TWO-FLUID GRAVITATIONAL INSTABILITIES IN A GALACTIC DISK

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We formulate and solve the hydrodynamic equations describing an azimuthally symmetric galactic disk as a two-fluid system. The stars and the gas are treated as two different isothermal fluids of different velocity dispersions ($C_s \gg C_g$), which interact gravitationally with each other. The disk is supported by rotation and random motion. The formulation of the equations closely follows the one-fluid treatment by Toomre (1964). We solve the linearized perturbation equations by the method of modes, and study the stability of the galactic disk against the growth of axisymmetric two-fluid gravitational instabilities.

We find that even when both the fluids in a two-fluid system are separately stable, the joint two-fluid system, due to the gravitational interaction between the two fluids, may be unstable. The ratio of the gas contribution to the stellar contribution towards the formation of two-fluid instabilities is substantially greater than μ_g/μ_s, the ratio of their respective surface densities--this is due to the lower gas velocity dispersion as compared to the stellar velocity dispersion ($C_g \ll C_s$). The two contributions are comparable when the gas fraction (μ_g/μ_s) is only $\simeq$ 0.10 -0.25. Therefore, the galactic disk is a meaningful two-fluid system even when the gas constitutes only 10%-20% of the total surface density. Figure 1 contains plots of ω^2=(angular frequency)^2 vs. λ^{-1} =(wavelength)$^{-1}$ for the two-fluid perturbation, at different gas fractions. The values used for κ, the epicyclic frequency, and μ_t, the total disk surface density, represent the solar neighbourhood (Caldwell and Ostriker 1981). As a result of the increasing gas fraction, the most unstable mode grows faster and $\Delta\lambda$, the range of unstable wavelengths, increases. The wavelength and the time of growth of a typical two-fluid instability in the inner Galaxy, for μ_g/μ_s = 0.1-0.2, are ~ 2-3 kpc and ~ 2-4 × 10^7 years respectively, and each of these instabilities contains gas of mass ~ 4 × 10^7 -10^8 $M_\odot$.

The existence of even a small fraction of the total disk surface density in a cold fluid (that is, the gas) makes it much harder to stabilize the entire two-fluid disk. $(C_{s,min})_{2-f}$, the critical stellar velocity dispersion for a two-fluid disk, is an increasing function of

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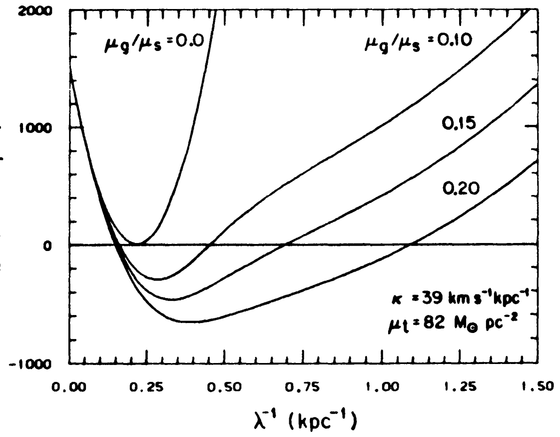

Figure 1. Influence of the gas content on the two-fluid gravitational instabilities.

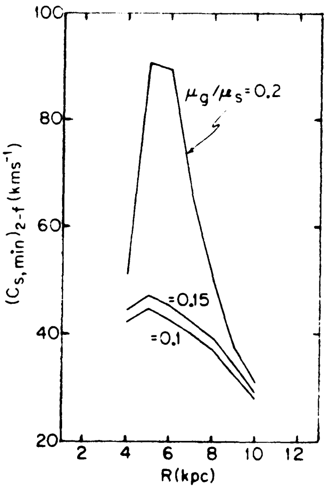

Figure 2. Results for $(C_{s,min})_{2-f}$ vs. R in the galactic disk.

μ_g/μ_s and μ_t/κ. In the Galaxy, $(C_{s,min})_{2-f}$ as a function of R, the galactocentric radius, peaks when μ_t/κ peaks--that is, at R ~ 5-7 kpc (see Figure 2); two-fluid instabilities are most likely to occur in this region. This region does coincide with the peak in the observed molecular cloud distribution in the Galaxy (see e.g., Scoville and Solomon 1975).

At the higher effective gas density resulting from the growth of a two-fluid instability, the gas may become unstable--even when originally the gas by itself is stable. The wavelength of such a typical (induced) gas instability in the inner Galaxy is 400-500 pc and it contains gas of mass ~ 1-2 × 10^7 $M_\odot$; this may be identified with a cluster of molecular clouds.

The above two-fluid analysis is applicable to any general disk galaxy consisting of stars and gas. The details of this analysis are given in Jog (1982) and Jog and Solomon (1984a,b).

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DISCUSSION

M. Iye: How do your results compare with those of others, for example by Kato (1972, Publ. Astron. Soc. Japan 24), who studied a similar problem for a two-component system, but treated the stellar component not as a fluid but as a collisionless system?

Jog: I am not aware of his work.

F. Shu: I made similar calculations in 1968, and I do not believe I was the first (Lin and Shu, 1968, Brandeis Lectures in Astrophysics; Lin, Yuan, and Shu, 1969, Ap. J. 155, 721). Without thickness corrections, the calculations preceded 1966. We always made the assumption that the combined star-gas system was stable.

Jog: As far as I am aware, this is the first time that rotation as well as random motion have been taken into account in a two-fluid calculation. Lynden-Bell derived in 1967 the criterion for instability, but I think he did not consider the rotation.

Lynden-Bell: That is probably correct. I believe Toomre had a preprint which he never published.

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Colin Norman (foreground) chairs at dinner table of conference secret-ariat, counter-clockwise: Ineke Rouwé, Jan de Boer, Eli Brinks (guest), Joke Nunnink, Marijke van der Laan, Leonard Bronfman LZ

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