FROM THE BIG BANG TO TABLE MOUNTAIN: 
the Cosmic Biography of Atoms

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Table Mountain Star Party
28 July 2011

Utah State University
Storyline

- Atoms
- The Beginning
- Stars
- Cosmic Recycling
What are we talking about?

- Look at the natural world around you. Not everything is the same.

- If I pick up two different rocks here at Table Mountain, they invariably look different.

- Not just size and shape, but their color and their composition.

- What are they made of?
Consider a cherry pie...
Consider a cherry pie...

- Suppose I cut a piece out of a cherry pie. And eat it.
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- I get **bigger**, and the cherry pie gets **smaller**.
Consider a cherry pie...

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- How many times do I have to cut the cherry pie in half before I get to the smallest piece of “stuff”? 4
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**Only about 90 times.**
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- How many times do I have to cut the cherry pie in half before I get to the smallest piece of “stuff”?
  - Only about **90 times**.

- These small bits of stuff are **atoms**, and everything is made from them.
What kinds of atoms?

- What are these atoms?

- A rock and a piece of cherry pie are quite different, but they are made up of the same building blocks, in different proportions and combinations.

- There are 92 known naturally occurring kinds of atoms. These are called the ELEMENTS.
Ordinary Earthly Organisms

For every 10,000 atoms in an average organism, there are:
Ordinary Earthly Organisms

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For every 10,000 atoms in an average organism, there are:

- 6500 oxygen atoms
- 1800 carbon atoms
- 1000 hydrogen atoms
- 300 nitrogen atoms
- 150 calcium atoms
- 100 phosphorus atoms
- 25 potassium atoms
- 25 sulfur atoms
- 15 chlorine atoms
- 15 sodium atoms
- 5 magnesium atoms
- 65: traces of other stuff...
The Earth’s Crust

For every 10,000 atoms in Earth’s crust, there are:

- 4640 oxygen atoms
- 2820 silicon atoms
- 830 aluminum atoms
- 560 iron atoms
- 410 calcium atoms
- 230 sodium atoms
- 230 magnesium atoms
- 210 potassium atoms
- 60 titanium atoms
- 10 hydrogen atoms
What is the Sun made of?

For every 10,000 atoms in the Sun, there are:

- 9149 atoms of hydrogen
- 779 atoms of helium
- 62 atoms of oxygen
- 6 atoms of carbon
- 3 atoms of neon
- 1 atom of nitrogen

and even less of everything else.

Hydrogen is the most common element in the universe!
In the beginning...

- How do we know what the Universe was like when it was very young?
- When you make things very small (planets, stars, the Cosmos) the compression energy makes them very hot.
- Immediately after the Big Bang, the temperature was $10^{32}$ °C. That’s: $100,000,000,000,000,000,000,000,000,000,000,000$ °C.
- At these temperatures, electrons won’t stick to protons — they keep getting knocked off!
- *Atoms (and other things we recognize as “matter”) did not exist in the beginning!*
Nucleosynthesis

- Electrons, protons, neutrons, and photons are in a **Primordial Soup**
- As the Universe expands, it **cools off**
Nucleosynthesis

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**Nucleosynthesis**

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Electrons, protons, neutrons, and photons are in a Primordial Soup.

As the Universe expands, it cools off.

By 100 seconds after the Big Bang, it has cooled off to a refreshing 10 billion °C. That’s 10,000,000,000 °C.

At this temperature, nuclei (the centers of atoms) can form.

This is called NUCLEOSYNTHESIS.
Making the first atoms...

- Atoms are nuclei with attached electrons.
- Electrons won’t stick to nuclei until it gets much colder in the Cosmos.
- By ~400,000 years, it has cooled off to ~3000° C and **atoms** formed
- This is called **Recombination**
Making the First Atoms...

- Atoms are nuclei with attached electrons.

- Electrons won’t stick to nuclei until it gets much colder in the Cosmos.

- By ~400,000 years, it has cooled off to ~3000° C and atoms formed.

- This is called **Recombination**.

- For every 1,000,000,000 atoms:
  - 1 **Lithium**
  - 100,000 **Helium**
  - 1,000,000 **Deuterium**
  - 998,899,999 **Hydrogen**
Photons (light) love electrons! They are easily distracted, and don’t travel far.

Once **recombination** happens, all the electrons are in the atoms, and the photons suddenly don’t have anyone to talk to.

They suddenly find themselves free — we call this **Decoupling**.
Photons (light) love electrons! They are easily distracted, and don’t travel far.

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All this light is reaching us today. We call it the **Cosmic Microwave Background**.
The Cosmic Microwave background arrives from every point on the sky. It is the signature of formation of the first atoms.
Getting together with friends...

- 400 million years after the birth of atoms, gas gathers together and stars begin to form.

- Gravity pulls the gas together into balls that collapse to become stars.

- When the stars “turn on”, stellar winds blow and cause new stars to form.
The Cosmos is alive...

- The births of the stars make wondrous sights in the Cosmos that you and I can see with small telescopes and binoculars!

- The nebulae are **stellar nurseries**

- There stars eventually blow away the remnants of their parent nebula, leaving an **open cluster**

- Some stars are born together as **binaries**, destined to always have a companion over their long lives

M8 : The Lagoon Nebula
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*M11: The Wild Duck Cluster*
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Albireo (Beta Cygni)
Stellar life...
**Stellar life...**

- Stars spend most of their lives “on the **main sequence**”
  - They get up in the morning, they burn hydrogen into helium...
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Hydrogen transformed...
Hydrogen transformed...

- In the cores of the stars, temperatures are so high **nuclear fusion** begins

- Bang hydrogen atoms together and they make new elements, like **helium**!

- Bang helium together, and make new elements like **carbon**!

- Process continues all the way up to **IRON**.

- In the process, you get energy (**LIGHT**) out of the star
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- Process continues all the way up to **IRON**.
- In the process, you get energy (**LIGHT**) out of the star.
The stars burn as long as there is hydrogen in the core to burn.

When too much helium builds up the fusion starts to sputter.

The star throws off its atmosphere, and the core shrinks to form a white dwarf.

These nebulae are called planetary nebulae (they are round).
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M57 (The Ring Nebula in Lyra)
What about all that other stuff?

PERIODIC TABLE OF THE ELEMENTS

http://www.ktf-split.hr/periodni/en/

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Editor: Aditya Vardhan (adivar@netlinx.com)

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(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)

Relative atomic mass is shown with five significant figures. For elements having no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.

However, three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

LANTHANIDE

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What about all that other stuff?
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What about all that other stuff?
High Mass Stars...

- High mass stars have an astonishing fate...

- Once they start making iron, nuclear fusion **shuts down**

- The star collapses, and explodes in a **supernova explosion**

- The explosion forces atoms together... everything heavier than iron is made by explosion
High mass stars have an astonishing fate...

Once they start making iron, nuclear fusion **shuts down**

The star collapses, and explodes in a **supernova explosion**

The explosion forces atoms together... everything heavier than iron is made by explosion
The explosion blows all the atoms outside the core back into the Cosmos
The explosion blows all the atoms outside the core back into the Cosmos

Western Veil Nebula (NGC 6960)
The gas goes back into the Cosmos, where it becomes the next generation of stars, the next planets, the next rocks under your feet here at Table Mountain...
During the early stages of star formation, gas that doesn’t become the star forms the planets.

All the atoms on the planet today came from the atoms of the nebula that formed our parent star. As of yesterday, there are 563 known planets...
What to do with atoms...
What to do with atoms...
WHAT TO DO WITH ATOMS...
What to do with atoms...
What to do with atoms...
What to do with atoms...
What to do with atoms...
Is that all there is?

- Suppose I count how much light I can see in the Cosmos (created by atoms)
- Suppose I count how much gravity I can see in the Cosmos
- Now suppose I compare these two numbers
- If atoms were all there was, these should be the same!
Is that all there is?

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- Suppose I count how much gravity I can see in the Cosmos
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Atoms are only 4% of all there is in the Cosmos.
More Reading....

- The First Three Minutes (Steven Weinberg)
- The Day We Found the Universe (Marcia Bartusiak)
- Observer’s Guide to Stellar Evolution (Mike Inglis)
- Wrinkles in Time (George Smoot)
Last Thoughts...

• Carl Sagan once wrote (Cosmos): “The desire to be connected with the Cosmos reflects a profound reality: we are connected. Not in trivial ways... but in the deepest ways.”

• In the lives of stars we see reflections of our own lives on Earth — stars are born, live long and lustrous lives, and eventually die, returning once again to the Cosmos from whence they came.
• Carl Sagan once wrote (Cosmos): “The desire to be connected with the Cosmos reflects a profound reality: we are connected. Not in trivial ways... but in the deepest ways.”

• In the lives of stars we see reflections of our own lives on Earth — stars are born, live long and lustrous lives, and eventually die, returning once again to the Cosmos from whence they came.

Thanks! Enjoy Observing!