

# SURVIVAL AND DISRUPTION OF OPEN CLUSTERS IN ENCOUNTERS WITH MOLECULAR CLOUDS

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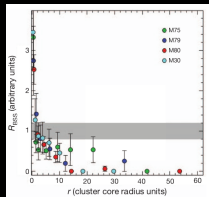
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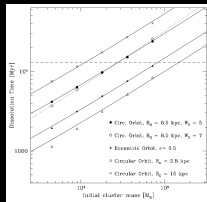
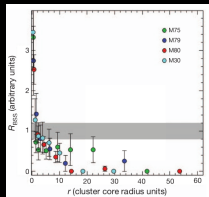
# Star clusters are evolving systems



(Ferraro et al. 2015)

- ☀ Relaxation, energy equipartition
- ☀ Dynamical mass segregation

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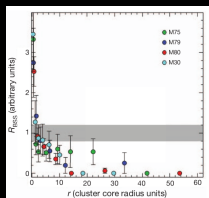
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- Dynamical mass segregation

(Baumgardt & Makino 2003)

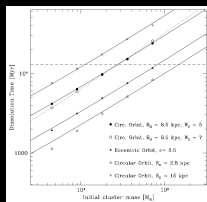
- Tidal field of the galaxy
- It facilitates cluster evaporation.

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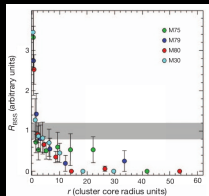
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(Bahcall & Hut 1983)

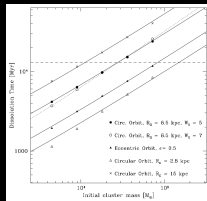
- Dynamics of binary stars.
- Dynamical hardening, softening.
- Halting core collapse.
- Production of runaway and walkaway stars

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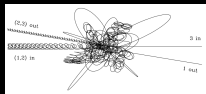
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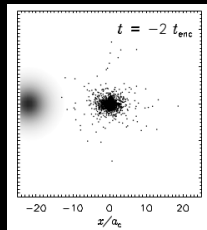
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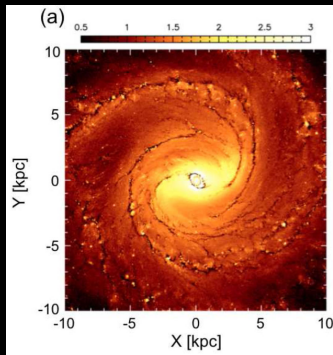
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(Gieles et al. 2006)

- Molecular clouds
- Current models idealised (spherical and static GMCs).

# Star clusters subjected to the Galactic gaseous environment

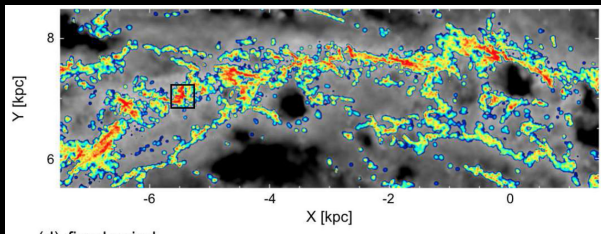


(Baba, Morokuma-Matsui, Saitoh 2017)

- The interstellar medium of the Galaxy is far from being spherically symmetric.
- The same holds for the assumption of being static.
- We opt for as much realistic interstellar medium as possible.

# Star clusters subjected to the Galactic gaseous environment

- Detailed SPH simulations including stellar feedback from HII regions and SNe due to Baba et al. 2017.
- Particle mass of  $750 M_{\odot}$ .

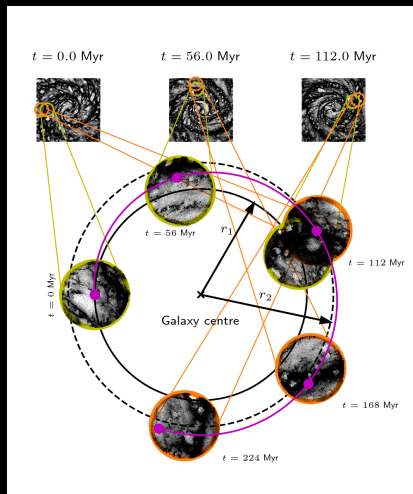


(Baba, Morokuma-Matsui, Saitoh 2017)

- NBODY6 code (Aarseth 2003) with modifications.
- Each star is subjected to the gravitational attraction of all other stars in the cluster.
- The smooth (analytic) gravitational field of the Galaxy.
- The gravitational field of each gaseous particle within radius of 500 pc from the cluster.
- We pre-calculate the position of each of the gaseous particles.

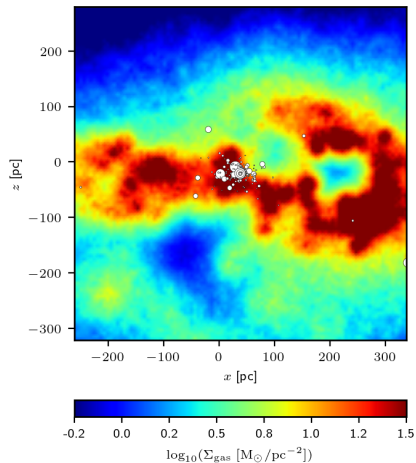
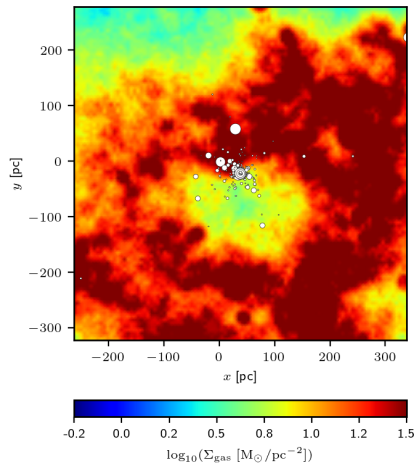
# Numerical approach

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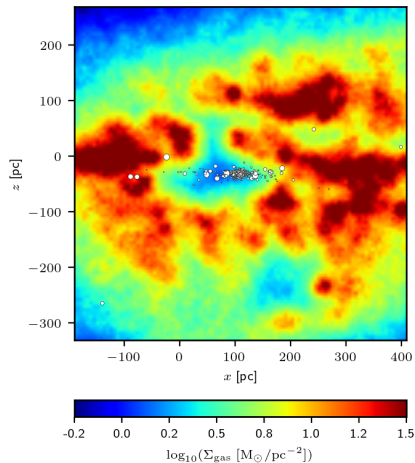
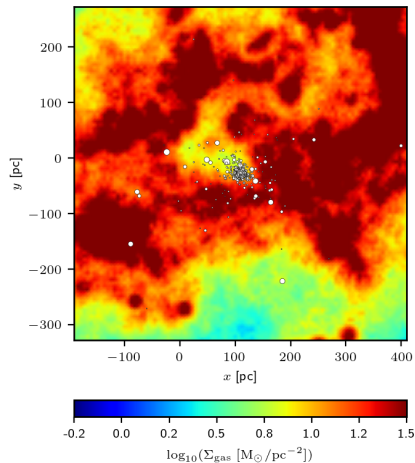
# Cluster dissolution under the influence of the ISM

$t = 13.6$  Myr



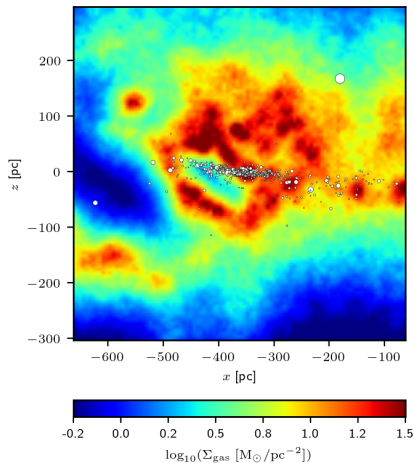
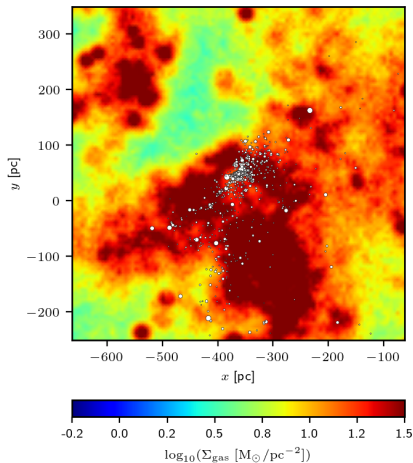
# Cluster dissolution under the influence of the ISM

$t = 27.3$  Myr



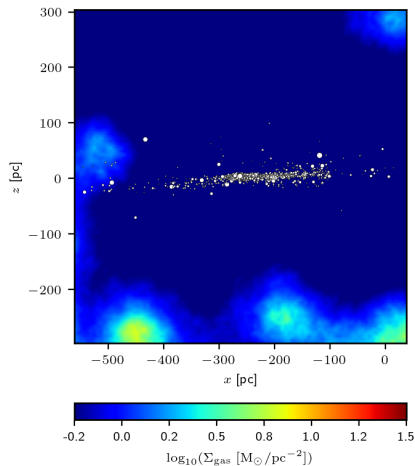
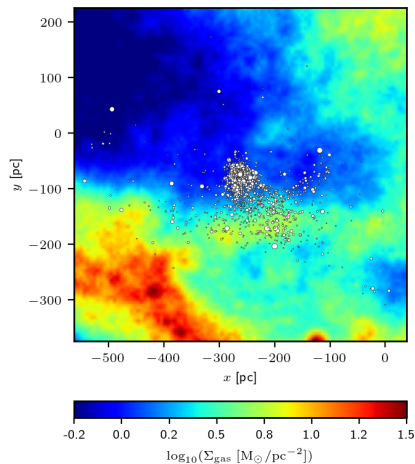
# Cluster dissolution under the influence of the ISM

$t = 211.4 \text{ Myr}$

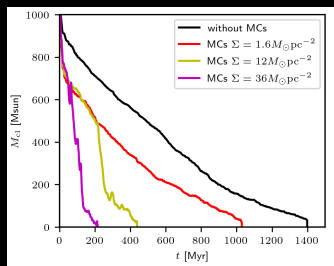


# Cluster dissolution under the influence of the ISM

$t = 243.7 \text{ Myr}$

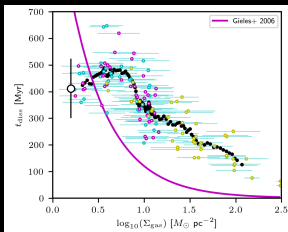


# Cluster dissolution under the influence of the ISM

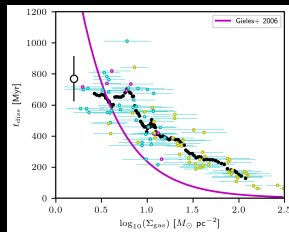


- Without gas (black line), the cluster is dissolved at 1400 Myr, very close to the analytic formula provided by Baumgardt & Makino (1440 Myr;  $t_{\text{lf}} \propto M_{\text{cl}}^{-0.75}$ )
- The cluster life-time decreases with increasing the gaseous surface density.

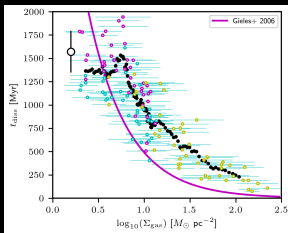
# The cluster dissolution time-scale



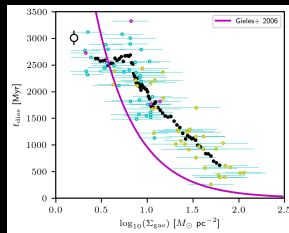
$$M_{\text{cl}} = 100 M_{\odot}$$



$$M_{\text{cl}} = 300 M_{\odot}$$

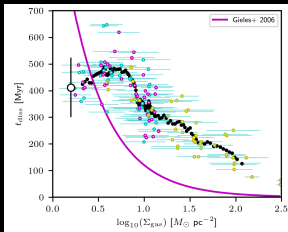


$$M_{\text{cl}} = 1000 M_{\odot}$$

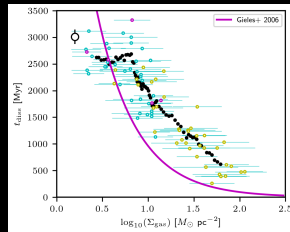


$$M_{\text{cl}} = 3000 M_{\odot}$$

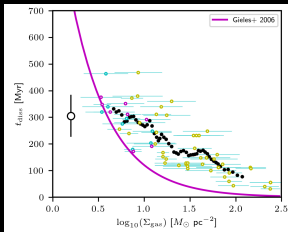
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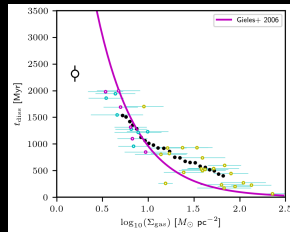
$M_{\text{cl}} = 100 M_{\odot}$ ;  $R_{\text{cl}} = 8 \text{ kpc}$



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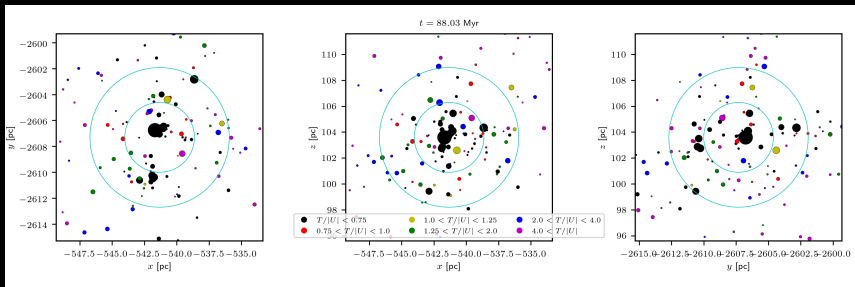


$M_{\text{cl}} = 100 M_{\odot}$ ;  $R_{\text{cl}} = 5 \text{ kpc}$

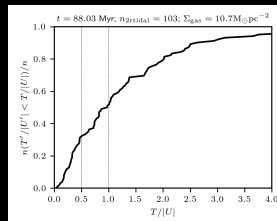
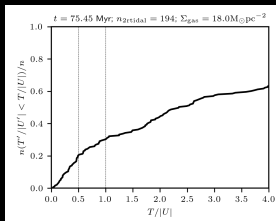
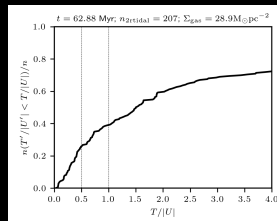
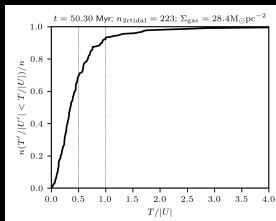


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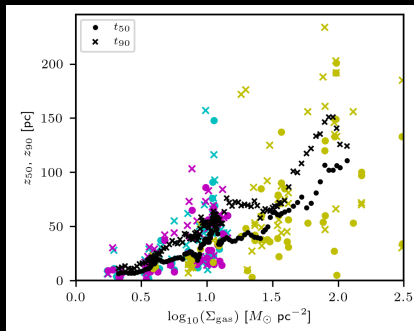
# Binding energy of stars during a GMC encounter



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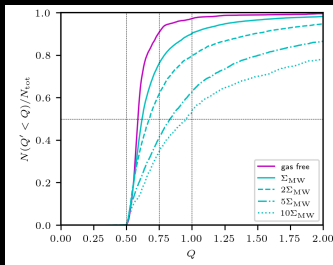


# The scattering of clusters out of the galactic disc

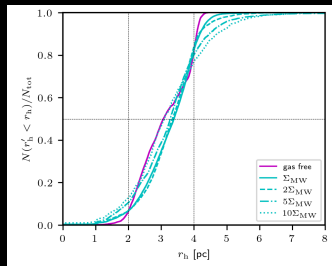


- The ISM is anisotropic.
- As the clusters get scattered out of the Galactic mid-plane, the encounter rate with GMCs decreases.
- The clusters move around the mid-plane in a similar way as harmonic oscillators ( $v_{\text{plane}} [\text{km s}^{-1}] \approx 0.1 z_{\text{max}} [\text{pc}]$ ).
- Since  $\Delta E \propto v^2$ , the encounters are less destructive.

# The dynamical state of the clusters



- The clusters have elevated virial ratio under the influence of the ISM.



- The half-mass radii of the clusters are not substantially affected by the ISM.

- The presence of the interstellar medium reduces the life-time of open star clusters.
- The influence is both on more massive and lower mass clusters.
- Clusters get scattered out of the Galactic mid-plane → they live for longer than expected previously.
- Many open clusters are expected to be supervirial as the outcome of encounters with molecular clouds.
- There is negligible influence of molecular clouds on the half-mass radius.

Thank you for your attention