From the Big Bang to Yellowstone: the Cosmic Biography of Atoms

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Stars Over Yellowstone
Yellowstone National Park
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Tonight's story...

The biography of atoms is a story about the beginning of the Cosmos...

...and the lives of the stars.
What are we talking about?

Everything around you here in Yellowstone is different...

- size
- shape
- color
- composition

What are they made of?
What happens if I cut a piece of cherry pie?

And eat it!

I get **bigger**
The pie gets **smaller**

How many times can I cut the pie in half before I get to the smallest piece of “stuff”? 
Only about 40 times!

These small bits of stuff are **ATOMS**

Everything is made from them
What are atoms?

A rock and a cherry pie are clearly different!

Same building blocks

different proportions
different 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:

- 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...
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!
Afterglow Light Pattern 400,000 yrs.
Inflation
Quantum Fluctuations

Dark Ages
Development of Galaxies, Planets, etc.

1st Stars about 400 million yrs.

Big Bang Expansion
13.7 billion years

TODAY
When the Cosmos was young...

It was HOT!

$10^{32}$ °C. That’s:

100,000,000,000,000,000,000,000,000,000,000,000

Atoms can’t stick together — crashes blast them apart

There were no atoms!
The Cosmos was filled with the **building blocks** of atoms...

**Protons**  
**Neutrons**  
**Electrons**  
**Light**

The Primordial Soup
Campbell's Condensed
Primordial
Soup
NET WT. 10 3/4 OZ. (305g)
The Universe is cooling off...

100 seconds after the Big Bang

10 billion °C. That’s:

10,000,000,000 °C
At 10 billion °C protons and neutrons can stick together.
It takes the Cosmos 400,000 years to cool to \(~3000\, ^\circ\text{C}\) 

Electrons can stick to nuclei — *atoms form*

**RECOMBINATION**
For every 1,000,000,000 atoms:

- 1 Lithium
- 100,000 Helium
- 1,000,000 Deuterium
- 998,899,999 Hydrogen
Before recombination photons crash into free electrons

They can’t travel very far
After atoms form, the photons don't see the electrons

DECOUPLING

We see this light as 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.
400 millions years later, stars begin to form.

Stellar nurseries give birth to thousands of stars.

M8: The Lagoon Nebula
Young stars blow away the remnants of the parent nebula, leaving an open cluster.

Many nurseries and clusters can be seen with small telescopes and binoculars.
Some stars are born with a partner, a companion for their entire long lives.
Stellar life...

Stars spend most of their lives “on the main sequence”

They get up in the morning, they burn hydrogen into helium...
Fusion: Banging hydrogen together to make helium and light...

Bang helium together to make carbon and light...
What about all that other stuff?
What about all that other stuff?

Fusion will create everything up to iron

How do we make all this other stuff?
Stars like the Sun sputter and cough at the end of their lives, shedding their atmospheres...
They leave behind a shrunken skeleton of themselves called a white dwarf — almost pure carbon.

... but what about the other stuff? The heavy elements...
Stars more massive than the Sun have an astonishing fate... They EXPLODE!
Supernovae explosions are brighter than their parent galaxy...

10 billion times brighter than the Sun
Supernovae 1054 was right enough to see during the day, and you could read by it at night.
Supernovae 1054 left behind the Crab Nebula
Supernova remnants are exploded skeletons of stars
Supernovae create all the elements heavier than iron.

The explosion throws all those atoms back out into the Cosmos.

Western Veil Nebula (NGC 6960)
Cosmic recycling...

- red giant
- average star
- massive star
- red supergiant
- gas & dust nebula
- planetary nebula
- neutron star
- white dwarf
- black hole

The gas becomes the next generation of “stuff”
Atoms in planets come from the same cloud of atoms that formed the stars.

As of today, there are 777 known planets.
What to do with atoms...
What to do with atoms...
Atoms are only 4% of all there is in the Cosmos.

How much light can I see in the Cosmos?

How much gravity can I see in the Cosmos?

Are these two numbers THE SAME?

Atoms are only 4% of all there is in the Cosmos.
Carl Sagan (*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.”

We are collections of atoms, with the ability to try and understand this and more...
More Reading....

The First Three Minutes (Steven Weinberg)

Observer's Guide to Stellar Evolution (Mike Inglis)

The Day We Found the Universe (Marcia Bartusiak)

Wrinkles in Time (George Smoot)

THANKS!