Detection Methods Of High Energy Astrophysical Events

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Introduction

The Michelson interferometer is used as the basic method for detecting gravitational waves (GW). The objective of a GW interferometer is to observe a GW signal that passes through the arms of the detector which will change the pattern of light display in the photodetector once it changes the of the arms of the detectors. This tidal effect is the basis of all present detectors which can detect GW strains of 10^{-21} or lower in the predicted observable magnitudes. The method of detecting neutrinos is through the Cherenkov radiation. When a neutrino interacts with atomic nuclei, it can produce charged particle which can emit Cherenkov radiation when it is within a dielectric medium (such as distilled water), traveling itself faster than the speed of light through the medium. In a water the charged particle generates a visible "optical shockwave" of Cherenkov radiation which is detected by photomultiplier tubes (PMTs), and the cone of emission reconstructed.

Gravitational Wave Detection Method

GWs itself can not be detected directly, but rather its effects caused by the light that travels through the arms of the interferometer displayed in the photodetector: The first detection of GWs was made in September 2015 by the Advanced LIGO observatories **[1]**, detecting a signal with wavelengths of a few thousand kilometers from a merging binary of stellar black holes. The current GW detectors, a laser beam is split and the two halves are recombined after travelling different paths, L-shaped arms, that travel back and forth through, bouncing between mirrors. As a GWs passes through the arms of the detectors, distance between these mirrors change, an actual measure in the lengths of the arms using interferometry. Such difference will change the interference patterns produced by the combination of two light sources in the photodetector. Such a technique is extremely sensitive to tiny changes in the distance or time taken to traverse the two paths. Mathematically, as the arm lengths (L) get modified, we can define the amplitude, strain (h) of the GW signal:

$$\Delta L(t) \propto h(t)L \qquad (1)$$

Such above equation shows how length of the arms are critical to the sensitivity of the detector. Also, to increase the effect of GW on the light phase a resonant optical cavity (Fabry-Perot) is used, by two test mass mirrors that can increase the effect of GW on the light phase by a huge factor 300. **[2]**

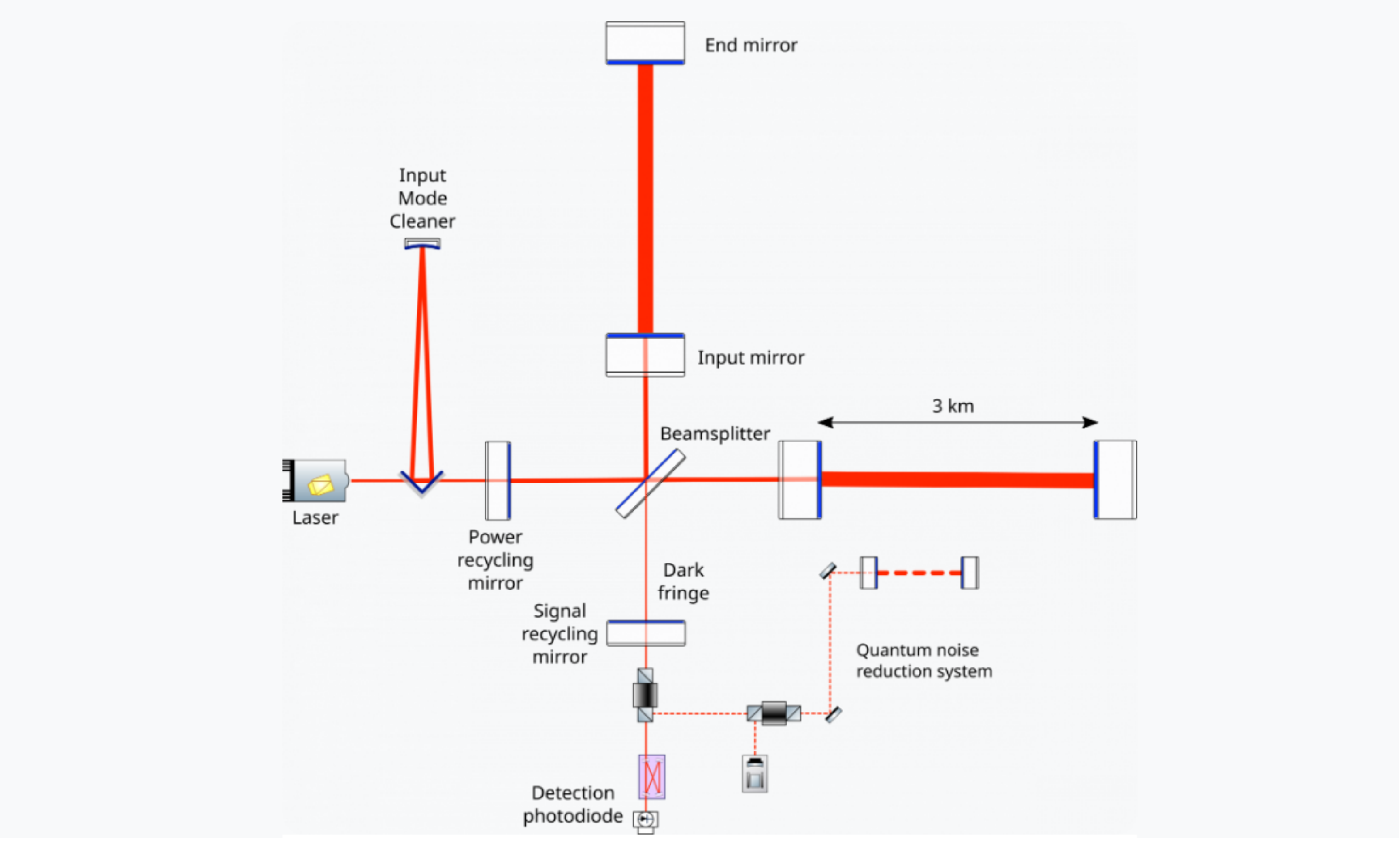

Figure 1. The optical layout of Advanced Virgo.

A Fabry-Perot cavity is an optical device consisting of two parallel reflective surfaces, usually mirrors, that form a resonance for electromagnetic waves, such as light. The two mirrors FP resonant cavity extends the effective optical length from 3 to more than 200 kilometers because of multiple reflections between the two mirrors, amplifying the extremely small arm length variation caused by a passing GW.

The GW strain has only two polarizations, h_+ and h_x , they are two independent polarizations that represent the two degrees of freedom of a GW that propagates in space-time. **[3]**

Located outside of Pisa, Italy, Virgo is a GW interferometer with arms 3 km long (LIGO's are 4 km long). Virgo is hosted by the European Gravitational Observatory (EGO), a collaboration of the Italian and French governments. In 2017, after completing a significant upgrade to improve its sensitivity, Virgo joined LIGO, and helping to localize the source of the GWs detected from merging neutron stars, an event that also emitted electromagnetic radiation, i.e., light, the first “multimessenger" involving GW and light.

Figure 2. Virgo Interferometer.

Neutrino Detection Method

The neutrino is a subatomic particle whose physical properties make it difficult to detect. The neutrino does not have electromagnetic interaction and has an extremely small mass. Despite the difficulty in detection, it is possible to detect neutrinos through Cherenkov radiation, also known as Cherenkov light. Cherenkov radiation is emitted when a charged particle, such as an electron, travels through a dielectric medium at a speed greater than the speed of light in that medium. For example, the ARCA (Astroparticle Research with Cosmics in the Abyss) neutrino telescope of KM3NeT, which is dedicated to the search for ultra-high energy cosmic neutrinos, is operating in the ocean at a depth of 3 km.

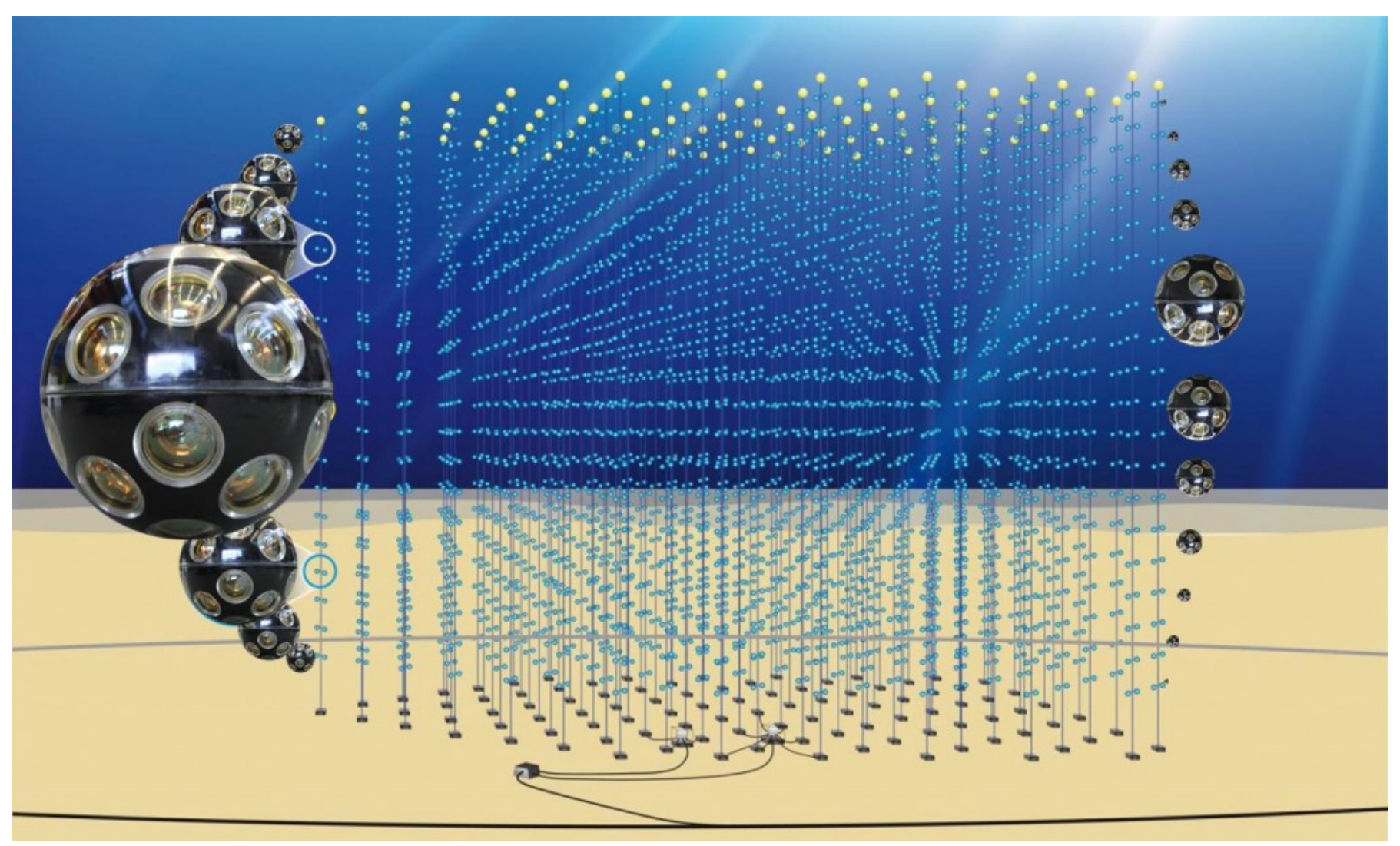

Figure 3. Representation of the construction of the ARCA neutrino telescope.

The emitted Cherenkov light is detected by photomultipliers (PMTs) that are located in the sea. The arrival time of the light at the different PMTs allows the determination of the direction, energy, and origin of the original neutrino.[**4**]

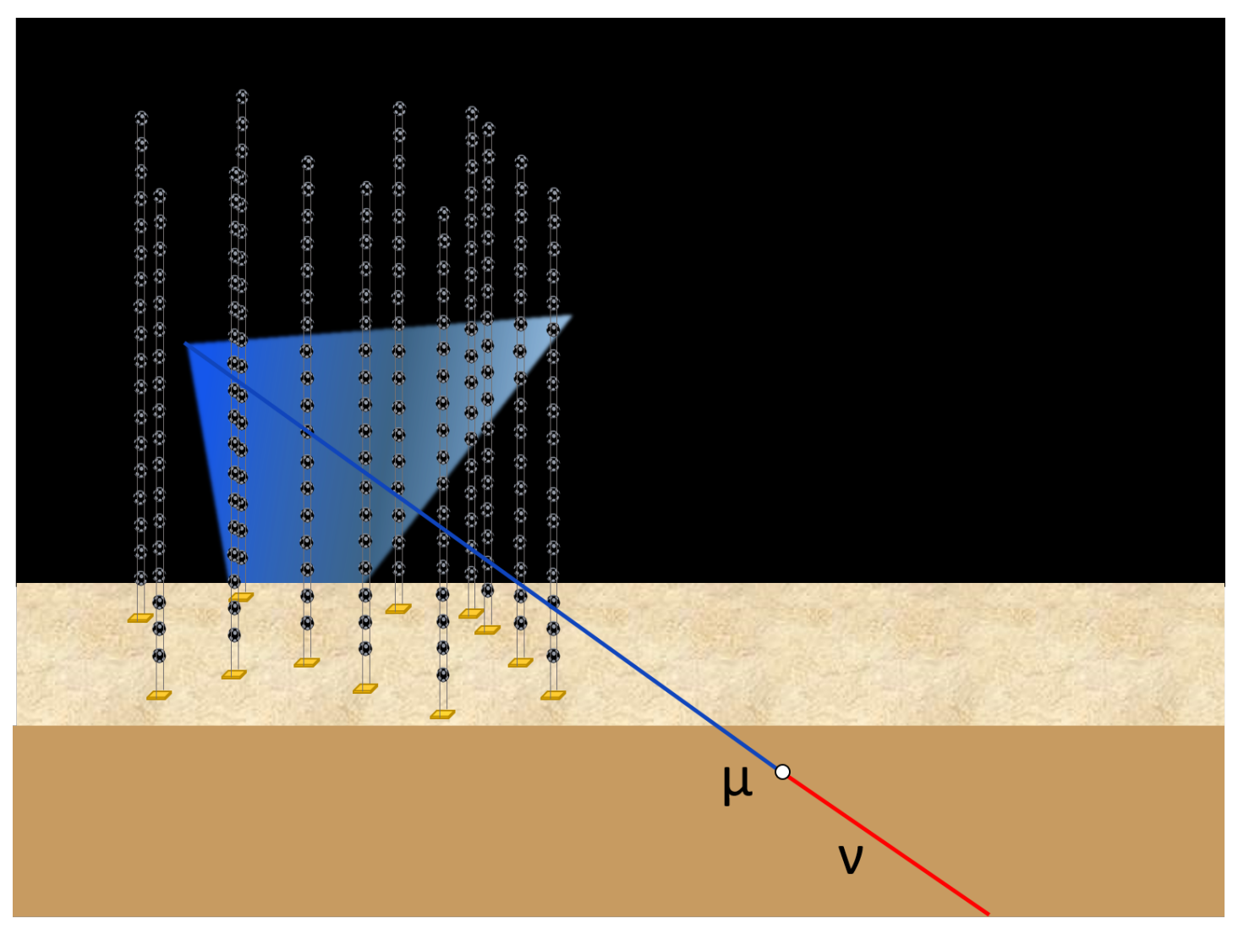

Figure 4. Illustration of the detection principle of the KM3NeT telescope with the trajectory of a muon (blue) from a collision (point) of a neutrino (red) with matter below the telescope.

The radiation is emitted in the form of a cone of light with a characteristic angle, called the Cherenkov angle. It is given by the following mathematical expression:

$$cos\boldsymbol{\theta} = \frac{c}{nv} \qquad (2)$$

Where **v** is the particle velocity, n is the refractive index of the medium, and c is the speed of light in a vacuum. The information from the light shows the arrival time, the light cone indicates where the particle came from, and the intensity of the light is represented by the length of the cone. The path traveled by the particle is mapped by the different colors, in the case on the side image, yellow is earlier than green.

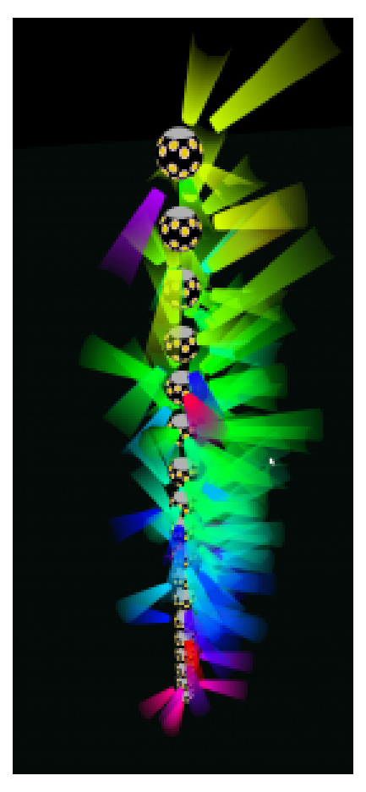

Figure 5. Representation of the light cone.

Concluding remarks

Therefore, gravitational waves and neutrinos, despite their properties posing a challenge for detection, both have efficient detection methods. Advanced technological equipment allows for the improvement of the detection process for both detectors, such as enhancing sensitivity in detection and distinguishing noise.

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