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Lopsided spiral galaxies

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ABSTRACT

The light distribution in the disks of many galaxies is 'lopsided' with a spatial extent much larger along one half of a galaxy than the other, as seen in M101. Recent observations show that the stellar disk in a typical spiral galaxy is significantly lopsided, indicating asymmetry in the disk mass distribution. The mean amplitude of lopsidedness is 0.1, measured as the Fourier amplitude of the $m = 1$ component normalized to the average value. Thus, lopsidedness is common, and hence it is important to understand its origin and dynamics. This is a new and exciting area in galactic structure and dynamics, in contrast to the topic of bars and two-armed spirals ($m = 2$) which has been extensively studied in the literature. Lopsidedness is ubiquitous and occurs in a variety of settings and tracers. It is seen in both stars and gas, in the outer disk and the central region, in the field and the group galaxies. The lopsided amplitude is higher by a factor of two for galaxies in a group.

The lopsidedness has a strong impact on the dynamics of the galaxy, its evolution, the star formation in it, and on the growth of the central black hole and on the nuclear fuelling. We present here an overview of the observations that measure the lopsided distribution, as well as the theoretical progress made so far to understand its origin and properties. The physical mechanisms studied for its origin include tidal encounters, gas accretion and a global gravitational instability. The related open, challenging problems in this emerging area are discussed.

Contents

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1. Introduction

It has been known for a long time that the light and hence the mass distribution in disks of spiral galaxies is not strictly axisymmetric, as for example in M101 or in NGC 1637 (Sandage, 1961), where the isophotes are elongated in one half of the galaxy. Despite this, however, astronomers have largely tended to ignore this fact and to assume the disks to be axisymmetric because it is much simpler to study the dynamics of axisymmetric disks. This phenomenon was first highlighted in the pioneering paper by Baldwin et al. (1980), where they detected an asymmetry in the spatial extent of the atomic hydrogen gas in the outer regions in the two halves of some galaxies, and gave these the apt name of 'lopsided' galaxies. A galaxy is said to be lopsided if it displays a global non-axisymmetric spatial distribution of type $m = 1$ where m is the azimuthal wavenumber, or a $\cos\phi$ distribution where ϕ is the azimuthal angle in the plane of the disk.

Surprisingly no further systematic work was done on this topic till the mid-1990s. Since then there has been a resurgence in this field. The lopsided distribution has now been detected and studied also in the old stellar component as traced in the near-IR starting with the observations of Block et al. (1994) and Rix and Zaritsky (1995). This exciting, new development of the imaging studies of spiral galaxies in the near-IR K-band (2.2μ) was made possible by the development of the NICMOS 3 array. The dust extinction effects are negligible in the near-IR, hence these studies reveal the spatial distribution of the underlying old stellar population, which constitutes the main mass component of the disk. These observations detected a non-axisymmetric $m = 1$ distribution of surface density of old stars in the inner/optical region of the disk. Rix and Zaritsky (1995) define A_1, the fractional amplitude of the first azimuthal Fourier component ($m = 1$) of surface brightness, to be the quantitative measure of disk lopsidedness. They find that A_1 increases with radius. The average value measured between 1.5–2.5 disk scalelengths is large ≥ 0.1, and 30% of the galaxies studied show a higher lopsidedness (Zaritsky and Rix, 1997).

A similar high average value of disk lopsidedness was confirmed in a recent Fourier-analysis study of a much larger sample of 149 galaxies from the Ohio State University Catalog (Bournaud et al., 2005b). Nearly one third of the 149 galaxies exhibit 10% or more asymmetry in the amplitude of the $m = 1$ Fourier component. Thus, *lopsided distribution in the disk is a general phenomenon*, and is stronger at larger radii. Hence it is important to understand the origin and dynamics of the lopsided distribution in spiral galaxies.

The lopsided distribution in the interstellar atomic hydrogen gas (HI) has been mapped spatially (Haynes et al., 1998), and also mapped kinematically for a few galaxies (Schoenmakers et al., 1997; Swaters et al., 1999), and by global velocity profiles for a much larger sample (Richter and Sancisi, 1994). Such an asymmetry has also been detected in dwarf galaxies (Swaters et al., 2002), and also in the star-forming regions in irregular galaxies (Heller et al., 2000). The asymmetry may affect all scales in a galaxy. While the large-scale lopsidedness is more conspicuous, the off-centering of nuclei is now often discovered at high spatial resolution. A prototype of this $m = 1$ nuclear distribution is the inner region of M31, where the central black hole is clearly off-centered with respect to its nuclear stellar disk (e.g., Tremaine (2001)). This frequent nuclear $m = 1$ perturbation will play a central role in the fuelling of the active galactic nucleus (AGN) in a galaxy.

The origin and the evolution of lopsidedness are not yet well understood, though a beginning has been made to address these problems theoretically. Like any other non-axisymmetric perturbation, the lopsided distribution would also tend to get wound up by the differential rotation in the galactic disk within a few dynamical timescales. Since a large fraction of galaxies exhibit lopsidedness, it must be either a long-lived phenomenon or generated frequently. Tidal interaction