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LOCAL INTERSTELLAR GASDYNAMICAL STABILITY IN SPIRAL ARM FLOW

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The stability of two-dimensional interstellar gas flow passing through a spiral potential has been investigated. The background flow is assumed to move in a tightly wound potential, which may be regarded as external or self-generated. The unperturbed flow, which may be time dependent, is self-gravitating and satisfies the Roberts (1969) equations of motion. A polytropic, single-fluid assumption has been used. Magnetic effects are not considered. The motivation behind this work is to try to understand how much of the diversity of spiral arm morphology can be understood by large scale gas dynamical processes alone. To this end, we suggest that "spurring and feathering", and forming molecular cloud complexes may be closely related in the sense of having dynamically similar origins.

The classic study of Goldreich and Lynden-Bell (1965; hereafter GLB) investigated the stability of a sheared infinite sheet (or slab) to general two-dimensional perturbations in the plane of the sheet. The motivation for this study was to better understand spiral arm formation in disk galaxies. In essence, the current investigation generalizes GLB to include arbitrary expansion and contraction of the sheet in such a way that specific angular momentum is conserved. These volume changes correspond physically to the compression and reexpansion of the fluid as it moves through the spiral arm region of the disk. The small wavelength perturbations are sensitive only to local flow conditions, and a fluid element behaves to leading order as though it were moving in an expanding (or contracting) sheared sheet. Thus, one asymptotic limit of our study is the GLB equation; another limit corresponds to the case studied by Balbus and Cowie (1985) in which the wavenumber points along the expansion velocity and is not sheared with the flow, but diminishes as the flow expands.

GLB found that perturbations which were stable to a Jeans type of gravitational collapse could nevertheless grow dramatically by the "swing amplification" mechanism (Toomre 1981). This amplifier works because the shear flow, which decreases outward in this problem, and the epicyclic motion, which is always retrograde, conspire to kinematically prolong the compressive phase of perturbative oscillation. This gives self-gravity an extended opportunity to amplify the compression. Therefore, in general nonaxisymmetric perturbations grow considerably more rapidly than their axisymmetric counterparts.

The situation is usually quite the opposite in the compressed gas regions of spiral arms. The reason is that locally the shear flow may be increasing outward. This is a simple consequence of angular momentum conservation in the compressed gas. In fact, in general it is not difficult to show that within the assumptions of the tight winding approximation,

$$\frac{d \ln\Omega}{d \ln r} = \frac{\kappa^2}{2\Omega^2}\left(\frac{\sigma}{2}\right) - 1 ,$$

where r is the radial location, Ω is the total angular velocity (including the small but rapidly changing piece induced by the spiral potential), κ is the epicyclic frequency, and σ is the density enhancement at r. For a flat rotation curve, if σ exceeds a modest factor of two, the shear flow will locally increase outward.

Now the swing amplification mechanism runs in reverse. The shear field and the retrograde epicyclic motion conspire to shorten the compressive phase of the oscillation, giving self-gravity <u>less</u> of a chance to amplify the perturbation. The result: wave numbers initially perpendicular to the arm (i.e. nearly radial) grow the fastest. This gives rise to extended structure preferentially along the arm. If the perturbation rapidly becomes non-linear and drops from the flow before the background shear flow draws it out from the arm, then regularly spaced structure along the arm is expected. The non-linear outcome of such large initial perturbations may be molecular complexes because of the rapid tendency to form molecules in cloud collisions (Smith 1980), of which there would be proportionately more compared with smaller initial amplitudes. (Such a model might fashionably be called "biased molecular cloud formation".) The smaller initial amplitude perturbations have smaller internal cloud collision rates, and plausibly less molecular gas. They take longer to become nonlinear and drop from the flow. Accordingly, they are more profoundly influenced by the reversed shear field near the arm. A trailing elongated perturbation would be drawn out away from the spiral arm on the convex side of the pattern. The downstream trailing portion of the perturbation would soon find itself in a region of normal (decreasing outward) shear flow, while the upstream leading portion of the perturbation would be in a region of reversed shear. The characteristic spur morphology would be shaped by such a flow environment. "Feathering" would result when the perturbation itself becomes nonlinear and repeats this process in the flow passing over it. In this manner, we suggest that molecular clouds and spiral arm features may be dynamically related.

The mathematical underpinnings of these ideas are presented in Balbus (1986).

REFERENCES

Balbus, S.A. 1986, preprint.
Balbus, S.A., and Cowie, L.L. 1985, *Ap. J.*, **297**, 61.
Goldreich P., and Lynden-Bell, D. 1965, *M.N.R.A.S.*, **130**, 125.
Roberts, W.W. 1969, *Ap. J.*, **158**, 123.
Smith, J. 1980, *Ap. J.*, **238**, 842.
Toomre, A. 1981, in *The Structure and Evolution of Normal Galaxies*, ed. S.M. Fall and D. Lynden-Bell (London: Cambridge University Press), p. 111.