Turbulence with Braginskii Viscosity

Dynamo and Statistical Equilibrium

- **Question(s)**: How Braginskii viscosity affects the dynamo and the saturated magnetic field state?
- **Present Status**: Wide open area.
  - No simulations.
  - No focus on Braginskii in experiments.
  - No comprehensive theory.

  Two theoretical calculations. First, estimates of saturation (Kulsrud)

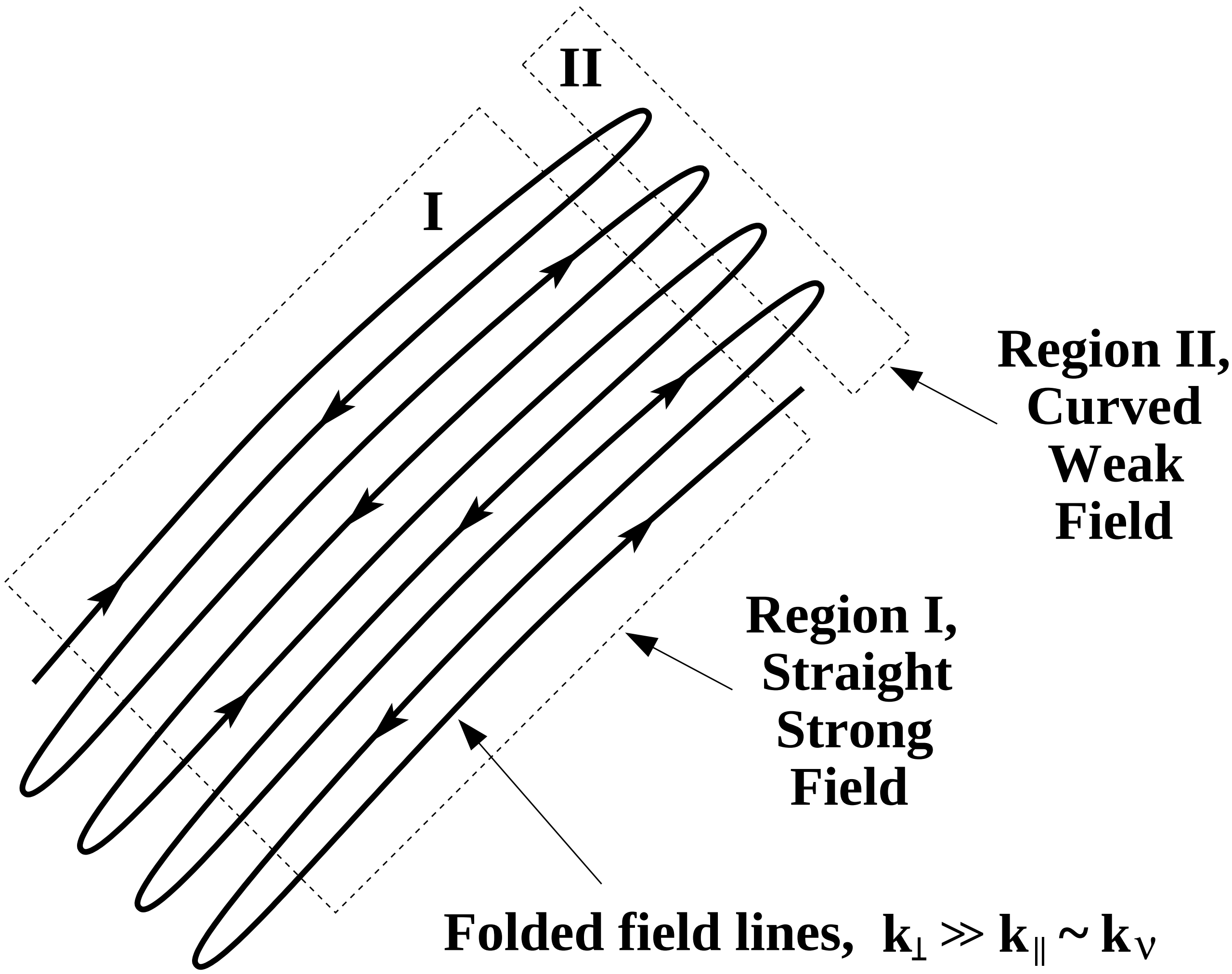
$$\frac{\partial V_\alpha}{\partial t} = -P_{,\alpha} + f_\alpha + F_\alpha^{\rm visc} + \frac{(\mathbf{B}\cdot\nabla)B_\alpha}{4\pi\rho} - (\mathbf{V}\cdot\nabla)V_\alpha$$

  Isotropic viscosity:

$$\begin{aligned} F_\alpha^{\rm visc} &= \nu\triangle V_\alpha \\ V_{\rm unwrap} &\sim V_A(k_\nu/k)^2(V_A/V_{k_\nu}) \end{aligned}$$

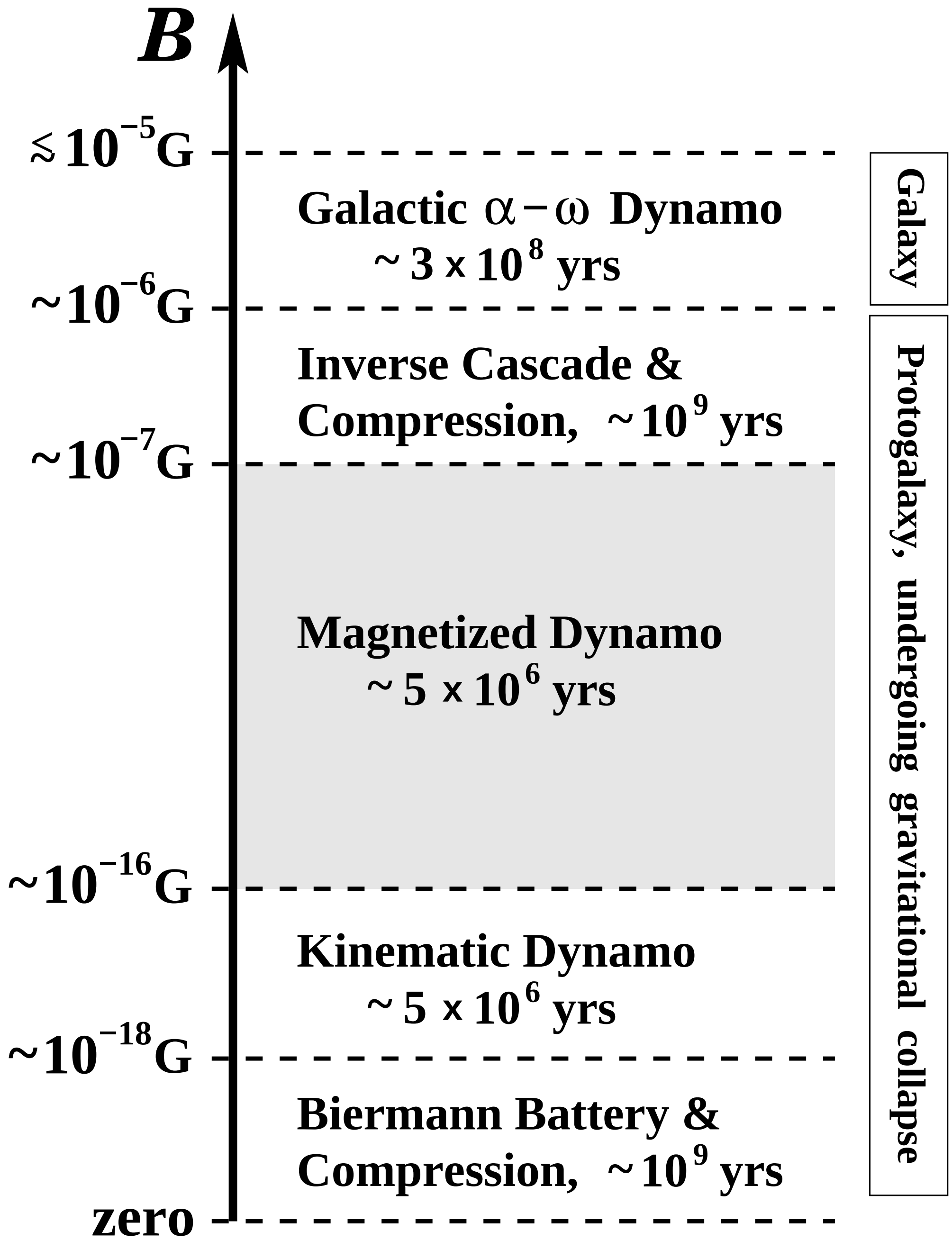
  Braginskii viscosity:

$$\begin{aligned} F_\alpha^{\rm visc} &= \nu[(3\hat{b}_\alpha\hat{b}_\beta - \delta_{\alpha\beta})\hat{b}_\mu\hat{b}_\nu V_{\mu,\nu}]_{,\beta} \\ V_{\rm unwrap} &\sim V_A(V_A/V_{k_\nu}) \end{aligned}$$


II
I
Region II, Curved Weak Field
Region I, Straight Strong Field
Folded field lines, $k_\perp \gg k_\parallel \sim k_\nu$

Second, magnetized dynamo (Kulsrud & Malyshkin):

- No kinematic dynamo when $r_i < \mathrm{mfp}$
- Several assumptions, need check
- Dynamo 10 times faster, need check
- Subviscous B-spectrum tail $\propto k$ ($\propto k^{3/2}$)



- **Proposed Tasks:**
  - Simulations: Add Braginskii viscosity to Flash code MHD module (as an explicit term) – *EASY*.
  - Theory:
    * Better qualitative understanding.
    * More heuristic models (e.g. for field unwinding).
    * Two-step model with field back reaction forces (delta-correlation in time).
    * Start with simulations?
- **Payoff/Impact:**
  - Primordial dynamo theory – *HUGE ASTRO*
  - Solar plasma physics – *SOME SOLAR*
  - Experiments – *MINOR LAB?*
  - Other topic(s): Dynamo, Momentum transport?
- **Required Resources:**
  - Simulations: 1 person (with Timur Linde's help); fast first results (if no obstacles, e.g. divergence of Braginskii code); need big computer.
  - Theory: cooperation (e.g., Chicago, PPPL,...).

Decaying Turbulence

- **Question(s)**: On what scales magnetic energy survives during field unwinding in a decaying turbulence?
- **Present Status**: Wide open area.
  - No simulations.
  - No any comprehensive theory.

  A heuristic theoretical model (Kulsrud):

$$\frac{\partial B}{\partial t} = \omega(k)B - \frac{kB}{\sqrt{4\pi\rho}}B,$$

$$\Uparrow \qquad\qquad \Uparrow$$

forcing unwinding

where the forcing and the unwinding term are set by hand. Fast unwinding helps to saturate magnetic energy on subviscous scales, which is then lost by the unwinding when the forcing is set to zero.

- **Proposed Tasks:** Extension of the previous problem, but can be approached separately and theoretically.
  - Simulations: Run MHD turbulence with Braginskii viscosity, then switch the forcing of turbulence off.
  - Theory:
    * Extend Russell Kulsrud's model.
    * Consider unwinding of magnetic field prescribed by hands.
    * The same with field prescribed by simulations of Braginskii dynamo.
  - Experiment: Is turbulence seen in MRX/MST decaying after reconnection events?
- **Payoff/Impact:**
  - New interesting perspective idea.
  - Problem of field small-scales – *HUGE ASTRO*
  - Other topic(s): Dynamo.
- **Required Resources:** Similar to the previous topic.

Transport in Magnetic Fields

Diffusion of charged particles

- **Question(s)**:
  - Quantitative theory of particle transport?
  - Apply to cosmic ray transport?
  - Apply to confinement of particles in labs?
- **Present Status**:
  - Simulations of diffusion of passive particle in:
    * fields prescribed by hand (Jokipii)
    * fields from MHD runs (Lazarian)
  - Single-scale field heuristic models (Rechester & Rosenbluth, Chandran & Cowley):

$$L_{RR} \sim l_0 \ln \frac{l_0}{\rho_e} \;\Rightarrow\; D \sim \frac{(L_{RR}/l_0) l_0^2}{L_{RR}^2/D_{\parallel}} \sim \frac{D_0}{3\ln(l_0/\rho_e)}$$

  - Multi-scale field heuristic models (Skilling *et al*):

$$L_{RR} \sim l_0 \;\Rightarrow\; D \sim D_0/3$$

  - A quantitative model with $\delta B << B_0$ (Jokipii).
  - MST measurements are not totally conclusive and do not confirm heuristic theoretical estimates.

- **Proposed Tasks:**
  - Simulations:
    - Use B-fields provided by turbulence/dynamo problems in existing codes – *EASY*.
    - Tracking of passive particles is available in Flash, back reaction may be included.
  - Theory:
    - Extend Jokipii model to finite field fluctuations, $\delta B \sim B$, – *NOT EASY*
    - Specific theoretical description of transport in experiments – *COOPERATION*
  - Experiment: Continue/improve measurements.
- **Payoff/Impact:**
  - Cosmic ray propagation – *HUGE ASTRO*
  - Plasma confinement – *HUGE LAB*
  - Other topic(s): Momentum transport.
- **Required Resources:** Passive particles tracking code is already in place (Lazarian *et al*). Wait for new results from turbulence/dynamo or for new theories. Theory done in collaboration (e.g., Wisconsin, PPL, Chicago,...).

Thermal conduction

- **Question(s)**:
  - Role of heat conduction for formation of galaxies and clusters of galaxies?
  - Is reduction of thermal conductivity qualitatively or/and quantitatively different from reduction of particle diffusivity? How much different?
- **Present Status**:
  - Theories assume that reduction of thermal conductivity is equal to the reduction of particle diffusivity.
  - Theories assume static fields.
  - A lot of recent astro observation, but they are not conclusive, and their interpretation relies on 1-D theoretical models.
  - There are some unanswered questions (like observed sharp boundaries of large temperature change).
  - Computer simulation codes of large-scale structure formation exist, but belong to outsiders (Chicago: Andrei Kavtsov, Princeton: Jerry Ostriker).

- **Proposed Tasks:**
  - Simulations:
    - Include energy exchange via collisions – *HARD*
    - Kinetic simulations – *HARD*
    - Energy exchange by Monte-Carlo methods?
    - Include self consistency effects into turbulence.
    - Collaborate with outsiders structure formation.
  - Theory:
    - Explore the case when $\mathrm{mfp} << L_{\mathrm{RR}}$
    - More rigorous theory, possibly kinetic theory for astrophysical problem – *HARD*
    - Specific theoretical description for experiments
  - Experiment: Continue/improve measurements.
- **Payoff/Impact:**
  - Large-scale structure formation, popular topic in astro community – *HUGE ASTRO*
  - Main heat loss mechanism in experiments, under active study – *HUGE LAB*
  - Other topic(s): Reconnection, Ion heating.
- **Required Resources:** Sophisticated simulations, comprehensive kinetic theory need serious resources.

Alfven waves in chaotic fields

- **Question(s)**:
  - Can coronal heating be explained by decay of Alfven waves propagating in stochastic fields?
  - Can unidirectional Alfven wave scatter into bidirectional waves?
- **Present Status**: Proposed by Christof Litwin. Could have been considered in coronal heating community.
- **Proposed Tasks:**
  - Theory: Toy problems, e.g. an Alfven wave propagating along field that suddenly jumps. Statistical averaging over distribution of jumps.
  - Simulations: Simulate the toy problem above. Flash can do it not efficiently. Use DEBS?
  - Experiments: Can we drive Alfven waves and then observe their decay in our plasma devices?
- **Payoff/Impact:** Solar corona – *HUGE ASTRO*. Other topic(s): Ion heating.
- **Required Resources:** Closely relevant to ion-heating. Aside of other turbulence/transport problems. Cooperation with outsiders (Aad Vanballegooijen,...).