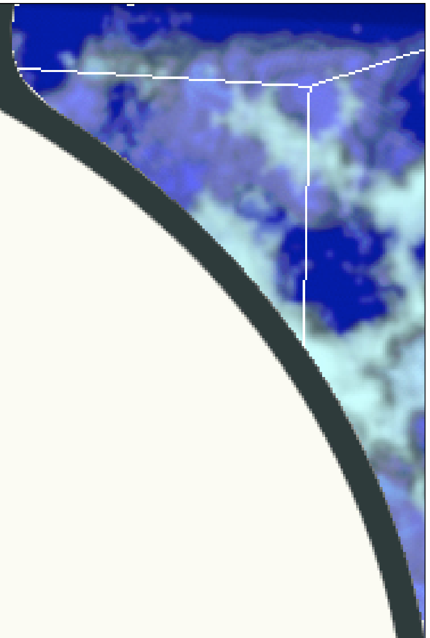
SimpleX

Radiative Transfer on an Unstructured Dynamic Grid



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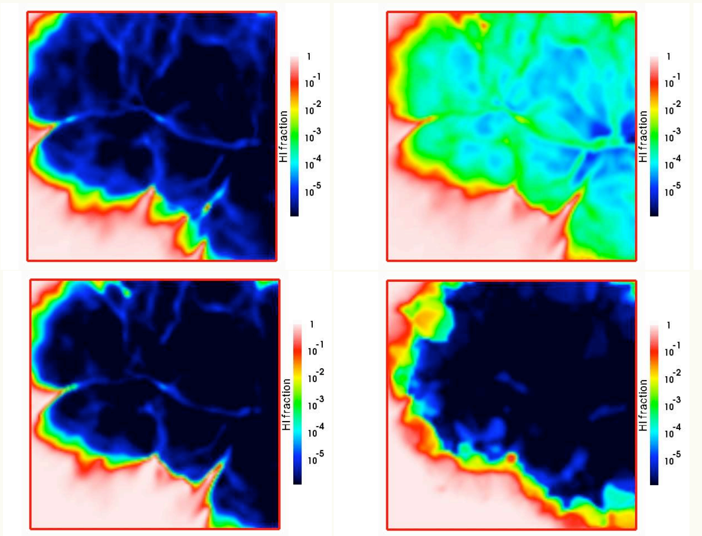
Comparison Paper 1

SimpleX participated in first comparison paper

New features:

- Parallel
- Better performance in optically thin regimes



Iliev et al. 2006

Nature is not cubical!

A regular mesh introduces errors

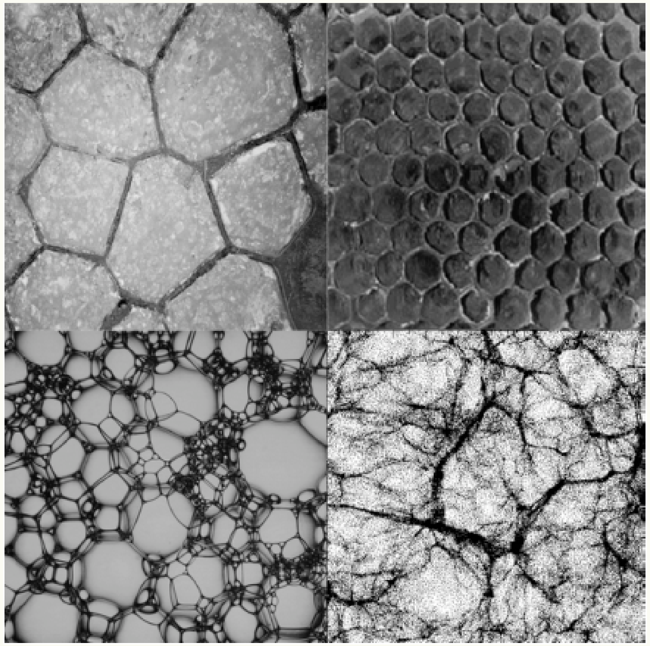
Physical symmetries are broken

- Rotational
- Translational

Unphysical conserved quantities

Superimposed scale lengths

Nature resembles Voronoi diagram!



Ritzerveld 2007

Reconstructed (density) fields are optimal in the sense of defining a continuous and unbiased representation of the data while retaining all information available in the point sample (Schaap, 2006)

Voronoi - Delaunay grid resembling underlying physics

Probabilistic treatment of radiative transfer

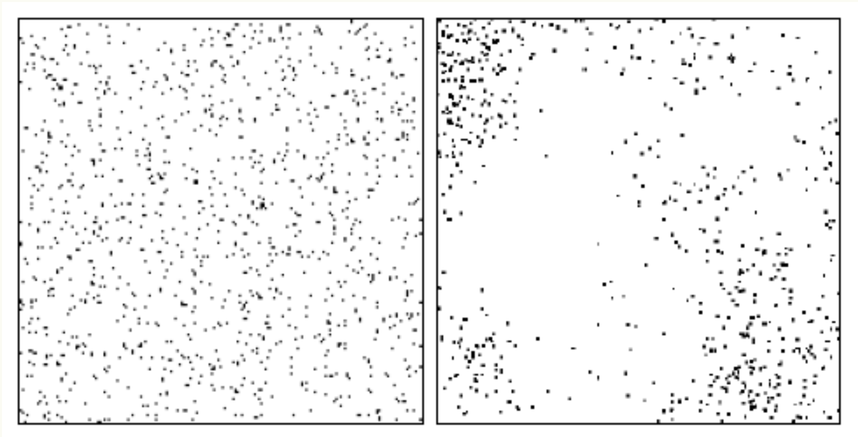
Migration of photons is Markov stochastic process

Microscopic statistics → Macroscopic quantities

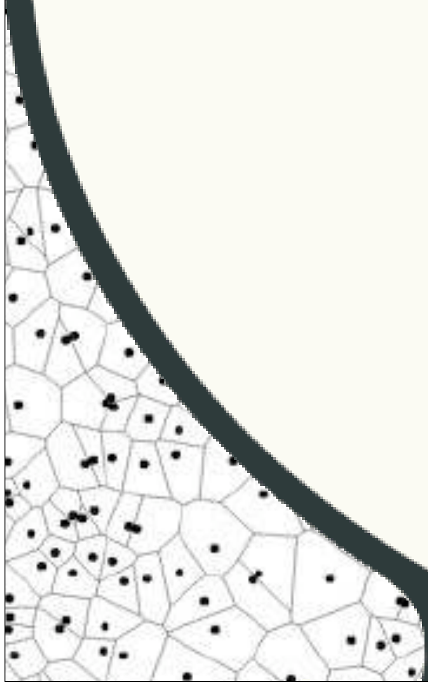
Unstructured Grid

Stochastic point process determines placement of grid points

Higher opacity ➡ More points



Homogeneous Poisson process | Clumpy Correlated process

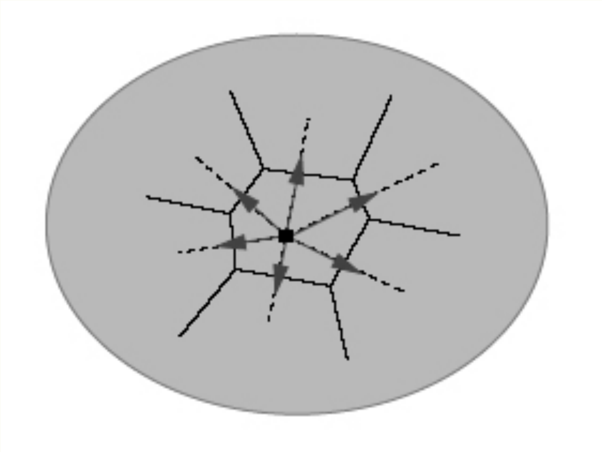


Voronoi Tesselation:

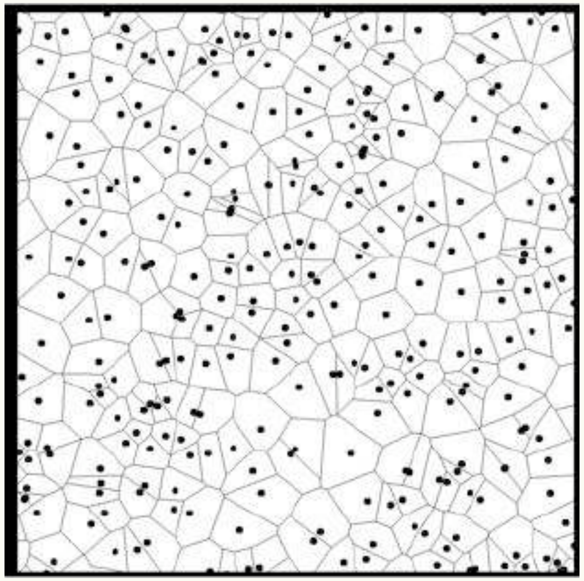
$$C_i = \{y \in R^d : \|x_i - y\| \leq \|x_j - y\| \ \forall \ x_i \neq x_j\}$$

Delaunay Triangulation:

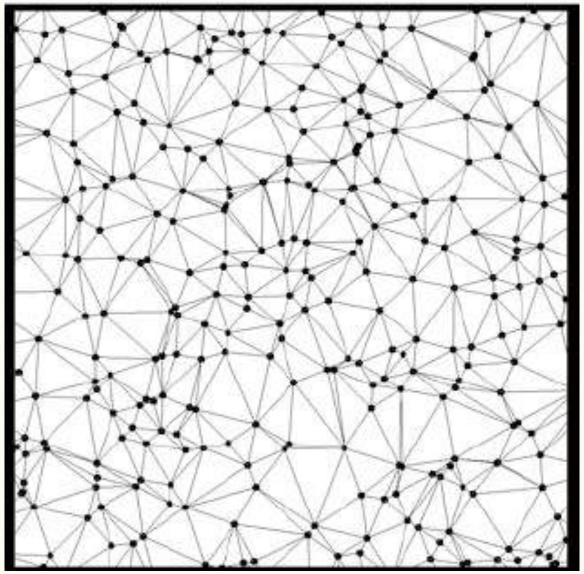
Connect all nuclei whose cells have a common facet



Homogeneous example



Voronoi Tesselation



Delaunay Triangulation

Properties of the Delaunay grid

Local mean free path:

$$\lambda(\vec{x}) = \frac{1}{n(\vec{x})\sigma}$$

$n(\vec{x})$ density distribution

Average Delaunay line length:

$$\lambda_D(\vec{x}) = \frac{\zeta}{n_D(\vec{x})^{\frac{1}{d}}}$$

$n_D(\vec{x})$ local point distribution

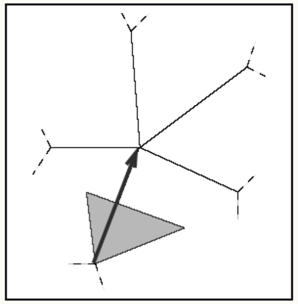
Choose point distribution sampling $n(\vec{x})^d$ **:**

$$\lambda_D(\vec{x}) = c\,\lambda(\vec{x})$$

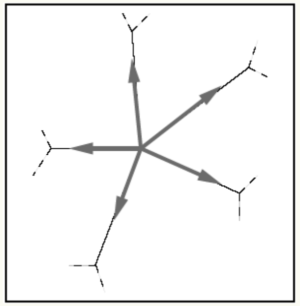
→ **Mean free path is constant on grid!**

Photon Transport

Photons are transported along Delaunay lines



A source sends photons to every neighbour



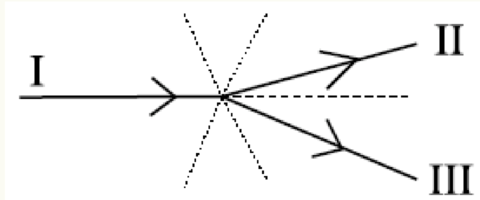
Travel distance of photons correlates linearly with the optical depth

$$c = \xi(d, N, D)\sigma$$

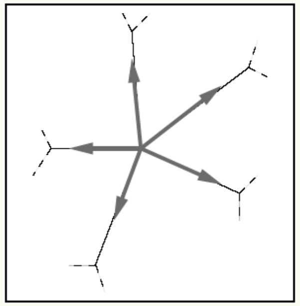
$\xi(d, N, D)$ constant

σ cross section

Outgoing intensity is $I_{out} = I_{in}e^{-c}$



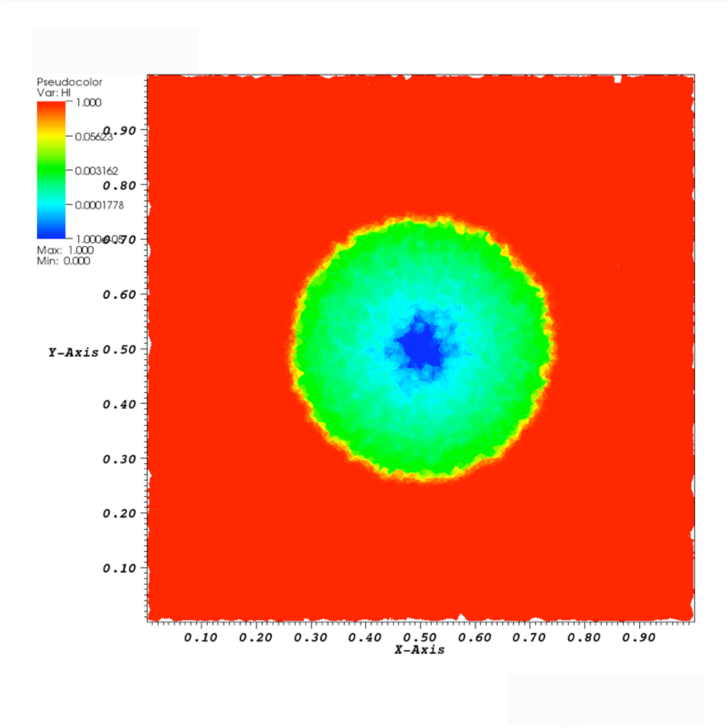
Retained intensity is $I_{ret} = I_{in}(1-e^{-c})$



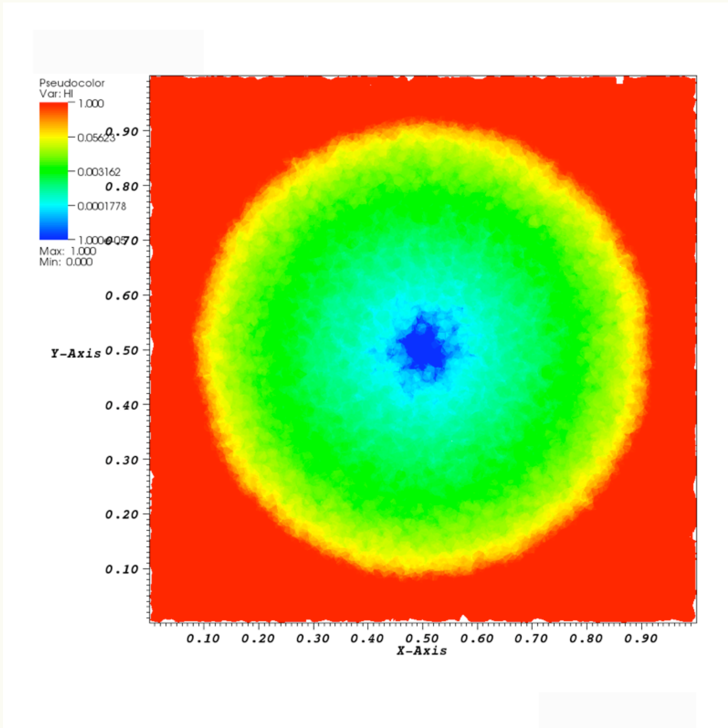
SimpleX does NOT scale with the number of sources!

HII region expansion in homogeneous medium (Test 1)

30 Myr

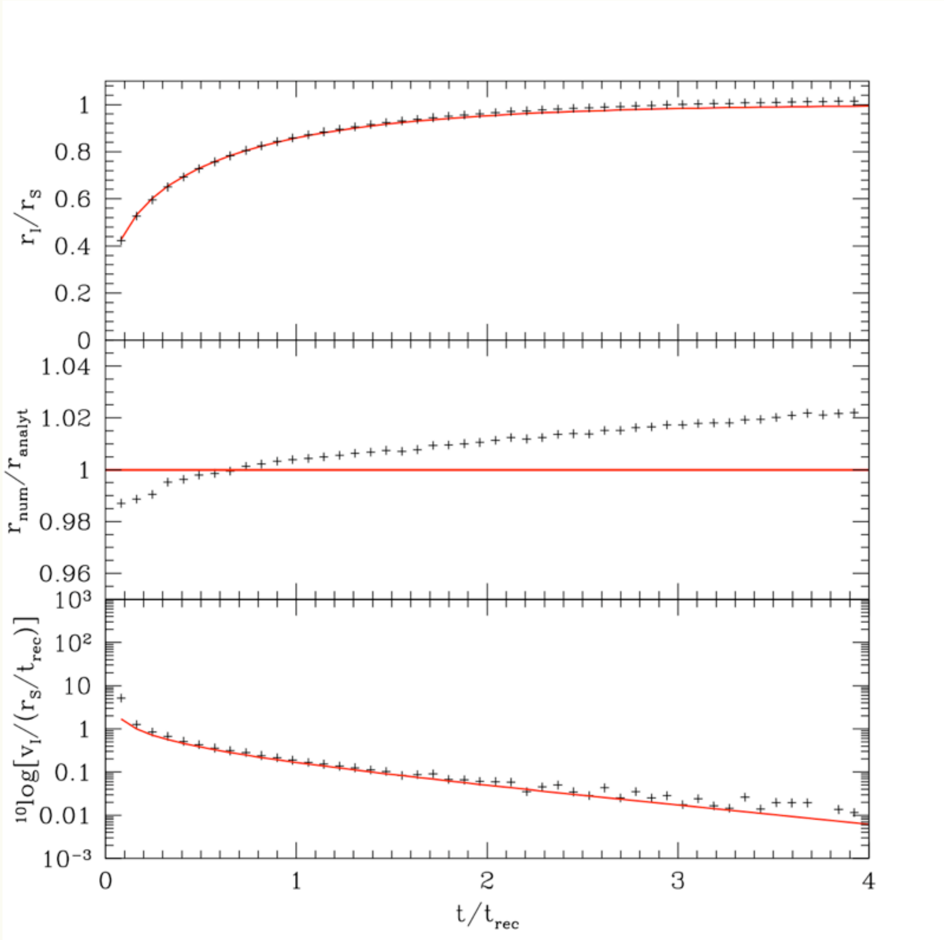


500 Myr



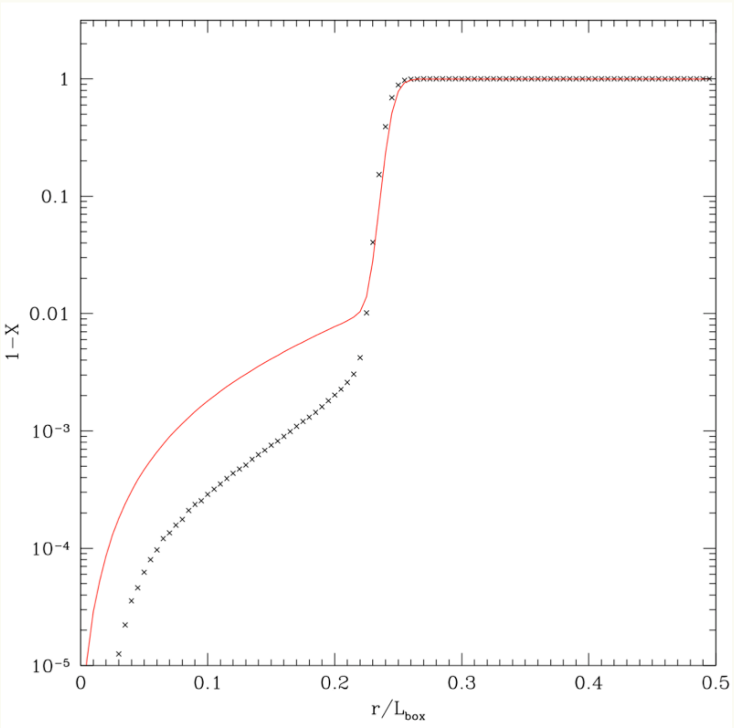
Results
Test 1

Ionisation front position in homogeneous medium (Test 1)

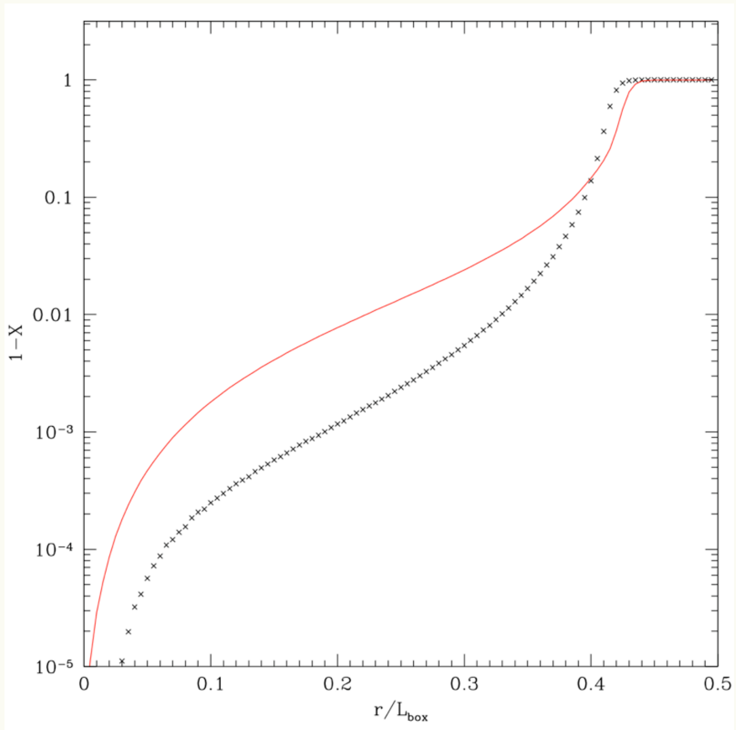


Ionised fraction

30 Myr

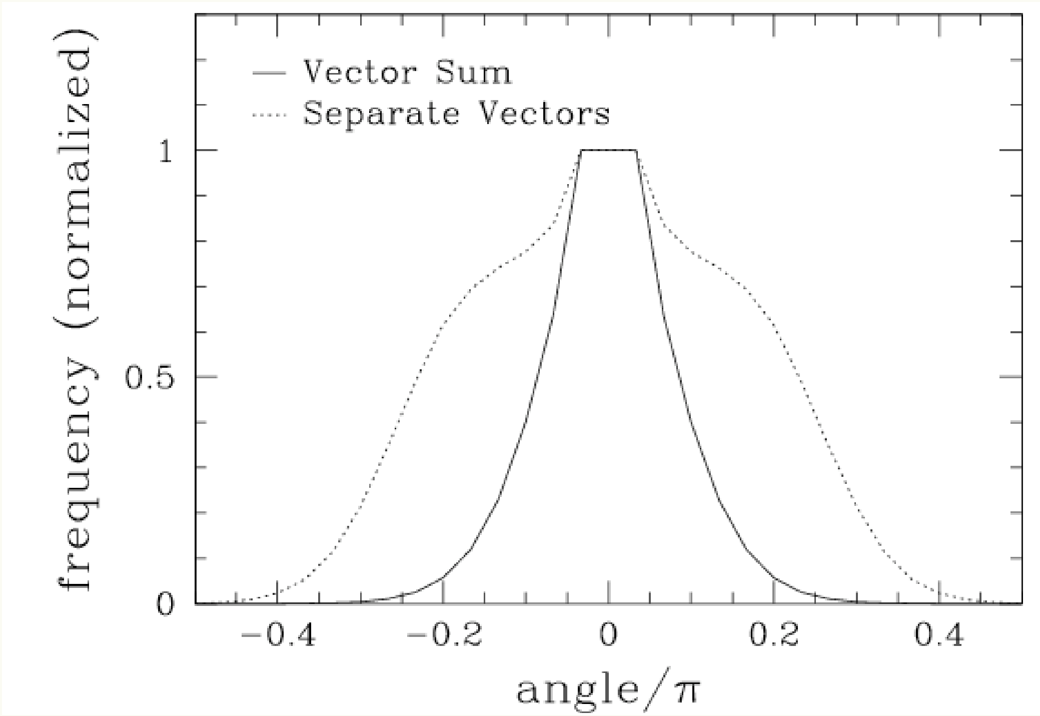


500 Myr



Inner regions of Stromgren sphere have low optical depth

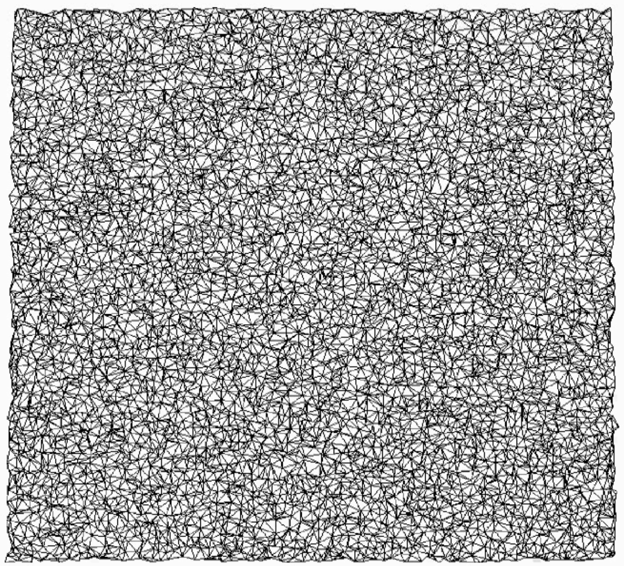
Numerical scatter



Origin of numerical scatter lies in changing optical depth

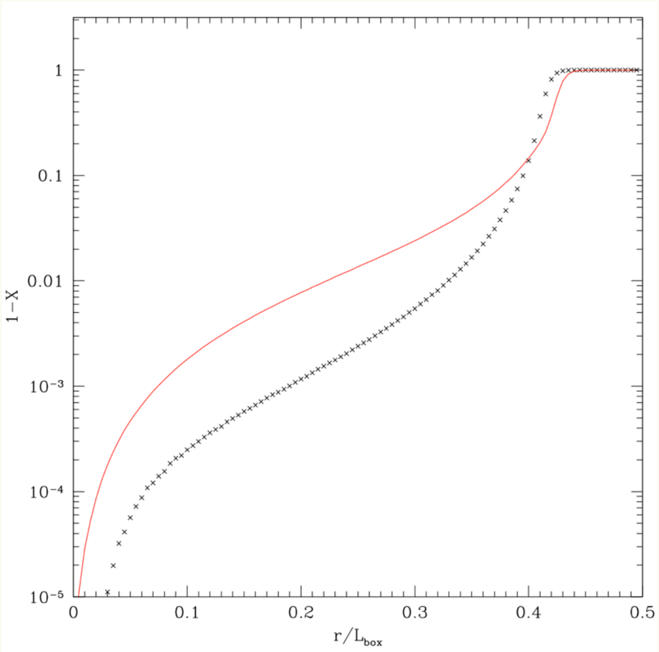
Grid no longer physical

Update the grid when optical depth changes

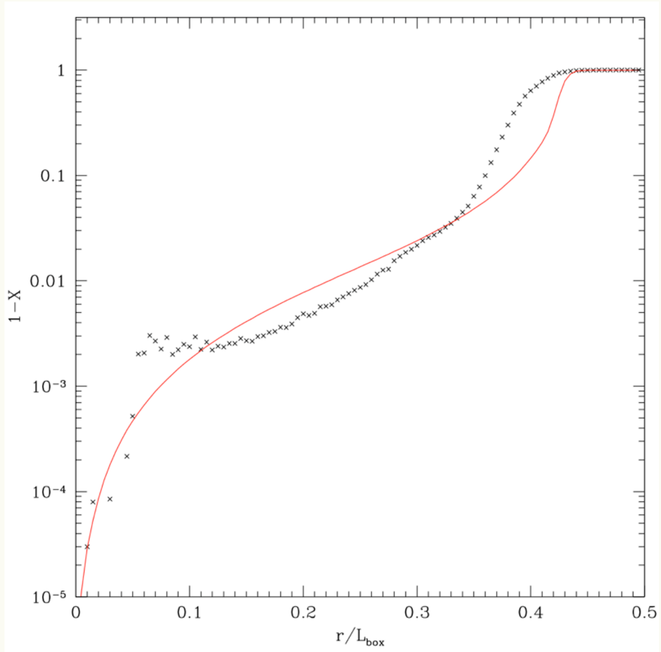


Dynamic Updates

Ionised fraction



128^3 no updates



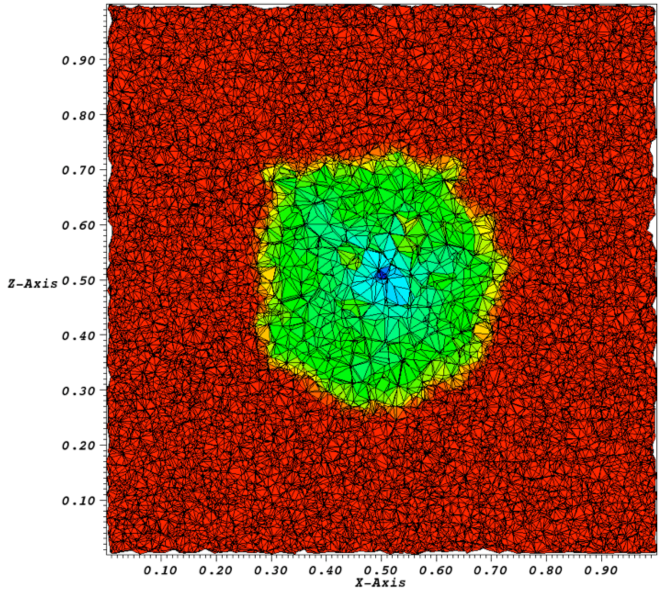
80^3 updates

Dynamic Updates

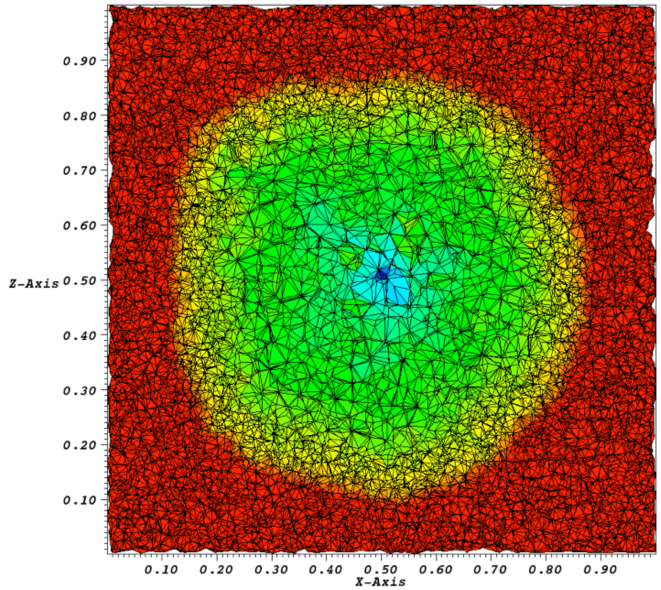
Better results but noisy

Noisiness caused by lack of points close to source

Work in progress!



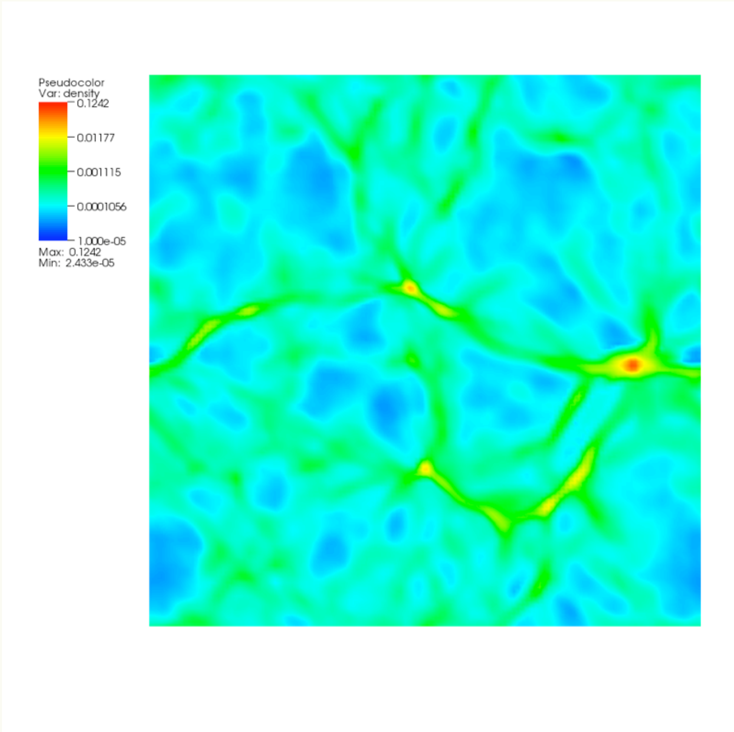
30 Myr



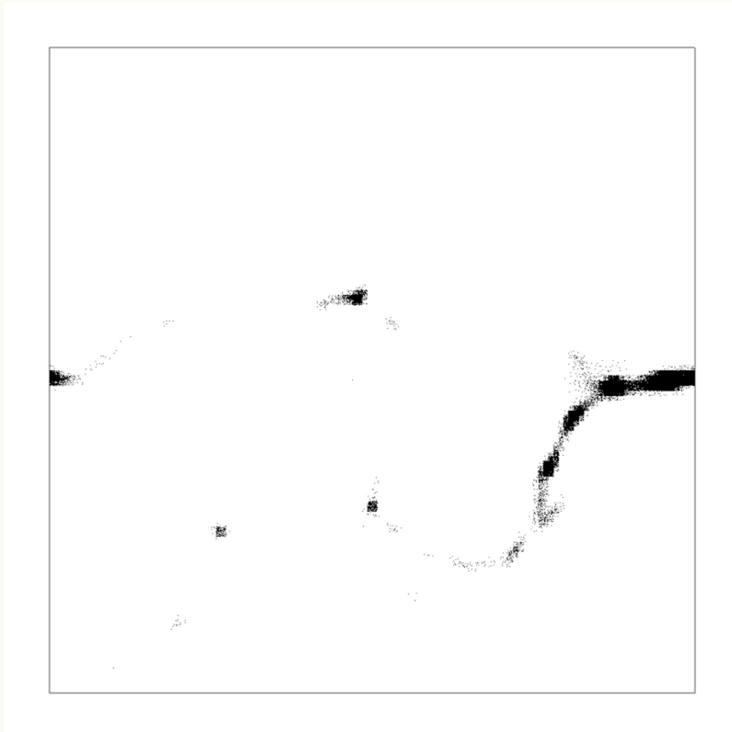
500 Myr

Cosmological density field and multiple sources (Test 4)

Sampling with density^3 results in undersampling of lower density regions



density

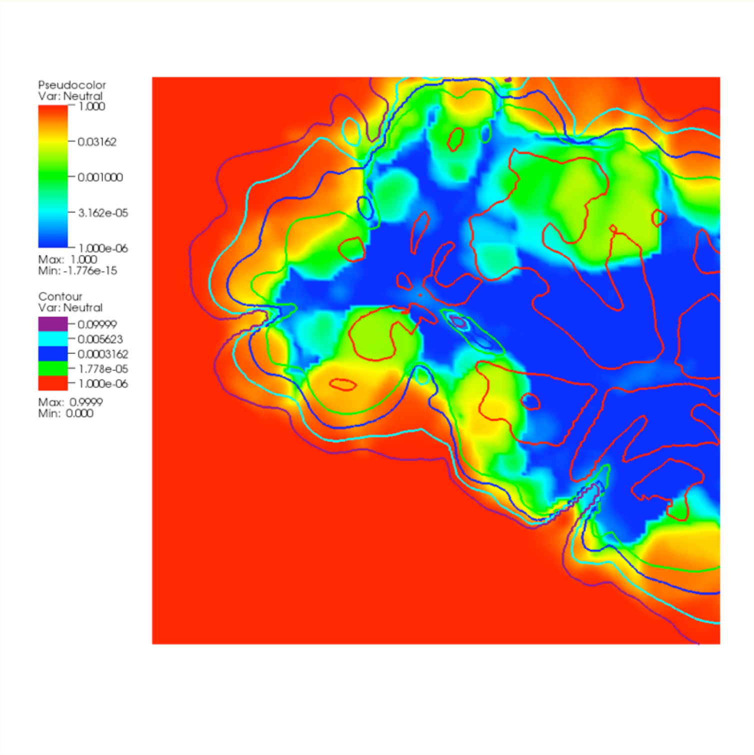


sampling

Results
Test 4

Bad sampling gives bad results!

Not enough directions into low density regions



Results after 0.2 Myr

sampling: density$^{1/2}$

128^3 points

contours: C^2Ray

New sampling function

$$f(n(\vec{x})) = \left(\left(\frac{n(\vec{x})}{n_0(\vec{x})} \right)^{-3} + \left(\frac{n(\vec{x})}{n_0(\vec{x})} \right)^{-\alpha} \right)^{-1}$$

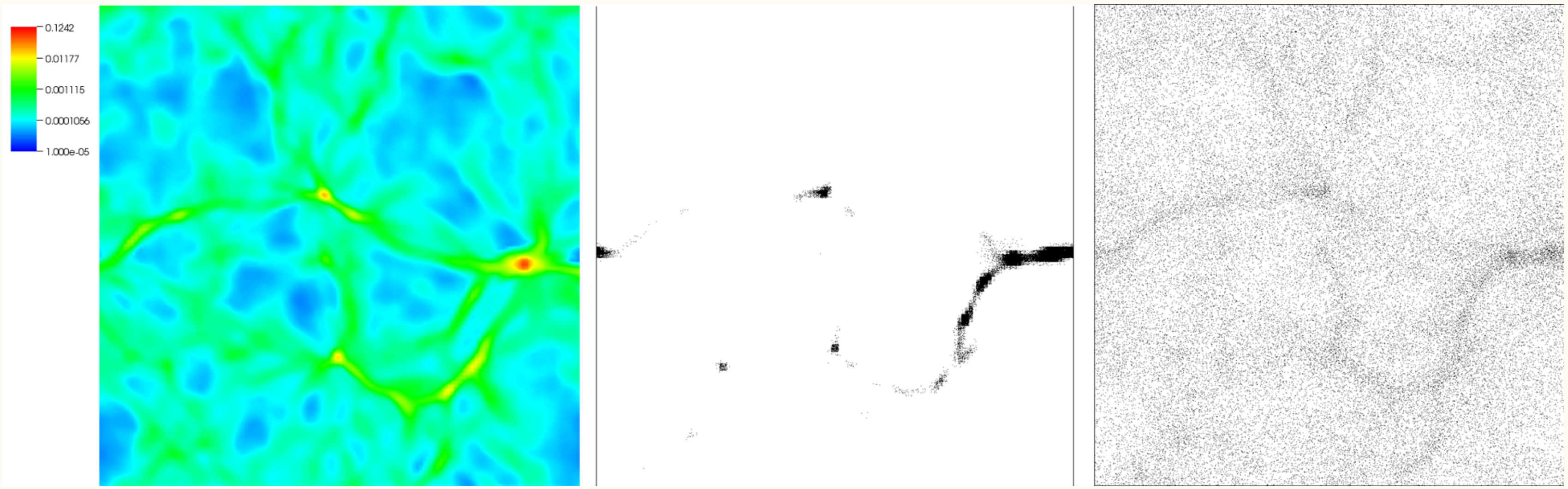
Different sampling recipe in high density regions

Change interaction coefficient accordingly

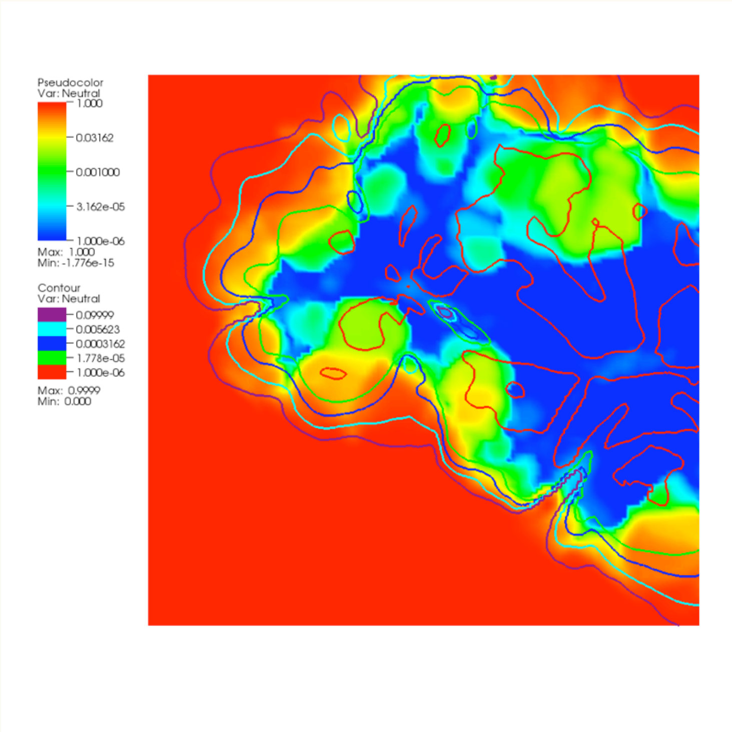
$n_0(\vec{x})$ and α depend on density distribution

Sampling Function

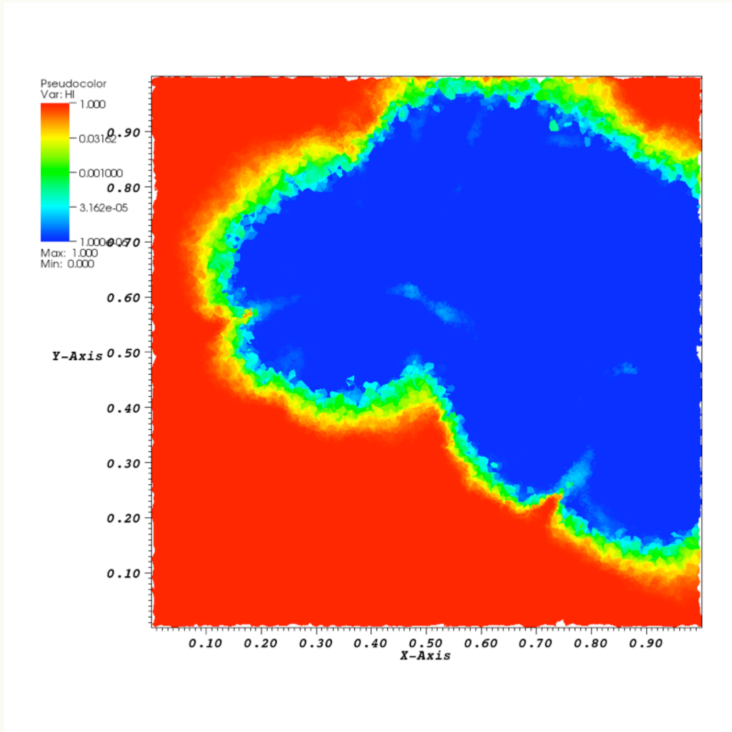
Better sampling in low density regions...



...leads to more realistic results

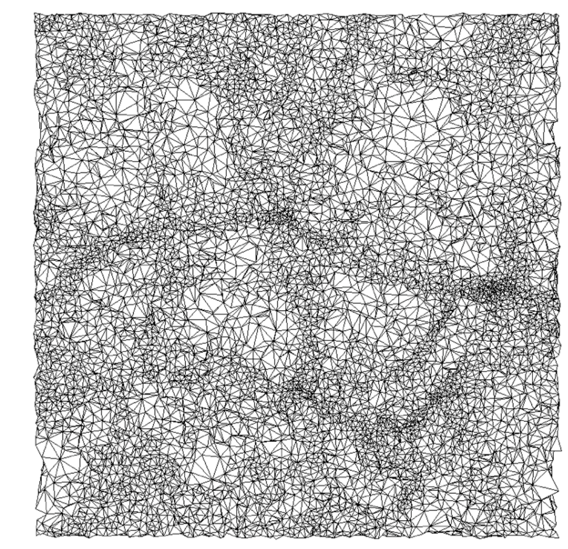


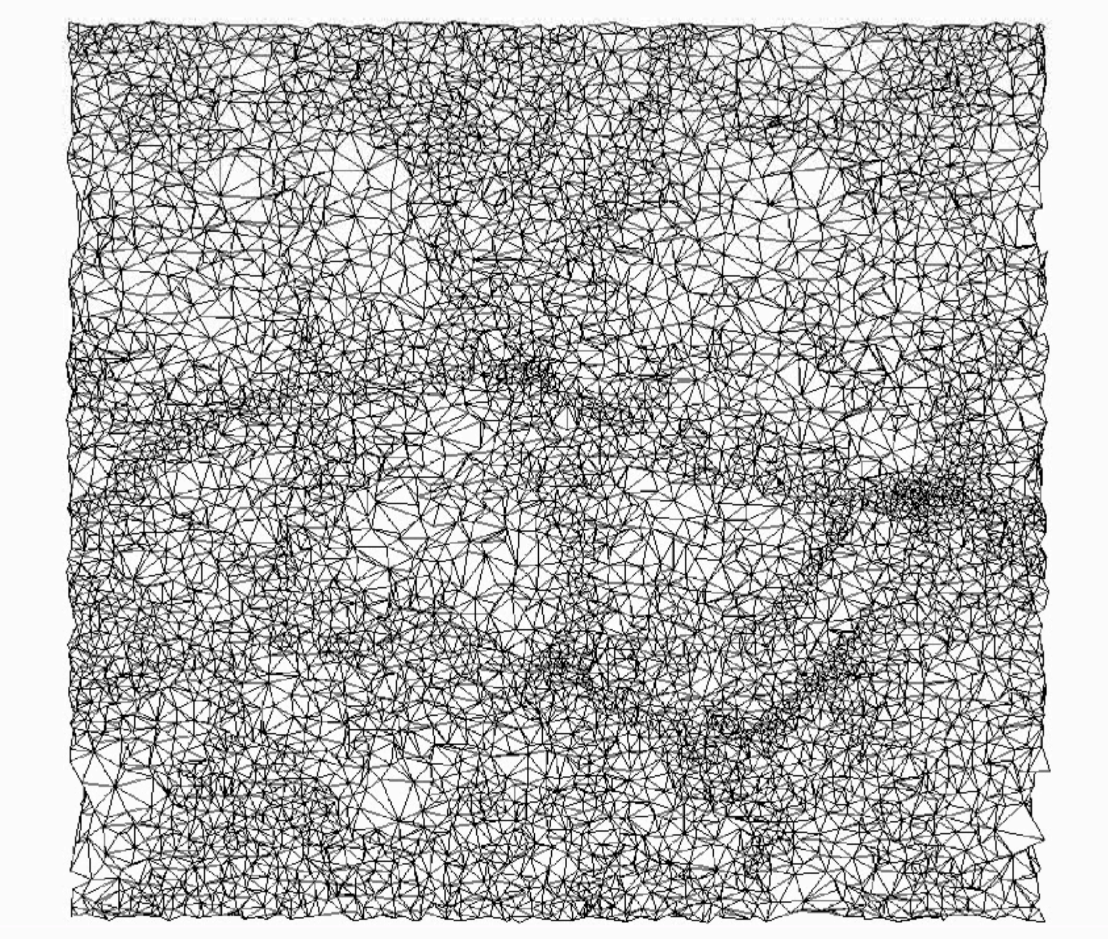
old sampling



new sampling

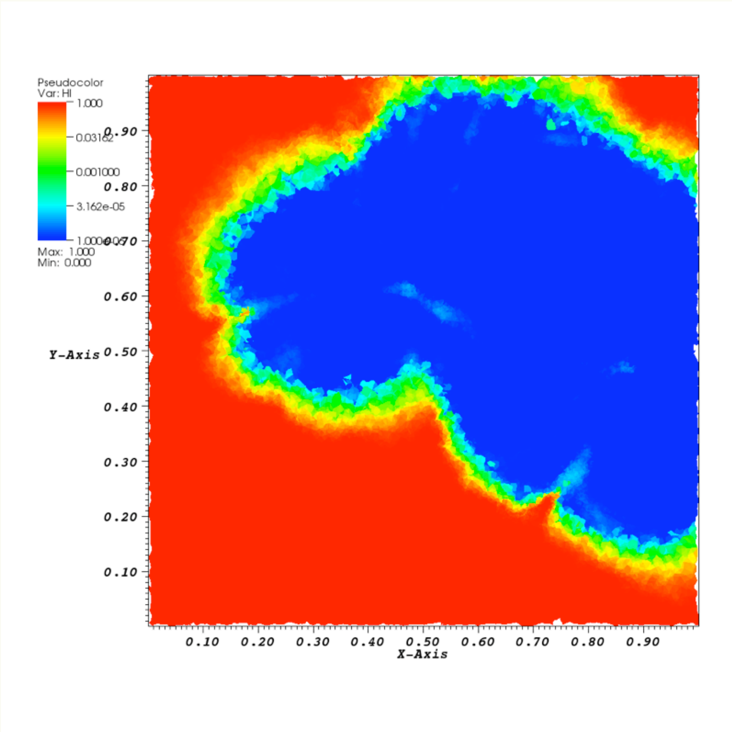
Results
Test 4



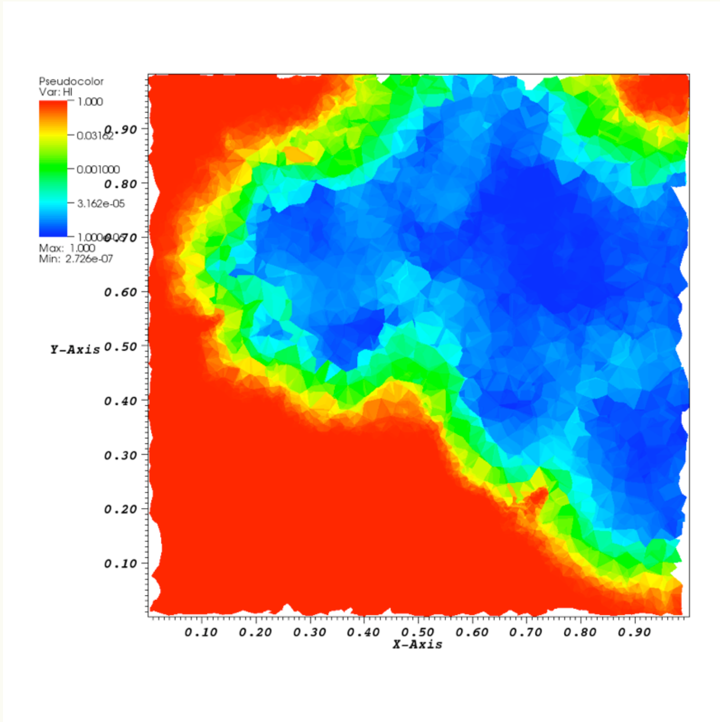


Results
Test 4

Inner structure of ionised regions shows up when grid is updated



128^3 no updates



80^3 updates

SimpleX

- is computationally very efficient
- does not scale with the number of sources

The inner parts of HII region are not very well represented

- updating the grid reduces the problem but also reduces resolution
- other solutions are currently developed

How severe is the problem?

- Inner parts of HII region are dominated by diffuse recombination radiation (Ritzerveld, 2006)