# Experiments on the Single-Mode Three-Dimensional Rayleigh-Taylor and Richtmyer-Meshkov Instabilities

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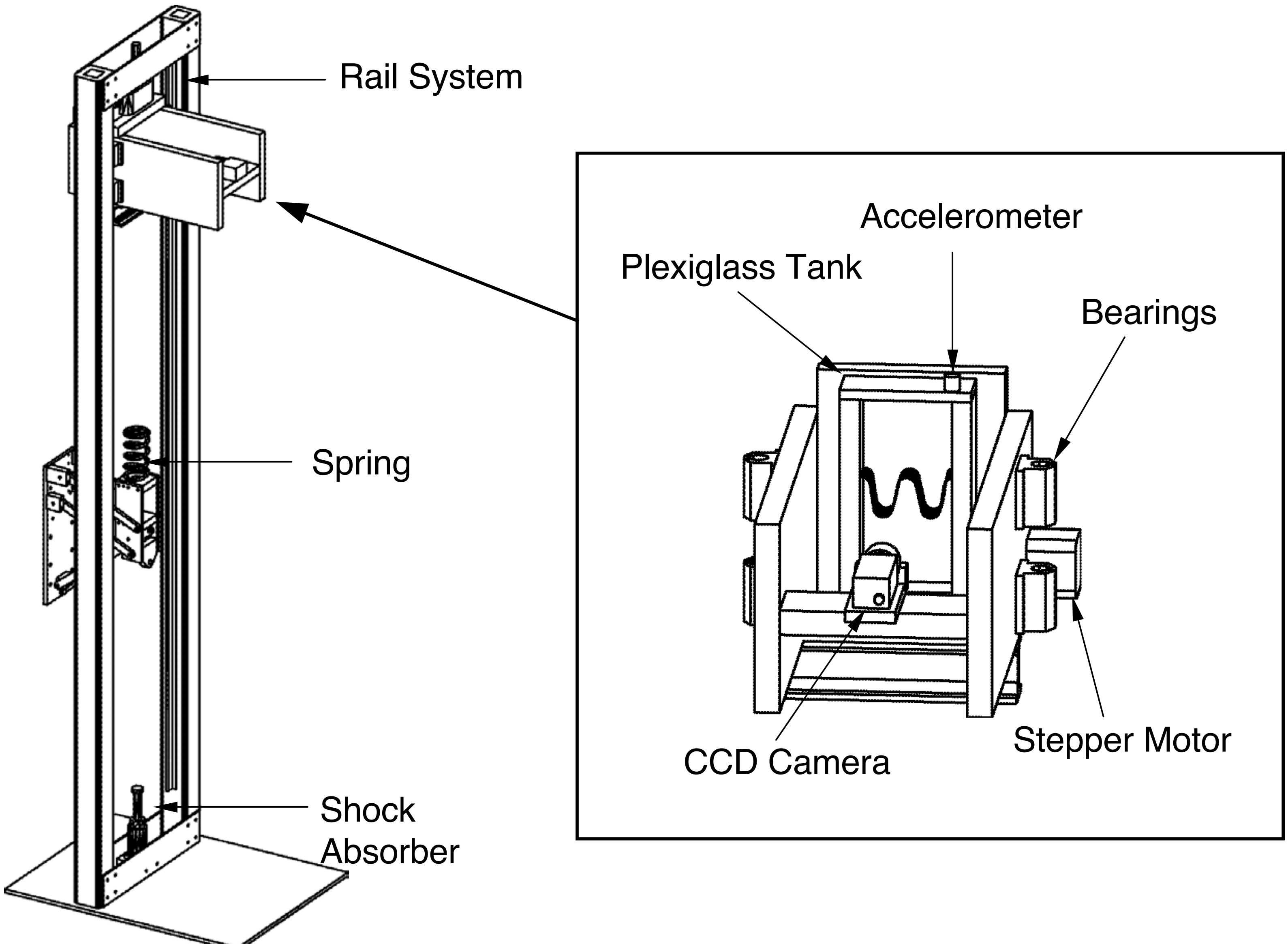
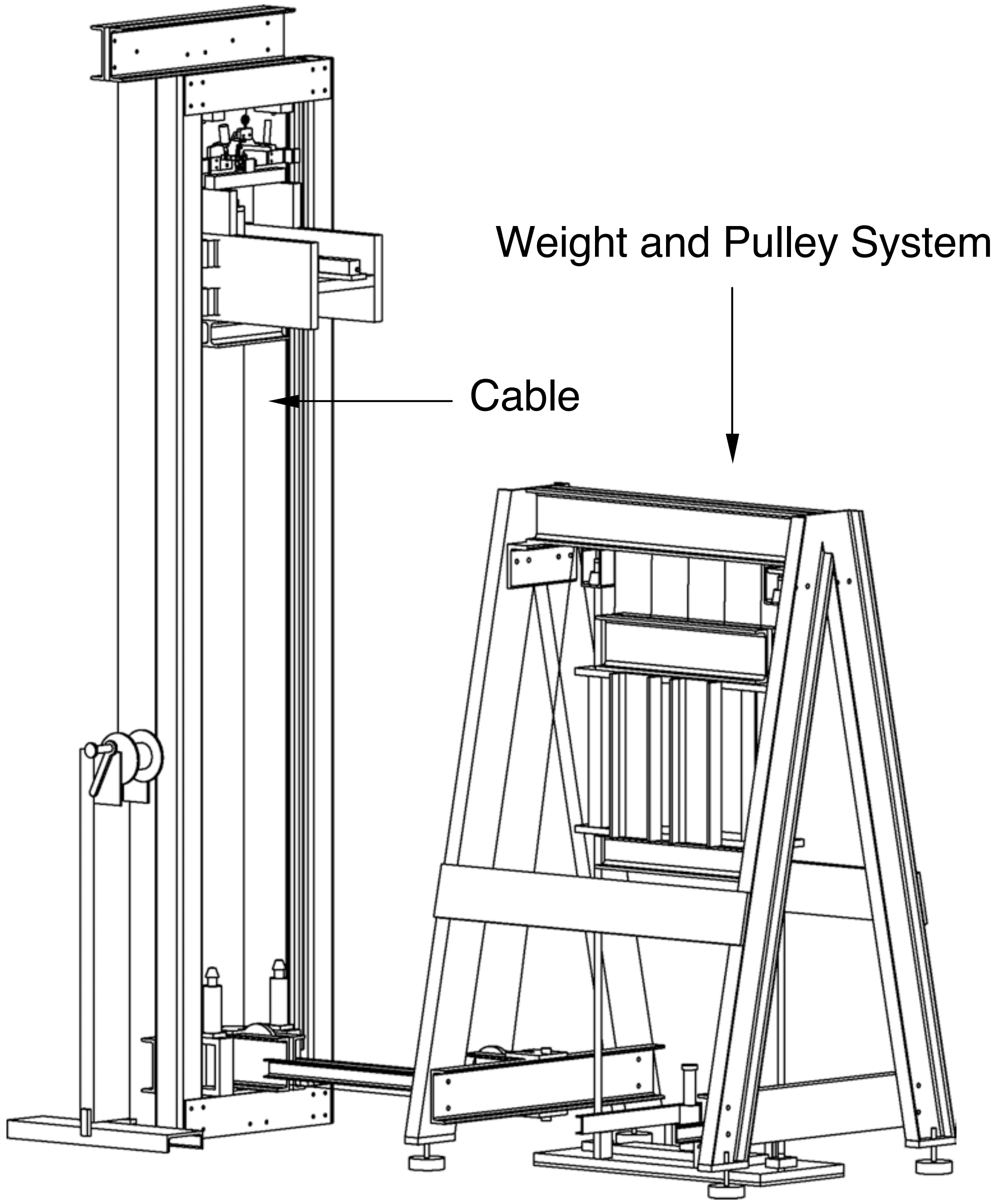
# Richtmyer-Meshkov Apparatus



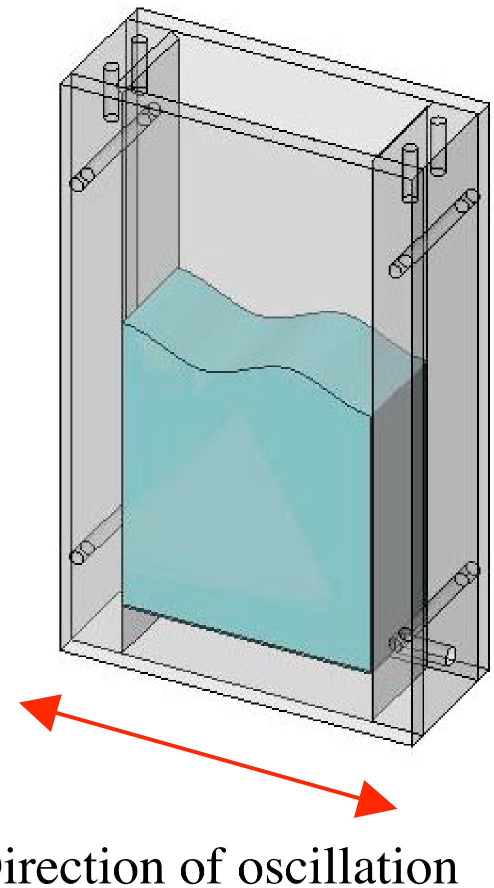

Fluids: Calcium nitrate/water and alcohol/water, $A \approx 0.15$

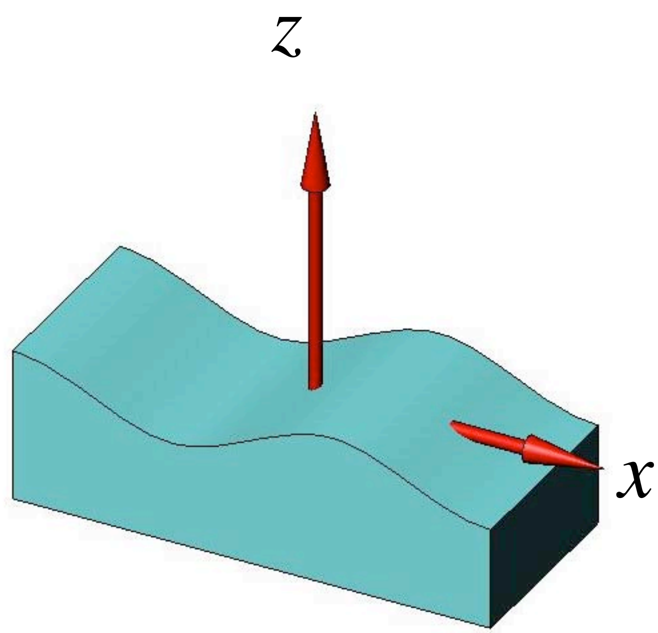
# Drop Tower Operation

# Rayleigh-Taylor Apparatus



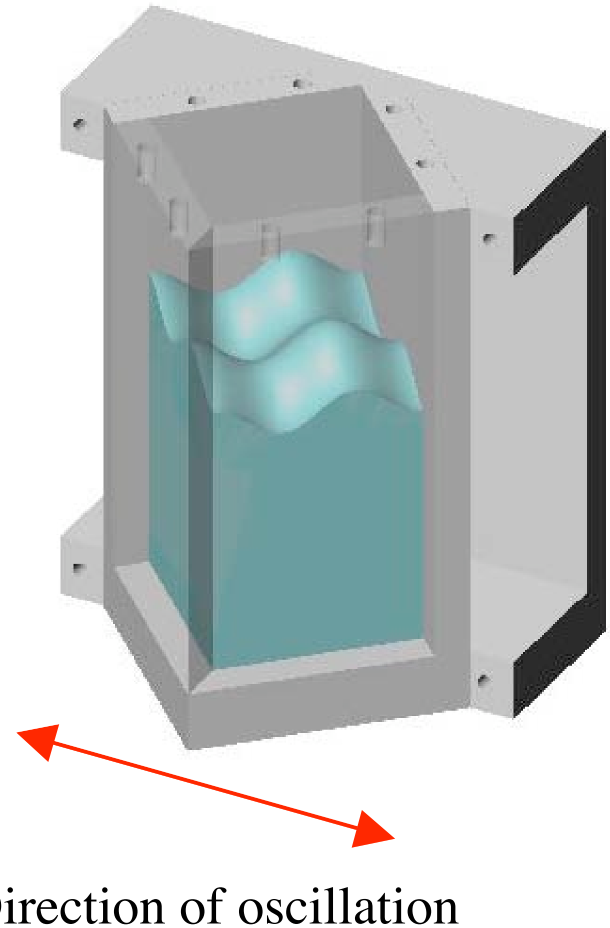
# 2-D Perturbation

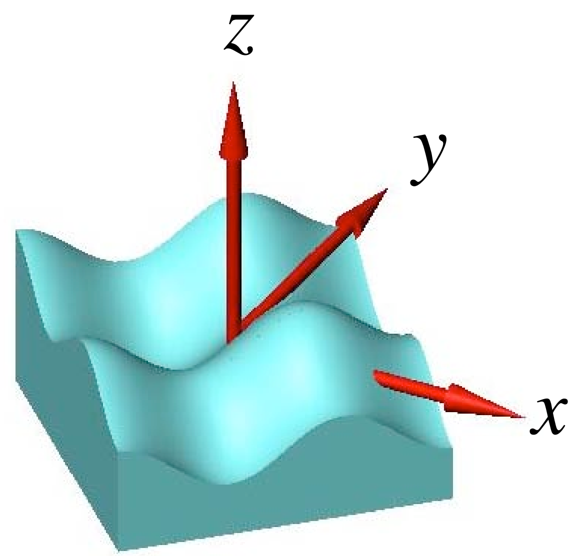



$$\eta = a_0 \sin(kx)$$

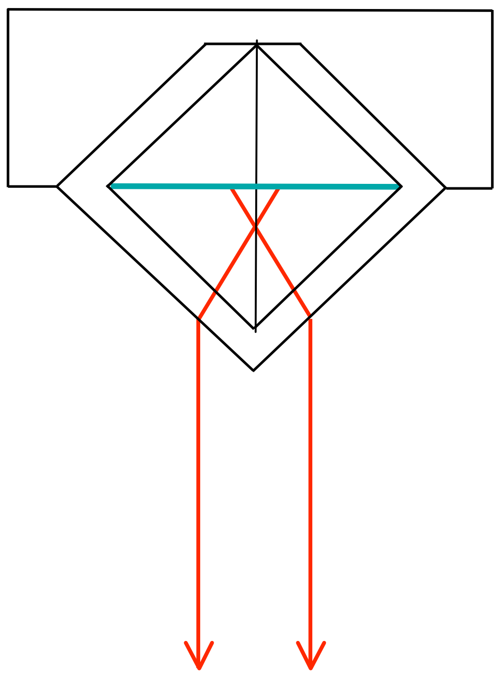
# 3-D Perturbation



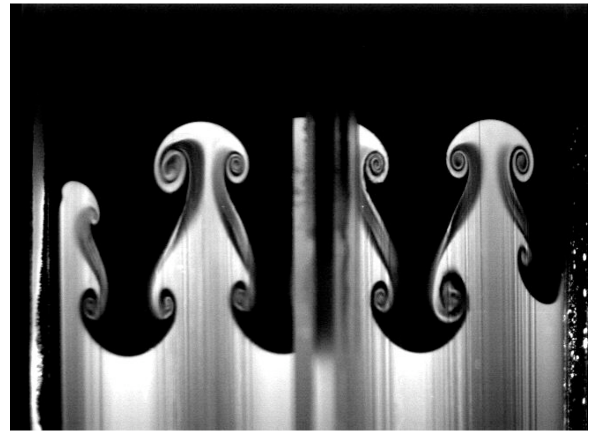




$$\eta = a_0 \sin(kx)\sin(ky)$$

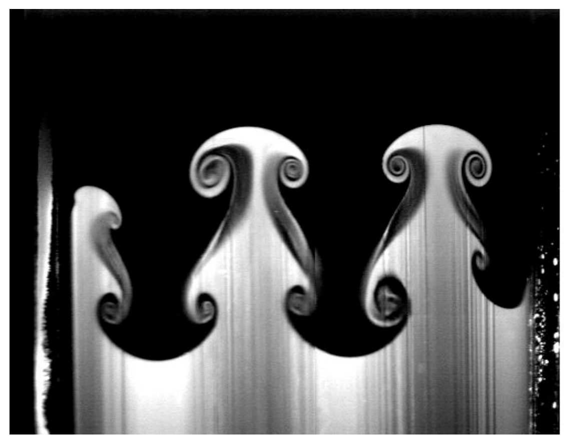
Top view of tank



Refraction index differences causes light rays to be bent thus forming a double image.

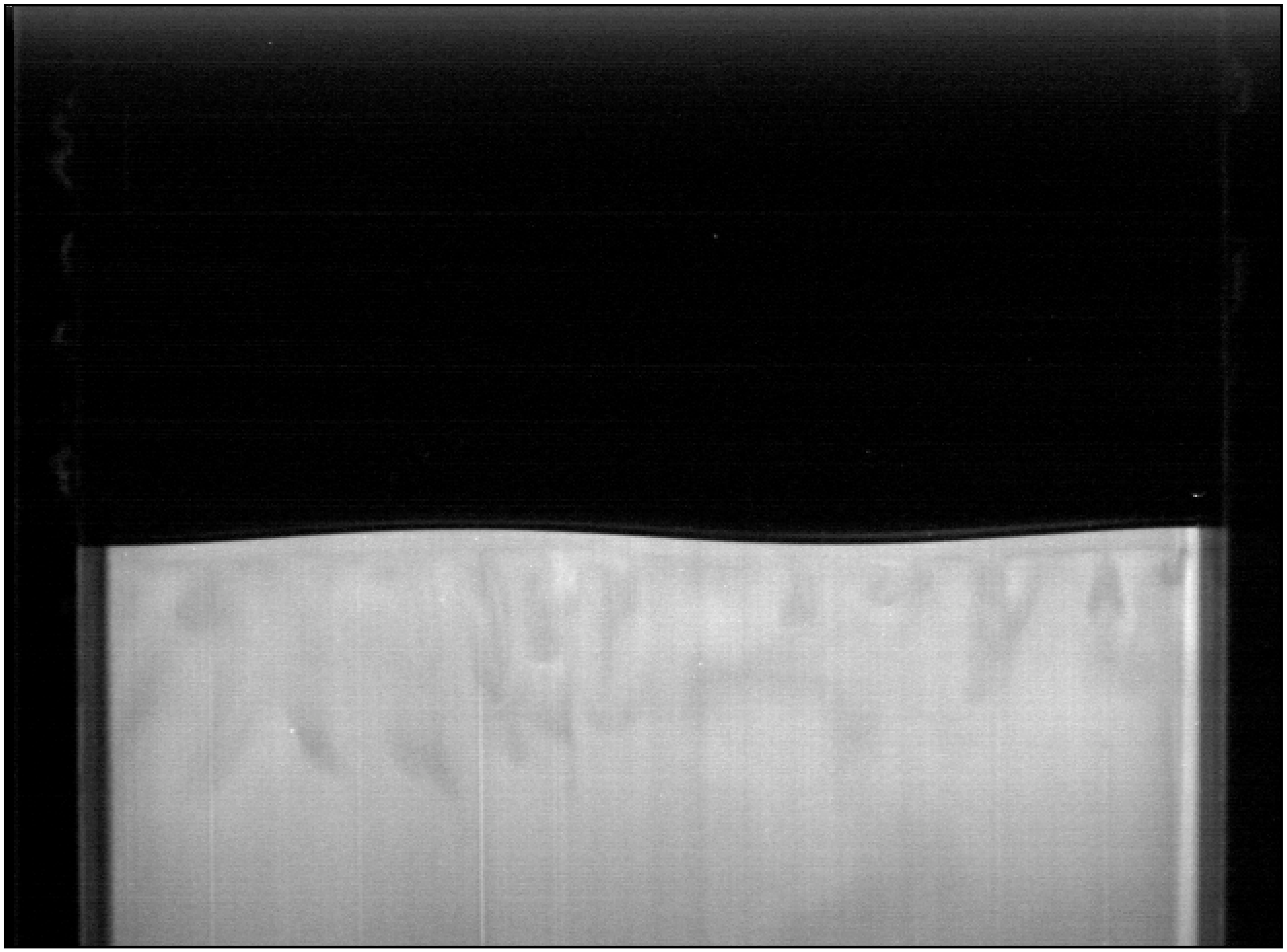


Original image

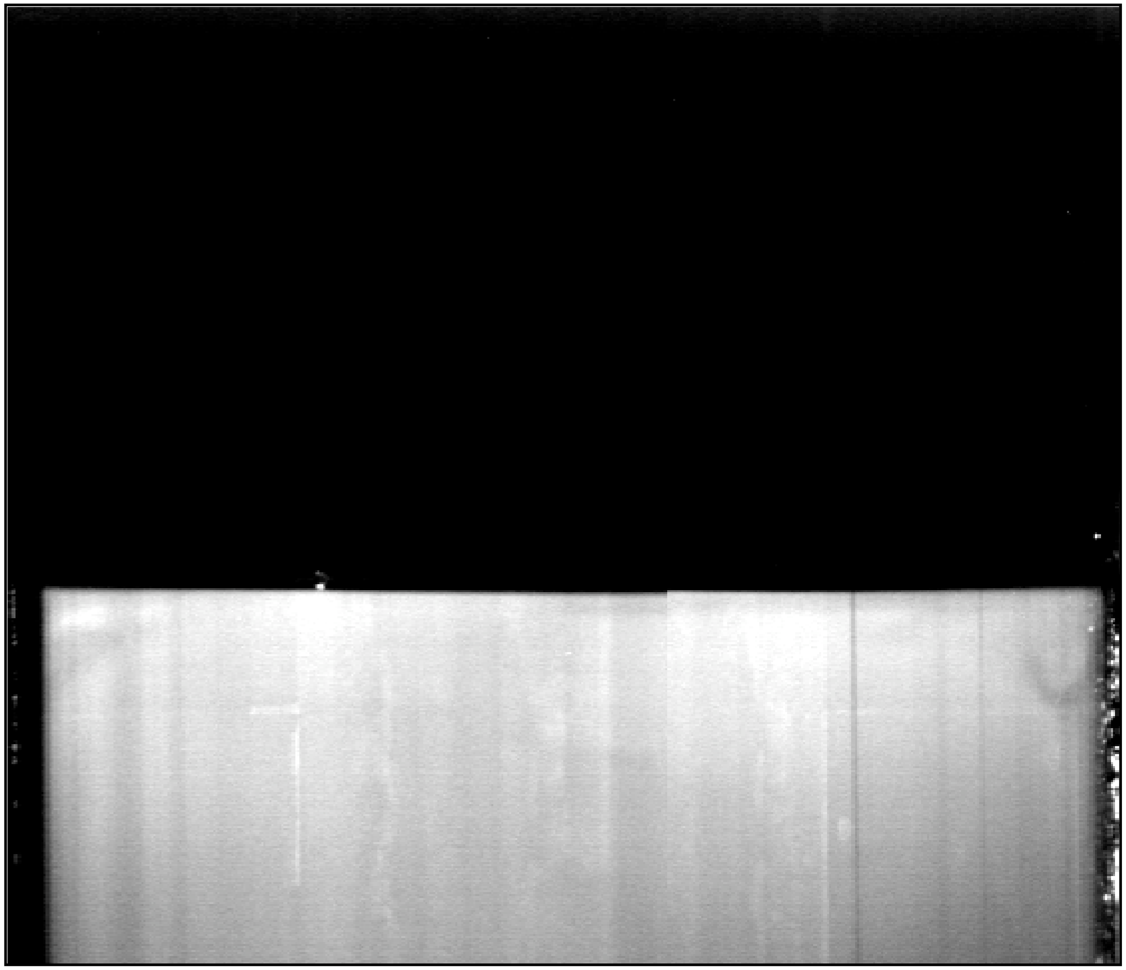


Corrected Image

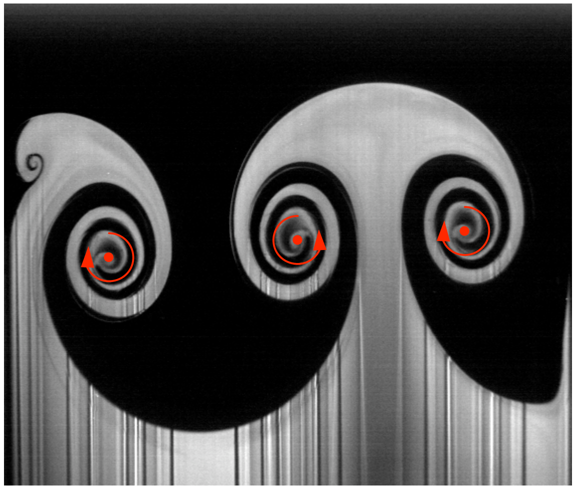
# 2-D RM Instability



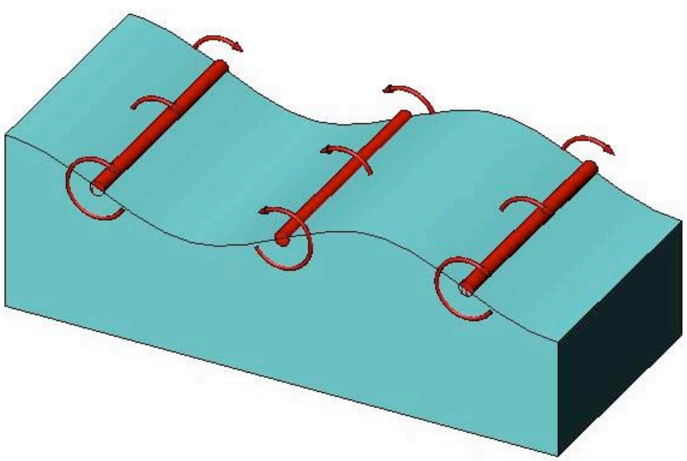
# 3-D RM Instability

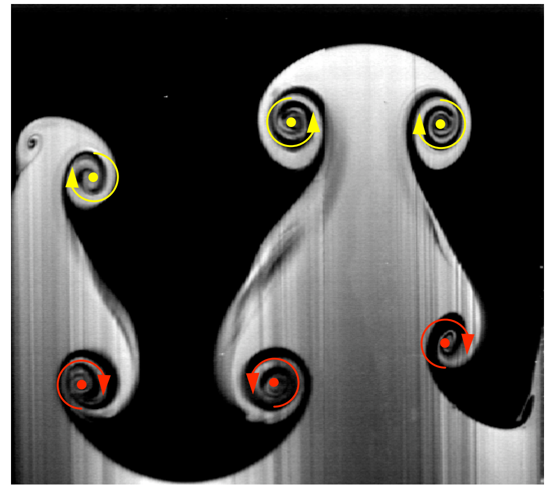


# Late-Time Vorticity Distribution

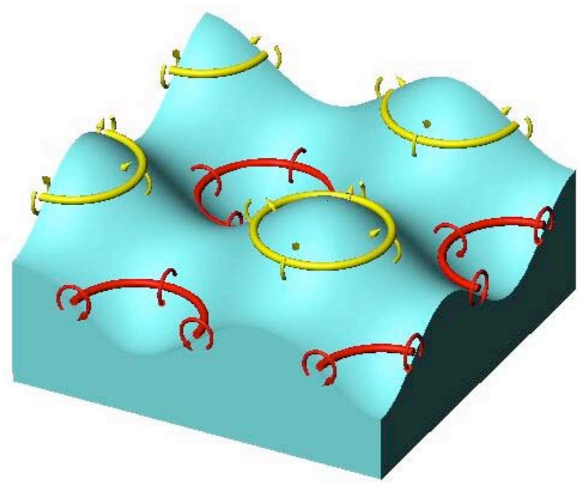


2-D

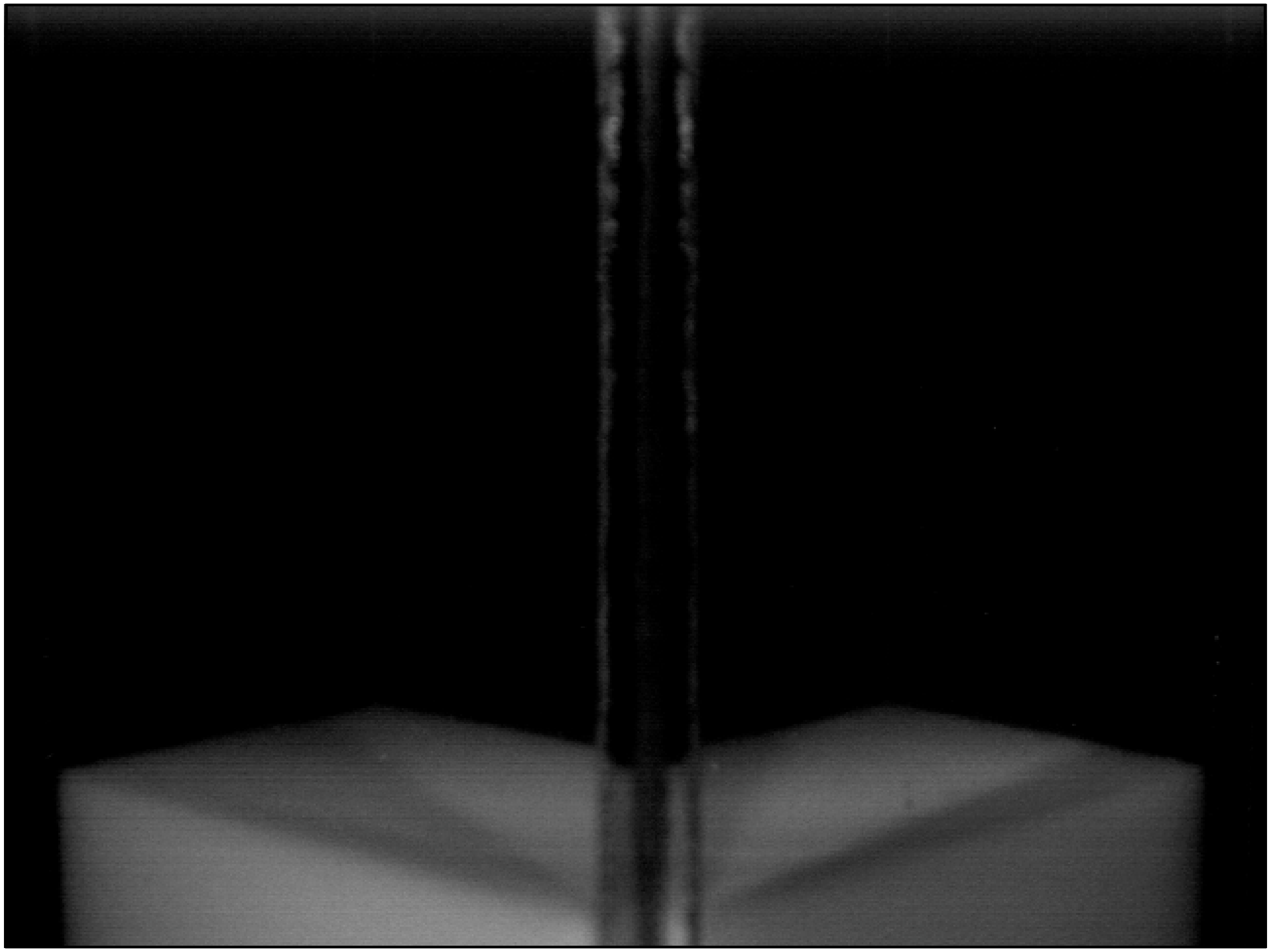




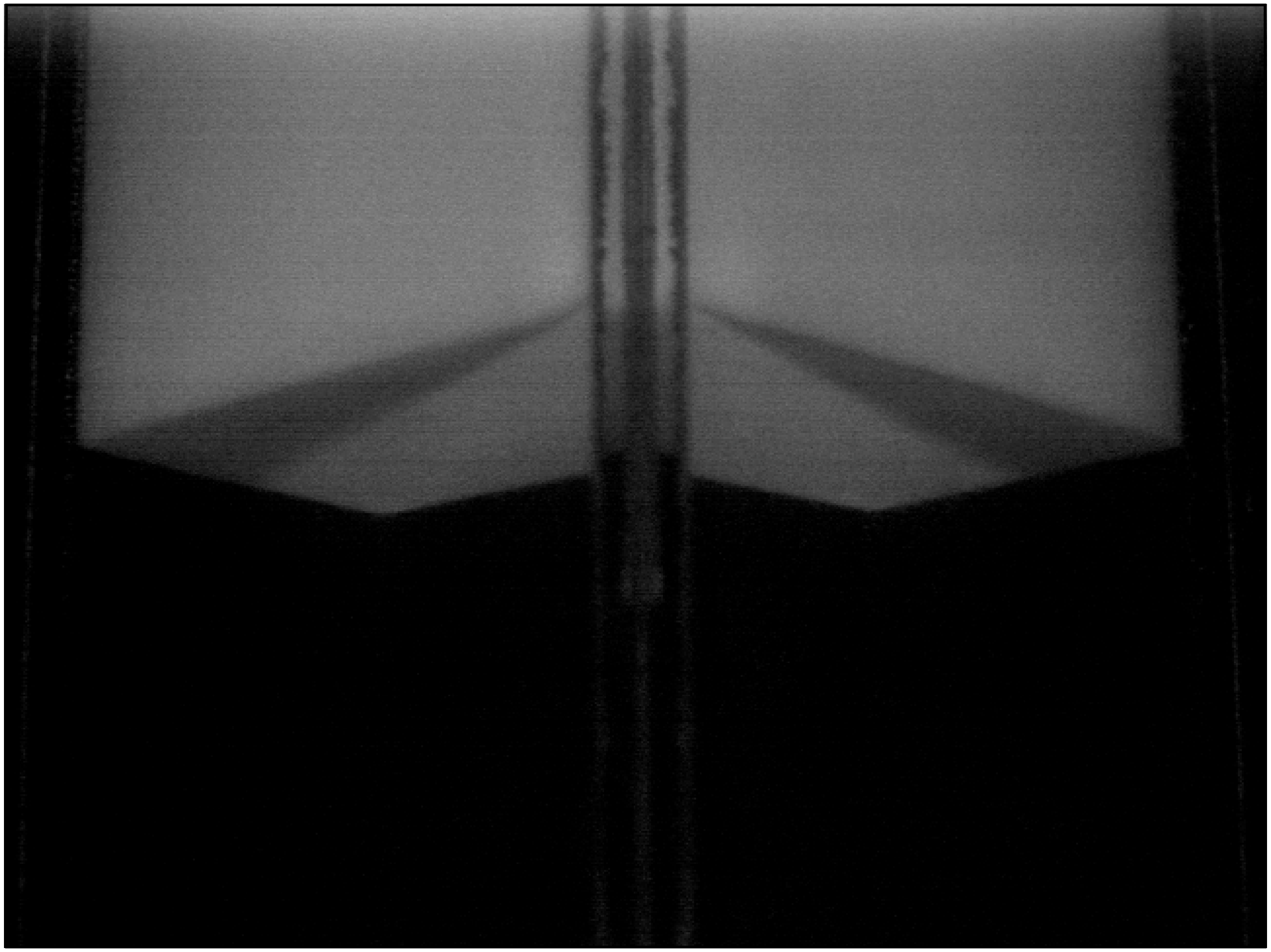
3-D



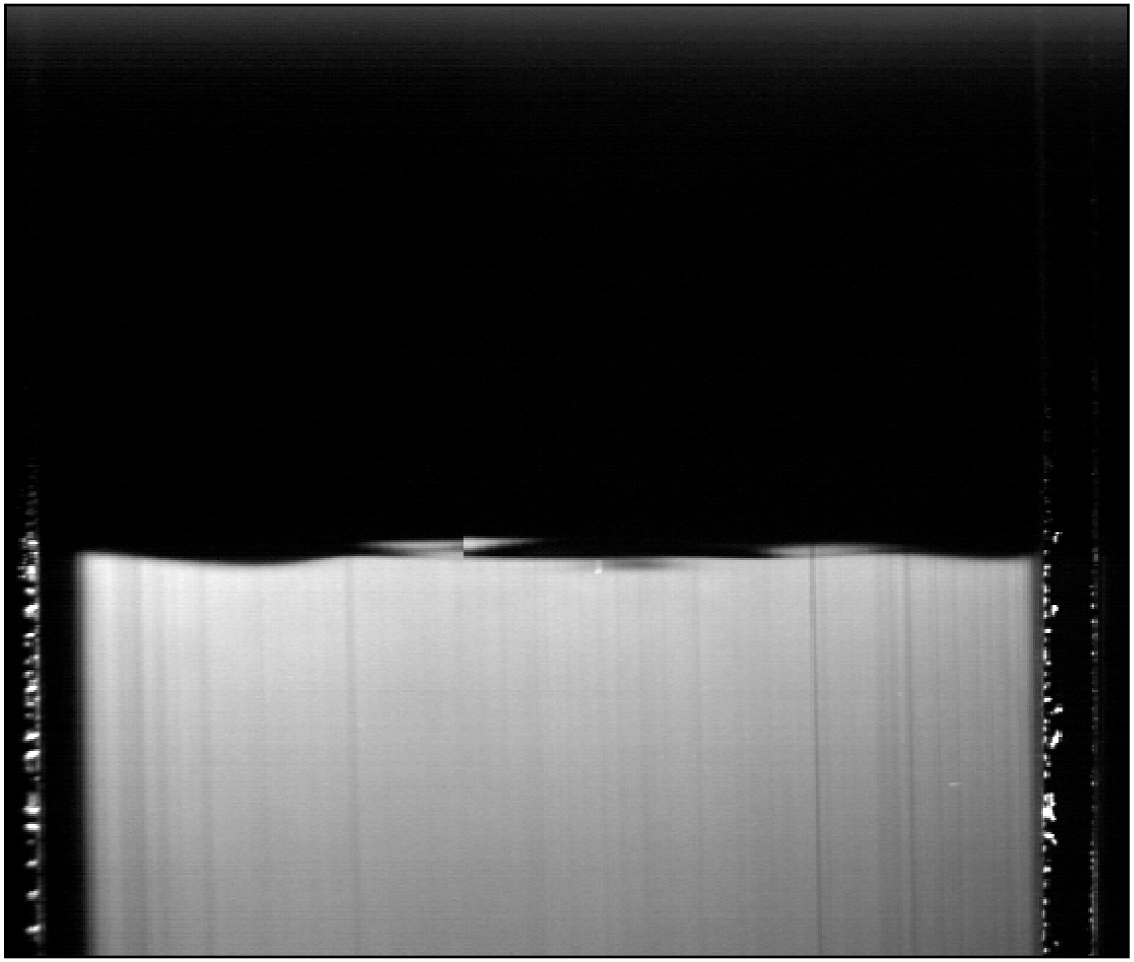
# 3-D RM Instability Opaque View



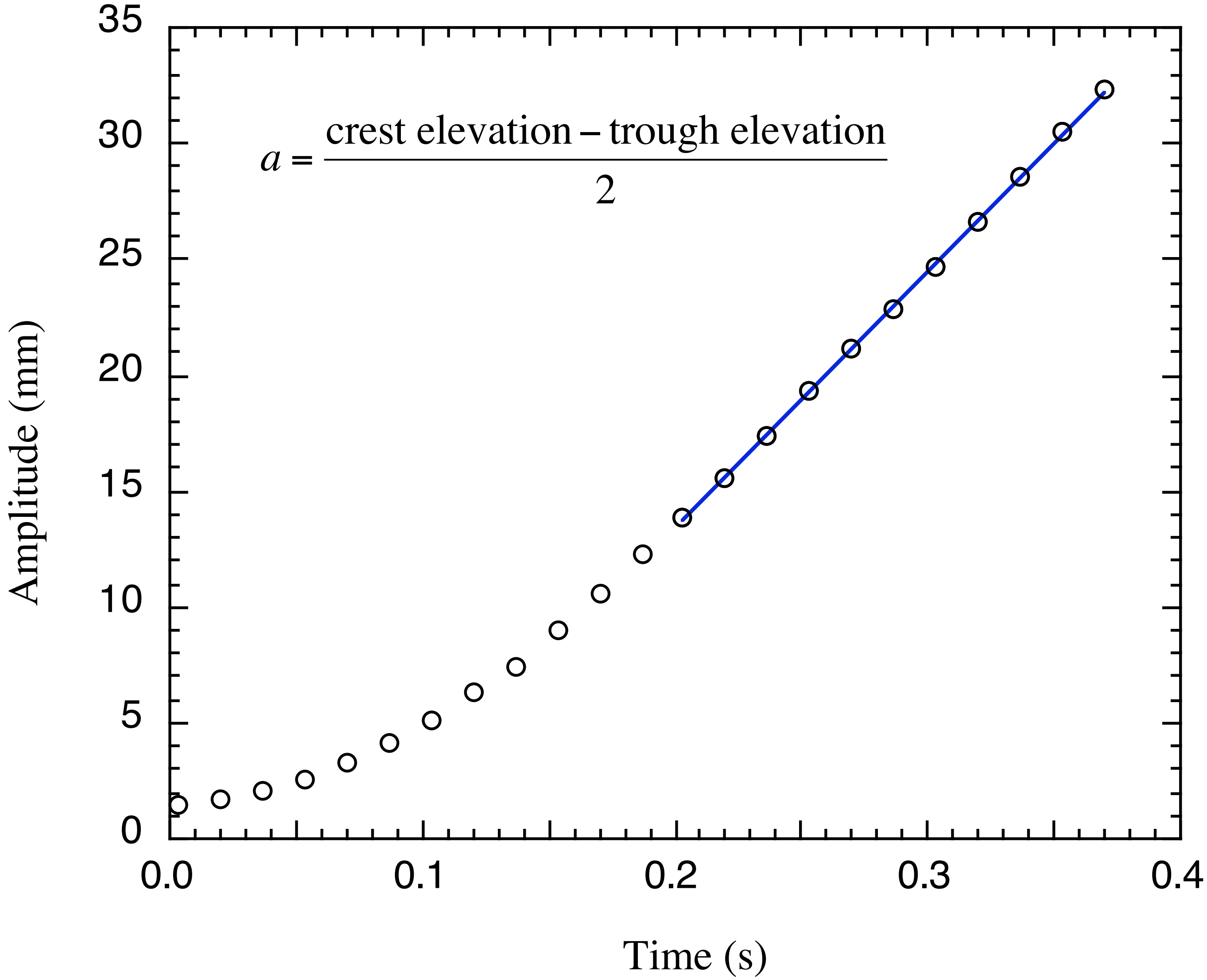
# Opaque Bottom View



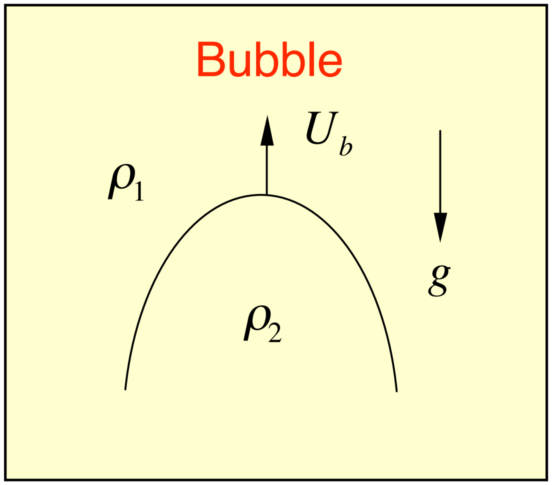
# 3-D RT Instability

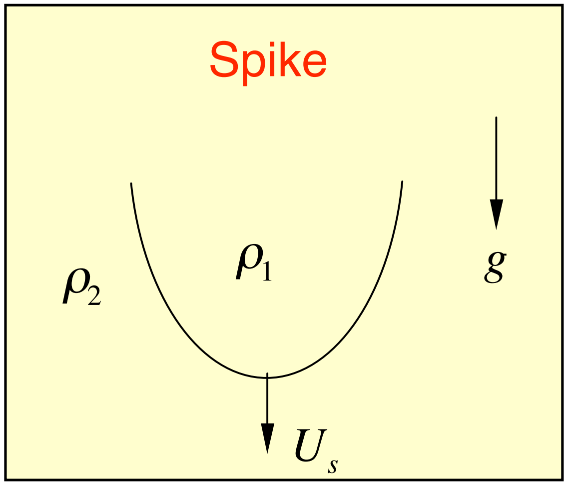


# RT Amplitude Measurements



# Buoyancy/Drag Model




$$(\rho_2 + \kappa\rho_1)V\dot{U}_b = -C\rho_1 U_b^{\,2} S + (\rho_1 - \rho_2)Vg$$

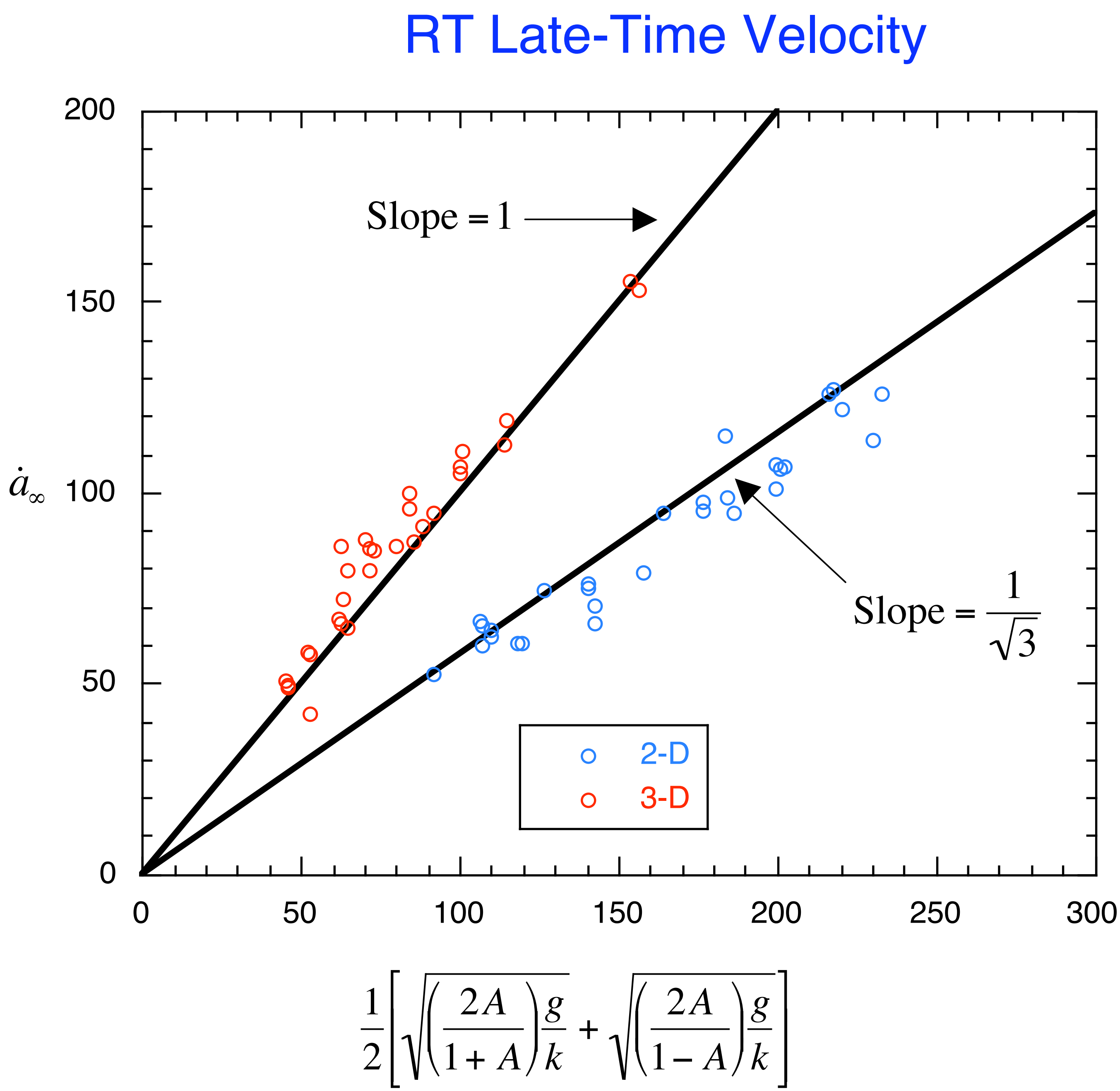
$$(\rho_1 + \kappa\rho_2)V\dot{U}_s = -C\rho_2 U_s^{\,2} S + (\rho_1 - \rho_2)Vg$$

For RT instability $\dot{U}_{b/s} = 0$ $\quad U_{b/s}^{\,2} = \frac{Vk}{CS}\left(\frac{2A}{1 \pm A}\right)\frac{g}{k}$ $\quad \frac{Vk}{CS} = \begin{cases} 1 & \text{for 2D} \\ 1/3 & \text{for 3D} \end{cases}$

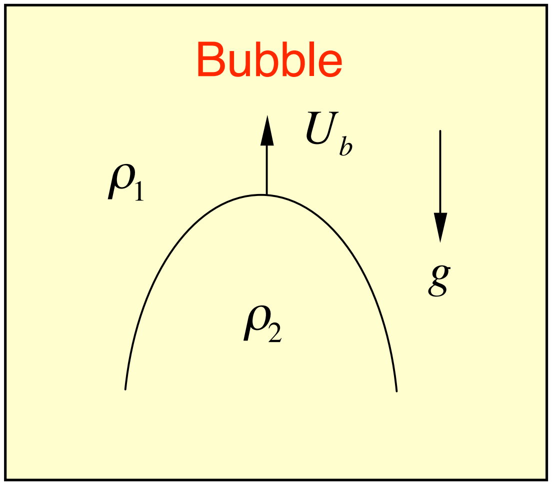
$$U_{b/s} = \begin{cases} \sqrt{\left(\frac{2A}{1 \pm A}\right)\frac{g}{3k}} & \text{for 2D} \\ \sqrt{\left(\frac{2A}{1 \pm A}\right)\frac{g}{k}} & \text{for 3D} \end{cases}$$

Obtained by Oron et al. (2001), Goncharov (2002)

Also in agreement with Layzer (1955) when $A \to 1$


RT Late-Time Velocity
200
150
100
50
0
0
50
100
150
200
250
300
$\dot{a}_\infty$
Slope = 1
Slope = $\frac{1}{\sqrt{3}}$
2-D
3-D
$\frac{1}{2}\left[\sqrt{\left(\frac{2A}{1+A}\right)\frac{g}{k}}+\sqrt{\left(\frac{2A}{1-A}\right)\frac{g}{k}}\right]$

# Buoyancy/Drag Model




$$\left(\rho_2 + \kappa\,\rho_1\right)V\dot{U}_b = -C\rho_1 {U_b}^2 S + \left(\rho_1 - \rho_2\right)Vg$$

For RM instability $\quad g = 0$

$$U_{b/s}{}^2 = -\frac{V\,k}{C\,S}\left(\frac{1 \mp A}{1 \pm A} + \kappa\right)\frac{\dot{U}_{b/s}}{k}$$

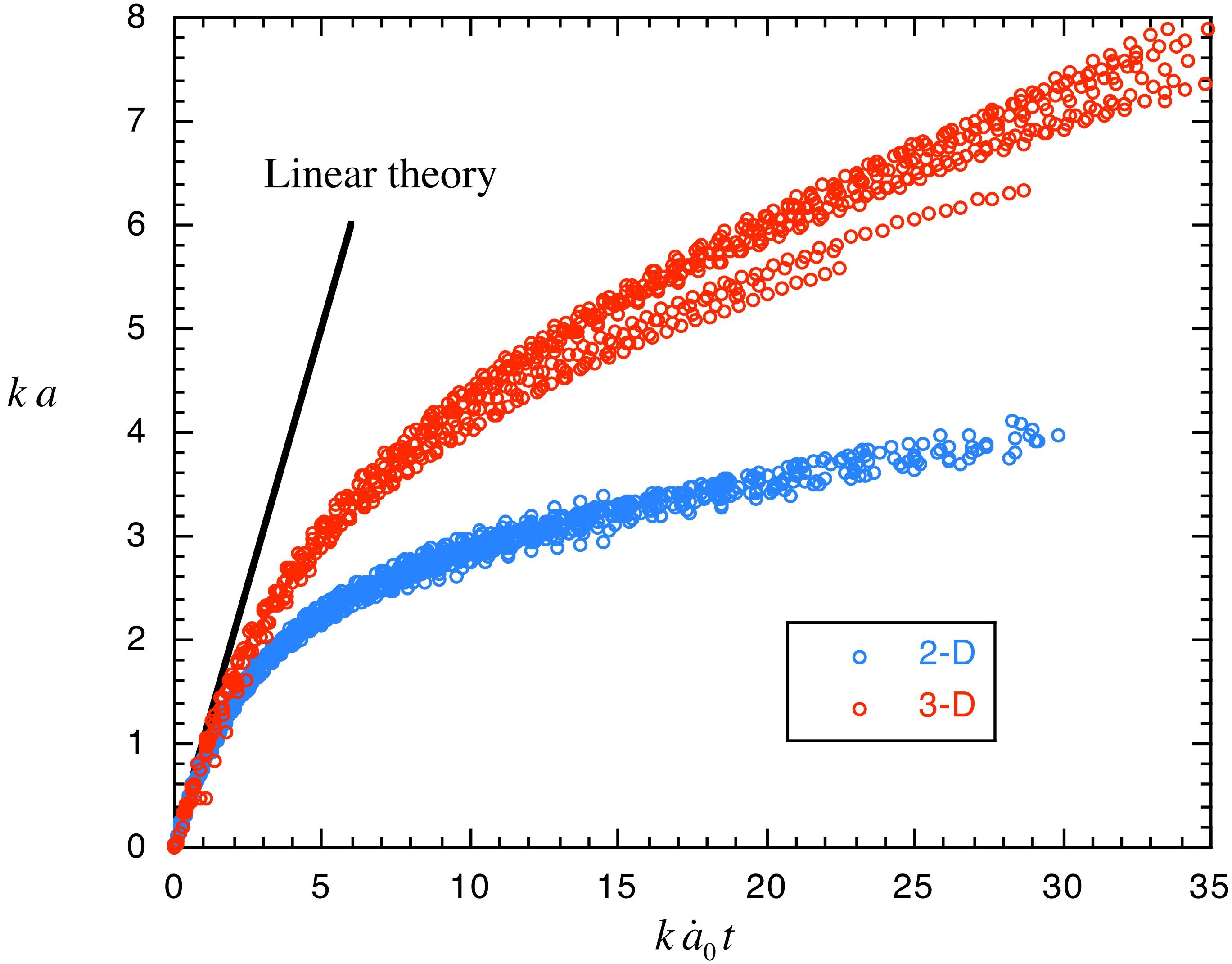
As before: $\quad \dfrac{V\,k}{C\,S} = \begin{cases} 1/3 & \text{for 2D} \\ 1 & \text{for 3D} \end{cases}$

New parameter: $\quad \kappa = \begin{cases} 1 & \text{for 2D} \\ 2 & \text{for 3D} \end{cases}$

$$U_{b/s} = \begin{cases} \dfrac{3 \pm A}{3(1 \pm A)}\dfrac{1}{kt} & \text{for 2D} \\ \dfrac{2}{(1 \pm A)}\dfrac{1}{kt} & \text{for 3D} \end{cases}$$

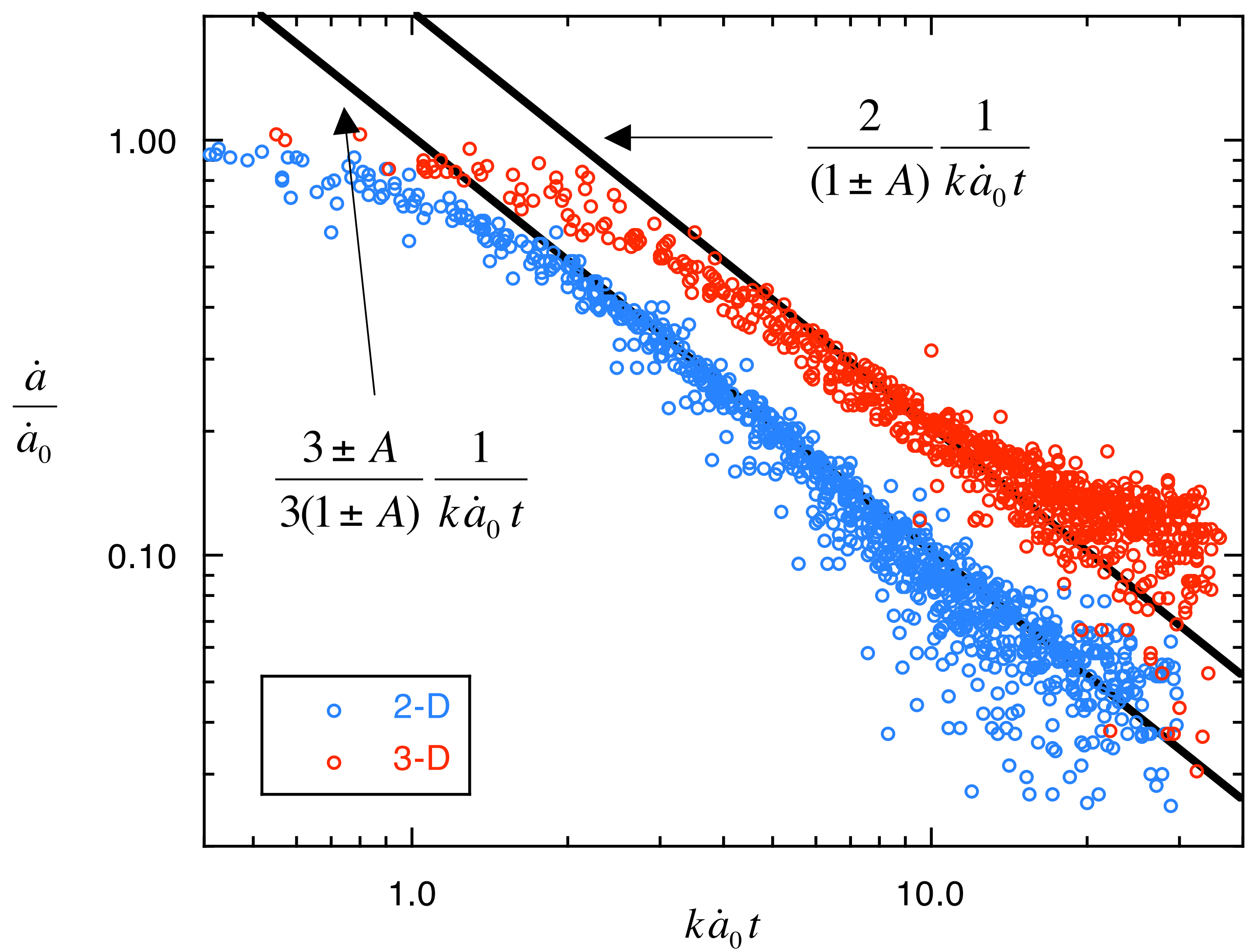
In agreement with vortex model when $A \rightarrow 0$

# RM Amplitude Measurements

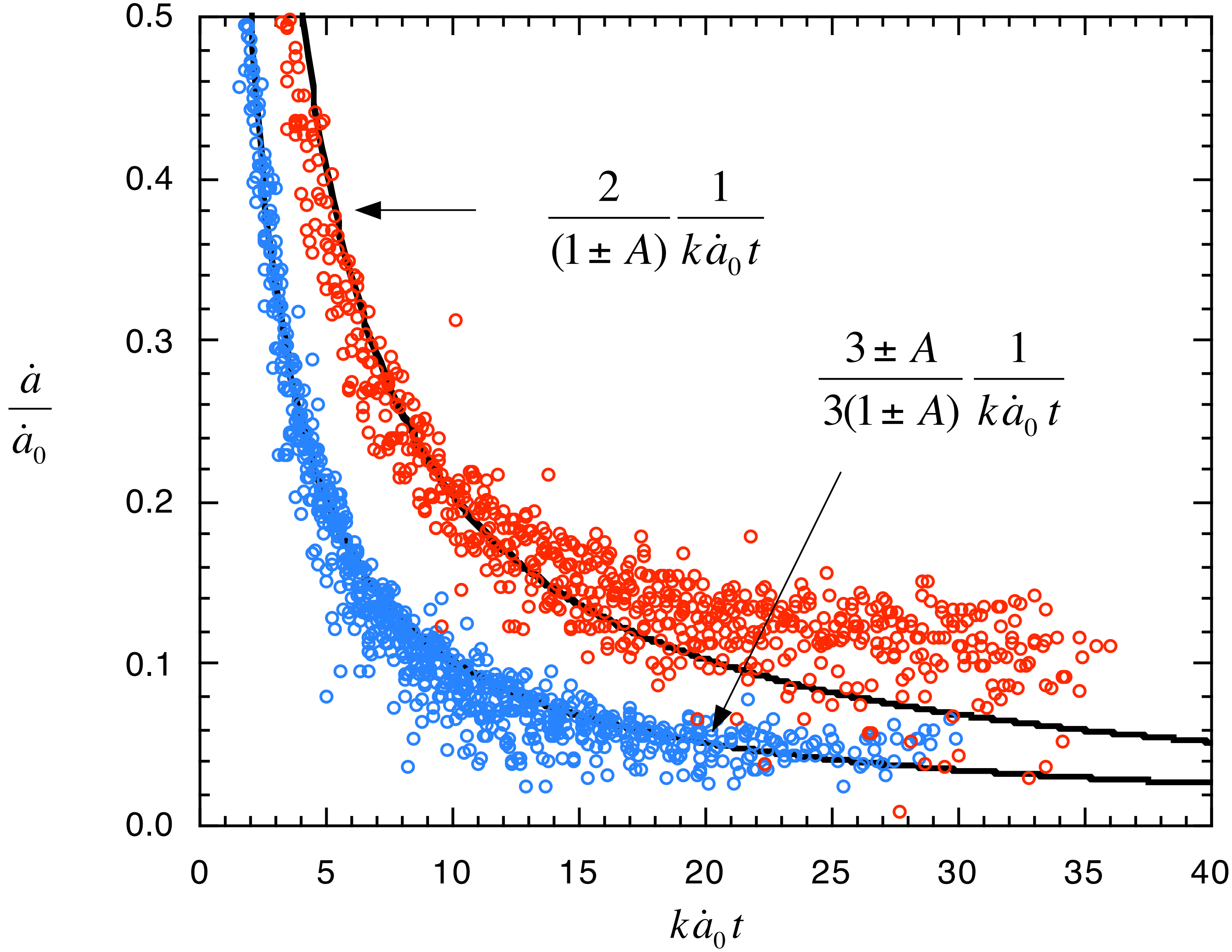



found by solving $\ddot{a} = -kAga$ with measured $g(t)$

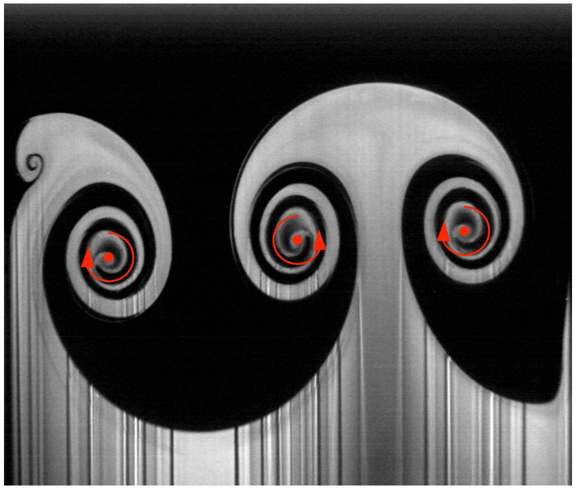
# RM Late-Time Velocity

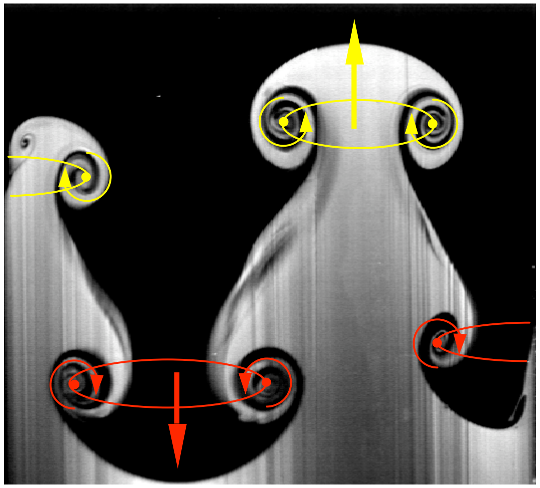


# RM Late-Time Velocity



# Vortex Dynamics





- The 2-D perturbation generates a nearly stationary vortex row.
- The result is bubble and spike velocities that decay as $1/kt$.

- The 3-D generates a square array of vortex rings that self-induce motion upward and downward.
- The result is a bubble and spike amplitude with constant velocity.

Low Atwood number RM instability is a vortex dominated.

Thus bubble models are not well suited for describing this flow.

# Conclusions

- Low Atwood number three-dimensional single-mode RM and RT instabilities look fundamentally different than their two-dimensional counterparts.
- Late-time 3D RT amplitude measurements shows faster growth than 2D in agreement with the standard models.
- Late time 3D RM amplitude measurements also show significantly faster growth but appear to diverge from the predicted $1/kt$ dependence as $t \rightarrow \infty$.
- The disagreement with the models can be attributed to the fact that bubble models are ineffective in modeling the vortex dynamics of this flow.