University of Houston Clear Lake

Numerical Analysis of the Biermann Battery Mechanism of Magnetogenesis for Relativistic MHD Turbulence

David Garrison

University of Houston Clear Lake

University of Houston Clear Lake

Background

- Primordial Magnetic Fields (PMFs) are believed to have played a role in the dynamics of the evolution of the universe
- PMFs may have seeded large-scale magnetic fields on the Mpc scale
- PMFs can't be directly observed so nobody knows how large they were or when they formed
- After Magnetogenesis, they could have been amplified by dynamo and compression

University of Houston Clear Lake

PMFs from Phase Transistions

- EW and QCD Phase Transitions studied
- Phase Transitions cause stirring with velocities comparable to the speed of sound in the fluid
- This results in a short-term intense turbulent RMHD fluid
- Biermann Battery effects describe how a turbulent magnetofluid can generate magnetic fields from no initial magnetic field

University of Houston Clear Lake

Biermann Battery

- MHD equations require an initial B-field
- The Biermann Battery works because of differences between temperature and density gradients
- The modified B-field MHD equation becomes

$$\partial_t \tilde{B} = \partial_j \left(v^i \tilde{B}^j - v^j \tilde{B}^i \right) + \frac{1}{q n_e} \nabla T_e \times \nabla n_e$$

University of Houston Clear Lake

Experiment

- Code developed in Cactus utilizing SRMHD equations
- All runs utilized 128^3 internal grid points on the UH UHPC Cluster
- 4^{th} order HRSC and ICN utilized
- Simulation domain ~1 Mpc adjusted for scale factor
- Initial temperature & density fluctuations ~ k
- Initial velocity fluctuations ~ k^3

University of Houston Clear Lake

Initial Conditions (EW)

- Energy = 246 GeV
- Temperature = 2.85×10^{15} K
- Scale Factor = 9.58×10^{-16}
- Initial Time = 2.09×10^{-11} s
- Mass Density = 9.70×10^{29} kg/m^3
- Maximum Velocity = 10^{-4} c

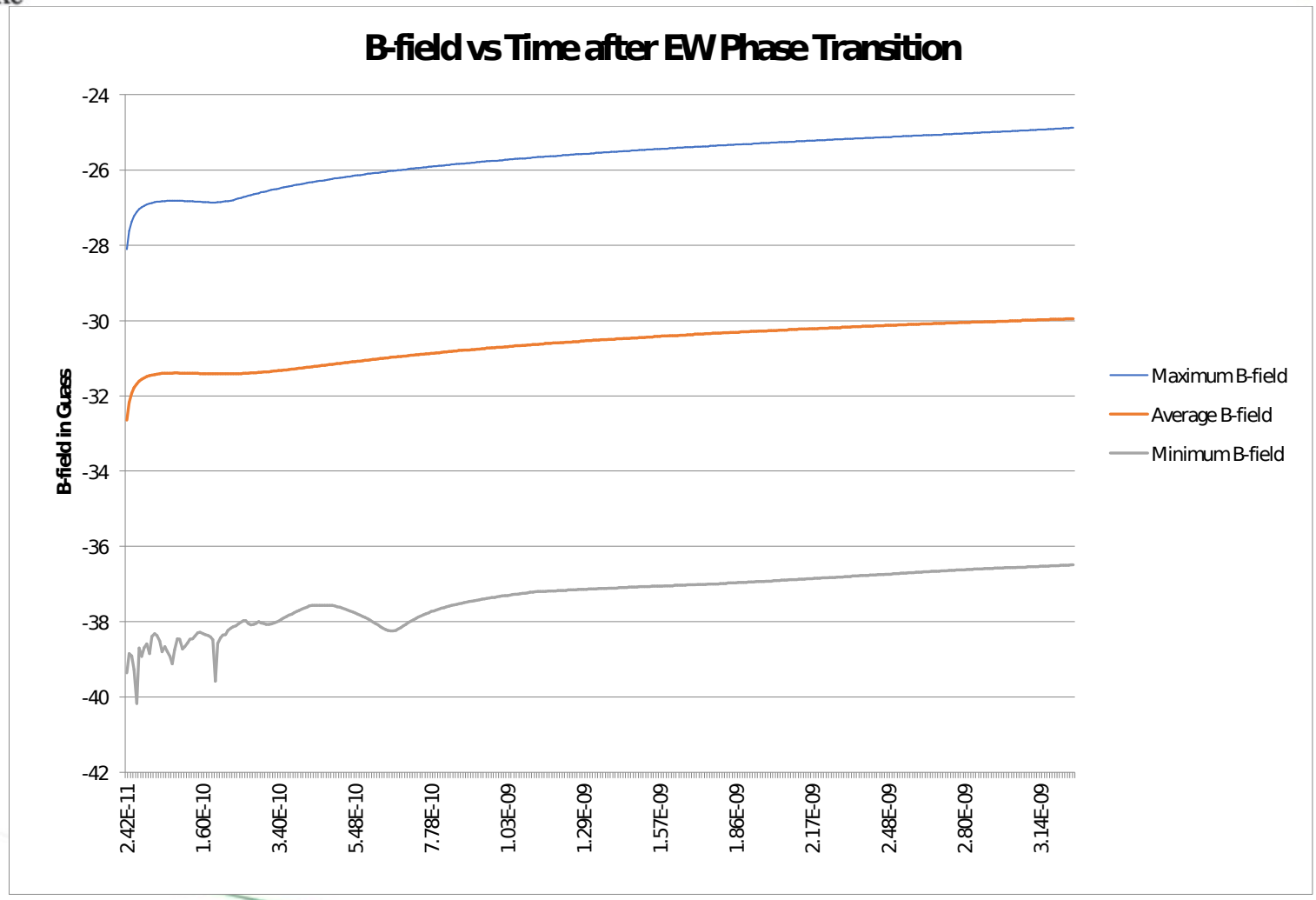
University of Houston Clear Lake

Initial Conditions (QCD)

- Energy = 170 MeV
- Temperature = 1.97×10^{12} K
- Scale Factor = 1.38×10^{-12}
- Initial Time = 4.36×10^{-5} s
- Mass Density = 2.22×10^{17} kg/m^3
- Maximum Velocity = 0.6 c

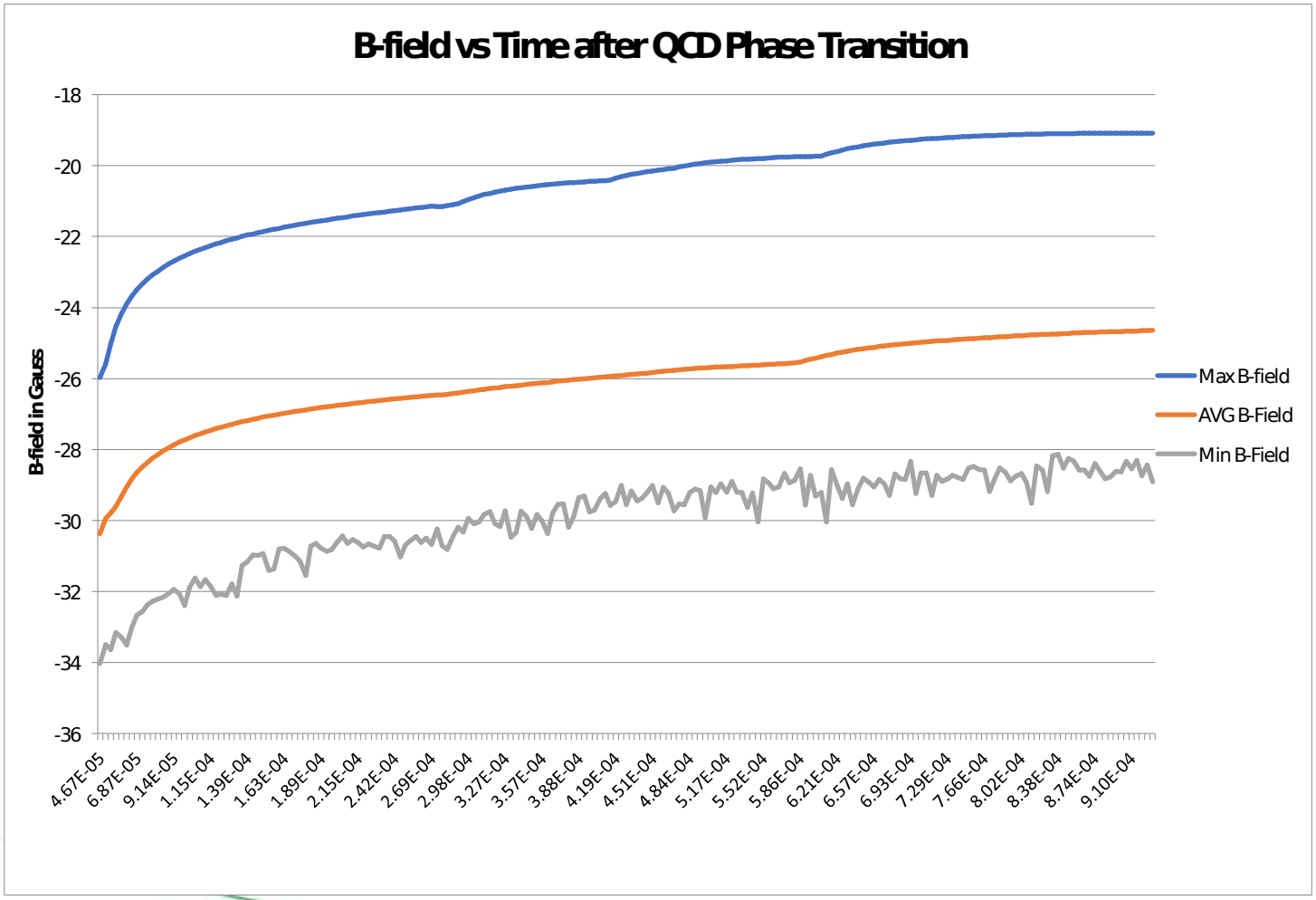
University of Houston Clear Lake

EW Phase Transition



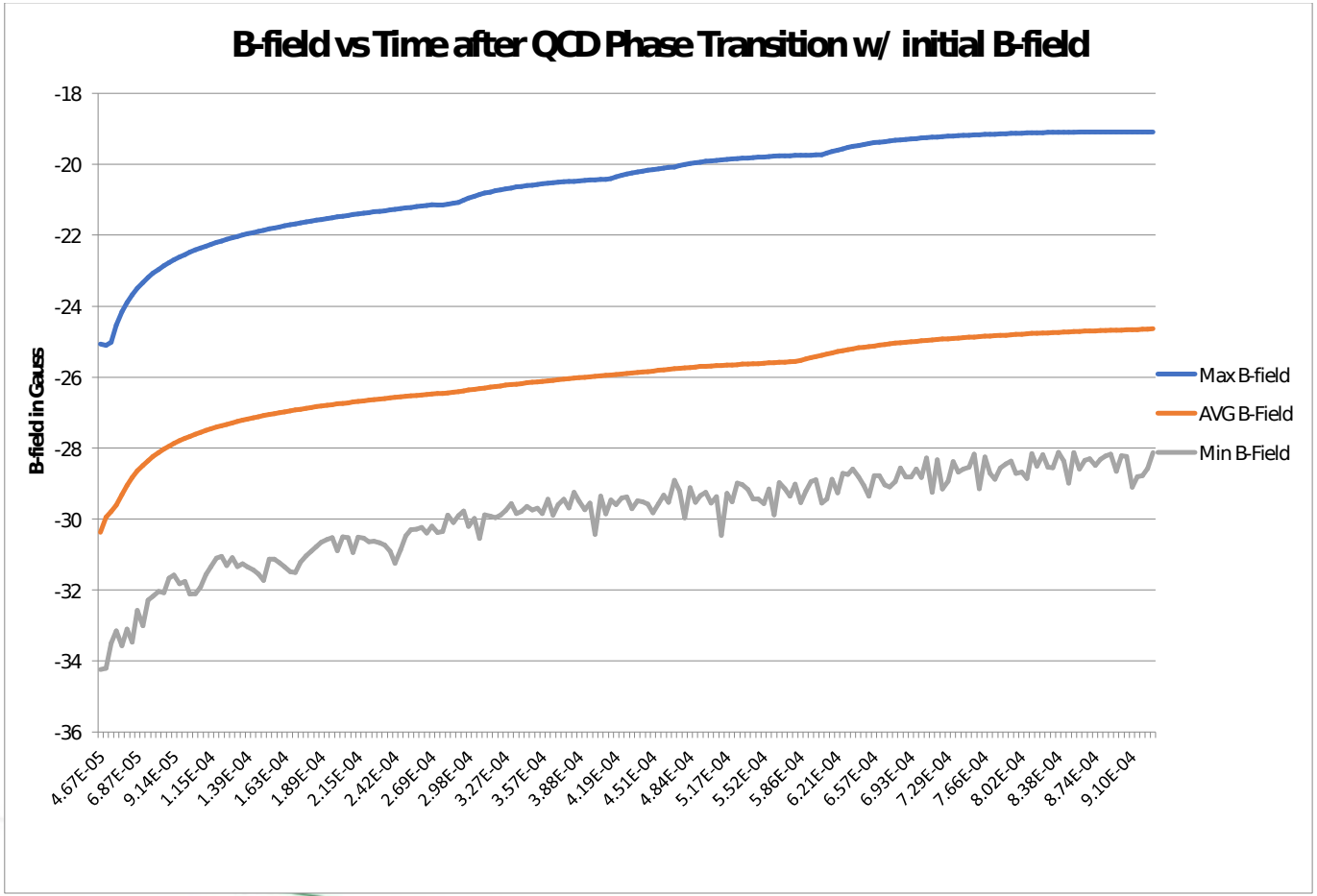
University of Houston Clear Lake

QCD Phase Transition



University of Houston Clear Lake

QCD Phase Transition with initial B-field



University of Houston Clear Lake

Conclusion

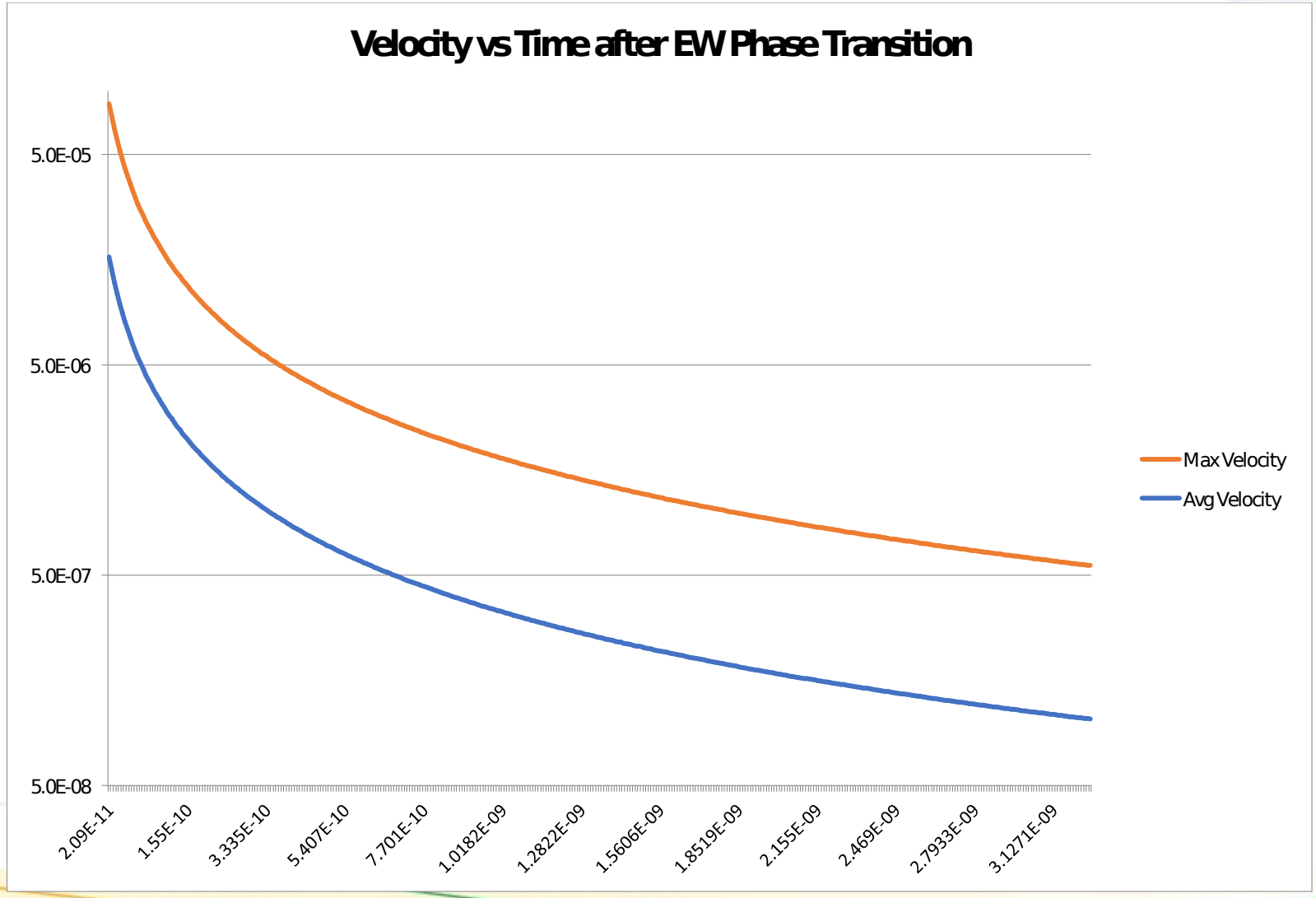
- B-fields as large as 10^{-19} G may have been produced by the end of the QCD phase transition
- These fields varied from 10^{-28} G to and average of 10^{-24} G over 1Mpc
- The strongest B-fields may have been isolated to small areas
- More work is needed to understand how these fields may have evolved until the first stars and galaxies formed

University
of Houston
Clear Lake

Questions???

University of Houston Clear Lake

EW Velocity



University of Houston Clear Lake

QCD Velocity