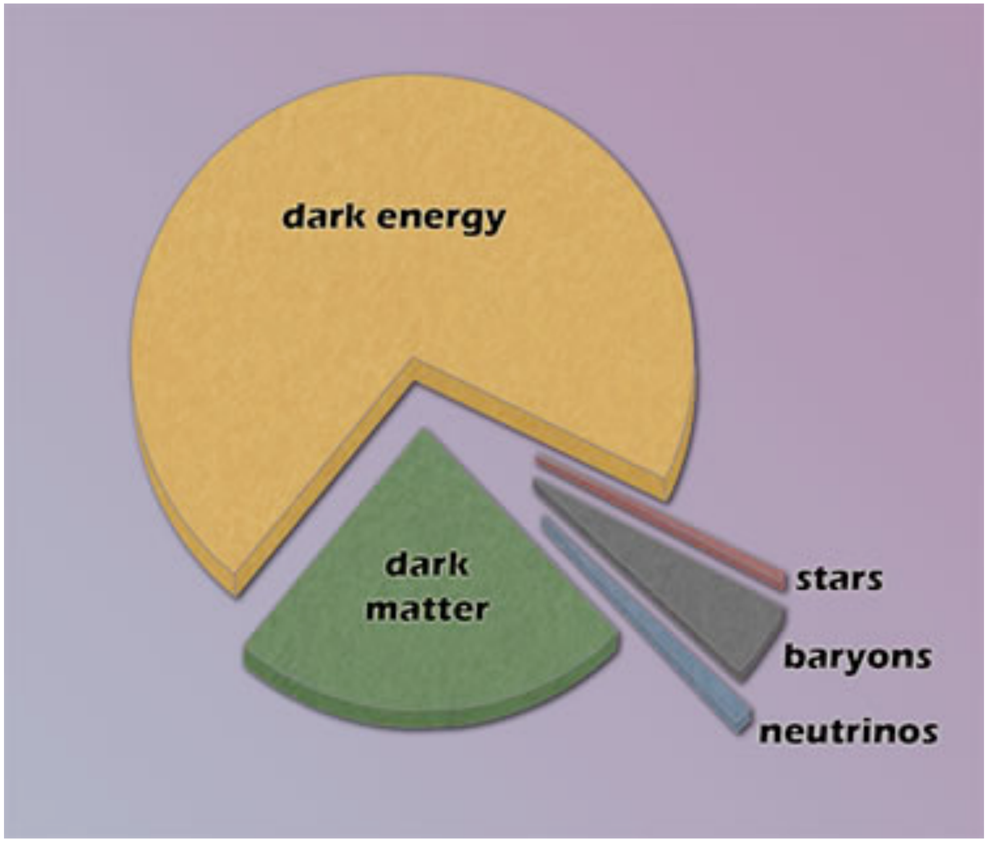
The Content of the Universe, and how we get heavy elements



http://www.lbl.gov/Science-Articles/Archive/sabl/2006/Jan/pie-chart.jpg

Outline

- The content of the universe
- How structure forms
- Elements heavier than helium
- Molecules

Reminder: HW due in one week

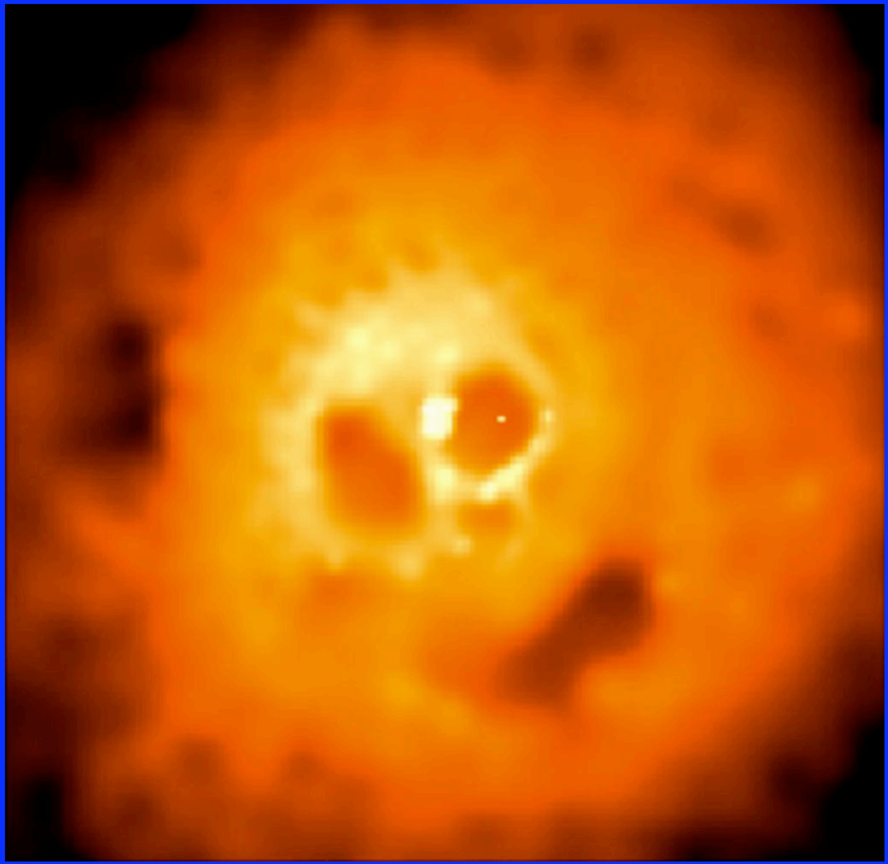
- Homework is on class webpage
- Due at beginning of class, Thursday, September 17
- If sick or can't make it at beginning:
  Notify me in advance
  Provide written documentation of excuse
  Can send PDF or Word file (or with friend), but will need hardcopy soon
  Send to *both* DJ and me

Last time...

- We concluded that the universe had to be old enough, clumped enough, and rich enough in complex atoms for life to appear
- We'll return to elements in a bit, but we now address the content of the universe

Neutrons and Protons

- Called "baryons"
  With electrons ->atoms
- Only 4% of mass!
- Form everything we can see
- Most baryons are in diffuse hot gas



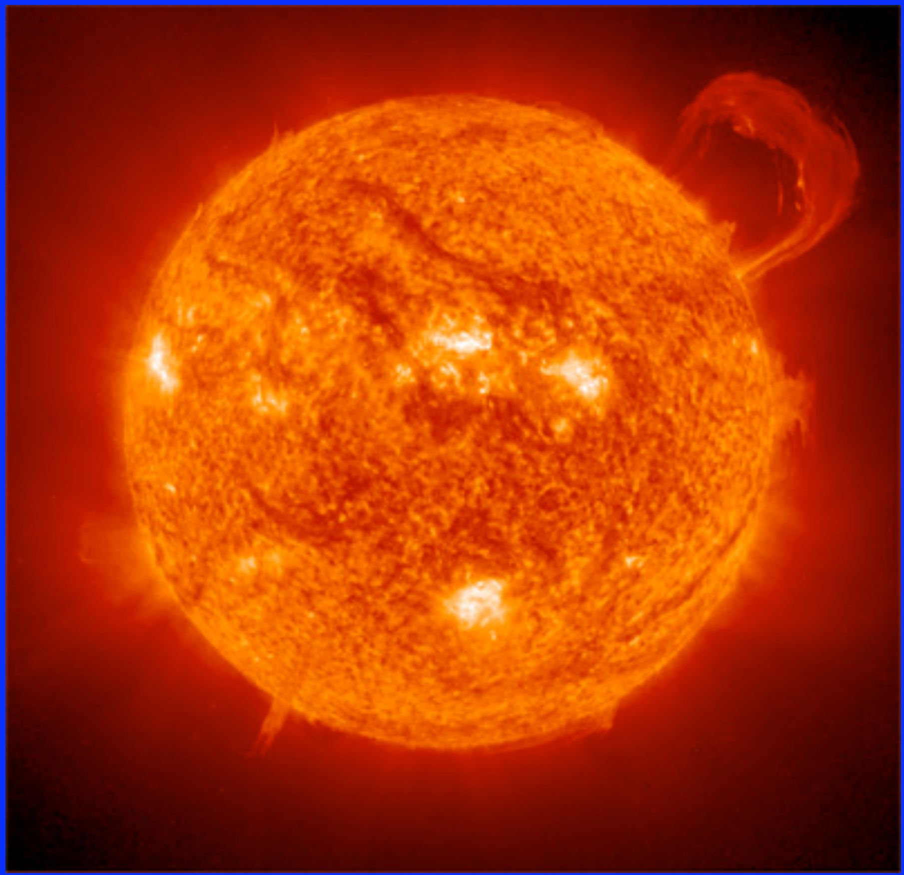
http://www.phys.ncku.edu.tw/~astrolab/mirrors/apod/image/0010/perseushalloween_cxc_big.jpg

What Do We Mean by Diffuse?

- As in so many ways, astronomical densities are far different from our experience
- Air has about 10^{20} atoms per cubic cm
- A "dense" interstellar cloud has 10^4
- Most hot diffuse plasma has 10^{-3} or less!
- Could you form life out of this?

Life in Plasma?

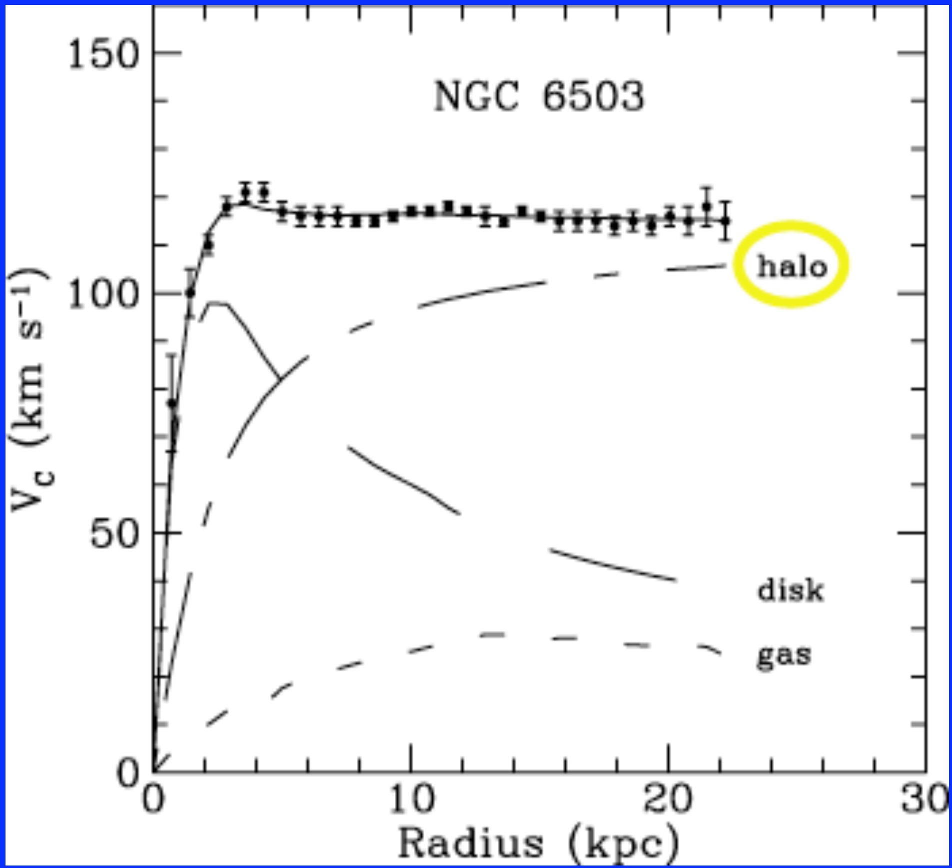
- Over 99% of baryons are in plasma (ionized matter, no molecules)
- Science fiction has imagined life there (e.g., Sundiver, David Brin)
- Do you think this is possible?



http://ocw.mit.edu/NR/rdonlyres/Global/7/77E722FA-4A00-476D-9D4A-3F86C9BDA2B3/0/chp_sun_plasma.jpg

Dark Matter

- But wait: there's more
- Can measure mass of galaxy by speed of rotation (Kepler's law)
- Also by adding up star mass
- Total mass way more than stars: dark matter? 23% of total mass-energy



http://www.robertrohde.com/classes/phys228/RotationCurve.gif

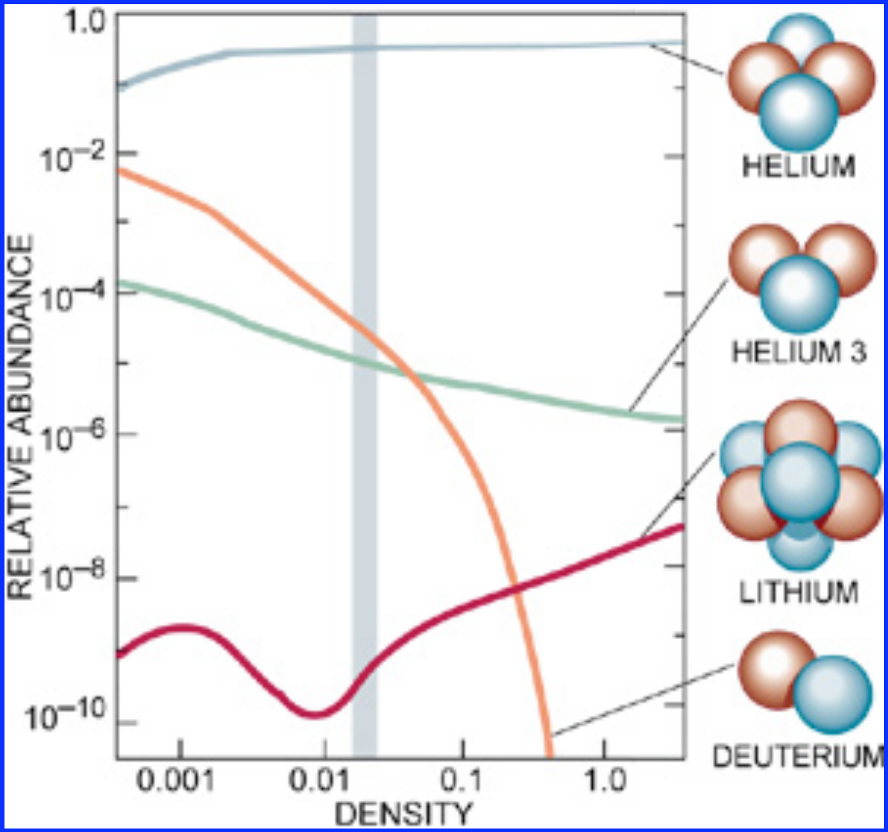
Here "halo" is dark matter

Big Bang Nucleosynthesis

- To narrow down on dark matter, must consider big bang nucleosynthesis (=production of light nuclei)
- More baryons means more chances to interact and produce helium
- Specific predictions about abundance of deuterium, lithium, ^{3}He, ^{4}He as function of density of baryons

Dark Matter=Ordinary Stuff?

- Could it be planets, white dwarfs, etc., made of normal stuff?
- No!
- More ordinary matter means more helium produced in early universe
- In all forms, ordinary matter is only 4% total



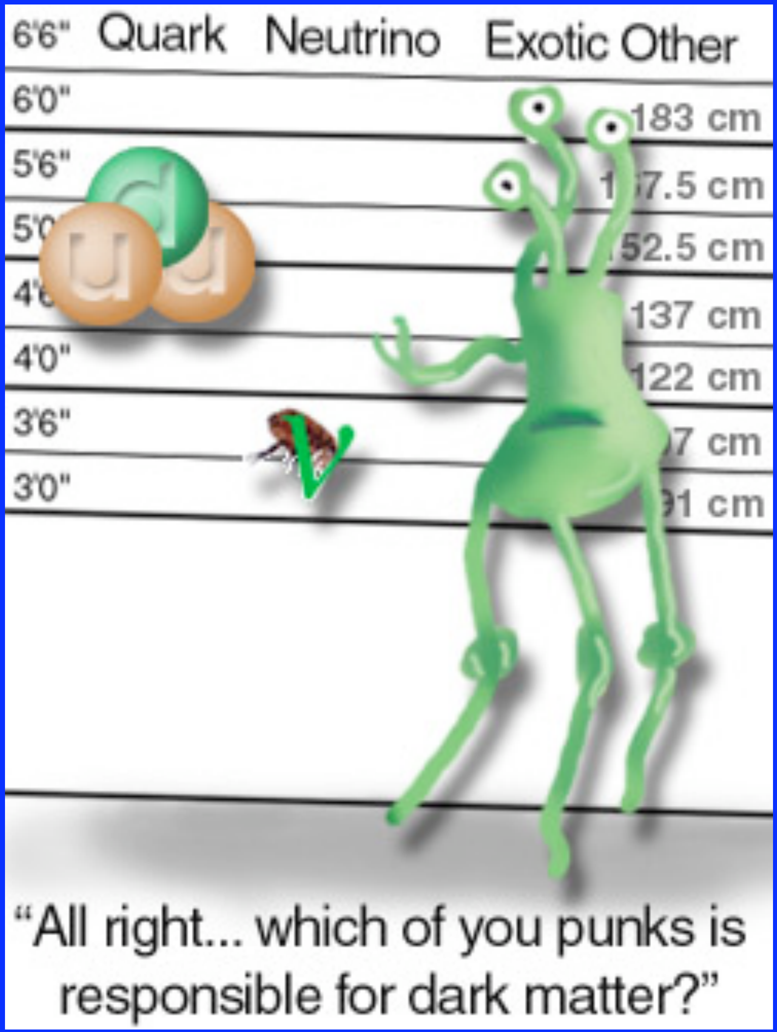
http://astro.berkeley.edu/~mwhite/darkmatter/altbbn.jpg

Dark Matter=Known Particle?

- No!
- Most particles are unstable, so need to focus only on stable ones
- Not electrons, neutrons, protons, photons
- Only reasonable candidate is neutrinos... but they are too light to matter
- What could dark matter be?

Candidates for Dark Matter

- Has to be something that doesn't interact with light
  New type of particle?
  Black holes?
- Some lab experiments claim detection
  Not verified yet
- Could we just be wrong about gravity?



http://physics33.creighton.edu/faculty/duda/punks.jpeg

Evidence for Dark Matter

- Collision of two clusters of galaxies
- Most mass (purple) follows stars, not gas (red)
- Consistent with collisionless component
- Expected for dark matter

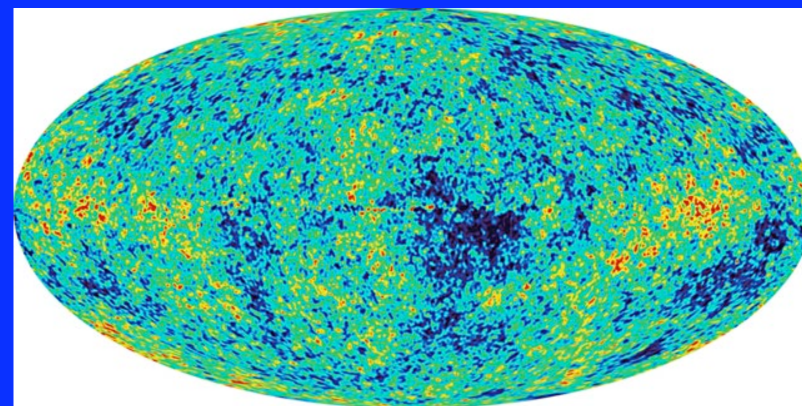
Bullet Cluster

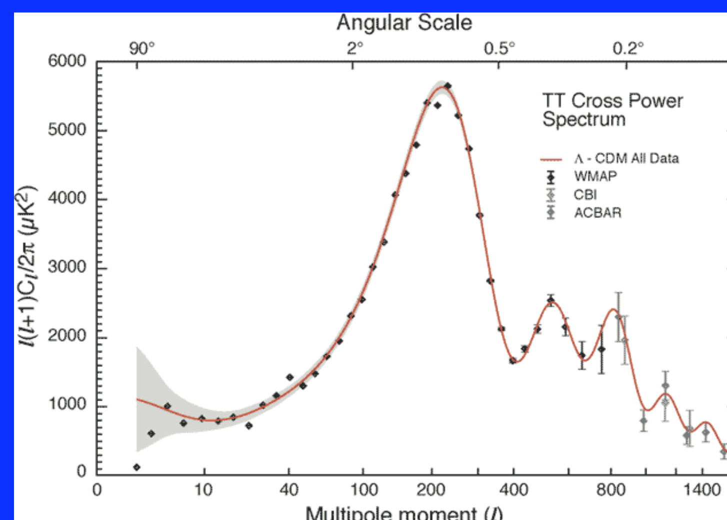
http://www.shef.ac.uk/physics/teaching/phy111/images/bullet_cluster_c60w.jpg

Evidence for Dark Matter

- Cosmic microwave background
- Hotter and colder spots
- Some spot sizes more common than others
- Fit model to it
- Confirms dark matter makes up 23% of universe
- Planck experiment (2009-10) will do more precisely

WMAP sky map

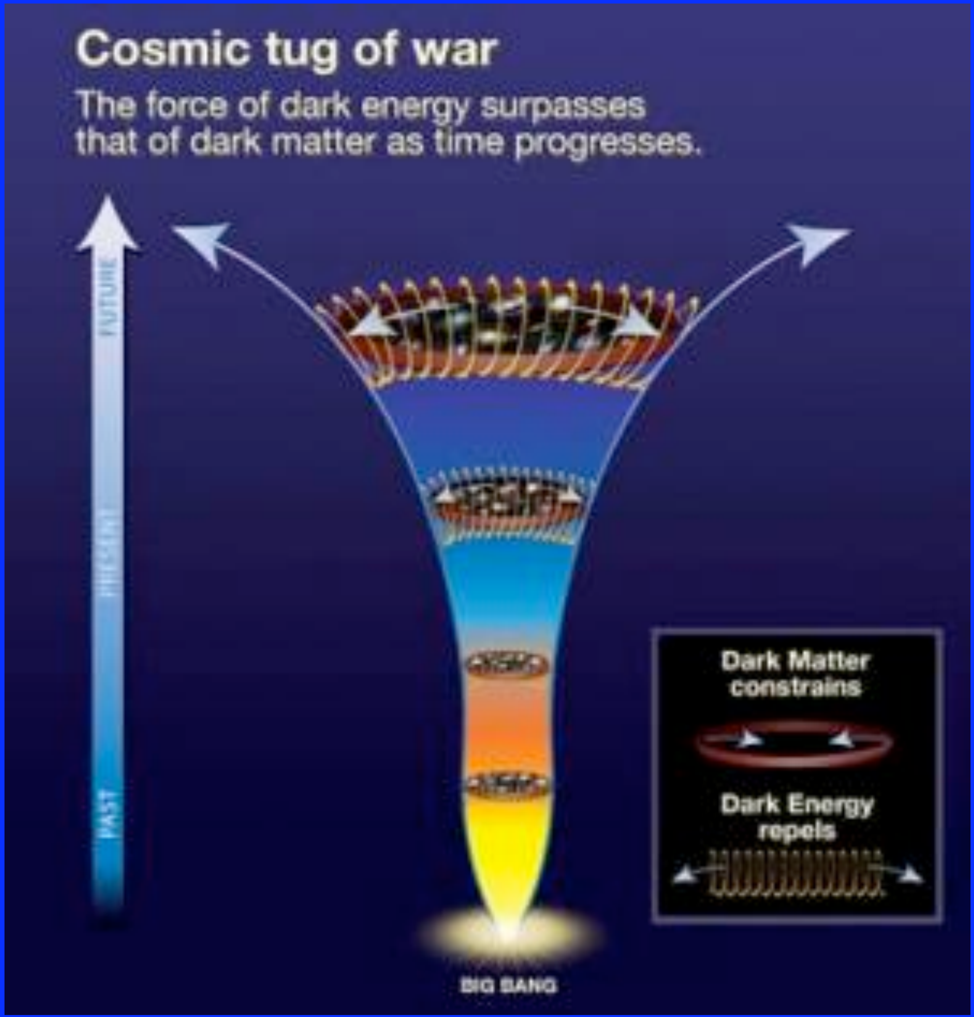




http://casa.colorado.edu/~ajsh/cosmo_04/wmapcl.gif

Dark Energy

- Even weirder!
- Some kind of field that pushes space apart
  73% of mass-energy!
- No one has a clue what this is
- Fortunately, ignorable in early universe



http://www.sciencedaily.com/images/2006/11/061116132026.jpg

Perspective: Baryon Bias

- For most of the history of astronomy, we were aware only of stars (not hot gas, not dark matter or dark energy)
- Why the bias?
  Selection effects
- Might there be big parts of the universe that we are still missing?

Candidates for Life

- Dark energy?
- Dark matter?
- Baryons?

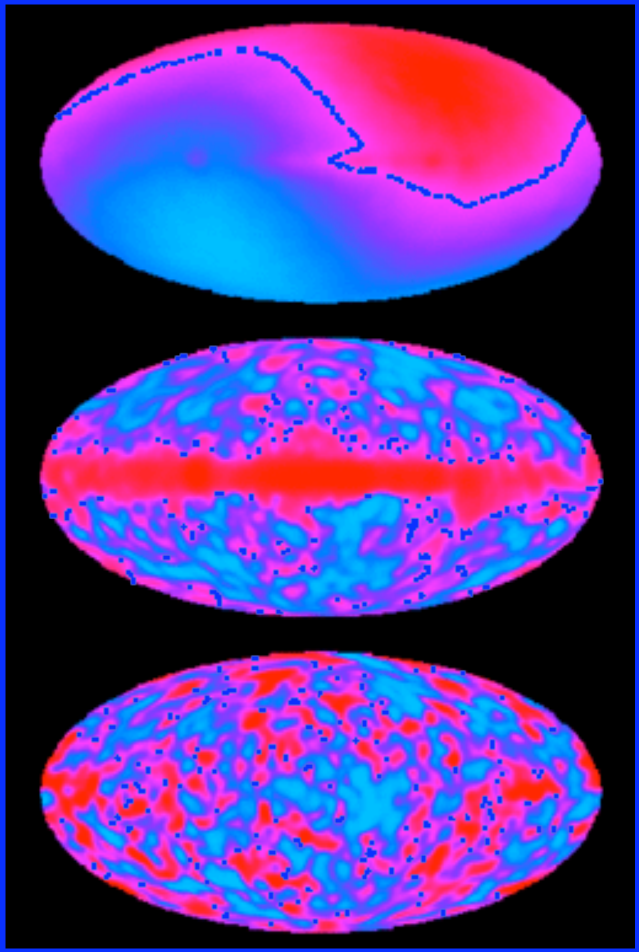
Candidates for Life

- Dark energy?
  No: too smooth, meaning it can’t clump together to form structure
- Dark matter?
  Probably not; although dark matter can clump it can’t cool and form complex structure
- Baryons?
  Well, sure! We’re made of them

Early Days: Smoothness!

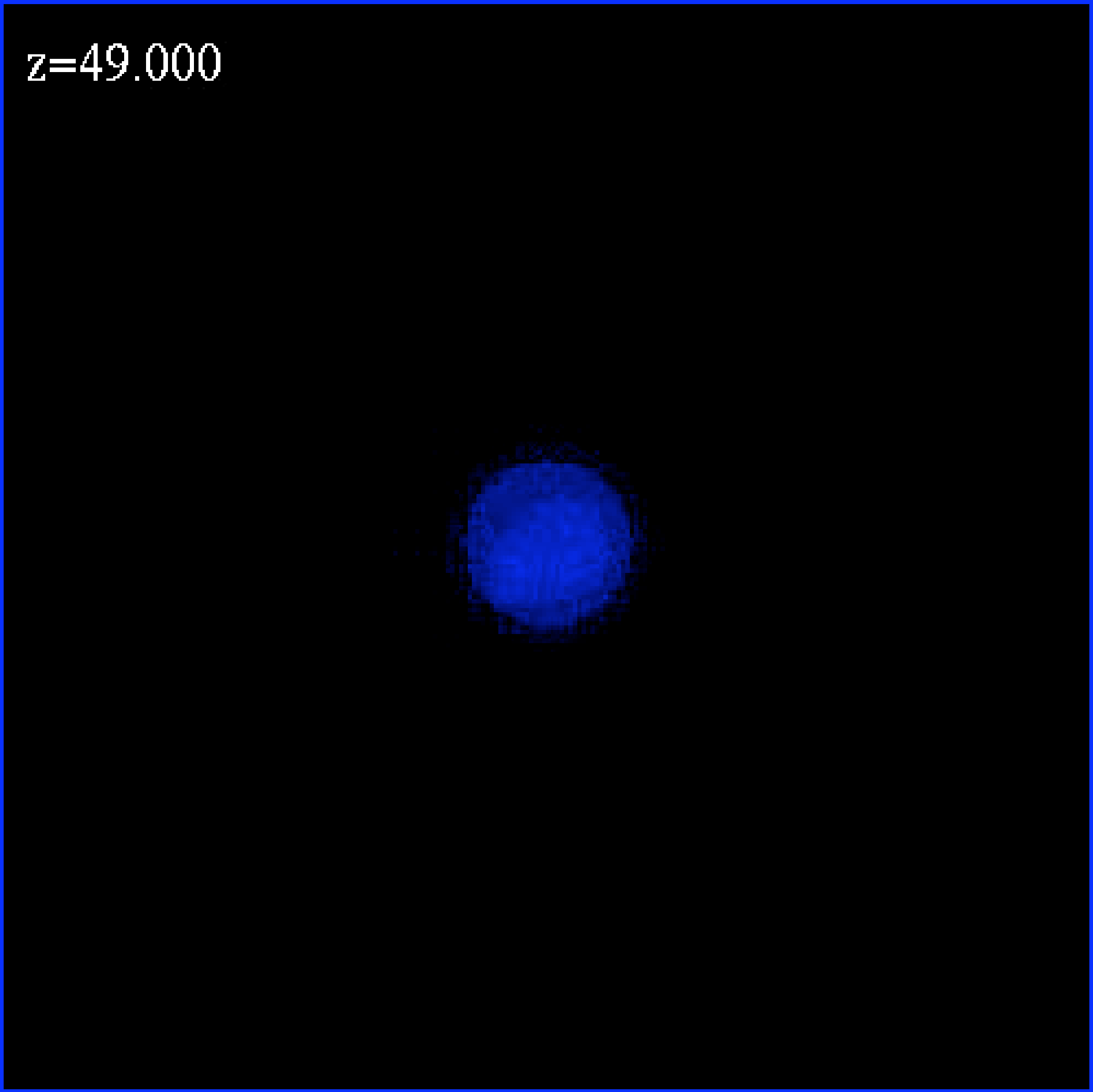
- 400,000 yr after Big Bang, smooth to one part in 10^5!
- But gravity makes dense parts denser
- Amazingly, this is enough to make current universe

We're 10^{30}x average!



http://upload.wikimedia.org/wikipedia/commons/thumb/0/09/Cobe-cosmic-background-radiation.gif/256px-Cobe-cosmic-background-

Structure Formation; Ben Moore

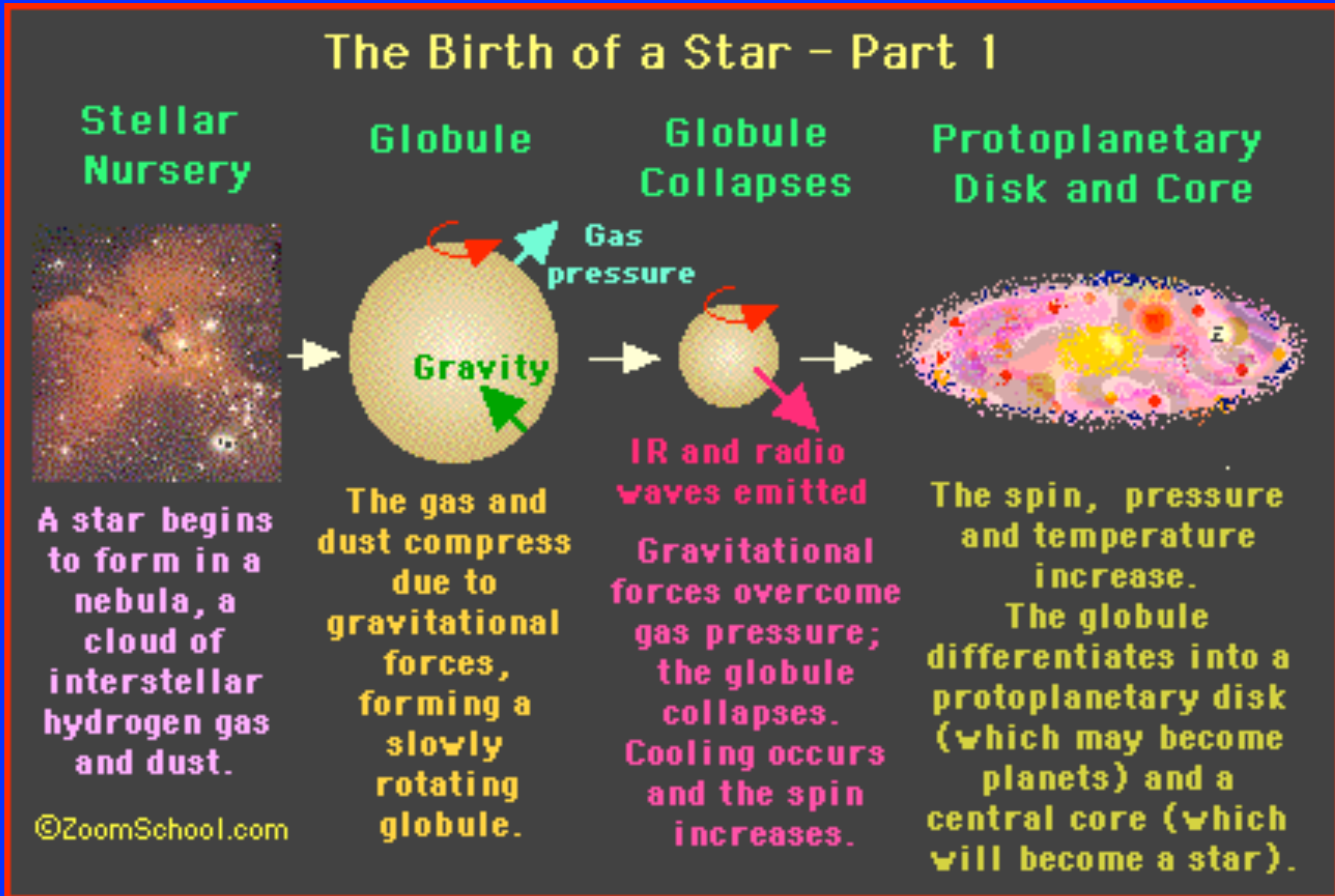


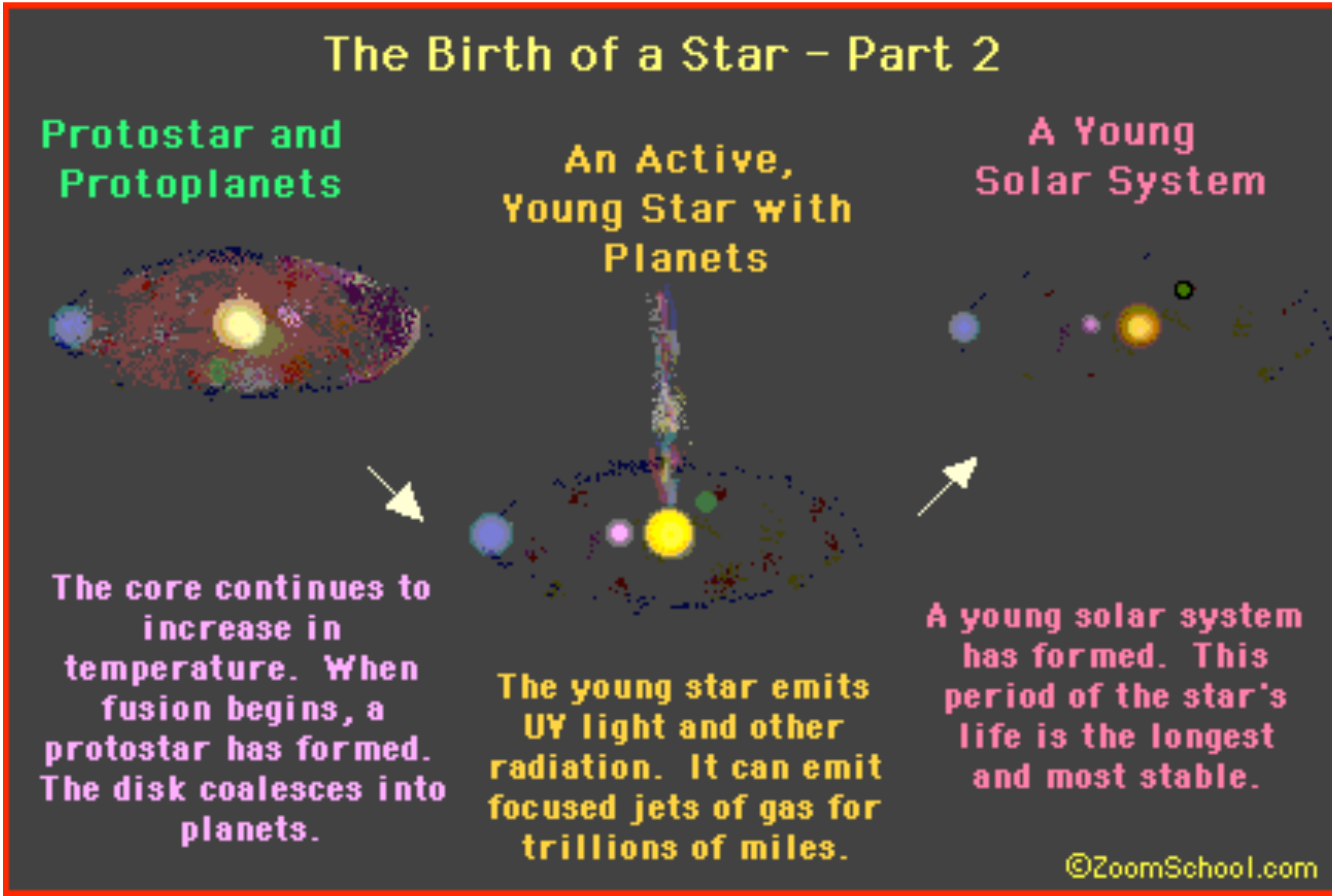
Structure Formation in Dark Matter

- Structure formation movie
- Slightly denser regions have more gravity
- These collect and become denser
  What prevents full collapse to black hole?
- Baryons are dragged into these denser regions by the gravity of dark matter

Structure in Ordinary Matter

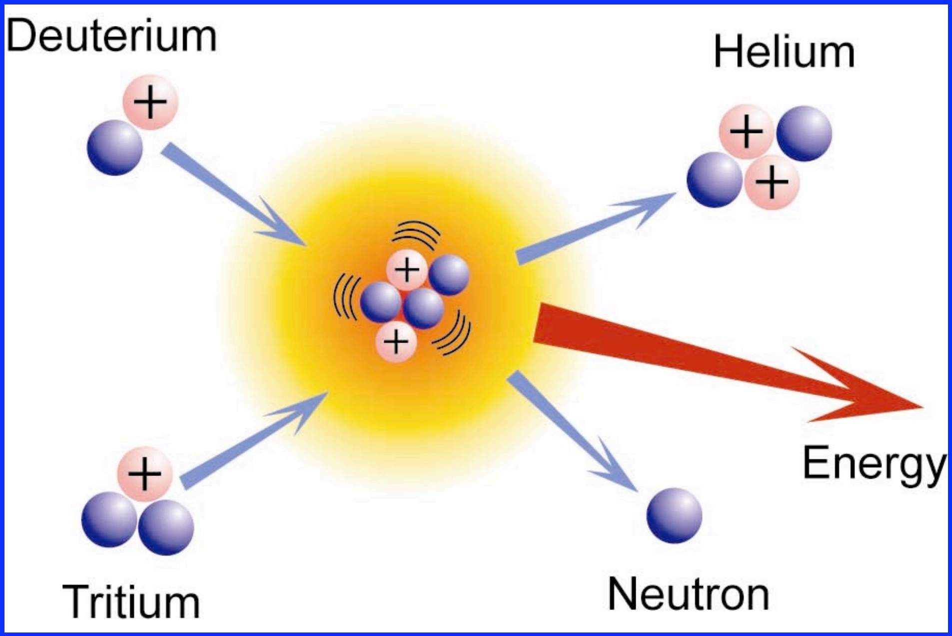
- Dark matter can’t radiate, but baryons can
- Allows them to settle, get denser, form stars
  First:~70 Myr after BB
- Stars are hot and dense
  Allow nuclear fusion
  Give us C, N, O, ...!


The Birth of a Star - Part 1
Stellar Nursery
Globule
Globule Collapses
Protoplanetary Disk and Core
Gas pressure
Gravity
IR and radio waves emitted
A star begins to form in a nebula, a cloud of interstellar hydrogen gas and dust.
The gas and dust compress due to gravitational forces, forming a slowly rotating globule.
Gravitational forces overcome gas pressure; the globule collapses. Cooling occurs and the spin increases.
The spin, pressure and temperature increase. The globule differentiates into a protoplanetary disk (which may become planets) and a central core (which will become a star).
©ZoomSchool.com


The Birth of a Star – Part 2
Protostar and Protoplanets
An Active, Young Star with Planets
A Young Solar System
The core continues to increase in temperature. When fusion begins, a protostar has formed. The disk coalesces into planets.
The young star emits UV light and other radiation. It can emit focused jets of gas for trillions of miles.
A young solar system has formed. This period of the star's life is the longest and most stable.
©ZoomSchool.com

Basics of Nuclear Fusion

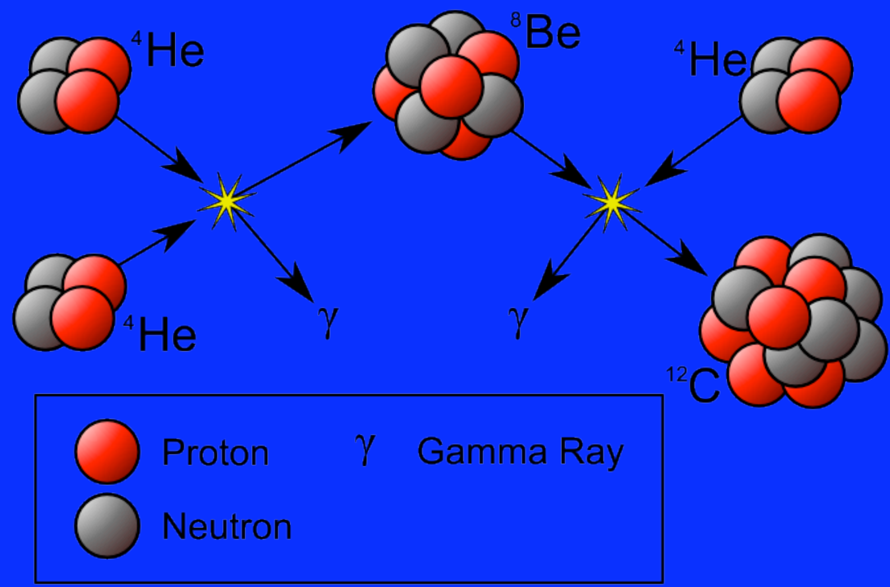
- Effect: light nuclei convert to heavy
  H to He, He to C, etc.
- In dense, ionized regions (no atoms, just nuclei and electrons)
- In "main sequence", H to He (requires 4H->He, but not all at once)



http://www.lancs.ac.uk/ug/hussainw/fusion.jpg

Making Heavy Elements

- Need 3He->C, but 2He are unstable
  Bind temporarily, then another He comes by
- Nearly impossible in early universe
- Requires high temp and density, long time

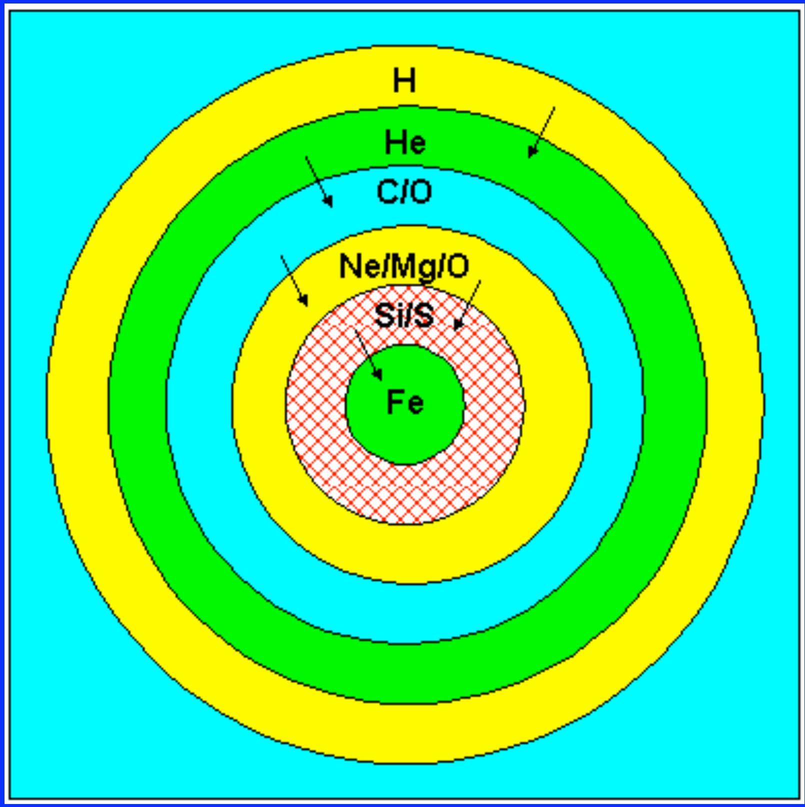


http://zebu.uoregon.edu/~imamura/122/images/Triple-Alpha_Process.png

Heavier and Heavier

- Can make nitrogen, oxygen, up to iron and nickel in this way
  Most stars too cold
- Beyond iron/nickel, does not release energy
  Core collapses
  Kaboom! Supernova...

Pre-supernova star

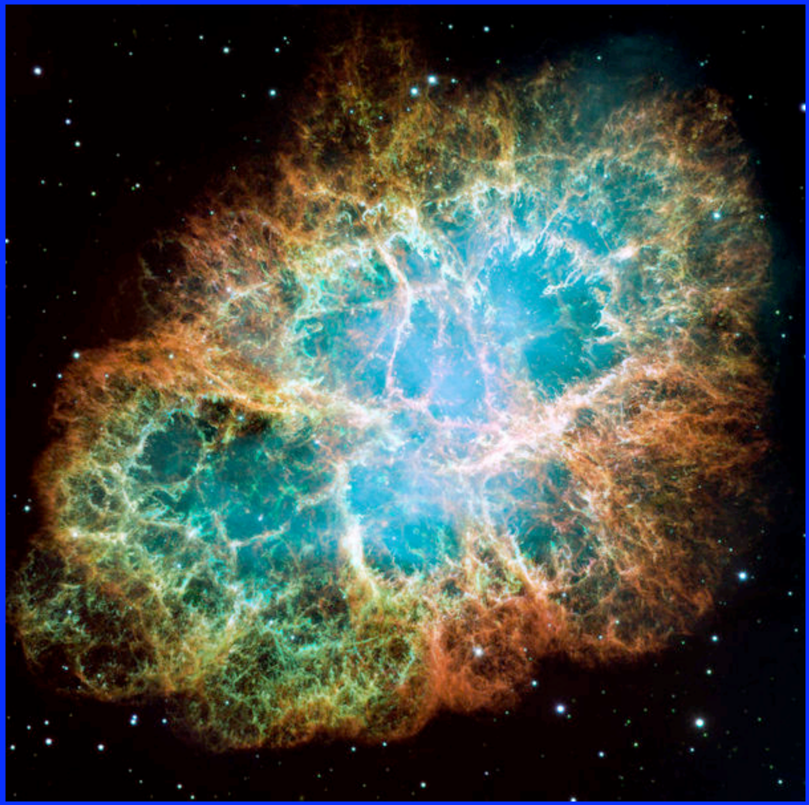


http://zebu.uoregon.edu/2000/ph123/snonion.gif

Getting the Lead Out (and other stuff too)

- All this is very well, but need to distribute the elements for life!
- Stellar winds?
  Weak for Sun-type
  Strong for more massive
- Supernovae
  Distributes almost everything!
  We are made of star stuff

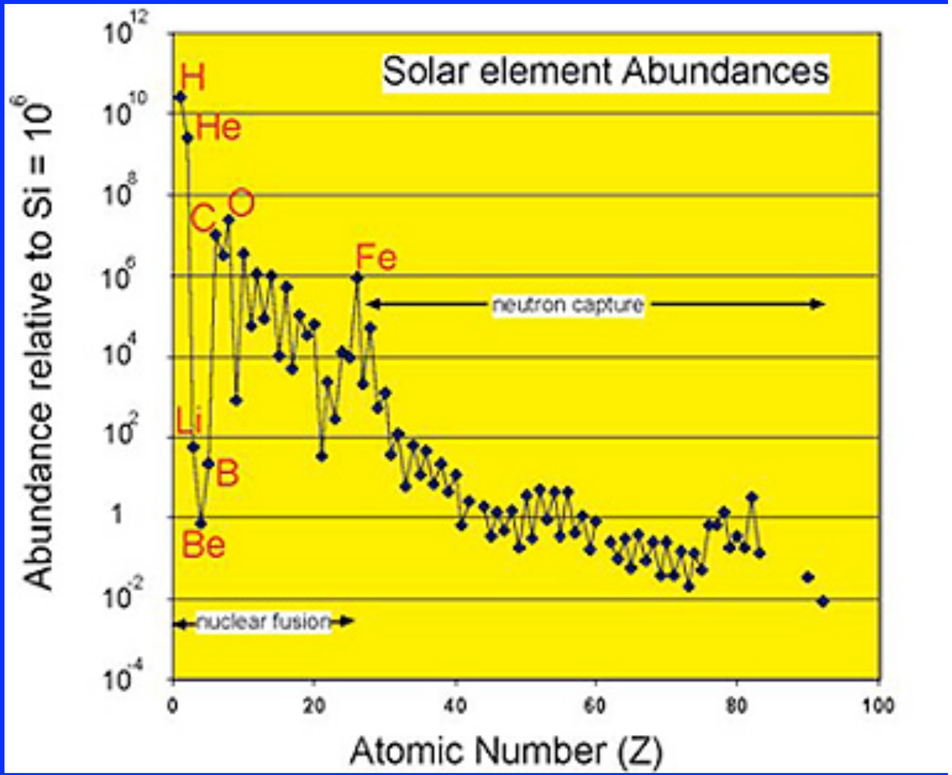
Crab SN remnant



http://www.lib.fit.edu/pubs/librarydisplays/colors/603px-Crab_Nebula.jpg

Solar Elemental Abundances

- Lots of H, He
- Main elements produced by fusion are abundant: C, N, O, Si, Fe
- Silicon and iron (make up rocky planets) are about 10^{-4} of H

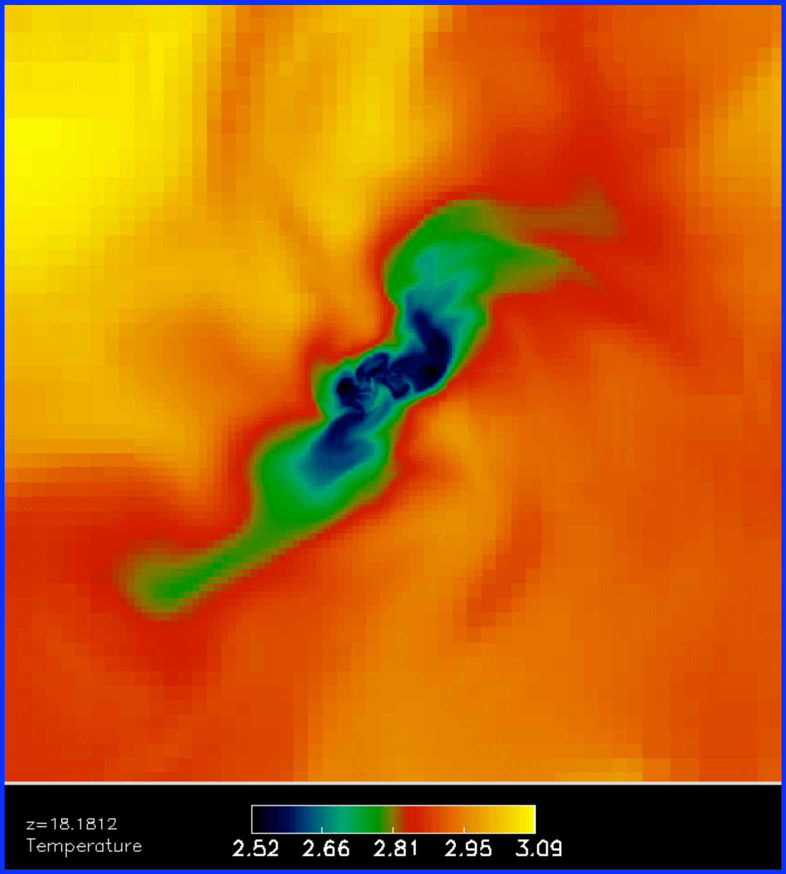


http://rst.gsfc.nasa.gov/Sect20/elements.jpg

Earliest Time for Life?

- Earliest stars: 10^8 to 10^9 yr after BB
  Many are massive
  Plenty of supernovae
- In principle, life could have started forming around 10 Gyr before we appeared
- Did it?

Simulation of first star



http://astronomy.swin.edu.au/sao/guest/abel/88_j64_T_4_e-7_z.gif

Abundances of First Stars

- Some very old stars have just 1/100,000 of the Sun’s fraction of iron
- How might this affect the possibility of life around them?

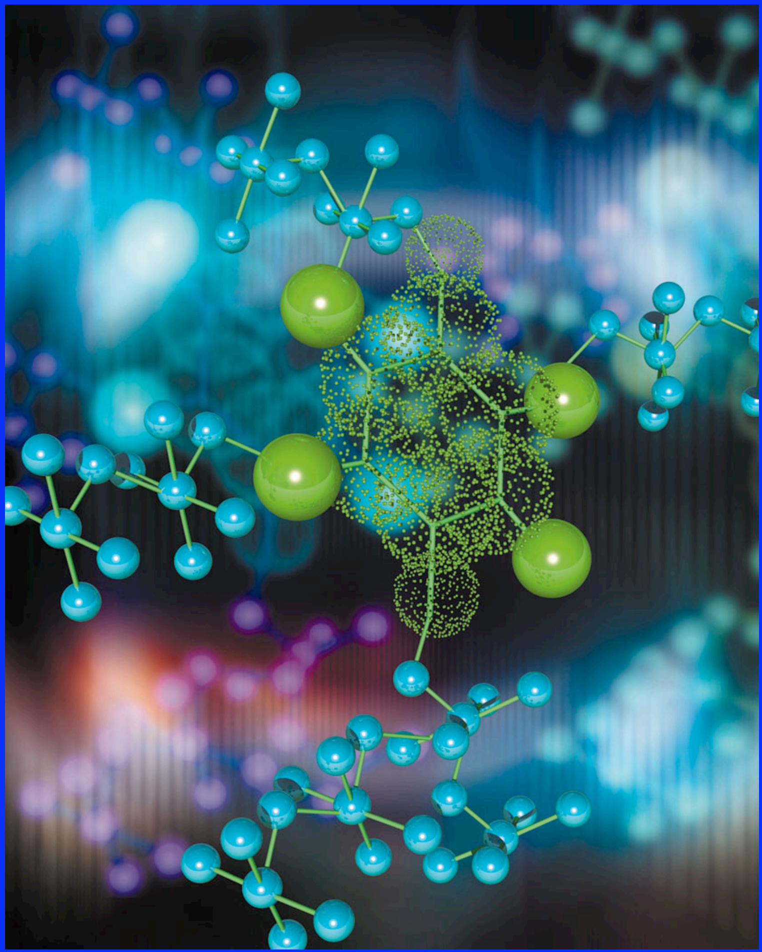
How Much Heavy Stuff is Enough?

- Do we need just a touch of C, N, O, etc.?
- Or do we need enough to form big rocky planets?
  If so, maybe we're not such latecomers
- What do you think?

http://wever.files.wordpress.com/2008/03/rocky-planet-1.jpg

Molecules in Space

- We argued we need complex molecules for life
- Is this unique to Earth, or is it elsewhere?
- First, how might we detect molecules in other places?



http://www.synfusion.com/Expertise/Molecules_and_Integration.JPG

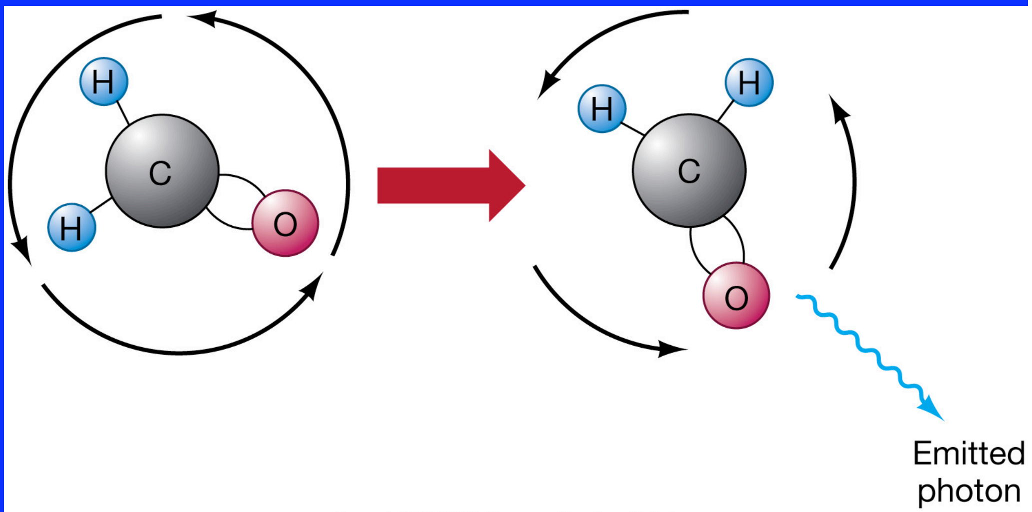
Of all objects, the planets are those which appear to us under the least varied aspect. We see how we may determine their forms, their distances, their bulk, and their motions, but we can never know anything of their chemical or mineralogical structure; and, much less, that of organized beings living on their surface ...

Augustus Comte
1840

(and he thought we could learn even less about stars!)

Spectra of Molecules

- Recall: can detect atoms by their specific interactions with light
- Same with molecules, but lower energy
  Typically radio waves
- Stars are too hot; look at cold regions



Where Do We Look?

- Where can molecules exist?

Where Do We Look?

- Where can molecules exist?
- Need cold areas, otherwise break apart

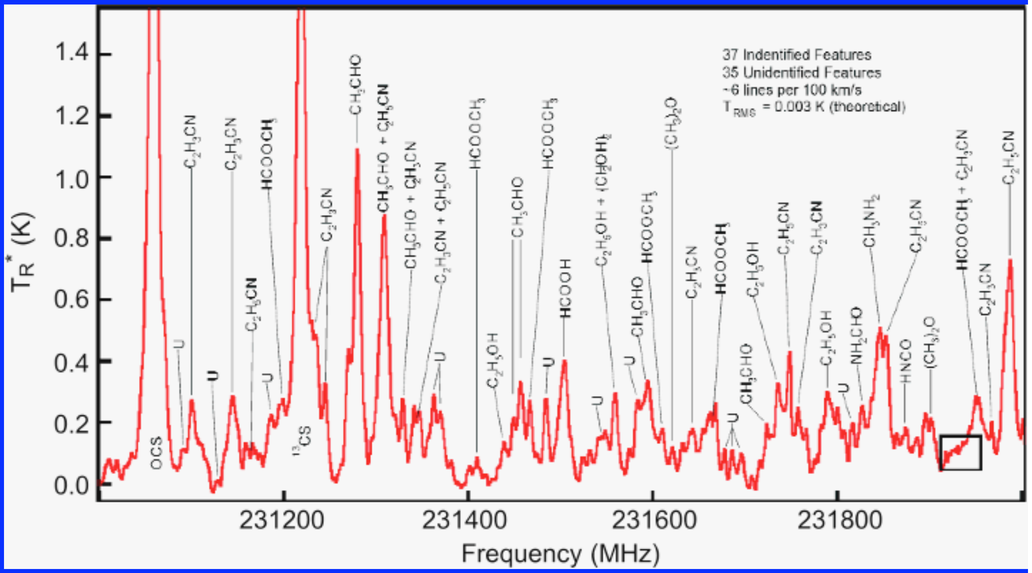
  Planets

  Molecular clouds

What Has Been Detected?

- H_2, easily (most common molecule)
- CO, SiO, OH, NaCl and many others
- But what about organic molecules? Have they been seen in space?

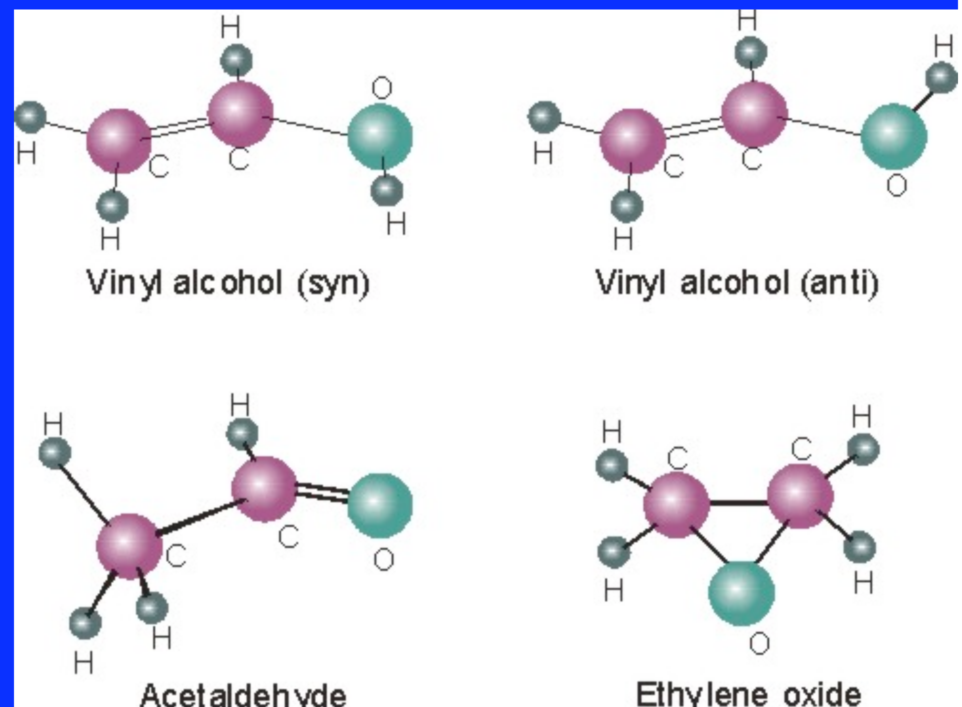
Spectrum of molecular cloud



http://www.cv.nrao.edu/course/astr534/images/bandscan.gif

Organic Molecules in Space

- Yes!!
  More than 130 so far
- Sugars, alcohol(!)
- Most importantly: simplest amino acid, glycine
- Apparently the building blocks of life are out there...



http://www.nrao.edu/pr/2001/vinylalco/vinyl_alcohol.jpg

Summary

- Life must form out of baryons and electrons, but that's only 4% of universe
- Gravity brings matter together, and baryons cool and condense into stars
- In cold, dense environments, many organic molecules have been detected
- But how do planets form with these materials?