# On the CCN (de)activation nonlinearities


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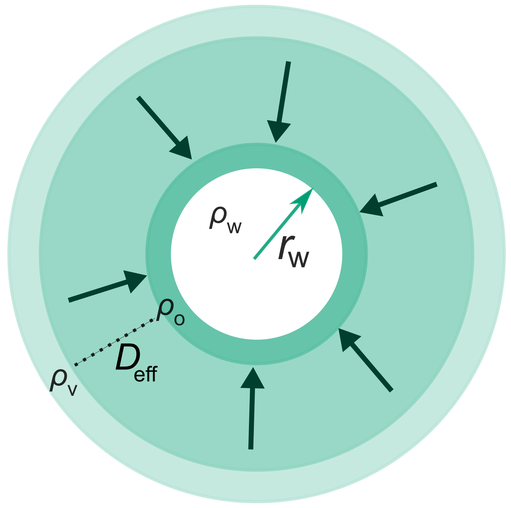
## droplet growth laws in a nutshell: mass and heat diffusion




Fick's and Fourier's laws combined

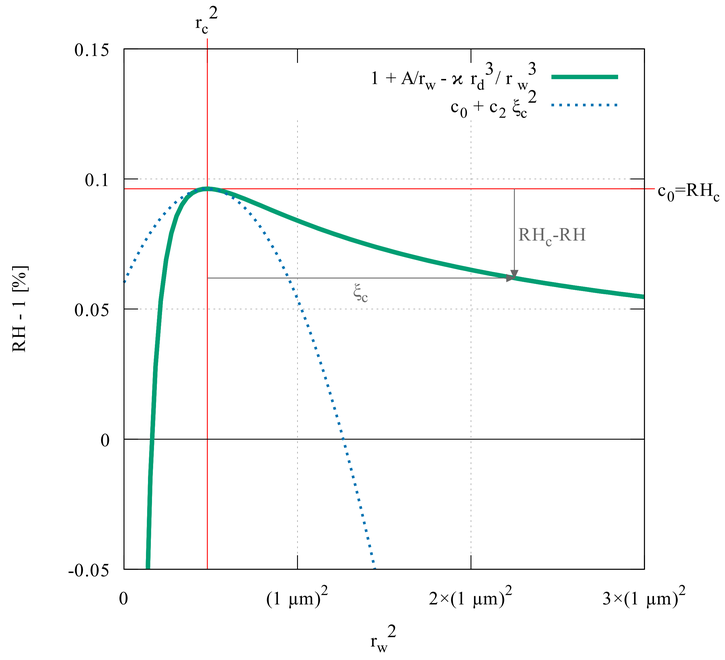
spherical geometry

$$\dot{r}_w = \frac{1}{r_w}\frac{D_{eff}}{\rho_w}(\rho_v - \rho_\circ)$$

non-dimensional numbers:

$$RH = \rho_v/\rho_{vs}$$
$$RH_{eq} = \rho_\circ/\rho_{vs}$$

$$\dot{r}_w = \frac{1}{r_w} D_{eff}\frac{\rho_{vs}}{\rho_w}(RH - RH_{eq})$$




kappa-Köhler:

$$RH_{eq} \approx 1 + \frac{A}{r_w} - \frac{\kappa r_d^3}{r_w^3}$$

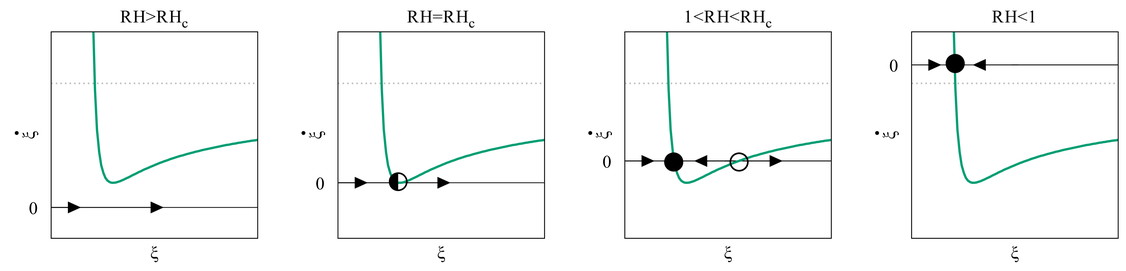
maximum at $(r_c, RH_c)$:

$$r_c = \sqrt{3\kappa r_d^3/A}$$
$$RH_c = 1 + \frac{2A}{3r_c}$$

$$\xi = r_w^2 + C$$

$$\dot{\xi} = 2D_{eff}\frac{\rho_{vs}}{\rho_w}(RH - RH_{eq}(\xi))$$

## phase portrait of the system: flipped Köhler curve




## saddle-node bifurcation at Köhler curve maximum

$$RH_{eq}(\xi_c) = c_0 + \cancel{c_1\xi_c} + c_2\xi_c^2 + \dots \qquad \dot{\xi}_c\Big|_{\xi_c\to 0} \sim \frac{RH - RH_c}{A/(4r_c^5)} + \xi_c^2 \qquad \dot{x} = r + x^2$$

## bifurcations (and catastrophe) in the RH-coupled system

simple moisture budget (const T,p):

$$\dot{RH} \approx \frac{\dot{\rho}_v}{\rho_{vs}} = -N\underbrace{\frac{4\pi\rho_w}{3\rho_{vs}}}_{\alpha} 3r_w^2\dot{r}_w$$

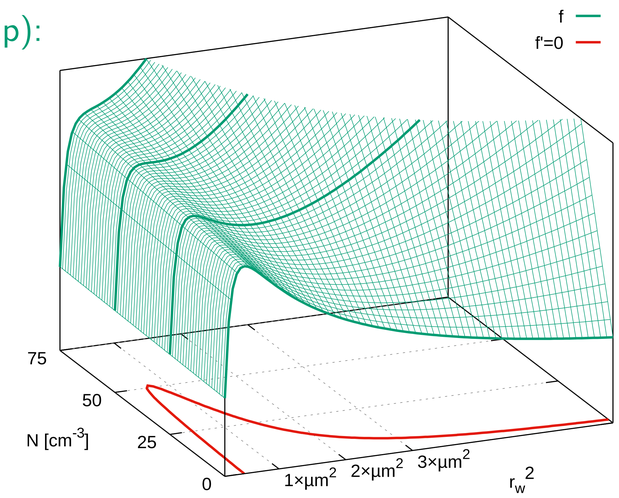
integrating in time:

$$RH = RH_0 - \alpha N r_w^3$$

new phase portrait:

$$\dot{\xi} \sim (RH_0 - 1) - \underbrace{\left(\frac{A}{\xi^{\frac{1}{2}}} - \frac{\kappa r_d^3}{\xi^{\frac{3}{2}}} + \alpha N \xi^{\frac{3}{2}}\right)}_{f}$$

regime-controlling params: RH, N




$$\mathrm{sgn}(f') = \mathrm{sgn}\left(\kappa r_d^3 - \frac{A}{3}r_w + \alpha N r_w^3\right)$$

!

- analytical estimation of the CCN activation timescale
- relevance to particle-based microphysics (super droplets)
- corroboration with numerical integration (cusp catastrophe related hysteresis)


NPG paper: Arabas & Shima 2017

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seminar next week at Laramie

UNIVERSITY OF WYOMING

Dept. of Atmospheric Science

Tue., July 17, 3:10 pm, EN6085


AMS Cloud Physics Conference, Vancouver, July 2018