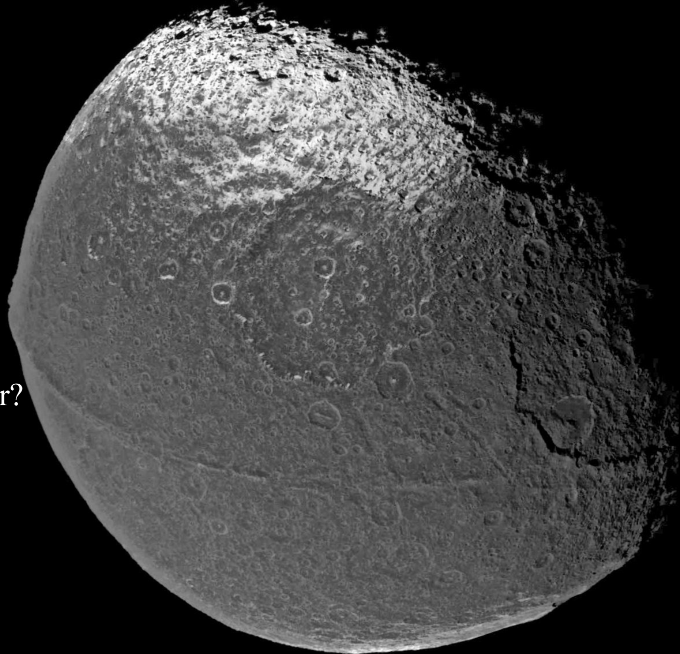
Dark matter, Dark energy in the universe



Are planets dark matter?

Description: (a) How does the gravity of an object affect light?

Part A

How does the gravity of an object affect light?

ANSWER:

- Less energetic light will not be able to escape from a compact massive object, such as a neutron star, but more energetic light will be able to.
- Light coming from a compact massive object, such as a neutron star, will be redshifted.
- Light doesn't have mass; therefore, it is not affected by gravity.
- Visible light coming from a compact massive object, such as a neutron star, will be redshifted, but higher frequencies such as X rays and gamma rays will not be aff
- Light coming from a compact massive object, such as a neutron star, will be blueshifted.

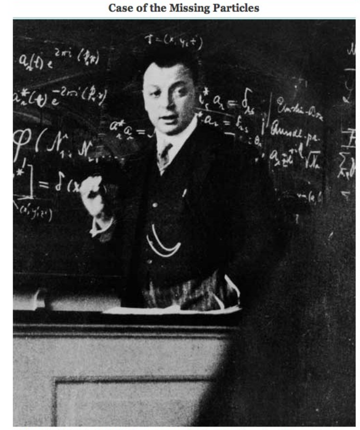
Answer Stats:	Students	% Correct	% Unfinished	% Req'd Solution	Wrong/student	Hints/student
Overall	313	77%	22.7%	0.3%	0.8	0
SCI199UOFT	42	61.9%	38.1%	0%	0.5	0

Wrong Answers for SCI199UOFT

% Wrong	Answer	Res
33.3%	Visible light coming from a compact massive object, such as a neutron star, will be redshifted, but higher frequencies such as X rays and gamma rays will not be affected.	
28.6%	Light coming from a compact massive object, such as a neutron star, will be blueshifted.	
23.8%	Light doesn't have mass; therefore, it is not affected by gravity.	
14.3%	Less energetic light will not be able to escape from a compact massive object, such as a neutron star, but more energetic light will be able to.	

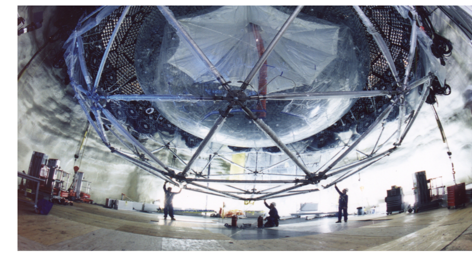
Gravity also affects dark matter!

Case of the Missing Particles



Wolfgang Pauli lecturing in 1929. The next year, when he devised the notion of the neutrino, he allegedly said to a friend, "I have done something very bad today by proposing a particle that cannot be detected; it is something no theorist should ever do."

First detected 1956;
Solar neutrinos regularly detected;
neutrinos are chameleons (they mutate 'flavor')

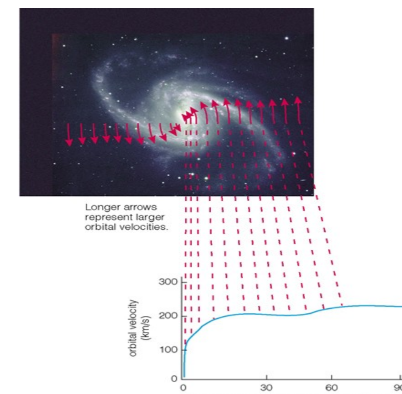


Sudbury neutrino observatory

leading to another Canadian Nobel Prize?

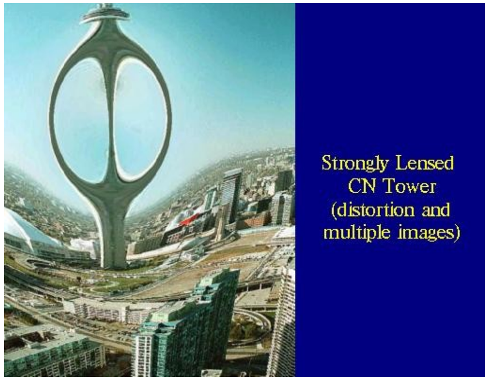
How do we weigh a galaxy?
The rotation of stars

How do we weigh the universe?
The movement of galaxies in a cluster
the gas temperature in a cluster
gravitational lensing



The faster galaxy (or gas) in a cluster moves, the larger mass the cluster has.

Use gravitational lensing to measure mass



If I know the distances to CN Tower and the gravitational lens, I can calculate mass of the lens.

Description: (a) No visible light can escape a black hole, but things such as gamma rays, X rays, and neutrinos can.

Part A

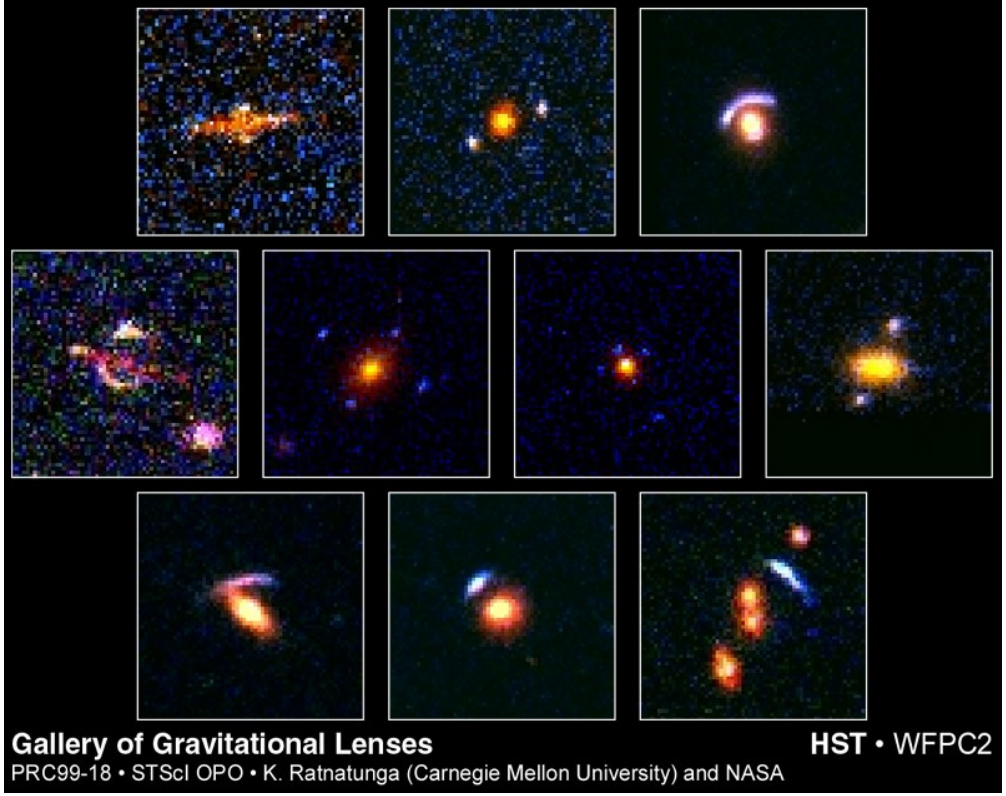
No visible light can escape a black hole, but things such as gamma rays, X rays, and neutrinos can.

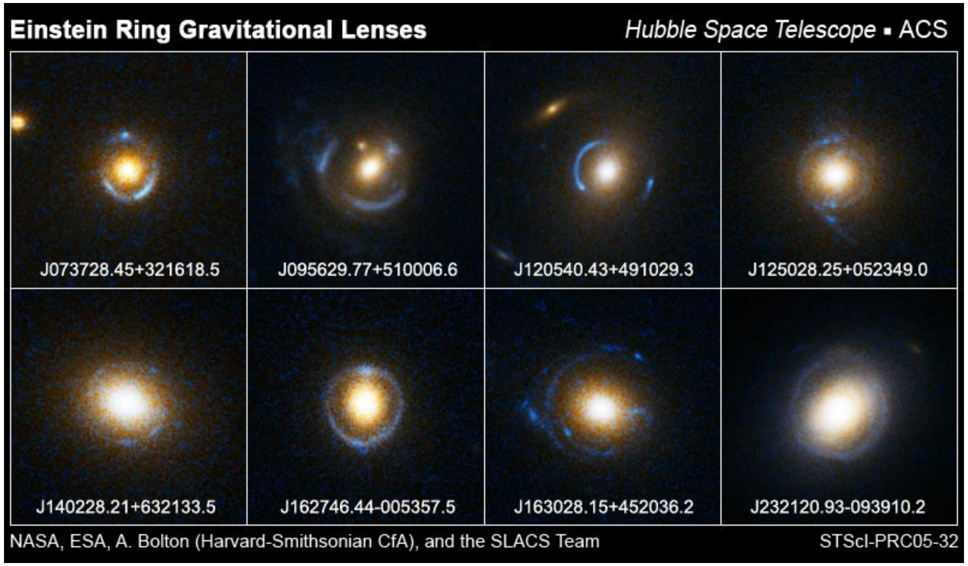
ANSWER: ○ True ⦿ False

Answer Stats:	Students	% Correct	% Unfinished	% Req'd Solution	Wrong/student	Hints/student
Overall	187	84%	15.5%	0.5%	0.5	0
SCI199UOFT	42	54.8%	45.2%	0%	0.5	0

Wrong Answers for SCI199UOFT		
% Wrong	Answer	Response
95%	True	

Background galaxies being lensed by a cluster

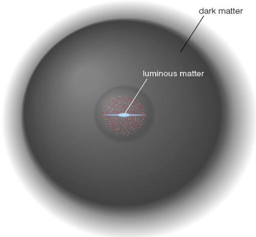


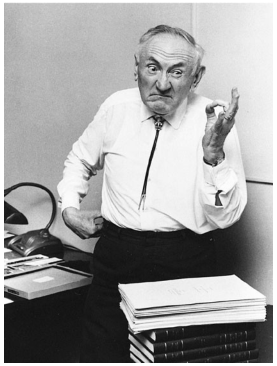


also see movie 'lens'

For galaxies, 90% of the mass is in 'dark matter'.

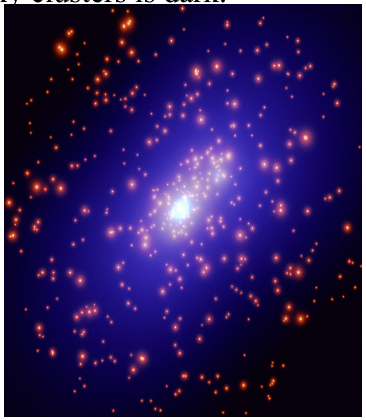
They circle around the galaxy further away than stars do, in a roundish shape ("galaxy halo")





95% of mass in galaxy clusters is dark.

Dark matter (blue) map for galaxy cluster CL0024+1654



My name is Fritz Zwicky,
I can be kind of prickly,
This song had better start
by giving me priority.
Whatever anybody says,
I said in 1933.
Observe the Coma cluster,
the redshifts of the galaxies
imply some big velocities.
They're moving so fast,
there must be missing mass!
Dark matter.

Dark Matter Rap, David Weinberg

So what is dark matter?

dark matter = under-luminous or non-luminous matter

"normal matter" candidates for dark matter
-- stars too low in mass and can't ignite hydrogen ('brown dwarfs')
-- interstellar clouds, white dwarfs...
-- planets, elephants, people...
excluded.... Not enough.

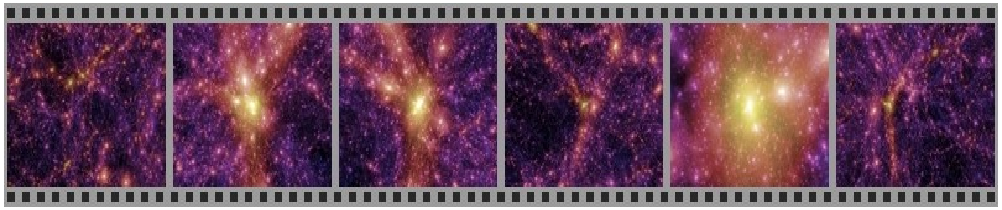
"exotic matter" candidates for dark matter -- realms of particle physics
-- neutrinos (hot-dark-matter)
every second trillions of solar neutrinos pass through your body,
neutrinos don't radiate photons, but do have masses,
however, moving with speed close to that of light,...

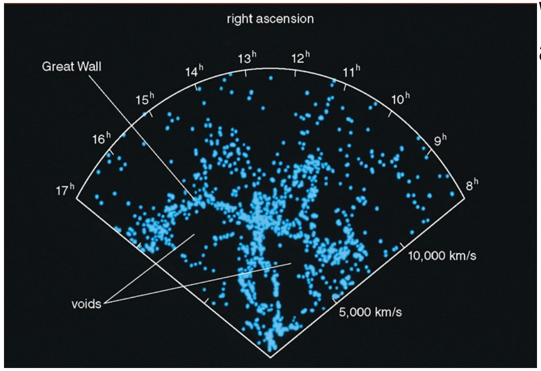
-- other un-known particles (cold-dark-matter)
hypothesized weakly-interacting massive particles (WIMP)
massive and slow-moving
do not sink to the centre due to friction

Quest for the origin of this dark matter is on-going.

Galaxies would have a hard time forming if it's not for dark matter.
And there won't be stars if there are no galaxies...

The "millennium simulation' of the evolution of the universe (Springel et al, '05.)





What you see in the movie are
all 'dark matter' (cold-dark-matter)

actual observed distributions
of galaxies and galaxy clusters
(wall, void, finger...
'the cosmic web')

Simulations of galaxy-galaxy collision

Dark matter dominates the
dynamics of galaxies.

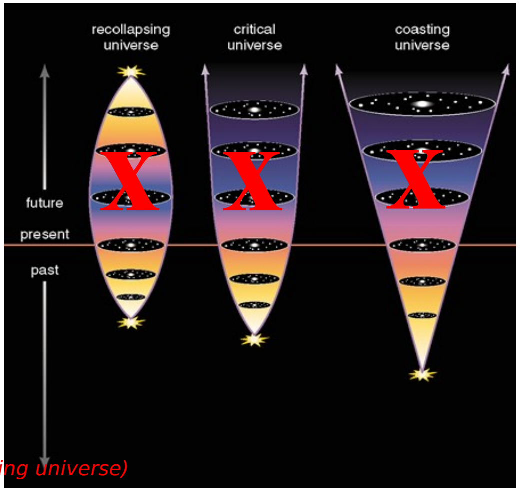
What you see in simulations
are actually 'dark matter'

The Mysterious 'dark energy'

Introducing dark matter can explain observations of galaxies, clusters of galaxies.

What about the universe?
The universe starts from a big-bang, a singularity point. An explosion is set in place.

But will the expansion followed by collapse (big crunch)?
if the universe has too much material (> critical density), gravity wins (recollapsing universe)



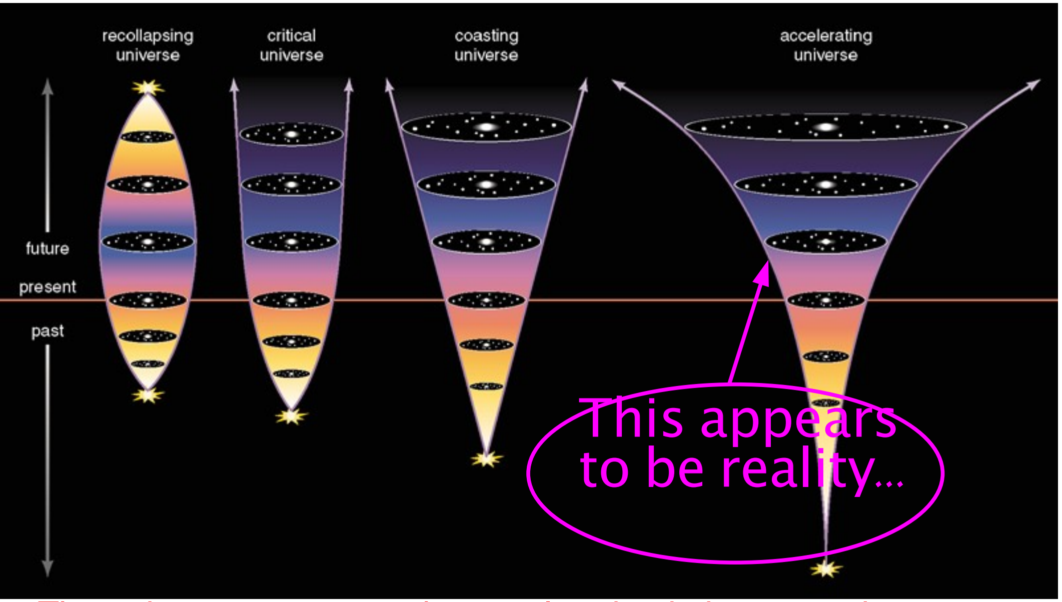
Or will the expansion proceed
forever?

if density = critical density, expansion stalls (critical universe)

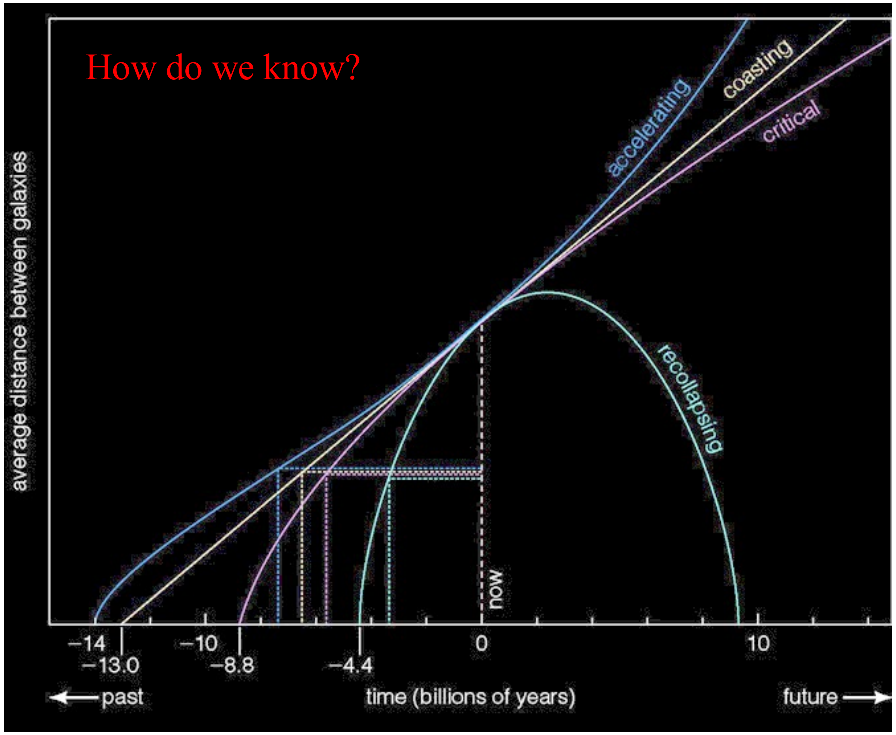
if density < critical density, expansion at the same speed (coasting universe)

Normal and dark matter adds up to ~30% of the critical density

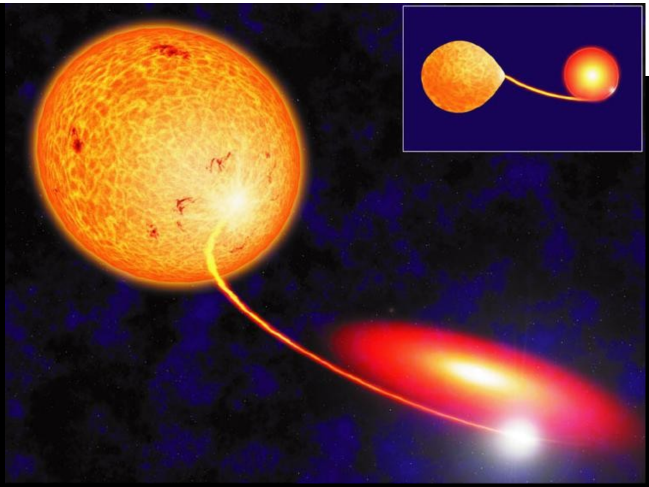
However....



The universe appears to be accelerating in its expansion.



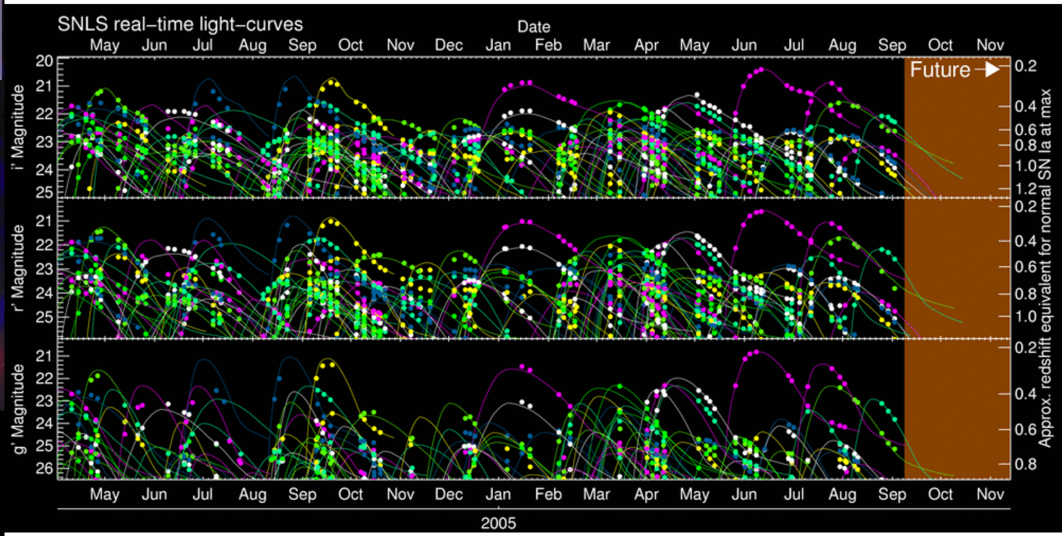
White Dwarf Supernovae



When the mass of the white dwarf reaches the critical mass, where electrons move almost at the speed of light, runaway nuclear fusion ensues, and the white dwarf explodes

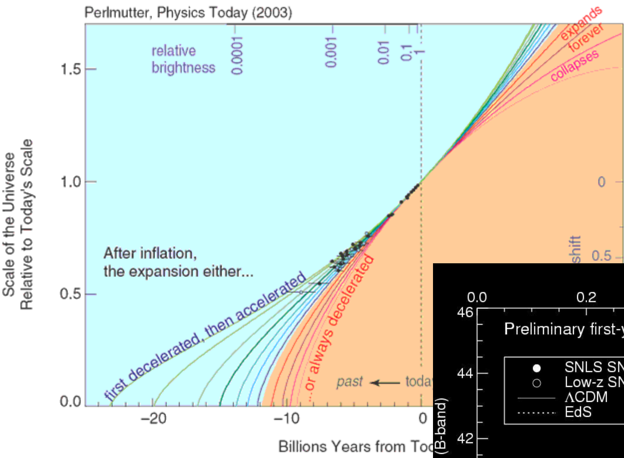
As the mass is always the same, the energy is similar, hence White-dwarf supernovae are good standard candles

Supernova Legacy Survey



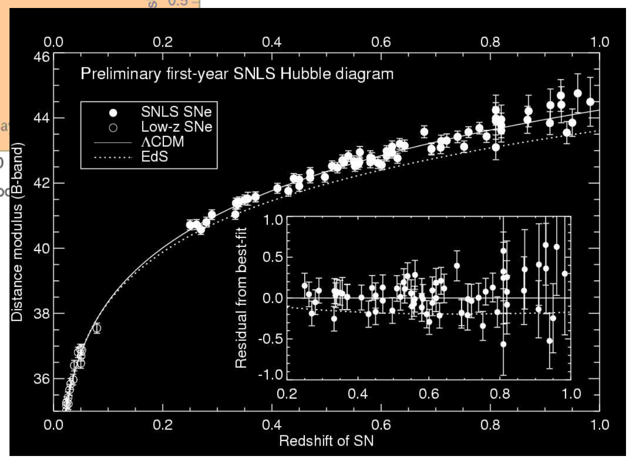
Roughly, the brightness of a SN tells the distance of its host galaxy, and its red-shift tells its expansion speed.
... the hard job is to catch the SNs...

Supernova Surveys

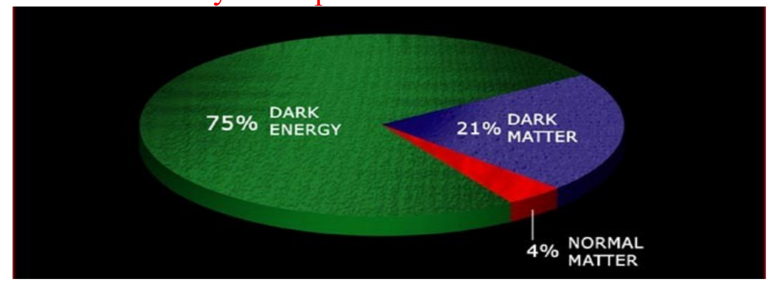


The theory

The data



Our understanding of the fundamental building blocks of the universe is still woefully incomplete.



1) normal matter: attractive gravity

or , 'baryonic matter', things around us,
hydrogen, helium, carbon, oxygen...
electrons, neutrons, photons, ...,
~ 5% the total density in the universe

2) dark matter: attractive gravity

~ 20% the total density

3) dark energy: the repulsive force

takes up 75% the total density in the universe

~ 20 years ago, the rumor of 'end of physics'...

Normal matters have three basic types of energy

Kinetic: energy of motion

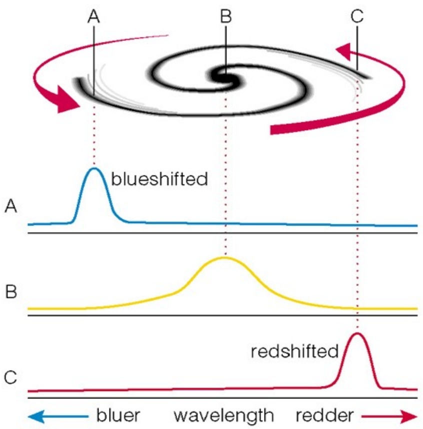
Potential: stored energy

Radiative: energy of light

We do **not** understand *70%* of the energy of the Universe! (nor *95%* of the remainder)

The Mysterious 'dark matter'

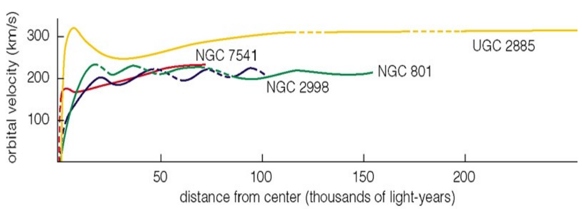
1) first detected in the “rotation curve” of galaxies



we can measure how fast different parts of the galaxy rotate, using the 'Doppler Effect'

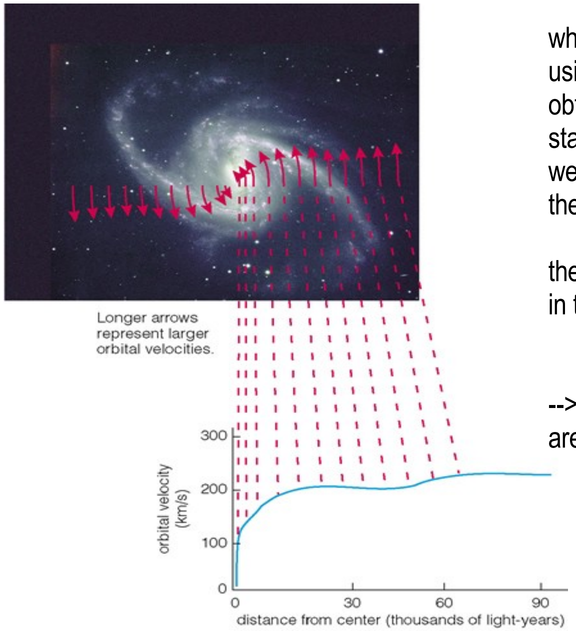
They are rotating for the same same reason that the Earth goes around the Sun – otherwise it would fall in.

The speed these stars/clouds rotate is related to the total amount of mass inside their orbit. The more mass, the stronger gravity, and hence the faster speed.



Rotation curve of a galaxy

--- the speed of rotation at different galactic radii



when we compare the mass obtained using Newton's laws, with that obtained by counting the number of stars (and summing up their masses), we find that the former well exceeds the latter

the discrepancy is as large as 10 in the outskirts of a galaxy

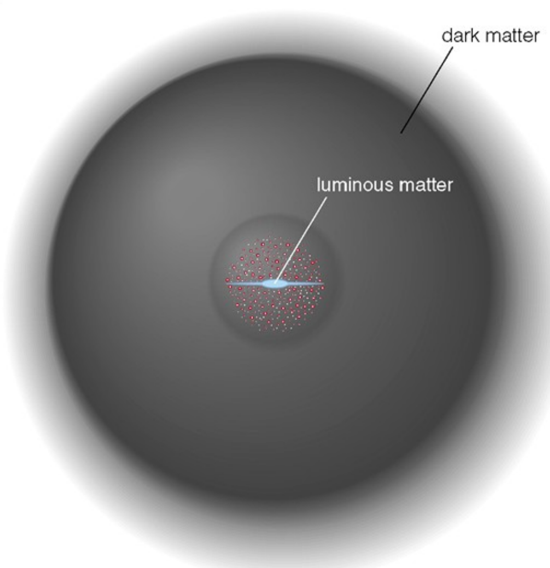
--> most of the mass in galaxies are not in the form of stars.

luminous matter vs. dark matter

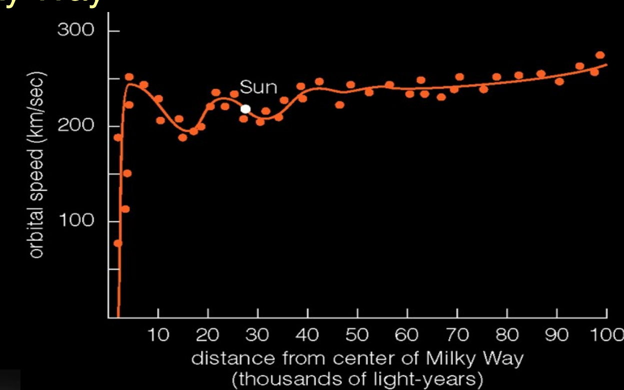
Dark matter halo:

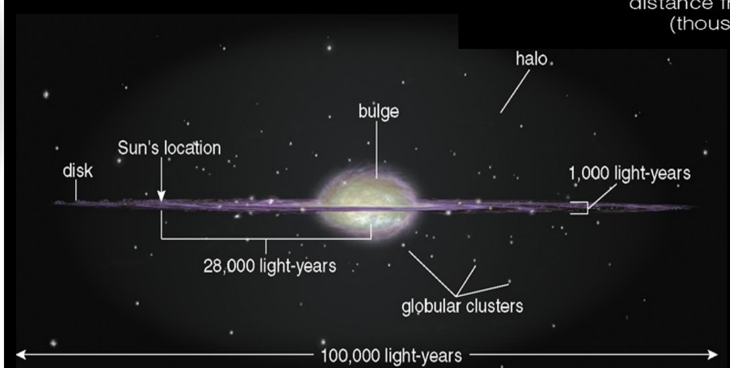
Dark matter forms an extended halo around a galaxy, with the luminous matter rotating near the middle of the galaxy.

study of the motion of nearby dwarf galaxies (our satellite galaxies) suggests that the total dark matter in the Milky Way ~ 10 times the mass of stars.

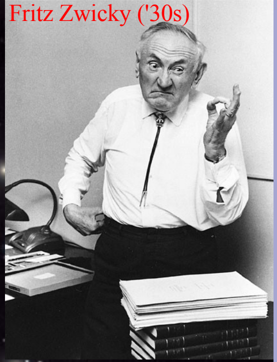


Dark matter in the Milky Way





Orbital Motion of Galaxies



Fritz Zwicky ('30s)

the Coma cluster of galaxies

individual galaxies are running around with exorbitant velocities (~ 1000 km/s)

the cluster doesn't boil off because it has a huge mass

visible stars ~ 1% of total mass

For nearly forty years,
the dark matter problems sits.
Nobody gets worried 'cause, “It's only crazy Fritz.”
The next step's not 'til the early 1970s,
Ostriker and Peebles,
dynamics of the galaxies, cold disk instabilities.
They say: “If the mass, were sitting in the stars,
all those pretty spirals, ought to be bars!”
Self-gravitating disks? Uh-uh, oh no.
What those spirals need is a massive halo.
And hey, look over here, check out these observations,
Vera Rubin's optical curves of rotation.
They can provide our needed confirmation:
those curves aren't falling, they're FLAT!
Dark matter's where it's AT!

Dark matter: Do we need it? What is it? Where is it? How much?
What is it? What is it? What is it? What is it?

And so the call goes out for the dark matter candidates:
black holes, snowballs, gas clouds, low mass stars, or planets.
But we quickly hit a snag because galaxy formation
requires too much structure in the background radiation
if there's only baryons and adiabatic fluctuations.
The Russians have an answer: “We can solve the impasse.
Lyubimov has shown that the neutrino has mass.”
Zel'dovich cries, “Pancakes! The dark matter's HOT.”
Carlos Frenk, Simon White, Marc Davis say, “NOT!
Quasars are old, and the pancakes must be young.
Forming from the top down it can't be done.”
So neutrinos hit the skids, and the picture's looking black.
But California laid-back, Blumenthal \& Primack
say, “Don't have a heart attack.
There's lots of other particles.
Just read the physics articles.
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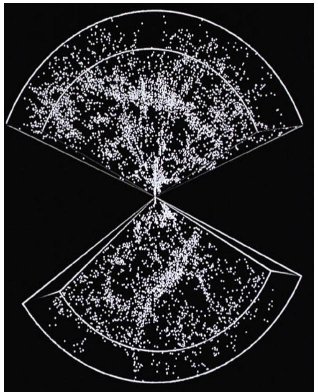
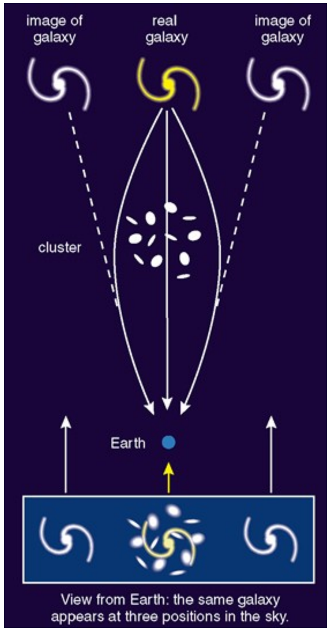
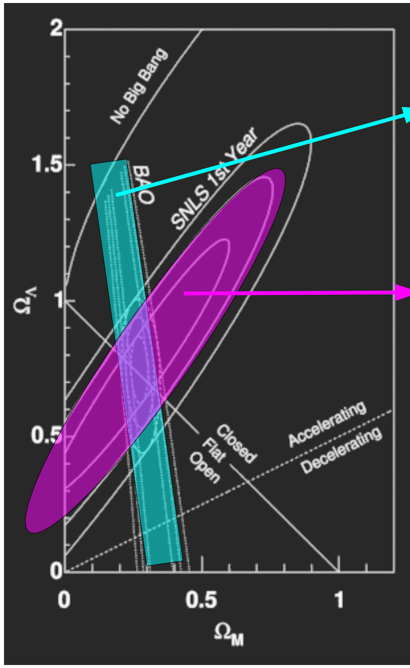


Gravitational lensing



larger cluster mass,
-> deeper potential well,
-> stronger light bending effect,
-> more remote (background) galaxies
get 'lensed' (stretched, displaced...)

Expansion of the Universe



Structure or “Clumpiness:”

Standard candles:

Table 4.1 Energy Comparisons

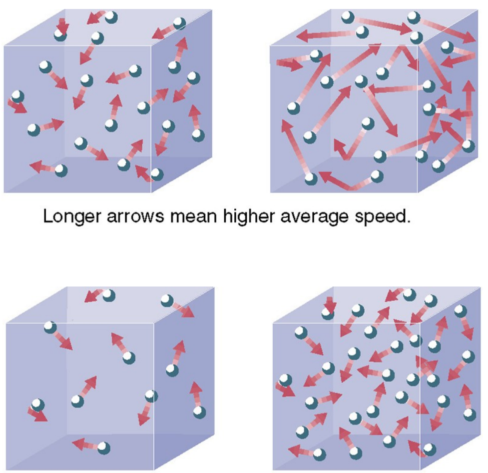
Item	*Energy (joules)*
Average daytime solar energy striking Earth, per m^2 per second	1.3×10^3
Energy released by metabolism of one average candy bar	1×10^6
Energy needed for 1 hour of walking (adult)	1×10^6
Kinetic energy of average car traveling at 60 mi/hr	1×10^6
Daily energy needs of average adult	1×10^7
Energy released by burning 1 liter of oil	1.2×10^7
Energy released by fission of 1 kg of uranium-235	5.6×10^{13}
Energy released by fusion of hydrogen in 1 liter of water	7×10^{13}
Energy released by 1-megaton H-bomb	5×10^{15}
Energy released by major earthquake (magnitude 8.0)	2.5×10^{16}
Annual U.S. energy consumption	10^{20}
Annual energy generation of Sun	10^{34}
Energy released by supernova (explosion of a star)	10^{44}–10^{46}

Kinetic energy: $E = \frac{1}{2} m v^2$

Temperature and Heat: another form of kinetic energy

Temperature
average kinetic energy
of randomly moving atoms

Heat = Thermal energy
total kinetic energy
of randomly moving atoms



Longer arrows mean higher average speed.

Potential energy: different types

Chemical potential energy
(e.g., Gasoline, Food, Battery)

Gravitational potential energy
(e.g., a suspended weight)

Electrical Potential energy
(e.g., supplied by power companies)

Mass energy: $E = m c^2$