Reading Assignment for The Physics of Galaxy Clusters

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in preparation of lecture 12

Answers to be uploaded to moodle

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

3.3.3 Cosmic Rays

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. On problem is quite tricky (indicated by *Bonus* problem). I do not expect you to fully solve this as I will provide the answer in the next week. 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!**

- **Cosmic Rays**
  - Describe how cosmic rays (CRs) interact with Alfvén waves. Please explain the physics of the wave-particle interactions in configuration and in Fourier space.
  - CRs are virtually collisionless (they only collide on average once per Hubble time with the ambient gas protons in clusters). How can they excert a pressure if they do not collide with the gas?
  - Which processes can accelerate and deaccelerate CRs?
  - How does the process of *diffusive shock acceleration* work (Section 3.3.3.2)? Please follow this derivation in great detail!
    - Why does the CR velocity not experience the deceleration by the shock?
    - Why are we allowed to take the non-relativistic limit of the Lorentz transformation if CRs are relativistic particles?
    - Why are the energy gains in the downstream and upstream media identical?
    - When exactly does a CR particle experience the energy gain during this process? during the crossing of the shock or during the scattering event?
    - Which property of shocks is eventually responsible for the energy gain of CRs?
    - Argue physically (without going to the details of the derivation), why the emerging CR spectrum must be a power law in momentum?
    - Does the process of *diffusive shock acceleration* work for collisional shocks in the Earth atmosphere?
  - Which hadronic and leptonic non-thermal emission processes do you know? What is the underlying physics of these emission processes?
  - Why is Fermi-II acceleration with Alfvénic turbulence inefficient? Please explain the reason for the inefficient acceleration in configuration and in Fourier space.
  - Explain how CRs can be accelerated via the Fermi-II process? What is the physical reason behind the more efficient interactions with fast magnetosonic modes in comparison to Alfvén modes.
  - Compare the pros and cons of Fermi-I vs. Fermi-II acceleration.