Few-Body Problem: Theory and Computer Simulations
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Inner resonance ring of NGC 3081, disk surface mass density, and the enhanced disk few-body process

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Abstract.

We complement our HST observations of the inner ring of NGC3081 using an analytical approach and N-body simulations. We find inner and outer rings of gas clouds form under a rotating bar perturbation. Very strong azimuthal cloud crowding and star formation occur where the ring crosses the bar major axis. From the dust distribution and radial velocities, the disk turns counterclockwise on the sky, like the bar. The inner ring shape turns at the bar pattern speed with the gas clouds and stars orbiting faster. From the ring shapes and spacing, the bar strength (maximum tangential/radial force) appears to be constant from 7 through 14 kpc. We derive how the perturbation, the fractional long wavelength two-fold intensity and the rotation curve can be used to calculate that the NGC 3081 disk surface density. At 7 kpc it is 13 solar masses/square pc rising to 19 solar masses/square pc at 13 kpc. The latter is insufficient by a factor of seven to generate the rotation curve (indicating halo domination thereof). The disk surface density may have been reduced at 7 kpc due to inner ring gas cloud scattering. Surface density plus the observed surface brightness gives a disk M/L which increases from 7 kpc through 13 kpc. The long ring lifetime of several Gyr in our simulations is consistent with our 400 Myr HST estimates of its age. Repeated passages by gas clouds can be effective in scattering of stars at the ring radius at either reducing the surface mass density or thickening the disk. With a sufficiently low mass halo, our simulations form gas cloud "associations" near the ends of the bar as observed. Too low a halo mass results in a chaotic non-ring gas disk.

Key words: NGC3081, star formation, galaxies, resonance rings

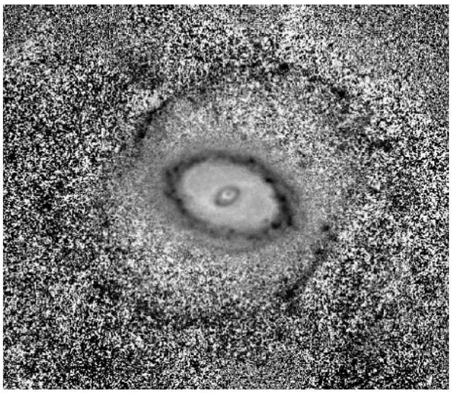

Figure 1. $B - I$ colour map of NGC 3081. Bluer disk colours are indicated by darker tones, and redder colours by lighter tones. Note the small nuclear (nr), larger inner r, and largest outer R_1, R_2 rings. Pattern co-rotation (CR) is between r and R_1 rings. The disk turns counter-clock-wise (CCW) on sky. Outer long dimension of r ring is about 38.5" (7 kpc). The galaxy is tilted about 34° with a 97° position angle line of nodes.

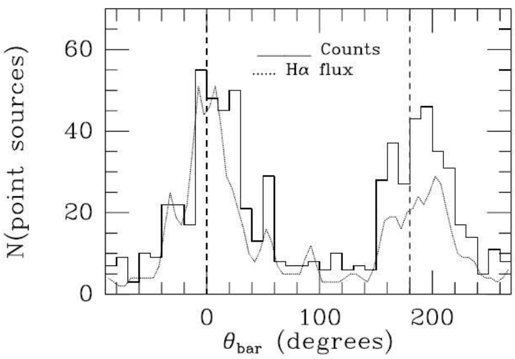

Figure 2. HST associations histogram versus angle around the ring in the galaxy plane (Buta, Byrd, and Freeman 2004). Note counter-clock-wise (CCW) asymmetry of peaks of numbers of sources and Hα young-association emission (dotted curve) at bar ends (dashed).

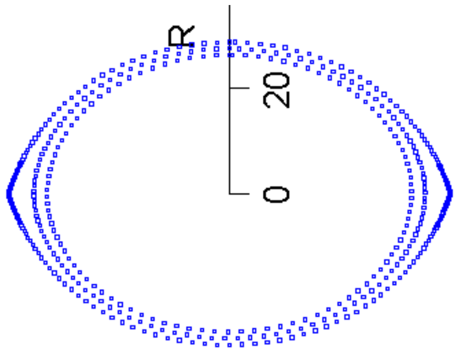

Figure 3. Analytic model of r ring. CR= 54". Flat rotation curve bar potential perturbation is $q = 0.03$. Long/short r dimensions are $(1+\sqrt{2q})/(1-\sqrt{2q})$. Squares are plotted at equal intervals of time. Note the transverse crowding at major axis favouring formation of associations there. Extreme crowding and slow motion relative to pattern speed occurs at the pointy ends, so that associations form and grow older there. At smaller radii the extremely young associations should form near the major axis then move to progressively larger counter-clock-wise (CCW) angles as they age.

Table 1. I_2/I_o at different distances from the center of NGC3081. disk surface densities, "halo/disk" parameter, and mass-to-light ratio (M/L) in solar units.

Radius	I_2/I_o	$\mu_{d,o}$ $M_\odot/pc^2$	$\mu_{M,100\%}/\mu_{d,o} = f_s$	I_o $L_{\odot,H}/pc^2$	M/L $(M_\odot/L_{\odot,H})$
40 arcsec; 7.20 kpc	0.68	12.8	19.4	122.8	0.104
50 arcsec; 9.00 kpc	0.59	11.8	16.9	47.4	0.249
70 arcsec; 12.6 kpc	0.25	19.4	7.14	21.28	0.912

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References

Buta, R., Byrd, G. and Freeman, T., 2004,*AJ*, , 127, 1982

Byrd, G. and Freeman, T. and Buta, R., 2006, *AJ*, , 131, 1377

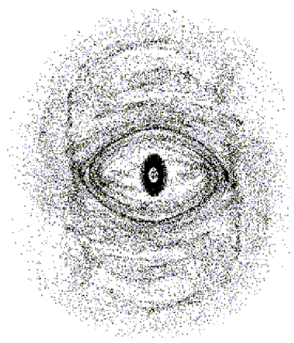

Figure 4. N-body gas cloud disk simulation about 4×10^9 yr after onset of bar perturbation (Byrd, Freeman and Buta 2004). Comparing to Fig. 1, note nr, r and R_1 rings. The disk gas cloud surface density is 1/15 that needed to create the flat rotation curve (i.e. the galaxy is halo halo dominated). Clumps (associations) form near the analytically predicted pointy ends of the rings as predicted. At lower gas cloud surface densities, the clumps do not form (as expected for the program "softening").

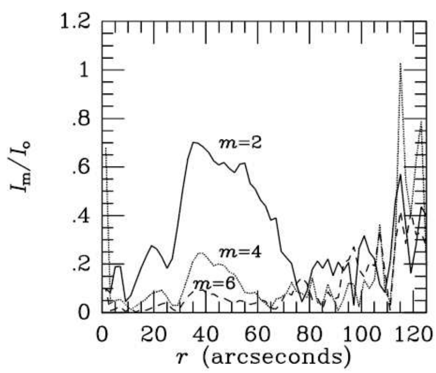

Figure 5. H band I_m/I_o component ratio for the NGC3081 disk. Note that the maximum of the $m = 2$ component to $m = 0$ occurs near the inner ring radius and subsequently declines going to larger radii. Note how smooth and well-defined this curve is over the 35" to 80" range of the inner, r, and outer R_1 rings. Note the dominance of the "two-fold" over other components. The disk surface density, $\mu_{d,o} = q_2\,(V_o^2/(2\pi\,G\,r_o))/(I_2/I_o) = q_2\,\mu_{M,100\%}/(I_2/I_o)$ where $\mu_{M,100\%}$ is the surface density of an imaginary thin disk which would fully create a flat 221 km/s rotation curve, like for NGC 3081. The halo/disk parameter f_s is the ratio of this 100% disk to the actual surface densities. Surface density and halo/disk values for NGC3081 are given in Table 1.

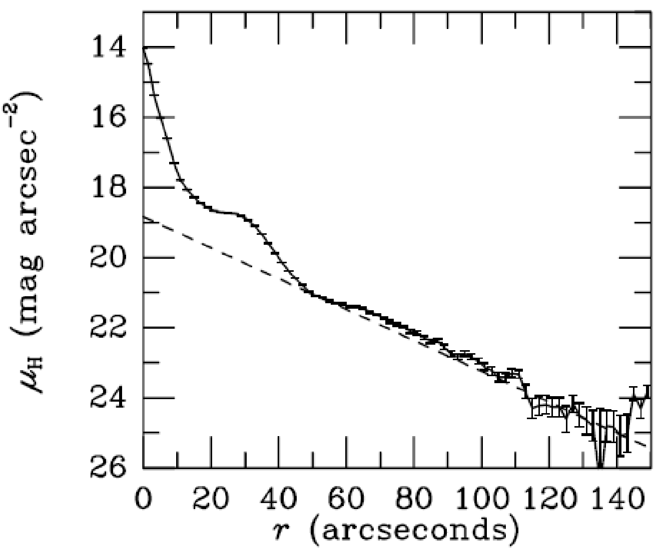

Figure 6. H band I_o versus radius for the NGC3081 disk. Note the "shoulder" or "lens" in the neighbourhood of the inner ring and co-rotation with a simple exponential decline beyond that. These observations are used with the disk surface densities to compute the M/L ratios which are given in the table.