

Solar Wind Interaction with Bodies in the Solar System

Adam Masters

SPAT PG Lecture Series

Outline

Today

- ✧ **Brief history of the field**
- ✧ **Diverse space plasma environments... So what?**
- ✧ **The solar wind + a reminder of key plasma physics**

Tomorrow

- ✧ Solar wind interaction with...
 - ✧ Unmagnetised bodies without an atmosphere
 - ✧ Unmagnetised bodies with an atmosphere
 - ✧ Magnetised bodies without an atmosphere
 - ✧ Magnetised bodies with an atmosphere
- ✧ The future of the field

Friday: Introduction to space mission design

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Friday: Introduction to space mission design

The Aurora

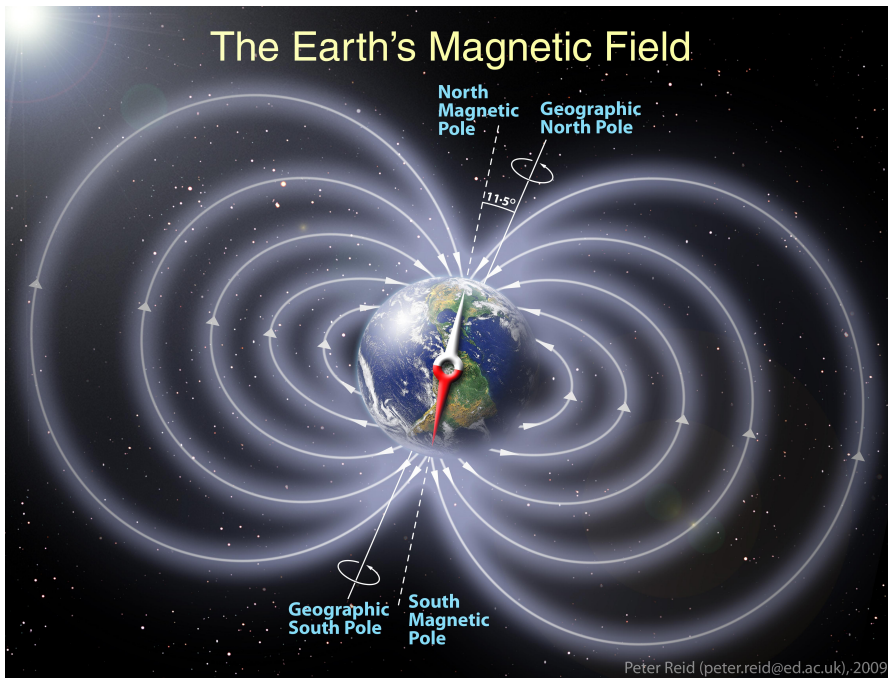
The Aurora

- ✧ Space physics began with the appreciation of Earth's auroras
- ✧ Accounts of auroral sightings go back as far as ~2000 B.C.
- ✧ Galileo Galilei coined the term “aurora borealis” (dawn of the North)
- ✧ In 1770 Captain James Cook reported the “aurora australis” (dawn of the South)
- ✧ In the 17th and 18th centuries there were competing explanations

The Earth's Magnetic Field

The direction-finding ability of the compass was the earliest indication that our planet has a magnetic field

The Earth's Magnetic Field



In the early 19th century a global network of instruments measuring the geomagnetic field (magnetometers) was constructed

Fluctuations of our planet's magnetic field were identified at an early stage

A Link Between the Sun and the Earth

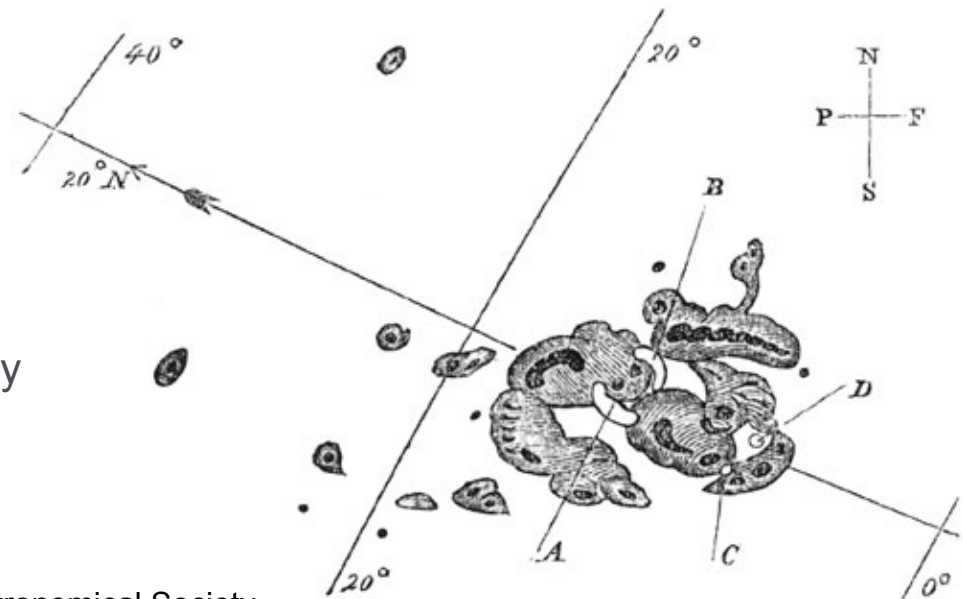
Olof Hiorter reported a correlation between geomagnetic and auroral activity in 1741

Scientists were also monitoring the Sun during this era of geomagnetic/auroral research

On 1 September 1859 Richard Carrington was sketching sunspots when he saw a great flare of white light – a solar flare

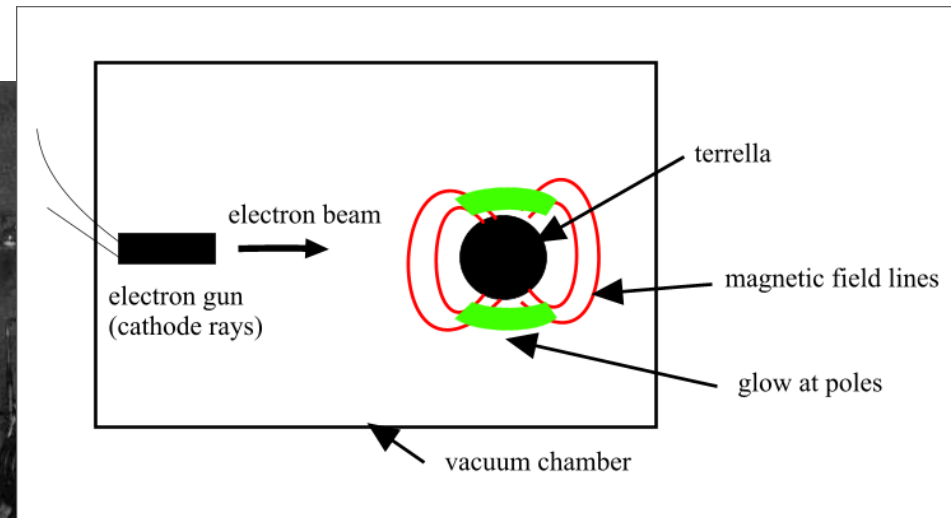
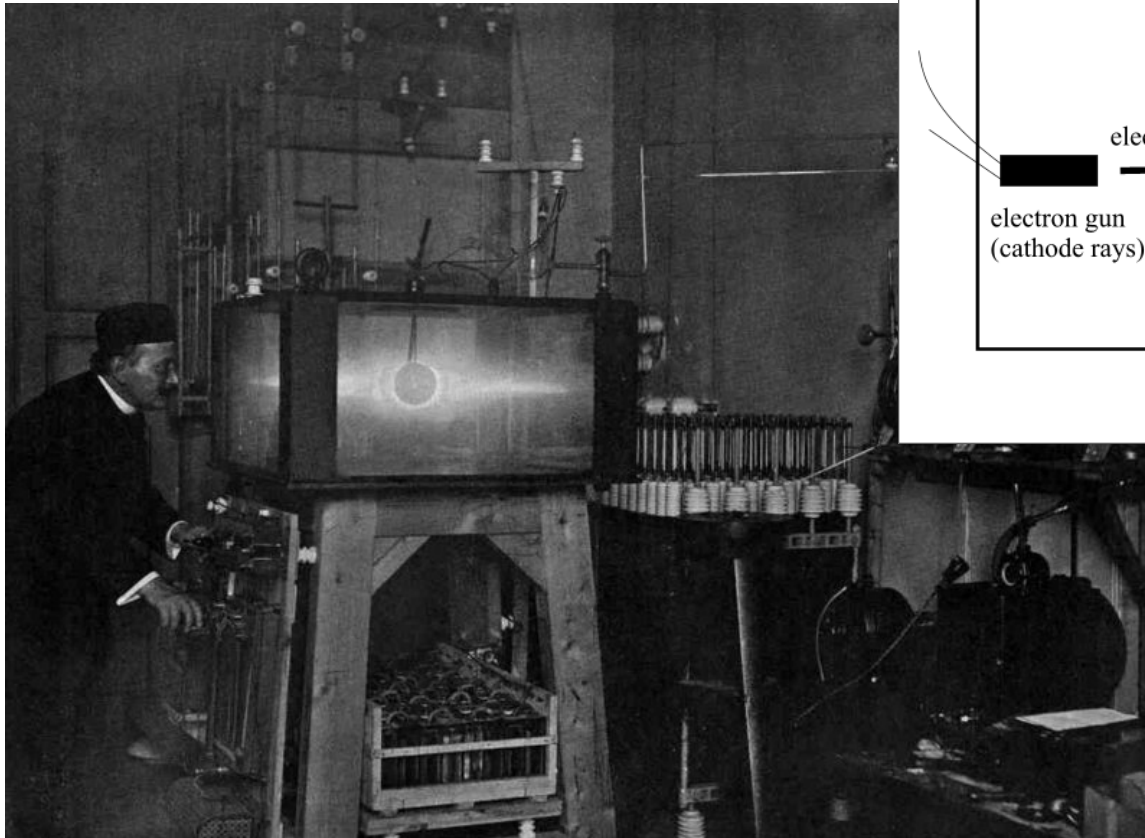
Following the flare there was an intense geomagnetic storm

There were significant geomagnetic fluctuations and an intense auroral display

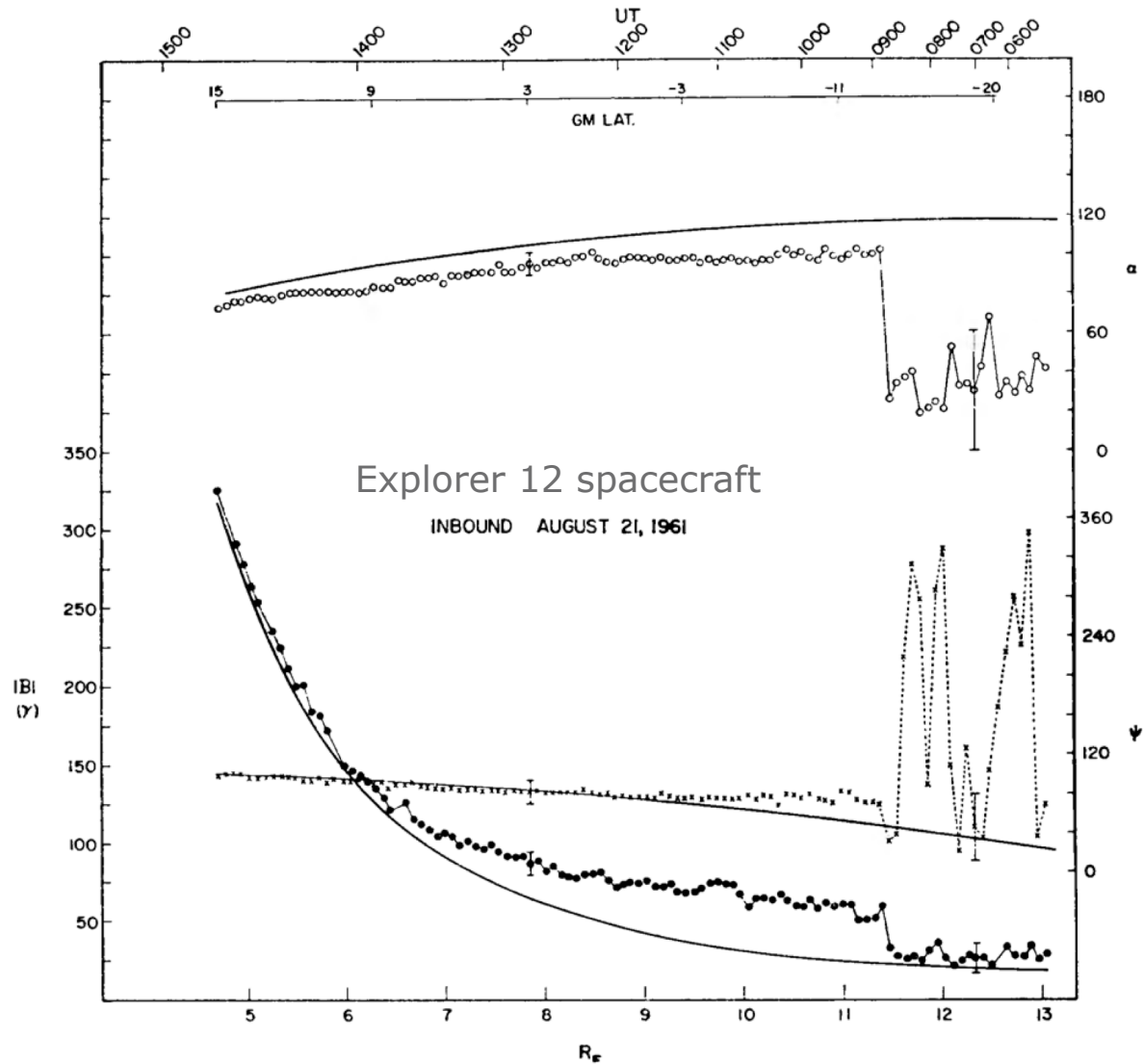


Kristian Birkeland

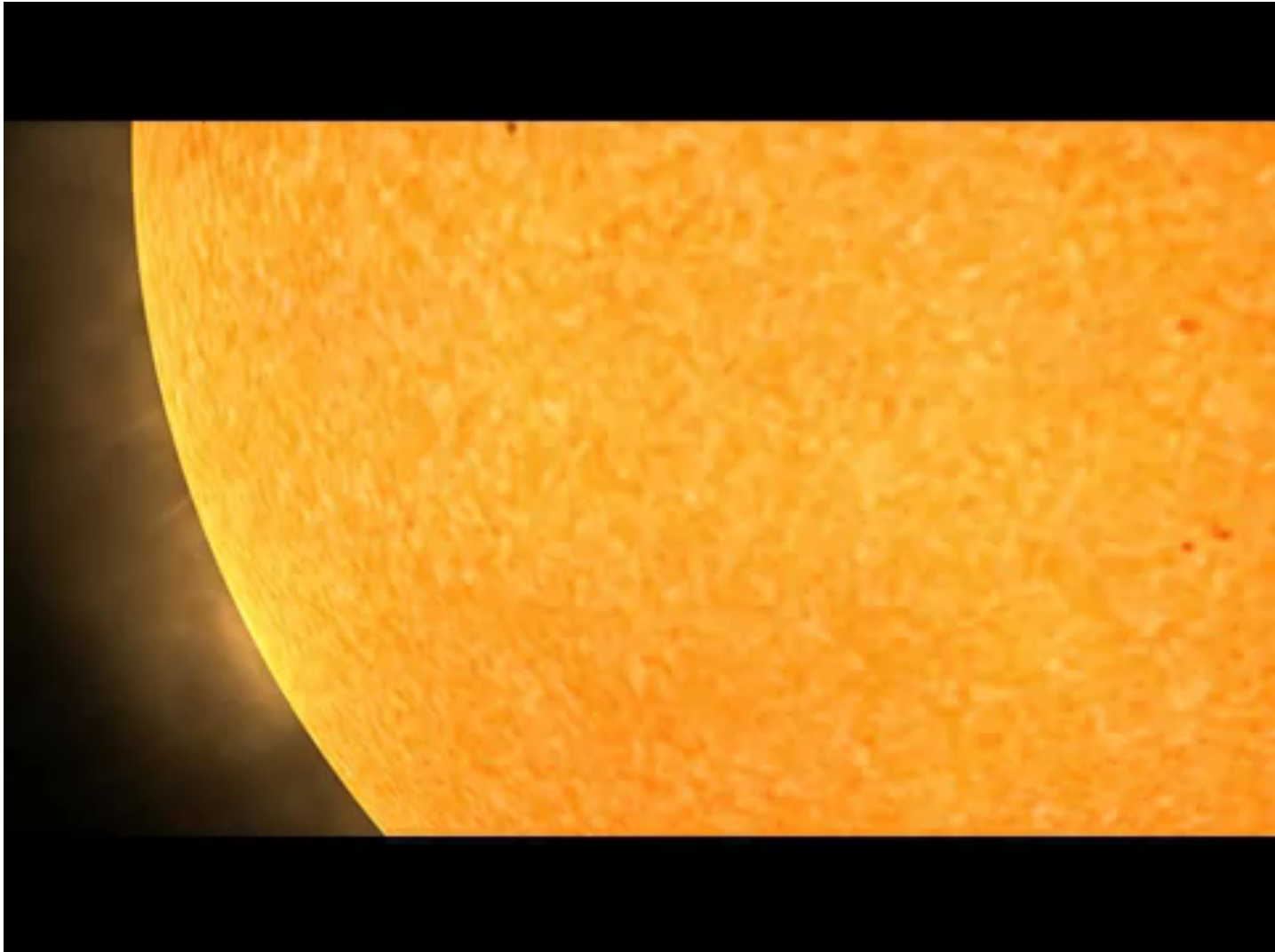
It seems to be a natural consequence of our points of view to assume that the whole of space is filled with electrons and flying electric ions of all kinds (1895)



The Dawn of the Space Age



Sun-Earth Connection: What we Know Today



Credit: NASA

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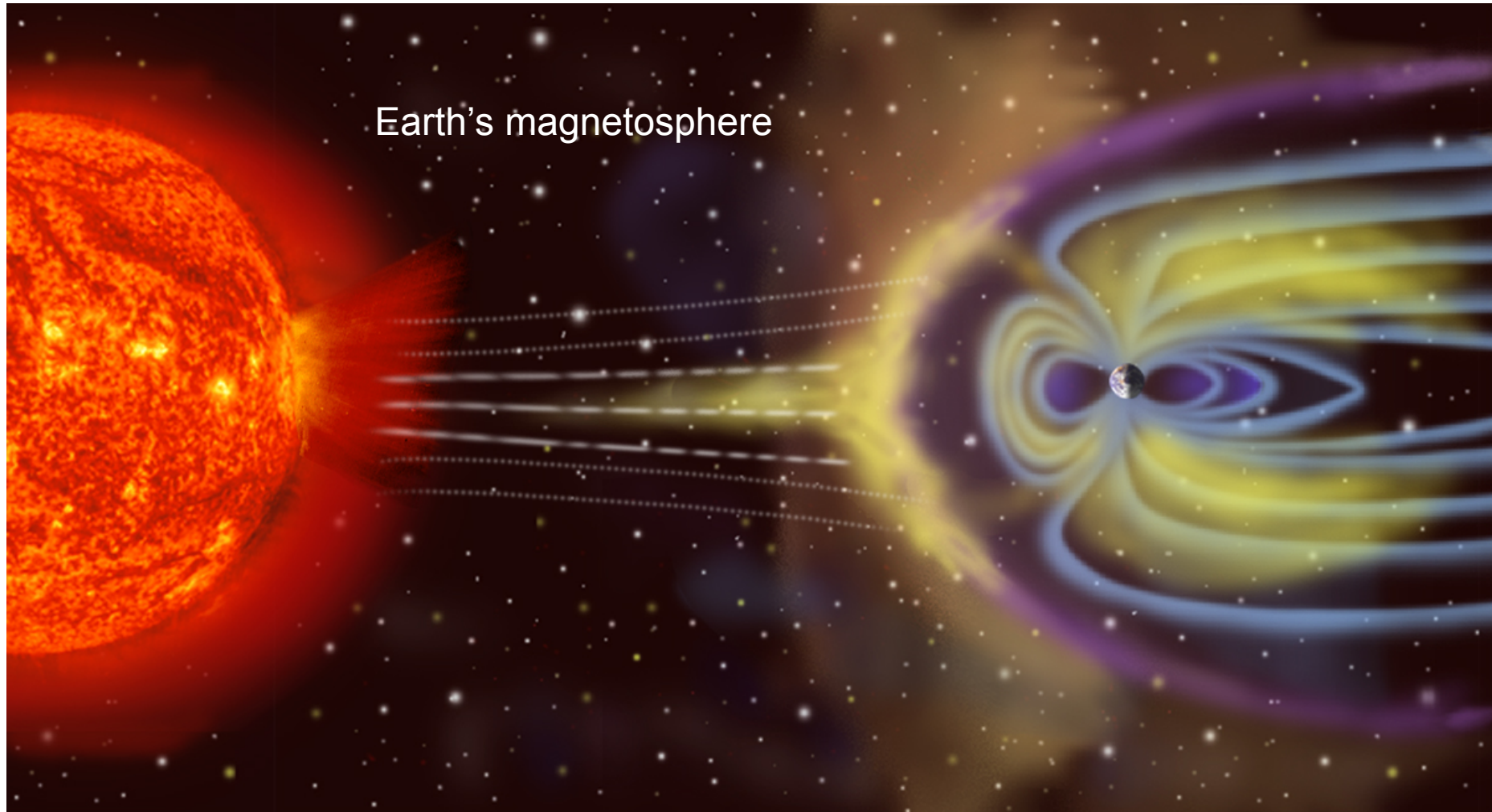
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Friday: Introduction to space mission design

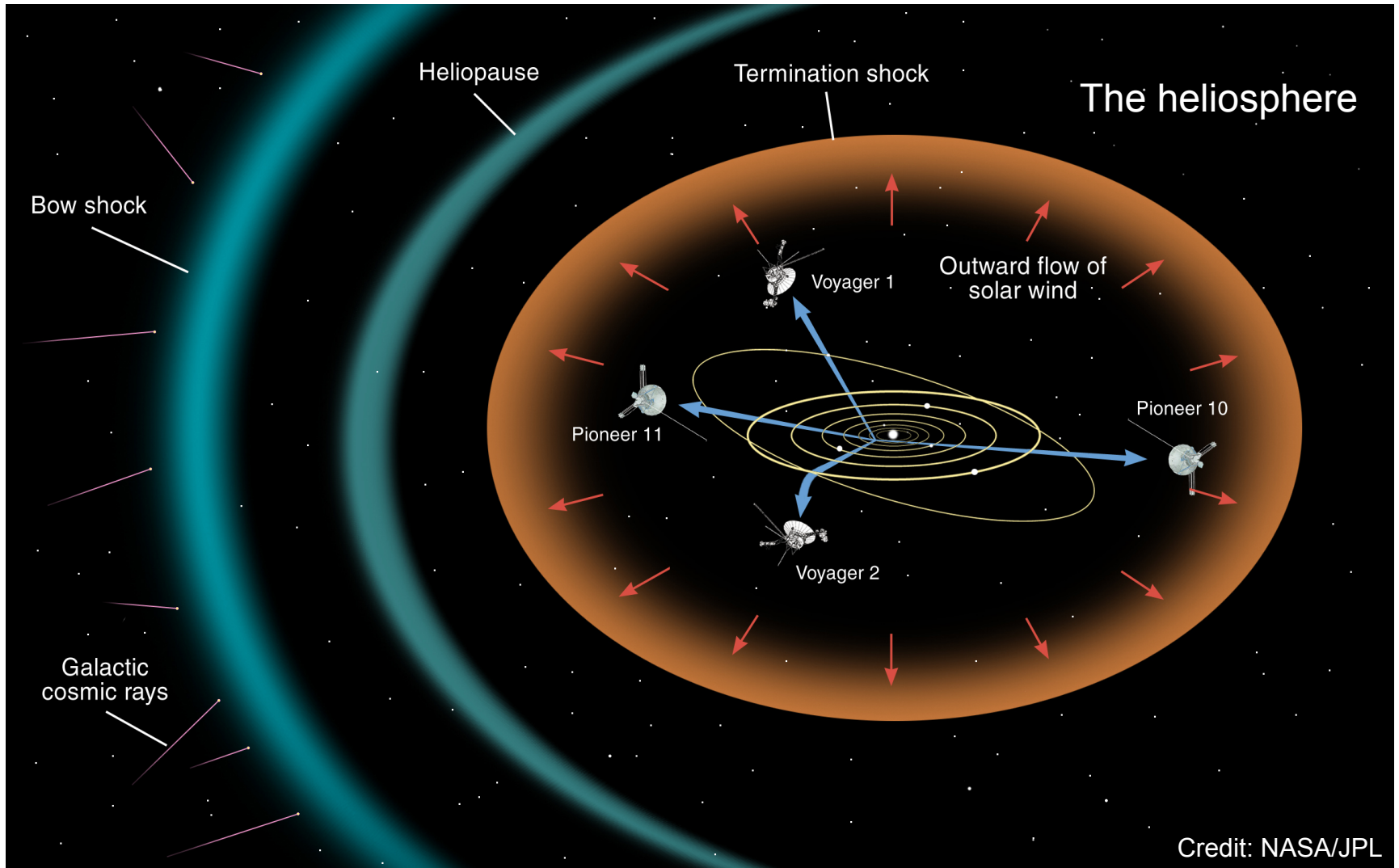
What is a Space Plasma Environment?

- ✧ Plasma: A gas that is sufficiently ionised for the medium to show a collective response to electromagnetic fields.
- ✧ Space plasma: A very low density plasma in which inter-particle collisions are effectively absent (a.k.a., a collisionless plasma), and so particles can only interact via the electromagnetic field.
- ✧ The Solar System is filled with diverse types of space plasma system, and this is just the beginning.
- ✧ These systems cannot yet be created in a laboratory, and it is very difficult to observe them remotely → Reliance on *in situ* measurement

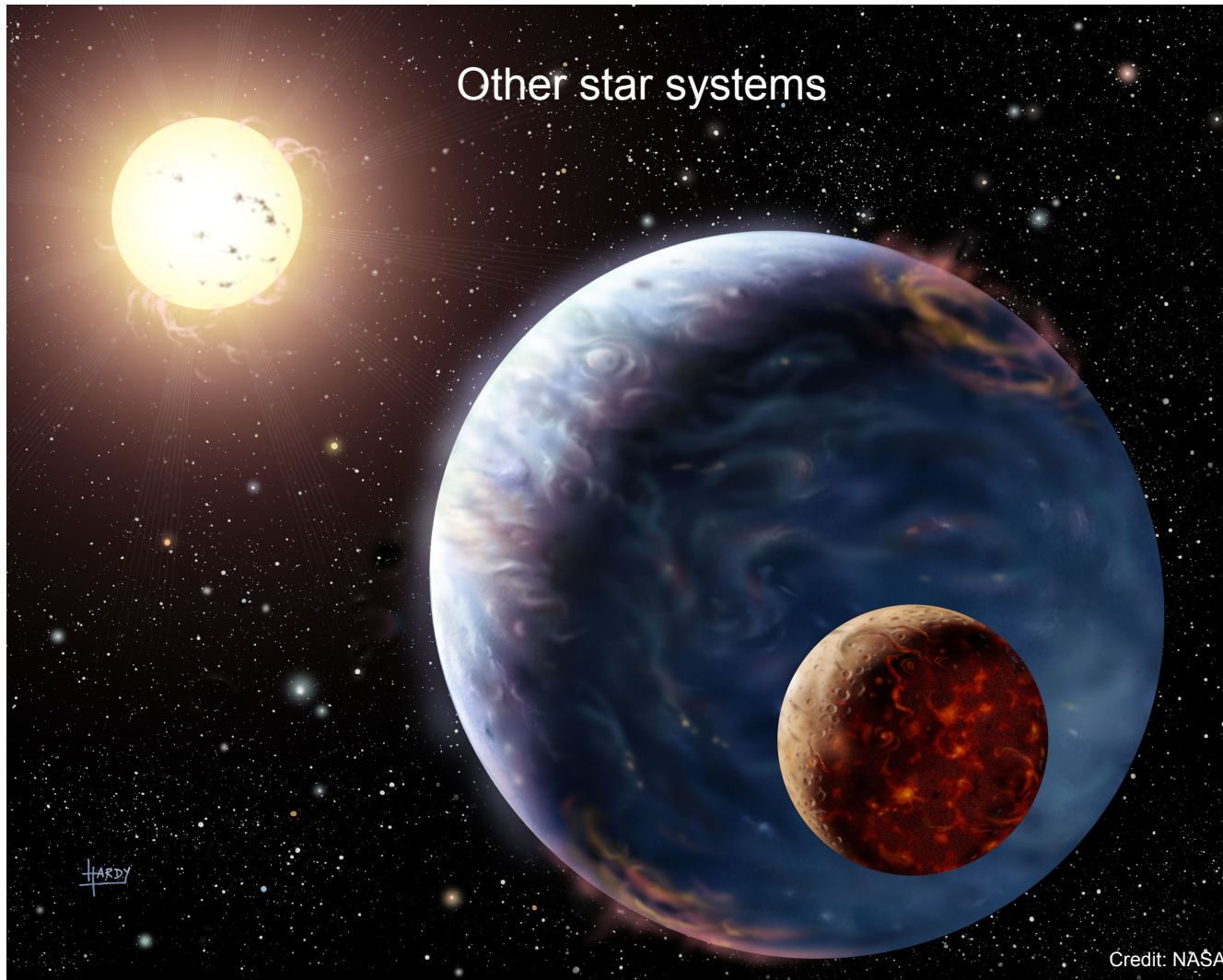
Examples of Space Plasma Systems



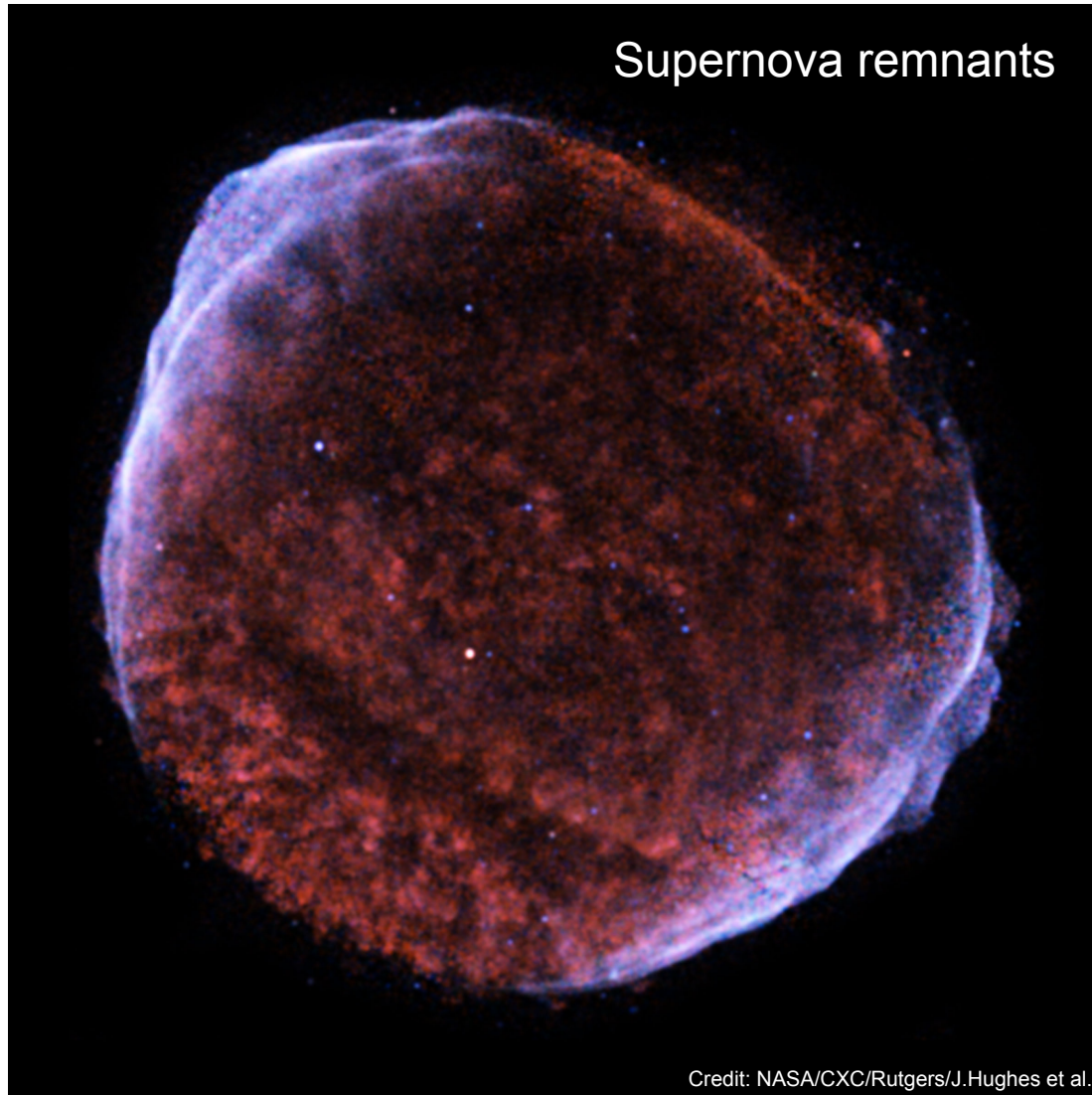
Examples of Space Plasma Systems



Examples of Space Plasma Systems



Examples of Space Plasma Systems



So What?

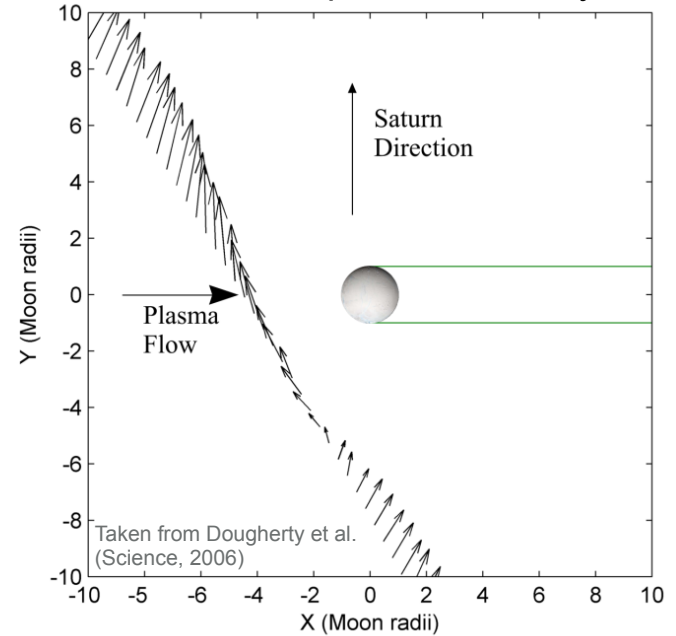
- ✧ Fundamental physics with broad implications
- ✧ Essential element of solar system science
- ✧ Space weather forecasting

An Essential Element of Solar System Science

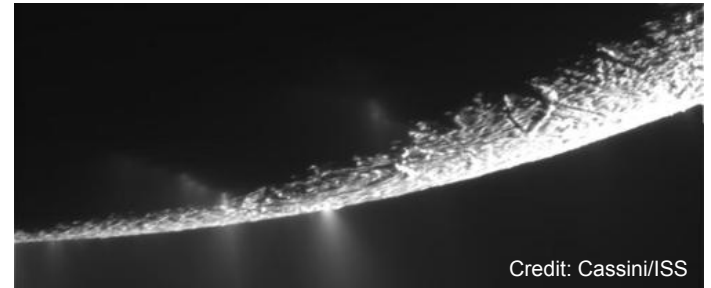
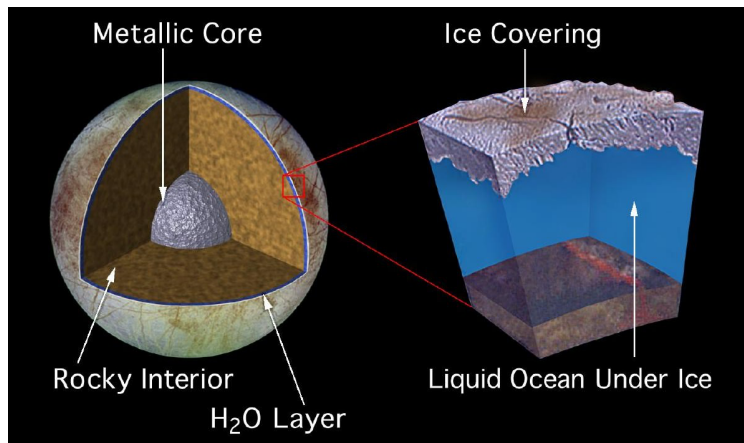
Loss of the Martian atmosphere



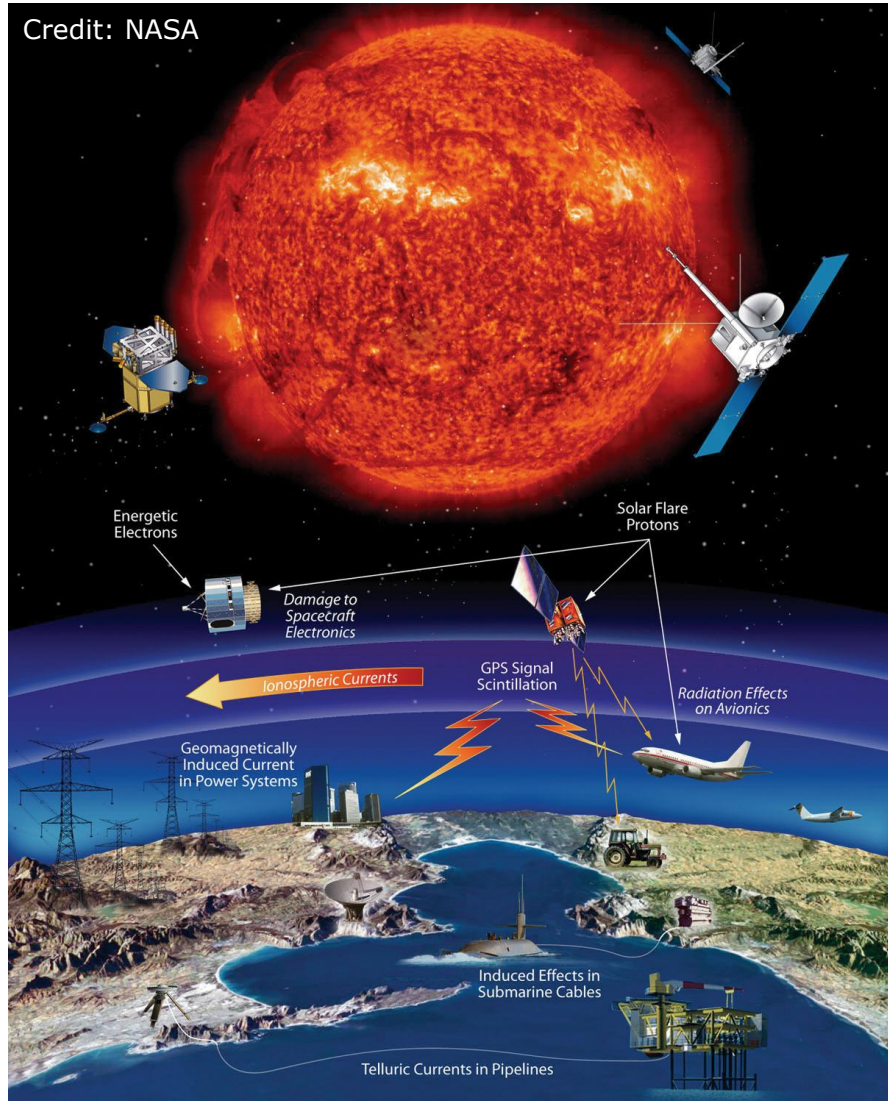
Enceladus plume discovery



Subsurface oceans at Europa and Ganymede



Space Weather Forecasting



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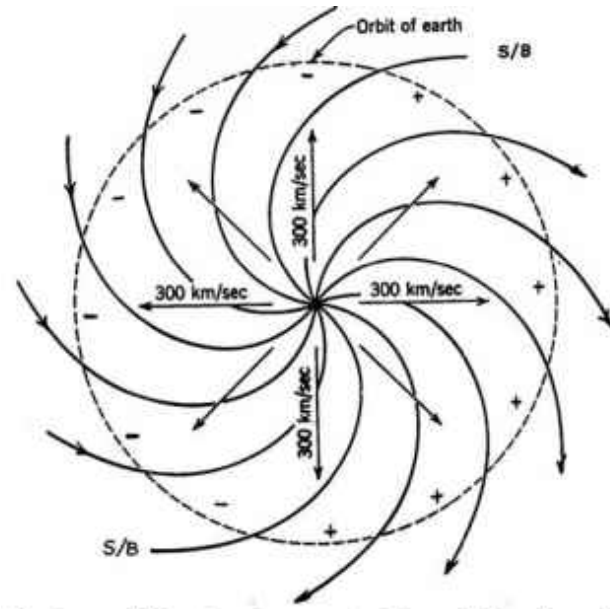
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Friday: Introduction to space mission design

The Solar Wind: An Overview



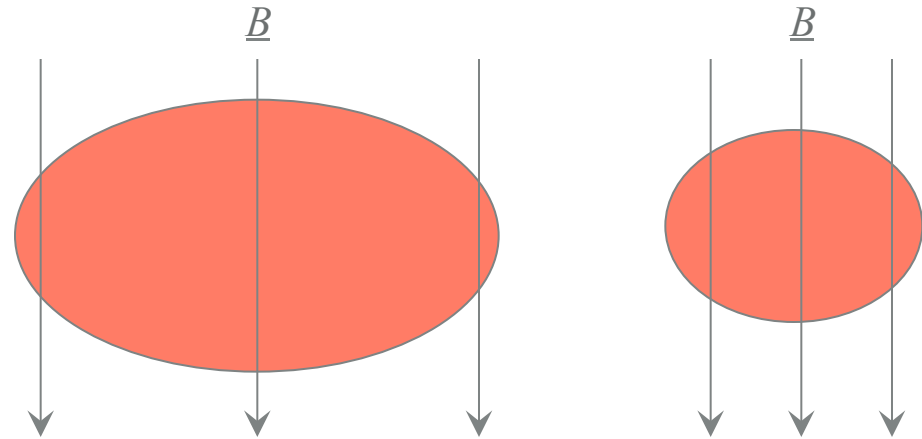
Properties at 1 Astronomical Unit (AU, the mean Sun-Earth distance, $\sim 150,000,000$ km)

Proton density	6.6 cm^{-3}
Electron density	7.1 cm^{-3}
He^{2+} density	0.25 cm^{-3}
Flow speed (nearly radial)	$450 \text{ km} \cdot \text{s}^{-1}$
Proton temperature	$1.2 \times 10^5 \text{ K}$
Electron temperature	$1.4 \times 10^5 \text{ K}$
Magnetic field (induction)	$7 \times 10^{-9} \text{ tesla (T)}$

Gas pressure	30 pPa
Sound speed	$60 \text{ km} \cdot \text{s}^{-1}$
Magnetic pressure	19 pPa
Alfvén speed	$40 \text{ km} \cdot \text{s}^{-1}$
Proton gyroradius	80 km
Proton-proton collision time	$4 \times 10^6 \text{ s}$
Electron-electron collision time	$3 \times 10^5 \text{ s}$
Time for wind to flow from corona to 1 AU	$\sim 4 \text{ days} = 3.5 \times 10^5 \text{ s}$

What Key Physics is at Work in the Solar Wind?

Alfvén's frozen-in flux approximation:
In a fluid with infinite electric conductivity magnetic field lines are frozen into the fluid and have to move along with it.



Resulting version of Ohm's law: $\underline{E} = - \underline{v} \times \underline{B}$

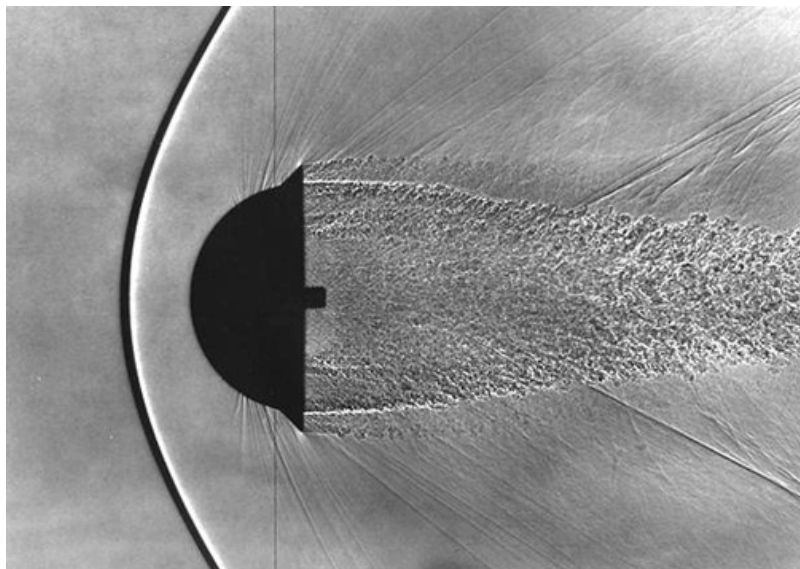
The plasma β (plasma pressure/magnetic pressure) indicates what controls system dynamics.

Also need to think about shocks, turbulence, and magnetic reconnection.

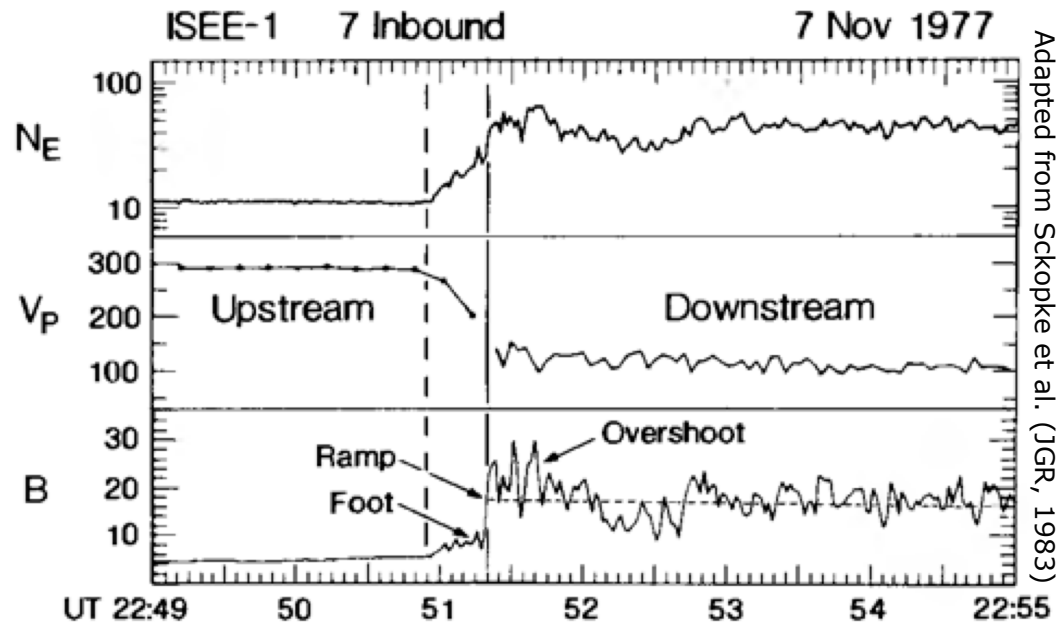
Collisionless Shocks

A shock forms around an obstacle to a flow when the speed at which information can be transferred via the medium is less than the flow speed \rightarrow Mach number

Collisionless shocks were not thought to be possible but they are widespread



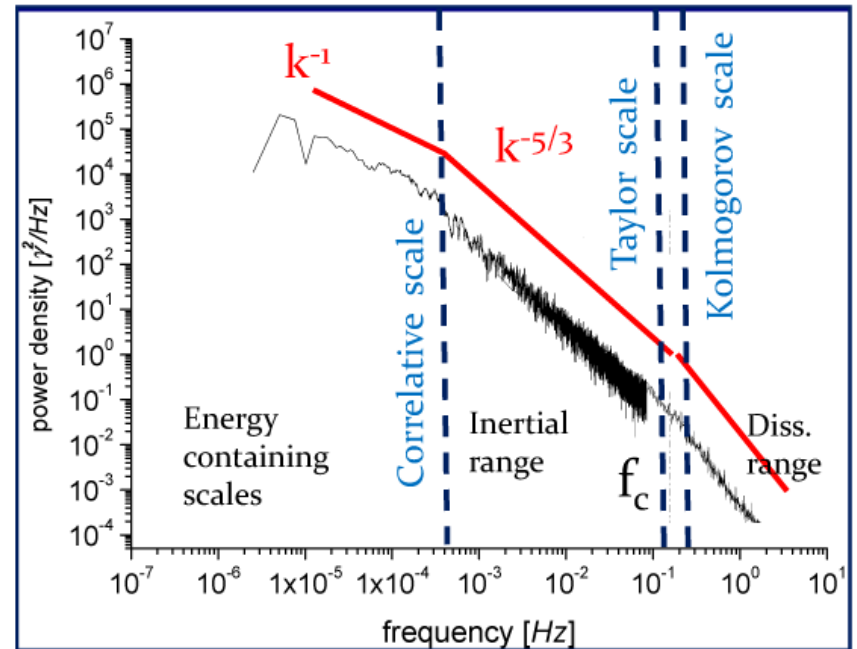
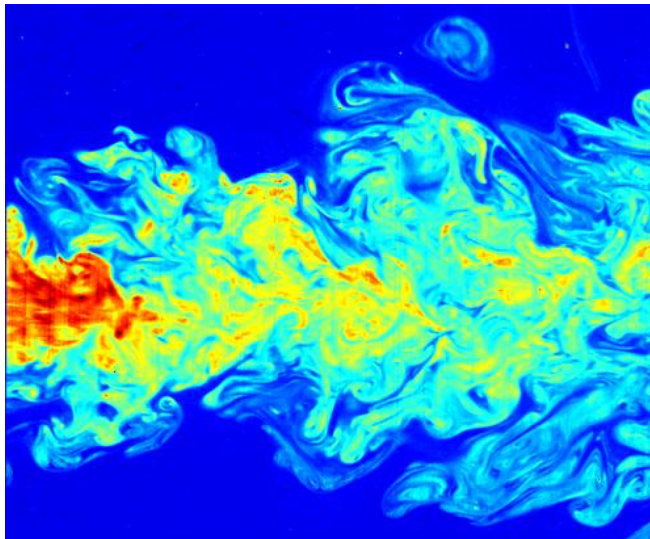
(NASA)



Turbulence

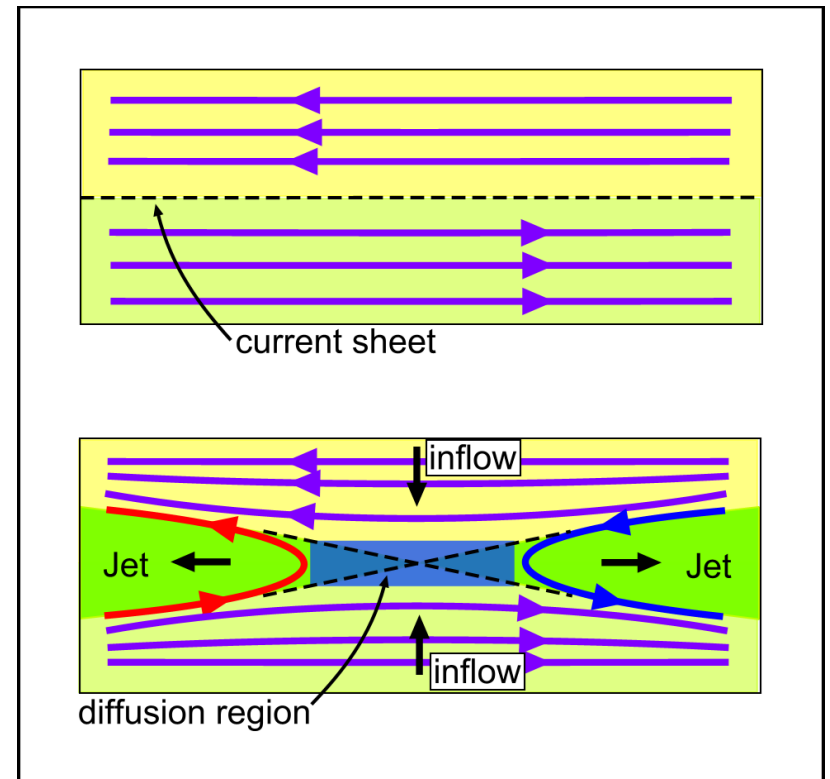
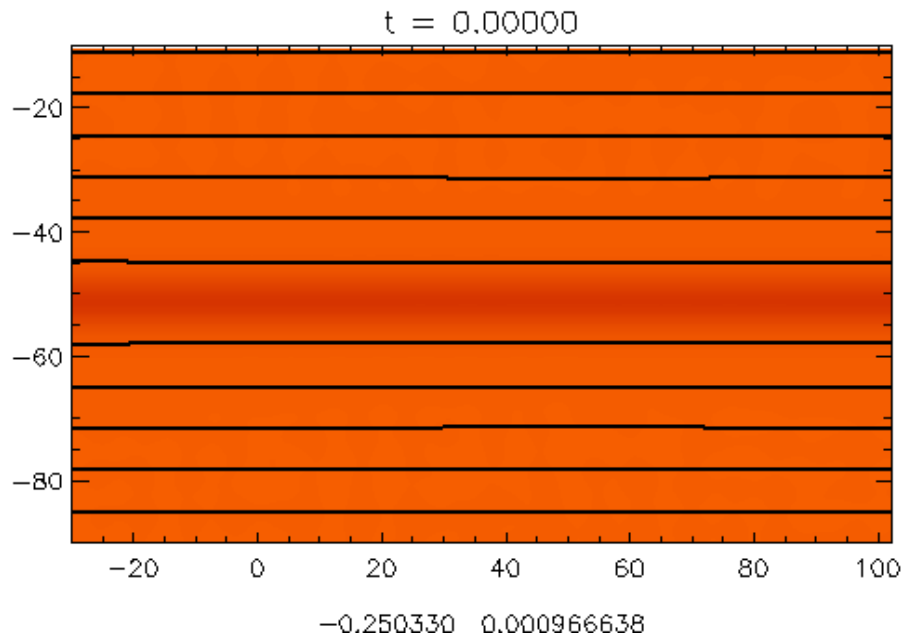
Turbulence is a flow regime characterised by chaotic property changes

MHD turbulence concerns the chaotic regimes of magnetofluid flow at high Reynolds number



Magnetic reconnection

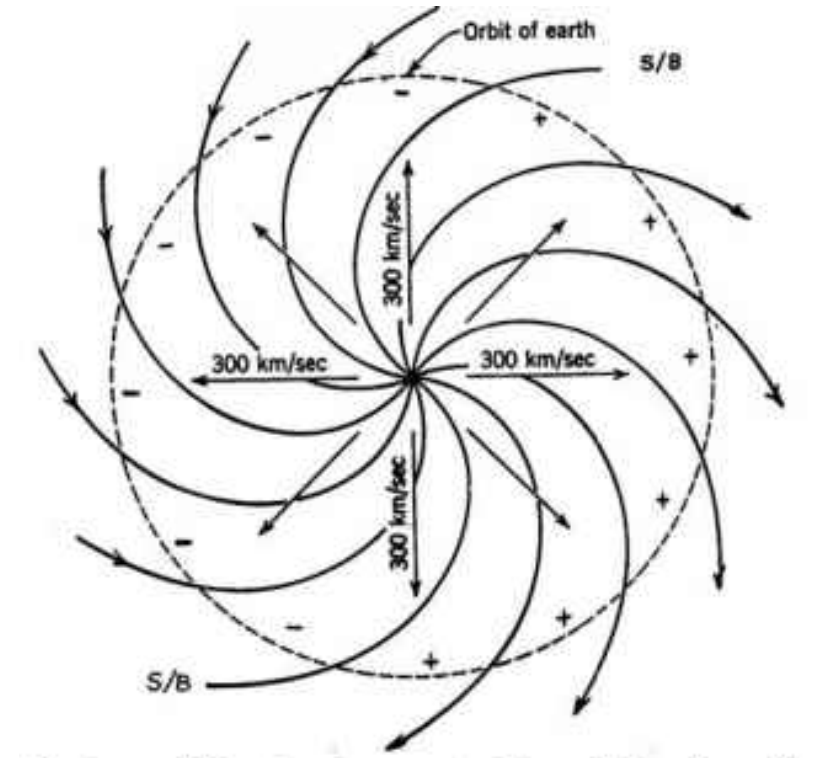
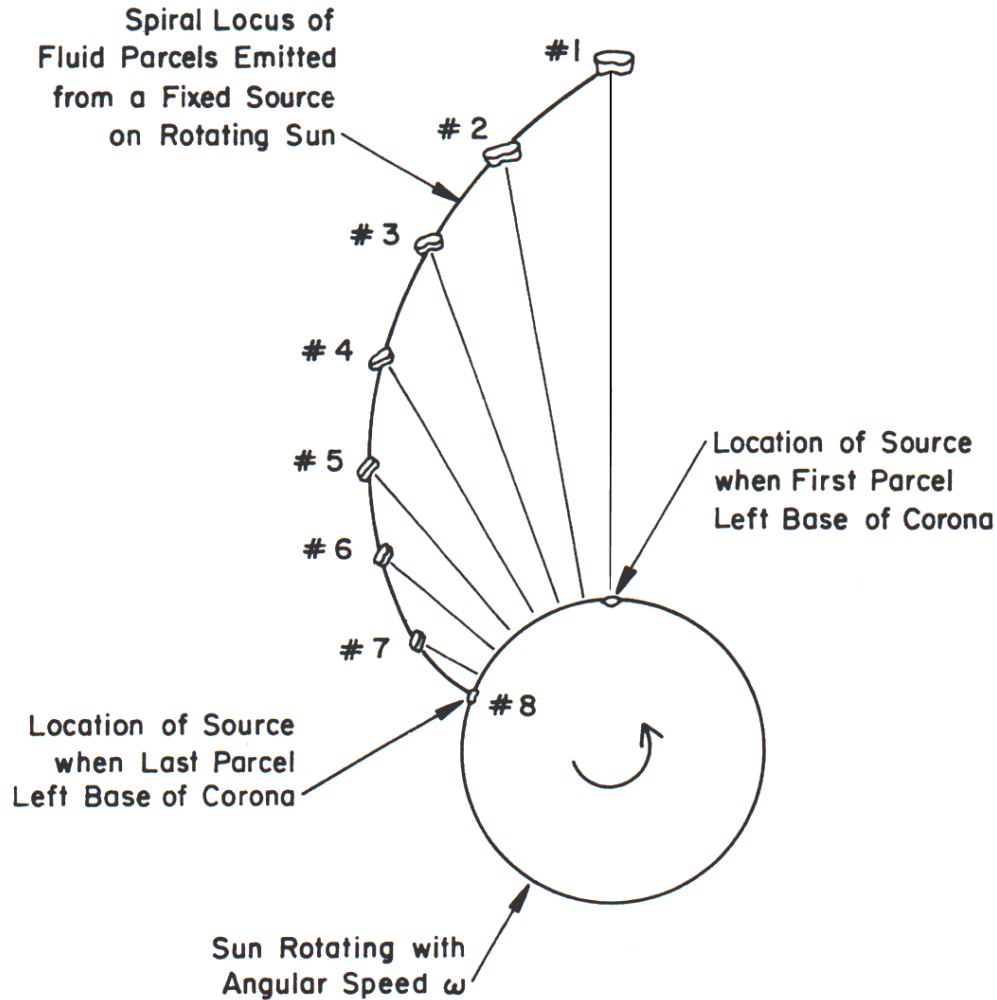
Magnetic reconnection changes the structure of the magnetic field and releases magnetic energy



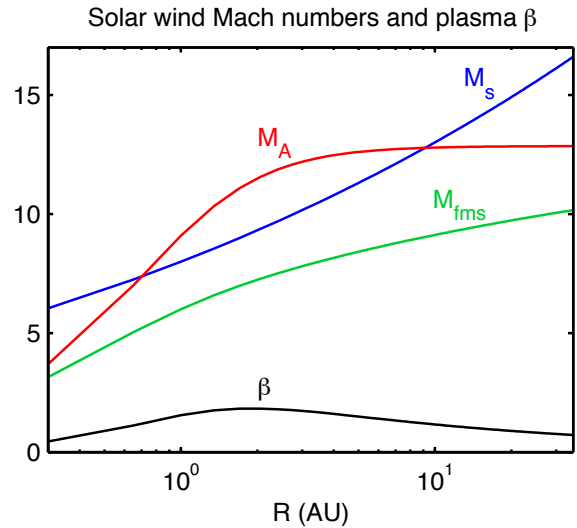
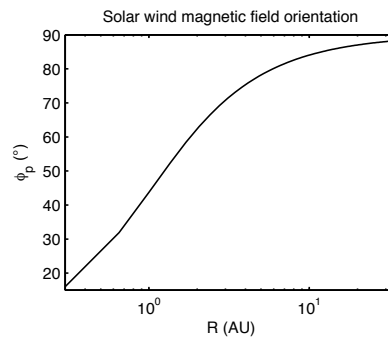
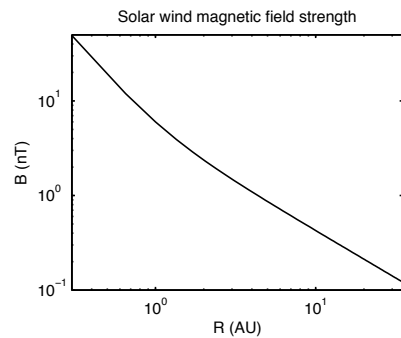
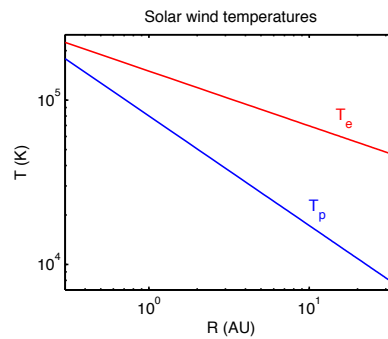
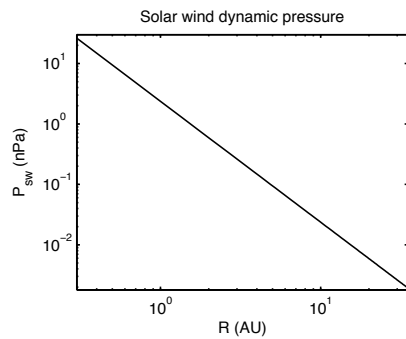
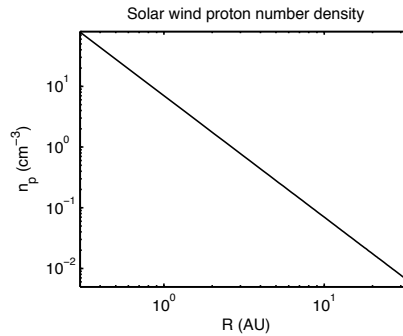
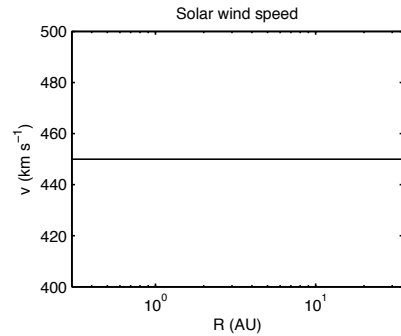
Coupling of Solar Wind Plasma and Magnetic Field



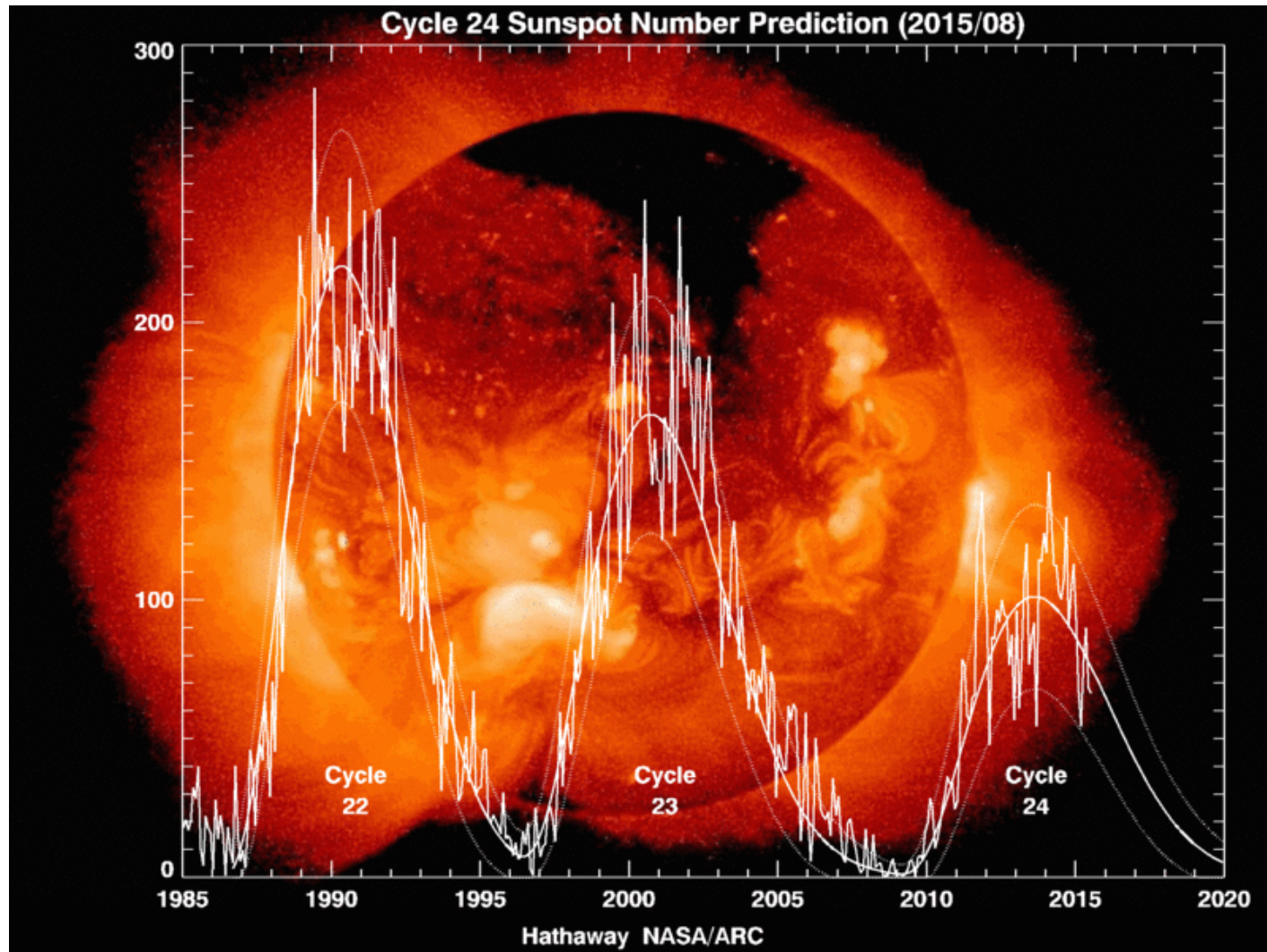
The Parker Spiral



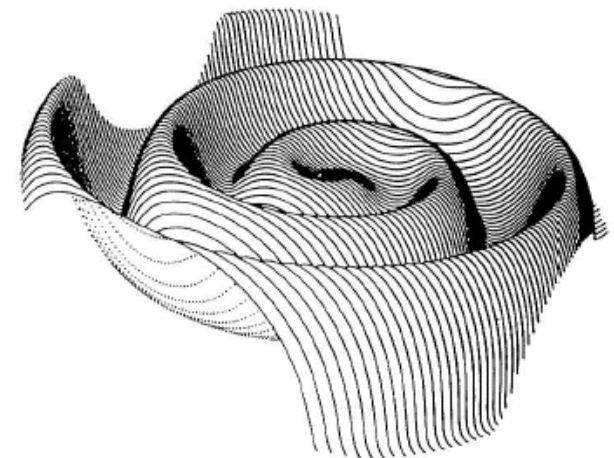
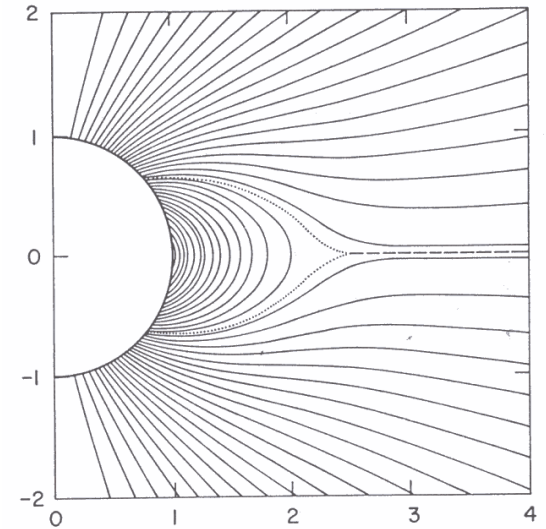
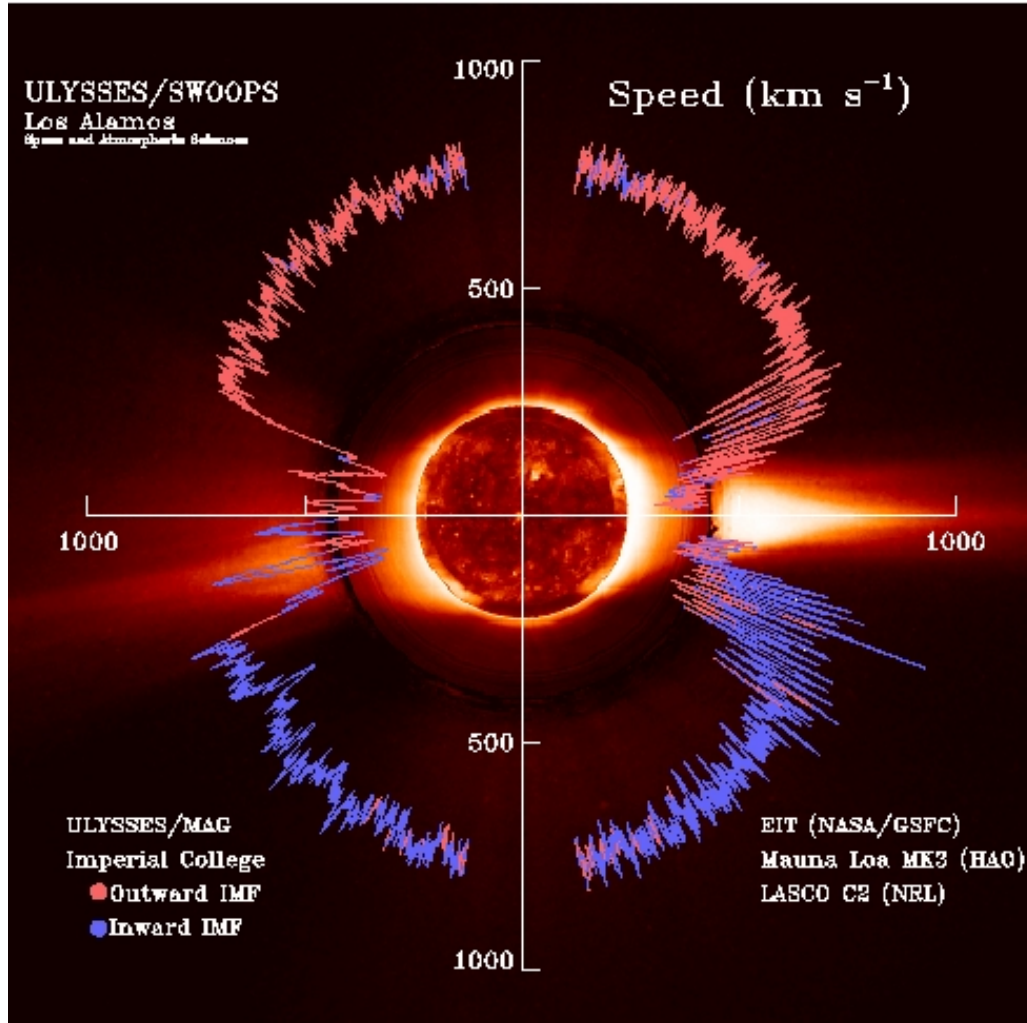
Evolution of Solar Wind Properties



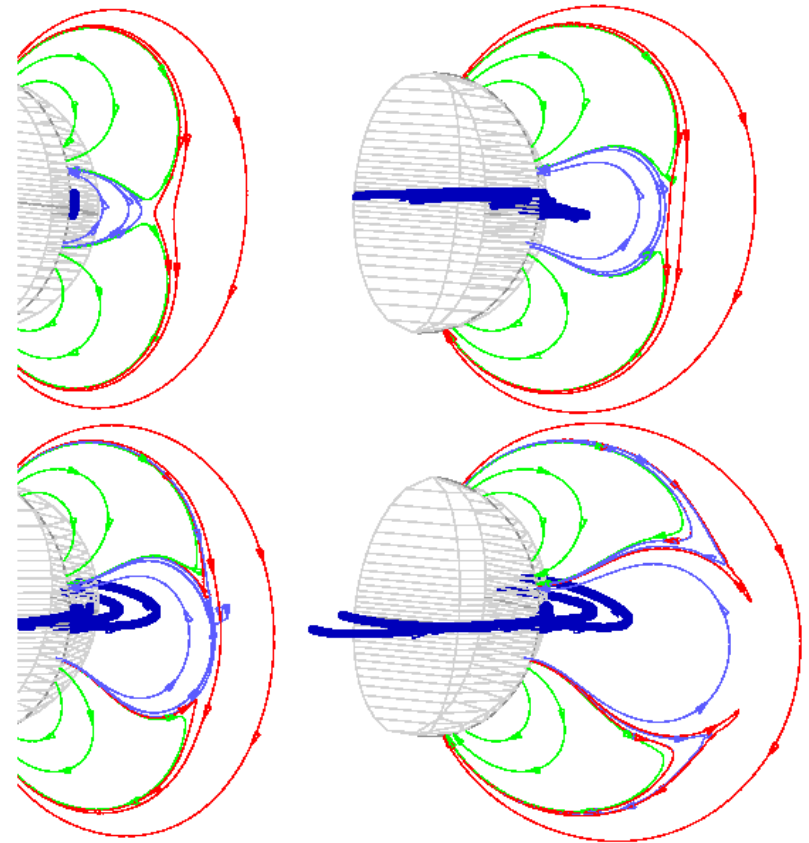
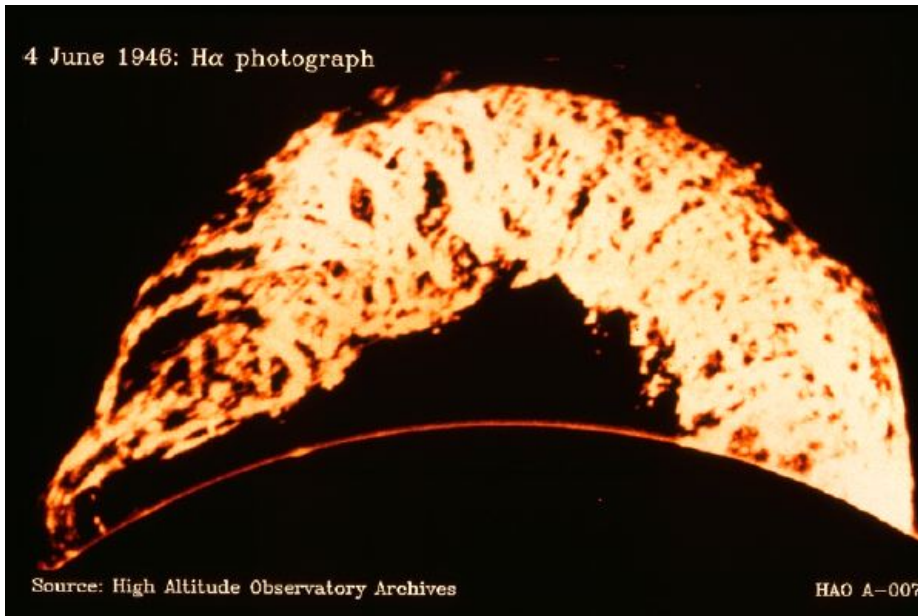
The Solar Cycle



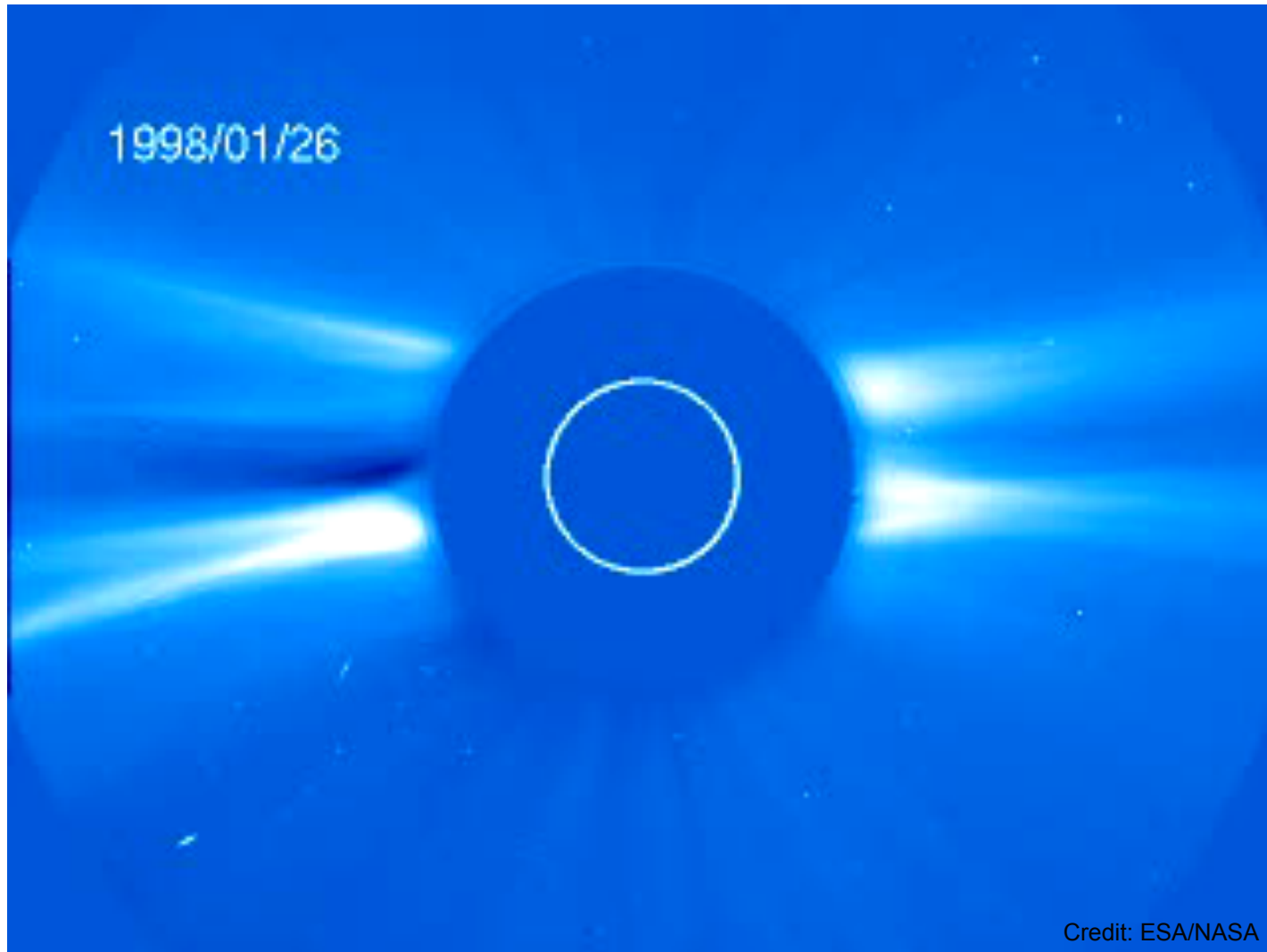
Large-Scale Dynamics of the Solar Wind



Transient Phenomena: Coronal Mass Ejections



Transient Phenomena: Coronal Mass Ejections



Solar Wind Summary

- ✧ Our general understanding of space plasma physics can explain the overall nature of the solar wind
- ✧ Solar wind properties change significantly with distance from the Sun
- ✧ The solar wind is highly variable on a range of timescales

What does this mean for the various solar system bodies immersed in it?

Bodies in the Solar System

