

# Your Cosmic Connection to the Elements

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National Aeronautics and Space Administration

## What is Your Cosmic Connection to the Elements?

**Small Stars**

**Large Stars**

**Supernovae**

**Cosmic Rays**

**Big Bang**

Hydrogen  
Helium

Carbon  
Nitrogen

Sulfur  
Calcium  
Oxygen  
Silicon

Gold  
Iron  
Titanium

Lithium

Imagine the Universe  
<http://imagine.gsfc.nasa.gov/>  
<http://www.nasa.gov/>

1	2																	10	11			
H	He																	Ne	Ar			
3	4																	6	7	8	9	10
Li	Be																	C	N	O	F	Ne
11	12																	14	15	16	17	18
Na	Mg																	Si	P	S	Cl	Ar
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36					
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Cu	Zn	Ga	Ge	As	Se	Br	Kr							
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54					
Rb	Sr	Y	Zr	Nb	Mo	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe						
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Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Po	At	Rn								
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Fr	Ra	Ac	Rf	Db	Sg	Bh	Hl	Tl	Pb	Bi	Po	At	Rn	--								
58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75					
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90	91	92	93	94	95	96	97	98	99	100	101	102	103									
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr									

# Elementary Connections

1 H																	2 He														
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne														
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar														
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr														
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe														
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn														
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	--	--	--		114 --		116 --		118 --														
																		58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
																		90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

# *Cosmic Connections*

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

Carl Sagan

# Your Cosmic Connection to the Elements?

National Aeronautics and Space Administration

## What is Your Cosmic Connection to the Elements?

The pie chart is divided into four segments, each representing a cosmic source of elements:

- Big Bang:** Hydrogen, Helium, Lithium
- Small Stars:** Carbon, Nitrogen
- Large Stars:** Sulfur, Calcium, Oxygen, Silicon
- Supernovae:** Gold, Iron, Titanium

**Cosmic Rays:** (indicated by a separate arrow pointing to the bottom left)

**Other elements shown in the periodic table:** He, Li, Be, Na, Mg, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Kr, Rb, Sr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Xe, Cs, Ba, La, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, Po, At, Rn, Fr, Ra, Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr.

**Other elements labeled in the diagram:** Gold, Iron, Titanium

**Other elements labeled in the diagram:** Carbon, Nitrogen, Sulfur, Calcium, Oxygen, Silicon

**Other elements labeled in the diagram:** Hydrogen, Helium, Lithium

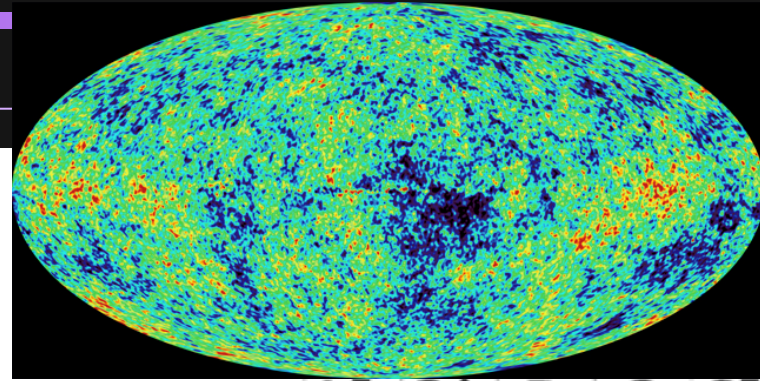
**Other elements labeled in the diagram:** Big Bang, Small Stars, Large Stars, Supernovae, Cosmic Rays

**Other elements labeled in the diagram:** HAPPY BIRTHDAY!

**Other elements labeled in the diagram:** NASA

**Other elements labeled in the diagram:** Imagine the Universe  
<http://imagine.gsfc.nasa.gov/>  
<http://www.nasa.gov/>

# The Big Bang



1																	2														
H																	He														
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																		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr



# *The Big Bang Cosmology*

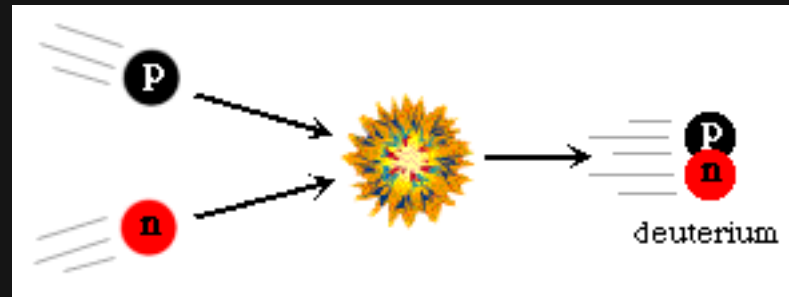
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- The expansion of the universe began at a finite time in the past, in a state of enormous density, pressure and temperature.
- “Big Bang” is a highly successful family of theories with no obvious competitor.
  - Explains what we see, and has made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

# Big Bang Nucleosynthesis

Within first three minutes, Hydrogen & Helium formed.

- At  $t = 1$  s,  $T = 10,000,000,000$  K: soup of particles: photons, electrons, positrons, protons, neutrons. Particles created & destroyed.
- At  $t = 3$  min,  $T = 1,000,000,000$  K:  $p + n \Rightarrow D$



- $D + D \Rightarrow He$

# *Big Bang Nucleosynthesis*

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

Hydrogen

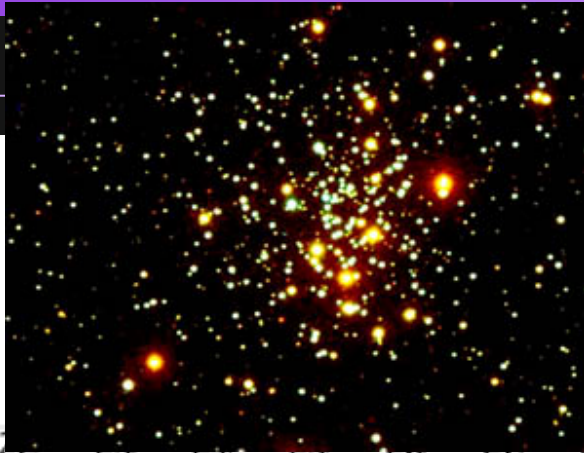
Helium

Lithium (a little bit)





# Small Stars

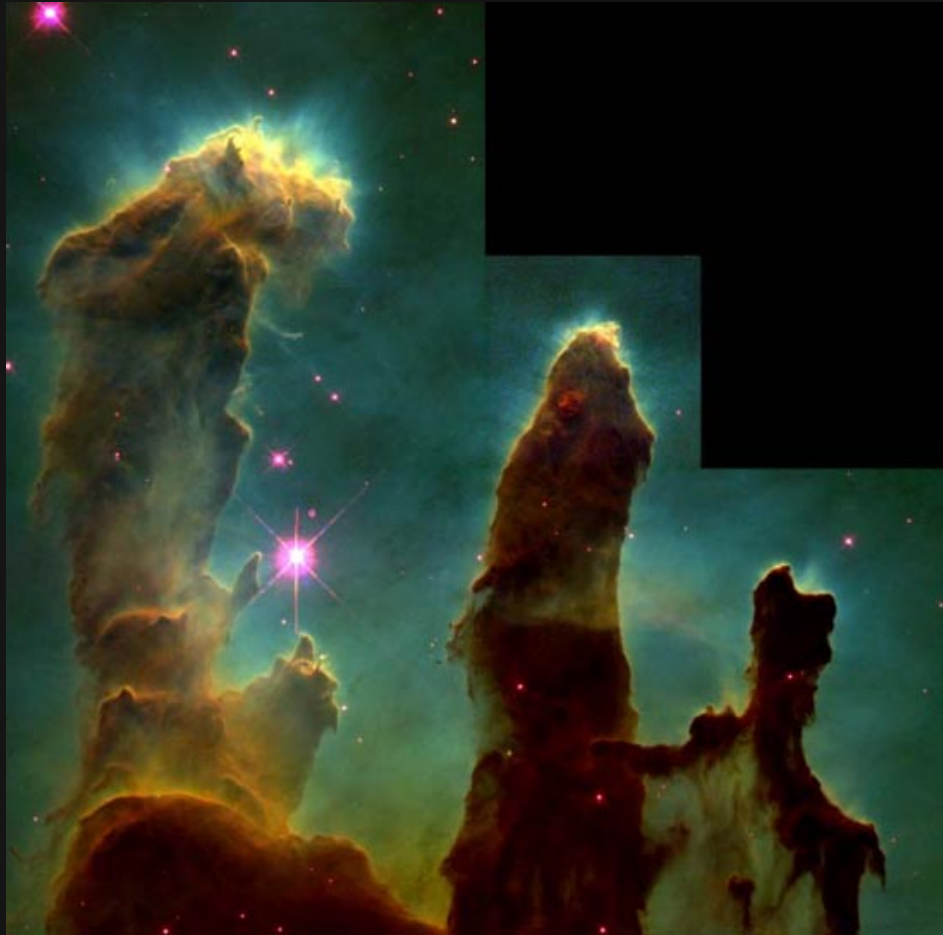


1 H																	2 He				
3 Li	4 Be															5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg															13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
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90 Th									91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr



# *Stellar Nursery*

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**Space is filled  
with the stuff to  
make stars.**

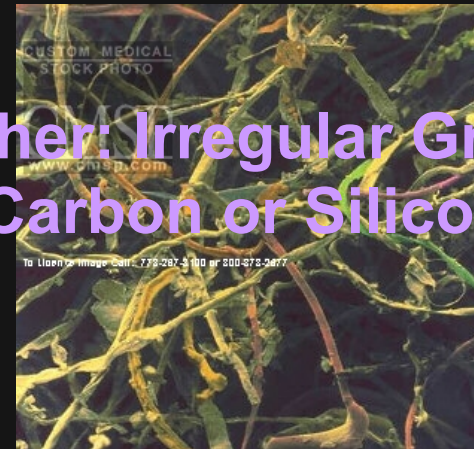
# Stars start from clouds



Clouds provide the gas and dust from which stars form.

But not this kind of dust

Rather: Irregular Grains Of Carbon or Silicon



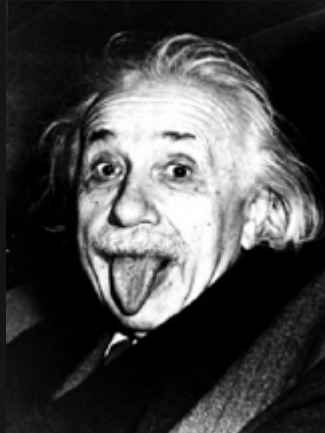
# *Small Stars: Fusion of light elements*

Fusion: (at 15 million degrees !)

$4 \text{ } (^1\text{H}) \Rightarrow \text{}^4\text{He} + 2 \text{ e}^+ + 2 \text{ neutrinos} + \text{energy}$

Where does the energy come from ?

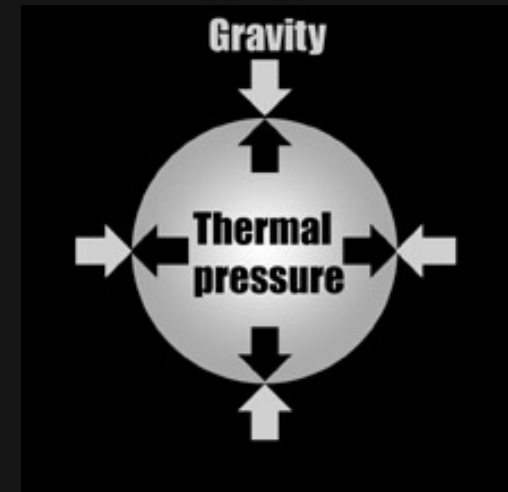
Mass of four  $^1\text{H} >$  Mass of one  $^4\text{He}$



$$E = mc^2$$

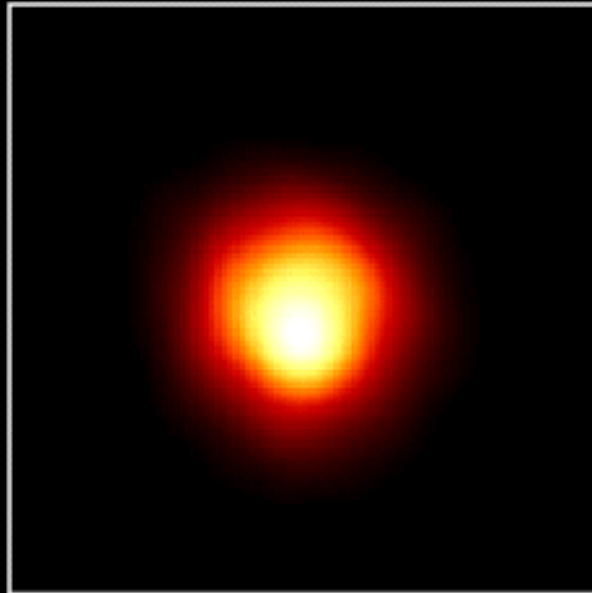
# Small Stars to Red Giants

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*



Size of Star

Size of Earth's Orbit

Size of Jupiter's Orbit



# *Beginning of Heavier Elements*

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At 100 million degrees Celsius, Helium fuses:



After Helium exhausted, small star not large enough to attain temperatures necessary to fuse Carbon.



# The end for small stars

After Helium exhausted, outer layers of star expelled

Ring Nebula



Hubble  
Heritage

## Planetary Nebulae

NGC 2440



Hubble  
Heritage

Planetary Nebula NGC 3132



Hubble  
Heritage



# Large Stars



1																	2									
H																	He									
3	4											5	6	7	8	9	10									
Li	Be											B	C	N	O	F	Ne									
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Fr	Ra	Ac	Rf											Mt	--	--	--			--			--			
			58	59											64	65	66	67	68	69			72	73	74	
			Ce	Pr											Gd	Tb	Dy	Ho	Er	Tm	Yb			Lu		
			90	91											96	97	98	99	100	101	102			106	107	108
			Th	Pa											Cm	Bk	Cf	Es	Fm	Md	No	Lr			--	



# *Heavy Elements from Large Stars*

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Large stars also fuse Hydrogen into Helium, and Helium into Carbon.

But their larger masses lead to higher temperatures, which allow fusion of Carbon into Magnesium, etc.

# Element Formation through Fusion

Light Elements → Heavy Elements

H																	He	
Li	Be											B	C	N	O	F	Ne	
Na	Mg											Al	Si	P	S	Cl	Ar	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
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Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub							
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		



# Supernova



1																	2						
H																	He						
3	4													7	8	9	10						
Li	Be													B	C	N	O	F	Ne				
11	12													13	14	15	16	17	18				
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19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36						
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		90	91													96	97	98	99	100	101	102	103
		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr								



# Supernova !



# Supernova

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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.

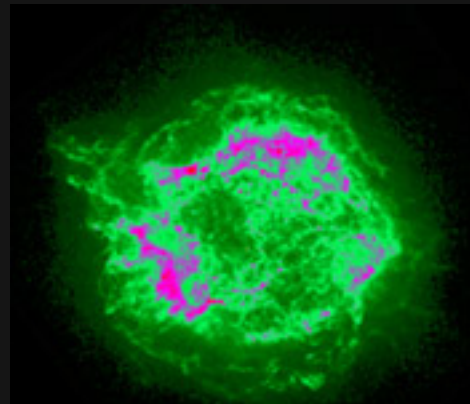
But now there is nothing to stop gravity.

Massive star ends its life in supernova explosion.

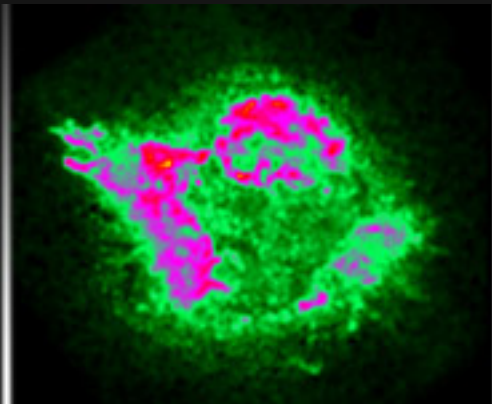
# Supernova

Explosive power of a supernova:

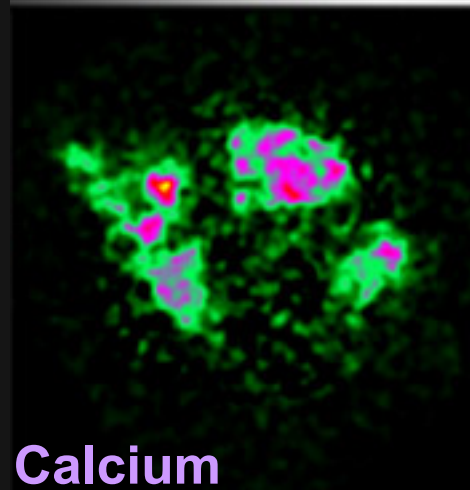
- Disperses elements created in large stars.
- Creates new elements, especially those heavier than Iron.



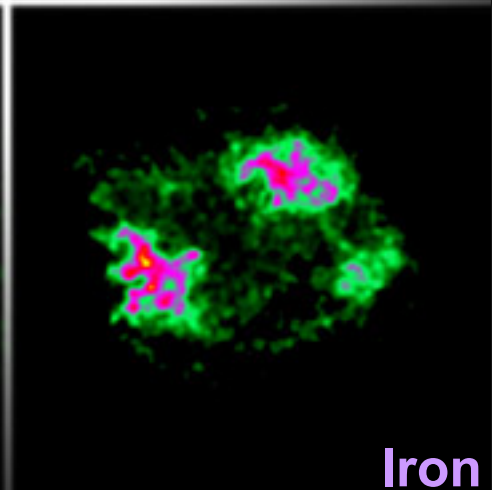
All X-ray Energies



Silicon



Calcium



Iron

# *From Death comes Life*

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Hodge 301 in the Tarantula Nebula



Hubble  
Heritage

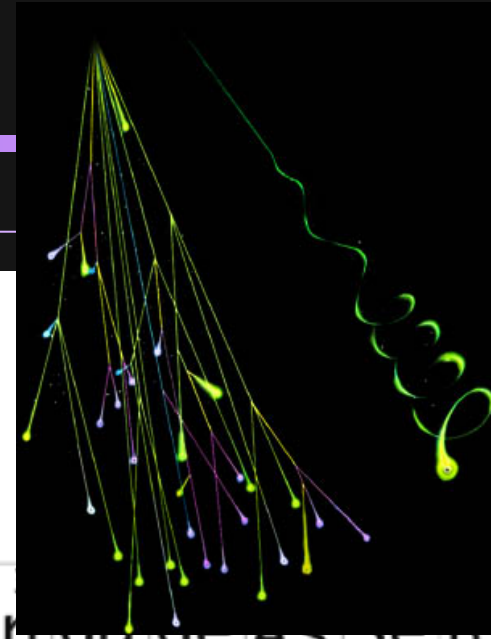
Supernovae compress gas and dust which lie between the stars. This gas is also enriched by the expelled material.

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





# Cosmic Rays



AA 4 PACK LITHIUM  
**Energizer**  
PHOTO  
LASTS 5X LONGER IN DIGITAL CAMERAS  
New for 2009

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# Cosmic Rays

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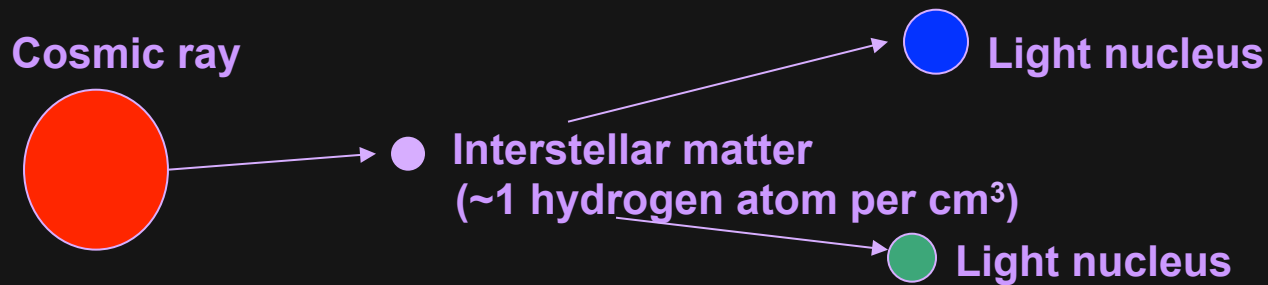
Lithium, Beryllium, and Boron are difficult to produce in stars.

(L, Be, and B are formed in the fusion chains, but they are unstable at high temperatures, and tend to break up into residues of He, which are very stable).

So what is the origin of these rare elements?

=> Collisions of Cosmic Rays with Hydrogen & Helium in interstellar space.

# Cosmic Rays Collisions with ISM



Lithium, beryllium, and boron and sub-iron enhancements attributed to nuclear fragmentation of carbon, nitrogen, oxygen, and iron with interstellar matter (primarily hydrogen and helium).



# Cosmic Elements

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<table border="1"> <tr> <td>58 Ce</td> <td>59 Pr</td> <td>60 Nd</td> <td>61 Pm</td> <td>62 Sm</td> <td>63 Eu</td> <td>64 Gd</td> <td>65 Tb</td> <td>66 Dy</td> <td>67 Ho</td> <td>68 Er</td> <td>69 Tm</td> <td>70 Yb</td> <td>71 Lu</td> </tr> <tr> <td>90 Th</td> <td>91 Pa</td> <td>92 U</td> <td>93 Np</td> <td>94 Pu</td> <td>95 Am</td> <td>96 Cm</td> <td>97 Bk</td> <td>98 Cf</td> <td>99 Es</td> <td>100 Fm</td> <td>101 Md</td> <td>102 No</td> <td>103 Lr</td> </tr> </table>																		58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr
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White - Big Bang

Pink - Cosmic Rays

Yellow - Small Stars

Green - Large Stars

Blue - Supernovae

# Your Cosmic Connection to the Elements?

National Aeronautics and Space Administration

## What is Your Cosmic Connection to the Elements?

The image features a woman sitting on a large globe. Lines connect various elements on a periodic table to their cosmic sources. The globe is divided into colored segments representing different sources: yellow for Small Stars, green for Large Stars, pink for Cosmic Rays, and blue for Supernovae. The woman is holding a white ball and a small potted plant.

**Small Stars**

- Carbon
- Nitrogen

**Large Stars**

- Sulfur
- Calcium
- Oxygen
- Silicon

**Cosmic Rays**

- Lithium

**Supernovae**

- Gold
- Iron
- Titanium

**Big Bang**

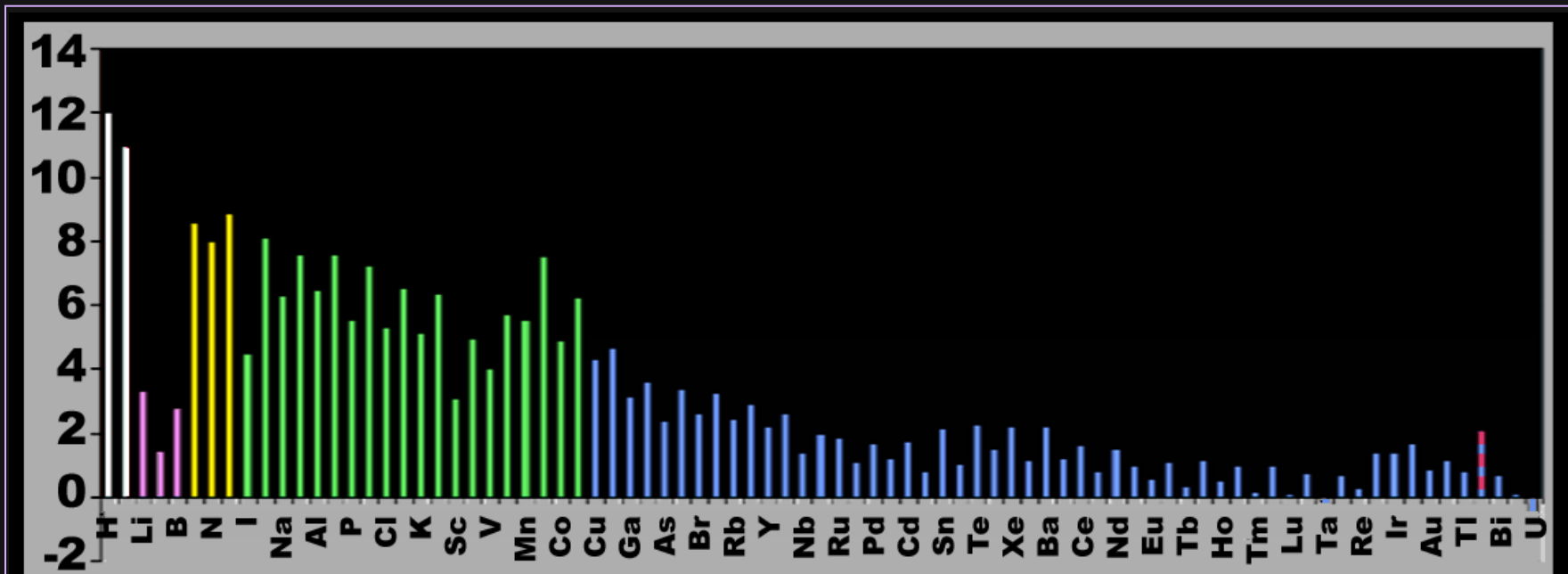
- Hydrogen
- Helium

**Periodic Table Elements:**

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		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr											

Imagine the Universe  
<http://imagine.gsfc.nasa.gov/>  
<http://www.nasa.gov/>

# Composition of the Universe



Actually, this is just the solar system.

Composition varies from place to place in universe, and between different objects.

# *“What’s Out There?”*

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(Developed by Stacie Kreitman, Falls Church, VA)

A classroom activity that demonstrates the different elemental compositions of different objects in the universe.

- Demonstrates how we estimate the abundances.

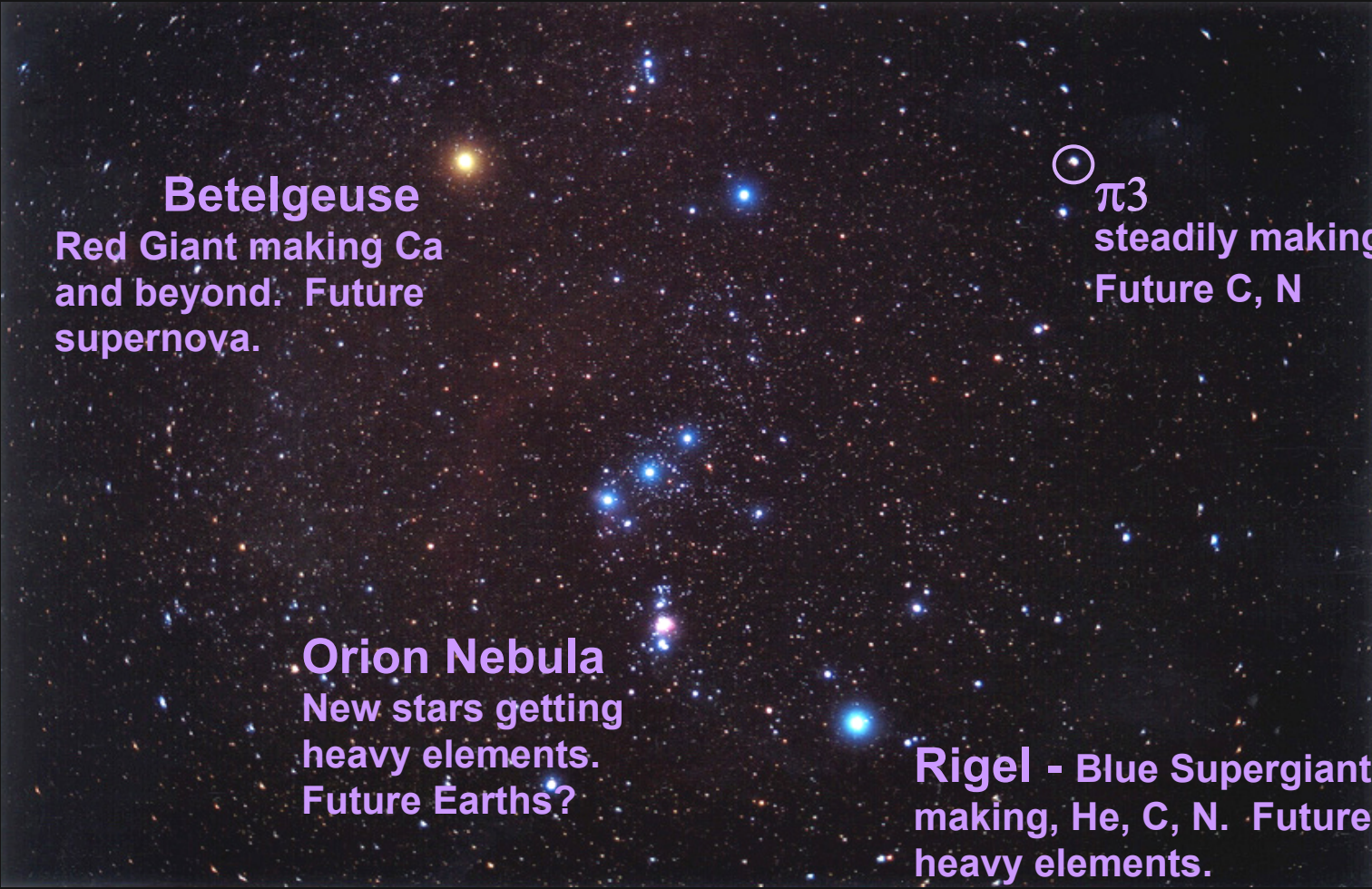
# Top 10 Elements in the Human Body

Element	Biological Process
10. Magnesium	SN
9. Chlorine (Cl)	
8. Sodium (Na)	
7. Sulfur (S)	LS
6. Phosphorous	
5. Calcium (Ca)	
4. Nitrogen (N)	LS
3. Carbon (C)	LS
2. Oxygen (O)	SS
1. Hydrogen (H)	





# What's Your Cosmic Connection to the Elements?

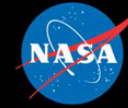


**Betelgeuse**  
Red Giant making Ca  
and beyond. Future  
supernova.

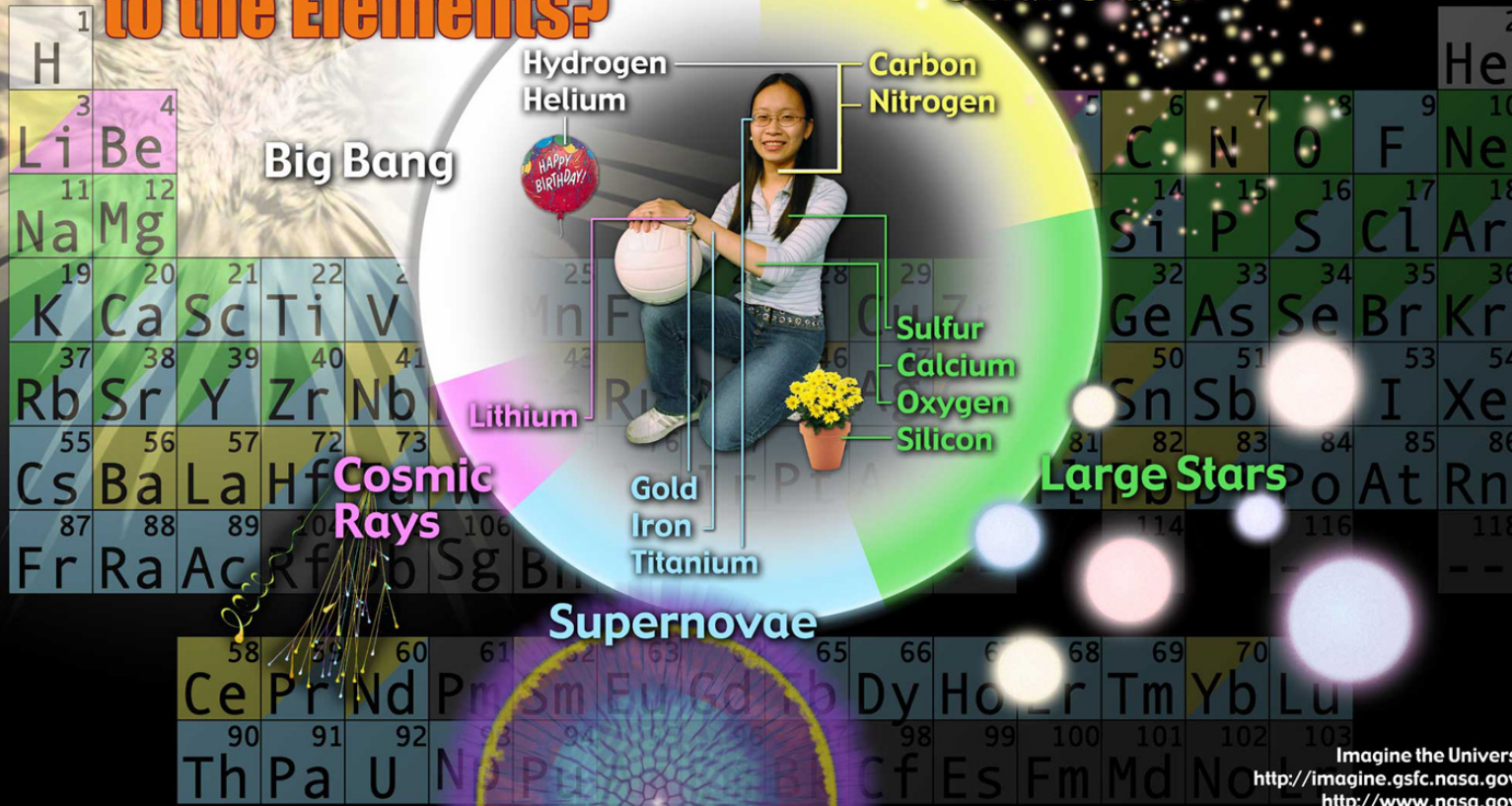
$\pi 3$   
steadily making He.  
Future C, N

**Orion Nebula**  
New stars getting  
heavy elements.  
Future Earths?

**Rigel - Blue Supergiant**  
making, He, C, N. Future  
heavy elements.



# What is Your Cosmic Connection to the Elements?



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<http://imagine.gsfc.nasa.gov/docs/teachers/elements/>

# *Spectral Analysis*

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

So we depend on light !

# *Spectral Analysis*

---

Each element has a unique spectral signature:

- Determined by arrangement of electrons.
- Lines of emission or absorption arise from re-arrangement of electrons into different energy levels.



Hydrogen

# Nickel-odeon Classroom Activity

(Developed by Shirley Burris, Nova Scotia)

Spread a rainbow of color across a piano keyboard



Then, “play” an element



Hydrogen

# *More Musical Elements*

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Now play another element

Helium



And Another

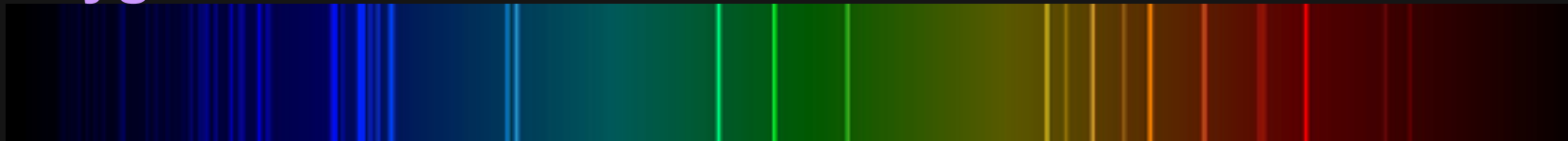
Carbon



# Getting a Handle on Water



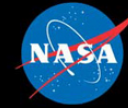
Oxygen



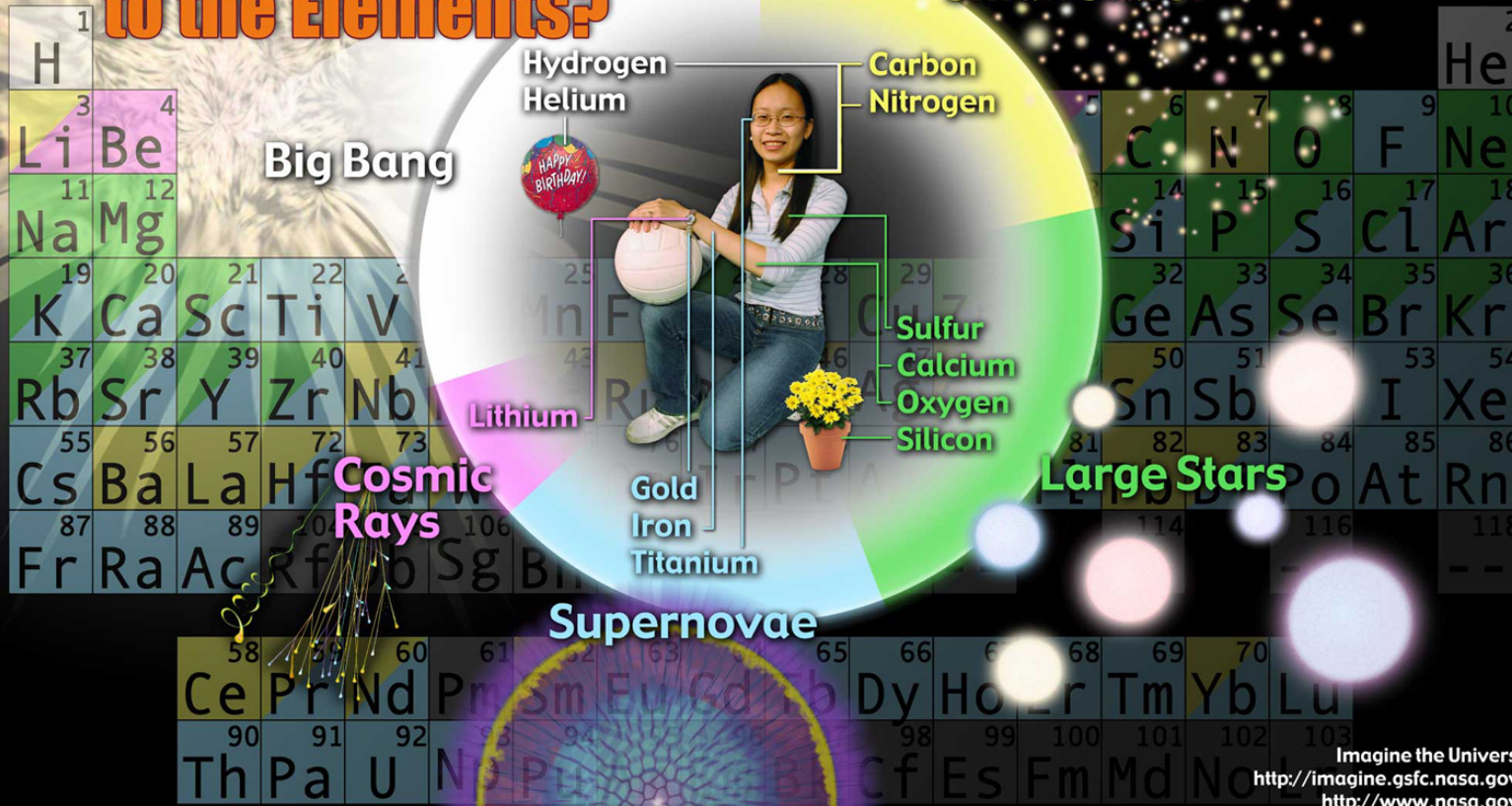
Hydrogen



All together now ... Water



# What is Your Cosmic Connection to the Elements?



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