From Science To Double Star Program (DSP)

(Part 1)

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Outline

Chapter 1

The Science concerning DSP

Outline

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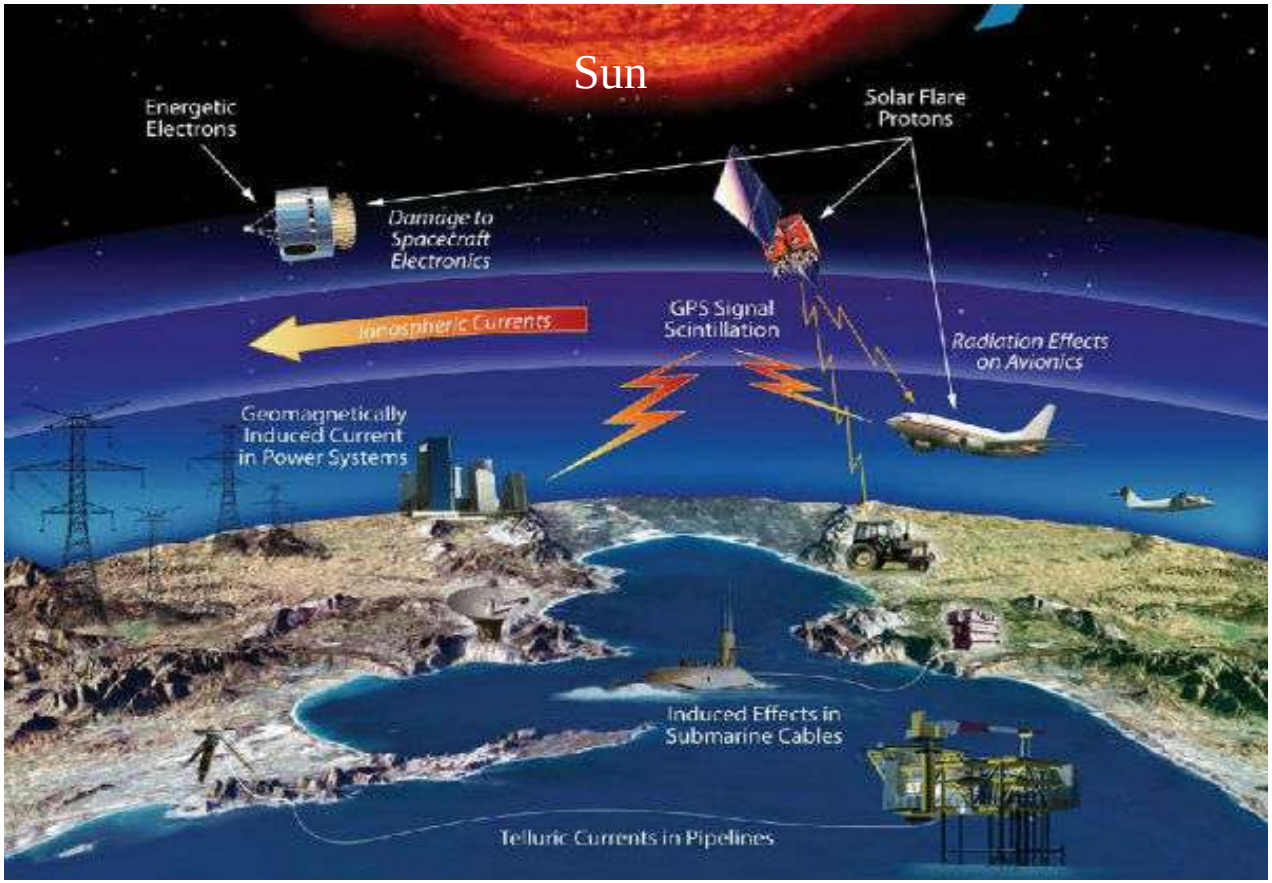
1. Introduction
2. The Sun and the solar wind
3. The Earth's magnetosphere
4. The Earth's ionosphere and upper atmosphere
5. Some concerning space science missions

1. Introduction

- With the commutation technique development, we know there is an ionopshere having an influence on the radio wave propagation.
- With the satellite going into space and the modern technique development, we found that upper atmosphere, ionosphere, magnetosphere, interplanetary space (out space) are important to human activities.

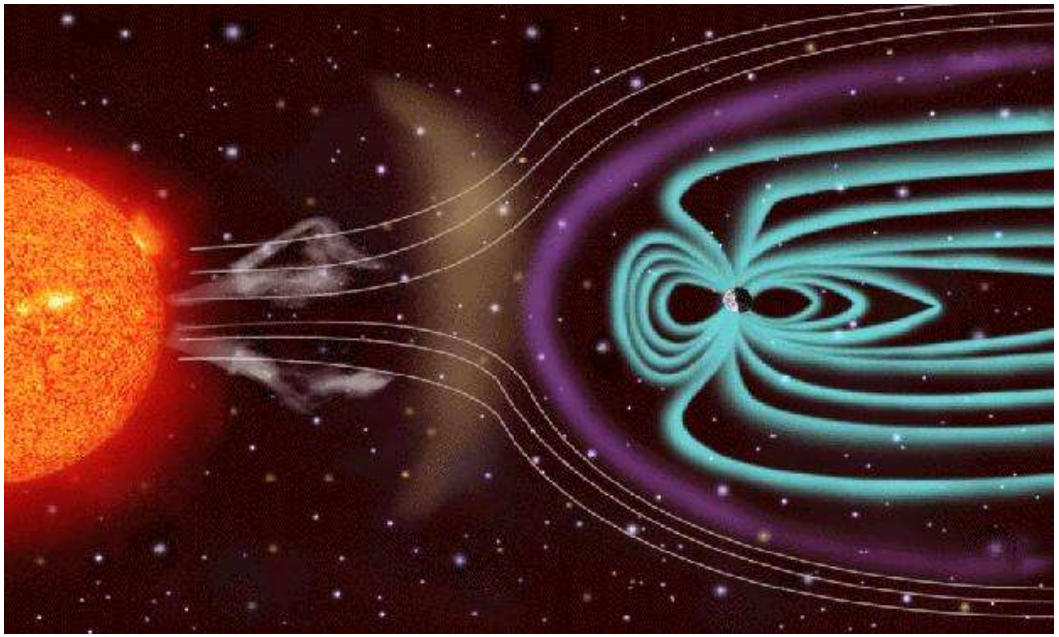


Interplanetary Space

Magnetosphere

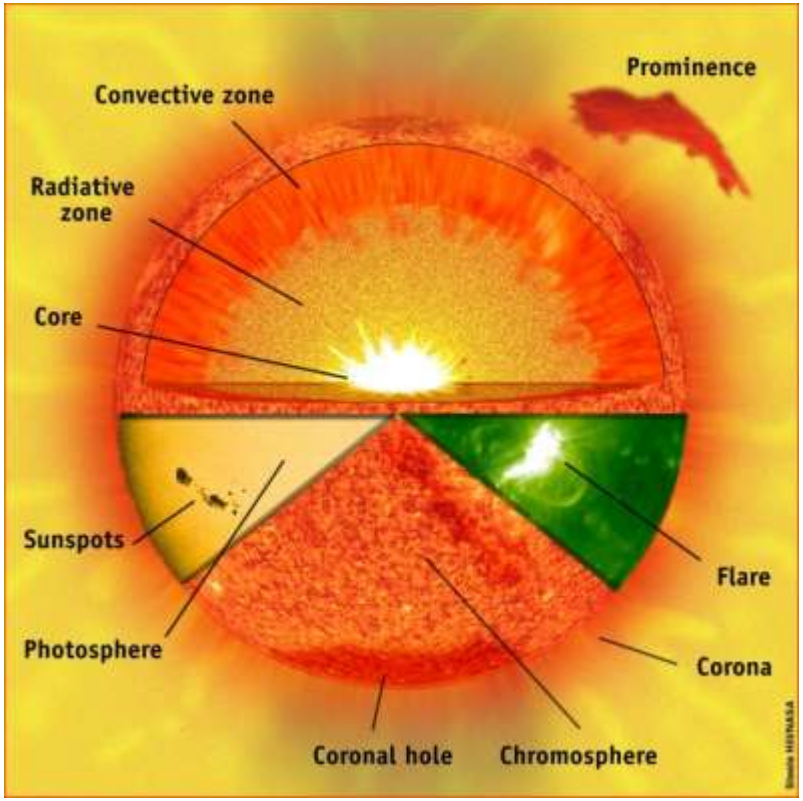
Ionosphere
Upper Atmosphere

- In the out space, solar activity is main source to result in the E- and M-field disturbance and particle dynamics
- It can cause the disaster influences on the human space activities, sometimes on the ground equipment, such as the power station at high latitude.



2. The Sun and the solar wind

1) Solar structure



- **Core**

All the solar energy is from the core, some can reach to the Earth.

- **Radiative Zone**

Light produced by nuclear fusion in the core travels out into the radiative zone.

- **Convection Zone**

The density becomes low enough and the light form energy is converted into heat.

- **Solar Atmosphere**

-- Photosphere

Temperature: ~ 6000 ° C

-- Chromosphere

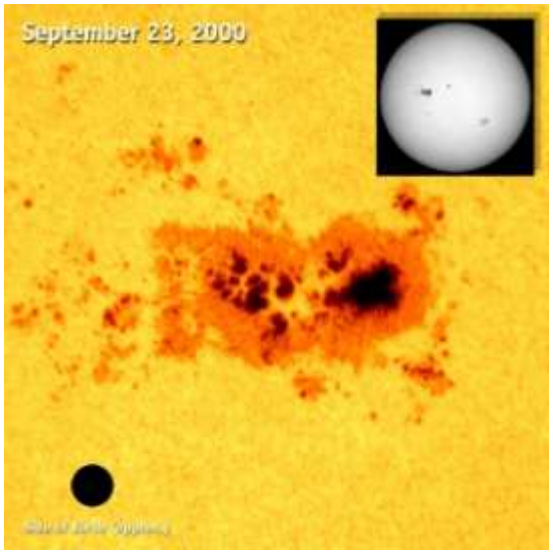
Temperature: ~ 20,000 ° C

-- Corona

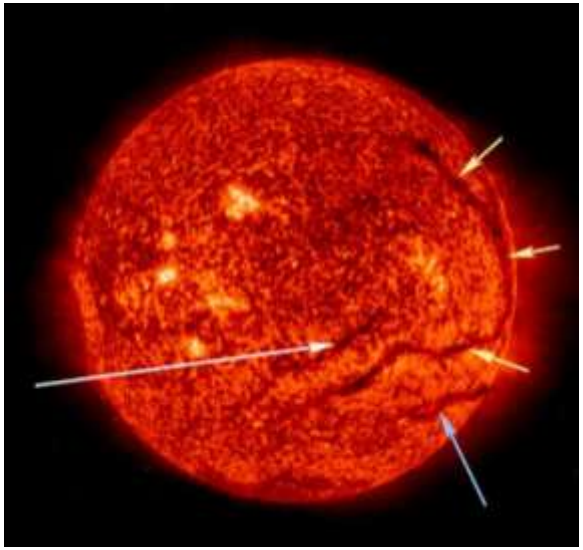
Temperature: 1×10^6 to 2×10^6 ° C

2) Solar Surface

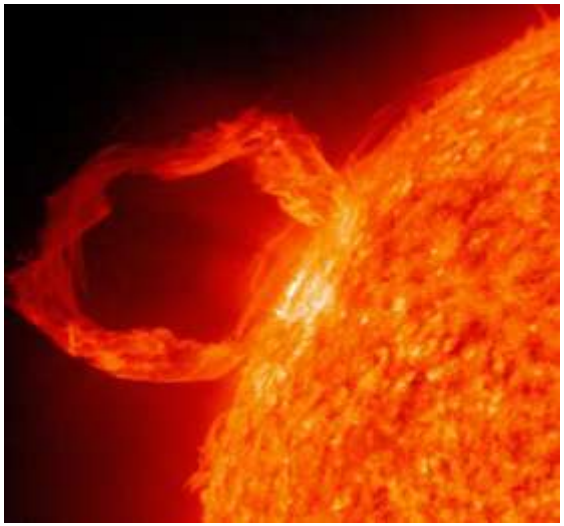
- Sun spot



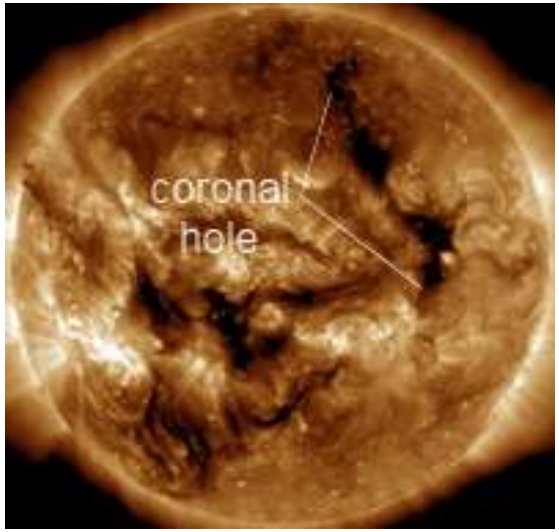
- Filament



- Prominence

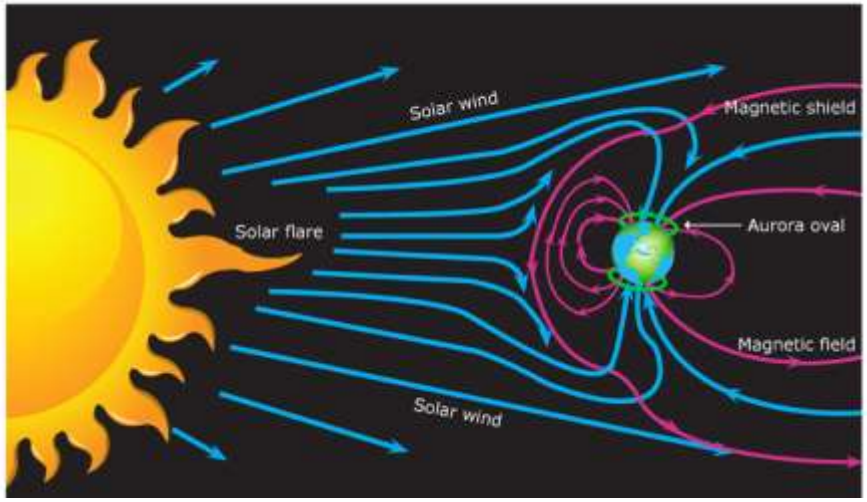


- Coronal hole



3) Solar activity

- Solar wind and IMF

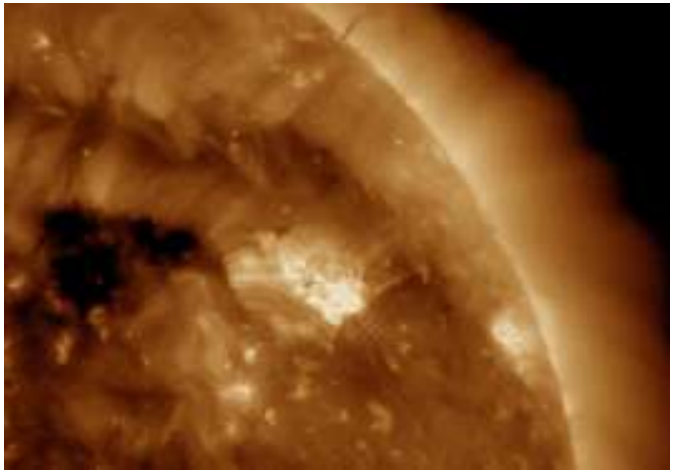


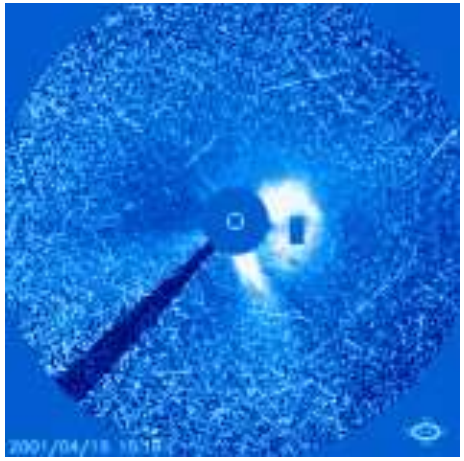
Parameter	Minimum	Average	Maximum
Flux ($cm^{-2}s^{-1}$)	1	3	100
Velocity (km/s)	200	400	900
Density (cm^{-3})	0.4	6.5	100
Helium %	0	5	25
B (nT)	0.2	6	80

- Solar flare

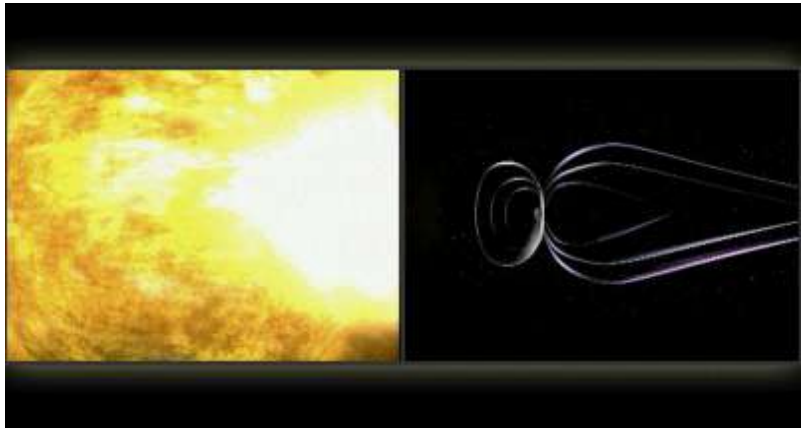
Solar flare is a sudden, explosive process of energy release
-- in the form of EM radiation and very fast atomic particles.
-- occurring in regions of concentrated M-field such as sunspots.

- Coronal Mass Ejections (CMEs)





Coronal mass ejections (CME) are huge bubbles of gas ejected from the corona hole in the solar surface over the course of several hours.

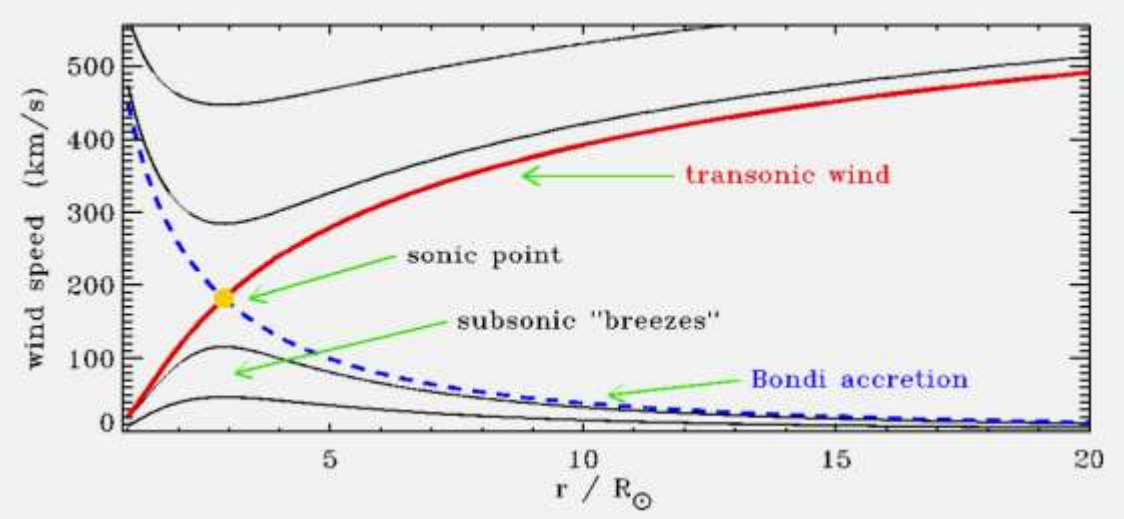


- Solar Energetic Particles (SEPs)

When a large solar flare or CME occurs, the particles can be accelerated to very high energies to form the SEPs.

4) Solar wind propagation

The Solar Wind Acceleration

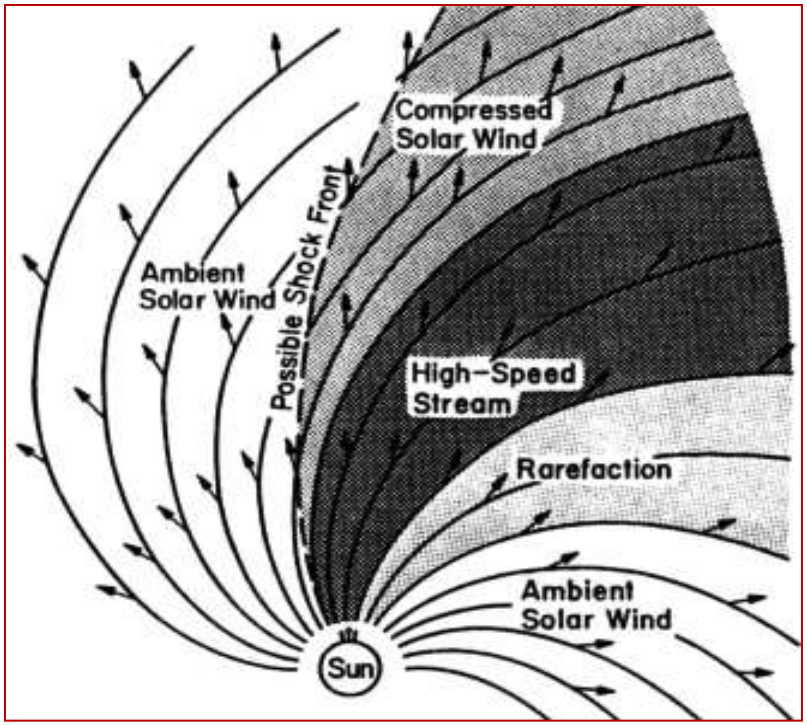


- During propagation out of solar surface, the solar wind acceleration to supersonic state
- There are two process in the propagation
  --- Wave pressure driven acceleration: by turbulent Alfven waves in the solar atmosphere;
  --- Magnetic reconnection driven acceleration: by MR between emerging magnetic loops and opening m-fields in the atmosphere.

The solar wind acceleration is still an open question

5) Co-rotation Interaction Region (CIR)

- The solar wind speed varies very much, sometimes the solar wind with a low speed, sometime with a high speed.

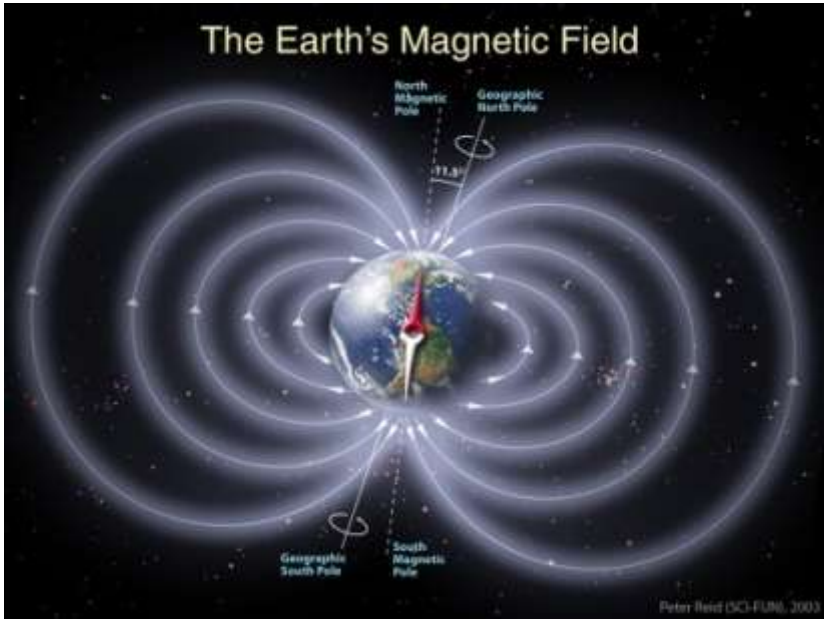


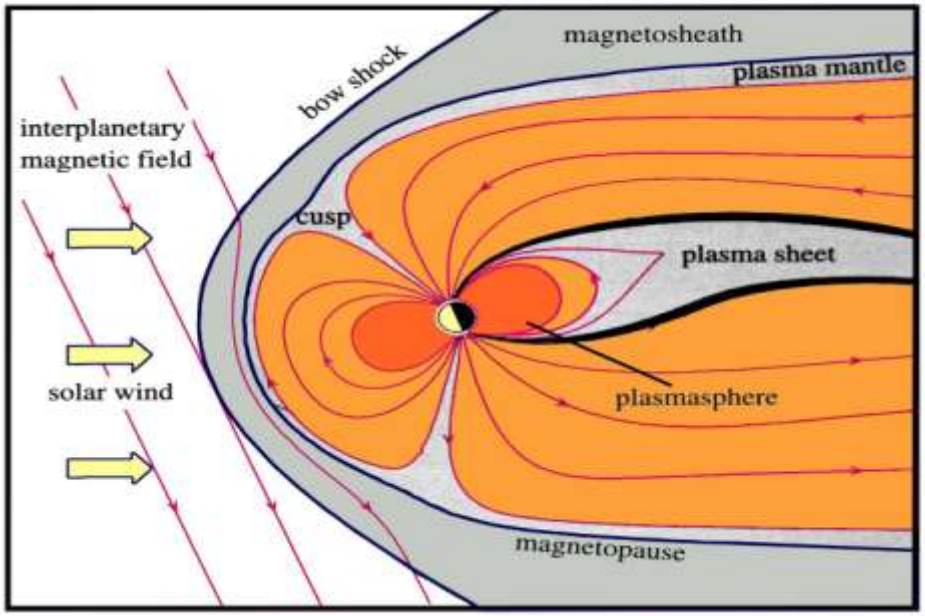
- The high speed solar wind compress the slow (ambient) solar wind, a shock in the CIR can be formed.

Solar wind and IMF structures, as well as the physical mechanism, are also an open question?

3. Earth's magnetosphere

- Earth has a strong dipole internal magnetic field with an axis tilted about 11 degrees from the spin axis.
- Because of interaction with solar wind, the geo-magnetic field is confined as a cavity called the magnetosphere.
- The magnetosphere structure are as:





1) Solar wind interaction with magnetosphere

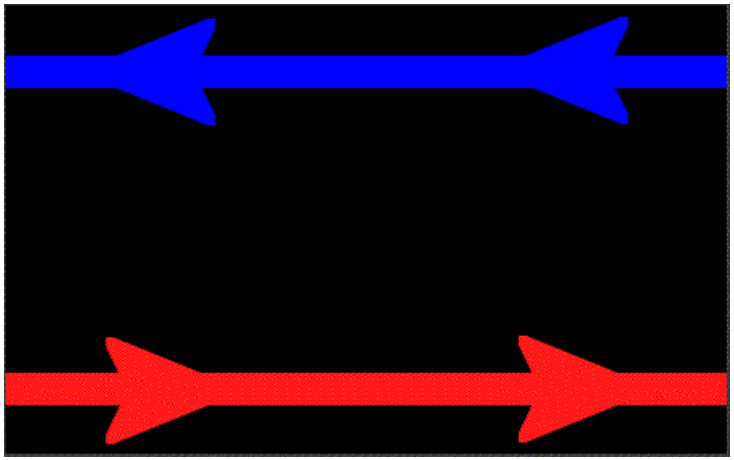
Solar wind energy transfers into the magnetosphere results in much disturbances in the magnetosphere

Magnetopause

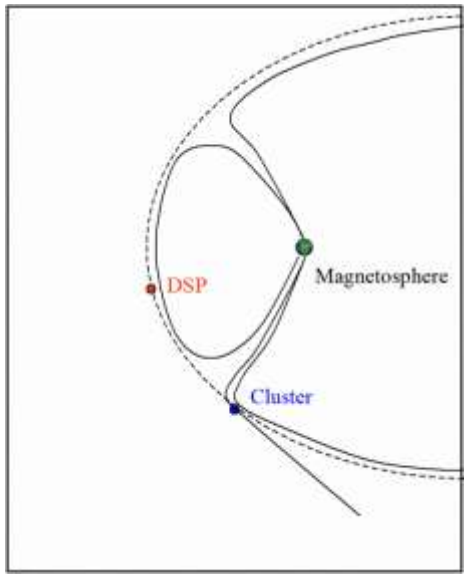
Magnetotail

Michael Zupanc, Davis Station, Antarctica
Aug. 7, 2010

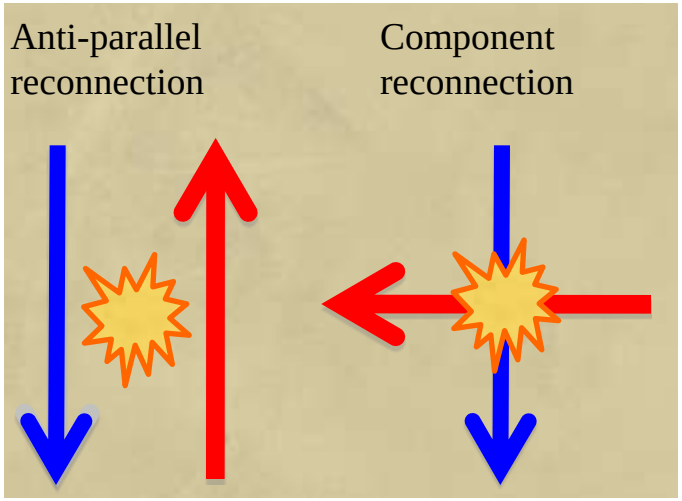
Solar wind energy transfers into magnetosphere



Magnetic reconnection
(IMF $B_z < 0$, southern ward)



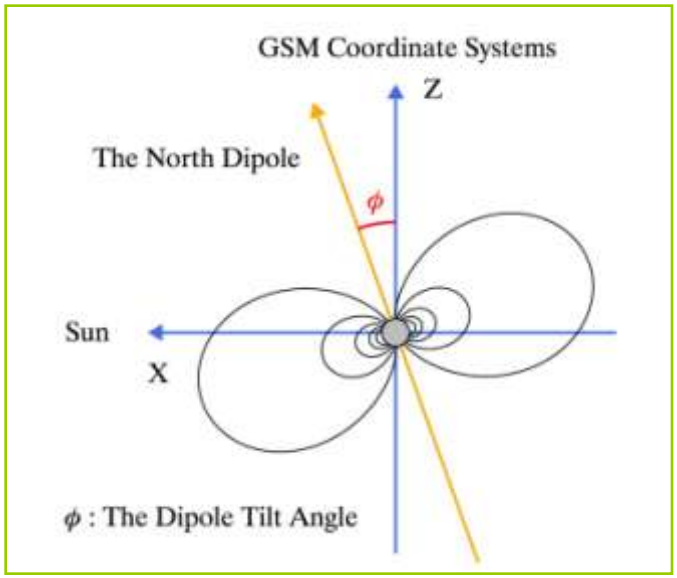
The “component” magnetic reconnection has been the subject of hot debate among space scientists for many years

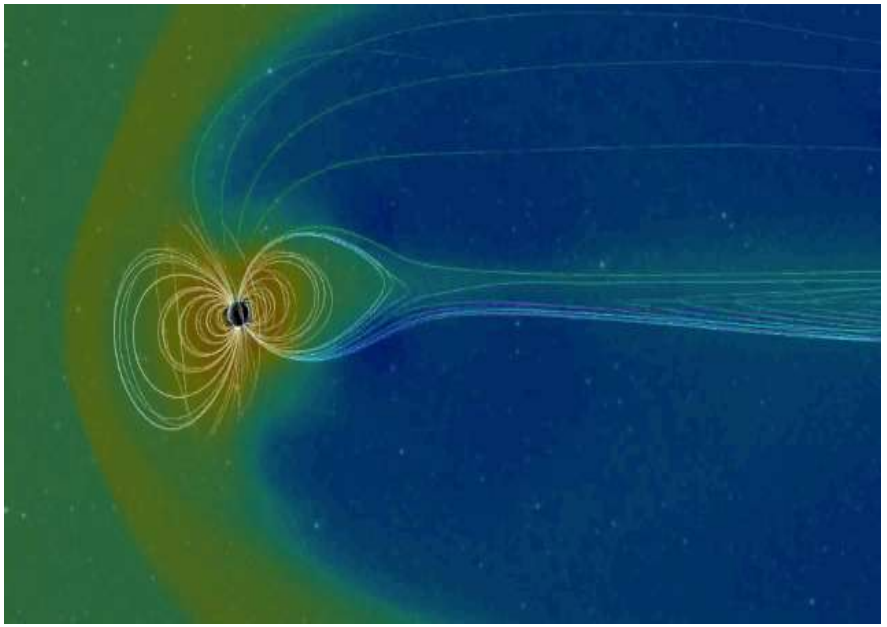


There was no observation evidence on the “component” reconnection before DSP.

A dynamic system responding to solar activity

Because of the solar wind is much disturbed and the tilt angle between the Earth spin axes and the magnetic dipole axes, the magnetosphere is a much dynamic system



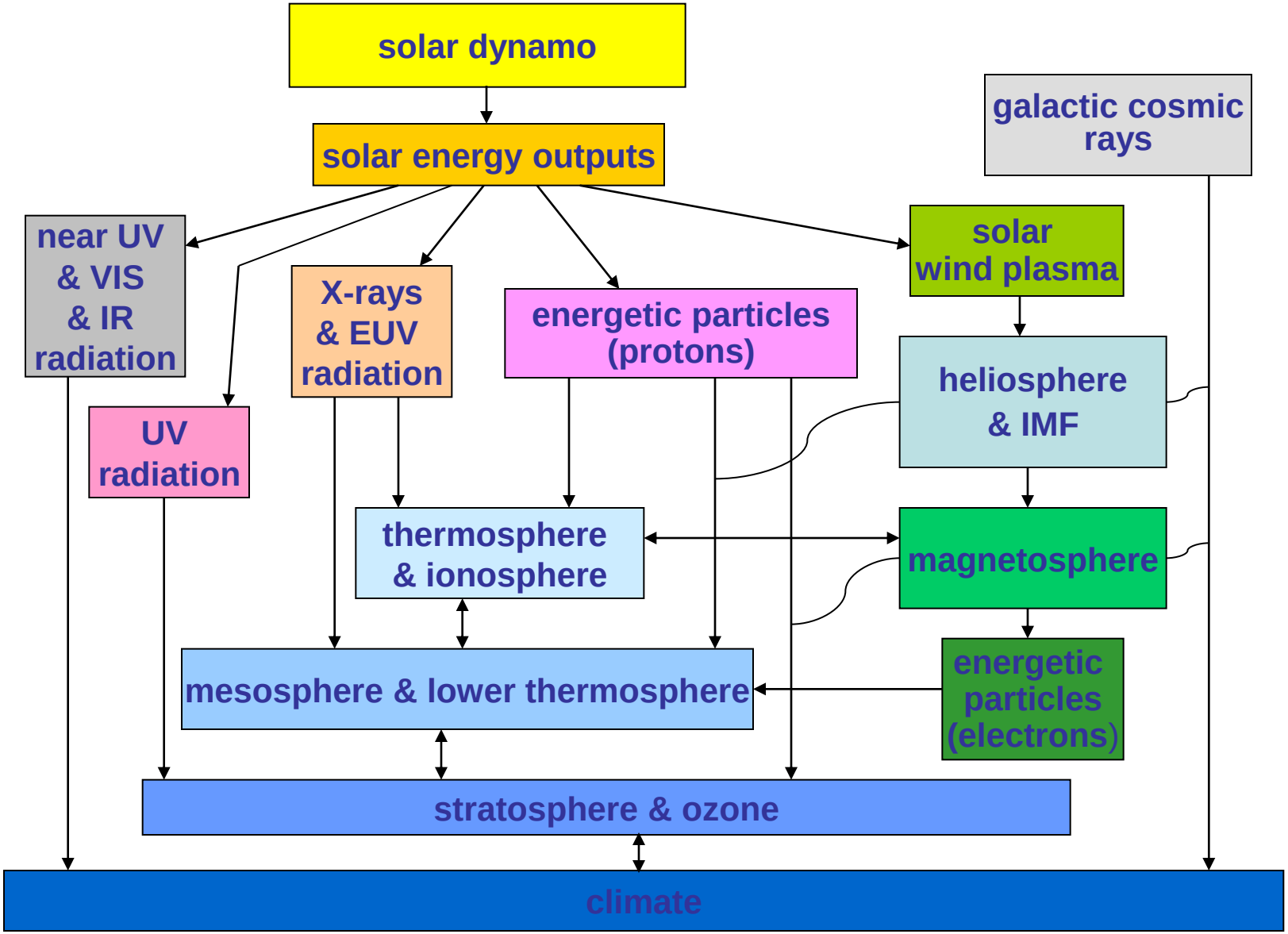


The solar wind energy into geo-space can

- drive the magnetospheric convection system and energizes the plasma inside the magnetosphere
- drive field line resonances and geomagnetic pulsations
- create geomagnetic activity
- heat the polar upper atmosphere
- drive large neutral atmospheric winds

The variation of the solar wind plasma parameters (density, velocity, etc.) and IMF are very important to magnetospheric and ionospheric physics, and the scientific community tries to have continuous monitoring of these parameters via satellites.

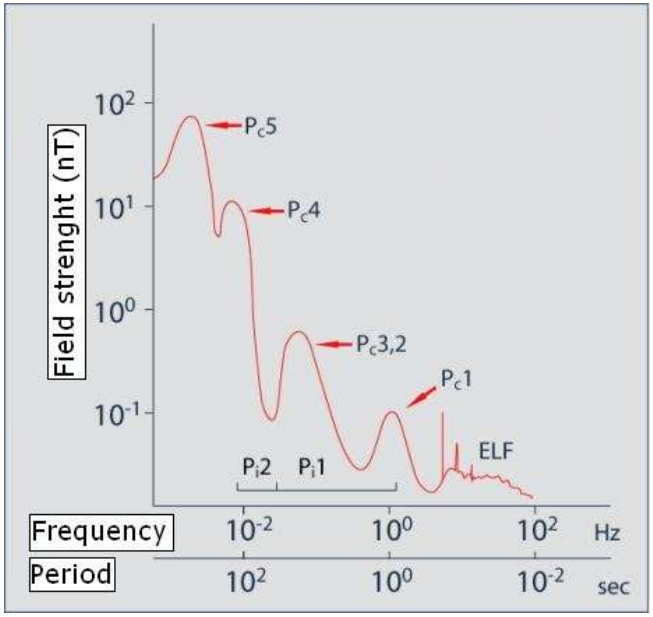
2) Solar influences on Earth



3) Geomagnetic pulsations

- Solar wind interaction with magnetosphere can cause the geo-magnetic pulsation, named Pc and Pi.

	Continuous pulsations						Irregular pulsations		
	Pc 1	**Pc 2**	**Pc 3**	**Pc 4**	**Pc 5**	**Pc 6**	**Pi 1**	**Pi 2**	**Pi3**
T [s]	0.2-5	5-10	10-45	45-150	150-600	>600	1-40	40-150	>150
f (Hz)	0.2-5	0.1-0.2	22-100 m	7-22 m	2-7 m	< 2m	0.025-1	2-25 m	< 2 m



All pulsations, derive their energy from the solar wind. It is because the particles taking part in the local instabilities are energized via the convection electric field.

4) Geomagnetic activity

Solar wind energy into magnetosphere often cause the dramatically magnetic activity: magnetic storms, substorms

Magnetic storms

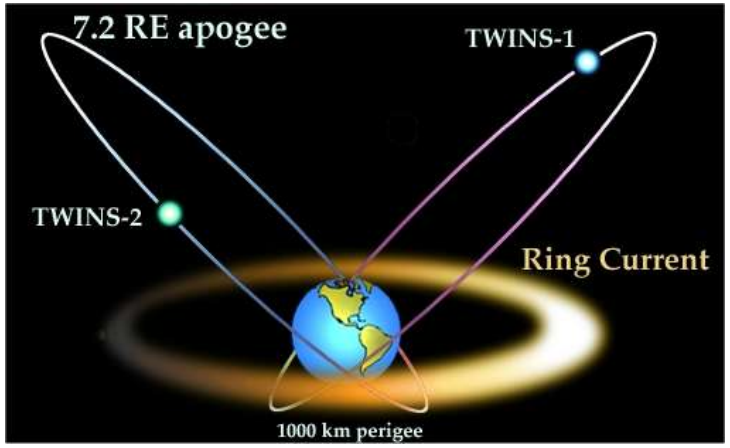
- It is an interval of time when a sufficiently intense and long-lasting interplanetary convection electric field leads, through a substantial energization in the M-I system, **to an intensified ring current strong enough to exceed some key threshold** of the quantifying.
- The Dst index is used to descript the storm.

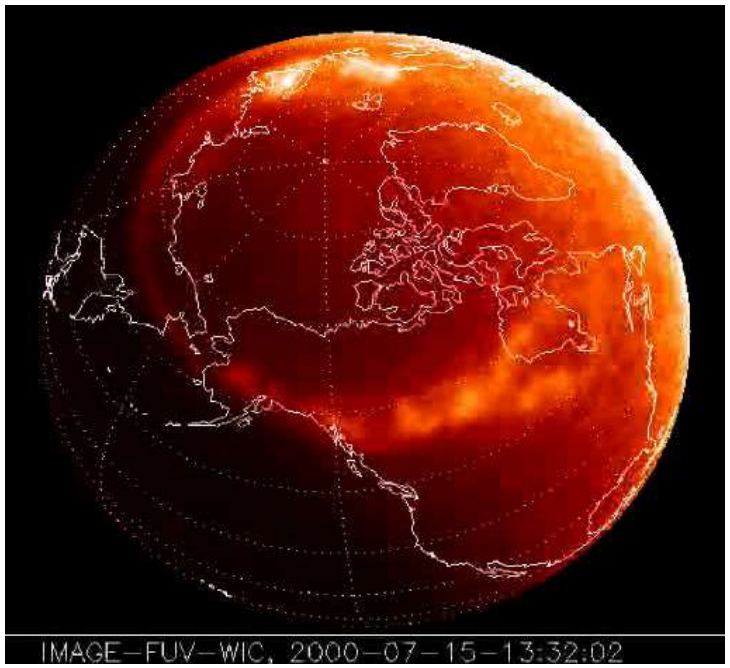
Storm strength	Dst [nT]	Bz [nT]	Duration (days)
Intense	<-100	-10	3
Moderate	-50-- -100	-5	2
Small	-30 -- -50	-3	1

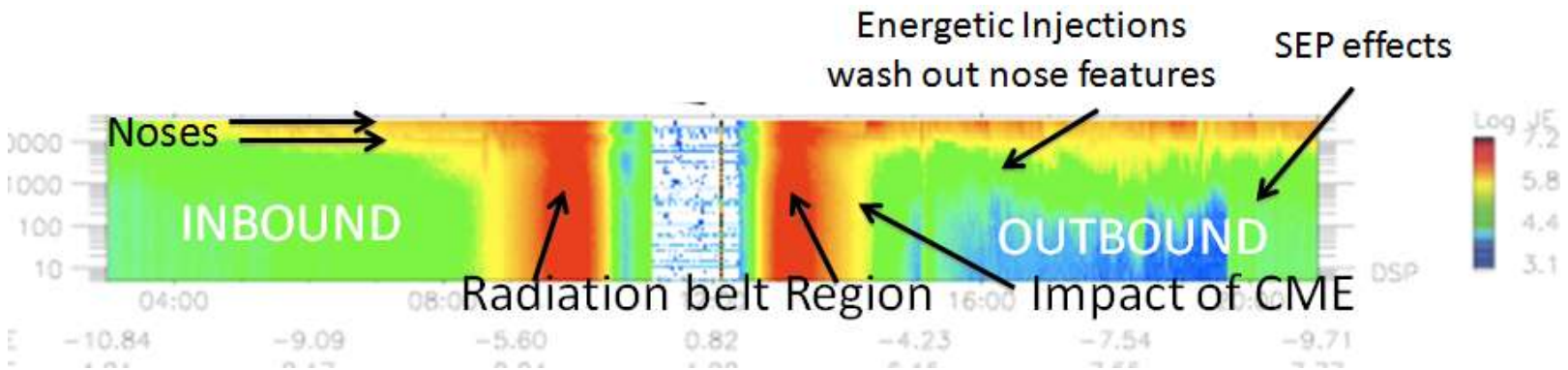
Super strength Storm with Dst of several -100 nT and lasts many days

◆ The ring current, in the storm time, will be enhanced in the main phase and gradually decreased in the recovery phase. More ionosopheric ions, such as H^+, He^+ and O^+, can be found in the ring current region and magnetotail.

◆ The auroural bursts will be enhanced and more frequently in the storm time.







- In the radiation belts, relativity electron enhanced in the storm time.

- Some authors proposed that the storm consisted a series of substorm. For the strong storm, it really is so.

- The strong storm is often resulted from the CME and a continuous southward IMF.

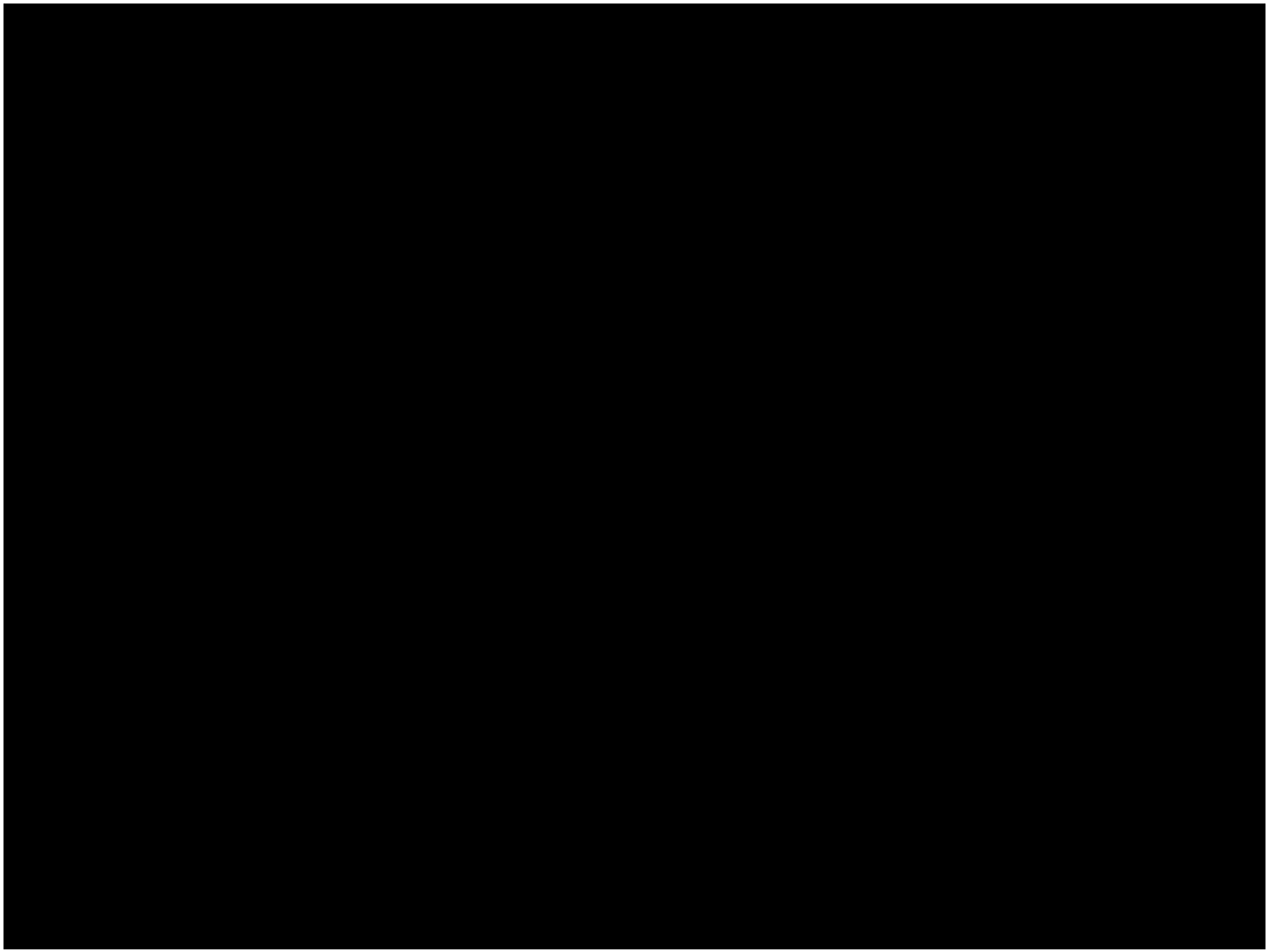
- The CIR shock can also result in storm, but it is, in general, not strong.

The physics mechanism, including the ring current variation, ionospheric ions transportation and acceleration, variation of relativity electron in the radiation belts, …, correlation with substorm, are still needed to be studied, especially by observation.

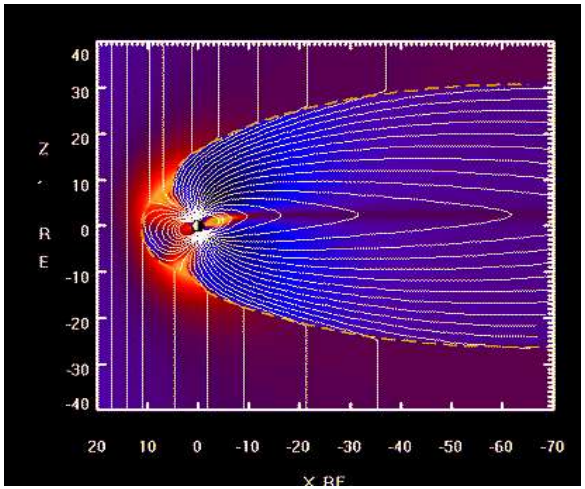
Substorms

- The physical processes involved in energy release to trigger the substorm have been divided into
  --- directly driven, and
  --- loading-unloading processes.
- According to the observation, substorms are divided into three phases:
  --- growth phase,
  --- expansion phase, and
  --- recovery phase.
- In the growth phase, the nightside M-field is drawn to tailward and the plasma sheet becomes thinner and thinner.
- In the expansion phase, the tail like M-field relaxes to the dipole like, which is called M-field “dipolarization”. With dipolarization, induced E-field is formed, the particle earthward ejection takes place, FAC is enhanced and the auroral bursts occur.
- In the recovery phase, all phenomenon gradually are recovered.

Solar Earth connection



Substorm

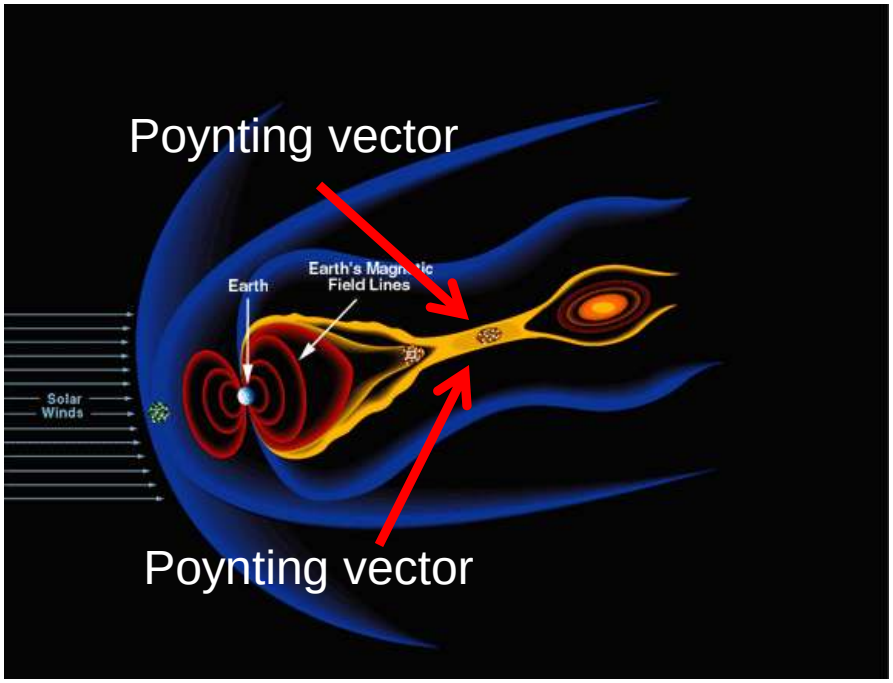


- The most important process that allows solar-wind plasma to cross the magnetopause and enter Earth's magnetosphere to trigger the substorm is the IMF and geo-magnetic fields reconnection.

- The reconnection at the dayside magnetopause occurs with IMF Bz < 0.

- The reconnections first in the dayside low latitude magnetopause, and then in the magnetotail

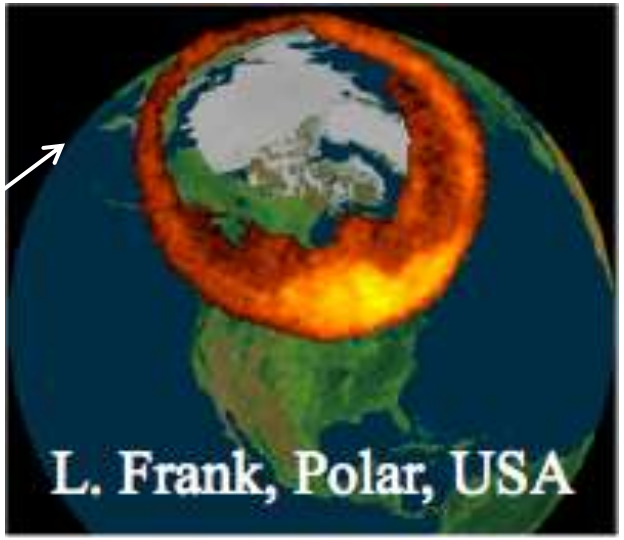
- As a result of the reconnection, two powerful energy streams are launched both towards Earth in the opposite direction.



Auroral burst

- The aurora can be caused:
  --- directly by solar wind in the dayside,
  --- In the nightside, by precipitation particles from M-sphere.

- During the storm and substorm, the auroral bursts will be more frequently.

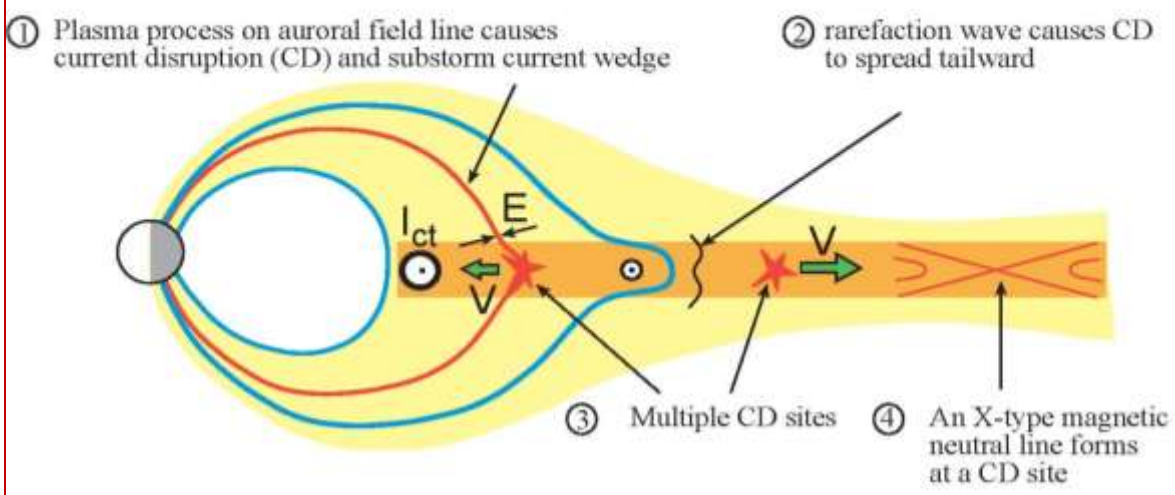


- The auroral bursts are always company with precipitation particles and Field Aligned Current (FAC).

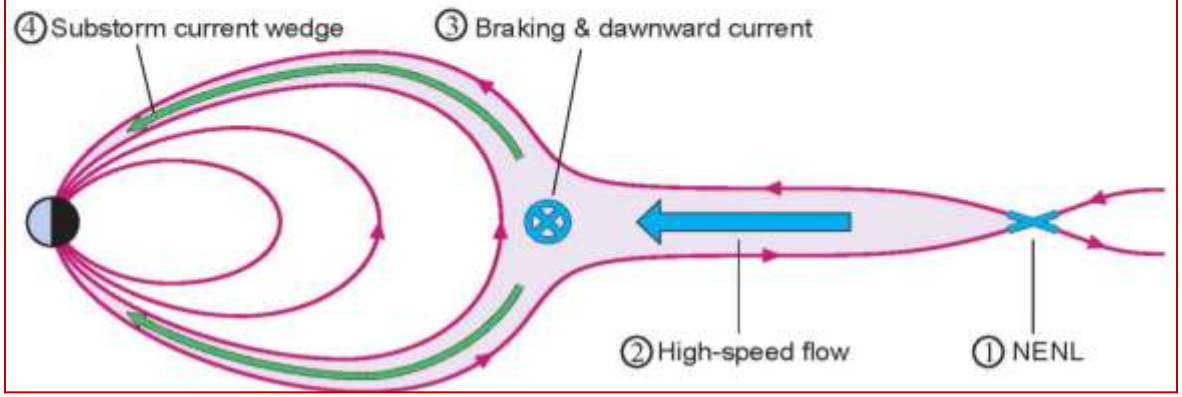
Substrom mechanism

The substorm onset models, the main two:

inside out: **Near-Earth Initiation Model**



outside in: **Mid-Tail Initiation Model**



- The models focus on the:
  --- Where is the substorm triggered?
  --- How is it developed?

- Both of the two models have some observation data support, has self advantage and disadvantage.

- Therefore, the time series of the physics process of the substorm is the main question to be further studied.

- Of course, the mechanism of the energy input, transport, storage, release and conversion, as well as the concerning field disturbance and particles dynamics during the substorm time are still open.

-- How the solar energy to go into the magnetosphere to results in the substorm?

-- Where and how the substorm is triggered?

-- How the charged particle is accelerated both in the magnetotail and auroral acceleration region during the substorm time?

-- How the auroral eletro-ejection development during the substorm?

-- Relativity electron acceleration and energy dissipation in the radiation belt.

-- How about the FAC variation concerning with the particle dynamics?

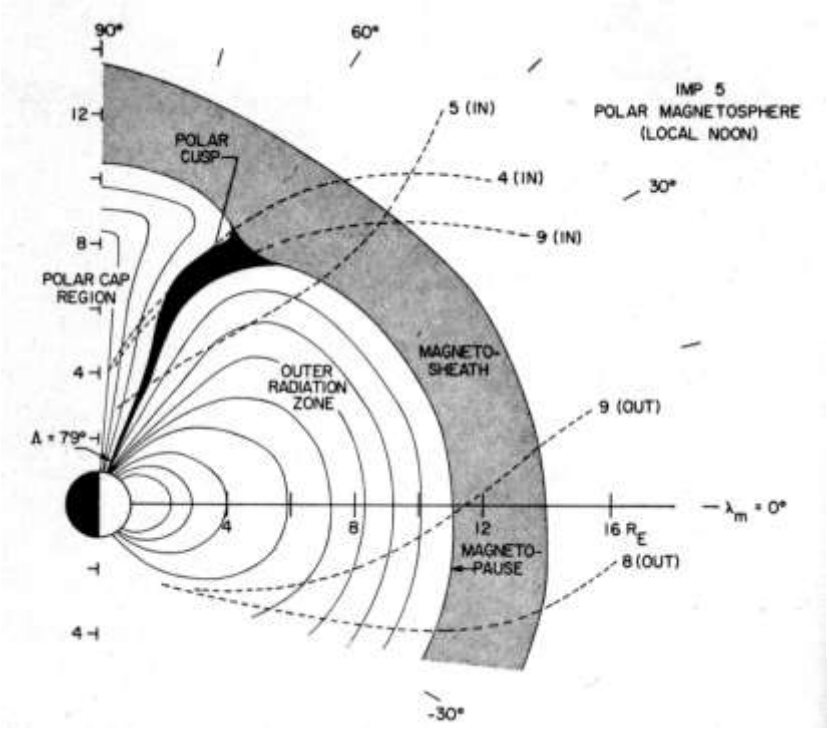
-- The FAC in the polar space is associated with that in the plasma sheet boundary layers?

-- The particle dynamics in the ring current region.

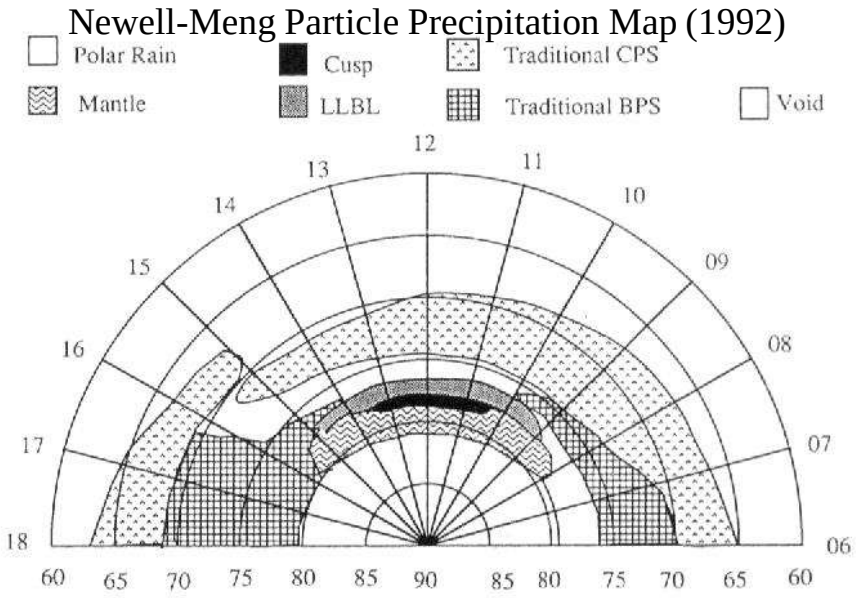
5) Polar Space (Cusp)

- Cusp region (Newell and Meng,1988): The entry of magnetosheath plasma to low altitude is most direct.

- The dayside aurora can be caused by the entry of the solar wind particles

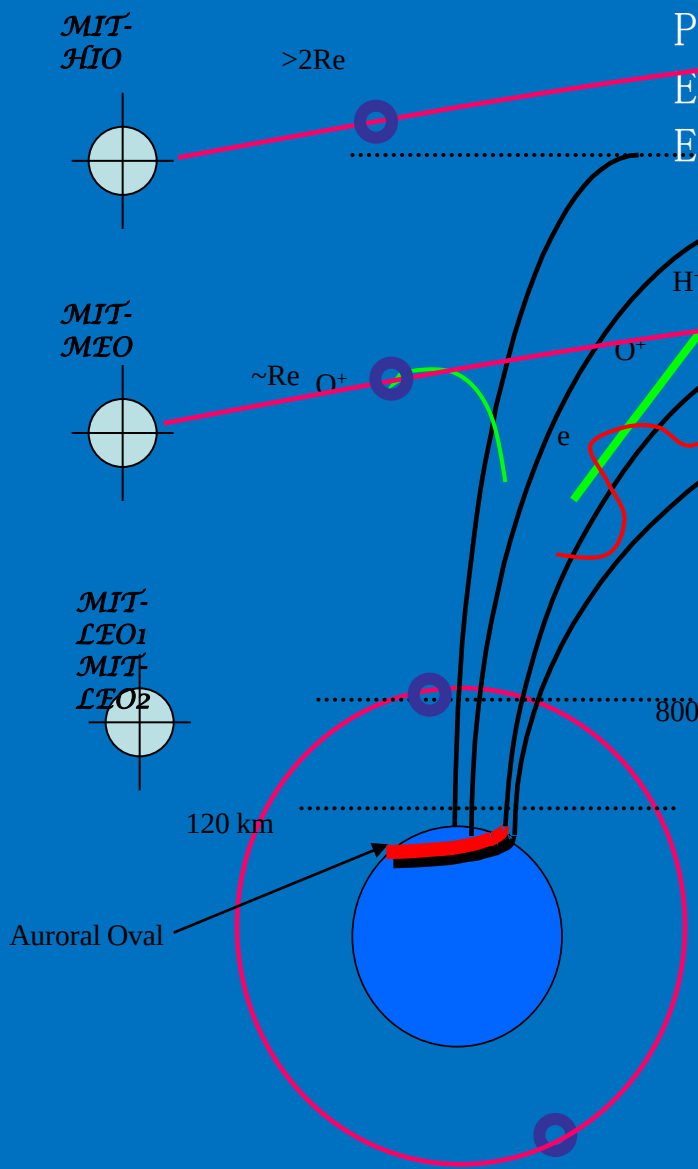


Cusp in the X-Z plane



Cusp project in the X-Y plane

Polar space (nightside)



Parallel E-Field
Electrostatic shock
Electro Double lays

Wave-particle intercation
Particle acceleration

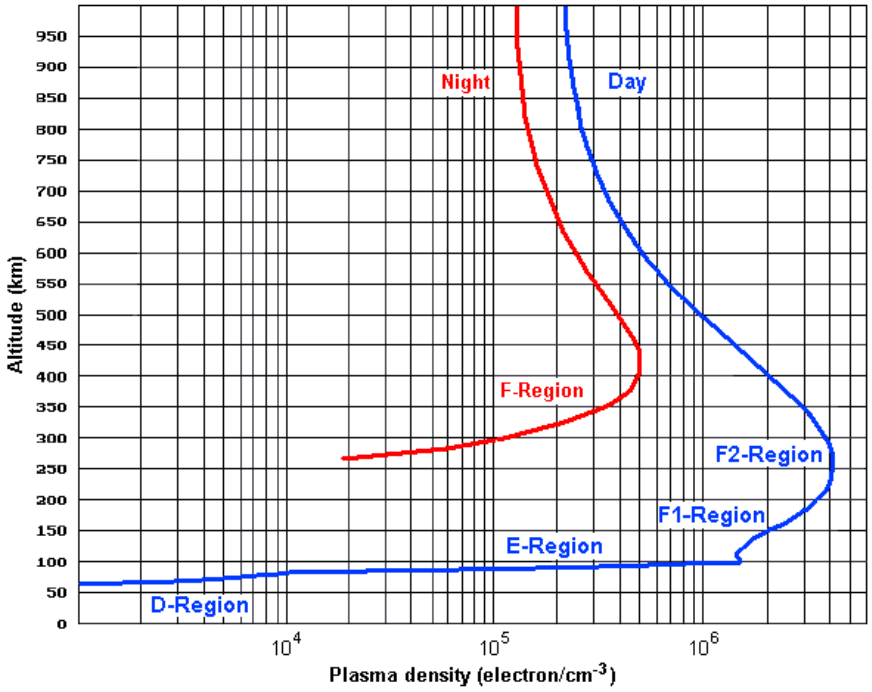
Field aligned current
Electron precipitation, collision
Energy dissipation
Joule heating

Polar space is very important to the solar wind-magnetosphere-ionosphere coupling

4. Earth's ionosphere and upper atmosphere

Because of the Sun's UV radiation, Earth's upper atmosphere is partly ionized into plasma at altitudes of 60-1000km and formed the ionosphere which is coupled to both the magnetosphere and the neutral atmosphere.

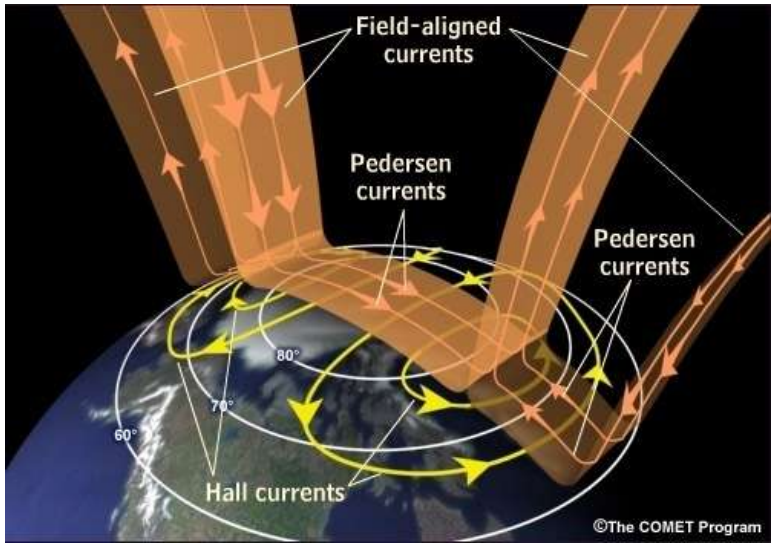
1) Ionospheric layers

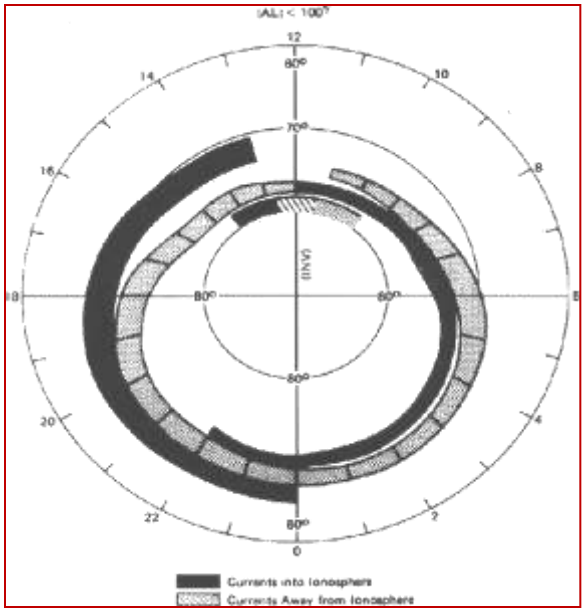


The ionosphere is a space plasma region, the ions inside are mainly H^+, O^+ and He^+.

3) Ionospheric currents (high latitude)

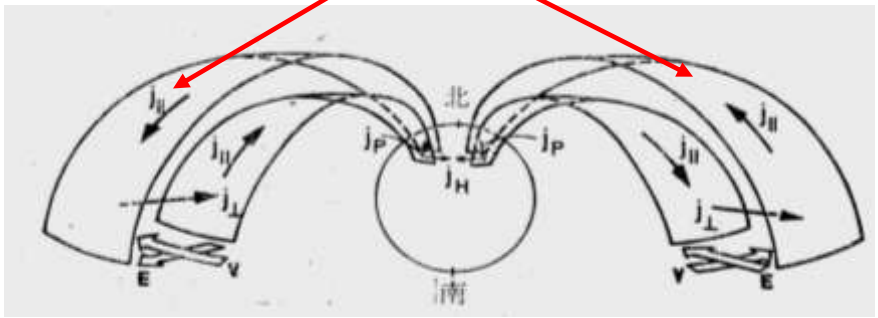
- Hall currents: flowing perpendicular to both the E- and M-fields, and strongest near 105 km altitude.
- Pedersen currents: flowing perpendicular to the M-field and parallel to the E-field, strongest near 125 km altitude.
- The two current systems connect via FAC to the magnetospheric current system.





Region 1 and 2 FACs

FACs flow into and out of the ionosphere



A Sketch map of the FACs going into polar region and out from polar region

5. Some concerning space science missions

Geotail mission

JAXA/NASA joint mission.

- Objective: to study the dynamics of the Earth's magnetotail over a wide range of distance
- Orbit extending: Near-Earth region (8 Re) to the distant tail (about 200 Re).
  -- Phase 1: two years, apogee was kept on the night side with maximum apogee about 200 Re)
  -- Phase 2: apogee was reduced to 30 Re.
- Launched: on July 24, 1992.

The Geotail mission measures global energy flow and transformation in the magnetotail to increase understanding of fundamental magnetospheric processes. This includes the physics of the
--- magnetopause,
--- the plasma sheet,
--- reconnection and neutral line formation (mechanism of input, transport, storage, release and conversion of energy in the magnetotail).

Cluster mission

- **Objectives**

Studying how the solar wind affects the Earth, making the most detailed investigation on the Sun and Earth interaction.

- **Science Payload**

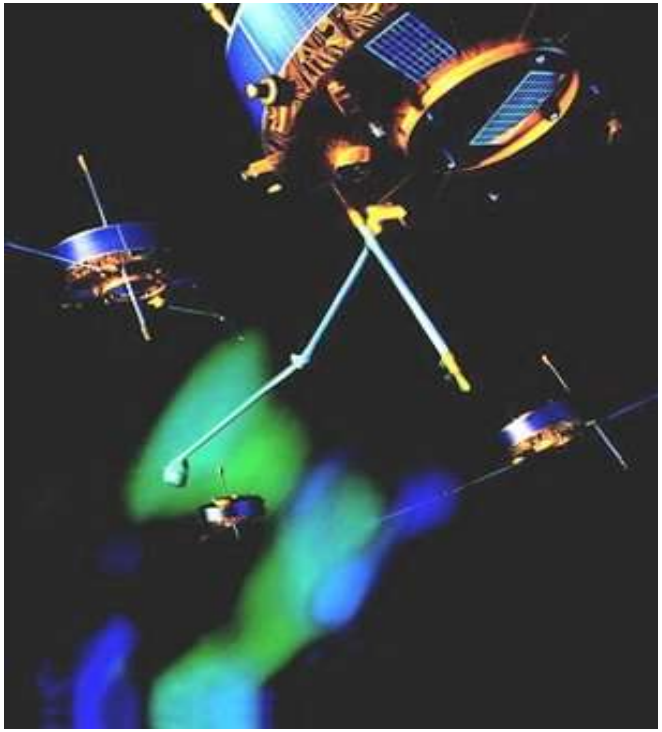
Each S/C carries an identical set of 11 instruments to investigate charged particles, E- and M-fields.

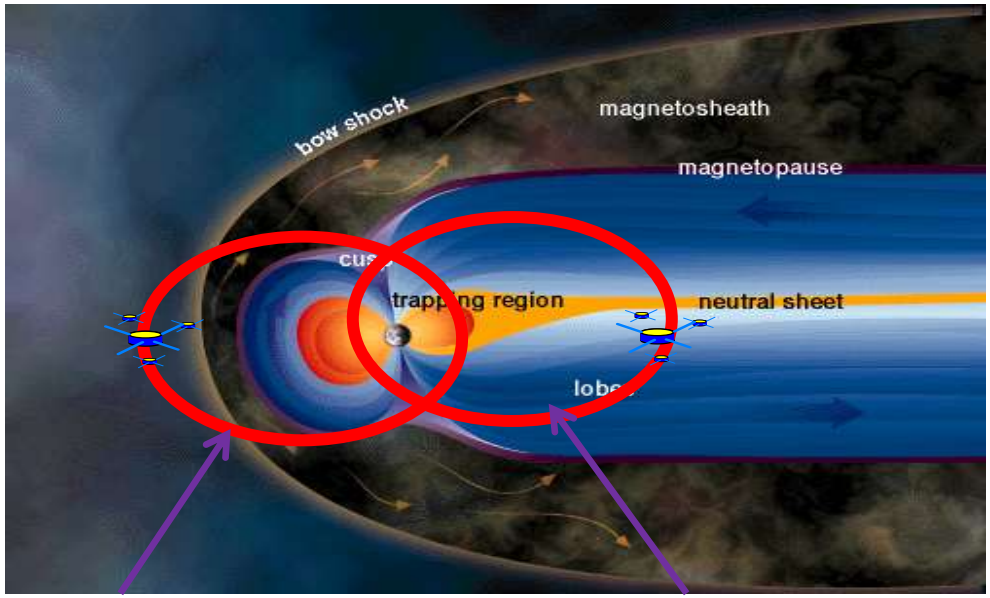
- **Cluster main goal**

to study the small-scale plasma structures in the key plasma regions:

--- solar wind and bow shock
--- magnetopause
--- polar cusp
--- magnetotail
--- auroral zone

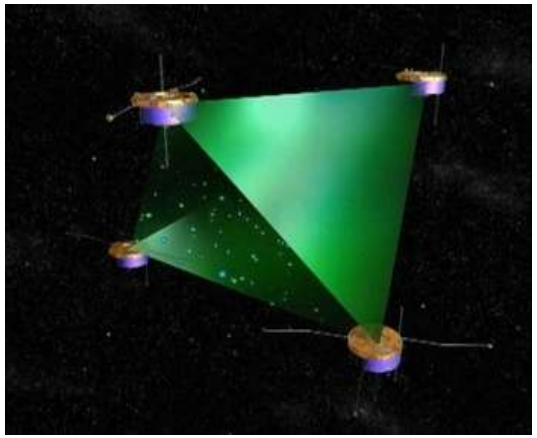
- Consists of 4 satellites
- Orbit: 4Re × 19.6Re
  Inclinque: 90°
  Period: 57h
- Launched: 2000
- Extending: to present





Dayside season orbit
apogee in solar wind

Nightside season orbit
apogee in magnetotail



4- satellites distribution
as a tetrahedron

Cluster is a joint ESA/NASA mission

To provides in-situ investigation of plasma processes in Earth's magnetosphere using four identical spacecraft. It with multi measurement observation has advantage:

--- to observe 3-D and time-varying phenomena

--- to distinguish between the spatial and temporal variations

--- to calculated the currents using the 4-points M-field observation

--- different geospace regions

Chapter 2

Double Star mission design

Outline

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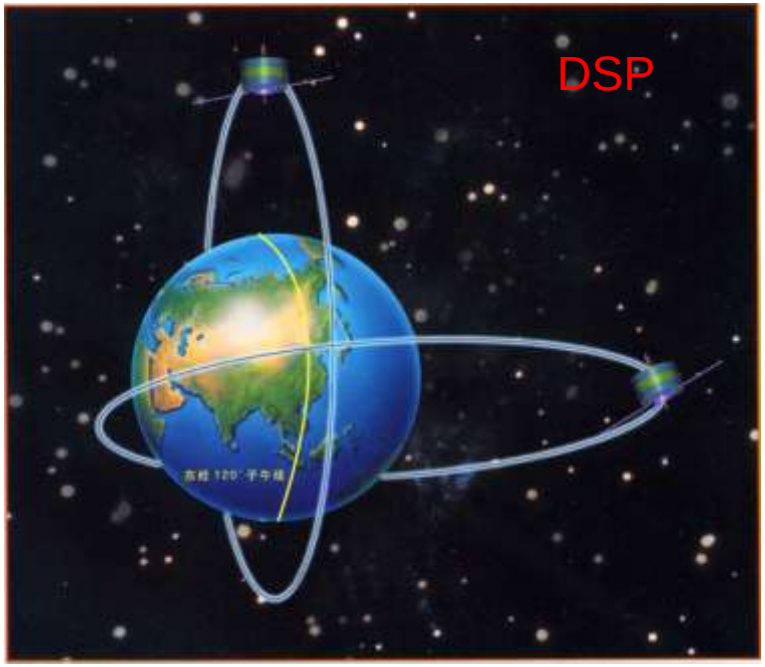
1. A general introduction to DSP
2. DSP Science objective
3. DSP Satellites orbits
4. DSP science payloads (instruments)
5. Coordinated observation with Cluster

1. A general introduction to DSP

- The DSP full name: “Geospace Double Star Program”
- It is the first space science satellite mission in China and the first grand international cooperative space science mission of China



- The DSP consisted of two spacecrafts
  --- A polar orbit S/C, and
  --- A equatorial orbit S/C

- According to the scientific research status and the international space science mission in that time, Prof. Liu, an academician of Chinese Academy of Science (CAS), a space physicist in National Space Science Center, CAS, proposed the DSP space science mission.

- The DSP proposal was in the consider of
  --- The Solar-Earth space science research requirement
  --- The international geospace exploration programs
  --- The so far space science missions (in that time)

- It is an independent space science mission

- It was proposed in 1997, and soon resulting in great interest of the European scientists, especially, the Cluster science community.

- China-ESA joint space science exploration program, to explore the multi-scale physics process in geospace

- Prof. Zhenxing Liu is the Chief scientist of DSP, and Dr. Philippe Escoubet is the project scientist in ESA side.
- 8 science payloads were developed by Chinese side and 7 science payloads were developed by European side, 1 payload was jointly developed
- The S/Cs and vehicle rocket were developed by China, and the launch was in China.

3. DSP Satellites orbits

- The two S/Cs of the DSP named TC-1 and TC-2, respectively. The TC is abbreviation of "TanCe" which is spell of the Chinese letter "探测" meaning exploration.

- In order to fulfil the main goal of the DSP, the two S/Cs have different orbits

  --- TC-1，with Equator orbit

  Inclination : 28°

  Perigee: 500km

  Apogee : 13 Re

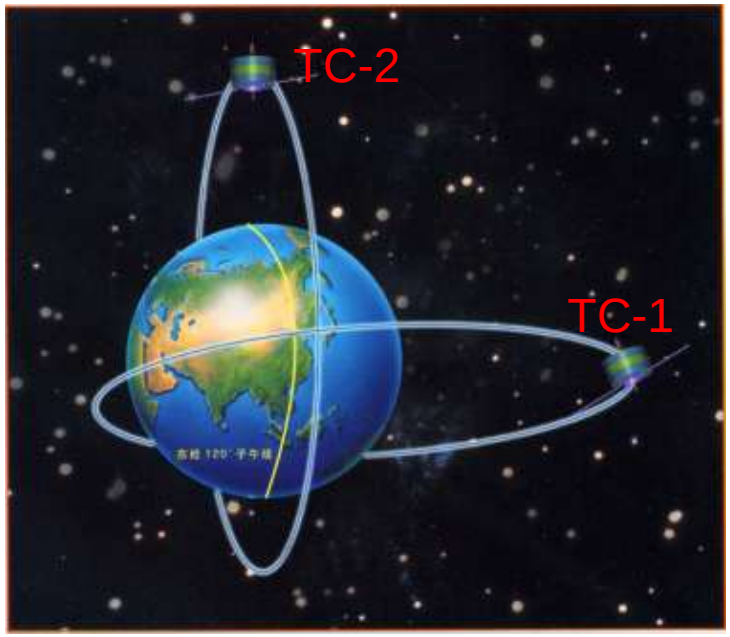
  --- TC-2, with Polar orbit

  Inclination 89°

  Perigee: 550km

  Apogee: 7 Re

- Both the TC-1 and TC-2 are spin stable



4. DSP science payloads (instruments)

TC-1		TC-2	
FGM	FluxGate Magnetometer (UK, Austria)	FGM	FluxGate Magnetometer (UK, Austria)
PEACE	Plasma Electron And Current Experiment (UK)	PEACE	Plasma Electron And Current Experiment (UK)
HIA	Hot Ion Analyzer (France)	LEID	Low Energy Ion Detector (China)
ASPOC	Active Spacecraft Potential Controller (Austria)	NUADU	NeUtral Atom Detector Unit (Ireland, China)
STAFF	Spatio-Temporal Analysis of Field Fluctuation (France, UK)	LFEW	Low Frequency E-M Wave Detector (China)
HEPD	High Energetic Proton Detector (China)	HEPD	High Energetic Proton Detector (China)
HEED	High Energetic Electron Detector (China)	HEED	High Energetic Electron Detector (China)
HID	Heavy Ion Detector (China)	HID	Heavy Ion Detector (China)

--- 8 instruments from China, 7 from ESA, 1 is the joint

(1) FGM: (TC-1 and TC-2, UK and Austria joint)

--- FluxGate Magnetometer

--- To measure the 3-D magnetic field and its fluctuation

--- Range: -65536 -- +65504 nT

--- Resolution: 7. 813 X 10^{-3} nT

(2) PEACE: (TC-1 and TC-2, UK)

--- Plasma Electron and Current Experiment

--- To measure spectrum and 3-D electron distribution function

--- Energy range:

Low Energy Electron Analyzer (LEEA): 1eV--1keV

High Energy Electron Analyzer (HEEA): 30eV--26keV

(3) LEID: (TC-2, China)

--- Low Energy Ion Detector

--- To measure low energy ion density and energy spectrum

--- Energy ranger: 30eV—40keV

(4) HIA: (TC-1, France)

--- Hot Ion Analyser

--- To measure ion energy spectrum, 3-D distribution function

--- Energy range: 5eV-30keV

(5) ASPOC (TC-1, Austria)

--- Active Space Potential Control

--- To control spacecraft potential for measurement of low energy ion and electron

--- S/C potential was controlled below 1V

(6) LFEW (TC-2, China)

--- Low Frequency Electromagnetic Wave Detector

--- To measure Low Frequency Electromagnetic Wave

--- Frequency range: 8 Hz– 10 KHz

(7) NUADU (TC-2, Ireland, China)

--- Neutral Atom Imager

--- To imager magnetotail plasma

--- Energy range: 0.1keV – 140keV

(8) HEED: (TC-1, TC-2, China)

--- High Energy Electron Detector

--- to measure high electron energy spectrum

--- Energy range： 150 keV～6 MeV

(9) HEPD: (TC-1, TC-2, China)

--- High Energy Proton Detector

--- To measure high energy proton spectrum

--- Energy range：30 ～400 MeV

(10) HID: (TC-1, TC-2, China)

--- Heavy Ion Detector

--- Energy range：10 MeV（He）～8 GeV（Fe）

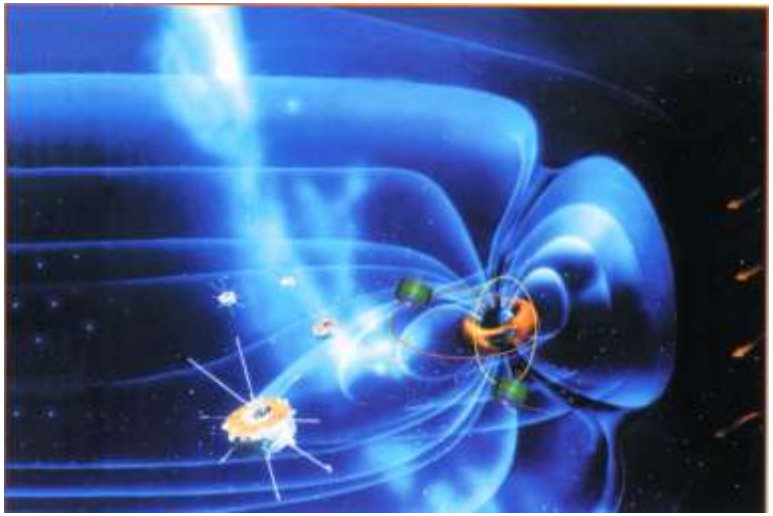
--- 9 energy channels to measure:

He^+, Li^+, Be^+, B^+, C^+, N^+, O^+, F^+, Ne^+, Na^+, Mg^+, Al^+, Ar^+, K^+, Fe^+, Co^+.

5. Coordinated observation with Cluster

DSP coordinated observation with Cluster to first ever realize coordinated six-point exploration of geospace in human history.

- The DSP orbit and Cluster orbit are complementary



- The science payloads are the same or similar
  --- FGM, PEACE, HIA, ASPOC, STAFF are the same
  --- LEID, LFEW are similar as HIA and STAFF
- Coordinated science operation plan, and data process

That's all for the first section

Thanks for attention!