ENERGY TRANSFER DURING THE TIDAL ENCOUNTER OF DISC GALAXIES

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Numerical simulations of merging galaxies do not include a disc component due to bar instability modes. Analytic work is based upon the impulsive approximation which leads to energy loss by the perturber. However, for the perturber to become bound we need consider parabolic encounters. Here we present an analytic technique suitable for all types of encounters.

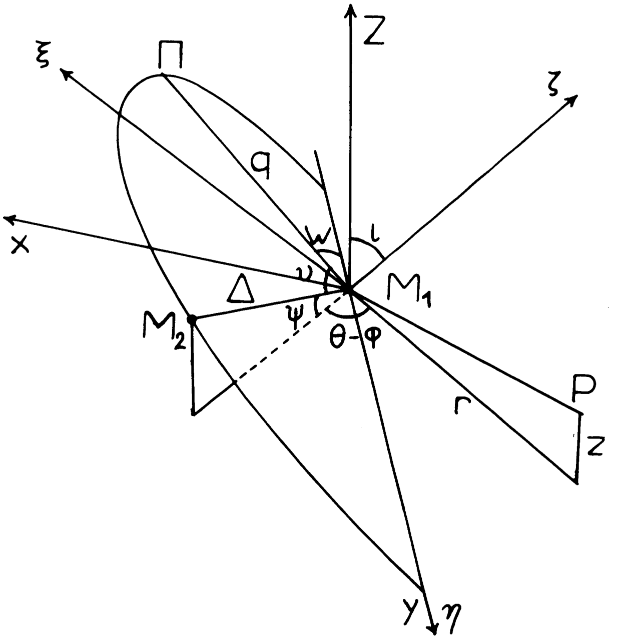

Fig.1: The geometry of the flyby. M_1: Perturbed galaxy; M_2: perturbing galaxy in Keplerian orbit about M_1. P: massless star in circular orbit about M_1. (M_1, ξ, η): plane of orbit of M_2; (M_1, x, y): plane of unperturbed orbit of P; $M_1 y$: line of intersection of orbital planes; υ: true anomaly of M_2 measured from $M_1 \Pi$; (r, ϑ, z): cylindrical co-ordinates of P.

E. Athanassoula (ed.), Internal Kinematics and Dynamics of Galaxies, 355–356.

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The reduced perturbing potential as seen from M_1 is:

$$U = \mu m(z\sin\phi + r\cos\phi\cos(\vartheta-\varphi))/\Delta^2 - \mu m(r^2+z^2+\Delta^2-2z\Delta\sin\phi-2r\Delta\cos\phi\cos(\vartheta-\varphi))^{-1/2}$$

where $\mu=GM_1$, $m=M_2/M_1$. This is then Fourier analysed taking z=0:

$$U = \sum_{n=-\infty}^{\infty}\int_{-\infty}^{\infty} a_n(r,\omega)e^{-i(n\vartheta-\omega t)}d\omega$$

The transforms a_n are calculated as integrals over the variable $Y=\tan\upsilon/2$.

We linearise the position of a star; $r=r_o+\delta$, $\vartheta=\vartheta_o+\Omega t+\lambda$ and $z=\zeta$ and define Fourier transforms for the perturbed quantities analogous to a_n. The linearised equations of motion are then solved for these transforms as functions of a_n and $\hat{a}_n\equiv\partial\hat{a}_n/\partial z_{z=0}$ ($\hat{a}_n$ is calculated as for a_n). The energy change of the disc is given by:

$$\Delta E = \int_{-\infty}^{\infty}\int_0^R\int_0^{2\pi} \partial U/\partial t\,\sigma(r)rdrd\vartheta dt$$

The 1st order terms average to zero and so we expand to 2nd order. The integral is then expressed in terms of the Fourier transforms. The ω contour is taken along the real axis with small indentations above the poles. Only the poles (resonant interactions) give a net energy transfer:
Corotation:

$$\Delta E = -\sum_{n=1}^{\infty}4n^2\pi^3\int_0^R a_n a_n^* \, d(\sigma/B)/dr\, dr \quad (\omega=n\Omega)$$

Lindblad:

$$\Delta E=\mp\sum_{n=1}^{\infty}\pi^3\int_0^R(n\Omega\mp\varkappa)(4n^2\Omega^2 a_n a_n^{*}\mp 2n\Omega r\varkappa d(a_n a_n^*)/dr+r^2\varkappa^2 a_n' a_n'^*)\sigma/(r\Omega\varkappa B)dr \quad (\omega=n\Omega\mp\varkappa)$$

$$\Delta E_z=+\sum_{n=1}^{\infty}4\pi^3\int_0^R\hat{a}_n\hat{a}_n^*\sigma(r)rdr \quad (\omega=(n\mp\eta)\Omega)$$

Radial:

$$\Delta E = +4\pi^3\int_0^R a_o' a_o'^*\sigma(r)rdr \quad (\omega=\varkappa)$$

$$\Delta E_z = +8\pi^3\int_0^R\hat{a}_o\hat{a}_o^*\sigma(r)rdr \quad (\omega=\eta\Omega)$$

($\varkappa^2=4\Omega B$; B=Oort's constant; $\eta\lesssim 1$). All energy exchanges are positive except the inner Lindblad term as $d(\sigma/B)/dr<0$.

In the impulsive limit the standard result can be rederived from the above formulae. The above integrals were evaluated for a disc with constant rotation velocity. The impulsive aproximation was found to be good for encounters with $V\gtrsim 3V_p$, where V_p is the parabolic velocity. For parabolic encounters the inner Lindblad resonance was found to dominate over almost all the parameter space. The disc component therefore tends to accelerate the perturber and inhibits merging. The effect is weaker for large inclinations.