Astronomy 330:

Extraterrestrial Life

This class (Lecture 6):

Fate of the Universe

Next Class:

Burning Stars

Presentation Synopsis due Sunday night.

Music: *Carl Sagan -Glorious Dawn*– Colorpulse
http://www.youtube.com/watch?v=zSgiXGELjbc&feature=fvw

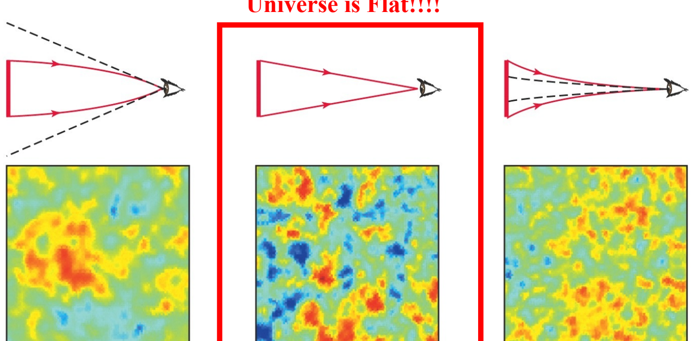
Origins Story

In small groups, write a 4-5 sentence explanation of the origin of hydrogen to a non-science major friend.

State some of the important facts.

CMB Measurements

Universe is Flat!!!!

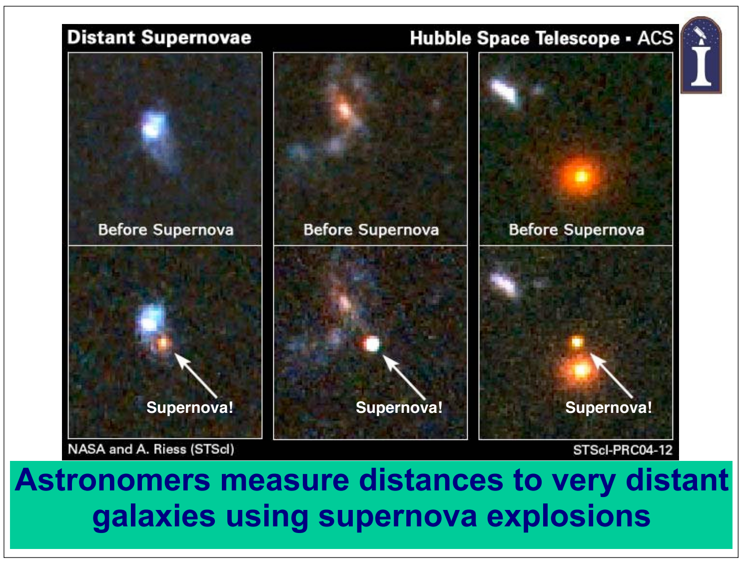


a If universe is closed, hot spots appear larger than actual size

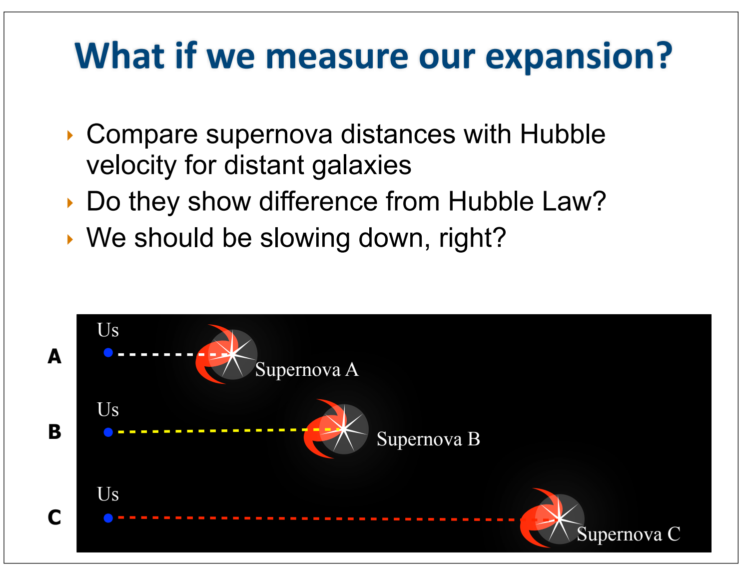
b If universe is flat, hot spots appear actual size

c If universe is open, hot spots appear smaller than actual size

Let’s check Hubble’s Law. We would expect a certain behavior.



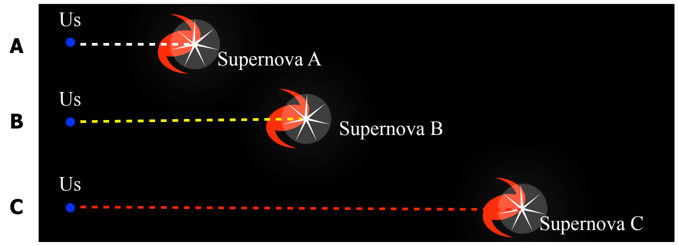
For decades, astronomers struggled to measure the distance to very distant galaxies directly, compare distances with redshifts, and thereby detect the slowing of the expansion.Measure distances to far galaxies using a certain class of supernovasType 1a supernovae have a known intrinsic luminosity and so bright they are visible billions of light years away. This makes them excellent standard candles for determining distances. Reiss won the Noble Prize for this work in Oct 2011!!!



Measuring distances (using the brightness of the supernova) and redshifts (using the galaxy spectrum) can help us determine how the expansion of the universe is changing with time.

Measure our expansion

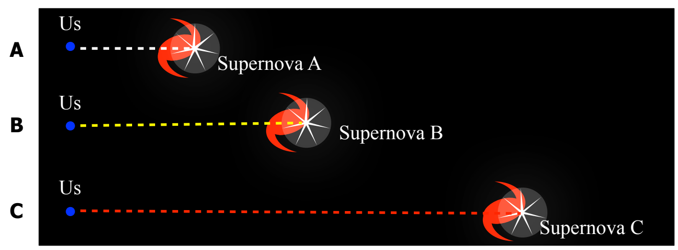
- Consider three supernovae: A, B, C
- Supernova B has twice the Hubble velocity of Supernova A
- Supernova C has four times the Hubble velocity of Supernova A



Measuring distances (using the brightness of the supernova) and redshifts (using the galaxy spectrum) can help us determine how the expansion of the universe is changing with time.

If the rate of expansion were constant

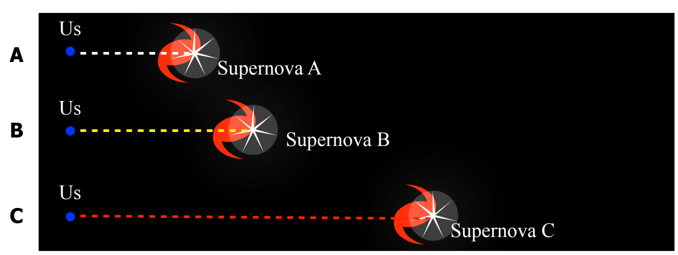
- Distance increases directly with velocity
- Supernova B is **twice** as far a Supernova A, and it has **twice** the velocity!
- Supernova C is **four** times as far Supernova A, and it has **four** times the velocity!



Gravity has no effect. This is Hubble's Law.

If the expansion is slowing down due to gravity

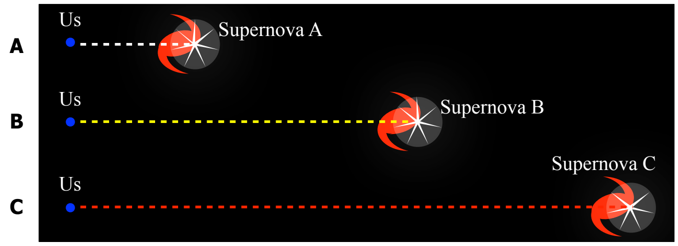
- The expansion was faster in the past
  - More velocity per distance traveled
  - Objects are closer than with constant expansion
- Supernova C is **three** times as far as Supernova A, but it has **four** times the velocity!



Galaxy C is closer than we expect, because Universe expansion is slowing down. It was following Hubble's Law, but now the expansion is slowing.

What was observed?

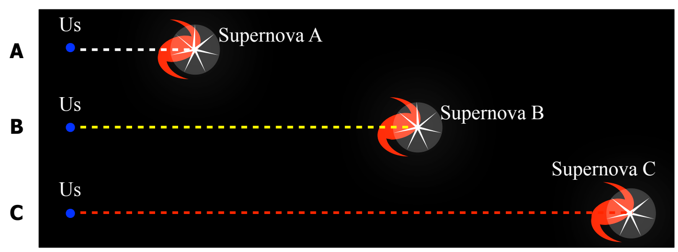
- Supernovae were **farther** than expected for a Universe with a constant rate of expansion!
- Supernova C is **five** times farther than Supernova A, but is only has **four** times the velocity!



Indicates that the expansion of the Universe isn't slowing down, it is speeding up!

What was observed?

- Indicates that the expansion of the Universe isn't slowing down, it is speeding up!
- Weird! This is the **opposite** of what was expected!

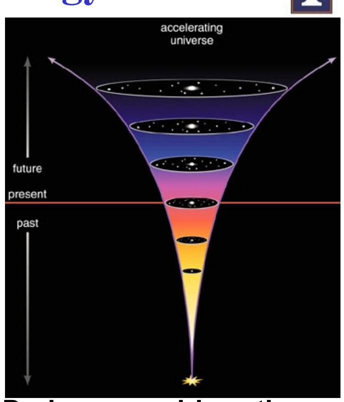


This is very weird!

Toss Newton's apple in the air and expect it to slow down as it goes up, but instead it rockets away!
What is up?

Dark Energy

- If the expansion of the universe is accelerating, then there must be a force of repulsion in the universe
- We call this force **dark energy**
- Astronomers today are struggling to understand what it could be
- This is the missing mass in the fate of the Universe since $E = mc^2$

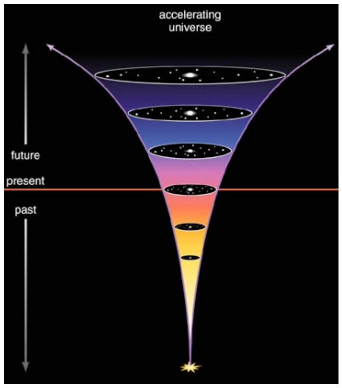


Dark energy drives the expansion faster with time

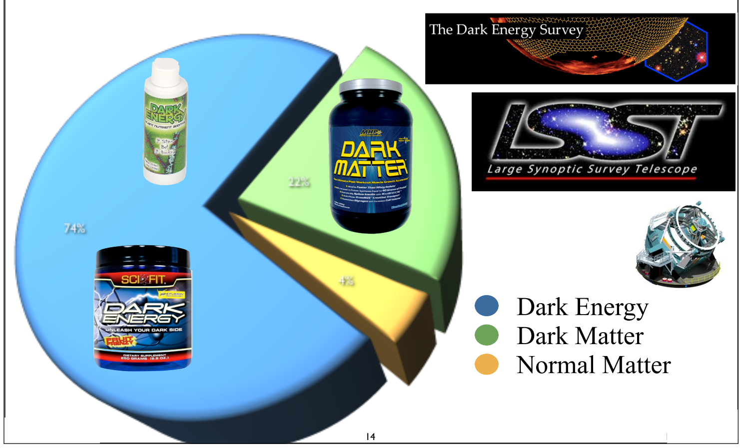
The observed acceleration is evidence that some form of energy is spread throughout space. Astronomers refer to this as dark energy. NOTHING to do with Dark Matter. This energy drives the acceleration of the universe. It, however, does not contribute to the formation of starlight or the CMB— why it is called dark. Astronomers are struggling to understand what it could be. This is one of the great mysteries of astronomy today

Dark Energy

- Spread throughout space
- Dark energy drives acceleration of the Universe today.
- This makes it the most abundant stuff in the Universe
- And we have NO idea what it is!!!!
- One of the greatest mysteries in science today!



The Universe



The Universe is dominated by dark matter and dark energy. About 4% is in form of normal matter (atoms). Only this normal matter can be directly detected with telescopes. About 85% of this is hot, intergalactic gas within rich galaxy clusters. Therefore, most of the universe is “unseen”, only detected by it effects on other matter and the expansion of the universe.

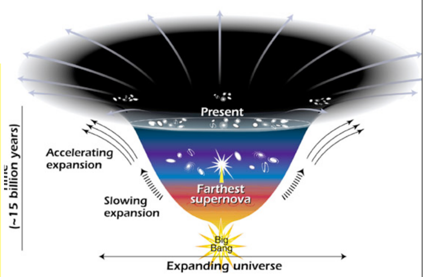
Where is the dark energy?

Dark energy is everywhere and is thought to be an inherent property of space itself

If Dark Energy is causing the Universe to expand, where is it? Dark energy is everywhere. Dark energy is thought to be an inherent property of space itself. However we don't notice dark energy mostly because it is an incredibly small amount of energy per volume. The effect is only seen acting on the universe as a whole, much like how we can feel a gust of wind, but cannot feel the individual particles in air.

Deceleration, Acceleration

Observations further show that the Universe's expansion initially slowed down and started accelerating ~6 billion years ago



Observations of galaxies over 6 billion light years away show that the universe expansion initially slowed down—but shifted gears about 6 billion years ago and is now accelerating

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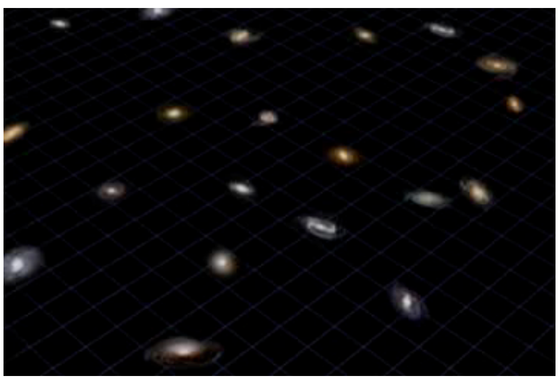
The Effects of Dark Energy



The expansion history of the Universe

This animation shows the expansion history of the Universe by modeling the Universe as a two-dimensional grid of galaxies. The Big Bang, shown as a flash of light, is immediately followed by rapid expansion of the Universe. This expansion then slows down because of the gravitational attraction of the matter in the Universe. As the Universe expands, the repulsive effects of dark energy become important, causing the expansion to accelerate. For clarity, the size of the deceleration and acceleration has been exaggerated. The ultimate fate of the universe depends on the nature of dark energy.

Our Most Likely Future

Constant Dark Energy: Big Freeze

If dark energy is a constant "energy of the vacuum", it will expand forever

The galaxies will get farther and farther apart – we can no longer see galaxies beyond the local group in 2 trillion years due to accelerating expansion. Gas and dust to make new stars runs out within 100 trillion years, last stars die within 10 trillion years of that. Each galaxy will be isolated, burnt out, dark, and alone. This is the most likely scenario, according to observations

Other Future: The Big Rip

What if the density of Dark Energy increases with time?

- current data don't require this
- but also don't rule it out!

If so, the cosmic repulsion gets ever larger, eventually overcoming all other attractive forces in the Universe:

Result is to tear the Universe apart: "the Big Rip"

- If repulsive force increases–first, galaxy groups torn apart.
  - Andromeda galaxy yanked away from view
- Gravity/E&M forces can not hold--galaxies shredded
- Would rip MilkyWay apart into isolated stars after ~40 billion years
- Earth gets ripped apart soon after
- You'd get ripped apart!
- Yikes.

An instant before the end, our very atoms would be torn apart!

Are we alone?

Life as we know it requires **HONC**

Carbon **H**ydrogen **O**xygen **N**itrogen

How did we get these elements?

One slide to summarize this class

Are we alone?

Life as we know it requires **CHON**

Big Bang 75% **H**ydrogen 25% **He**lium

One slide to summarize this class

The Early Universe?

- In early Universe, Hydrogen (75%) and Helium (25%) by mass. What does that mean for life in the early Universe?
- Globular clusters contain the oldest stars in the Milky Way– about 10 to 13 billion years old. Should we look for life around these stars?

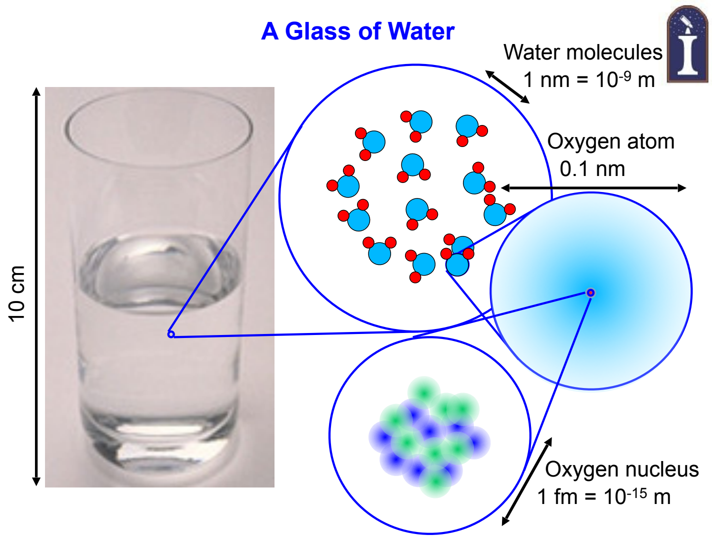
http://www.shef.ac.uk/physics/research/pa/DM-introduction-0397.html

Earth Chemistry

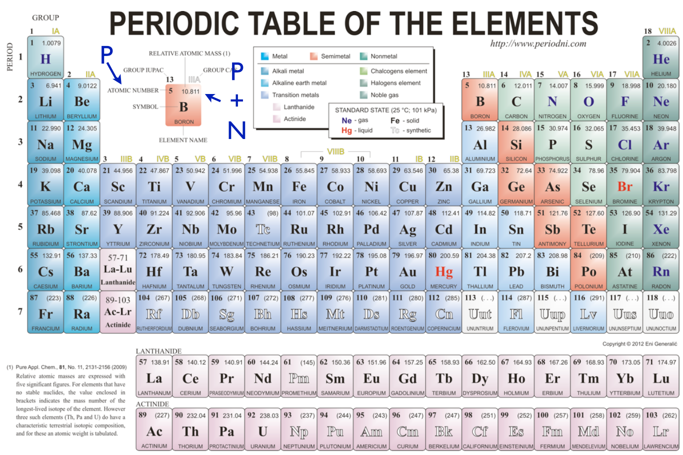
0.1% **H**ydrogen **He**lium

Earth is made of elements generated ***POST*** Big Bang!

By Mass Life on Earth does not require any helium and only small amounts of non-H_2O hydrogen. Life's Elements were actually forged inside of stars! ONC was formed in stars. That means 2nd or 3rd or nth generation of stars are required before life can really get going. These elements were not originally formed in the Big Bang



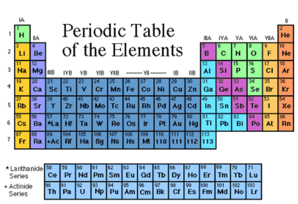
Elements



The number of protons in an atom determines the type of element, and the number of protons and neutrons determine the atomic weight.

Chemical Basis for Life

- The average human has:
  - 6×10^{27} atoms (some stable some radioactive)
  - During our life, 10^{12} atoms of Carbon 14 (^{14}C) in our bodies decay.
  - Of the 90 stable elements, about 27 are essential for life. (The elements from the Big Bang are not enough!)



http://www.genesismission.org/science/mod2_aei/

Chemical Basis for Life

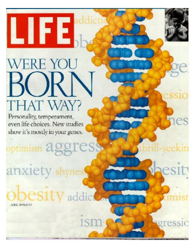
By Number…

- Life on Earth is mostly:
  - 60% hydrogen
  - 25% oxygen
  - 10% carbon
  - 2% nitrogen
  - With some trace amounts of calcium, phosphorous, and sulfur.
- The Earth's crust is mostly:
  - 47% oxygen
  - 28% silicon

- The Universe and Solar System are mostly:
  - 93% hydrogen
  - 6% helium
  - 0.06% oxygen
  - 0.03% carbon
  - 0.01% nitrogen

Little Pink Galaxies for you and me

- Life as we know it needs more elements than the Big Bang could provide.
  - Composition of life is unique.
- Does the environment of the Galaxy nourish life?
- At the vary least we need galaxies to process the material from the Big Bang into materials that life can use.
- The Universe does this through star formation.



http://www.chromosome.com/lifeDNA.html

Drake Equation

Frank Drake

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	? stars/ yr	systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

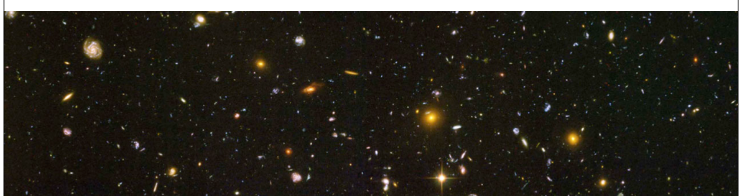
Question

What can say about the elemental make-up of life on Earth, the Earth, and the Universe?

a) All three are made up of the same elements in the same amounts.
b) The Universe is mostly hydrogen, but the Earth and life on Earth are mostly oxygen.
c) The Earth and the Universe are mostly hydrogen.
d) Life on Earth and the Universe are mostly carbon.
e) They are made up of the same elements but different concentrations.

E

Are we alone?



Life as we know it requires **CHON**

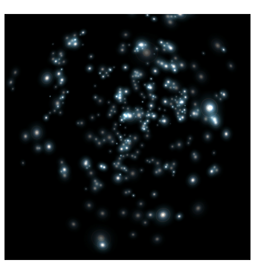
Big Bang 75% **H**ydrogen 25% **He**lium

Galaxies Star Factories Stars Element Factories

One slide to summarize this class

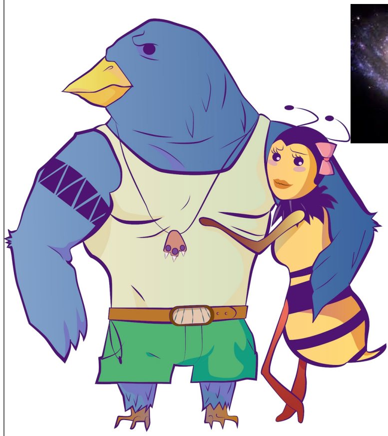
The First Stars

- From the initial seeds of the Big Bang, our local group of galaxies probably broke into clumps of hydrogen and helium.
- First Stars may have formed as early as 400 million years after the Big Bang.
- Probably more massive than stars today, so lived quickly and died quickly.



http://www.blackshoals.net/ImageBank/gallery/gallery/huge/The-first-stars-clustering.jpg

Cosmic Birds & Bees



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What are Galaxies?

- Stars die and eject material back into the galaxy.
- New stars are formed.
- And so on.

- Crucial to the development of life!
- Let's spend some time talking about star formation today to get a handle on star formation in the Universe.

Stellar Evolution Re-Cycle

Galaixes are really giant re-cycling plants separated by large distances.

Stars are born in galaxies out of dust and gas.

Stars turn hydrogen into helium, then into heavier elements through fusion for millions or billions of years.

Making Stars

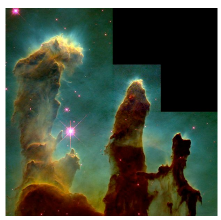
Interstellar Medium

Interstellar Clouds

Contain GMCs

Not Boring!

Molecular Clouds



T < 100 K

$10^2 – 10^5$ H_2 /cm^3

30 – 300 lyrs

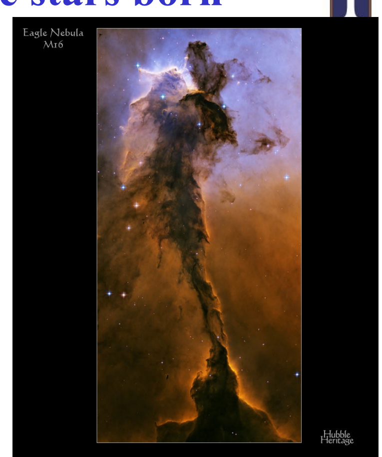
$10^5 – 10^6\ M_\odot$

Stuff between the stars in a galaxy.
Sounds sort of boring, but actually very important. Features complex physical processes hidden in safe dust clouds

Every star and planet, and maybe the molecules that led to life, were formed in the dust and gas of clouds.

Where are stars born

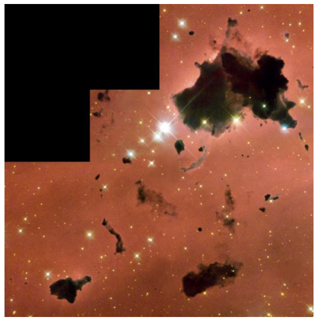
- To find where stars are born, we look at young stars
  - Often occur in *clusters*
  - Generally found near their birthplaces
- Young stars are found near *nebulae*
  - Clouds of gas and dust in space



A portion of the Eagle Nebula

Stars are born in cold clouds of gas & dust

- Stars are born in giant, dusty gas clouds called molecular clouds
  - Most of the matter in star-forming clouds is in the form of molecules (H_2, CO,…)
  - Also contain icy dust
- These clouds are **cold**!
- Temperatures of just 10-30 K! (-405 F!)



Stars form within dark, cold dusty clouds in space seen here in absorption against a bright background.

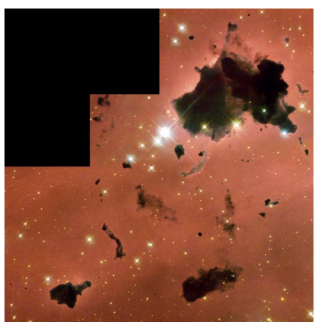
Clouds consist mostly of hydrogen molecules

Cool: ~10 K, Dense: $10^2 - 10^5$ H_2 molecules/cm^3, Huge: 10 – 100 pc across, $10^3 - 10^6$ solar masses

Stars are born in molecular clouds

You might be wondering how the unimaginably cold gas of an interstellar cloud can heat up to form a star. The answer is gravity.

When the clouds are heated up, we can see them in optical light.



Clouds consist mostly of hydrogen molecules

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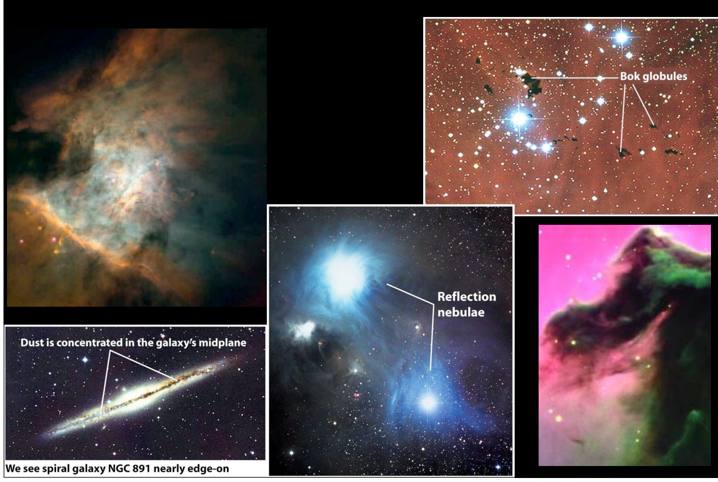
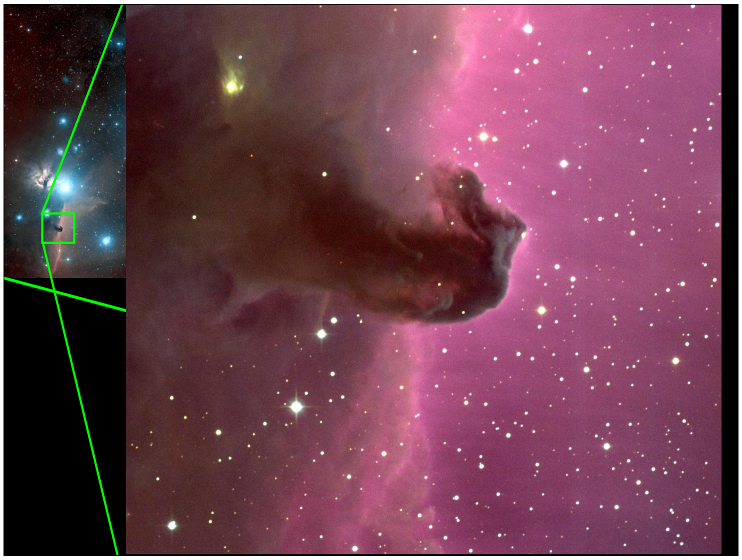
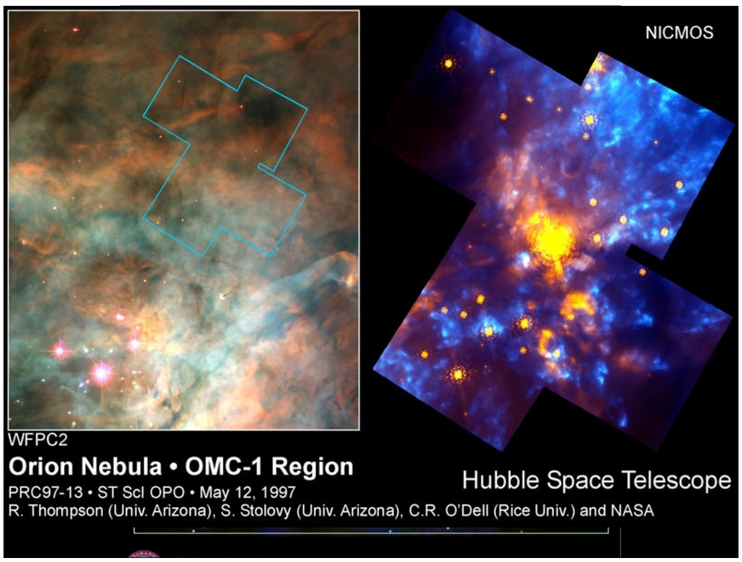
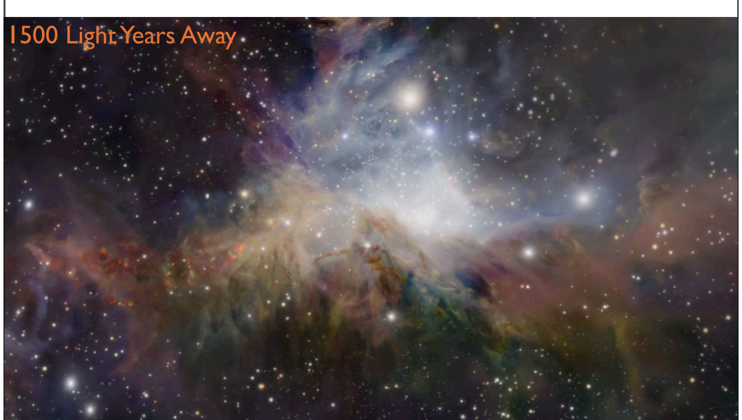
Interstellar Clouds

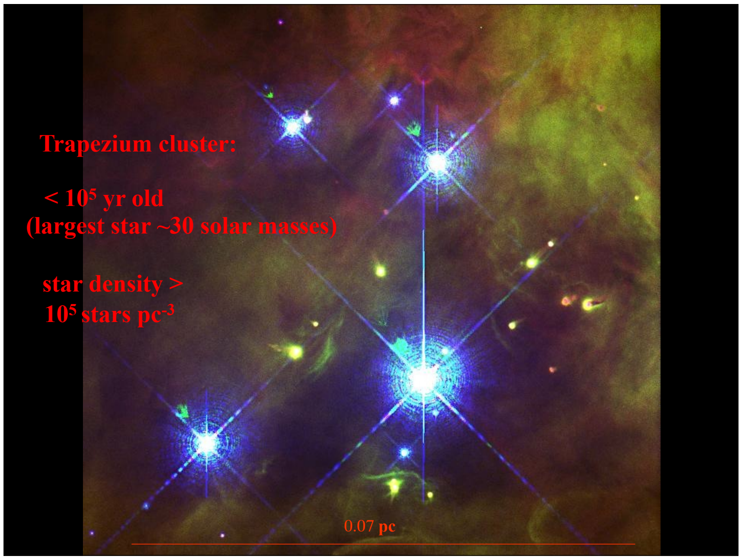






Orion Nebulae

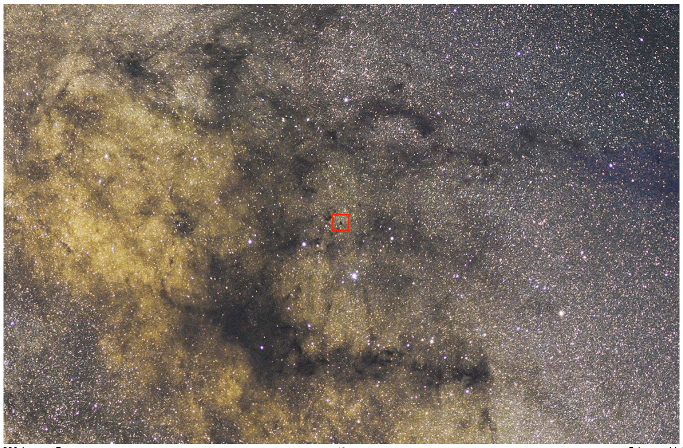



Trapezium cluster:
< 10^5 yr old
(largest star ~30 solar masses)
star density >
10^5 stars pc^{-3}
0.07 pc

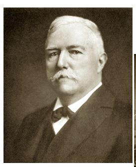

Trifid Nebulae
47

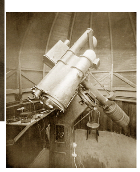

NGC 2244
48

Interstellar Medium



Dark Cloud



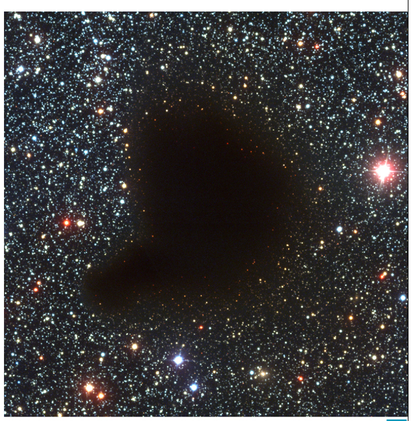


Edward Emerson Barnard

Giant Molecular Cloud

Barnard Cloud

Bok Globule



The "Black Cloud" B68
(VLT ANTU + FORS1)

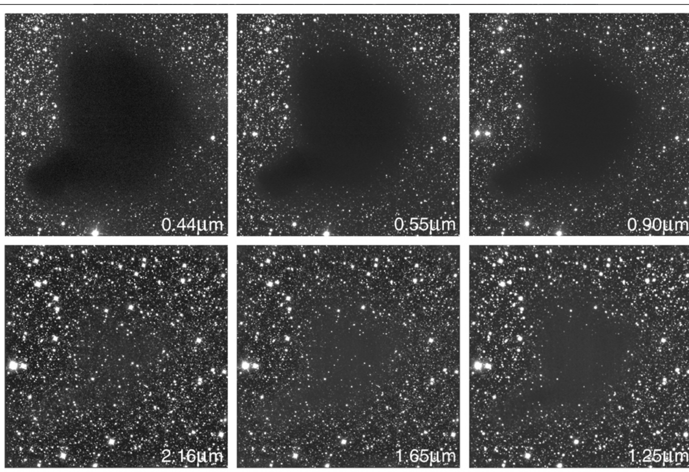
ESO PR Photo 20a/99 (30 April 1999)

A tiny black spot lost amongst the myriad stars in the Milky Way, Barnard 68, a compact interstellar cloud, is nearly invisible, eclipsed by the vast, dark clouds which criss-cross the galactic disk in the Sagittarius, Scorpius and Ophiuchus constellations. It was discovered on an image of the Milky Way by astronomer **Edward Barnard in 1919**. Barnard 68 is a molecular cloud, which as its name suggests contains gas and interstellar dust made up of atoms and molecules of varying degrees of complexity: hydrogen, oxygen, helium, molecular hydrogen, carbon monoxide, etc.

But Barnard 68 can be distinguished from its immense neighbors, the Pipe, Snake, Great Rift and Coalsack dark nebulae, due to its tiny size and compactness: located 500 light-years away, this cloud only measures half a light-year across, around five thousand billion kilometers.

Barnard 68 appears as a black spot on photographs because it is completely opaque. Imagine if you were plunged into darkness on one side of this cloud, with the Sun on the other side; you would need a telescope just to catch a faint glimmer of light! Astronomers describe this opacity in the following manner: Barnard 68′s degree of obscuration stands at **35 magnitudes**. Is Barnard 68 dense? Well, yes and no… This cloud is ten times denser than the interstellar medium. However, compared with a cloud in the Earth's atmosphere, Barnard 68 is… a hundred million billion times less dense!

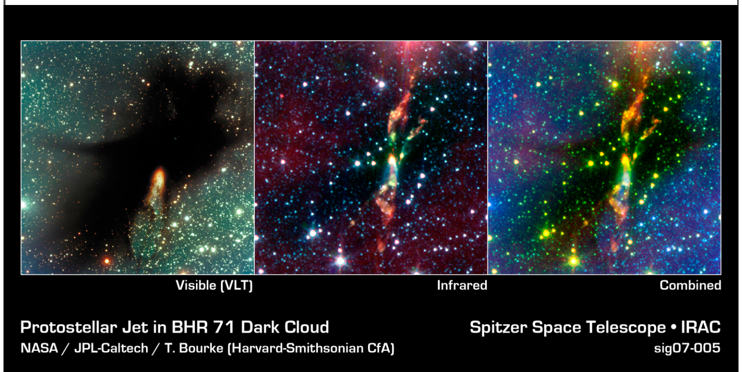
Although this little molecular cloud is therefore mainly empty, it still contains the equivalent of twice the Sun's mass in gas and dusts, at an extremely low temperature: -258 °C.



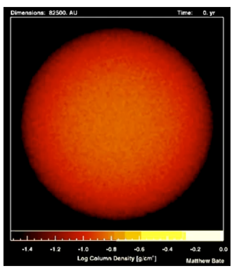
The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

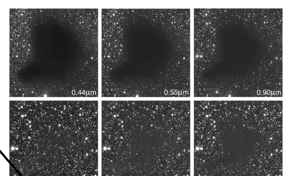
ESO PR Photo 29b/99 (2 July 1999)

Dark Cloud

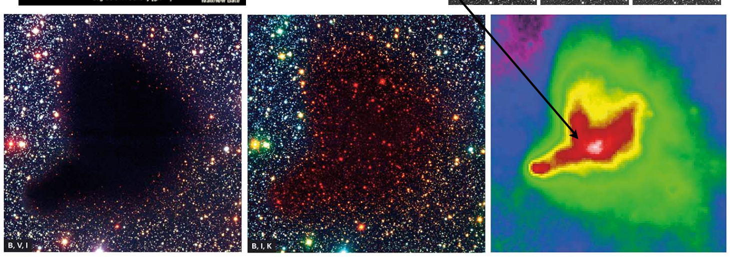


GMC





Collapse



The Barnard 68 interstellar cloud, photographed by the 8.2 m diameter Very Large Telescope and the Herschel Space Observatory, equipped with a 3.5 m mirror. On the right the infrared image reveals the center of the cloud, which is beginning to collapse in on itself upon contact with a second cloud - on the bottom left of the image. Photos ESO and ESA.

Question

Star formation occurs in

a) Alien laboratories.

b) Dense interstellar clouds of gas and dust.

c) Throughout the galaxy.

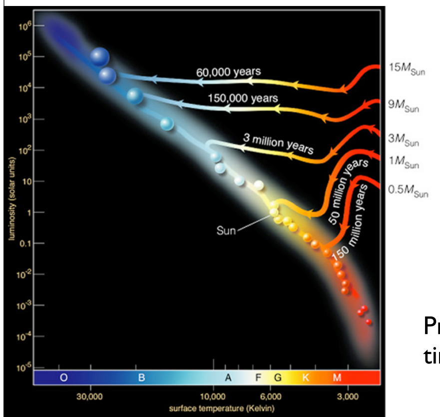
d) In isolated regions away from other stars.

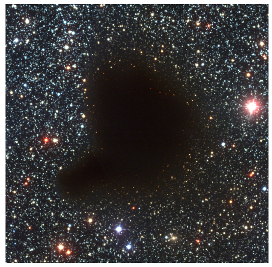
e) Large, diffuse gas clouds.

iClicker

E

Formation Timescale





Protostar mass determines timescale for collapse.

Drake Equation

Frank Drake

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

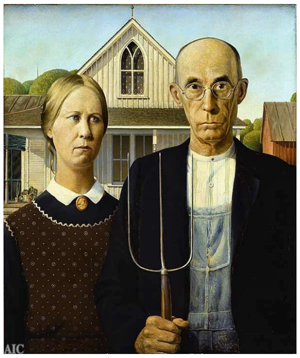
N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	? stars/ yr	systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

Lifecycle of a Star

- Star formation
  - Take a giant molecular cloud core with its associated gravity and wait for 10^4 to 10^7 years.

- Star Death
  - Exhaust hydrogen
  - Red giant / supergiant or supernova
  - White dwarfs, neutron stars, black holes

Stellar Lifestyles



Low-mass stars

many of these

Massive stars

few of these

Lifecycle of a Star

- Star formation
  - Take a giant molecular cloud core with its associated gravity and wait for 10^4 to 10^7 years.

- Star Death
  - Exhaust hydrogen
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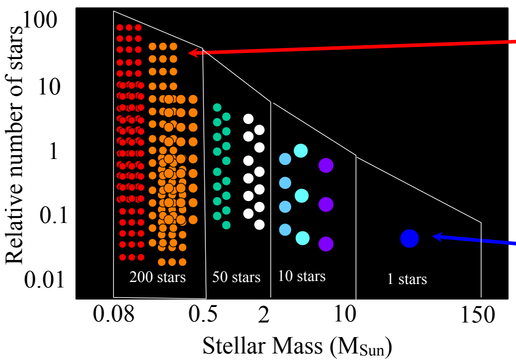
  - White dwarfs, neutron stars, black holes
- Life (depends on mass!)
  - Few x 10^6 years to more than age of Universe
  - Most of the time spent thermonuclear burning of H to He

Stars

- The fundamental building blocks of the Universe.
- High mass stars are 8 to 100 solar masses
  - Short lived: 10^6 to 10^7 years
  - Luminous: 10^3 to 10^6 L_{sun}
  - Power the interstellar medium– input of energy
- Intermediate mass stars are 2 to 8 solar masses
- Low mass stars are 0.4 to 2 solar masses
  - Long Lived: $>10^9$ years
  - Good for planets, good for life.
  - Not so luminous: 0.001 to 10 L_{sun}

More low mass stars form than high mass stars



Stars more massive than 150 M_{Sun} would blow apart. Stars less massive than 0.08 M_{Sun} can't sustain fusion.

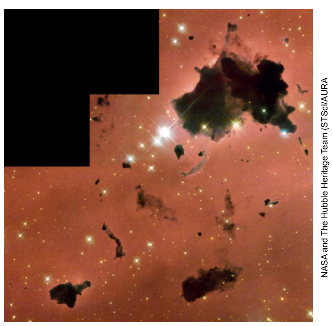
For every 200 stars less that 0.5 solar masses, there are 50 stars between 0.5 and 2 solar masses, 10 stars between 2 and 10 solar masses, and 1 star with more than 10 solar masses

Stars more massive than 150 MSun would blow apart

Stars less massive than 0.08 MSun can't sustain fusion

From Clouds to Stars

You might be wondering how the unimaginably cold gas of an interstellar cloud can heat up to form a star. The answer is gravity.



Clouds consist mostly of hydrogen molecules

Cool: ~10 K, Dense: 10^2 – 10^5 H_2 molecules/cm^3, Huge: 10 – 100 pc across, 10^3 – 10^6 solar masses

Water Power?

Does a bottle of water have any stored energy? Can it do work?

Yes!

The water has potential energy. It wants to flow downhill. If I pour it out, the conservation of energy tell us that it must turn that potential energy into kinetic energy (velocity). The water wants to reach the center of the Earth. This is how we get hydro energy from dams.

Gas powered

- Initial gas clumps want to reach the center of their clump-ness.
- Center gets hotter and hotter.
- It is a run-away feature (or snowballing), the more mass at the center, the more mass that wants to be at the center.
- The center of these clumps gets hotter and denser.

http://www.rob-clarkson.com/duff-brewery/snowball/04.jpg

The gravitational energy potential turns into heat (same as velocity actually).

Runaway— The center of these clumps gets hotter and denser.

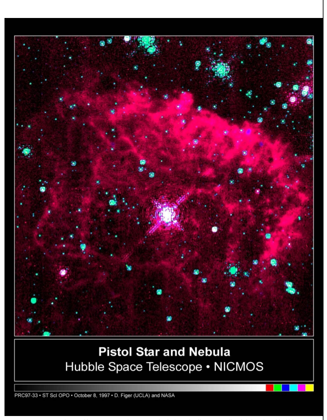
Cooking with Gas: First Stars

- For the first time, since 1-month after the Big Bang, the centers of the clumps get above 10^7 K.
- Now hot enough for nuclear fusion to occur. If that had not happened, life would never have existed.
- But are things different than today? These are the First Stars after all.
- Likely VERY massive objects

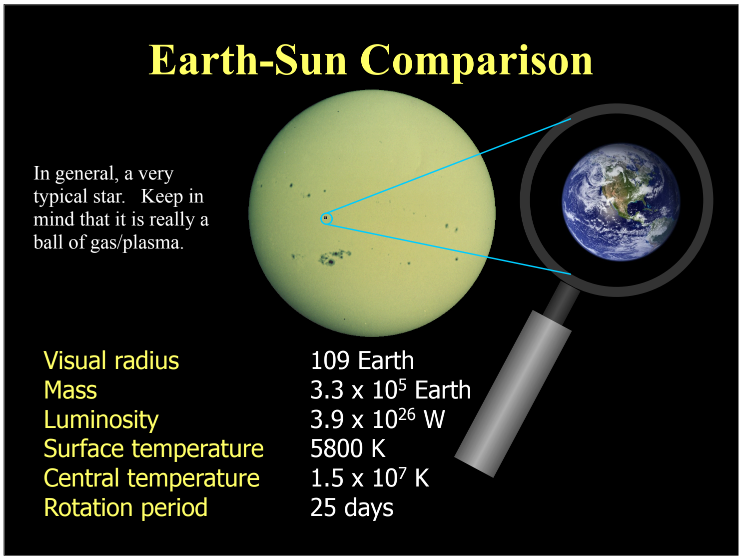
http://lgeku.energyunderground.com/images/images-deepearth/BURNERBL.jpg

The Most Massive Star in the Milky Way Today

- The Pistol star near the Galactic center started as massive as 200 solar masses.
- Releases as much energy in 6 seconds as the Sun in a year.
- But it blows off a significant fraction of its outer layers.
- How did the first stars stay so massive?



http://www.u.arizona.edu/~justin/images/hubblepics/full/PistolStarandNebula.jpg


Earth-Sun Comparison
In general, a very typical star. Keep in mind that it is really a ball of gas/plasma.
Visual radius 109 Earth
Mass 3.3 x 10^5 Earth
Luminosity 3.9 x 10^26 W
Surface temperature 5800 K
Central temperature 1.5 x 10^7 K
Rotation period 25 days