# A journey across the M33 disk

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Abstract. The Local Group member M33 is a pure disk galaxy bearing no prominent bulge or stellar halo. It constitutes a challenge for any hierarchical galaxy formation theory and an ideal laboratory for studying quiescent star formation. Using multiwavelength observations of the gas and stellar component in this nearby galaxy we are able to constrain the gas accretion and star formation history. In the centermost region we find kinematical evidence of a weak bar, which explains the central light excess and the enhanced metallicity. In the more extended disk the lack of strong gradients of metal and dust abundances supports the picture that the slow radial decline of the star formation rate is due to a change in the large scale disk perturbations: bright HII regions and giant molecular clouds being born only in the inner disk. The analysis of the infrared Spitzer maps has however revealed hundreds of low luminosity star forming sites in places with a variety of dust content. These are essential ingredients for understanding the overall gas to star formation process in M33 and in more distant late type galaxies.

### 1. Introduction

Our knowledge of the processes in the interstellar medium that favor the birth of stars is mostly based on Galactic studies and on luminous, gas rich galaxies with high star formation rates. Scaling factors across our galactic disk are difficult to estimate, being our Sun deeply embedded in it. Imaging the gas and the newly star forming sites in external galaxies with high sensitivity and resolution is necessary in order to evaluate whether the ingredients necessary to trigger star formation vary along the Hubble sequence, to identify the role of large scale perturbations and to define the relationship of newly born stars to other ISM components across the disk. Before the next generation of telescopes will resolve distant galaxies with a wide range of physical and dynamical properties, it is desirable to focus on the closest galaxies. M33, at a distance of 840 kpc (Freedman, Wilson & Madore 1991), has a high star formation rate per unit area compared to M31 and a low extinction towards star forming regions. It bears no prominent bulge and no signs of recent mergers. In addition, star counts in the outer disk indicate that any stellar halo component contributes for less than a few percent to the total luminosity (Barker et al. 2006; McConnachie et al. 2006). It is therefore a prototype for any meeting focused on 'disk galaxies', a challenge for any hierarchical galaxy formation theory, and a reference point for any evolutionary scenarios involving blue, low luminosity objects. Being relatively undisturbed, its blue color and prominent HII regions require some quiescent feeding mechanisms to sustain the extended star formation activity.

We outline here some aspect of the gas pathway to stars: from the needs of gas accretion to the formation of molecular clouds, from the imprints of a weak central bar to properties of the outermost star forming sites.

## Fueling star formation across the disk

The innermost 1 kpc region of M33 deserves particular attention of the because the enhancement in the light distribution, metal abundance and molecular hydrogen surface density. Recent optical observations of gas and stellar radial velocities in this region (Corbelli & Walterbos 2007) show ordered but noncircular motion down to about 1" from the center. The most likely explanation for the observed velocity patterns are streaming motions along a weak inner bar with a position angle close to that of the minor axis, consistent with the central enhancements.

Using the rotational velocity gradient and the surface density of baryonic matter, derived by the mass model fit to rotational data, it is possible to explain the 7.5 kpc size of the star forming disk of M33. The disk is in fact gravitationally unstable for R < 7.5 kpc according to the Toomre stability criterion for a two component fluid: the gas and the stars (Corbelli 2003). Inside this region and excluding the innermost 1 kpc, the radial variations of several quantities are very shallow: the atomic to molecular gas ratio is  $\propto R^{0.6}$  (Heyer et al. 2003), the O/H metallicity gradient is  $\leq 0.07 \text{ dex kpc}^{-1}$  (Magrini et al. 2007; Rosolowsky & Simon 2007), the gas surface density and the dust to gas ratio are almost constant (Verley et al. 2008, to be submitted). However the spiral pattern is much more prominent for R < 4 kpc and most of the giant molecular clouds lie inside this region. One possibility is that the fading of the spiral pattern, coincident with the corotation radius or with the outer Lindbland resonance of the bar, limits the formation of giant clouds and large stellar complexes. A comparison between single dish and interferometric surveys of the CO J=1-0line moreover shows that Giant Molecular clouds contain only a small fraction of the total molecular mass (Corbelli 2003, Engargiola et al. 2003, Heyer et al. 2004, Gardan et al. 2007) and that the mass spectrum is much steeper than our Milky Way (Blitz & Rosolowsky 2005). The atomic to molecular gas conversion in a galaxy with a low molecular fraction like M33 (about 10% of the total gas mass inside the star forming disk is molecular) is regulated by the balance between the interstellar radiation field and the hydrostatic pressure due to stars and gas (Elmegreen 1993; Heyer et al. 2003). Fragmentation then locks most of the mass in small clouds. It is still unclear whether these are all gravitationally bound units but they are the main triggers of star formation at large radii.

A chemical evolution model for M33, constrained by the distribution of stars, gas, and chemical abundances in stellar populations of different ages, shows that a continuous gas infall of about  $1 M_{\odot} \text{ yr}^{-1}$  is needed to fuel a star formation and that this is slowly declining with cosmic time (Magrini, Corbelli, & Galli 2007). The model and 21-cm observations (Westmeier, Braun & Thilker 2005) favor an extended phase for the inside-out formation of the disk, with the intergalactic medium providing the gas supply to it.

#### The Cluster Birthline

From the  $24\mu m$  Spitzer map of M33 (Verley et al. 2007) we extracted hundreds of sources which have H $\alpha$  counterpart (Hoopes & Walterbos 2000). Most of these sources are likely to be young stellar clusters, and the proximity of M33 gives the possibility of selecting even the low luminosity ones, which contain only single OB associations, or clusters not massive enough to have made an O-type star. We can look in detail to the properties of sites where clusters of different masses are born and evolve. Verley et al (2007) have already shown that the relation between the infrared luminosity and H $\alpha$  for these sources has a large scatter. In general, if one looks to young clusters of different masses the expected relation is far from being linear and depends on the Initial Mass Function and on the fraction of the bolometric luminosity absorbed by dust and re-emitted in the infrared. Figure 1 shows this expected relation for a Salpeter IMF (dashed line) under the assumption that most of the cluster bolometric luminosity is radiated by the surrounding dust in the infrared. We shall call this relation The Cluster Birthline. From left to right the cluster luminosity as well as its mass and its maximum stellar mass increase. Star symbols indicates the corresponding values for single main sequence stars, of spectral type equal or later than O3. We infer the total infrared luminosity (between 3-1100  $\mu$ m) using Eq. (1) of Calzetti et al. (2006) and an  $8\mu m/24\mu m$  flux ratio equal to unity, as it is on average in M33 (i.e.  $L(TIR) = \log L(24) + 0.908$ ). Data should all lie above the sequence marked by the star symbols and mostly around the Cluster Birthline if the dominant population are young star clusters. Any aging, extinction, as well as the loss of ionizing photons leaking out from the HII region will bring the data points above it. Instead there are few points above the birthline and many below it. The conclusion is that the abundance of dust around those sources is low and varying and that the bolometric luminosity of most sources is recovered only complementing the IR photometry with UV and optical data. This will be shown in detail in a forthcoming paper. The fraction of bolometric luminosity absorbed by grains and re-emitted at IR wavelengths is higher for the most luminous sources which are surrounded by high column density gas (filled points in the figure with  $N_{Htot} > 10^{21} \text{ cm}^{-2}$ ). The absence of sources in the bottom right corner of the figure is due to the absence of stars more massive than O3 type stars in our sample.

### Conclusions

The M33 disk is made up of four distinct zones: the central one where there is kinematic evidence for a weak bar. This limit the ability to constrain the dark matter density profile in its center and in more distant, less resolved galaxies. The second zone is the inner disk, where spiral arms trigger the formation of giant molecular clouds and of bright star forming sites. The third one, at larger galactocentric radii, where active star formation proceeds in smaller subunits. These give a substantial contribution to the global star formation rate and have a patchy dust to gas ratio. And finally the outer regions. Here a warped outer disk is in place, linking the active star forming disk to the environment, to the surrounding intergalactic space, which is providing the fuel to star formation.



Figure 1. Total Infrared Luminosity (TIR) of  $24\mu$ n selected sources with H $\alpha$  counterpart (square symbols) versus the TIR/H $\alpha$  luminosity ratio. The dashed curve is the Cluster Birthline, where young stellar clusters with a Salpeter IMF should lie. Filled square symbols are for sources in a high column density environment. Open star symbols are the expected values for single main sequence stars. The dash-dotted line connects the expected values for single O3 stars to clusters which have their maximum stellar mass equal to an O3-type star. See Section 3 for more details.

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#### References

- Barker, M. K., Sarajedini, A., Geisler, D., Harding, P., & Schommer, R. 2006, Astron. J., 133, 1138
- Blitz, L., & Rosolowsky, E. 2005 in The Initial Mass Function 50 years later. eds. E. Corbelli, F. Palla, & H. Zinnecker, ASSL 327 (Springer:Dordrecht), p.287
- Calzetti, D. et al. 2005, ApJ, 633, 871
- Corbelli, E., & Walterbos, R.A.M. 2007, ApJ, 669, 315
- Elmegreen, B. G. 1993, ApJ, 411, 170

Engargiola, G., Plambeck, R. L., Rosolowsky, E. & Blitz, L. 2003, ApJS, 149, 343

- Freedman, W. L., Wilson, C. D., & Madore, B. F. 1991, ApJ, 372, 455
- Gardan, E., Braine, J., Schuster, K. F., Brouillet, N., & Sievers, A., 2007, A&A, 473, 91
- Heyer, M. H., Corbelli, E., Schneider, S. E., & Young, J. S. 2004, ApJ, 602, 723
- Hoopes, C. G., & Walterbos, R. A. M. 2000, ApJ, 541, 597
- Magrini, L., Corbelli, E., & Galli, D. 2007, A&A, 470, 843
- McConnachie, A. W., Chapman, S. C., Ibata, R. A., et al. 2006, ApJ, 647, 25
- Rosolowsky, E., & Simon, J. D., 2007, ApJ, in press
- Verley, S., Hunt, L. K., Corbelli, E., & Giovanardi, C. 2007, A&A, 476, 1161
- Westmeier, T., Braun, R., Thilker, D. 2005, A&A, 436, 101