Shooting Stars at the Speed of Light

By Avi Loeb on April 5, 2021

*E*very kid knows that the universe is full of elementary particles but not everyone knows that it is also full of extremely fast stars, moving freely through space like fish in the ocean. These stars are ejected by gravitational slingshots, located at the focal point of galaxy mergers - where a pair of supermassive black holes coalesces by kicking stars out of the host galaxy like a batter hitting a series of home-run baseballs out of the park. As the black hole pair tightens, its orbital speed rises - providing a more forceful batting motion. Eventually, this process launches some stars up to the speed of light in accordance with Albert Einstein's Theory of Relativity, making them "relativistic".

In collaboration with my former postdoc, James Guillochon, we calculated in 2014 the abundance of free relativistic stars in the vast space between galaxies and the difficulties in detecting them at the large distances involved. It must be thrilling to live on a planet around one of these ejected stars and to witness its trip through space. The journey starts at the center of the parent galaxy, continues through many points of interest out to edge of the galaxy's halo within a million years, and culminates in between galaxies for billions of years – passing by cosmological destinations that we can barely see through telescopes.

These relativistic stars represent the most attractive travel packages that intergalactic tourist agencies can offer. But they also provide health benefits. With travel near to the speed of light, the trip entails the perk of time dilation - slowing down the natural aging process of all travelers relative to family members and friends they left behind.

Even in the absence of a galaxy merger, stars tugged by the strong gravity near a single black hole at the center of a galaxy could reach the speed of light. The 2020 Nobel Prize in Physics was awarded to Reinhard Genzel and Andrea Ghez for their monitoring program of stars moving at a few percent of the speed of light near the Milky Way's supermassive black hole, Sagittarius A*. Relativistic stars are expected to be gravitationally bound to black holes at the centers of many other galaxies.

If relativistic stars in a galactic nucleus cross paths with each other by chance, the resulting head-on collision can produce an explosion much more energetic than a typical supernova, triggered by the collapse a massive star after its nuclear fuel is exhausted. In order for the two-star collision to occur near the speed of light, the central black hole must weigh more than a hundred million suns. At higher masses, the gravitational tide at its event horizon, which scales inversely with the square of the black hole mass, is sufficiently weak so as not to disrupt a passing star. At lower black hole masses, like the case of Sagittarius A* which weighs "only" four million suns, the strong tidal force of the black hole spaghettifies stars when they come close to it. The disrupted stars are spread into a stream of gas long before they can get close enough to the black hole horizon to reach the speed of light, as shown in the PhD thesis of my former student, Nick Stone. At larger distances where tidal disruption is avoided, the stars move at lower speeds and their collisions result in weak explosions, as

I showed in a paper with my former graduate student, Doug Rubin, and in a follow-up paper with Shmuel Balberg and Re'em Sari.

But what happens close to the most massive black holes, where stars can roam near the speed of light without being tidally disrupted? In a new paper with my current graduate student, Betty Hu, we showed that collisions of stars near these obese black holes trigger the most energetic explosions in the universe, outpouring up to thousands of times more energy than normal supernova explosions. These super-luminous explosions in galactic nuclei would be detectable out to the edge of the Universe by the *Legacy Survey of Space and Time (LSST)* of the Vera C. Rubin Observatory, scheduled to start its operation within a couple of years.

There is yet another way to launch stars from galactic centers at high speeds. A pair of bound stars passing close to a supermassive black hole can be separated by its gravitational tide. One of the stars is kicked closer to the black hole while the other is ejected at a high speed, as predicted theoretically by Jack Hills in 1988. The kick that one star gets towards the black hole could account for the closest stars to Sagittarius A* discovered by Genzel and Ghez. The ejection of their companions is the likely origin of the hypervelocity stars discovered in 2005 by Warren Brown and collaborators in the halo of the Milky Way. These hypervelocity stars move at up to two percent of the speed of light and potentially carry planets with them for the ride. Planets that are freed by the ejection process itself constitute a population of hypervelocity planets, as theorized in a 2012 paper I wrote with my former student, Idan Ginsburg.

All in all, galactic nuclei offer launching sites for the fastest habitable platforms that nature offers for free. It would not be surprising if advanced technological civilizations choose to migrate towards galactic centers for the same reason that astronauts and spectators flock to Cape Canaveral during rocket launches. With that perspective in mind, Searches for Extraterrestrial Intelligence (SETI) should check for radio signals coming from riders of hypervelocity stars. We might also notice celebratory fireworks from their relatives at the Galactic center whenever a high speed star is shot out of there.

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