Evolution of the Universe

Topic 2: After The First Three Minutes

Big Bang, Black Holes, No Math

ASTR/PHYS 109

Dr. David Toback

Lectures 22 & 23
Was due Today - L23

- **Reading:**
  - Unit 5: Was due before class
- **Pre-Lecture Reading Questions Quiz:**
  - Unit 5 Quiz: Due before next class
- **End-of-Chapter Quizzes:**
  - Chapter 13:
    - (Do worksheet on class homepage to help prepare for EOC quizzes, Does not need to be turned in)
    - (Chapter 13 parts A-D)
    - Chapter 13 Parts E-F: Was due before class
- **Papers (All items due at 11:55PM in Peerceptiv)**
  - There will be a make-up paper on Dark Energy for those of you who missed either the text or a Review/Back-evaluations. Can only replace one of those for one assignment
  - Paper 2:
    - Grades posted. Let us know if you think you were misgraded
    - If you want to do a Revision, due Monday Nov 18th by 11:55 in TurnItIn
  - Paper 3: (Best guesses)
    - Rough Draft (if desired): Was due Friday Nov 8th, will do our best for late submissions
    - Text: Due tonight, Wednesday Nov 13th (Grace period with late penalties)
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The Universe at ~700,000 Years Old

- At a temperature of about 3000K photons, on average, can’t knock apart atoms
- Stable atoms can form and most electrons become part of atoms
- The atoms are now free to form into stars and galaxies
Give this special time in history a name

Call this time “Recombination” Crappy Word! Atoms are combining for the first time, not recombining!
Atoms in the Universe

Early Universe

Lots of protons and electrons:
Can combine to form atoms

Very little water in tub = very few atoms in the Universe

A couple hundred Thousand Years Later

Lots of protons and electrons:
Can combine to form atoms

The amount of water in the tub is rising

These days

Almost all the protons and electrons are in atoms: Very few available to form new atoms

The tub is now as full as it will ever be

Lots of high energy photons:
Quickly break apart any atom created

Very few high energy photons:
Can't break apart atoms

Very few high energy photons:
Can't break apart atoms

Big Bang, Black Holes, No Math  Evolution of the Universe  Topic 2: After The First Three Minutes
Before and After the Creation of Atoms

Universe Cooling After Big Bang

Before:
Lots of free electrons and protons in the Universe
\(\rightarrow\) Photons scatter from charged particles

After:
Protons and electrons combine to form atoms
\(\rightarrow\) Universe becomes transparent for photons

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Transparent Universe

The Universe now **LOOKS** different!

- The light (photons) have no free electrons to interact with

- Since all the electrons are in atoms, because of Quantum Mechanics, they largely ignore the photons

- Photons just travel in a straight line → Like traveling through glass
Atoms in the Universe

Early Universe
Phots bust apart atoms

A couple hundred Thousand Years Later
Photons can only excite atoms

These days
Universe is transparent to photons

Big Bang, Black Holes, No Math
Evolution of the Universe
A Cartoon...

Before Recombination:
Photons interact with charged particles
Photons travel in straight lines forever

After Recombination:
Atoms ignore the photons
Cosmic Background Radiation

- The photons we see in the cosmic background radiation are essentially the photons AFTER they interacted with their last charged particle

- Well... they've been traveling for awhile so they've changed a bit
Photons in the Universe

After recombination, photons can travel freely through space. Their wavelength is only stretched (red shifted) by cosmic expansion.

→ Observe most photons as the cosmic background radiation!

→ Also can observe photons emitted from Galaxies a billion years ago (just reaching us now) as being red-shifted.
A Neutral Universe

- After the electrons and protons combine to form atoms the Universe is almost completely neutral i.e., neutrally charged

- Why is this so important? All the particles in the Universe stop attracting each other due to their electric charge
  - Not completely true, just true outside the atoms
  - Basically can ignore electric charge from here on out
The Transition From a “Charged” Universe to a “Neutral” Universe

Proton, Deuterium Nucleus, Photon, Electron, $^4$He Nucleus
Aside on Dark Matter

• Dark matter is a BIG part of this story because there is 5 times more mass in the Universe in dark matter than in atoms
  - Will come back to this in Chapter 15
• However, the story doesn't change much with Dark Matter since we think it is just another neutral particle
A Gravity Dominated Universe

• **The only thing left is gravity!**

• The gravitational attraction between massive things ONLY makes them move **towards each other through** space

• Any single atom would be most attracted to the closest place with lots of mass
Wait a Half Billion Years

• As the years go by, mass clumps together
• By a half a billion years after the bang, most of the mass is in one of a large number of “clumps”
• Huge numbers of these clumps, each becomes part of a galaxy!
After less than ~0.5 billion years, the first stars form

Stars produce heavy elements ("Stellar Cooking")
Fast Forward...

- Fast forward 13 billion years
  - Temperature of space is now ~3 Kelvin
  - Cosmic Background Radiation
- We get people...
- More on Stellar and Galaxy Formation next
Lecture on Chapter 14 now complete
Looking Forward

• Finished Unit 4
  - Evolution of the Universe

• Starting Unit 5
  - From half a billion years until today
  - Big Objects and Black Holes
Evolution of the Universe

Topic 2: After The First Three Minutes

Big Bang, Black Holes, No Math

Full set of Readings So Far

• Required:
  - BBBHNM: Chaps. 1-15

• Recommended:
  - TFTM: Chaps. 1-5
  - BHOT: Chaps. 1-7, 8 (68-85), 9 and 11 (117-122)
  - SHU: Chaps. 1-3, 4(77-93), 5(95-114), 6, 7 (up-to-page 159)
  - TOE: Chaps. 1-3
Quick Review: Various Times

Walking through what happens during each of a number of different periods in time

- The VERY early universe
- The first three Minutes
- The next 300,000 years
- The next billion years
- ~13 billion years later (now)
- The ultimate fate of the universe?

Chap 13
Chap 14
Chaps 15-17
Unit 6
Unit 5 Overview

• Next, spend more time on what happens from 500 million years until today: Stars, Galaxies and Black Holes

• It turns out that the way Galaxies and Stars form have similarities... start there

• The way stars die depends on the star itself... sometimes they die to form a Black Hole

• Black Holes are some of the weirdest things in the Universe...
  - In many ways the formation of Black Holes is like the Big Bang in Reverse
Unit 5: Big Objects and Black Holes

1. Galaxies
2. Star Birth and Death
   • Black Hole Formation
3. Properties of Black Holes
Galaxies: Overview

• What do Galaxies “look like”?
• How do galaxies form?
• When do galaxies form?
What do Galaxies “Look Like”?  

All have common properties

1. Stars (produce the light we see)
2. Gas (atoms not in stars)
3. Dark Matter (most of the mass)
Visualizing a Galaxy

- The light comes from the stars
- Most of the mass is Dark Matter

In some ways, Dark Matter surrounds the stars in a galaxy like the water in a fishbowl surrounds a fish in the middle of the bowl. Not exactly the same... denser in the middle because of the pull of gravity.
Two example “Types” of Galaxies

**Spiral Galaxy:** like the Milky Way
- Bulge in the middle
- Disk on the sides

**Elliptical Galaxy:**
- One giant bulge, stars are like bees buzzing around the center
- Biggest galaxies are ellipticals
How Galaxies Form: From the Early Universe to Galaxies

- After about ~3 minutes, things are cool enough for nuclei to form.
- After ~300,000 years, things are cool enough for electrons and nuclei to combine to form atoms.
- Let’s move to about half a billion years after the bang.
Where are we now in the history?

Half a billion years after the bang

Big Objects and Black Holes

Topic 1: Galaxies

Big Holes, No Math
Big Picture

A half a billion years after the bang we get

• Galaxies forming
• Stars forming
A Gravity Dominated Universe

• The gravitational attraction between massive things ONLY makes them move towards each other through space

• Dark Matter and atoms are neutral and massive

• Both are most attracted to the closest place with lots of mass
  - Biggest dent in space-time
Matter falls to the center over time.
There is also spinning, but we'll get to that in a bit.
Galaxy Formation Analogy: People Jumping on a Trampoline

If two people touch, then they will stick together

If they fall they create a big dent in the trampoline (like a dent in space-time)

Once you get that first dent on the trampoline everyone starts falling into it
Wait a Half Billion Years

• As the years go by, mass clumps together

• By a half a billion years after the bang, most of the mass is in one of a large number of “clumps”

• Huge numbers of these clumps, each helps form galaxies!
Galaxy Creation Over Time

Soon after the big bang

A region of the universe soon after the big bang is filled with hot, dense gas and radiation.

Now

The same region now has expanded and cooled, and the matter has formed galaxies.
Big Picture: Stars in Galaxies

- Atoms fall towards the center of the galaxy or orbit around it
- Stars form where there are lots of atoms
- Once the atoms form stars there is a large amount of distance between stars
  - About 4 light years between us and our nearest neighbor star
  - An important exception is binary stars where two stars formed together
- Stars can orbit around the center of the galaxy
Slow Atoms Outside the Galaxy

Where does the disk of the Milky Way come from?

Lots of atoms moving around, far outside the center of the galaxy
Need More Analogies...

1. Water being poured into a bowl and flowing to the bottom

2. Water swirling in a bowl

3. Water in a bathtub with the drain open (and ignoring what happens to the water that goes down the drain)
Water Flowing

- Think about water moving towards a drain in the bathtub
  - All falls in quickly → can get bubbling at the drain
  - Falls in medium → Get swirling
  - Falls in slowly → Just goes straight down

- This is how different types of galaxies can form
Visualize the process

Start right after things start to contract...

A slowly rotating cloud of gas begins to contract.
Spinning into Shape

• Gravity attracts mass to the densest place
  - Center of the Galaxy

• As the mass is pulled in, it starts moving slightly around the center

• Why does this happen?
**Analogy: Ice Skater**

Matter far away from the center ➔ Spins slowly

Pull the Matter in ➔ Spins faster

- You’ve seen this on TV
- Try this at home in a chair that rotates
- Get yourself spinning with your arms and legs stretched out, then pull them in

For those of you who have taken PHYS 218, this is Conservation of Angular Momentum

Can also think about water falling into a drain
Dark Matter Vs. Atoms

- Dark Matter and Atoms behave differently in galaxies
- When atoms get near each other they can bump into each other like people trying to exit a movie theater
- Dark Matter is more like two ships passing in the night
Why is there a disk? Analogy

- Think about atoms in the outer part of the galaxy as being like racecars going around a track
- Since they are all going basically the same speed and direction, there aren't that many crashes
  - They can just keep going around and around
- If a car tried to cross the track, or go the wrong way we'd quickly get a wreck, and neither would move with the main flow anymore
  - Because of gravity, just falls to center
- After all the wrecks, we are just left with the bulge and the cars that are basically going the same speed and direction
Why is there a disk on the outside?

- Focus on the atoms in the outer part of the galaxy... Not very dense out there, so stars don't form quickly
- As atoms fall toward the center they are like the water from the outer part of a sink
  - They start bumping into other atoms, which changes the direction they move
- Once enough atoms are going in different directions a swirl CAN start; atoms moving WITH the swirl can keep moving nicely and can orbit like a planet around the sun
  - Like in a sink, an effective swirl can continue
  - Atoms that go into other directions bang into the swirl and lose energy (fall down the drain, or go off into space)
- Eventually, most of the atoms have either fallen to the center or become part of the swirl
- Eventually, the cloud gets drawn in close enough that the atoms get close enough that they form stars
  - Stars just stay in the disk orbit
- Call this the disk
Visualize: As time progresses

As the galaxy contracts, things can start moving very quickly

A spherical cloud of turbulent gas gives birth to the first stars and star clusters.
More time Passes

Things start to “flatten out”
Said differently, the flat part can continue, but the non-flat-part (the stuff going in other directions) gets bumped out of orbit.

The rotating cloud of gas begins to contract toward its equatorial plane.
More time...

Stars and clusters are left behind in the halo as the gas cloud flattens.
Even more time...

New generations of stars have flatter distributions.
Even more time..

The disk of the galaxy is now very thin.
Stable Galaxies

The stuff in this stable state forms Stars: Call this a Galaxy

- Can give us disk-like rotating galaxies
- Can also form other types like elliptical galaxies
- Galaxies often collide and get even more complicated
Fun video

• Move from the simple view of a galaxy forming to a more complete computer model from NASA

• How a disk galaxies gets created

https://www.youtube.com/watch?v=_Ssc1GsqHds
Another fun video

Simulation of a future collision between Andromeda and the Milky Way, where the two would create a combined galaxy

http://people.physics.tamu.edu/toback/109/Video/andromeda.avi
For Next Time - L23

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