



Photo by Ashley Pagnotta

I am a PhD student at LSU, currently finishing up my thesis and planning to graduate May 2012. I did my undergrad work in physics and mathematics at Texas A&M University. I have been interested in space and astronomy for as long as I can remember, an interest that was fueled by growing up just an hour from NASA's Johnson Space Center. I work with Brad Schaefer at LSU, and my research focuses on various types of exploding white dwarfs—novae, recurrent novae, and Type Ia supernovae—and the connection between all of them. I am a classic observer, and I love nothing more than long, clear nights at a telescope. In my elusive spare time, I am an avid knitter.

The supernova remnant project described here has been very exciting and full of new experiences for me. My colleagues and I used data from three different Hubble instruments to definitively identify the progenitor of a Type Ia supernova for the first time!

"Astronomy Picture of the Day" Leads to a Research Breakthrough

by Ashley Pagnotta, Louisiana State University

This is the first time anyone has been able to definitively identify the progenitor of a Type Ia supernova.

Type Ia supernovae have been in the news quite a lot lately. Caused by the thermonuclear explosion of a carbon-oxygen white dwarf that has reached the Chandrasekhar mass limit (1.4 times the mass of the sun, i.e., $M_{\text{Ch}} = 1.4 M_{\text{sol}}$), these supernovae provide the best cosmological distance measurements in modern astronomy because of the supposedly identical nature of their explosions. Observations of Ia supernovae provided the crucial datasets that were used by two teams in the late 1990s to discover the acceleration of the expansion of the universe, which has been attributed to the mysterious dark energy. But despite the broad importance of Ia supernovae, astronomers are still not entirely

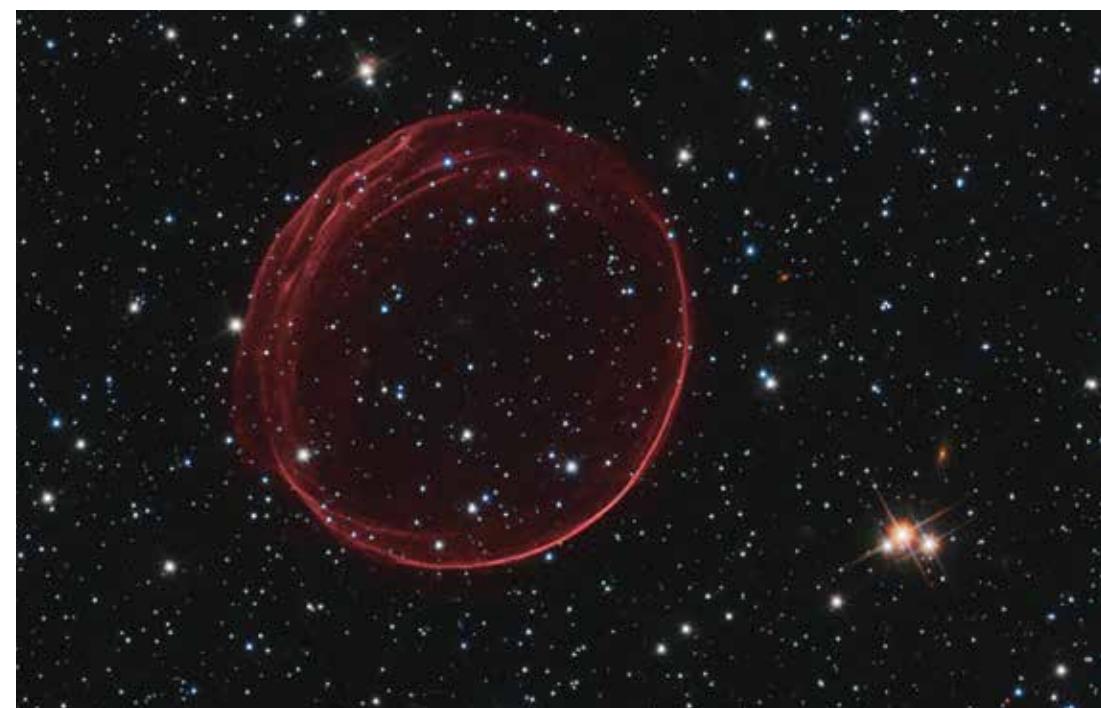
sure what causes them.

At this point in the supernova cosmology game, the systematic uncertainties are larger than the statistical (measurement) uncertainties. While it is important to continue to observe Ia explosions, especially as we are able to push to higher and higher redshifts (distances), the biggest challenge to the upcoming "era of precision cosmology" is the high systematic uncertainty, caused in part by a lack of knowledge about the Ia progenitors. If the progenitor systems change with, for example, delay time (the time between local star formation and the first of the supernovae), the luminosity of the explosions can be affected. Once astronomers are able to quantify this progenitor evolu-

tion, the cosmological measurements that depend on supernova observations can be improved.

There are two main possible progenitor subclasses, double degenerates and single degenerates. Double degenerates consist of two white dwarfs in a tight binary orbit, while single degenerates consist of a white dwarf and a nondegenerate companion star such as a red giant. In either case, interaction with the companion causes the primary white dwarf to reach the Chandrasekhar limit and explode.

One way to identify the progenitor of a given Ia supernova is to look near the site of the explosion many years later and see if anything is "left over" from the explosion. Supernova remnants (SNRs), beautiful



The Astronomy Picture of the Day on January 25th, 2011, The Rippled Red Ribbons of SNR 0509. Image Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA); Acknowledgment: J. Hughes (Rutgers Univ.).

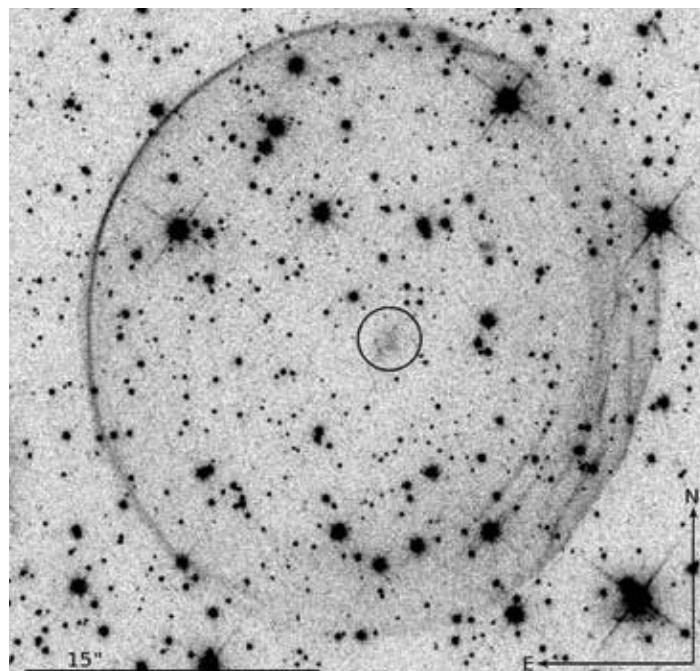
bubbles of expanding gas from the explosion, can be used to locate the site of nearby supernovae that happened anywhere from a few centuries to a few millennia ago. If the progenitor system of that particular supernova was a single degenerate, the nondegenerate star will be left behind, now an ex-companion, and will be near the center of the remnant, looking mostly unchanged. The first group to go treasure hunting for ex-companions was led by Pilar Ruiz-Lapuente, who looked at the Tycho supernova remnant in our galaxy. They found a subgiant star near the center that appears to show signs of being the ex-companion, but unfortunately, the observations are not conclusive and have been much debated over the past several years.

My research group decided to use the same method in the Large Magellanic Cloud (LMC), one of the satellite galaxies of our Milky Way. We began preparing to write observing proposals, gathering information about the targets and the instruments we wanted to use. One step we had not yet gotten to was checking the public archives to see what was already available. On the morning of January 25, 2011, during the usual morning survey of arXiv, science blogs, etc., we pulled up the Astronomy Picture of the Day (APOD) and saw an absolutely gorgeous multiwavelength image of one of our targets, SNR 0509-67.5. The picture was a combination of H α images taken by PI John P. Hughes of Rutgers University to measure the proper motion and shock velocities of the remnant and BVI images taken by the Hubble Heritage Team (PI Keith Noll) for outreach use, which had just been made public the previous month. Combined, they provided exactly what we needed to investigate this remnant. In fact, with a printout of the APOD

and a ruler, within 30 minutes we had already obtained the answer to zeroth order—there are no stars near the center of SNR 0509-67.5, which argues strongly against all single-degenerate progenitors.

Of course, a ruler and a printout do not provide quite enough proof, so we immediately downloaded the raw data from the Hubble archive and set to work finding the center of the remnant. Averaging together the centers from three independent methods gave a final geometric center, but for this remnant, the geometric center and the supernova explosion site are not in the same exact location. Although the remnant is nearly symmetric, it is not perfectly so. The shell is a bit "squished" in the southwest direction, as evidenced by radius measurements as well as the apparent pileup of the shell material in that direction, which can be seen in H α . The cause of this deformation is evident when looking at the remnant in the infrared: Spitzer 24 μm images (Borkowski et al., 2006) show excess emission in that quadrant, which must be caused by pre-existing dust. Since we had measured the amount of deformation in the remnant shell and knew the direction in which it occurred, we could calculate an offset from the geometric center of the remnant back to the actual explosion site.

Around the explosion site we constructed a central region in which any possible ex-companion must be located. This region accounts for three things: uncertainty on the measurement of the explosion site, the orbital velocity of the ex-companion star (it was previously in a tight binary orbit with the white dwarf, and therefore can be moving at up to 390 km/s, depending on the type of star), and kicks due to the supernova explosion itself. Within this region, which is



A black and white image of SNR 0509-67.5 to which a circle has been added to show the region that must contain the ex-companion star. Image Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA); Acknowledgment: J. Hughes (Rutgers Univ.).

designed for maximal (99.73%, or 3σ) containment, there are no point sources, which means no stars down to the limiting magnitude of the image. Since these are good Hubble images, the limiting magnitude is very deep, $V = 26.9$, which corresponds to an absolute magnitude of $M_v = 8.4$ in the LMC. If we look at all of the currently published models for single-degenerate progenitors, the faintest of the possible ex-companions would be $V = 22.7$, nearly four magnitudes brighter than our limit and therefore easily visible if there. From this we conclude that we can eliminate all single-degenerate models and are therefore left with the double-degenerate model as the only possible progenitor for SNR 0509-67.5.

This is the first time anyone has been able to definitively identify the progenitor of a Type Ia supernova, but it is important to note that this is only for one particular system. If it were true that all Ia supernovae came from the same type of progenitor, then we could

extend this conclusion to the entire population, but a number of different avenues of research indicate that there could be multiple progenitor channels. We are applying this method to other nearby Ia remnants, all of which have possible single-degenerate ex-companion stars in their central regions, to see what we find. As is often the case in astronomy, the key to understanding what is really going on is to keep looking, and see what more observations tell us. ●

For more information on this project, see a Nature article authored by Ashley and her advisor at www.nature.com/nature/journal/v481/n7380/full/nature10692.html (subscription required); a related paper published in The Astrophysical Journal Letters, coauthored by an undergraduate student who Ashley mentored at <http://iopscience.iop.org/2041-8205/747/2/L19/>, and a press release and images at www.phys.lsu.edu/SNprogenitor/.