RevMexAA (Serie de Conferencias), **44**, 98–98 (2014)

XIV Latin American Regional IAU Meeting (Florianópolis/SC, Brazil, 25-30 November 2013)
Editors: A. Mateus, J. Gregorio-Hetem & R. Cid Fernandes

GAP FORMATION IN CIRCUMBINARY AGN DISKS

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We study the formation of gaps in circumbinary disks of comparable mass massive black holes binaries (q ∼ 1) using numerical simulations. We vary the disk properties (mass, thermodynamics, etc.) and we found that the most massive and thickest disks are able to prevent the gap formation in them. We contrast our numerical results against analytical models of the angular momentum exchange between the binary and the disk. This models successfully predicts in which disks a gap is formed and are based on the gravitational interaction between the binary and a non-axisymetric density enhancement in the disk.

The gravitational interaction between a binary and a gas disk leads to an exchange of angular momentum. This exchange can perturb strongly the distribution of gas around the binary and, at some cases, can drive the formation of a central cavity or gap in the gaseous disk. This is illustrated in Figure 1 which shows the surface density of eight SPH simulations of circumbinary disks.

The different types of density profiles that are shown in the Figure 1 are also found in the literature and they can be associated to different time scales of the binary separation shrinking. For example for systems like the ones studied by Escala et al. (2005) and Dotti et al. (2006) (that correspond to the panels A and E of Figure 1) it is found that the coalescence time scale of the binary is of the order of a few initial orbital times. In contrast for systems like the ones studied by Artymowicz & Lubow 1994 and Milosavljevic & Phinney 2005 (that correspond to the panels C, D, G and H of Figure 1), it is found that the coalescence time is on the order of several thousands of local orbital times which for MBH $\geq 10^7 M_\odot$ is even longer than the Hubble time (Cuadra et al. 2009).

We model the exchange of angular momentum considering the gravitational interaction between the binary and the strong non-axisymmetric density perturbation that is produced in the circumbinary disk. Using this approach we found that the gap formation requires that

$$\frac{\alpha_{\rm ss}}{2K_{\rm q}}\left(\frac{c_{\rm s}}{v_{\rm gas}}\right)\left(\frac{v_{\rm gas}}{v_{\rm bin}}\right)^2\left(\frac{H_{\rm disk}}{a}\right)^2 \leq 1 \qquad (1)$$

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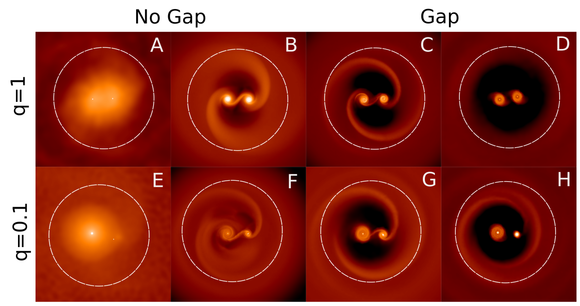

Fig. 1. Surface density of eight simulations. The white dashed line enclose the region $r < 2a$ of the disk. From left to right the figures show A and E: binary that is far from the gap-forming regime, B and F binary with parameters in the vicinity of the gap-forming regime that does not form a gap on the disk, C and G: binary that begins to excavate a gap on the disk and, D and H: binary that excavate a gap on the disk

where $H_{\rm disk}$ is the disk thickness, a is the binary separation, $\alpha_{\rm ss}$ is the dimensionless viscosity parameter of Shakura & Sunyaev (1973) and $K_{\rm q}$ is a dimensionless parameter that depends on the geometry of the density perturbation.

From this gap-opening criterion we estimate that, the SMBH binaries in the nuclear region of gas-rich galaxies mergers will typically fail to excavate a gap on the nuclear disk due to the high values of viscosity ($\alpha_{\rm ss} \sim 0.2$ - 1.0) on these regions. This will allow to the gas extract enough angular momentum from the binary to shrink it separation down to scales where gravitational wave emission can drive the final coalescence of the binary

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