SM32B-06

How do heavy ions affect plasma entry and transport processes?

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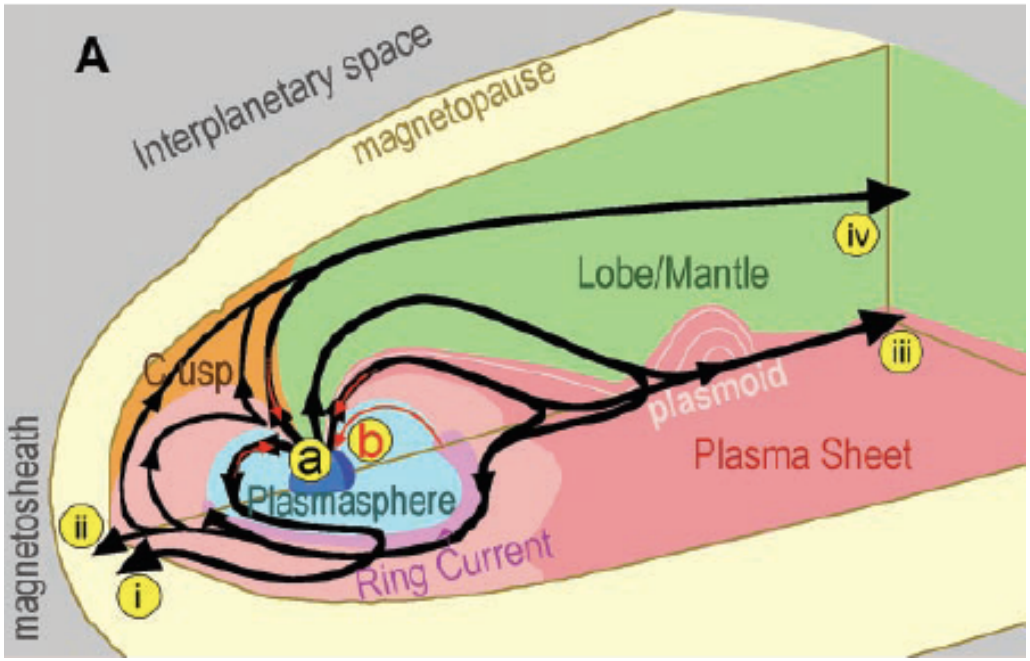
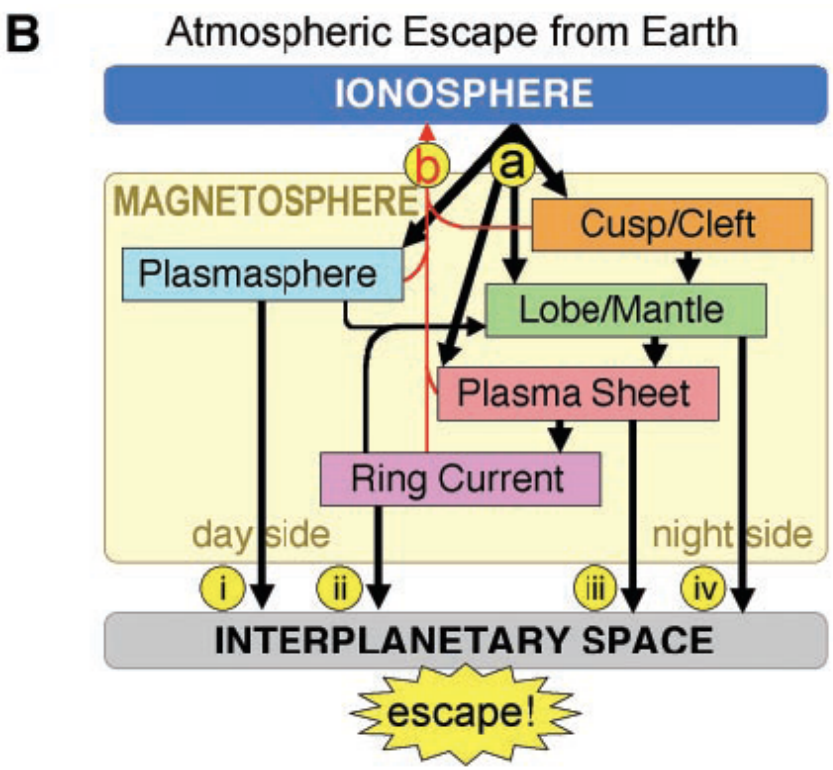
- Reconnection
- Kelvin-Helmholtz Instability
- Kinetic Alfven Waves

Escape Paths of Heavy Ions



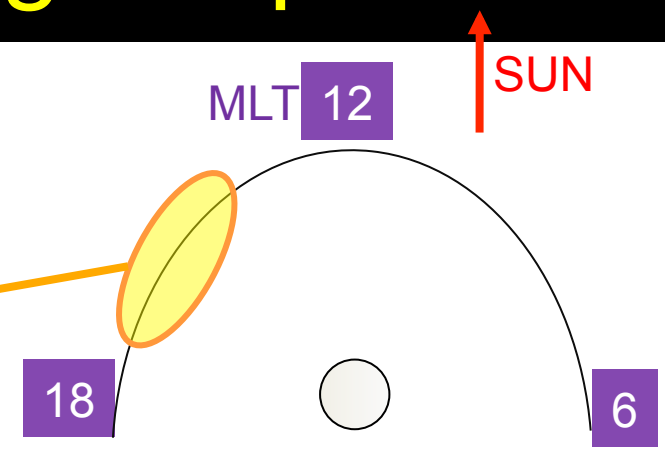


Seki, 2001

Heavy Ions at the Magnetopause

	MSPBL			MSHBL		
Parameter	Dawn	Noon	Dusk	Dawn	Noon	Dusk
O^+ number density (cm^{-3})	0.014	0.021	0.053	4×10^{-3}	6×10^{-3}	0.011
O^+ mean energy (keV)	4.28	3.62	3.85	14.6	14.0	14.4
O^+ poleward velocity (km s^{-1})	57.0	66.9	52.0	88.0	162.5	119.4
O^+ normal velocity (km s^{-1})	2.4	−17.2	5.1	34.8	−16.5	15.6
Probability $P(r>1)$	0.031	0.042	0.306	[illegible]	~0	~0

Bouhram, 2005



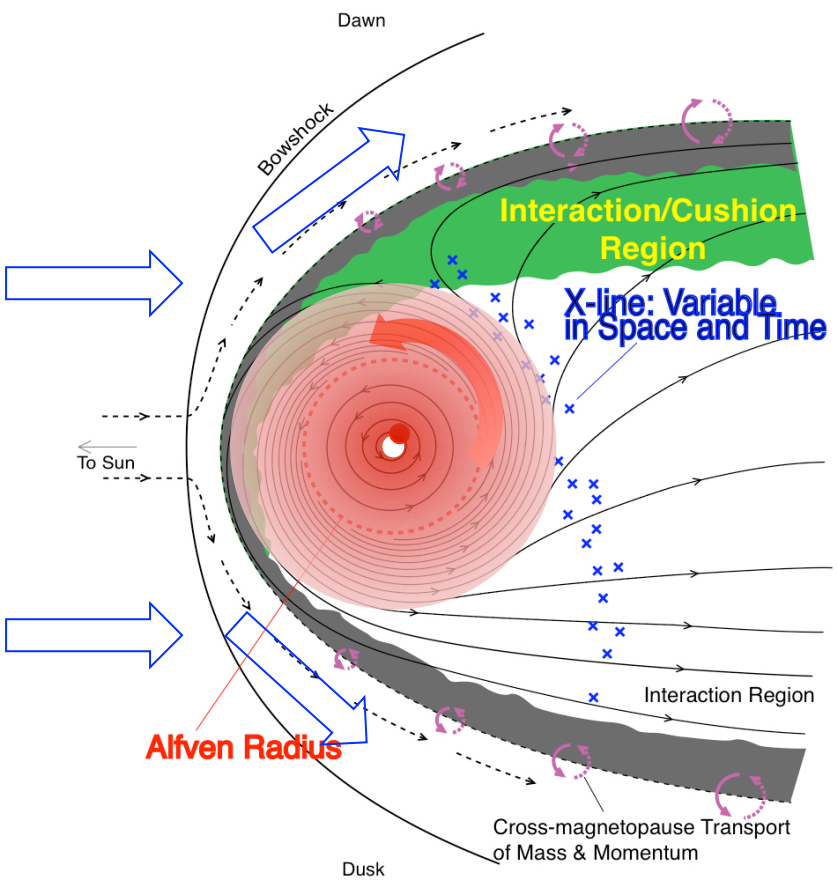
- Heavy ions can dominate the mass content as much as 30% of the time on the dusk flank!!

ISSUE

How do heavy ions affect plasma transport?

Reconnection, Kelvin-Helmholtz, Kinetic Alfven Wave

Transport at Jupiter



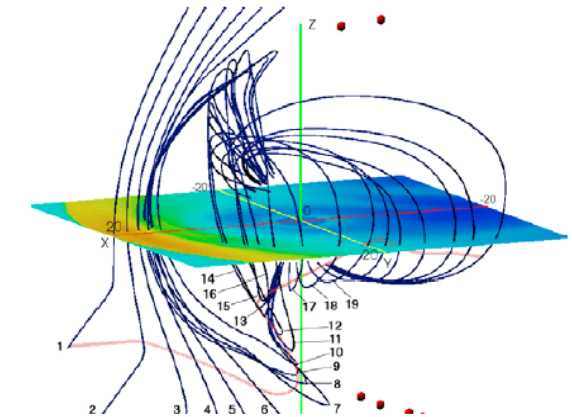
Delamere and Bagenal, 2010

- Iogenic Source of Corotating Heavy Ions Transported Radially Outward
- Dawn-Dusk Flow Asymmetry
- Strong Shears at the Magnetopause Boundary
-

Mechanisms for Magnetopause Transport

Reconnection

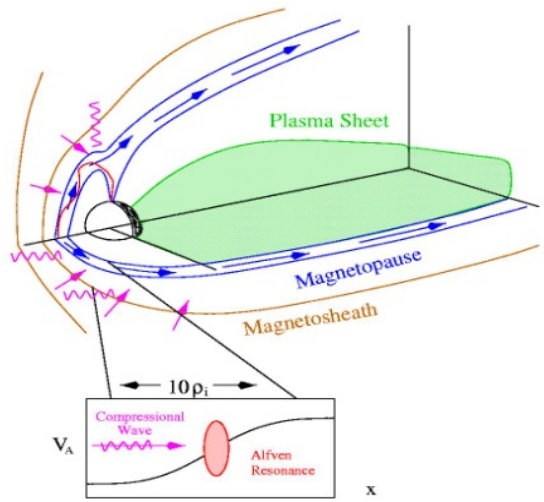
Song and Russell, 1992



Li et al., 2005

Kinetic Alfven Waves

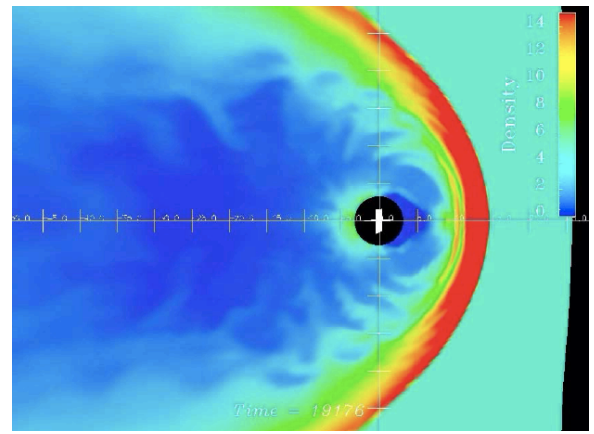
Lee et al., 1994
Johnson and Cheng, 1997



Johnson and Cheng, 1997

Kelvin-Helmholtz Instability

Otto and Fairfield, 2000

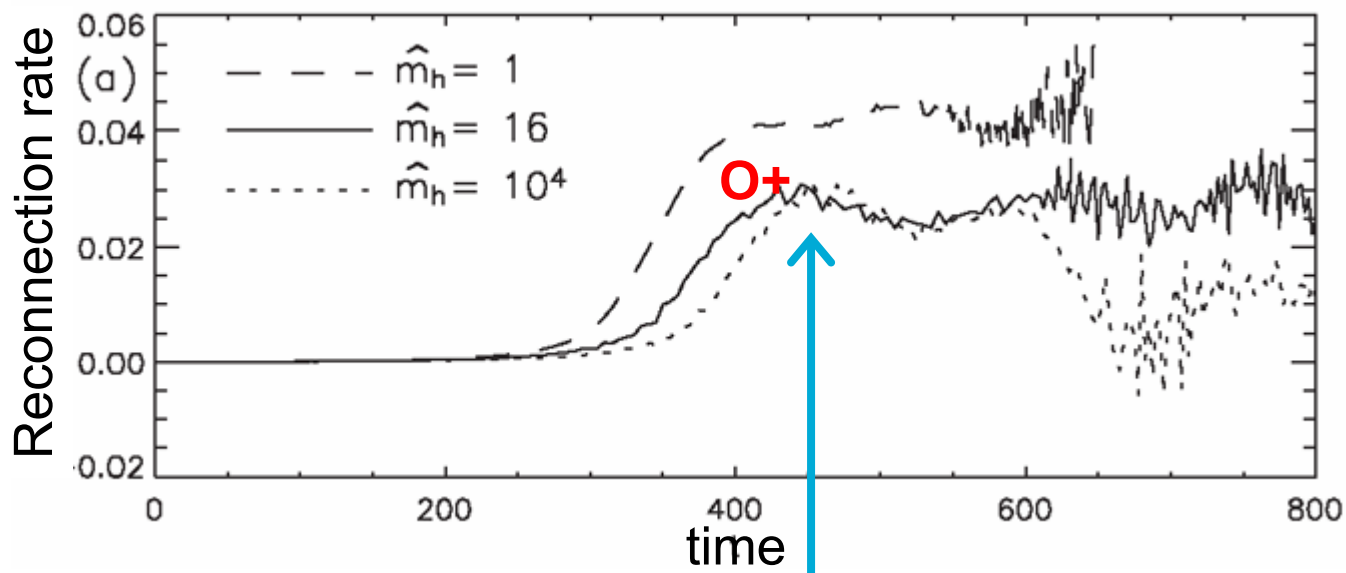


Lyon et al., 2007

Heavy Ions and Reconnection

Proton-electron-heavy ion fluid simulation

Shay and Swizdak, 2004

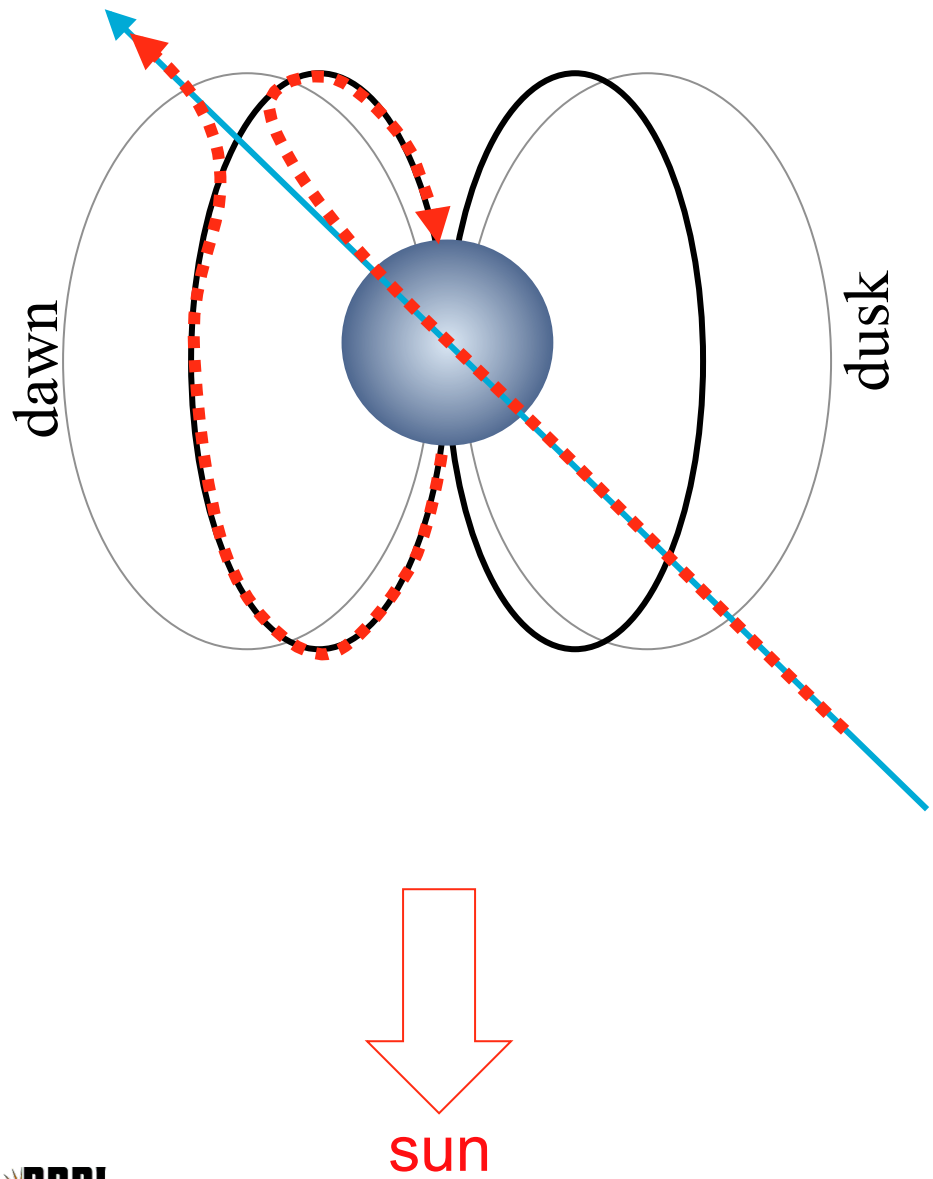


$\hat{m}_h = m_h / m_i$

Reduction of reconnection rate
(V_A is reduced)

A

Implications for Reconnection



- For configurations with **IMF B_y**
- flux transfer in steady state may be favored on the dawn flank (where there is *less oxygen*) and could lead to enhanced mass, momentum transfer on the dawn flank consistent with observations
- Single cusp reconnection could be favored ?

B

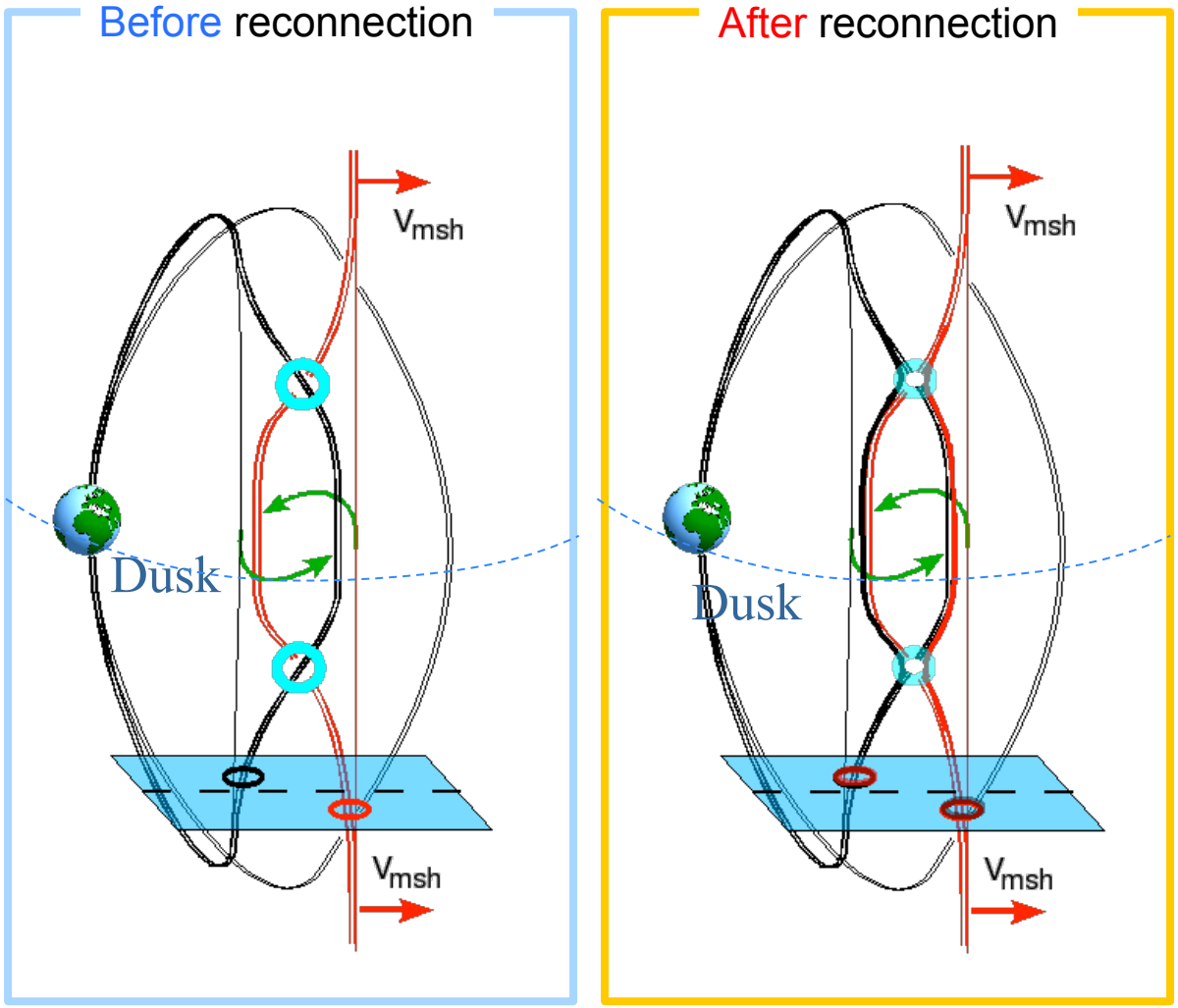
Heavy Ions and Kelvin-Helmholtz

$$(k \cdot V)^2 > \frac{(k \cdot B_{msh})^2 + (k \cdot B_{msp})^2}{4\pi\rho^*}$$

where $\rho^* = \dfrac{\rho_{msh}\rho_{msp}}{\rho_{msh} + \rho_{msp}}$

Heavy ions increase the K-H growth rate by reducing the stabilizing effect of magnetic tension

B Implications for transport resulting from reconnected flux in KH instability



Otto, 2007

Competing Effects

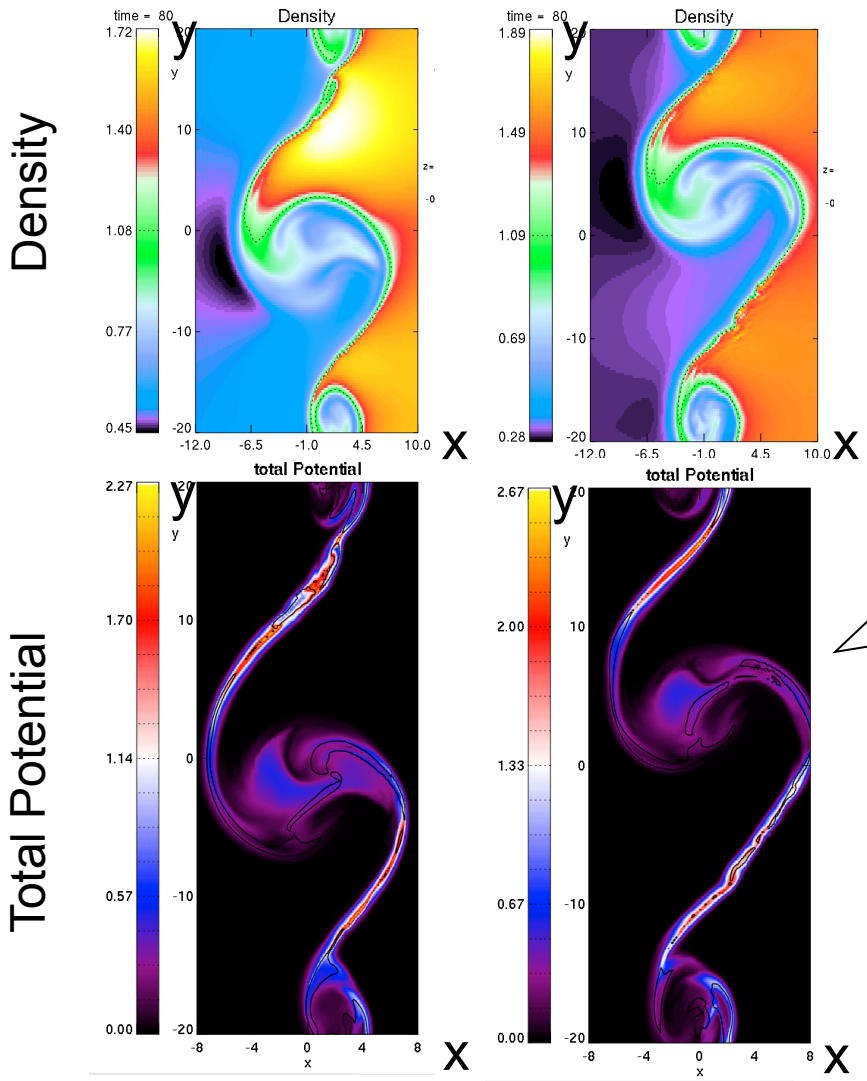
- Increased KH growth
- Reduction in V_A

Question:

Does flux transfer depend more on the interchange of flux (vortex size/growth rate) or on the reduction of V_A ?

B Implications for transport resulting from reconnected flux in KH instability

$\rho_{sphere}/\rho_{sheath}$: 1:3 1:5



Small magnetic shear : 10°

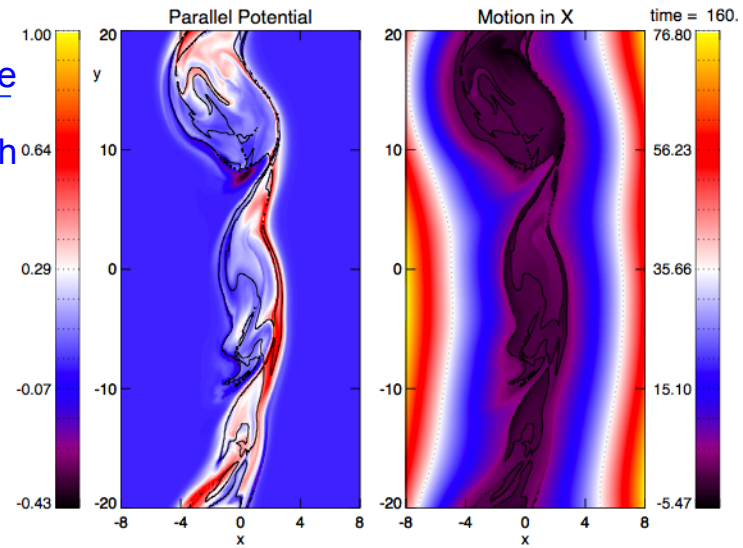
- When vortices form, the reconnection rate adjusts to reconnect the interchanged flux

Integrated potential is a measure of the reconnection rate and is roughly the same

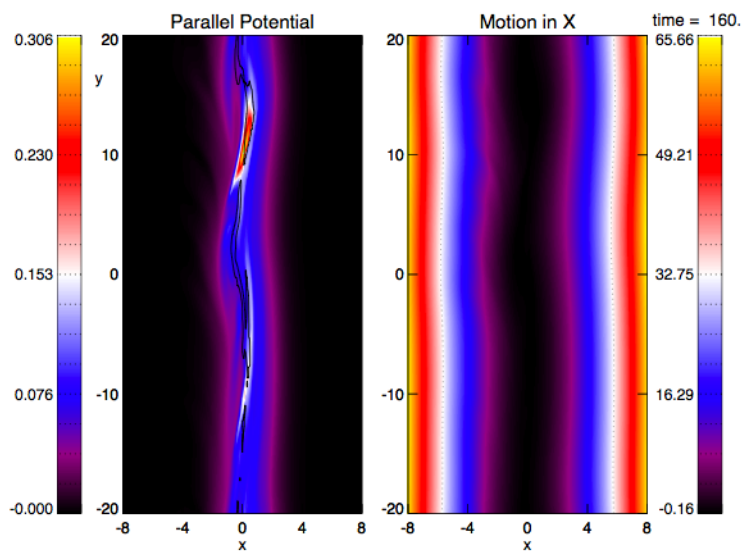
B Implications for transport resulting from reconnected flux in KH instability

$\frac{\rho_{sphere}}{\rho_{sheath}}$

1/3



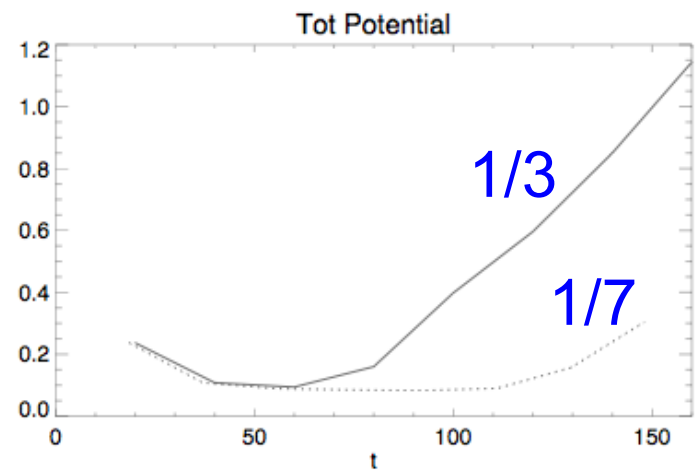
1/7



Large magnetic shear : 70°

Growth rate (→ vortex size) is larger for heavy ions

Reconnection rate larger for heavy ion case because much more flux interchange



B

Implications of MHD for KH

- Reconnection rate is determined more by the line-tying condition (forcing) rather than the Alfven speed
- Effect of Magnetic Shear & Heavy Ions
  - Small shear →
    - Not as much stabilization from heavy ions
    - Not much difference in transport
  - Large shear →
    - More stabilization so KH instability is faster for large mass density (favoring the dusk flank)
    - Expect increased rate of flux transfer
    - More transport and thicker boundary layer

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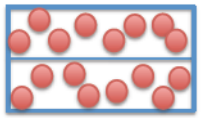
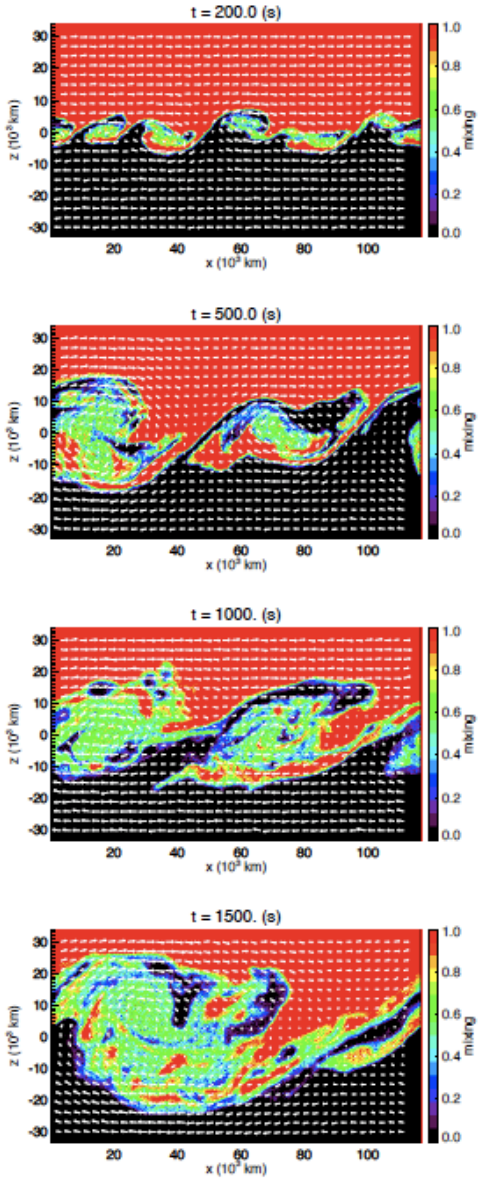
B Hybrid Simulations: Kelvin-Helmholtz





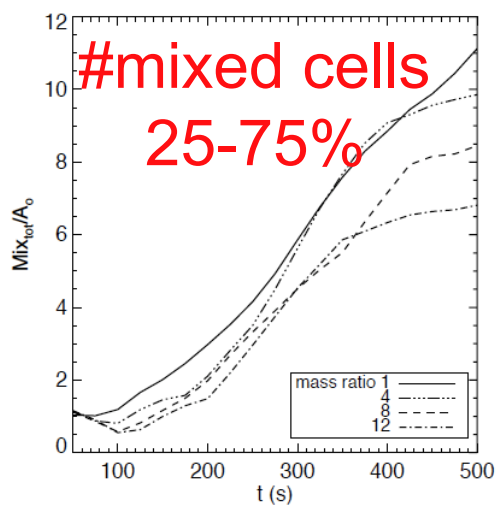
162x328 c/ω_{pi}
M_{ms} = 1.25
ρ_i/L=1/3
B inclined 3°
Ωt ~ 1000

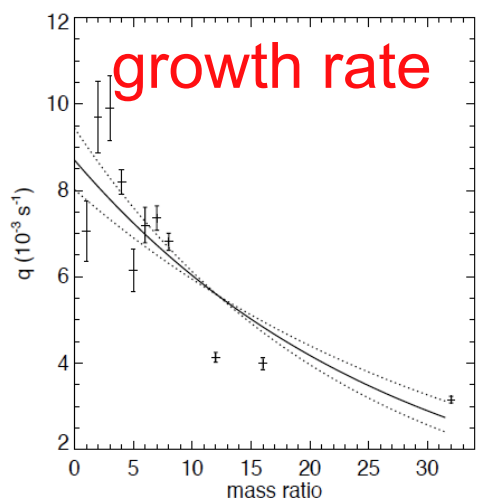
Delamere et al., 2010

Hybrid Simulations:

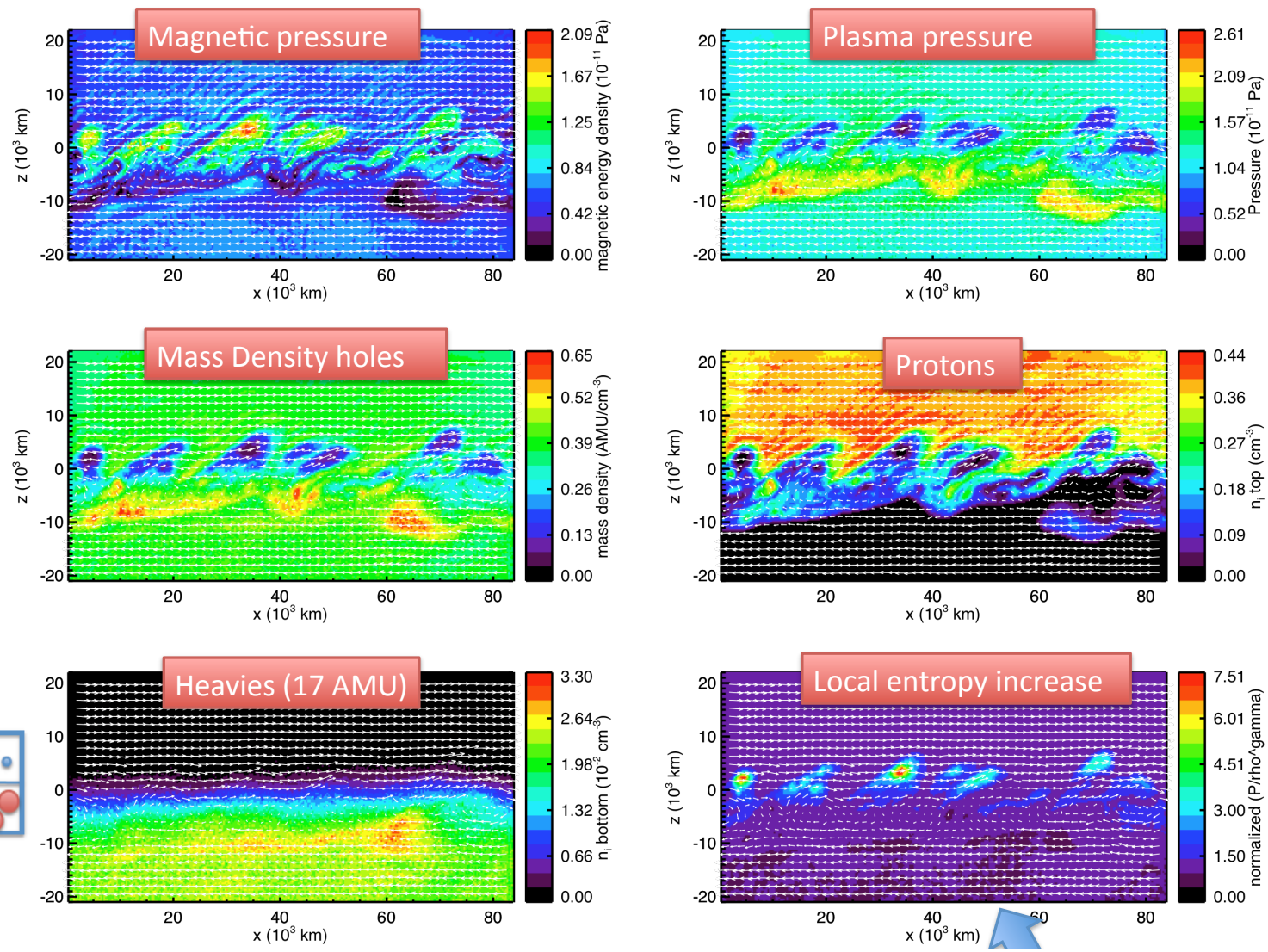
Heavy ions stream through vortices and inhibit growth on ion inertial scales

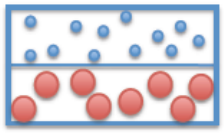
inhibits vortex formation reduces mixing on kinetic scales

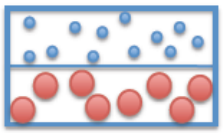




B Heavy Ions Effects on KH Instability

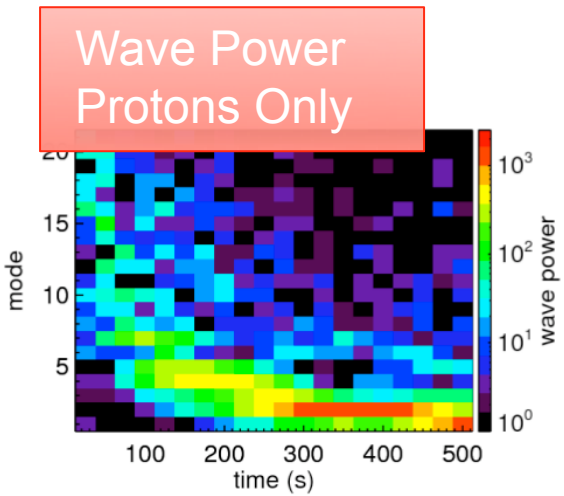




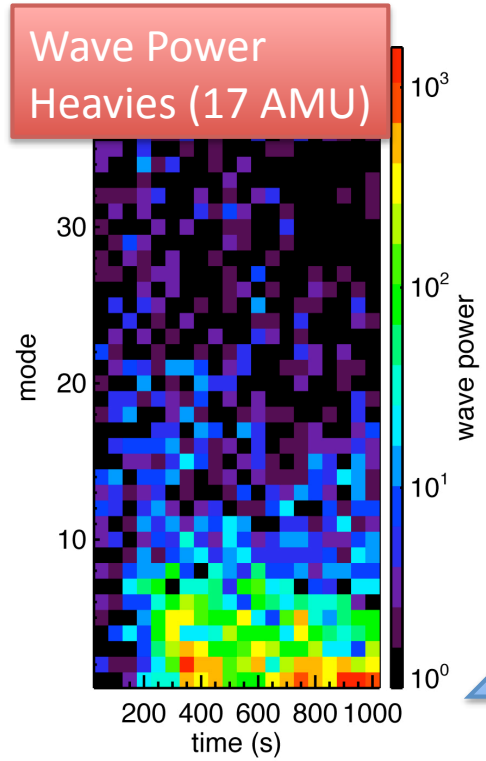


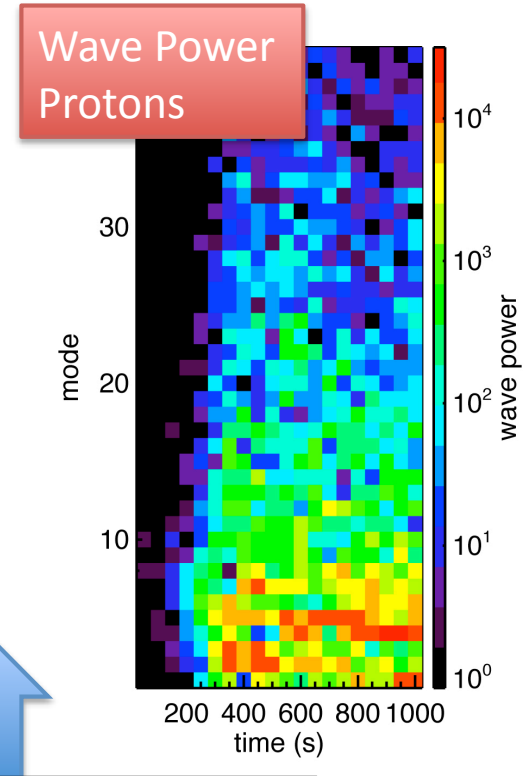
B

Specral Differences



Inverse Cascade:
Coalescence

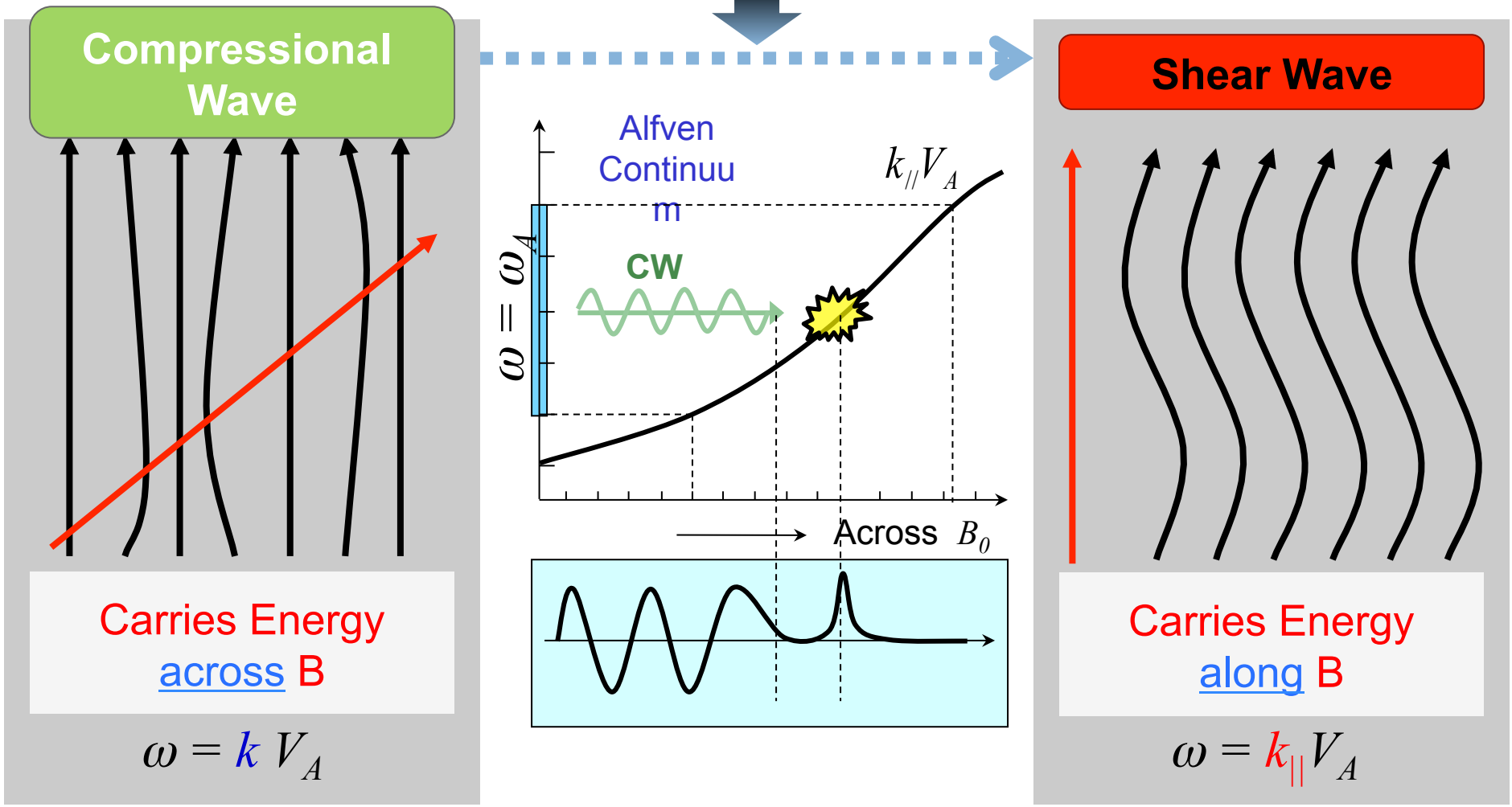




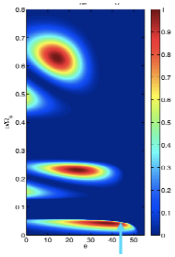
Inverse Cascade:
m=7➔m=1

Forward Cascade:
➔m=5
(Fastest Growing Mode)

c Compressional Waves Mode Convert at the Alfven Resonance



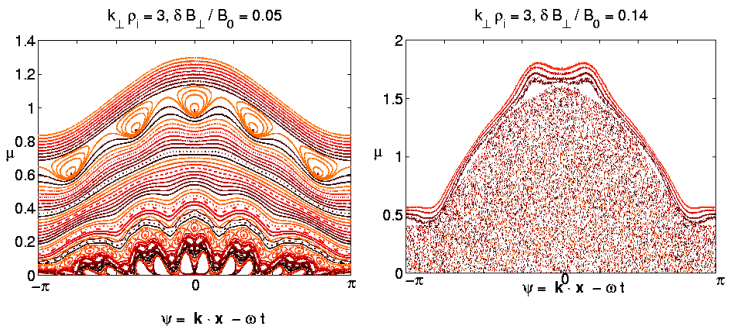
Heavy Ion Effects on KAWs



- Ehnahced wave absroption at low freq
- Increase parallel electric field ($E_{||}$~m_i)
- Reduce threshold for stochastic heating of heavy ions

$$k_y x_p = k_y E_y/(B\Omega) \sim 1$$

➔ $E_y \sim 1/m$



- Enhance light ion transport

$$D_{\mu\nabla\delta B} \sim 2\pi k_y^2 \rho_i^2 \frac{v_i^2}{|k_z|} \left|\frac{\delta B_{||}}{B_0}\right|^2 f_{i,res} \sim 2 \left|\frac{\delta B_{||}}{B_0}\right|^2 \left|\frac{T}{e\psi}\right|^2 D_{HM}$$

$$\psi, \delta B_{//} \propto \rho_{mass}$$

$$f_o \sim e^{-\frac{7\sim16}{\beta}} \qquad f_H \sim e^{-\frac{1}{\beta}}$$

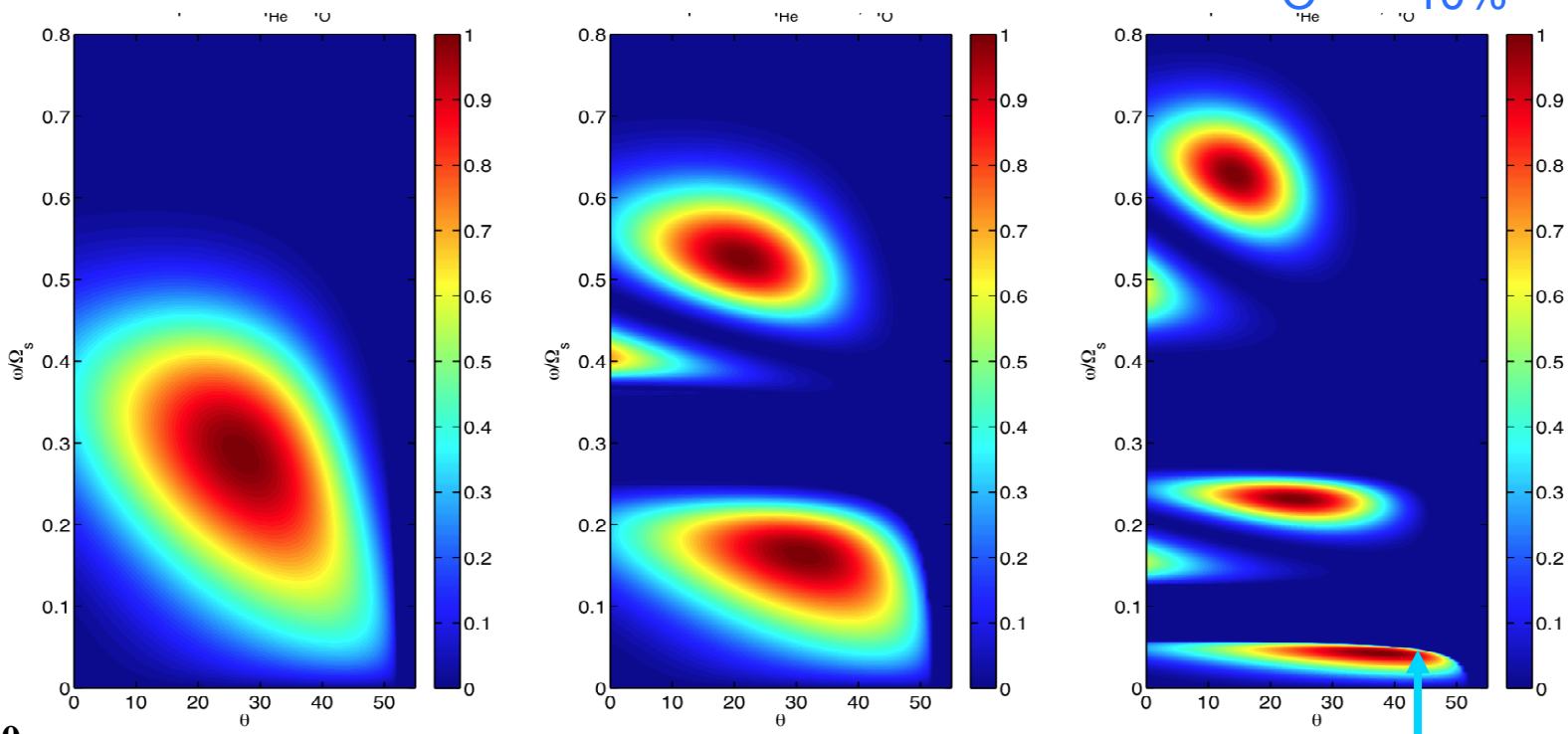
Efficiency of Mode Conversion is Enhanced at Low Frequency by Heavy Ions

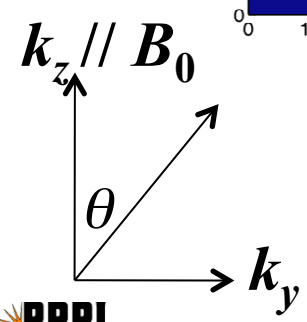
H^+ = 100%

H^+ = 90%
He^+ = 10%

H^+ = 80%
He^+ = 10%
O^+ = 10%

Frequency





Normalized to f_{ci} at resonance

At MP~25 mHz
(Pc3 range)

c Mass dependence Quasilinear Transport

$qE_{\parallel}$ force

$$D_{HM} \sim \pi \frac{k_y^2 \psi^2}{|k_z| B_0^2} f_{i,res} \sim \pi \frac{k_y^2 E_z^2}{k_z^2 |k_z| B_0^2} f_{i,res}$$

$D_{HM} \sim 2\times10^9 m^2/s$

$qV_D \times \delta B_{\perp}$

$$D_{V_d \times \delta B_{\perp}} \sim \pi \frac{k_y^2 \phi^2 \omega_d^2}{|k_z| B_0^2 \omega^2} f_{i,res} \sim \frac{k_y^2 v_i^2}{\omega^2} \left(\frac{\rho_i}{L_B}\right)^2 \left|\frac{\phi}{\psi}\right|^2 D_{HM}$$

$D > 100 D_{HM}$

$-\mu \nabla \delta B$ force

$$D_{\mu \nabla \delta B} \sim 2\pi k_y^2 \rho_i^2 \frac{v_i^2}{|k_z|} \left|\frac{\delta B_{\parallel}}{B_0}\right|^2 f_{i,res} \sim 2 \left|\frac{\delta B_{\parallel}}{B_0}\right|^2 \left|\frac{T}{e\psi}\right|^2 D_{HM}$$

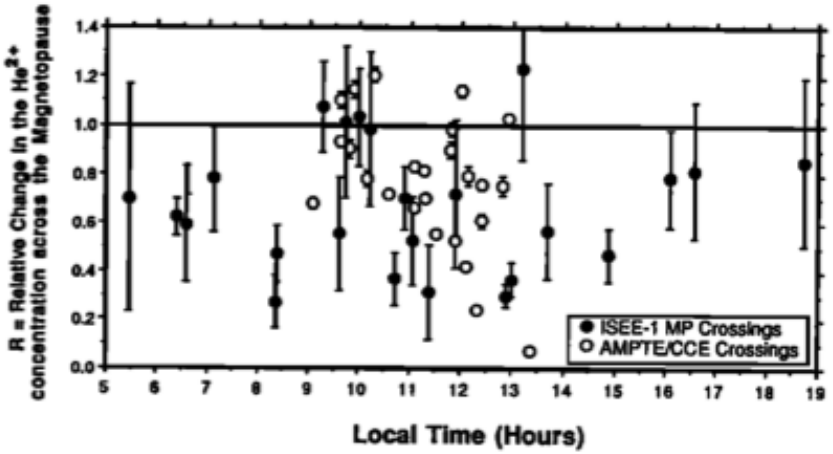
$D > 100 D_{HM}$

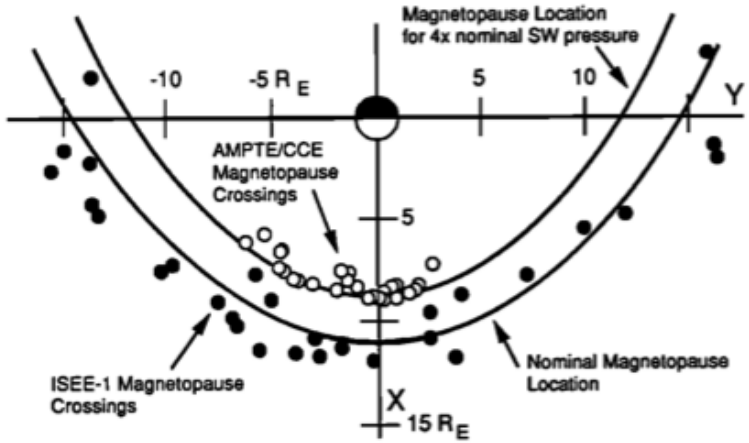
$$\psi, \delta B_{//} \propto \rho_{max}$$

$$f_c \sim e^{-\frac{7\sim16}{\beta}} \qquad f_H \sim e^{-\frac{1}{\beta}}$$

Magnetopause is a Filter of Heavy Ions

Overall about 40% reduction of He^{2+} at dawn flank and 17% at dusk flank





Fuselier et al., 1997

Key Points

- Heavy Ions Can Affect Magnetopause Entry

- Reconnection (Alfven velocity)
  - Increased transfer of momentum at dawn?
- Kelvin-Helmholtz
  - Increased growth rate can lead to larger transport in MHD
  - Heavies stream across vortices due to large inertia inhibiting growth and size of vortices in hybrid simulations
  - Heavy ion transport barrier
  - MHD favors dusk, hybrid favors dawn
- KAWs
  - More wave absorption
  - Heavy ions heated
  - Light ions transport more efficiently

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