SECULAR DYNAMICAL EVOLUTION OF SPIRAL GALAXIES AND THE FORMATION OF GALACTIC BULGES

XIAOLEI ZHANG
Harvard-Smithsonian Center for Astrophysics
60 Garden St., MS 78, Cambridge, MA 02138, USA

Abstract. We show that a recently discovered spiral-induced radial mass accretion process could account for the formation of the Galactic Bulge in a Hubble time. This process is thus expected to be important in the formation of bulges in spiral galaxies, and in the secular evolution of galaxies along the Hubble sequence from late to earlier types.

1. Introduction

The past proposed bulge bulge formation mechanisms include the primordial mechanisms and the evolutionary mechanisms. While the primordial bulge formation mechanisms would have a hard time explaining the observed age and abundance gradient of bulge stars, the past proposed evolutionary mechanisms, which focus mainly on the radial gas accretion and on the vertical pumping of stars through bar resonances, could not explain why many late type galaxies show no evidence for a bulge, even though they were found to contain bars. Furthermore, the bar-driven vertical resonant pumping mechanism alone, without a corresponding radial accretion flux from the outer disk to the inner disk, could not explain the observed correlation between abundance and kinematics for the bulge stars; the radial accretion of the interstellar medium alone also is not capable to gather enough matter to account for the formation of those massive bulges in early type galaxies.

2. Secular Heating of the Disk Stars and Secular Radial Mass Accretion Induced by a Quasi-Stationary Spiral Structure

It has recently been found that spiral galaxies undergo significant redistribution of disk surface density during their lifetime, through a collective

Y. Sofue (ed.), The Central Regions of the Galaxy and Galaxies, 29-30.

https://doi.org/10.1017/S0074180900083868 Published online by Cambridge University Press

dissipation process induced by the galactic spiral structure. The detailed description of this process can be found in Zhang (1996) and Zhang (1998a).

In the above papers, is was shown that through the spiral induced collective dissipation process an average star inside corotation radius tends to drift towards the central region of a galaxy. During its radial migration, the random velocity of the star also increases through the very same collective dissipation process, due to the difference in the pattern speed Ω_p of the wave and the circular speed Ω of the stars. Because this heating is due to a local gravitational instability, it is three-dimensional in nature and all three spatial components of a star's random velocity increase as a result of spiral-induced heating. The radial profile of stellar velocity dispersion produced by this heating process has increasing velocity dispersion with decreasing galactic radius. Consequently, when the vertical component of a star's velocity dispersion becomes comparable to its circular velocity, the star will rise out of the galactic plane and become a bulge star.

3. Formation of the Bulge of Our Galaxy

As an example, we now estimate the rate of mass accretion for the formation of the Bulge of our Galaxy. Assuming that the spiral pattern during the past 10^{10} years has an average pitch angle of 20^o, and 20% fractional amplitude around the solar neighborhood, the radial orbital decay rate of an average star due to the presence of the spiral can be found to be about $2kpc$ in 10^{10} years (Zhang 1998b). Furthermore, we use an average local surface density of $\Sigma \approx 60 M_\odot pc^{-2}$, the rate of radial inflow of mass is therefore $dM/dt = 2\pi r dr_*/dt \Sigma \approx 0.8 M_\odot/yr$. This means that in a Hubble time the amount of mass accreted towards the center of the Galaxy is of the same order as the mass of the Galactic Bulge, $10^{10} M_\odot$.

4. Implications

The spiral-induced secular evolution process leads to the gradual central concentration of matter in a galaxy, together with the build-up of an extended outer envelope. It therefore leads to the evolution of the Hubble type of a galaxy from late to early. The mass accretion in the outer disk is also the preparatory stage for the triggering of nuclear activity in galaxies, through the formation of nuclear structures associated with the inner Lindblad resonances (Zhang et al. 1993).

References

Zhang X. 1996, ApJ 457, 125
Zhang X. 1998a, ApJ 494, in press
Zhang X. 1998b, ApJ submitted
Zhang X., Wright M., Alexander P. 1993, ApJ 418, 100