

## Galaxy clustering with dark matter—14 Nov

- Homework 8
  - Average is 30/35
  - One paper has no name
- Homework 10 is due next Fri. No late papers.
- Test 3 is Nov 24<sup>th</sup>
  - See practice test on web site.
  - Mostly on material covered since Test 2 through today.
  - 3 cheat sheets.
- Important events in the history of the universe
  - Formation of helium at 3min (Done)
  - Universe becomes un-ionized at 300000yr. Radiation and matter decoupled (Mon)
  - Galaxies and stars form at 200Myr (Wed)
  - How galaxy clusters formed (Today)

Ast 207 F2008

## Simulations with dark matter

- Dark matter does not interact with light.
  - Dark matter interacts with ordinary matter only through gravity.
1. I have some dark matter at rest in my cupped hand. What happens to it?
    - A. It stays in my hand.
    - B. It floats away.
    - C. It falls through my hand.

Ast 207 F2008

## Simulations with dark matter

- Dark matter does not interact with light.
  - Dark matter interacts with ordinary matter only through gravity.
1. I have some dark matter at rest in my cupped hand. What happens to it? It falls through my hand because my hand, which is made of ordinary matter, does not interact with it.
- Simulations (simplest) of the universe
    - Dark matter only. (Amount of dark matter is much greater than amount of ordinary matter.)
    - Dark matter feels the gravity of other matter.
    - Starting point: a uniform universe with small density variations as measured by WMAP.

Ast 207 F2008

## Simulations with dark matter

- Simulations (simplest) of the universe
  - Dark matter only. (Amount of dark matter is much greater than amount of ordinary matter.)
  - Dark matter feels the gravity of other matter.
  - Starting point: a uniform universe with small density variations as measured by WMAP.
- Caltech simulation shows how density changes with time.
  - Start when distances were 1/33 of present. Very uniform
  - Matter clusters together because of gravity.

Ast 207 F2008

## Simulations with dark matter

- Warren et al. simulation shows how density changes with time.  
<http://qso.lanl.gov/pictures/cdm100e.mpg>
  - Start when distances were 1/33 of present. Very uniform
  - Matter clusters together because of gravity.
1. Both clusters of galaxies and the solar system form because gravity. In what way does the simulation of a galaxy cluster look different from the solar system?

Ast 207 F2008

- Solar system
    - 99.9% of the mass is in the center.
    - Remaining mass (the planets) is mostly confined to a plane.
  - Galaxy cluster
    - The mass is spread out.
    - The mass is not in a plane.
  - The mass in the proto solar system can radiate energy and contract.
1. Why does the mass in galaxy clusters not radiate and contract?
    1. Dark matter cannot make light.
    2. Galaxies are too big.
    3. There is not enough time.

Ast 207 F2008

- Springel et al. ([astro-ph/0504097](http://arxiv.org/abs/astro-ph/0504097)) Millennium Simulation shows results at the present time.
  - <http://www.mpa-garching.mpg.de/galform/millennium/>
  - Focus on an unusually large cluster of galaxies.

Ast 207 F2008

1. When the universe was 1 minute old, did helium & stars exist?
  - A. NN
  - B. NY
  - C. YN
  - D. YY
2. When the universe was 1 Myr old, did helium & stars exist?
3. When the universe was 1 Gyr old, did stars exist?
  - A. N
  - B. Y

Ast 207 F2008