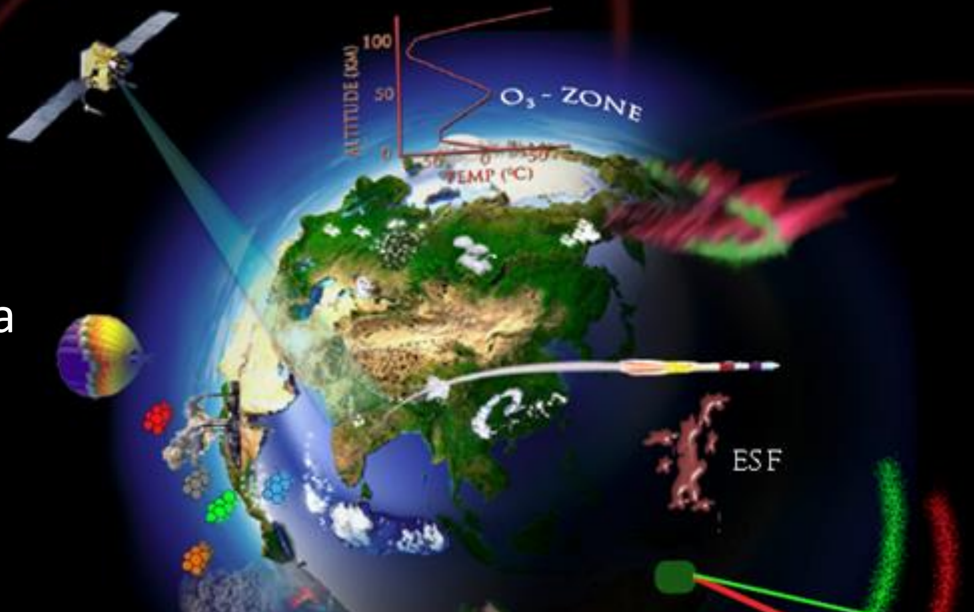
Aditya Solar wind Particle Experiment on-board India's Aditya-L1 mission



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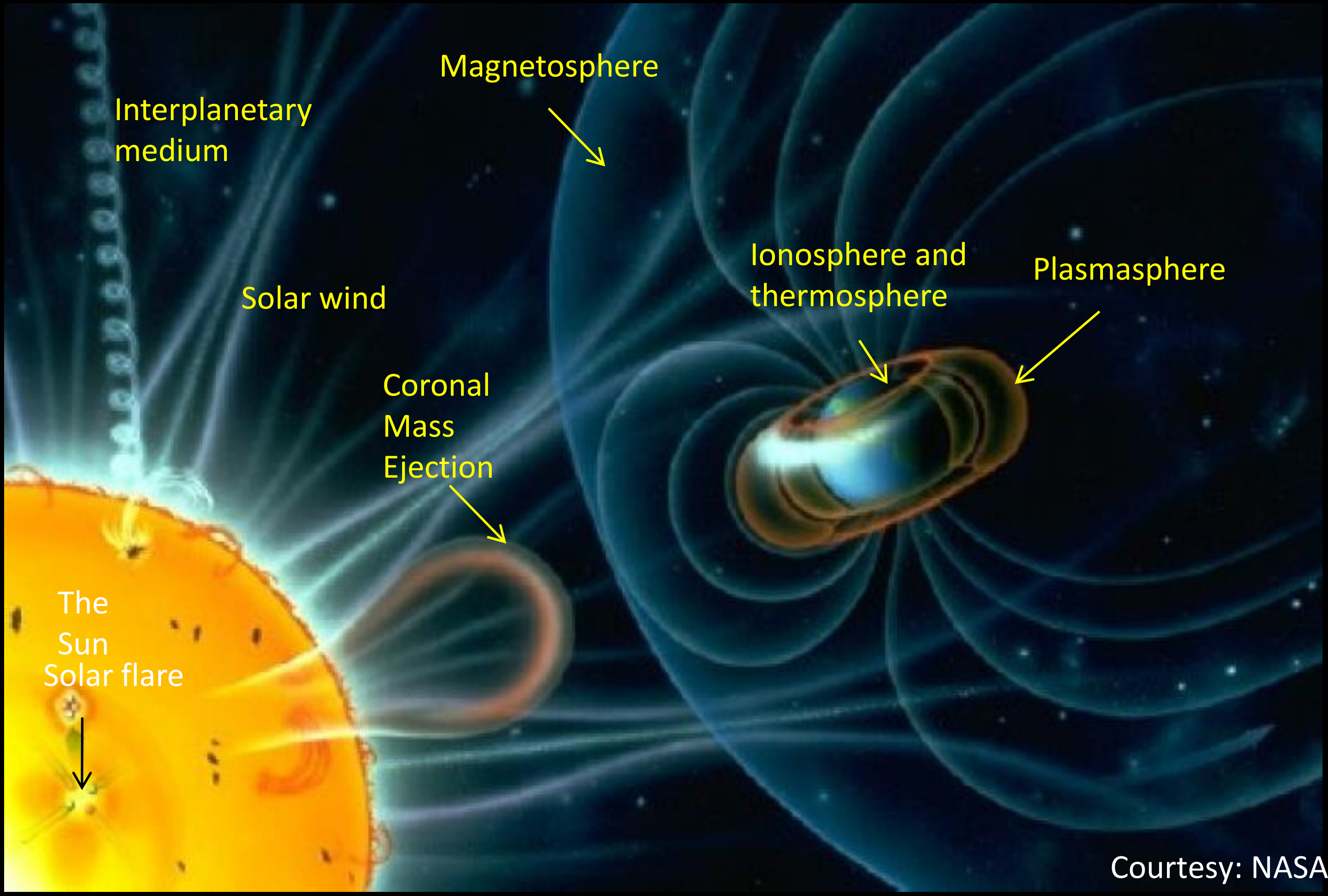
United Nations/Germany Workshop on the International Space Weather Initiative: *Preparing for the Solar Maximum*

Neustrelitz, Germany

13 June, 2024

Space weather



Different plasma domains with multi-scales, coupling across scales, different configurations of magnetic field, mix-up with neutrals (e.g. ionosphere) make space weather assessment a complex task.

Why L1 ?

Three reasons.

1. One can observe the Sun 24x7 without any eclipse from L1.

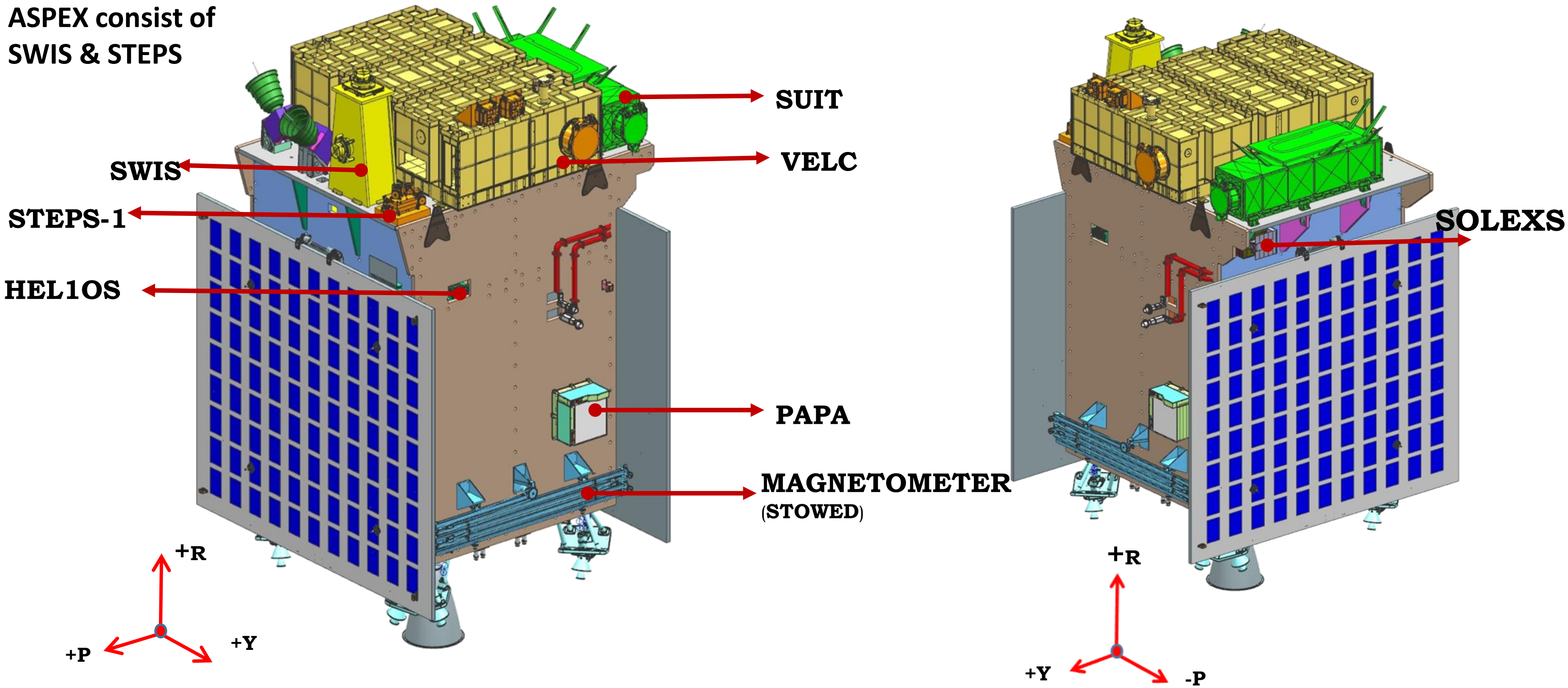
2. One can sample pure solar wind as the satellite is completely outside of the Earth's magnetic field.

3. If we consider typical solar wind velocity (~400 km/s), L1 point is almost an hour away. So measurements from L1 can help in making space weather forecasting models. This may help in preventing damage to space and technological assets in the long run.

ADITYA-L1 – The first Observatory class dedicated mission from India for Solar & Heliospheric studies

Mission life – 5-years

ASPEX consist of SWIS & STEPS



Payloads– Stowed View of Satellite

Aditya-L1: Four Remote sensing experiments

- **Visible Emission Line Coronagraph (VELC):** To study the dynamics and origin of CMEs in 1.05 - 1.5 solar radii, with a field of view (FOV) covering 3 solar radii using 3 visible and 1 Infra-Red channels. Magnetic field measurement of solar corona down to tens of Gauss.

- **Solar Ultraviolet Imaging Telescope (SUIT):** To image the spatially resolved Solar Photosphere and Chromosphere in near Ultraviolet (200-400 nm) and measure solar irradiance variations.

- **Solar Low Energy X-ray Spectrometer (SoLEXS) :** To monitor the X-ray flares for studying the heating mechanism of the solar corona in 1-30 keV. The Sun as a Star measurements.

- **High Energy L1 Orbiting X-ray Spectrometer (HEL1OS):** To understand the non-thermal component of the eruptive events in the solar corona in 10-150 keV. The Sun as a star measurements.

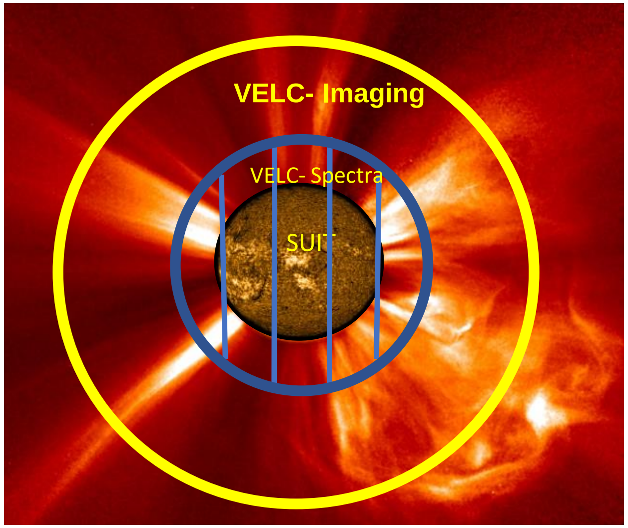


Image Courtesy: STEREO
Modified to include FOVs of Aditya-L1

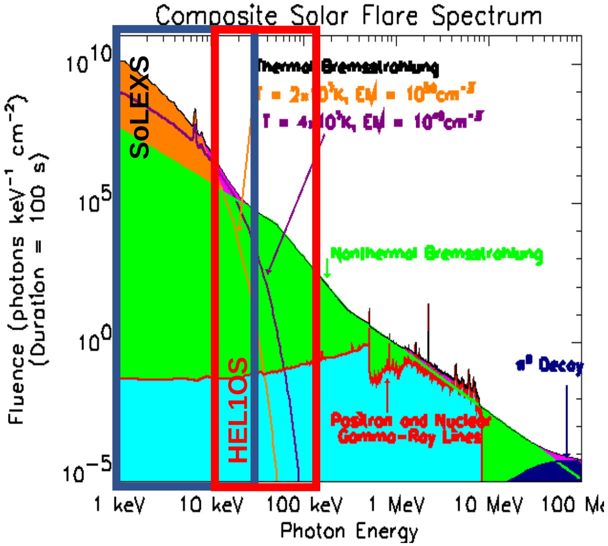
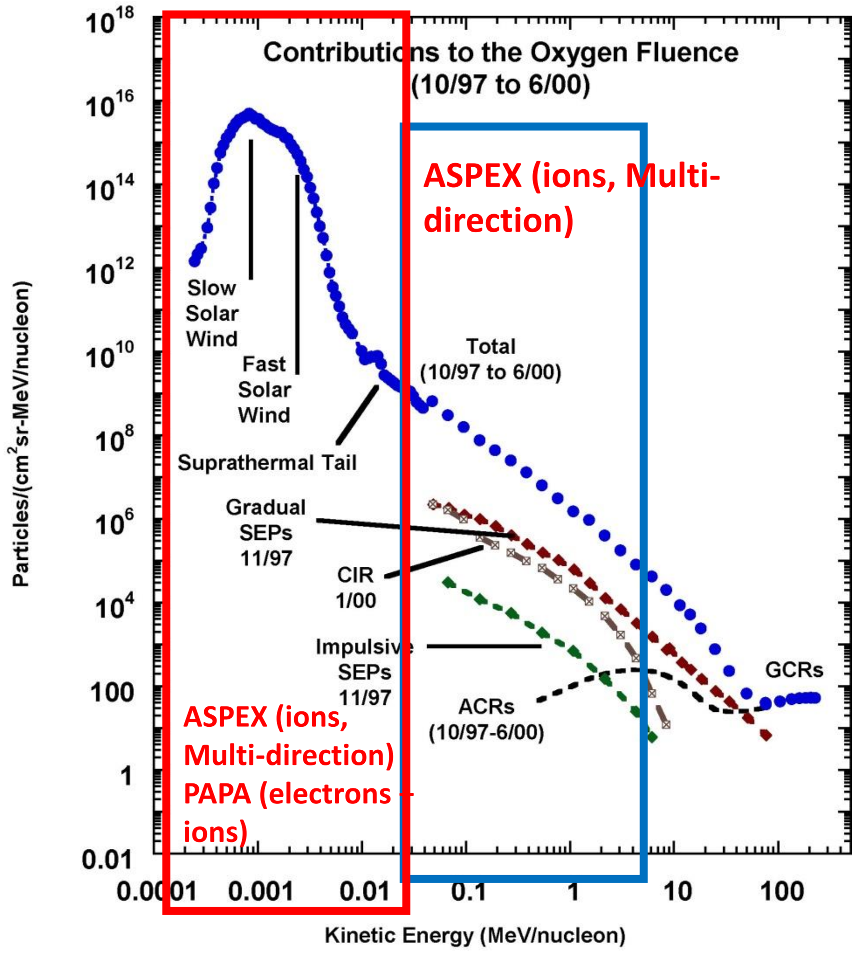


Image Courtesy: NASA
Modified to include Energy Ranges of Aditya-L1

Aditya-L1: Three in-situ plasma experiments

- **Aditya Solar wind Particle Experiment (ASPEX) :** Multi-directional, high cadence measurements of H+ and He++ right from 100 eV to 5 Mev/n to understand the Sun, solar wind properties and processes.
- **Plasma Analyser Package for Aditya (PAPA) :** To understand the ion composition of solar wind and electron energy distribution.
- **Magnetometer:** To measure the magnitude, polarity and nature of the Interplanetary Magnetic Field.

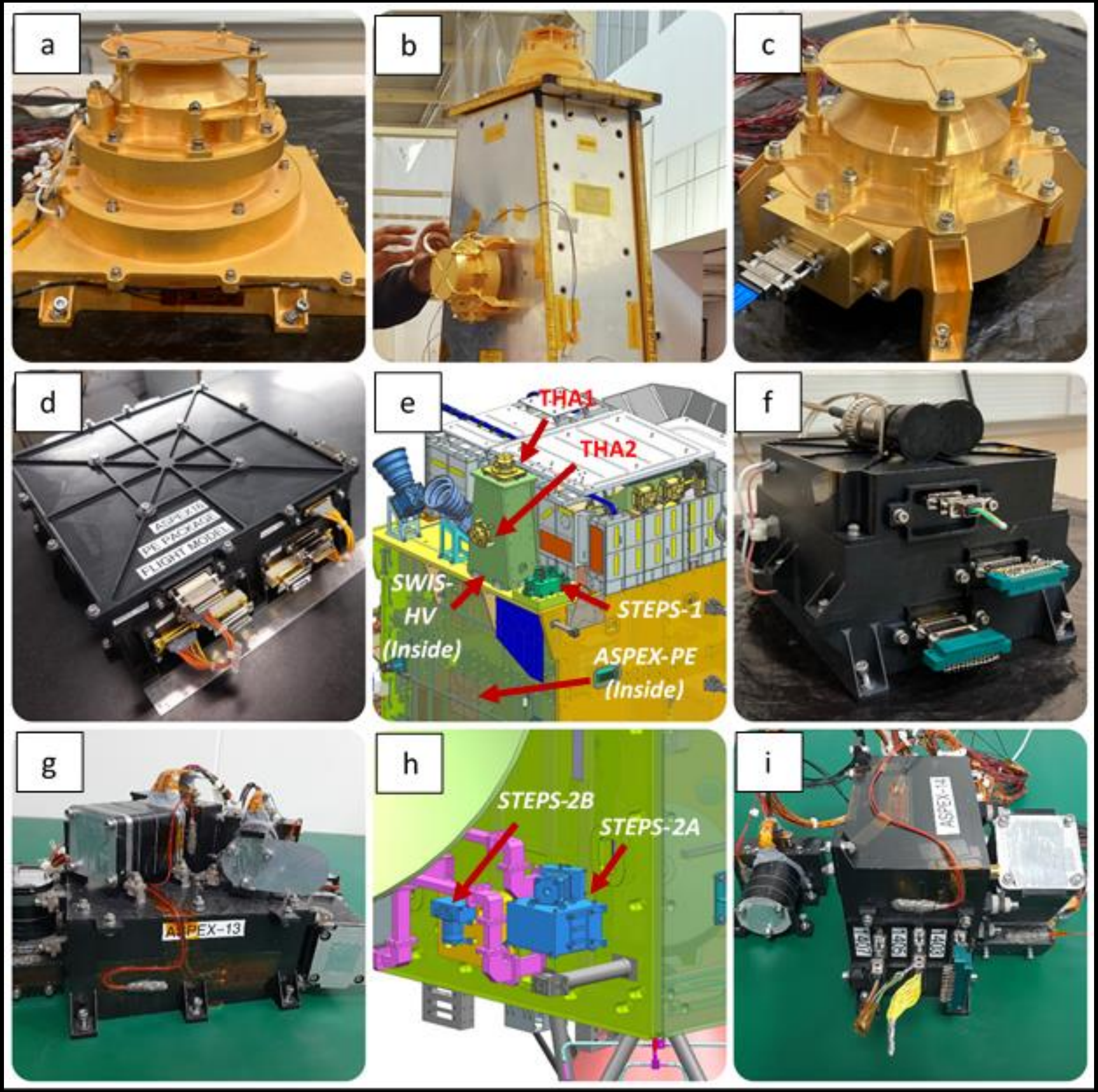


Mewaldt et al., 2007

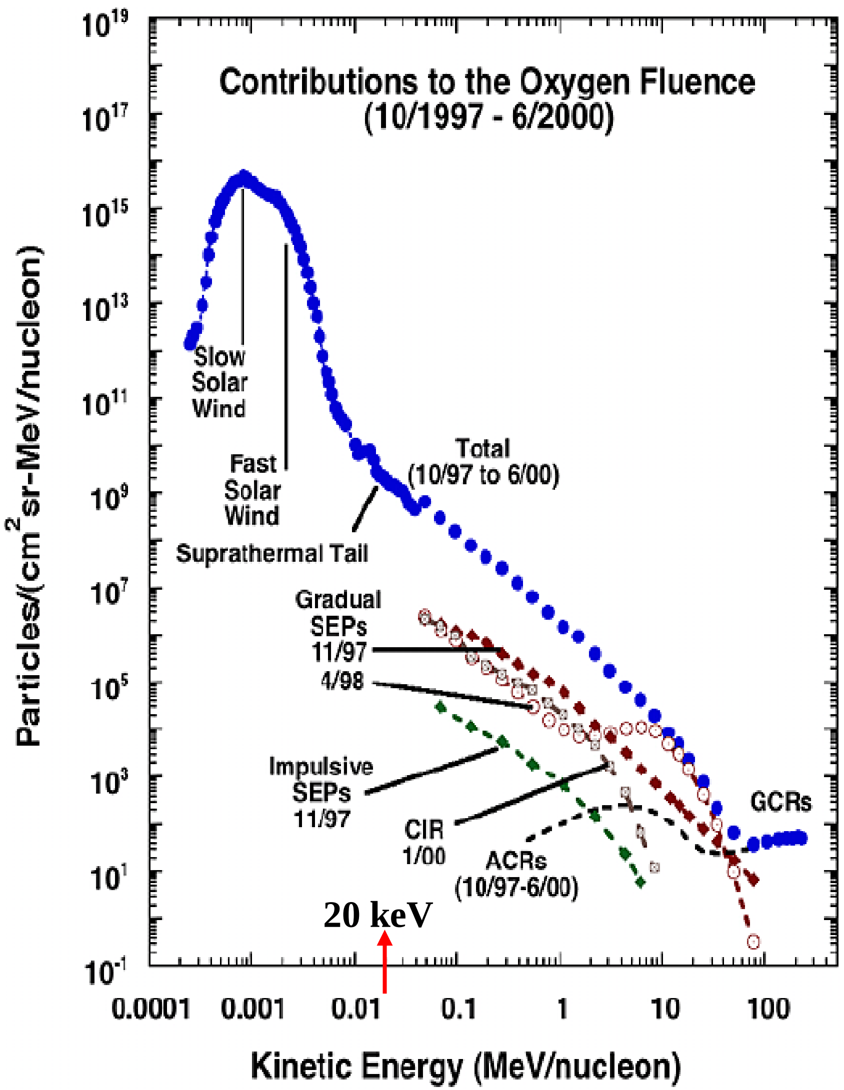
Uniqueness of Aditya-L1

- **CME dynamics closer to the disk** ($1.05R_{sun}$) providing information in the acceleration regime which is not observed consistently
- Coronal Magnetic Field and topology of Active regions
- **Spatially resolved solar disk observations in the near UV** providing information on the radiation output from different structures
- On-board intelligence to detect CMEs and Flares for optimized observations and data volume
- **All flares observed without spectral break between hard and soft X-rays**
- **Solar wind protons, and alpha particles fluxes with direction information.** Also electrons.
- Specific identified flags and count information through telemetry for early information on the space weather events

Aditya Solar wind Particle EXperiment (ASPEX)



Solar wind Ions in the interplanetary medium



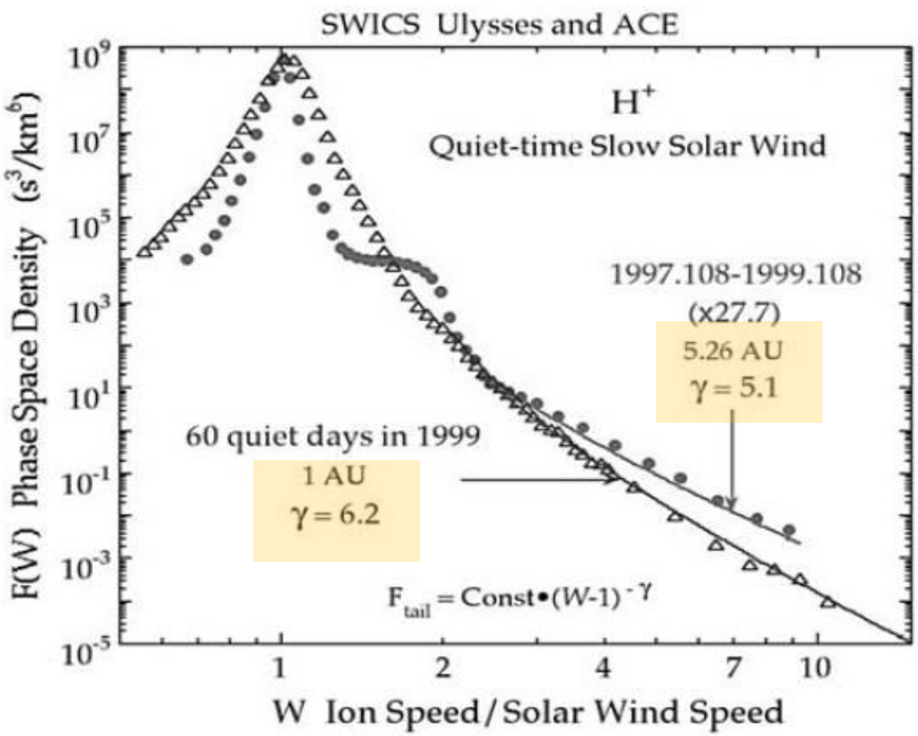
Mewaldt et al., 2007

Three distinctly different regimes

- **Slow and Fast solar wind particles** (upto ~3 keV)
- **Suprathermal particles** (3 keV to a few hundreds of keVs)
- **Solar Energetic Particles, SEP** (~ a few to tens or hundreds of MeVs)

✓ **Generation**
✓ **Inter-connection**
✓ **Energization**
✓ **Anisotropy**
✓ **Impact**

Suprathermal populations



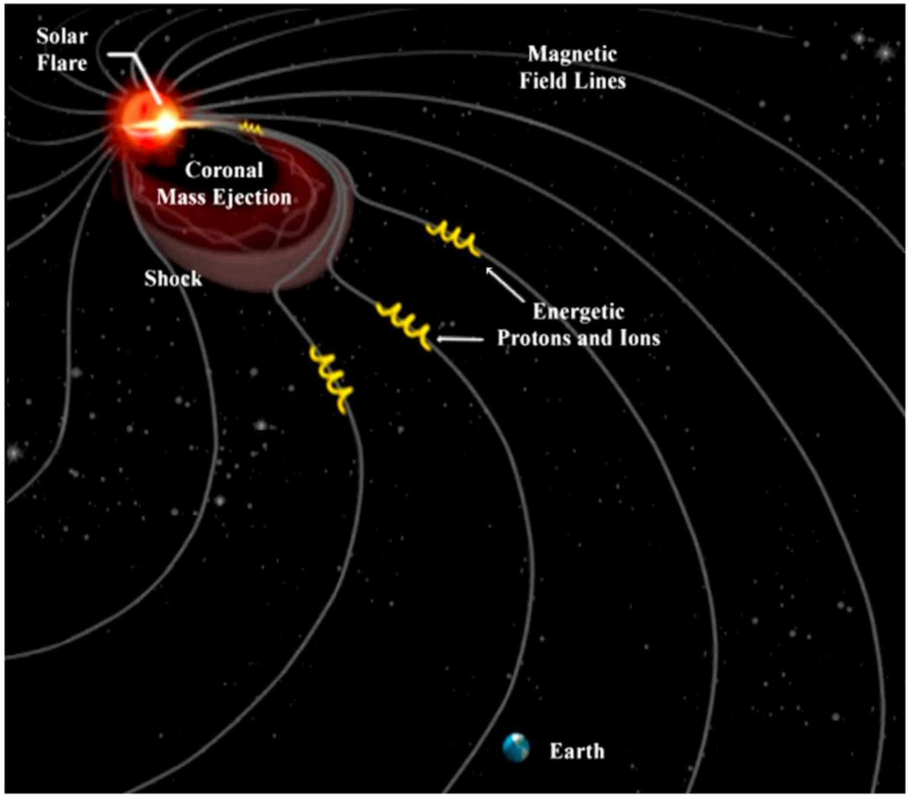
Note that 10 times the solar wind speed is close to 100 keV nucleon^{-1}.

- ❑ Recent results show that "Universality" of spectral index 5 is not always valid
- ❑ The generation mechanism(s) is (are) not clear
- ❑ **Nature of association between suprathermal population and SEPs**
- ❑ 360° coverage in the ecliptic and across the ecliptic plane are important to address these issues

McComas et al., 2001

Solar Energetic Particles (SEP)

(~ a few to tens of MeVs)



Nunez et al., 2016

- ❑ Two sources of particle acceleration (Flare and CME-driven shocks)
- ❑ Lower end of SEP measurements
- ❑ Processes are important that convert Suprathermal population to SEP
- ❑ Space weather implications

Solar atmospheric abundances

Photospheric composition w.r.t. H

- He ~ 8 %
- O ~ 0.049 %
- C ~ 0.0269 %
- Ne ~ 0.0085 %
- Fe ~ 0.0032 %

Asplund et al., 2009

$$A_{He} = \frac{n_{He}}{n_H} \times 100$$

- A_{He} ~ 8% (Photosphere)
- A_{He} ~ 4-5% (Corona)
- A_{He} ~ 2-5% (Solar Wind)
- A_{He} ~ 2-30% (ICMEs)
- Mass Flux (He)~ 25%

Helium abundance in solar wind

$$A_{He} = n_{He}/\ n_{H}\ *100$$

- Helium does not couple as strongly to the gravitational and pressure gradients in the corona as hydrogen, **so it does not directly experience the classical Parker mechanism** that accelerates coronal hydrogen to supersonic speeds.

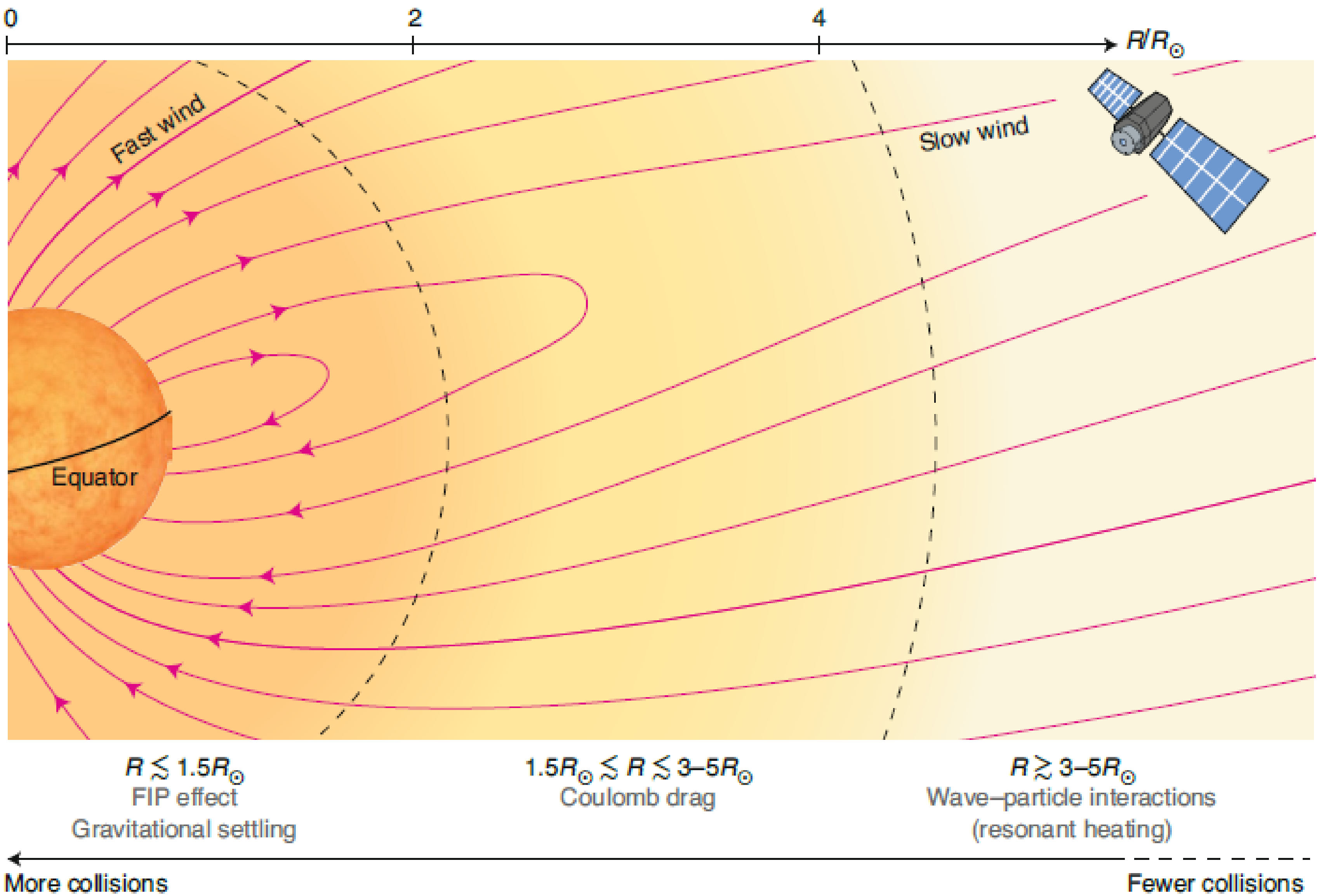
- Instead, helium is reliant on other mechanisms for acceleration out of the corona, such as **coupling to accelerated hydrogen through Coulomb collisions**.

- Helium being heavier may undergo **enhanced gravitational settling**.

- **FIP processing** is expected to be significant in Helium.

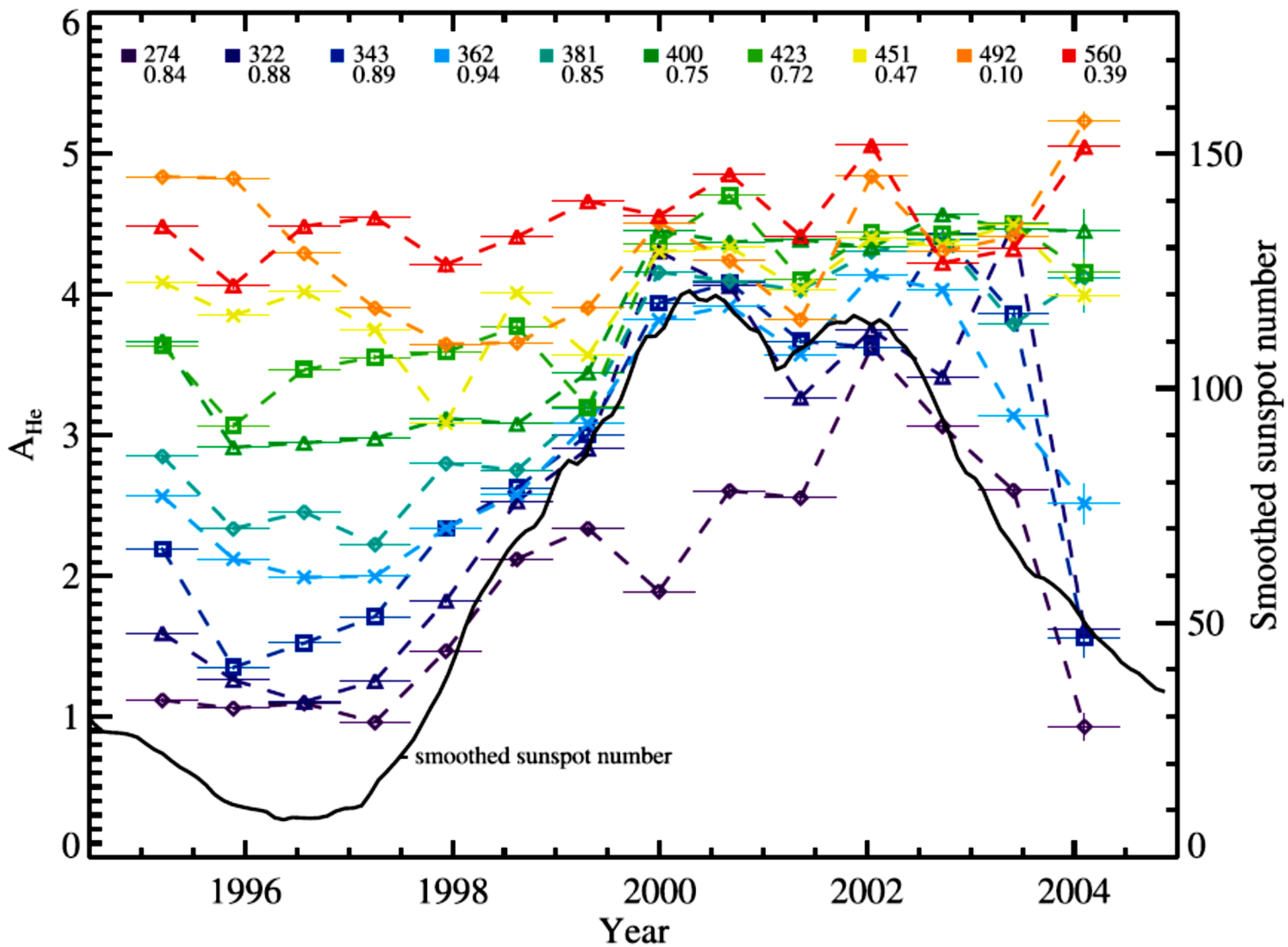
- In addition, **helium may enter cyclotron resonance with cascading turbulent Alfvenic fluctuations in the corona**, and the variable intensity of those fluctuations may account for the variability of interplanetary A_{He}.

Solar atmospheric processes and elemental abundances



Moses et al., 2020

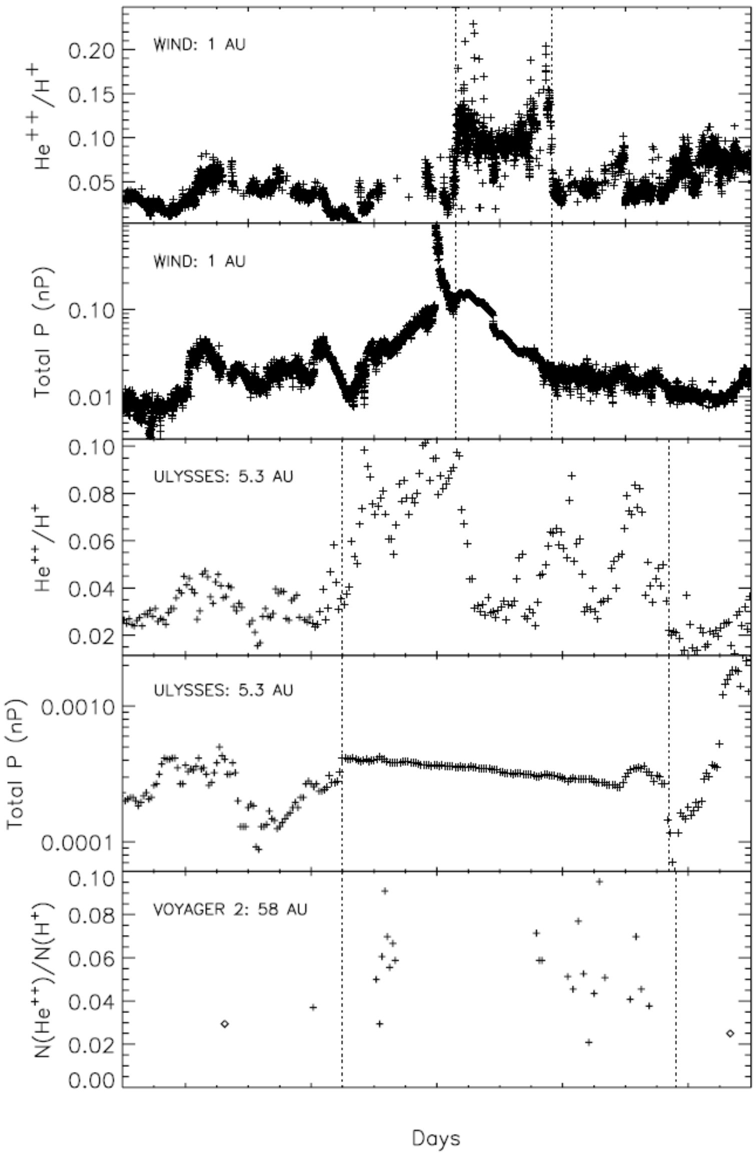
Variation of A_{He}



Kasper et al., 2007

- **Helium abundance:** Low in slow wind, high in fast wind, solar activity dependence and lags behind sunspot numbers (e.g. Alterman, 2019)

Alpha proton ratio (He^{++}/H^{+}) enhancement as Space Weather Flag



Steiger and Richardson, 2006

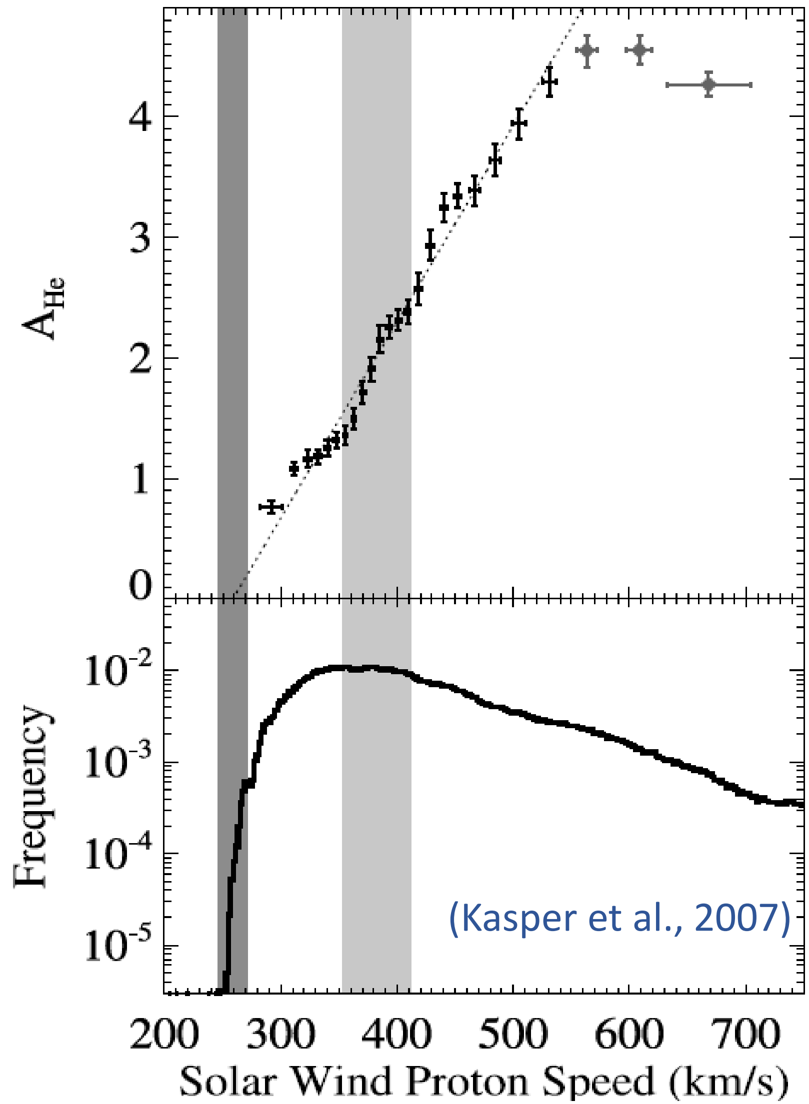
- **Determine the arrival** of solar and interplanetary events at L1
- **Address** the He^{++} enrichment process (e.g. Yogesh et al., MNRAS Letters, 2022)
- How effective is this ratio as **compositional flag**?
- **Space weather application**

Why understanding helium abundance is important: examples

- Helium doesn't follow Parker's theory for solar wind.
- Two fluid models => proton flux should increase with coronal heating rate but it is roughly constant and independent of speed (Feldman et al. 1978; Neugebauer 1981).
- Three fluid model => proton flux nearly remains constant at 1AU (Geiss et al. 1970; Bürgi 1992).

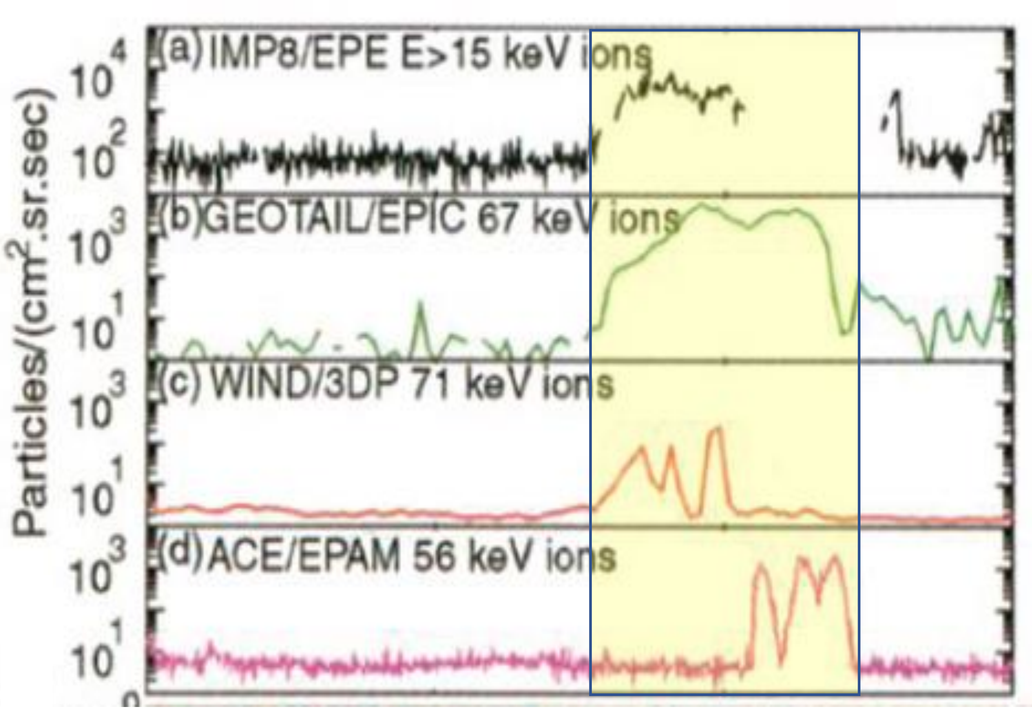
It is believed that helium controls proton flux

- **Top panel:** A_{He} v/s wind velocity
- (Gray shade: Heliospheric modulations removed)
- Extending the linear relation gives Helium vanishing speed of 259±12 km/s.
- **Bottom panel:** Frequency of solar wind velocity
- the frequency of solar wind observations drops by 3 orders of magnitude.

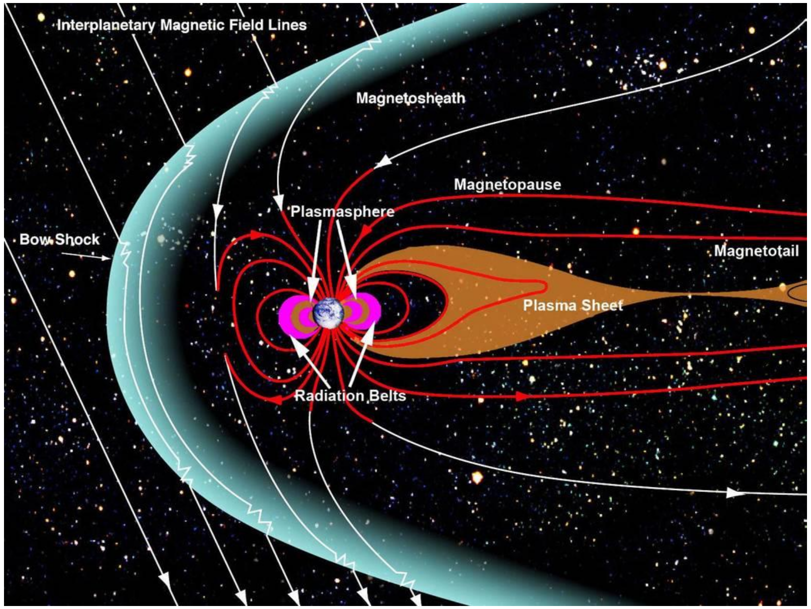


Does helium decide the lower limit of solar wind velocity?

Energetic ions from the Earth's bow shock

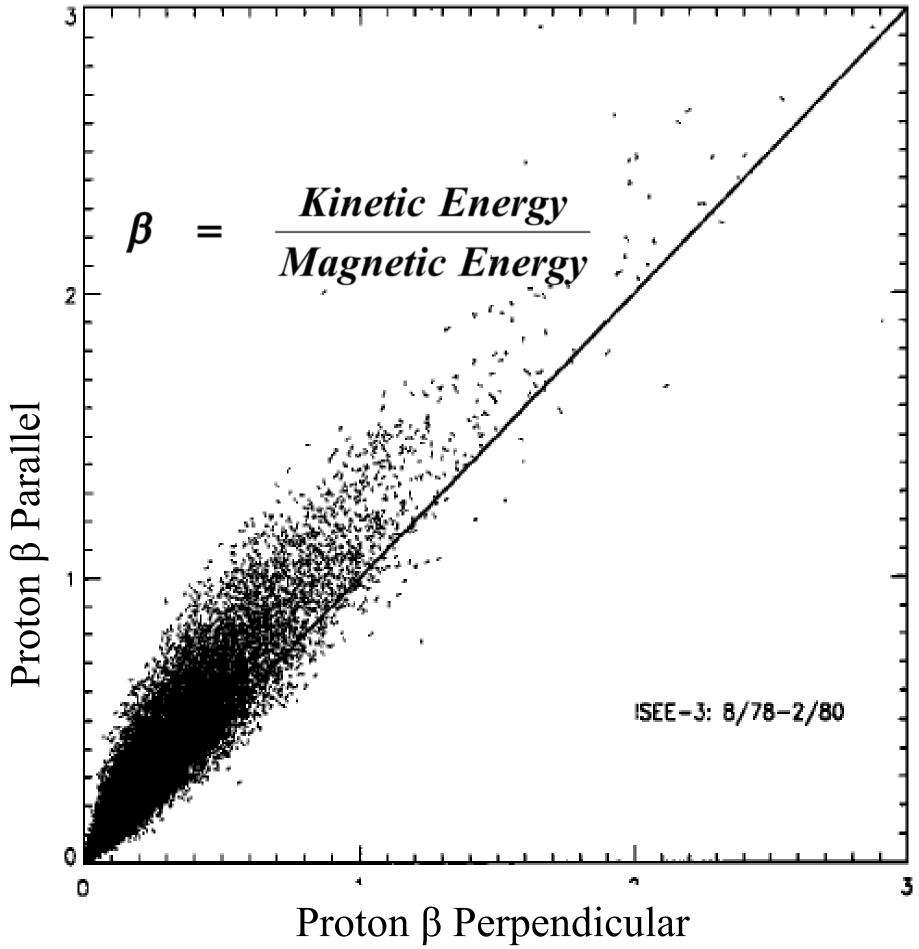


Haggerty et al., 2006



- Energetic ions (>15 keV) moving upstream from the earth's bow shock frequently appear at the sunward L1 point upstream from the earth.
- **How do these particle fluxes change with varying solar conditions?**
- Do the bow shock generated particle spectra tell us about the space weather impact?

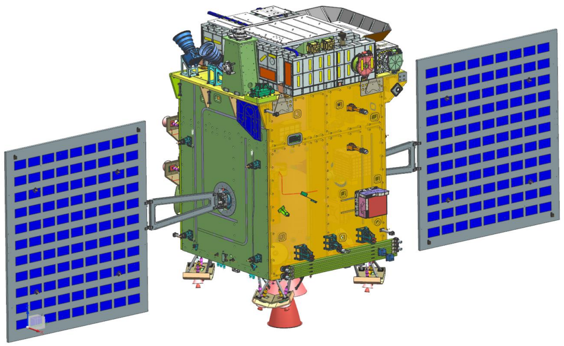
Thermal anisotropies in the solar wind

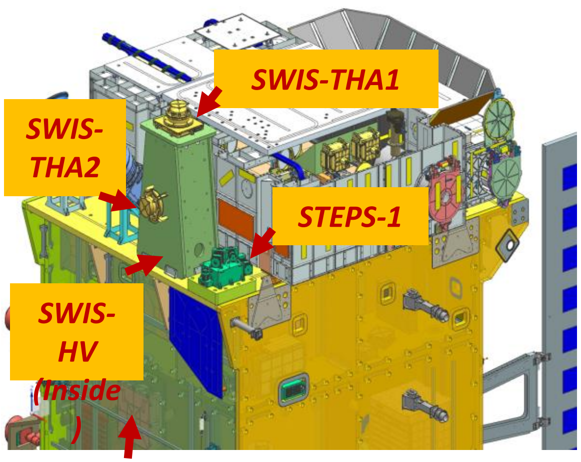


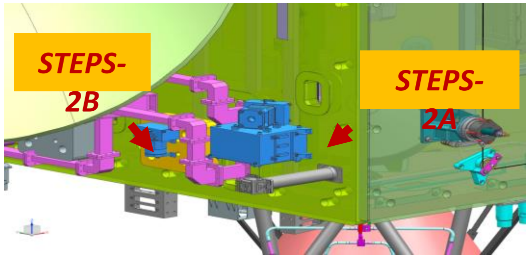
Richardson et al., 1996

Aditya Solar wind Particle EXperiment (ASPEX) On-board Aditya-L1 mission

Conceived, Designed and Developed at PRL with support from ISRO





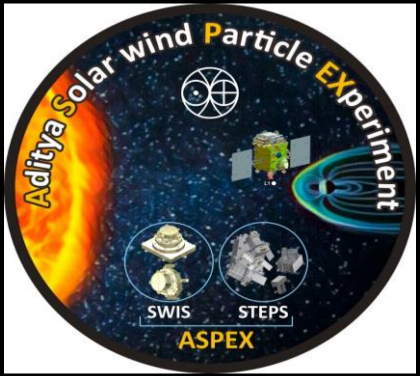


Science Objectives

- What are the processes that give rise to the solar wind and upstream ions (primarily protons and alphas) with different energies?
- Directional and thermal anisotropies of solar wind
- Source and acceleration processes of the Suprathermal and Energetic ions
- Signatures of Supra-thermal population as seed of SEP
- Changes of A_{He} during various solar events (Flares, CME's, CIR's)
- Efficacy of A_{He} as a space weather forecasting tool
- What processes make the solar wind turbulent?

Aditya Solar wind Paticle EXperiment (ASPEX)

- ✓ Multi-directional measurements
- ✓ Alpha-Proton separation
- ✓ Both low and high energies



SWIS: Solar wind Ion Spectrometer

100 eV- 20 keV

Two planes: 2π in and across ecliptic

Species (H^+ and He^{++}) separated in the ecliptic and integrated across ecliptic

STEPS: Supra Thermal and Energetic Particle Spectrometer

20 keV/n – 5 MeV/n

Six directions

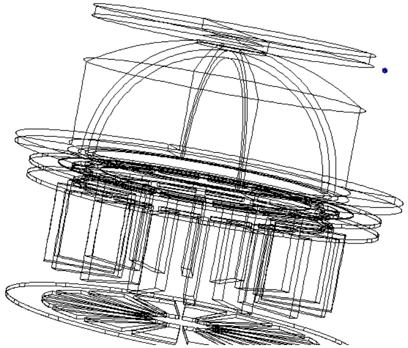
H^+ and He^{++} separated -- Radial, Parker, Anti-sun,

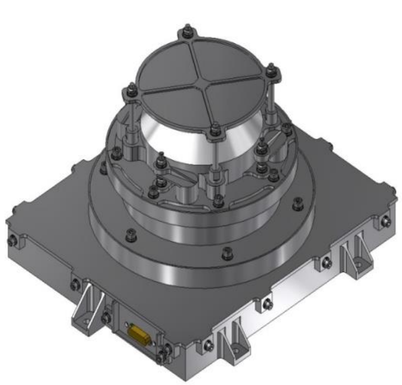
H^+ and He^{++} integrated -- Intermediate, North and South

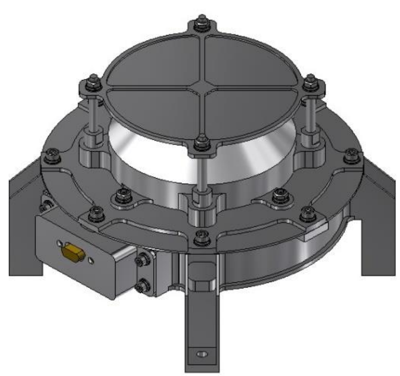
SWIS /ASPEX

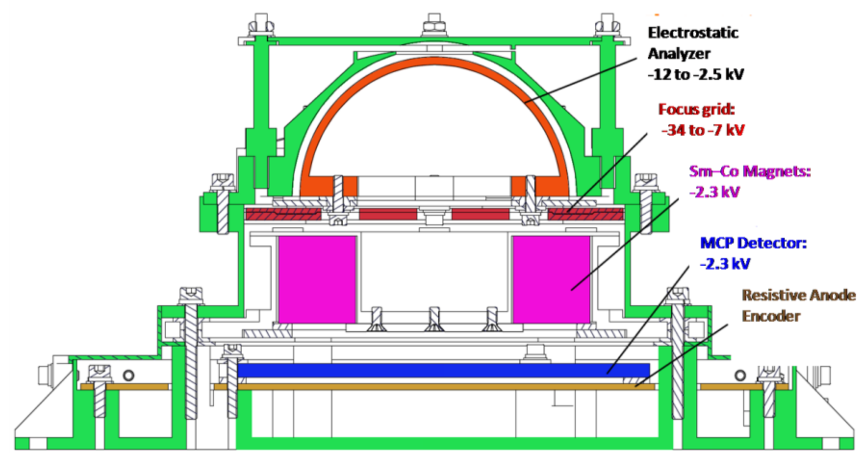
Configured as two sub-packages

- Top-hat analyser-1 (THA-1) and Top-hat analyser-2 (tha-2)
- A common HV package to provide necessary bias to both these units
- A common processing electronics package
- Both THAs use micro-channel plate(MCP) detectors and position sensitive anode developed in-house (Resistive Anode Encoder, RAE)



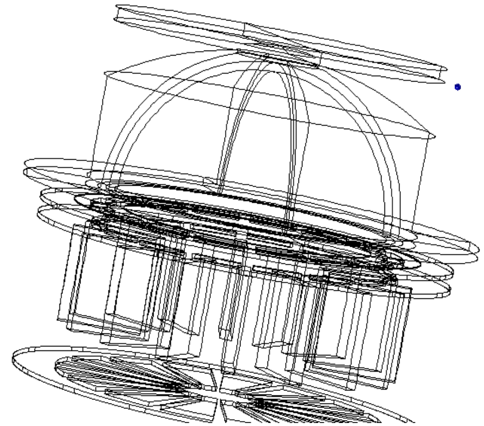


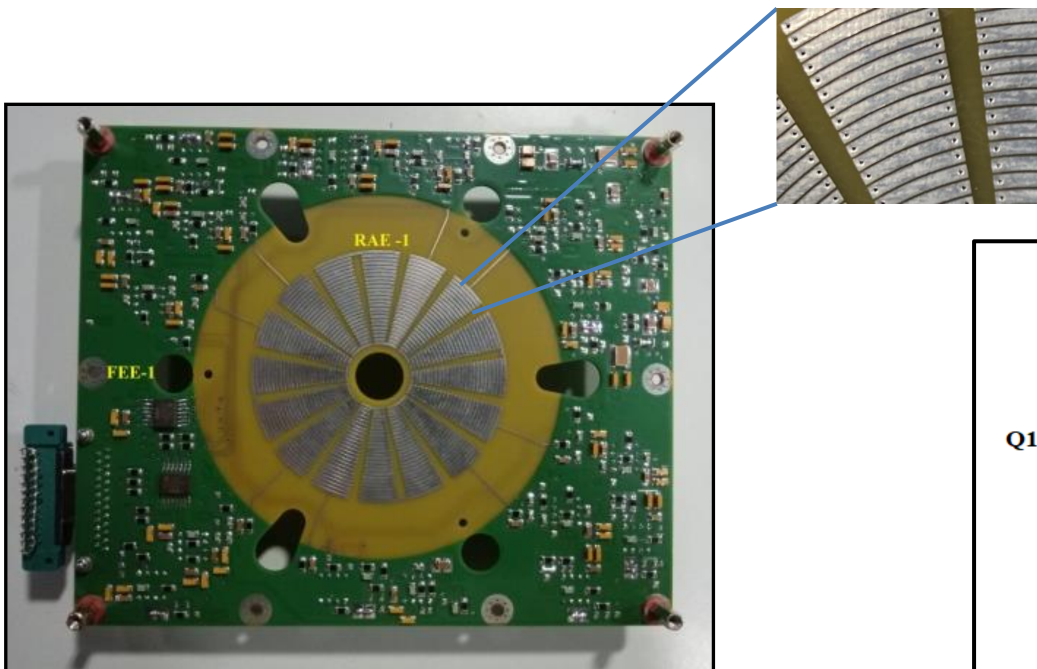


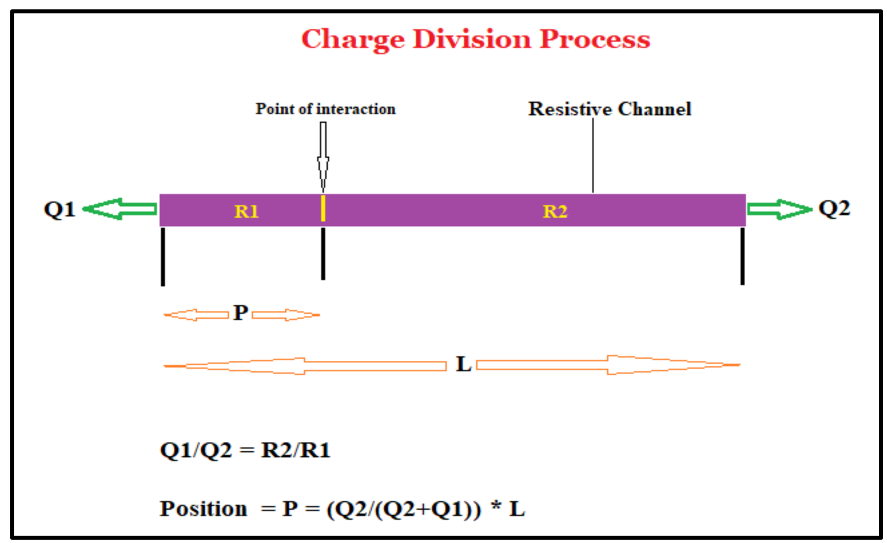


Directional information from RAEs

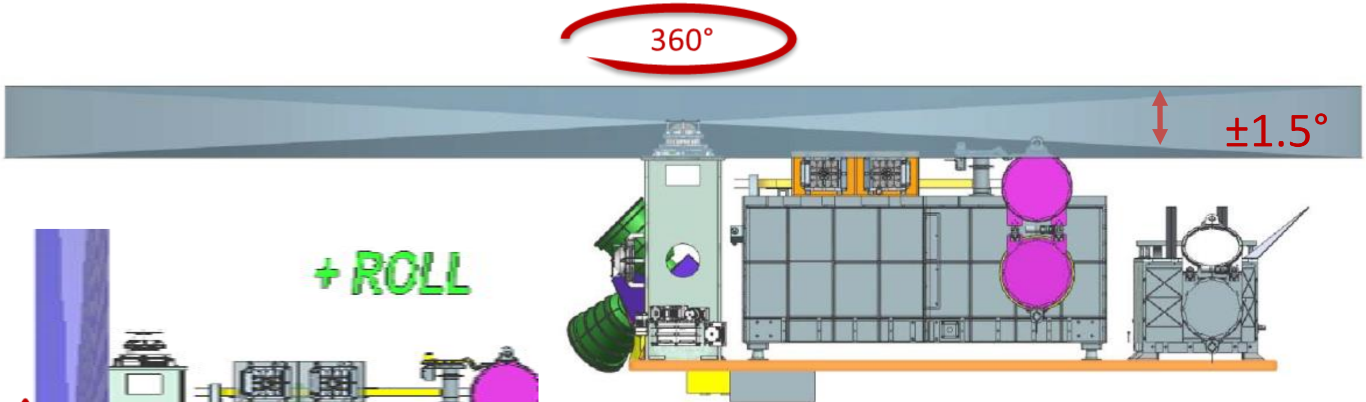
- ❑ Position sensitive anode developed in PRL
- ❑ Based on principle of charge division



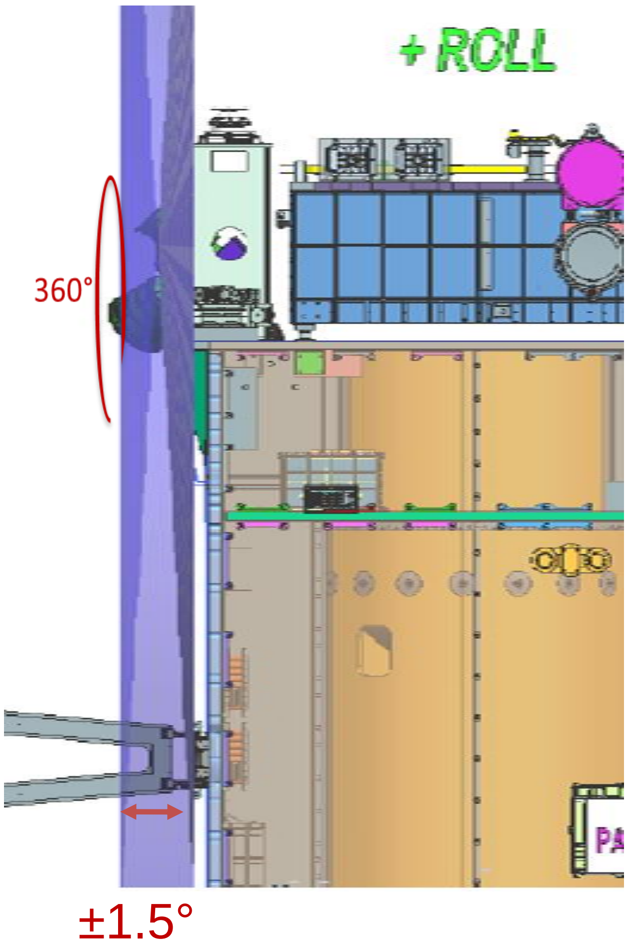




SWIS Field of View



THA-1 FOV
VIEW FROM + YAW

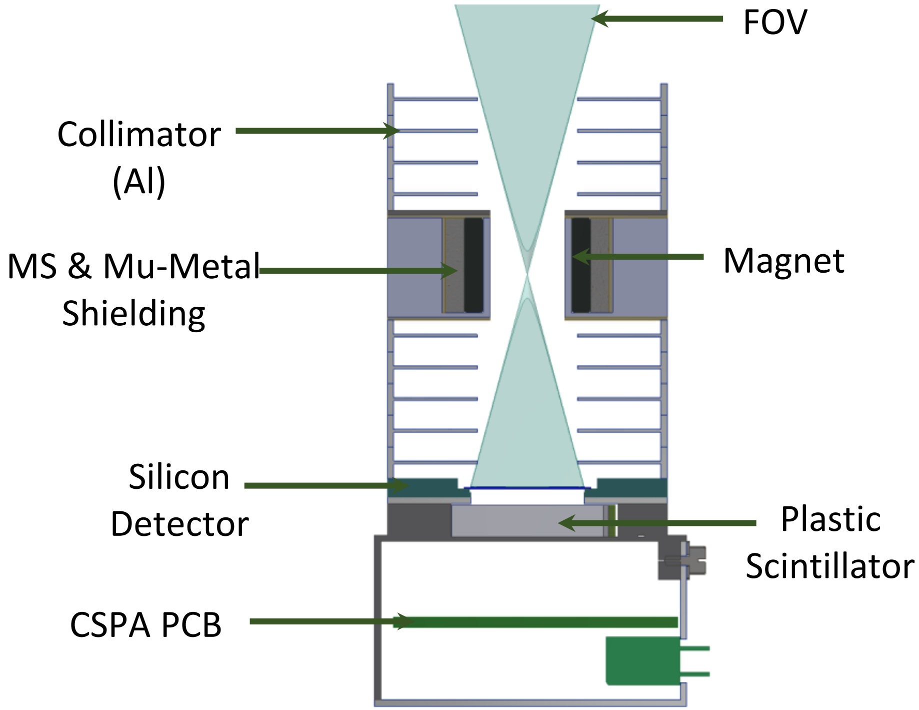


THA-2 FOV
VIEW FROM + YAW

STEPS /ASPEX

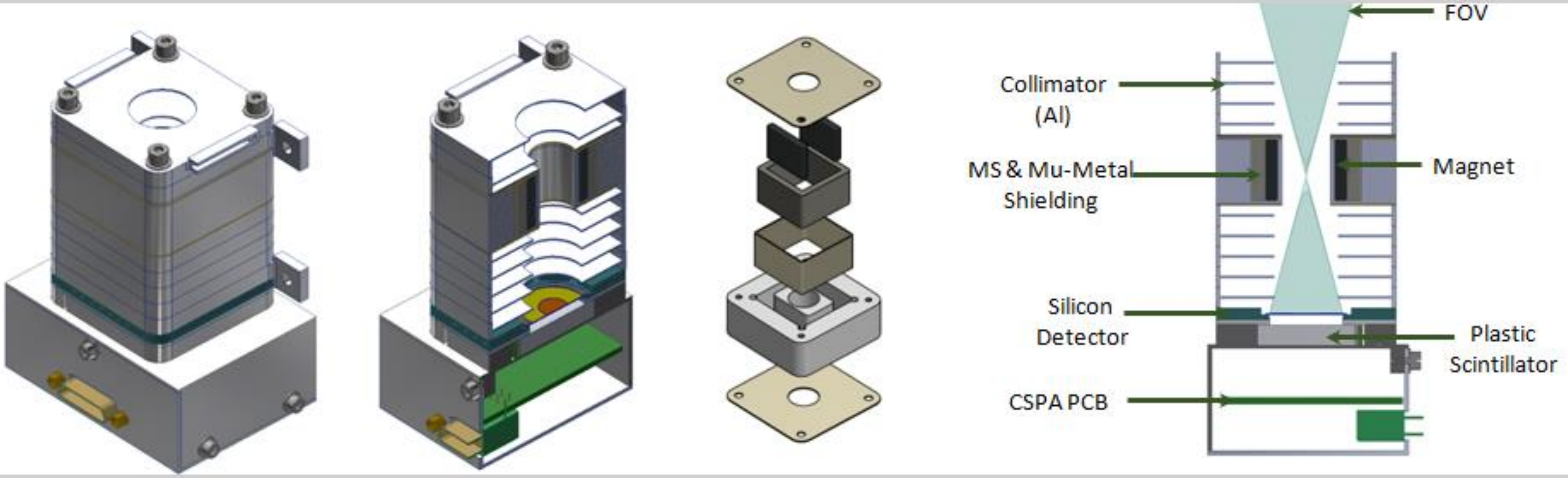
Configured as six different detector units

- Covers an energy range from 20 keV/n – 5 MeV/n
- Uses silicon detectors, 3 units additionally has plastic scintillator and SiPM for alpha particle differentiation
- 4 detector units mounted on top deck, two on the back panel (earth side)
- Magnets to deflect electrons

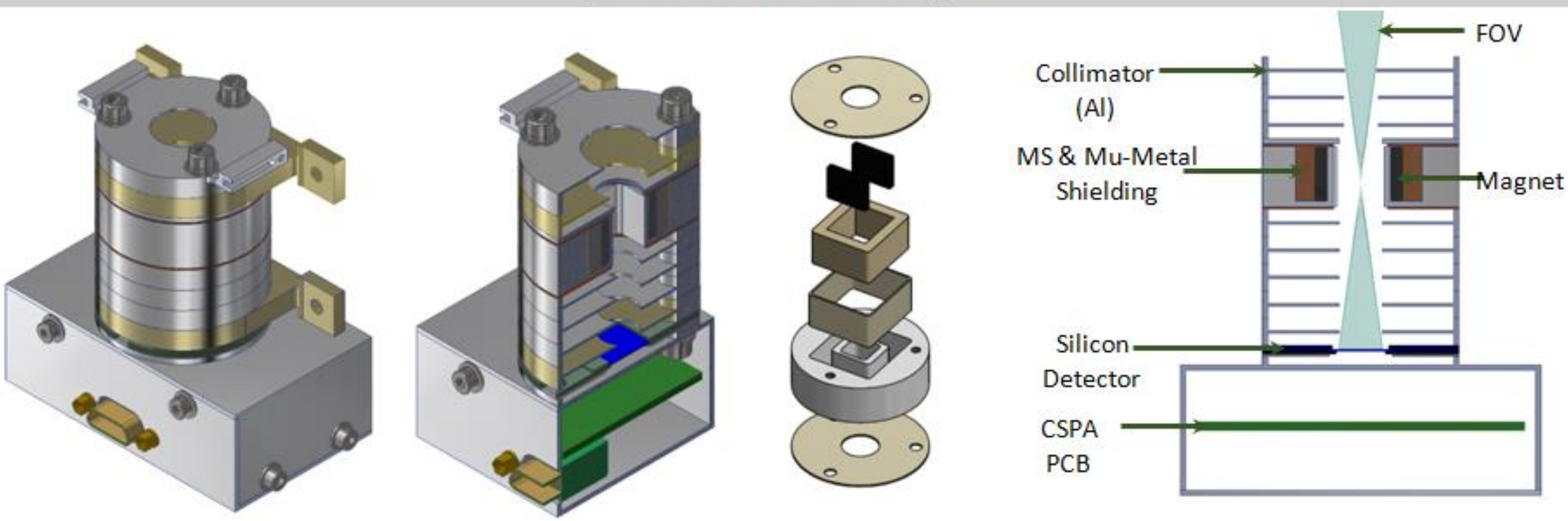


STEPS /ASPEX

Alpha and Proton Separated 3 units



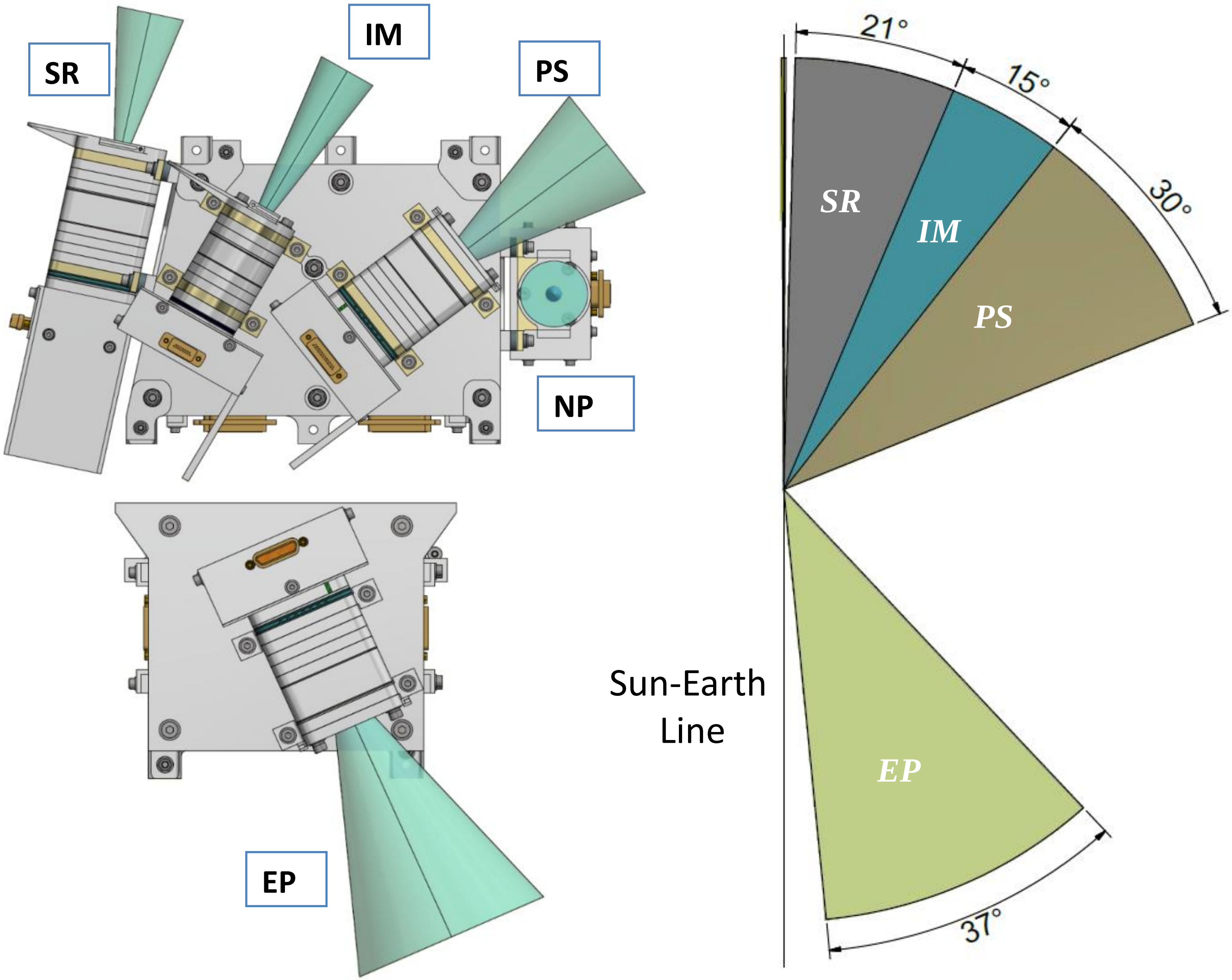
Alpha and Proton Integrated 3 units



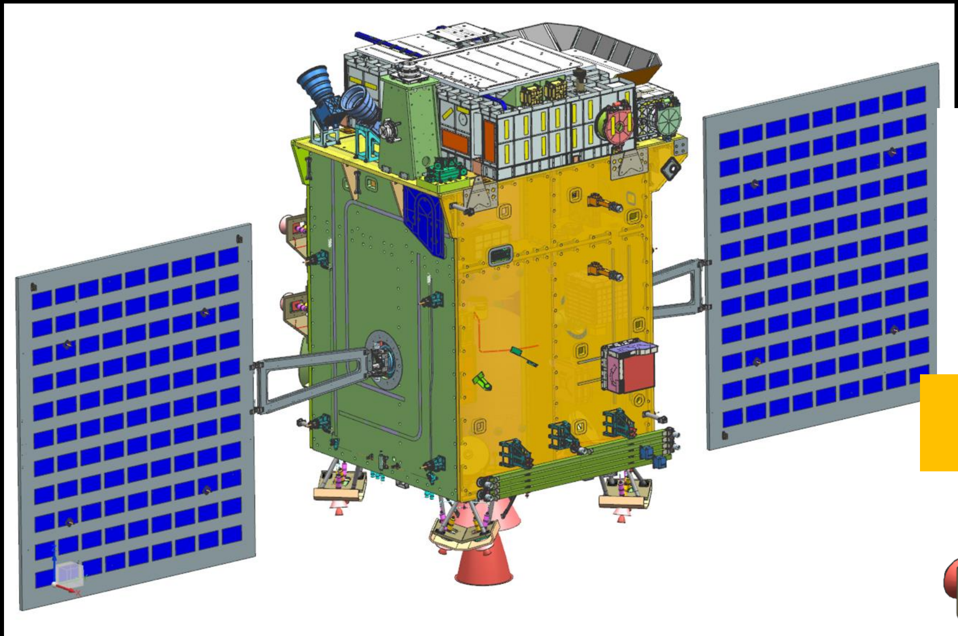
STEPS /ASPEX

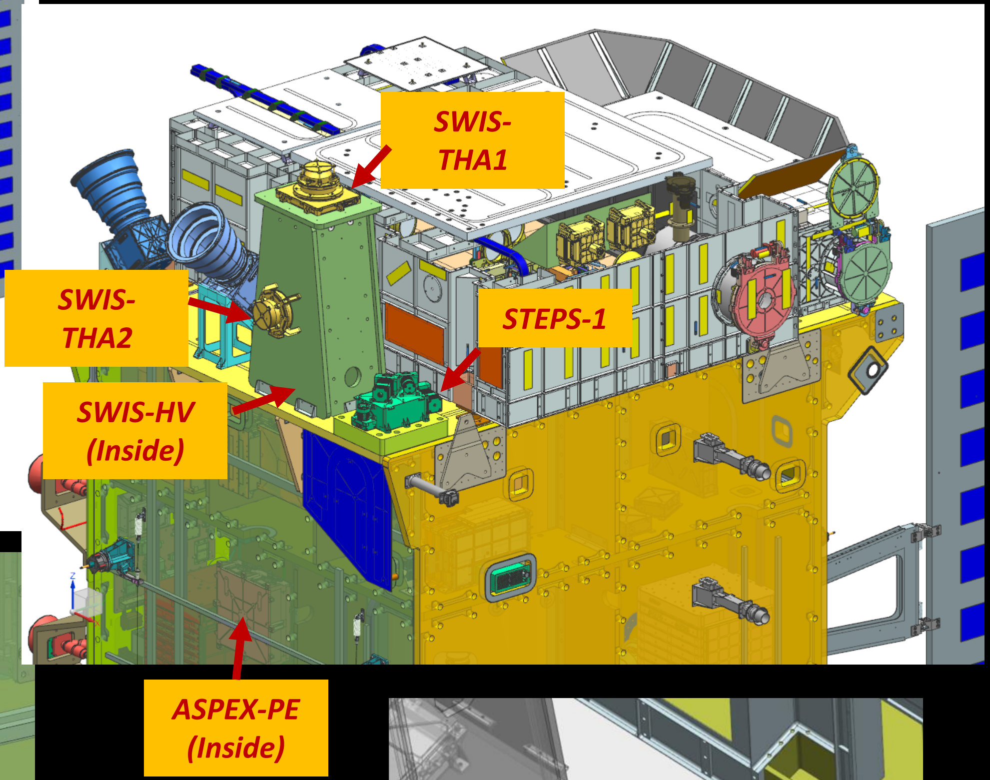
Type	Direction	FOV axis	FOV cone
Species (alpha-proton) separated spectra	Sun Radial (SR)	12^{o} W of Sun - spacecraft line, In ecliptic plane	$\pm 10.5^{o}$
	Parker Spiral (PS)	52.5^{o} W of Sun - spacecraft line, In ecliptic plane	$\pm 15^{o}$
	Earth Pointing (EP)	24^{o} W of Sun - spacecraft line, In ecliptic plane	$\pm 18.5^{o}$
Species integrated spectra	Intermediate (IM) - between Sun and Parker spiral	30^{o} W of Sun - spacecraft line, In ecliptic plane	$\pm 7.5^{o}$
	North Pointing (NP)	Perpendicular to ecliptic plane towards North	$\pm 14^{o}$
	South Pointing (SP)	Perpendicular to ecliptic plane towards South	$\pm 14^{o}$

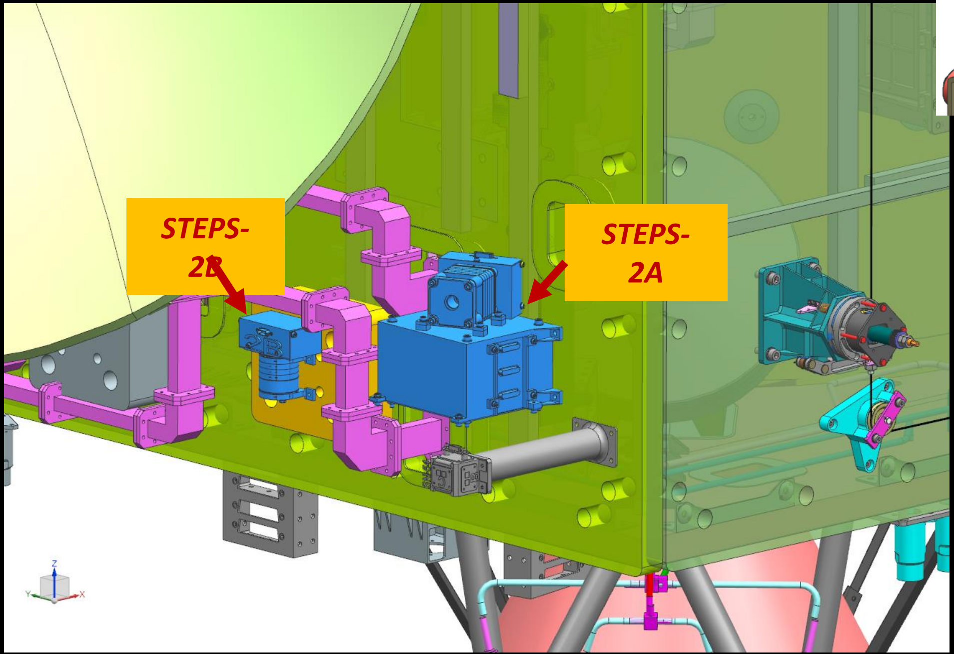
STEPS /ASPEX

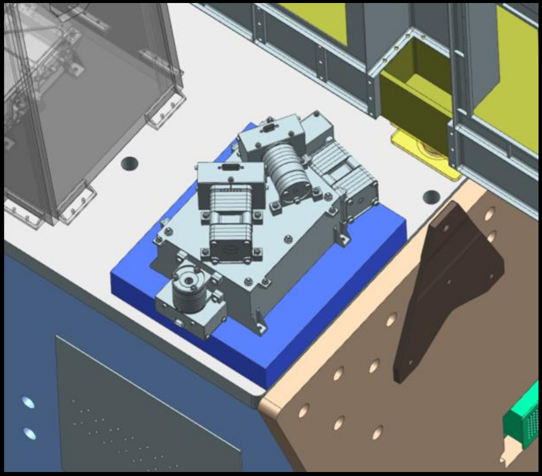


ASPEX package mounting locations on Aditya-L1







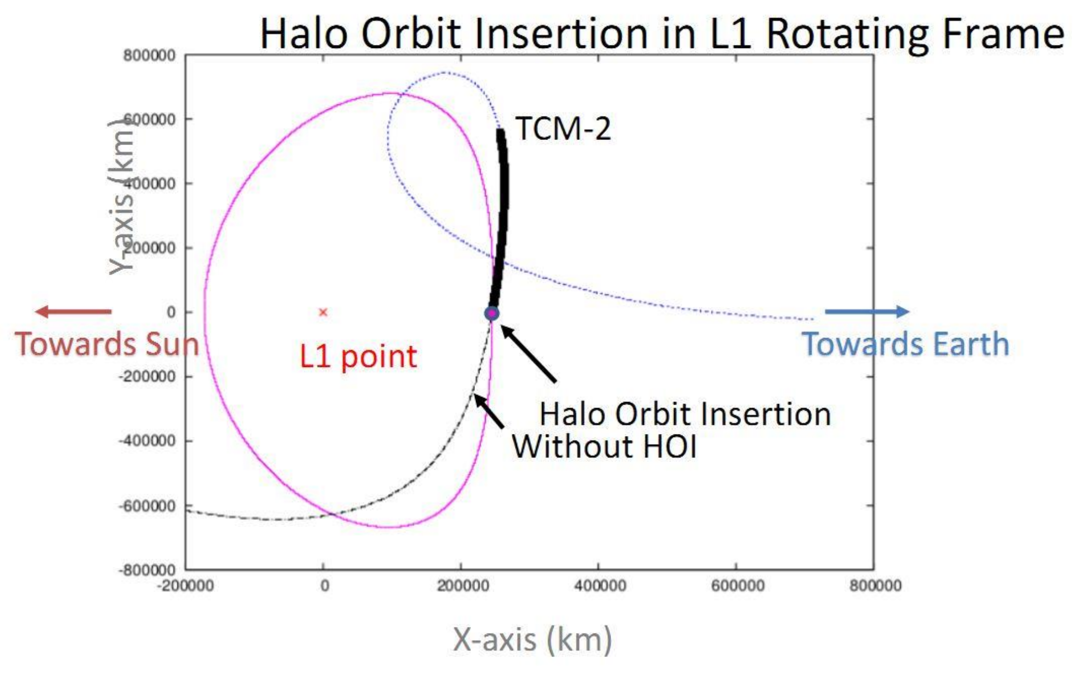


PSLV C57 was launched at 11:50 IST on 02 September 2023.

It successfully achieved its intended orbit nearly an hour later, and separated from its fourth stage at 12:57 IST.

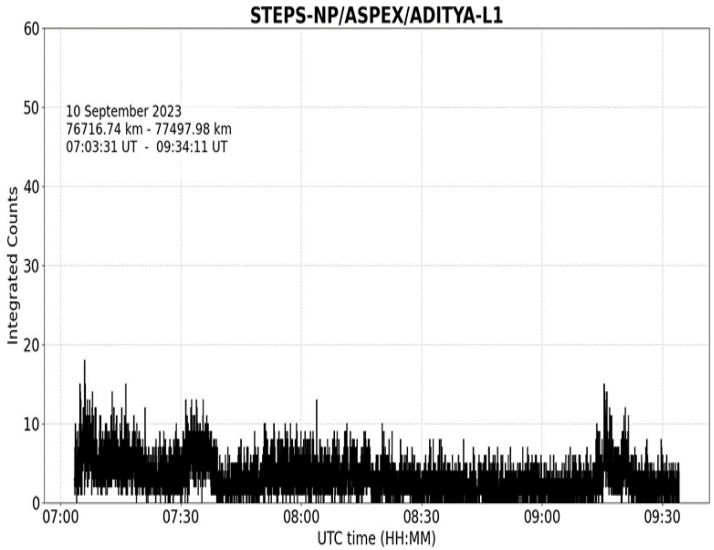
Cruise phase starts at 02:00 hrs IST on 19 September, 2023

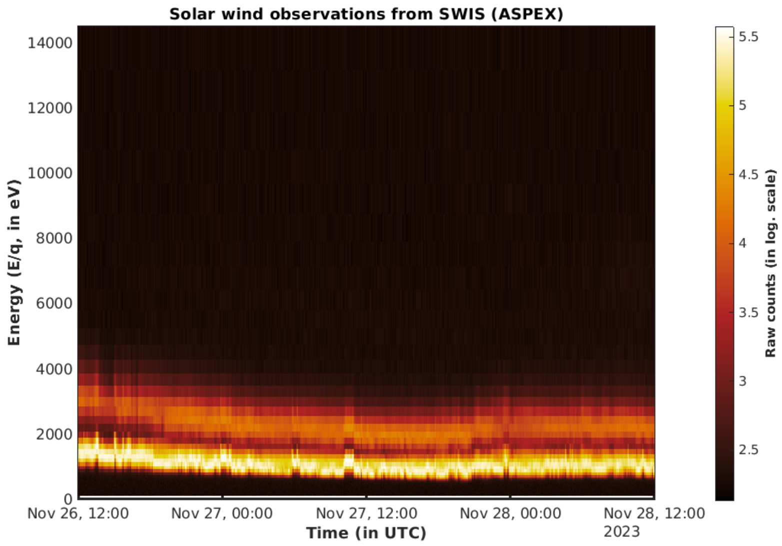
Halo Orbit Insertion at the L1 point on 6 January 2024, at 4:17 pm IST.




VDOS/URSC
VDOS/URSC

ASPEX : First light



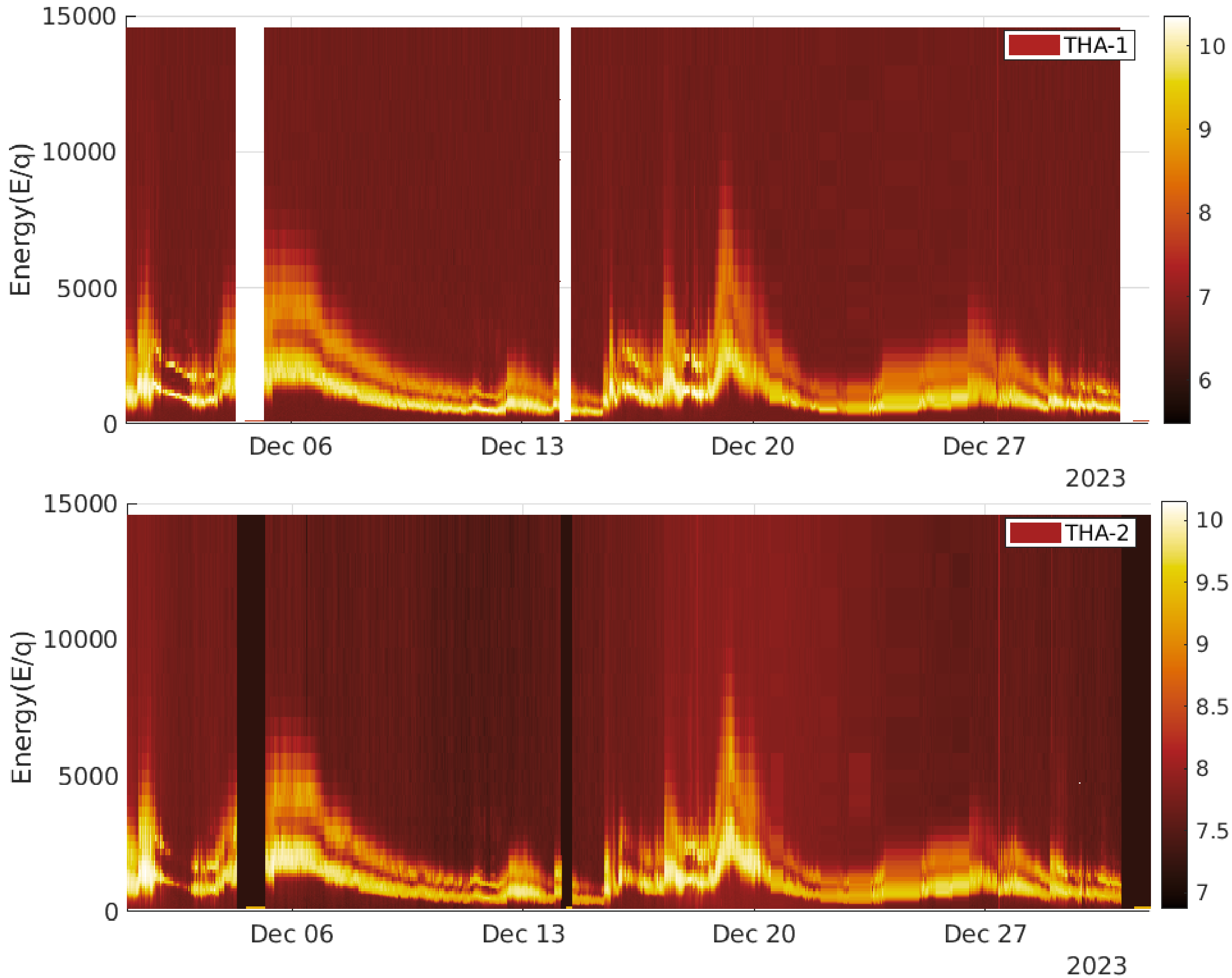


STEPS/ASPEX was commissioned on 10th September 2023. First light curve above.

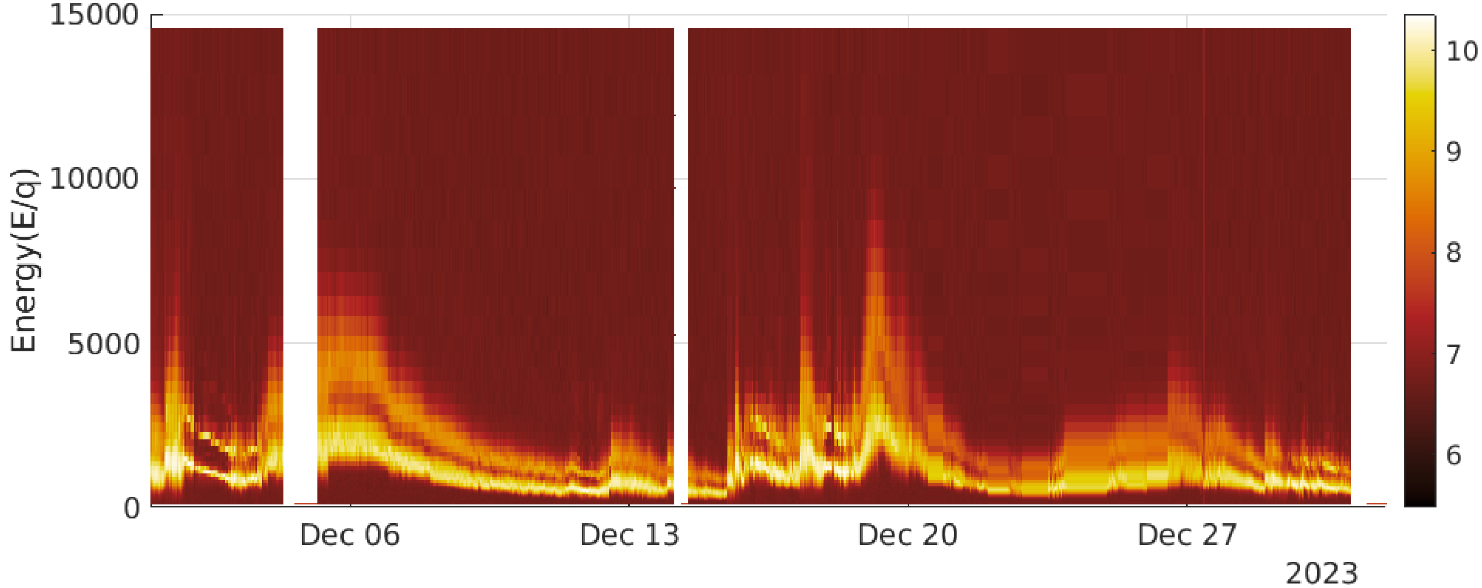
SWIS/ASPEX was commissioned on 2nd November 2023. Sample light curve above.

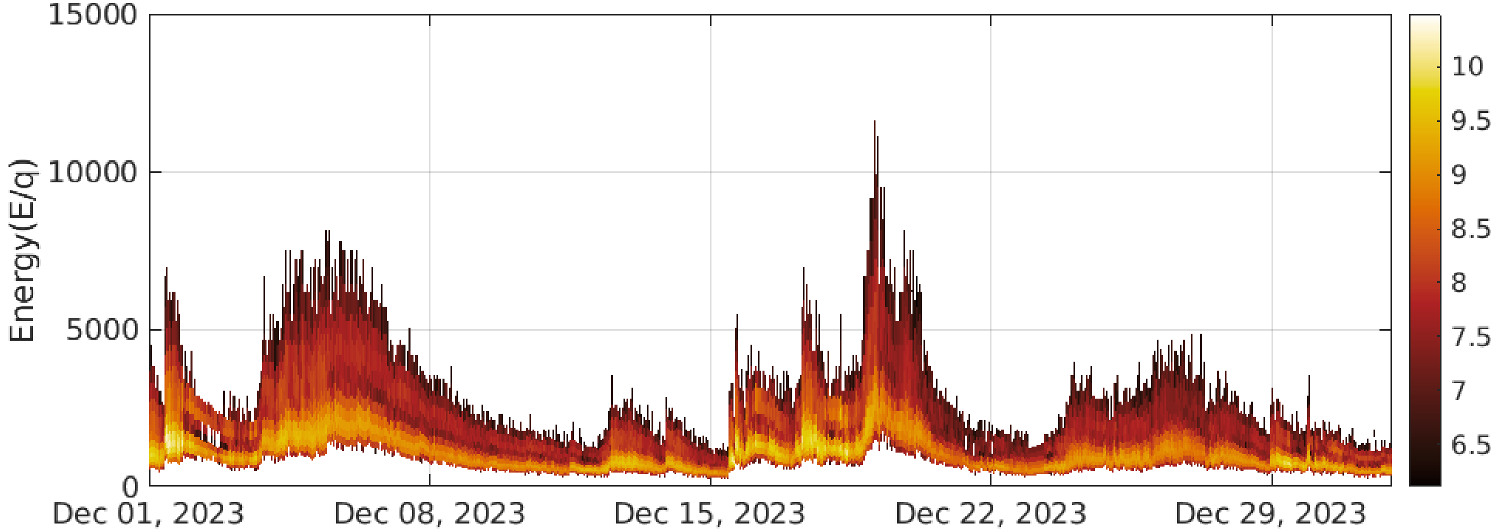
Both the instruments are continuously ON since commissioning

Comparison of THA-1 and THA-2



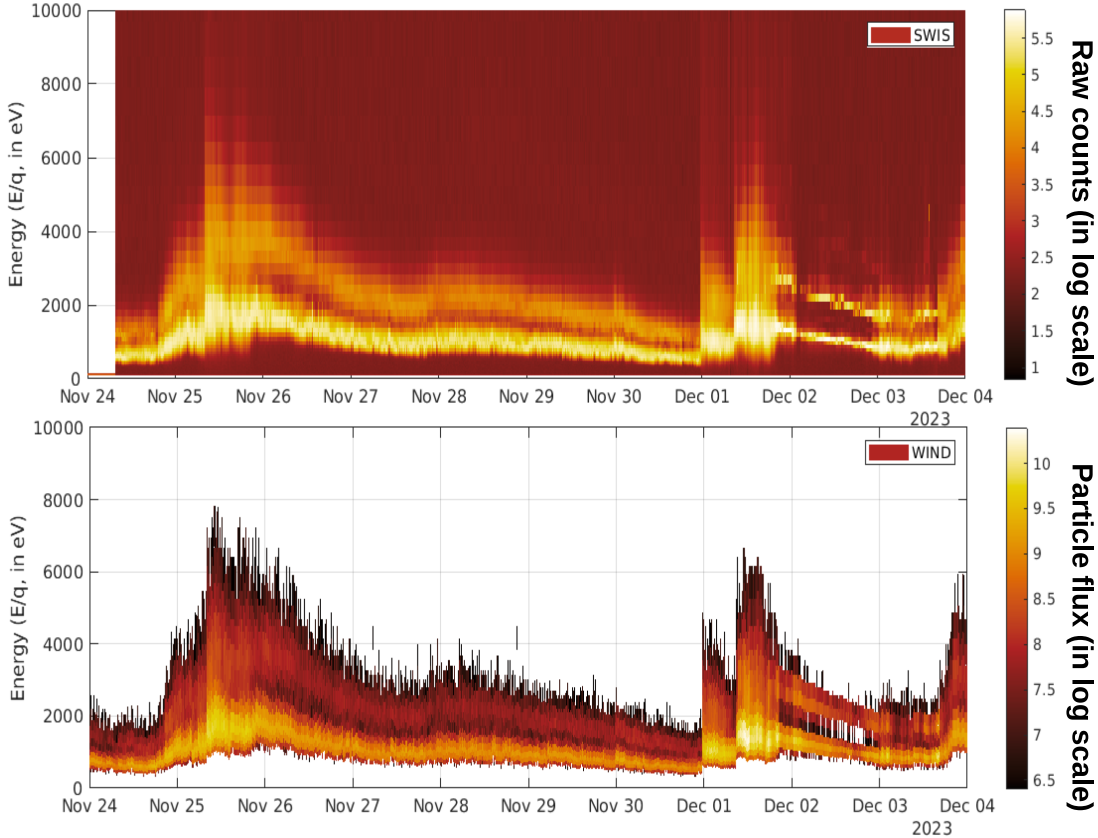
Comparison of THA-1 and WIND

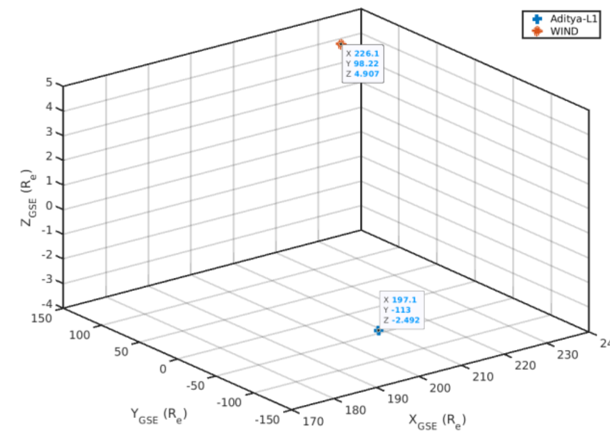




CMEs (~25 Nov and ~01 Dec, 2023) detected by ASPEX-SWIS-THA1

Comparison with WIND measurements

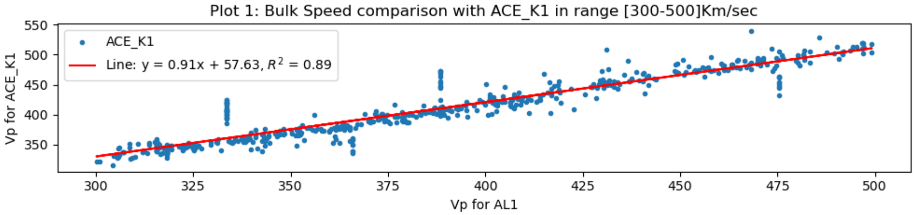


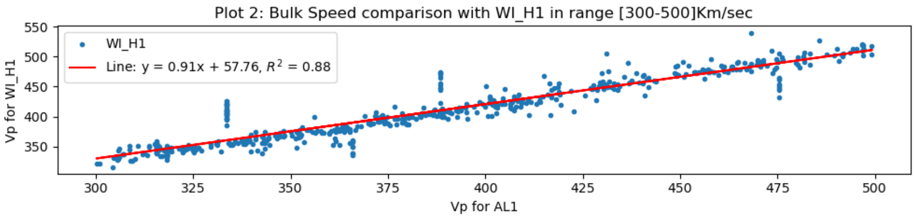


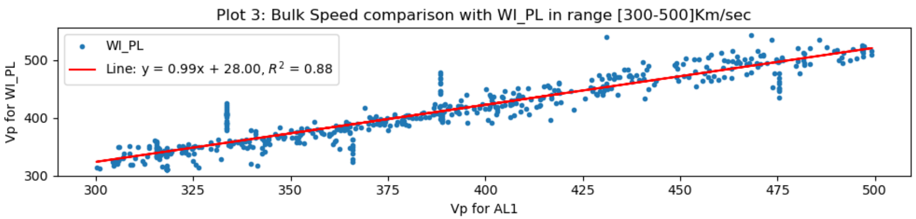
Position coordinates of Aditya-L1 and WIND

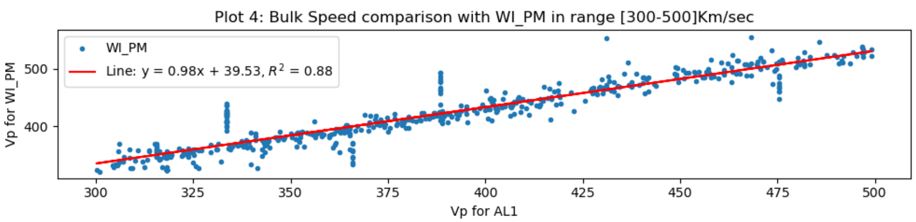
The two lines in the above curves correspond to Proton and Alpha particles

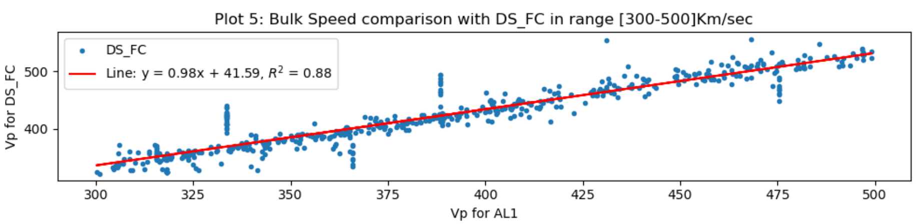
Comparison of Bulk parameters with WIND/ACE

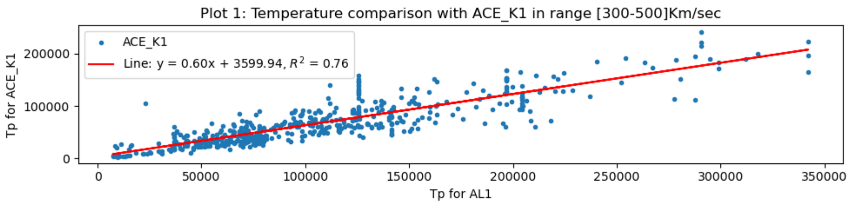


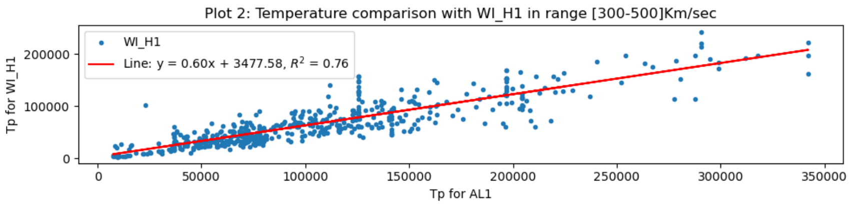


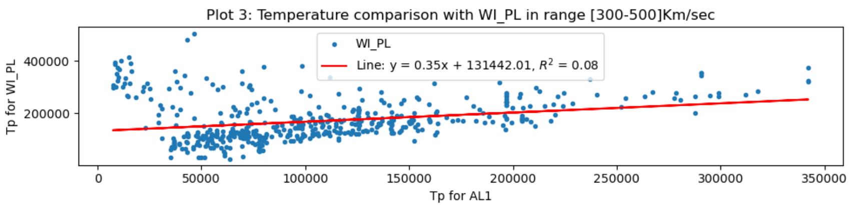


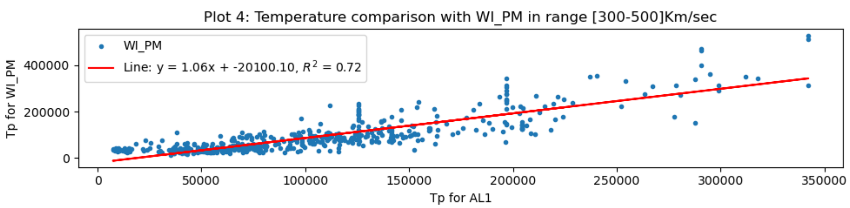


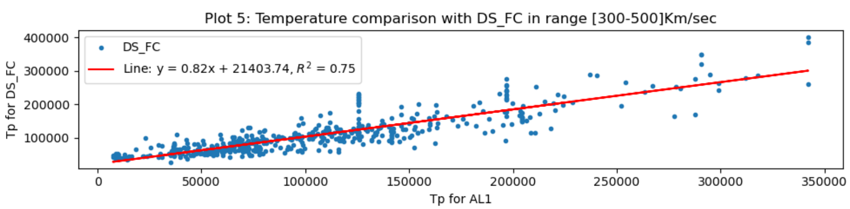






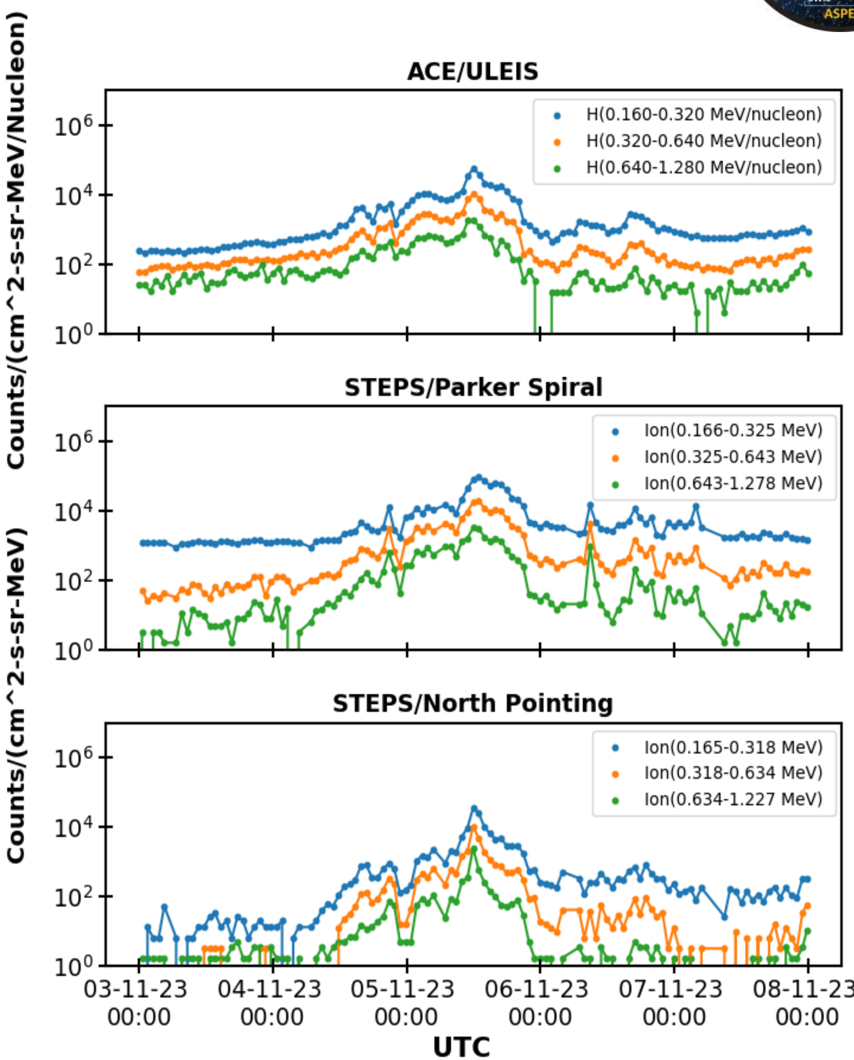


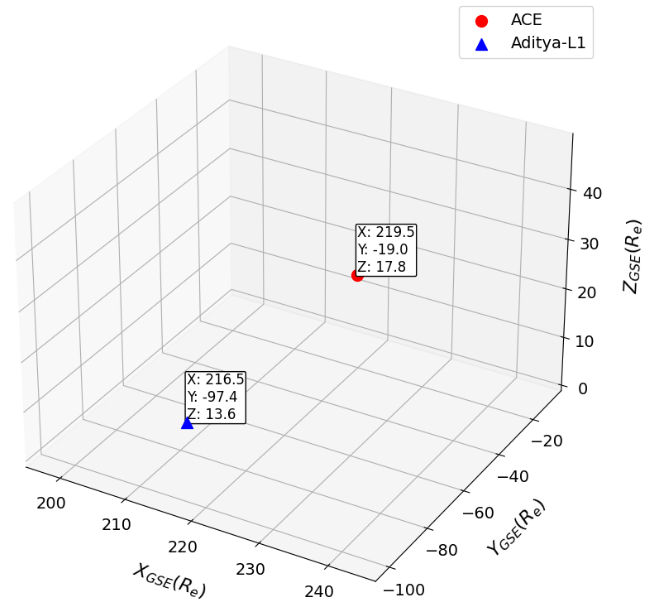




SEP events (~6 Nov, 2023) detected by ASPEX-STEPS-PS and NP units

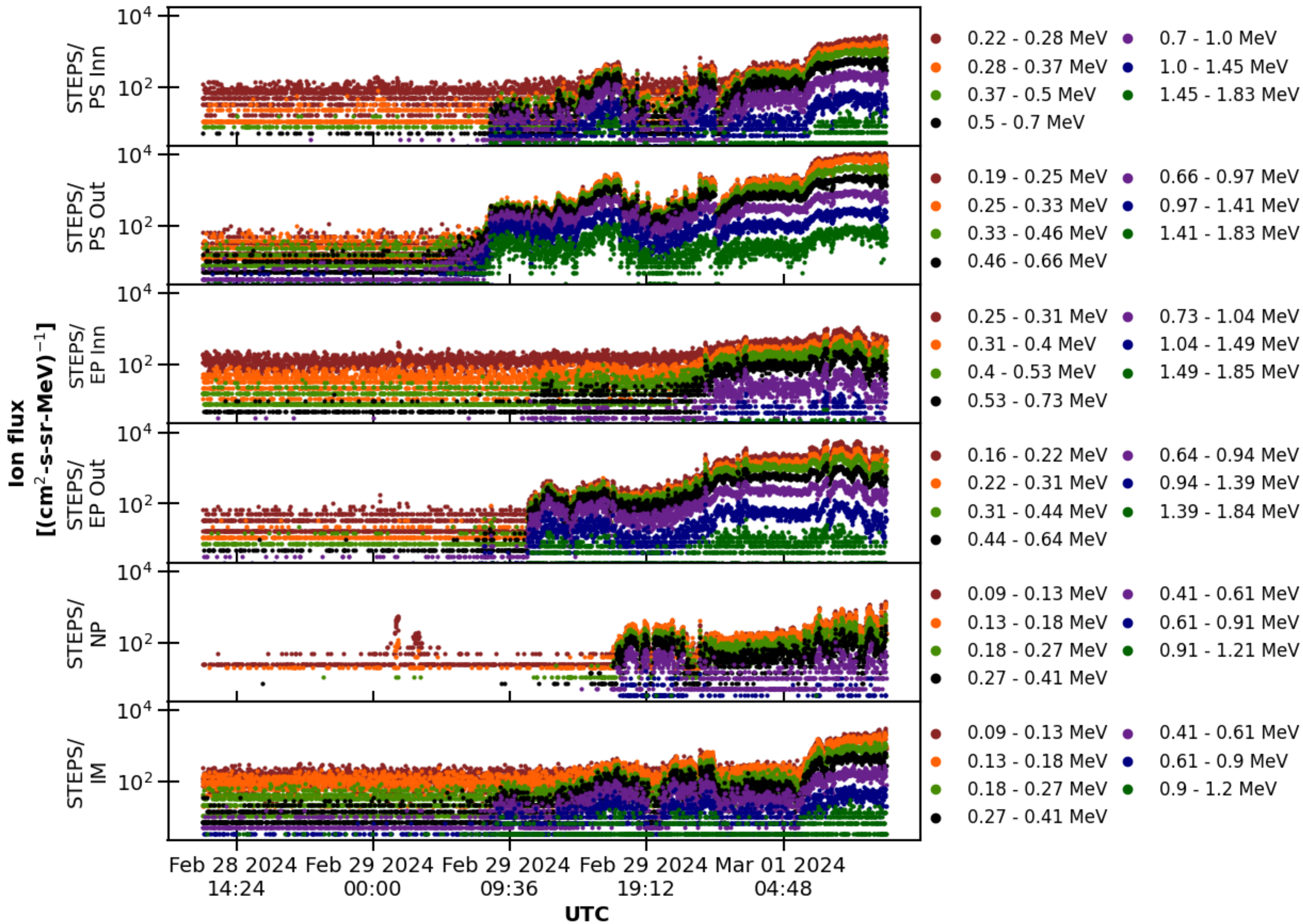
Comparison with ACE measurements



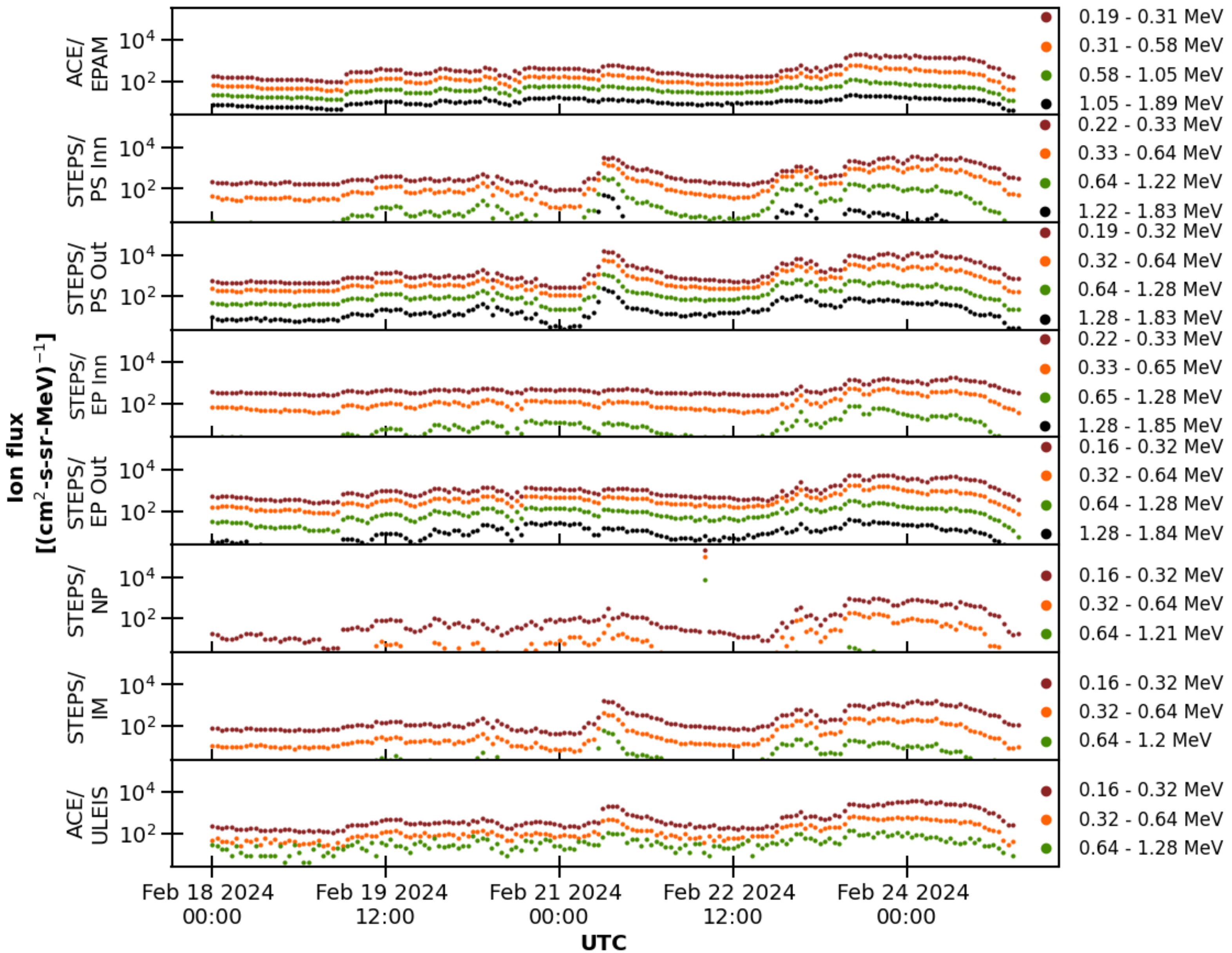


Position coordinates of Aditya-L1 and ACE

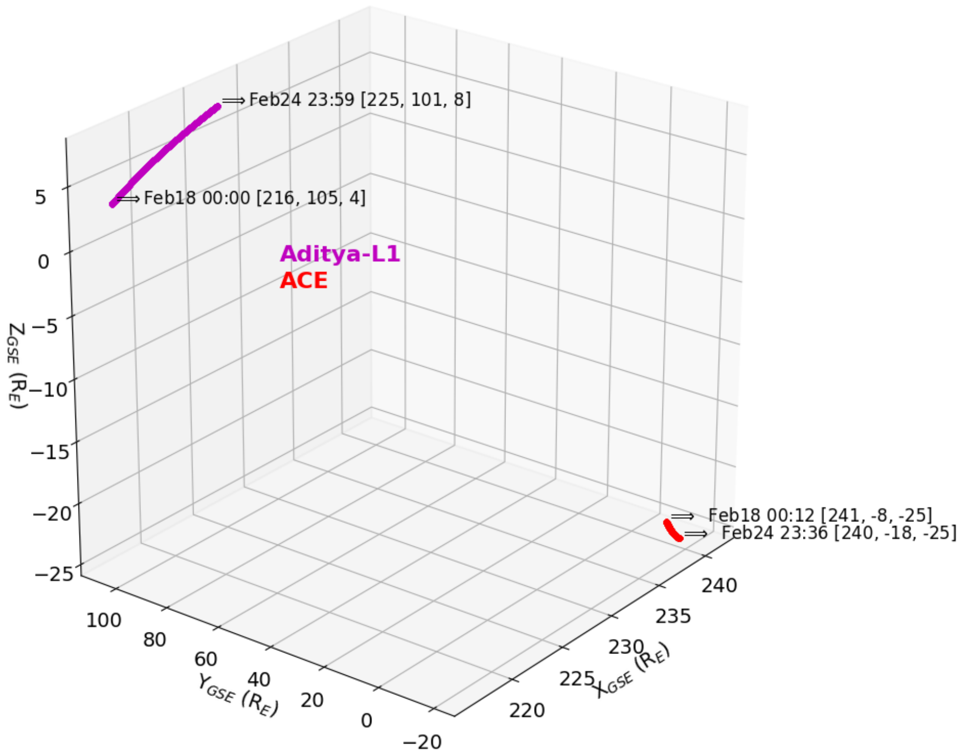
STEPS light curve

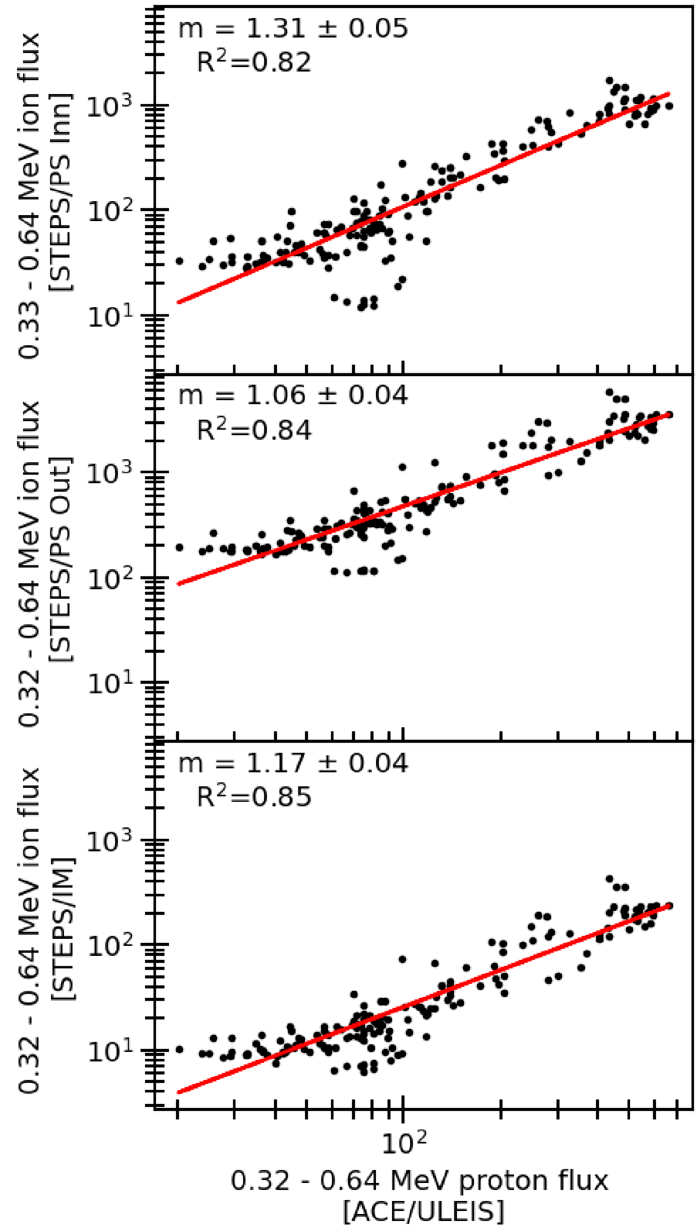


Comparison of STEPS with ULEIS/ACE

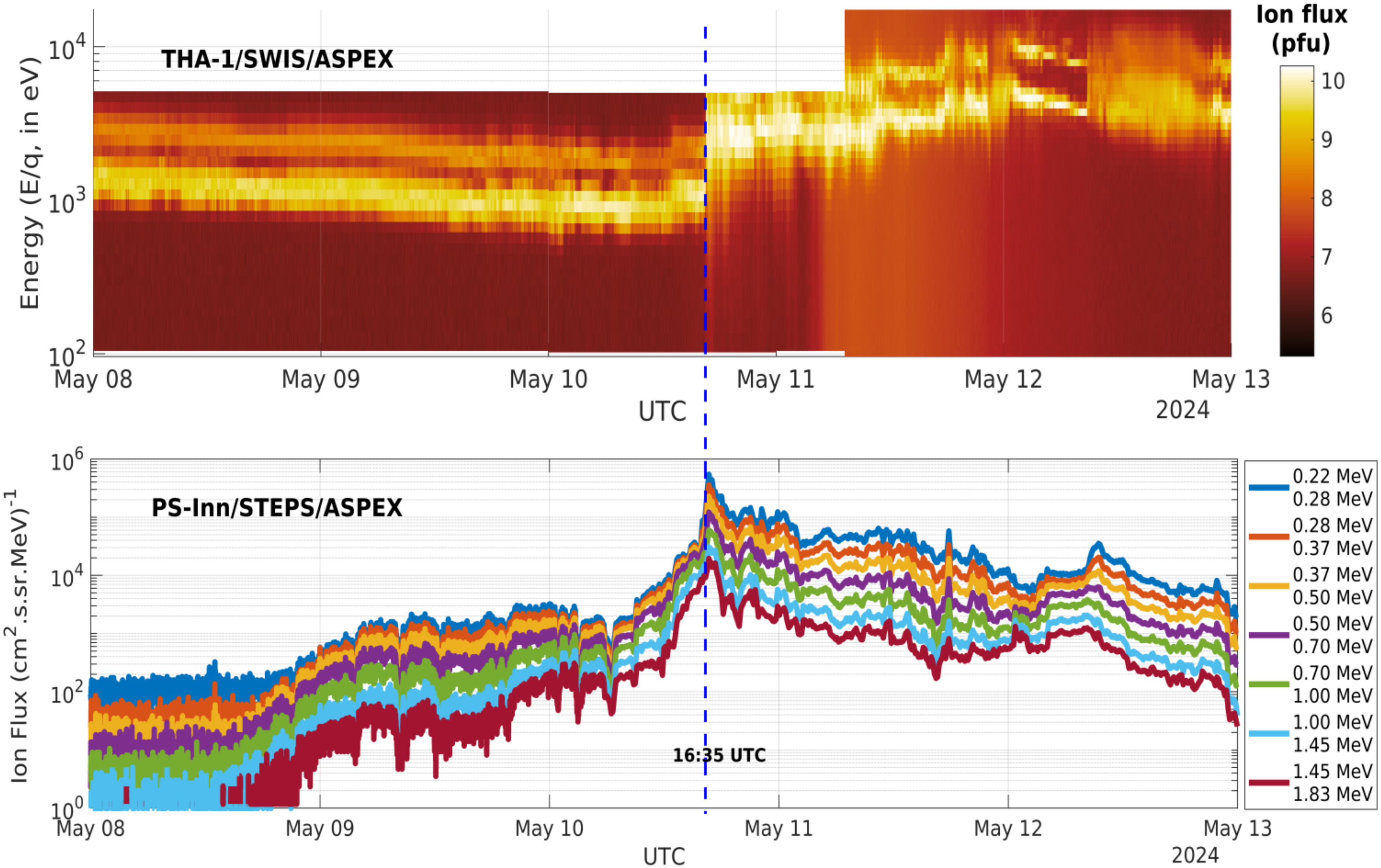


Comparison of STEPS with ULEIS/ACE





May 2024 Storm: Observations by SWIS and STEPS



Operation modes and Data description

Operation modes

SWIS operation modes

- Energy range, number of steps are programmable
- Data will be available at https://www.issdc.gov.in/
- Observations based on proposal submitted through ISSDC-Aditya L1 Proposal Processing System (AL1PPS)
- Predefined two modes of operation based on integration time (50 ms, 450 ms for 50 energy steps)
- By default, bulk parameters can be obtained at 25 or 5 sec cadence, can be programmed to even faster rates by limiting energy range and steps

STEPS operation modes

- Will operate only in the default mode with 1 sec integration time

Data levels

Data level	Description
Level 0	Raw data (12 hour dump) obtained from ISSDC. L0 tar consisting of the payload frame, time correlation, TM, HK and orbit and attitude information (SPICE kernels).
Level 1	Combined valid payload frames and UT derivation from L0 data, segregated science and auxiliary data CDF Format
Level 2 (SWIS)	Direction differentiated flux for proton and alpha particles at each energy obtained after final calibration, bulk parameters: number density, velocity and temperature CDF Format
Level 2 (STEPS)	Level-2 will be calibrated spectrum data file for six directions. It contains particle differentiated spectra in SR, PS and EP detectors and particle integrated spectrum in IM, NP and SP detectors. CDF Format

CDF : Common Data Format

CDF files are made ISTP compliant as per NASA's SPDF requirements

ASPEX : Resources

ASPEX website (https://www.prl.res.in/ASPEX/)

- ❑ Quick look of data
  - ❑ Light curves (STEPS) and Energy histogram (SWIS)
- ❑ Software to read level 1 and level 2 data files of SWIS and STEPS
- ❑ Calibration database
- ❑ Relevant documents (Software manual, proposal guidelines (SWIS), etc.)

ASPEX Team

Thank you for your attention