Origin of the twin reverse convection cells for northward interplanetary magnetic field periods

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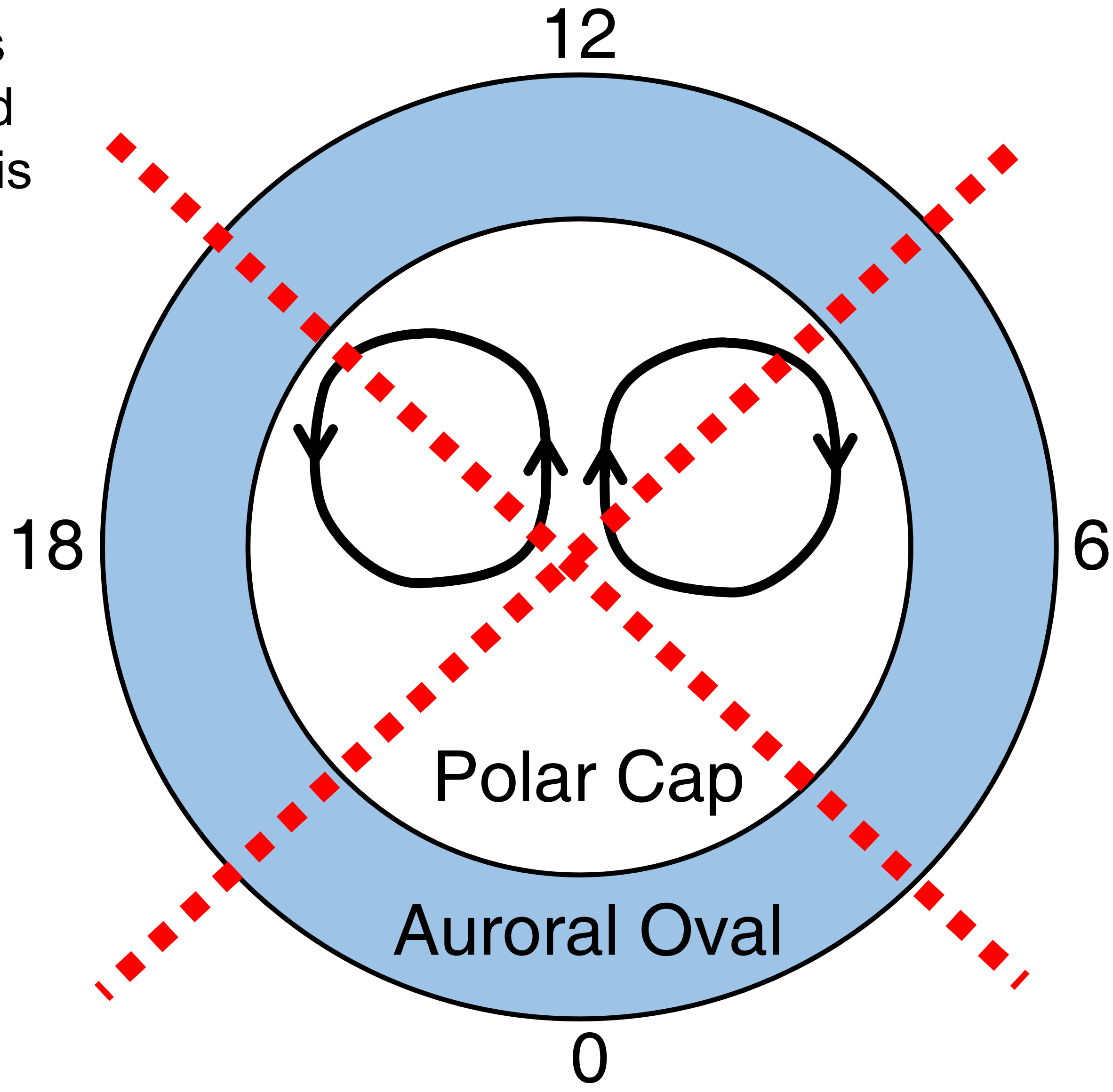
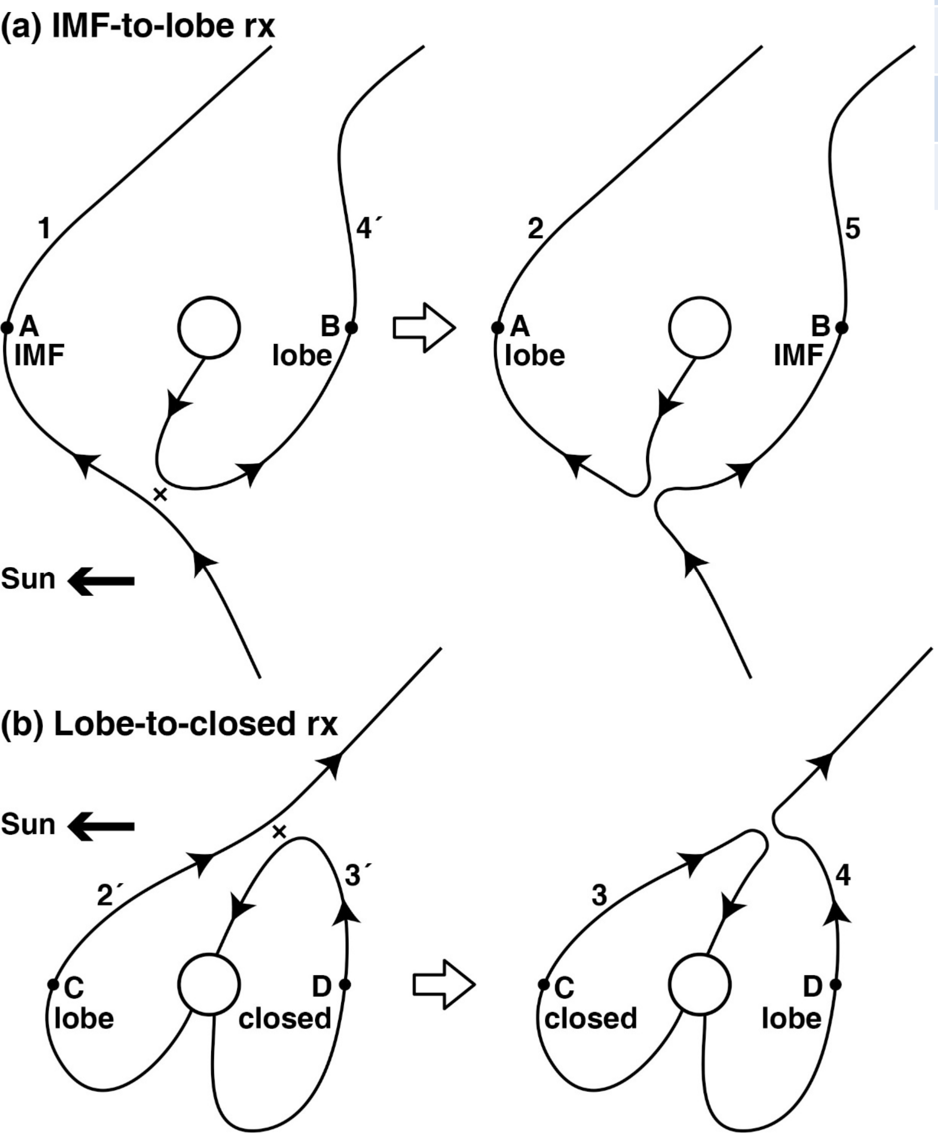
Conventionally, the twin reverse cells for northward IMF have been interpreted as the lobe cells circulating in the open field line region. However, this interpretation is not necessarily correct.

The interchange cycle can produce a reverse cell circulating in the closed field line region (the reciprocal cell).

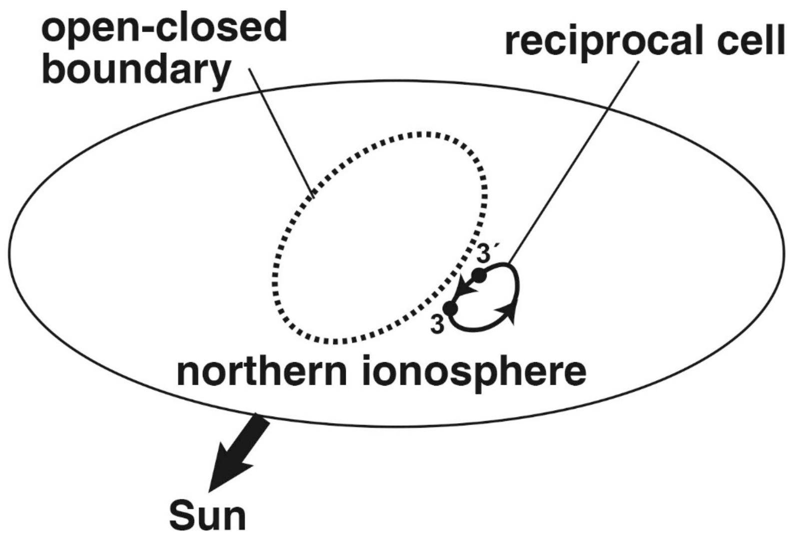


Interchange cycle

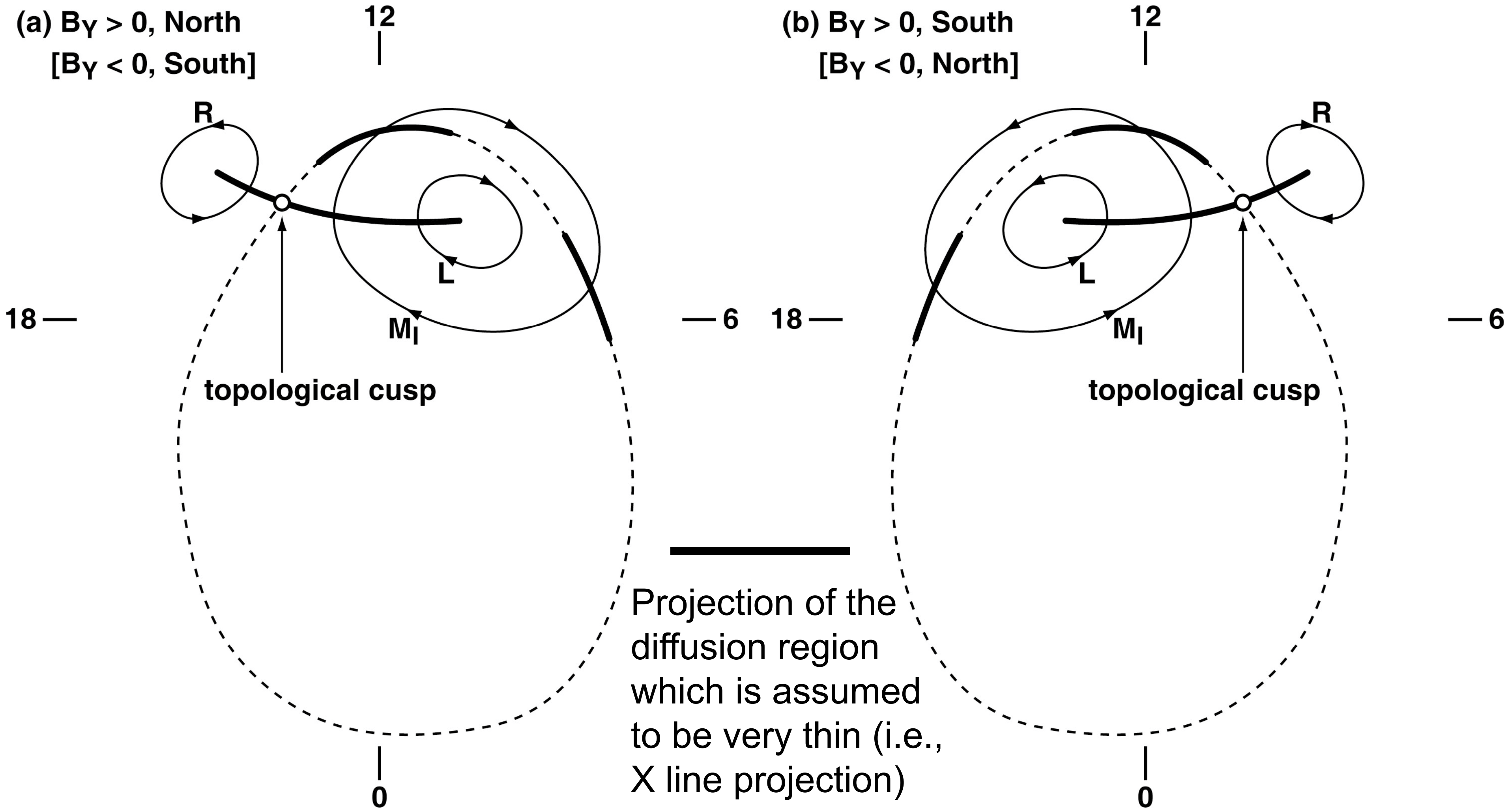


Reconnection	topology	Combination	
IM F+ closed → lobe + lobe	Dungey-type	Dungey cycle (normal/reverse)	Hybrid cycle
lobe + lobe → closed + IMF			
lobe +closed → closed + lobe	Interchange-type	Interchange cycle	
IMF + lobe → lobe + IMF			Lobe cycle

The interchange cycle consists of IMF-to-lobe reconnection in one hemisphere followed by lobe-to-closed reconnection in the opposite hemisphere. An ionospheric consequence is an appearance of a reciprocal cell in the latter hemisphere circulating in the closed field line region.



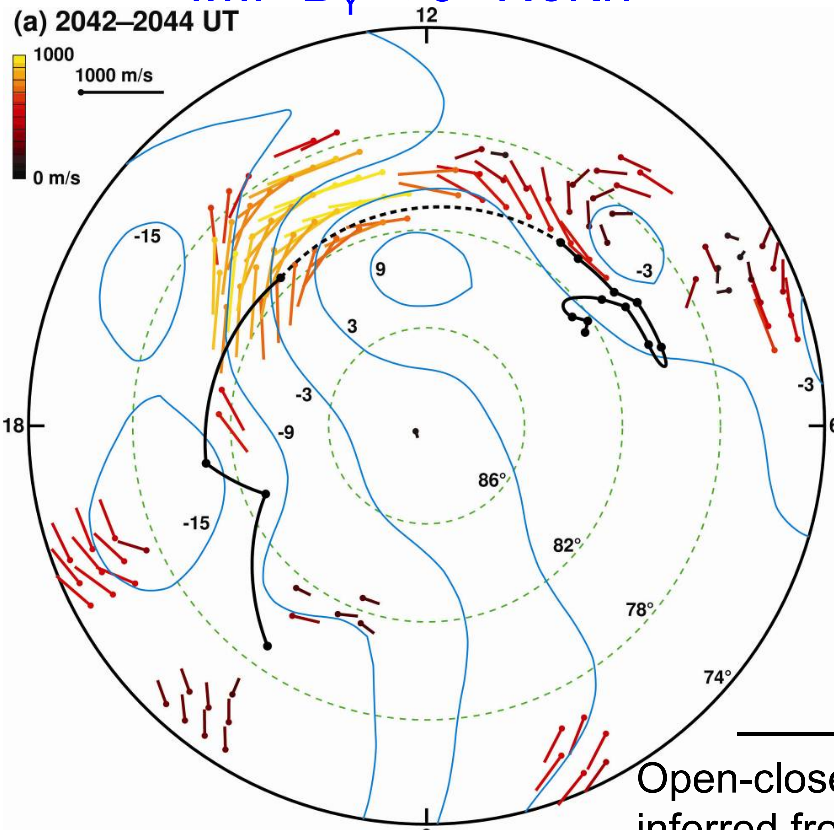
Interchange cycles in the presence of finite IMF B_Y



The reciprocal cell appears either on the dawnside or duskside.

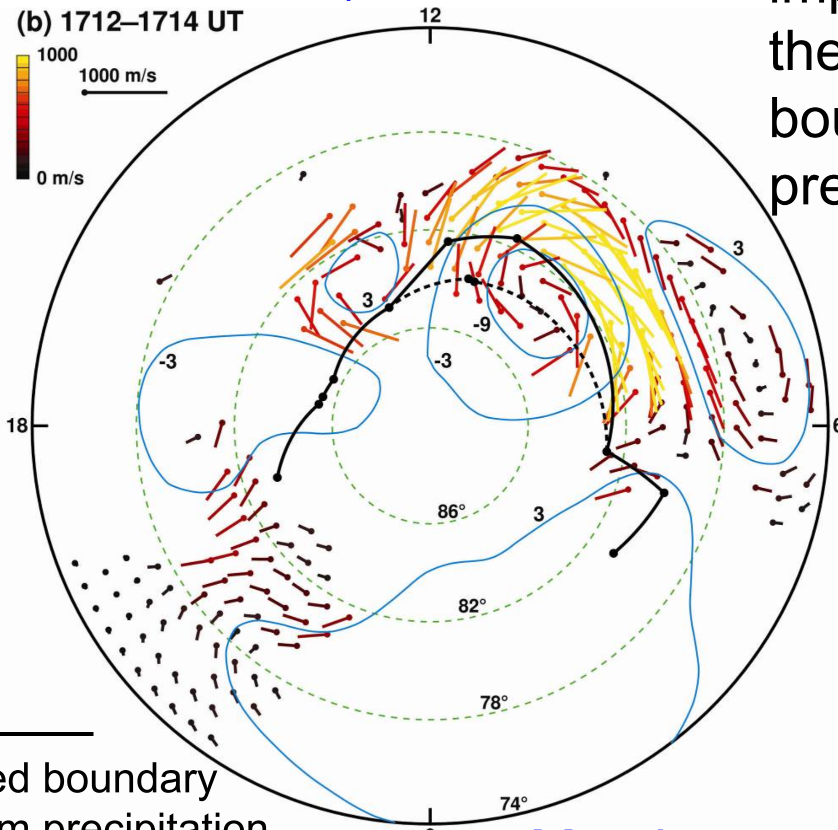
There are some observations suggesting reciprocal cells.

IMF $B_Y < 0$ North



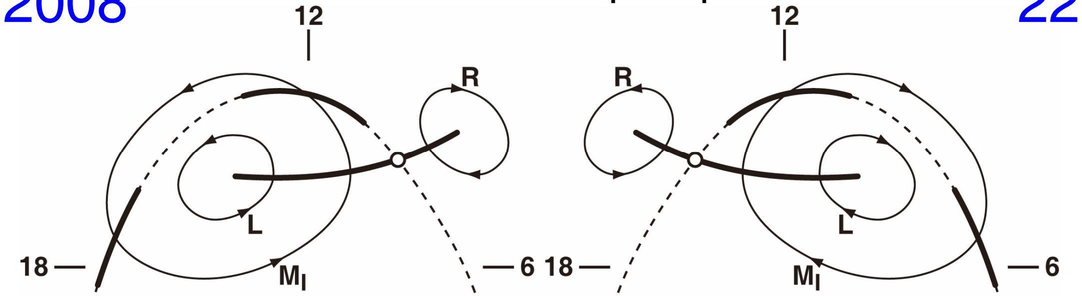
8 March 2008

IMF $B_Y > 0$ North



22 March 2008

Open-closed boundary inferred from precipitation

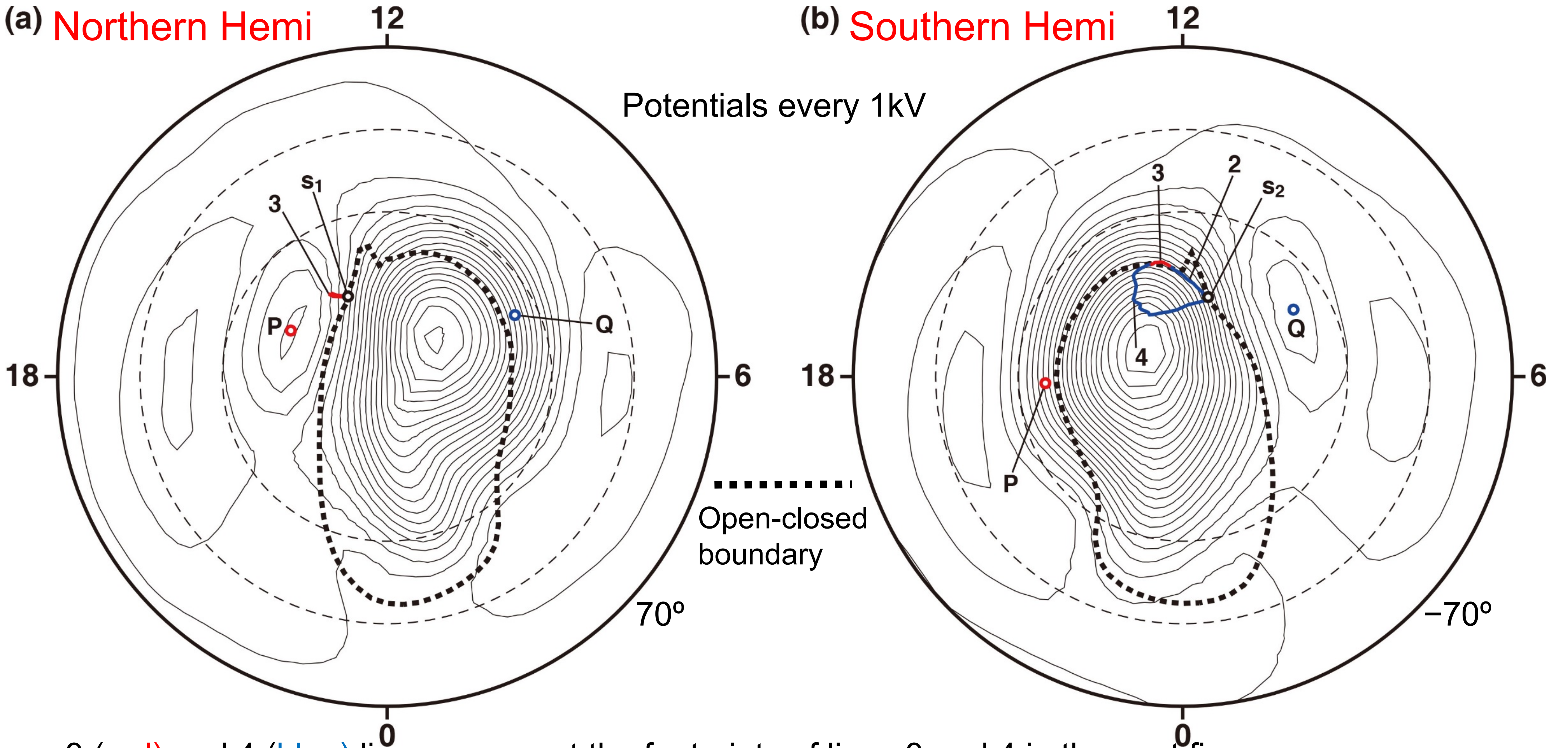


However, it is in principle impossible to determine the open-closed field line boundary from precipitating particles.

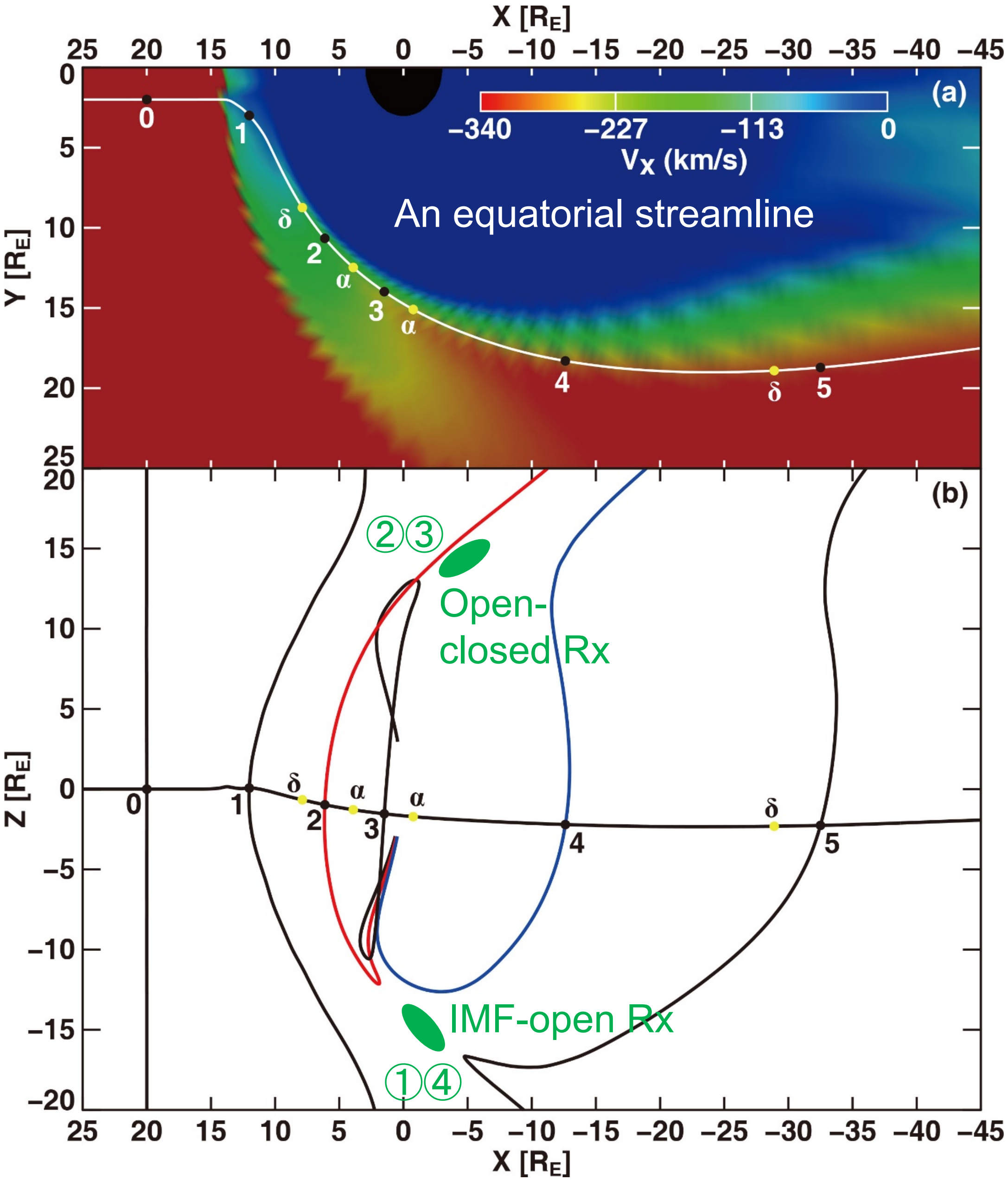
⇩

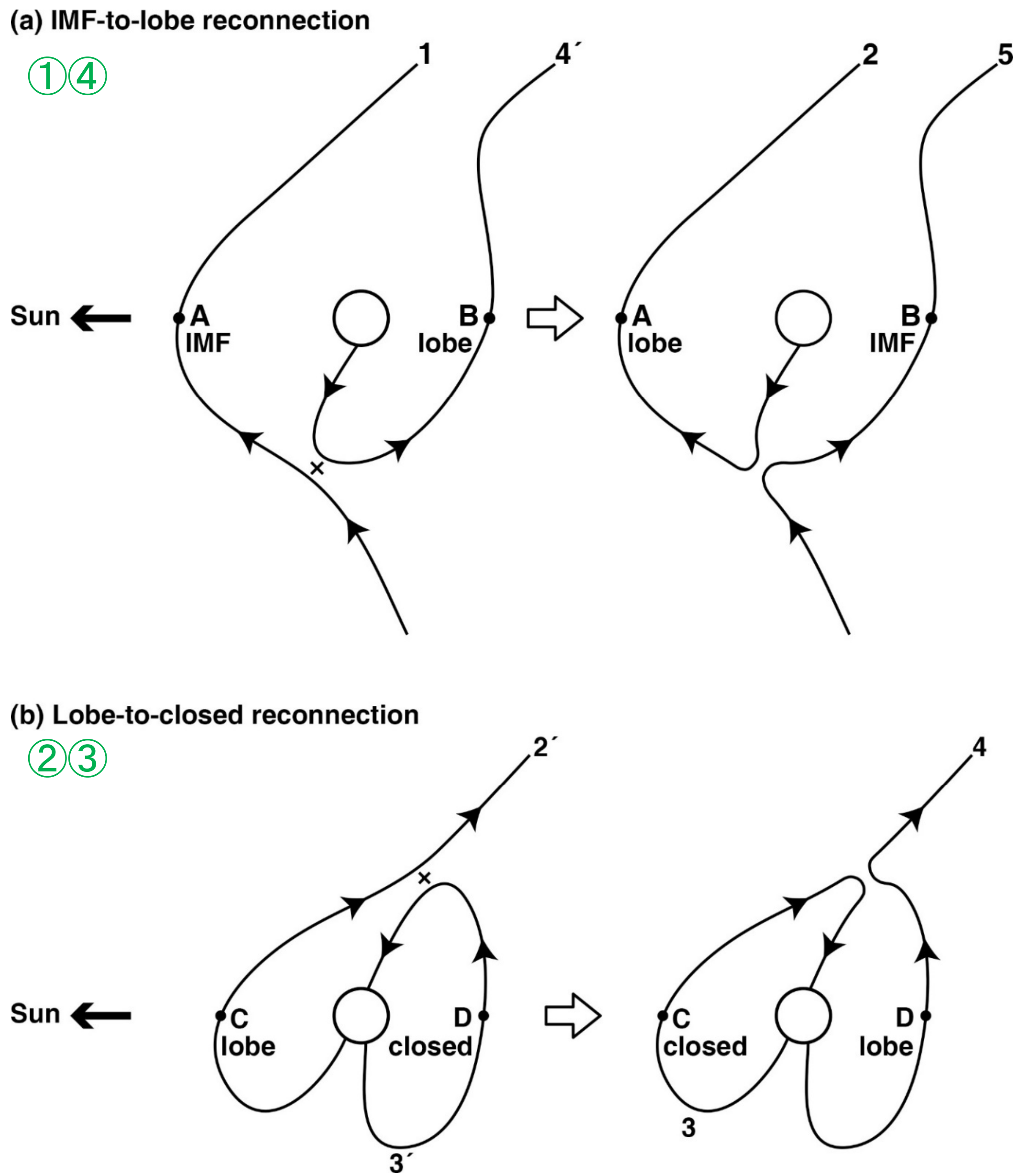
Quantitative modeling is needed.

We successfully reproduced the interchange cycle for finite IMF B_Y by MHD simulation.
(V_{SW}=400km/s, N_{SW}=5/cm^3, T_{SW}=50,000K; B_X=0nT, B_Y=1.7nT, B_Z=4.7nT [B_T=5nT, θ_C=20º])



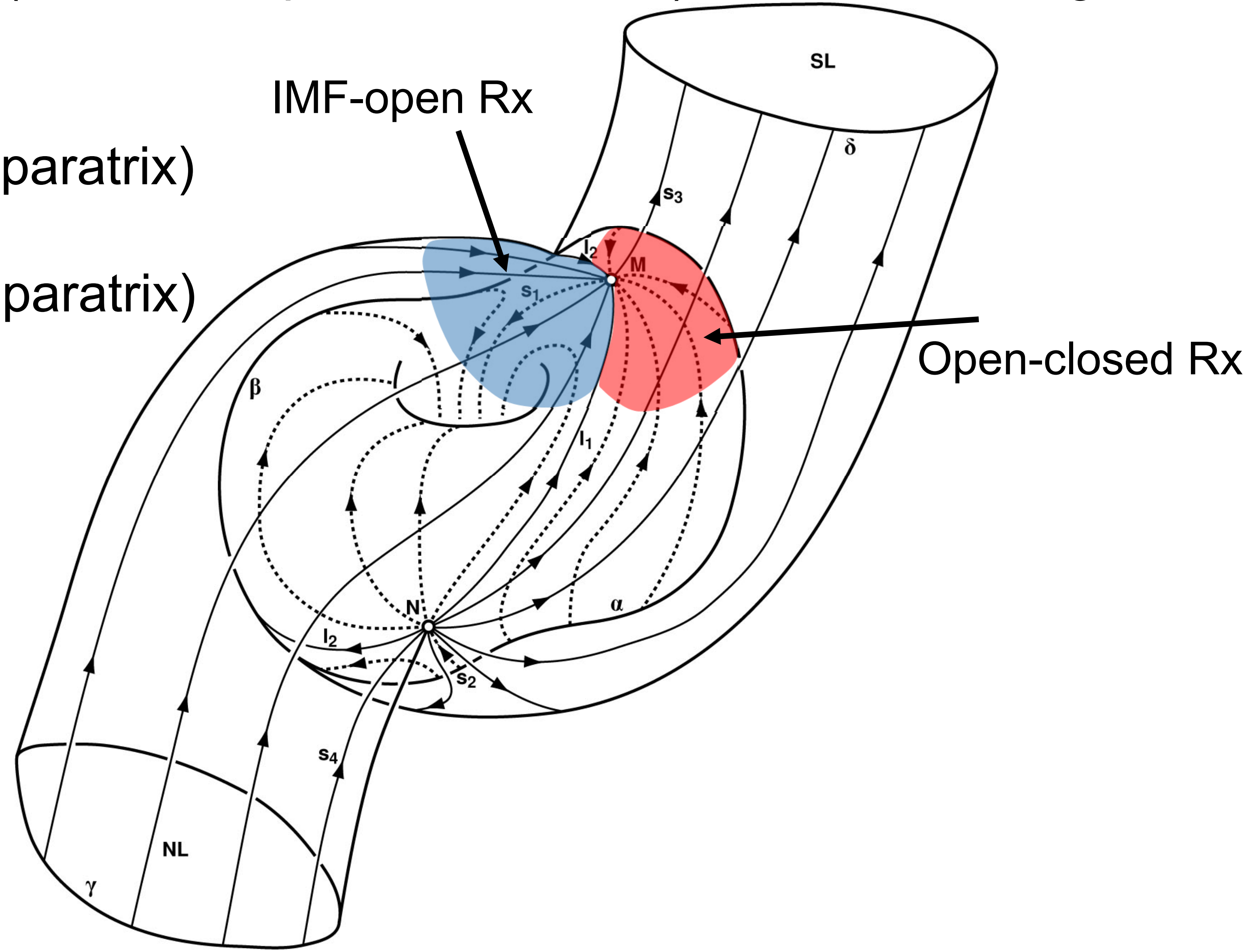
Lines 3 (red) and 4 (blue) lines represent the footprints of lines 3 and 4 in the next figure.


X [R_E]
(a)
−340 −227 −113 0
V_X (km/s)
An equatorial streamline
Y [R_E]
(b)
②③
Open-closed Rx
IMF-open Rx
①④
Z [R_E]
X [R_E]

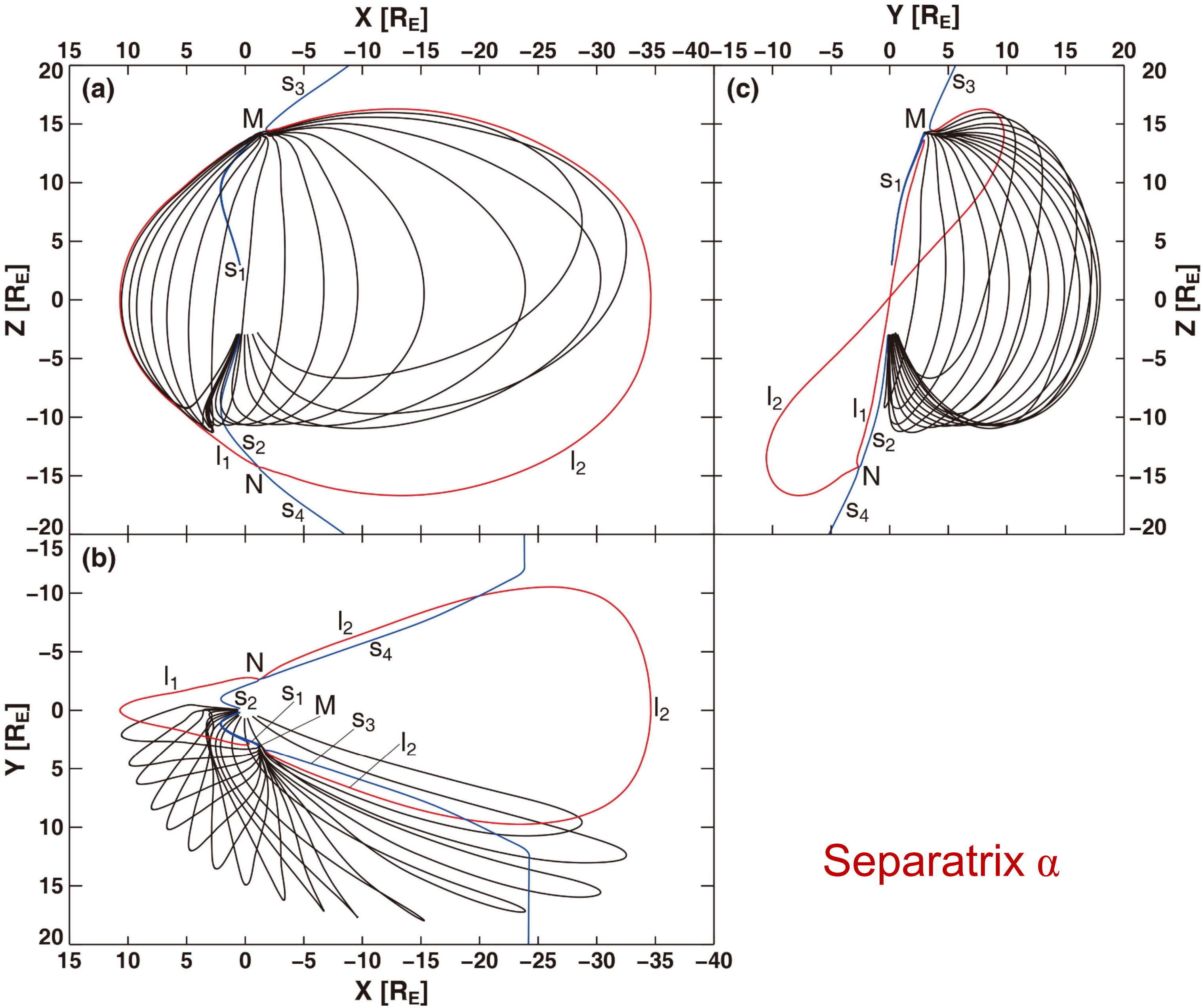

(a) IMF-to-lobe reconnection
①④
Sun
A IMF
B lobe
A lobe
B IMF
(b) Lobe-to-closed reconnection
②③
Sun
C lobe
D closed
C closed
D lobe

Magnetic field topology (2-null, 2-separator structure) and diffusion regions

Torus (open-closed separatrix)
+
Cylinder (IMF-open separatrix)

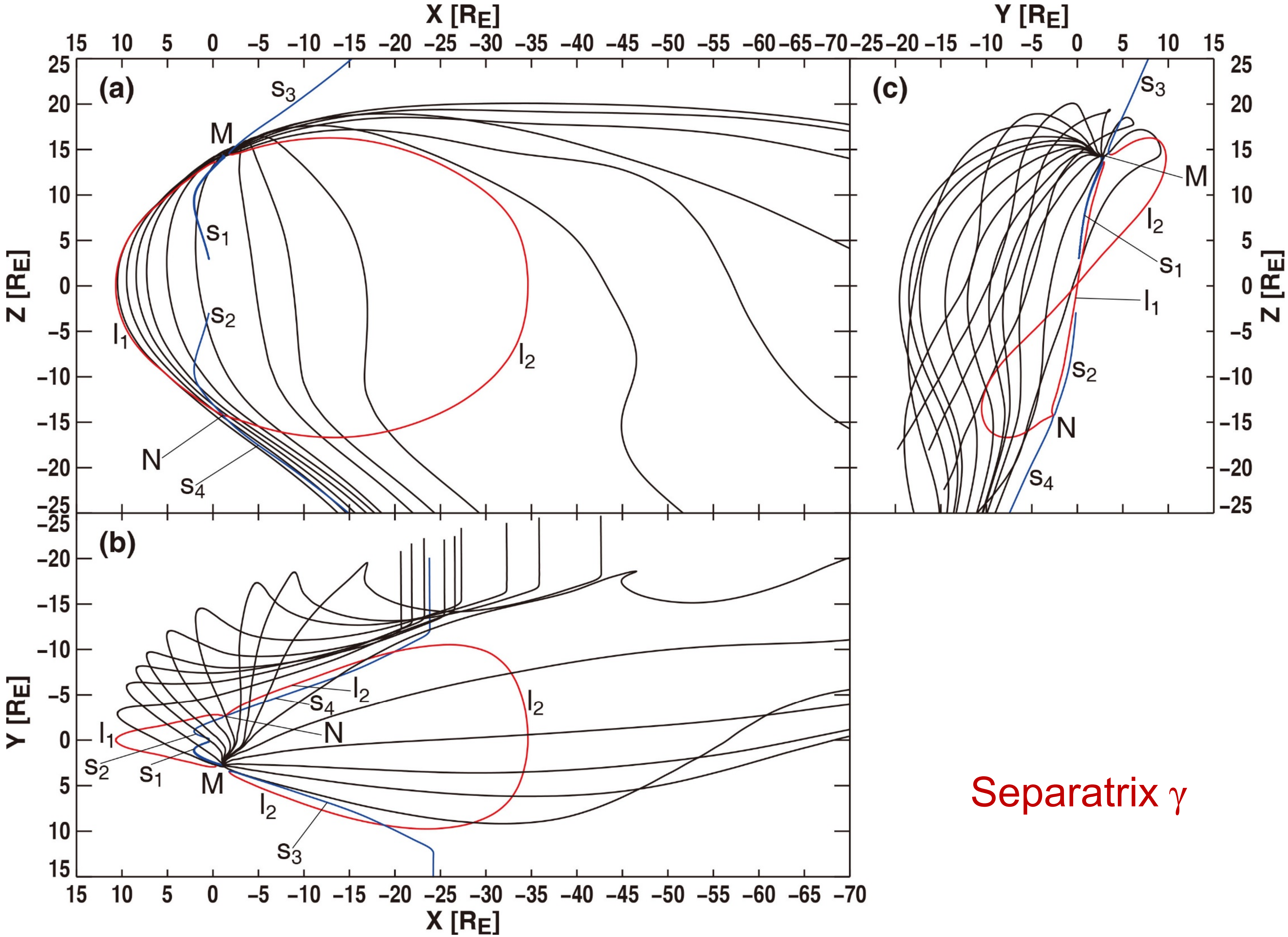


Duskside half of the torus in the simulated magnetosphere



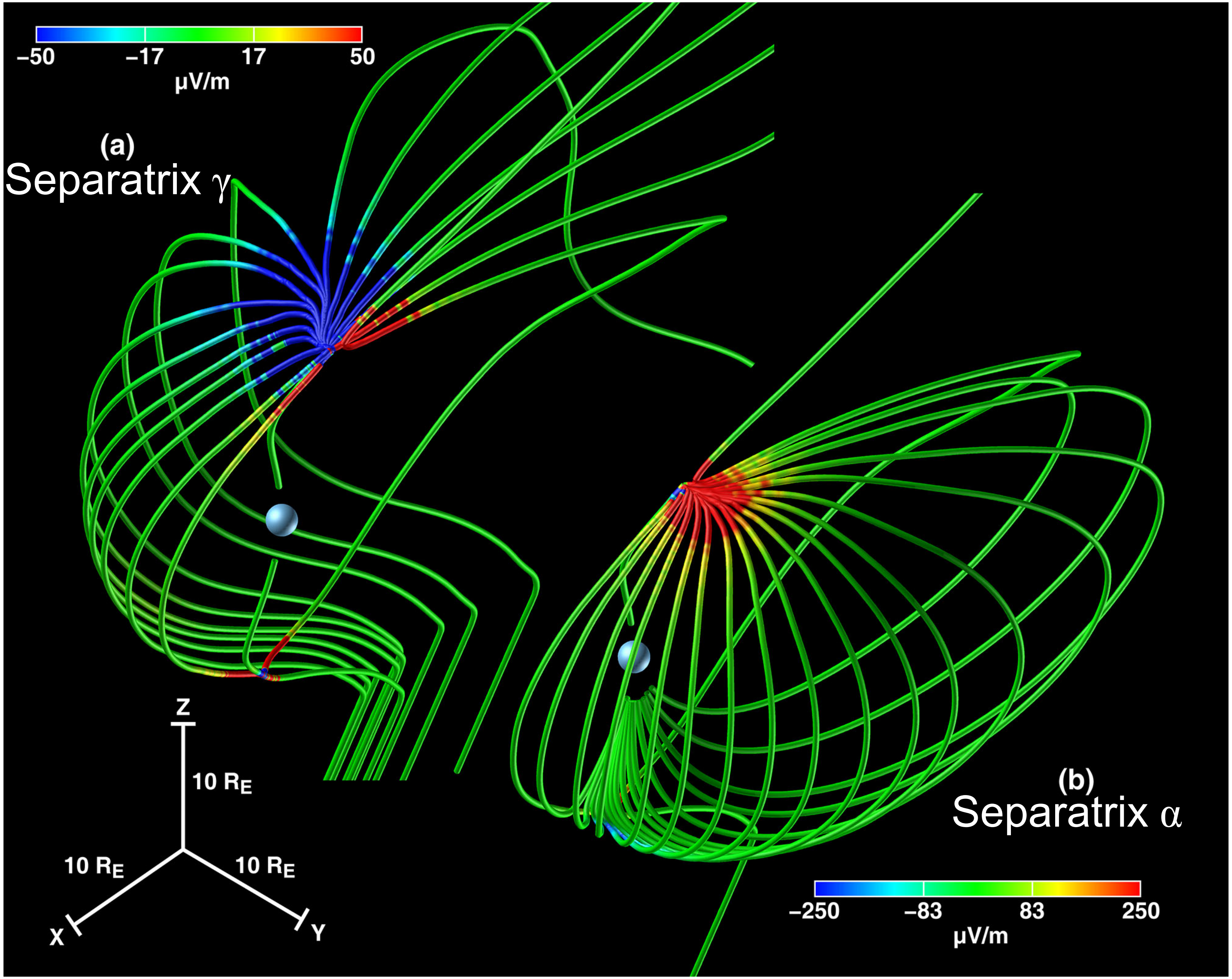
Separatrix α

Dawnside half of the cylinder in the simulated magnetosphere

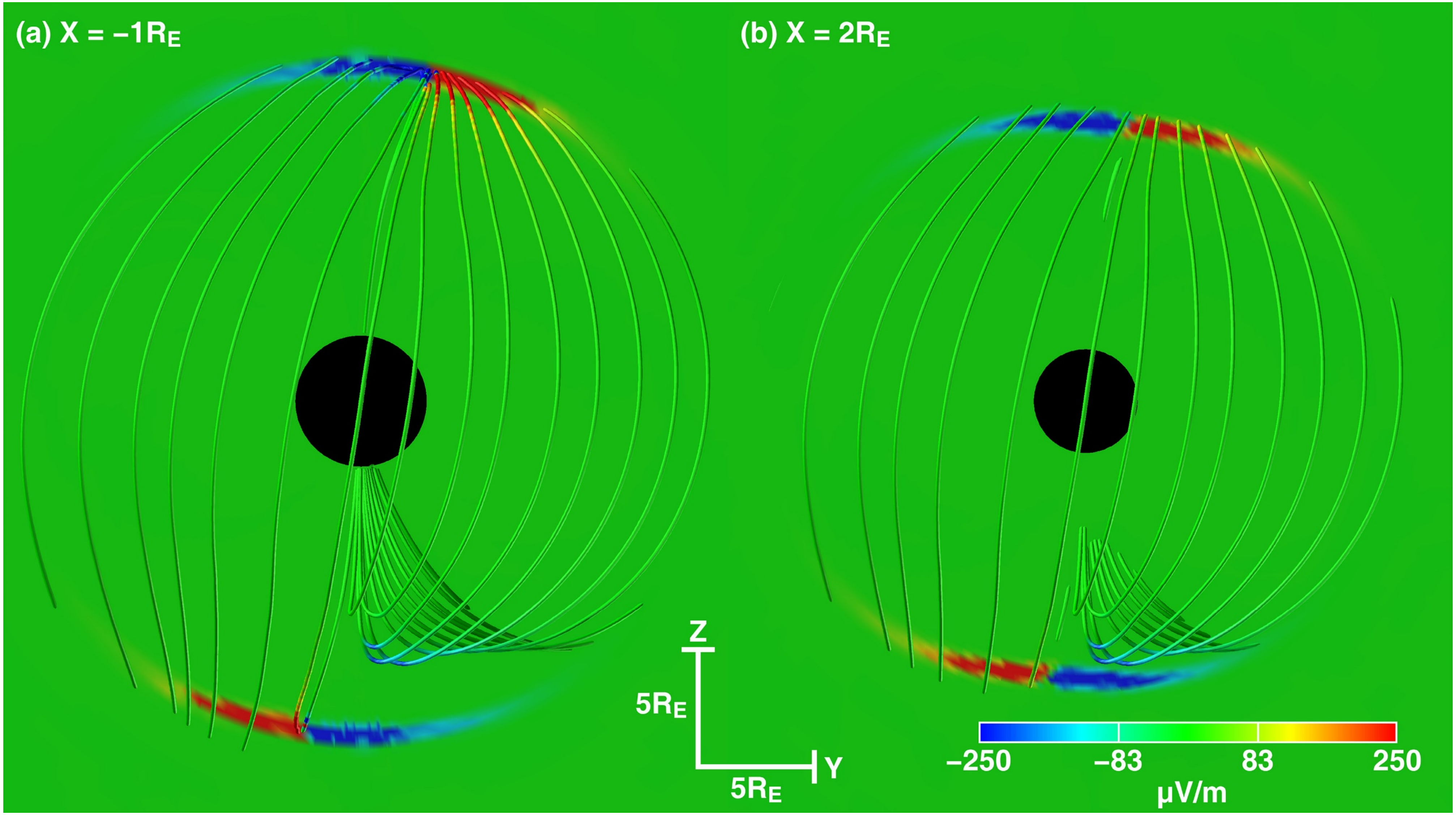


Separatrix γ

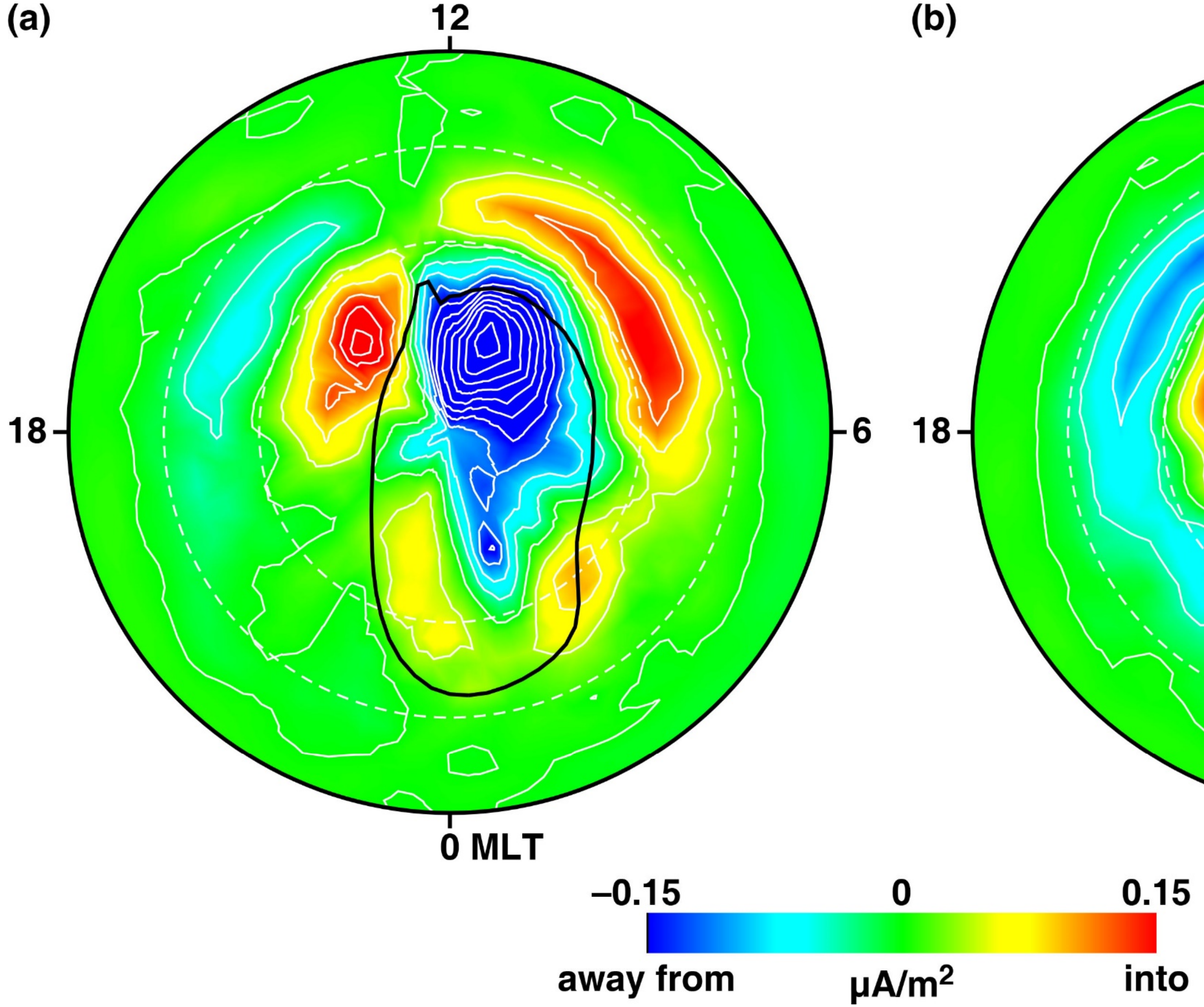
Field-aligned electric fields on separatrices (diffusion regions)



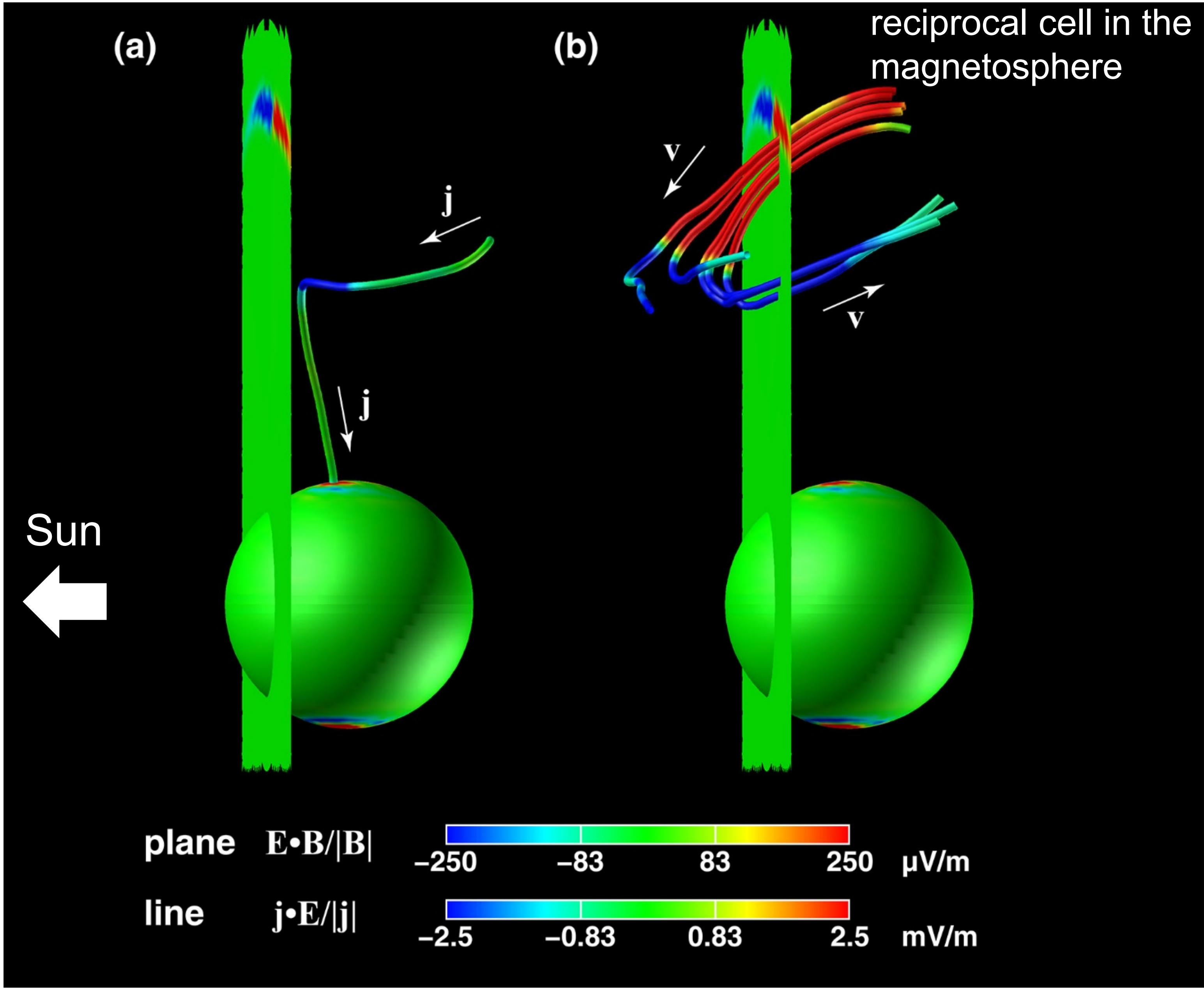
Thickness of the diffusion regions (~$1R_E$)



Of course, ionospheric potentials are produced by field-aligned currents.



- The reciprocal cell is not the magnetic projection of the diffusion region.
- The dynamo of field-aligned currents responsible for the reciprocal cell is located near earth.
- The diffusion region and the dynamo region is linked by plasma flow streamlines (streamlines of kinetic energy flux).
- Thus, at least partly, the kinetic energy created in the diffusion region is transferred to the dynamo region by convection.



Conclusions

We performed numerical modeling for oblique northward IMF (θ_C=20º) and successfully reproduced the interchange cycle in the magnetosphere-ionosphere convection system. We therefore conclude that the interchange cycle does exist in the real solar wind-magnetosphere-ionosphere system. However, the simulation revealed that the reciprocal cell is not a direct projection of the diffusion region as predicted by the vacuum model in which diffusion is added a priori to the vacuum magnetic topology. Instead, the reciprocal cell is a consequence of the plasma convection system coupled to the NBZ field-aligned current system.