Cosmology Exam

3 December, 18.30-21.30 uur

Rules:

- Closed book part $\leq$ 2 hours, open book part all remaining time.
- Please formulate clearly and concisely. Read carefully.
- Grade $= 1 + \frac{score}{10}$.

1. **General Relativity [5+5=10 points]**

   (a) Formulate the strong equivalence principle in less than 200 words, relating to the concept of space-time through one of Einstein's thought experiments.

   (b) Argue thermodynamically, using the notion of de Sitter space, that our universe must enjoy quantum fluctuations (use less than 200 words).

2. **Nature of the Universe [5+5=10 points]**

   (a) State the Copernican principle, in less than 200 words.

   (b) State and criticize the Anthropic principle, using not more than 200 words.

3. **Cosmic Phase Transitions [5+5=10 points]**

   (a) Explain why our universe is expected to go through different phases for matter to enjoy, in the first few minutes of its existence, using not more than 200 words.

   (b) Explain why the photon and neutrino background currently have different temperatures, in less than 200 words.

4. **Dynamics of the Universe [5+5=10 points]**

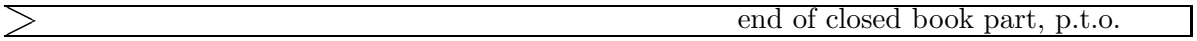
   (a) Argue how the universe can currently be in a vacuum energy dominated state, and whether this can always be true, using not more than 200 words.

   (b) Use the Einstein equation to derive a qualitative conclusion about the stability and overall dynamics of the universe.

5. **The CMB [5+5=10 points]**

   (a) Describe two secondary anisotropies, using not more than 100 words for each.

   (b) Give a qualitative indication of their appearance and relevance as a function of cosmic time, using not more than 100 words for each.



6. **Cosmic Expansion [10 points]**

Write down the Friedmann equation and solve it for both a radiation and a matter dominated universe. Briefly interpret your result using the concept of particle horizon.

7. **Dark Matter [10 points]**

Provide a mathematical formulation of the main empirical evidence for dark matter. Provide an example of both a cold and a hot dark matter candidate.

8. **Expansion and Horizons [10 points]**

Consider conformal time for photons and determine what cosmic expansion laws $R(t)$ yield a linear time dependence for the particle horizon. Be careful with the $t = 0$ singularity.

9. **Expansion and Redshift [10 points]**

Start from the cosmological Hubble law, with dark matter. Then derive the overall scaling of the comoving particle horizon size as a function of redshift for a flat universe and a cosmic time earlier than $z \sim 10^5$.

end of exam