Buoyancy of Cosmic Ray Loaded Magnetic Flux Tubes in the Galactic Disk

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Funded by NSF grant AST-2007323

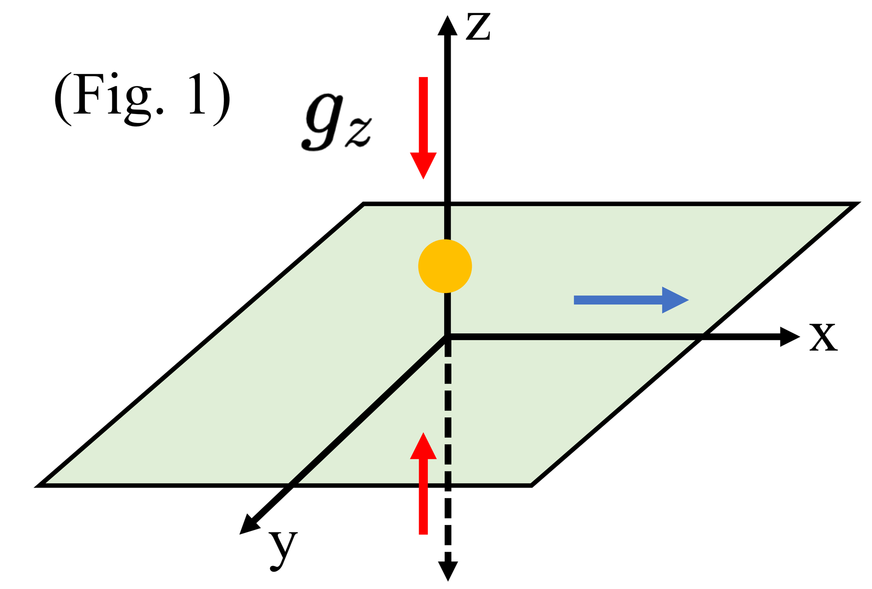
ABSTRACT

Interstellar gas in disk galaxies is vertically supported against gravity by the pressure of thermal gas, magnetic fields, and cosmic rays. When nonthermal pressure support exceeds a threshold, the Parker instability can appear. Like the Rayleigh-Taylor instability, over-dense regions sink, and under-dense regions rise. This produces peaks and valleys in the magnetic field. Gravitational energy provides the free energy necessary to compress the interstellar gas into the valleys [1].

Since cosmic rays are unaffected by the galaxy's gravity, they increase the buoyancy of the ISM. However, the cosmic ray fluid has a finite compressibility, increasing the energy required to form valleys. **Linear theory suggests this compressibility dominates buoyancy, suppressing the instability** [2,3].

To address this counterintuitive result, we run local simulations of injections of cosmic ray pressure in the galactic disk. This assumes a supernova as the source. If this physically motivated perturbation creates buoyant magnetic flux tubes, then it is likely the Parker instability can develop in the ISM even if instability criteria from linear theory are not met.

(Fig. 1)



FOR FIGURE CAPTIONS:
Use this QR code

Or go to https://roarkhabegger.github.io/projects/apsdpp2021/

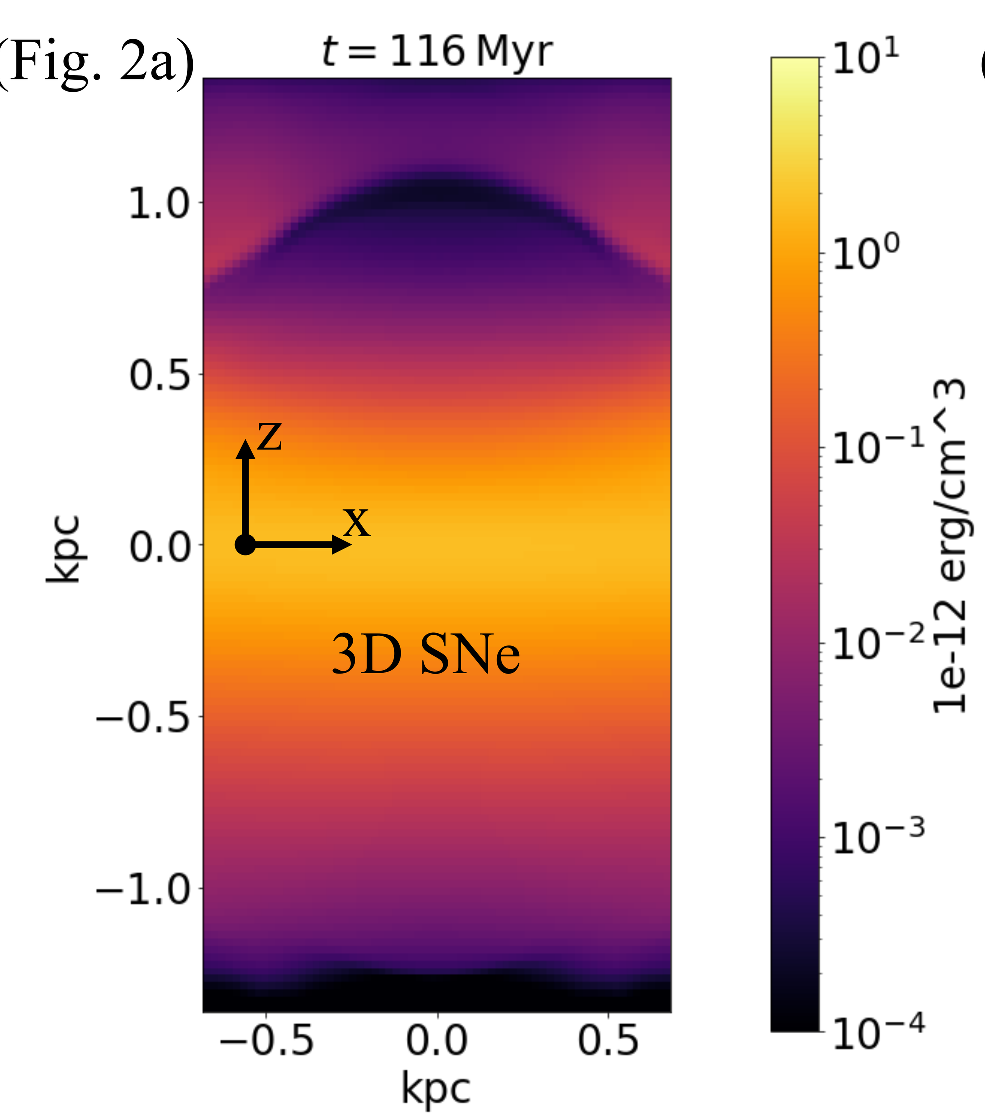
INITIAL CONDITIONS & METHODS

- 3D Cosmic Ray Fluid MHD Simulations in Athena++ [4]
- Vertical stratification via gravitational field created by distribution of stars in galactic disk (Eqn. 1, 2) [5]
- Localized injection of cosmic rays, modelling the effects of a supernova explosion
- Include cosmic ray Alfvenic streaming due to self confinement by kinetic instabilities, along with diffusion and compressibility of the cosmic ray fluid
- Use scalar dye to track flux tube with initial cosmic ray injection

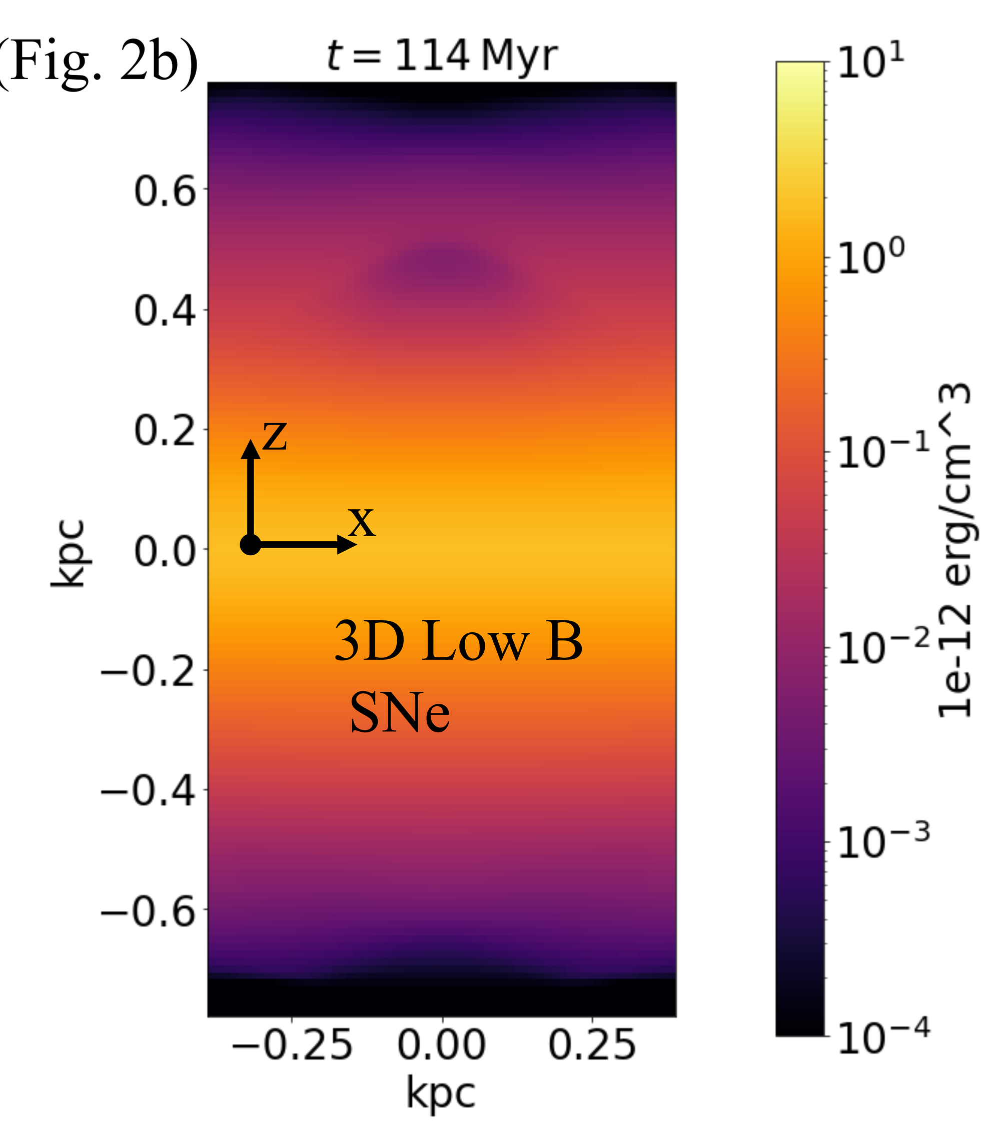
$$\frac{d}{dz}[P_g + P_B + P_{cr}] = \rho g_z \quad (1)$$

$$g_z \propto -\tanh\left(\frac{z}{H}\right) \quad (2)$$

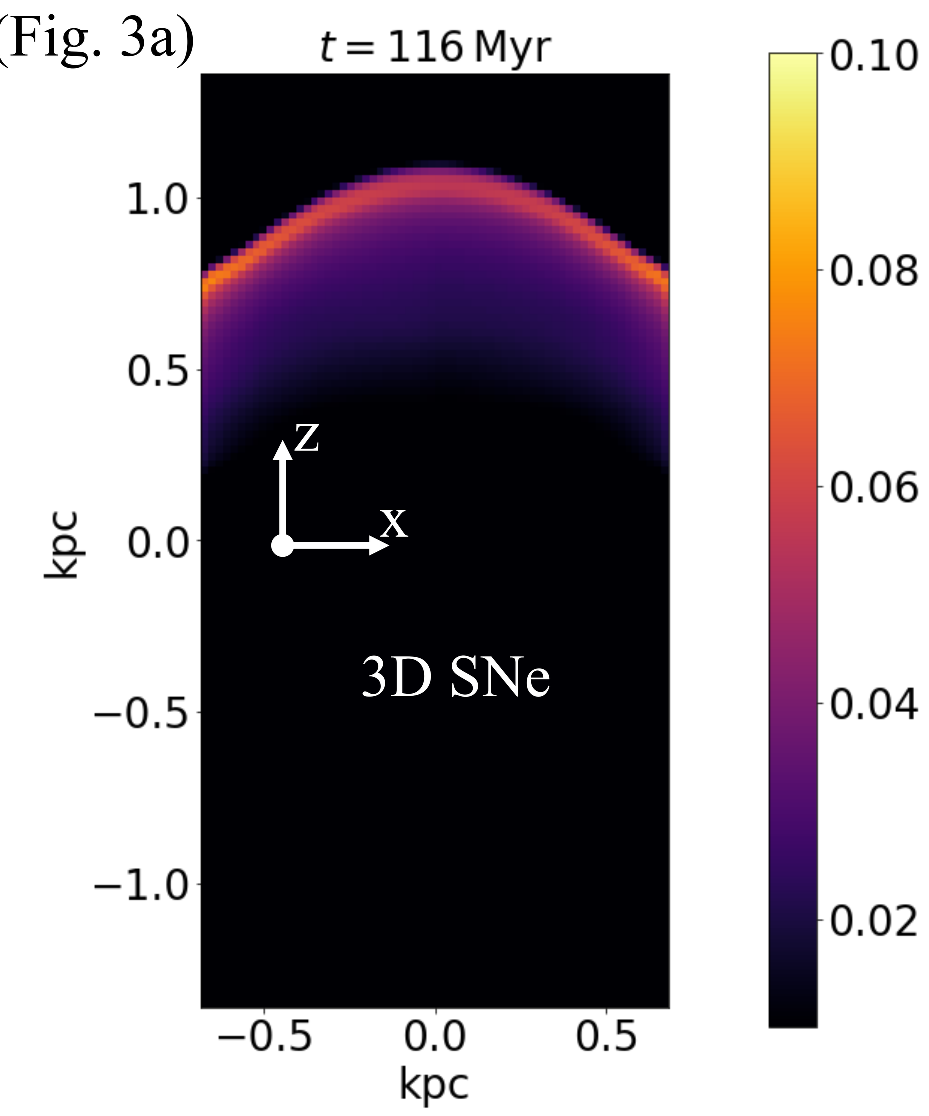
(Fig. 2a)



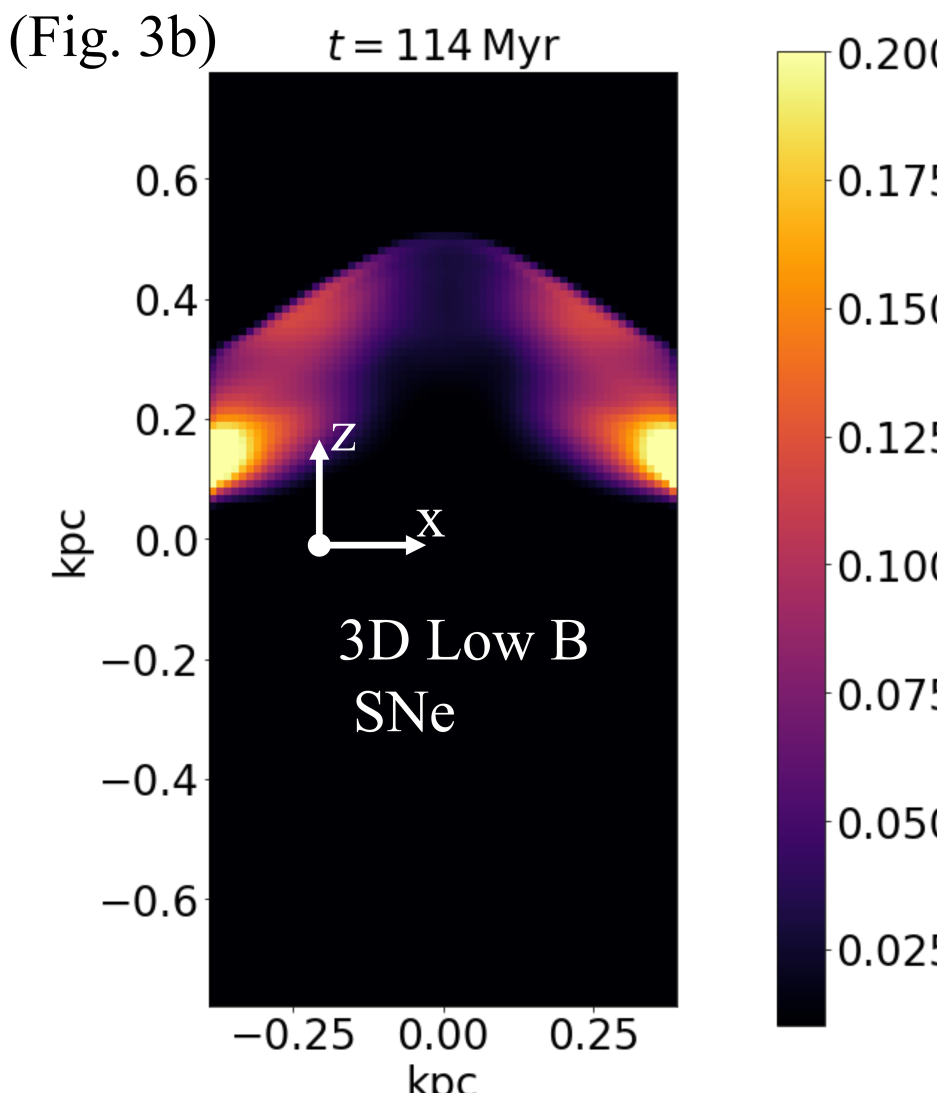
(Fig. 2b)



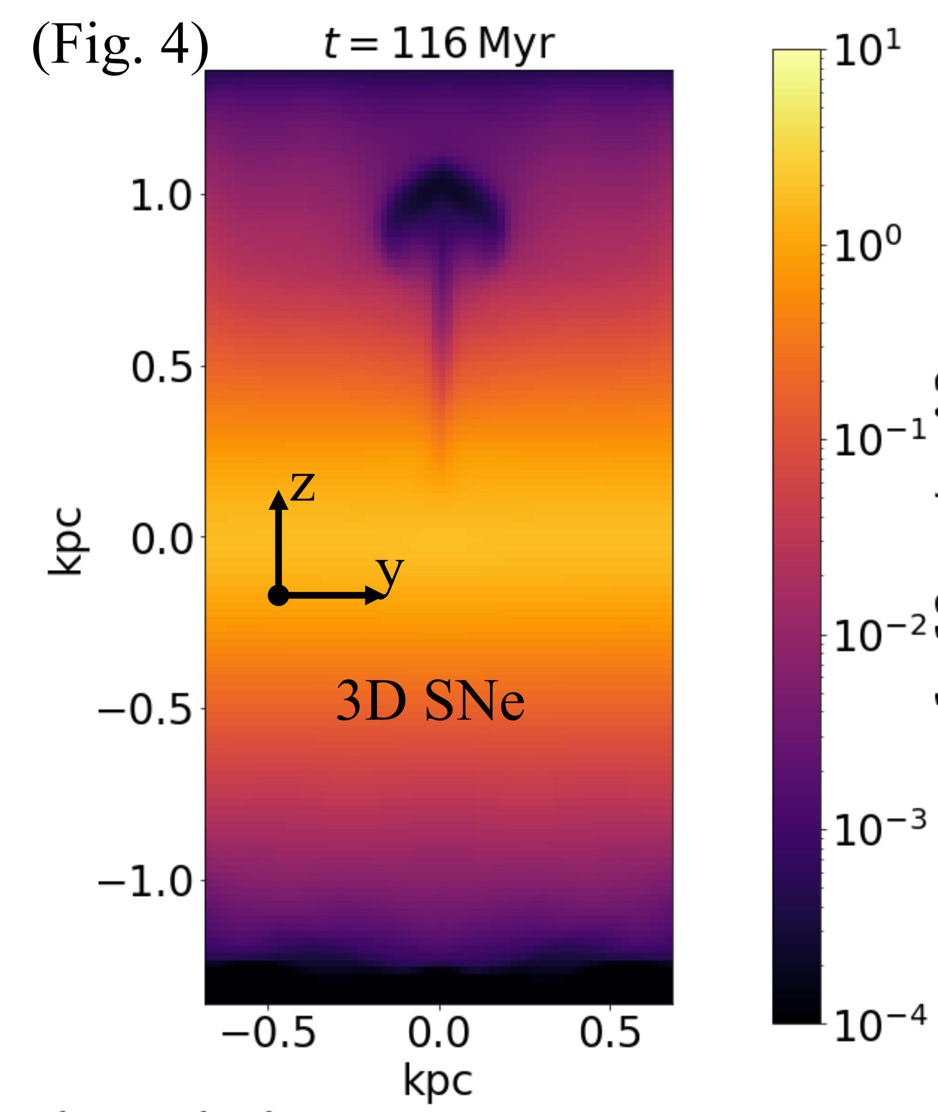
(Fig. 3a)



(Fig. 3b)



(Fig. 4)



CONCLUSIONS

- The instability may occur in highly magnetized, star-bursting galaxies
- 3D simulations are necessary to accurately study the Parker Instability
- However, this instability is overshadowed by radiative cooling and large scale MHD turbulence (these show dynamical effects on time scales of ~10 Myr)
- Instability takes too long to develop (turbulent time scale is)

Our results re-affirm the insignificance of the Parker Instability in the dynamical evolution of galactic disks and the interstellar medium of galaxies like the Milky Way [6].

CITATIONS

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[2] Heintz, E., Zweibel, E. (2018) ApJ, **860** 2, 97.
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[4] Jiang, Y.-F., Oh, S. P. (2018) ApJ, **854**, 1, 5
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(Fig. 5)