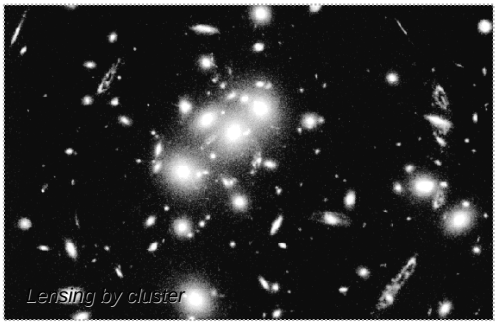
ASTR 1120: Stars & Galaxies



Prof. Juri Toomre TA: Ben Brown

Lecture 41 Fri 22 Apr 05

zeus.colorado.edu/astr1120-toomre

Today's Events

- Today look further at *evidence* of *dark matter* in clusters of galaxies
- *Gravitational lensing* helps us get information from very distant galaxies – thus look *very far back in time*
- Implications for *models for our universe*

- *Homework Set 10* due today; all *extra-credit observing projects* due next Wed
- Complete reading of *Chap 23 Beginnings of Time* for Monday lecture

Thinking clicker – looking back in time

- *If we can detect light from a quasar and decide that its emission line spectrum is at redshift Z = 4, how much bigger has the universe grown since that light left?*

C.

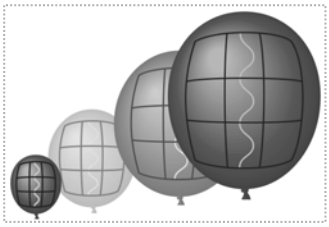
- *A.* 2 times bigger
- *B.* 3 times bigger
- *C.* 5 times bigger
- *D.* 16 times bigger

Redshift is "expansion factor"

REMINDER

1 + Z also measures how much universe has expanded

As universe expands, wavelength of light is also lengthened



1 + Z =

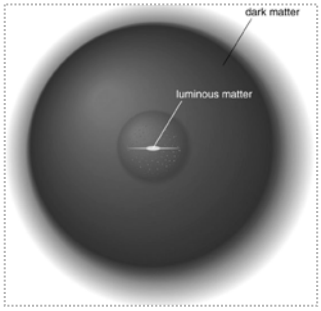
distance between galaxies now

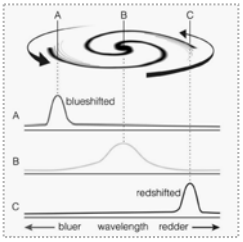
distance between galaxies then

Dark Matter: individual galaxies show it

RECALL

- *Rotation curves: motions of stars in the galaxy*
- *Reveal that dark matter extends beyond visible part of the galaxy, mass is 10x stars and gas*

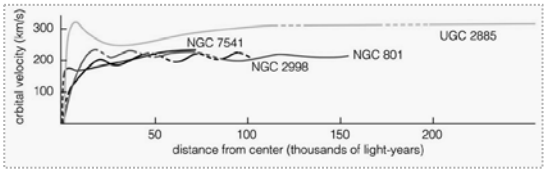




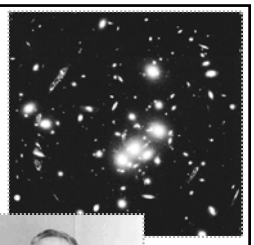
REMINDER

Spiral galaxy ROTATION CURVES

- *Controversial discovery by Vera Rubin until many rotation curves confirmed*



Galaxy Clusters: reveal dark matter in three ways

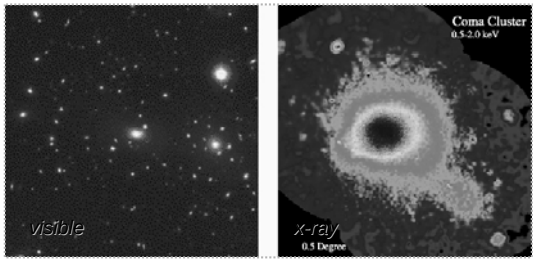


REMINDER

- *# 1: Galaxy velocities too large to be explained by gravity of visible galaxies*
- *Expected ~100 km/sec for a typical cluster, found 1000 km/sec!*
- *Discovered in 1930's by Fritz Zwicky – few believed him then*

REMINDER

2: Hot x-ray emitting gas in cluster

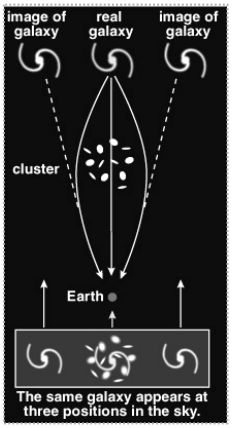


- *Gas between galaxies is also moving fast because of gravity of dark matter: gets very hot ~100 million K: emits x-rays!*

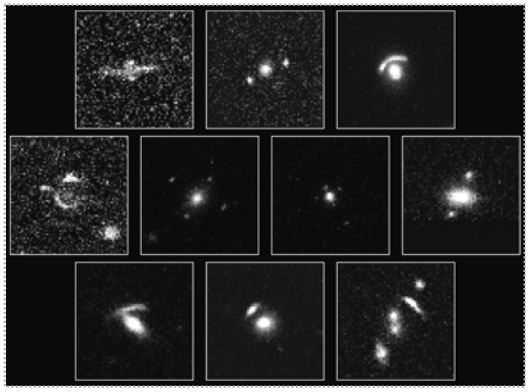
3 Gravitational Lenses

- *Dark (& visible) matter warps space → acts like a lens and distorts and magnifies the view of more distant galaxies*
- *Can form circular arc segments*

Gravitational lensing: how it works

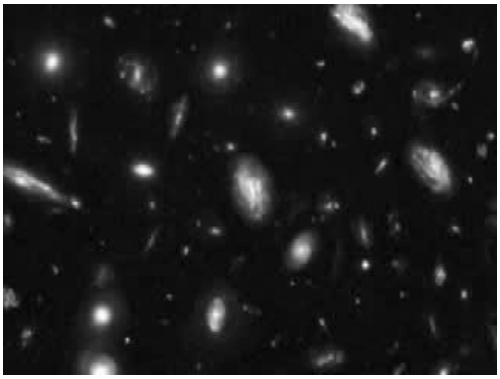


Medley of best HST gravitational lensing

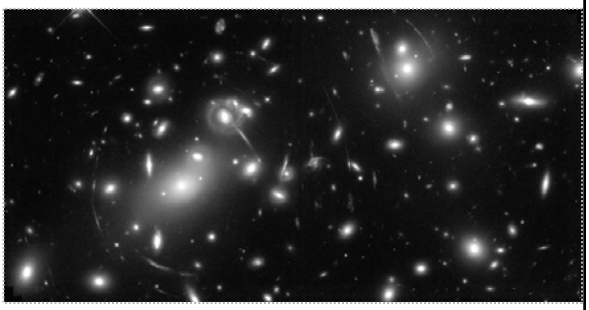


Gravitational lens drifts across your harbor view

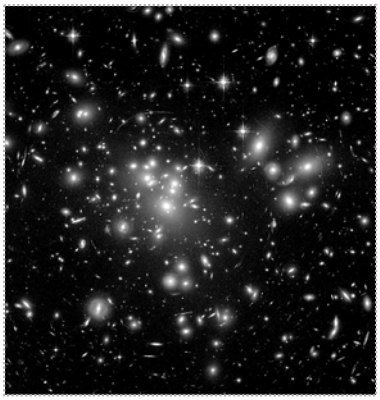
Effects of gravitational lensing on background galaxies



Bending of light by cluster Abell 2218



Lensing by massive galaxy cluster Abell 1689



Reading clicker: gravitational lens

- *If you measure the redshifts of the yellowish and blue objects, you'll find:*

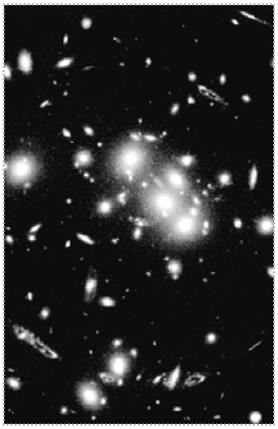
A. The yellow galaxies have similar redshifts, all higher than the blue galaxies

B. The blue galaxies have the same redshift, which is higher than the yellow galaxies

C. Yellow and blue galaxies have similar redshifts

Lensing

- B. *The blue images are a single BACKGROUND galaxy being lensed by the foreground cluster (yellow galaxies)*
- *The blue galaxy is farther from us and thus will have a higher redshift*

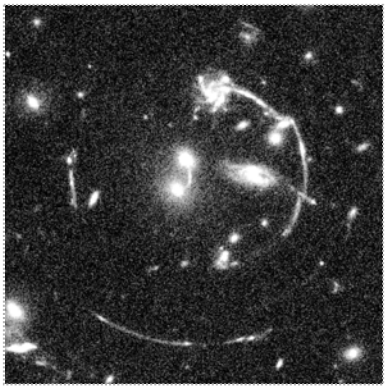


"The Beast"

4 or 5 different galaxies!

Red arc at the bottom: Z = 4.8

Have not gotten the other Z's yet



Erica Ellingson -- HST

How much dark matter overall?

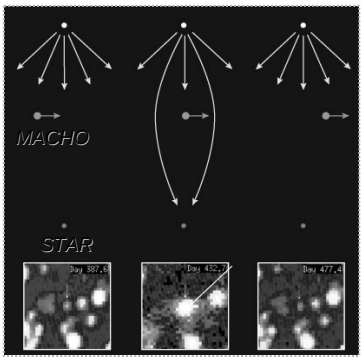
- *All cluster methods generally agree*
- *About 10 times as much dark matter as "normal" matter overall in the universe*
- *Note: Our solar system has much more light matter than dark matter here! (DM probably immeasurable)*

What is Dark Matter?

- *Two flavors for Dark Matter:*
- *Possibility 1. MACHOs*
- *Massive Compact Halo Objects*
- *Stuff we've studied already: very faint, actual things; baryonic matter*
- *Brown dwarfs, black holes, black dwarfs … etc.*
- *May be floating through the galaxy halo unnoticed*

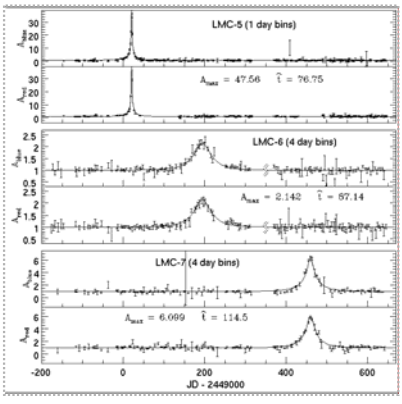
MACHO Searches

- *Use gravitational lensing*
- *When a MACHO floats in front of a star, the star suddenly brightens*
- *Focusing effect of compact massive object*



MACHO hunt results: 2005

- *MACHOs are detected*
- *But not enough to explain all dark matter*



Possibility 2. WIMPs

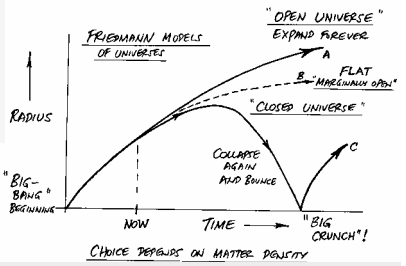
- *Weakly Interacting Massive Particles*
- *Non-baryonic → subatomic particle*
- *Neutrinos? probably not…. they move too fast and cannot be collected into stable galaxy halos*

Other unknown particles ???
Slower particles: "Cold Dark Matter"

COSMOLOGY : NATURE OF THE UNIVERSE

Models of our universe

Dark matter has big influence on "open" vs "closed"



If enough mass, gravity eventually wins!

Models of universe – and its fates