NEWTONIAN FREE FALL WITH AN EINSTEINIAN VIEW

Alessandro D.A.M. Spallicci

Presenting Author: Alessandro D.A.M. Spallicci (spallicci@cnrs-orleans.fr)
Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E) UMR 7328, Université d'Orléans (UO), Centre National de la Recherche Scientifique (CNRS), Centre National d'Etudes Spatiales (CNES), 45071 Orléans; Institut Denis Poisson (IDP) UMR 7013, Université d'Orléans (UO) et Université de Tours (UT), Centre National de la Recherche Scientifique (CNRS), 37200 Tours; UFR Sciences et Techniques, Université d'Orléans (UO), 45100 Orléans; Observatoire des Sciences de l'Univers en région Centre (OSUC) UMS 3116, Université d'Orléans (UO), 45071 Orléans, France

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Free fall is revisited through the legendary Pisa tower experiment. We suppose the absence of air friction and neglect the Earth non-spherical shape, its inhomogeneities and rotation. Asking whether 1kg stone falls like one of 2kg, young pupils may reply negatively, possibly supposing a difference of a factor two. Instead, teachers may say "exactly yes". The right reply is multi-faceted. It is "exactly yes" only in the Earth fixed frame, that by construction is unaffected by any falling mass, whereas in all other frames the answer is "approximately yes". We start considering each mass being released separately and keep the Earth-stone initial distance as fixed throughout the work.

If the observer is at a fixed distance from the Earth centre, e.g., on the Earth surface, he will measure the sum of the acceleration of the stone towards the Earth and of the Earth towards the stone: the larger the stone, the larger the sum perceived by the observer. If the observer is at a fixed distance from the system (Earth and stone) centre of mass (or else imagine that the stone is that heavy to shift the system centre of mass outside the Earth), he will observe the Earth and the stone falling toward him and reaching the system centre of mass at the same instant. Keeping the initial distance Earth-stone constant, by increasing the mass of the stone, the system centre of mass will shift towards the stone and this latter will undergo a smaller acceleration having to cover a smaller distance: the larger the stone, the smaller the acceleration.

In these two last frames, the difference in fall is minuscule, being of the order of the stone/Earth mass ratio, thus not yet measurable by state-of-the-art technology. For the Commander Scott of Apollo 15, the difference in fall between the plume and the hammer was in the order of 6×10^{-24} s. Nevertheless, this ratio may take large values and be of considerable impact in astronomy. But most stimulating, the heavier stone falls faster or slower than the lighter one depending on the observer. The physics dependency on the observer rises to feature of paramount significance in Einstein's general relativity and thus Newtonian radial fall may be used to introduce gauge dependence. Dealing with two masses released simultaneously, the answer to the three body-problem is numerical, knowing that the system centre of mass will not be equidistant to the two small, but different, masses. The preceding doesn't violate in any manner the equivalence principle of inertial and gravitational mass.

We briefly deal with radial fall in general relativity where the motion of the falling mass is influenced by the mass ratio as in Newtonian gravity but also by the radiation emitted. In the context of the Pisa tower, the energy-time Heisenberg indetermination impedes measuring the gravitational radiation. Instead, the capture of small black holes falling into supermassive ones is the source targeted by LISA to explore general relativity in the strong field. Finally, the analysis of falling observers in black holes during emission of Hawking radiation is of interest for combining quantum mechanics and general relativity.

FURTHER READING

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