Can molecular clouds live long?

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It is generally accepted that the lifetime of molecular clouds (MCs) does not exceed $3x10^7$ yr due to disruption by stellar feedback. We put together some arguments giving evidence that a substantial fraction of molecular clouds (primarily in the outer regions of a disc) may avoid destruction process for at least 10^8 yr or even longer. A molecular cloud can live long if massive stars are rare or absent. Massive stars capable to destroy a cloud may not form for a long time if a cloud is low massive, or stellar initial mass function is top-light, or if there is a delay of the beginning of active star formation. A long duration of the inactive phase of clouds may be reconciled with the low amount of the observed starless giant molecular clouds if to propose that they were preceded by slowly contraction phase of the magnetized dark gas, non-detected in CO-lines.

Molecular clouds
(two ways of evolution)

VOLGA
View On the Life of GAlaxies

Collisions of gaseous flows (the expanding envelopes, supersonic turbulence, large-scale density waves)	Magnetogravitational instabilities of interstellar medium
↓ Mainly unbound	↓ Mainly bound
↓ Short lifetime is $<10^7$ yr. Clouds are disrupted by shear motions or by stellar feedback soon after the beginning of star formation due to radiation pressure, stellar winds, SN explosions and the expansion of HII regions.	↓ Long lifetime is about 10^8 yr or more. A delay of formation of massive stars may play a crucial role.

The relative role of these two ways of cloud formation is the subject of our interest. Are there regions of galaxies where the less popular slow evolution of clouds plays a larger role?

Cases of a long lifetime

We can interpret some observations as a delay of gas in molecular phase:

– There is a significant amount of H_2 in molecular gas-rich galaxies remains non-involved in the process of star formation (Kasparova & Zasov 2006, Shetty+2014).

– The scaleheights (perpendicular to the Galactic disc) of the giant MCs as a function of their mass gives evidence that they have achieved approximate energy equipartition. This requires the clouds to survive at least several cloud-cloud scattering times $>10^8$ yr (Scoville 2013).

Central regions of discs

1. To support a balance condition of transitions between molecular and atomic gas in the interior of galaxies where H_2 dominates in mass compared to HI the lifetime of a molecular gas may be as large as 10^9 yr (Scoville 2013).

2. In the inner part of M33 the position of GMCs does not correlate with the HI distribution. It was shown that dynamical friction may really change the orbits of GMCs in the central 2-kpc region. However, in this case the typical lifetimes of GMCs should be close to or greater than 10^8 yr, which is larger than the usually accepted values (Zasov & Khoperskov 2015).

Interarm space

The star formation does not destroy the giant MCs in the arms completely, but it breaks them into smaller molecular clouds (Koda+2009, Egusa+2010, Sawada+2012).

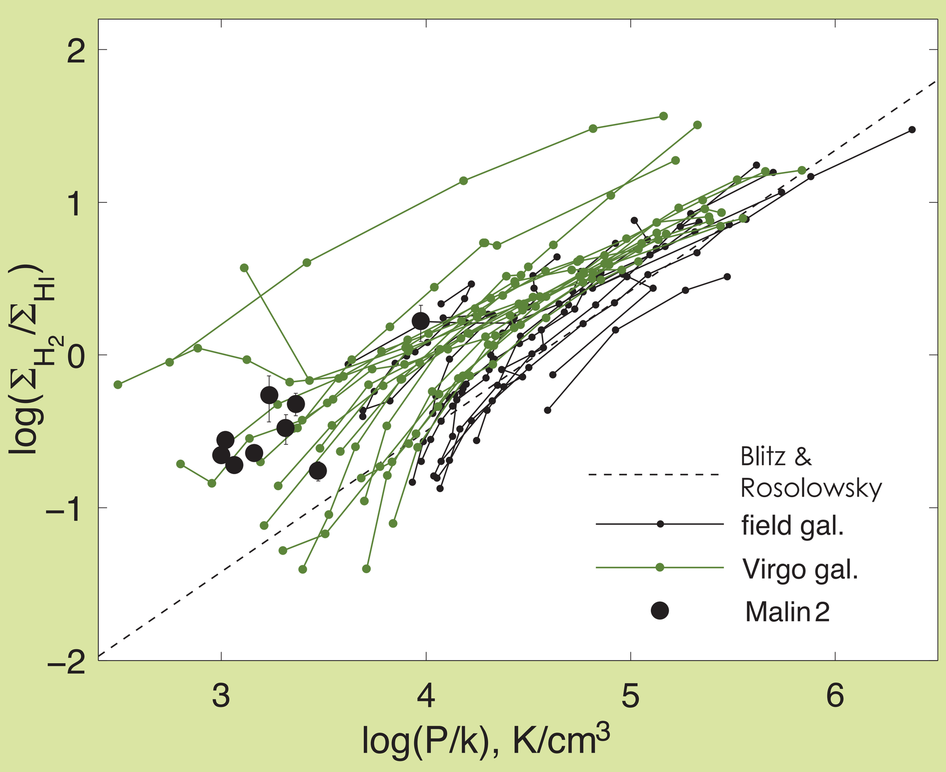
Star formation in tidal structures

In most cases, the surface density of HI clouds far from parent galaxies is very low, which excludes gravitational instability. If the clouds were drawn from the galactic periphery, their age is about 10^8 – 10^9 years.

Disc peripheries

The molecular to atomic gas fraction in the periphery of some HI-deficient Virgo galaxies and in the disc of giant LSB galaxy Malin 2 is unusually high for a given gas pressure (Kasparova 2012, Kasparova+2014).

Since the Virgo galaxy undergo the ram pressure, the observed excess of molecular gas should be in the form of clouds but not diffuse.



Pros and cons

1. The most observation facts supporting the short lifetime refer mainly to the **massive** molecular clouds ($>10^6 M_{sun}$):
– such clouds are rare observed outside the arms of spiral galaxies (or in HI filaments in such galaxies as LMC). Such clouds are destroyed within $\sim 10^7$ yr;
– their average age measured using the star clusters is 10^6 – 10^7 years (Murray 2011, Kawamura+2009).

2. Models show that the energy of young **massive** stars is enough to destroy the MCs. However, there are reasons to believe that the formation of massive stars needs a special conditions, so that in some molecular clouds thay may not be formed.

3. There may be two different interpretations of the low frequency of occurrence of starless MCs (Jijina+2009, Ballesteros-Paredes & Hartmann 2007, Gratier+2012). Either the mean lifetime of MCs is very short which favours their origin in colliding flows or the observed star-forming clouds do not contain a bulk of molecular gas in the Galaxy. A growth of gas density during the process of formation of MCs may begin long before they reach their observed density (Dobbs et al. 2012).

The survival conditions of clouds (or how to provide their longevity)

I. A lack of massive stars

Top-light IMF

– There are some reasons to suspect the deficit of massive stars for dwarf (McWilliam +2013) and for LSB galaxies (Lee+2004);

– The flatter the density profile of the cloud nucleus, the less the probability of a massive star arising (Girichidis+2011);

Low massive clouds

– For MCs with mass $<10^5$ Msun a mean lifetime may reach 10^8 yr or more even in the case of continuing star formation with the usually adopted IMF, because the massive stars as the principal agents of cloud destruction are rare (Williams & McKee 1997);

– A study of spiral galaxy M33 shows a significant fraction of low massive MCs at large radial distances (Gratier+2012).

II. Delay of star formation

The other way to provide a longevity of MCs is to assume that there is a mechanism which inhibits a fast cloud contraction and delays the beginning of formation of dense cores and stars.

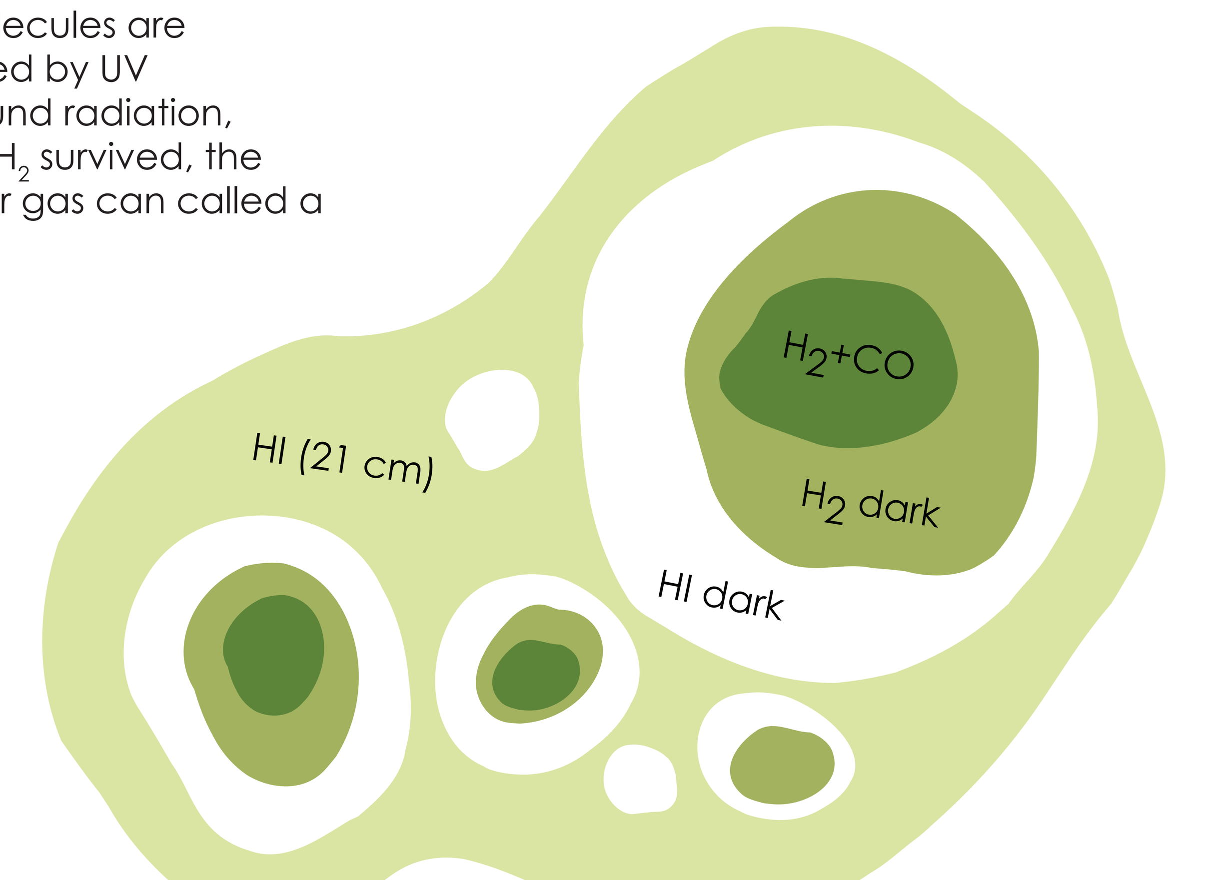
There are reasons to assume a crucial role of **magnetic field** at all stages of evolution of MCs:

– non-random geometry of magnetic field inside of clouds found in M33 and in our Galaxy evidences that the field governs the internal dynamics of clouds (Li & Henning 2011; Li+2014);

– in many cases the magnetic energy clearly prevails over other types of internal energies (Giannetti+2013; Heyer+2009).

Ambipolar diffusion and dark gas

If CO-molecules are dissociated by UV background radiation, whereas H_2 survived, the molecular gas can called a dark.



A total mass of the dark gas in the Galaxy is comparable with the total mass of CO-traced molecular gas, especially in the outer parts of galactic disc where it prevails.

The cloud will avoid collapse a very long time, if **ambipolar diffusion** is not efficient enough (Basu & Dapp 2010; Bertram+2012).

The analytical expression for the ambipolar diffusion time depends on gas ionization, determined by balancing the rate of the ion formation with the rate of their recombination. And taking into account the degree of ionization of the gas dark ($Xi \sim 10^{-4}$):

$$t_{AD} \sim 1.6 \times 10^{14} Xi \sim 10^8 - 10^9 \text{ yr}$$

It confirms that the gravitational contraction of a subcritical cloud containing a dark gas may be slowed down by magnetic tension for a long time interval.

Summary

We put together several arguments supporting the idea that at least a fraction of gravitationally bound molecular clouds may live much longer that it is usually accepted (up to $\sim 10^8$–10^9 yr). In particular, it may explain a high H_2 over HI ratio in the peripheries of HI-deficient Virgo galaxies experienced a ram pressure, as well as the observed star formation in the tidal structures and in the intergalactic space far from parent galaxies. Most probably, in these cases molecular gas is not in equilibrium with HI.

We considered two possibilities for MCs to have a long lifetime:

1. A low probability of formation of massive stars, capable to destroy a cloud, if a cloud mass is low ($<10^4$ Msun) or stellar IMF is top-light;

2. A delayed star formation in MCs. The latter scenario may be reconciled with the small amount of the observed starless GMCs if to propose that molecular clouds slowly formed from the magnetized CO-silent (dark) gas before they become detected in CO-lines. This picture agrees with the observations revealing a large amount of dark gas in the Galaxy, especially at large radial distance.

For more details see:
A. Zasov and A. Kasparova, Astrophys Space Science (2014) 353:595–602