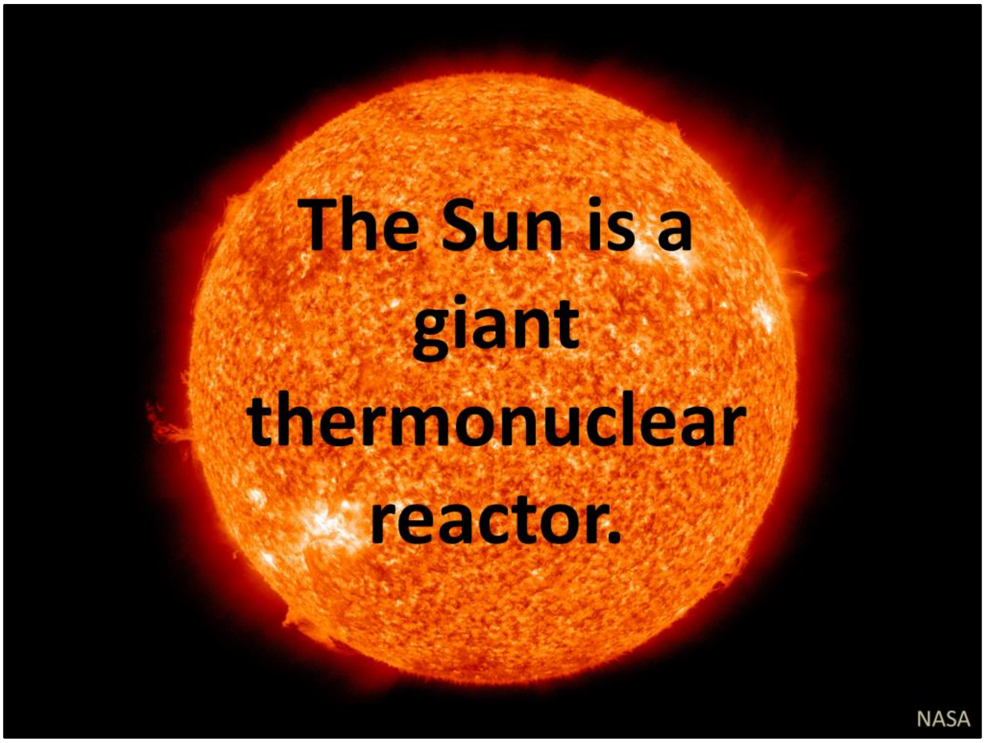
Where does carbon come from?

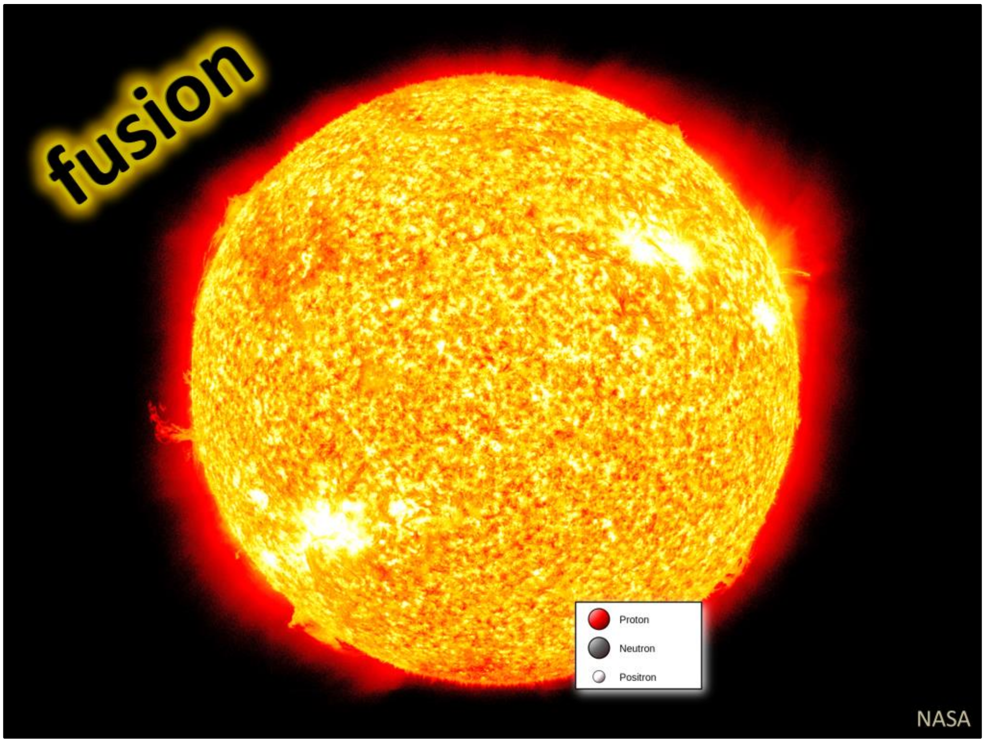
Where does carbon come from, ultimately? Since we are focused on the geological and biological cycling of this important element, we might as well take a few moments to consider where it all came from in the first place, and how it got to Earth.

This brief presentation covers thermonuclear fusion in the Sun (and other stars). There are 14 slides in this PowerPoint (image heavy, with notes for instructor included). Time estimate: 6.5 minutes. A video version of the mini-lecture has been created and is available free online at http://vimeo.com/85844716 (6 minutes & 26 seconds long).



The sun is a giant thermonuclear fusion reactor. The sun gives off energy (light) because that energy is the “leftovers” as the Sun fuses together small atoms like hydrogen and helium to make bigger atoms, like oxygen or carbon.

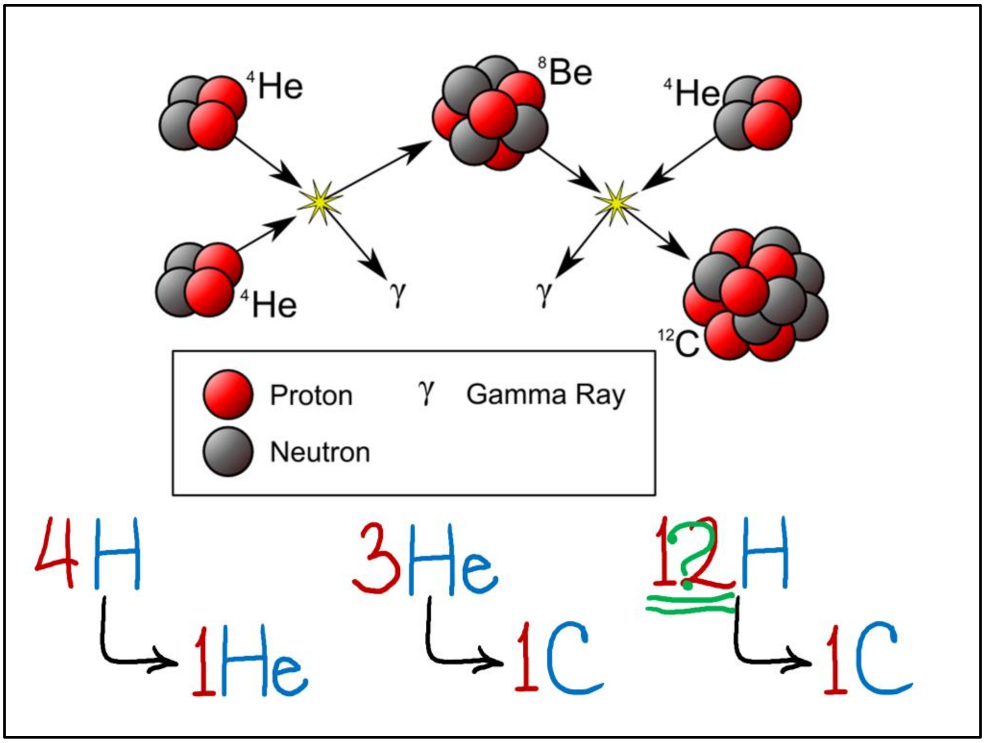
Credit: NASA, Image source: https://solarsystem.nasa.gov/multimedia/gallery/PIA03149.jpg, accessed: 8/1/2014



The most basic kind of fusion in the Sun takes hydrogen atoms (H) and fuses them together into helium atoms (He). We need Helium-4 in order to make carbon. So let's make some Helium-4.

This slide will animate with successive mouse clicks, revealing the steps by which ^{4}He is made. It takes 4 hydrogen atoms to make 1 atom of ^{4}He.

Credit: NASA, Image source: https://solarsystem.nasa.gov/multimedia/gallery/PIA03149.jpg, accessed: 8/1/2014



Helium atoms can get fused together to make carbon atoms. It takes 4 hydrogen atoms to make one helium-4 atom. It takes 3 helium atoms to make one carbon atom. Therefore, students, do the math: How many hydrogen atoms are needed to make a single carbon atom? (Answer = 12, revealed onscreen with a click).

Bottom line: in the ultimate sense, over the timescale of the universe, carbon-12 is 12 hydrogen atoms compressed into one.

Credit: Borb (via Wikimedia Commons), Image source: http://en.wikipedia.org/wiki/File:Triple-Alpha_Process.png, accessed: 8/1/2014

fusion

$$^{1}H + {}^{1}H + {}^{1}H + {}^{1}H \rightarrow {}^{4}He$$

$$^{4}He + {}^{4}He \rightarrow {}^{8}Be$$

$$^{8}Be + {}^{4}He \rightarrow {}^{12}C$$

A review, in three steps: 4 hydrogens make one helium-4; two helium-4’s make one beryllium-8; and one more helium-4 can be fused with the beryllium-8 to make an atom of carbon-12.

How did carbon get to Earth?

Guiding question for the next section, on the relationship between Earth's carbon and a pre-existing (long since supernovaed) star: so carbon is made through nuclear fusion reactions in stars. But we're on a planet, not a star. So where did Earth get its carbon?

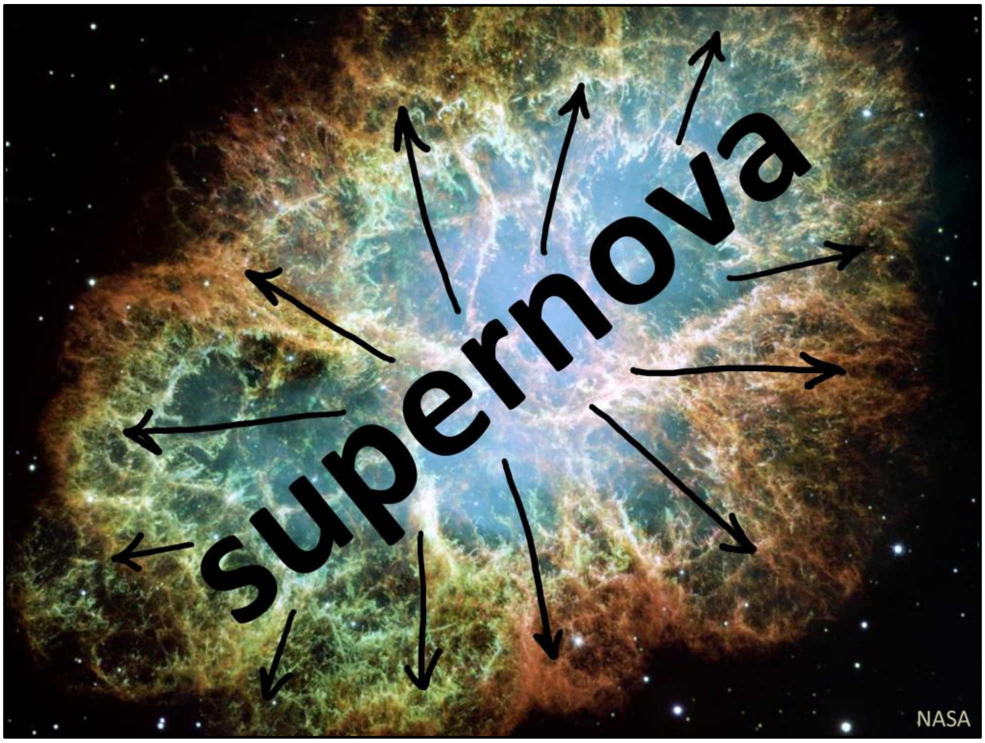
Short answer to this question: it was here from the beginning.

Our solar system formed from the condensation of a big cloud of space dust and gas called a nebula.

Credit: NASA, Image source: http://apod.nasa.gov/apod/image/0910/carinagigazoom_eso_big.jpg, accessed: 8/1/2014

Where did the nebula come from?

Self-explanatory – leads to next slide.



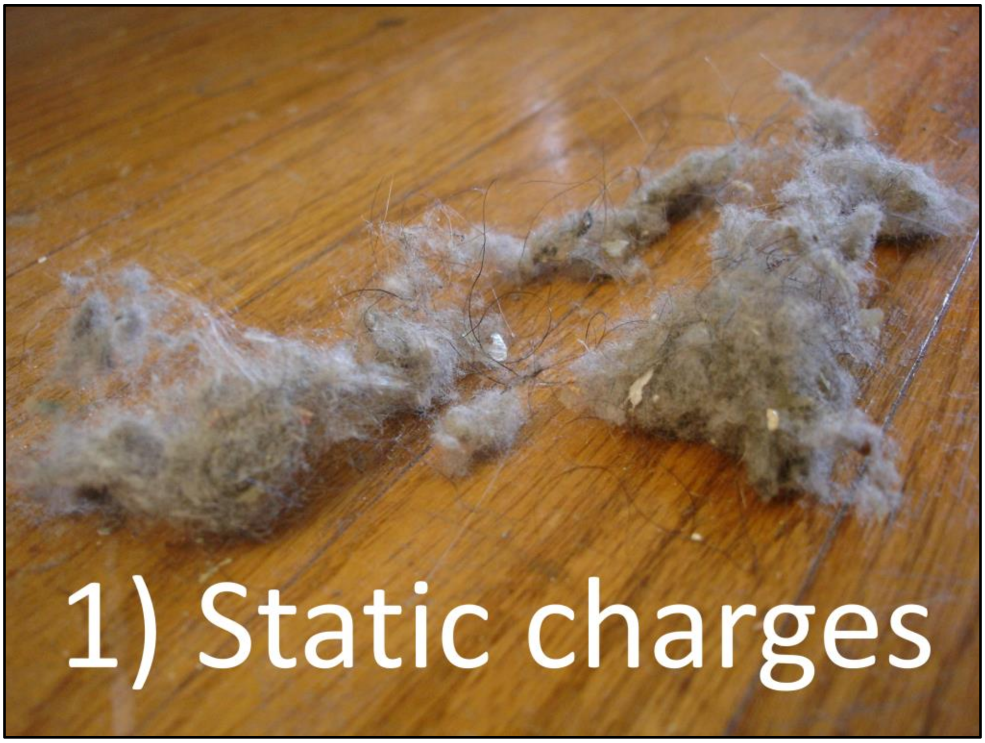
The nebula that formed our solar system came from the explosion of a former star. We know this because **no** elements heavier than iron form due to thermonuclear fusion alone. **They require the super-high energy conditions of a supernova explosion** to form. Because we find these elements (uranium, for instance, or cobalt or mercury or gold) in our solar system and in our planet, and our Sun hasn't (yet?) exploded in a supernova of its own, that's an indication that **our solar system is built from the remnants of a former solar system that blew up.**

Credit: NASA, Image source: http://en.wikipedia.org/wiki/File:Crab_Nebula.jpg, accessed: 8/1/2014

How did the nebula contract to make the solar system?

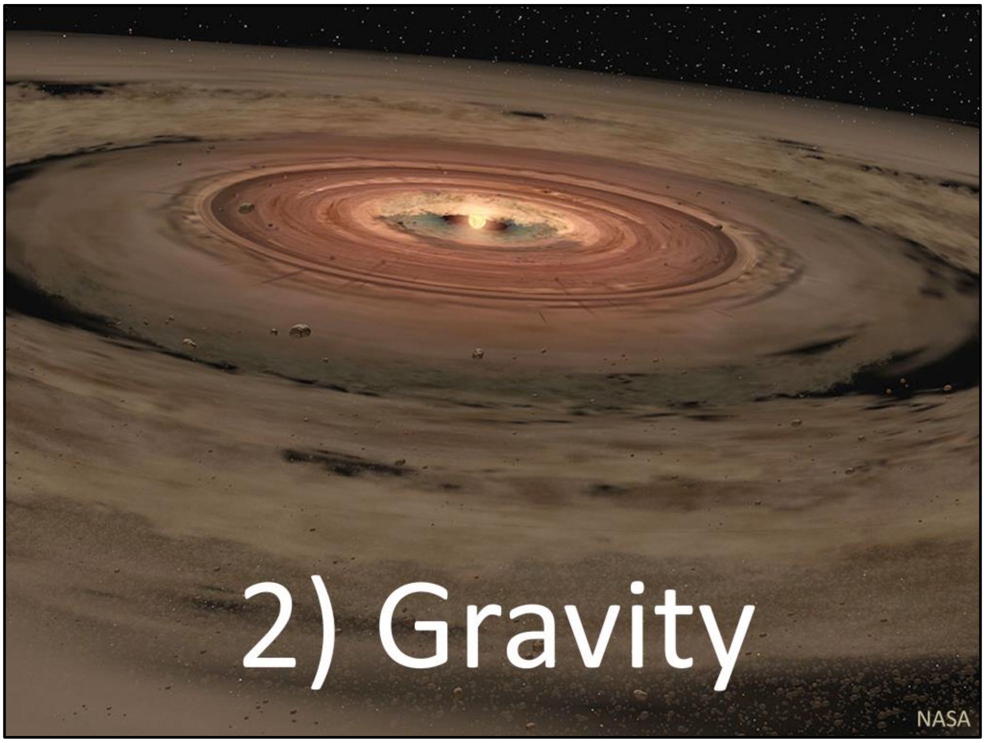
Another guiding question, which the following slides will address.

Pose it to the students: what do they think. Hopefully someone will suggest gravity, but gravity is a weak force, and probably not initially responsible for the fist stages of contraction. Instead….



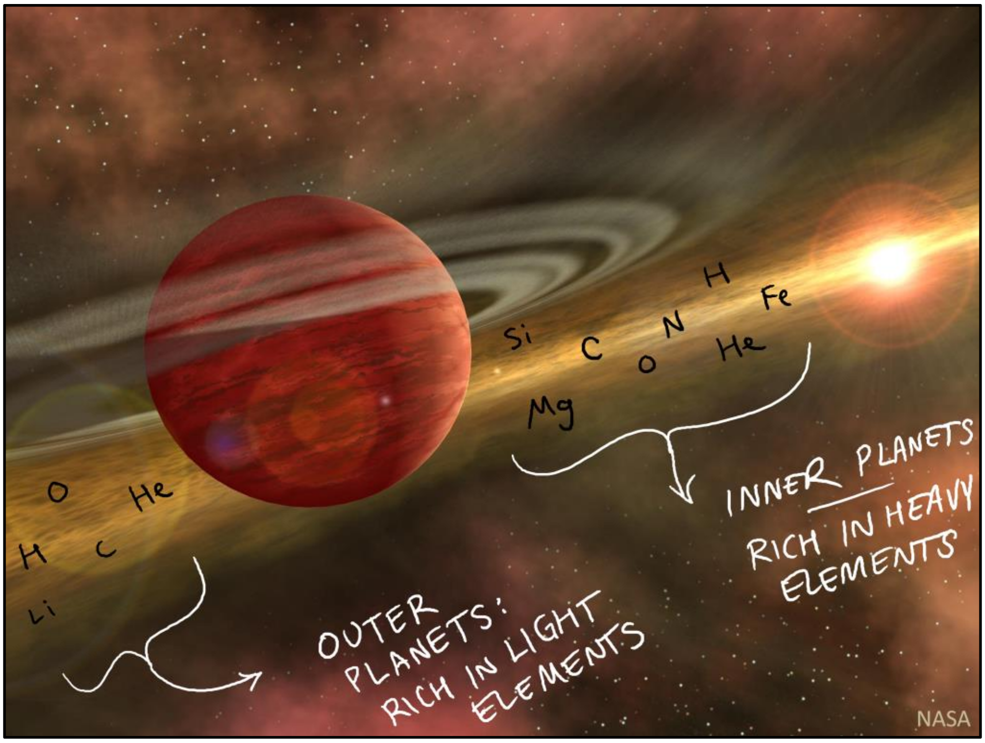
Gravity is most important for condensing a nebula into a solar system, but it's a very weak force. Much more powerful on small scales are static charges, like those that make dust "bunnies" from the tiny bits of dust under your bed or couch. In the nebula, small particles of gas and dust could be drawn together much more efficiently by static charges (opposites attract) than gravity. However: once the "space dust bunnies" get big enough (get enough mass), gravity can take over as the dominant force.

Credit: Stromcarlson (Wikimedia Commons), Image source: http://en.wikipedia.org/wiki/File:Dust_bunnies.jpg, accessed: 8/1/2014



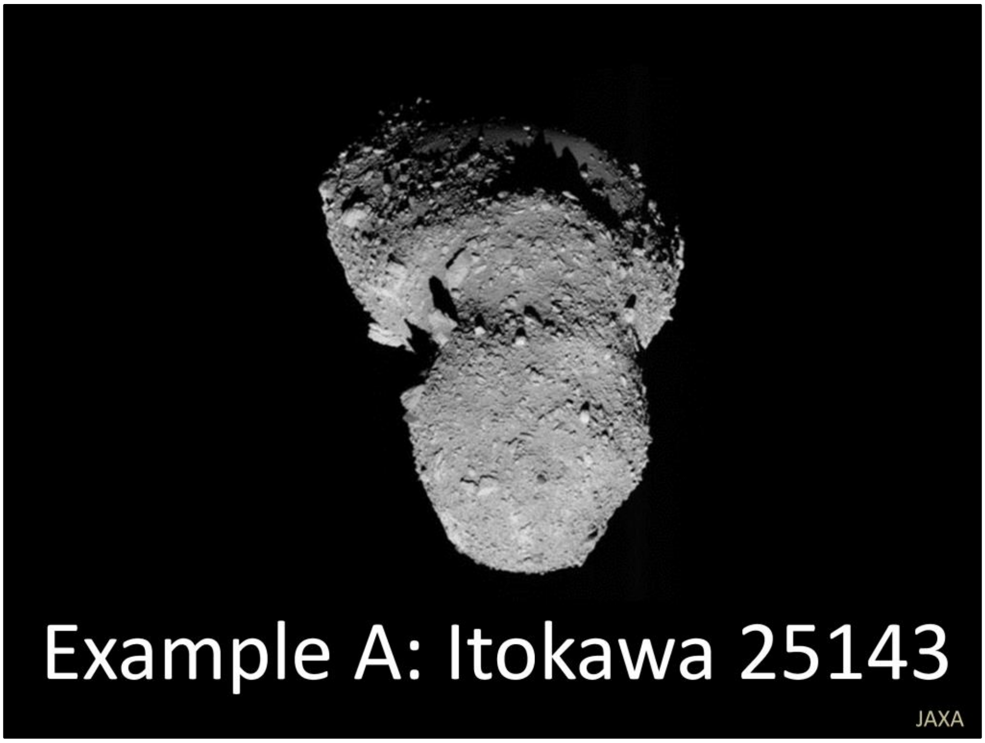
Big particles are sufficiently massive to exert a significant gravitational tug on their neighbors. Gravity's overall pattern for organizing a nebula into a solar system: **Make It Clumpy**. The same amount of mass, organized into a lesser and lesser number of objects, each of larger and larger size. Small chunks attract other small chunks, and become medium sized chunks. Medium sized chunks have a greater gravity, and pull in more small and medium sized chunks, getting bigger and bigger over time.

Credit: NASA, Image source: http://www.nasa.gov/images/content/113035main_image_feature_310_ys_full.jpg, accessed: 8/1/2014



An artist's conception of what it would look like as the accretionary disc was condensing, with light elements (less susceptible to the Sun's gravity) skimming out to the farther reaches of the spinning disk (future gas giant planets), while the Sun's mass keeps most of the heavy stuff close to home (future rocky / inner planets).

Credit: NASA, Image source: http://www.nasa.gov/images/content/122373main_image_feature_366_ys_full.jpg, accessed: 8/1/2014



Asteroid in the asteroid belt, imaged by the Japanese space agency. Basically a big pile of rocks in space, held together by gravity. Top to bottom, this thing is about as tall as the Eiffel Tower. Engage students with questions like: What would the gravity be like on Asteroid Itokawa 25143 compared to Earth? What would happen if you kicked a grapefruit-sized rock on Itokawa?

Credit: JAXA, Image source: http://www.isas.jaxa.jp/j/snews/2005/1101_hayabusa.shtml, accessed: 8/1/2014

A somewhat bigger pile of rocks, so big in fact it has compacted and differentiated into layers of different composition. The carbon we care about is mostly at the top, but the long-term carbon cycle has some of it traveling through the mantle – subducted and then degassed from later volcanic eruptions (or else forming crystals of diamond, which may stay in the mantle forever, or be brought to the surface via a kimberlite eruption).

Credit: NASA, Image source: https://www.flickr.com/photos/gsfc/4426654941/sizes/o/in/pool-34427469792@N01/, accessed: 8/1/2014