Turbulent Reacceleration of Streaming Cosmic Rays: Fluid Simulations

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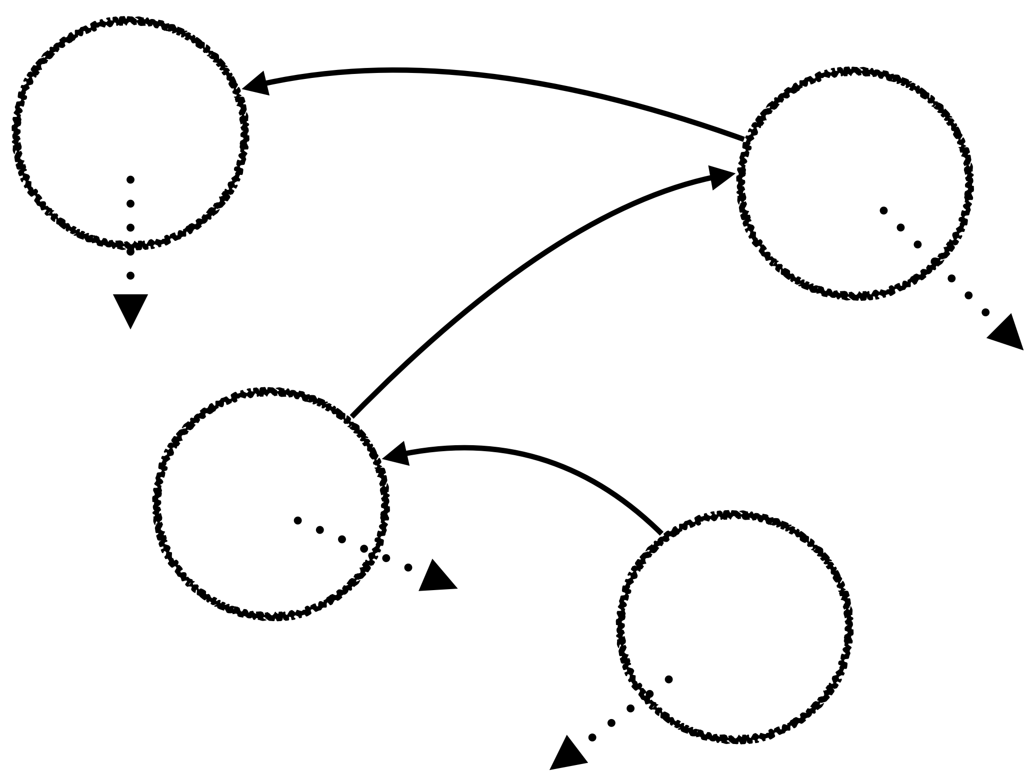
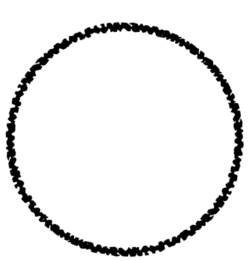
Turbulent Reacceleration (2nd order Fermi mechanism)



$$\frac{\Delta E}{E} \sim \mathcal{O}\left(\frac{v^2}{c^2}\right)$$



= magnetic perturbations

- Size ~ r_g (resonant scale)
- Size ~ L_{outer} (non-resonant)

Our regime of interest

- **Non-resonant** reacceleration
- **Subsonic, compressive** turbulence
- Self-confined cosmic rays (**E < 300 GeV**)
  - Energy transfer from cosmic rays to thermal gas is important

$$\frac{\partial E_{cr}}{\partial t} \sim -v \cdot \nabla P_{cr} + v_A \cdot \nabla P_{cr}$$

Energy loss (gain) from rarefaction (compression)

Energy transferred from CRs to Alfven waves: $t_{loss} \sim L/v_A$

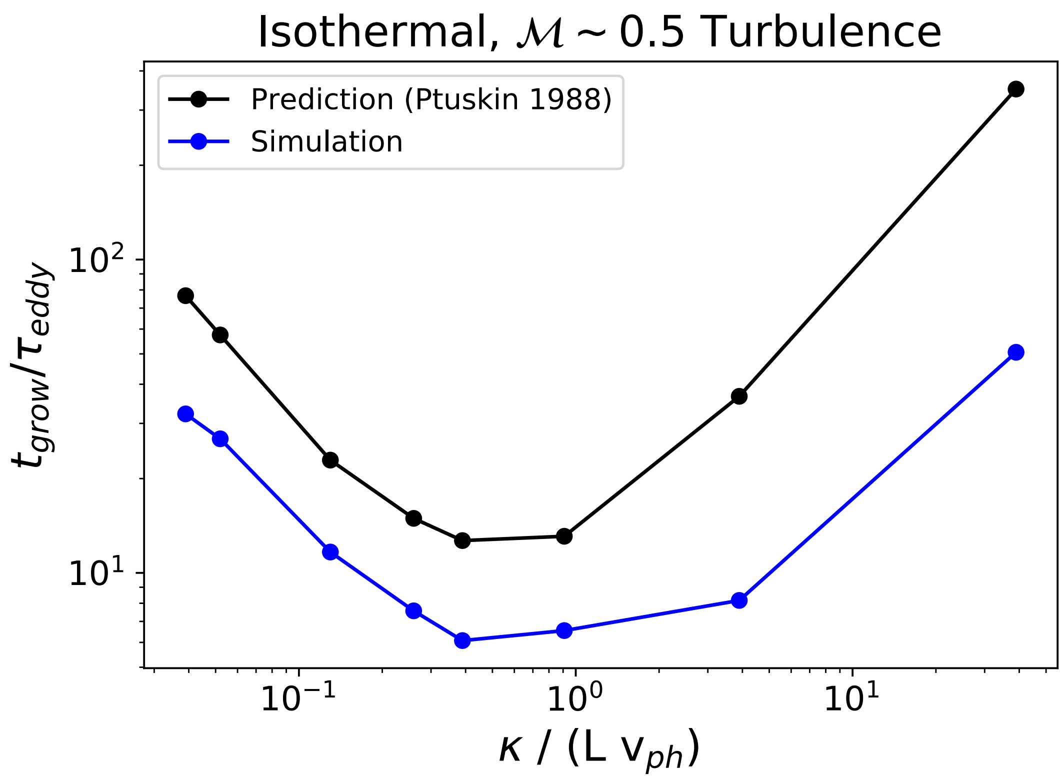
$$t_{grow,crit} \sim \frac{v_{ph} L}{v^2}$$

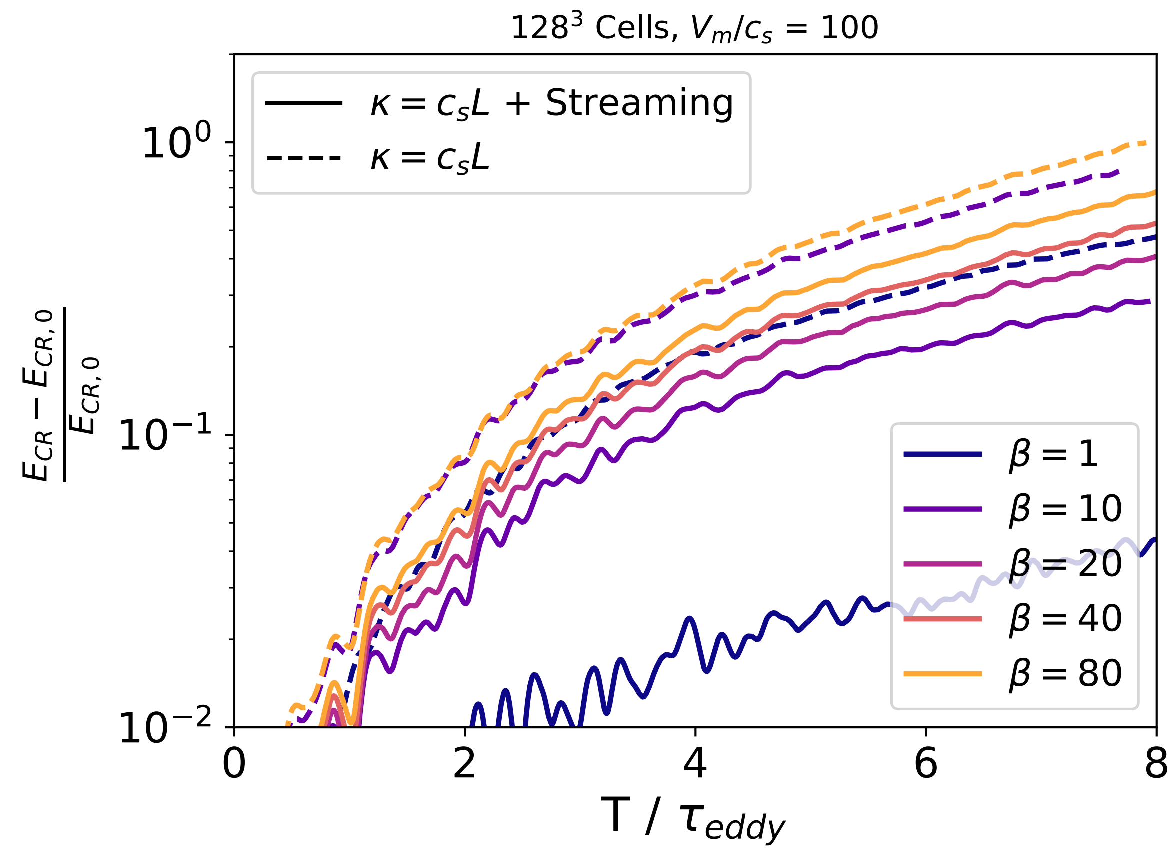
$$\frac{t_{grow,crit}}{t_{loss}} \sim \frac{1}{\sqrt{\beta} M_s^2}$$

→ **Unless $\beta \gg 1$, energy loss prevails over energy gain from subsonic turbulence**

Some references: *Ptuskin 1988, Brunetti and Lazarian 2011, Lynn+ 2013, Zweibel 2017, Amato and Blasi 2018*

Athena++ MHD Simulations





Simulations with pure diffusion (no streaming) recover analytic growth rates *(Ptuskin 1988)* within a factor of 2, at least with $\kappa \lessapprox \kappa_{crit}$

Pure diffusion with $\kappa = \kappa_{crit}$ results in fast growth over a few eddy turnover times. Adding in streaming, even with $\kappa = \kappa_{crit}$, gives slow growth unless β is large. t_{grow} monotonically decreases with increasing β

Conclusions:

- Non-resonant reacceleration of streaming CRs is greatly stunted by streaming energy loss
- Resonant reacceleration is incompatible with streaming

→ Canonical equations for reacceleration are on shaky ground for GeV CRs