Evolution of Rising Magnetic Cavities and UHECR acceleration

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in collaboration with M. Lyutikov

Structure of Clusters and Groups of Galaxies in the Chandra Era,
Boston, July 12-14 2011

Outline

- Solutions for static cavities
- Self similarly and quasi statically expanding cavities
- Formation of reconnection layer and cosmic ray acceleration

X-ray cavities

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- Areas of lower X-ray emission in galaxy clusters (Fabian et al. 2001, Churazov et al. 2001, Birzan et al. 2004, Diehl et al. 2008)

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- They are related to AGN activity

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Hydra A cluster, z=0.054, T=10^7K, size ~ 200kpc,
Image: NASA/CXC/U.Waterloo/C.Kirkpatrick et al. 2009

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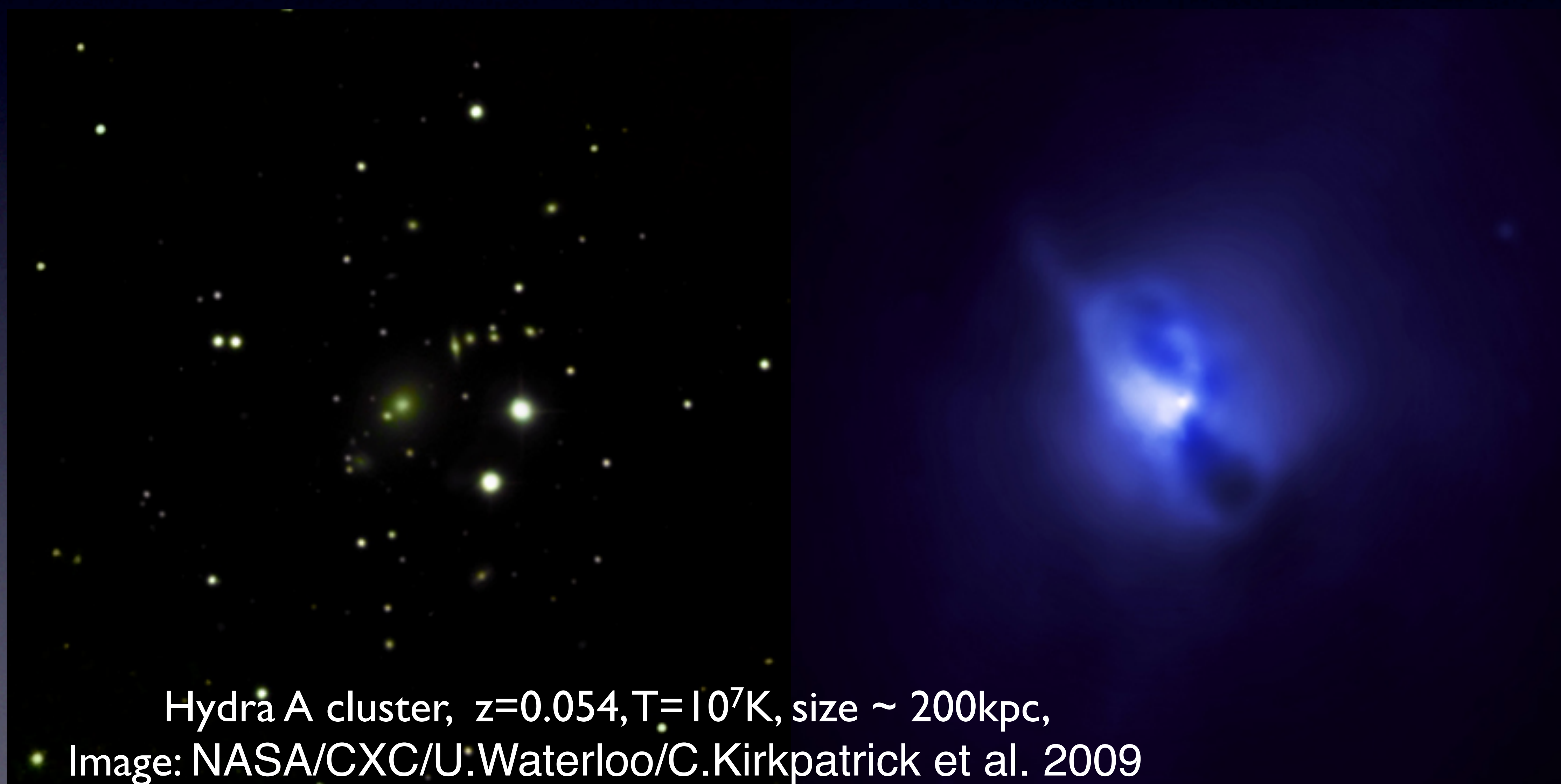

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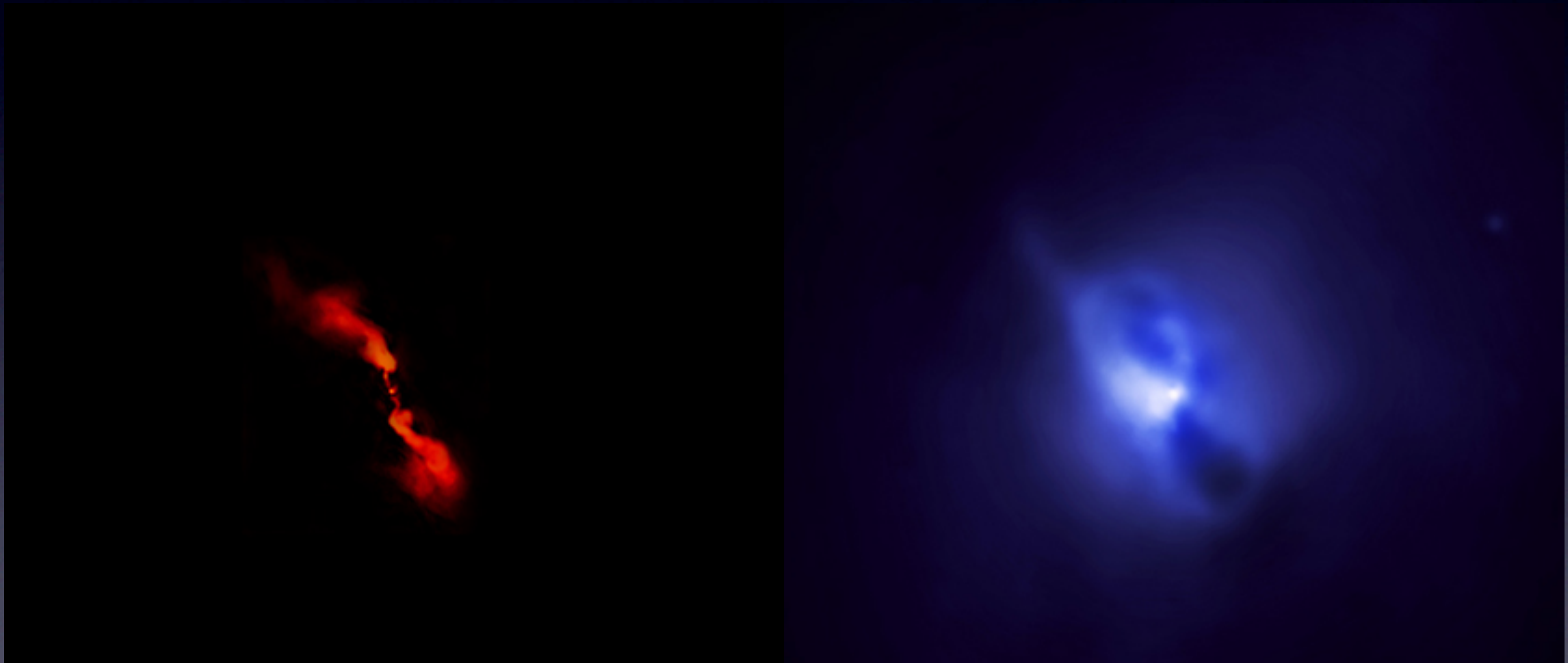

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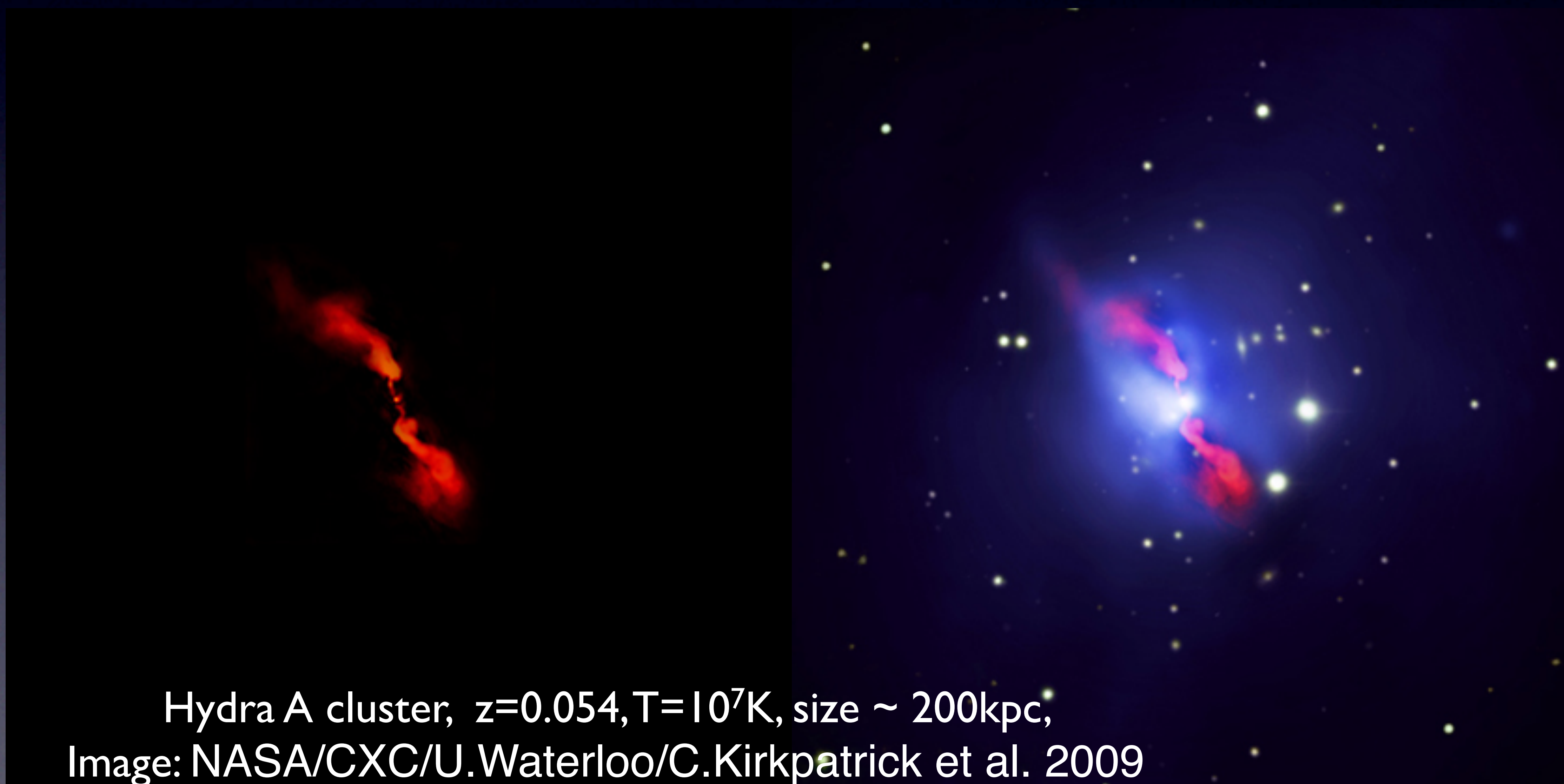

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- We start from static solutions of the Grad-Shafranov equation (Shafranov 1966)

Grad-Shafranov equation and solution

We look for equilibrium between the magnetic field and the plasma pressure

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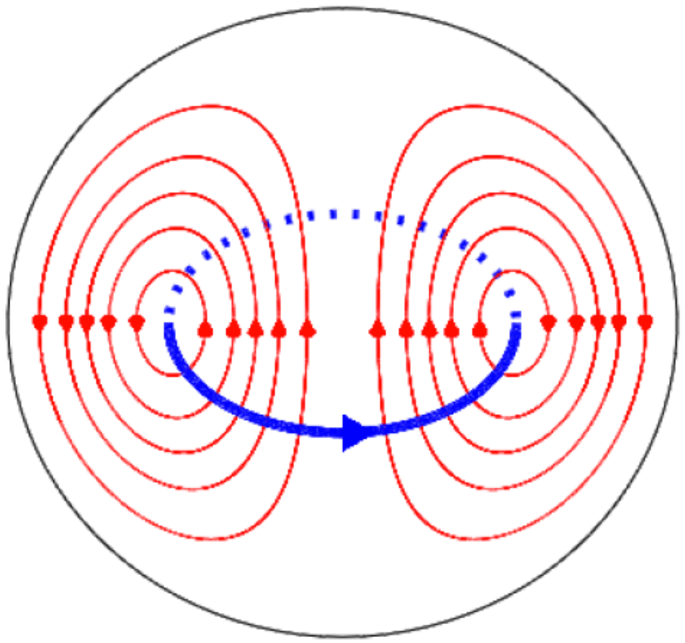

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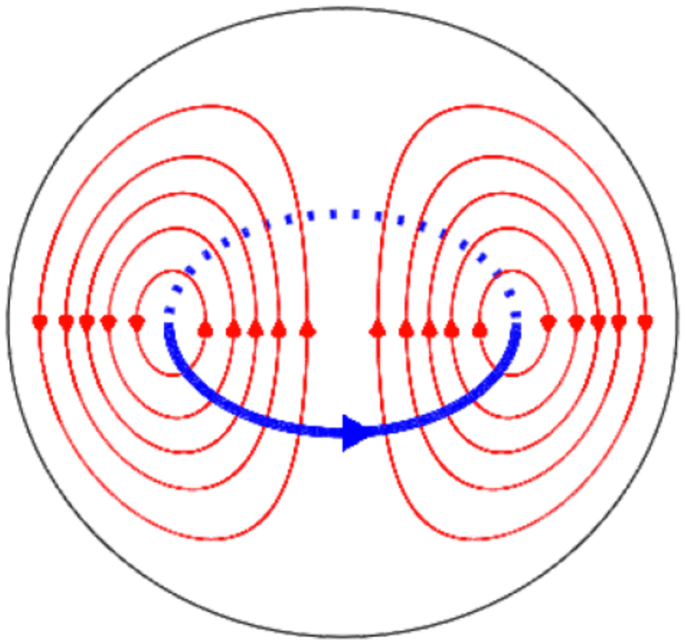

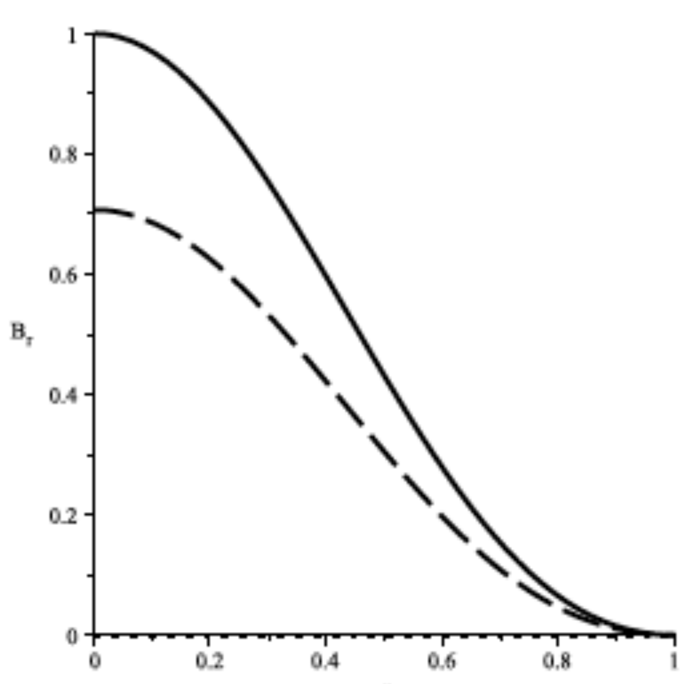

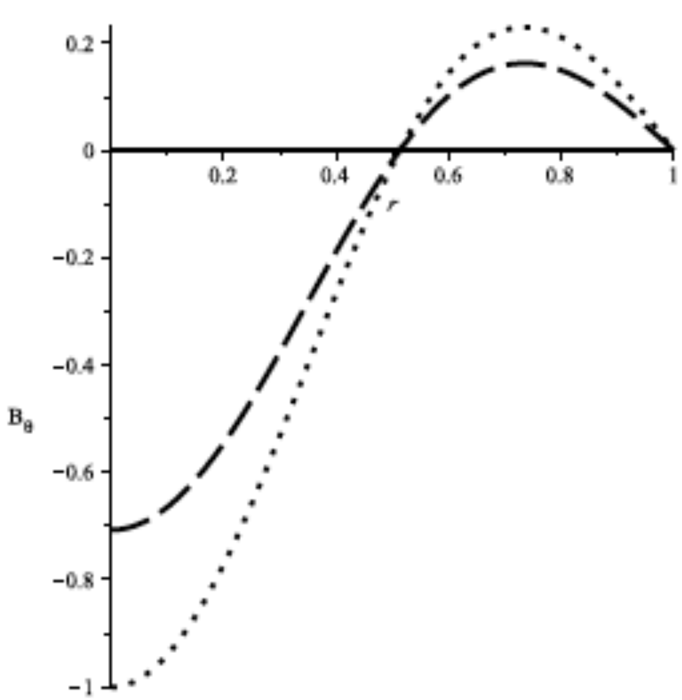

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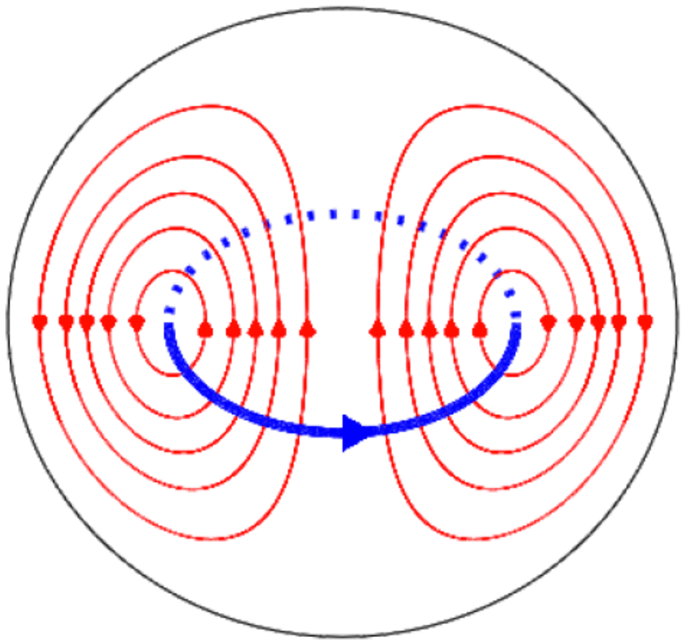

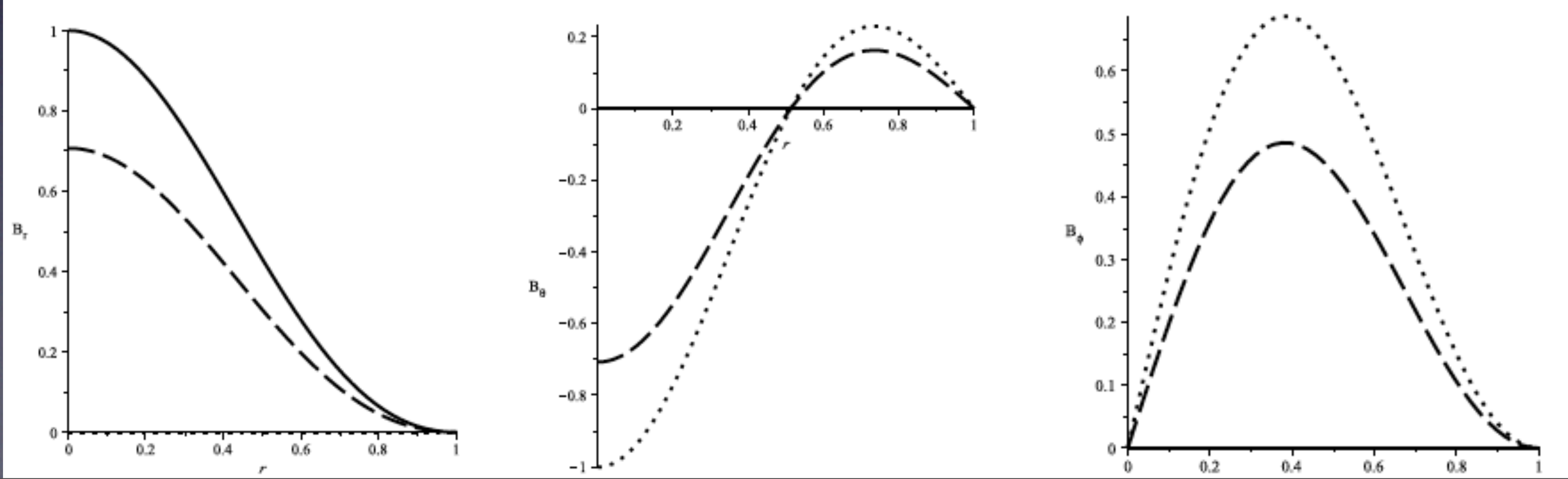

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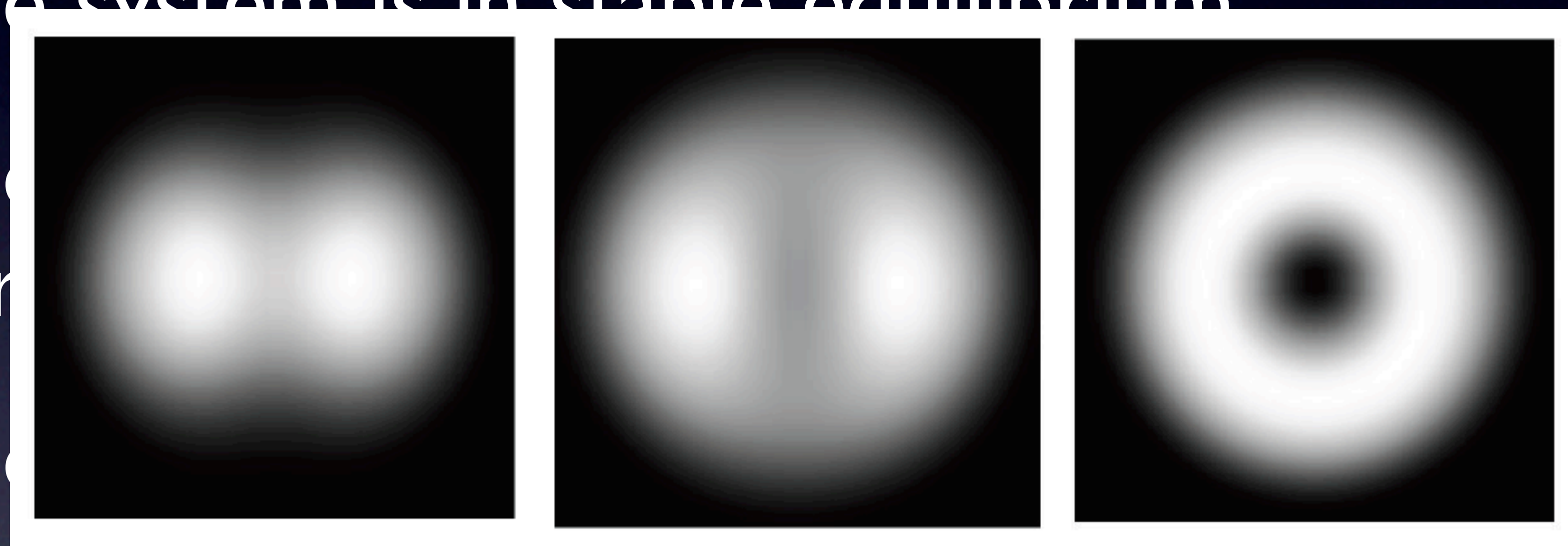

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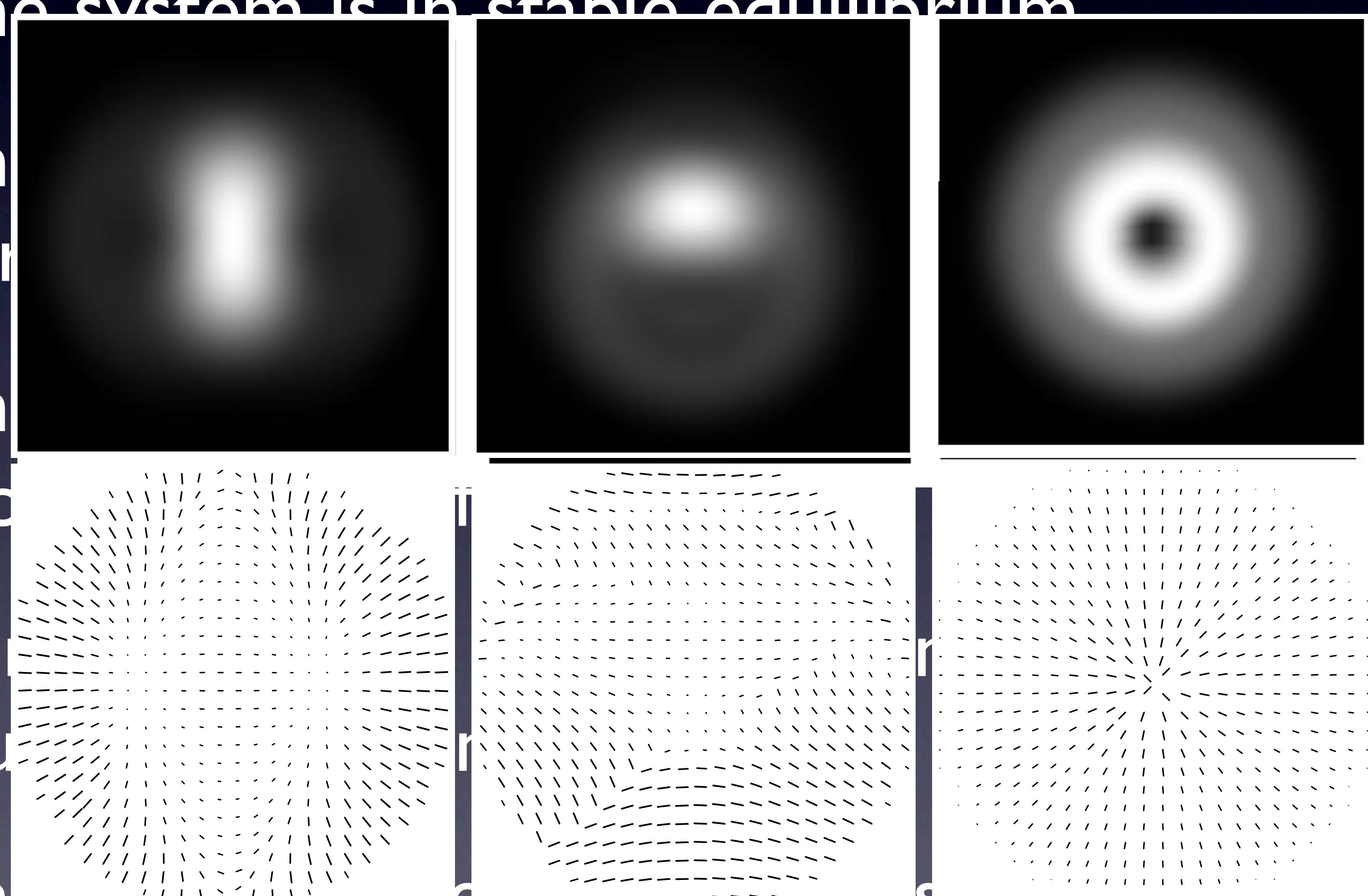

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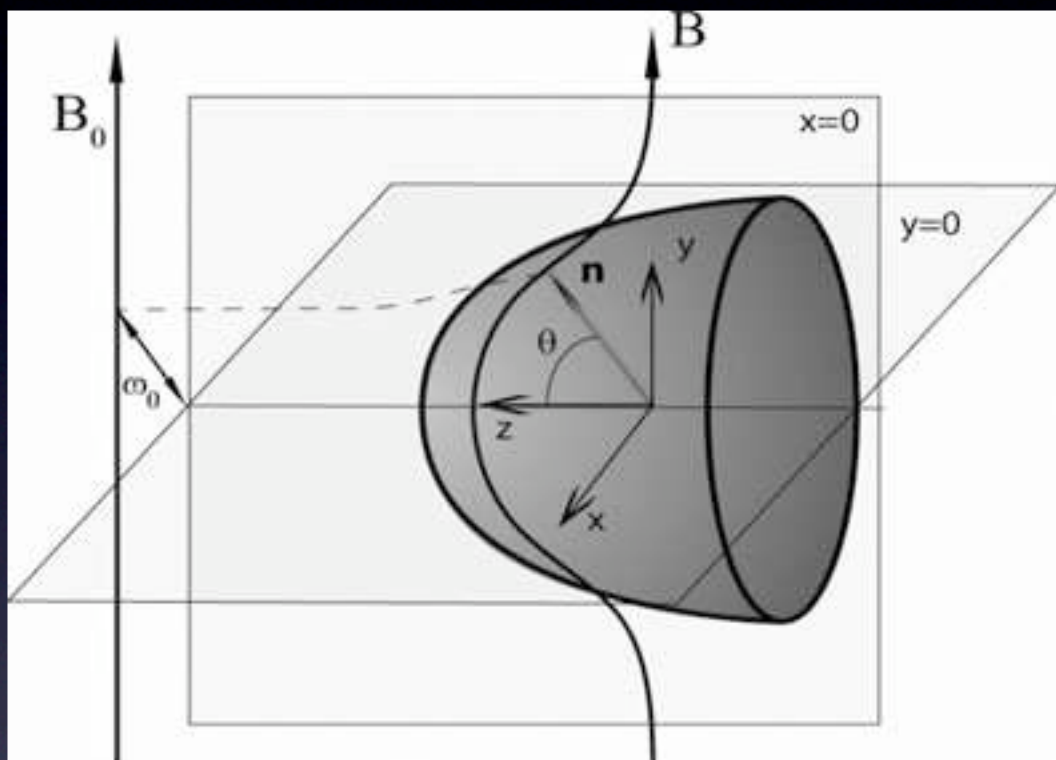

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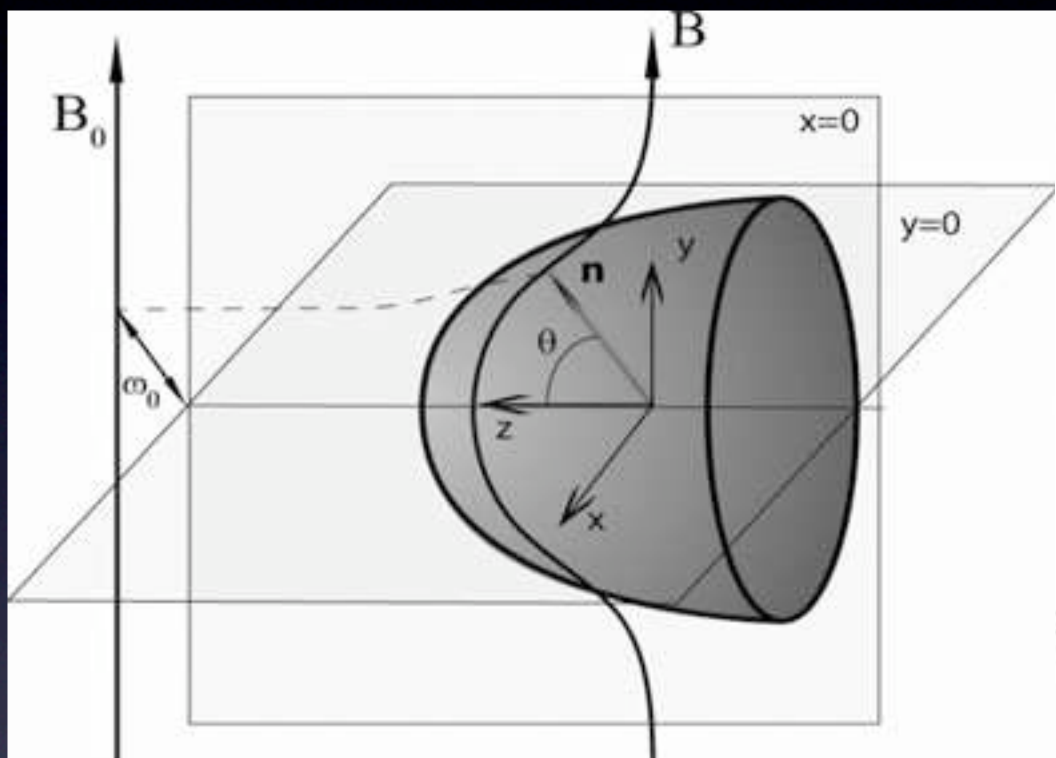

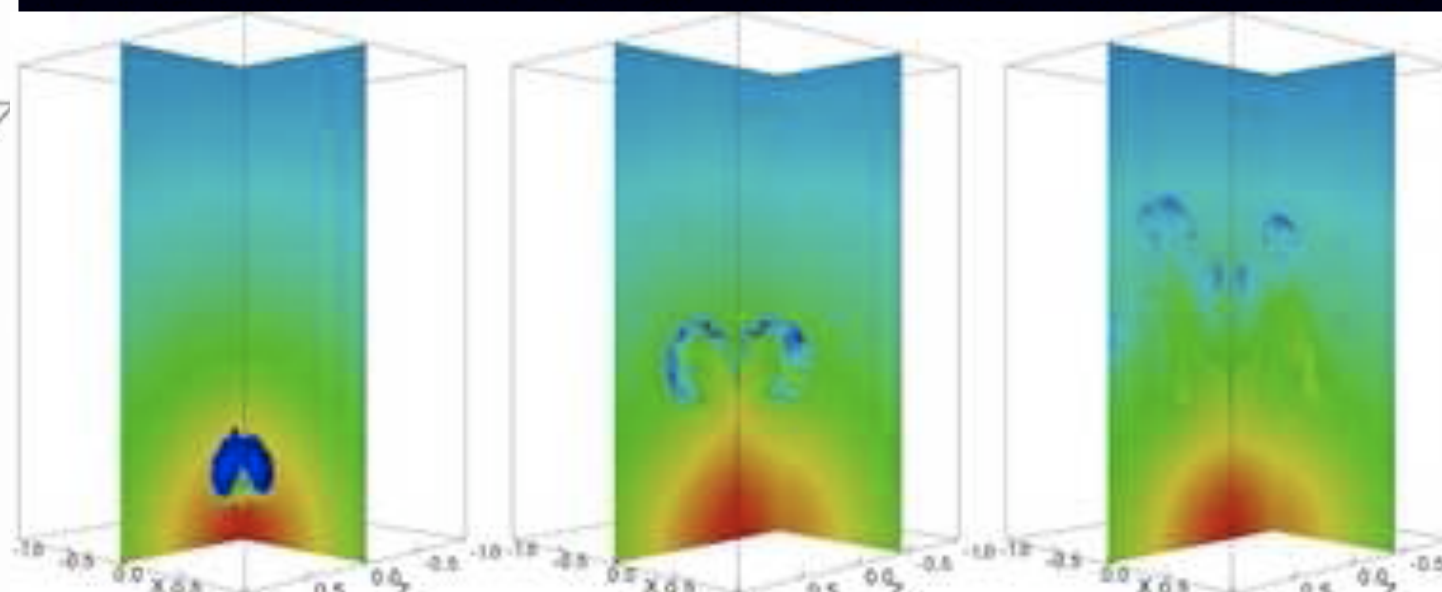

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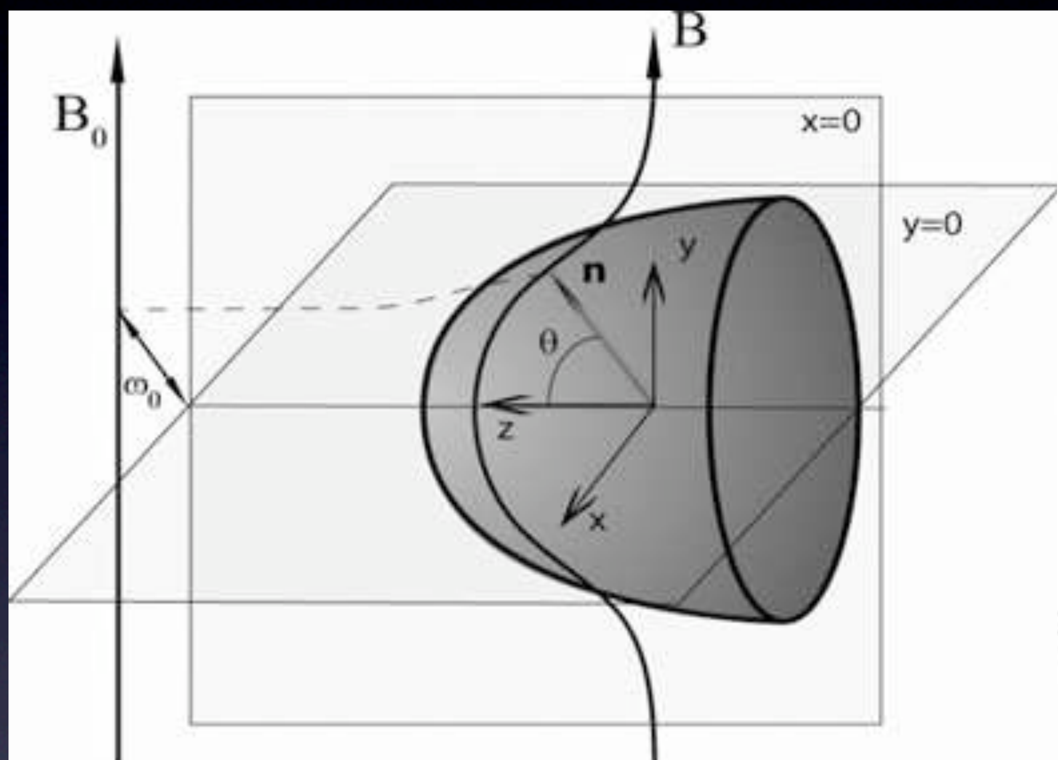

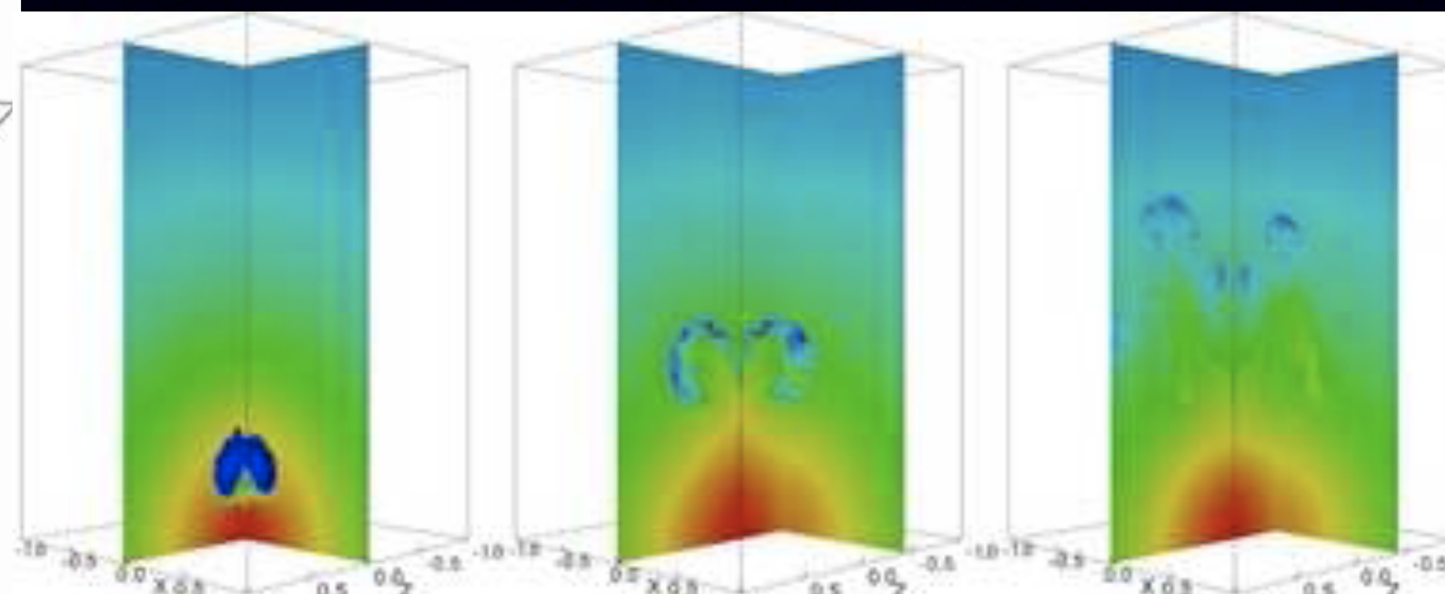

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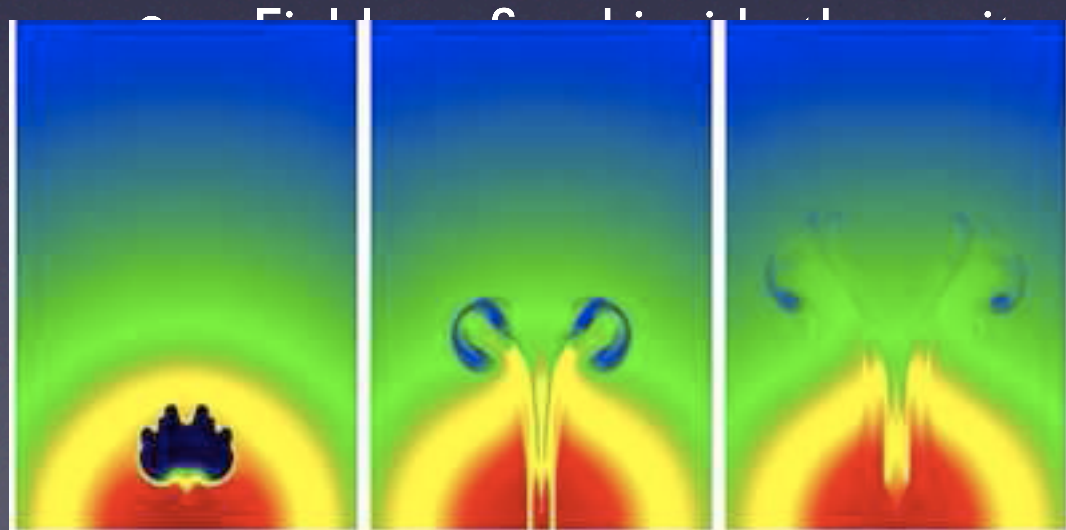

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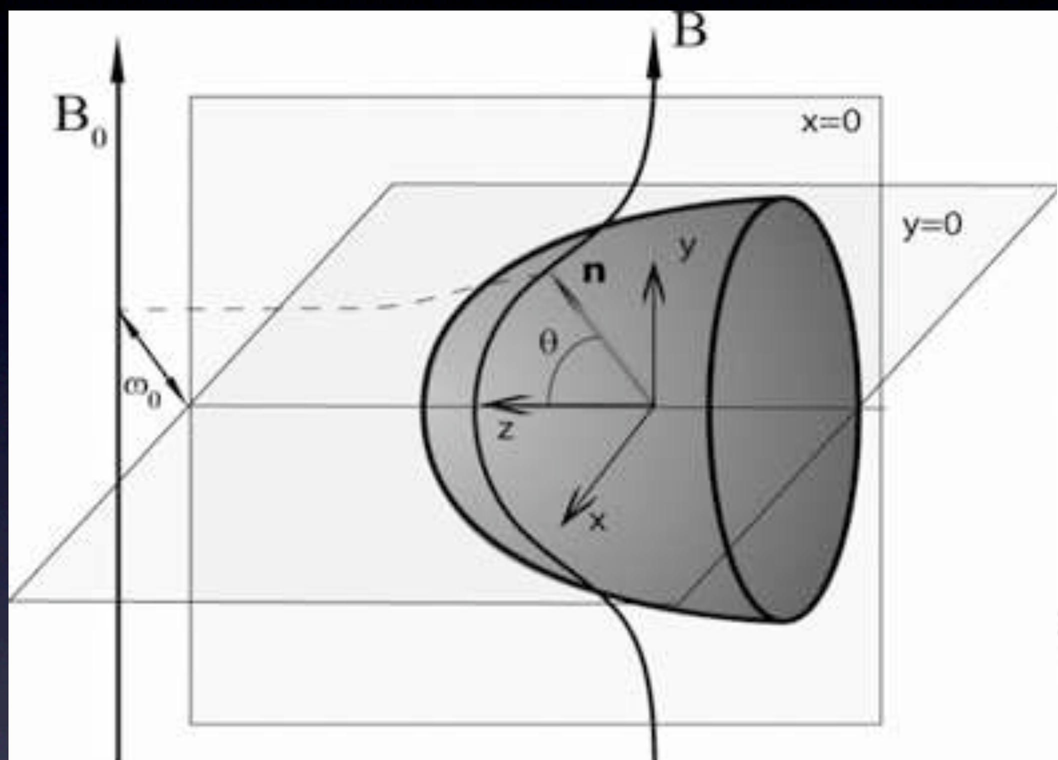

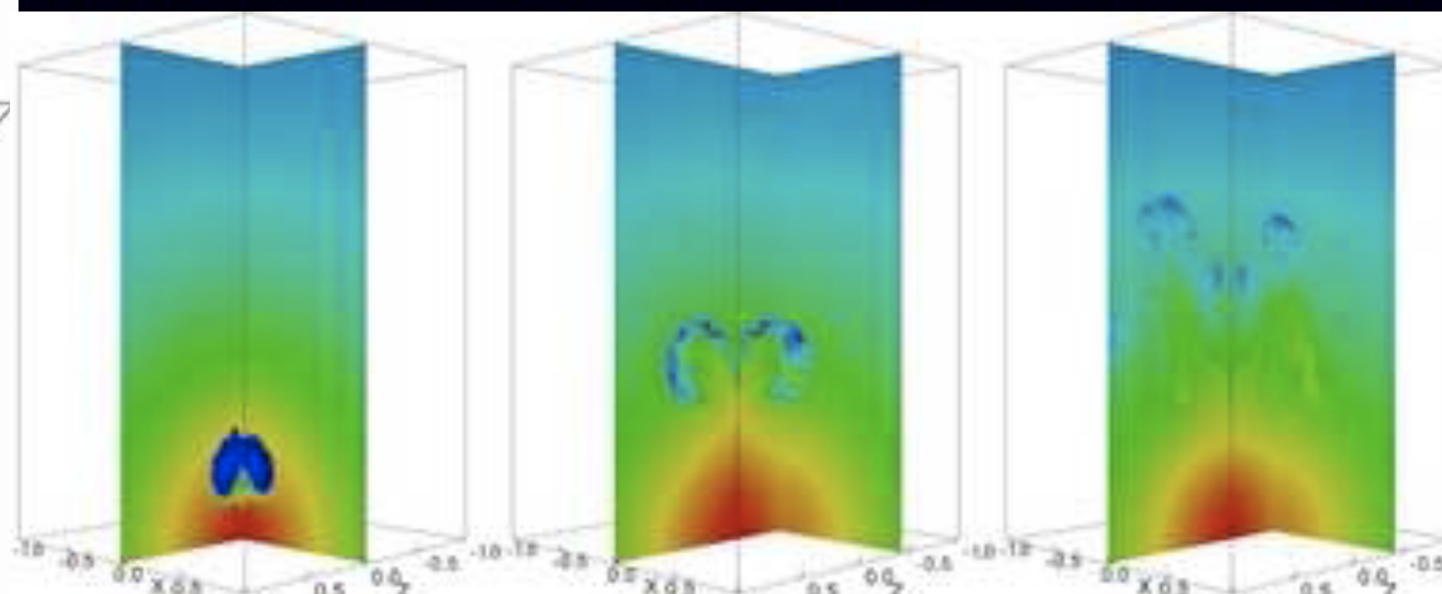

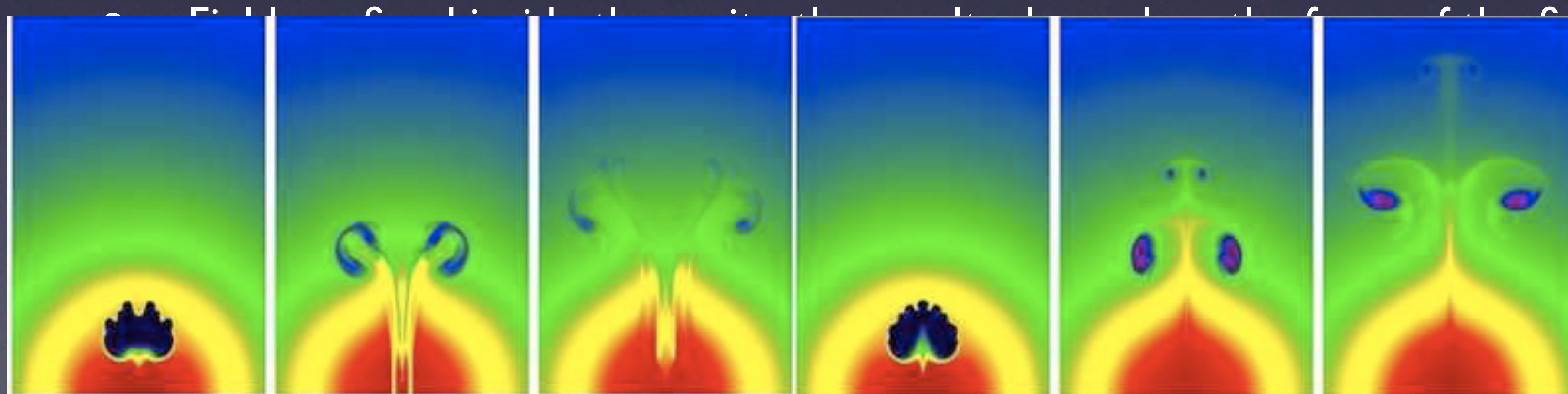

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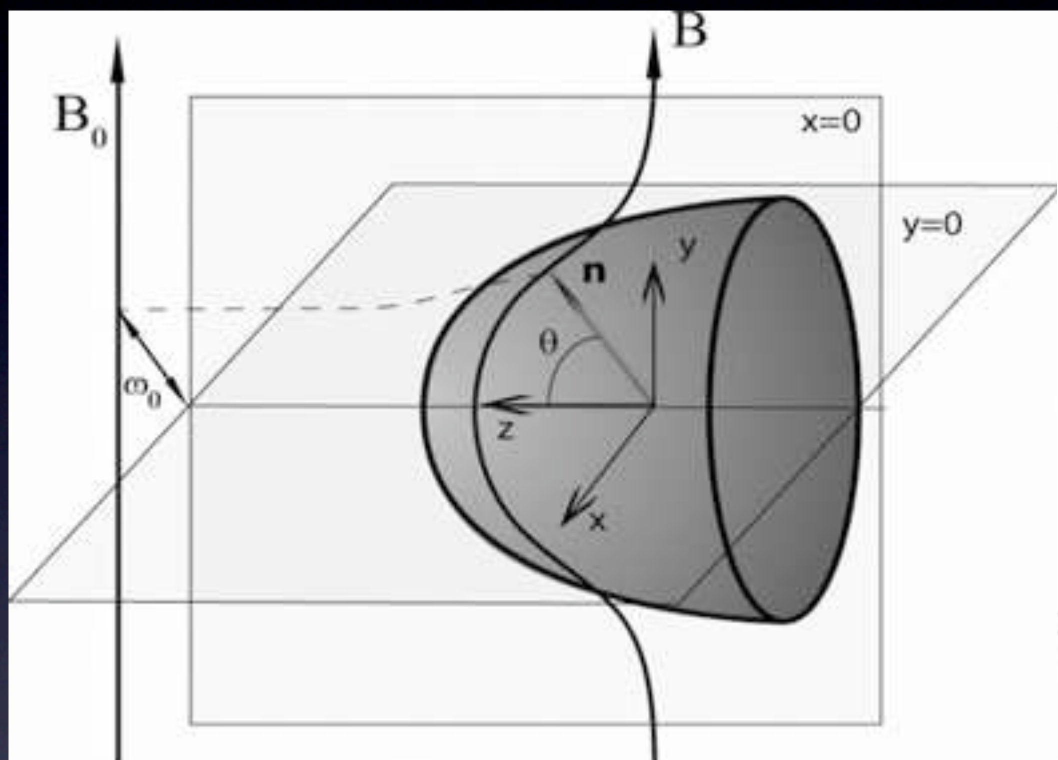

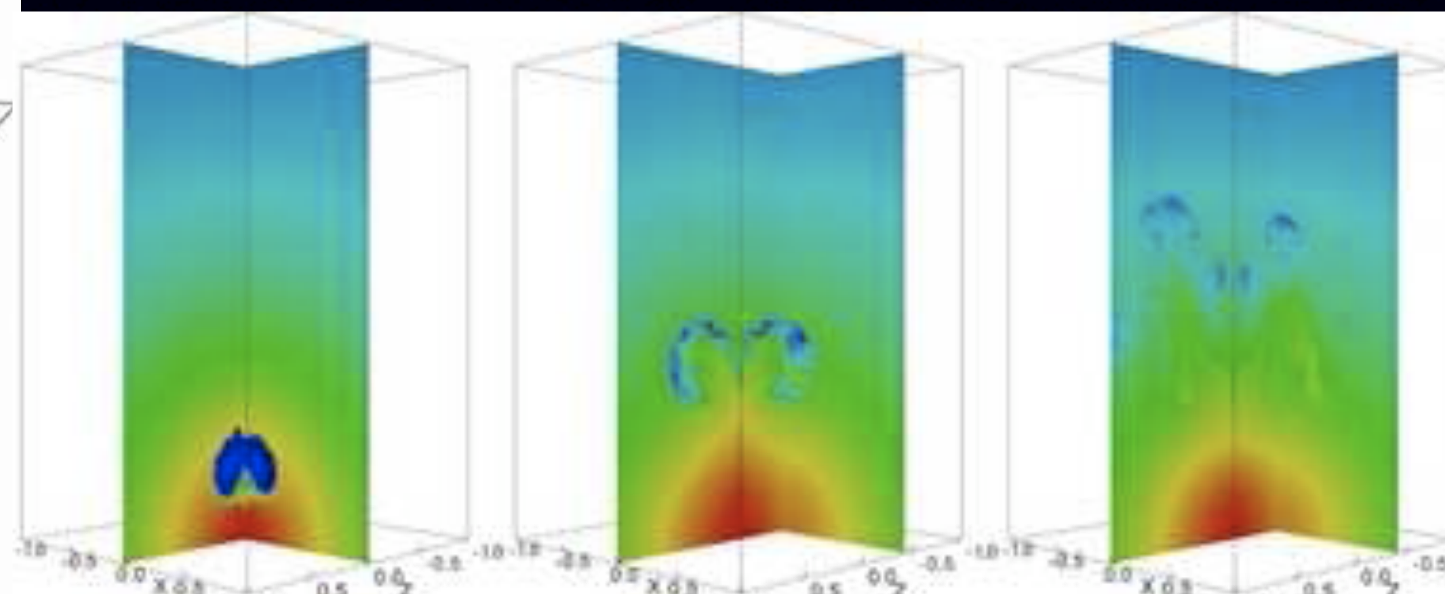

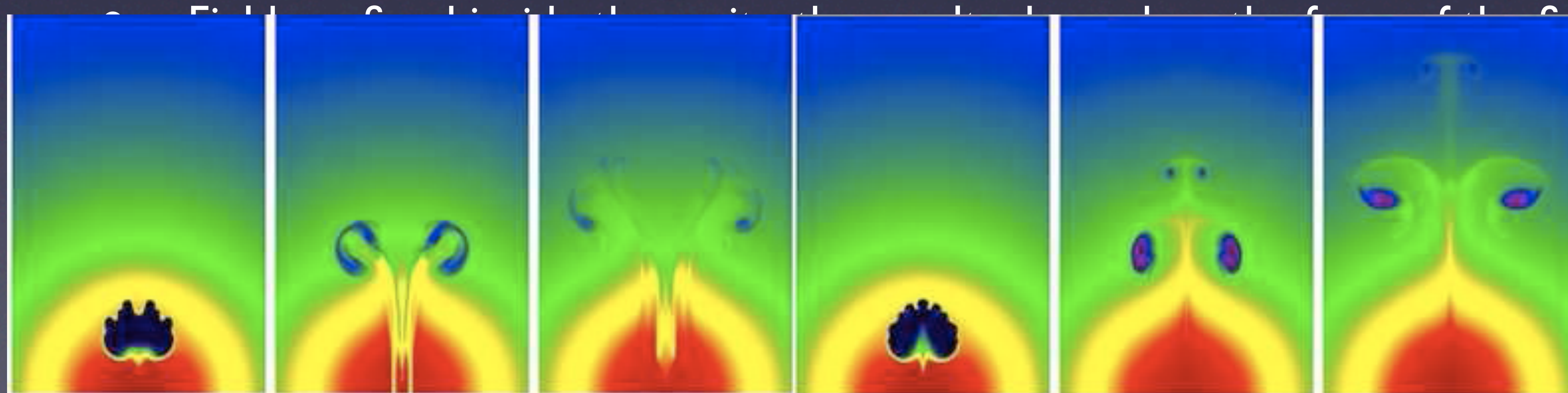

Figures: Lyutikov 2006, Dong & Stone 2009

Expanding bubbles

$$\rho\Big(\frac{\partial}{\partial t} + \boldsymbol{v}\cdot\nabla\Big)\boldsymbol{v} = -\nabla p + \frac{\boldsymbol{j}\times\boldsymbol{B}}{c}$$

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In the quasi-static formulation we require:
- conservation of magnetic flux, helicity and mass
- force equilibrium (RHS of momentum equation)
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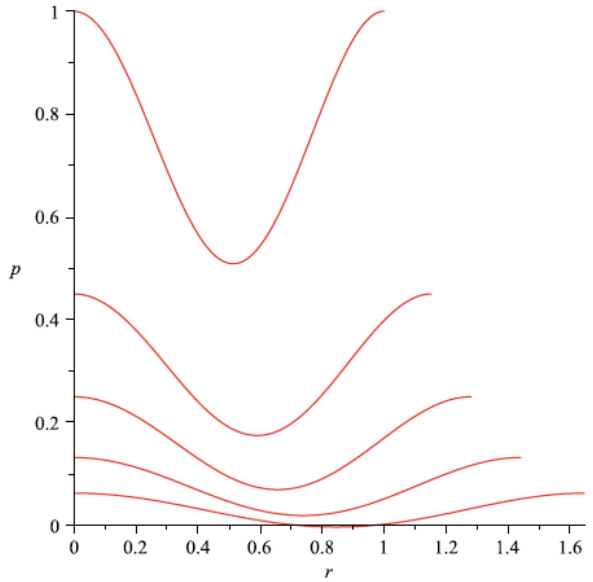

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- The resulting electric field will accelerate UHECRs. Order magnitude estimates show that there is sufficient potential.

Evolution

- We have three regimes:
  - For Γ=4/3: the ratio of magnetic to plasma pressure does not change with expansion
  - For Γ<4/3: after some expansion the plasma pressure dominates, the magnetic field is diluted
  - For Γ>4/3: the magnetic pressure dominates, we expect to have areas with magnetic field but no plasma pressure, the magnetic field there will be force-free and contain current sheets

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- Acceleration sites: jets-shocks (AGN and GRBs, i.e. Lazarian & Vishniak1999, Giannios 2011), Fossil lobes (Benford & Protheroe 2008)

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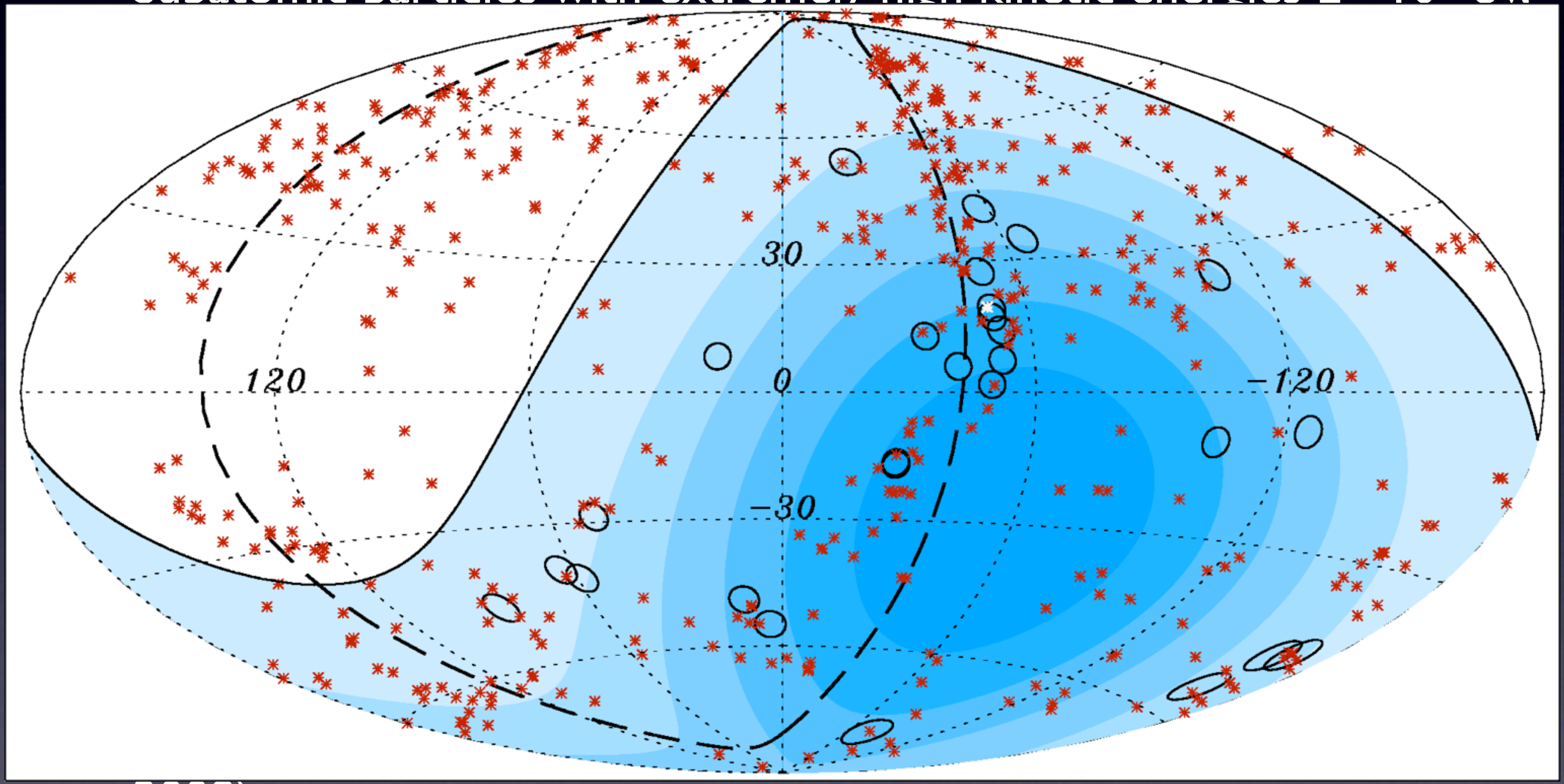

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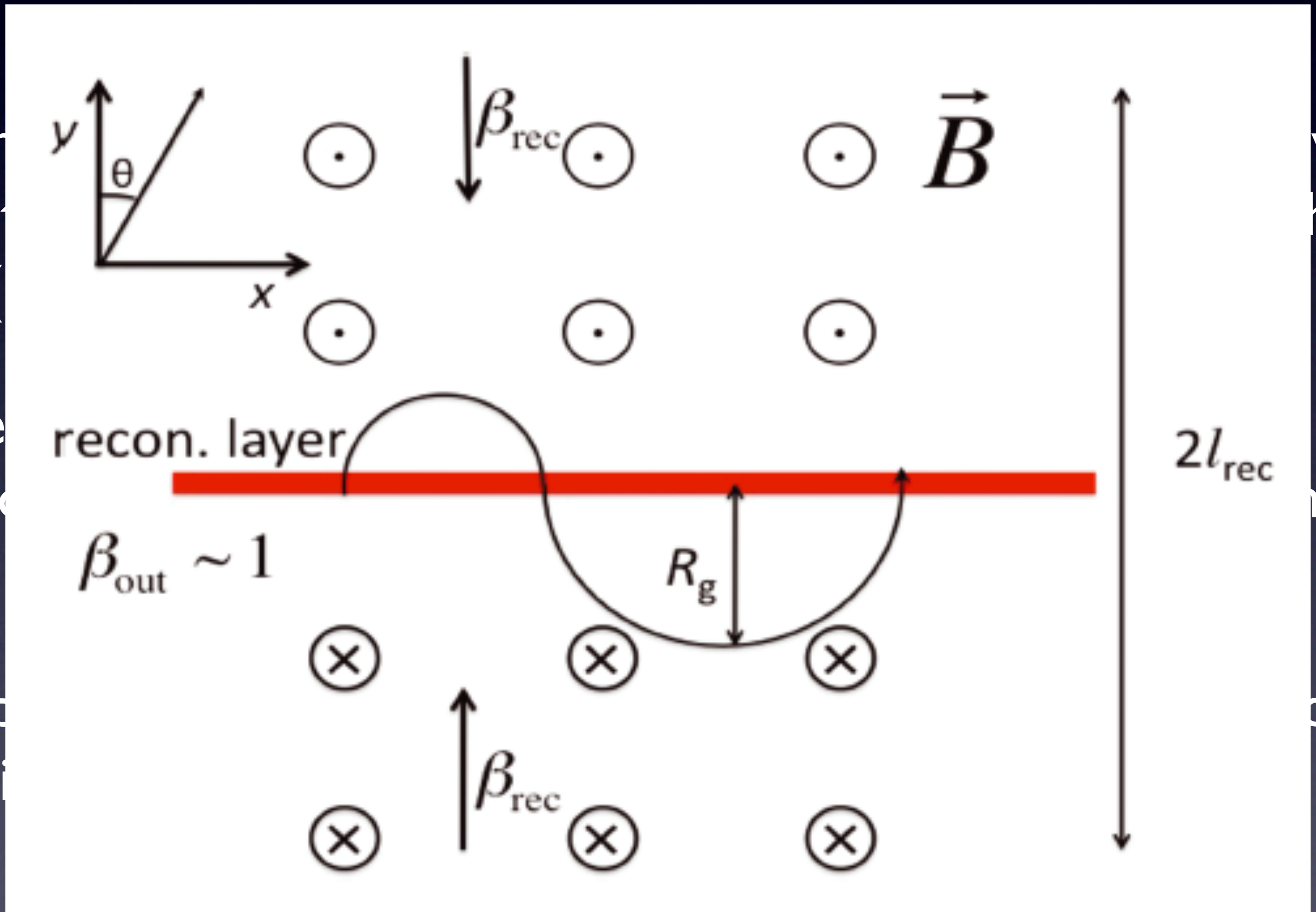

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- Their evolution can be traced by quasi-static evolution, simulation is essential however
- They provide the essential potential for UHECR acceleration if we consider one of the known mechanisms
- When reconnection layers form we break the initial assumption of ideal-MHD, formally we cannot predict the next step of evolution, but we do not expect destruction of the cavity