Dying stars' cocoons might explain fast blue optical transients

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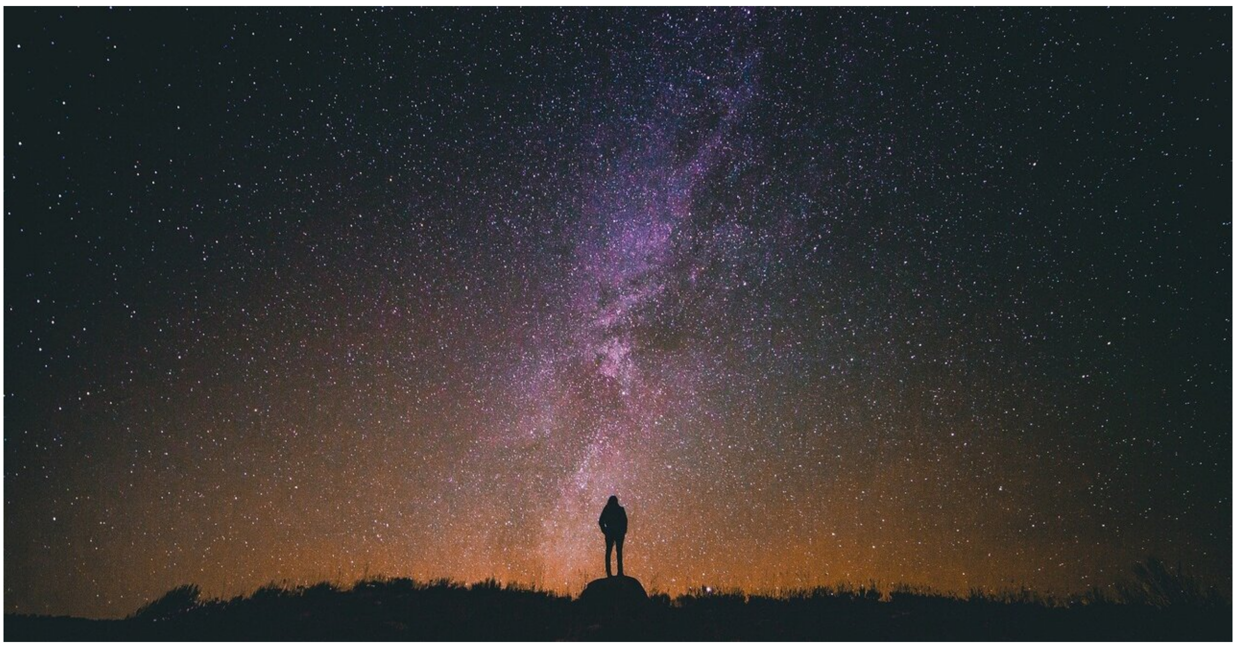

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Ever since they were discovered in 2018, fast blue optical transients (FBOTs) have utterly surprised and completely confounded both observational and theoretical astrophysicists.

So hot that they glow blue, these mysterious objects are the brightest known optical phenomenon in the universe. But with only a few discovered so far, FBOTs' origins have remained elusive.

Now a Northwestern University astrophysics team presents a bold new explanation for the origin of these curious anomalies. Using a new model , the astrophysicists believe FBOTs could result from the actively cooling cocoons that surround jets launched by dying stars. It marks the first astrophysics model that is fully consistent with all observations related to FBOTs.

The research was published April 11 in the *Monthly Notices of the Royal Astronomical Society*.

As a massive star collapses, it can launch outflows of debris at rates near the speed of light. These outflows, or jets, collide into collapsing layers of the dying star to form a "cocoon" around the jet. The new model shows that as the jet pushes the cocoon outward—away from the core of the collapsing star—it cools, releasing heat as an observed FBOT emission.

"A jet starts deep inside of a star and then drills its way out to escape," said Northwestern's Ore Gottlieb, who led the study. "As the jet moves through the star, it forms an extended structure, known as the cocoon. The cocoon envelopes the jet, and it continues to do so even after the jet escapes the star, this cocoon escapes with the jet. When we calculated how much energy the cocoon has, it turned out to be as powerful as an FBOT."

Gottlieb is a Rothschild Fellow in Northwestern's Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA). He coauthored the paper with CIERA member Sasha Tchekovskoy, an assistant professor of physics and astronomy in Northwestern's Weinberg College of Arts and Sciences.

The hydrogen problem

FBOTs (pronounced F-bot) are a type of cosmic explosion initially detected in the optical wavelength. As their name implies, transients fade almost as quickly as they appear. FBOTs reach peak brightness within a matter of days and then quickly fade—much faster than standard supernovae rise and decay.

After discovering FBOTs just four years ago, astrophysicists wondered if the mysterious events were related to another transient class: gamma ray bursts (GRBs). The strongest and brightest explosions across all wavelengths, GRBs also are associated with dying stars. When a massive star exhausts its fuel and collapses into a black hole, it launches jets to produce a powerful gamma ray emission.

"The reason why we think GRBs and FBOTs might be related is because both are very fast—moving at close to the speed of light—and both are asymmetrically shaped, breaking the spherical shape of the star," Gottlieb said. "But there was a problem. Stars that produce GRBs lack hydrogen. We don't see any signs of hydrogen in GRBs, whereas in FBOTs, we see hydrogen everywhere. So, it could not be the same phenomenon."

Using their new model, Gottlieb and his coauthors think they might have found an answer to this problem. Hydrogen-rich stars tend to house hydrogen in their outermost layer—a layer too thick for a jet to penetrate.

"Basically, the star would be too massive for the jet to pierce through," Gottlieb said. "So the jet will never make it out of the star, and that's why it fails to produce a GRB. However, in these stars, the dying jet transfers all its energy to the cocoon, which is the only component to escape the star. The cocoon will emit FBOT emissions, which will include hydrogen. This is another area where our model is fully consistent with all FBOT observations."

Putting the picture together

Although FBOTs glow bright in optical wavelengths, they also emit radio waves and X-rays. Gottlieb's model explains these too.

When the cocoon interacts with the dense gas surrounding the star, this interaction heats up stellar material to release a radio emission. And when the cocoon expands far enough away from the black hole (formed from the collapsed star), X-rays can leak out from the black hole. The X-rays join radio and optical light to form a full picture of the FBOT event.

While Gottlieb is encouraged by his team's findings, he says more observations and models are needed before we can definitively understand FBOTs' mysterious origins.

"This is a new class of transients, and we know so little about them," Gottlieb said. "We need to detect more of them earlier in their evolution before we can fully understand these explosions. But our model is able to draw a line among supernovae, GRBs and FBOTs, which I think is very elegant."

"This study paves the way for more advanced simulations of FBOTs," Tchekovskoy said. "This next-generation model will allow us to directly connect the physics of the central black hole to the observables, enabling us to reveal otherwise hidden physics of the FBOT central engine."

More information: Ore Gottlieb et al, Shocked jets in CCSNe can power the zoo of fast blue optical transients, *Monthly Notices of the Royal Astronomical Society* (2022). DOI: 10.1093/mnras/stac910

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