Tutorial II
Using the adaptive mesh refinement & spherical shell geometry

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Overview

- At the end of this tutorial, you should be able to:
  - Set up a model with Earth-like geometry and temperature in Aspect
  - Set up a model with adaptive mesh in Aspect
  - Decide which mesh refinement strategy to use
  - Know a bit more about how the mesh influences the flow field ☺

Setup: Convection in a Shell
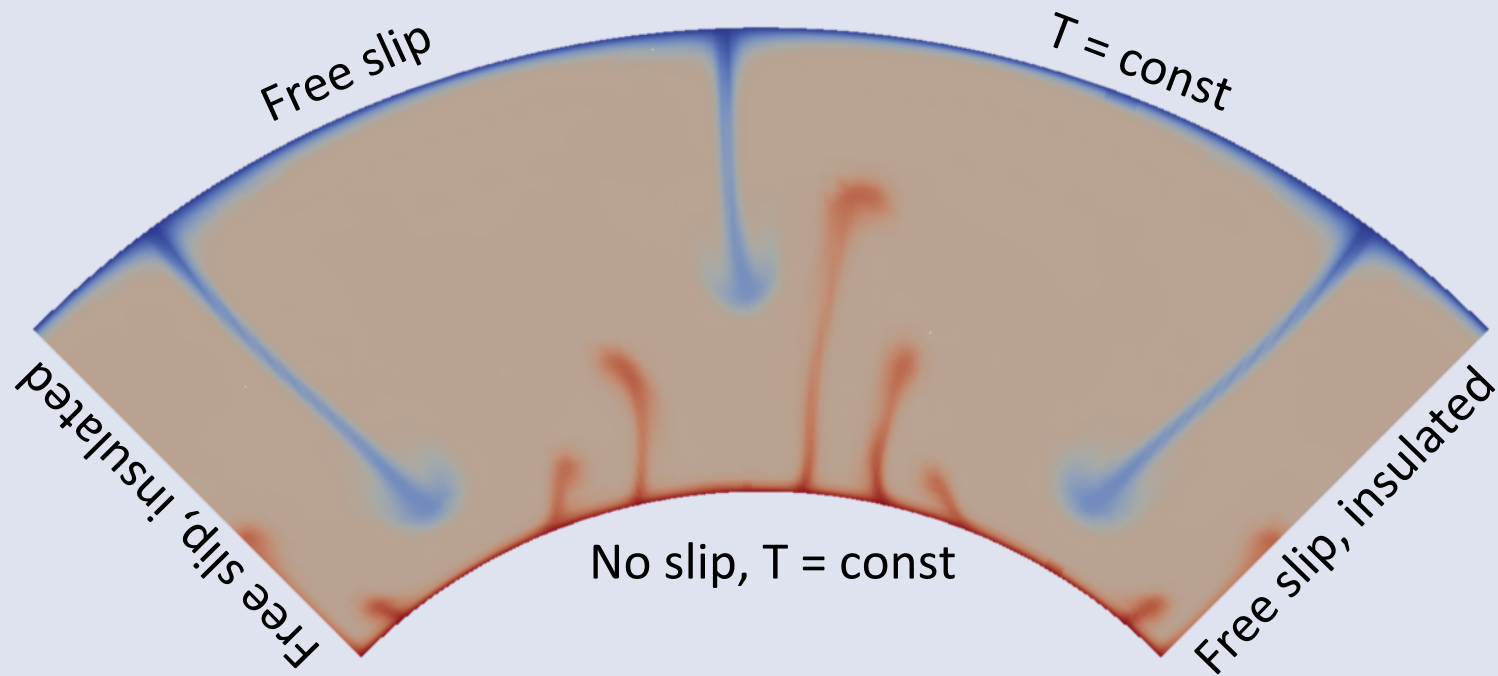
- Geometry: Quarter of a spherical shell
- Constant initial temperature with a perturbation to start the upwelling

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Tasks

- We will split the class into multiple groups identified by the mesh refinement (number of global refinements)

- You will need to:
  1. Modify the spherical_shell.prm file to use your assigned refinement number/strategy
  2. Run the simulation
  3. Visualize the results and make sure they are realistic
  4. Check which features of the flow field are resolved
  5. Note: to halt a simulation, press "Control-C"

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Using ASPECT

- We will begin by editing the input file

1. Change to the appropriate directory

   cd ~/ASPECT_TUTORIAL/models

2. Open the parameter file for editing

   gedit spherical_shell.prm

Material model

```
set Adiabatic surface temperature     = 1600

subsection Material model
  set Model name = simple
  subsection Simple model
    set Thermal expansion coefficient = 2e-5
    set Viscosity                = 3e21
    set Thermal viscosity exponent    = 3
    set Reference temperature         = 1600
  end
end
```

These should be the same

Temperature-dependent viscosity

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Geometry & gravity model

```
subsection Geometry model
  set Model name = spherical shell

  subsection Spherical shell
    set Inner radius  = 3481000
    set Outer radius  = 6336000
    set Opening angle = 90
  end
end


subsection Gravity model
  set Model name = radial earth-like
end
```

The gravity model has to be changed together with the geometry

Initial conditions

```
set Adiabatic surface temperature     = 1600
```
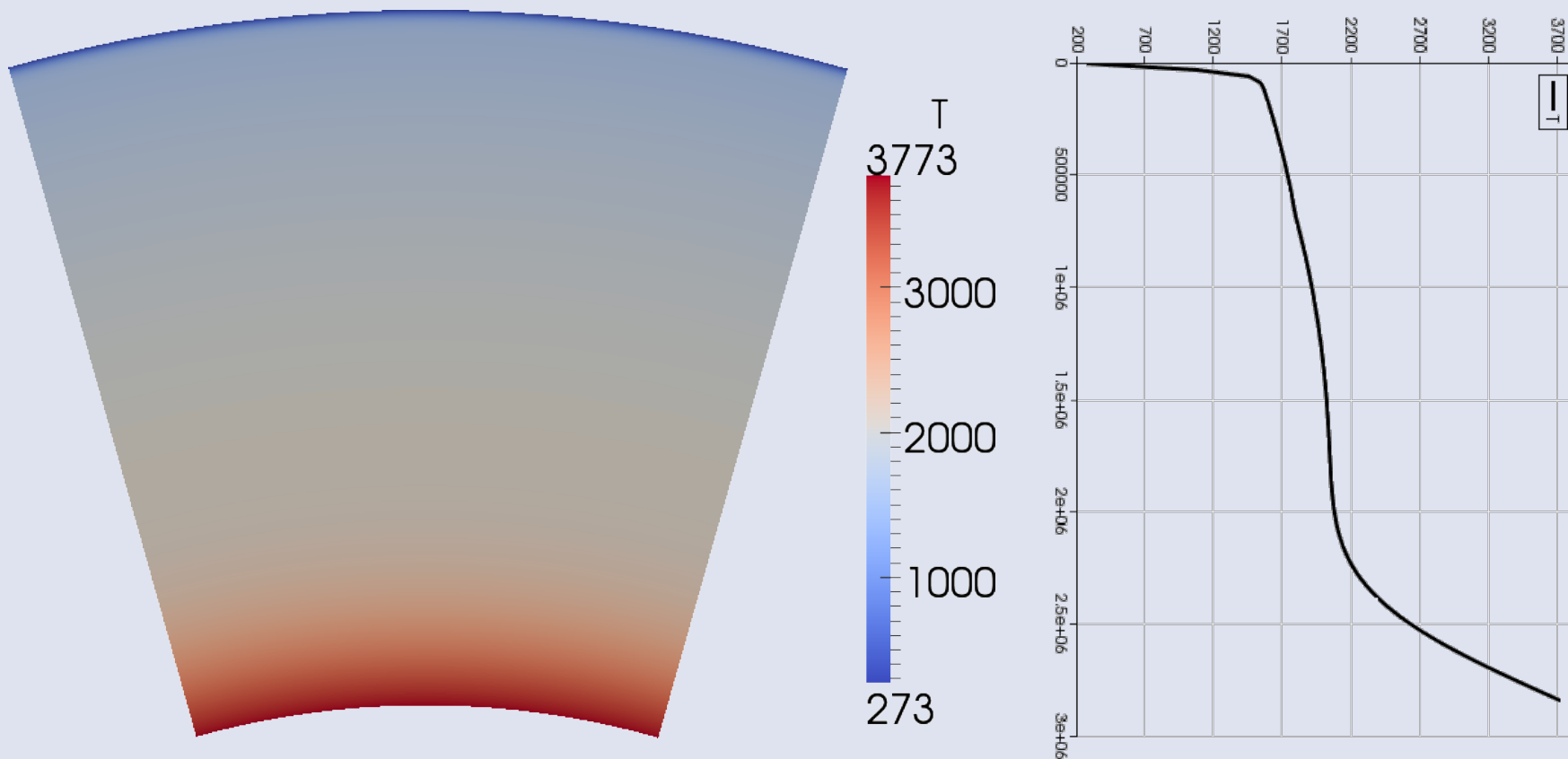
```
subsection Initial conditions
  set Model name = adiabatic

  subsection Adiabatic
    set Amplitude = 10
    set Radius = 500000
  end
end
```

This is the temperature used as initial condition

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Adiabatic initial conditions

- Calculated using depth-dependent ρ, α, c_p

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Boundary conditions

```
subsection Model settings
  set Zero velocity boundary indicators      = 0
  set Tangential velocity boundary indicators = 1, 2, 3
  set Prescribed velocity boundary indicators =
  set Fixed temperature boundary indicators   = 0, 1

  set Include shear heating               = false
  set Include adiabatic heating            = false
end
```

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Boundary conditions

```
subsection Model settings
subsection Model settings
  set Zero velocity boundary indicators      = inner
  set Tangential velocity boundary indicators = outer, left,        right
  set Prescribed velocity boundary indicators =
  set Fixed temperature boundary indicators   = inner, outer

  set Include shear heating               = false
  set Include adiabatic heating            = false
end
```
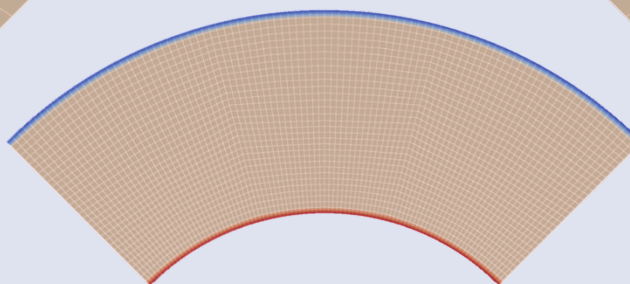
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Mesh refinement

```
subsection Mesh refinement
    set Initial global refinement         = 5
    set Initial adaptive refinement        = 0
    set Strategy                  = temperature
    set Time steps between mesh refinement = 0
    set Coarsening fraction          = 0.05
    set Refinement fraction          = 0.3
end
```

Global refinement = 5
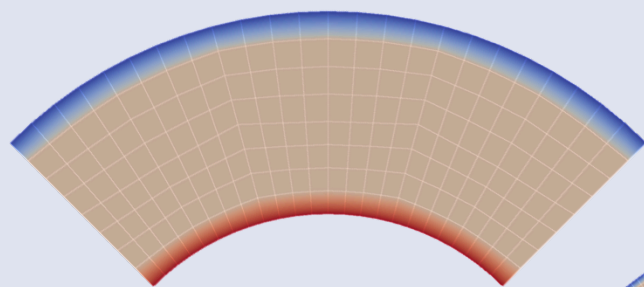
Global refinement = 3
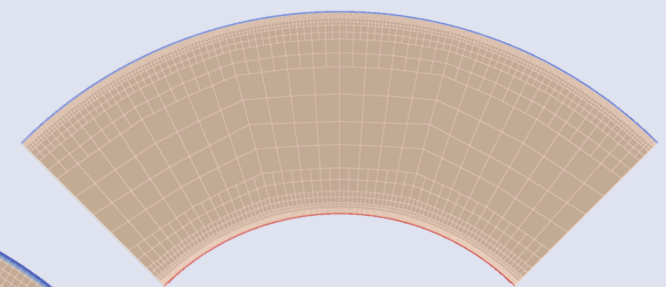
Global refinement = 4
Adaptive refinement = 2

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Mesh refinement

```
subsection Mesh refinement
  set Initial global refinement        = 5
  set Initial adaptive refinement       = 0
  set Strategy                = temperature
  set Time steps between mesh refinement = 0
  set Coarsening fraction          = 0.05
  set Refinement fraction          = 0.3
end
```

Running the model

aspect spherical_shell.prm

Or in parallel

mpirun –np 2 aspect
spherical_shell.prm

This is what we want to change:
- Group 1:   3
- Group 2:   4
- Group 3:   5
- Group 4:   6

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Numerical Challenges

Different scales

temperature anomaly in K

-1000 -800 -600 -400 -200 0 200 400 600 800 1000

Distance from CMB in km

1000 500 0 500 1000
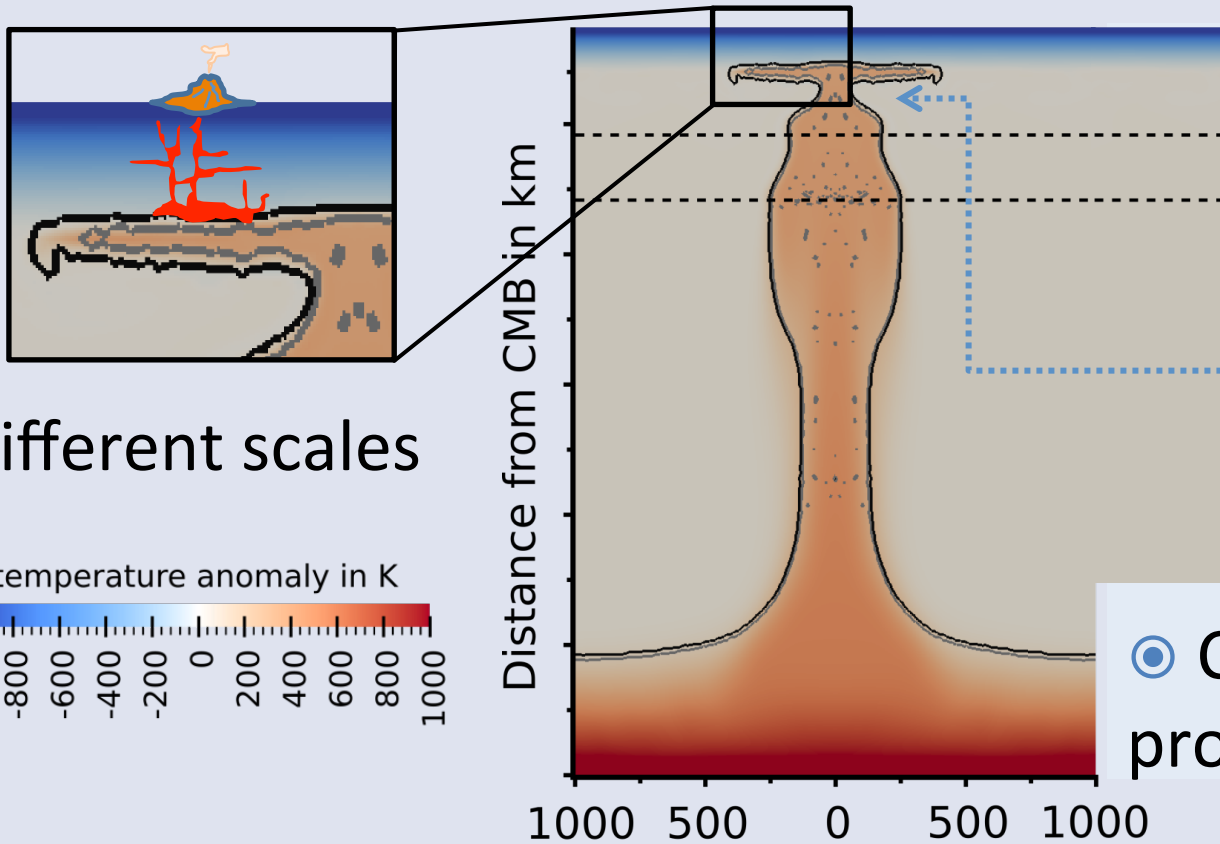
◉ High viscosity contrasts

◉ Advection of steep thermal/ compositional gradients

◉ Complex material properties

◉ Problems with large number of DOFs

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Mesh adaptation
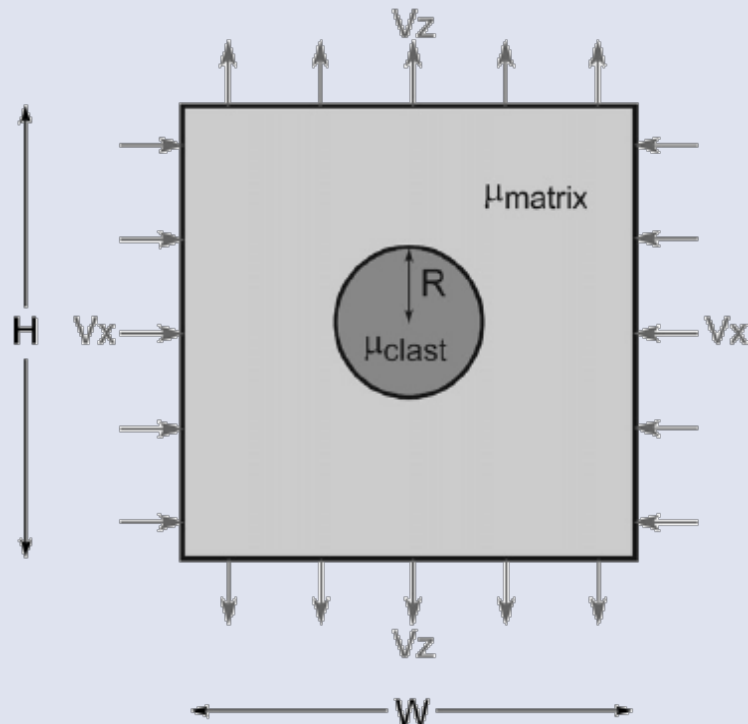

- Example: Composition as refinement strategy
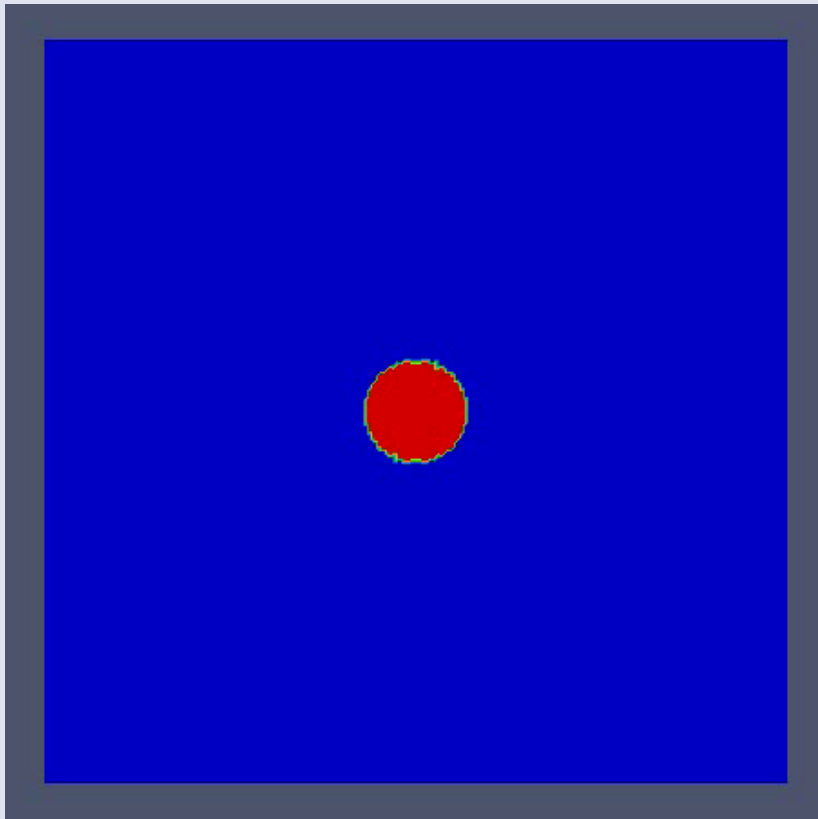
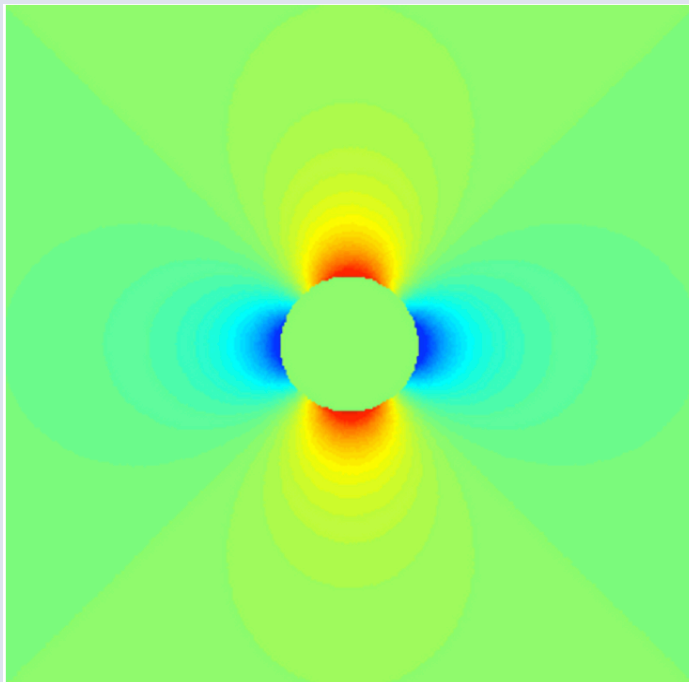Compositional field
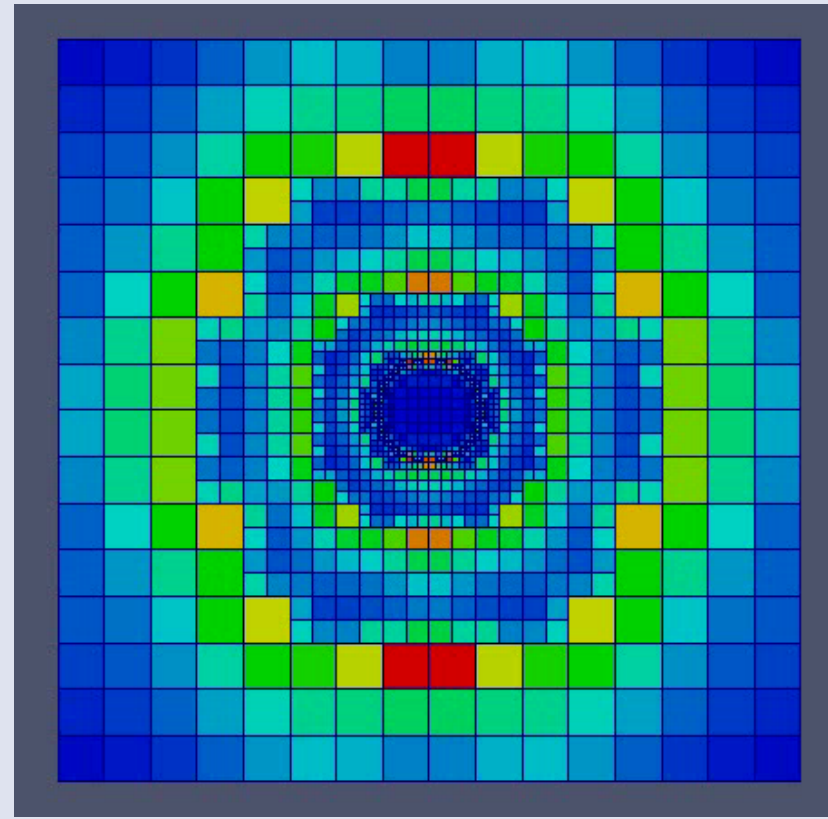
Mesh cells, colors indicate the estimated error

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Mesh adaptation

- Stokes solver for problems with complex interfaces and high viscosity ratios

Circular inclusion test, viscosity constrast 10^3

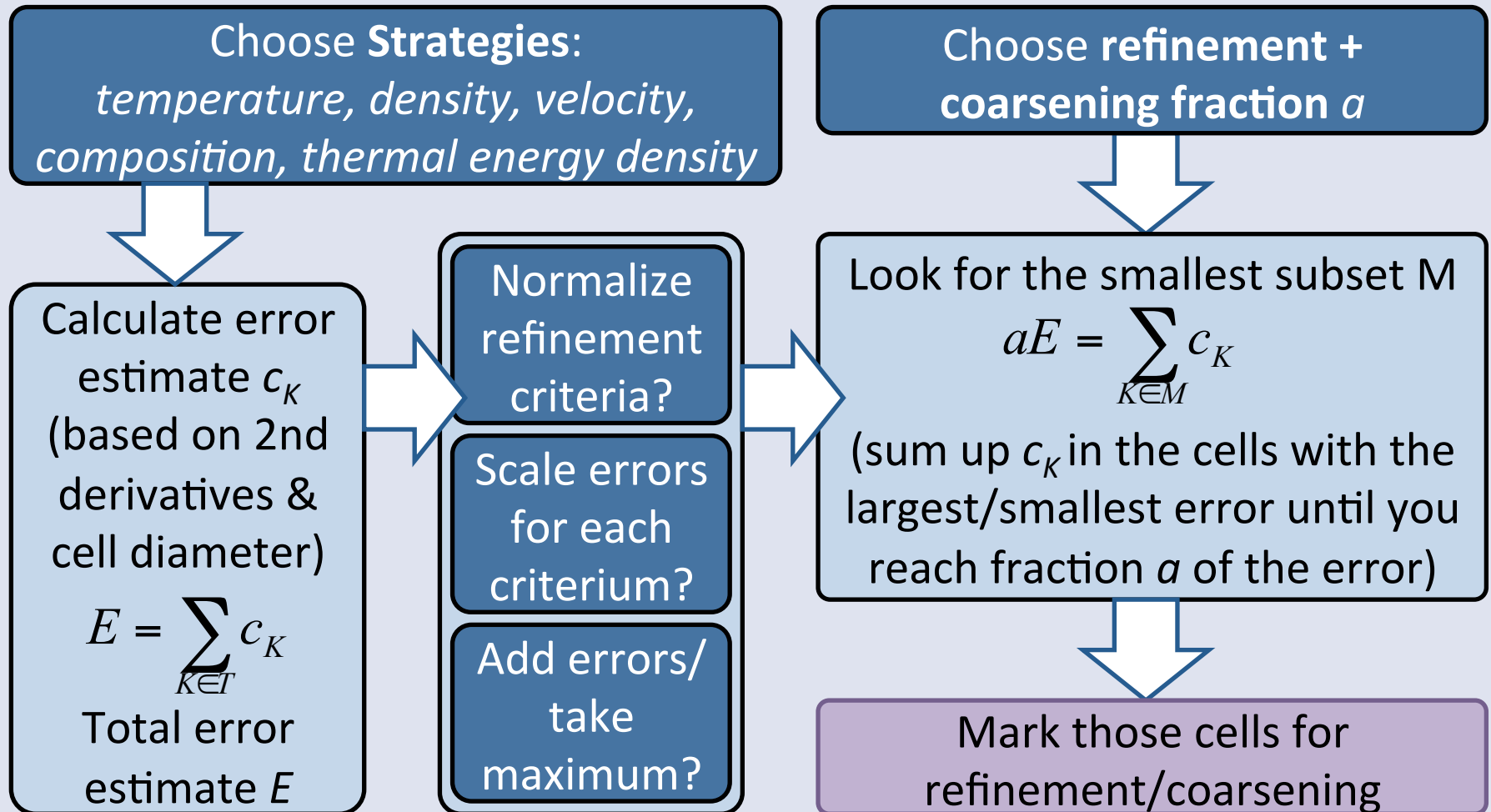# Mesh adaptation

Analytical Solution for Pressure:

(Schmid, Podladchikov, 2003)

Aspect's solution for Pressure:

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Mesh adaptation

Choose **Strategies**:
temperature, density, velocity, composition, thermal energy density

Choose **refinement + coarsening fraction** a

Calculate error estimate c_K (based on 2nd derivatives & cell diameter)

$$E = \sum_{K \in T} c_K$$

Total error estimate E

Normalize refinement criteria?

Scale errors for each criterium?

Add errors/ take maximum?

Look for the smallest subset M

$$aE = \sum_{K \in M} c_K$$

(sum up c_K in the cells with the largest/smallest error until you reach fraction a of the error)

Mark those cells for refinement/coarsening

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Mesh refinement options

- Strategies: (nonadiabatic) temperature / pressure, composition, density, velocity, viscosity, thermal energy density…

- Refinement criteria scaling factors

- min/max refinement level function

  ➢ Phase transitions / jump in material properties

- Additional refinement times

  ➢ Onset of new processes (convection? melting? plate velocities?)

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Inspecting the results

1. With Paraview

   paraview

2. How does the flow field change with varying the resolution?

3. How does the runtime change with the adaptive refinement compared to global refinement?

4. What refinement / coarsening fraction is sufficient?

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Results

Time snapshots of models with different resolution
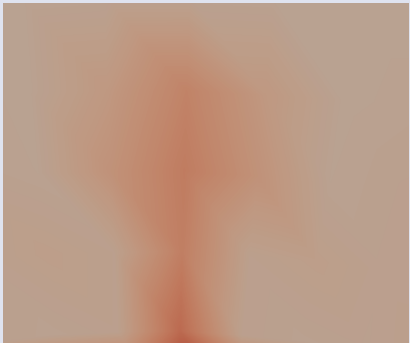
| Group 1: | 3 | Group 2: | 4 | Group 3: | 5 | Group 4: | 6 |
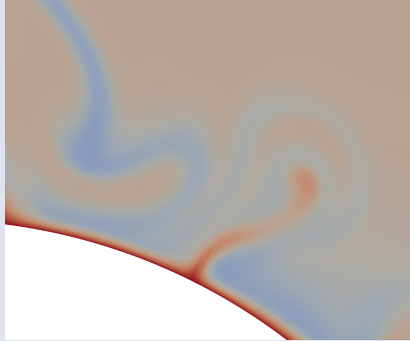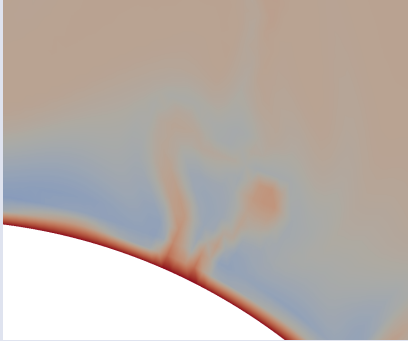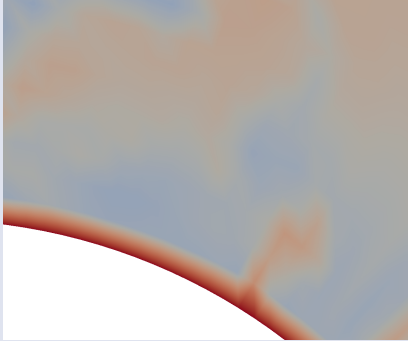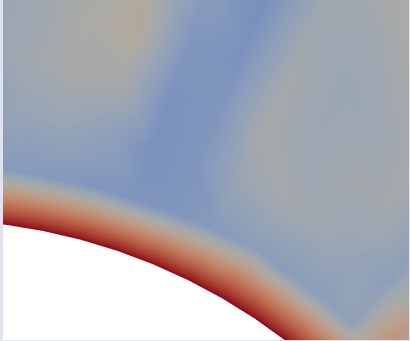
Mesh refinement

```
subsection Mesh refinement
   set Initial global refinement      = 5
   set Initial adaptive refinement     = 0
   set Strategy                  = temperature
   set Time steps between mesh refinement = 0
   set Coarsening fraction          = 0.05
   set Refinement fraction          = 0.3
end
```

This is what we want to change:
- Group 1:   4 + 0
- Group 2:   5 + 0
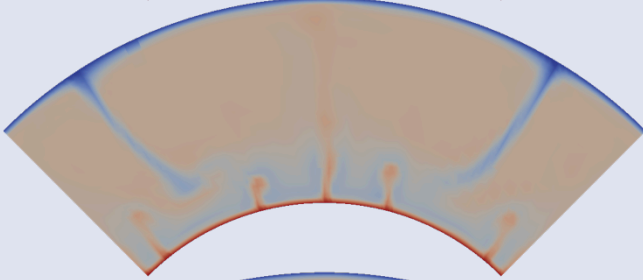- Group 3:   6 + 0

Set to a value > 0 to enable adaptive refinement

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Results

global

adaptive

3 | 4

4 | 5

5 | 6

6 | 7

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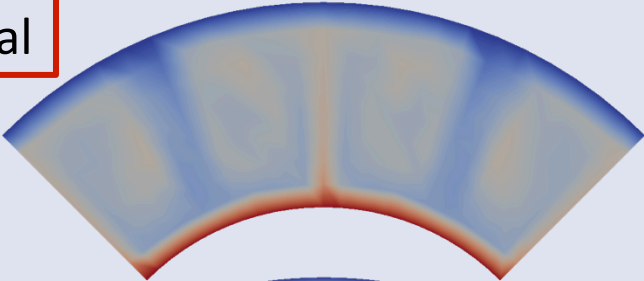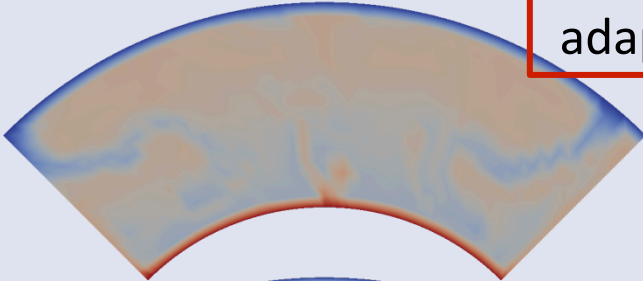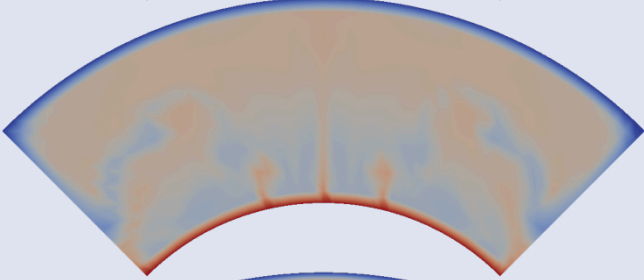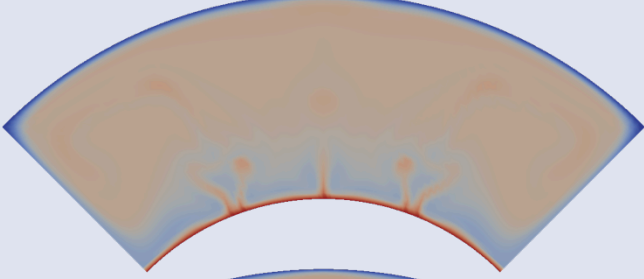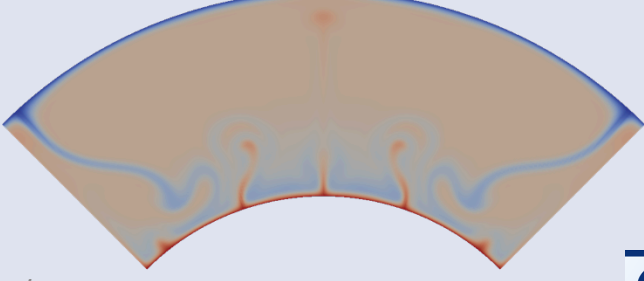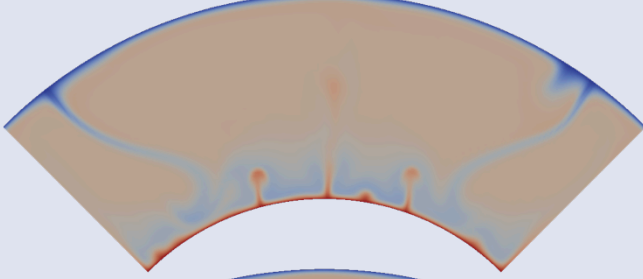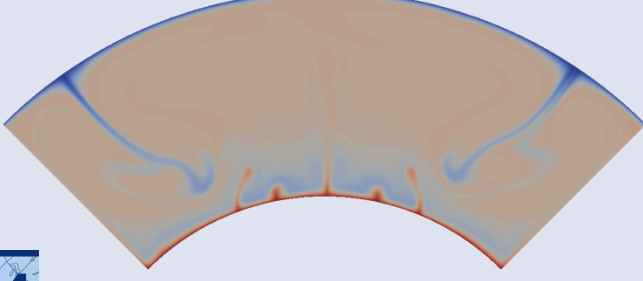
Results

Global 6

Adaptive 6

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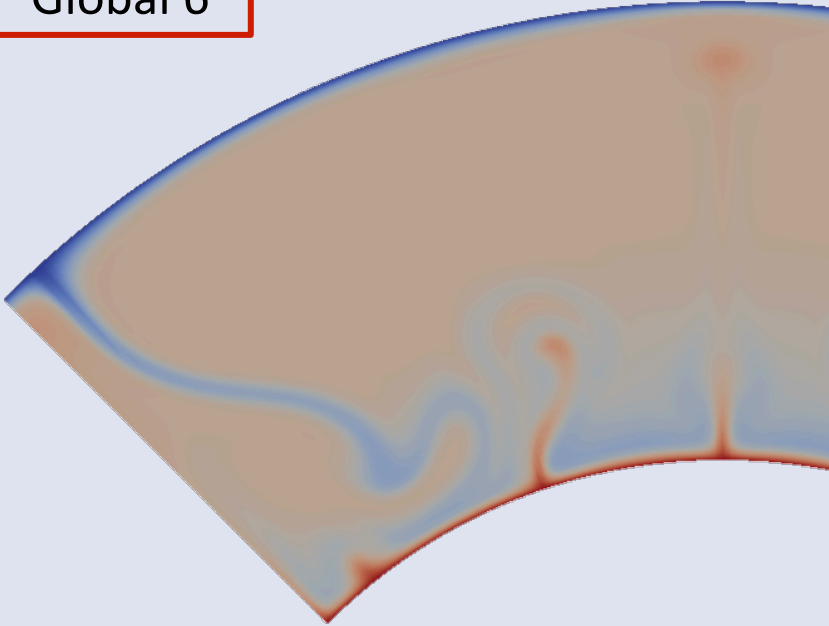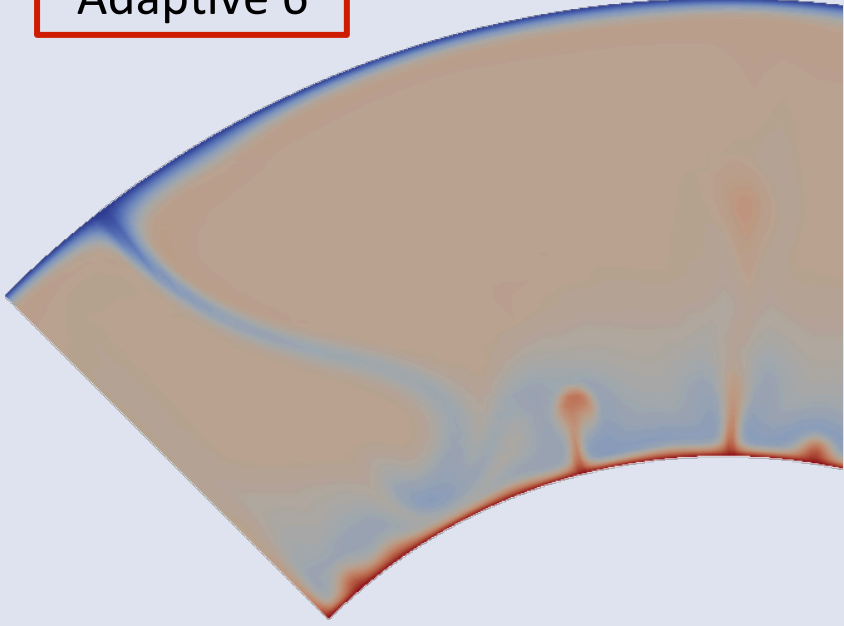
Results

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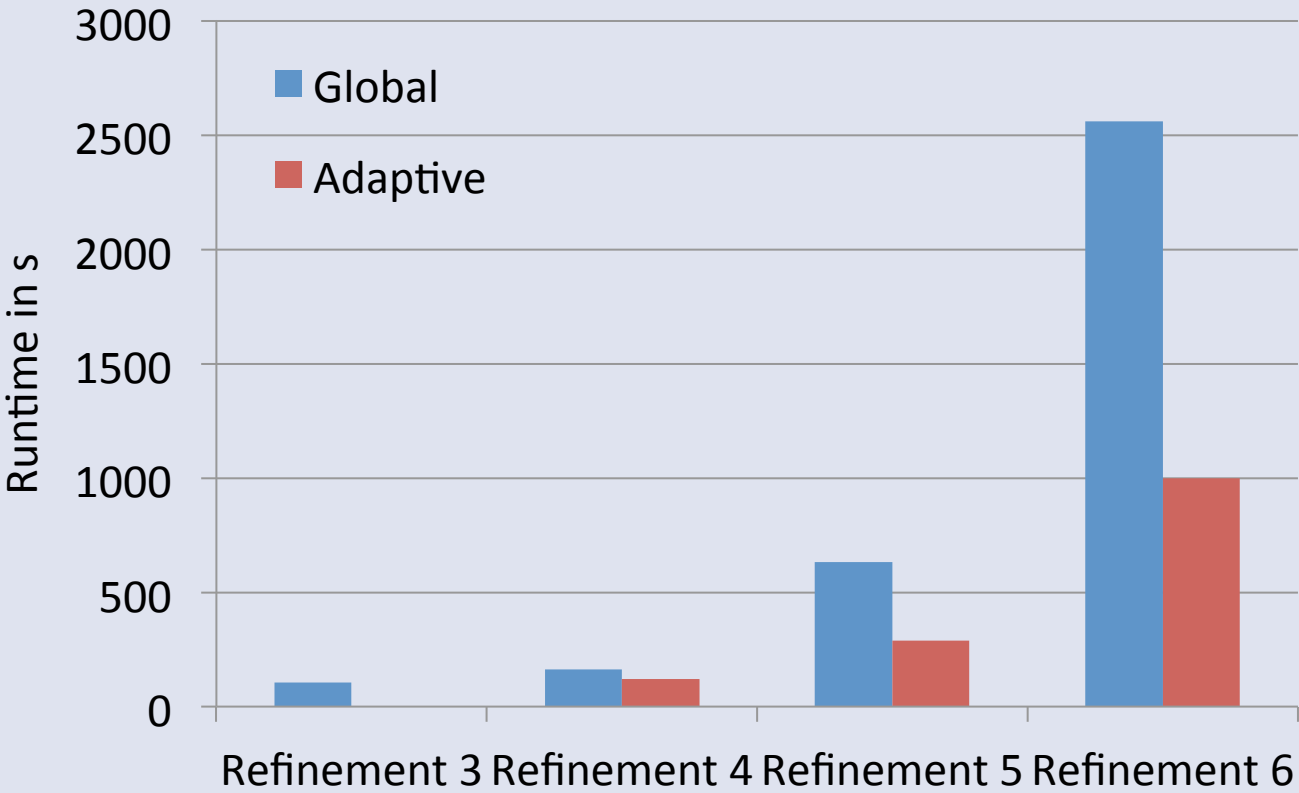
Mesh refinement

```
subsection Mesh refinement
  set Initial global refinement        = 4
  set Initial adaptive refinement      = 2
  set Strategy                 = temperature
  set Time steps between mesh refinement = 5
  set Refinement fraction          = 0.3
  set Coarsening fraction          = 0.05
end
```

This is what we want to change:
- Group 1:   0.6 + 0.01
- Group 2:   0.1 + 0.1

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Results

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