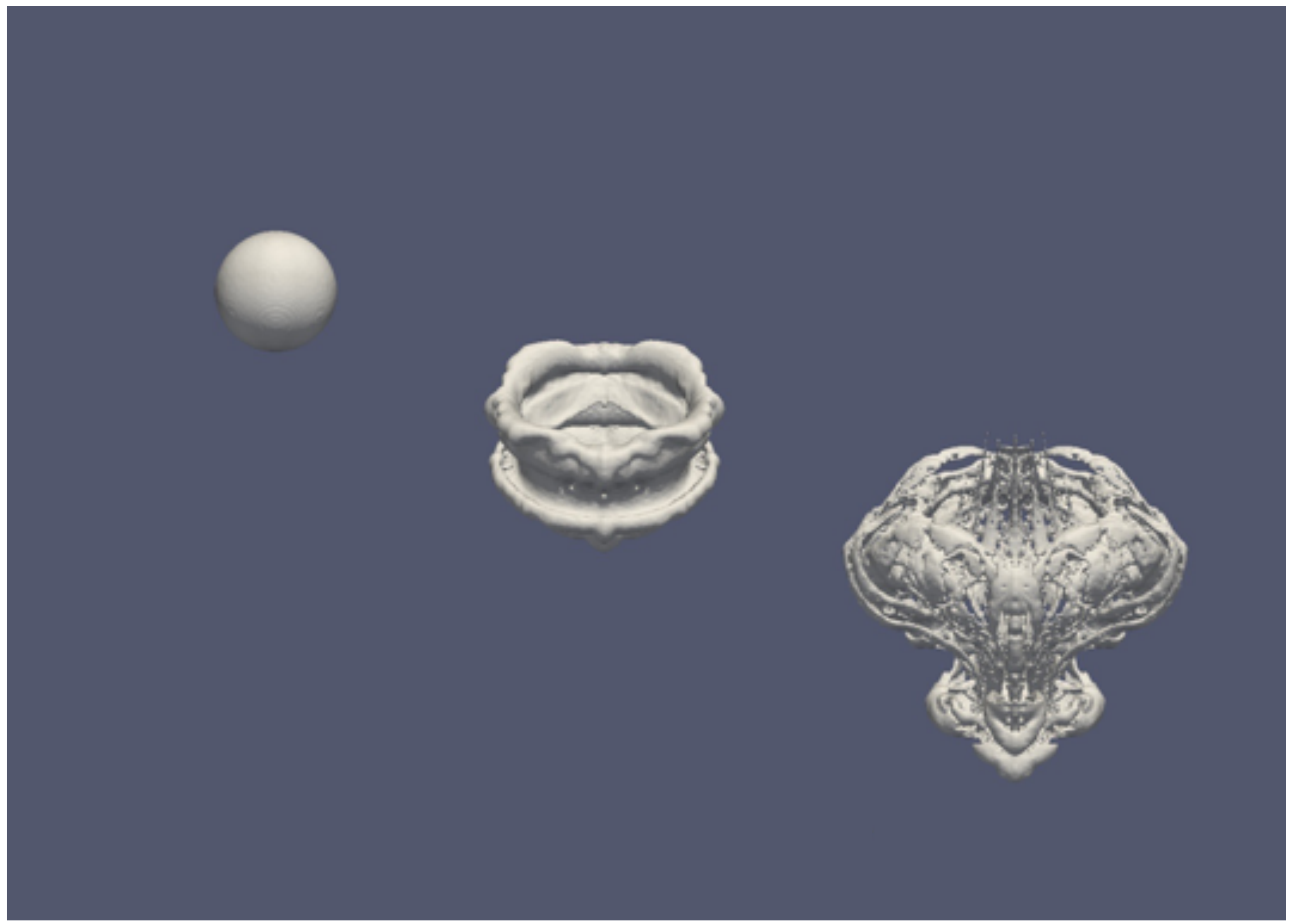
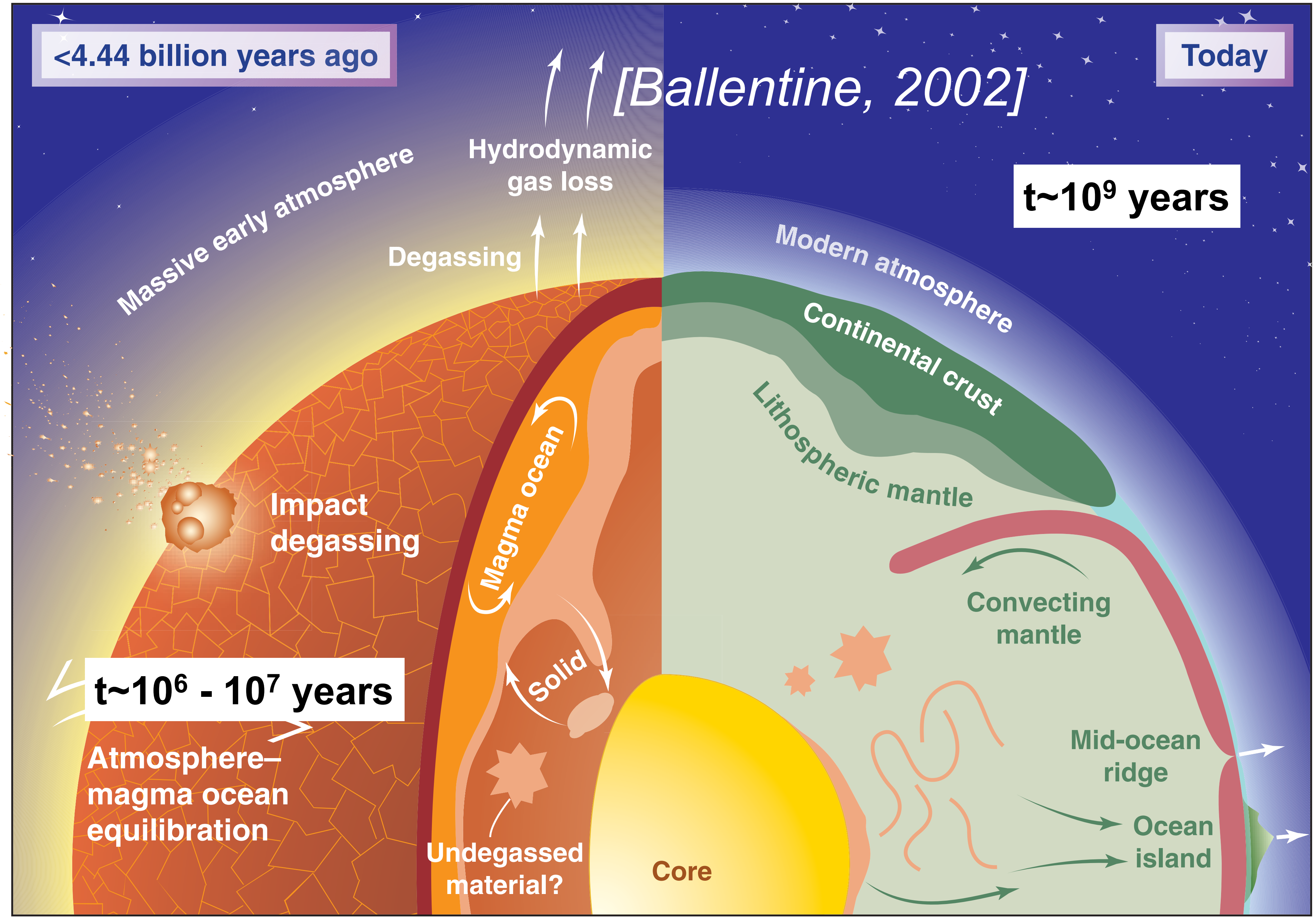
Iron flow in Earth's molten silicate proto-mantle



Henri Samuel

The early stages of planetary evolution

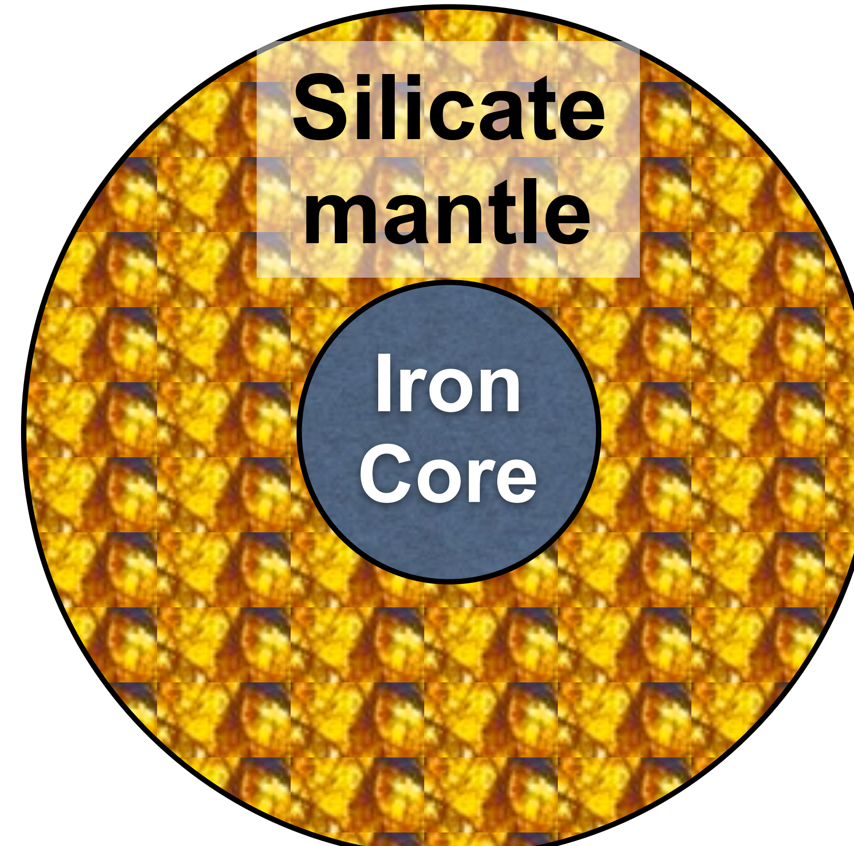


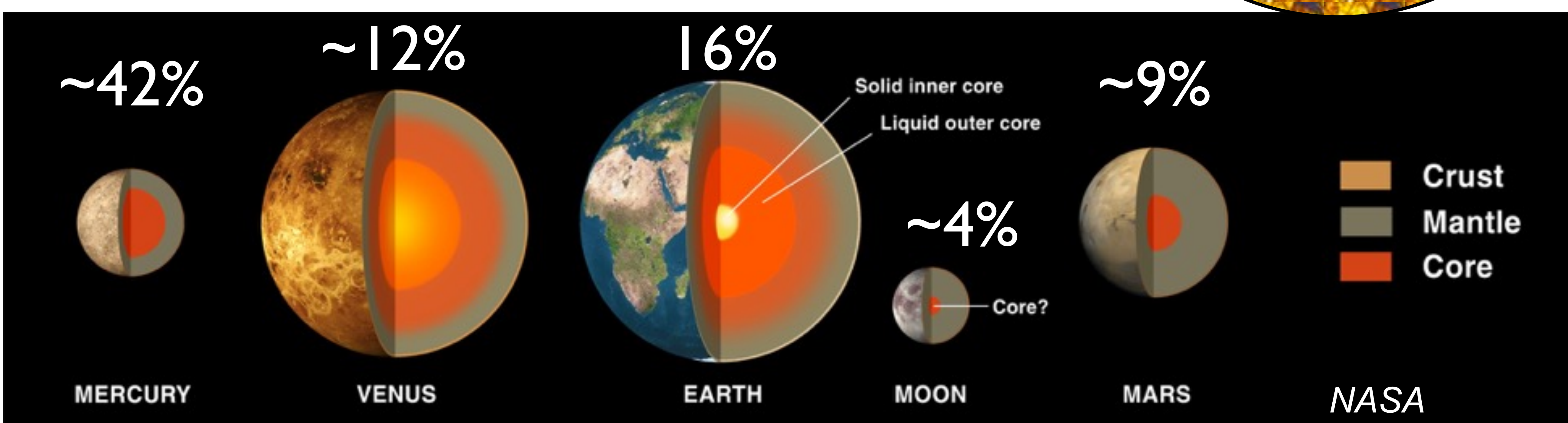
Early stages = Initial condition ➪ long term evolution

Early differentiation: Core Formation

- ✓ Metallic core present on several terrestrial bodies
- ✓ Core formation: First major differentiation event in terrestrial planets

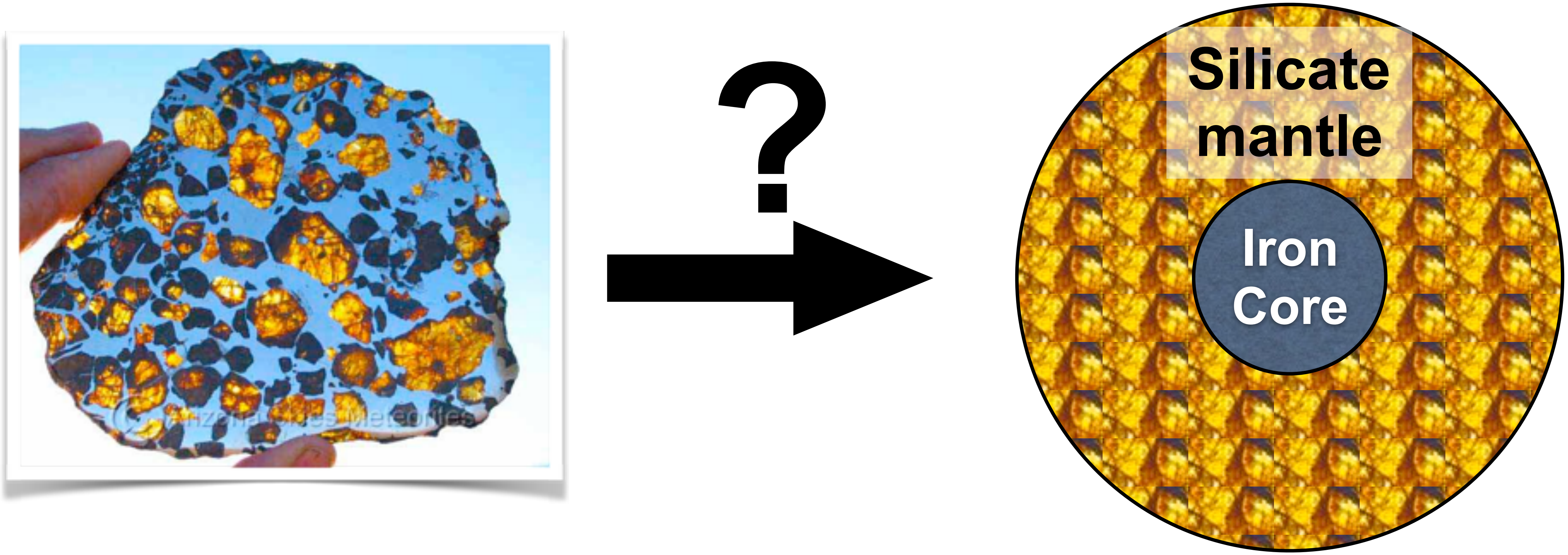
?





What are the constraints?

Constraints on core formation: Summary



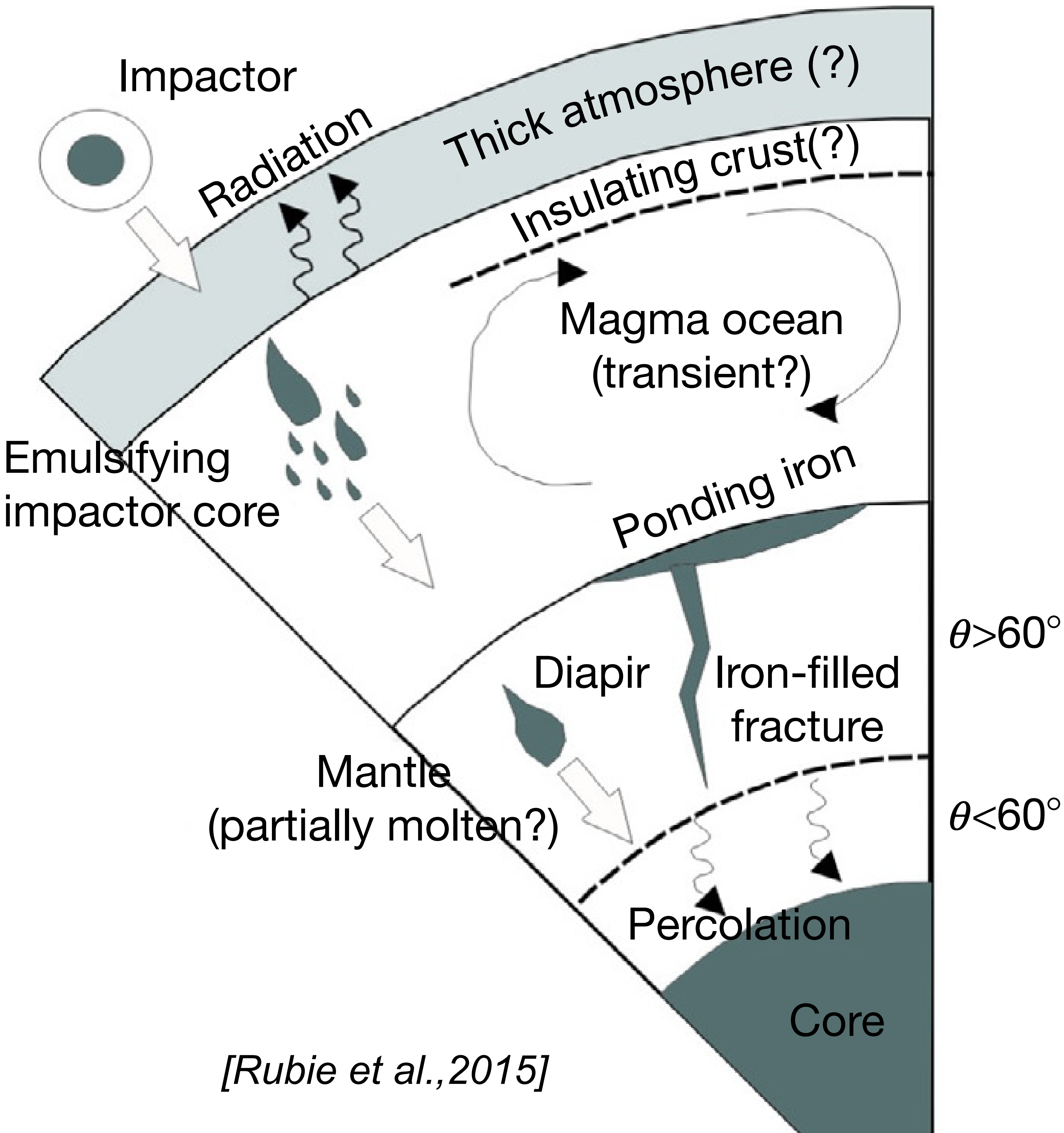
✓Hf/W chronometry
➪ Fast process: t <100 Myrs

✓ Overabundance of siderophile elements (Ni, Co...) in mantle
➪ Requires time for Fe-Si equilibration

✓High T process ("Si-Fe" separation)
➪ Melting

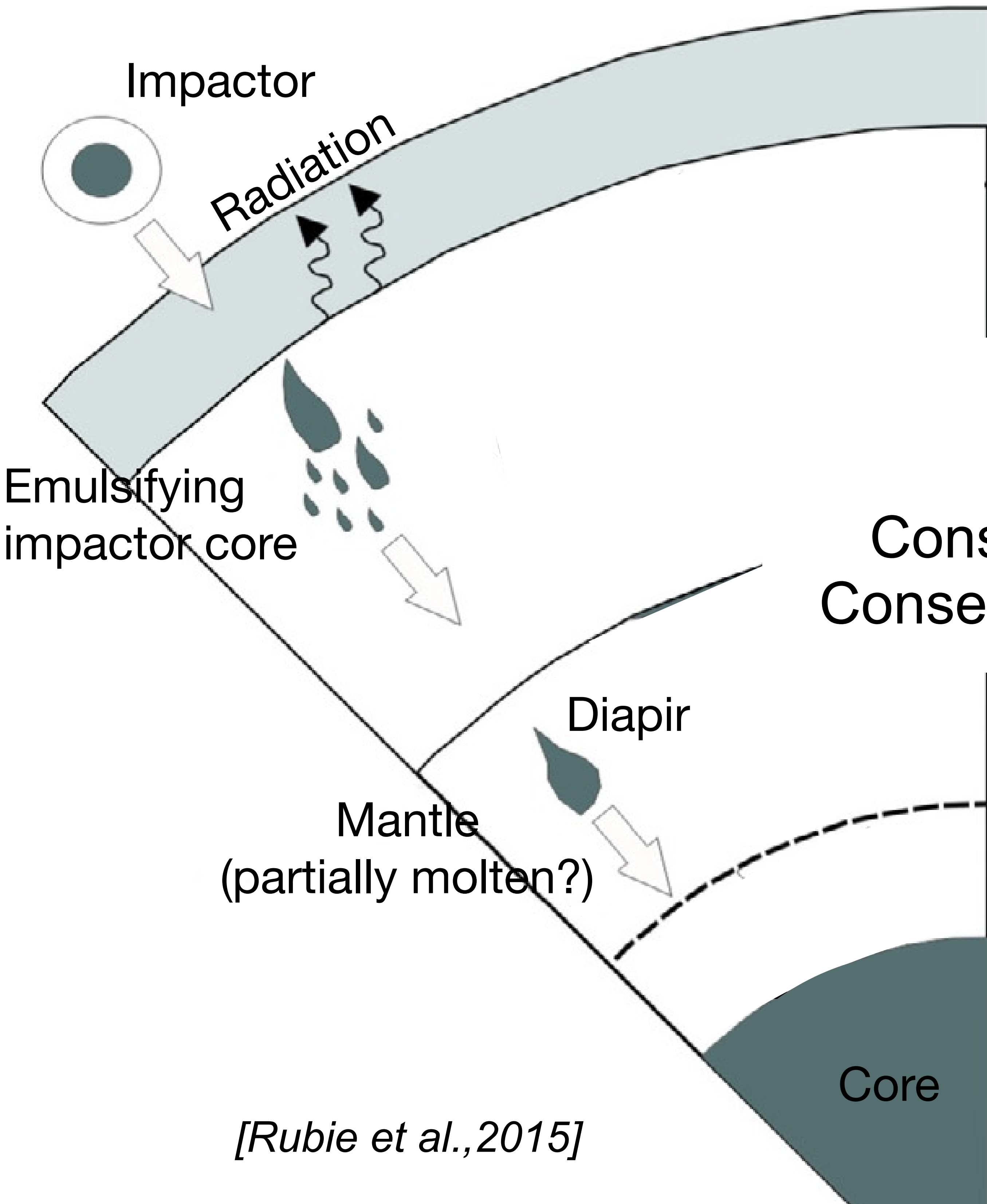
How did it happen?

Several possible core formation scenarios



[Rubie et al.,2015]

Several possible core formation scenarios



[Rubie et al.,2015]

Focus on negative diapirism in:
✓ partially molten proto-mantle
✓ fully molten magma ocean

Do diapirs breakup?
Timing for fragmentation?
Consequences for Fe-Si equilibration?
Consequences for Fe-Si heat partitioning?

1. Setup and parameter space

2. Influence of the parameters

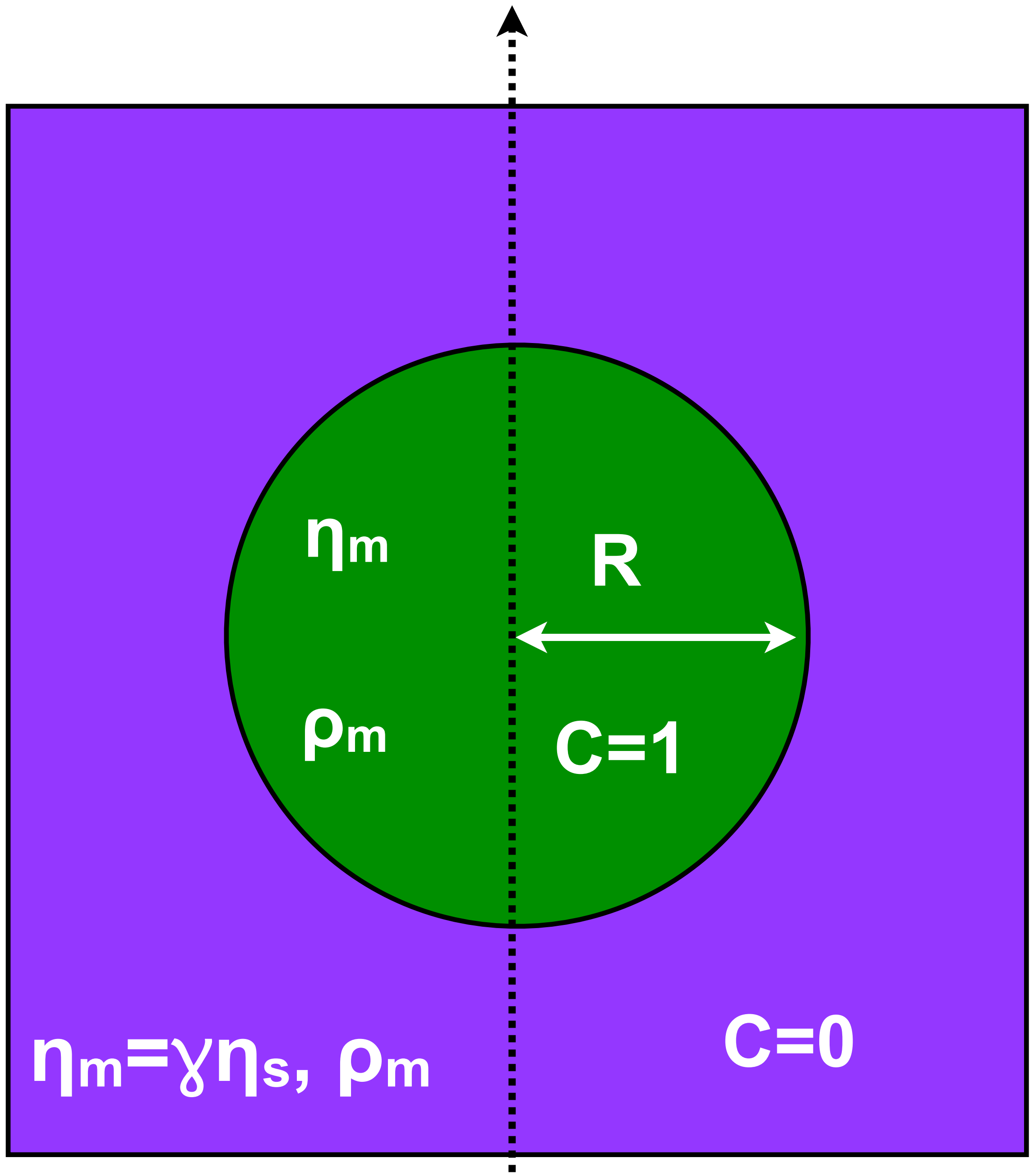
3. Implications

Fluid dynamics description of negative diapirism

Governing conservation equations

Momentum: $\rho D_t \mathbf{u} = -\nabla p + Re^{-1}\nabla\cdot(\eta\sigma) + Fr^{-1}C\mathbf{e}_g + We^{-1}\kappa\delta(d)\mathbf{n} - Ro^{-1}\boldsymbol{\Omega}\times\mathbf{u}$

Mass: $\nabla\cdot\mathbf{u} = 0$ Composition: $D_t C = 0$



Governing parameters

Re = Inertia / Viscous effects: $\dfrac{\rho_s V_\infty R}{\eta_s}$

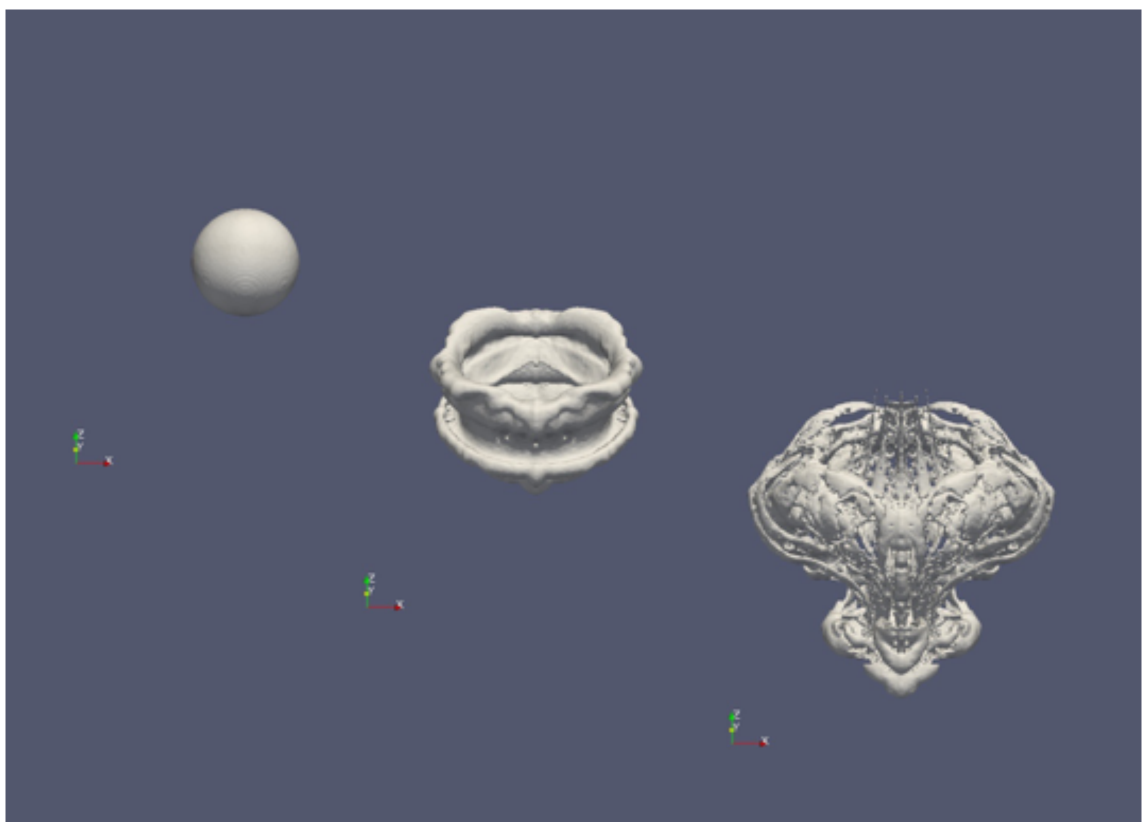
Fr = Inertia / Effective Buoyancy: $\dfrac{{V_\infty}^2}{gR}$

We = Inertia / Surface tension: $\dfrac{\rho_s {V_\infty}^2 R}{\sigma}$

+ rheological parameters (***n***, $\boldsymbol{\eta_s / \eta_m}$)

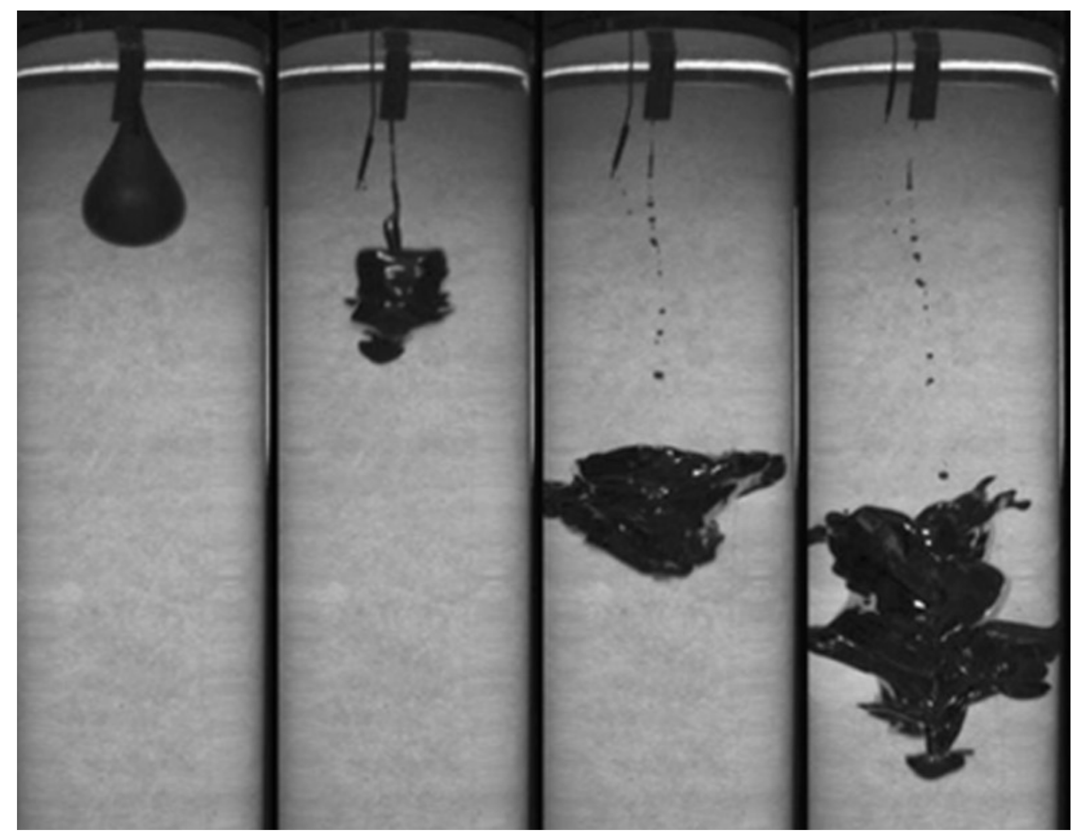
Modelling approach

Numerical experiments



[Ichikawa et al., 2010]
[Samuel, 2012]

Analog/"Tank" experiments

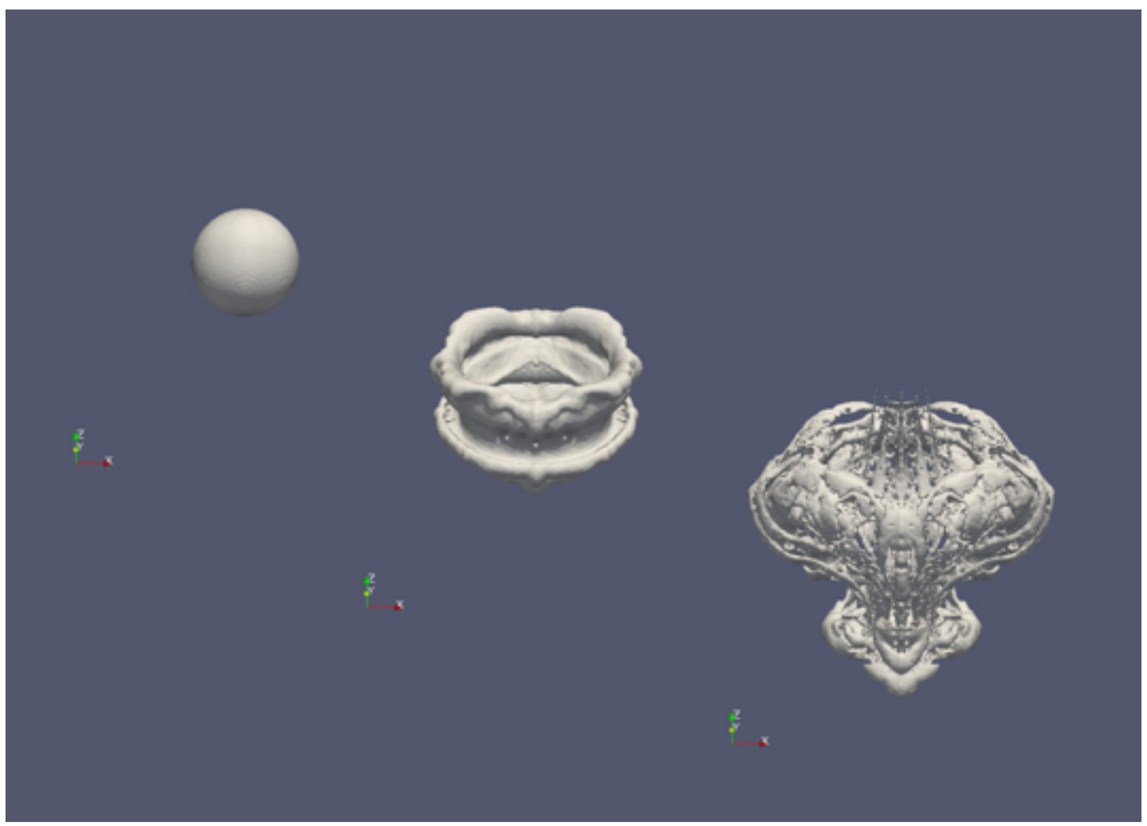


[Villermaux, 2007]
[Wacheul et al., 2014]

Modelling approach

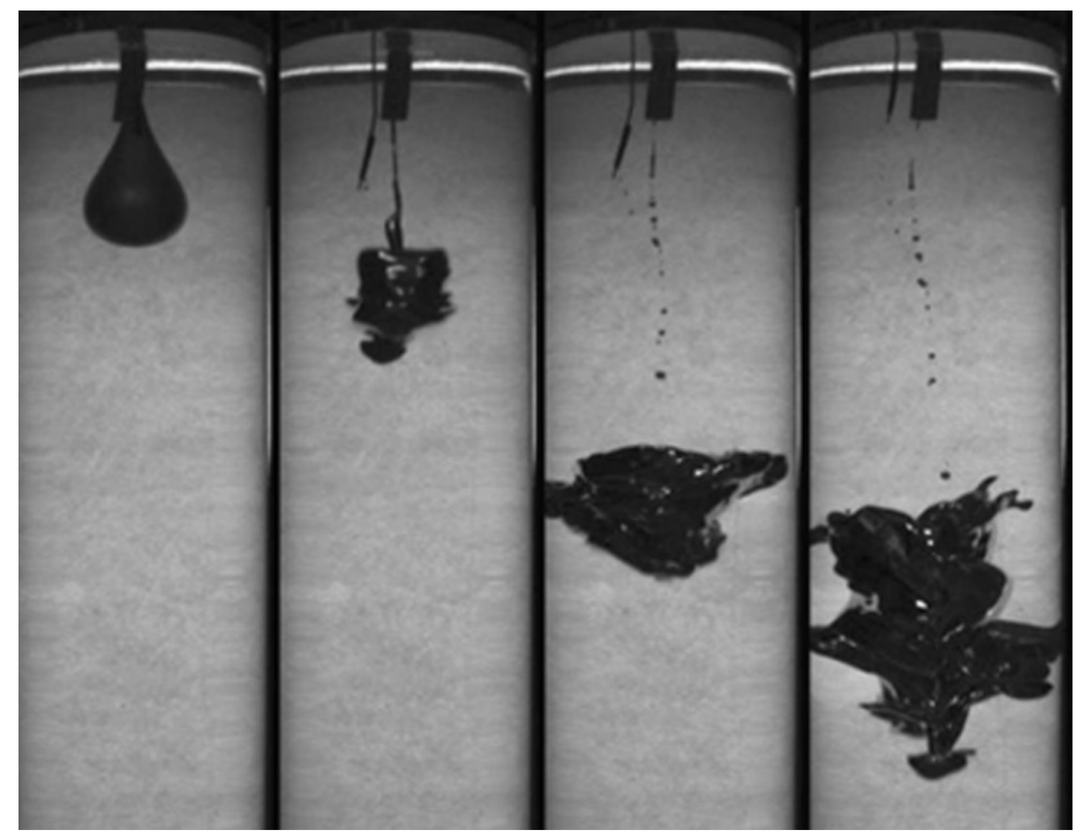
"A theory is something nobody believes, except the person who made it. An experiment is something everybody believes, except the person who made it." —Albert Einstein

Numerical experiments



[Ichikawa et al., 2010]
[Samuel, 2012]

Analog/"Tank" experiments

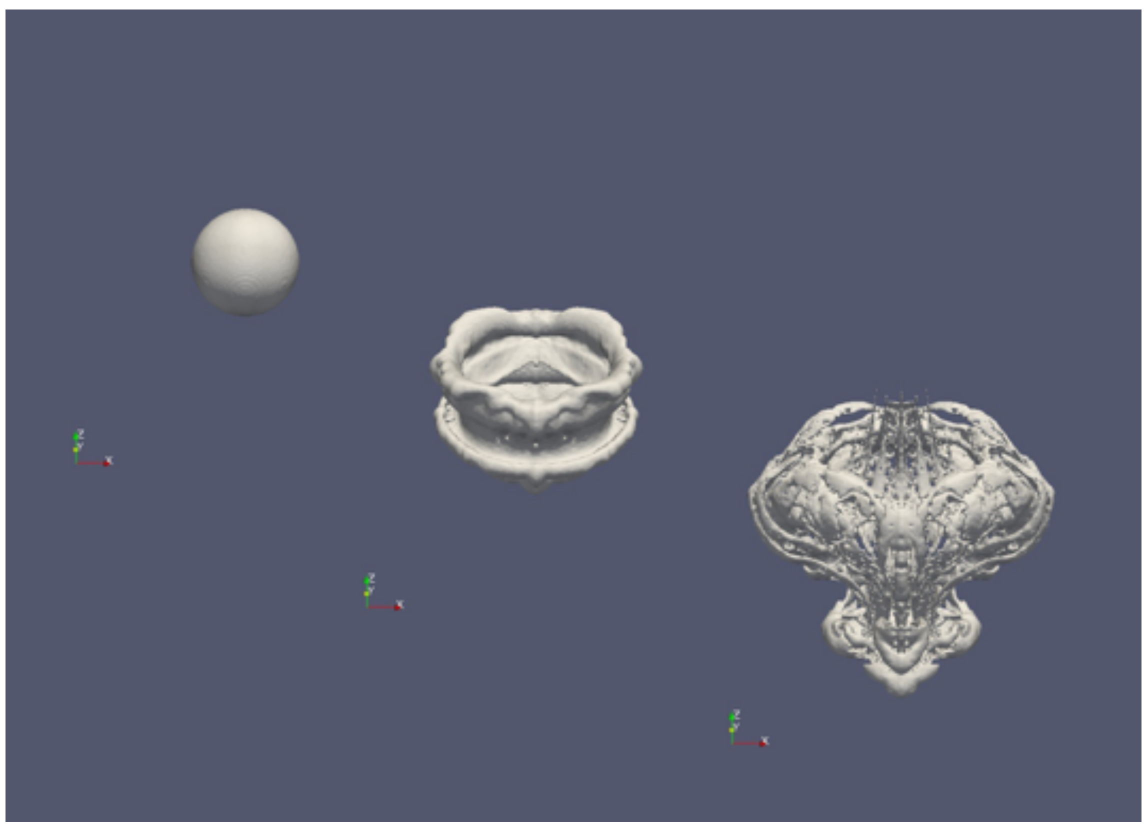


[Villermaux, 2007]
[Wacheul et al., 2014]

Modelling approach

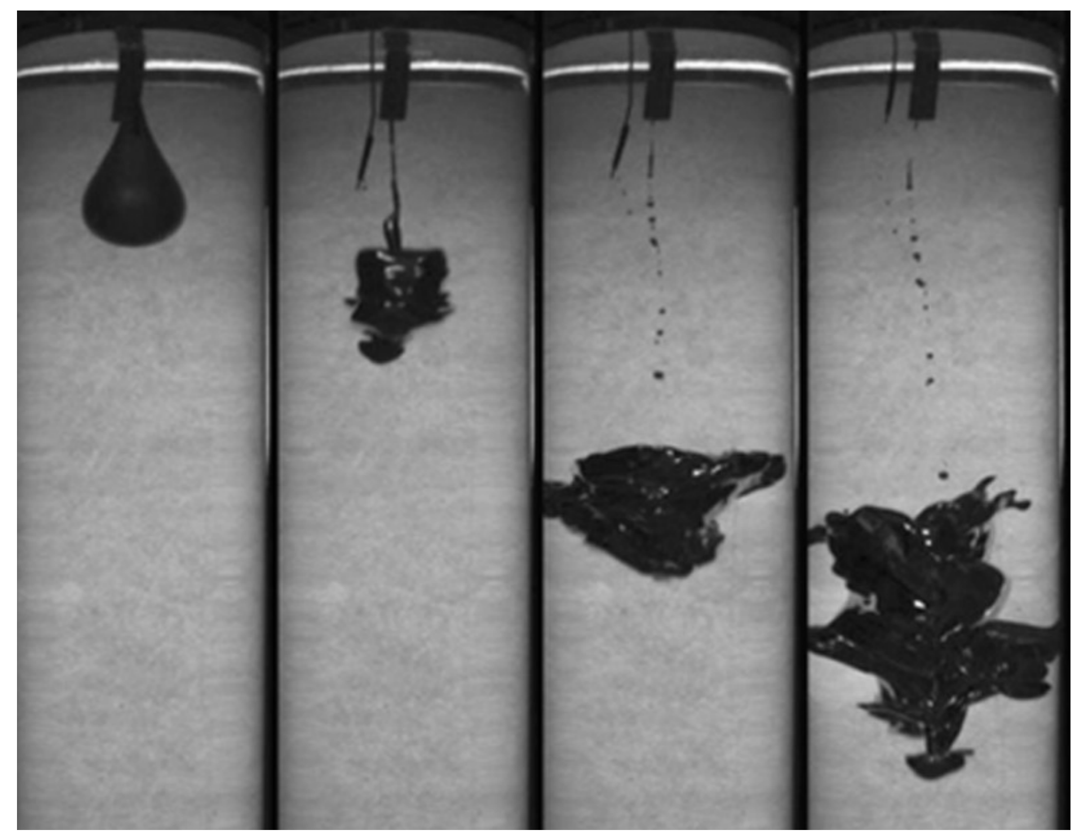
"A numerical experiment is something nobody believes, except the person who made it. A laboratory experiment is something everybody believes, except the person who made it."

Numerical experiments



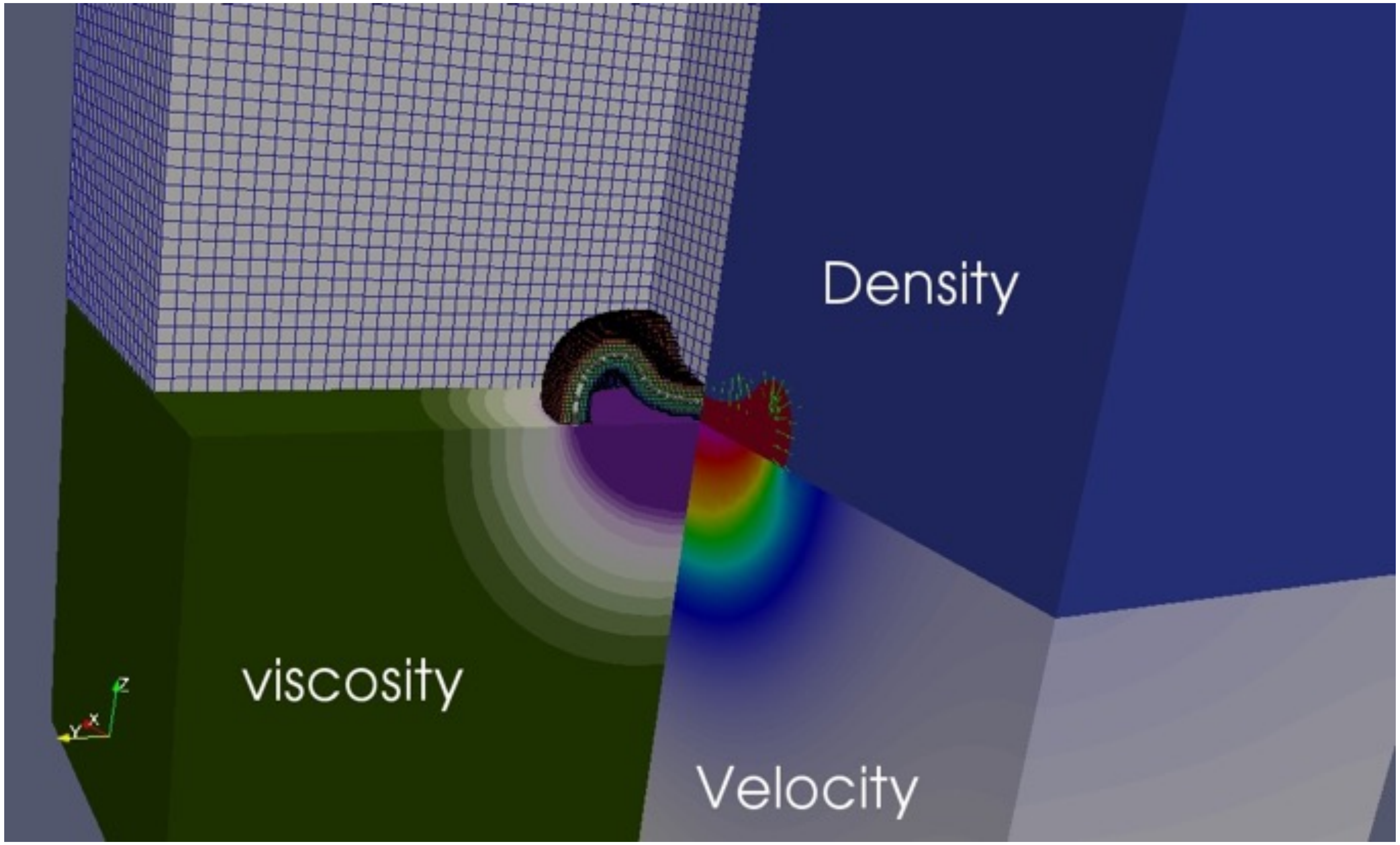
[Ichikawa et al., 2010]
[Samuel, 2012]

Analog/"Tank" experiments



[Villermaux, 2007]
[Wacheul et al., 2014]

3D Eulerian-Lagrangian Finite-Volume modeling



✓ Momentum & continuity: Implicit with exponential scheme / TVD RK explicit projection scheme with 3rd order WENO discretisation of non-linear advection terms

➪ Essentially monotone, efficient for both large and small Reynolds number values

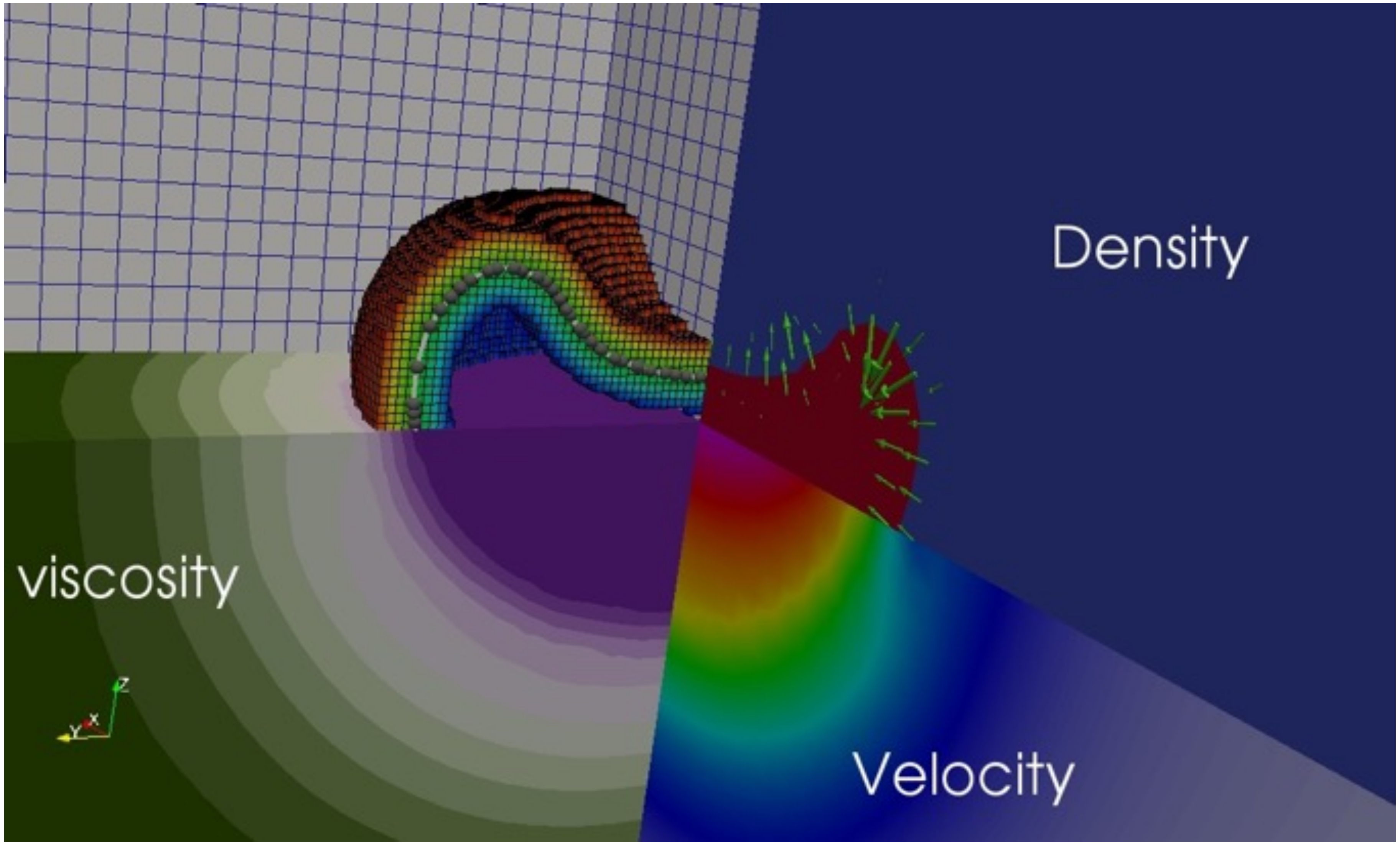
✓ Cons. composition: Particle-Marker two-way *[Samuel, 2014]* refined narrow-band Level-set

➪ Sub-grid-scale resolution with good mass preservation at all times (error < 1%)

➪ Surface tension accurately accounted for via a Continuum Surface Force Model

✓ Benchmarked against analytical and numerical solutions

3D Eulerian-Lagrangian Finite-Volume modeling



✓ Momentum & continuity: Implicit with exponential scheme / TVD RK explicit projection scheme with 3rd order WENO discretisation of non-linear advection terms

➪ Essentially monotone, efficient for both large and small Reynolds number values

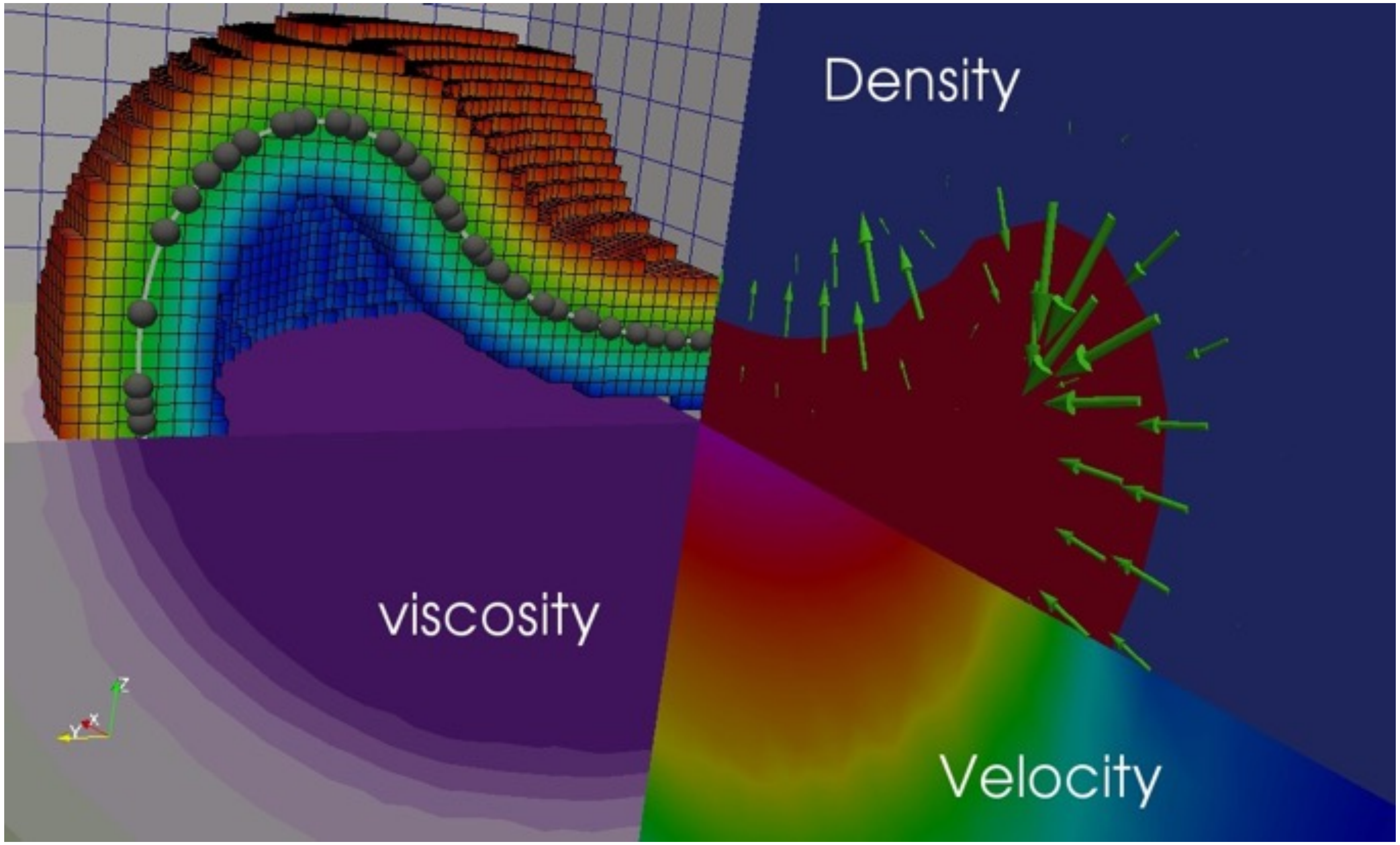
✓ Cons. composition: Particle-Marker two-way *[Samuel, 2014]* refined narrow-band Level-set

➪ Sub-grid-scale resolution with good mass preservation at all times (error < 1%)

➪ Surface tension accurately accounted for via a Continuum Surface Force Model

✓ Benchmarked against analytical and numerical solutions

3D Eulerian-Lagrangian Finite-Volume modeling



✓ Momentum & continuity: Implicit with exponential scheme / TVD RK explicit projection scheme with 3rd order WENO discretisation of non-linear advection terms

➪ Essentially monotone, efficient for both large and small Reynolds number values

✓ Cons. composition: Particle-Marker two-way *[Samuel, 2014]* refined narrow-band Level-set

➪ Sub-grid-scale resolution with good mass preservation at all times (error < 1%)

➪ Surface tension accurately accounted for via a Continuum Surface Force Model

✓ Benchmarked against analytical and numerical solutions

Parameter space

Re = Inertia / Viscous effects: $\frac{\rho_s V_\infty R}{\eta_s}$ **We** = Inertia / Surface tension: $\frac{\rho_s {V_\infty}^2 R}{\sigma}$

✓diapir radius, R= 10^{-3}-10^{5} m
✓silicate viscosity, η_s =10^{-4}-10^{14} Pa s

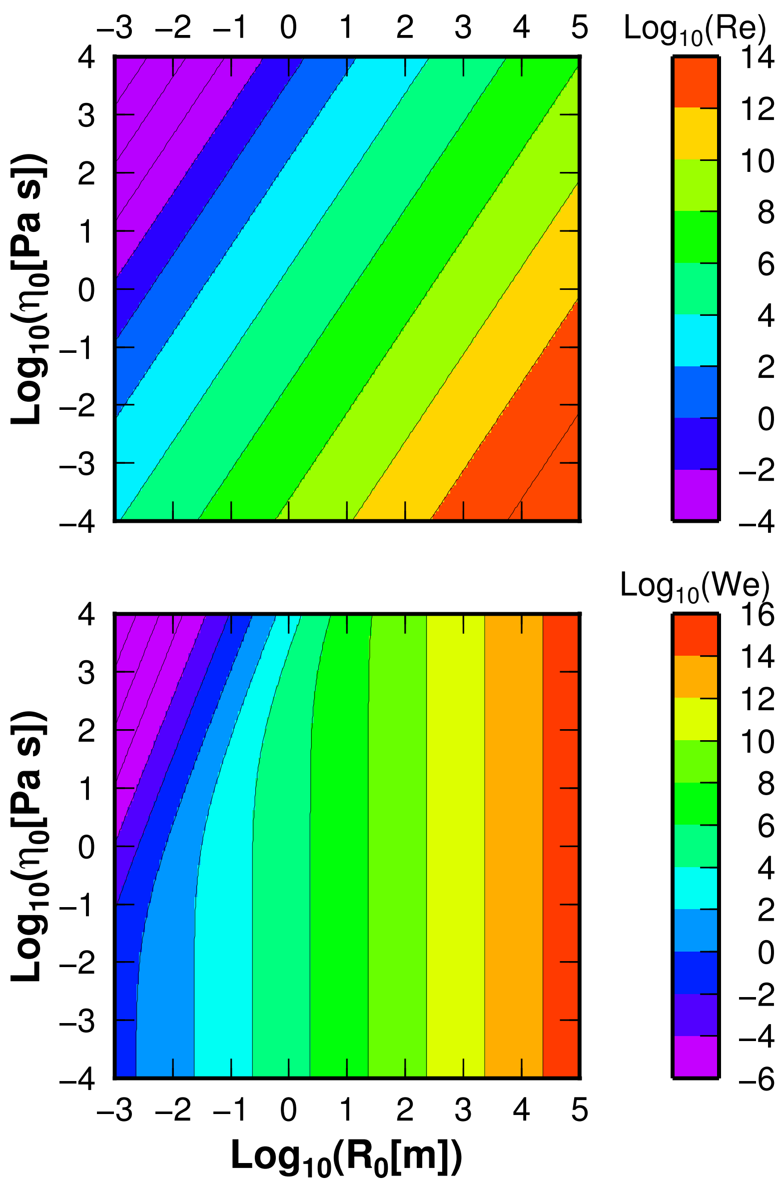
Parameter space

Re = Inertia / Viscous effects: $\dfrac{\rho_s V_\infty R}{\eta_s}$

We = Inertia / Surface tension: $\dfrac{\rho_s {V_\infty}^2 R}{\sigma}$

✓diapir radius, $R = 10^{-3}$-10^{5} m
✓silicate viscosity, $\eta_s = 10^{-4}$-10^{14} Pa s

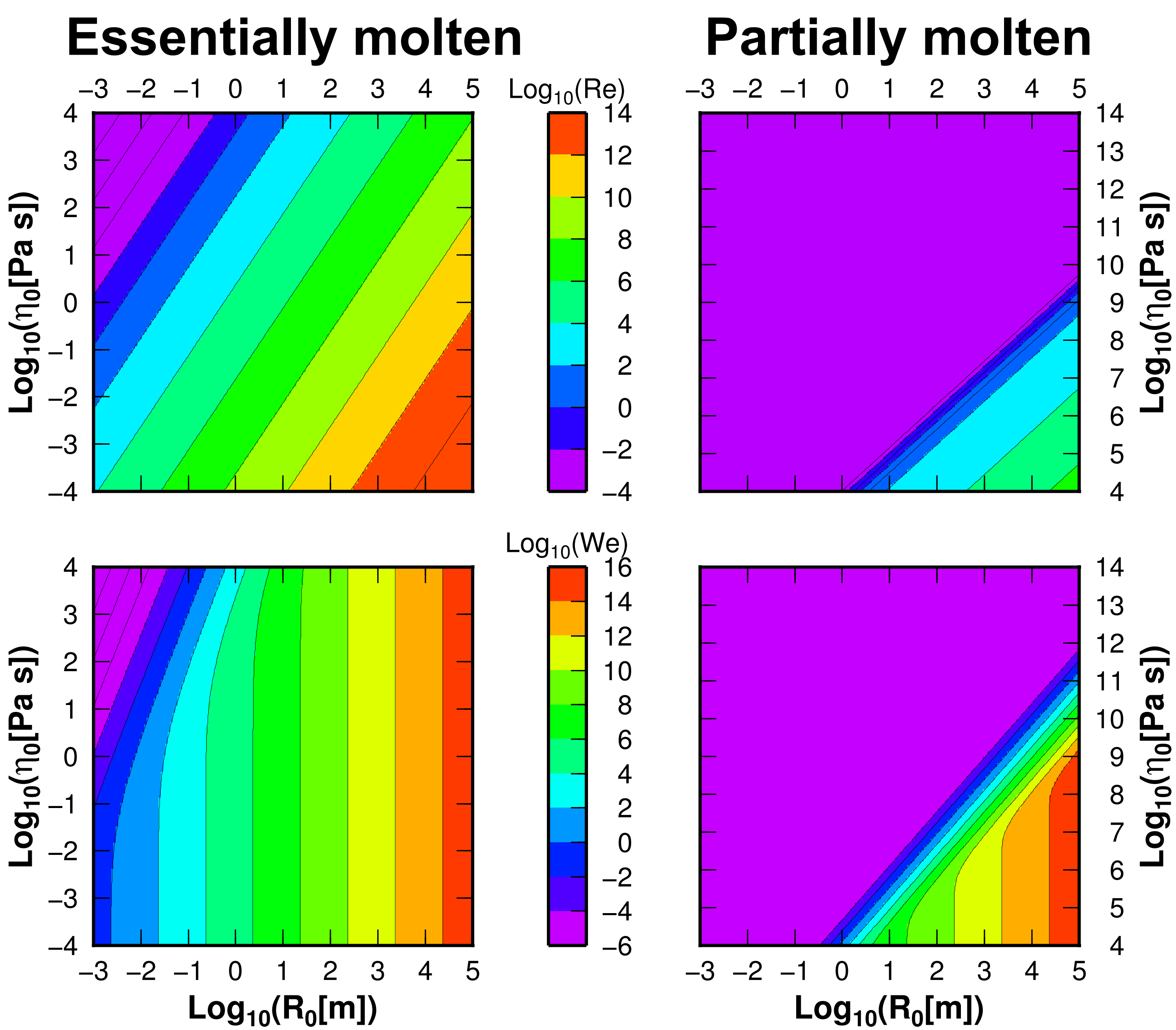
Essentially molten



Parameter space

Re = Inertia / Viscous effects: $\dfrac{\rho_s V_\infty R}{\eta_s}$ **We** = Inertia / Surface tension: $\dfrac{\rho_s {V_\infty}^2 R}{\sigma}$

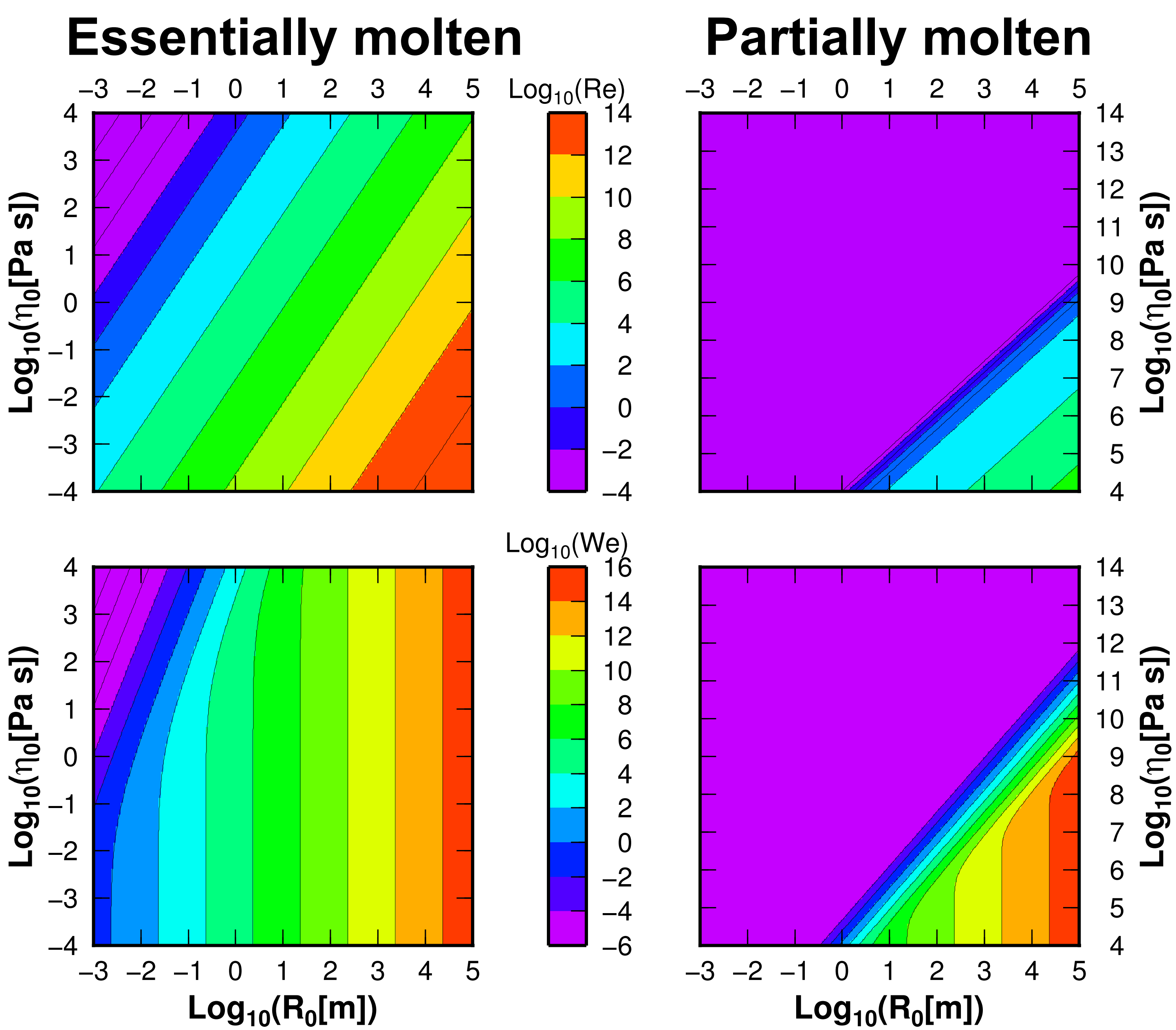
✓diapir radius, R= 10^{-3}-10^{5} m
✓silicate viscosity, η_s =10^{-4}-10^{14} Pa s



Parameter space

Re = Inertia / Viscous effects: $\dfrac{\rho_s V_\infty R}{\eta_s}$ **We** = Inertia / Surface tension: $\dfrac{\rho_s {V_\infty}^2 R}{\sigma}$

✓diapir radius, R= 10^{-3}-10^{5} m
✓silicate viscosity, η_s =10^{-4}-10^{14} Pa s

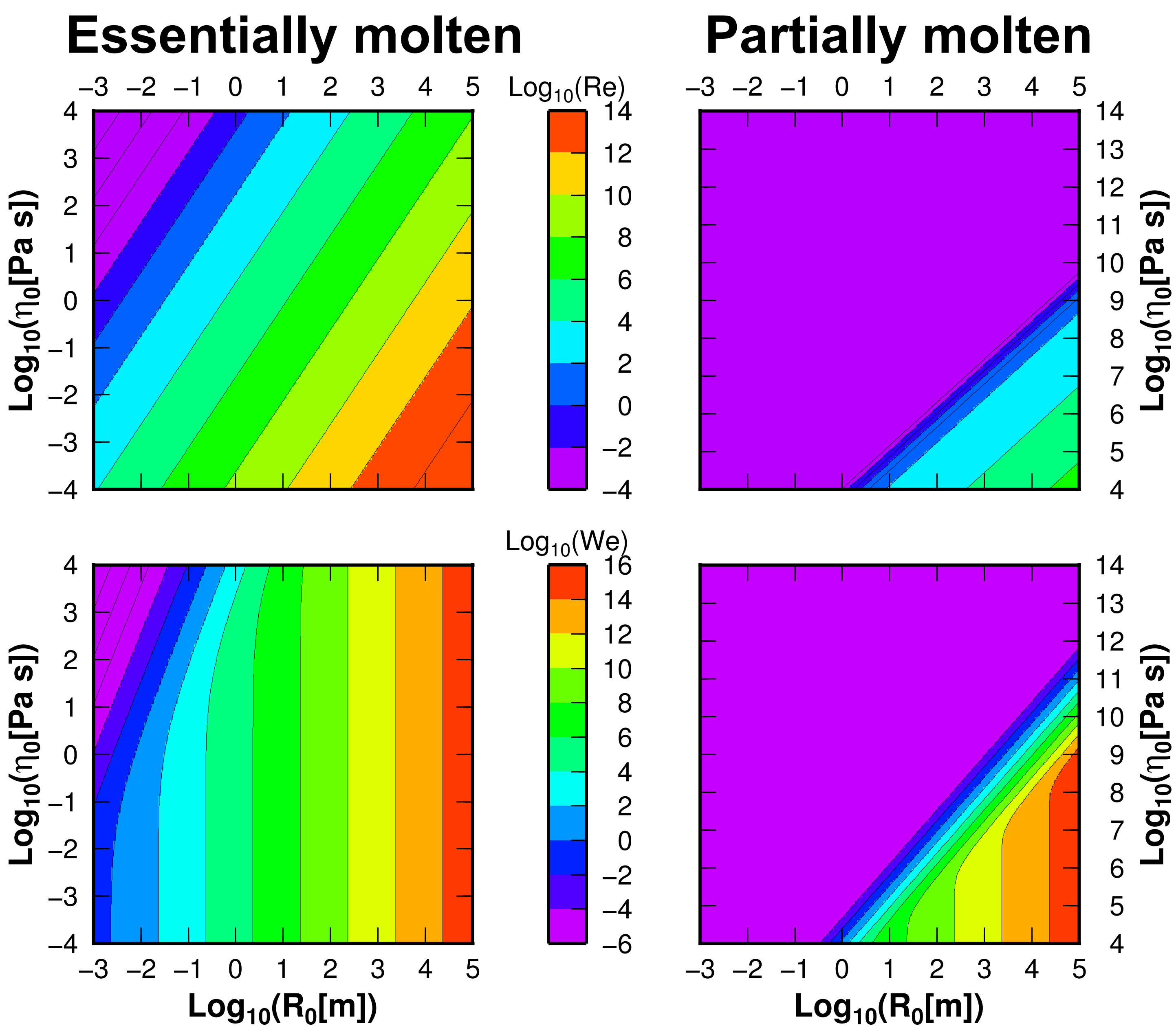


Large Plausible range of rheology and diapir sizes
Re = [10^{-97}-10^{16}]
We = [10^{-100}-10^{15}]
➪Huge parameter space

Parameter space

Re = Inertia / Viscous effects: $\dfrac{\rho_s V_\infty R}{\eta_s}$ **We** = Inertia / Surface tension: $\dfrac{\rho_s {V_\infty}^2 R}{\sigma}$

✓diapir radius, R= 10^{-3}-10^{5} m
✓silicate viscosity, η_s =10^{-4}-10^{14} Pa s



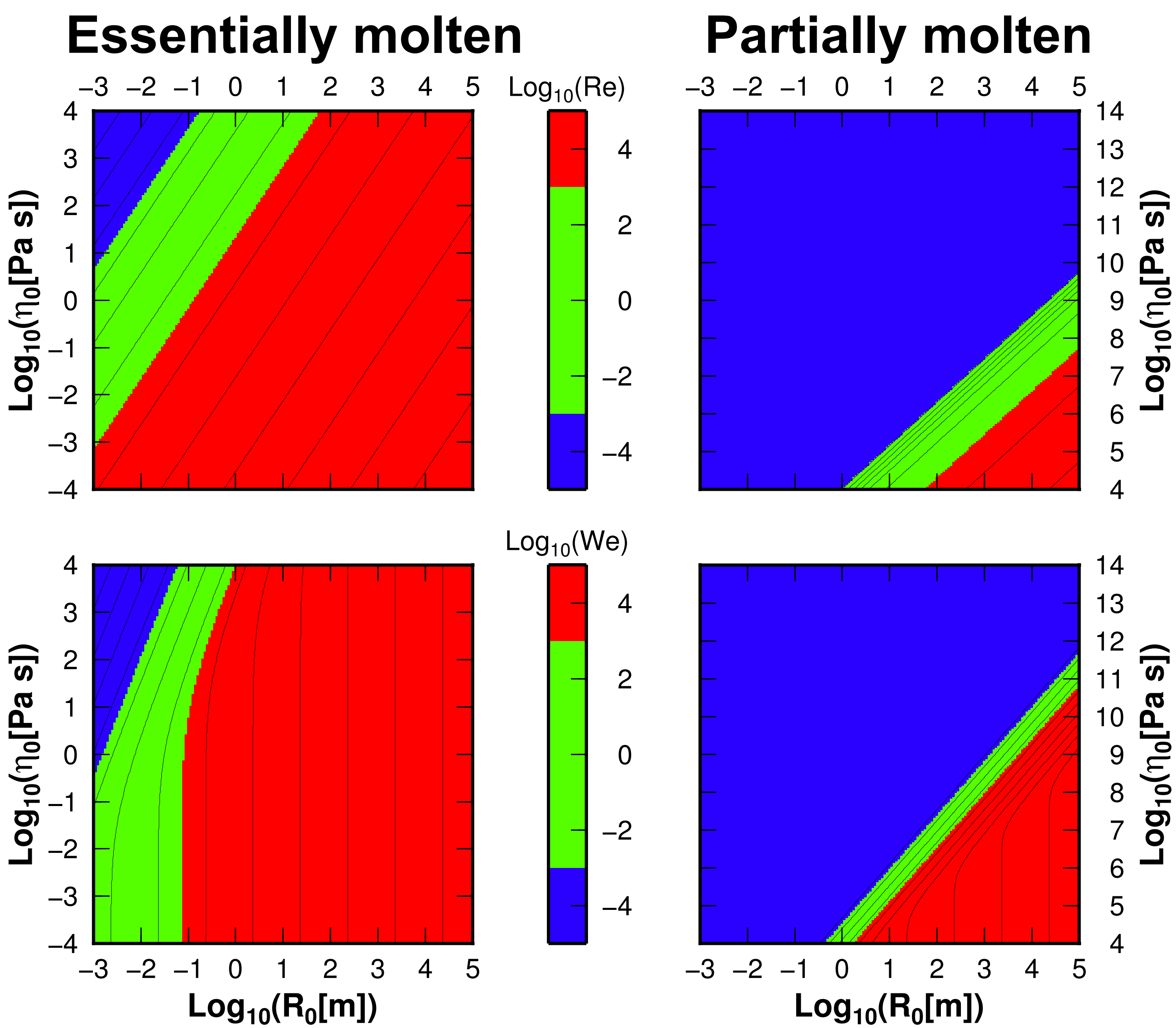
Large Plausible range of rheology and diapir sizes
Re = [10^{-97}-10^{16}]
We = [10^{-100}-10^{15}]
⇨Huge parameter space

Large, small and intermediate values must be considered

Parameter space

Re = Inertia / Viscous effects: $\dfrac{\rho_s V_\infty R}{\eta_s}$ **We** = Inertia / Surface tension: $\dfrac{\rho_s {V_\infty}^2 R}{\sigma}$

✓diapir radius, R= 10^{-3}-10^{5} m
✓silicate viscosity, η_s =10^{-4}-10^{14} Pa s



Large Plausible range of rheology and diapir sizes
Re = [10^{-97}-10^{16}]
We = [10^{-100}-10^{15}]
➪Huge parameter space

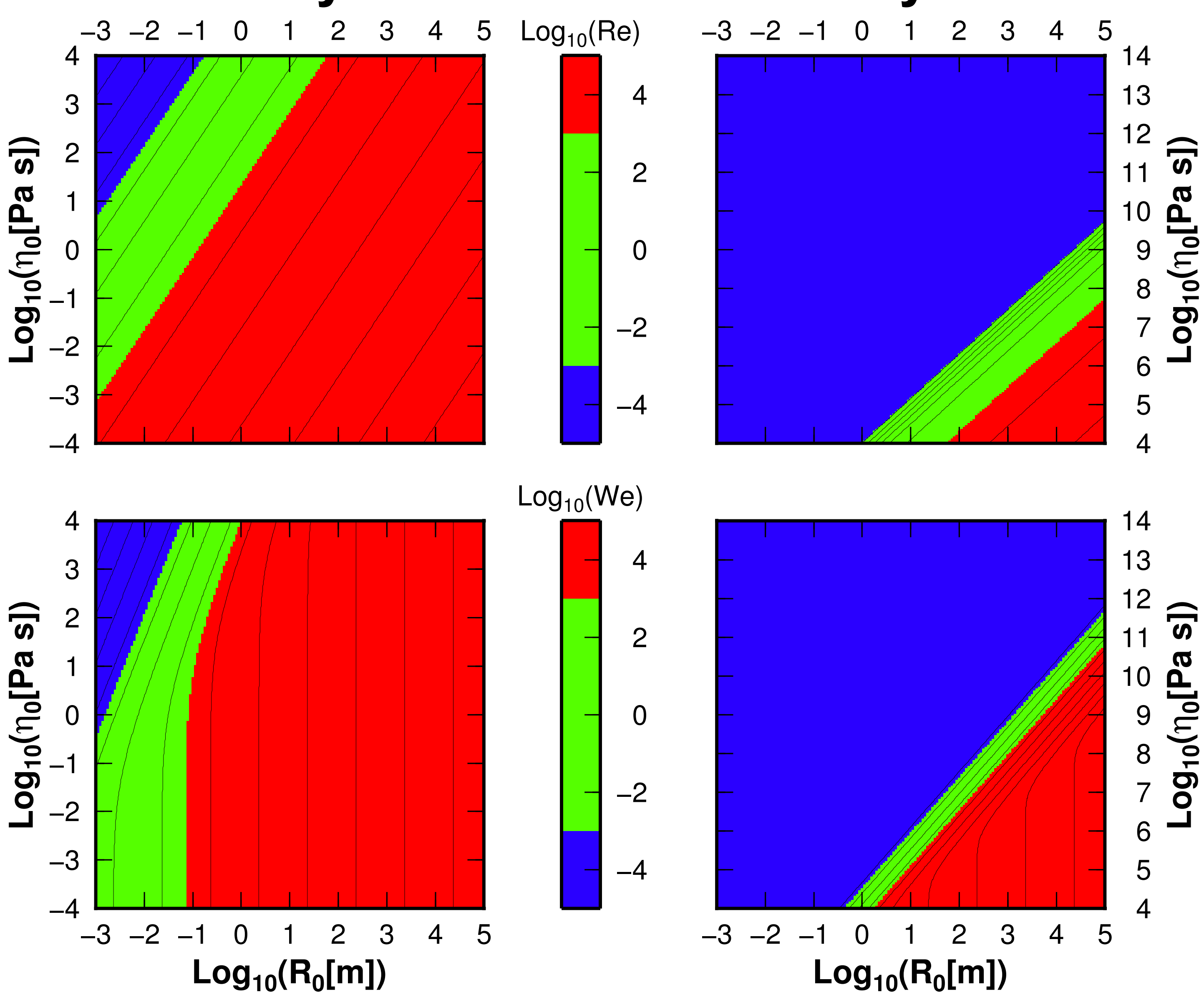
Large, **small** and **intermediate** values must be considered

Parameter space

Re = Inertia / Viscous effects: $\dfrac{\rho_s V_\infty R}{\eta_s}$ **We** = Inertia / Surface tension: $\dfrac{\rho_s {V_\infty}^2 R}{\sigma}$

✓diapir radius, R= 10^{-3}-10^{5} m
✓silicate viscosity, η_s =10^{-4}-10^{14} Pa s

Essentially molten **Partially molten**



Large Plausible range of rheology and diapir sizes
Re = [10^{-97}-10^{16}]
We = [10^{-100}-10^{15}]
➪Huge parameter space

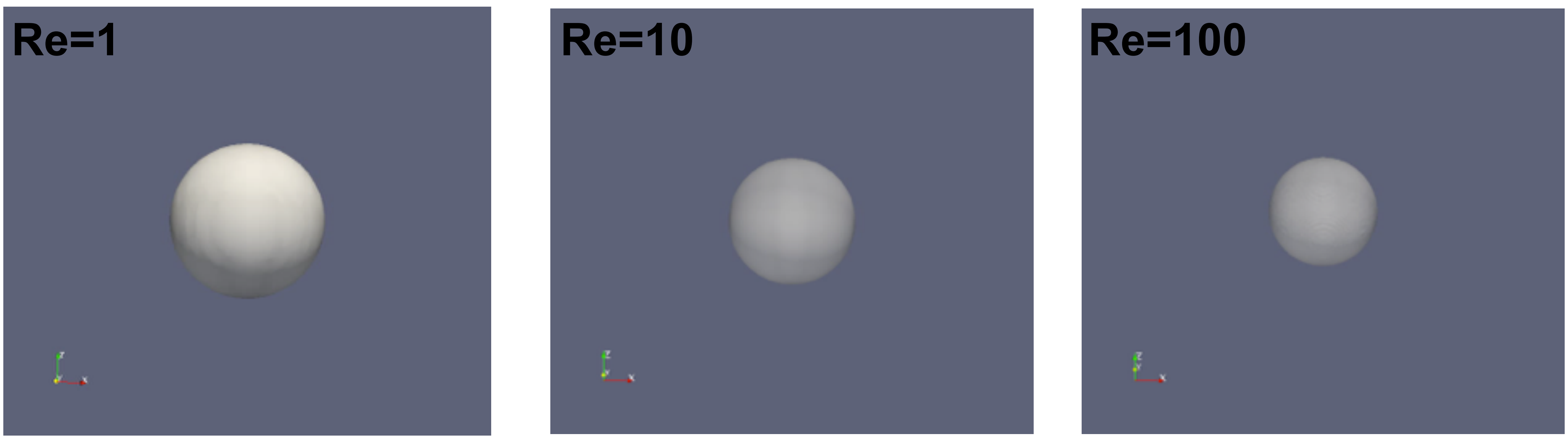
Large, small and intermediate values must be considered

Systematic exploration for (Re,We)=[10^{-3}-10^{3}] and beyond:
➪ ~200+ experiments

Influence of inertia vs. viscous effects (Re)

We→∞ (no surface tension)

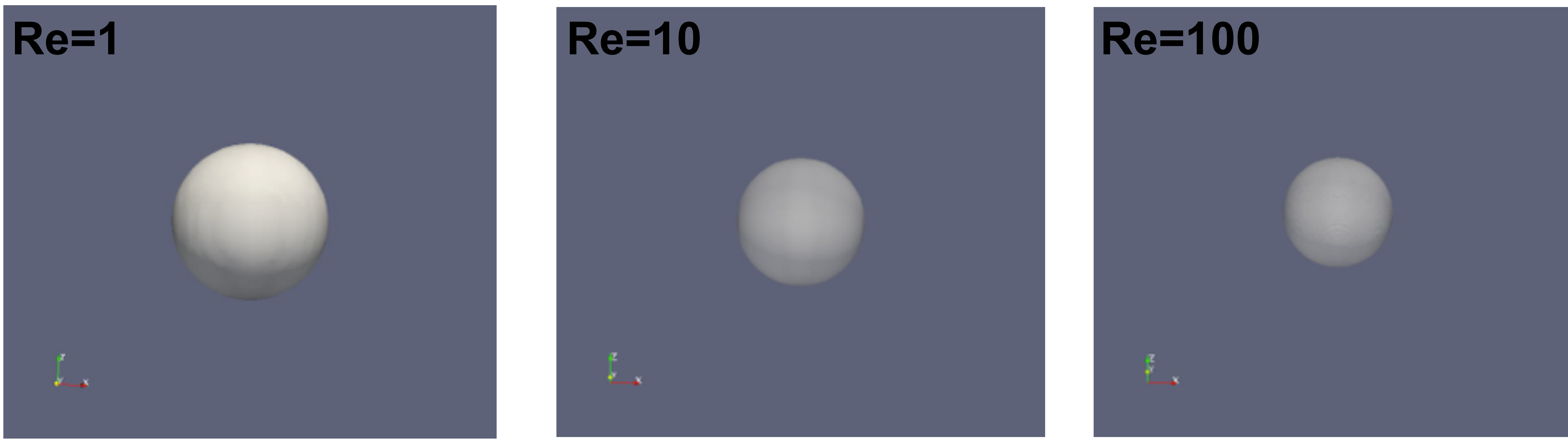
Re = Inertia / Viscous effects: $\frac{\rho_s V_\infty R}{\eta_s}$



Influence of inertia vs. viscous effects (Re)

We$\rightarrow\infty$ *(no surface tension)*

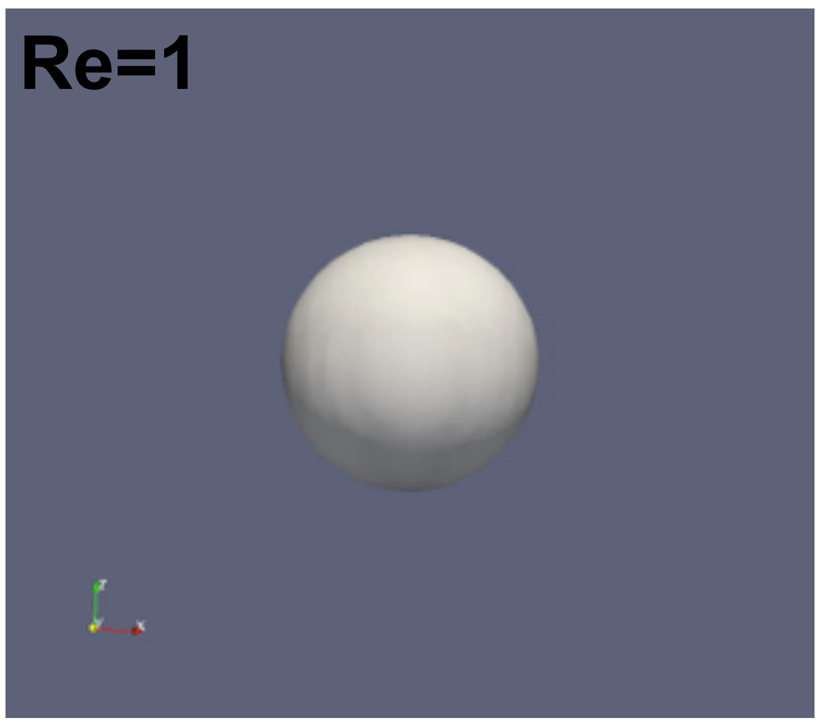
Re = Inertia / Viscous effects: $\frac{\rho_s V_\infty R}{\eta_s}$

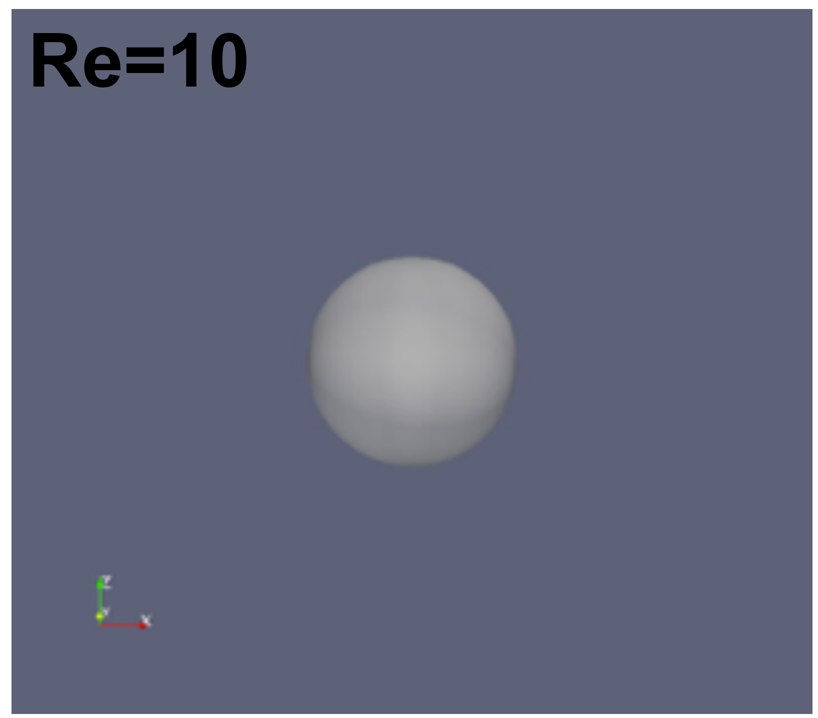


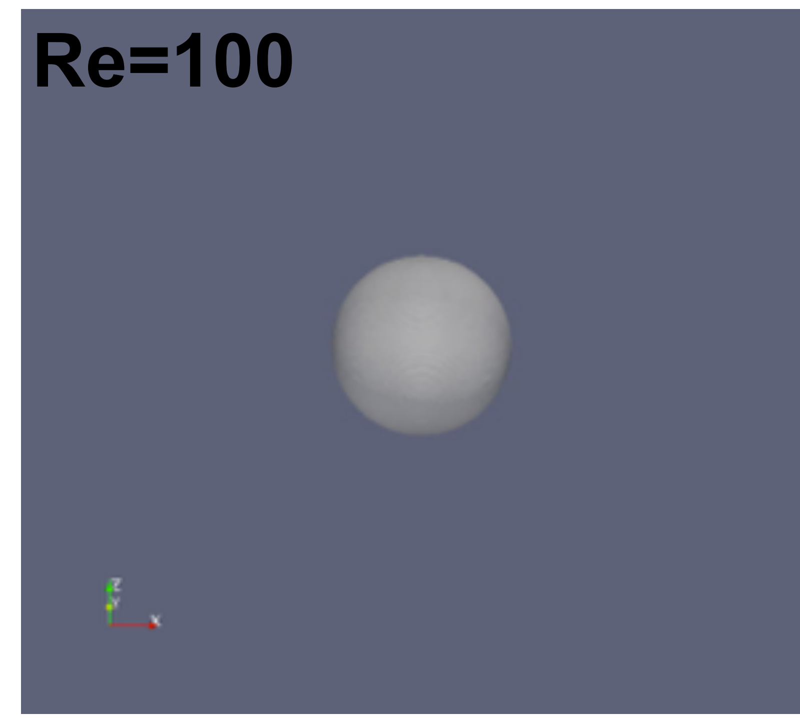
Influence of inertia vs. viscous effects (Re)

We$\rightarrow\infty$ *(no surface tension)*

Re = Inertia / Viscous effects: $\dfrac{\rho_s V_\infty R}{\eta_s}$



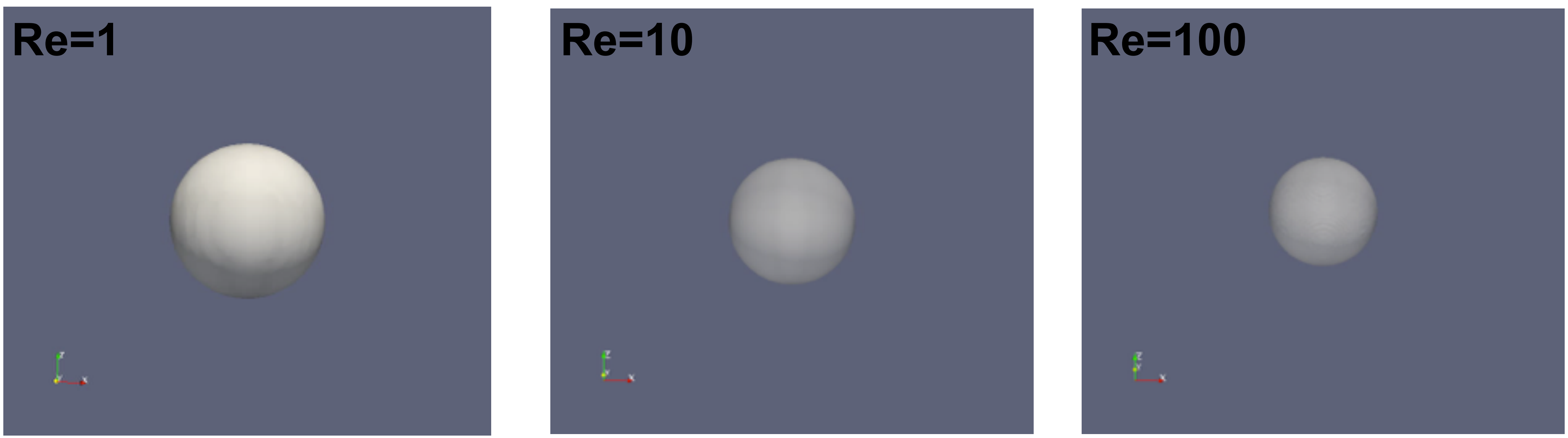




Influence of inertia vs. viscous effects (Re)

$We \rightarrow \infty$ *(no surface tension)*

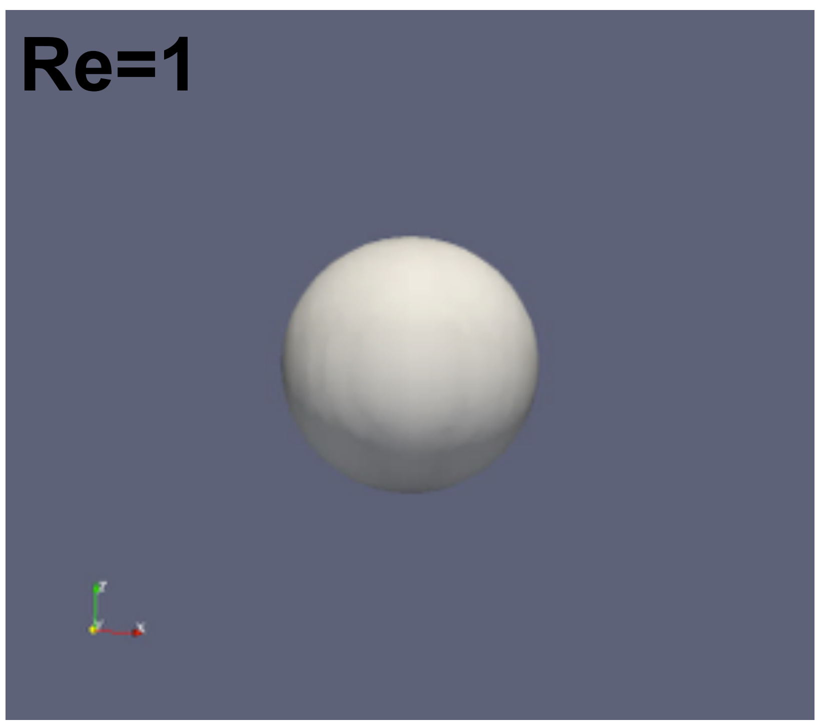
Re = Inertia / Viscous effects: $\dfrac{\rho_s V_\infty R}{\eta_s}$

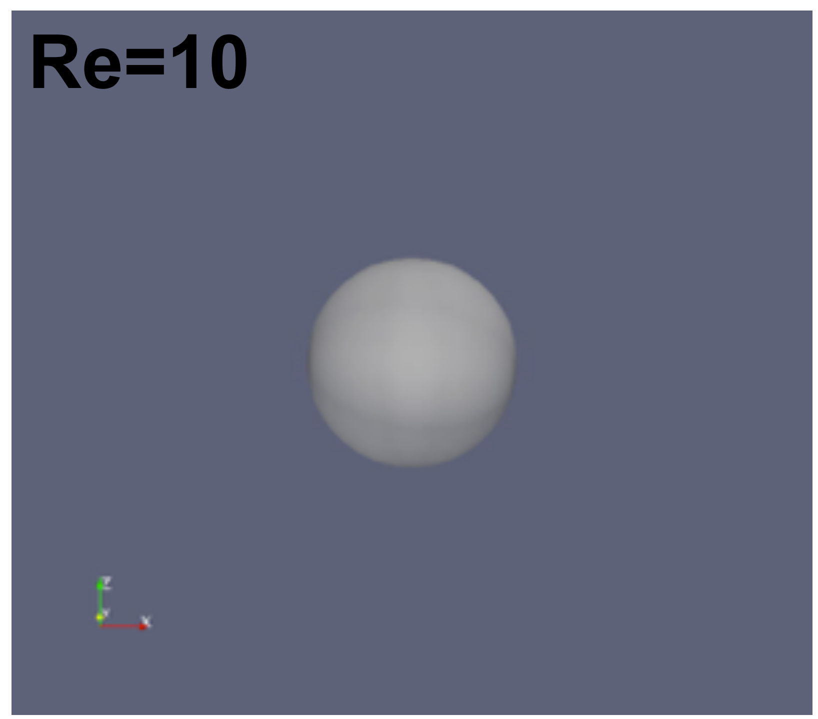


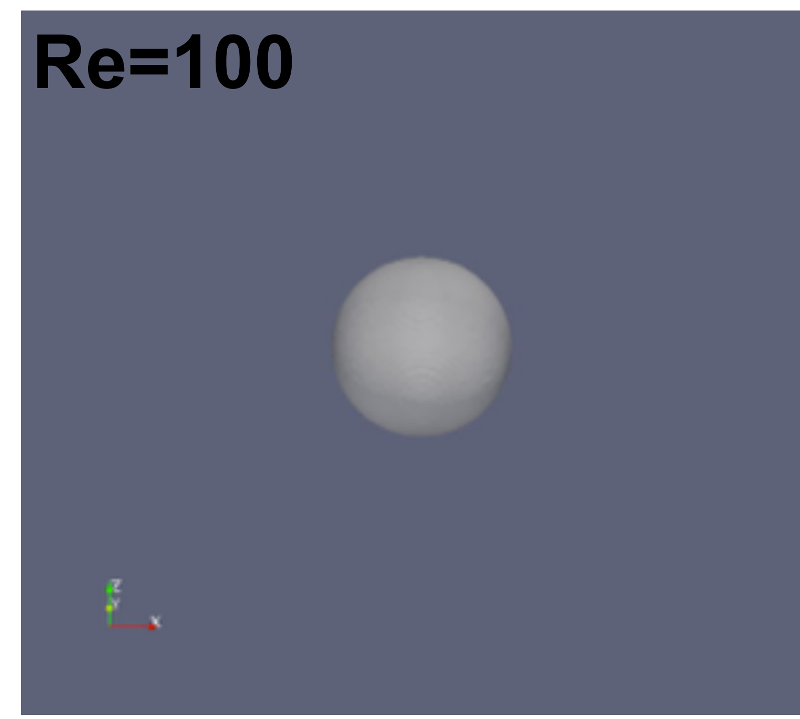
Influence of inertia vs. viscous effects (Re)

We$\rightarrow\infty$ *(no surface tension)*

Re = Inertia / Viscous effects: $\dfrac{\rho_s V_\infty R}{\eta_s}$

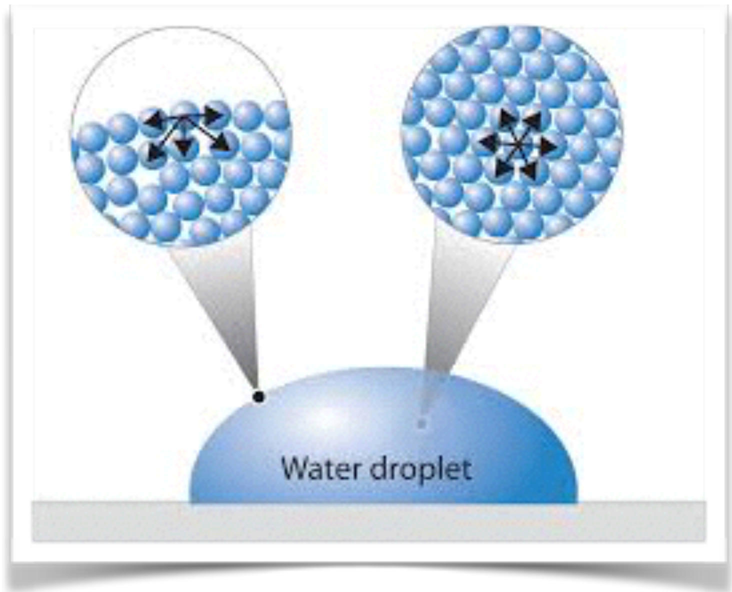




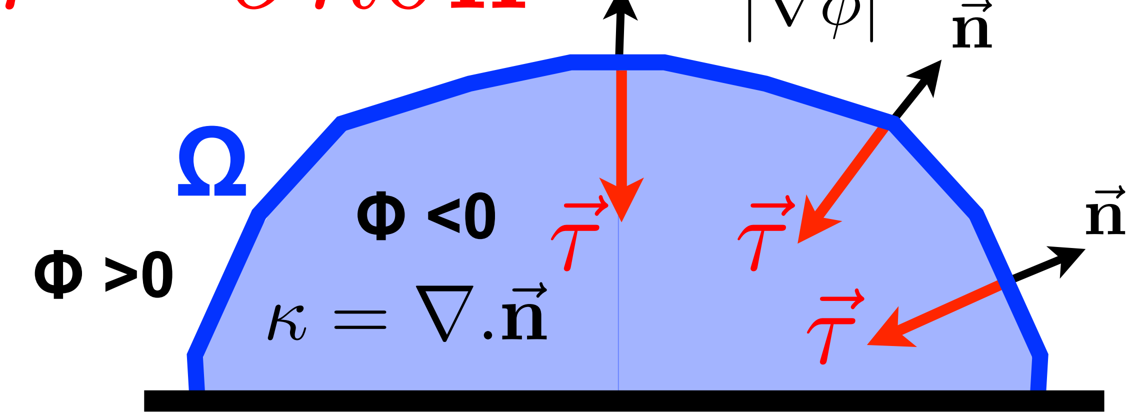


Large Re (small viscous effects) favour breakup
Post-breakup diapir sizes decrease with increasing Re

Influence of surface tension (We)

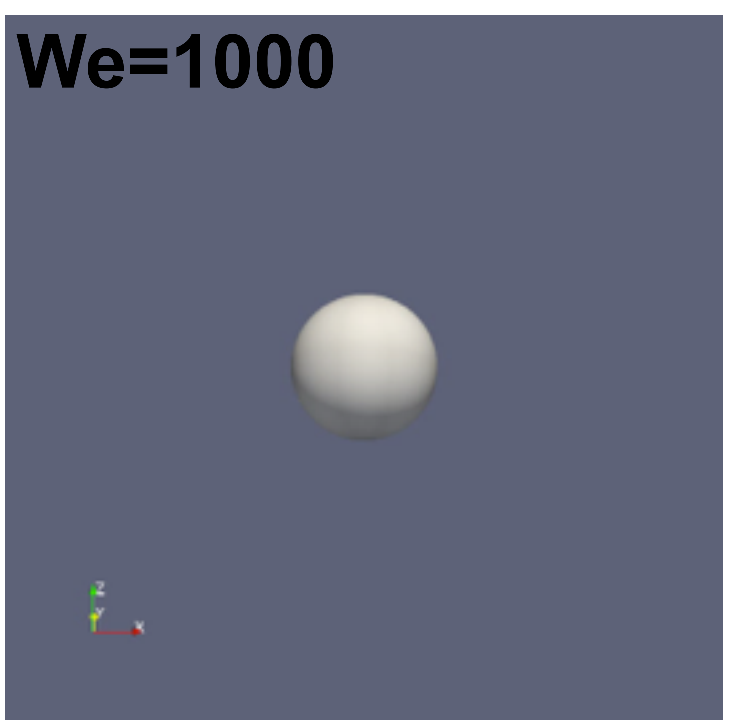


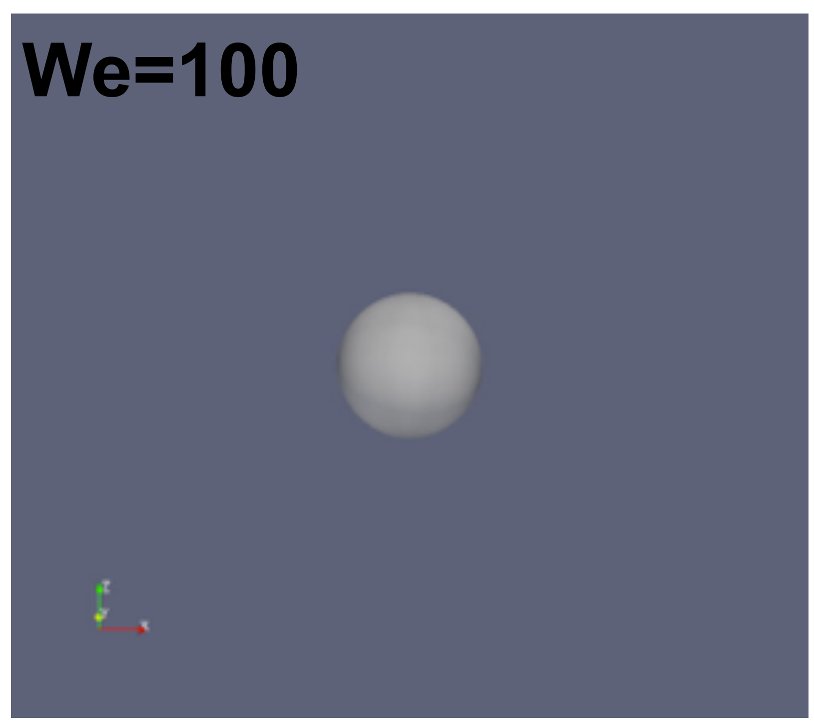
$$\vec{\tau} = \sigma \kappa \delta \vec{\mathbf{n}} \qquad \vec{\mathbf{n}} = \frac{\nabla \phi}{|\nabla \phi|}$$

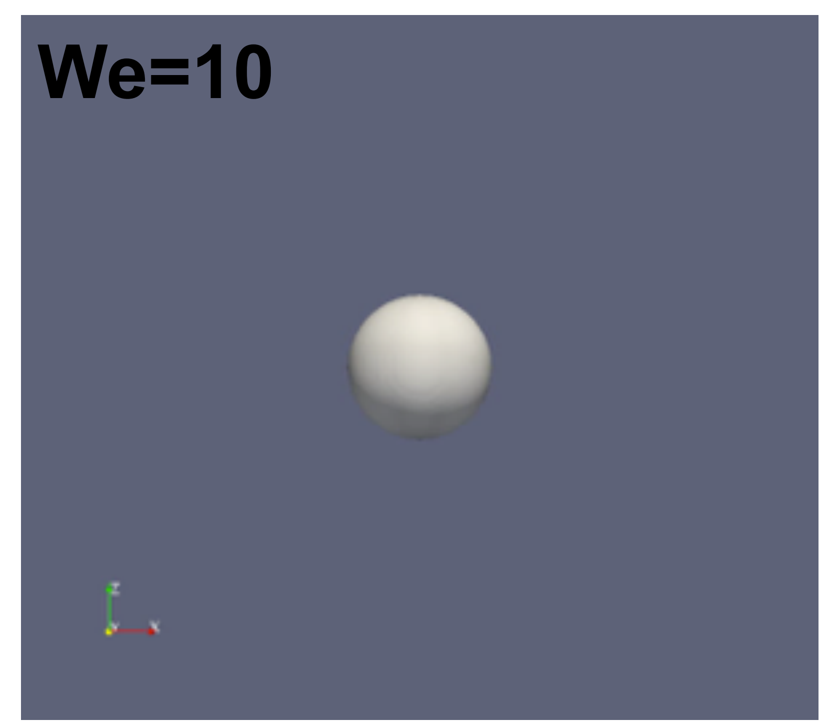


We = Inertia / Surface tension: $\dfrac{\rho_s {V_\infty}^2 R}{\sigma}$

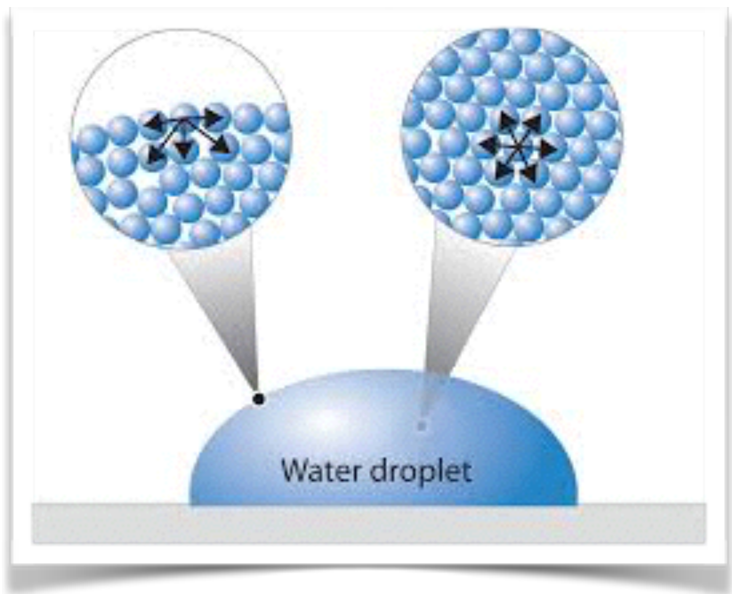
Re=100

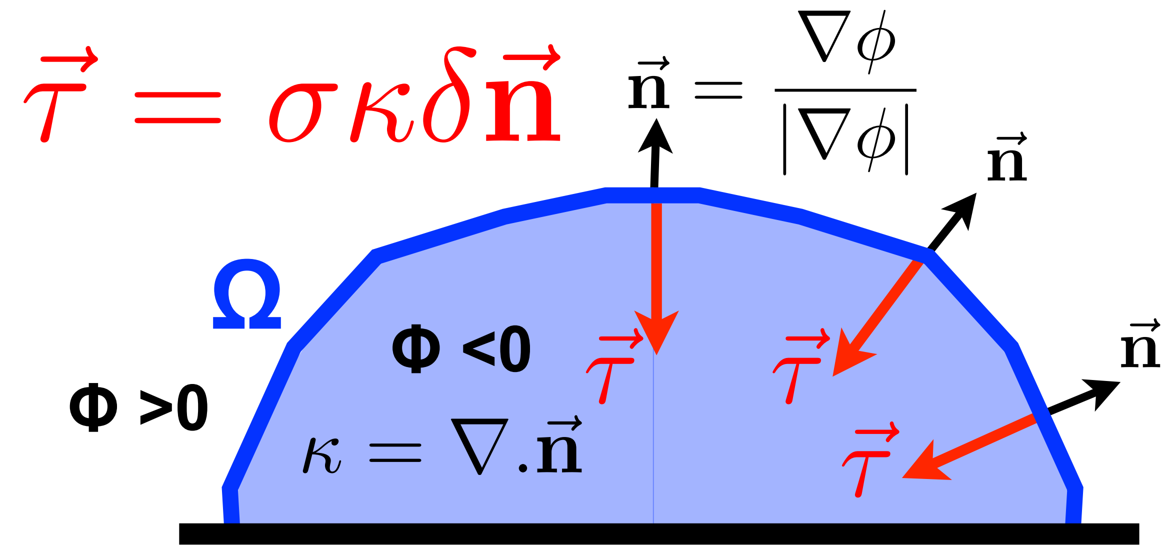






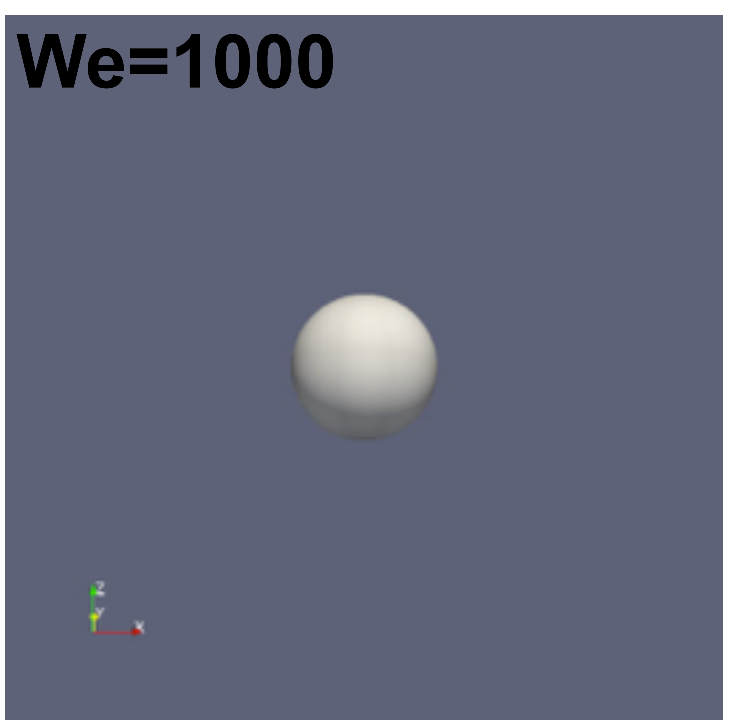
Influence of surface tension (We)

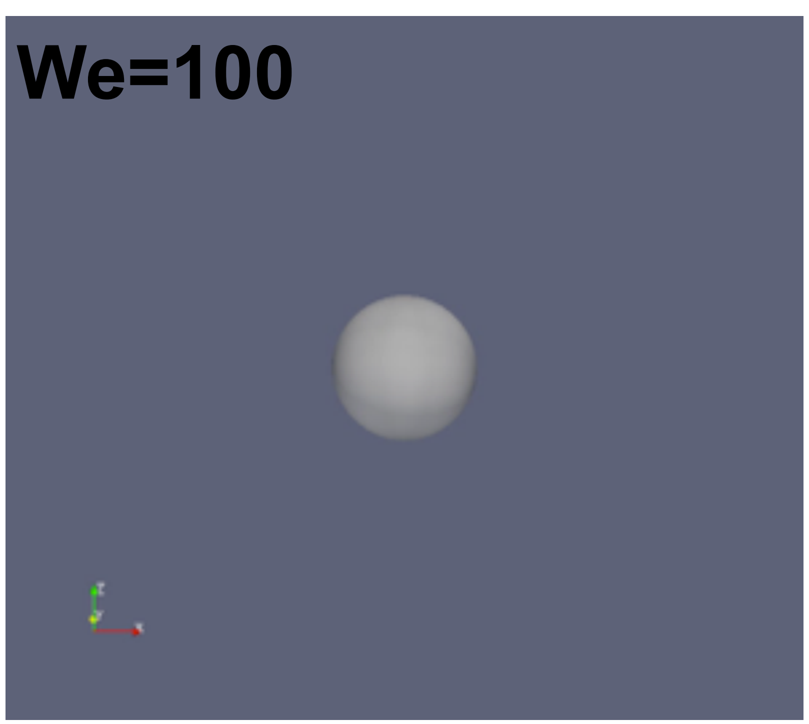


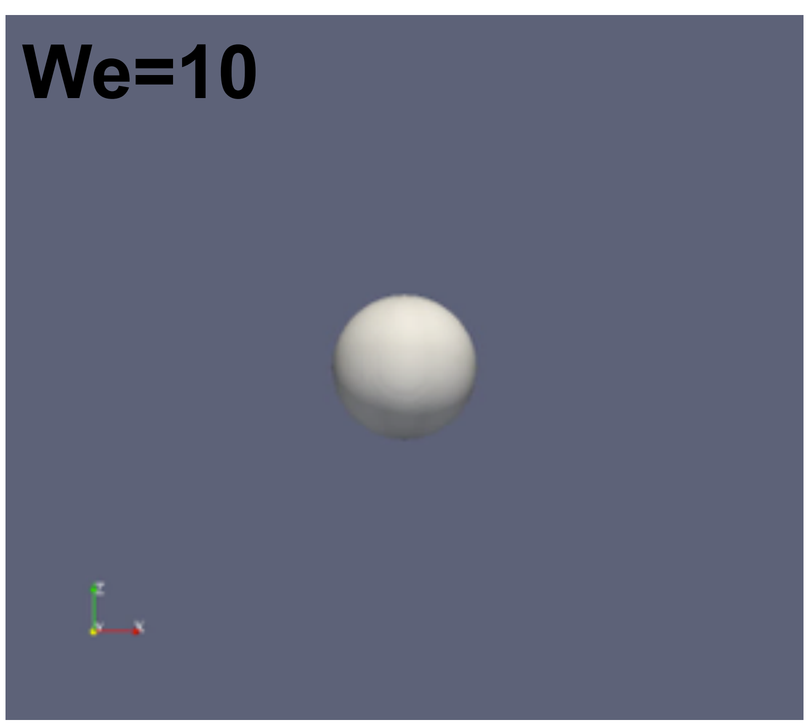


We = Inertia / Surface tension: $\frac{\rho_s {V_\infty}^2 R}{\sigma}$

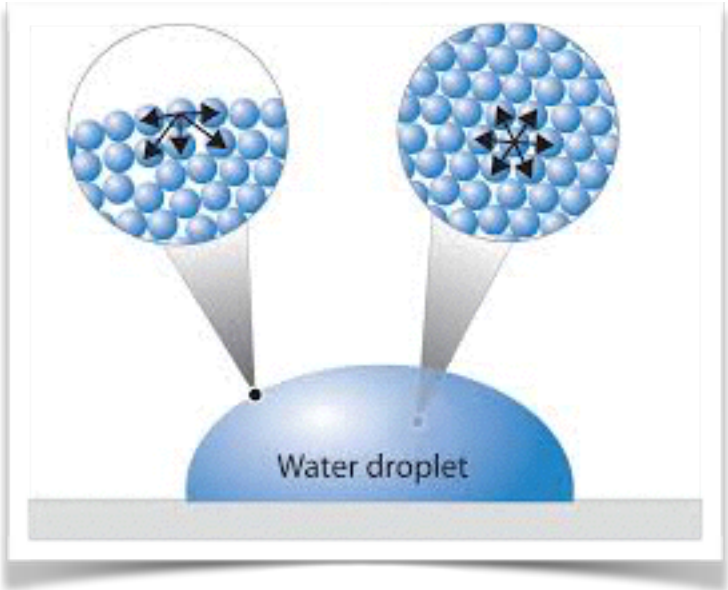
Re=100

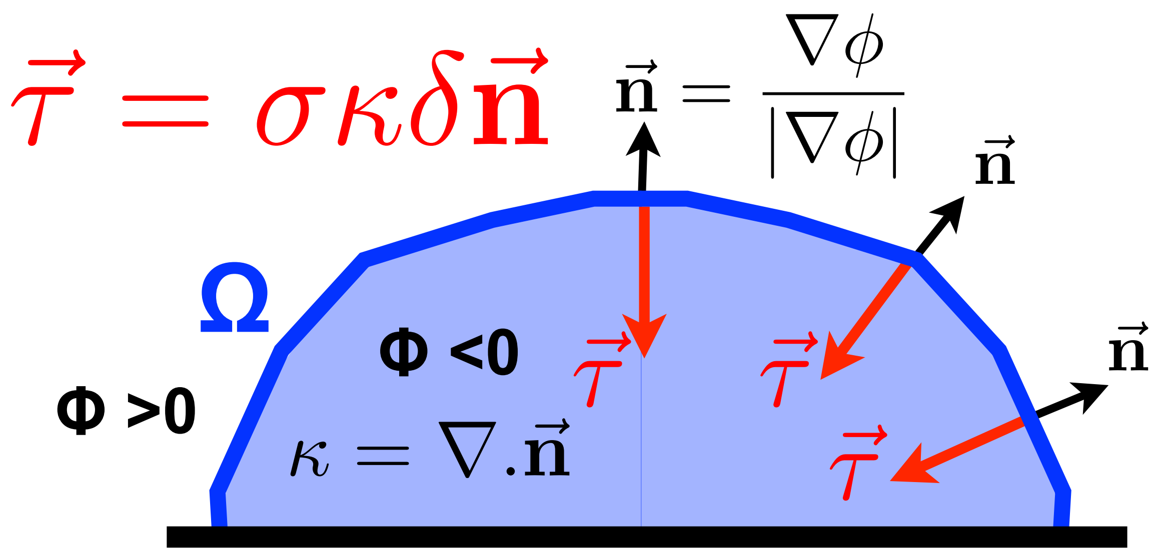






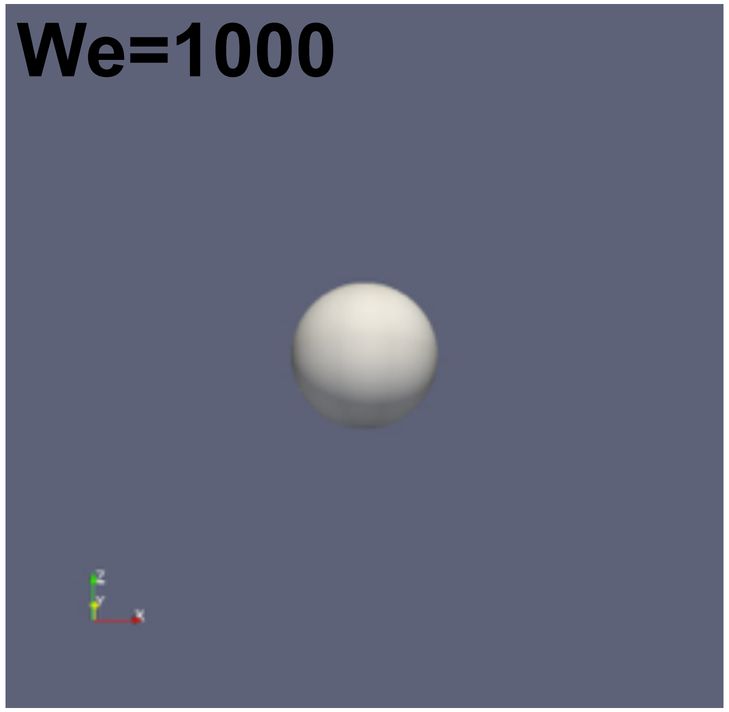
Influence of surface tension (We)

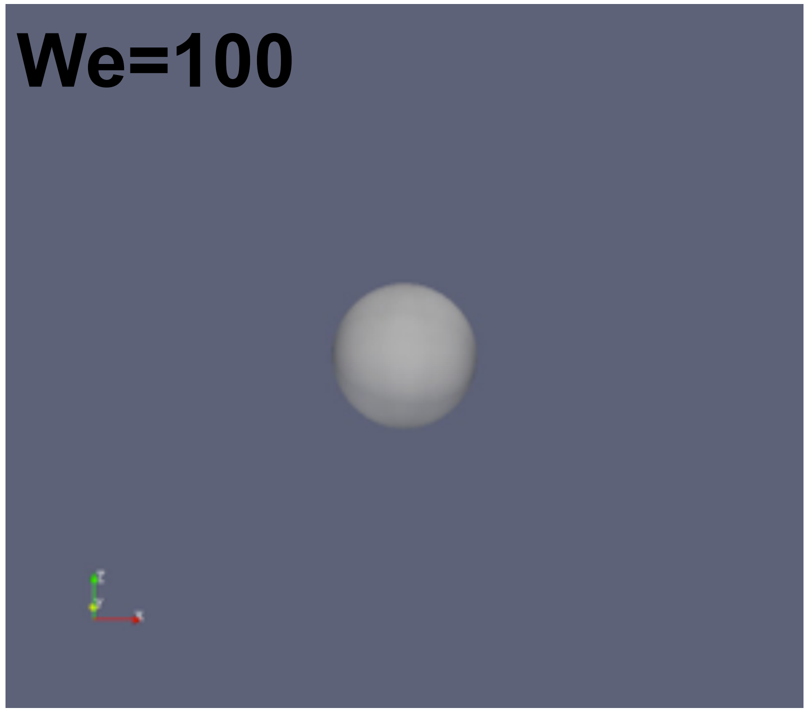


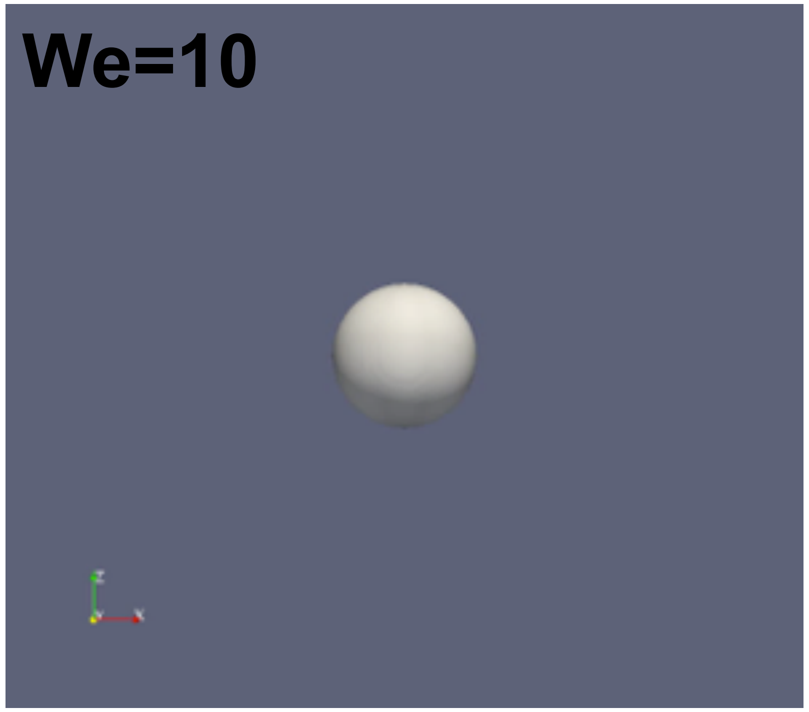


We = Inertia / Surface tension: $\frac{\rho_s {V_\infty}^2 R}{\sigma}$

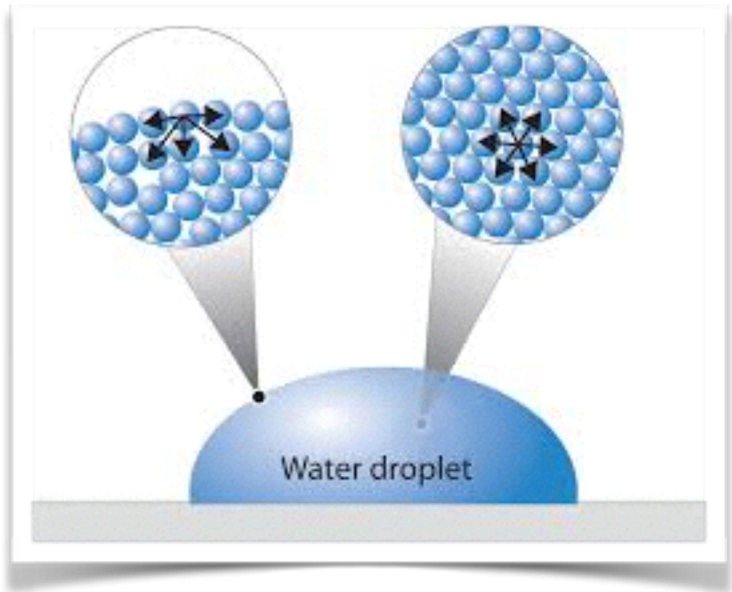
Re=100

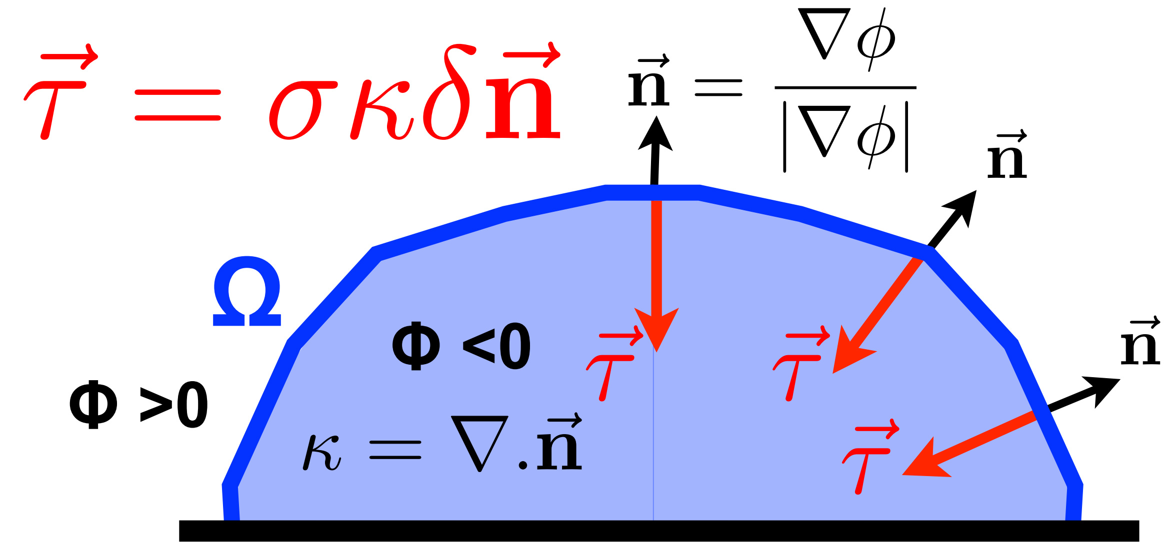






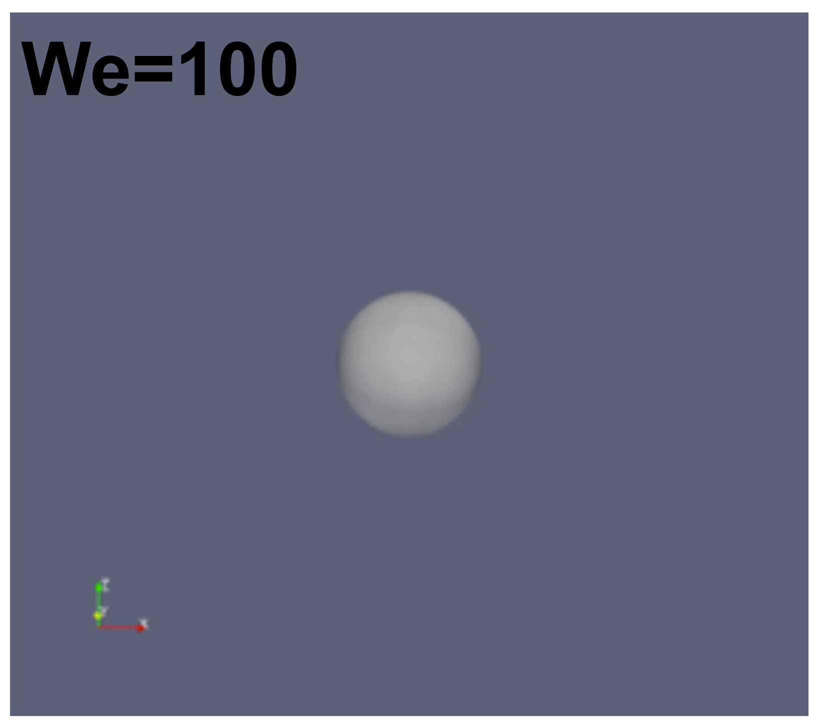
Influence of surface tension (We)

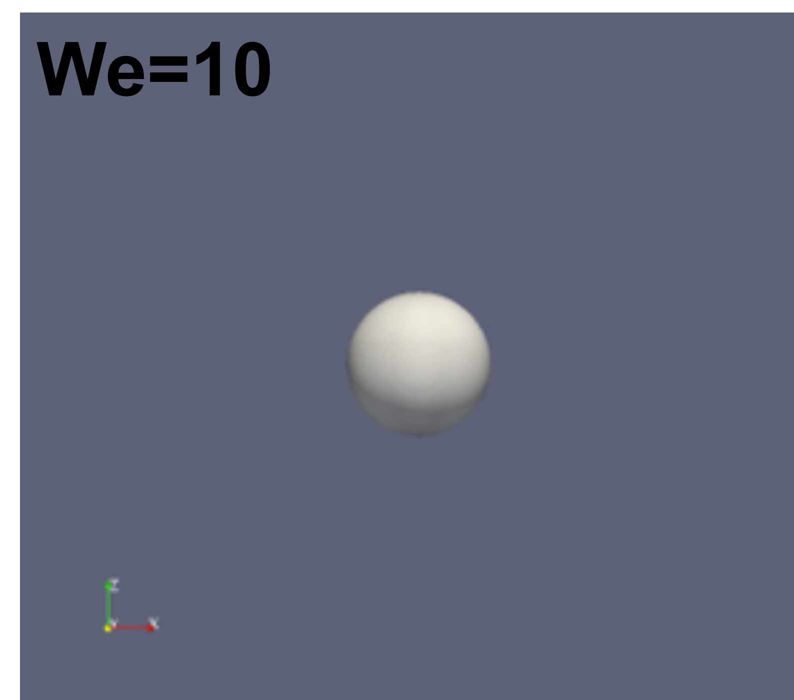




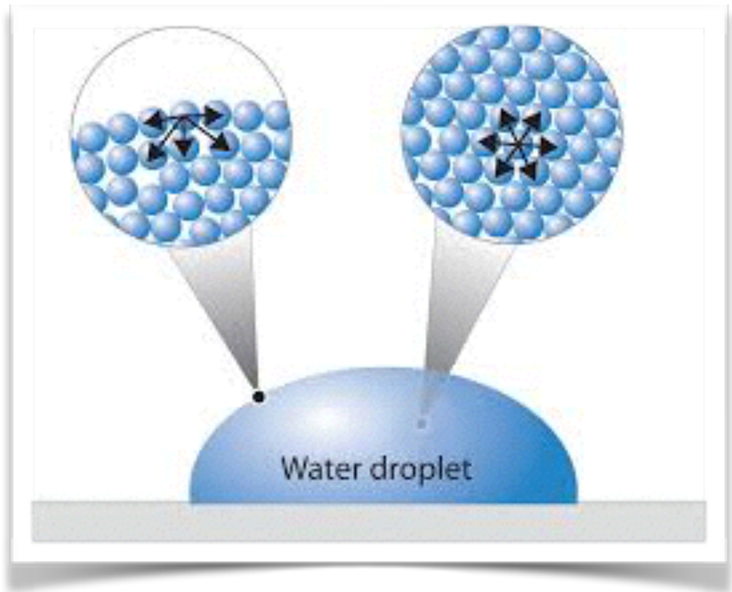
We = Inertia / Surface tension: $\frac{\rho_s {V_\infty}^2 R}{\sigma}$

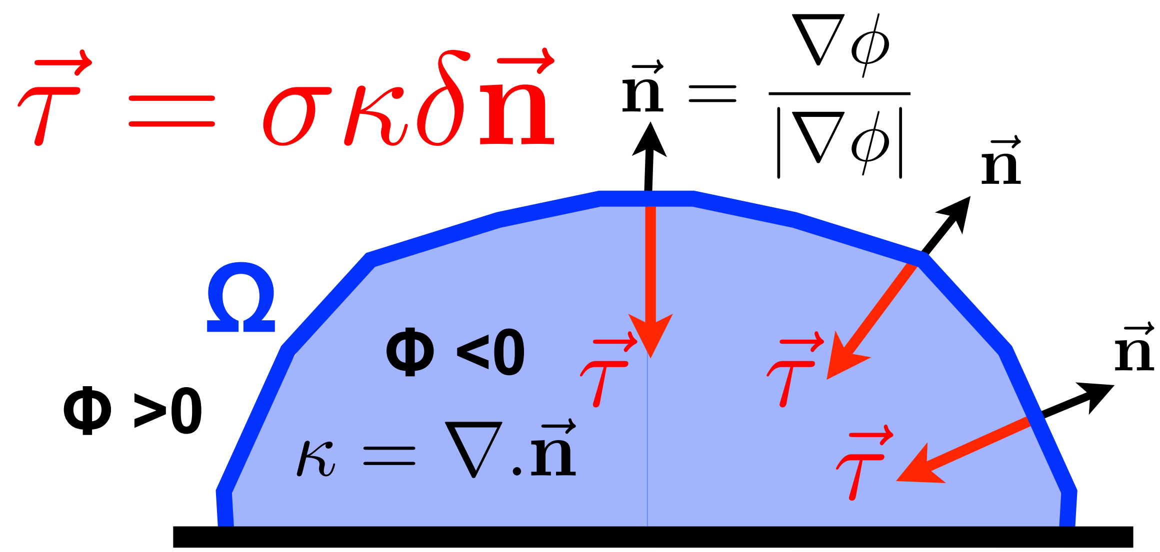
Re=100





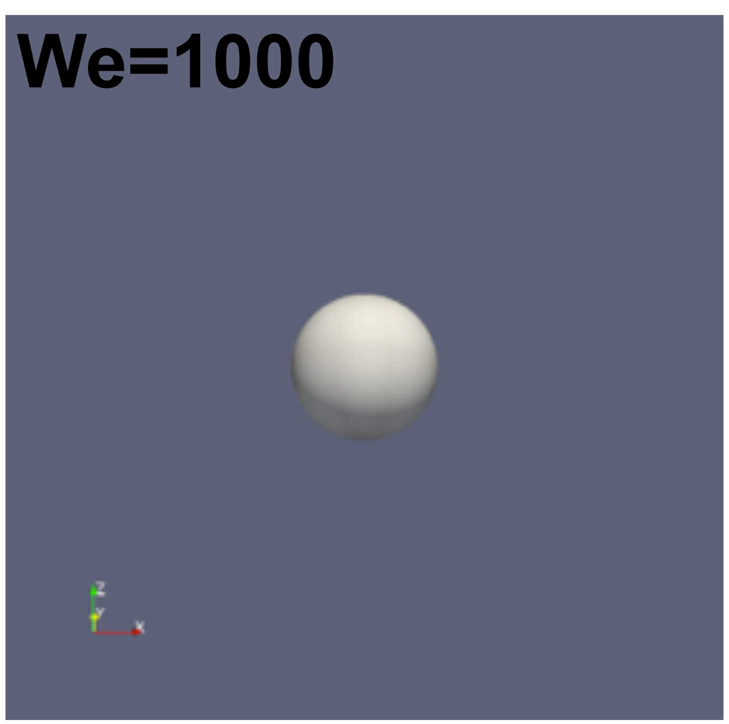
Influence of surface tension (We)

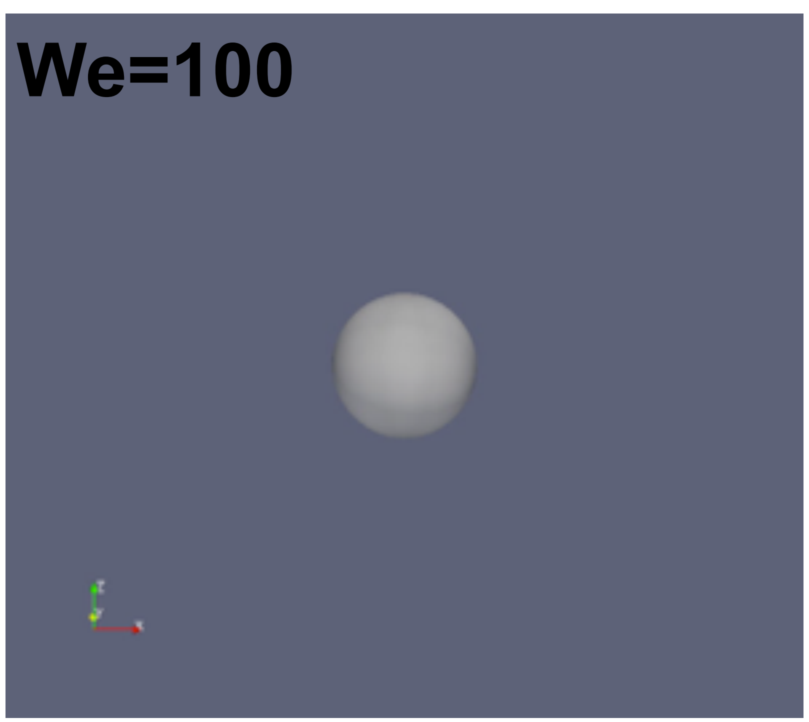


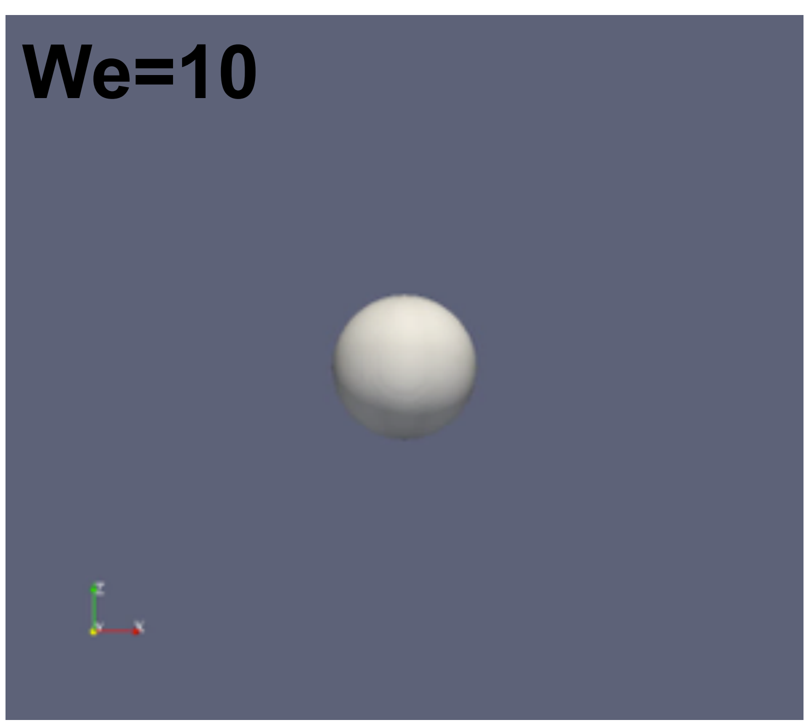


We = Inertia / Surface tension: $\dfrac{\rho_s {V_\infty}^2 R}{\sigma}$

Re=100

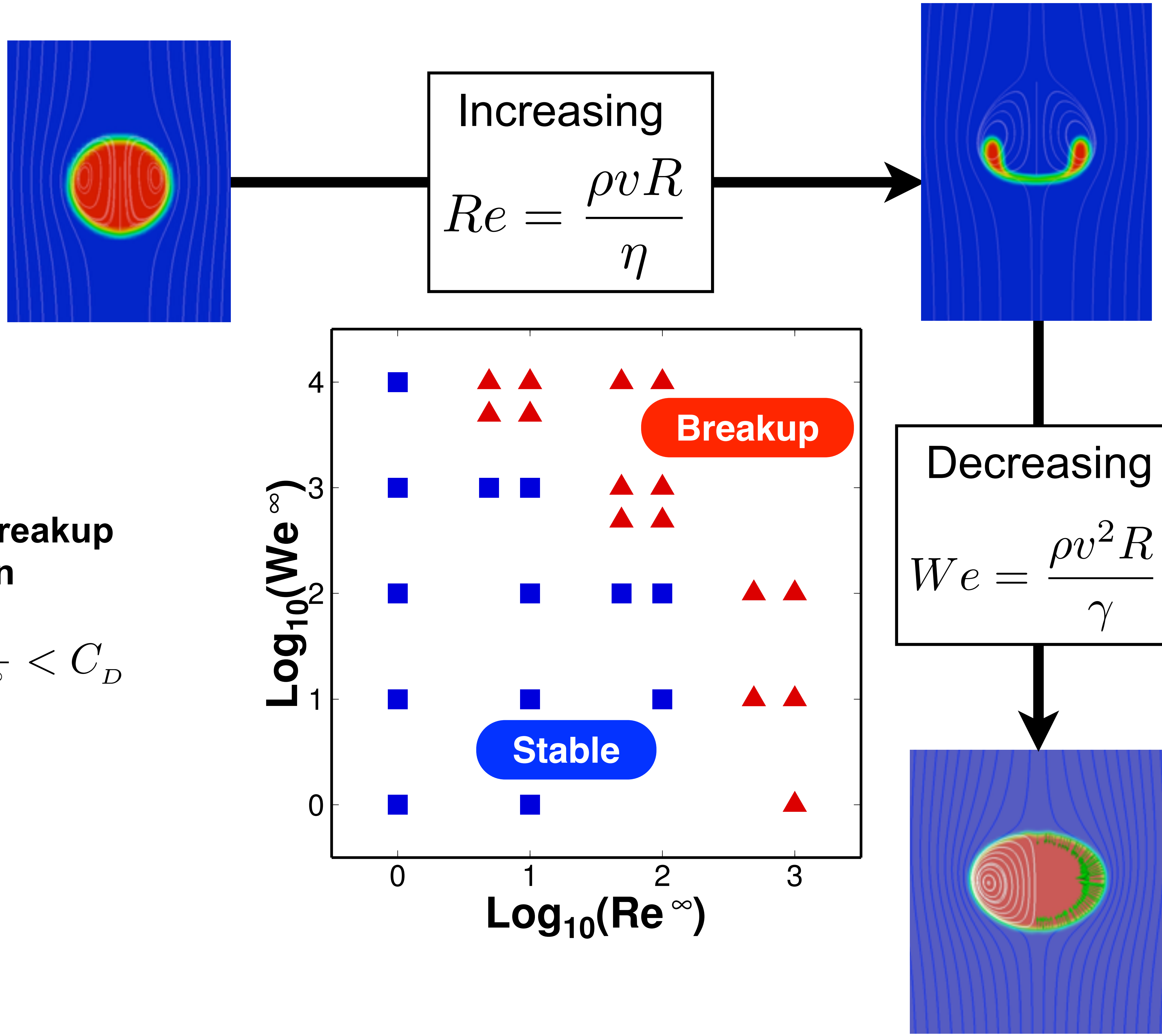






Small We (strong surface tension) efficiently reduces/prevents breakup

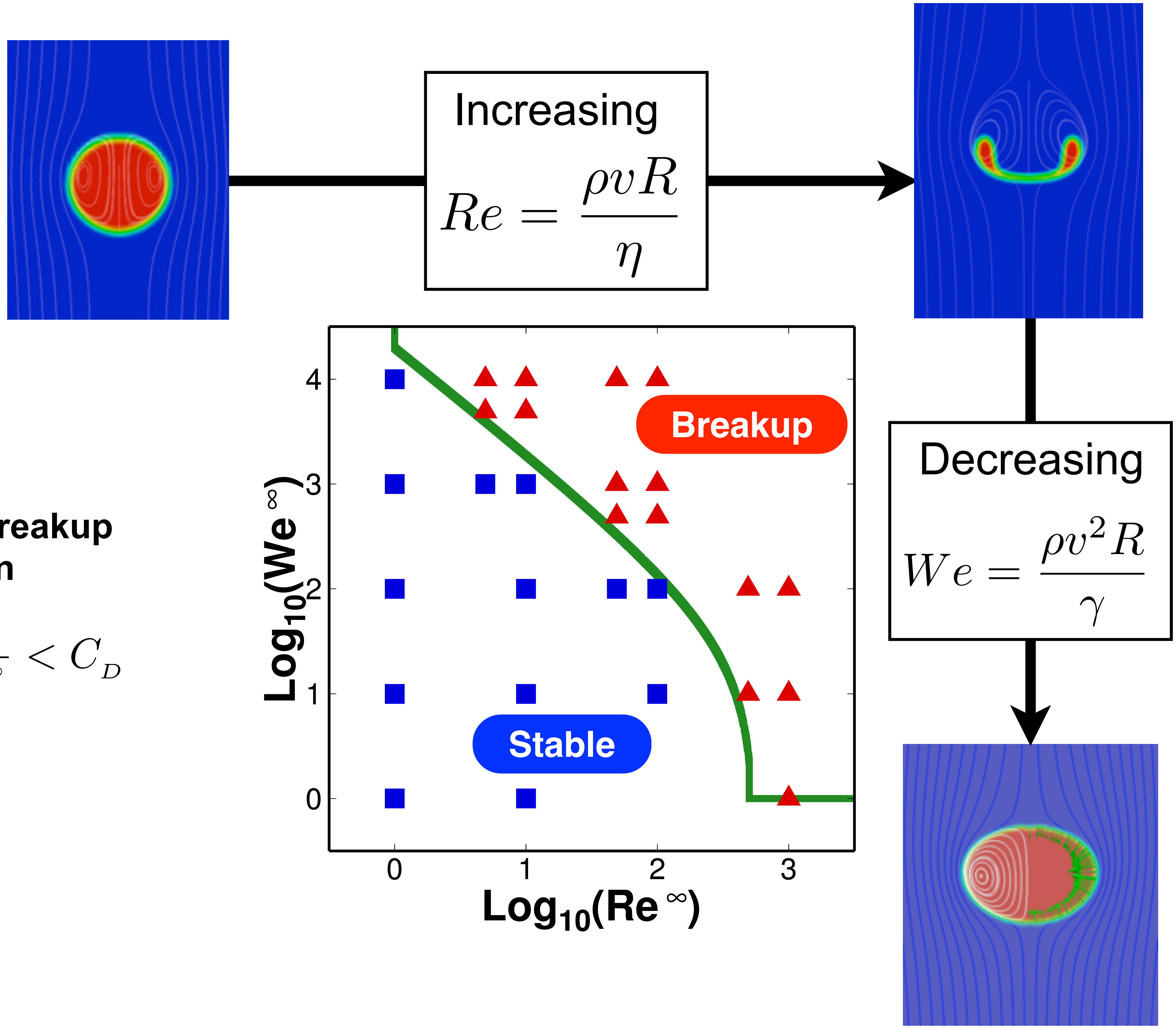
Experimental breakup / Stability criterion



Theoretical breakup criterion

$$\frac{a_1}{Re^{\infty}} + \frac{a_2}{We^{\infty}} < C_D$$

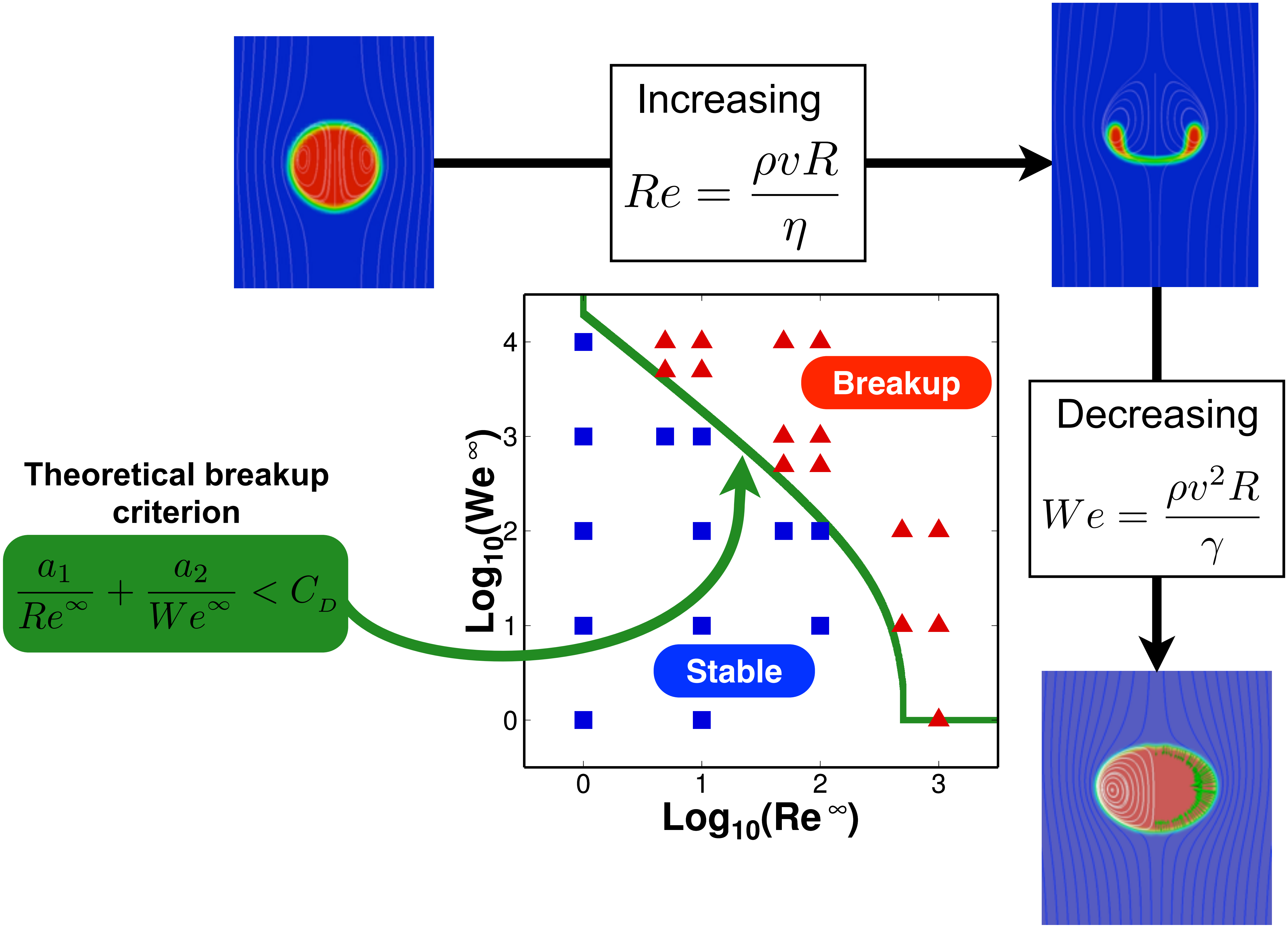
Experimental breakup / Stability criterion



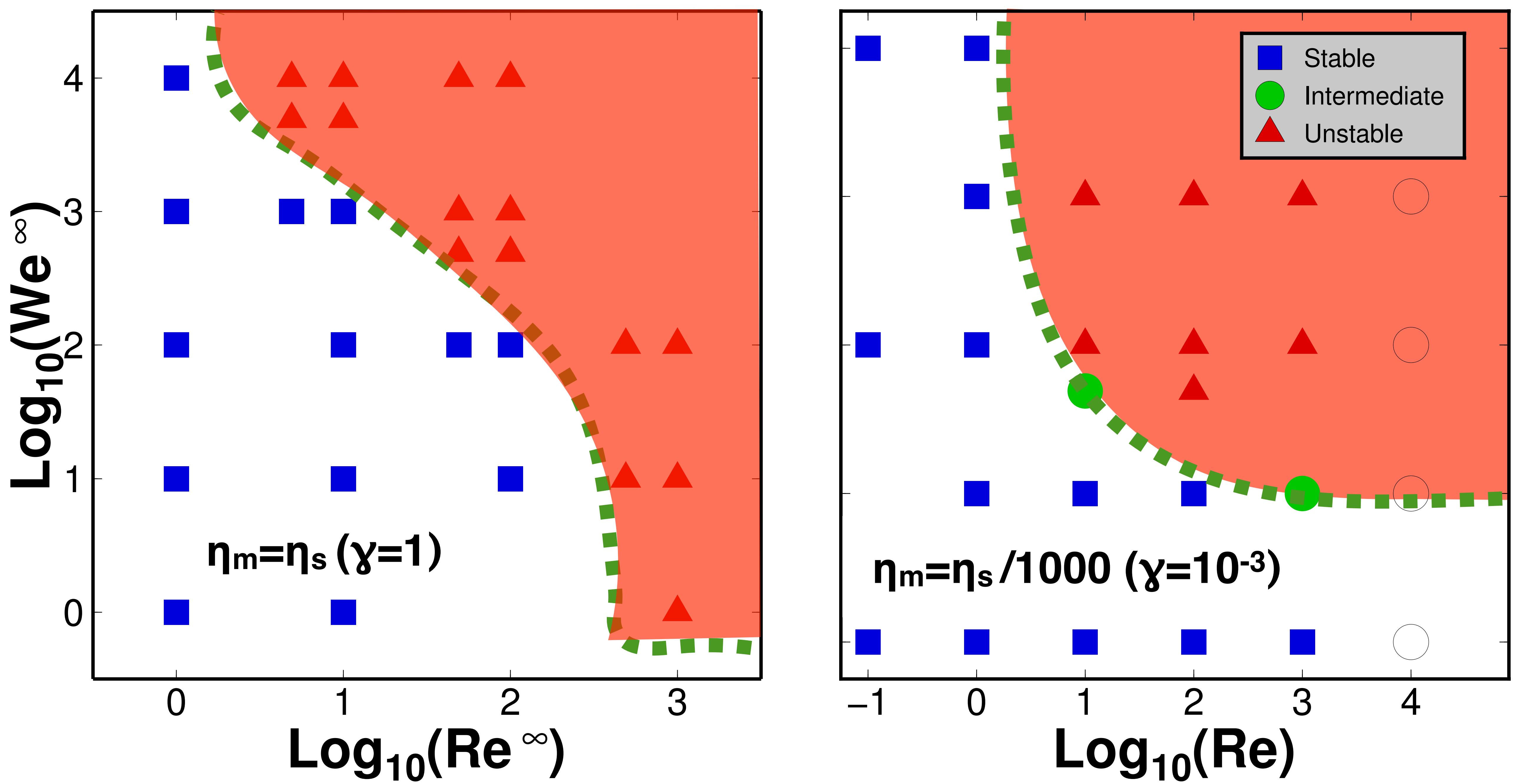
Theoretical breakup criterion

$$\frac{a_1}{Re^{\infty}} + \frac{a_2}{We^{\infty}} < C_D$$

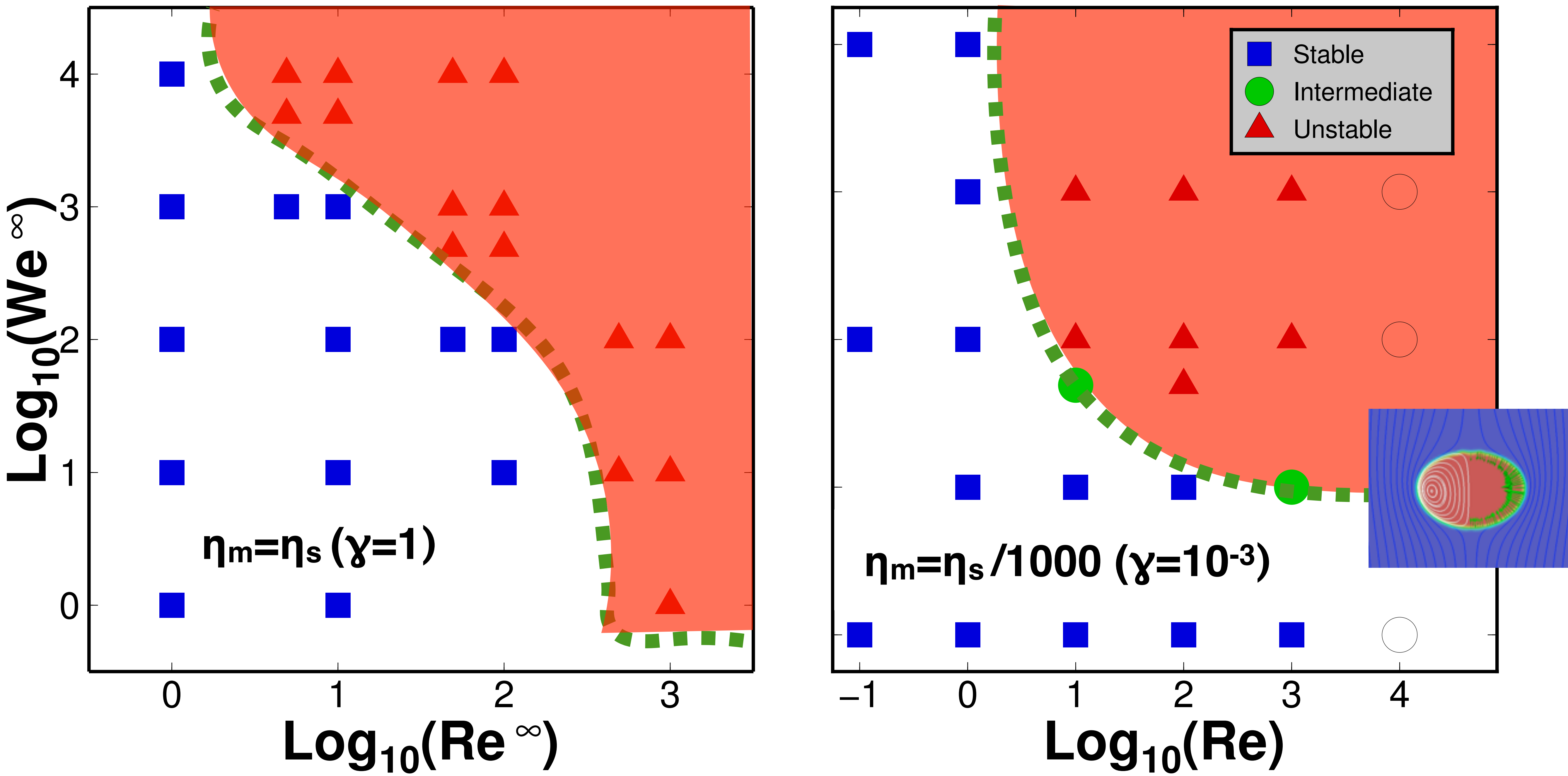
Experimental breakup / Stability criterion



Newtonian rheology: Influence of the Fe-Si viscosity contrast

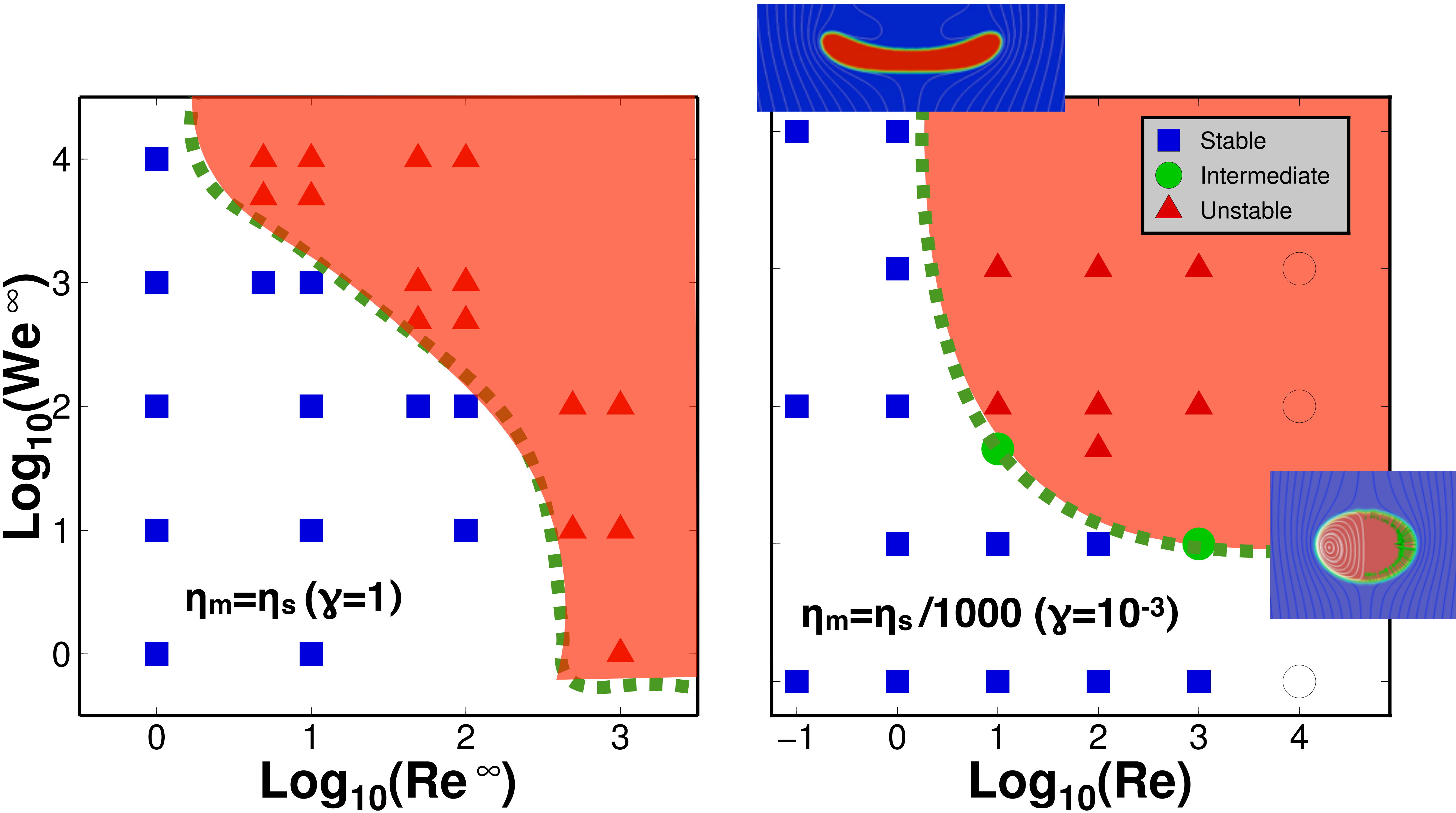


Newtonian rheology: Influence of the Fe-Si viscosity contrast



A high Re, internal circulation reduces breakup ([*Wacheul et al., 2014*])

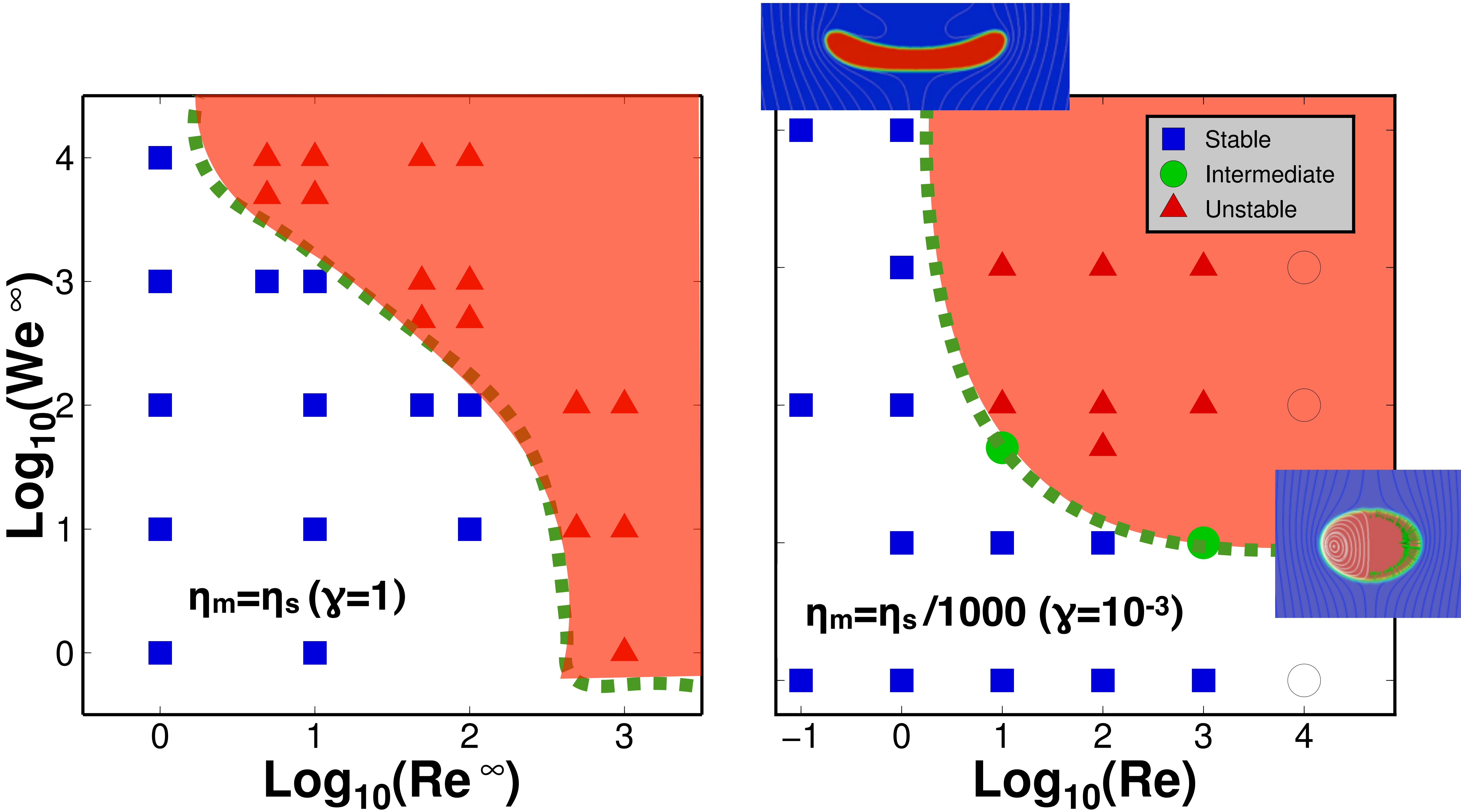
Newtonian rheology: Influence of the Fe-Si viscosity contrast



A high Re, internal circulation reduces breakup ([*Wacheul et al., 2014*])

At moderate and small Re, viscous resistance to deformation reduces breakup

Newtonian rheology: Influence of the Fe-Si viscosity contrast

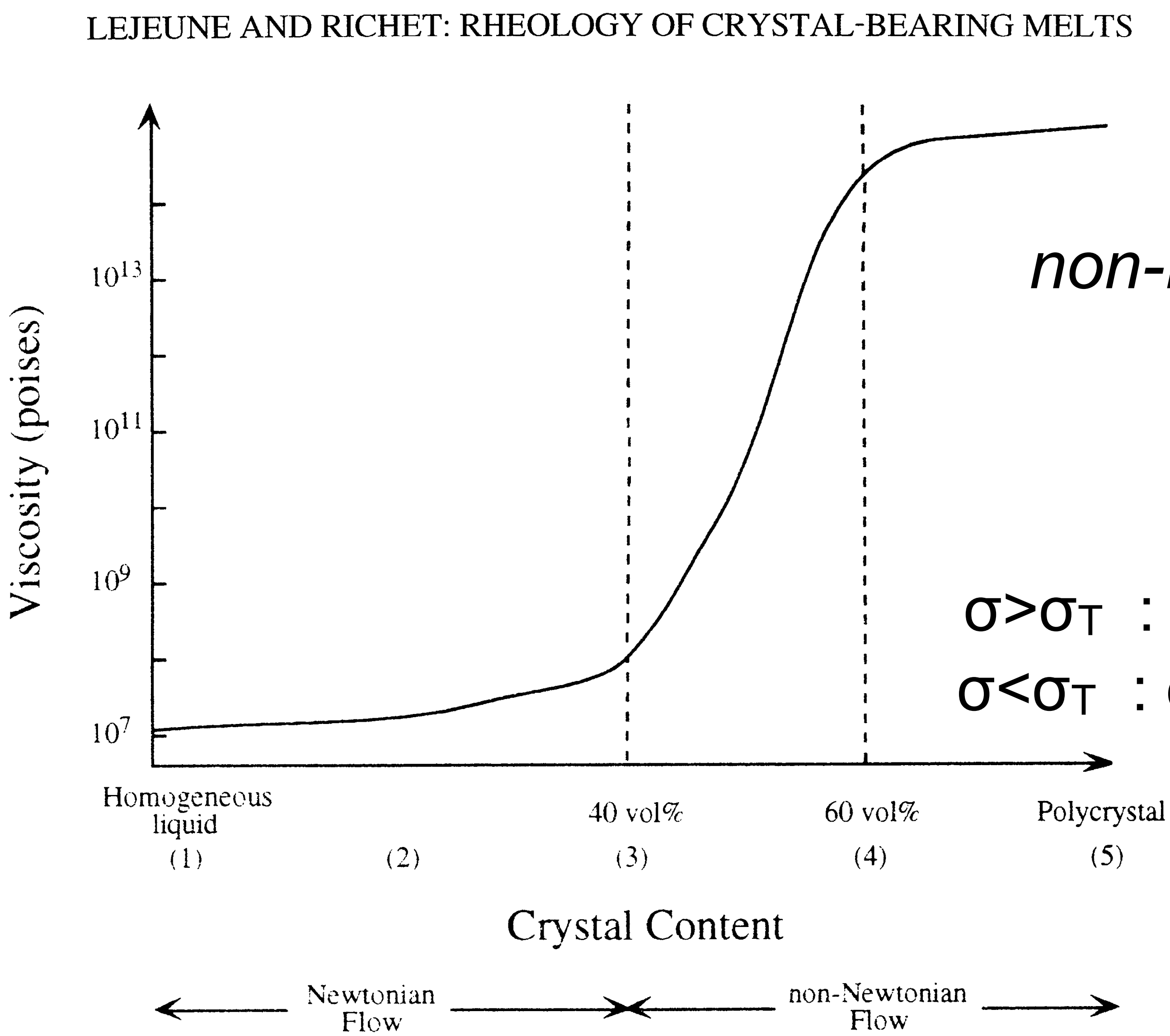


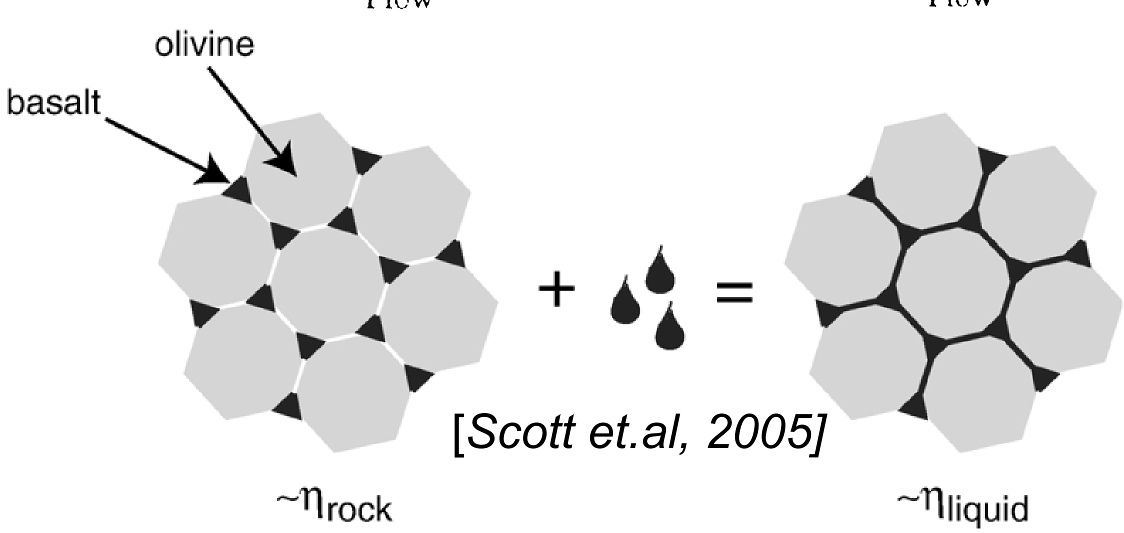
A high Re, internal circulation reduces breakup ([*Wacheul et al., 2014*])

At moderate and small Re, viscous resistance to deformation reduces breakup

Small $\gamma=\eta_s/\eta_m$ stabilises diapirs at high Re, but favours breakup at low Re

Rheological transitions & non-Newtonian rheology for partially molten silicates





Newtonian case (fully molten diapir):

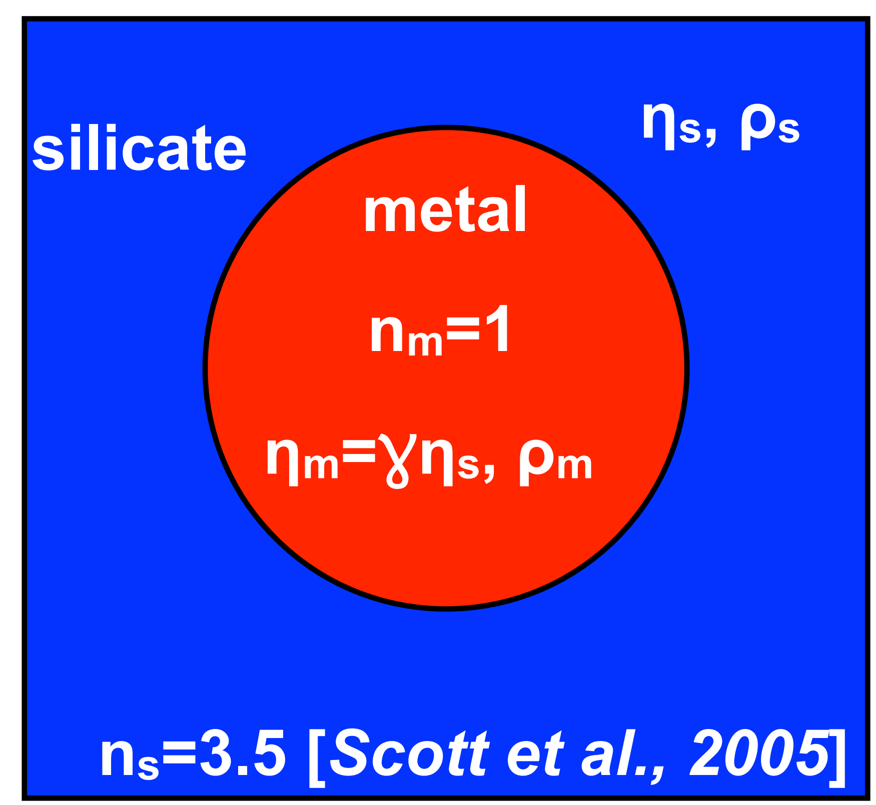
$$\eta = \eta_{0_{\mathrm{diff}}}$$

non-Newtonian case (partially molten silicates):

$$\eta = \eta_{0_{\mathrm{diff}}} \left[1 + \left(\frac{\sigma}{\sigma_T} \right)^{n-1} \right]^{-1}$$

$\sigma > \sigma_T$: dislocation creep (non-Newtonian) dominated

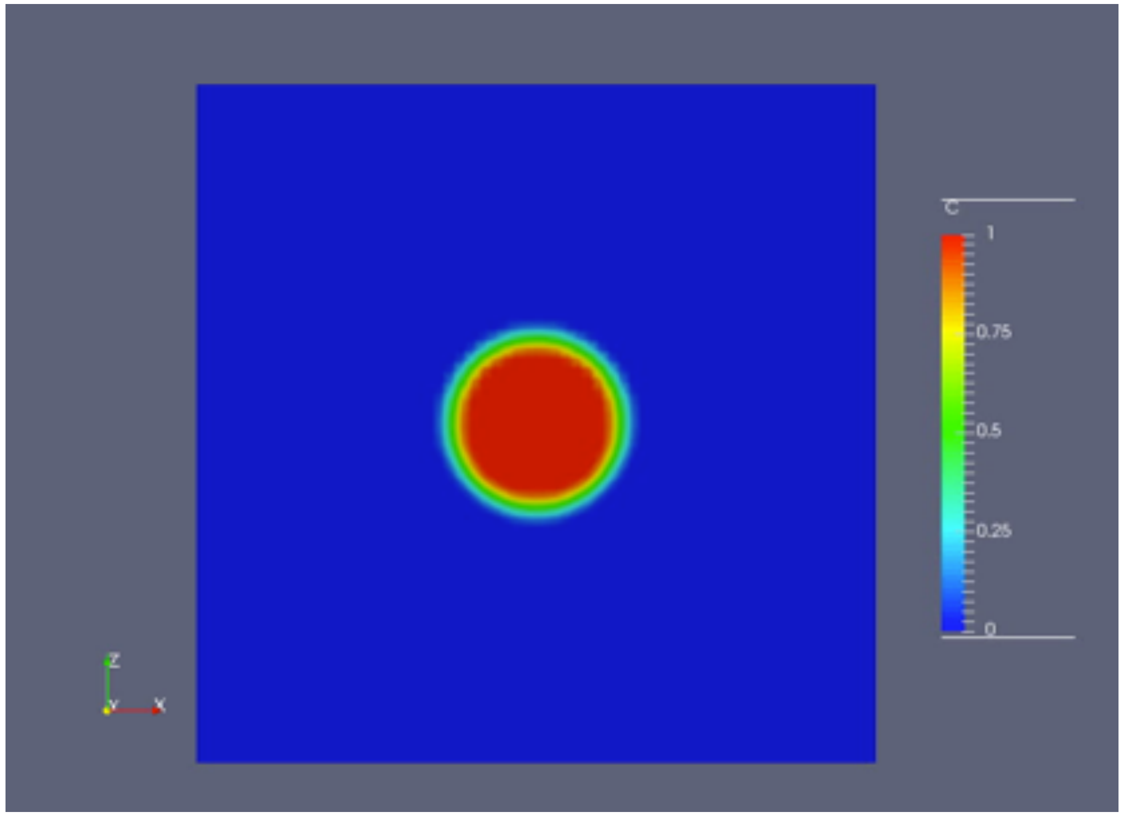
$\sigma < \sigma_T$: diffusion creep (Newtonian) dominated



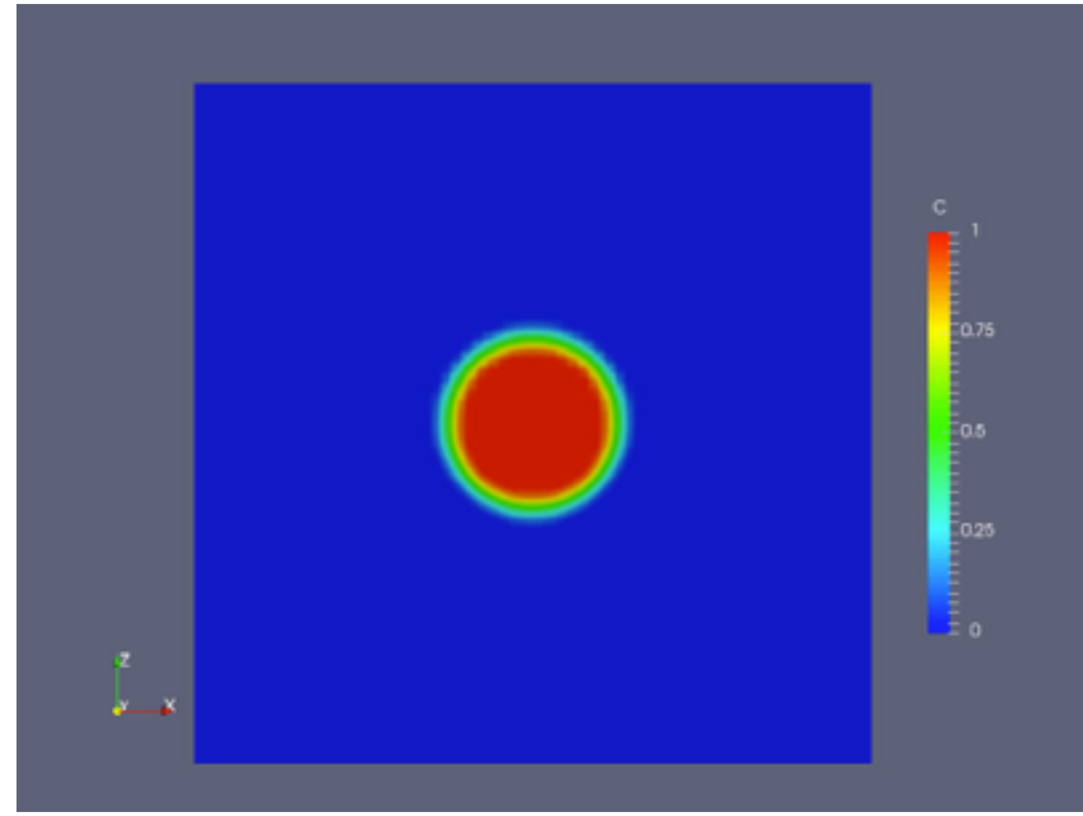
Newtonian vs. non-Newtonian rheology

Re = 100 We=10

n=1



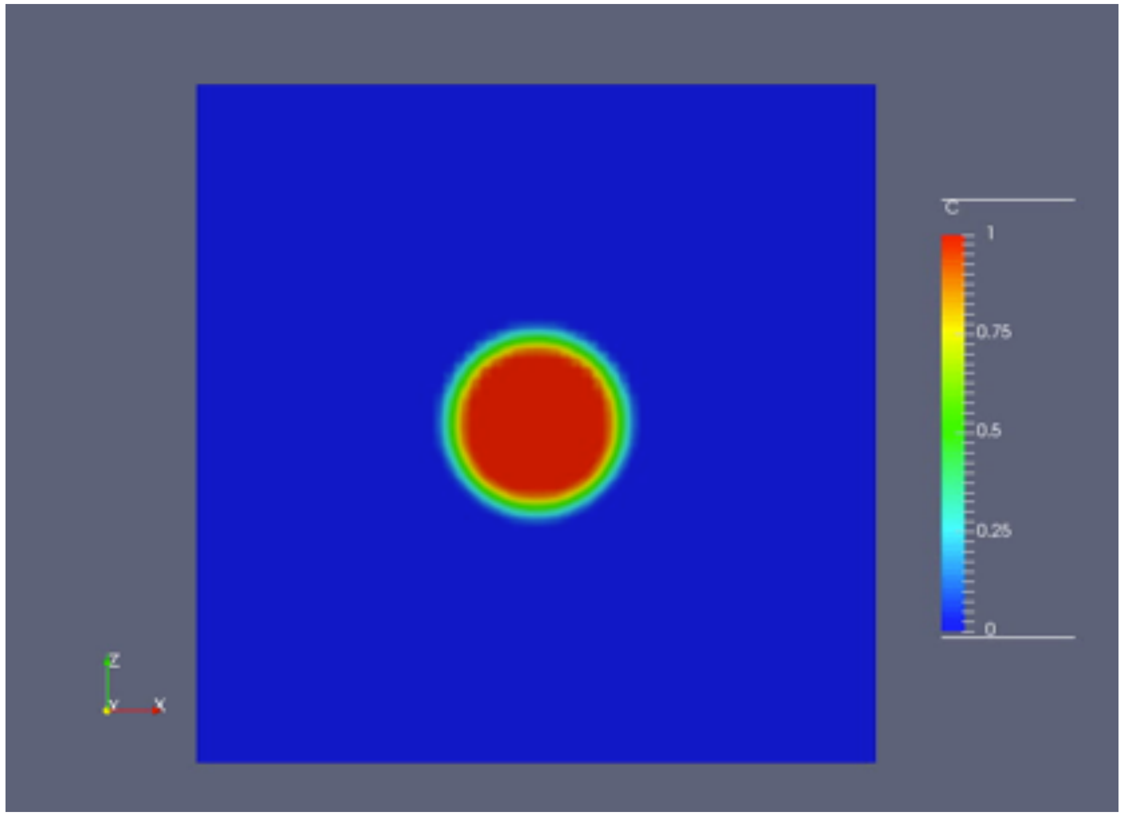
n=3.5



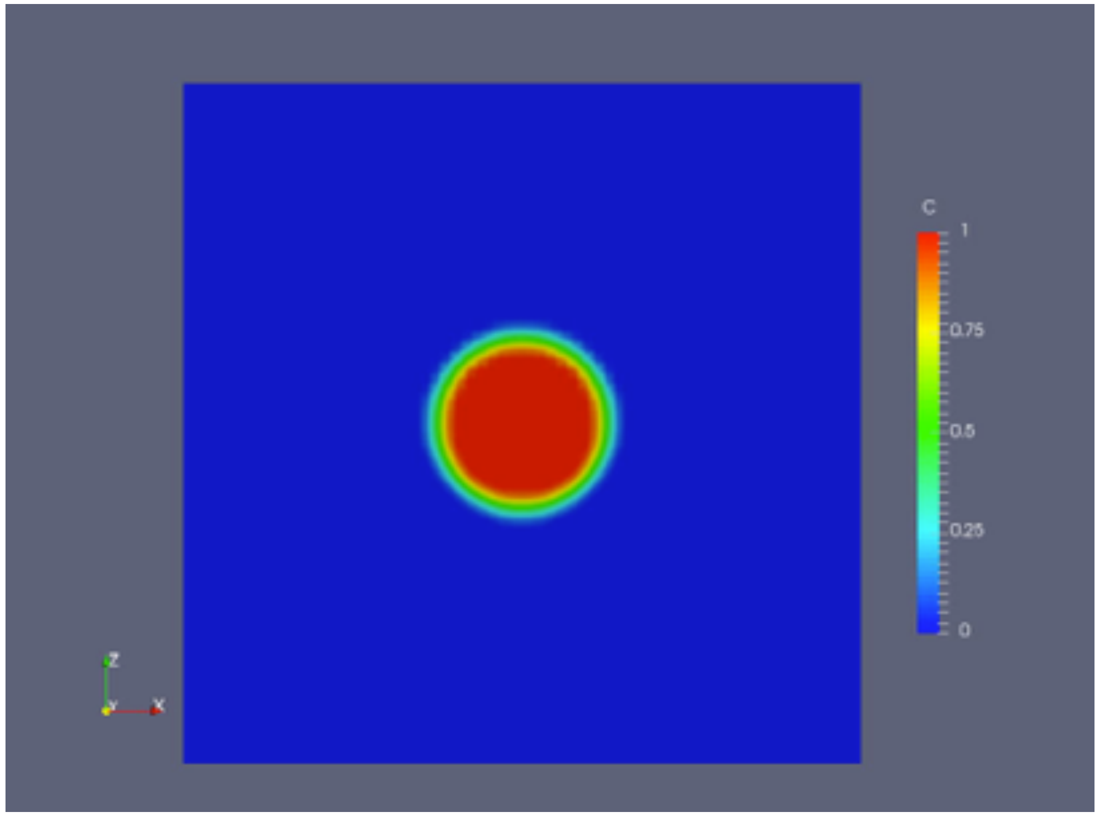
Newtonian vs. non-Newtonian rheology

Re = 100 We=10

n=1



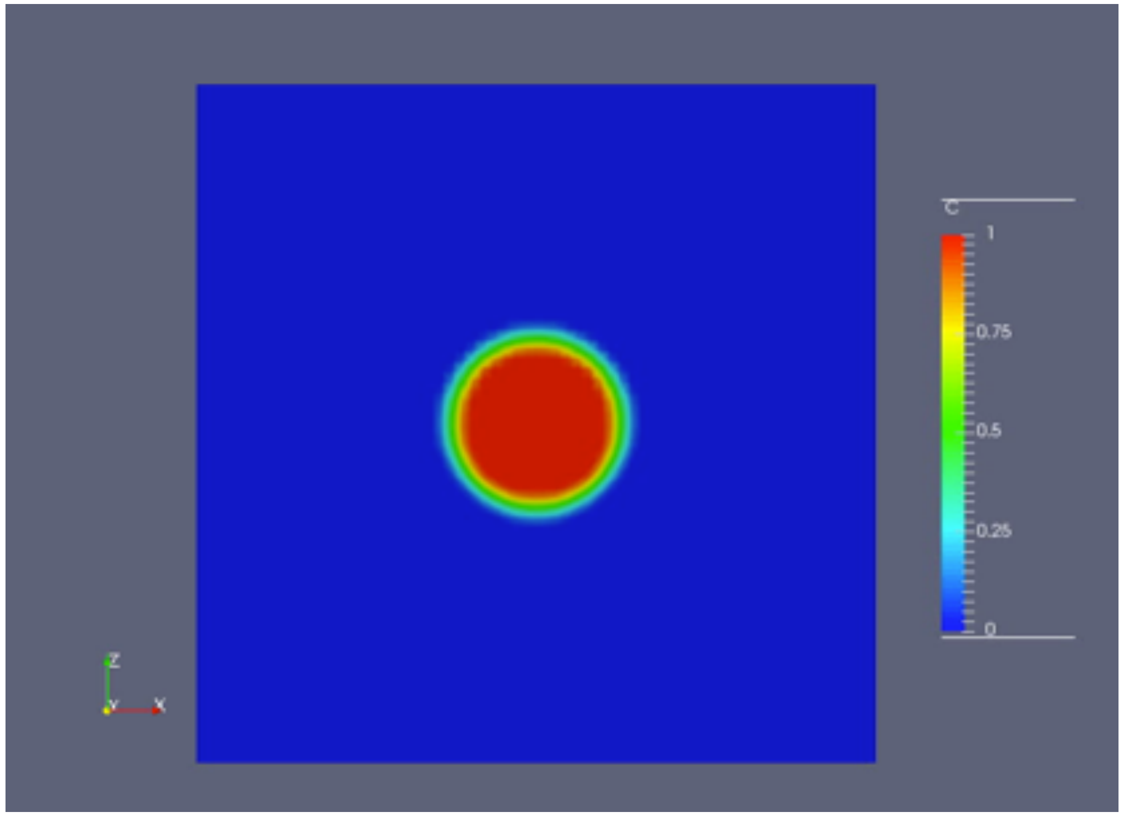
n=3.5



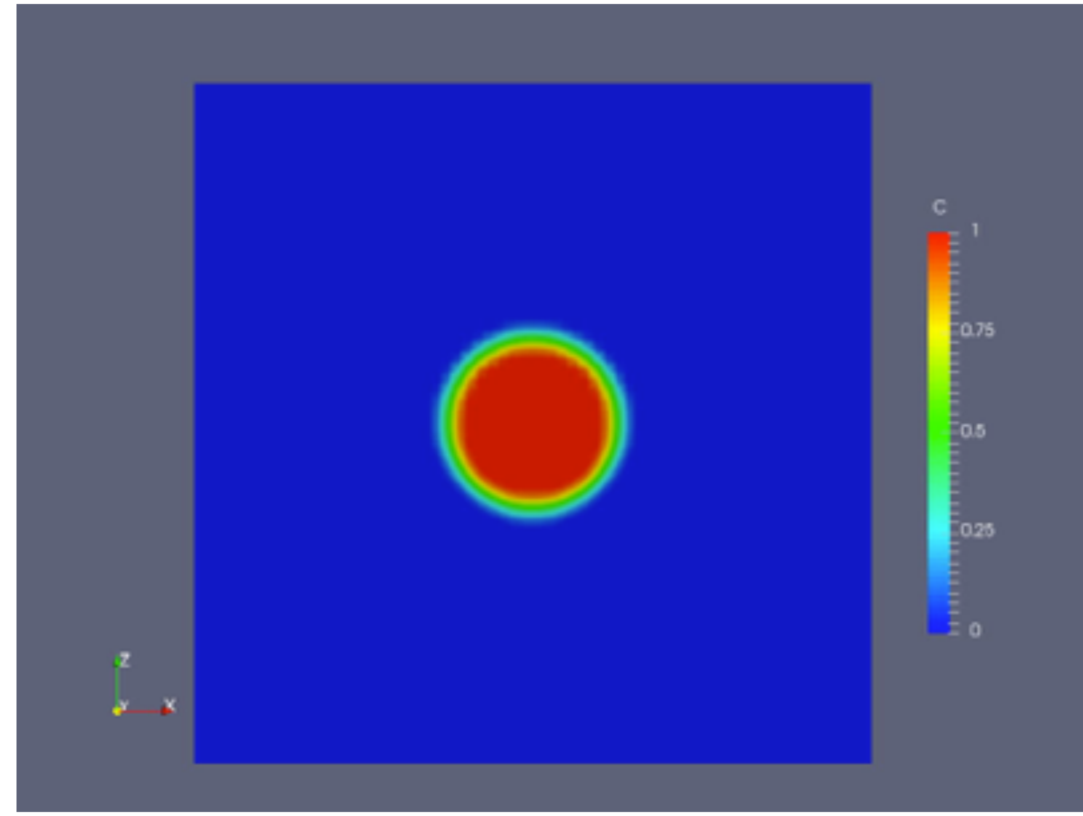
Newtonian vs. non-Newtonian rheology

Re = 100 We=10

n=1

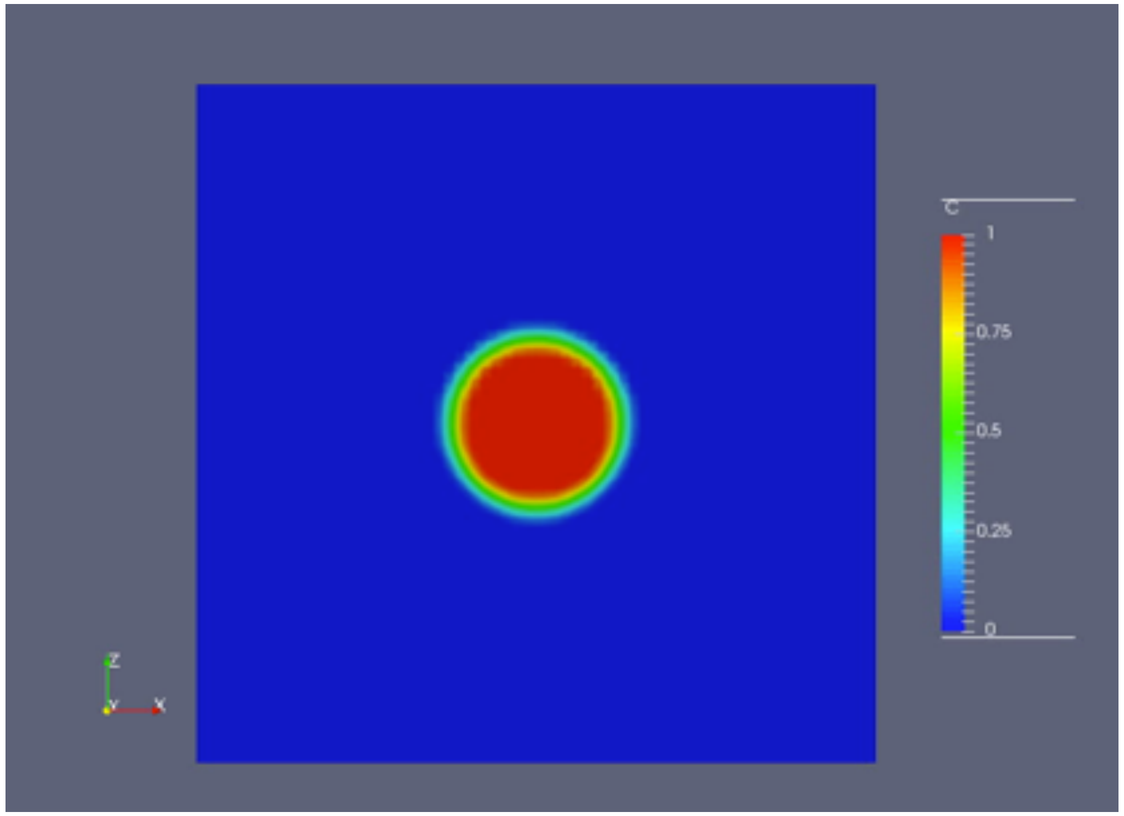


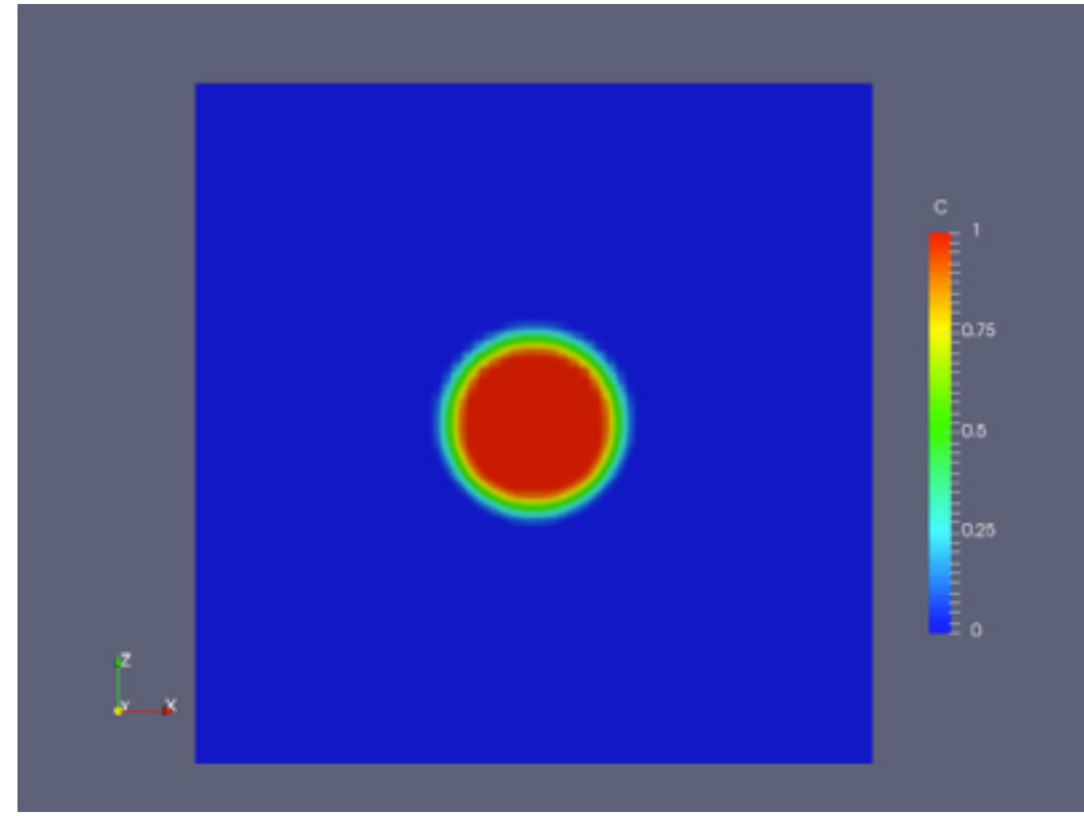
n=3.5

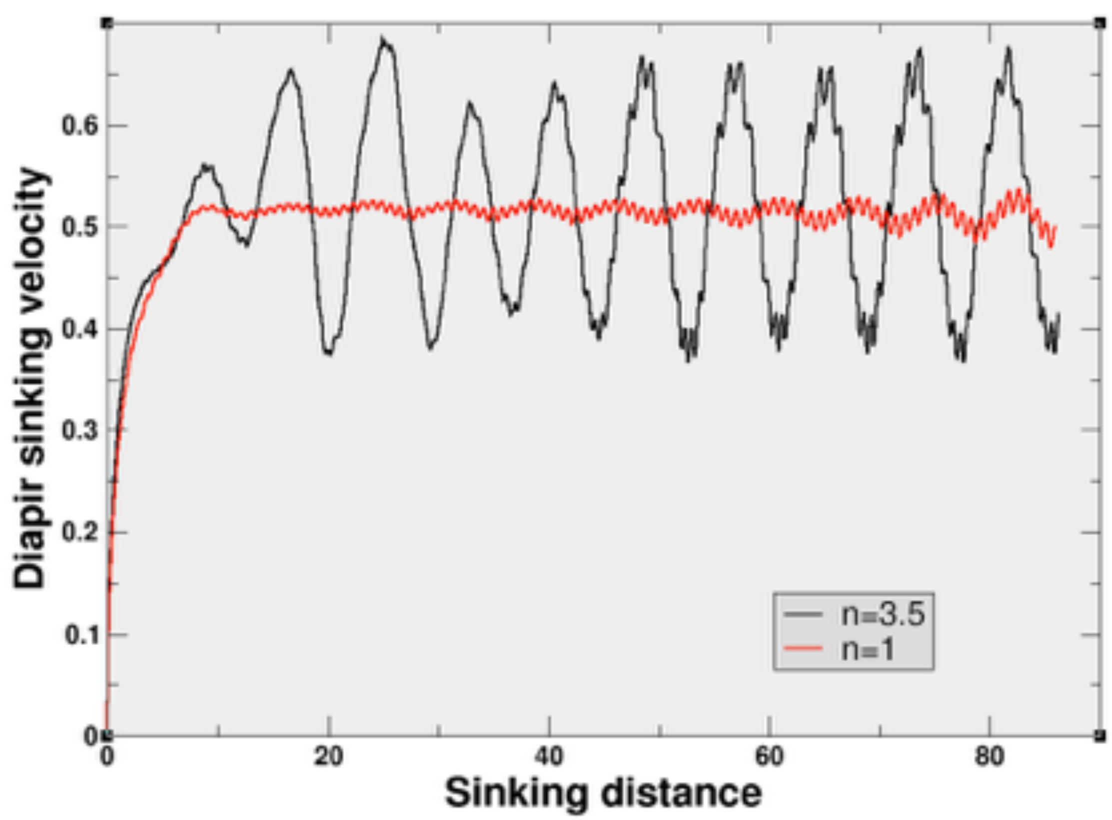


Newtonian vs. non-Newtonian rheology

n=1 **Re = 100 We=10** **n=3.5**



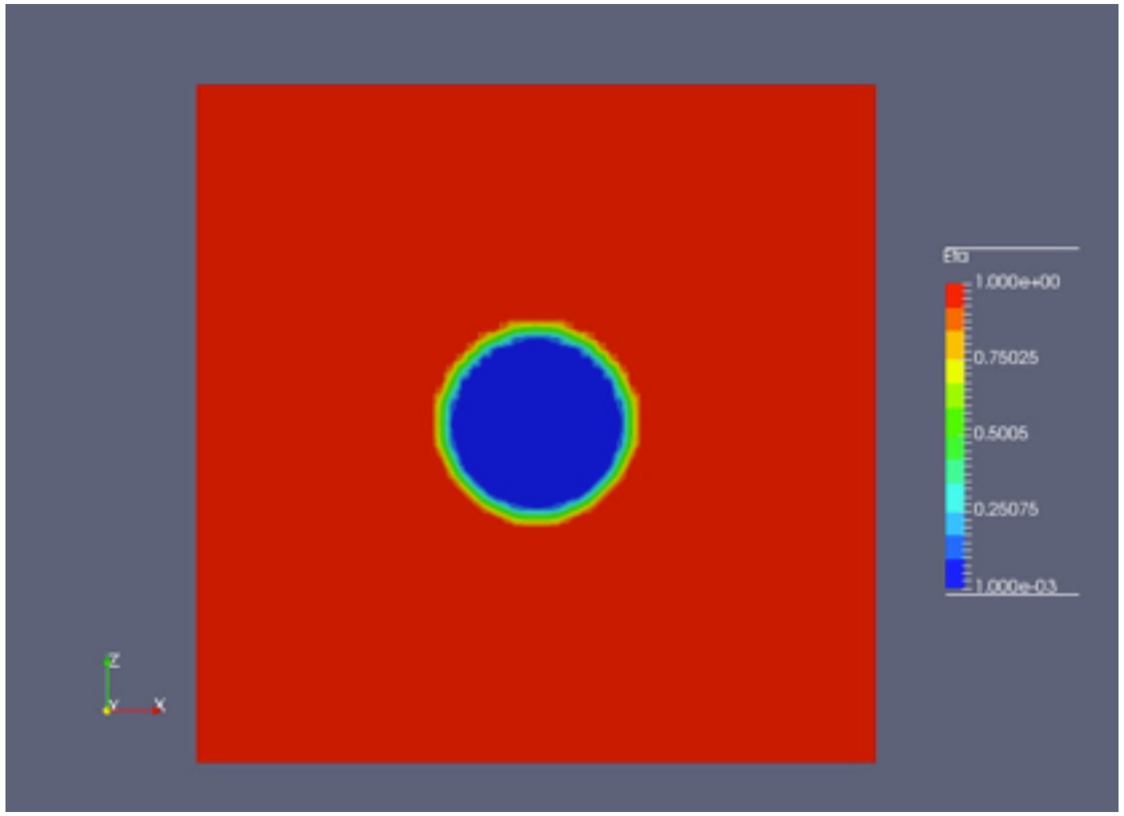




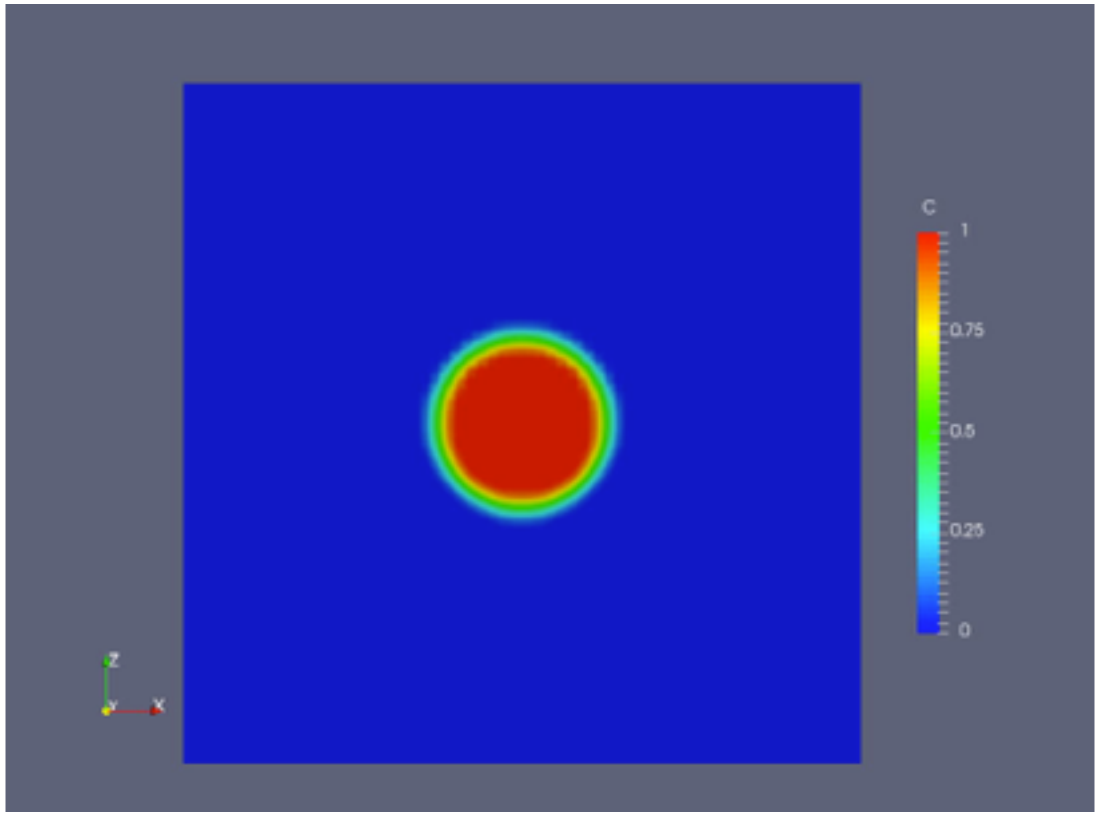
Newtonian vs. non-Newtonian rheology

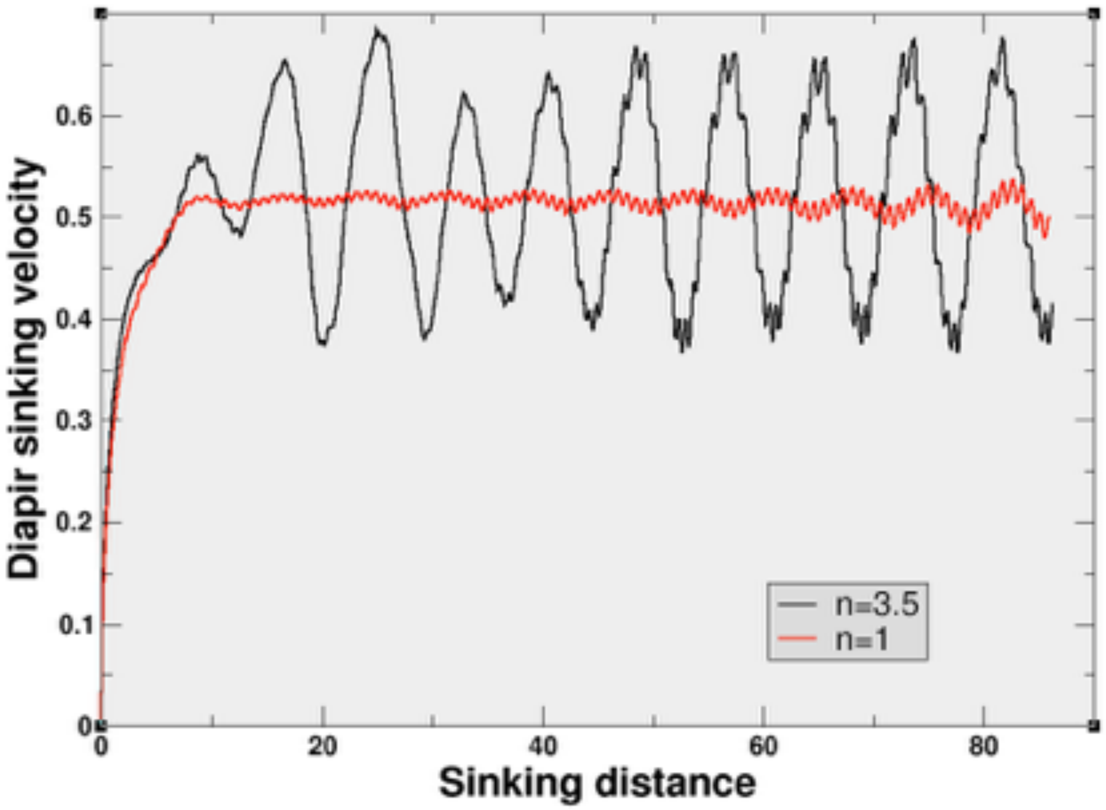
Re = 100 We=10

n=1



n=3.5

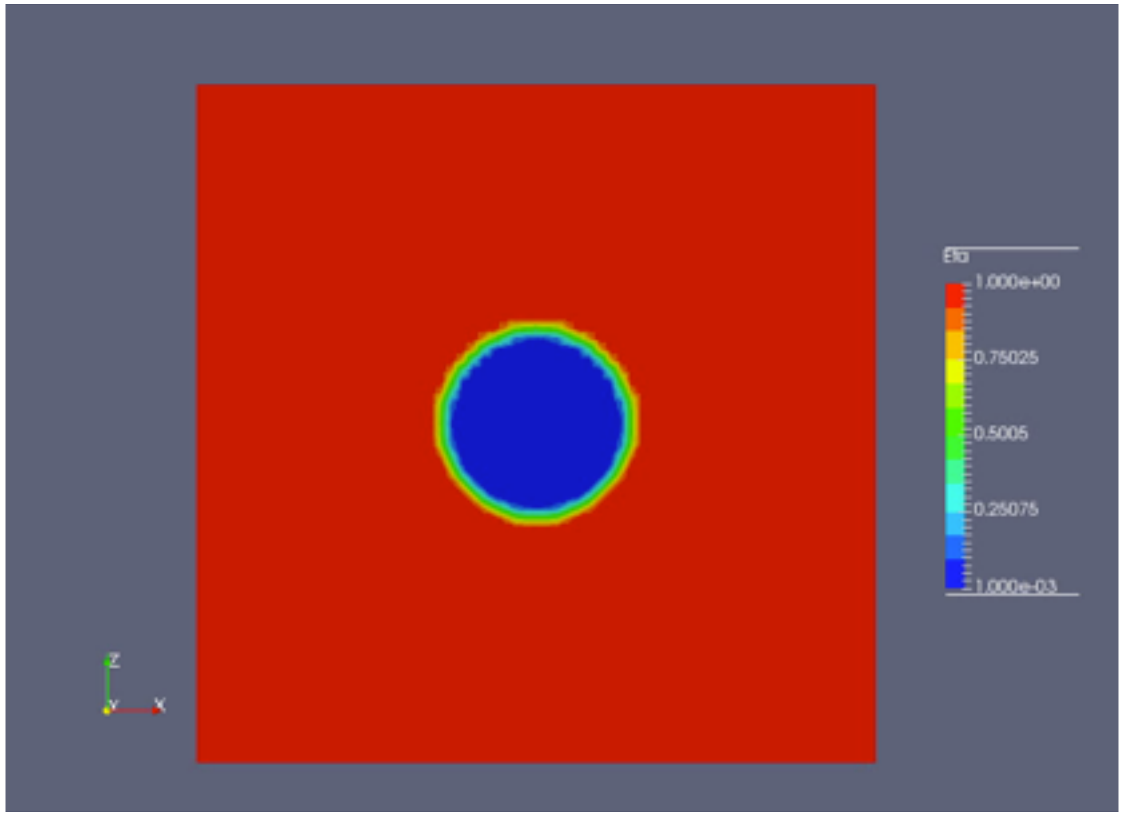




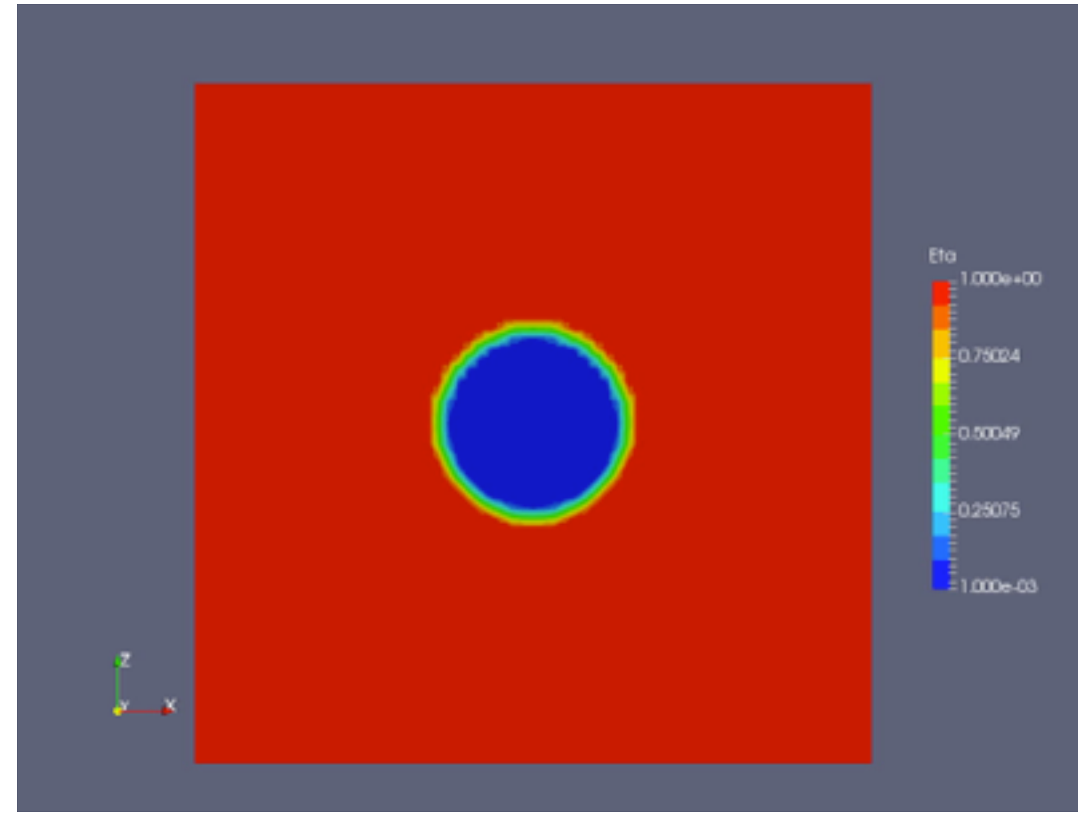
Newtonian vs. non-Newtonian rheology

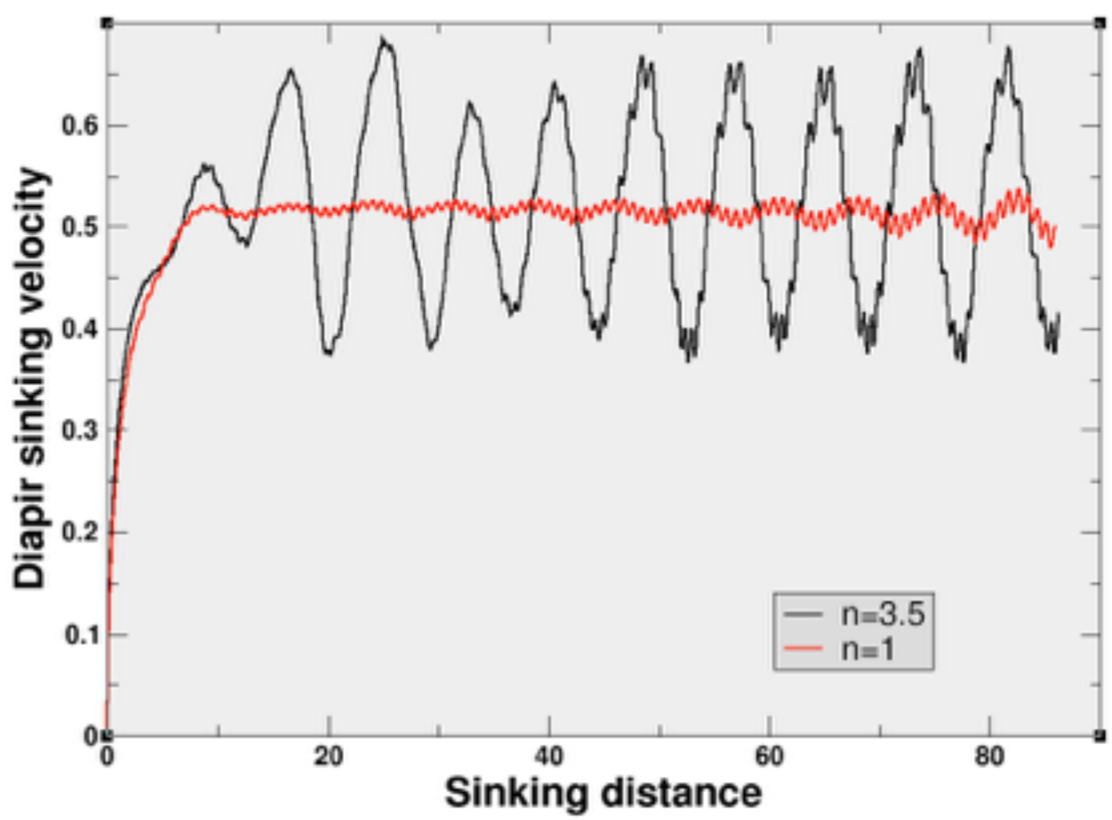
Re = 100 We=10

n=1



n=3.5

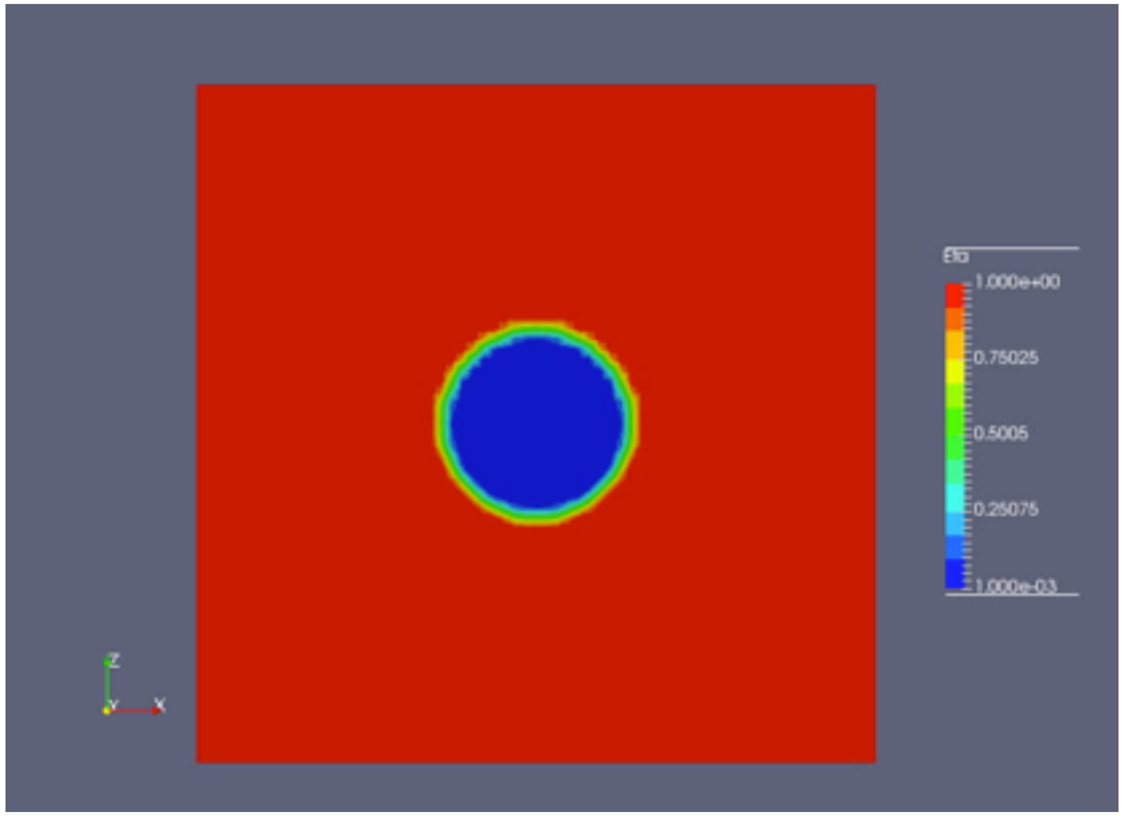




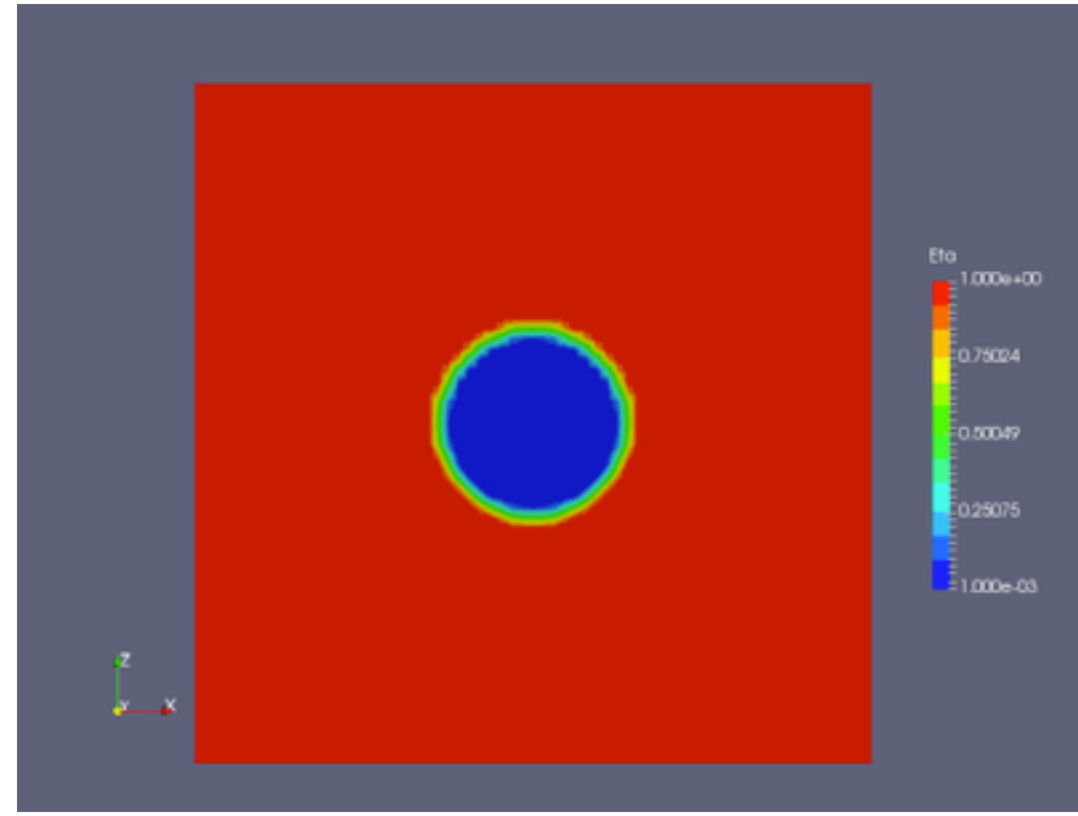
Newtonian vs. non-Newtonian rheology

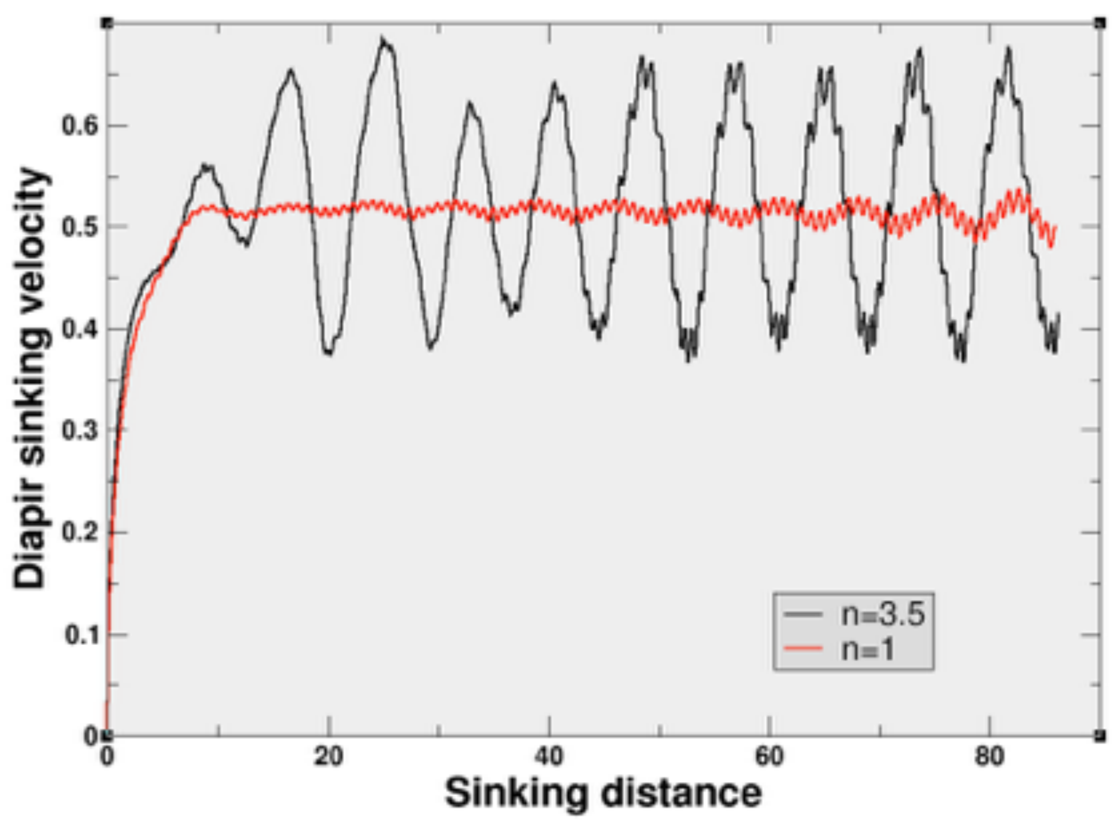
Re = 100 We=10

n=1



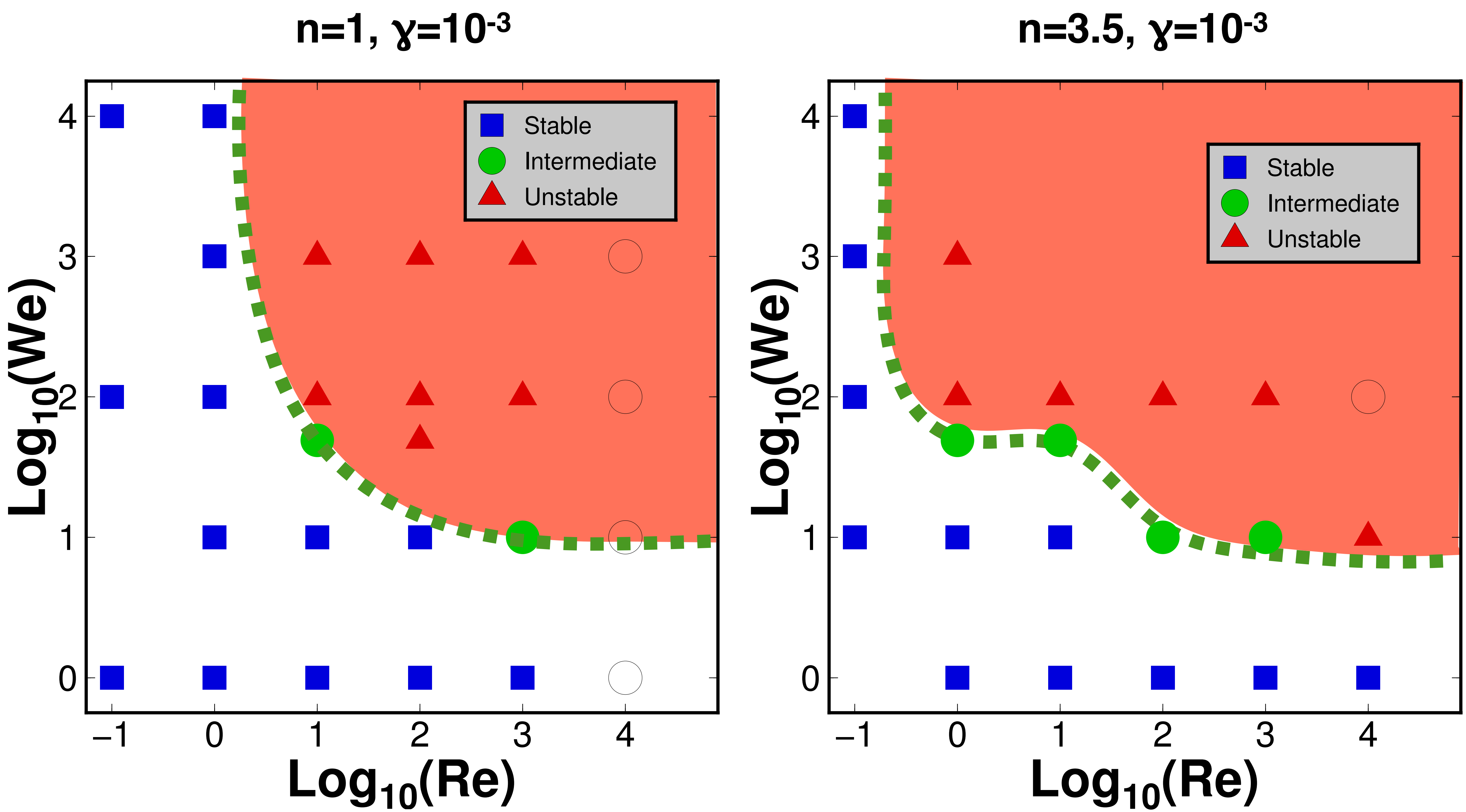
n=3.5





non-Newtonian rheology favours breakup

Newtonian (n=1) vs. Non-Newtonian rheology (n=3.5) stability diagrams

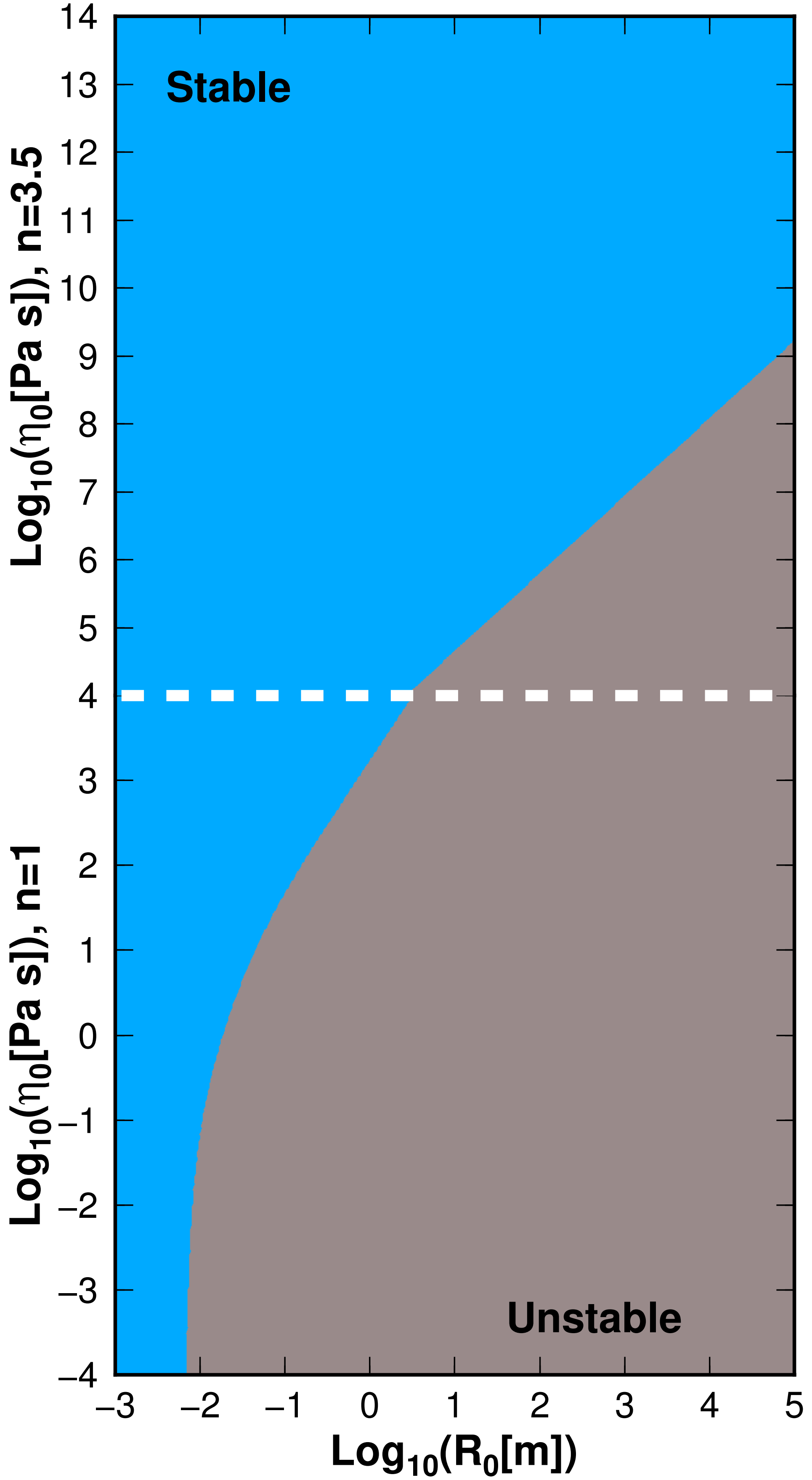


non-Newtonian rheology influence is stronger for smaller Re values

non-Newtonian rheology favours breakup

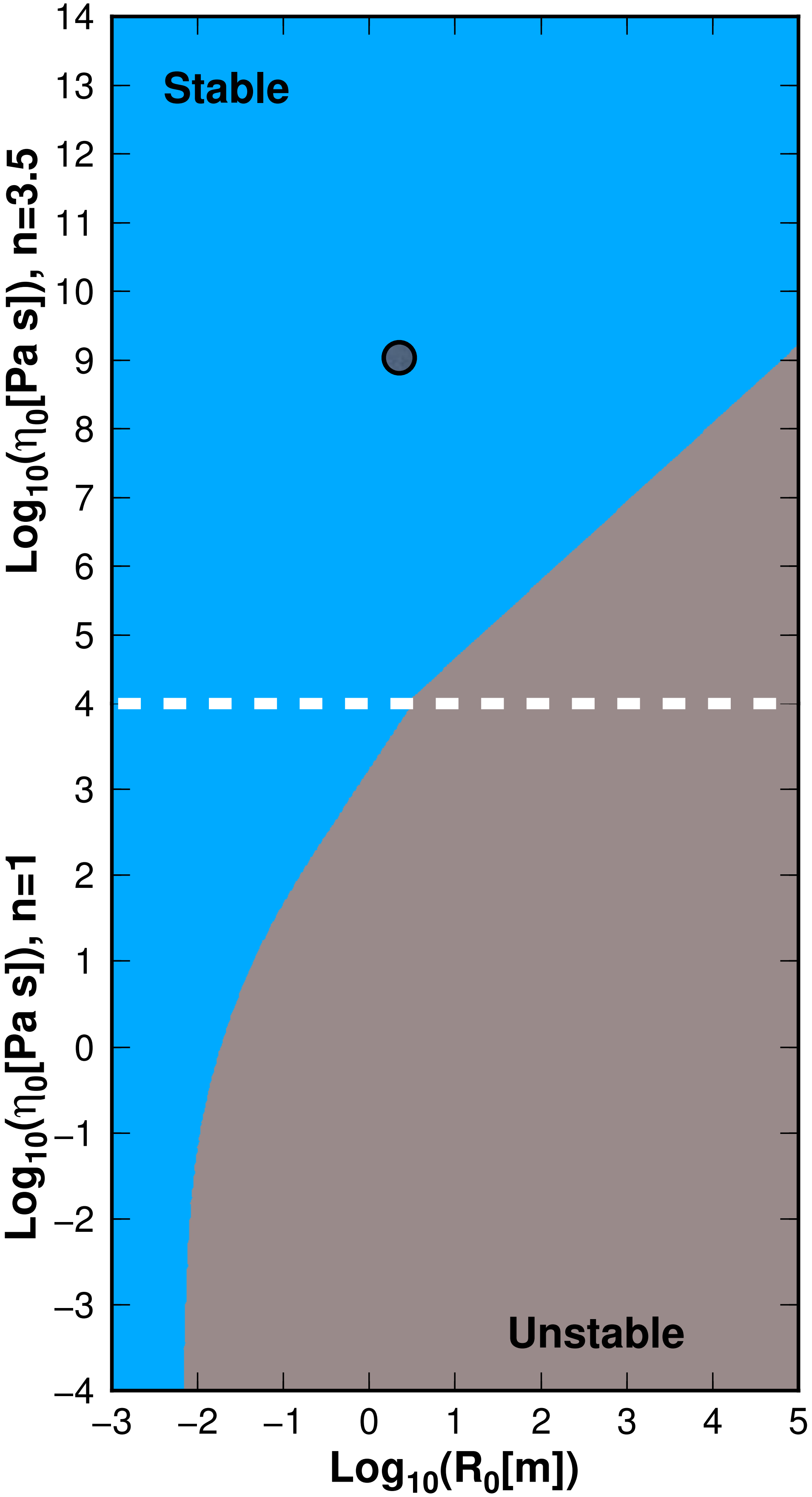
Summary: stability region

We-Re stability condition: $a_1/Re + a_2/We < C_D$



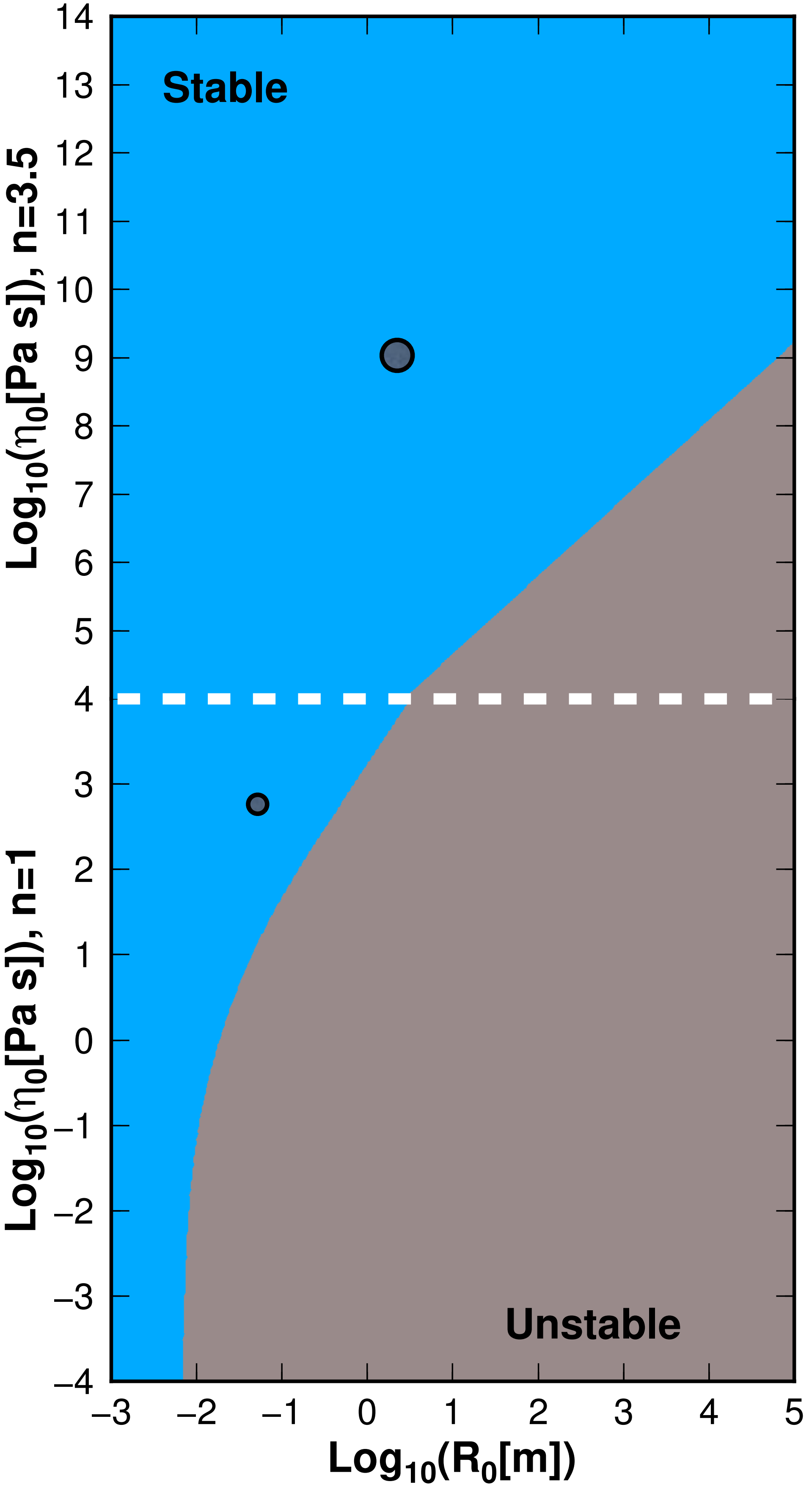
Summary: stability region

We-Re stability condition: $a_1/Re + a_2/We < C_D$



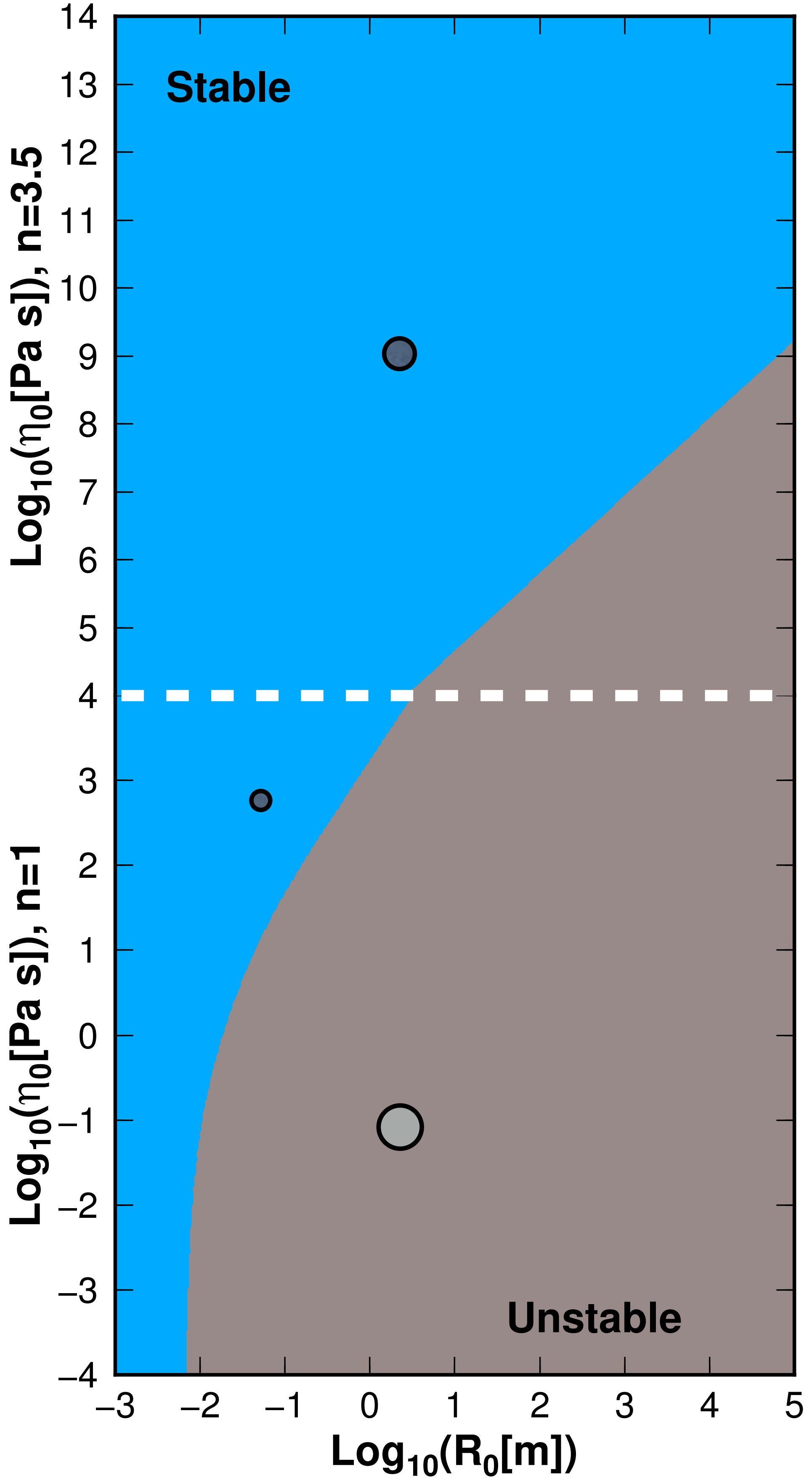
Summary: stability region

We-Re stability condition: $a_1/Re + a_2/We < C_D$



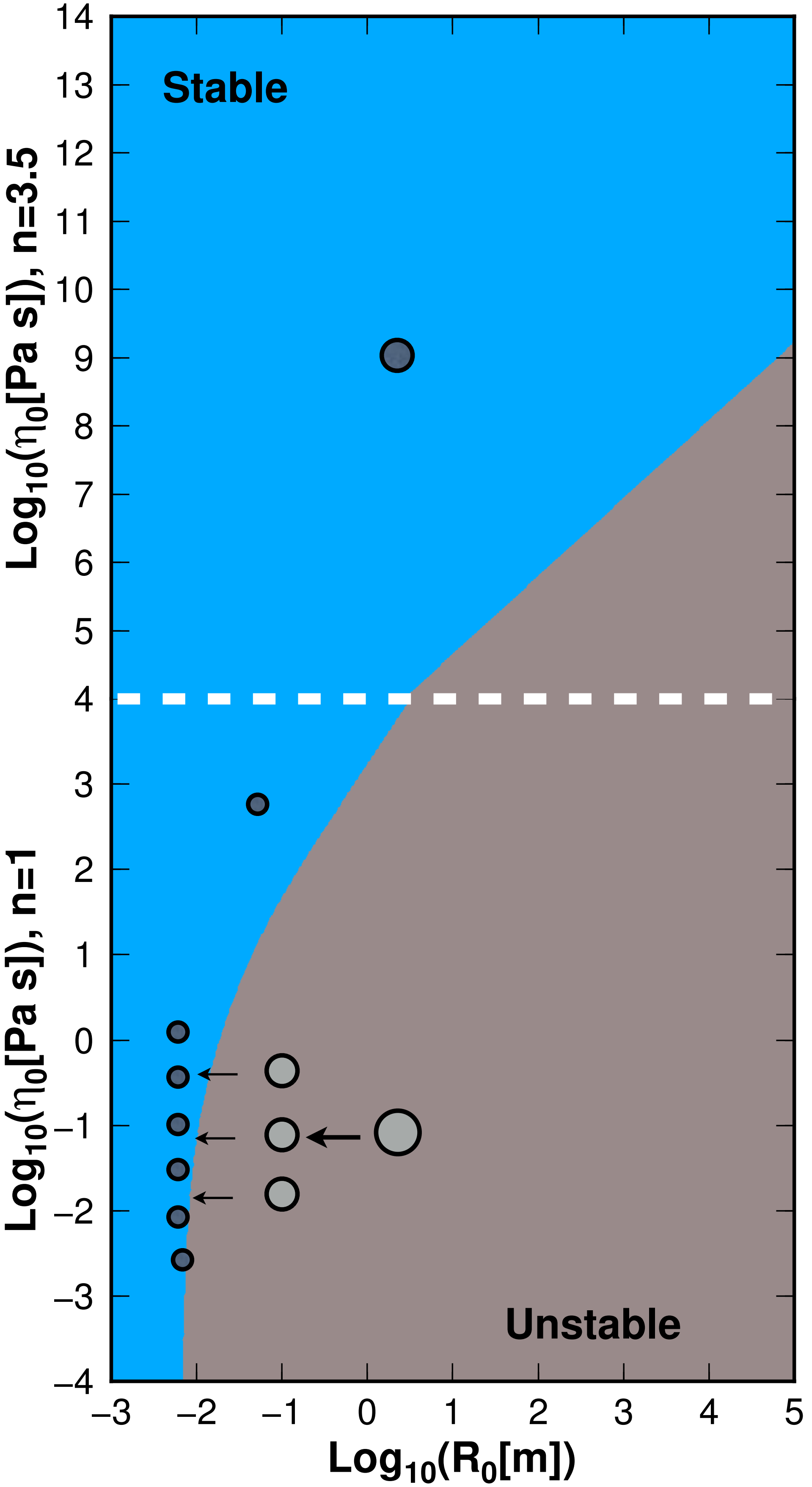
Summary: stability region

We-Re stability condition: $a_1/Re + a_2/We < C_D$



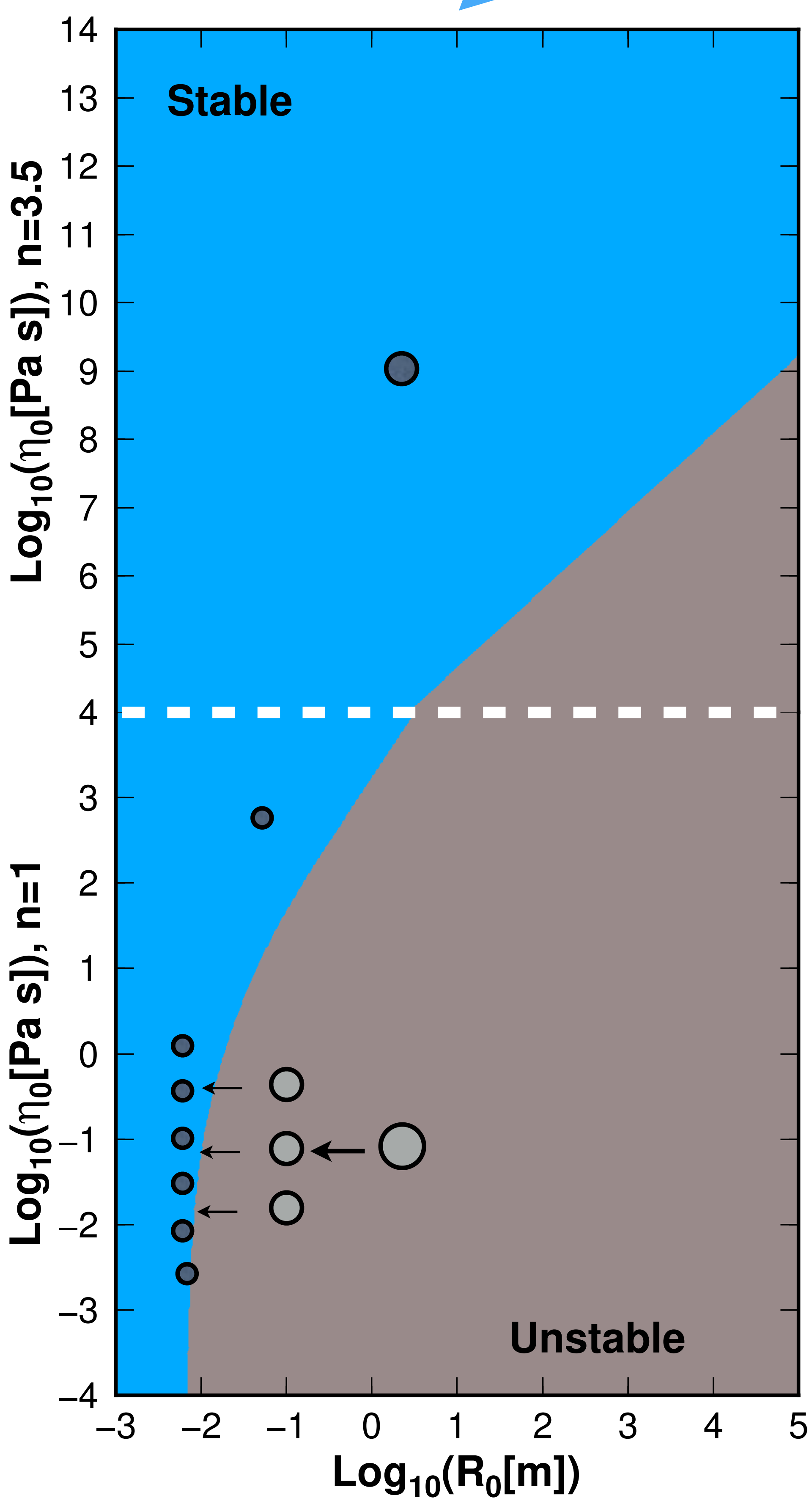
Summary: stability region

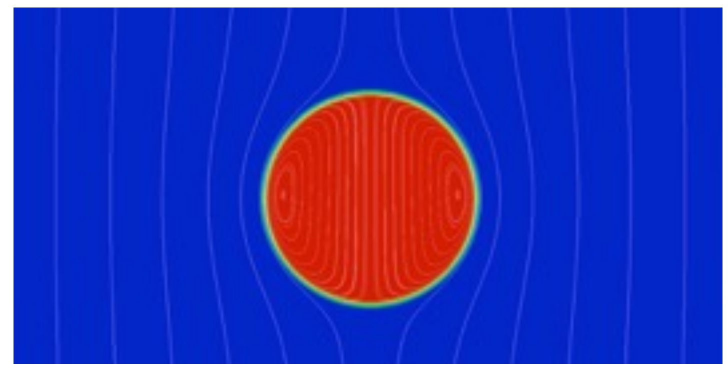
We-Re stability condition: $a_1/Re + a_2/We < C_D$



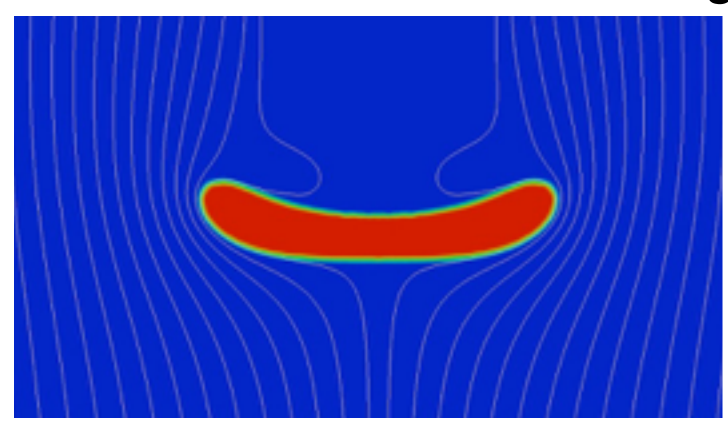
Summary: stability region

We-Re stability condition: $a_1/Re + a_2/We < C_D$

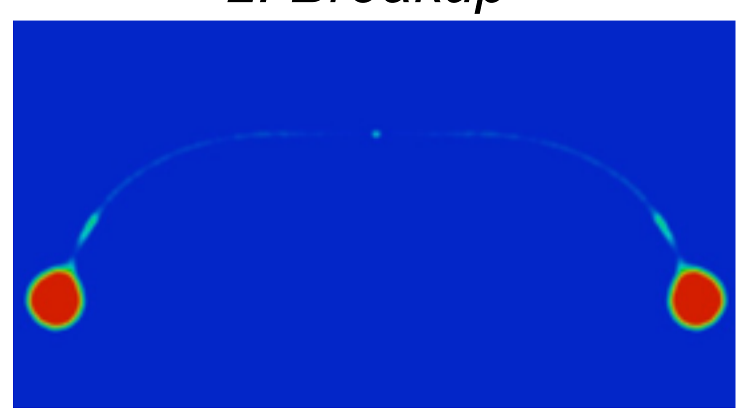


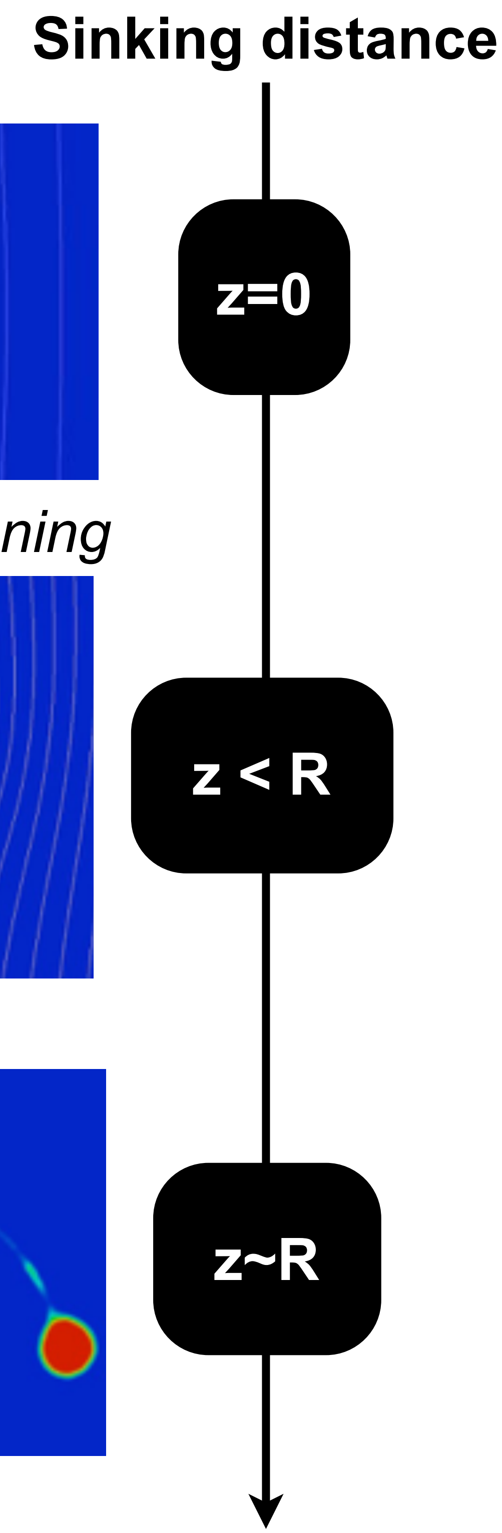


1. "Pancake-like" flattening



2. Breakup

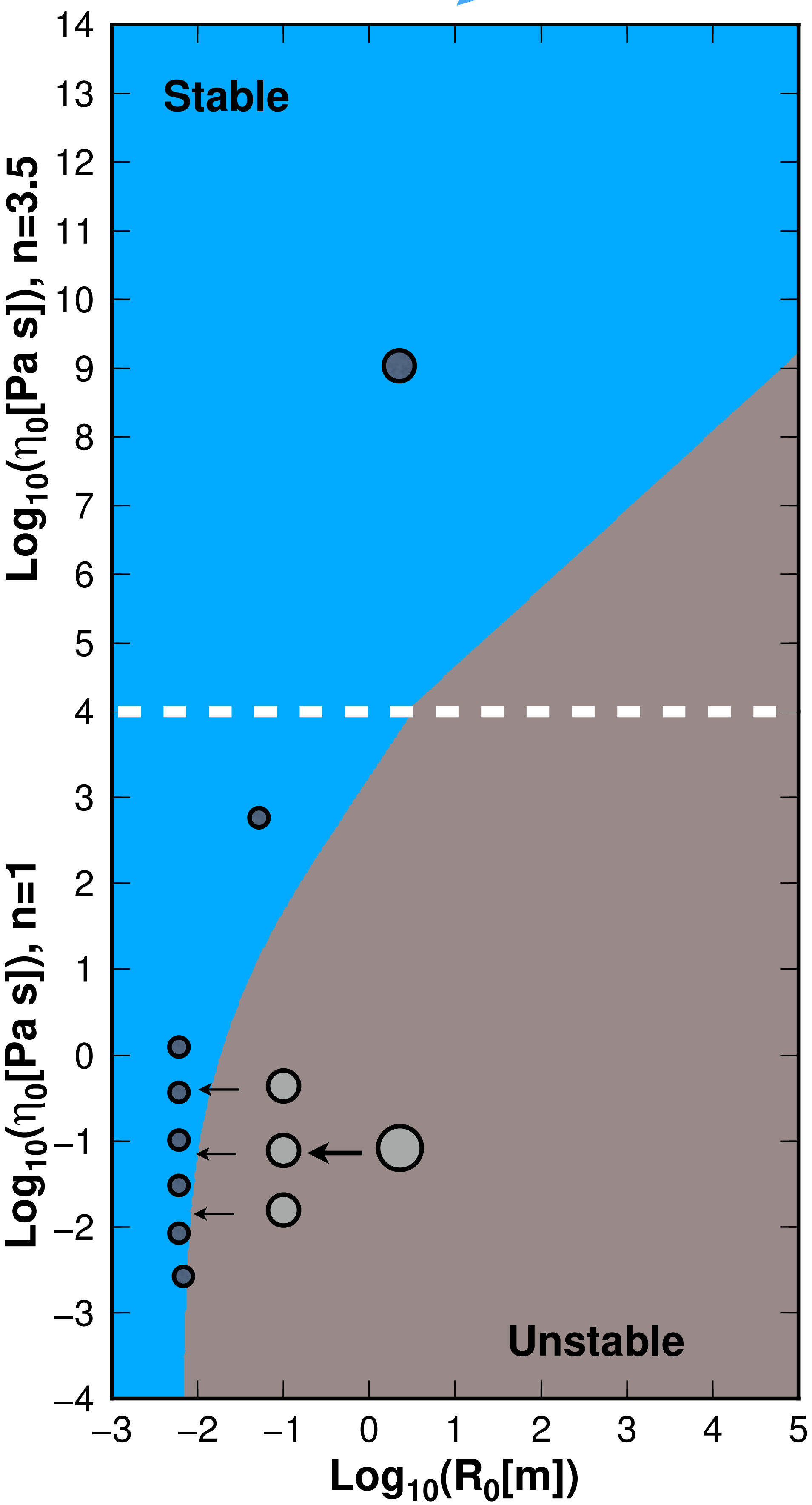


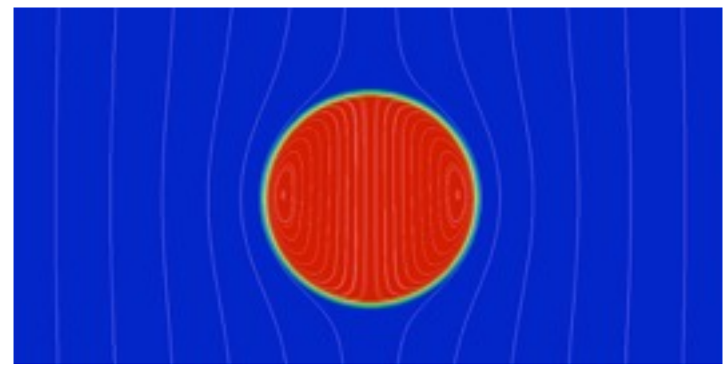


[Samuel, 2012]
+ this work

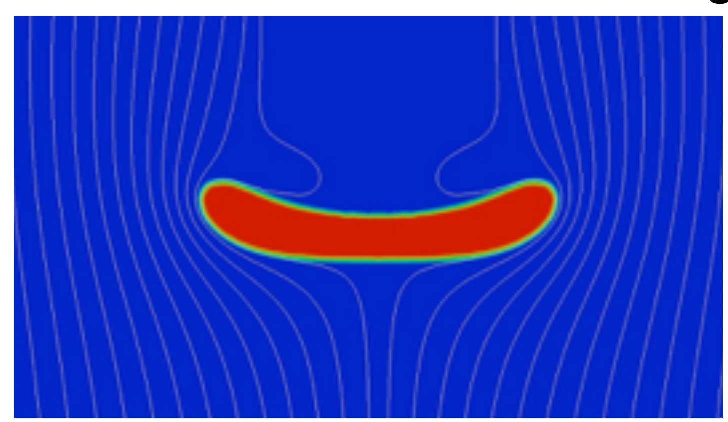
Summary: stability region

We-Re stability condition: $a_1/Re + a_2/We < C_D$

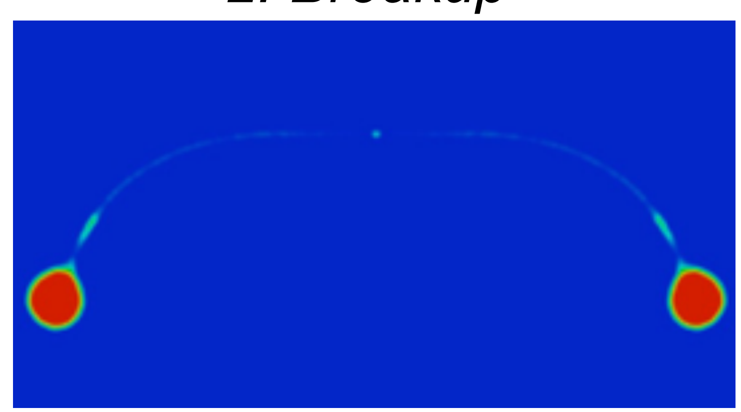




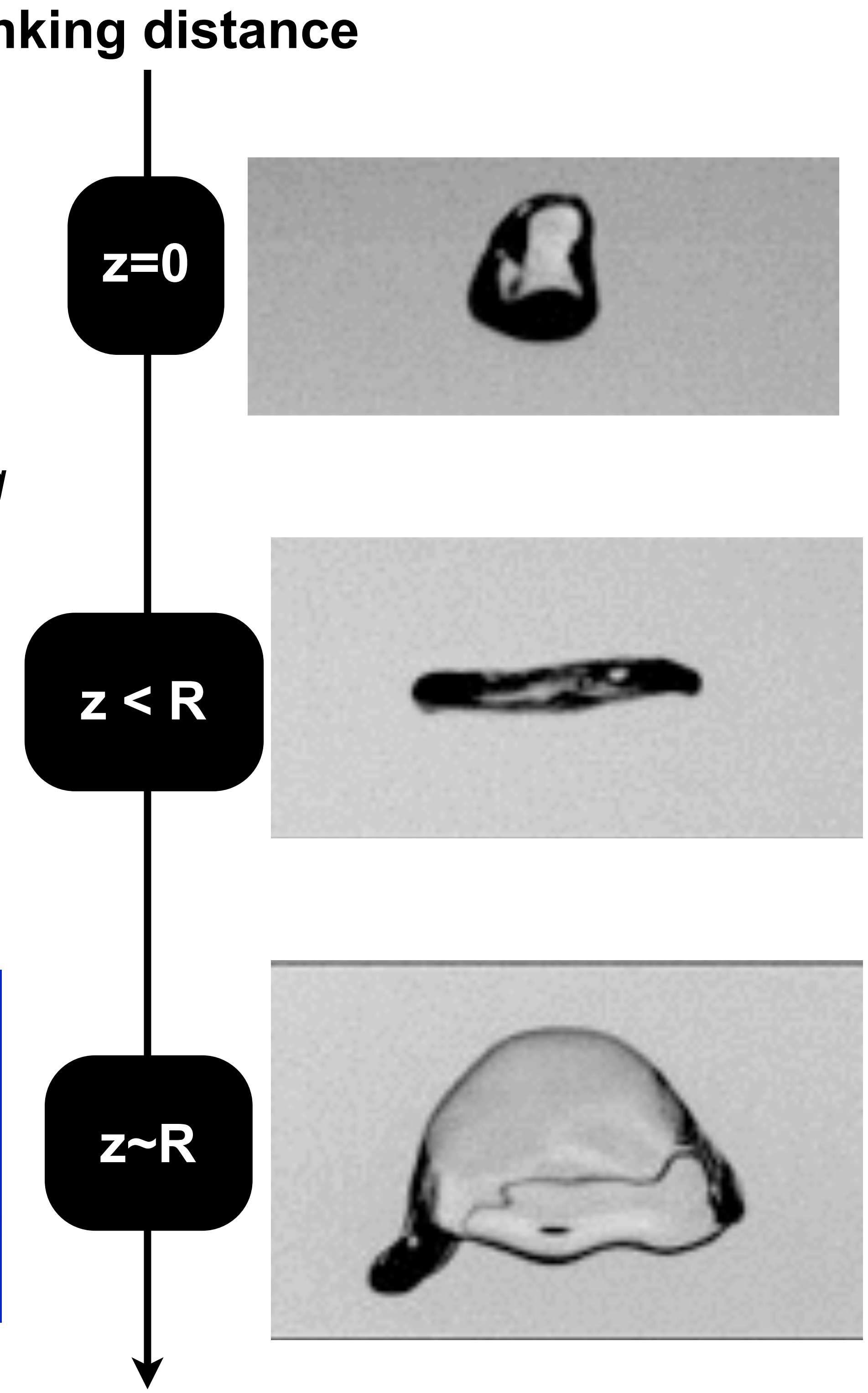
1. "Pancake-like" flattening



2. Breakup



[Samuel, 2012]
+ this work



[Villermaux, 2007]

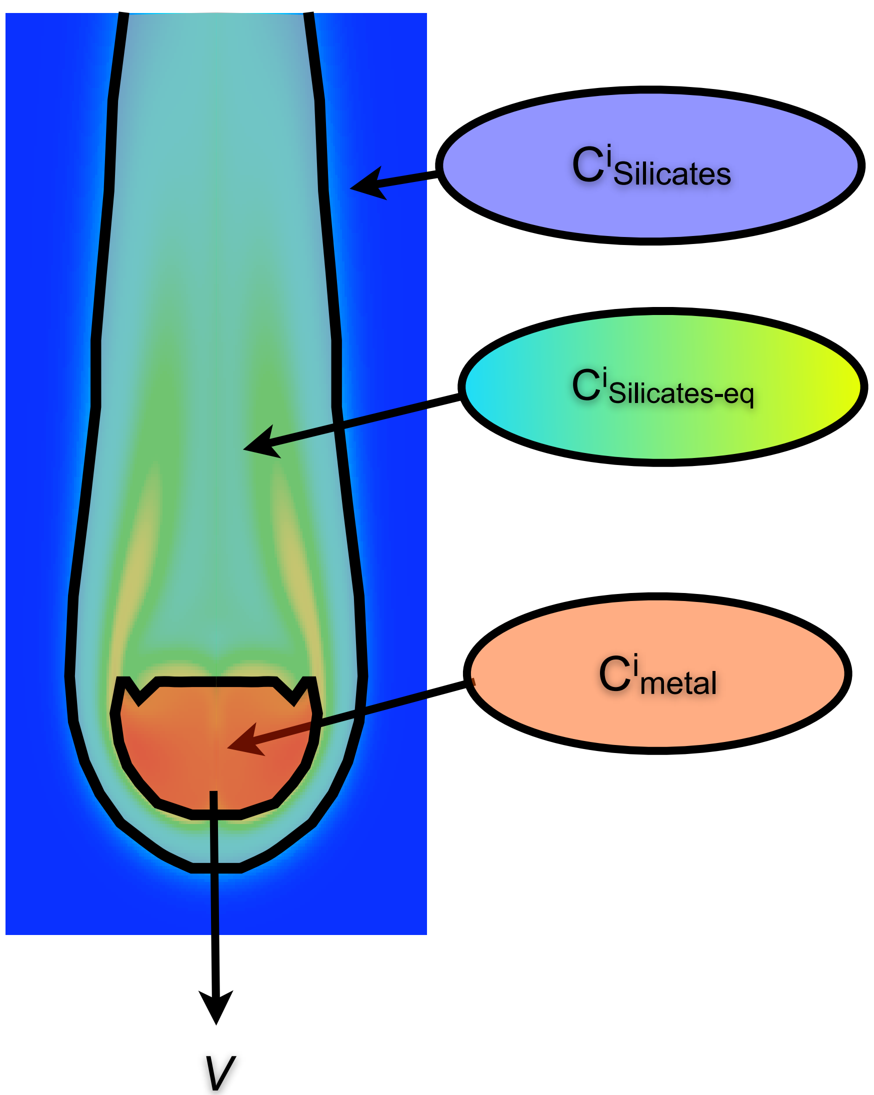
Metal-Silicate Equilibration in magma oceans

Fick's law: $$\frac{dC_m}{dt} = (1 - C_m)\sqrt{\frac{9}{2}\frac{1}{Pe}}$$

Chemical Péclet number: $$Pe = \frac{v_\infty R_0}{\kappa_c}$$

Degree of equilibration: $$C_m(t) = 1 - \ e^{-t\ \sqrt{\frac{9}{2}\frac{1}{Pe}}}$$

Essentially molten, Newtonian magma ocean



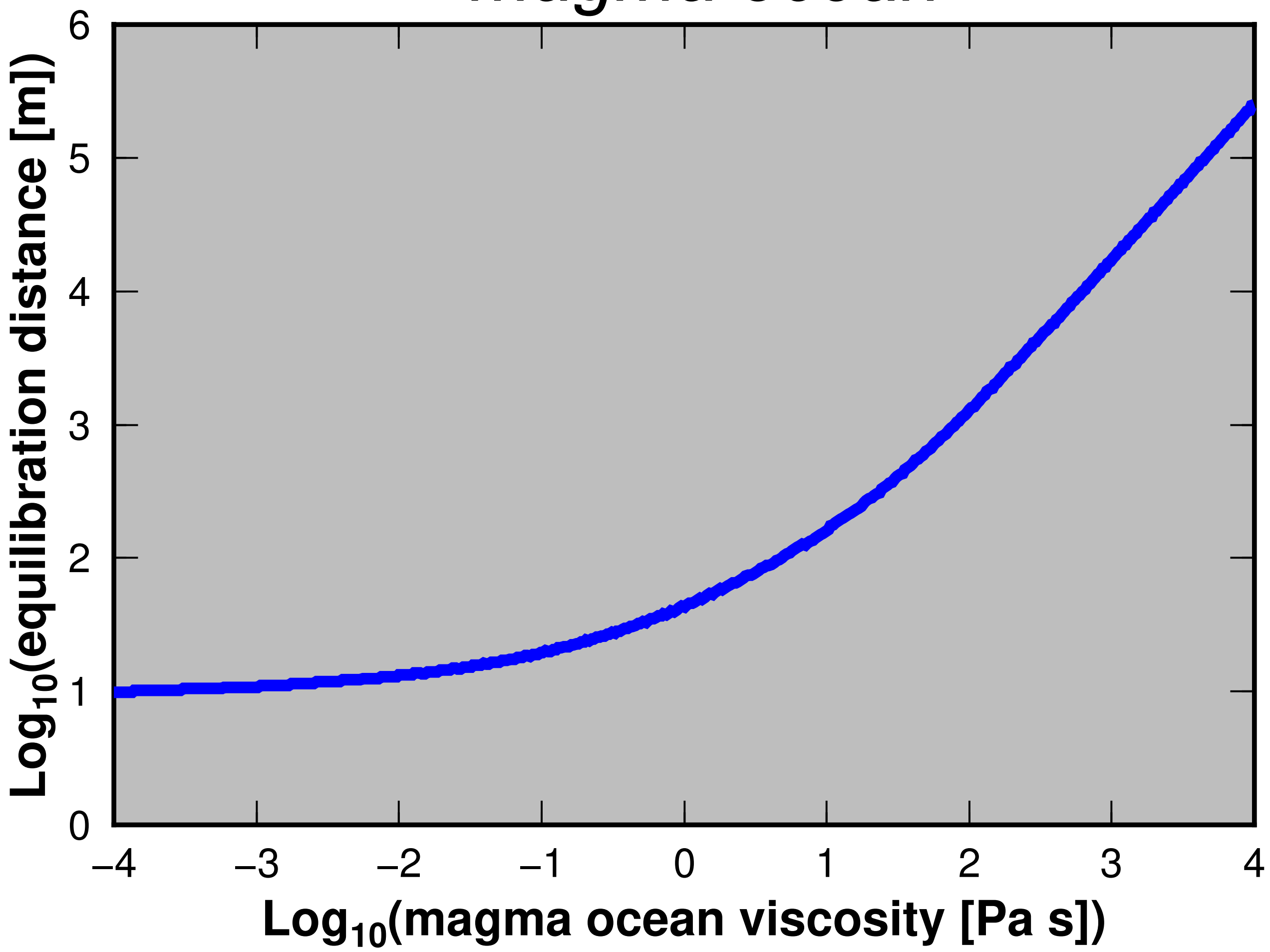
Metal-Silicate Equilibration in magma oceans

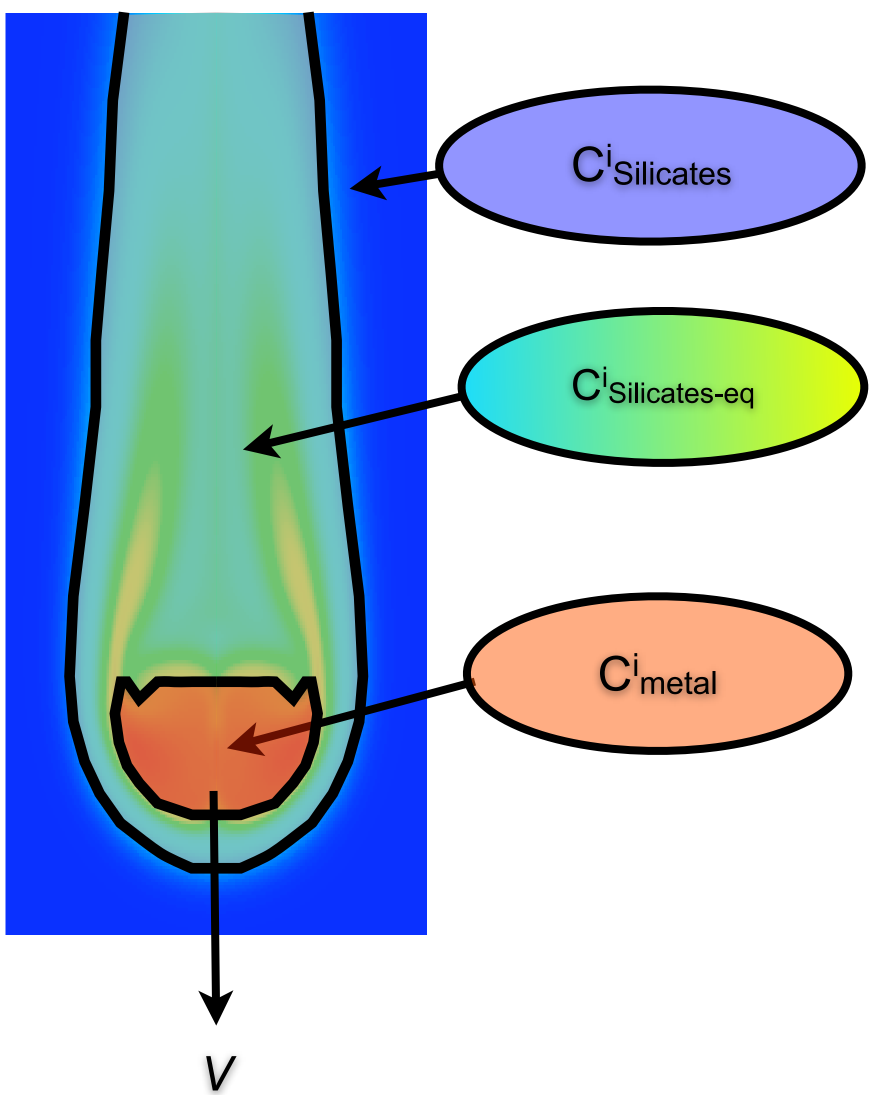
Fick's law: $\frac{dC_m}{dt} = (1 - C_m)\sqrt{\frac{9}{2}\frac{1}{Pe}}$

Chemical Péclet number: $Pe = \frac{v_\infty R_0}{\kappa_c}$

Degree of equilibration: $C_m(t) = 1 - e^{-t\sqrt{\frac{9}{2}\frac{1}{Pe}}}$

Essentially molten, Newtonian magma ocean



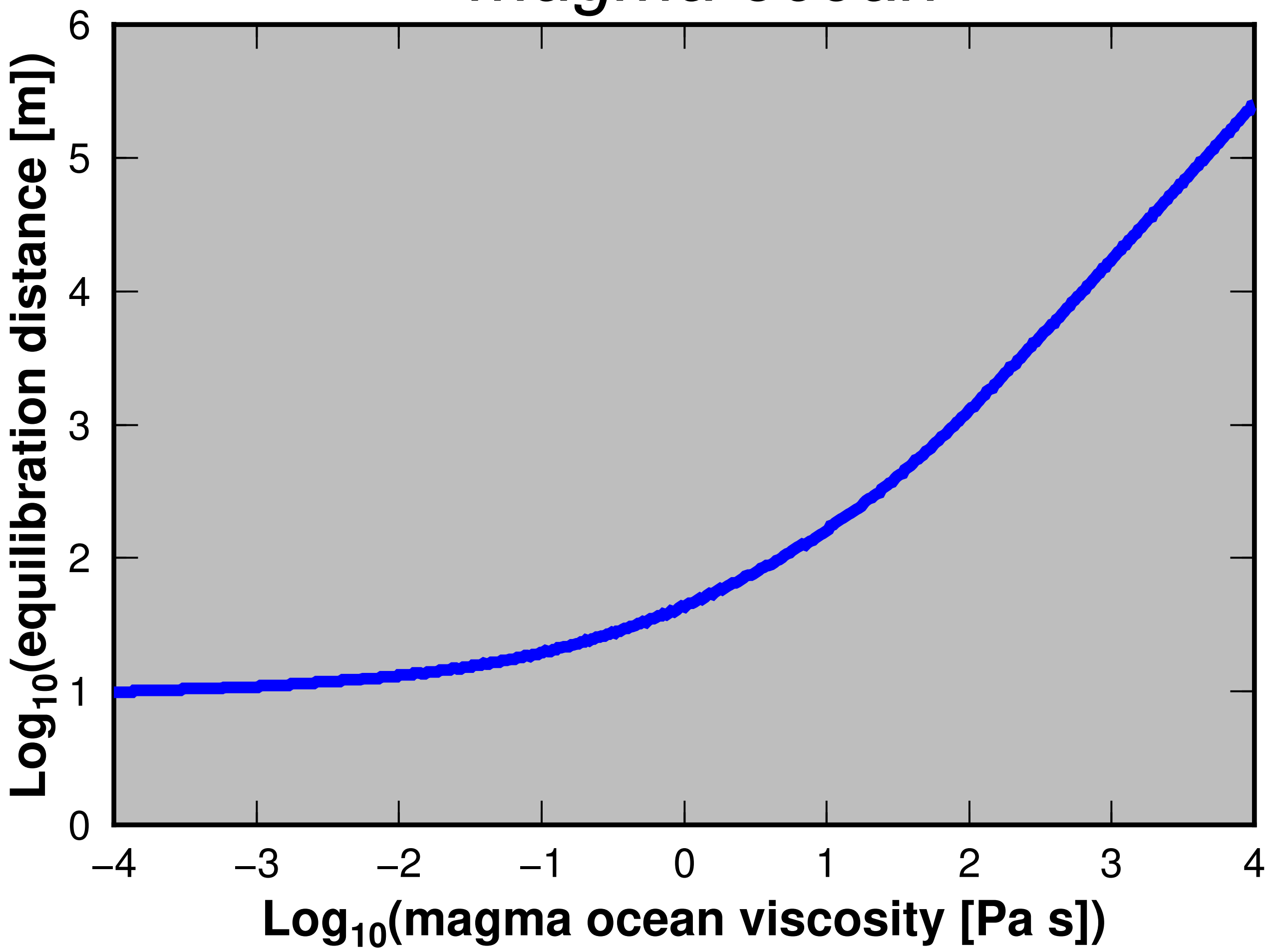


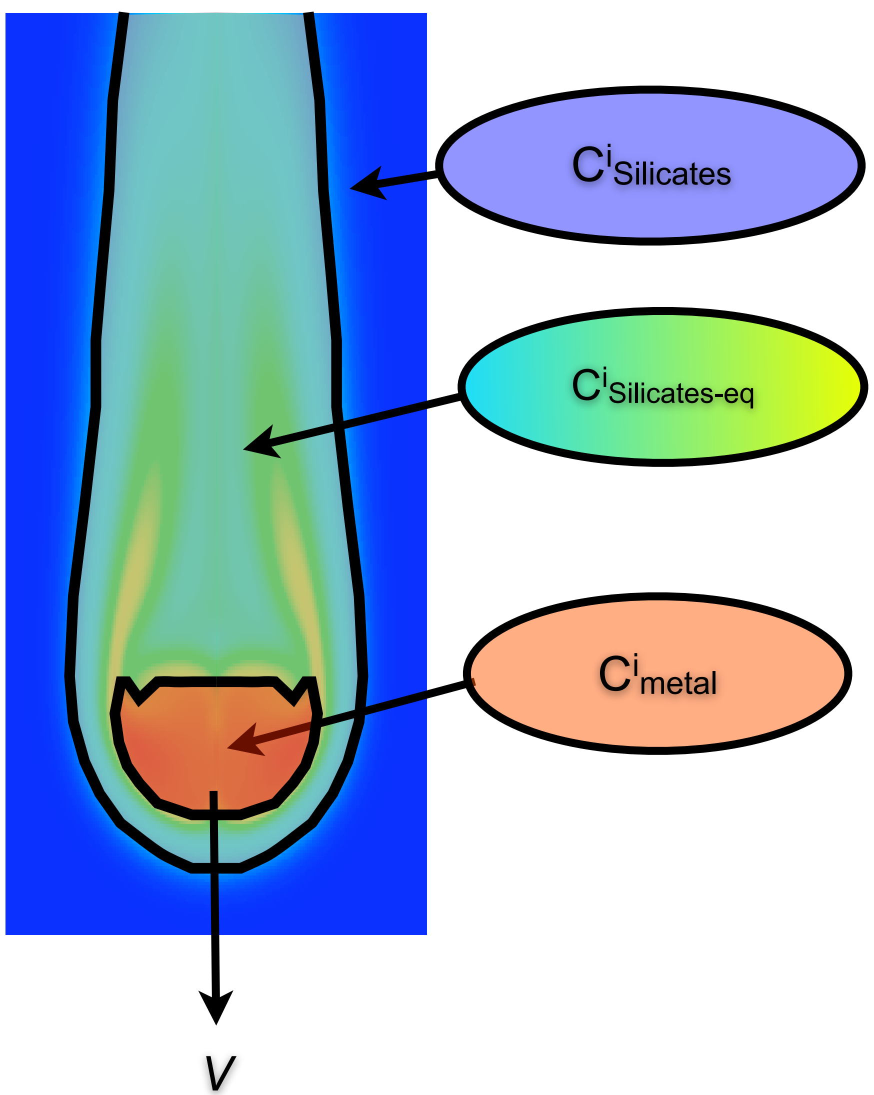
Metal-Silicate Equilibration in magma oceans

Fick's law: $\frac{dC_m}{dt} = (1 - C_m)\sqrt{\frac{9}{2}\frac{1}{Pe}}$ **Chemical Péclet number:** $Pe = \frac{v_\infty R_0}{\kappa_c}$

Degree of equilibration: $C_m(t) = 1 - \ e^{-t\ \sqrt{\frac{9}{2}\frac{1}{Pe}}}$

Essentially molten, Newtonian magma ocean





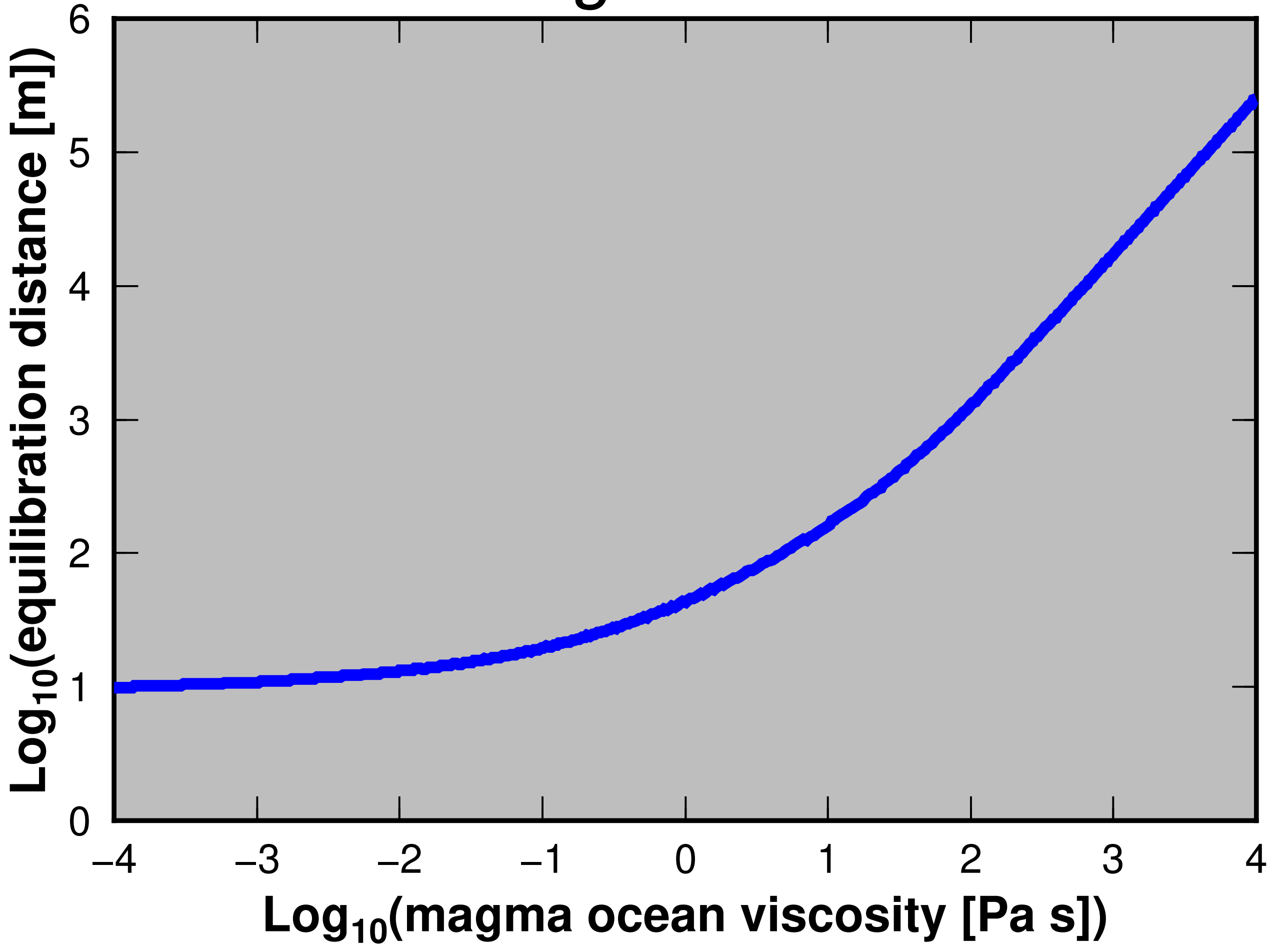
➪**Complete or partial equilibration likely for plausible values of magma ocean viscosities**

Metal-Silicate Equilibration in magma oceans

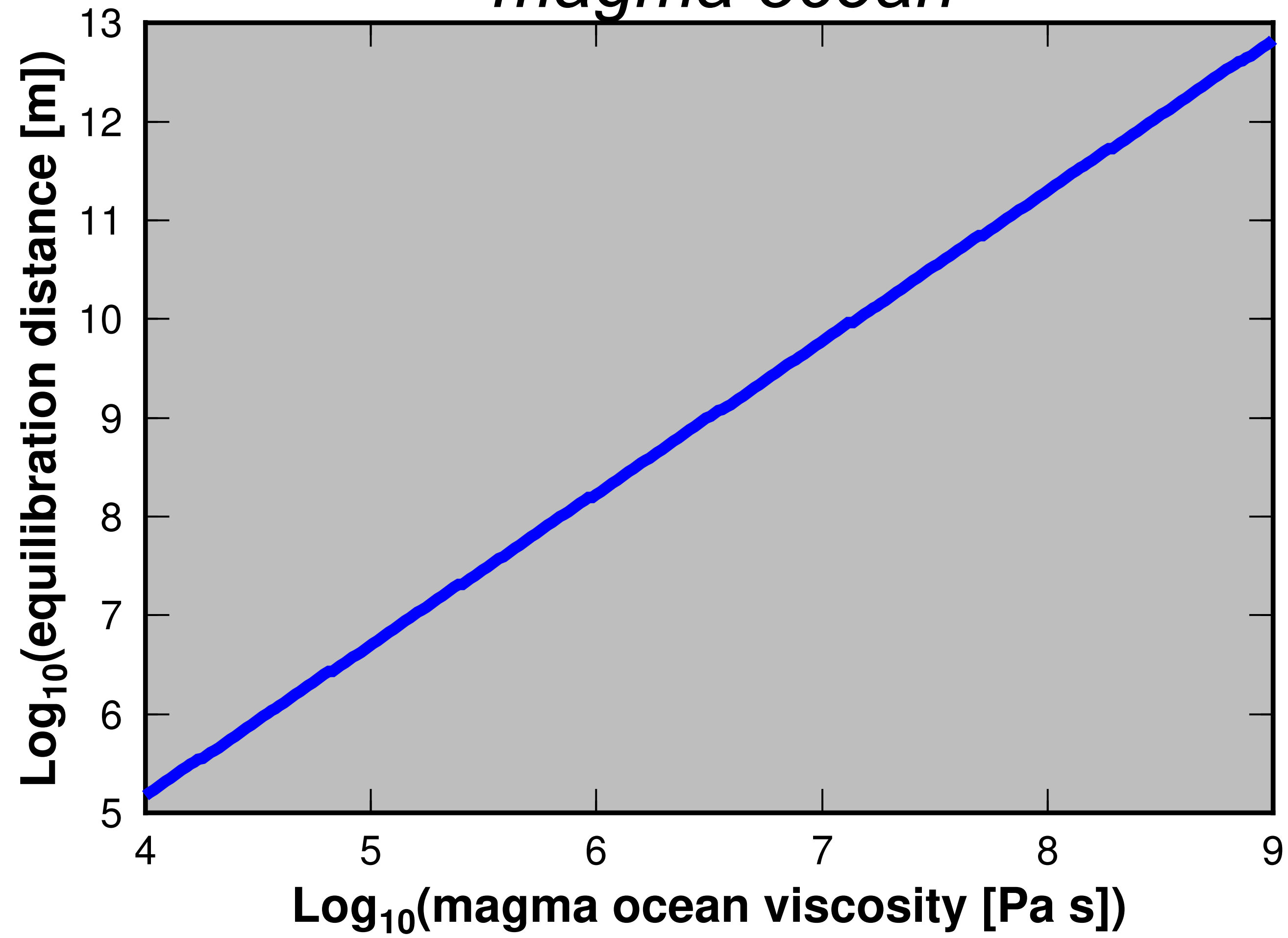
Fick's law: $\dfrac{dC_m}{dt} = (1 - C_m)\sqrt{\dfrac{9}{2}\dfrac{1}{Pe}}$ **Chemical Péclet number:** $Pe = \dfrac{v_\infty R_0}{\kappa_c}$

Degree of equilibration: $C_m(t) = 1 - \ e^{-t\ \sqrt{\frac{9}{2}\frac{1}{Pe}}}$

Essentially molten, Newtonian magma ocean



Partially molten, non-Newtonian magma ocean



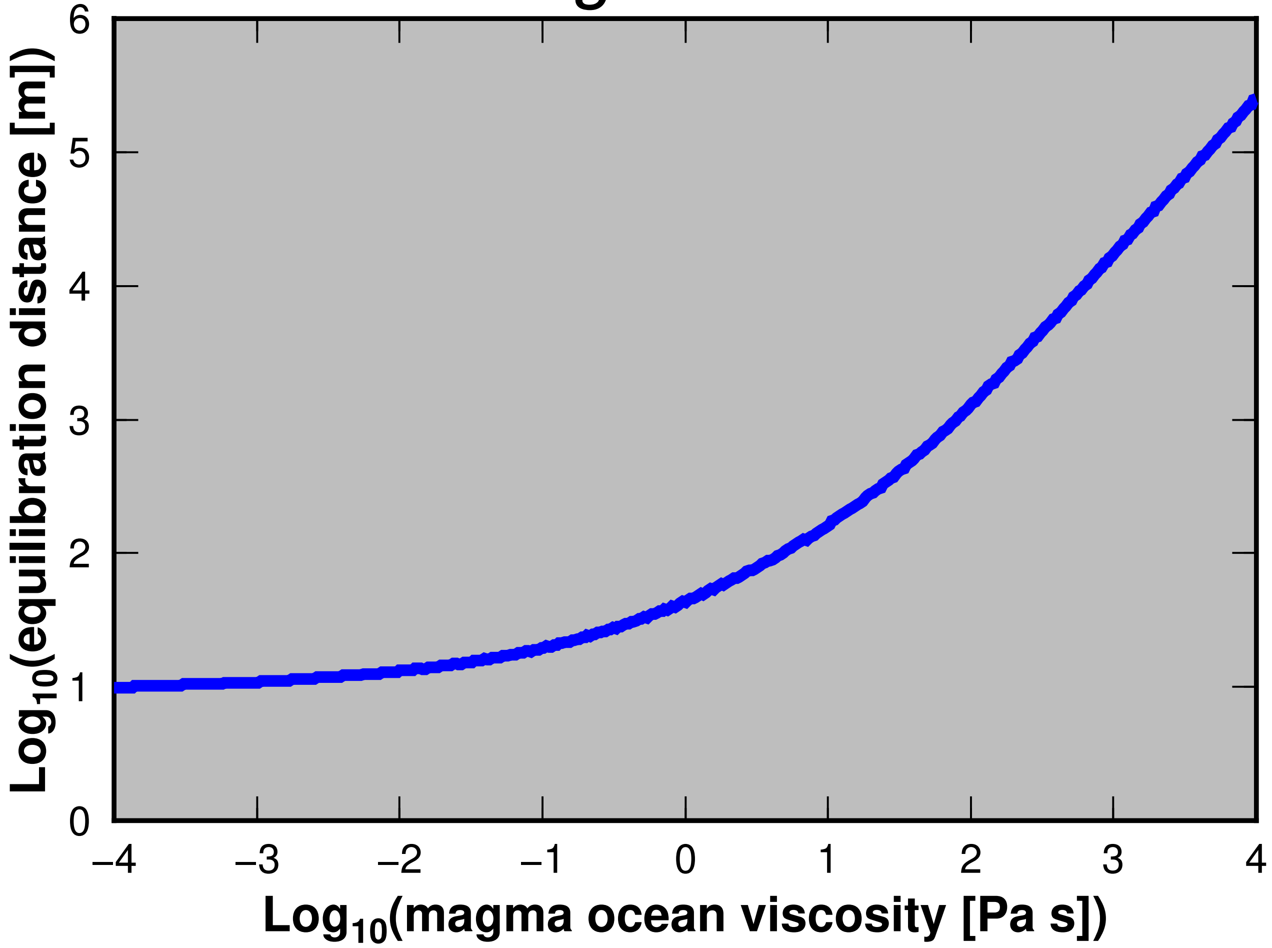
➩Complete or partial equilibration likely for plausible values of magma ocean viscosities

Metal-Silicate Equilibration in magma oceans

Fick's law: $\frac{dC_m}{dt} = (1 - C_m)\sqrt{\frac{9}{2}\frac{1}{Pe}}$ **Chemical Péclet number:** $Pe = \frac{v_\infty R_0}{\kappa_c}$

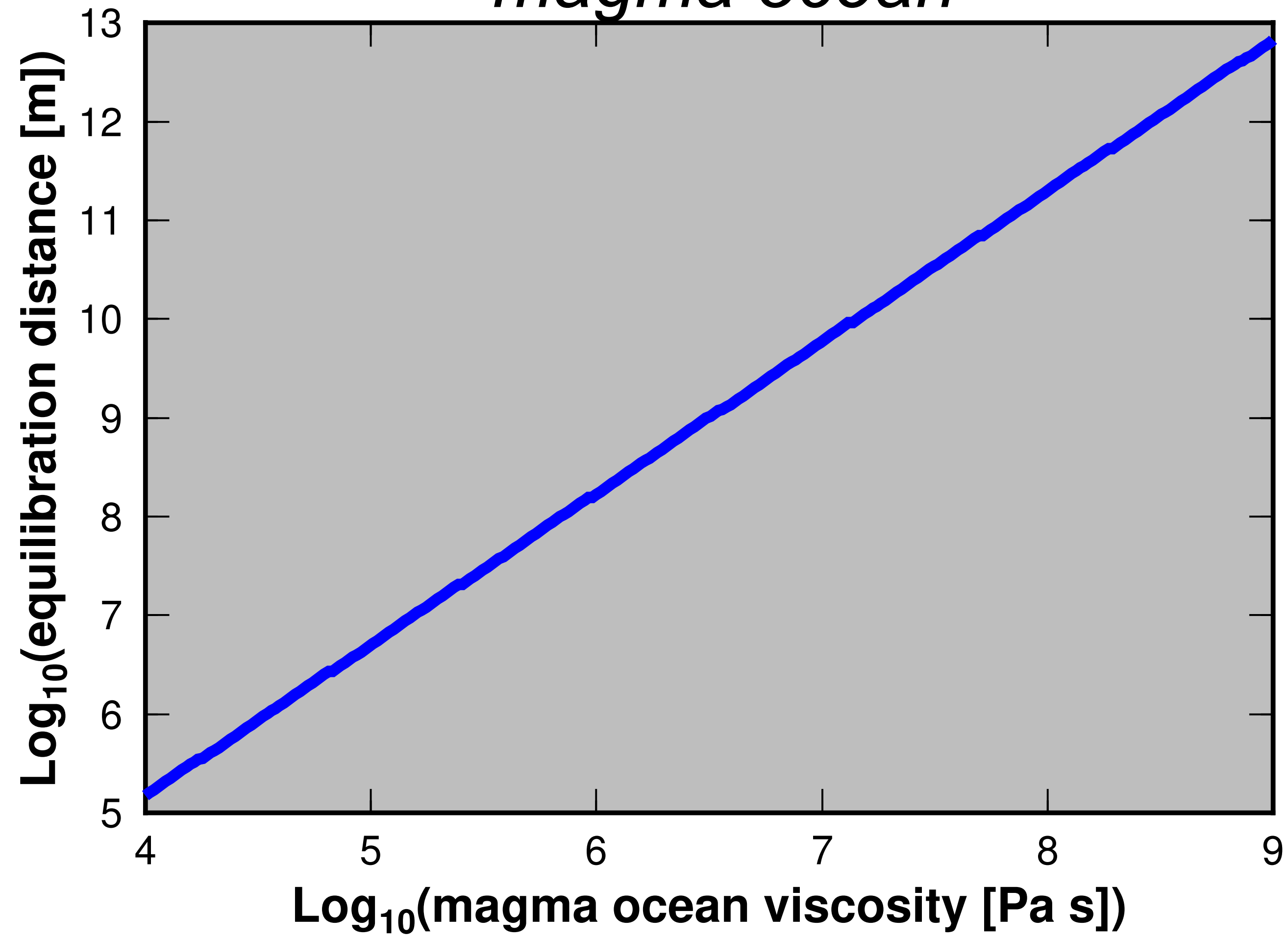
Degree of equilibration: $C_m(t) = 1 - e^{-t\sqrt{\frac{9}{2}\frac{1}{Pe}}}$

Essentially molten, Newtonian magma ocean



➯Complete or partial equilibration likely for plausible values of magma ocean viscosities

Partially molten, non-Newtonian magma ocean

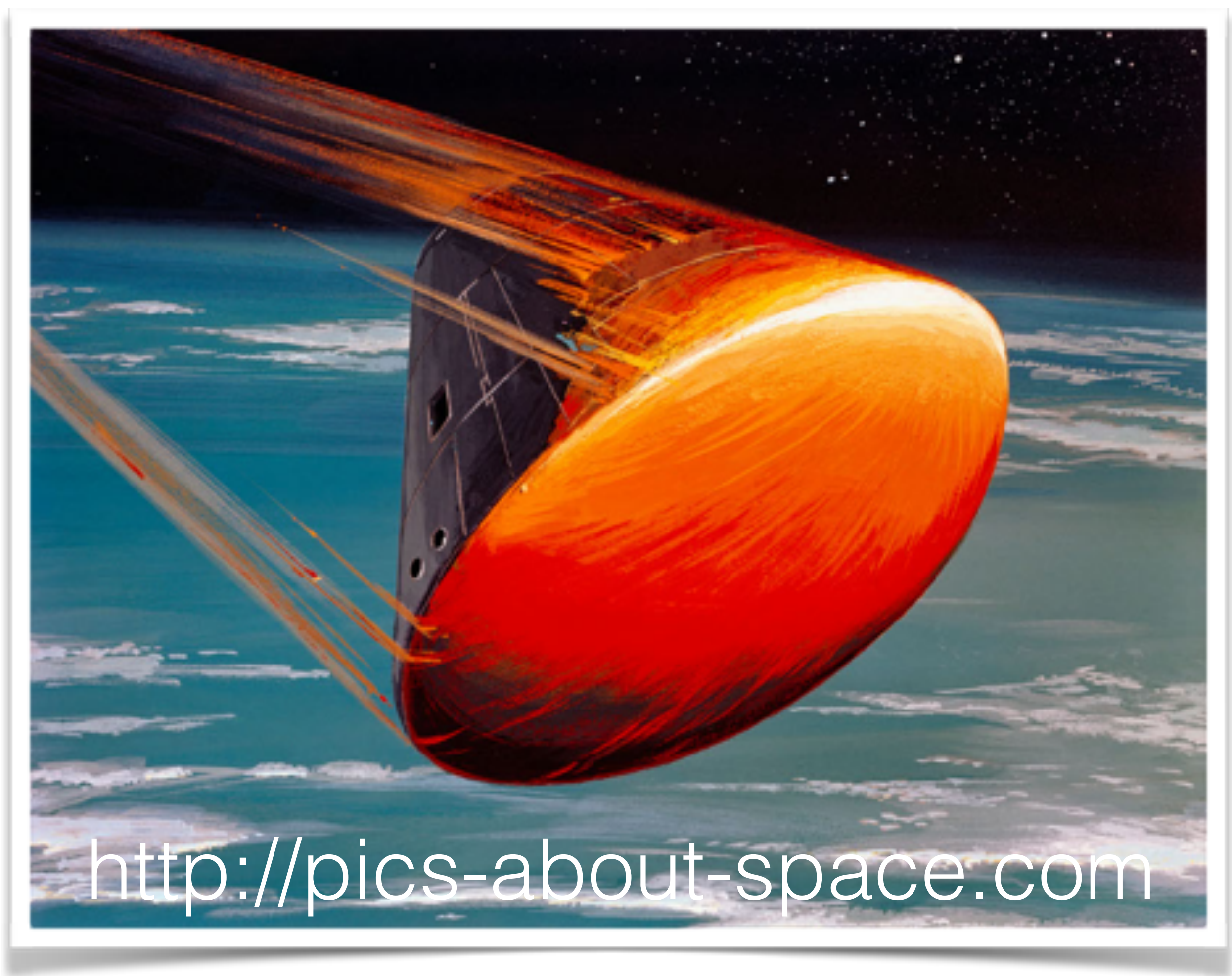


➯Complete equilibration unlikely

Viscous heating and heat partitioning

Gravitational potential energy ➪ Kinetic Energy ➪ Heat

$E_p = (\rho_m - \rho_s) g \ \Delta h \ V_d$ $E_k(t,Si,Fe) = (\rho/2) V u^2$? $E_T(t,Si,Fe) = \rho \ \Delta T \ C_p \ V$?



Viscous heating and heat partitioning

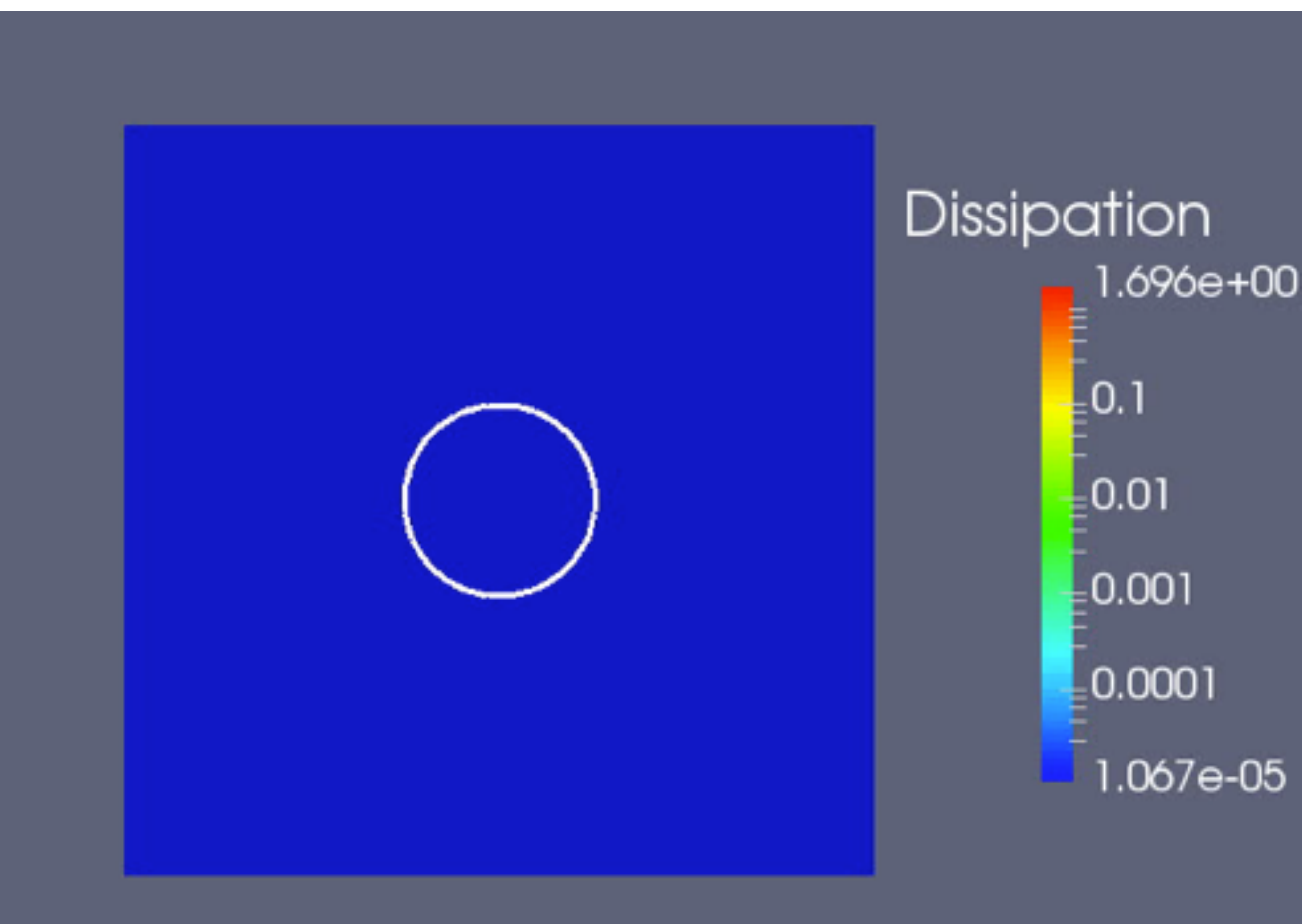
Conservation of internal energy: $\rho D_t T = Pe^{-1} \nabla^2 T + \Pi_v \ \tau : \dot{\varepsilon}$

diffusion viscous heating

$$\Pi_v = \frac{\eta_s V_\infty}{R \ \rho_s C_p \ \Delta T}$$

$$Pe = \frac{V_\infty R}{\kappa}$$

Π_v=10



Viscous heating and heat partitioning

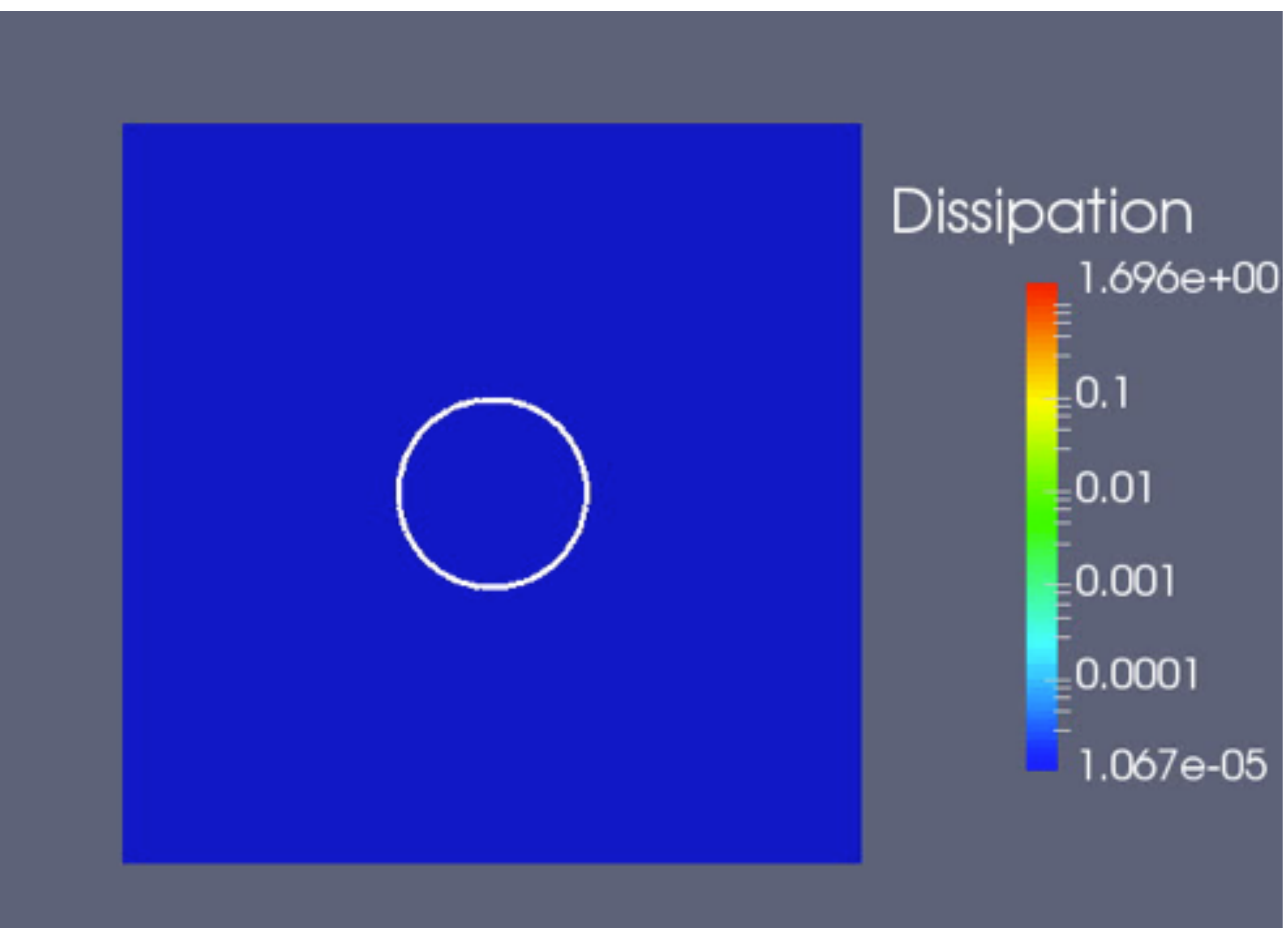
Conservation of internal energy: $\rho D_t T = Pe^{-1}\nabla^2 T + \Pi_v \; \tau : \dot{\varepsilon}$

diffusion viscous heating

$$\Pi_v = \frac{\eta_s V_\infty}{R \; \rho_s C_p \; \Delta T}$$

$$Pe = \frac{V_\infty R}{\kappa}$$

Π_v=10



Viscous heating and heat partitioning

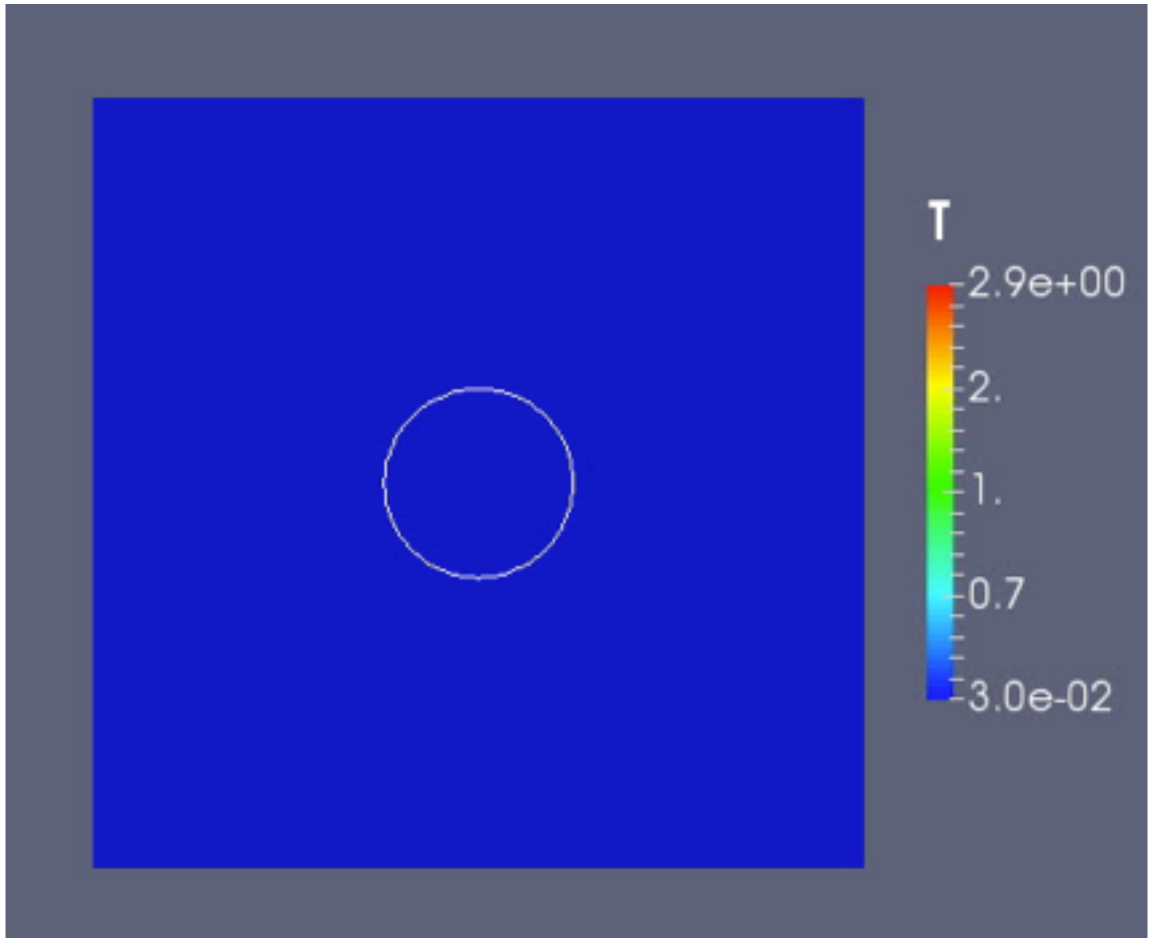
Conservation of internal energy: $\rho D_t T = Pe^{-1} \nabla^2 T + \Pi_v \ \tau : \dot{\varepsilon}$

diffusion viscous heating

$$\Pi_v = \frac{\eta_s V_\infty}{R \ \rho_s C_p \ \Delta T}$$

$$Pe = \frac{V_\infty R}{\kappa}$$

Π_v=10



Viscous heating and heat partitioning

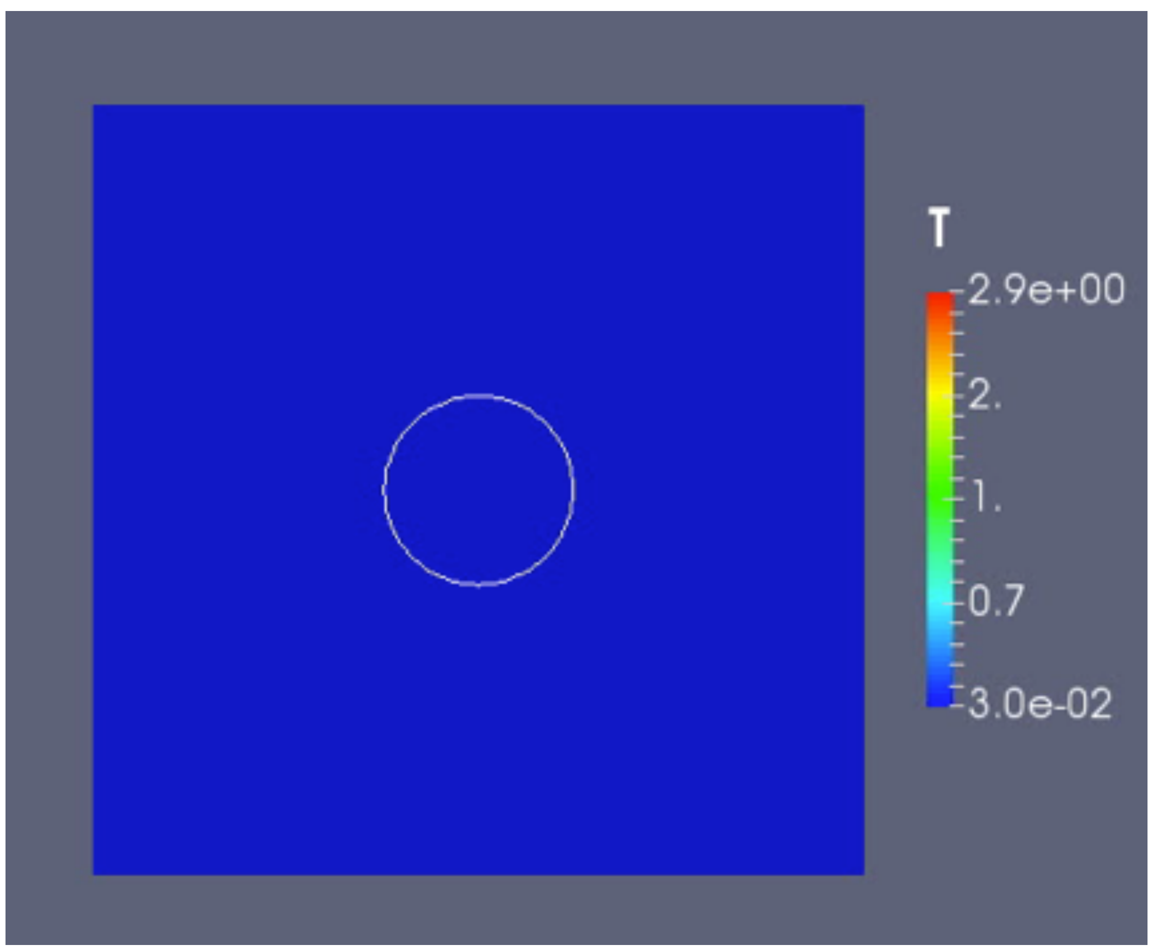
Conservation of internal energy: $$\rho D_t T = Pe^{-1} \nabla^2 T + \Pi_v \ \tau : \dot{\varepsilon}$$

diffusion viscous heating

$$\Pi_v = \frac{\eta_s V_\infty}{R \ \rho_s C_p \ \Delta T}$$

$$Pe = \frac{V_\infty R}{\kappa}$$

Π_v=10



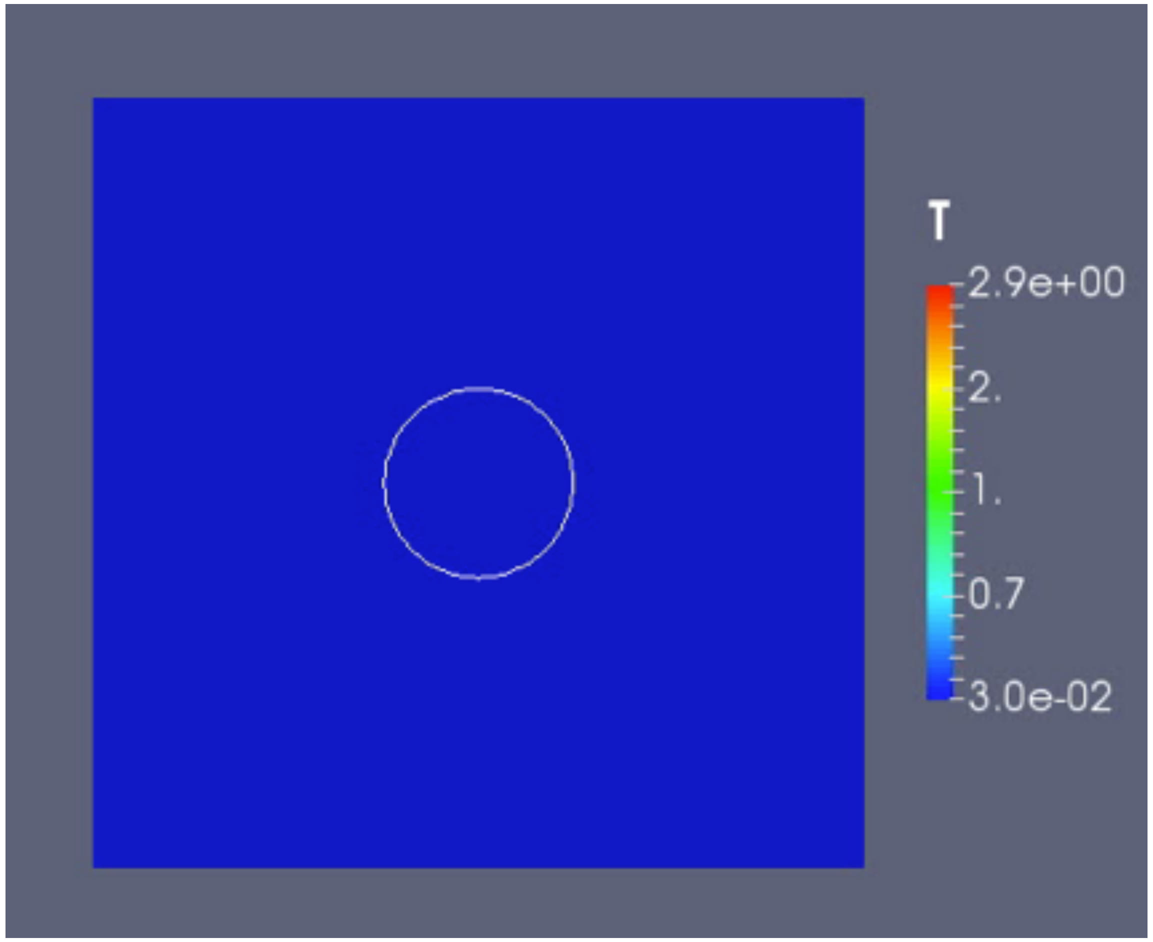
Viscous heating and heat partitioning

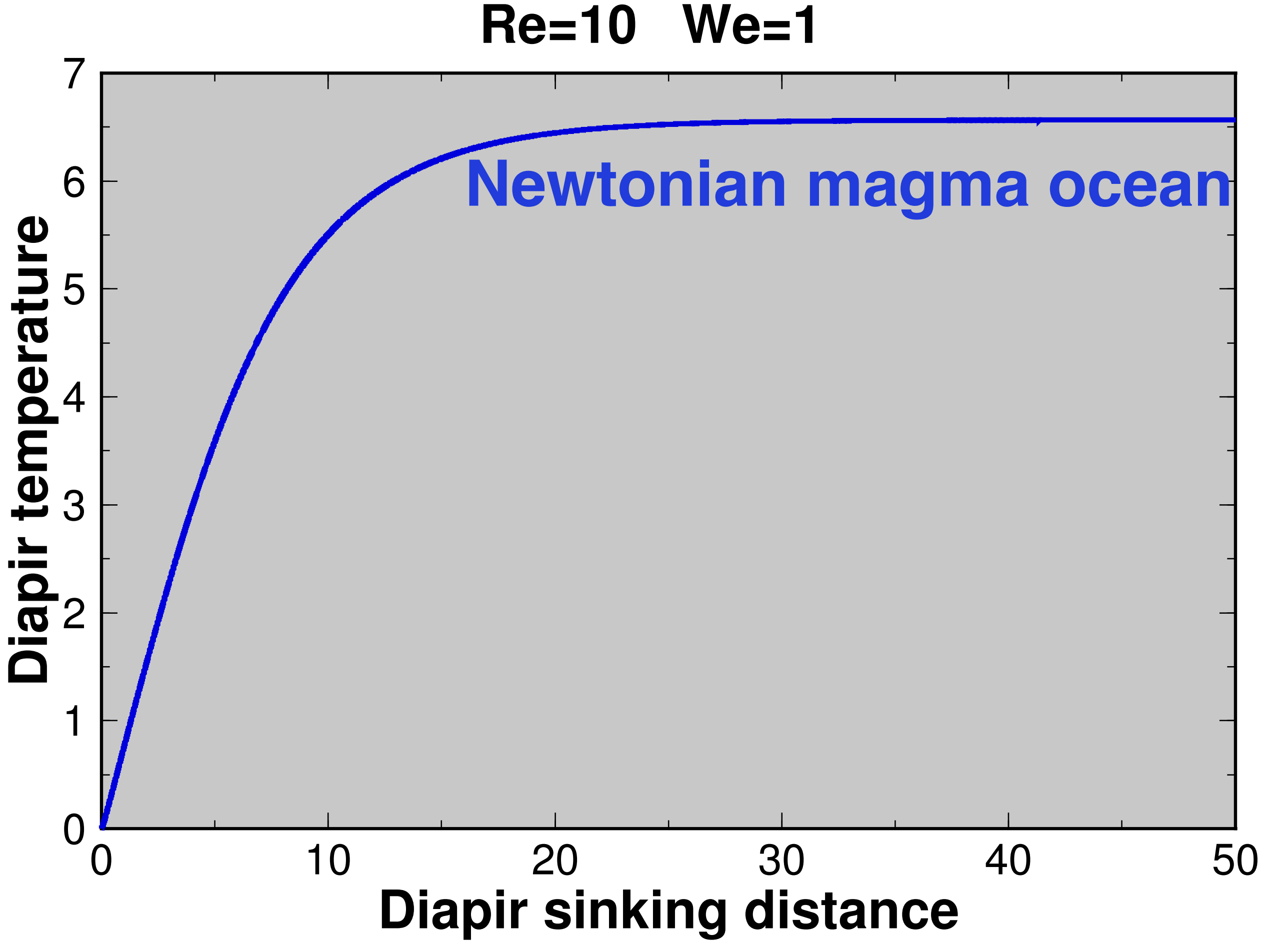
Conservation of internal energy: $\rho D_t T = Pe^{-1} \nabla^2 T + \Pi_v \; \tau : \dot{\varepsilon}$

diffusion viscous heating

$$\Pi_v = \frac{\eta_s V_\infty}{R \; \rho_s C_p \; \Delta T} \qquad Pe = \frac{V_\infty R}{\kappa}$$

Π_v=10





Viscous heating and heat partitioning

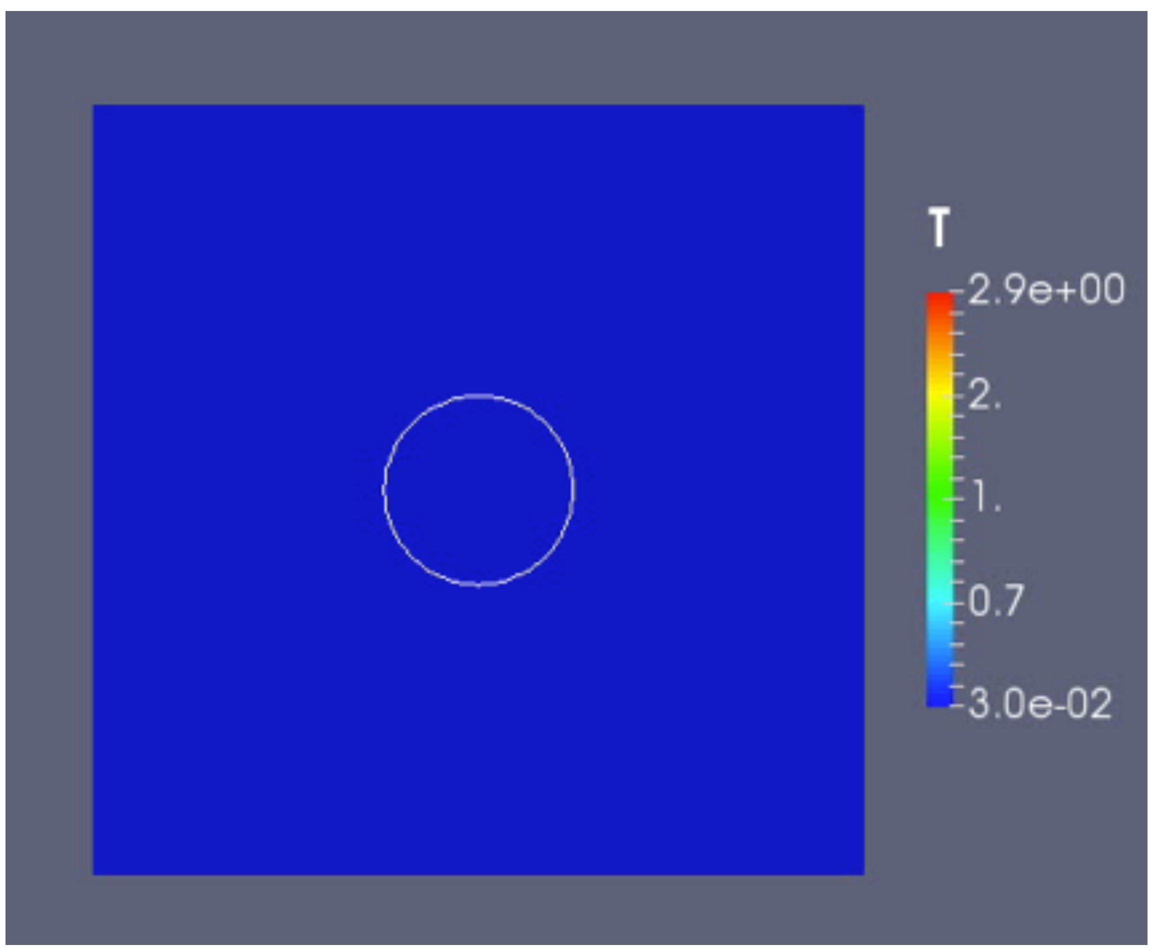
Conservation of internal energy: $\rho D_t T = Pe^{-1}\nabla^2 T + \Pi_v\ \tau : \dot{\varepsilon}$

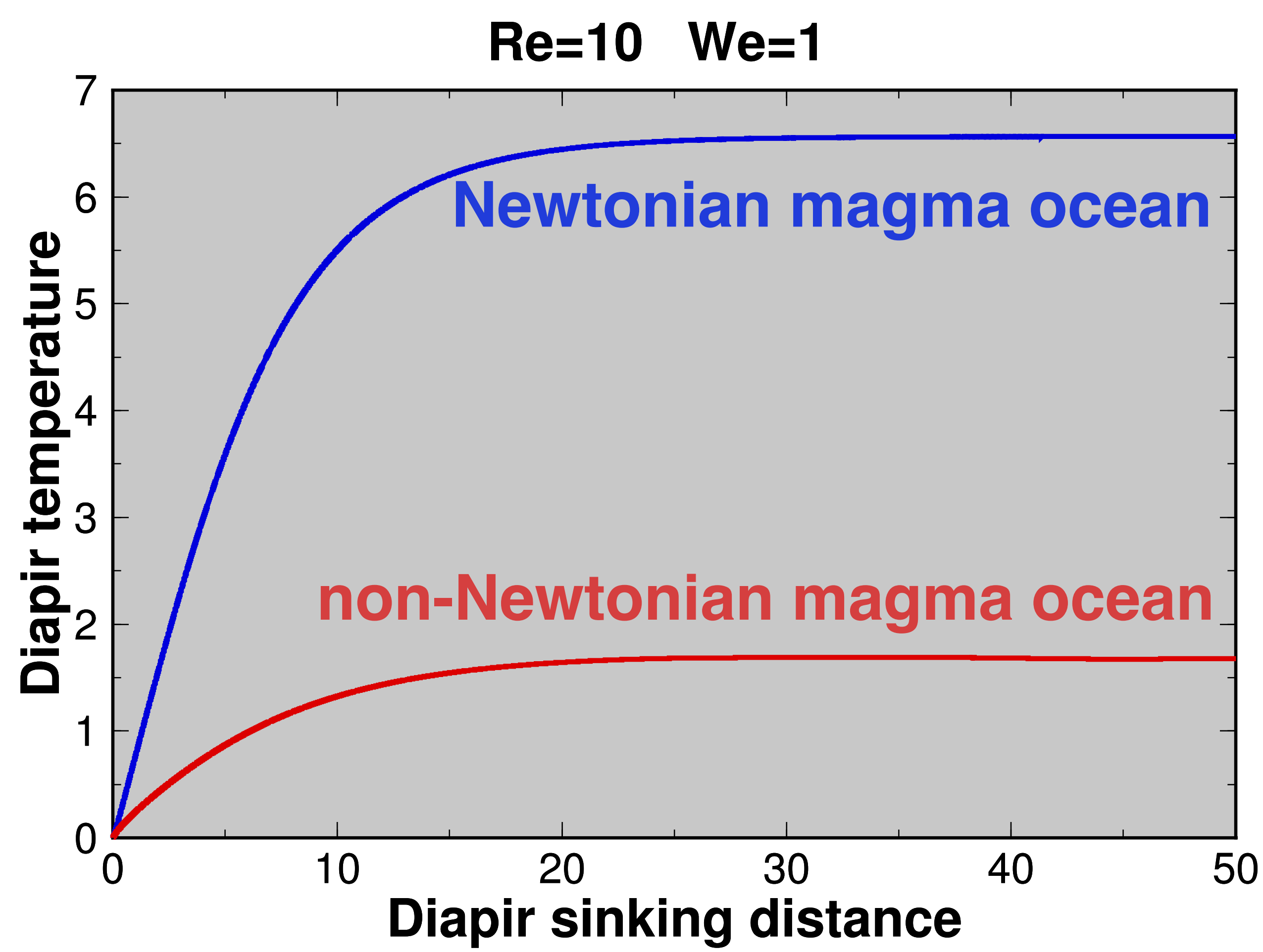
diffusion   viscous heating

$$\Pi_v = \frac{\eta_s V_\infty}{R\ \rho_s C_p\ \Delta T}$$

$$Pe = \frac{V_\infty R}{\kappa}$$

Π_v=10





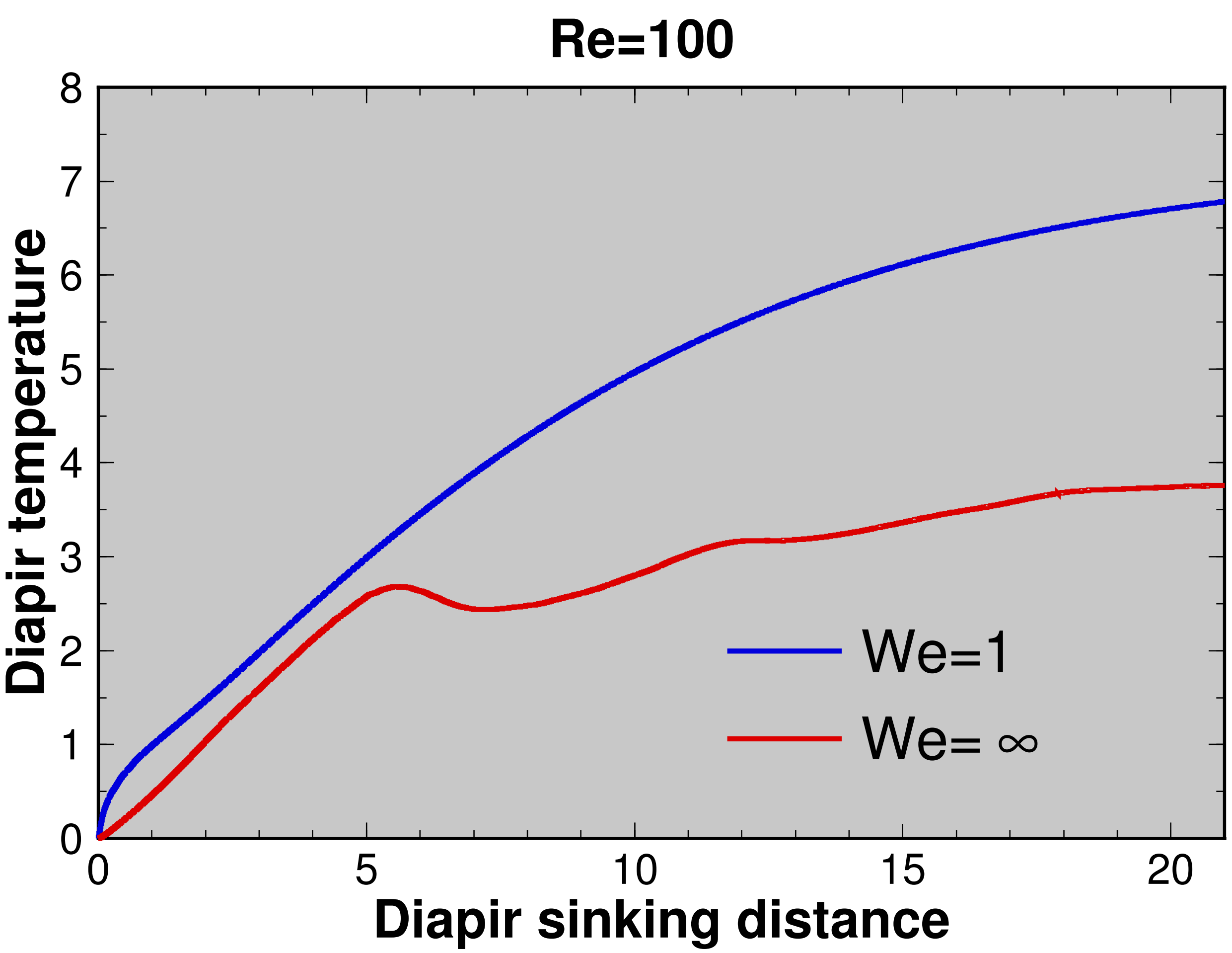
Viscous heating and heat partitioning

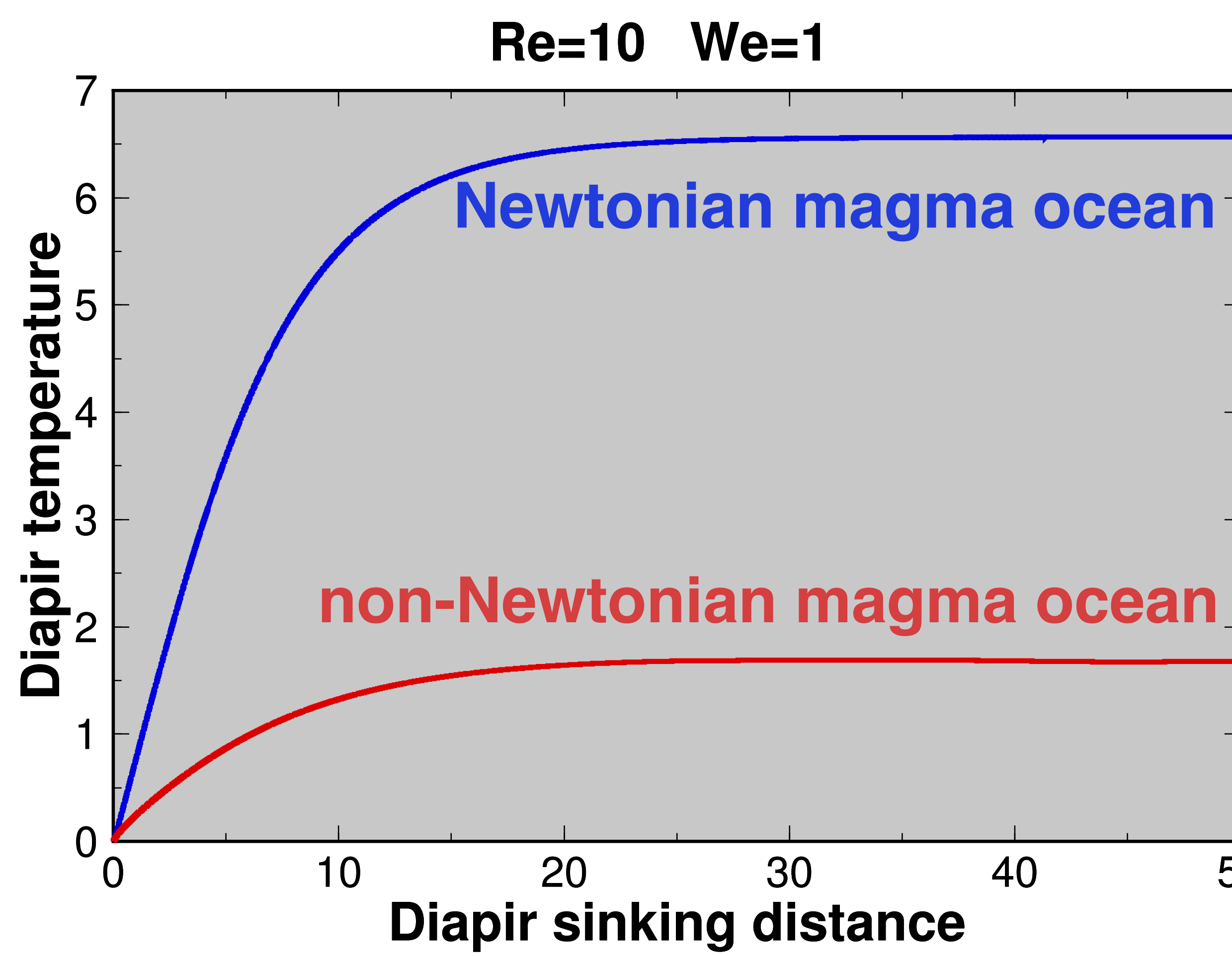
Conservation of internal energy: $\rho D_t T = Pe^{-1} \nabla^2 T + \Pi_v \; \tau : \dot{\varepsilon}$

diffusion — viscous heating

$$\Pi_v = \frac{\eta_s V_\infty}{R \; \rho_s C_p \; \Delta T} \qquad Pe = \frac{V_\infty R}{\kappa}$$

Π_v=10





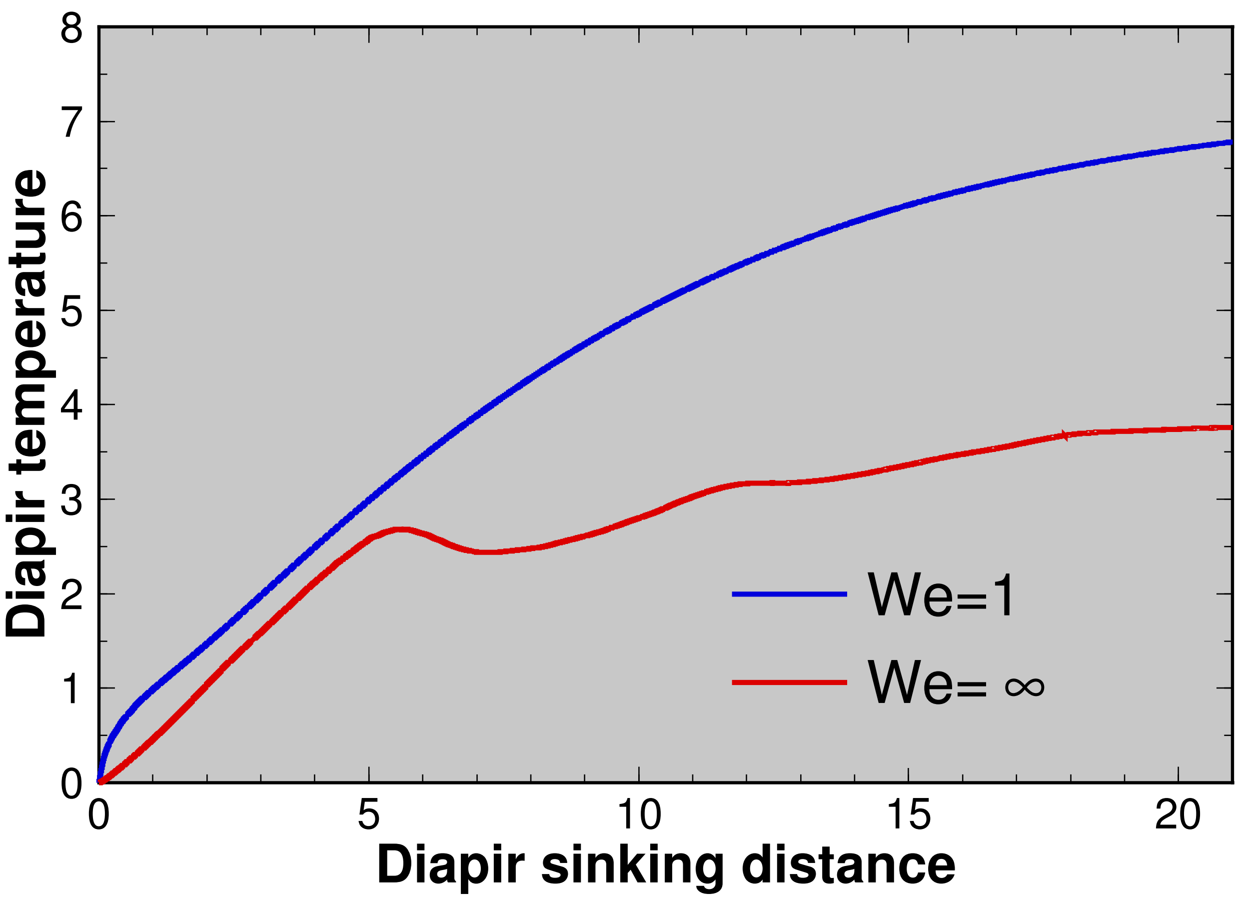
Viscous heating and heat partitioning

Conservation of internal energy: $$\rho D_t T = \underbrace{Pe^{-1}\nabla^2 T}_{\text{diffusion}} + \underbrace{\Pi_v \; \tau : \dot{\varepsilon}}_{\text{viscous heating}}$$

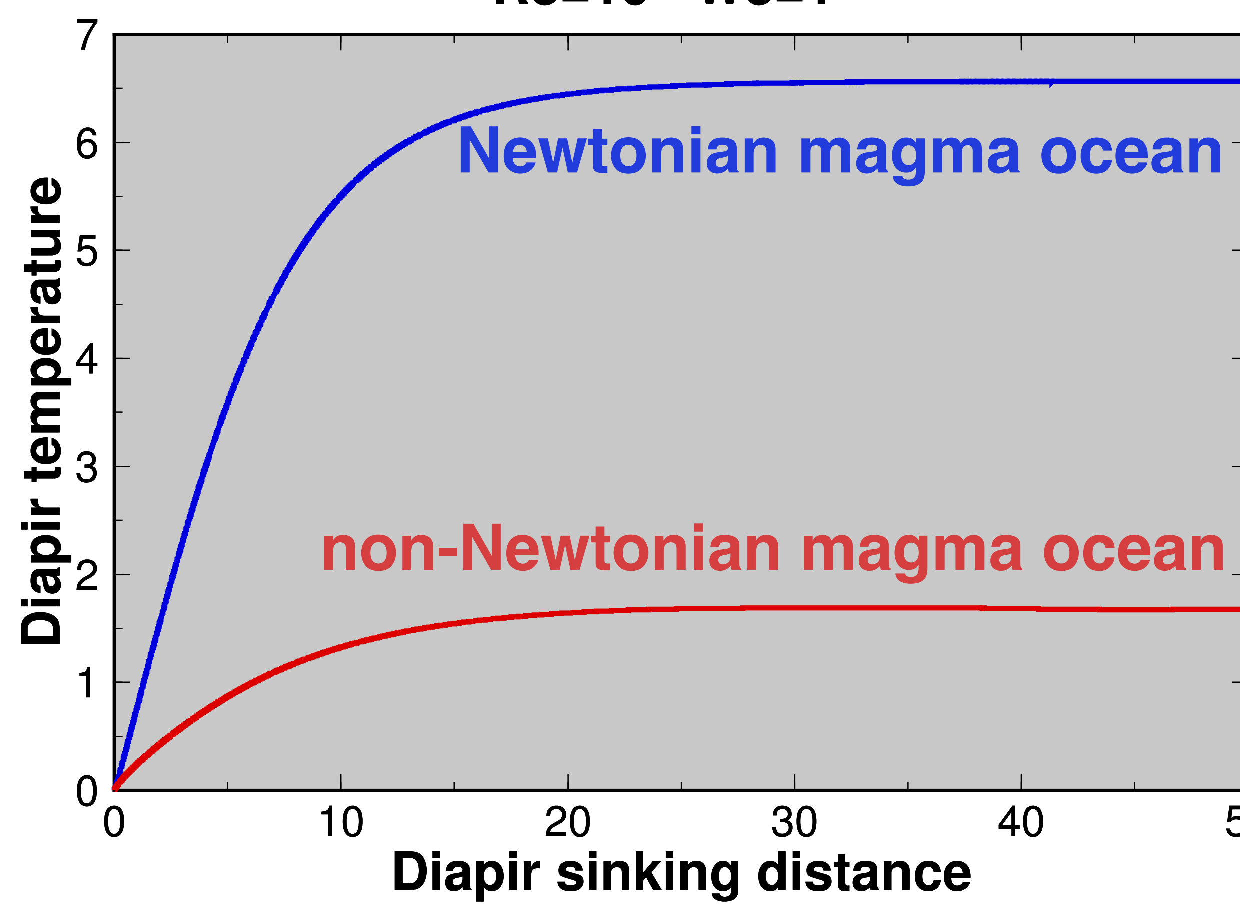
$$\Pi_v = \frac{\eta_s V_\infty}{R \; \rho_s C_p \; \Delta T} \qquad Pe = \frac{V_\infty R}{\kappa}$$

Π_v=10

Re=100

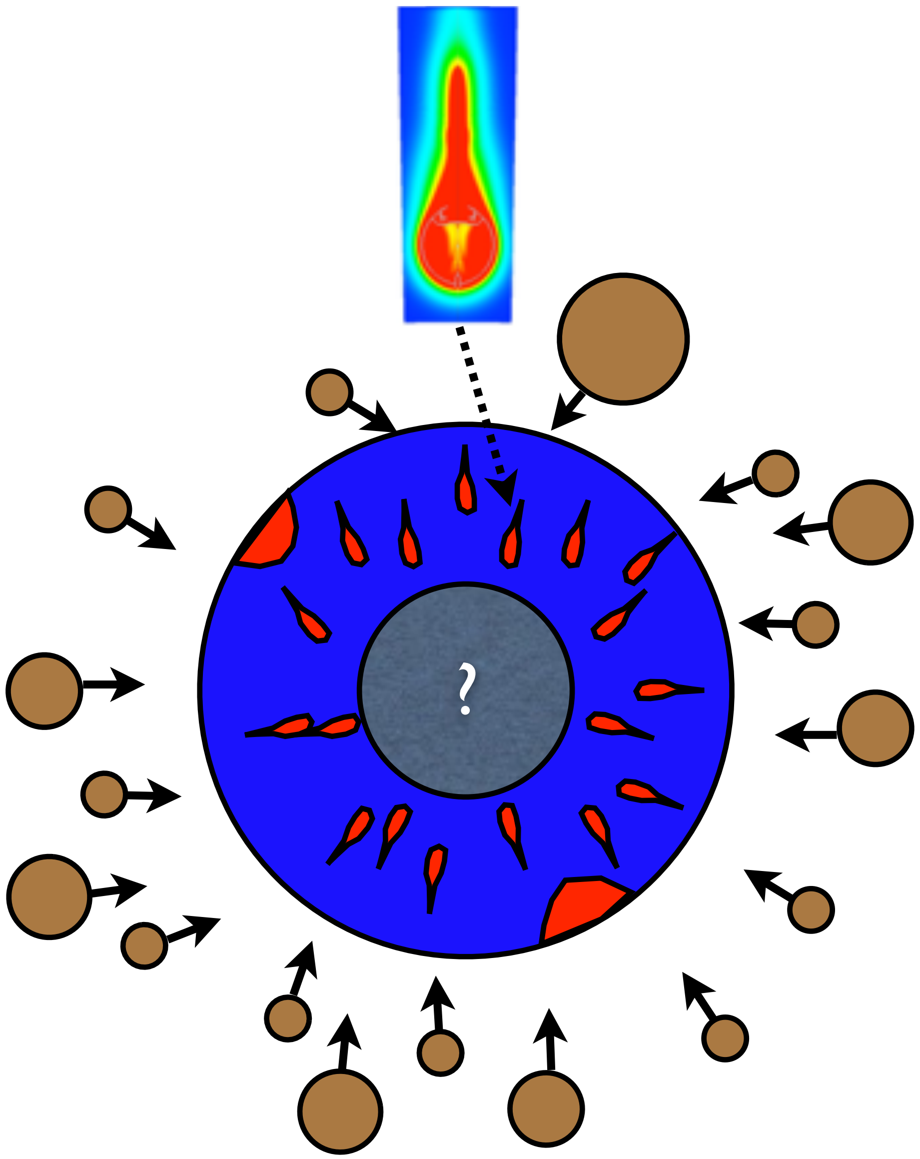


Re=10 We=1

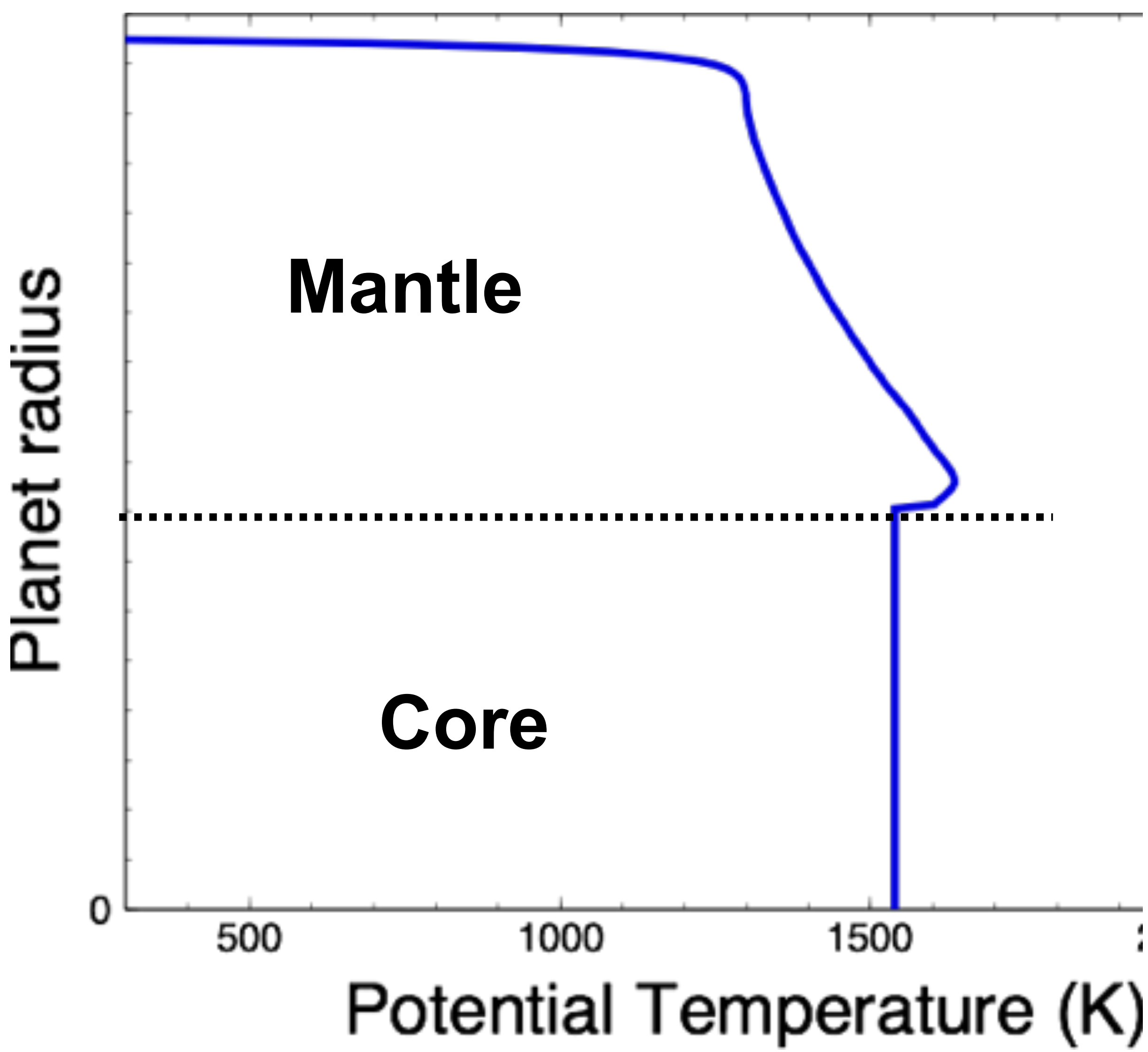


Rheology and dynamical history have a strong influence on Fe-Si heat partitioning

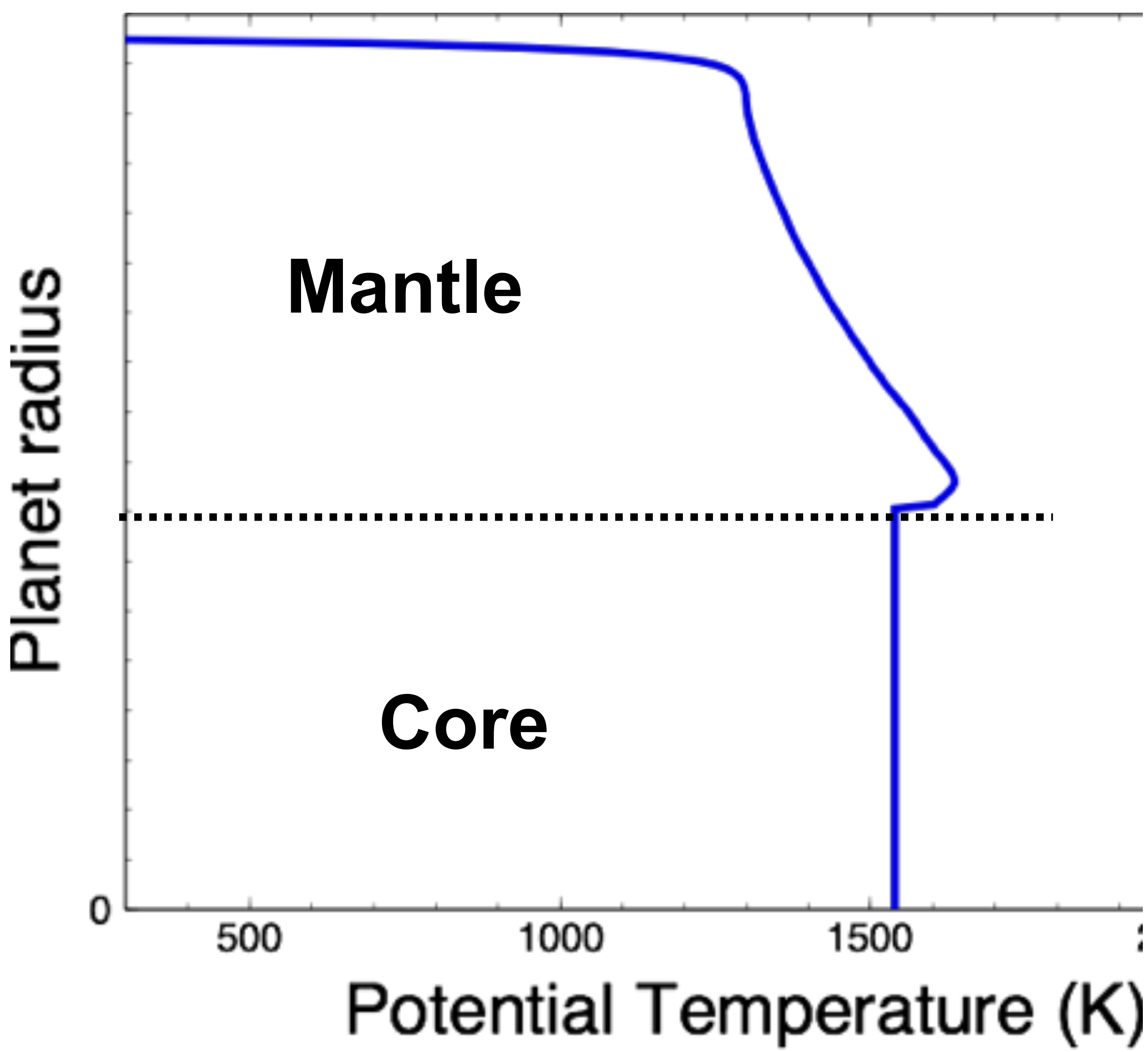
Early heat distribution



Early heat distribution

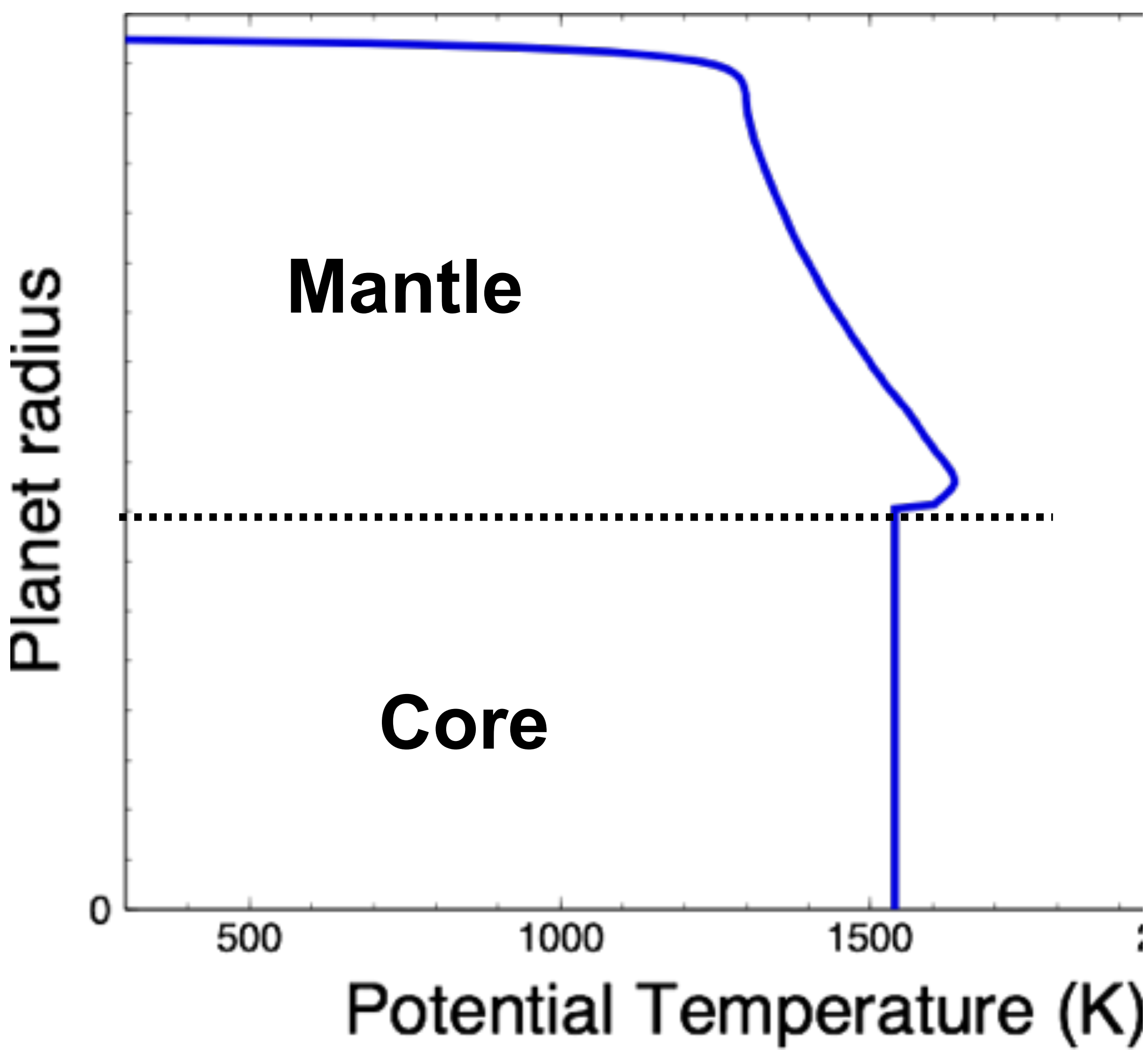


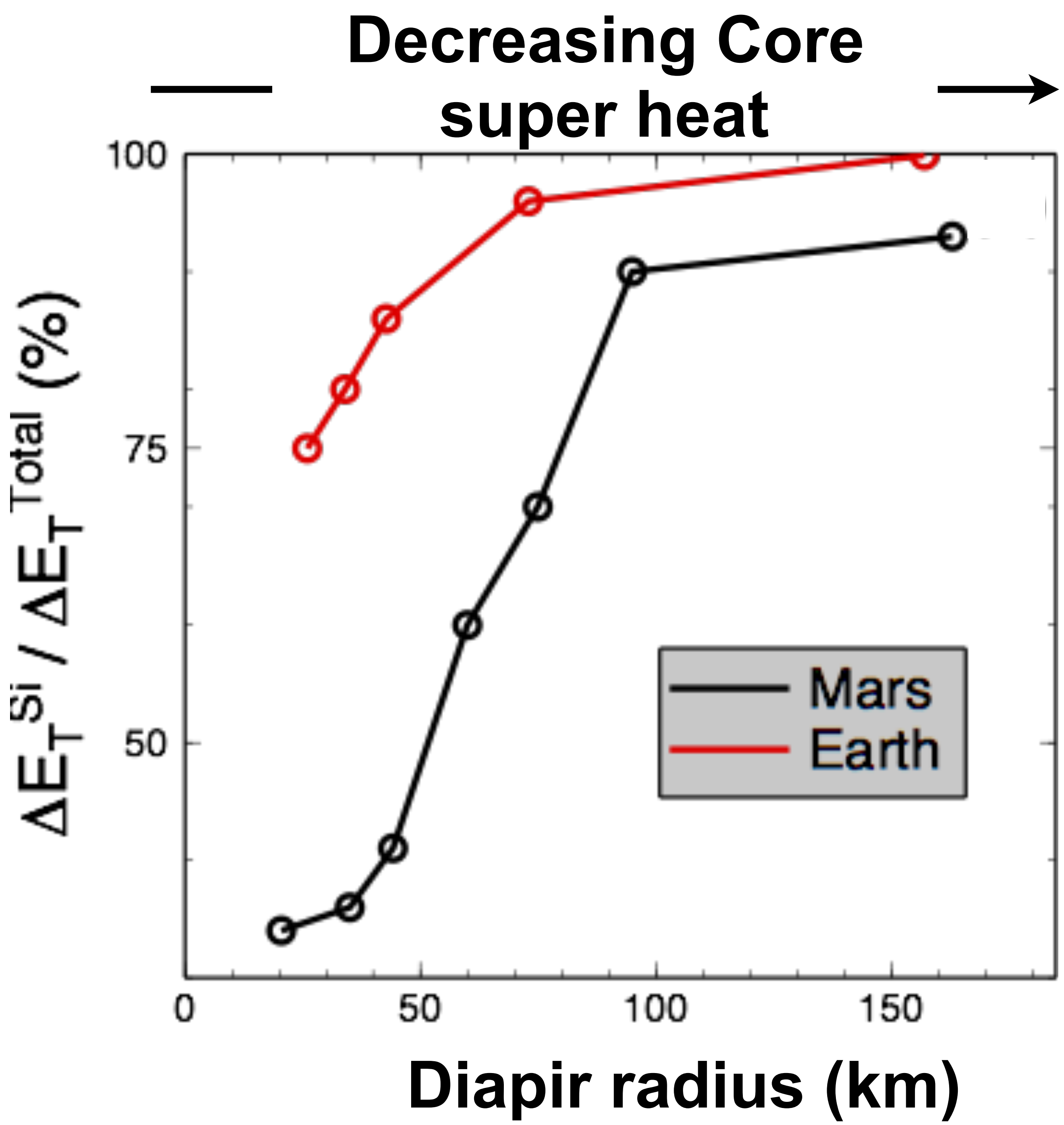
Early heat distribution



Favours a hotter lowermost mantle with melting (BMO?)

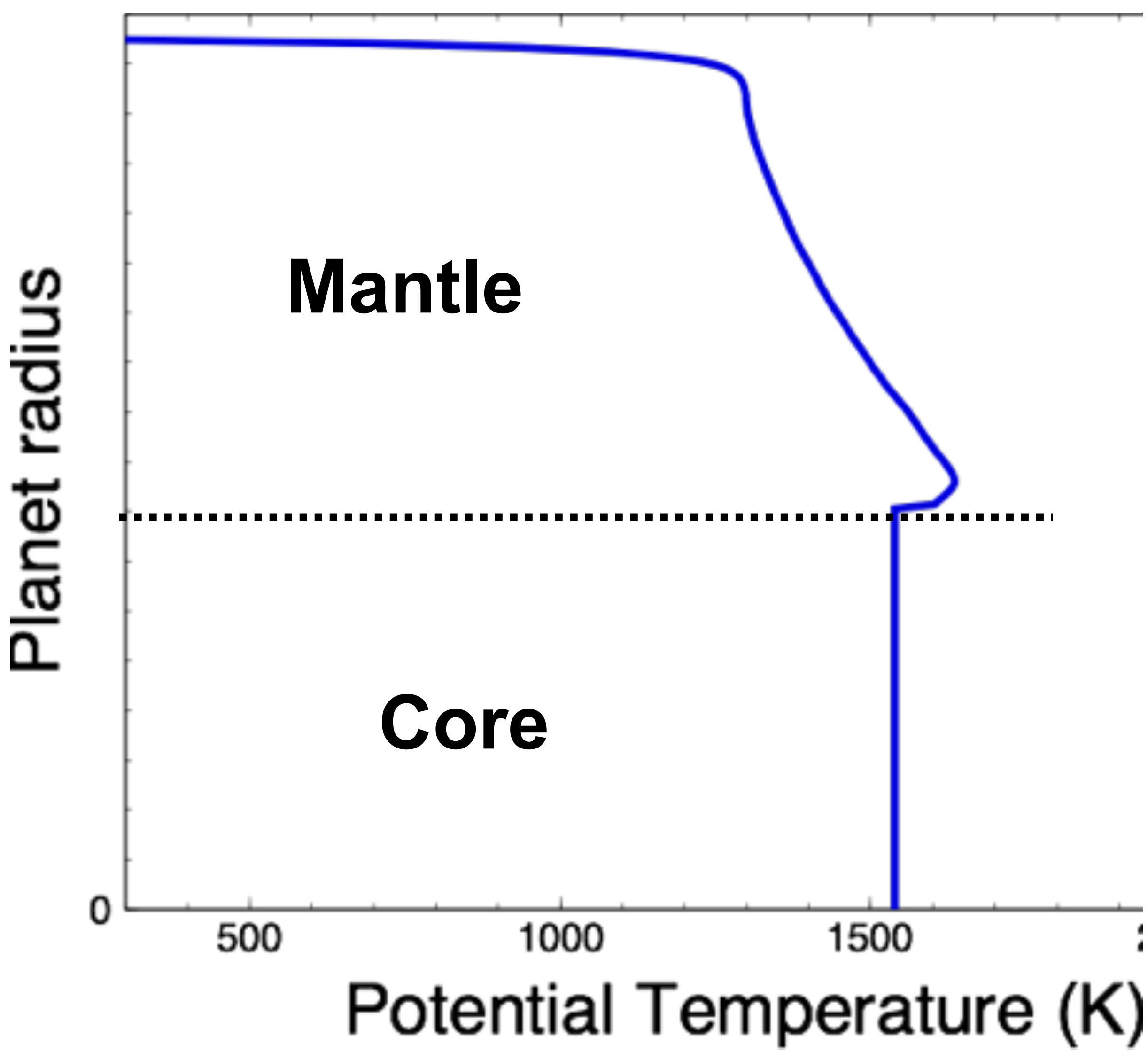
Early heat distribution

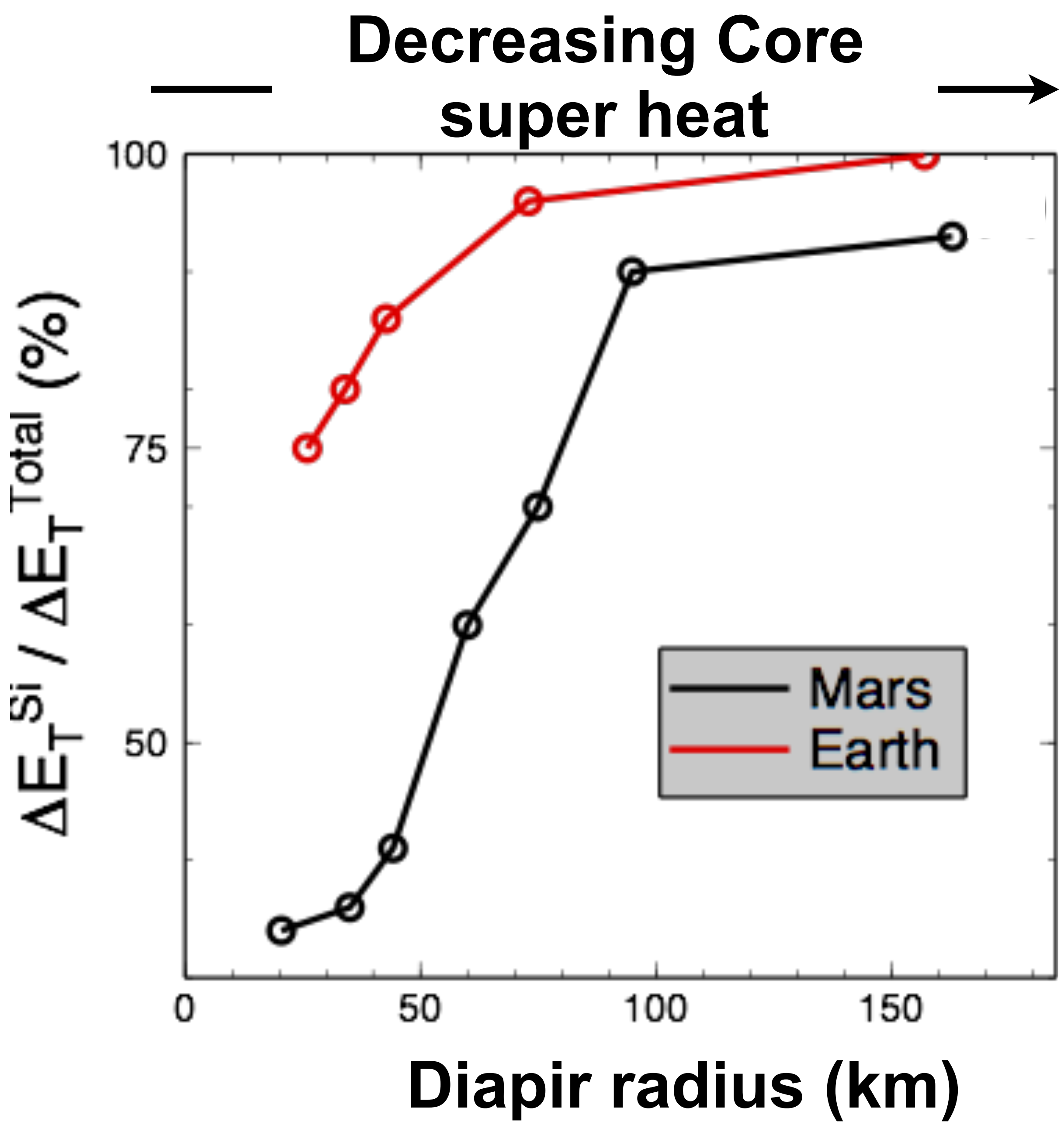




Favours a hotter lowermost mantle with melting (BMO?)

Early heat distribution





Favours a hotter lowermost mantle with melting (BMO?)

Can explain the presence and sustainability of geodynamo on Earth or Mars

Conclusions

Core formation has an huge influence on Earth evolution

1. Negative diapirism in a fully liquid or partially molten silicate magma ocean
✓ Stability favoured for small Re and We and Newtonian rheology
✓ Low viscosity diapirs favour breakup at low Re but prevents breakup at high Re
➪ Characterised via scaling laws

2. Equilibration silicate magma ocean on a proto-earth
➪ Fully Terrestrial magma ocean: most likely achieved
➪ Partially Terrestrial magma ocean: unlikely / uncertain

3. Viscous heating and heat partitioning
✓ Maximum viscous dissipation (thus temperature increase) @ interface
✓ Negative diapirism favors higher lower mantle temperatures
✓ Small diapirs lead to hotter core (“stronger” dynamos)
✓ Silicate rheology has a strong influence on heat partitioning: non-Newtonian (partially molten) viscosity favours hotter silicates and colder metal diapirs

What next?

Need better constraints on the rheology of silicates
Partially molten case ➪ σ_T=f(melt fraction, pressure, composition)
Fully molten case ➪ η=f(melt fraction, pressure, temperature,composition)

Future/ongoing investigations
➪ Effect of turbulence on heat partitioning
… and many other things…

Thanks to my sponsors/support:

calmip

PALLAS

Thanks to my sponsors/support:

calmip

PALLAS

… and thank you