MATHEMATICAL SIMULATION OF ATMOSPHERE DYNAMICS AND DUST ENVIRONMENT AT HIGH-POWER VOLCANIC EXPLOSIONS

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The Objectives of the Present Research

- ♦ Development of physical and mathematical models for predicting the gasdynamic airflows and dynamics of ashes and dust particles resulting from high-power volcanic explosion
- ♦ Investigation of the factors and processes having an influence on the transport of dust particles in the atmosphere
- ♦ Development of computer code to embody the developed theory for numerical simulation of volcanic explosion, obtaining results on dust distribution for different time moments, estimation of possible destruction zones due to the explosion

Physical Model

The following processes are taken into consideration:

- The formation and propagation of the blast wave outward from the burst point
- The formation and rising motion of the rarefied burst area containing dust particles
- The early phase of the growth and continued settling of the dust cloud

The following assumptions are made in the dust cloud model:

- ► The motion of the dust ejected into the air is identical to the gross motion of the air
- ► The gas dynamic fields are essentially the same as those existing in the absence of the dust
- ► The motion of any particle or group of particles is independent of the existence or motion of any other particle or groups of particles

<u>The following forces acting upon individual dust particles are taken into account:</u>

- ◘ The aerodynamic forces of the gross motion of the air due to which the dust particles are transported in the direction of the flow
- ◘ The turbulent action of the air resulting in diffusion of the dust particles in all directions and mixing
- ◘ The action of gravitational force which will settle out of the dust cloud in the vertical direction

Mathematical Model

- □ The differential equations of gas dynamics conservation laws are used to simulate the evolution of volcanic explosion in the atmosphere
- □ The numerical method of spatial differences is applied for solution of the Eulerian gas dynamic equations
- □ The gas dynamics system is discretized in space by a second-order TVD (Total Variation Diminishing) scheme and in time by a two-stage TVD Runge-Kutta scheme which is second-order accurate in time
- □ The problem of volcanic explosion is studied in three-dimensional Cartesian coordinates within the computational domain the size of which is determined by the area perturbed by the air motion

Model of Discrete Particle Sizes

- A small group of individual dust particles (of the same size) which are ejected into the air is considered as one dust packet having specified mass, spatial coordinates and velocity components
- The movement of dust packet is performed on the basis of the Monte Carlo method
- The distribution of the mass of dust packets on sizes is determined according to the lognormal law with constant dispersion and median

Results of Numerical Simulation

- Numerical simulation of volcanic explosions with different yields and with account of dust ejection was carried out using the developed code VEDEM. The results concerning the dynamics of the area perturbed and formation of the dust cloud were obtained
- As an example the results on the dust cloud formation and on the gas dynamics of air flows are presented in Figures for the following variant: Radius - 10 km, Height - 3 km, Energy yield in hemisphere - 800 Mt, Ejected mass - 1 Gt, Temperature - 1750 K, Pressure - 6,5 bar, Density - 1,29 mg/cm^3, Computational domain - 80x80x80, Range of dust sizes - from 0,2 microns up to 2 mm, Number of dust sizes -20, Number of dust particles in group - 4000
- The motion of shock wave front along the ground surface for explosions of different yields has a property of similarity. The shock wave causes the destruction of ground plants on a distance exceeding the initial radius of energy release in 4-5 times.

- ❖The formation and separation of the dust cloud from the ground surface are occurred during the time period about 1 min. In consequent time moments the rise of dust cloud in the atmosphere, separation of dust particles on sizes and their settling out are taken place.
- ❖The main part of the dust mass is settled out on the square of initial ejection. The area of significant dust settlement exceeds more than twice the radius of ejection.

Conclusion

- ❒ The results of numerical simulation demonstrate that the developed model describes adequately the dynamics of dust cloud formation and the gas dynamic processes originating in the atmosphere at high-power volcanic eruptions
- ❒ The model presented can be applied to simulate the explosive phenomena such as the meteorite explosion at its impact on the surface of the Earth, the high-power volcanic and nuclear explosions in the inhomogeneous atmosphere and to predict the consequences
- ❒ The model presented was successfully evaluated for numerical simulation of the volcanic explosion and the formation of the dust cloud in a three-dimensional Cartesian coordinates despite the investigated problem has a cylindrical symmetry. It is a rather good test for a three-dimensional code VEDEM developed and this model will also enable in future to investigate the three-dimensional problems associated, for example, with the action of horizontal wind

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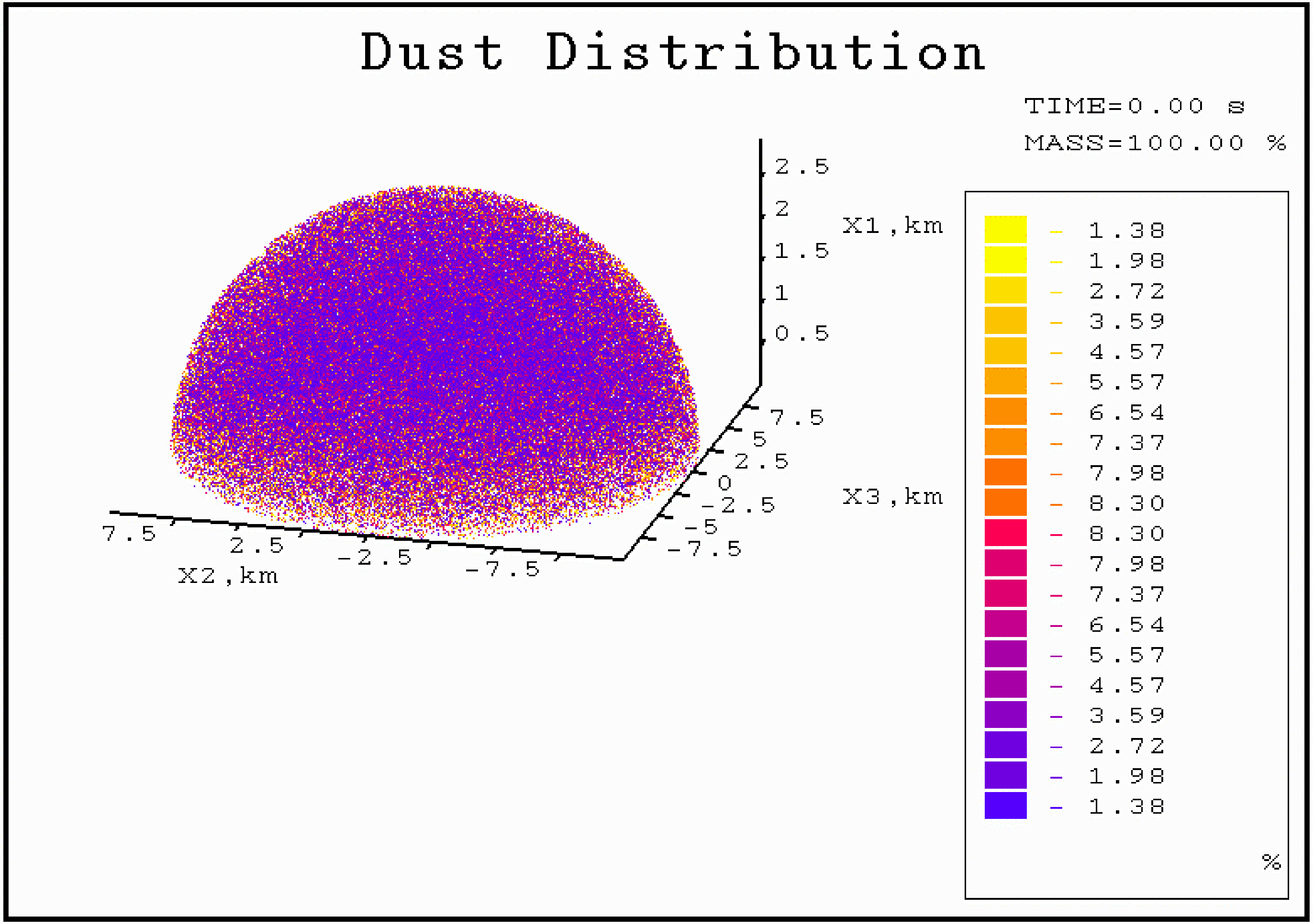
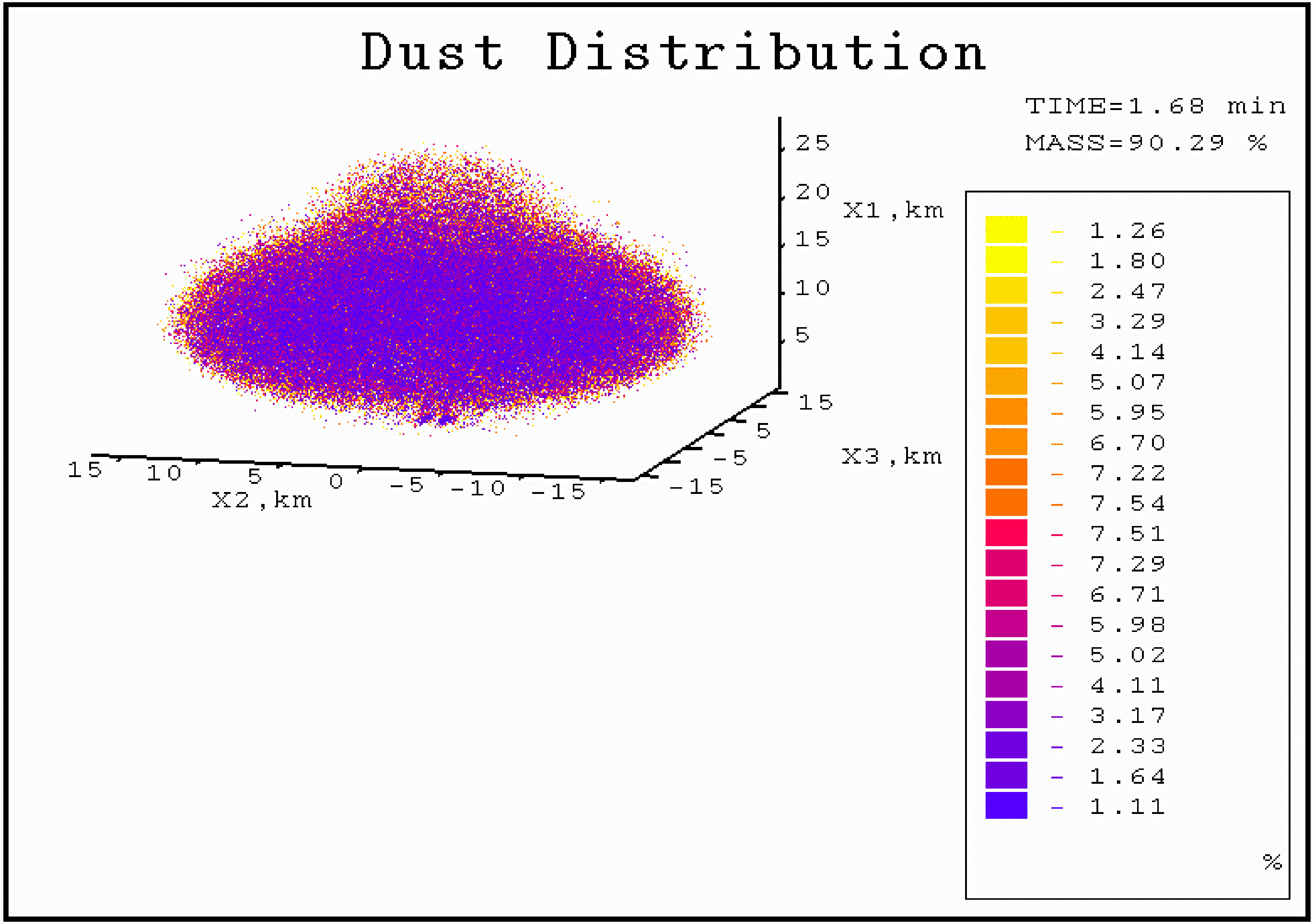
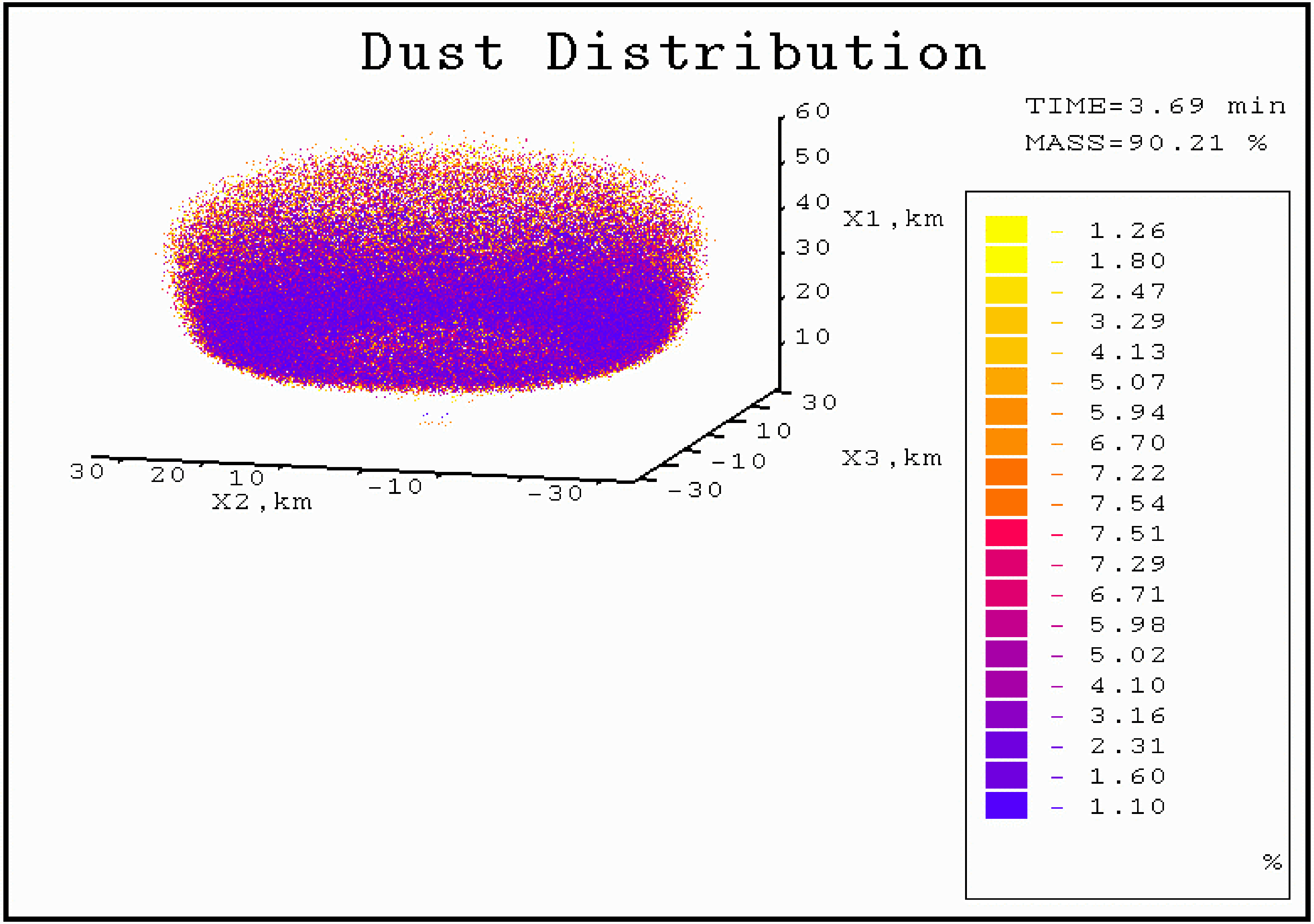
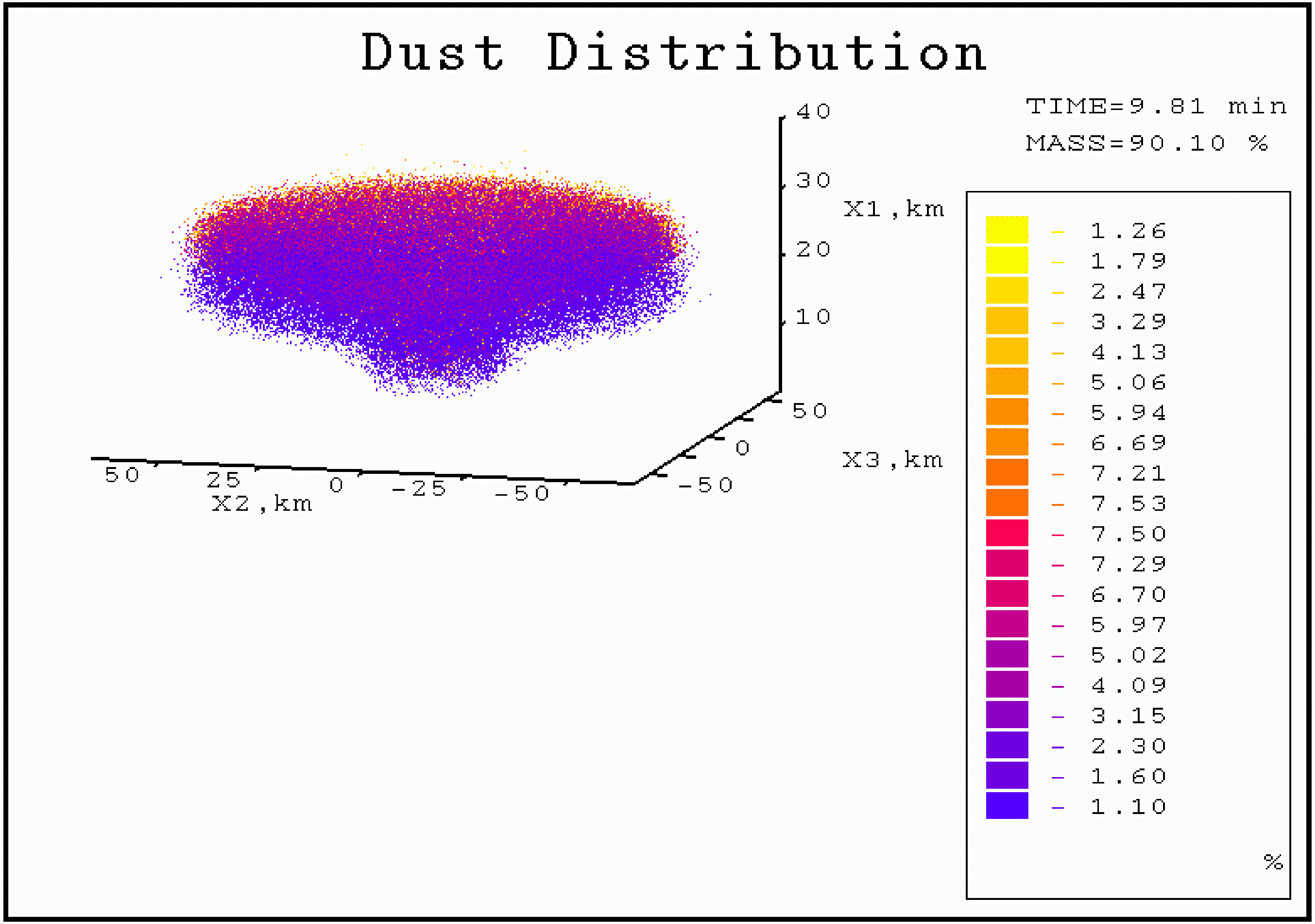


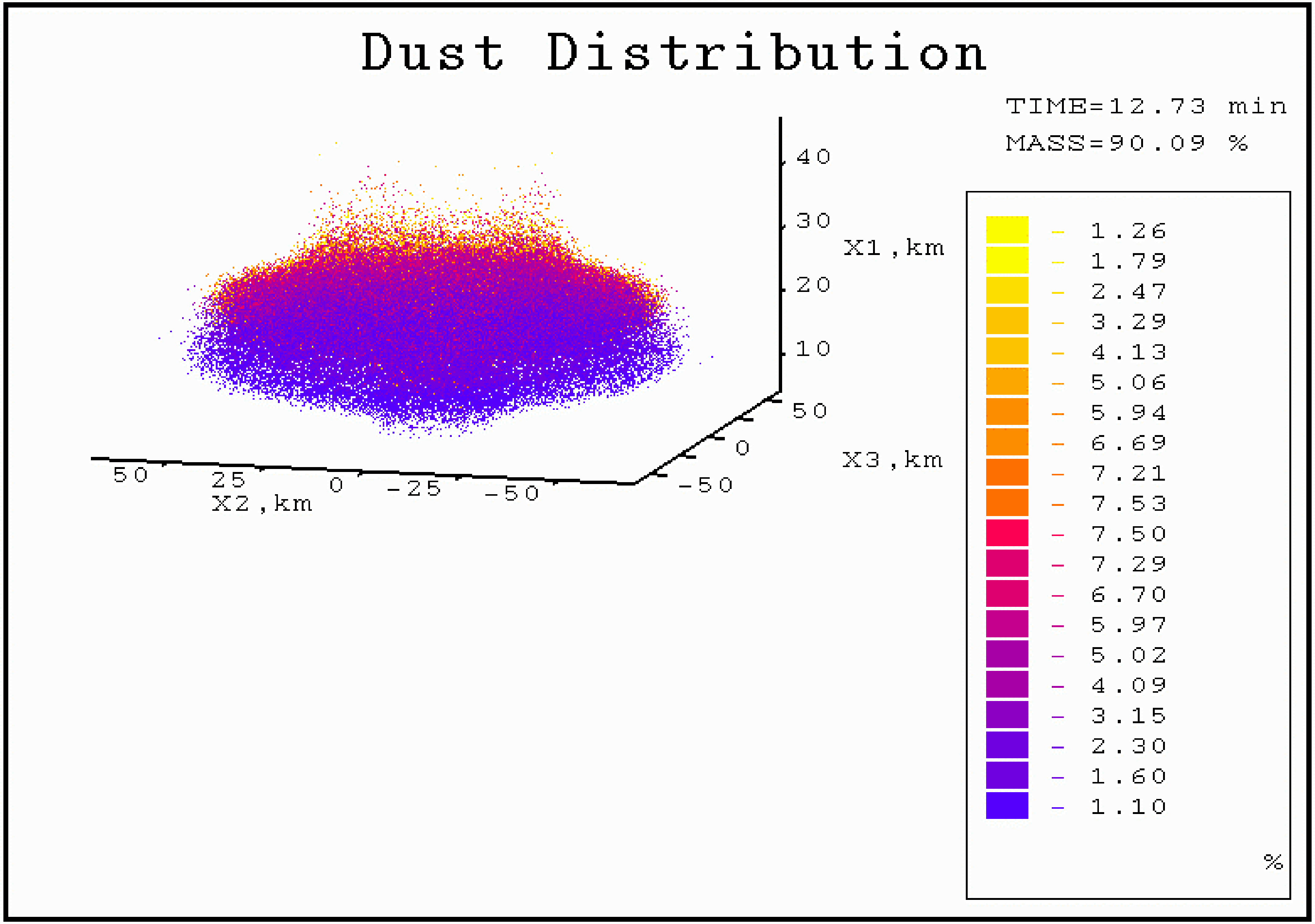
Dust Distribution
TIME=0.00 s
MASS=100.00 %
X1,km
2.5
2
1.5
1
0.5
X3,km
7.5
5
2.5
0
-2.5
-5
-7.5
X2,km
7.5
2.5
-2.5
-7.5
1.38
1.98
2.72
3.59
4.57
5.57
6.54
7.37
7.98
8.30
8.30
7.98
7.37
6.54
5.57
4.57
3.59
2.72
1.98
1.38
%



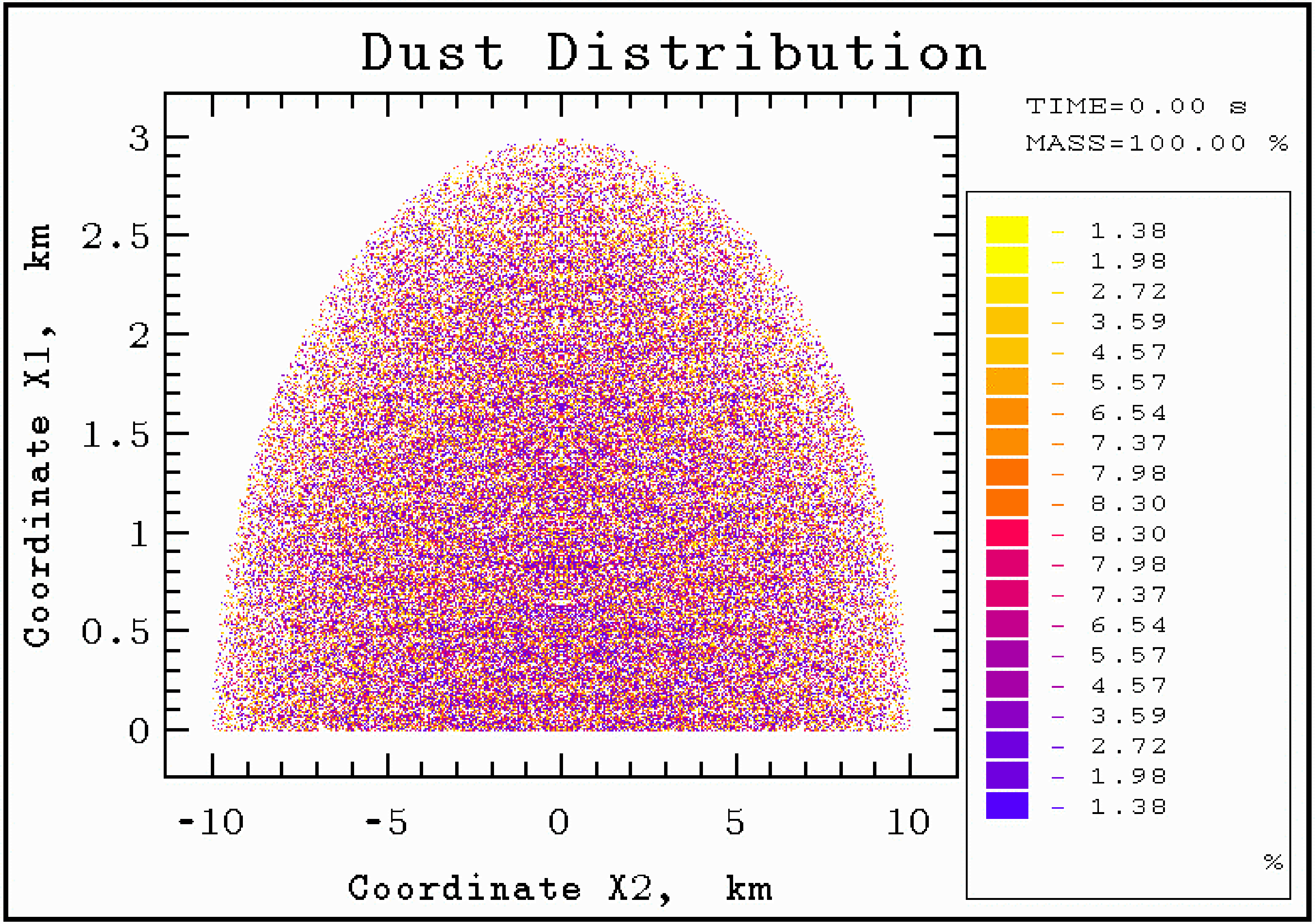
Dust Distribution
TIME=1.68 min
MASS=90.29 %
25
20
15
10
5
X1,km
15
5
-5
-15
X3,km
15
10
5
0
-5
-10
-15
X2,km
1.26
1.80
2.47
3.29
4.14
5.07
5.95
6.70
7.22
7.54
7.51
7.29
6.71
5.98
5.02
4.11
3.17
2.33
1.64
1.11
%


Dust Distribution
TIME=3.69 min
MASS=90.21 %
X1,km
60
50
40
30
20
10
X3,km
30
10
-10
-30
X2,km
30
20
10
-10
-30
1.26
1.80
2.47
3.29
4.13
5.07
5.94
6.70
7.22
7.54
7.51
7.29
6.71
5.98
5.02
4.10
3.16
2.31
1.60
1.10
%

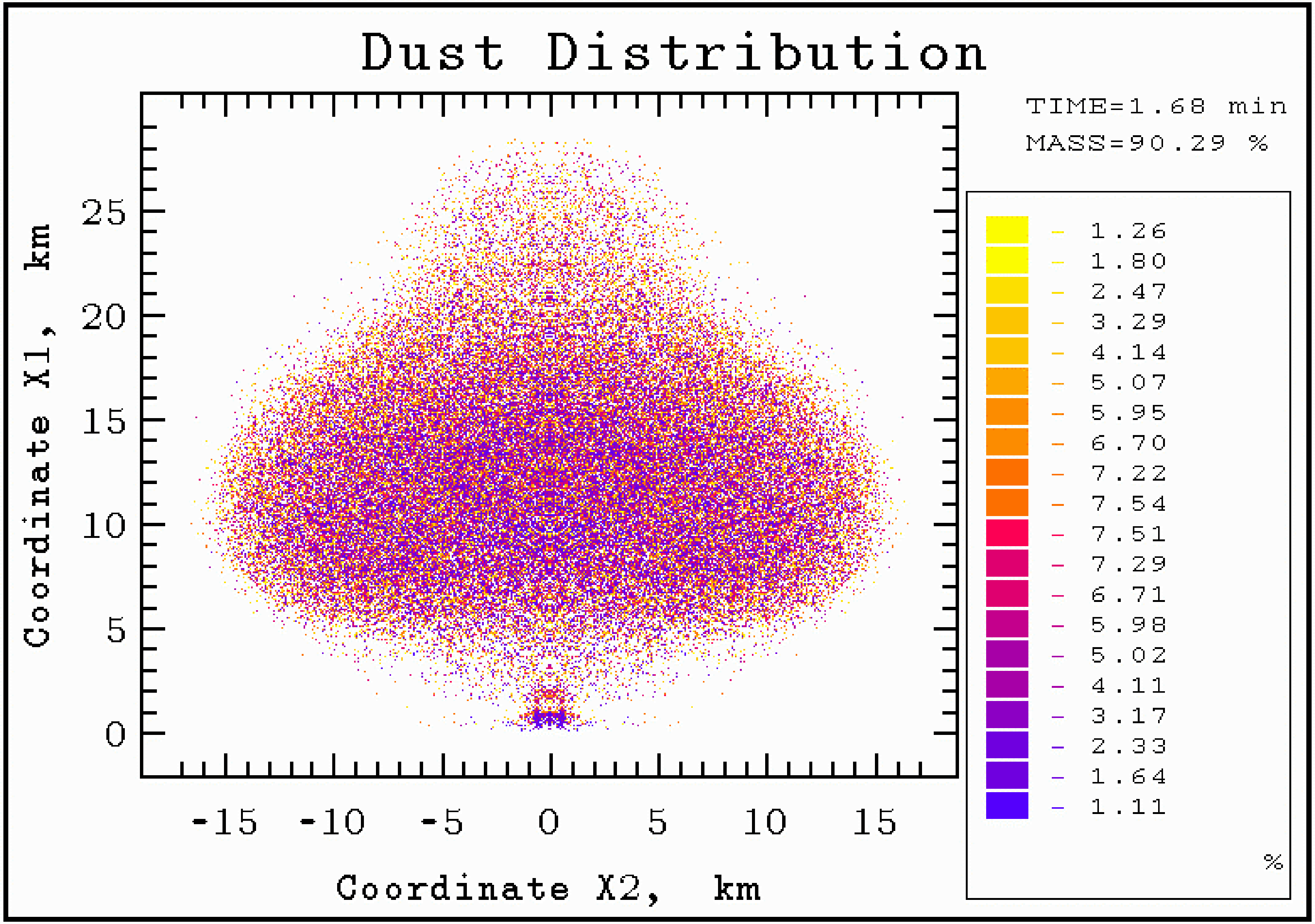

Dust Distribution
TIME=9.81 min
MASS=90.10 %
40
30
20
10
X1,km
50
0
-50
X3,km
50
25
0
-25
-50
X2,km
1.26
1.79
2.47
3.29
4.13
5.06
5.94
6.69
7.21
7.53
7.50
7.29
6.70
5.97
5.02
4.09
3.15
2.30
1.60
1.10
%

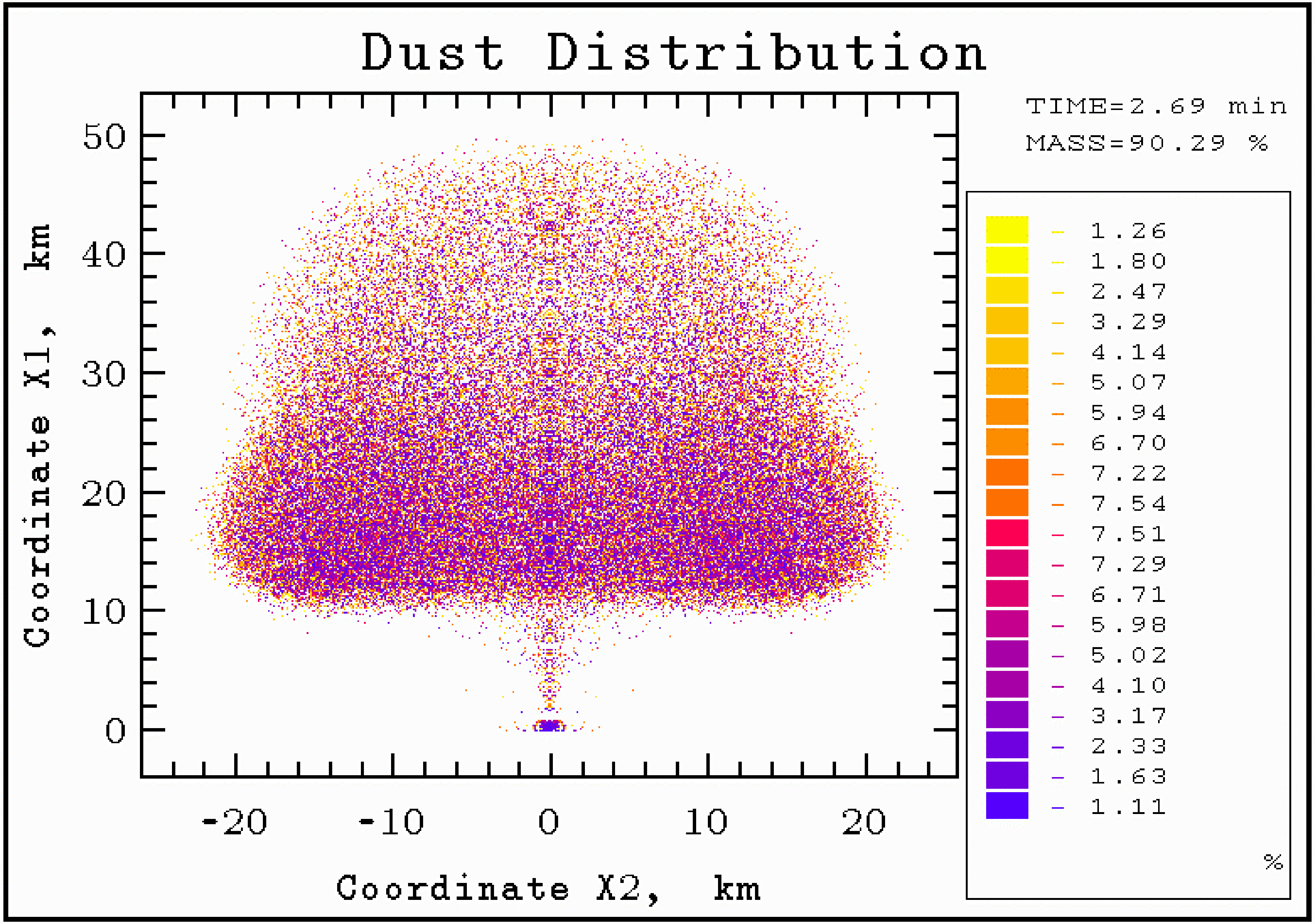


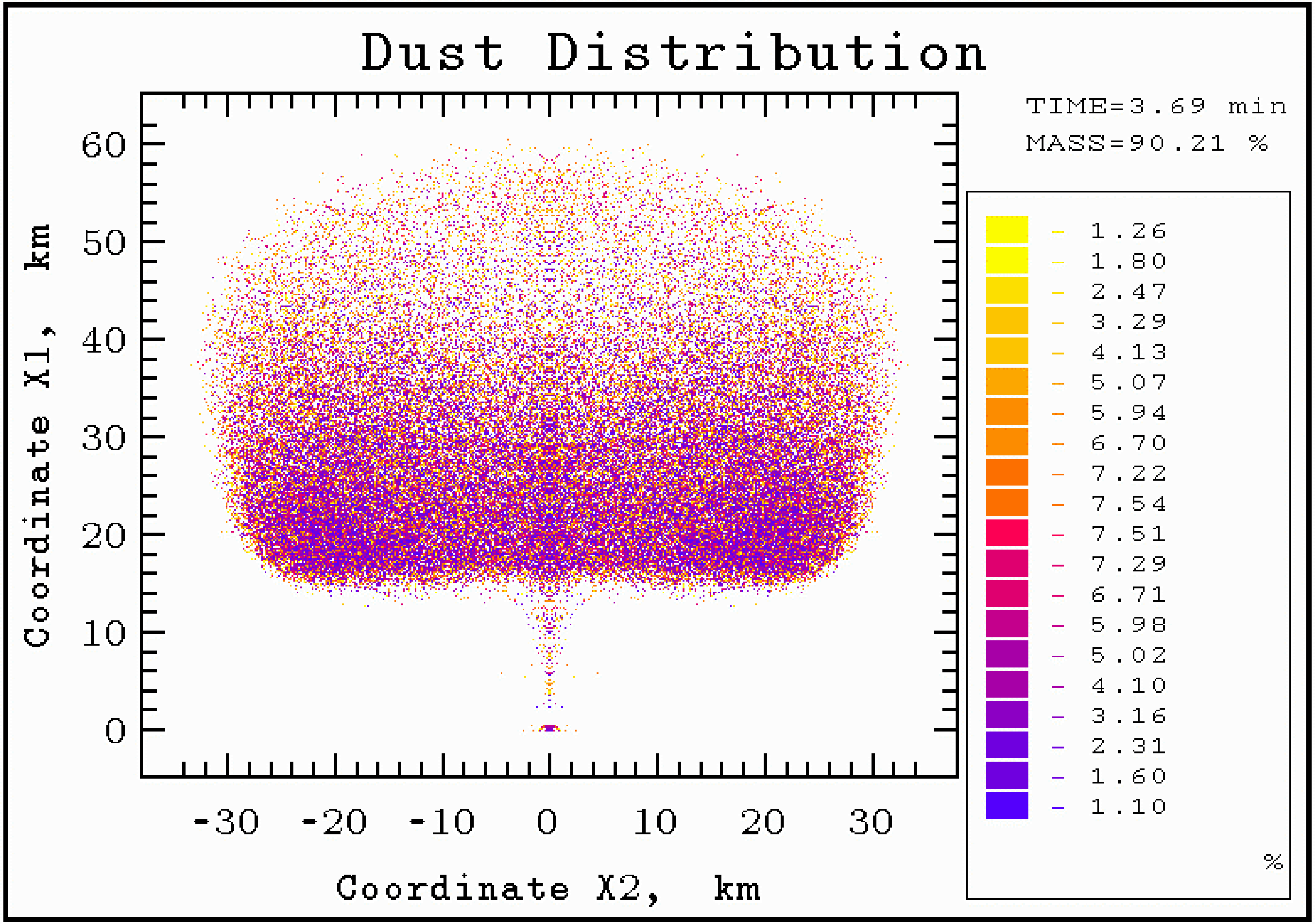
Dust Distribution
TIME=12.73 min
MASS=90.09 %
40
30
20
10
X1,km
50
0
-50
X3,km
50
25
0
-25
-50
X2,km
1.26
1.79
2.47
3.29
4.13
5.06
5.94
6.69
7.21
7.53
7.50
7.29
6.70
5.97
5.02
4.09
3.15
2.30
1.60
1.10
%

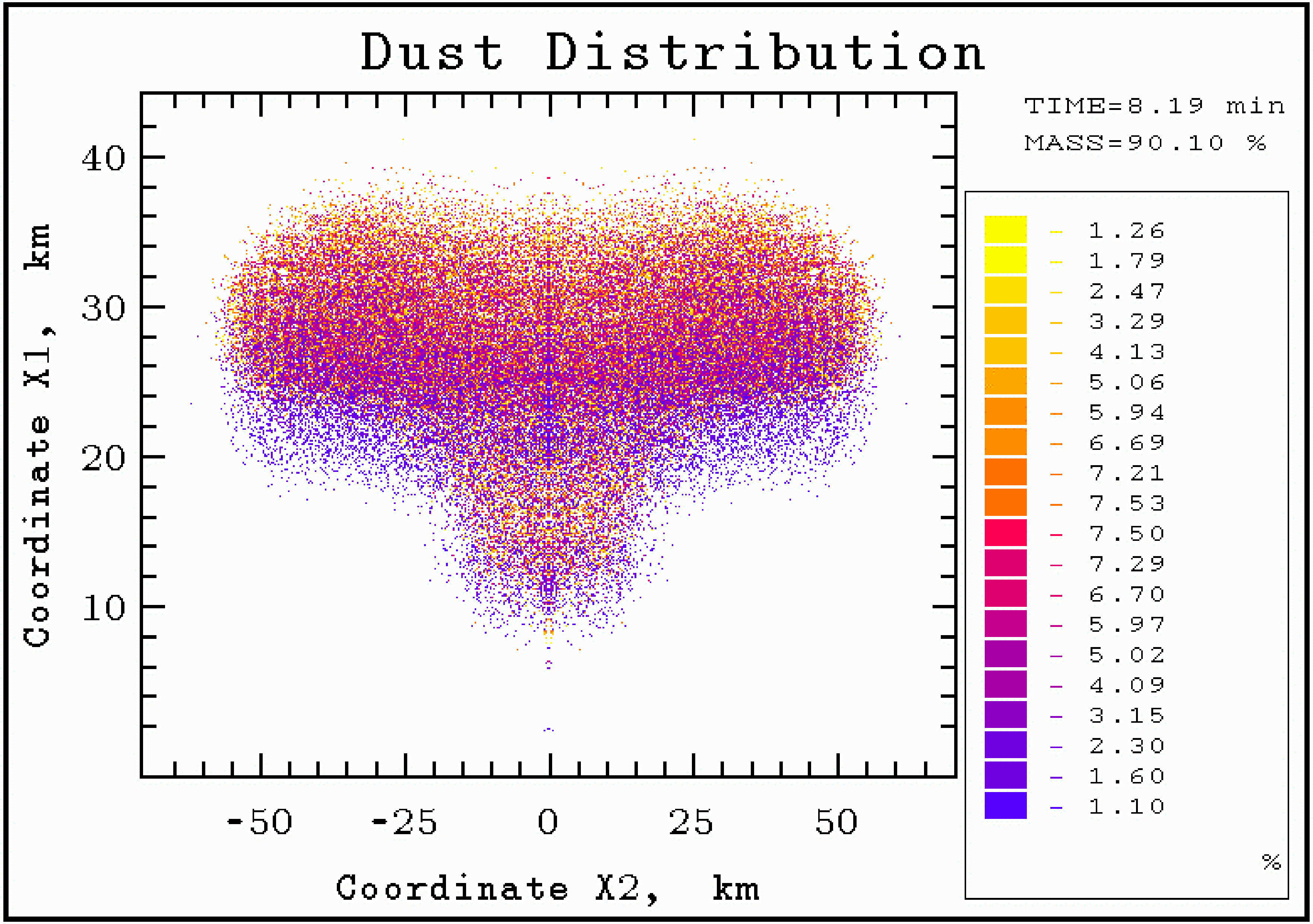


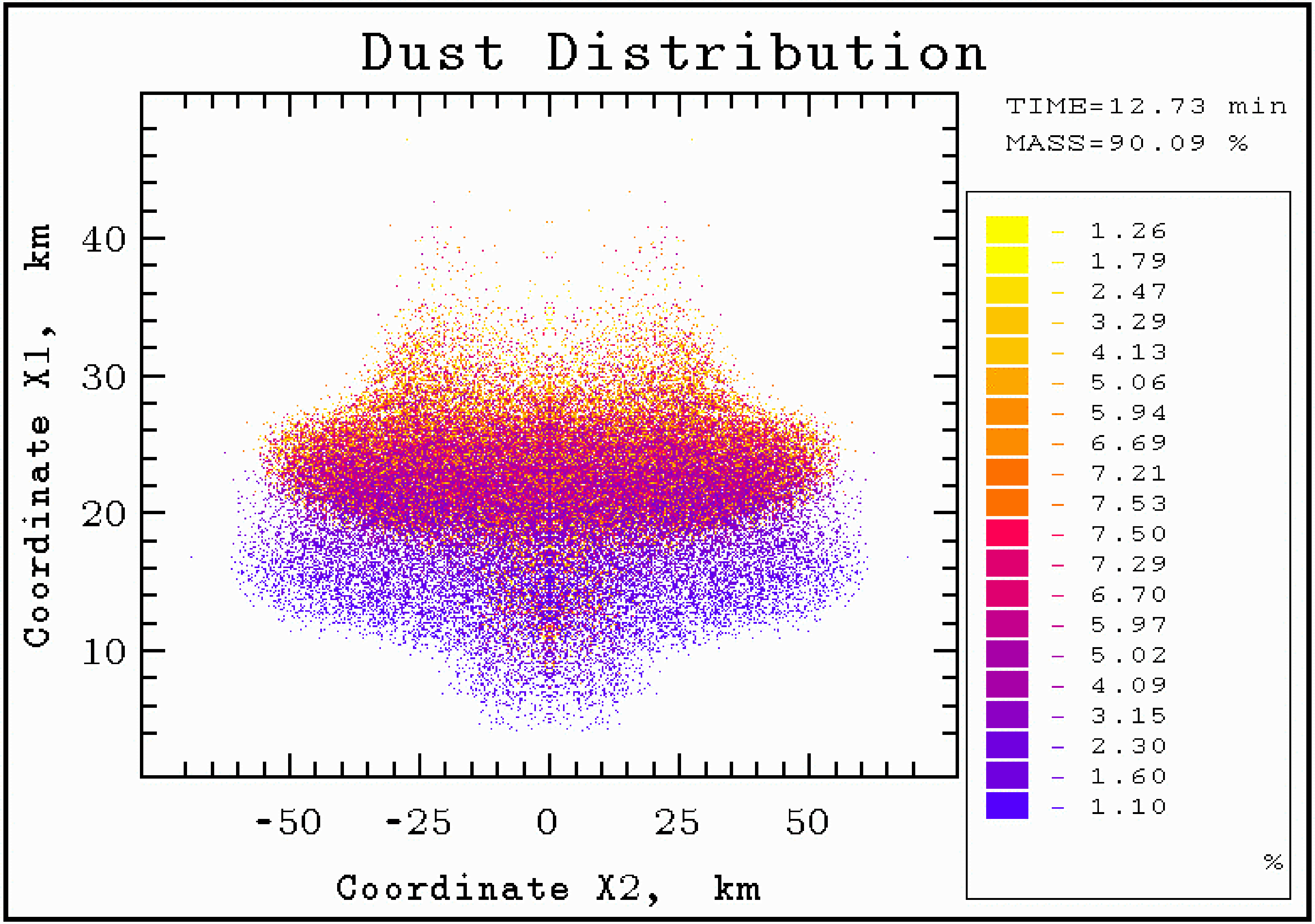
Dust Distribution
TIME=0.00 s
MASS=100.00 %
Coordinate X1, km
Coordinate X2, km
3
2.5
2
1.5
1
0.5
0
-10
-5
0
5
10
1.38
1.98
2.72
3.59
4.57
5.57
6.54
7.37
7.98
8.30
8.30
7.98
7.37
6.54
5.57
4.57
3.59
2.72
1.98
1.38
%


Dust Distribution
TIME=1.68 min
MASS=90.29 %
Coordinate X1, km
25
20
15
10
5
0
-15
-10
-5
0
5
10
15
Coordinate X2, km
1.26
1.80
2.47
3.29
4.14
5.07
5.95
6.70
7.22
7.54
7.51
7.29
6.71
5.98
5.02
4.11
3.17
2.33
1.64
1.11
%

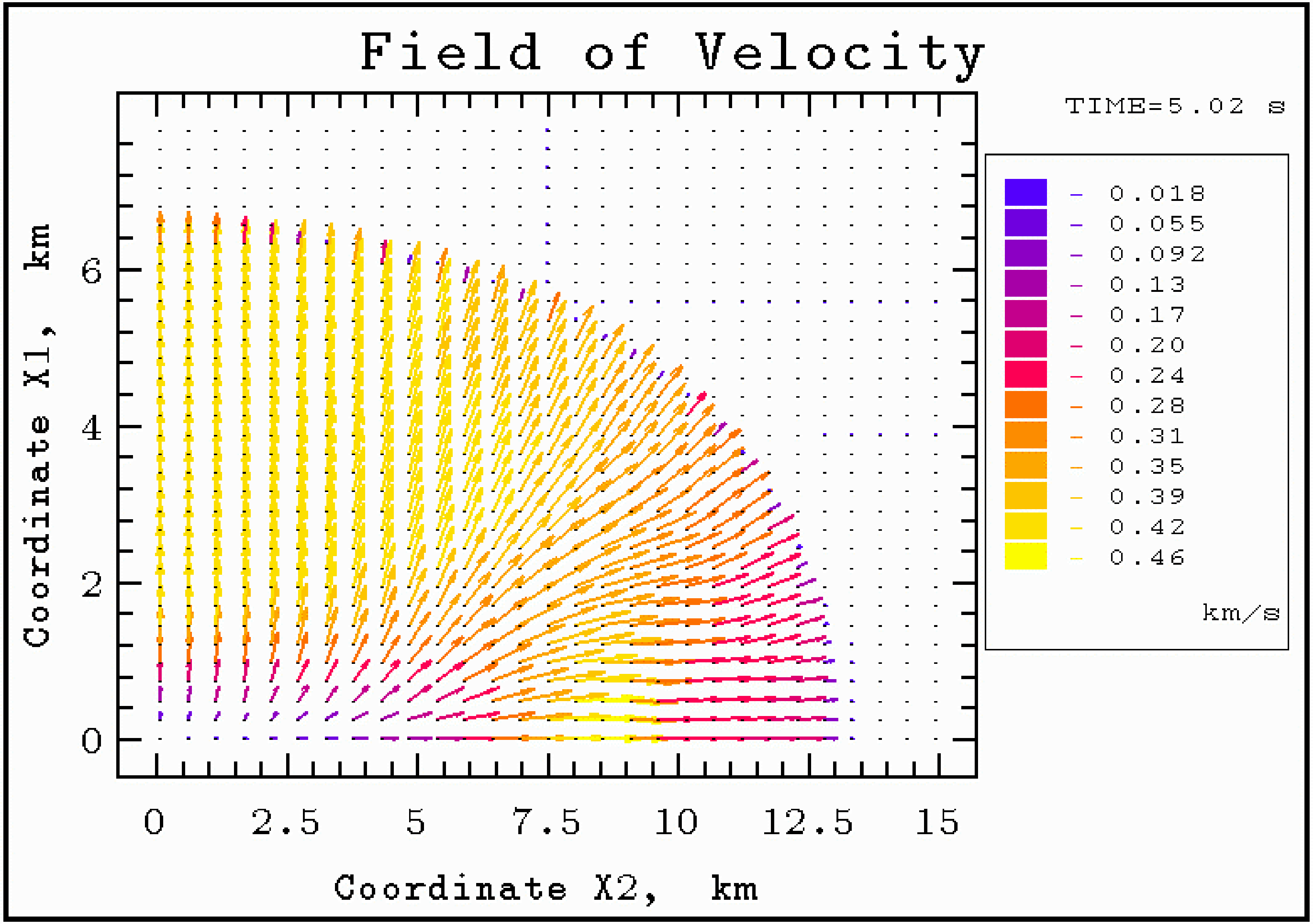

Dust Distribution
TIME=2.69 min
MASS=90.29 %
Coordinate X1, km
50
40
30
20
10
0
-20
-10
0
10
20
Coordinate X2, km
1.26
1.80
2.47
3.29
4.14
5.07
5.94
6.70
7.22
7.54
7.51
7.29
6.71
5.98
5.02
4.10
3.17
2.33
1.63
1.11
%


Dust Distribution
TIME=3.69 min
MASS=90.21 %
60
50
40
30
20
10
0
Coordinate X1, km
-30
-20
-10
0
10
20
30
Coordinate X2, km
1.26
1.80
2.47
3.29
4.13
5.07
5.94
6.70
7.22
7.54
7.51
7.29
6.71
5.98
5.02
4.10
3.16
2.31
1.60
1.10
%

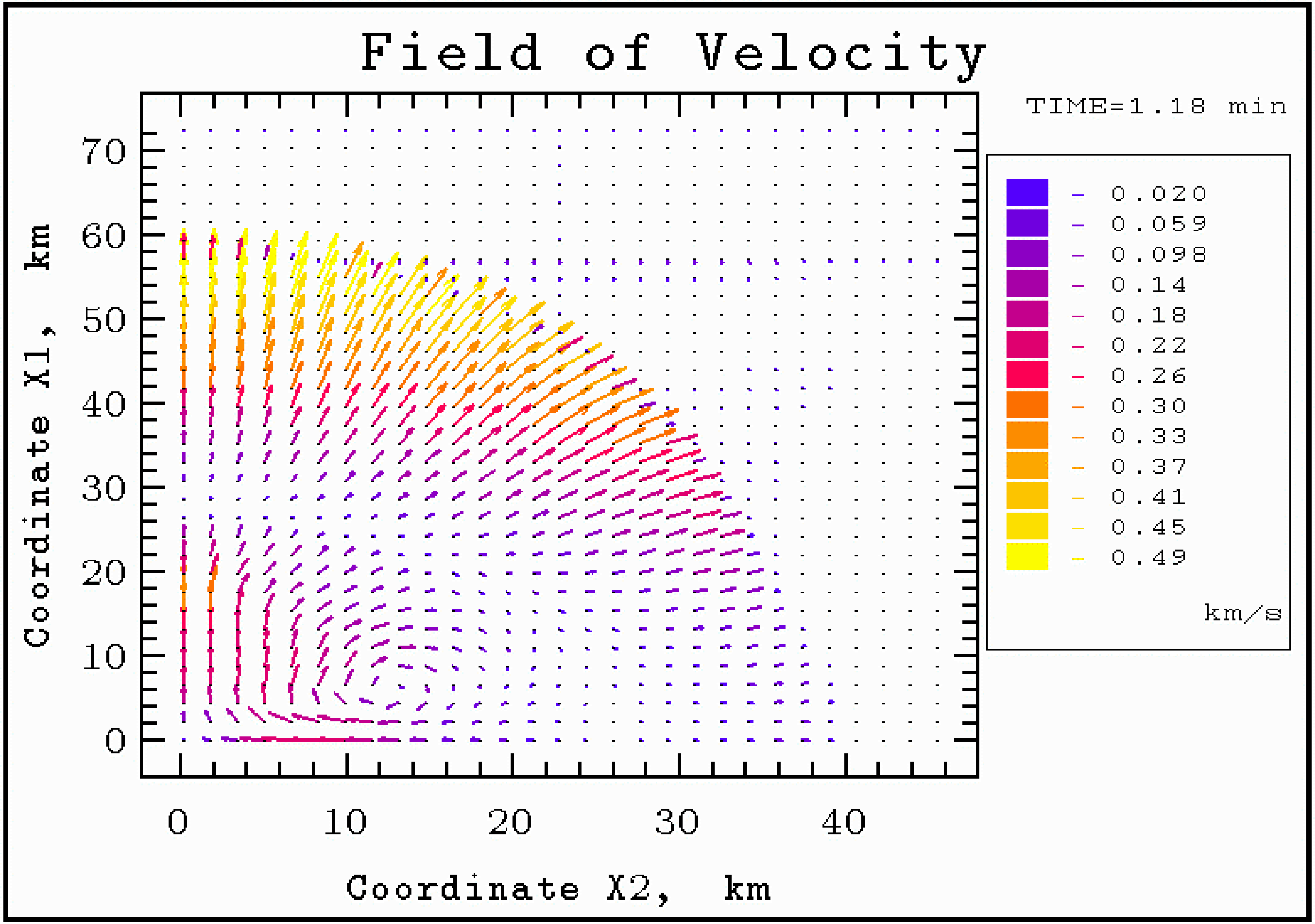

Dust Distribution
TIME=8.19 min
MASS=90.10 %
40
30
20
10
Coordinate X1, km
-50
-25
0
25
50
Coordinate X2, km
1.26
1.79
2.47
3.29
4.13
5.06
5.94
6.69
7.21
7.53
7.50
7.29
6.70
5.97
5.02
4.09
3.15
2.30
1.60
1.10
%

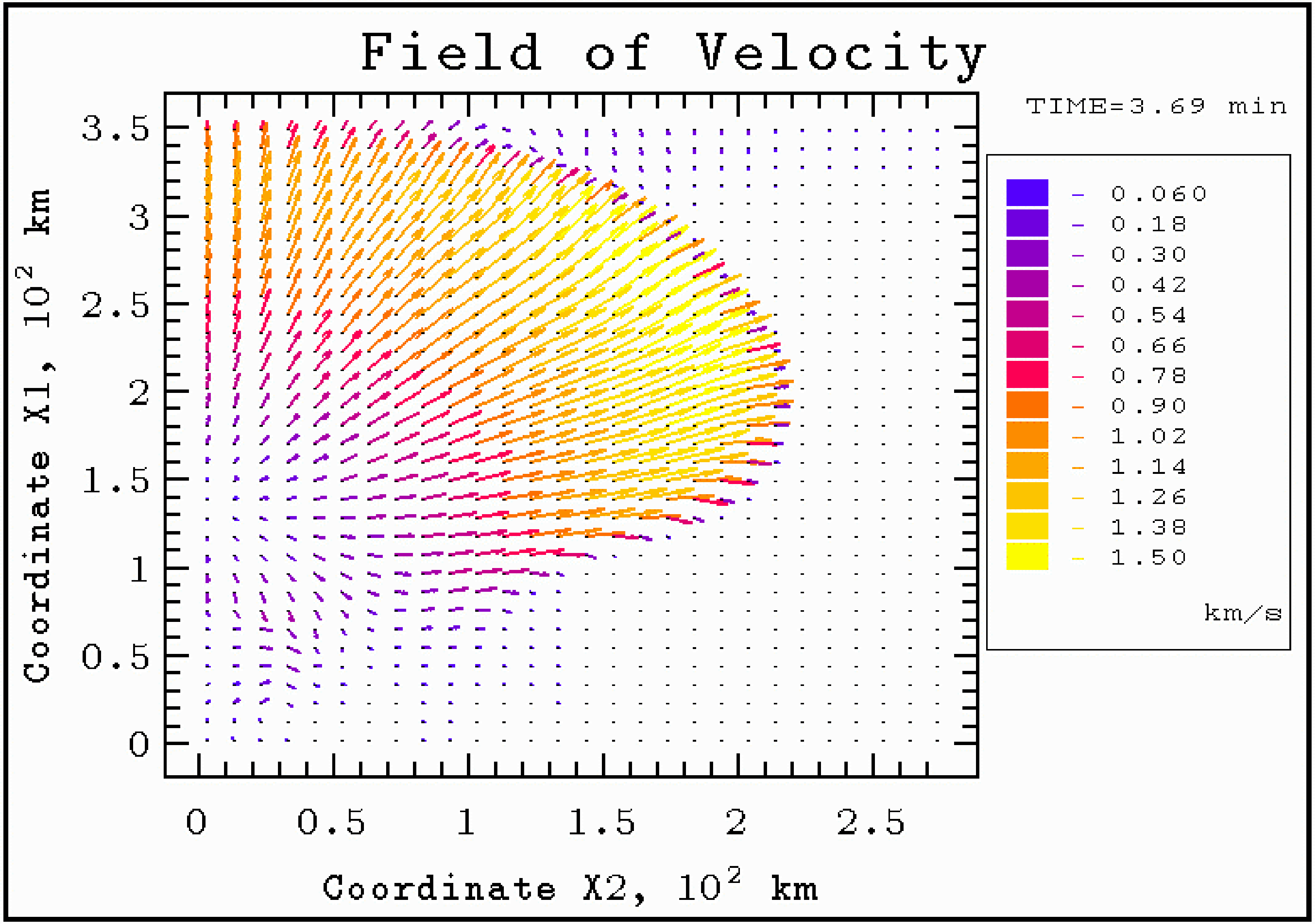


Dust Distribution
TIME=12.73 min
MASS=90.09 %
Coordinate X1, km
40
30
20
10
-50
-25
0
25
50
Coordinate X2, km
1.26
1.79
2.47
3.29
4.13
5.06
5.94
6.69
7.21
7.53
7.50
7.29
6.70
5.97
5.02
4.09
3.15
2.30
1.60
1.10
%

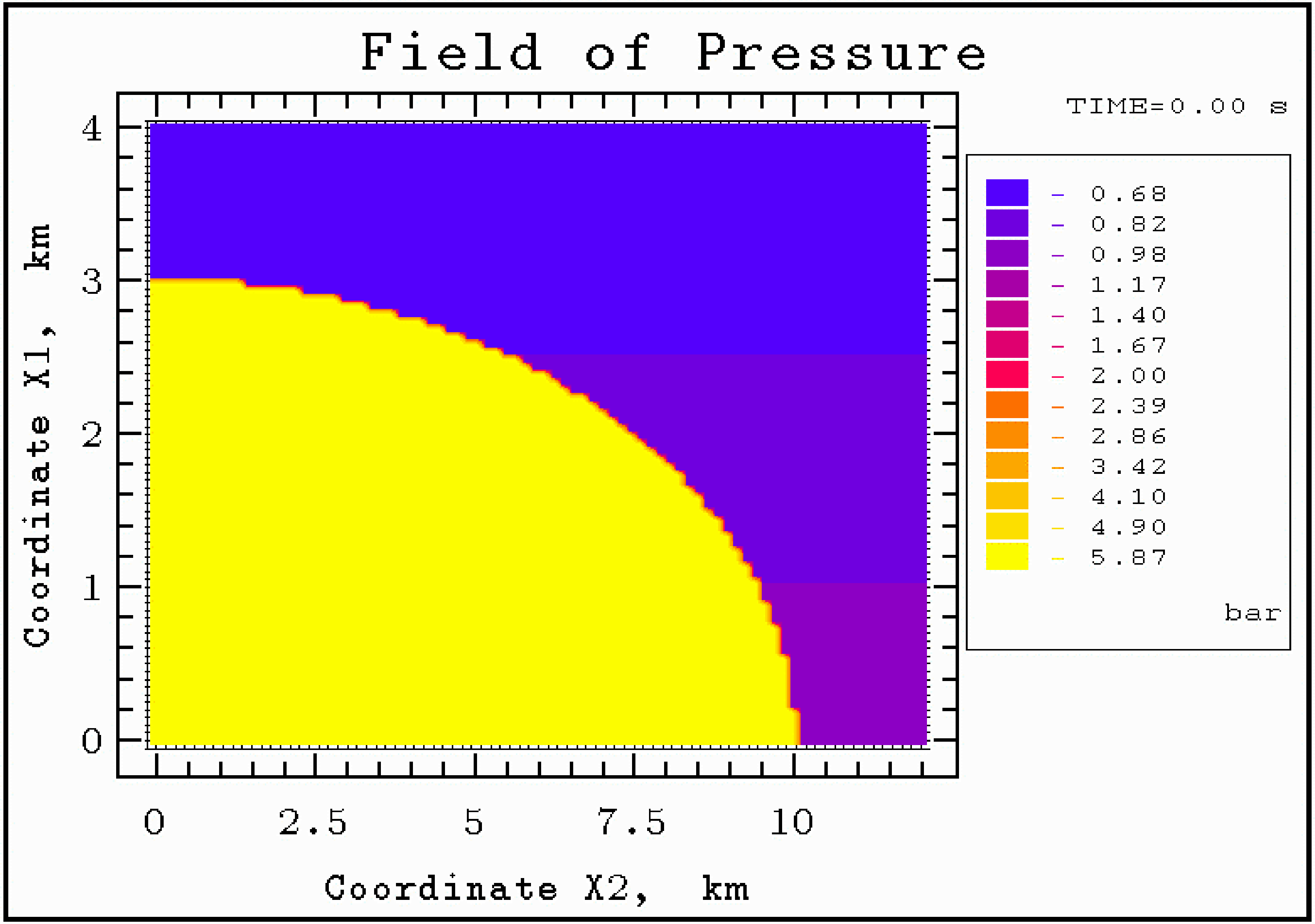


Field of Velocity
TIME=5.02 s
0.018
0.055
0.092
0.13
0.17
0.20
0.24
0.28
0.31
0.35
0.39
0.42
0.46
km/s
Coordinate X1, km
0
2
4
6
0
2.5
5
7.5
10
12.5
15
Coordinate X2, km

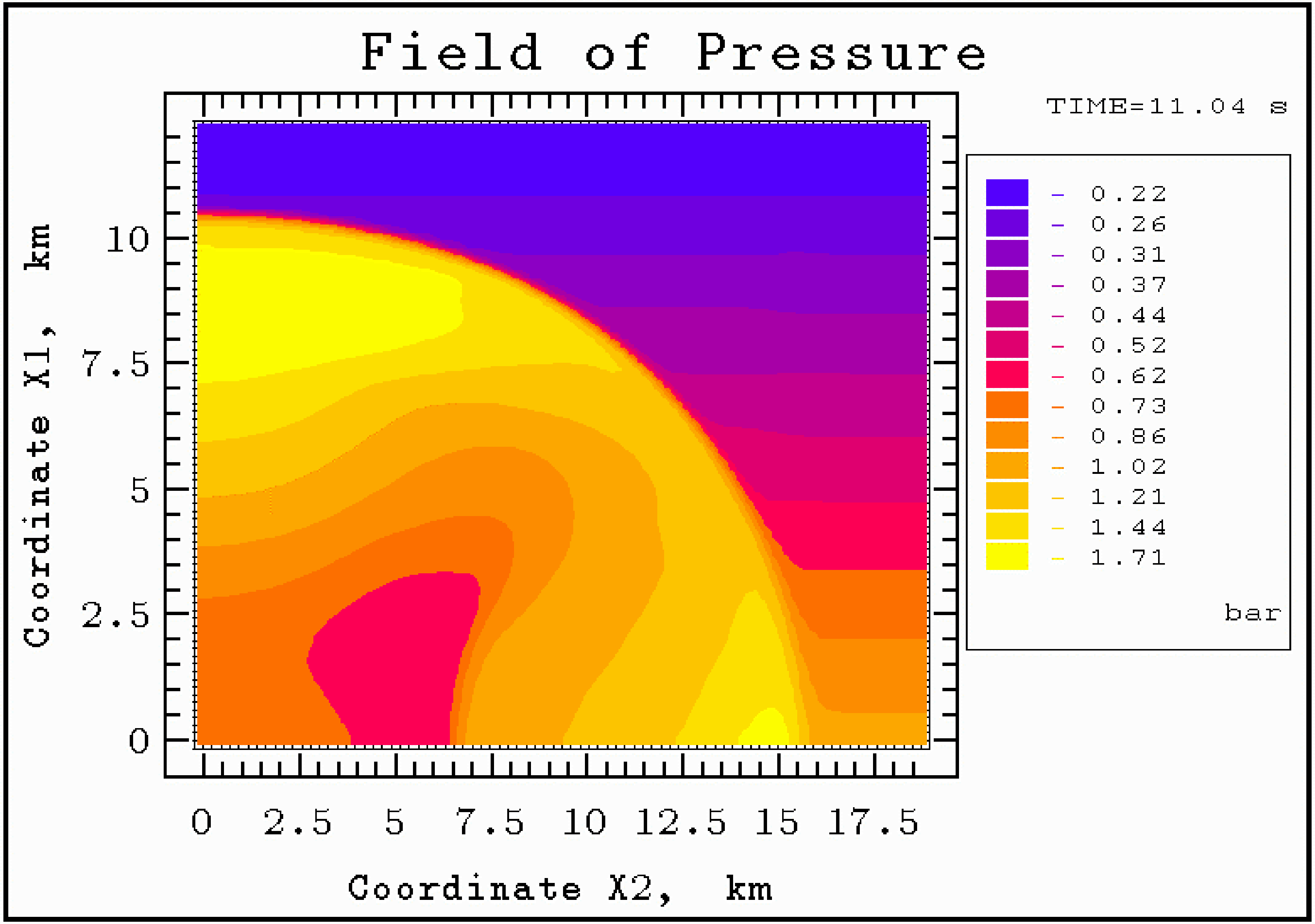

Field of Velocity
TIME=1.18 min
0.020
0.059
0.098
0.14
0.18
0.22
0.26
0.30
0.33
0.37
0.41
0.45
0.49
km/s
Coordinate X1, km
70
60
50
40
30
20
10
0
Coordinate X2, km
0
10
20
30
40



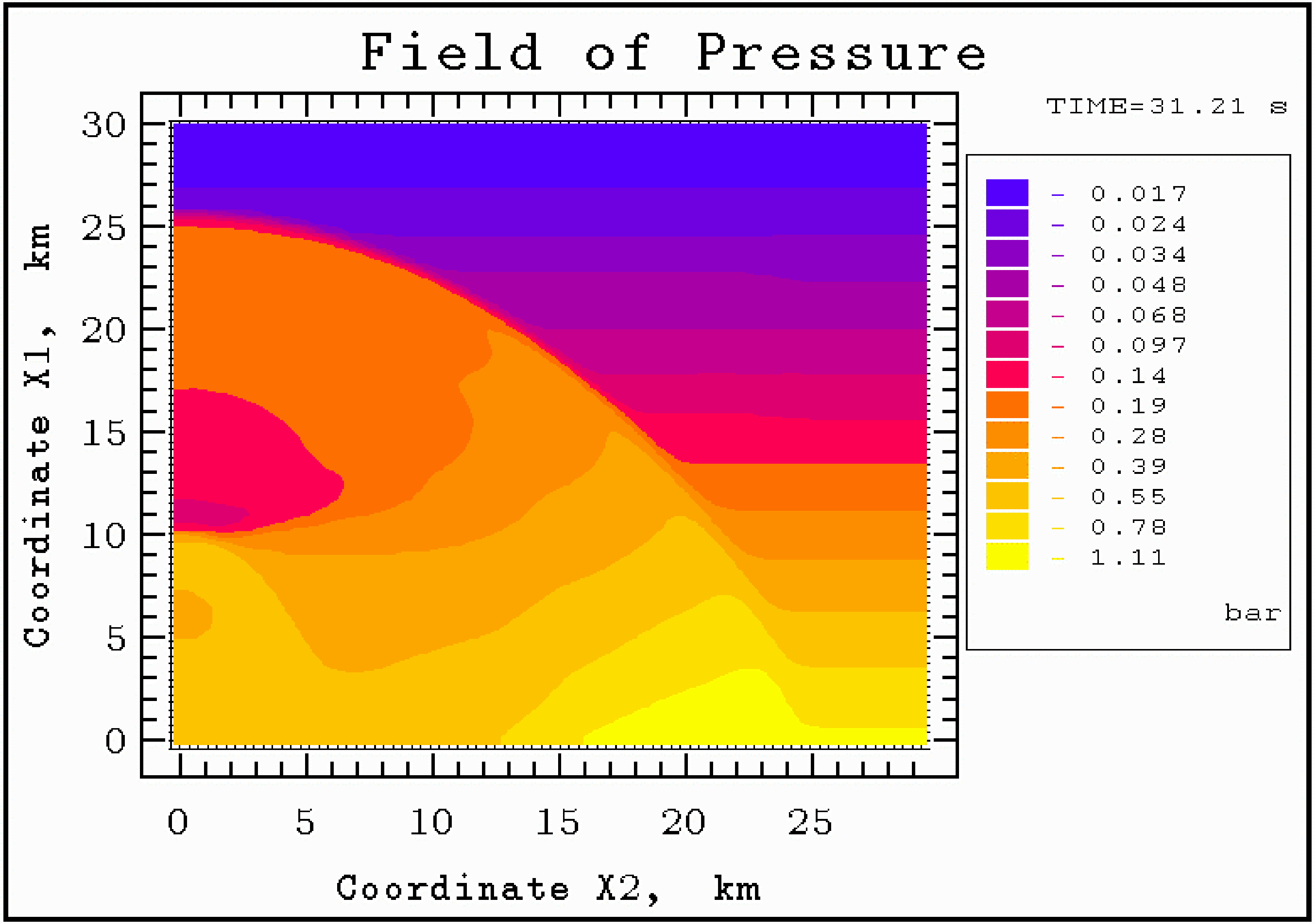
Field of Velocity
TIME=3.69 min
0.060
0.18
0.30
0.42
0.54
0.66
0.78
0.90
1.02
1.14
1.26
1.38
1.50
km/s
Coordinate X1, 10^2 km
Coordinate X2, 10^2 km
0
0.5
1
1.5
2
2.5
3
3.5



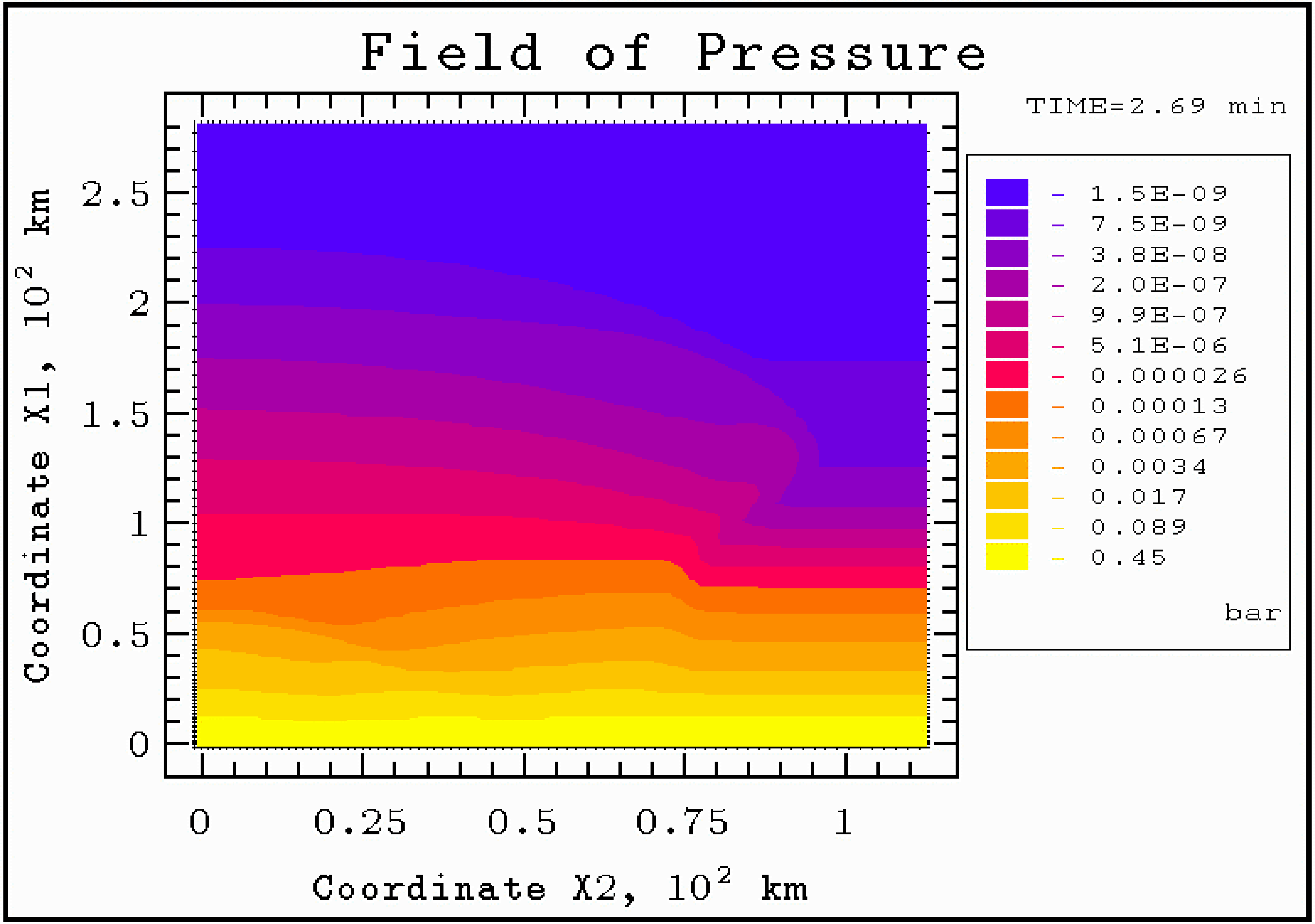
Field of Pressure
TIME=0.00 s
4
3
2
1
0
Coordinate X1, km
0
2.5
5
7.5
10
Coordinate X2, km
0.68
0.82
0.98
1.17
1.40
1.67
2.00
2.39
2.86
3.42
4.10
4.90
5.87
bar

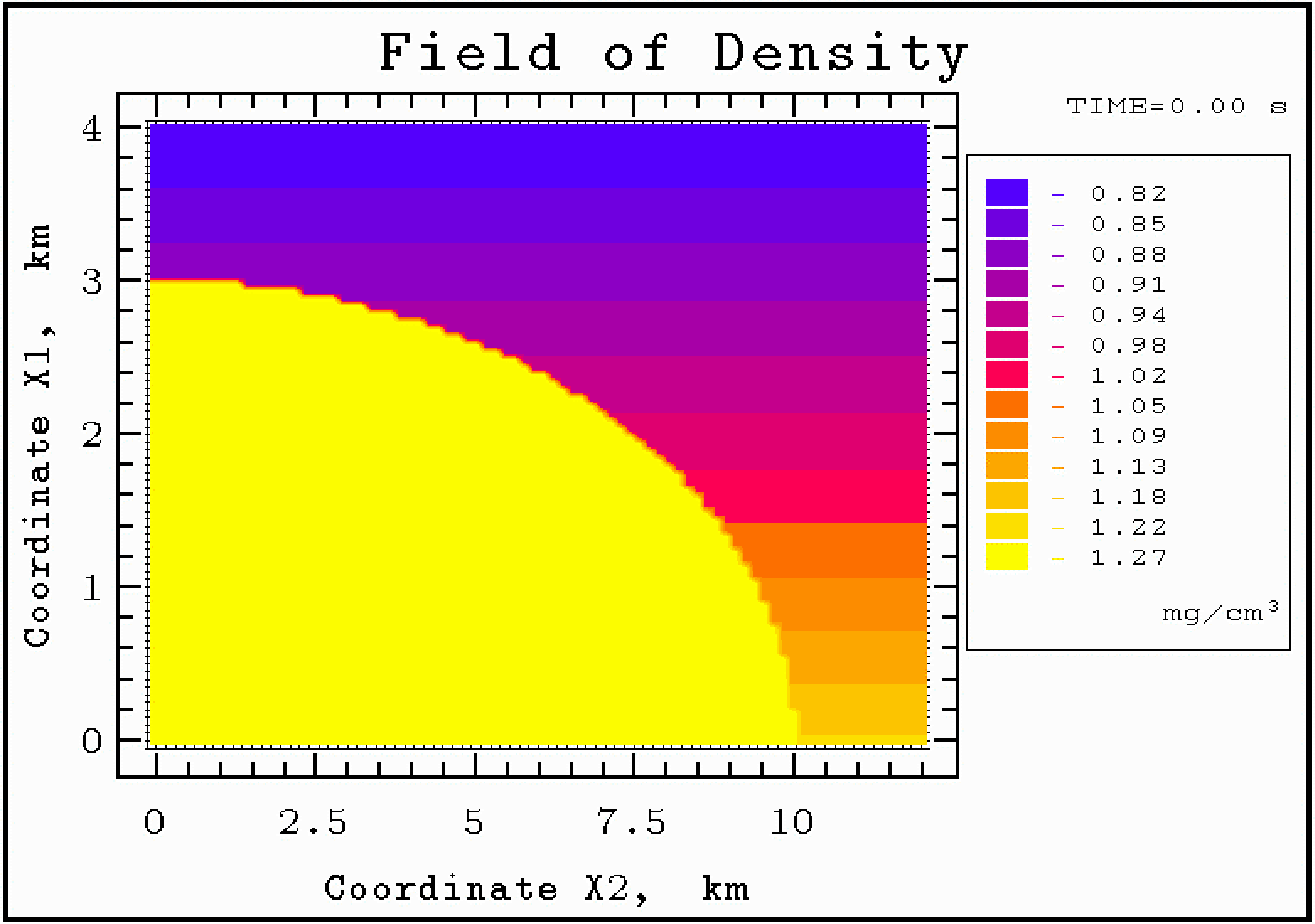


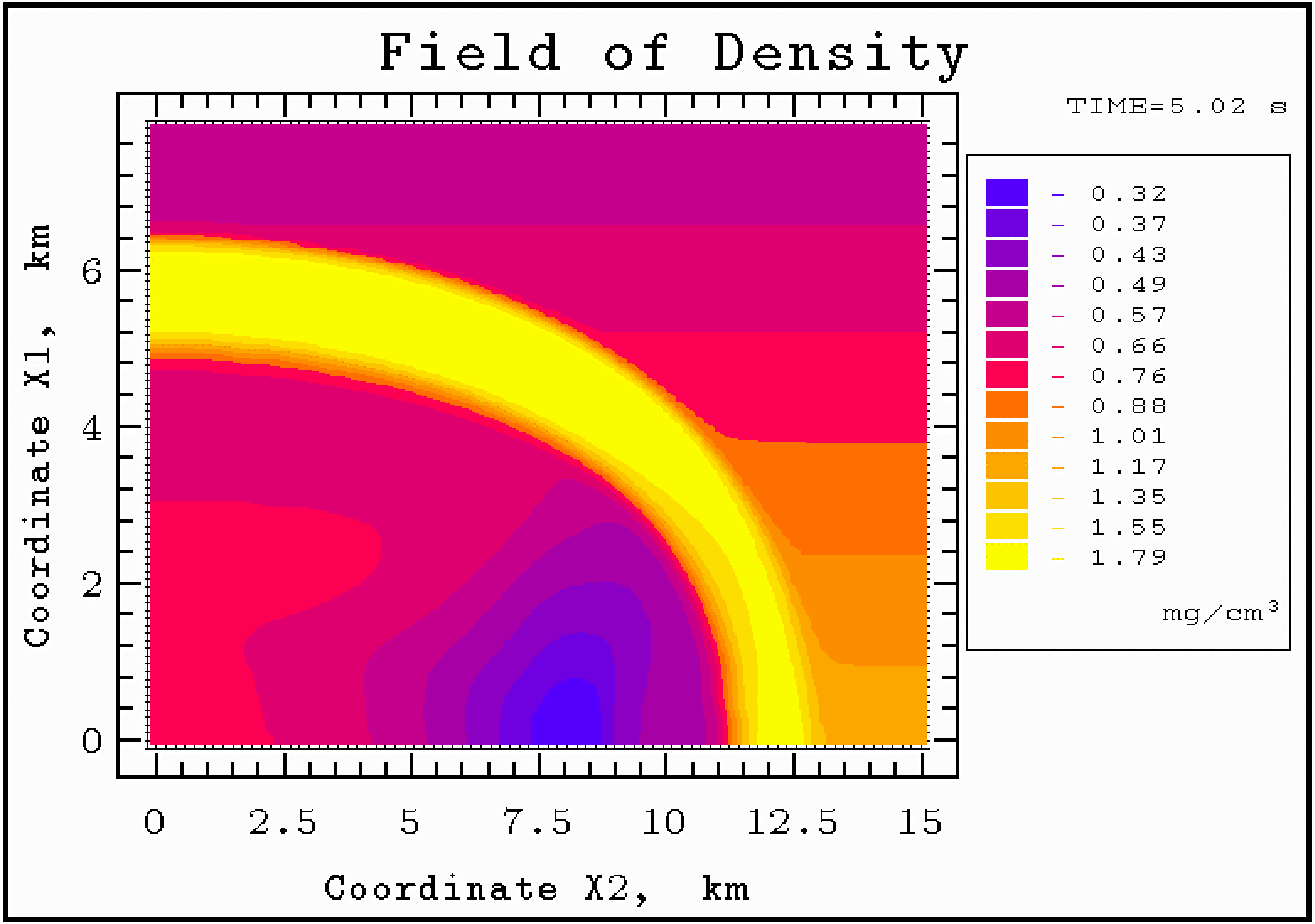
Field of Pressure
TIME=11.04 s
0.22
0.26
0.31
0.37
0.44
0.52
0.62
0.73
0.86
1.02
1.21
1.44
1.71
bar
Coordinate X1, km
0
2.5
5
7.5
10
0
2.5
5
7.5
10
12.5
15
17.5
Coordinate X2, km



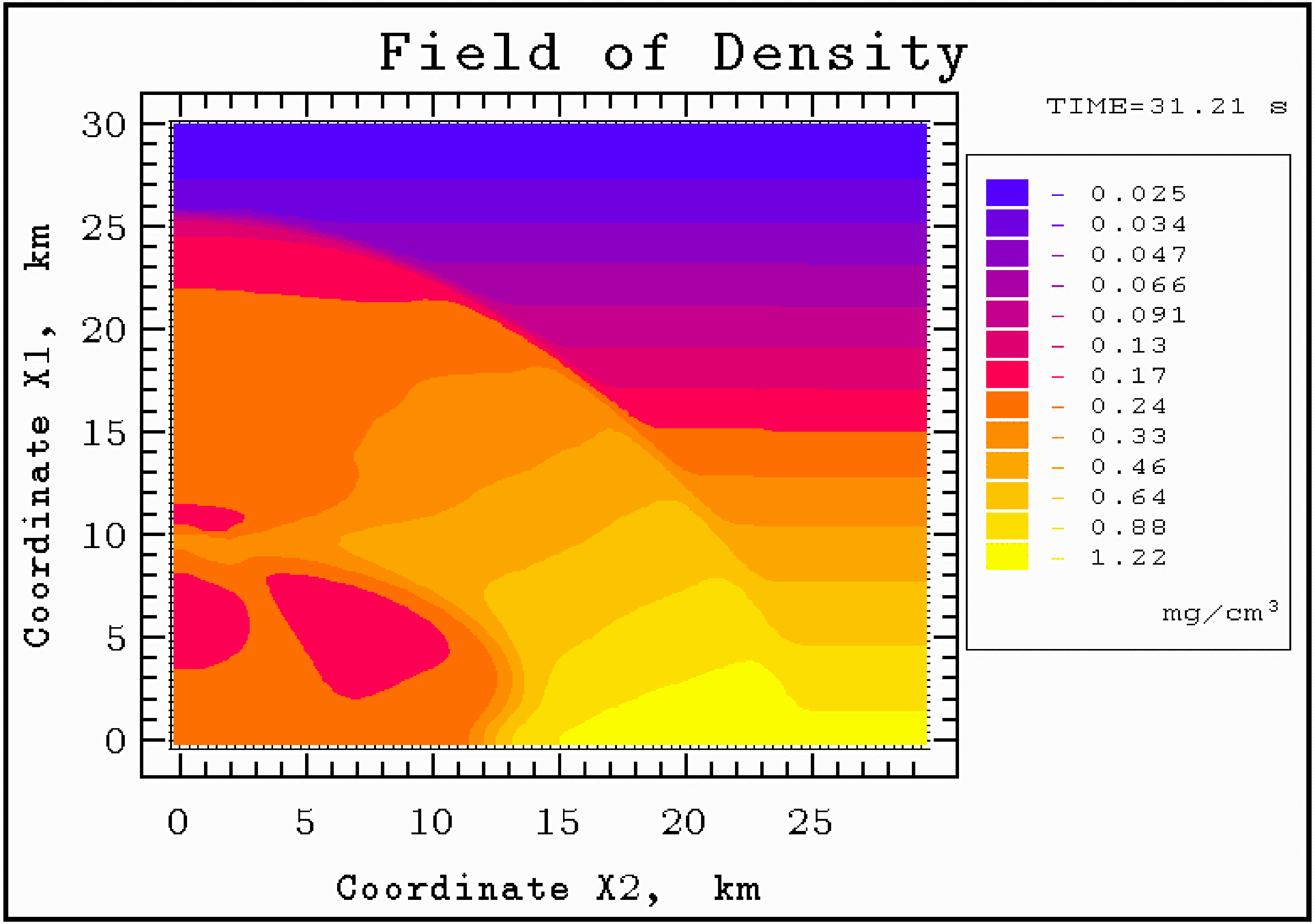
Field of Pressure
TIME=31.21 s
30
25
20
15
10
5
0
Coordinate X1, km
0
5
10
15
20
25
Coordinate X2, km
0.017
0.024
0.034
0.048
0.068
0.097
0.14
0.19
0.28
0.39
0.55
0.78
1.11
bar


Field of Pressure
TIME=2.69 min
1.5E-09
7.5E-09
3.8E-08
2.0E-07
9.9E-07
5.1E-06
0.000026
0.00013
0.00067
0.0034
0.017
0.089
0.45
bar
2.5
2
1.5
1
0.5
0
Coordinate X1, 10^2 km
0
0.25
0.5
0.75
1
Coordinate X2, 10^2 km

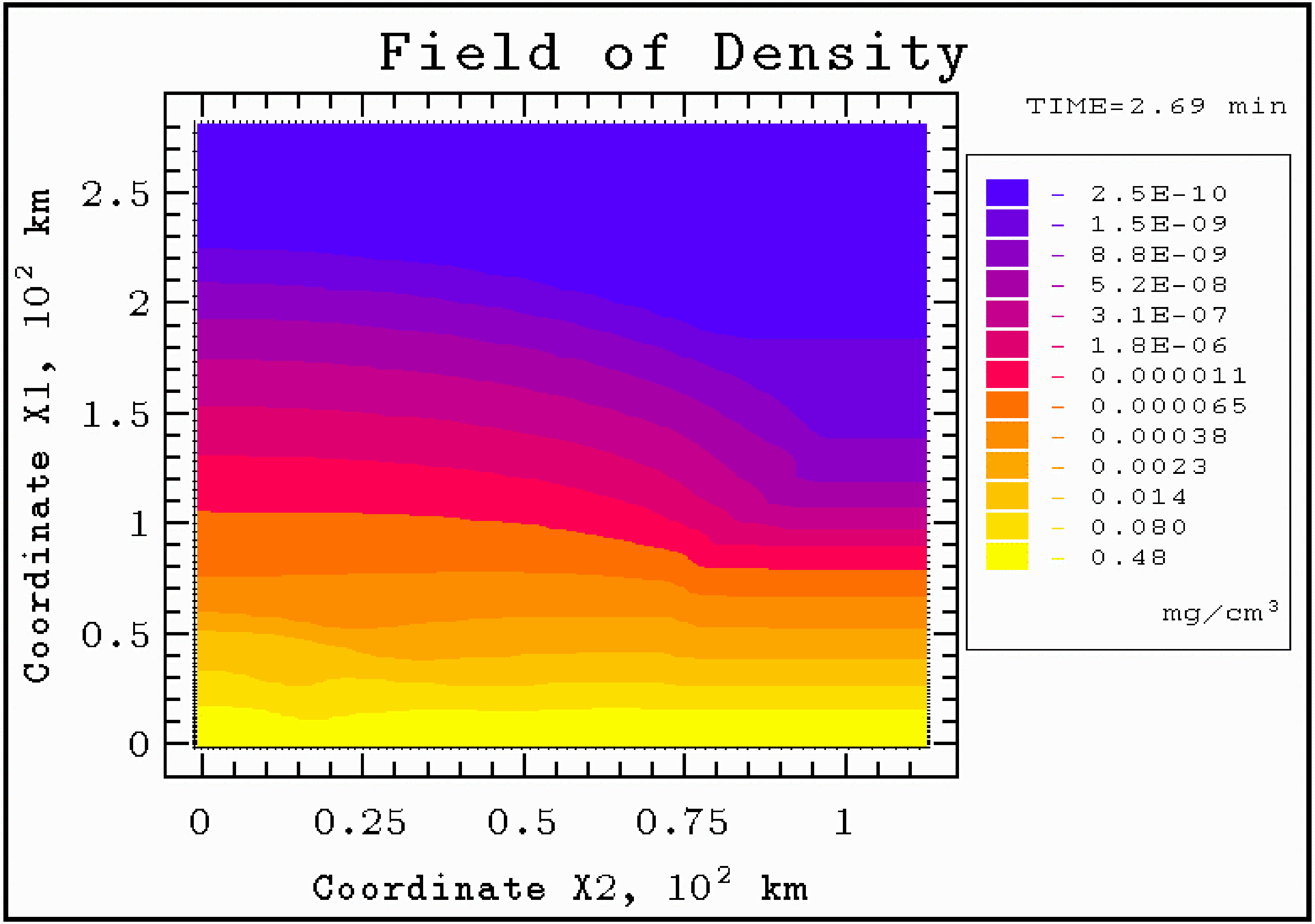

Field of Density
TIME=0.00 s
Coordinate X1, km
4
3
2
1
0
Coordinate X2, km
0
2.5
5
7.5
10
0.82
0.85
0.88
0.91
0.94
0.98
1.02
1.05
1.09
1.13
1.18
1.22
1.27
mg/cm3



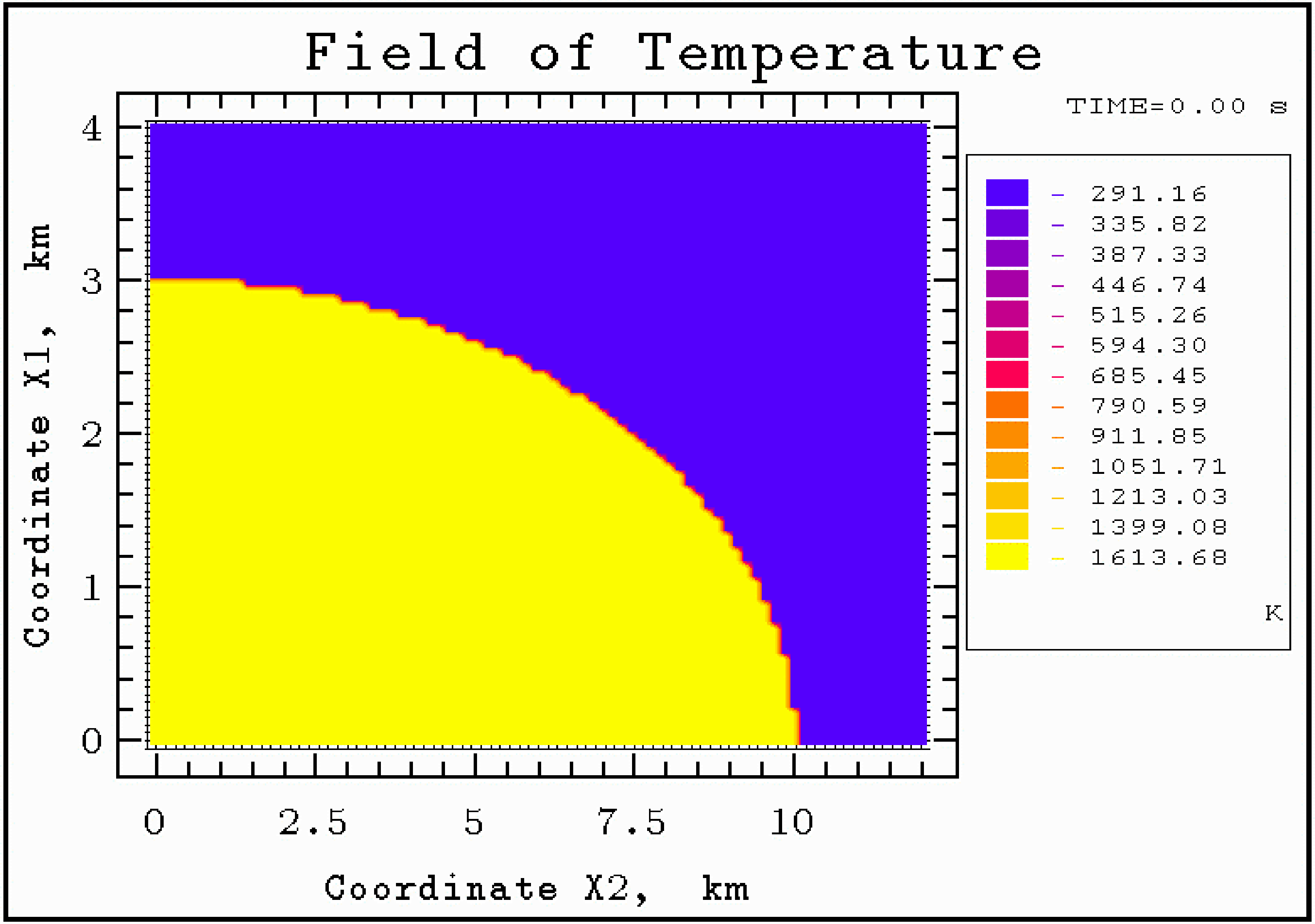
Field of Density
TIME=5.02 s
Coordinate X1, km
0
2
4
6
0
2.5
5
7.5
10
12.5
15
Coordinate X2, km
0.32
0.37
0.43
0.49
0.57
0.66
0.76
0.88
1.01
1.17
1.35
1.55
1.79
mg/cm³



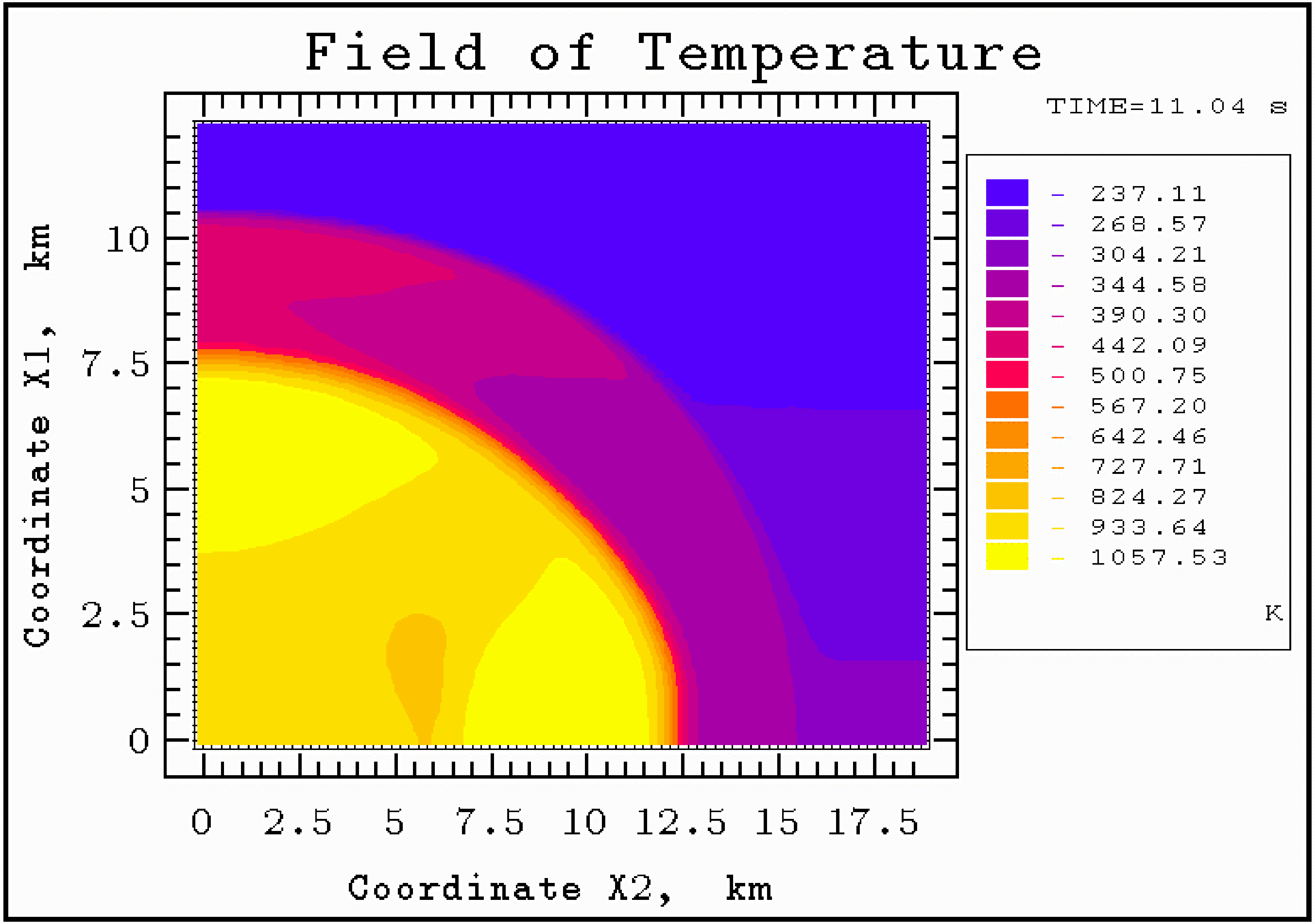
Field of Density
TIME=31.21 s
30
25
20
15
10
5
0
Coordinate X1, km
0
5
10
15
20
25
Coordinate X2, km
0.025
0.034
0.047
0.066
0.091
0.13
0.17
0.24
0.33
0.46
0.64
0.88
1.22
mg/cm³



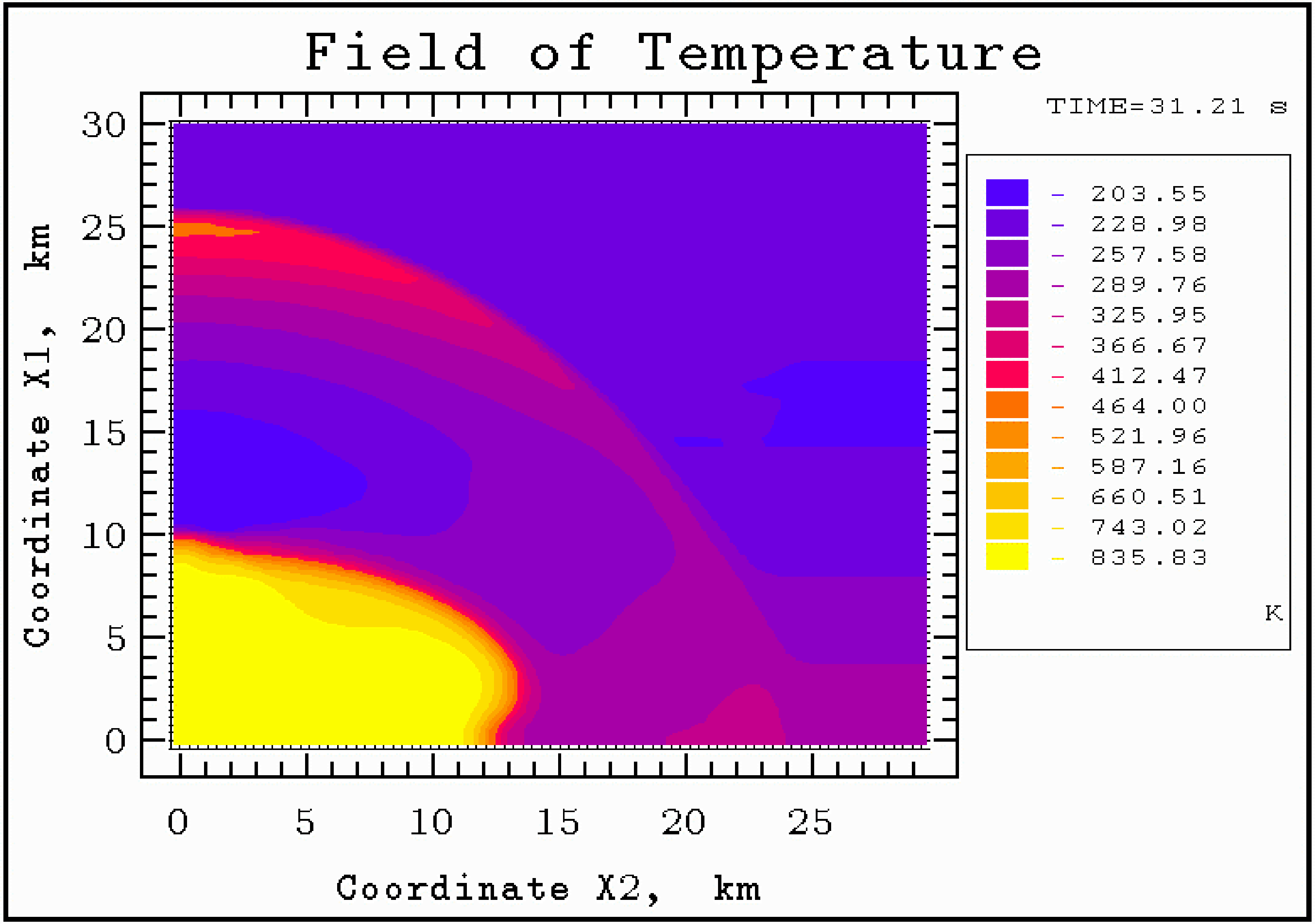
Field of Density
TIME=2.69 min
2.5E-10
1.5E-09
8.8E-09
5.2E-08
3.1E-07
1.8E-06
0.000011
0.000065
0.00038
0.0023
0.014
0.080
0.48
mg/cm3
Coordinate X1, 10^2 km
0
0.5
1
1.5
2
2.5
0
0.25
0.5
0.75
1
Coordinate X2, 10^2 km



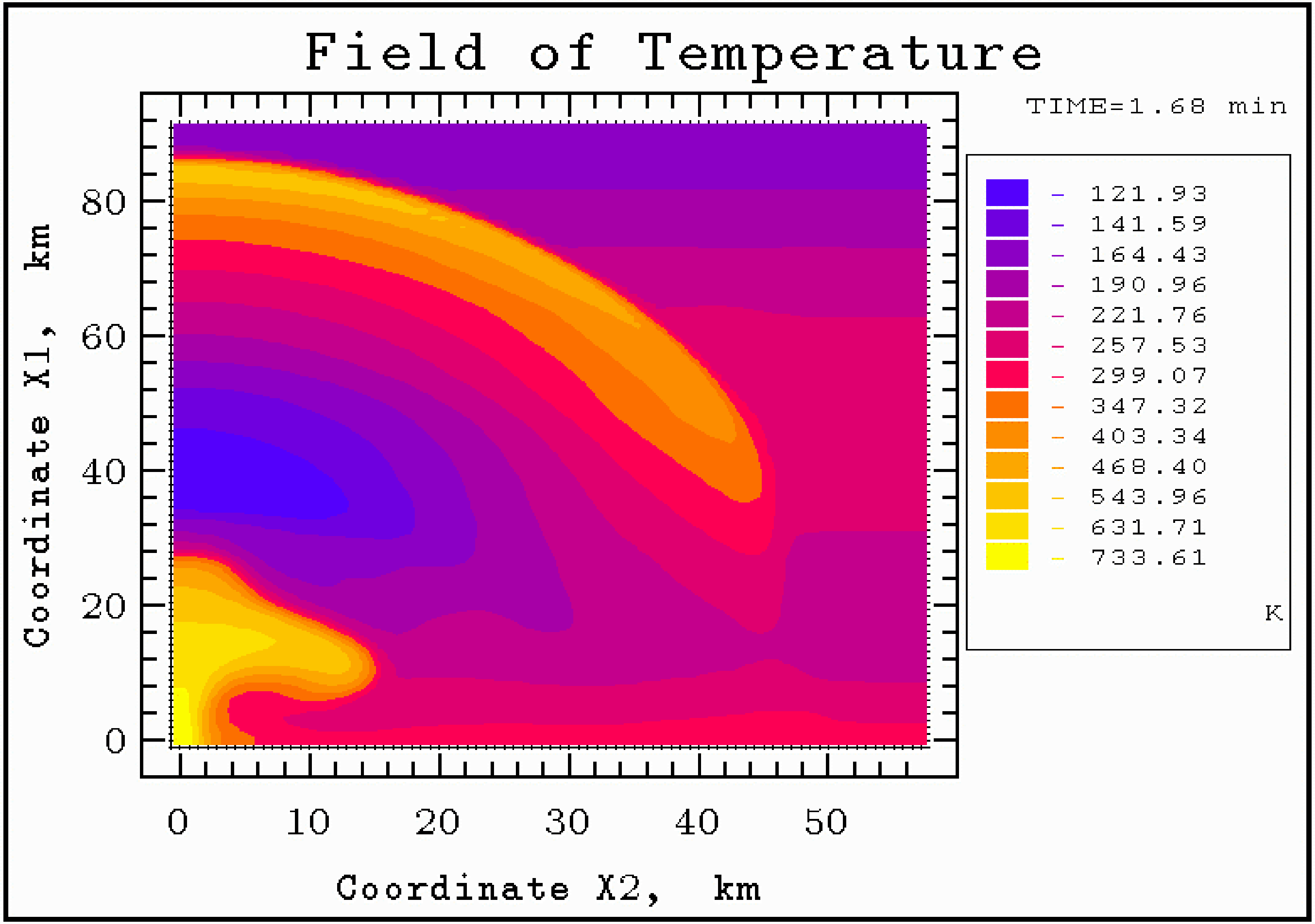
Field of Temperature
TIME=0.00 s
4
3
2
1
0
Coordinate X1, km
0
2.5
5
7.5
10
Coordinate X2, km
291.16
335.82
387.33
446.74
515.26
594.30
685.45
790.59
911.85
1051.71
1213.03
1399.08
1613.68
K

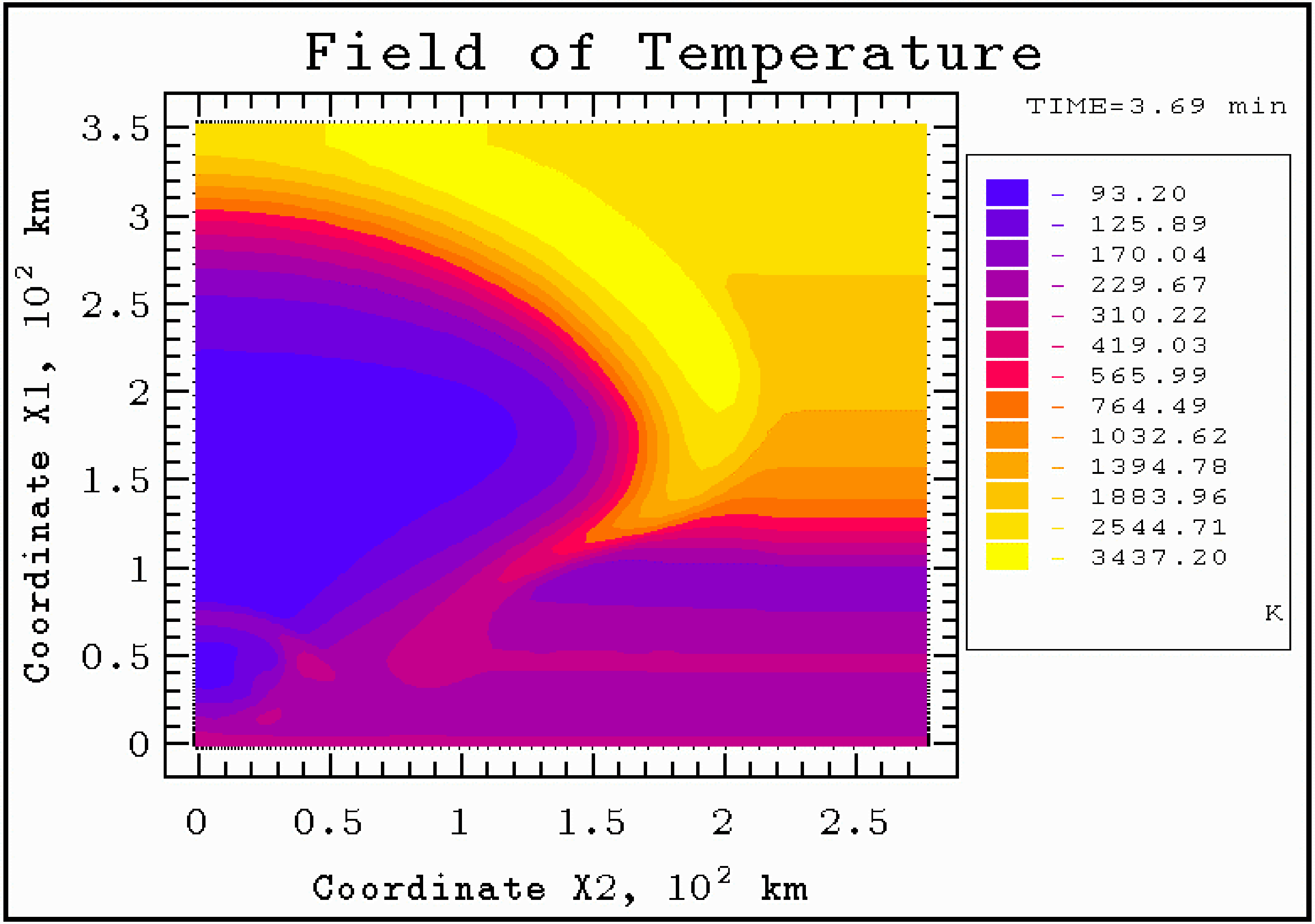


Field of Temperature
TIME=11.04 s
Coordinate X1, km
10
7.5
5
2.5
0
0
2.5
5
7.5
10
12.5
15
17.5
Coordinate X2, km
237.11
268.57
304.21
344.58
390.30
442.09
500.75
567.20
642.46
727.71
824.27
933.64
1057.53
K



Field of Temperature
TIME=31.21 s
30
25
20
15
10
5
0
Coordinate X1, km
0
5
10
15
20
25
Coordinate X2, km
203.55
228.98
257.58
289.76
325.95
366.67
412.47
464.00
521.96
587.16
660.51
743.02
835.83
K


Field of Temperature
TIME=1.68 min
Coordinate X1, km
Coordinate X2, km
0
20
40
60
80
0
10
20
30
40
50
121.93
141.59
164.43
190.96
221.76
257.53
299.07
347.32
403.34
468.40
543.96
631.71
733.61
K


Field of Temperature
TIME=3.69 min
3.5
3
2.5
2
1.5
1
0.5
0
Coordinate X1, 10^2 km
0
0.5
1
1.5
2
2.5
Coordinate X2, 10^2 km
93.20
125.89
170.04
229.67
310.22
419.03
565.99
764.49
1032.62
1394.78
1883.96
2544.71
3437.20
K