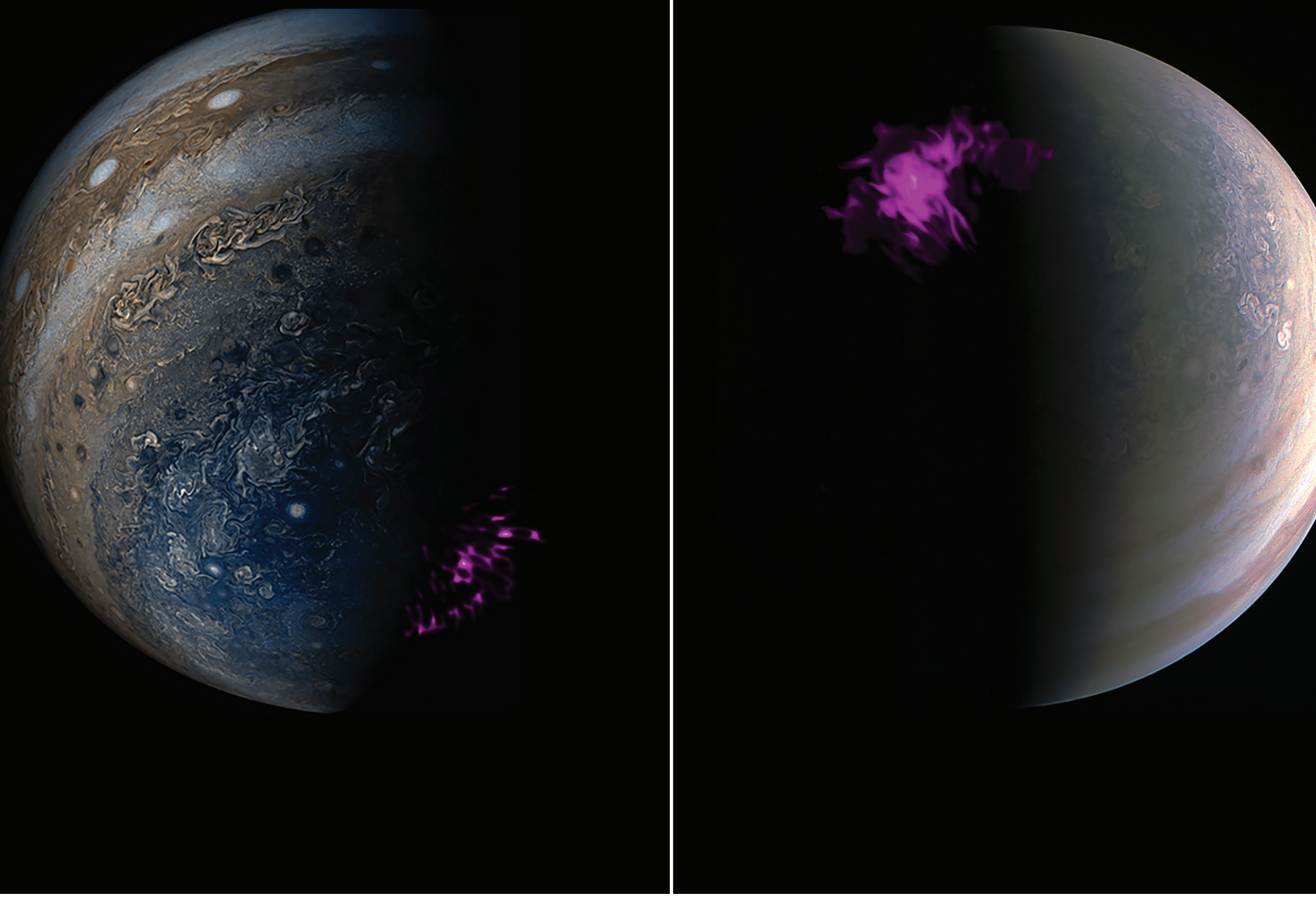
National Aeronautics and
Space Administration

EXPLORING *the* INVISIBLE

20 YEARS OF NASA'S CHANDRA X-RAY OBSERVATORY

2019

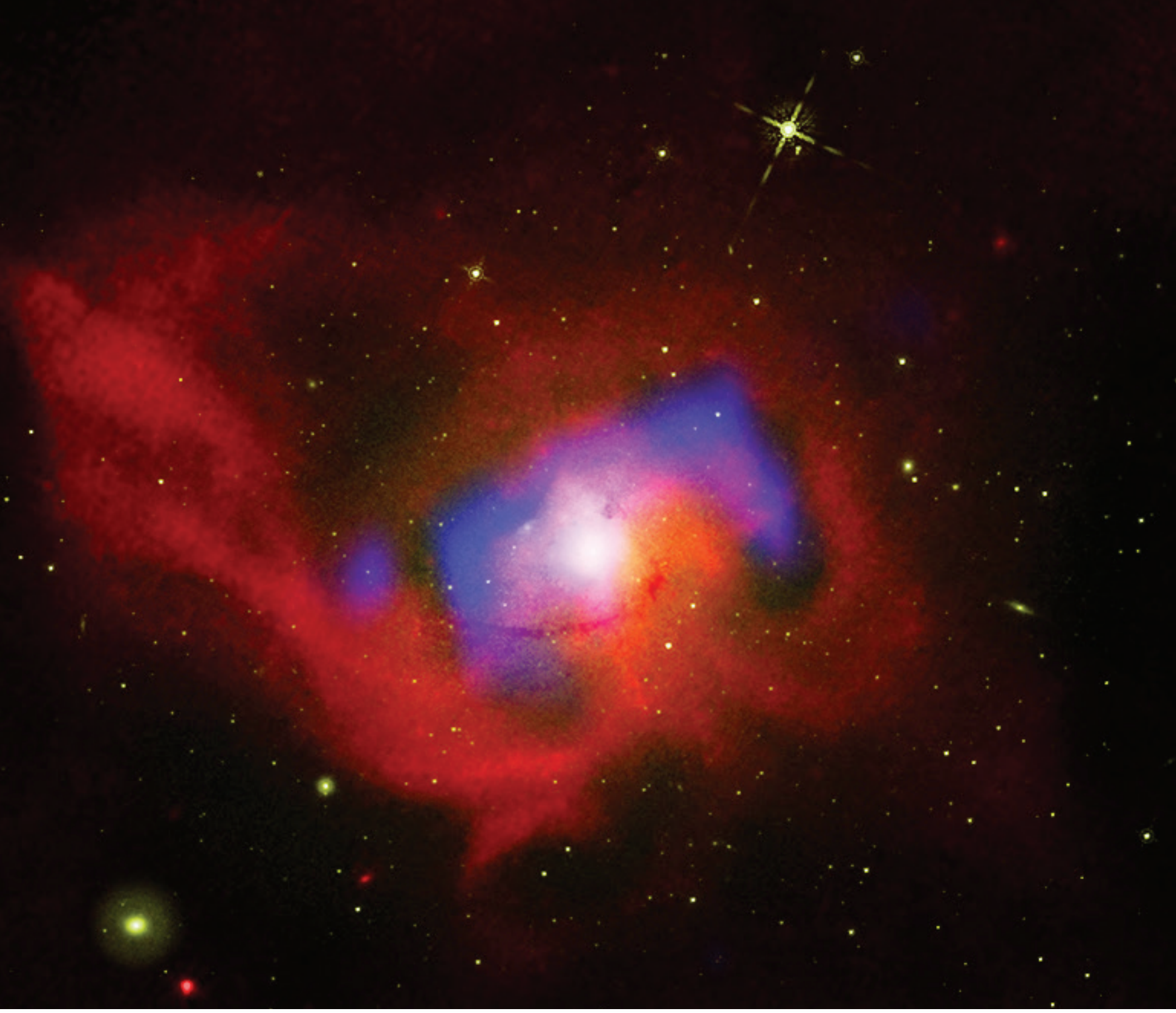


JUPITER

Jupiter, the fifth planet from the Sun in our Solar System, has remarkable auroras. A study with NASA's Chandra X-ray Observatory and ESA's XMM-Newton reveals that unlike those on Earth and Saturn, the auroras at Jupiter's poles behave independently of one another. These images combine X-ray data from Chandra (purple) with data from the NASA's Juno spacecraft, which is currently in orbit around Jupiter.

JANUARY 2019

S	M	T	W	Th	F	Sa
		1 New Year's Day	2	3	4	5 ○
6	7	8	9	10	11	12
13	14 ◗	15	16	17	18	19
20	21 ● Martin Luther King, Jr.	22	23	24	25	26
27 ◖	28	29	30	31		



CENTAURUS CLUSTER

Chandra is unrivaled for studying the hot gas that pervades galaxy clusters — megastructures that are the largest objects in the Universe held together by gravity. This composite image of the Centaurus Cluster, located 145 million light years from Earth, shows a vast cloud of hot gas seen by Chandra (red) surrounding high-energy bubbles revealed in radio waves (blue). These structures flank a supermassive black hole buried in the bright white area in the center. Galaxies in the cluster are shown by optical light data from NASA's Hubble Space Telescope (green).

FEBRUARY 2019

S	M	T	W	Th	F	Sa
					1	2
3	4 ○	5	6	7	8	9
10	11	12 ◗	13	14 Valentine's Day	15	16
17	18 Presidents' Day	19 ●	20	21	22	23
24	25	26 ◖	27	28		

CRAB NEBULA

The Crab Nebula, one of the most famous objects in the sky, represents the remains of an exploded star about 6,500 light years from Earth. Chandra has observed the Crab many times, uncovering a whirling magnetic dynamo that powers jets of matter and anti-matter moving away from the dead star's core. This image of the Crab combines X-rays from Chandra (blue and white), optical data from Hubble (purple), and infrared data from NASA's Spitzer Space Telescope (pink).

MARCH 2019

S	M	T	W	Th	F	Sa
					1	2
3	4	5	6 ○	7	8	9
10	11	12	13	14 ◗	15	16
17	18	19	20 ●	21	22	23
24	25	26	27	28 ◖	29	30
31						

NGC 602

This stellar vista is a landscape of young stars in the Small Magellanic Cloud (SMC), located about 180,000 light years from Earth and one of the closest galaxies to the Milky Way. Astronomers used Chandra observations to make the first detection of X-ray emission from young stars with masses similar to our Sun outside our Galaxy. This composite image reveals a region known as the “Wing” of the SMC in X-rays from Chandra (purple), optical data from Hubble (red, green and blue), and infrared emission from Spitzer (red).

APRIL 2019

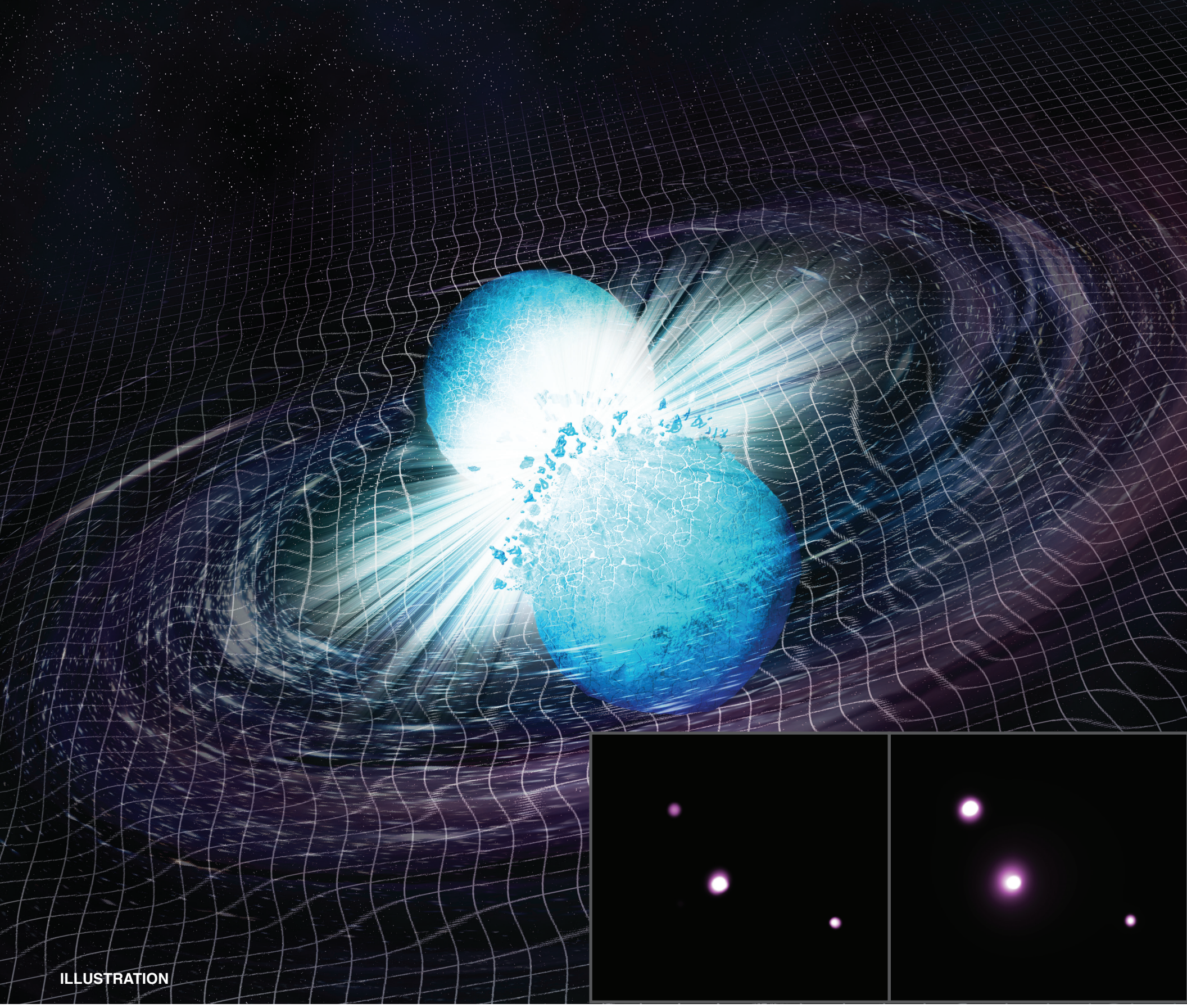
S	M	T	W	Th	F	Sa
	1	2	3	4	5 ○	6
7	8	9	10	11	12 ◗	13
14	15	16	17	18	19 ●	20
21	22	23	24	25	26 ◖	27
28	29	30				

EAGLE NEBULA

Using Chandra, researchers detected over 1,700 X-ray sources in the field of the Eagle Nebula, which is one of the most iconic images in astronomy. The so-called Pillars of Creation are located in the southern portion of the Eagle Nebula, which is about 7,500 light years from Earth, where stars are being born. Hubble data reveal dusty nebula (brown) and a few stars (pink), while Chandra data expose young stars and other X-ray sources (red, green, and blue).

MAY 2019

S	M	T	W	Th	F	Sa
			1	2	3	4 ○
5	6	7	8	9	10	11 ◗
12	13	14	15	16	17	18 ●
19	20	21	22	23	24	25
26 ◖	27 Memorial Day	28	29	30	31	



GW170817

Astronomy entered a new age with the discovery of gravitational waves from space in 2015. Another major step was achieved when scientists also detected light from a gravitational wave source, known as GW170817, less than two years later. Chandra observations of this historic object provided evidence that this was caused by the merger of two neutron stars as depicted in the artist's illustration. The change in brightness of the X-rays seen by Chandra over time (bottom panel) suggests that the event also formed a new black hole.

JUNE 2019

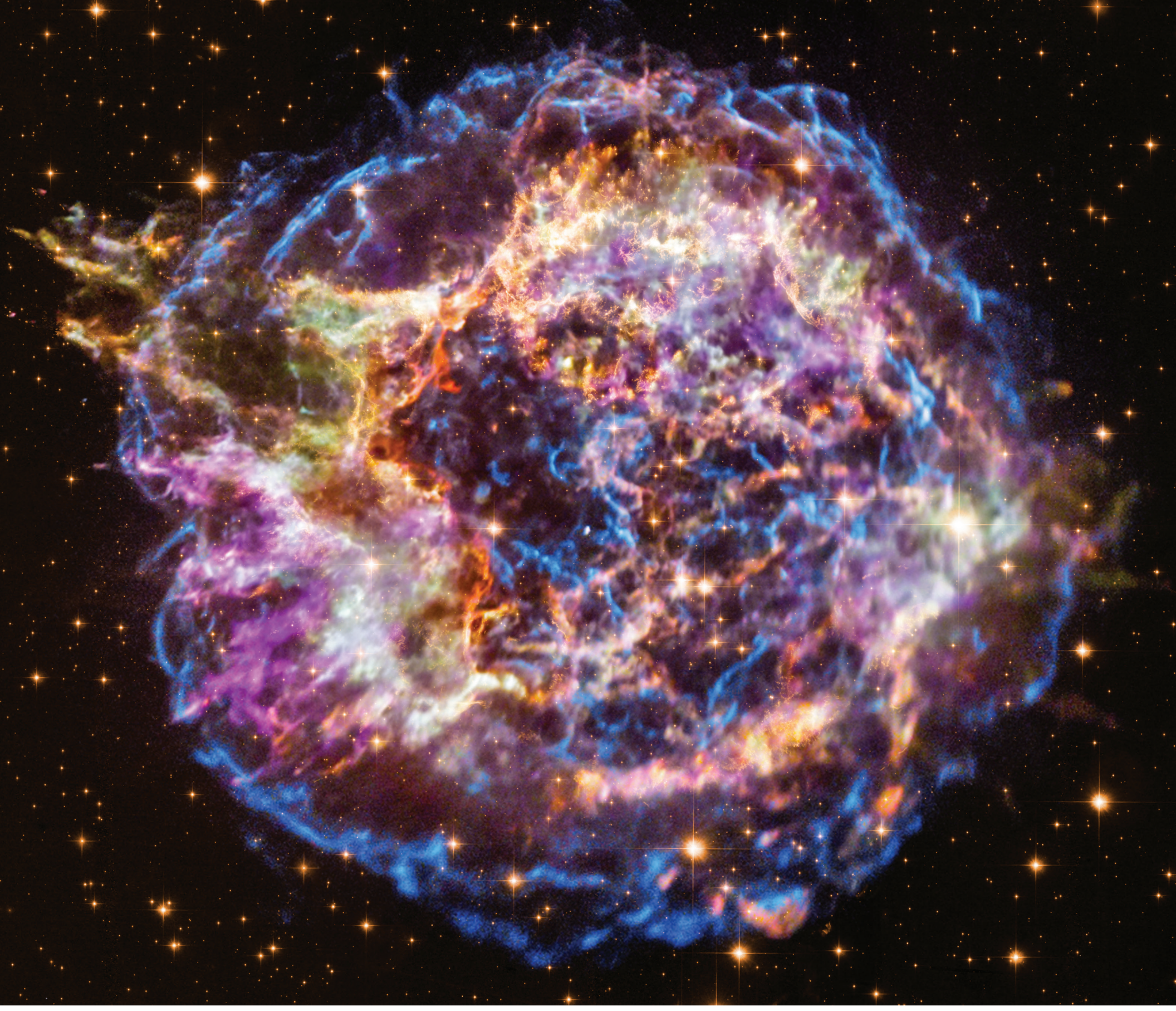
S	M	T	W	Th	F	Sa
						1
2	3 ○	4	5	6	7	8
9	10 ◗	11	12	13	14	15
16	17 ●	18	19	20	21	22
23	24	25 ◖	26	27	28	29
30						

LAUNCH

On July 23, 1999, the Space Shuttle Columbia lifted off the launch pad at John F. Kennedy Space Center in Cape Canaveral, Florida. Its mission was to carry NASA's Chandra X-ray Observatory into space. The astronauts aboard Columbia that night were Eileen Collins (mission commander), Michel Tognini (mission specialist), Steven Hawley (mission specialist), Jeffrey Ashby (pilot), and Cady Coleman (mission specialist).

JULY 2019

S	M	T	W	Th	F	Sa
	1	2 ○	3	4 Independence Day	5	6
7	8	9 ◗	10	11	12	13
14	15	16 ●	17	18	19	20
21	22	23	24 ◖	25	26	27
28	29	30	31 ○			



CASSIOPEIA A

This exquisitely detailed image from Chandra shows the location of different elements in the Cassiopeia A supernova remnant including silicon (red), sulfur (yellow), calcium (green), and iron (purple). The blue outer ring is the blast wave from the explosion of the collapsed massive star, located about 11,000 light years from Earth. Optical data from Hubble are shown in gold. Astronomers study supernova remnants to better understand how stars produce and then disseminate many of the elements found on Earth and in the cosmos at large.

AUGUST 2019

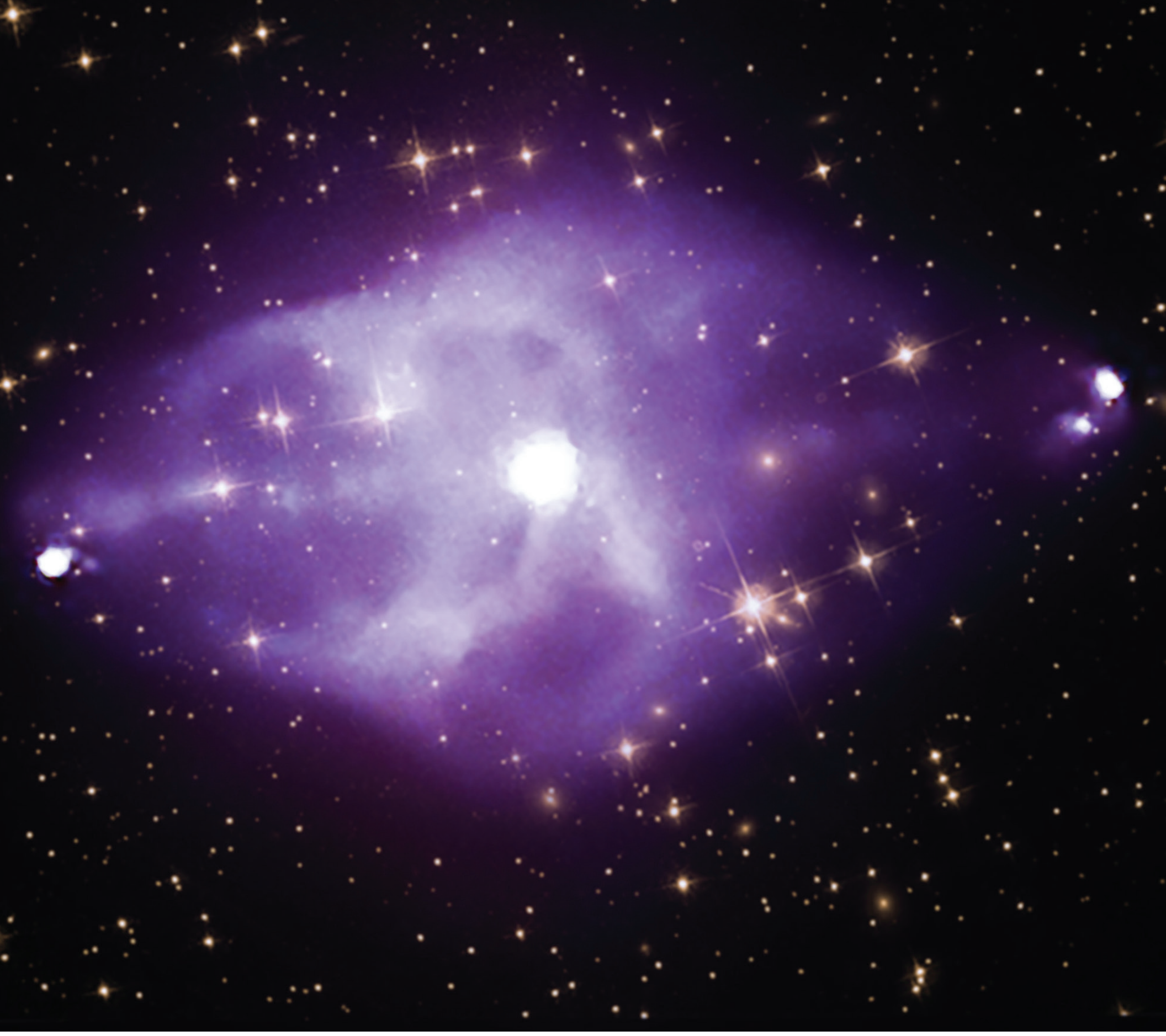
S	M	T	W	Th	F	Sa
				1	2	3
4	5	6	7 ◗	8	9	10
11	12	13	14	15 ●	16	17
18	19	20	21	22	23 ◖	24
25	26	27	28	29	30 ○	31

CARTWHEEL GALAXY

When galaxies collide, cosmic fireworks can ensue. The Cartwheel galaxy likely got its ring shape when one galaxy punched through another. This image combines data from four different wavelengths of light: X-rays from Chandra (purple), infrared data from Spitzer (red), optical light from Hubble (green), and ultraviolet emission detected by GALEX (blue). The bright, white X-ray sources on the rim are due to matter falling into black holes or neutron stars left behind by the explosion of massive stars.

SEPTEMBER 2019

S	M	T	W	Th	F	Sa
1	2 Labor Day	3	4	5 ◗	6	7
8	9	10	11	12	13	14 ●
15	16	17	18	19	20	21 ◗
22	23	24	25	26	27	28 ○
29	30					



CYGNUS A

Cygnus A, at a distance of some 700 million light years, is a galaxy that contains giant bubbles in hot gas detected by Chandra (red, green, and blue). These galactic superbubbles were carved out by powerful jets blasting out from the vicinity of the black hole at the center of Cygnus A. These bubbles have been used to study how powerful the black hole's outbursts have been, and the composition of the jets. Optical data from Hubble complete this view.

OCTOBER 2019

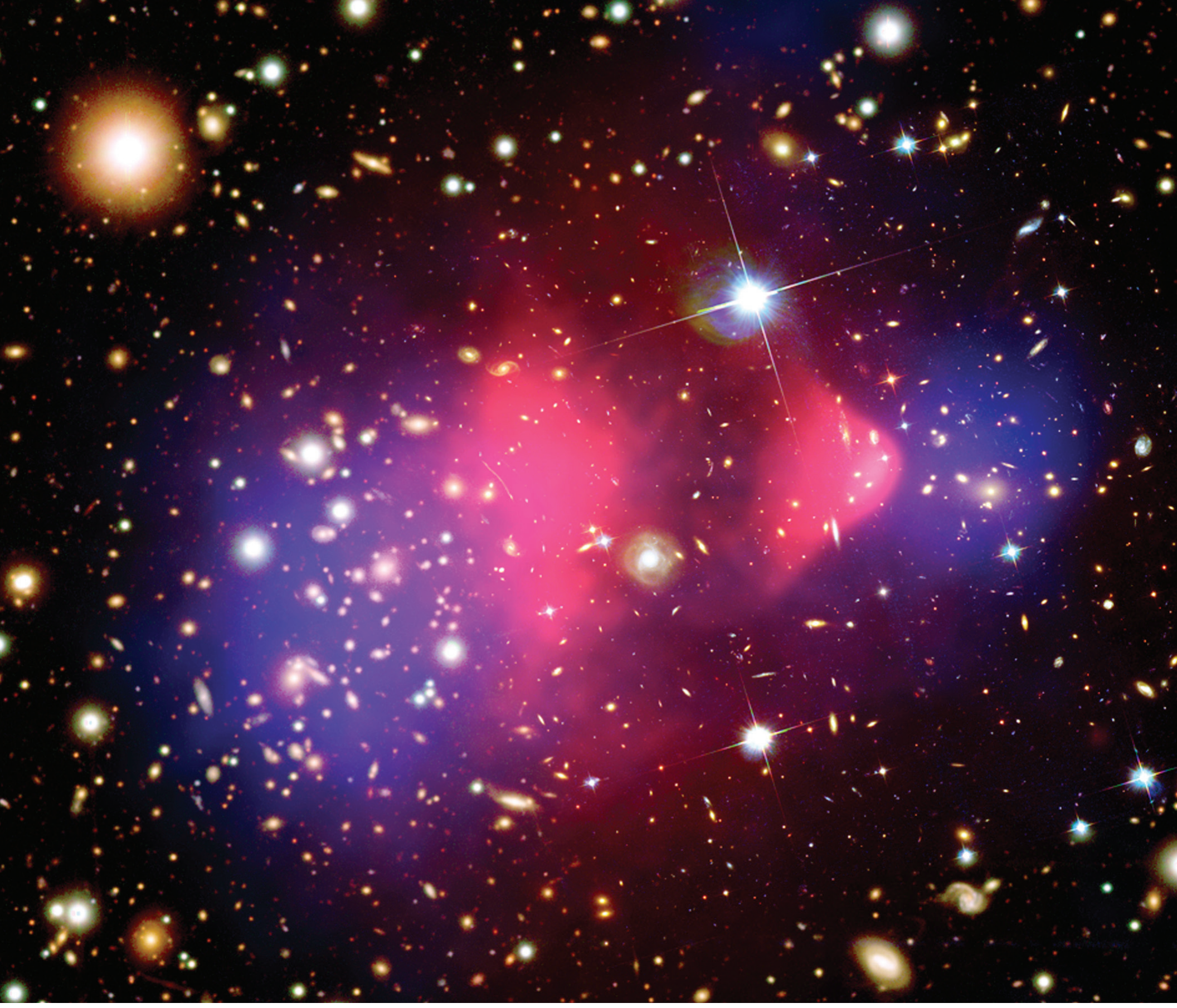
S	M	T	W	Th	F	Sa
		1	2	3	4	5 ◗
6	7	8	9	10	11	12
13 ●	14 Columbus Day	15	16	17	18	19
20	21 ◗	22	23	24	25	26
27 ○	28	29	30	31		

SAGITTARIUS A*

The supermassive black hole at the center of the Milky Way contains about four million times the mass of the Sun. In its two decades of operation, Chandra has made many discoveries about our local, supermassive black hole including evidence for neutrino production, observations of eruptions and light echoes, and hints of the possible consumption of asteroids by the black hole. This image shows Chandra data of the area around the black hole in different bands of X-ray light (red, green, and blue).

NOVEMBER 2019

S	M	T	W	Th	F	Sa
					1	2
3	4 ◗	5	6	7	8	9
10	11 Veterans Day	12 ●	13	14	15	16
17	18	19 ◖	20	21	22	23
24	25	26 ○	27	28 Thanksgiving Day	29	30



BULLET CLUSTER

Dark matter, by its definition, does not emit light. It can, however, be detected by the effects it has on other matter through gravity. The Bullet Cluster, located about 3.4 billion light years from Earth, represents one of the best pieces of evidence to date for the existence of dark matter. When two galaxy clusters violently collided, it wrenched “normal” matter from the dark matter in this system. Chandra data (pink) reveals the hot gas that has been separated from the dark matter, which has been mapped using gravitational lensing data in optical light from Hubble (blue).

DECEMBER 2019

S	M	T	W	Th	F	Sa
1	2	3	4 ◗	5	6	7
8	9	10	11	12 ●	13	14
15	16	17	18 ◖	19	20	21
22	23	24	25 Christmas Day	26 ○	27	28
29	30	31				

In 2019, NASA's Chandra X-ray Observatory celebrates its 20th year in space exploring the Universe. In these past two decades, Chandra has made profound discoveries and contributed invaluable information about the cosmos and the wondrous objects within it.

Chandra is part of a rich legacy of telescopes. Its X-ray lineage stretches back to the Space Age when scientists and engineers pioneered instruments that were sent above the Earth's atmosphere. This allowed astronomers to observe X-rays from cosmic objects for the first time. Each decade has brought new innovations and new capabilities, culminating in Chandra's launch aboard the Space Shuttle Columbia in 1999.

Chandra also has strong astronomical family ties across the electromagnetic spectrum. As part of NASA's "Great Observatories" program, Chandra was designed and built to observe X-rays alongside the Hubble Space Telescope in ultraviolet, visible and infrared light, the Spitzer Space Telescope in infrared light, and the Compton Gamma-ray Observatory in gamma rays.

Today, the quest to explore the Universe is both multiwavelength and multimessenger in nature, with many of the very significant and exciting discoveries requiring information from different types of light as well as gravitational waves and particle physics. In its 20 years of operation, Chandra and X-ray astronomy as a whole have played a pivotal role in uncovering and solving the mysteries of the Universe. We look forward to what the next years may bring.

Acknowledgements
The Chandra X-ray Observatory Center (CXC) is operated by the Smithsonian Astrophysical Observatory (SAO) in Cambridge, MA, for the National Aeronautics and Space Administration (NASA). The CXC controls science and flight operations of the orbiting observatory, supports the international community of observers, disseminates science results, and carries out an education and public outreach program. The CXC program is managed by NASA's Marshall Space Flight Center for the Science Mission Directorate, NASA Headquarters, Washington, D.C.

The entire Chandra community is deeply indebted to NASA, the Space Shuttle Columbia, and the STS-93 astronaut crew for expertly placing Chandra in its proper orbit.

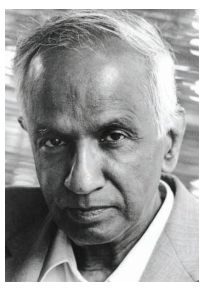
Crew
On Flight Day 5, the five STS-93 astronauts pose for the traditional inflight crew portrait on Columbia's middeck.

In front are astronauts Eileen M. Collins, mission commander, and Michel Tognini, mission specialist representing France's Centre National d'Etudes Spatials (CNES). Behind them are (from the left) astronauts Steven A. Hawley, mission specialist; Jeffrey S. Ashby, pilot; and Catherine G. (Cady) Coleman, mission specialist.

Spacecraft and Instruments
Prime Contractor: TRW (now NGST), Redondo Beach, CA

Telescope Mirrors:
Design: SAO
Glass: Schott Glaswerke, Mainz, Germany
Mirror fabrication: Perkin-Elmer/Hughes-Danbury (now Goodrich), Danbury, CT
Coating: Optical Coating Laboratory, Inc., Santa Rosa, CA
Assembly: Eastman-Kodak (now ITT), Rochester, NY

Science Instruments:
The Advanced CCD Imaging Spectrometer (ACIS): Pennsylvania State University (PSU) & Massachusetts Institute of Technology (MIT)
The High Resolution Camera (HRC): SAO
HETG and METG diffraction grating spectrometers: MIT
LETG diffraction grating spectrometer: Space Research Organization of the Netherlands (SRON), Utrecht, Netherlands, & Max-Planck-Institut fur extraterrestriche Physik, Garching, Germany
Aspect Camera and Science Instrument Module: Ball Aerospace & Technologies Corporation, Boulder, CO



The man behind the name
NASA's premier X-ray observatory was named the Chandra X-ray Observatory in honor of the late Indian-American Nobel laureate, Subrahmanyan Chandrasekhar (pronounced: su/bra/mon'/yon chandra/say/kar). Known to the world as Chandra (which means "moon" or "luminous" in Sanskrit), he was widely regarded as one of the foremost astrophysicists of the twentieth century. Trained as a physicist, he was one of the first scientists to combine the disciplines of physics and astronomy. Early in his career, he demonstrated that there is an upper limit — now called the Chandrasekhar limit — to the mass of a white dwarf star. Chandra was a popular teacher who guided over fifty students to their Ph.D.s. His research explored nearly all branches of theoretical astrophysics and he published ten books, each covering a different topic, including one on the relationship between art and science. In 1983, Chandra was awarded the Nobel prize for his theoretical studies of the physical processes important to the structure and evolution of stars.

Cover Illustration: James Vaughan & NASA/CXC

January, Jupiter: X-ray: NASA/CXC/UCL/W.Dunn et al.; Optical: South Pole: NASA/JPL-Caltech/SwRI/MSSS/Gerald Eichstädt /Seán Doran; North Pole: NASA/JPL-Caltech/SwRI/MSSS

February, Centaurus Cluster: X-ray: NASA/CXC/MPE/J. Sanders et al.; Optical: NASA/STScI; Radio: NSF/NRAO/VLA

March, Crab Nebula: X-ray: NASA/CXC/SAO; Optical: NASA/STScI; Infrared: NASA-JPL-Caltech

April, NGC 602: X-ray: NASA/CXC/Univ.Potsdam/L. Oskinova et al.; Optical: NASA/STScI; Infrared: NASA/JPL-Caltech

May, Eagle Nebula (M16): X-ray: NASA/CXC/INAF/M. Guarcello et al.; Optical: NASA/STScI

June, GW170817: NASA/CXC/Trinity University/D. Pooley et al. Illustration: NASA/CXC/M.Weiss

July, Launch: NASA

August, Cassiopeia A: X-ray: NASA/CXC/SAO; Optical: NASA/STScI

September, Cartwheel Galaxy: Composite: NASA/JPL/Caltech/P.Appleton et al. X-ray: NASA/CXC/A.Wolter & G.Trinchieri et al.

October, Cygnus A: X-ray: NASA/CXC/SAO; Optical: NASA/STScI

November, Sgr A*: NASA/CXC/Univ. of Wisconsin/Y.Bai, et al.

December, Bullet Cluster: X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.

cxc.harvard.edu
chandra.si.edu

Since its launch on July 23, 1999, the Chandra X-ray Observatory has been NASA's flagship mission for X-ray astronomy, taking its place in the fleet of "Great Observatories."

NASA's Chandra X-ray Observatory is a telescope specially designed to detect X-ray emission from very hot regions of the Universe such as exploded stars, clusters of galaxies, and matter around black holes. Because X-rays are absorbed by Earth's atmosphere, Chandra must orbit above it, up to an altitude of 139,000 km (86,500 mi) in space.