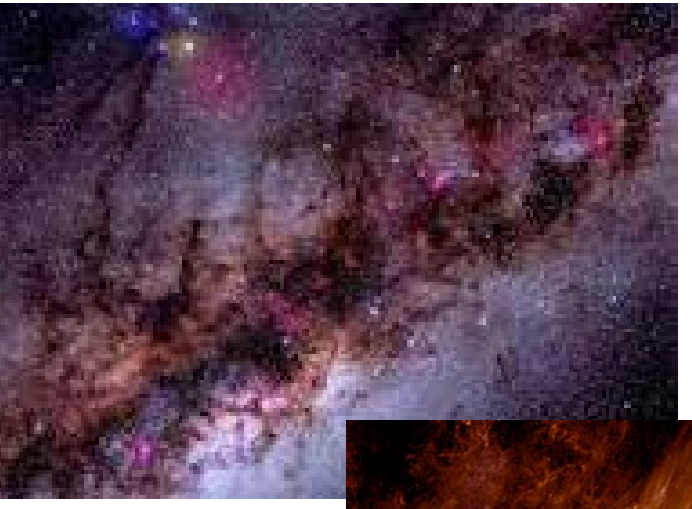
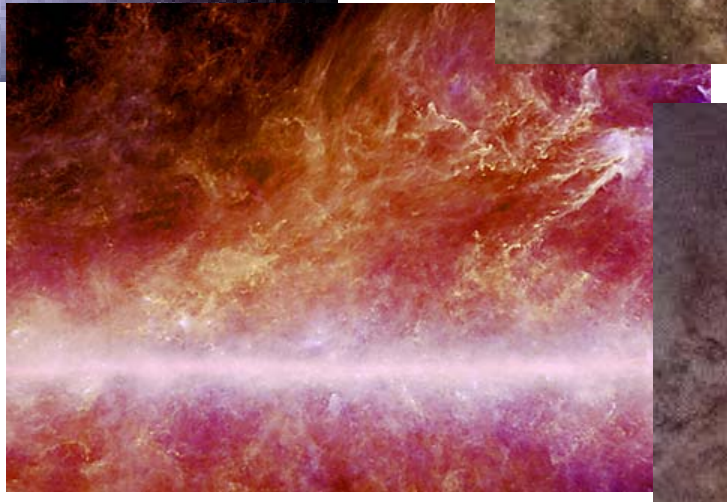
Analysis of coherence in spatial variations between dust and turbulent interstellar gas

M.A. Bezborodov, V.V. Korolev, I.G. Kovalenko
Volgograd State University, Volgograd, Russia

The low-metallicity ISM
Chemistry, Turbulence and Magnetic Fields,
Göttingen, October 8-12, 2012

Dust structures





Application domain

1) Protoplanetary disks & development of planetesimals

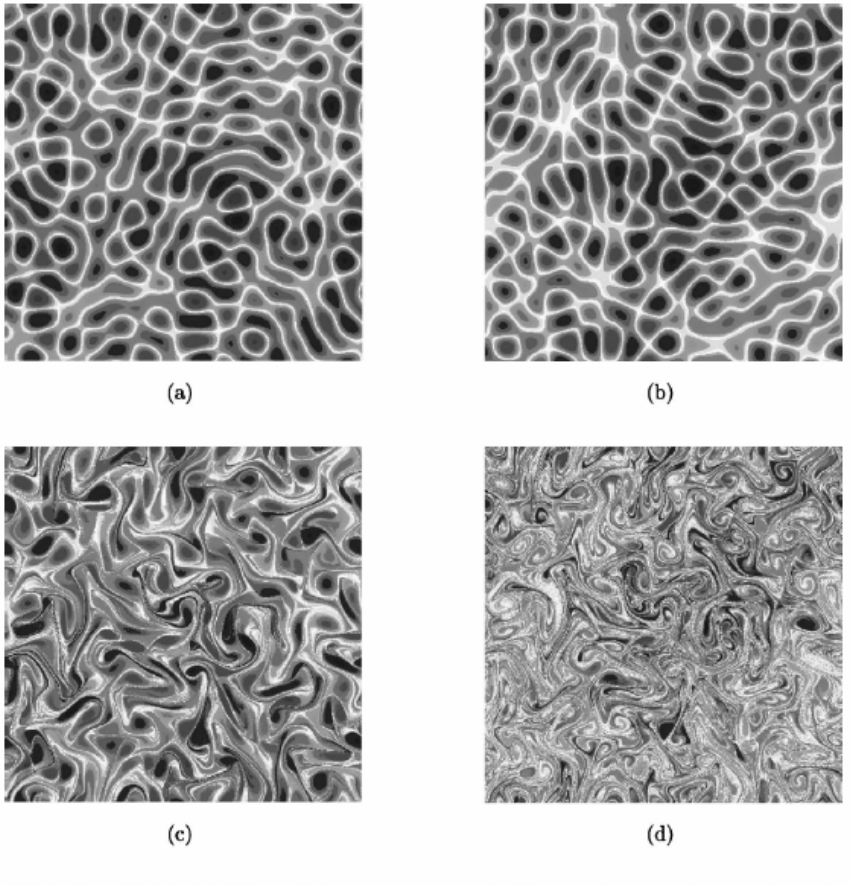
2) Protoslellar gaseous-dust clouds & star formation

3) Dust distribution within spiral waves and galactic discs

Purpose

1)Simulation gas-dust flow of the galactic disk in the vicinity of the galactic spiral arm

2) Analysis of structures of the turbulent interstellar gas-dust medium

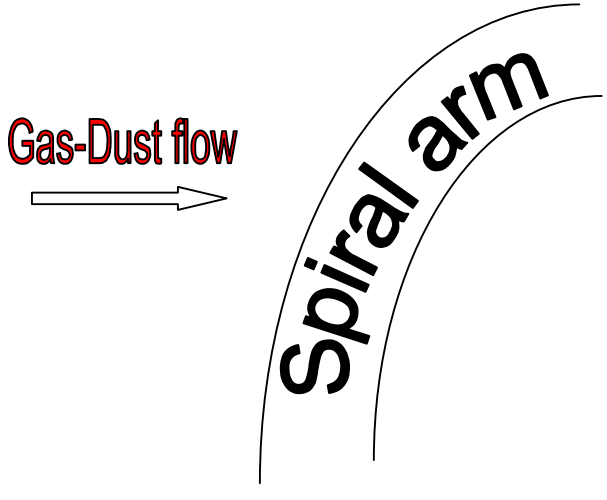


(Lapeyre et al 2001)

FIG. 2. (a), (c), (e) Vorticity field at time $t=0$, 1.02, 10.02 for simulation LARGE. (b), (d), (e) Passive scalar field at the same times.

Key points of the model

- We consider gas-dust flow in the equatorial plane of the galactic disk in the vicinity of the gravitational well of the galactic spiral arm.
- The spiral arm is approximated by a rectilinear gravitational potential well . Gravitation in a spiral arm arises from stellar component only.
- Gas motion is calculated by integration of the system of hydrodynamic equations for an adiabatic compressible gravitating fluid.
- Dust is considered to be the passive scalar polydisperse admixture.
- Only kinematic evolution of dust is studied. We suggest no dust formation or destruction.
- Dust electric charge is considered to be zero. So electromagnetic forces are not taken into account.
- The primary forces for the dust dynamics are the drug force and gravity.
- Considering dust as a low-mass component we neglect the inverse dust influence on gas.
- Motion of dust particles is calculated as N-body.



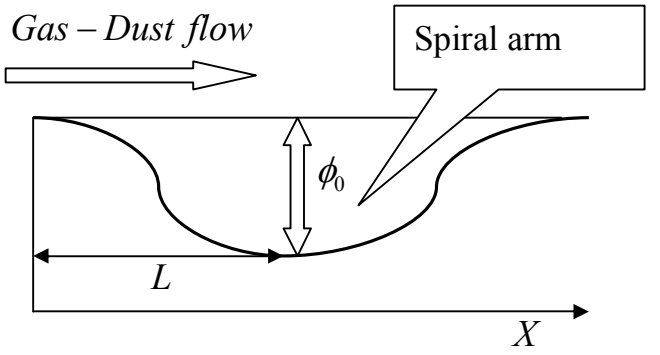
Analytical solution for steady-state flow

Equations for gas

$$\rho_g v_g = J,$$

$$\frac{v_g^2}{2} + \frac{\gamma}{\gamma - 1}\frac{p}{\rho_g} + \Phi = B,$$

$$\frac{p}{\rho_g^\gamma} = A,$$



$$\Phi(x) = -\frac{\phi_0}{2}(\cos(\frac{2\pi x}{L}) + 1),$$

Equations for dust

$$\rho_d v_d = J_d,$$

$$v_d \frac{\partial v_d}{\partial x} = \beta\rho_g(v_g - v_d) - \frac{\partial \Phi}{\partial x},$$

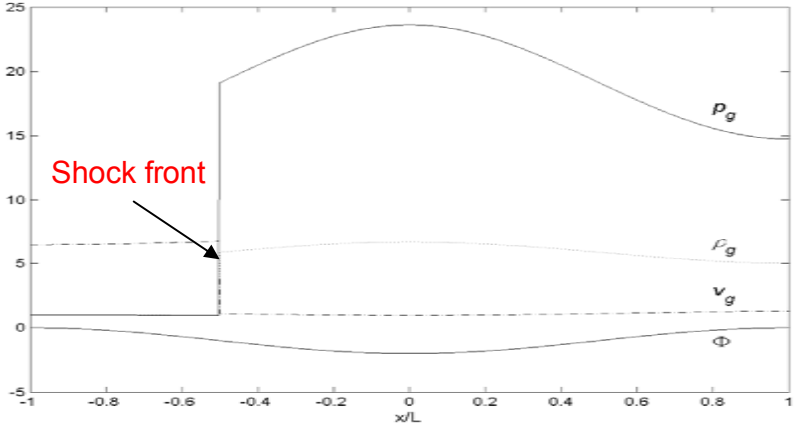
β - friction koefficient

L - the half-width of arm

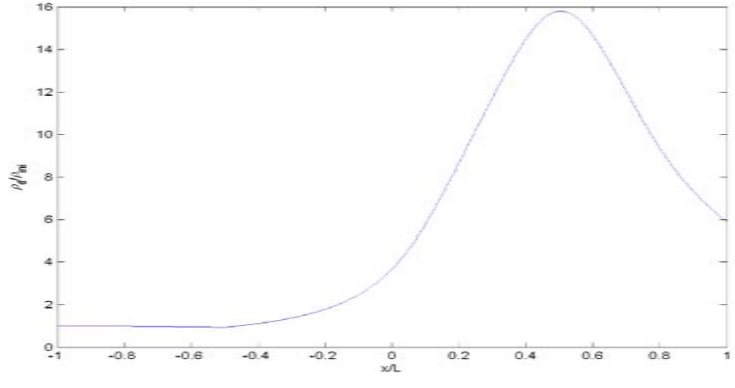
ϕ_0 – depth of potential well

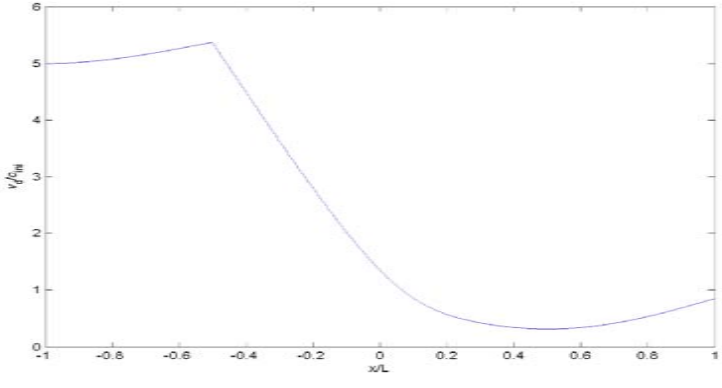
Analytical solution

Flow profiles for gas



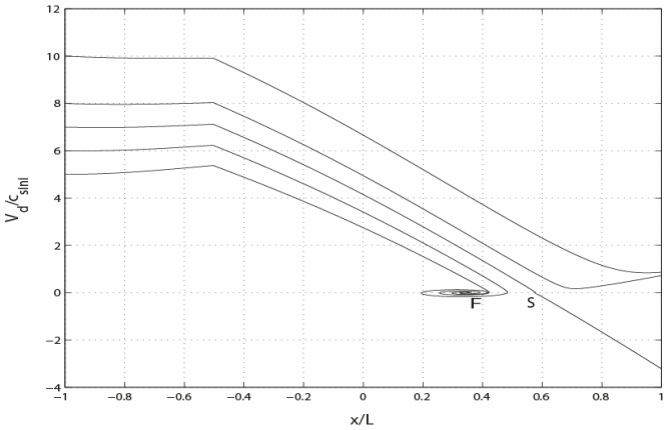
Flow profiles for dust

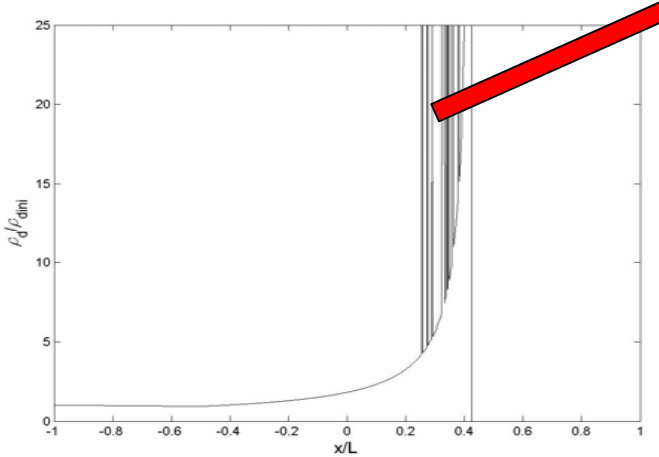


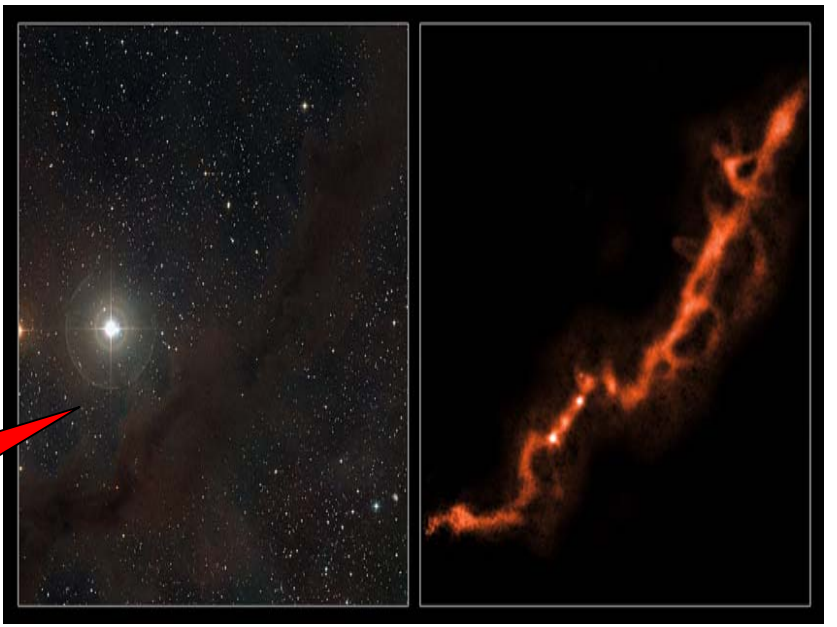


Dust lanes

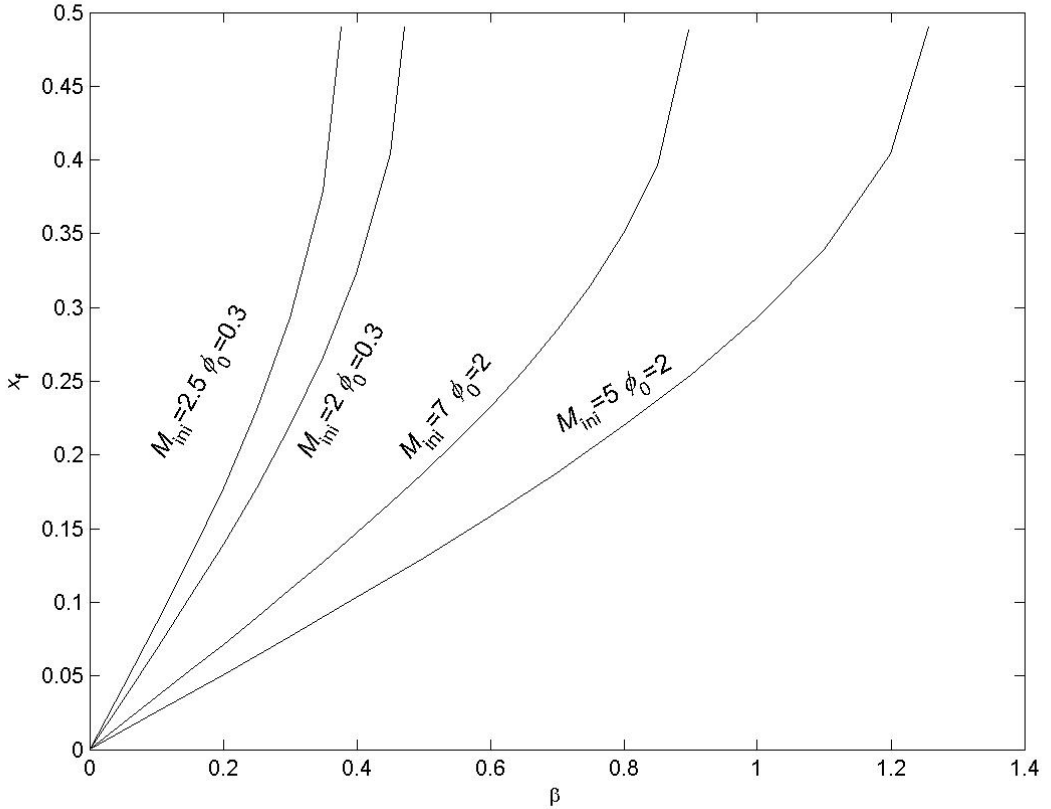
$If\ F_{friction} = F_{\text{gravity}},\ then$







Dust lanes


0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
x_f
0
0.2
0.4
0.6
0.8
1
1.2
1.4
β
M_{ini}=2.5 ϕ_0=0.3
M_{ini}=2 ϕ_0=0.3
M_{ini}=7 ϕ_0=2
M_{ini}=5 ϕ_0=2

Turbulent flow

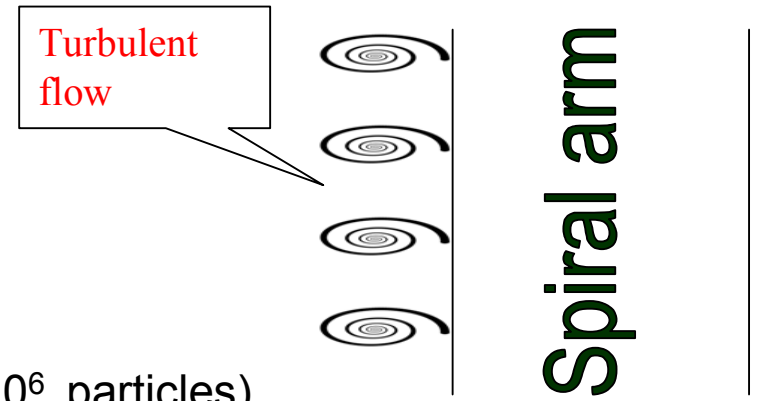
Equation of gas (TVD MUSCL)

$$\frac{\partial \rho_g}{\partial t} + div(\rho_g v_g) = 0,$$

$$\frac{\partial \rho_g v_g}{\partial t} + div(\rho_g v_g \otimes v_g + p_g I) = -\frac{\partial \Phi}{\partial r},$$

$$\frac{\partial (\rho_g E)}{\partial t} + div(\rho_g v_g E + p_g v_g) = 0,$$

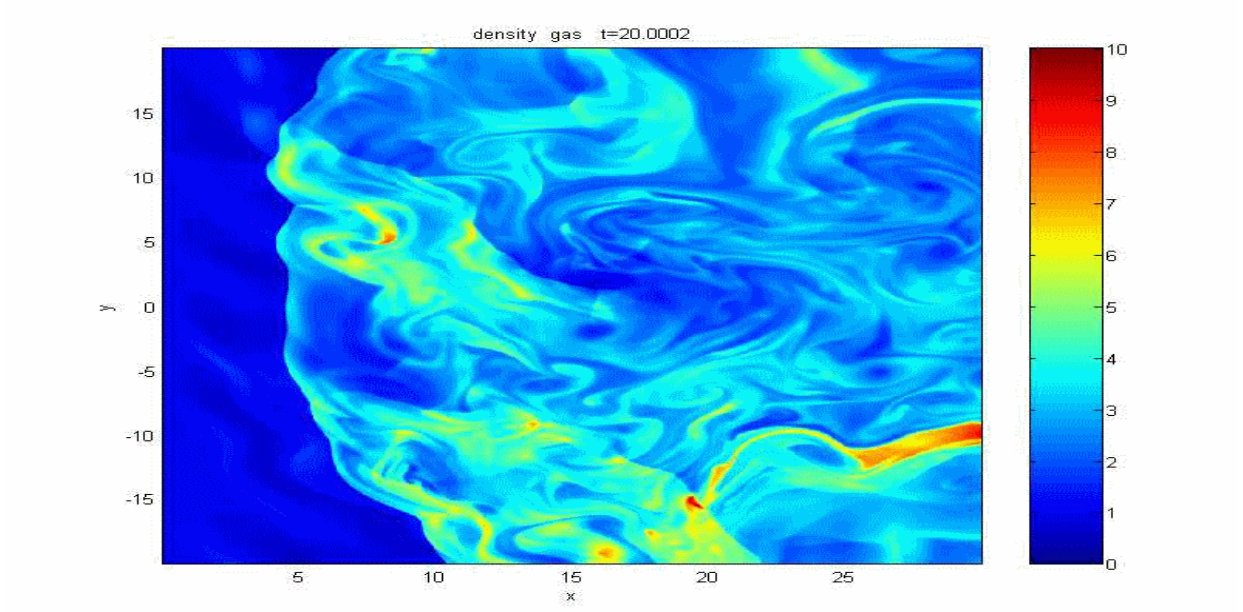
$$\Phi(r) = -\frac{\phi_0}{2}(\cos(\frac{2\pi x}{L}) + 1), \quad E = \frac{p_g}{(\gamma - 1)\rho_g} + \frac{v_g^2}{2} + \Phi,$$

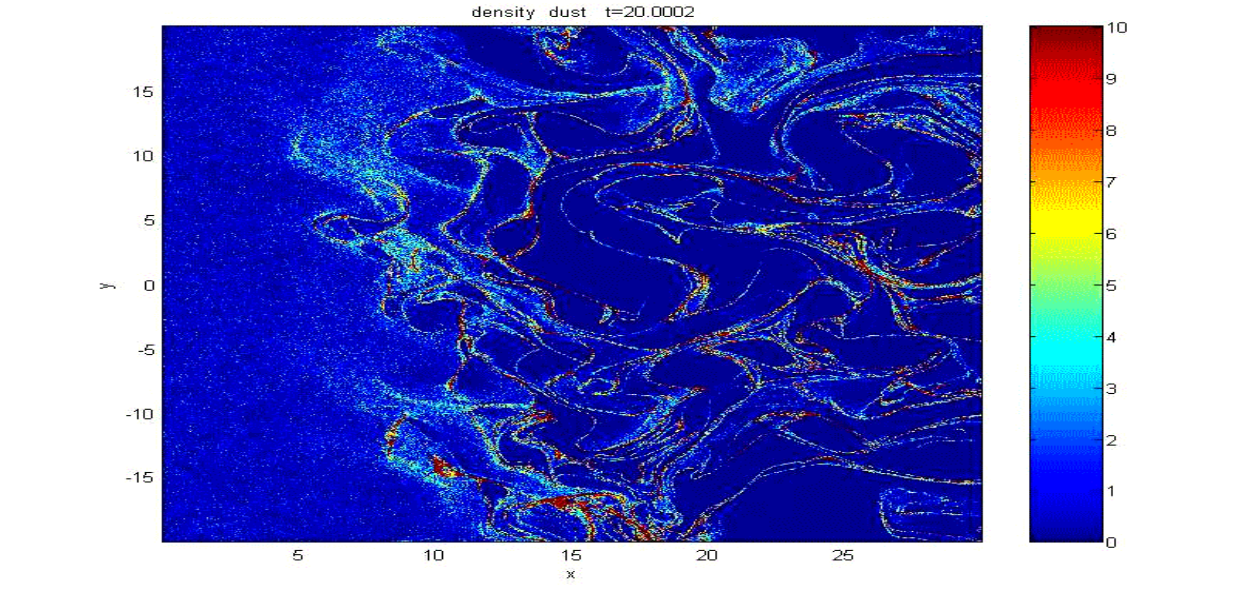


Equation for dust (N-body, about 10^6 particles)

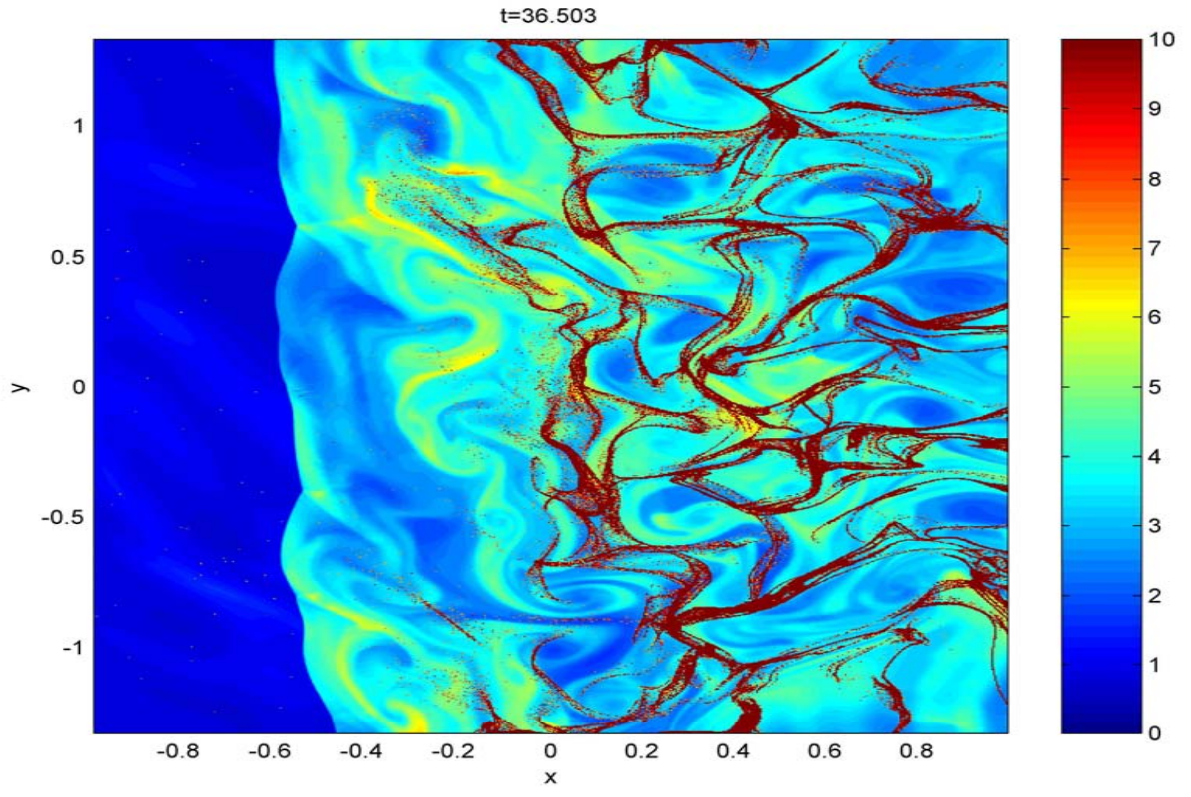
$$\frac{dr}{dt} = v_d,$$

$$\frac{du_d}{dt} = \beta \rho_g (u_g - u_d) - \frac{\partial \Phi}{\partial r}.$$


density gas t=20.0002
15
10
5
0
-5
-10
-15
y
5
10
15
20
25
x
10
9
8
7
6
5
4
3
2
1
0

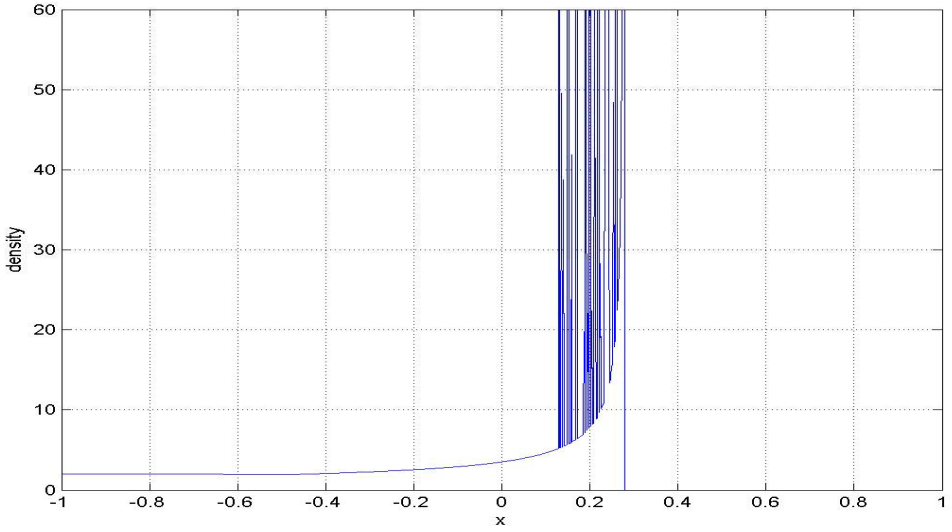

density dust t=20.0002
15
10
5
0
-5
-10
-15
y
5
10
15
20
25
x
10
9
8
7
6
5
4
3
2
1
0

Gas and Dust density

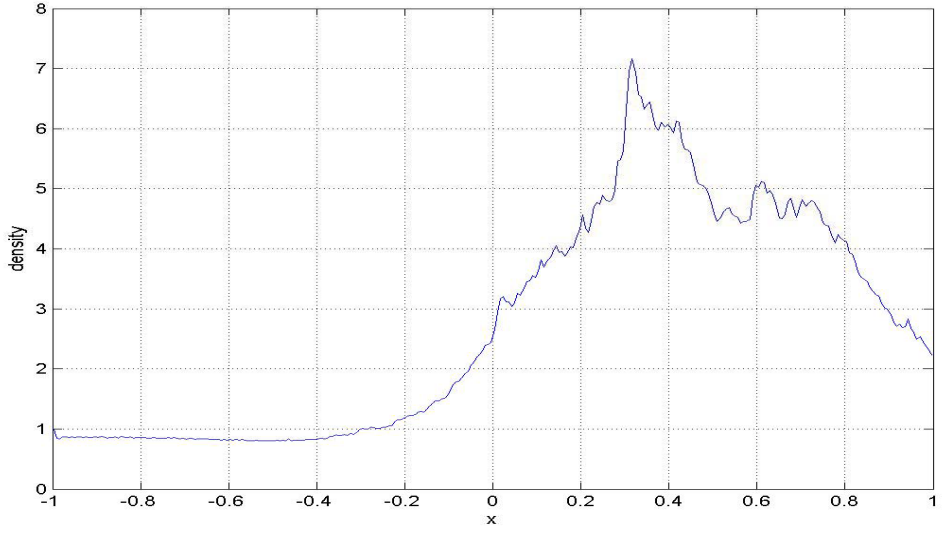


-The typical gas-dust distribution in the turbulent flow in the spiral arm. Gas flows from left to right. The rippled galactic shock front stands close to the left boundary. Dark red indicates dust clusters.

Dust density

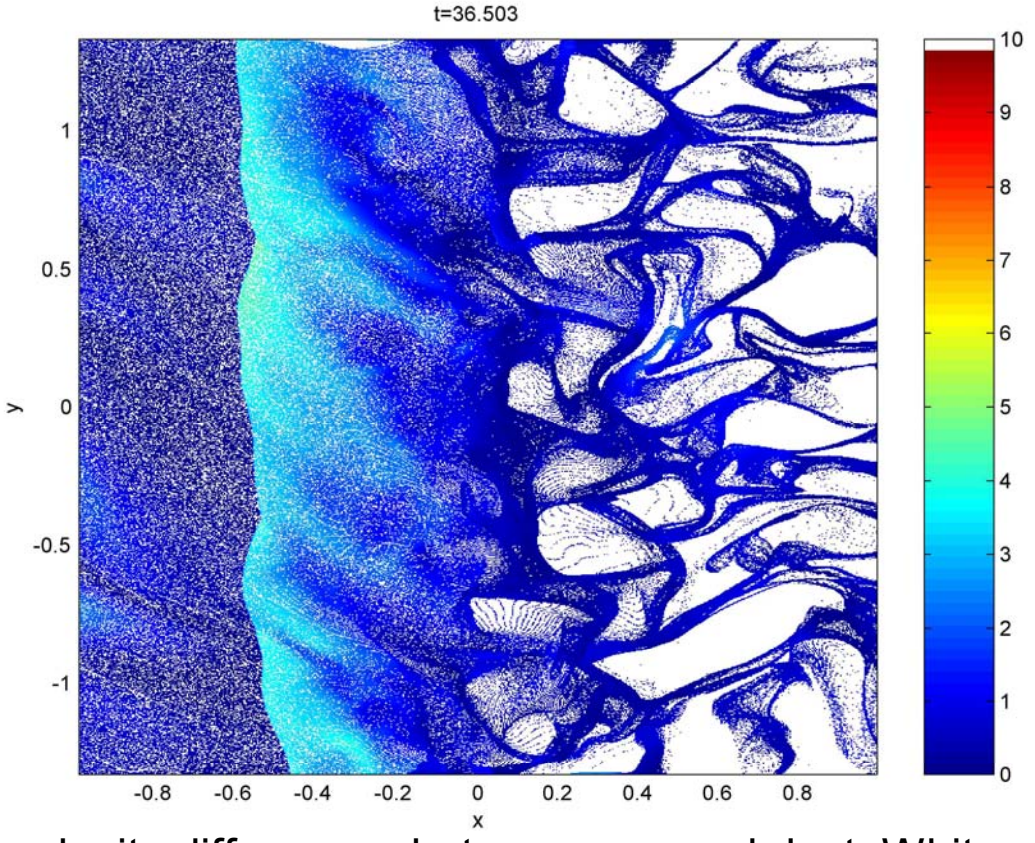


steady state flow



The averaged along y-axis distributions of dust in the turbulent model . We see that maximum of dust concentration is located at the rear side of the arm.

Difference of velocity between gas and dust



The map of velocity differences between gas and dust. White color indicates dust-free area. Large values (light blue) correspond to areas of small correlation between gas and dust

Conclusion

- Dust particles have a tendency to accumulate at the periphery of turbulent vortices promoting contrast enhancement of the turbulent field, and
- Systematically concentrate at the rear side of the spiral arm whereas the galactic shock front stands at the front side.

Thank you