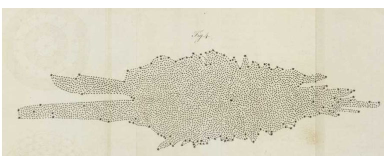
The Milky Way

1. Attempts to survey
    1. Herschel
2. Milky Way Structure
    1. Thin & Thick disks
    2. Milky way stats
3. Motion of Stars
    1. Measuring the rotation curve
4. Dark Matter
5. The Galactic Center
    1. If we were closer...

1. Attempts to survey

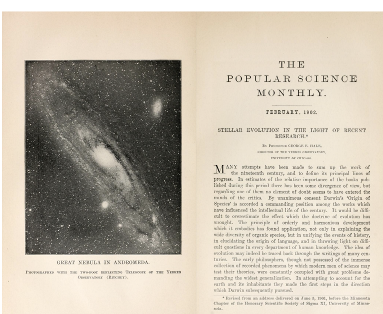
1.1 Herschel



Herschel's 1785 map of the galaxy.

doi: 10.1098/rstl.1785.0012
Phil. Trans. R. Soc. Lond. 1785 vol. 75 213-266

Incorrect assumptions lead to this model of the galaxy, where our sun was roughly near the center. We can't see all the stars in our galaxy due to interstellar dust.



GREAT NEBULA IN ANDROMEDA.

PHOTOGRAPHED WITH THE TWO-FOOT REFLECTING TELESCOPE OF THE YERKES OBSERVATORY (RITCHEY).

THE
POPULAR SCIENCE
MONTHLY.

FEBRUARY, 1902.

STELLAR EVOLUTION IN THE LIGHT OF RECENT RESEARCH.*

BY PROFESSOR GEORGE E. HALE,
DIRECTOR OF THE YERKES OBSERVATORY,
UNIVERSITY OF CHICAGO.

MANY attempts have been made to sum up the work of the nineteenth century, and to define its principal lines of progress. In estimates of the relative importance of the books published during this period there has been some divergence of view, but regarding one of them no element of doubt seems to have entered the minds of the critics. By unanimous consent Darwin's 'Origin of Species' is accorded a commanding position among the works which have influenced the intellectual life of the century. It would be difficult to overestimate the effect which the doctrine of evolution has wrought. The principle of orderly and harmonious development which it embodies has found application, not only in explaining the wide diversity of organic species, but in unifying the events of history, in elucidating the origin of language, and in throwing light on difficult questions in every department of human knowledge. The idea of evolution may indeed be traced back through the writings of many centuries. The early philosophers, though not possessed of the immense collection of recorded phenomena by which modern men of science may test their theories, were constantly occupied with great problems demanding the widest generalization. In attempting to account for the earth and its inhabitants they made the first steps in the direction which Darwin subsequently pursued.

* Revised from an address delivered on June 5, 1901, before the Minnesota Chapter of the Honorary Scientific Society of Sigma XI, University of Minnesota.

Andromeda as seen in 1902.

Popular Science Monthly

The Great Debate

April 26 1920

Harlow Shapley and Heber Curtis

→ How big is the Milky Way (and the universe)

Write up: Bulletin of the National Research Council

Globular Cluster

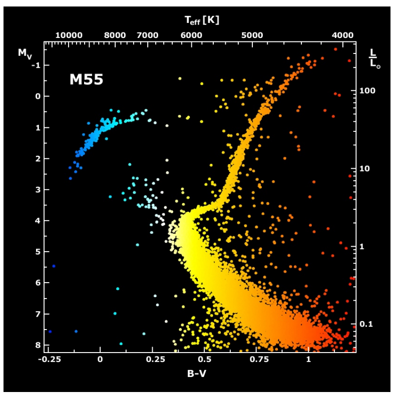
Globular Cluster

A dense cluster of old stars.

The stars contained within are gravitationally bound to each other.

Messier 68, a globular cluster. Might have 10^6 stars within a small (30 pc) diameter.

ESA/Hubble & NASA

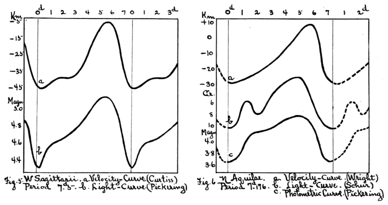


HR Diagram for a globular cluster (M-55)

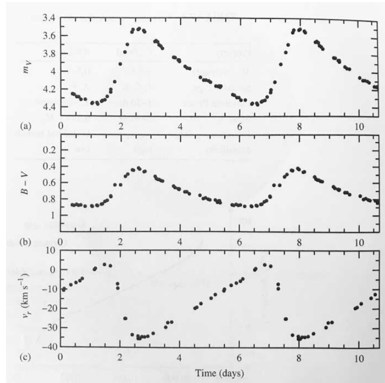
https://apod.nasa.gov/apod/ap010223.html

Variable Stars

Cepheids



Brightness of some stars was found to be periodic.



Ryden & Peterson Fig 17.7

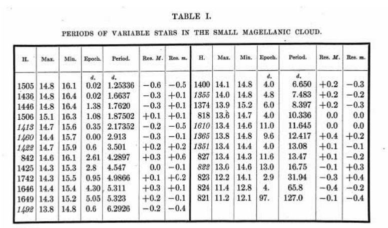
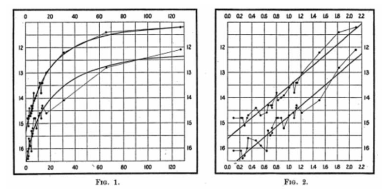


TABLE I.

PERIODS OF VARIABLE STARS IN THE SMALL MAGELLANIC CLOUD.

H.	Max.	Min.	Epoch.	Period.	Res. M.	Res. m.	H.	Max.	Min.	Epoch.	Period.	Res. M.	Res. m.
			d.	d.						d.	d.		
1505	14.8	16.1	0.02	1.25336	−0.6	−0.5	1400	14.1	14.8	4.0	6.650	+0.2	−0.3
1436	14.8	16.4	0.02	1.6637	−0.3	+0.1	1355	14.0	14.8	4.8	7.483	+0.2	−0.2
1446	14.8	16.4	1.38	1.7620	−0.3	+0.1	1374	13.9	15.2	6.0	8.397	+0.2	−0.3
1506	15.1	16.3	1.08	1.87502	+0.1	+0.1	818	13.6	14.7	4.0	10.336	0.0	0.0
1413	14.7	15.6	0.35	2.17352	−0.2	−0.5	1610	13.4	14.6	11.0	11.645	0.0	0.0
1460	14.4	15.7	0.00	2.913	−0.3	−0.1	1365	13.8	14.8	9.6	12.417	+0.4	+0.2
1422	14.7	15.9	0.6	3.501	+0.2	+0.2	1351	13.4	14.4	4.0	13.08	+0.1	−0.1
842	14.6	16.1	2.61	4.2897	+0.3	+0.6	827	13.4	14.3	11.6	13.47	+0.1	−0.2
1425	14.3	15.3	2.8	4.547	0.0	−0.1	822	13.0	14.6	13.0	16.75	−0.1	+0.3
1742	14.3	15.5	0.95	4.9866	+0.1	+0.2	823	12.2	14.1	2.9	31.94	−0.3	+0.4
1646	14.4	15.4	4.30	5.311	+0.3	+0.1	824	11.4	12.8	4.	65.8	−0.4	−0.2
1649	14.3	15.2	5.05	5.323	+0.2	−0.1	821	11.2	12.1	97.	127.0	−0.1	−0.4
1492	13.8	14.8	0.6	6.2926	−0.2	−0.4							

Periods of 25 Variable Stars in the Small Magellanic Cloud. Leavitt, Henrietta S.; Pickering, Edward C. ; Harvard College Observatory Circular, vol. 173, pp.1-3



"A straight line can readily be drawn..."

Periods of 25 Variable Stars in the Small Magellanic Cloud. Leavitt, Henrietta S.; Pickering, Edward C. ; Harvard College Observatory Circular, vol. 173, pp.1-3

Absolute magnitude is related to period:

$$\bar{M}_v = -2.76 \log\left(\frac{P}{10 \text{ days}}\right) - 4.16 \tag{1}$$

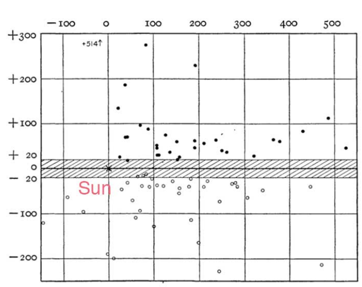
where $\bar{M}_V$ is the absolute magnitude in the V band, measured over one complete period.

With this relation, if we know M and m, then we can get distance, d.

$$M = m - 5 \log\left(\frac{d}{10 \text{ pc}}\right) \tag{2}$$

Obtaining this relationship requires knowing the distance to at least a few Cepheids. Parallax can get us a few.

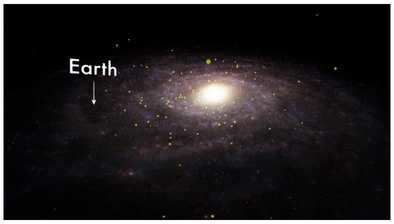
Shapley's Map



Astrophysical Journal, 48, 154-181 (1918)

The realization was that we are not in the center of the globular cluster distribution. The center is 'over there'. Shapley didn't account for dust, so his Milky way was about twice as big.

Globular Clusters - more near the center.



The known Globular Clusters around our Milky Way

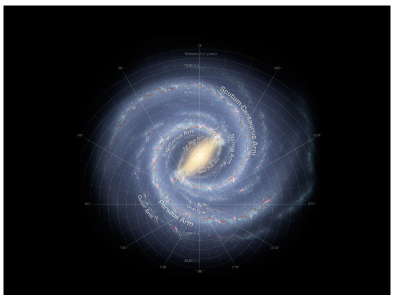
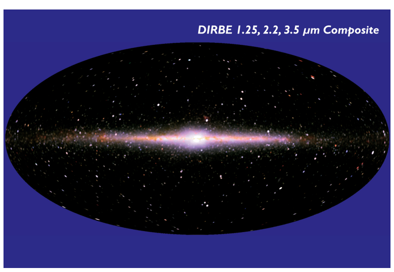


image by: [NASA/Adler/U. Chicago/Wesleyan/JPL-Caltech]

2. Milky Way Structure



NASA, GSFC, COBE

False-color image of the near-infrared sky as seen by the DIRBE. Data at 1.25, 2.2, and 3.5 μm wavelengths are represented respectively as blue, green and red colors. The image is presented in Galactic coordinates, with the plane of the Milky Way Galaxy horizontal across the middle and the Galactic center at the center. The dominant sources of light at these wavelengths are stars within our Galaxy. The image shows both the thin disk and central bulge populations of stars in our spiral galaxy. Our Sun, much closer to us than any other star, lies in the disk (which is why the disk appears edge-on to us) at a distance of about 28,000 light years from the center. The image is redder in directions where there is more dust between the stars absorbing starlight from distant stars. This absorption is so strong at visible wavelengths that the central part of the Milky Way cannot be seen. DIRBE data will facilitate studies of the content, energetics and large scale structure of the Galaxy, as well as the nature and distribution of dust within the Solar System. The data also will be studied for evidence of a faint, uniform infrared background, the residual radiation from the first stars and galaxies formed following the Big Bang.

2.2 Thin & Thick disks

Thin disk:

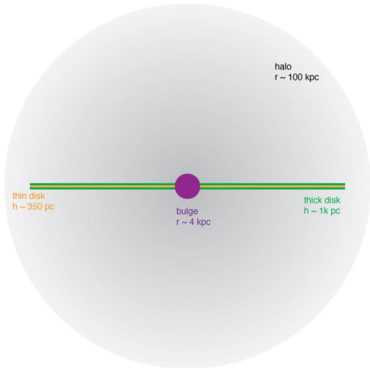
M: 6×10^{10} M⊙

form: $e^{-z/h}$

$$h \sim 0.350 \text{ kpc}$$

[Fe/H]: -0.5 to +0.3

Thick disk:



Schematic showing the main features: two disks and two spherical elements: bulge and halo.

M: 0.2-0.4 × 10^{10} M⊙

form: $e^{-z/h}$

$h \sim 1 \text{ kpc}$

[Fe/H]: -2.2 to -0.5

Metallicity

The ratio of Fe to H in the spectra of stars can be used to quantify a star.

$$[\text{Fe/H}] \equiv \log_{10}\left[\frac{(N_{Fe}/N_H)_{\text{star}}}{(N_{Fe}/N_H)_{\text{sun}}}\right] \tag{3}$$

This is called the **metallicity**. (N_{Fe} and N_H are the number of Iron and Hydrogen atoms atoms.) Stars with the same proportion as the sun, will have values of [Fe/H] = 0. More metal rich stars have higher positive values. Less metal rich stars have negative values.

In general, younger stars will have higher metallicity than older stars.

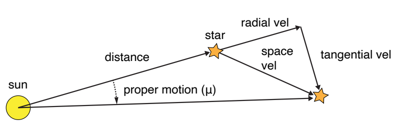
2.3 Milky way stats

- 200 Billion Stars
- Type: Barred spiral galaxy
- Diameter: 100–180 kly (31–55 kpc)
- Thickness of thin stellar disk: 2 kly (0.6 kpc)
- Oldest known star ≥ 13.7 Gyr
- Whole thing is moving at 600 km per second w.r.t the extragalactic frame of reference

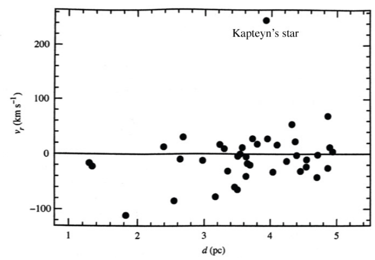
And our place in it:

- Distance to center: 26.4 ± 1.0 kly (8.09 ± 0.31 kpc)
- Sun's galactic rotation period: 240 Myr

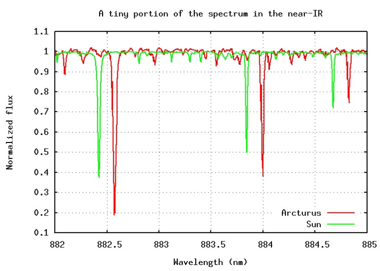
3. Motion of Stars



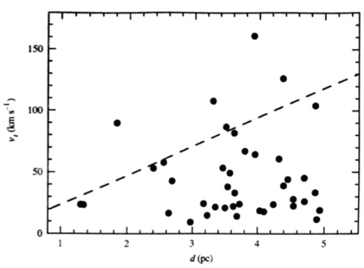
Radial velocity: v_r. Measured using doppler shift of the star's absorption lines.



Ryden & Peterson, Fig 19.10



http://spiff.rit.edu/classes/phys301/lectures/doppler/doppler.html



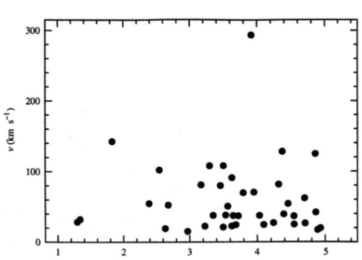
Tangential velocity: v_t. Measured using proper motion, μ and distance d.

$$\mu = \frac{v_t}{d} \tag{4}$$

(in the small angle limit)

Ryden & Peterson, Fig 19.11

http://www.backyardastronomer.com/ccd/Barnard_Mortfield_Cancelli_crop_labels1.gif

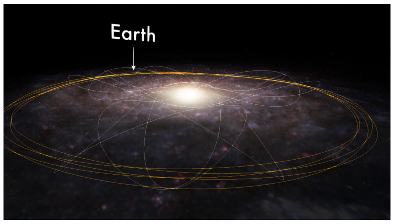


Space motion is the resultant of the radial and tangential velocities:

$$v = \sqrt{v_r^2 + v_t^2} \tag{5}$$

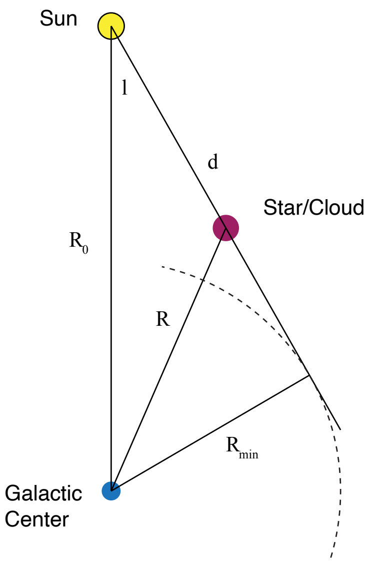
Space motion

Ryden & Peterson, Fig 19.12



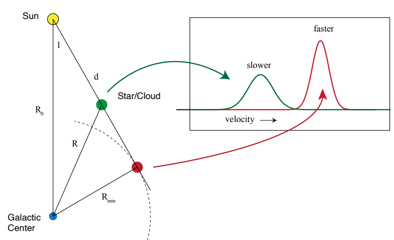
Two stars (sun = orange, Kapteyn's Star = white)

3.4 Measuring the rotation curve



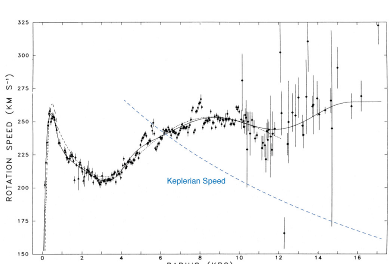
Geometry for measuring the R value for a star/cloud.

We would like to know the distance R. Let's say we can't measure d, but we know R_0 and l.



If we look along the line d, chances are likely there will be several gas clouds. Each with a different radial velocity. This difference is noted in the doppler shift of the light coming from some atomic process. For example, H_2 molecules collide with CO molecules and create a radio emission withe wavelengths of 2.6 and 1.3 mm, as measured in the lab. Deviations from these speeds are indicative of doppler shifts due to relative velocities.

We can measure these different velocities for the different gas clouds along the line of sight. The fastest will likely be closest to R_{min}. (this is a limitation of this measurement.)



Astrophysical Journal, Part 1 (ISSN 0004-637X), vol. 295, Aug. 15, 1985, p. 422-428, 431-436.

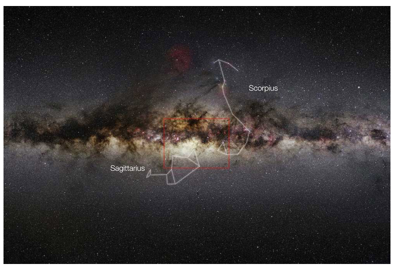
4. Dark Matter

There's more stuff there that we just can't see, so it's called dark...

Astrophycisists and Cosmology folks are still figuring out what it is.

The leading candidate is WIMPS: Weakly Interacting Massive Particle. These are hypothetical particles that don't follow the same rules as the others in the standard model of particles physics.

5. The Galactic Center

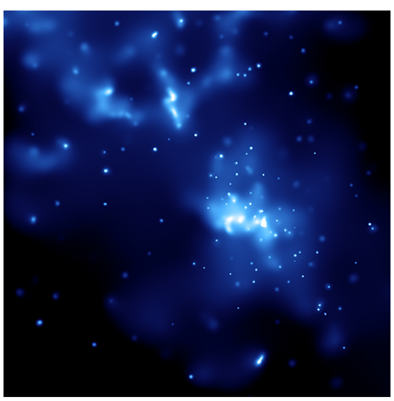


Can't see it too well

5.5 If we were closer...

Let's move the solar system to half a parsec away from the galactic center.

- The nearest star would be ~ 1000 AU away
- The night sky would have 10^6 stars brighter than Sirius
- The total starlight would be ~ 200 times brighter than the moon
- Stars might collide!



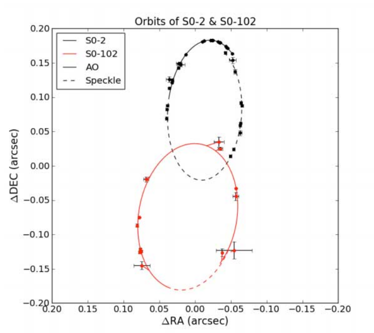
Chandra X-ray Image of Sagittarius A*

NASA/CXC/Caltech/M.Muno et al.

Based on the orbital parameters, we can get the semi-major axis of S2:

$$a_{S2} = \frac{r_p}{1-e} = 1.4 \times 10^{14}\ \mathrm{m} \tag{6}$$

Based on Kepler's Third law, and a period of 15.24 ± 0.36 yr:

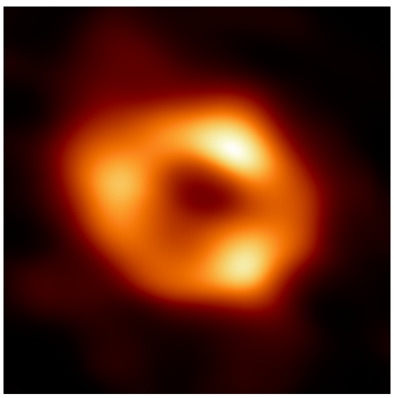


The orbits of S0-2 (black) and S0-102 (red). The data points and the best fits are shown. Both stars orbit clockwise

http://science.sciencemag.org/content/338/6103/84

$$
\begin{aligned}
M &= \frac{4\pi^2 a_{S2}^3}{GP^2} \\
&\simeq 7\times 10^{36}\ \mathrm{kg} \\
&\simeq 3.5\times 10^{6}\, M_{\mathrm{Sun}}
\end{aligned}
\tag{7}
$$

Image of Black Hole at the center of the Milky Way



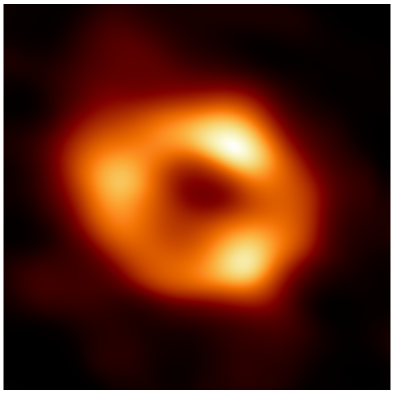
First image of the black hole at the centre of the Milky Way

Credit: EHT Collaboration:

An Introduction to the EHT | Event Horizon Telescope

Light's Odyssey: The Journey from a Black Hole to Earth

The Black hole at the center of the Milky Way, as imaged by the Event Horizon Telescope



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