Molecular cloud disruption and chemical enrichment of the ISM caused by massive star feedback

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Interactions between stars and the ISM

Massive stars have a drastic impact on the interstellar medium (ISM). Their Wolf-Rayet winds and subsequent supernovae shape the ISM and enrich it with heavy elements. These processes can be studied with the radioactive trace element ^{26}Al. It is mainly produced in massive stars and supernova explosions and can therefore serve as a valuable means to understand their interaction with the ISM. Its average lifetime of 1 Myr is long enough to trace the flow but not long enough to fully mix with the ISM.

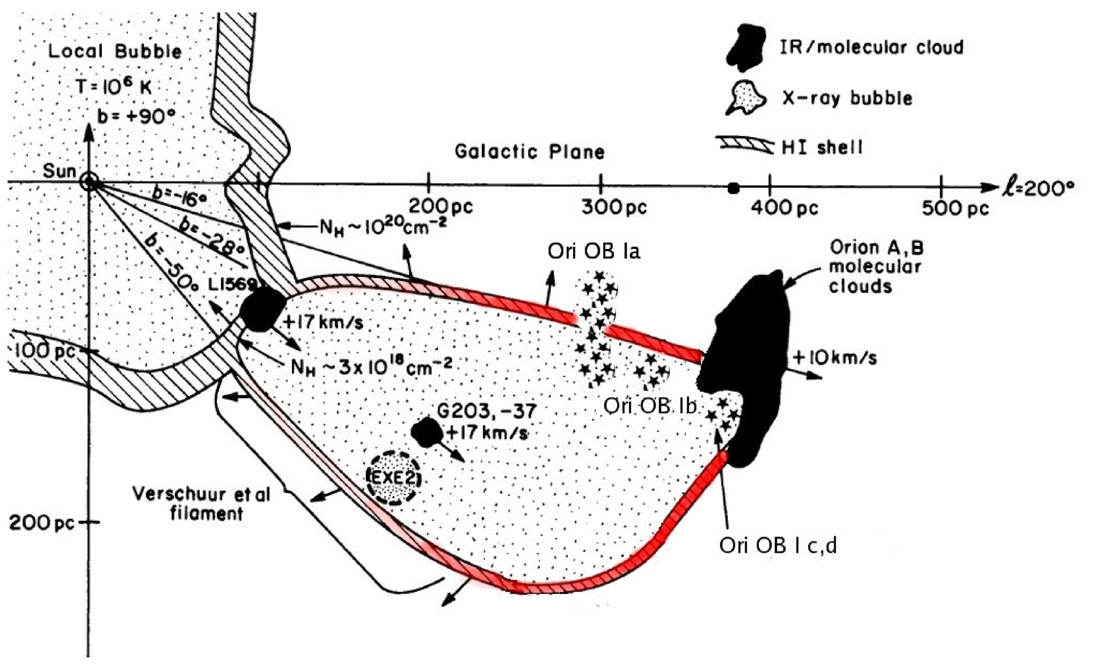

Figure 1. *Sketch of the Orion Eridanus superbubble's shape and the ^{26}Al distribution therein (Burrows et al. 1993; Diehl et al. 2004) adapted to Voss et al. 2010 distances.*

A good example of a well observed region revealing such interactions between stars and the ISM is the Orion-Eridanus superbubble (OES). An ^{26}Al signal from this region was reported by Diehl et al. (2004). The current model, that was derived from multiwavelength observations, is shown in figure 1.

Stellar feedback models

To better understand how OB associations shape the ISM surrounding them, we perform numerical simulations with recent models for time-dependent stellar feedback.

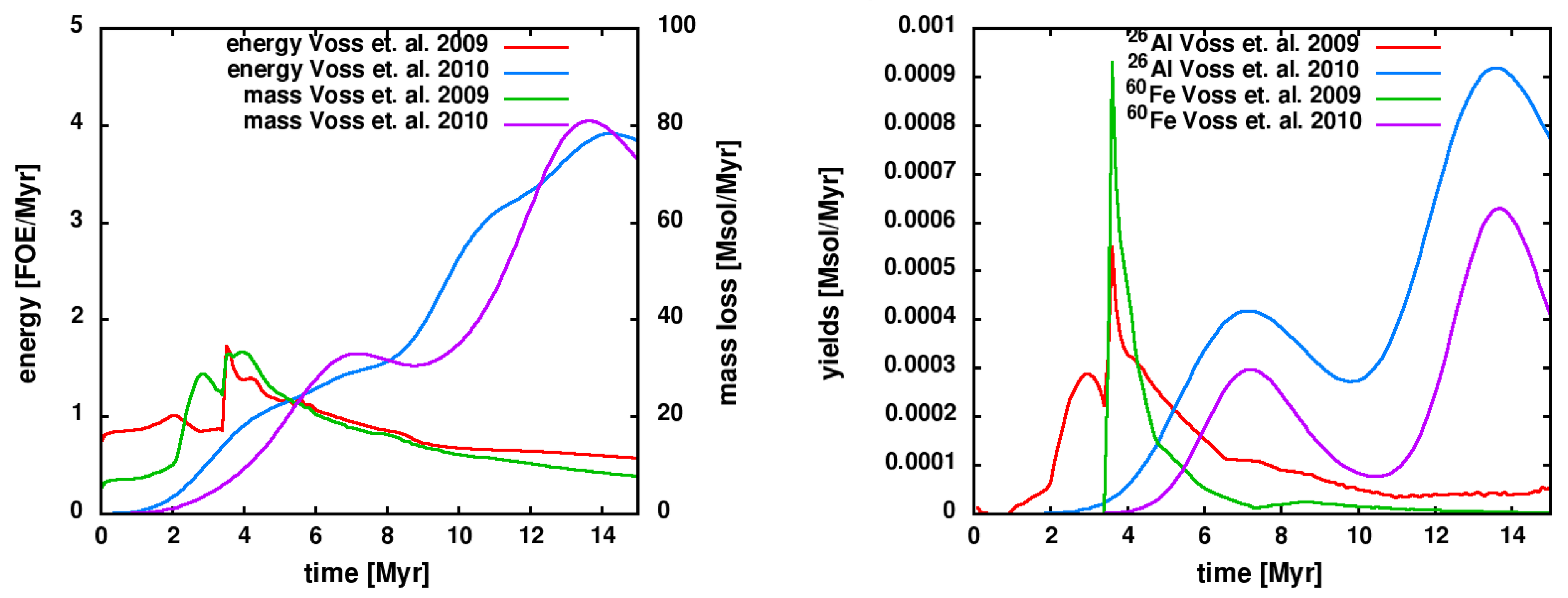

Figure 2. *The Voss et al. (2009, 2010) feedback models: 20 average stars taken from Voss et al. (2009) are compared to the stars of the Orion OB 1 associations (Voss et al. 2010). Voss et al. (2009) assumes that all stars formed at the same time whereas Voss et al. (2010) takes the different ages of the sub-association into account and uses a Gaussian star-formation rate with a dispersion of 1 Myr. The peak near 7 Myr in the Voss et al. (2010) models is caused by the approx. 23 massive stars of the Orion OB 1a sub-association. The second maximum is due to OB 1b, OB 1c and λ Ori. Time dependent injection of mass and energy (left) and radioactive tracers (right).*

Our implementation is based on a realistic model for the population synthesis of the OB associations in the Orion-Eridanus region (Voss et al. 2009, 2010). These two prescriptions of the stellar feedback are compared in figure 2. The main difference is that the Voss et al. (2009) model uses an IMF of a typical OB association whereas Voss et al. (2010) considers the observed OB stars near the Orion A and B molecular cloud region and uses an IMF only to estimate the number of the already exploded stars.

Simulations

A series of hydrodynamic simulations has been performed with a version of the RAMSES code (Teyssier 2002) which uses the stellar feedback according to (Voss et al. 2009, 2010). The radioactive tracers were implemented as passive scalars with a decay law.
Different models for initial density and velocity distributions in the giant molecular clouds (MCs) have been tested (figures 3 and 4): we have applied the Voss et al. (2009, 2010) feedback to homogeneous MCs, turbulent MCs (Ntormousi et al. 2011) and MCs from SPH simulations (Dobbs et al. 2011). For these different initial conditions and stellar feedback models we carried out a sensitivity analysis. We studied (among others) the impact of (1) the initial density distribution, (2) the star formation history and (3) the position of the stellar associations inside the cloud onto the shape of the superbubble formed by these stars and the efficiency of energy injection.

Results

All simulations showed that our prescription of the stellar feedback has a fairly disruptive effect on molecular clouds. Whereas homogeneous clouds are disrupted within a few Myr, more realistic molecular clouds with irregular density structure have longer lifetimes, since they manage to channel more energy into their surroundings. They also show asymmetric morphologies, resembling the Orion-Eridanus bubble. The very disruptive effect of the stellar feedback can be understood by taking into account that the motion of the Orion OB 1 associations is along the line of sight and might thus lead to an overestimation of the stellar content. Also energy losses in colliding winds of individual stars were not considered. For example Guedes et al. (2011) use an efficiency factor $\epsilon_{\rm SN}$= 0.8 to estimate the fraction of the supernova energy coupling to the ISM. Thus our future work will comprise a parameter study on a scaling factor converting the feedback from individual stars into the feedback of a whole OB association.

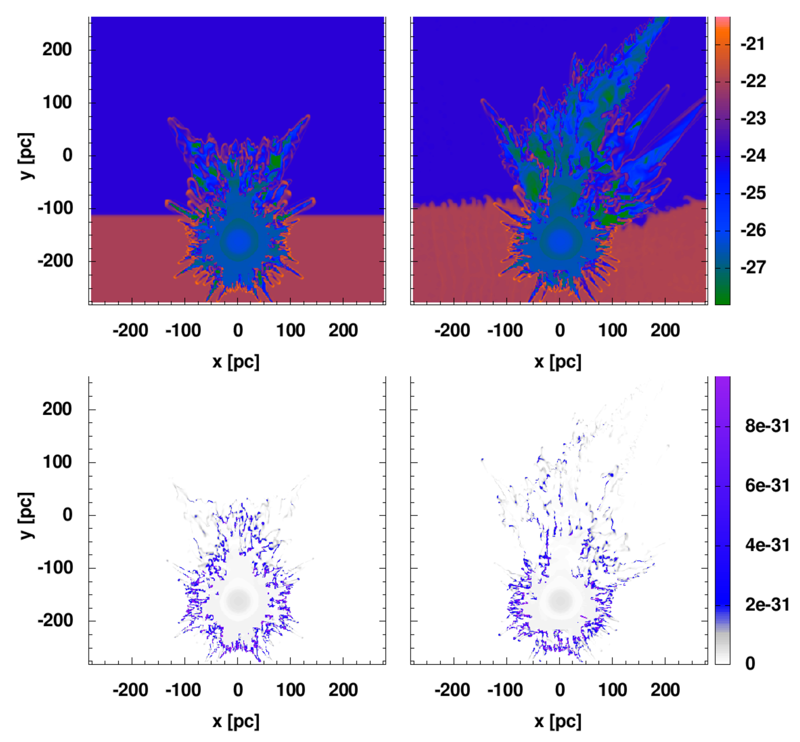

Figure 3. *2d simulations of a semi-infinite molecular cloud. The left upper panel shows logarithmic density in [g/cm^3] for a homogeneous cloud, 6 Myr after the Voss et al. (2009) stellar feedback started. On the right upper panel the corresponding time step of the simulation of a turbulent cloud is shown. The lower panels show ^{26}Al density in [g/cm^3].*

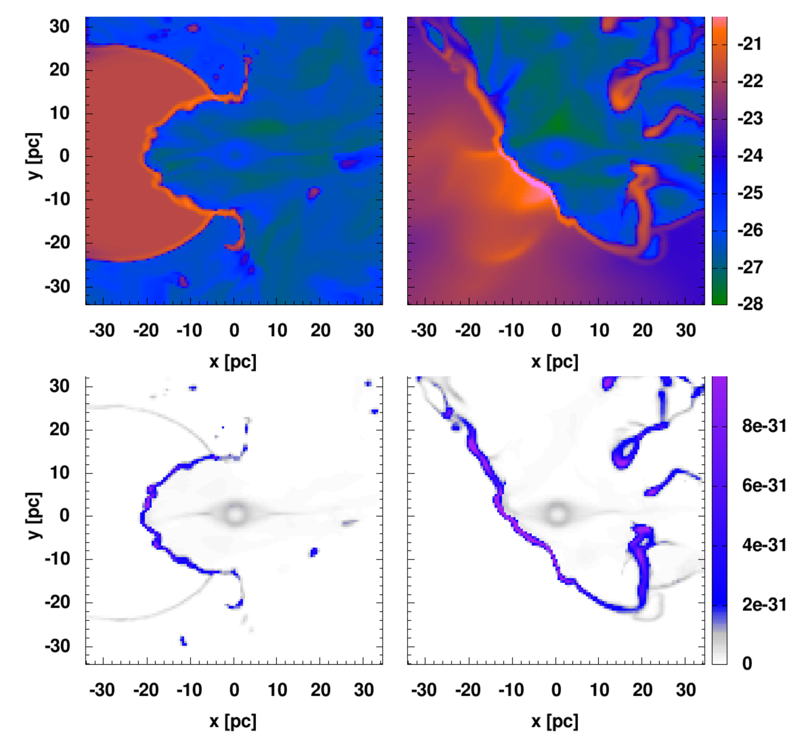

Figure 4. *3d simulations of giant molecular clouds with masses of $\sim 10^5\,M_\odot$. The left upper panel shows the logarithmic density in [g/cm^3] along a cut through the center of a homogeneous cloud, 5 Myr after the Voss et al. (2010) feedback started. On the right, we show the corresponding time step of a simulation with an irregularly structured cloud, extracted from a larger scale simulation (Dobbs et al. 2011). ^{26}Al density in [g/cm^3] is shown in the lower panels.*

Conclusions

The energy of the stellar winds and supernovae primarily increases the kinetic energy and reshuffles the cloud gas. Only a small fraction of the energy is converted into thermal energy. Due to gas cooling the total thermal energy in the computational box decreases with time. It is therefore important to have a good model for energy and mass injection. Threedimensional simulations with an irregularly structured density distribution are essential to reproduce the observational constraints on the Orion-Eridanus region for a reasonable simulation time. Our results may be tested by deep Integral observations, which should reveal an expanding shell in the ^{26}Al -line. For the future, we plan to study a wider parameter range for the energy, mass and ^{26}Al injection.

Acknowledgments

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