Probing the mass accretion process in the Large Magellanic Cloud

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Introduction: Investigating the star formation history of the Magellanic Clouds (MCs) is one of the most obvious goals in the study of nearby galaxies, for it keeps a record of the past interactions between both the Clouds and the Milky Way, which are still to be properly understood. Moreover, the MCs are also a rich laboratory for studying of star formation and evolution thanks to the simultaneous presence of a wide variety of interesting objects such as pre-main sequence (PMS) stars, red clump giants, carbon stars, planetary nebulae, etc. In the past two decades, many authors have demonstrated that such studies are indeed feasible using deep Hubble Space Telescope (HST) optical imaging. In particular, we have recently presented a novel method to determine the PMS mass accretion rate (M_{acc}) that relies solely on HST photometry. The knowledge of the M_{acc} is of paramount importance to constrain the models of star formation and early stellar evolution and has so far mostly relied on spectroscopy, which has proved hard or impossible to obtain in dense, distant star-forming regions. We have now started a pilot project aiming at applying this technique to the existing and extensive HST photometry of star-forming regions in the Milky Way and MCs.
In this contribution, we present the first results of this study in four 3'×3' areas in the Large Magellanic Cloud (LMC) located between the 30 Doradus star forming complex and the supernova SN1987A (Fig.1). The observations were performed with HST/WFPC2 in the f300w (U), f450w (B), f606w (V), f656n (Hα) and f814w (I) filters; these data were acquired from February 1999 to November 2003. The four selected regions present different environmental conditions (such as vicinity to OB stars and amount of interstellar gas and dust) and are then expected to be site of different star formation events.

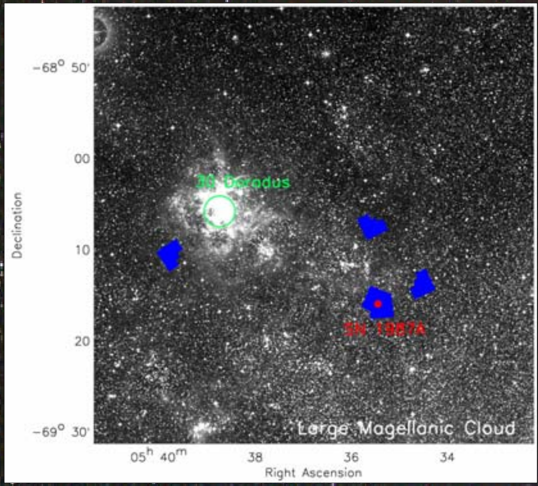


Fig.1 SDSS image of a 40'×40' area in the LMC. The blue polygons display the four regions observed with HST/WFPC2.

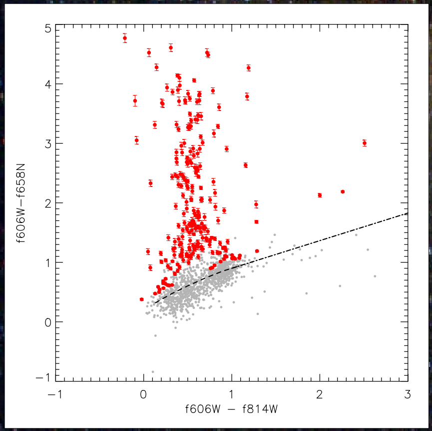


Fig.2 V-Hα vs. V-I diagram for stars in one of our fields. Stars with photometric errors smaller than 0.1 mag in V, I and Hα (grey dots) define the reference template of normal stars with no Hα emission (dashed line). Stars with emission exceeding 4 times the photometric uncertainty are highlighted in red.

Method: We select PMS stars in each of the four fields and determine their mass accretion rates using narrow-band Hα and broad-band V and I dereddend photometry, as described in De Marchi et al. (2009, ApJ, in press). Since we expect differential reddening, we divide each of the four field in 22 regions each 32"×32" in size and obtain the V vs. (V-I) diagram for each sub-image. The reddening in each of these snapshots is then determined by applying a method similar to that described in Piotto et al. (1999, AJ 118, 1727). We use the median (V–Hα) dereddened colour of stars with small (≤0.1) photometric errors in the three (V, I and Hα) bands, as a function of (V–I), to define the reference template with respect to which the excess Hα emission is sought (Fig.2). We select a first sample of stars with excess Hα emission by considering all those with a (V–Hα) colour above that of the reference line by 4 times their intrinsic photometric uncertainty. Then we derive the equivalent width of the Hα emission ($EW_{H\alpha}$) from the measured colour excess ($\Delta H\alpha = H\alpha_{ref} - H\alpha_{star}$). We finally consider as *bona fide* PMS stars those objects with $EW_{H\alpha}$>20Å and V-I>0; this allows us to clean our sample from possible contaminants (i.e. older stars with chromospheric activity and Ae/Be stars, respectively). We derive the effective temperature (T_{eff}), radius (R*) and luminosity (L*) of our *bona fide* PMS stars from their dereddened (V-I) colour and V magnitude. We adopt the distance of 51.4 kpc to the LMC and use the tabulation of HST/WFPC2 photometry as a function of T_{eff} by Bessel et al. (1998, A&A 333, 231). Mass (M*) and age of each star are then derived by comparing its L* and T_{eff} with expectations from the theoretical evolutionary models for PMS stars calculate on purpose by P. G. Prada Moroni for the metallicity of the LMC (Z=0.007). The mass accretion rate is finally derived from the free-fall equation as:

$$\log M_{acc}\,(M_\odot/yr) = -7.39 + \log L_{acc}/L_\odot + \log R^*/R_\odot - \log M^*/M_\odot$$

where L_{acc} is the energy released by the accretion process, directly proportional to the Hα luminosity (Dahm 2008, AJ 136, 521).

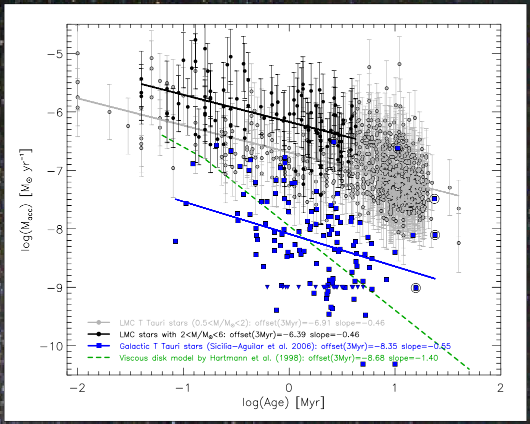
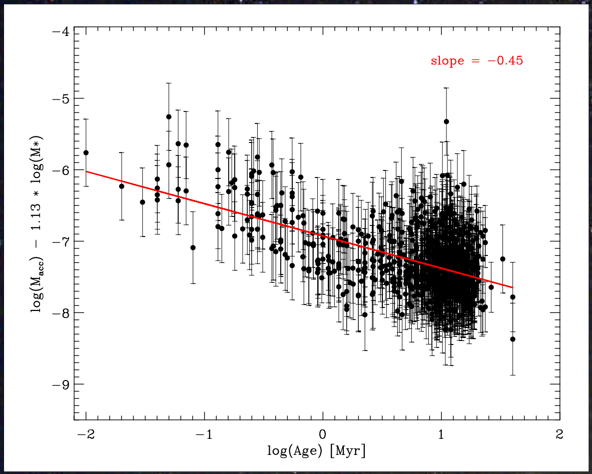


Fig.3 Mass accretion rate vs. age for PMS stars in the LMC and the Galaxy. Symbols and lines are as in the legend.

Results: We have determined the mass accretion rates of about 950 *bona fide* PMS stars in the LMC with mass between 0.5 and 6 $M_\odot$ and age between 0.01 and 25 Myr, thereby increasing by a factor of five the current sample of PMS stars with a measured M_{acc}.

Fig.4 Mass accretion rate to stellar mass ratio as a function of age for PMS stars in the LMC. The red line is the fit to the points.



➢ We find that M_{acc} considerably increases for younger PMS stars and is a strong function of stellar mass, in line with both the theory of stellar evolution and observations of PMS stars in our Galaxy. As shown in Fig. 3, we find that M_{acc} decreases with age as $\log M_{acc} \propto (\log Age)^{-\alpha}$ where α=0.50±0.03 for TT stars (0.5<M/$M_\odot$<2) and α=0.47±0.08 for more massive PMS stars (2<M/$M_\odot$<6), though M_{acc} values for these latter are systematically higher by a factor of 0.5 dex in log(M_{acc}). For the sample of galactic TT stars by Sicilia-Aguilar et al. (2006, AJ 132, 2135, and reference therein), we find an α-slope (0.55±0.13) consistent within the errors with the LMC PMS stars, though the relation is more scattered. Both in the LMC and in the Galaxy, M_{acc} seems to decrease slower than predicted by the viscous disk evolution model by Hartmann et al. (1998, ApJ 495, 385).

➢ M_{acc} for galactic PMS stars appears to be proportional to the stellar mass squared over a wide range in stellar mass (Vorobyov et al. 2008,ApJ 676, L139; Natta et al. 2006, A&A 452, 245; Muzerolle et al. 2005, ApJ 625, 906; Sicilia-Aguilar et al. 2006, AJ 132, 2135). However, this relation still contains an intrinsic scatter due to the age dependency of M_{acc}. In order to investigate the simultaneous dependency of M_{acc} on M* and Age, we performed a double linear regression fit, setting M* and age as independent variables and M_{acc} as dependent variable (Fig.4). In a logarithmic scale, we find that M_{acc} increase almost linearly with the stellar mass and decreases approximately with the square root of age:

$$\log [M_{acc}\,(M_\odot/yr)] = -6.91 + (1.13\pm0.15) \times \log [M^*/M_\odot] - (0.45\pm0.03) \times \log [Age\,(Myr)]$$

➢ Finally, our results further confirm that the accretion rates for TT stars in the LMC are systematically higher, by up to a factor of ten, than for Galactic TT stars of the same age (see offset values at 3 Myr in Fig.3). Our sample of TT stars in the LMC is biased toward higher masses (0.5<M/$M_\odot$<2) with respect to the galactic sample, which goes down to the brown dwarf regime. However, the same result has been found by De Marchi et al. (in preparation) using a sample of PMS stars with 0.4<M/$M_\odot$<0.8 in the Small Magellanic Cloud. This might indicate that M_{acc} is also inversely proportional to the stellar metallicity ($M_{acc} \propto Z^{-1}$). This hypothesis needs further investigation.