Non-universal star formation in turbulent interstellar medium

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**ABSTRACT.** Recent observational evidence indicates variation of efficiencies at which giant molecular clouds (GMCs) convert their gas into stars. Consistent theory of galaxy formation must explain such variation. Common numerical models, in which star formation efficiency (SFE) is assumed constant (at the level of few %) above certain density threshold, by their design are not suitable for this purpose. Theoretically, variation of SFE is attributed to the turbulent nature of interstellar medium. Unfortunately, state-of-art galaxy formation models lack relevant small-scale motions due to limited resolution that hardly reaches typical scale of the largest GMCs (few 10 pc). However, with an appropriate subgrid model of turbulence star formation can be connected to resolved dynamics with the aid of theoretical and numerical models of star formation in turbulent medium. In this work we implement such model coupled with prescription for star formation in compressible MHD turbulence. We find that our model predicts distribution of random turbulent velocities consistent with local and extragalactic observations (on average few km/s on 100 pc scale). In our model turbulence is produced in warm gas (T $\sim$ 10$^4$ K) at level of few km/s and is amplified by compression in spiral arms up to few tens km/s. As far as star formation is concerned, in our simulation we observe distribution of rates that is in a good agreement with both local GMCs data and resolved extragalactic star formation maps. The resulting variation of efficiency is found to be due to scatter in turbulent properties. Our model predicts high abundance of molecular gas inefficiently forming stars along with existence of very efficient GMCs.

**FACE-ON MILKY WAY LIKE GALAXY** (simulation results):

The implemented subgrid model treats turbulence as an additional energy field. This field is self-consistently evolved by a separate hydrodynamical equation similarly to thermal energy. Subgrid turbulence is coupled to resolved dynamics via turbulent cascade and non-thermal component of pressure. As well as thermal pressure this turbulent component does work during volume change, thus, turbulence heats up (cools down) during adiabatic contraction (expansion) of gas (Roberson & Cechalov, 2012). In our simulations this proved to be the main source of supersonic turbulence production in the regions of high star formation rate. The star formation efficiency (SFE) is typically assumed to be universal (few %) with some artificial thresholds in density and temperature (T < $T_\text{cr}$ and $\rho > \rho_\text{cr}$). However, numerical simulations of self-gravitating supersonic MHD turbulence show that star formation efficiency does vary depending on turbulent properties of GMCs. Padoan et al. (2012) found that SFE exponentially decreases with increasing ratio of the free-fall time to the turbulent crossing time. Free-fall time depends only on gas density and therefore is easily accessible in simulations. Turbulent crossing time on the other hand can be derived from the output of the subgrid turbulence model.

**REFERENCES:**


**CONNECTION BETWEEN TURBULENCE AND STAR FORMATION.** Stars are formed in turbulent dense regions of interstellar medium (ISM) called giant molecular clouds. Typical size of these clouds varies from few pc up to about hundred pc. These clouds are relatively cold (T $\sim$ 10$^4$ - 10$^5$ K) and typical turbulent velocities of their gas ($\sim$ few km/s) are supersonic. In this regime turbulence becomes compressible. Supersonic random motions produce shock waves. Overlapping shocks create density caustics where gas may become gravitationally unstable. Further collapse results in formation of stars. Therefore, overall rate at which gas is converted into stars in GMCs is a result of interplay between gravity and MHD turbulence. In the trans- and subsonic regime outside GMCs, hot gas is well supported against gravity by thermal motions. Turbulence is weakly compressible and velocity field is solenoidal. Therefore, this gas does not produce stars. Turbulence heats up (cools down) during adiabatic contraction (expansion) of gas. In numerical simulations star formation is usually parametrized by the efficiency at which gas is converted into stars per free-fall time: 

$$\eta = \frac{\rho_{\text{ff}}}{\rho_{\text{cr}}}$$

The star formation efficiency ($\eta$) is typically assumed to be universal (few %) with some artificial thresholds in density and temperature ($T < T_\text{cr}$ and $\rho > \rho_\text{cr}$). However, numerical simulations of self-gravitating supersonic MHD turbulence show that star formation efficiency does vary depending on turbulent properties of GMCs. Padoan et al. (2012) found that SFE exponentially decreases with increasing ratio of the free-fall time to the turbulent crossing time. Free-fall time depends only on gas density and therefore is easily accessible in simulations. Turbulent crossing time on the other hand can be derived from the output of the subgrid turbulence model.