Space Plasma Physics

Key words: Magnetosphere, Aurora, Geospace, Substorm, Space Storm

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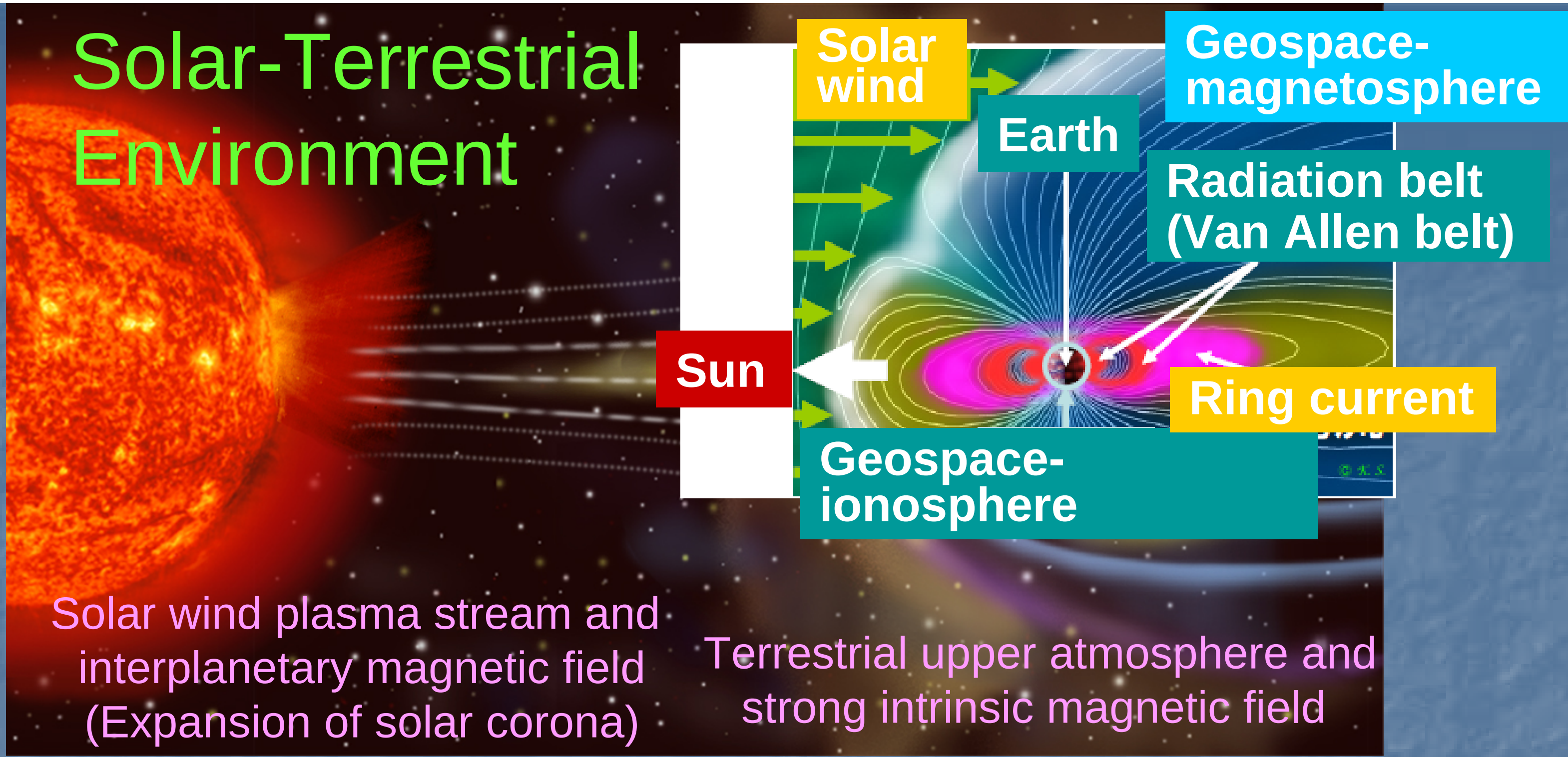
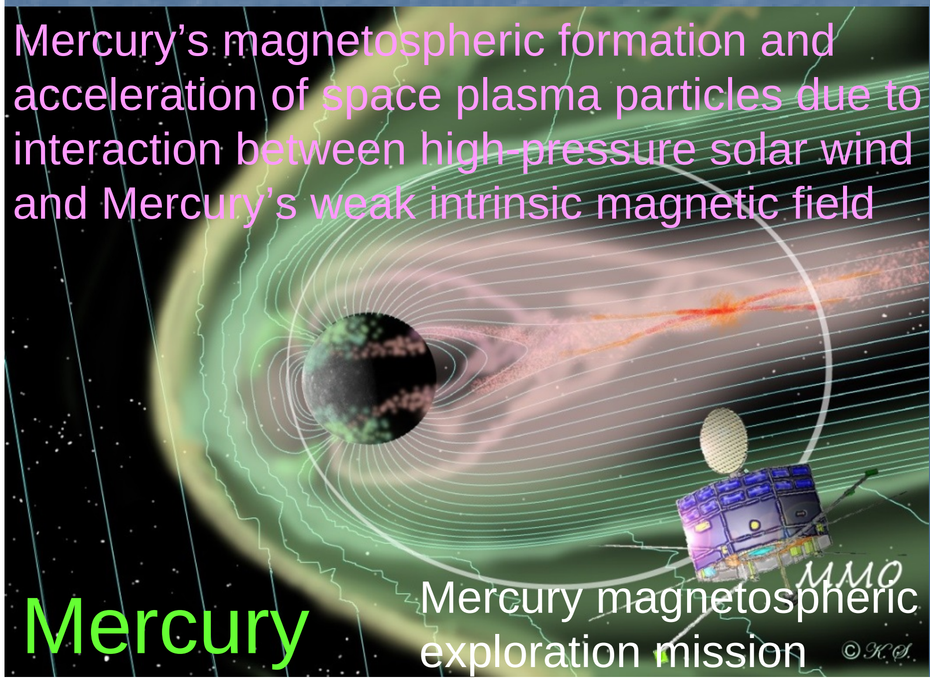
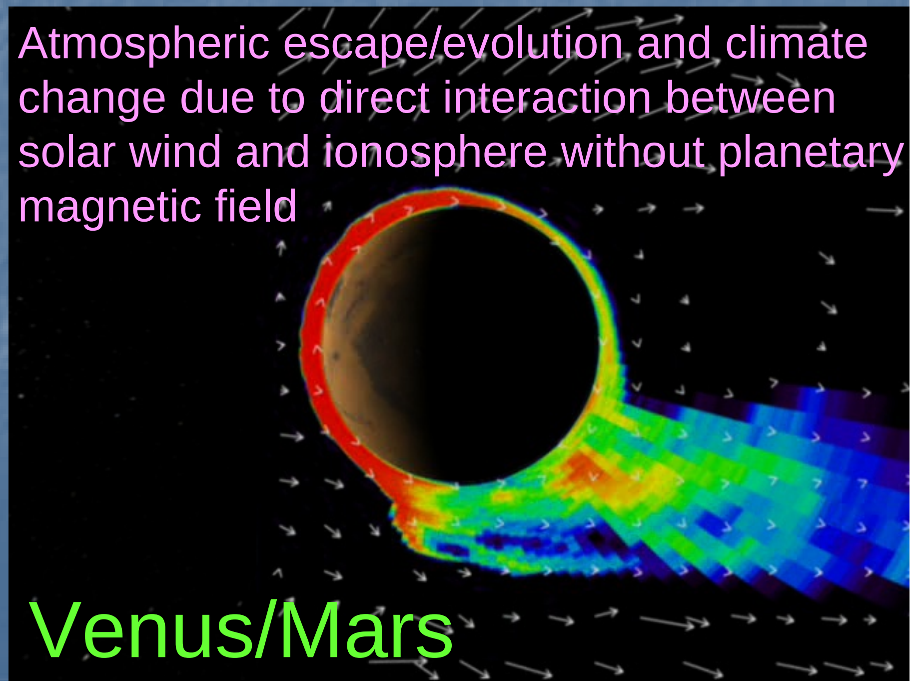
Basic Physical Units/Quantities

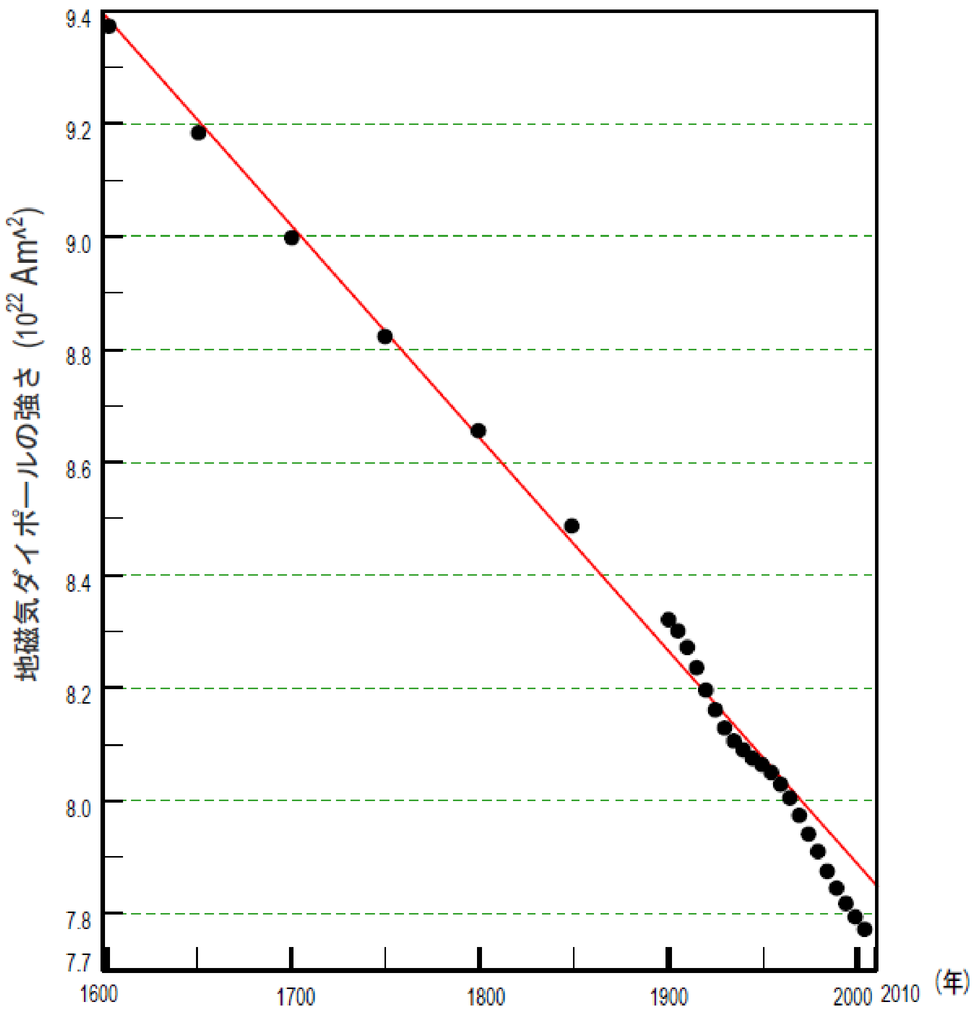
- Unit
  - MKS unit used in equation, but "STP" unit also common
  - Magnetic flux density：T, Gauss, γ
  - Energy：$mv^2/2$, kT, qV
- Proton mass：$m_p=1.67\times10^{-27}$ [kg]
- Electron mass：$m_e=9.11\times10^{-31}$ [kg]
- Elementary charge：$e=1.60\times10^{-19}$ [C]
- Boltzmann constant：$k_B=1.38\times10^{-23}$ [J/K]
- Permittivity (vacuum)：$\varepsilon_0=8.85\times10^{-12}$ [F/m]
- Magnetic permeability (vacuum)：$\mu_0=4\pi\times10^{-7}$ [H/m]
- Speed of light：3.00×10^{8} [m/s]
- Radius/mass of Earth：6378 [km]・$M_E=5.97\times10^{24}$ [kg]
- Radius/mass of Sun：696000 [km] ・$M=1.99\times10^{30}$ [kg]
- Distance between Sun and Earth： 1.496×10^{11} [m]（1 AU)
- Gravitational constant： $G= 6.67\times10^{-11}$ [$N\cdot m^2/kg^2$]


Solar-Terrestrial Environment
Solar wind
Geospace-magnetosphere
Earth
Radiation belt (Van Allen belt)
Sun
Ring current
Geospace-ionosphere
Solar wind plasma stream and interplanetary magnetic field (Expansion of solar corona)
Terrestrial upper atmosphere and strong intrinsic magnetic field


Mercury's magnetospheric formation and acceleration of space plasma particles due to interaction between high-pressure solar wind and Mercury's weak intrinsic magnetic field
MMO
Mercury
Mercury magnetospheric exploration mission

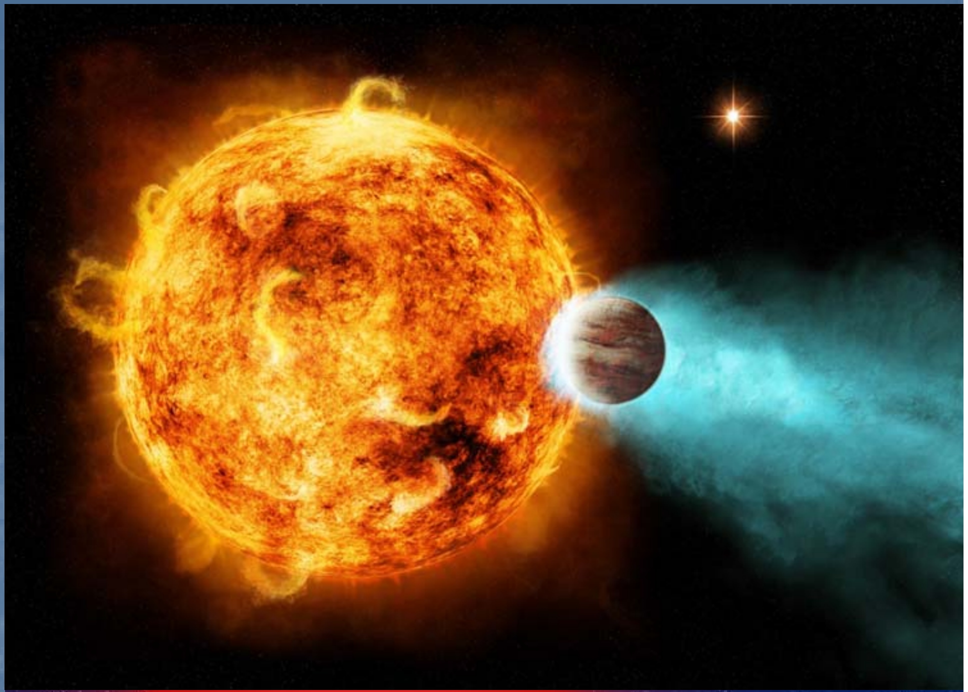

Atmospheric escape/evolution and climate change due to direct interaction between solar wind and ionosphere without planetary magnetic field
Venus/Mars

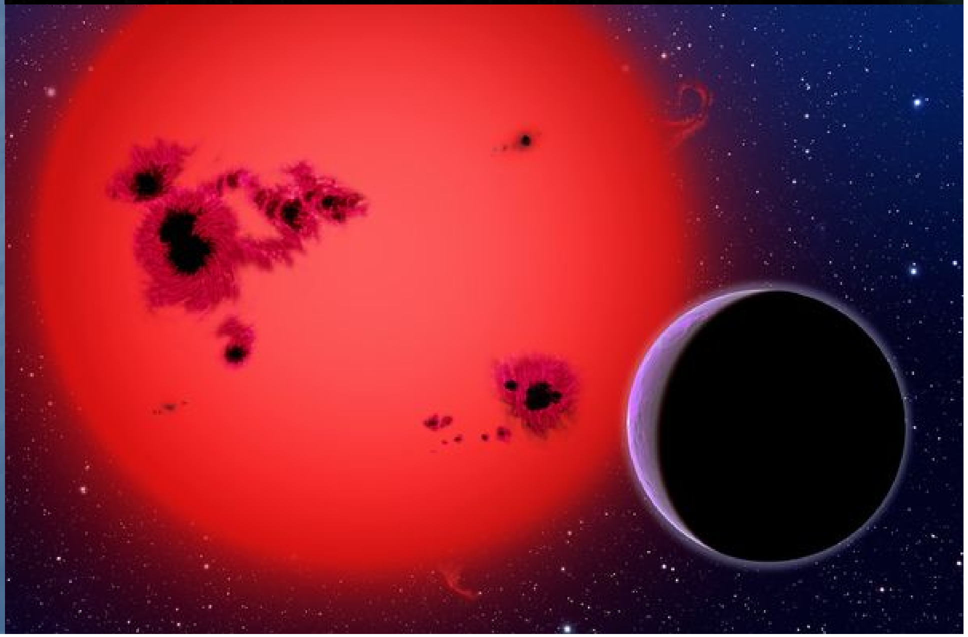
Long-term Variation of Geomagnetic Field Intensity



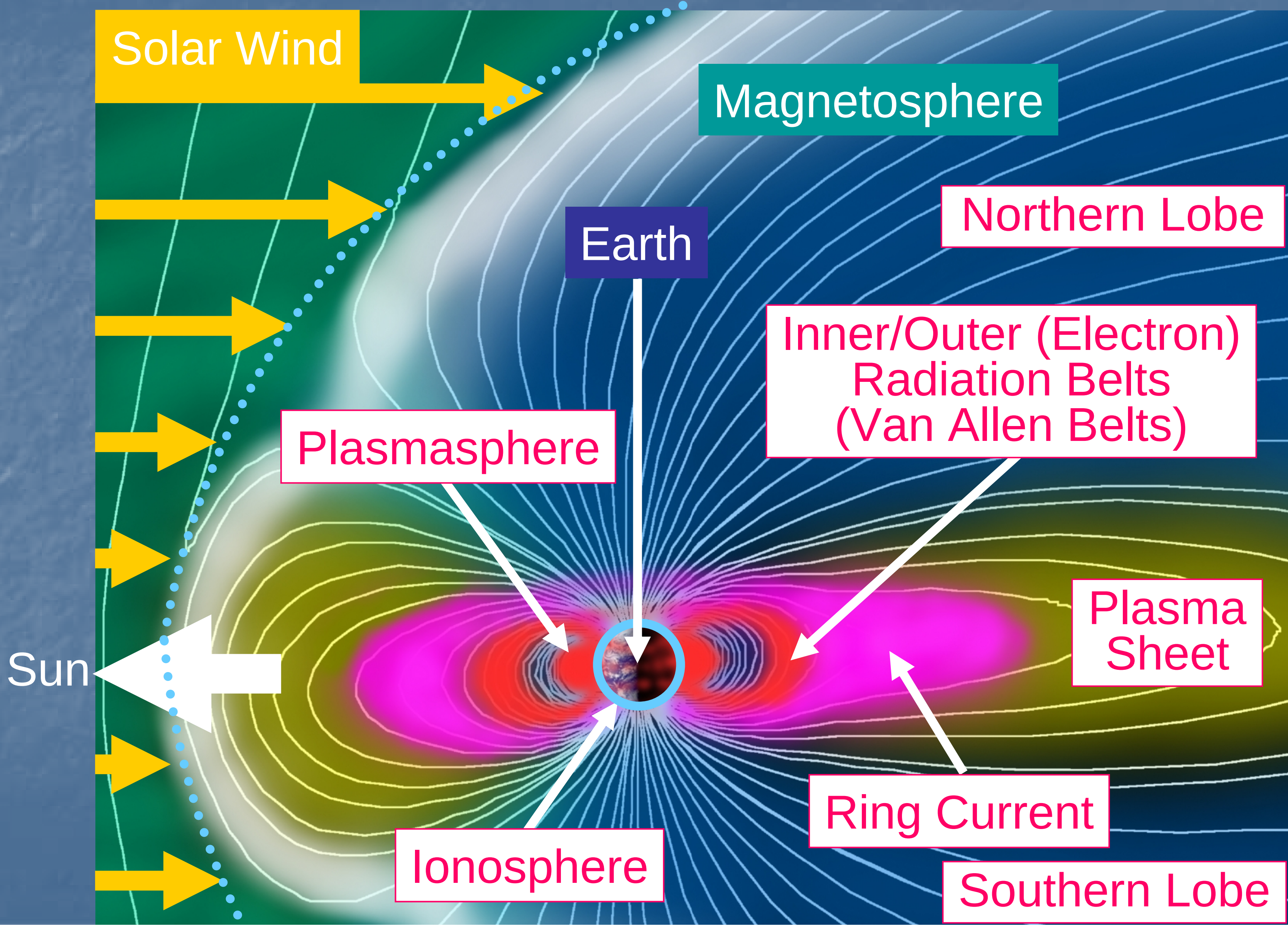
地球磁場の強さの変動
地球磁場はこの数100年あまりの間減少を続けています。この速さで減少を続けると、あと1000年足らずで消失する計算になりますが、将来本当にその通りになるのか、または、一時的な現象で再び磁場強度が回復していくのか、結論を出すことは容易ではありません。

Hot Jupiter, Super Earth

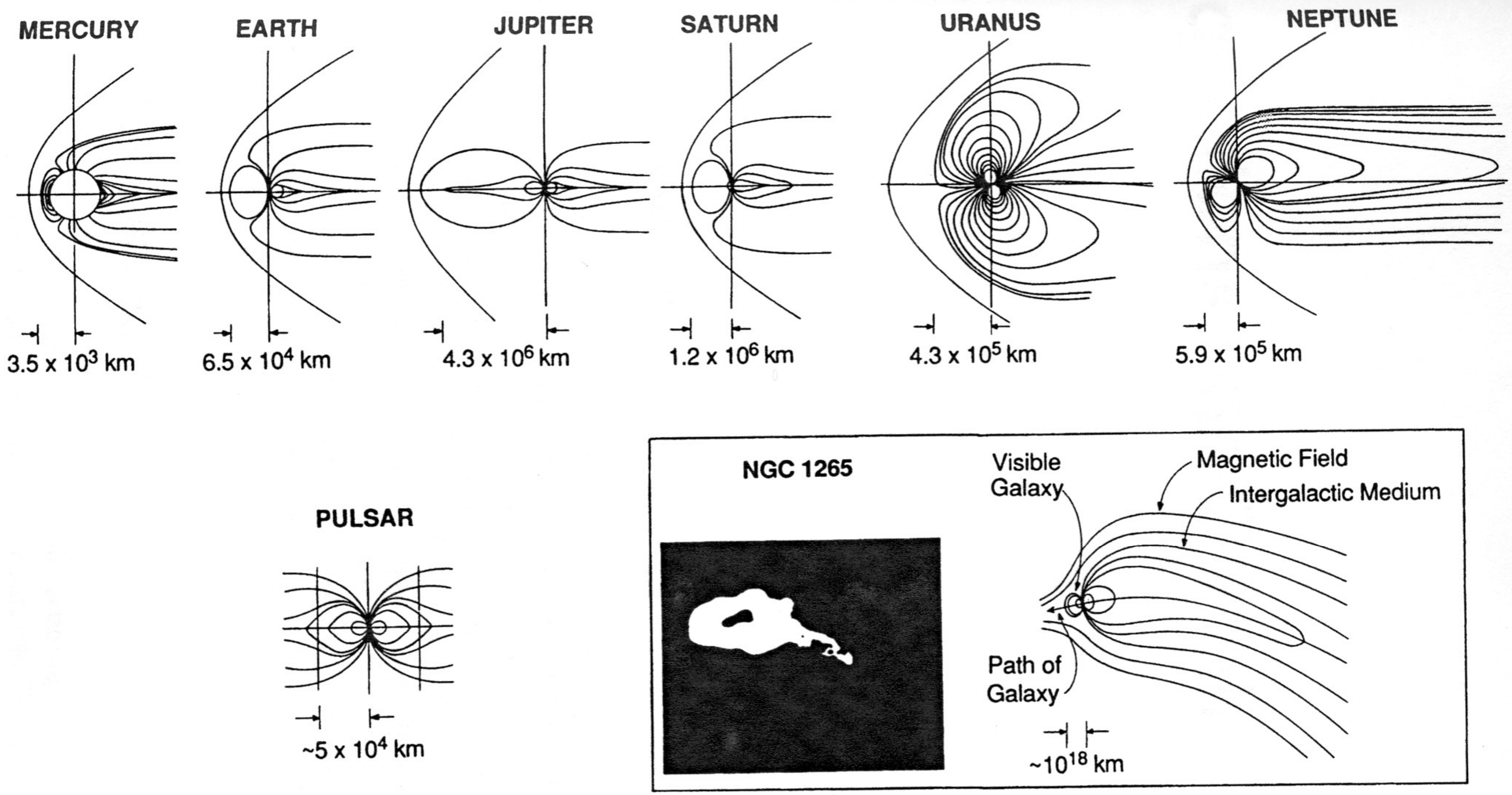




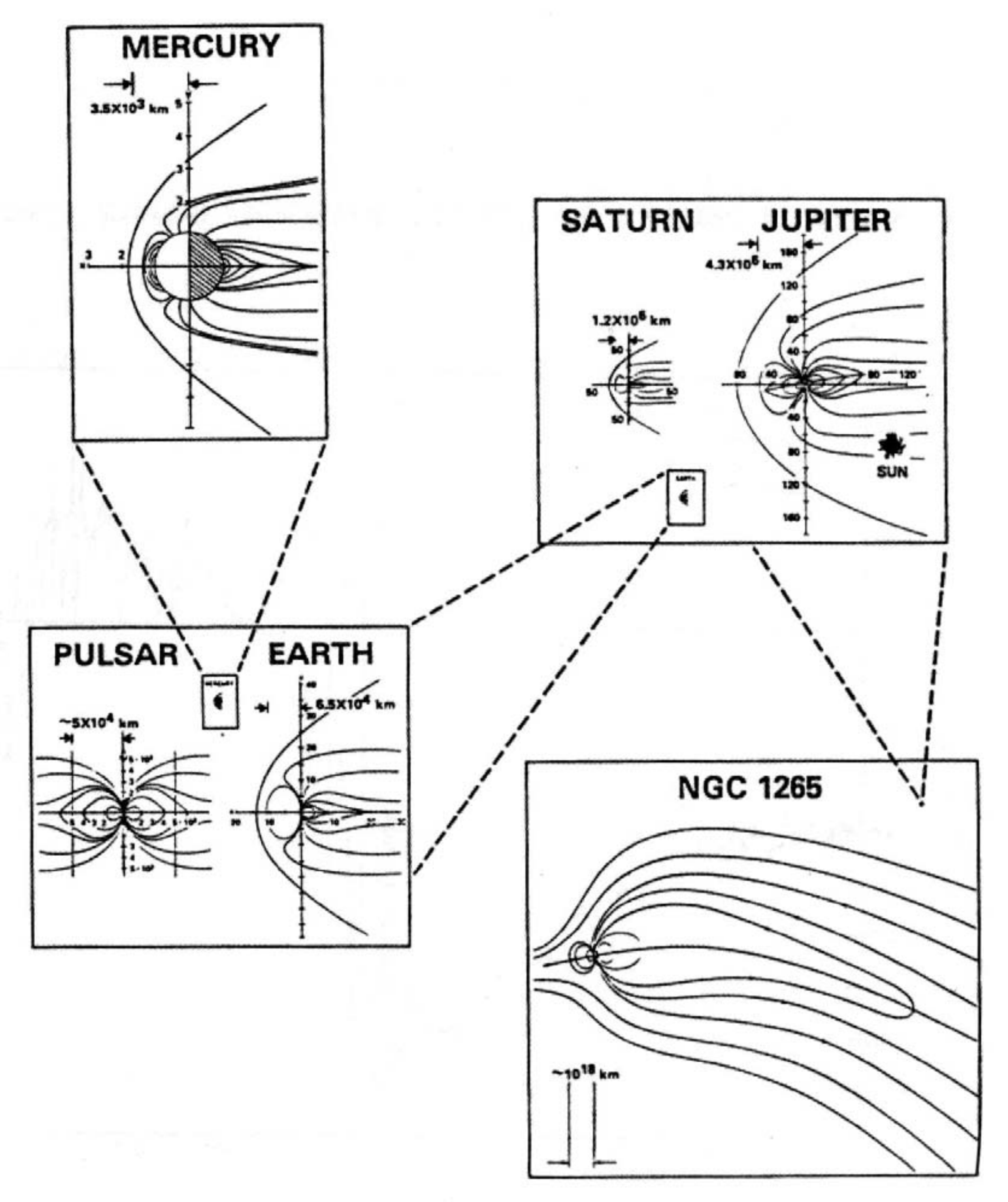
Formation and Structure of Geospace



A Variety of Magnetospheres



Comparison of Various Magnetospheres



Features of the Space Plasma in the Vicinity of Earth/Planets

- Tenuous, almost collision-less, but often hot and energized/accelerated
- Affected by or affecting magnetic/electric fields in space
- Interaction with plasma waves
  - Cross-energy coupling via wave-particle interaction
    e.g., Internal acceleration of the radiation belt electrons by whistler waves
- Sometimes dominated also by non-MHD processes
  - Significant role of non-MHD drifts especially for the high-energy particles
    e.g., curvature/gradient drifts in the ring current
  - Importance of particle motions in boundaries
    e.g., pick-up ions as an escape process in non-magnetized planetary space
- Spread and highly variable 3-dimensional velocity or pitch angle-energy distributions in a wide energy range
  - Less than 1 eV up to tens of MeV
  - Numerous types of acceleration/transport/interaction mechanisms
- Multi-composition ions
  - Solar-wind (H^+, He^{2+}, highly charged heavy atoms) and ionospheric (H^+, He^+, singly charged heavy atoms/moleculars) origins
- Cross-sphere coupling
  - Magnetosphere (plasma sheet, ring current, radiation belt), ionosphere, plasmasphere, solar wind

Science Objectives of ERG

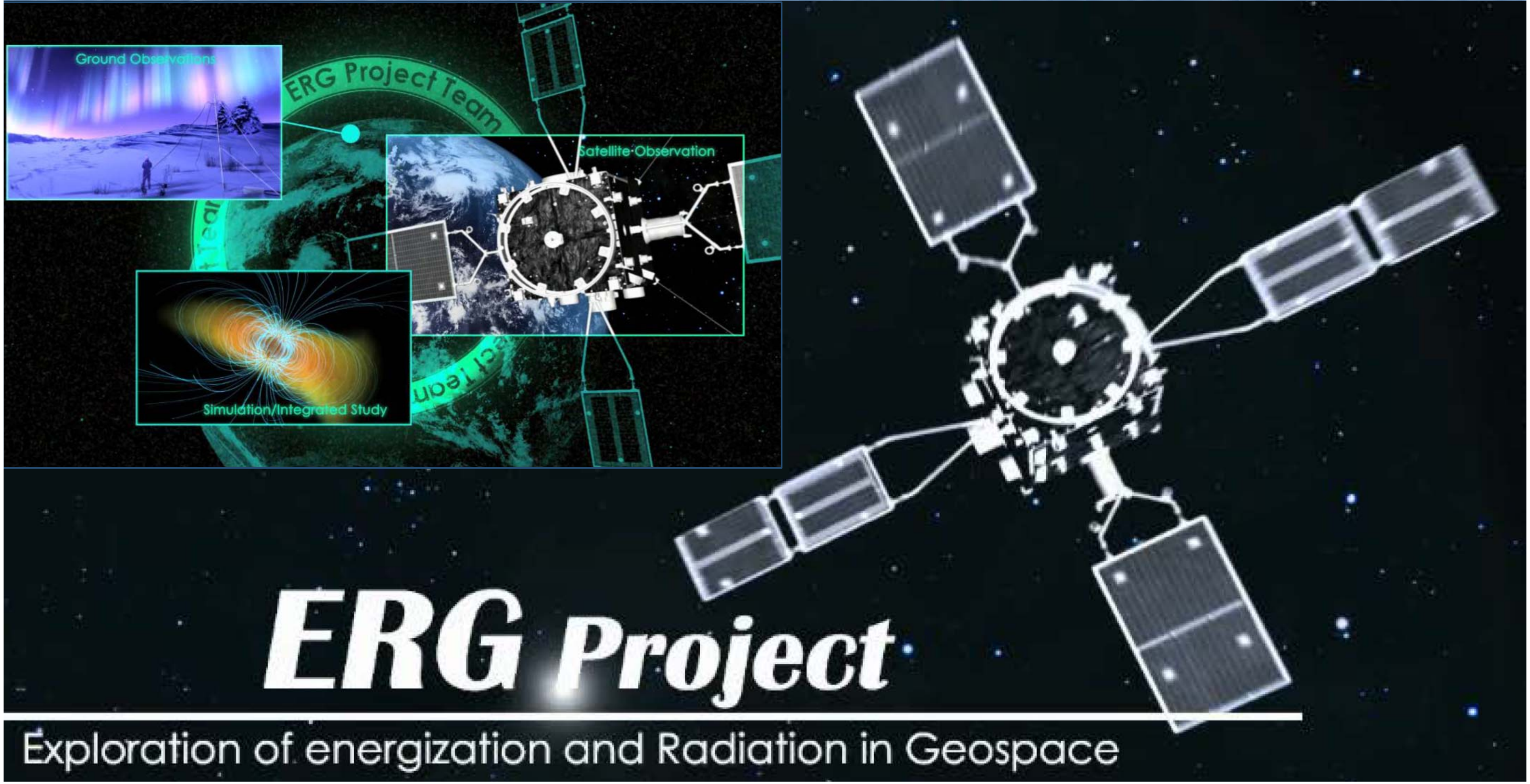
Dynamics of the radiation belt particles due to the cross-energy couplings

Acceleration, Transport, and Loss Processes of the Relativistic Particles

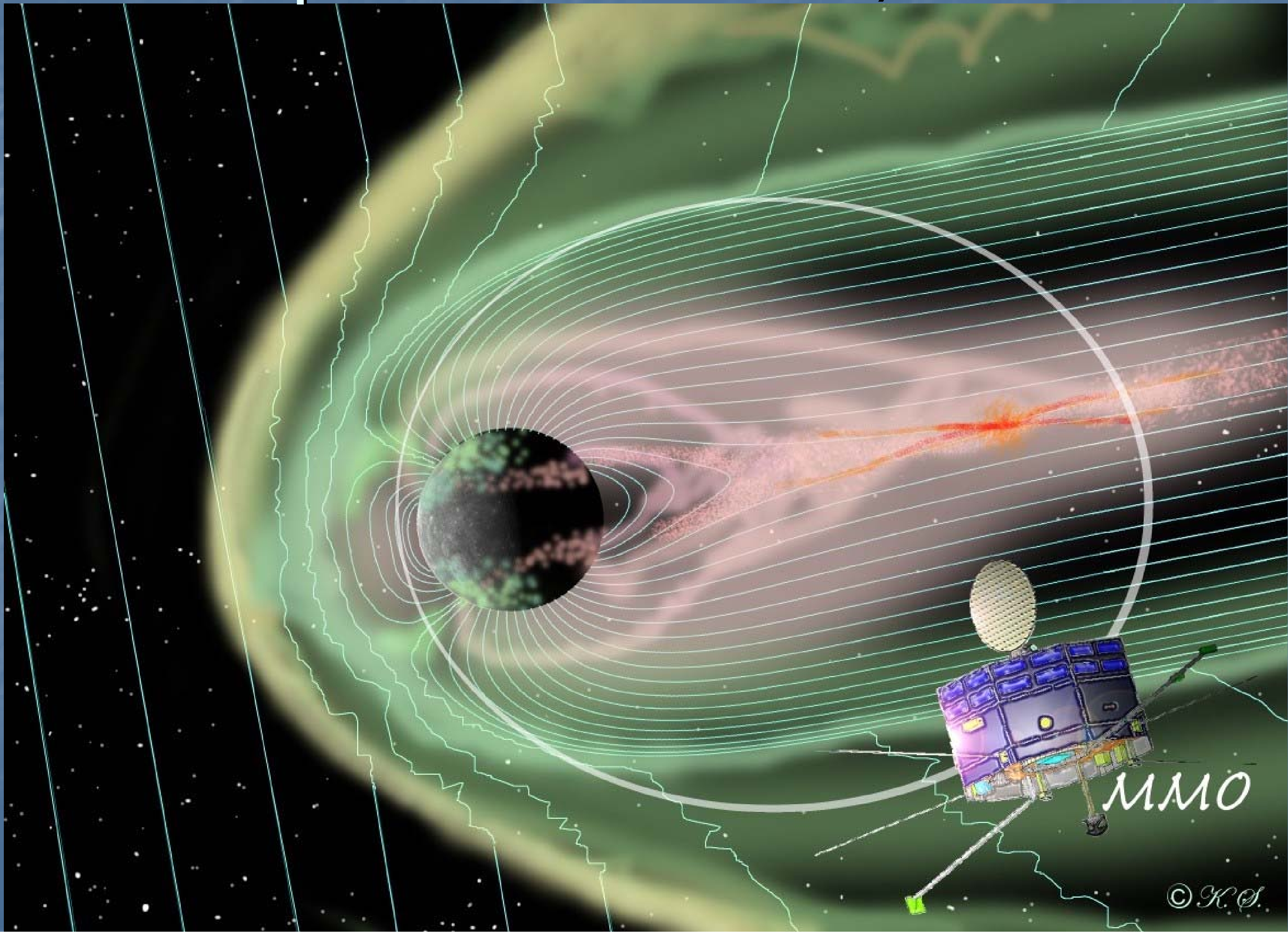
--- Radiation Belt (Wave-Particle-Field Coupling)

Conditions for the Acceleration, Transport, and Loss Processes

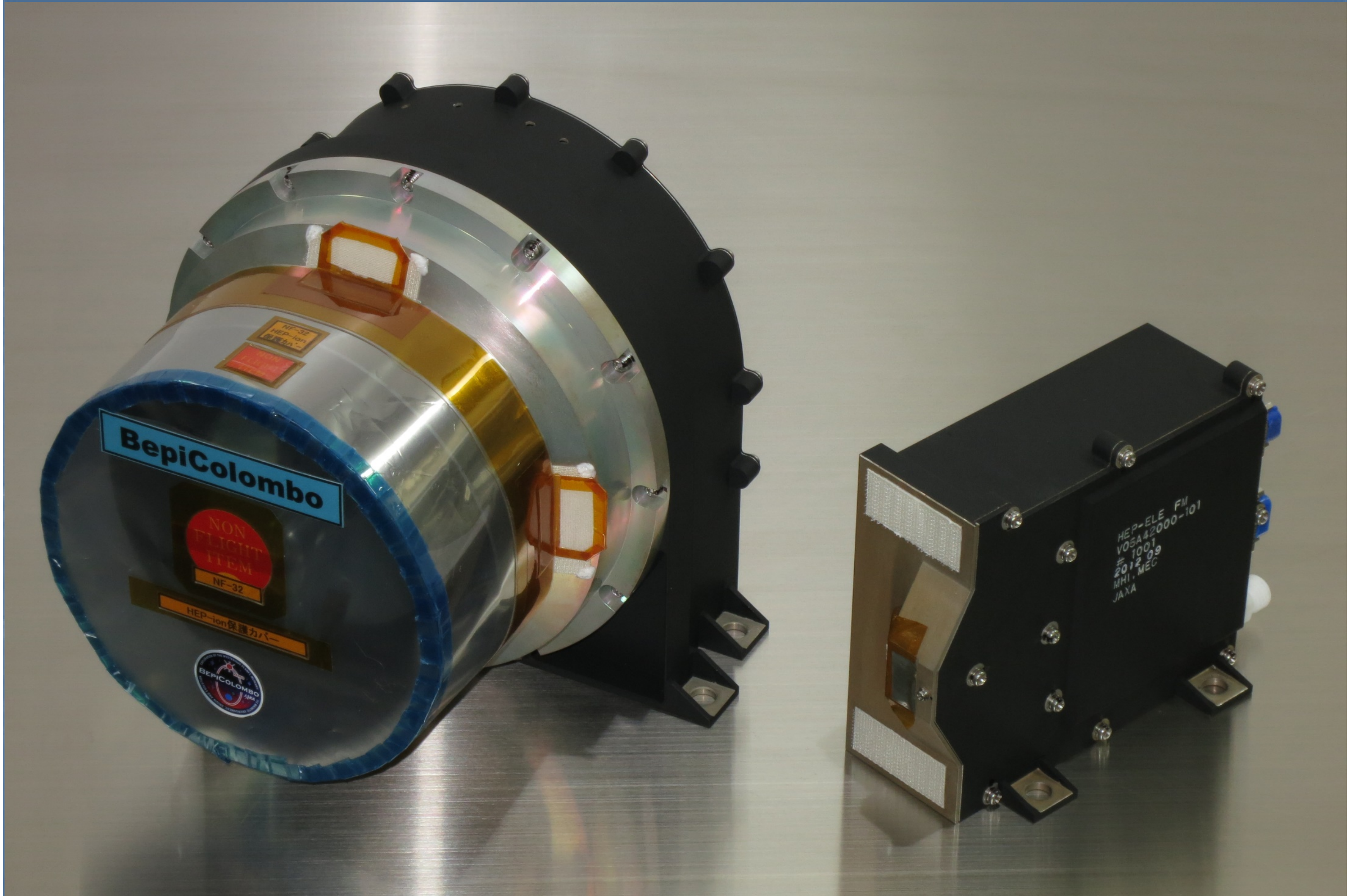
--- Space Storm (Cross-Energy/Sphere Coupling)



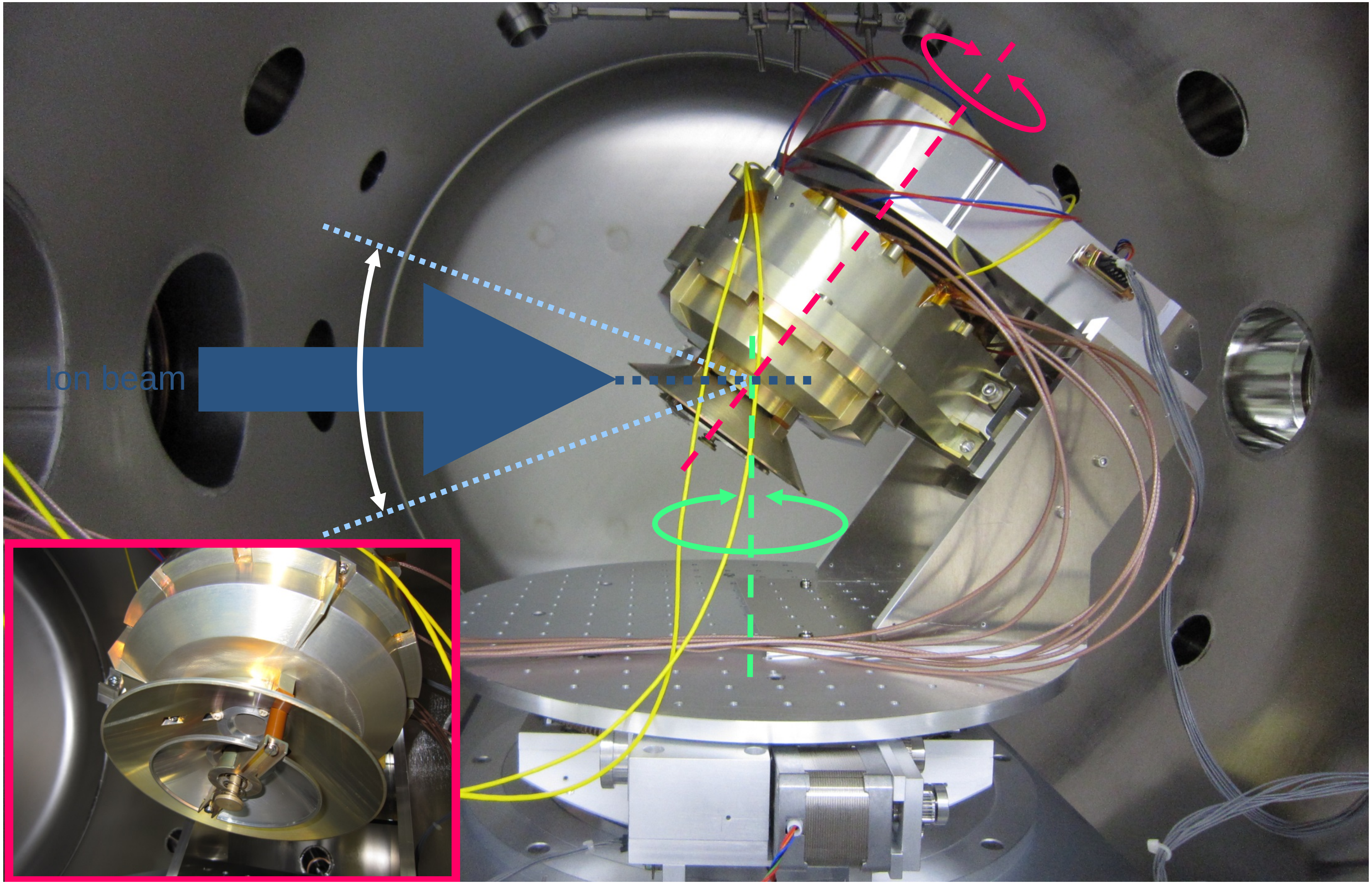
ESA-JAXA Joint Mercury Exploration Mission
BepiColombo – MPO, MMO



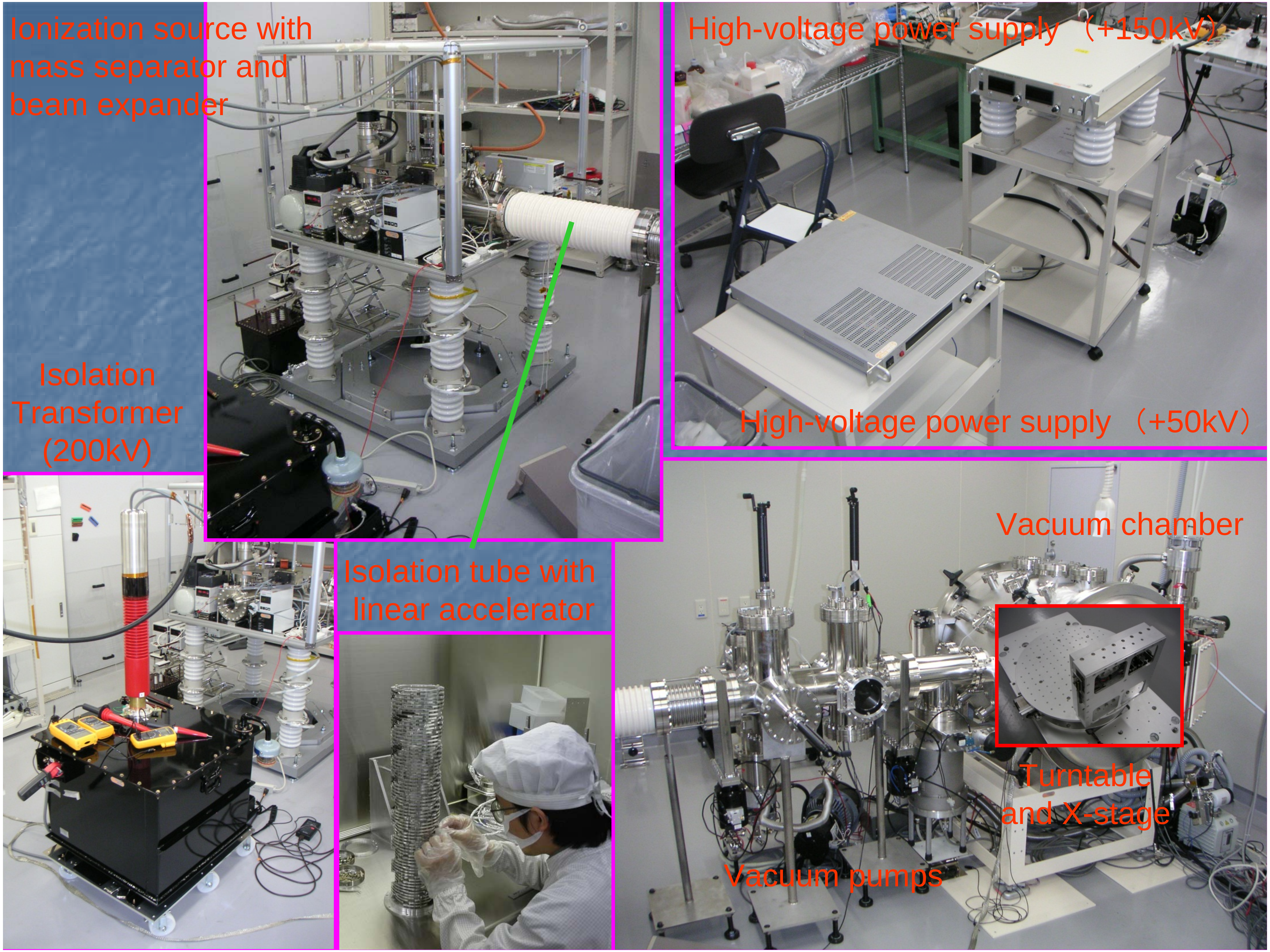
Flight Models of MMO HEP-i and HEP-e



Engineering Model of MMO HEP-i on a Multi-Axial Turntable System in the Vacuum Chamber

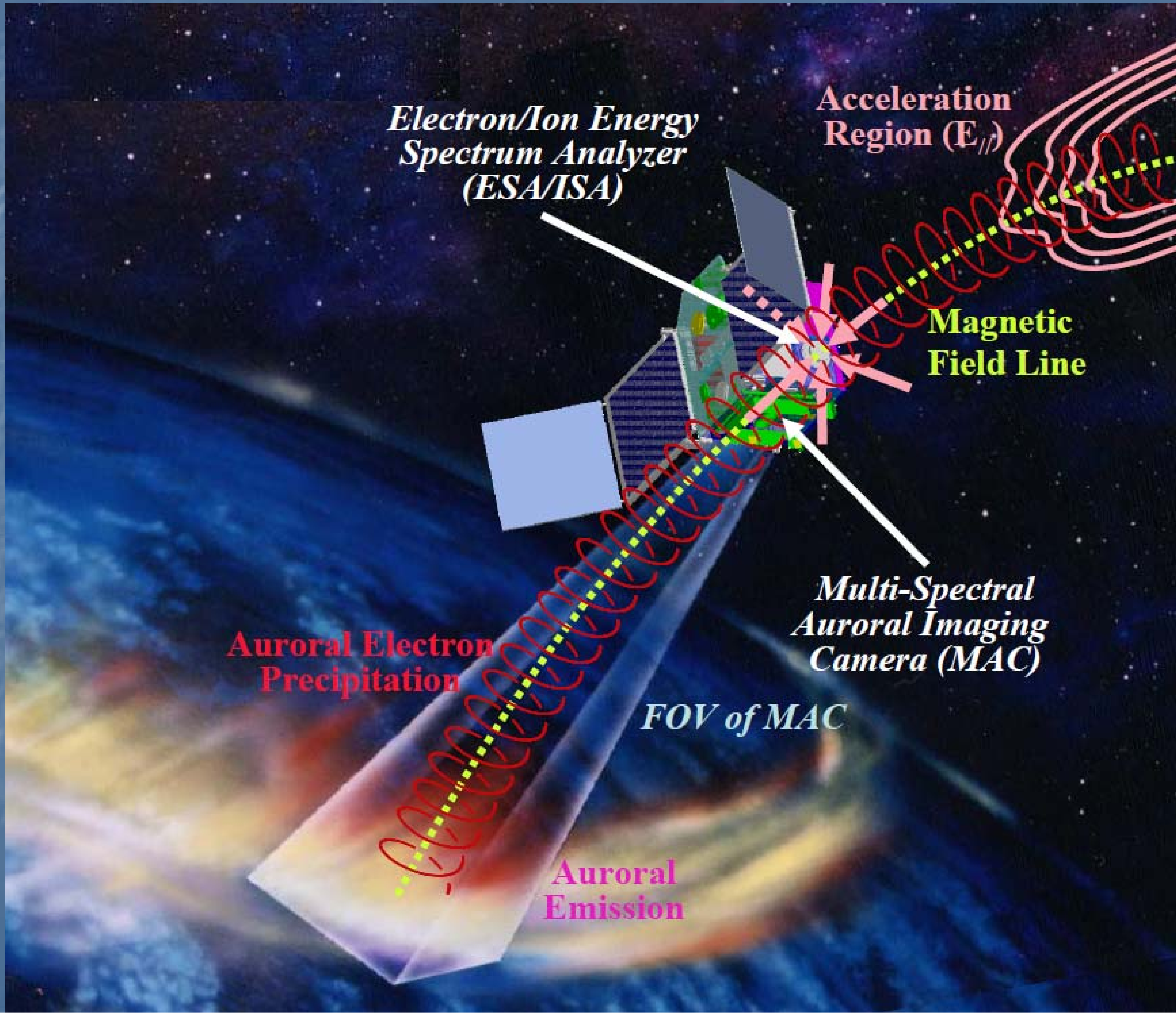


Calibration Facility (Beam Line and Vacuum Chamber)

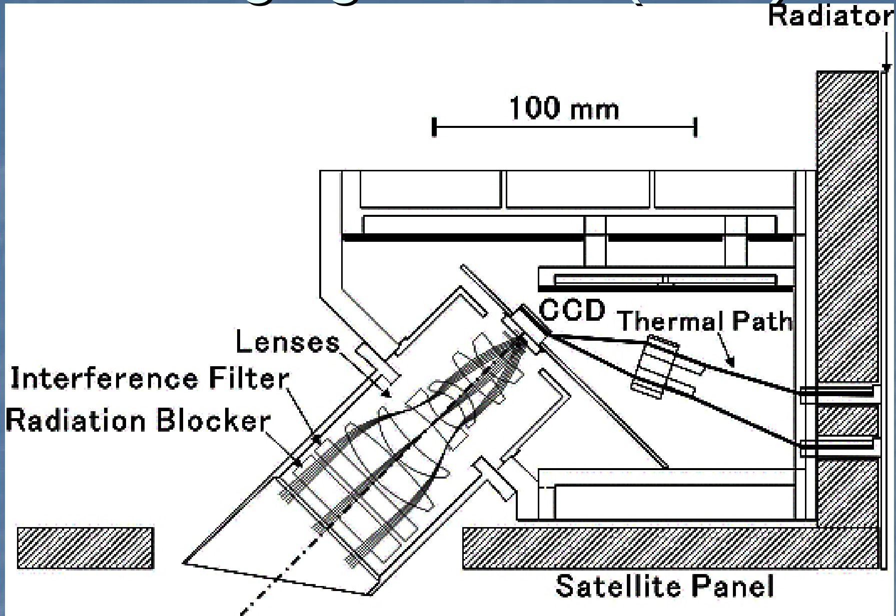

Ionization source with mass separator and beam expander
Isolation Transformer (200kV)
High-voltage power supply （+150kV）
High-voltage power supply （+50kV）
Isolation tube with linear accelerator
Vacuum chamber
Turntable and X-stage
Vacuum pumps

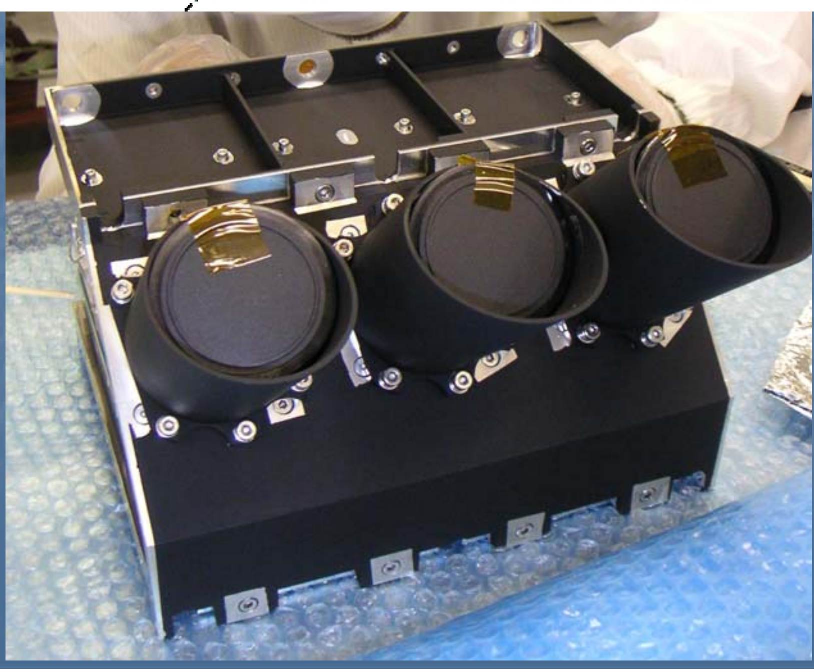
Aurora emission and particle observations by Reimei

Emission-particle simultaneous measurements with high time/spatial resolutions

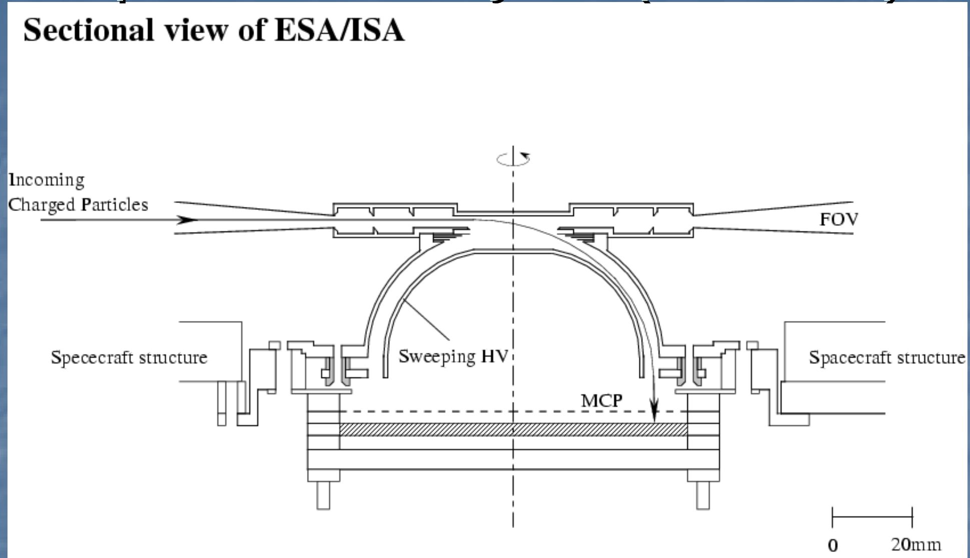


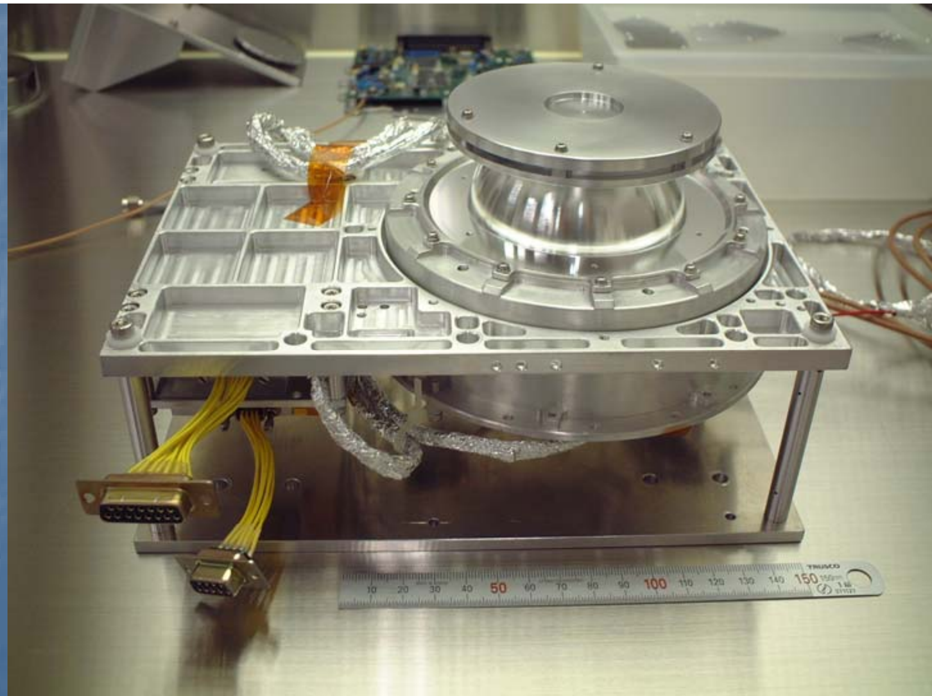
Multi-Spectral Auroral Imaging Camera (MAC)





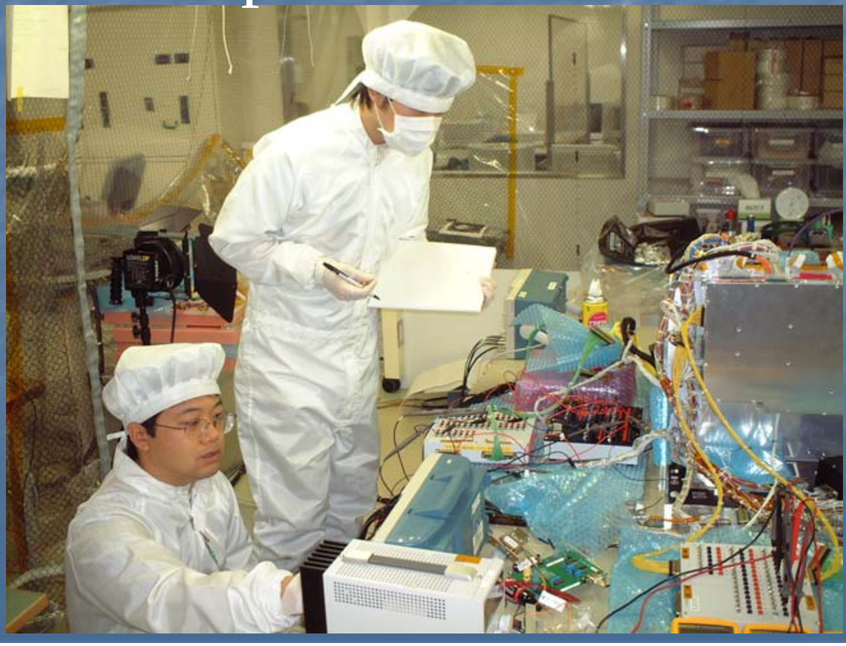
Electron/Ion Energy Spectrum Analyzer (ESA/ISA)



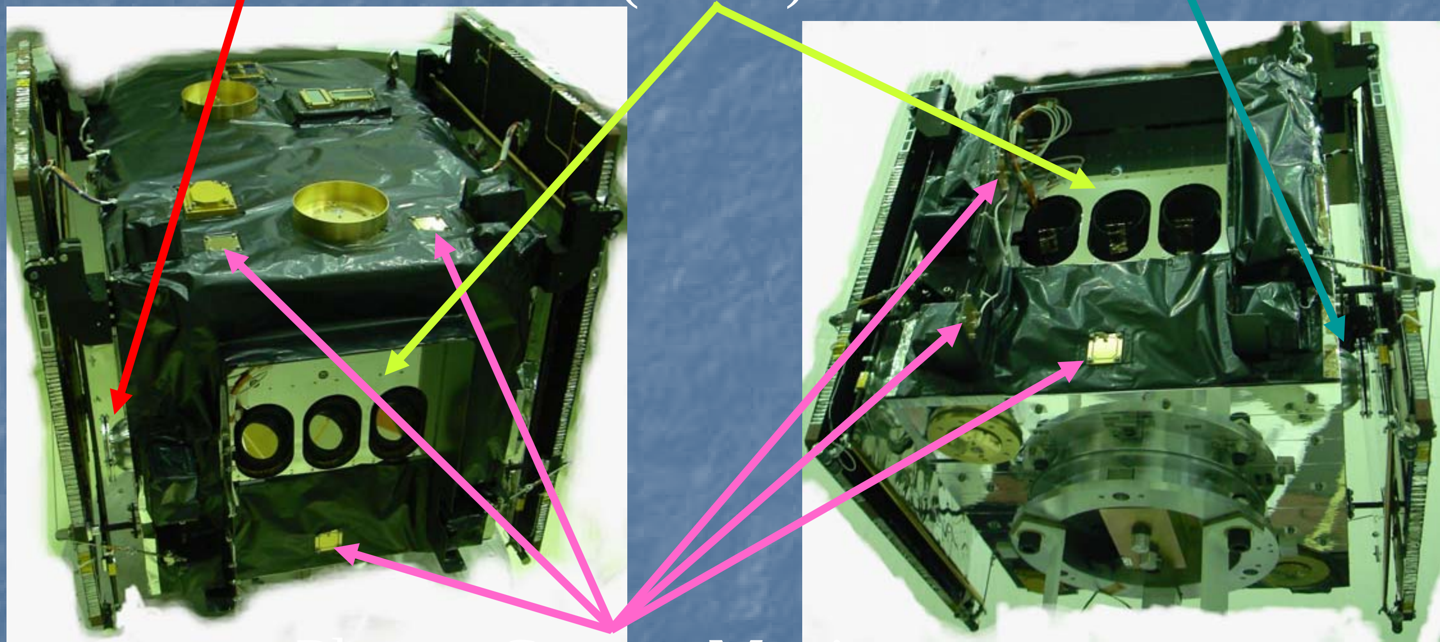


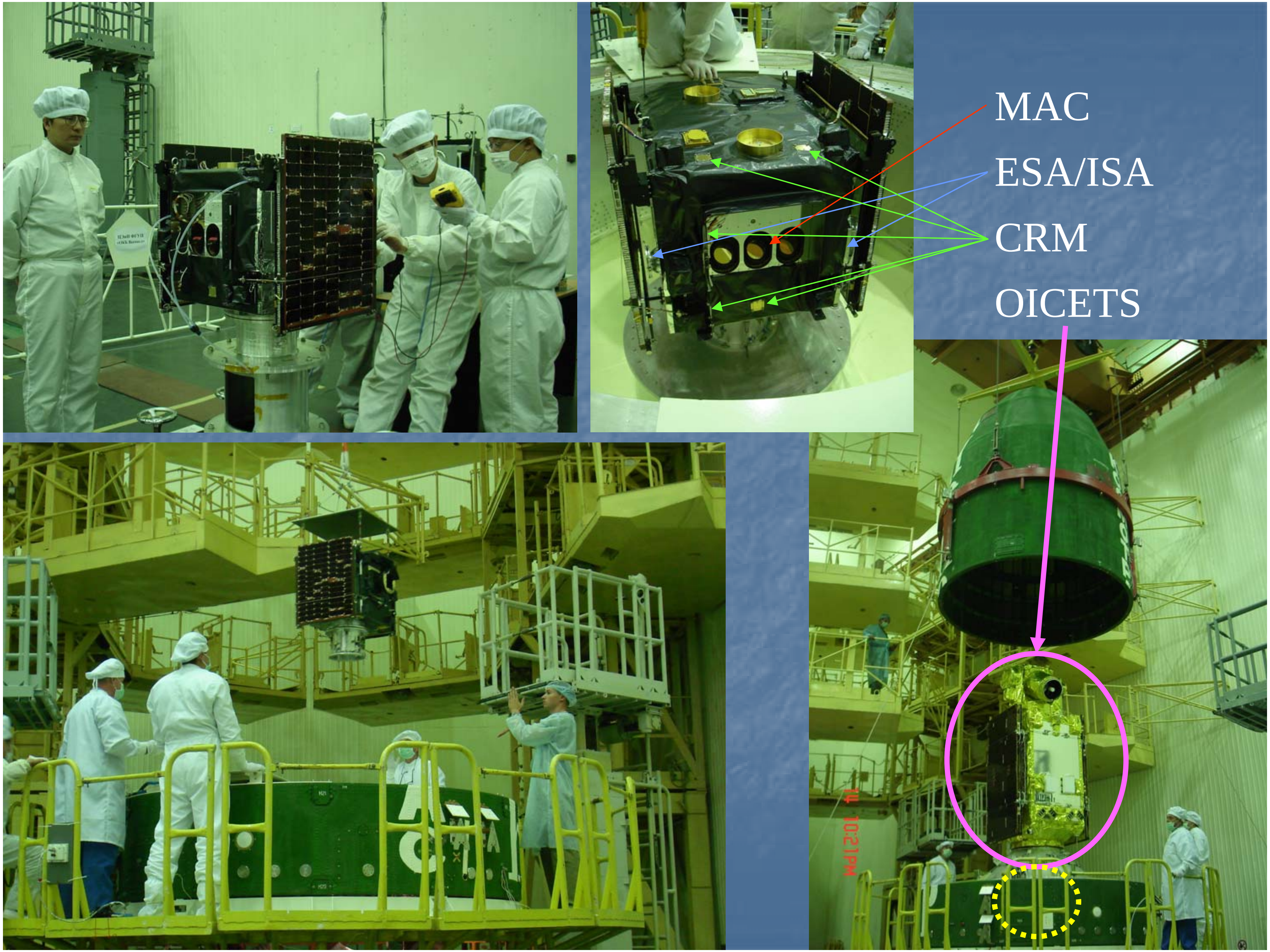
Calibration of ESA/ISA

Development of MAC



Appearance of Reimei



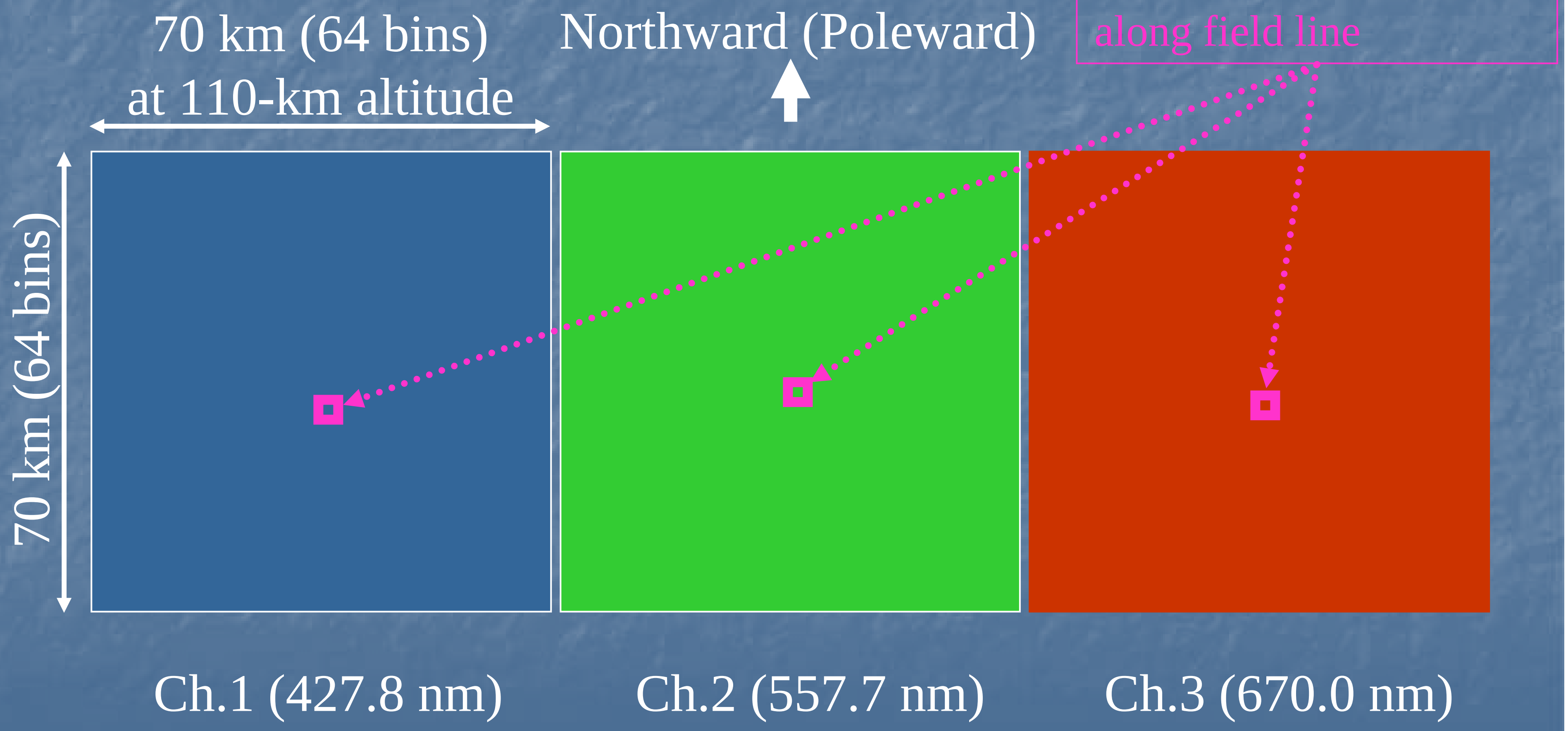

MAC
ESA/ISA
CRM
OICETS
14 10:21PM

	LEO Payload (metric tons) 200 km x 46 deg	GTO Payload (metric tons)	Configuration	Liftoff Height (meters)	Liftoff Mass (metric tons)	Est Price
Dnepr-1	4.5 t		3 Stage R-36M2	34 m	211 t	$10-15 million
Dnepr-M	4.2 t		R-36M2 with modified Stg 3	34 m	211 t	$10-20 million
Dnepr-1/ST-1		0.15 t	Dnepr-1 + 4th & 5th Stgs	34 m	211 t	$10-20 million

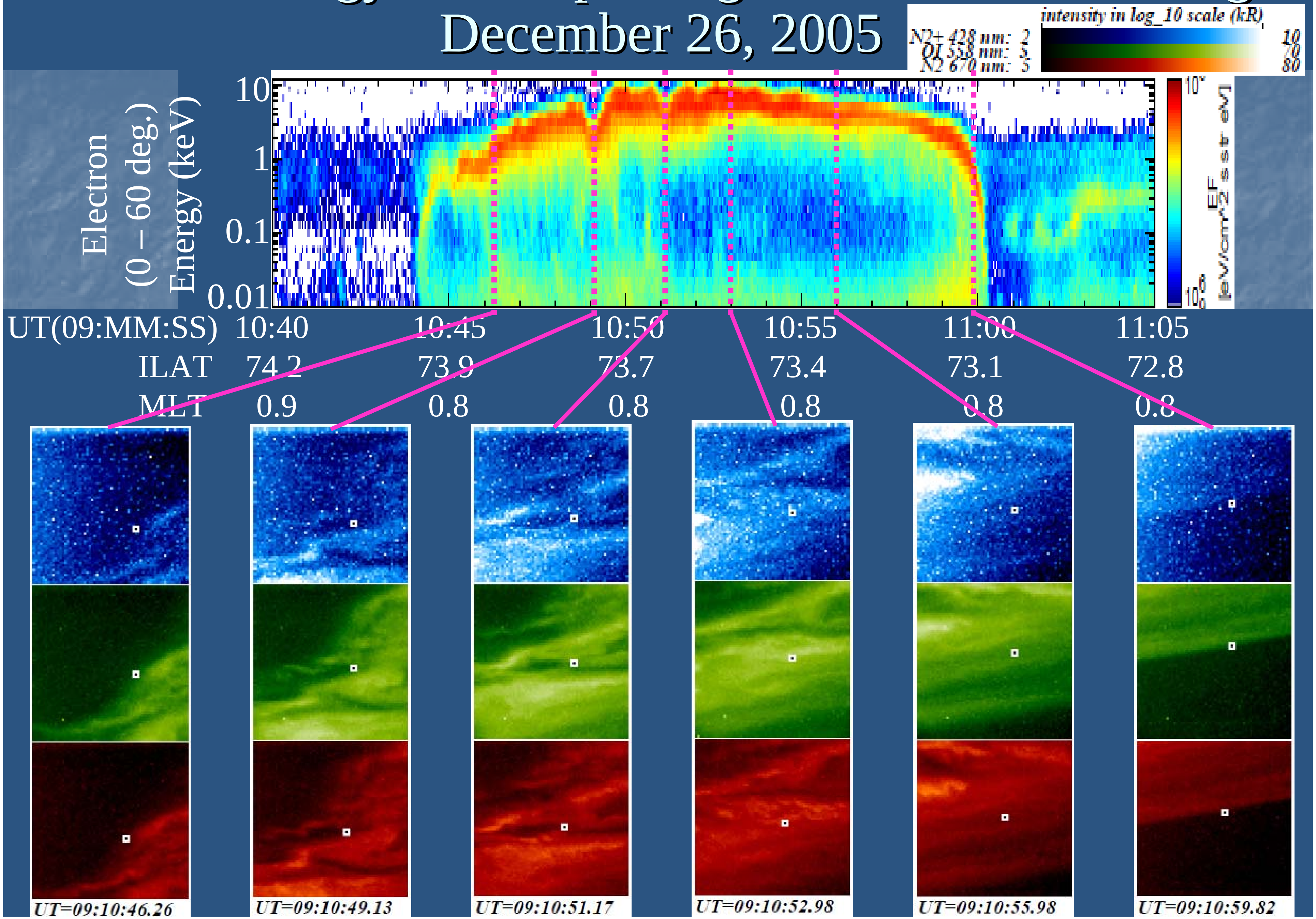
Dnepr Rocket offered by the Russian/Ukrainian Kosmotras consortium, is a modified three-stage R-36M2 Voyevoda intercontinental ballistic missile (ICBM), known as SS-18 “Satan” missiles.
http://www.geocities.com/launchreport/dnepr.html#config

Movie of Aurora Images
December 26, 2005

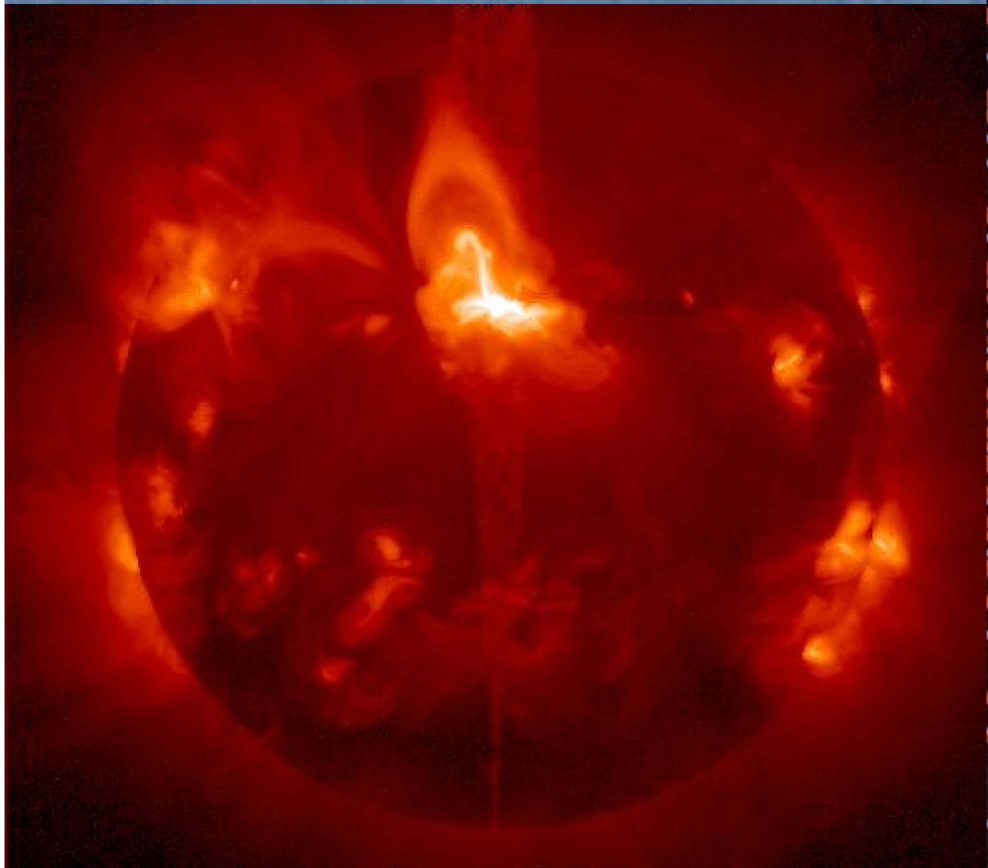
Exposure time: 60 msec.
Exposure cycle: 120 msec.



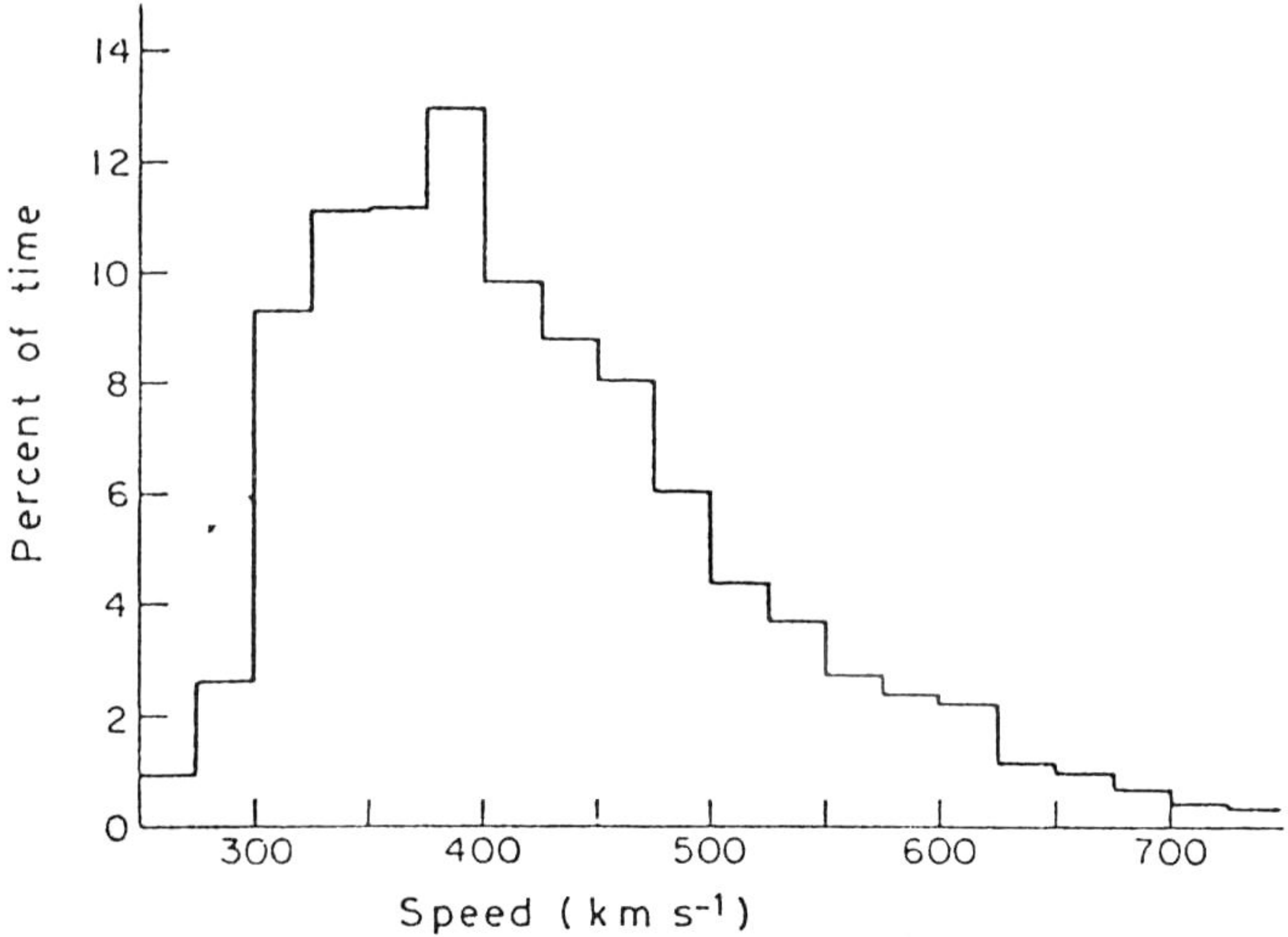
Electron Energy-Time Spectrograms and Aurora Images
December 26, 2005



Solar Activity and Magnetic Field

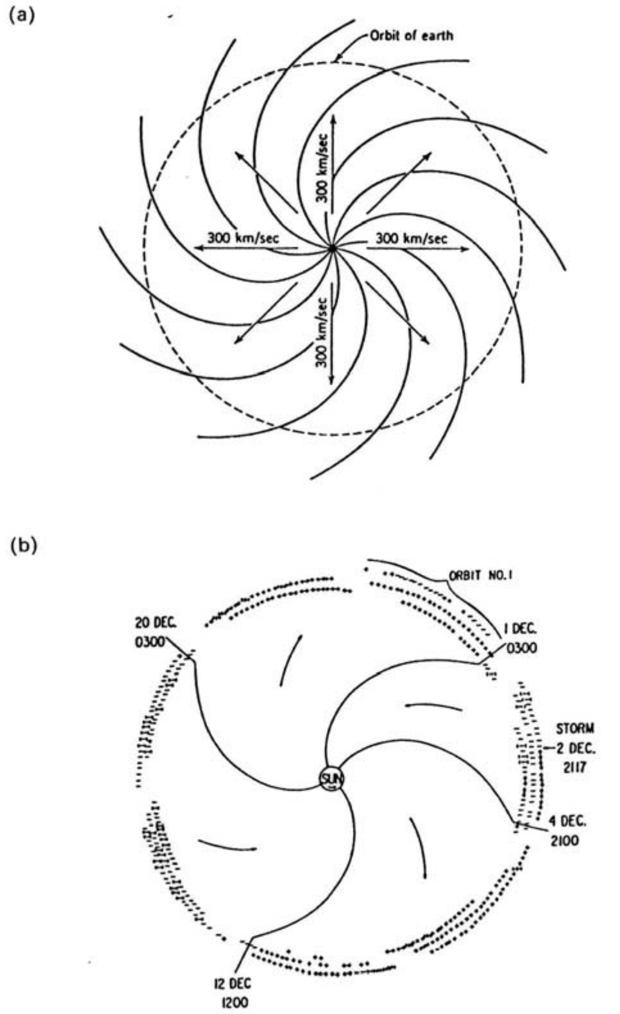


Statistical Data of Solar Wind Speed

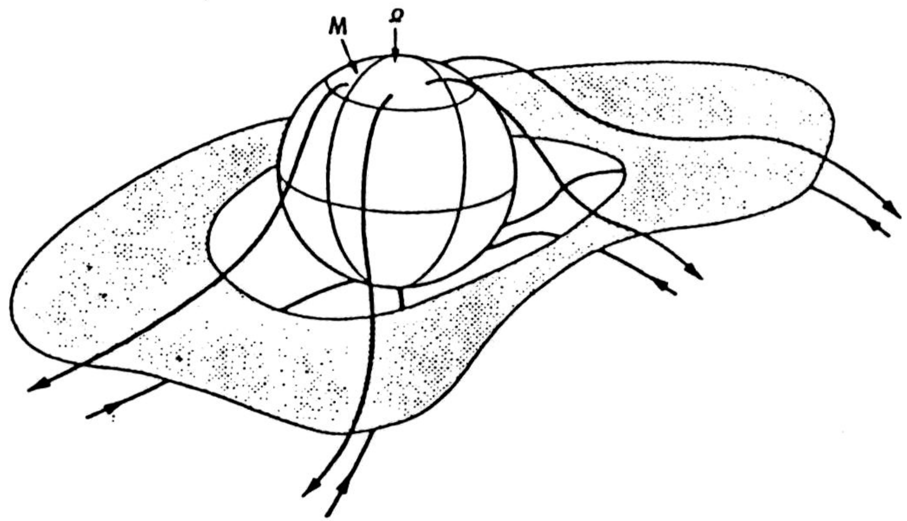


Speed of the solar wind: a histogram of measurements between 1962 and 1970. (J. T. Gosling, in *Solar Activity Observations and Predictions* (eds. McIntosh and Dryer). MIT Press, 1972)

Rough Structure of Solar Wind and Interplanetary Magnetic Field

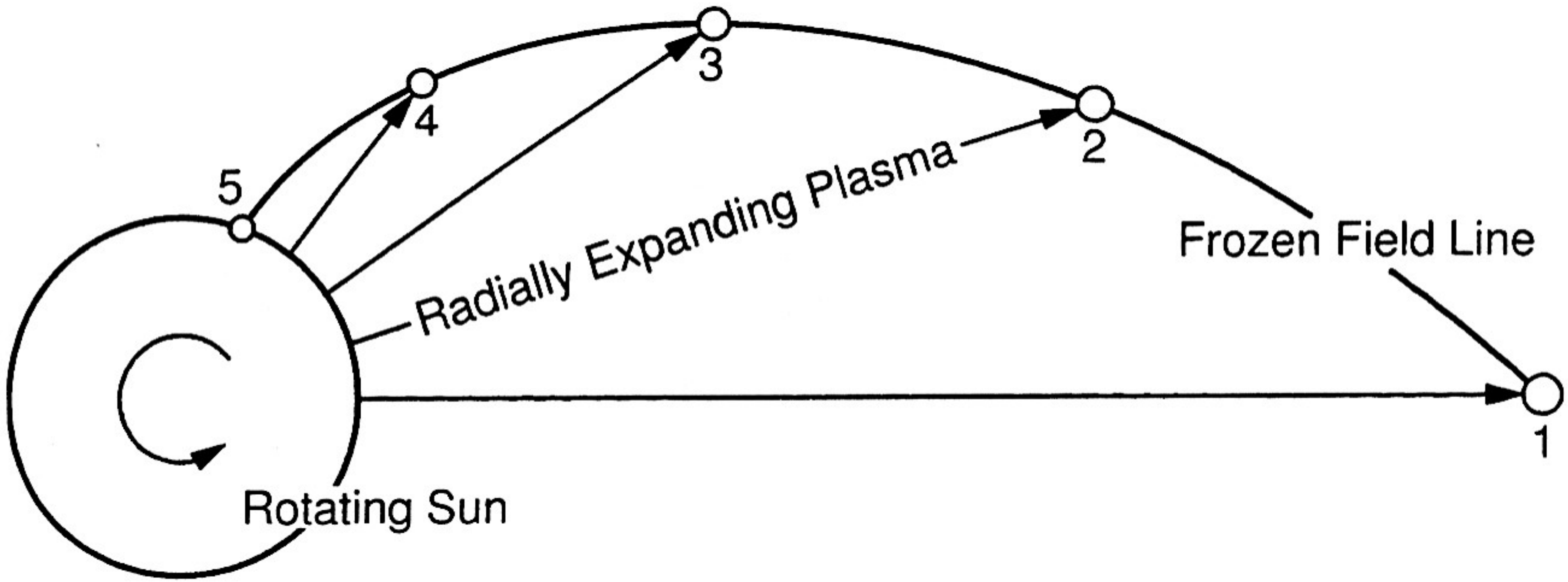


Form of the interplanetary magnetic field in the solar equatorial plane, corresponding to a solar wind speed of 300 km/s. (T. E. Holzer, *Solar System Plasma Physics*, *Vol I.* North-Holland, 1979, p. 103. Elsevier Science Publishers) (b) Sector structure of the solar wind in late 1963, showing inward (−) and outward (+) IMF. (J. M. Wilcox and N. F. Ness, *J.Geophys. Res.* **70**, 5793, 1965, copyright by the American Geophysical Union)

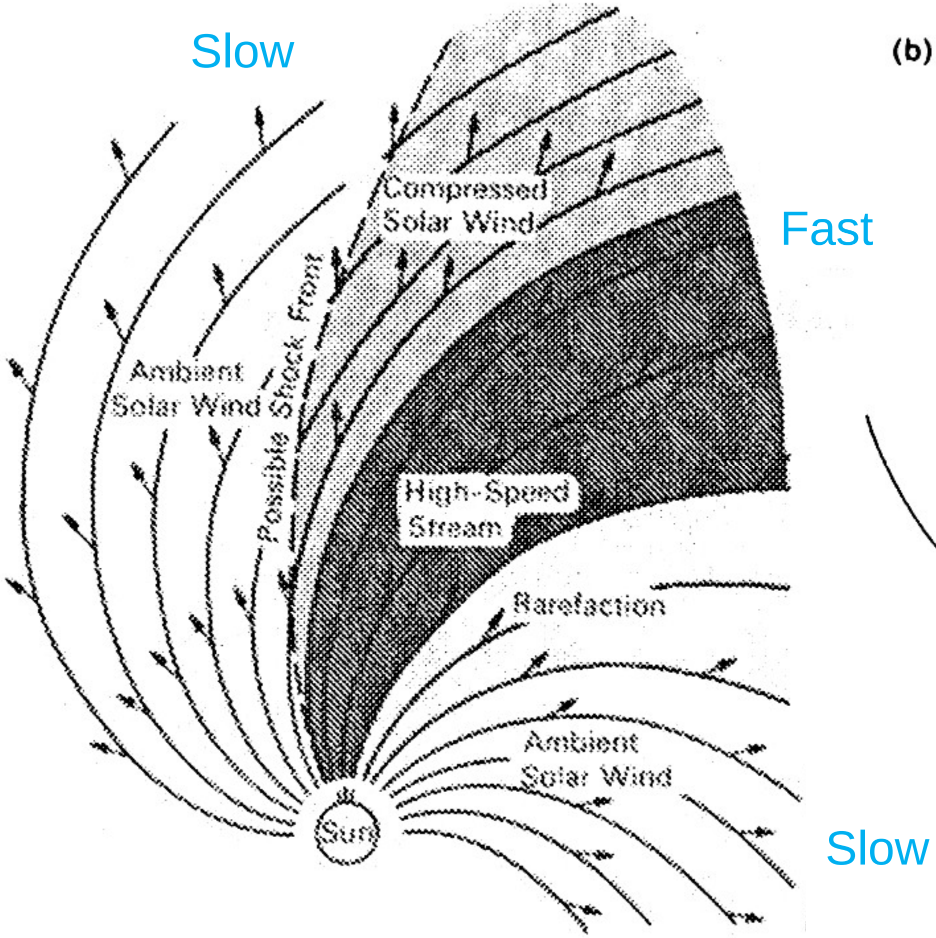


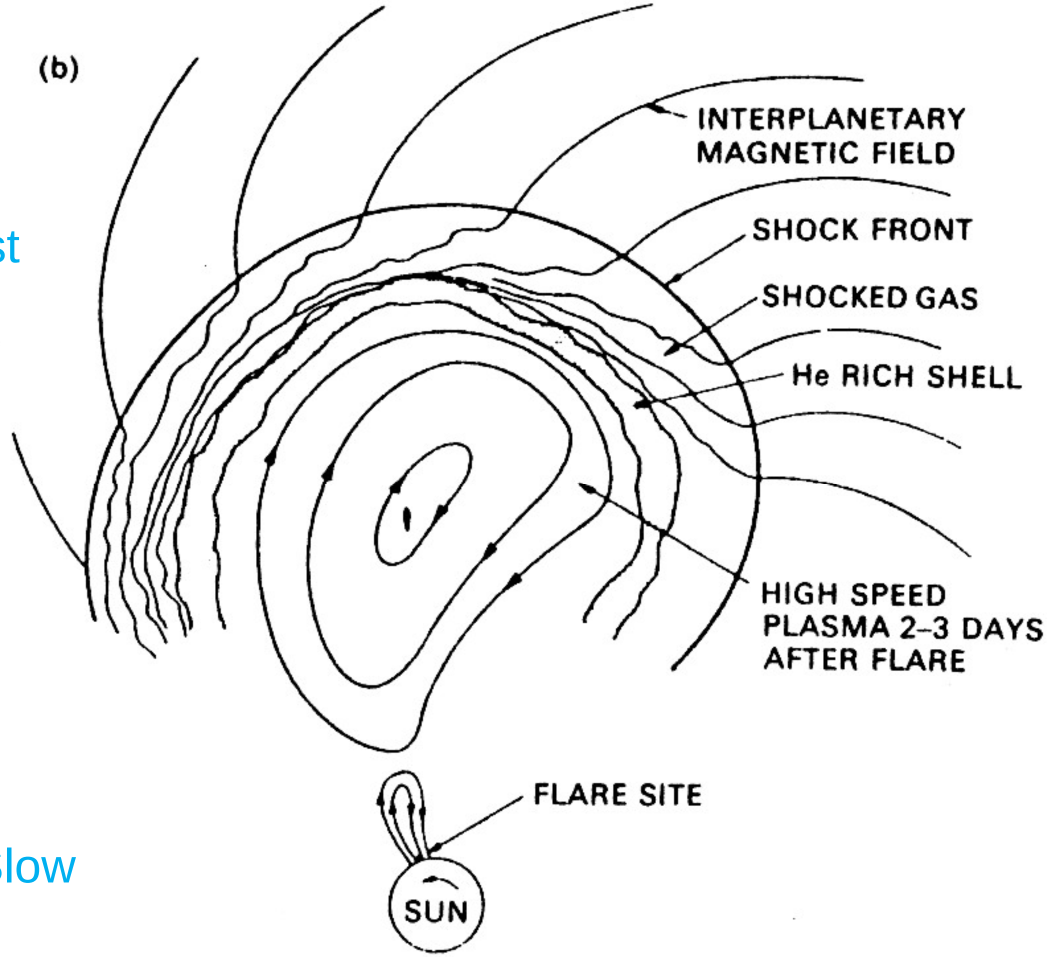
Ballerina model of current sheet in the solar wind. M is the axis of the current sheet and Ω is the Sun's rotation axis. (E. J. Smith, *Rev. Geophys. Space. Phys.* **17**, 610, 1979, copyright by the American Geophysical Union)

Interplanetary Magnetic Field Line Carried by Solar Wind Plasma "Parker Spiral"

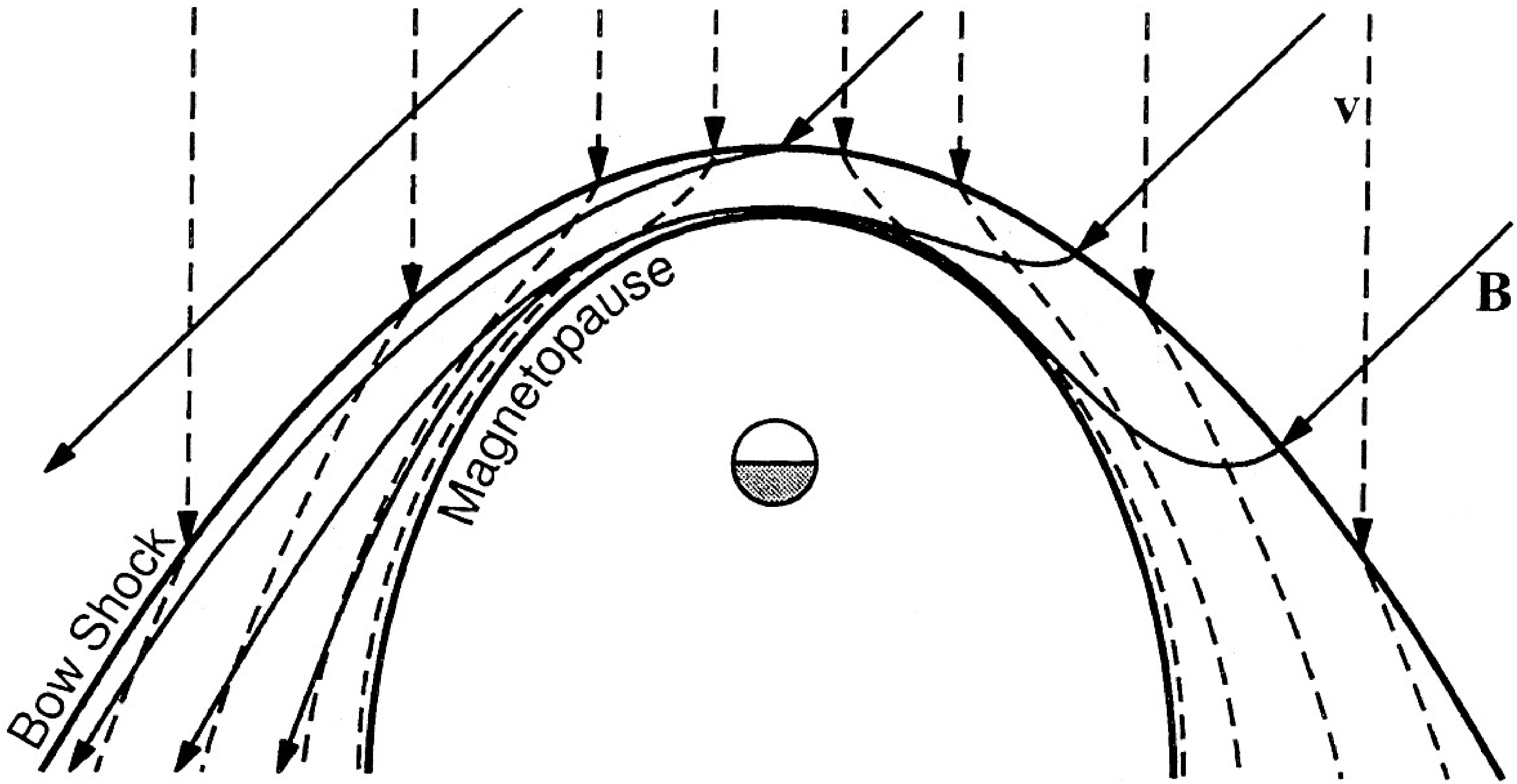


CIR (Corotating Interaction Region)
CME (Coronal Mass Ejection)

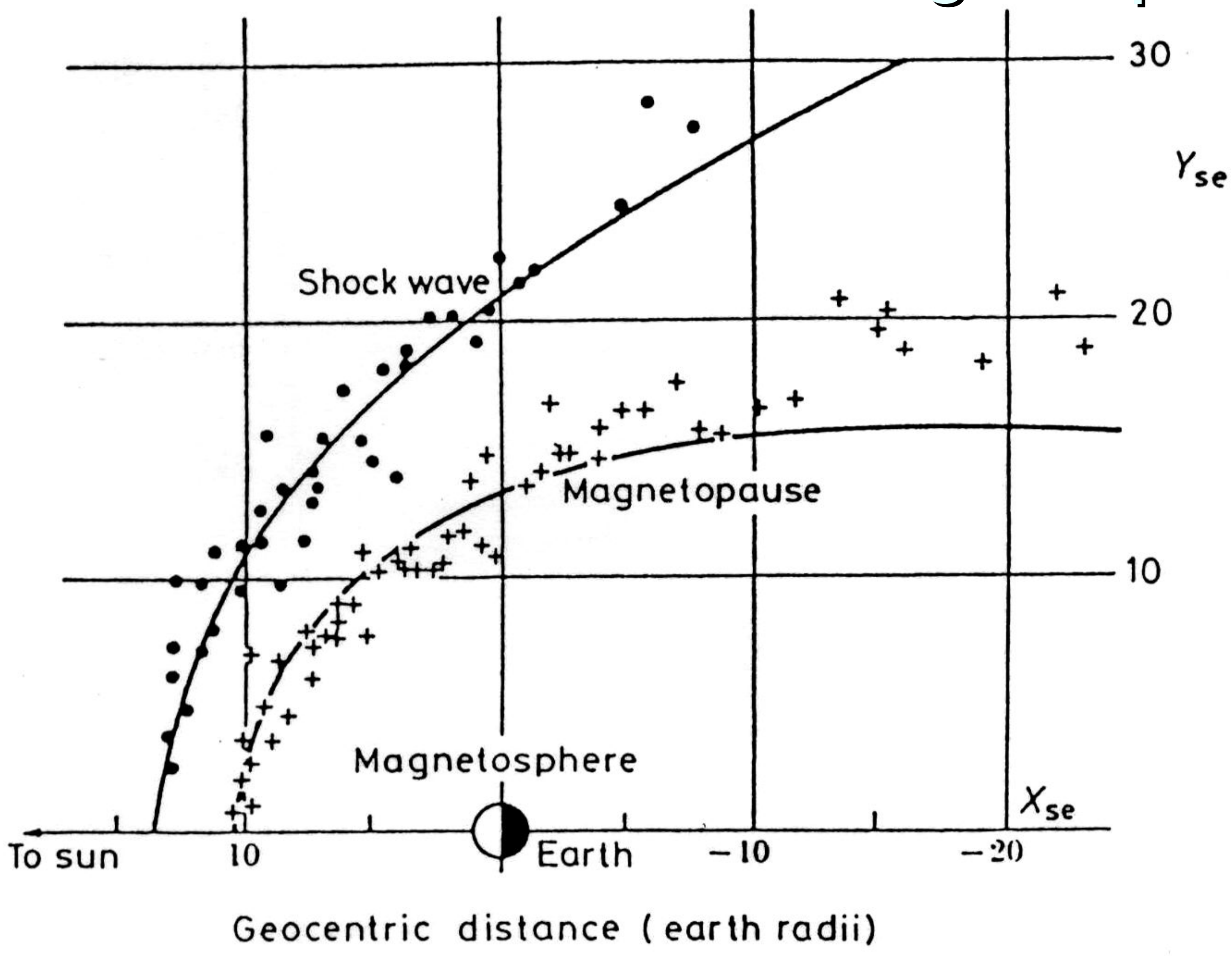




Draped Interplanetary Magnetic Field Lines and Formation of Shock and Magnetopause near the Earth

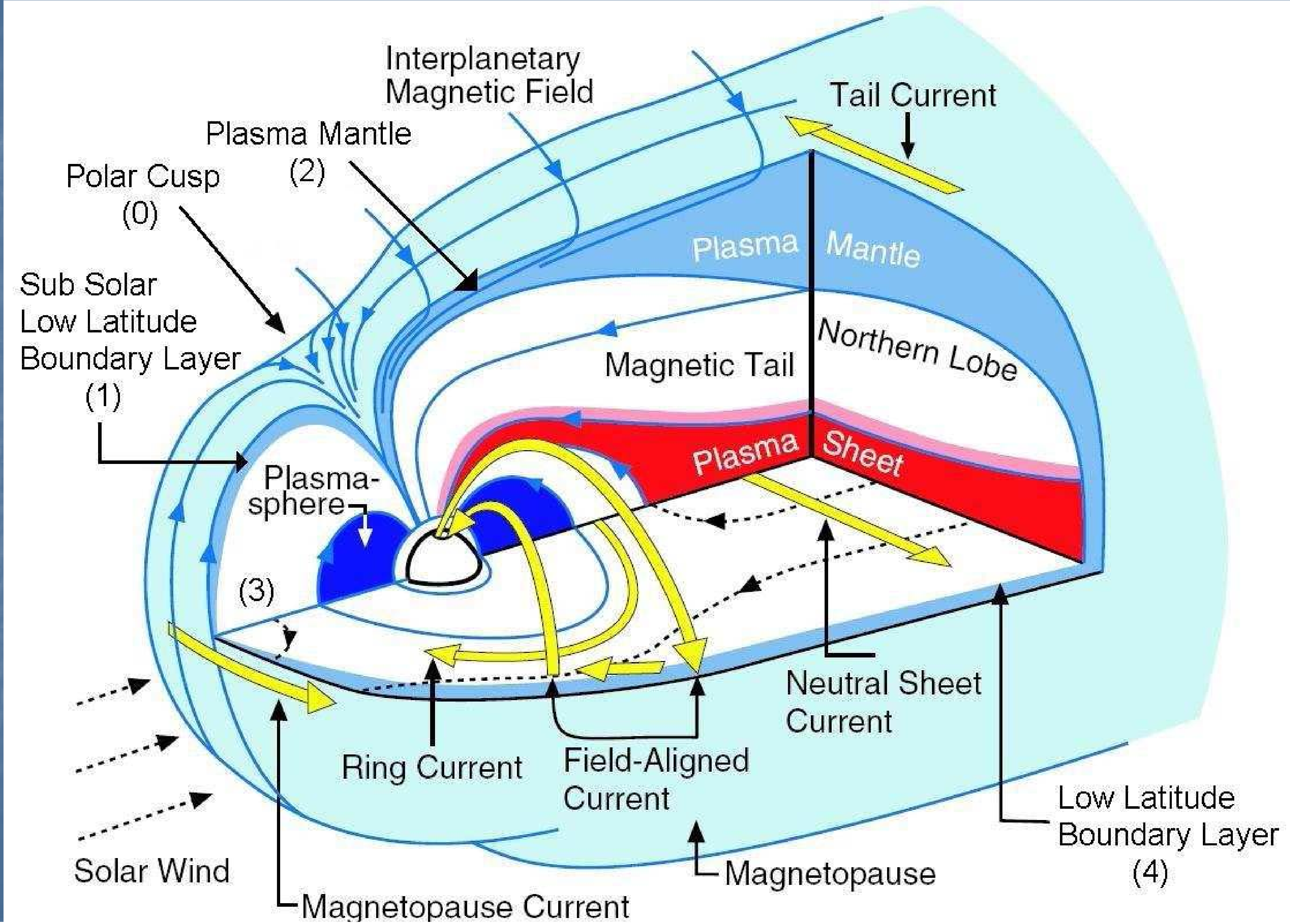


Location of Shock and Magnetopause



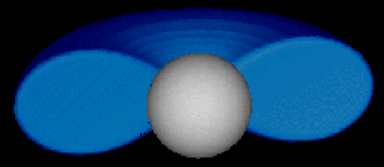
Observed and calculated positions of the magnetopause and the shock in the solar–equatorial plane. (After N. F. Ness *et al.*, *J. Geophys. Res.* **69**, 3531, 1964, copyright by the American Geophysical Union)

Structure of Earth's Magnetosphere



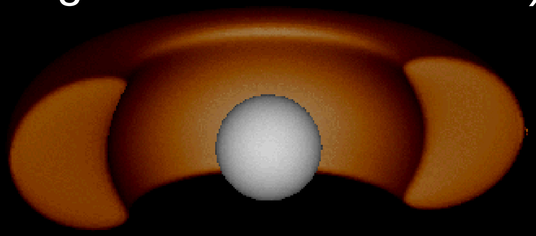
‘Energy-layered’ Geospace

Plasmasphere (~1 eV)



- High density (up to several thousands of #/cm^3)
- Cold plasma of ionospheric origin
- Contribution to Coulomb collision
- Control to plasma wave excitation and properties

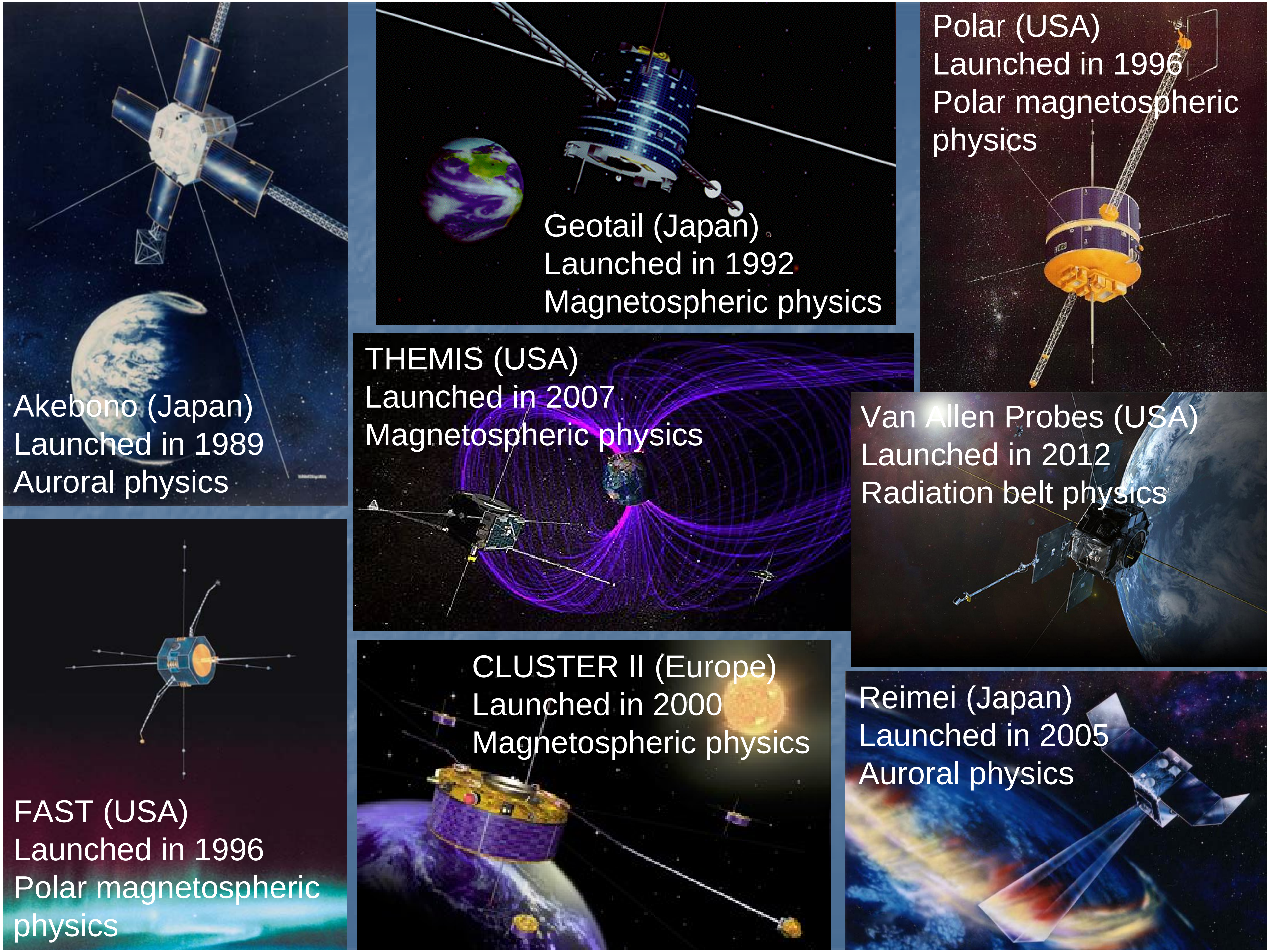
Ring current (~10^3-10^5 eV)



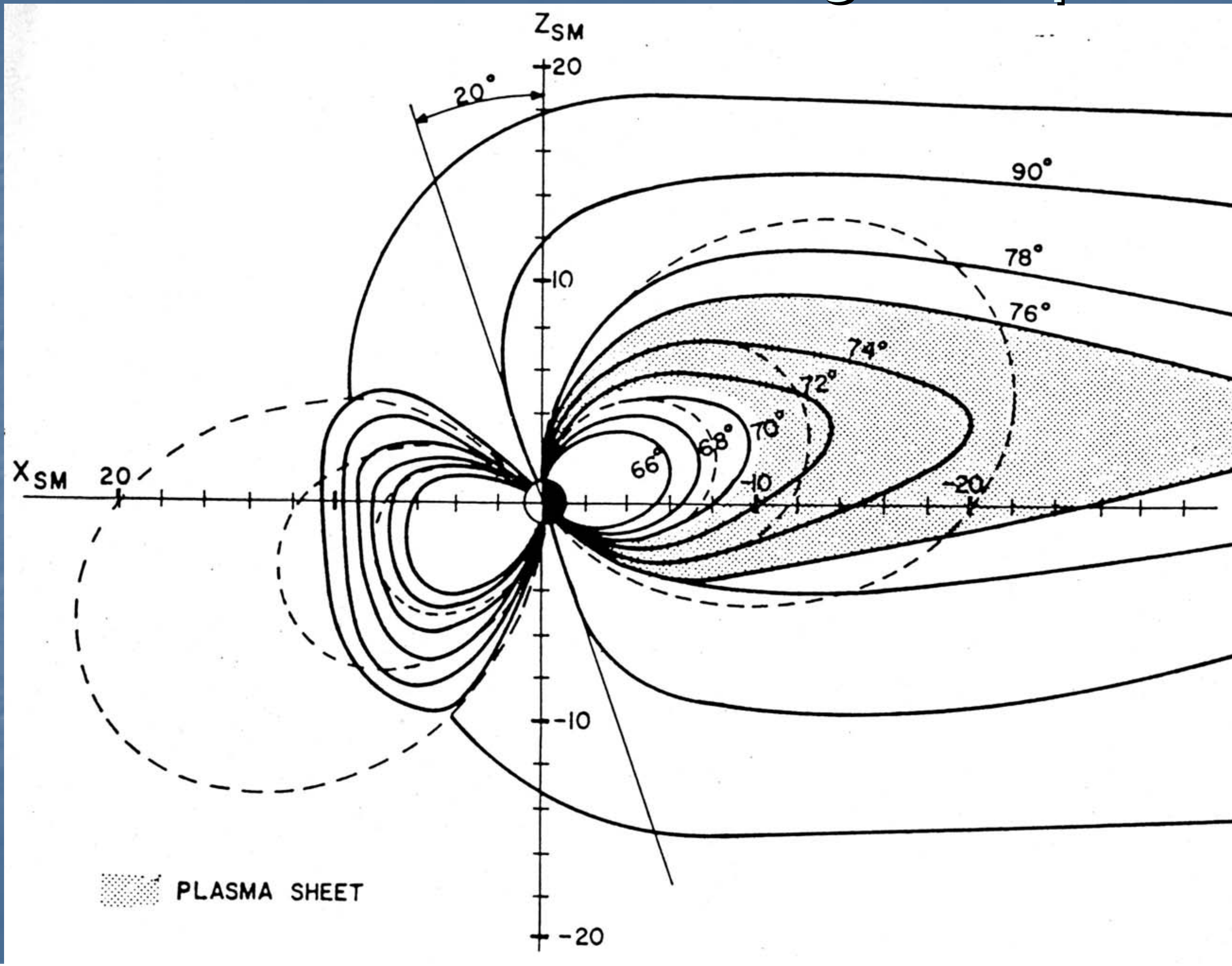
- Low density (less than 1 #/cm^3)
- Hot (energized) plasma of solar-wind or ionospheric origin
- Contribution to space electric current and magnetic field in the magnetosphere

Radiation belt (>10^5 eV)

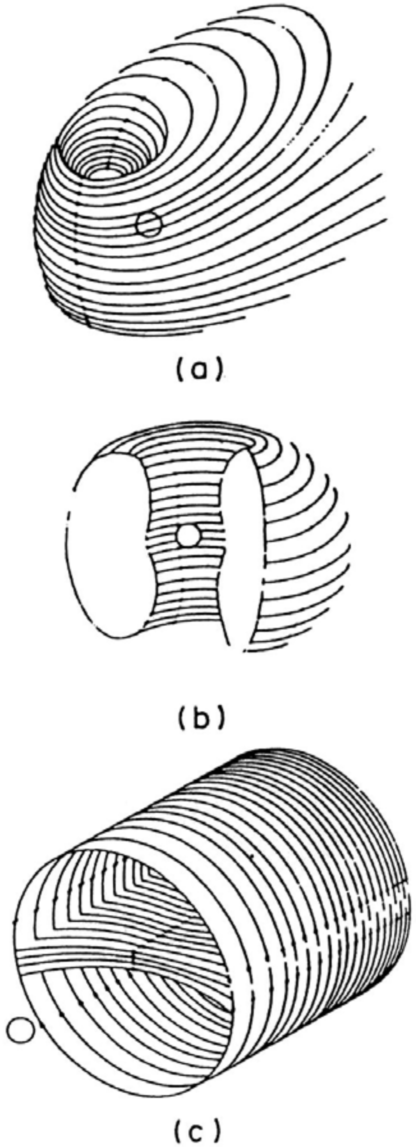
- Tenuous but highly accelerated particles (electrons) of solar-wind or ionospheric origin
- Negative impacts to space infrastructure due to electronics damages of spacecraft


Akebono (Japan)
Launched in 1989
Auroral physics
Geotail (Japan)
Launched in 1992
Magnetospheric physics
Polar (USA)
Launched in 1996
Polar magnetospheric physics
THEMIS (USA)
Launched in 2007
Magnetospheric physics
Van Allen Probes (USA)
Launched in 2012
Radiation belt physics
FAST (USA)
Launched in 1996
Polar magnetospheric physics
CLUSTER II (Europe)
Launched in 2000
Magnetospheric physics
Reimei (Japan)
Launched in 2005
Auroral physics

Section of Terrestrial Magnetosphere

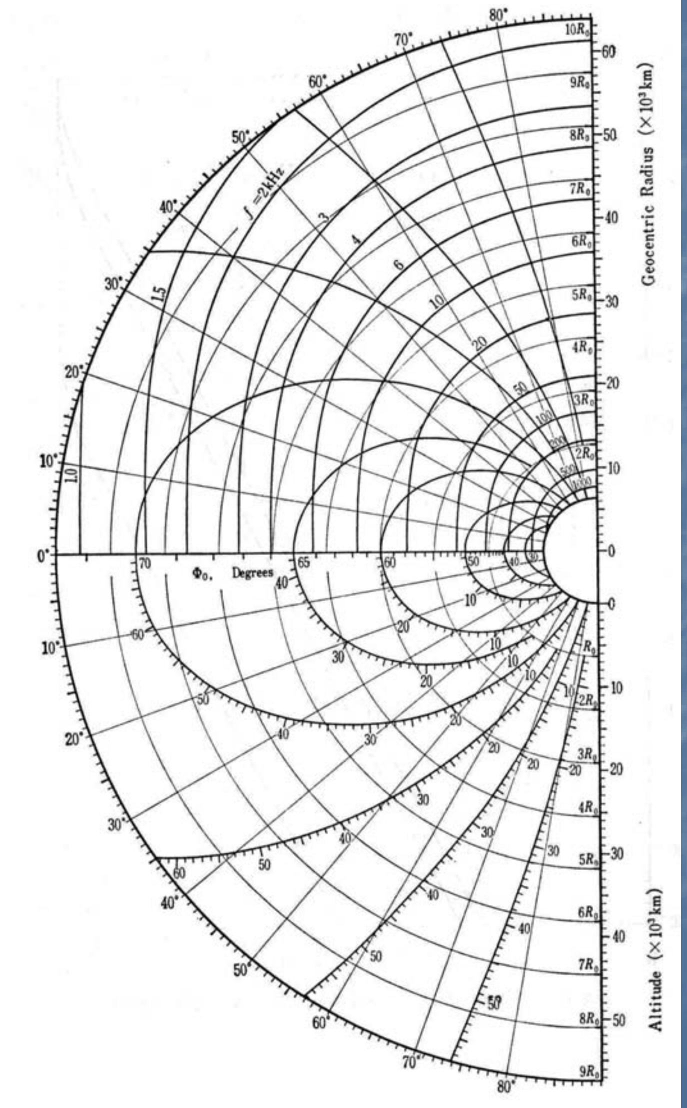


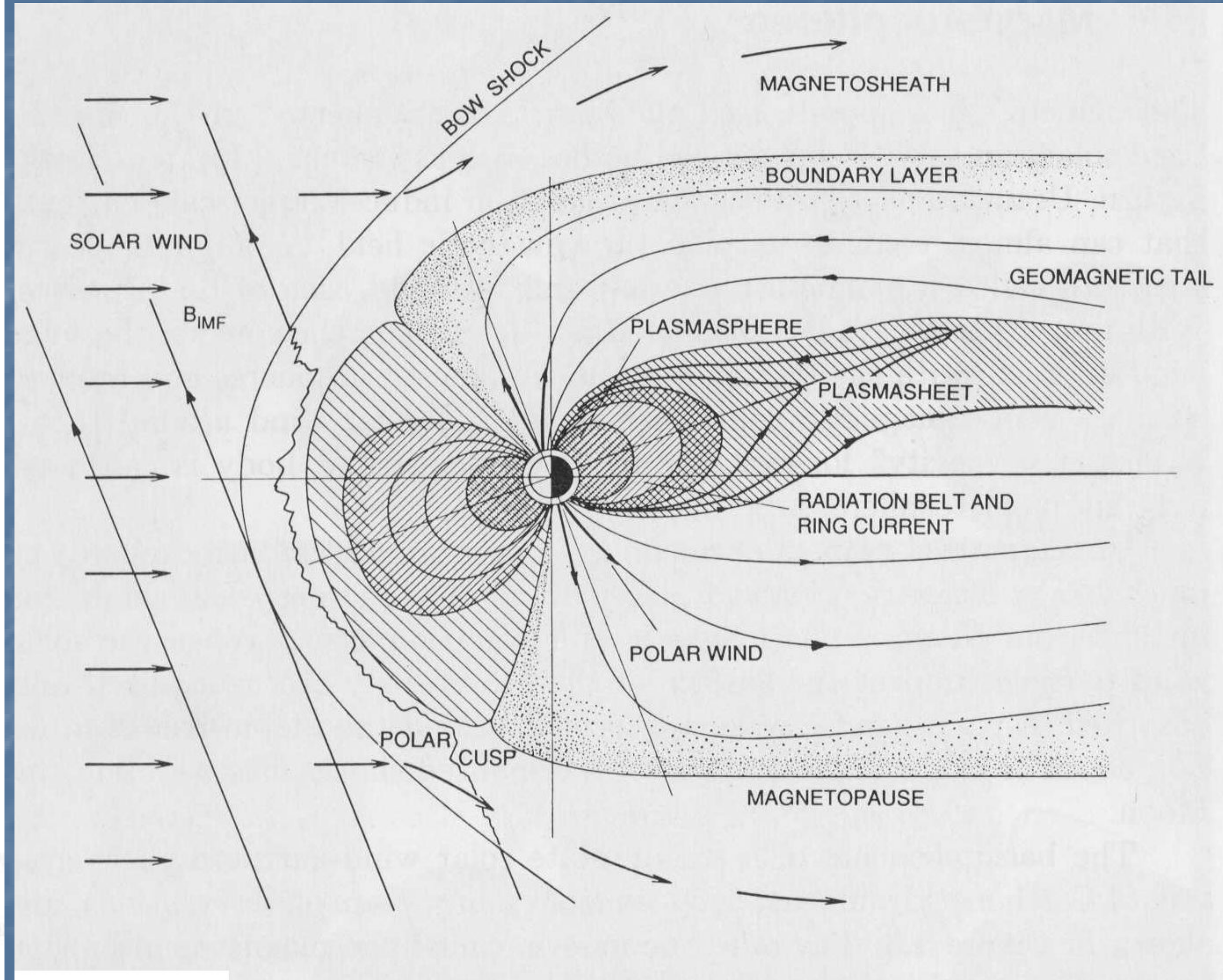
Space Electric Current Systems in the Magnetosphere



Magnetospheric current systems: (a) magnetopause (Chapman–Ferraro); (b) ring; (c) tail. (Reprinted with permission from W. P. Olsen, *Adv. Space Res.* **2**, 13, copyright (1982) Pergamon Press PLC)

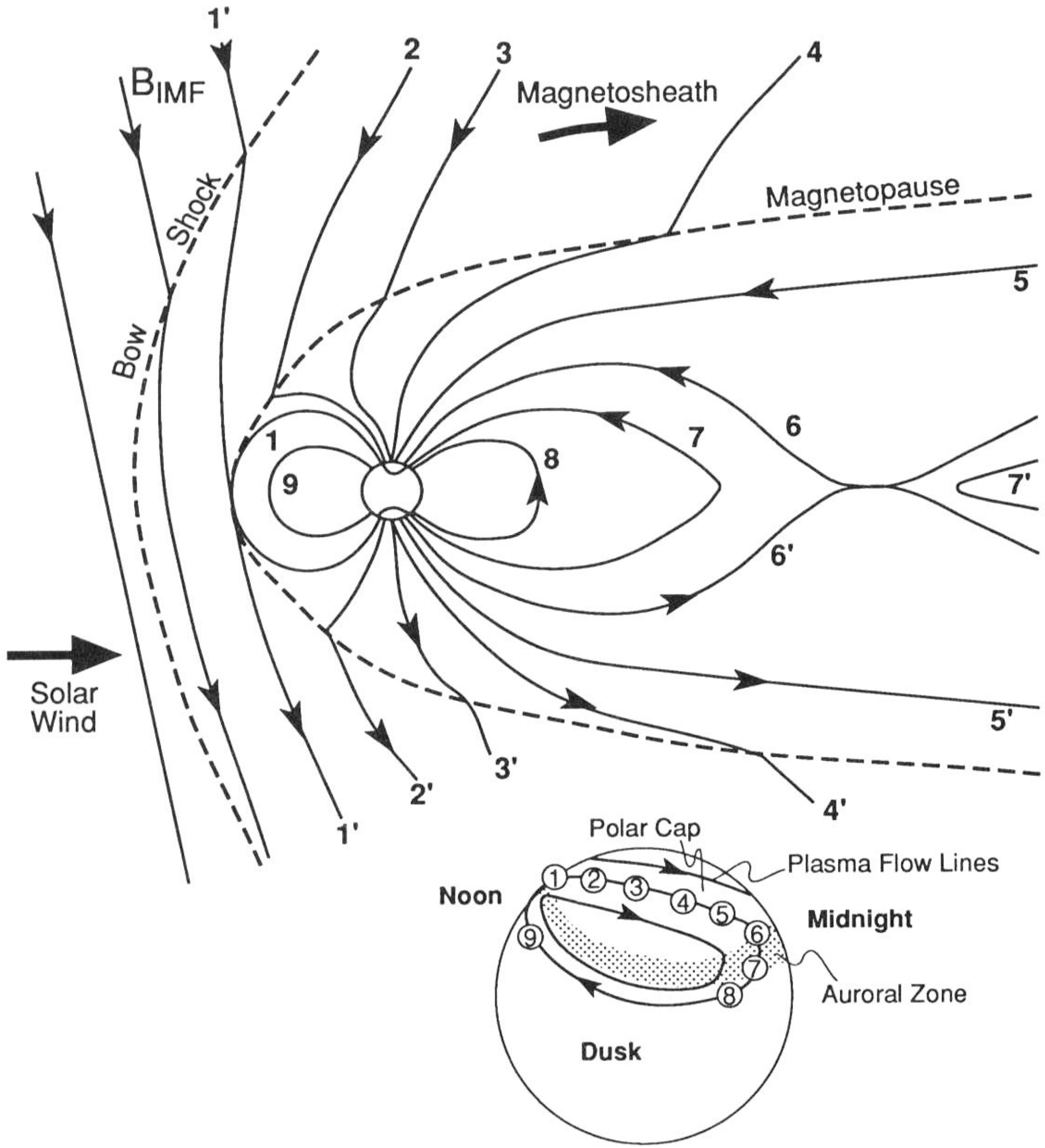
Intrinsic Geomagnetic Field and Structure of Actual Terrestrial Magnetosphere





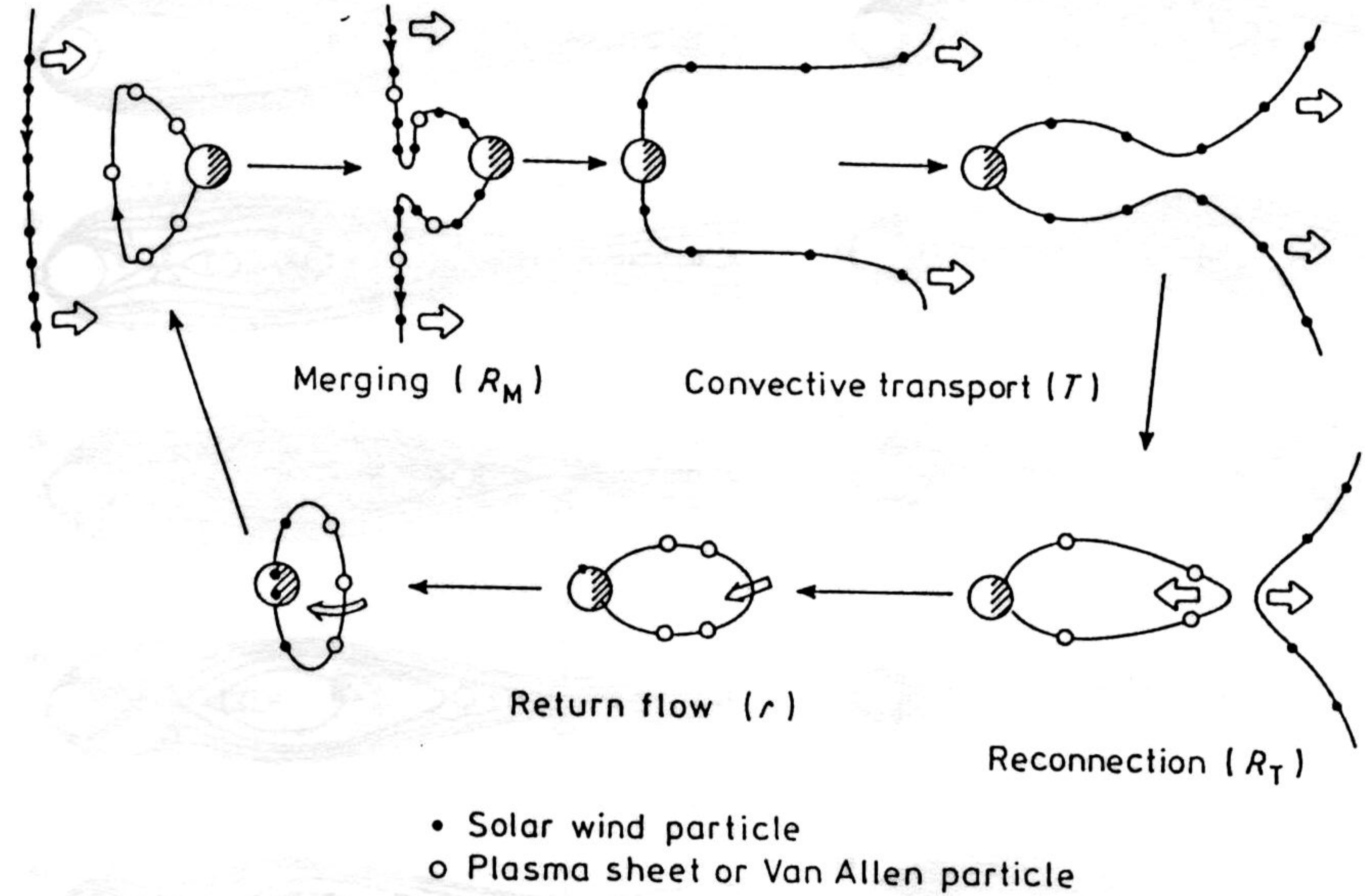
A schematic diagram of Earth's magnetosphere in the noon-midnight plane. The basic particle and magnetic field features are representative of other planetary magnetospheres although the details can be different.

Connection and Transport/Circulation of the Interplanetary Magnetic Field and Magnetospheric Field



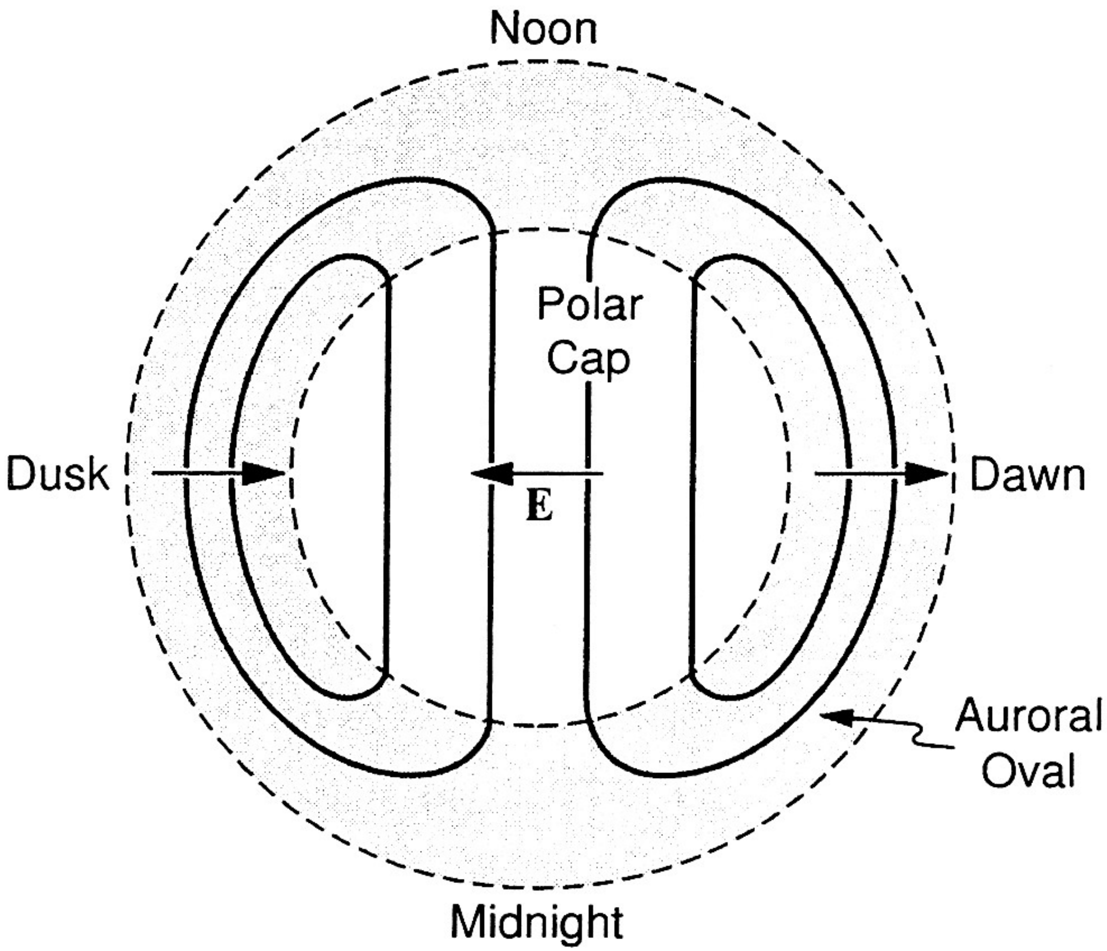
Flow of plasma within the magnetosphere (convection) driven by magnetic reconnection. The numbered field lines show the succession of configurations a geomagnetic field line assumes after reconnection with an IMF field line (1′) at the front of the magnetosphere. Field lines 6 and 6′ reconnect at a second *x*-line in the tail, after which the field line returns to the dayside at lower latitudes. The inset shows the positions of the feet of the numbered field lines in the northern high-latitude ionosphere and the corresponding high-latitude plasma flows, an antisunward flow in the polar cap, and a return flow at lower latitudes.

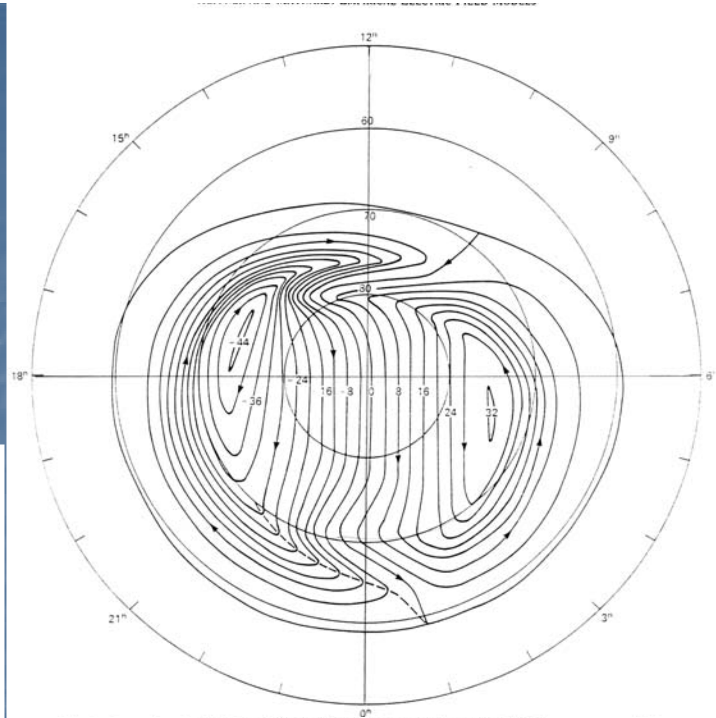
Sequence of Connection and Transport/Circulation of the Interplanetary Magnetic Field and Magnetospheric Field



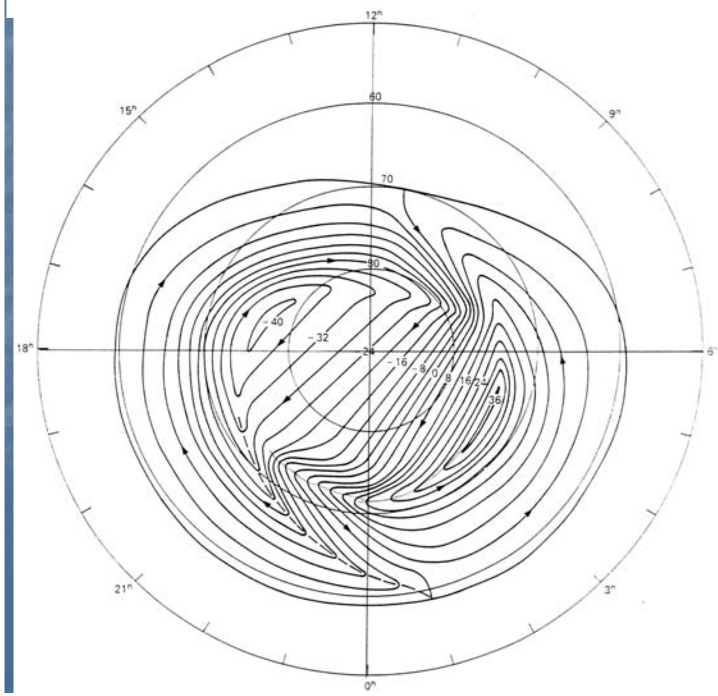
History of a selected field-line.

Plasma Convection in the Polar Ionosphere due to the Magnetic Field Line Circulation

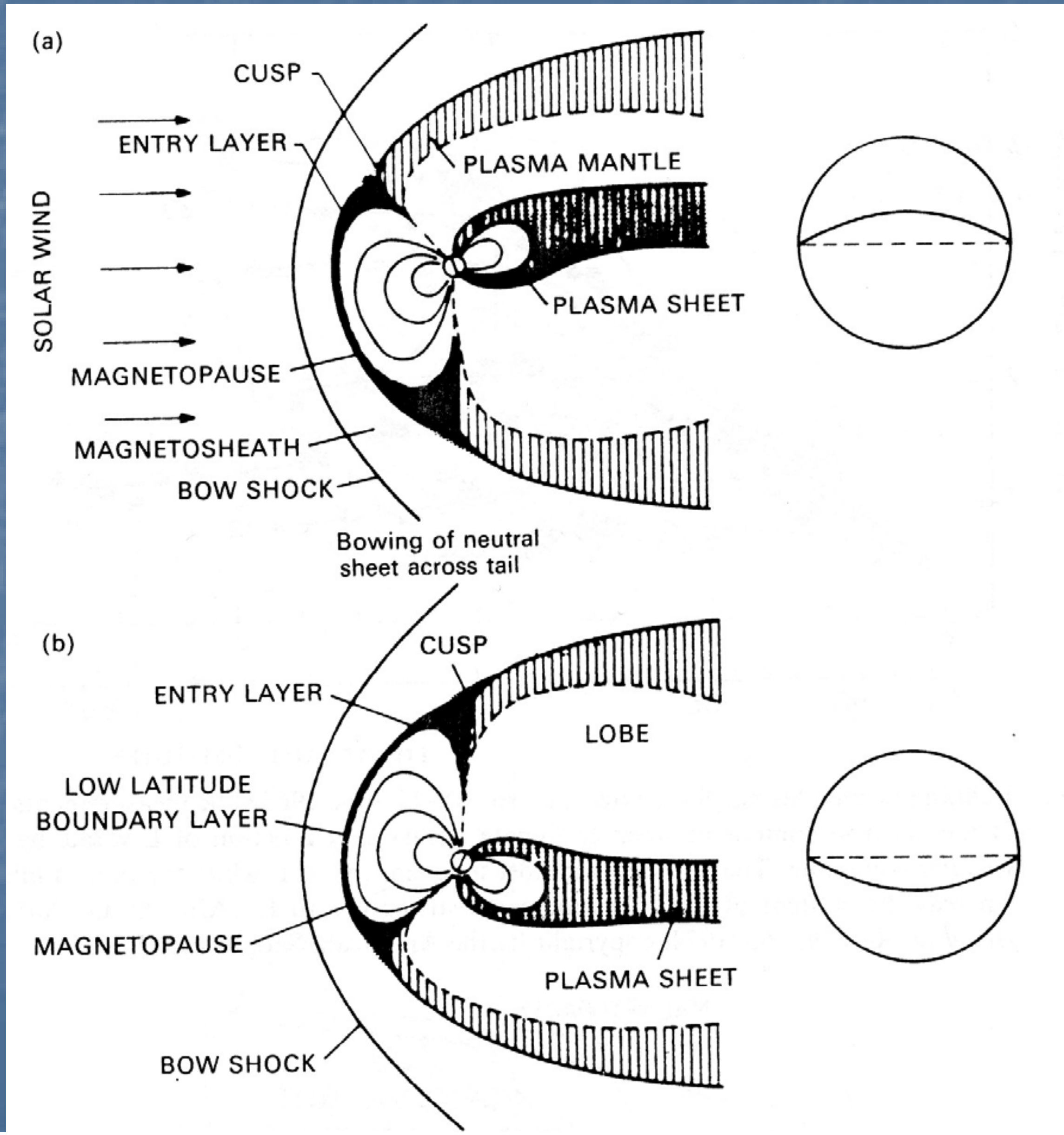




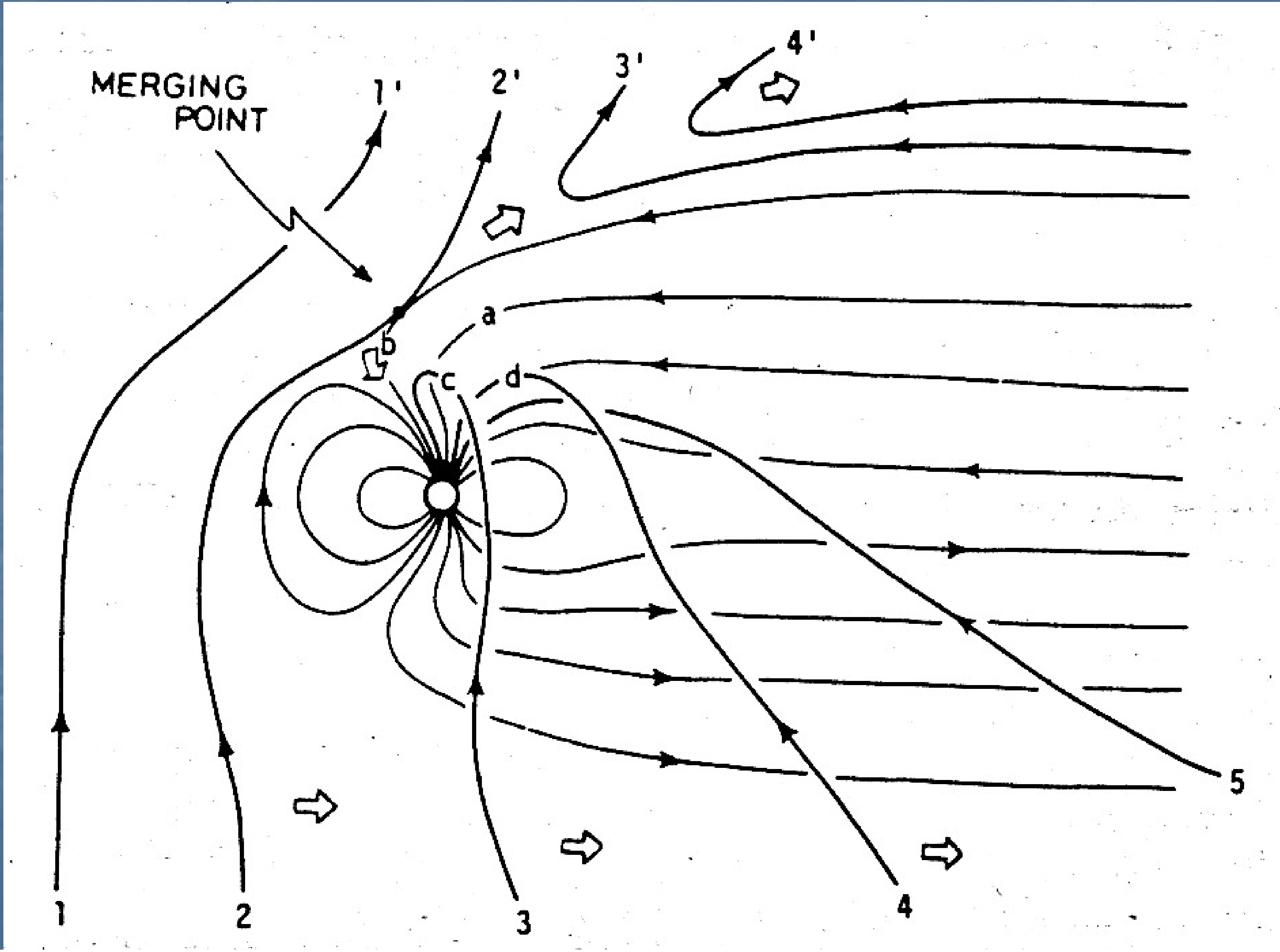
Heppner and Maynard: Empirical Electric Field Models



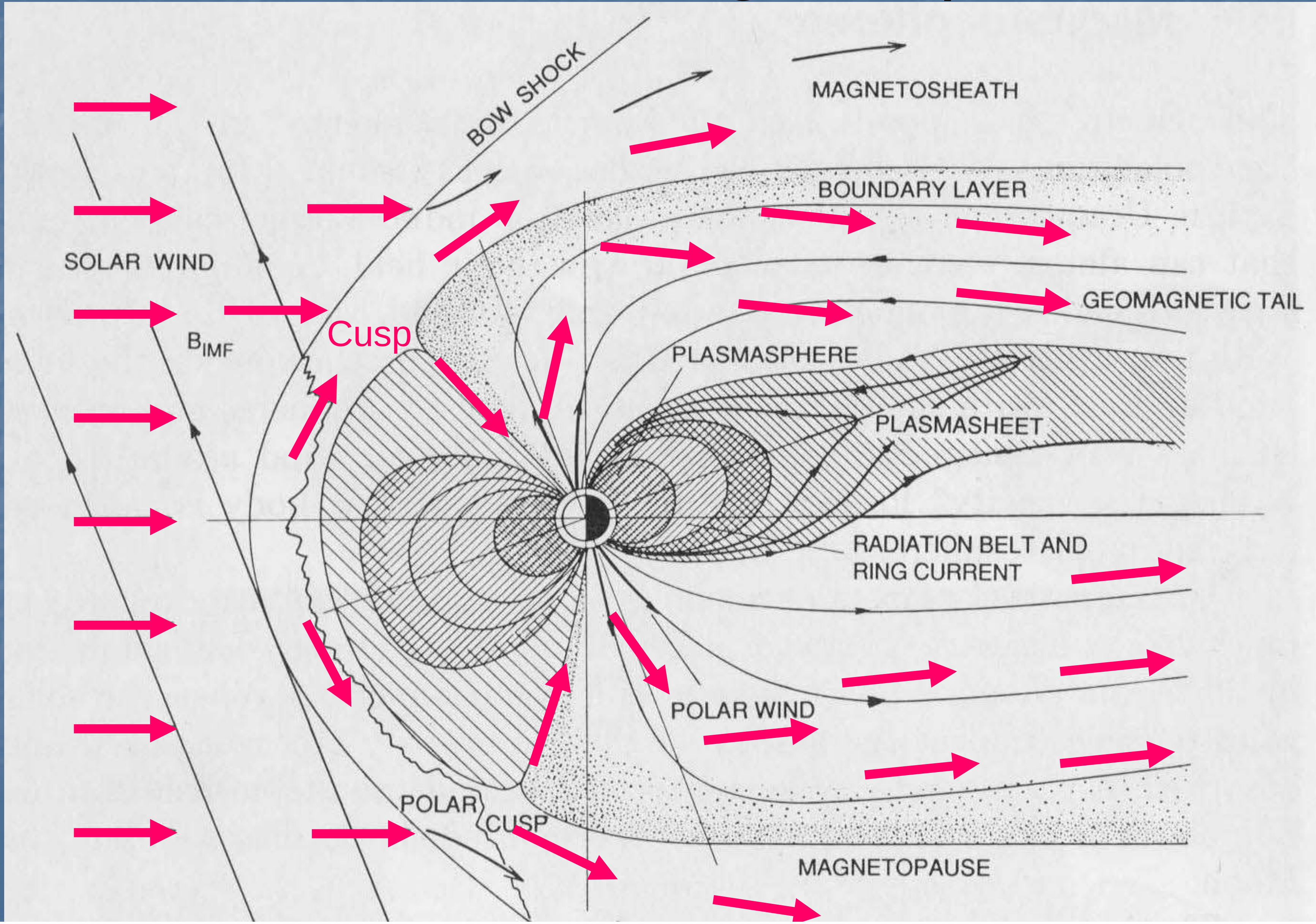
Large-scale Daily/Seasonal Variation of the Magnetospheric Structure



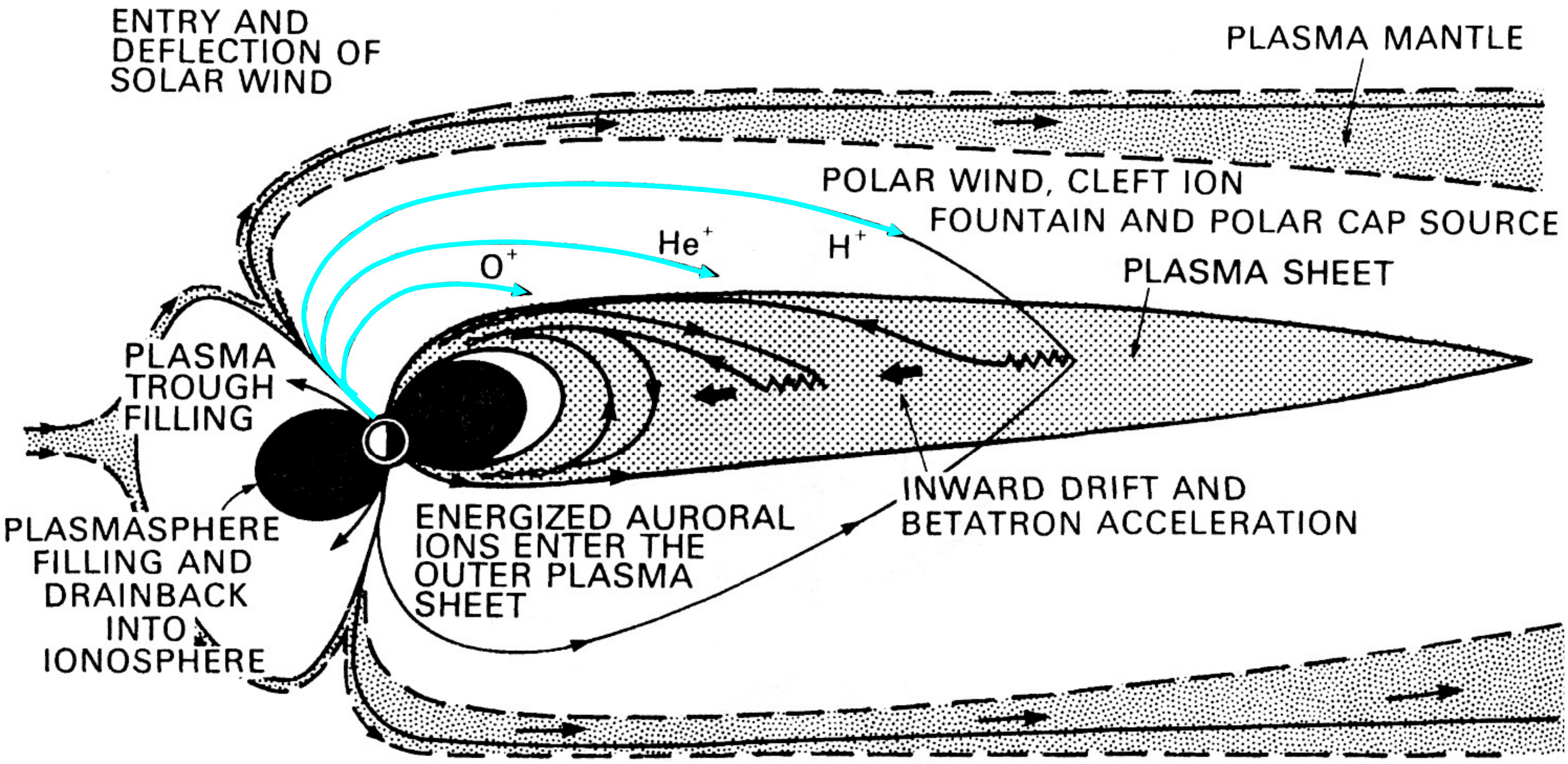
Reconnection for the Northward IMF



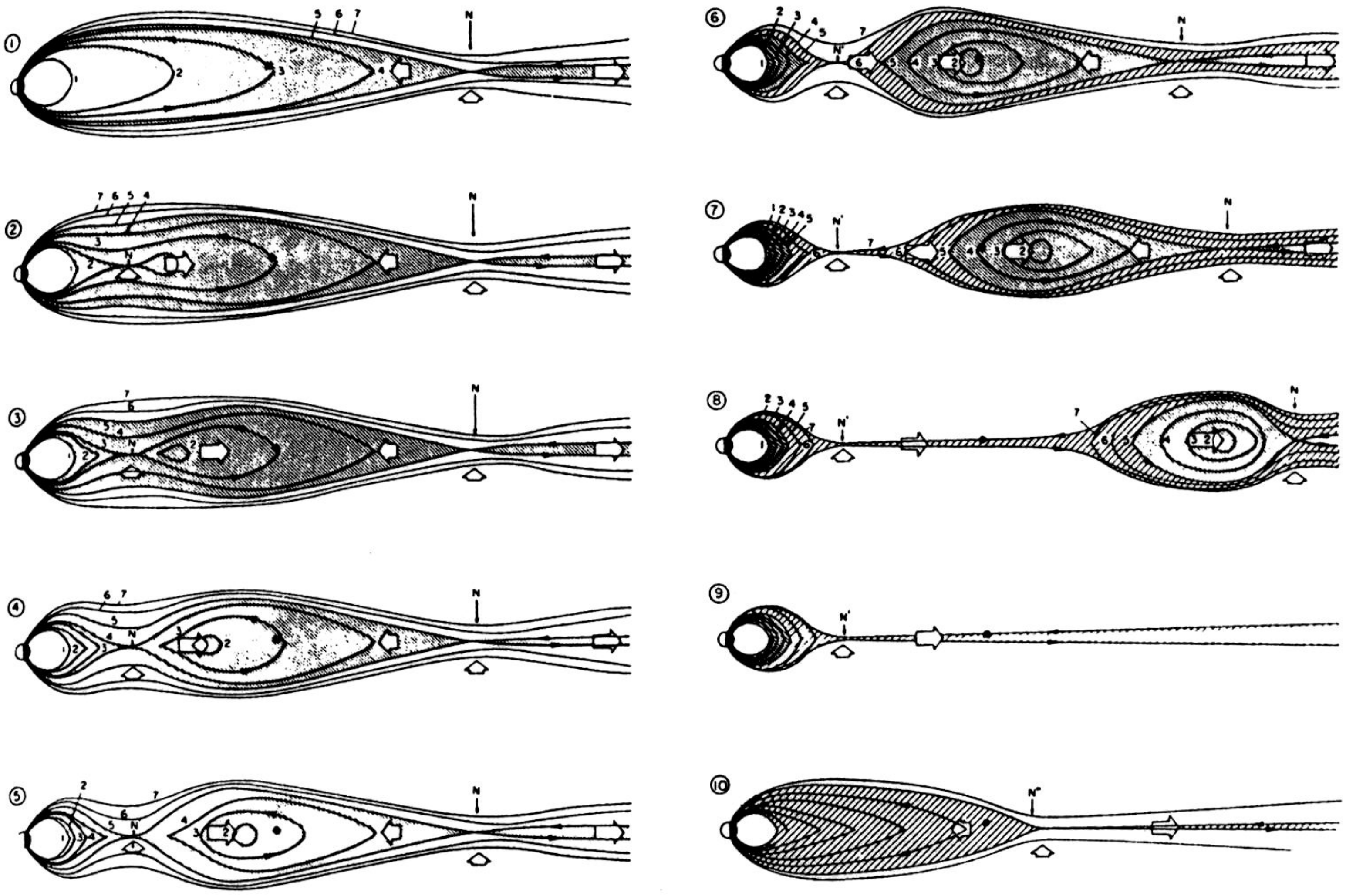
Solar Wind Entry and Transport in Terrestrial Magnetosphere



Ionospheric Plasma Escape to and Transport in Terrestrial Magnetosphere



Development of Plasmoid during Substrom



Sequence of events in the magnetotail during a substorm. White arrows indicate plasma flows. The plasma sheet is bounded by field-line 5. N′ is the second neutral line that forms in the substorm, and picture 8 shows the plasmoid being expelled down the tail. (E. W. Hones, in *Magnetic Reconnection* (ed. Hones). A.G.U. Monograph 30, 1984)

Typical Types of Charged Particle Motions in the Geomagnetic Field