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

INSTANT

INvestigation of Solar-Terrestrial Activity aNd Transients

ESWW11, November 2014, Liège, Belgium

Outline

- Context and motivations
- Limitations of other missions
- Scientific objectives and requirements
- Mission profile
- Model payload
- Spacecraft
- Conclusions

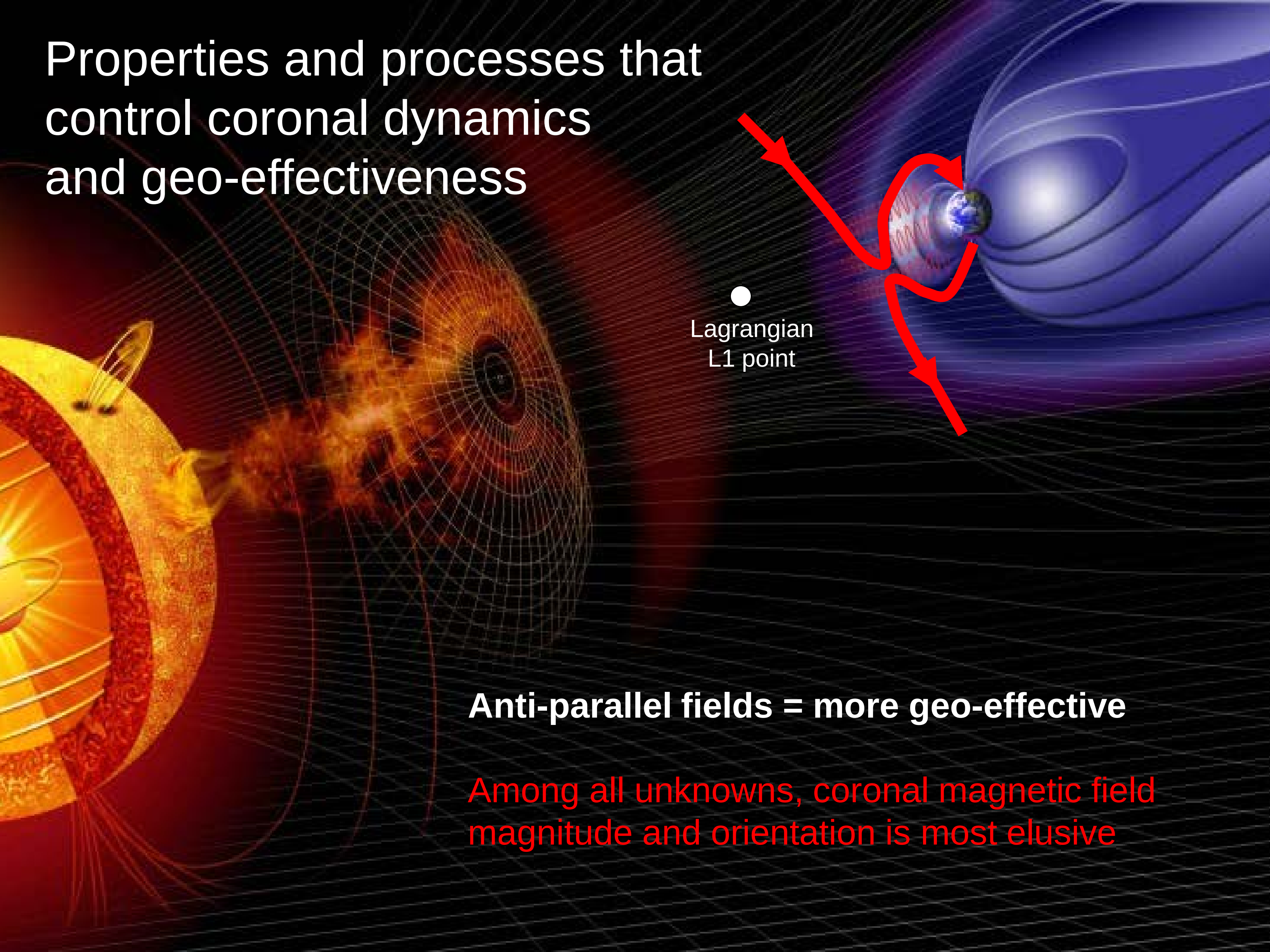
Context

- S2: ESA S-class mission opportunity with China
- S-class mission with 50 M€ ESA + equivalent China
- Launch and payload costs may be additional
- Spacecraft mass ~300 kg + possibly propulsion module
- 60 kg/65 W for payload
- Launch in 2021

Timeline:

- First workshop in Chengdu last February
- Second workshop in Copenhagen in September
- Call issued around December 2014
- Proposals likely due May-June 2015.

Properties and processes that control coronal dynamics and geo-effectiveness



Anti-parallel fields = more geo-effective

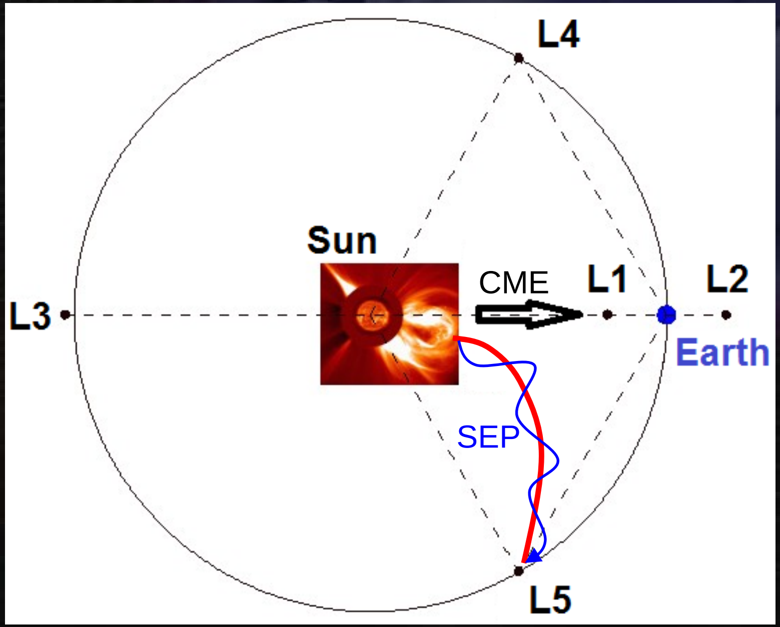
Among all unknowns, coronal magnetic field magnitude and orientation is most elusive

Limitations of past and future missions

Limitations of L1 observations:
- Rough solar observations (halo CMEs …)
- 1-hour delay for in situ observations

Limitations of STEREO:
- During solar minimum (low CME statistics)
- Only drifted through L5: not continuous

Limitations of Solar Orbiter and Solar Probe +:
- Solar Orbiter imagers off at aphelion
- Orbits rarely appropriate



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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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:

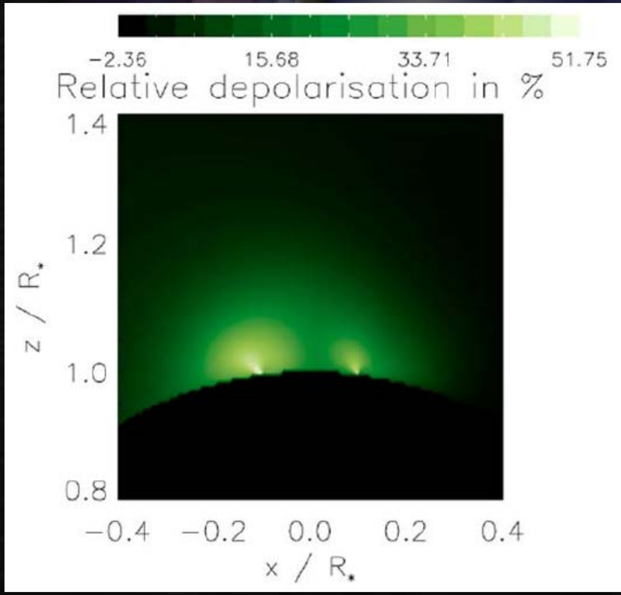
6. 3-days advance knowledge of CIR properties that reach Earth
7. Twelve hours to 2 days advance warning of Earth-directed CMEs
8. Twelve hours to 2 days advance warning of CME-driven SEPs
9. ***Unprecedented ability*** to reconstruct the magnetic field magnitude and orientation of Earth-bound CMEs early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

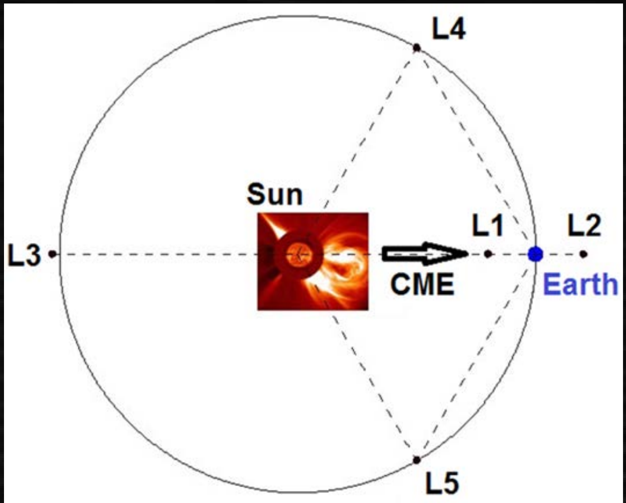
Requirements for objectives 1 and 2

→ 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

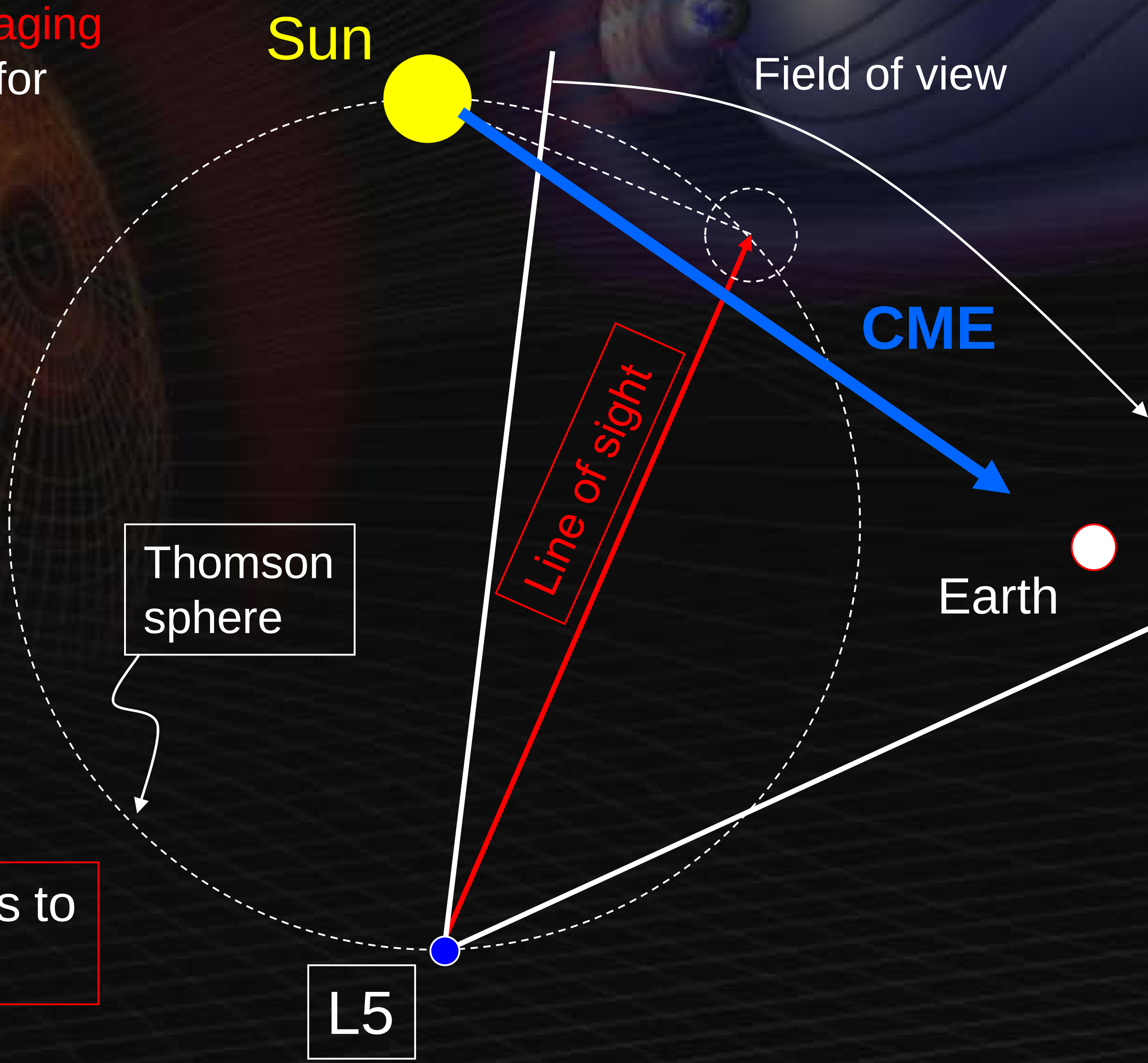




Requirements for objective 3

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

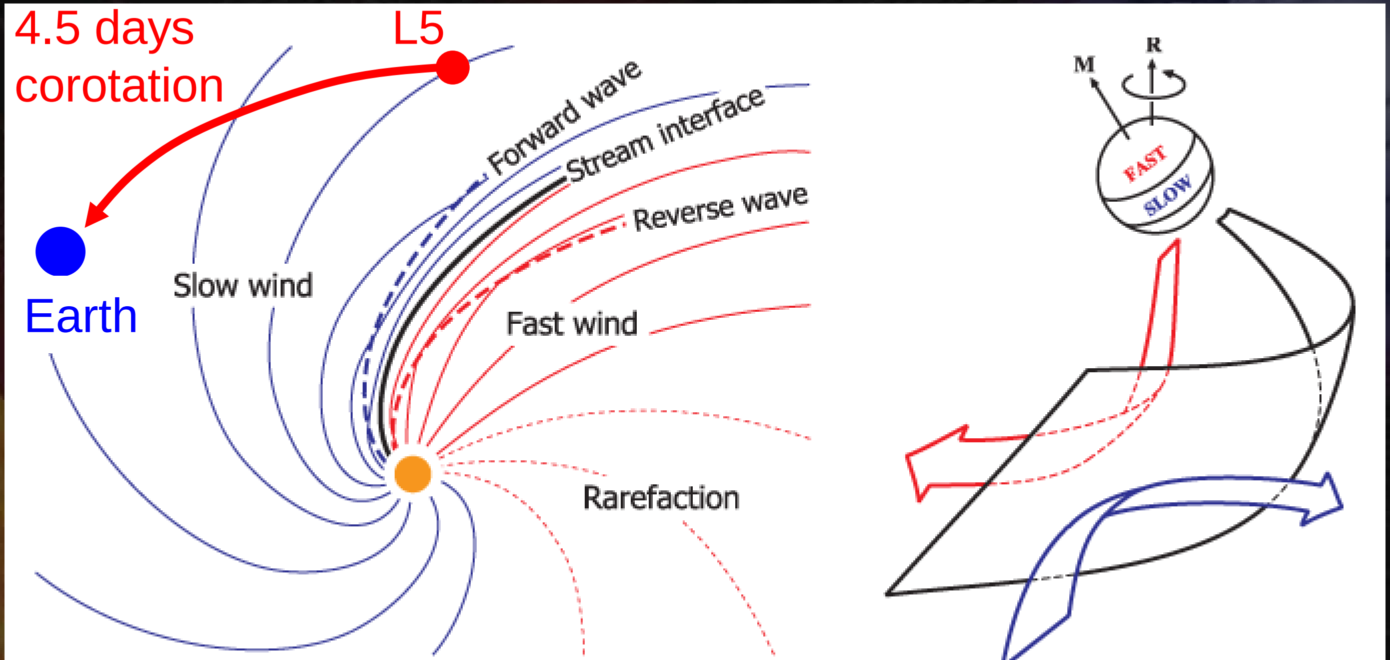
- High cadence white light imaging in low corona (1.15 – 4 Rs) for CME acceleration
- Wide angle heliospheric imagers to track CME/CIR interactions in heliosphere
- Polarization information for accurate trajectory
- Off-Sun-Earth line location for tracking of Earth-bound CMEs



→ 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?



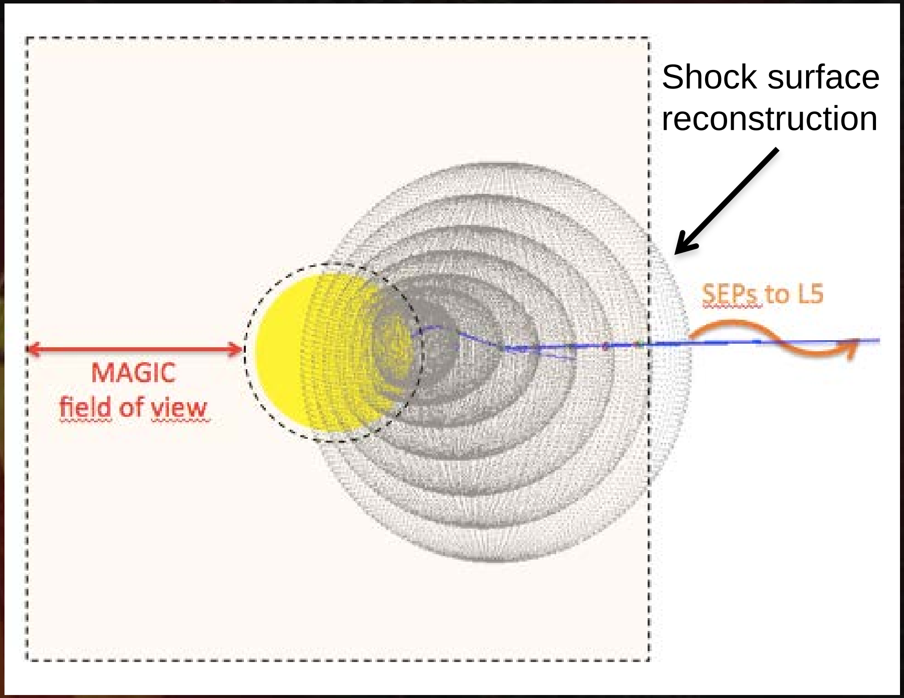
Adapted from Owens and Forsyth (2013)

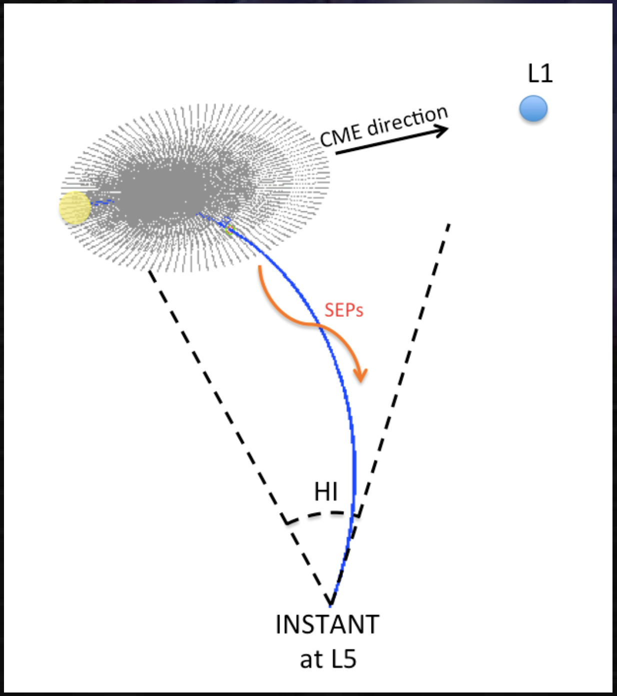
- Multipoint measurements of B-field, protons and suprathermals
- Lyman-α and white light imaging of corona and heliosphere
- Off-Sun-Earth line location for advance measurement of Earth-bound corotating structures

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

Requirements for objective 5

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

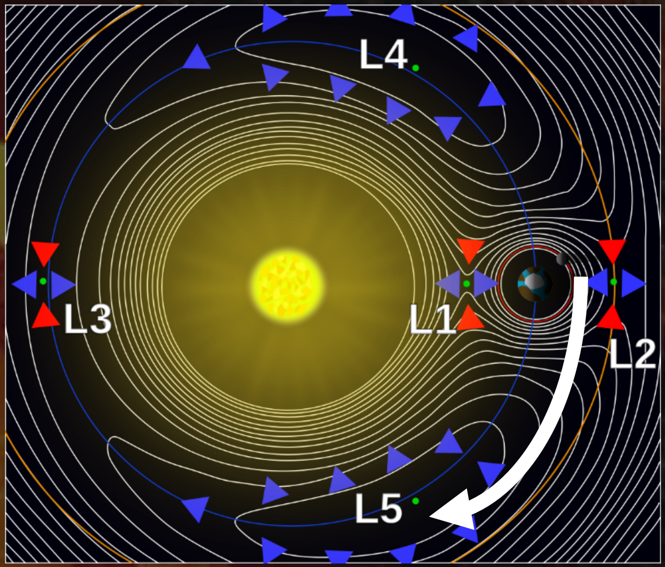




- Early imaging of shock formation in low corona (up to 4 Rs)
- Magnetic field and density imaging for shock properties
- Multipoint, off-Sun-Earth line measurement of energetic particles

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

Mission profile: orbital/phasing requirements

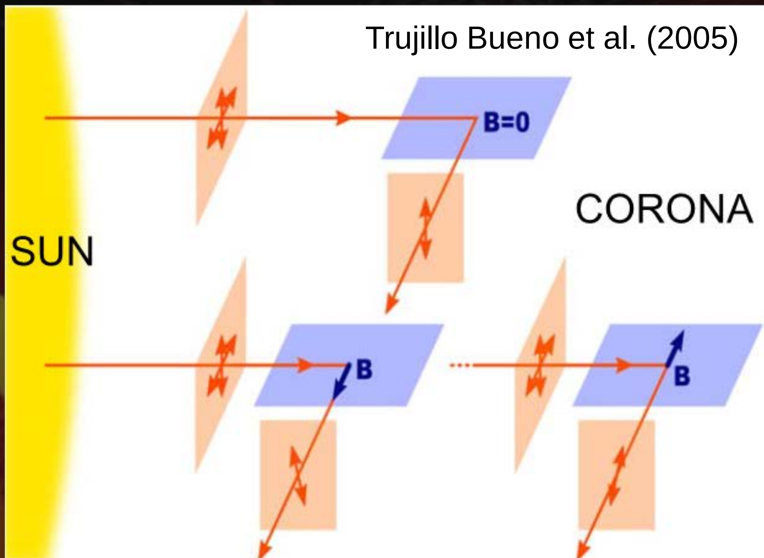


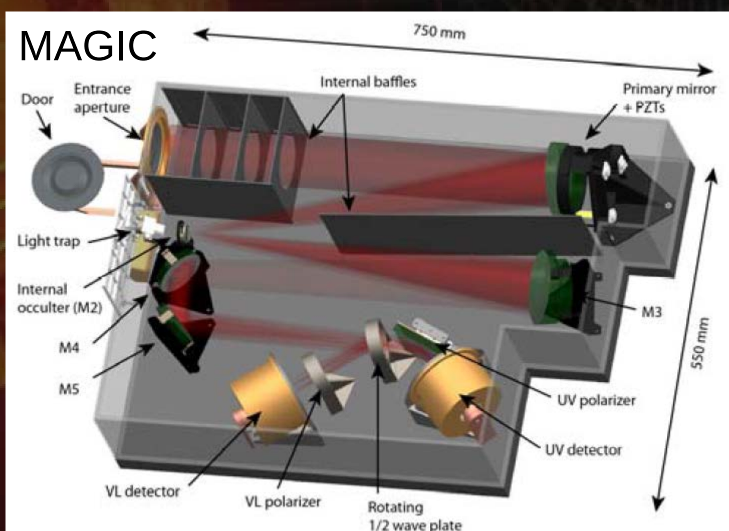
- Observation off-Sun-Earth line is a key for innovative science of Earth-directed CMEs
- Towards L5 rather than L4 (CIRs and SEPs)
- Science operations start after commissioning (~few months)
- Science phase 1 with high telemetry (1 year) Space weather science in phase 2
- L5 insertion after ~2 years operation

3 years operation sufficient to address key science objectives

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

Payload: innovative coronal imaging





MAGIC: MAGnetic Imaging Coronagraph

→ Lyman-α and white light coronagraph (1.15 – 4 Rs) at up to 2 min res.

HI: Heliospheric Imager

→ Polarized white light imager for enhanced accuracy in trajectory determination

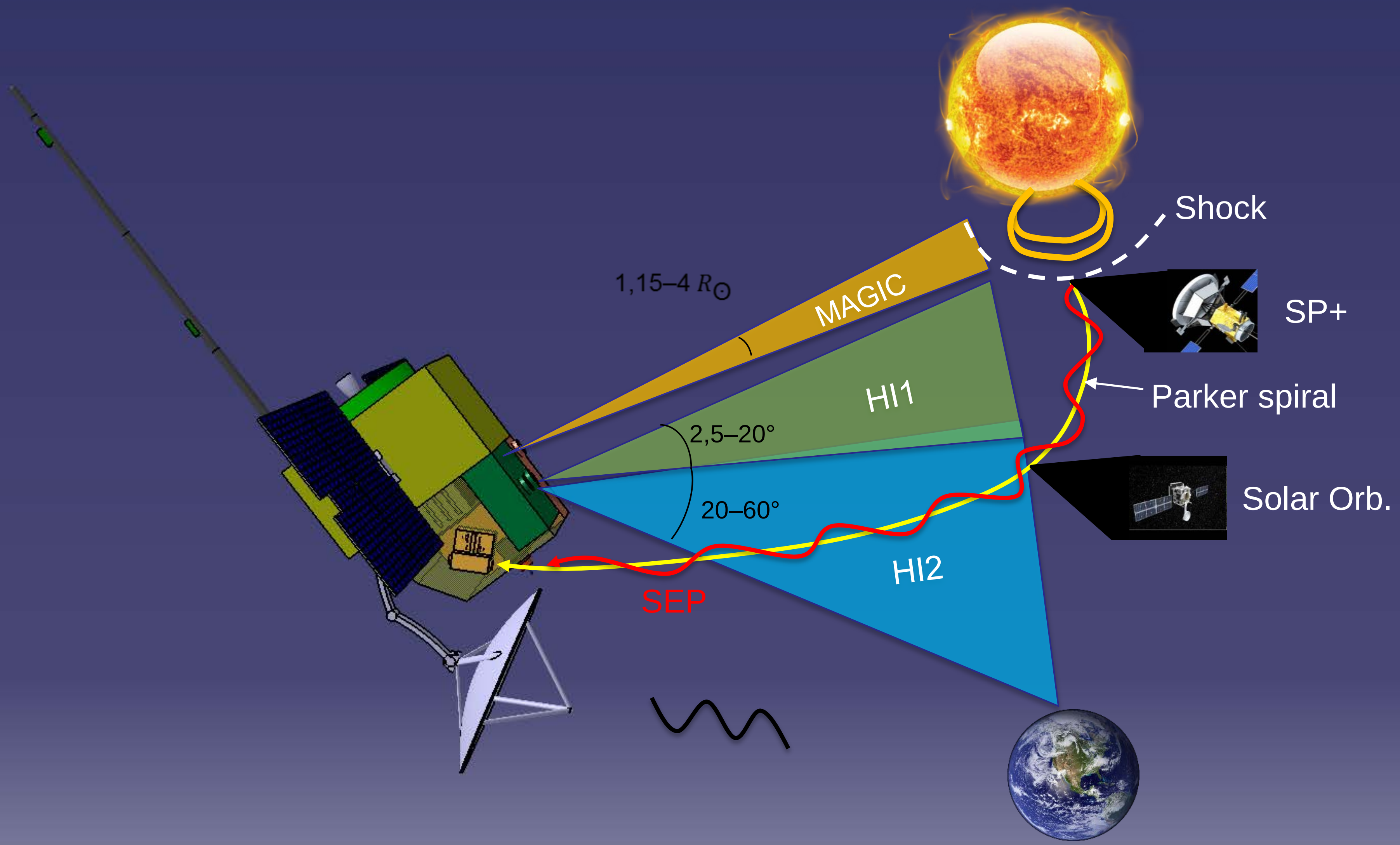
MAG: In situ magnetometer (Chinese PI)

PAS: Proton and Alpha Sensor (Chinese PI)

HEPS: High Energy Particle Sensor

MAGIC has TRL 6+, all others TRL 9

Payload fields of view



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.)

The team

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Harrison RA[3], Liu W[2], Auchère F[4], Gan W[5], Lamy P[6], Xia L[7], Zhang H[8], Eastwood JP[9], Kong L[2], Wang J[2], Wimmer-Schweingruber R[10], Zhang S[1], Zong Q[11], Soucek J[12], Prech L[13], Rochus P[14], Rouillard AP[1], Davies JA[3], Vial JC[4], Maksimovic M[15], Temmer M[16], Escoubet CP[17], Kilpua EK[18], Tappin J[3], Vainio R[19], Poedts S[20], Dunlop M[3,11], Savani N[21], Gopalswamy N[22], Bale S[23], Li G[24], Howard T[25], DeForest C[25], Webb DF[26], Segura K[1]

and the broader INSTANT science team

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[2]National Space Science Center, Beijing, China
[3]Rutherford Appleton Laboratory, Didcot, UK
[4]Institut d'Astrophysique Spatiale, Orsay, France
[5]Purple Mountain Observatory, Nanjing, China
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[8]Changchun Institute of Optics, China
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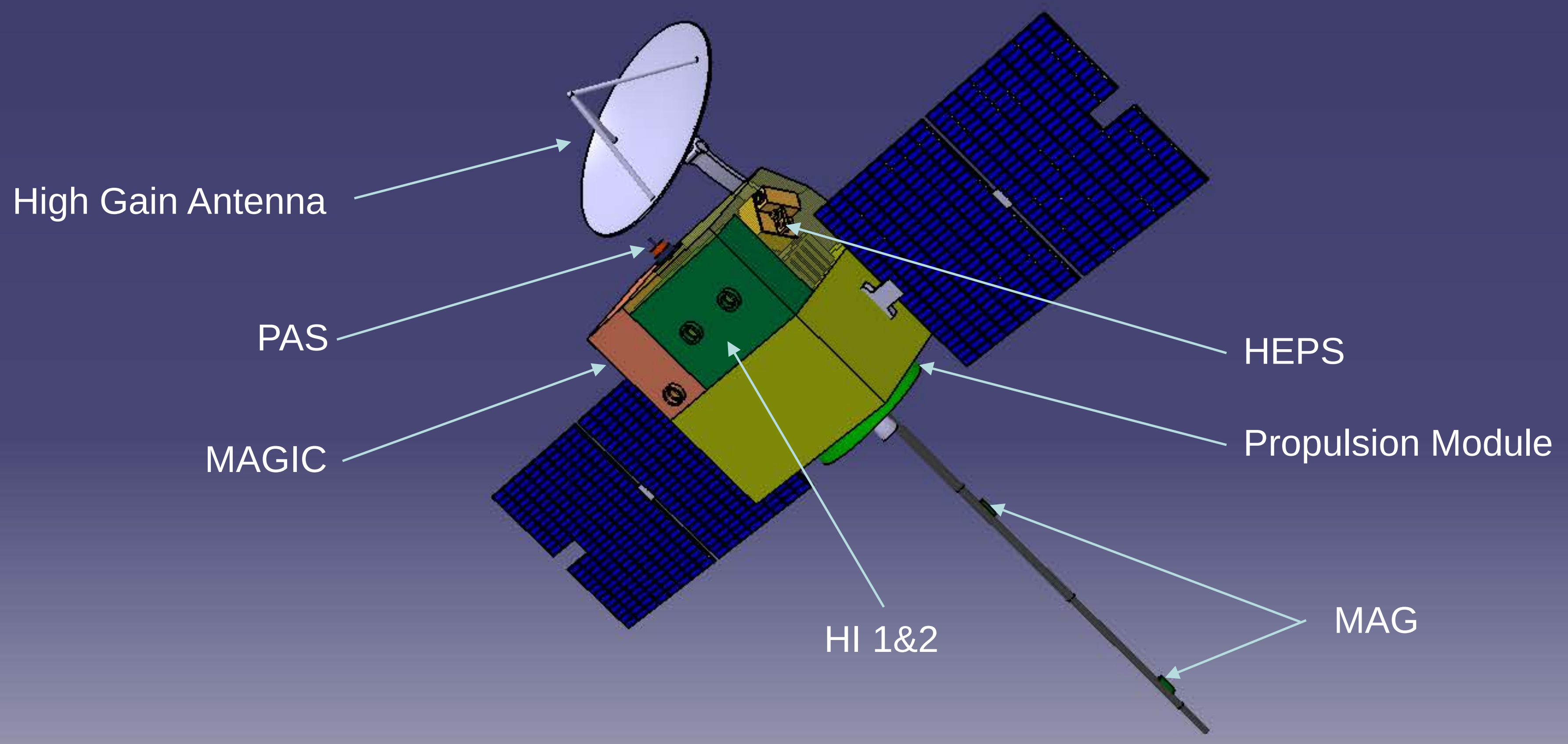
[10]Christian Albrechts University, Kiel, Germany
[11]Peking University, Beijing, China
[12]Institute of Atmos. Phys., Prague, Czeck Rep.
[13]Charles University, Prague, Czeck Rep.
[14]Centre Spatial de Liège, Belgium
[15]Observatoire de Paris, Meudon, France
[16]University of Graz, Austria
[17]European Space Agency, The Netherlands
[18]University of Helsinki, Finland
[19]University of Turku, Finland
[19]Katholieke Universiteit Leuven, Belgium
[21]Naval Research Laboratory, Washington, USA
[22]NASA Goddard Space Flight Center, USA
[23]Space Sciences Laboratory, Berkeley, USA
[24]University of Alabama, Huntsville, USA
[25]Southwest Research Institute, Boulder, USA
[26]Boston College, Boston, USA

EXTRA SLIDES

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

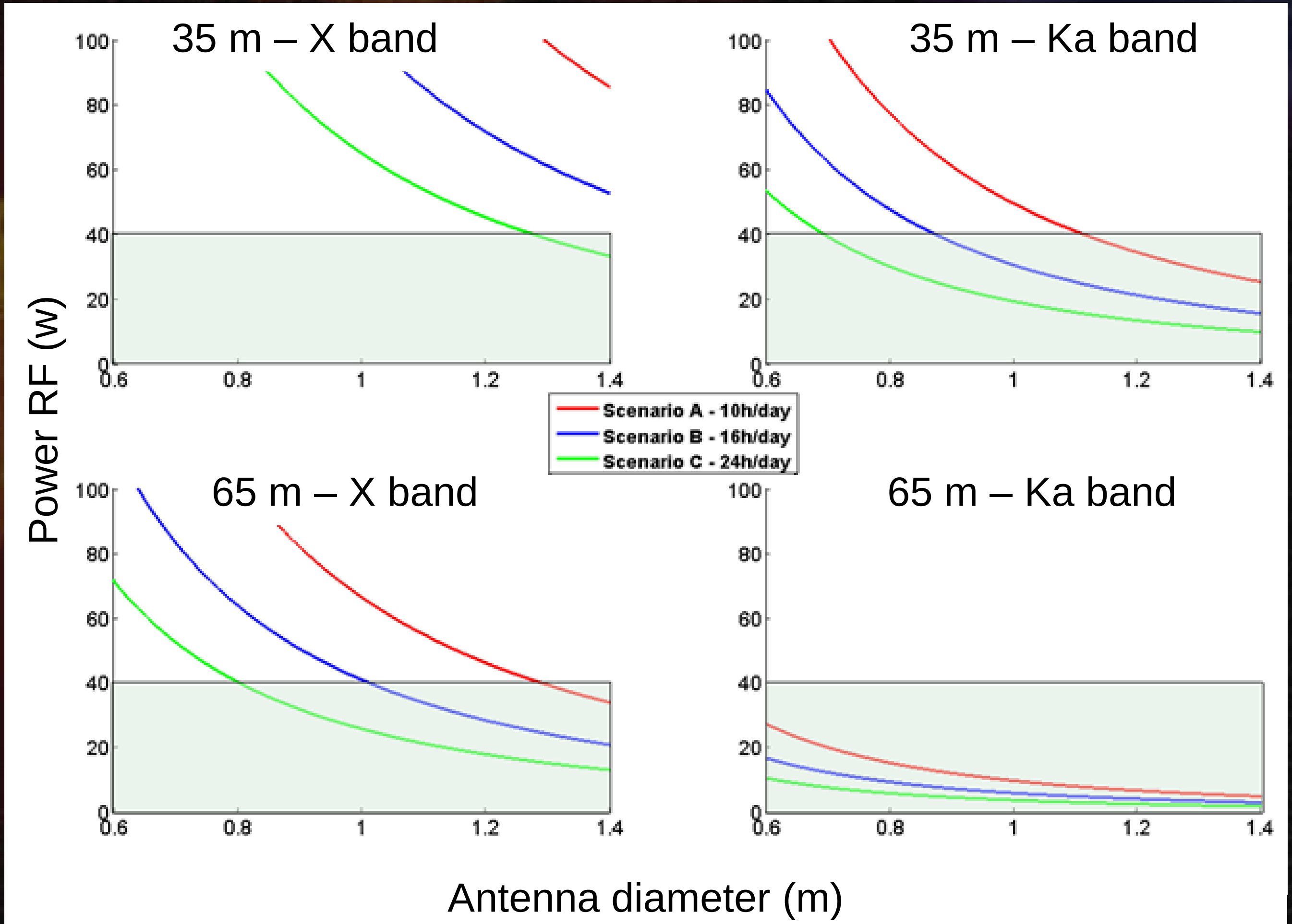


Telemetry requirements

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



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**	

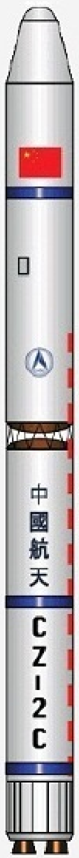
The mission and payload satisfy the technical constraints

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**	

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

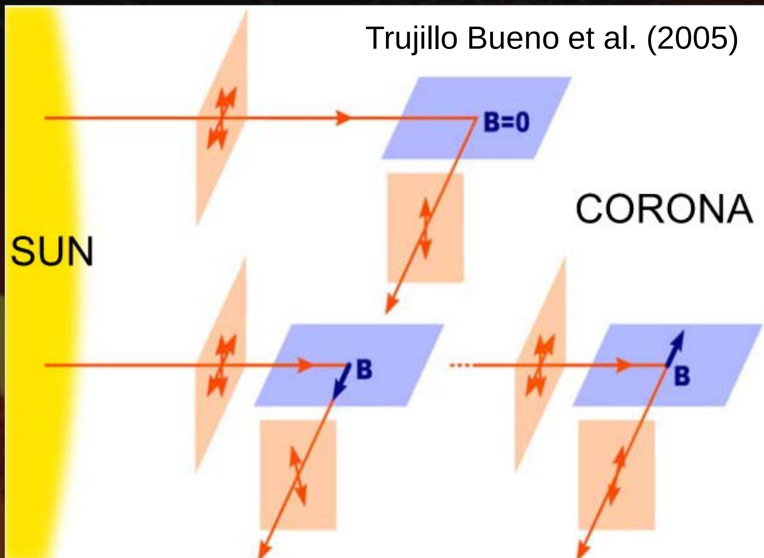
European platform (Myriad Ev., Proba, else)

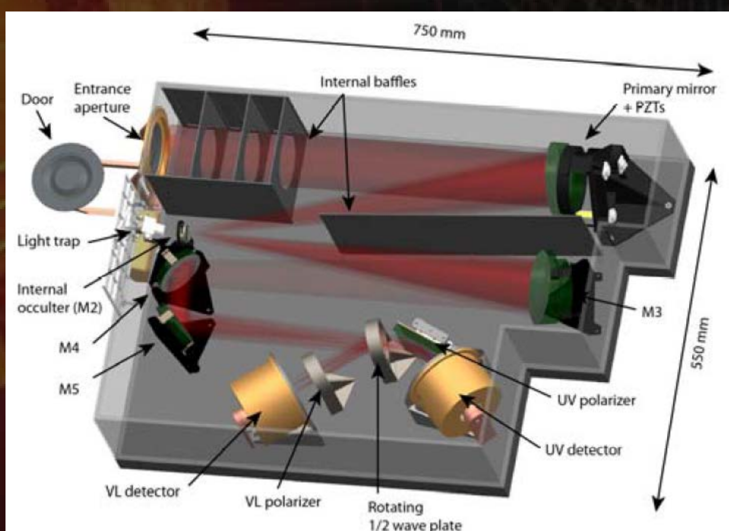
- Additional propulsion module for:
  - exit to L5, and
  - insertion at L5

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

→ Exact orbit and propulsion details are still under study

Payload: innovative coronal imaging





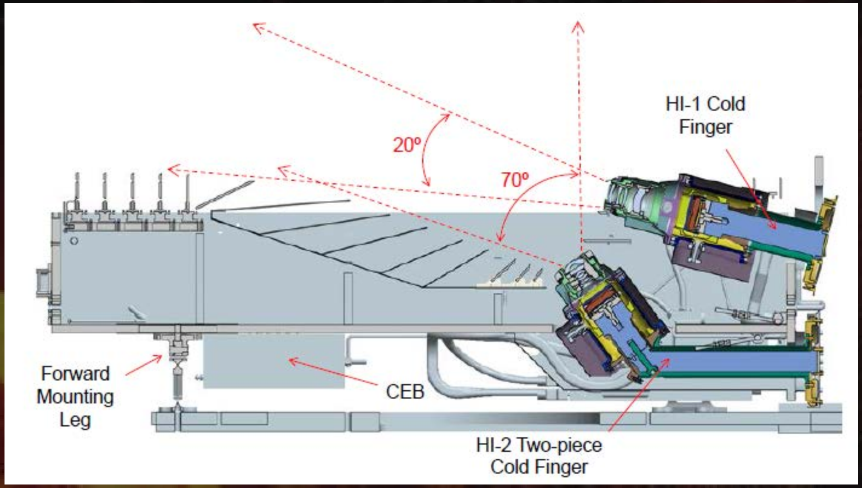
MAGIC: MAGnetic Imaging Coronagraph

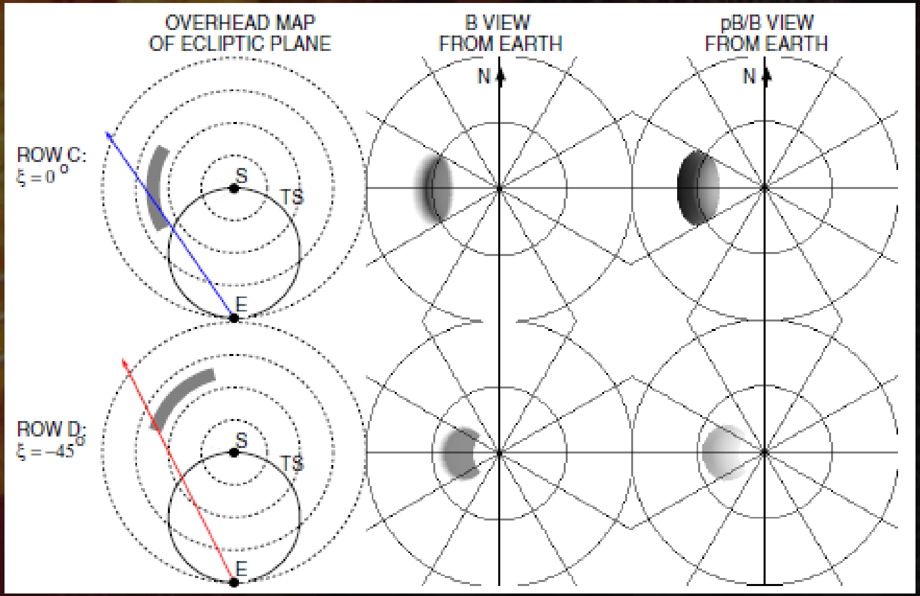
- Novel Lyman-α measurements to determine line-of-sight magnetic field component through the **Hanle** effect
- High cadence (5-7 min) measurement in low corona (1.15–4 Rs) for reconstruction of magnetic field topology
- White light for electron density estimates
- Off-Sun-Earth line for early determination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

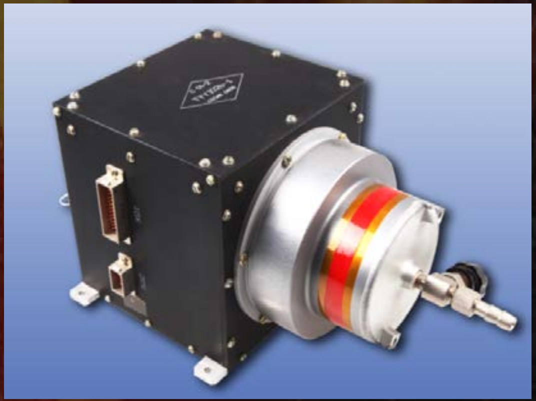
HI: Heliospheric Imagers

- 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)

Heritage: Cluster, Chang'E, Solar Orb…

TRLs 9