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ORIGIN OF THERMONUCLEAR SUPERNOVA DISCOVERED

Three Louisiana-based astronomers report the solution to a long standing fundamental problem: they have determined that the star system that produced an important (Type Ia) thermonuclear supernova was a closely orbiting pair of white dwarf stars that spiraled in for an explosive collision. For four decades this progenitor problem has been a keystone question for much of astrophysics, and the problem has greatly increased in importance over the last decade, as Type Ia supernovae are now the premier tool for cosmology. Because of this, the latest Decadal Review by the *National Academy of Sciences* has identified the Ia progenitor problem as one of the top nine questions currently facing astronomy. The solution was discovered using images from the *Hubble Space Telescope* of a supernova remnant named SNR 0509-67.5 that show the lack of any possible surviving companion star to the exploding white dwarf, which rejects all possible classes of progenitors except for the close pair of white dwarfs.

Thermonuclear supernovae are tremendous explosions in which the light from the exploding star is often so bright that it outshines all of the other stars in the rest of the galaxy combined. They occur when a white dwarf star reaches a maximum mass, at which point a runaway explosion, much like that which occurs in an H-bomb, is triggered. The progenitor problem, then, is to identify the type of star system that causes the explosion. Many possibilities have been suggested, and all but one of these requires that a companion star near the exploding white dwarf be left behind after the explosion. One way to distinguish between the various progenitor models is to look deep in the center of an old supernova remnant to find (or not find) the ex-companion star.

Early last year, Bradley E. Schaefer and Ashley Pagnotta (two astronomers at Louisiana State University) were preparing a proposal to look deep for any ex-companion stars in the centers of four supernova remnants in the nearby Large Magellanic Cloud galaxy, including SNR 0509-67.5. Then, the January 25 astrophoto on *Astronomy Picture for the Day* (*APOD*) showed that the *Hubble Space Telescope* had just taken the desired image. Immediately, from the *APOD* picture, the center of the supernova shell was measured with a ruler, the allowed region for the ex-companion star was calculated, and the central region was seen to be completely empty of stars. The lack of any possible ex-companion stars contradicts the predictions of all published progenitor models except for one. Within half an hour of seeing the *APOD* picture, it was realized that this was proof that at least this particular Type Ia supernova must have had a progenitor consisting of two white dwarfs (the so called 'double degenerate' model).

Any such result requires extensive data processing and analysis as well as detailed theory calculations before any conclusion can be finalized. When finished, the central region of SNR 0509-67.5 (see Figure on back) was found to be starless to a very deep limit (visual magnitude 26.9). The faintest possible ex-companion star for all models (except the double degenerate) is a factor of 50 times brighter than the observed limit, which rejects all models except for the double degenerate model. The logic here is the same as expressed by Sherlock Holmes (in *The Sign of the Four*) that "when you have eliminated the impossible, whatever remains, however improbable, must be the truth". For SNR 0509-67.5, all but one model has been eliminated as impossible, so the one model remaining must be the truth.

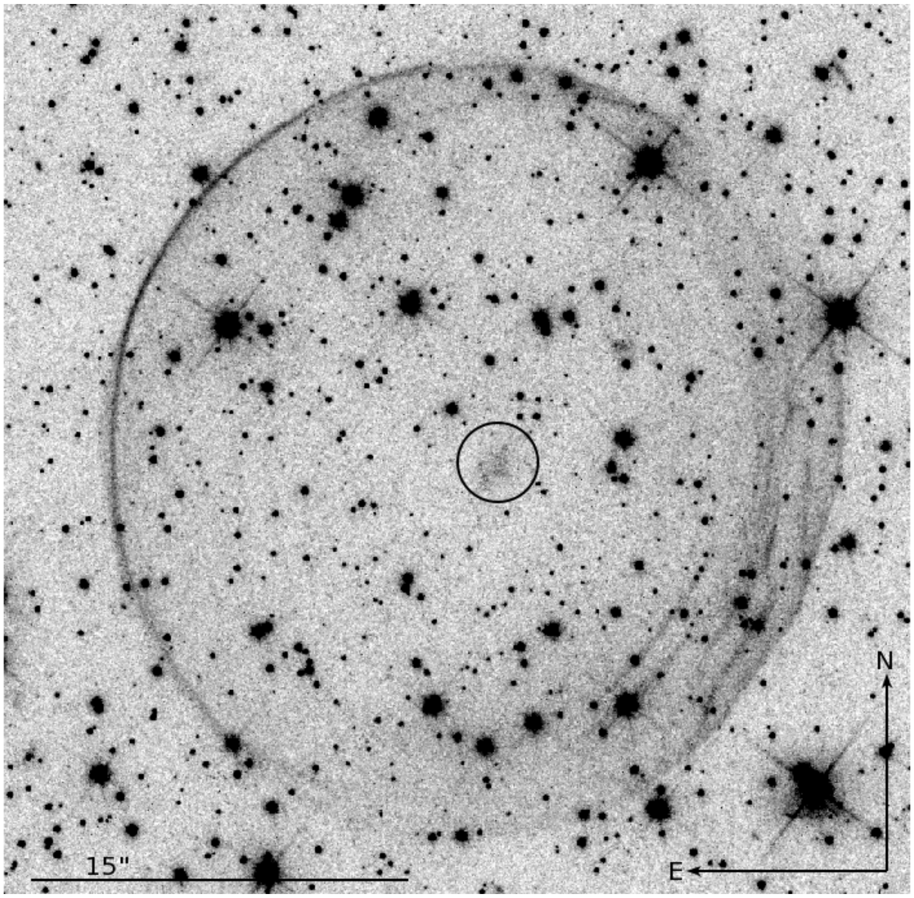

FIGURE: SNR 0509-67.5, the Type Ia supernova remnant in the Large Magellanic Cloud. This image was created using data from the *Hubble Space Telescope* (*HST*). The large, diaphanous ellipse is the now-tenuous gas shell ejected by the supernova 400 (±50) years ago. The circle in the middle marks the site of the explosion, and the size of the circle represents the maximum allowed position for any possible ex-companion star after accounting for its motion over the 400 years since the explosion. The error circle has no stars in it, and the nebulous object is a random far-background galaxy of no connection. The lack of any possible ex-companion stars to deep *HST* limits rejects all single-degenerate progenitors.

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SN 0509-67.5 pictures with and without central circled region in TIFF and JPEG formats
Press release, slides from press conference, plus additional information

For the full Nature paper, go to http://dx.doi.org/10.1038/nature10692

For further information and images, see http://heritage.stsci.edu/2010/27/index.html, http://apod.nasa.gov/apod/ap110125.html, & http://chandra.harvard.edu/photo/2010/snr0509/

BACKGROUND:

Supernovae Supernovae are powerful explosions, in which the explosion of one small star temporarily outshines the entire rest of the galaxy in which is it located. One of the main classes of supernovae, called Type Ia, is the result of a white dwarf star (with a mass comparable to that of our Sun packed into a volume about the size of our Earth) made up mostly of carbon and oxygen that reaches a critical mass limit. The compression ignites runaway thermonuclear burning (as in an H-bomb) that completely destroys the white dwarf. A very long-standing problem of high importance is the question of what type of a system will produce a white dwarf that is pushed over the critical mass.

The Progenitor Problem The possible types of precursor system types (called progenitors) are either a pair of white dwarfs in a close binary orbit that spiral into each other due to gravitational attraction (called the double-degenerate model) or another type of binary where the ordinary companion star in orbit around the white dwarf is feeding material onto the white dwarf until it reaches the critical mass (called the single-degenerate model). For decades the debate has raged, with no decisive evidence, and currently a roughly evenly divided opinion amongst astronomers. In the late 1990s, the stakes of this debate were raised tremendously when astronomers with the Supernova Cosmology Project and the High-Z Supernova Search Team used Type Ia supernovae as distance markers to prove that the expansion of the Universe is accelerating. This is the discovery of what we now call Dark Energy, which was awarded the 2011 Nobel Prize in Physics last month in Stockholm. To improve on this result, astronomers must be able to correct for the change of supernovae as we look to the young Universe, and this requires that we know the Type Ia progenitor system. In the last Decadal Review, a broad overview of astronomy from the National Academy of Sciences, the Type Ia progenitor question was listed as being amongst the top nine most important questions in current astrophysics.

Solving the Mystery One way to distinguish between double-degenerate and single-degenerate models is to look for the leftover ex-companion star that might have been near the exploding white dwarf. If the progenitor was a single-degenerate, then there must be a largely-intact ex-companion still visible near the center of the expanding shell of gas, known as the supernova remnant, ejected from the explosion. If the progenitor was a double-degenerate, then there will be no ex-companion. This idea was first proposed and applied by Pilar Ruiz-Lapuente (Universidad de Barcelona) and coworkers in 2004 for the remnant of the 1572 supernova of Tycho. She identified a star near the center of the remnant that apparently has unusual properties as the ex-companion. If correct, then this supernova would have had a single-degenerate progenitor. Unfortunately, a variety of technical issues have arisen, so this case is currently unresolved. Nevertheless, the basic idea is sound, and this served as inspiration for applying the same method to supernova remnants in the nearby galaxy called the Large Magellanic Cloud.

A Brief History of SNR 0509-67.5 The supernova remnant SNR 0509-67.5 is from a Type Ia supernova that exploded roughly 400 years ago (±50 years). It is confidently known to be a Type Ia event because Armin Rest (Harvard University) and coworkers have identified a light echo (light from the original explosion reflected off dust near the line of sight) such that they can get a spectrum of the supernova at peak light. This remnant appears as a nice symmetric shell for which the geometric center can be accurately determined. These properties make SNR 0509-67.5 the perfect case for searching for any ex-companions. That is, we are certain that the original supernova was Type Ia, the fairly low age means that the ex-companion must be close to the center, and the symmetrical supernova remnant means that its geometric center can be accurately determined. The location in the LMC means that we know the distance (and hence luminosity) of all stars, while the dust reddening and star crowding are low. In all, SNR 0509-67.5 is perfect.

FURTHER DETAILS:

As with all science results, we must consider alternatives and loopholes to the basic conclusion. One possibility is that a theorist will come up with a new model that is still consistent with the lack of any ex-companion stars to deep limits. But many theorists have worked hard for decades to consider all possibilities, so some alternative seems very unlikely. A possible loophole is that there might be *two* classes of progenitors. If so, then the strong result for SNR 0509-67.5 provides the solution for only *one* of the two progenitor classes. Even in this case, the SNR 0509-67.5 result is still a great advance because it solves half of a fundamental problem with no prior decisive answer.

For confirmation and for sampling any supposed second progenitor population, further supernova remnants can be tested for ex-companion stars in the center. For this, the Large Magellanic Cloud has three other remnants that are certainly of Type Ia. Schaefer & Pagnotta were joined at Louisiana State University by undergraduate Zachary Edwards (Columbus State University) for a summer research program aimed at performing a search for any ex-companion star within the second remnant. SNR 0519-69.0 is the result of a Type Ia supernova that occurred 600 (±200) years ago. Fortunately, archival *HST* images were also available for this remnant. Unfortunately, the allowed region for the ex-companion was substantially larger (than in the SNR 0509-67.5 case) and the star field is more crowded, so the search is not decisive. Nevertheless, there are no red giant or subgiant stars in the central region, and this forces the elimination of all but two progenitor models. So the supernova leading to SNR 0519-69.0 must have come from either a double-degenerate system or a supersoft X-ray binary.

Ashley Pagnotta is reporting preliminary results for the last two Type Ia supernova remnants in the Large Magellanic Cloud. She finds that these two have sufficiently large central regions and relatively high crowding of background stars that both contain red giants, subgiant, and massive main sequence stars, so that all progenitors are allowed. This null-result might be changed with upcoming spectroscopy of the central stars, with such spectroscopy currently scheduled with the Gemini telescope in Chile.

With the confident identification of the progenitor system for SNR 0509-67.5 plus the results from the other remnants, a strong case can be made that the progenitor mystery is solved.

ACKNOWLEDGMENTS:

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The *Hubble Space Telescope* and the *Hubble Heritage Program* took the images that formed the basis of the work being reported. The images were taken under programs with Principal Investigators Keith Noll and John P. Hughes.

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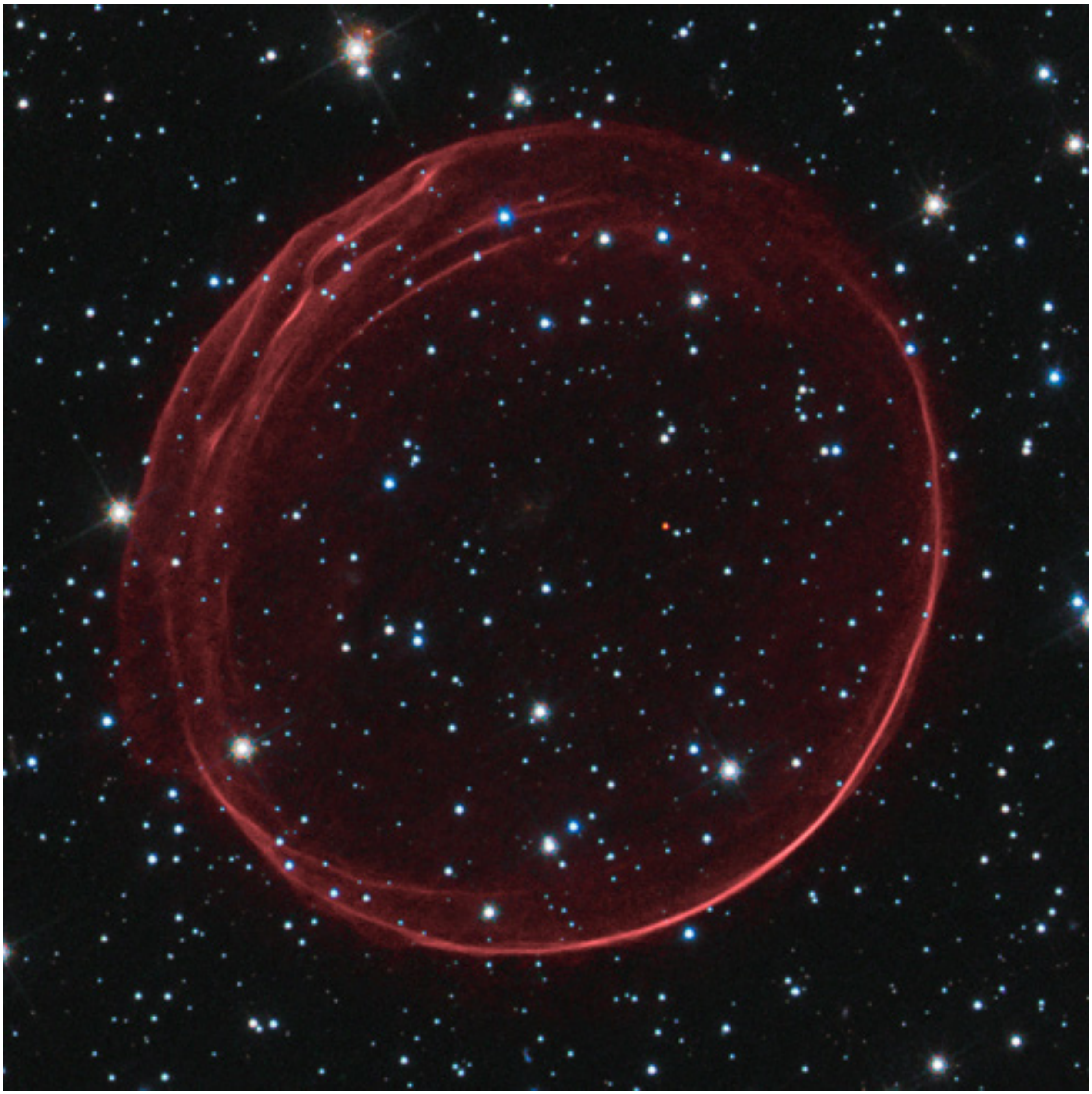
SNR 0509-67.5: Hubble Heritage image, see http://heritage.stsci.edu/2010/27/index.html . This image is in the public domain. Photo credit to the Hubble Heritage Project.

The point of this image is that the central region of this supernova remnant is empty of stars, so the original supernova system (i.e., the progenitor of the Type Ia supernova) cannot be any of the so-called single-degenerate models, while this rules out all but one possible progenitor so that we know that this one supernova must have come from a double-degenerate system. In this image, the stars appear as white dots on the black sky, while the diaphanous elliptical ring is the gas ejected by the supernova eruption close to 400 years ago.



SNR 0509-67.5: Chandra X-ray image on the Hubble Space Telescope optical image, see http://chandra.harvard.edu/photo/2010/snr0509/ . This image is in the public domain. Photo credit to the X-ray: NASA/CXC/SAO/J.Hughes et al, Optical: NASA/ESA/Hubble Heritage Team (STScI/AURA). The blue nebula throughout is the X-ray light from the hot gas in the supernova remnant.