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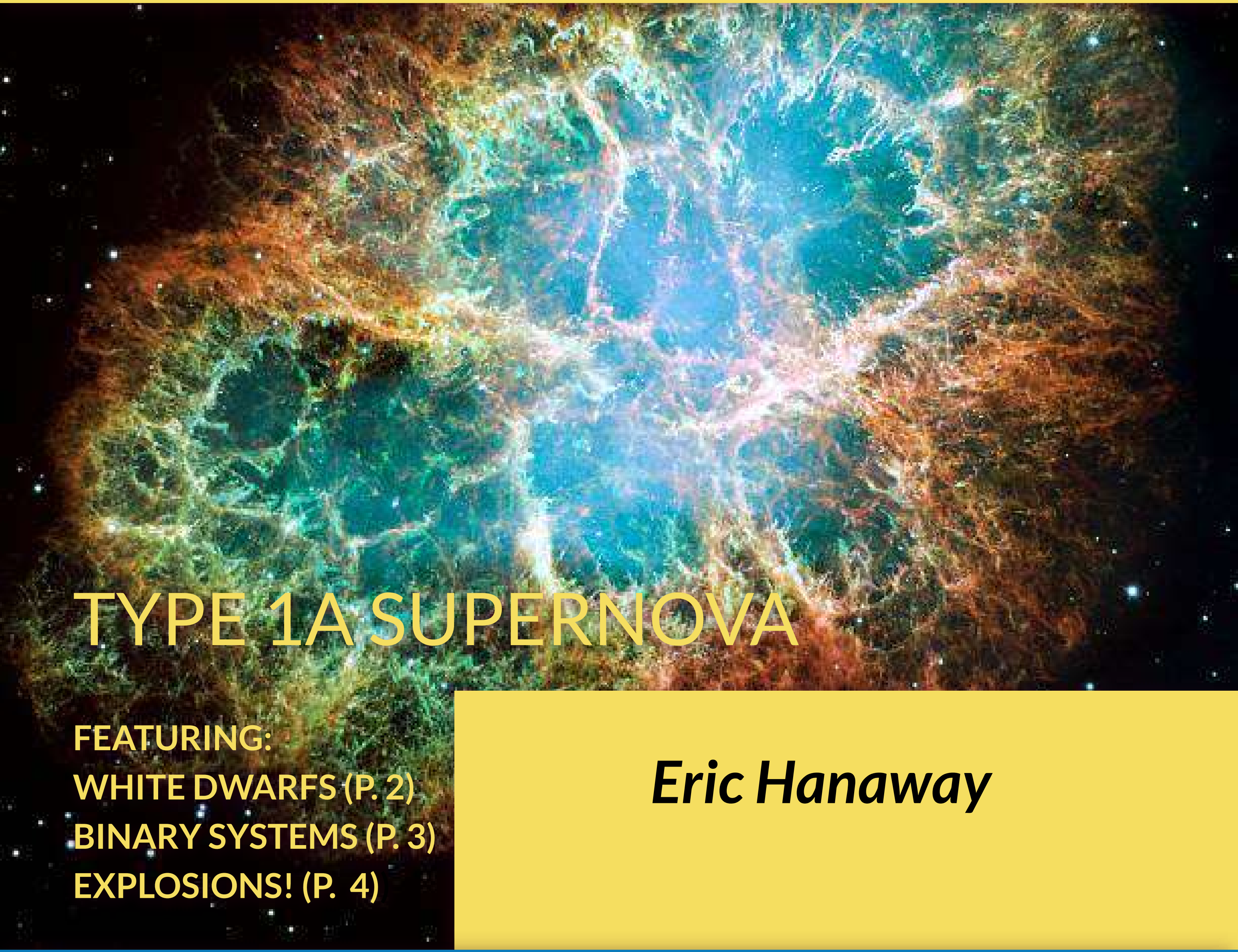
Astro



TYPE 1A SUPERNOVA

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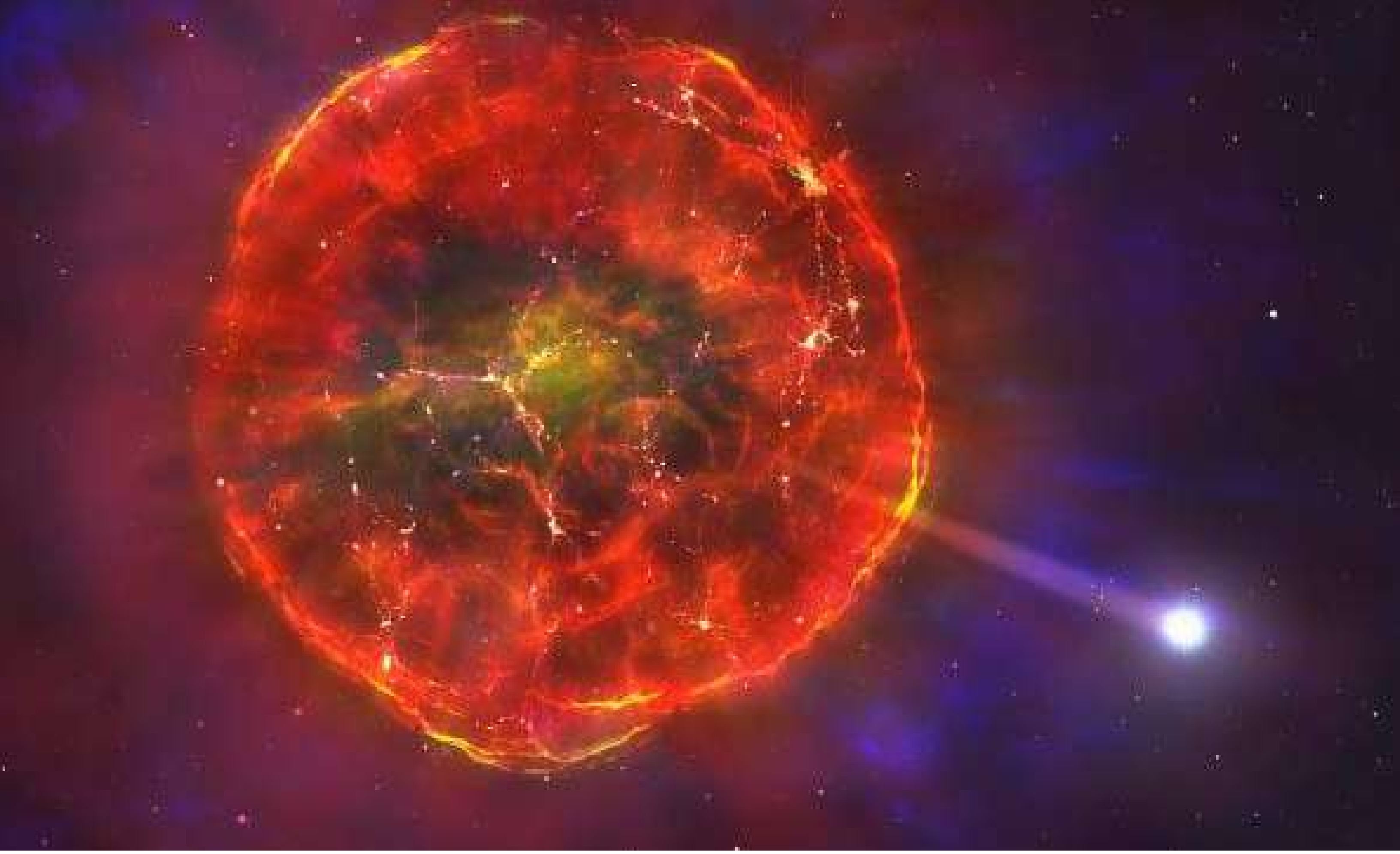
Eric Hanaway



TYPE IA SUPERNOVA

By Eric Hanaway

As a young child, I had an old set of Time-Life books from the 1970s that covered interesting topics of science from rain forests to Earth's frozen poles. My favorite two books from that collection were The Universe and The Desert. I liked to look at the pictures of baron deserts with their stark beauty and, at the same time, hidden dangers. I remember I enjoyed The Universe book for that same reason. The Universe book had pictures of black holes, galaxies, and supernova explosions. At the time, the raw power of stellar explosions really interested me. I never thought I could understand what I was looking at, but I just liked the pictures during that time. Years later, I finally had the opportunity to study one particular type of stellar explosion; the Type Ia supernova (SNIa)!!! I discovered that astronomers use SNIa explosions as interstellar measuring sticks, and cosmologists use them to confirm the speed of light. Also, there are different types of supernovae; for example, a Type II Supernova occurs when a star that is at least eight times the mass of our Sun stops burning its fuel, collapses, then bounces into an explosion. Unlike a Type II Supernova, a Type Ia Supernova is the explosion of a highly dense white dwarf star who stole some mass from a neighbor star.

BUT, WHAT IS A WHITE DWARF?

A white dwarf is the dead nuclear core of an old star that was initially three to ten times more massive than our own Sun (Yoshii, 1996). Long before it turns into a white dwarf, the star expands into a large red giant (RG) as it grows old. After a star burns all of its hydrogen, it begins burning helium while it expands into an RG. When a star's fuel changes, it expands in size. To offer a size comparison of a red giant, in about five billion years, our own Sun will go RG and grow to a larger size than the orbit of Mars (Tillman, 2022)!!! As time evolves for the RG, the future white dwarf slowly sheds its layers, creating a large cloudy planetary nebula. What remains in the center of the planetary nebula is the original star's core. That core is a dense and small in volume white dwarf. With a mass that is approximately equivalent to the mass of the Sun, the volume of a white dwarf is roughly the size of our Earth, making it one of the densest objects in the Universe. Let me back up to make a few clarifications: 1). an object the size of our Earth has more mass than the Sun; 2). in physics, mass can be thought of as an object's weight; 3). as a star's mass increases, so does its gravity. Back to the white dwarf. To compare a white dwarf's density to something here on Earth, if you managed to scoop up one tablespoon of white dwarf material, it would weigh 15 tons (Dunbar, 2022). A white dwarf can not explode on its own; it needs a nearby companion star.

Image of the final stages of a red giant star. The outer layers expanded into a planetary nebula with a white dwarf at the center.

THE UNLUCKY NEIGHBOR

Most stars in the universe orbit with a companion around a common center of mass. The companion could be a large planet that never got massive enough to fuse hydrogen, or the companion could be as large as a red giant star (Scholz, 2022). To help astronomers understand what type of binary system caused the SNIa, they turn to stellar spectroscopy. Stellar Spectroscopy is the study of spectral lines from objects in space.

Stellar spectroscopy is the most essential tool an astronomer has to infer data from their observations. Spectral lines are like astrophysical fingerprints; they tell astronomers what atomic elements are present in a star, nebula, or galaxy (Spectroscopy, 2022). If astronomers observe hydrogen in the spectral lines of an SNIa, they believe the white dwarf's companion was a hydrogen-burning star. If no hydrogen is observed in the SNIa's spectra, the companion star was another white dwarf (Justham, 2011).

If a massive and dense white dwarf has a neighbor whose distance is close enough, it will begin inhaling the companion star's gaseous material; this process is called accretion. Like the hose of a vacuum cleaner, the dense white dwarf sucks up material from its neighbor star (Korreck et al., 2007). However, the accretion rate is generally minimal, usually on the order of .000001 times the Sun's mass per year; that' is about 1000 Jupiters a year (Han, 2006)!

Recall from above that the initial mass of a white dwarf will be approximately equal to our own Sun's mass. However, as the white dwarf's mass increases due to accretion from the neighbor star, it reaches a limit where it explodes. From birth to explosion, the lifespan of the precursor SNIa stars is one to five billion years (Yoshii et al. 1996).

Image of a white dwarf (left) with a companion star (right). Notice the accretion disk surrounding the white dwarf.

THE EXPLOSION

At the end of the accretion process, when a white dwarf’s mass reaches the Chandrasekhar limit of 1.4 times the mass of the Sun, it explodes into an SNIa (Sarmah, 2022). A balloon can be used as an analogy of the Chandrasekhar limit: when you blow into a balloon, it gets larger and larger until it explodes when the rubber stretches to its limit. Much like a balloon, a white dwarf always explodes when its mass reaches the Chandrasekhar limit of 1.4 times the mass of our Sun!!! Having said that, there is some evidence that a white dwarf with a mass that is greater than 1.4 times the Sun can turn into an SNIa, but astronomers believe that could be an effect of the white dwarf's rotation speed at the time of the explosion (Hachisu et al. 2011). In general, however, 1.4 times the mass of the Sun is the widely accepted mass limit.

It should be noted that there is no agreement on what mechanism triggers the explosion, nor is there an agreement on what the explosion looks like. One model says that a single spot ignition begins in a small volume deep inside the star. The thermonuclear runaway that follows "culminates in the explosion of a Chandrasekhar mass white dwarf as a Type Ia supernova begins centuries before the star actually explodes" (Kuhlen et al. 2006). In another model of a single spot ignition, the thermonuclear flame propagates through the dense WD in a fluid motion at roughly sixty-five miles per hour (Hoflich et al., 2002). In another disagreement, the explosion can simultaneously ignite at multiple locations too.

A multi-spot ignition "favors an ignition in multiple sparks distributed around the center or on only one side of it, depending on the large-scale convective flow pattern" (Röpke, 2006). In yet another model, flames will ignite ~150 km off-center, with exponential growth of ignition sources for a few tenths of a second until a runway develops (Woolsey et al. 2004).

Once the ignition process begins, a slow-moving thermonuclear flame makes its way from the center of the white dwarf to the surface in the shape of a cone (Calder et al., 2007). As the flame reaches the lower pressure outer layers and surface, the ash travels entirely around the star. As the ash converges on the other side of the star, compression heats the fuel, and detonation is launched (Seitenzahl et al., 2016). Finally, the white dwarf erupts into SNIa, and takes its neighbor star with it! What’s left is a majestic light show that can be seen throughout the entire observable Universe!

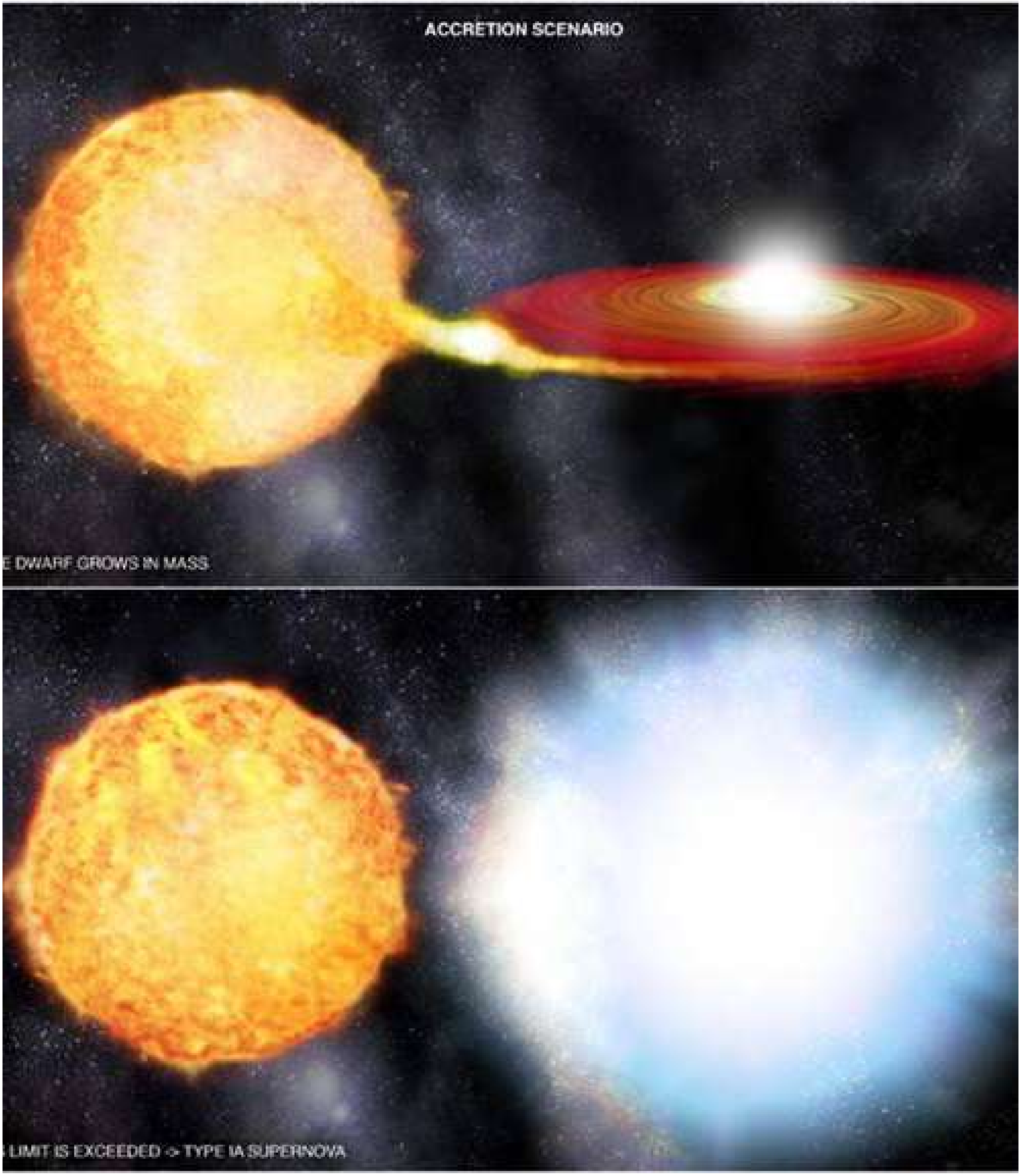


Image of the accretion disk (top) and the explosion (bottom). As a white dwarf accretes mass from its companion star, its mass gets closer to the Chandrasekhar limit of 1.4 times the mass of our Sun. Our own Sun weighs 4.4x10^30 lbs. That's 44 followed by twenty nine zeros. The Chandrasekhar limit is 6.6 x 1-^30 lbs. The explosion that follows can be seen around the observable universe.

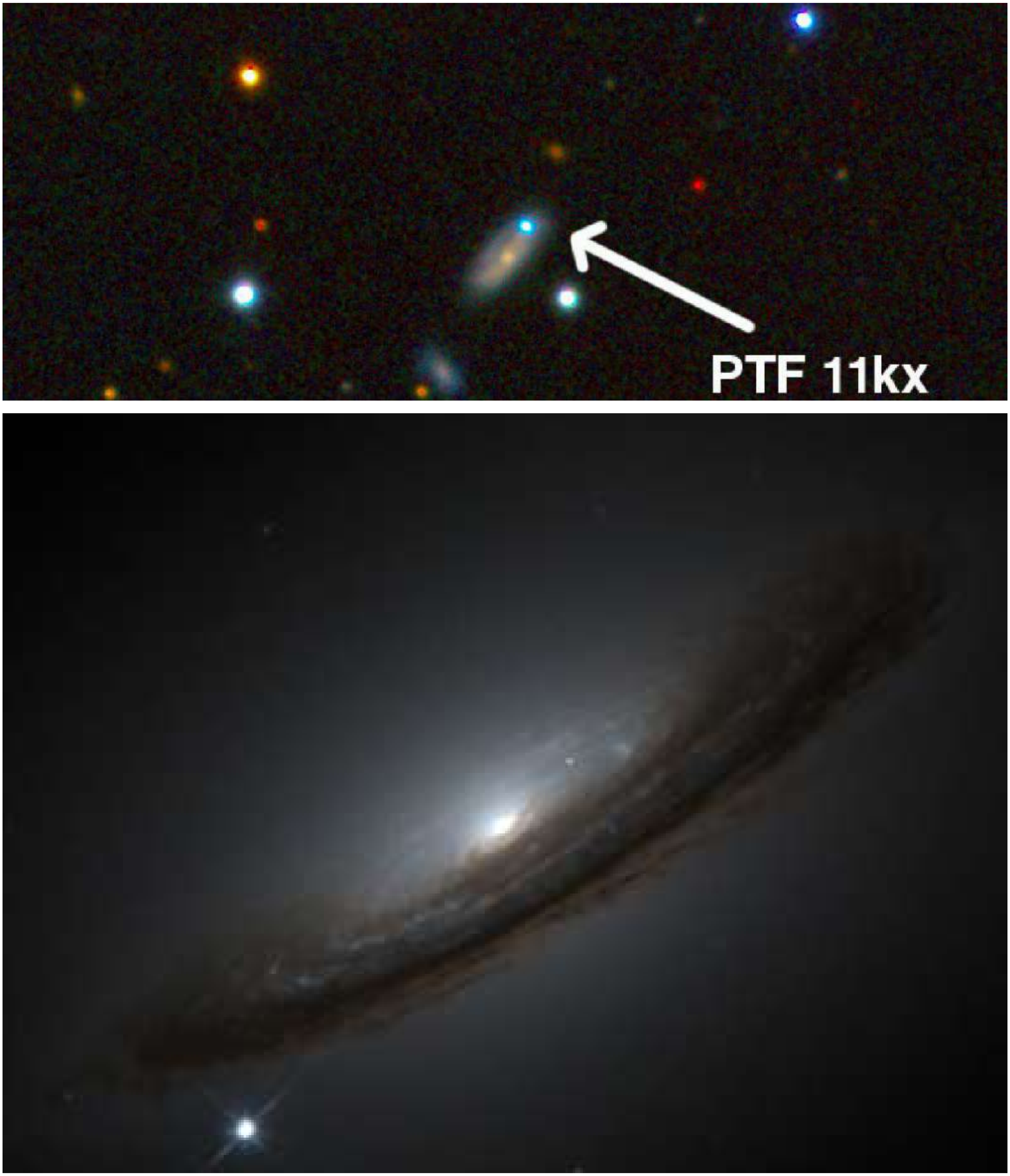


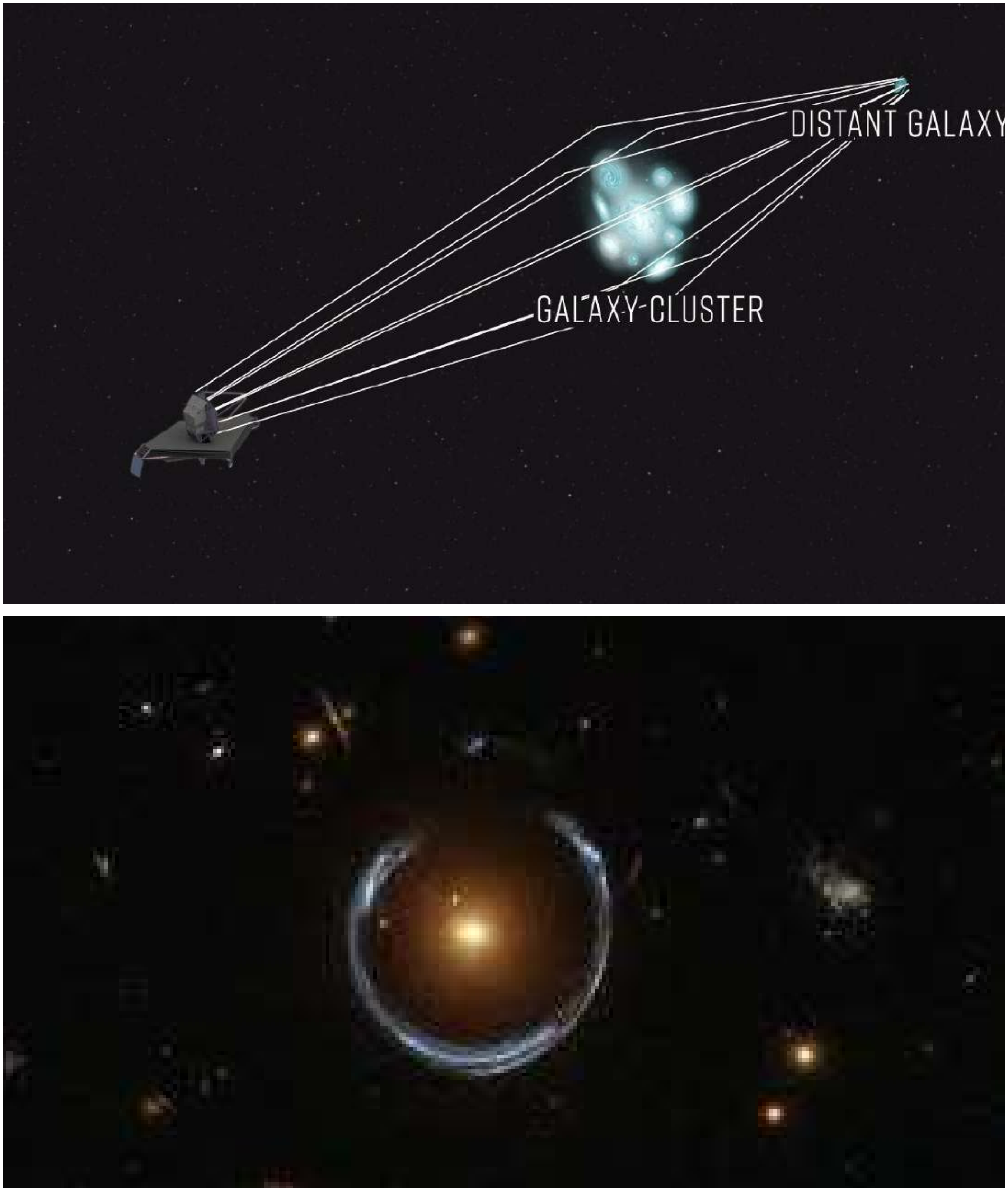
Image of Type ia Supernova PTF 11kx (top) in distant spiral galaxy. Notice that the supernova outshines the entire galaxy. Image of spiral galaxy NGC 4526 (bottom), with a bright supernova just beyond the disk.

WHY DO WE CARE?

Type Ia supernovae play an important role in astrophysics research. UC Davis theoretical physicist, Dr. Andrew Wetzel said, besides their use as standard candles, “they also drive feedback that affects how galaxies form, and they generate heavy elements. For example, SNIa generate most of the iron in the Universe.” In astronomy, one of the astrophysicists' most difficult jobs is determining the distance to the object of interest. Since a white dwarf usually explodes at the same mass limit of 1.4 times the mass of the Sun, the resulting SNIa always shines with the same luminosity (think of the consistency see between 1000 different 100 watt light bulbs). An object that shines with a known luminosity is said to be a *standard candle*. Given a precise luminosity n astronomer can easily calculate the distance with a simple math relation called the distance modulus. UC Davis PhD candidate, Pratik Gandhi said, “on the largest scales, they [SNIa] are often used as standard candles to measure the distances to faraway objects and also measure the expansion rate of the Universe.” Standard candles have been used in many scientific experiments as a test to confirm the speed of light at cosmological distances.

Although in 1676, Danish astronomer Ole Roemer measured the speed of light in a vacuum to be 299,792,458 meters per second, that value has never been confirmed on distant cosmological time scales. When physicists discuss cosmological time scales, they refer to billions of years in the past. When they observe an object that is ten billion light-years away, they are literally looking back in time by ten billion years which is soon after God created the Universe. So the question they want to solve is: was the physics of light speed the same in the early Universe? A proposed experiment to prove the speed of light on cosmological scales will use a "time delay difference in peaking of the luminosity between two gravitationally lensed images of type 1a-supernova" to determine whether the value of the speed of light was the same during different epochs in time (Gupta, 2021). Gravitational lensing is an effect of Albert Einstein’s theory of General Relativity, where a massive galaxy bends light. Suppose a very massive galaxy sits before a second galaxy in our line of sight. In that case, the first galaxy can bend the distant galaxy’s light to make it appear as though the more distant galaxy is a large circle around the closer galaxy. In that case, you may see a galaxy with a large ring around it. Using a relation between time and space, cosmologists may confirm the speed of light on cosmological scales.

Type Ia supernovae are fascinating objects. In fact, in 2011, Saul Perlmutter, Brian Schmidt, and Adam Riess received the Nobel Prize in Physics for their work on SNIa’s standard candle function (Nobel, 2011). SNIa is an area of study that promises many rewards for future researchers



Concept of gravitational lensing (top). As light travels from the galaxy near the right corner, it passes a massive galaxy that bends the light's path before it reaches the observer near the bottom left corner. Image of LRG 3-757 (bottom). The reddish-yellow galaxy in the center bends the light of the galaxy in the background. The distant galaxy looks like a large circle.

FINAL THOUGHTS

When I first looked at those pictures from the Time-Life books, I had no idea I would one day rigorously study them. At the time, I just enjoyed what I was looking at. To share my findings with the reader has been an absolute pleasure. We took a journey through white dwarfs and binary star systems. We learned why Type Ia Supernovae are so important to scientists. We also learned about the explosions of the SNIa. Although the scientific study of Type Ia supernovae is still young, future projects and telescopes will hopefully solidify the science in our lifetimes.

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ABOUT

Eric Hanaway spent 15 years in the real estate industry before turning to an astrophysics track at UC Davis and UC Santa Cruz. With a bachelor in Science, he will graduate in 2022. His passions include writing, astronomy, particle physics, data science and guitar playing. Eric is open to all writing and data science positions.

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