# Galactic Oscillations

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B. F. Smith (NASA/Ames) and R. H. Miller (U.Chicago)

**Summary**: Several oscillations have been identified in spherical galaxy models. These are normal mode oscillations in a stable galaxy. Each has its own distinct period and spatial form, and each rings without detectable damping through a Hubble time. The most important are: (1) a simple radial pulsation (fundamental mode), in which all parts of the galaxy move inward or outward with the same phase; (2) a second spherically symmetrical radial mode with one node, so material inside the node moves outward when material outside moves inward.

Numerical experiments suggest that normal mode oscillations may be present in nearly all galaxies at a considerably higher amplitude than has previously been thought. Amplitudes (variations in total KE, for example) typically run a few percent of equilibrium values, and periods are around 50 – 300 Myrs in typical galaxies. These time scales are long enough that gas trapped near the center could cool during an oscillation cycle, allowing star formation activity. The second mode oscillations could cause bursts of star formation.

**Disturbances**: Fairly large systematic motions near the centers of galaxies reported earlier (Miller and Smith 1988, 1992) can produce effects often seen in the observations, such as the 50 km/sec velocity difference between galaxy and nucleus recently reported in $M87$ (Jarvis and Peletier 1991). Bajaja *et al.* (1984) reported that "the center of the HI distribution lies about 300 pc westward of the coincident optical and radio continuum nuclei" in the Sombrero galaxy, NGC 4594. They commented that this asymmetry is smaller than that which they usually find in spiral galaxies. The optical nucleus is 170 pc away from the rotational center in NGC 2903 (Simkin 1975). Other examples are given in Miller and Smith (1992). These center motions are local disturbances as the nucleus orbits around the galaxy's mass centroid. They naturally raise the question whether global motions that affect the galaxy as a whole are also present and whether these might be found experimentally. Galactic oscillations were found as we pursued that question.

Fundamental mode oscillations show up as continuing oscillations in the total kinetic energy. Peak-to-peak variations typically ran 2 – 5% of the mean (time averaged) total kinetic energy, with periods around 300 Million years. They continued with large amplitude (22% peak-to-peak fractional variations in the kinetic energy) throughout 6 billion years without detectable damping in one experiment. A 5% decrease in amplitude could have been detected easily, but none was seen. This sets a lower limit to the damping time at around 100 billion years. This experiment allowed us to study oscillations with high signal-to-noise. Even so, study of these disturbances requires large numbers of particles and a stable experiment that extends over many crossing times because of severe signal-to-noise problems. The 22% peak-to-peak variation in kinetic energy corresponds to 8% RMS variation, about 80 times expected random fluctuations allowed by the virial theorem for the 400,000 particles of this experiment, and it is several thousand times the energy expected in a normal mode for a system that has undergone violent relaxation to a steady state.

The second radial mode is spherically symmetrical with a radial node, and its period ranges from $100 - 150$ million years (it is *not* commensurate with the fundamental mode). It shows up clearly in plots of Lagrangian radii, and it is strongest in the inner parts of the galaxy. The radial node is about 6 kpc from the center, but we have seen it at radii as small as 2.5 kpc in other experiments. The central density varies by a factor three in this experiment, and the variation is due to the second radial mode. This mode was identified as an instability by Hénon (1973), but here it acts like a normal mode in a stable galaxy.

An $\ell = 2$, $m = 2$ mode was identified in plots showing the time dependence of elements of the virial tensors. An $\ell = 1$ mode has also been seen. Its amplitude is much smaller than either of the spherically symmetrical modes. Its period ranges from $140 - 190$ million years in various experiments, and it is not commensurate with either of the other modes. Other disturbances that act like global modes may be present in these galaxy models as well; the ones described here are those for which we have been able to design experimental probes. Searches would be facilitated by good predictions from analytic theory about frequencies and spatial forms of the disturbances, but these are not available.

**Discussion**: Several results emerge from this series of experiments.

1. Galaxy models support long-lived oscillations, which are normal modes of a stable system near equilibrium. They are not instabilities.

2. Four different patterns (or modes) have been identified, but others are likely to be present as well.

3. Periods of the oscillations are on the order of the galaxy's dynamical time scale (a crossing time, about 100 Million years).

## References


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