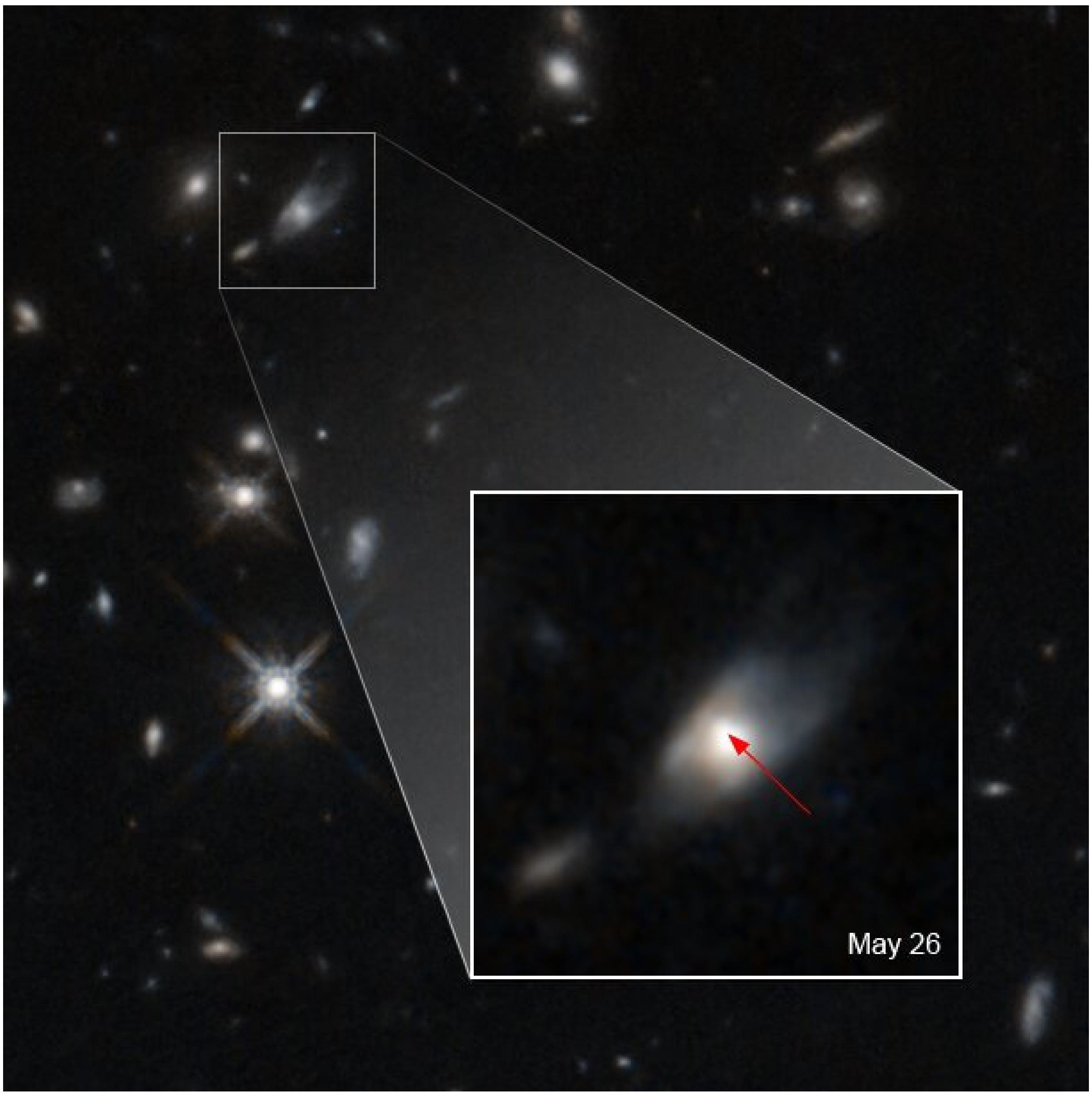
Neutron star merger results in magnetar with brightest kilonova ever observed

November 12 2020, by Amanda Morris



This image shows the glow from a kilonova caused by the merger of two neutron stars. The kilonova, whose peak brightness reaches up to 10,000 times that of a classical nova, appears as a bright spot (indicated by the arrow) to the upper left of the host galaxy. The merger of the neutron stars is believed to have produced a magnetar, which has an extremely powerful magnetic field. The energy from that magnetar brightened the material ejected from the explosion. Credit: NASA, ESA, W. Fong (Northwestern University), and T. Laskar (University of Bath, UK)

Long ago and far across the universe, an enormous burst of gamma rays unleashed more energy in a half-second than the sun will produce over its entire 10-billion-year lifetime.

After examining the incredibly bright burst with optical, X-ray, near-infrared and radio wavelengths, a Northwestern University-led astrophysics team believes it potentially spotted the birth of a magnetar.

Researchers believe the magnetar was formed by two neutron stars merging, which has never before been observed. The merger resulted in a brilliant kilonova—the brightest ever seen—whose light finally reached Earth on May 22, 2020. The light first came as a blast of gamma-rays, called a short gamma-ray burst.

"When two neutron stars merge, the most common predicted outcome is that they form a heavy neutron star that collapses into a black hole within milliseconds or less," said Northwestern's Wen-fai Fong, who led the study. "Our study shows that it's possible that, for this particular short gamma-ray burst, the heavy object survived. Instead of collapsing into a black hole, it became a magnetar: A rapidly spinning neutron star that has large magnetic fields, dumping energy into its surrounding environment and creating the very bright glow that we see."

The research has been accepted by The *Astrophysical Journal* and will be published online later this year.

Fong is an assistant professor of physics and astronomy in Northwestern's Weinberg College of Arts and Sciences and a member of CIERA (Center for Interdisciplinary Exploration and Research in Astrophysics). The research involved two undergraduates, three graduate students and three postdoctoral fellows from Fong's laboratory.

'A new phenomenon happening'

After the light was first detected by NASA's Neil Gehrels Swift Observatory, scientists quickly enlisted other telescopes—including NASA's Hubble Space Telescope, the Very Large Array, the W.M. Keck Observatory and the Las Cumbres Observatory Global Telescope network—to study the explosion's aftermath and its host galaxy.

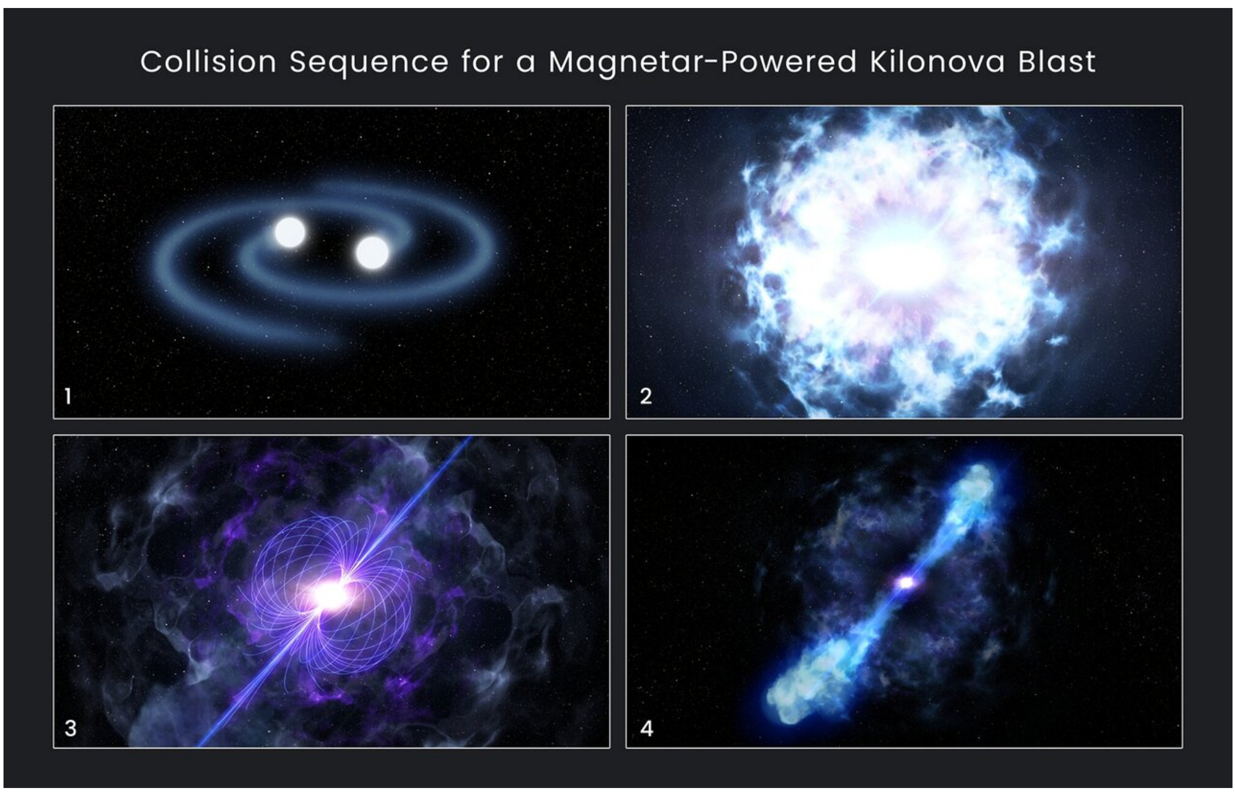
Fong's team quickly realized that something didn't add up.

Compared to X-ray and radio observations, the near-infrared emission detected with Hubble was much too bright. In fact, it was 10 times brighter than predicted.

"As the data were coming in, we were forming a picture of the mechanism that was producing the light we were seeing," said the study's co-investigator, Tanmoy Laskar of the University of Bath in the United Kingdom. "As we got the Hubble observations, we had to completely change our thought process, because the information that Hubble added made us realize that we had to discard our conventional thinking and that there was a new phenomenon going on. Then we had to figure out about what that meant for the physics behind these extremely energetic explosions."

Magnetic monster

Fong and her team have discussed several possibilities to explain the unusual brightness—known as a short gamma-ray burst—that Hubble saw. Researchers think short bursts are caused by the merger of two neutron stars, extremely dense objects about the mass of the sun compressed into the volume of a large city like Chicago. While most short gamma-ray bursts probably result in a black hole, the two neutron stars that merged in this case may have combined to form a magnetar, a supermassive neutron star with a very powerful magnetic field.



This illustration shows the sequence for forming a magnetar-powered kilonova, whose peak brightness reaches up to 10,000 times that of a classical nova. 1) Two orbiting neutron stars spiral closer and closer together. 2) They collide and merge, triggering an explosion that unleashes more energy in a half-second than the Sun will produce over its entire 10-billion-year lifetime. 3) The merger forms an even more massive neutron star called a magnetar, which has an extraordinarily powerful magnetic field. 4) The magnetar deposits energy into the ejected material, causing it to glow unexpectedly bright at infrared wavelengths. Credit: NASA, ESA, and D. Player (STScI)

"You basically have these magnetic field lines that are anchored to the star that are whipping around at about 1,000 times a second, and this produces a magnetized wind," Laskar explained. "These spinning field lines extract the rotational energy of the neutron star formed in the merger, and deposit that energy into the ejecta from the blast, causing the material to glow even brighter."

"We know that magnetars exist because we see them in our galaxy," Fong said. "We think most of them are formed in the explosive deaths of massive stars, leaving these highly magnetized neutron stars behind. However, it is possible that a small fraction form in neutron star mergers. We have never seen evidence of that before, let alone in infrared light, making this discovery special."

Strangely bright kilonova

Kilonovae, which are typically 1,000 times brighter than a classic nova, are expected to accompany short gamma-ray bursts. Unique to the merger of two compact objects, kilonovae glow from the radioactive decay of heavy elements ejected during the merger, producing coveted elements like gold and uranium.

"We only have one confirmed and well-sampled kilonova to date," said Jillian Rastinejad, a co-author of the paper and graduate student in Fong's laboratory. "So it is especially exciting to find a new potential kilonova that looks so different. This discovery gave us the opportunity to explore the diversity of kilonovae and their remnant objects."

If the unexpected brightness seen by Hubble came from a magnetar that deposited energy into the kilonova material, then, within a few years, the ejected material from the burst will produce light that shows up at radio wavelengths. Follow-up radio observations may ultimately prove that this was a magnetar, leading to an explanation of the origin of such objects.

"Now that we have one very bright candidate kilonova," Rastinejad said, "I'm excited for the new surprises that short gamma-ray bursts and neutron star mergers have in store for us in the future."

More information: "The broadband counterpart of the short GRB 2005221 at z = 0.5536: A luminous kilonova or a collimated outflow with a reverse shock?" arXiv:2008.08593 [astro-ph.HE] arxiv.org/abs/2008.08593

Provided by Northwestern University