Large-Scale Gravitational Instability and Star Formation in the Large Magellanic Cloud

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Large-scale star formation in disk galaxies is hypothesized to be driven by global gravitational instability (Li, Mac Low, & Klessen 2005). The observed gas surface density is commonly used to evaluate the strength of gravitational instability, but according to this criterion star formation often appears to occur in gravitationally stable regions. One possible reason is that the stellar contribution to the instability has been neglected. We have examined the gravitational instability of the Large Magellanic Cloud (LMC) considering the gas alone, and considering the combination of collisional gas and collisionless stars. We compare the gravitationally unstable regions with the on-going star formation revealed by *Spitzer* observations of young stellar objects (YSOs) (Gruendl et al., in preparation).

To derive the total gas surface density distribution, we combine the HI column density map of Kim et al. (2003) and the NANTEN CO survey (Fukui et al. 1999, 2001) with heavy-element corrections. The resulting map is shown in Figure 1a. In addition, we use the rotation curve from Kim et al. (1998) to find the epicycle frequency. The Toomre stability parameter for the gas Q_g can then be calculated locally, as shown in Figure 1b. The region where $Q_g < 1$ is gravitationally unstable for a gas-only thin disk against axisymmetric perturbations. Also marked are the massive YSOs indicating current star-forming sites. As shown in the top panel of Figure 2, only 62% of the YSOs are in regions where the gas alone is unstable. A significant fraction of the star-formation activity cannot be accounted for by considering only the gas component.

We further employ the instability condition for a composite disk consisting of collisional gas and collisionless stars (Gammie 1992; Rafikov 2001). To find the stellar surface density distribution, we use the number density of asymptotic giant branch (AGB) and red giant branch (RGB) stars and normalize it with the total stellar mass deduced from the rotation curve. The resulting map is shown in Figure 1c, and the derived stability parameter for the star+gas disk Q_{sg} is shown in Figure 1d along with the massive YSO candidates. Some 85% of the YSOs lie in regions unstable due to the combination of gas and stars, as shown in the bottom panel of Figure 2. The combined stability analysis better describes where star formation occurs. In agreement with other observations and numerical models, a small fraction of the star formation occurs in regions with gravitational stability parameter $Q > 1$.

We also measure the dependence of the YSO surface number density, a rough indicator of the star formation timescale, on the strength of gravitational instability, as shown in Figure 3. An exponential dependence exists, which is also found from global analysis of numerical simulations (Li et al. 2005). The resemblance between the results from local and global analyses will be further investigated.

Conclusion: ***By measuring the strength of gravitational instability in the LMC and comparing to the locations of current star-formation, we conclude that large-scale gravitational instability can be responsible for the majority of star formation activity. The stellar contribution to the instability must not be ignored. The star formation rate depends exponentially on the strength of instability.***

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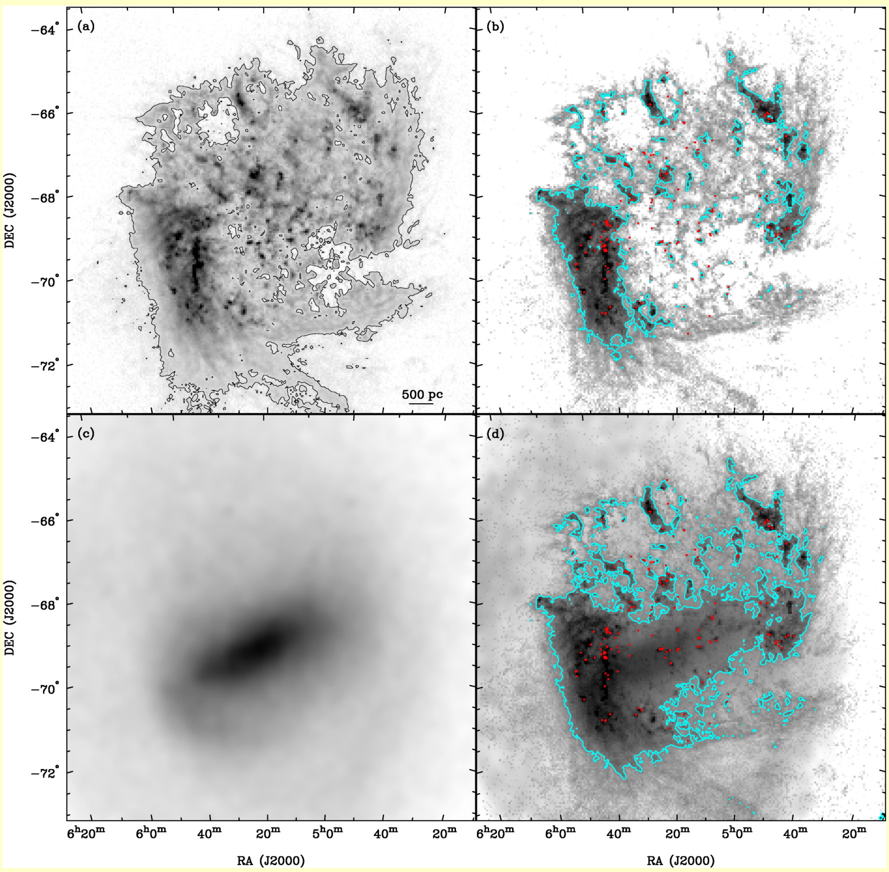

Fig. 1 – (a) Total gas surface density distribution in the Large Magellanic Cloud. Only neutral species are included in this map. The grayscale runs linearly from 0 to 100 $M_\odot$ pc^{-2}. The contour lines show a surface density of 4 $M_\odot$ pc^{-2}. (b) Comparison between massive star-forming sites traced by young stellar object candidates (*red dots*) and regions where the gas alone is gravitationally unstable. The Toomre parameter for the gas Q_g is shown in grayscale, running logarithmically from 5.0 to 0.2. The *solid* lines delineate the critical value of $Q_g = 1$ inside which the regions are gravitationally unstable. (c) Total stellar surface density distribution. The grayscale runs linearly from 0 to 200 $M_\odot$ pc^{-2}. (d) As in (b), but for regions where the gas and stars together are gravitationally unstable, rather than just the gas alone.

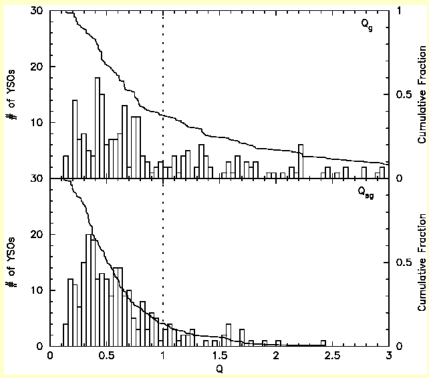

Fig. 2 – Number distribution of YSO candidates with respect to the Toomre stability parameter of the pixel in which they are located. The *top* and *bottom* panels show respectively the Toomre parameters for the gas alone Q_g, and the stars and gas together Q_{sg}. The *solid* lines show the cumulative fractions of YSOs with decreasing Q. The vertical *dotted* lines denote the critical value $Q = 1$.

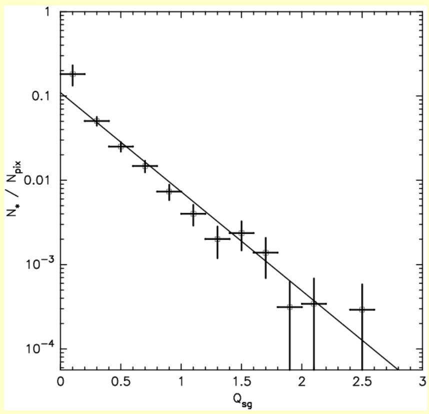

Fig. 3 – Ratio of the number of YSO candidates N_* to the number of pixels N_{pix} in each Q_{sg} bin, denoted by squares. The vertical error bars are estimated by Poisson statistics, while the horizontal error bars show the bin sizes. The *solid* line is the best-fit, of slope -2.7 ± 0.2.