the WINNOWER

PHYSICS

Type 1a: The Other Type of Supernova

JONAH MILLER

CORRESPONDENCE:
jonah.maxwell.miller@gmail.com

DATE RECEIVED:
February 22, 2016

FIGURE 1. FOR JUST A MOMENT, A TYPE 1A SUPERNOVA (BRIGHT SPOT IN THE LOWER LEFT) OUTSHINES AN ENTIRE GALAXY. (IMAGE DUE TO THE HUBBLE SPACE TELESCOPE . COPYRIGHT OWNED BY NASA AND THE ESA.)

When people hear “supernova” they usually think of a star that runs out of fuel. Without the engine of nuclear fusion to heat it, the star collapses under its own weight, which triggers a huge explosion. This is a “core-collapse supernova,” one of the most energetic events in the universe. The result is usually a neutron star or a black hole.

However, there's another type of supernova, one in which a star whose nuclear fires long ago petered out is reignited, causing a catastrophic explosion. This is the type Ia supernova. We start our story with the type of star that explodes: the white dwarf.

WHITE DWARFS

A star is a balancing act. On the one hand, these massive objects exert an enormous gravitational pull on themselves, driving all the gas to collapse towards the centre of the star. On the other hand, the nuclear fusion reaction at the core of the star heats it up, and hot gas likes to expand, holding the star apart. Paradoxically, the driver of this nuclear reaction is the gravitational pull of the star itself. The weight of the star pushes the stuff in the core together so much that the atoms fuse together, releasing huge amounts of energy.

(Surprisingly, stars need quantum mechanics to burn. When atoms fuse together in a star, the fusion only occurs because the atoms quantum tunnel together. Astrophysicist Brian Koberlein has a nice article on this.)

The eventual fate of a main sequence star like our sun depends on its mass. If the star is more than about 1.4 times the mass of our sun (this is called the Chandrasekhar limit) then, once the nuclear reaction stops, the star collapses under its own weight, triggering a core-collapse supernova explosion. However, if the star is less massive, something amazing happens: the star collapses down to a *tiny fraction of its original size*–a white dwarf star might have a radius only 4 times or so larger than that of the Earth–but it doesn't explode. Now the star isn't held up by heat or nuclear fusion. It's held up by a quantum-mechanical effect called Pauli exclusion principle.

Basically, a white dwarf is a hot, ultradense fluid made of electrons and atomic nuclei, packed together so tightly that the only thing holding them apart is their inability to occupy the same physical space. This means white dwarfs are incredibly dense. A tablespoon white dwarf starstuff would weigh about 100 *tonnes*. **Figure 2** shows a white dwarf star next to a larger type A main sequence star on the left and our sun on the right. Keep in mind: that tiny little white dwarf star *has the same amount of mass as our sun.*

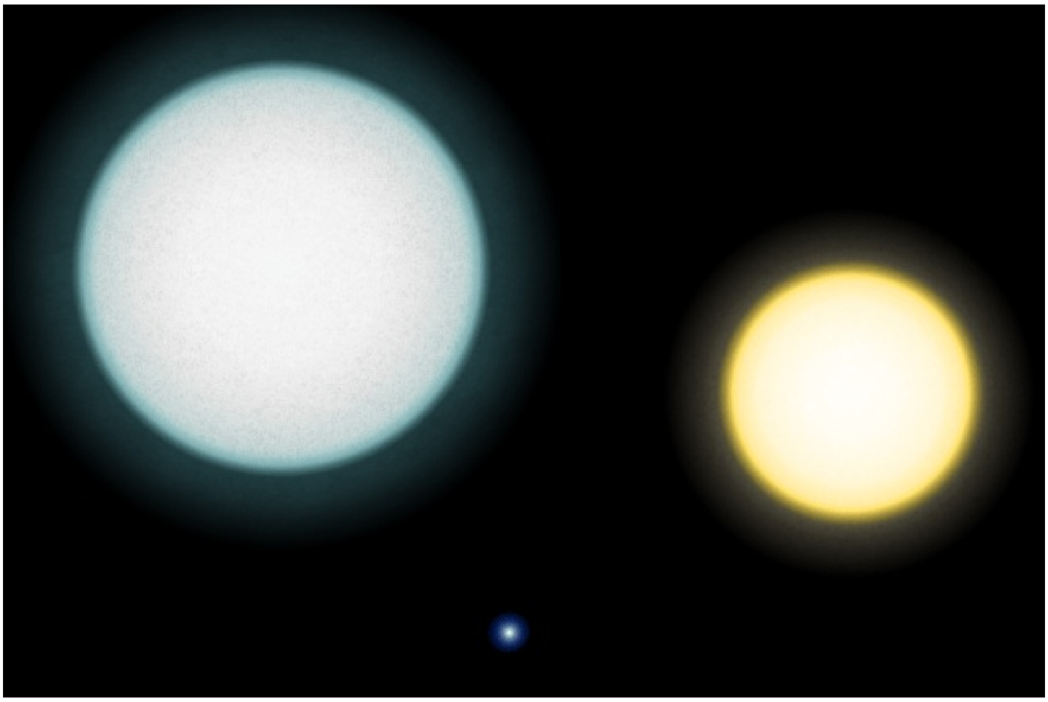


FIGURE 2. THE SIZE OF A WHITE DWARF STAR (CENTER) NEXT TO A TYPE A MAIN SEQUENCE STAR (LEFT) AND OUR SUN (RIGHT). (IMAGE DUE TO RJHALL ON WIKIMEDIA COMMONS.)

(Neutron stars are very much like white dwarfs, and they are held apart by similar principles. However neutron stars are, unsurprisingly, made mostly of neutrons, and can be about ten times denser and smaller than white dwarfs.)

But sometimes, a white dwarf can reignite. And the results are explosive.

REIGNITION

The nuclear fires of a white dwarf have died down. But these fires were first produced by intense pressure. So if the pressure in the core of the white dwarf is ever high enough, then the carbon atoms in the core of the star will start fusing and, temporarily, the nuclear furnace will reignite. **Figure 3** shows a computer simulation of the beginning of this process. The core of the star becomes hot due to nuclear fusion and this spreads across the star.

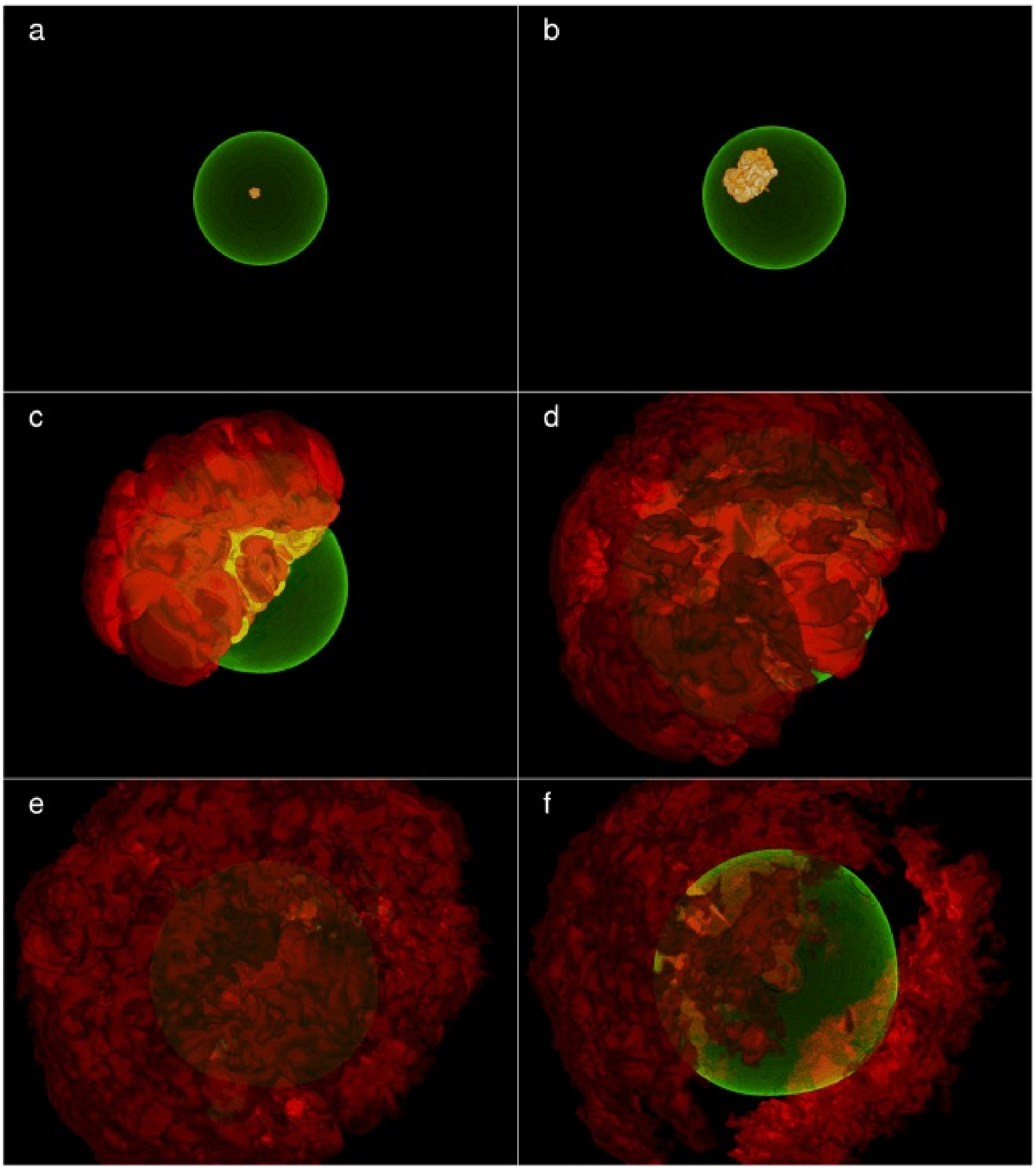


FIGURE 3. SNAPSHOTS OF A COMPUTER SIMULATION OF THE FIRST PART OF A WHITE DWARF REIGNITING. TIME FLOWS SEQUENTIALLY FROM FRAME A TO FRAME F. THE COLOR SHOWS TEMPERATURE RANGING FROM ONE TO FIVE TRILLION DEGREES. IMAGE DUE TO G.C. JORDAN ET AL.

The end results of stellar nuclear fusion are carbon and oxygen. So a white dwarf is made up of carbon and oxygen nuclei… and as we know, oxygen reactions are what make fire. So once the nuclear fires reignite, the star doesn't just become hotter or expand. The entire star literally *burns.* That's what **figure 3** is showing. The bright orange stuff in the images is actually ash.

ROCKET STAR

Although the fusion reaction ignites the star, it doesn't produce enough energy to make the star explode completely. Instead, all of the fire that spread across the star eventually concentrates on one *side* of the star in a concentrated burst, which can accelerate the star up to *thousands* of kilometres per second like a rocket. Stars moving this fast are, awesomely, called hypervelocity stars. **Figure 4** shows the next part of the simulation in **figure 3**, where now one side of the star explodes in a pulse.

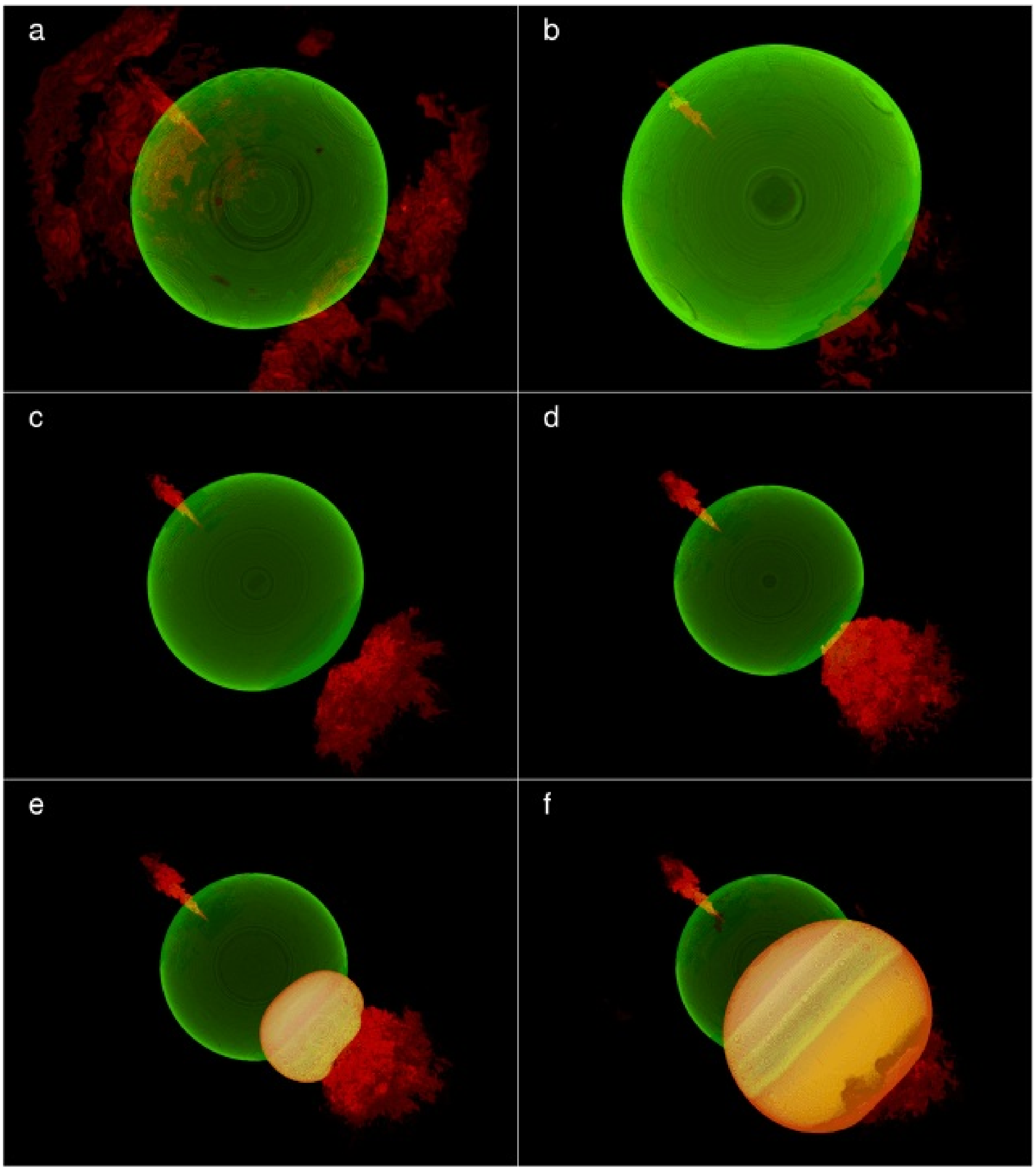


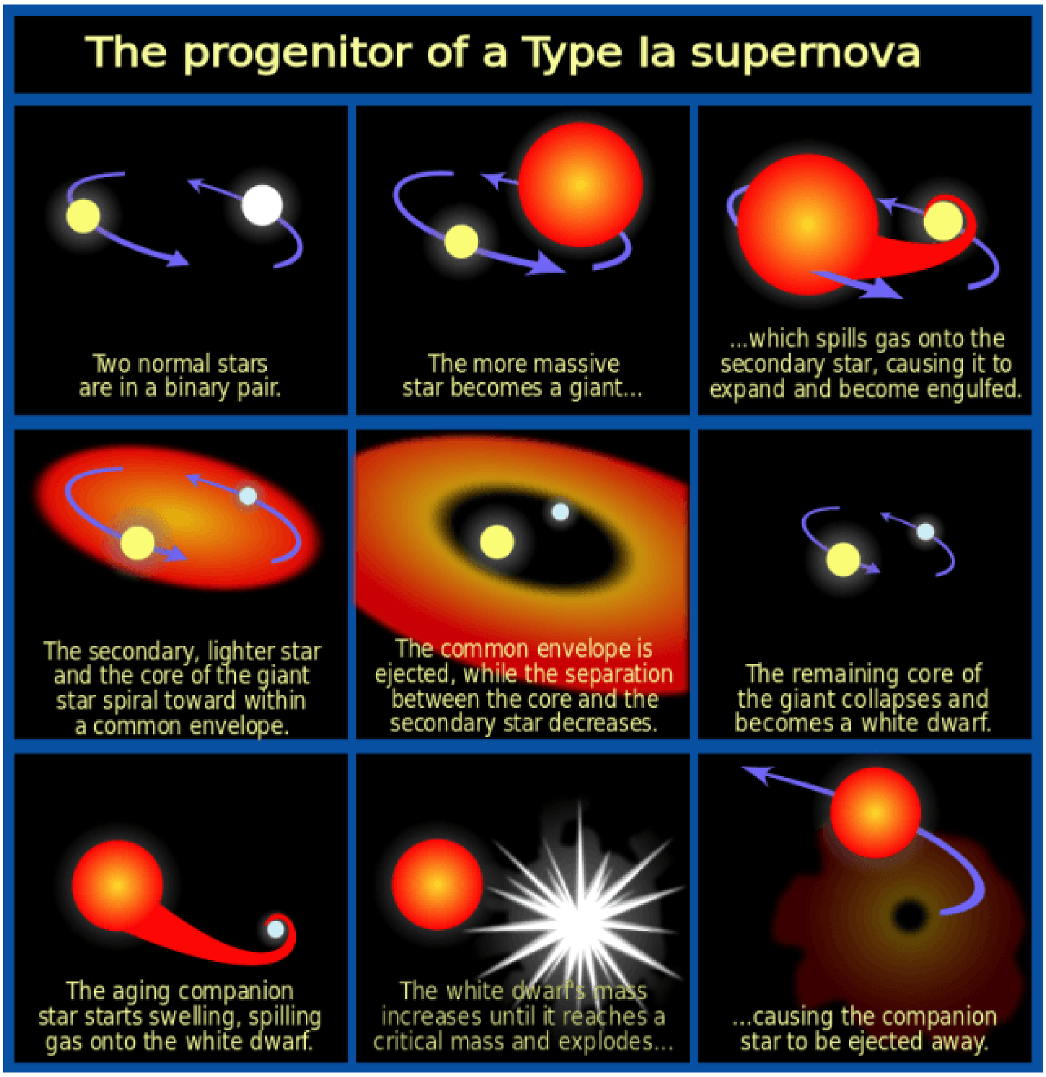
FIGURE 4. THE REST OF THE SIMULATIONS SHOWN IN FIGURE 3. THE FLAMES THAT SPREAD OVER THE WHOLE STAR CONVERGE AND FORM AN ASYMMETRIC JET ON ONE SIDE OF THE STAR. THE TEMPERATURE SCALE IS THE SAME AS BEFORE. IMAGE DUE TO G.C. JORDAN ET AL.

After the burning in **figure 3** and the explosion in **figure 4**, things calm down. The nuclear fusion in the star stops, and it returns to normal… albeit with a very different velocity.

BEFORE THE EXPLOSION

So now I've described how the star explodes… but I still haven't told you *why* it explodes. I said that if the pressure in the core of the star becomes high enough, it can re-ignite. But how does that happen? Quite simply, the star has to put on weight. Usually, this means that the white dwarf in question has a companion star–another star nearby such that the two stars orbit each other. And over time, the white dwarf steals material from the companion until it gains enough mass that the weight of the star on the core causes it to reignite.

It's not known what type of star the companion must be. One possibility is that it must be a massive star near the end of its life. **Figure 5** shows the stellar evolution process that might result in a white dwarf stealing from a massive companion. Another possibility is that two white dwarfs might collide. Distinguishing between these models, or perhaps some combination of the two, and identifying which stars will become supernovae is a long-standing problem in astrophysics.



THE STELLAR EVOLUTION PROCESS THAT MIGHT RESULT IN A WHITE DWARF STEALING STARSTUFF FROM A LARGE COMPANION. IMAGE CREDIT DUE TO NASA, ESA, AND A. FIELD.

DIFFERENT MODELS AND THE IGNITION PROBLEM

It is worth noting that the precise mechanism by which the nuclear fusion restarts in the star is not completely known. There are also a number of models that describe the details of the supernova explosion. The simulation I showed is one such model, but there are others. However, all models are qualitatively the same and they all produce predictions that match the supernovae we observe in the sky.

FURTHER READING

As we've learned, core-collapse supernovae are not the only kind of supernovae. Indeed, the study of white dwarfs and type 1a supernovae is an active field of research with a rich history. Here I include some resources for your reading enjoyment.

- Measurements of type 1a supernovae were used to measure the accelerated expansion of the universe. I wrote about this in my article on the expanding universe.
- Imagine the Universe! by NASA has a great article on white dwarfs with some cool pictures.

- Universe Today has a nice article on the Chandrasekhar limit, which defines how massive a white dwarf can be before it collapses into a black hole.
- For the experts, this is the simulation by Jordan et al. that I showed you above.
- This is is a review article of various models of type 1a supernova explosions.
- And this is a review article on the physics of white dwarf stars.
- Finally, this is a review of the supernova progenitor problem.

RELATED READING

If you enjoyed this post, you might enjoy some of my other posts on astrophysics.

- In this post, I discuss how planets are formed.
- In this post, I describe simulations of what happens when a black hole eats a neutron star.
- In this post, I describe one speculative idea that says black holes can explode.