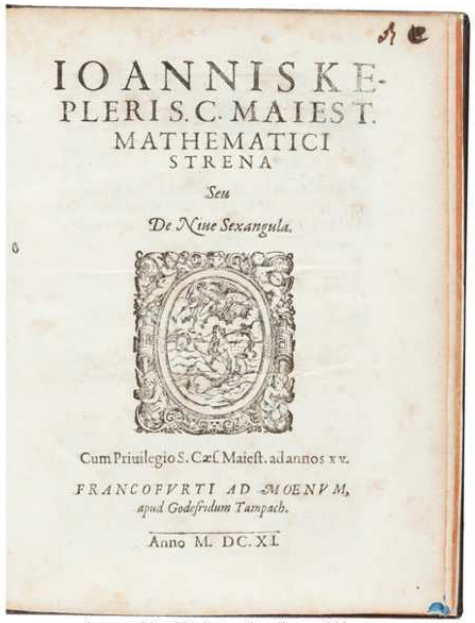
Cloud modeling with the particle-based microphysical model McSnow

Jan-Niklas Welß, Christoph Siewert, Axel Seifert (DWD)
Leonie von Terzi, Stefan Kneifel (Uni Köln)
PROM Meeting Bonn, 23.-24.10.2019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PLERI S. C. MAIEST.
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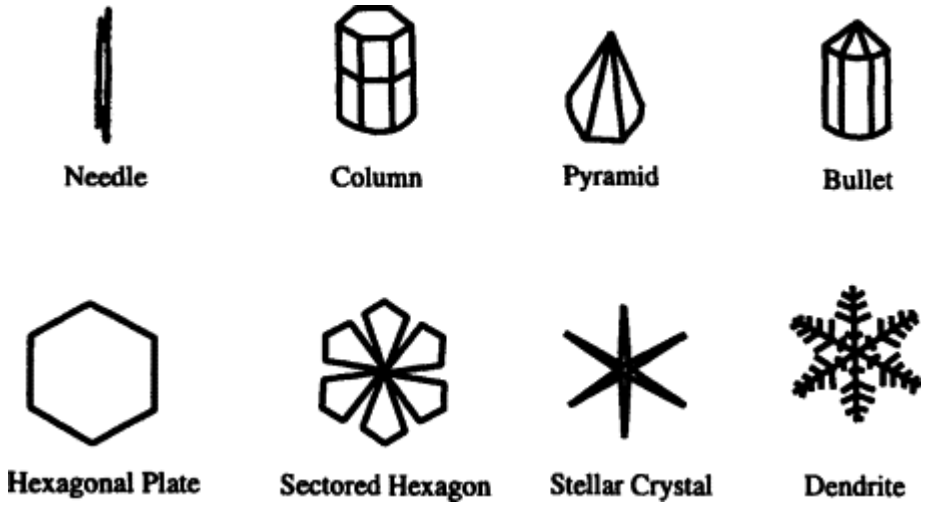
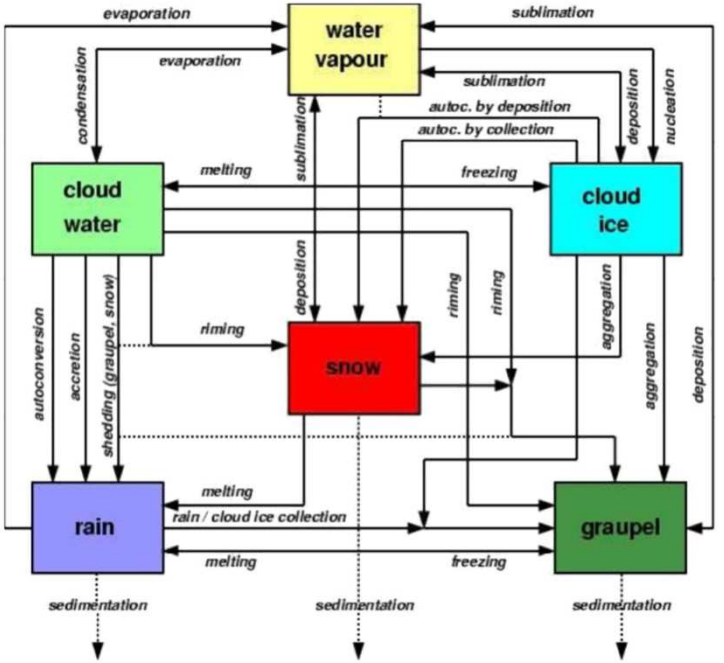
Imaged by Heritage Auctions, HA.com



Via Mixed-Phase Clouds, 2018

Model simulations and polarimetric observations – The need for sufficient hydrometeor information



T. Reinhard, A. Seifert, 2005

Model simulations and polarimetric observations – The need for sufficient hydrometeor information

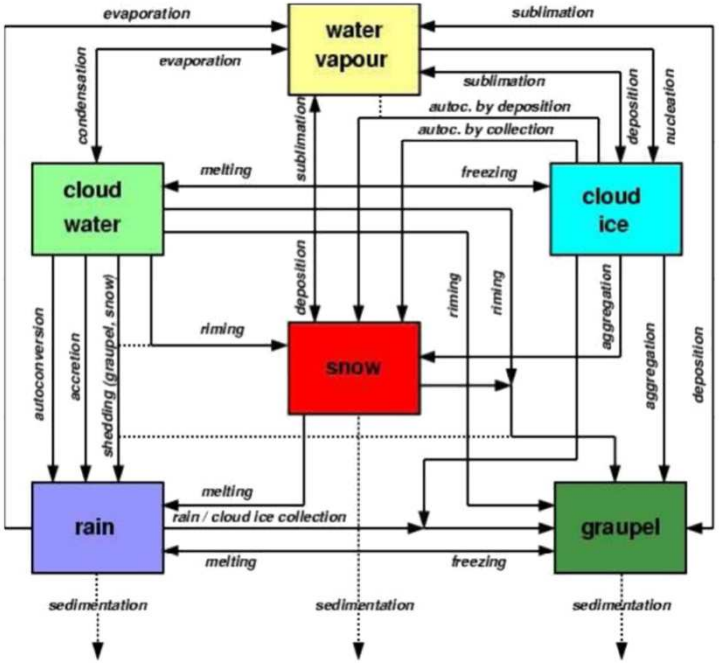
Current simplifications in microphysical modeling:

- Fixed form of size distribution

$$f(x) = A\, x^{\nu}\, e^{-\lambda\, x^{\mu}}$$

- Categorization of hydrometeors

Locatelli and Hobbs 1974



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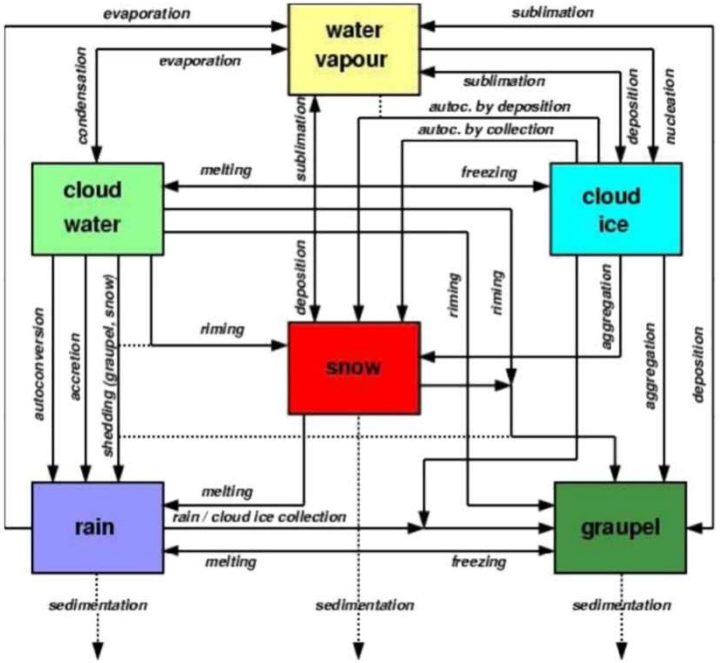

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Monte-Carlo Langrangian particle model McSnow

Why McSnow?

- Information about hydrometeors: **size**, **mass**, **rime mass**, etc.

- Allows implementation of current knowledge about cloud microphysical properties

S. Brdar and A. Seifert (2018). ***McSnow*** – *A Monte-Carlo particle model for riming and aggregation of ice particles in a multidimensional microphysical phase space*, Journal of Advances in Modeling Earth Systems 10, 10.1002/2017MS001167

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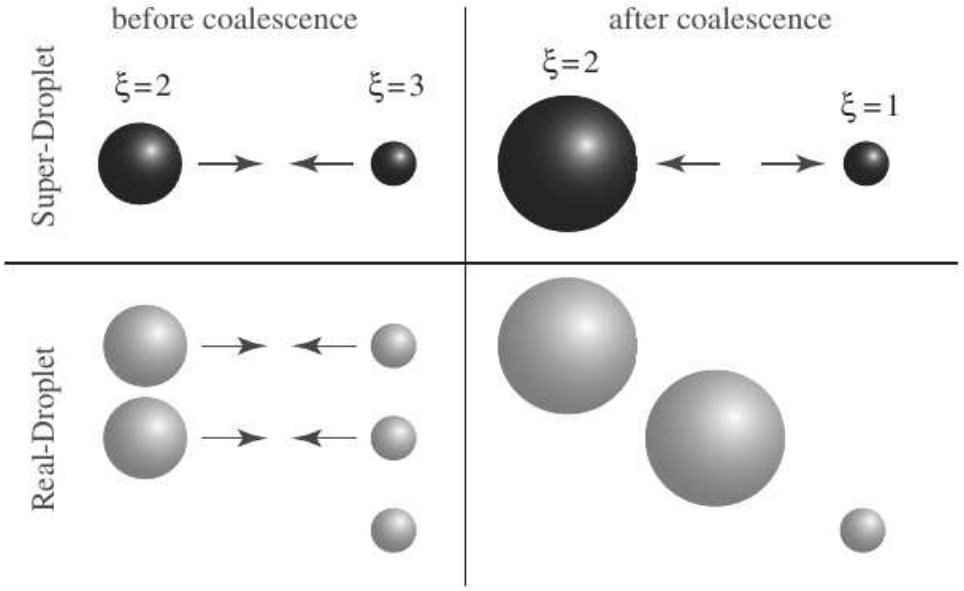

Shima et al., 2009

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Why McSnow?

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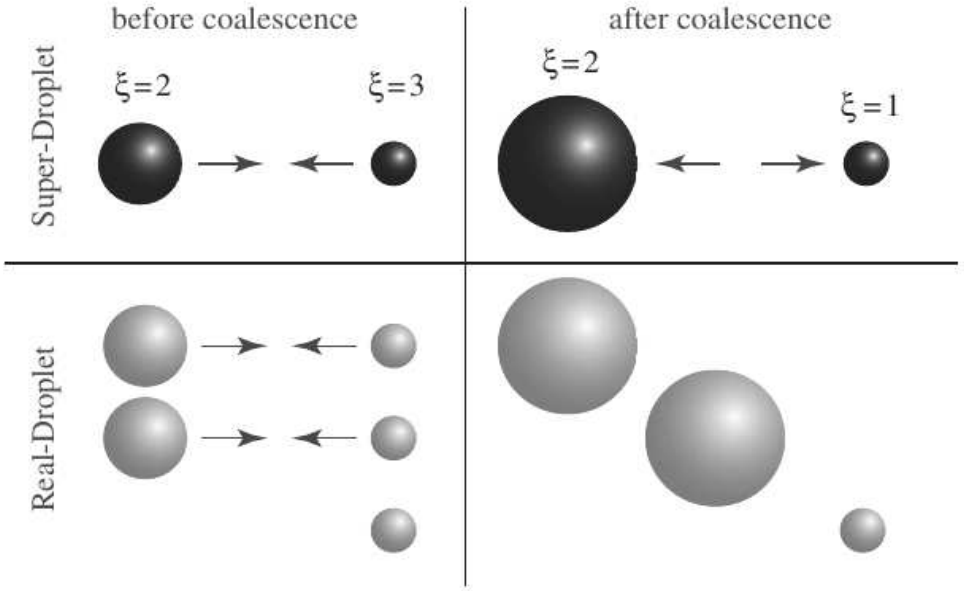
- Allows implementation of current knowledge about cloud microphysical properties
- 1D rain shaft-like simulations
- 2D/3D coupled simulations with ICON



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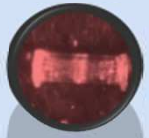
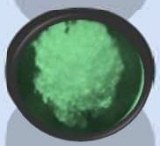
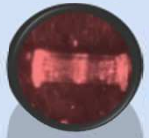
Synergies of observations and modeling

Processes		Prognostic Variables
nucleation vapor diffusion		ice mass m_i
sedimentation coalescence		number of monomers N_m
aggregation		rime mass m_r
riming rime splintering		rime density ρ_r
melting & shedding hydrodynamic breakup		liquid mass m_w
collision breakup		

Locatelli & Hobbs 74

Synergies of observations and modeling

Processes		Prognostic Variables
nucleation		ice mass m_i
vapor diffusion		
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coalescence		
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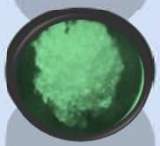
riming		
rime splintering		rime density ρ_r
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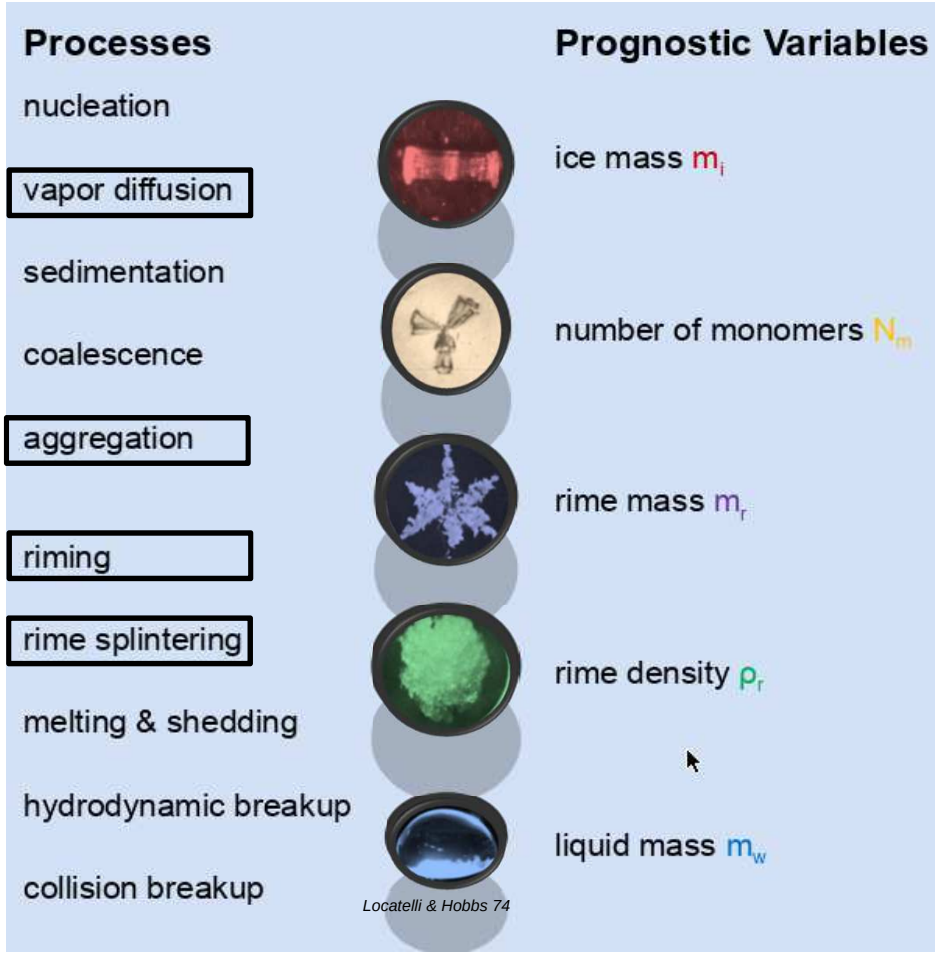
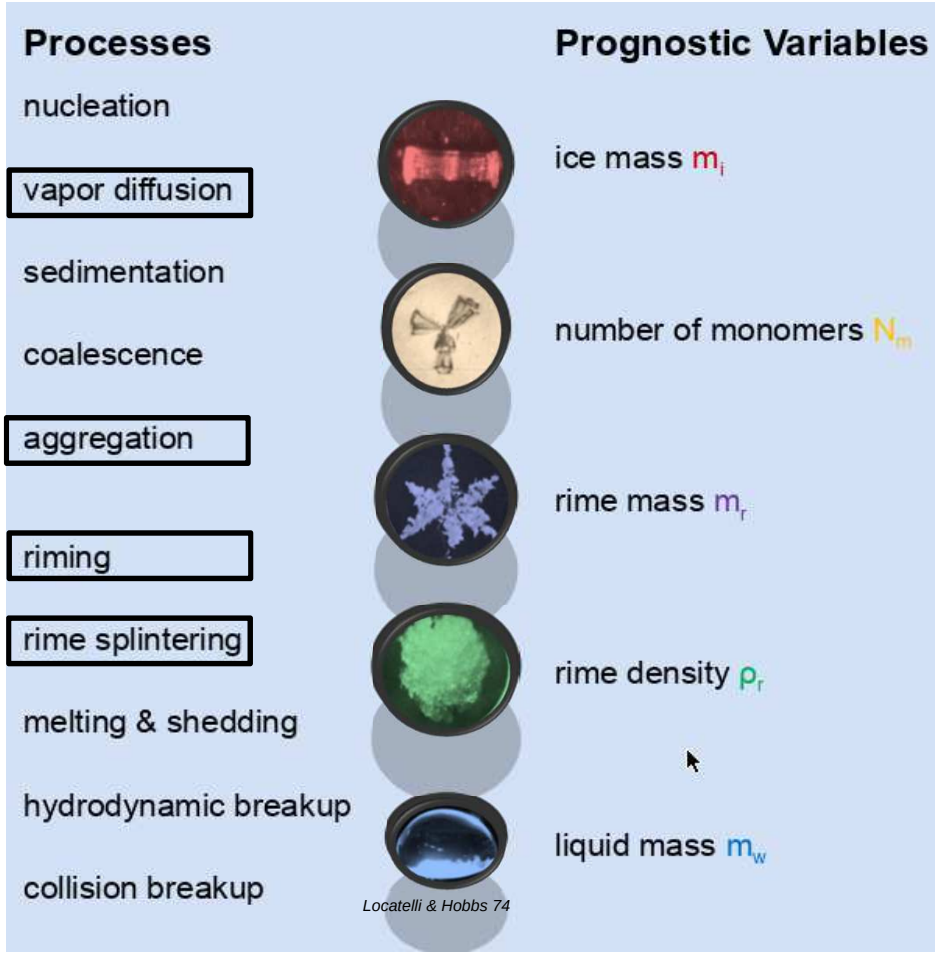
Locatelli & Hobbs 74

Synergies of observations and modeling



1. **vapor diffusion**:
   asymmetry of single crystals

Synergies of observations and modeling



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2. **aggregation**:
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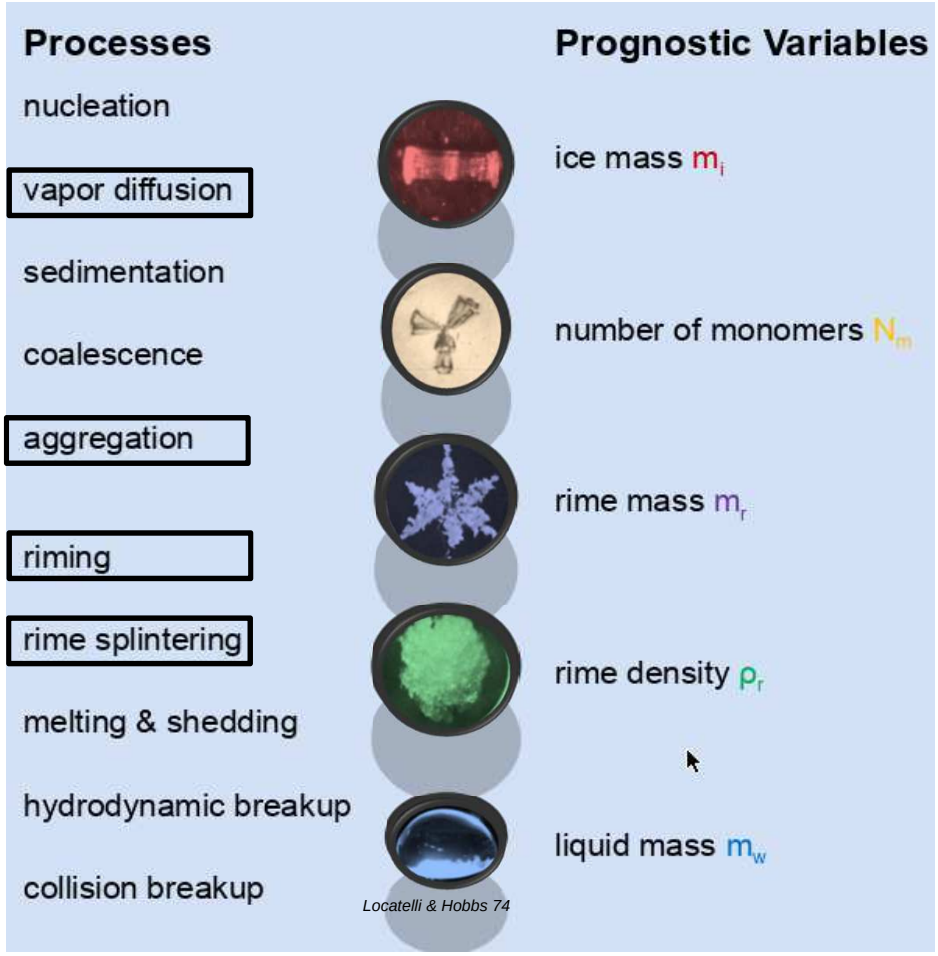
Synergies of observations and modeling



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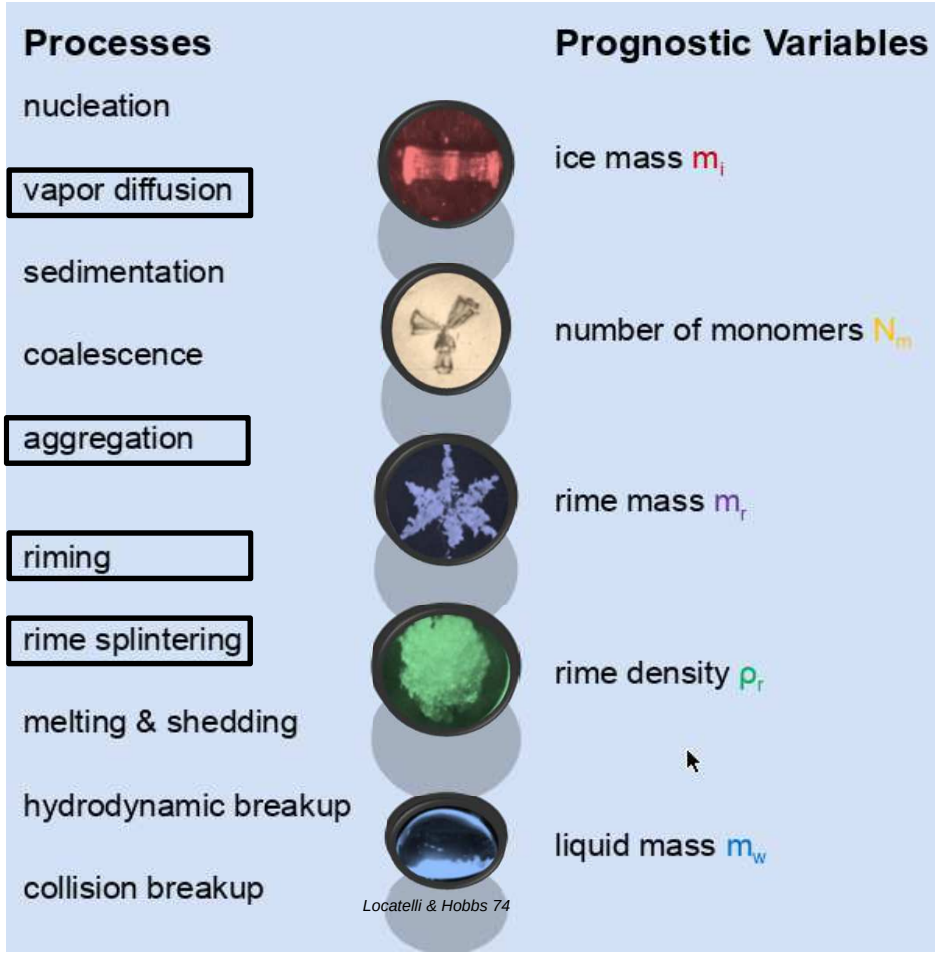
Synergies of observations and modeling



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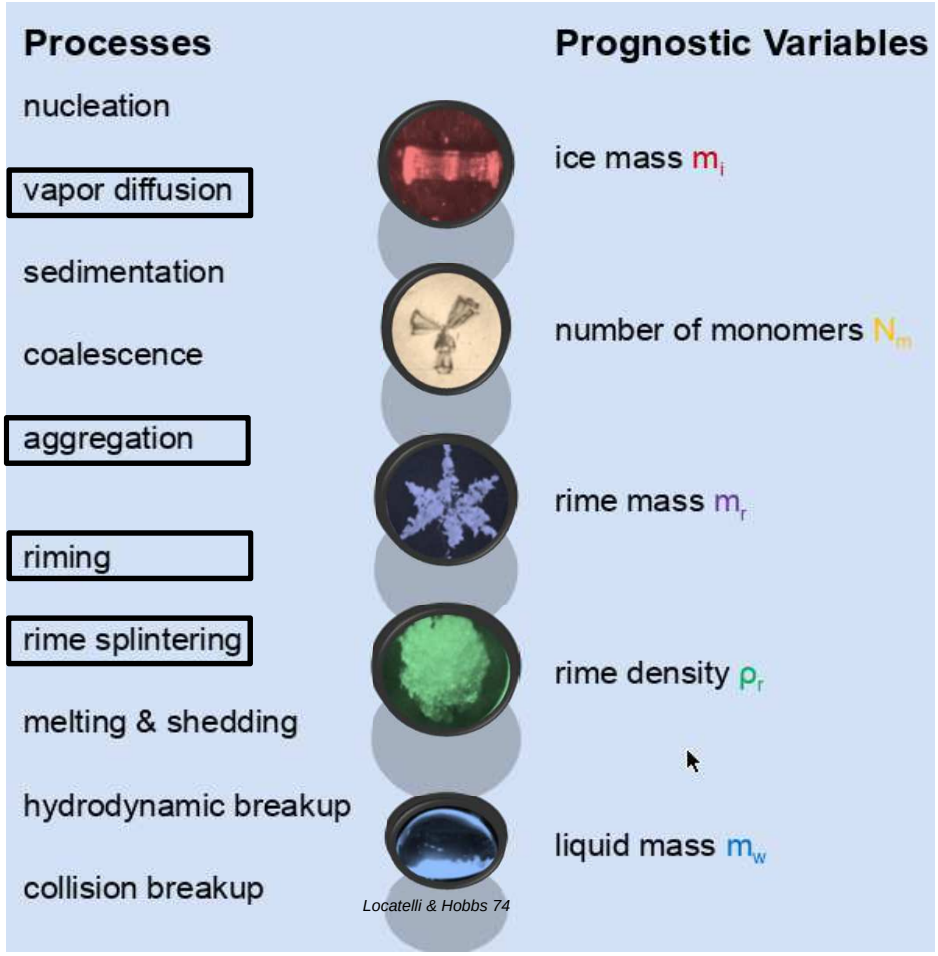
4. **rime splintering / SIP**:
   secondary modes in Doppler spectrum and their origin

Synergies of observations and modeling



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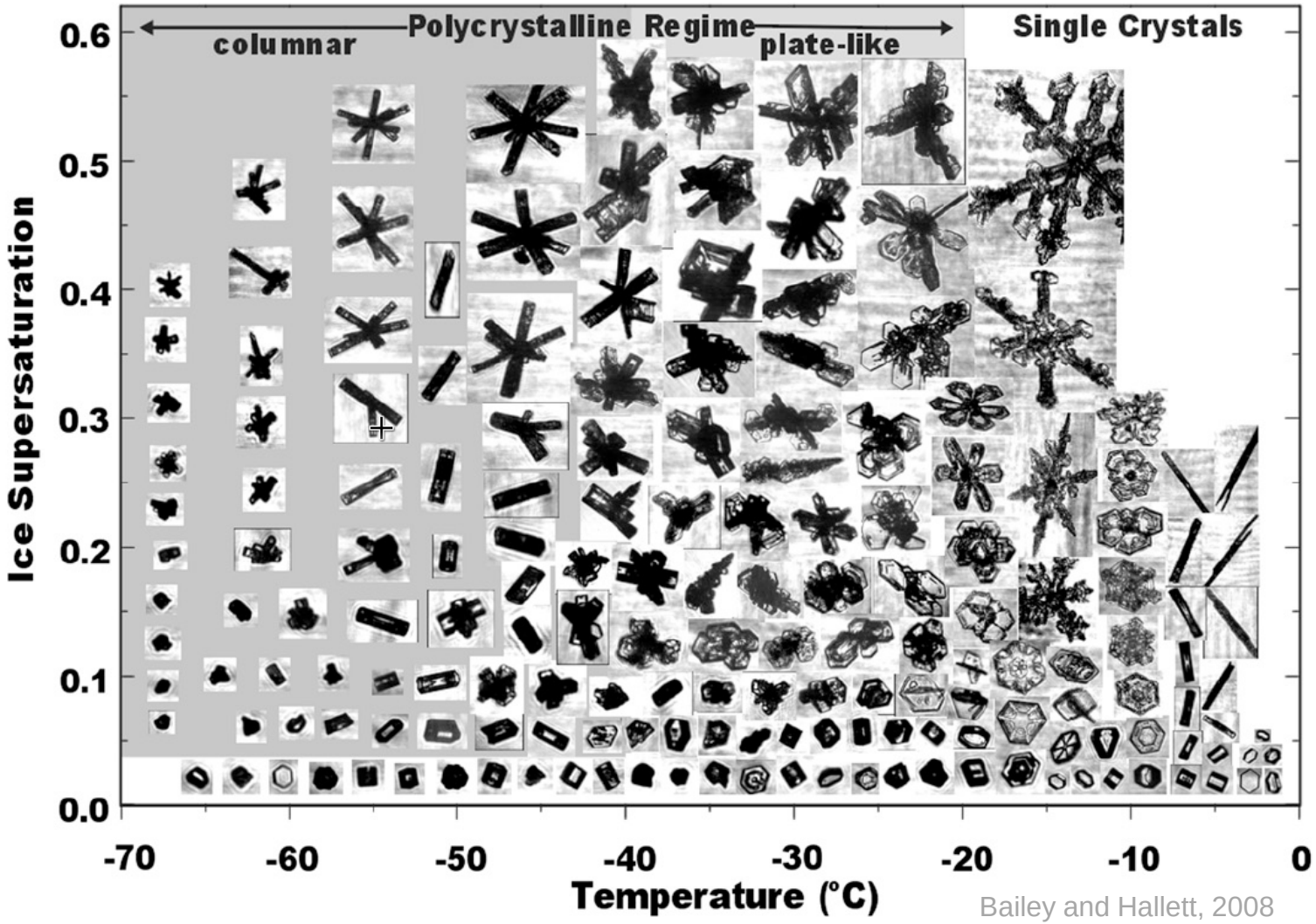
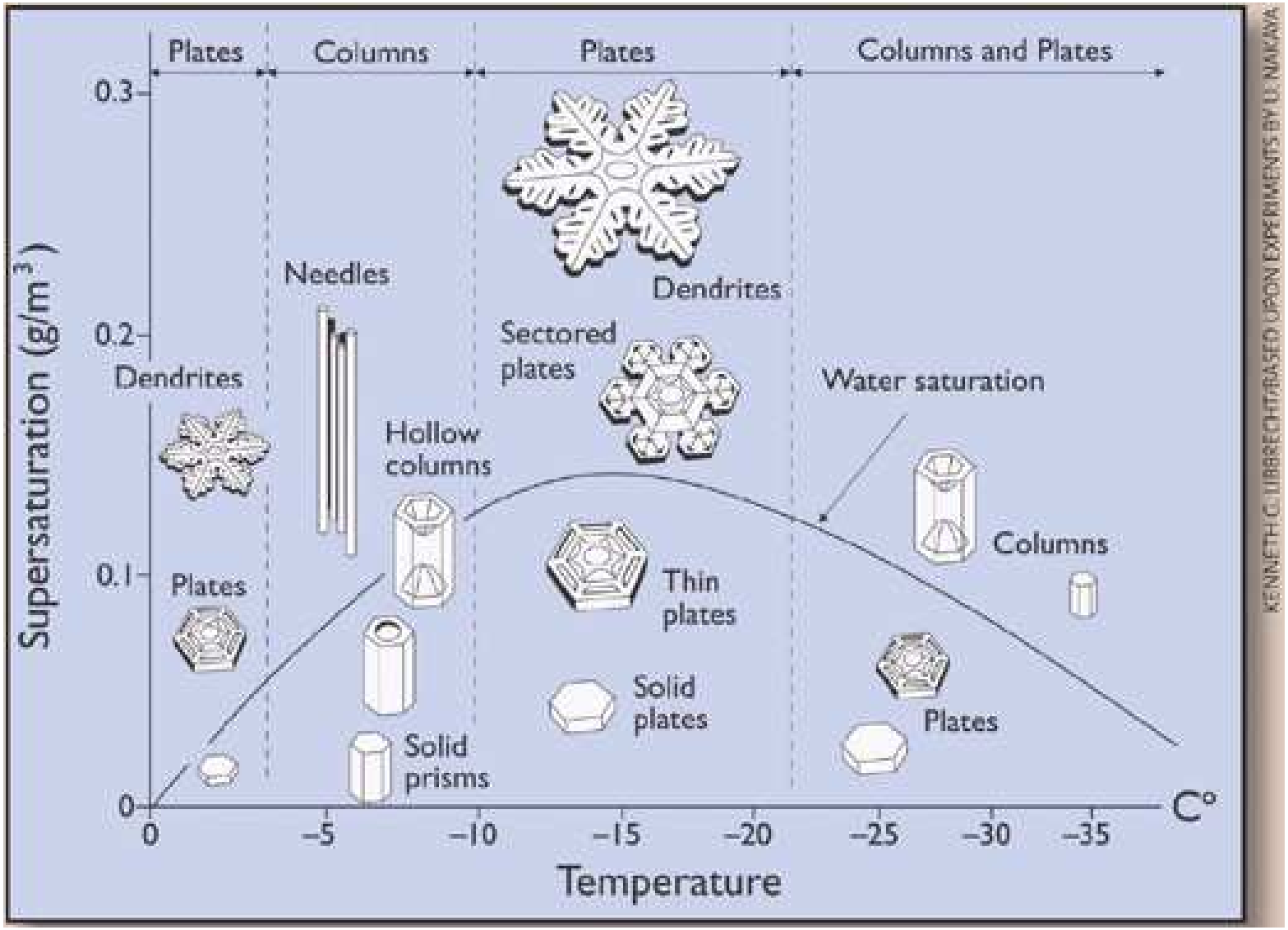
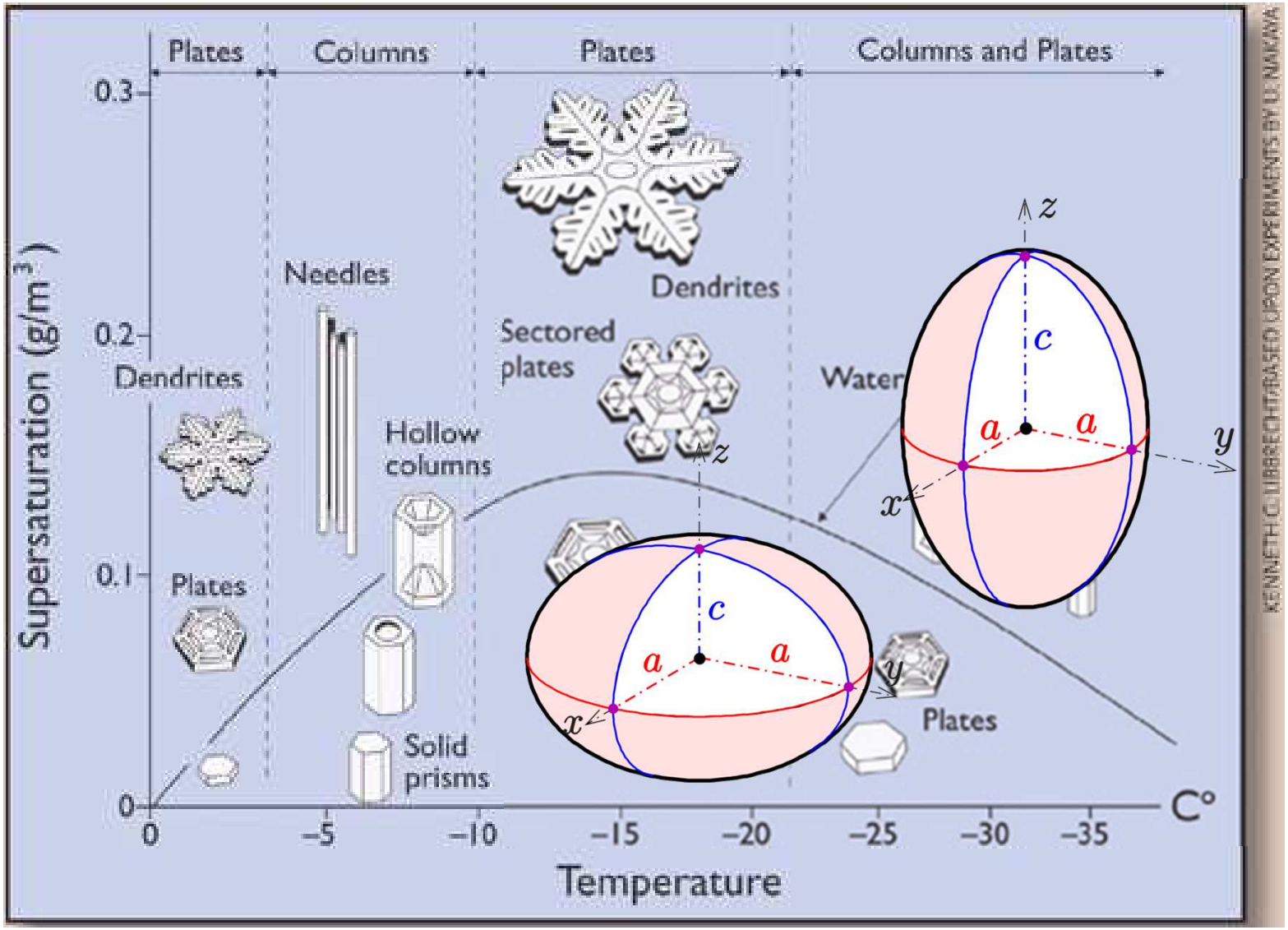
↔ ***different scenarios paired with observations to find explanation***



Bailey and Hallett, 2008


Plates
Columns
Plates
Columns and Plates
0.3
0.2
0.1
0
Supersaturation (g/m³)
Needles
Dendrites
Sectored plates
Dendrites
Water saturation
Hollow columns
Columns
Thin plates
Plates
Solid plates
Plates
Solid prisms
C°
0
−5
−10
−15
−20
−25
−30
−35
Temperature
KENNETH G. LIBBRECHT BASED UPON EXPERIMENTS BY U. NAKAYA


Plates
Columns
Plates
Columns and Plates
0.3
0.2
0.1
0
Supersaturation (g/m³)
Needles
Dendrites
Sectored plates
Dendrites
Hollow columns
Plates
Solid prisms
Water
z
c
a
a
y
x
Plates
0
−5
−10
−15
−20
−25
−30
−35
C°
Temperature
KENNETH G. LIBBRECHT BASED UPON EXPERIMENTS BY U. NAKAYA

$$\frac{d\,m_{\mathrm{i,v}}}{d\,t} = 4\,\pi\,C(V,\phi)\,D_{\mathrm{v}}\,\bar{f}\,\frac{S_{\mathrm{i}}}{T}\,\beta$$

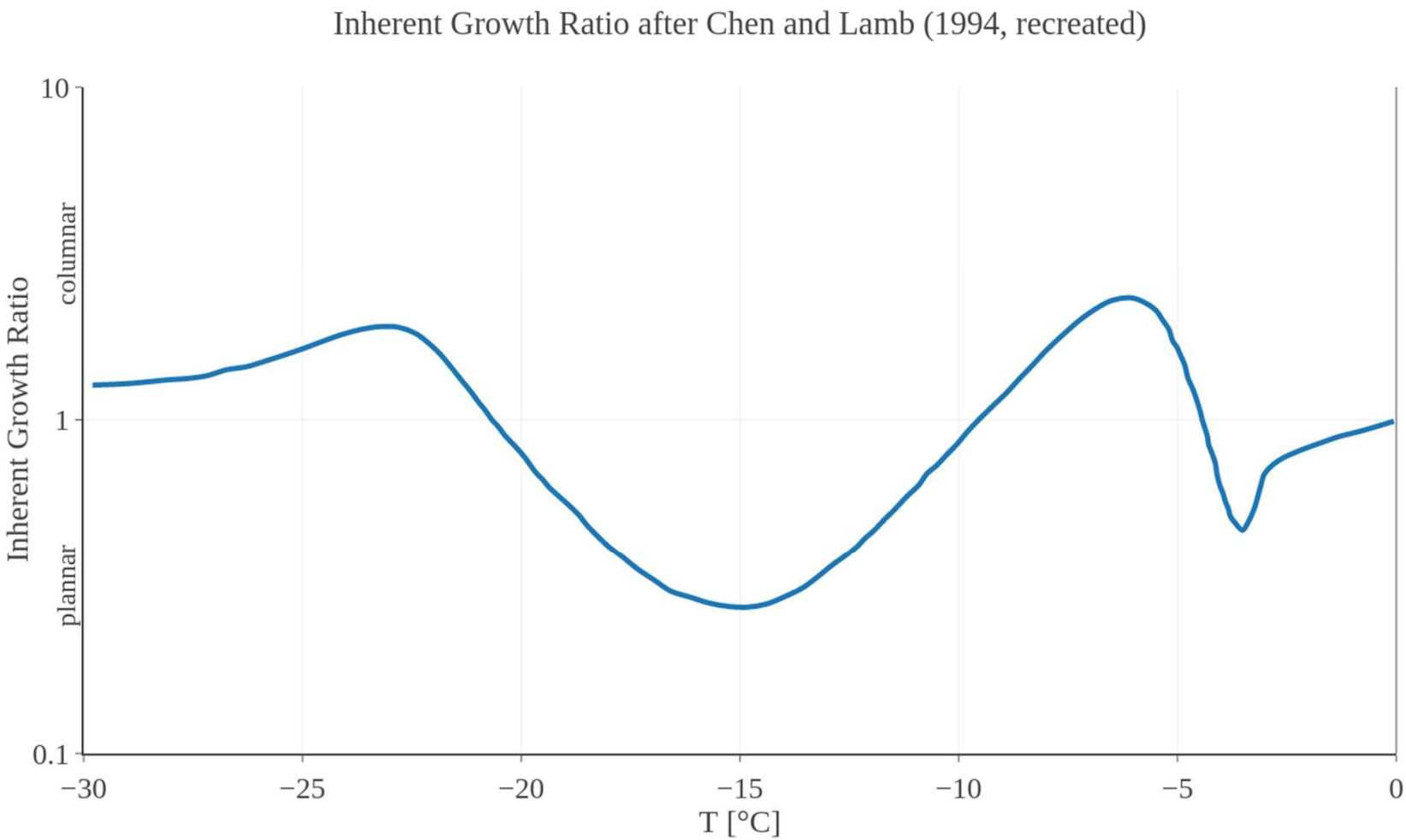
$$d\,V_{\mathrm{i}} = \frac{1}{\rho_{\mathrm{depo}}}\,d\,m_{\mathrm{i,v}}$$

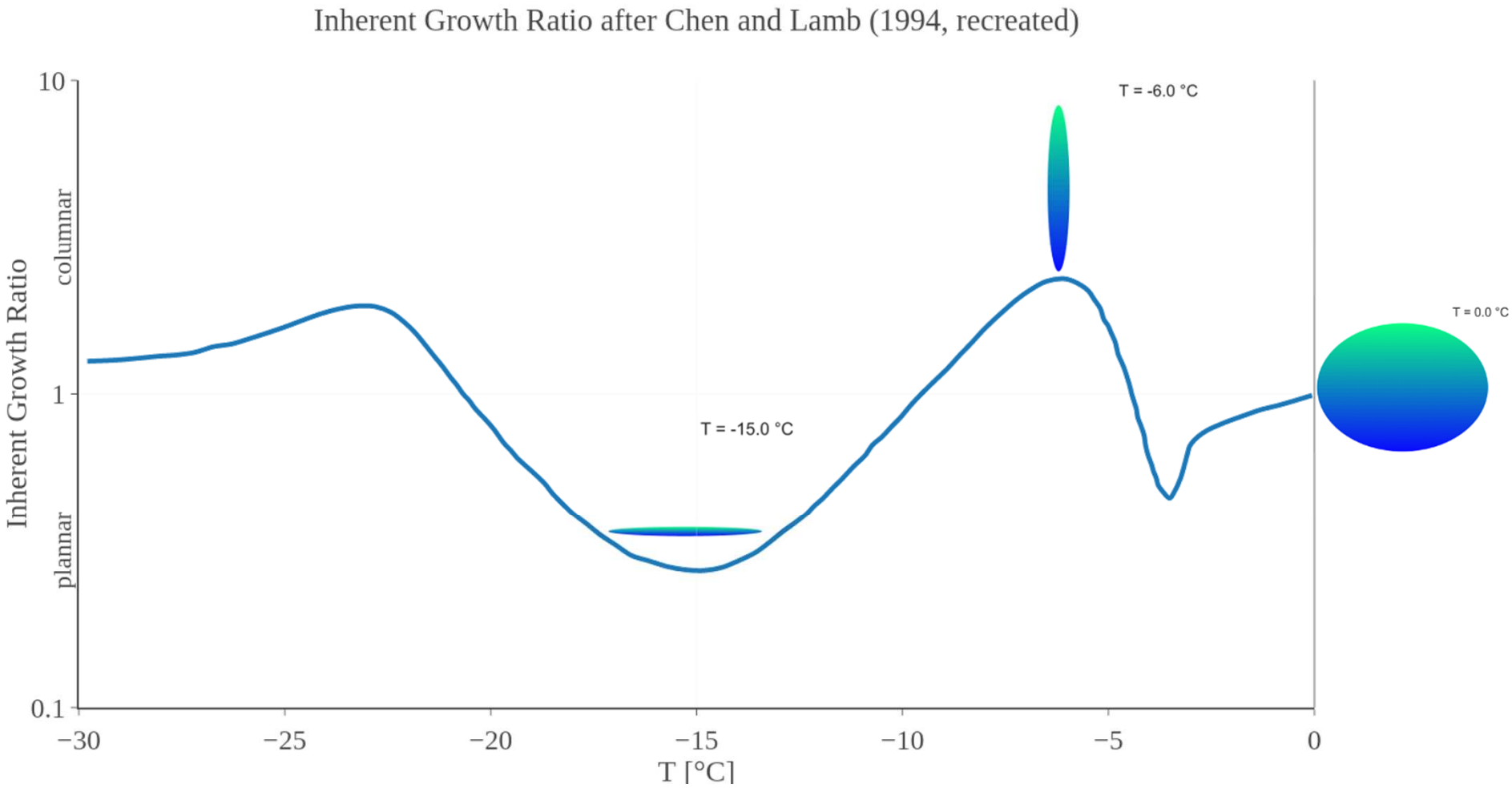
$$\frac{d\,m_{\mathrm{i,v}}}{d\,t} = 4\,\pi\,C(V,\phi)\,D_{\mathrm{v}}\,\bar{f}\,\frac{S_{\mathrm{i}}}{T}\,\beta$$

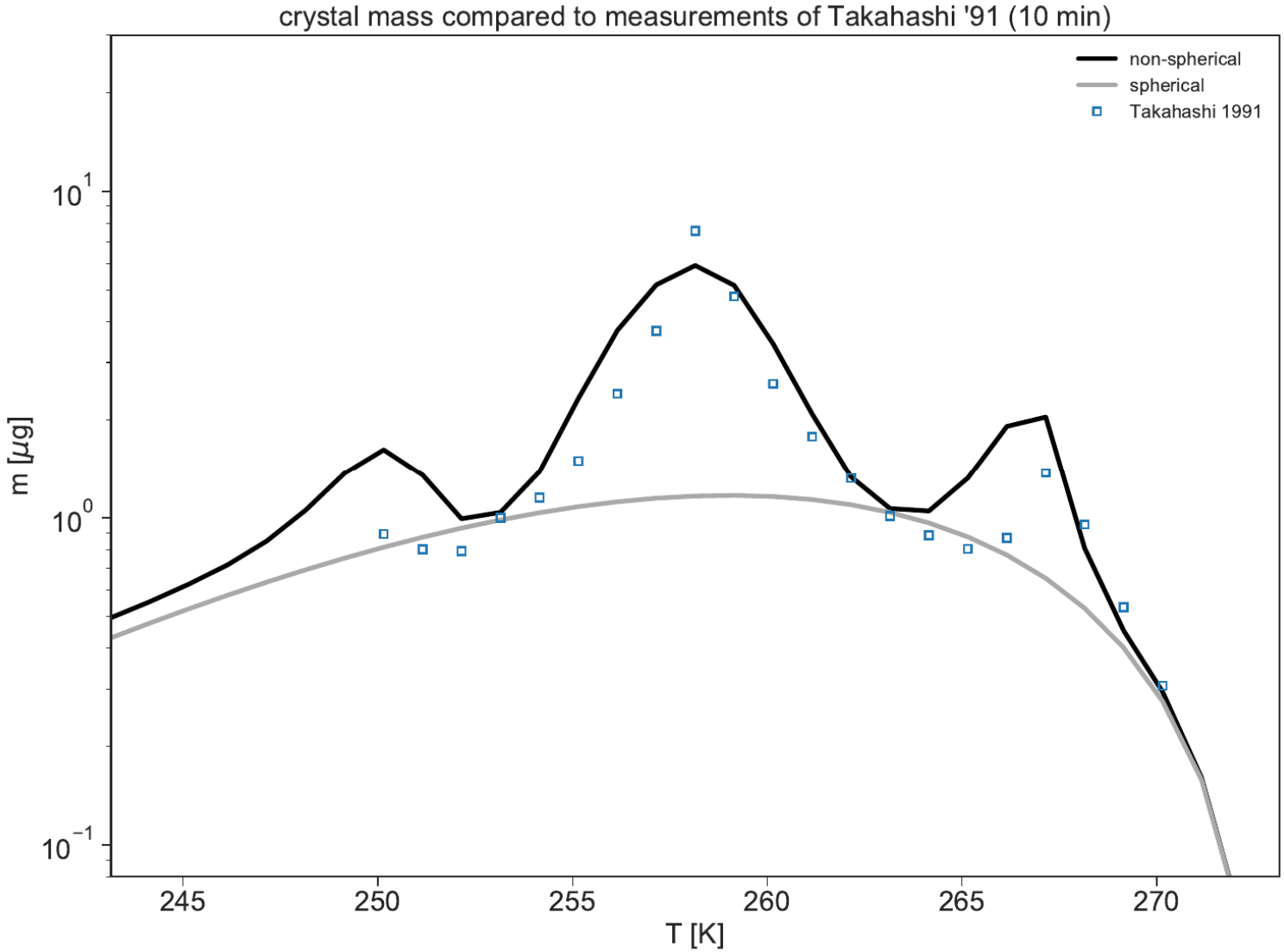
$$d\,V_{\mathrm{i}} = \frac{1}{\rho_{\mathrm{depo}}}\,d\,m_{\mathrm{i,v}}$$

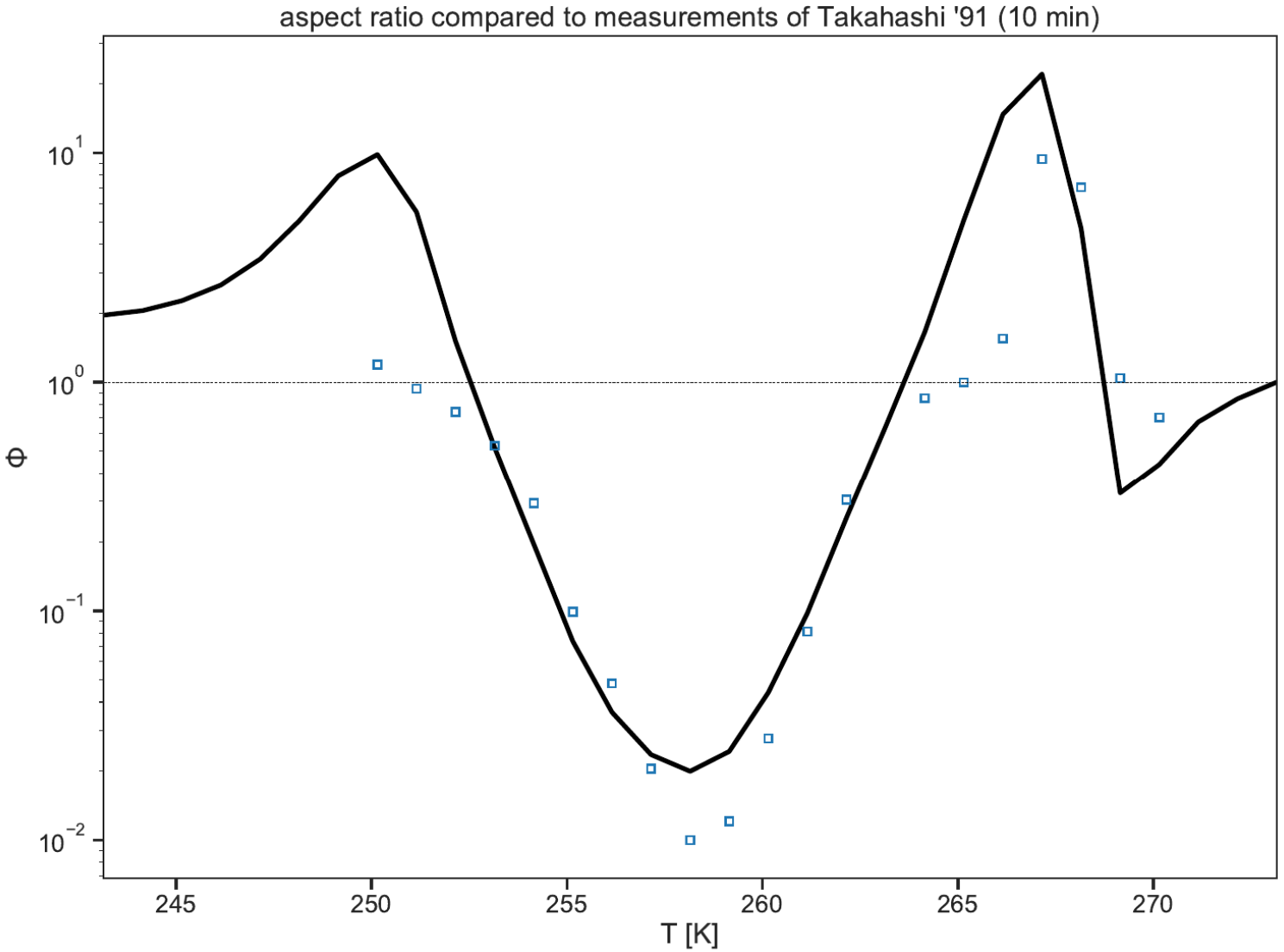
$$d\ln\phi = \frac{\Gamma-1}{\Gamma+2}\,d\ln V$$

$$V = \frac{4}{3}\,\pi\,a^3\,\phi$$

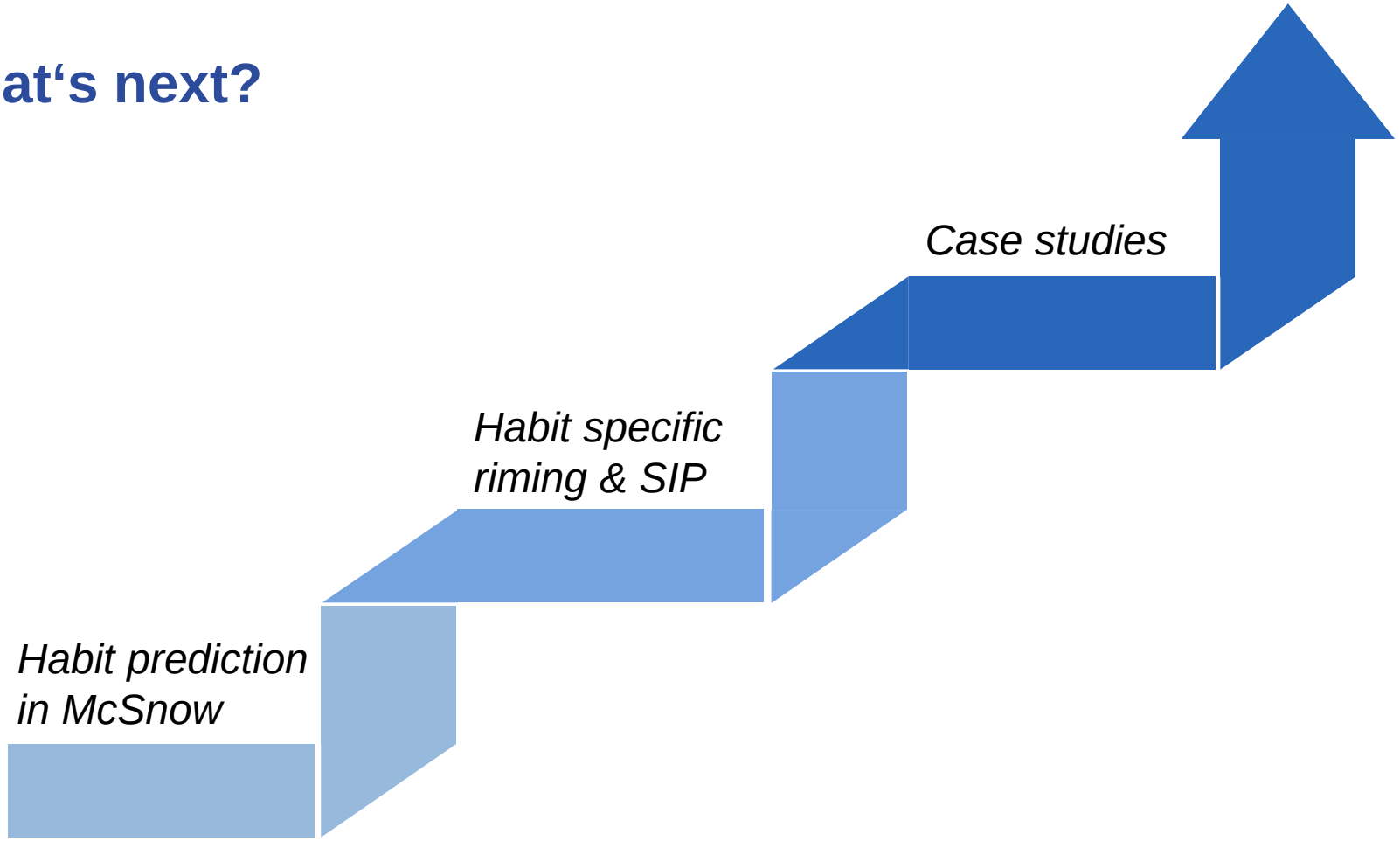

Inherent Growth Ratio after Chen and Lamb (1994, recreated)
Inherent Growth Ratio
10
1
0.1
columnar
plannar
−30
−25
−20
−15
−10
−5
0
T [°C]


Inherent Growth Ratio after Chen and Lamb (1994, recreated)
Inherent Growth Ratio
10
1
0.1
columnar
plannar
T = -6.0 °C
T = -15.0 °C
T = 0.0 °C
−30
−25
−20
−15
−10
−5
0
T [°C]


crystal mass compared to measurements of Takahashi '91 (10 min)
non-spherical
spherical
Takahashi 1991
m [μg]
10^1
10^0
10^{-1}
245
250
255
260
265
270
T [K]


aspect ratio compared to measurements of Takahashi '91 (10 min)
10^{1}
10^{0}
10^{-1}
10^{-2}
ϴ
245
250
255
260
265
270
T [K]

What‘s next?

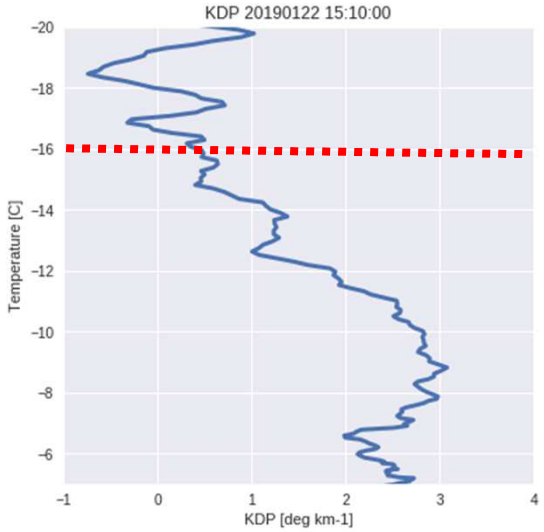

Case studies
Habit specific
riming & SIP
Habit prediction
in McSnow

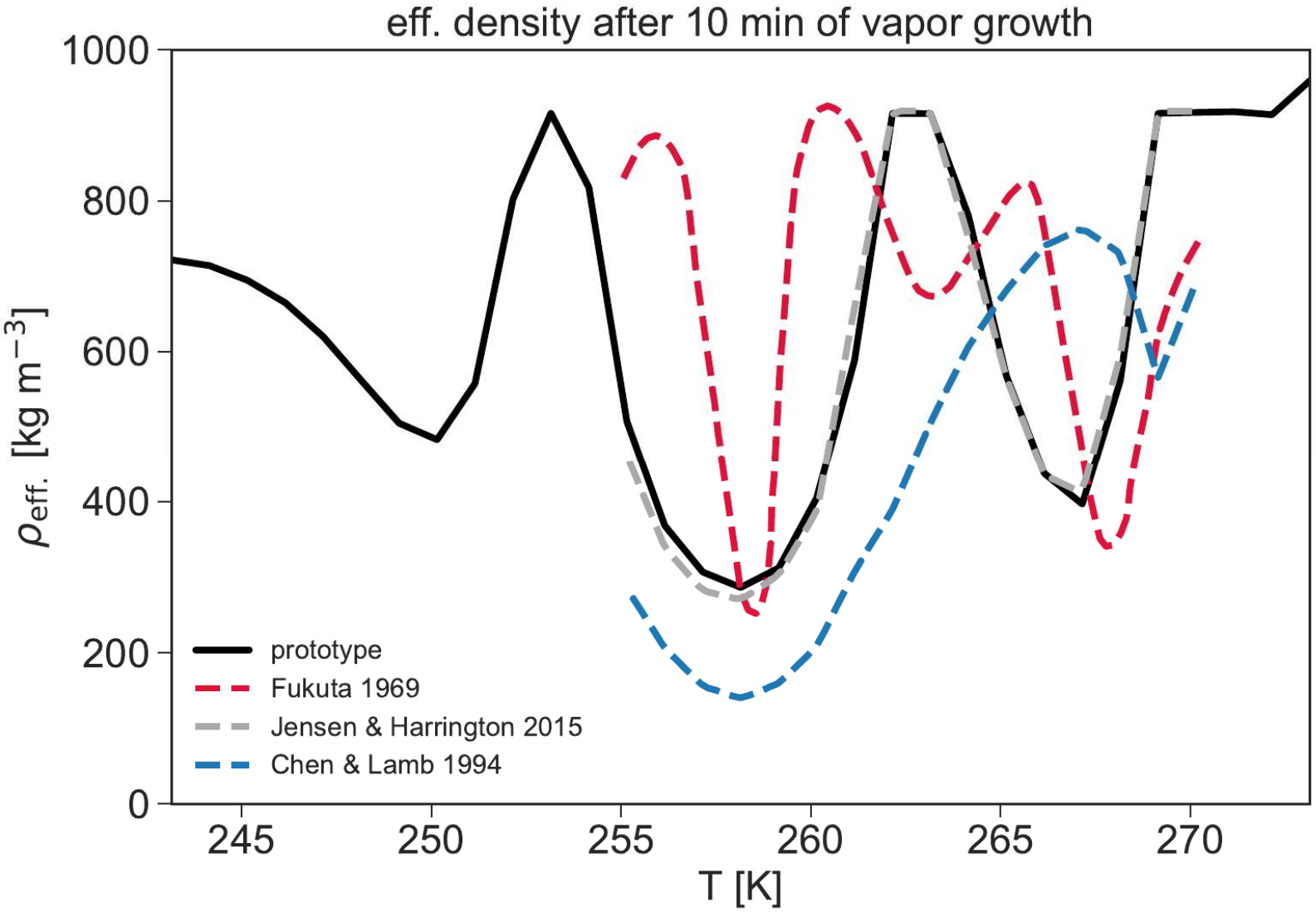
What‘s next?

Habit prediction in McSnow

Habit specific riming & SIP

Case studies




eff. density after 10 min of vapor growth
1000
800
600
400
200
0
$\rho_{eff.}$ [kg m^{-3}]
245
250
255
260
265
270
T [K]
prototype
Fukuta 1969
Jensen & Harrington 2015
Chen & Lamb 1994