On the role of quasi-adiabaticity in
Plasma circulation and precipitation at Mercury

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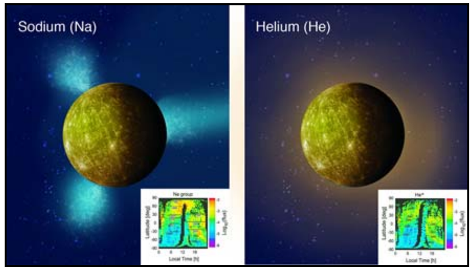
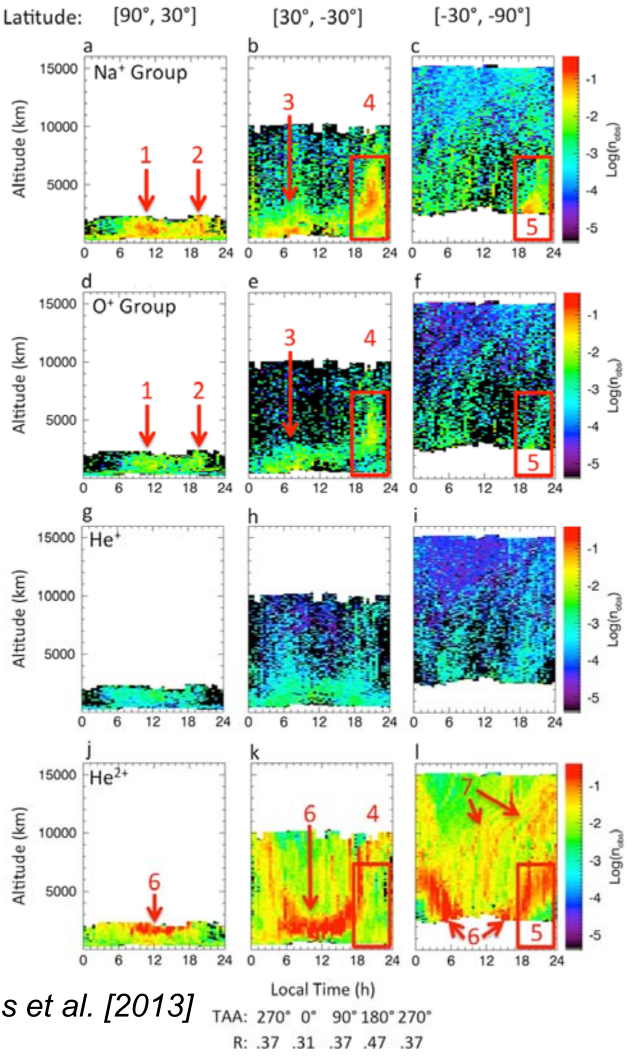
Abstract : Because of the small spatial scales of Mercury's magnetosphere, most of the ion populations are transported nonadiabatically through the magnetotail. A regime of paramount importance in this nonadiabatic transport is the Speiser (or quasi-adiabatic) regime that is responsible for prominent energization (during the so-called "unmagnetized" trajectory sequence), thin current sheet buildup, and subsequent precipitation onto the planet surface due to negligible diffusion of the particle magnetic moment. However, one the main results of MESSENGER is that Mercury's magnetosphere is highly dynamical, with in particular series of rapid reconfigurations of the magnetotail on time scales of the order of seconds. Because the Speiser regime has been put forward for steady field configurations, it is worth examining the robustness of this regime in the case of a rapidly changing field. We show that during rapid reconfigurations, two types of Speiser regimes can be identified, viz., a "weak" one characterized by significant change of magnetic moment, and a "strong" one with negligible change of magnetic moment (i.e., conserving quasi-adiabatic properties). Taking into account the adiabaticity parameter K, the former and latter regimes are obtained for K > KExB and K < KExB, respectively, where KExB is the K parameter of ions having the peak ExB drift speed during the field reconfiguration. Although Mercury's magnetosphere is highly variable, it thus appears that Speiser regime may have significant implications for plasma circulation and precipitation, especially for the high energy populations.

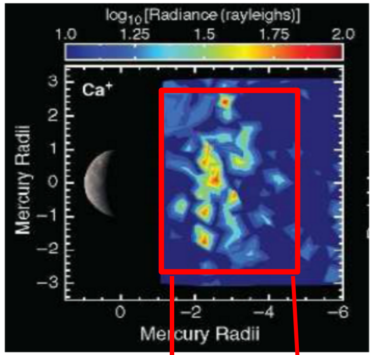
Ion transport in Mercury's magnetotail

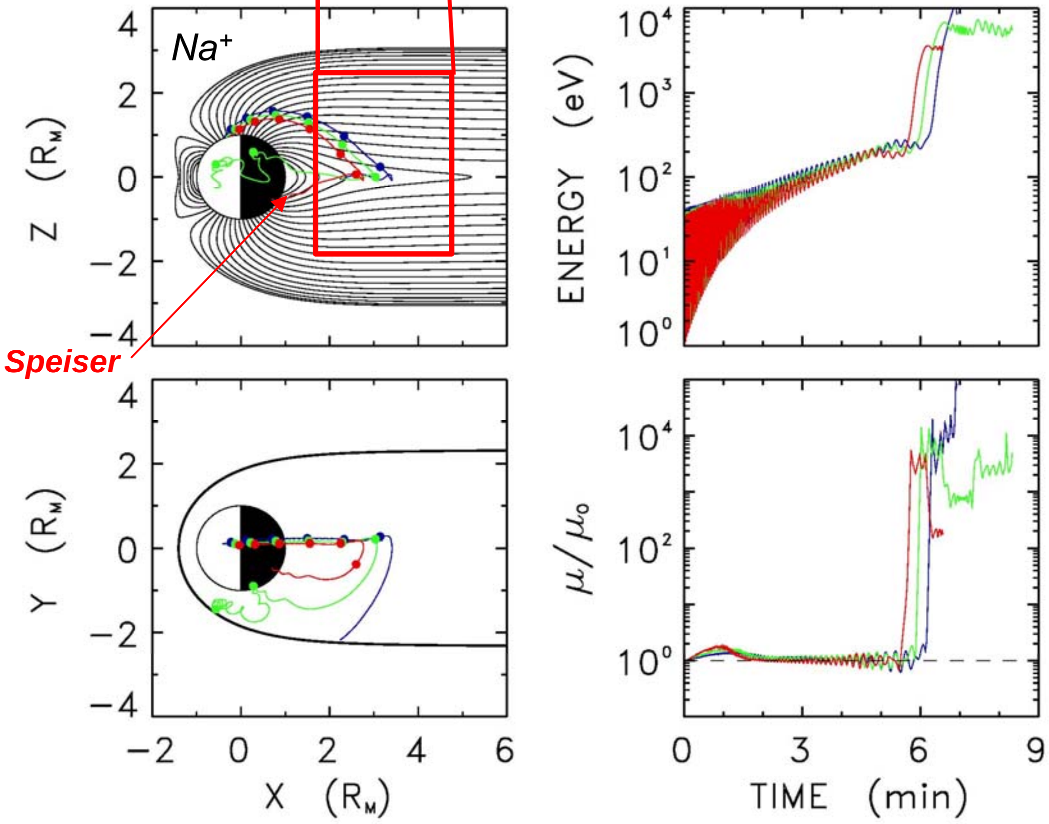




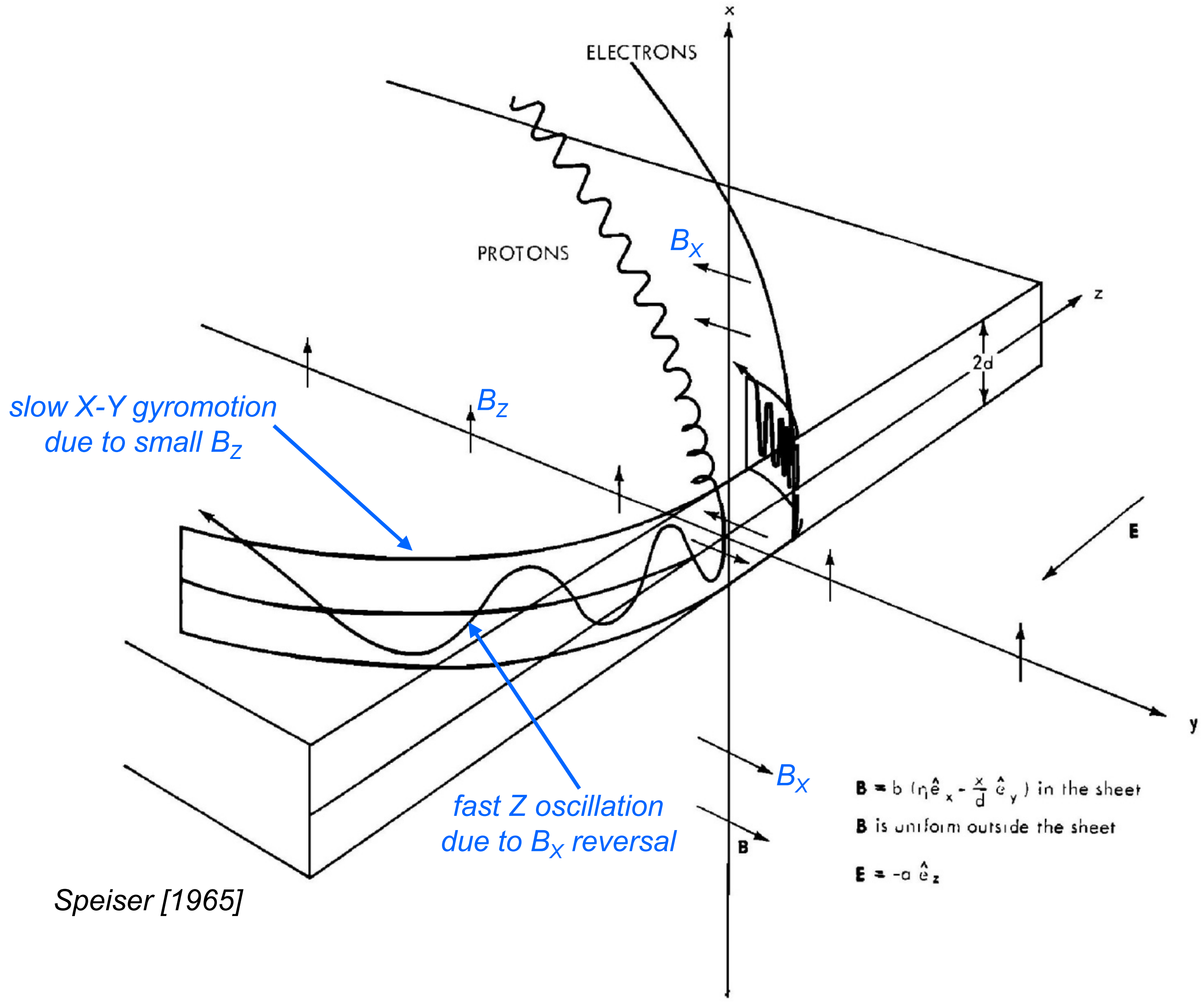
Raines et al. [2013]

Vervack et al. [2010]





Speiser regime ($\kappa < 1$)

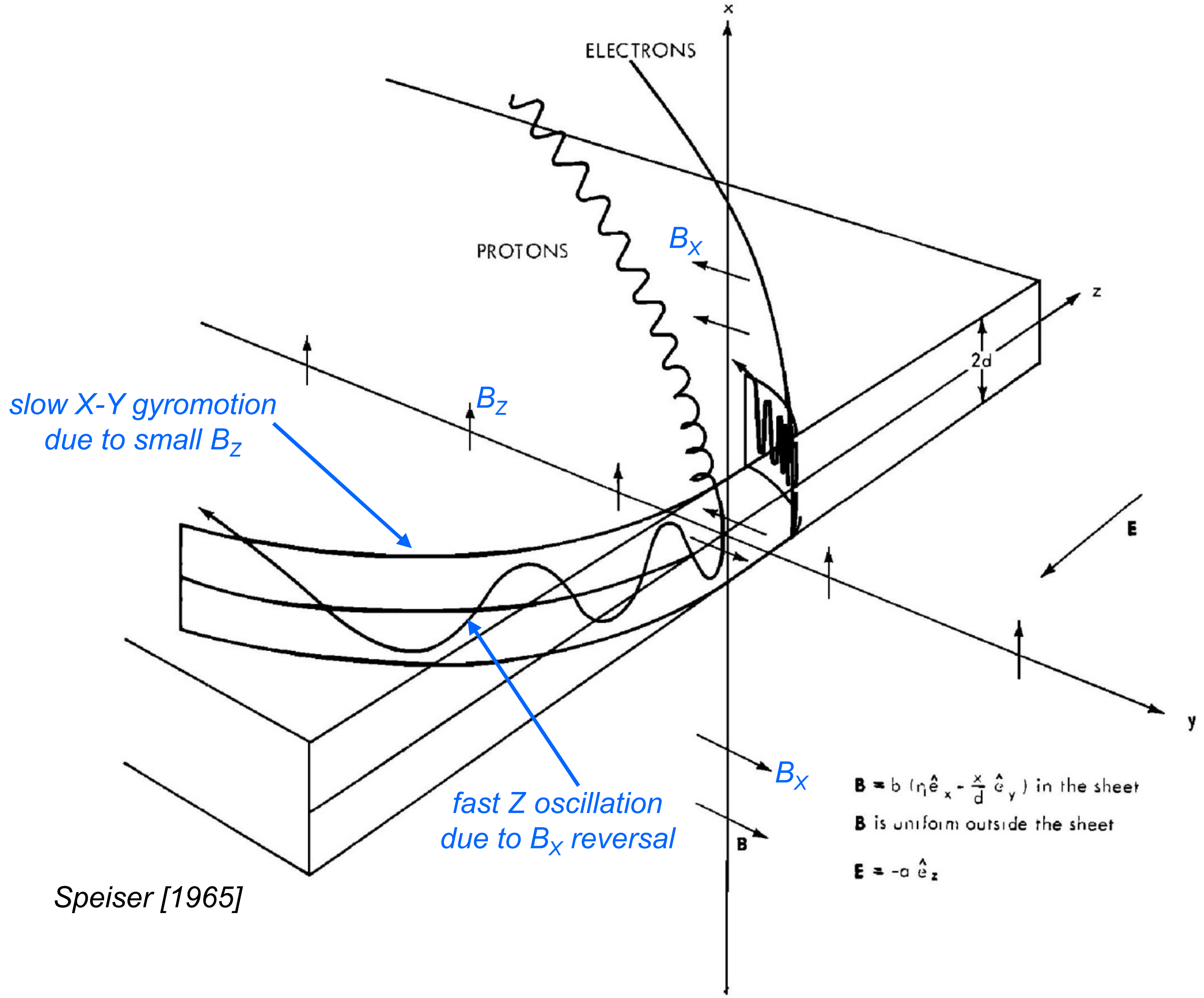


slow X-Y gyromotion due to small B_Z

fast Z oscillation due to B_X reversal

Speiser [1965]

Speiser regime ($\kappa < 1$)



slow X-Y gyromotion due to small B_Z

fast Z oscillation due to B_X reversal

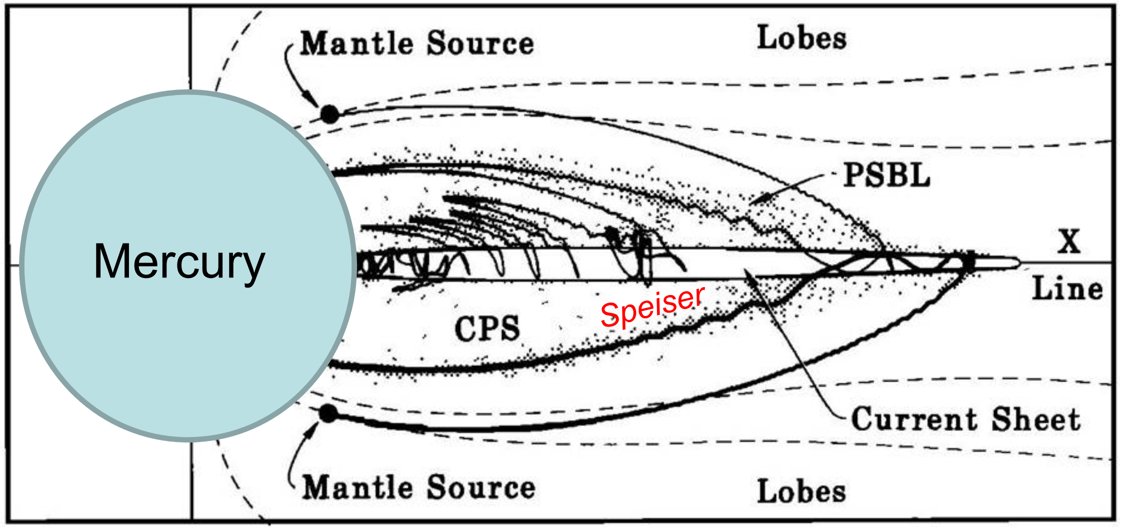
Speiser [1965]

$\Rightarrow$ *Speiser (quasi-adiabatic) regime plays a prominent role in build-up of thin magnetotail current sheet and low-altitude particle precipitation*

Château Margaux [1961]

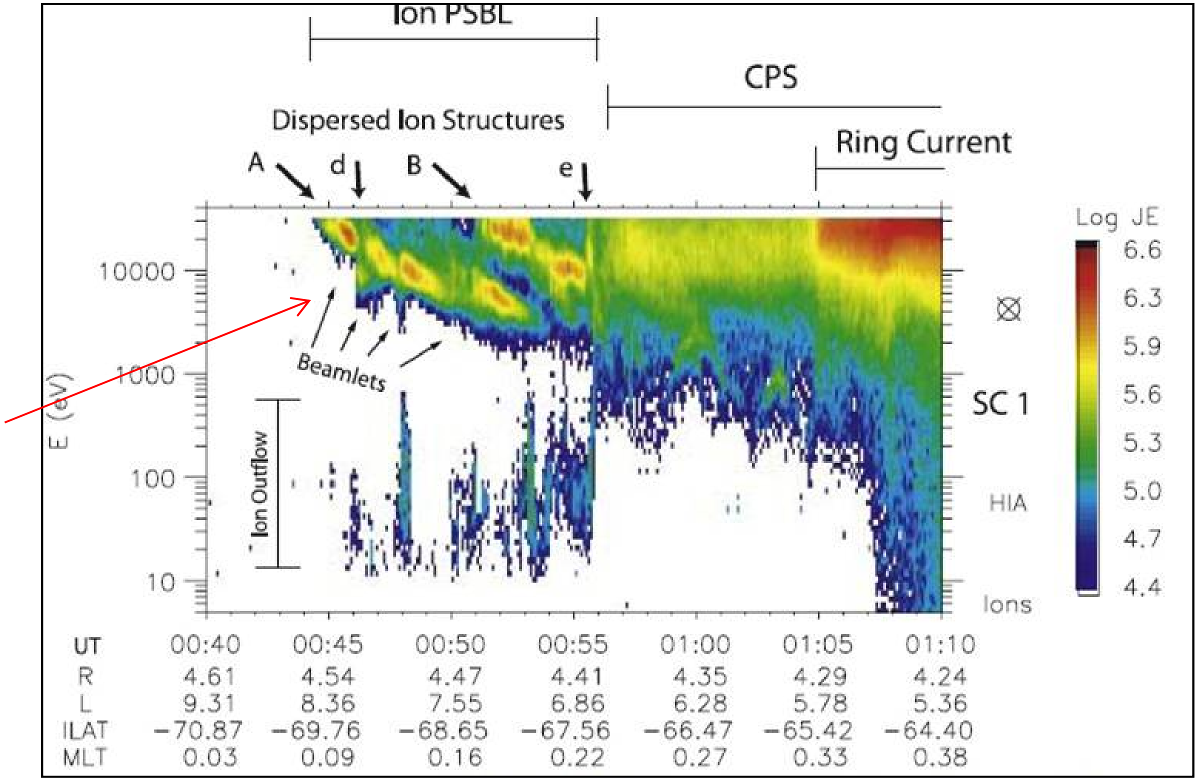
Ichinokura [2019]

Speiser regime ($\kappa < 1$)

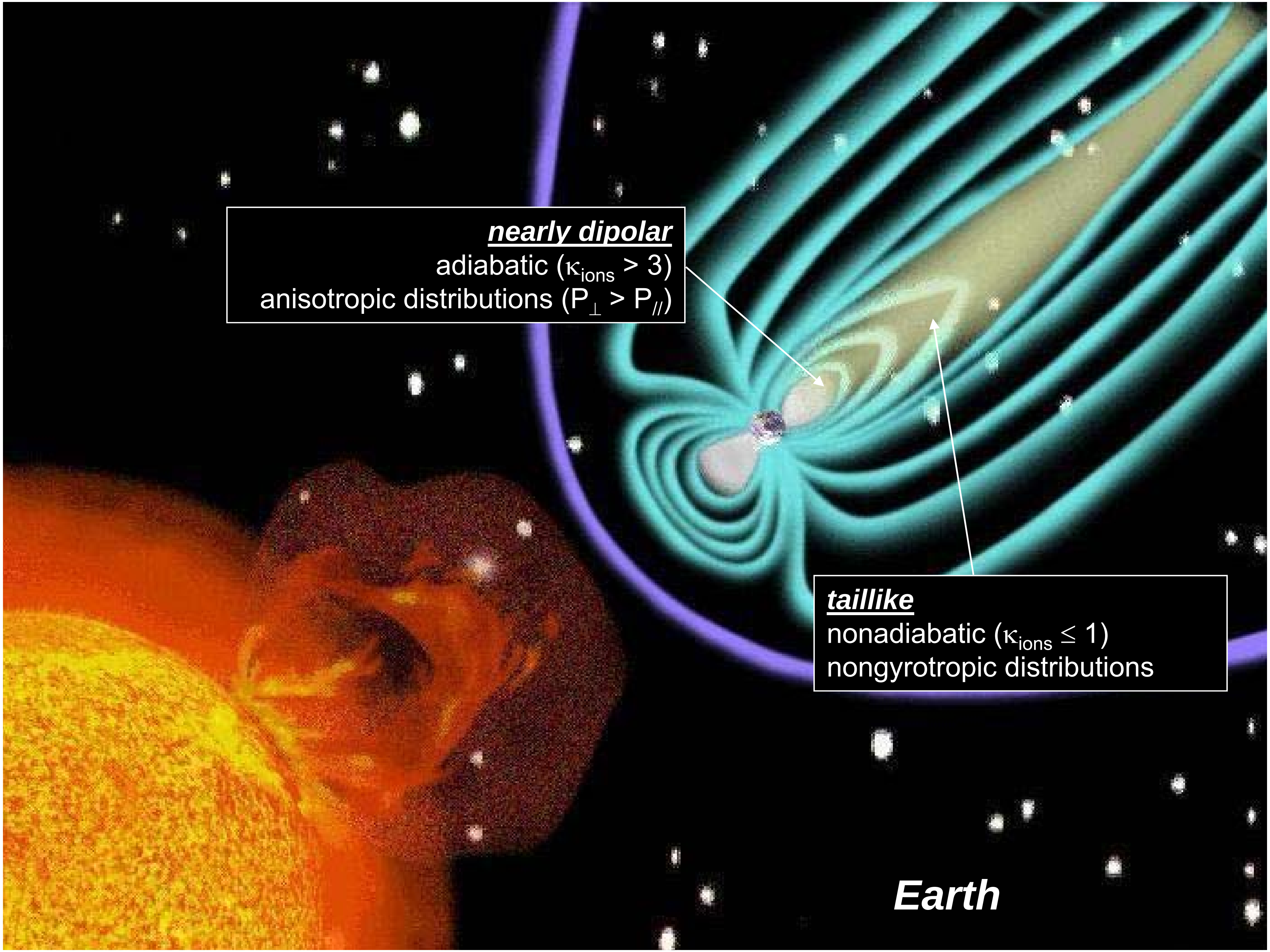


Ashour-Abdalla et al. [1993]

precipitating Speiser ions

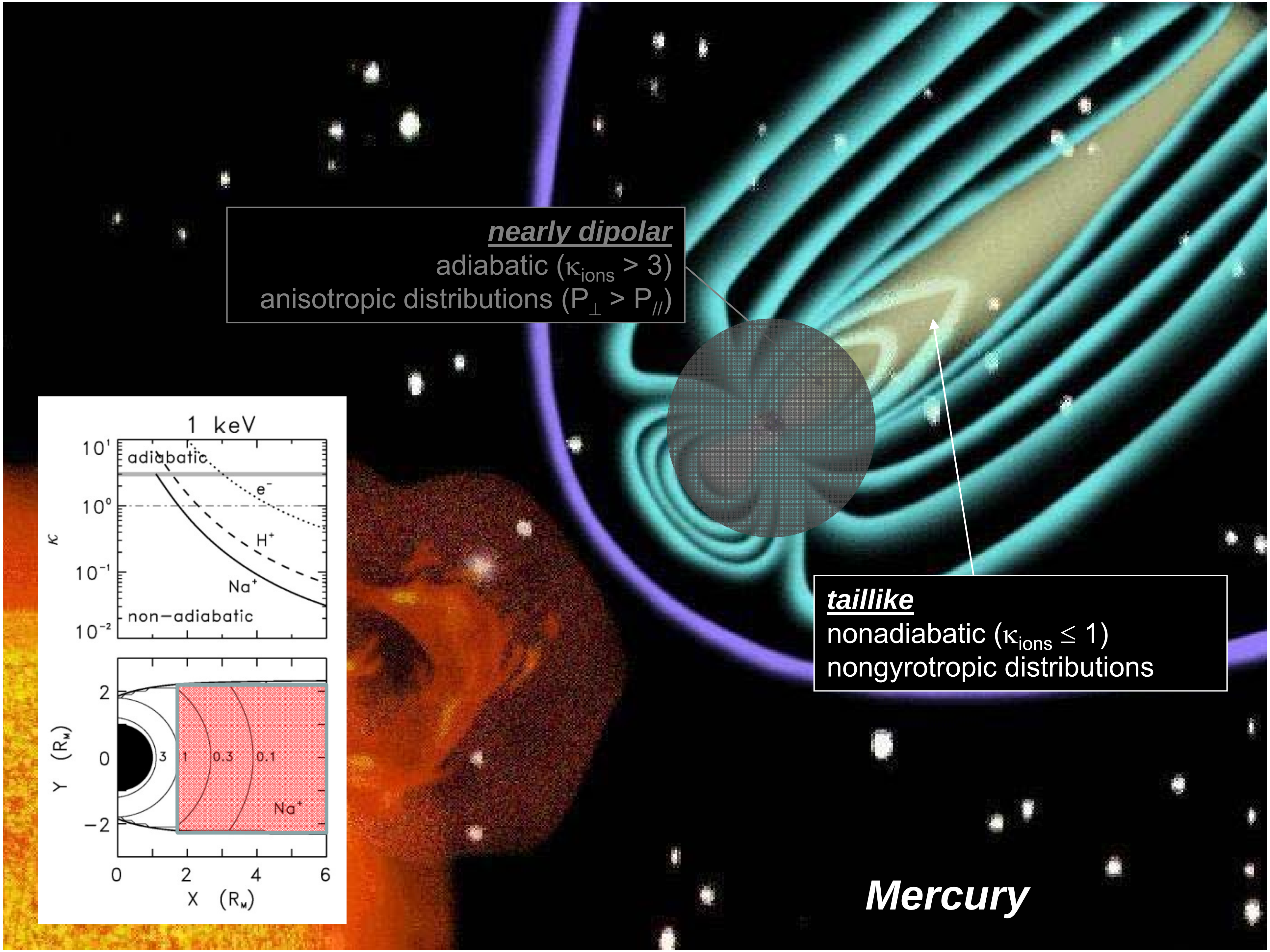


Keiling et al. [2004]



nearly dipolar
adiabatic ($\kappa_{ions} > 3$)
anisotropic distributions ($P_\perp > P_{//}$)

taillike
nonadiabatic ($\kappa_{ions} \leq 1$)
nongyrotropic distributions



nearly dipolar

adiabatic ($\kappa_{ions} > 3$)

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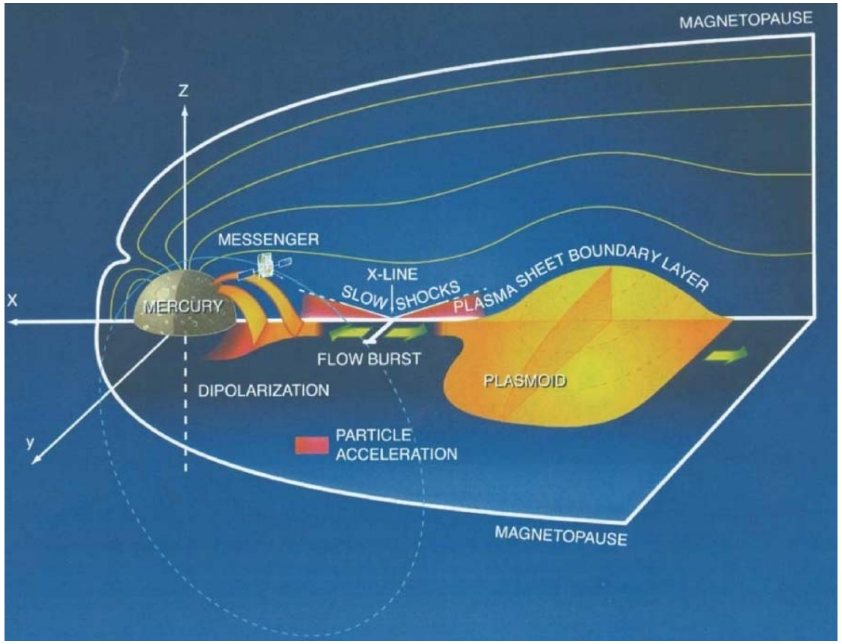
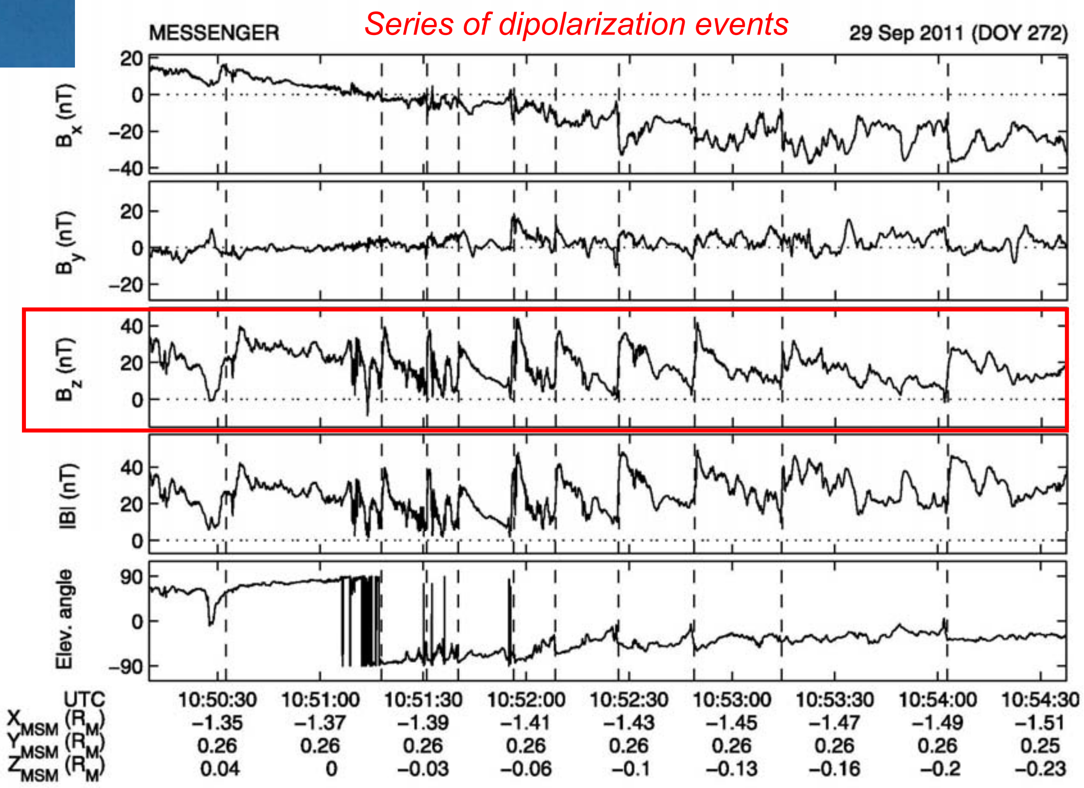
Mercury



Slavin [2004]

(MESSENGER) « Mercury's magnetosphere is highly dynamical »

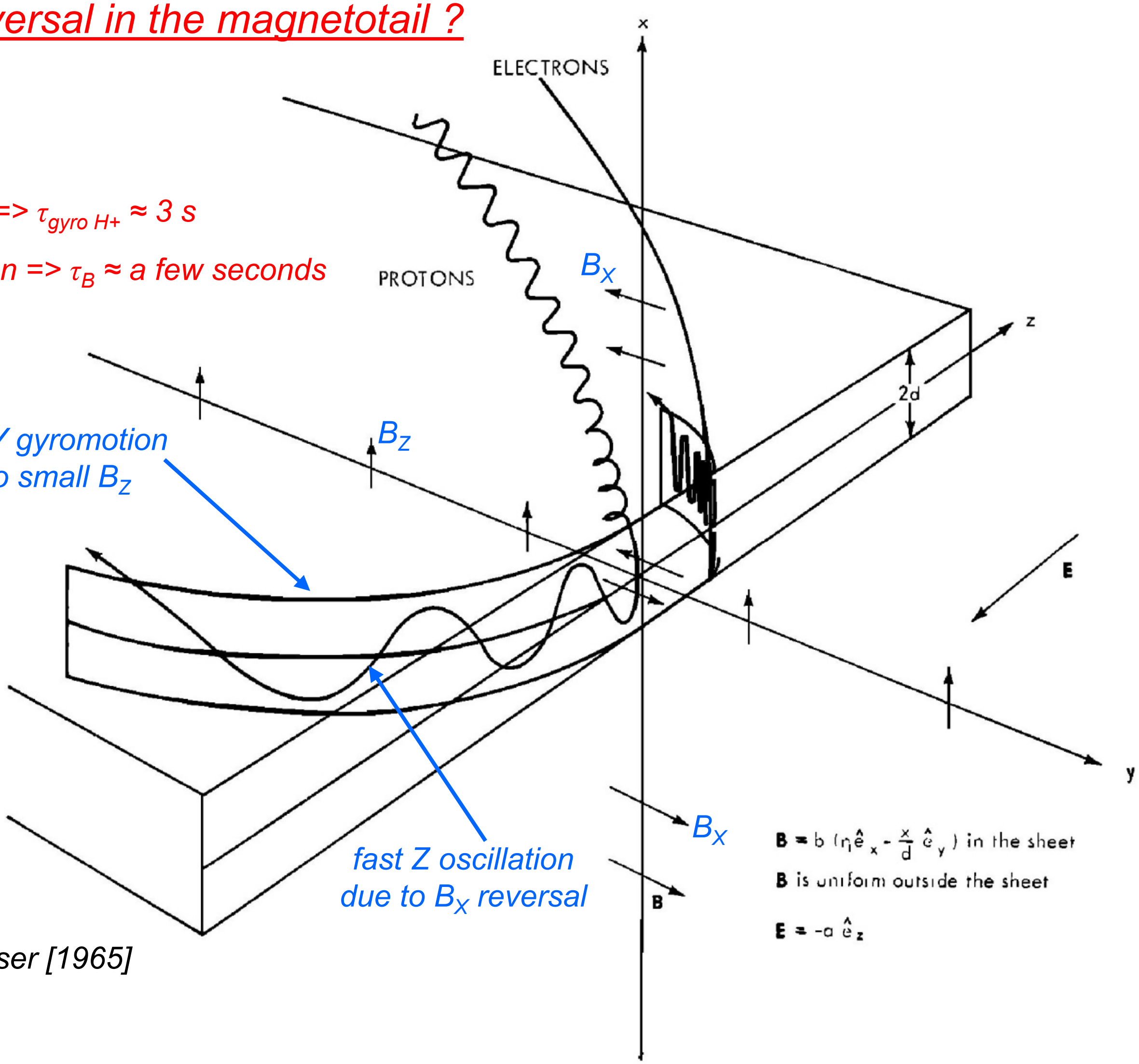

Series of dipolarization events

Sundberg et al. [2012]

Speiser regime ($\kappa < 1$)

What if not steady but time-varying sharp field reversal in the magnetotail ?

- $\Rightarrow B_Z = 20$ nT => $\tau_{gyro\ H+} \approx 3$ s
- $\Rightarrow$ dipolarization => $\tau_B \approx$ a few seconds

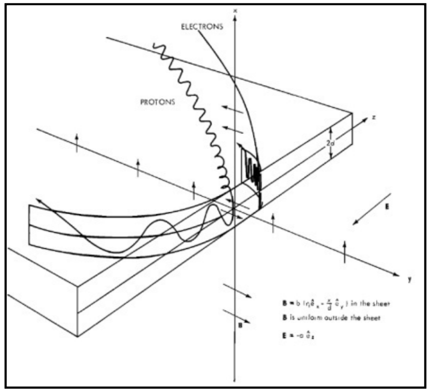


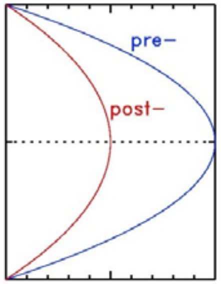
slow X-Y gyromotion due to small B_Z

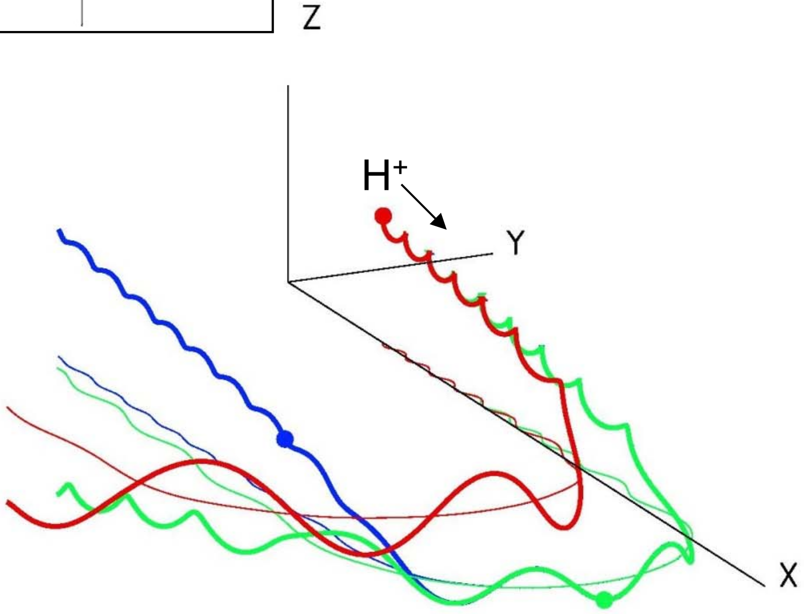
fast Z oscillation due to B_X reversal

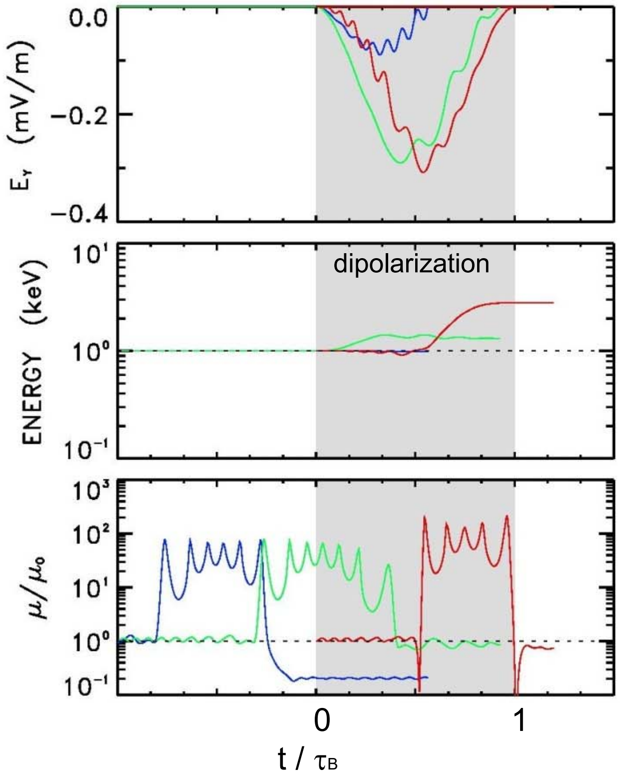
Speiser [1965]

Speiser regime in « dipolarizing » field reversal

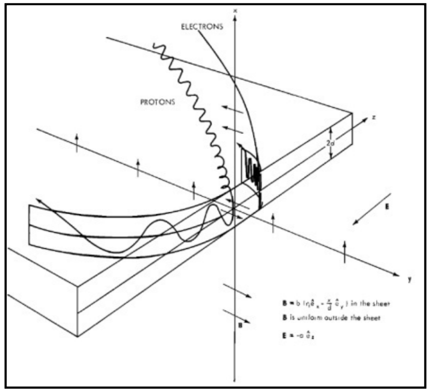








Speiser regime in « dipolarizing » field reversal

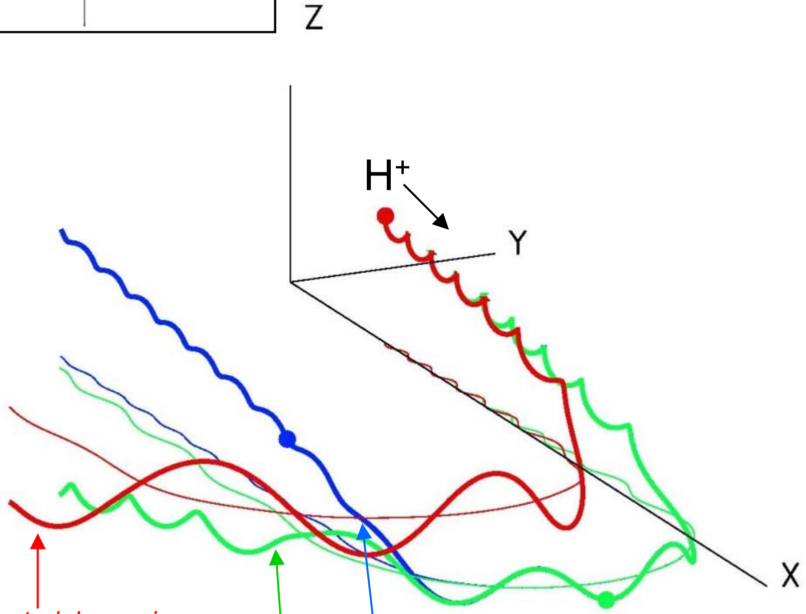


$$\kappa^2 = R_C / \rho_L = \omega_{gyro} R_C / V = \omega_{gyro} / \omega_{Z\text{-oscillation}}$$

increase due to B dipolarization

increase due to energization by induced E-field

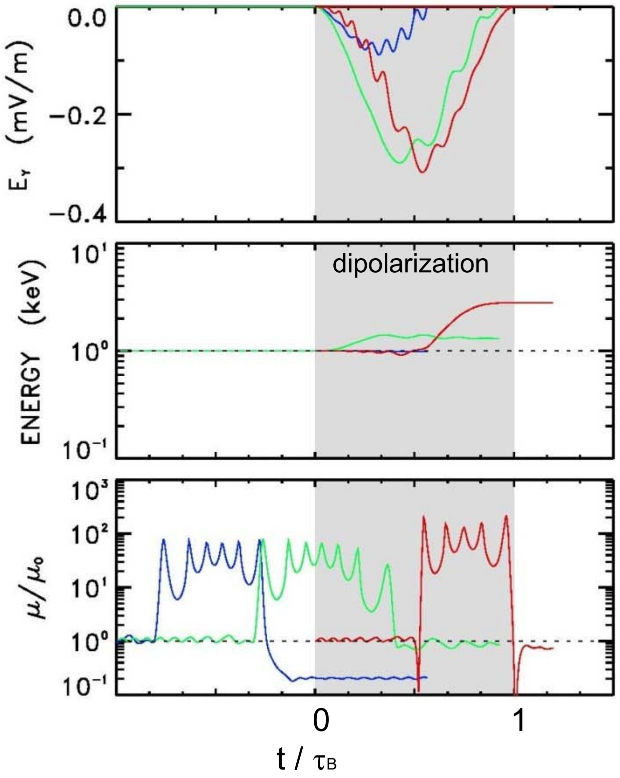
increase or decrease



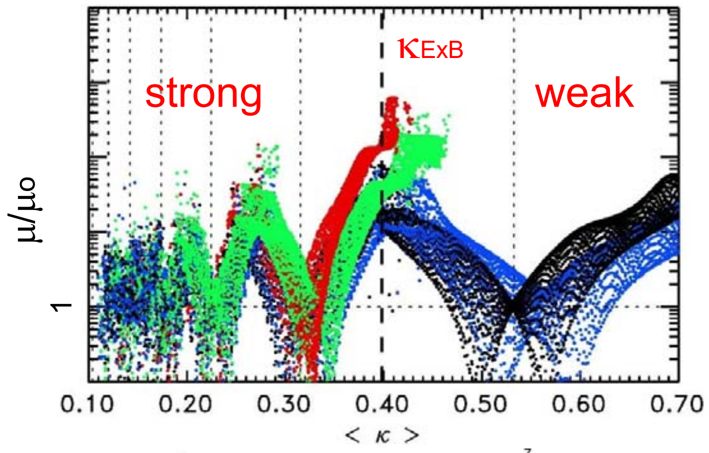
5 equatorial crossings in late phase of dipolarization ($\omega_{Z\text{-oscillation}}$ decrease)

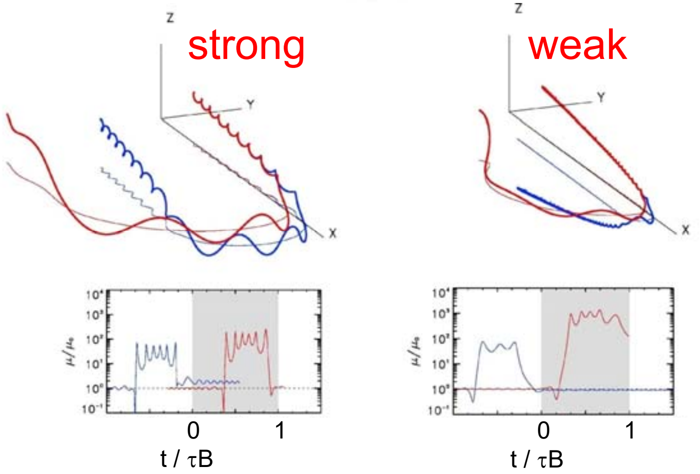
6 equatorial crossings in pre-dipolarization phase

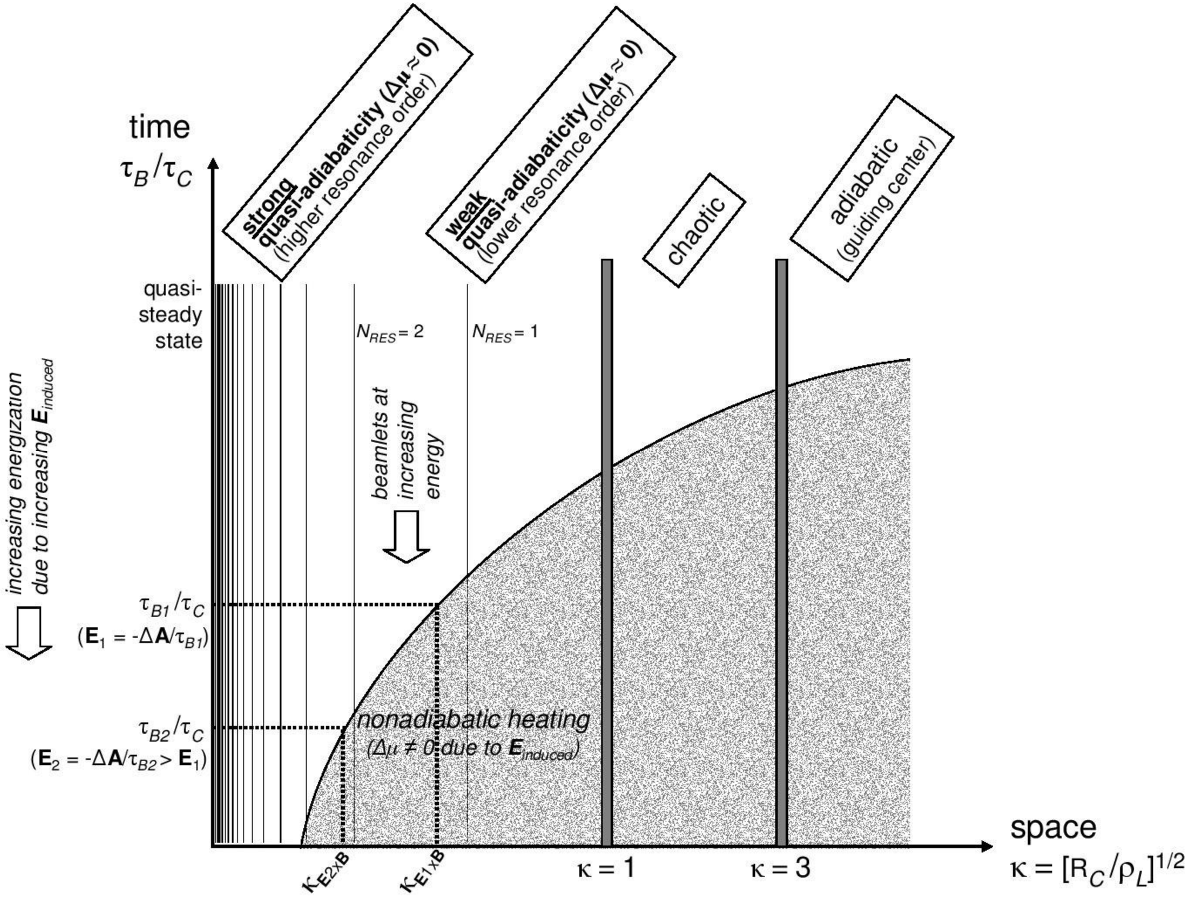
7 equatorial crossings in early phase of dipolarization ($\omega_{Z\text{-oscillation}}$ increase)

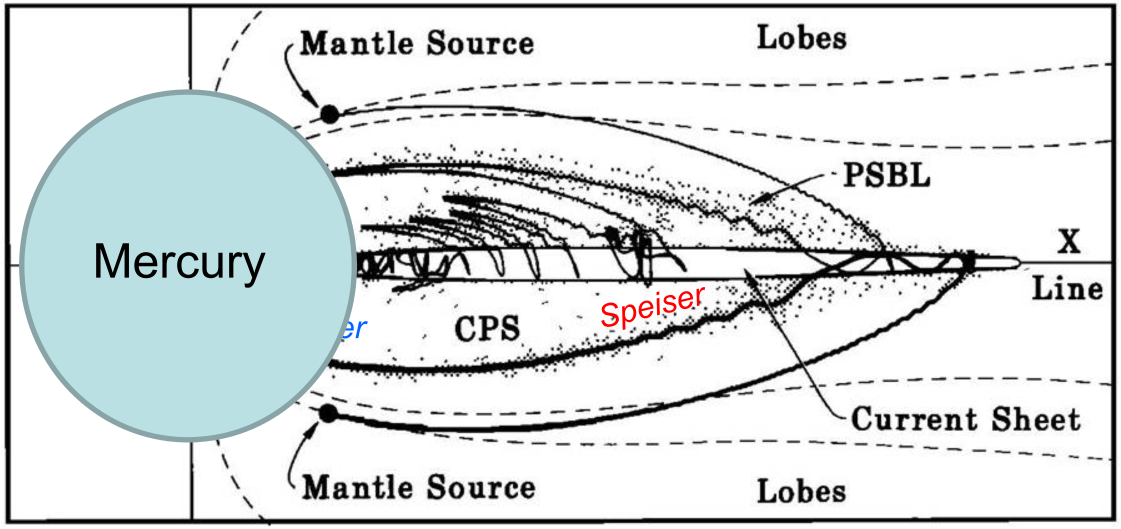


« Weak » and « strong » Speiser regimes

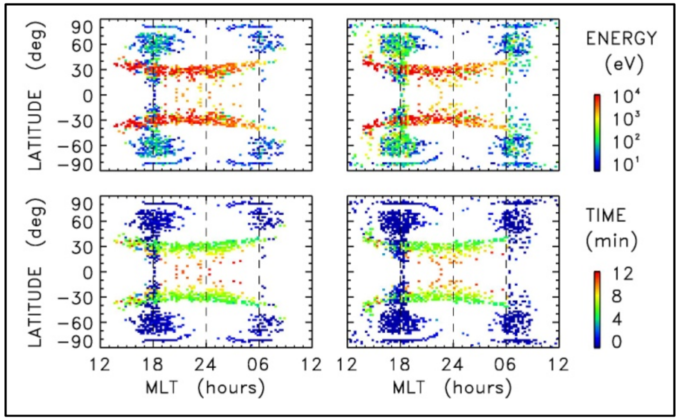






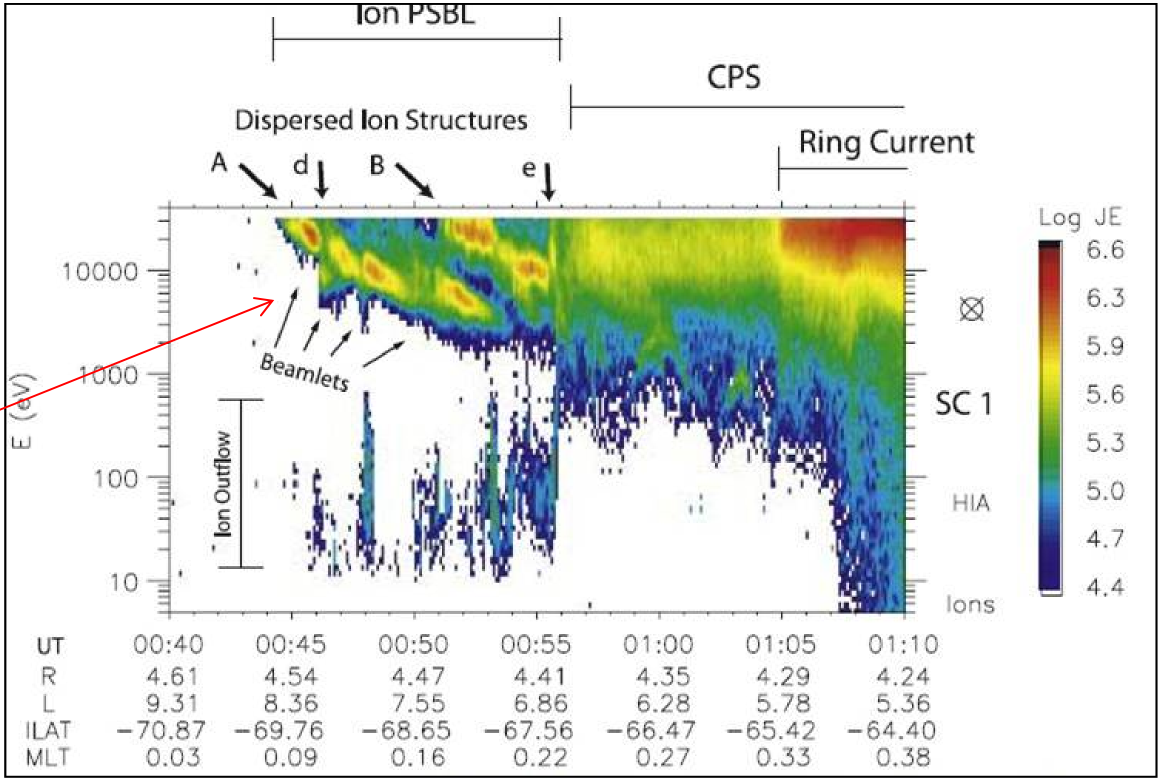


Ashour-Abdalla et al. [1993]



This steady-state Speiser regime with large acceleration followed by precipitation may persist in rapidly changing magnetotail

precipitating Speiser ions



Keiling et al. [2004]

In short :

- Ion behavior in Mercury's magnetotail mostly is nonadiabatic.

- Precipitation following Speiser-type acceleration in magnetotail is a **steady state** concept *(but Mercury's magnetotail is **highly dynamical**).*

- This Speiser regime persists during rapid reconfigurations of the magnetotail at large « enough » (i.e., $\kappa < \kappa_{ExB}$) energies (« strong » Speiser regime).