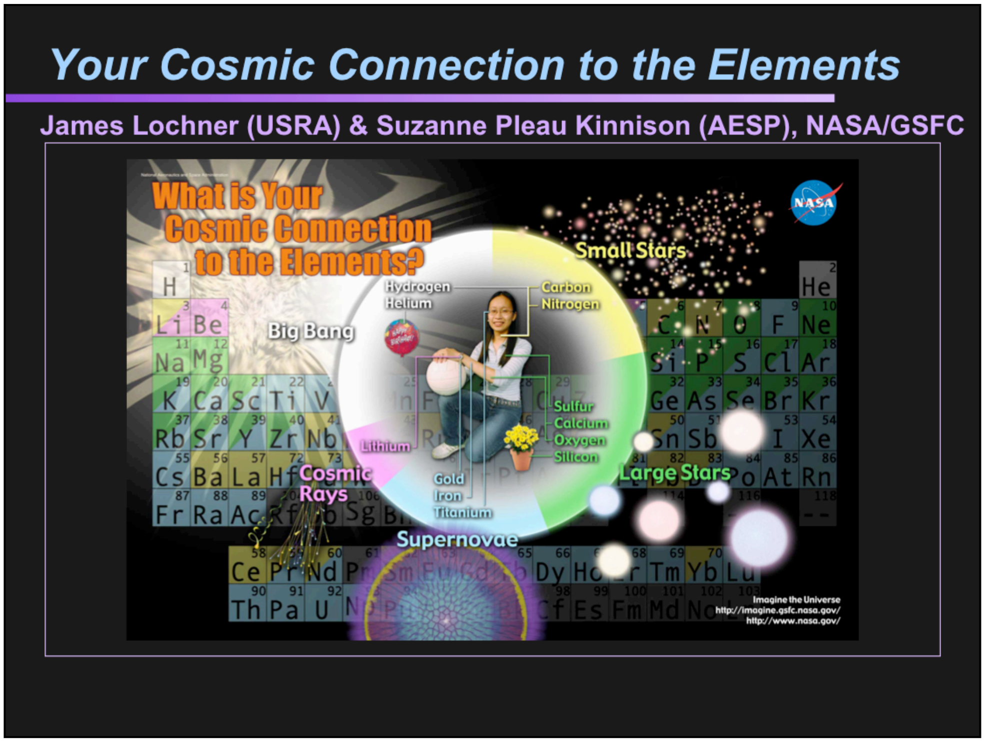


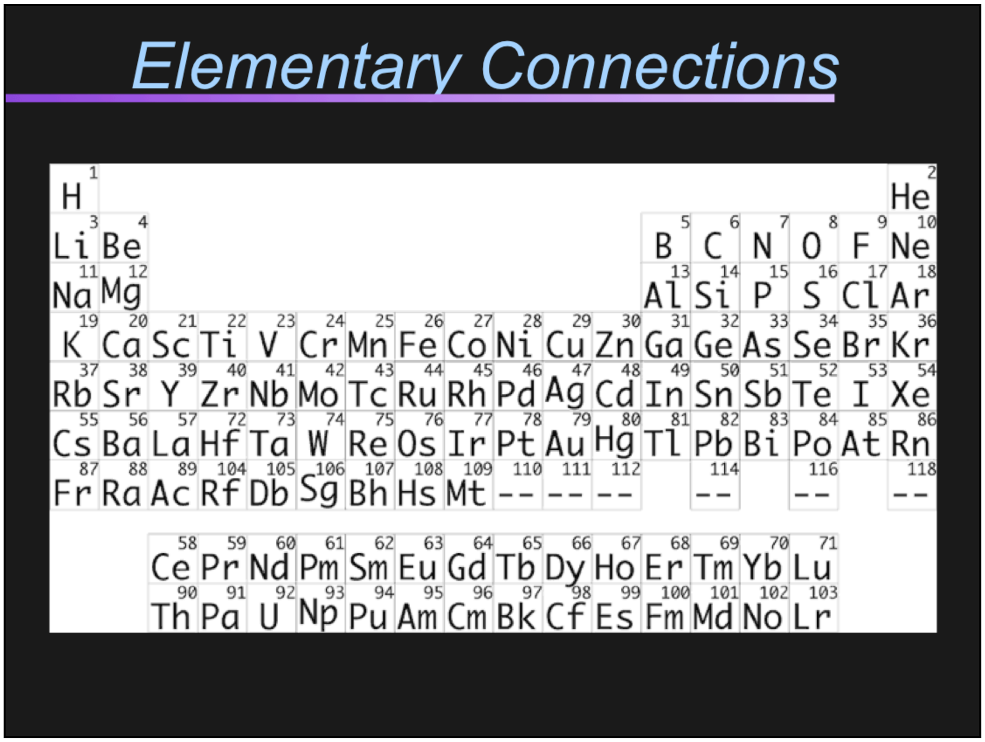
March 2007 (v2.5): modification of 2.4, re-arranging the first few slides and using the Orion slide from the NPS presentation.

Sept 2006 (v2.4) - version with Life Cycles of Stars. (LOS slides taken from elements_life_cycles_9.ppt and life_cycles_41.ppt [both on laptop])

July 2006 - a revision to update this with the new version of the poster and periodic table. Slide #6 now contains links to relevant portions of the talk. Also, Meredith fixed the inclusion of the sound files for the Nickelodion demo (slides 26-28)

First public version. Notes are from presentation by Sara Mitchell in Aug 2003. The notes provide a script that may be used with the slides.

Tell participants that we will be pondering the question asked on the poster, "What is your cosmic connection to the elements?"



What is this? [Periodic Table]

What does it show? How is it arranged?

Can you tell me some of the elements you encounter every day, in the objects all around you? Tell me an object and the element(s) in it.

[Have audience make the connection between everyday objects and the elements in the periodic table. For example:

Gold in jewelry

Aluminum in soda cans

Titanium in eye glass frames

Hydrogen and oxygen in water

Calcium in milk and bones

Nitrogen in the air]

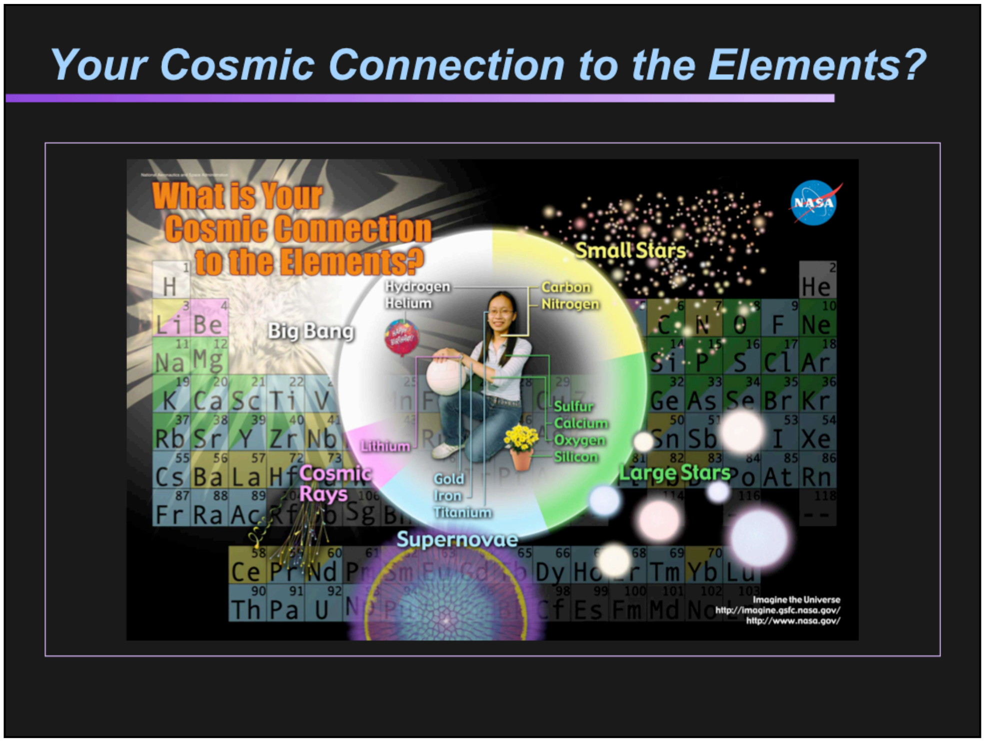
Make sure they identify some elements heavier than Iron.

End with question: Where do these elements come from? (Some may say, the earth. Let this lead to solar system (and its formation), and ultimately the stars.)

Cosmic Connections

To make an apple pie from scratch,
you must first invent the universe.

Carl Sagan



On this page, certain elements are linked to other sections of the presentation:

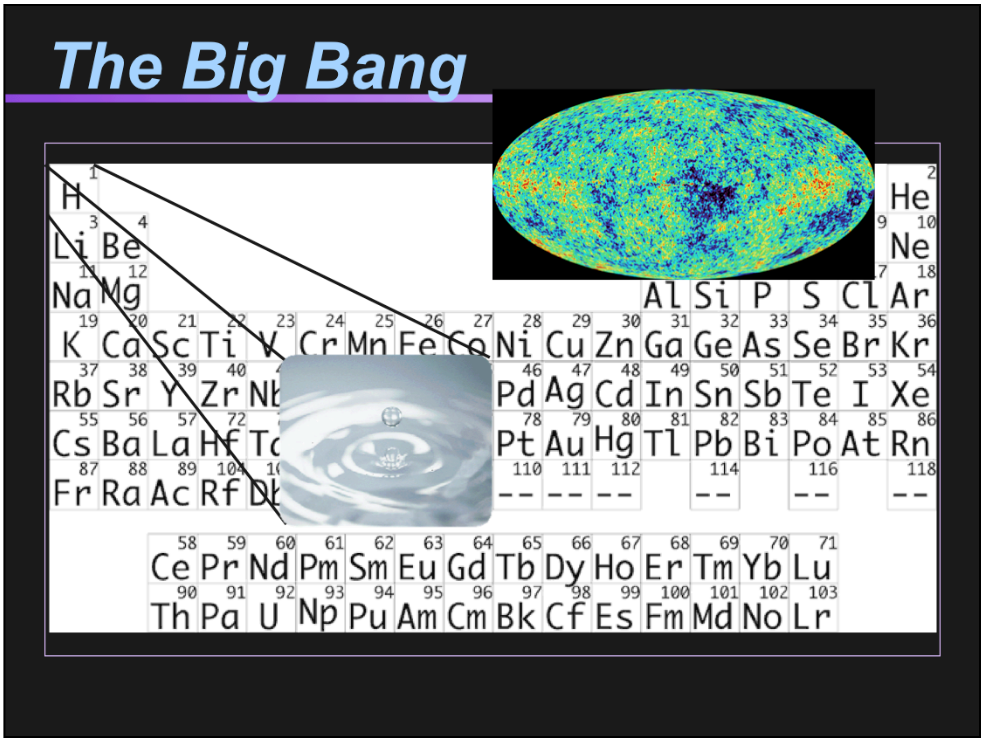
“carbon” -> small stars

“calcium -> large stars

“iron” -> supernovae

“lithium” -> cosmic rays

At the end of each of those sections (except cosmic rays), there is a thumbnail poster in the lower right corner. Clicking on it will return you to this page. Hence this page may be used as an anchor and reference throughout the talk.



Now let's start at the beginning, with the Big Bang. The Big Bang created Hydrogen, Helium, and a tiny amount of Lithium. [Click for WMAP.]

The image is from the Wilkinson Microwave Anisotropy Probe, which is a long and fancy name that we usually shorten to "WMAP." This is a baby picture of the universe, from when it was a mere 379,000 years old.

The image shows differences in the temperature of the microwave background. The average background temperature is 2.73 degrees above absolute zero. The red areas are "warmer" than this, and the blue areas are "cooler."

WMAP is sensitive to measuring differences in temperature as small as millionths of a degree, so when we say "warmer" or "cooler," we may be referring to fluctuations of thousandths or millionths of degrees.

The WMAP results confirmed several ideas we had about the universe -- the age of the universe is 13.7 billion years, and stars started forming 200 million years after the Big Bang. It did this using the fluctuations measured this image.

The Cosmic Microwave Background was one of the strongest pieces of evidence for the Big Bang theory.

The Big Bang Cosmology

- The expansion of the universe began at a finite time in the past, in a state of enormous density, pressure and temperature.
- "Big Bang" is a highly successful family of theories with no obvious competitor.
  - Explains what we see, and has made several successful predictions.

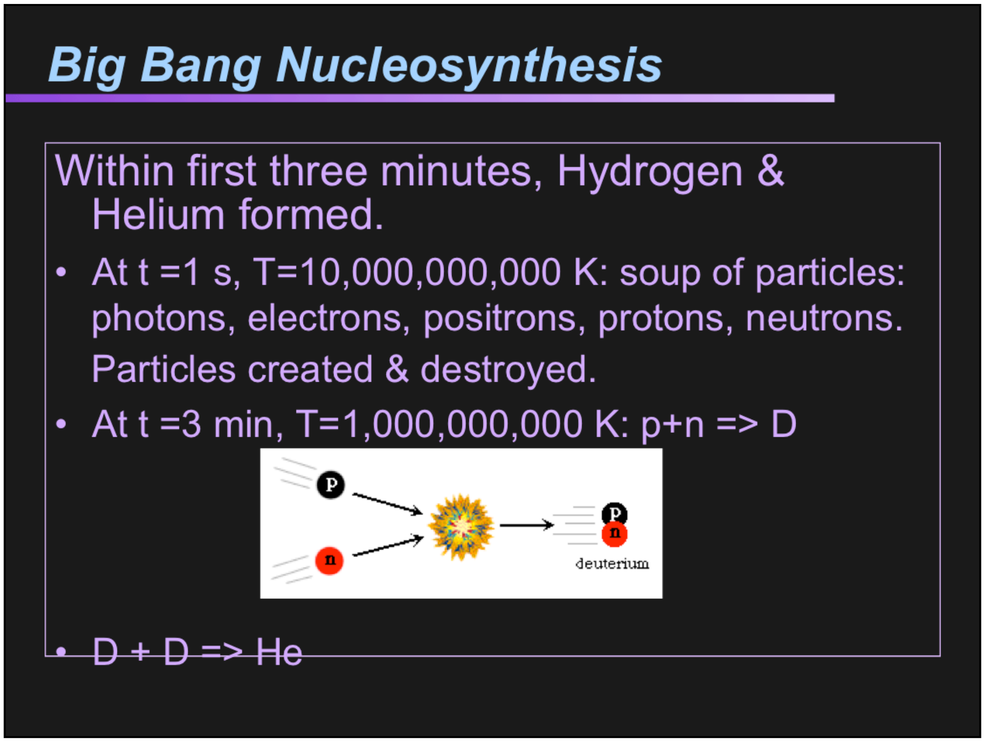
The first important question is:

What is the Big Bang?

Most astronomers theorize that the Universe started with a massive explosion. This happened at a finite time, and everything was very hot, very dense, and under a lot of pressure.

The Big Bang is a very successful family of theories that explains what we see and has made several predictions that have been confirmed. The Big Bang is consistent with observations we've made.

[This explanation of what the Big Bang is and why it is used may be helpful to some teachers in areas where formation of the universe is a sensitive topic.]



Right after the explosion, things are very, very hot, over 10^32 degrees! Matter and energy are expanding outward.

At one second after the Big Bang, the temperature is ten billion degrees and we have a “particle soup.” It’s really too hot and energetic for any nuclei heavier than Hydrogen to form, so we mostly have lots of particles being created and destroyed -- protons, electrons, neutrons, positrons, and plenty of other “-ons.”

But things are cooling down pretty quickly. After three minutes have passed, the temperature has dropped to one billion degrees, and we see the first particles coming together. A proton and a neutron join to form Deuteron, the nucleus of Deuterium (or “heavy water”).

From the Deuterium, we can get Helium -- two Deuterons join to form one Helium. Very occasionally, enough Deuterium collide to form Lithium, but this was rare.

As the Universe expands, the temperature falls and soon it is too cool for more nuclei to form. This is what the Big Bang forms in the first few minutes -- 95% Hydrogen and 5% Helium (and a trace amount of Lithium).

Atoms form at T=3,000K when the electrons “recombine” with the nuclei to form atoms. At this “recombination”, the universe becomes transparent. This 3,000K black body radiation has been redshifting ever since, and is now 2.7K.

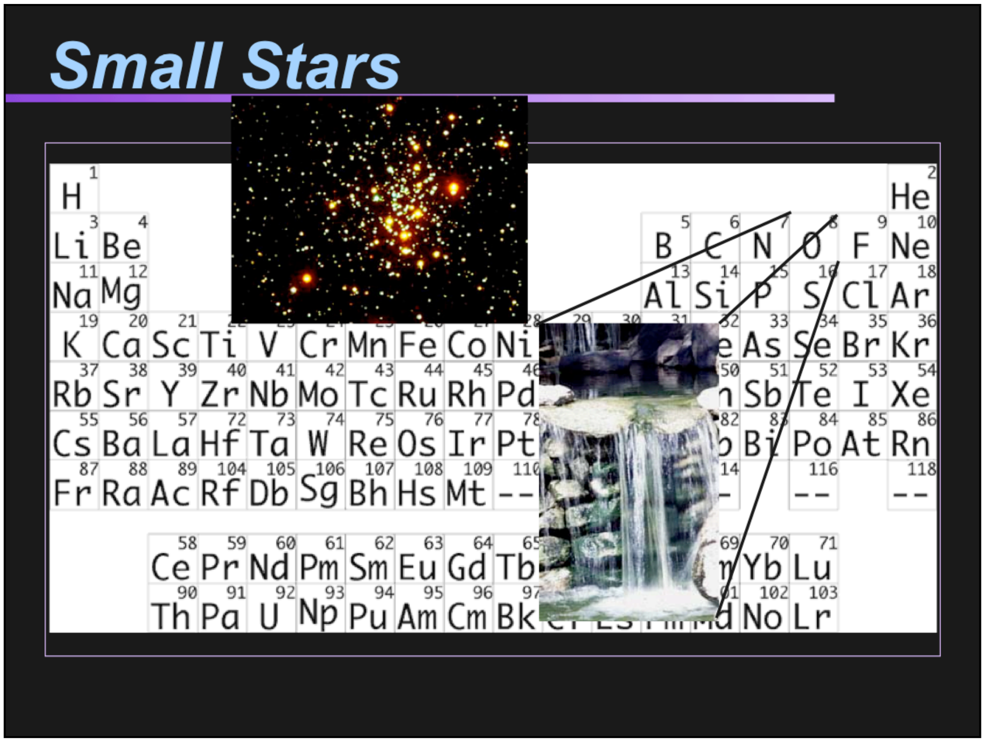
Big Bang Nucleosynthesis

Note that the only elements that come from the Big Bang are:

Hydrogen

Helium

Lithium (a little bit)



So where do we get the rest of these elements?

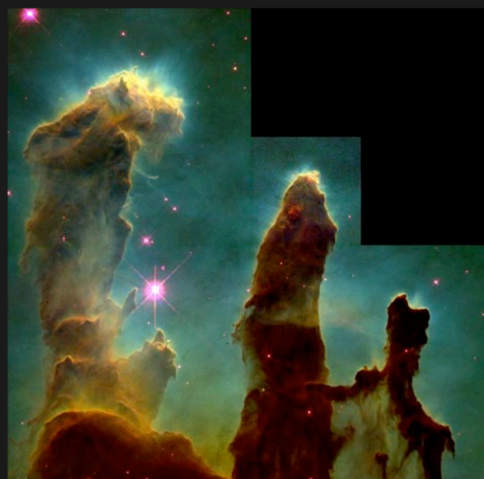
Let's move along, to small stars. What do we mean by "small"?

Well, only in astronomy can you call something 2 x 10^30 kg "small"! Our Sun is a small star, and so are stars smaller than about five times the mass of our Sun. These stars run on similar processes, and share a similar fate.

[click to show waterfall]

These small stars form Helium, Carbon, Nitrogen, and Oxygen in their cores through FUSION

Stellar Nursery



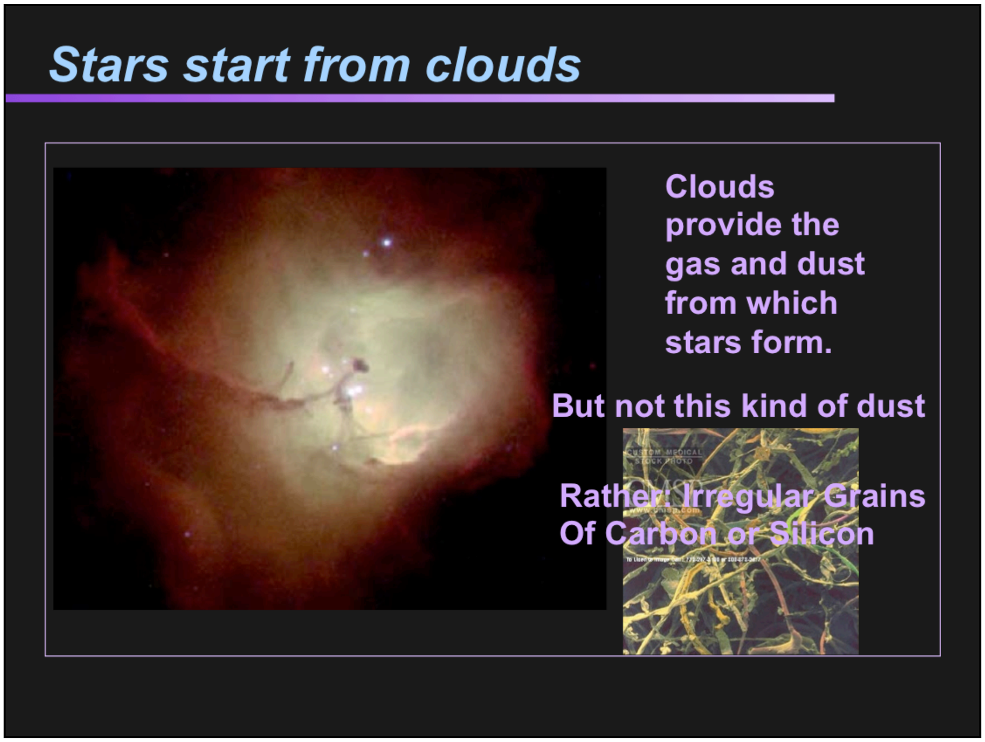
Space is filled with the stuff to make stars.

M16 - Eagle Nebula Pillars

(from Hubble, http://oposite.stsci.edu/pubinfo/PR/95/44.html

These are columns of cool interstellar hydrogen gas and dust that are also incubators for new stars. Dense clouds of molecular hydrogen gas (two atoms of hydrogen in each molecule) and dust that have survived longer than their surroundings in the face of a flood of ultraviolet light from hot, massive newborn stars (off the top edge of the picture).

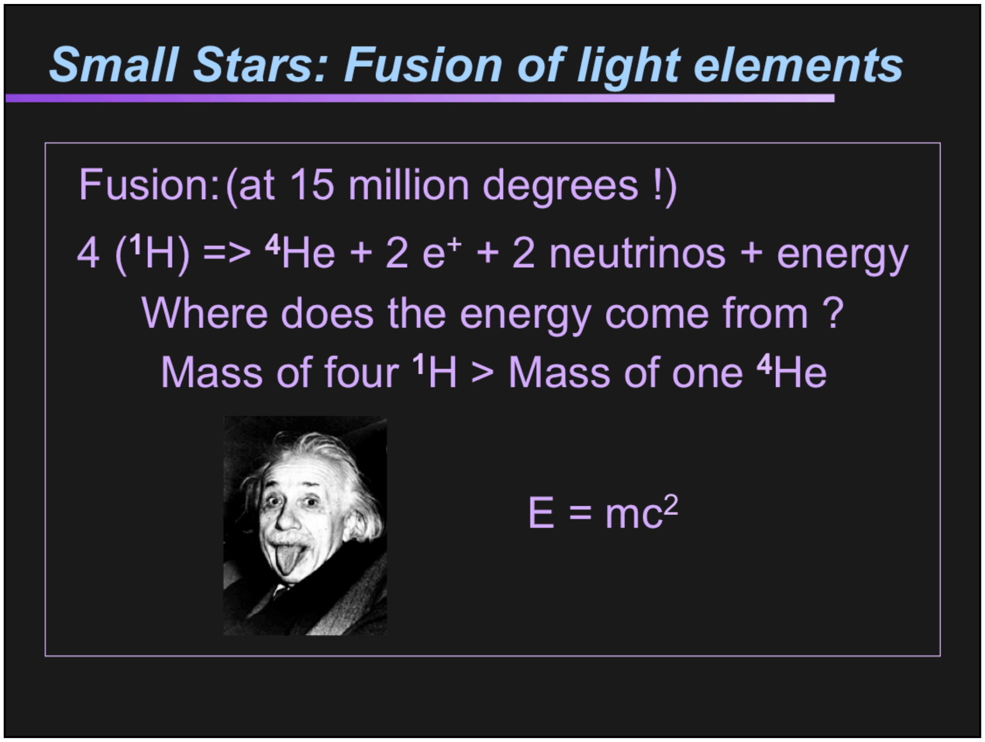
As the pillars themselves are slowly eroded away by the ultraviolet light, small globules of even denser gas buried within the pillars are uncovered. These globules have been dubbed "EGGs." EGGs is an acronym for "Evaporating Gaseous Globules," but it is also a word that describes what these objects are. Forming inside at least some of the EGGs are embryonic stars -- stars that abruptly stop growing when the EGGs are uncovered and they are separated from the larger reservoir of gas from which they were drawing mass. Eventually, the stars themselves emerge from the EGGs as the EGGs themselves succumb to photoevaporation.



N81 from Hubble Heritage - stellar nursery in SMC. These are massive stars whose stellar winds are hollowing out the nebula. Cooler clouds of molecular H and dust are silhouetted against the nebula. It offers a look at the turbulent conditions accompanying the birth of massive stars. See http://heritage.stsci.edu/public/2000oct5/n81table.html

Another candidate would be the Hubble Heritage image of Hubble-X in NGC 6822 (also a site of formation of massive stars). See http://heritage.stsci.edu/public/2001jan/table.html

Household dust is made up of skin, hair, cloth fibers, plants, spider silk, bits of sand and soil. This image is taken from the collection at http://catalog.cmsp.com/datav3/cg060001.htm



[Click to reveal "Fusion."]

Elements in small stars are formed through FUSION. At what temperature does fusion start? Does anyone remember?

[let people "bid" on the temperature until ~15 million degrees]

[Click to reveal answer]

Why does it after to be that hot?

[To overcome the electrostatic repulsion of the positive protons.]

[Click for equation.]

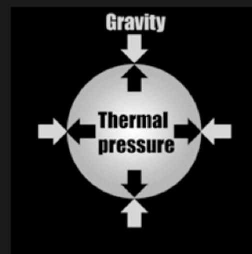
These small stars fuse Hydrogen into Helium in their cores.

The energy comes from the slight excess of mass of the 4 input H as compared to the resulting He. The mass gets converted into energy via E=mc^2

Small Stars to Red Giants

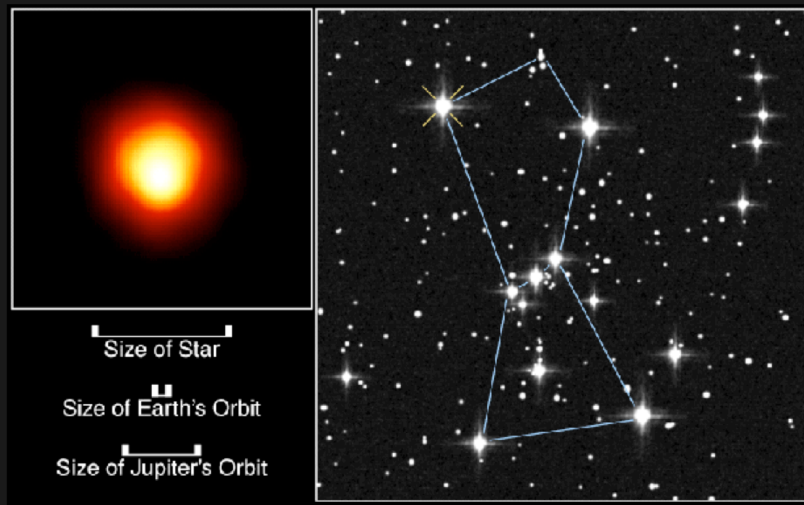
After Hydrogen is exhausted in core,

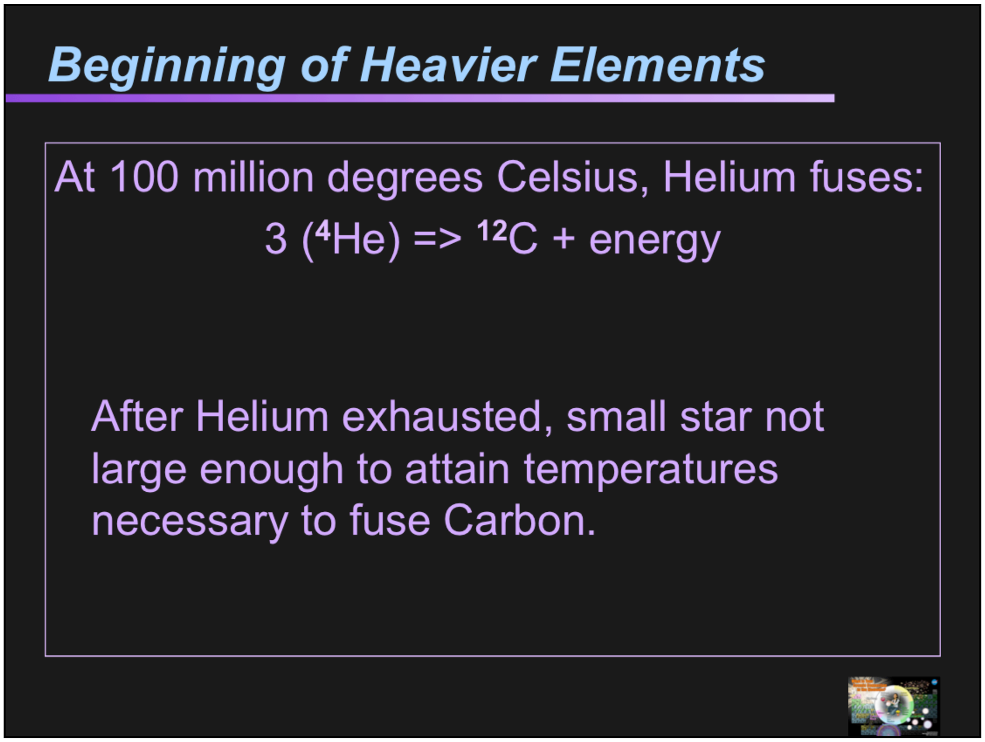
Energy released from nuclear fusion no longer counter-acts inward force of gravity.



- Core collapses,
  - Kinetic energy of collapse converted into heat.
  - This heat expands the outer layers.
- Meanwhile, as core collapses,
  - Increasing Temperature and Pressure ...

A Red Giant You Know





The core continues to increase in temperature and pressure, reaching 100 million degrees. At this temperature, it is hot enough to fuse Helium into Carbon. The energy from this fusion keeps the star from collapsing. Nitrogen and Oxygen fuse in a similar way.

But eventually, the core runs out of materials again, and we don’t make any heavier elements. In fact, this cycle ends with another core collapse, expelling the extended atmosphere as a planetary nebula.

So where do we get the heavier elements? At this point, we only have Hydrogen, Helium, Carbon, Nitrogen, and Oxygen.

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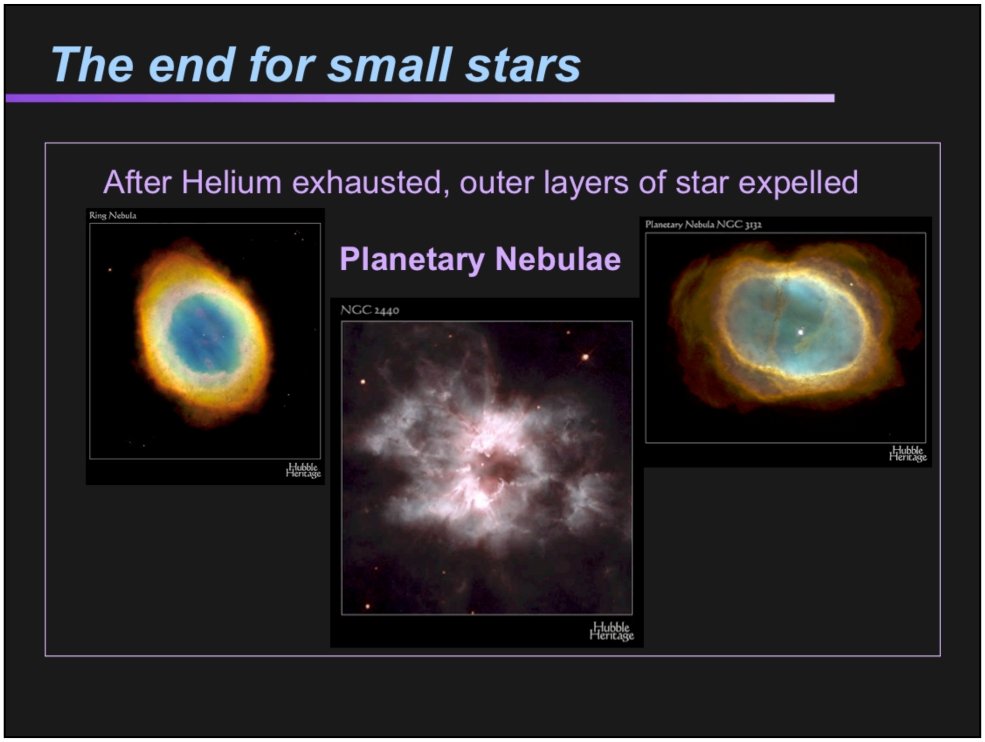
Click on the poster icon in the lower right to return to slide #6.



Planetary nebula - after He consumed, core collapses again. Outer atmosphere expelled, and then ionized (I.e. glows) by the hot remaining core

From Left to Right:

Ring Nebula - true colors, representing different elements. helium (blue), oxygen (green), and nitrogen (red).

NGC 2440 - The central star of NGC 2440 is one of the hottest known, with surface temperature near 200,000 degrees Celsius. The complex structure of the surrounding nebula suggests to some astronomers that there have been periodic oppositely directed outflows from the central star, but in the case of NGC 2440 these outflows have been episodic, and in different directions during each episode. The nebula is also rich in clouds of dust, some of which form long, dark streaks pointing away from the central star. In addition to the bright nebula, which glows because of fluorescence due to ultraviolet radiation from the hot star, NGC 2440 is surrounded by a much larger cloud of cooler gas which is invisible in ordinary light but can be detected with infrared telescopes. NGC 2440 lies about 4,000 light-years from Earth in the direction of the constellation Puppis.

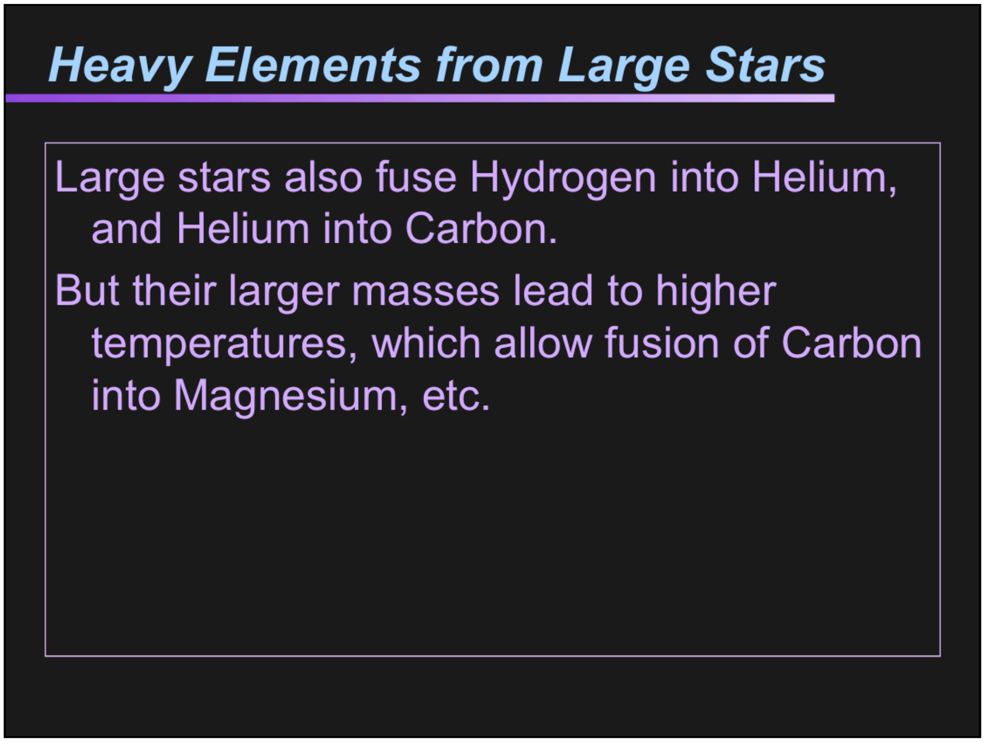
NGC 3132 - colors represent temperatures. Filaments made of dust condense out from the cooling gas. These filaments are rich in carbon

[Images from Hubble Heritage: http://heritage.stsci.edu/public/gallery/

Large stars continue where small stars leave off.
These are stars larger than 5 times the mass of our Sun.

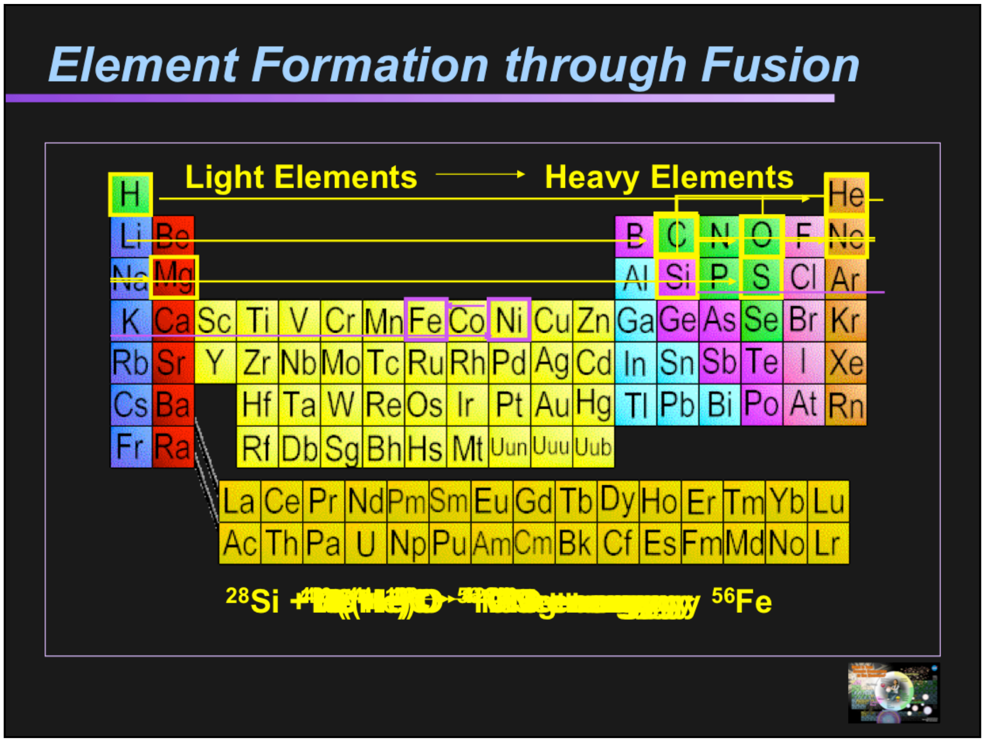
[Click twice to reveal Calcium and Aluminum examples.]

Large stars create many of the heavier elements beyond what the small stars produce, like the Calcium in milk and the Aluminum in cans.



Just like small stars, large stars fuse Hydrogen into Helium, and Helium into Carbon.

But the larger mass leads to higher temperatures, and a series of core collapses create heavier elements through fusion.



This periodic table demonstrates the fusion reactions in large stars. [click] Notice that we’re always moving from lighter to heavier, from left to right.

We’ve seen (click #1) $^{1}H \rightarrow {}^{4}He$ and (2) $^{4}He \rightarrow {}^{12}C$.

These are further representative reactions that occur in massive stars:

(3) Carbon to Magnesium (^{12}C -> ^{24}Mg)

(4) Helium and Carbon to Oxygen ($^{4}He + {}^{12}C$ -> ^{16}O)

(5) Oxygen to Silicon (^{16}O -> ^{32}Si) or Oxygen to Sulfer and He

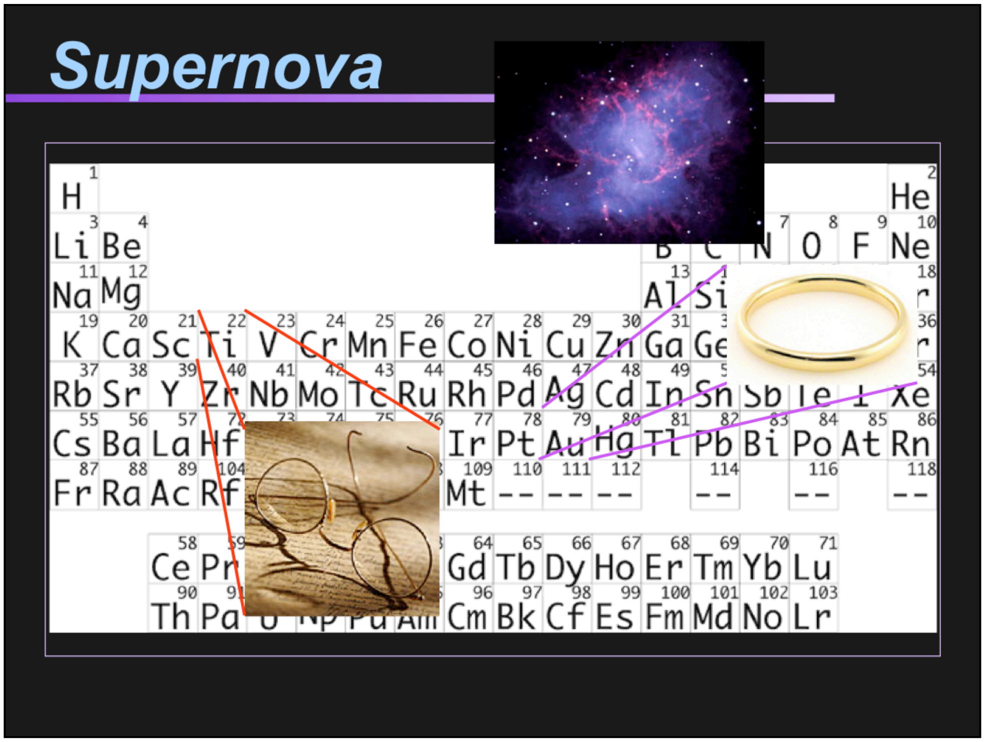
(6) Helium and Oxygen to Neon ($^{4}He + {}^{16}O$ -> ^{20}Ne)

(7) Helium and Silicon to Nickel (which decays to Cobalt and then to Iron via successive positive beta decays) ($^{28}Si + 7(^{4}He)$ -> ^{56}Ni -> $^{56}Co + e^{+}$ -> $^{56}Fe + e^{+}$

NEARLY ALL ELEMENTS THROUGH IRON ARE CREATED THROUGH FUSION IN LARGE STARS.

Energy is no longer released in the reactions to form elements heavier than Iron. These heavier elements require the INPUT of energy for creation. Again, we lose the balance between internal pressure and the force of gravity, and the star collapses again.

Click on the poster icon in the lower right to return to slide #6.



The collapse of a large star causes an explosive shock wave, blowing most of the star’s mass into space in a SUPERNOVA.

A supernova is very hot and energetic, and able to create heavier elements than fusion created in the star’s core.

[Click to reveal Gold and Titanium.]

The input of energy needed the create elements beyond Iron is available in the supernova. From this we get the remaining naturally occurring elements, like the Gold in jewelry and Titanium in glasses frames.

Supernova !

SN1987A before and after image from Anglo-Australian Observatory. It's in the LMC, 160,000 light-years distant.

When fusion process no longer produces energy to support the star, the core of the star collapses. With nothing to stop it, the atoms are crushed together, and the infalling material bounces off the superdense core, causing the explosion.

A supernova produces 10^{40} erg/s (a million times more than the sun). The supernova disperses the elements it has created. In addition, the energy of the explosion creates elements heavier than iron.

Supernova

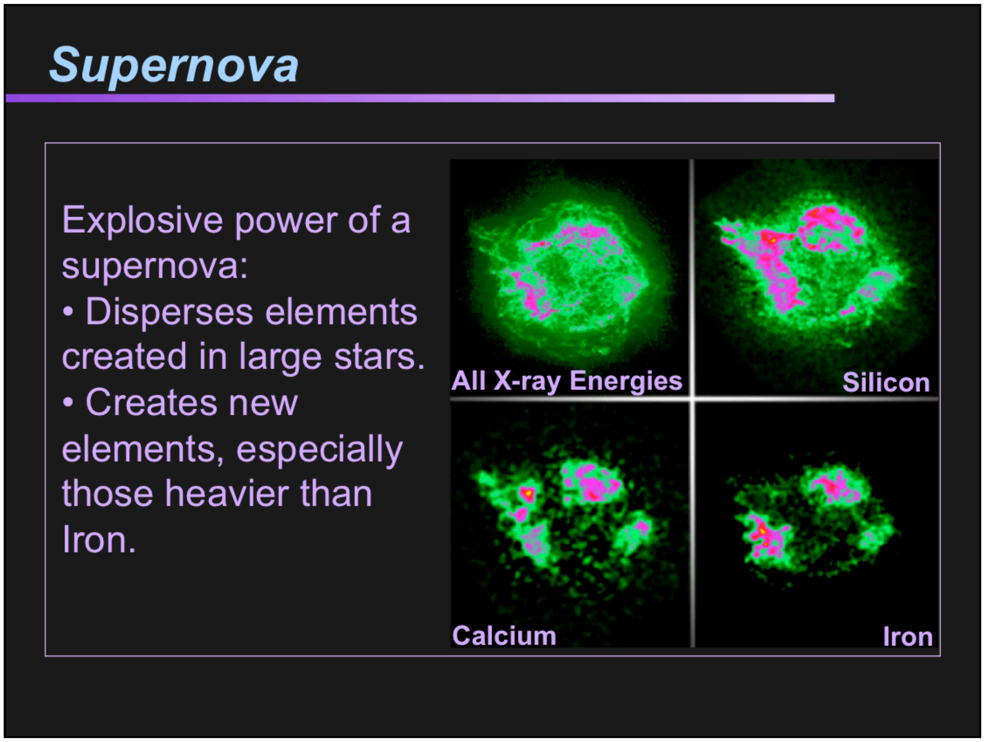
Fusion of Iron takes energy, rather than releases energy.

So fusion stops at Iron.

Energy released from nuclear fusion no longer counter-acts inward force of gravity.

But now there is nothing to stop gravity.

Massive star ends its life in supernova explosion.



Supernovae are able to do two very important things:

(1) Create new, heavier elements.

(2) Disperse the elements that were created in the star that exploded.

These images are from Chandra, showing the Cassiopeia A supernova remnant in different x-ray energies. These images show the distribution of elements ejected in the explosion. They are part of a gas that's about 50 million degrees.

In these images, yellow regions show the most intense concentration, followed by red, purple, and green.

The upper left image is from all X-ray energies, and the others are centered on the lines of particular elements (Silicon, Calcium, and Iron).

Note the asymmetry, especially in silicon, possibly due to an asymmetry in the explosion. The iron image suggests that the layers of the star were overturned either before or during the explosion.

Click on the poster icon in lower right to return to slide #6

[All images are 8.5 arc minutes on a side (28.2 light years for a distance to Cas A of 11,000 light years).]

From Death comes Life

Supernovae compress gas and dust which lie between the stars. This gas is also enriched by the expelled material.

This compression starts the collapse of gas and dust to form new stars.

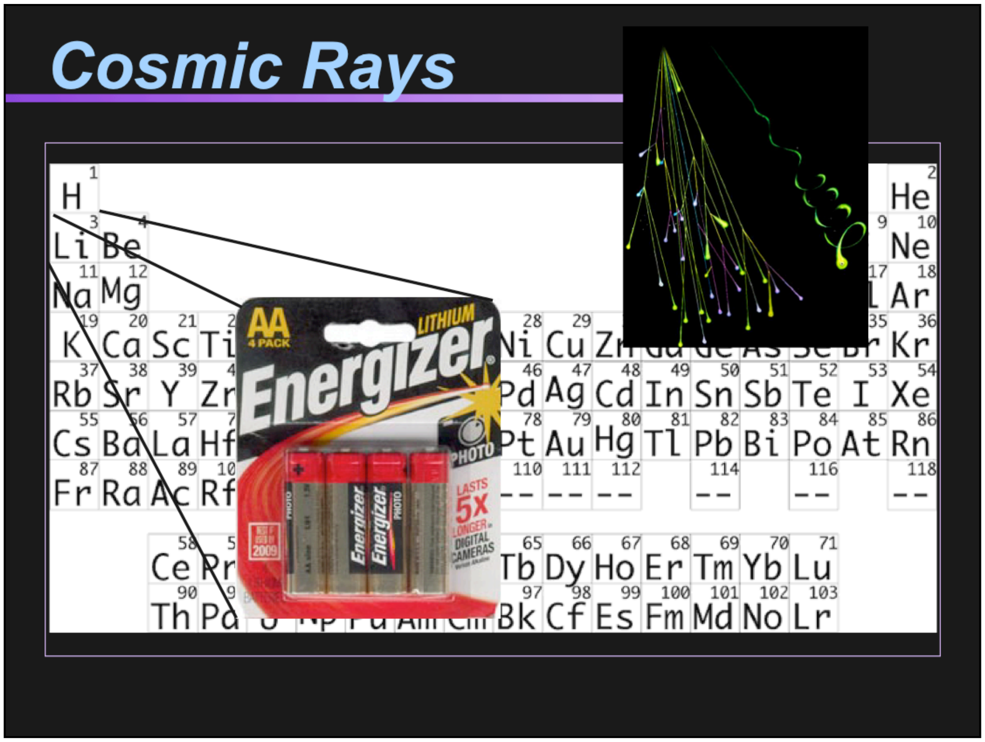
Shocks from SN's cause collapse of clouds in the ISM and it starts over.

Astronomers call 2nd generation stars Population I stars

Image:

Hodge 301 is the cluster of massive stars in the lower right of this image of the Tarantula Nebula. It lies in the LMC. Many of the stars in Hodge 301 are so old that they have exploded as supernovae. These stellar explosions have blasted material out into the surrounding region at high speeds. As the ejecta plow into the surrounding Tarantula Nebula, they shock and compress the gas into a multitude of sheets and filaments, seen in the upper left portion of the picture. Also present near the center of the image are small, dense gas globules and dust columns where new stars are being formed today, as part of the overall ongoing star formation throughout the Tarantula region. These features are moving away from Hodge 301 at speeds of more than 200 miles per second. Hodge 301 is also bathed in the X-rays resulting from the shocks of all its supernovae.

The Hubble Image of Hodge 301 is from http://heritage.stsci.edu/public/gallery/galindex.html



Did anyone notice that we missed a few elements?

We get H and He from the Big Bang, and C through Iron in stars, and heavier elements from supernovae… what did we miss?

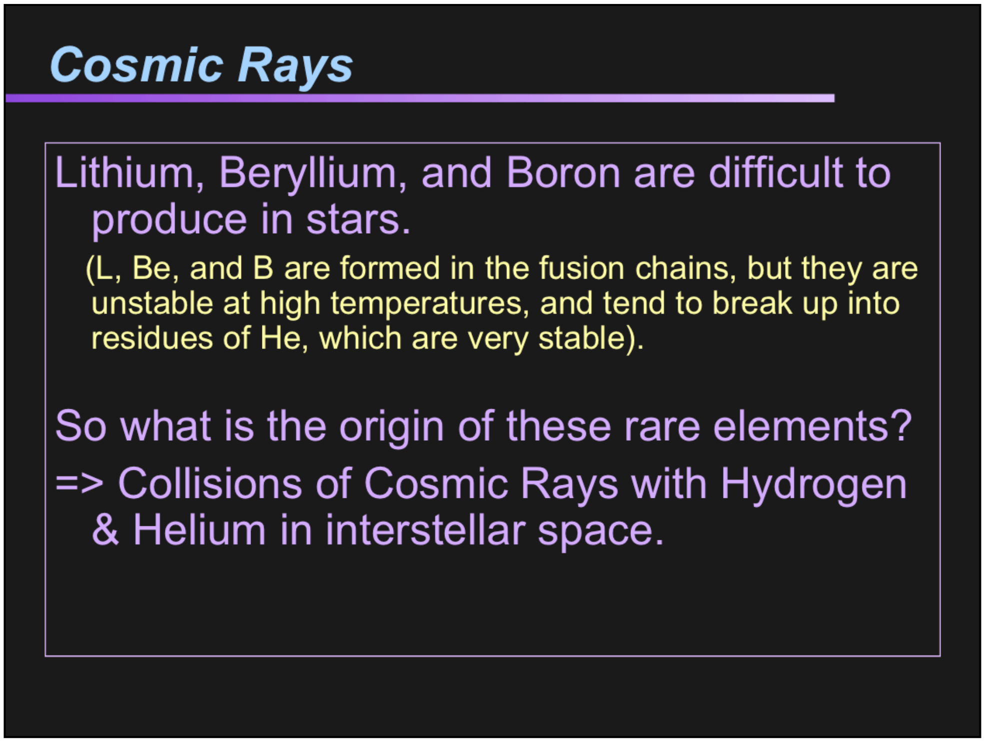
LITHIUM, BERYLLIUM, AND BORON!

[Click to reveal Lithium batteries.]

These elements are mostly formed through cosmic ray interactions.

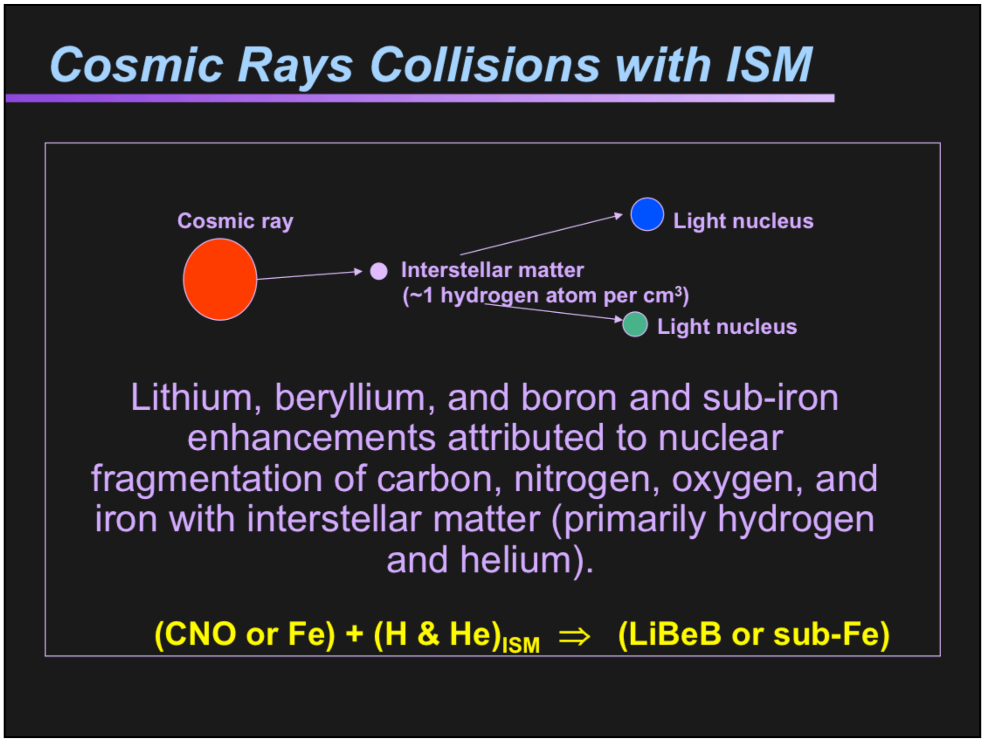
What are cosmic rays?

Cosmic rays are high-energy particles moving through space at velocities close to the speed of light. They're little bits of matter, often the nuclei of the elements, most likely sent zinging through space by supernova explosions (or perhaps stellar winds).



Lithium, Beryllium, and Boron are formed in stars, but they're very unstable at the high temperatures in the core of stars. Therefore, they break down quickly into Helium.

These elements are predominantly created through the collision of cosmic rays with the atoms of Hydrogen and Helium found in interstellar space. When cosmic rays hit atoms, they produce new elements.



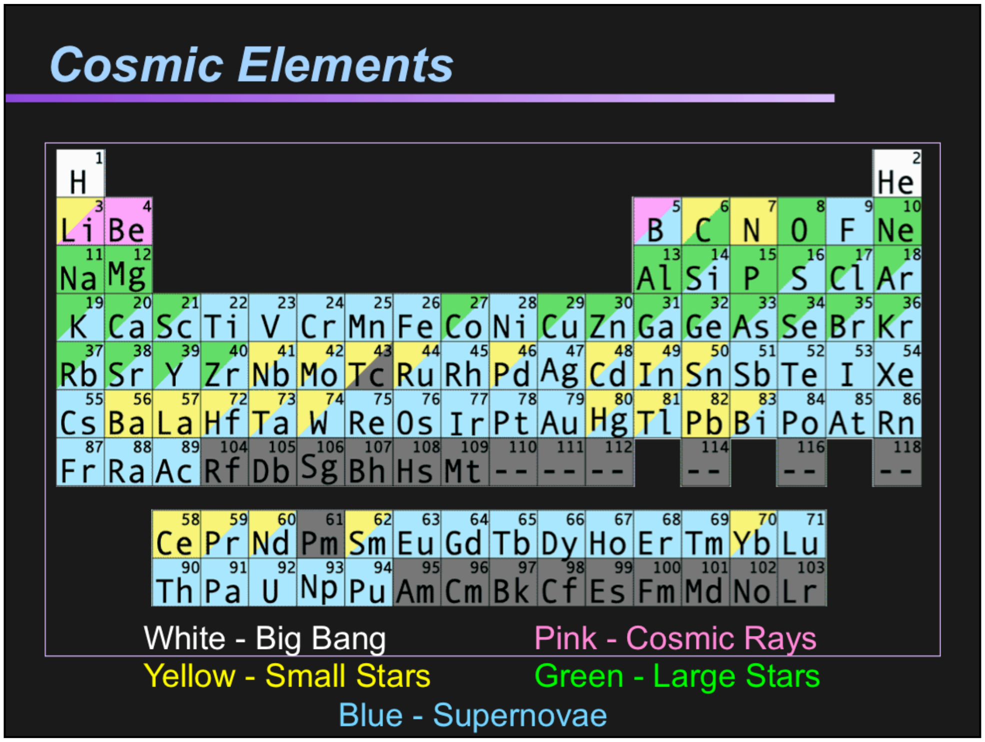
The cosmic rays are travelling so fast through space, it hits the Hydrogen or Helium with a lot of force, and parts of its nucleus can be "chipped off."

Here's a diagram of such a collision!

When the cosmic ray hits the Hydrogen or Helium, it fragments into two smaller, lighter nuclei.

In the equation at the bottom of this slide, Carbon, Nitrogen, Oxygen, or Iron nuclei collide with Hydrogen or Helium in the interstellar medium to create lighter elements -- Lithium, Beryllium, Boron, or other elements lighter than Iron.

So these interactions create elements that weren't stable enough to be created at the high temperatures required for fusion in a star.

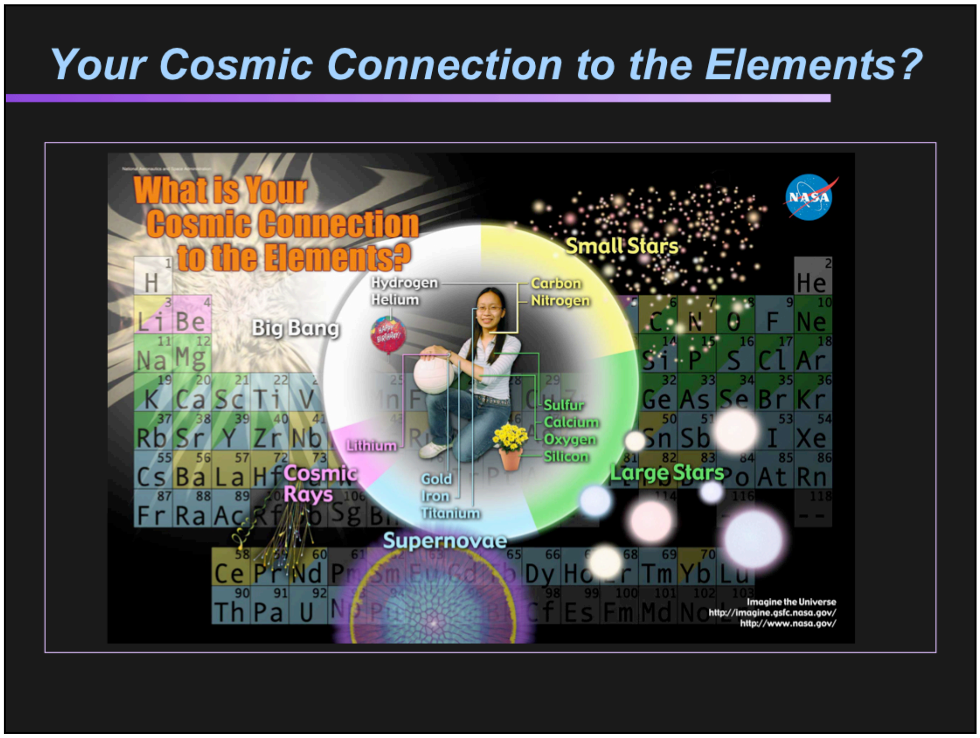


This is a summary of the major production mechanisms for each of the elements. Note that it is the background for the poster.

Many elements are generated from more than one process, and where there are two nearly equal contributors (each contributing at least 30% of the abundance), we gave the element two colors.

This table presents a slightly more complicated story than the narrative for the talk. Small stars contribute to some of the heavier elements through the process of neutron capture in Asymptotic Branch Giants, a stage in the life cycle of “small” stars with masses 2-8 times that of the sun. In the core of this Giant, free neutrons may be captured by heavy elements (e.g. Iron) existing in the core. After enough neutron captures, the core becomes unstable, with the neutron decaying into a proton and electron, producing a heavier element (e.g. Fe -> Co). Conditions in these Giants are right to produce elements from niobium to bismuth.

7Li is also made in AB Giants. (6Li is made via Cosmic Ray interactions)



The poster draws together all of the ideas in this presentation.

We' re in the center, surrounded by all sorts of everyday objects (glasses, balloon, plants, etc.).

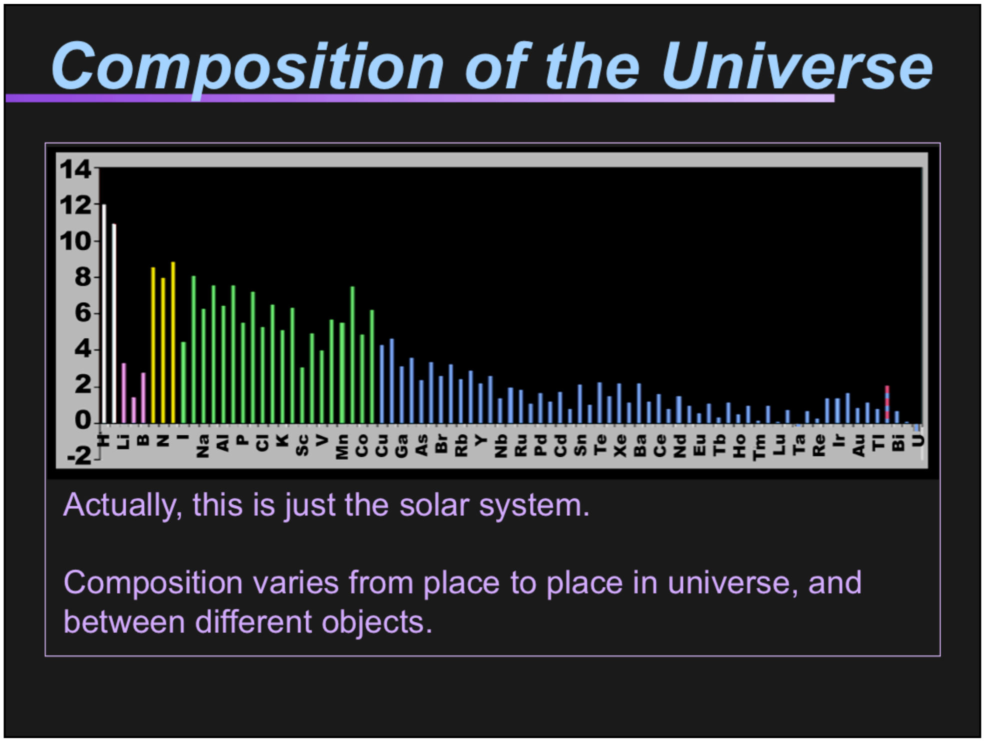
These objects demonstrate our connection to the elements of which they are composed.

The background is the periodic table, which represents all of the elements.

And the sphere around the center connects the elements (and the objects) to the cosmic processes which created them!

So we are all made of stars (or at least of space)!

Note that the back of the poster has some of the basic information from this presentation for a quick guide to the poster.



This is a graph of elemental composition.

The vertical scale is logarithmic, with H arbitrarily set to 10^12 so that the elements with the lowest abundance still have a value of 10^0, or 1.

So this scale reflects powers of ten -- Hydrogen is at 10^12, Helium is around 10^11, and so on.

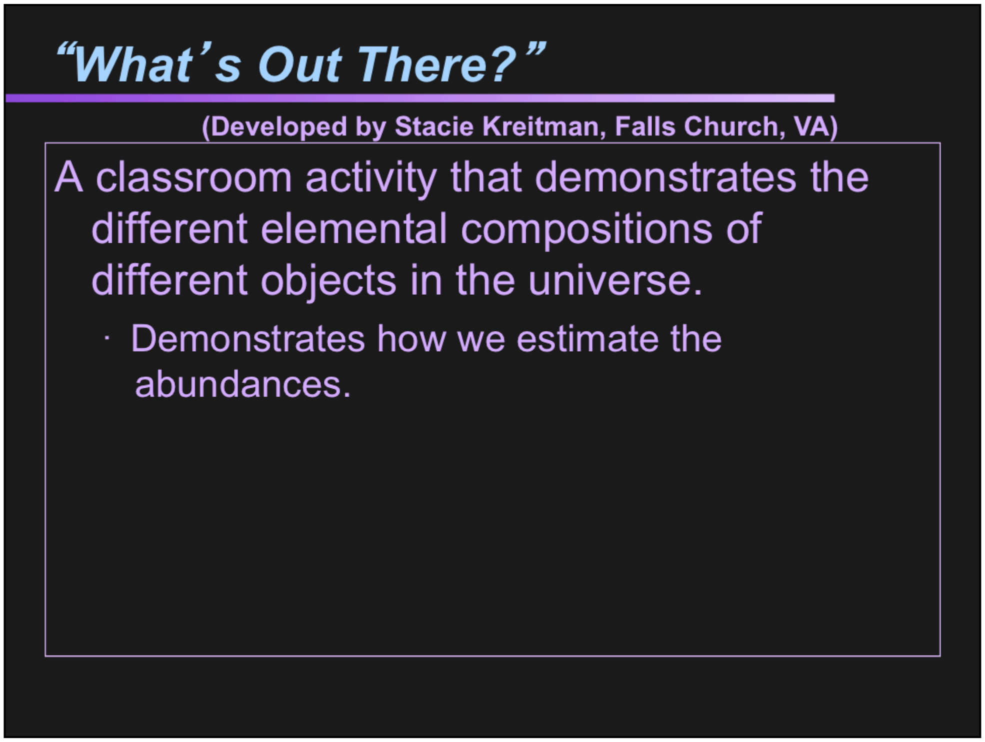
This is color-coded in a simple manner, and does not reflect the complexities of the 2005 revision.

You can see the big peaks for Hydrogen and Helium, both produced in the Big Bang. There's a dip for Lithium, Beryllium, and Boron because they're not really produced through fusion, but by cosmic ray interactions. From there, there's a relatively steady decrease in abundance, moving through the elements made in small stars to the ones only made in large stars, then supernovae…

[Lead is striped to show creation by radioactive decay.]

[Click for the text!]

This is really just the solar system! It's hard to get a picture like this for the whole universe -- composition varies in different areas of the universe. Our solar system makes a nice model.



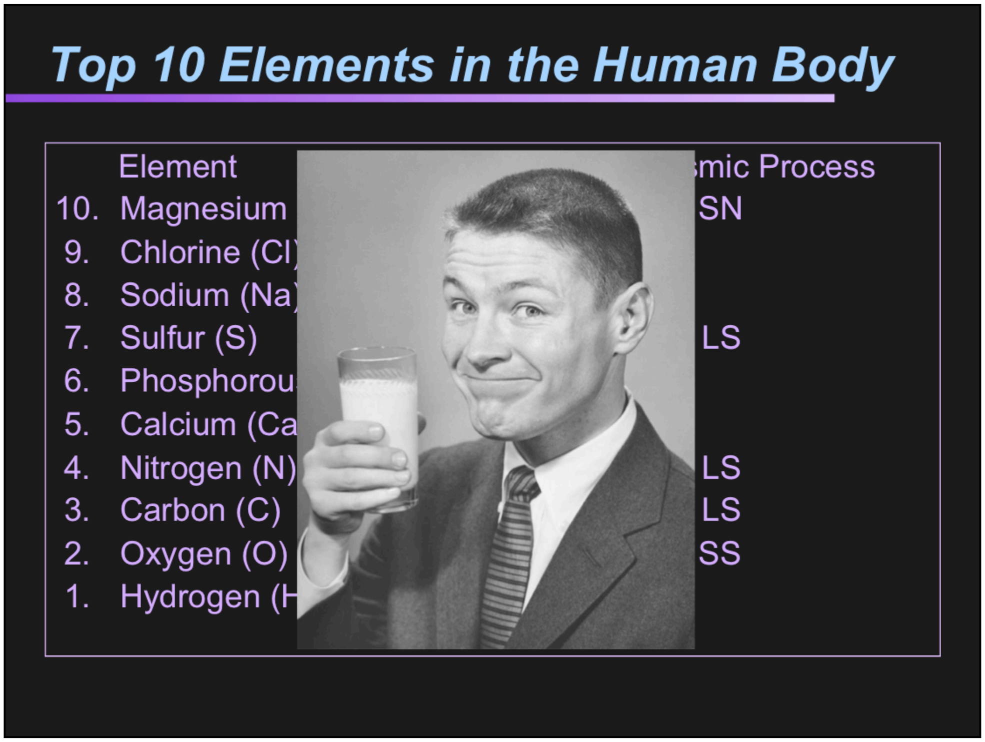
Allow 10-15 minutes for the activity.

Participants are given bottles which model the elemental composition of the Sun, the interstellar medium, carbonaceous Chondrites (meteorite), the earth’s atmosphere, and the elements formed in a supernova explosion. Participants are also given a key as to what element each substance represents, and the abundances in each substance.

Give 1 bottle to each group of 2-3. After they’ve all had time to determine what they have, have each group say what they have and how they determined that.

The activity includes a “mystery” bottle with a substance not listed on the key. Those groups should first share what they think the composition is. Then the entire audience can attempt to determine what the substance is.

See http://imagine.gsfc.nasa.gov./docs/teachers/elements/ for the activity.



Source: http://www.sciencenet.org.uk/database/Biology/9608/b00600d.html

Element	Symbol	%	Notes
Oxygen	O	65.0	Water; organic compounds
Carbon	C	18.5	Organic compounds
Hydrogen	H	9.5	Water; organic compounds
Nitrogen	N	3.2	Part of all protein molecules
Calcium	Ca	1.5	Bones/teeth; clotting; hormones
Phosphorous	P	1.0	Nucleic acids/ATP; bones/ teeth
Sulfur	S	0.3	Component of many proteins
Chlorine	Cl	0.2	Water movement between cells
Sodium	Na	0.2	Water balance; extracellular fluid
Magnesium	Mg	0.1	Muscle contraction and nerves
Iodine	I	<0.1	Production of thyroid hormone
Iron	Fe	<0.1	Basic component of hemoglobin

Elements that make up less than 0.1% of the body are "trace elements", like:
Some trace elements are:

cobalt	copper	fluorine

What’s Your Cosmic Connection to the Elements?

Betelgeuse - Red Giant - As a red supergiant, it is making heavy elements starting with helium burning.

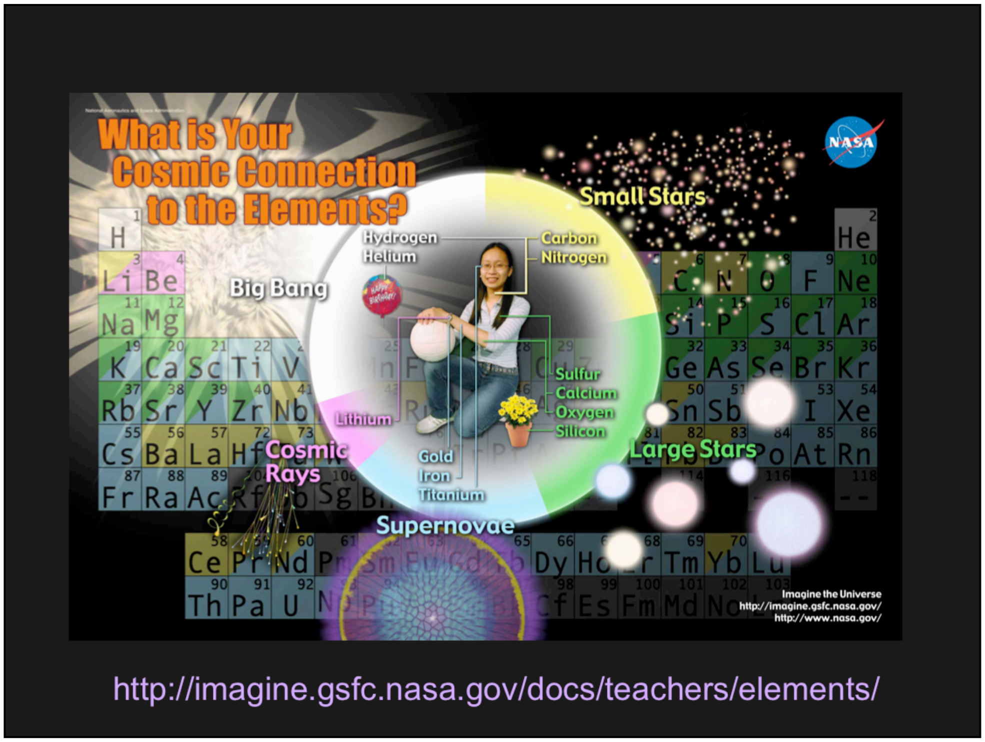
Pi-3 - Slightly more massive than our sun. Likely CNO cycle

Rigel - Blue supergiant. Currently steady fusion but someday supernova

Orion Nebula - stellar nursery.

Consider ending with the end of Frost’s “Star Splitter:

“After all, where are? Do we know any better where we are? …”



You can end by explaining the poster:

The girl in the middle is us.

We are surrounded by objects familiar with us. Each of these objects is composed of one or more elements.

These elements are connected (via color coding) to their cosmic origin.

The pie sections along the edge of the "bubble" are related to the "logarithmic" abundances of the elements made by that process in the universe.

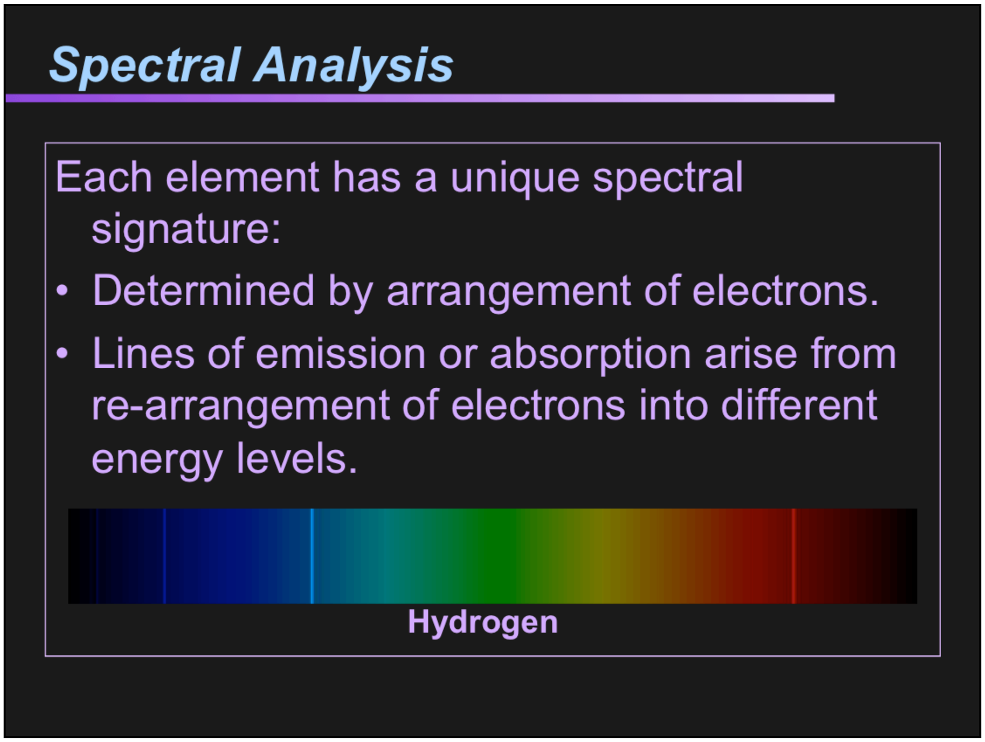
Check out the website at the bottom of this slide for this presentation and more activities and materials. The web site contains an on-line version of the booklet which accompanies these materials, and a link to an order form for requesting a hard copy of the poster and booklet.

So we have pondered this question, and hopefully we have some better ideas about the answer.

Spectral Analysis

We can't always get a sample of a piece of the Universe.

So we depend on light !

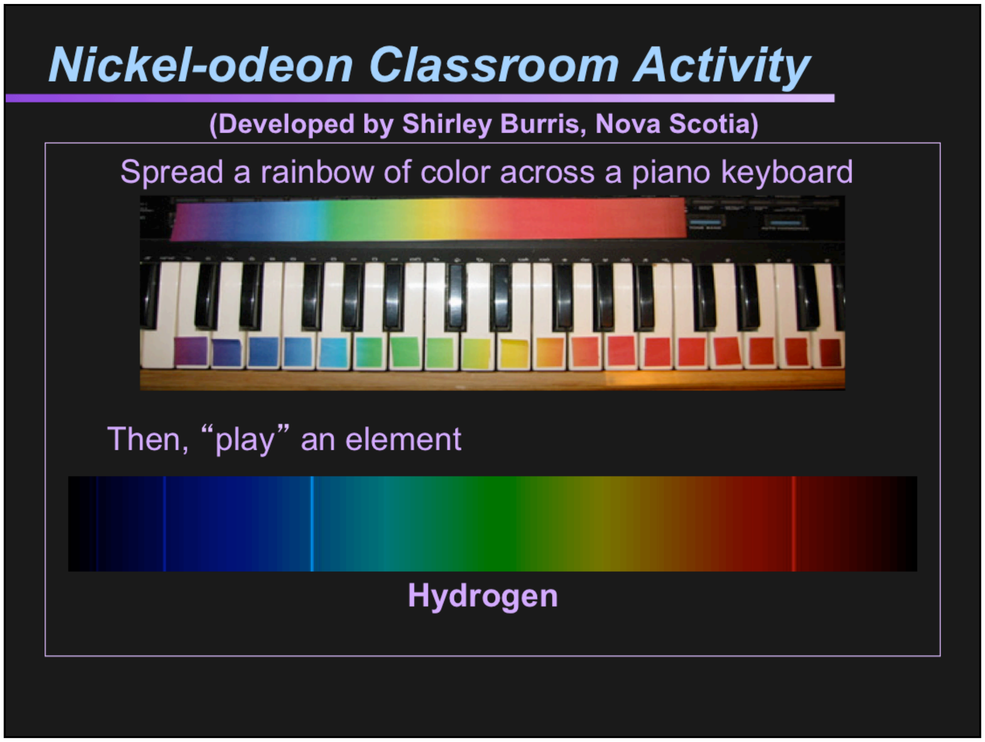


Composition is usually determined through spectroscopy. Each element gives off a unique “signature” of specific wavelengths of light, which we see as bright lines in its spectrum.

By measuring the relative intensities of the lines from different elements, we can determine their abundance in an object being observed.

The optical spectrum of H shows the Balmer lines - transitions to/from the n=2 electron shell. From red to blue, this spectrum shows H-alpha (transition from n=3 to n=2), H-beta (transition from n=4), H-gamma (transition from n=5), and H-delta (faintly).

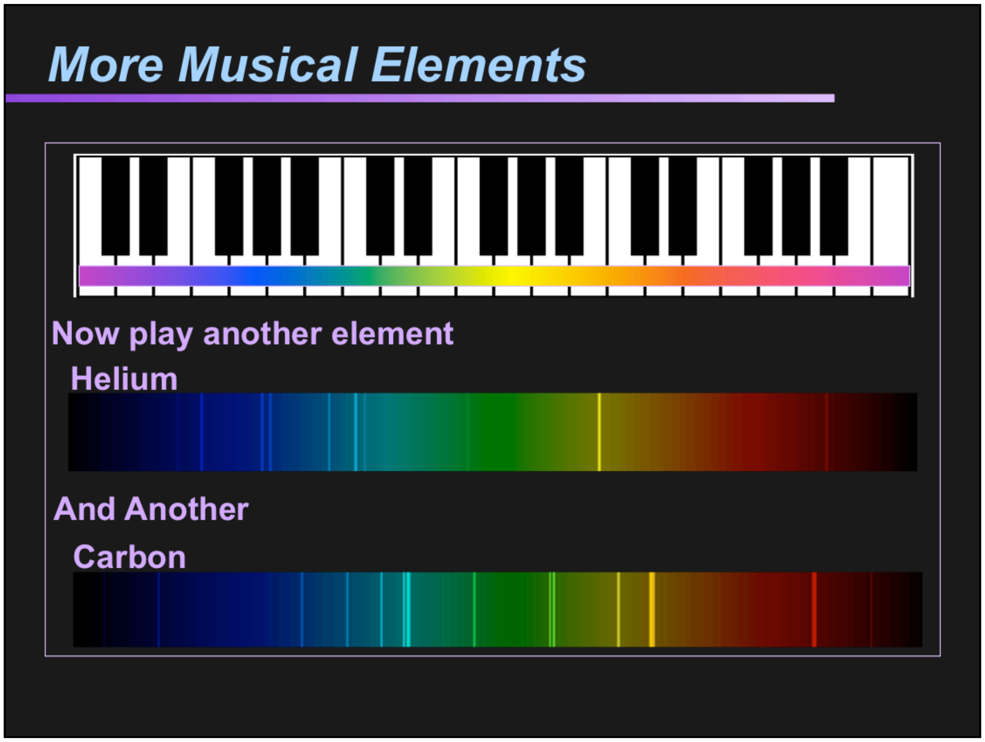
We’re used to seeing these spectra. What if you could hear them ?



Print a colored spectrum, cut it into strips, and lay the strips on the keys of a musical keyboard.

Then put down the emission spectrum of an element, and line up the lines with the keys.

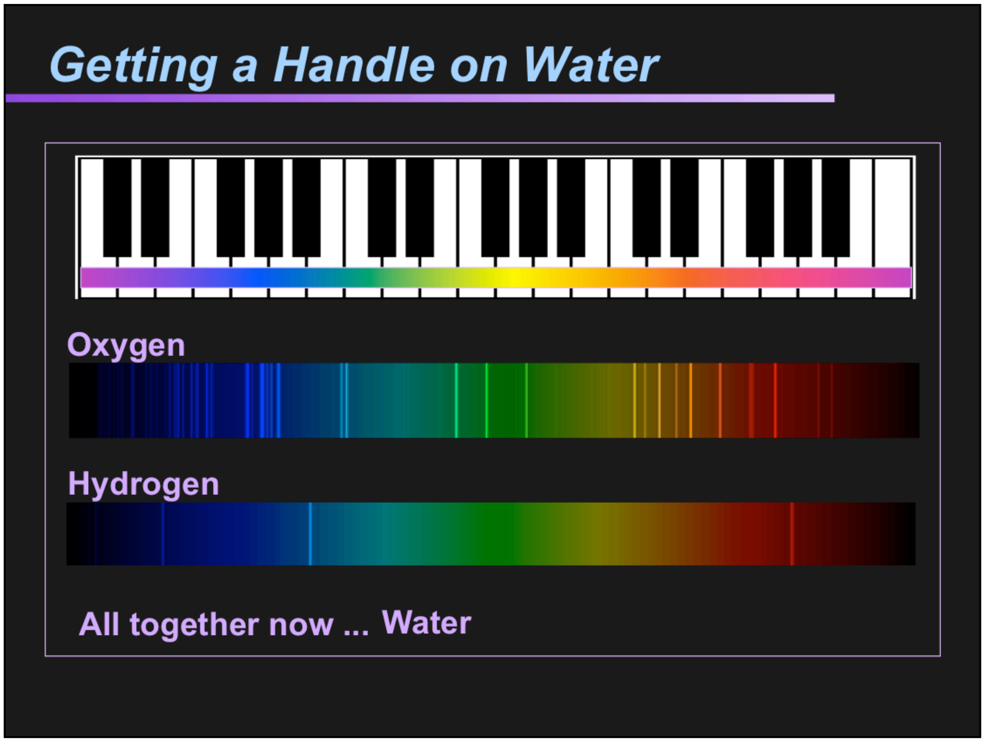
Then play the element.



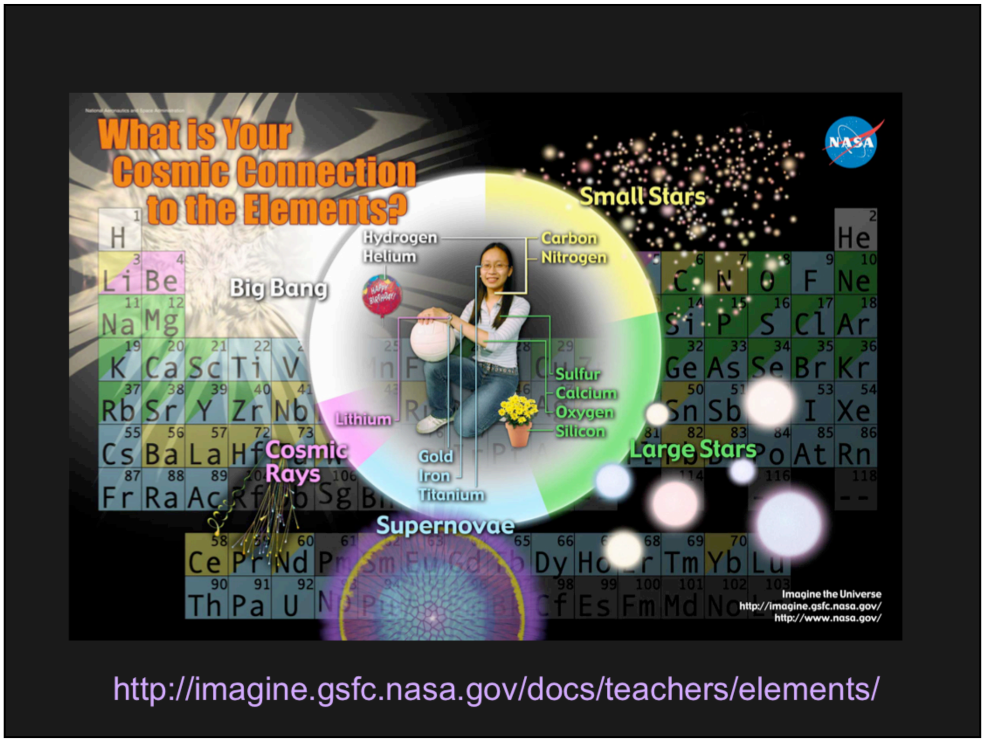
Play helium. Go back and play H again, and ask them to listen for the difference. The difference arises from the yellow-green line.

After you play carbon, note that you can play the elements either as chords (as we did) or as individual notes up the scale. Also note that you can place the spectrum any where you want, but around middle C is usually best.

The chords won't sound familiar, which is good, because you want participants (and students) to listen for the differences (rather than for something they recognize).



You can now combine elements, either to create molecules or to create the substances we analyzed in the bottles.



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