Star counts. Number counts of stars as a function of apparent magnitude can be used to infer the shape and extent of the Galaxy. Initially consider a toy model where (1) the star number density per cubic parsec, D, is constant, (2) the star system is infinite in extent, (3) there is no interstellar absorption and (4) all stars have the same absolute magnitude, M.

In a volume defined by a solid angle, ω, out to a limiting distance, d, the total number of stars is given by

$$N(d) \;=\; volume \times density \;=\; \frac{1}{3}\,\omega\, d^3\, D$$

For an apparent magnitude limit, m, the limiting distance, d, is given by $m - M \;=\; 5\,\log d - 5$. So if all stars are like the Sun, i.e. $M = 4.8$, for $m = 9$, then the limiting distance d would be 69 pc and similarly for $m = 10$, $d = 110$ pc, etc. Hence we can transform the $N(d)$ equation to one in terms of m, i.e.

$$N(m) \;=\; k\,10^{0.6\,m} \quad \text{i.e.} \quad N(m) \;\propto\; 10^{0.6\,m}$$

where $N(m)$ is the number of stars observed down to the limiting magnitude, m, and k is a constant that depends on D, ω and M. Hence for this toy model the number of stars brighter than m should vary simply as $10^{0.6\,m}$. Thus for each fainter magnitude probed, there should be about four times as many stars seen.

The assumption of all stars having the same absolute magnitude, M, is not necessary as various groups of stars with different M will all have a similar relationship, i.e. $N_1(m) \;=\; k_1\,10^{0.6\,m}$, where k_1 depends on D_1 and M_1. By adding the various groups of stars we obtain $N_{total}(m) \;=\; (k_1 + k_2 + \cdots)\,10^{0.6\,m}$, i.e. $N(m) \;\propto\; 10^{0.6\,m}$.

William Herschel in the 1790s visually made star counts along about 700 lines of sight and undertook this type of analysis. He found that the number counts of stars in all directions grows much more slowly than that predicted. He interpreted the star counts data as evidence of a finite size for our star system. He concluded that the Sun lies near the centre of a flattened, roughly elliptical system that extends about five times further in the galactic plane direction as compared to the galactic poles.

The Kapteyn Universe. From around 1900, the new technology of photography was used to investigate the structure of our star system. A major initiative was instigated by Jacobus Kapteyn who conceived a plan to solve the "problem of the sidereal world". He organised an international project to study 206 Selected Areas, each $75' \times 75'$; it was totally impractical to survey the whole sky. He enlisted the help of most observatories to take the necessary plates, to make star counts, spectroscopic classification, proper motion and radial velocity measurements. From the analysis of the proper motions, Kapteyn and van Rhijn were able to estimate average distances of stars at the various magnitude levels. Kapteyn was fully aware of the potential problem of interstellar absorption and spent considerable effort over many years searching carefully for absorption effects, but was unable to find any convincing evidence. Hence he assumed that interstellar space was essentially transparent; this opinion was shared by virtually all astronomers at the time.

The Selected Area project confirmed Herschel's picture; our star system is a flattened elliptical shape with the star density decreasing in all directions from the centre. The Sun is located 650 pc from the centre in the galactic plane direction. The star density drops to half its central value at a distance of about 800 pc in the galactic plane and 150 pc in the direction of the galactic poles. The total size was estimated as approximately 5000×1000 pc. This picture is commonly referred to as the Kapteyn Universe. As a model, the Kapteyn Universe is fundamentally flawed because the assumption of no interstellar absorption is wrong. In fact, there is roughly 0.8 mag kpc^{-1} of interstellar absorption in the galactic plane direction.