

ASTR 1040: Stars & Galaxies

2 billion light years
500 million light years
Cosmic Web

Prof. Juri Toomre TAs: Piyush Agrawal, Connor Bice
Lecture 30 Thur 4 May 2017
zeus.colorado.edu/astr1040-toomre

Our Schedule and Topics

- **Final Exam on Wed May 10, 1:30pm-4:00pm**, here, closed book, 2 crib sheets allowed (4 sides), bring pencils
- All **observatory reports**, "virtual" or actual project A, due **D2L dropbox** by **Mon May 8**
- **After first three minutes** in our universe
- **Computer models of cosmology in action**
- **Cosmic web of galaxies emerges**: cold dark matter crucial to structure formation
- Current big **outstanding questions or issues in astronomy**

OVERVIEW

1 billion years

380,000 years

3 minutes

Evolution of Universe

Timeline and Events Since Big Bang

- 14 billion years (present day) Galaxies form (cosmic)
- 1 billion years (present day) Galaxies form (cosmic)
- 380,000 years (present day) Atoms and plasma (atoms begin to form)
- 3 minutes (present day) Nucleosynthesis (nuclei, neutrons, electrons, neutrinos, antineutrinos)
- 200,000 years (present day) Atoms and plasma (atoms begin to form)
- 3 minutes (present day) Nucleosynthesis (nuclei, neutrons, electrons, neutrinos, antineutrinos)
- 10⁻¹² second (present day) Elementary particles (quarks, leptons, gluons, photons)
- 10⁻¹¹ second (present day) Elementary particles (quarks, leptons, gluons, photons)
- 10⁻¹⁰ second (present day) Elementary particles (quarks, leptons, gluons, photons)
- 10⁻⁸ second (present day) Elementary particles (quarks, leptons, gluons, photons)
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- 10⁸ second (present day) Elementary particles (quarks, leptons, gluons, photons)
- 10¹⁰ second (present day) Elementary particles (quarks, leptons, gluons, photons)

During first 3 minutes

Making the elements

How much DEUTERIUM made depends on density of ordinary matter (baryons)

FORMATION OF ELEMENTS DURING FIRST 3 MINUTES AFTER THE "BIG BANG"

Fraction by mass

HELIUM 25% (⁴He)

DEUTERIUM (observed) 0.01

DEUTERIUM (predicted) 0.1

TIME

10 sec 3 min 15 min

10⁹K 7 × 10⁸K 10⁸K (TEMP)

²H: HIGH DEUTERIUM ⇒ LOW DENSITY OF ORDINARY MATTER

LOW DEUTERIUM ⇒ HIGH DENSITY

OBSERVED ⇒ Ω ≈ 0.05

ONLY 1/20 OF WHAT NEEDED TO CLOSE UNIVERSE!

THIS ORDINARY MATTER IS NOT SUFFICIENT TO STOP EXPANSION OF UNIVERSE (OPEN)

Sensitivity in making the light elements

abundance of light nuclei (relative to hydrogen)

deuterium predicted

deuterium measured

helium-3 predicted

helium-3 measured

lithium-7 predicted

lithium-7 measured

density of ordinary matter (percentage of critical density)

Timeline

Big Bang

Gravity freezes out

Strong Force freezes out

Weak Force freezes out

Neutral atoms form, light decouples from matter (Cosmic Microwave Background)

Matter consists largely of quarks, electrons, positrons, & neutrinos

Quarks combine into protons, neutrons, & their antiparticles

Virtually all anti-matter is annihilated. Fusion creates Helium

Very good but complex: Fig 22.4 + 22.5

After first 3 minutes

RADIATION ERA
→ 380,000 yr

MATTER ERA

AFTER THE FIRST 3 MINUTES :

RADIATION ERA : 1 sec → 1 MILLION YR
10¹⁰ K → 3000 K

- INCLUDES EPOCH OF ELEMENT FORMATION
- MOST ENERGY IN UNIVERSE IN FORM OF RADIATION
- RADIATION PRESSURE PREVENTS STRUCTURE FROM FORMING

ENDS WITH RECOMBINATION H and He BECOME NEUTRAL, RADIATION UNCOUPLES FROM MATTER

MATTER ERA : 1 MILLION YR → NOW (15 BILLION YR)
3000K → 2.7 K

- CLUMPING OF MATTER (MATTER NOW NOT AFFECTED BY RADIATION PRESSURE)
- QUASARS FORM, THEN GALAXIES AND CLUSTERING OF GALAXIES

After "recombination": Era of Atoms

- Finally cool enough for electrons to combine with nuclei to form atoms (380,000 yrs)
- Photons now "decoupled" = free to become CMB of future
- Universe becomes transparent to light

Era of Atoms
380,000 – 1 billion yr
< 3000 K

- Cool enough that neutral atoms form through the joining (recombination) of protons and electrons.

Matter: neutral atoms

Once the electrons are not free to scatter photons, the photons could move freely.

- General Theory of Relativity was giant step forward, but then ...
- Alarming ideas like:
 - 1: expanding universe (Hubble)
 - 2: CMB (big bang)
 - 3: 1 part in 100,000 uniform (inflation)
 - 4: white dwarf SN (dark energy)
- These could trouble even Einstein ...!

"Observational Pillars" of Big Bang Theory

1. The universe is aglow with thermal radiation, the Cosmic Microwave Background (CMB)
2. The observed abundances of light elements agree with Big Bang predictions
3. The universe is expanding
4. The night sky is dark

REMINDER

Quantum Fluctuations

Inflation

1st Stars about 400 million yrs.

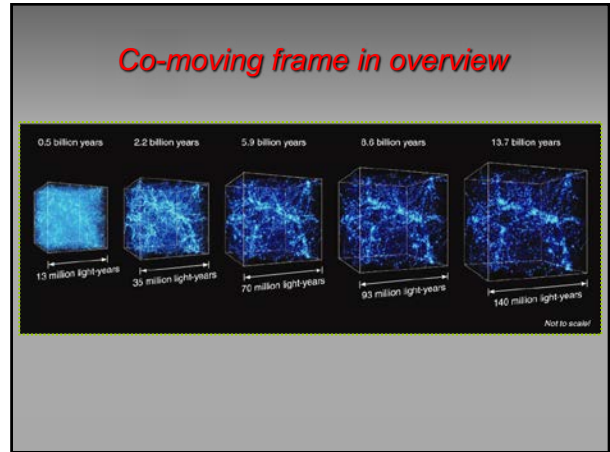
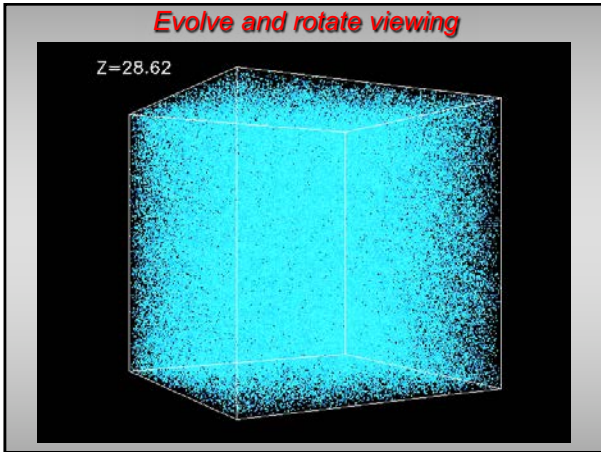
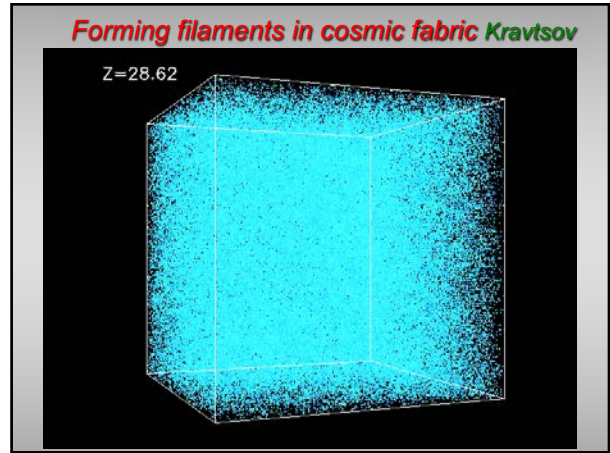
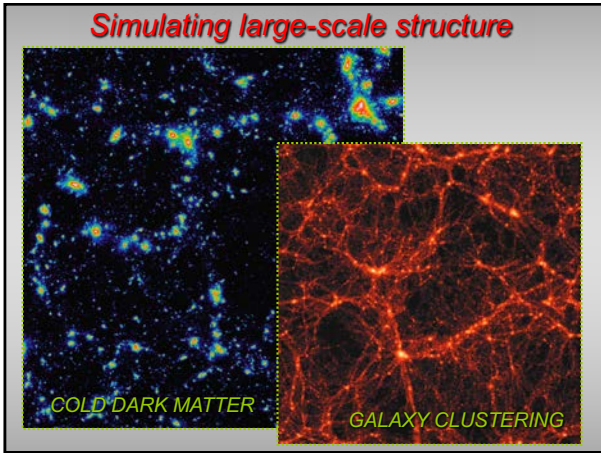
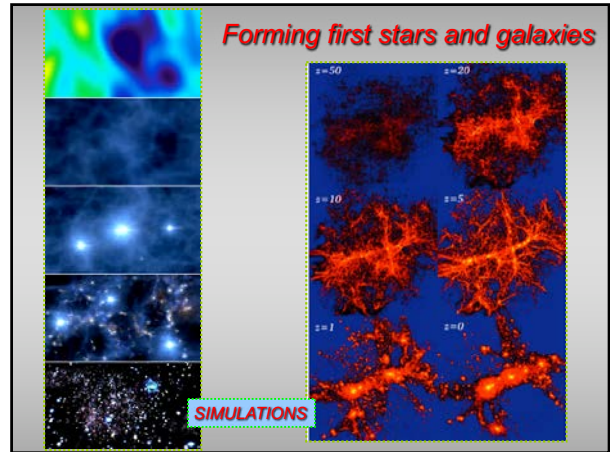
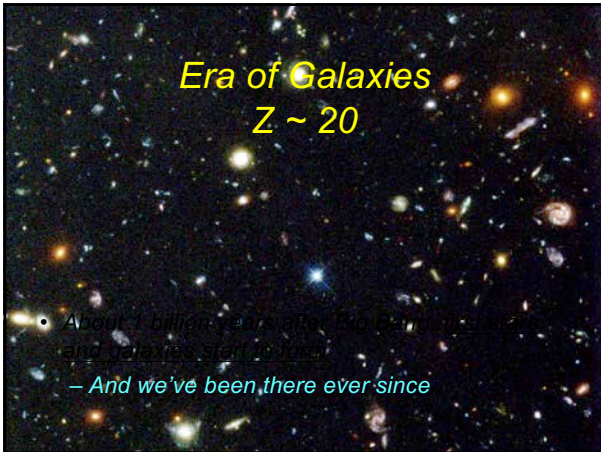
Dark Ages

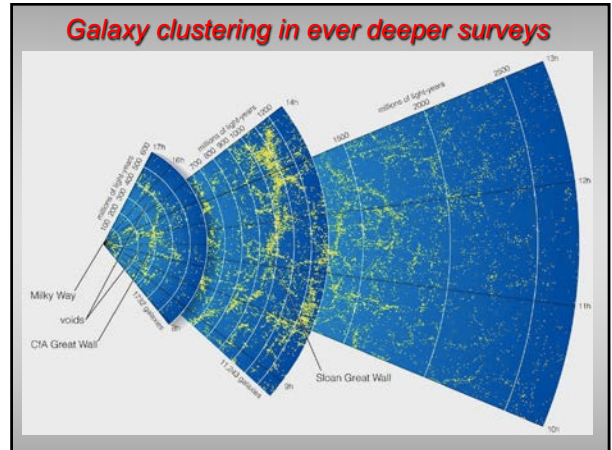
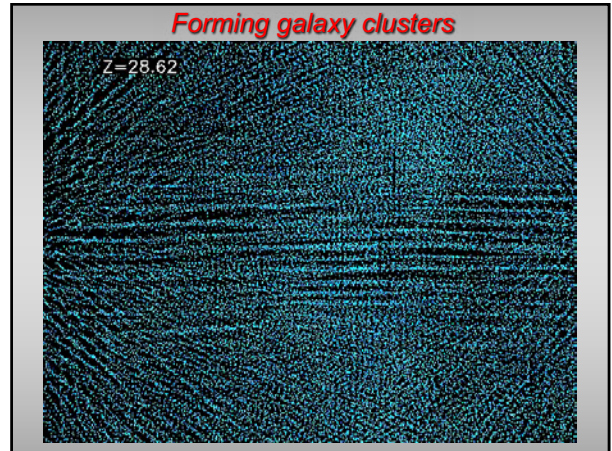
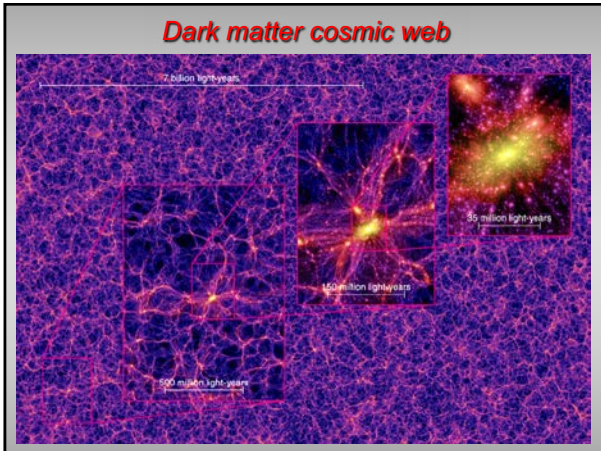
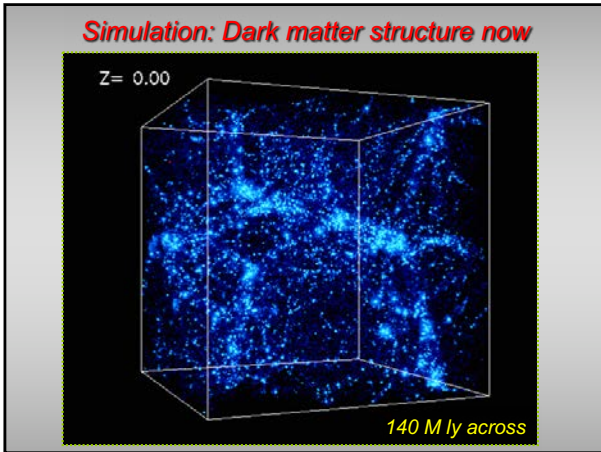
Development of Galaxies, Planets, etc.

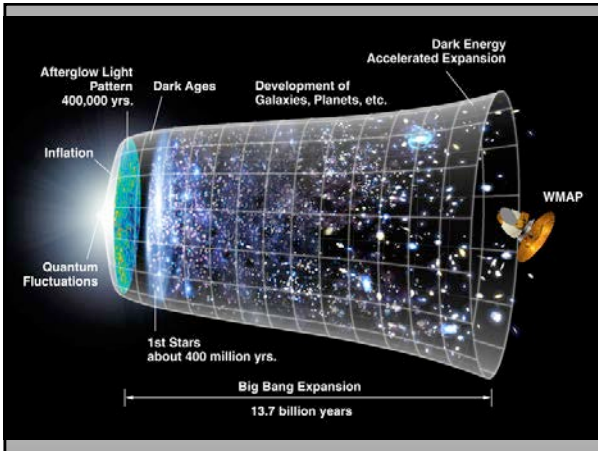
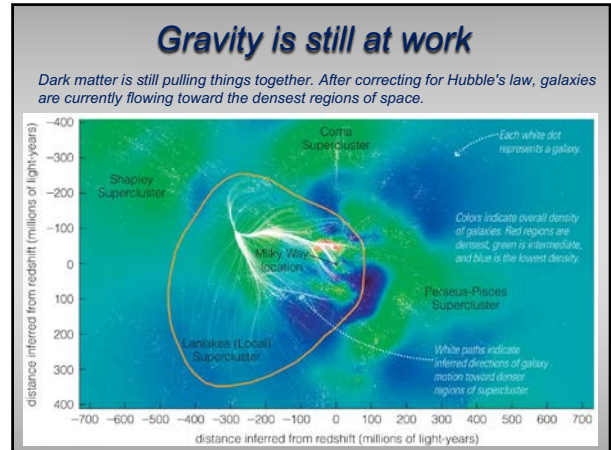
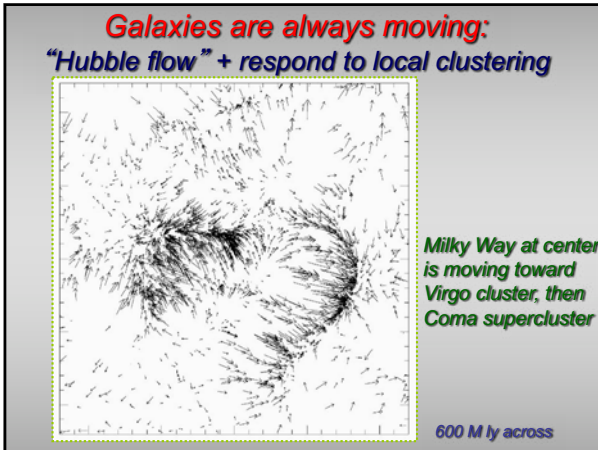
Dark Energy Accelerated Expansion

WMAP

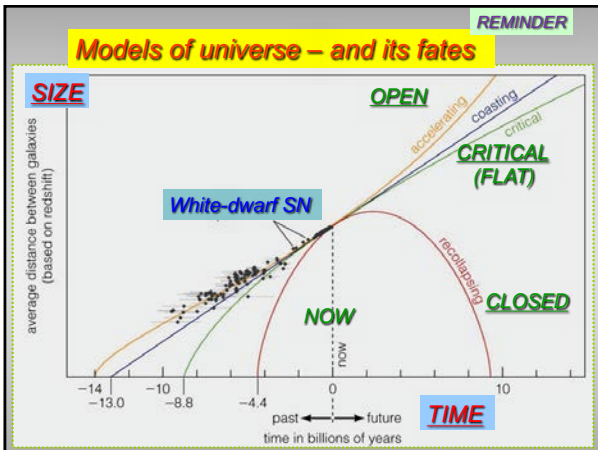
Big Bang Expansion
13.7 billion years







- The Big Mysteries**
- What will be the fate of the universe ?
 - What is the universe made of ?
 - What is the dark matter ?
 - Is the theory of inflation correct ?
 - What is the dark energy ?
 - Which of this, if any, should we believe?
- Science is not about belief, it's about exploration...
- Is there life elsewhere ?

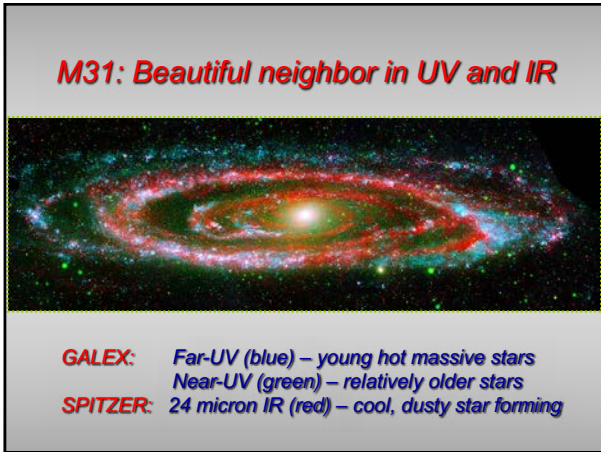
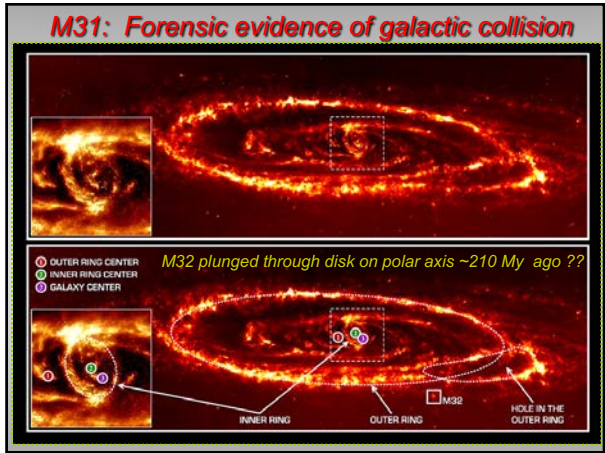
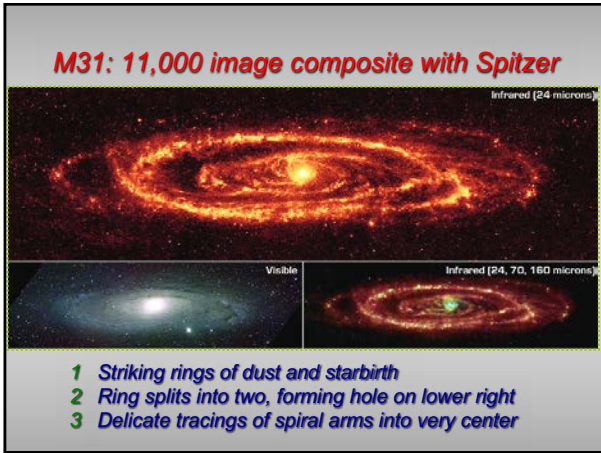
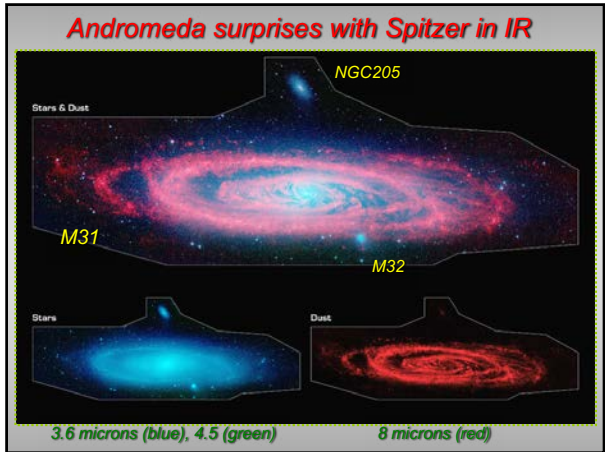


Some say the world will end in fire
 Some say with ice
 From what I've tasted of desire
 I hold with those who favor fire
 But if I had to perish twice
 I think I know enough of hate
 To say that for destruction ice
 Is also great
 And would suffice

-- Robert Frost

National Poet Laureat

A final visit to our
nearest big neighbor:
Andromeda



We wish you good fortunes with the
Final Exam next Wed (1:30pm here)
-- please bring pencils, crib sheets, ID

... and we hope you've enjoyed this
course that has touched the universe