

课程大纲

- 绪论
- 等离子体的概念和基本性质
- 单粒子轨道理论
- 磁流体力学（MHD）
- 等离子体波和不稳定性
- 太阳大气和太阳活动
- 太阳风
- 磁层物理

第三章

Charged Particle Motion

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带电粒子在均匀电磁场中的运动

● 带点粒子在均匀恒定磁场中的运动

如果 $\mathbf{B} = B\mathbf{e}_z$, 则有

$$v_x = v_{\perp} \cos(\Omega t + \alpha)$$

$$v_y = -v_{\perp} \sin(\Omega t + \alpha)$$

● 均匀恒定电磁场中的电漂移

$$\mathbf{v}_E = \frac{\mathbf{E} \times \mathbf{B}}{B^2}$$

● 重力漂移

$$\mathbf{v}_E = \frac{m\mathbf{g} \times \mathbf{B}}{qB^2}$$

带电粒子在变化磁场中的运动

● 梯度漂移

$$\mathbf{v}_{\nabla B} = \frac{W_{\perp}}{qB^3} \mathbf{B} \times \nabla B = \frac{W_{\perp}}{qB^2 R^2} \mathbf{R} \times \mathbf{B}$$

● 曲率漂移

$$\mathbf{v}_{DBC} = \frac{2W_{\parallel}}{qB^2 R^2} \mathbf{R} \times \mathbf{B} = \frac{2W_{\parallel}}{qB^2} \mathbf{B} \times \left(\frac{\mathbf{B}}{B} \cdot \nabla \right) \frac{\mathbf{B}}{B}$$

$$\mathbf{v}_{DB} = \mathbf{v}_{\nabla B} + \mathbf{v}_{DBC} = \frac{(2W_{\parallel} + W_{\perp})}{q} \frac{\mathbf{R} \times \mathbf{B}}{B^2 R^2}$$

绝热不变量

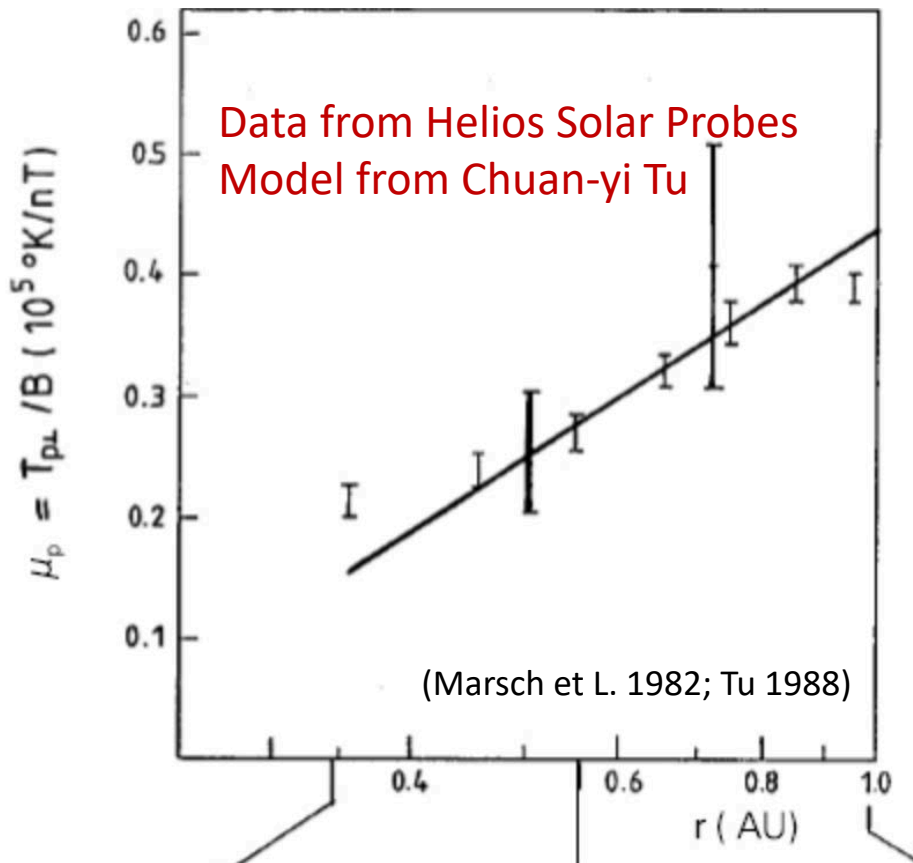
- 磁矩不变量和磁镜



- 纵向不变量和费米加速



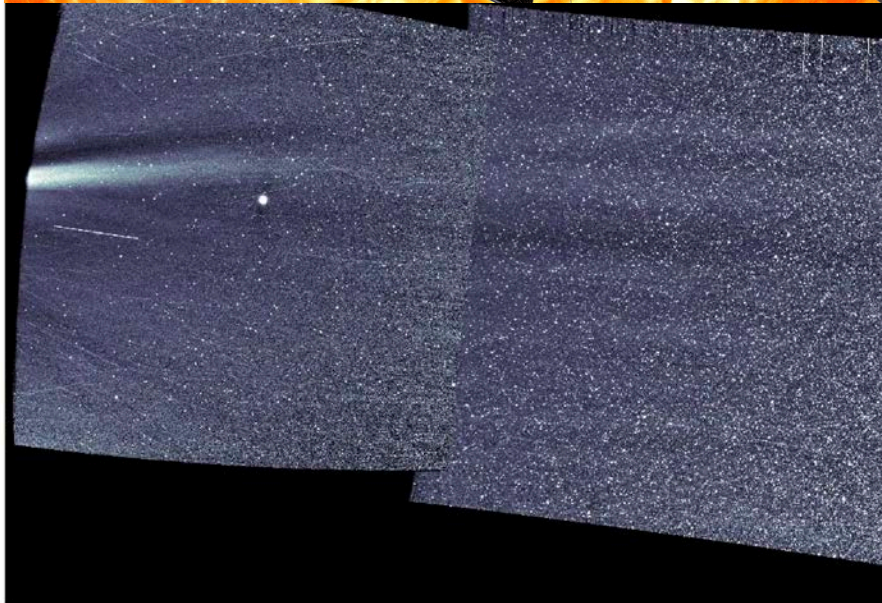
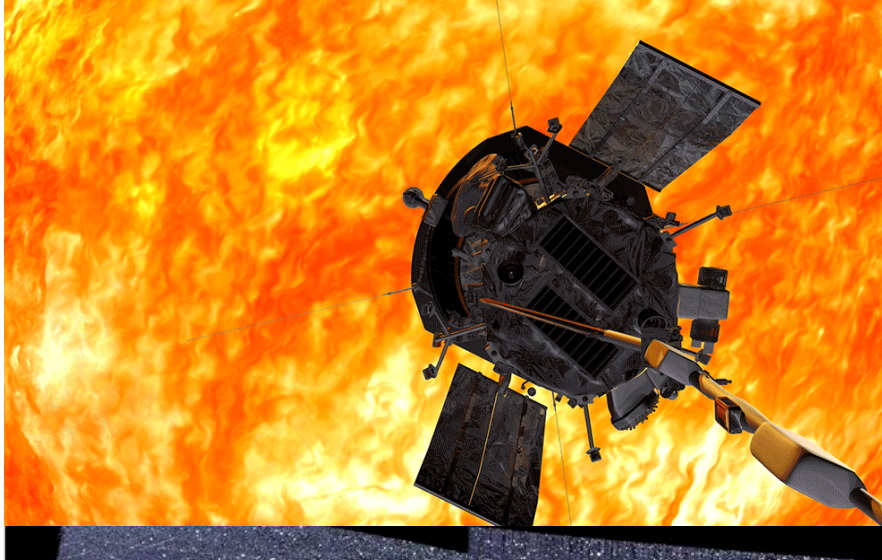
太阳风中质子磁矩不守恒



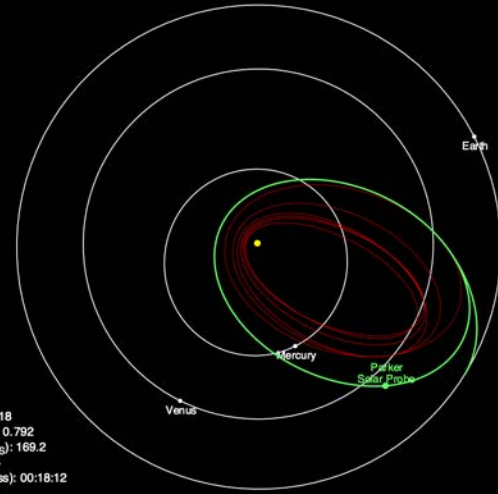
Eckart Marsch (born 1 February 1947 in Friedrichstadt) is a **German theoretical physicist**, who worked from 1980 to 2012 at the originally named Max Planck Institute for Aeronomy, from 2004 on named Max Planck Institute for Solar System Research (MPS) in Lindau on the physics of the solar wind, solar corona and space plasmas and taught at the University of Göttingen, **received 2018 Hannes Alfvén Medal**.

Q: 磁矩不守恒说明了什么？

Parker Solar Probe 太阳风加热

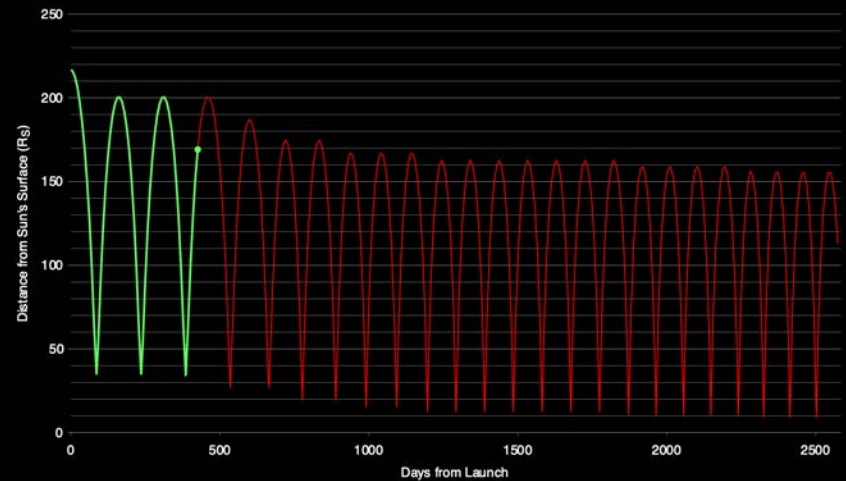


Parker Solar Probe Mission Trajectory and Current Position

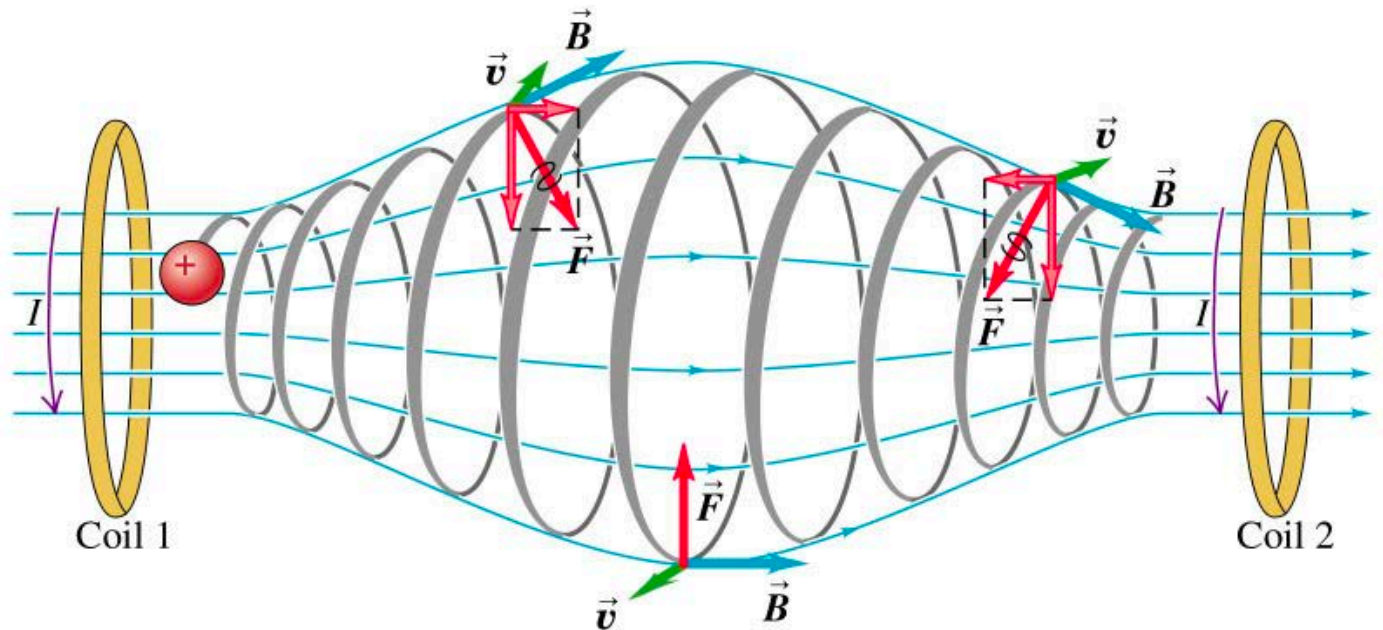


Heliocentric Velocity (km/s): 25.18
Distance from Sun Center (AU): 0.792
Distance from Sun's Surface ($R_{\odot}$): 169.2
Distance from Earth (AU): 1.094
Round-Trip Light Time (hh:mm:ss): 00:18:12
12 Oct 2019 02:00:00 UTC

Parker Solar Probe Distance from Sun

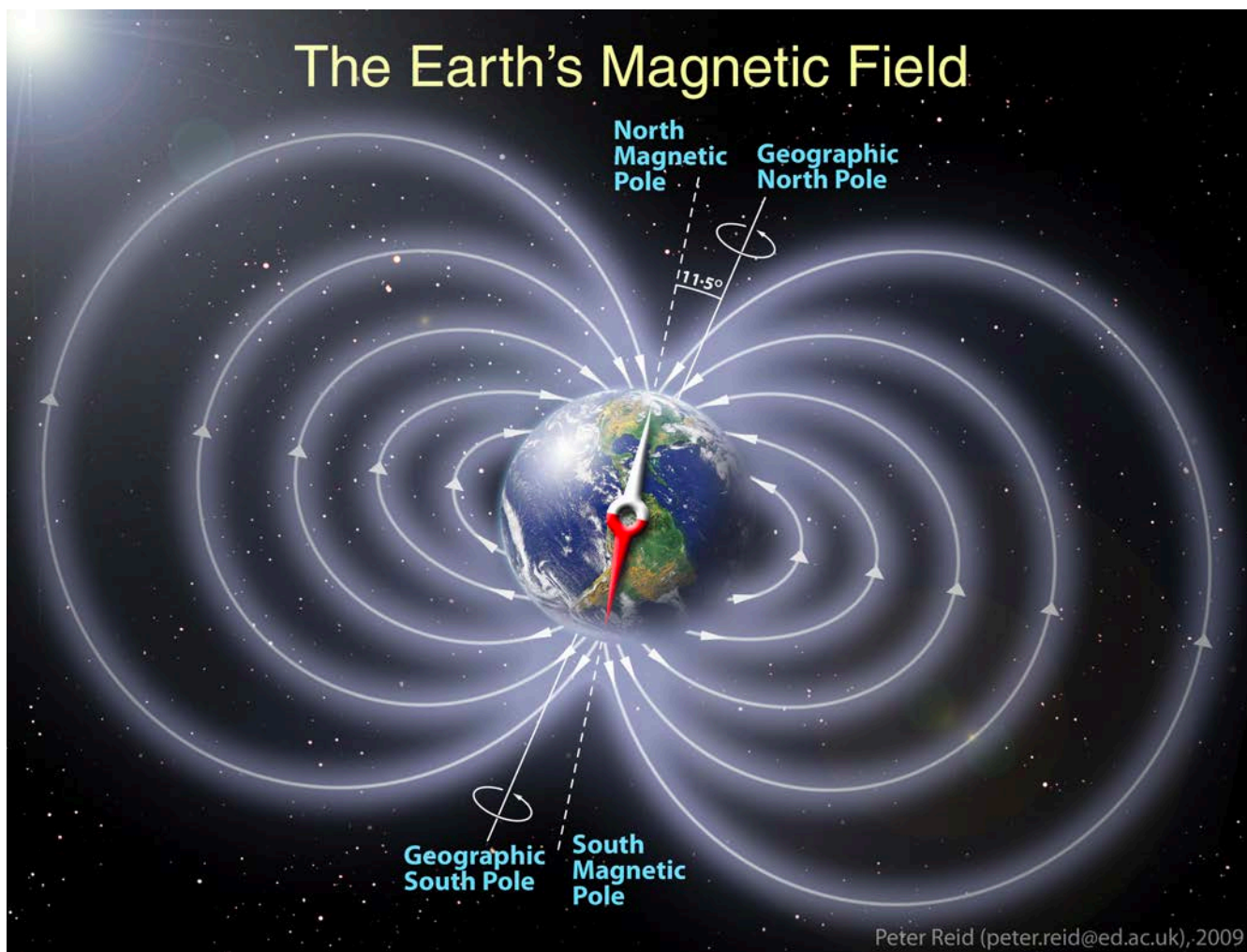


Magnetic Mirror

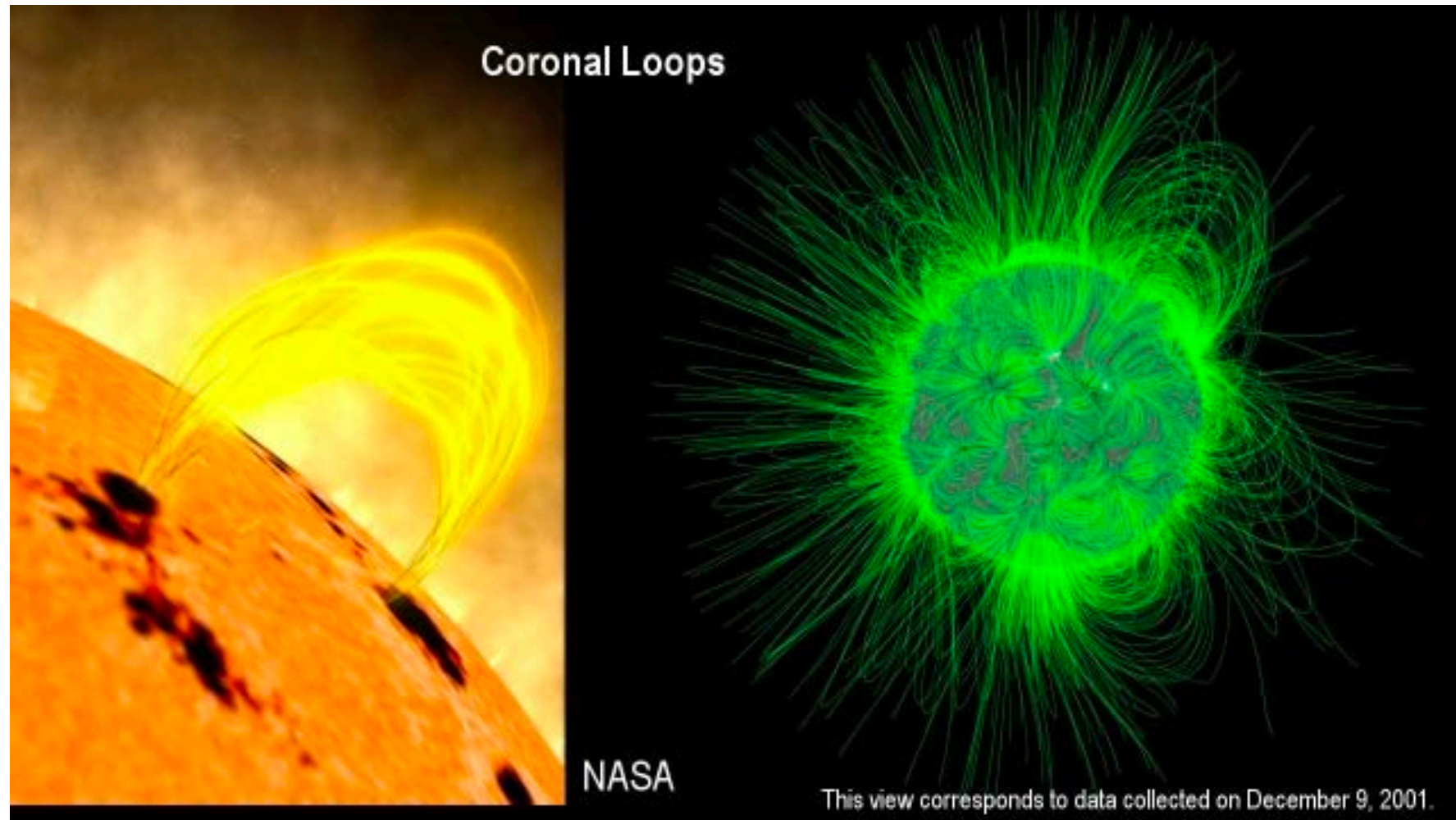


Q: 在磁镜中心放置热平衡状态的等离子体，是否所有粒子都被约束在磁镜中？

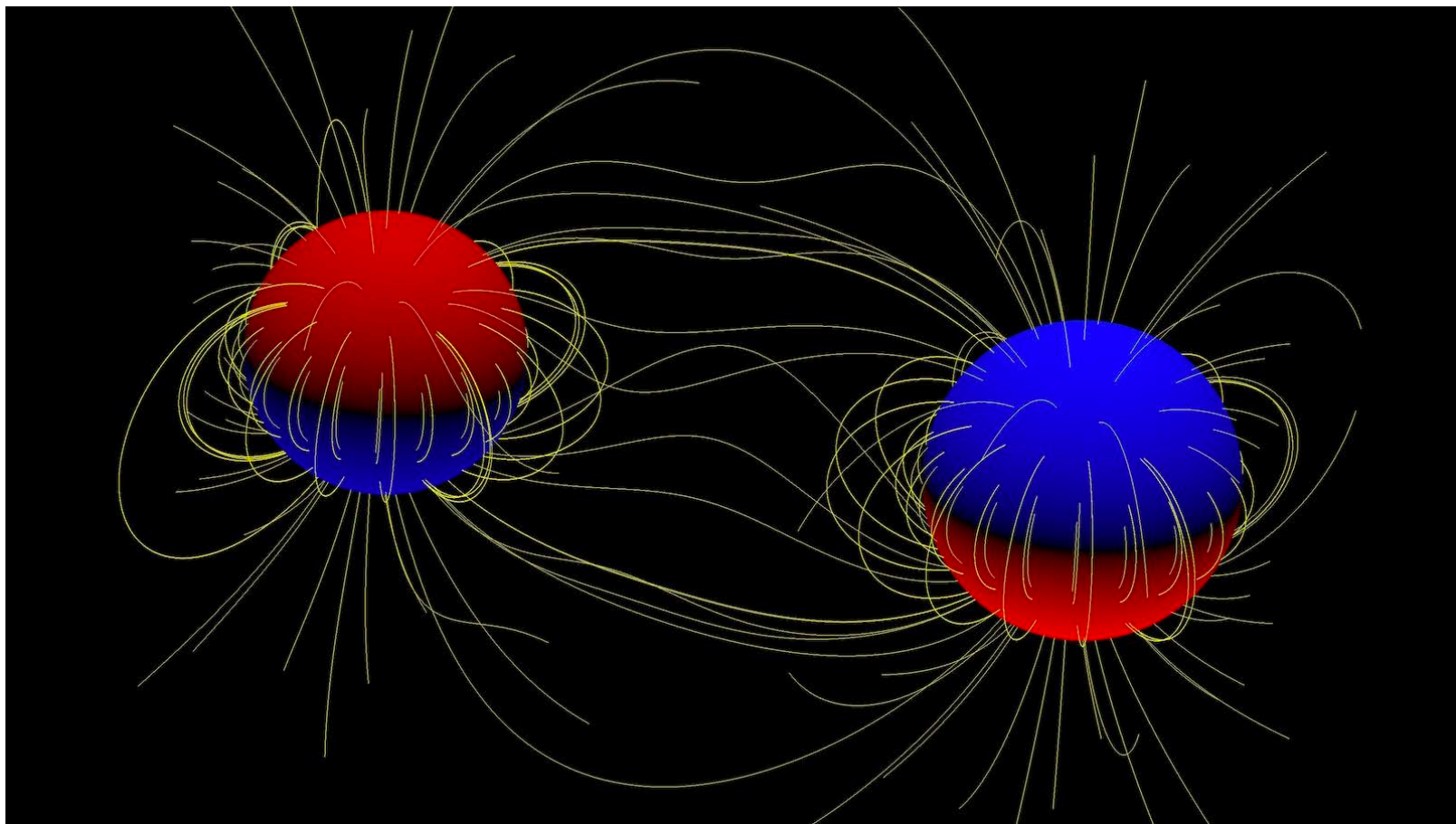
磁镜的例子：地磁场



磁镜的例子：冕环



磁镜的例子：双磁星系统



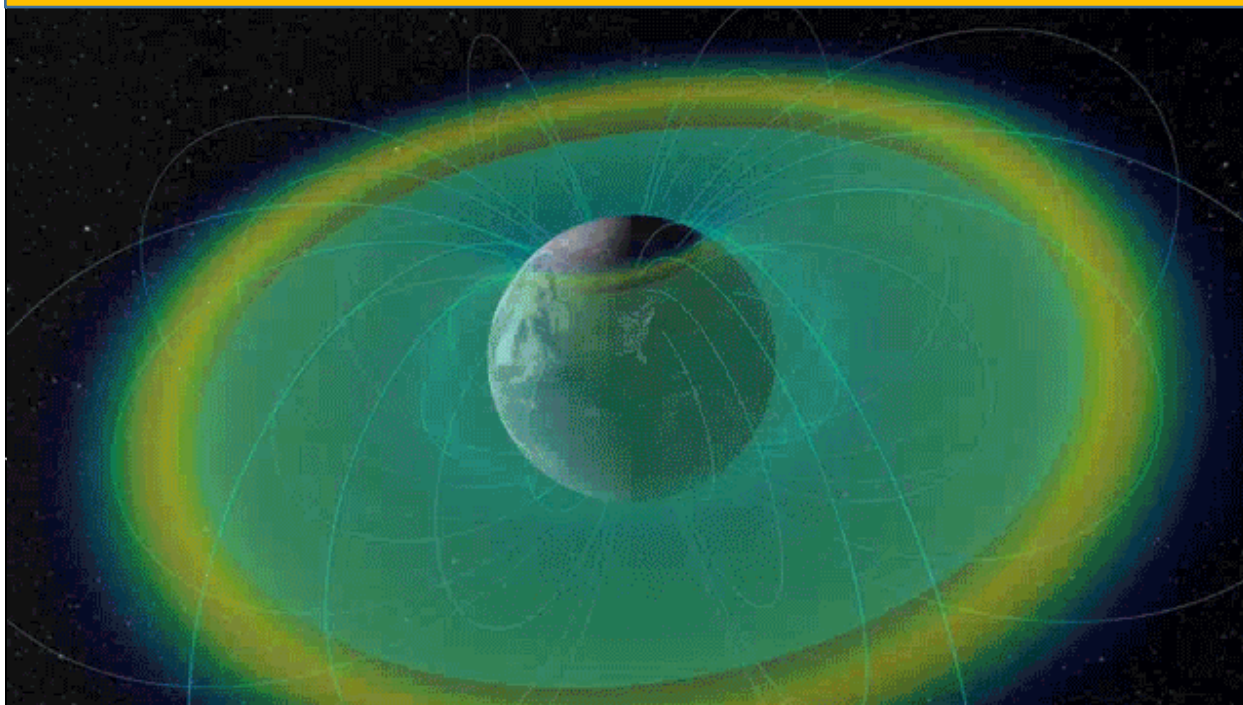
地磁场中带电粒子的运动

周期运动

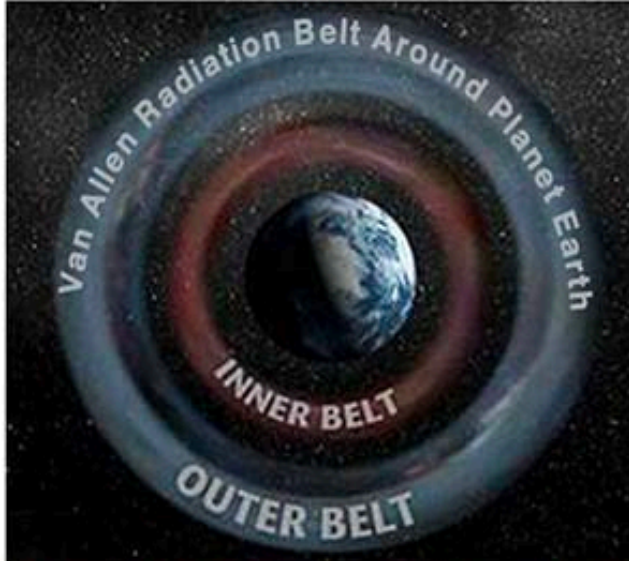
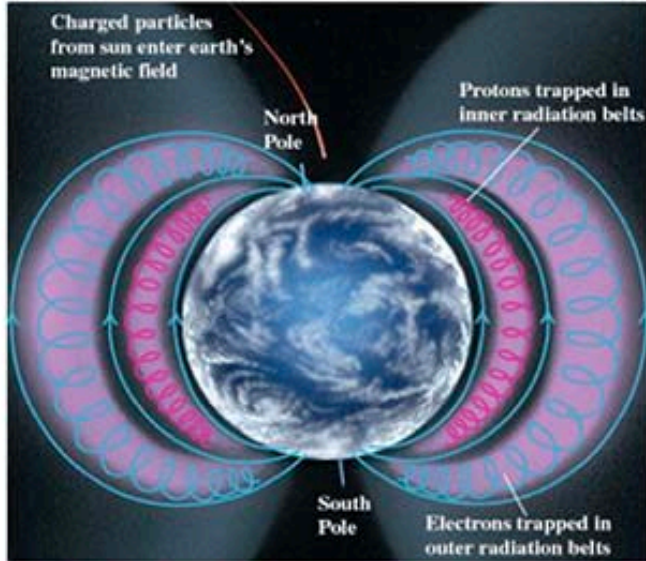
缓变条件

周期

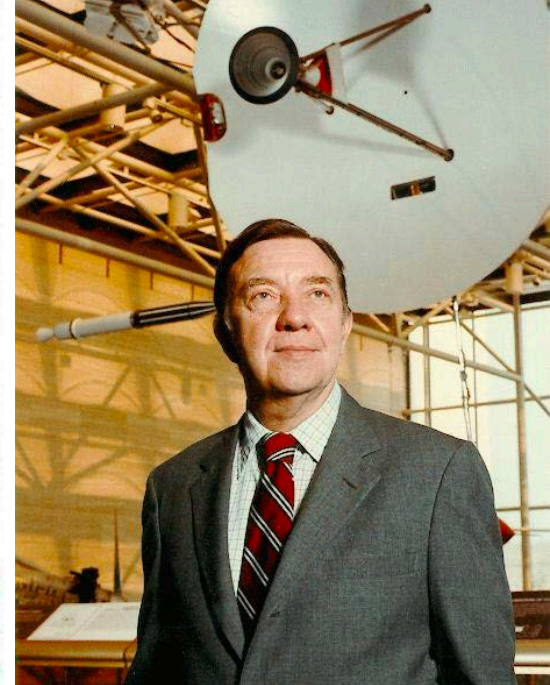
Q: 带电粒子在磁层中都有几种周期运动？



Van Allen 辐射带



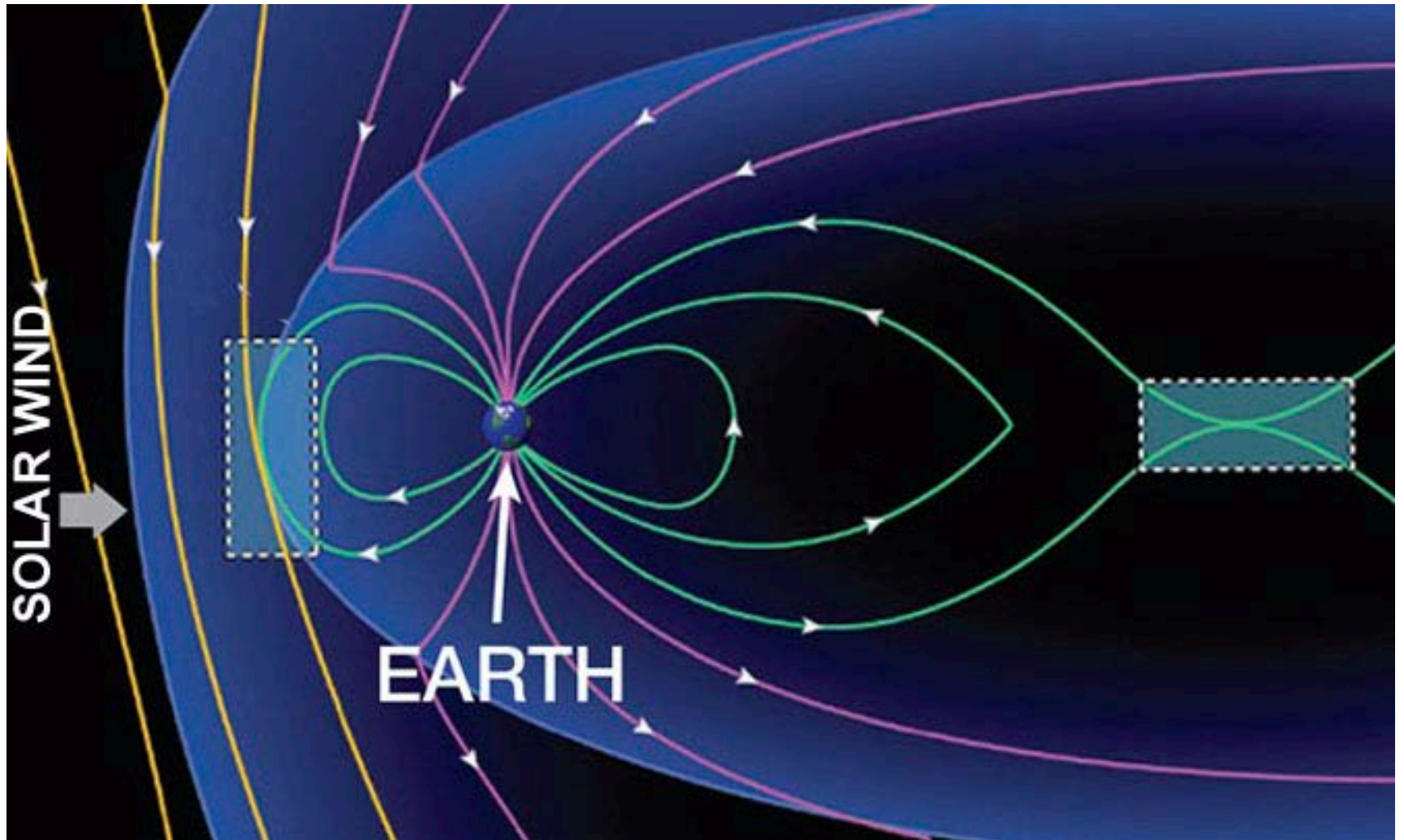
Van Allen Radiation Belt is a large outer radiation belt around planet Earth, generated by the highly charged solar radioactive particles and plasma released from the upper atmosphere of our star, the Sun. Extending from an altitude of about 13,000 to 60,000 kilometers, or 8,100 to 37,300 miles above and all around planet Earth's surface. No living creature from Earth using 1960's primitive, or even today's technologies could possibly get through the belt and survive. This highly charged radioactive emission of ionizing radiation or particles would vaporize any living creature traveling through it. In order to get to the moon over 221,567 miles, or 374,448 kilometers from planet Earth. Apollo astronauts had to pass through Van Allen Radiation Belt and would have been vaporized instantly!



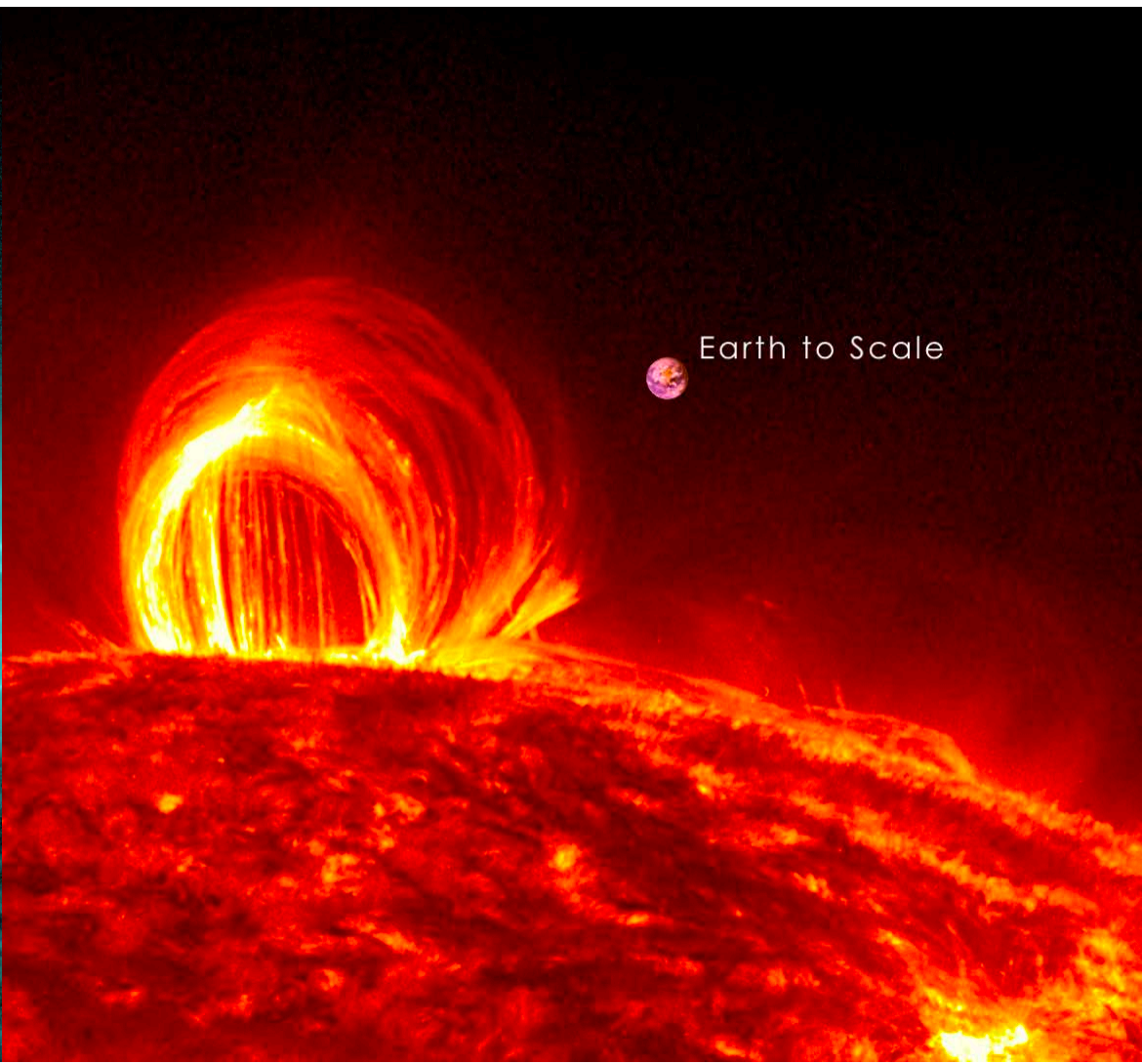
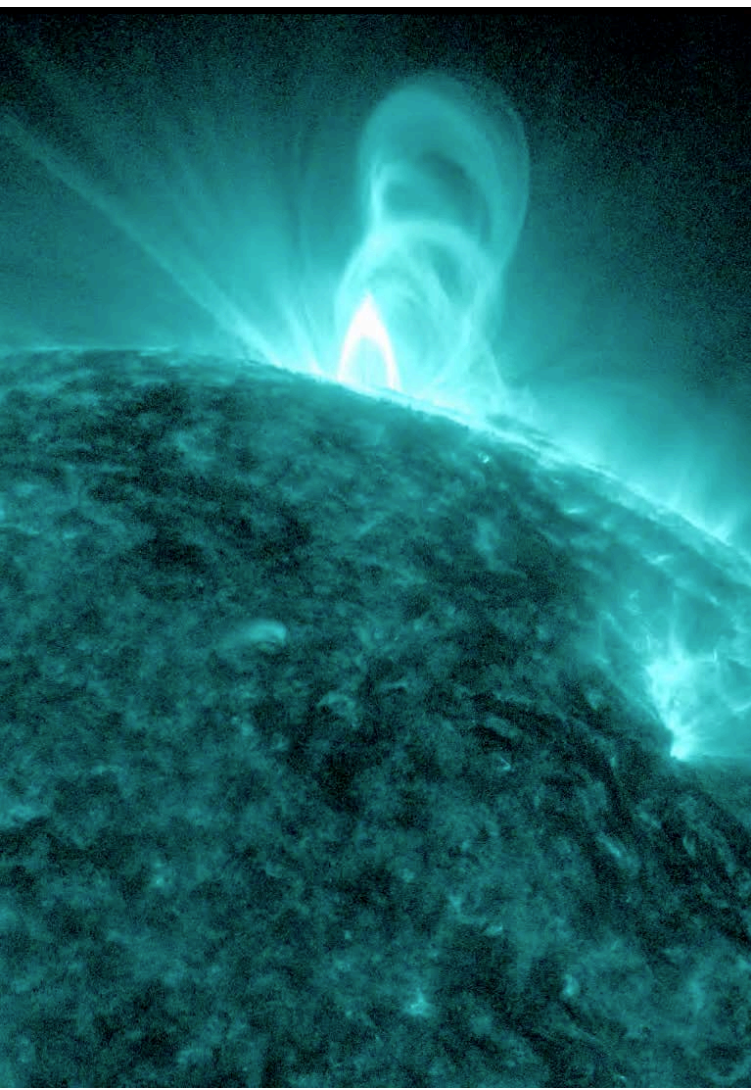
**James Van Allen
(1914--2006)**

Q: Van Allen辐射带为何是规则的？

Fermi 加速机制 —磁尾



Fermi 加速机制 —耀斑环



"observe" magnetic reconnection
in a standard flare configuration

magnetic
reconnection

flare
loops

flare ribbons

(adapted from Forbes & Acton, 1996)

