A New Method of Determining the Pattern Speed of the LMC

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Abstract. We focus on the idea proposed by de Vaucouleurs that constellation III would be regarded as the Lagrange point in a rotating non-axisymmetric bar potential. Based on this idea, we identify the center of constellation III with the Lagrange point L4 and have determined the pattern speed of the LMC as 21 ± 3 km/s/kpc. Using this pattern speed, we estimate the velocity with which the constellation III captures matter around, and we find that the estimated value of velocity is consistent with the observation. In this presentation, using the LMC we describe our method of determining a pattern speed and present the dynamics around each of the Lagrange points in detail.

1. Introduction

In galactic dynamics, one of the fundamental parameters is a pattern speed that describes the angular speed of rotation of a bar or spiral arms. So far, many authors proposed methods to estimate the pattern speed of galaxies, based on various assumptions. Tremaine & Weinberg (1984) proposed an analytic form of the pattern speed as a function of velocity and surface brightness (or mass), assuming that they satisfy the continuity equation in the disk. Canzian (1993) showed how to determine the corotation radius through the change in residual velocity field if the spiral density wave is present. However, these methods cannot be applied straightforwardly to the LMC, because active star-forming regions are distributed irregularly and the spiral structure in this galaxy does not play a major role on the velocity field. In this work, based on simple dynamics we developed a new method for determining the pattern speed and applied it to the LMC.

2. Method and Discussion

Our method is based on the fact that the location of Lagrange points related to the pattern speed. We consider a non-axisymmetric potential composed by the disk and the bar rotating with the pattern speed \( \Omega_p \). Figure 1 (Left) shows contours of the effective potential in corotating frame, which is characterized by five equilibrium points called Lagrange points. The linear perturbation analysis shows that the Coriolis force makes \( L_4 \) and \( L_5 \) stable (Binney & Tremaine 2008), so that gases are likely to gather, which triggers star formation. A star forming region far away from the bar may be explained by this scenario, and if so, finding such regions will reveal the location of Lagrange points. Let \( V_L \) and \( r_L \) denote the rotation speed at the Lagrange point and the distance...
Figure 1. Contours of the effective potential of asymmetric galaxy for two case: the co-centered bar with the disk (Left) and the off-centered bar with the disk (Right). The points marked L are Lagrange points.

between dynamical center and the Lagrange point, respectively. Since \( L_4 \) and \( L_5 \) are corotating, we have \( V_L = r_L \Omega_p \).

The LMC, composed of prominent bar and disk, has active star formation, and a region of the highest star formation is located far from the bar, which is called Constellation III. One of the important features of the LMC is the off-centered bar from the dynamical center (de Vaucouleurs 1973). Figure 1 (Right) shows the effective potential of a LMC-like galaxy with an off-centered bar. In this case, \( L_5 \) becomes unstable, so that a star formation would occur only on the one side of the bar, which is reminiscent to the situation in the LMC if we regard Constellation III as \( L_4 \). Based on this idea, we can determine the pattern speed of the LMC as \( 21 \pm 3 \) km/s from the 21 cm observation (Luks 1992).

We also examined the motion of gas around the stable Lagrange point, where the Coriolis force and centrifugal force are balanced. As a result, we found a relation between the size of gas and its rotational velocity. In the cases of Constellation III, the observed radius of \( \sim 0.5 \) kpc implies that the velocity of trapped gas cannot exceed \( \sim 20 \) km/sec. Dopita et al. (1985) reported three peaks in the spectrum of Constellation III, which are interpreted as Doppler shifted HI lines due to expanding star formation region. If Constellation III is actually rotationally supported, three peaks indicate rotational velocity of \( \sim 18 \) km/sec, which is close to our above estimation. Application of our method to other Magellanic-type galaxies is now in progress.

References

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de Vaucouleurs, C., G. K Freeman 1973, Structure and Dynamics of Barred Spiral galaxies, in particular of the Magellanic Type (Pergamon Press)