

X-ray observatory spots a possible planet in another galaxy

Even if the discovery is never confirmed, the method it uses may spawn a new generation of exoplanet searches.

In 1995 Michel Mayor and Didier Queloz detected a hot Jupiter-sized planet 50 light-years from Earth that orbits its host star more closely than Mercury orbits our Sun. That discovery—the first exoplanet confirmed around a sunlike star—recast the thinking about how planets form. It also so captivated the imagination that efforts to search for them soon became mainstream astronomy (see *PHYSICS TODAY*, December 2019, page 17).

Just five years later, 34 exoplanets had been spotted around sunlike stars. Nearly all of them were observed by Doppler spectroscopy, which measures the periodic redshifts and blueshifts in a star's wobble from an exoplanet's gravitational tug. In 1999, Harvard University's David Charbonneau debuted a complementary approach—the transit method, in which an observer looks for the brief dip in the brightness of a star when an exoplanet passes in front of it.

Together, the two methods are responsible for more than 4800 confirmed exoplanets. All of them are in the Milky Way and less than 3000 light-years from Earth. The vast majority were spotted by the *Kepler* and *TESS* (*Transiting Exoplanet Survey Satellite*) space telescopes. The more recently launched *TESS* looks for Earthlike planets by monitoring 85% of the sky every 27 days. (See *PHYSICS TODAY*, March 2019, page 24.)

Planets are ubiquitous in the Milky Way, and astronomers estimate that one third of all sunlike stars host planetary systems. But they've also found hot Jupiters, icy giants, and smaller rocky planets orbiting more exotic stars. An important goal is to explore planetary diversity in all its forms and settings.

In 2018, Rosanne Di Stefano and Nia Imara, both then at the Harvard-Smithsonian Center for Astrophysics, made a bold proposal: To find planets in exotic or extreme environments, astronomers should turn their attention toward x-ray binary systems.¹ Each binary consists of a collapsed star—a black hole,

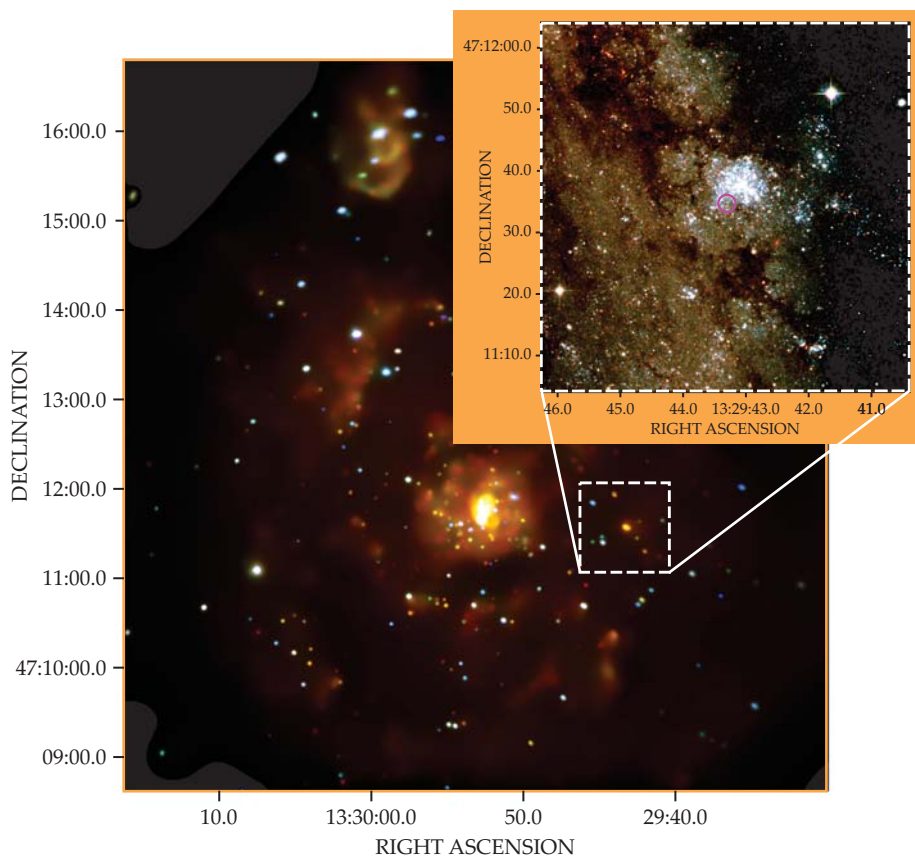


FIGURE 1. CHANDRA AND HUBBLE. This *Chandra X-Ray Observatory* image of Messier 51, known as the Whirlpool galaxy, reveals discrete x-ray light sources. The boxed region near a cluster of young stars contains an x-ray binary system. In the inset, the *Hubble Space Telescope* reveals an optically more crowded environment (the binary is circled in magenta). Insensitive to those optical signals, *Chandra* isolates the dip in the binary's x-ray flux when a putative planet blocks it along Earth's line of sight. (Adapted from ref. 2.)

neutron star, or white dwarf—that accretes plasma from a much larger companion star. Spiraling inward through an accretion disk, the plasma reaches temperatures high enough to emit x rays.

The x-ray-emitting region is exceedingly compact, possibly even smaller than the diameter of Jupiter. If the binary hosts a planet, the dip in the x-ray light curve during a transit could be huge. It could even produce a total eclipse. Planets orbiting ordinary stars typically cast a far smaller shadow from the host star, which makes them more difficult to spot.

Di Stefano, Imara (now at the University of California, Santa Cruz), and their collaborators now report finding what may be a planet orbiting one of the brightest x-ray binaries in Messier 51, the Whirlpool galaxy.² Shown in figure 1,

the binary resides 31 million light-years from Earth, about 400 times as distant as the far edge of the Milky Way's disk.

To find it, the astronomers mined the vast archives of the *Chandra X-Ray Observatory*, NASA's flagship satellite x-ray telescope. Their automatic search of 2640 point sources in three galaxies yielded the features of an exoplanet transit in a 2012 light curve (see figure 2). The researchers could not distinguish whether the compact, accreting star was a black hole or a neutron star, but in either case it was gravitationally bound to a blue supergiant companion whose luminosity and spectrum is that of a 20–30 solar mass star.

If the accreting object is a black hole, the exoplanet (M51-ULS-1b) would be the first ever spotted in orbit around one.

And the companion would be the highest-mass host star of any exoplanet yet discovered. From the light curve, the researchers estimate that the new exoplanet candidate is comparable in size to Saturn. And using Kepler's laws, they estimate its distance from the binary's center of mass to be tens of astronomical units—about 45 AU multiplied by a scaling factor that depends on the binary's mass. That inference puts the planet up to a quarter of a light-day from the stars—roughly equal to the distance between the Sun and the outer Kuiper belt in our own solar system—and its orbital period around 70 years.

The burden of confirmation

That orbital period would be the longest ever found for a transiting exoplanet. And it likely puts the exoplanet's confirmation—either from a repeat transit observation, Doppler spectroscopy, or both—out of reach for the current generation of astronomers. It's not alone: Beyond the confirmed exoplanets in the Milky Way—4878 as of December 2021—are thousands of candidates that require more observations to be considered authentic.

"Much of our paper is devoted to analyzing the transiting object's identity," says Di Stefano. Irregular blobs of gas and dust can affect light-curve data, for instance, as the density enhancement elicits spectral changes. But the *Chandra* data exhibit no changes in x-ray color. Di Stefano and her colleagues reasoned that only planets and white dwarfs could have produced plausible dips in the range of likely transiter radii. But they eliminated a white dwarf from consideration because its gravitational-lensing effect would have increased, not decreased, the amount of light received from the x-ray source.

The data shown in figure 2 exhibit a well-defined baseline before and after the photon count dips to zero and recovers mere hours later. But other possibilities for such a drop beyond the presence of a planet cannot be ruled out. For example, the x-ray emission could be interrupted if a flare or coronal mass ejection from the companion star diverted the flow of plasma fuel.

The uniqueness of the observation unsettles some astronomers. Of the 2640 light curves in the survey, only that one three-hour segment revealed a transit signature. "We may have been lucky to have

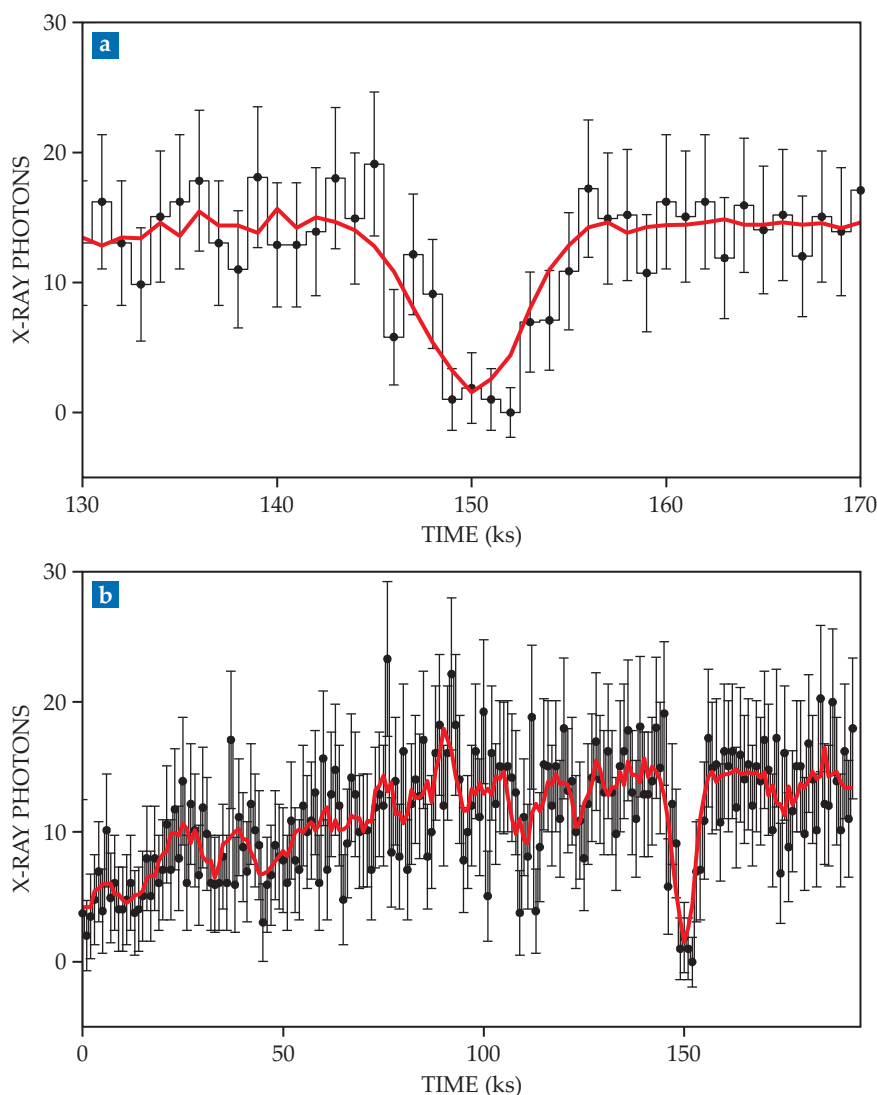


FIGURE 2. LIGHT CURVES. A short-duration eclipse is observed in the x-ray flux from the accretion disk around a black hole or neutron star that siphons gas from a massive companion star. **(a)** The telltale feature of a planetary transit—an abrupt dip and subsequent rise in flux—is consistent with the presence of a Saturn-sized planet. **(b)** In this entire duration of the observation, intrinsic variability can cause the flux rate to drop to zero even during periods not associated with the transit. (Adapted from ref. 2.)

caught this planet in the act," admits Di Stefano. Indeed, accounting for the number of light curves examined, the planet's long orbital period, and detections that can occur only along Earth's line of sight, the chances of finding it are about one in a million. "Despite discouraging odds the method is sound," says MIT's Andrew Vanderburg. "And I think it's sure to find multiple candidates if it were to be adapted into a search scheme that, like *TESS*, scans hundreds of thousands of stars at a time."

Although finding extragalactic planets is unsurprising, establishing an extragalactic search campaign is still important. Different galaxies present different snapshots in cosmic history. The planets

in each one would be representative of the age and gas composition of that galaxy. Questions abound: What's the earliest time a planet could have formed in the universe? How many stars must have died and gone supernova before rocky planets started to emerge? Vanderburg puts the significance of the questions more generally: "How does the location in which you're born affect the planet you become?"

R. Mark Wilson

References

1. N. Imara, R. Di Stefano, *Astrophys. J.* **859**, 40 (2018).
2. R. Di Stefano et al., *Nat. Astron.* (2021), doi:10.1038/s41550-021-01495-w.