Neutron stars could be capturing primordial black holes

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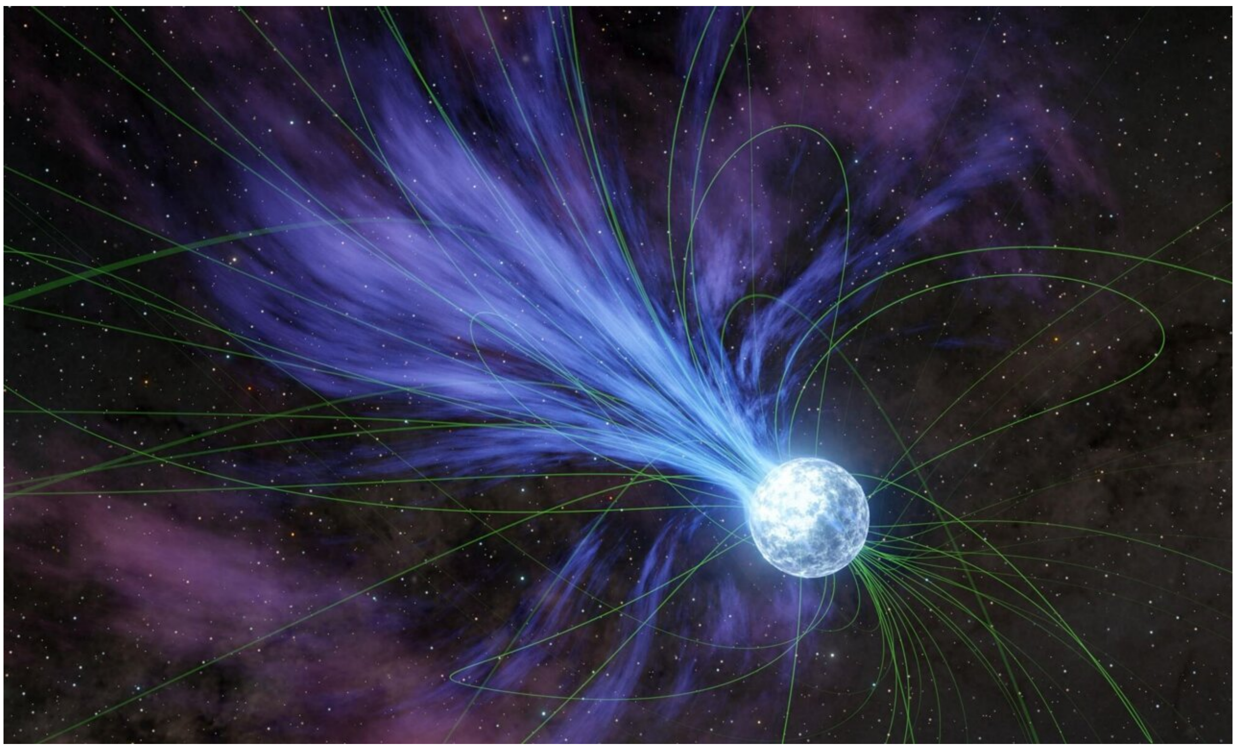

This magnetar is a highly magnetized neutron star. This artist's illustration shows an outburst from a magnetar. Neutron stars that spin rapidly and give out radiation are called pulsars, and specific pulsars are rare in the core of the Milky Way. Credit: NASA/JPL-CalTech

The Milky Way has a missing pulsar problem in its core. Astronomers have tried to explain this for years. One of the more interesting ideas comes from a team of astronomers in Europe and invokes dark matter, neutron stars, and primordial black holes (PBHs).

Astronomer Roberto Caiozzo, of the International School for Advanced Studies in Trieste, Italy, led a group examining the missing pulsar problem. "We do not observe pulsars of any kind in this inner region (except for the magnetar PSR J1745-2900)," he wrote in an email.

"This was thought to be due to technical limitations, but the observation of the magnetar seems to suggest otherwise." That magnetar orbits Sagittarius A*, the black hole at the core of the Milky Way.

The team examined other possible reasons why pulsars don't appear in the core and looked closely at magnetar formation as well as disruptions of neutron stars. One intriguing idea they examined was the cannibalization of primordial black holes by neutron stars.

The team explored the missing-pulsar problem by asking the question: could neutron star-primordial black hole cannibalism explain the lack of detected millisecond pulsars in the core of the Milky Way? Let's look at the main players in this mystery to understand if this could happen.

Neutron stars, pulsars, and little black holes, oh my

Theory suggests that primordial black holes were created in the first seconds after the Big Bang. "PBHs are not known to exist," Caiozzo points out, "but they seem to explain some important astrophysical phenomena." He pointed at the idea that supermassive black holes seemed to exist at very early times in the universe and suggested that they could have been the seeds for these monsters.

If there are PHBs out there, the upcoming Nancy Grace Roman Telescope could help find them. Astronomers predict they could exist in a range of masses, ranging from the mass of a pin to around 100,000 the mass of the sun. There could be an intermediate range of them in the middle, the so-called "asteroid-mass" PBHs. Astronomers suggest these last ones as dark matter candidates.

Dark matter makes up about 27% of the universe, but beyond suggesting that PBH could be part of the dark matter content, astronomers still don't know exactly what it is. There does seem to be a large amount of it in the core of our galaxy. However, it hasn't been directly observed, so its presence is inferred. Is it bound up in those midrange PBHs? No one knows.

The third player in this missing pulsar mystery is neutron stars. They're huge, quivering balls of neutrons left over after the death of a supergiant star of between 10 and 25 solar masses. Neutron stars start out very hot (in the range of 10 million K) and cool down over time.

They start out spinning very fast and they do generate magnetic fields. Some emit beams of radiation (usually in radio frequencies) and as they spin, those beams appear as "pulses" of emission. That earned them the nickname "pulsar." Neutron stars with extremely powerful magnetic fields are termed "magnetars."

The missing pulsar problem

Astronomers have searched the core of the Milky Way for pulsars without much success. Survey after survey detected no radio pulsars within the inner 25 parsecs of the galaxy's core. Why is that? Caizzo and his co-authors suggested in their paper, posted to the *arXiv* preprint server, that magnetar formation and other disruptions of neutron stars that affect pulsar formation don't exactly explain the absence of these objects in the galactic core.

"Efficient magnetar formation could explain this (due to their shorter lifetime)," he said, "But there is no theoretical reason to expect this. Another possibility is that the pulsars are somehow disrupted in other ways."

Usually, disruption happens in binary star systems where one star is more massive than the other and it explodes as a supernova. The other star may or may not explode. Something may kick it out of the system altogether. The surviving neutron star becomes a "disrupted" pulsar. They aren't as easily observed, which could explain the lack of radio detections.

If the companion isn't kicked out and later swells up, its matter gets sucked away by the neutron star. That spins up the neutron star and affects the magnetic field. If the second star remains in the system, it later explodes and becomes a neutron star. The result is a binary neutron star. This disruption may help explain why the galactic core seems to be devoid of pulsars.

Using primordial black hole capture to explain missing pulsars

Caizzo's team decided to use two-dimensional models of millisecond pulsars—that is, pulsars spinning extremely fast—as a way to investigate the possibility of primordial black hole capture in the galactic core.

The process works like this: a millisecond pulsar interacts in some way with a primordial black hole that has less than one stellar mass. Eventually, the neutron star (which has a strong enough gravitational pull to attract the PBH) captures the black hole. Once that happens, the PBH sinks to the core of the neutron star. Inside the core, the black hole begins to accrete matter from the neutron star.

Eventually, all that's left is a black hole with about the same mass as the original neutron star. If this occurs, that could help explain the lack of pulsars in the inner parsecs of the Milky Way.

Could this happen? The team investigated the possible rates of capture of PBHs by neutron stars. They also calculated the likelihood that a given neutron star would collapse and assessed the disruption rate of pulsars in the galactic core. If not all the disrupted pulsars are or were part of binary systems, then that leaves neutron star capture of PBHs as another way to explain the lack of pulsars in the core. But, does it happen in reality?

Missing pulsar tension continues

It turns out that such cannibalism cannot explain the missing pulsar problem, according to Caizzo. "We found that in our current model PBHs are not able to disrupt these objects but this is only considering our simplified model of 2 body interactions," he said. It doesn't rule out the existence of PHBs, only that in specific instances, such capture isn't happening.

So, what's left to examine? If there are PHBs in the cores and they're merging, no one's seen them yet. But, the center of the galaxy is a busy place. A lot of bodies crowd the central parsecs. You have to calculate the effects of all those objects interacting in such a small space. That "many-body dynamics" problem has to account for other interactions, as well as the dynamics and capture of PBHs.

Astronomers looking to use PBH-neutron star mergers to explain the lack of pulsar observations in the core of the galaxy will need to better understand both the proposed observations and the larger populations of pulsars.

The team suggests that future observations of old neutron stars close to Sgr A* could be very useful. They'd help set stronger limits on the number of PBHs in the core. In addition, it would be useful to get an idea of the masses of these PBHs, since those on the lower end (asteroid-mass types) could interact very differently.

More information: Roberto Caiozzo et al, Revisiting Primordial Black Hole Capture by Neutron Stars, *arXiv* (2024). DOI: 10.48550/arxiv.2404.08057

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