International Astronomical Union - Opportunities

Regional Office for Astronomy for Development:
http://www.astro4dev.org/regional-offices-contacts/

If based in Africa, to sign up to the Africa astronomy mailing list at this link:
https://list.saao.ac.za/wws/info/africalist We do forward many opportunities to this mailing list.

Plasmas

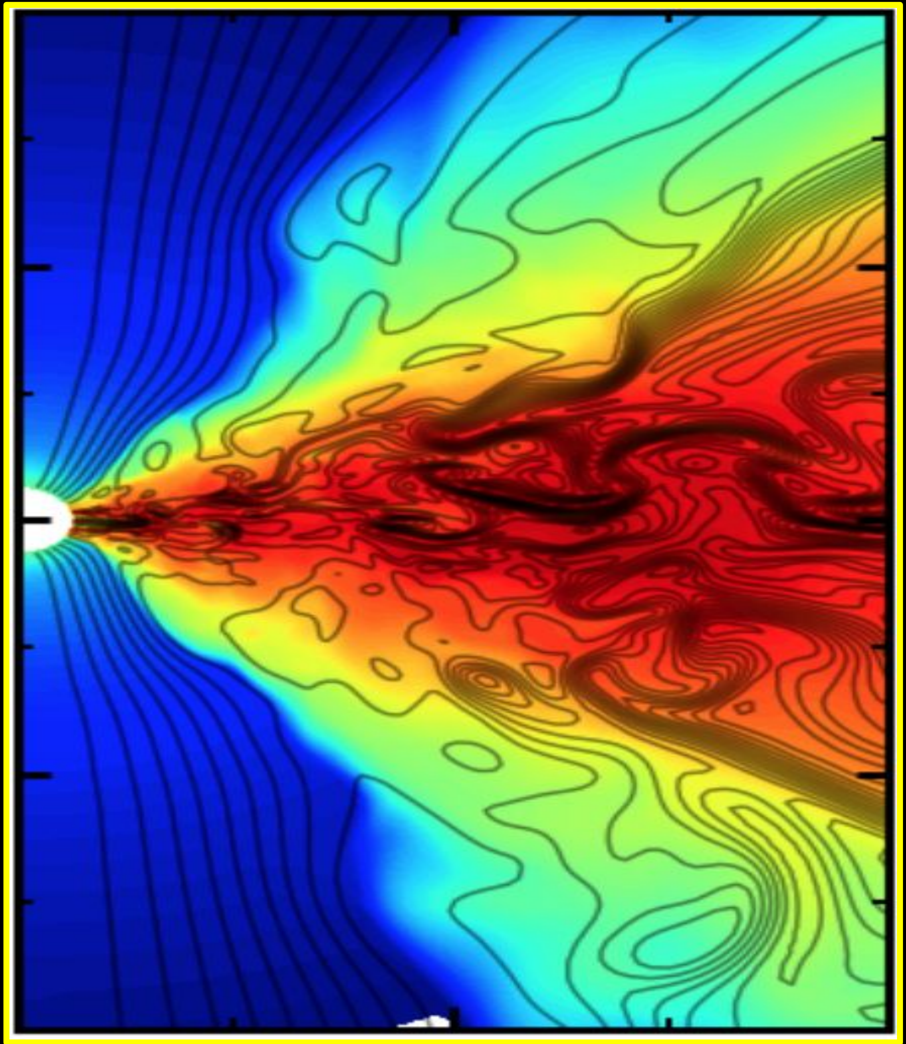
Why do I care??

When do I care??

So far, ideal MHD:

- Maxwell's equations (with infinite conductivity; B-flux frozen in to fluid)

- Fluid equations (conservation of mass, momentum and energy)



Is that ok?

What’s a plasma?

* = relevant particle (electron, proton, ion)

Relevant Frequencies

$$\omega_{plasma} = \sim 10^{-9} (n_*/m_*)^{1/2} \ s^{-1}$$

$$\omega_{gyro} = 10^{-20} (B/m_*) \ s^{-1}$$

$$\omega_{collision} = 10^{-5} (n_*/T_*^{3/2}) \ s^{-1}$$

Plasma Length scales

Inertial length = $c/\omega_p = (m_* c^2/4\pi n_* q^2)^{1/2}$

Debye length = $(kT_e/4\pi n q^2)^{1/2}$

Gyroradius = $v_*/\omega_g = (m_* c v_*/qB)$

Mean free path = $v/\omega_{collision}$

Inertial Length

- fundamental scale of the plasma!

$d_{inertial} = c/\omega_p \sim$

$5x10^5\ n_e^{-½}$ cm

$2x10^7\ n_p^{-½}$ cm

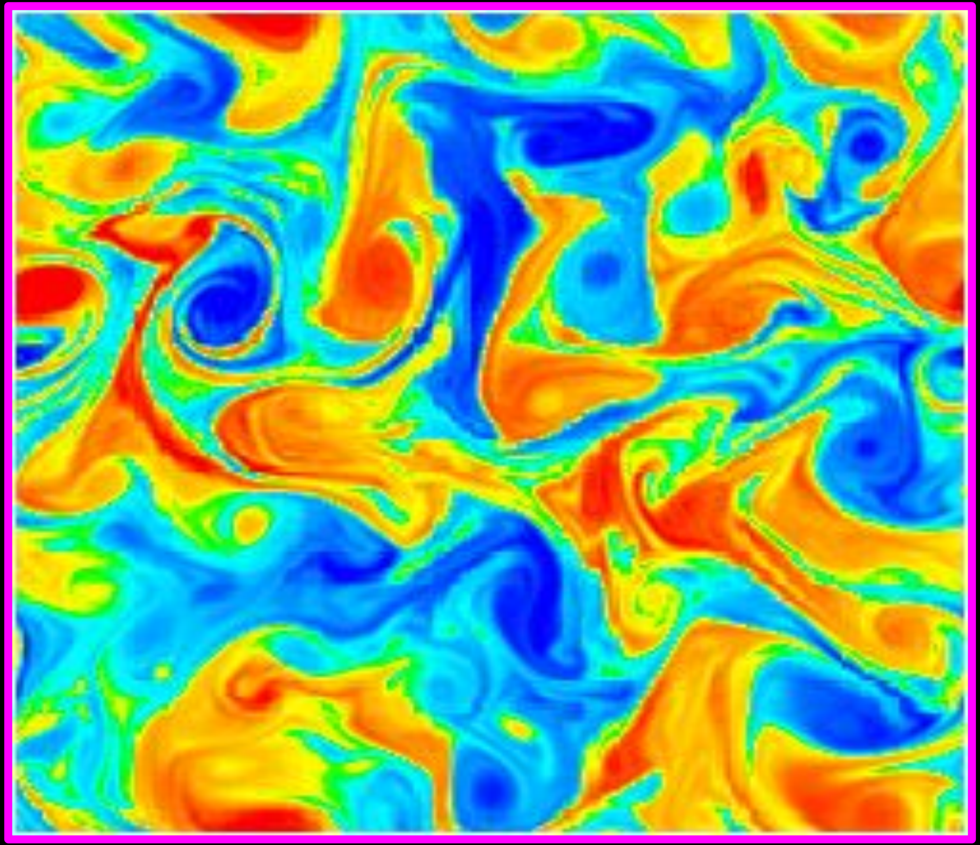
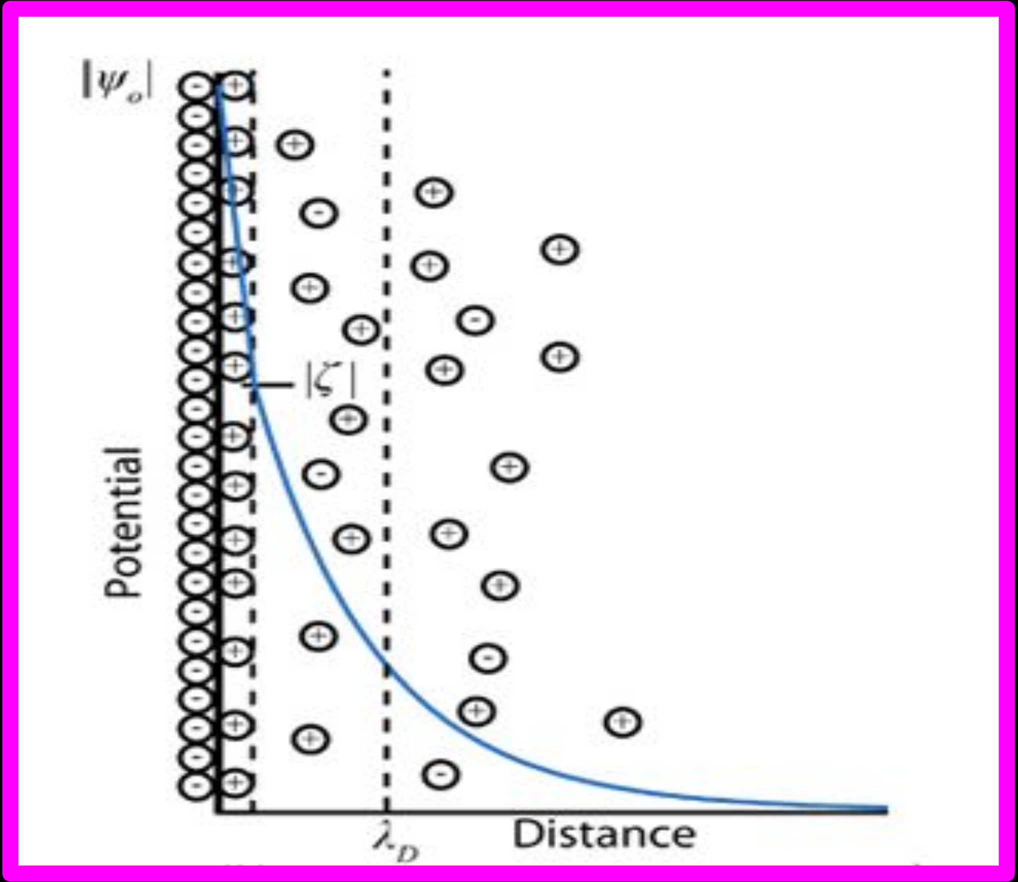


Image Credit: Sunn

Debye Length

- Length at which electric fields screened

$\lambda_D = v/\omega_p \sim 7\text{x}10^2 (T_e/n_e)^{1/2}$ cm

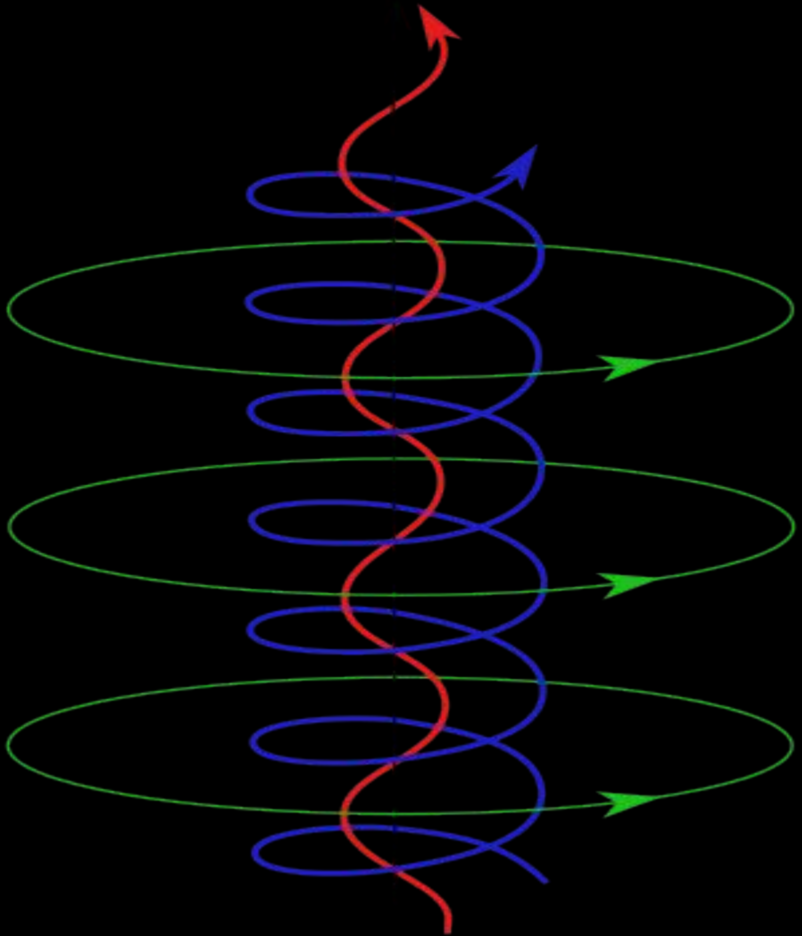


Gyroradius

$$v_*/\omega_g = (m_* c v_*/qB)$$

$$\sim 2.38\ T_e^{1/2} B^{-1}\ \text{cm}$$

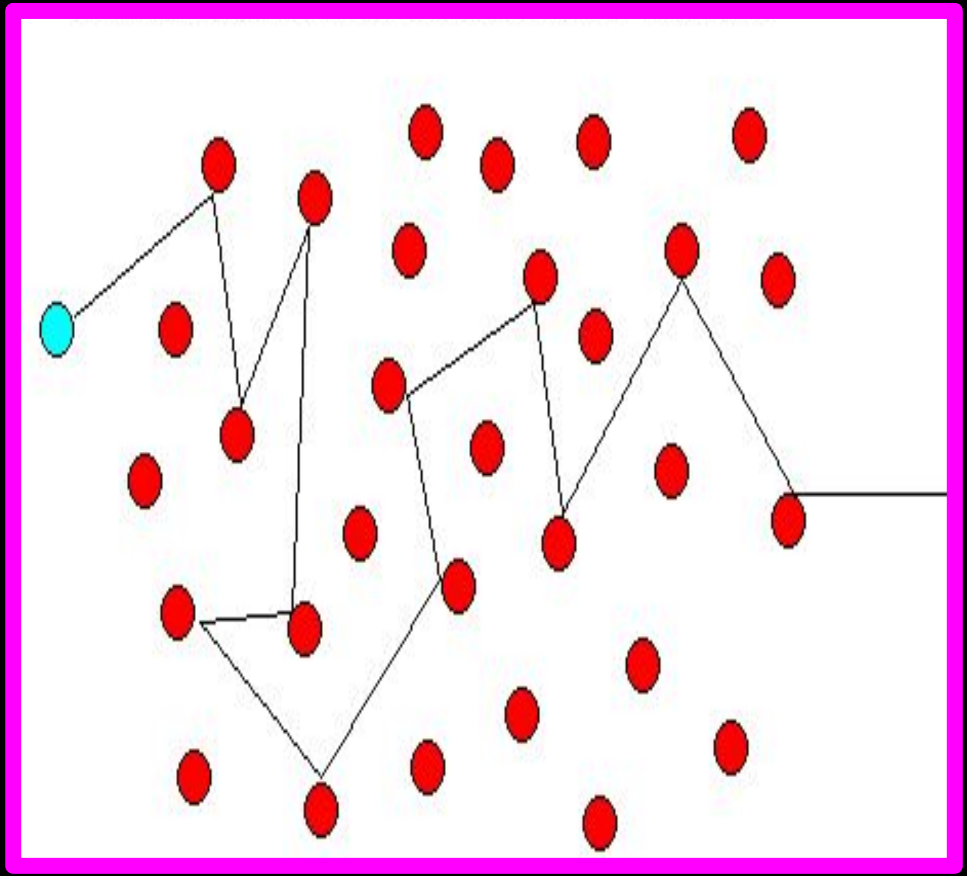
$$\sim 100\ T_i^{1/2} B^{-1}\ \text{cm}$$



Mean Free Path (plasma)

$v_*/\omega_{collision}$

$10^5\ (v_* n_*^{-1} T_*^{3/2})$ cm



Is it fair to describe a 10^9 K (~100 keV) plasma with n ~ 10^6 cm^{-3} as a collisional fluid?

$$\omega_p/\omega_{coll} \sim 3\mathrm{x}10^8\ n_e^{-1/2}T^{3/2}$$

$$\sim 10^{19}$$

... so, no!

Is it fair to describe a ?? K plasma with n ~ ?? cm^{-3} as a collisional fluid?

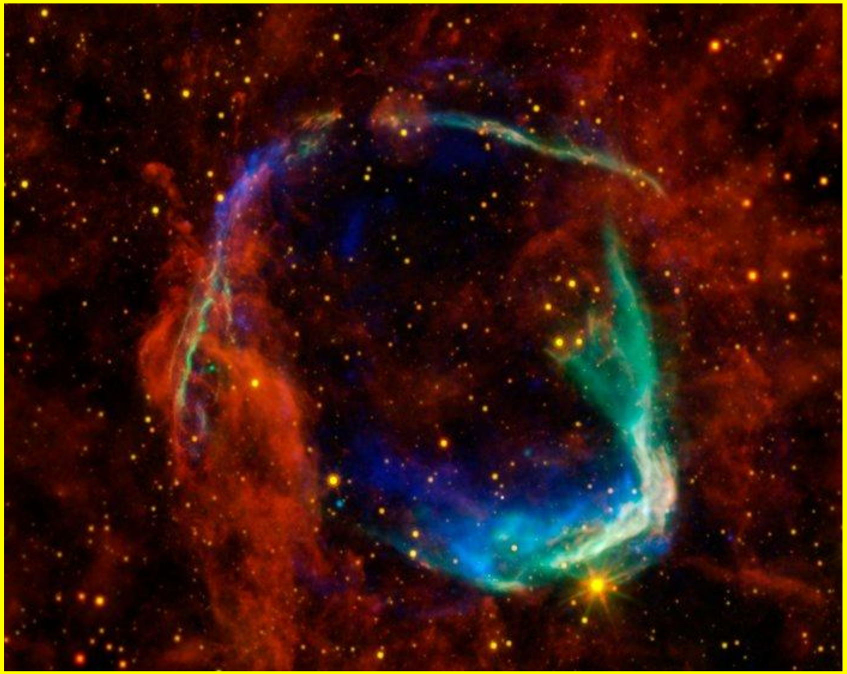
So what's the verdict (for you) - plasma or fluid?

Why might a fluid description still be ok?

When should I zoom in* and explore plasma effects?

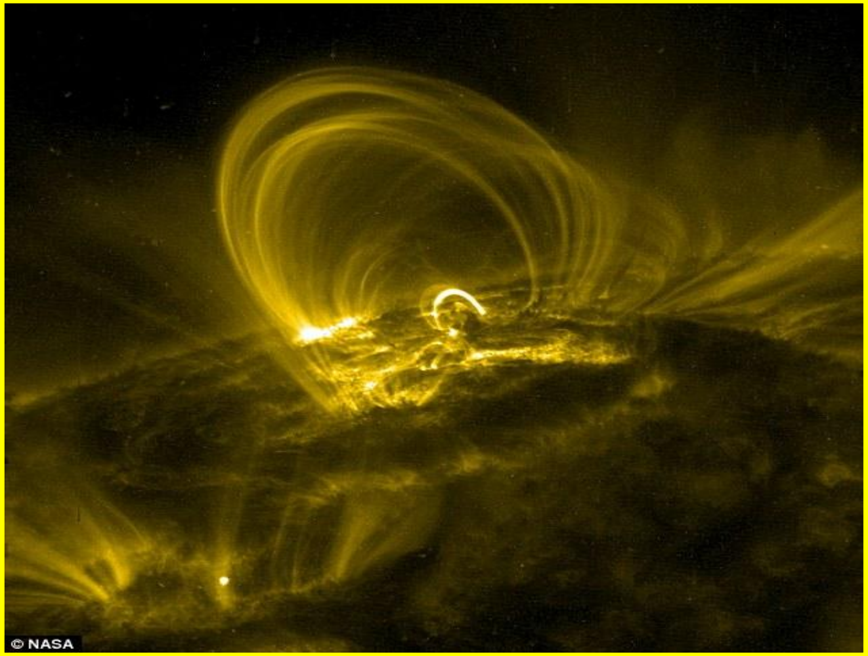
***why do I say zoom in?**

Plasmas in Astrophysics



SHOCKS

RECONNECTION



Collisionless Shocks

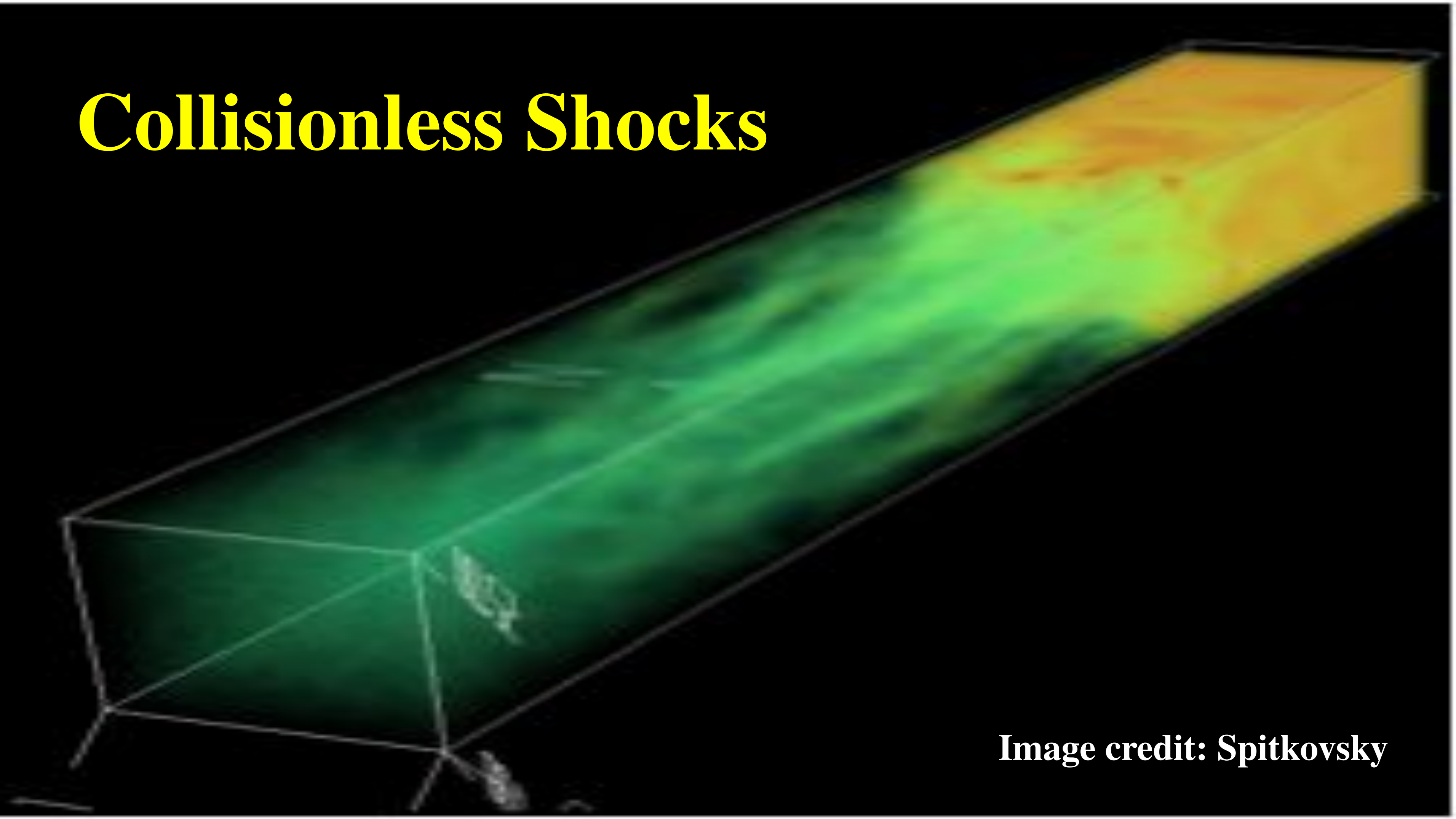
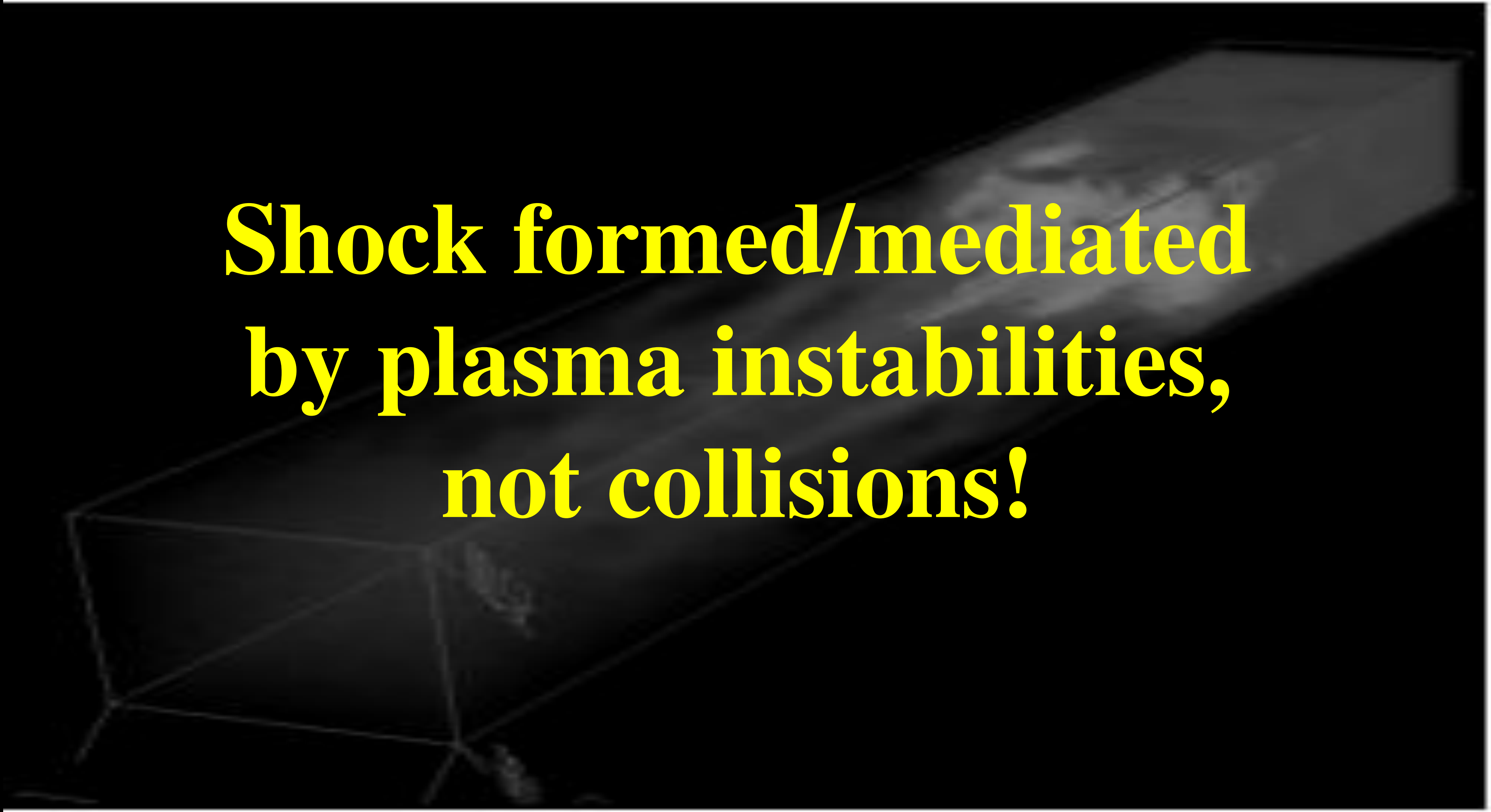
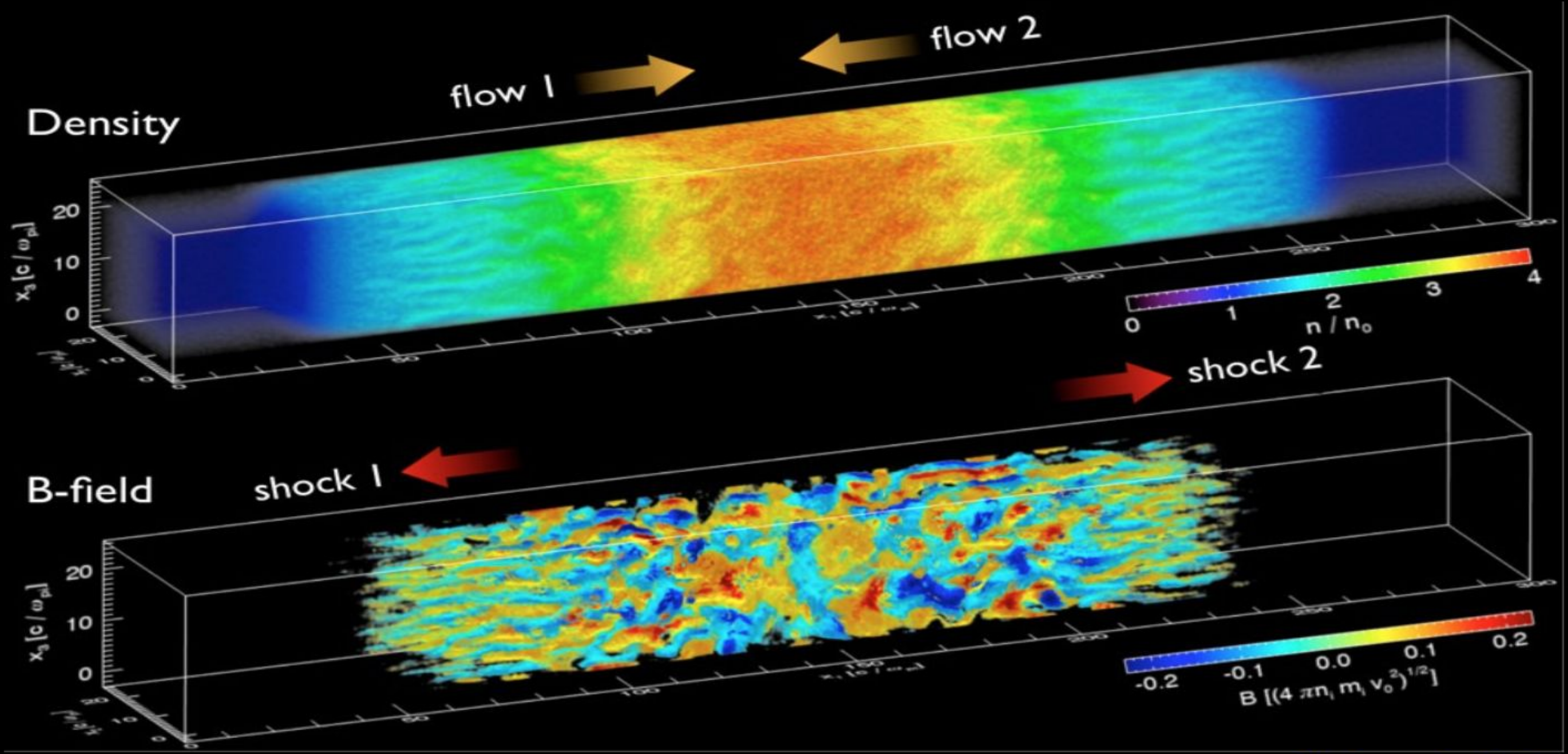


Image credit: Spitkovsky



Shock formed/mediated by plasma instabilities, not collisions!

Particle-in-Cell Simulations



Fuiza et al. 2015

Particle in Cell Simulations

Deposit Charge and Current onto Spatial Grid

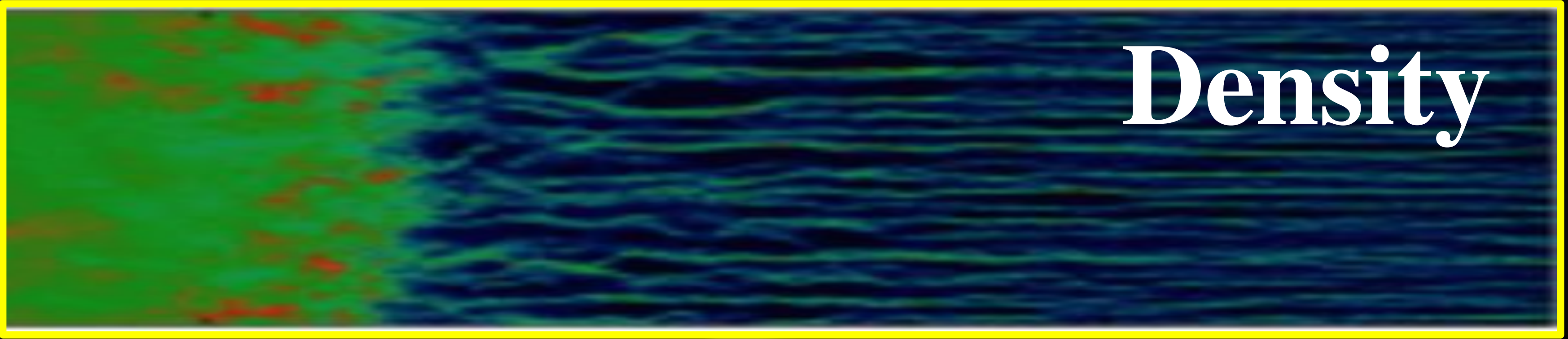
Solve Maxwell's Equations for Fields

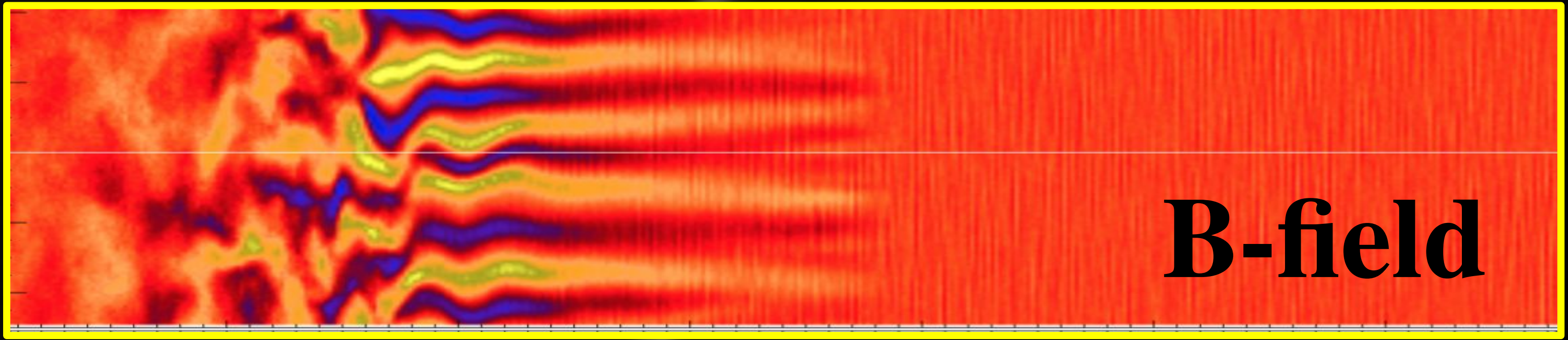
Interpolate Fields to particle positions

"Push" particles with Lorentz Force: $q(E+v/c \times B)$

REPEAT!
(every time step)

Inertial length sets distance scale
Plasma frequency sets timescale





Imagine I simulated a proton plasma with density 10^{10}cm^{-3}over a region of 100,000 inertial lengths for 100,000 inverse plasma frequencies.

What is the physical size of the region and physical time of the simulation?

- $100{,}000 * d_{inertial} = 10^5 (c/\omega_{plasma}) \sim 100$ cm

How does that compare to the size scale of your accretion disk?

- $100{,}000/\omega_{plasma} \sim 10^{-3}$ s

How does that compare to timescales in your accretion disk?

- **What is the ratio of electron to proton inertial lengths assuming they have the same density?**

- **Why does that matter?**

Magnetic Reconnection

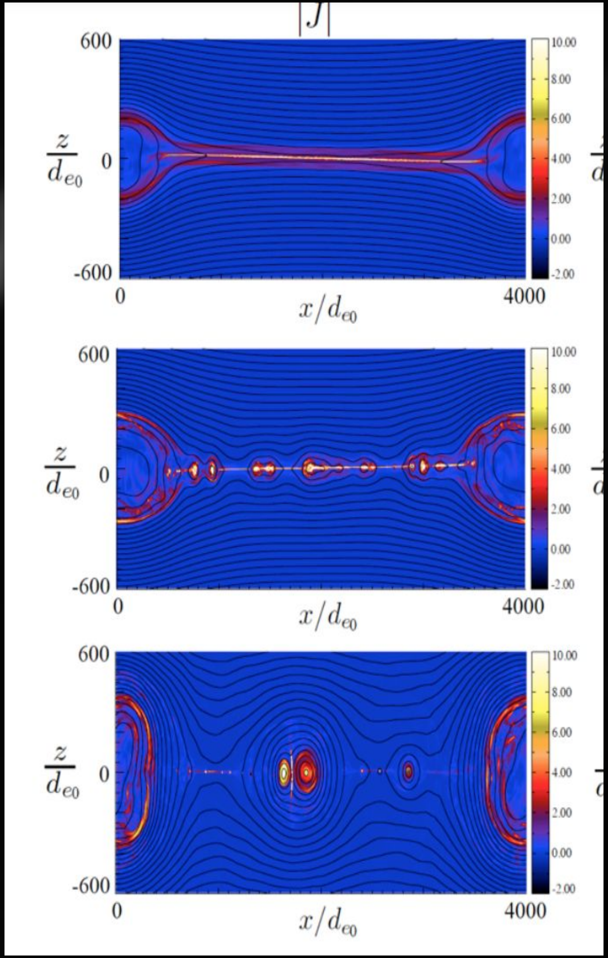
Magnetic Reconnection Basics

$$\partial_t B = \nabla\times(v\times B) + \eta(\nabla^2 B)$$

Resistivity (cm^2/s)

$$R_B = vL/\eta$$

When η not zero, topology not invariant, flux not frozen -> Reconnection!



Exercise:

- If electrons are moving with internal Lorentz factor γ, how is the plasma frequency modified?

- What about if, in addition, there is relativistic bulk flow of the plasma? Is the plasma frequency modified?

Exercise:

- For a pair plasma of density 100 cm^{-3}, a temperature of 10^8K in an external magnetic field of .1G, compute and compare the inertial length, Debye length, gyroradius, and mean free path.

Exercise:

- Compute the ratio of the plasma frequency to collision frequency in terms of density and temperature.

- For a plasma with electron temperature 1keV, what is the density needed to be considered collisional?

Exercise:

For a current sheet of width Δ, what is an order of magnitude estimate of the reconnection speed?

Collisionless Plasma Equations (Boltzmann + Maxwell)

$$\frac{\partial f_e}{\partial t} + \mathbf{v}_e \cdot \nabla f_e - e\left(\mathbf{E} + \frac{\mathbf{v_e}}{c} \times \mathbf{B}\right) \cdot \frac{\partial f_e}{\partial \mathbf{p}} = 0$$

$$\frac{\partial f_i}{\partial t} + \mathbf{v}_i \cdot \nabla f_i + Z_i e\left(\mathbf{E} + \frac{\mathbf{v_i}}{c} \times \mathbf{B}\right) \cdot \frac{\partial f_i}{\partial \mathbf{p}} = 0$$

$$\nabla \times \mathbf{B} = \frac{4\pi \mathbf{j}}{c} + \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t}$$

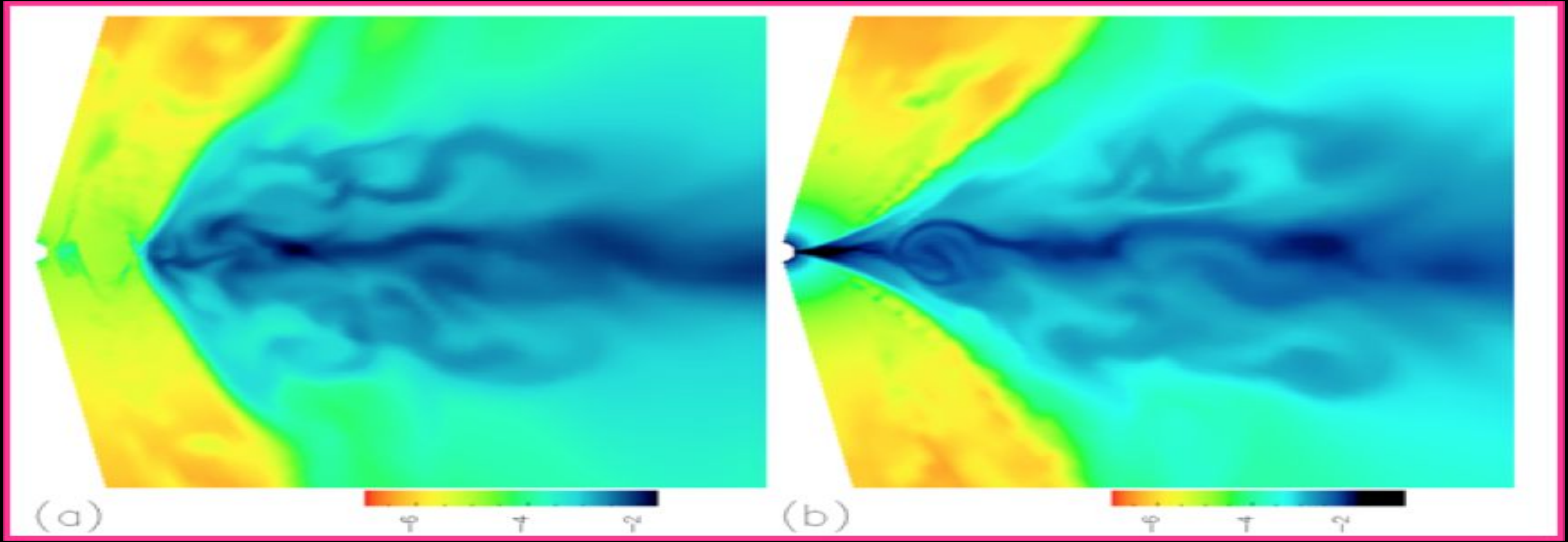
$$\nabla \times \mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \cdot \mathbf{E} = 4\pi\rho$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\rho = e\int (Z_i f_i - f_e) d^3p, \quad \mathbf{j} = e\int (Z_i f_i \mathbf{v}_i - f_e \mathbf{v}_e) d^3p,$$

OoMs for Magnetically Arrested Disks (MADs)



Magnetic pressure balances infalling gas pressure!

$$GM\Sigma/R^2 \sim B_z^2/2\pi,$$

$$\Sigma = \dot{M}/(2\pi R\epsilon v_{\rm ff})$$