hypothesis about the origin of high velocity clouds and formation of galaxies.

1. Oort, J. H., *Bull. Astron. Inst. Neth.*, 1938, **8**, 233–264.
2. Oort, J. H. and van de Hulst, H. C., *Bull. Astron. Inst. Neth.*, 1946, **10**, 187–204.
3. Oort, J. H., *Mon. Not. R. Astron. Soc.*, 1946, **106**, 159–179.
4. Merrill, P. W. *et al.*, *Astrophys. J.*, 1937, **86**, 274.
5. Wilson, O. C. and Merrill, P. W., *Astrophys. J.*, 1937, **86**, 44.
6. Adams, W. S., *Astrophys. J.*, 1943, **97**, 105.
7. Adams, W. S., *Astrophys. J.*, 1949, **109**, 354.
8. Blaauw, A., *Bull Astron. Inst. Neth.*, 1952, **11**, 459.
9. Strömgren, B., *Astrophys. J.*, 1939, **89**, 529.
10. Spitzer, L., *Astrophys. J.*, 1948, **107**, 6.
11. Spitzer, L. and Savedoff, M. P., *Astrophys. J.*, 1950, **111**, 593.
12. Oort, J. H., *Bull. Astron. Inst. Neth*, 1954, **12**, 177.
13. Oort, J. H. and Spitzer, L., *Astrophys. J.*, 1955, **121**, 6.
14. Muller, C. A., Oort, J. H. and Raimond, E., *C. R. Acad. Sci. Paris*, 1963, **257**, 1661.
15. Oort, J. H., *Astron. Astrophys.*, 1970, **7**, 381.

# Oort's 1965 review of stellar dynamics

**Rajaram Nityananda**

Raman Research Institute, Bangalore 560 080, India

ORIGINAL and productive scientists often fight shy of writing review articles. One therefore sees an interesting and different facet of Oort's scientific personality revealed in the review article on stellar dynamics which he contributed to the famous *Stars and Stellar Systems* series initiated by Kuiper and Middlehurst and published by the University of Chicago Press. Volume V of this series was edited by Blaauw and Schmidt and devoted to Galactic structure. Given that the subject of stellar dynamics had already been covered in treatises by the likes of Eddington, Jeans, and Chandrasekhar, it is natural to ask what was Oort's special touch in these fortysix pages (plus an appendix) which have rightly been required reading ever since for entrants to the subject. The first characteristic is that material not directly connected with observations of our Galaxy or their interpretation is uncompromisingly omitted. Equally ruthlessly, all mathematical derivations are left out, giving reference to where they may be found. In lesser hands, this approach would have produced a fragmented and unreadable compendium. It does not, in this article, for two reasons. For one thing, physical principles and interpretation of the equations are given a full and clear discussion. Secondly, the ordering of the material is very logical—random motions, vertical motions, circular motion, small and then large deviations from circular motion. The primary requisites of a review article, readability and comprehensibility, are present in full measure.

Coming to individual sections, the one on motion perpendicular to the galactic plane represents the author's own special interests and contributions. The basic method, due to Oort himself, of determining the mass density from the vertical distribution and velocities of a group of stars (K. giants) is straightforward at least with hindsight. What is special is the insistence on precise numbers and the careful comparison of the dynamical estimate with known forms of matter —stellar and gaseous. Even when direct observations were not available at that time, as in the case of molecular hydrogen, ingenious astrophysical arguments are advanced to constrain the density. The final conclusion, that about half the mass density in the midplane of the Galaxy is in some unknown form, has not really been disproved by later work, and continues to intrigue astronomers even at present when the empirical data and computational power have multiplied manifold. This is one factor of two which is vital to astrophysics! One may remark in passing that in discussing the physical basis of the study of vertical motions, Oort relies more on the properties of individual orbits rather than on constants of motion (i.e., Jeans theorem). This passage has the basic idea of Schwarzschild's computational approach to galaxy dynamics which proved so useful more than a decade later.

The section on small deviations from circular motion is of course based on Oort's early work on galactic differential rotation, a topic covered in more detail in Chanda Jog's article in this issue. Again, Oort's attention goes unerringly to the empirical fact which may be telling us something new—the so-called 'vertex deviation'. The principal axes of the distribution of random velocities deviate from what the simplest model would predict, viz. parallel and perpendicular to the direction of the galactic centre. Non-circular motions due to spiral structure are brought in as a possible cause. Another interesting observed effect which is discussed is 'asymmetric drift'. This asymmetry between the numbers of stars moving faster and slower than the sun translates into information on their radial distribution in the galaxy.

Large deviations from circular motion mean that we can observe, near the sun, starry messengers from the outer and inner galaxy. These motions must also reflect some properties of the early collapse phase of the galaxy—a theme which of course underlies the celebrated work of Eggen, Lynden-Bell, and Sandage and its later successors.

Having mentioned Oort's avoidance of theory for its own sake, it is remarkable to note that the seeds of the currently very fashionable field of Hamiltonian chaos were put down in early studies of large amplitude motions perpendicular to the galactic plane. The appendix to Oort's article by his colleague Ollongren represents one of the earliest of such studies, lesser known (and possibly less comprehensive) than the work of Henon and Heiles somewhat later which is rightly viewed as a landmark. Oort's motivation came, of course, from high velocity stars. It is again worth noting that Oort was ready to harness computer power to reach astronomical goals at a time when many others suffered from ideological inhibitions which have not entirely disappeared even today.

It is worth quoting from the remarks with which the article concludes '... requirements that should ultimately be satisfied by a model of the galaxy is that not only should there be consistency between velocity and density distributions for each of the populations but that (they should *imply a*) *field of force fitting the* rotation curve'. The spirit of doing justice both to dynamical principles and to all the observations when one builds models could scarcely be expressed more concisely or forcefully.

It would be a daunting task indeed to review stellar dynamics about a decade later in the same series of volumes. Yet advances in observation, especially of external galaxies, and in theory and computation made this necessary and the result was Freeman's article 'Stellar dynamics and the structure of galaxies' in Volume IX, edited by Sandage, Sandage and Kristian. This excellent successor to Oort's article is worth mentioning, especially valuable to students and others entering this field of astronomy. More than a decade later, the subject finally found its *magnum opus* with the publication of 'Galactic dynamics' by Binney and Tremaine (Princeton 1987). Much water has indeed flowed under the bridge since 1964, but it is remarkable how much can still be learnt from Oort's fortysix pages.

# Oort and the comets

**H. C. Bhatt**
Indian Institute of Astrophysics, Bangalore 560 034, India

To an unaided eye the most spectacular sights in the sky are undoubtedly the 'comets'. For their sudden appearance, peculiar shapes (a compact head surrounded by a coma and extended tail pointing away from the Sun), large dimensions (sometimes spanning almost the entire sky) and swift movement across the sky, comets must have been viewed with awe and fear by our ancestors. The physical nature of comets and their origin had not been clearly understood even by the first half of the twentieth century. Not until 1950, when Oort[1] published his theory of a huge reservoir of comets surrounding the solar system, in which he showed that there must exist a spherical cloud of about 200 billion comets reaching out to about 150,000 AU from the Sun, where 1 AU (the Astronomical Unit= $1.5\times10^8$ km) is the mean distance of the earth from the Sun. This cloud of comets is now popularly called the 'Oort Cloud' and is schematically shown in Figure 1.

Oort's theory is based on the observed frequency distribution of the original semimajor axes ($a$) of the orbits of the long-period ($\gtrsim$ 200 yr) comets determined from cometary positions before they enter the perturbing influence of the planets. The distribution is sharply peaked toward very small positive values of the inverse semimajor axes $1/a$. The peak is at $1/a \simeq 3.2\times10^{-5}$ AU$^{-1}$ with a width $\Delta(1/a)$ of only $\simeq 2\times10^{-5}$ AU$^{-1}$. Thus the aphelion distances ($Q=a(1+e)\simeq 2a$, where $e\simeq 1$ is the eccentricity of the orbit) of the comets are concentrated in the range $\sim 2\times10^4$ to $\sim 10^5$ AU. Although the long-period comets come from great distances, they cannot be visitors from interstellar space (as had been generally believed earlier), because no hyperbolic orbits ($1/a<0$) are known. Oort therefore argued that there must exist a cloud of comets bound to the solar system in a shell between ~20,000 and ~100,000 AU from the Sun. The narrow peak in the frequency distribution of $1/a$ is however surprising. In 1948 Van Woerkom[2], then a student of Oort, had shown that a single passage of a comet through the inner planetary system (where a