STRUCTURE AND DYNAMICS OF GALAXIES

1. Distribution of stars in the Milky Way Galaxy

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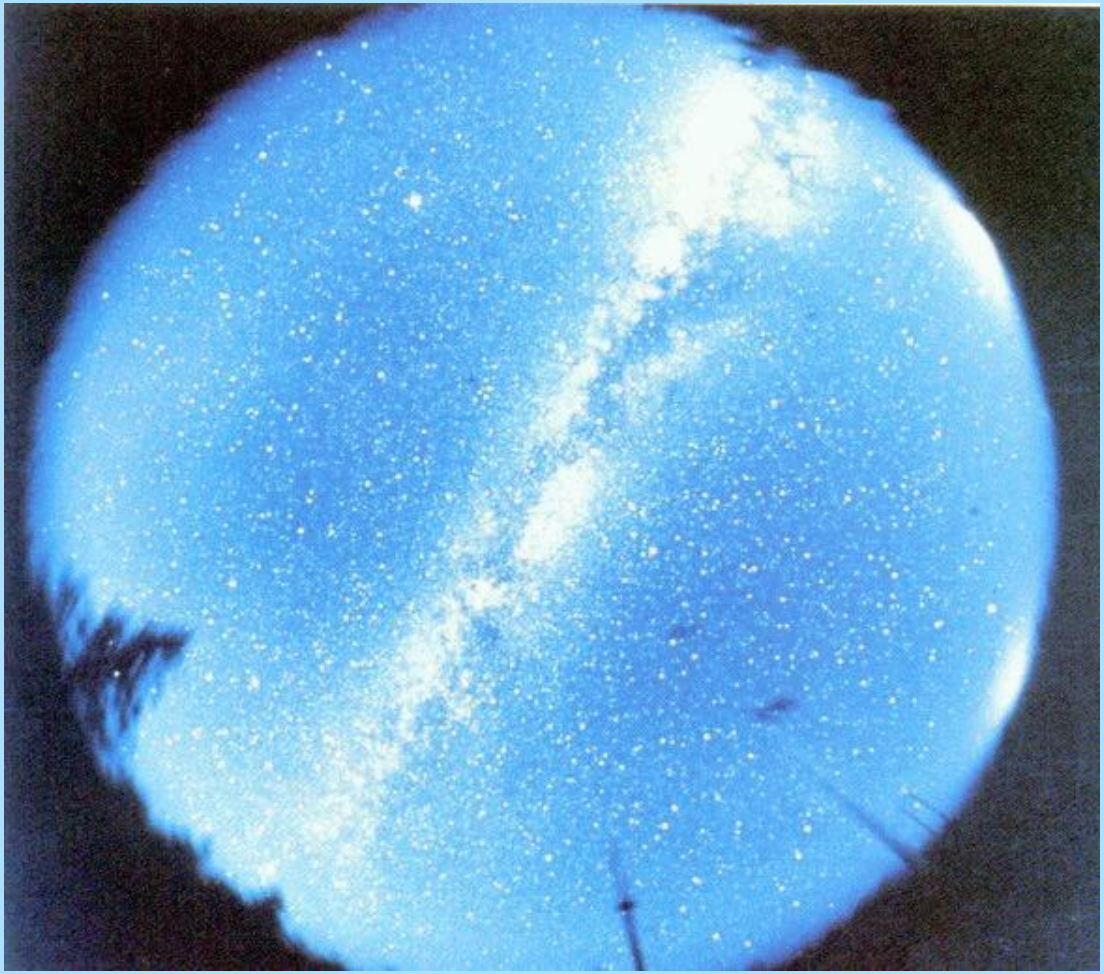
- Shapley and Hubble

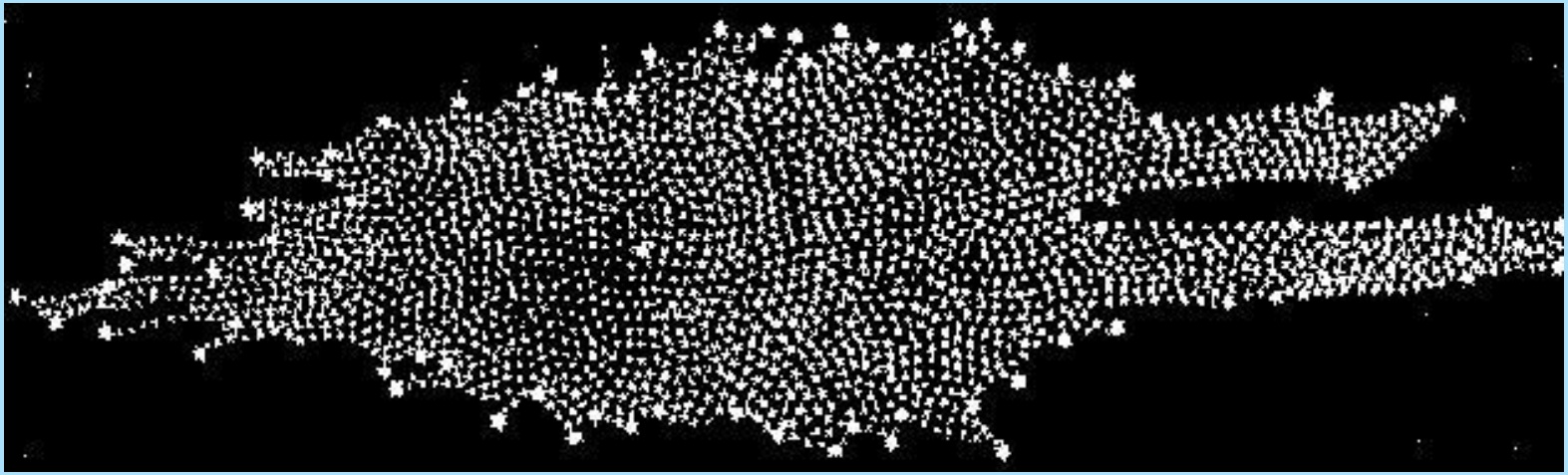
The luminosity distribution in the Galaxy
- Modern views of the Milky Way
- Pioneer 10 photometry

Historical introduction

Herschel and Kapteyn

Our **Galaxy** can be seen on the sky as the Milky Way, a band of faint light.



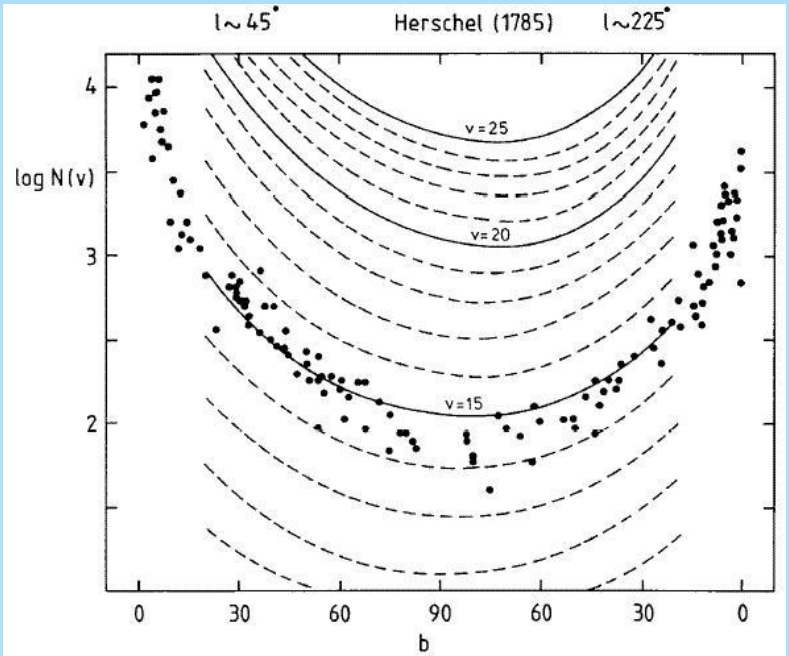


The earliest attempts to study the structure of the Milky Way Galaxy (the Sidereal System; really the whole universe) on a global scale were based on star counts.

William Herschel (1738 – 1822) performed such "star gauges" and assumed that (1) all stars have equal intrinsic luminostities and (2) he could see stars out ot the edges of the system.

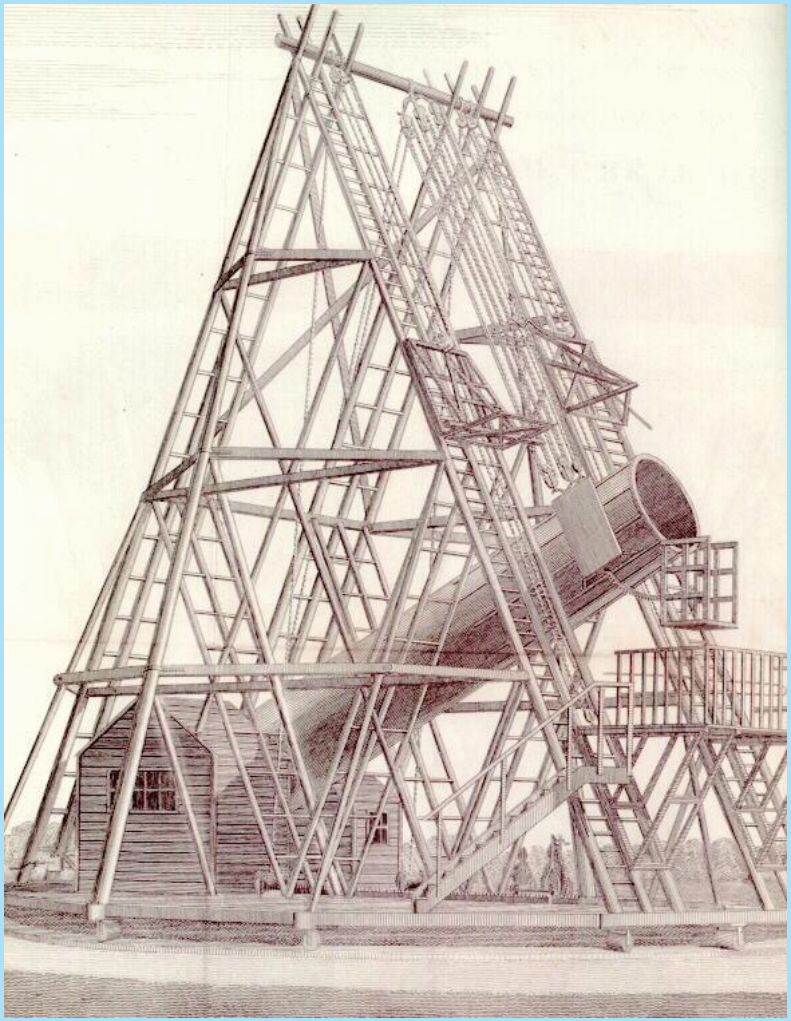
Then the distance to the edge of the system in any direction is proportional to the square-root of the number of stars per square degree.

It can be shown by comparing to current star counts that Herschel counted stars down to about visual magnitude 14.5[1].



⇒ Counted down to ≈ 15 V-mag.

[1] P.C. van der Kruit, A.&A. 157, 244 (1986)



From "Equalisation of starlight"-experiments Herschel estimated his "Space-penetrating powers":

Unaided eye: 12 times Sirius

20-ft telescope: 75 times unaided eye

$\Rightarrow$ 14.8 mag fainter than brightest stars.

Jacobus C. Kapteyn (1851 – 1922) improved upon this by determining locally the luminosity function $\Phi(M)$, that is the frequency distribution of stars as a function of their absolute magnitudes.

The observed distribution of stars $N_{\rm m}$ in a given direction as a function of apparent magnitude m relates to the space density of stars $\Delta(\rho)$ at distance ρ as

$$\frac{dN_{\rm m}}{dm} = 0.9696 \int_0^\infty \rho^2 \Delta(\rho) \Phi(m - 5 \log \rho) d\rho$$

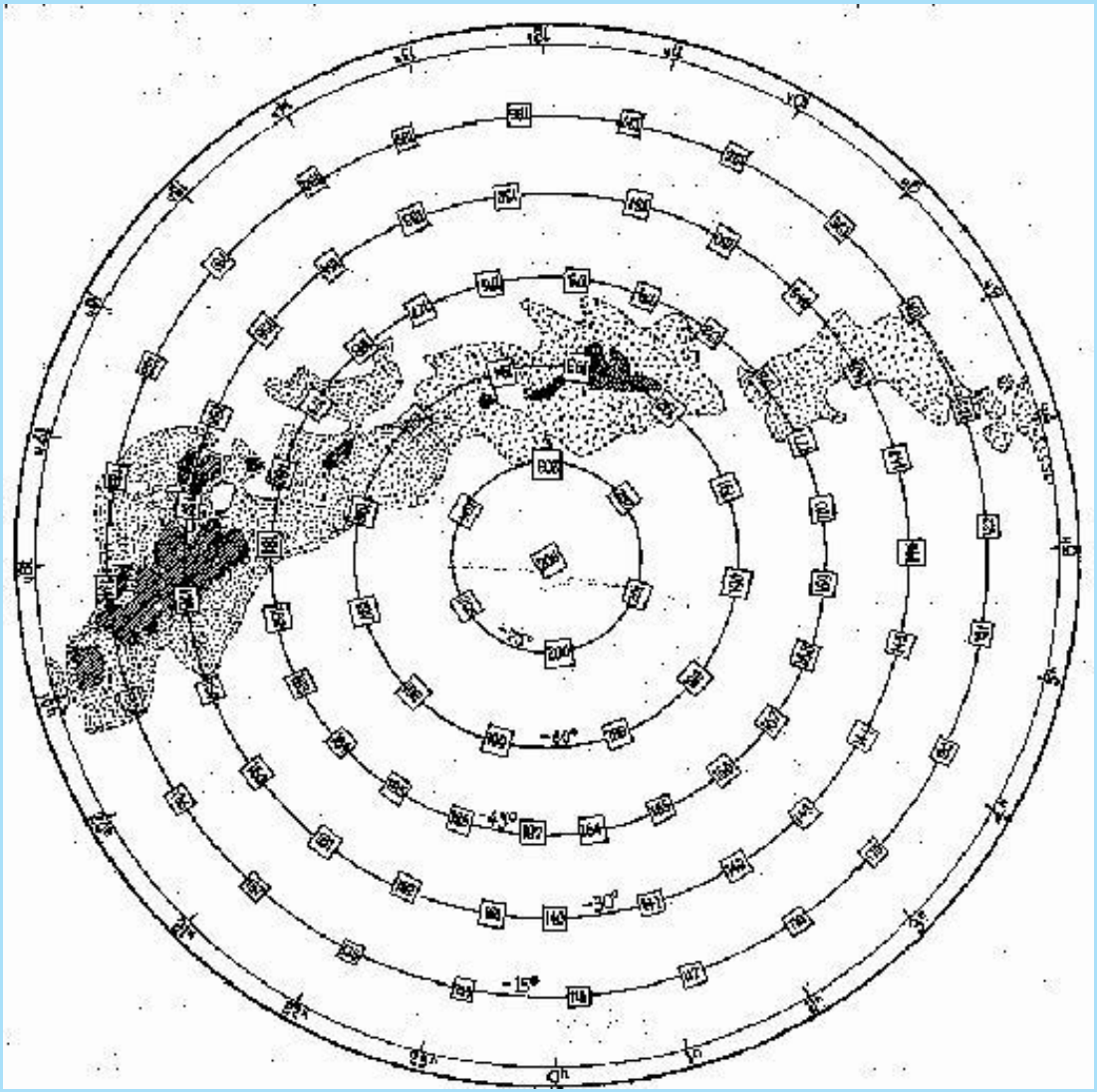
Kapteyn proceeded to investigate (numerical) methods to invert this integral equation in order to solve it.

Kapteyn suspected that interstellar absorption was present and even predicted that it would give rise to reddening[2].

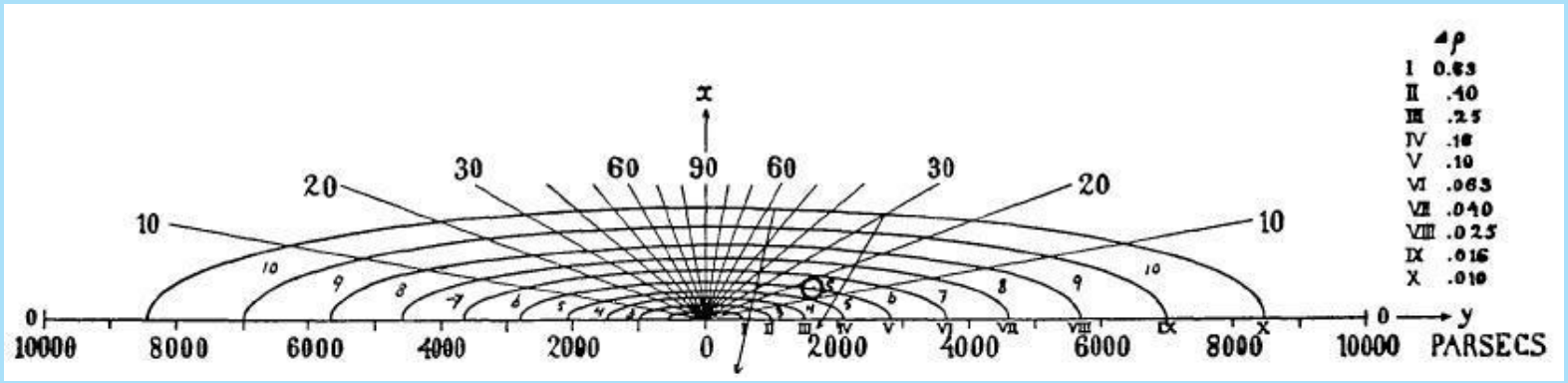
But he found that the reddening was small (0.031 ± 0.006 mag per kpc in modern units) and chose to ignore it.

Under Kapteyn's leadership an international project on Selected Areas over the whole sky to determine star counts (and eventually spectral types and velocities) in a systematic way was started.

[2] J.C. Kapteyn, Ap.J. 29, 46 & 30, 284/398 (1909)



Towards the end of his life he used star counts to construct what became known as the Kapteyn Universe[3]:



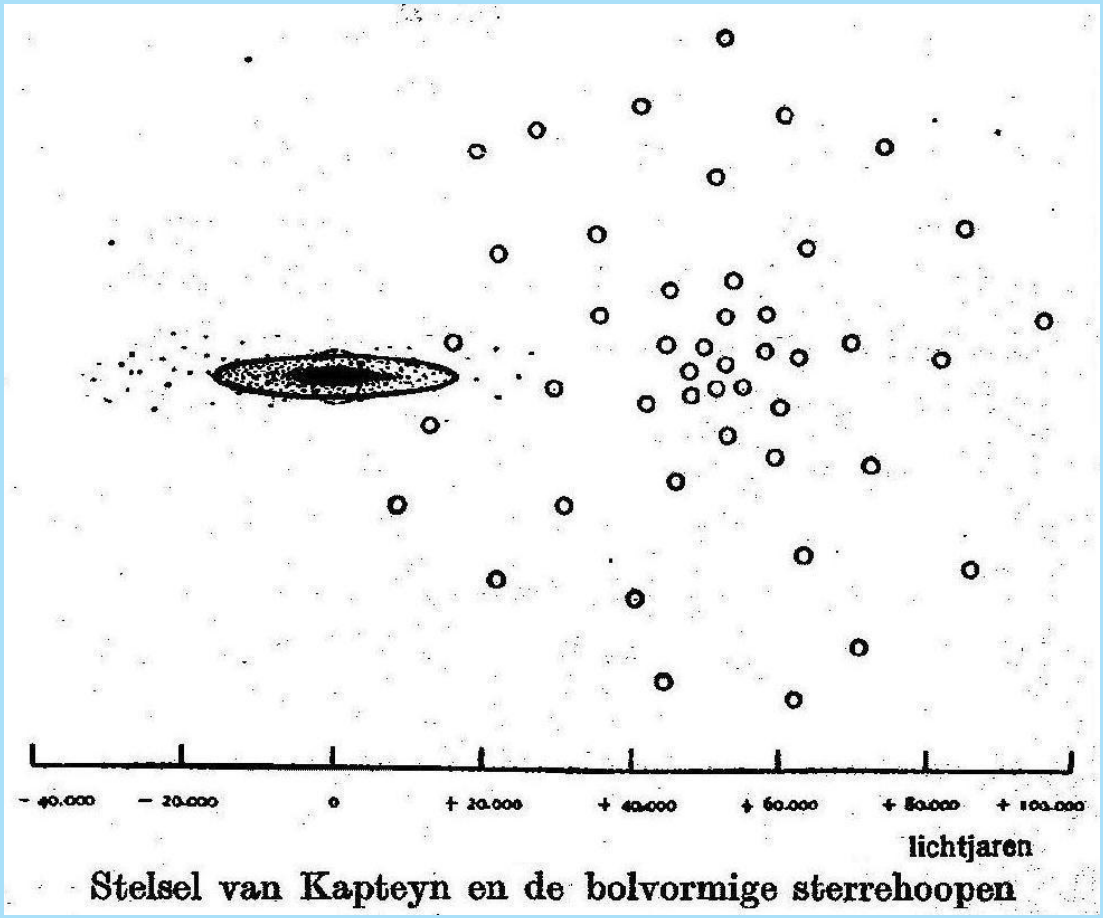
The Sun is near the center.

That was suspicious and later was found to result from the neglect of instersteller absorption.

[3] J.C Kapteyn & P.J. van Rhijn, Ap.J. 52, 23 (1920); J.C. Kapteyn, o.J. 55, 302 (1922)

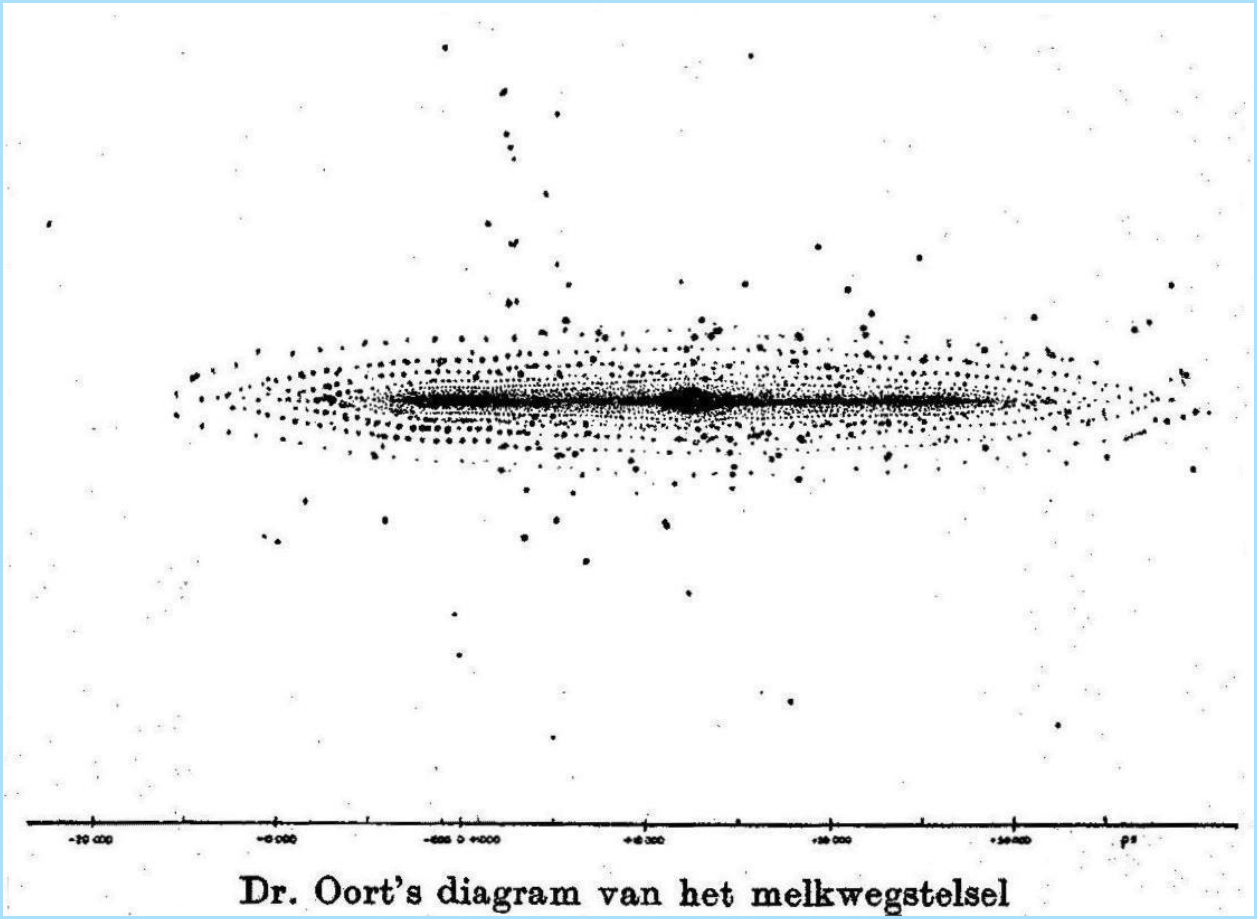
Shapley and Hubble

Indeed the work of Harlow Shapley (1885 – 1972) on the distances of Globular Clusters showed that the Sidereal System really was much larger.

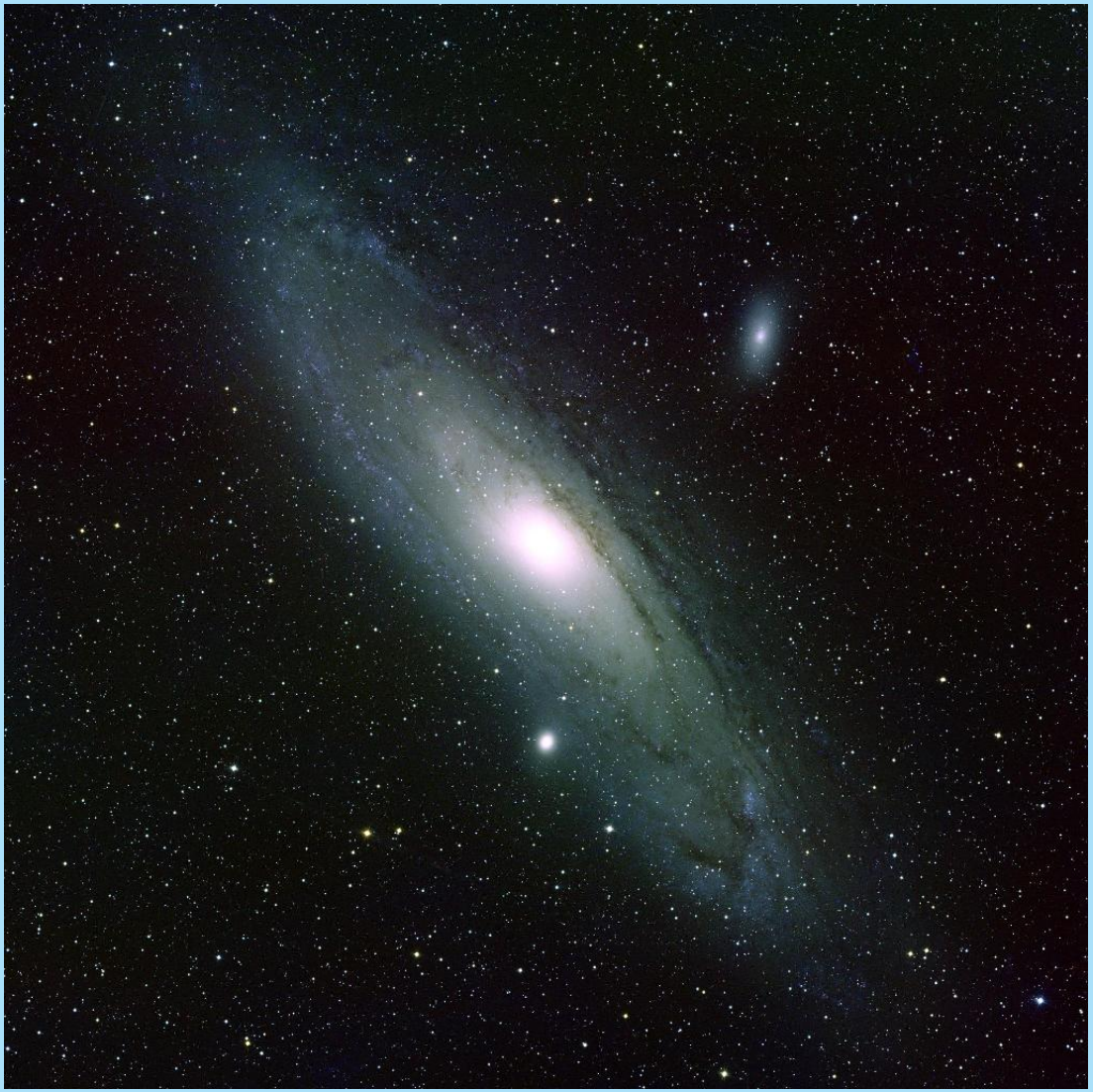


Stelsel van Kapteyn en de bolvormige sterrehoopen

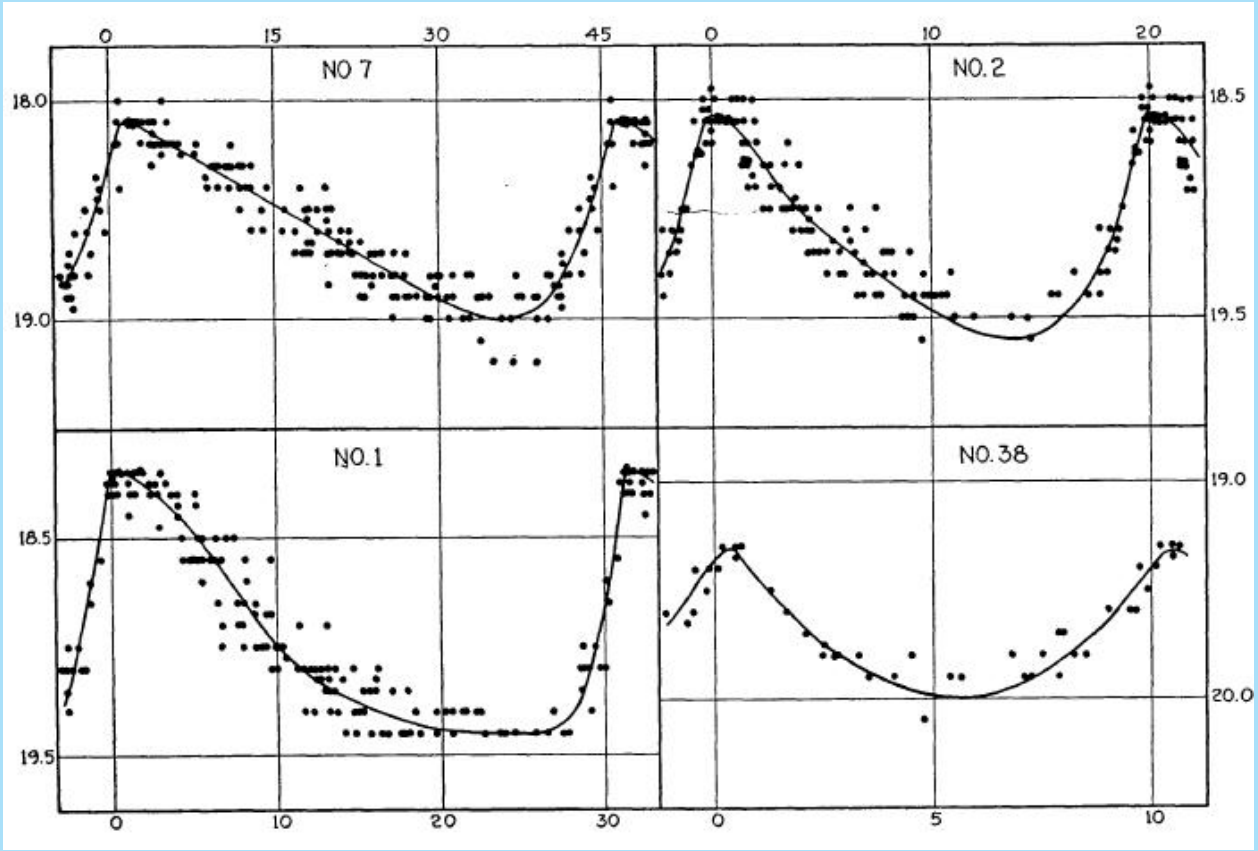
Astronomers like Jan H. Oort (1900 – 1992) found that absorption reconciled the two models.



Dr. Oort's diagram van het melkwegstelsel



An important step was made by Edwin Hubble (1889–1953), who showed, using Cepheids, that the Andromeda Nebula is an 'Island Universe', a separate stellar system outside the Galaxy.



Hubble[4] found a distance of 275 kpc. The current value is 780 kpc.

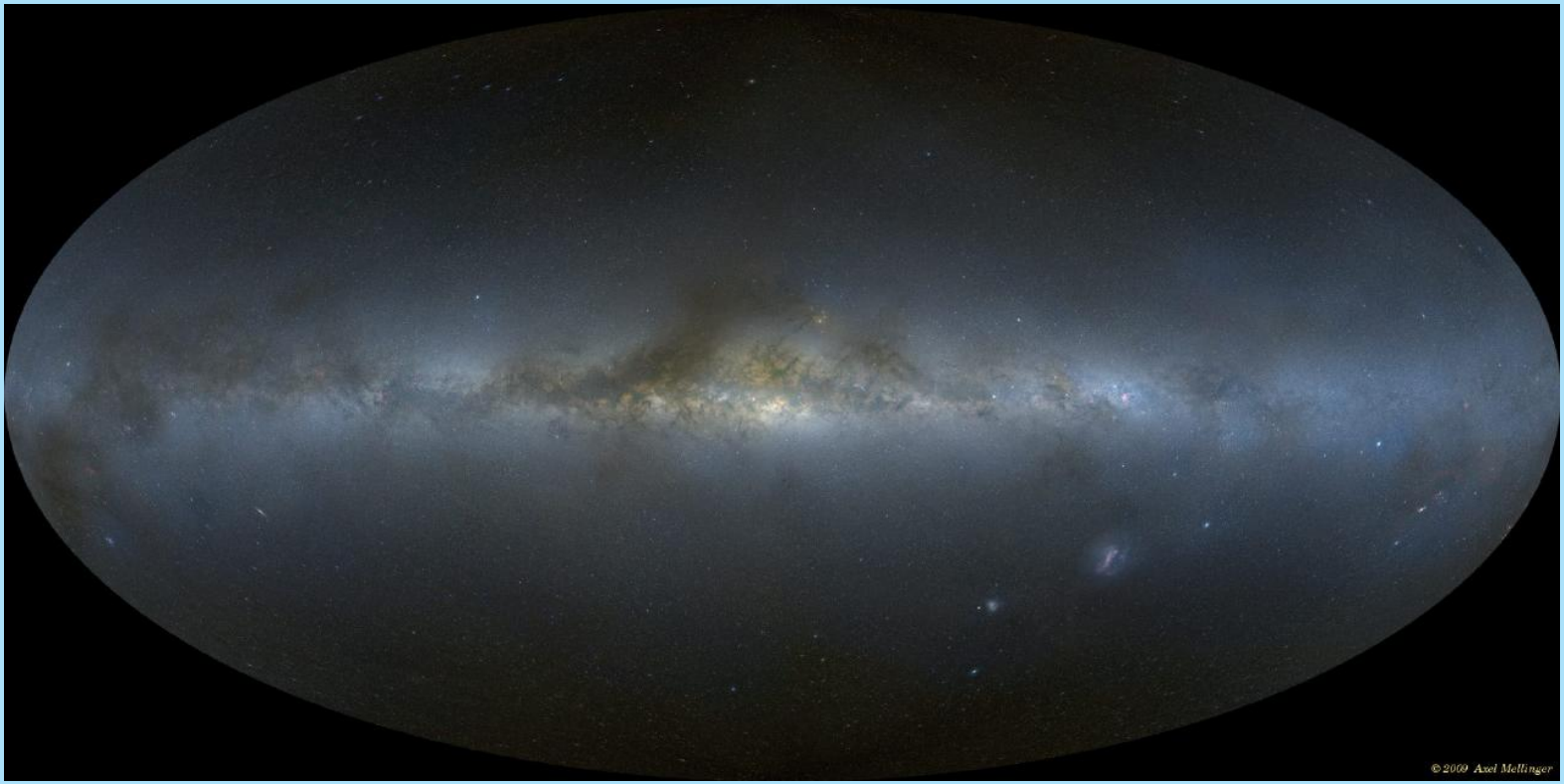
[4] E. Hubble, Ap.J. 69, 103 (1929)

So the Galaxy is one of very many, seen edge-on.

Luminosity distribution in the Galaxy

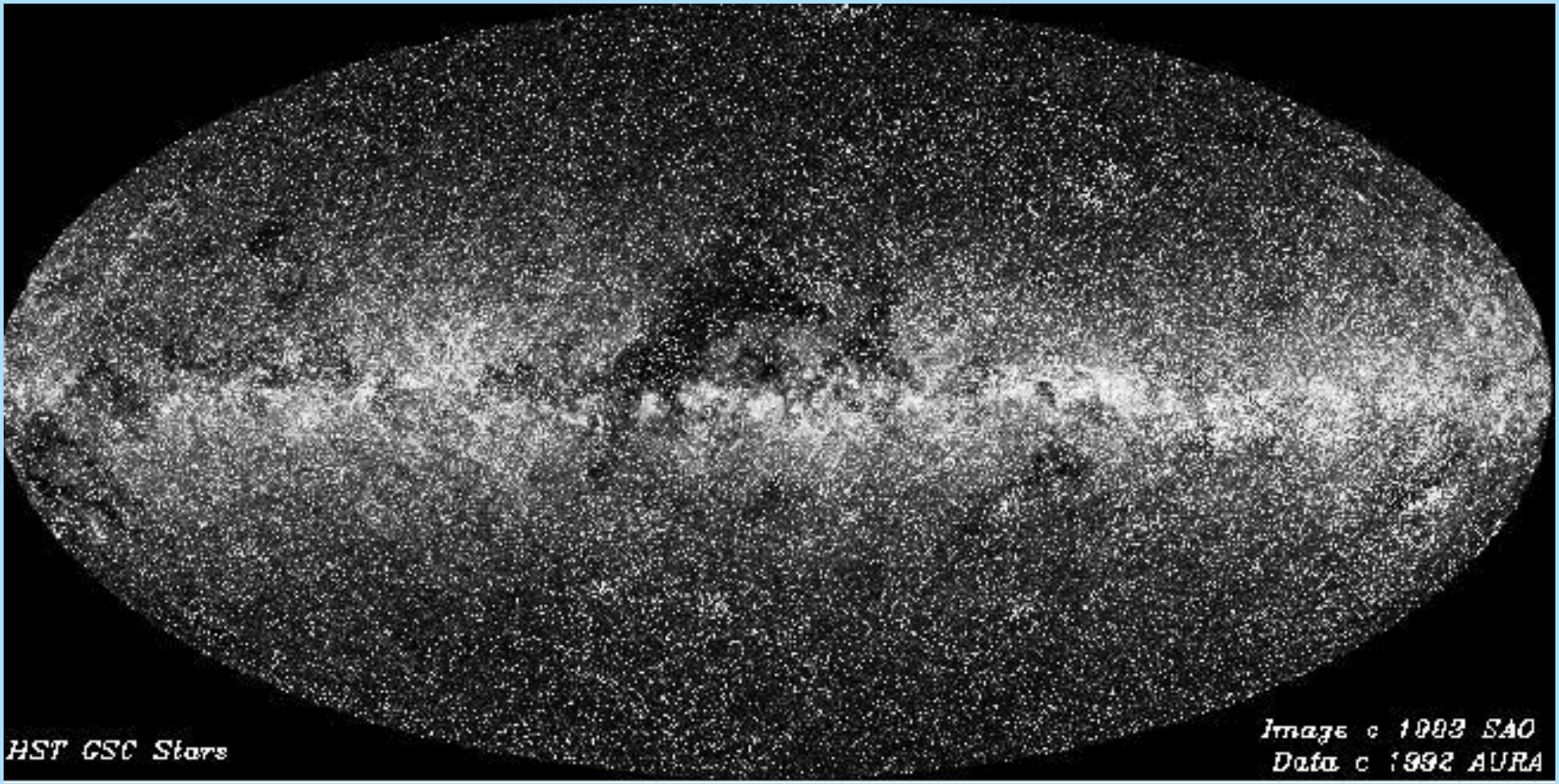
Modern views of the Milky Way

Here is a composite picture[5] covering the full sky at $36''\text{pixel}^{-1}$.

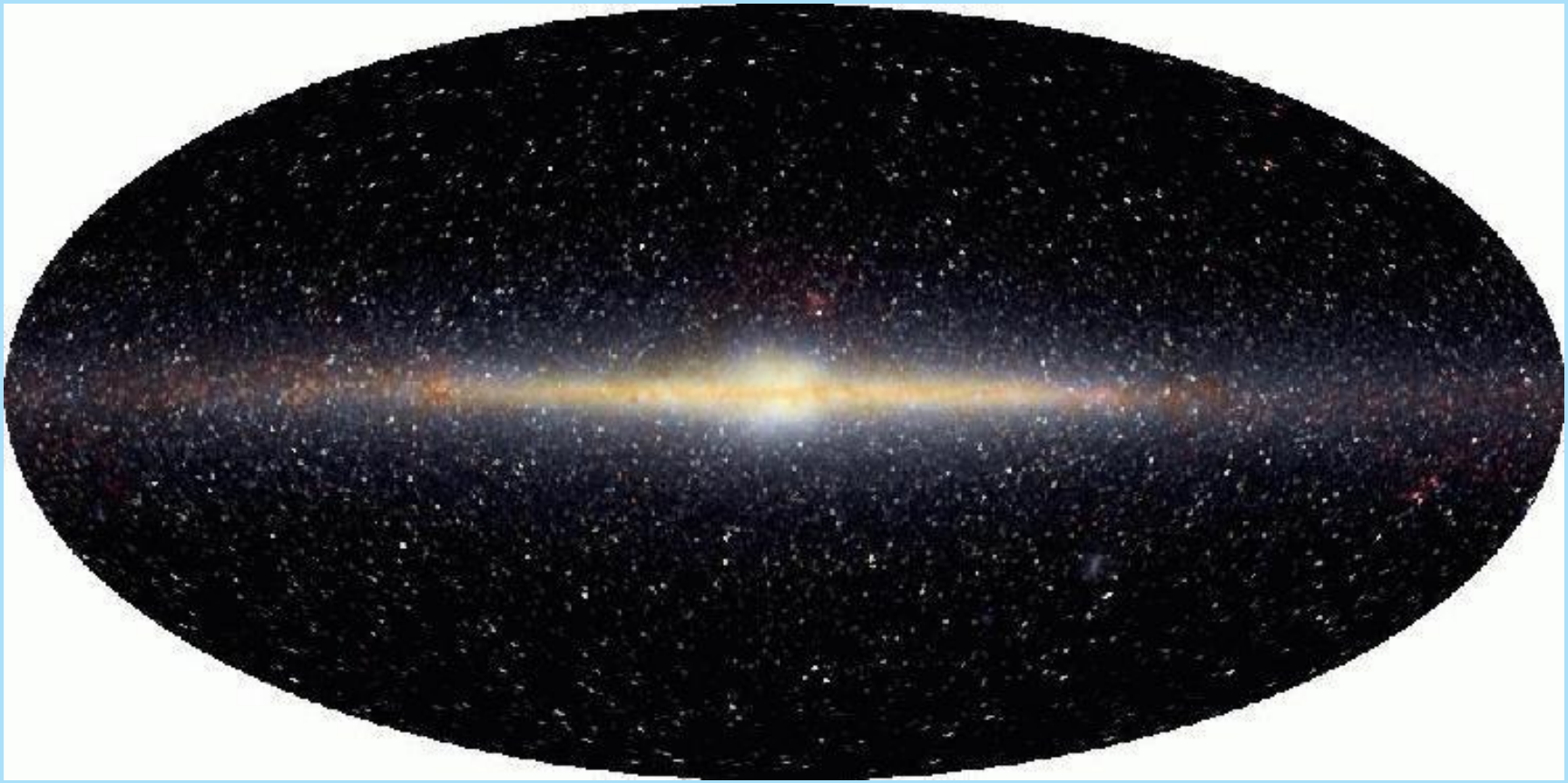


[5] A. Mellinger, P.A.S.P. 121, 1180 (2009); also Astronomy Picture of the Day for 2009 November 25: antwrp.gsfc.nasa.gov/apod/ap091125.html

Here is a plot of all stars in the Guide Star Catalogue of the Hubble Space Telescope down to about magnitude 16.



The Cosmic Background Explorer (COBE) satellite did see the Milky Way in the near-infrared as follows:



Direct measurements of the surface brightness of the Galaxy are difficult due to other contributions:

The sky contributions in the visual with some comparisons are as follows:

	$S_{10}(V)_{\mathrm{G2V,V}}$	V-mag arcsec^{-2}
Disk of sun	$\sim 10^{17}$	$\sim$ -15
Daylight	$\sim 3 \times 10^{11}$	$\sim$ -1
Full moon	$\sim 10^{11}$	0.5
Airglow	50	23.5
Zodiacal light (ecliptic)	180	22.0
Zodiacal light (pole)	80	23.0
Bright stars ($m_{\mathrm{V}} < 6$)	20	24.5
Integrated starlight (plane)	300	21.5
Integrated starlight (pole)	30	24.0
Diffuse Galactic light (plane)	50	23.5
Diffuse Galactic light (pole)	2	27.0
Cosmic background	~ 1	$\sim$ 28.0

The property $S_{10}(V)_{\mathrm{G2V},\lambda}$ denotes the equivalent number of G2V-stars in the λ-band per square degree that have magnitude 10 in the V-band.

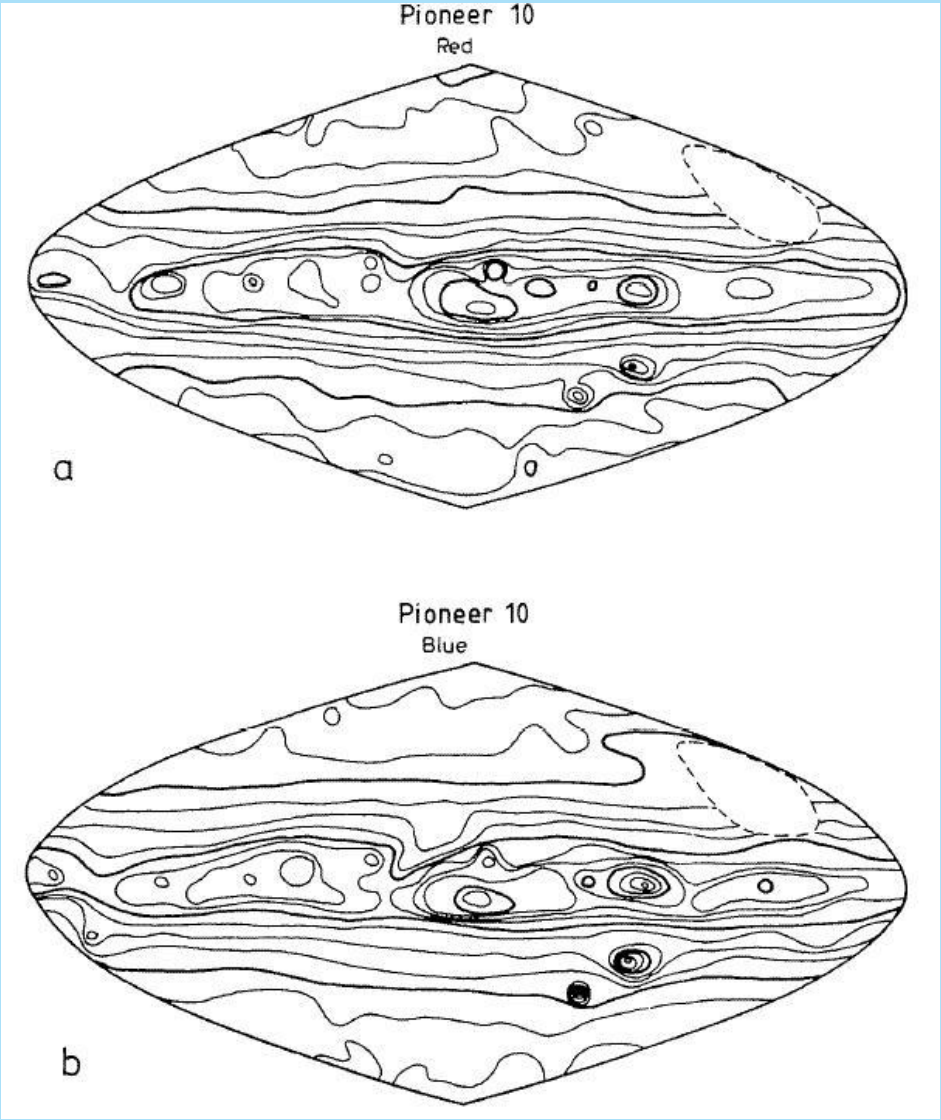
Pioneer 10 photometry

The zodiacal light is the biggest problem when studying the background distribution of starlight.

The problem is the reverse for people interested in studying zodiacal light.

The satellite Pioneer 10 was launched in March 1972 and reached Jupiter in December 1973.

During its trip in the asteroid belt and beyond it swept the skies and made a map of the background starlight free of zodiacal light.


Pioneer 10
Red
a
Pioneer 10
Blue
b