Nonlinear interaction of strong gravitational and electromagnetic waves in the expanding universe

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Wonderful events – the long awaited direct observations of gravitational waves by LIGO collaboration, which happened at the turn of the century of General Relativity theory, and subsequent observations of gravitational waves by LIGO-Virgo collaborations as well as the identifications of the sources of the recorded signals with black holes and neutron stars mergers marked the beginning of a new era in the studies of the Universe – the era of gravitational wave astronomy. In addition to the information which can be received now from various parts of electromagnetic spectrum, a new information channel was opened and it can bring important information about physical processes in various (particularly – very distant) astrophysical objects, about the structure and evolution of the Universe.

The recorded gravitational wave signals showed that these waves were produced at very large (in cosmological scale) distances in the processes of massive black holes as well as neutron stars close inspiral motions and mergers, i.e. these waves originally had been created with large amplitudes and might pass throw the regions of strong gravitational and probably, electromagnetic fields. The existence of electromagnetic counterparts of the registered gravitational bursts obviously becomes a question of a present interest for observations. Possible sources of such electromagnetic signals can possess different nature: these can arise from the interaction of strong gravitational waves with ionized plasma which may surround the inspiralling and merging black holes and/or neutron stars, or as a result of a direct interaction of gravitational waves with strong external electromagnetic fields or even with electromagnetic wave bursts of high energy which also may exist in the regions surrounding these objects or along the paths of these waves from merging objects to the detectors.

The interaction of electromagnetic and gravitational fields and waves is predicted by General Relativity (the Einstein - Maxwell theory). The studies of these interactions possess a long history since a pioneer work of M.E.Gertsenstein (1962) who showed that a gravitational wave can be exited during the propagation of electromagnetic wave through a strong background electromagnetic field.

Later, periodic mutual transformations of gravitational and electromagnetic waves in a strong external electromagnetic field had been discovered and studied in the papers of Zel'dovich, Braginskii&etal (model equations), Sibgatullin, GA&Sibgatullin and others (the Einstein-Maxwell equations). However, in these studies the interaction of waves was considered in linear approximation only.

In this talk we discuss different aspects of nonlinear interaction of arbitrary strong gravitational and electromagnetic waves using a large class of exact solutions of Einstein - Maxwell equations found by the author in [1]. These solutions describe a head-on collision of plane linearly polarised waves – the soliton gravitational waves with electromagnetic waves of arbitrary amplitudes and profiles.[1] The most interesting features of nonlinear interaction of these waves are

- In contrast to our posible intuitive expectations, an arbitrary strong electromagnetic wave of any profile can't destroy a gravitational soliton wave.
- Constant parameters, which characterise the gravitational soliton before interaction, begin to evolve inside electromagnetic wave and become constant again (with changed values) after passing the back front of this wave.
- During a collision, a partial mutual conversion of gravitational and electromagnetic waves (similar to that known in the linear case) takes place.
- After a collision, a gravitational soliton can change its profile so that, e.g., the "dark"soliton can become a "light"soliton.
- After a collision, a gravitational soliton gets its electromagnetic counterpart with a profile very similar to the gravitational one.
- A part of "energy"of gravitational soliton is scattered and a gravitational wave which goes back and follows the electromagnetic wave is created.

Another process – a collision of electromagnetic soliton wave with another electromagnetic wave of arbitrary profile, their mutual nonlinear scattering and creation of gravitational waves in this collision is also discussed in the talk.

[1] G.A.Alekseev, "Collision of strong gravitational and electromagnetic waves in the expanding universe", Phys.Rev. D 93, 061501(R) (2016)

[1] A choice of a homogeneous anisotropically expanding universe as a background for waves (instead of e.g., Minkowski space-time) simplifies the solutions considerably because it prevents the mutual focusing of waves and creation of singularities on the caustics.