Reading Assignment for The Physics of Galaxy Cluster

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in preparation of lecture 11

Answers to be uploaded to moodle

Please read and work through the lecture notes, covering the following topics:

3.3.1 Non-thermal Processes and

3.3.2 Magnetic Fields

I prepared the following questions that should help you to understand the topics. Please read a topic first, think about it and then work through my set of questions on this topic. Some questions are going beyond what you have read in the lecture notes (indicated by *Bonus* questions). I do not expect you to answer these questions as well, but I would like you to start thinking about them and they will certainly be the starting point for our next zoom meeting. Ideally you can come up with many more questions yourself. **If you have problems with a derivation or if something is unclear, please email me those points well before the lectures**!

- **Non-thermal processes.**
  - Explain the physics of synchrotron emission and explicate why radio synchrotron emission proves the existence of relativistic electrons and magnetic fields. Which relation between magnetic field strength and electron energy does this imply?
  - Review the observational properties of radio halos and relics.
  - Review the process of Faraday rotation measurements (RMs). If you decrease the magnetic coherence length while leaving the gas density and magnetic field strength invariant, what happens to the value of RM on average?
  - Explain the phenomenon of the $n\pi$ ambiguity for the observable polarization angle. What could you do to circumvent it?
- **Magnetic fields**
  - Derive the Biermann battery equation. Why can we neglect the momentum equation for protons and the time derivative on the left-hand side?
  - Explain the physical meaning of the terms in the Biermann battery equation.
  - Calculate to order of magnitude the expected magnetic field strength that is generated by the Biermann battery in a collapsing proto-galaxy.
  - How does the magnetic pressure act on the surrounding plasma? Which force does magnetic tension apply to the surrounding plasma? Does a straight magnetic field have magnetic tension?
  - Starting with the equations of magneto-hydrodynamics (MHD), derive the flux-freezing property of magnetic fields.
  - Going back to our derivation of the dispersion relation for sound waves by perturbing the mass, momentum and entropy equation of a hydrodynamic fluid without conduction and viscosity. How many equations do you have and how many eigenvalues does the linearized system of equations allow for? Identify them.

– Add magnetic fields to the system in the MHD approximation. How many equations and eigenvalues do you have now? Identify them.
– Derive the scaling of the eddies in Alfvénic turbulence. What does this imply for the resulting turbulence and how does this differ from Kolmogorov turbulence?