CLAB9: Gravitational Waves (Andrey Saveliev, Uni HH/KIAM Moscow)

As a direct consequence of General Relativity, gravitational waves are a highly promising candidate to study this basic theory of modern physics. Furthermore, since they are predicted to occur for various astrophysical and cosmological phenomena, together with the multimessenger approach in combination with neutrinos and electromagnetic radiation it is a powerful tool to gain insight into processes of sources like supernovae, pulsars and different kinds of binaries.
In this Dedicated Master Class we want to give a general overview over the theoretical basics of gravitational wave physics [Sat09]. To do so, we first recapitulate the fundamental concepts of General Relativity applied to cosmology, focusing on the Einstein Equations together with the definitions necessary to understand them. That is then used to introduce Linearized Gravity by assuming the universe to be flat with gravitational waves being a small perturbation of the underlying Minkowski metric.
Subsequently, we study two variants of the resulting wave equations [Gui03]: First, we consider the vacuum case for which an analytical solution is derived and then discussed in detail, in particular also comparing it to the corresponding situation in electromagnetism. Second, we present the wave equations for an arbitrary energy-momentum tensor and discuss estimates of their solution for the case of a binary system. The resulting predictions for signals are then analyzed concerning their detectability and visualized in a convenient way.
Finally, as an additional approach, we discuss the general concept of the so-called Pulsar Timing Arrays (PTAs), a technique for which the pulse arrival times from different millisecond pulsars are correlated in order to detect small deviations in the observed signals which may be caused by gravitational waves [Jos13]. We derive estimates on the size of such deviations and list several running and planned efforts in that field.

[Gui03] M. Guidry, *Astrophysics 616: General Relativity, Black Holes and Cosmology [Notes for lectures at the University of Tennessee, Knoxville]* (2013), http://eagle.phys.utk.edu/guidry/astro616/lectures/lecture_ch21.pdf

[Jos13] B. C. Joshi, *Pulsar Timing Arrays*, Int. J. Mod. Phys. D 22, 1341008 (2013), DOI: 10.1142/S0218271813410083 [arXiv:1301.5730 [astro-ph.IM]]

[Sat09] B. S. Sathyaprakash, B. F. Schutz, *Physics and Astrophysics of Gravitational Waves [Notes for lectures at Cardiff University]* (2009), https://indico.desy.de/materialDisplay.py?contribId=30&sessionId=2&materialId=7&confId=12535