ACADEMY OF FINLAND

UNIVERSITY of OULU
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Aalto University

Space instrumentation
for solar wind studies

Magnetism & Applications 2023

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EVERY SATELLITE ORBITING EARTH

AND WHO OWNS THEM

Earth has

4,550

satellites in orbit

(as of 9/1/21)

139

Medium Earth orbit (MEO)

Satellites in this orbit are used for navigation systems.

3,790

Low Earth orbit (LEO)

Satellites here are used for communications and remote sensing satellite systems. The International Space Station and Hubble Space Telescope are also in this orbit.

565

Geosynchronous orbit (GSO) & geostationary orbit (GEO)

Satellites in this orbit are used for telecommunications and Earth Observation

56

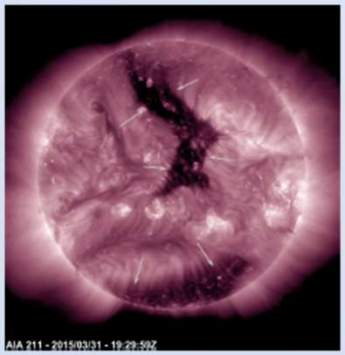
Highly elliptical orbit (HEO)

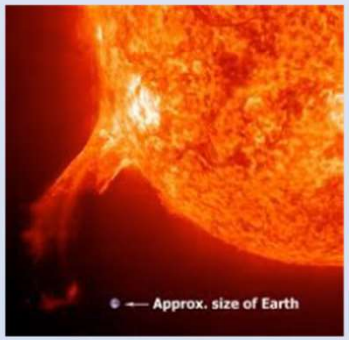
Satellites in this orbit are used for communications, satellite radio, remote sensing, and other applications.

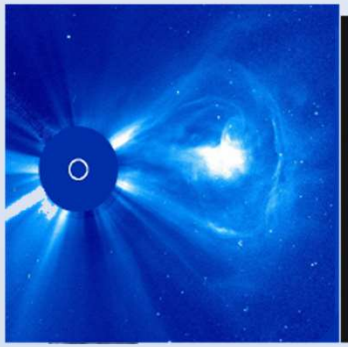
https://dewesoft.com/blog/every-satellite-orbiting-earth-and-who-owns-them

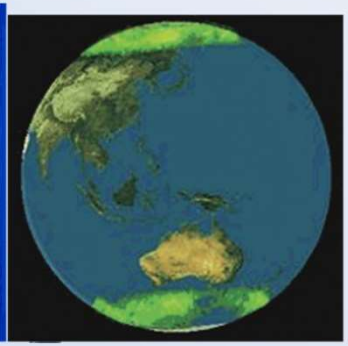
Solar wind measurements

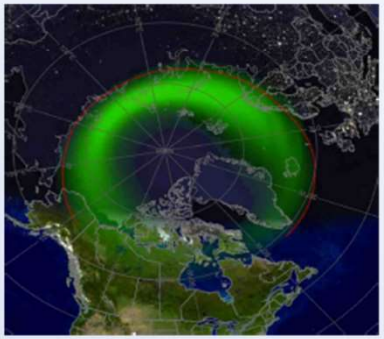
- History of solar wind studies: How it began
- What is studied?
- Locations of study
- About instruments
- Missions and their targets



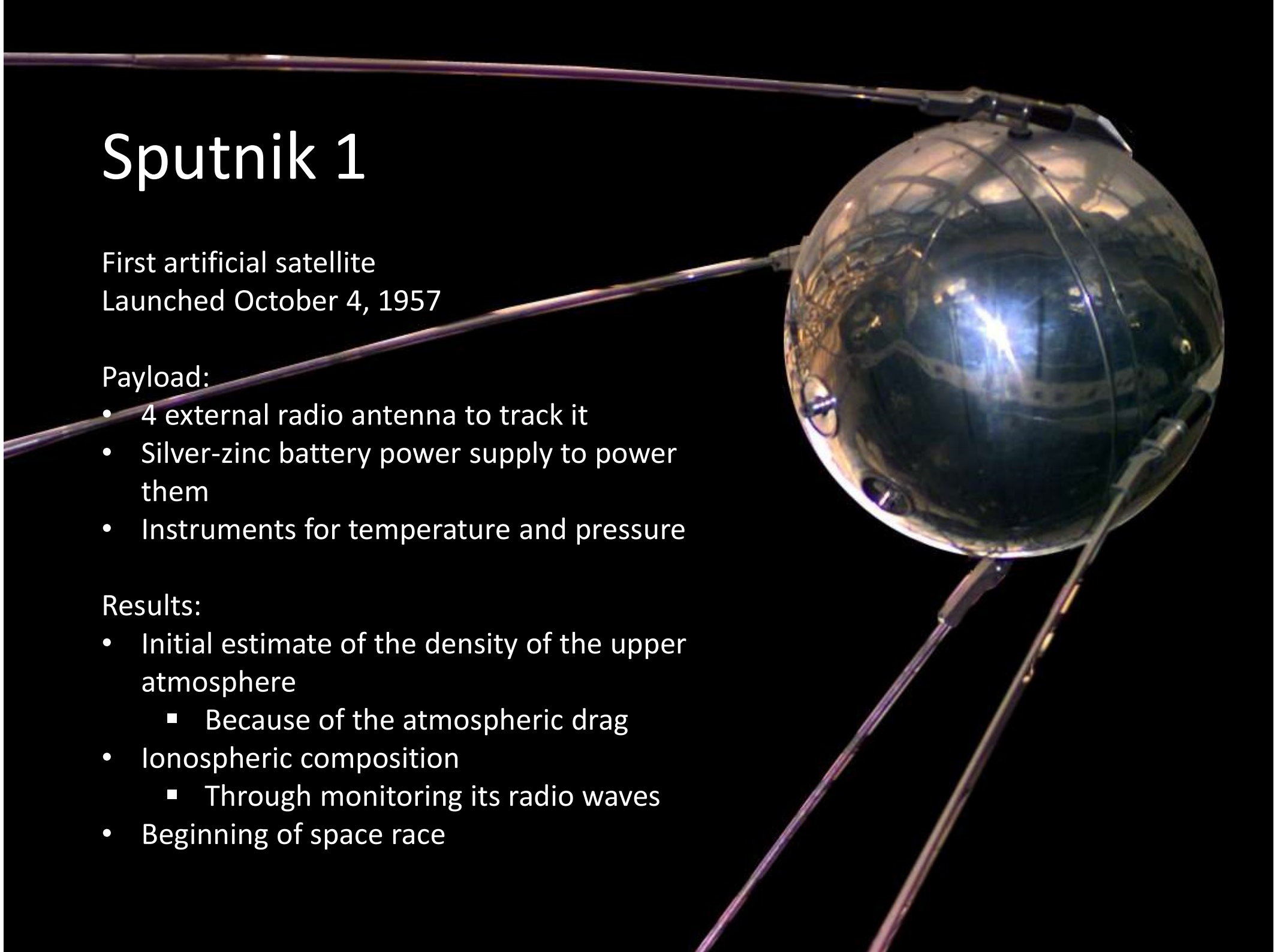








Sputnik 1



First artificial satellite
Launched October 4, 1957

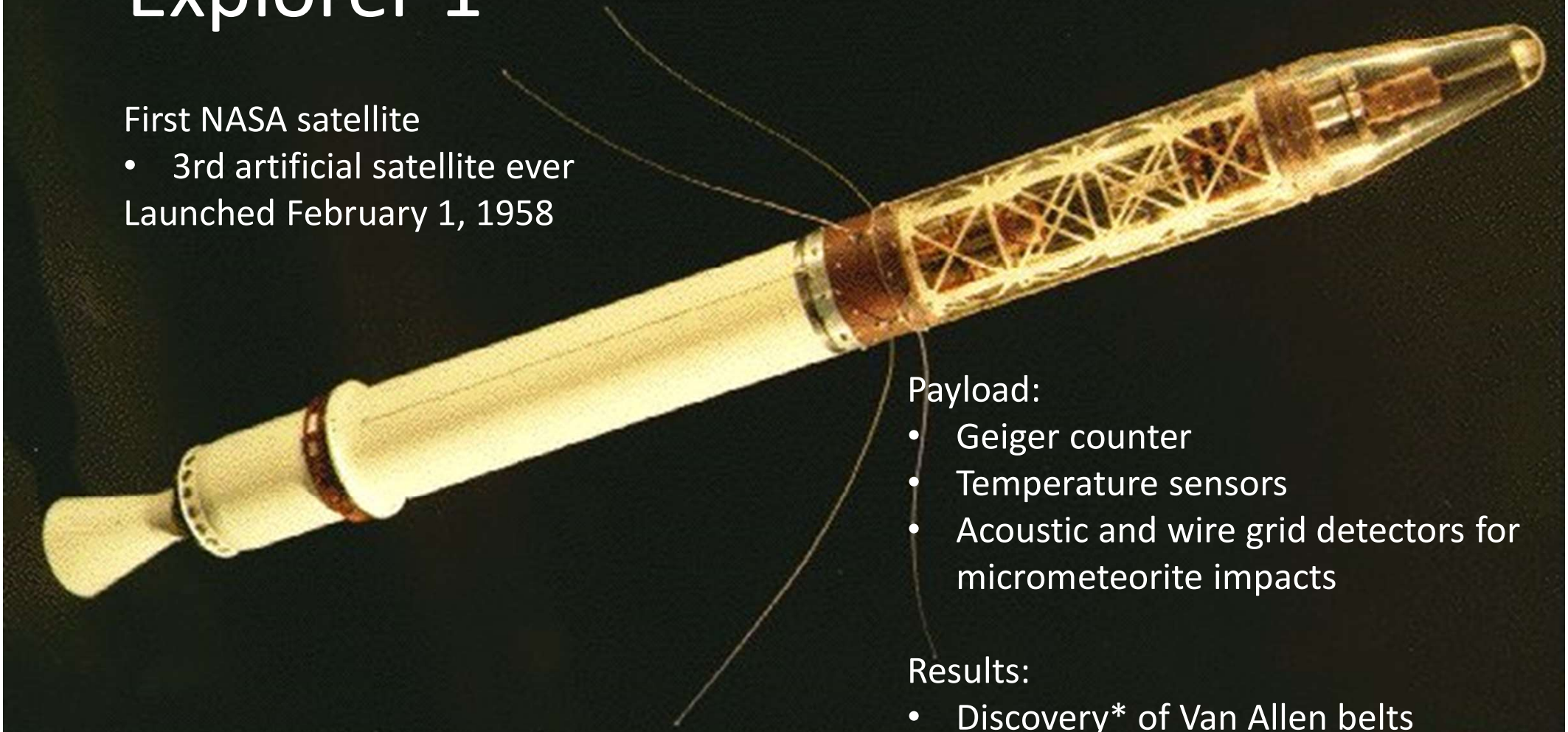
Payload:

- 4 external radio antenna to track it
- Silver-zinc battery power supply to power them
- Instruments for temperature and pressure

Results:

- Initial estimate of the density of the upper atmosphere
  - Because of the atmospheric drag
- Ionospheric composition
  - Through monitoring its radio waves
- Beginning of space race

Explorer 1



First NASA satellite
- 3rd artificial satellite ever

Launched February 1, 1958

Payload:
- Geiger counter
- Temperature sensors
- Acoustic and wire grid detectors for micrometeorite impacts

Results:
- Discovery* of Van Allen belts
- Cosmic dust estimates

* Technically Sputnik 2 measured them first

Decades of space science: Voyager space probes

- Launched in August (Voyager 2) and September 1977 (Voyager 1)

Mission to study:

- The outer reaches of the solar system
- ...and boundaries of heliosphere

Journey:

- 2005 (1) and 2007 (2) reached the termination shock
- 2012 (1) and 2018 (2) reached the interstellar space

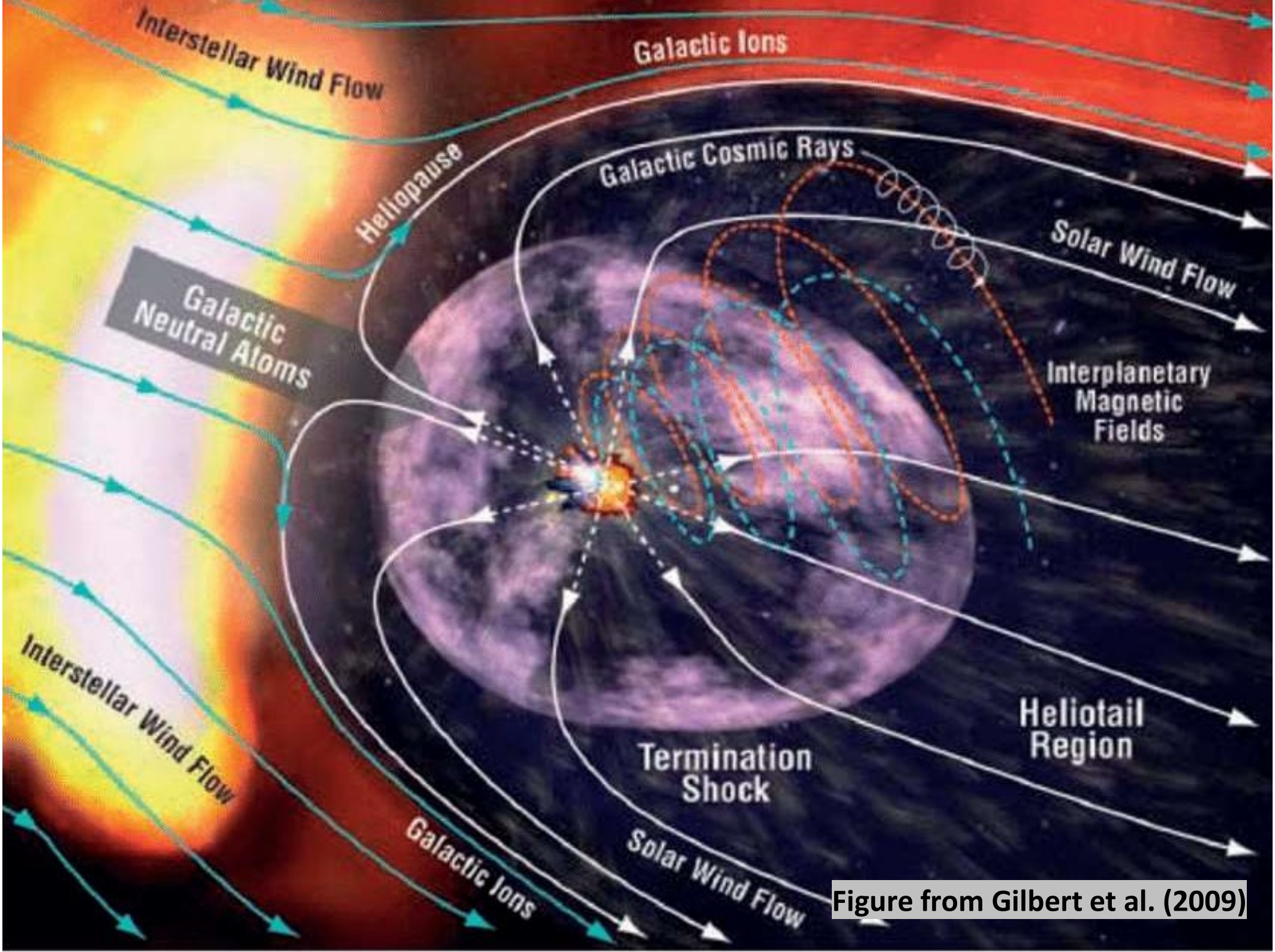


Figure from Gilbert et al. (2009)

Where are Voyagers now?

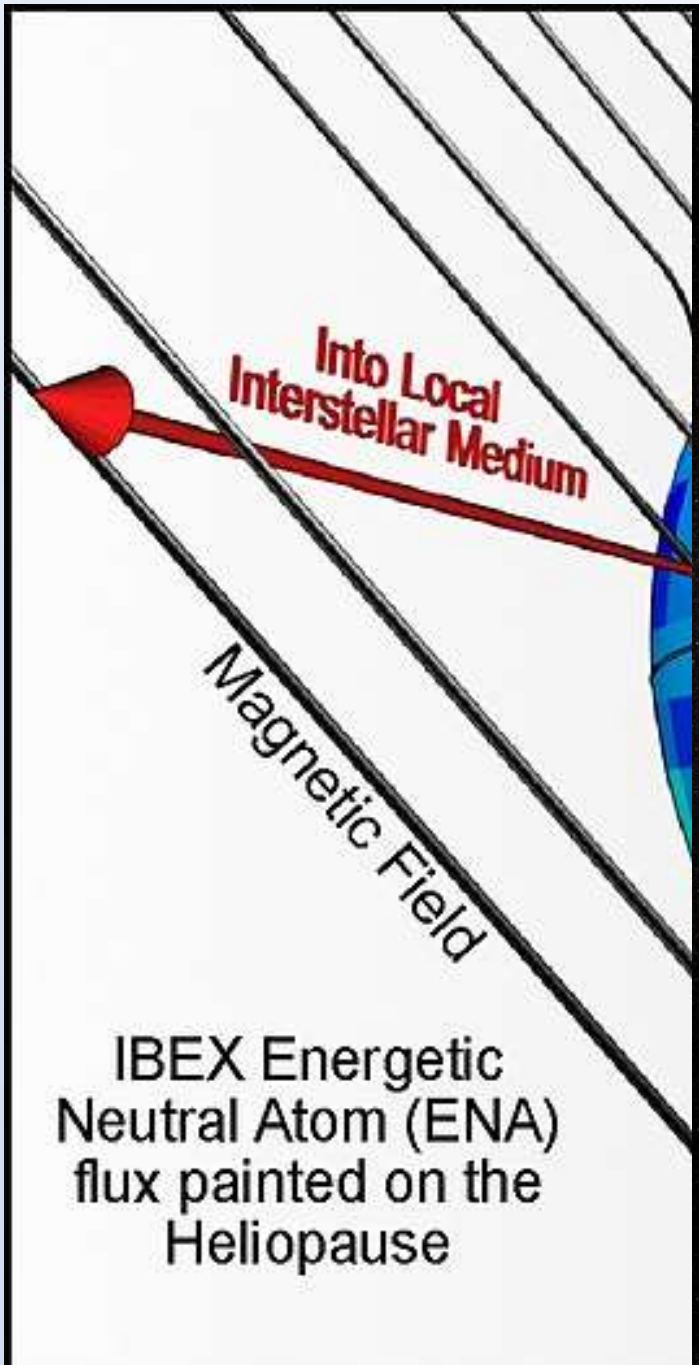
What's next for Voyagers?

Running out of power:

- Operated by plutonium batteries
- Need to shut down instruments to conserve power for V2
- Coming up next year for V1 since it lost an instrument early on

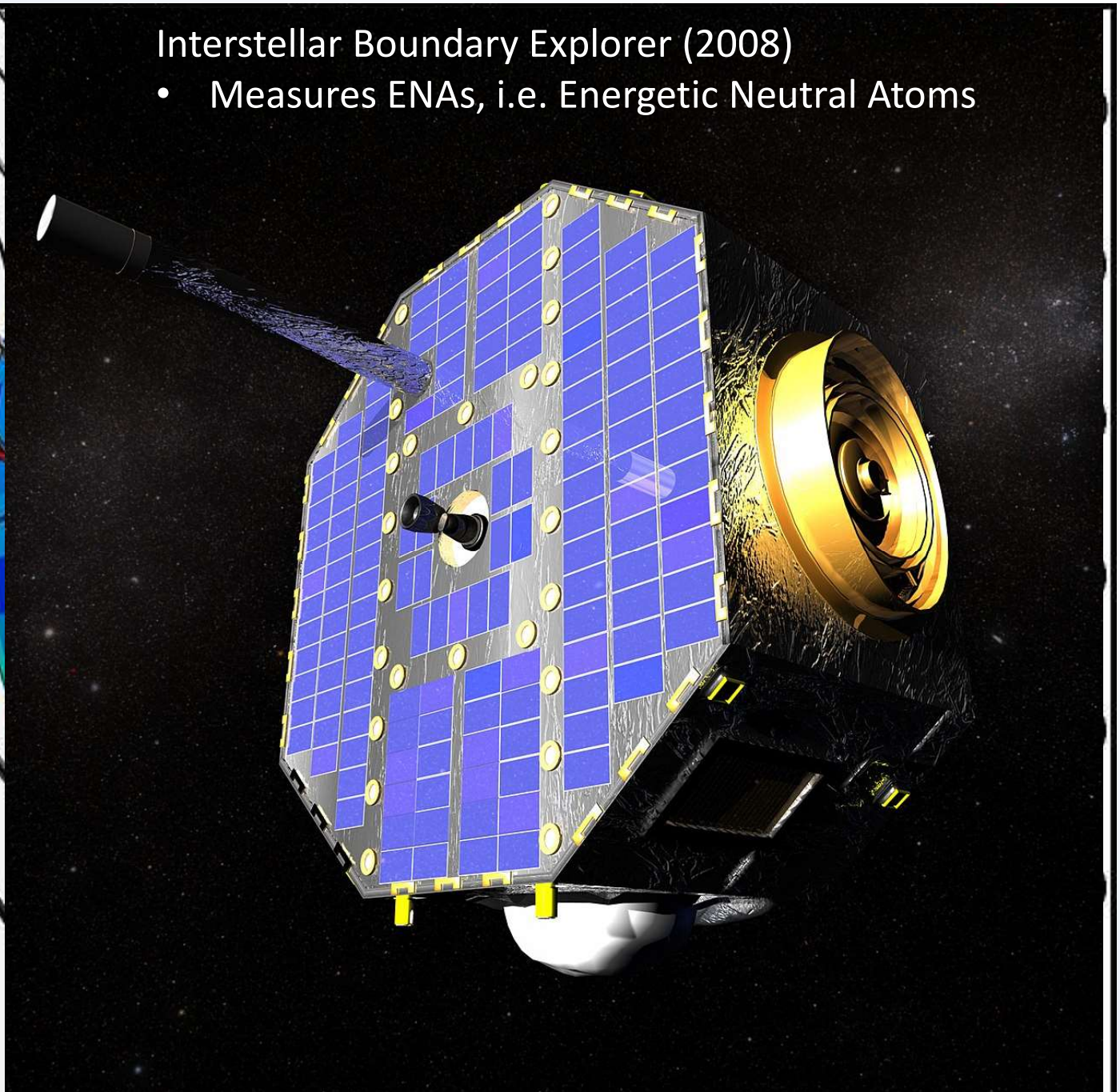
Expected end: '25 (V1), '26 (V2)

Heliospheric boundary: IBEX measurements

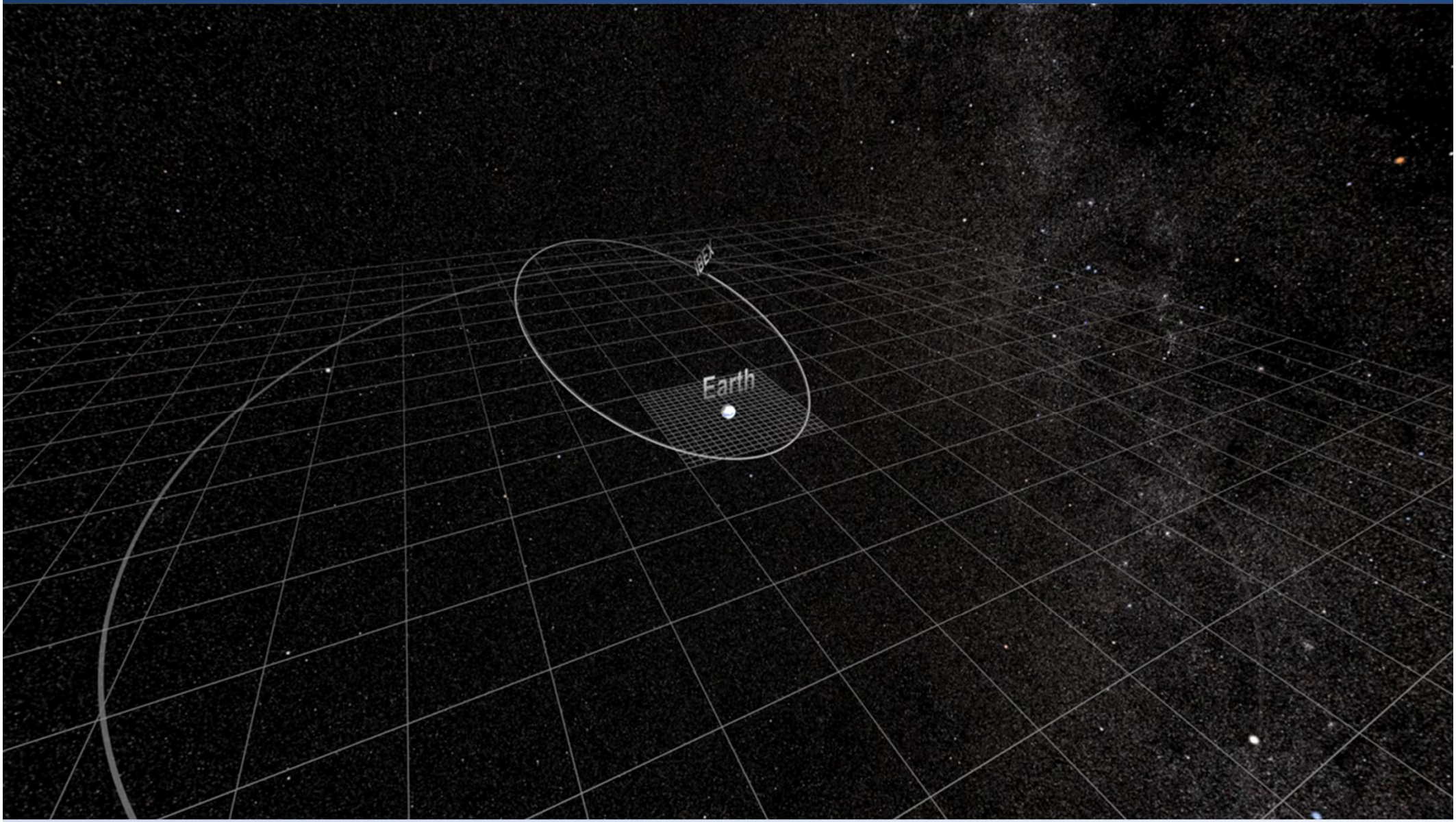


Interstellar Boundary Explorer (2008)

- Measures ENAs, i.e. Energetic Neutral Atoms

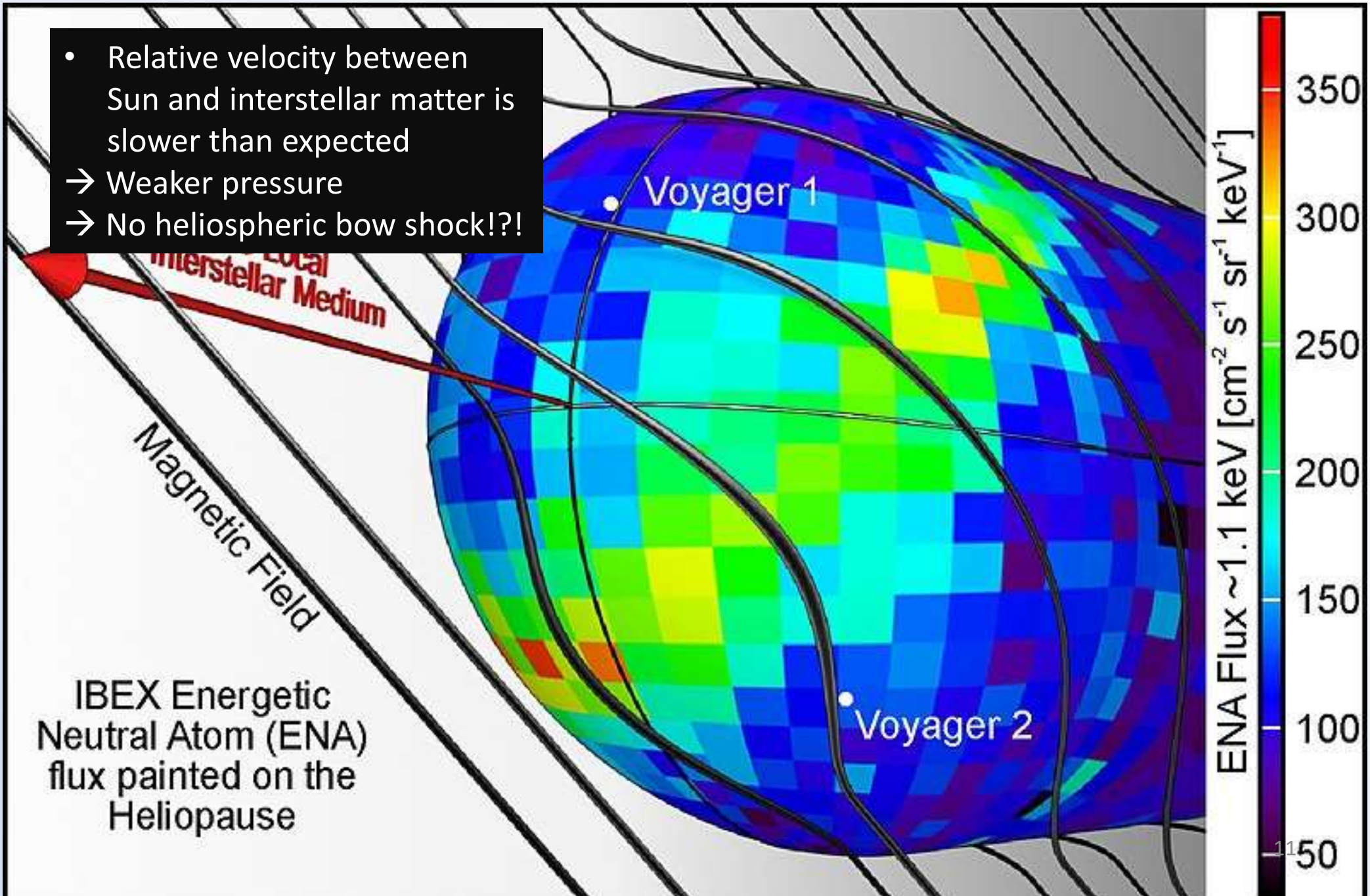


IBEX measurements

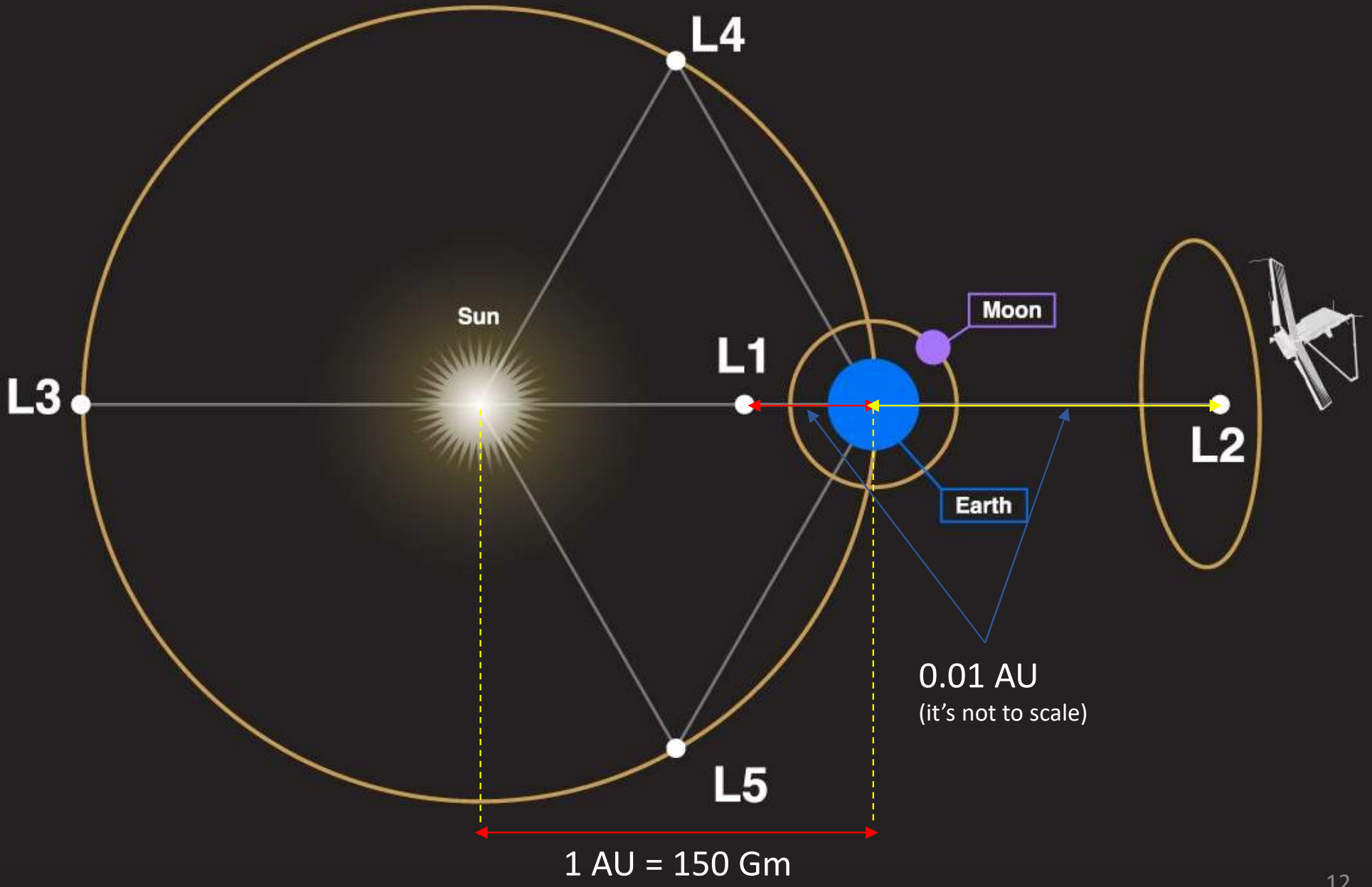


source: https://svs.gsfc.nasa.gov/4087

Heliospheric boundary: IBEX measurements



Observing Sun and solar wind: Lagrange points



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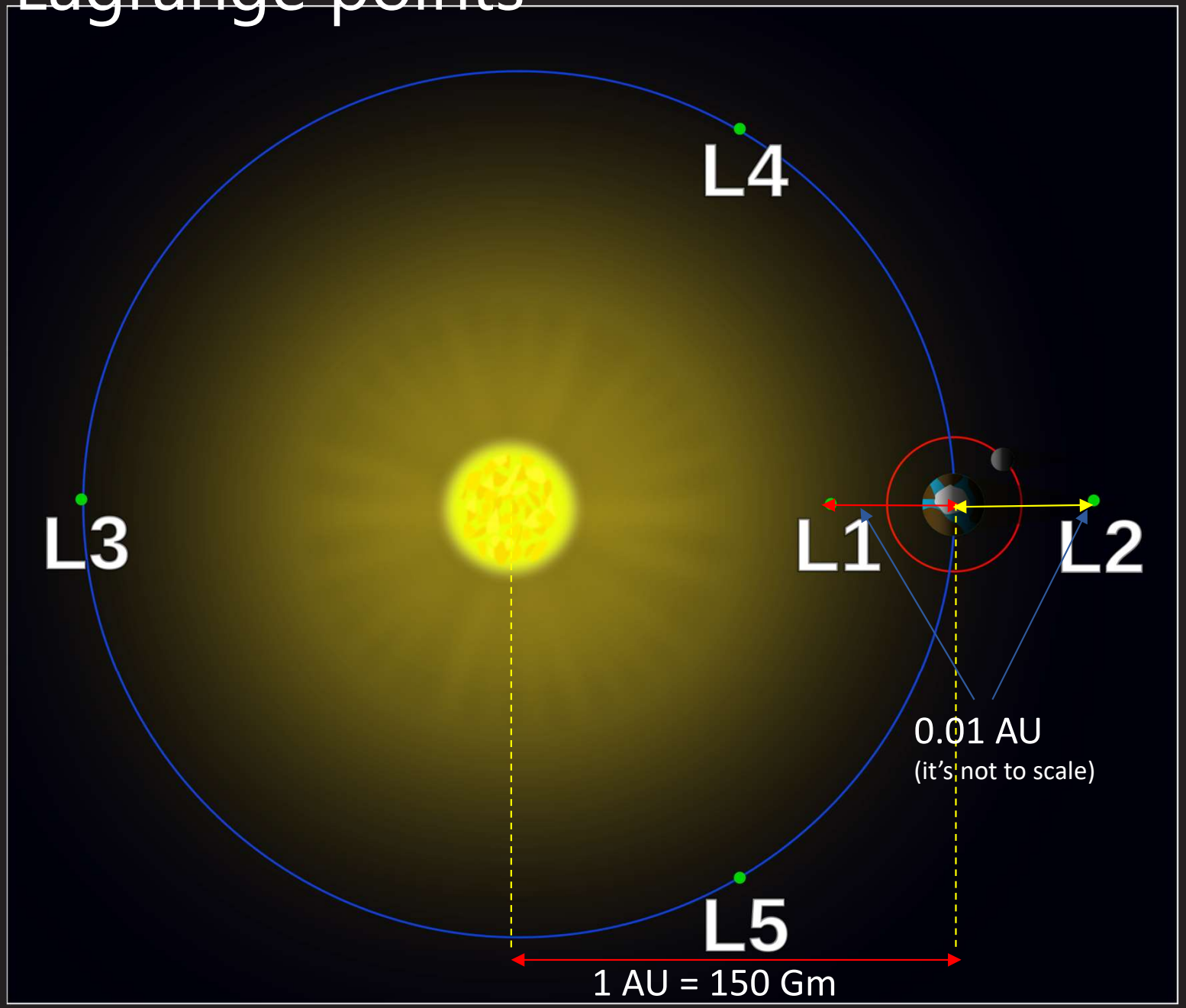


SOHO

- Solar and Heliospheric Observatory

LASCO coronagraph images

- **Solar disc is covered similarly to a solar eclipse**
- **The light from the flanks is captured**

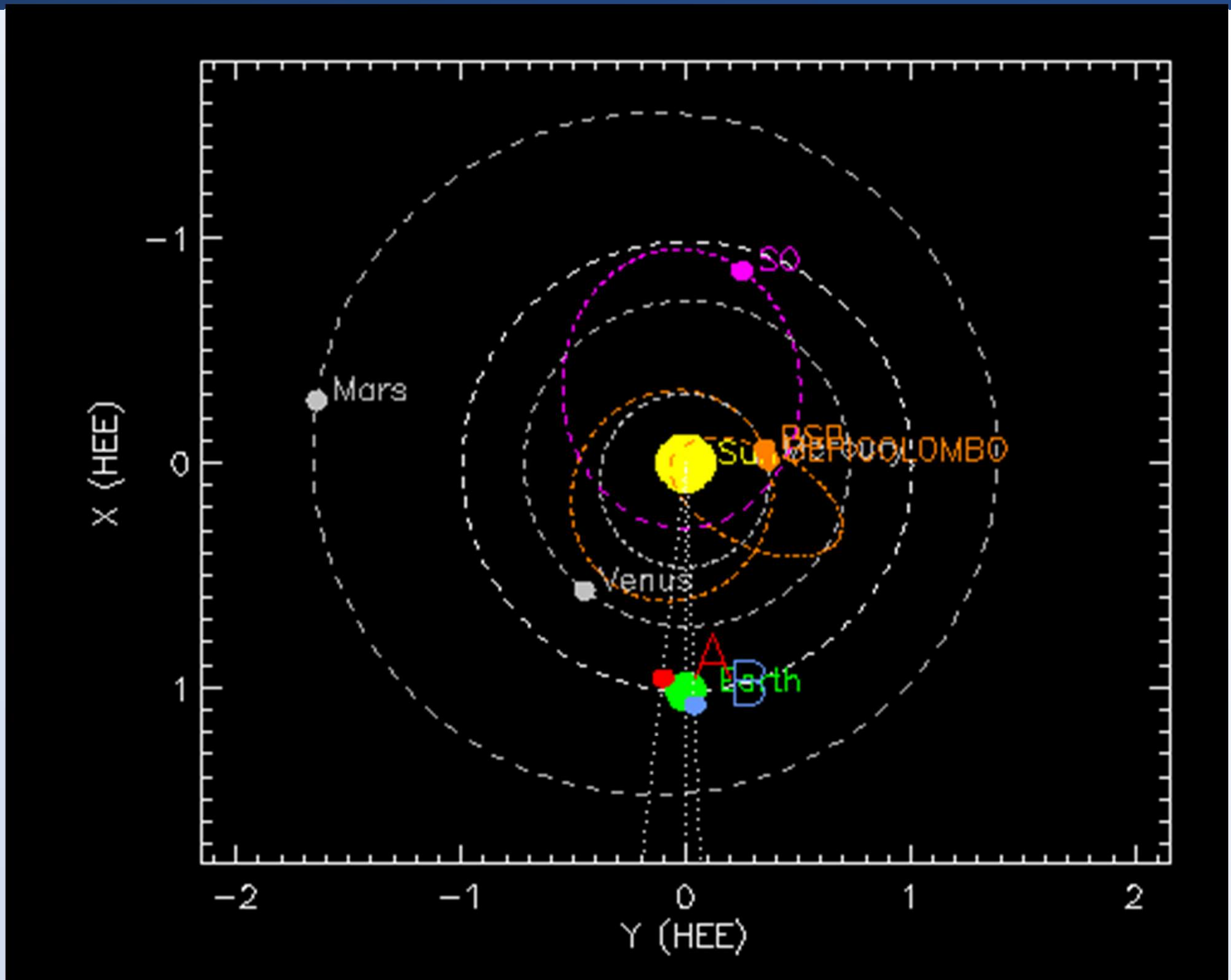
Extreme ultraviolet imaging at 304 nm superimposed on the coronagraph

https://soho.nascom.nasa.gov/home.html

STEREO spacecraft

- Two spacecraft:
  - STEREO-A (ahead) leading Earth in its orbit
  - STEREO-B (behind) staying behind
- Similarly armed with coronagraphs and solar imagers, they (used to) let us capture a 3D picture

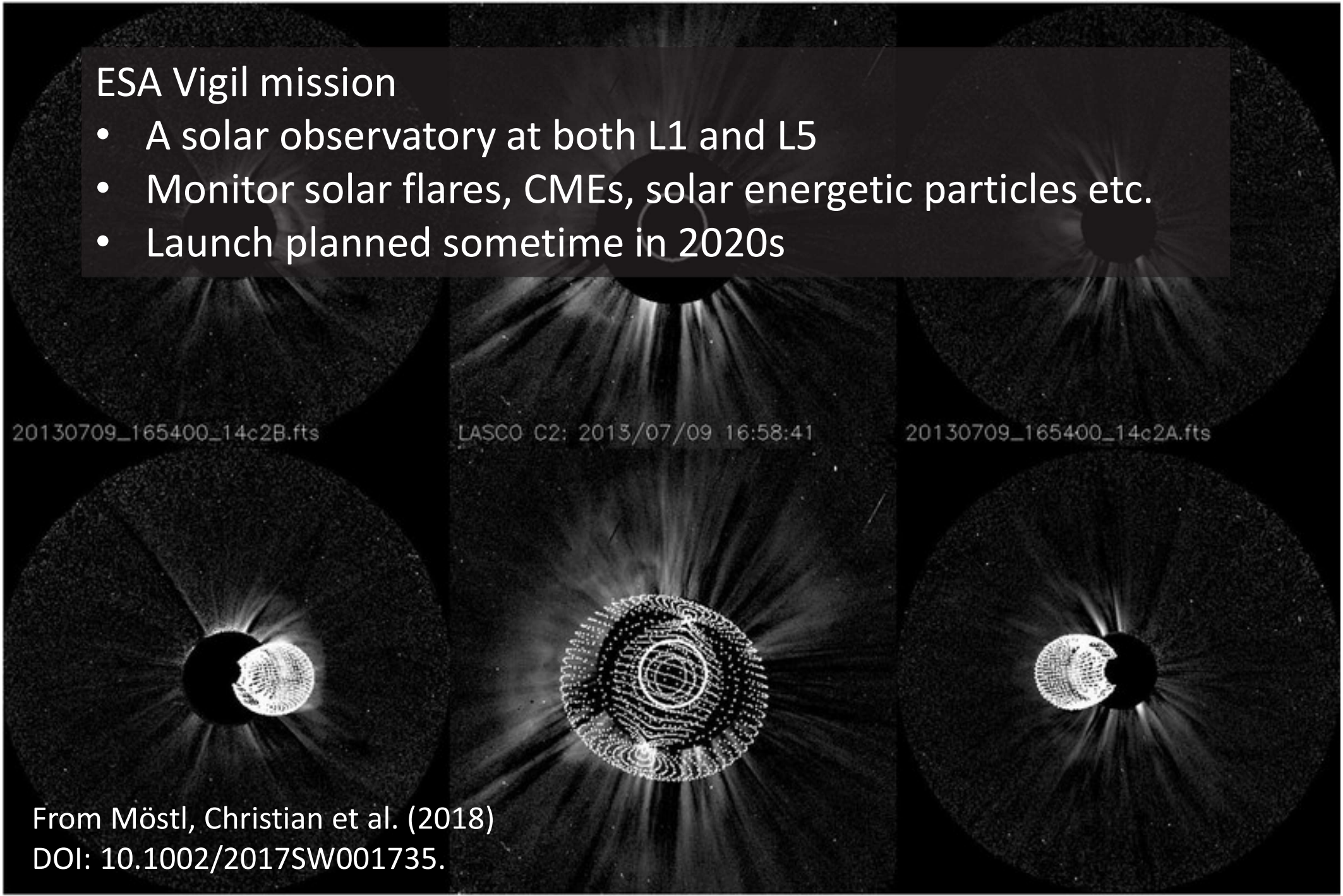
STEREO spacecraft



STEREO spacecraft

ESA Vigil mission

- A solar observatory at both L1 and L5
- Monitor solar flares, CMEs, solar energetic particles etc.
- Launch planned sometime in 2020s



From Möstl, Christian et al. (2018)
DOI: 10.1002/2017SW001735.

Observing Sun

Solar observatories

- SOHO (1995 – present)
- SDO (2010 – present)
- STEREO-A (2006 – present) (and STEREO-B – 2014)
- Hinode (2006 – present)
- Vigil (planned)
- IRIS (2013 – present)
  - Solar limb, flares

Missions to study Sun head-on

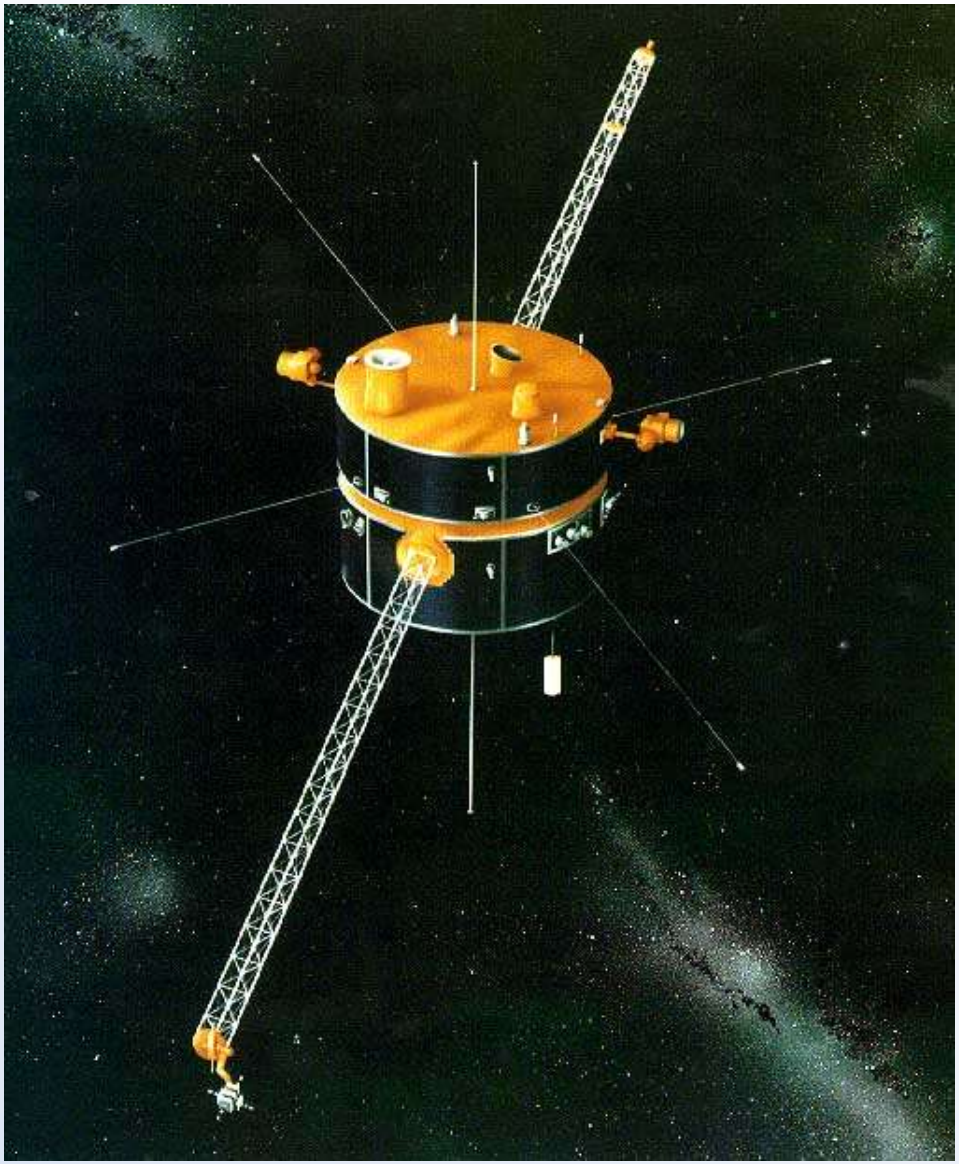
- Solar Orbiter (2020 – present)
- Parker Solar Probe (2018 – present)
  - Study coronal heating, solar wind formation, solar dynamo

Observing solar wind at L1: **ACE**, Wind, and DSCOVR

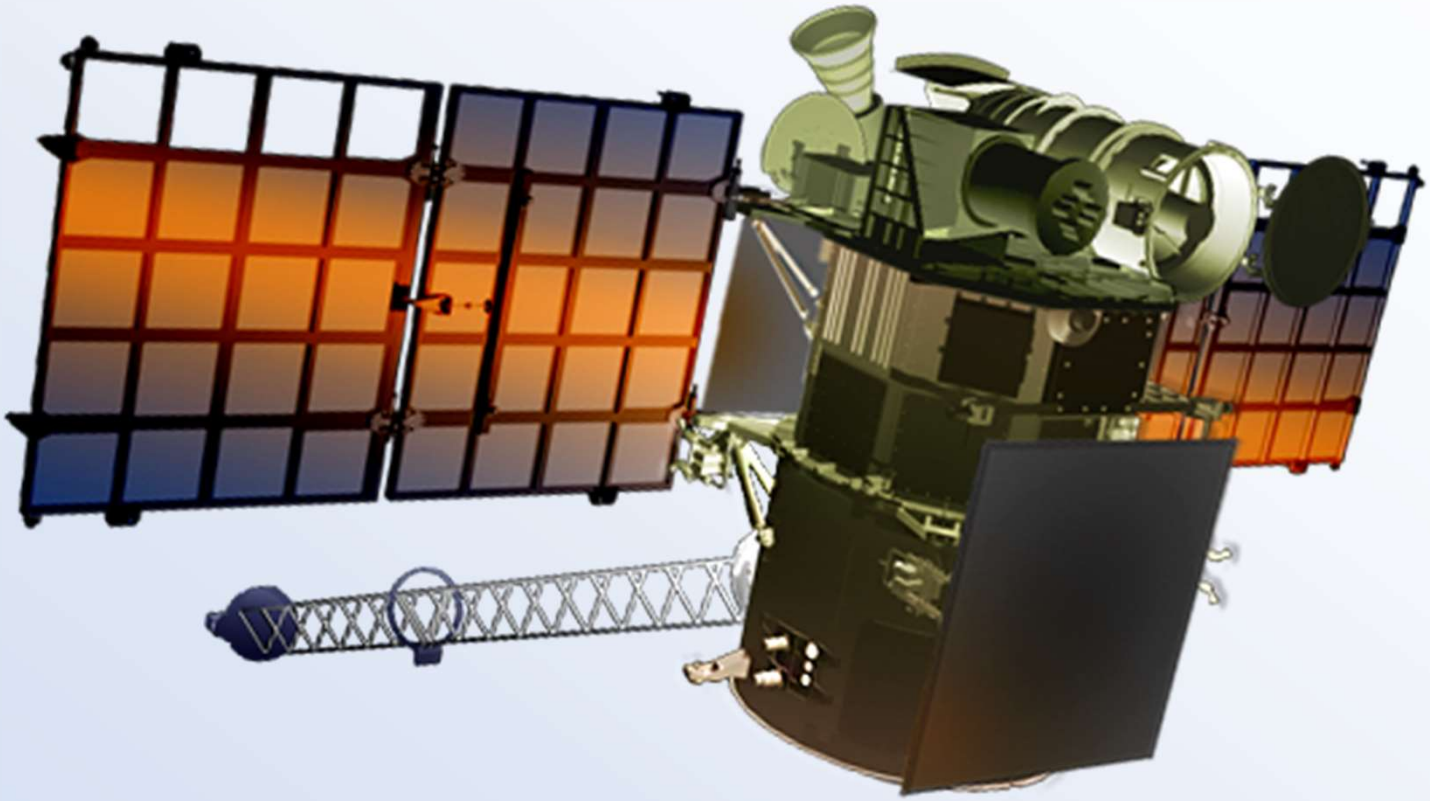
- ACE, Advanced Composition Explorer (1998 – present)
- Planned for 5 years
- Measures e.g.:
  - magnetic field
  - solar wind particles (speed, density, temperature
  - cosmic rays
- Aged instruments
  - Solar Energetic Particle analyzer broken in 2008
  - Halloween storm 2003 malfunctions

Observing solar wind at L1: ACE, **Wind**, and DSCOVR

- 1994 – present
- Started out by studying magnetosphere, including magnetotail
- Since 2004 at L1 with ACE
- Significant instruments:
  - Search coil magneto-meters to study waves
  - Fluxgate magnetometer for slower changes of field
  - Solar wind, ion velocity distribution



Observing solar wind at L1: ACE, Wind, and **DSCOVR**

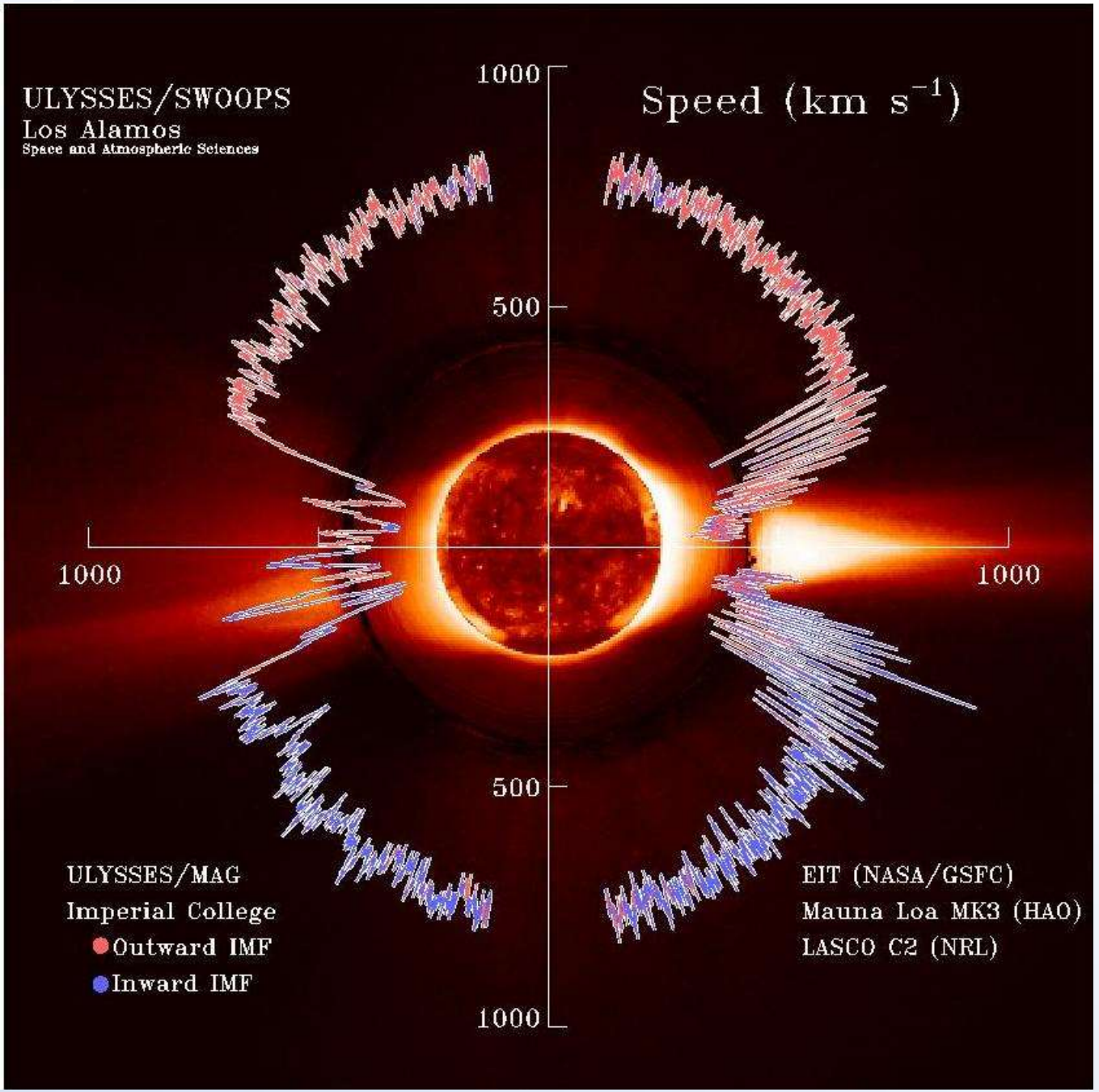


- **D**eep **S**pace **C**limate **O**bser**v**ato**r**y
- 2015 – present
- To replace ACE, eventually

Observing high heliographic latitudes: **Ulysses**

- 1990 – 2009

Mission to orbit Sun at "all latitudes"



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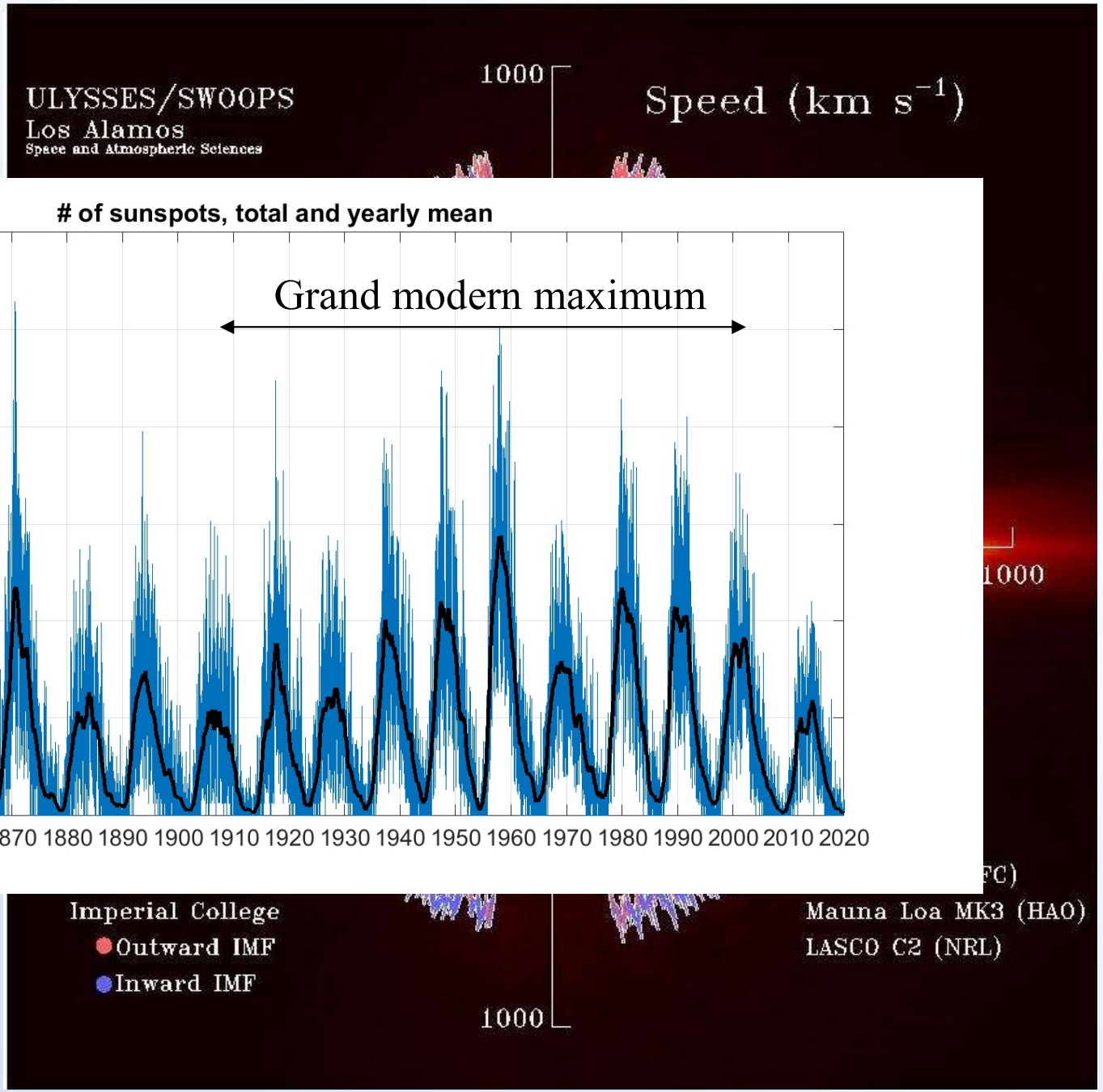
- 1990 – 2009

Mission to orbit Sun at



Exploring other planets

- **Mercury:** Messenger and Bepicolombo (on-going)
- **Venus:** Venus Express, VERITAS (upcoming)
- **Jupiter:** Voyagers, Juno, Juice (on-going)
- **Saturn:** Pioneer, Voyagers, Cassini