

Migration of Star Clusters in Nuclear Rings

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Introduction



Figure 1. NGC 4314 from Benedict et al (2002)



Figure 2. NGC 1512 from Maoz et al (2001)

Nuclear rings in barred spiral galaxies are regions of large gas surface densities and high star formation. Their existence is intimately related to the stellar bars with which they are associated. The stellar bar drives the interstellar medium (ISM) into the nuclear ring.

These nuclear rings are the largest population of nearby star bursting regions. They form star clusters in prodigious amounts and are the only environment where super star clusters (SSCs) might be found in abundance in normal galaxies (Maoz et al 2001). These SSCs can have masses in excess of $10^6 M_\odot$ and may be the progenitors of globular clusters if they can survive for 10^{10} years.

In some of these systems the location of these star clusters is curious. They appear to be at larger radii than the gas ring from which they are presumably formed. For instance in NGC 4314 (Figure 1) and NGC 1512 (Figure 2) the star clusters are at larger radii than the gas in the nuclear ring (Benedict et al. 2002). Why do these star cluster appear at slightly larger radii than the gas? We attempt to answer this question in arxiv:0807.2437. The basic picture is that if a star cluster form near the outer edge of the nuclear ring, tidal interaction between the gas and the star cluster will push the star cluster outward and the gas inward, creating a separation akin to gap opening by protoplanets in a protoplanetary nebula.

Basic Picture

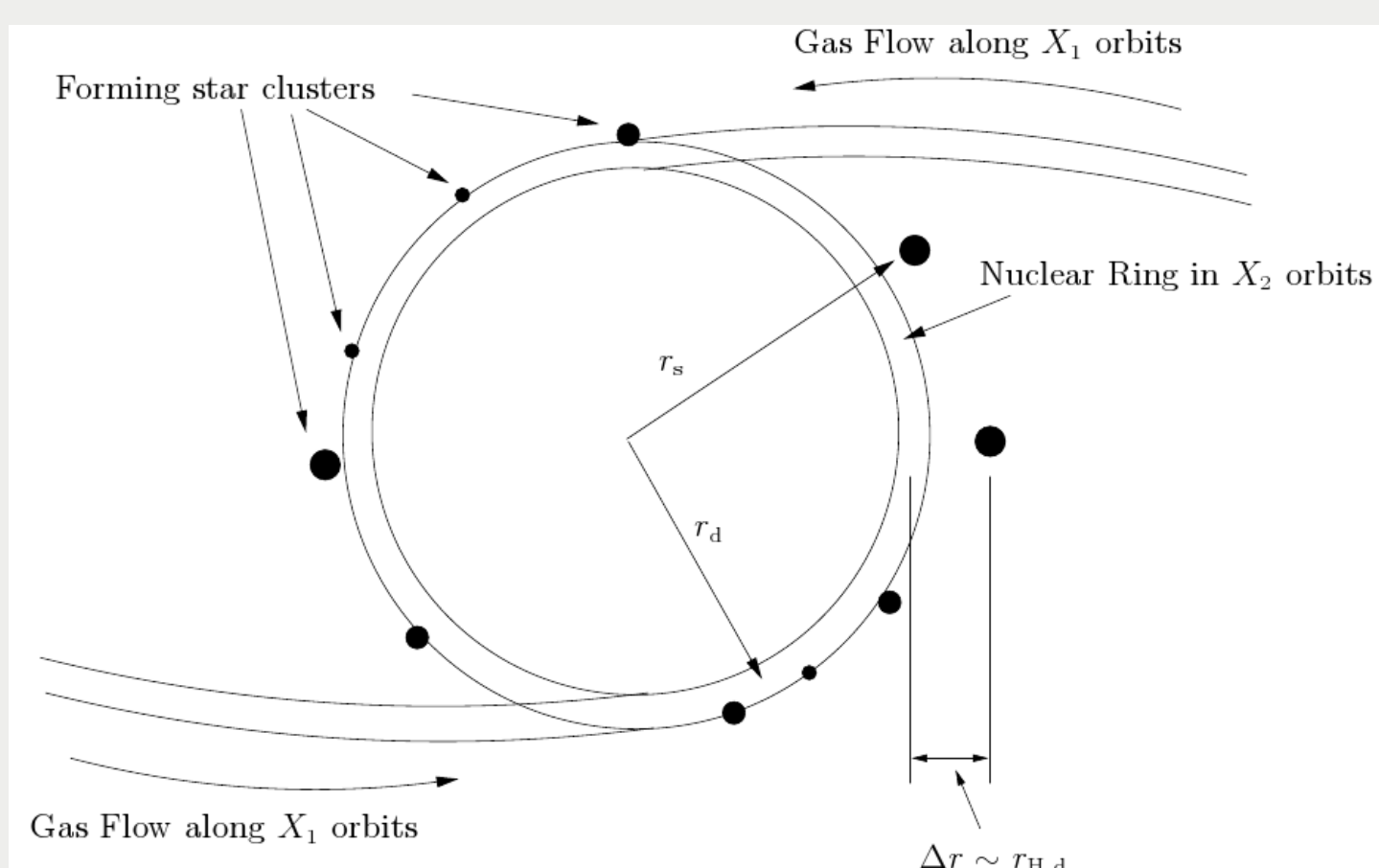


Figure 4. Cartoon of the basic model.

- ▶ Gas flowing in a bar potential along the X_1 orbits transitions to X_2 orbits making up the nuclear ring. Part of this gas collapses to form star clusters near the outer edge of the ring.
- ▶ These clusters migrate outward to a radius r_s under the influence of dynamical friction with the bulge stars and tidal interactions with the gas in the nuclear ring.
- ▶ At the same time, the star cluster pushes the outer edge of the nuclear ring to a smaller radius r_d .
- ▶ The net separation between the star cluster and nuclear ring, $\Delta r = r_s - r_d$, is of order the “Hill radius” of the nuclear ring, $r_{H,d} \equiv r_s (M_d/M_{enc,s})^{1/3}$, where M_d is the mass of the ring with radius r_d and $M_{enc,s}$ is the mass enclosed and is typically $r_{H,d}/r_s \approx 0.2$ in line with observed separations.

Equations and Estimates

The evolution of a *viscous* gas ring under the influence of an external torque is given by equations for continuity and angular momentum. The equation of continuity is

$$\frac{\partial \Sigma}{\partial t} + \frac{1}{r} \frac{\partial (rv_r \Sigma)}{\partial r} = 0, \quad (1)$$

The angular momentum equation is

$$\frac{\partial (\Sigma \Omega r^2)}{\partial t} + \frac{1}{r} \frac{\partial (rv_r \Sigma \Omega r^2)}{\partial r} = -\frac{1}{2\pi r} \left(\frac{\partial T_{\text{visc}}}{\partial r} - \frac{\partial T_{\text{disk}}}{\partial r} \right) \quad (2)$$

where T_{visc} is the viscous torque and T_{disk} is the tidal torque. We give an order of magnitude estimate for the rate at which a newly formed star cluster will separate itself from the nuclear ring. If the gas does not react significantly to the tidal torque, then the timescale for separation is

$$\left(\frac{r_s - r_{d,0}}{r_{H,d}} \right)^4 \sim \frac{r_{d,0}}{r_{H,d}} \frac{t}{t_{df,0}}, \quad (3)$$

where $t_{df,0}$ is the initial dynamical friction timescale. The observed range of $M_d/M_{enc} = 0.01 - 0.03$ implies $t_{sep}/t_{df,0} \sim 0.2 - 0.3$. Hence for cluster-to-ring mass ratios from $q' = 0.01$ to $q' = 0.1$, or about 500 Myr to 50 Myr for a typical crossing (orbital) time of $t_{cross} = 20$ Myr.

Results

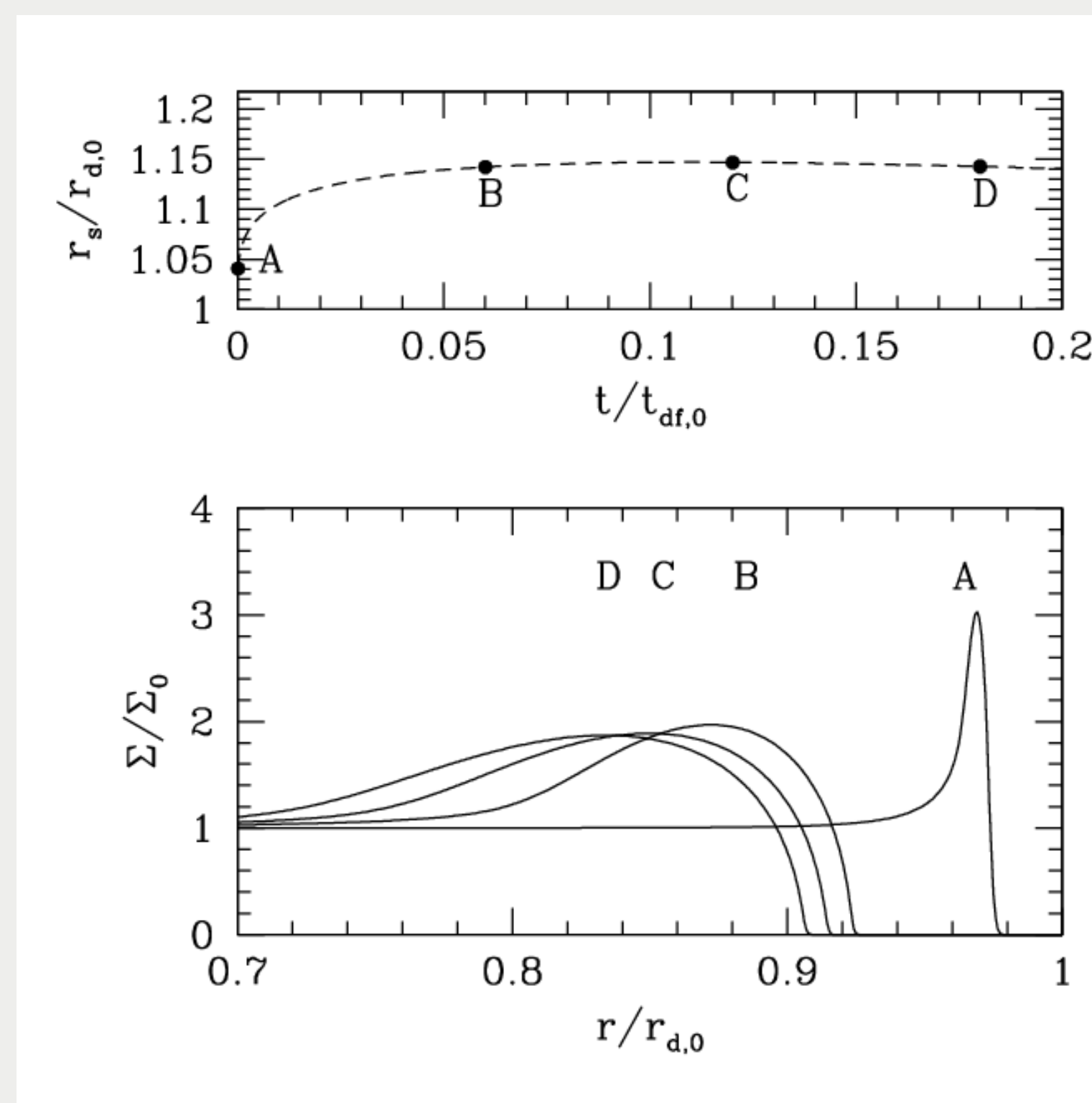


Figure 5. The case of $M_s/M_d = 0.1$ from Van der Ven and Chang (2008)

We illustrate the basic result in Figure 5 for the case where $M_s/M_d = 0.1$, i.e., the mass of the star cluster is 10% the mass of the nuclear ring. An initial surface mass density enhancement of three times its initial value is built at point A. The star cluster moves outward, reaching about 115% of its initial radial position between point B and C. After it reaches its maximum, the effect of dynamical friction causes the star cluster to “turn around” and it starts moving inward. The radial separation between the star cluster and the (edge of the) nuclear ring approaches the Hill radius of the ring, $r_{H,d}$, as we expect from order-of-magnitude estimates.

Conclusions

- The star clusters which are formed near the outer edge of the ring migrate outward. The final separation is of the order of the Hill radius of the ring, which is 20 – 30% of its radius. The time to reach this final separation is about 20 – 30% of the dynamical friction time though the initial separation is reached very rapidly, reaching half the Hill radius within only 1% of the dynamical friction time. This can be as short as a few million years for a massive enough ($\gtrsim 10^6 M_\odot$) star cluster.
- While such a massive cluster moves out the surface mass density of the gas at the edge of the nuclear ring is pushed inward and gets enhanced by a factor of a few. This enhancement might trigger new star cluster formation and would be in addition to the (ongoing) formation of star clusters.
- For massive enough star clusters are massive, the cluster-ring system migrates inward as a whole. This would suggest that star cluster formation may aid the radial transport of gas toward the center of the host galaxy.