Heliophysics System Observatory

NASA Heliophysics Data Resources

Exploring HDRL, SDAC, SPDF, HelioCloud, & Open Science

Heliophysics Summer School 2025

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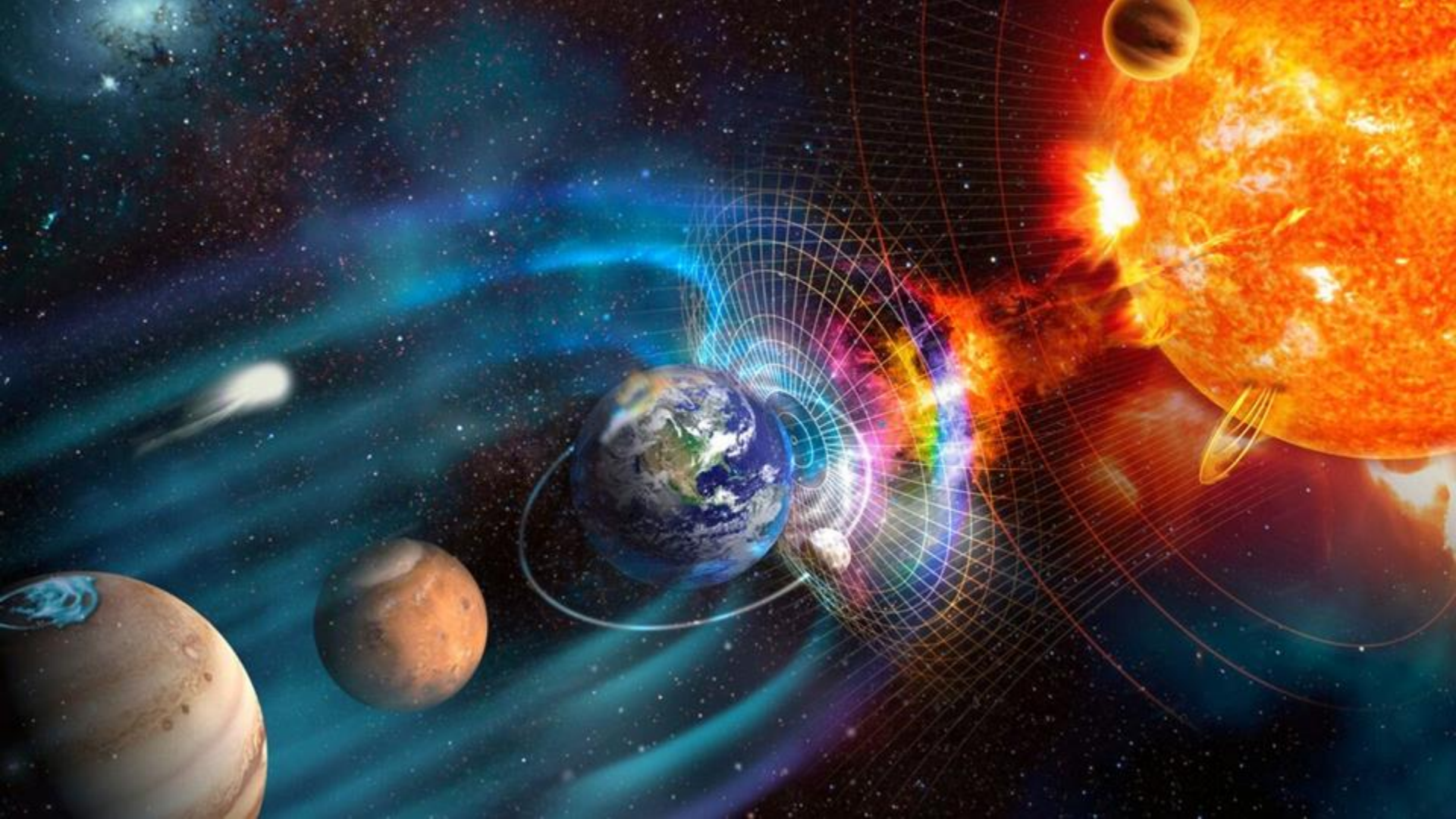
Heliophysics Science Division

Associate Director for Science Communication

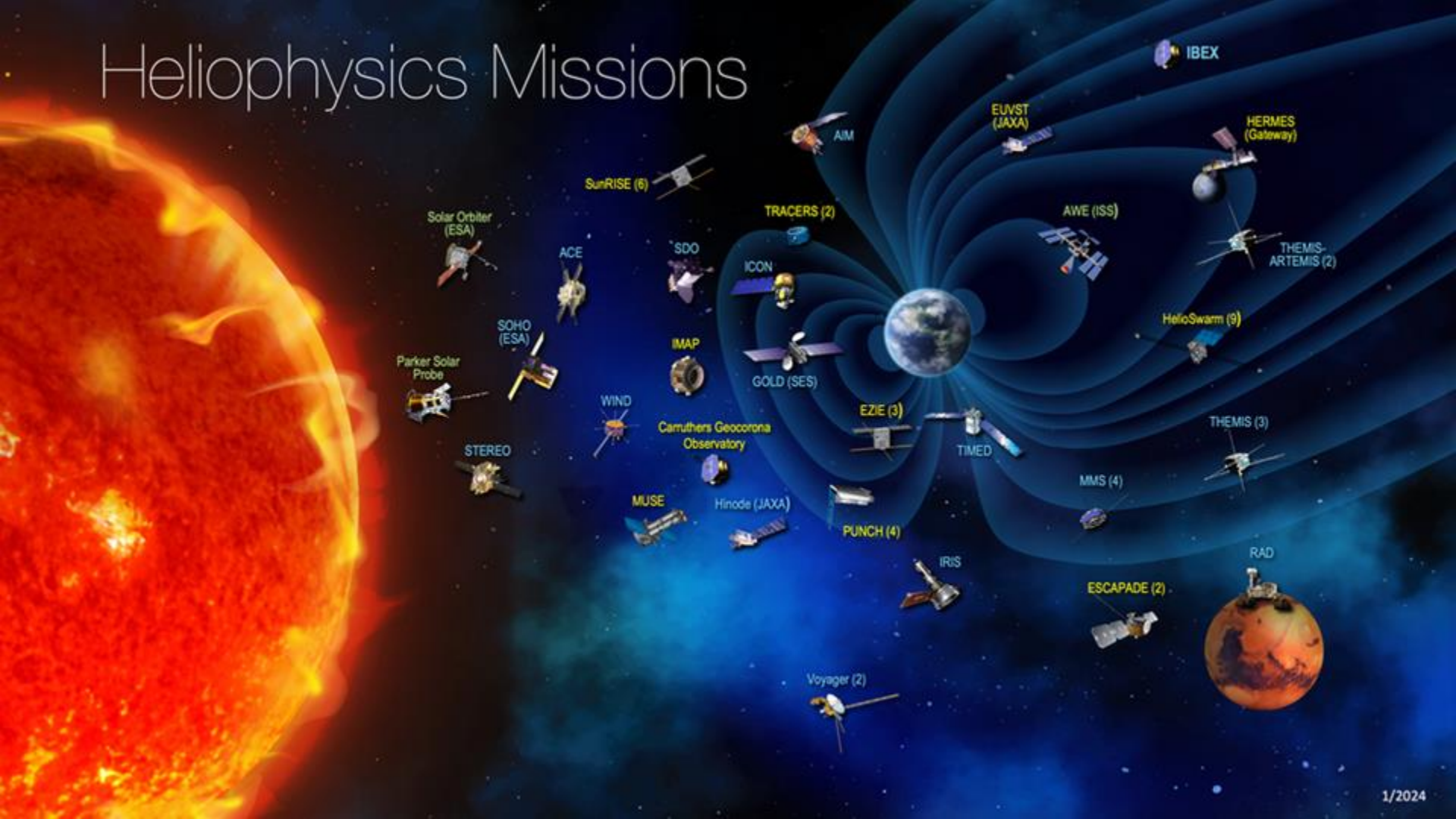
Benefits

Enable you to do your science by making data and computing resources available.

Help you find the knowledge and connections to facilitate research and collaborations.



Heliophysics Missions



Features

Legacy Coverage

65+ Years of Space Missions

Comprehensive data coverage in heliophysics

Solar Missions

- SOHO: LASCO, EIT, SUMER, VIRGO
- SDO: AIA, HMI
- STEREO: Dual perspective

Wind & Magnetospheric

- ACE: Solar Wind Ionosphere
- Cluster: Magnetic Field
- THEMIS: Aurora borealis

Legacy & Historical

- SMM, Yohkoh, TRACE
- Helios, Ulysses
- Legacy data: 1970s to present

Data Coverage Impact

Multi-decade observations

Comprehensive spatial coverage

Detailed temporal resolution

Why HDRL Matters

The scale and impact of heliophysics data infrastructure

Massive Scale

2.5 PB

Data across 300 million files

Legacy Coverage

65+

Years of space missions

Open Science Impact

- Real-time space weather forecasting
- NOAA & NASA mission support
- National security systems
- International research collaboration

Time-Centric
Search by time intervals

Mission-Centric
Cross-mission analysis

Event-Centric
Solar event correlation

SPASE Metadata
Standardized discovery

"Enabling reproducible, collaborative heliophysics research at global scale"

Research Applications

HDRL enables diverse research applications across the heliophysics ecosystem:

Analysis Tools

- SolarSoft (IDL): Legacy instrument packages
- SunPy (Python): Modern analysis framework

Cloud Platforms

- HelioCloud: Cloud-native research infrastructure
- 600+ TB: Scalable analysis environment

Visualization Tools

- 4-D Orbit Viewer: Interactive 3D + Time visualization
- Web-based Solar: Browser visualization

Web Interfaces

- CDAWeb: Browser-based access to Level-2 datasets
- OMNIWeb: Solar wind data visualization

Python Ecosystem

- SunPy: Solar physics analysis
- PySPEDAS: Multi-mission data analysis

Data Standards

- CDF Format: Self-describing data format
- SPASE Model: Standardized metadata

Python Ecosystem for Space Physics

Python has become the de facto programming language for heliophysics data analysis, providing powerful tools for data processing and visualization.

SunPy

Core package for solar physics data analysis

- Map Objects: 2D spatial solar observations
- TimeSeries: 1D temporal measurements
- Astropy: Full ecosystem integration

PySPEDAS

Multi-mission analysis framework

- 30+ Missions: MMS, THEMIS, PSP, etc.
- tplot Model: Multi-panel time series plots
- Unified Loading: Consistent data interface

PyHC

Community resources for Python training

- Summer School: 5-day intensive training
- Core Packages: Kamodo, PlasmaPy, pysat, SpacePy
- Open Access: Free attendance + NSF travel support

Additional Resources:

- Hands-on Jupyter Notebooks
- Comprehensive Documentation
- Community Support Forums

Advanced Modeling & Analysis Platforms

HDRL provides advanced platforms that enable sophisticated analysis and modeling of heliophysics data

HelioCloud Advanced

AI/ML Integration
Frontier Development Lab for machine learning on heliophysics data

Anomaly Detection
Pattern recognition algorithms to identify unusual solar events

Citizen Science
Public engagement projects enabling community participation

Scalable Compute
GPU clusters for deep learning and high-performance computing

Kamodo Framework

NASA CCMC
Model-agnostic framework for multi-physics modeling

Global Models
Support for TIE-GCM, SWMF, OpenGGCM and other global models

Run-on-Request
Interactive model execution with parameter customization

Format-Agnostic
Universal data readers supporting multiple formats

Introduction & Context

What challenges do you face accessing heliophysics data?

HDRL Ecosystem

- NASA's federated "system-of-systems"
- Three cooperating pillars: SDAC, SPDF, HP Consortium
- Unified access with standardized formats
- RESTful/HAPI interfaces for automation

Comprehensive Data Registry & Analysis Tools

Think about your current data workflow challenges as we explore solutions together

Open Science Discussion

Findable

- ✓ SPASE metadata with persistent DOIs
- ✓ Comprehensive registries
- ✓ Time/mission/event-based discovery

Interoperable

- ✓ Standard formats (CDF, FITS, netCDF)
- ✓ Unified metadata schemas (FITS, SOLARNET, ISTP)
- ✓ HAPI protocol compliance

Accessible

- ✓ Multiple access methods (web, API, bulk)
- ✓ Clear licensing and documentation
- ✓ Zero-embargo by end-2025

Reusable

- ✓ Open-source analysis tools
- ✓ Documented workflows
- ✓ Version control & reproducibility

Community Experiences

What open repositories have you used? What worked well?

Common Challenges

Data discovery, format inconsistencies, documentation gaps

How HDRL addresses Open Science barriers

Common Challenges

Data Fragmentation
Scattered across multiple repositories with different access methods

Format Inconsistencies
Varying data formats requiring specialized tools and knowledge

Metadata Gaps
Insufficient documentation for data discovery and interpretation

HDRL Solutions

Federated Access
Single entry point to **2.5** PB across all major heliophysics archives

Standardized Formats
CDF, FITS, netCDF with ISTP compliance and unified interfaces

Rich Metadata
SPASE model with DOI citations and comprehensive documentation

NASA Policy Alignment

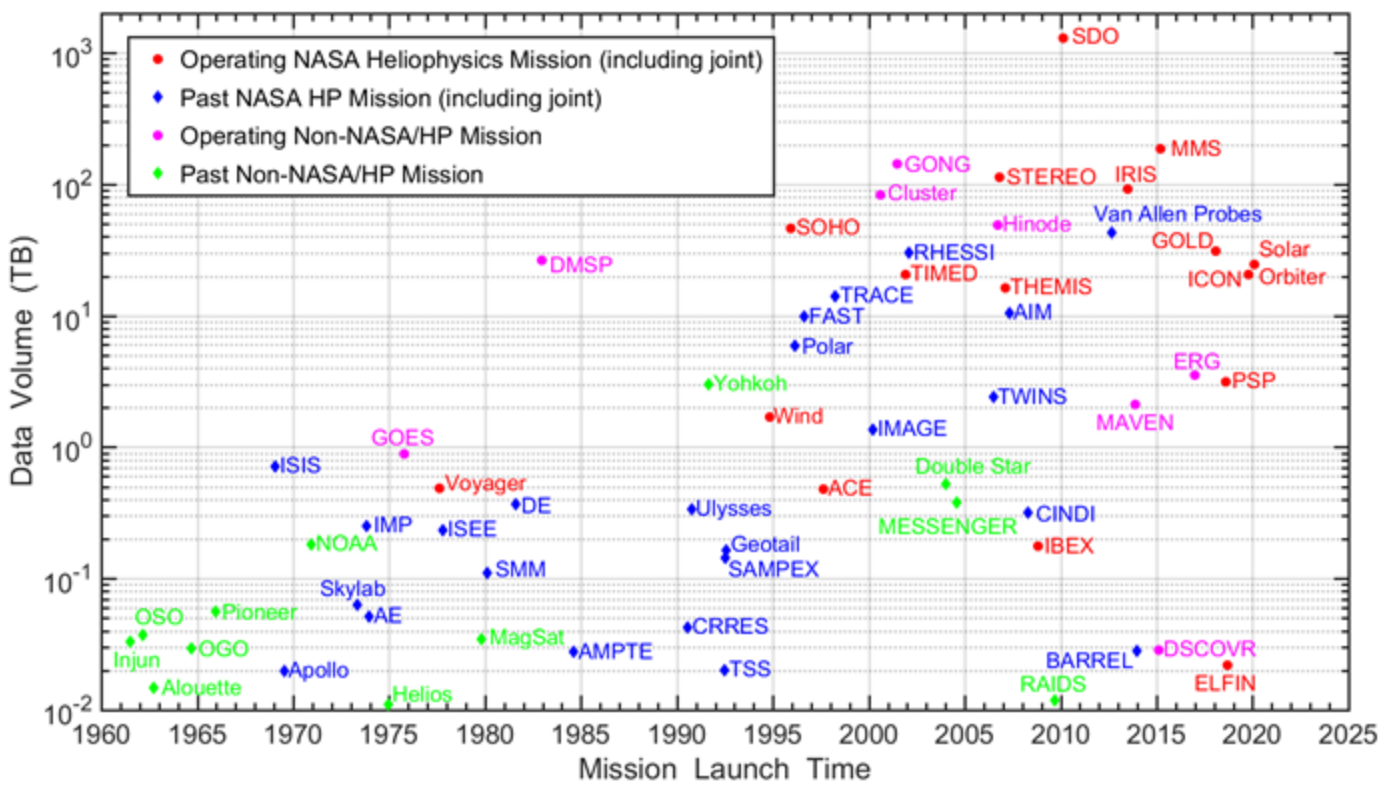
SPD-41a Compliance: Public data at publication

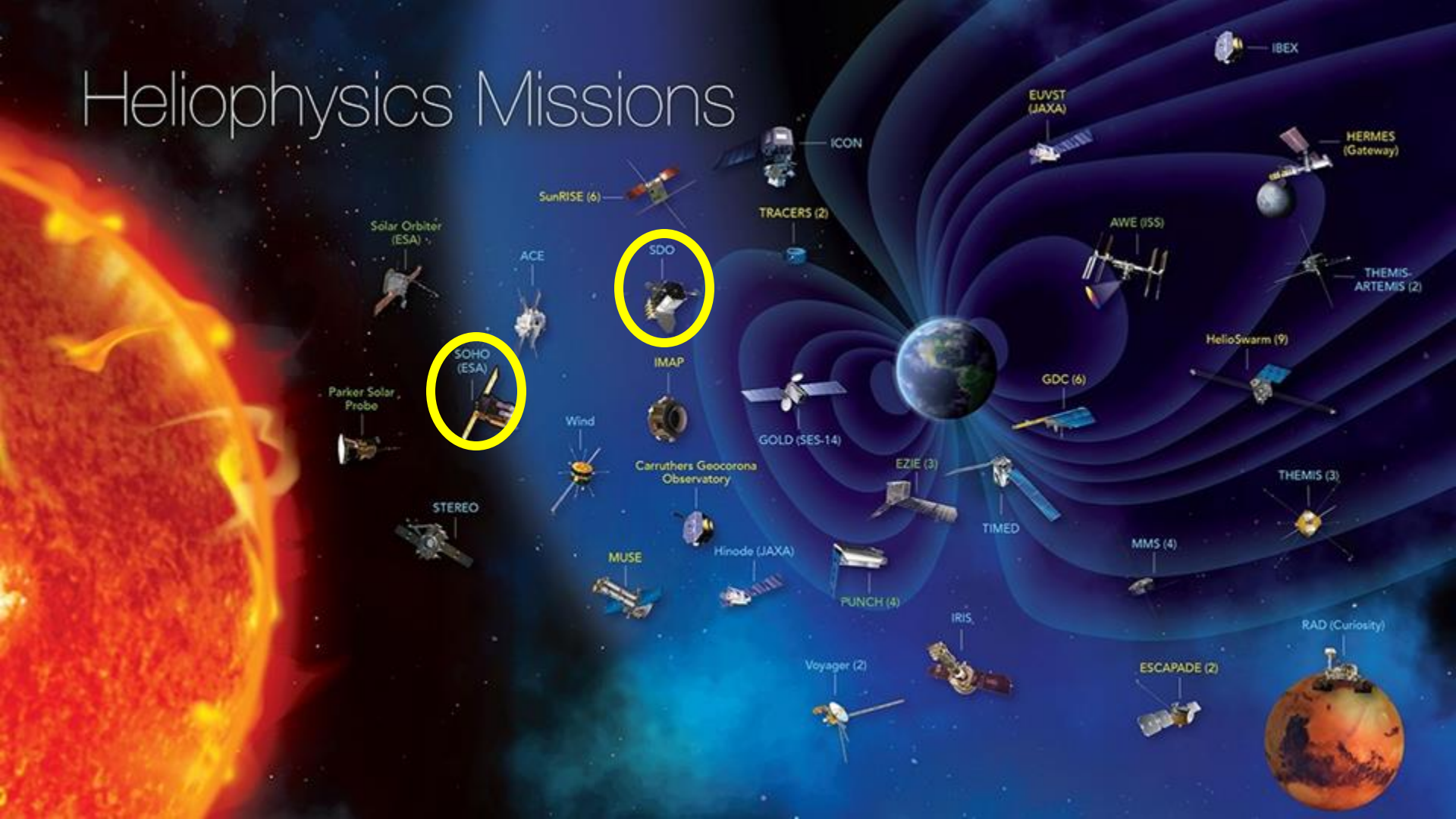
Open Source: Public repositories & collaboration

International: COSPAR HAPI & schema.org standards

Mission Data Archived at HDRL

100+ missions over 65 years, covering from the Sun to the local interstellar medium
~300 million files, 8000+ datasets, 600+ instruments




Heliophysics Missions
IBEX
EUVST (JAXA)
ICON
HERMES (Gateway)
SunRISE (6)
TRACERS (2)
Solar Orbiter (ESA)
ACE
SDO
AWE (ISS)
THEMIS-ARTEMIS (2)
SOHO (ESA)
IMAP
HelioSwarm (9)
Parker Solar Probe
GDC (6)
Wind
GOLD (SES-14)
Carruthers Geocorona Observatory
EZIE (3)
THEMIS (3)
STEREO
TIMED
MMS (4)
MUSE
Hinode (JAXA)
PUNCH (4)
IRIS
RAD (Curiosity)
Voyager (2)
ESCAPADE (2)

Hands-On with SDAC

Solar Data Analysis Center

NASA's Primary Solar Physics Archive

Mission Coverage

- **SOHO:** LASCO, EIT, SUMER, VIRGO
- **SDO:** AIA, HMI comprehensive datasets
- **STEREO:** Dual perspective observations
- **Legacy:** SMM, Yohkoh, TRACE, Hinode

Analysis Tools

- **SolarSoft (IDL):** Legacy instrument packages
- **SunPy (Python):** Modern analysis framework
- **Helioviewer:** Browser-based access and API

Virtual Solar Observatory

Web browser interface and software API

EUV Images
171, 195, 284, 304 Å

Coronagraph
LASCO C2/C3

Spectroscopy
SUMER spectra

Irradiance
VIRGO time series

Helioviewer

Web-Based Solar Visualization & RESTful API

Platform Features: RESTful API v2

Web-Based Interface
No installation required

Image Retrieval
JPEG 2000 format

Open Source
ESA & NASA funded

Movie Generation
Time sequences

Multi-Mission Support
SDO, SOHO, etc.

Screenshot API
Easy sharing

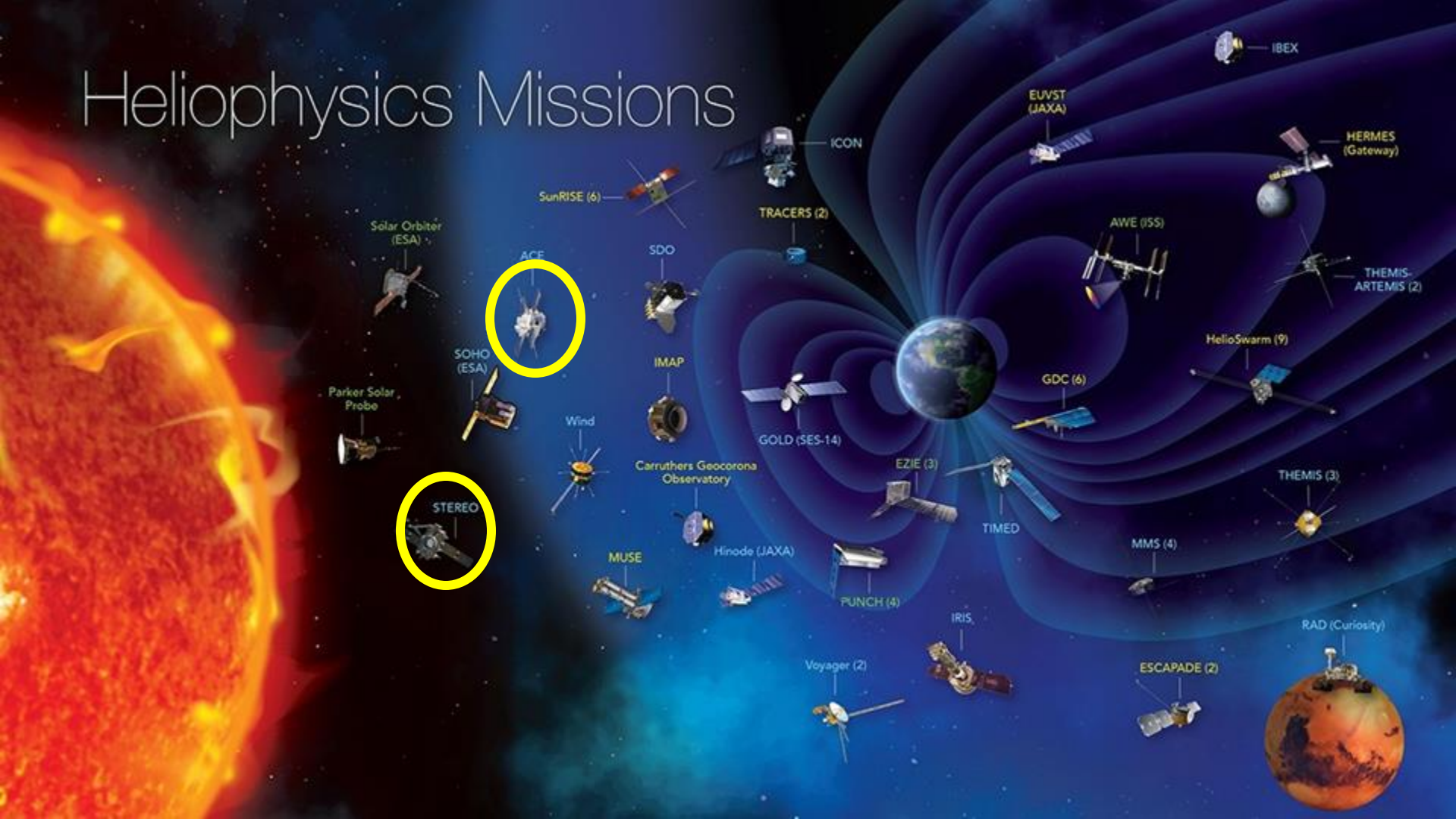
Real-Time Access
Latest observations

Event Queries
HEK integration

Example API Call:

```
https://api.helioviewer.org/v2/getJP2Image/?date=2024-01-
01T00%3A00%3A00&instrument=SDO/AIA&wavelength=171&size=512
```

The RESTful API allows users to access solar images from different missions and tools, making it possible to create custom visualizations and automate data processing.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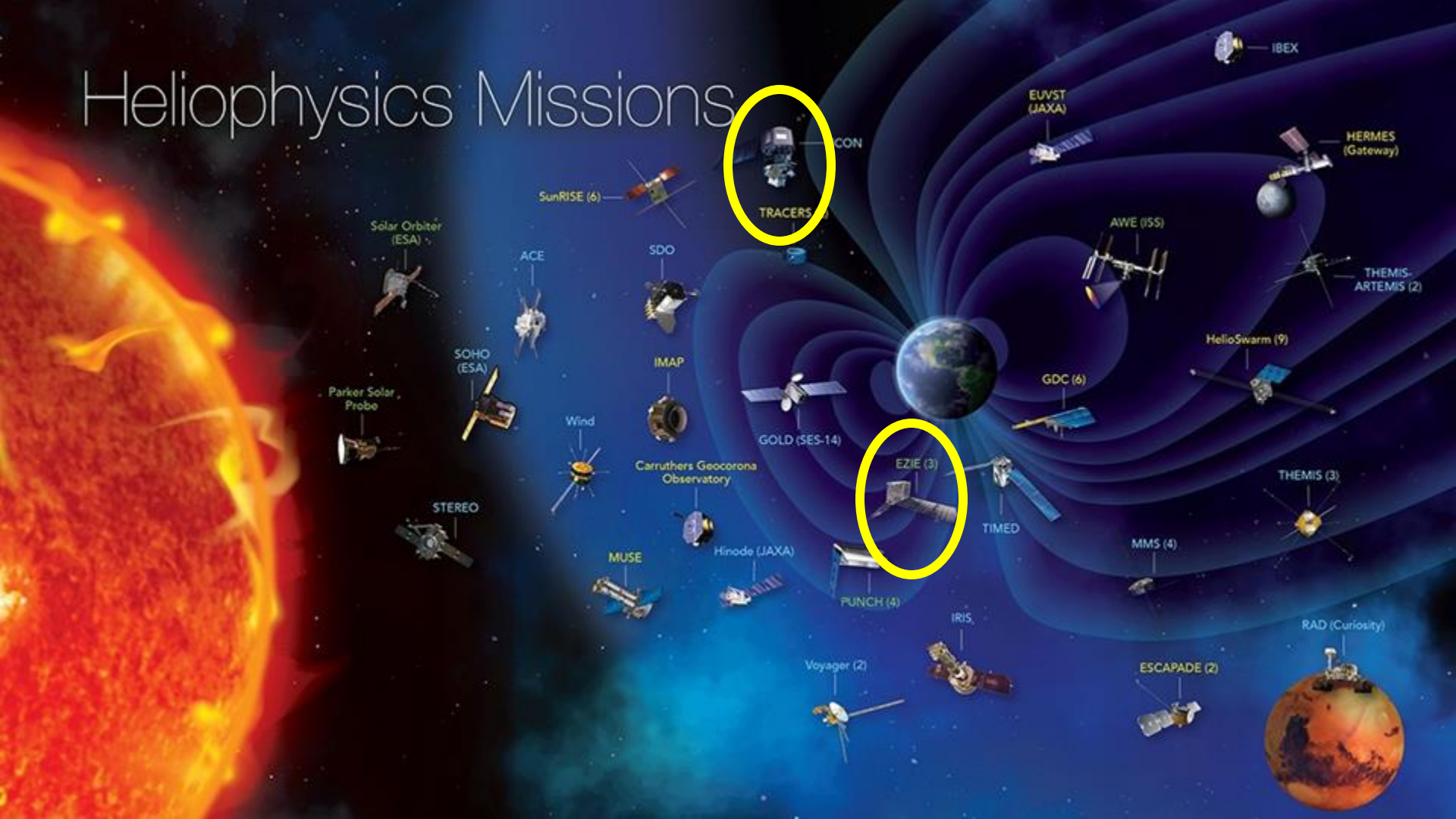
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Hands-On with SPDF

Space Physics Data Facility

Four Integrated Services for Heliophysics Research

CDAWeb

- **Web Browser:** Level-2 heliophysics datasets
- **Customizable:** Time, variables, spacecraft subsetting
- **Visualization:** Plots, movies, spectrograms

SSCWeb

- **Spacecraft Orbits:** 3D trajectory database
- **4-D Viewer:** Interactive 3D+time visualization
- **Advanced Queries:** Magnetospheric regions

OMNIWeb

- **Near-Earth:** Cross-normalized solar wind data
- **Multi-Resolution:** 1-hour, 1-minute, 5-minute bins
- **Long-term:** 1963 to present coverage

CDF Tools

- **Self-describing:** Platform-independent format
- **Complete Toolset:** Libraries, editors, utilities
- **Multi-language:** IDL, C, Fortran, Java, Python

A

CDAWeb + OMNIWeb
Data browsing **&** time series analysis

B

SSCWeb + 4-D Orbit Viewer Trajectory
visualization **&** conjunctions

Linking SPDF Services with Missions

https://spdf.gsfc.nasa.gov/data_orbits.html (Partial Screenshot Below)

Click an SPDF service name to check mark (✔) the spacecraft whose data are available.
Click a spacecraft name to check mark (✔) the SPDF services with its data.
See Info for New Users for more information about these data services.

160+ missions

GO =Go to Service's Home Page =Show Source Info *= Orbit/Trajectory Data Only

DATA SERVICES:

✔ CDAWeb GO
High-resolution, current space physics data with graphics and listings from many missions.

OMNIWeb Plus GO
Hourly-averaged solar wind magnetic field and plasma, etc.

✔ Plot Walk GO
Browse pregenerated data and orbit plots

✔ SPDF FTPS Site GO
Read FTP to FTPS information.

✔ SPDF HTTPS Site GO

ORBIT/ TRAJECTORY SERVICES:

✔ SSCWeb Services GO
Display and download trajectory data

✔ 4-D Orbit Viewer GO
Interactive visualization of satellite orbits

HelioWeb GO

SOURCE SPACECRAFT:

ACE, Active*, Aditya-L1, Aerocube, Aeros, AIM, Akebono*, Alouette1, Alouette2, AMPTE, APEX-MAIN*, Apollo, Aqua, Ariel-4, Arase (ERG), ARCAD, ARTEMIS, ASTRID II*, AE, Aura, Aureol2, AWE, BARREL, BepiColombo, BioSentinel, CALIPSO, Cassini*, Cassiope, Cirbe, Cluster

DE, ELFIN, Endurance, Equator-S, Explorer, FAST, FIREBIRD*, Formosat, Freja*, Galileo*, Gateway*, GCOM W1, Genesis, Geotail, Giotto*, GOCE, GOES18, GOES19, GOLD, GPS, GMS 3, GRACE*, Granat, Hawkeye, Helios, Hinode, Hinotori, IBEX, ICE, ICON, IMAGE

Jupiter, Kepler, KPLO (Danuri), Lagrange Point 1 (L1), Landsat, LANL, LRO, LUNA, Magsat, MAP, Mariner 10, Mars, MAVEN, MESSENGER, MGS, Microlab 1, Mir*, MMS, MRO, MSL, MSX*, Munin, Neptune, New Horizons, NOAA*, Oersted, OGO, Ohzora, OSIRIS-REx (-APEX), PARASOL, Parker Solar Probe

RHESSI, SAMPEX, Sakigake*, San Marco, Saturn, SCATHA*, SDO, SET-1/DSX, SMILE, SNOE, SOHO, Solar Orbiter, SORCE, Spartan-A, Spitzer, SPORT, Sputnik 1, STEREO, Suisei, Swarm, Tatiana, THEMIS, TIMED, TRACE, TSS-1R, TWINS, UARS*, Ulysses, Uranus, Van Allen Probes, Vega

OTHER DATA SOURCES:

Planet & Comet Positions

Ground-based

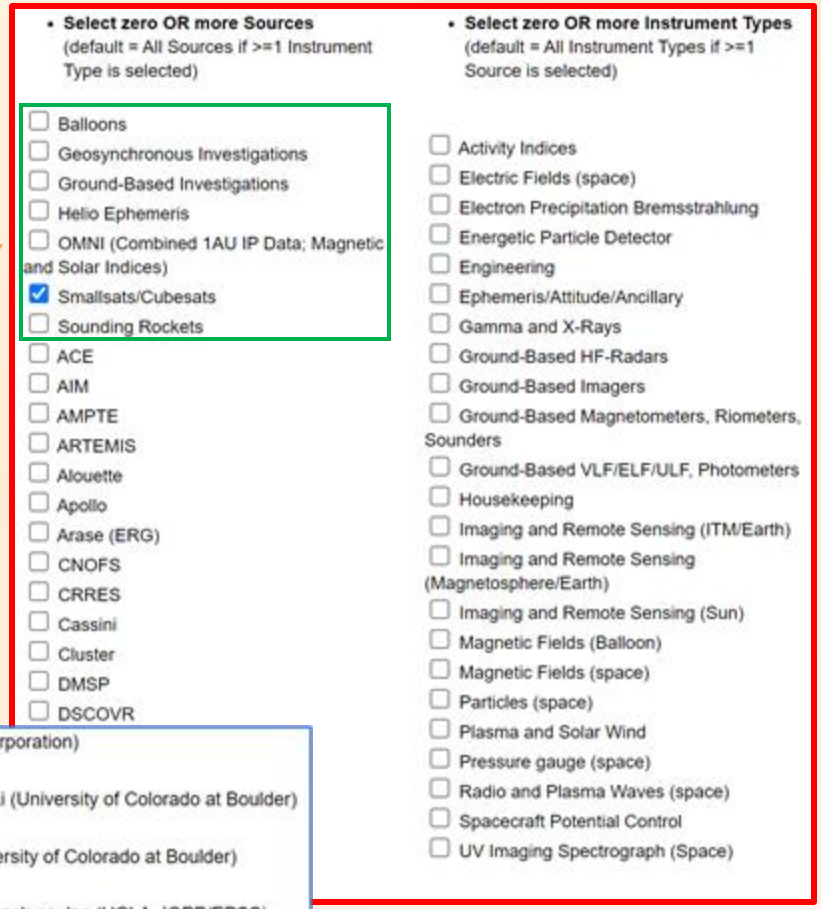
Activity Indices

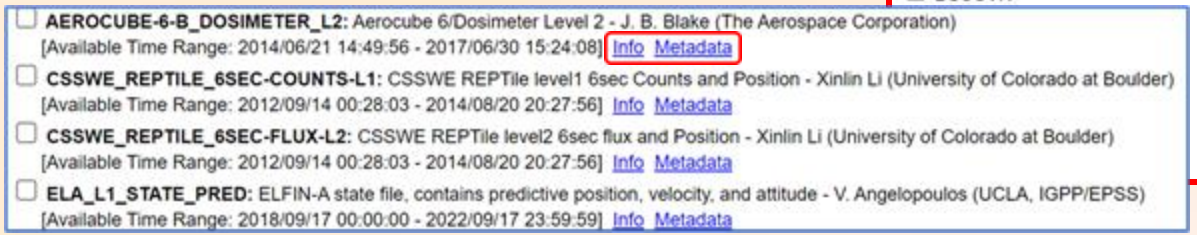
60+ Missions or Mission Groups ➡

Coordinated Data Analysis Web (CDAWeb)

https://cdaweb.gsfc.nasa.gov/

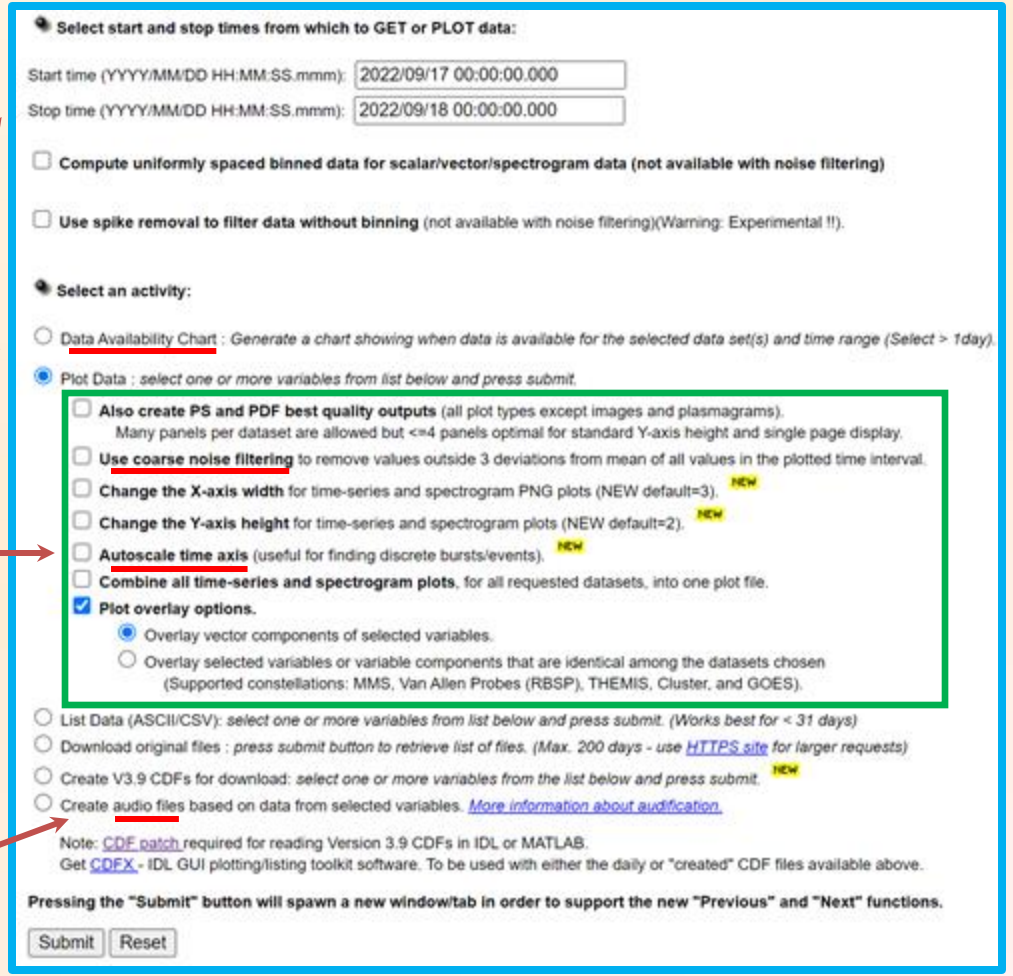
- **Special data source groups**: balloons, ground-based investigations, cubesats, sounding rockets, etc.
- Enable Systems Science: cross-mission, multi-instrument science
- Present dataset view rather than individual files
- 70% of 2744 datasets in CDAWeb have SPASE records; 57% have DOIs





CDAWeb Data Explorer

- Time interval is automatically set by the last available day of the selected dataset(s)
- Remove spikes or filter coarse noise
- **Plot data availability**
- Adjust X and Y lengths for plotting
- **Auto scale time axis for finding discrete bursts or events**
- Overlay vector components of selected variables, or selected variables that are identical among multiple datasets
- Output a subset or a superset of datasets in CDF, ASCII/CSV, JSON
- Create **audio** and **movie** files for selected variables



Each supported dataset also provides links to IDL and Python code examples for downloading and working with the data files independently (outside of the CDAWeb system)

CDAS Web Service Client Code Examples

The following web service client code examples demonstrates how to access data from the AEROCUBE-6-B DOSIMETER_L2 dataset from particular programming environments.

Jupyter Notebook on Binder

The following link launches a Python Jupyter Notebook that demonstrates using the cdasws library to access AEROCUBE-6-B DOSIMETER_L2 data in a Jupyter Notebook. It is merely an example and does not show all the capabilities of the library. You should edit the code to suit your needs.

launch binder

cdasws Python Library

The following code demonstrates using the cdasws library to access AEROCUBE-6-B
should edit the code to suit your needs.

```
#  Install these prerequisites once before executing the example code:
#  Option 1.
#    Install CDF from https://cdf.gsfc.nasa.gov/
#    pip install -U spacepy
#    pip install -U cdasws
#  Option 2.
#    pip install -U xarray
#    pip install -U cdflib
#    pip install -U cdasws

from cdasws import CdasWs
cdas = CdasWs()

#  Edit the following vars, time variables, and printing to suit your
environment
# (spacepy or cdflib) and needs.
vars =
['alt','lat','lon','XYZ_GEO','dos1l','dos1m','dos1rate','dos2l','dos2m'
```

cdasws IDL Library

The following code demonstrates using the cdasws library to access AEROCUBE-6-B DOSIMETER_L2 data in IDL. It is merely an example and does not show all the capabilities of the library. You should edit the code to suit your needs.

```
compile_opt idl2
savFilename = filepath('spdfcdas.sav', /tmp)
oUrl = obj_new('IDLnetUrl')
;  For IDL installations with old root certificates
oUrl->setProperty, SSL_VERIFY_PEER=0
savFilename = oUrl->get(filename=savFilename,
url='https://cdaweb.gsfc.nasa.gov/WebServices/REST/spdfcdas.sav')
restore, savFilename

;  Edit the following vars and time variables to suit your needs.
vars =
['alt','lat','lon','XYZ_GEO','dos1l','dos1m','dos1rate','dos2l','dos2m','dos2rat
e','dos3l','dos3m','dos3rate','flag','Sample_Rate','Lm_IGRF','Bmag_IGRF','MLT_IG
RF','InvLat_IGRF','Lm_OPQ','Bmag_OPQ','MLT_OPQ','InvLat_OPQ','Loss_Cone_Type','B
xyz_GEO','Beq','I','K','K_I','Lstar','Lstar_I','Hmin','Hmin_I','Loss_Cone_Near',
'Loss_Cone_Far','B100N','LAT100N','LON100N','B100S','LAT100S','LON100S','Alpha',
'Alpha_X','Alpha_Y','Alpha_Eq','Beta','Beta_X','Beta_Y','Phi_B','OmegaXYZ_GEO',
'B_spin','Spin_Sun','Dist_In_Track','Lag_In_Track','Dist_Cross_Track_Horiz','Dist
_Cross_Track_Vert','Dist_Total','alt_10Hz','lat_10Hz','lon_10Hz','dos1l_10Hz','d
os1m_10Hz','dos1rate_10Hz','dos2l_10Hz','dos2m_10Hz','dos2rate_10Hz','dos3l_10Hz
','dos3m_10Hz','dos3rate_10Hz','flag_10Hz','Subcom_10Hz','Lm_OPQ_10Hz','Bmag_OPQ
_10Hz','MLT_OPQ_10Hz','InvLat_OPQ_10Hz','Loss_Cone_Type_10Hz','K_I_10Hz','Lstar_
I_10Hz','Hmin_I_10Hz','Alpha_10Hz','Beta_10Hz','Dist_In_Track_10Hz','Lag_In_Trac
```

Copy code to clipboard | Download code

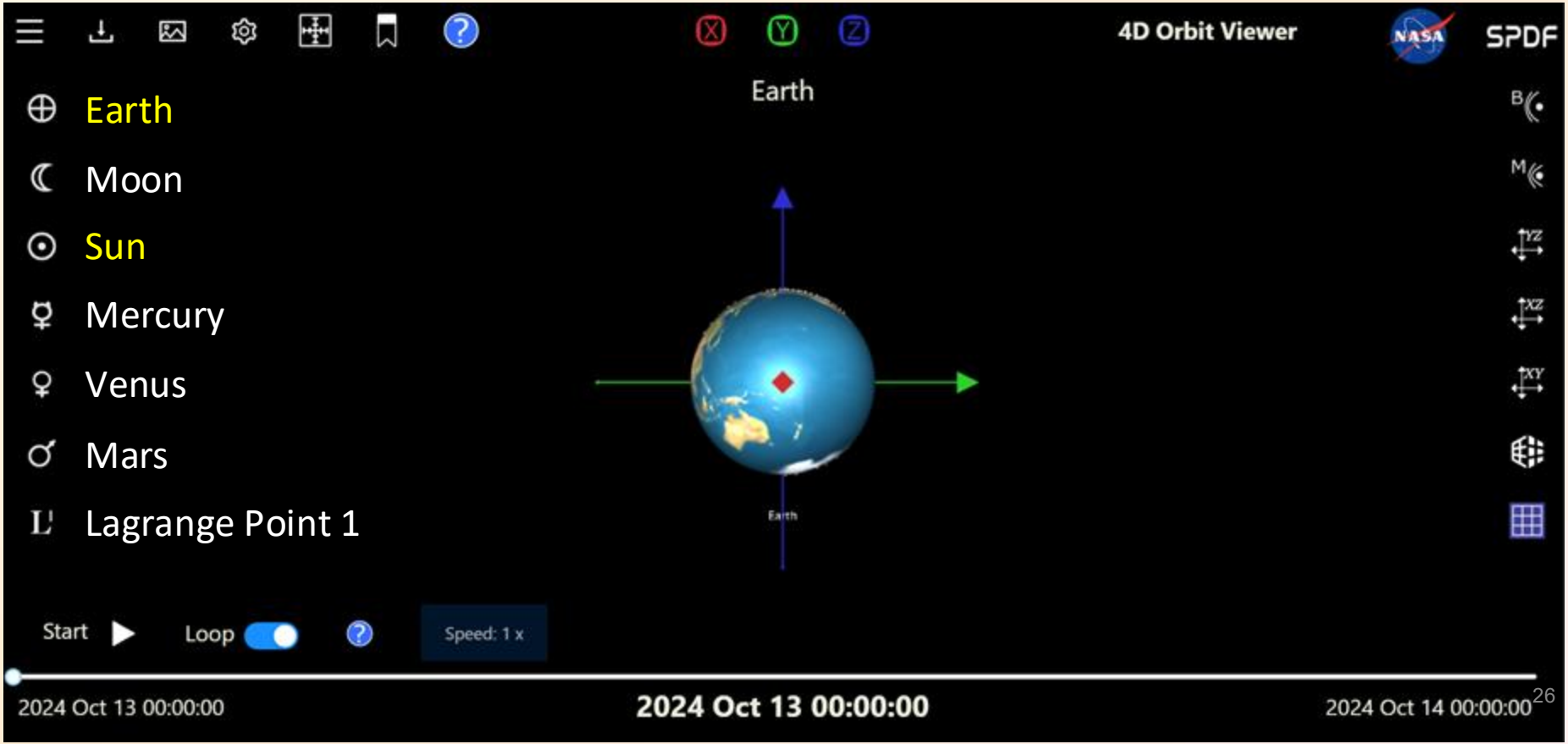
More information about using this library is available from the following:

- IDL library description cdasws
- Jupyter IDL notebook example
- Application Programming Interface description API

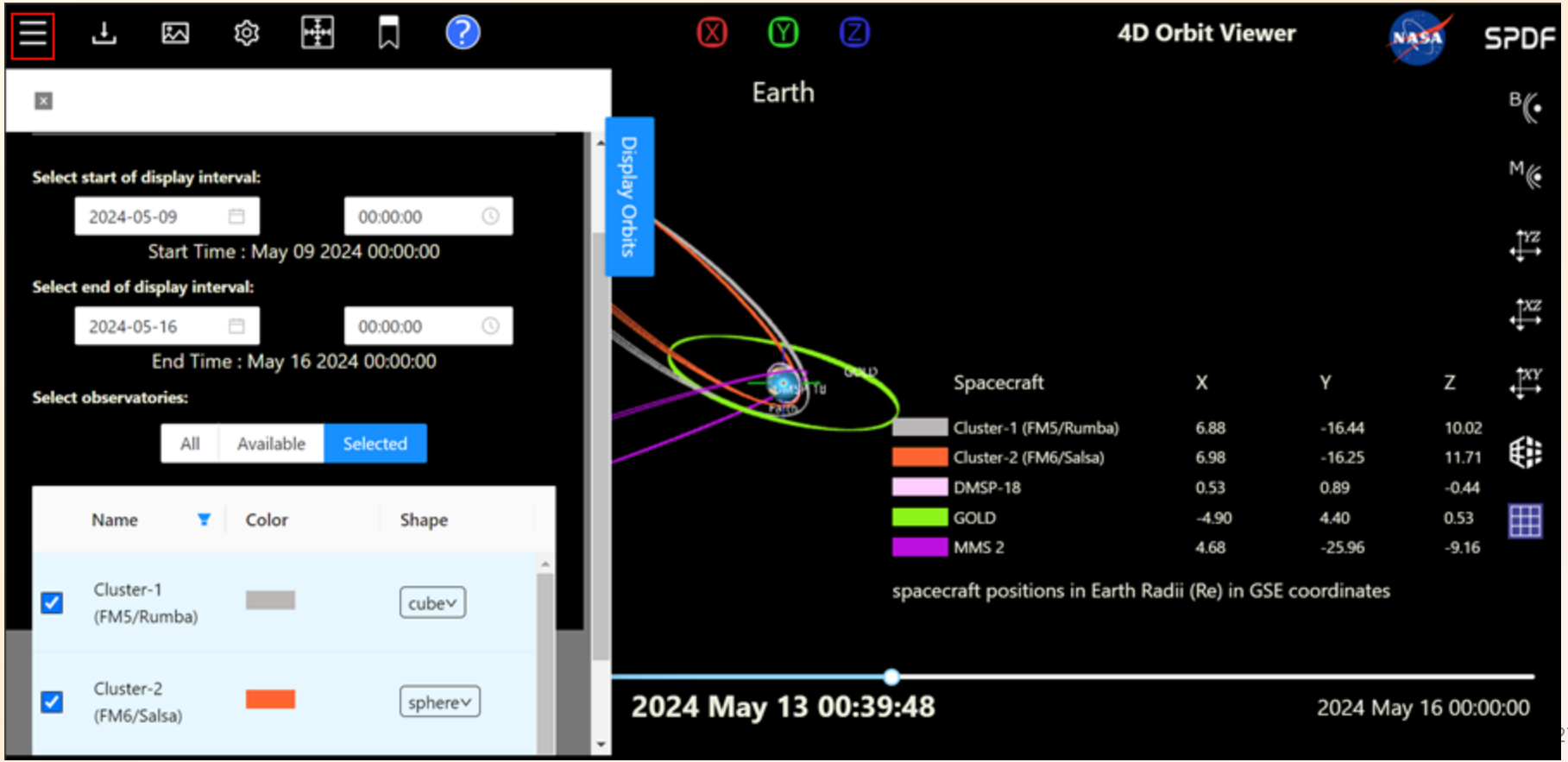
Alternative data access methods https://cdaweb.gsfc.nasa.gov/alternative_access_methods.html

4-D Orbit Viewer (160+ Spacecraft)

https://sscweb.gsfc.nasa.gov/4dorbit/



4-D Orbit Viewer: Time and Spacecraft Selection



NSF-Supported Geospace Data Infrastructure

Tai-Yin Huang
Program Director
Geospace, AGS Division
Geosciences Directorate, NSF

National Science Foundation

August 15, 2025
Heliophysics Summer School

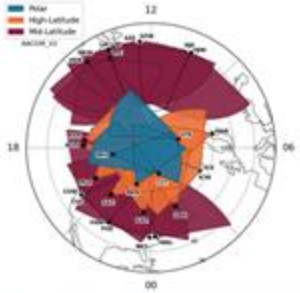
AGS-Supported Data Infrastructure

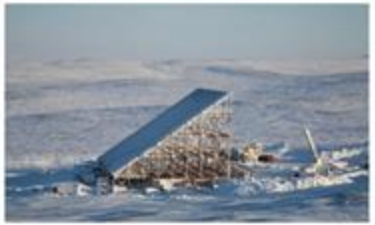
Madrigal: manages and serves archival and real-time data from a wide range of instruments such as radars, ionosondes, Fabry-Perots, satellite instruments, DMSP, Michelson Interferometers, Lidars, imagers, magnetometers, radiometers, photometers, riometers, VLF, and modelled data. Madrigal database at Millstone

SuperDARN: provides access to SuperDARN data (line-of-sight velocity, spectral width, power of backscattered signal, and thermospheric neutral wind) in platform-independent netCDF files and data visualizer. VT SuperDARN and Superdarn

AMISR (Advanced Modular Incoherent Scattered Radar): provides electron temperatures, plasma line, ion-neutral collision frequency. AMISR

MIT HAYSTACK OBSERVATORY





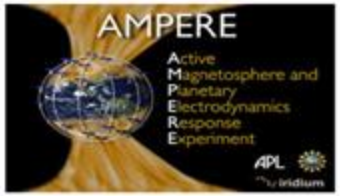
AGS-Supported Data Infrastructure

SuperMAG: provides easy access to validated ground magnetic field perturbations in the same coordinate system, identical time resolution and with a common baseline removal approach. Global magnetic field observations and products made possible by the contributors.

SuperMAG

AMPERE (Active Magnetosphere and Planetary Electrodynamics Response Experiment): provides AMPERE magnetic perturbation data and data products derived from the Iridium constellation

AMPERE



AGS-Supported Data Infrastructure

LISN (Low Latitude Ionospheric Sensor Network): provides GPS, magnetometer, and ionosonde data. LISN

Community Coordinated Modeling Center (with NASA): provides access to modern space research models; tests and evaluates models; supports Space Weather forecasters; supports space science. Home | CCMC

COMMUNITY COORDINATED MODELING CENTER

MANGO (Midlatitude Allsky-imaging Network for Geospace Observations): A network of all-sky cameras and FPIs to observe wave activity in the thermosphere). MANGO Network

AGS-Supported Data Infrastructure

The US NSF National Center for Atmospheric Research (NSF NCAR)

Geoscience Data Exchange (GDEX): public data repository.

Information Systems Lab (CISL): provides supercomputing, analysis and visualization resources, stores, develops, and curates data

High Altitude Observatory (HAO): provides data (MLSO and PFI) and models.

(CDG): provides long-term stewardship for data assets related to geo- and helio-science model output that are generated as a result of NCAR

To search and discover datasets across all of NCAR's data repositories, use: https://data.ucar.edu/.
To submit a request to deposit data at NCAR, do so through: https://submit-data.ucar.edu.

NSF-Supported Data Infrastructure

Data Access - NSO - National Solar Observatory

- Dkist data, DKIST Data Center Archive
- NISP **SOLIS (Synoptic Optical Long-term Investigations of the Sun)**, NSO/NISP: SOLIS Data Information
- NISP **GONG** (**Global Oscillation Network Group**), NSO/GONG: Data Access
- Historical Archive, Historical Archive - NSO - National Solar Observatory
- VSO data, Virtual Solar Observatory

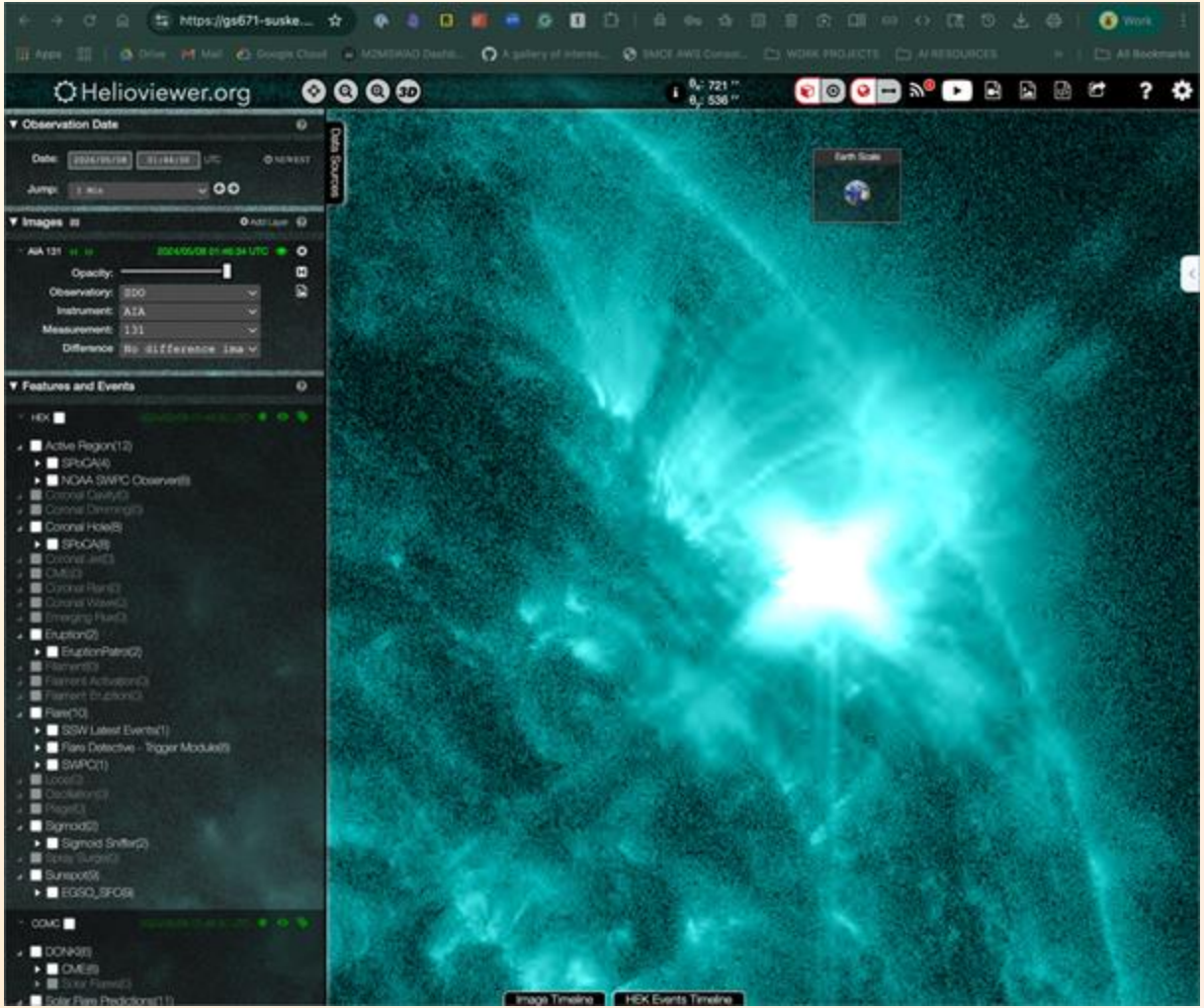
Examples

What can you do with these resources?
Try it for yourself.

Helioviewer

SDO and SOHO data visualized easily without processing yourself

Helioviewer



The **Helioviewer Project** is an open platform for exploring solar and heliospheric imagery **-**

via the **Helioviewer.org** web app, the **JHelioviewer** desktop viewer, and **public APIs -**

letting you browse **near-real-time** and **historical data**, **overlay events**, and generate **screenshots** and **movies**.

CDAWeb

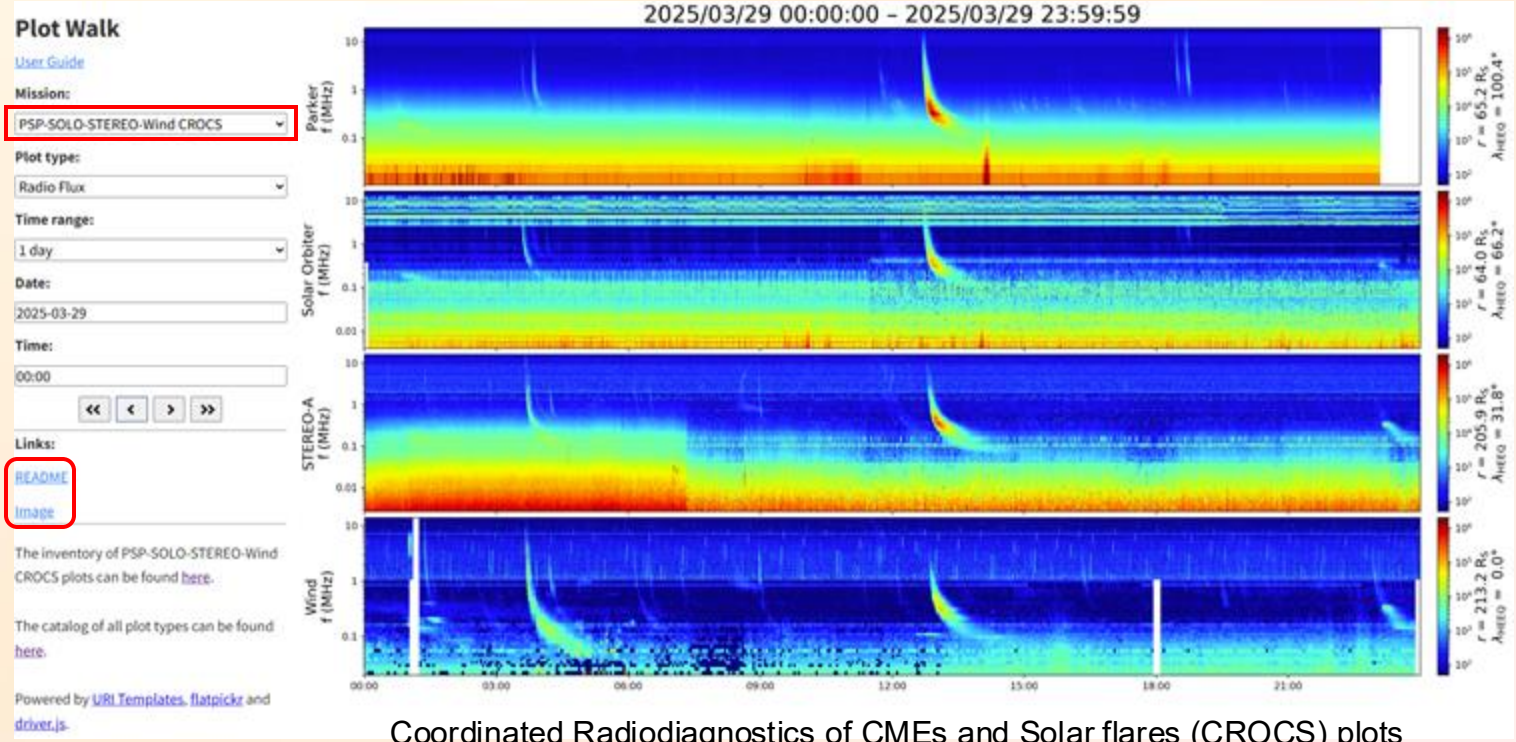
Coordinated **D**ata **A**nalysis **Web**

Non-solar heliophysics data from current and past heliophysics missions and projects

Plot Walk for Pre-Generated Plots

https://spdf.gsfc.nasa.gov/plot_walk/

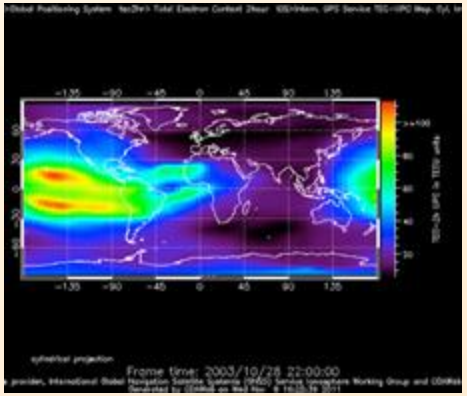
Summary or quick-look plots from 20+ missions (12.5 million plots)

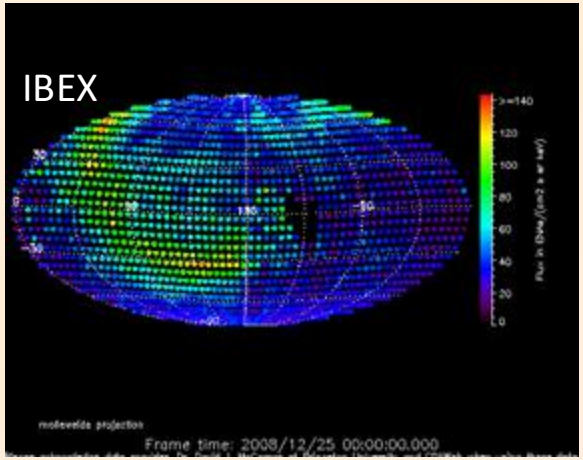


Coordinated Radiodiagnostics of CMEs and Solar flares (CROCS) plots using radio data from PSP, Solar Orbiter, STEREO A, and Wind missions

Example Parameter Displays in CDAWeb

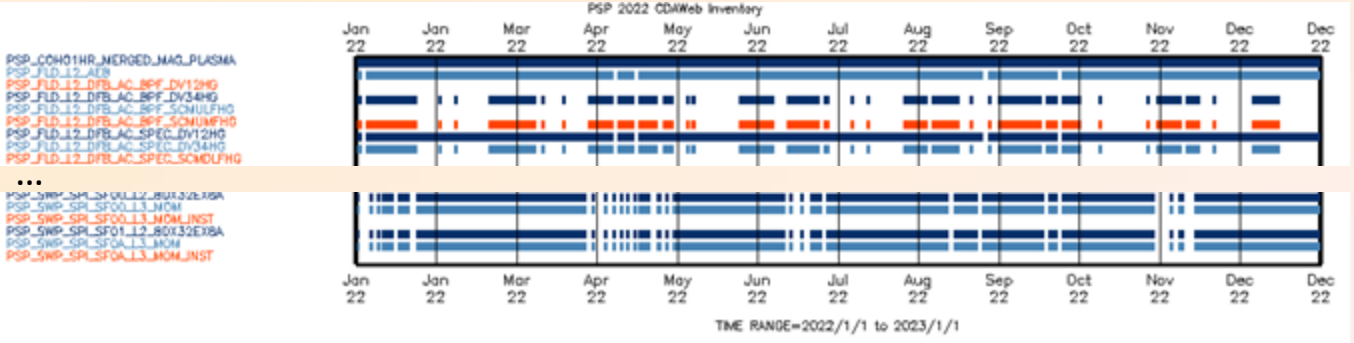
GPS International GNSS Service
Total Electron Content





More at https://cdaweb.gsfc.nasa.gov/about.html

Inventory Plot for Mission Datasets

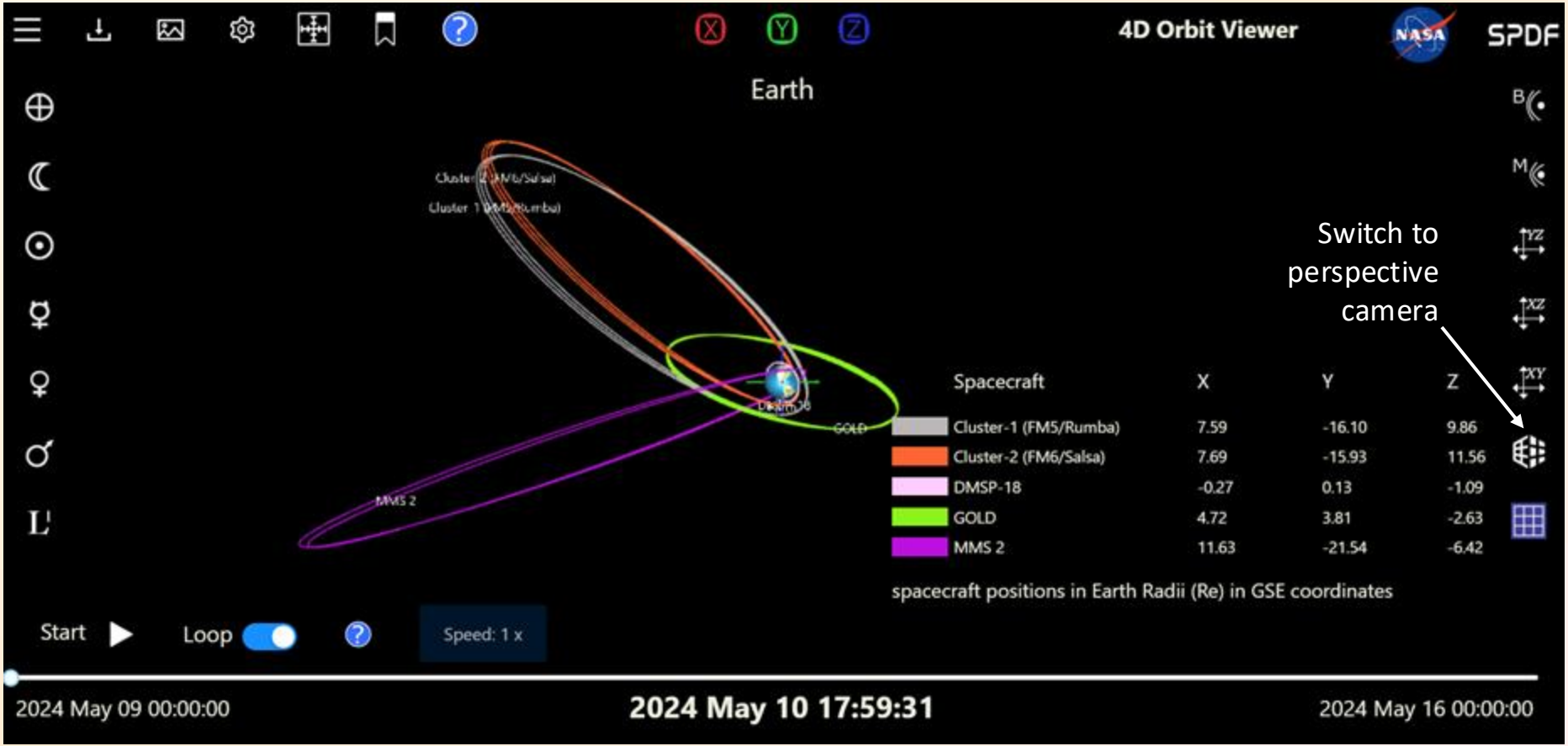


https://cdaweb.gsfc.nasa.gov/sc_inventory_plots/

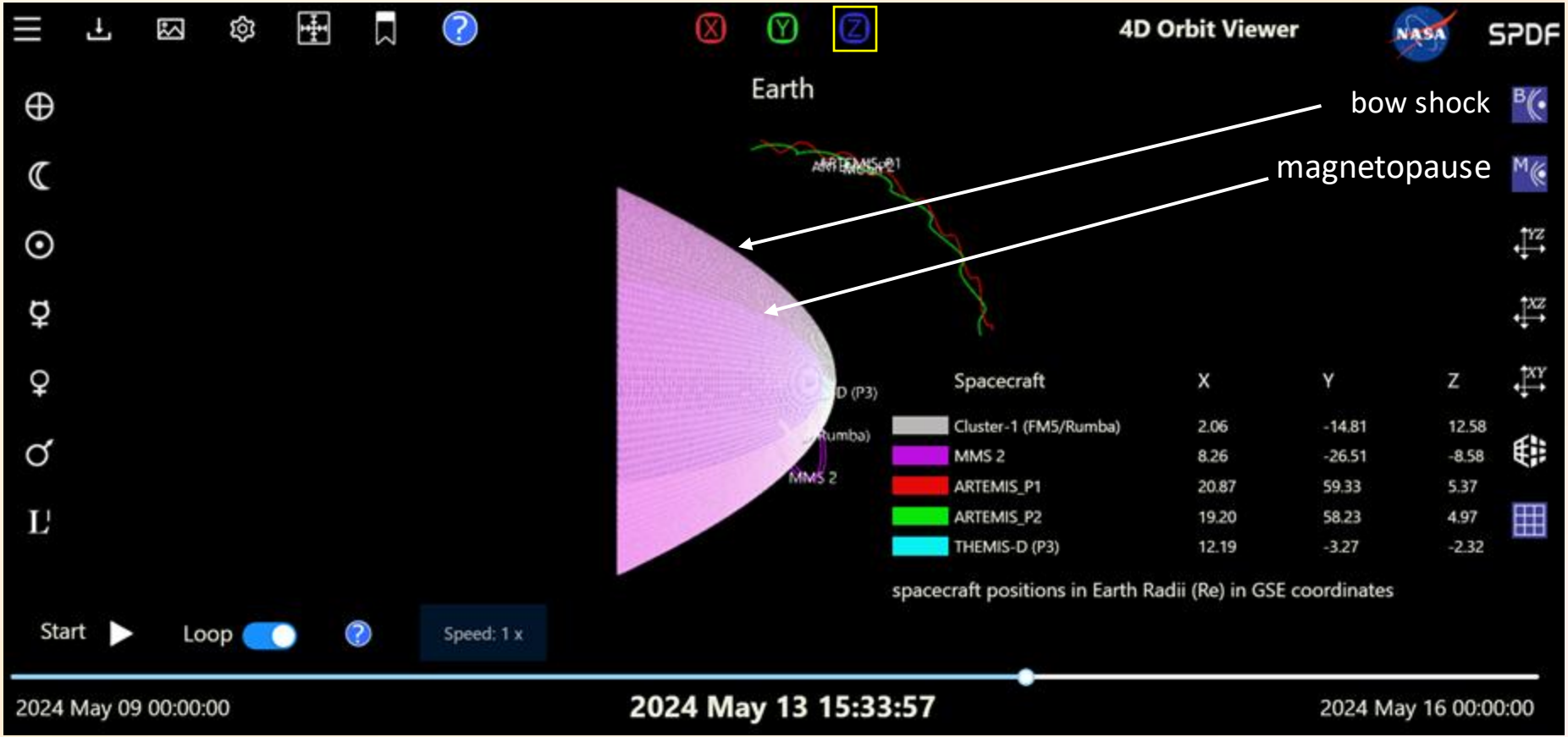
4-D Orbitviewer

Provides an interactive 4-D animation of spacecraft orbits over time

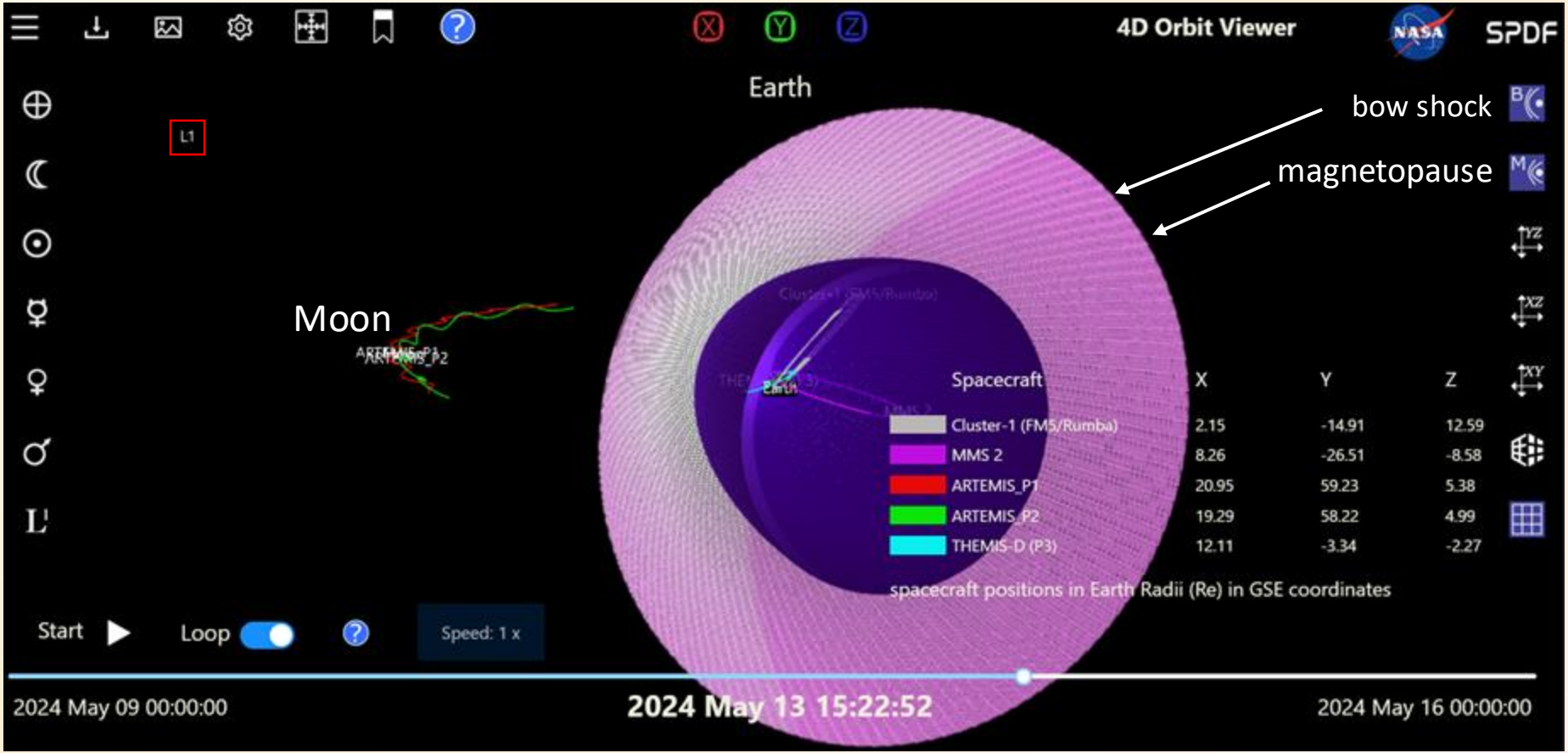
4-D Orbit Viewer: Different Perspectives



4-D Orbit Viewer: Bow Shock and Magnetopause



4-D Orbit Viewer: Rotation of Coordinates

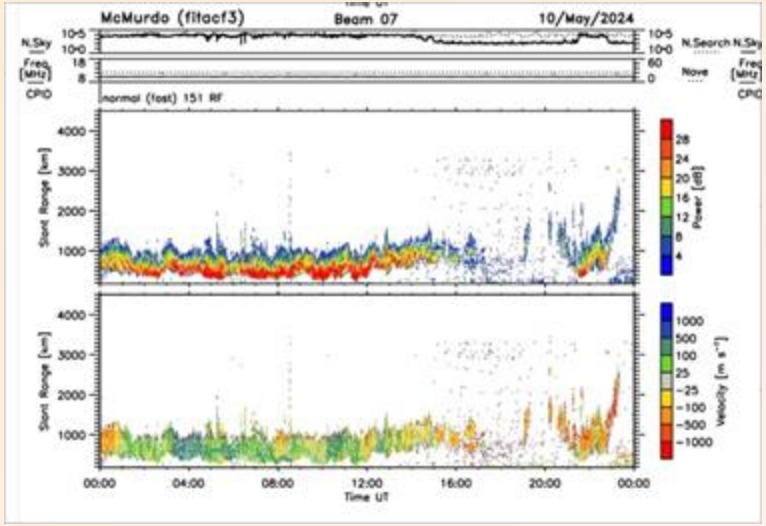


VT SuperDARN

Virginia **T**ech Super **D**ual **A**uroral **R**adar **N**etwork

VT SuperDARN is the **Virginia Tech** research group within the international **Super Dual Auroral Radar Network** (SuperDARN)

The SuperDARN is a global array of high-frequency (HF) radars that continuously observe the ionosphere to map plasma convection and other geospace dynamics, which are crucial for space-weather research and operations.



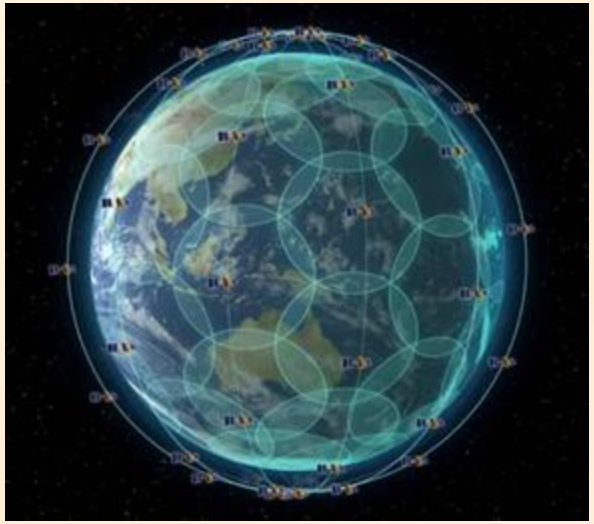
VT SuperDARN

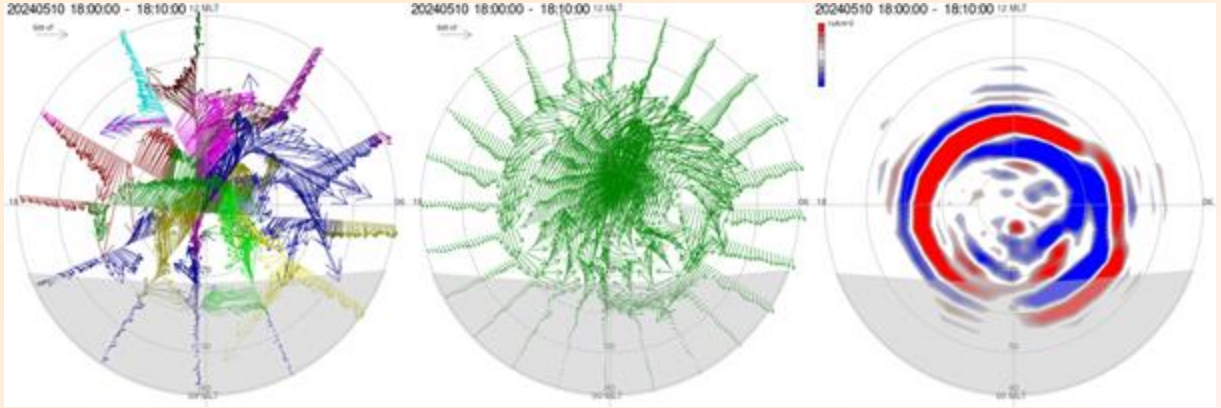
AMPERE

Active **M**agnetosphere and **P**lanetary **E**lectrodynamics **R**esponse **E**xperiment

AMPERE (**Active Magnetosphere and Planetary Electrodynamics Response Experiment**) is a space-weather observing system run by Johns Hopkins Applied Physics Lab (with NSF, Iridium, and Boeing)

It uses the Iridium communications satellites' onboard engineering magnetometers to continuously map field-aligned (Birkeland) currents and large-scale ionospheric electrodynamics.





AMPERE JHUAPL

Thank you!!

What can we do to help you do your science?

What data and what tools do you need?

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