We Are Made of Stardust

Toward a New Periodic Table of Elements

compiled by Connie Barlow

www.thegreatstory.org
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"Thank you for spending so much time with us. You were so energetic. It was unbelievable that we are 14 billion years old! and that we are made out of stardust. It makes me feel like a Goddess. I don't like it. I love it." — Love, Eileen, a student at a Montessori school in Minneapolis.

"Thank you for telling us that we all are 14 billion years old. When you said I am made of star dust, I was very happy because I like space and I want to be part of it. I feel like a alien. Please please please come again." Love, Liza, a Montessori student

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PERHAPS THE DEEPEST SPIRITUAL CONNECTION to the vast Universe that science has given us is an awareness that ancestral stars are part of our genealogy. We can now know and feel our connection to the heavens, for stars are among our ancestors. Every atom in our bodies, other than hydrogen, was forged in the fiery belly of a star who lived and died before our own star, the Sun, was born.

"Stars mimic living systems. They are born, live to maturity at metabolic rates determined by their masses, and die, spewing forth the matter by which their stellar offspring can take form. Throughout, they convert the light atoms of their birth into the heavier ones dispersed at death. The chemicals that constitute our beings were manufactured in the bowels of stars that today exist only as memories." George A. Seielstad, *Cosmic Ecology*, 1983.

When the Siberian chemist, Dmitri Mendeleev, conceived The Periodic Table of Elements around 1870, he catalogued atoms according to the number of protons in each nucleus and grouped the elements by chemical properties. This was a huge achievement. It has been the basis for the science of chemistry ever since. Today, however, we have an opportunity to construct another version of the Periodic Table of Elements — one that can highlight *where* each element arose.

This awareness of atomic origins was made possible by scientific discoveries beginning in the 1920s and culminating in the late 1950s and 60s. Wikipedia recounts the history of this understanding in the topic **Stellar Nucleosynthesis**. Each year new discoveries flesh out even more details, enhancing our appreciation of stellar ancestors and the cosmic recycling of atoms.

CONTENTS:

Note: Stellar nucleosynthesis is a complex process to understand. The author will happily correct and update this file when errors are brought to her attention. Contact: Connie@TheGreatStory.org

1. The Highlights

Learning The Story of Stardust ("**Stellar Nucleosynthesis**") can elicit awe and wonder in a number of ways. Before moving into more detailed explanations of astronomy and chemistry from which the story is drawn, here in brief are the points that elicit the most "Wow" responses:

• Almost all the atoms of HYDROGEN within water, within our bodies, and everywhere else on and within Earth are more than 13 billion years old.

• If many of the atoms within us are 13 billion years old, and as "we" are our bodies, not just our minds, then, in a way, WE TOO ARE 13 BILLION YEARS OLD.

• ALL THE OTHER CHEMICAL ELEMENTS were forged by nuclear fusion inside of stars that flared forth and died before our Sun was born.

• *We are made of STARDUST — recycled stardust!*

• We are star stuff, PONDERING the stars.

• Humans are star stuff evolved to the point that it can begin to know and marvel at its own magnificent STORY.

• Our ANCESTORS include ancient stars. Stars are part of our GENEALOGY.

• HELIUM is the only chemical element within Earth that was created right here (from decay of radioactive elements).

• OUR SUN, when it is dying, will contribute CARBON back into the galaxy — perhaps for future generations of living planets to make use of.

• Most of the NITROGEN cycling within the Earth system was forged in the bellies of RED GIANT STARS who lived and died before our Sun was born.

• Our scientific understanding of the origin of CALCIUM in our bones is as fantastical a story as the notion that one might combine the contents of a child's balloon (HELIUM) with grains of sand (which include SILICON) and voila! There be calcium! Yet this is precisely what happened inside an ancestral star.

• The build-up of complex atomic nuclei from the simpler comes to a dead halt with IRON. Iron builds up in the core of a star.

• Every atom of IRON within our blood was at one time inside the core of a star and gumming up the works, so to speak.

• As more iron forms, the star cools, becomes less luminous, and then gravity takes over. Everything collapses, then rebounds in a SUPERNOVA EXPLOSION.

• All of our "precious metals" (GOLD, SILVER, PLATINUM) were created in that supernova explosion.

• When a single star explodes as a supernova, it shines brighter than 100 galaxies for several days, and it remains BRIGHTER THAN ALL THE STARS IN A SINGLE GALAXY for about 3 or 4 months.

• The more MASSIVE a star is, the faster it "burns" — and thus the SHORTER ITS LIFE. The biggest stars may live for only 20 million years.

• Stars SMALLER than our Sun may live for hundreds of billions of years and create nothing more complex than helium

• The greater the CREATIVITY of a star, the shorter its life.

• DEATH IS A NATURAL AND GENERATIVE process of the cosmos. Death of biological organisms offers the opportunity for evolution to build complexity and consciousness on Earth, and to ensure that there will always be room on a finite planet for new generations of children of all species. The explosive death of stars is also the way that complex elements were recycled into space, whence they could become planets and life. Without stellar death there would be no planets, no life!

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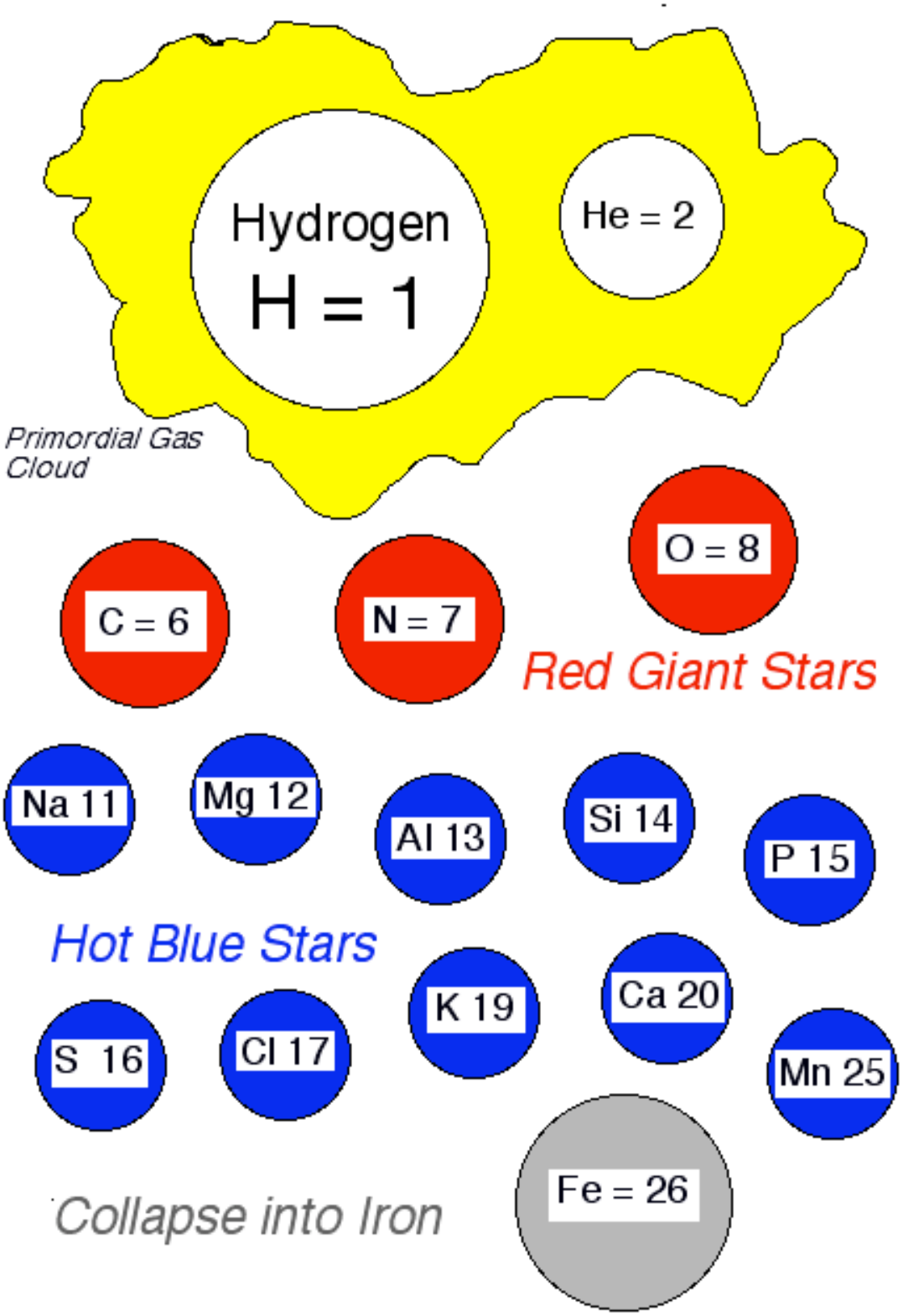
2. A New Periodic Table of Elements (by mode of origin)


Hydrogen
H = 1
He = 2
Primordial Gas Cloud
C = 6
N = 7
O = 8
Red Giant Stars
Na 11
Mg 12
Al 13
Si 14
P 15
Hot Blue Stars
S 16
Cl 17
K 19
Ca 20
Mn 25
Fe = 26
Collapse into Iron


Nickel
28
Copper
29
Zinc
30
Arsenic
33
Selenium
34
Molybdenum
42
Supernova
Explosion
Silver
47
Iridium
77
79
Gold
Mercury
80
86
Radon
82
Lead
Radioactive
88
Radium
92
Uranium

3. Stellar Alchemy in Cosmic Cauldrons

Note: In the above charts, only the most familiar elements are shown. For example, some Lithium and Beryllium did form in the pre-star cosmos, but these elements do not play a role in living organisms.

Note: To see the Standard Periodic Table of Elements, look up "Periodic Table" in the dictionary, or go to http://www.webelements.com.

Circular arrangements of the standard table can be accessed via
http://www.sciencekit.com/Products/Display.cfm?categoryid=294919
http://www.wardsci.com/EC/Products/Catalog/index.cfm?categorylD=4215
http://www.umit.maine.edu/~sean_birkel/periodic_circle/periodic_circle.html

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A. **Creation of HYDROGEN** (one proton) **in the beginning.**

Hydrogen (H) is the elder among all the chemical elements, and it is also, by far, the most abundant element in the Universe. Each and every atom of hydrogen in our bodies, in water, in the food we eat has been in existence almost since the beginning of space and time — ever since matter congealed from quarks some 14 billion years ago. This was before the first stars lit up, and before the galaxies formed.

B. **Creation of HELIUM** (2 protons) **inside Main Sequence stars, like our sun.**

Helium (He) is the second most abundant element in the Cosmos. Although most helium is nearly as old as hydrogen, here since the beginning, this element is also generated inside MAIN SEQUENCE stars like our Sun. Such stars fuse hydrogen into helium, releasing nuclear energy. The closest star of the night sky, **Alpha Centauri A** (within the constellation Centaurus), is very similar in mass, size, color, and brightness to our own sun. It is just 4.3 light years away. **Sirius**, the brightest star in the night sky, located just 8.7 light years away, is also a main sequence star, but it is white hot. Only about twice the mass of our sun, it is nevertheless 23 times more luminous.

Probably none of the helium on Earth, however, is primordial. And none was generated in ancestral stars. This is because all of the primordial or stellar helium was lofted off our small, rocky planet during the early bombardment of meteors. Atomic helium is just too light to be retained in the atmosphere by Earth's gravity. And unlike hydrogen (which readily bonds with oxygen, carbon, sulfur, and nitrogen), helium is a noble gas that never links up with heavier atoms. Helium never forms molecules of any sort; it is always just isolated atoms. This means that all the helium recovered from natural gas wells (which is what is used to fill children's balloons) derives from the radioactive decay of unstable elements,

notably uranium. *Helium is thus the one chemical element that is created naturally within Earth.*

C. Creation of CARBON, NITROGEN, and OXYGEN (6, 7, and 8 protons) inside Red Giant stars.

These elements are created in the cores of stars when enough helium has been generated during the hydrogen-fusing phase for that helium to begin fusing into carbon (C). At this phase shift, the star transforms into a RED GIANT. Stars that are between 80% and 3 times the mass of our Sun will create nothing heavier than carbon during their Red Giant phase. Stars that are 3 to 7 times the mass of our Sun have enough gravity to forge nitrogen (N) and oxygen (O), too.

Strong STELLAR WINDS generated by Red Giants periodically blow carbon, nitrogen, and oxygen out into space. Cooling, the atoms readily associate with one another (and with hydrogen), forming molecules of carbon monoxide, molecular nitrogen, water, ammonia, cyanide, formaldehyde, methane, and other hydrocarbons. On their journeys through space, these molecules may be captured by the gravitational attraction of hydrogen gas clouds that may later aggregate into stars and possibly planets.

Oxygen is the third most abundant element in the cosmos (after hydrogen and helium), followed by carbon and nitrogen.

Because intermediate size stars (80% to 7 times the size of our Sun) are more common in our galaxy than the bigger stars that forge silicon and calcium (to be discussed next), and because these intermediate stars expire after forging carbon, nitrogen, and oxygen, most of the nitrogen now on Earth was produced by ancestral stars that went no further than Red-Giant creation of carbon, nitrogen, and oxygen.

D. Creation of SODIUM, MAGNESIUM, ALUMINUM, SILICON, PHOSPHORUS, SULFUR, CHLORINE, POTASSIUM, CALCIUM, MANGANESE (11 protons in sodium through 25 in manganese) inside Blue-White stars that become Red Supergiants

All these elements (and the lesser known elements whose atomic numbers are within this sequence too) are created by nuclear fusion in massive stars that coalesce from hydrogen gas clouds at least 8 times more substantial than those that gave birth to our Sun. As with all stars, these giant stars begin by fusing hydrogen into helium on the "Main Sequence" of star creativity. During this time, however, they burn much hotter and brighter than does our yellow sun; these large stars burn BLUE-WHITE. And their stronger gravity makes them burn faster too. Once a threshold level of helium has been generated (for very large stars, after only a few tens of millions, rather than billions, of years), that helium starts to fuse into carbon and oxygen and nitrogen in the star's core, as the star enters its RED SUPERGIANT phase, which may last for only a few million years.

Stars at least 8 times greater than our Sun will continue the fusion process beyond oxygen, however. After a threshold of carbon has been generated, carbon

atoms begin to fuse into sodium (Na), magnesium (Mg), aluminum (Al), and silicon (Si). After a threshold of silicon has been reached, the silicon atoms begin fusing with helium into phosphorus (P), sulfur (S), chlorine (Cl), Potassium (K), Calcium (Ca), and Manganese (25). *Note: This is a bit of a simplification; the actual process is far more complicated, with some of the less abundant elements of these intermediate atomic weights actually formed during the decay of iron into lighter elements during the supernova phase, to be discussed next.*

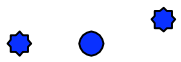
The blue-white star **Rigel** (the left foot of Orion the Hunter) is the 7th brightest star in the night sky. It is 55,000 times brighter than our sun, but its location 900 light years distant prevents it from outshining all the other stars. If Rigel were to swap places with Sirius (just 8.7 light years away), Rigel would be visible even during the day, shining at about a fifth of the brightness of the full moon.

Rigel was not around during the time of the dinosaurs. A star that massive lasts for only a few tens of millions of years. When it exhausts its helium fuel and leaves the "main sequence," it will look like another prominent star in the constellation Orion. It will look like **Betelgeuse**, a RED SUPERGIANT, which will die and diminish into a white dwarf in perhaps a million years.

Betelgeuse marks the right armpit of Orion the Hunter (to us, it appears on the left side of Orion). It is 650 light years away, and still the 12th brightest star in the night sky. It actually looks red to the naked eye.

Betelgeuse

Orion



Rigel

E. Creation of IRON (26 protons)

MASSIVE, BLUE-WHITE STARS at least 8 times the size of our sun, once they become RED SUPERGIANTS, will continue creating heavier elements by nuclear fusion all the way up to iron (Fe). Unlike the other nuclear reactions, fusion into iron *consumes* rather than generates energy. The synthesis of iron, the most stable of all elemental nuclei, is like a fire extinguisher. The process quenches the violence of nuclear fusion, cooling the core of the star. And so stellar fusion processes come to a near standstill after iron saturates the core. Iron is the sixth most abundant element in the cosmos.

F. Creation of NICKEL, COPPER, ZINC, SILVER, GOLD, MERCURY, LEAD, URANIUM in SUPERNOVAS

All the elements with atomic numbers greater than that of iron (up to uranium, atomic number 92) are fused into existence when a massive star with an iron-rich core collapses into itself. A rebound follows the implosion, and all these heavier elements are fused in the shock wave during a time interval of only about one second! This is the SUPERNOVA explosion, and this is how the dying star offers up its creativity to future generations of stars and planetary systems yet to form. Atoms soar away from the exploding star in all directions, and some will be captured by the gravitation within diffuse hydrogen gas clouds from which later generations of stars (and planets) will arise.

It is now thought that the atoms of silicon, calcium, iron, and so on that comprise Earth are the gifts of at least 20 distinct supernova explosions that occurred in our sector of the galaxy during the first 8 billion years of this Universe's existence, before our own solar system aggregated from a primordial gas cloud enriched by stellar debris some 5 billion years ago.

> "We are the local embodiment of a Cosmos grown to self-awareness. We have begun to contemplate our origins: starstuff pondering the stars." — Carl Sagan, *Cosmos*, 1980

NOTE: A scientifically rigorous but poetic rendering of the **forms and uses of each of the most familiar elements**, especially those crucial for life, can be accessed:

http://www.thegreatstory.org/Feastofelements.html

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4. Stellar Longevity v. Creativity

For stars, there is a price to be paid for creativity:

The more kinds of atoms created, the shorter-lived the star.

Only the chemically laconic are long-lived. The reason pertains to gravity and how gravity determines the extent and pace of nuclear fusion.

The more mass (more hydrogen) that a star begins with, the greater the force of gravity. And the greater the gravity, the denser the star. The denser the star, the faster and more extensive the fusion process. The star is able to more strongly squeeze together the atomic nuclei within its core. Paradoxically, thus, the more massive the star, the sooner it uses up its stores of primordial hydrogen fuel; the sooner it begins to die.

Aggregations of hydrogen gas (perhaps enriched by elements forged in previous generations of stars) that are not much bigger than Jupiter will become **BROWN DWARFS** — radiating in the infrared zone, but not flaring forth as nuclear reactors. Technical sources say that the threshold mass for nuclear fusion to begin (hydrogen fusing into helium, as in our Sun) is somewhere between 10 and 20% the mass of our Sun. Brown dwarfs are thus halfway between being a planet and a true star.

Clumps of hydrogen gas more than about 20% the mass of our Sun will light up as stars (fusing hydrogen into helium), but their luminosity will be much less. For example, a star that is 30% the mass of our Sun has a brightness only 0.4% that of our Sun. **Sirius**, the brightest star in the night sky, is only about double the mass of our sun, but it is 23 times brighter. Sirius is a white star that is only 8.7 light years away, making it the 7^{th} closest star to us, after our own sun.

These lesser stars are longer lived. A star that is 30% the size of our Sun will placidly continue nuclear fusion for upwards of 800 billion years, but helium is the only element it will ever create.

In contrast, our Sun has an expected lifespan on the **MAIN SEQUENCE** of nuclear fusion (fusing hydrogen into helium) of some 10 billion years. It will then spend another billion years as a **RED GIANT**, whose outer shell will expand to 20 times bigger than the outer limits of the Sun today, thus encompassing Earth's orbit. As helium fuses into carbon, this Red Giant will burn 100 times brighter than our Sun is burning today. Following the Red Giant phase, our Sun will close out its stellar life as a **WHITE DWARF** about the size of Earth, after its outer shells have been violently shed, expanding outward as a NEBULA. The gravity of the dense white dwarf generates intense heat and light, but no fusion of atomic nuclei is occurring any longer. The nuclear fires have vanished.

Our Sun has been on the Main Sequence of hydrogen fusion for some 5 billion years, and has thus has another 5 billion to go before becoming a **RED GIANT**. Our Sun is not large enough, however, to ever create anything more than carbon.

It is not massive enough to forge oxygen and nitrogen. In this we are fortunate, because if our Sun were large enough to forge oxygen and nitrogen, it would already have become a Red Giant, and self-aware life forms may not have had time to evolve on this Earth, to appreciate the Story of Stardust.

It is comforting to know that, although Earth will be burned to a cinder during the Sun's red giant phase, eventually solar **CARBON** will be **RECYCLED** into the cosmos, perhaps to assist future planetary systems in birthing life. For a lovely photograph of a white dwarf surrounded by its expanding shells of atomic creations that were shed at the end of the Red Giant phase, go to the Hubble photograph of the "Cat's Eye Nebula": http://hubblesite.org/newscenter/archive/1995/01/

A star that aggregates from a cloud of hydrogen gas just 30 times more massive than our Sun will remain on the Main Sequence for a mere 60 million years, burning as a hot **BLUE-WHITE STAR** during that time. Its luminosity is 100,000 times brighter than our cooler, **YELLOW-WHITE STAR**, the Sun. After exhausting its supply of hydrogen in its core, the massive blue-white star will turn into a Red Supergiant, fusing helium into carbon and oxygen and nitrogen, and then carbon into phosphorus and silicon and silicon into calcium and all the way to iron, then imploding and exploding all the natural elements up through Uranium.

Massive stars that shower the Cosmos with their creativity as **SUPERNOVAS**, burn brighter than a whole galaxy for several months. These supernova stars give new meaning to a short poem by Edna St. Vincent Millay:

> "My candle burns at both ends, it will not last the night.
> But ah, my foes, and oh, my friends, it gives a lovely light!"

What remains after the "candle" burns out will be either a Neutron Star or a Black Hole. A **NEUTRON STAR** is only about the size of Manhattan. It forms because the gravitational force is so strong that protons and electrons fuse into neutrons (1 proton + 1 electron yield 1 neutron), emitting neutrinos in the process. A Neutron Star with a fast rotation that generates a strong magnetic field is called a **PULSAR**.

If the star initially began its fusion journey with more than 30 times the mass of our Sun, it has a different fate after the supernova phase explodes much of its creativity back into the galaxy. What remains is not a neutron star or a pulsar but a **BLACK HOLE**. Gravity is so great even photons of light cannot escape to give us a clue of what is inside. For an artist's rendering of how a black hole might affect its surroundings, visit:
http://hubblesite.org/newscenter/archive/2002/30/

For a beautiful photograph of the streamers of atoms moving away from a supernova remnant, see the Hubble photograph of the "Crab Nebula", which exploded about 7500 years ago, the photons of light from that explosion reaching Earth in 1054 (recorded by Chinese astronomers). For several weeks in 1054 that supernova was so bright it was visible even in the daytime sky. The parent star is

estimated to have begun its stellar life with a mass ten times greater than that of our sun.
http://hubblesite.org/newscenter/archive/2000/15/

See also the supernova remnant "Cas Q", which exploded 14,000 years ago, and whose photons of light first reached Earth in the late 1600s.
http://hubblesite.org/newscenter/archive/2002/15/

Scroll down to see a chart of Star mass, lifespan, and fate.

MASS	LIFE SPAN	LIFE SPAN	BRIGHTNESS
1/10	2,000,000,000,000	2 trillion years	3/1000
1/2	200,000,000,000	200 billion years	3/100
1 X (our Sun)	10,000,000,000	10 billion years	1
3 X	200,000,000	200 million years	60 X
5 X	70,000,000	70 million years	600 X
10 X	20,000,000	20 million years	10,000 X
60 X	800,000	4 million years	800,000 X

- Note: The data for this table is at: http://outreach.atnf.csiro.au/education/senior/astrophysics/stellarevolution_mainsequence.html

	Mass	Lifespan	Fate
Brown Dwarf	< 10% our sun	*IMMORTAL*	Brown Dwarf
Yellow Star	half our sun	*IMMORTAL* > 500 billion years	Yellow Star
Yellow Star	OUR SUN	10 billion years	Red Giant then White Dwarf
Hot Blue Star	30 X our sun	60 million years	Super nova explosive death plus neutron star at core
Black Hole	50 X our sun	???	Mystery!

5. More Details on the Sequence of Stellar Nucleosynthesis

NOTE: In 1956, William A. Fowler et al (Hoyle, Burbridge, and Burbridge) published "Origin of elements in Stars" in *Science.* But their key paper is their "Synthesis of the elements in Stars, published in 1957 in *Reviews of Modern Physics.*

1. Great Clouds of HYDROGEN AND HELIUM Gas

IN THE BEGINNING, some 13.7 billion years ago, the only matter that existed in the young Universe were the two simplest elements: HYDROGEN (with one proton), and HELIUM (with two protons). These two elements formed great clouds of gas — mostly hydrogen, with a sprinkling of helium. (Because atoms may also contain neutrons, present near the beginning were ISOTOPES of hydrogen and helium. For example, deuterium is a less common isotope of hydrogen whose nucleus contains one proton and one neutron; tritium contains 1 proton and 2 neutrons.) Stellar nucleosynthesis (the synthesis of heavier atoms from lighter atoms inside stars) is what the Universe was doing (and still is) for the 8 billion years from its birth to the time our own star, the Sun, ignited from a primordial gas cloud. All this time was necessary to build atomic complexity before our Earth could form.

2. Gravitational collapse into the first generation of STARS

As gravity began its work of aggregating small clumps of matter into larger clumps, some bundles of gas were massive and dense enough to ignite nuclear fusion (not nuclear *fission*) reactions deep inside the core. Within stars, 4 HYDROGEN nuclei (each a single proton) are squeezed together, fusing into a single nucleus of HELIUM (2 protons + 2 neutrons). The transformation of two of the original protons into neutrons would produce a rush of energy: the heat and light of a newborn star. A note on nuclear fusion v. fission: Nuclear weapons and nuclear power plants created by humans operate by atomic *fission*: energy is derived when complex atoms are pried apart into simpler atoms. Stellar nuclear *fusion* is constructive: simple atoms (nuclei) are fused together to make more complex forms. Humans are seeking ways to do nuclear fusion themselves, in order to eliminate the problem of radioactive waste.

3. Sunlike stars of the MAIN SEQUENCE

Fusion of HYDROGEN nuclei into HELIUM is precisely what has been energizing our own star, the Sun, ever since the solar system formed nearly 5 billion years ago. Sufficient hydrogen fuel remains in our star to keep the Sun shining as it does today for perhaps another 5 billion years. The average star spends 90% of its energy-producing existence along this "main sequence" of hydrogen fusion.

4. The STABILITY of Main Sequence Stars

Main sequence stars have a remarkable built-in stability: the crush of gravity is offset by the expansive release of nuclear energy. If gravity collapses the gas just a little bit denser in the core, the reactions speed up, and the core expands, diminishing the effect of gravity in a feedback loop. Likewise, if reactions speed up just a tiny bit beyond the stable point, so that the core expands, then the diminished density means that fusion slows down in tandem. Stability is once again restored.

5. NO PLANETS yet

The stability of Main Sequence Stars makes life possible on surrounding planets. But then, there were no planets in the first generations of stars, because there was no solid matter in the Universe: no silicon or oxygen to form silicate rocks, no iron, no magnesium, no aluminum. There were only great clouds of hydrogen/helium gas, some of which had lit up into stars.

Earth exists today (and life on Earth) only because, for some 8 billion years prior to the birth of our solar system, previous generations of stars were creating all the elements that now elevate the continents, swirl in Earth's atmosphere, and give form to life.

5. Creation of CARBON in RED GIANT STARS

After about 10 percent of the hydrogen inside the core of a Main Sequence Star has been converted into helium and energy, the star goes through a transformation, becoming a RED GIANT, or (for massive stars) RED SUPERGIANTS.

Red giants emerge when the collapsing force of gravity in a helium-rich star exceeds the expansive force of hydrogen nuclear reactions. The pressure at the stellar core increases. Pressure is now strong enough to begin fusing HELIUM nuclei into CARBON nuclei. Three helium nuclei (each with 2 protons and 2 neutrons) are used up in synthesizing one carbon nucleus. Each carbon nucleus contains 6 protons, with a variable number of neutrons (6 to 8), depending on isotope.

6. A Note on Nuclei and Plasmas

We speak of helium and carbon *nuclei* — not atoms — because inside the cores of stars the pressure is too high for electrons to gather around a single nucleus. Rather, all the nuclei float in a sea of electrons, a condition known as the *plasma* state (not solid, not liquid, not gas, but plasma).

7. Why RED GIANTS are red and big

When a Main Sequence Star transforms into a Red Giant, the core condenses. The intensity of energy released, however, forces the outer shells of gas to expand far beyond the core. The expansion cools the gases in the outer shells from the hot yellow, white, or blue-white color of a main sequence star to the cooler red of a Red

Giant, even though the *core* of a Red Giant is much hotter than the core of a Main Sequence Star. When our own sun becomes a red giant, its outer envelopes of gas will expand outward to encompass Mercury, Venus, and even Earth.

8. Creation of OXYGEN AND NITROGEN in large Red Giant Stars

Our Sun will have the ability to synthesize CARBON in its Red Giant phase, and nothing more. But stars that initially lit up from clumps of hydrogen gas 2 to 6 times more massive than our Sun will also be able to create NITROGEN (7 protons in the nucleus) and OXYGEN (8 protons), too. One carbon nucleus plus one helium nucleus, fused, yields one oxygen nucleus plus a release of energy. Nitrogen (as will be explained later) is created by a more complicated process in which a heavy isotope of oxygen decays into nitrogen plus helium.

9. The importance of STELLAR WINDS of Red Giants

Red giants are not as stable as stars in the Main Sequence. Periodically they emit very strong "STELLAR WINDS" that send atoms streaming outward into space. These emanations are crucial for the life to come. For the atoms of CARBON, NITROGEN, and OXYGEN sent forth occasionally meet up with hydrogen gas clouds scattered through space, and enrich these clouds with the very elements that will prove essential for life, once planets have a chance to form.

10. We thank Red Giants for NITROGEN atoms

Chemical reactions are such that almost all the NITROGEN on Planet Earth and in our bodies owes to the stellar winds of Red Giant Stars who launched atoms into space long before our Sun formed. Although counterintuitive, nitrogen (atomic number 7) is actually formed in Red Giants after oxygen (atomic number 8) has been created. Nitrogen arises from an energy-releasing decay of a heavy isotope of oxygen that yields nitrogen and helium.

In the Northern Hemisphere, we can appreciate Red Giants by looking into the night sky, finding the Constellation Scorpio, and gazing at the reddish star near the scorpion's heart. This is a Red Supergiant, and it is the 15th brightest star in the night sky: **Antares** (meaning, "rival of Mars"). Antares holds 10 to 15 times the mass of our sun; it burns 9,000 times brighter, and it is 520 light years away. Another Red Supergiant is the brightest star in the constellation Orion. This is **Betelgeuse**, the 12th brightest star in the night sky, located in the hunter's shoulder area.

11. We thank Supernovas and the hot Blue Stars that preceded them for the CALCIUM in our bones, the IRON in our blood, the SILVER that adorns us.

Rigel is a massive, blue star that will, within a few tens of millions of years, explode as a supernova. Rigel is the brightest star in one of the feet of the constellation Orion, the Hunter. The Hubble Space Telescope has captured many

beautiful pictures of long streamers of glowing atoms extending vast distances from the remnants of Supernova explosions.

6. Playful Ways to Experience the Stardust Story

• **WATER.** Do you like to drink water? What's another name for water? (H2O) What does the H mean? What does the O mean? Do these atoms live and die like plants and animals do? Where did they come from? How old are the hydrogen atoms? How old are the oxygen atoms?

• **SAND, BALLOONS, AND BONES.** The story of Stardust is as magical as any fairy tale. Consider this: Take a handful of sand from a beach (silicon and oxygen) and add to it the contents of a child's balloon (helium). Press together inside a giant star and, Voila! Calcium! Thus the very stuff that forms the "backbone" of rocks (silicates) is the foundation for building the stuff that forms our own backbone: calcium. (See also the "Buddha Bowl" evolutionary parable, by Paula Hirschboeck, www.TheGreatStory.org/BuddhaBowl.html)

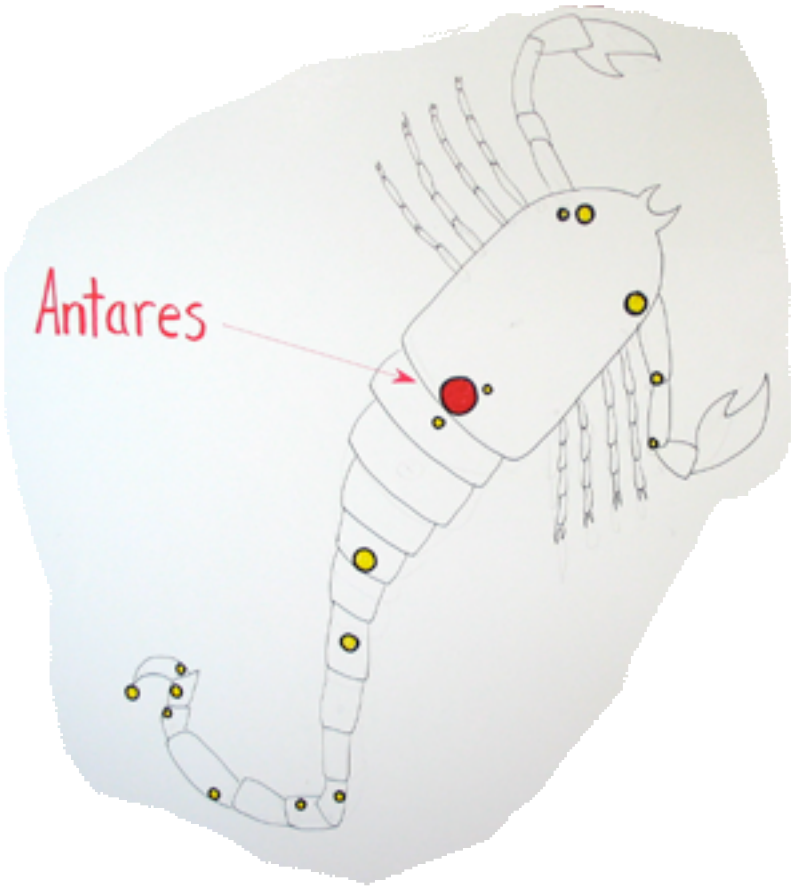
• **RITUAL OF GLITTER AND SONG.** See the "We Are Made of Stardust Ritual" at www.TheGreatStory.org/StardustRitual.html

• **BIRTHDAY STARS.** Among the 50 brightest stars in the night sky are those close enough to Earth that we can celebrate particular birthdays, knowing/seeing that these stars, at this moment, are being seen *as they were* the year of our birth! That is, the stars are a distance in light-years away equivalent to our age. You can find a list of the brightest stars, and how to see them at:

http://www.cosmobrain.com/cosmobrain/res/brightstar.html

The bright stars include these, shown with distance in light years:

Sirius	8.6
Procyon	11.4
Altair	16.8
Vega	25.3
Pollux	33
Arcturus	36.7
Castor	51.5
Aldebaran	65
Alioth	80.9
Gacrux	87.9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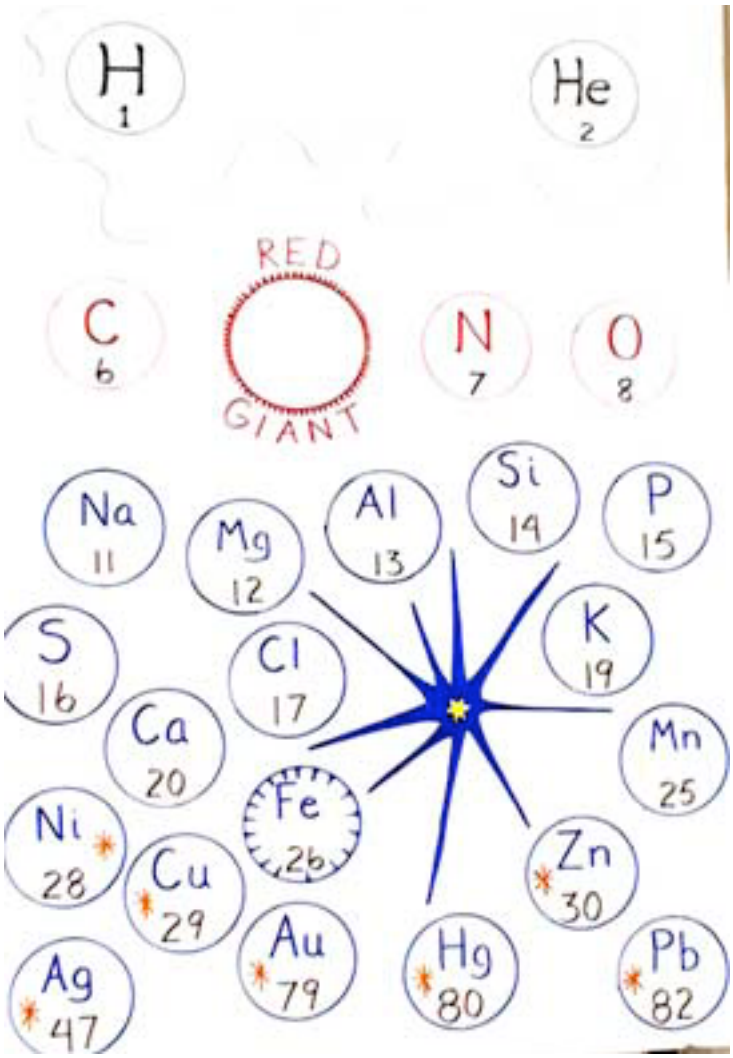

7. Connections to Other Mythic Stories

● **THE LION KING:** Q: What did the Lion King believe stars were? A: the great kings of the past (ancestors). Q: What did the Wart Hog believe? A: "big balls of burning gas billions of miles away." Q: Who is right? A: [before the stardust lesson, most children will answer the wart hog is right; after the lesson most will answer that both are right.]

● **THE LITTLE PRINCE:** In Antoine de St-Exupery's 1943 tale, the Little Prince said, "If you love a flower that lives on a star, it is sweet to look at the sky at night. All the stars are a-bloom with flowers."

● **TWINKLE TWINKLE LITTLE STAR** was written in 1806, before we knew what stars were!