Recent Advances in Star Formation: Observations and Theory
ASI Conference Series, 2012, Vol. 4, pp 139 – 143
Edited by Annapurni Subramaniam & Sumedh Anathpindika

Recent star formation history of the Large and Small Magellanic Clouds

G. Indu* and Annapurni Subramaniam†
Indian Institute of Astrophysics, Bengaluru 560034, India

Abstract. Recent interactions between the Large and the Small Magellanic Clouds (LMC and SMC) and the Milky Way can be understood by studying their recent star formation history. We traced the age of the last star-formation event (LSFE) in the inner Large and Small Magellanic Cloud (L&SMC) using the photometric data in V and I passbands from the Optical Gravitational Lensing Experiment (OGLE-III) and the Magellanic Cloud Photometric Survey (MCPS). The spatial distribution of the age of the LSFE shows that the star-formation has shrunk to within the central regions in the last 100 Myr in both the galaxies. We detect peaks of star-formation at 0 - 10 Myr and 90 - 100 Myr in the LMC, and 0 - 10 Myr and 50 - 60 Myr in the SMC. We propose that the HI gas in the LMC has been pulled to the north of the LMC in the last 200 Myr because of the gravitational attraction of our Galaxy at the time of perigalactic passage. The shifted HI gas was preferentially compressed in the north during the time interval 200 - 40 Myr and in the north-east in the last 40 Myr, owing to the motion of the LMC in the Galactic halo. The recent star-formation in the SMC is due to the combined gravitational effect of the LMC and the perigalactic passage.

Keywords : galaxies: Magellanic Clouds – galaxies: star-formation – stars: formation – galaxies: evolution – galaxies: kinematics and dynamics

1. Introduction

The Large and Small Magellanic Clouds (LMC & SMC) were believed to be long term satellites to our Galaxy and the bursts of star formation episodes seen in both

*email: indu@iiap.res.in
†email: purni@iiap.res.in

the Clouds were attributed to their perigalactic passage and the tidal effects (Harris & Zaritsky 2004). On the other hand, the recent estimates of the proper motion of the Clouds find that the Magellanic System is probably passing close to the Milky Way (MW) for the first time (Besla & Kallivayalil 2007). Thus the star formation episodes which were attributed to the perigalactic passage need to be reconsidered. In this work, we study the pattern of recent star formation in the Clouds, with specific interest to trace the origin and nature of the interaction which caused it. To achieve a better spatial as well as temporal resolution, we adopted a different method of identification of the main sequence (MS) turn-off, to trace the propagation of star formation.

2. Data and analysis

This study makes use of two photometric catalogs produced by the third phase of Optical Gravitational Lensing Experiment (OGLE-III Udalski, Soszynski, Szymanski et al. (2008a), Udalski, Soszynski, Szymanski et al. (2008b)) and the Magellanic Cloud Photometric Survey (MCPS Zaritsky, Harris, Thompson et al. (2002), Zaritsky, Harris, Thompson et al. (2004)). In this statistical study we do area binning with different bin sizes, to identify the turn-off magnitude and estimate the age of the last star formation event (LSFE). For uniformity, we use the V and I photometric data from both the catalogs.

The reddening is estimated and the turn-off magnitude is corrected for extinction. The corresponding ages are estimated using Marigo et al. (2008) isochrones. The spatial map of age of the LSFE is used to identify the presence of any propagating star formation. **LMC:** The estimated extinction A_v of the LMC is compared with that of Zaritsky, Harris, Thompson et al. (2004) in the form of statistical distribution and found to be more or less similar. The peaks of both the distributions coincided at A_v = 0.5 mag. The top left panel of figure 1 shows the LSFE map of the LMC with an age range of 0–120 Myr. We deprojected the map to the plane of the LMC in which the line of nodes lie at the same position angle as in the sky plane using the conversion relations from (van der Marel 2001). The age of the LSFE is found to increase progressively when we go towards the outer regions. The average age is around 20 Myr in the central regions, whereas it is about 80 Myr near the periphery. There are more number of star forming regions in the north of the LMC, compared to the southern LMC. With respect to the optical center at RA = $5^h19^m38^s$; Dec = -69°27"5.2' (J2000.0 de Vaucouleurs, G. & Freeman (1973)), one can notice a lopsidedness in the recent star formation towards the northern regions. We also show concentric circles of radius 2°, 3°, & 4° with respect to the center to substantiate this point. We studied the distribution of HI clouds using the data from Kim et al. (2007) in the LMC plane. The massive HI clouds are seen to be preferentially populated in the north compared to the south. The spatial distribution of young clusters (age <120 Myr) from Glatt et al. (2010) was also studied in the LMC plane. The young (≤ 40 Myr) clusters seem to accumulate in the north-east north direction, except for a small group in the south-west of the bar, probably due to the presence of the bar. We summarise that

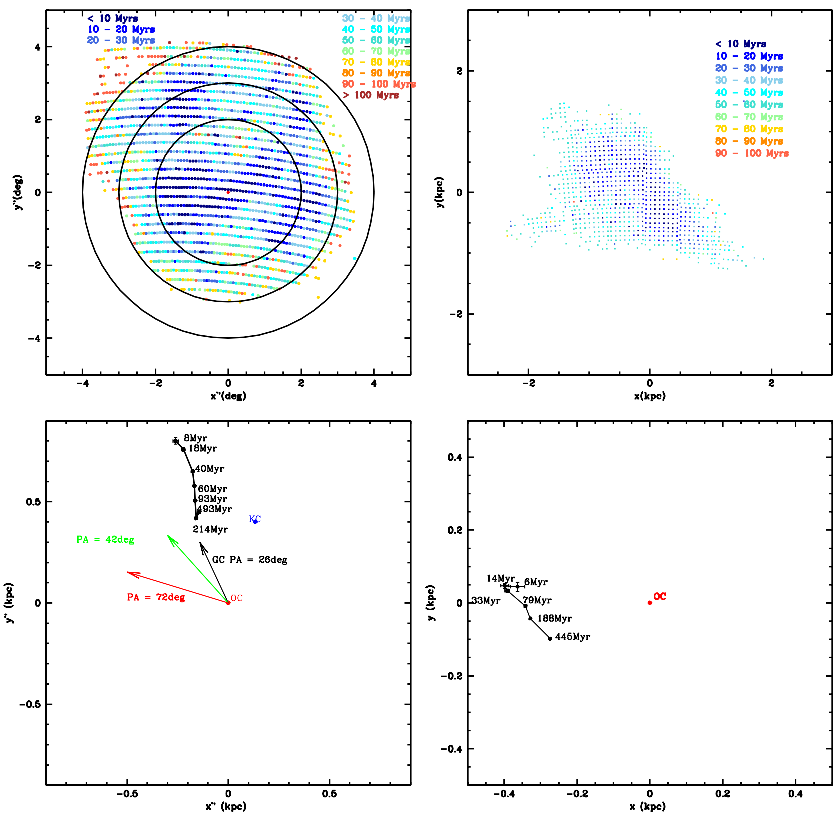

Figure 1. Top left:The LSFE map of the LMC color coded according to the age. Top right: The LSFE map of the SMC color coded according to the age. Bottom left: The centers of the stellar population in the LMC for various ages with error bars. The direction of velocity vector of the LMC is shown in red at a position angle of 72^o, (calculated from the proper motion values provided by Piatek et al. (2008)) & the line of interaction of the MW & the LMC according to our convention at a position angle of 26^o. The direction given in van der Marel (2001) is shown in green. KC is the HI kinematic center (shown in blue), & OC is the optical center (shown in red) of the LMC. Bottom right: Similar center plot for the SMC, here OC is the SMC optical center. The plots of the LMC is shown in the deprojected plane whereas the SMC plots are in the sky plane.

the clusters in the age range 60 - 100 Myr show lopsidedness towards north, whereas clusters younger than 40 Myr show lopsidedness towards north and north-east. This might suggest that the north-east enhancement in the star formation is likely to have happened in the last 40 Myr, whereas the northern enhancement is seen in the last 100 Myr. We have seen that the ages estimated for the sub-regions are similar to the ages of youngest clusters in the vicinity. To study this shift in the distribution of young population as a function of age we used MS star counts to estimate the distribution of stars younger than a particular age using MCPS data. In the MS, stars brighter than a cut-off magnitude are identified. The age tagged with such a population will be the age of the oldest population in the group. The centers of stellar population in the LMC plane, for various ages are shown in bottom left panel. The center of the distribution does not shift between 500 - 200 Myr, even though a small shift towards the south can be noticed. We find that the center of the distribution of stars shifts northward in the age range 200-40 Myr, and the center is found to shift in the north-east direction for population younger than 40 Myr. It can be seen that the direction of shift of the center is almost in the direction towards the Galactic center. The LMC is moving past our Galaxy after the closest approach. Thus the lopsidedness in the stellar as well as HI distribution to the north may be due to the gravitational attraction of our Galaxy on the gas of the LMC disk and the enhanced compression in the northern regions. The movement of the LMC could cause compression of the gas in the north- eastern side resulting in enhanced star formation in the north-east. The center shifts and the time-scales derived in this section can be used to understand the details of the above two processes on the gas resulting in star formation.

SMC: The extinction towards the SMC is estimated and compared with the values of Harris & Zaritsky (2004). In general, both distributions match well and both have a peak in the range, 0.2 - 0.4 mag. The spatial distribution of age of the LSFE in the sky plane is estimated and the maps are presented in figure 1 top right panel. We find that the star formation in the inner SMC is not very structured, when compared to the LMC. We could identify the eastern wing in the map. Most of the inner regions have experienced star formation in the last 0 - 20 Myr. Similar to the LMC, we find a marginal evidence for outside to inside quenching of star formation in the last 60 Myr. The north-east and the south-west substructures of the LSFE age map match well with the locations of high HI column density. We used MS stars younger than various age cut-offs to study the shift of centroids in the SMC. The data used here is OGLE III, taking in to account its higher resolution and larger number of stars. Since the geometry of the SMC is not well understood, the center of the distribution of these stars are estimated in the x & y coordinates (with respect to the optical center RA = $0^h52^m12.5^s$; Dec = -72°49″43′ (J2000.0 de Vaucouleurs, G. & Freeman (1973))) as shown in the bottom right panel of figure 1. We detected a shift in the center between 500 - 200 Myr in the north-east direction which may be due to this star formation episode and enhanced star formation in the north-eastern region. This may also be due to the appearance of the wing in this age range. We detected an enhanced center shift in the 200 - 30 Myr age range, which could be caused by the gravitational attraction of our Galaxy during the perigalactic passage.

3. Summary and conclusions

The recent star formation in the Clouds is dictated by the perigalactic passage. We found an off-centred radially inward propagating star formation in both the LMC &

the SMC. The star formation peaks found at 0–10, 90–100 Myr in the LMC & 0–10, 50–60 Myr in the SMC correlate well with the previous studies. HI gas in the LMC is preferentially located in north. The stellar population & cluster population younger than 40 Myrs are lopsided towards north-east. We propose that the HI gas in the LMC is pulled to the north as a result of the perigalactic passage 200 Myr ago. There is an enhanced star formation in the last 40 Myr due to effective compression of gas towards north-east caused by the LMC's movement in the galactic halo.The combined gravitational effect of the LMC and the MW dominates the recent star formation in the SMC.

References

Besla G., Kallivayalil N., 2007, ApJ, 668, 949
de Vaucouleurs G., Freeman K. C., 1973, Vistas Astron., 14, 163
Glatt K., Grebel E. K., Koch A., 2010, A&A, 517, 50
Harris J., Zaritsky D., 2004, AJ, 127, 1531
Harris J., Zaritsky D., 2009, ApJ, 138, 1243
Kim S., Rosolowsky E., Lee, Y., 2007, ApJS, 171, 419
Marigo et al., 2008, A&A 482, 883
Piatek S., Pryor C., Olszewski E. W., 2008, AJ, 135, 1024
Pietrzynski G., Udalski A., 2000, AcA, 50, 337
Udalski A., Soszynski I., Szymanski M., et al., 2008, Acta Astron., 58, 89
Udalski A., Soszynski I., Szymanski M., et al., 2008, Acta Astron., 58, 329
van der Marel R. P. 2001, AJ, 122, 1827
Zaritsky D., Harris J., Thompson I. B., et al., 2002, AJ, 123, 855
Zaritsky D., Harris J., Thompson I. B., et al., 2004, AJ, 128, 1606