# A Heating Mechanism via Magnetic Pumping in the Intracluster Medium

FRANCISCO LEY,[1] ELLEN ZWEIBEL,[1,2] MARIO RIQUELME,[3] LORENZO SIRONI,[4] DRAKE MILLER,[1] AND AARON TRAN[4]

[1] *Department of Astronomy, University of Wisconsin-Madison, Madison, Wisconsin 53706, USA*
[2] *Department of Physics, University of Wisconsin-Madison, 1150 University Avenue, Madison, WI, USA 53706*
[3] *Departamento de Física, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Chile*
[4] *Department of Astronomy, Columbia University, New York, NY 10027, USA*

To be Submitted Soon!

Francisco Ley - fley@wisc.edu

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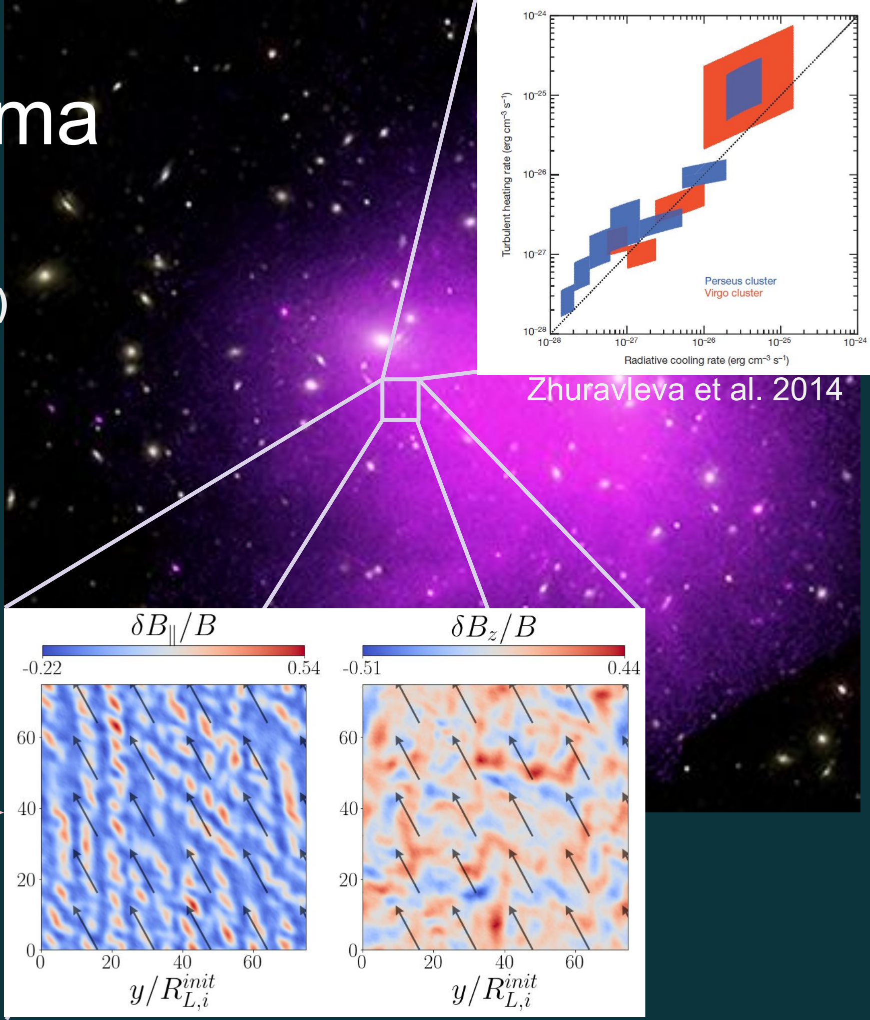
# ICM as an astrophysical plasma

- $\beta \equiv 8\pi P/B^2 \sim 10\text{-}10^3$
- **Turbulent: $V \sim 10^2$ km $s^{-1}$ (Rebusco+2006,Li+2020)**
- **Weakly collisional:**
  - **$\lambda_{mfp}$ ~1 - 10 kpc ~ $10^{21}$ cm**
  - **$\rho_i \sim 10^9$ cm**
- **Pressure Anisotropy** $\Delta P \equiv P_\perp - P_\parallel \neq 0$

**Weakly collisional, high-β, magnetized Plasma**

**Kinetic Realm**

(e.g. Kunz+2011, Arzamasskiy+2022)




Mirror Modes Firehose Modes

# A Turbulent Heating Mechanism for the ICM:

- Gyroviscous Heating/Anisotropic Viscosity (e.g. Kulsrud,1983)

$$\frac{dU}{dt} = \frac{\dot{B}}{B}(P_{\perp} - P_{\parallel})$$

U: Internal Energy Density
B: Magnetic Field Strength
$P_j$: Pressure components

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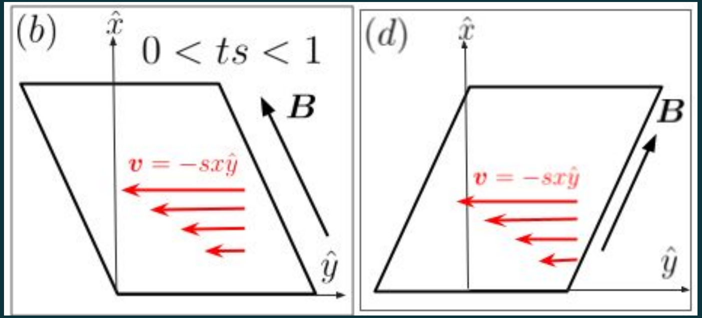
**Magnetic Pumping** (e.g. Lichko+2017,2020):

Large-scale turbulent eddy acting locally




**Pressure Anisotropy Instabilities** (Kunz+2011):

$\Delta P > \beta^{-1}$ (Mirror, Firehose)

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If no scattering: adiabatic invariance

- $P_\perp$ and $P_{//}$ follow CGL evolution (Chew, Goldberger, Low 1956)
- No net heating is possible

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**Pressure Anisotropy Instabilities** (Kunz+2011):

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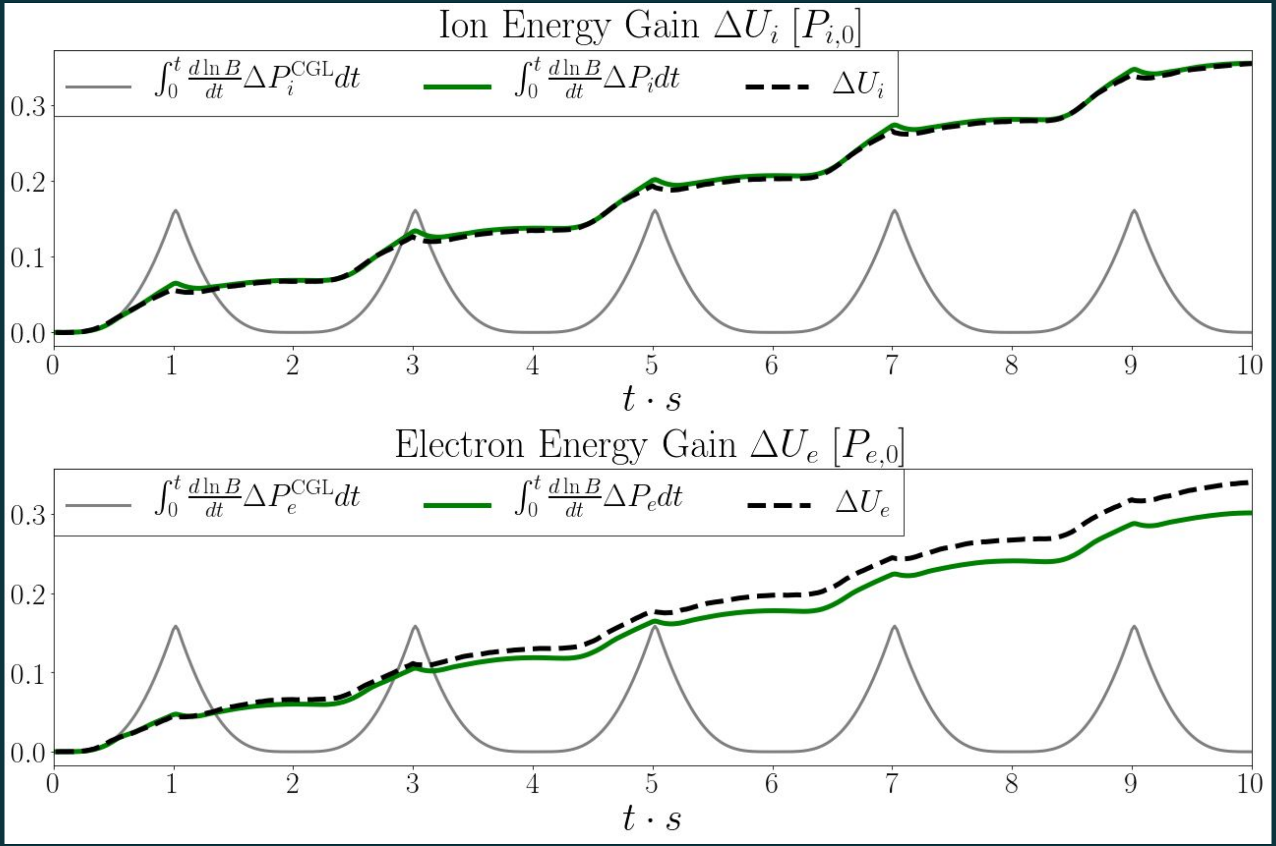
<u>If scattering present:</u>

- Adiabatic invariance is broken.
- **Net heating is possible!**

# Results: Energy Density Evolution

$$\frac{dU}{dt} = \frac{B}{B}\Delta P$$

- 2D fully kinetic PIC Simulations (TRISTAN-MP, Spitkovsky+2005, Riquelme+2012).
- Shearing-box periodically driven. ($\beta$=20, $k_B T/m_i c^2$=0.1)
- Mirror & Firehose instabilities self-consistently excited.
- Heating depends on shear frequency.



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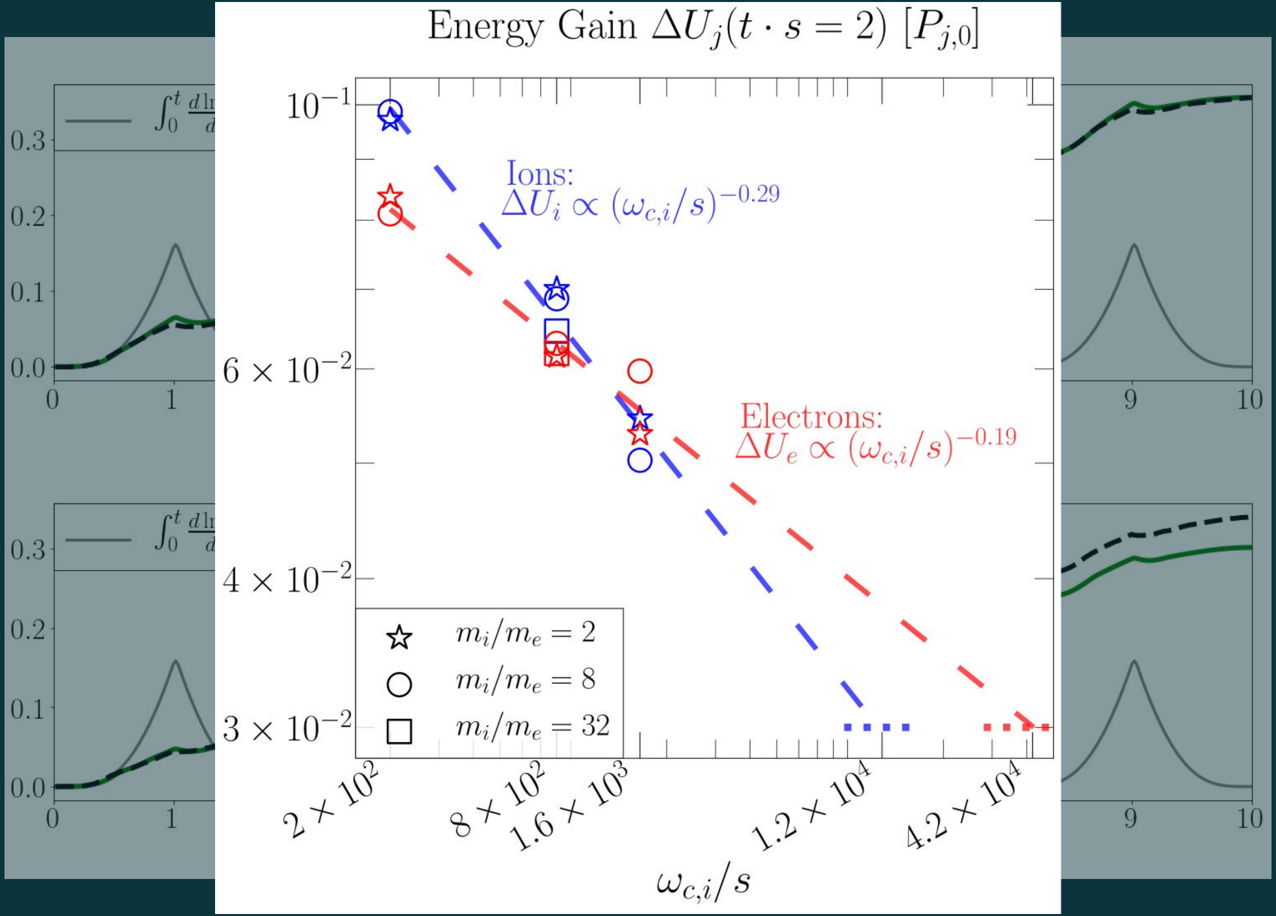

# Conclusions

- We perform fully kinetic 2D PIC simulations to show that a high-β plasma can gain energy by gyroviscous heating via magnetic pumping in presence of mirror and firehose instabilities.

- Heating rate depends on the shear frequency (~frequency of the large-scale turbulent eddy), higher frequencies provide more heating.

- In a fully developed turbulent cascade, particles can tap energy from each eddy. (Future Work)

- Good measurements and observations of turbulence in ICM are very important.