2. STARS, GALAXIES, ETC.

THE EVOLUTION OF THE UNIVERSE
(ELEMENTARY PARTICLE UNIVERSE)

	t = Time	T = Temperature	Events
Elementary particles	10^{-35} s	10^{14} GeV	Big Bang, Strings, Inflation. Very early. Current particle theory no good
	10^{-11} s	100 GeV	Electroweak Phase Transition. Particles (Higgs) get masses. Particly theory ok. Baryogenesis? (more particles than antiparticles)
	10^{-6} s		Start of QCD phase transition
Hadronic particles	10^{-5} s	100 MeV	QCD (quark−hadron) phase transition. Quarks(elementary) condense to Protons
	1−100 s	1.0×10^{9} ^{o}K	Nucleosynthesis: Helium, light nuclei formed. Superconducting Universe
	380,000 years	0.25 ev, 3,000 ^{o}K	Atoms (electrically) neutral. Last scattering of light (electromagnetic radiation) from big bang: Cosmic Microwave Background
	1 billion years		early galaxies form
	14 billion years	2.7 ^{o}K	Now

.

EVOLUTION OF OUR SOLAR SYSTEM, GALAXIES-DARK MATTER, SUPERNOVAE-PULSARS AND BLACK HOLES

EVOLUTION OF OUR SOLAR SYSTEM:

NEBULAR THEORY–Rene' Descartes

OVERVIEW OF THE EVOLUTION OF OUR SOLAR SYSTEM. Why is it a flat disk?

FIND 1 A.U.= DISTANCE FROM EARTH TO SUN

PROVE USING NEWTON'S LAW OF MOTION THAT THE TIME FOR EARTH TO GO AROUND THE SUN IS ONE YEAR

OUR SUN IS A NUCLEAR FUSION PLANT

GALAXIES AND DARK MATTER

SUPERNOVAE: There are heavy elements which could not be formed by nuclear processes in stars like our sun. Our stellar gas cloud must have had material from supernovae as well as primary dust from the early universe.

PULSARS AND BLACK HOLES

PULSAR KICKS: Neutrino production and emission, sterile neutrinos

FORCE OF GRAVITY

F_g=Force of gravity on mass m a distance R from mass M:

$$F_g = G\frac{mM}{R^2} \qquad (1)$$

in the direction toward M, with G=Newton's gravitational constant.

The force of gravity plays the major role in forming atronomical structures in the universe:

Starting about 1 billion years gravity collapsed primary cosmic dust to form galaxies.

Within the galaxies being formed gravity collapses rotating clumps of cosmic dust to form stars with planets rotating about the star, and moons rotating about the planets. Our solar system is an example, with secondary as well as primary cosmic dust.

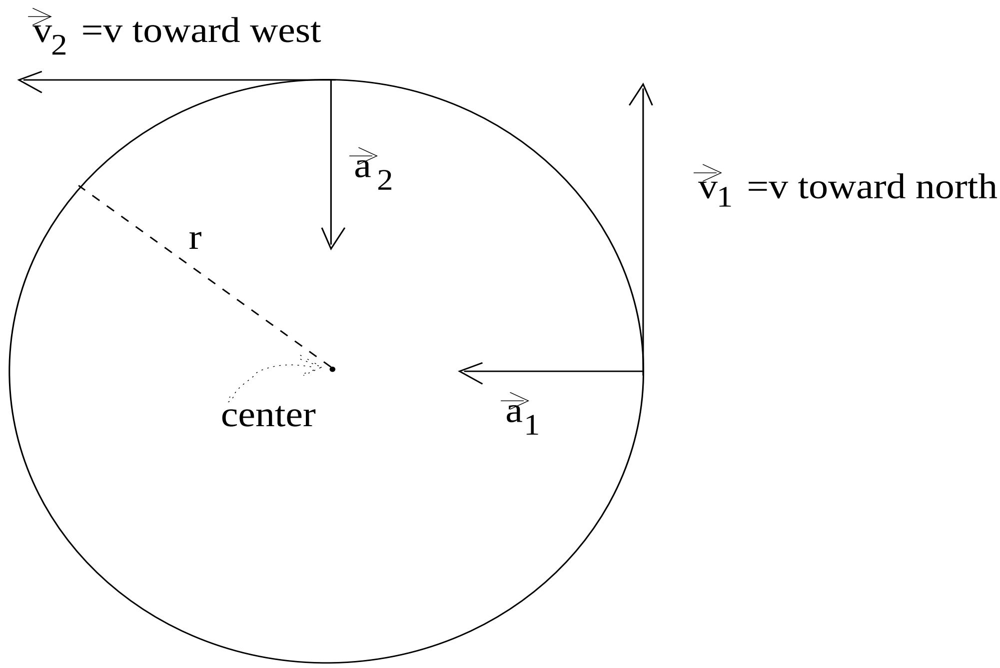
Stars like our sun are nuclear furnaces, with gravity pulling the fusing atomic nuclei together

Stars more massive than our sun quickly burn up their nuclear fuel and undergo gravitational colapse. This process creates supernovae.

Supernovae play an important role in the universe, creating heavy atomic nuclei, pulsars and black holes.

FORCE OF GRAVITY ATTRACTS EARTH TO SUN.
QUESTION: WHY DOES IT NOT FALL?

CONSTANT CIRCULAR SPEED: CENTRIPITAL ACCELERATION



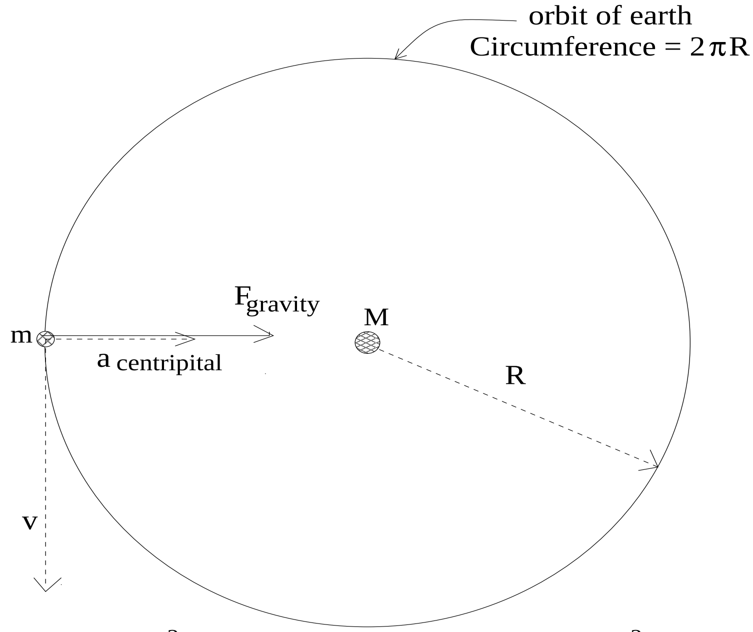
v=constant=speed around a circle
r =radius of circle

a=CENTRIPITAL ACCELERATION= V^2/R

ANSWER. EARTH'S ACCELERATION OF GRAVITY =EARTH'S CENTRIPITAL ACCELERATION

NEXT WE SHOW THAT IT TAKES ONE YEAR FOR THE EARTH TO CIRCLE THE SUN

How much time does it take earth to orbit the sun Use Newton's second law: F=mass x acceleration, and the fact that an object moving in a circle with constant v feels a centripital acceleration = v x v /R



Centripital force = mv^2/R = Gravitational force = $mM\,G/R^2$

Therefore $v^2 = MG/R$

Constants: $G=6.67 \times 10^{-11}\ m^3/(kg\ s^2)$ M=sun mass=$1.99\ 10^{30}$ kg

R= radius of earth's orbit = 1 A.U. = 1.5×10^{11} m

2

Therefore $v = 3 \times 10^4$ m/s

With v=constant, time to move some distance = distance/v

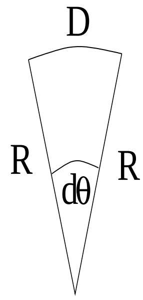
Distance earth travels in one year = circumferance= $2\pi R$

Time for earth to go around the sun = $2\pi R/v = 3.15 \times 10^7$ s = 1 year

r

OPTIONAL: THIS DERIVATION NOT NEEDED!!!

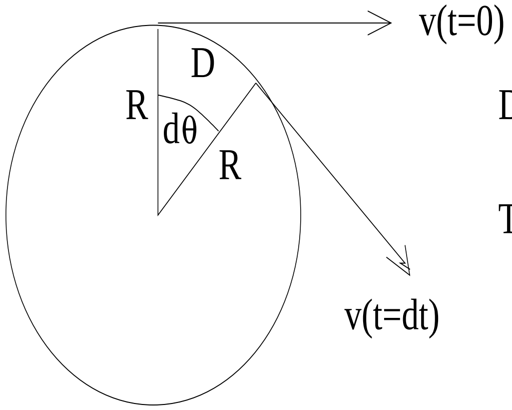
DERIVATION OF CENTRIPITAL ACCELERATION FOR AN OBJECT MOVING WITH CONSTANT SPEED V IN A CIRCLE OF RADIUS R



D = length of arc with interior angle $d\theta$ and radius R

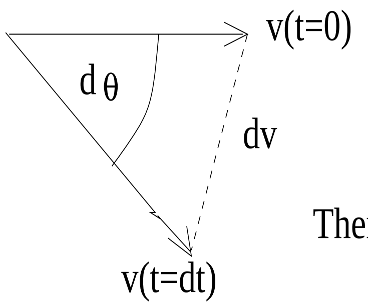
$D = R\, d\theta$ θ in units of radians, with 2π radians in a circle

Therefore, circumference of circle = $2\pi R$



$D = R\, d\theta = v\,dt$ (distance travelled in time dt with constant speed v)

Therefore $d\theta = \frac{v}{R}\, dt$



Note for $d\theta$ small dv is the arc length:

$dv = v\, d\theta$

Therefore acceleration = $\frac{dv}{dt} = \frac{v^2}{R}$

THIS IS CENTRIPITAL ACCELERATION

NEBULAR THEORY OF OUR SOLAR SYSTEM

–Rene' Descartes, 17th century:

Start with a cloud of instellar gas.

Gravity collapses cloud to form the sun at center

In outer regions planets, moons, etc are formed

MODEL'S OBSERVATIONAL REQUIREMENTS:

Planets isolated, not bunched together

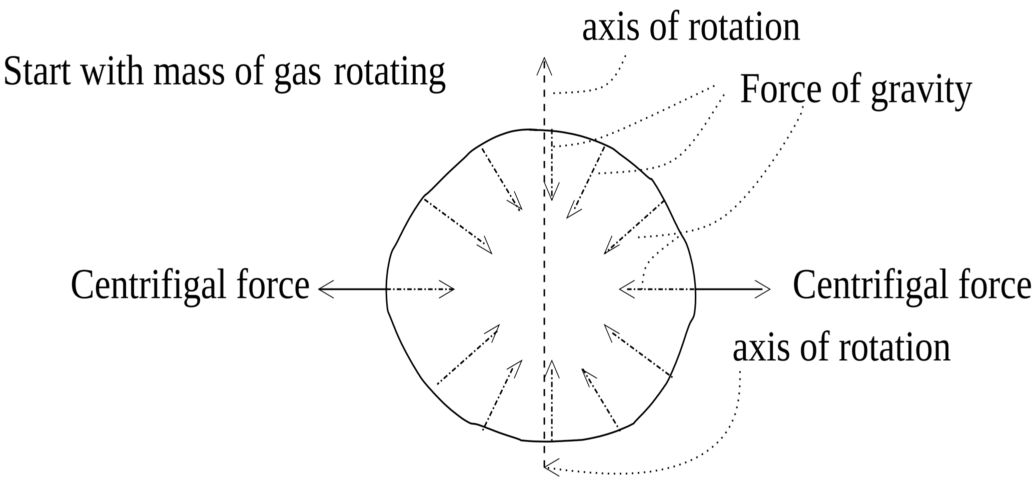
Planet orbits are nearly circular and in one plane

All planets rotate about the sun in the same direction as the sun's rotation, and the axis of rotation for most planets is the same as the sun's.

Most axes of rotation for most moons is the same as their parent planets.

Also asteroids and comets (primitive, small)

WHY IS OUR SOLAR SYSTEM AND GALAXY A FLAT DISK: GRAVITY AND CENTRIPITAL ACCELERATION ("CENTRIFIGAL FORCE")

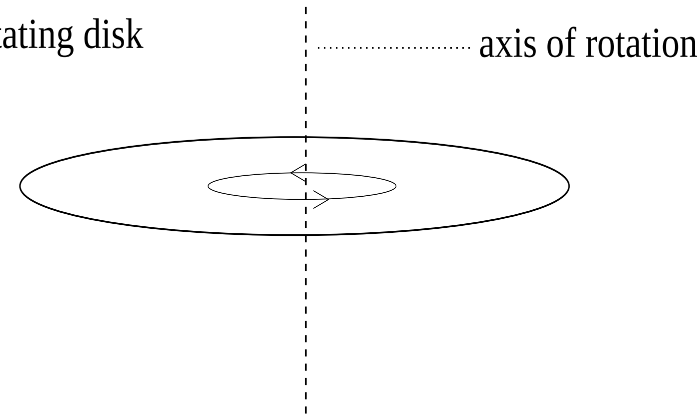


Centrifigal force balances gravitational force when perpendicular to rotation

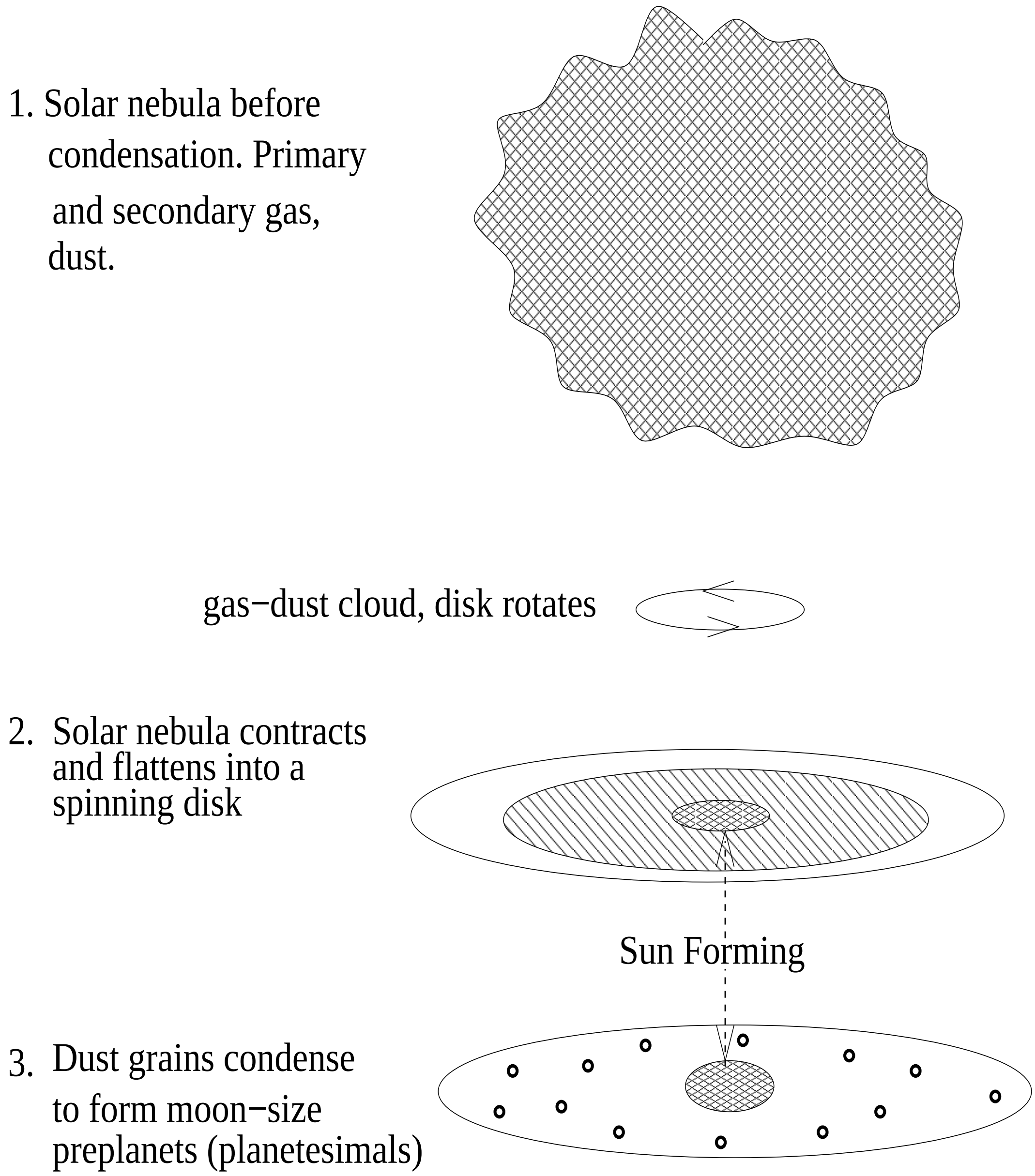
No centrifigal force along axis of rotation.

Gravitational force collapses gas mass along rotational axis to form a disk.

Result, flat rotating disk

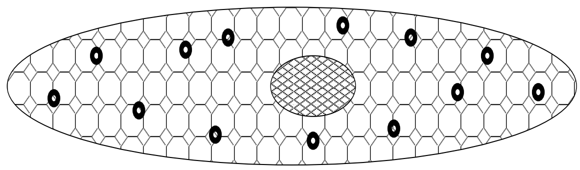


EARLY STAGES OF EVOLUTION OF OUR SOLAR SYSTEM

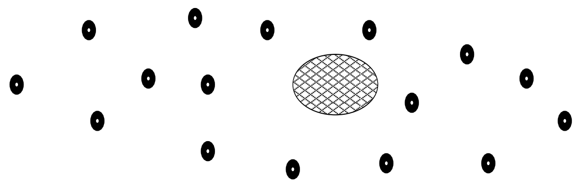


LATER STAGES OF EVOLUTION OF OUR SOLAR SYSTEM

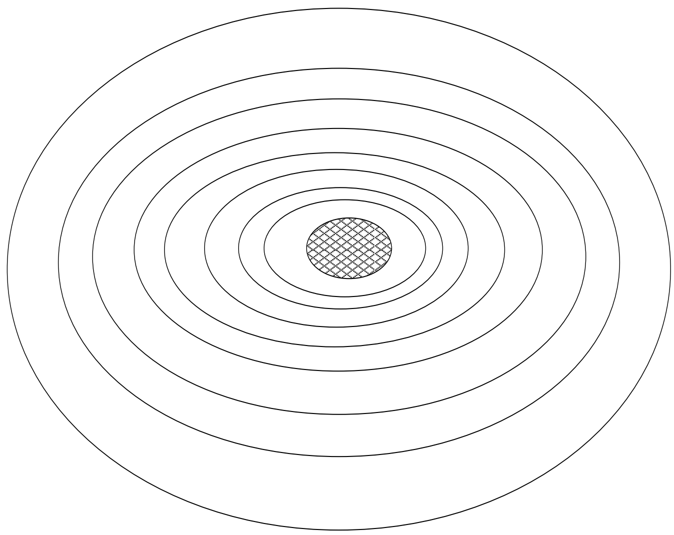
4. Strong winds from evolving sun expel nebular gas



5. Planetesimals collide and grow

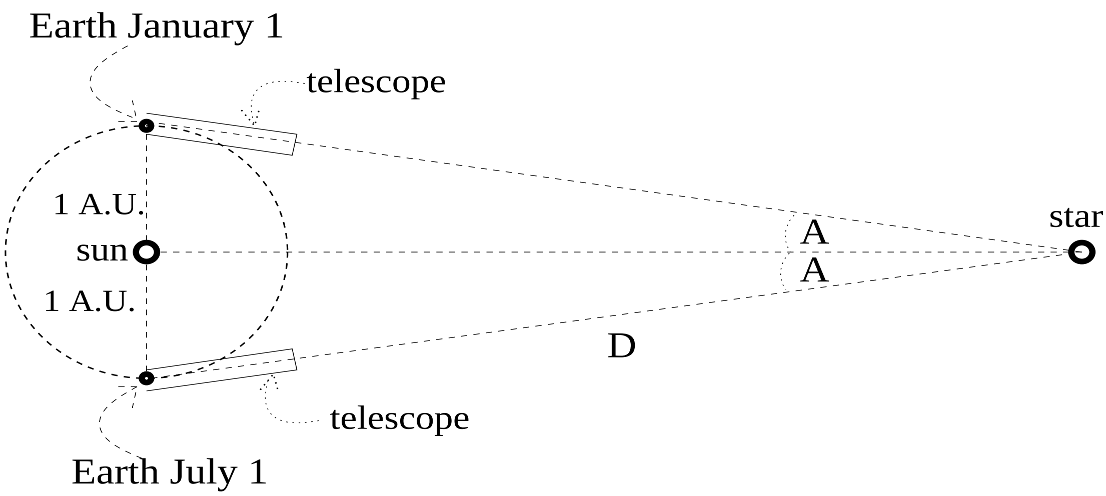


6. About 100 x 10^6 years Planetesimals form a few planets which move in approximately circular orbits



TO MEASURE THE DISTANCE FROM THE EARTH TO THE SUN

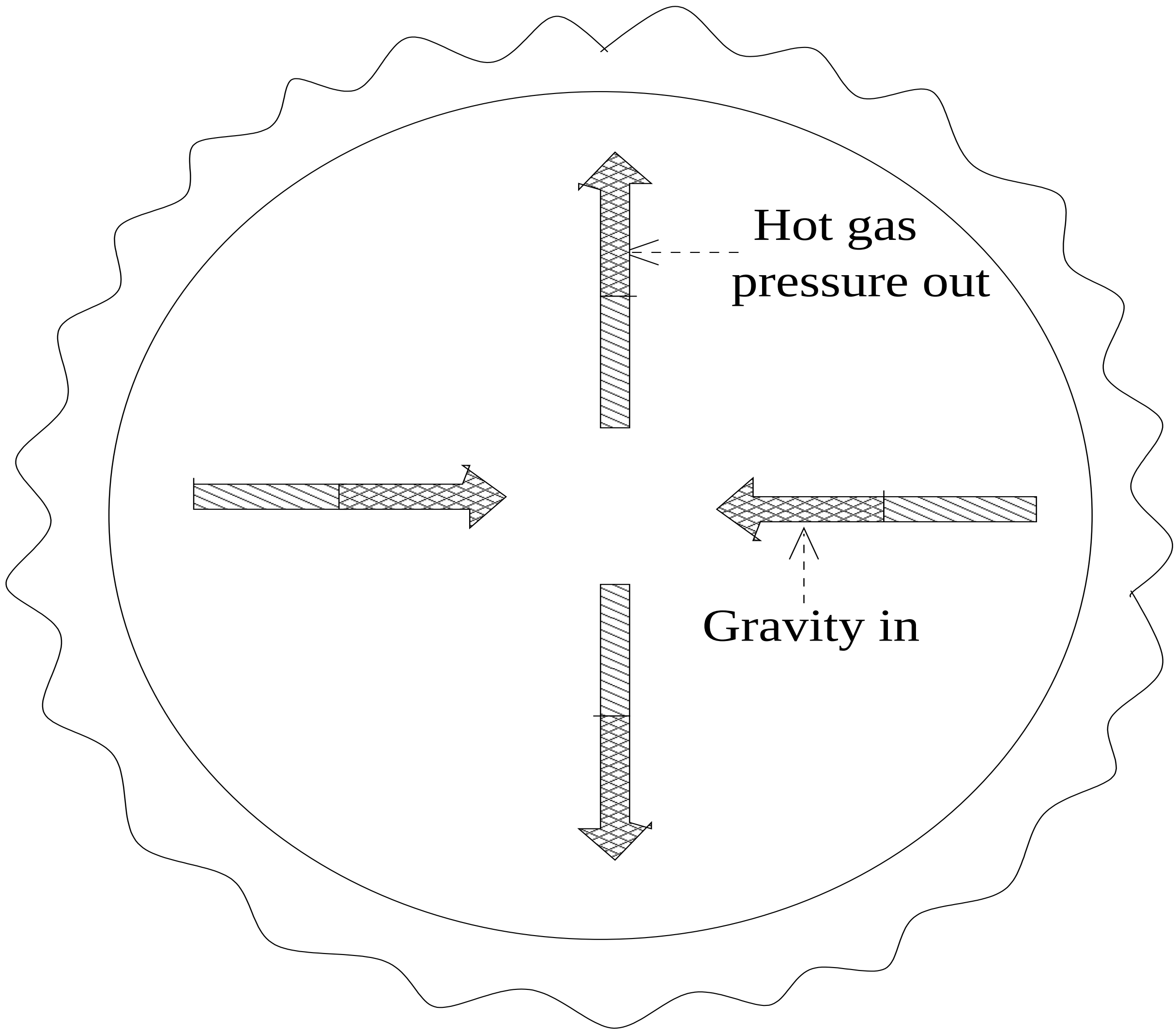
Traditional method. Pick a star with distance D from earth known



Measure the angle 2A using a telescope aimed at a distant star.
D = distance from earth to star is known.
1 A.U./D = sin(A) ~ A (very small).
1 A.U.=distance from earth to sun ~ DxA = 1.5×10^{11} m

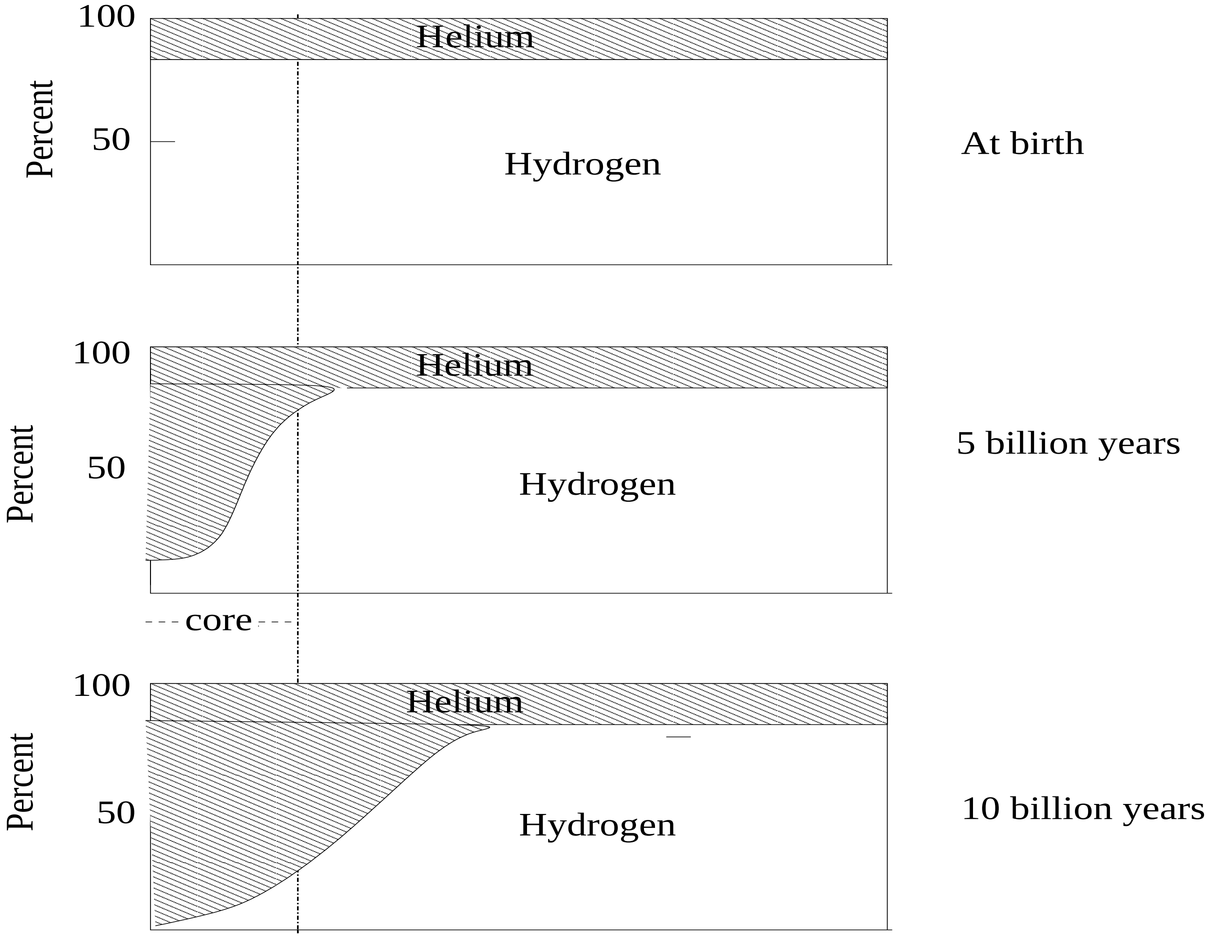
Modern method. Use radar to measure the distance of earth from the planet Venus. Use trigonometry and measured angles of Earth and Venus with respect to the sun and one can accurately determine the distance of the earth from the sun, with average value = 1 A.U.

STEADY STATE: INWARD PULL OF GRAVITY BALANCED BY OUTWARD PRESSURE OF HOT SOLAR MATTER



SUN'S COMPOSITION OVER 10 BILLION YEARS

HELIUM VS HYDROGEN OVER 10 BILLION YEARS



NUCLEAR ENERGY $\Rightarrow$ OUTWARD PRESSURE VS GRAVITY-NUCLEAR FUSION

NUCLEAR ENERGY STARTS WITH PROTON - PROTON REACTIONS (H^1, H^2, He=PROTON, DUTERIUM,HELIUM):

$$
\begin{aligned}
H^1 + H^1 &\rightarrow H^2 + \text{ positron } + \text{ neutrino} \\
H^1 + H^2 &\rightarrow He^3 + \text{ energy} \\
He^3 + He^3 &\rightarrow He^4 + H^1 + H^1 + \text{ energy} ,
\end{aligned}
$$

FOLLOWED BY HELIUM FUSION

$$
\begin{aligned}
He^4 + He^4 &\rightarrow Be^8 + \text{ energy} \\
Be^8 + He^4 &\rightarrow C^{12} + \text{ energy} .
\end{aligned}
$$

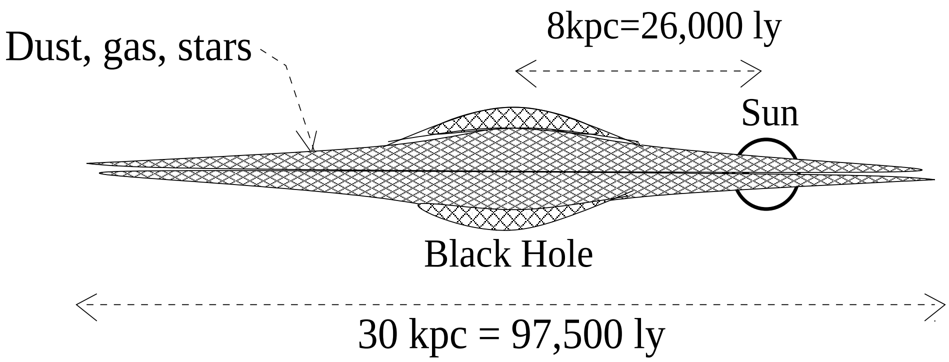
ANOTHER CHAIN IS THE CNO CYCLE, IN WHICH CARBON SERVES AS A CATALYST. WITHOUT GOING THROUGH THE ENTIRE CHAIN, IT CAN BE REPRESENTED By:

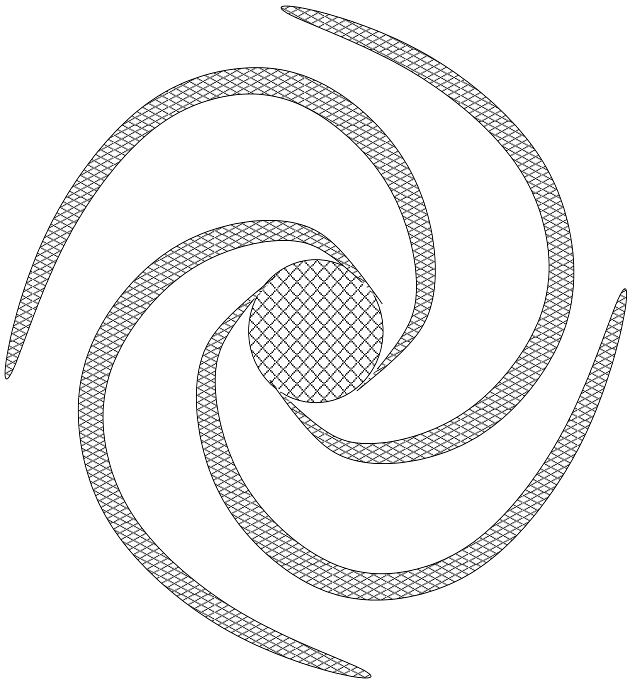
$$C^{12} + 4(H^1) \rightarrow C^{12} + He^4 + \text{ 2positrons } + \text{2neutrinos} + \text{ energy} .$$

OUR AGING SUN WILL DEVELOPE A CORE AND ENVELOPE THAT DO NOT BURN. THERE DEVELOPES A HYDROGEN SHELL THAT BURNS AND EXPANDS OUR AGING SUN INTO A RED GIANT

GALAXY: A GARGANTUAN COLLECTION OF STARS GAS, DUST, BLACK HOLES HELD TOGETHER BY GRAVITY AND ISOLATED IN SPACE

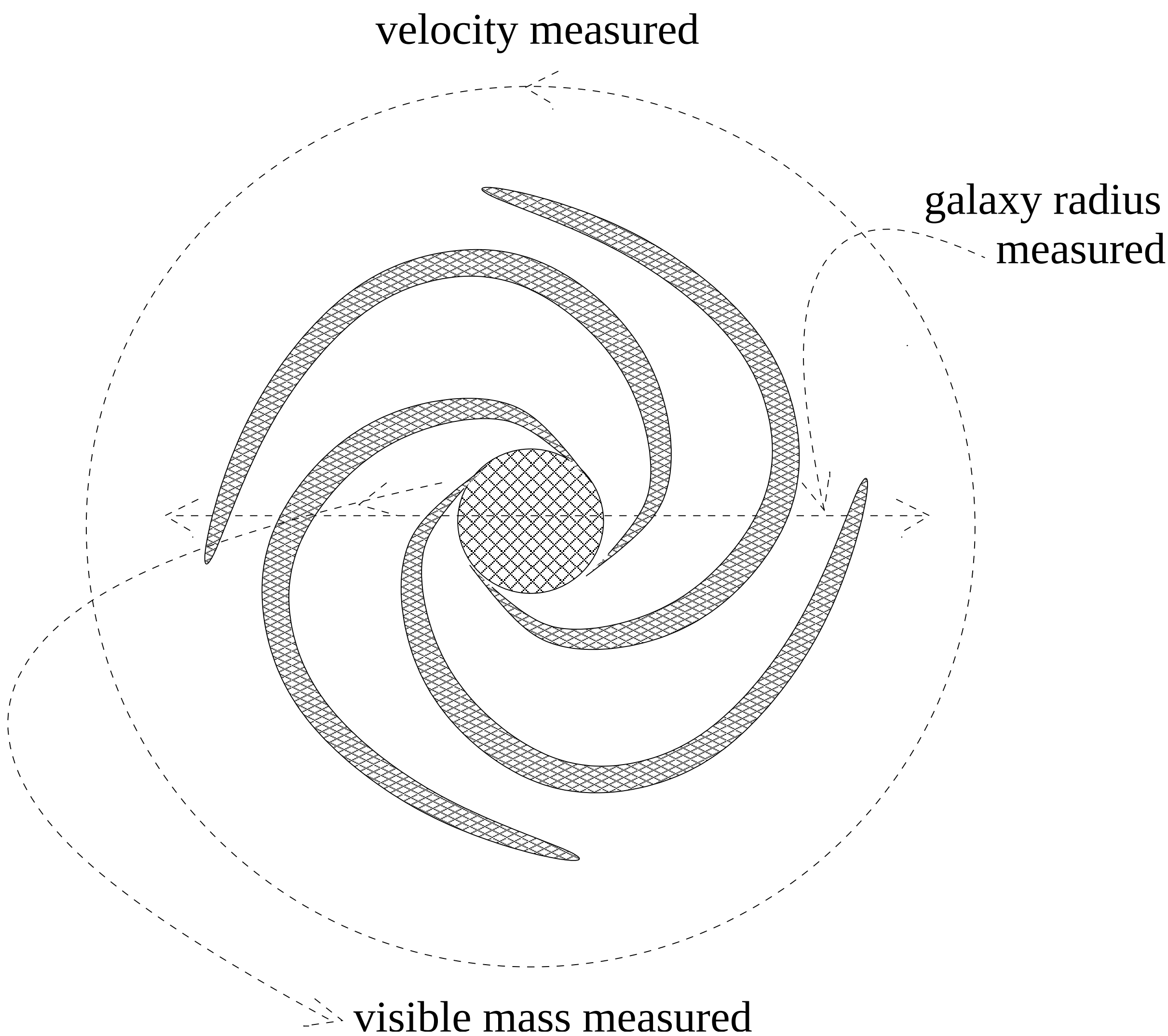
OUR GALAXY: THE MILKY WAY





Milky Way is a spiral galaxy

GALAXY ROTATION AND DARK MATTER



From the angular velocity and size of our galaxy, one can determine the mass. MORE MASS THAN SEEN. THERE IS DARK MATTER. After years of study of galaxy formation, cosmic background light, etc., we know that dark matter is not burned-out stars or other ordinary matter.

QUESTION: WHAT IS DARK MATTER–session 5

From arXiv:1204.3924/astro/ph 17 April, 2012

Kinematical and chemical vertical structure of the Galactic thick disk1, 2II. A lack of dark matter in the solar neighborhood.

C. Moni Bidin et al, Departamento de Astronoma, Universidad de Concepcion, Casilla 160-C, Concepcion, Chile

ABSTRACT We estimated the dynamical surface mass density at the solar position between Z=1.5 and 4 kpc from the Galactic plane, as inferred from the kinematics of thick disk stars. The resulting trend of matches the expectations of visible mass alone, and no dark component is required to account for the observations. We demonstrate that a DM halo would be detected by our method, and therefore the results have no straightforward interpretation. The results challenge the current understanding of the spatial distribution and nature of the Galactic DM.

THIS ARTICLE SHOWS THE PROBLEMS OF MEASURING DARK MATTER VIA GALAXY OBSERVATIONS

Other publications, however, have found flaws in the Bidin et al methods. We discuss this next.

ANOTHER (PROBABLY MORE JUSTIFIED) POINT OF VIEW

DARK MATTER DENSITY AT THE SUN'S LOCATION, Paolo Salucci, Fabrizio Nesti, Gianfranco Gentile, Christiane Frigerio Martins: arXiv:1003.3101 (2010)

AIMS: We derive the value of the dark matter density at the Suns location without globally mass-modeling the Galaxy.

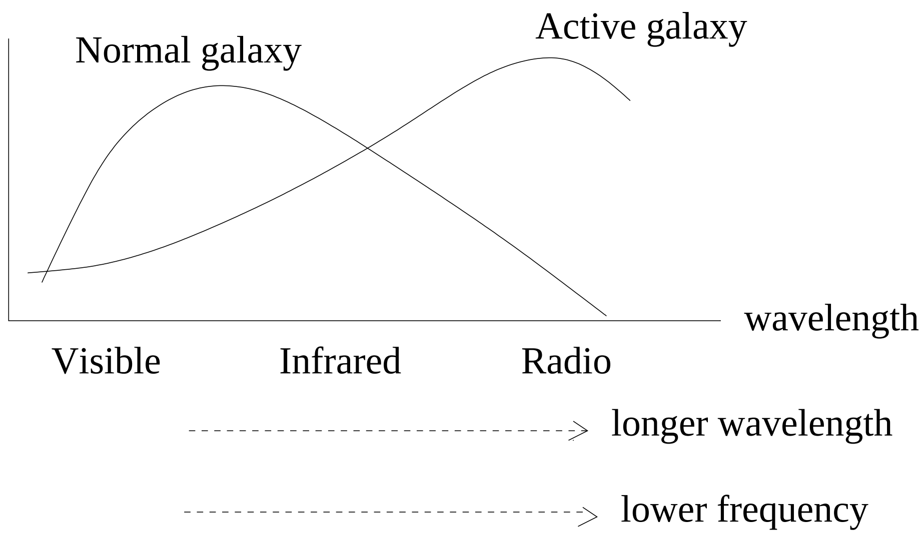
METHODS: The proposed method relies on the local equation of centrifugal equilibrium and is independent of i) the shape of the dark matter density profile, ii) knowledge of the rotation curve from the galaxy center out to the virial radius, and iii) the uncertainties and the non-uniqueness of the
bulge/disk/dark halo mass decomposition.

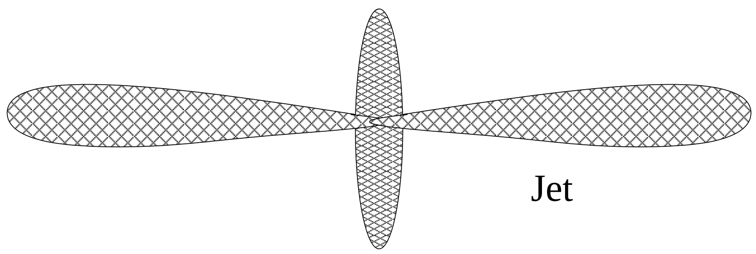
RESULTS:The result can be obtained in analytic form and it explicitly includes the dependence on the relevant observational quantities and takes their uncertainties into account.

CONCLUSIONS: We obtained a reliable estimate of the Sun's location. In addition it is ready to take into account any future change/improvement in the measures of the observational quantities it depends on.

ACTIVE GALAXIES, QUASARS

Active galaxies have greater luminoscities than normal (spiral, ellipitical) galaxies, and emit radiation with much longer wavelengths (mainly radio) rather than mainly visible radiation of normal galaxies.





Active galaxies (quasars) emit energy as jets perpendicular to accretion disk, with the jets probably powered by large black holes.

QUASARS are a type of active galaxies detected at very large distances. They are the brightest objects that have been discovered in the universe.

SUPERNOVAE, NEUTRON STAR, AND BLACK HOLE FORMATION

Massive Stars, M $>\sim 8 \times M_{sun}$, burn their nuclear fuel quickly

Collapse to density $> 10^{14}$ g cm^{-3} $>$ nuclear density. Heavy elements formed

Shocks, bounce, etc–Hydrodynamic phase

Protoneutron star formed $\sim$ 0.01 s.

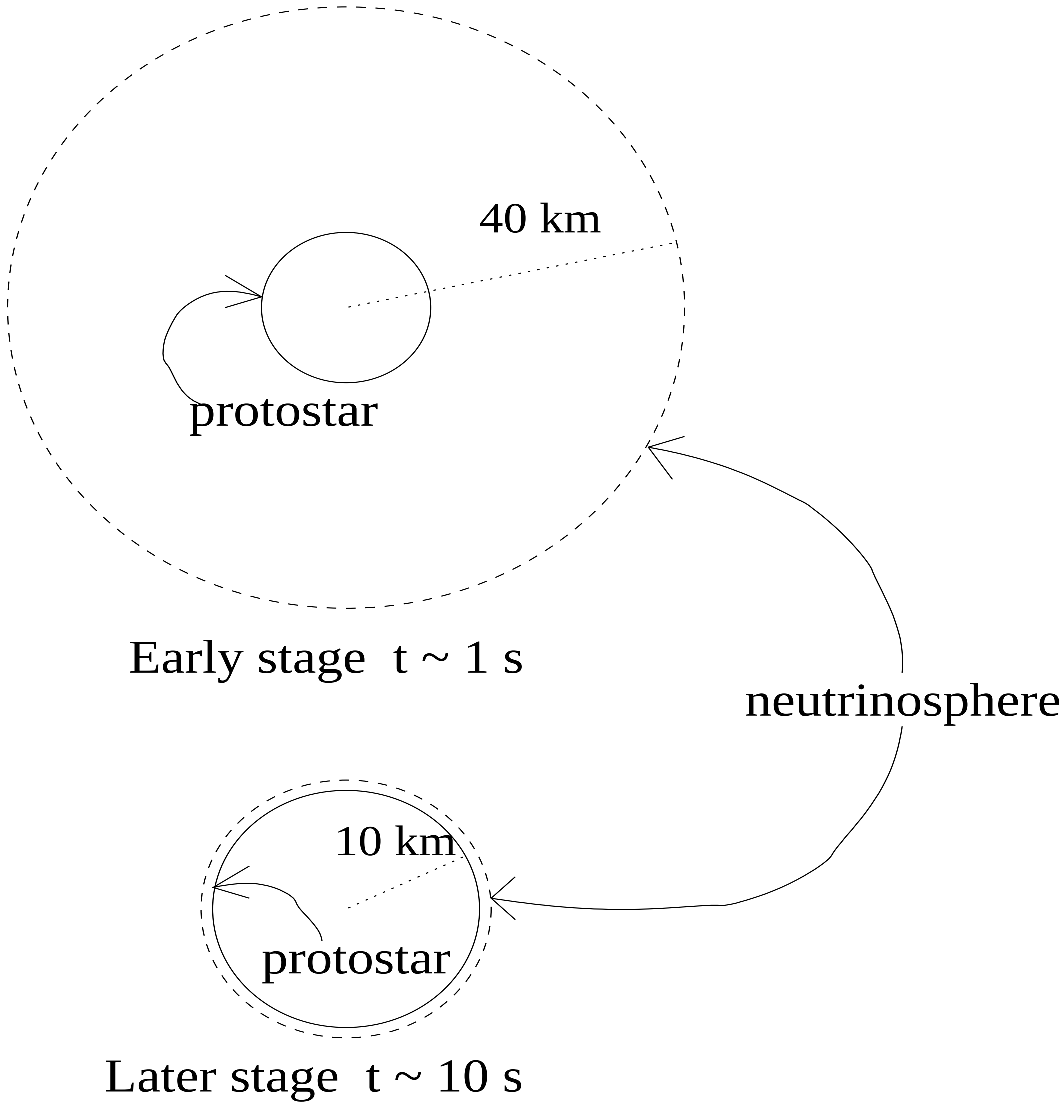
Neutrinos trapped in neutrinosphere, with radius of neutrinosphere $\sim$ 40 km.

From 0.1 to 10 sec neutrinosphere contracts from $\sim$ 40 km to protostar radius $\sim$ 10 km. Neutrinos carry gravitational energy from the emerging star via URCA process

$$n \;\rightarrow\; p + e^- + \bar{\nu}_e$$

From $\sim$ 10 to $\sim$ 50 sec n-n collisions dominate neutrino production: star cooling via MODIFIED URCA process

$$n + n \;\rightarrow\; n + p + e^- + \bar{\nu}_e$$


40 km
protostar
Early stage t ~ 1 s
neutrinosphere
10 km
protostar
Later stage t ~ 10 s

THE FINAL STATE OF THE PROTO-STAR: PULSARS AND BLACK HOLES

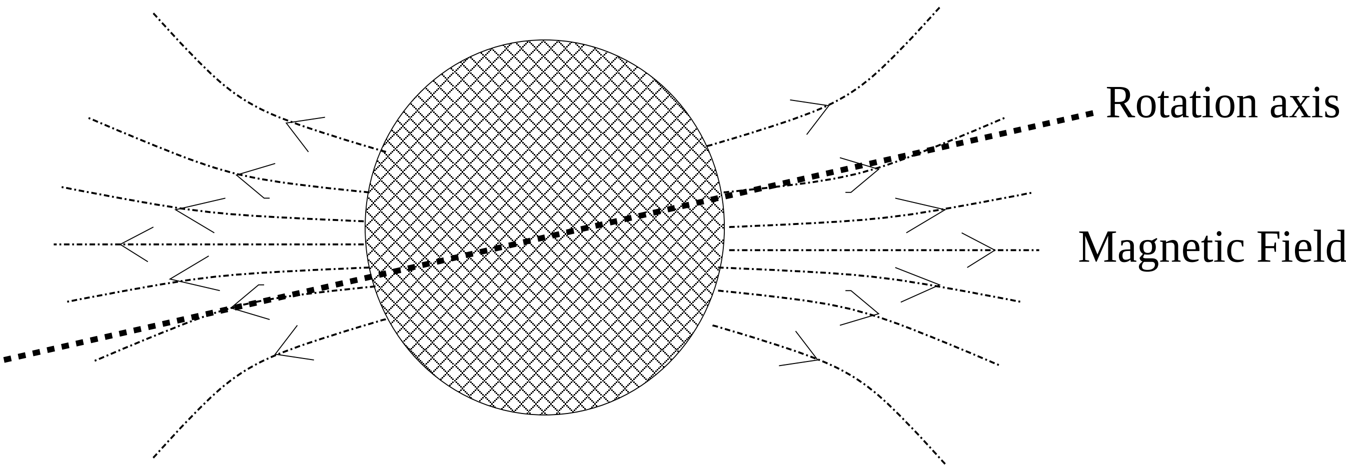
After the interior star reaches temperature equilibrium, it is made of nuclear matter, largely neutrons, except in the interior where the nuclear matter is highly compressed.

Final star has a radius of about 10 km (big as Pittsburgh). If it's mass is less than 1.5 M_s, it becomes a neutron star, a pulsar. If its mass is greater than 1.5 M_s it continues to collapse to become a black hole

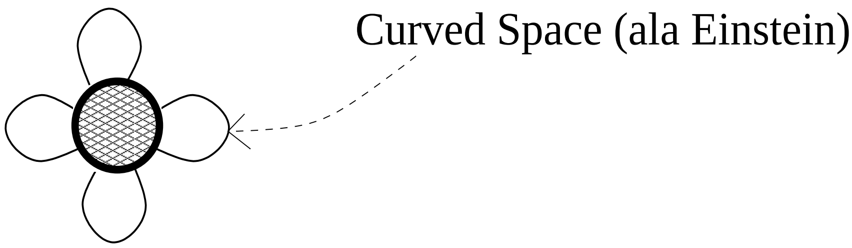
The neutron star has a large magnetic field (arising from the original star's magnetic field), and spins very fast conservation of angular momentum. THIS RAPIDLY SPINNING MAGNETIC FIELD SENDS OUT RADIATION: IT IS A PULSAR

GRAVITY KEEPS COMPRESSING A MASSIVE NEUTRON-LIKE STAR. WHEN IT REACHES A CRITICAL RADIUS, LIGHT EMITTED IS BENT BACK BY GRAVITY: IT IS A BLACK HOLE

PULSAR



BLACK HOLE



PULSAR KICKS: SOME PULSARS MOVE WITH A VERY HIGH VELOCITY, $\geq$ 1500 km/s

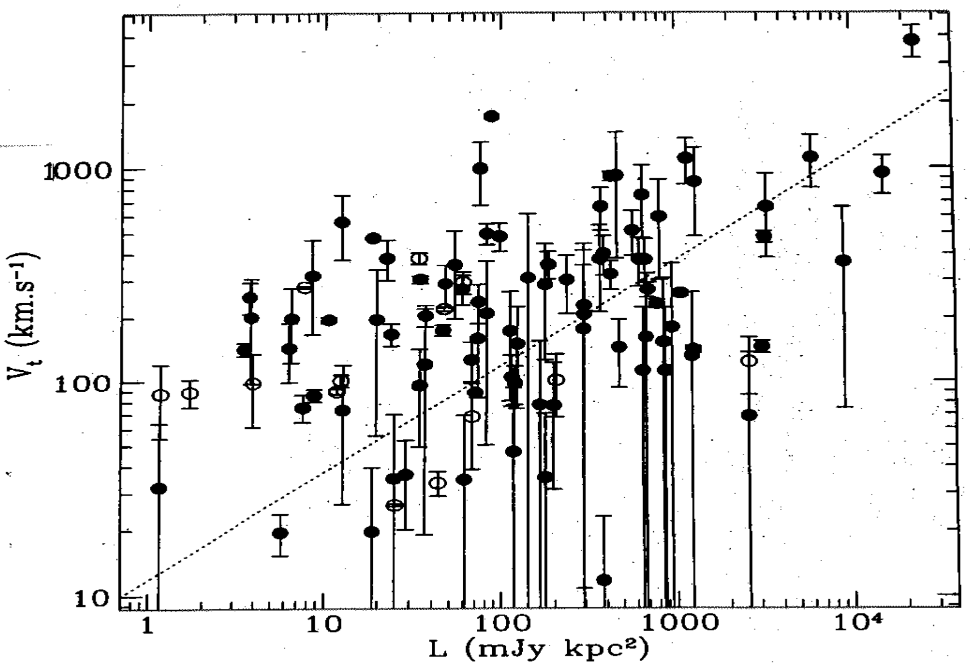


Figure: Pulsar Speed vs. Luminoscity

PULSAR KICKS FROM THE MODIFIED URCA PROCESS WITH ELECTRONS IN LANDAU LEVELS IN A STRONG MAGNETIC FIELD (10-20 SEC)

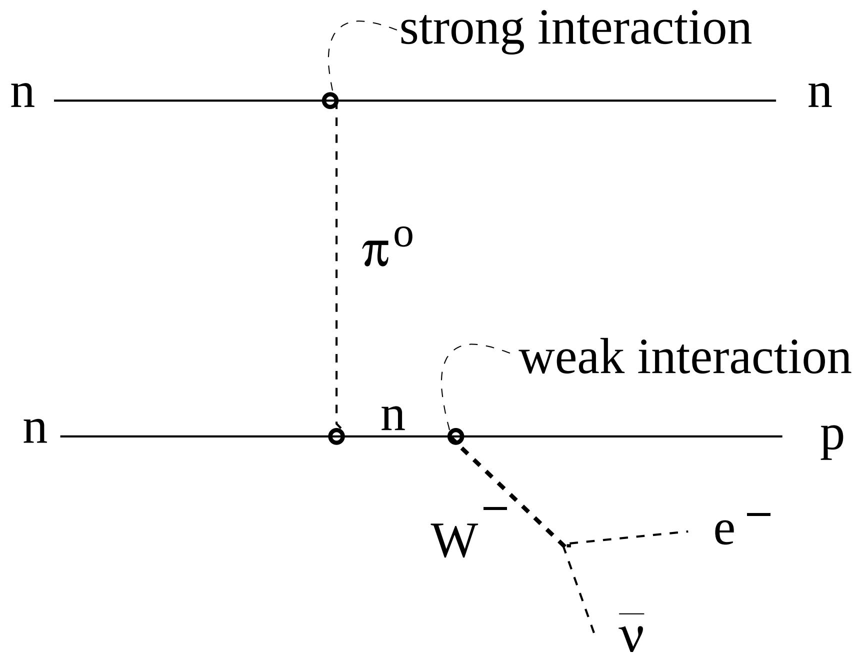
Ernest M. Henley, Mikkel B. Johnson and Leonard S Kisslinger, astro-ph/0706.1511 (2007), Phys. Rev. D 76, 125007 (2007)

In the later stage ($t >\sim 10s$) the Modified URCA process:

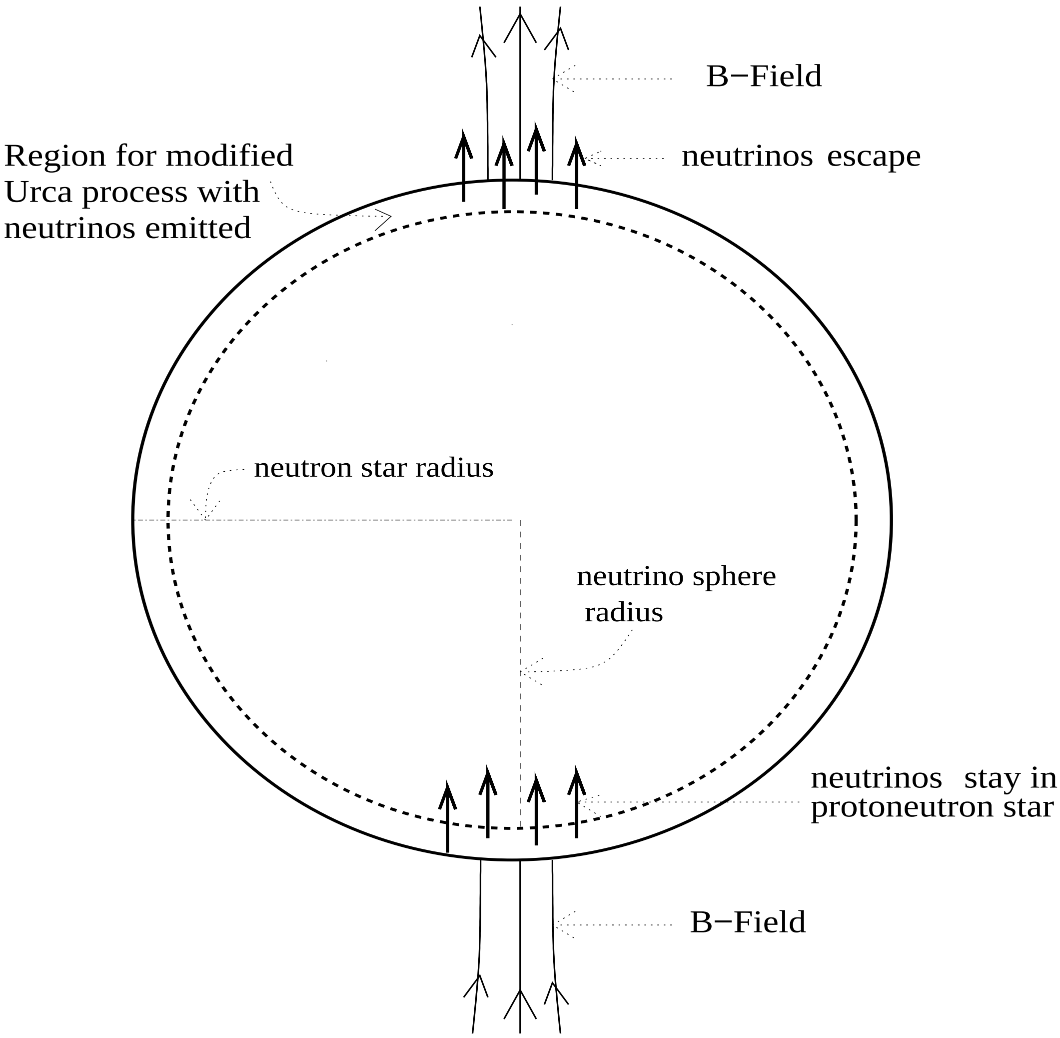
$$n + n \;\rightarrow\; n + p + e^{-} + \bar{\nu}_e \tag{2}$$

dominates the cooling of the neutron star.

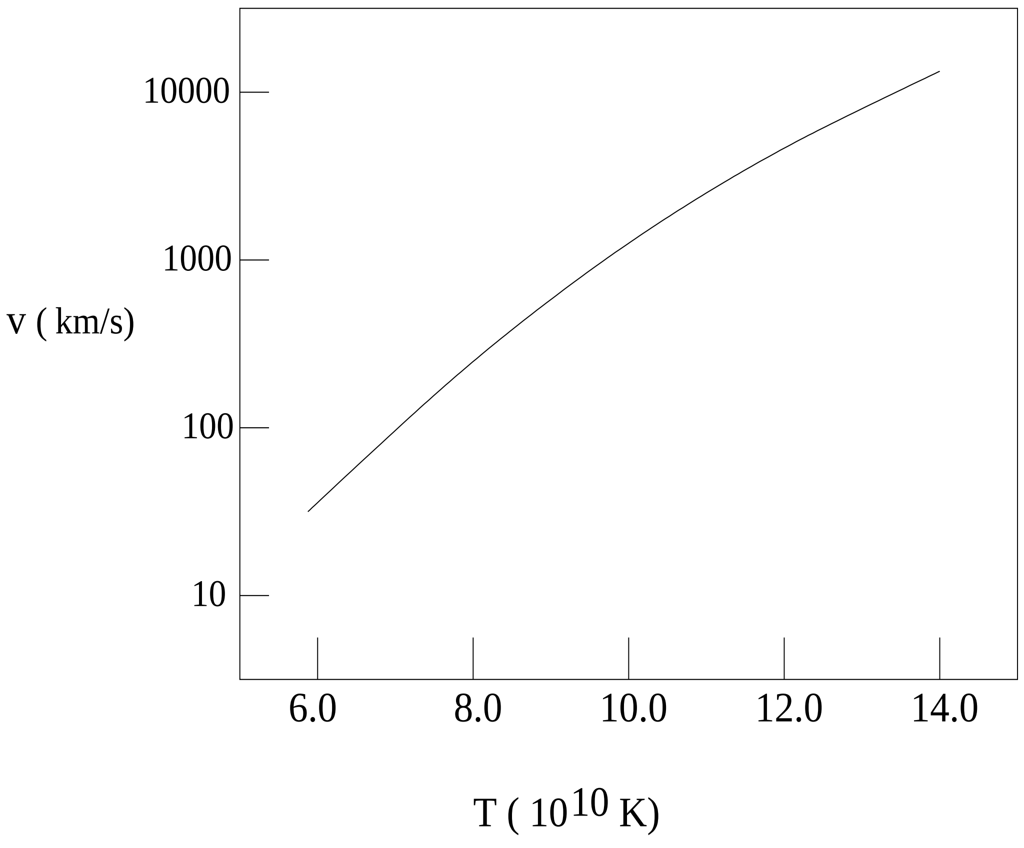
TYPICAL MODIFIED URCA DIAGRAM



ELECTRONS IN n=0 LANDAU LEVEL:
NEUTRINOS EMITTED IN B−FIELD DIRECTION



The figure shows the velocity in the T-range when the neutrinosphere is just inside the neutron star surface for electrons in n=0 Landau level.



Pulsar velocity vs T assuming constant emission volume

PULSAR KICKS FROM STERILE NEUTRINOS WITH LANDAU LEVELS IN A STRONG MAGNETIC FIELD (FIRST 10 SEC). STERILE NEUTRINOS HAVE NO INTERACTIONS!!

Sterile/active neutrino mixing given by mixing angle $|\theta_m|$, which has been found to be a very small angle. For example, an electron neutrino can become a sterile neutrino

$$|\nu_e > \;\Rightarrow\; |\nu_s >$$

Opacities of sterile neutrinos are small: they escape from the neutrinosphere

Strong magnetic fields result in neutrino asymmetries. Sterile neutrinos are emitted from the neutrinosphere in the direction of the magnetic field

PULSAR KICK, TWO STERILE NEUTRINOS FOUND IN MINIBOONE EXPERIMENT AT FERMILAB, LSND EXPERIMENT AT LOS ALAMOS, ETC.

LSK, E. Henley and M. Johnson, Mod. Phys. Lett. A24, 2507 (2009): Find for P_s = ratio of emission in direction of magnetic field to total emission:

$$P_s \;=\; 0.007 \leftrightarrow 0.10\;,$$

which includes values of 1-2% needed to explain high velocity pulsar kicks.

OTHER TOPICS FOR CURRENT ASTRONOMY:

GALAXY CLUSTERS, FILIMENTS, STRINGS AND THINGS, DARK MATTER, DARK ENERGY, PLANETS WITH LIFE AND POSSIBILITY INTELLIGENT LIFE.

WE NOW MOVE BACKWARD TO THE EVOLUTION OF THE EARLY UNIVERSE AT EARLY TIMES