Isaac Newton published in the year 1687 ***„The Philosophiae Naturalis Principia Mathematica"***. This book describes the sky movements and is accepted to be the most important work of natural Science. There is no doubt that these Laws of Nature are right, because the satellites we send to the planets inside our sun system get their destinations very precisely. ***The question is whether Newtonians physics are fully valid for galaxies?*** The cosmological theory model needs a lot of Dark Matter to explain the development of the galaxies. On the other side a minority of astronomical scientists prefer a modification of Newtonians physic. The study you find here about the Milky Way follows the question about its ***development and the origin of its rotational energy***.

Hubble Space Telescope

developed by American and European space organization NASA / ESA

launched: 1990 April 24

distance from earth surface 547 km

orbit velocity: 7.6 km / sec

one orbit takes 96 minutes

reflector diameter: 2,4 m

The **Hubble Space Telescope** delivers very precise data to research galaxies and shows fantastic pictures which are far away in the deep sky and helps to understand the mystery of universe.

1.0 Astronomical observations tell us that galaxies are rotating faster than expected from their visible mass. To match cosmological model with astronomical observation there is a lot of mass missing. This missing mass is called ***Dark Matter***. But there is a big problem, because very great efforts to find this Dark Matter were done without any success. Dark Matter therefore seems possibly to be a fantasy idea.

We do know that the cosmological model is basing on the theory of relativity of Albert Einstein. If universe is homogeneous and isotropic, the theory seems to be right, but in smaller scales – in dimension of galaxies – it is very clear that universe is not homogeneous. In this case the theory may be wrong. Here we focus on the Milky Way, which is embedded in a galactic halo. Halo means the spherical space around the galaxy. Before talking about Dark Matter we want to know the mass of the Milky Way including the mass of its Halo, which is the so called "atmosphere" around the glowing spiral disc. Having a bird view on the galaxy, astrophysicists calculate the mass by the luminosity – but that measurement is unsafe. The best data to calculate the mass you will get from the rotation speed.

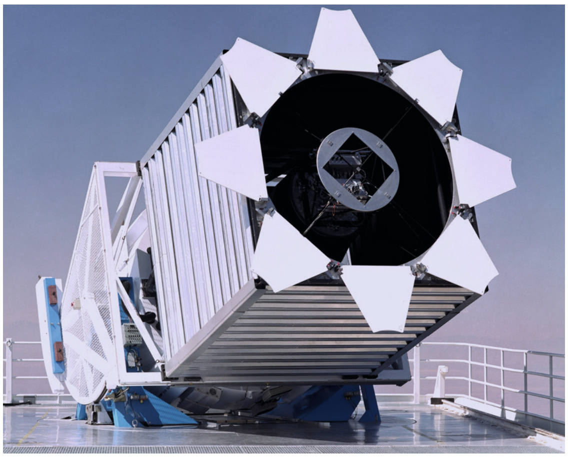
We consider three astronomical studies, which give solid information about the mass of the halo around our Milky Way. Here we discuss three astronomic studies, which calculate the Milky Way by measurement of rotational speed in different distance of its galactic center. The first study 1.1 was published by the University of Bonn (Germany), the second study 1.2 was published by the Max-Planck-Institute of astronomy in Heidelberg and the third study 1.3 was released by the Astronomy Department of University of Arizona.

1.1 Milky Way: **170 billion of solar masses** radius R 50 000 light years (15,3 kpc)
The University of Bonn (Germany) published a study in the year 2015 by Dr. Andreas Küpper
"*Globular cluster streams as galactic high-precision scales – the poster child Palomar-5*"
The star cluster of Palomar-5 is circling nearly perpendicular to the galactic level of the Milky Way. This special orbit is clearly dominated by gravity of the Milky Way – so this is a good data base. 170 billion = **170** x $\mathbf{10^9}$

1.2 Milky Way: **400 billion of solar masses** radius R 200 000 light years (61,4 kpc)
Max Planck Institute for Astronomy Heidelberg / Department of Galaxies and Cosmology
"*The Milky Way – a leightweight after all*"
Autoren: Xue, Xiang-Xiang; Rix, Hans-Walter; van den Bosch, Frank; Bell, Eric; Kang, Xi
A group of astronomers headed by the Max Planck Institute for Astronomy has measured the velocity of the stars in the galactic halo and thereby derived the most accurate value to date for the total mass of the galaxy: **The region within a radius of 200 000 light years contains** $\mathbf{4\times10^{11}}$ **solar masses.** An extrapolation to 800 000 light years leads to 10^{12} solar masses. 400 billion solar (galactic mass = **400** x $\mathbf{10^9}$ solar mass)

1.3 Milky Way: **900 billion of solar masses** radius R 800 000 light years (245,4 kpc)
"Estimating the Mass of the Milky Way Using the Ensemble of Classical Satellite Galaxies"
Ekta Patel, Gurtina Besla, Kaisey Mandel, Sangmo Tony Sohn
Department of Astronomy of University of Arizona arXiv: 1803.01878 vl (on 5 Mar 2018)
Ekta Patel and her team did research the ***orbital angular momentum of ten dwarf satellite*** galaxies of the Milky Way and conclude the halo mass is **nearly 0,9 x** $\mathbf{10^{12}}$ **of solar masses**.

2.0 The orbit of the star group Palomar-5 reveals the weight of the Milky Way



The ***Sloan Digital Sky Surveys (SDSS)*** has mapped the northern galactic sky in the past ten years very precisely.

Two teams of astrophysicists used the measurements of SDSS to research the orbit of the star group Palomar-5. There is nearly no outside influence on the orbit, that's why it is well suited to determine the mass of the Milky Way.

Researcher of Max-Planck-Institute (MPI) Heidelberg published a study about Palomar-5 in 2005:

A comprehensive model for the Monoceros tidal stream"
Astrophysical Journal 626, 128–144, year 2005:
von Penarrubia J.; D. Martinez-Delgado; Dr. H.-W. Rix (MPI); and more other researchers et al.
Dr. Eva K. Grebel (MPI)

parameters of the Palomar-5 – researched by MPI-Heidelberg in 2005
- Palomar-5 did transfer the Milky-Way-Disc **150** million year ago
- the next transfer of the Milky Way will take **110** million years

in the year 2015 Researchers of University of Bonn (Germany) published a study:
"Globular cluster streams as galactic high-precision scales - the poster child Palomar-5"
Dr. Andreas Küpper; Prof. Dr. Pavel Kroupa (doctor father University of Bonn) other scientists

parameters of the elliptical orbit – researched by University of Bonn in 2015:
- present orbit point **P** is nearly 61 300 light years far away from galactic center
- acceleration at point **P**: $a_P = 0{,}81 \times 10^{-10}$ m/sec² tolerance +/- 0,14
- velocity at point B (transverse velocity of palomar-5) **v = 253** +/- 16 km/sec
- apogalactic distance referring to galactic center: 61 940 light years (19 kpc)
- perigalactic distance referring to galactic center: 26 080 light years (8 kpc)

These astronomical data makes it possible to calculate the mass of the Milky Way, but it should be clear that the results are not better than the tolerance.

The time to circle the Milky Way on ***Palomar-5-Orbit*** depends on the mass of the Milky Way. To get balance of gravity and centrifugal force means that high gravity corresponds with high orbit velocity. Because the velocity of an elliptical orbit is changing currently we compare the time for one complete orbit. The results of the calculation are shown at the sheet 2.1 below.

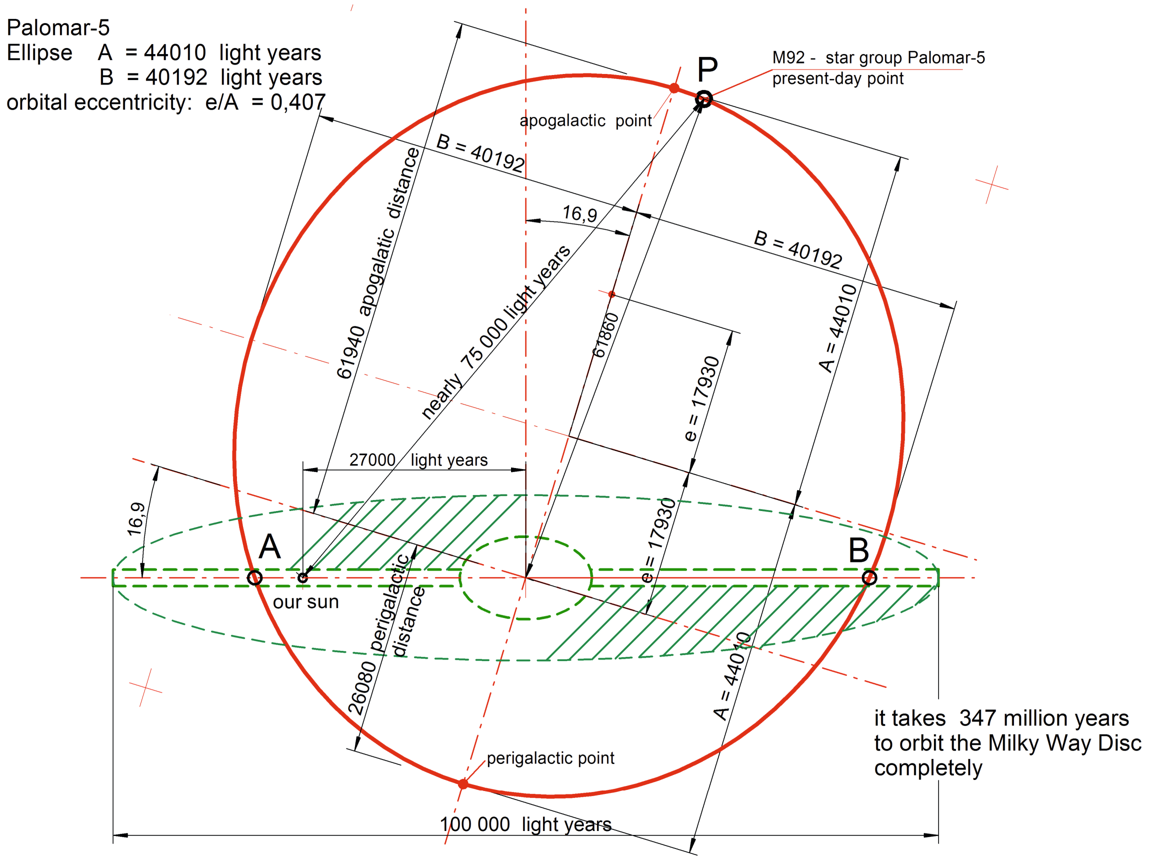
2.1 Galactic mass of Milky Way

	160 billion solar mass	**180 billion** solar mass	**200 billion** solar mass
Palomar-5 time for orbit	in million years	in million years	in million years
orbit from A to P	158	**149**	141
orbit from P to B	116	**109**	103
orbit from B to A	94	**89**	85
time for complete orbit	368	**347**	329
orbit-velocity at point B	238,6 km/sec	253 km/sec	266,7 km/sec

mass of the Milky Way = 36×10^{40} kg = 180 billion solar mass
one billion = 10^9; solar mass = 2×10^{30} kg

2.2 Elliptical orbit of Palomar-5

The star group orbits the Milky Way almost vertical to its galactic disc and contains nearly 5000 solar masses. Astrophysicists found out: The star group Palomar-5 crossed the disc of the Milky Way at point 'A' ***150 million years*** ago and it will take ***110 million years*** before the star group will reach the disc of the Milky Way again at point 'B'. The star group is presently at point 'P' in the northern galactic region, 75 000 light years far away from our sun. The time to orbit the Milky Way completely takes 347 million years. The orbit of the star group is well suited for ***mass determination*** because the separate elliptical circle is nearly without influence. The mass of the Milky Way can be calculated from the orbit parameter of Palomar-5 and the orbital period.



When crossing the disc of the Milky Way the Palomar star group was stretched out like a comet's tail. The Astrophysicists researched that the group lost parts of their stars every time when passing the disc. Currently the star group has only 10 % of their original mass.

3. Kepler's law formula:

Squares of orbital times relate to third powers of mayor semiaxes: $\frac{T_1^{\,2}}{T_2^{\,2}} = \frac{A_1^{\,3}}{A_2^{\,3}}$

$T_1 = 347$ million years $= 3{,}47 \times \mathbf{10^8}$ years (Palomar-5 orbit round the galactic center)

$T_1^{\,2} = 12{,}041 \times \mathbf{10^{16}}$ years^2

$T_2 = 1$ year (earth orbit around the sun)

$A_1 = 44\,010$ light years $= 44\,010 \times 9{,}5 \times \mathbf{10^{15}}$ m $= 4{,}181 \times \mathbf{10^{20}}$ m (Palomar-5)

$A_1^{\,3} = 73{,}087 \times \mathbf{10^{60}}$ m^3

$A_2^{\,3} =$ (150 million km)$^3 = 3{,}375 \times \mathbf{10^{33}}$ m^3 (distance earth to sun)^3

The galactic orbit is related to the earth orbit round our sun. But the galactic mass is much more greater than the solar mass. galactic mass = Z x solar mass

$Z\,(T_1^{\,2} / T_2^{\,2}) = (A_1^{\,3} / A_2^{\,3})$

$Z\,(12{,}041 \times \mathbf{10^{16}} / 1) = (73{,}087 \times \mathbf{10^{60}} / 3{,}375 \times \mathbf{10^{33}})$

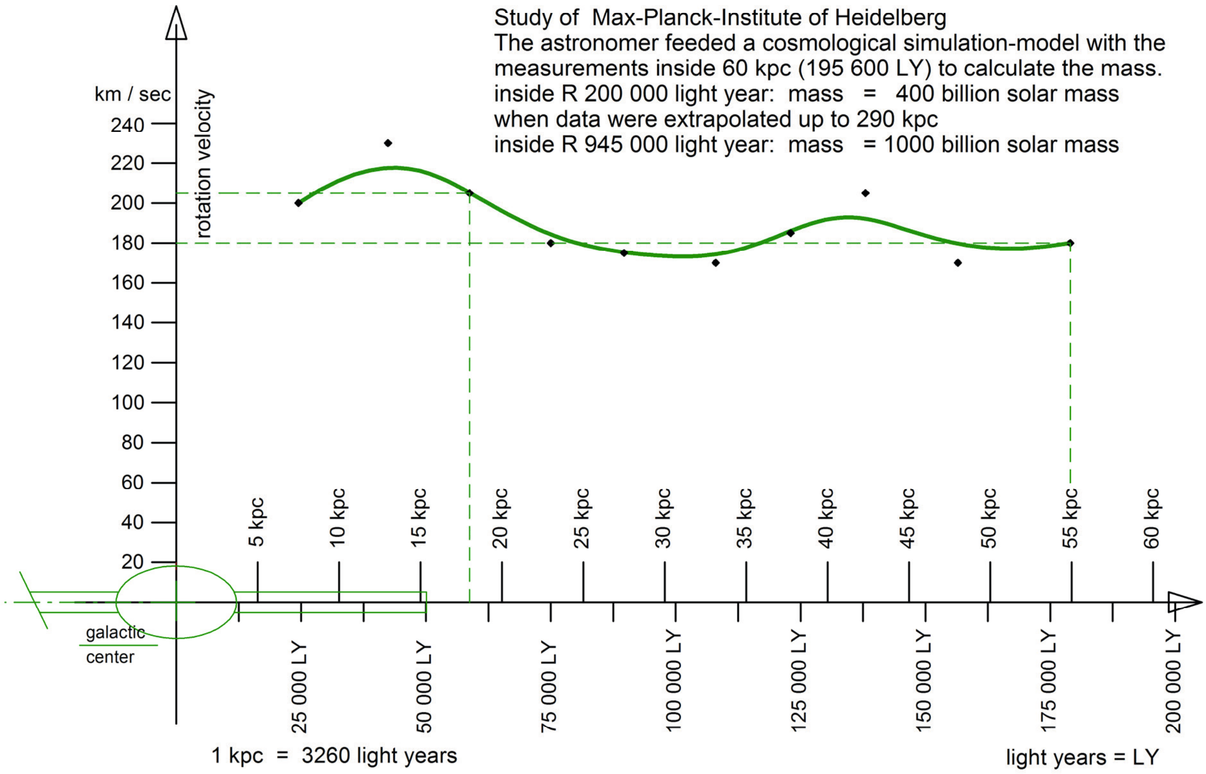
$Z = 21{,}655 \times \mathbf{10^{27}} / 12{,}041 \times \mathbf{10^{16}} = \mathbf{1{,}798} \times \mathbf{10^{11}}$ x solar mass

result: Milky-Way mass = 180 billion solar mass

2.3 2400 stars tell the mass of the Milky Way and its galactic Halo

research report: ***The Milky Way – a leightweight after all***
published by Max-Planck Institute for Astronomy Heidelberg / Jahrbuch 2008 / 2009
Autoren: Xue, Xiang-Xiang; Rix, Hans-Walter; van den Bosch, Frank; Bell, Eric; Kang, Xi
A group of astronomers headed by the Max Planck Institute for Astronomy has measured the velocity of the stars in the galactic halo and thereby derived the most accurate value to date for the total mass of the galaxy: ***The region within a radius of 200 000 light years contains 4×10^{11} solar masses.*** An extrapolation to 800 000 light years leads to 10^{12} solar masses.

The ***astrophysicists selected 2401 stars*** by spectral analysis in the outer region of the galactic disc. The stars used were in the Hertzsprung-Russell-Diagram on the blue horizontal branch, BHB. The massive bright stars are in the late phase of their development. They burn helium in the core. That's why the absolute luminosity is well known – therefore their distance can be determined quite precisely.



look the original information in the study of Max-Planck-Institute Heidelberg >Milky Way - a leightweight after all< Jahrbuch 2008 / 2009

2.4 The rotation of the hot gas around the Milky Way

author Edmund J. Hodges-Kluck et al. published April 27, 2016
- The Astrophysical Journal Letters 822,21 arXiv: 1603.07734 astro-ph

The gaseous halo of our Milky Way Galaxy is spinning in the same direction and at a similar speed as the galaxy's disk, which contains stars, planet's gas, and dust, according to a team of Astronomers using data from ESA's *XMM-Newton X-ray Observatory*.
The ***researchers of Michigan*** measured a shift in the wavelength of light around the sky using lines of very hot oxygen. What they found was groundbreaking: The line shifts measured show that the galaxy's halo spins in the same direction as the disk of the Milky Way and at a similar speed – about ***183 Kilometer pro sec*** (+/- 41 km/sec).
"The rotation of the hot halo is an incredible clue to how the Milky Way formed. It tells us that this hot atmosphere is the original source of a lot of the matter in the disk", said Hodges Kluck. This result suggests that the hot gas rotates and that it contains an amount of angular momentum comparable to that in the stellar disk.