Aspect Ratio Evolution in Two-Moment Bulk Models

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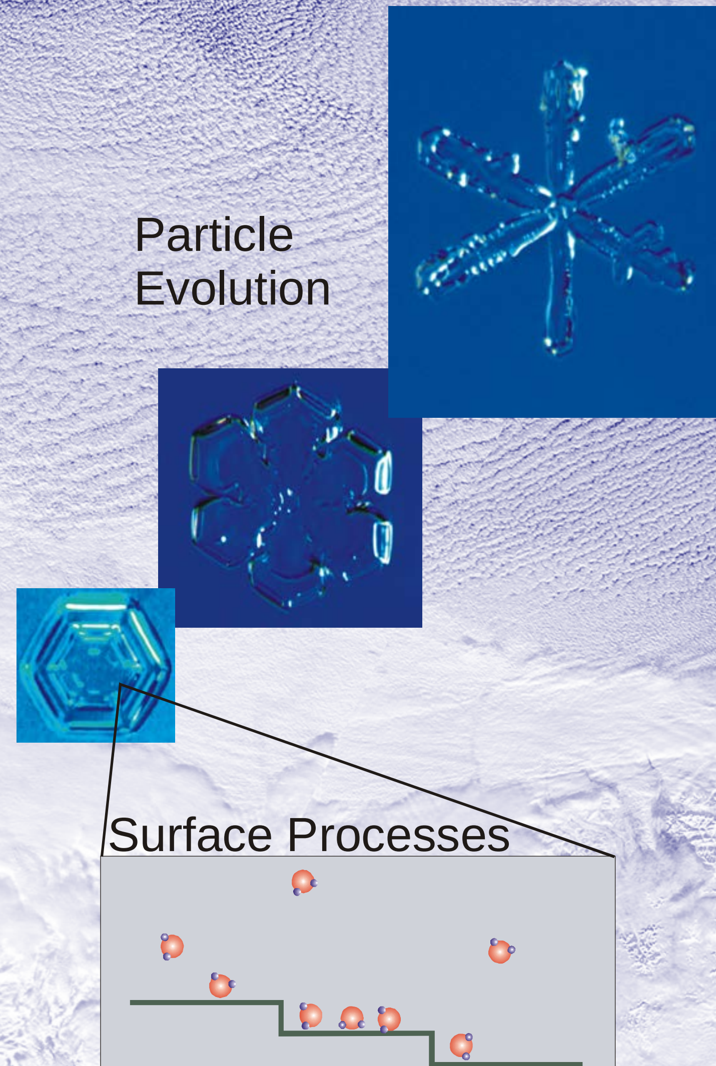
With Special Thanks to:

Dennis Lamb, Kara Sulia, Chengzhu Zhang, and Hugh Morrison



Capacitance Model

$$\frac{dm}{dt} = 4\pi D_v C(c, a)(\rho_{v,\infty} - \rho_{v,sfc})$$

All Cloud Models Use It

Capacitance Model

$$\frac{dm}{dt} = 4\pi D_v C(c, a)(\rho_{v,\infty} - \rho_{v,sfc})$$

Captures Increasing Non-Spherical Vapor Gradients

But Provides No Information For **How** Aspect Ratio Changes.

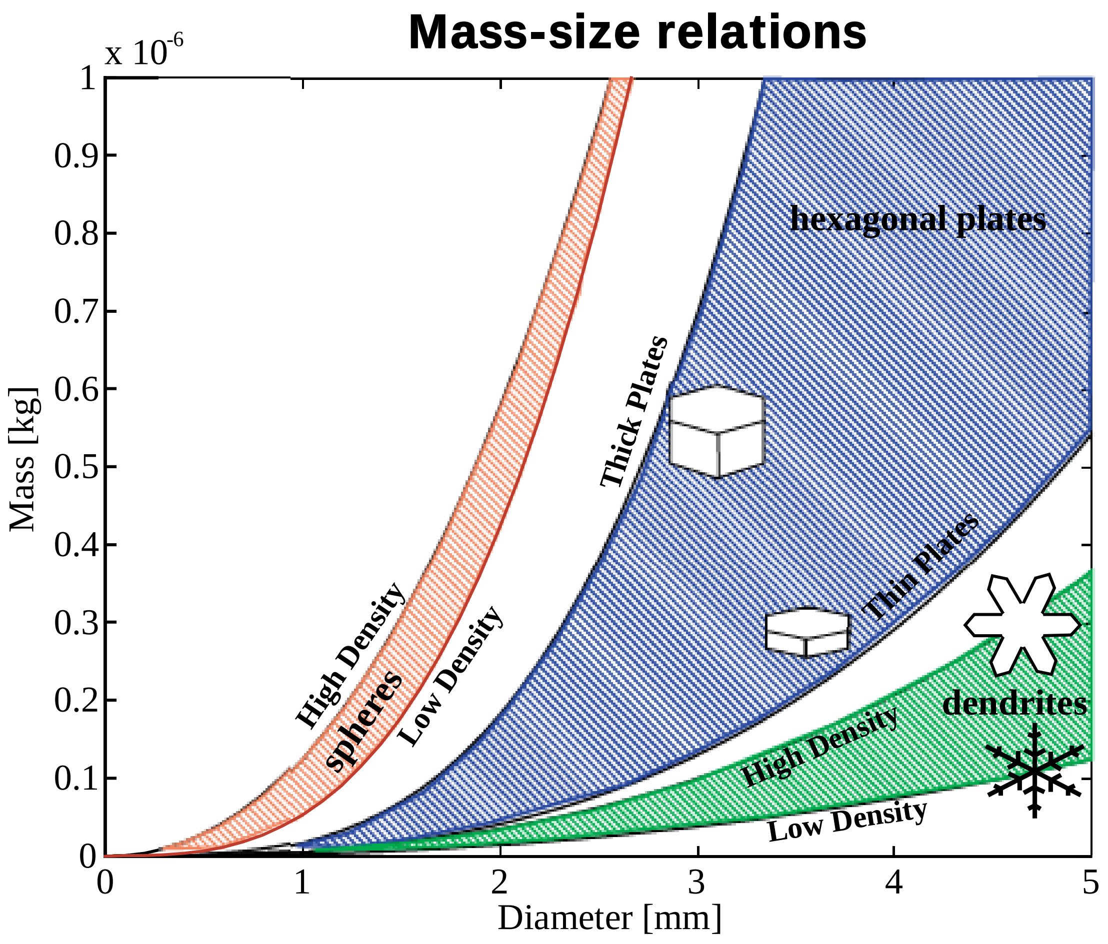
Method to Distribute Gained Mass Needed.

Mass-Size: Aspect Ratio Implicit

$$m(D) = \alpha_m D^{\beta_m}$$

- *One Method to Distribute Mass. Make it constant.*

- *Issues:*
  - How are α_m and β_m related to particle area/aspect ratio? Density?



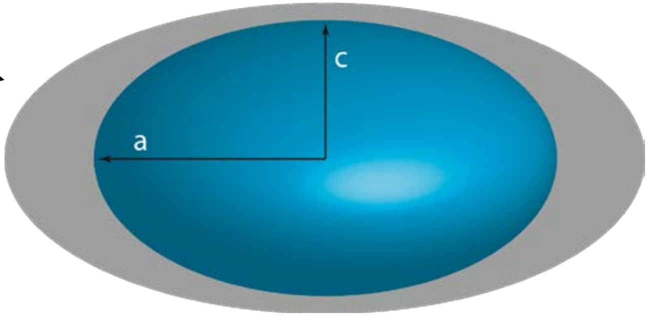
Avramov and Harrington (2010)

Adaptive Habit Method

Mechanistic Distribution of Mass: Predict α_m and β_m

$$\frac{dc}{da} = \frac{\alpha_c}{\alpha_a}\frac{c}{a}$$

$= \delta(T)$



Measured in the lab or in-situ

δ(T) distributes mass along a and c

Chen and Lamb (1994)

Bulk Adaptive Habit Method

Same idea except for distributions

(1) Distribution of a-axis assumed to be gamma.

(2) $$\frac{dc_n}{da_n} = \delta \frac{c_n}{a_n}$$

a and c distributions related through mass distribution equation.

Bulk Adaptive Habit Method

Same idea except for distributions

(1) Distribution of a-axis assumed to be gamma.

(2) $$\frac{dc_n}{da_n} = \delta \frac{c_n}{a_n}$$

a and c distributions related through mass distribution equation.

$$c_n(t) = \alpha_* a_n(t)^{\delta^*}$$

δ distributes mass, δ^* links c_n to a_n diagnostically

Bulk Adaptive Habit Method

Same idea except for distributions

(1) Distribution of a-axis assumed to be gamma.

(2) $$\frac{dc_n}{da_n} = \delta \frac{c_n}{a_n}$$ a and c distributions related through mass distribution equation.

$$c_n(t) = \alpha_* a_n(t)^{\delta^*}$$

(3) Linked to coefficients in mass, area, fall-speed, and capacitance

$$m(a_n) = \alpha_m(\rho_{p,}\delta_*)\, a_n(t)^{\beta m(\delta^*)}$$

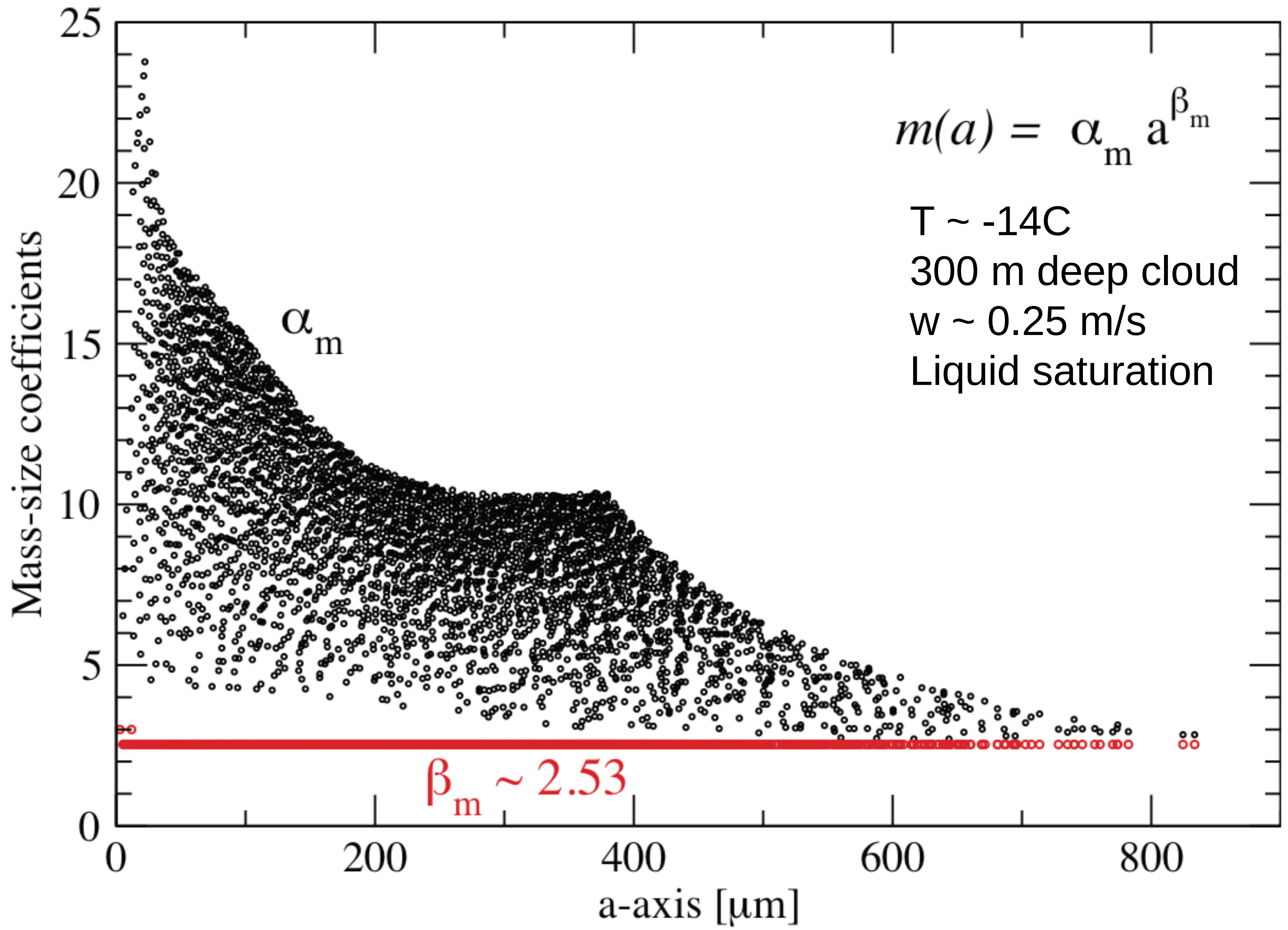
What do we need to test habit evolution methods?

- An important question is whether any method (mass-size, adaptive habit) correctly captures ice vapor diffusion as temperature and saturation varies.

- Difficult to do because habit evolution depends on particular growth histories through particle trajectories.

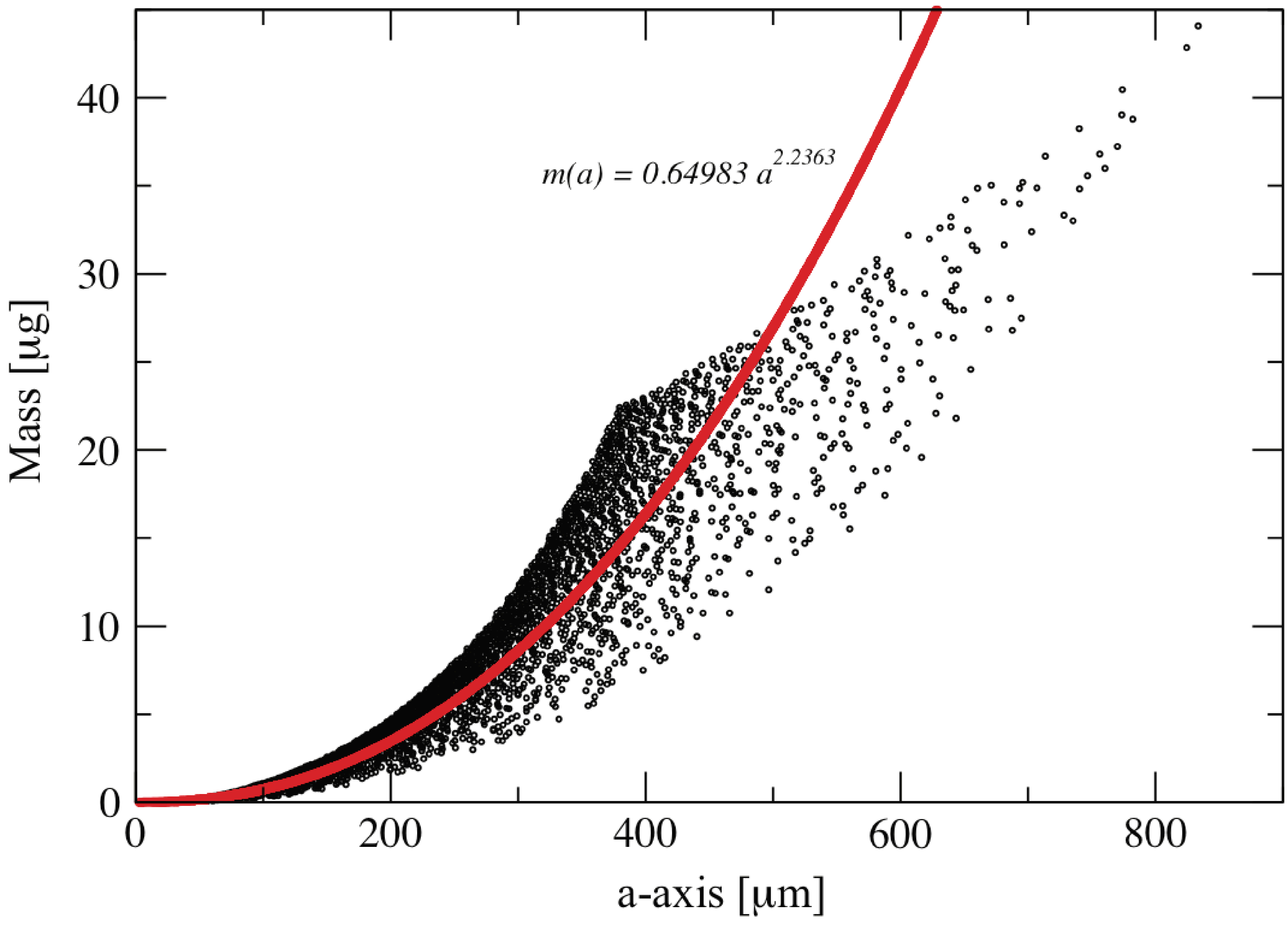
- Single measurements are not enough, even for mass size methods.

Example: Predicted Mass-Size Coefficients

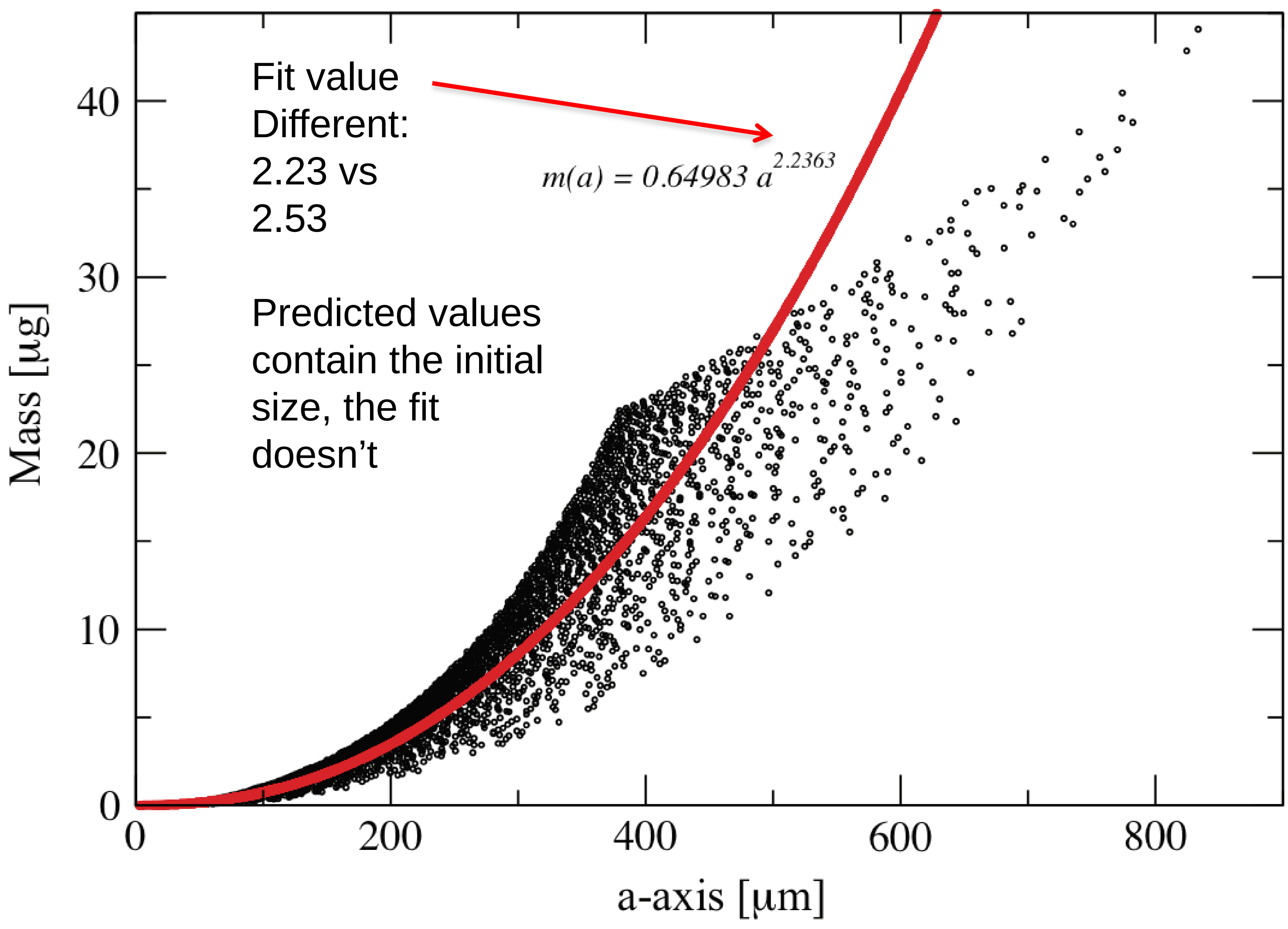


Variability in α_m: density and initial size

Fit to Mass and Size



Fit to Mass and Size

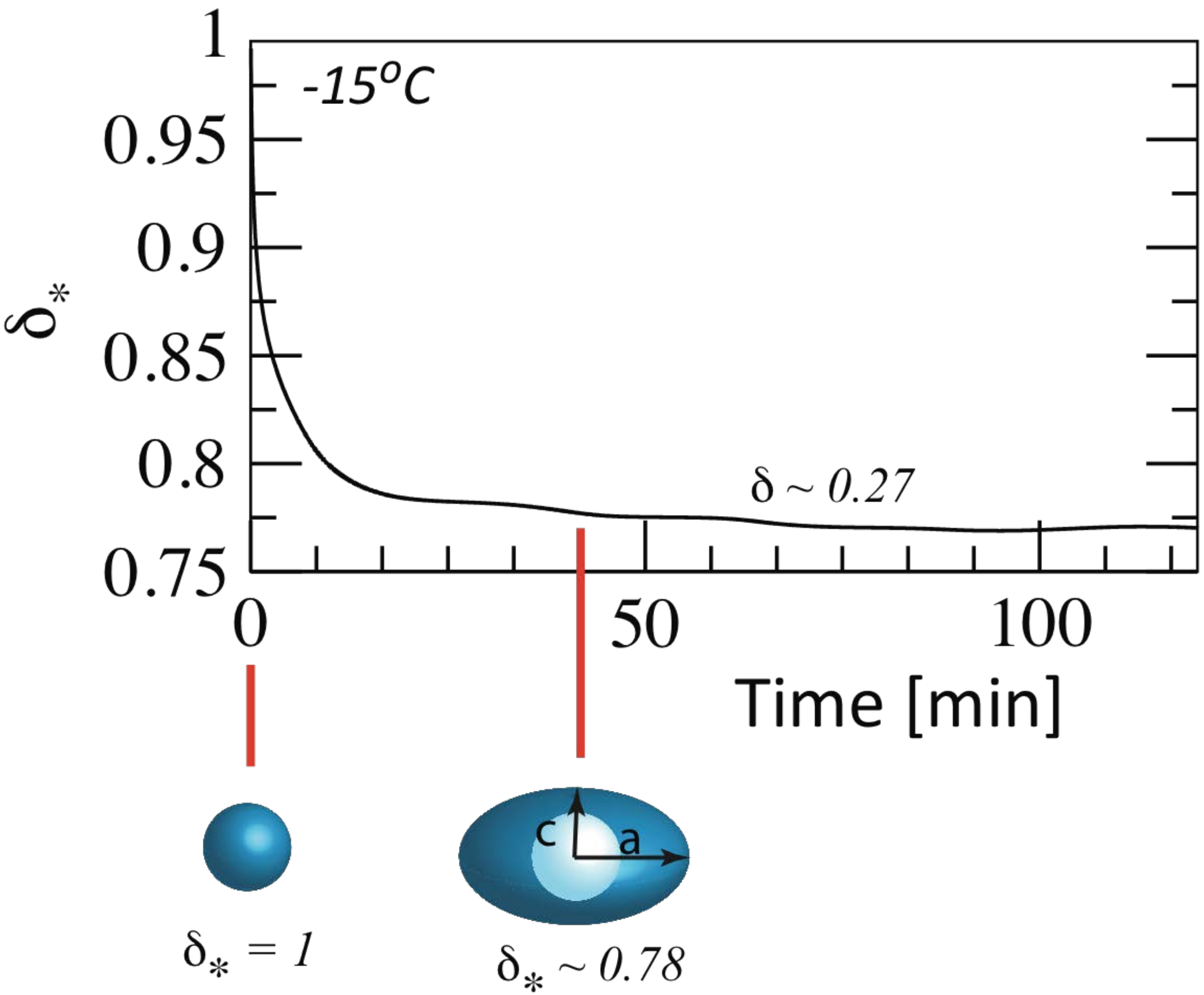


So What Do We Need To Test This?

- Spatial information on habit in clouds would be quite useful, but a better approach may be to determine mean parameters that make up mass-size coefficients.

- Need mass-size information, certainly. But we also need at least one other concomitant physical characteristic: Particle density, and fall-speed if possible.
  - Allow testing of adaptive habit approaches, and riming methods
  - Also may be able to derive varying coefficients for mass-size methods.

Bulk Adaptive Habit Method

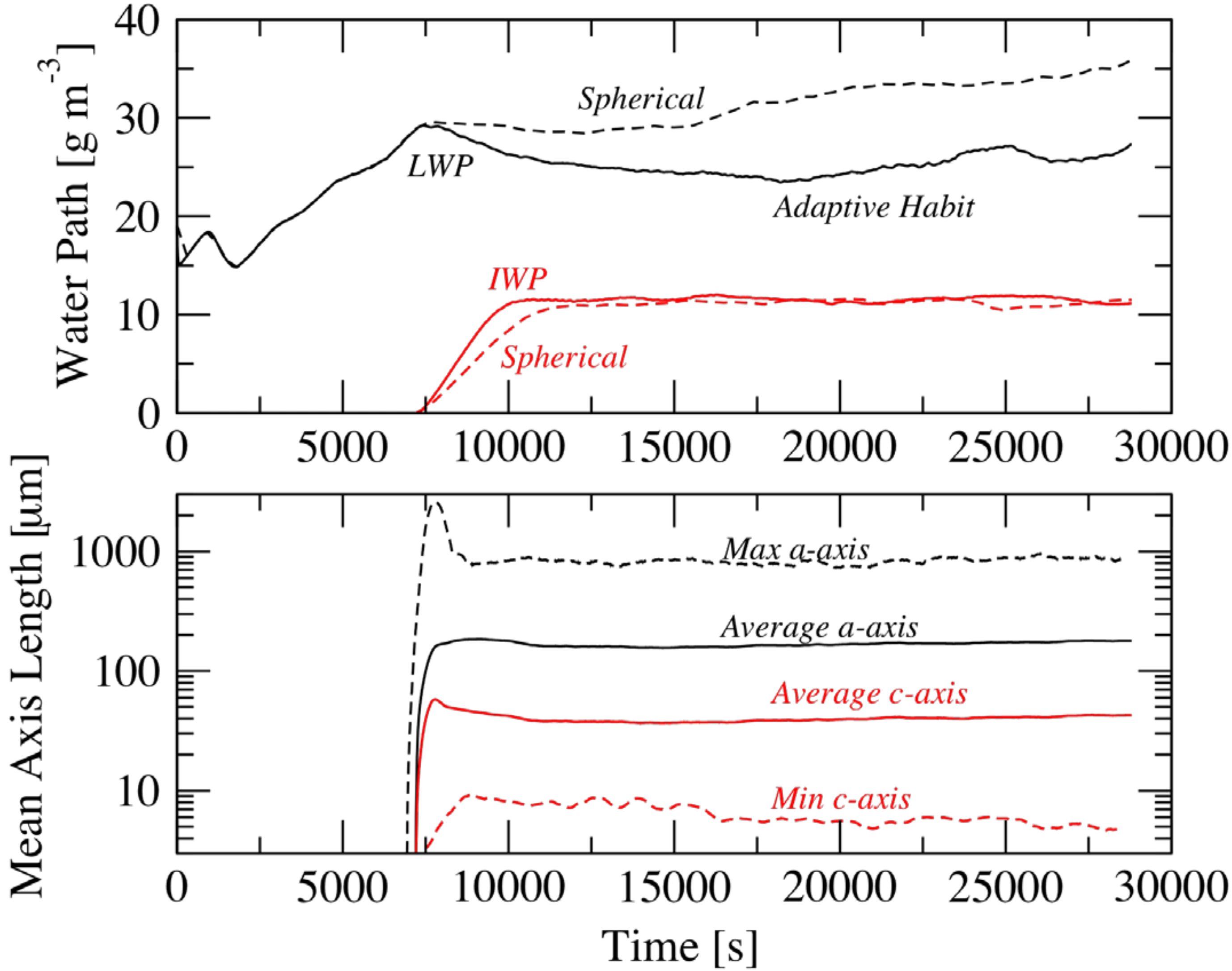


$$c_n(t) = \alpha_* \, a_n(t)^{\delta^*}$$

ISDAC LES Mixed-Phase

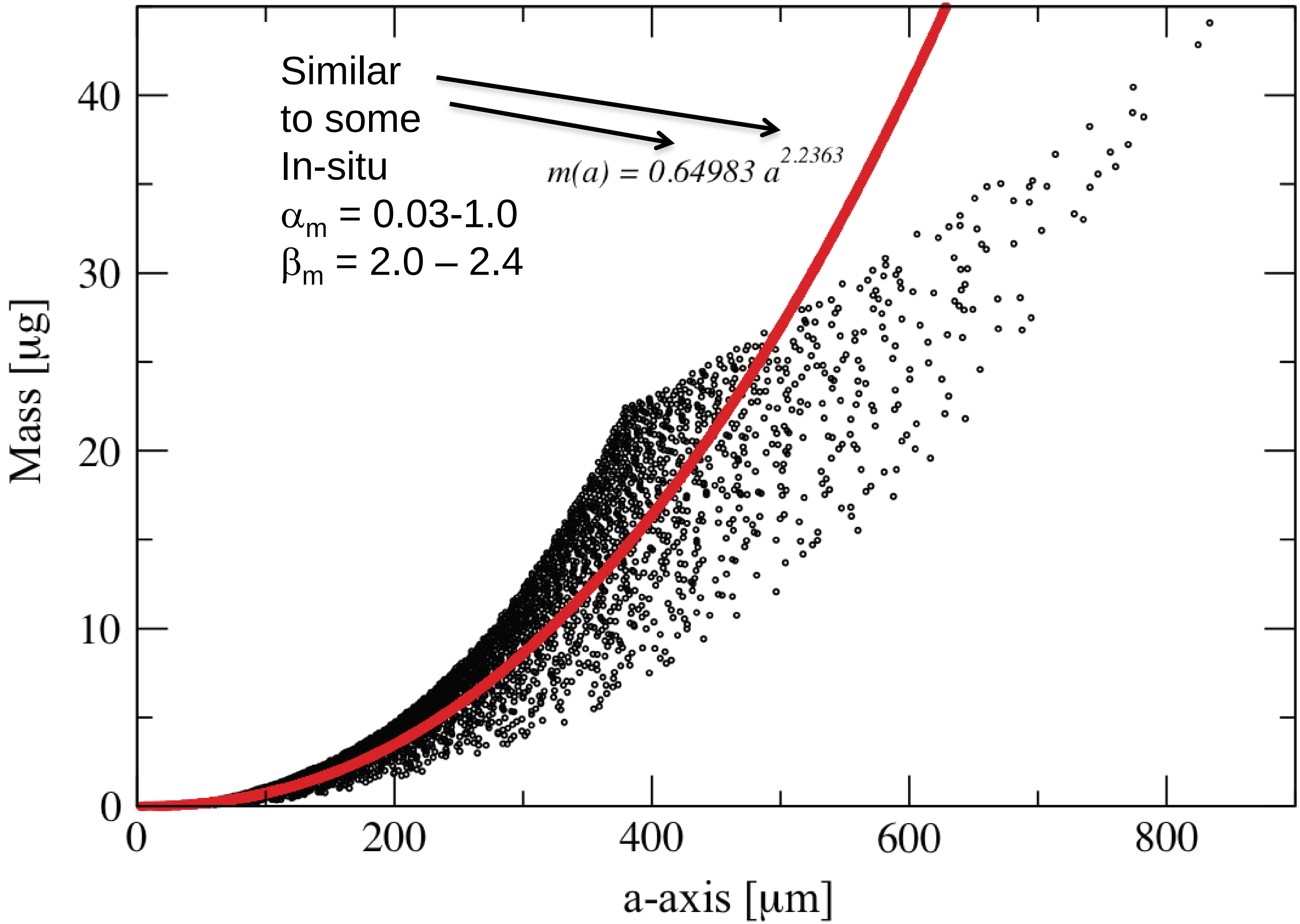
Sustains mixed-phase state with dendritic growth.

Mix of thicker plates and thin dendrites



Sulia et al. (2013)

Fit to Mass and Size



- Particle Property Methods -

- Idea is to move away from parameterizations that require boundaries that can be arbitrary.

- Instead, the goal is to evolve overall particle properties in a way that is more physical.

- Such methods have been successfully applied for riming and other properties.

- We recently put forth such a method to predict ice particle aspect ratio. Currently only for vapor diffusion, but are extending to riming and aggregation.

How does aspect ratio vary spatially in real precipitating systems?

- It is only recently that the adaptive habit model has been running in LES. But, the method produces more extreme habits (lower density, larger major axes) in the updrafts.

- We think this may affect phase partitioning as extreme habits remain in the region where strong liquid production occurs.

- If these simulations are right, then information on how aspect ratio is distributed in space would be vital. We may be able to derive a measure of this from size and density information, if they can be derived from data.

Bulk Adaptive Habit Method

Same idea except for distributions

(1) Distribution of a-axis assumed to be gamma.

(2) $$\frac{dc_n}{da_n} = \delta \frac{c_n}{a_n}$$ a and c distributions related through mass distribution equation.

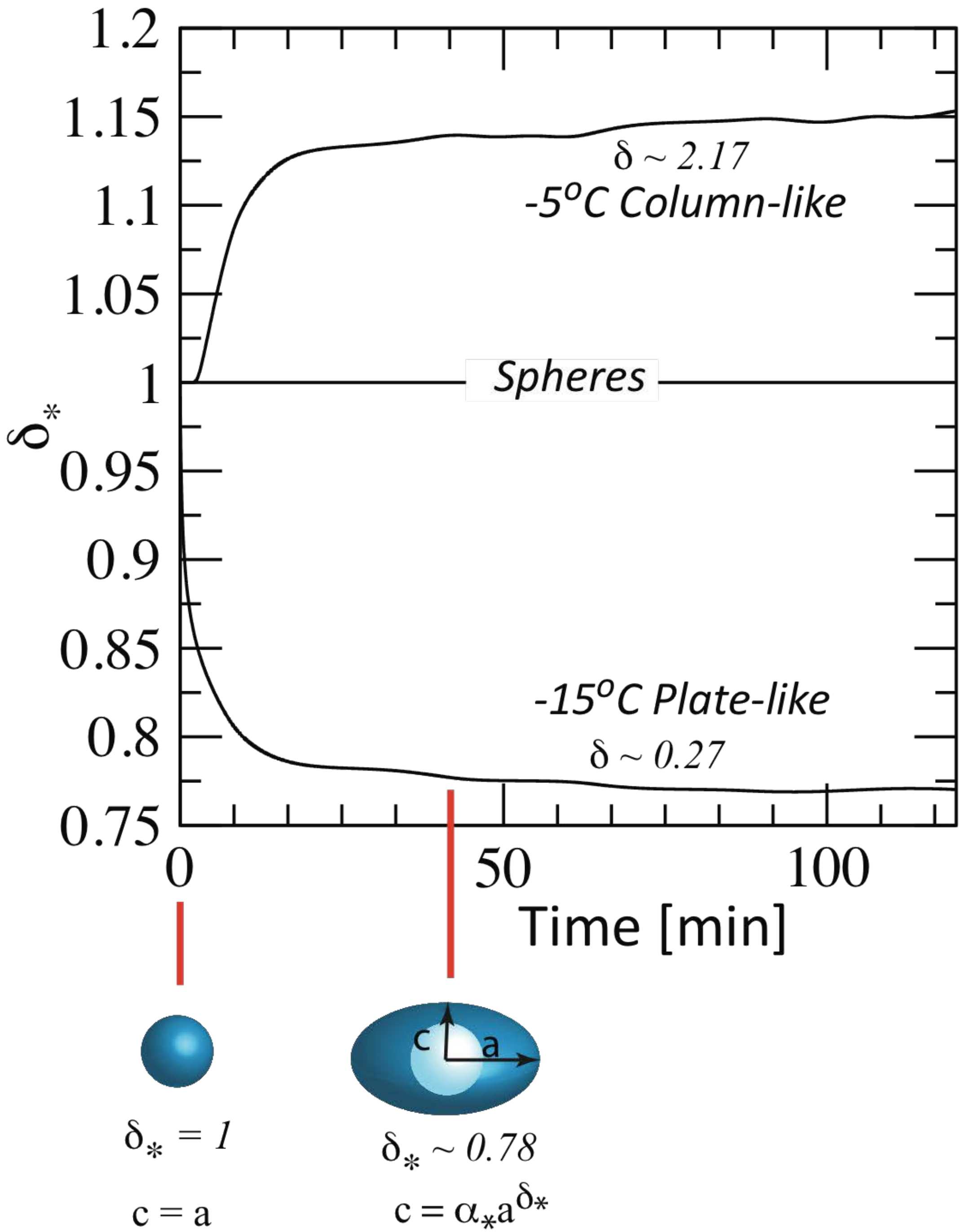
$$c_n(t) = \alpha_* a_n(t)^{\delta^*}$$

(3) Allows coefficients in mass, area, fall-speed, and capacitance to change

$$m(a_n) = \alpha_m(\rho_{p,} \delta_*)\, a_n(t)^{\beta_m(\delta^*)}$$

(4) **Four prognostic variables:** number, mass, and a and c axis mixing ratios allow diagnosis of δ_* and mean density.

Axis Ratio Prediction

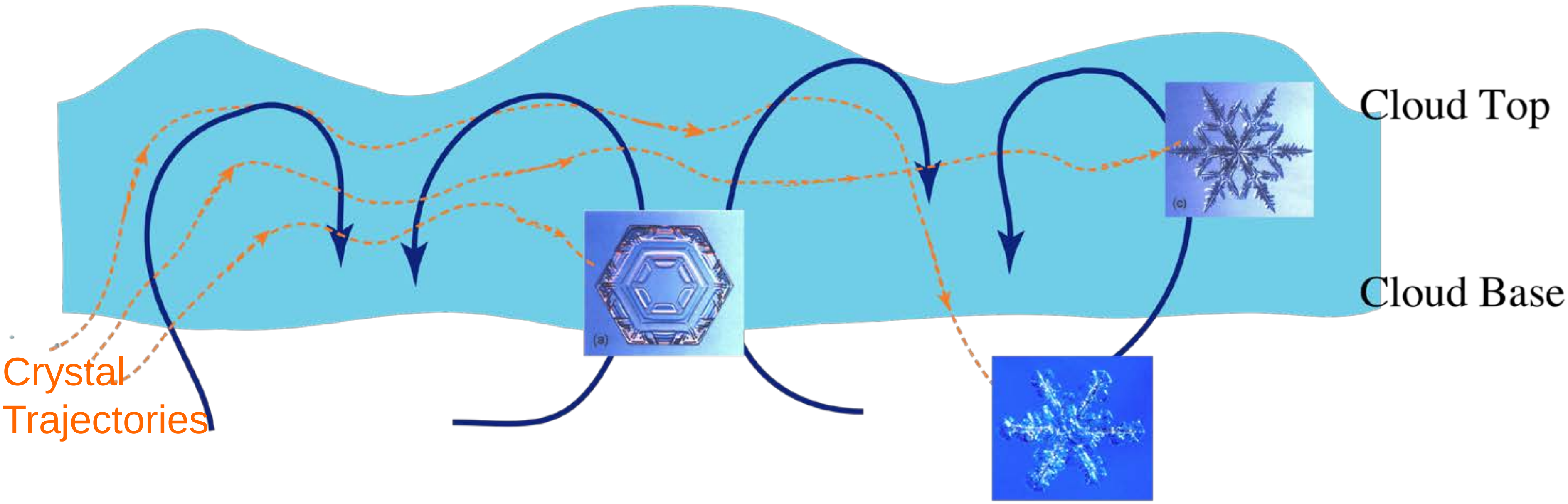


The quantity δ_* relates the characteristic a and c axes.

Evolves away from unity as particles become non-spherical.

Area and fall-speed all vary consistently with mass and density.

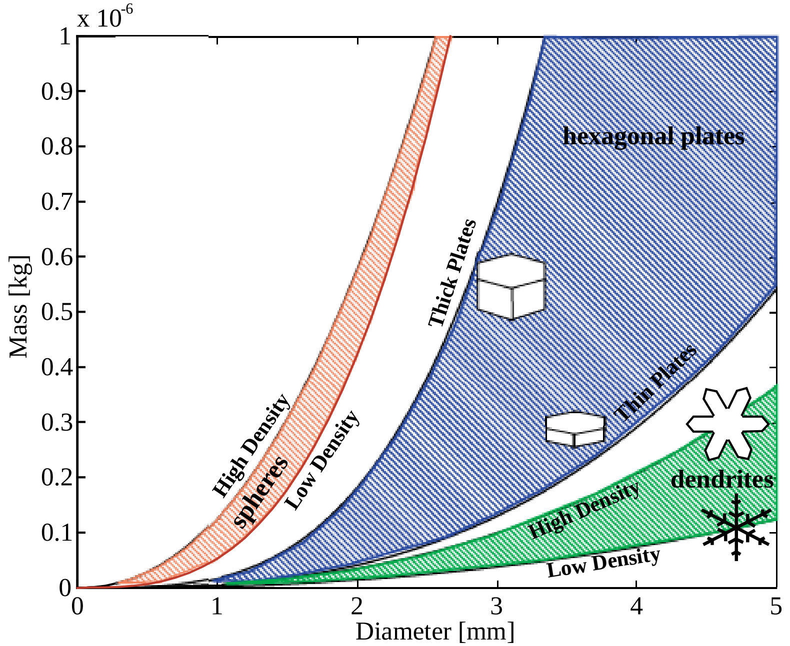
- Mass-size Inconsistency -



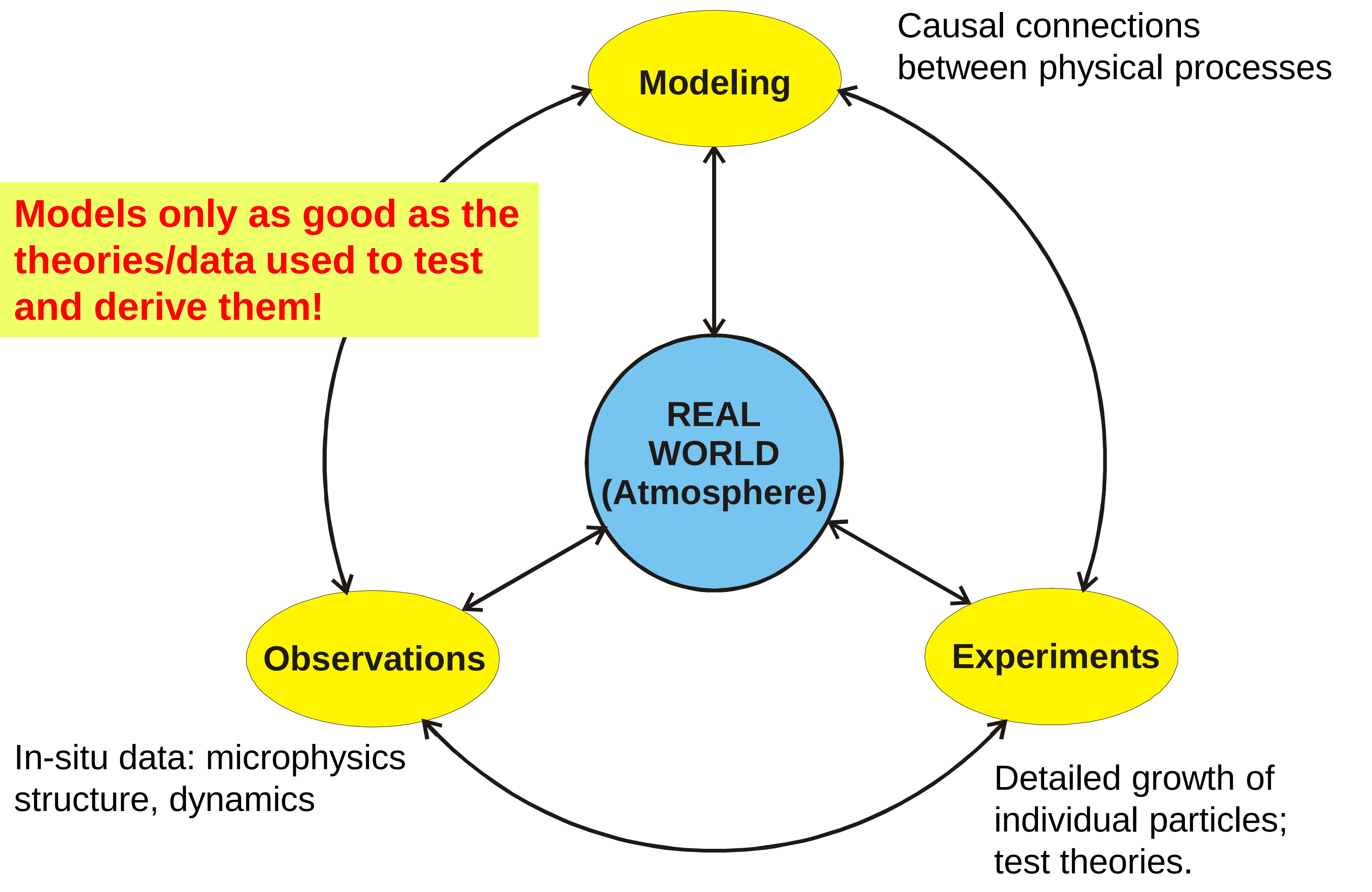
Each point in $m = aL^b$

$\Rightarrow$ lifecycle of an entire crystal

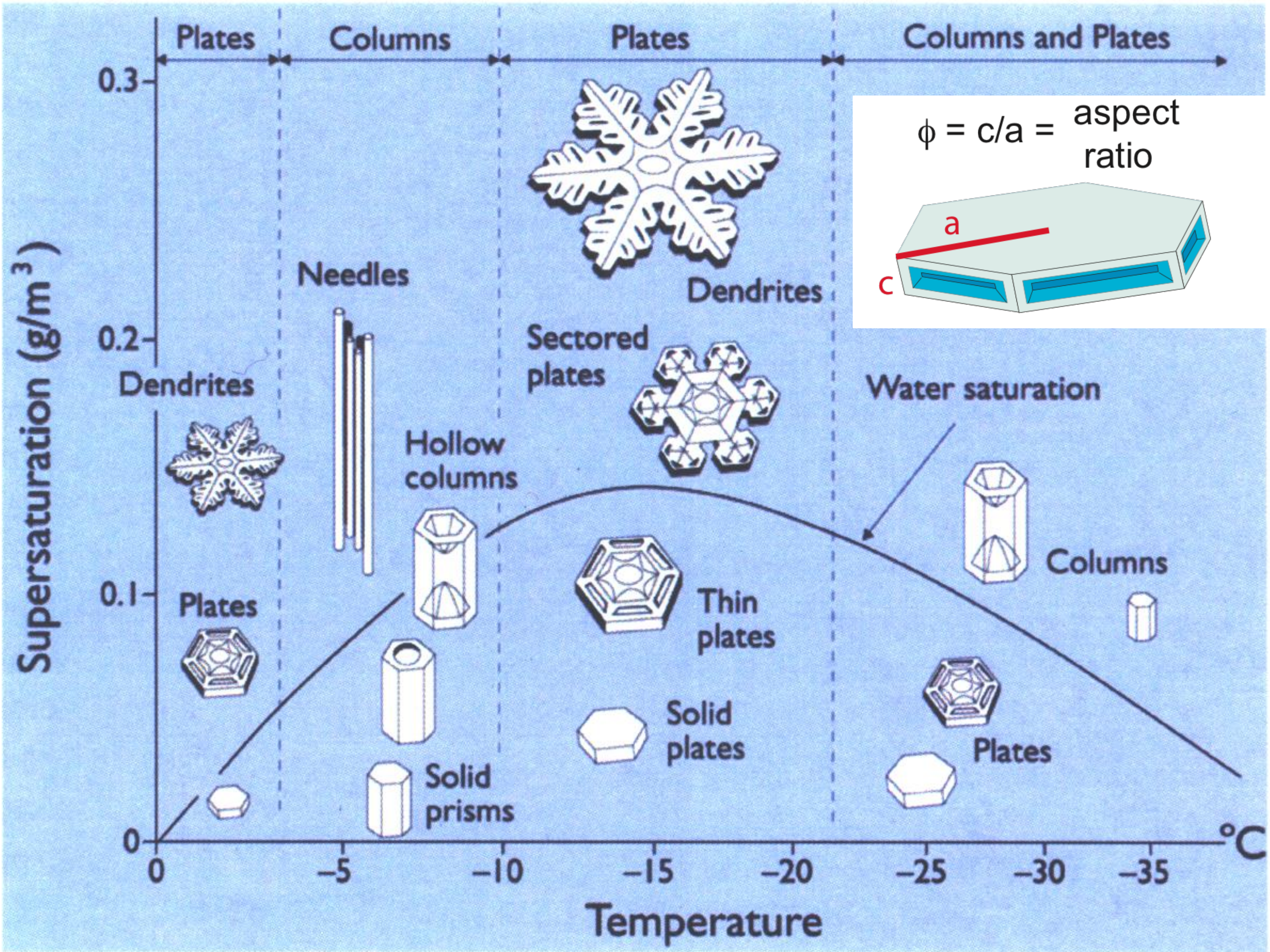
$\Rightarrow$ Inconsistent with dm/dt



Modeling: One Link to The Real World!



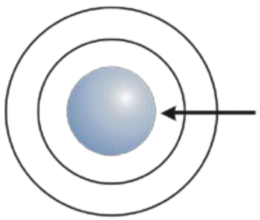
Why is the problem difficult? Wide Variety of Ice Crystal Habits!

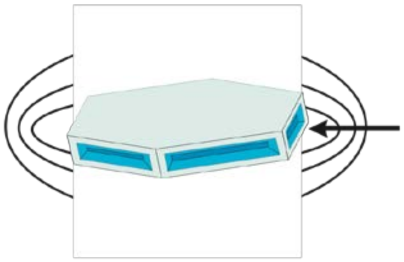


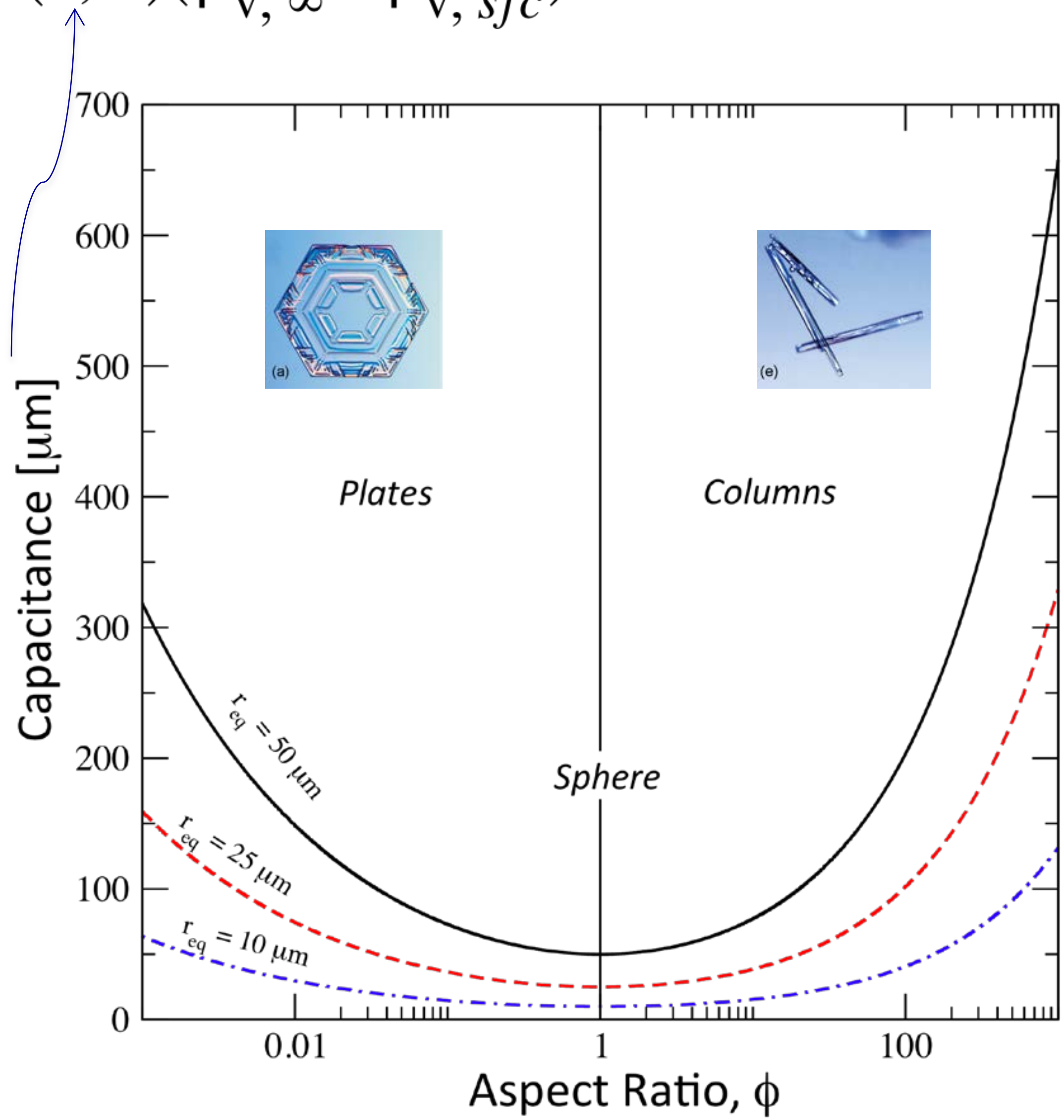
Libbrecht (2005)

Typically Used: Capacitance Model

$$\frac{dm}{dt} = 4\pi D_v C(c, a)(\rho_{v,\infty} - \rho_{v,sfc})$$







Capacitance: Captures strong gradients as particle deviates from spheres/isometric