Dust - Gas dissociation in observations of molecular clouds

Rémi Monceau-Baroux
Rony Keppens

CmPA – KU Leuven

Difficulties in observations

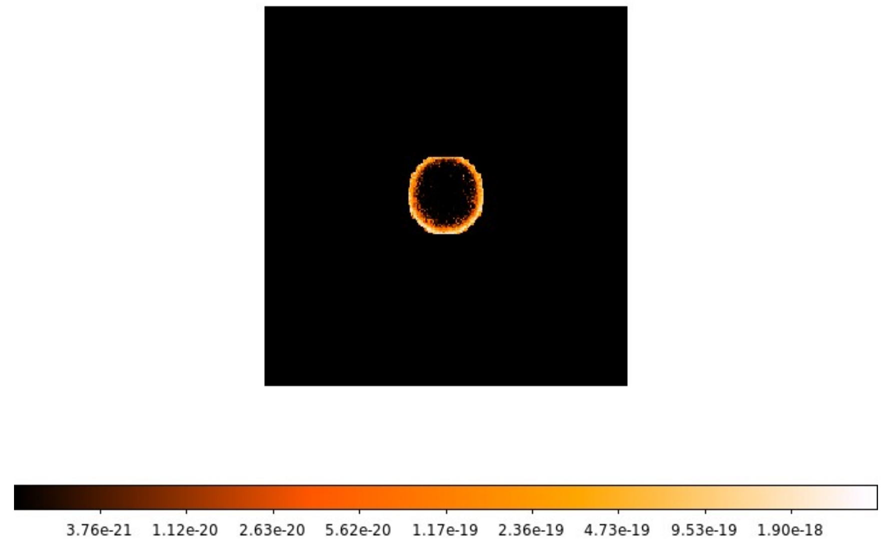
- We don't have the instrument to observe it. (Wavelength, timing)
- There is nothing to see. (Low flux, no emission processes)
- Hydrogen gas is *mostly* boring (from an observer point of view).
- CO limitation for dense region.

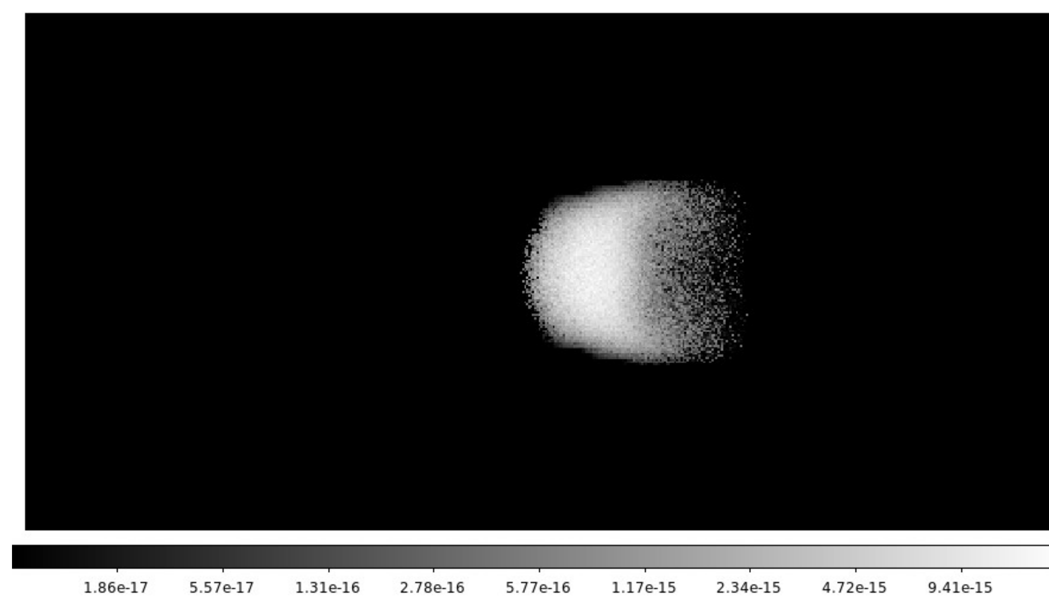
Molecular clouds – Dusty places

Dust (and molecules) are thought to be less than 1% of the gas content BUT play a spectacular role in emission.

Why do we study dust in MC?

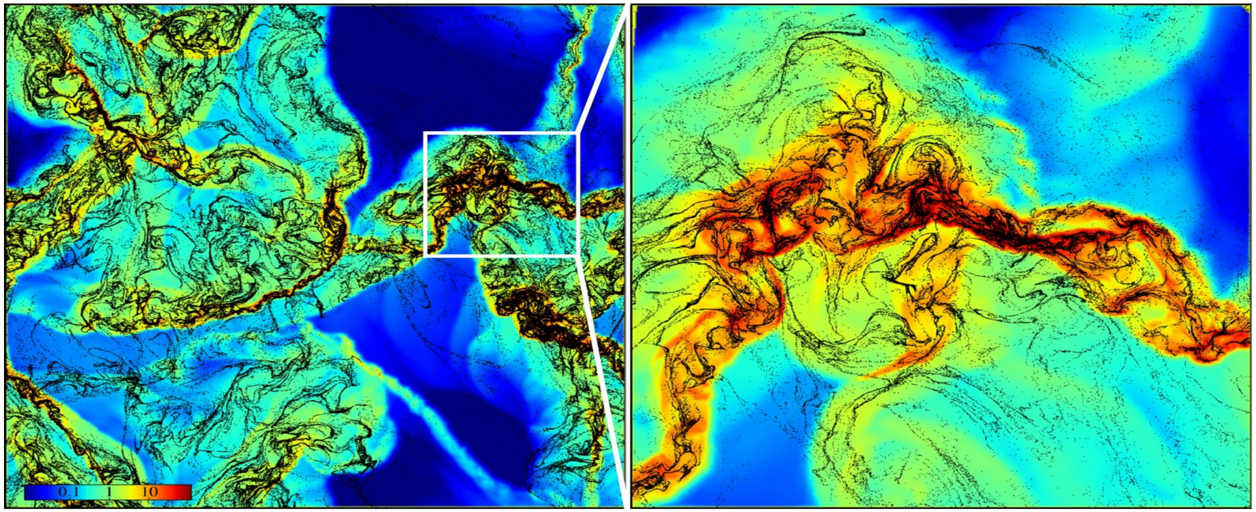
- Composition and shape mostly unknowed
- Shadows (absorption)
- Scattered light
- Continuum of emission
- But is the dust and the gas in the same place?

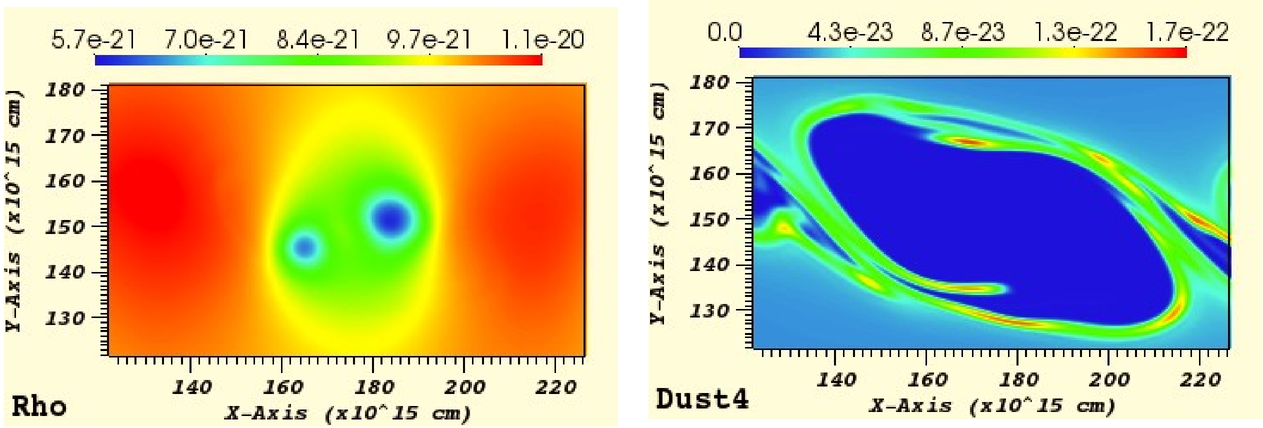




Probably not... in fine structures?

- Hopkins et al 2015: Dust regroup in filaments which do not correspond to high gas density regions
- Hendrix et al 2014: Big grain dust tend to be push away from the vorticies of KH instabilities.





*A simple setup: Destruction of a molecular cloud by a shock.

*Back to astronomy: synthetic imaging of a galactic molecular cloud.

Cloud destroyed by a shock

Table 1. A representative (but incomplete) summary of previous numerical investigations of shock-cloud and wind-cloud interactions. χ is the density contrast of the cloud with respect to the ambient medium and M is the shock Mach number. The interaction types are: SCS = shock-cloud (single); SCM = shock-cloud (multiple); WCS = wind-cloud (single). The references are as follows: [a]Stone & Norman (1992); [b]Klein et al. (1994); [c]Mac Low et al. (1994); [d]Mellema, Kurk & Röttgering (2002); [e]Fragile et al. (2004); [f]Orlando et al. (2005); [g]Nakamura et al. (2006); [h]van Loo et al. (2007); [i]Orlando et al. (2008); [j]Shin et al. (2008); [k]Poludnenko et al. (2002); [l]Gregori et al. (2000); [m]Poludnenko et al. (2004); [n]Marcolini et al. (2005); [o]Raga et al. (2007); [p]Vieser & Hensler (2007).

Authors	Interaction type	Geometry	Typical (max) resolution	χ	M	Cooling?	Conduction?	Magnetic fields?
SN92[a]	SCS	3D XYZ	60 (60)	10	10			
KMC94[b]	SCS	2D RZ	120 (240)	3,10,30, 100,400	10,100,1000			
MC94[c]	SCS	2D RZ,XY	50 (240)	10	10,100			✔
MKR02[d]	SCS	2D RZ,XY	200 (200)	1000	10	✔		
F04[e]	SCS	2D XY	200 (200)	1000	5,10,20,40	✔		
O05[f]	SCS	2D RZ, 3D XYZ	132 (132)	10	30,50	✔	✔	
N06[g]	SCS	2D RZ, 3D XYZ	120 (960)	10,100	1.5,10,100,1000			
V07[h]	SCS	2D RZ	640 (640)	45	1.5,2.5,5	✔		✔
O08[i]	SCS	2.5D XYZ	132 (528)	10	50	✔	✔	✔
SSS08[j]	SCS	3D XYZ	68 (68)	10	10			✔
PFB02[k]	SCM	2D XY	32 (32)	500	10			
G00[l]	WCS	3D XYZ	16 (26)	10,30,100	1.5,3			✔
PFM04[m]	WCS	2D RZ	128 (128)	100	10-200	✔		
M05[n]	WCS	2D RZ	150 (150)	100,500	3,6.67	✔	✔	
R07[o]	WCS	3D XYZ	77 (77)	10	242	✔		
VH07[p]	WCS	2D RZ	33 (51)	0.6,1.2, 6.1×10^4	0.3	✔	✔	

Notes: Patnaude & Fesen (2005) and Cooper et al. (2009) consider a cloud with substructure. Multiple-cloud interactions were also considered by Fragile et al. (2004) and Melioli et al. (2005), though this was not the main focus of their work. Simulations with continuous mass-injection (to mimic the destruction of very long lived clouds) have been presented by Falle et al. (2002), Pittard et al. (2005), Dyson et al. (2006), and Pope et al. (2008). Pittard et al. (2005) investigated the interaction of a wind with multiple mass-injection sources.

Pittard et al. 2010

Model: multi-fluid approach

- Plasma = fluid: Euler + source term
- Dust = pressure-less fluid
- Interaction – Source term: Drag force

$$\frac{\partial \rho}{\partial t} + \bigtriangledown \cdot (\rho \vec{v}) = 0$$

$$\frac{\partial (\rho \vec{v})}{\partial t} + \bigtriangledown \cdot (\rho \vec{v}\vec{v}) + \bigtriangledown p = \sum_{d=1}^{N} \vec{f_d}$$

$$\frac{\partial e}{\partial t} + \bigtriangledown \cdot [(p+e)\vec{v}] = \sum_{d=1}^{N} \vec{v} \cdot \vec{f_d}$$

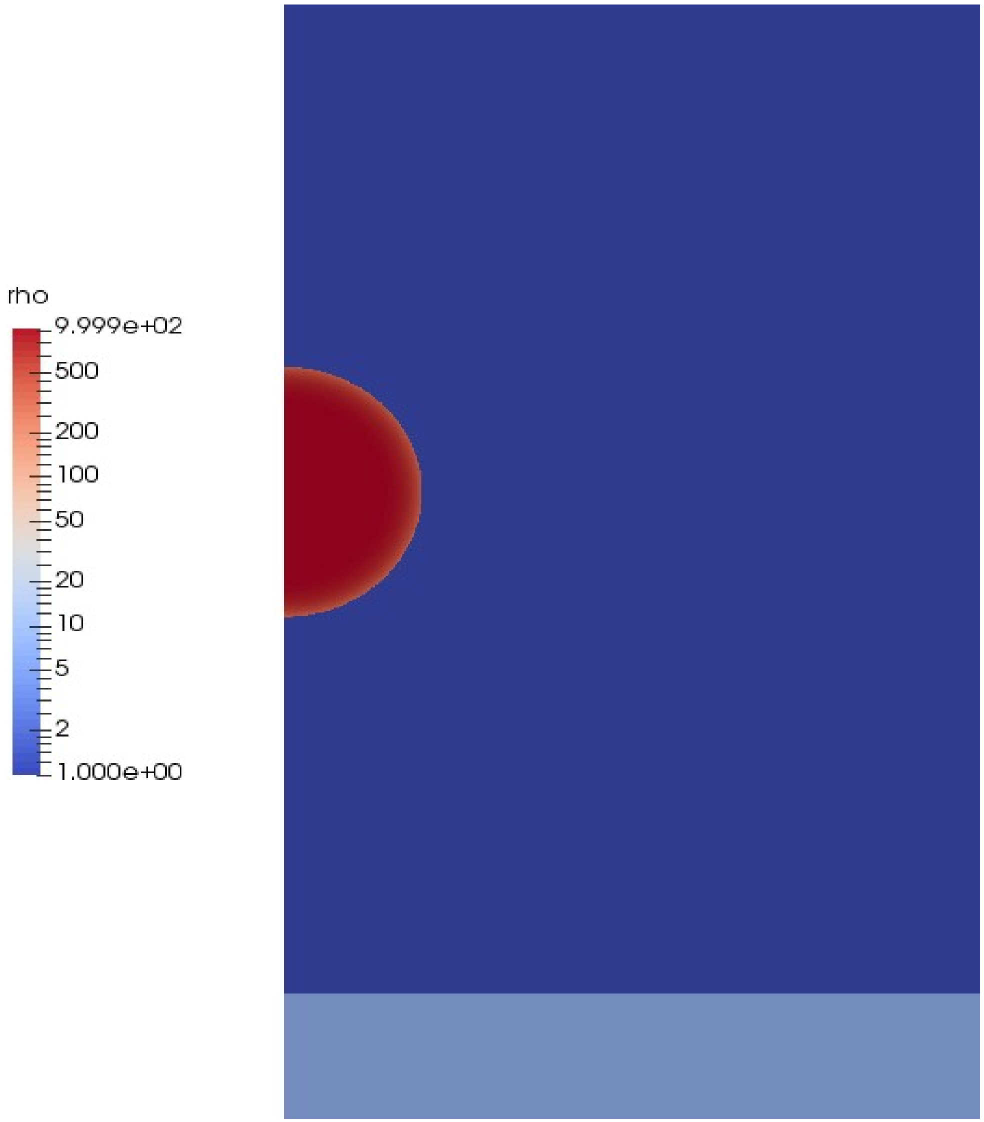
$$e = \frac{p}{\gamma - 1} + \frac{\rho v^2}{2}$$

$$\frac{\partial \rho_d}{\partial t} + \bigtriangledown \cdot (\rho_d \vec{v_d}) = 0$$

$$\frac{\partial \rho_d \vec{v_d}}{\partial t} + \bigtriangledown \cdot (\rho_d \vec{v_d}\vec{v_d}) = -\vec{f_d}$$

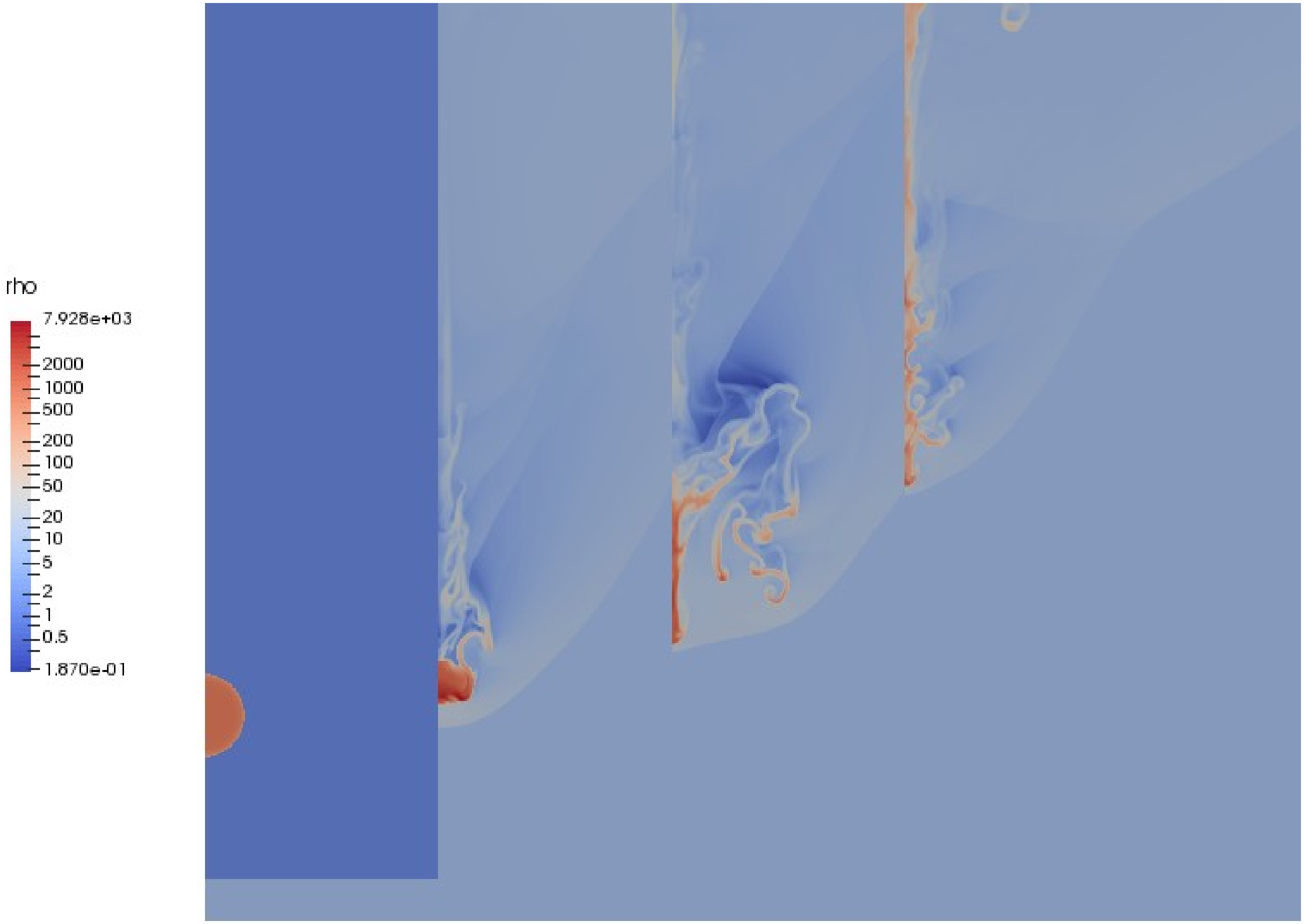
$$\vec{f_d} = -(1-\alpha)\pi n_d \rho a_d^2 \sqrt{\Delta v^2 + v_t^2}$$

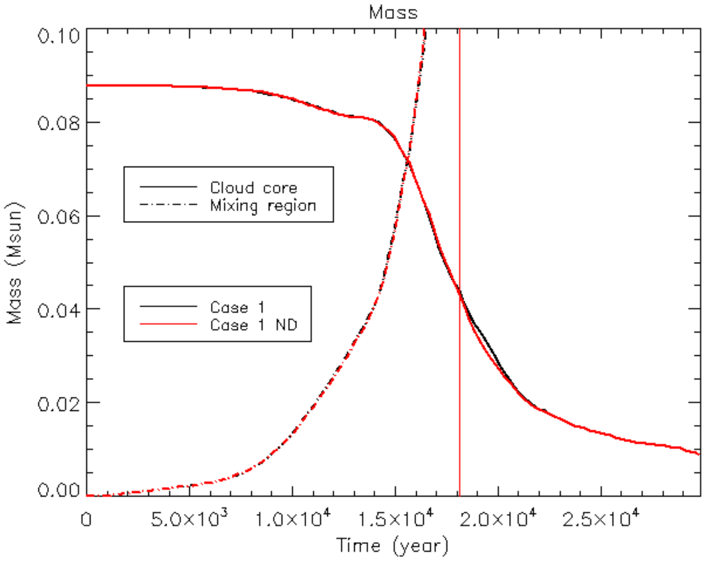
Set-up in 2D axis-symmetry with MPI-AMRVAC



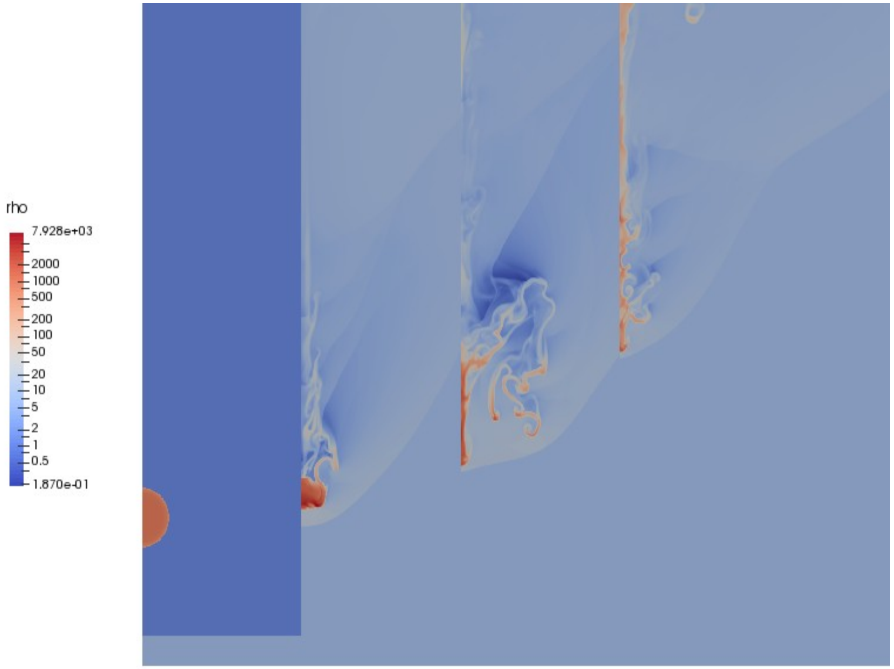
- Shock define by its mach number: (Rankine-Hugoniot)
- MC represent as a spherical over-density of the gas (with smooth edge)
- 4 dust species with discrete sizes. Only present in the MC.

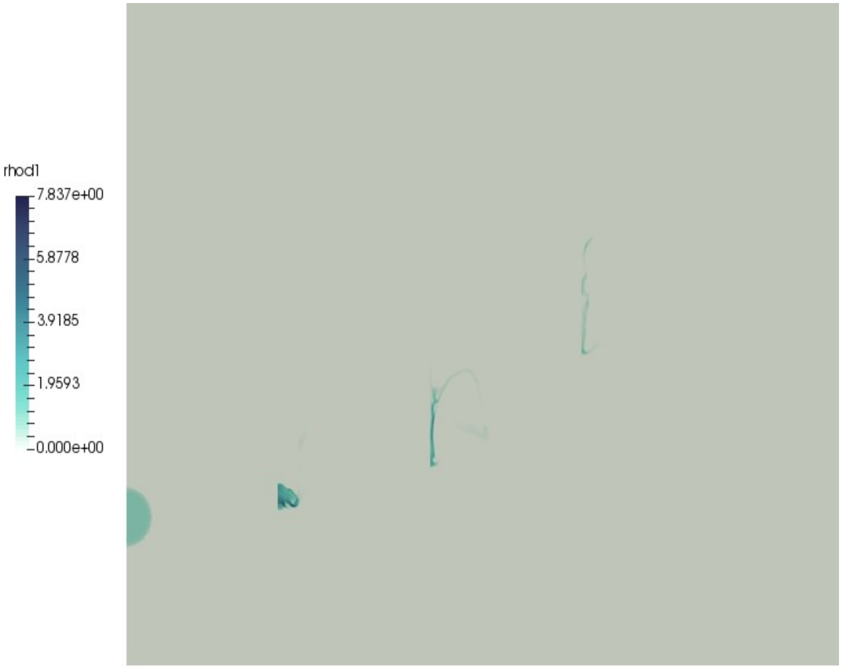
Destruction of a MC by a shock





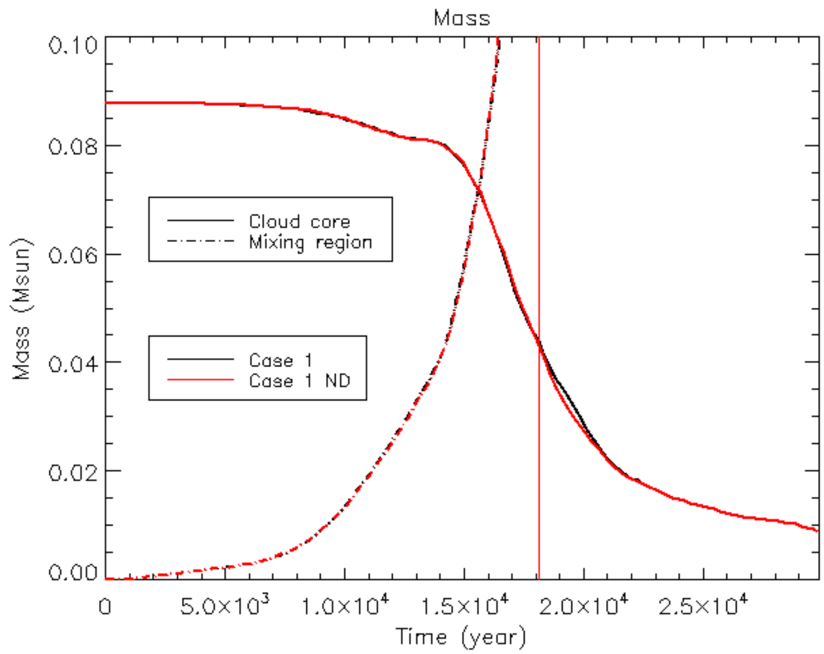
Behavior of shocked dust

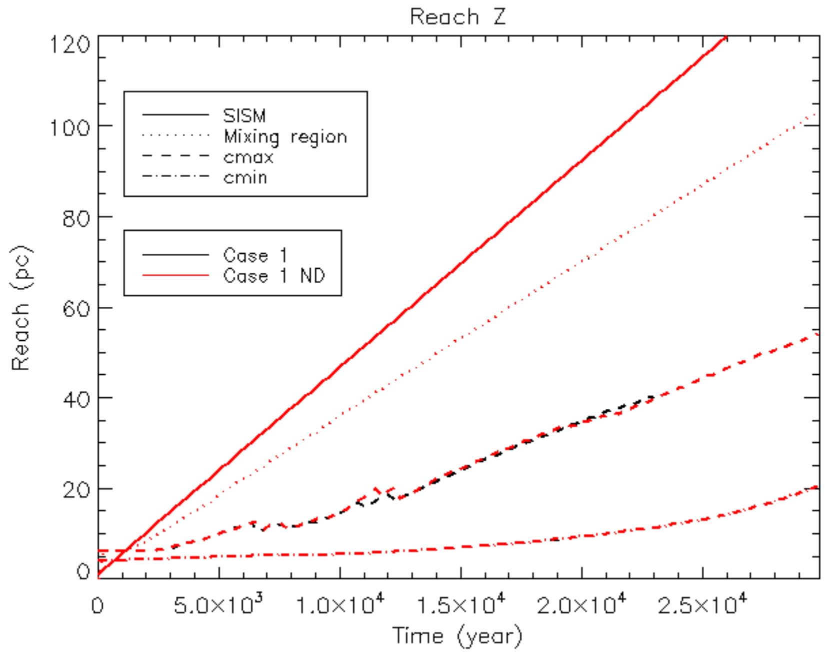




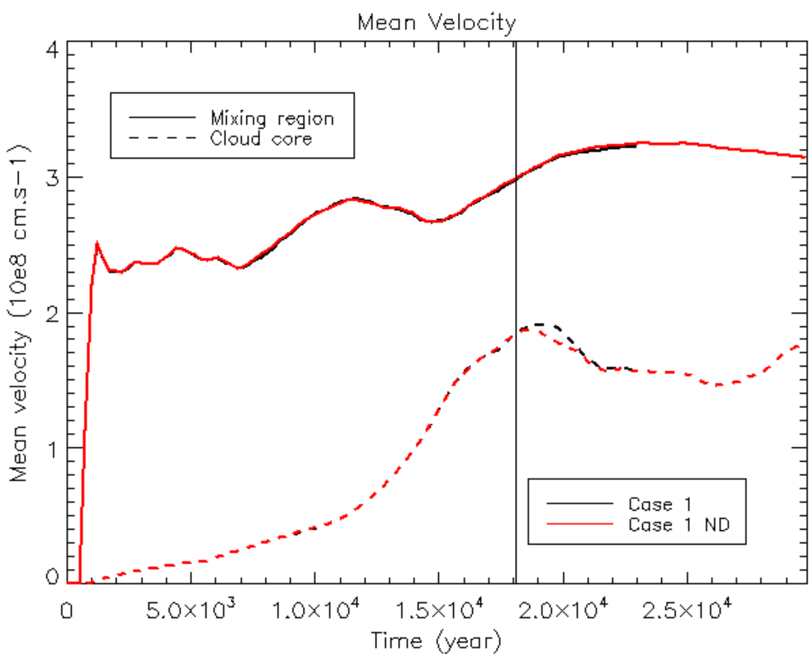
- Small dust grains (top right) are mostly locked in the gas evolution.
- Large dust grains (bottom right) have close to no evolution.

Effect of dust: no dust vs dust

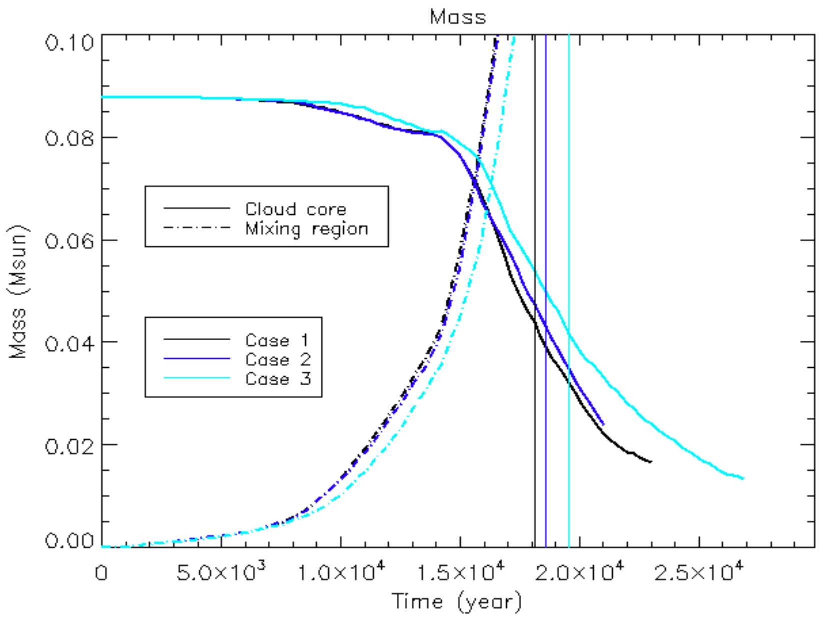


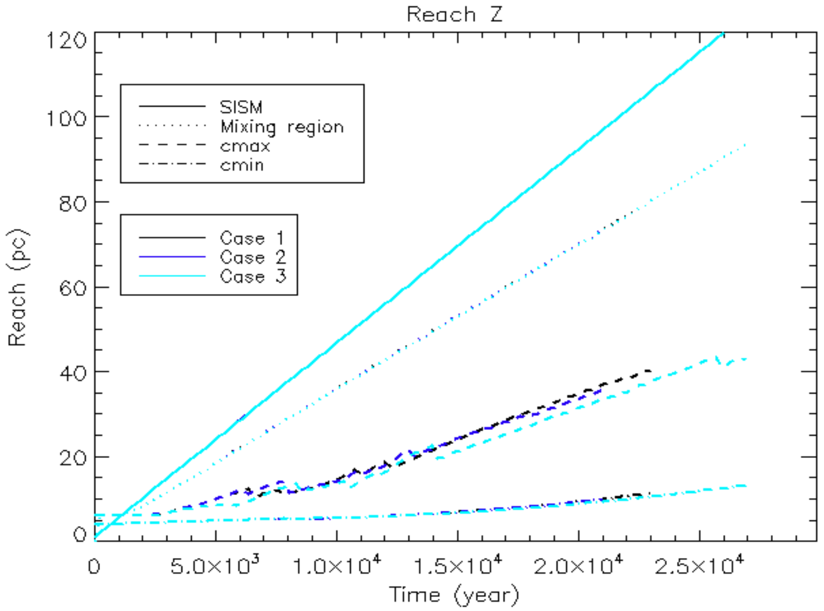


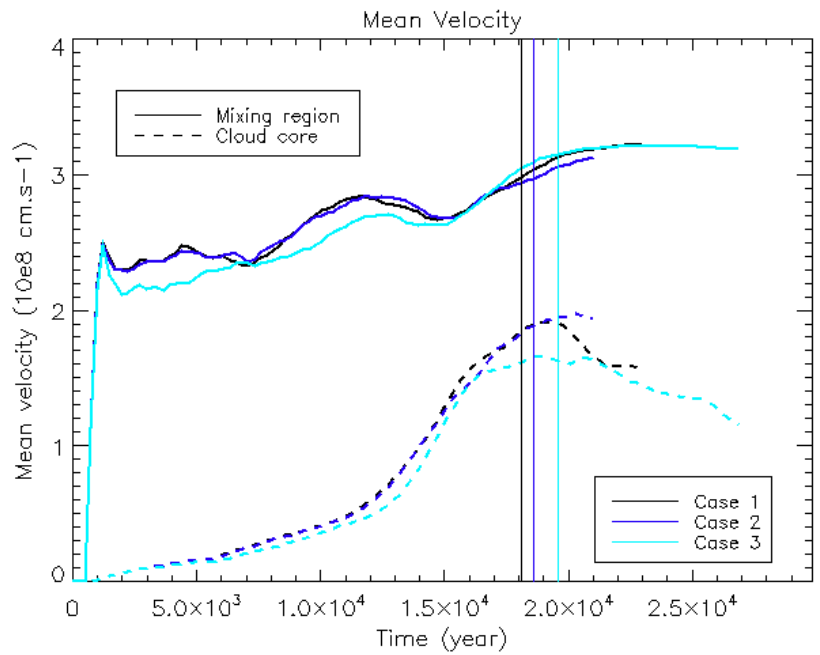
- Case 1: 0.4% dust; Case 1ND: no dust
- In realistic proportion (<1%) the dust have no visible effect on the dynamics.



Effect of dust: dust proportion

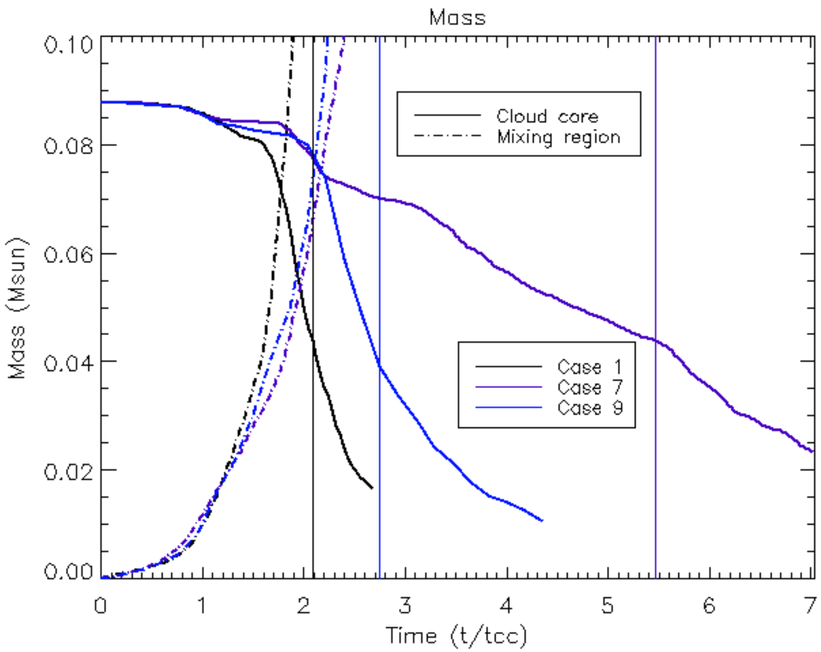


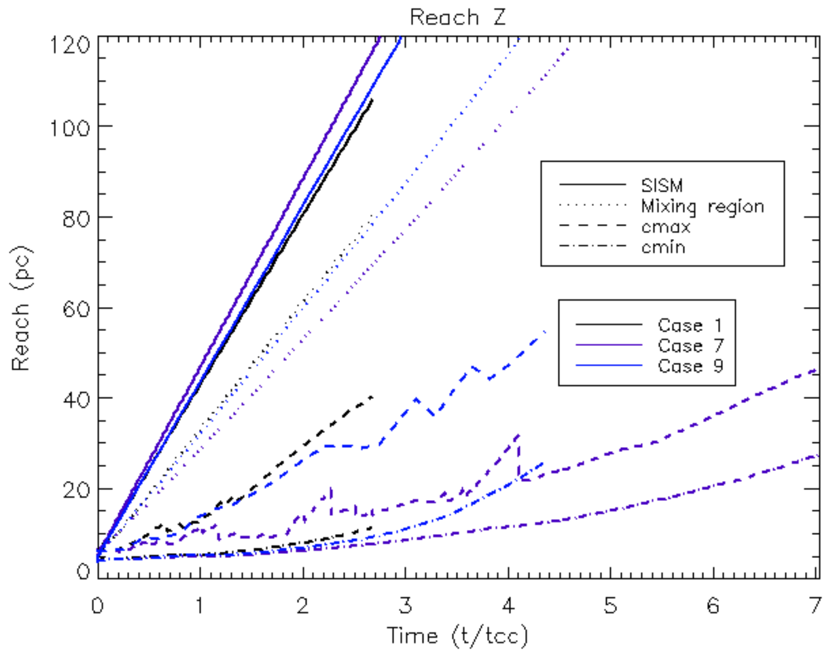




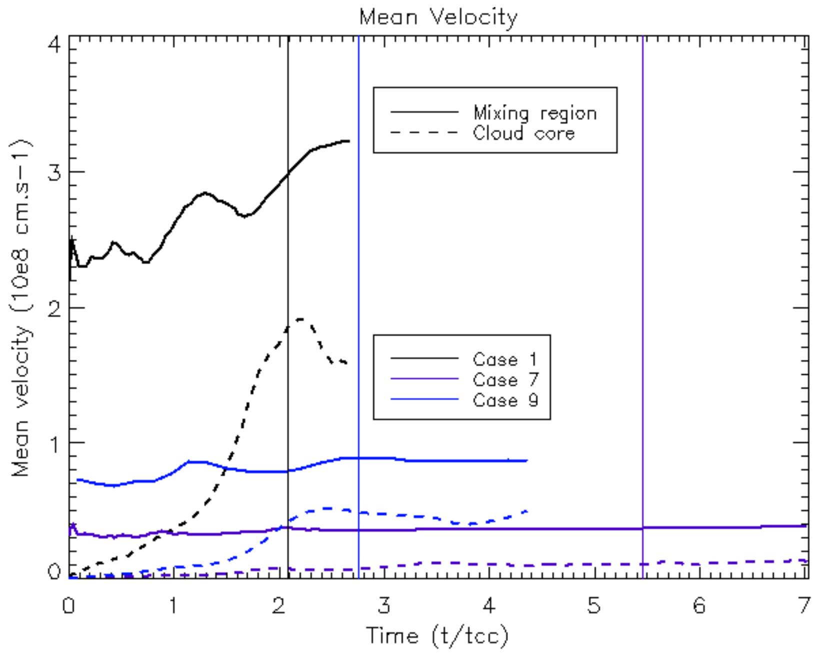
- Case 1 : 0.4% dust; Case 2 : 4% dust; Case 3 : 40% dust
- Up to 4% there is no significant effects of the dust on the dynamics

Effect of shock properties: mach number



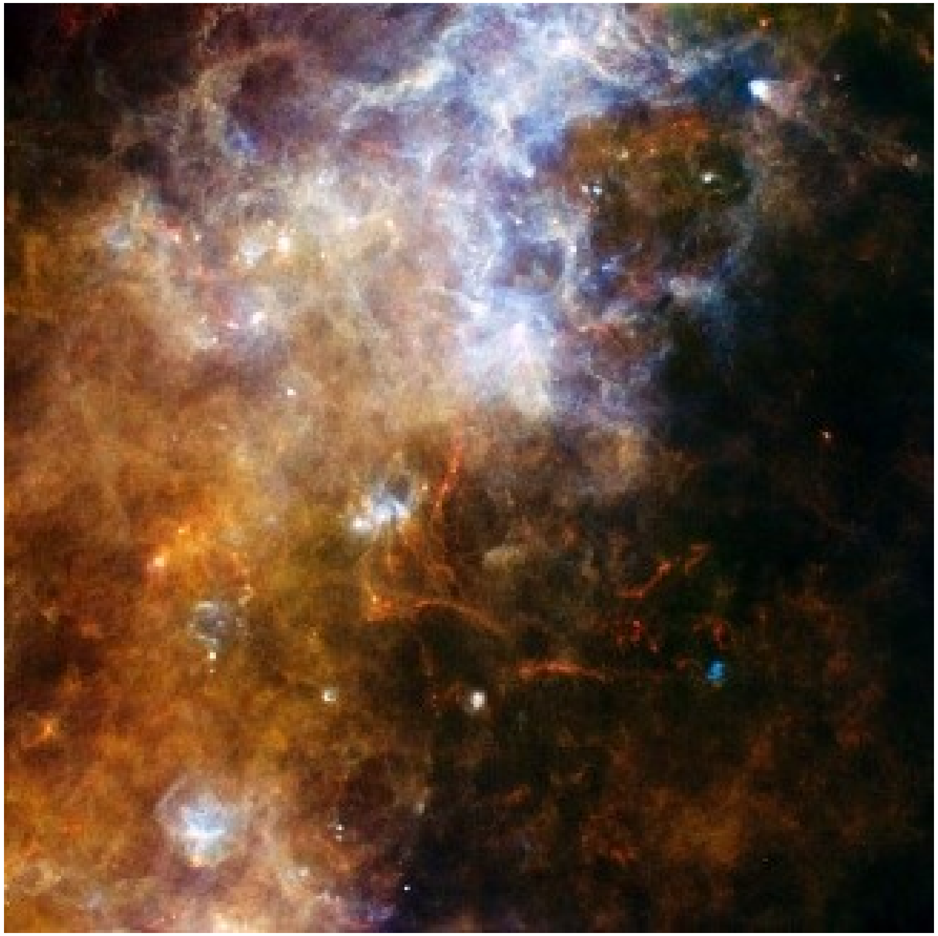


- Case 1: M=10; Case 7: M=1.5; Case 9: M=3
- The destruction by a weak shock is linear.
- As soon as the shock become significantly supersonic (M>2) we have a characteristic destruction pattern.



Filament structures

Southern Cross

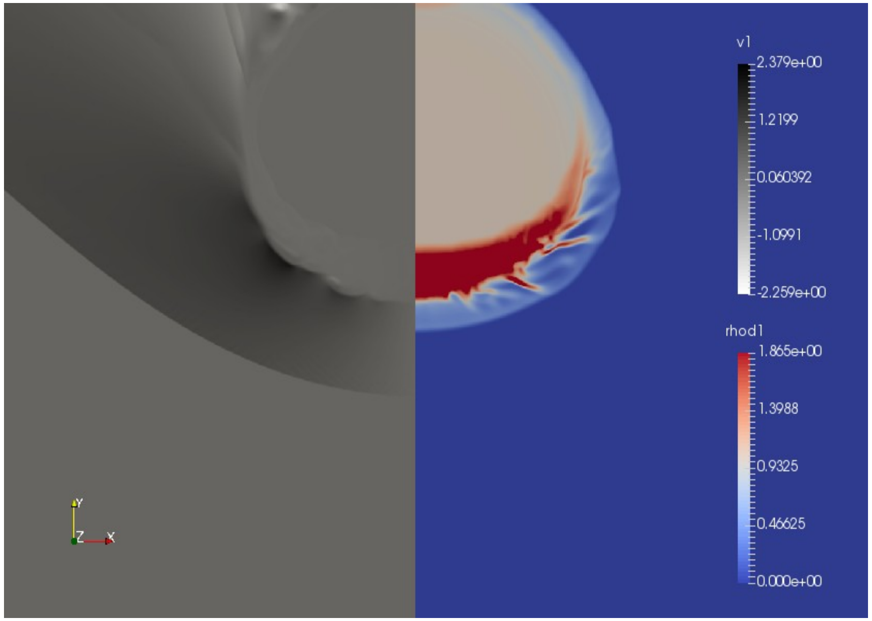


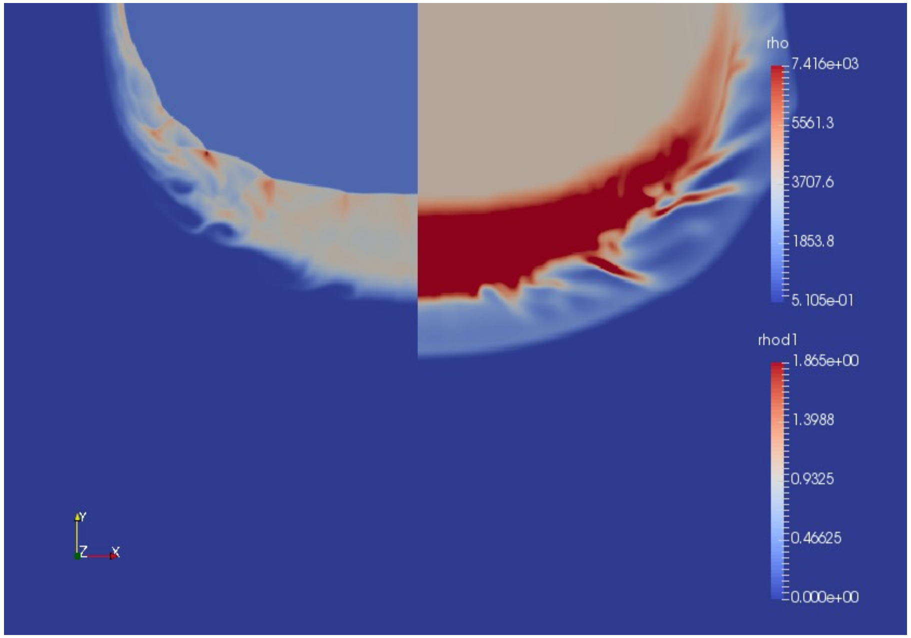
Credit: ESA and the SPIRE & PACS consortium

Orion

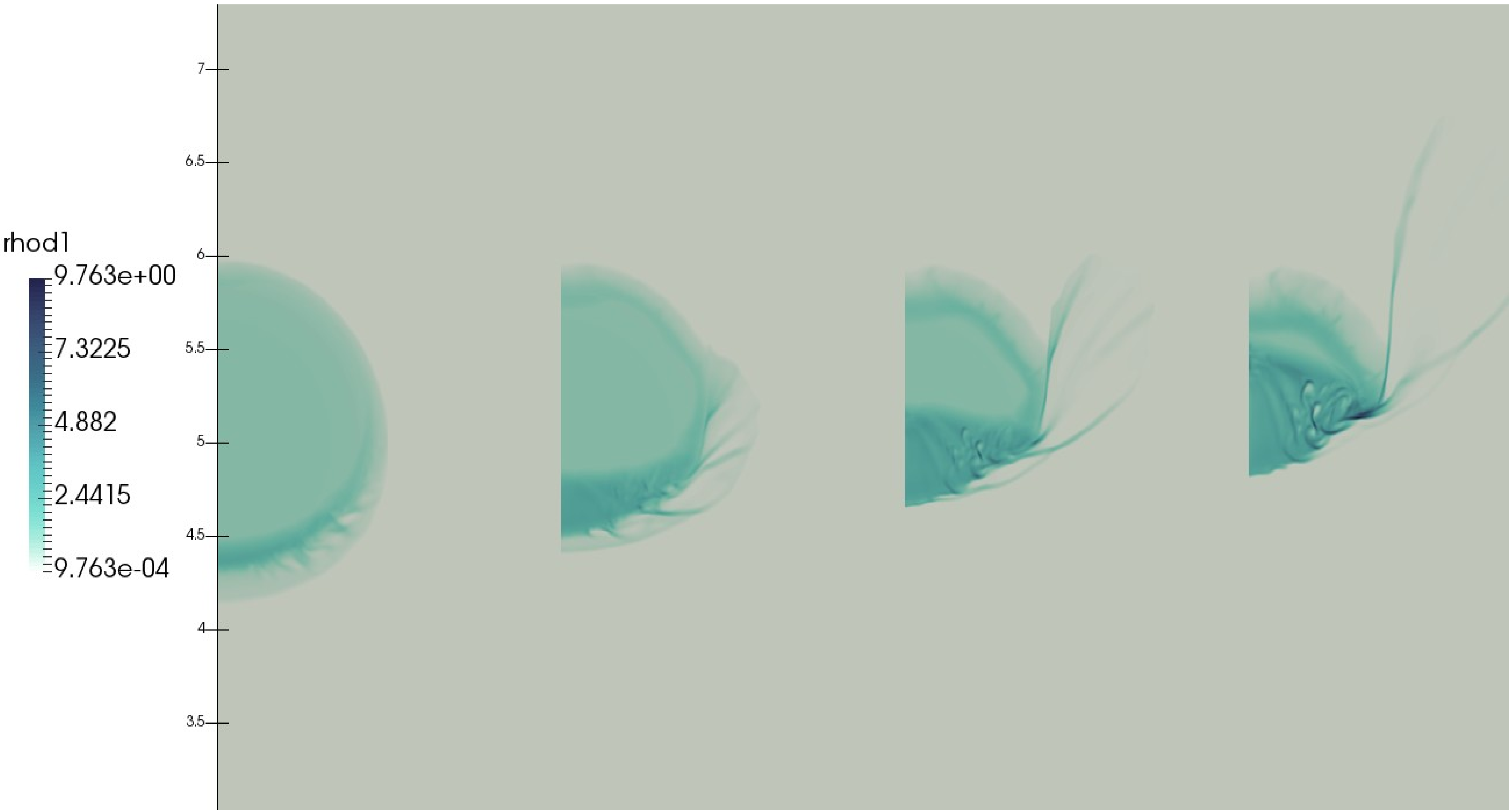
Credits: ESA/Herschel/Ph. André, D. Polychroni,
A. Roy, V. Könyves, N. Schneider
for the Gould Belt survey Key Program

The Sand Bank effect



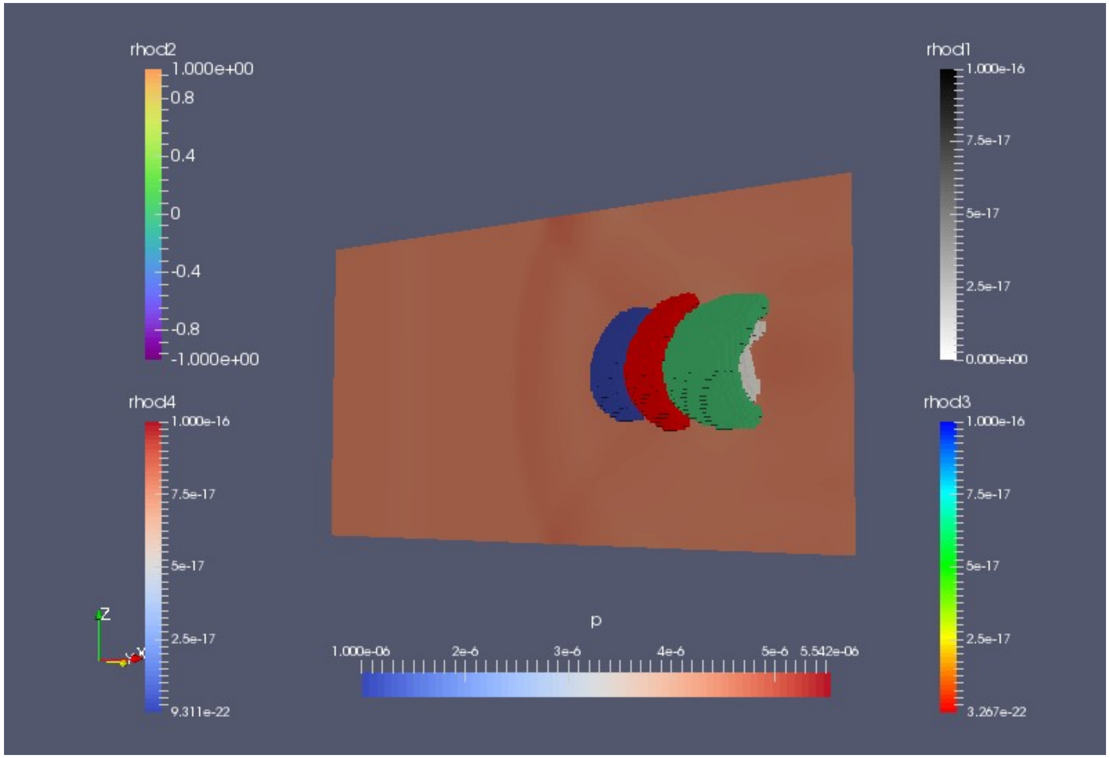


Formation of filaments

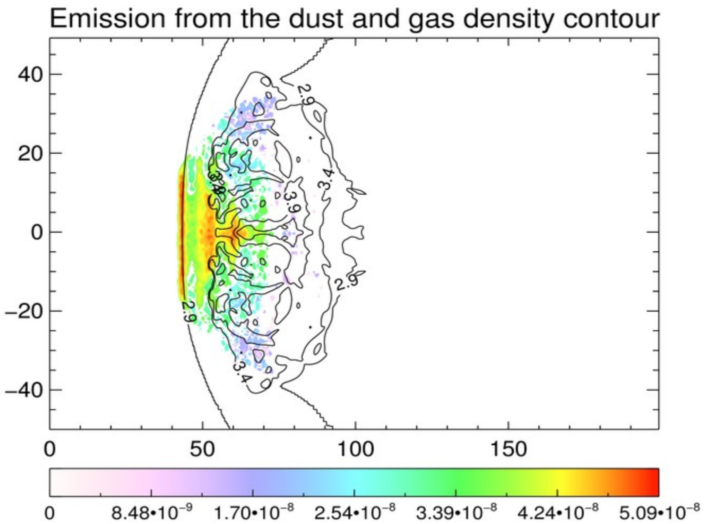


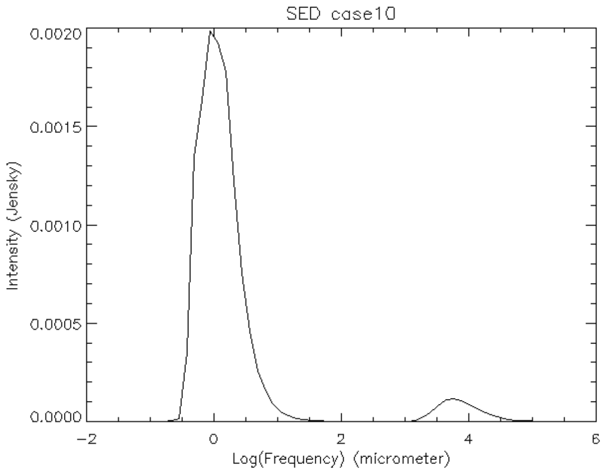
Synthetic observation: SKIRT

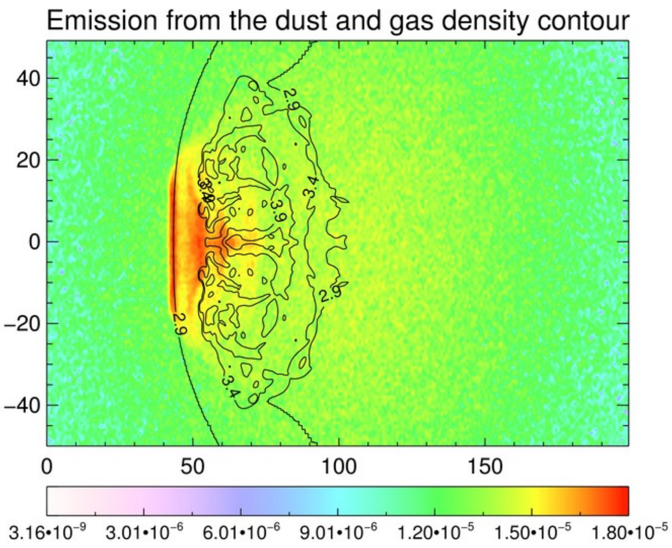
- What do we see from earth?
- Move to 3D Cartesian setup.
- Use SKIRT (3D continuum radiative transfer in dusty systems).
- Can readily read MPI-AMRVAC data files.



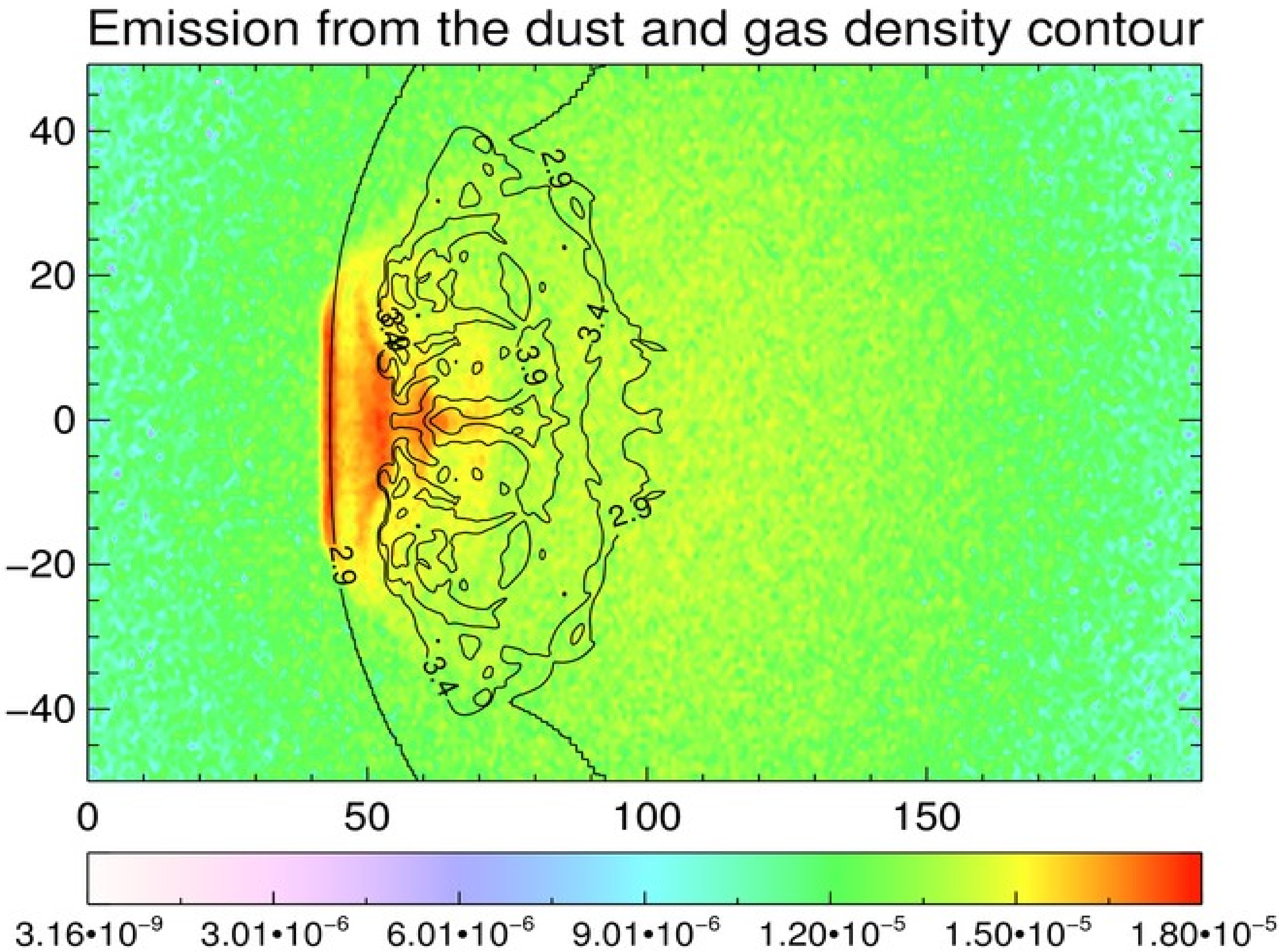
Synthetic observations





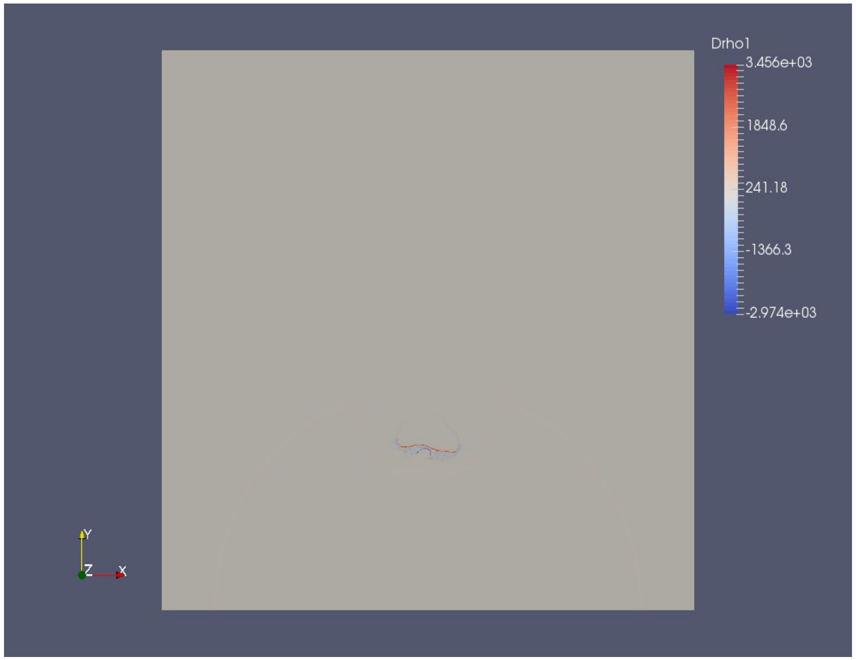


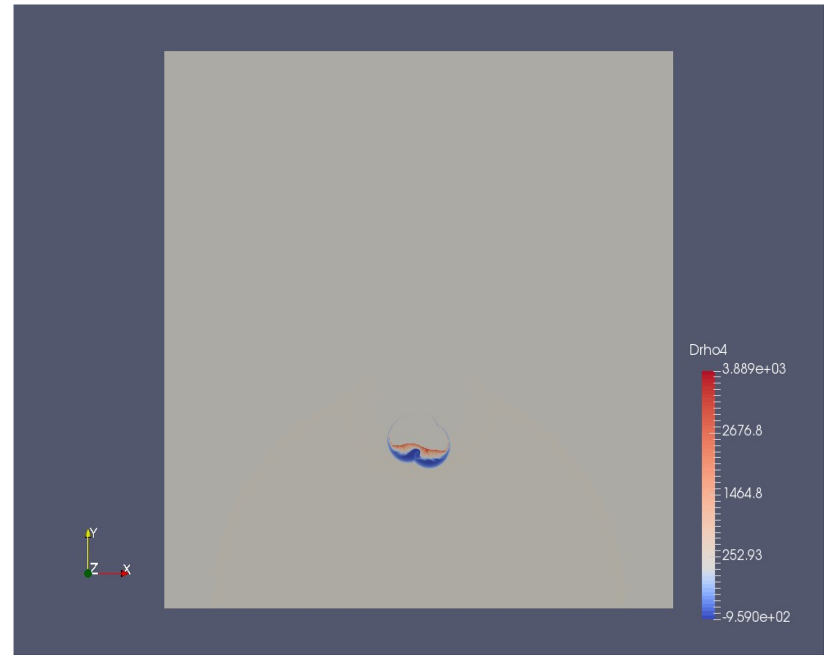
- Emission at 75 mm (left) and for the whole simulated bandwidth (0.09 µm – 10 mm) (right)
- Contour of the logarithm of the gas density integrated along the line of sight: predicted emission if spatial correlation.

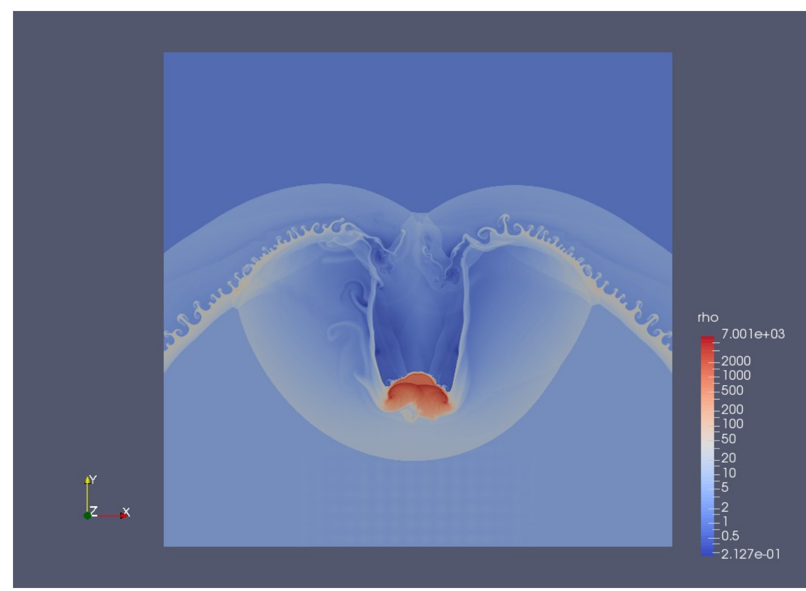


Emission from the dust and gas density contour
40
20
0
−20
−40
0
50
100
150
2.9
3.4
3.9
3.16•10^−9
3.01•10^−6
6.01•10^−6
9.01•10^−6
1.20•10^−5
1.50•10^−5
1.80•10^−5

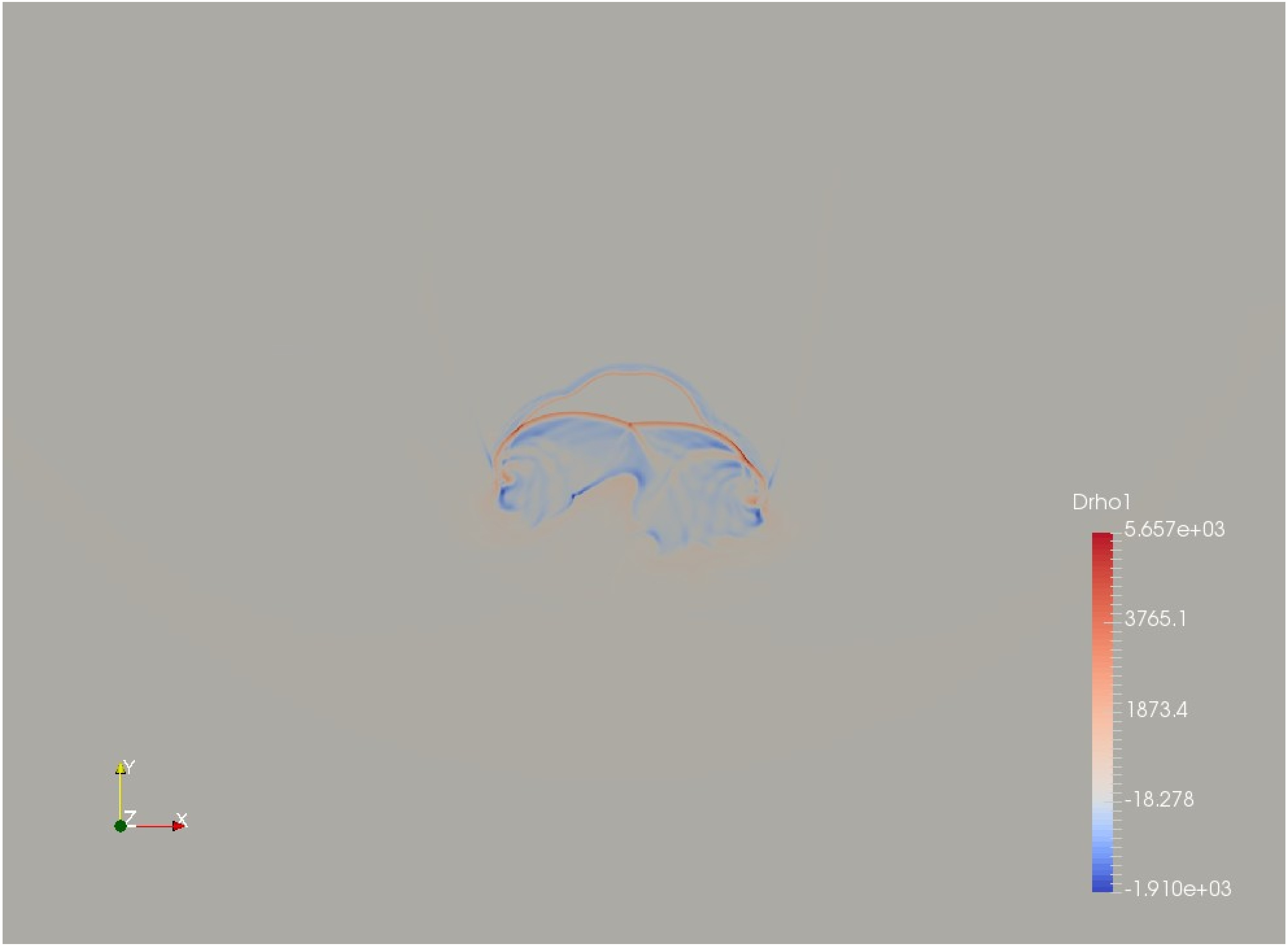
None continuous shock: SNR explosion



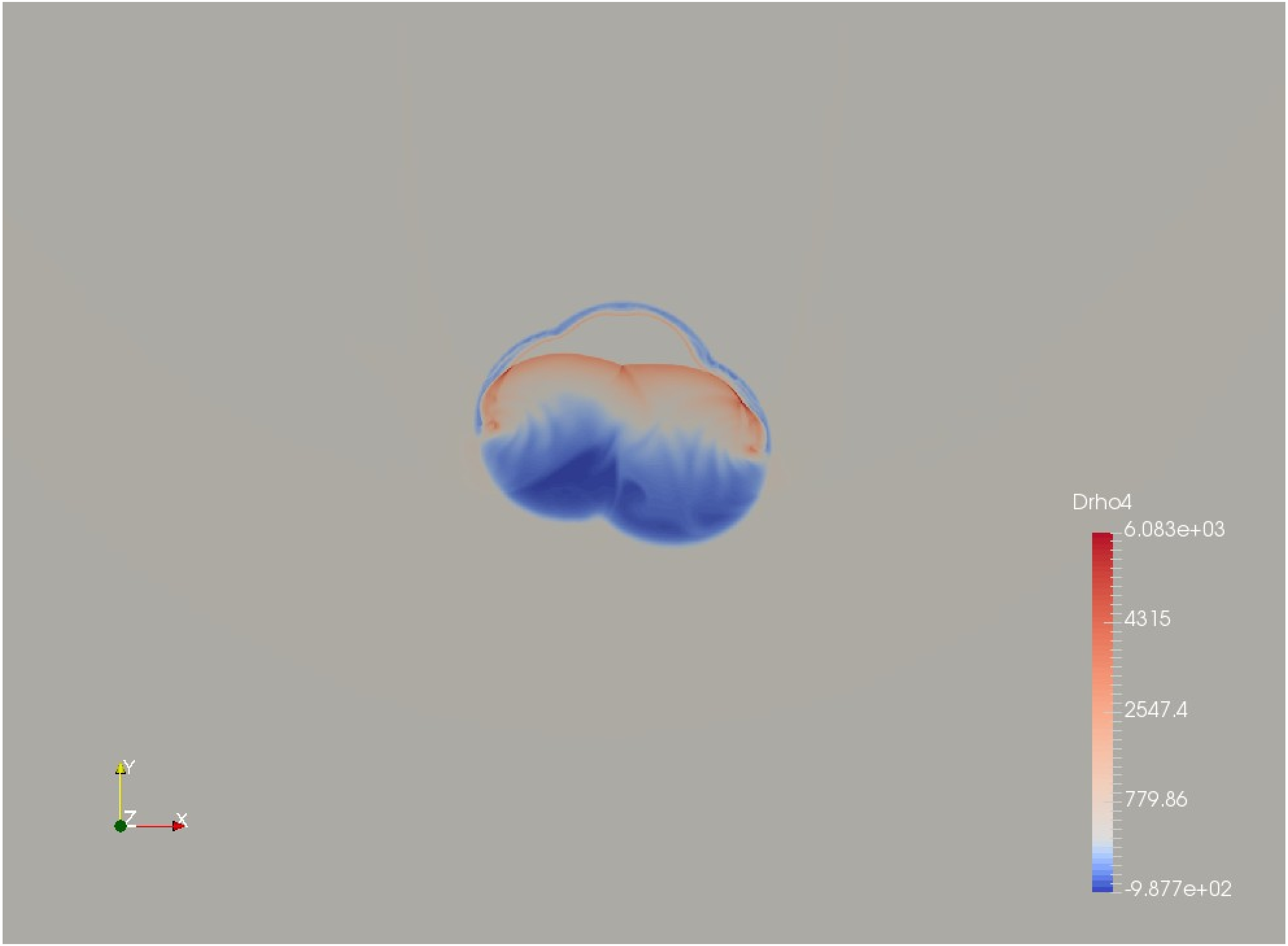




- Bottom: log(density). Top: Spatial divergence small dust (left) and big dust (right).
- Even with a short but powerful shock, spatial discrepancy appear.



Drho1
5.657e+03
3765.1
1873.4
-18.278
-1.910e+03
Y
Z
X



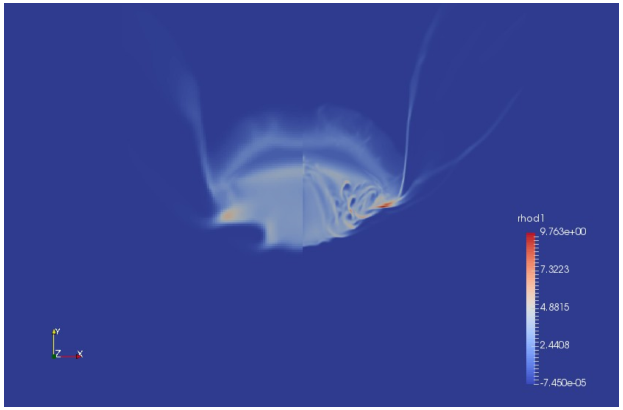
Drho4
6.083e+03
4315
2547.4
779.86
-9.877e+02
Y
Z
X

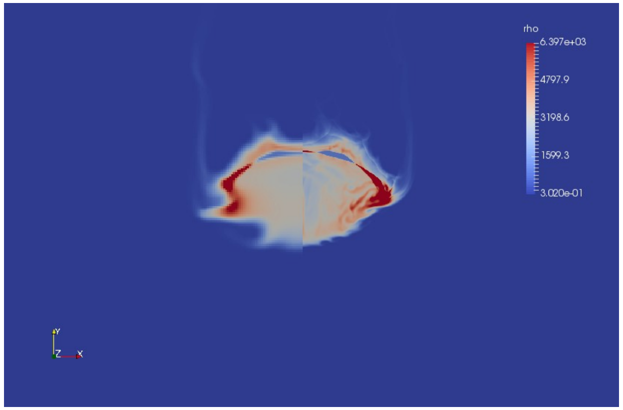
Conclusions

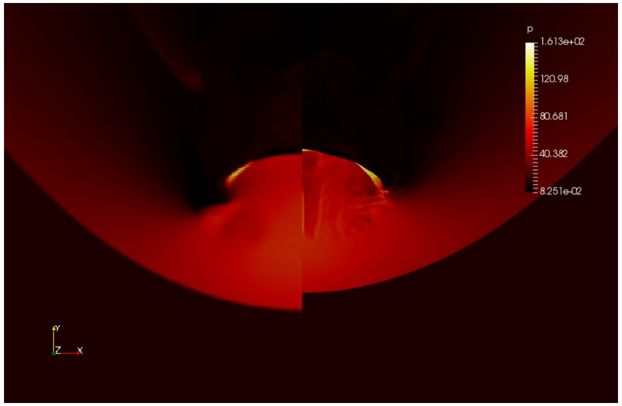
- In realistic proportions, the dust does not play a dynamical role in the evolution of the MC. You need to go higher than 10% to see a retro-action
- Destruction of a MC under a powerful shock is a 3 stage mechanism
- Some of the structures in observation can result from dust pilling up in filaments. These filaments can than be stretch over long distances.
- In the presence of strong dynamics, the gas and the dust spatial distribution can become significantly different.

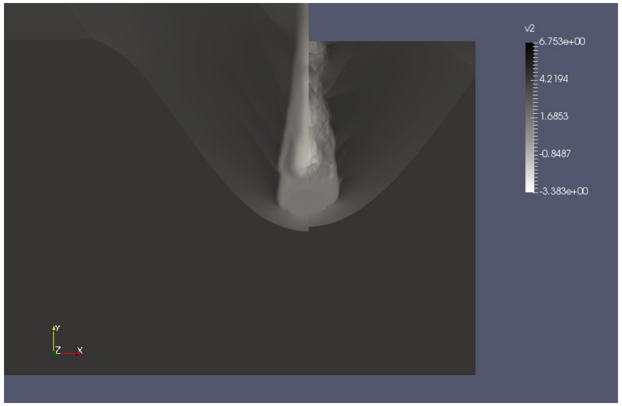
Thank you

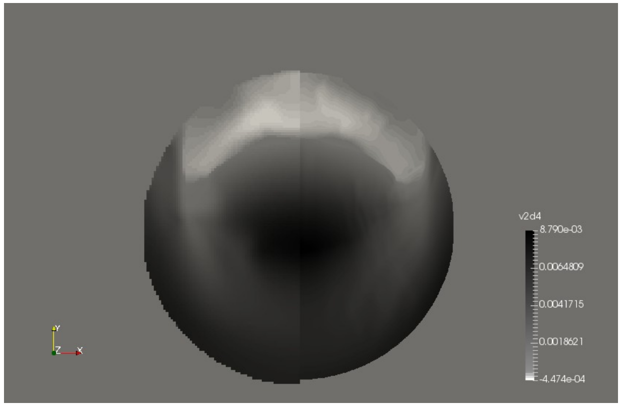
Resolution and instabilities











C-O observation

2600 / 1300 / 2720 μm