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Improved limits on Relativistic Interstellar Objects near Earth

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Abstract

It was recently shown [Loeb (2024)] that exotic asteroid-sized objects moving at relativistic speeds in the vicinity of the Earth could be detected by their gravitational waves in the LIGO-Virgo-KAGRA experiments, thereby leading to a constraint on their local number density. Here I show that a much stronger limit can be derived from the fact that no such object has ever impacted the Earth.

Loeb (2024) recently argued that exotic asteroid-sized objects moving at relativistic speeds could be detectable through their gravitational wave emission at ongoing experiments. Based on the lack of any corresponding signal so far, a limit on their number density was derived, $n < 30\,\mathrm{au}^{-3}$, assuming masses $m > 10^{14}\,\mathrm{g}$. If a population of such objects existed, saturating this bound, it is pertinent to ask how often they would impact the Earth. The answer is

$$\frac{1}{\tau} = n\sigma c \cong \frac{1}{90\,\mathrm{y}}\,, \tag{1}$$

where σ is the cross sectional area of Earth. Would we have noticed such an event?

Given that a conventional asteroid is expected to impact the Earth with a speed of $v \sim 10\,\mathrm{km/s}$, while the relativistic one has a kinetic energy of order $mc^2 > 10^{28}\,\mathrm{J}$, such an impact would deposit the same amount of energy as a conventional asteroid of mass $10^{20}\,\mathrm{kg}$. Let us compare that to a previous impact event. The Chicxulub event, 65 million years ago, produced the second largest extant crater on Earth and led to the extinction of the dinosaurs. It was estimated that the diameter of the impacting asteroid was around 10 km [Alvarez et al. (1980)], corresponding to a mass of order $10^{15}\,\mathrm{kg}$, five orders of magnitude smaller than the effective mass of a relativistic interloper. The Vredefort event was of a similar size Allen et al. (2022), but occurring 2 billion years ago. There is no evidence for any impact larger than these over the history of the Earth,

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allowing us to set the stronger limit on the density of such relativistic objects,

$$n < 30\,\mathrm{au}^{-3}\left(\frac{90\,\mathrm{y}}{4.5\times10^{9}\,\mathrm{y}}\right) \sim 10^{-8}\,\mathrm{au}^{-3}\,. \qquad (2)$$

Hence LIGO-Virgo-KAGRA will have to observe for some time before they reach the needed sensitivity. It should be noted that no plausible mechanism for accelerating an object of mass $10^{14}\,g$ to relativistic speeds has been proposed.

REFERENCES

Allen, N. H., Nakajima, M., WÃ¼nnemann, K., Helhoski, S., & Trail, D. 2022, Journal of Geophysical Research: Planets, 127, e2022JE007186, doi: https://doi.org/10.1029/2022JE007186

Alvarez, L. W., Alvarez, W., Asaro, F., & Michel, H. V. 1980, Science, 208, 1095, doi: 10.1126/science.208.4448.1095

Loeb, A. 2024, Res. Notes AAS, 8, 214, doi: 10.3847/2515-5172/ad73da