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Local stability criterion for a two component galactic disk

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Abstract. The criterion for stability against local, axisymmetric perturbations in gravitationally coupled stars and gas in a galactic disk is obtained. The new feature is the inclusion of both stars and gas in the study, and a two-component analog of the standard one-component Q-criterion is obtained which is applicable to realistic galaxies consisting of stars and gas. The Q_{s-g} value is shown to be always less than the Q values for the stars-alone and the gas-alone cases, thus a two-component system is more unstable than either component by itself. Hence, future studies of galaxies must use Q_{s-g} as a measure of disk stability. The results obtained are general, and several applications for the stability, structure, and evolution of galaxies are discussed.

Key words : galaxies : kinematics and dynamics - galaxies : ISM - galaxies : Spiral - instabilities

1. Introduction

The stability of a thin, one-component (purely stellar) galactic disk to local, axisymmetric perturbations is a classic problem in galactic dynamics, and is solved by a normal mode, linear perturbation analysis, to yield the following Q-criterion for local stability (Goldreich & Lynden-Bell 1965; Toomre 1964) $Q = \kappa c / \pi G \mu$ where $Q > 1$ denotes a stable, $Q = 1$ deenotes a marginally stable, and $Q < 1$ denotes an unstable disk. Here, κ is the epicyclic frequency, c is the 1-D r.m.s. stellar velocity dispersion, and μ is the disk mass surface density.

2. Q_{s-g} criterion for a two-component galactic disk

A real galactic disk, however, consists of two dynamically distinct components, namely stars (with μ_s, and c_s) and gas (with μ_g, and c_g), such that the gas dispersion is low ($c_g << c_s$). The stars and gas are coupled gravitationally, hence each can affect the stability of the other as was shown by Jog & Solomon (1984 a, b). Using the dispersion relation obtained by them, we show that the Q_{s-g} parameter for this system can be defined in terms of the stellar and gaseous contributions at the most unstable dimensionless wavelength l_{s-g} (which is obtained numercially), by the following expression :

$$\frac{(1-\varepsilon)/l_{s-g}}{1+[Q_s^{\,2}(1-\varepsilon)^2]/(l_{s-g}^{\,2}4)} + \frac{\varepsilon/l_{s-g}}{1+[Q_g^{\,2}\varepsilon^2]/(l_{s-g}^{\,2}4)} \equiv \frac{2}{1+[Q_{s-g})^2} \tag{1}$$

where Q_s and Q_g are the Q-parameters for stars-alone and gas-alone respectively, and ε is the gas mass fraction in the disk. $Q_{s-g} > 1, = 1, < 1$ respectively denotes a stable, marginally stable, and an unstable two-component (star-gas) galactic disk.

We obtain results for Q_{s-g} and l_{s-g} as functions of Q_s, Q_g and ε over the entire parameter space (Jog 1996). *The results are presented as contour plots* so that they are readily accessible to others (see Figs. 1-2, Jog 1996).

3. Results

The main results from this work are :

1. Q_{s-g} value is always less than the Q value for the stars-alone and the gas-alone cases, thus a two-component system is more unstable than either component by itself. Hence, future studies of galactic stability must use Q_{s-g} as a measure of disk stability.

2. From the observed values for the input parameters, we find that the disk is close to neutral equilibrium ($Q_{s-g} \geq 1$) over the inner Galaxy. This quantitatively confirms the prediction of a self-regulated galactic disk by Goldreich & Lynden-Bell (1965).

3. For the Galaxy, l_{s-g} gives a typical size of a star-gas feature to be ~ 1kpc, in good agreement with observed sizes of features in spiral galaxies. In contrast, the one-fluid stellar value (Toomre 1964) is too large ~ 5.8 kpc.

4. The critical gas density for star formation to occur will be given by $Q_{s-g} < 1$ - rather than by $Q_g < 1$ (Kennicutt 1989), so that the star formation will set in at a smaller critical μ_g than for the gas-alone case.

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