FORMATION OF MOLECULAR GAS RINGS IN GALAXIES

without Density Waves, Merging or Nuclear Activity

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Ringlike structures (in H_α, CO and radio continuum) in central galactic regions have been observed in a number of objects. They seem to be a basic feature of galactic structure (for references see Dickman et al., 1988). These observations can be summarized as follows:
The typical mass of these rings is $10^8 - 10^9 M_\odot$.
The gas distribution is smoothly decreasing from the ring into the innermost galactic regions.
The rings appear always at the turnover radius where the galactic rotation turns from rigid to differential rotation.

It is a well-known fact that angular momentum is transferred outwards in viscous, differentially rotating disks, which leads to an inward massflow (Lüst, 1952; Icke, 1979). Therefore it is plausible that mass accumulation occurs somewhere near that radius where the rotation curve begins to tend appreciably towards constant Ω. Here Ω denotes the angular velocity of the gas (Ω is constant in the rigid rotating regions and decreases with increasing radius in the differentially rotating disk). This behaviour follows from the diffusion equation for the surface density in the disk σ

$$\frac{\partial\sigma}{\partial t} = -\frac{\alpha_T < v_T^2 >}{R}\frac{\partial}{\partial R}\left(\frac{\partial}{\partial R}\left[\frac{\sigma R^3}{\Omega}\frac{d\Omega}{dR}\right] / \frac{dj}{dR}\right). \tag{1}$$

According to Eq. (1) mass accretion in a viscous differentially rotating disk occurs down to that radius where the differential rotation turns into solid body rotation.
From Eq.(1) one can define an accretion timescale (Duschl, 1988):

$$t_{ACCR}(R) = \frac{R^2\Omega}{\alpha_T < v_T^2 >}\frac{\mid \frac{d}{dR}(R^2\Omega) \mid}{\mid R^2 \frac{d}{dR}(\Omega) \mid}. \tag{2}$$

In order to build up a gaseous ring the accretion time must increase strongly at the turnover radius. We consider whether observed rotation laws of spiral galaxies lead to such large accretion timescales.
Observations (Rubin et al., 1982;) indicate that most disk galaxies have rotation curves which approach solid body rotation inside and constant velocity outside. The law

$$\Omega(R) = \Omega_0 / [1 + (R/R_{BULGE})^n]^{1/n} \tag{3},$$

presents a general family of such a behaviour, where n describes the sharpness of the turnover. To produce a sharp transition at the inner boundary of the ring, we clearly require a dramatic increase

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in t_{ACCR} this condition requires $n > 2$ (Lesch et al., 1989). The formation of a ring then puts a constraint on the gravitational potential which fixes the rotation law. *In the following we in fact assume that* $n > 2$. The disk matter accumulates approximately at the radius where $\frac{d\Omega}{dR} \to 0$ in a typical timescale

$$t_{ACCR}(R) = \frac{\Omega_C\, R^2_{BULGE}}{\alpha_T < v_T^2 >} = \frac{v_{ROT}\, R_{BULGE}}{\alpha_T < v_T^2 >} =$$

$$3 \cdot 10^8\, yr\, \alpha_T^{-1} \left[\frac{v_{ROT}}{10 v_T}\right] \left[\frac{R_{BULGE}}{300pc}\right] \left[\frac{v_T}{10\, km\, s^{-1}}\right]^{-1}. \tag{4}$$

Eq. (4) can be rewritten as a mass flow with a "typical" gas surface density σ:

$$\frac{dM}{dt} = \frac{2\pi R^2 \sigma}{t_{ACCR}} = 2\pi R^2_{BULGE}\sigma \frac{\alpha_T \; < v_T^2 >}{v_{ROT}\, R_{BULGE}}$$

$$= \frac{0.03\, M_\odot}{yr} \left[\frac{R_{BULGE}}{300\, pc}\right] \left[\frac{\sigma}{30\, M_\odot\, pc^{-2}}\right] \left[\frac{v_T}{10\, km\, s^{-1}}\right] \left[\frac{v_{ROT}}{200\, km\, s^{-1}}\right]^{-1}. \tag{5}$$

After 10 galactic rotation periods ($\sim 3\,10^9$ *years*), this flux would build up a ring of about $10^8\, M_\odot$. The numerical simulations of Däther and Biermann (1990) support our result.
Summarizing the model of ring formation by viscous accretion explains the mass of the rings and their position in a galaxy in a very simple and plausible manner. It follows that, unless rings selfdestruct easily by starbursts, all early Hubble type galaxies should show a maximum of the surface density of cool gas in the form of a ring at the location of the turnover of the rotation law.

Table 1 shows the agreement of the data and our model. However, it has been shown that other mechanisms lead also to the formation of gas rings in galactic central regions. The model of Umemura et al., (1988) includes nuclear activity. Combes and Gerin 1985 (see also Combes et al., 1990) have shown that the excitation of a density wave in a galaxy leads also to the formation of ringlike structures in galaxies. This model is discussed in detail by Combes (1990b).

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Table 1

Object	Hubble sequence parameter T RC2	observed ring distance from the center (kpc)	turnover radius (kpc)	reference for the rotation curve
M82	-	0.25-0.4	0.2	Loiseau et al. 1988
NGC 1068	3	1.-2.4	1	Atherton et al., 1985
NGC 1097	3	0.7-1.2	0.5	Gerin et al., 1988
NGC 2841	3	4.5	4.5	Combes, 1989
NGC 4321	4	1.5	1.5	Arsenault et al., 1988
NGC 7331	4	4.5	4.5	Bosma, 1981