Star, not so bright: Model explains evolution of unusual binary system, why large star not so luminous

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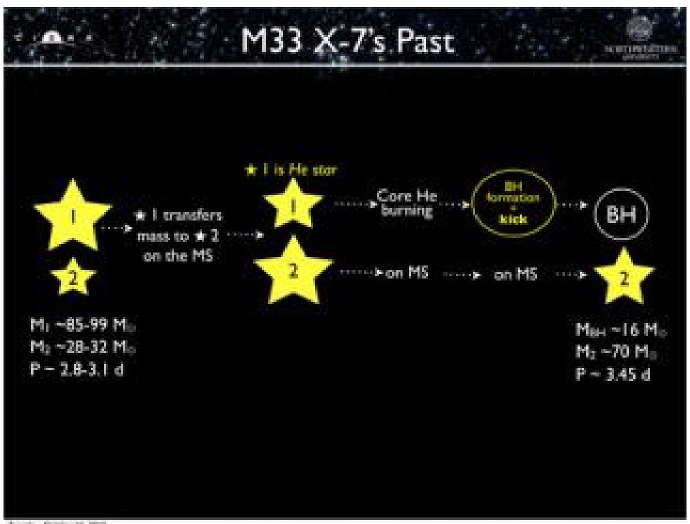


This map of M33 X-7's past shows how mass transferred from a larger star to a smaller star, turning the smaller star into a 70 solar-mass star and the larger star into a black hole. Francesca Valsecchi/Northwestern University

In a galaxy far away, an exceptionally massive black hole is traveling around a massive star in an unusually tight orbit. Also odd, the star is not as bright as it should be.

Astronomers have puzzled over this X-ray binary system, named M33 X-7, but no one could explain all of its features. Now a Northwestern University research team has.

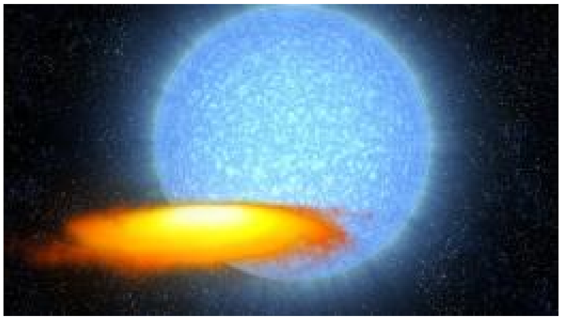
The researchers have produced a model of the system's evolutionary history and formation that explains all of the system's observational characteristics: the tight orbit, the large masses of the star and black hole, the X-ray luminosity of the black hole and why its companion star is less luminous than one would expect, given its mass.

The evolutionary model will be published Oct. 20 by the journal *Nature*. The research will improve astronomers' understanding of how massive stars evolve and interact with their host environment as well as shed light on the physics behind the process of black hole formation.

"We were attracted to this system because it has one of the most massive black holes to have formed from a star, and yet the rest of its characteristics, especially the mass of its companion star and its orbit, did not make any sense from an evolutionary point of view," said Vicky Kalogera, professor of physics and astronomy in the Weinberg College of Arts and Sciences.

M33 X-7 is one of the few known X-ray binary systems containing a black hole outside our galaxy, and its star is the most massive star ever discovered in such a system.

The researchers' evolutionary model of M33 X-7 starts with two stars in a binary system (or in orbit one around the other). One star is 100 solar masses (100 times the sun's mass), and the other is 30 solar masses. The stars are in a close orbit, with the larger star growing faster until it nearly envelops the other. The initially smaller star then gains material from its companion, while the initially larger and more massive star collapses into a black hole at the end of its nuclear-burning lifetime. The orbit becomes even tighter.



The massive black hole in M33 X-7 is hidden in the center of the X-ray-bright, pancake-shaped accretion disk of matter (orange). In a tight binary orbit, the black hole's hot and massive stellar companion (blue) is losing mass via a stellar wind to the black hole, with the wind matter settling into a disk around the black hole. (Credit: Matthew McCrory, Francesca Valsecchi and Vicky Kalogera, Northwestern University)

The star, which is now 70 solar masses, is not as luminous as stars of similar mass partially because of the way it gained its mass and partially because of the inclination of the system with respect to us. On one hand, the star accreted matter so quickly from its interaction with the other star (now a black hole) that it could not adjust fast enough to its new, greater mass. Therefore, the star does not burn as bright as an undisturbed star of this greater mass would. On the other hand, the star is deformed due to the close presence of the massive black hole, and the star's temperature and luminosity are not uniform across the surface. This effect, combined with the inclination of the system with respect to our line of sight, means we are looking at the star's dimmest equatorial regions.

And now the massive black hole is growing even larger. The companion star is feeding matter, via a stellar wind, to the black hole. In the process X-rays are emitted, allowing astronomers to observe the black hole.

"Solitary black holes are very difficult to observe, but X-ray binary systems, such as M33 X-7, make black holes visible to us," said Francesca Valsecchi, a doctoral student in Kalogera's research group and lead author of the paper. "These systems provide a unique physical laboratory for the study of massive compact objects."

Valsecchi, Kalogera and colleagues performed detailed binary system evolution calculations to explore possible evolutionary tracks. They used information known about the physics of binary stellar interactions and black hole formation processes.

In their initial work, they ran more than 200,000 sequences on a high-performance computing cluster, which took a couple of months. The researchers then examined a number of these sequences in further detail and were able to identify the final model, consistent with all observational characteristics of M33 X-7.

M33 X-7 is an X-ray binary system discovered in 2007 in the Messier 33 galaxy, known as M33. (An X-ray binary system is a class of binary stars luminous in X-rays.) The Messier 33 galaxy, slightly farther away from us than the Andromeda galaxy, is among the farthest permanent objects that can be viewed with the naked eye.

More information: The title of the paper is "Formation of the black-hole binary M33 X-7 via mass-exchange in a tight massive system."

Provided by Northwestern University

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