Reading Assignment for The Physics of Galaxy Clusters

Lecturer: Christoph Pfrommer

in preparation of lecture 2

Answers to be uploaded to moodle

Please read and work through the lecture notes, starting on page 11 and cover the following topics:

1.2.4 Sunyaev-Zel'dovich Effect

1.2.5 Synthesis of Observational Windows

1.2.6 Relation to the Average Universe

2.1 The Growth of Perturbations: Newtonian Equations and Density Perturbations

2.2.1 Power Spectra

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. 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 lecture. Ideally you can come up with many more questions yourself!

- **Sunyaev-Zel'dovich Effect**
  - Why do galaxy clusters appear as holes in the cosmic microwave background sky at $\nu < \nu_0$ and as extended sources above?
  - Why is the Compton-y parameter independent of redshift? Is the observable (solid-angle) integrated Compton-y parameter independent of redshift?
- **Synthesis of Observational Windows**
  - Which observational method would you prefer to observe the inner parts of a cluster and which for the outer parts?
  - Which problem do you see arising for studying small clusters with galaxy observations? How reliable can you estimate the cluster mass here?
  - Which method is most powerful to do cluster cosmology? Which criteria would you find most important for this?
- **Relation to the Average Universe**
  - Explain why clusters are rare objects.
  - In the notes, I state that we typically find $\bar{\rho}_{\rm cl} \sim 10^3 \bar{\rho}_{\rm m,0}$. Which processes determine this relation?
- **The Growth of Perturbations**
  - Equation (2.13) is an ordinary differential equation for the density contrast δ. Which mathematical form has this equation? What is the physical meaning of the term including H?

- I mentioned in my notes that the growing mode solutions of equation (2.22) are responsible for growing a cluster? Which mode grows cosmic voids (huge volumes of nearly empty space)? Are decaying modes responsible for growing these? Justify your answer.
- In the derivation, the pressure term provides the restoring force. It communicates the pressure gradients via collisions and sound waves to the gas. However, dark matter does not interact via sound waves? How would you need to conceptually change the derivation to account for a collisionless dark matter component? How does dark matter influence structure formation?

- **Power Spectra**
  - Why does the Dirac delta distribution appear in the definition of the power spectrum in equation (2.26)? Why does the power spectrum only depend on the magnitude of the wave vector and not its direction?
  - How does the window function influence the density contrast? Draw some one-dimensional function that varies widely. How does this look after you applied a top-hat or a Gaussian window? Imagine you have a field δ with two spatial scales (one with a large and one with a small wavelength). Then you apply the filter which has a scale in between. Which of the two scales survives (if any)? How does the power spectrum look if you draw it before and after filtering?