Black Holes

Mark Bergemann

The late Stephen Hawking's most famous discovery was on black hole radiation. NASA remembered Hawking with these words,

> Hawking's best known work found that black holes should glow, emitting what is now known as Hawking radiation. Hawking's theories have unlocked a universe of possibilities that NASA and the world are exploring today.[1]

"What Is a Black Hole?"

NASA answers this question in an article with that title,

> A black hole is a region in space where the pulling force of gravity is so strong that light is not able to escape. The strong gravity occurs because matter has been pressed into a tiny space. …Because no light can escape, black holes are invisible. However, space telescopes with special instruments can help find black holes. They can observe the behavior of material and stars that are very close to black holes.[2]

How Can We Detect Something Invisible?

NASA answers this question in that same article,

> If Black Holes Are "Black," How Do Scientists Know They Are There? A black hole can not be seen because

1 Sarah Loff, ed., "NASA Remembers Dr. Stephen Hawking," NASA, updated March 16, 2018. (accessed August 3, 2018) https://www.nasa.gov/feature/nasa-remembers-dr-stephen-hawking

2 Heather R. Smith, "What Is a Black Hole?," ed. Flint Wild, NASA Educational Technology Services, updated Aug. 7, 2017. www.LutheranScience.org/NASAbh (accessed August 3, 2018)

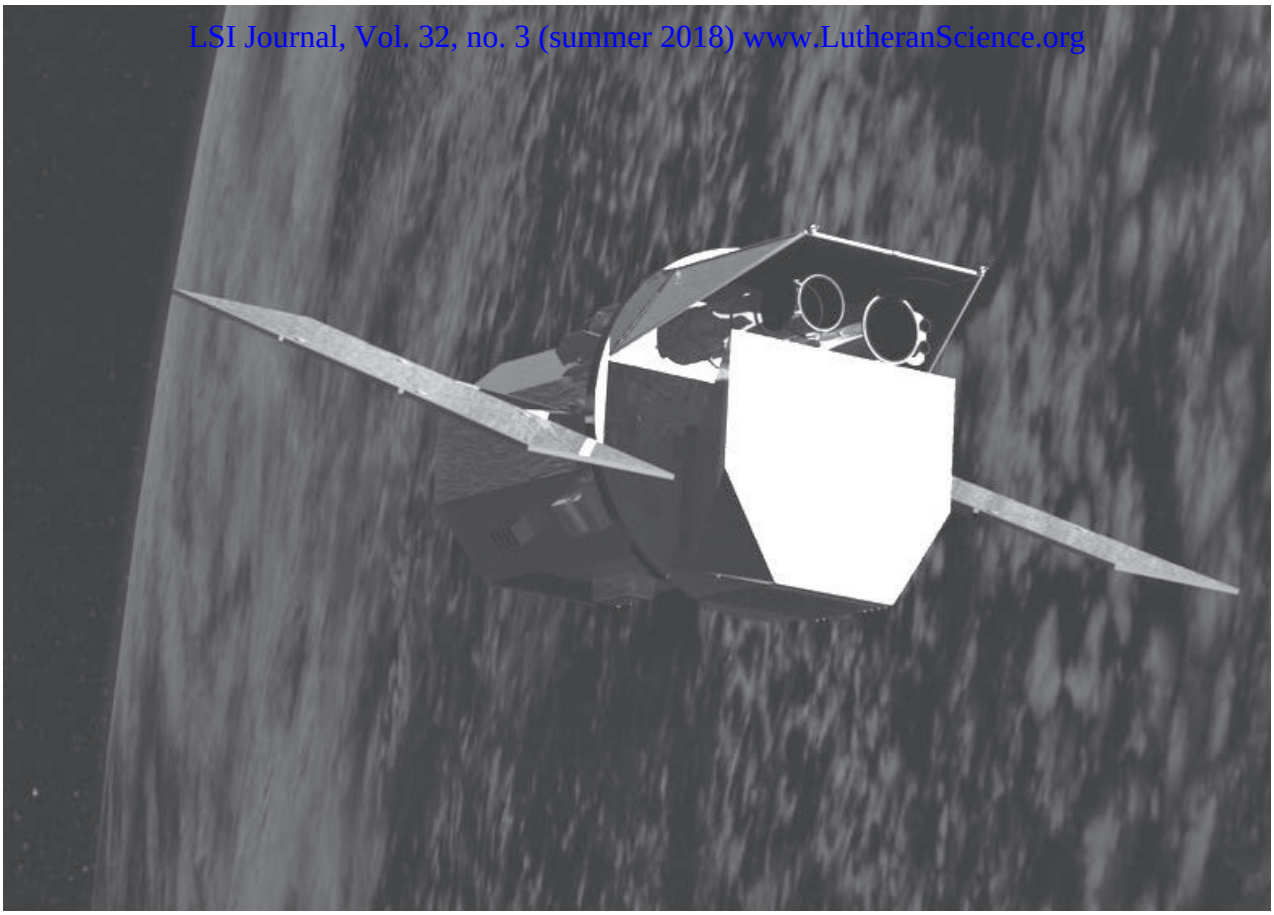
> of the strong gravity that is pulling all of the light into the black hole's center. However, scientists can see the effects of its strong gravity on the stars and gases around it. If a star is orbiting a certain point in space, scientists can study the star's motion to find out if it is orbiting a black hole. When a black hole and a star are orbiting close together, high-energy light is produced. Scientific instruments can see this high-energy light. …How Is NASA Studying Black Holes? NASA is learning about black holes using spacecraft like the Chandra X-ray Observatory, the Swift satellite and the Fermi Gamma-ray Space Telescope. Fermi launched in 2008 and is observing gamma rays - the most energetic form of light – in search of supermassive black holes and other astronomical phenomena.[3]

"NASA's Swift Satellite Spots Black Hole Devouring A Star"

NASA Reported the discovery of a black hole using an article with this title. NASA reports,

> In late March 2011, NASA's Swift satellite alerted astronomers to intense and unusual high-energy flares from a new source in the constellation Draco. They soon realized that the source, which is now known as Swift J1644+57, was the result of a truly extraordinary event — the awakening of a distant galaxy's dormant black hole as it shredded and consumed a star. …Most galaxies, including our own, possess a central supersized black hole weighing millions of times the sun's mass. According to the new studies, the black hole in the galaxy hosting Swift J1644+57 may be twice the mass of the four-million-so-

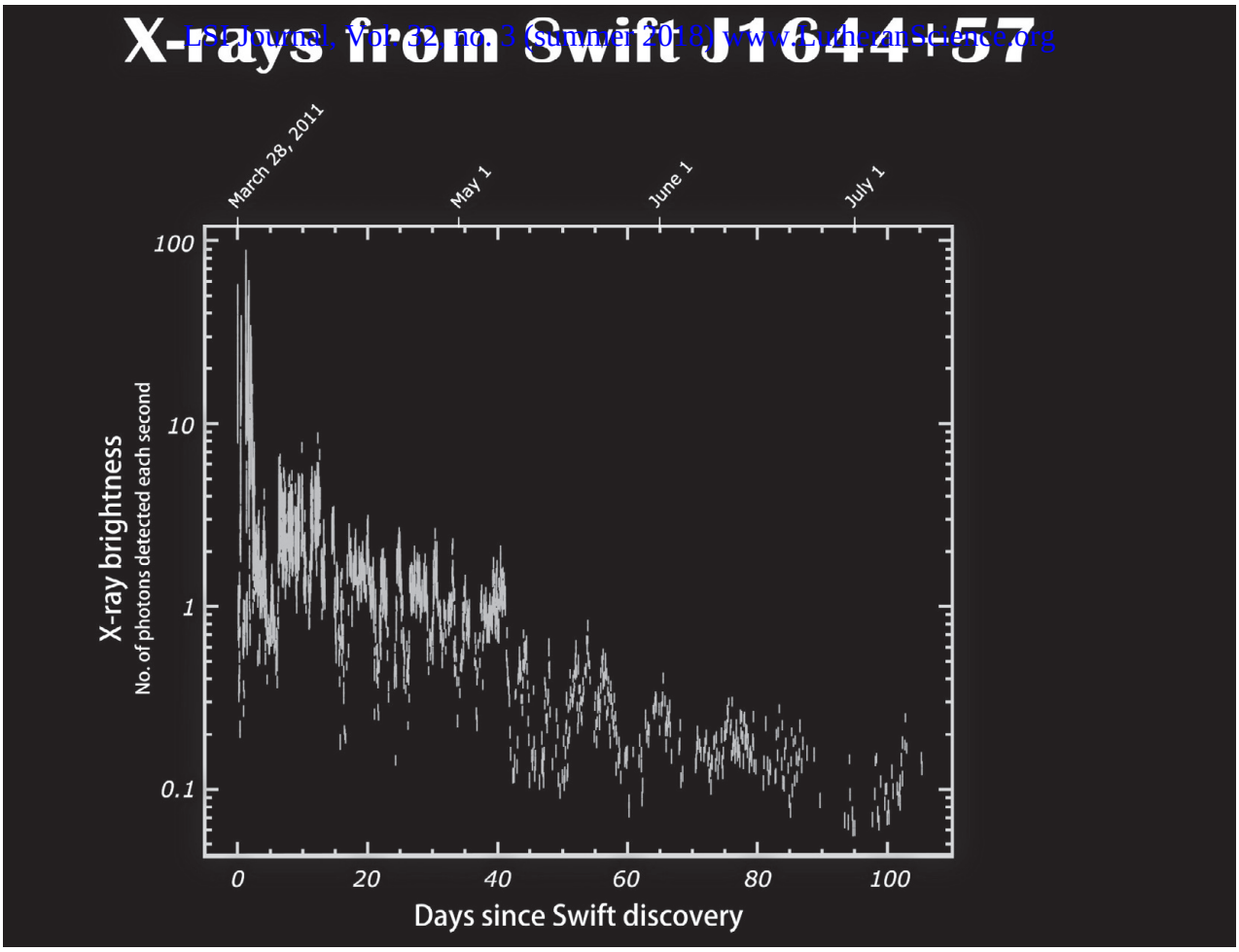
3 Smith.



NASA's Swift Satellite with X-Ray and Optical Telescopes
credit: NASA/Goddard Space Flight Center

lar-mass black hole lurking at the center of our own Milky Way galaxy. As a star falls toward a black hole, it is ripped apart by intense tides. The gas is corralled into a disk that swirls around the black hole and becomes rapidly heated to temperatures of millions of degrees. The innermost gas in the disk spirals toward the black hole, where rapid motion and magnetism creates dual, oppositely directed "funnels" through which some particles may escape. Particle jets driving matter at velocities greater than 80-90 percent the speed of light form along the black hole's spin axis. In the case of Swift J1644+57, one of these jets happened to point straight at Earth.[4]

4 Francis Reddy, "NASA's Swift Satellite Spots Black Hole Devouring A Star," NASA Goddard Media Studios, August 24, 2011, http://svs.gsfc.nasa.gov/10807 (accessed August 3, 2018)

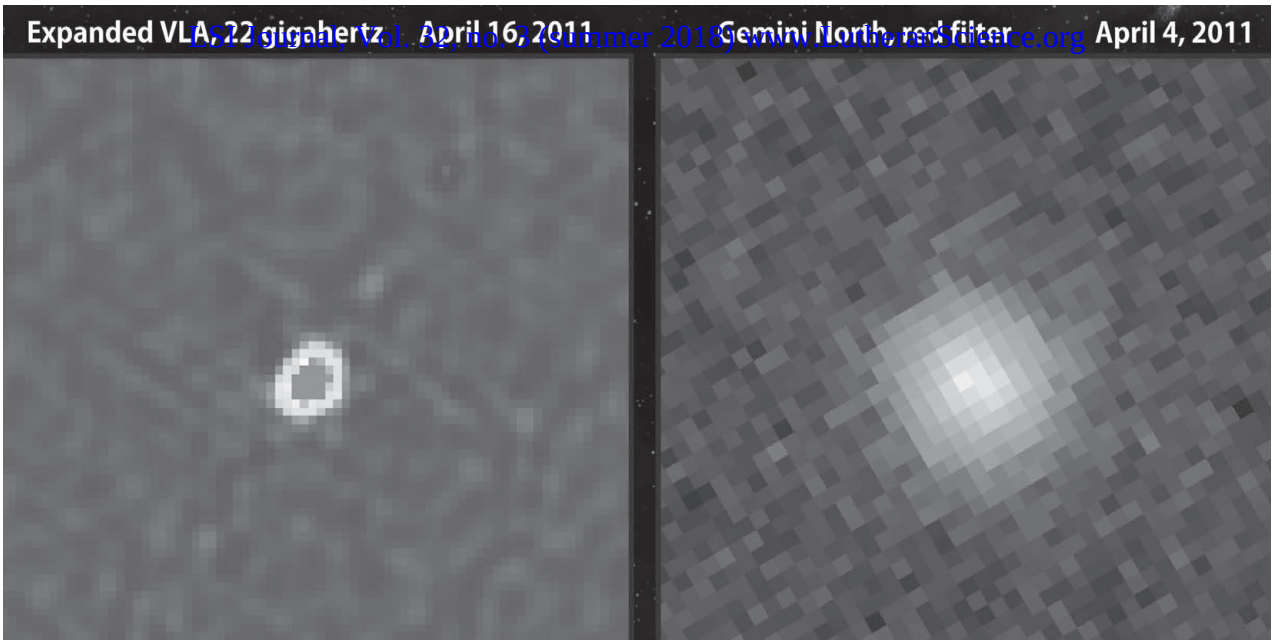


What Did Swift "See"?

NASA's Swift satellite recorded spikes of x-ray energy, and that has been interpreted as a particle jet reaching the earth from a black hole which may be consuming a star. The brightness of the x-rays as measured by the Swift satellite is graphed in the image[5] above. NASA describes that image with these words,

> Swift's X-Ray Telescope continues to record high-energy flares from Swift J1644+57 more than three months after the source's first appearance. Astronomers believe that this behavior represents the slow depletion of gas in an accretion disk around a supermassive black hole. The first flares from the source likely coincided with the disk's creation, thought to have occurred when a star wandering too close to the black hole was torn apart.[6]

5 Image credit: NASA/Swift/Penn State.
6 Reddy.



NASA's Swift satellite has both x-ray and optical telescopes. This is important as it allows us to correlate data from two different parts of the electromagnetic spectrum (x-ray and optical). Data from each is combined into the image shown on page 31.

What Did Other Imaging Equipment "See"?

Radio wave images of this same patch of sky taken by other imaging equipment, show what is assumed to be a distant galaxy emitting strong radio waves. A gray-scale image[7] of those radio waves is shown above (the NASA original is colorized). NASA writes about this image [XRT is the x-ray telescope on the Swift satellite],

> Positions from Swift's XRT constrained the source to a small patch of sky that contains a faint galaxy known to be 3.9 billion light-years away. But to link the Swift event to the galaxy required observations at radio wavelengths, which showed that the galaxy's center contained a brightening radio source. Analysis of that source using the Expanded Very Large Array and Very Long Baseline Interferometry (VLBI) shows that it is still expanding at more than half the speed of light.[8]

7 Image credit: NRAO/CfA/Zauderer et al.
8 Reddy.

Interpreting Data

All of this data must be interpreted. What may explain such data? Scientists make "models," which are proposed explanations for the data. One model that may explain the data discussed above, is that of a black hole consuming a star. NASA describes this interpretation,

> Theoretical studies of tidally disrupted stars suggested that they would appear as flares at optical and ultraviolet energies. The brightness and energy of a black hole's jet is greatly enhanced when viewed head-on. The phenomenon, called relativistic beaming, explains why Swift J1644+57 was seen at X-ray energies and appeared so strikingly luminous. When first detected on March 28, the flares were initially assumed to signal a gamma-ray burst, one of the nearly daily short blasts of high-energy radiation often associated with the death of a massive star and the birth of a black hole in the distant universe. But as the emission continued to brighten and flare, astronomers realized that the most plausible explanation was the tidal disruption of a sun-like star seen as beamed emission.[9]

Artistic Depictions

NASA has a video[10] showing an artistic depiction of this proposed interpretation of the data. Still images from that video are shown on page 32. NASA describes this video with these words,

> On March 28, 2011, NASA's Swift detected intense X-ray flares thought to be caused by a black hole devouring a star. In one model, illustrated here, a sun-like star on an eccentric orbit plunges too close to its galaxy's central black hole. About half of the star's mass feeds an accre-

9 Reddy.
10 Reddy.

> tion disk around the black hole, which in turn powers a particle jet that beams radiation toward Earth.[11]

Quasars

Back in the 60s and 70s I remember hearing about quasars all the time in TV shows and magazines. Quasar was even a line of Motorola television sets. Quasar is a contraction of "quasi-stellar radio source." NASA reports that "Quasars are capable of emitting hundreds or even thousands of times the entire energy output of our galaxy."[12] Fifty years ago, quasars were very mysterious, since almost nothing was known about them.

Today, it is commonly accepted that quasars are black holes feeding on matter and streaming massive amounts of energy across the universe. The European Space Agency (ESA) explains,

> Today most astronomers believe that quasars, radio galaxies and the centres of so-called active galaxies just are different views of more or less the same phenomenon: a black hole with energetic jets beaming out from two sides. When the beam is directed towards us we see the bright lighthouse of a quasar. When the orientation of the system is different we observe it as an active galaxy or a radio galaxy. This 'unified model' has gained considerable support through a number of Hubble observational programs. The simplistic early ideas have however been replaced by a more complex view of this phenomenon – a view that will continue to evolve in the years to come.[13]

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11 Reddy.
12 ESA/Hubble & NASA, "NASA's Hubble Gets the Best Image of Bright Quasar 3C 273," https://www.nasa.gov/content/goddard/nasas-hubble-gets-the-best-image-of-bright-quasar-3c-273/#.W1zAl_ZFxzx (accessed August 3, 2018)
13 The Hubble European Space Agency Information Centre, "Black holes, quasars and active galaxies," Hubble Space Telescope, http://www.spacetelescope.org/science/black_holes/ (accessed August 3, 2018)

Science

Personally, I think it likely that the scientific modeling of this data as depicted in the artistic renderings and video is reflective of what actually emitted this radio and x-ray energy. Alternatively, it may be completely incorrect. That is the nature of science. As Paul Boehlke wrote in the *Lutheran Educator*, "Science changes; new ideas replace the old. Science does not generate truth, but rather, useful explanations."[14]

Mark Bergemann is a retired electrical engineer with a B.S. from UW-Milwaukee. He serves as president of the Lutheran Science Institute, and as a Martin Luther College adjunct instructor, where he teaches the online courses Creation Apologetics 101 and 102. He is a member of Good Shepherd's Evangelical Lutheran Church in West Allis, Wisconsin.

Page 32: NASA descriptions of these images,[15]

Top left image on page 32
"A sun-like star on an eccentric orbit plunges toward the supermassive black hole in the heart of a distant galaxy."

Top right image on page 32
"Strong tidal forces near the black hole increasingly distort the star. If the star passes too close, it is ripped apart."

Bottom left image on page 32
"The part of the star facing the black hole streams toward it and forms an accretion disk. The remainder of the star just expands into space."

Bottom right image on page 32
"Near the black hole, magnetic fields power a narrow jet of particles moving near the speed of light. Viewed head-on, the jet is a brilliant x-ray and radio source."

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14 Paul Boehlke, DINOSAURS, GOD'S CREATURES, The Lutheran Educator, 31, no. 3 (1991): 57. (accessed August 3, 2018) https://mlc-wels.edu/library/wp-content/uploads/sites/14/2015/12/luthed313.pdf
15 Reddy.

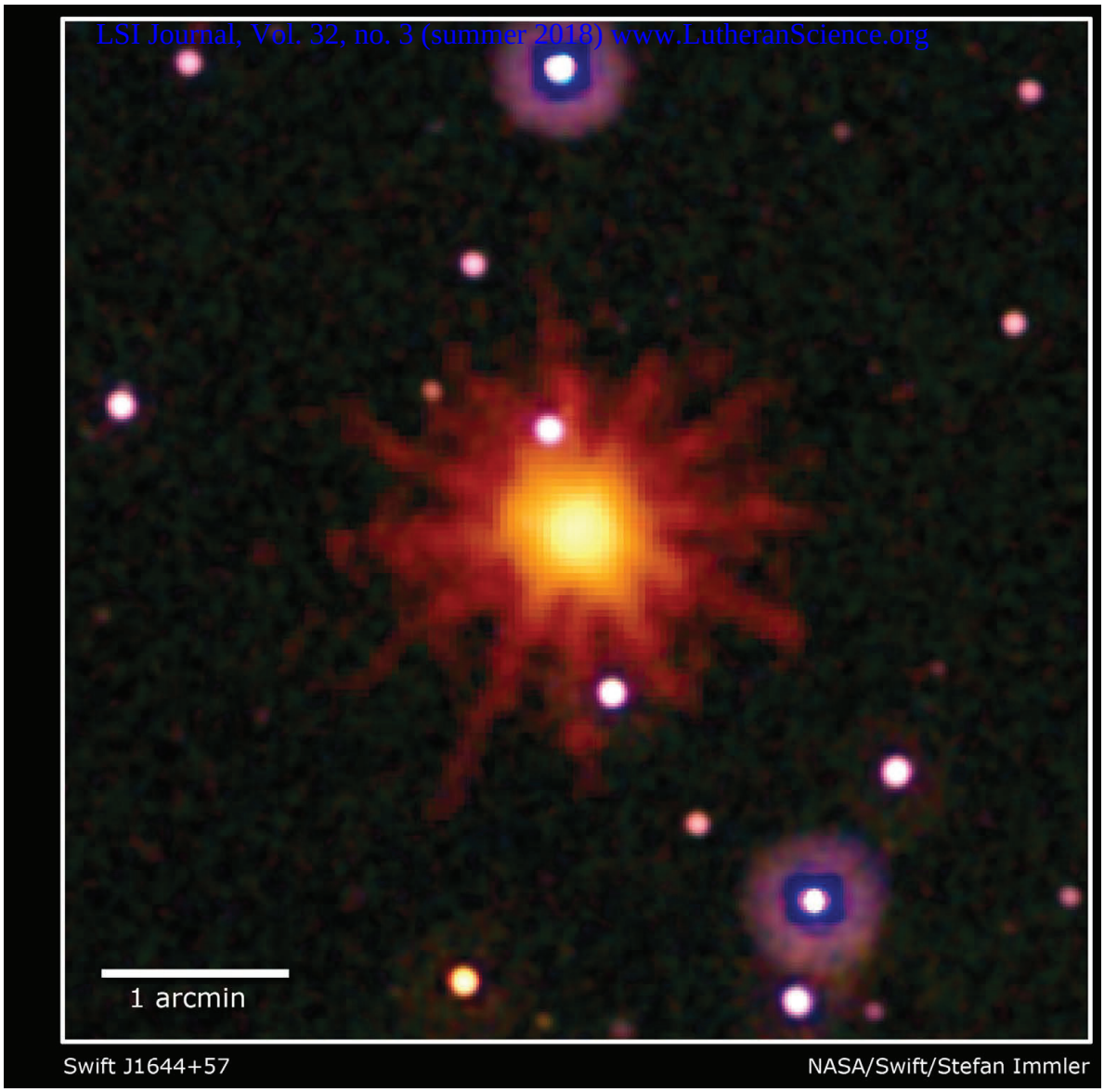
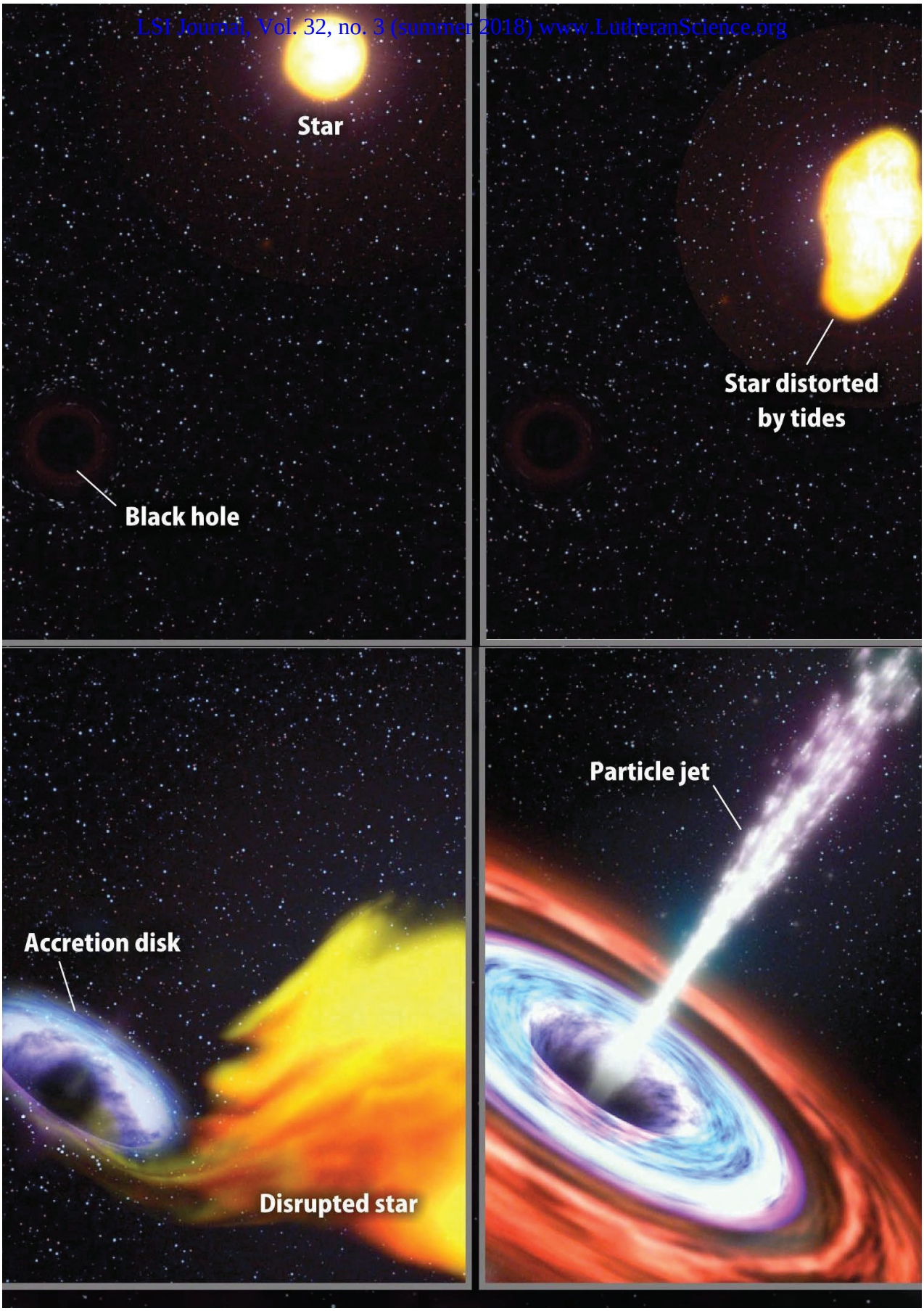


Image Depicting Actual Data from the Swift Satellite

The data depicted in the above image, along with other data, must be interpreted using various scientific models about black holes (various ideas of how black holes behave). One interpretation of the data resulted in the artistic drawings shown on page 32. NASA explains the above actual data image,

> Images from Swift's Ultraviolet/Optical (white, purple) and X-Ray telescopes (yellow and red) were combined to make this view of Swift J1644+57. Evidence of the flares is seen only in the X-ray image, which is a 3.4-hour exposure taken on March 28, 2011.[16]

16 Reddy.



Sequential Artistic Depictions (top left to bottom right) of How Some Scientists Think a Black Hole May Be Able to Consume a Star.

Details on page 30. credit: NASA/Goddard Space Flight Center/Swift