DO SPIRAL GALAXIES HAVE A VARIABLE DISK THICKNESS?

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Estimating the forces in the z-direction that affect the disks of spiral galaxies in reasonable galactic mass models we find (Rohlfs and Kreitschmann 1981) that all external forces are small compared to the self-gravity of the disk so that Spitzer's (1942) self-consistent sheet model should give a good description for the z-distribution of the disk where it is well visible. But then the three parameters describing this shape are connected by the formula

$$\Delta(r) = \frac{\langle v_z^2 \rangle}{\pi G \cdot \mu(r)} \tag{1}$$

Now $\mu(r)$ varies strongly with r according to Freeman (197o)

$$\mu(r) = \mu_o \cdot \exp(-ar) \tag{2}$$

and therefore either $\Delta(r)$ or $\langle v_z^2 \rangle$ or both should vary with r too.

NGC 4244 and NGC 59o7 are spiral galaxies seen edge-on that seem to be pure disk systems, and thus should be well suited to test the question whether Δ is variable or not. Such a test was made by van der Kruit and Searle (1981), and they obtained a satisfactory fit to their photometry using a model with a constant disk thickness.

Some systematic deviations between model and observation remained, however, and therefore this fit was repeated by Rohlfs and Wiemer (1982) using models with variable disk thickness

$$\Delta(r) = b + c \exp(ar). \tag{3}$$

Both galaxies resulted in a fit with $c > o$ thus giving an increase of Δ with r, but the mean error of c is so large that only a 2.4 σ (NGC 4244) or 1.8 σ (NGC 59o7) effect was found.

Such effects are usually not considered to be statistically significant, but here some theoretical arguments will be given that causes to accept $c > o$ as a viable result. For this let us expound the consequences of (3) on $\langle v_z^2(r) \rangle$.

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$<v_z(r)>$ could vary in almost any way if its shape resulted from the processes leading to the formation of the disk. But as Wielen (1977) showed this is highly improbable, it would require that the gaseous disk keeps a highly supersonic turbulence over timescales of several 10^9 a.

We are thus left with a velocity dispersion $<v_{z0}^2>$ = const. which the stars attain at the moment of their birth, and the magnitude of which perhaps would be determined by the mechanism of formation. As Wielen (1977) has shown for stars of the solar neighbourhood their velocity dispersion slowly increases with the time t according to the relation

$$<v_z^2(t)> = <v_o^2> (1 + \frac{t}{\tau}) \tag{4}$$

here t is the age and τ a relaxation time, which is of the order of $\tau \simeq 2 \cdot 10^8$ a in the solar neighbourhood.

If we now assume that (4) describes the general behaviour of the stellar velocity dispersion in galactic disks, and if the relaxation time depends on the position in the disk, then we would observe

$$<v_z^2(r)> = <v_o^2> (1 + \frac{\bar{t}}{\tau(r)}) \tag{5}$$

where $<v_o^2>$ is the (constant) velocity dispersion of the stars at birth, and $\bar{t}$ their mean age. Combining (1), (2), (3) and (5) we then find

$$c = \frac{<v_o^2>}{\pi G \cdot \mu_o} \tag{6}$$

$$b = \frac{c}{\tau_o} \cdot \bar{t} = \frac{<v_o^2>}{\pi G \cdot \mu_o} \cdot \frac{\bar{t}}{\tau_o} \tag{7}$$

provided

$$\mu(r)\, \tau(r) = \mu_o \tau_o \tag{8}$$

Thus c will remain constant with time, while b will grow linearly. The observable ratio $b/c = \bar{t}/\tau_o$ gives the dynamical age of the disk in units of the relaxation time at the centre. NGC 4244 and NGC 59o7 are thus fairly old system with $\bar{t}/\tau_o$ = 316 and 163 resp. It is remarkable that these results can be obtained without specifying which relaxation processes are responsible for (4).

If such processes are specified, formulae relating τ to other disk parameters can be given. As Wielen (1977) and van der Kruit and Searle (1982) showed,the Spitzer-Schwarzschild (1953) mechanism is a definite possibility. The resulting formula for τ is derived by Rohlfs and Wiemer (1982) and is given here in Table 1, but the required abundance of giant clouds is far greater than observed. Therefore contributions of all kinds of density perturbation from spiral arms to interstellar clouds were included in in an expression derived by Rohlfs (1982) given here in Table 1 too. They are compared in the following synopsis

Table 1

Spitzer-Schwarzschild mechanism	general perturbation of surface mass density
$\frac{\tau}{a} = 8.27\cdot 10^{6} \frac{\left\langle\left(\frac{v_z}{km\ s^{-1}}\right)^2\right\rangle^{3/2}}{\gamma\cdot\left(\frac{m_c}{10^6 M_o}\right)\left(\frac{\mu(r)}{M_o pc^{-2}}\right)}$	$\frac{\tau}{a} = 3.26\cdot 10^{7} \frac{\left\langle\left(\frac{v_z}{km\ s^{-1}}\right)^2\right\rangle^{1/2}}{\eta^2\cdot\left(\frac{\mu(r)}{M_o pc^{-2}}\right)}$
$\gamma\cdot\mu(r)$: total mass density contained in massive clouds	$\eta = \frac{\mu_s}{\mu(r)}$ average rms perturbation of surface mass density
$\gamma\cdot m_c = \begin{cases} 6.2\cdot 10^4\ M_o \\ 3.2\cdot 10^4\ M_o \\ 5.0\cdot 10^4\ M_o \end{cases}$	$\eta = \begin{cases} 9.9\ \% & \text{Solar neighbourhood} \\ 7.1\ \% & \text{NGC 4244} \\ 8.9\ \% & \text{NGC 5902} \end{cases}$

Both mechanisms obey the relation (8) and therefore cause a run of Δ as given by (3). But both mechanisms have difficulties too in explaining the short required relaxation times of $\tau \sim 10^8$ a. To do this either a large abundance of massive interstellar clouds with $\gamma \cdot m_c \simeq 5\cdot 10^4\ M_o$ is required, or a rms variation of the surface mass density of 8 - 10 % is needed. It should, however, be noted, that adopting $\Delta \sim$ const. makes this situation even worse, because then $\bar{t}/\tau_o$ should be even larger.

References

Freeman, K.C. 1970, Astrophys. J. 160, 811
Rohlfs, K. 1982, in prep.
Rohlfs, K. and Kreitschmann, J. 1981, Astrophys. Space Sci. 79, 289
Rohlfs, K. and Wiemer, H.J. 1982, Astron. Astrophys. 112, 116
Spitzer, L. 1942, Astrophys. J. 95, 329
Spitzer, L. and Schwarzschild, M. 1953, Astrophys. J. 118, 106
van der Kruit, P.C. and Searle, L. 1981, Astron. Astrophys. 95, 105
van der Kruit, P.C. and Searle, L. 1982, Astron. Astrophys. 110, 61
Wielen, R. 1977, Astron. Astrophys. 60, 263

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