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# The evolution of bulges of galaxies in minor fly-by interactions

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**Abstract.** We investigate the minor interactions of two disk galaxies with mass ratio of 10:1 in fly-by encounters that do not lead to the merging of the galaxies. In our N-body simulations, we vary only the pericenter distances to see the effect of the fly-by on the bulge of the major galaxy over the course of the trajectory. At different time steps of the evolution, we did two-dimensional fittings of disk, bulge and bar to trace the variation in the sersic index of the bulge. Our results suggest that galaxy bulges can become boxy/disky through flyby interactions of galaxies.

**Keywords.** Methods: N-body simulations, Galaxies: Bulges, Galaxies: Interactions

## 1. Introduction

Galaxies are the fundamental components of the large scale structure in the Universe. Morphologically, there are many types of galaxies in our universe, such as ellipticals, spirals and irregular galaxies. In the centers of most disk galaxies, there is usually a spherical or quasi-spherical shaped bulge that is composed of mainly old stars. Bulges are basically of two types : classical bulges that appear spherical in shape, and oval bulges that are less spherical in shape. Oval bulges are often called pseudo-bulges in the literature (Gadotti 2009). Classical bulges are dynamically hot and are supported by the random motion of the stars. But pseudo bulges are dynamically colder, flatter in shape and their stars show significant rotational motion. Pseudo bulges can be further divided into disky bulges and boxy/peanut bulges. Disky bulges are as flat as disks and look like the inner disks of galaxies but, boxy/peanut bulges have a vertical thickness out of the disk plane, and are always associated with bars (Laurikainen *et al.* 2016).

The similarity between classical bulges and elliptical galaxies suggests that they have a common formation history. Studies show that elliptical galaxies formed from the merger of smaller galaxies or the collapse of large gas clouds at early epochs. Similarly classical bulges are also thought to be formed from monolithic collapse of gas clouds and their growth is driven by the accretion of satellite galaxies. But pseudo bulges grow through the secular evolution of galaxies (e.g., Gadotti 2009; Kataria & Das 2018).

In the literature, there has been a lot of study of classical bulges and pseudo bulges in scenarios of mergers and secular evolution of the galaxies. But fly-by interactions, which do not lead to mergers, are largely ignored. In this study we show that fly-bys are also very important for the evolution of bulges in galaxies (Sinha *et al.* 2012). Here we discuss the results of our N-body simulations of the evolution of classical bulges in galaxies that undergo fly-by interactions with a much smaller galaxy.

## 2. Methods

We did N-body simulations of fly-by interactions of two disk galaxies with mass ratio 10:1 for varying pericenter distance ($r_p$). Each of the two galaxies consists of the classical

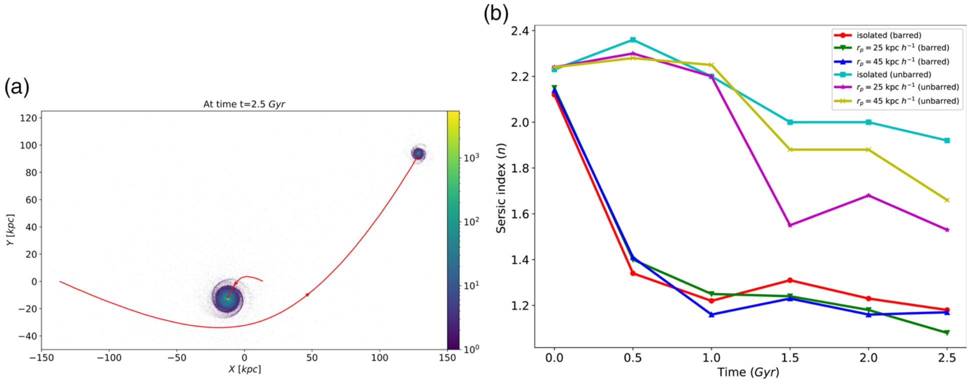


**Figure 1.** (a) Left: orbits of the galaxies for $r_p = 25\ kpc\ h^{-1}$ at t=2.5 Gyr. (b) Right: evolution of sersic index '$n$' of the major galaxy where '$h$' is hubble parameter ($H = 100\ h\ km\ s^{-1}\ Mpc^{-1}$).

bulge (hernquist profile), stellar disk (exponential profile) and dark matter halo (hernquist profile). The initial pairs of galaxies were generated separately using an open-source code GalIC (Yurin & Springel 2014). Our major galaxy has $10 \times 10^5$ halo particles, $5 \times 10^5$ disk particles and $1 \times 10^5$ bulge particles. To perform a fly-by, we put them on parabolic orbits (left panel of Fig. 1) and evolved them with an open-source code Gadget-2 (Springel 2005). We then did two-dimensional fittings of the disk, bulge and bar (if required) of the major galaxy using an open-source code Galfit (Peng *et al.* 2011) to track the evolution of the classical bulge in flyby interactions. We used sersic index '$n$' as a proxy to distinguish classical bulges from pseudo bulges. If $n > 2$ then it is a classical bulge and if $n < 2$ then it is a pseudo bulge (Fisher 2006).

## 3. Results and conclusions

Right panel of Fig. 1 shows the evolution of the classical bulge of two types of major galaxies: one with a bar instability and the other without bar instability. The classical bulges become boxy/disky either due to minor fly-by interactions or secular evolution. In the galaxies which have bar kind of instabilities, the evolution of classical bulge remains almost unaffected of fly-by interactions. But in galaxies which do not have bars, the evolution of the classical bulge is affected by fly-by interactions. The final diskyness of the bulge increases with decreasing pericenter distance ($r_p$).

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