Bursting Bubbles: From Champagne to Mudpots

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Physics of Fluids

UNIVERSITY OF TWENTE.

The full presentation (with videos) can be found at following links:

BurstingBubble_Paris.key (MacOs) - https://www.dropbox.com/s/ayi36ak69pwgtv8/BurstingBubble_Paris.key?dl=0

Bursting_Paris.pptx (Others) - https://www.dropbox.com/s/i6sh57k0owwqjyq/BurstingBubble_Paris.pptx?dl=0

Bursting Bubble: Process

1. Bubble approaches the free surface

2. Bubble deforms the interface

Princen (1963), J. of Colloid Sc.

3. Rupture of film to form droplets

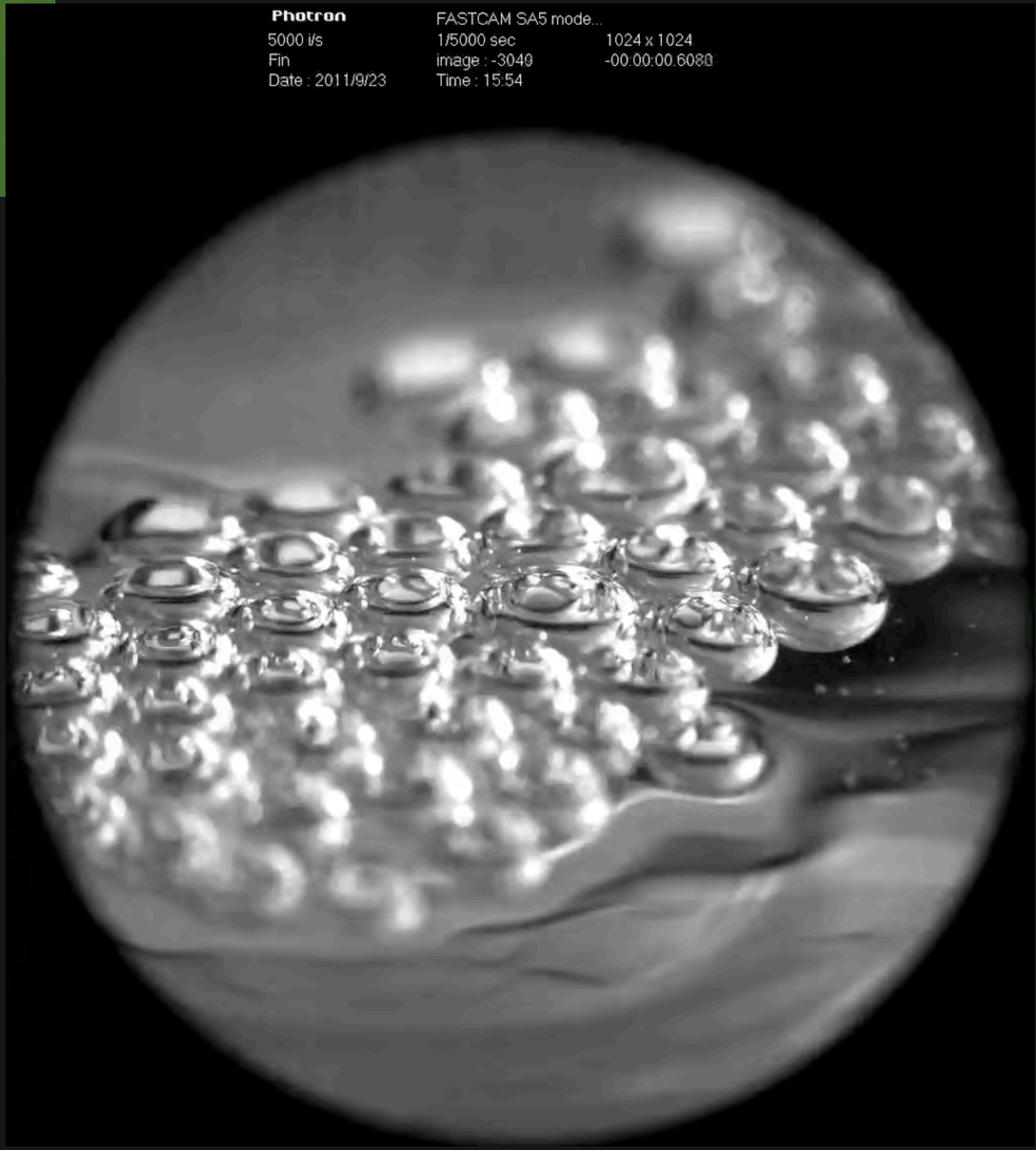
Lhuissier & Villermaux (2012), JFM
Boulton-Stone & Blake (1993), JFM

4. Collapse of bubble cavity

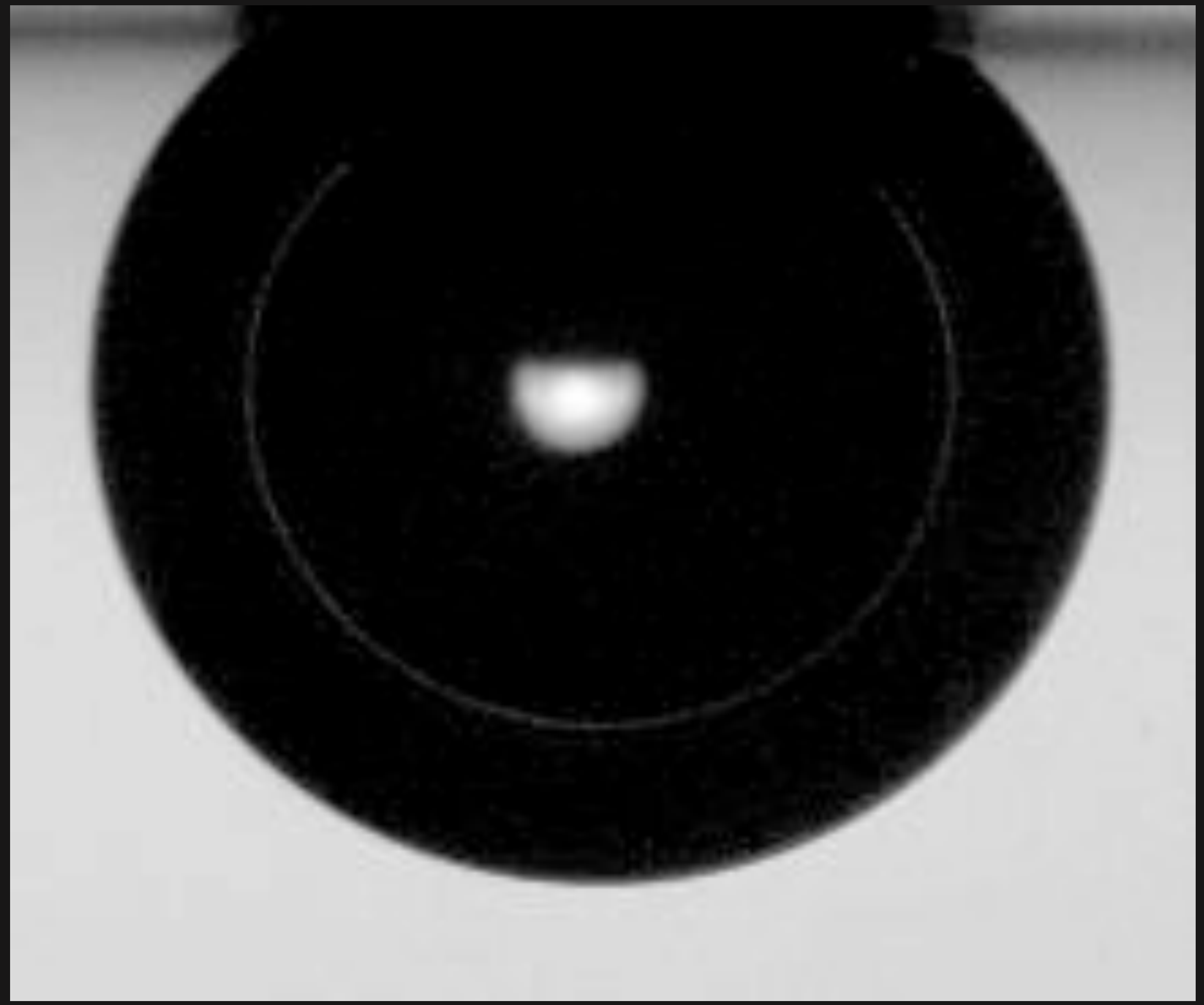
Duchemin et al. (2002), PoF
Deike et al. (2018), PRF
Singh & Das (2019), PRF

Walls et al. (2015). PRE

Singh & Das (2019). PRF



Source: Dr. Arup K. Das



Ghabache et al. (2014). PoF

Gabache et al. (2016), Sc. Rep.
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Gabache et al. (2016), Sc. Rep
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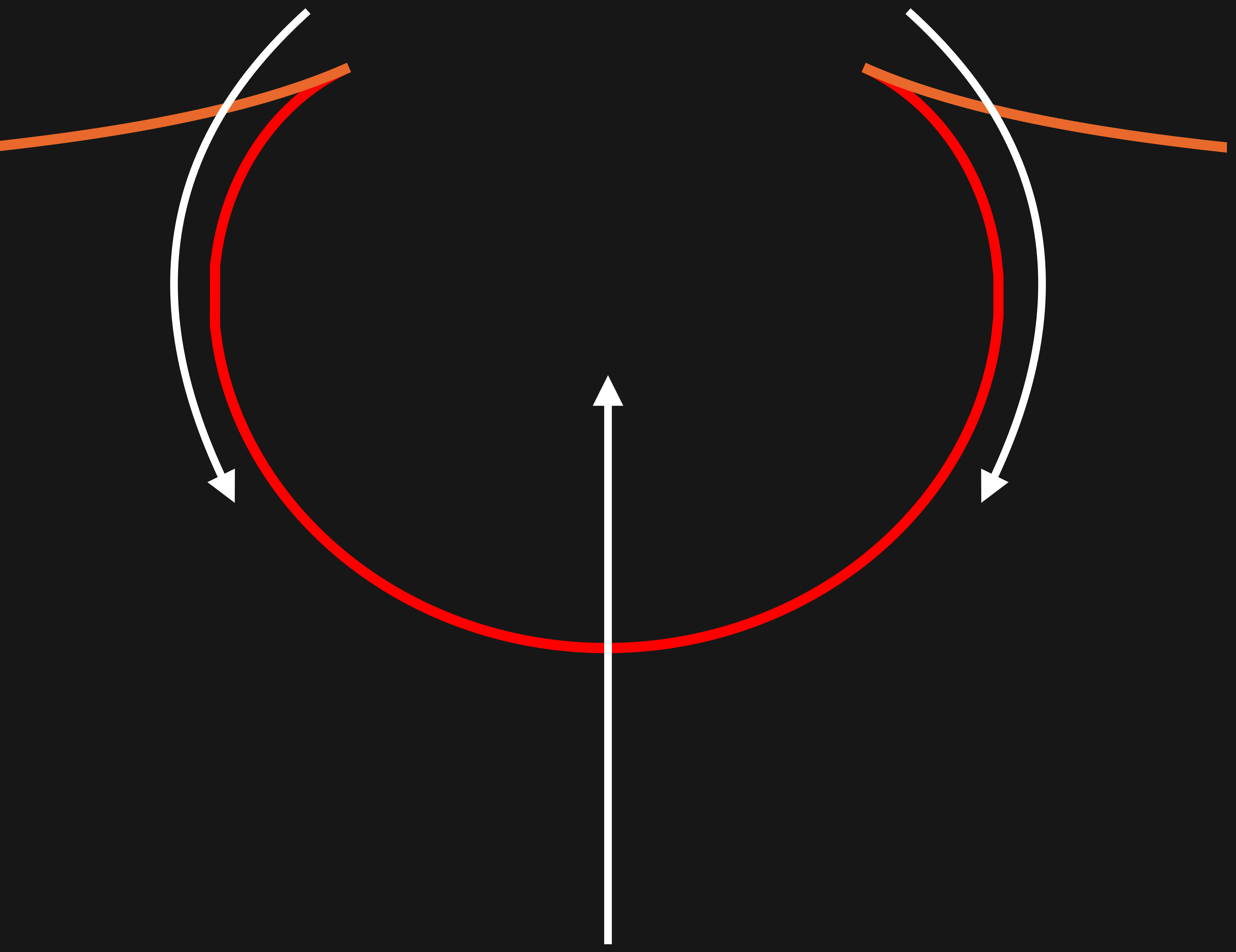
Yellow Stone National Park: Video from https://www.youtube.com/watch?v=a9hUsVq9q7U

Surface Tension driven Flow



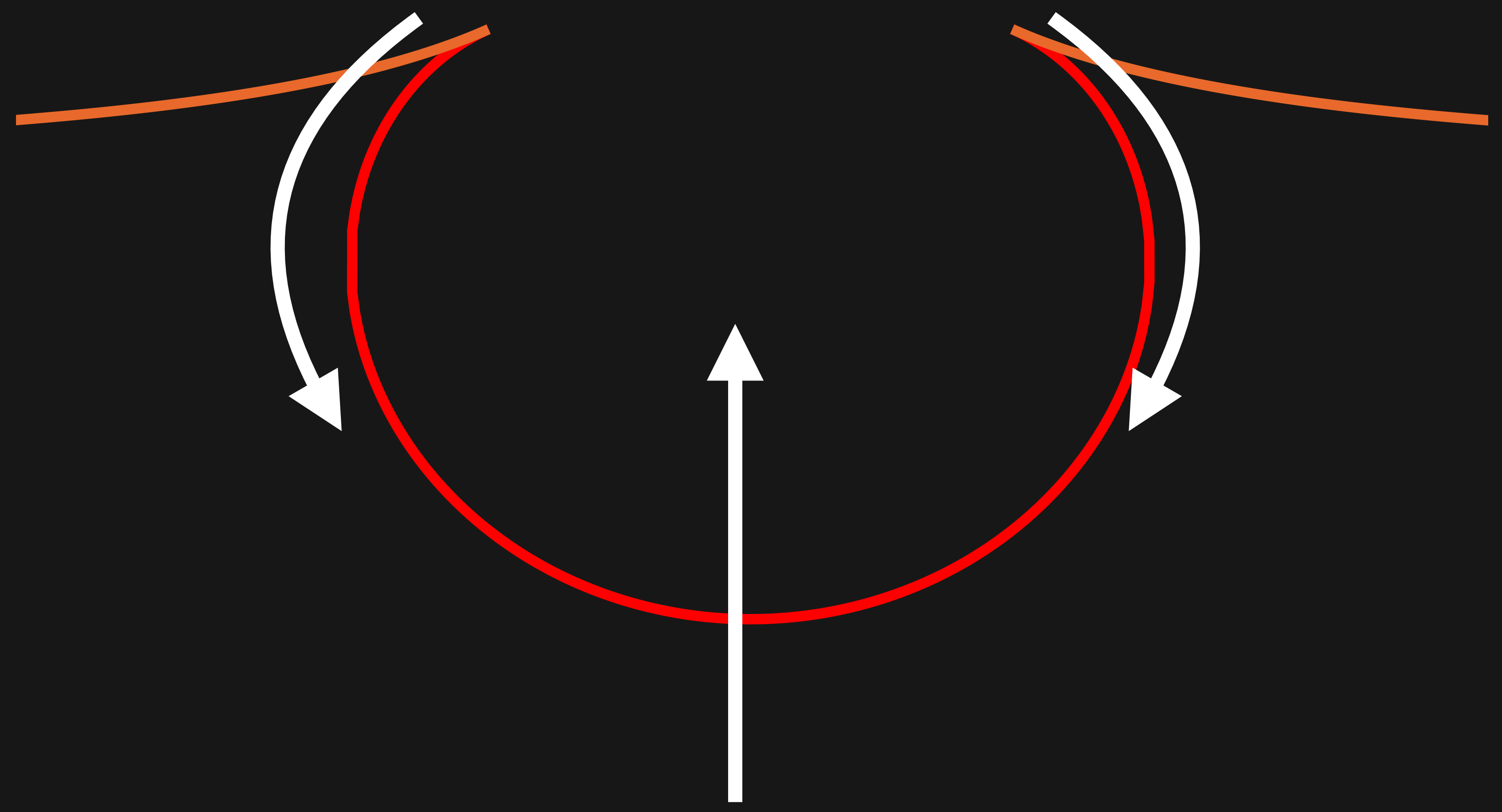
Yield-Stress Fluids

Assumptions

Bubble approaches the free surface

Bubble deforms the interface

Rupture of the film & Collapse of bubble cavity



Shape at the free surface: Newtonian

Bubble resting at a free surface

Thin liquid layer

$$\frac{\delta}{R_0} \sim \mathcal{O}\left(10^{-6}\right)$$

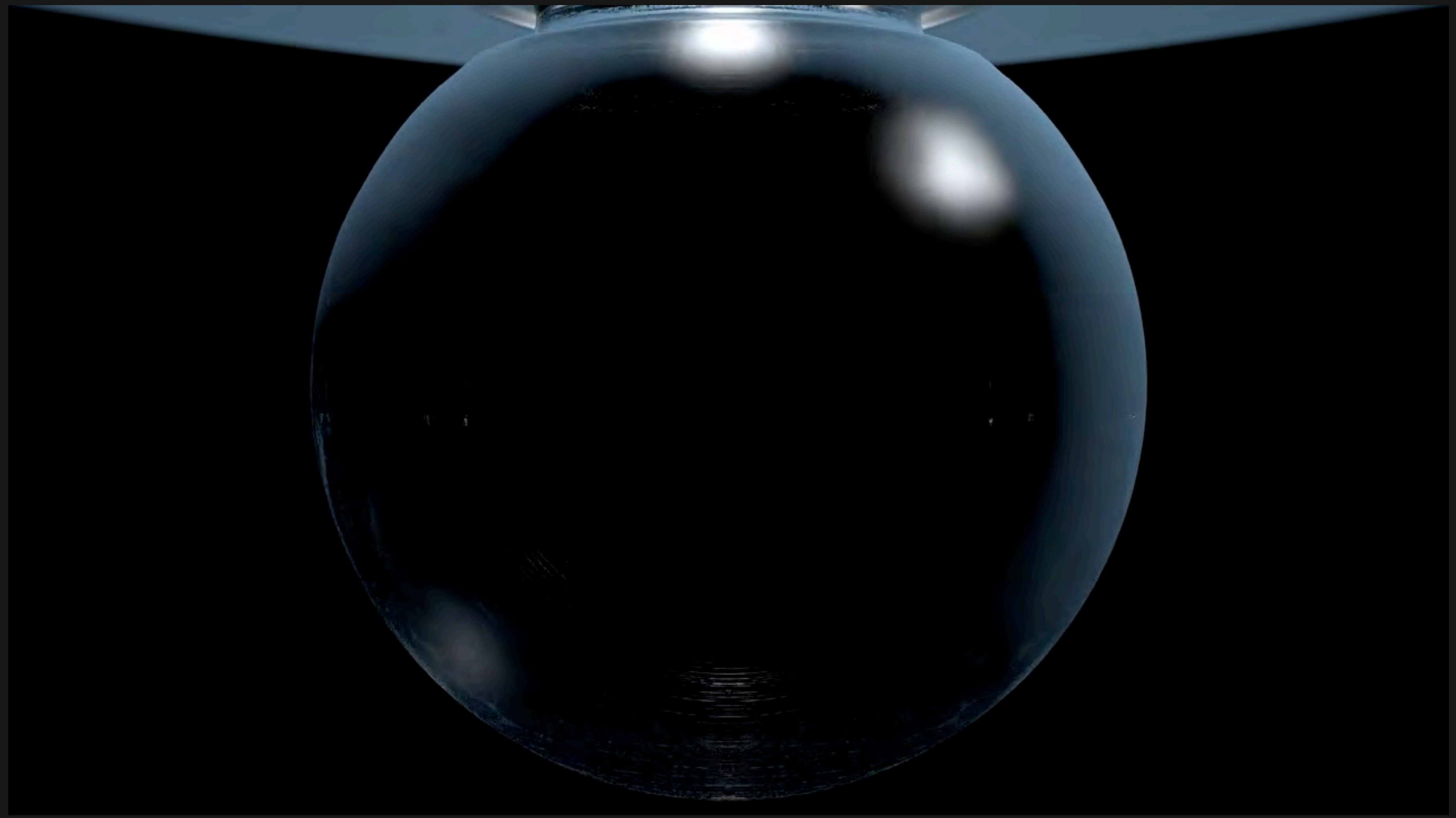
Bubble resting at a free surface

Idea

Toba (1959), J. Oc. Soc. Jap.
Princen (1963), J. Col. Sc.

Bubble resting at a free surface

Ghabache et al. (2014), PoF

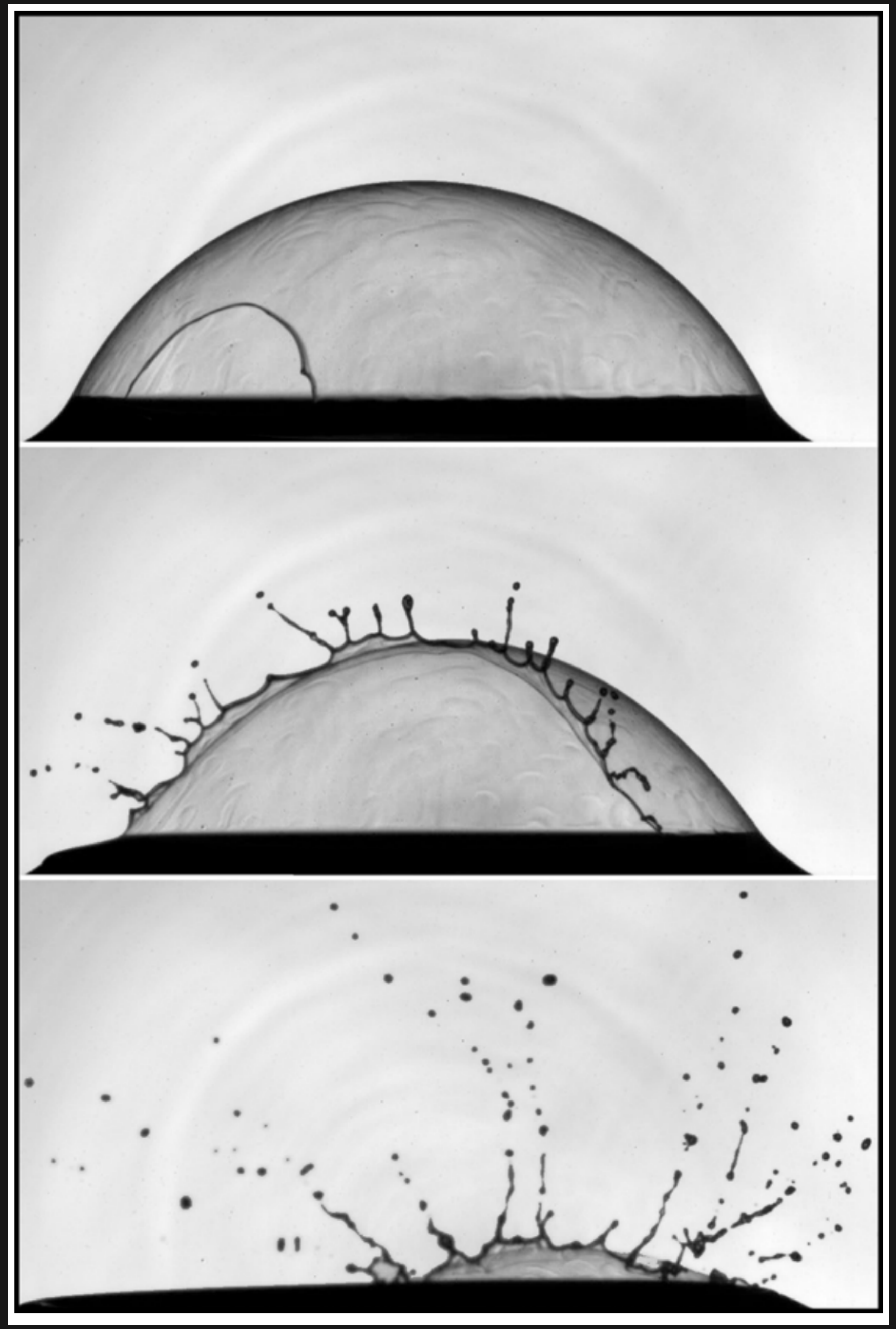


Alexis Berny, youtube

Idea

Toba (1959), J. Oc. Soc. Jap.
Princen (1963), J. Col. Sc.

Lhuissier & Villermaux (2012), JFM

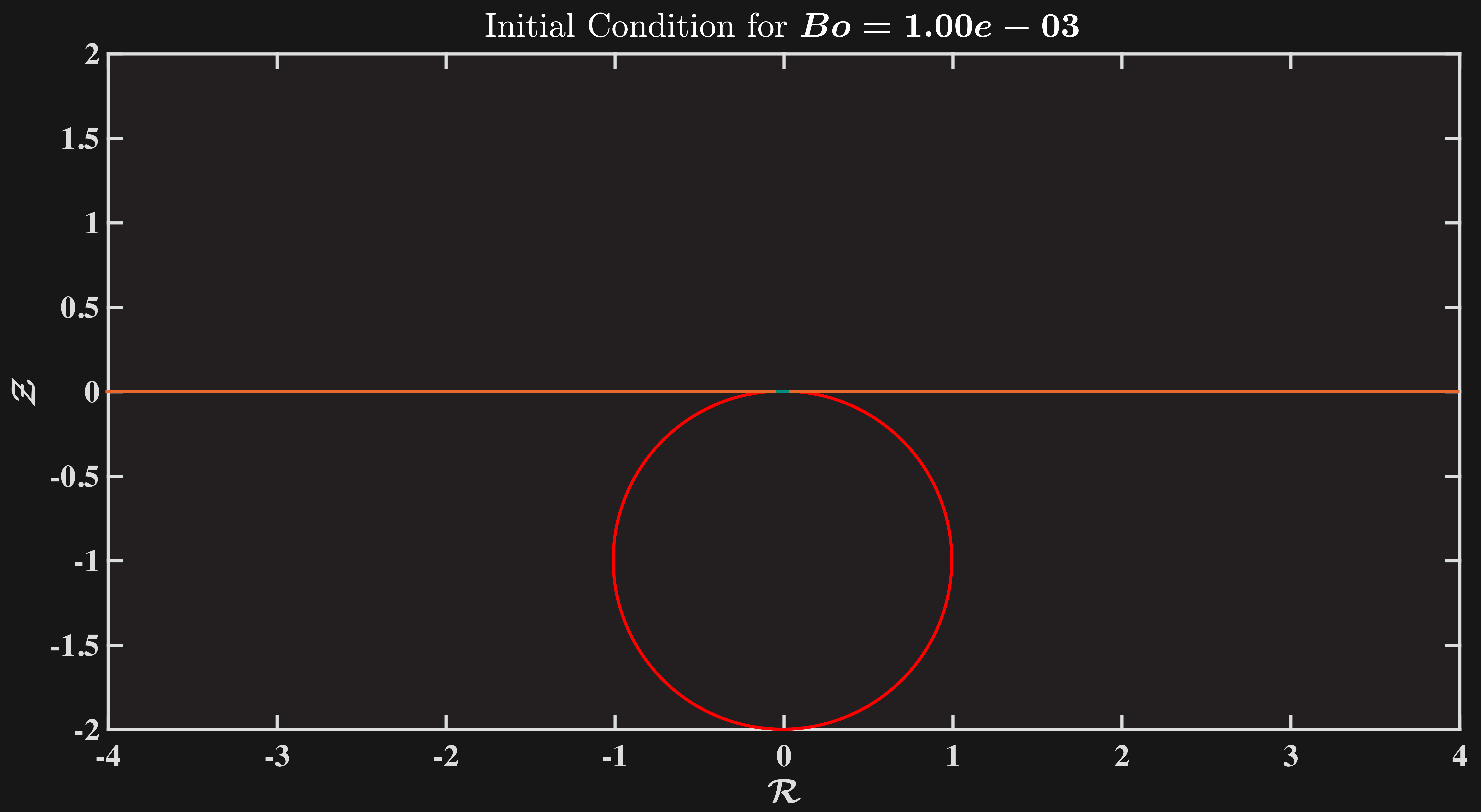


Bubble resting at a free surface

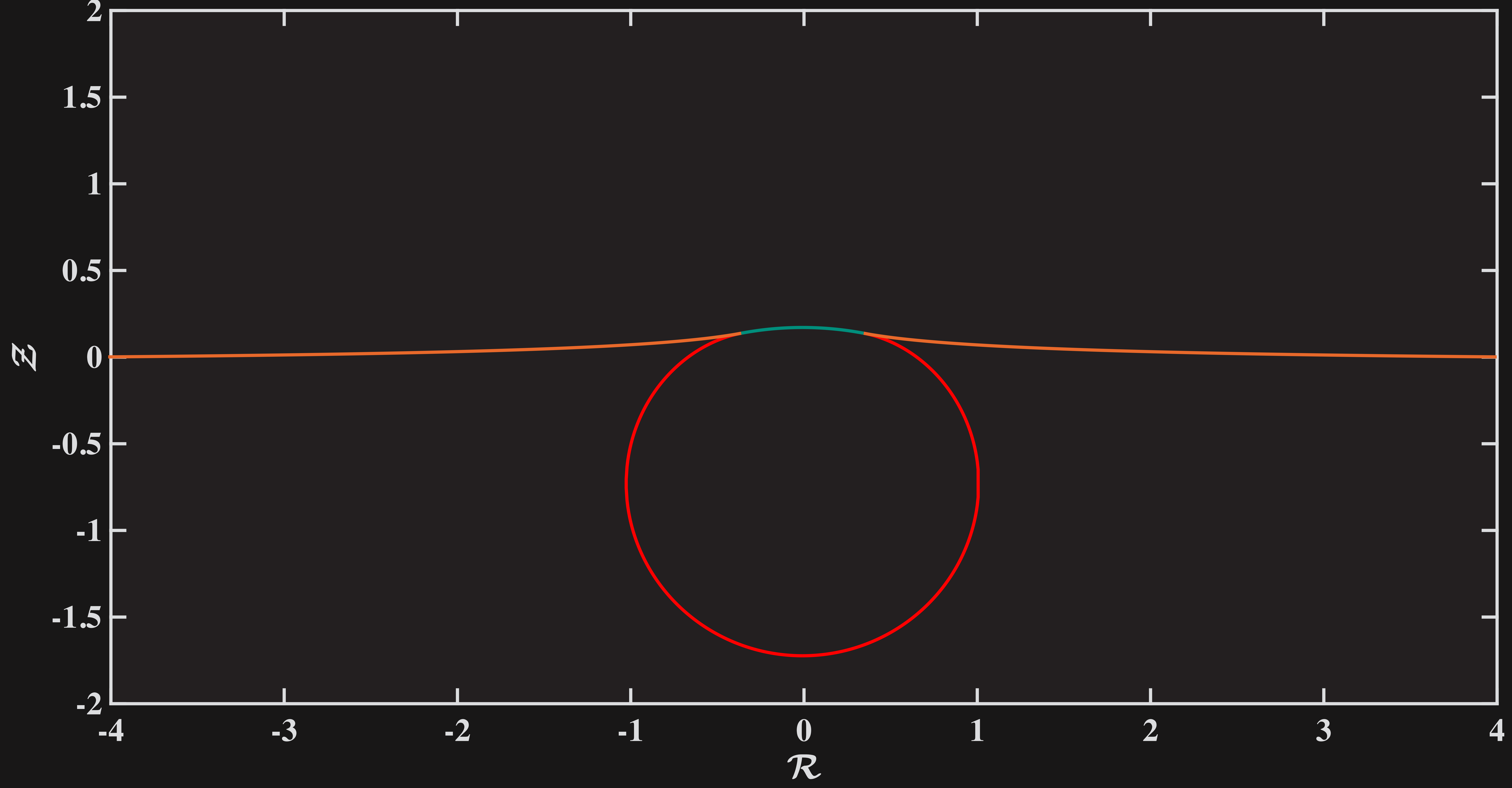
Bubble inside the liquid pool $$\frac{1}{\mathcal{R}}\frac{d}{d\mathcal{R}}\left(\mathcal{R}\sin\phi\right) = 2\kappa_B + Bo\mathcal{Z}$$

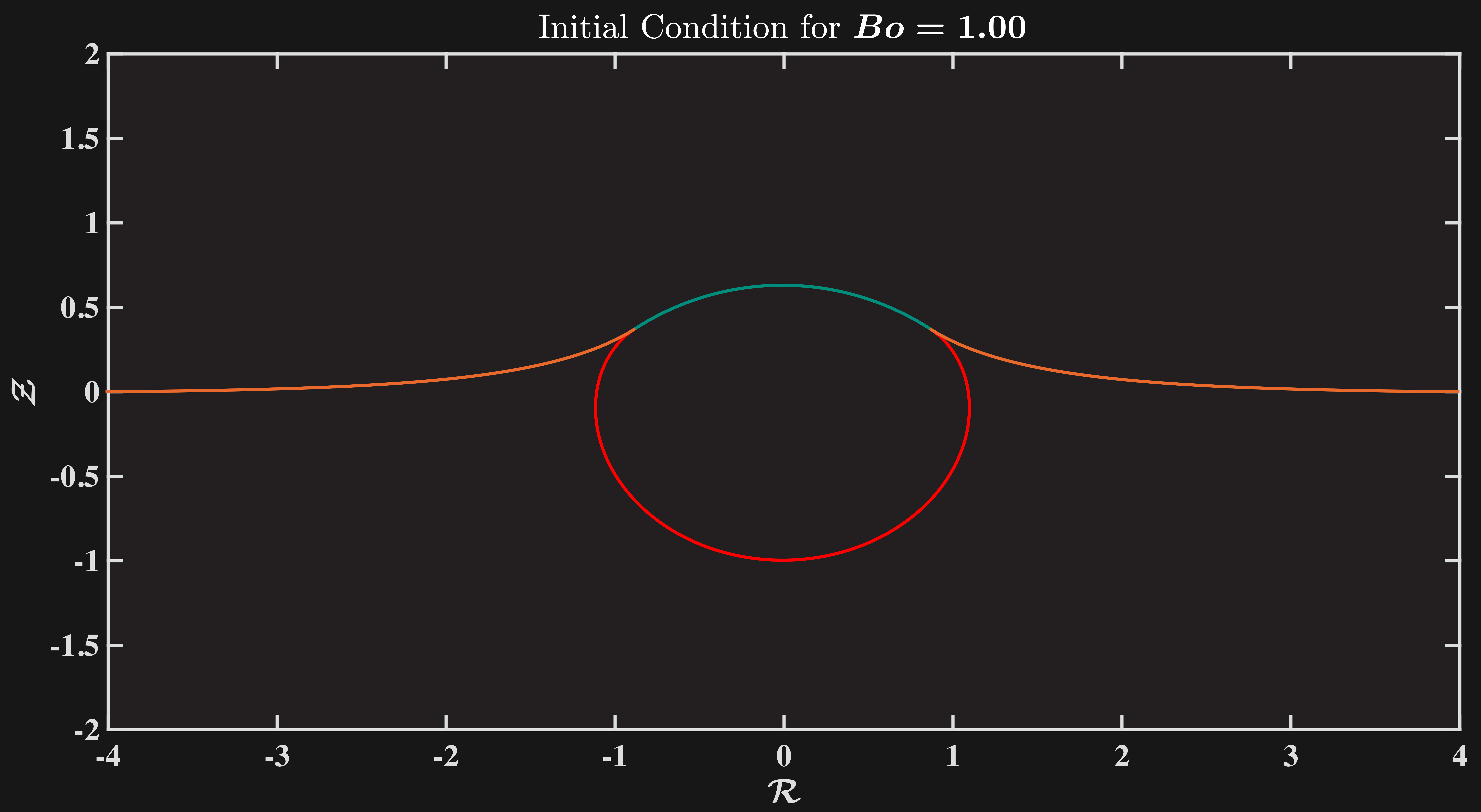
Tail: Pool Interface $$\kappa_1 + \kappa_2 = \left(\mathcal{Z} - h_\infty\right) Bo$$

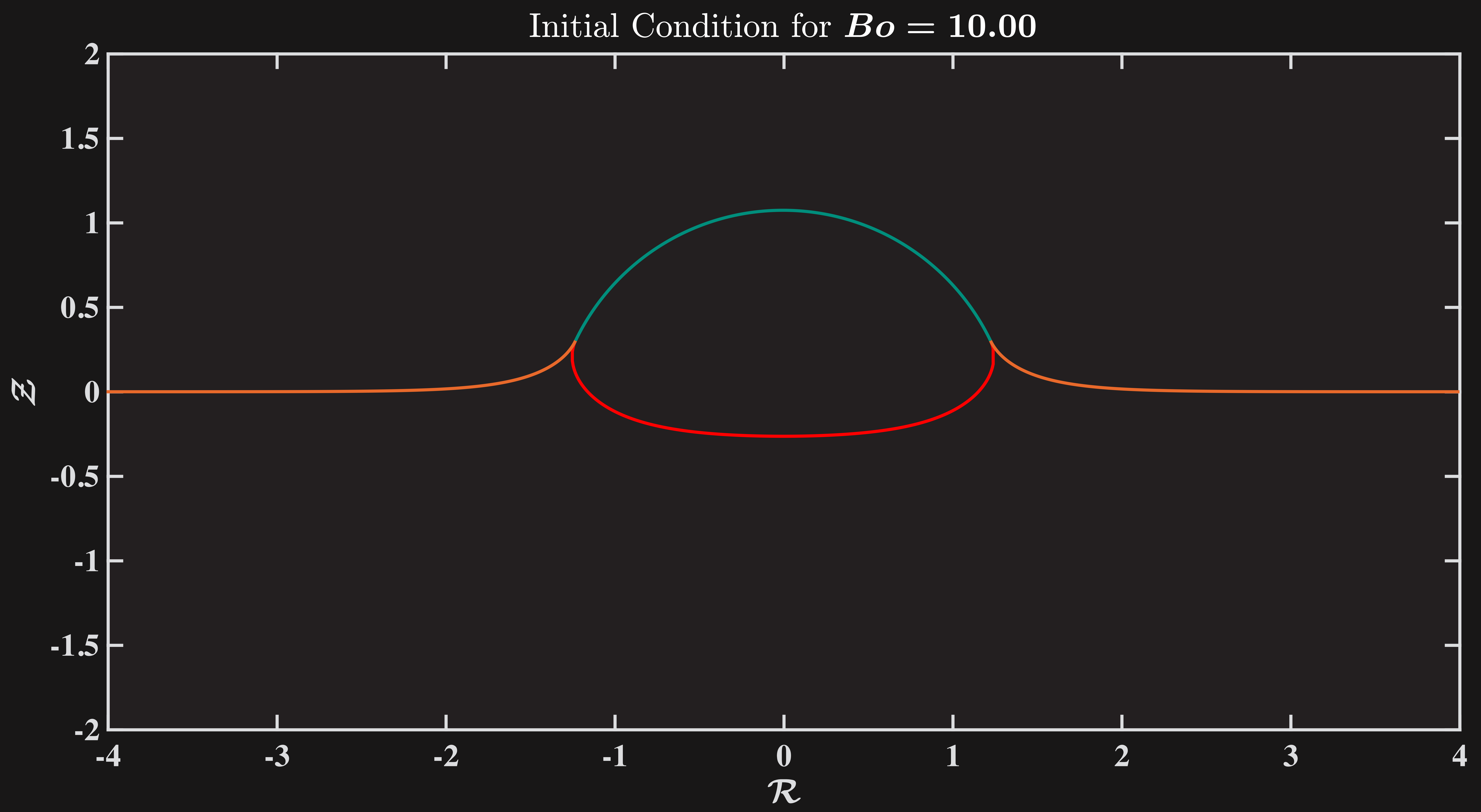
Spherical bubble cap $$\kappa_1 + \kappa_2 = 2\kappa_c$$

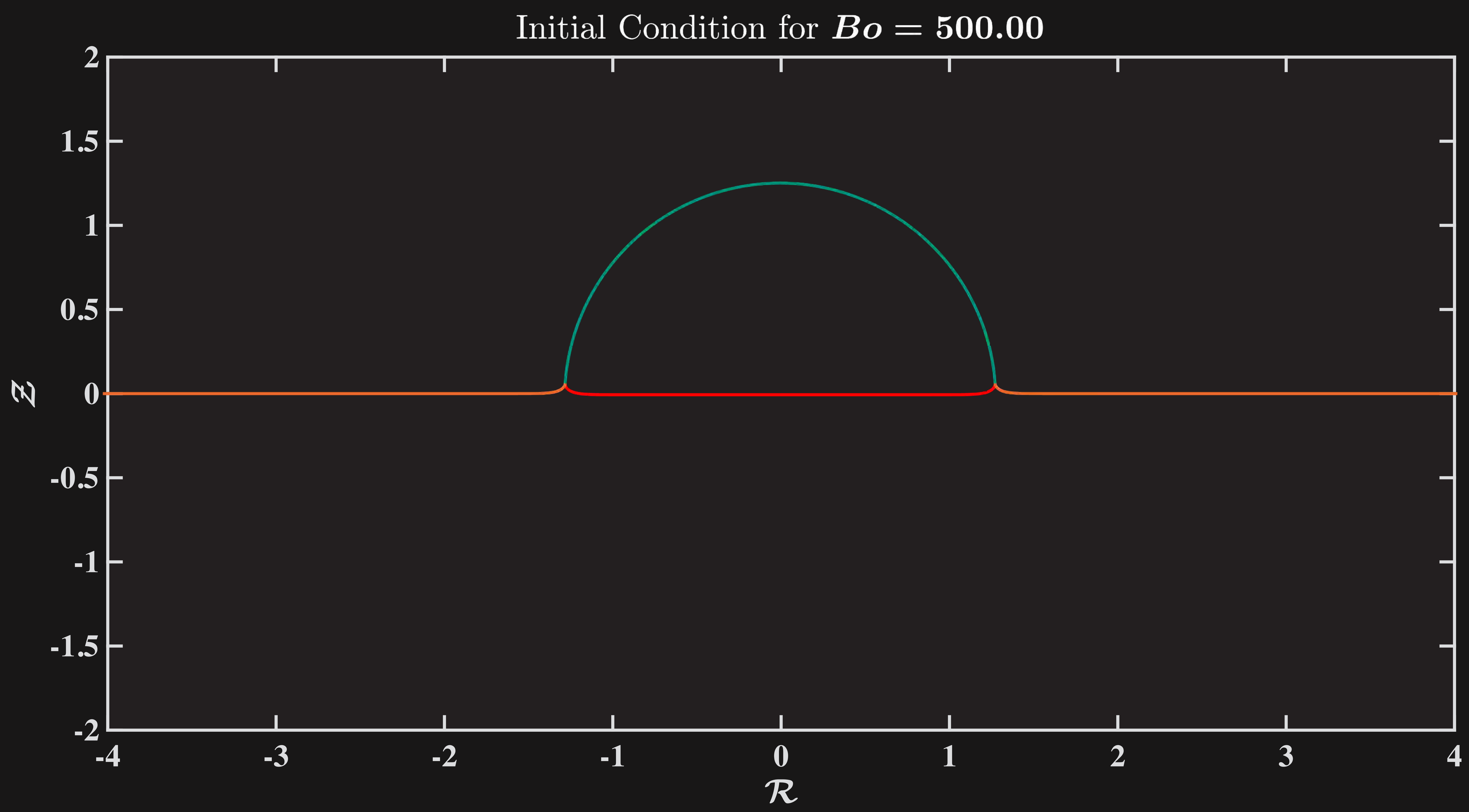

Initial Condition for $\boldsymbol{Bo = 1.00e - 03}$
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
$\mathcal{Z}$
-4
-3
-2
-1
0
1
2
3
4
$\mathcal{R}$

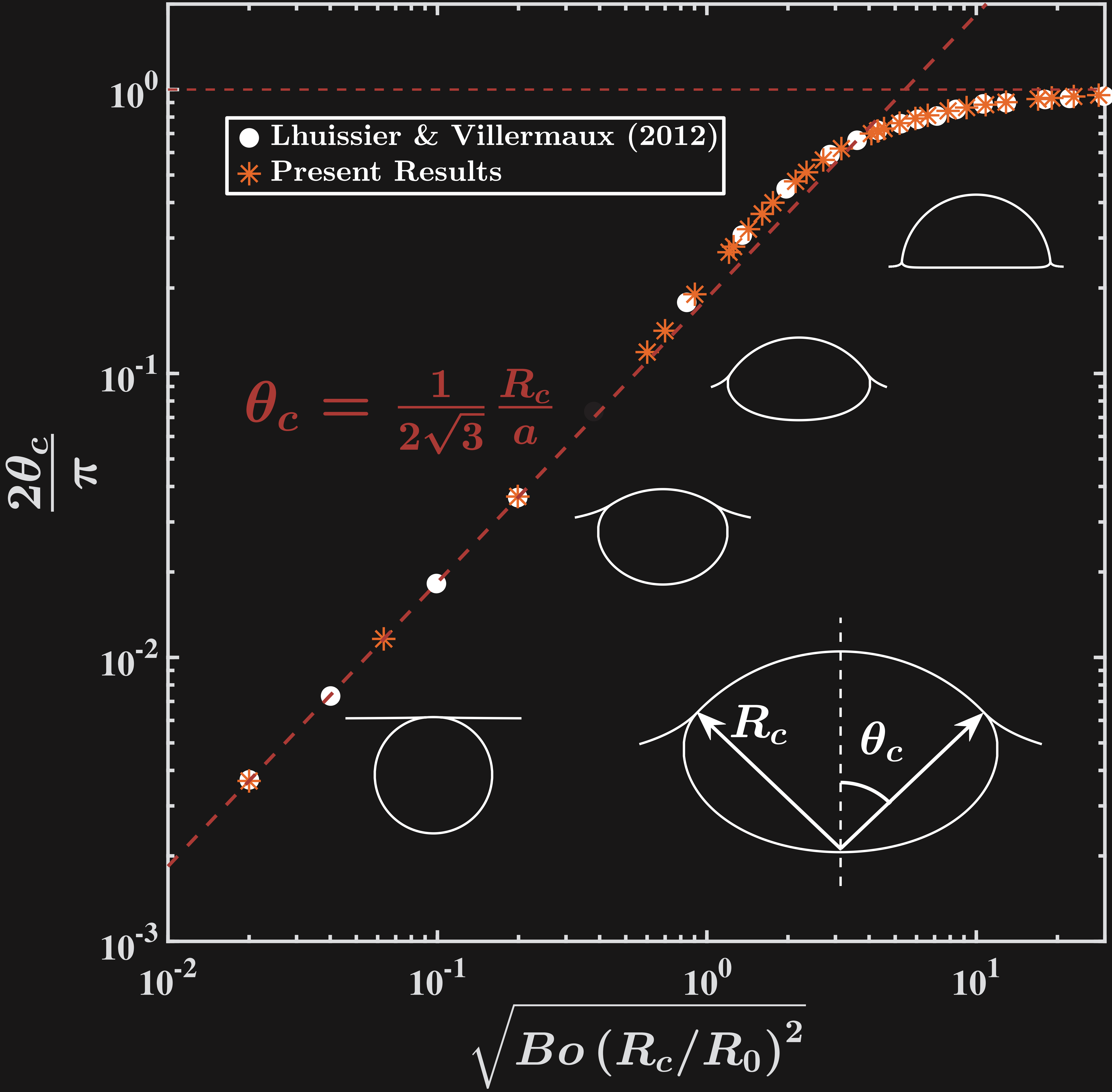
Initial Condition for $Bo = 1.00e-01$




Initial Condition for $Bo = 1.00$
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
$\mathcal{Z}$
-4
-3
-2
-1
0
1
2
3
4
$\mathcal{R}$


Initial Condition for $Bo = 10.00$
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
$\mathcal{Z}$
-4
-3
-2
-1
0
1
2
3
4
$\mathcal{R}$


Initial Condition for $\boldsymbol{Bo} = \mathbf{500.00}$
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
$\mathcal{Z}$
-4
-3
-2
-1
0
1
2
3
4
$\mathcal{R}$



Lhuissier & Villermaux (2012)
Present Results
$\theta_c = \frac{1}{2\sqrt{3}}\frac{R_c}{a}$
$\frac{2\theta_c}{\pi}$
$\sqrt{Bo\,(R_c/R_0)^2}$
R_c
θ_c
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1

Simulation Methodology

Simulation Methodology

Simulation Methodology

Velocity & Time Scales

$$U_\sigma \equiv \sqrt{\frac{\sigma}{\rho_l R_0}} \qquad t_\sigma \equiv \frac{R_0}{U_\sigma}$$

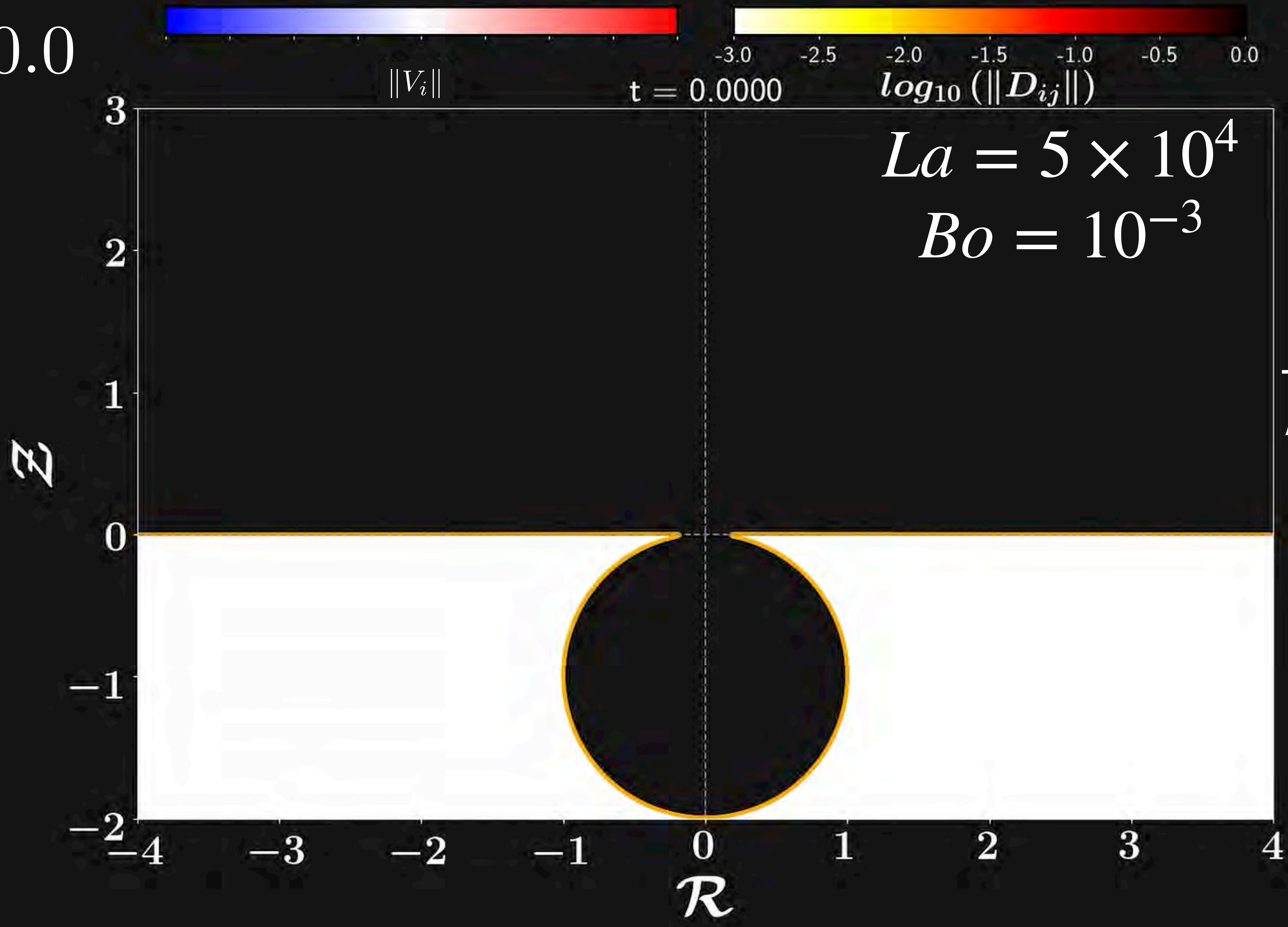
$$La = \frac{\rho_l \sigma R_0}{\mu_l^2} \qquad Bo = \frac{\rho_l g R_0^2}{\sigma}$$

$$Oh = \frac{1}{\sqrt{La}} = \frac{\mu_l}{\sqrt{\rho_l \sigma R_0}}$$

Navier-Stokes Equation

$$\hat{\rho}\left(\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial X_j}\right) = -\frac{\partial P}{\partial X_i} + \frac{\partial}{\partial X_j}\left(2\left(\hat{\mu}\mu_{\text{eq}}\right) D_{ij}\right) + \kappa \delta_s \hat{n}_i + Bo\,\hat{g}_i$$

$$\mathcal{J} = 0.0$$



$$La = 5 \times 10^4$$

$$Bo = 10^{-3}$$

$$\frac{\rho_l}{\rho_g} = 10^3$$

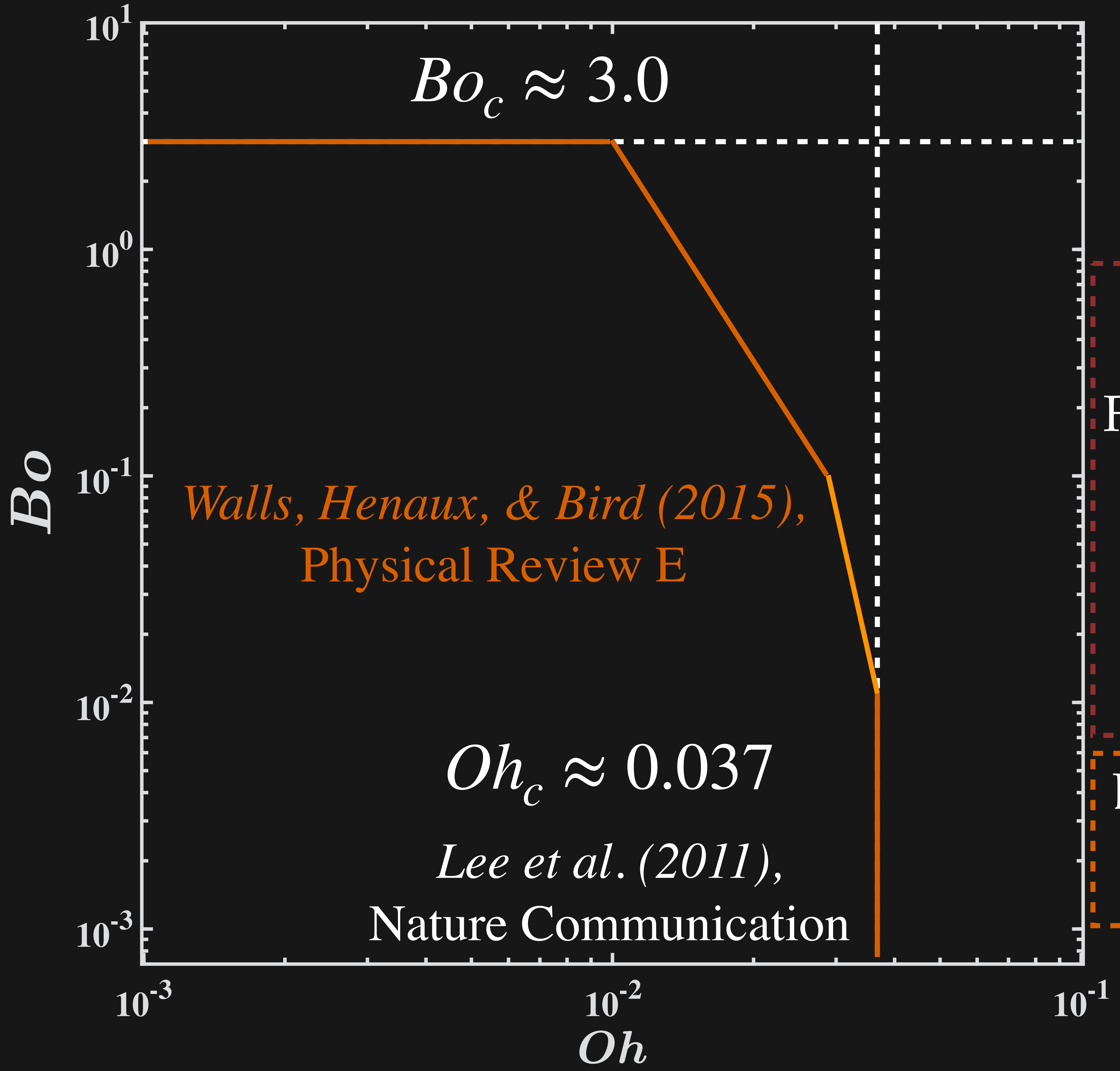
$$\frac{\mu_l}{\mu_g} = 50$$

Bursting Bubbles: Newtonian

$La = 5 \times 10^2$ $Bo = 0.25$

$La = 5 \times 10^4$ $Bo = 0.25$

$La = 5 \times 10^4$ $Bo = 3.25$



Georgescu, Achard, & Canot (2002),
European Journal of Mechanics-B/Fluids

No Jet-breakup event

Flat initial shape supresses breakup

$$Bo > Bo_c \forall Oh \rightarrow 0$$

Viscosity damps the waves:

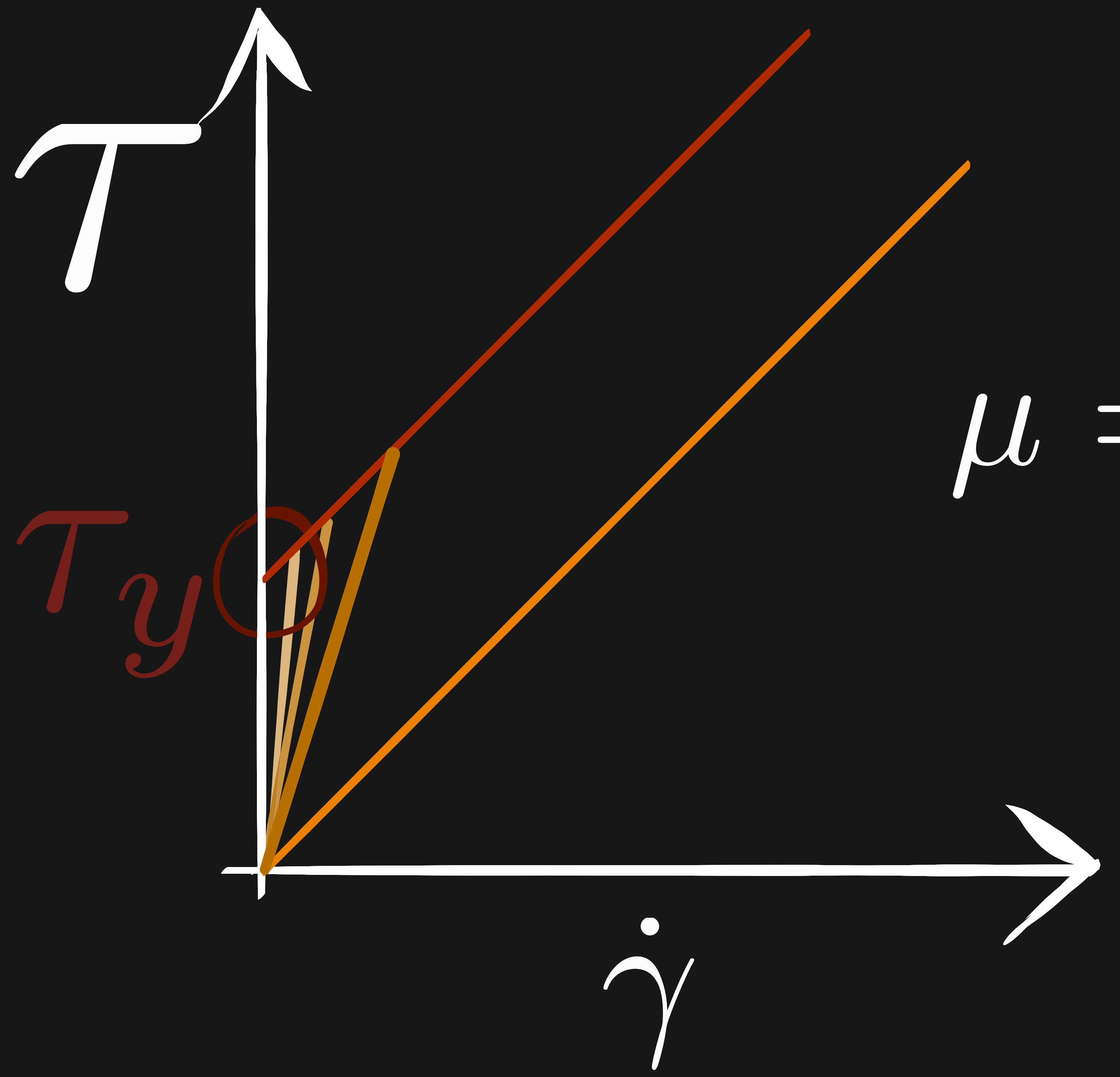
$$Oh > Oh_c \forall Bo \rightarrow 0$$

Both gravity & viscosity important

$$Bo \propto Oh^{-3}$$

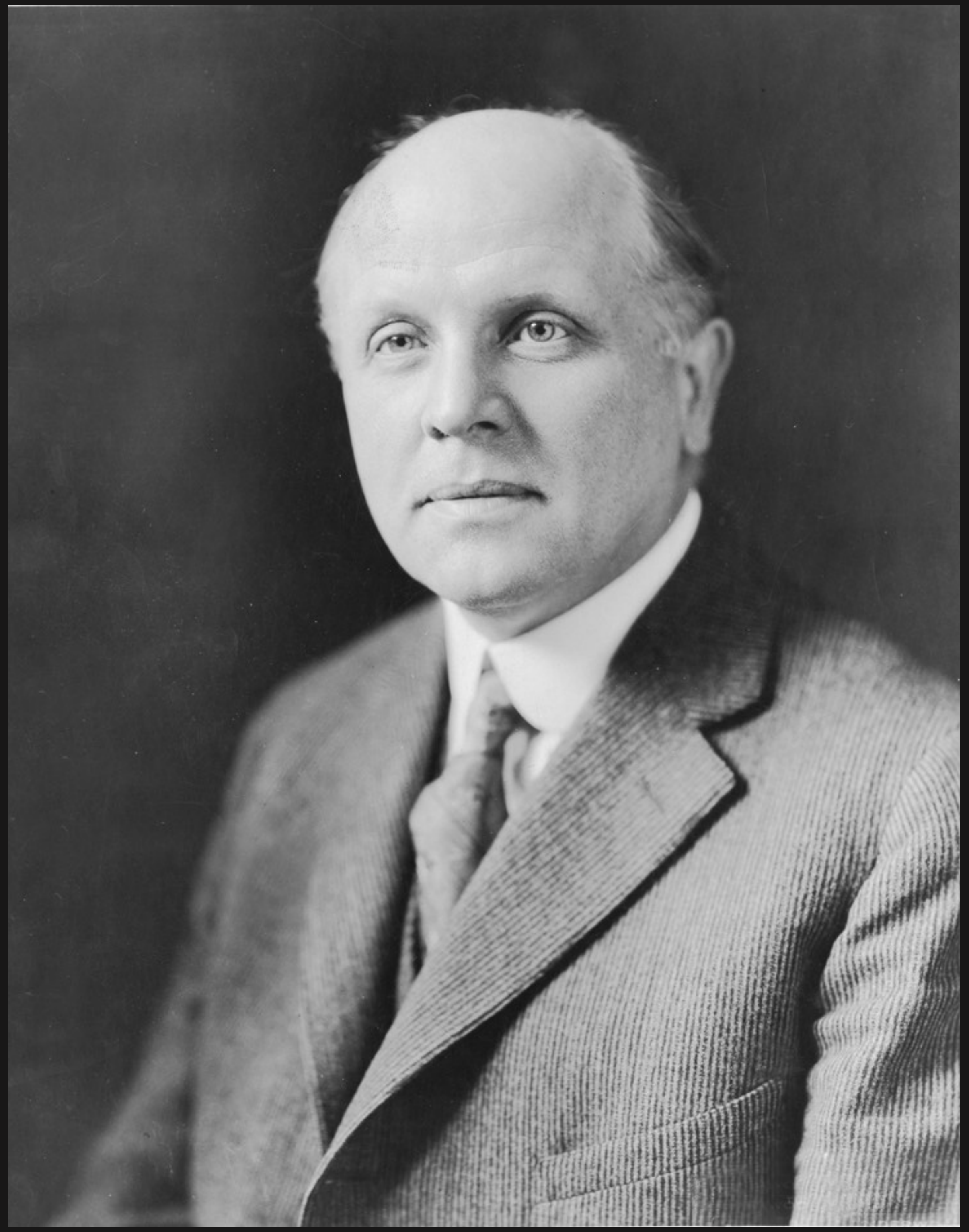
Not (-3)

Viscoplastic 101



$$\mu = \min\left(\mu_{\text{eq}},\ \mu_{\text{max}}\right)$$

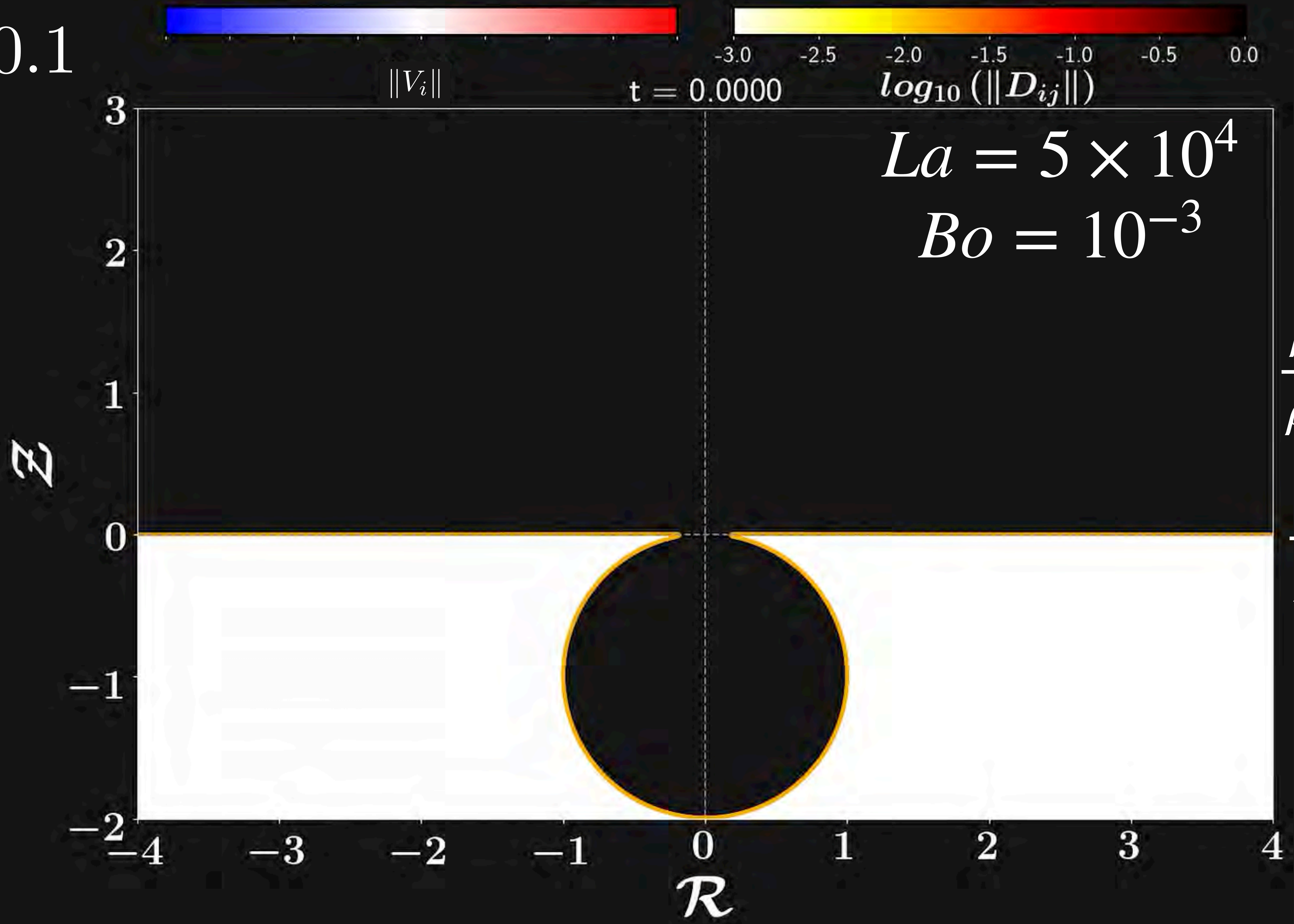
$$\mu_{\text{eq}}$$



Eugene C. Bingham
(1878 - 1945)

$$\begin{cases} \dot{\tilde{\gamma}}_{ij} = 0 & \forall\ \|\tilde{\tau}_{ij}\| < \mathcal{J} \\ \tilde{\tau}_{ij} = \left(\dfrac{\mathcal{J}}{\|\dot{\tilde{\gamma}}_{ij}\|} + Oh\right)\dot{\tilde{\gamma}}_{ij} & \forall\ \|\tilde{\tau}_{ij}\| \geq \mathcal{J} \end{cases}$$

$\mathcal{J} = 0.1$



$$\frac{\rho_l}{\rho_g} = 10^3$$

$$\frac{\mu_l}{\mu_g} = 50$$

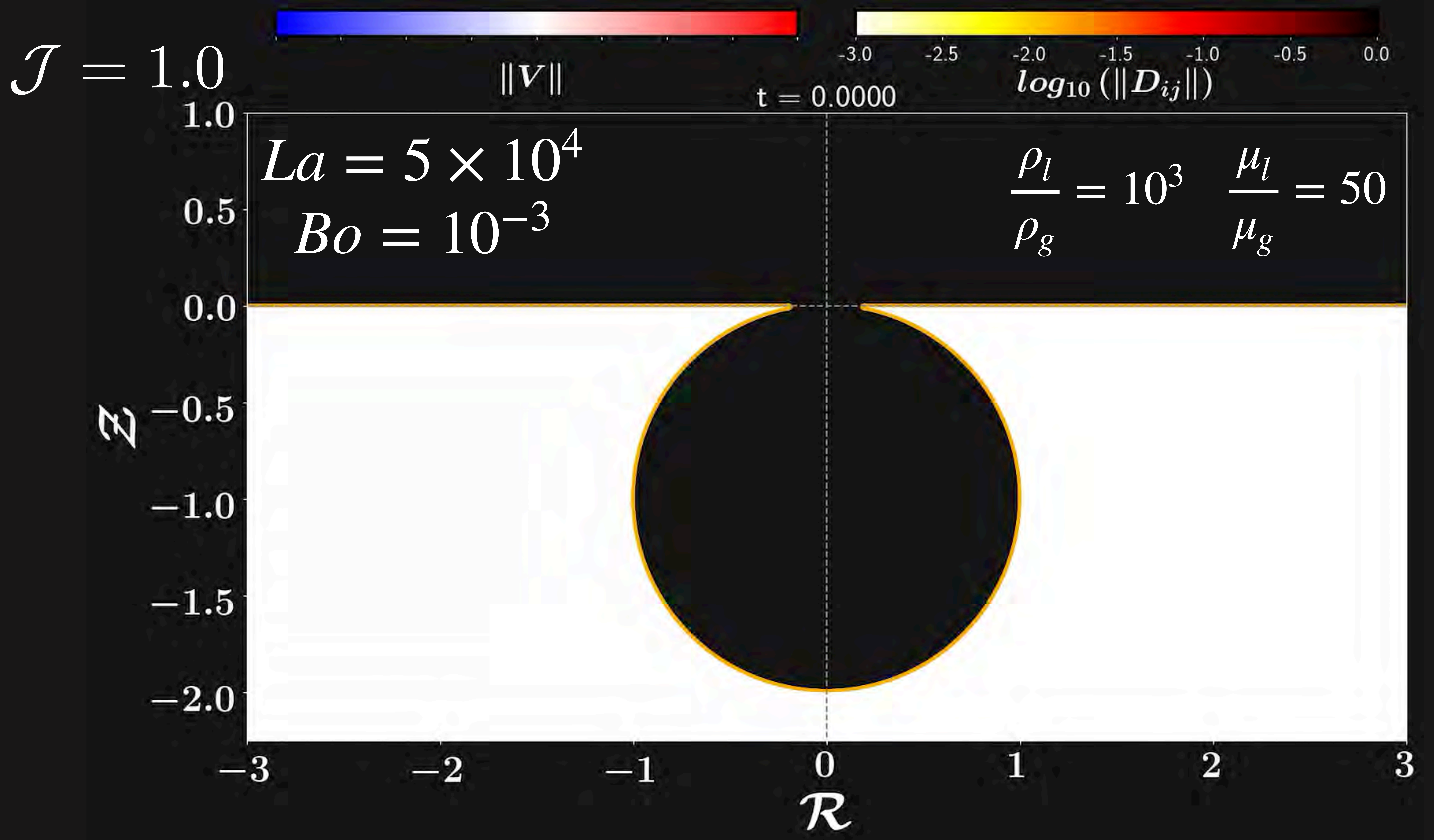
t = 0.0000
$\mathcal{J} = 0.1$
$La = 5 \times 10^4$
$Bo = 10^{-3}$
t = 0.0000
$\mathcal{J} = 0.1$
$La = 5 \times 10^4$
$Bo = 1.0$
t = 0.0000
$\mathcal{J} = 0.1$
$La = 5 \times 10^2$
$Bo = 10^{-3}$
t = 0.0000
$\mathcal{J} = 0.3$
$La = 5 \times 10^4$
$Bo = 10^{-3}$
$\mathcal{Z}$
$\mathcal{R}$

$\mathcal{J} = 0$
Bo
Oh
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-3}
10^{-2}
10^{-1}
t = 0.0000
$\mathcal{Z}$
$\mathcal{R}$
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−4
−3
−2
−1
0
1
2
3
4
$\mathcal{J} = 0.1$
$La = 5 \times 10^{4}$
$Bo = 10^{-3}$
$\mathcal{J} = 0.3$
$La = 5 \times 10^{4}$
$Bo = 10^{-3}$
t = 0.0000
$\mathcal{Z}$
$\mathcal{R}$

Bo
Oh
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-3}
10^{-2}
10^{-1}
$\mathcal{J}\uparrow$
t = 0.0000
$\mathcal{Z}$
$\mathcal{R}$
$\mathcal{J} = 0.1$
$La = 5 \times 10^4$
$Bo = 10^{-3}$
$\mathcal{J} = 0.3$
$La = 5 \times 10^4$
$Bo = 10^{-3}$
t = 0.0000
$\mathcal{Z}$
$\mathcal{R}$

Work in Progress


$\mathcal{J} = 0.5$
$\|V\|$
-3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0
$log_{10}(\|D_{ij}\|)$
t = 0.0000
$La = 5 \times 10^4$
$Bo = 10^{-3}$
$\frac{\rho_l}{\rho_g} = 10^3$ $\frac{\mu_l}{\mu_g} = 50$
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
$\mathcal{Z}$
−3 −2 −1 0 1 2 3
$\mathcal{R}$


$\mathcal{J} = 1.0$
$\|V\|$
-3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0
$log_{10}(\|D_{ij}\|)$
t = 0.0000
$La = 5 \times 10^4$
$Bo = 10^{-3}$
$\frac{\rho_l}{\rho_g} = 10^3$
$\frac{\mu_l}{\mu_g} = 50$
1.0 0.5 0.0 −0.5 −1.0 −1.5 −2.0
$\mathcal{Z}$
−3 −2 −1 0 1 2 3
$\mathcal{R}$

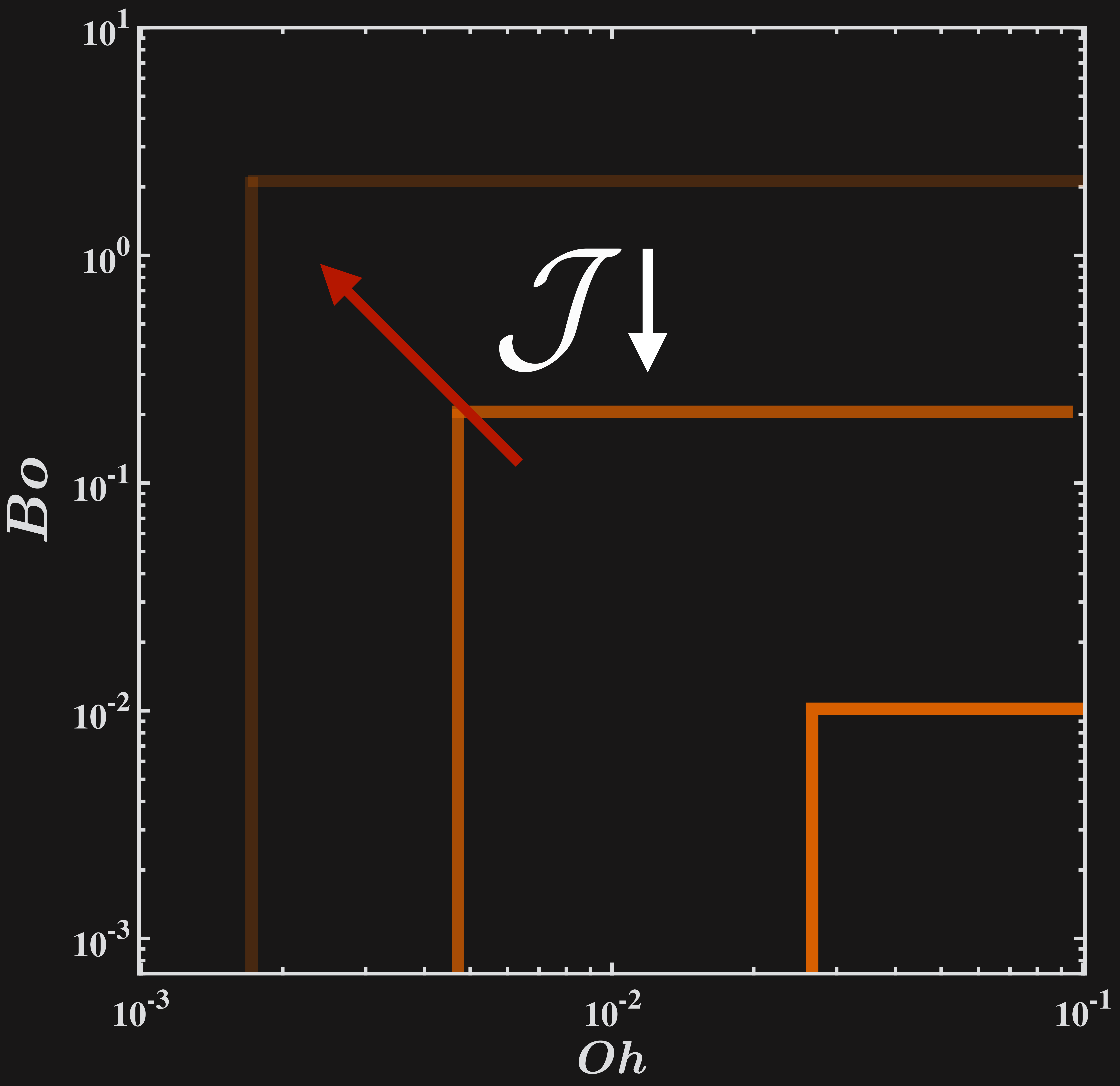
What we know?

$La = 5 \times 10^4$

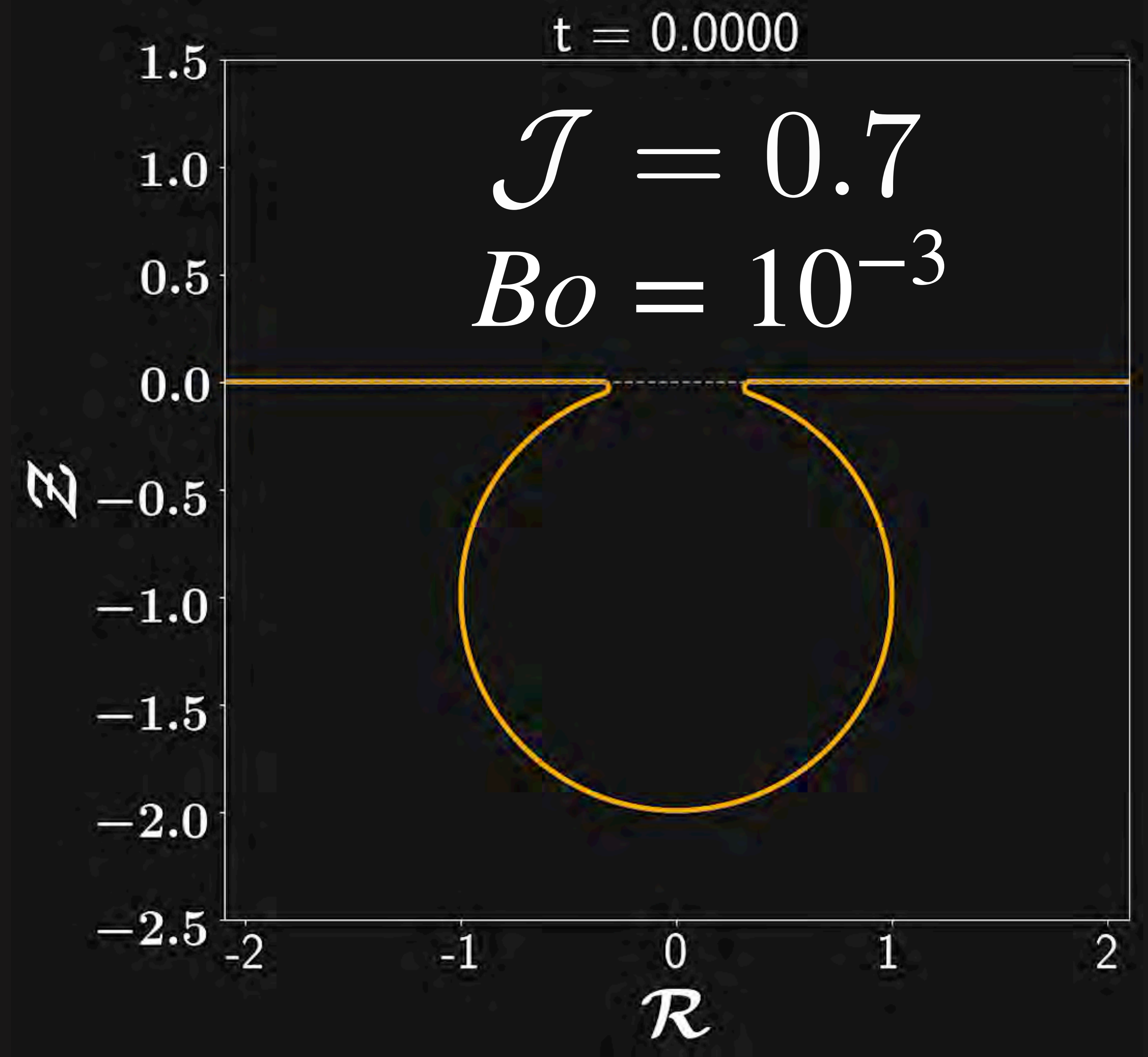
$\mathcal{J} = 0.7$ $Bo = 3.25$

$\mathcal{J} = 0.7$ $Bo = 10^{-3}$

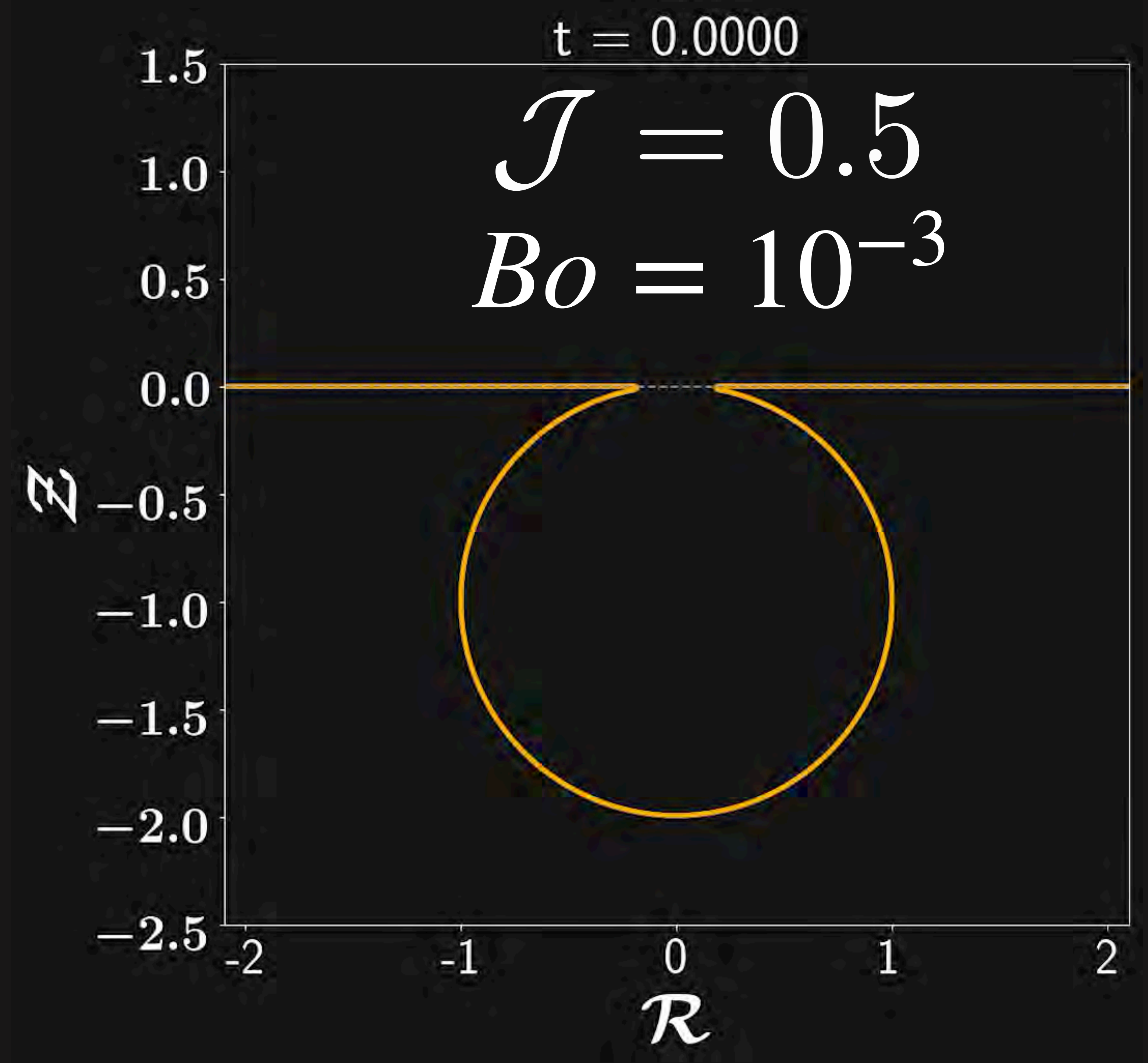
$\mathcal{J} = 0.5$ $Bo = 10^{-3}$



Bo
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
$\mathcal{J}\downarrow$
10^{-3}
10^{-2}
10^{-1}
Oh

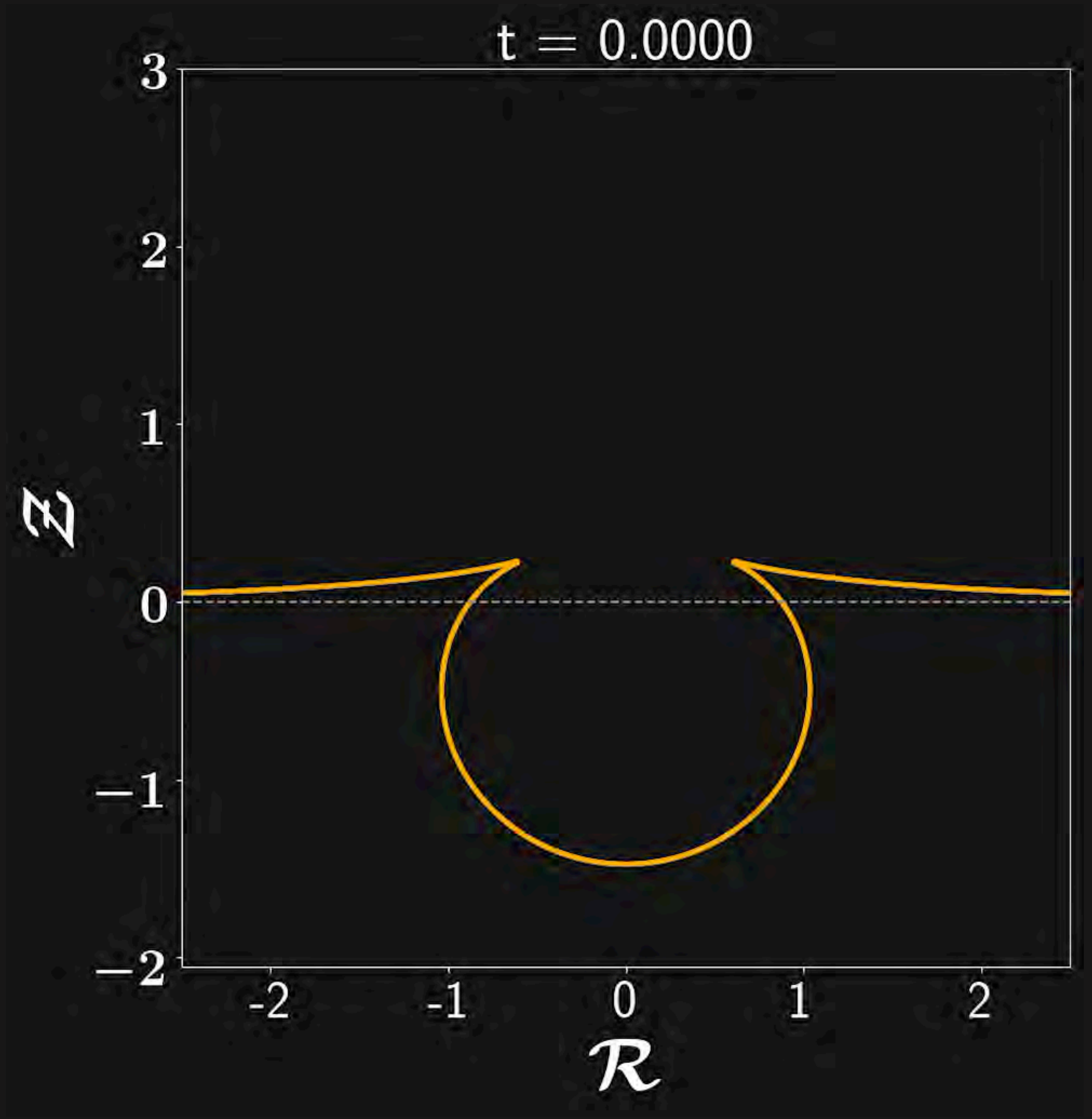


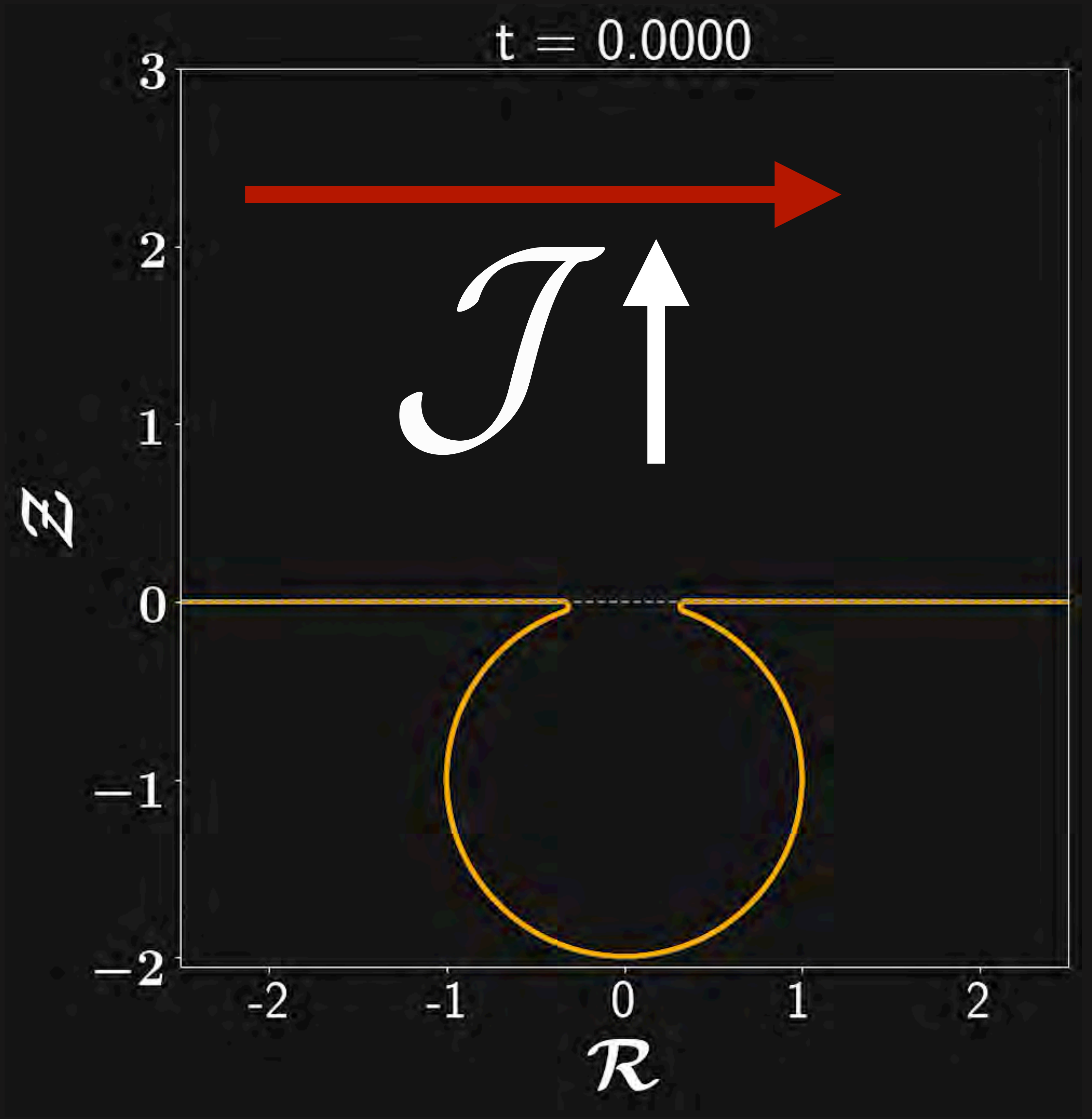
t = 0.0000
$\mathcal{J} = 0.7$
$Bo = 10^{-3}$
$\mathcal{Z}$
$\mathcal{R}$

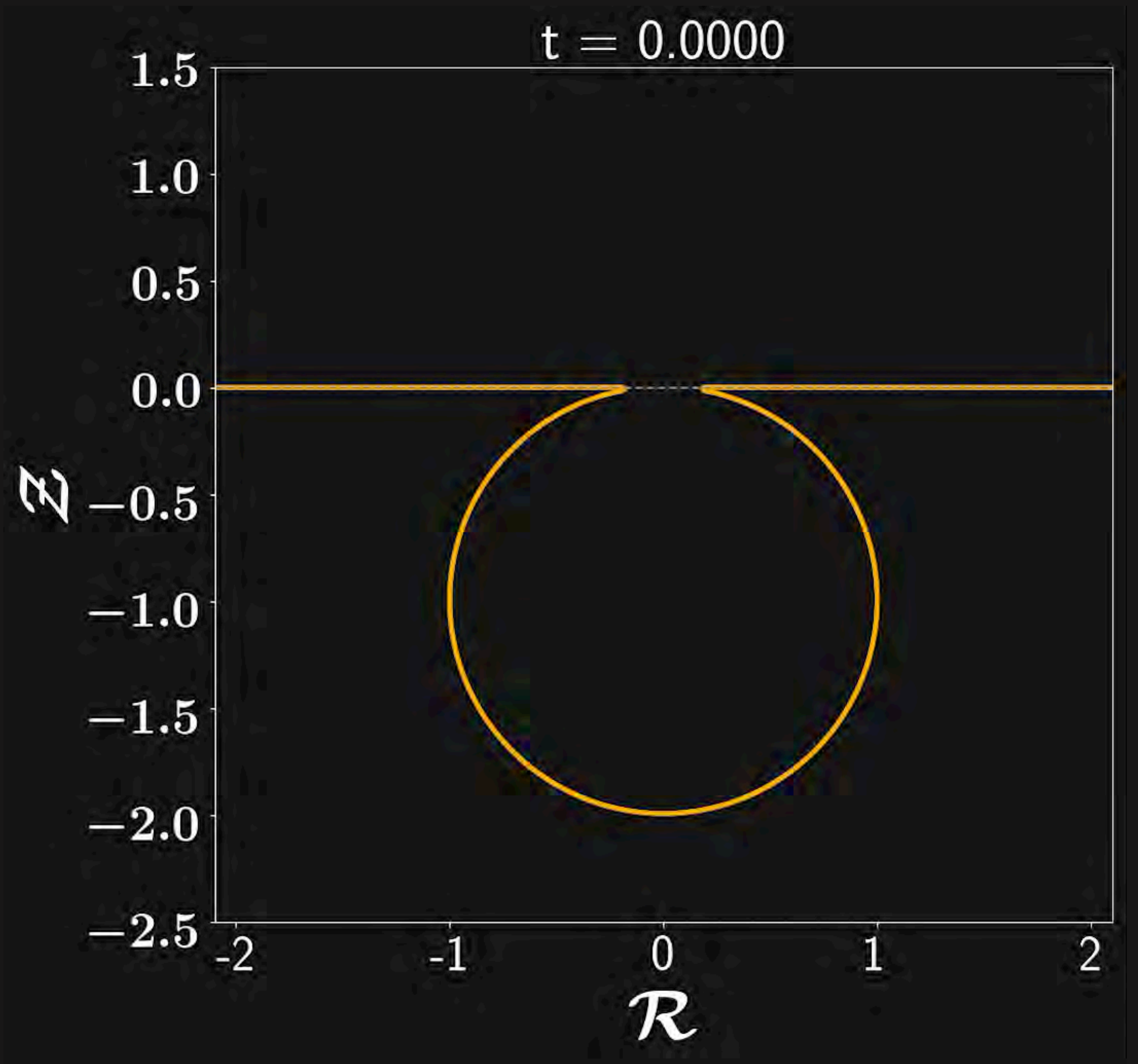


t = 0.0000
$\mathcal{J} = 0.5$
$Bo = 10^{-3}$
$\mathcal{Z}$
$\mathcal{R}$

Thank You!







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