Optimal Navigation in a Plasma Medium

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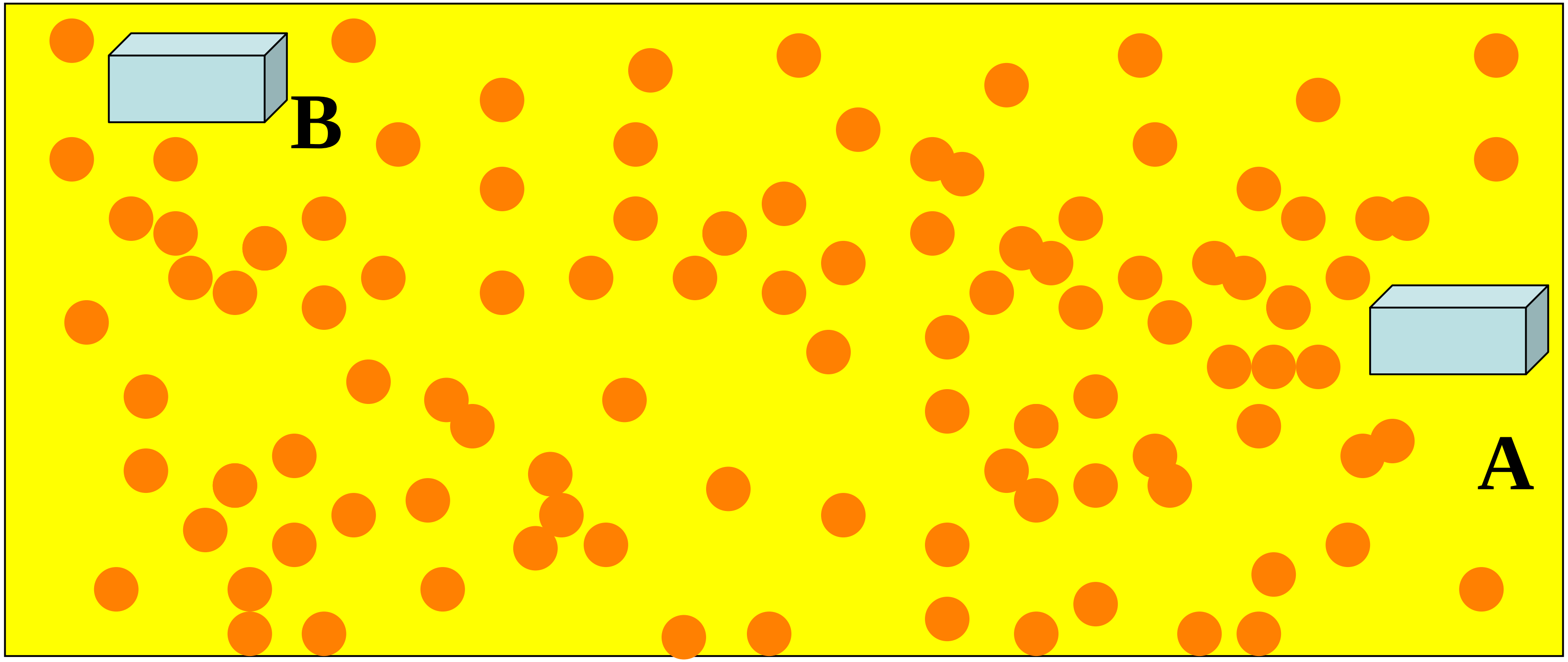
NIAC Phase I Report

Arlington VA

March 24, 2004

Constraints on Travel



Get from A to B
incurring the least energy cost in finite time

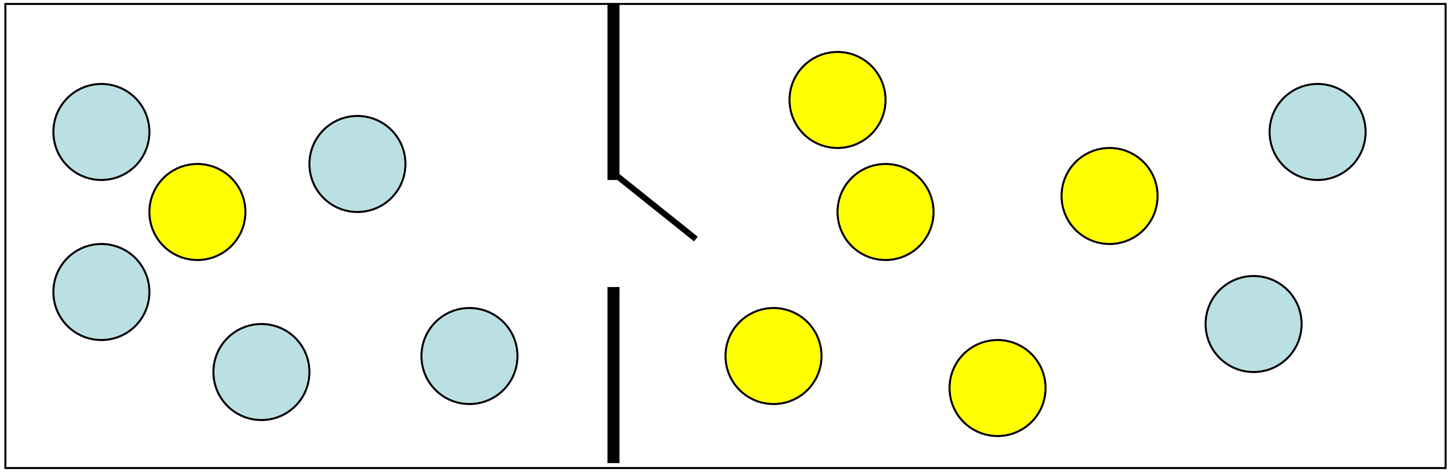
Entropy in Travel

Suppose travel from point A to point B in a frictional medium. If the friction is proportional to v, then the power dissipated is proportional to v^2. Since the time of travel varies inversely with v, it means that the energy spent goes as v. So small energy consumption is at the expense of long travel time.

However, this argument is dynamic (depends on friction model), not statistical mechanical. In principle, in moving from point A to point B, the entropy of the system can be left constant. Travel in finite time at zero energy consumption does not appear to be excluded by thermodynamic arguments.

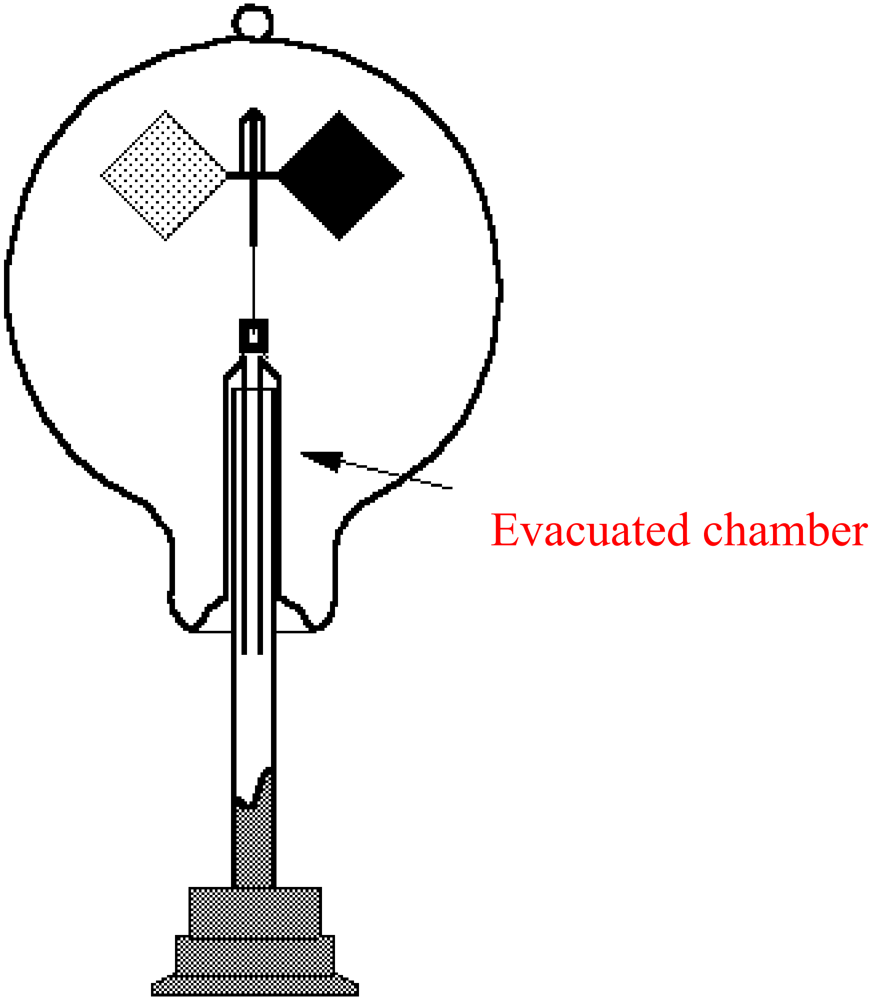
Accessing Ambient Momentum

"Maxwell demon" cannot change entropy



But what about riding long wavelength ambient equilibrium fluctuations. Note: in plasma long wavelength fluctuations dominate energy spectrum.

Radiometer

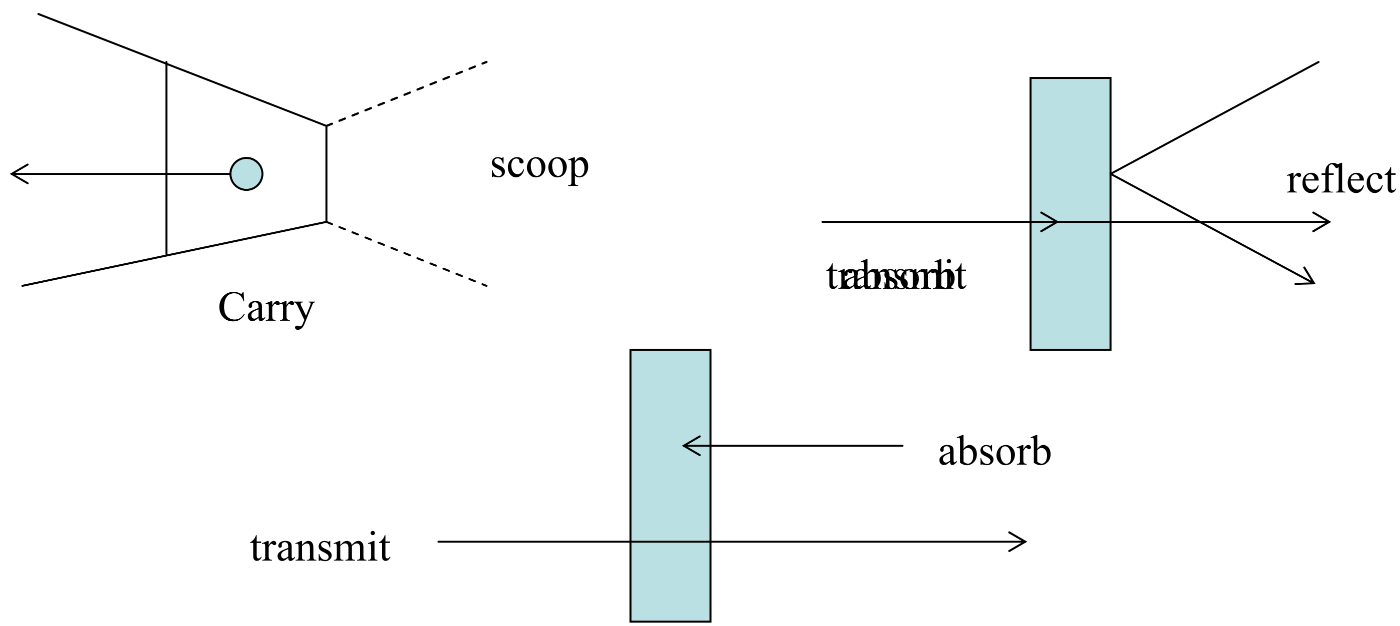


Depending on how "evacuated" the chamber is, the radiometer spins one way or the other

Momentum Transfer to Plasma Medium

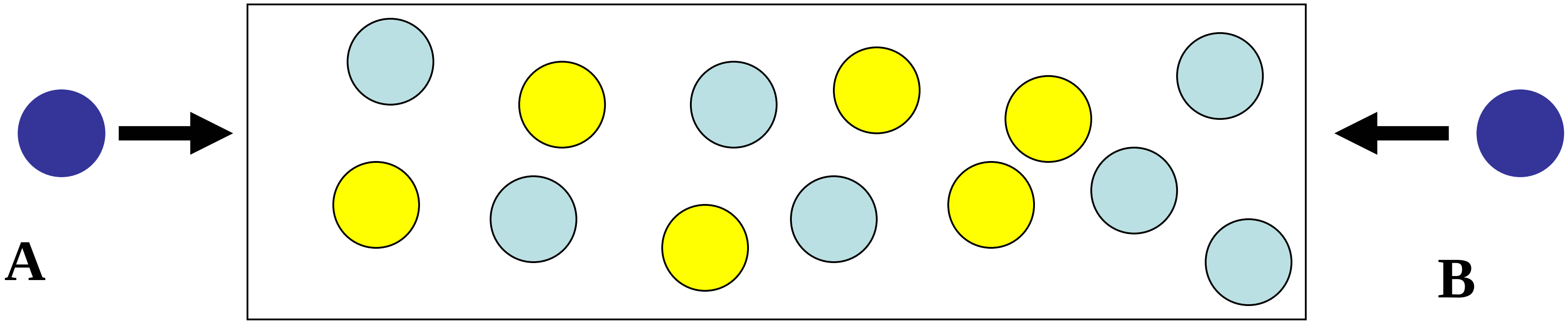
1. Passive (compare to radiometer)
2. Active (make medium active)
3. Hamiltonian vs Dissipative constraints
4. Eject plasma waves
5. Use large scale fluctuations (Szilard engine)

Propulsion Paradigms



"Accessing" Ambient Momentum

Suppose incoming momentum streams do not collide the same amount with target plasma

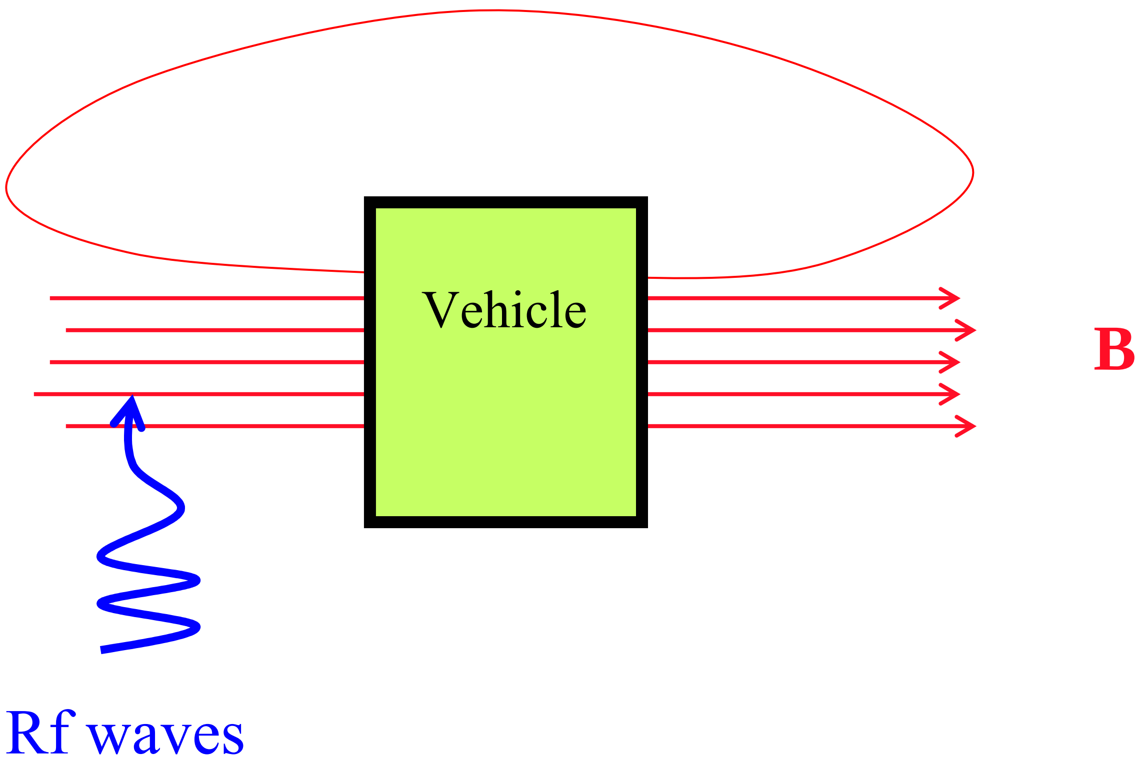


There are equal numbers of ambient particles impinging on plasma trap.

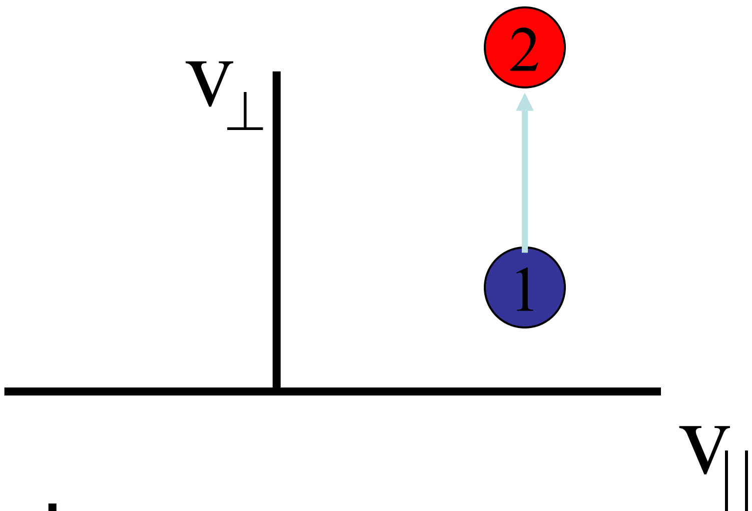
Suppose particle **B** is more collisional than particle **A**. Then it drops more momentum in the trap than does particle **A**. We put energy into particle **A** to accomplish this.

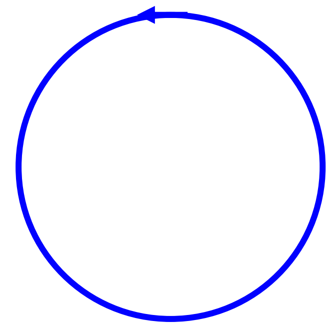
But it might be efficient to do so. And it uses no propellant.

Asymmetric Momentum Transfer (active)

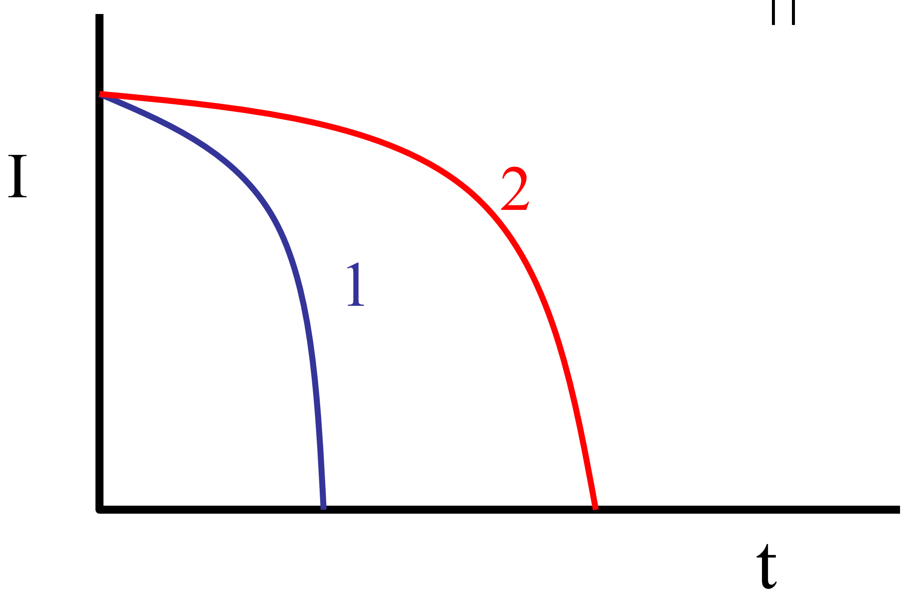


Asymmetric Slowing Down in Plasma





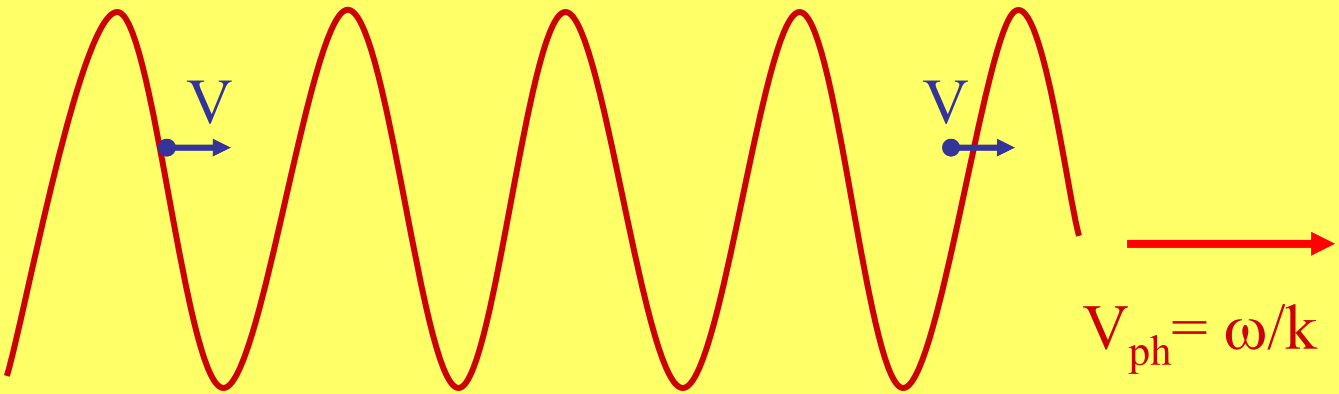
Cyclotron motion



$$\omega - \vec{k}\cdot\vec{v} = n\Omega$$

$$\Omega \equiv eB/m$$

Radio Frequency "Surfing" Effect



Resonance condition

$$\omega - \vec{k} \cdot \vec{v} = 0$$

$$\mathrm{v} \rightarrow \mathrm{v} + \Delta \mathrm{v}$$

$$J = en\Delta \mathrm{v}$$

$$\Delta E = mn\mathrm{v}\Delta \mathrm{v}$$

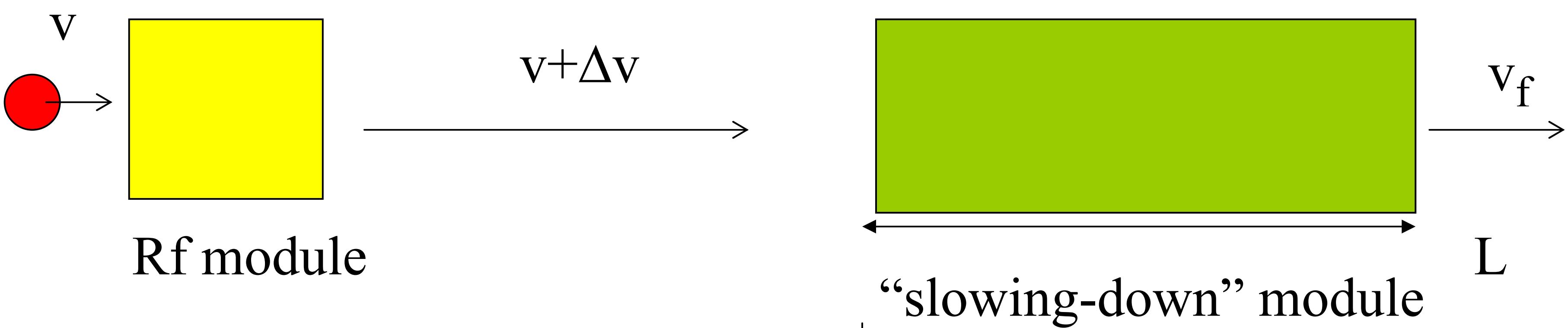
$$P_{\mathrm{D}} = \nu \Delta E$$

$$J/P_{\mathrm{D}} = e/m\mathrm{v}\nu(\mathrm{v})$$

$$\nu(\mathrm{v}) \approx \mathrm{v}^{-3}$$

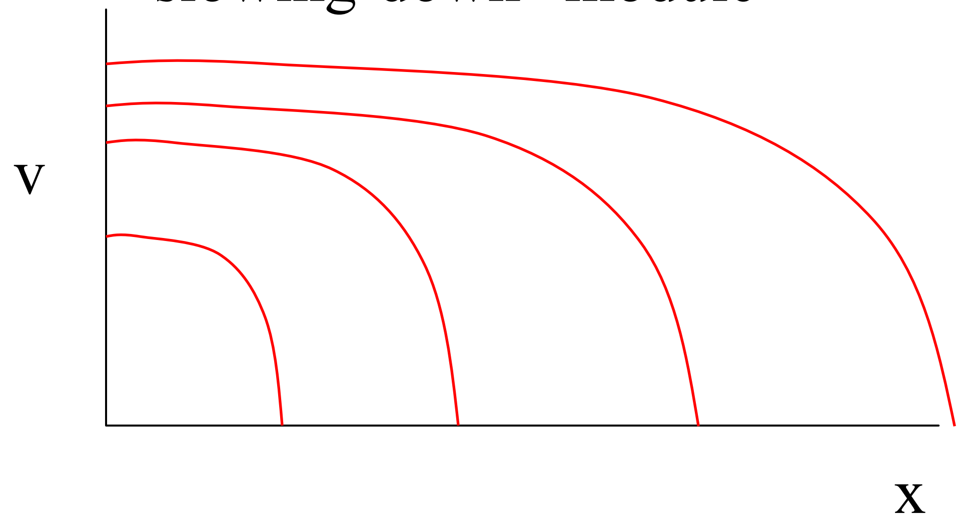
Fisch (1978)

Examples of Asymmetric Absorption (1D)



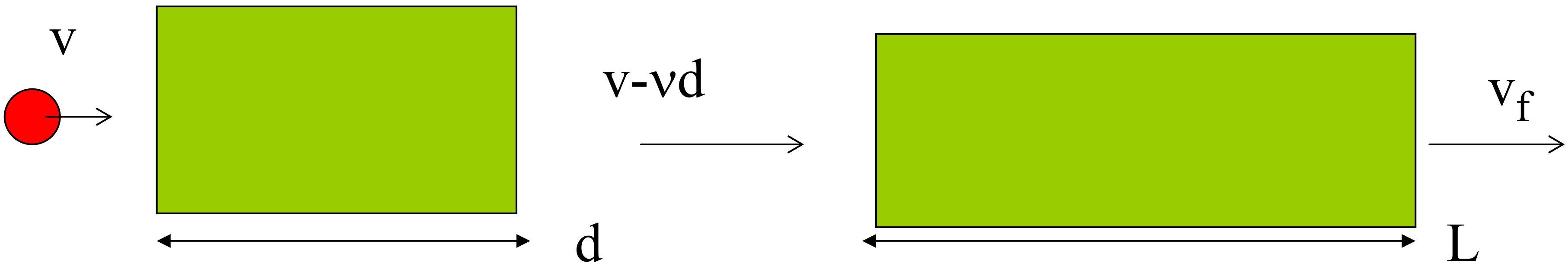
$$\frac{dv}{dt} = v\frac{\partial v}{\partial x} = -\frac{\Gamma}{v^3}v$$

$$v(x, v_0) = \left(v_0^4 - 4\Gamma x\right)^{1/4}$$



Momentum transfer is “anomalous” if $\frac{d\left(v_0 - v_f\right)}{dv_0} < 0$

Passive Asymmetric Absorption



“slowing-down” module I

$$\frac{dv}{dt} = v\frac{\partial v}{\partial x} = -w$$

“slowing-down” module II

$$\frac{dv}{dt} = v\frac{\partial v}{\partial x} = -\frac{\Gamma}{v^3}v$$

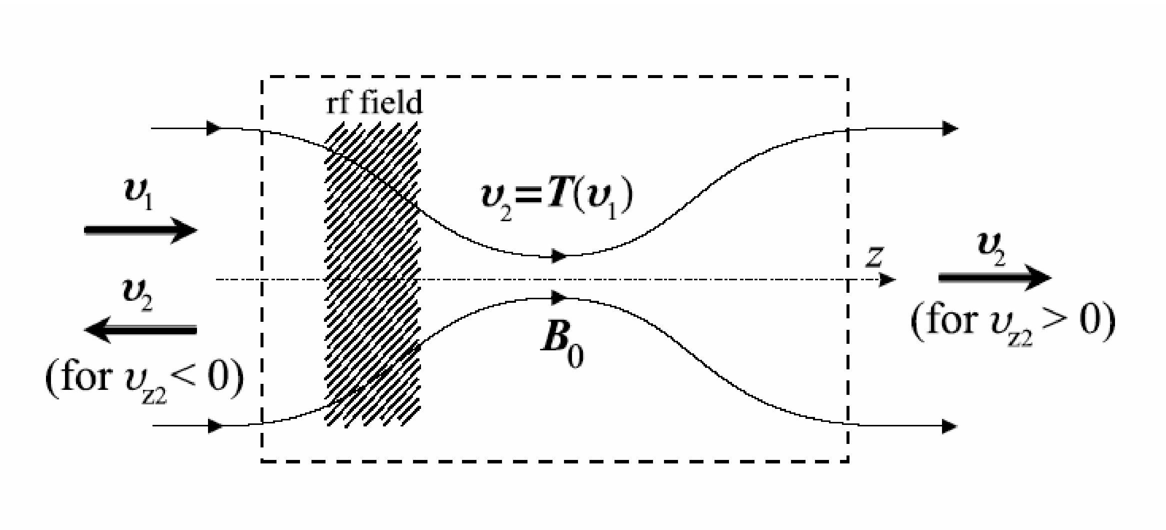
Particles coming from left suffer small slowing down in module I which results in large slowing down in module II,

if v_f(v-νd,L)≅0.

Yet particles coming from right have small slowing down in module II and then small slowing down in module I

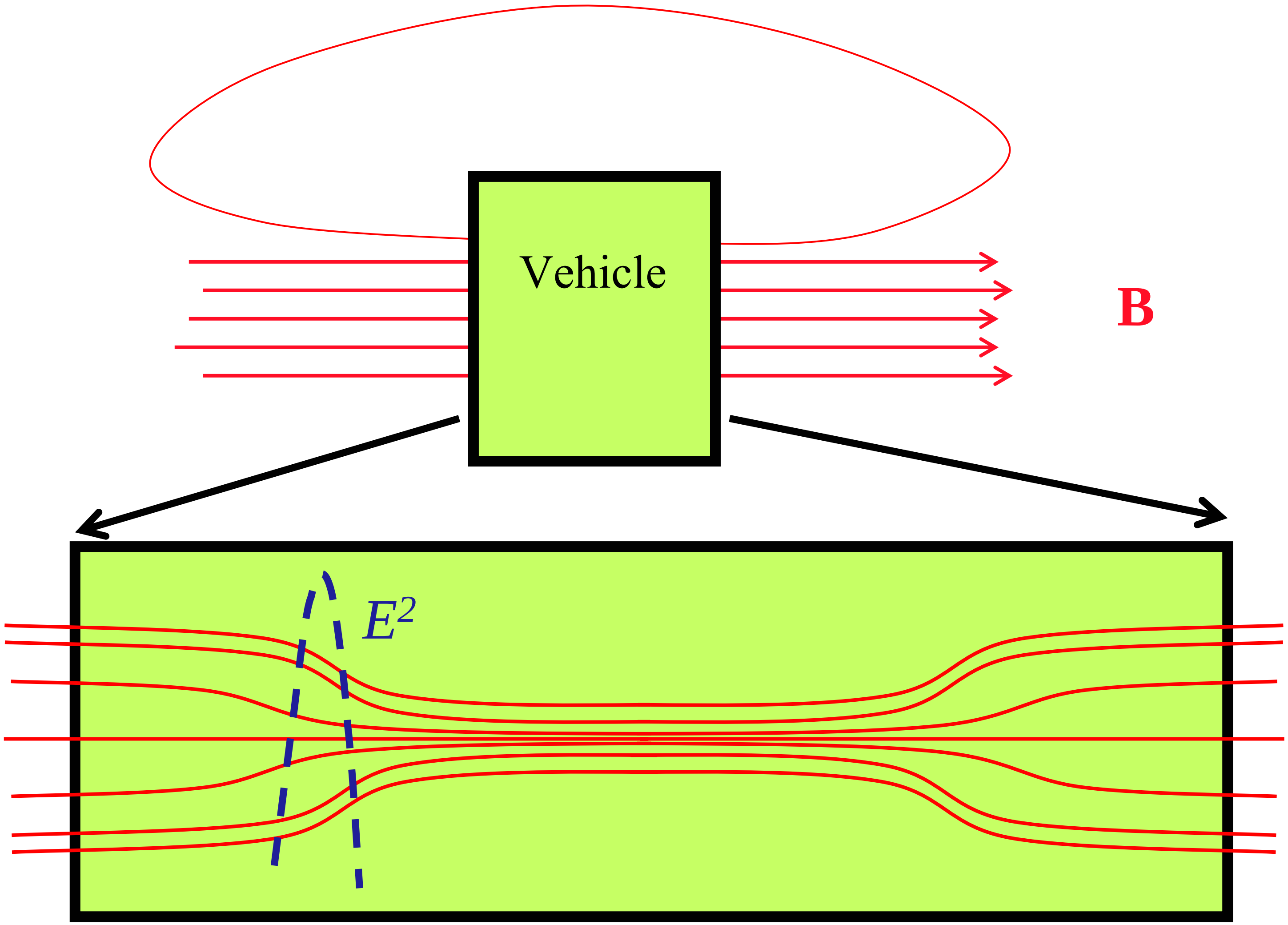
Accessing Ambient Momentum -- non-dissipative

Suppose incoming momentum streams do not collide the same amount with target plasma

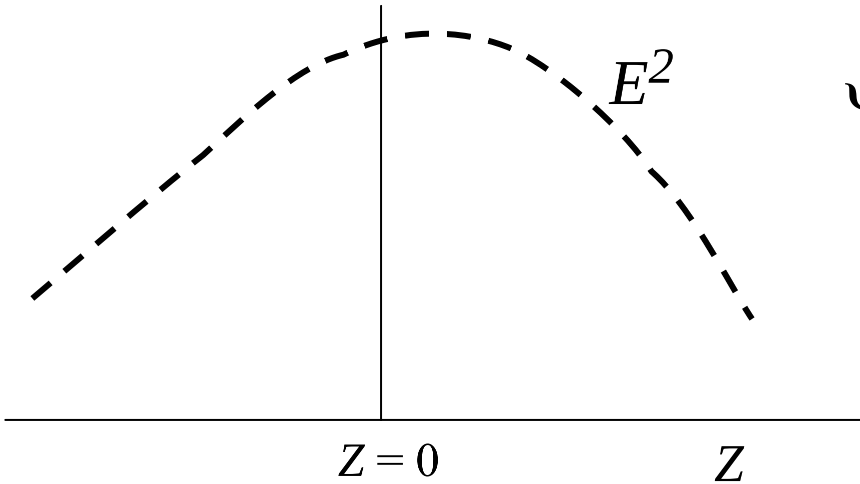


For example, try a ponderomotive potential with sign reversal
So-called "one-way magnetic wall"

Implementation of Asymmetric Ponderomotive Force



Usual (Symmetric) Ponderomotive Potential



$$\Psi(z) = \frac{1}{2} m v_{osc}^2(z) \left[\frac{\omega^2}{\omega^2 - \Omega^2} \right]$$

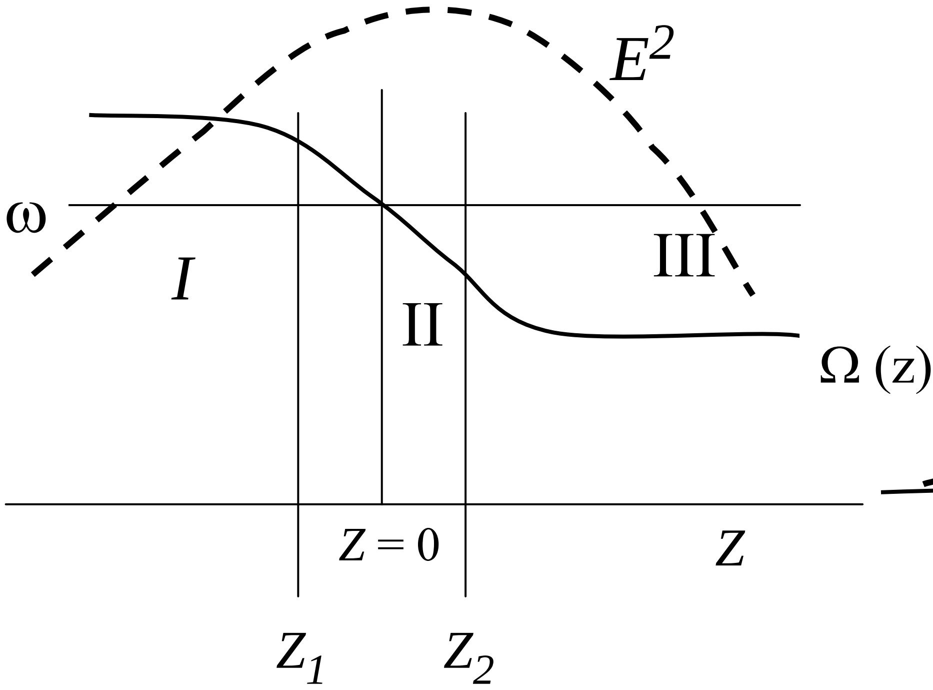
Ponderomotive Potential

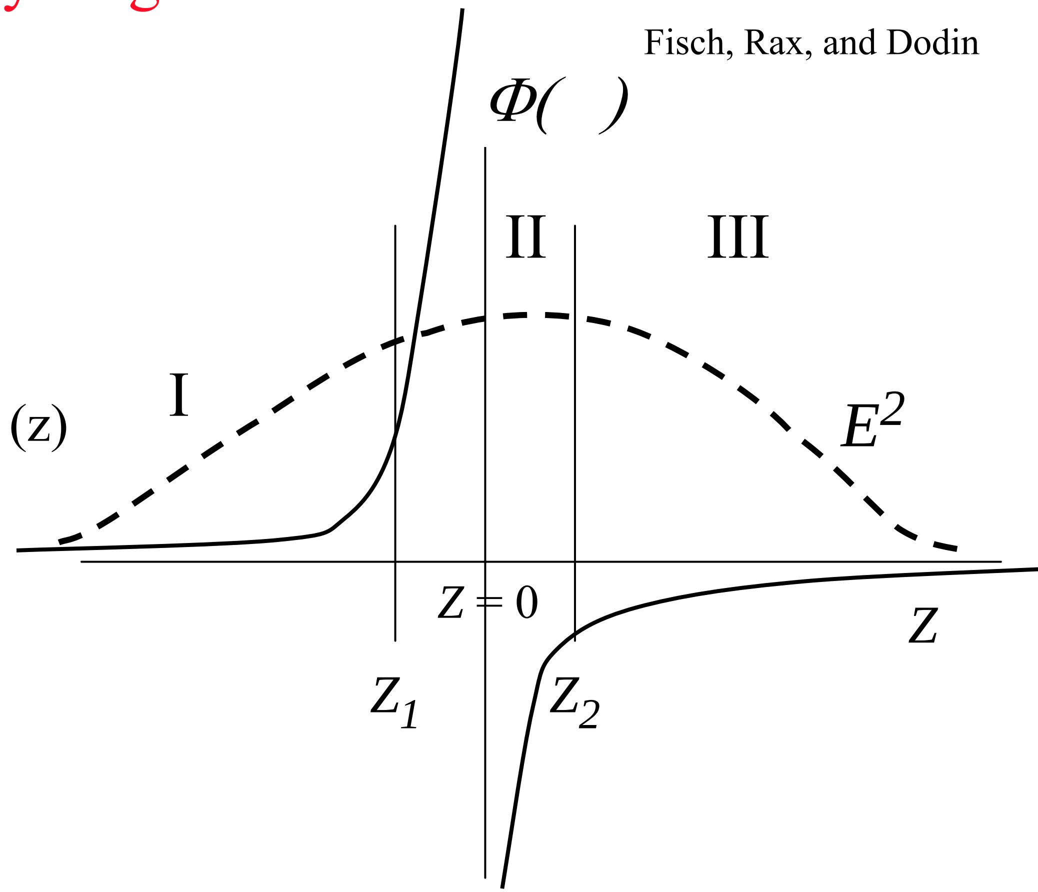
Suppose Ω= Ω(z)

$$\psi(z) = \frac{1}{2} m v_{osc}^2(z) \left(\frac{\omega}{\omega - \Omega(z)} + \frac{\omega}{\omega + \Omega(z)} \right)$$

Ponderomotive Force with Resonance and Sign Reversal
"one-way magnetic wall"

Fisch, Rax, and Dodin





$$\psi(z) = \frac{1}{2} m v_{osc}^2(z) \left(\frac{\omega}{\omega - \Omega(z)} + \frac{\omega}{\omega + \Omega(z)} \right)$$

Asymmetric ponderomotive barrier

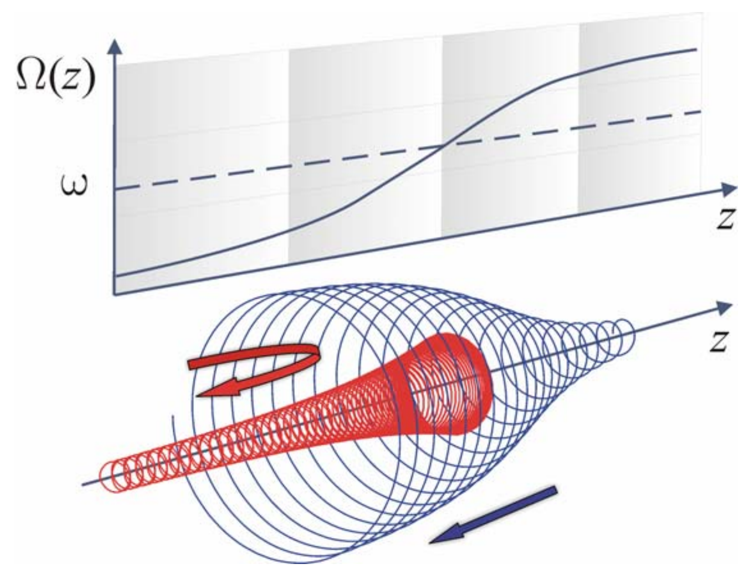
Ponderomotive barrier
without dc magnetic field

QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

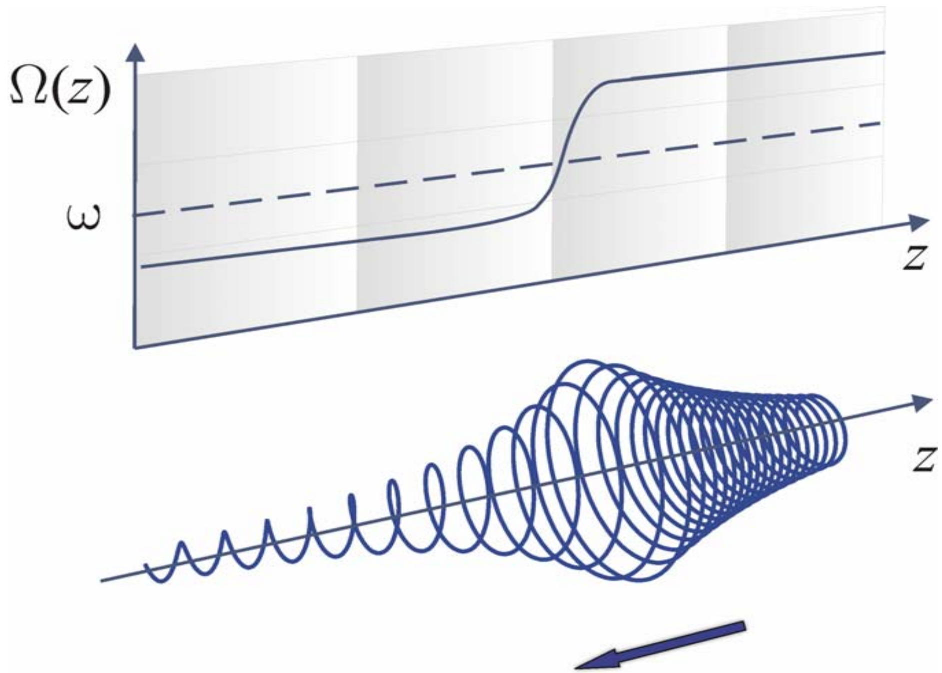
rf wave region

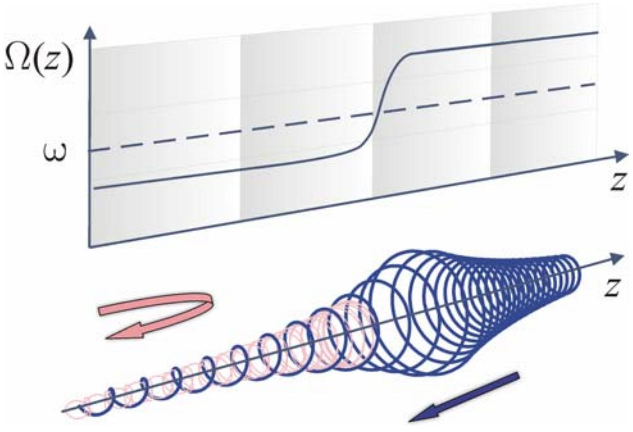
Resonant ponderomotive barrier
with nonuniform dc magnetic field

QuickTime™ and a
Cinepak decompressor
are needed to see this picture.



Asymmetric barrier with reduced heating





QuickTime™ and a
Cinepak decompressor
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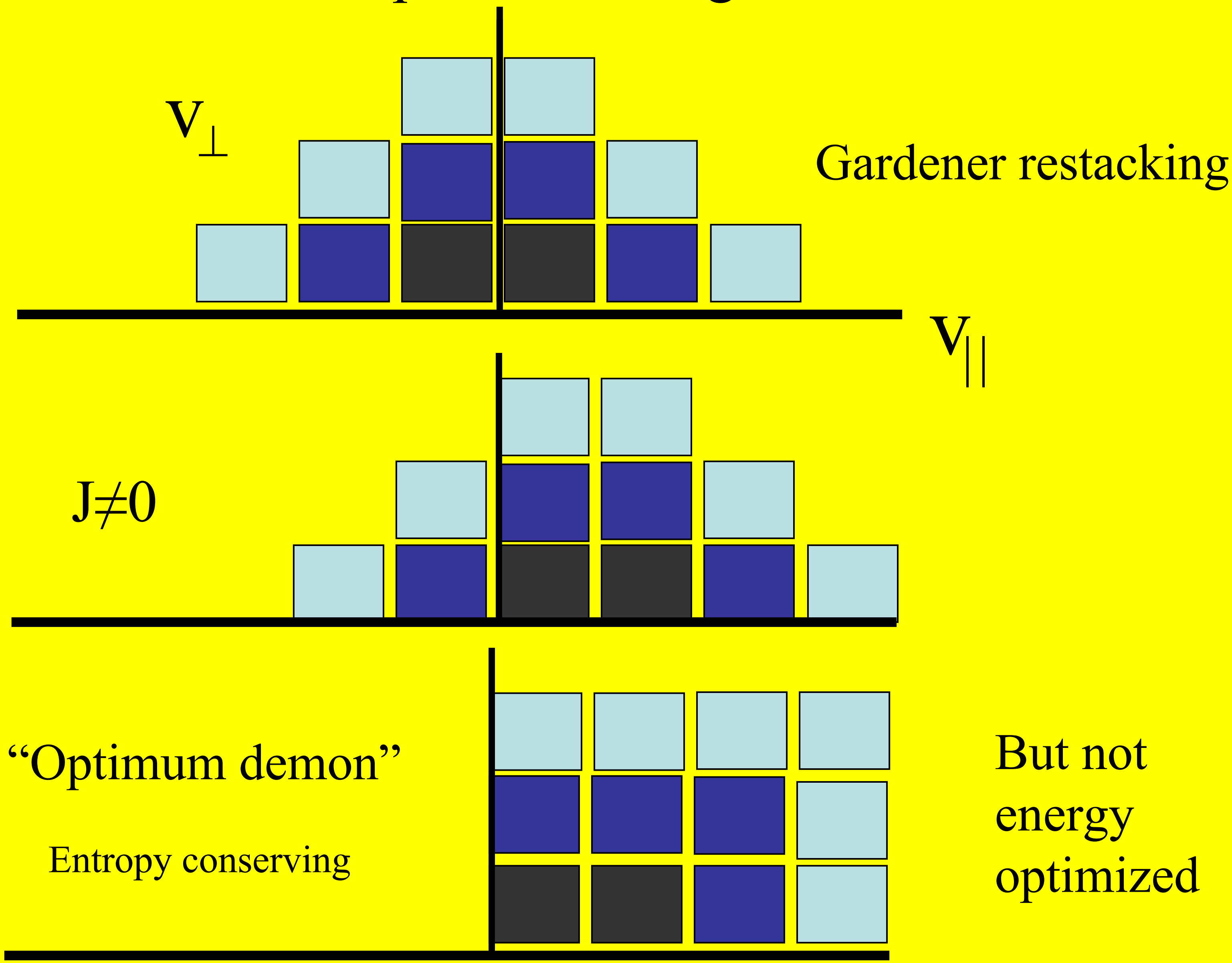
Phase Space Rearrangements



Summary

Advantages of Plasma

1. Capture and hold plasma particles (propellant utilization)
2. Passive asymmetric momentum transfer
3. Active momentum control (dissipative or Hamiltonian)
4. Reject momentum using plasma waves
5. Reject heat at low frequency using plasma waves (speculative heat engine)
6. Exploit long scale equilibrium fluctuations for navigation (speculative Maxwell demon)