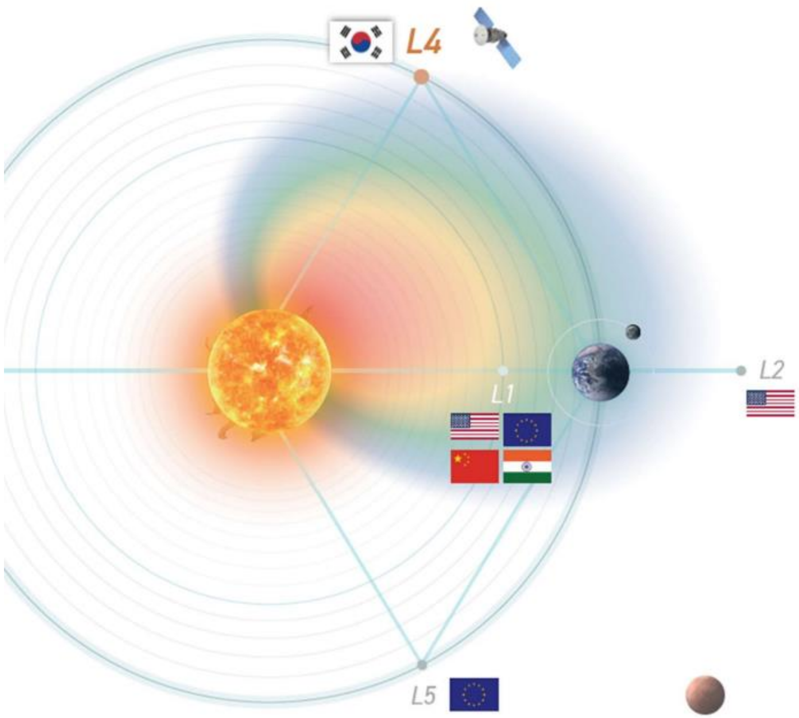
Opening New Horizons with the Korea-led L4 Mission: Vision and Plan



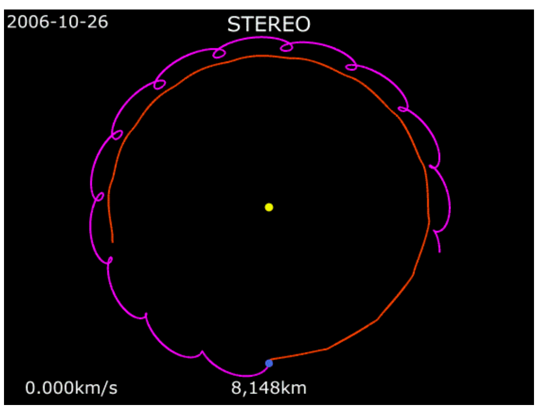
한국천문연구원
Korea Astronomy & Space Science Institute

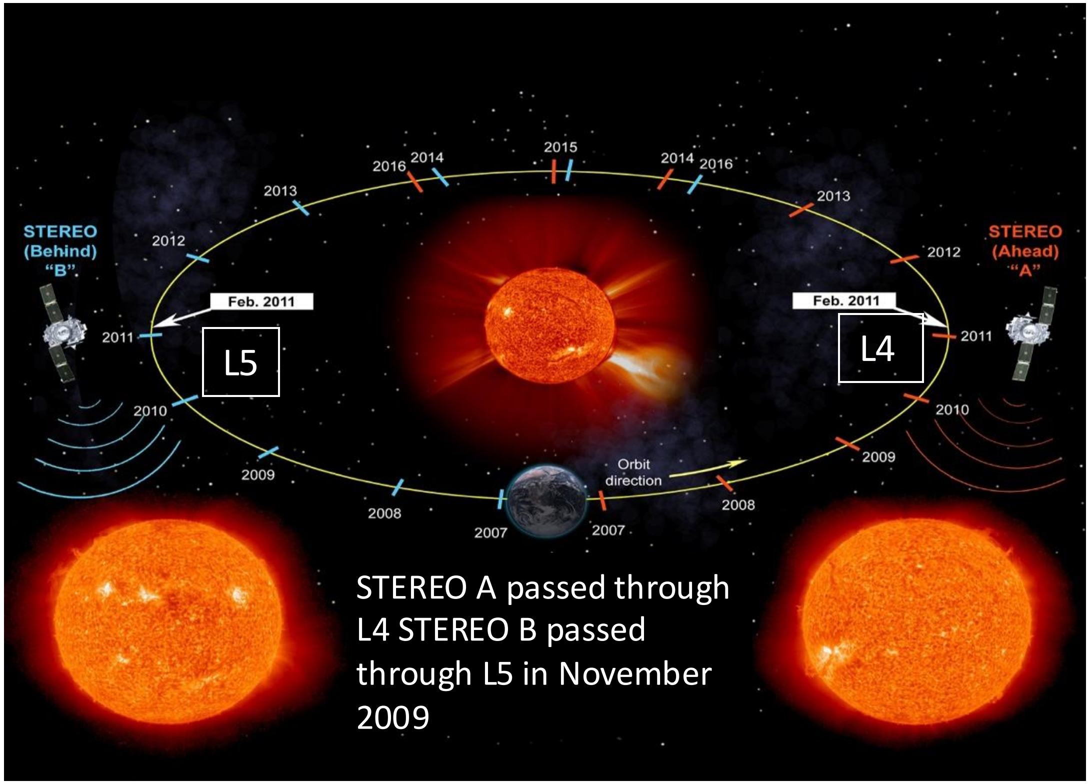
Kyung-Suk Cho
PI of KASI L4 Team

Lesson Learned from STEREO

→ Combined STEREO and SOHO observations determined that many particle events at Earth originate from the region behind the solar limb, best viewed from L4.

- Measuring magnetic properties of CMEs and solar wind structure is central to future Lagrange missions
- Would have done a lot more if it had magnetographs





Demonstrated the utility of observing the sun from vantage points off of the sun-earth line and the utility of the heliospheric imager concept from those vantage points.

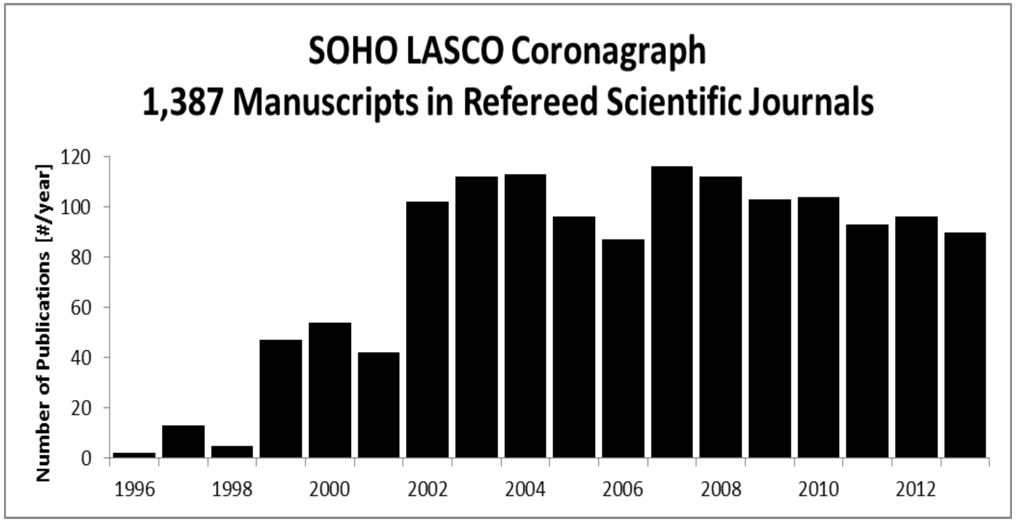
Benefits of Lagrange Points

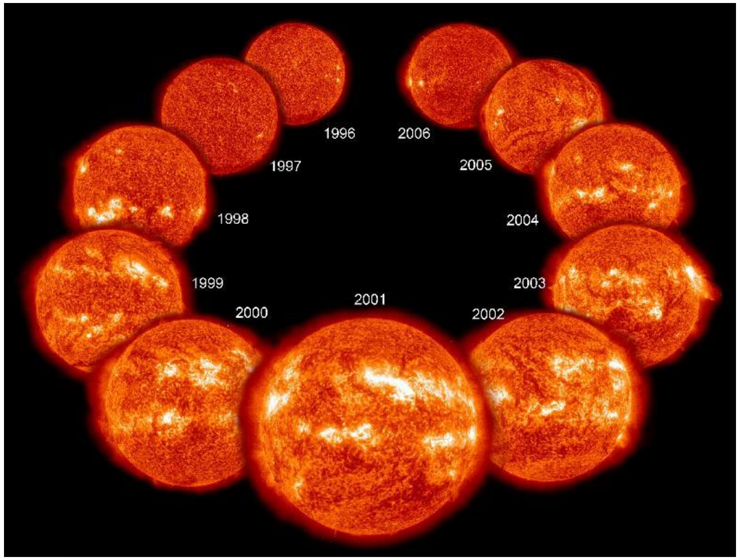
(1) Lagrange points are positions in space where the gravitational forces of a two-body system like Sun & the Earth produce enhance regions of attraction. **It will become static forces equal.**

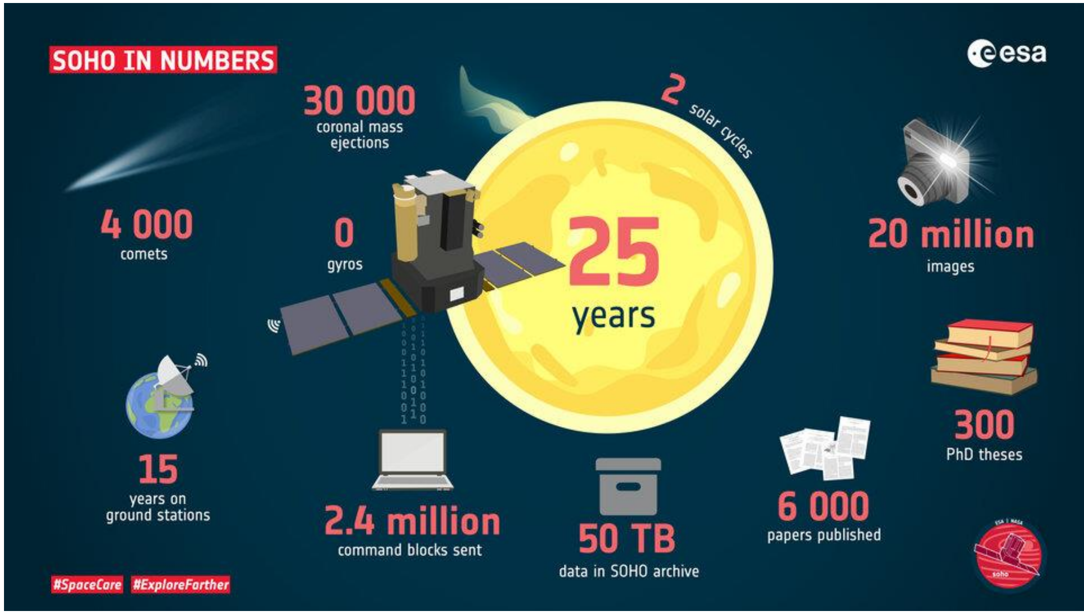
(2) These points can be used by **spacecraft to reduce fuel consumption** needed to remain in position. They are also **called as parking spaces of space**, since gravitational force is almost zero.

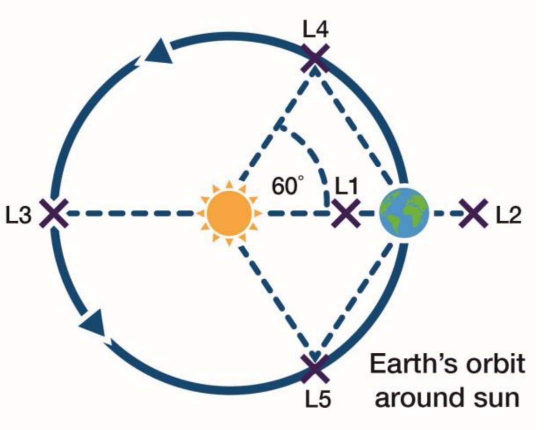
(3) These payloads have to be placed **outside the interference from the Earth's magnetic field**.

Solar observation : SOHO @L1









Korea AeroSpace Administration (KASA)

South Korea launches its own NASA

New agency aims to boost science and commercial space projects

27 MAY 2024 • 12:01 AM ET • BY DENNIS NORMILE

SHARE:

There's no shortage of ideas. A team led by Kyung-Suk Cho, a solar physicist at the Korea Astronomy and Space Science Institute (KASI), is studying the feasibility of placing a satellite to monitor solar activity from the Sun-Earth Lagrangian point L4, a "parking spot" where gravitational forces help keep satellites in a fixed position with minimal fuel consumption. Observations from that vantage could probe solar phenomena and provide warnings of solar eruptions that might threaten astronauts.

KASA Policy Direction

Space Launch Vehicle

Enter the global market

Satellite

Provide science and public service

Space Exploration

Explore the Moon, Mars and beyond

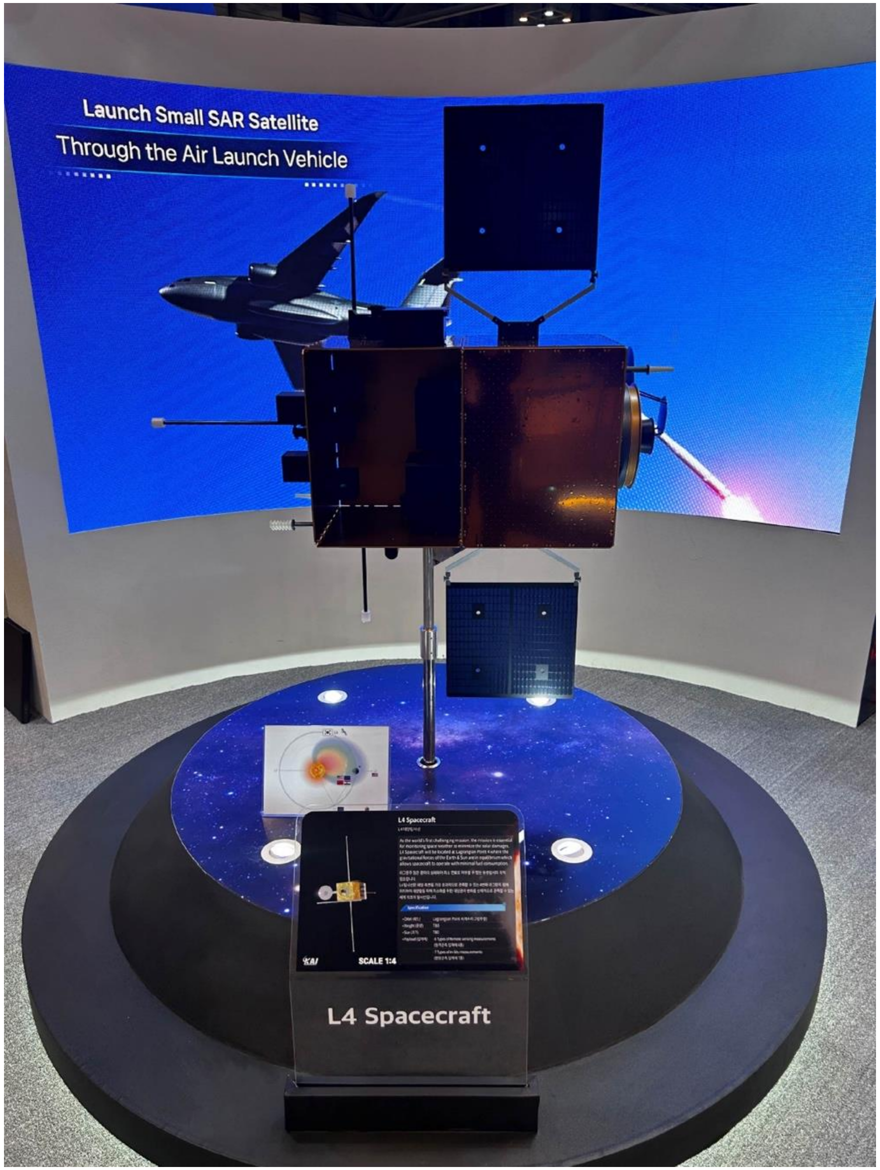
Aeronautics

Promote industry

According to the policy direction announced on May 30th2024, **the L4 Mission is one of the highest priorities** in KASA's space exploration initiatives.

KASI is currently conducting a feasibility study of 'Korea-led L4 mission for Heliospheric Observation through international collaboration from 2023 to 2025.

Korea-led L4 Heliospheric Observatory



KAI 한국항공우주산업(주)
KOREA AEROSPACE INDUSTRIES, LTD.

Advertised Throughout
COSPAR2024 at Busan, Korea

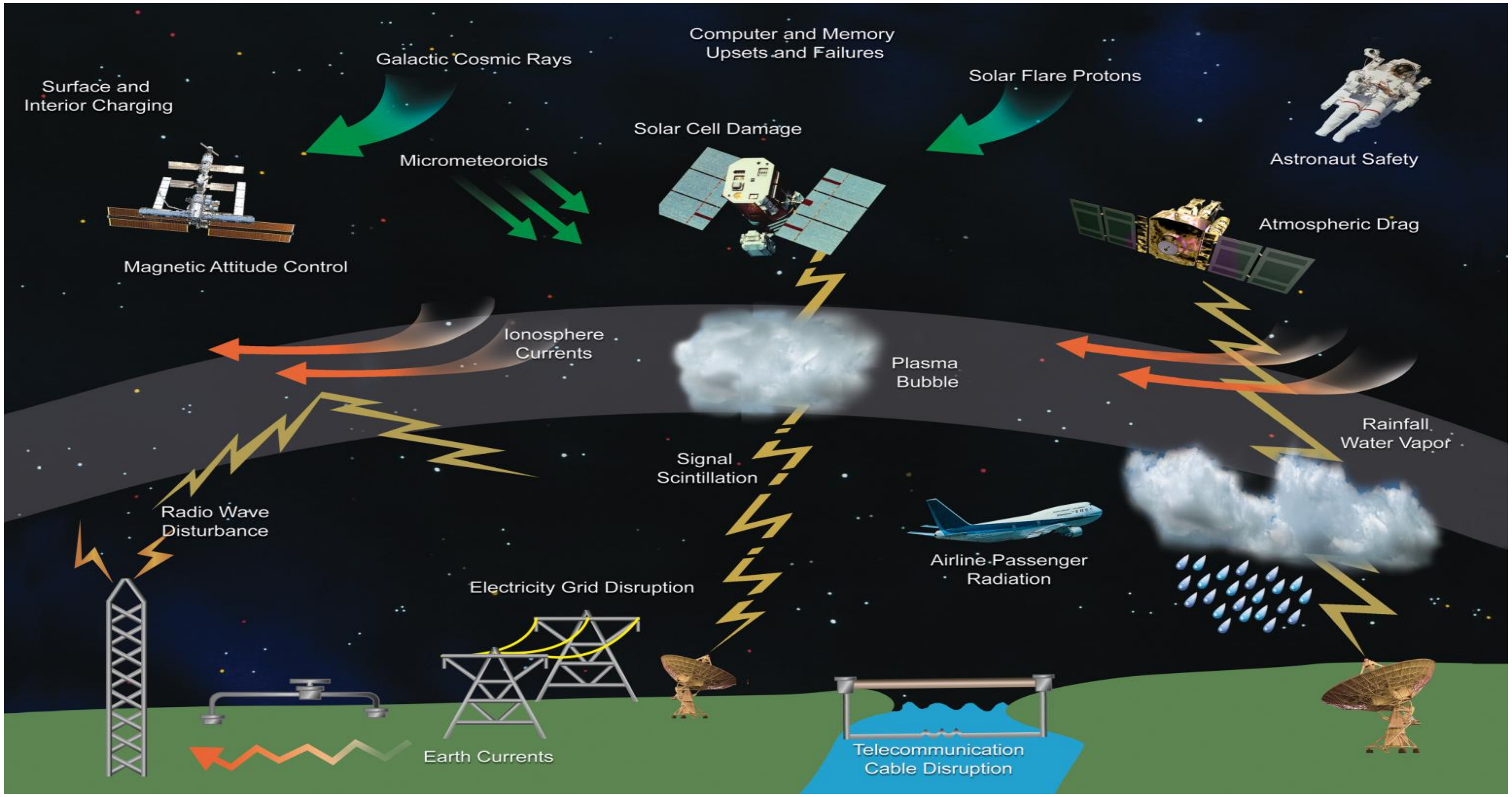
← Mock-up Model

한국천문연구원
Korea Astronomy & Space Science Institute

CONTENTS

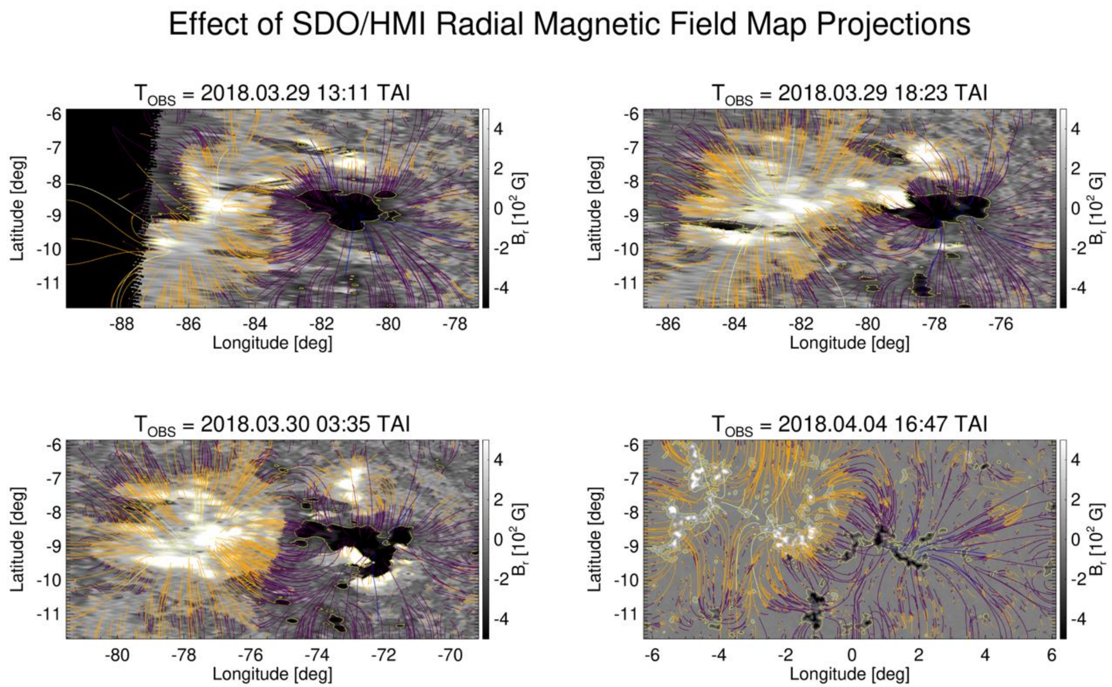
I Science Benefits

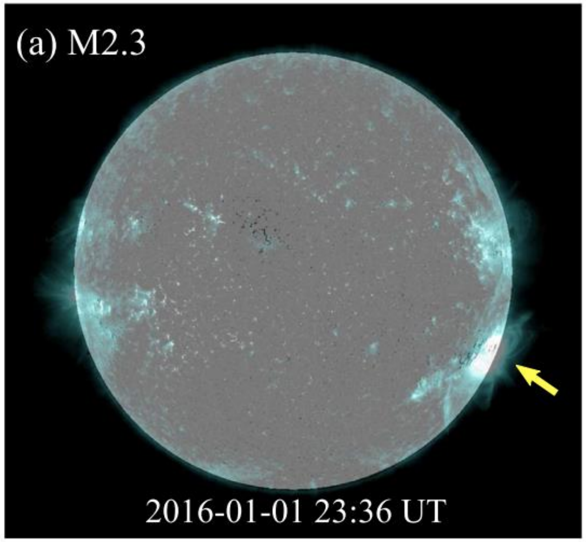
Benefits: More reliable Space Weather Forecasting



- Forecasts are used to support activities that are impacted by space weather such as electric power transmission, satellite operation, humans in space, navigation, and communication.
- **Accuracy rate of solar flares and geomagnetic storms is very low.**
- The L4 mission will significantly contribute to improve space weather forecasting capability.

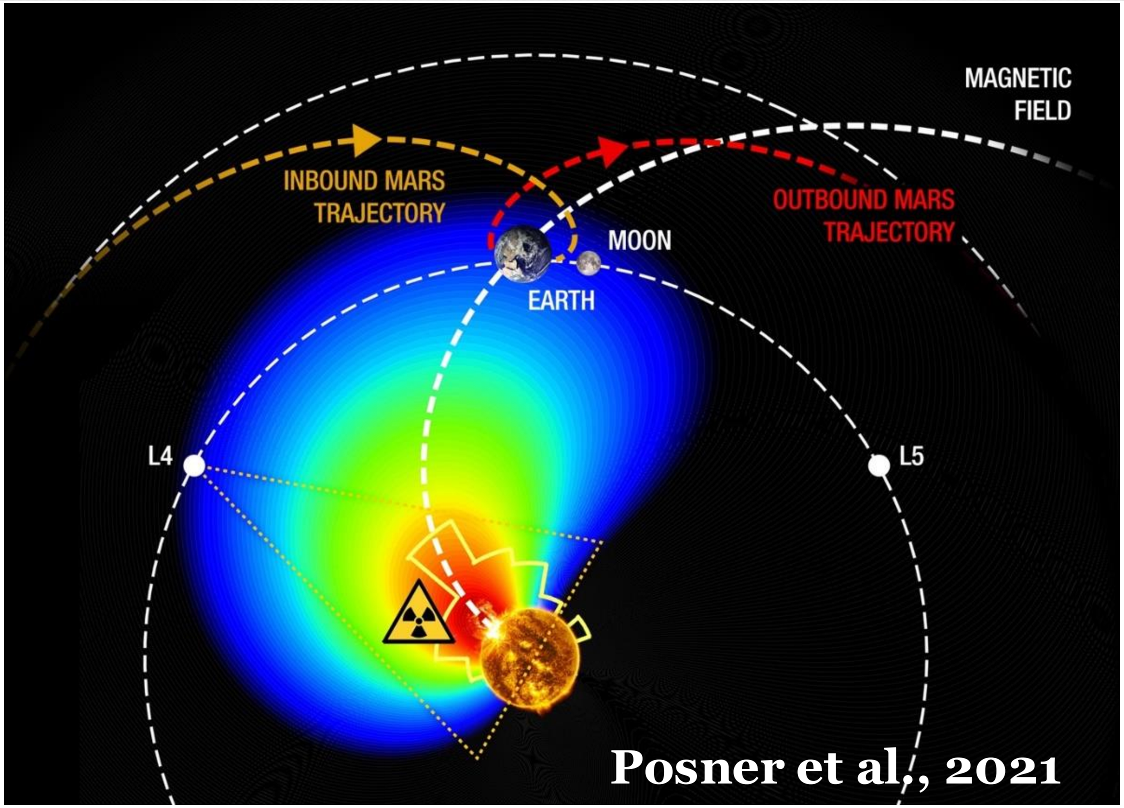
E.g. Flare Forecasting





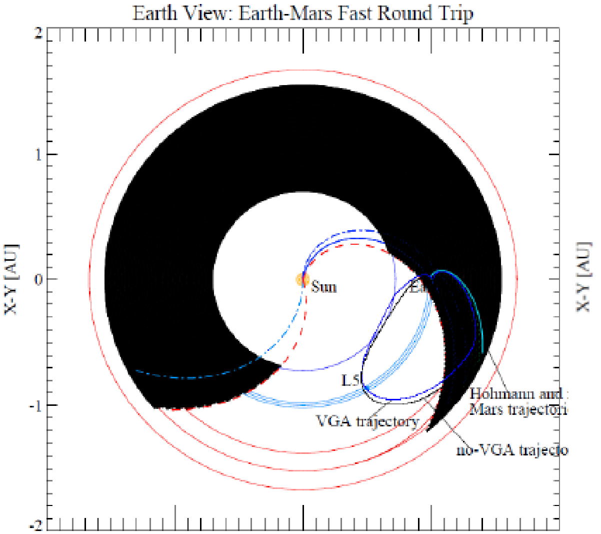
- 2017: International Workshop on Solar Flare Forecast Model Evaluation by ISEE
- Performance **evaluation of a total of 19 flare forecast models** (including U.S./NOAA, U.K. Meteorological Office, Japan/NICT, etc.)
- During the 2016-2017 evaluation period, **all models failed to forecast for 15% of the total number of M-class or higher flares**.
- **All correspond to flares that occurred at the edge**

Benefits: Speed up Solar radiation detection

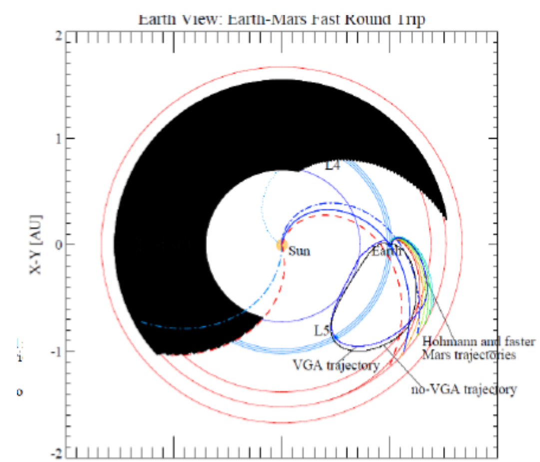


Science Benefits

Fast Mars Round Trips and



SWx Safety Zone supported by L1 only



SWx Safety Zone supported by L1 and L4

- L4 is a meta-stable locations at 1 AU and the best location for a solar remote sensing observatory that would **oversee the entire solar radiation hemisphere.**
- The unusual attribute of L4 is that it covers entire “Solar Radiation Hemisphere” that is relevant for M2M architeure.

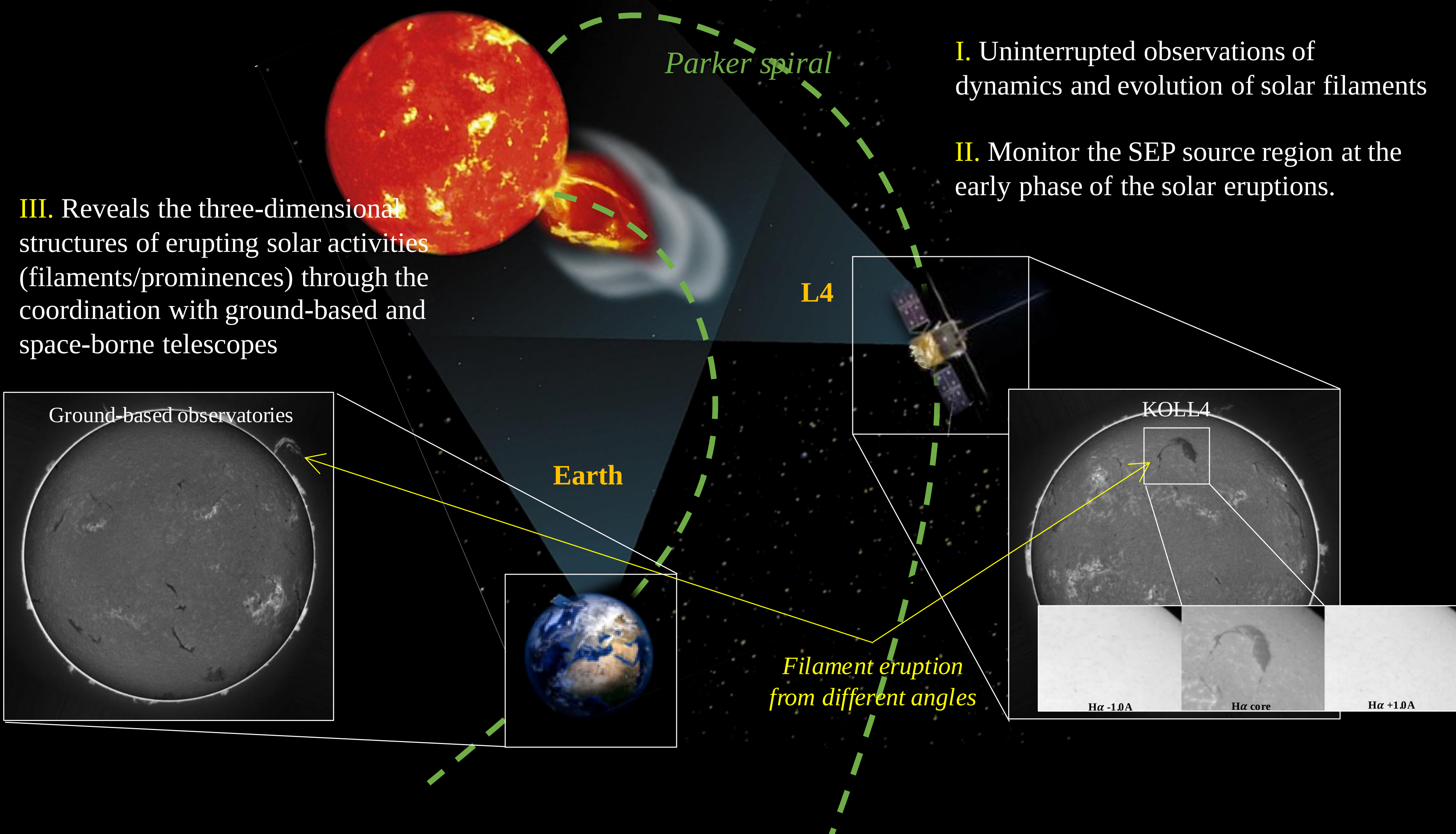
Benefits: Direct Observations @ L4

Space Weather

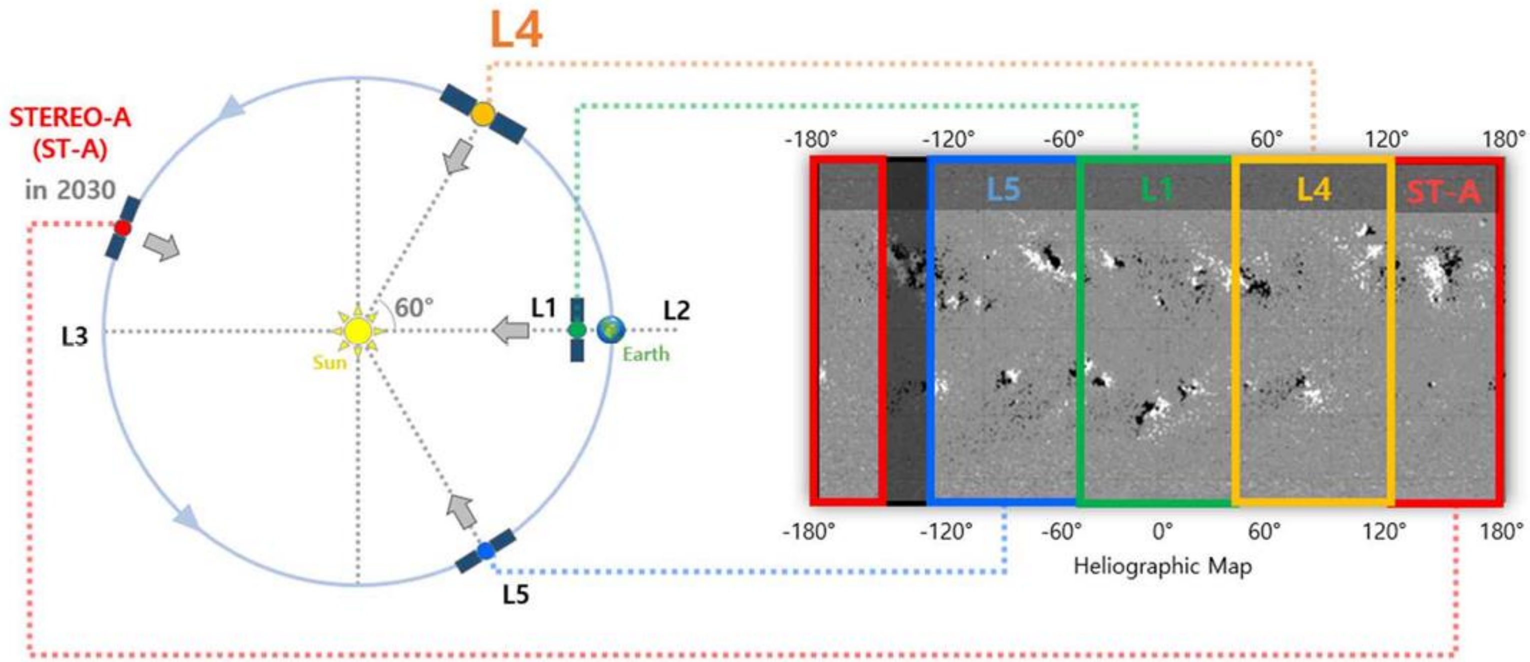
I. Uninterrupted observations of dynamics and evolution of solar filaments

II. Monitor the SEP source region at the early phase of the solar eruptions.

III. Reveals the three-dimensional structures of erupting solar activities (filaments/prominences) through the coordination with ground-based and space-borne telescopes



Benefits: OSEL Mission for new science



More reliable synoptic map from multi-view observations

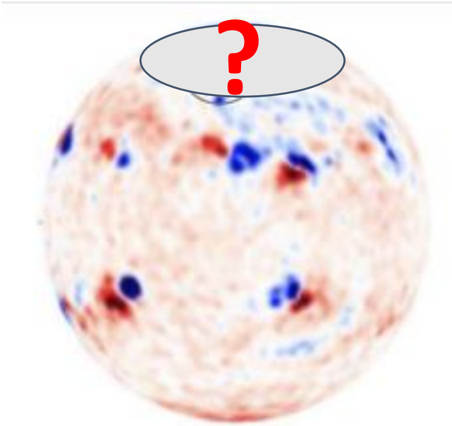
: The L4 mission will contribute to generate a near real-time synoptic map constructed from multi-viewpoint observations of the photospheric vector magnetic field at L4 + L1, L5, and ground.

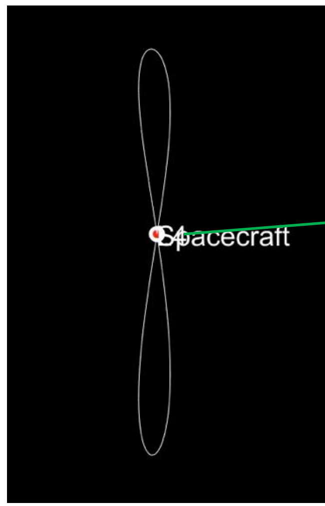
OSEL: Off-Sun-Earth-Line

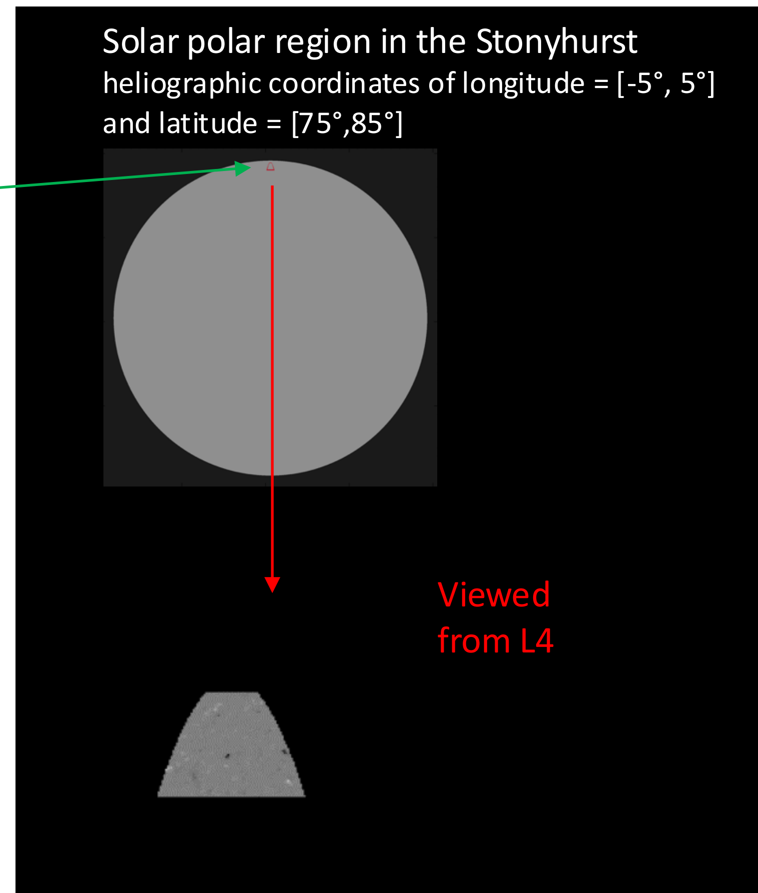
Benefits: OSEL Mission for new science

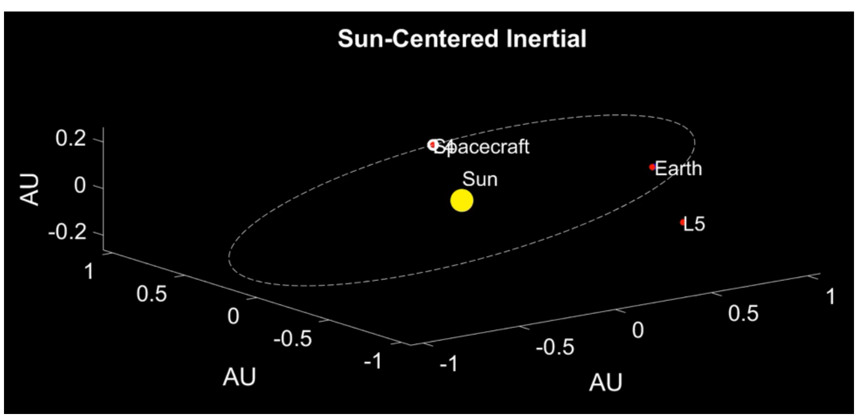
Seeing solar polar region

: L4, in coordination with ESA/NASA Solar Orbiter, will open new science that has never been studied in detail before such as **the structure of the Sun's polar region, large scale flows from the Sun's low latitude to high latitude, and the evolution of the solar magnetic fields and their effect on the next solar cycle**





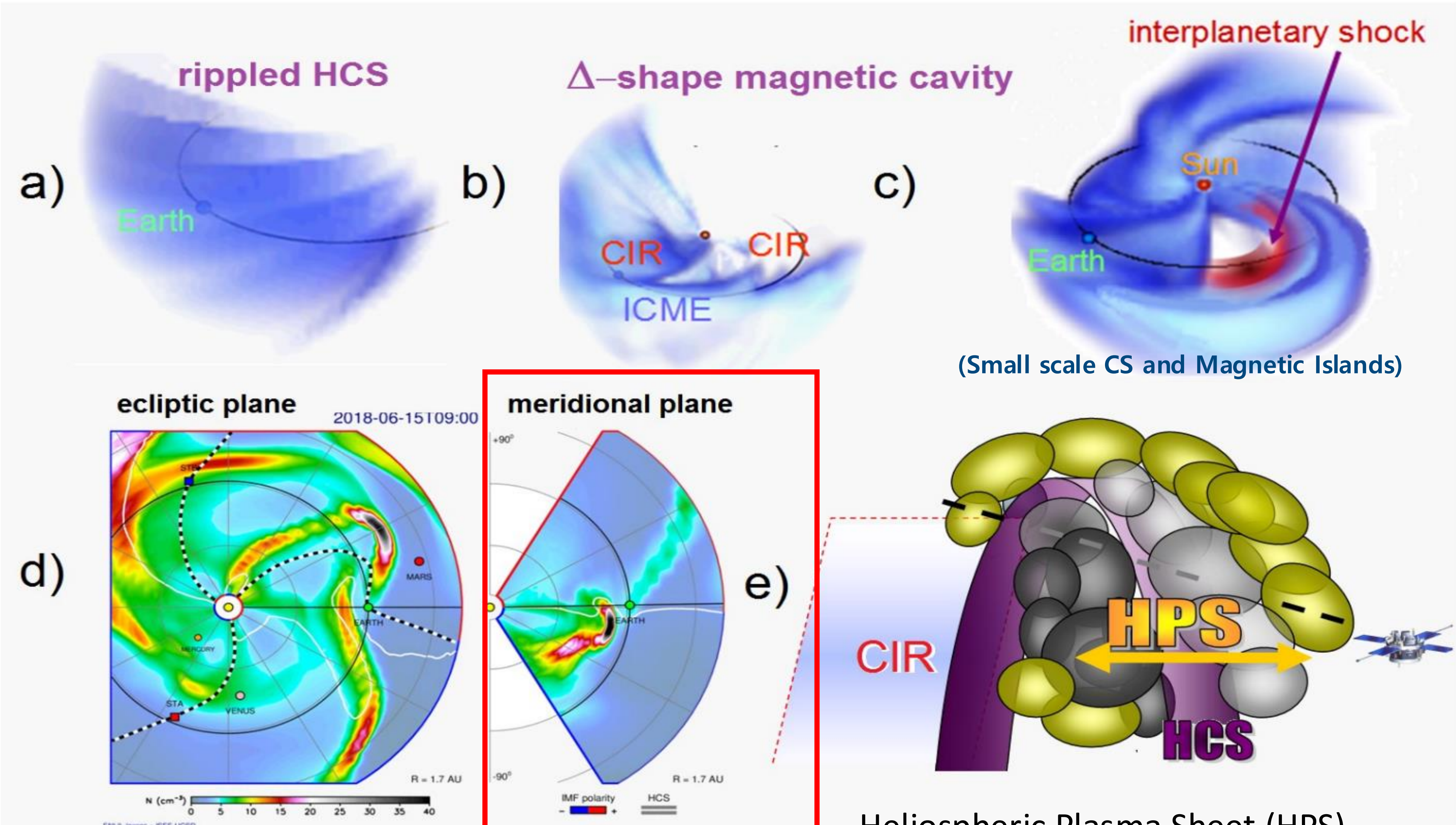




Benefits: 3D Heliospheric Structure

Contribute to understand 3D Heliospheric Structure

Olga Khabarova et al., (2021)



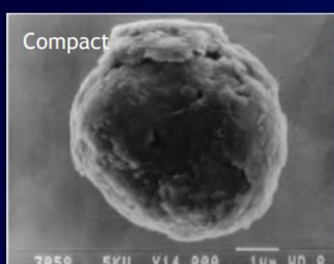
http://www.helioweather.net/models/ipsbd/den3/index.html

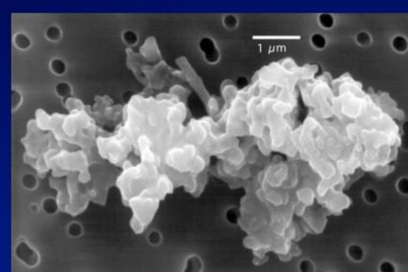
Heliospheric Plasma Sheet (HPS)

Benefits: Interplanetary Dust Science

Open Science Questions for Dust in the Heliosphere

- What is the vertical extent of the zodiacal dust cloud?
- What is its symmetry planes and what dynamics cause it to be inclined?
- What amount of ß-meteoroids are escaping the system?
- Is there nanodust to be detected that is related to solar phenomena?



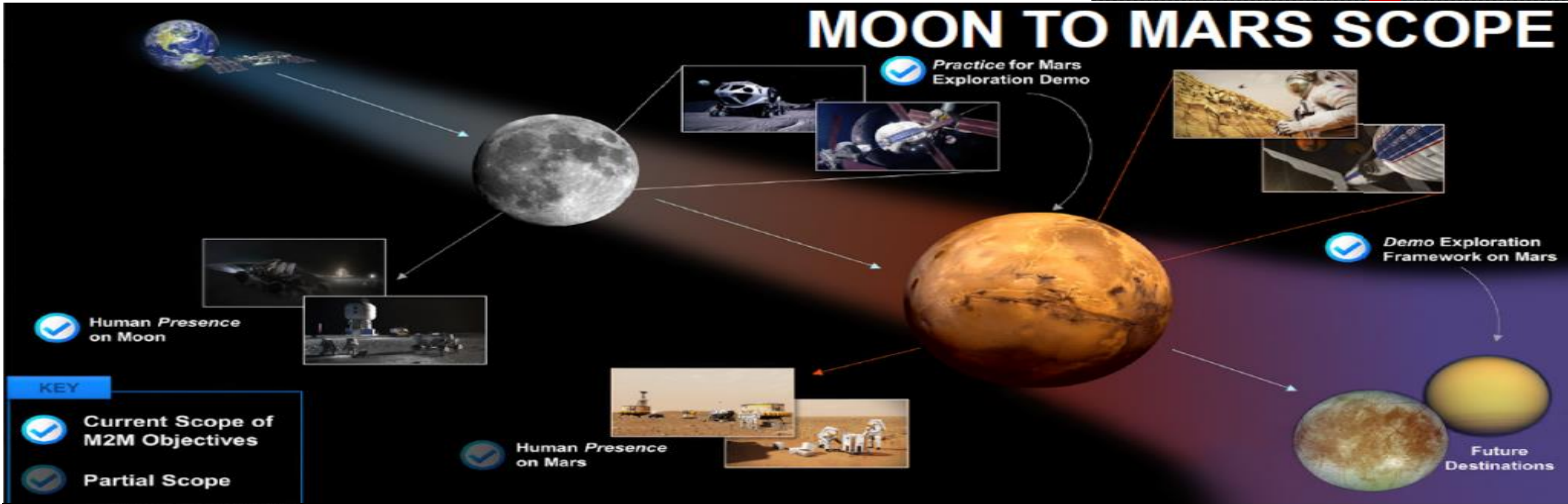


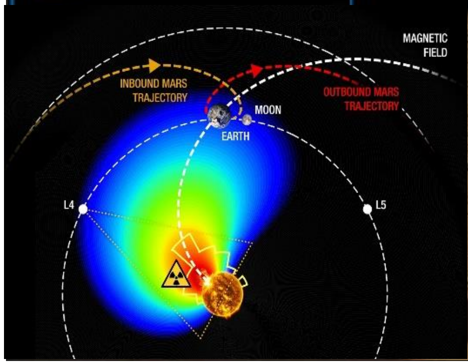
- Unique space mission on L4, and IDP accumulation on the L4 point
- Offer in-situ measurements of ISD and IDPs at L4
- One a year into and against interstellar dust flow. Can probe smaller and higher end of dust size distribution due to difference in impact velocity
- Existing dust detector technologies and affordable

- ISD: Interstellar Dust
- IDP: Interplanetary Dust Particle

Veerle Sterken et al., 2012; Hoang et al. KSSS presentation, 2024

Benefits: Expanding of Space Weather to M2M





- Through continuous observation of the heliosphere at the L4 position, we can provide more **reliable space weather forecast and space radiation environment information** for deep space exploration to the Moon and Mars.

Benefits: L5 vs. L5+L4

Potential Benefit	L1/Earth	L5+Earth	L4+Earth	L4+L5+Earth	Forecast/ science
Improved coverage of solar surface	~180° (50%)	~240° (66%)	~240° (66%)	~300° (83%)	Forecast and science
Early view of solar surface	0 days	4-5 days	(9-10 days)	4-5 days	Forecast
Better view of SEP source regions	No	No	Yes	Yes	Science
Better representation of polar fields	6(S) – 6(N)	4(S) – 4(S+N) – 4(N)	4(S) – 4(S+N) – 4(N)	2(S)-8(S+N)-2(N)	Forecast and science
Improved SW forecast for planetary missions	No	Yes	Yes	Yes	Forecast

Credit: COSPAR ILWS Report (2018)

Action Team on "**Promoting international collaboration in multi-vantage observations of the Sun, with a special focus on unique scientific advantages of L4+L5 combined observations.**"

Concluding Remarks

- ILWS Action Team on "Promoting international collaboration in multi-vantage observations of the Sun, with a special focus on unique scientific advantages of L4+L5 combined observations" had positive impact on promoting international collaboration in the important area of space weather research/operational forecasting.
- However, there is a general lack of funding for the international cooperation in heliophysics. How this collaborative effort could be funded, and what ILWS can do to ensure such funding?
- Some issues raised by the team will be continued via other channels (e.g. ISWCF and ISWAT)

References of the L4 mission

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Opening New Horizons with the L4 Mission: Vision and Plan

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Scientific Perspectives of the Heliophysics L4 Mission by Remote-Sensing Observations

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JASS Journal of Astronomy and Space Sciences

Long-Term Science Goals with *In Situ* Observations at the Sun-Earth Lagrange Point L4

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manuscript submitted to *Space Weather*

Visibility Analysis of the Sun as Viewed from Multiple Spacecraft at the Sun-Earth Lagrange Points

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[3]NASA/HQ, Washington, DC, USA

Key Points:

- Multi-spacecraft observations of the Sun from the Sun-Earth Lagrange points L1, L4 and L5 can provide a clear and wide-angle view to investigate the Sun-Earth, Sun-Moon and Sun-Mars connections
- Visibility of the solar surface is analyzed based on remote-sensing observations from single (L1), double (L1 and L4) and multi-space missions (L1, L4 and L5)
- A quantitative comparison of the solar surface visibility is made in the context of (1) observation days per year for a given solar latitude, (2) a chance of observing a limb flare from one spacecraft and its on-disk counterpart from the others, and (3) continuous tracking of a target feature (such as sunspots) on the solar disk

Primary Science Objectives

(From the L4 mission's science requirements document currently in preparation)

1. Reveal the characteristics of solar and interplanetary source regions that produce solar energetic particles (SEPs) and understand their propagation properties through the heliosphere

2. Explore the initiation and dynamic evolution of magnetized plasma structures erupting from the Sun's low atmosphere to interplanetary space, such as coronal mass ejections (CMEs) and corotating interaction regions (CIRs)

3. Investigate the influence/effects of solar activity on the varying physical conditions in the heliospheric environment (space weather)

Overview of L4 Science Requirement

(From the L4 mission's science requirements document currently in preparation)

Overview of L4 Science Requirements

Major Science Themes	Major Open Questions	Science Objectives	Measurements Required from L4	Relevant Science Payloads
1. Space weather in the heliosphere	**(Q1-1)** Sun - Which solar activities need to be explored to better understand and predict adverse space weather in the heliosphere?	**(O1-1)** Investigating solar source regioins based on continuous observations from a stable point off the Sun-Earth line (assoc. with Q1-1,Q1-2,Q1-3)	**(M1-1)** Inferring the magnetic field and plasma properties of solar source regions and their evolution	Photospheric Vector Magnetograph, H-alpha Imaging Spectrograph, EUV Imager, X-ray Spectrometer
	(Q1-2) Heliosphere - How can we broaden our understanding of the heliospheric environment with multi-point observations?	**(O1-2)** Investigating the heliospheric disturbances driven by solar eruptive events such as flares, CMEs, SEPs and CIRs (assoc. with Q1-1,Q1-2,Q1-3)	**(M1-2)** Identifying and characterizing solar eruptive events and the consequent space weather conditions	Photospheric Vector Magnetograph, H-alpha Imaging Spectrograph, EUV Imager, Coronagraph, Helispheric Imager, X-ray Spectrometer, FIELDS, Solar Wind Plasma Detector, Energetic Particle Detector
	(Q1-3) Forecast - How can we enhance space weather forecasting capabilities?	**(O1-3)** Investigating the nominal heliospheric environment: solar wind, electric and magnetic fields, dust particles (assoc. with Q1-2,Q1-3)	**(M1-3)** Monitoring the heliospheric environment: solar wind, electric and magnetic fields, dust particles	FIELDS, Solar Wind Plasma Detector, Energetic Particle Detector, Dust Detector
		(O1-4) Improving the accuracy of space weather forecasting models through multi-point obsevations (assoc. with Q1-1,Q1-2,Q1-3)		
2. Magnetized plasma structures erupting from the Sun: initiation and dynamic evolution	**(Q2-1)** How do solar eruptions form, accelerate and evolve through the solar corona and the inner heliosphere?	**(O2-1)** Physical properties of flare-CME productive active regions and Initiation of CMEs (assoc. with Q3-1,Q3-2)	**(M2-1)** Deriving the characteristics of CME-productive solar active regions	Photospheric Vector Magnetograph, H-alpha Imaging Spectrograph, EUV Imager, Coronagraph, X-ray Spectrometer
	(Q2-2) What are the three-dimensional characteristics of CMEs? How do CMEs evolve and propagate in the interplanetary space?	**(O2-2)** Tracking 3D CMEs propagation and evolution (assoc. with Q3-1,Q3-2,Q3-3)	**(M2-2)** Determining the 3D propagation and evolution of CMEs from the Sun into interplanetary space	Coronagraph, Helispheric Imager, FIELDS, Solar Wind Plasma Detector, Energetic Particle Detector
	(Q2-3) How do global and small-scale structures of the solar wind plasma form in the inner heliosphere?	**(O2-3)** Global and local structures of heliospheric plasma (assoc. with Q3-2,Q3-3)	**(M2-3)** 1-AU magnetized plasma structures and properties from large to small scales	FIELDS, Solar Wind Plasma Detector, Energetic Particle Detector, Helispheric Imager
3. Solar energetic particles: origin, properties and propagation characteristics	**(Q3-1)** Injection - What are the seed populations for energetic particles? How and where are the seed particle populations injected into the acceleration mechanism (i.e., the birthplace of SEPs)?	**(O3-1)** Statistical analysis of event-to-event variations in SEP properties (assoc. with Q2-1,Q2-2,Q2-3)	**(M3-1)** Remote-sensing observations of geoeffective SEP source regions (assoc. with O2-1)	Photospheric Vector Magnetograph, H-alpha Imaging Spectrograph, EUV Imager, Coronagraph, Helispheric Imager, X-ray Spectrometer
	(Q3-2) Acceleration - how and where are energetic particles accelerated at the Sun and in the interplanetary medium?	**(O3-2)** Extreme SEP events: origin and radiation impact on the heliosphere (assoc. with Q2-1,Q2-2,Q2-3)	**(M3-2)** Deriving the physical properties of SEP-related solar eruptions (assoc. with O2-1,O2-2,O2-3)	Photospheric Vector Magnetograph, H-alpha Imaging Spectrograph, EUV Imager, Coronagraph, Helispheric Imager, X-ray Spectrometer

Subject I

Solar magnetic field structure and evolution

> Scientific subjects

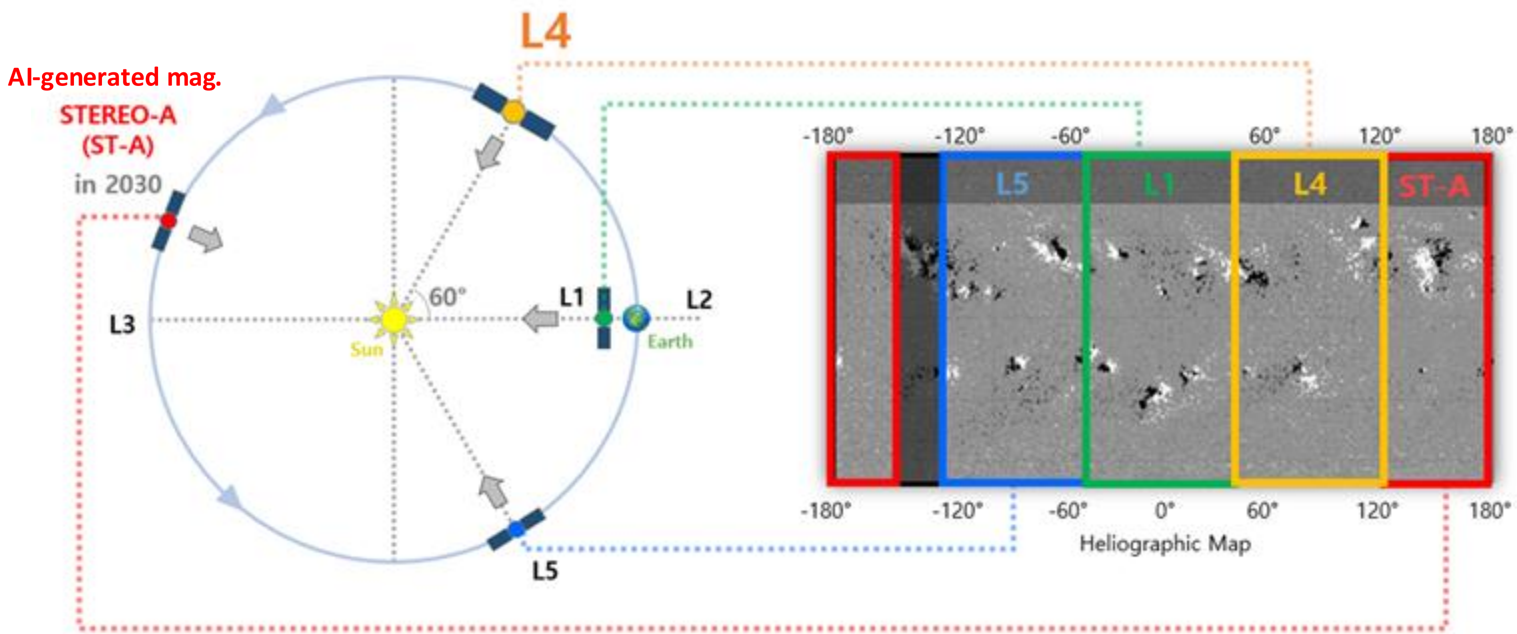
1. **Investigation of global solar photospheric fields**
2. **Disambiguation of solar vector magnetograms**
3. **Observations of the Sun's polar magnetic fields**
4. **Coronal and Heliospheric magnetic field**

A. Remote Observations

I. Solar magnetic field structure and evolution

L4 MISSION

1. Construction of a more reliable synoptic map from multi-view observations



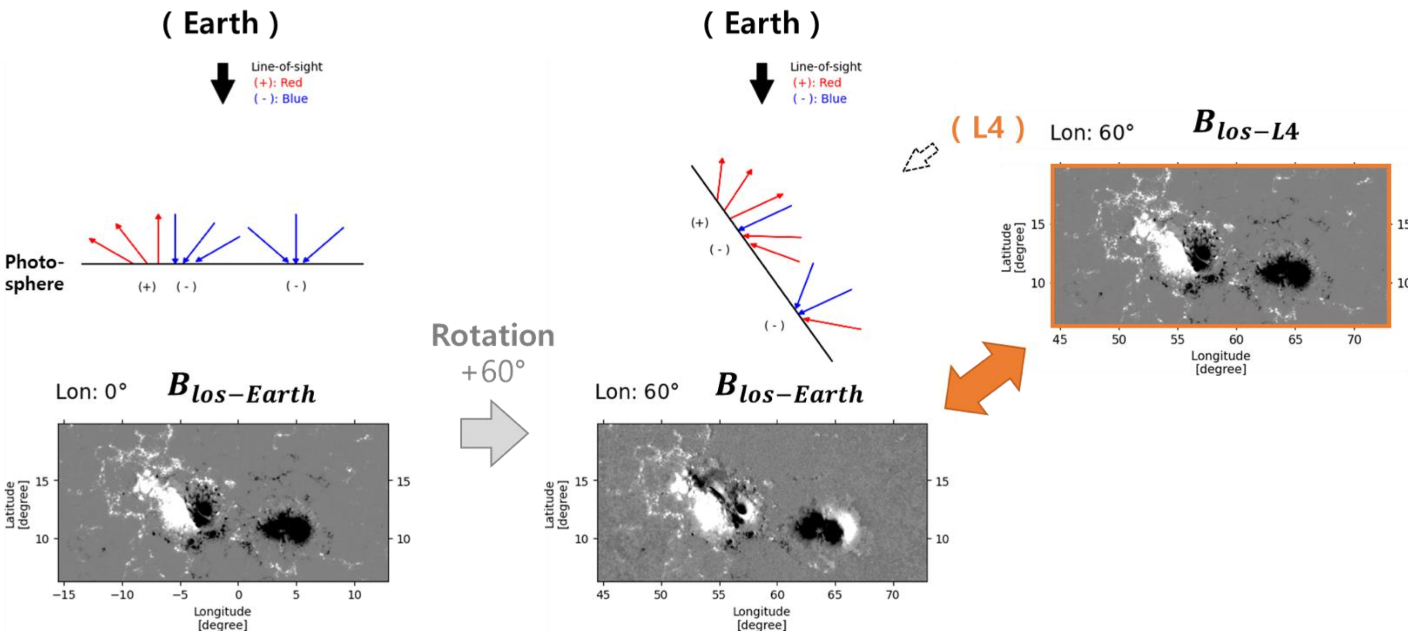
Credit: Cho et al. (2022, whitepaper submitted for NASA's Heliophysics Decadal Survey)

Using a near real-time synoptic map constructed from multi-viewpoint observations of the photospheric vector magnetic field at L4 + L1, L5, ground, as well as other in-situ space missions (Solar Orbiter, etc.)

A. Remote Observations

L4 MISSION

2. Construction of a more reliable synoptic map from multi-view observations



Credit: H.-J. Jeong (Figure is made for this paper)

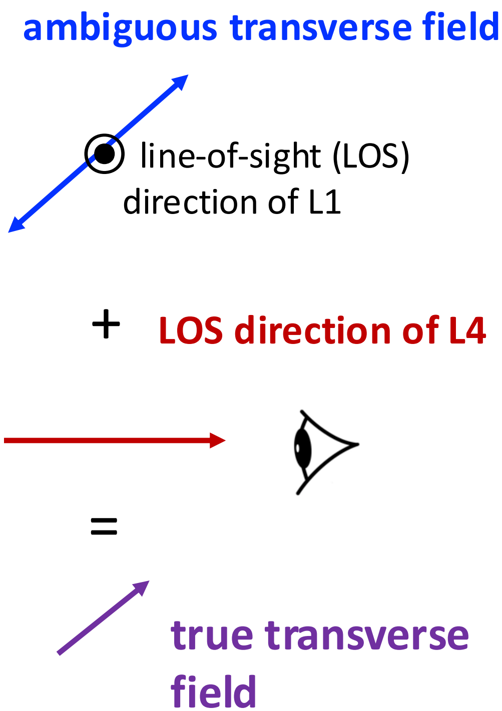
Using a more reliable synoptic map constructed from stereoscopic observations of the photospheric vector magnetic field at L4 + L1, L5, ground, as well as other in-situ space missions (Solar Orbiter, etc.)

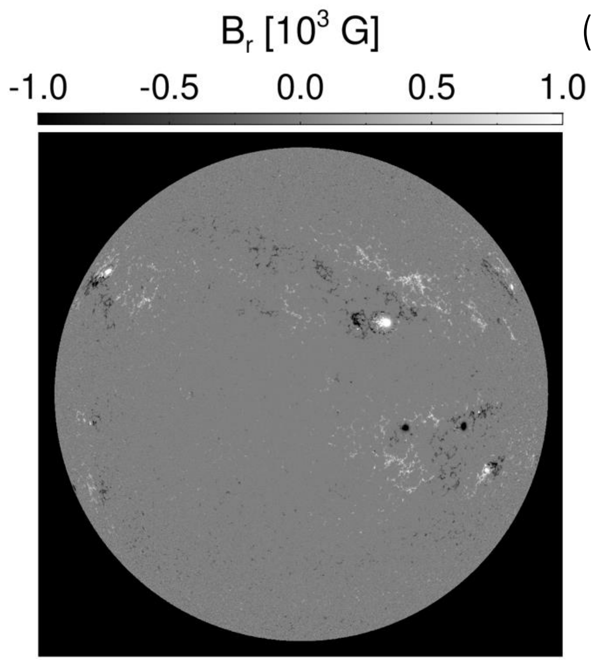
A. Remote Observations

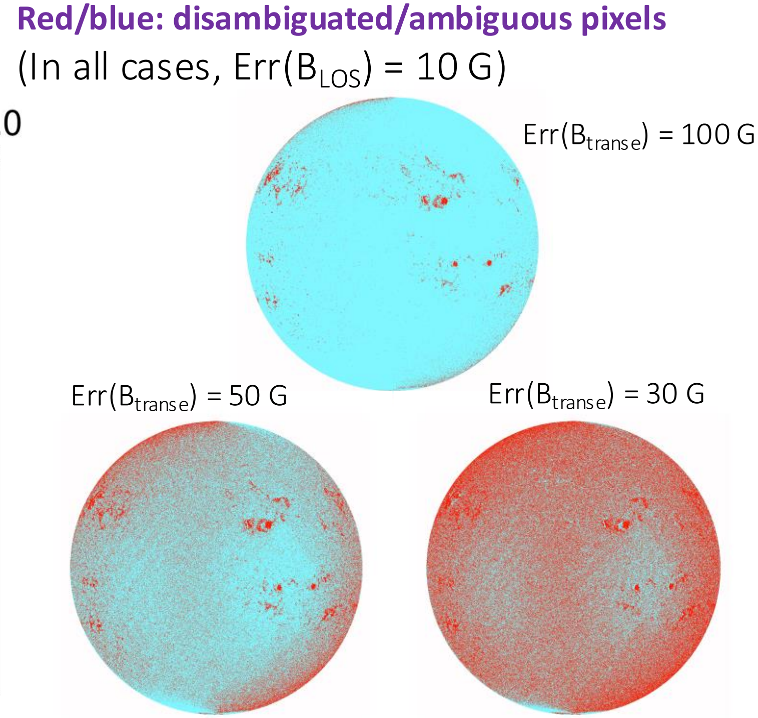
L4 MISSION

3. Disambiguation of solar vector magnetograms

- **From a continuous observation of a target AR for a longer period**
- **Deriving a more reliable/accurate vector magnetogram with a stereoscopic disambiguation method**



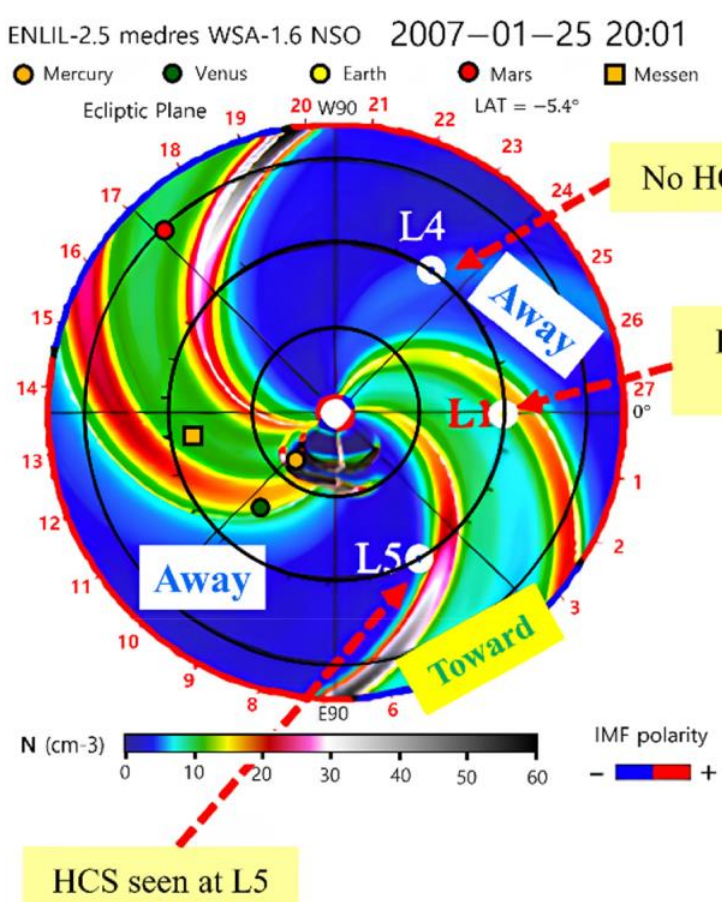




Credit: S.-H. Park (Figure is made for KASI's preliminary study of an L4 mission)

A. Remote Observations

4. Interplanetary Magnetic Field



Note that the IMF is deduced based on the Photospheric Magnetic Field only from the Earth.

Based on multi-view observations, if a rapidly constructed map of the full-surface magnetic fields is available, this will improve MHD simulations of the (inner) heliosphere.

Inclusion of a vector magnetograph at L4 would be great for magnetic field modeling for space weather forecasting (specifically, connecting from western limb or behind the solar front disk to the Earth)

Subject II

L4 MISSION

Source Regions of Geoeffective SEPs
> Scientific subjects

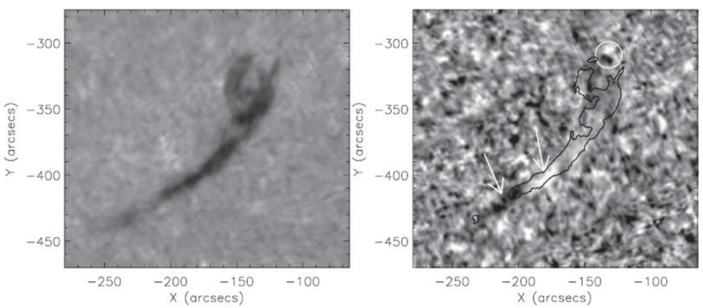
1. Face-on observations of geoeffective SEP source region
2. SEP study based on EUV wave parameters
3. SEP study based on CME parameters
4. SPE detection and warning

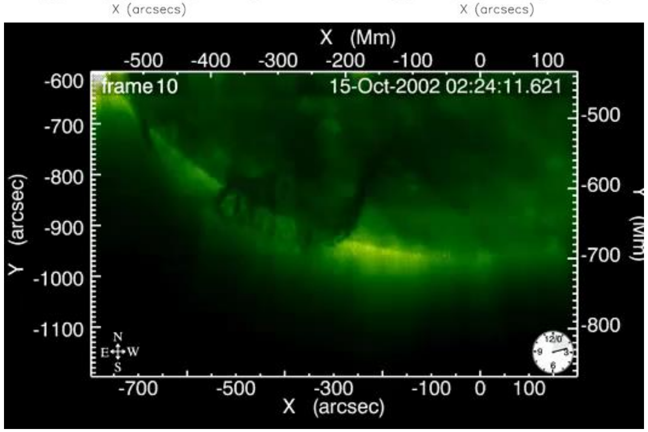
A. Remote Observations

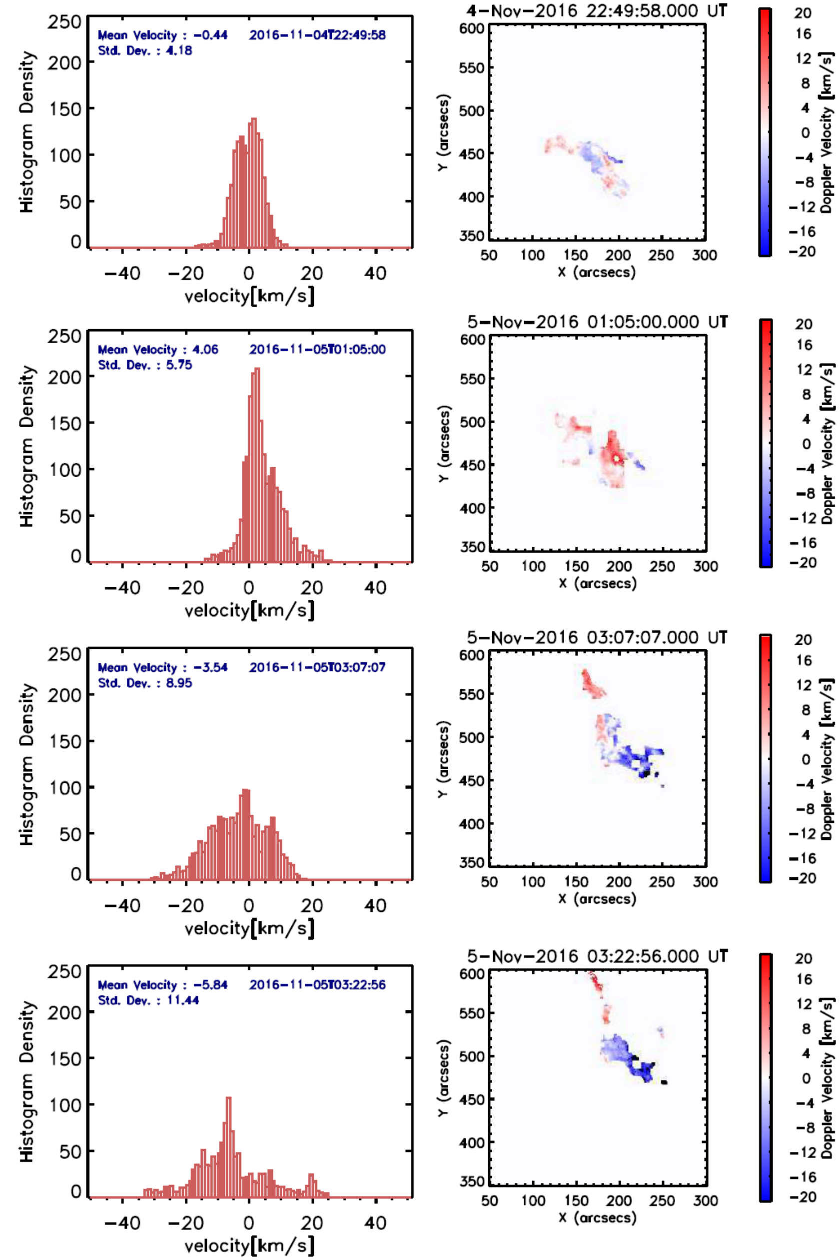
II. Source Regions of Geoeffective SEPs

1. Face-on observations of SEP source regions

- **Increase of mass or turbulent motion inside prominence**
- **Hα intensity variation in a segment of a filament**
- **Prominence oscillations in the pre-erupting phase**





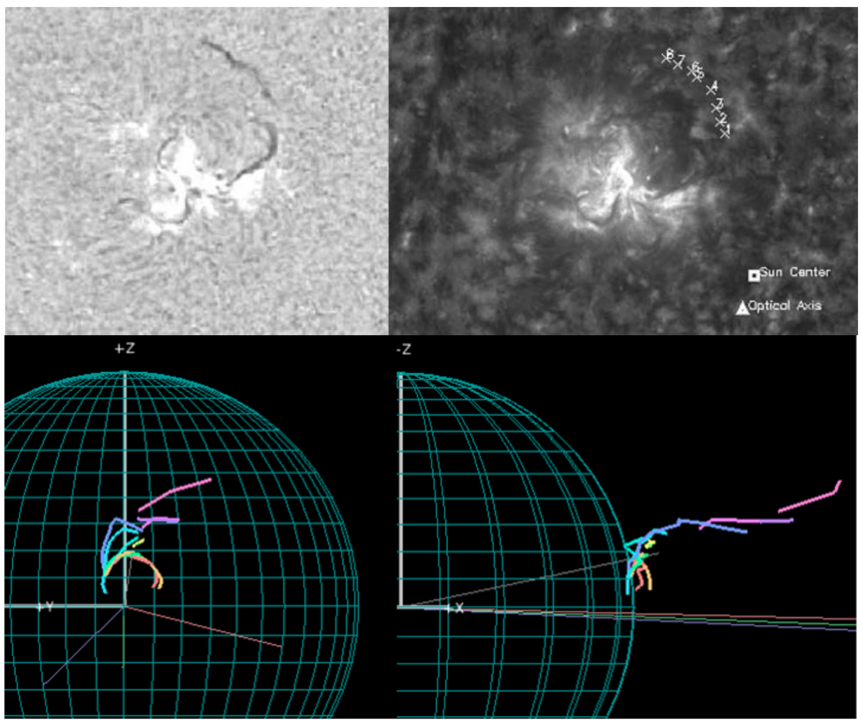


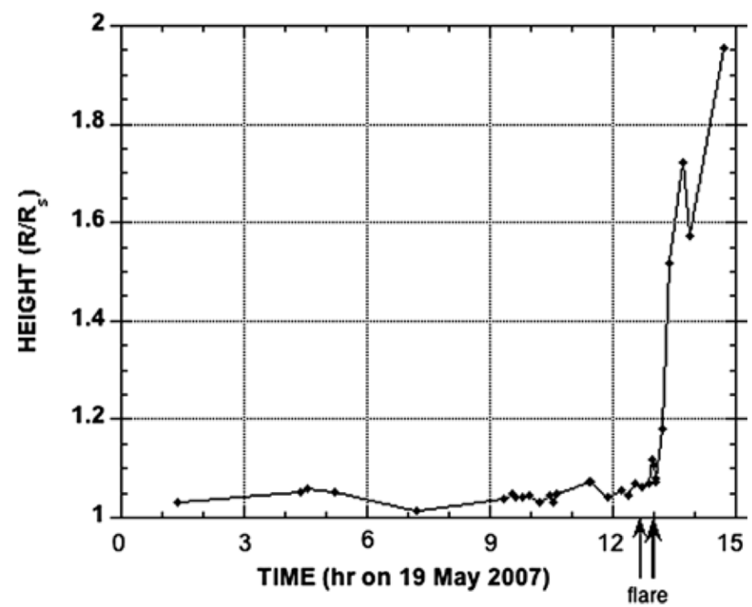
A. Remote Observations

L4 MISSION

2. SEP acceleration and propagation at early phase

- **SEPs and 3D dynamics of an erupting prominence**
  Stereoscopy using Hα data from ground-based/CHASE and L4





Credit: Liewer et al. (2009)

A. Remote Observations

3. SEP acceleration and propagation at early phase

- **SEPs and EUV wave propagation**

  SEP peak flux prediction based on

  1. **SEP vs. 3D dynamics of erupting prominence**
  2. **SEP vs. EUV wave propagation**

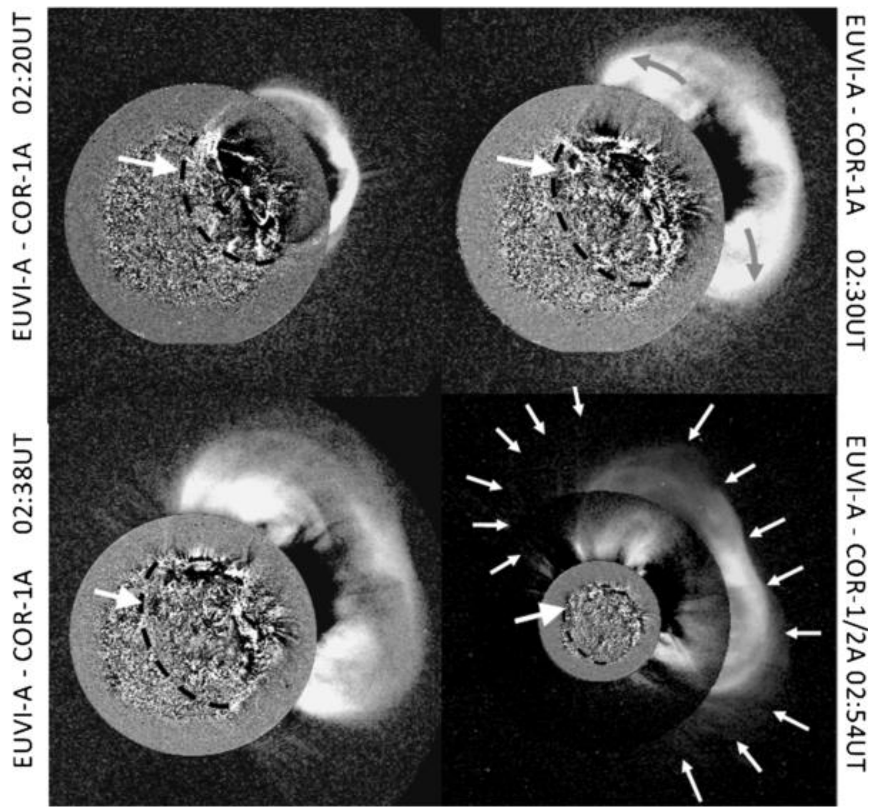
✓ **EUV waves:**

- generated in solar eruptions (Thompson & Myers 2009; Warmuth 2010)

- Show up as faint fronts moving with velocities up to 1000 km/s

- with large dimming regions in their wakes

Credit: Rouillard et al. (2012)



L4 MISSION

Subject III

Stereoscopic views from the sun to the solar wind
> Scientific subjects

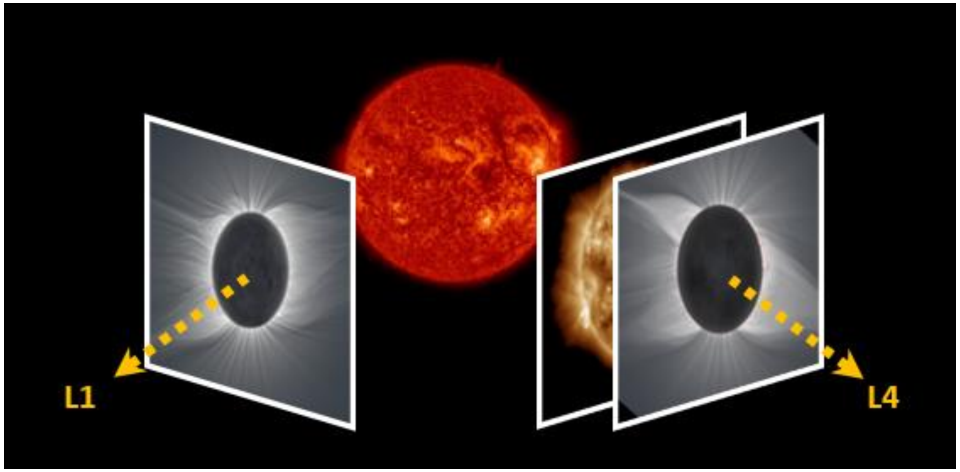
1. **Coronal structures and solar wind origin**
2. **CME 3D properties and propagation**
3. **Small and Large Scale Solar wind**

A. Remote Observations

1. Coronal structures

3D coronal electron density reconstruction

- Conventional tomography requires a synoptic map generated from at least of 14 days of observation and assumes a symmetric distribution.
- By utilizing L4 observations, this requirement can be reduced to 9 days of observation, and even further to 4.5 days by combining L4 and L5 observations together.
- If we use data from more and more positions, the measurement error will significantly decrease.



Triangulation: on the point-like and line-like structures
Tomography: on the structure of extended objects (Kramar et al. 2009, Inhester 2006)

A. Remote Observations

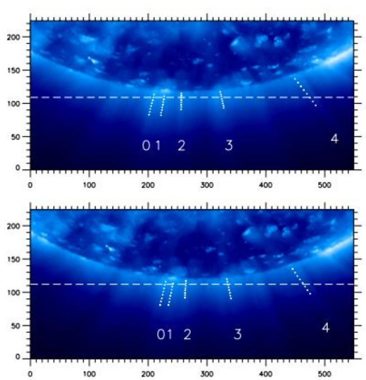
L4 MISSION

1. Coronal structures

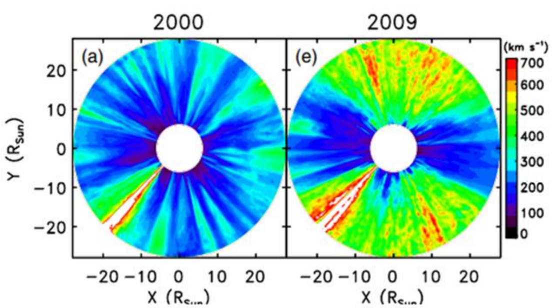
Stereoscopic observation of coronal rays

- **Triangulations (e.g., Feng et al. 2009, Liu et al. 2010) on point-like structures at different times or ray-like structures at different heights observed by WL coronagraphs would enable to study temporal and geometrical evolutions of the coronal structures in 3D.**

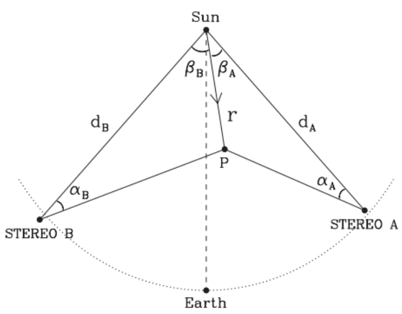
- **2D solar wind speed was calculated by using the Fourier speed filtering technique (e.g., Cho et al. 2018), which provides the solar wind speed at any given point. Treating the solar wind as a point-like structure, one would try to obtain a 3D wind speed by using the triangulation method on 2D speeds obtained from two different view-points.**



Credit: Feng et al. (2009)



Credit: Cho et al. (2018)



$$\frac{r\sin(\alpha_A+\beta_A)}{\sin\alpha_A}=d_A,$$

$$\frac{r\sin(\alpha_B+\beta_B)}{\sin\alpha_B}=d_B,$$

$$\beta_A+\beta_B=\gamma,$$

Credit: Liu et al. (2010)

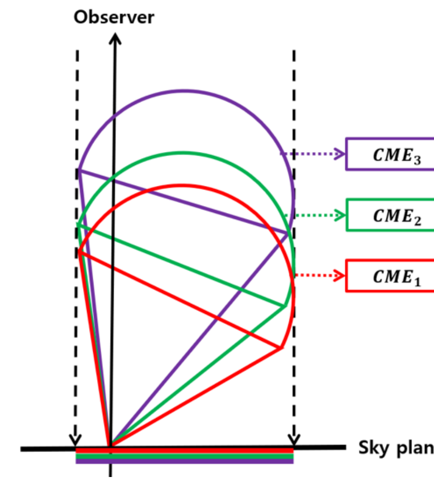
A. Remote Observations

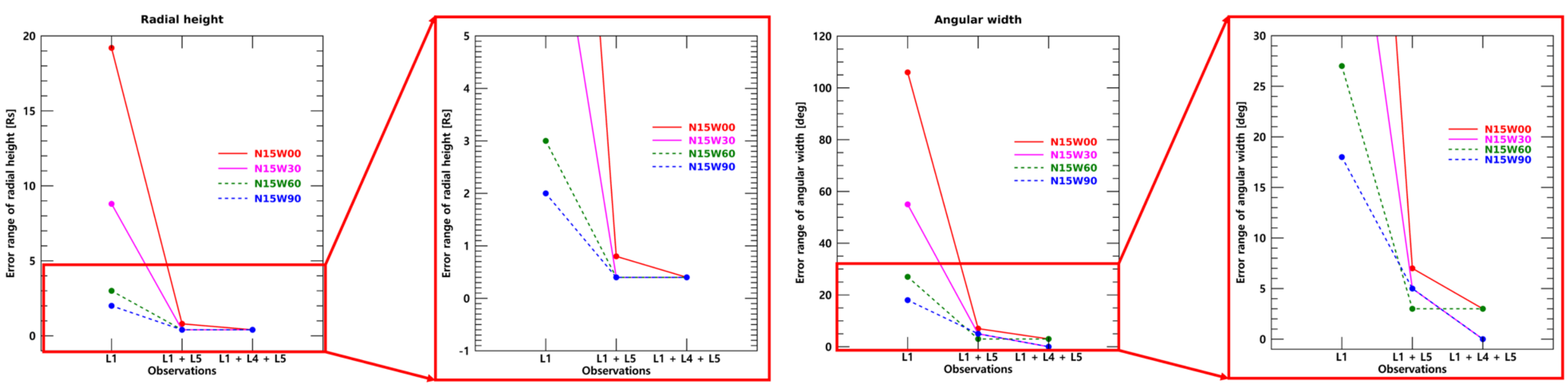
L4 MISSION

2. CME 3D properties and propagation

Reduction of the error ranges of CME 3-D parameters

- Using CME geometrical model, we can determine CME 3-D parameters from a single-view observation data.
- However, it is difficult to determine a unique CME 3-D parameters using a single observation because the same projected structures are generated from different three-dimensional structures.
- The multi-view observation data (L1 + L4 + L5) significantly decrease the error ranges of the CME 3-D parameters.





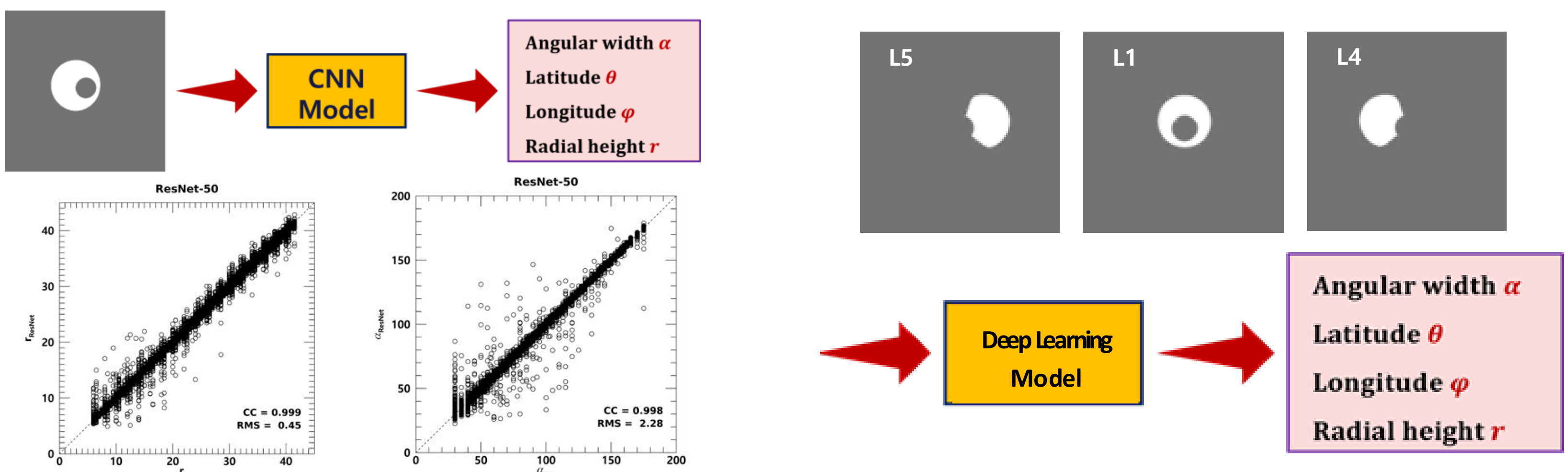
Credit: Na et al. (2024, preparation)

A. Remote Observations

2. CME 3D properties and propagation

Determination of CME 3-D parameters using Deep learning

- We develop automatic determination models of CME 3-D parameters from a single CME image using convolutional neural networks (CNNs).
- These models are trained on synthetic CME images, generated using a variety of three-dimensional parameter sets.
- The use of multi-view observations is expected to improve the accuracy of the determination of CME 3-D parameters.



Credit: Na et al. (2024, preparation)

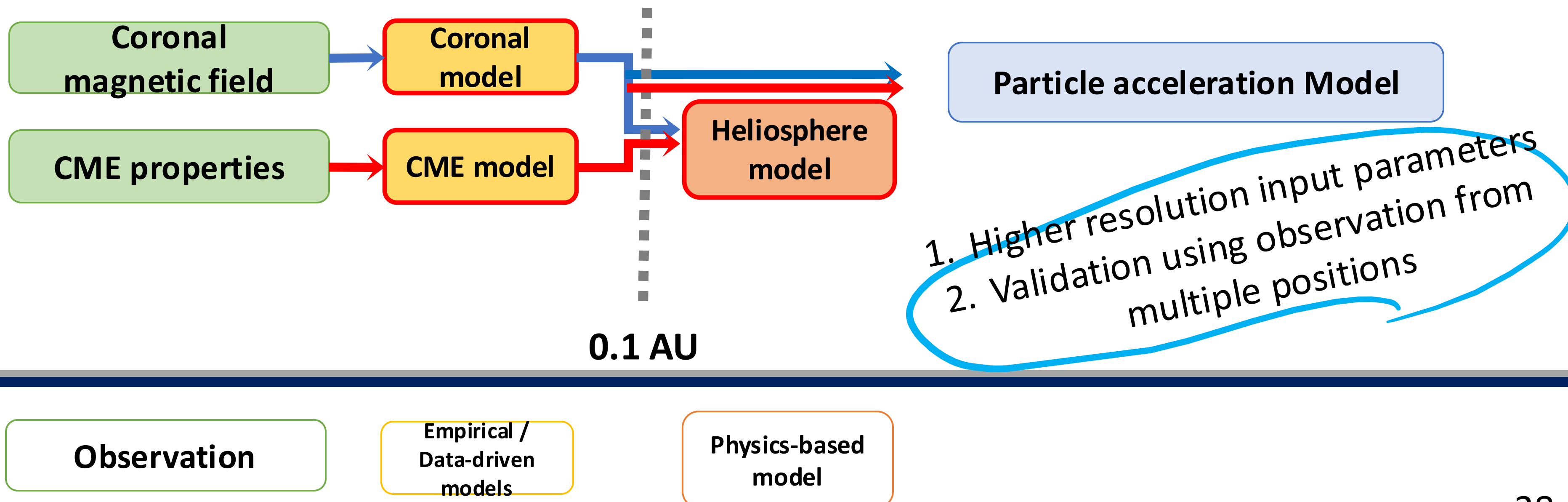
A. Remote Observations

L4 MISSION

3. SW & Heliosphere models

→ CME propagation, interaction, and particle acceleration

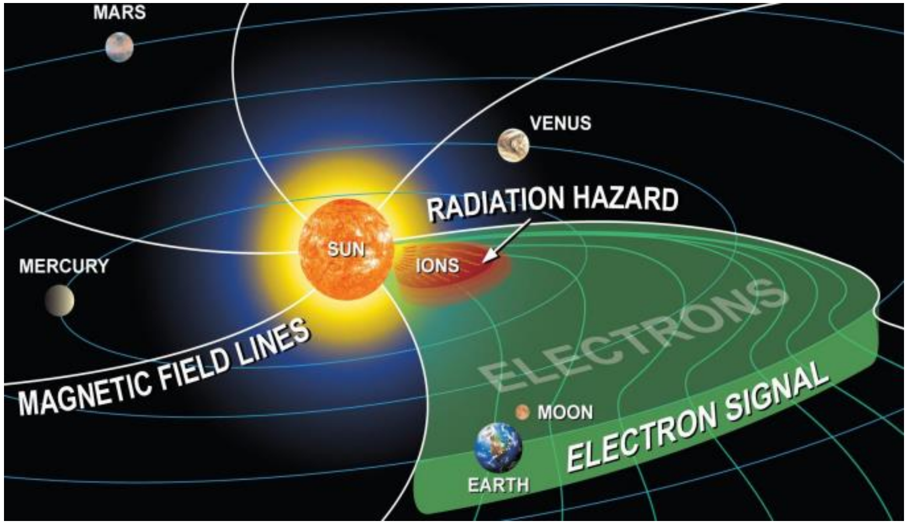
- Conventional solar wind propagation models are the combination of
  - Coronal model: WSA, EUHFORIA-corona
  - CME model: cone, spheromak, torus, FRi3D, …
  - Heliosphere model: Enlil, EUHFORIA-heliosphere
- Particle acceleration model: SEPMOD, PARADISE

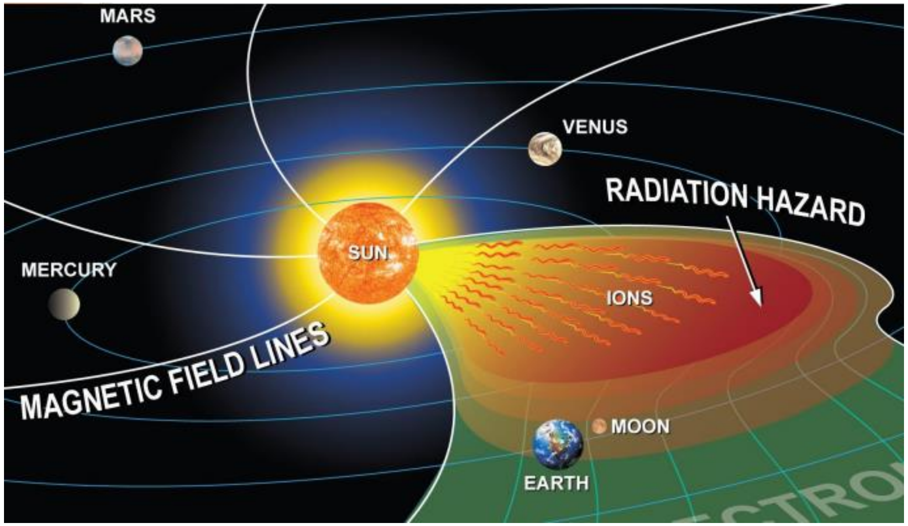


B. Insitu Observations

4. SEP Forecasting

- 1 hour proton forecasting can be achieved with relativistic electrons.
- Empirical forecasting matrix instantly translates electron observations into future proton fluxes.
- Needs more reliable SEP forecasting model based on the remote observation of the solar source region at L4.



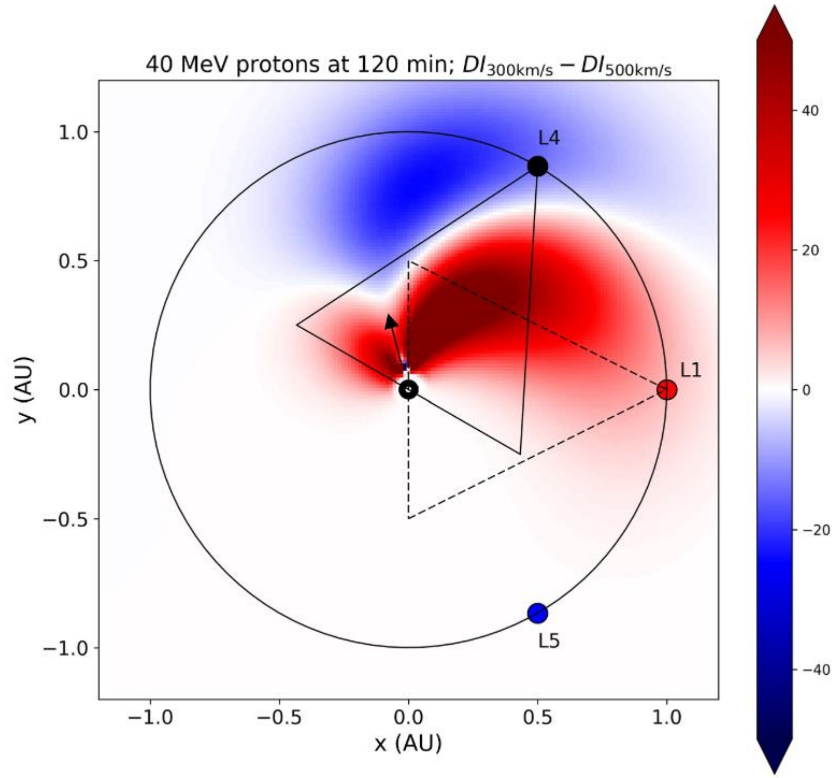


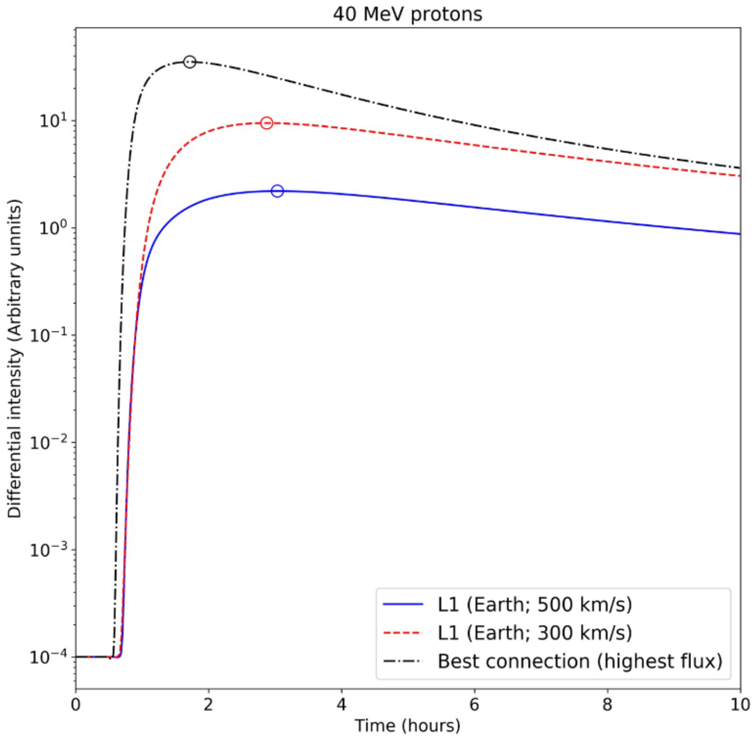
Credit: Posner et al. (2009)

B. Insitu Observations

L4 MISSION

4. SEP Forecasting (Need global IMF connectivity and Solar Wind distribution)





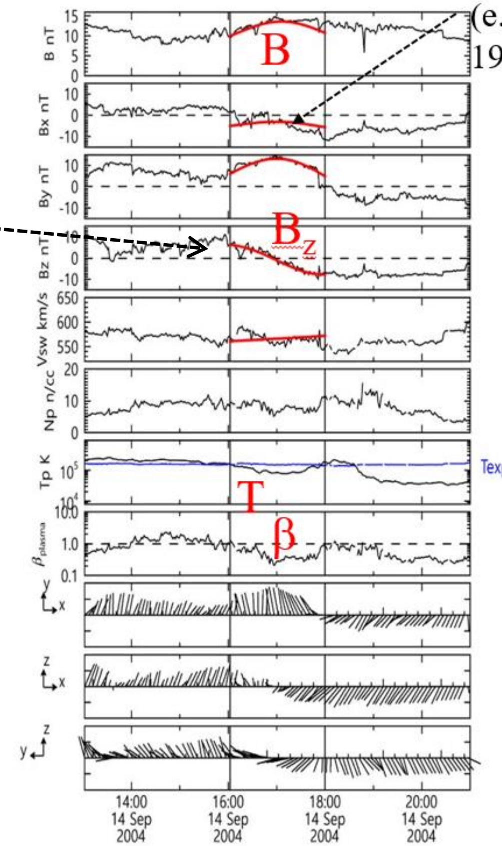
- Slow solar wind shifts the particle flux significantly eastward, toward the Earth-Moon system.
- The intensity can rise very rapidly at L1, indicative of the good magnetic connection of the region behind the W solar limb.

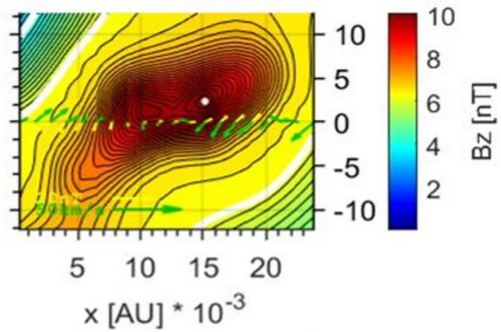
B. Insitu Observations

5. Small flux ropes

- Similar to magnetic clouds
  - Stronger B field than background (though not always),
  - Rotating **B** (not clear sometimes)
  - Often (but not always) lower T, N, β than background
- In contrast to MCs
  - Short-duration (10s min to ~12 hrs, even seconds scale),
  - Small spatial scale (~10^{-3}-10^{-1}au)

Force-free fitting (e.g., Moldwin et al., 1995)





Grad-Shafranov reconstruction of flux surfaces (e.g. Zheng et al., 2017, Hu et al. 2018)

B. Insitu Observations

L4 MISSION

5. Small flux ropes

① High occurrence rates (far more frequent than CME/MC)

- Often geo-effective due to southward Bz of flux ropes

② Radially:

- Broad distance range of occurrence: ~0.2 au to ~7 au

③ Vertically:

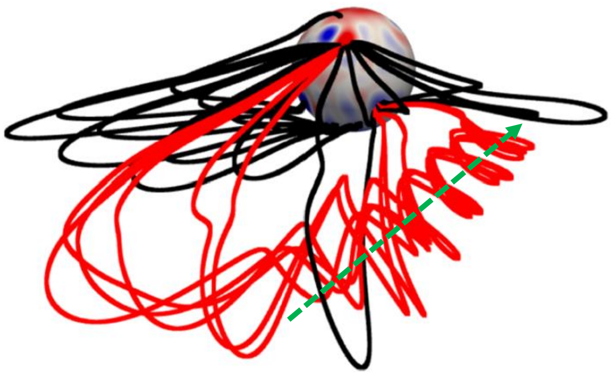
- Both near (more often) and away from heliospheric current sheet

④ Geometrically:

- Mostly open field with one end at the sun; rarely closed or disconnected
- Flux rope axis orientation issue

⑤ Relations to various issues:

- Reconnection in corona and within SW, small solar eruptions, SW turbulence, etc.



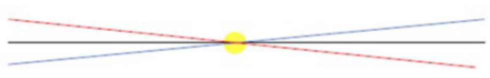
Q: What are the structure and origin of small-scale flux rope?

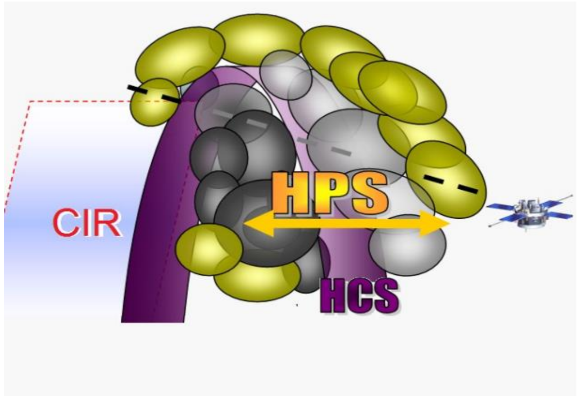
B. Insitu Observations

L4 MISSION

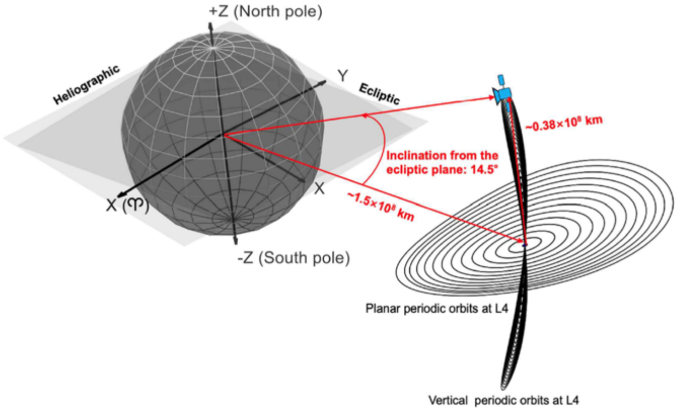
6. Helispheric Current Sheet

- Maximum extent of in-situ latitude coverage by inclined L4 and L5 (Posner et a. 2021)





- Two possible orbits for L4 spacecraft (Cho et al. 2023)



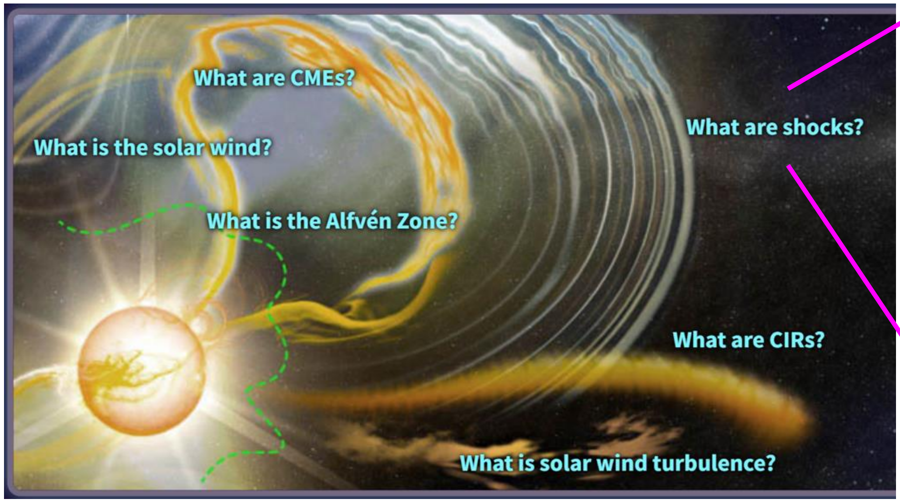
Variety of sciences with inclined L4 orbit:

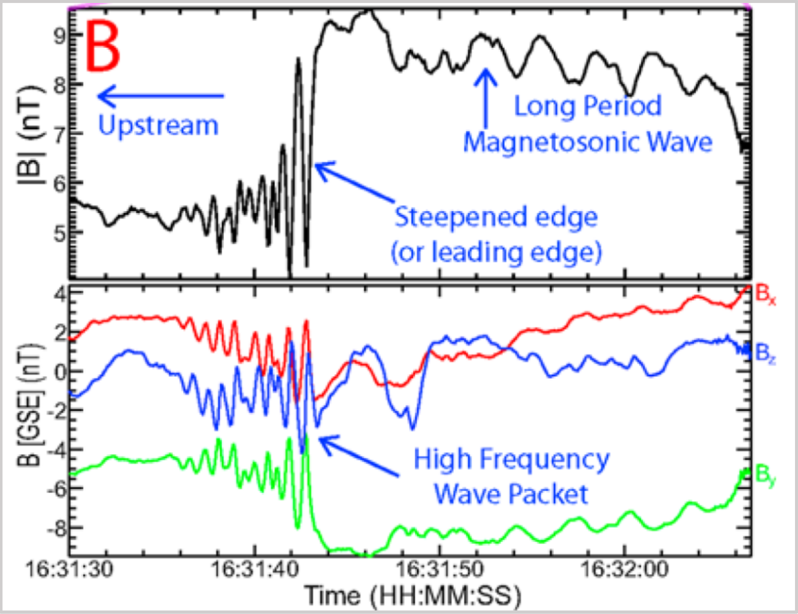
- SW structures at various distances from HCS
- Better coverage of Sun's polar field

Q: What's the vertical structures of HCS and CIR?
Q: What's the structure of HCSs for different Lagrange points and different radial distances?
Q: What's the interplanetary field line structure and current sheets?

B. Insitu Observations

7. Waves in the solar wind structures





Q: What is the impact of large-scale plasma structures, such as CIRs, ICMEs, and IP shock, on the generation of plasma waves?

Q: What is the role of these plasma waves in the dynamics of these transient structures?

Association of Whistler-mode Wave Groups with Solar Wind Structures

	Number	Coh. Wave Group	Any Wave Group	≥1 Whistler
SIRs	54	68%	76%	98%
ICMEs	9	33%	67%	89%
IP Shocks	34		9%	55%

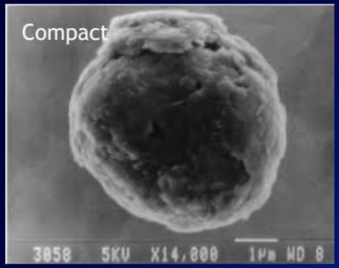
Cattell et al. 2020

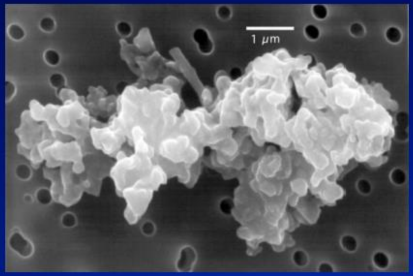
B. Insitu Observations

8. Dust Science in Heliosphere

Open Science Questions for Dust in the Heliosphere

- What is the vertical extent of the zodiacal dust cloud?
- What is its symmetry planes and what dynamics cause it to be inclined?
- What amount of ß-meteoroids are escaping the system?
- Is there nanodust to be detected that is related to solar phenomena?





- Unique space mission on L4, and IDP accumulation on the L4 point
- Offer in-situ measurements of ISD and IDPs at L4
- One a year into and against interstellar dust flow. Can probe smaller and higher end of dust size distribution due to difference in impact velocity
- Existing dust detector technologies and affordable

- ISD: Interstellar Dust
- IDP: Interplanetary Dust Particle

Veerle Sterken et al., 2012; Hoang et al. KSSS presentation, 2024

Main Subjects

Scientific subjects of L4 & L5

L4 MISSION

The primary scientific subjects are:

1. Face-on observations of geoeffective SEP source regions
2. SEP study based on EUV waves
3. SEP study based on CMEs
4. Structure and origin of small-scale flux ropes
5. Kinetic plasma waves and instabilities, their interaction physics, coupling to large-scale structure and solar wind expansion, and their spatial dependence

The secondary scientific subjects are:

1. Solar magnetic structure and its long-term evolution
2. Disambiguation of solar vector magnetograms
3. Observation of Sun's polar regions by non ecliptic L4 orbits
4. Coronal structure and solar wind origin
5. CME 3-D properties and propagation
6. Interplanetary field line structure and current sheets

Payloads & Spacecraft

Science Payloads

Remote Instruments

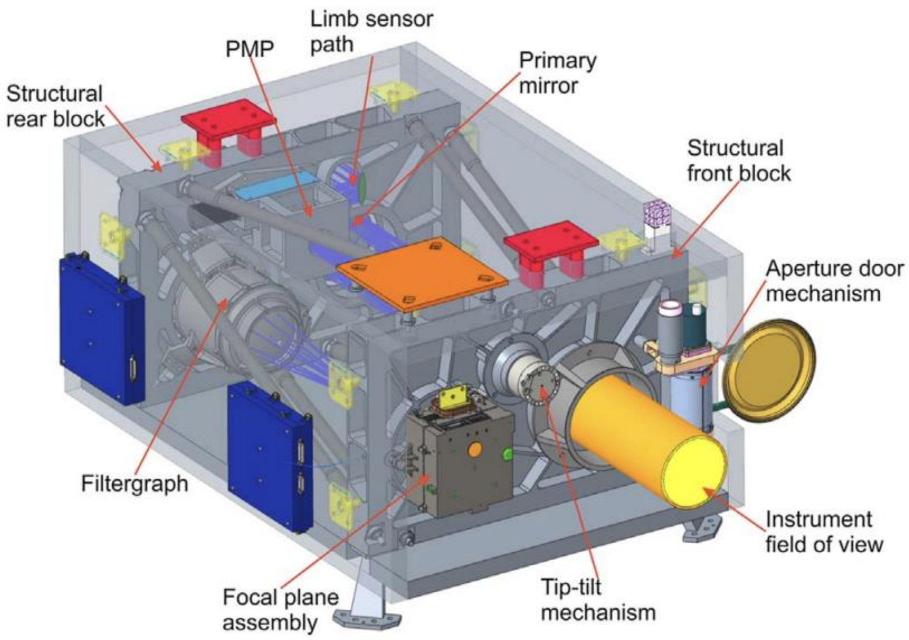
	Size (L×W×H) (cm)	Weight (kg)	Power (W)	Spatial Resolution (arcsec)	Time Cadence (min)	Telemetry (kbps)
Photospheric VMG	70×40×50	23	40	2	$\leq$30	60
Hα Imaging Spectrograph	70×40×50	23	40	2–5	$\leq$5	60
EUV Imager	70×20×20	30	35	∼8	2–10	70
WL Coronagraph	90×50×50	22	14.2	65	15	38.7
Heliosphere Imager	60×40×50	16.5	13.5	360	15–60	70
X-ray Spectrometer	30×30×30	15	15	1–5 keV @ 1–150 keV	1 sec	40
Total	—	129.5	157.7	—	—	338.7

In-situ Instruments

	Size (L×W×H) (cm)	Weight (kg)	Power (W)	Time Resolution	Measurement Resolution	Telemetry (kbps)
Solar Wind Plasma Analyzer (SWPA)	20×20×25	3.75	5	30 sec	$\Delta E/E < 20\%$	4
High Energy Particle Detector (HEPD)	10×15.6×14.7	5	5	1 min	$\Delta E/E < 20\%$	4
Fluxgate Magnetometer	Boom: 300×10×15	7.2	13	32 Hz	0.1 nT	0.4
Search Coil Magnetometer	Boom: 300×10×15	1.8	1.4	0.1–0.4 kHz	<1 pT @ 10 Hz	0.24
Radiation Monitor (RM)	27×27×27	7.5	5.1	1 sec	<10%	0.4
Radio/Wave Detector	600×2.5×2.5	10	5.6	16 sec	$16\ nV/\sqrt{Hz}$	4.5
Dust Detector	30×30×30	12.5	25	—	$\Delta M/M = 100–200$	0.2 (12.6 MB/week)
Total	—	47.75	60.1	—	—	13.74

Photospheric Vector Magnetograph

Purpose: to investigate the characteristics of source regions that produce solar energetic particles (SEPs), the magnetic drivers of solar eruptions, structure and evolution of magnetic fields in the Sun's polar or high-latitude regions, and the origin of magnetic switchback events and high-speed turbulent solar winds.



Credit: PHI (Polarimetric and Helioseismic Imager) @ L5 Vigil mission

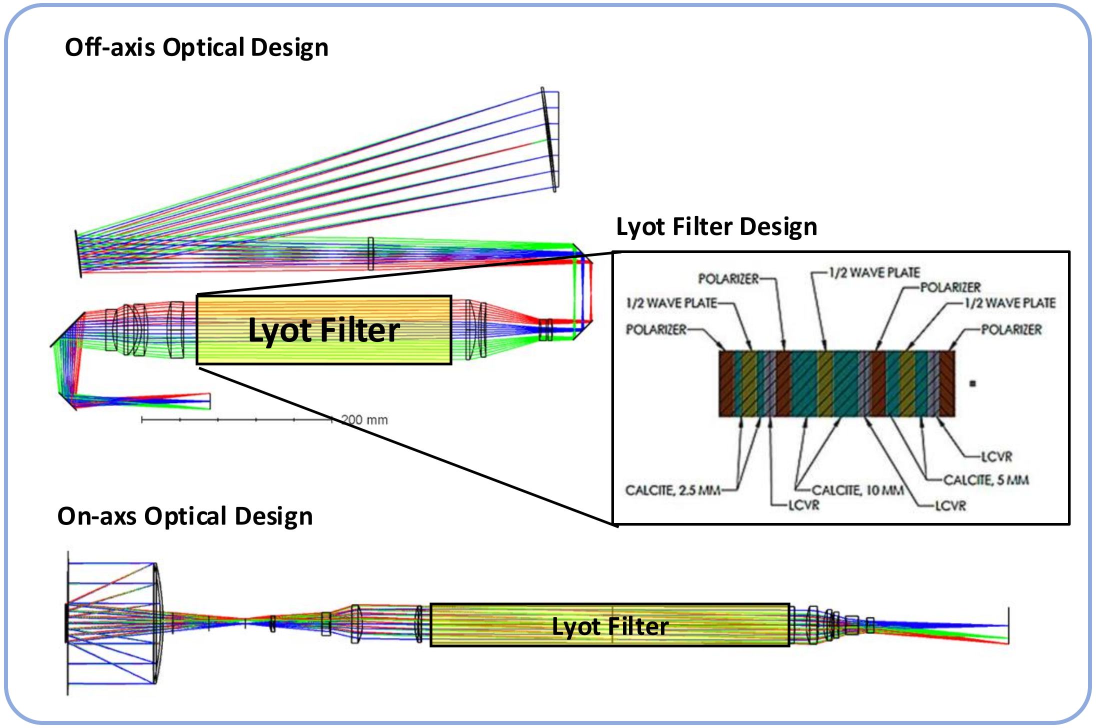
Wavelength range	Fe I 617.3 nm±0.014 nm
FOV	34.5′×34.5′
Spatial resolution	2″
Temporal resolution	$\lesssim$ 30 min
Spectral resolution	~0.01 nm
Photon noise level	10^{-3}
Mass	33 kg
Power	62 W
Telemetry	60 kbps

Instrument Requirement

Chromospheric Imaging Spectrograph

Purpose:

- to conduct 24/7 monitoring of solar filaments
- to perform spectroscopy of the early phases of fast filament eruptions to capture their precursors and understand physics
- to reveal the 3-dimensional dynamics of erupting filaments through stereoscopy



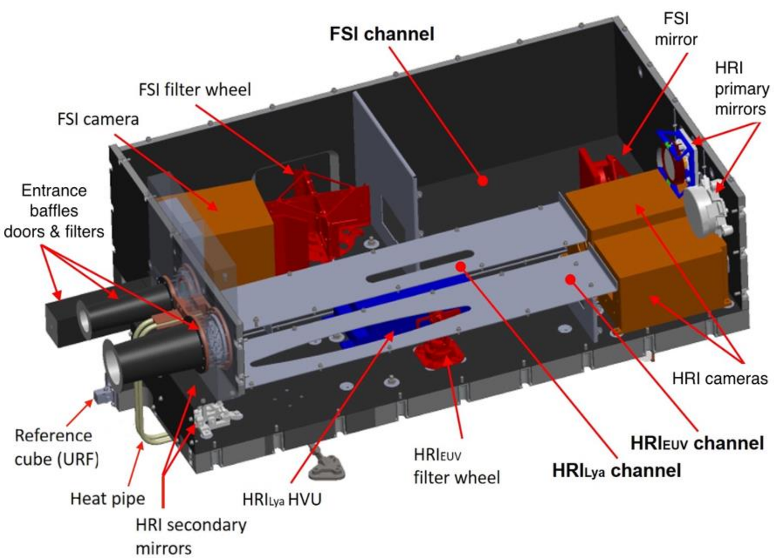
Concept designs for Optical layout & Lyot filter

INSTRUMENT REQUIREMENTS	
Type	Lyot Type Spectrograph
Wavelength	656.28 nm in air & 656.46 nm in vacuum
Spatial resolution	2 arcsec
Spectral Window	±1 nm
Spectral resolution	33000 ($\Delta\lambda$ = 0.02 nm)
Temporal resolution	5 min
Field-of-View	42′ x 42′

Instrument Requirement

EUV imager

Purpose: to determining the physical nature of the solar middle corona that shapes the space environment in the heliosphere and investigating the evolution of major disturbance events from the solar middle corona



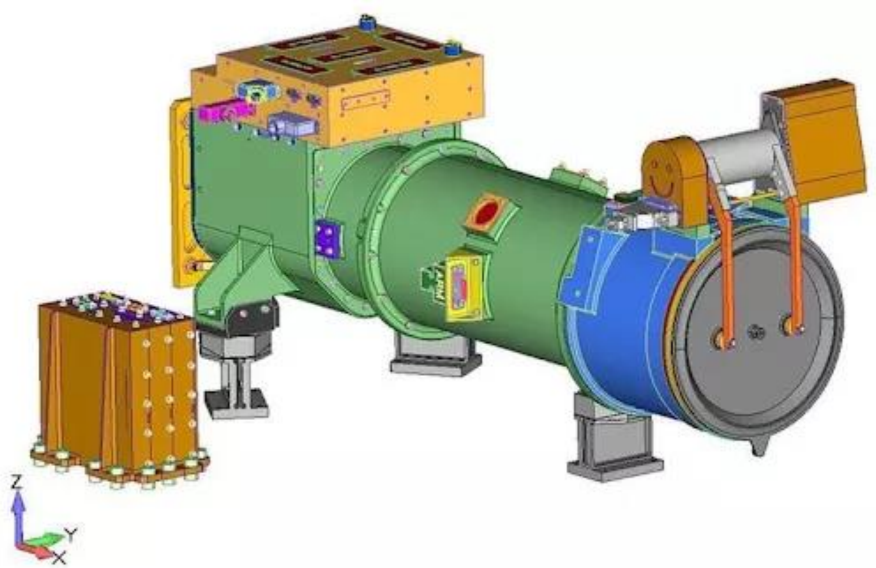
Credit: Solar Orbiter EUV Imager

Wavelength range	Fe IX 17.4 nm ± 1.5 nm He II 30.4 nm ± 1.5 nm
FOV	3 Rs (2.15°) 6 Rs (4.3°)
Spatial resolution	8”, 16”
Temporal resolution	≲ 1 sec for disk 10 min for corona
Mass	≲ 30 kg
Power	≲ 20 W
Telemetry	≲ 1,200 kbps

Instrument Requirement

White-Light Coronagraph

Purpose: By employing the same instruments at different vantage point, it will be possible to track quiescent and transient 3-D coronal structure from EUV FOV to the heliosphere imager FOV. The main purpose of the instrument is to inspect the 3D stereoscopic features and kinematics of CMEs, and their relationship with SEPs.



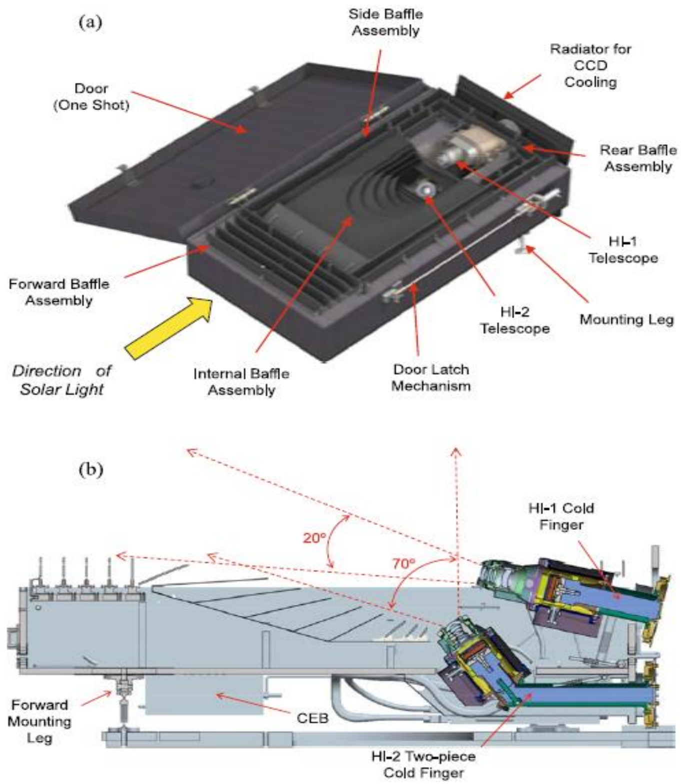
Credit: CCOR-2 for SWFO @ L1

Matrix	Requirement
Bandpass	450~750 nm
FOV	3.0~23.5 Rs
Spatial resolution	65 arcsec
Time cadence	15 min
Minimum corona intensity	10^{-11} B_s
Mass	22.1 kg
Power	14.2 W
Telemetry	38.7 kbps

NOAA Compact Coronagraph Requirement

Heliospheric Imager

Purpose: To understand the 3D characteristics of CMEs, including their geometry, kinematics, and magnetic flux-rope structure, as well as their evolution during propagation and interaction with the solar wind and other CMEs, and to predict space weather more accurately by monitoring CME propagation from the Sun through the heliosphere beyond Earth.



Credit: STEREO/HI-1 and HI-2 (Eyles et al. 2009)

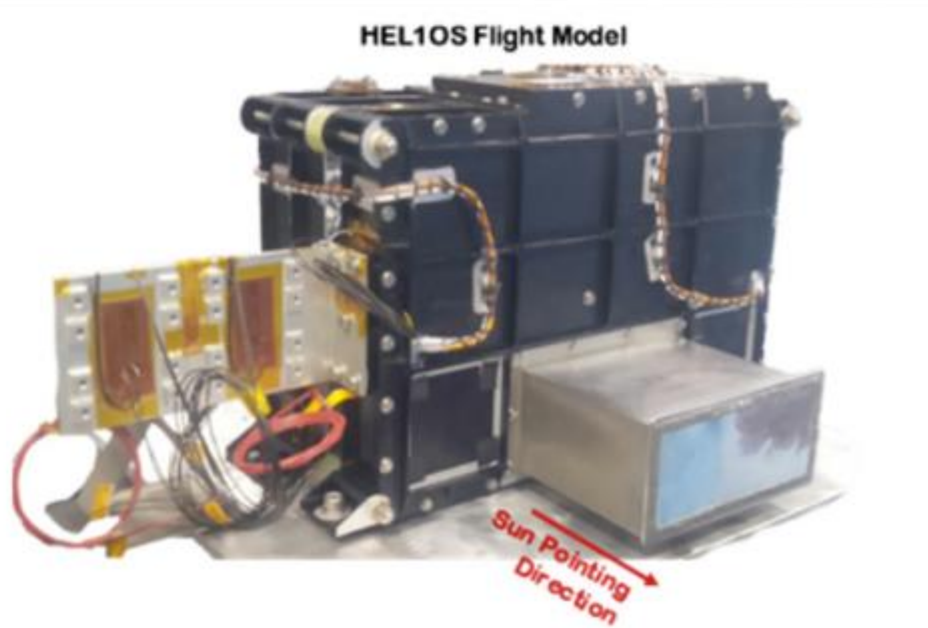
Matrix	Inner	Outer
Bandpass	630~730 nm	400~1000 nm
FOV	30 deg	50 deg
Elongation range	3.75~33.75 deg	20~70 deg
Spatial resolution	3.5 arcmin	6 arcmin
Time cadence	15/30 min	20/60 min
Brightness sensitivity	3×10^{-15} B_s	3×10^{-16} Bs
Stray-light rejection	3×10^{-13} Bs	10^{-14} Bs
Mass	16.5 kg	
Power	13.5 W	
Telemetry	70 kbps	

Instrument Requirement

X-ray spectrometer

Science Instruments

Purpose: To probe the solar phenomena during the quiet as well as active phases of the solar cycle. It is expected to be utilized for developing the alarm mechanisms of the space weather affecting solar eruptive flares which will trigger various observing modes for coronagraph and EUV imager.



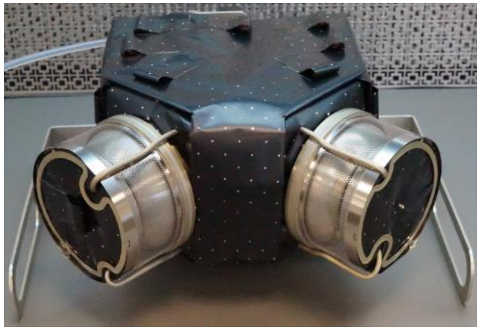
Credit: Aditya-L1 High Energy L1 Orbiting X-ray Spectrometer(HEL1OS)

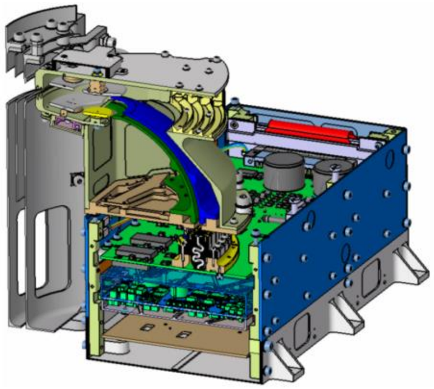
Key Elements	Soft X-ray: Silicon drift detector(SDD) Hard X-ray: CdTe and CZT detector
Mass	15 kg
Size	300×300×300 mm^3
Power	15 W (8W for Soft X-ray, 7 W for Hare X-ray)
Required Telemetry Rate	40 kbps
FOV	2 degree (Full Sun)
Time Cadence	$\lesssim$ 1 sec (flare time)
Spectral resolution	Soft X-ray (SDD: ⟨ 180 eV @ 5.9 KeV) Hard Xray (CdTe: ⟨ 1 keV@22 keV, CZT 5 keV@60 keV)
Wavelength Range	Soft X-ray (SDD: 1-20 keV) Hard Xray (CdTe: 10-40 keV, CZT: 10-150 keV)

Aditya-L1 HEL1OS Requirement

Solar Wind Plasma Detector

Purpose: To study the solar wind ions and electron properties at the L4 location, specifically the 3-dimensional phase space density of each particle species, in order to characterize solar wind plasma and to compare them with the near-Earth space.





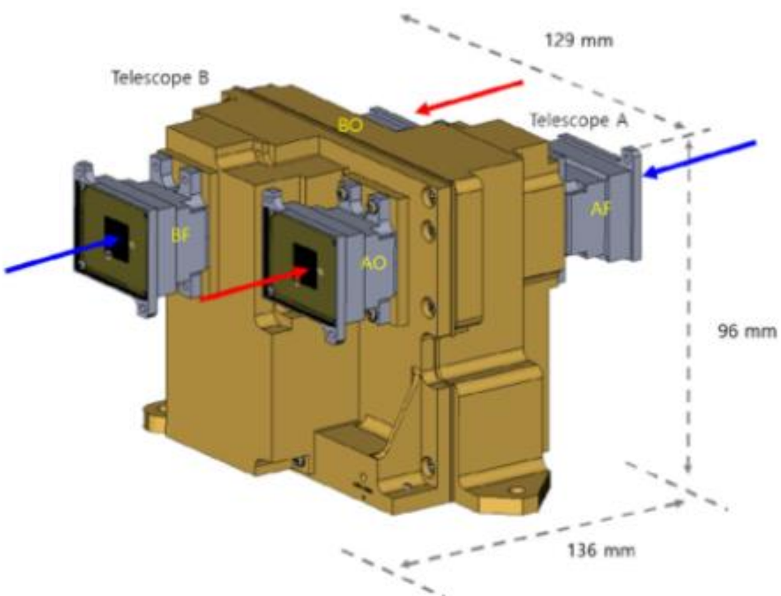
Credit: SWA-EAS and SWA-PAS for Solar Orbiter

Type	Top hat electrostatic anlyzer
Energy range	1 eV ~ 3 keV for both electrons and ions
Field of View	Angular scan: 360° × 180° for electrons(EAS) Angular scan: 66° × 45° for ions(PLA)
Energy resolution	10 % (dE/E)
Temporal resolution	less than 4 second
Mass	3.4 kg / 3.5 kg for EAS & PLA
Power	10.2 W / 5.1 W for EAS & PLA
Telemetry	~ 4.3 kbps / ~ 4.5 kbps for EAS & PLA

SWPD Requirement

High Energy Particle Detector

Purpose: To monitor population of electrons and positive ions during energetic events that may significantly impact space weather.



Credit: INSEPT
for GEO-KOMPSAT-2
@ Magnetosphere

Type	Stacked Silicon Detector
Energy range	30 keV ~ 2 MeV for electrons 30 keV ~ 100 MeV for ions
Field of View	4° × 52.8° for electrons 4° × 52.0° for proton
Energy resolution	< 10 % (dE/E)
Temporal resolution	1 second
Mass	5 kg
Power	5 W
Telemetry	~ 4kbps

HEPD Requirement

Radiation Monitor

Purpose: to measure and analyze the intensity and energy spectrum of cosmic and solar radiation in space. This includes understanding the radiation environment by characterizing the temporal and spatial variations in radiation levels and assessing the potential impact of radiation on spacecraft systems and biological organisms, including astronauts.

RDS/ APDS

RDS/ TED

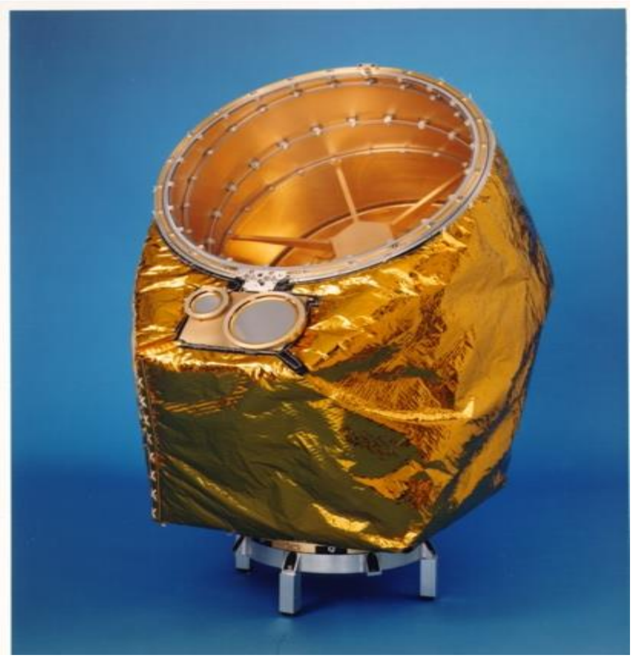
Credit: LEO-DOS (Low-Earth Orbit space radiation DOSimeter) for NEXTSat-2 (Korea Next Generation. Small Satellite 2) & LVRAD (Lunar Vehicle Radiation Dosimeter) for CLPS (Commercial Lunar Payload Services) @ Magnetosphere & Moon

Type	Radiation Dosimeter and Spectrometer and Radiation Monitor
Measurement direction	APDS: Top with 50° field of view TED: Omni – direction
Time resolution	1024 channel spectrum/1 min
Measurement range	APDS: Proton 1~500 MeV, 0.2~1,000 keV/µm TED: 0.2~1,000 keV/µm
Size	$300 \times 300 \times 200$ mm^3
Mass	7 kg
Power	9 W
Telemetry	0.3 kbps

RM Requirement

Dust Detector

Purpose: To advance our understanding of dust and their interactions with solar wind, solar radiation, and the heliosphere by measuring the flux, mass, surface charge, and chemical composition of dust grains



Cassini Cosmic Dust Analyzer (CDA) (https://en.wikipedia.org/wiki/Cosmic_Dust_Analyzer)

Instrument name	Units	Dust Detector
Target particles		Dust & Nanodust
Dust Analyzer		DESTINY+ DDA (IID + TOF-MS)
Nanodust Detector		Filmed-microchanel plate (MCP)-based detector or NMS
Number of sensors	2	Trajectory Sensor
Dust detector size (LxWxH)	cm	30x30x30
FOV	degree	±45
Grain Size Range		> 0.2 micron
Grain Speed Range	km/s	2-8
Dust Mass Resolution	Y/N	m/Δm~ 100-200
Nominal temporal resolution (duration of a scan cycle)	second	100
Instrument mass	kg	12.5
Power consumption	W	25
Data rate	kbits/sec	0.2 (12.6 MB/week)

DD Requirement

Fluxgate Magnetometer

Purpose: To understand the magnetic properties and evolution of solar wind structures by measuring three-dimensional magnetic field vectors

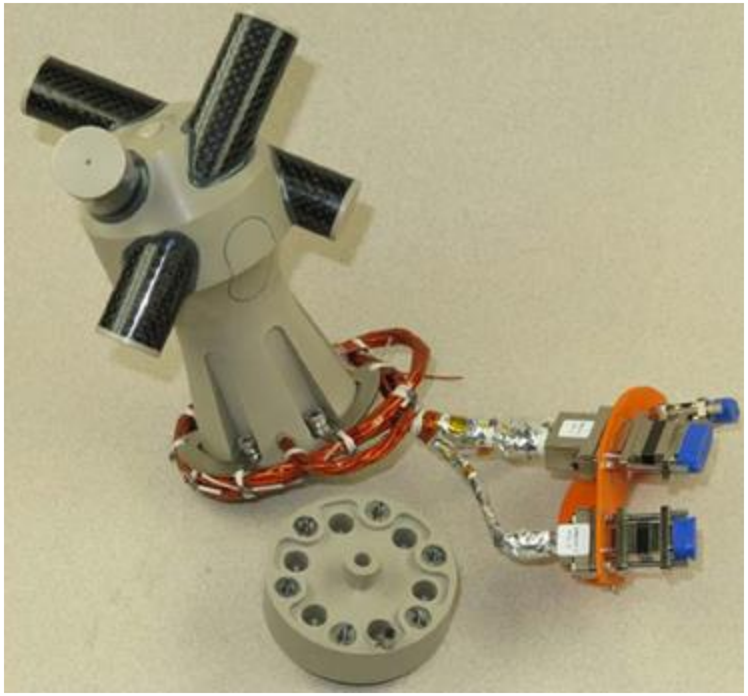
Credit: KMAG for KPLO @ L1 & Moon

Type	Triaxial Fluxgate
Measurement range	+- 512 nT
Resolution	< 0.1 nT
Sampling rate	16 Hz (normal mode) 128 Hz (burst mode)
Noise level	< 10 pT/sqrt(Hz) @ 1Hz
Mass	5.5 kg (Boom: 2.5 kg)
Power	13 W (w. Heater)

FM Instrument Requirement

Search Coil Magnetometer

Purpose: To understand the properties of plasma waves and turbulence by providing detailed measurements of magnetic field fluctuations over a wide range of frequencies



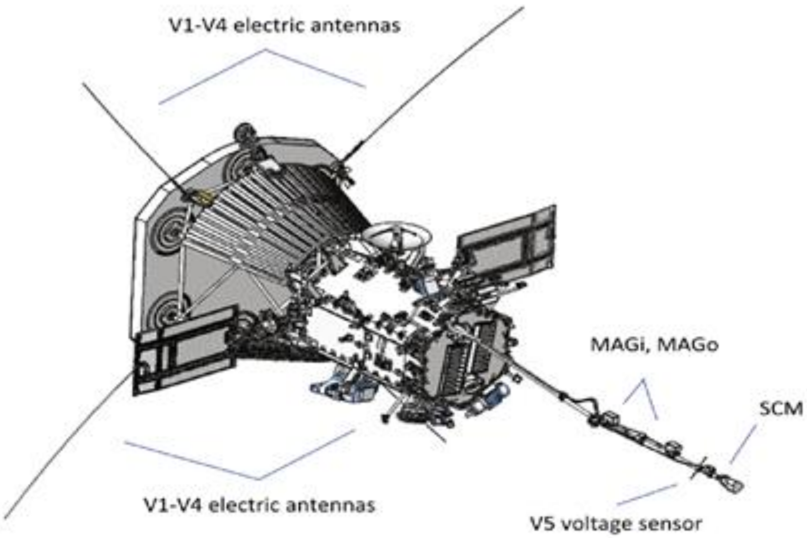
Credit: Search Coil Magnetometer
for Solar Orbiter @ Interpanetary space

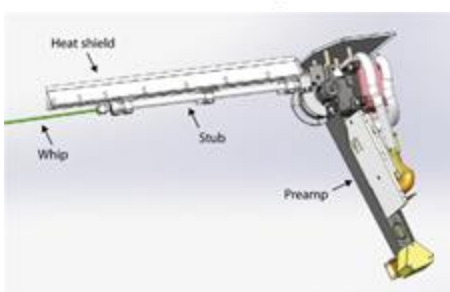
Type	Triaxial Search Coil
Measurement range	~ 100kHz
Resolution	< 0.1 nT
Required Relemetry Rate	0.24 kbps
Noise level	< 80 nT/sqrt(Hz) @ 2Hz
Mass	1.8 kg
Power	1.4 W

SCM Requirement

Radio and Wave Instrument

Purpose: To provide measurements of the electric field in a broad frequency range from almost DC to 16 MHz covering characteristic frequencies in the interplanetary medium and to determine the characteristics of electromagnetic and electrostatic waves at the L4 point for understanding the heliospheric environment and physics.

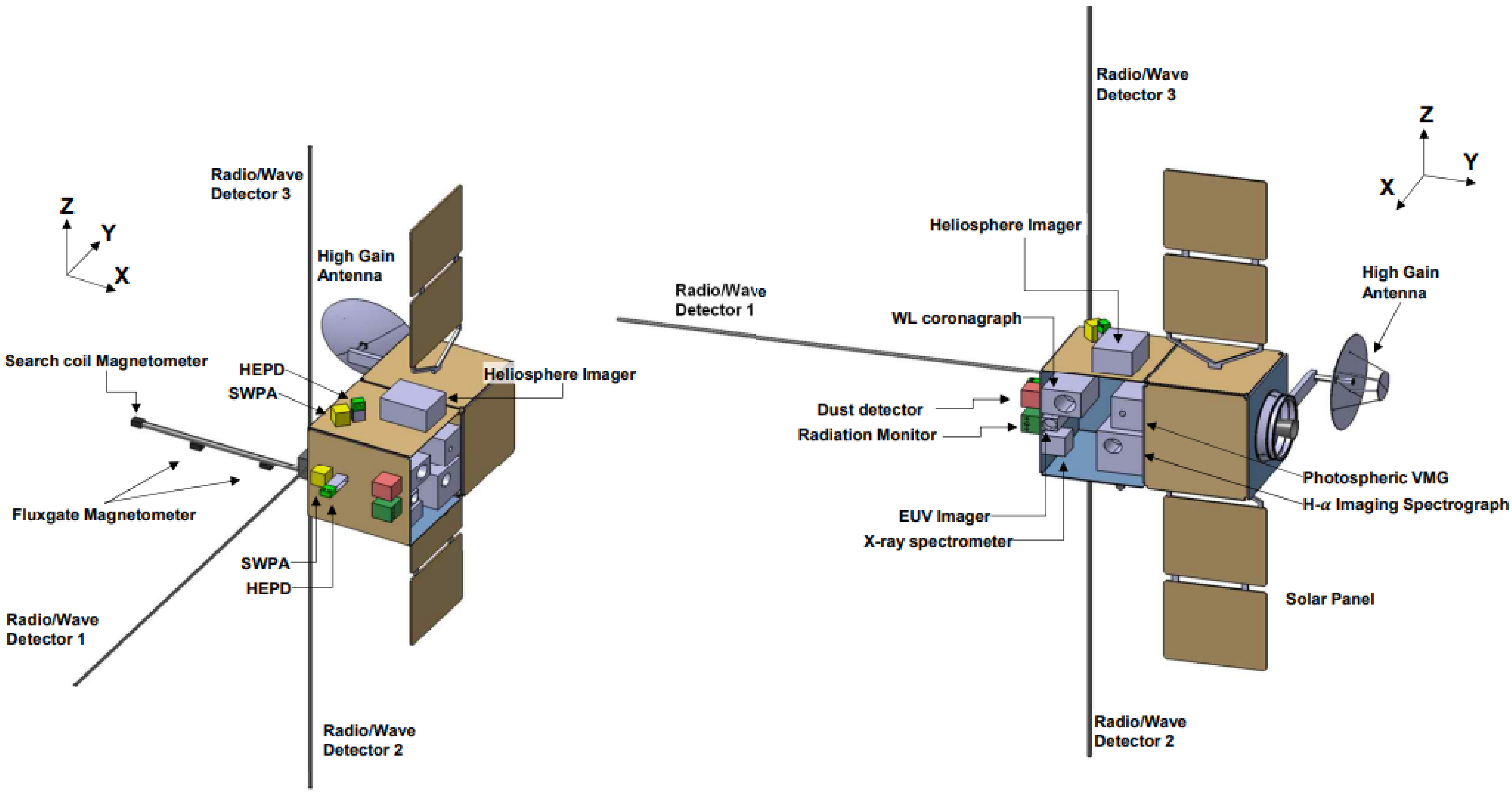




Credit: ESA Solar Orbiter mission

Data type	2 or 3 E components
Sampling rate	DC to 10 kHz (low-frequency receiver) 4-1024 kHz (thermal noise receiver) 0.4-16 MHz (high-frequency receiver)
Time resolution of spectra	1 s (low-frequency receiver) 1.13-12 s (thermal noise receiver) 2-22 s (high-frequency receiver)
Measurement resolution	16 nV/sqrt(Hz)
Mass	10 kg
Power	5.6 W
Telemetry	4.5 kbps

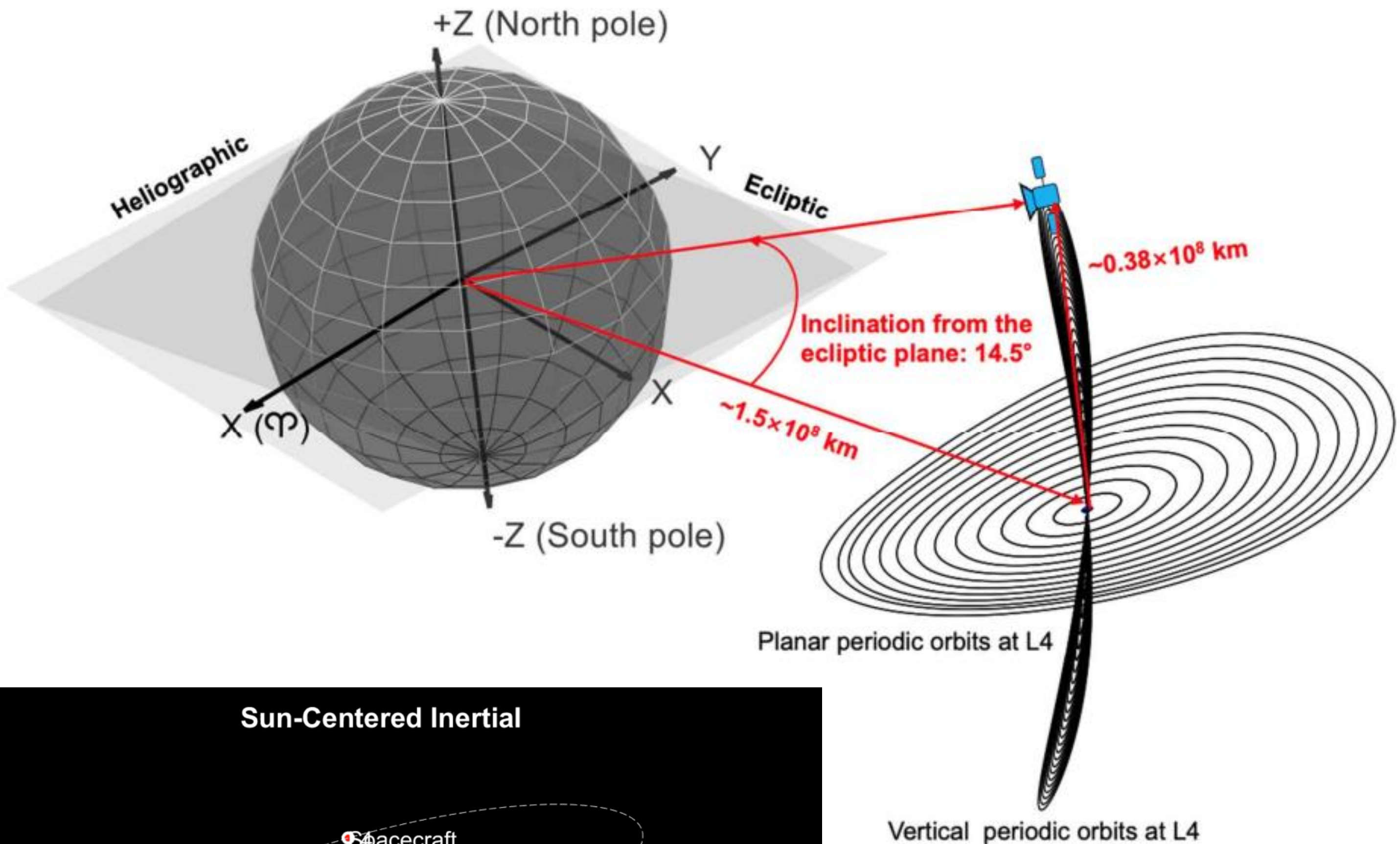
L4 Spacecraft

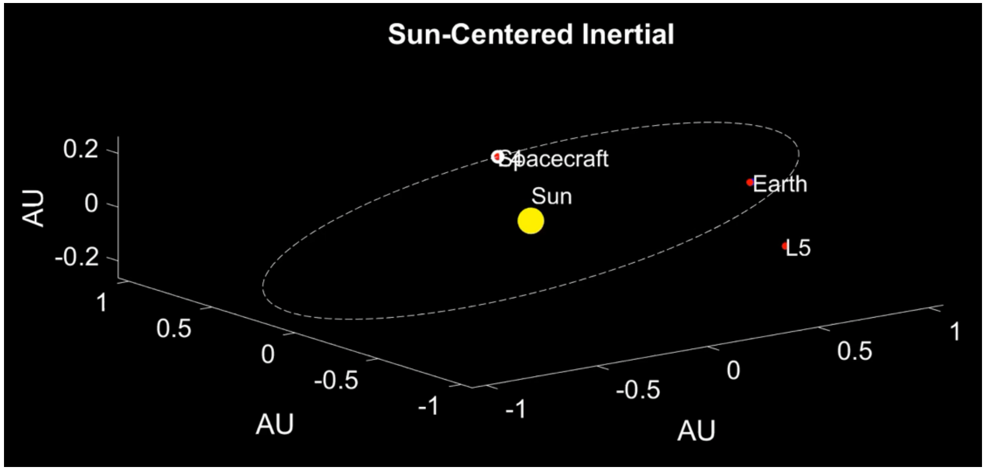


Concept design based on the GEO-KOMSAT platform

Trajectory & Communication

Locations of L4 spacecraft (이진성)

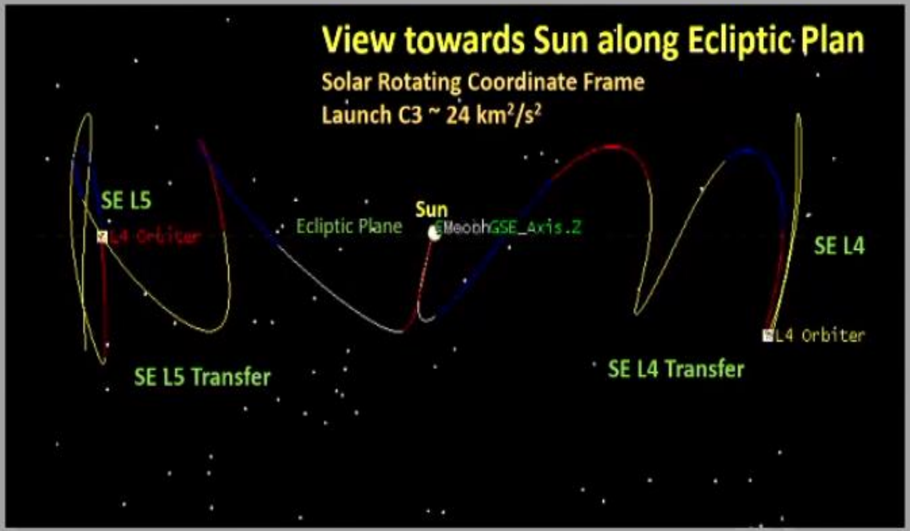


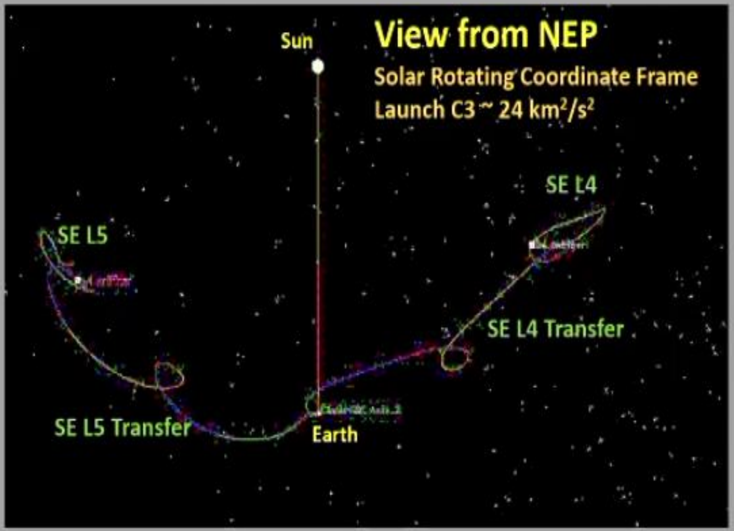


L4 Trajectory (Posner et al., 2021)

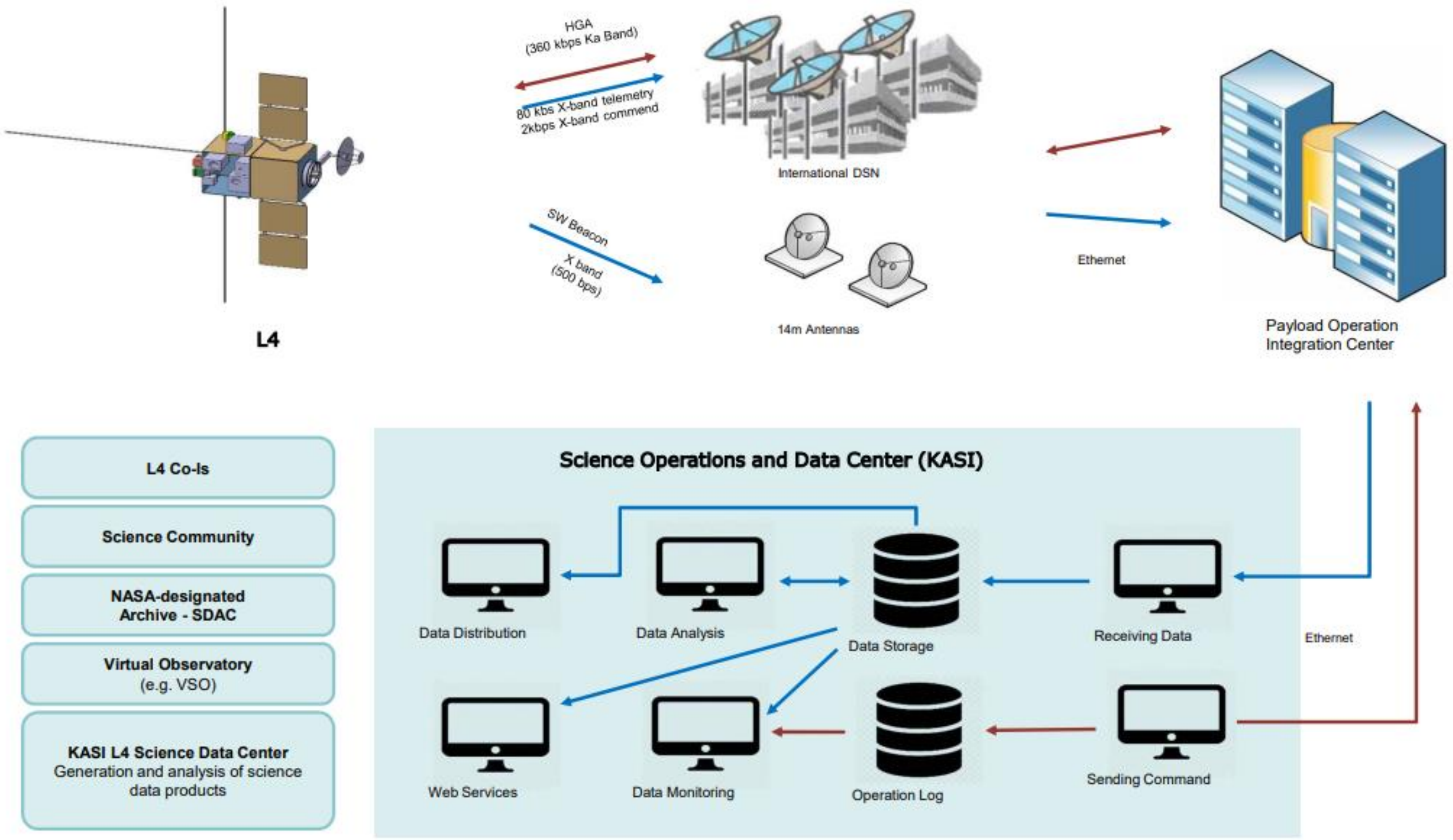
SUN CHASER TRAJECTORY DESIGN

- Example of single launch of two spacecraft on Oct 1, 2030 with injection C3 of 24 km^2/sec^2 to an initial 10 deg ecliptic inclination or 54 km^2/sec^2 to a 14 deg ecliptic inclination.
- Both designs require Dv (fuel) to enter L4 or L5 orbits, chemical (~55% bi-prop mass of 320 sec Isp) or low thrust (~20% prop mass using GRC H71M Hall-effect thruster ~40 mN, ~1600 sec Isp). Low thrust also provides the Dv for the separate L5 transfer, increases inclination, and SEL4 or SEL5 orbit insertion.
- Achieves up to 16 deg ecliptic inclinations and arrives on-station within two years.
- Launch vehicle capabilities of 500kg to 3000kg via Falcon Heavy and Vulcan and Antares or New Glenn for lower C3.
- Trajectory design can vary with longer transfers to minimize fuel load or to inclination.
- Figures show trajectories and SEL4 and SEL5 orbits in a solar rotating coordinate frame (fixed Sun-Earth line)



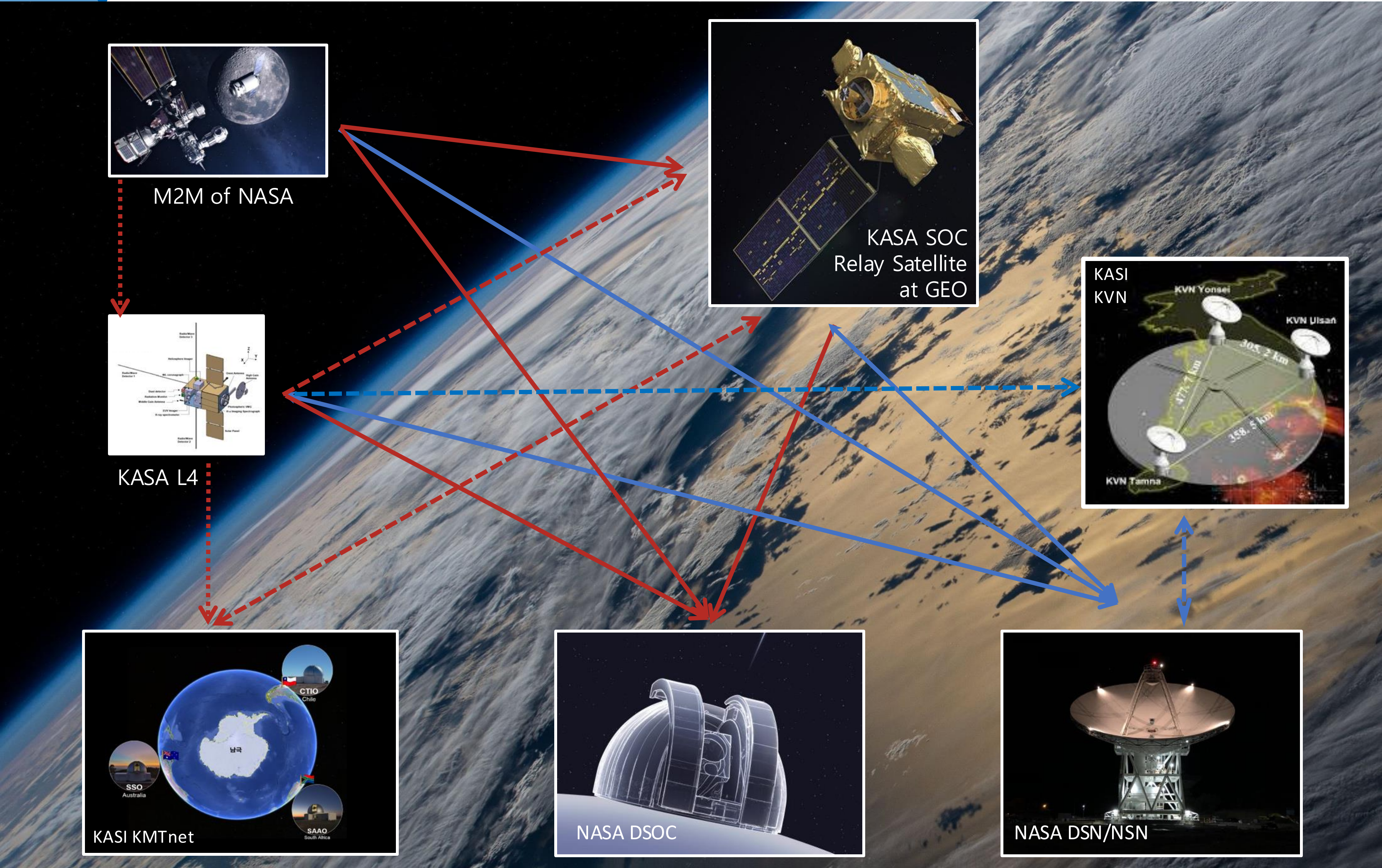


RF Communication



The Deep Space Network will be used for science and house-keeping data and 14 meter antennas will be used for space weather beacon data.

Radio and Optical Communications



* DSN (Deep Space Network), DSOC (Deep Space Optical Communication), NSN (Near Space Network), SOC (Space Optical Communication)

Timeline

Things to do (Planning Contents)

Timeline

- Goal: Prepare Proposal to be submitted to Korean Space Agency

- Purpose: Develop analysis, plans, and strategy to receive a approval to proceed with the L4 mission

: Discuss at NASA-KASI Working Group meetings regarding L4 science and payload collaboration

: Review technical capability of domestic payloads, satellites, launch vehicles, etc

: Propose unique Korean payloads for L4.

: Secure international partners or develop strategies to develop domestically

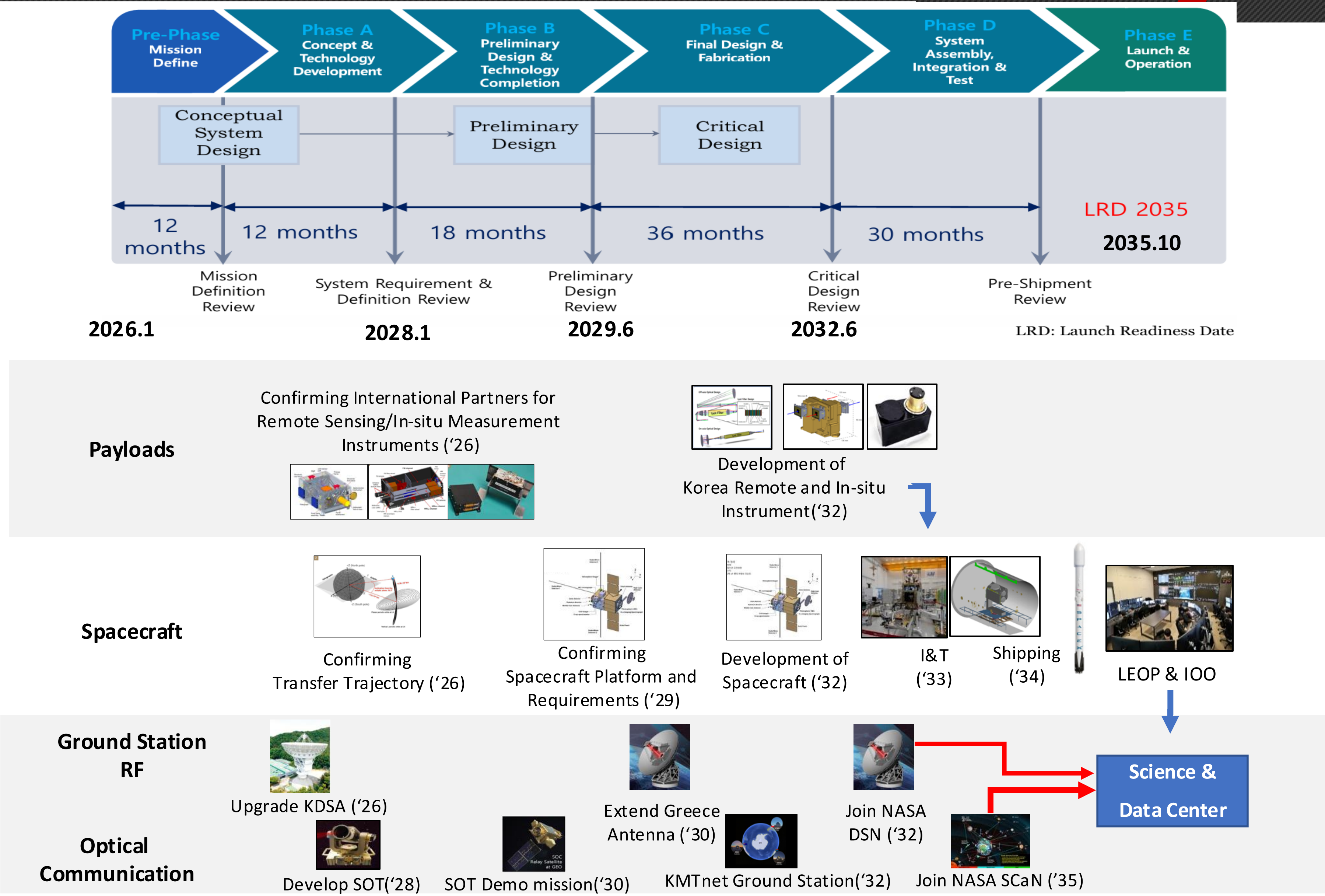
: Select which elements of L4 should be developed domestically

(e.g. Payloads + Satellites + Launch vehicles)

L4 기획연구 로드맵

1. Policy Research & Consulting **(2022. 11)**
2. Feasibility Analysis (R&D, Industry)
3. Project planning **(2023. 12)** KASI-NASA WG
4. Derive Action Plan
5. Prepare Budget Feasible Plan (2024.10 ~ 2025. 7)
6. National Preliminary Feasibility Review Report (2025. 8)
7. Update National Preliminary Feasibility Review Report

Time Line

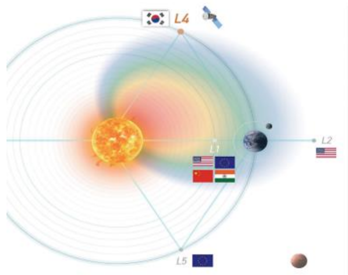


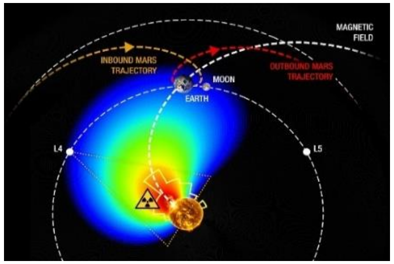
SOT: Space Optical Terminal; LEOP: Launch and Early Orbit Phase; IOO: In Orbit Operation

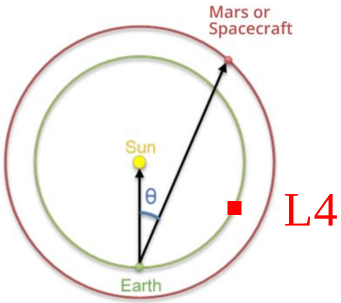
V

M2M Contribution

L4 Contribution to M2M (Study Agreement)





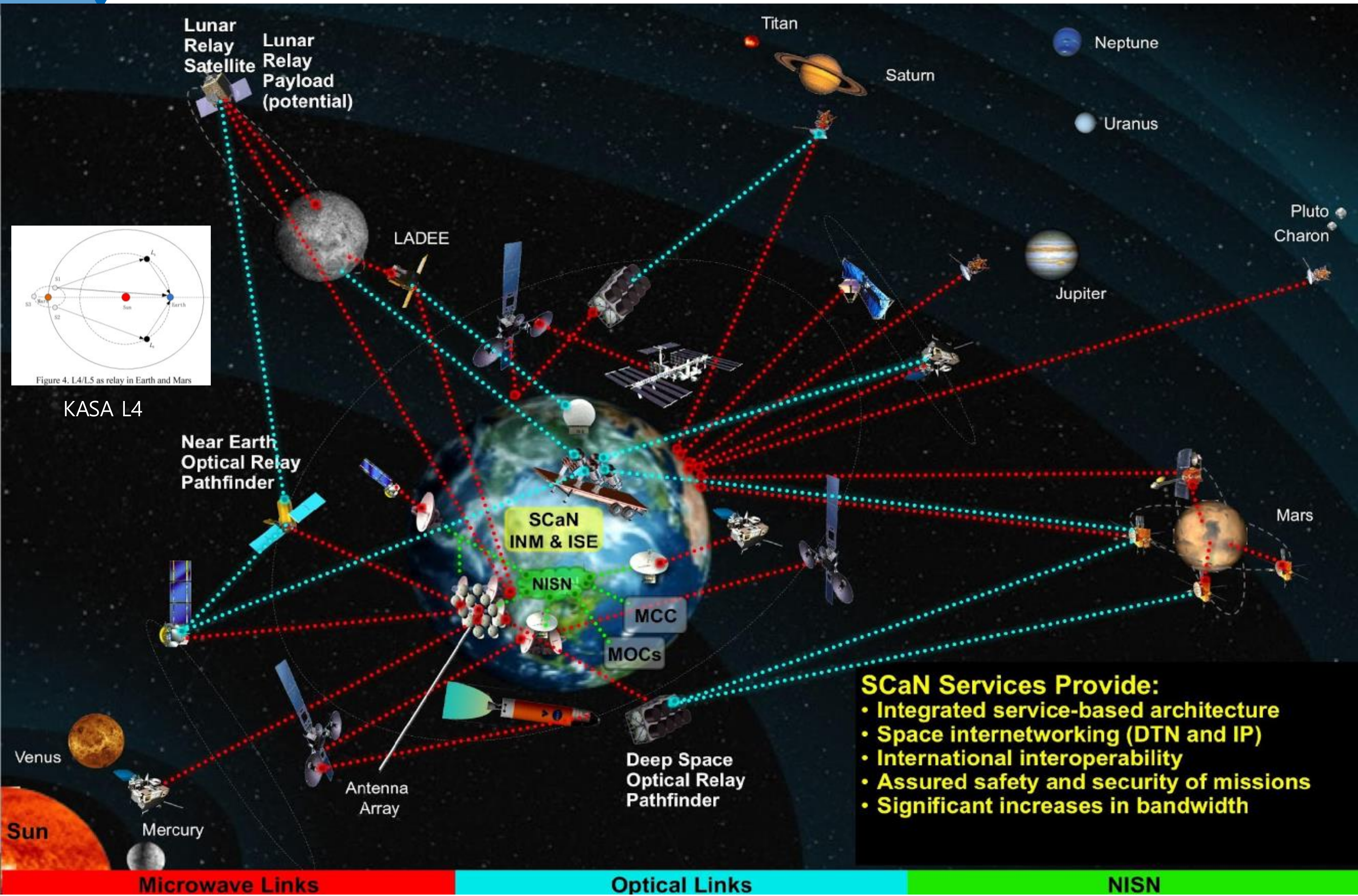


- KASA is preparing the development of an international heliospheric observatory positioned at L4 for innovative solar and space weather research and forecast.
- Korea-led L4 mission will produce unprecedented synergy for future human exploration of the Moon, Mars, and beyond.
- This study aims to define the potential scientific/exploration scope of the proposed L4 mission in the following three areas

Study Group	KASI Leaders	Potential Korea and US Team Members
Space Weather	Sung-Hong Park, Rok-Soon Kim (KASI)	Young-Jae Moon (KHU, Remote observations) Dae-Young Lee (CBNU, Insitu observations)
Space Radiation effects on Human safety	Jaejin Lee, JongDae Sohn (KASI)	Insoo Jun (JPL, space radiation) Mansoo Kim (KHU Hospital, Medical Doctor) David Francisco (OCHMO)
Optical Space Communication	SeongHwan Choi, HyungChul Lim (KASI)	Hyosang Yoon (KAIST, Pointing) Kyeong-il Choi (KTsat)

OCHMO: Office of the Chief Health and Medical Officer

L4 Contribution to M2M (Radio & Optical Comm)



International Collaborations (TBD)

- NASA
  - Align with the Decadal Survey
  - Collaborate with Sun CHASER and MOST
  - Provide Solar EUV instrument
  - Request NASA's Deep Space Networking for downlinking data from the mission
  - Start Study Agreement for L4 contribution to M2M
- NOAA
  - Completed the Letter Of Intent (LOI) between KASI and NOAA/NESDIS
  - Provide a compact Solar coronagraph
  - Share science and operation data
  - Use of NOAA's ground stations for downlinking (possibly)
- ESA
  - Align with the L5 mission and share science and operation data
  - 32 m Antenna Conversion for L4 mission (Greece)
  - Collaborate on Radio and Plasma Wave (RPW, CNES)
- Max Plank Institute (Solar System Research)
  - Collaborate on Polarimetric and Helioseismic Imager (PHI)
- UK
  - Collaborate on Heliosphere Imager (HI, RAL-SPACE)
  - Collaborate on Solar wind detector (Electrostatic Analyzer, UCL)
- Japan
  - Discuss with Nagoya and Kyoto Universities
- Other nations
  - Find partner nations for dust detector

SUMMARY

- L4 Mission will advance heliophysics science and significantly improve space weather forecasting capability by providing continuous and unique observations of the heliosphere at the metastable vantage point.
- In-situ observations, combined with remote sensing, will significantly enhance the scientific value, given the high-performance capabilities of the instruments
- **An inclined orbit for the L4 spacecraft will enable a diverse range of scientific investigations**
- Combined with planned L1 and L5 missions, the L4 mission will produce unprecedented synergy for future human exploration of the Moon, Mars, and beyond.
- **We would like to get a support from NASA on this project since contribution from NASA is significant for the L4 mission. We hope for this project to be included in the Heliophysics 2024 Decadal Survey.**

Thank You

한국천문연구원
Korea Astronomy & Space Science Institute