Toward Turbulent Galaxy Formation Modeling

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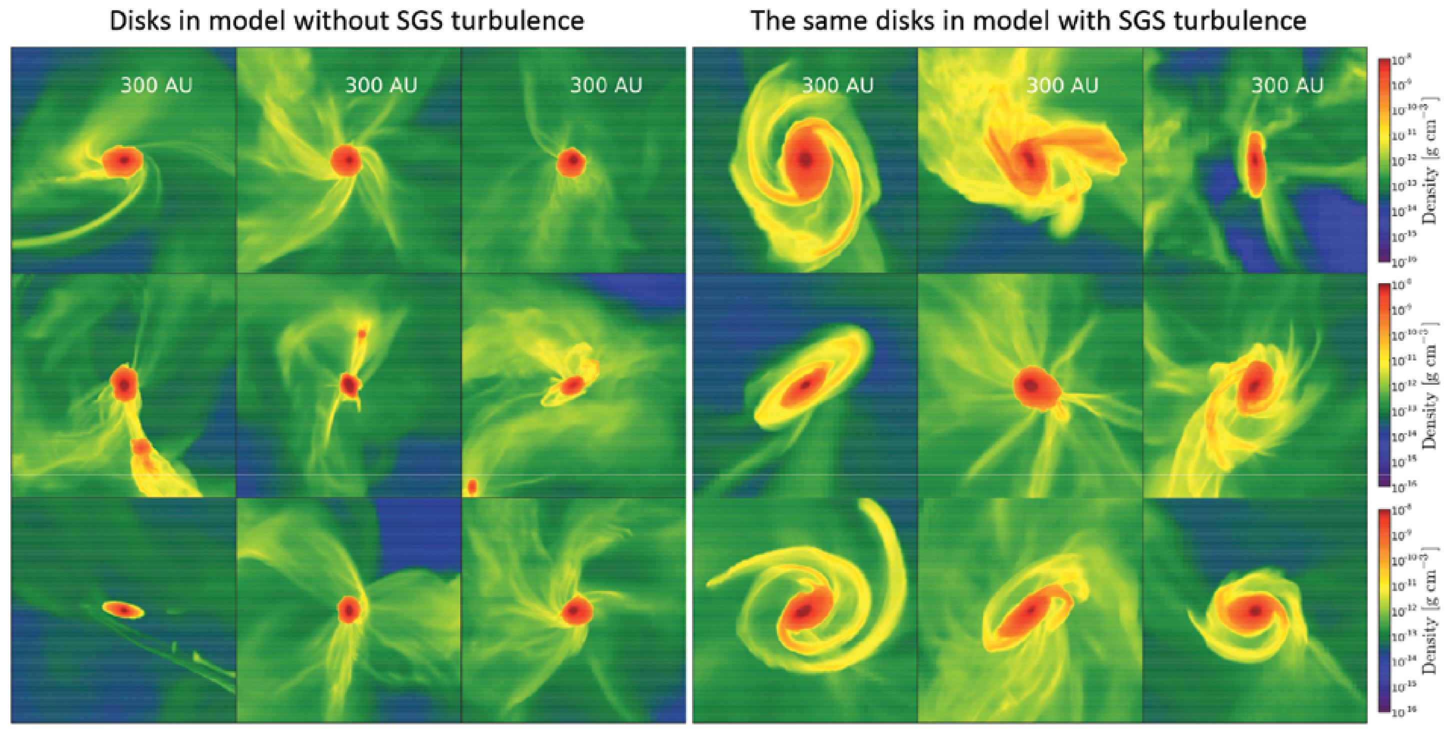
Abstract

Typical astrophysical flows are highly turbulent (with Reynolds numbers as high as few billions). On the contrary, simulations have limited resolution and highest achievable Reynolds numbers in simulations are about thousand at best. Consequently, simulations hardly capture the transition from laminar flow to turbulence and turbulent cascade on small scales is not resolved. The unresolved turbulent motions exert pressure which is not taken into account in modern cosmological simulations. To model this additional pressure support we need a Sub-Grid Scale (SGS) model of turbulence. Following the method described by [1-2] such model was implemented in cosmological code ART. Fully turbulent box tests performed with ART show that the model works fairly well for developed isotropic turbulence. However, the model needs to be improved to reproduce dynamics of stratified turbulent flows which are the most important ones from the practical point of view. In future such models can be used to improve connection between resolved dynamics of gas and sub-grid scale models of star formation and feedback.

Why is SGS turbulence important?

Effect on disk structure and star formation. One of the well known problems of modern cosmological simulations is overproduction of stars. Sub-grid scale turbulent energy may resolve this problem. Associated with this energy pressure support results in more extended, rarefied galactic disks (see the figure below). The decrease of gas density slows down the star formation rate.



Gaseous disks In simulations with SGS turbulence appear to be more extended and less dense. The two panels compare density of the same objects found in simulation with and without SGS turbulence [3]

Effect on flows dynamics and morphology. Overall dynamics of viscous and inviscid flows differs dramatically. The effectively resolved Reynolds numbers of simulated flows are quite low (about few hundreds or thousands at best). As a result, gas in cosmological simulations behaves as rather viscous substance. In contrast, observations show that real astrophysical flows have complex fragmented structure which corresponds to highly turbulent motions. Accounting for unresolved motions may change the resolved dynamics as well.

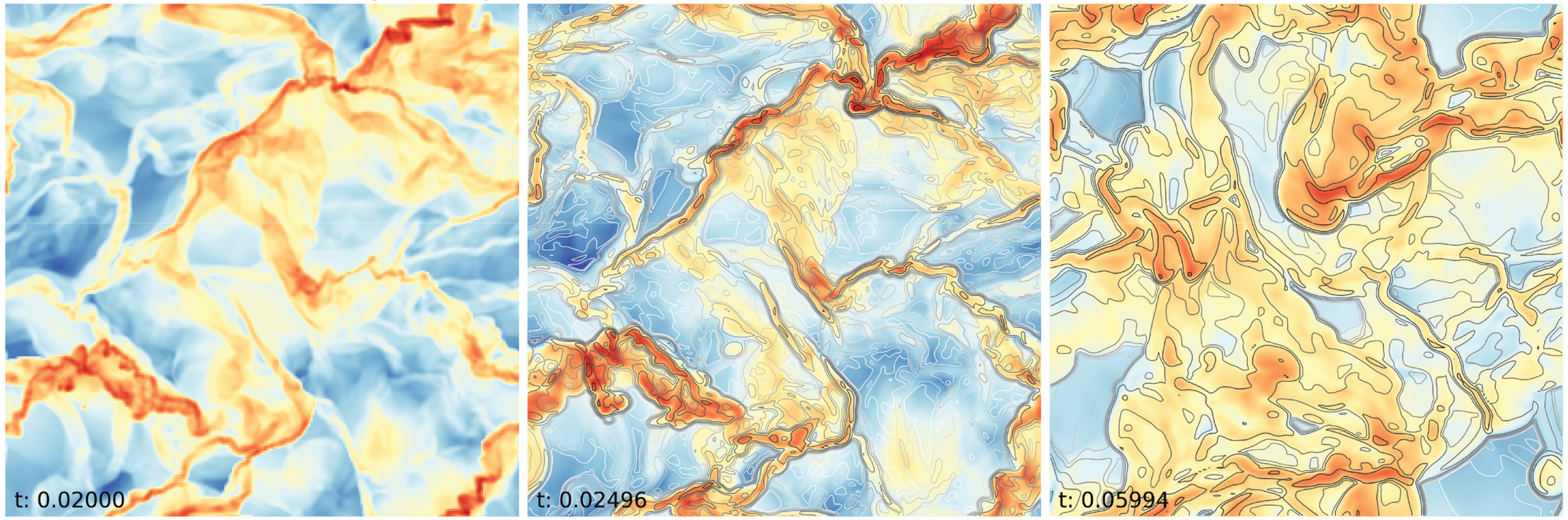
Connection to models of star formation. Given the resolution limits we always have to make certain assumptions about unresolved physical processes. For instance, we have to include certain prescription of how stars form. Recent theoretical results show that stars mostly form on density caustics in highly turbulent medium. A SGS model of turbulence may be used to describe unresolved structure of gas distribution and consequently to improve existing models of star formation.

Connection to stellar/AGN feedback. Radiation from young stars, Supernovae explosions and activity of galactic nuclei have a significant effect on large-scale dynamics of gas (the so-called feedback effect). Apart from blowing the gas away from galaxies, these processes give rise to unresolved turbulent motions. The SGS model of turbulence describes further evolution of this energy.

References:
[1] Schmidt, Federrath - Astronomy & Astrophysics **528** A106 (2011)
[2] Schmidt et al. - MNRAS **440** (4) 3051 (2014)
[3] Latif et al. - MNRAS **433** (2) 1607 (2013)

Results of the model for fully developed turbulence.

Three slices of density (color) and SGS turbulent energy (contours):



Initial conditions. The model was tested for a box with fully developed isothermal supersonic turbulence (M = 4). t = 1 is a box sound crossing time.

After Δt = 0.005 SGS turbulence is developed on density peaks. Shown contours are logarithmically spaced .

After Δt = 0.04 SGS turbulence fills the whole volume. The total SGS turbulent energy of the box is about several percent of the total resolved kinetic energy.

The model agrees with the results of direct simulation.

Left set of figures show that the model reproduces the spatial distribution of SGS turbulent energy (orange color). Correlation diagrams on the right show that actual values of turbulent energy are also captured fairly well, although the spread is rather significant. Solid black lines denote median of obtained values for a fixed actual value; thin lines encompass 45% of cells with higher and lower values (thus, 90% of all cells are between the two thin lines).