



Astro 358/Spring 2006
(48915)



Galaxies and the Universe

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Figures from Lecture 22 + 23: Tu Apr 11 + Th Apr 13

Mapping the Dark Matter in Galaxies and in the Universe

What is Dark Matter? How much of it is there?

Dark matter is mass that does not emit any radiation and is not visible at electromagnetic wavelengths

We detect dark matter through the force of gravity that any mass (be it dark or visible) exerts on a surrounding mass.

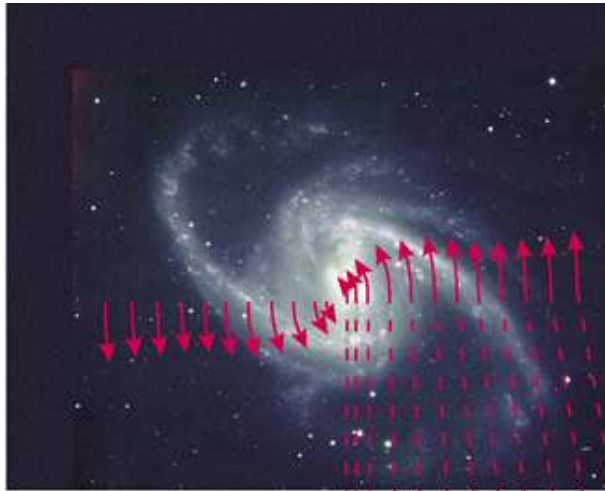
The mass of dark matter is measured via the steps below

- à We estimate the total mass of a system (e.g, a galaxy or cluster of galaxies) by measuring the force of gravity that it exerts.
- à We estimate the total luminous of the galaxy, based on its total luminosity L
- à The mass of dark matter = Total Mass - Luminous Mass

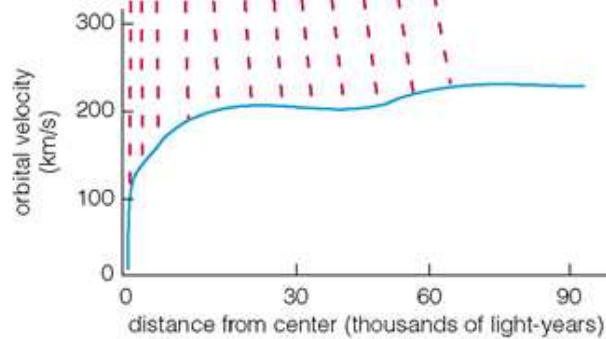
We find that dark matter makes up a very large fraction of the total mass:

- à Spirals/ Ellipticals: 90% of total mass within $R = 150,000$ ly is dark
- à Cluster of galaxies: 90% of total mass within the cluster is dark

How To Measure The Total Mass of A Spiral Galaxy?



Longer arrows represent larger orbital velocities.



Measure circular speed $V(R)$ of a mass m (gas or star) that is orbiting at radius R in the disk of the galaxy. This speed is set by the gravitational force F exerted by the total mass M enclosed within radius R

$$GMm/R^2 = m V^2 / R$$

$$M = V^2 R / G \quad \text{propto } V^2 R$$

$$M = M_{\text{dark}} + M_{\text{star}} + M_{\text{gas}} + M_{\text{dust}}$$

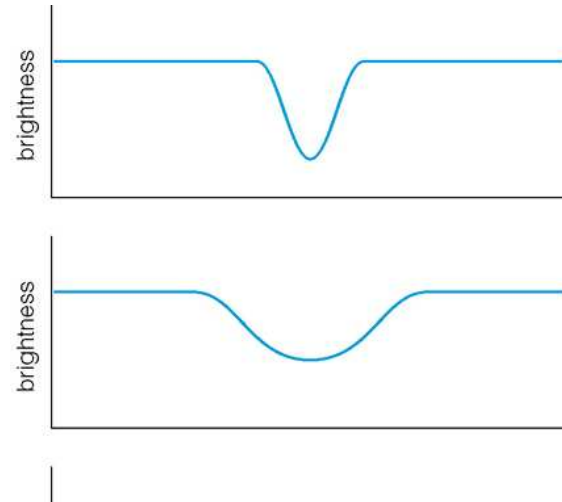
Rotation curve $V(R)$ of spirals at large radii is FLAT and does not show Keplerian falloff
 $\rightarrow M \propto R$ at large R

Yet, enclosed luminosity within radius R
 $\rightarrow L$ falls with R at large R

Implies most of the mass accounting for total mass is dark matter and NOT stars or gas or dust

See in class notes for different examples
 See Hwk 2 and Exam 1

Hot To Measure The Total Mass of An Elliptical Galaxy?



In elliptical galaxies, stars do not have ordered motion in circular orbits like those in spiral galaxies. Instead, stars have disordered motions, called velocity dispersion σ

The value of σ for a star at a given radius R measures the total mass M which is enclosed within that radius and exerts a pull of gravity on the star. By measuring σ from the width and profile of stellar absorption lines, can estimate M .

There is little gas in ellipticals, so can only use stars. Cannot trace M at large radii

à Only 10% of total mass M comes from stars that emit at visible wavelengths

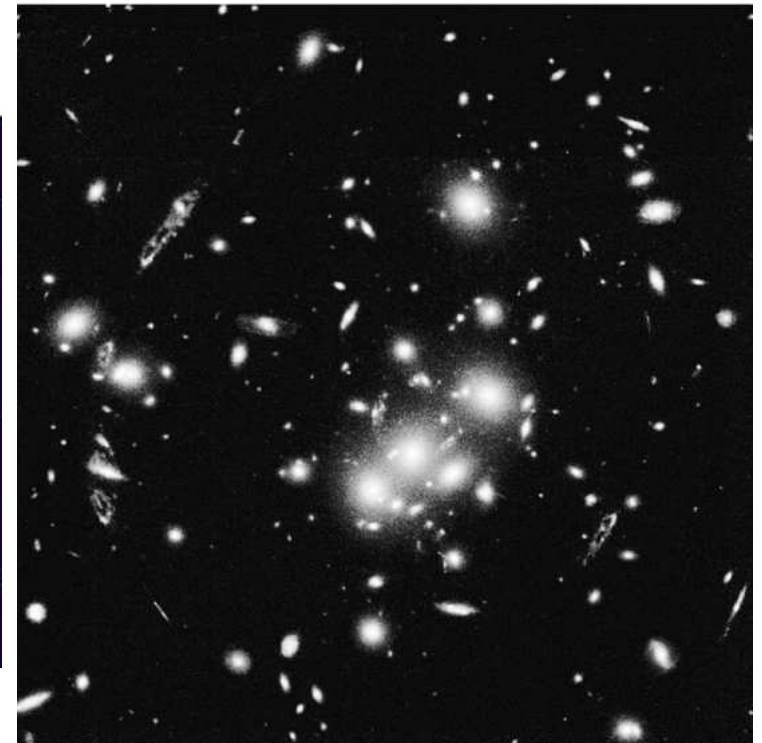
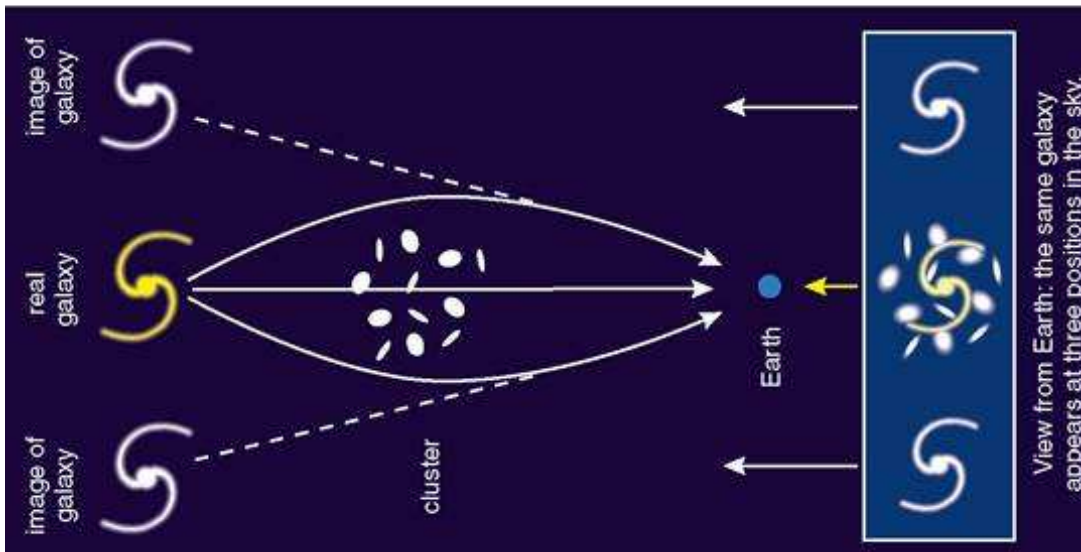
à 90 % of the total mass comes from dark matter

How To Measure The Total Mass of A Cluster of Galaxies

If light from a distant background galaxy passes near a foreground cluster on its way to Earth, the light will be bent by the force of gravity exerted by the total mass of the cluster.

This makes us see multiple images of the background galaxy, forming arcs (Einstein's rings)
This is called gravitational lensing: the cluster acts as a lens for the light of background galaxy

See in-class notes for derivation of Einstein's radius for a gravitational lens of mass M

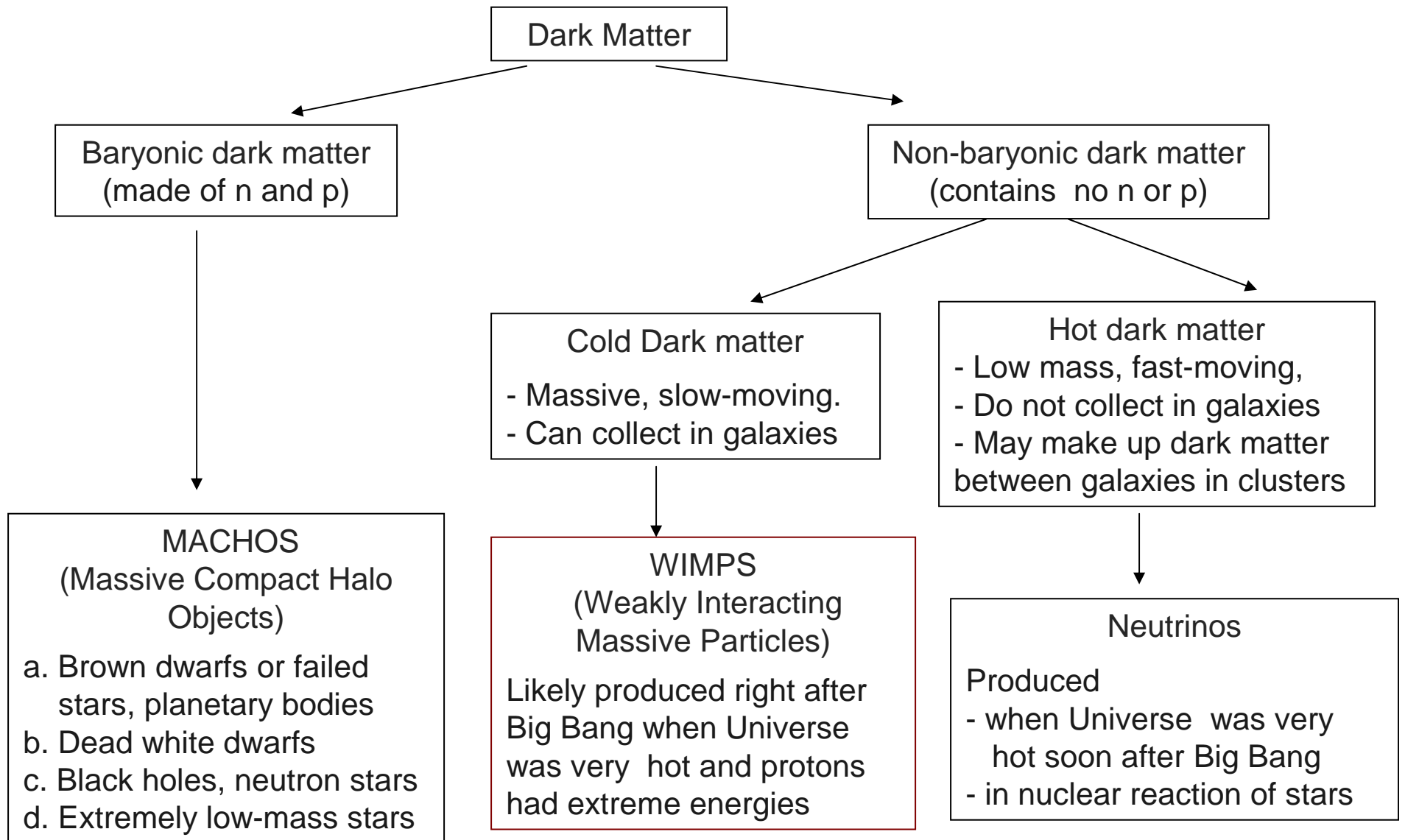


Candidates for Dark Matter

Can rule OUT candidates below

- high and intermediate mass stars: emits UV, optical light
- low mass stars : emit near-IR light
- hot gas : emits X-ray light
- warm gas and dust: emit mid-IR light
- cold gas : emits radio light

Candidates for Dark Matter

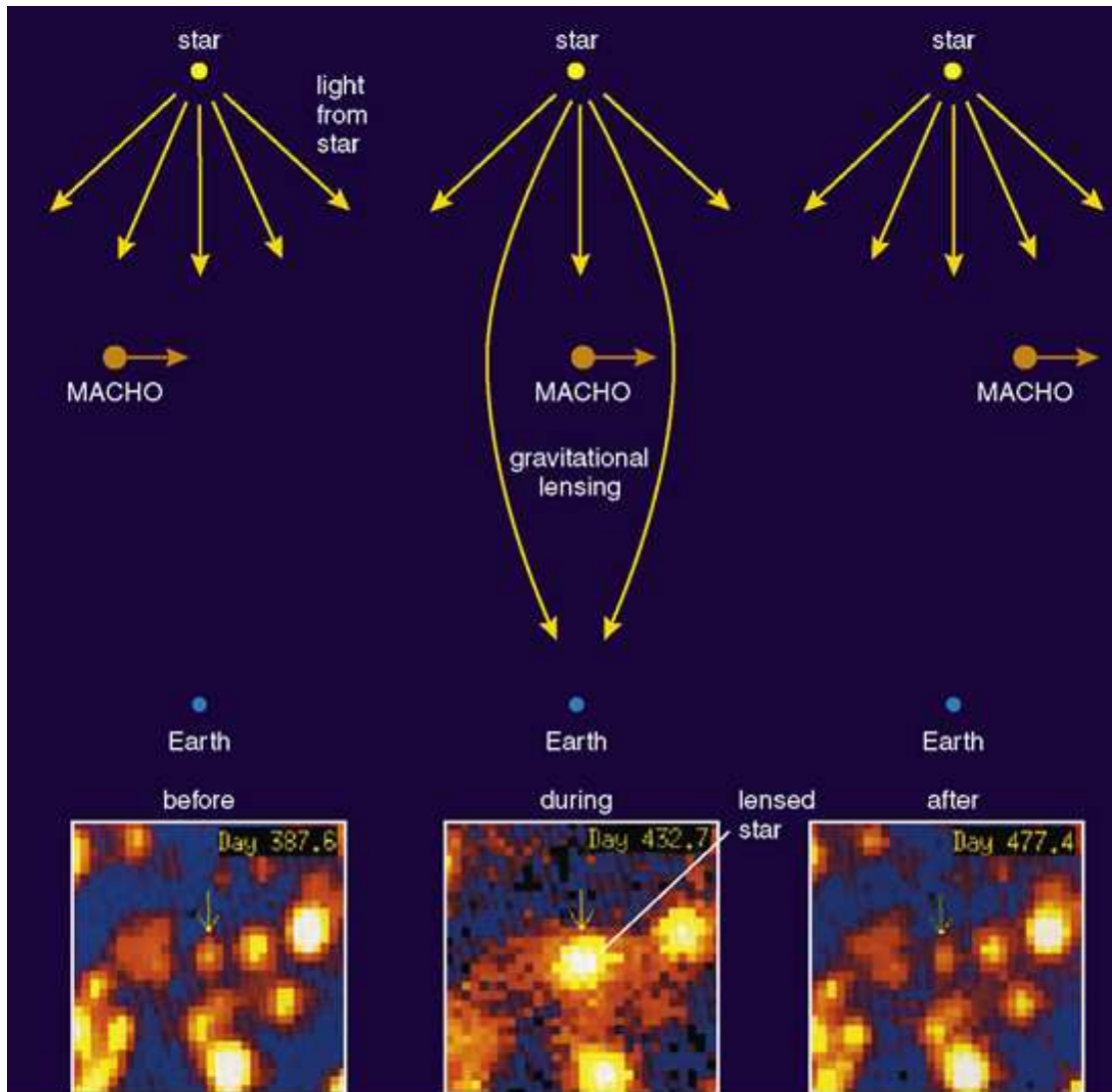


Leading candidate = Cold dark matter = WIMPS

How Do We Detect Dark Matter Candidates

Detecting MACHOS in our Galaxy via Microlensing

See in-class notes for derivation of Einstein's radius for case of microlensing



As light from a bulge star or halo star travels to us, it can be bent by the force of gravity from a passing MACHO if the latter crosses the light's path.

The light gets focused and the apparent brightness of the star increases for a short period until the MACHO moves away.

Results to date: MACHOS make up only a small fraction of the dark matter in Milky Way.

Characterizing WIMPS with Large Hadron Collider



CERN particle collider reached ($E = 10^{11}$ eV or $T \sim 10^{15}$ K) in 1983

→ detected W+Z bosons predicted by electroweak theory

→ validate Nobel prize in 1979 to Glashow, Weinberg and Salam

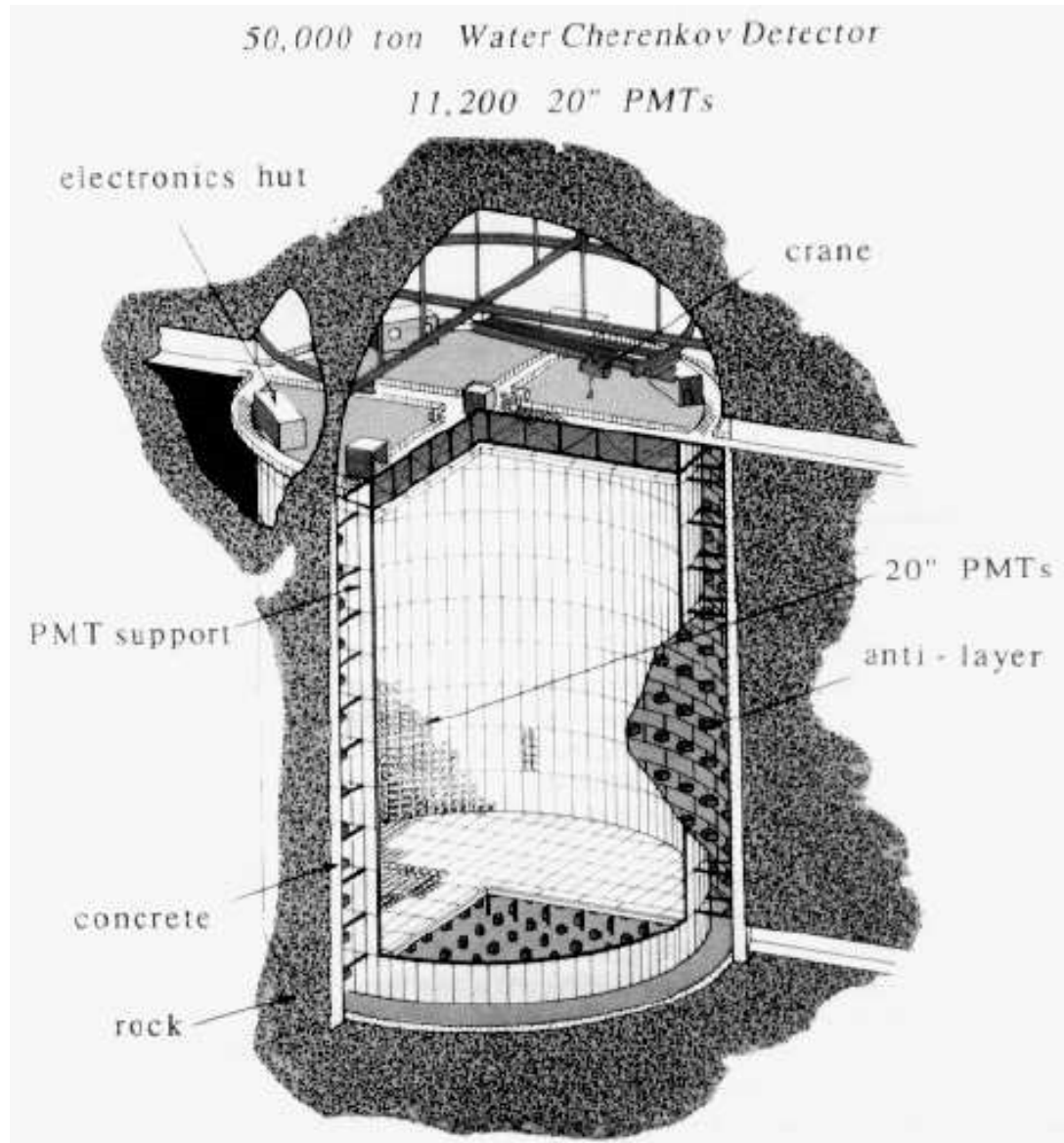
Large Hadron Collider (LHC) will be online in 2007 at CERN

→ an accelerator that will collide protons and ions head-on at higher energies ($E = \text{TeV}$ or 10^{12} eV or $T = 10^{17}$ to 10^{17} K) than ever achieved before and thus recreate the conditions just after the "Big Bang".

→ will characterize WIMPS

WIMPS are leading candidates for dark matter

Detecting Neutrinos



Super-Kamiokande
experiment in Japan

Huge Water Cherenkov
Detector for Cosmic
Particles

Has detected over
44,000 solar neutrinos
and is characterising
their properties

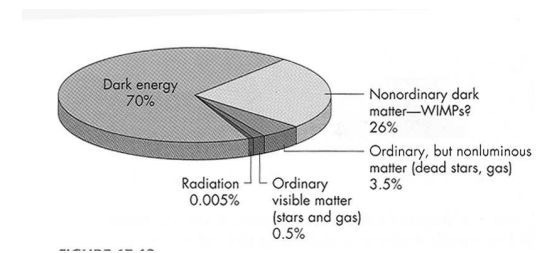
Fate of the Universe : Matter vs Dark Energy

Fate of the Universe : Matter vs Dark Energy

- Matter (dark +luminous) exerts an attractive force of gravity that tries to make Universe contract
- Dark energy is a repulsive force or pressure that tries to make the Universe expand.
 - à Whether the Universe contracts or expands depends on the competition between matter (both dark and luminous) versus dark energy
- Observations show
 - à the Universe is expanding and this expansion is accelerating with time
 - à (dark matter + visible matter + radiation) make up only 30% of the total energy density
 - à dark energy makes up a whopping 70% of the total energy density

Radiation like CMB	0.005%
Visible matter :	0.5 %
Baryonic dark matter (e.g., MACHOS)	3.5 %
Non-baryonic cold dark matter (e.g., WIMPS)	26.5%

Total energy density in (dark matter+ luminous matter + radiation)	30.0 %
Total energy or mass density in dark energy	70.0 %



- Expect the Universe to keep expanding for ever!

Fate of the Universe : Matter vs Dark Energy

Before $t=30,000$ yrs,

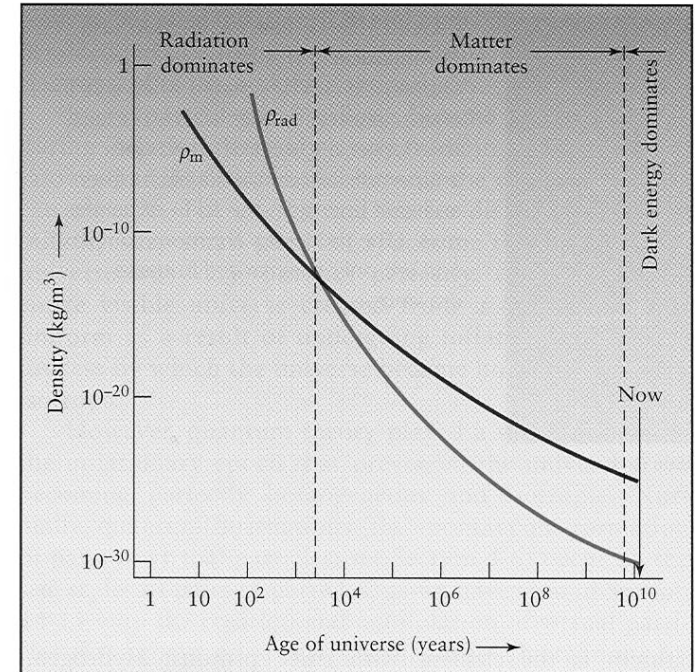
à the Universe was radiation-dominated

At $t=30,000$ yrs,

à the Universe became matter-dominated and structures (density enhancements, star, galaxies, clusters) started to grow,

At present times,

à the Universe is dominated by dark energy



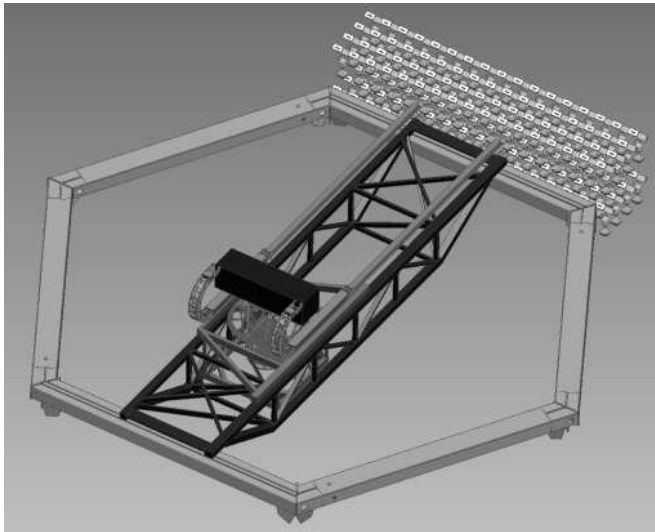
Yet we know practically nothing on the nature of dark energy

Nature of Dark Energy

HETDEX = Hobby Eberly Telescope Dark Energy Experiment at UT Austin

Will survey large scale structure of 1 million galaxies in a volume 10x that of the SDSS at $2 < z < 4$

These data will constrain the nature of dark energy in 8 years



VIRUS (instrument for HETDEX)

- VIRUS is an integral field spectrograph on the HET, that is 100 times more powerful than any in existence
- Will detect Ly- α emission from star forming galaxies