# Dimensional Growth Rate Time Series Measurements of Cirrus-like Ice Crystals

**Gwenore Pokrifka**, Alfred Moyle, and Jerry Y. Harrington
The Department of Meteorology and Atmospheric Science,
The Pennsylvania State University

## Background:

- Clouds: large uncertainty in climate models
- Cold clouds: cover ~1/3 of Earth
- Cloud ice: diverse shapes and growth rates
  - Primary growth mode at cirrus temperatures is unknown
  - Fundamental growth rate time series measurements are lacking
  - Models typically treat ice with constant shapes, often spherical, using capacitance theory
  - Assumptions about ice shape influence simulated precipitation and radiation

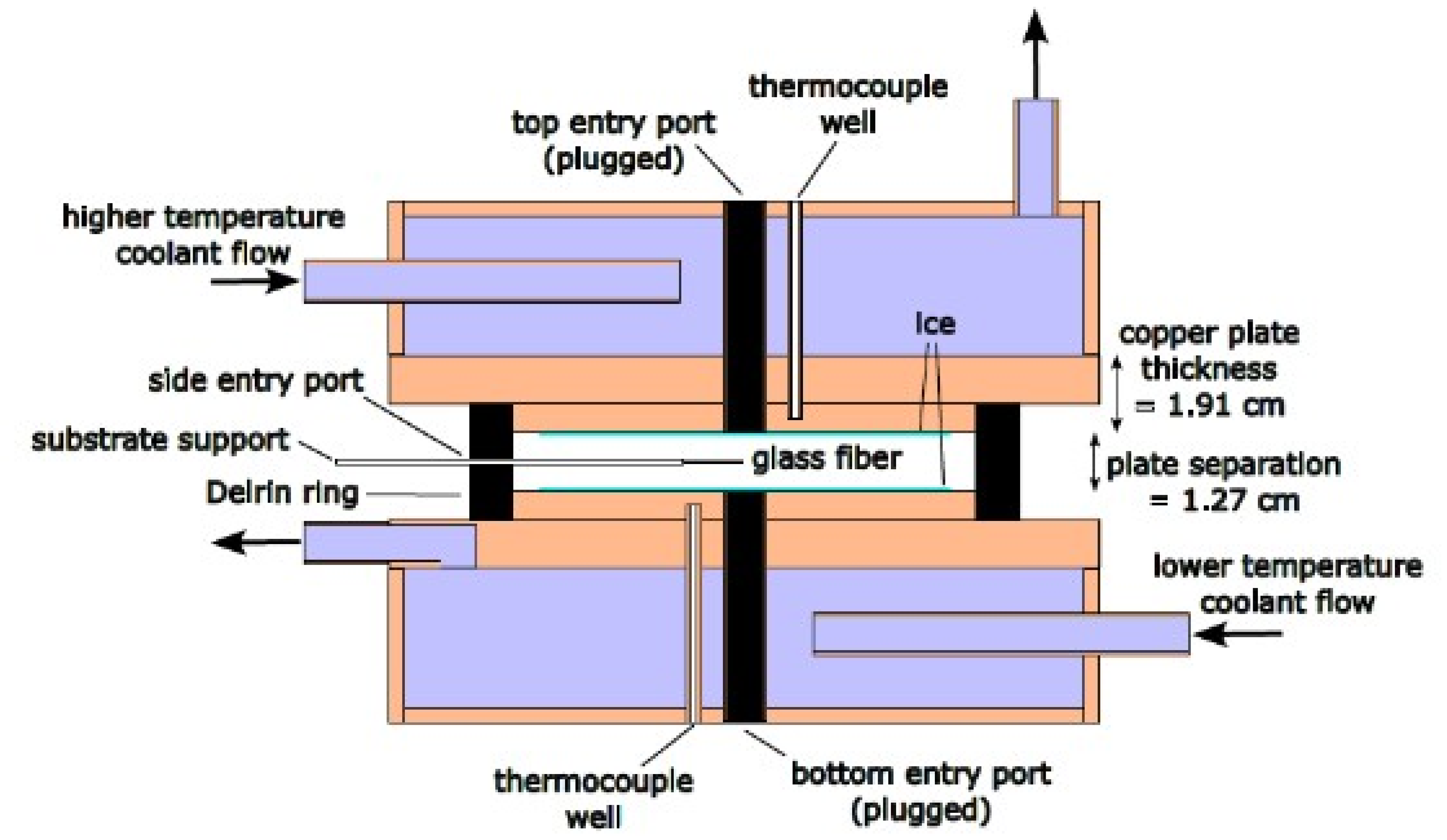
## Experiments:

Substrate Crystal Imaging (SCI) chamber

Grow ice from fiberglass
- Frozen pure water → vapor deposition
- Unimpeded vapor diffusion

- Stable conditions
  - Temperature ($T$) -66.9 to -46.1 °C
  - Supersaturation ($s_i$) 27.7 to 80.4%

- Growth observed at two orthogonal angles
  - High-resolution images
  - Regular intervals for growth time series

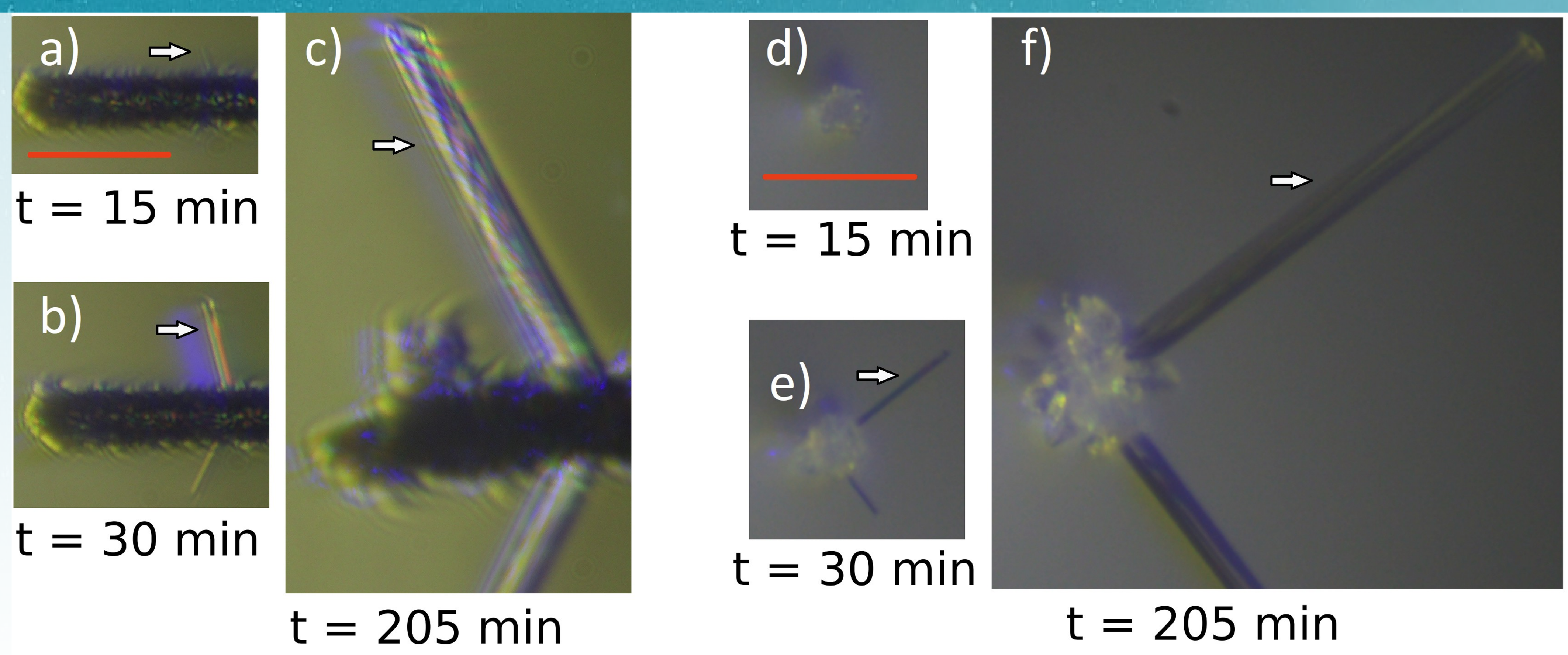


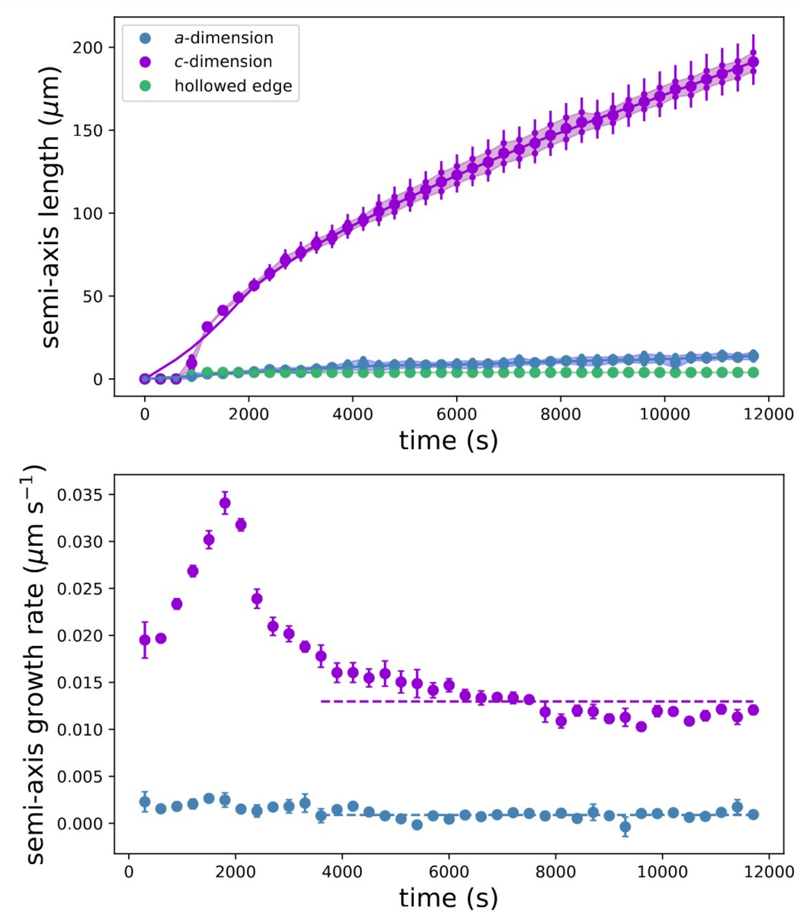

## Example:

$T$ = -59.9 °C; $s_i$ = 60.9%

- Views perpendicular to (a, b, c) and along (d, e, f) the substrate
  - Red line = 100 μm
  - Data for crystal indicated by white arrow

- About an hour of growth…
  - $c$- and $a$-dimensional growth rates asymptote → Aspect ratio ($c/a$) approaches a constant

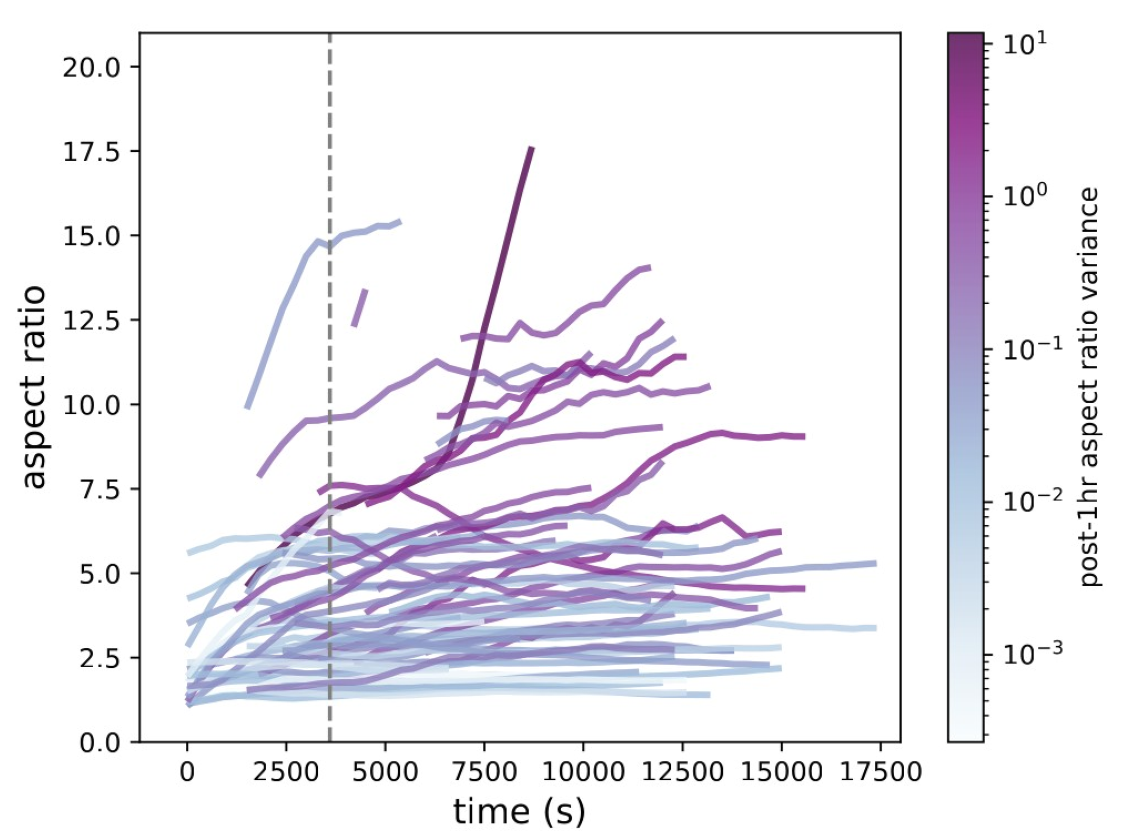


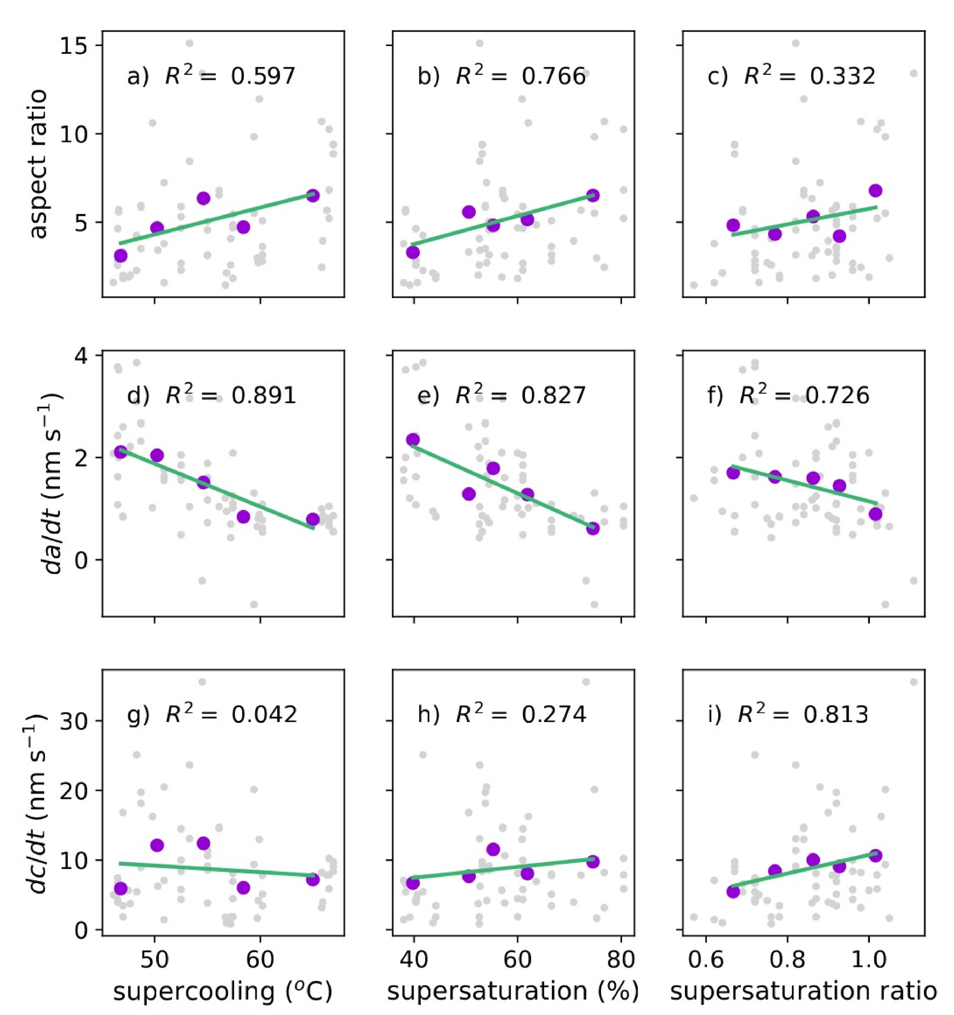




## Trends:

- Typically columnar crystals
  - Some planar polycrystals as $T$ → -40 °C

Aspect ratios asymptote often by ~1 hr of growth (blue curves)
- Occasional faceting instabilities
- Basal facet hollowing is common




Asymptotic values of growth rates relation to $T$ and $s_i$…
[linear fits (green lines) through $s_i$-binned means (purple points)]
- $da/dt$ decreases with $T$, but $dc/dt$ is insensitive
  → Increases aspect ratio with $T$
- $s_i$ correlates with $dc/dt$, negatively with $da/dt$
  - Related to basal facet instabilities
  → Increases aspect ratio with $s_i$

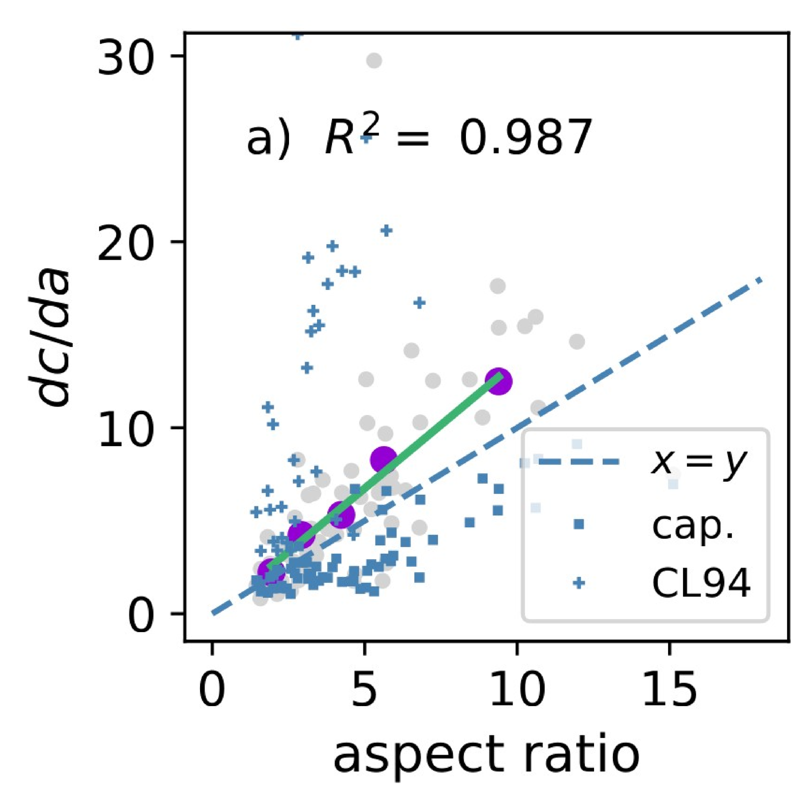
- Note: supersaturation ratio = $si$ / liquid-equilibrium value of $s_i$
- Removes $T$-dependence of $si$

## Theory:

- How does the ratio of the dimensional growth rates ($dc/da$) compare to the mean aspect ratio after an hour?

- Data: linear relationship (almost 1:1)
- Capacitance: fixed at initial $dc/da$
- Adaptive habit (CL94): $dc/da$ always increases
- Step nucleation by facet edges: → 1:1

- **Most data follows facet growth theory**
- **Cases with faceting instabilities follow adaptive habit model**

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