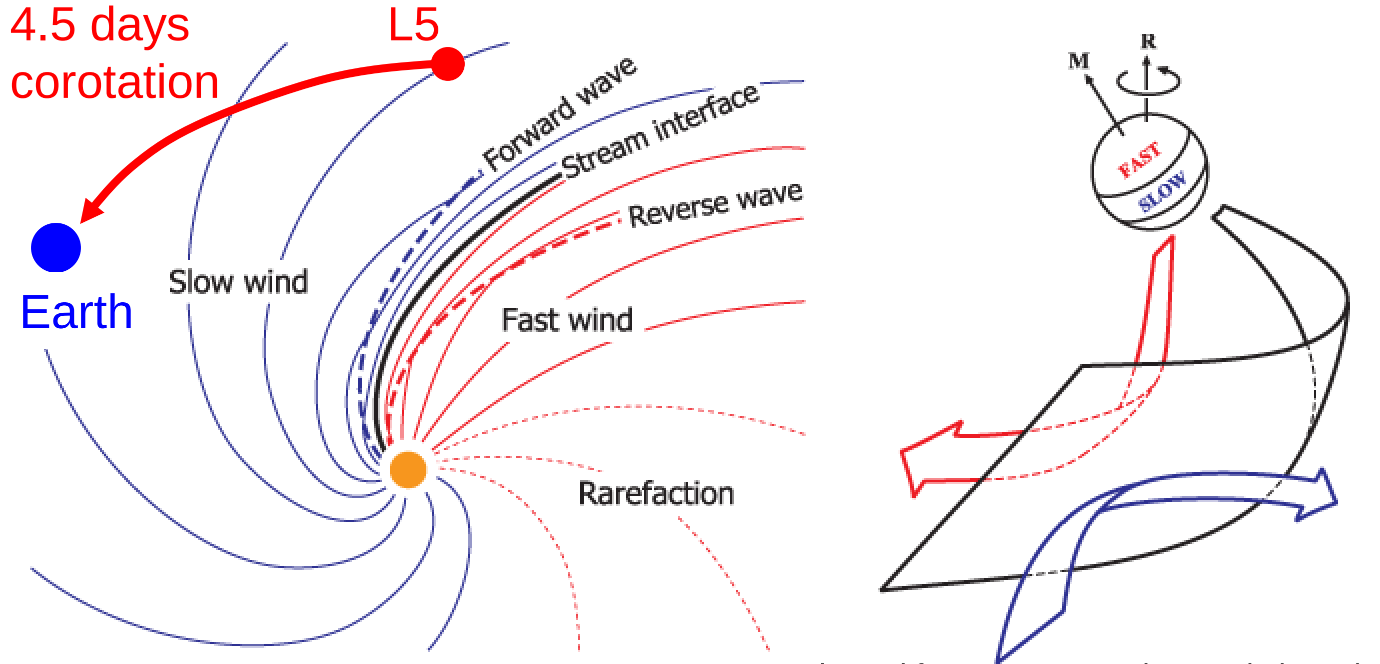
- High cadence white light imaging in low corona (1.15 – 4 Rs) for CME acceleration
- Wide angle heliospheric imagers to track CME/CIR interactions in heliosphere
- Polarization information for accurate trajectory
- Off-Sun-Earth line location for tracking of Earth-bound CMEs



→ Also key measurements to address objectives 4, 5, 7

Requirements for objective 4

→ What are the sources of and links between slow and fast solar winds?



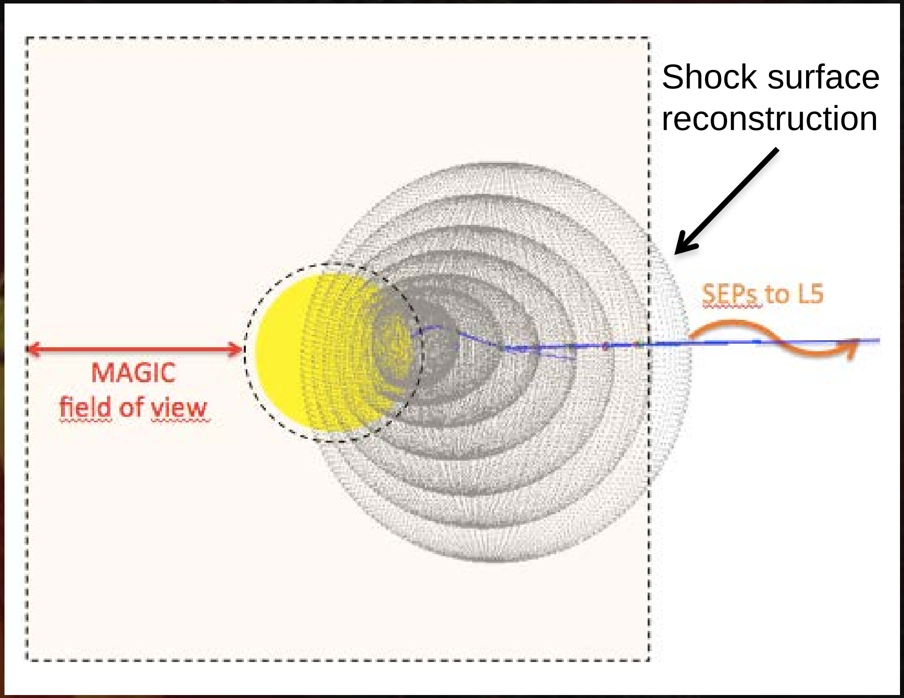
Adapted from Owens and Forsyth (2013)

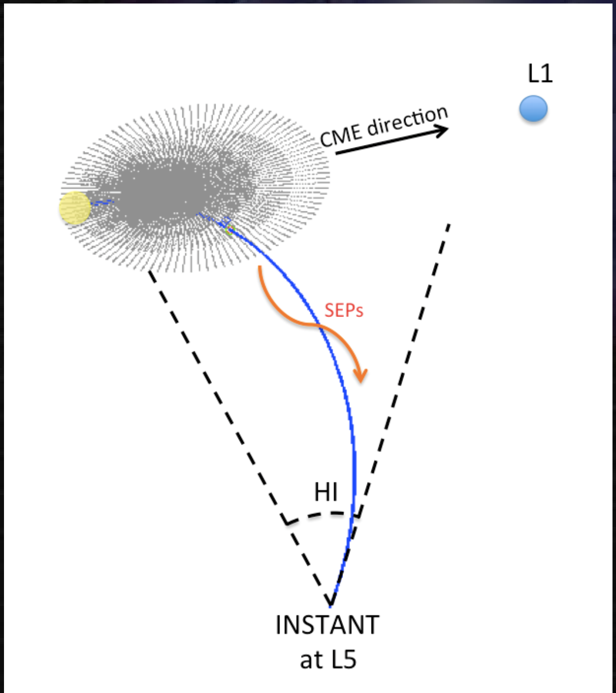
- Multipoint measurements of B-field, protons and suprathermals
- Lyman-α and white light imaging of corona and heliosphere
- Off-Sun-Earth line location for advance measurement of <u>Earth-bound corotating structures</u>

→ Also key measurements to address objectives 3, 5, 6, 8

Requirements for objective 5

→ Where do shocks form and how do they accelerate particles?





- Early imaging of shock formation in low corona (up to 4 Rs)
- Magnetic field and density imaging for shock properties
- Multipoint, off-Sun-Earth line measurement of energetic particles

→ Key measurements to address objectives 3, 4, 5, 6, 8

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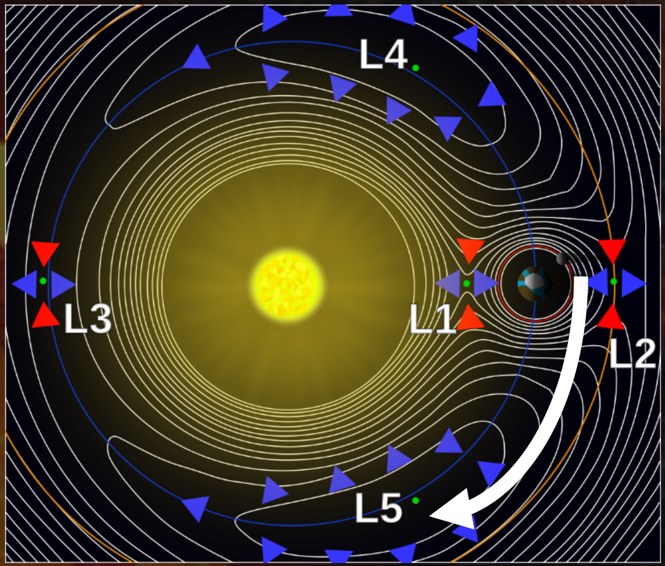
Mission profile: orbital requirements

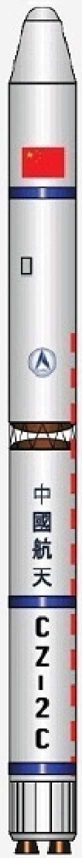


- Observation off-Sun-Earth line is a key for innovative science of Earth-directed CMEs
- Towards L5 rather than L4 (CIRs and SEPs)
- Science operations start after commissioning (~few months)
- Earth-directed CMEs can be studied after S/C has drifted by ~ 20° towards L5
- L5 insertion after ~2 years operation

3 years operation sufficient to address key science objectives

Launch in 2021 allows synergy with Solar Orb., SP+ and Bepi-C

Mission profile: launcher, platform, propulsion



Long March 2C

Launch Service Provider
CGWIC
Company Headquarters
China
Manufacturer
SAST
Mass, kg (lb)
233,000 (513,677)
Length, m (ft)
41-42 (134.5-137.8)
Diameter, m (ft)
3.4 (11.2)
Year of First Launch
LM-2C: 1975, LM-2D: 1992
Number of Launches
LM-2C: 32, LM-2D: 11
Reliability
LM-2C: 100%, LM-2D: 100%
Launch Sites
Jiuquan Taiyuan Xichang
GTO Capacity, kg (lb)
1,250 (2,756)
LEO Capacity, kg (lb)
3,850 (8,488)
SSO Capacity, kg (lb)
1,300-1,900 (2,866-4,189)

- Launcher should allow exit to L5

Launch with Long-March 2

- Spacecraft mass max. 300 kg
  as per boundary conditions

European platform (Myriad Ev., Proba, else)

- Additional propulsion module for:
  - exit to L5, and
  - insertion at L5

Classic or electric propulsion (Smart-1) may be considered

→ Exact orbit and propulsion details are still under study

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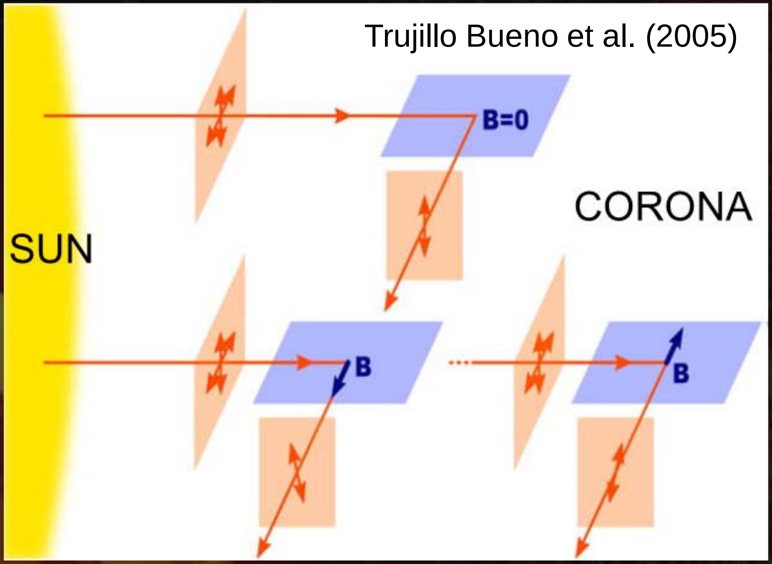
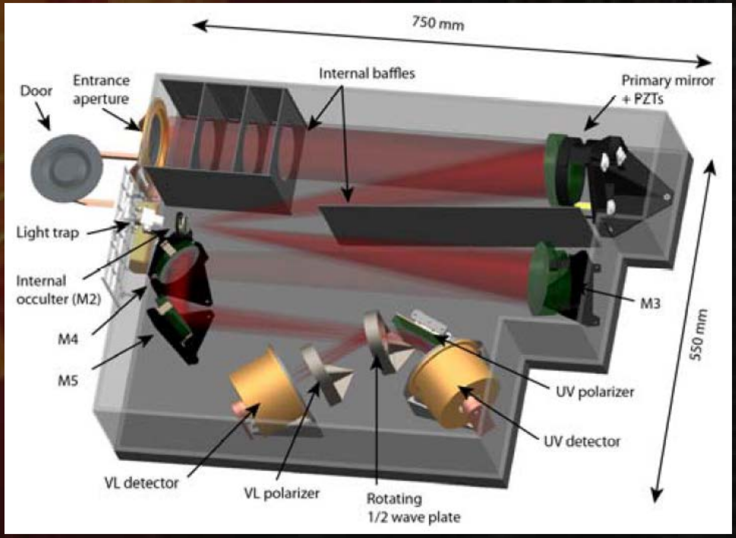
Payload: innovative coronal imaging





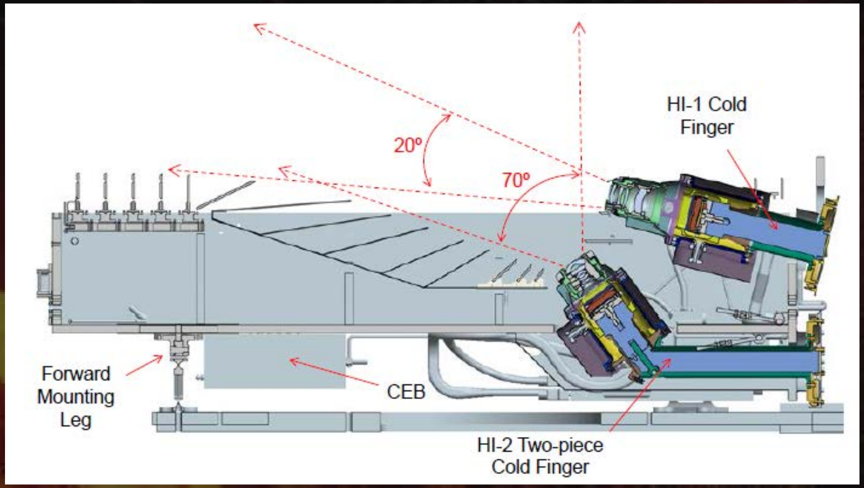
MAGIC: MAGnetic Imaging Coronagraph

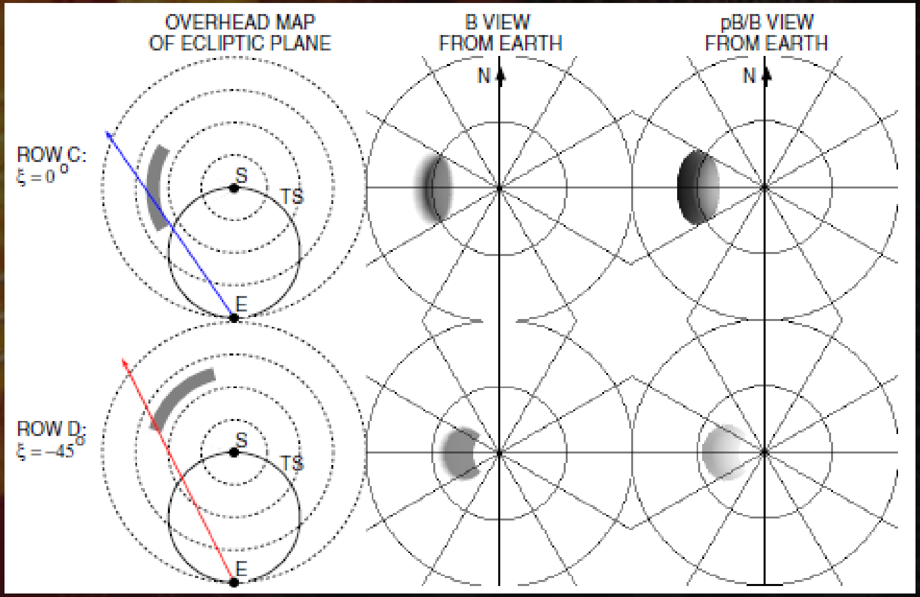
- Novel Lyman-α measurements to determine line-of-sight magnetic field component through the **Hanle** effect
- High cadence (5-7 min) measurement in low corona (1.15–4 Rs) for reconstruction of magnetic field topology
- White light for electron density estimates
- Off-Sun-Earth line for early determination of magnetic structure of Earth-bound CME and comparison with *in situ* data

Heritage: R&T, SOHO, Solar Orb., ground, …

TRL 6+

Payload: new 'polarized' heliospheric imagers





Howard et al. [2013]

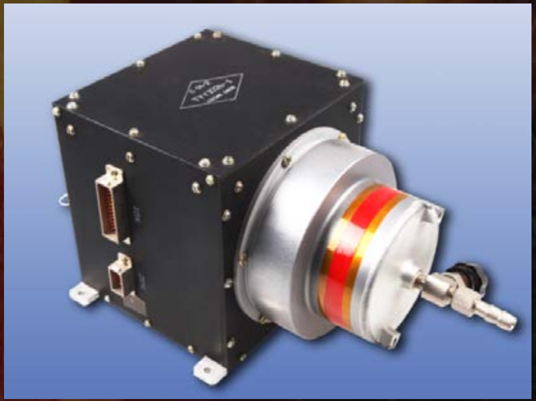
HI: Heliospheric Imagers

- Wide angle (2.5 – 60°) white light imagers to track CME and CIR interactions in heliosphere
- Polarization measurements for accurate trajectory
- Off-Sun-Earth line for early determination of trajectory of Earth-bound CME and comparison with *in situ* data in heliosphere

Heritage: R&T, STEREO, SOHO

TRL 9

Payload: *in situ* instruments



- In situ, off-Sun-Earth line (towards L5) measurement of B-field and thermal protons for CMEs and corotating structures
- 1 AU (towards L5) measurement of energetic particles for direct detection and study of SEPs

MAG: Flux-gate Magnetometer

PAS: Proton and Alpha Sensor

HEPS: High energy Particle Sensors
(e-/p+ and heavies in 10s keV – 10s MeV)

<u>Heritage</u>: Cluster, Chang'E, Solar Orb…

TRLs 9

Payload budgets and related objectives

All instruments have TRL 6 to 9

NAME	INSTRUMENT TYPE	MASS (kg)	POWER (W)	SCIENCE OBJECTIVES
MAGIC	Visible light and Lyman-α coronagraph	26	20	1, 2, 3, 5, 7, 9
HI	White light polarized heliospheric imagers	16	16	3, 4, 5, 7
MAG	Magnetometer	3	4	3, 4, 6
PAS	Ion sensor	4	4	3, 4, 6
HEPS	High Energy Particle Sensor	2	6	4, 5, 8
DPU	Data Processing Unit	3	5	
TOTAL		**54**	**55**	

The mission and payload satisfy the technical constraints

S/C mass ≤ 300 kg, payload mass ≤ 60 kg and power ≤ 65 W

Payload telemetry and hardware teams

NAME	INSTRUMENT TYPE	TELEMETRY kbits/s	HARDWARE CONTRIBUTORS
MAGIC	Visible light and Lyman-α coronagraph	70	**IAS (France)** Nanjing U. (China) NSSC (China)
HI	White light polarized heliospheric imagers	4	**RAL (UK)** Shandong (China) Changchun (China)
MAG	Magnetometer	2	**NSSC (China)** Imperial C. (UK)
PAS	Ion sensor	2	**NSSC (China)** IRAP (France)
HEPS	High Energy Particle Sensor	2	**U. Kiel (Germany)** NSSC (China)
DPU	Data Processing Unit	-	**IAP&CU (Czech R.)** NSSC (China)
TOTAL		**80**	

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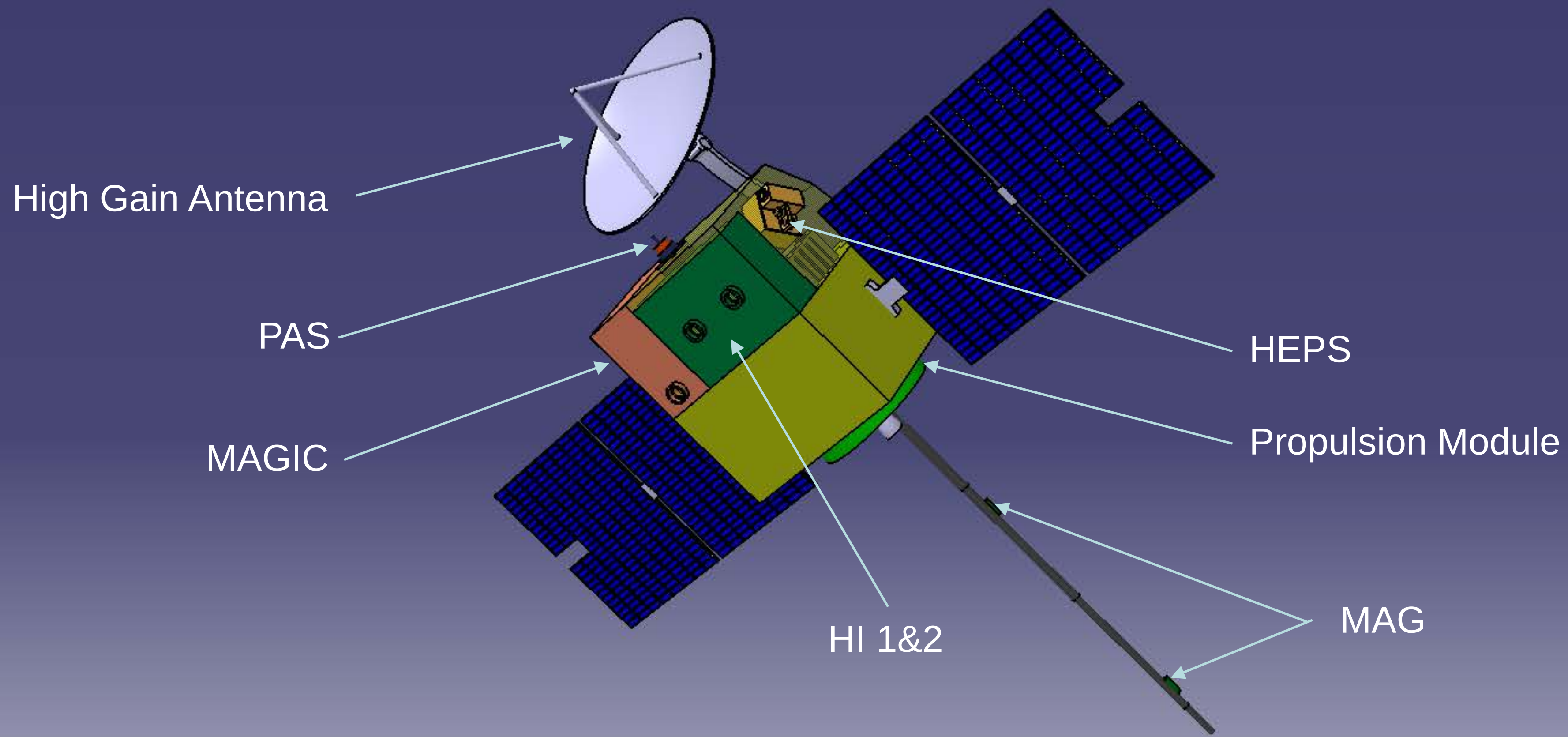
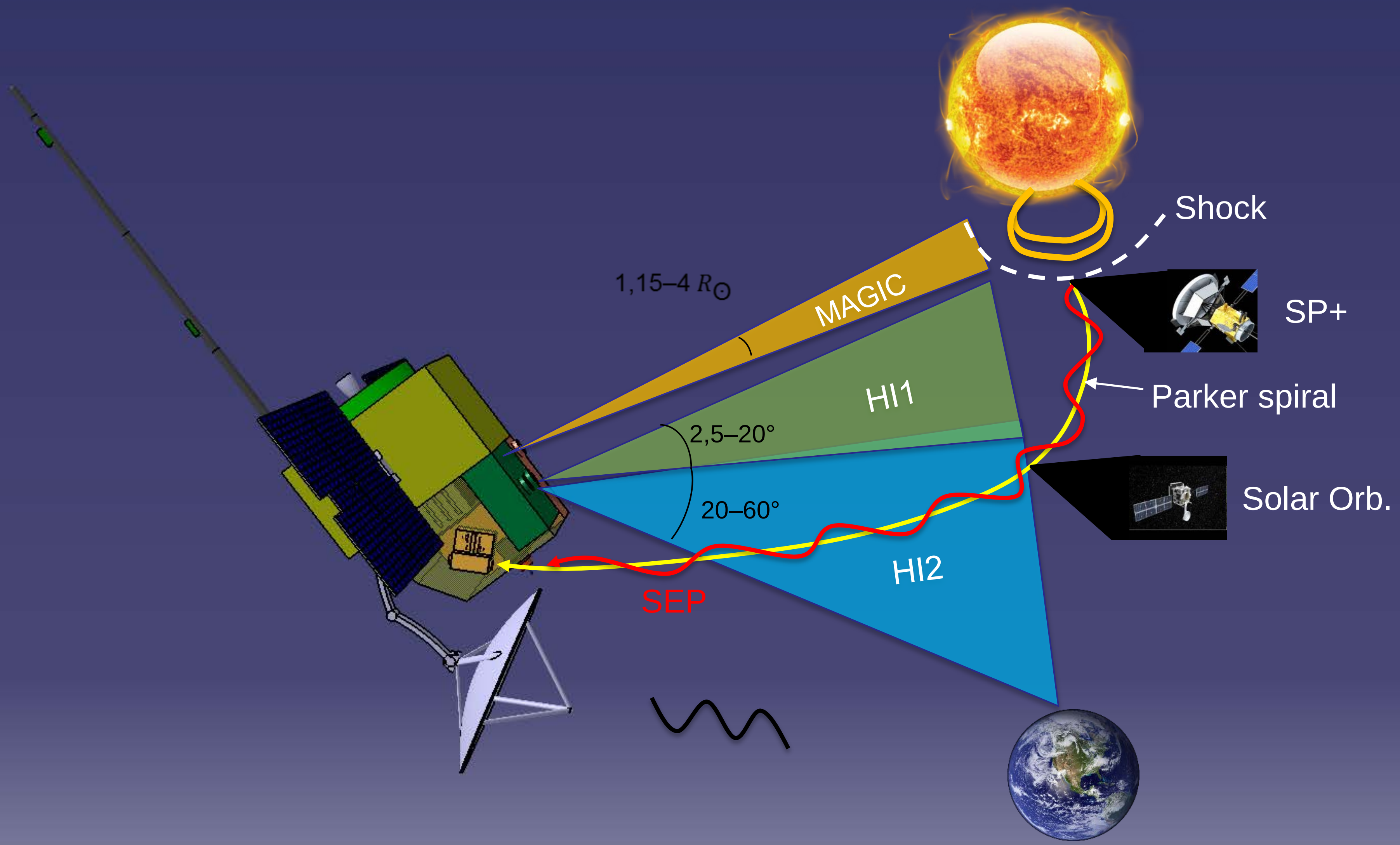
Spacecraft design and payload

- Based on existing or in development micro-satellite bus
  - Myriad Evolution as a baseline (up to 300 kg)
- 3-axis stabilized
- Additional propulsion module might be required for L5 orbit insertion



Payload fields of view

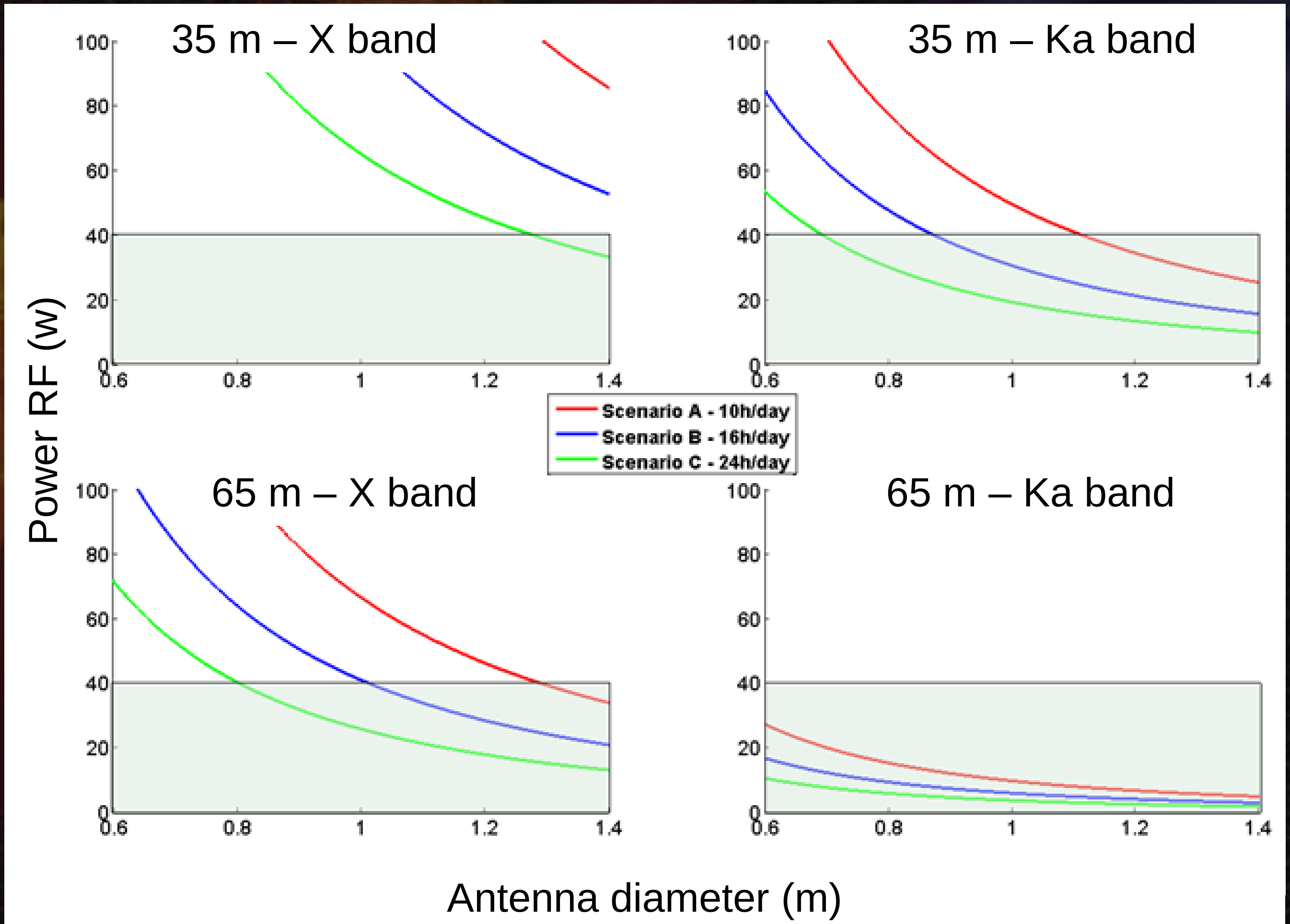


Telemetry requirements

The telecommunication subsystem is a key factor:

- 6.5 Gbits to be downlinked daily (preferred in X and/or Ka band)
- Ground antennas: 10 – 16 – 24 h daily contact scenarios studied
- 1m High Gain Antenna and transponder with < 40W RF assumed

→ Combined ESTRACK / Chinese DSN is sufficient



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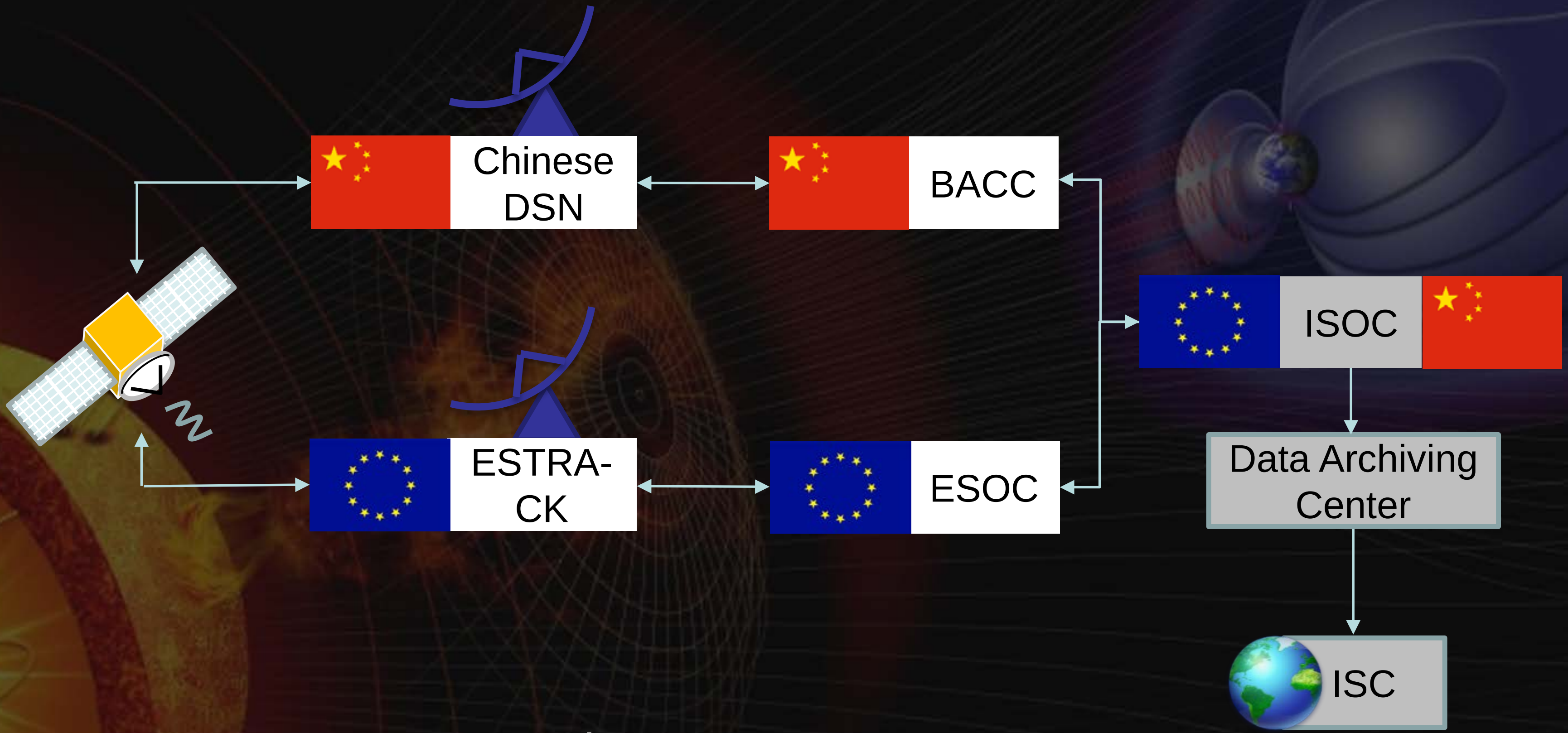
Ground Segment



DSN : Deep Space Network
BACC : Beijing Aerospace Command and Control Center
ESTRACK : ESA Tracking Station Network
ESOC : European Space Operation Center
ISOC : INSTANT Science Operation Center
ISC : INSTANT Scientific Community (Institution, University…)

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Summary of mission key elements

We place ourselves within the boundary conditions:

- S-class mission with 50 M€ ESA + equivalent by China
- Additional contribution to payload by national agencies
- Spacecraft mass 300 kg + possibly propulsion module
- 60 kg/65 W for payload

The proposed approach to shared contribution is:

- Launch by China (Long March)
- Platform by ESA (Myriad Evol., Proba, SSTL, …)
- Payload shared by ESA member states and China
- Ground segment shared by ESA and China

Timeline: 2015 — 2021 — 2023 — 2024

Selection — Development — Launch+Com. — Orbit drift — Insertion L5 — End nominal mission

3-year nominal science

Conclusions

Innovative concept that tackles compelling solar and heliospheric science objectives, and space weather as bonus, through:

- → unique measurements: Lyman-α and polarized HI
- → view from L5 for system-wide science
- → launch at Solar Maximum (2021)
- → synergy/timeliness with SolO and SP+
- → large, supportive communities in EU – China (and US)

The mission proposed falls into the S-class constraints

All countries/space agencies involved in space physics are currently designing and pushing for an L5 mission (INSTANT, RESCO, EASCO, HAGRID, 'KuaFu', etc.)