Update on CAM5 Microphysical Improvements Regarding Ice Particle Mass- and Area-dimensional Expressions

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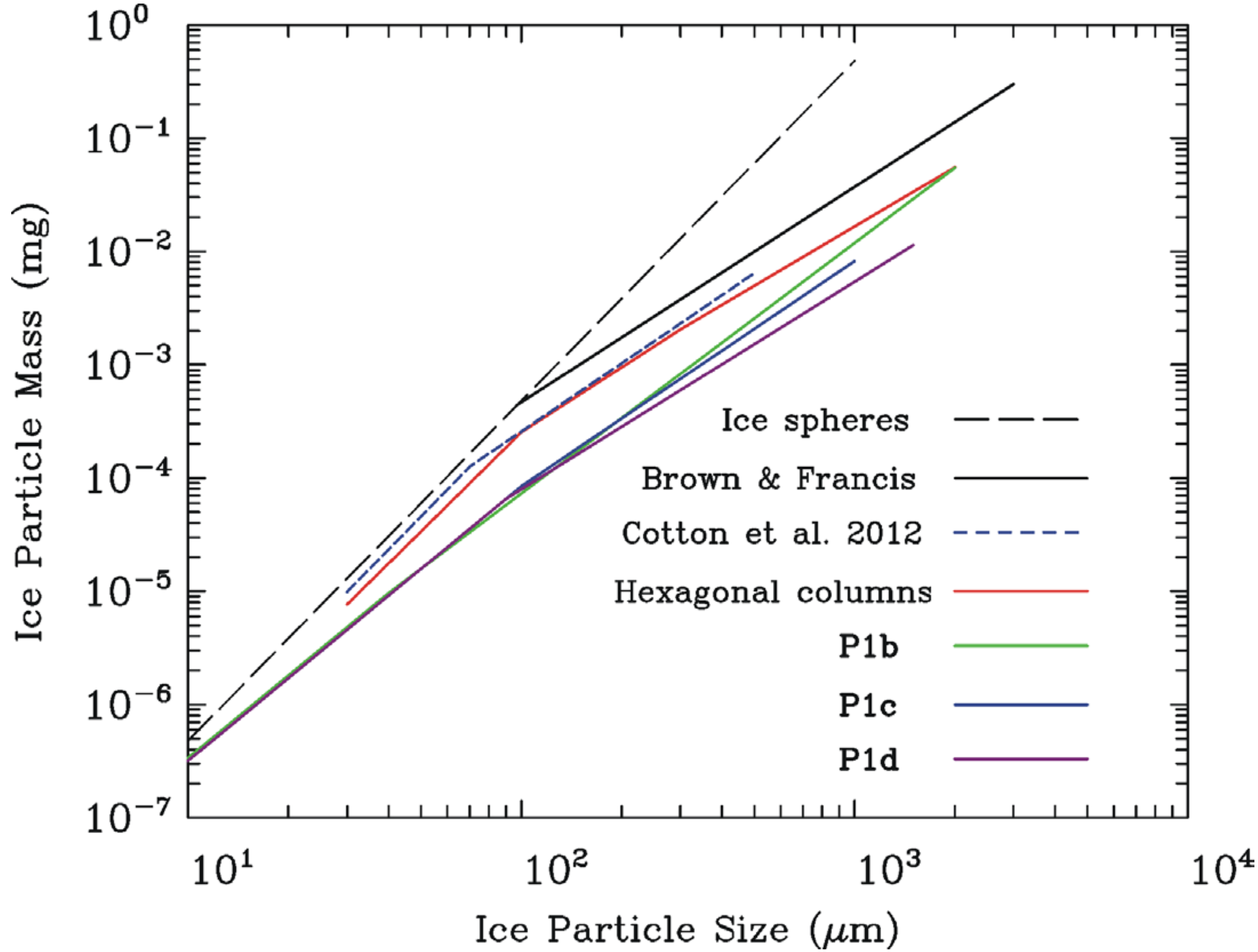
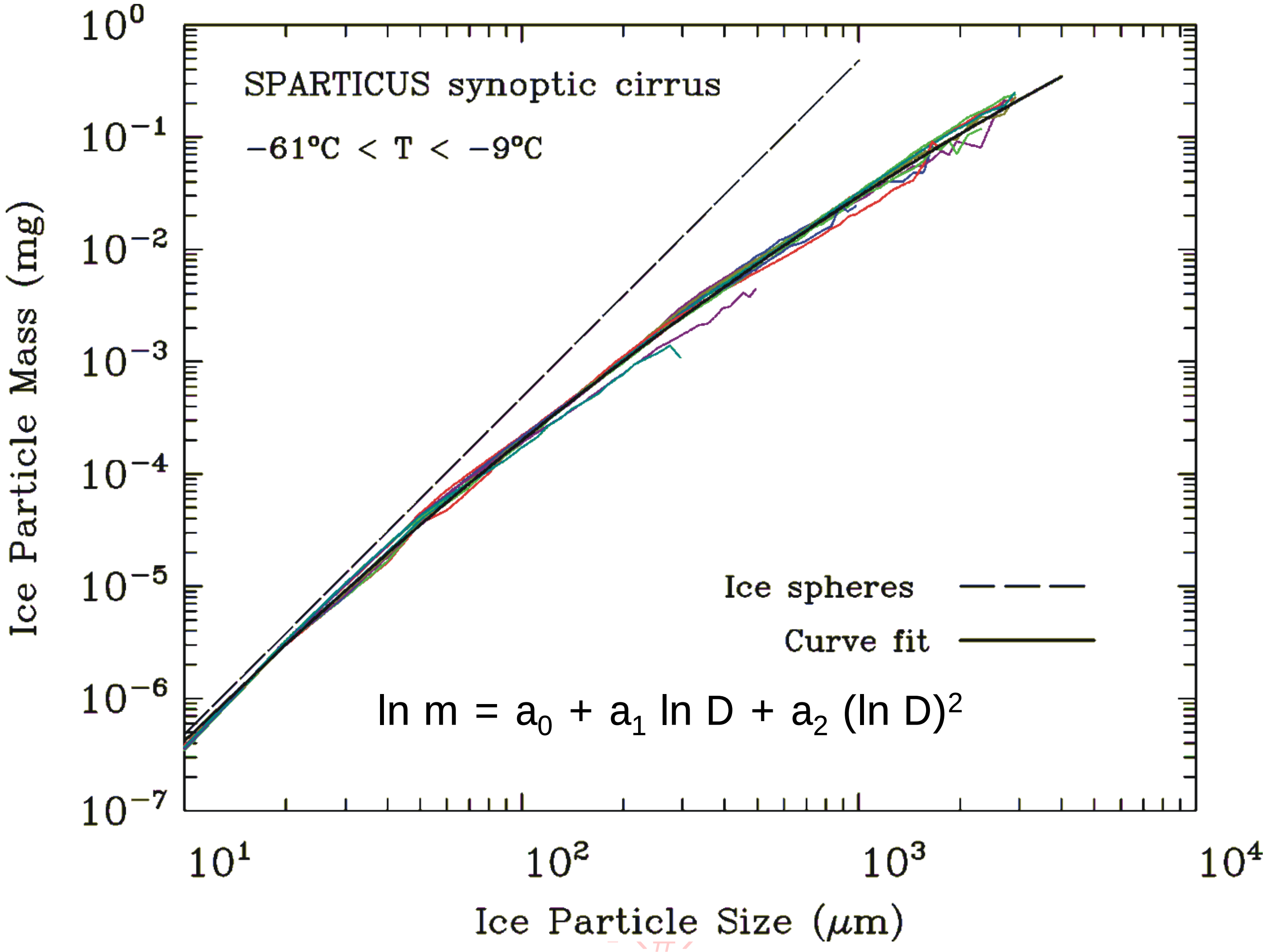
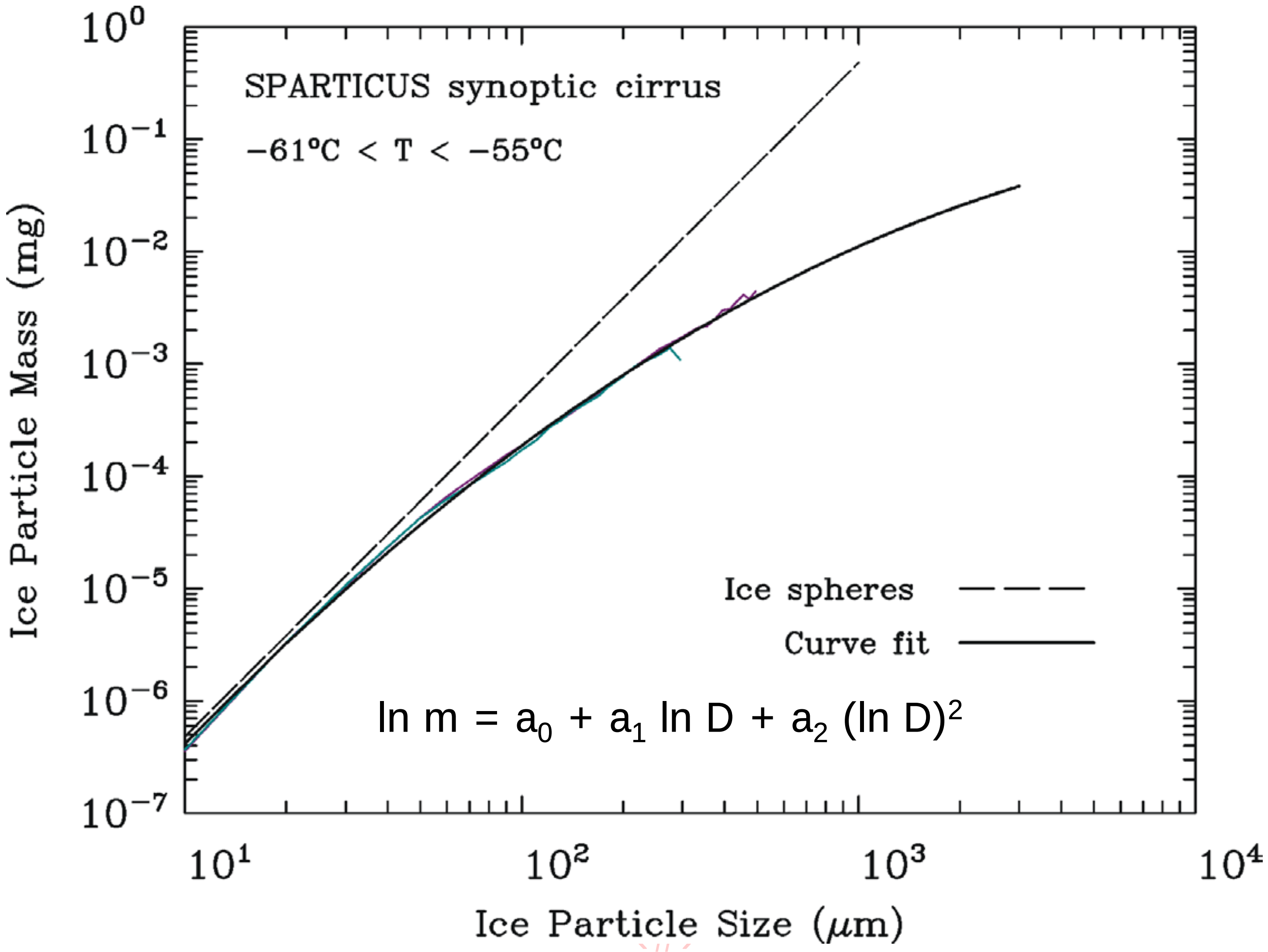

Ice Particle Mass (mg)
Ice Particle Size (μm)
Ice spheres
Brown & Francis
Cotton et al. 2012
Hexagonal columns
P1b
P1c
P1d

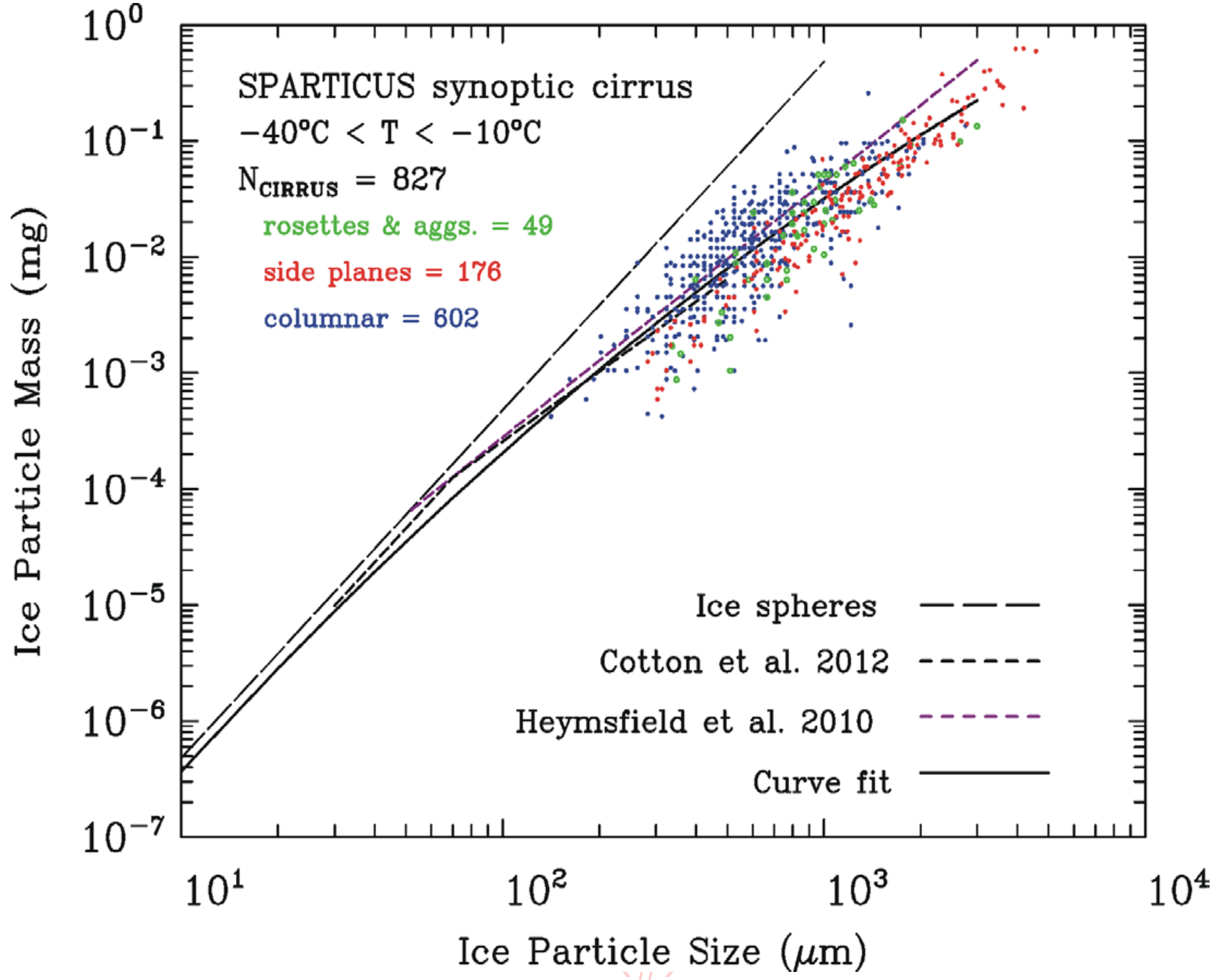
Dependence of log(m) on log(D) is not linear



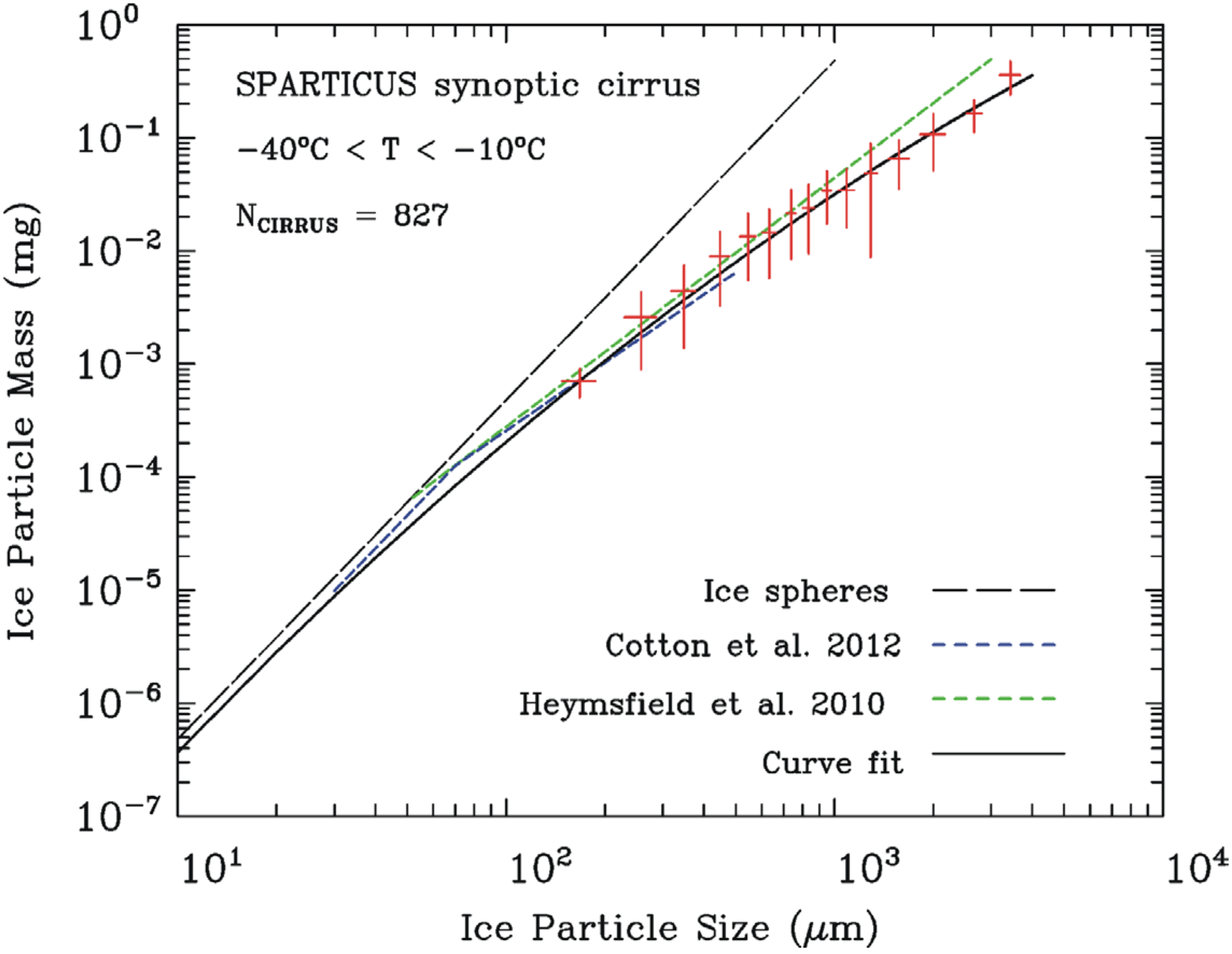
Data was grouped into 3 temperature-categories for synoptic and anvil cirrus, with a m-D and A-D curve fit for each category



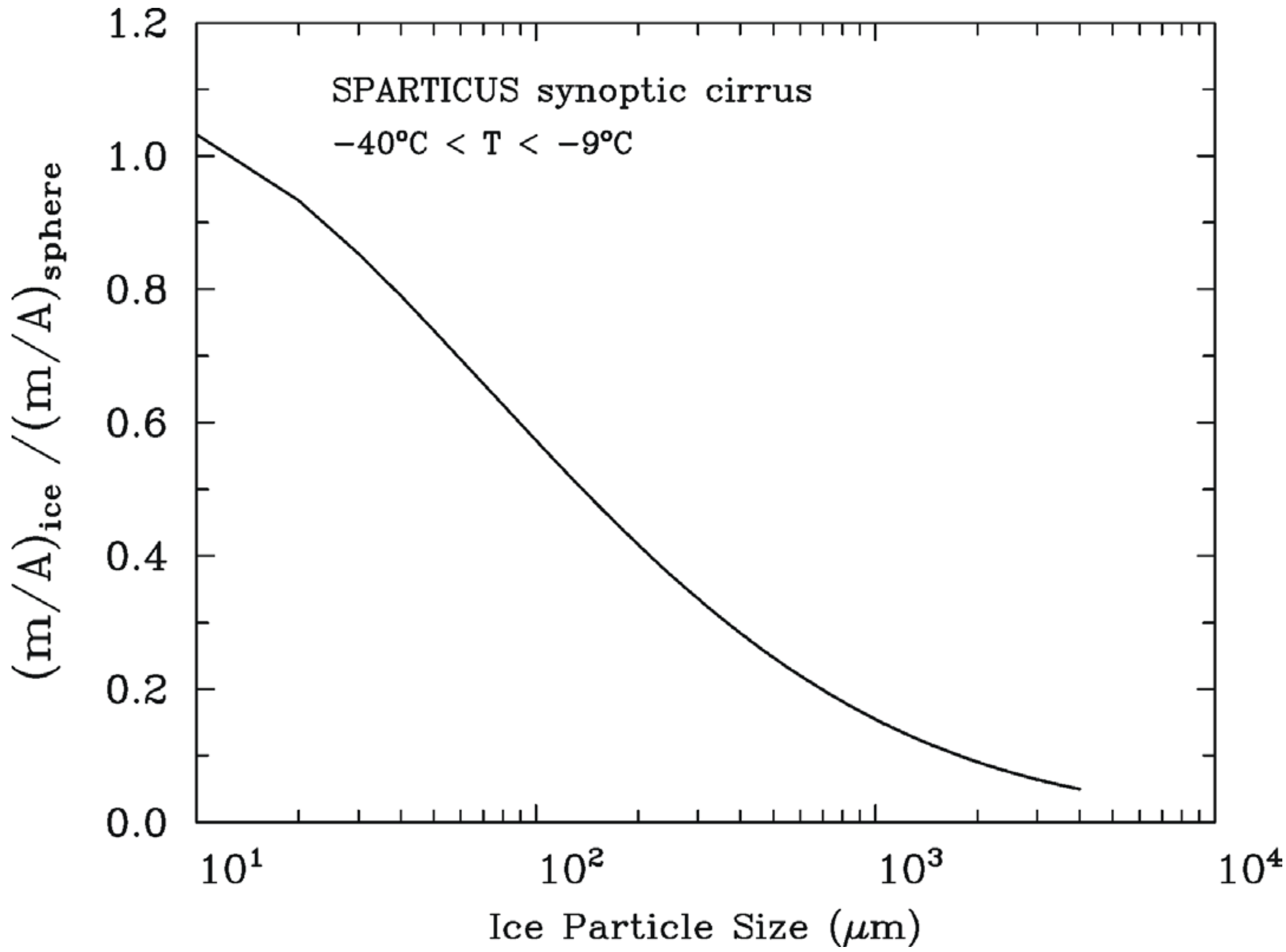
Comparisons with other field data and other studies



Mean uncertainty = ± 54.4%



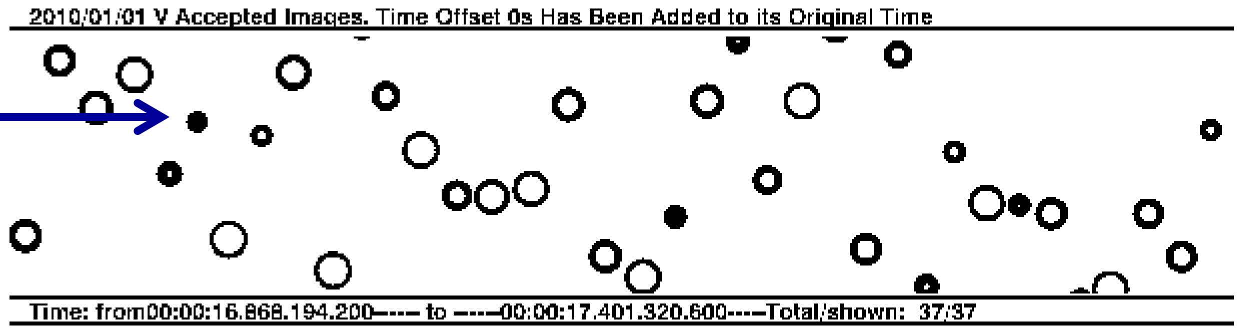
Testing for self-consistency and physical realism



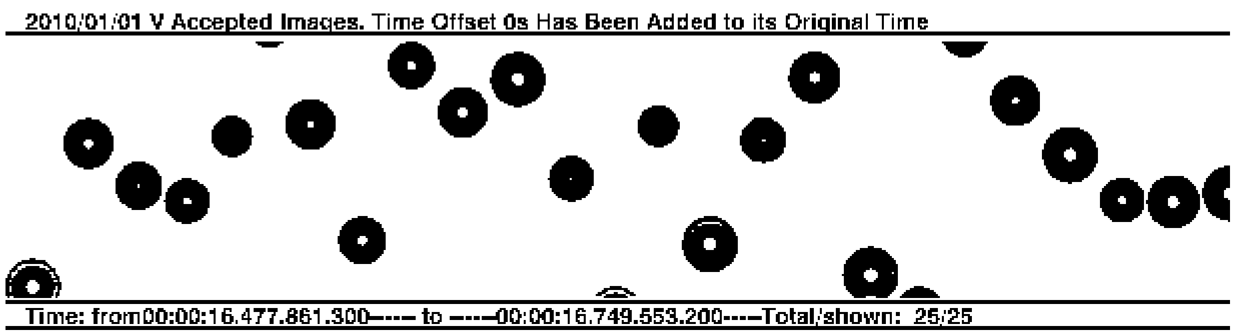
2D-S probe (and other optical probes) cannot accurately measure ice particle area ratios for D < 200 µm.

Out-of-focus problem demonstrated for glass spheres having diameter of 100 µm, but image size varies depending on proximity to depth-of-field.

In focus



Out-of-focus problem is greatly reduced for 200 µm glass spheres



Proposed solution: Use Cloud Particle Imager (CPI) data when ice particle length D < 200 μm. The CPI and 2D-S probes were co-located during SPARTICUS cirrus cloud sampling. The CPI spatial resolution is 2.3 μm and there is no out-of-focus problem. Ice particle area & area ratios are very accurate.

Calculation of ice particle mass for D < 200 μm:

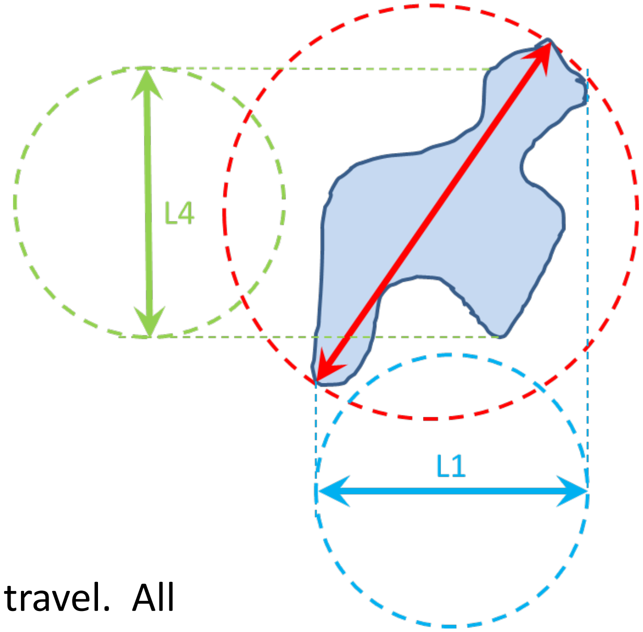
For each ice particle, define an ice sphere having the same projected area as the ice particle and calculate the mass of this ice sphere.

Expected error: For D < 200 μm, ice particles are generally compact, quasi-spherical or blocky in shape, making the above mass estimate a good approximation. For aspect ratios < 3, errors should not exceed ~ 30%.

2nd Problem: The dimension the 2D-S reports is not always the maximum dimension.

Solution: Change the data processing algorithm

New Algorithm (M7)



M1 Method

- The M1 method uses the length scale L1, which is the maximum particle dimension along the direction of travel. All particles are included in area and number concentration calculations.

M7 Method

- The M7 method uses the length scale MaxLength, which is the maximum particle dimension of the projected image. Only particles that are 'all-in' are included (particles intercepting the edge of the 2DS field of view are excluded from area and number concentration calculations).

Conclusions based on one synoptic cirrus and one anvil cirrus flight:

- New algorithm has a larger effect on particle size and total projected area for anvil cirrus than for synoptic cirrus, because particles are often 1mm or larger in anvil cirrus, and are therefore more likely to intercept the edge of the 2D-S field of view.

Using M1 instead of M7 results in:

- < 5% bias in sample area for synoptic cirrus
- < 13% bias in sample area for anvil cirrus

Summary and Conclusions

1. When considering all sizes, ice particle mass and projected area are better estimated by 2nd order polynomial fits than by power laws.

2. Method's accuracy is evident through comparisons with two recent studies and ground field measurements.

3. Uncertainties in ice particle area and mass are considerable for $D < 200$ μm, but these uncertainties will be greatly reduced by using CPI imagary.

4. The standard 2D-S data processing estimates an ice particle's maximum dimension D, but the new SPEC algorithm will actually measure D. Also, only particles completely within the 2D-S field of view are counted and analyzed.

Generating m-D and A-D Relationships Using the 2D-S Probe

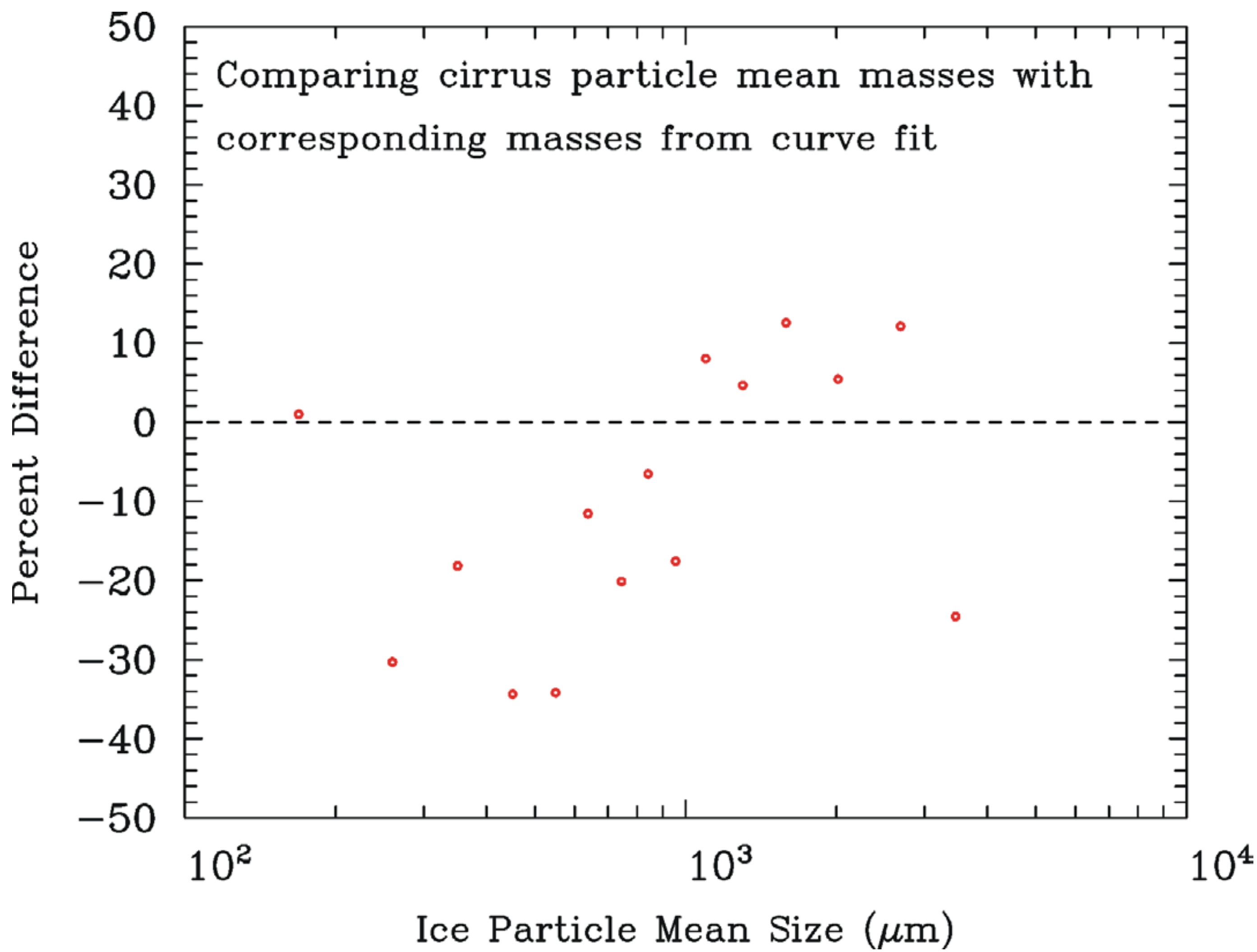
The 2D-S probe measures the size resolved concentrations of ice particle number, projected area and estimated mass from 10 to 1280 μm, using the Baker-Lawson mass-area power law to estimate particle mass. The mean ice particle mass for each size-bin is given as

$$m = M/N$$

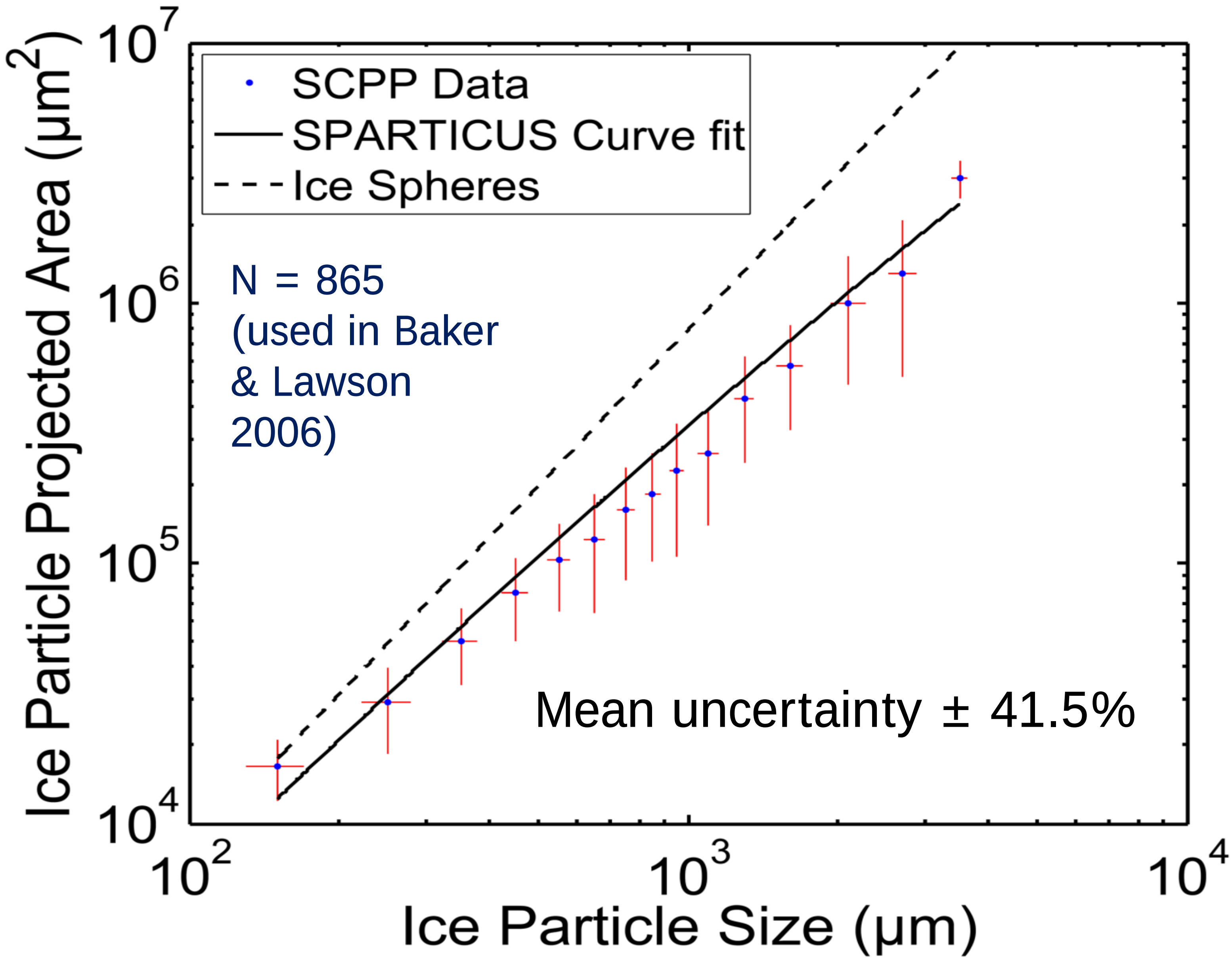
where M and N are mass and number concentration for a given size-bin. Relating m to the midpoint size of each bin, the dependence of m on D is revealed. The dependence of mean ice particle projected area on D is found in a similar manner.

A mean PSD was produced for each 5°C T-interval that reduces scatter while focusing the curve fit. Temperature categories were identified where m-D & A-D curves were similar. A single m-D or A-D curve fit was produced per T-category.

The main objective here was to evaluate the dependence of m and A on D over a much greater range of ice particle size than done before (especially the size range between 10 and 100 μm).



Comparing cirrus particle mean masses with
corresponding masses from curve fit
Percent Difference
50
40
30
20
10
0
−10
−20
−30
−40
−50
10^2
10^3
10^4
Ice Particle Mean Size (μm)


SCPP Data
SPARTICUS Curve fit
Ice Spheres
N = 865
(used in Baker
& Lawson
2006)
Mean uncertainty ± 41.5%
Ice Particle Projected Area (µm²)
Ice Particle Size (µm)
10⁴
10⁵
10⁶
10⁷
10²
10³
10⁴

$$m = \alpha\, D^{\beta}$$

$$A = \gamma\, D^{\delta}$$

For a given D, we can obtain these power laws

$$\ln m = a_0 + a_1 \ln D + a_2 (\ln D)^2$$

$$d(\ln m)/d(\ln D) = \beta = a_1 + 2a_2 \ln D$$

$$\alpha = \exp[a_0 + a_1 \ln D + a_2 (\ln D)^2] / D^{\beta}$$

β uncertainty << α uncertainty

Synoptic cirrus, exponent of m-D power law

	Ice particle size (μm)				
	50	150	500	1500	4500
	Power β				
Temperature Range					
-40 < T ≤ -10°C	2.632	2.368	2.079	1.814	1.550
-55 < T ≤ -40°C	2.564	2.280	1.968	1.684	1.399
-65 < T ≤ -55°C	2.477	2.057	1.597	----	----
Mean β	2.558	2.235	1.881	1.749	1.475
Standard deviation of β	0.064	0.131	0.206	----	----

Mean uncertainty for β as 100 × σ/ mean value : 6.74%

Application to Cloud Modeling

$N(D) = N_o D^{\nu} \exp(-\lambda D)$

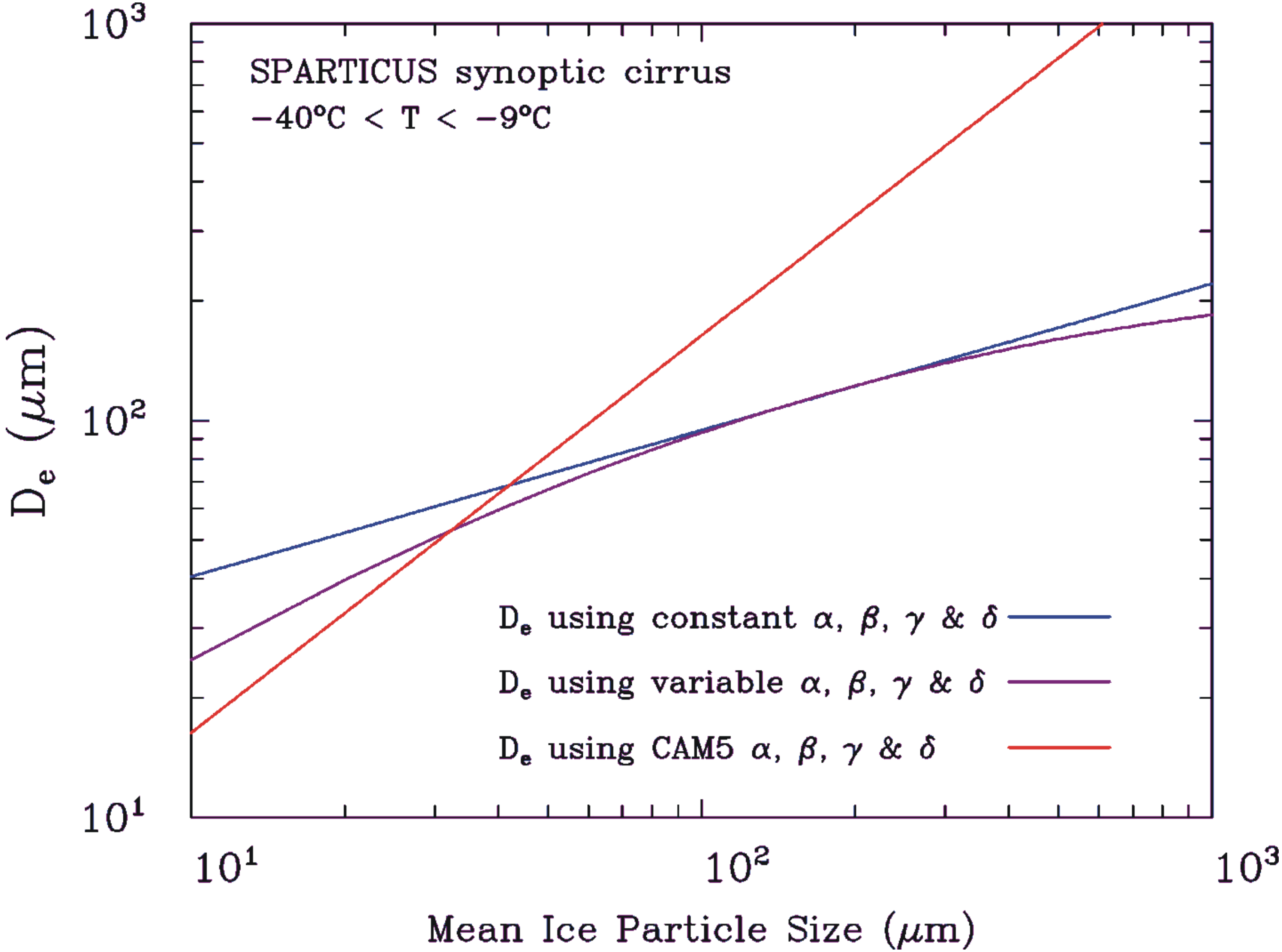
$$\lambda = \left(\frac{\alpha \, \Gamma(\beta+\nu+1) \, N}{\Gamma(\nu+1) \, IWC} \right)^{1/\beta}$$

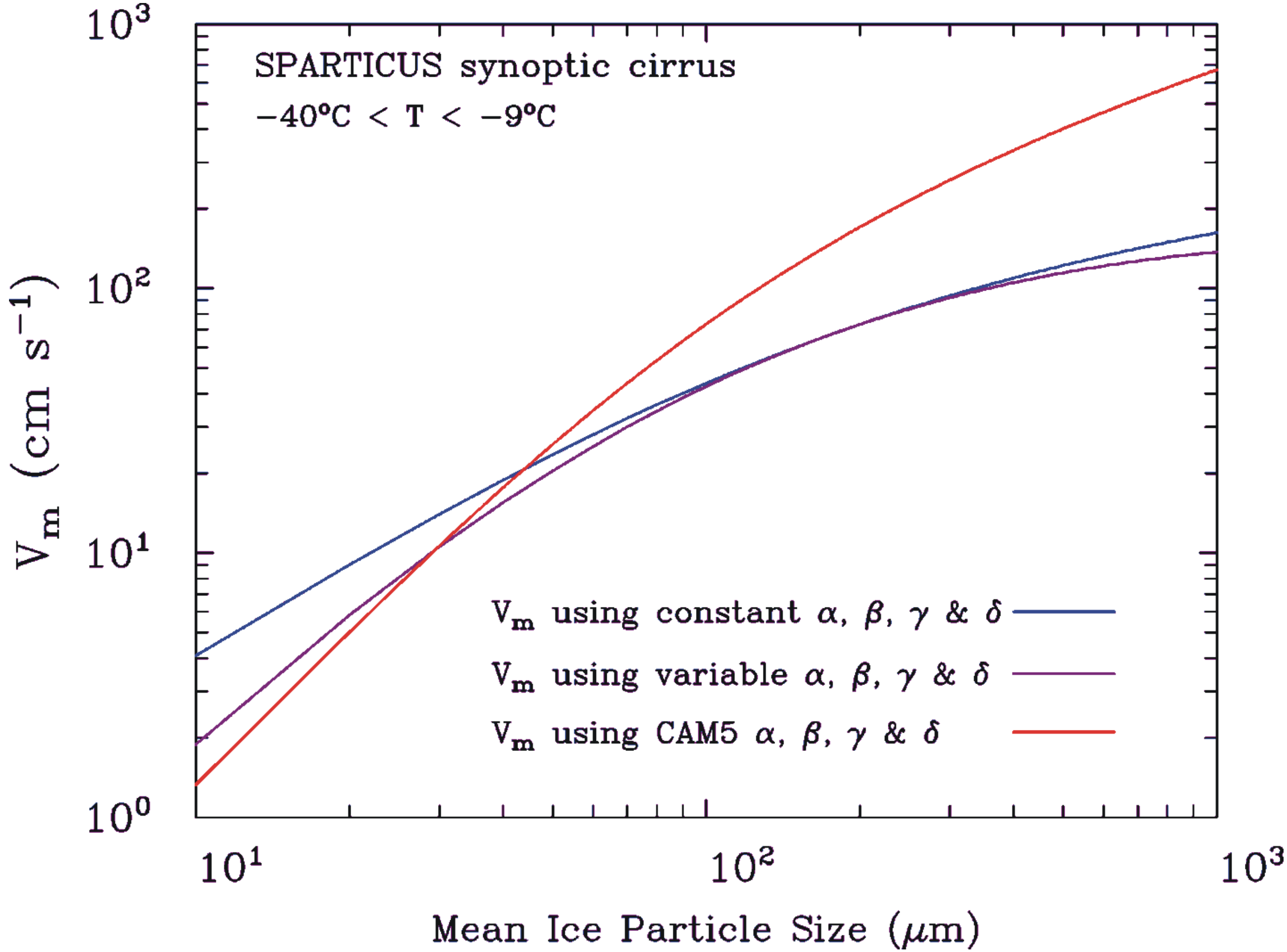
Used in CAM5

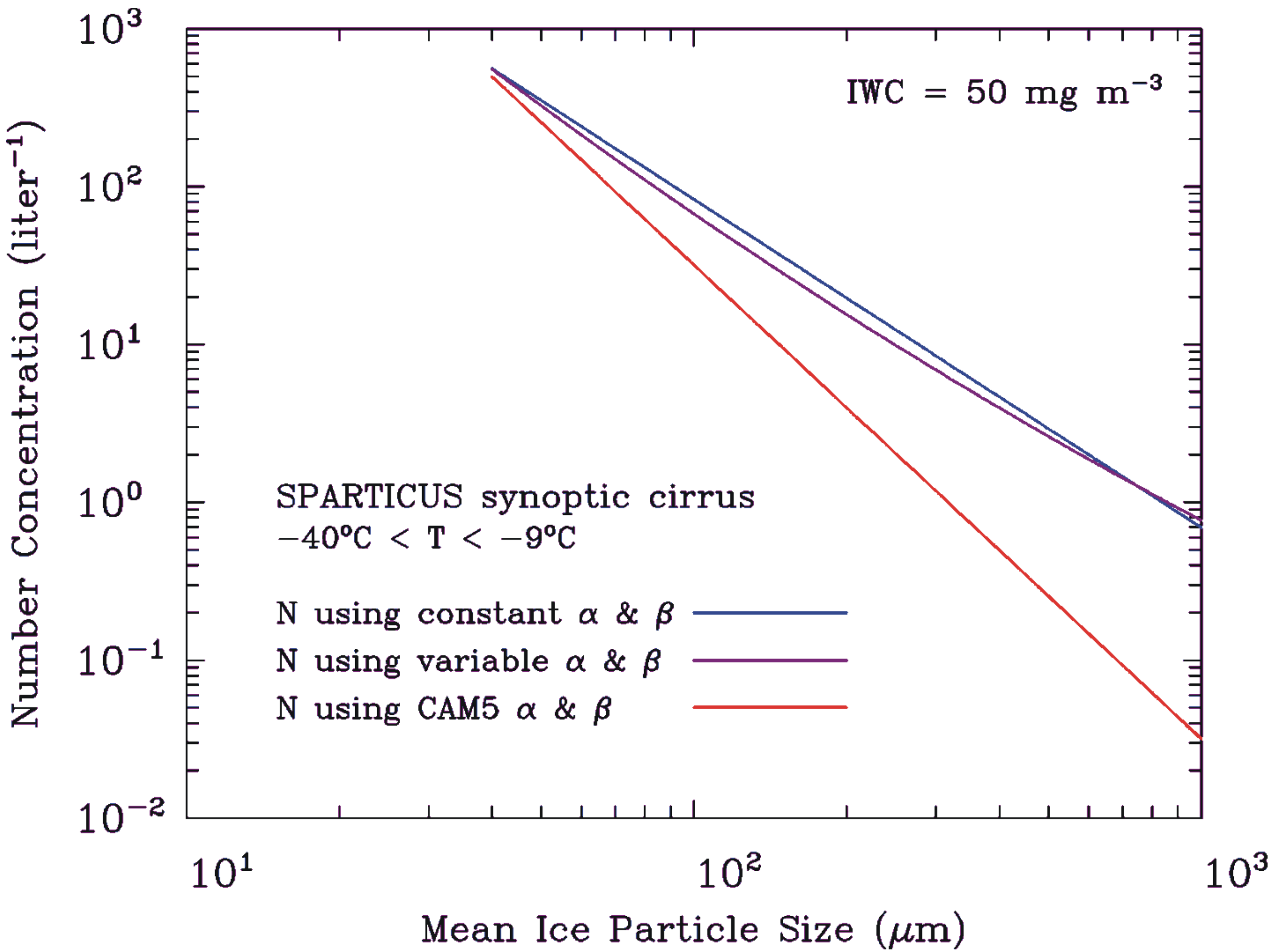
To a good approximation, λ is obtained by evaluating α & β at D = 500 µm. Then estimate the D for the cloud property or process of interest by evaluating β and δ at D = 500 µm:

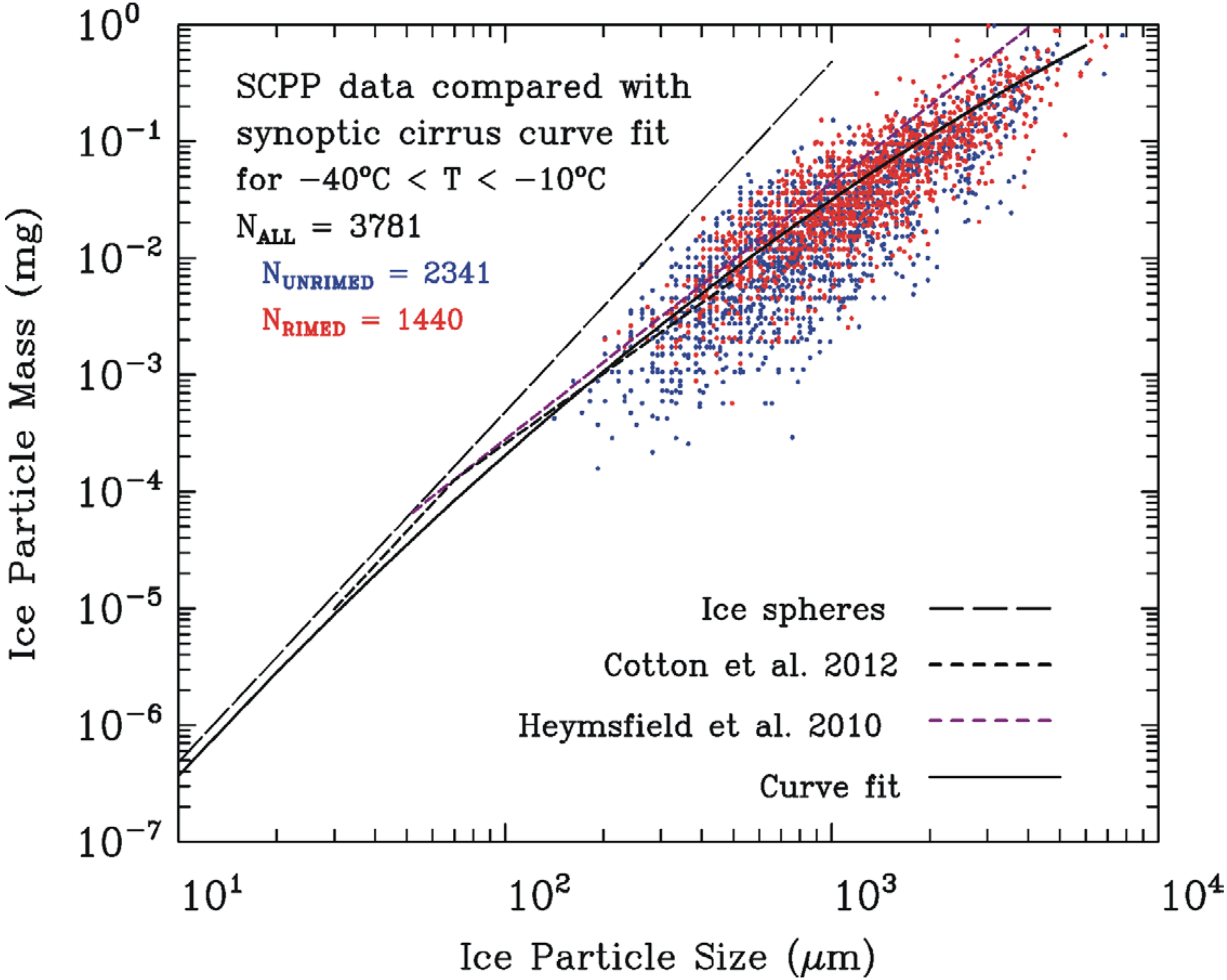
$D_N = (\nu + 0.67)/\lambda$	Median number conc. dimension
$D_a = (\delta + \nu + 0.67)/\lambda$	Median area dimension
$D_m = (\beta + \nu + 0.67)/\lambda$	Median mass dimension
$D_Z = (2\beta + \nu + 0.67)/\lambda$	Median radar reflectivity dimension

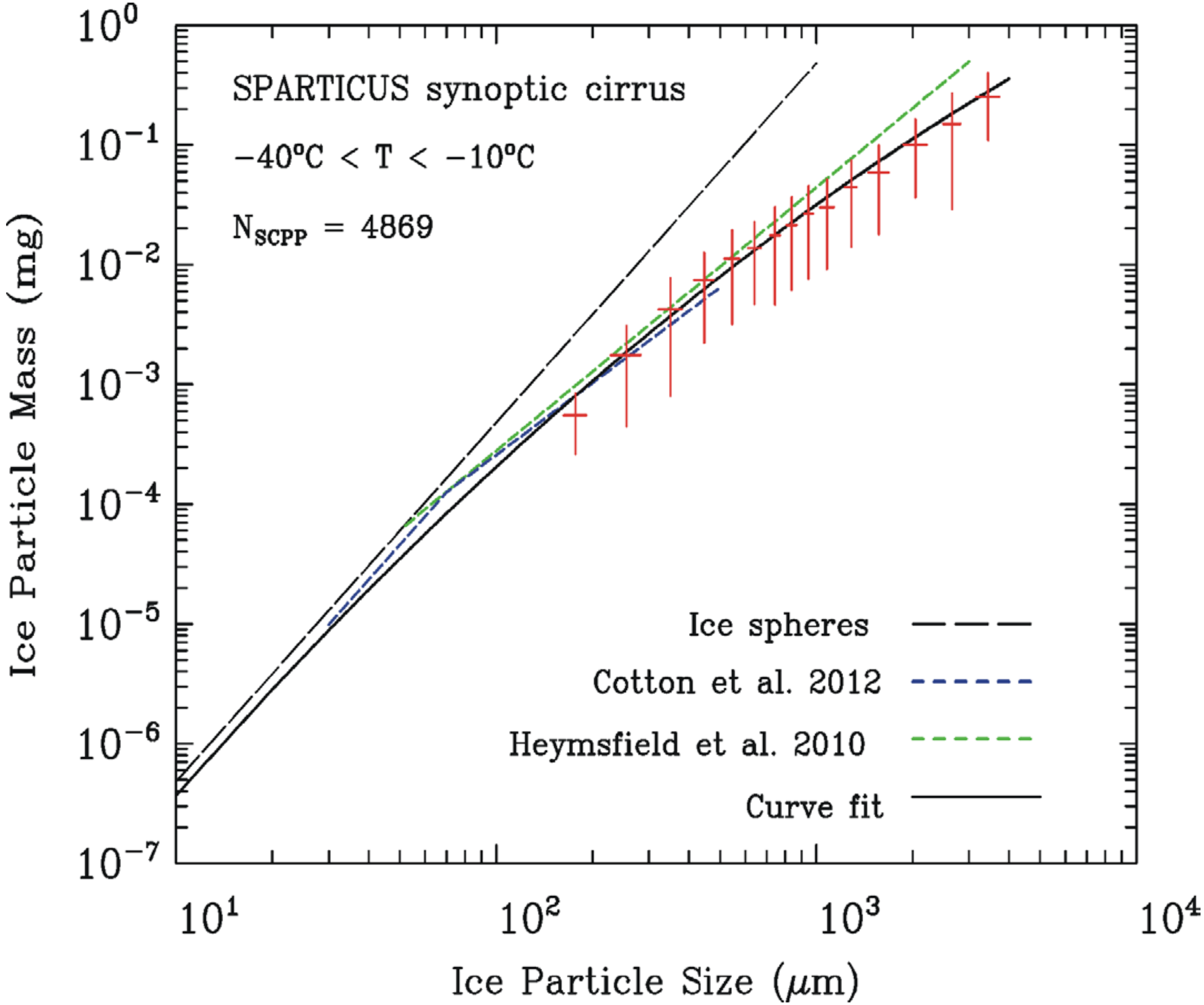
Then calculate α, β, γ and δ for the selected D value.


SPARTICUS synoptic cirrus
−40°C < T < −9°C
D_e using constant α, β, γ & δ
D_e using variable α, β, γ & δ
D_e using CAM5 α, β, γ & δ
D_e (μm)
10^1
10^2
10^3
Mean Ice Particle Size (μm)

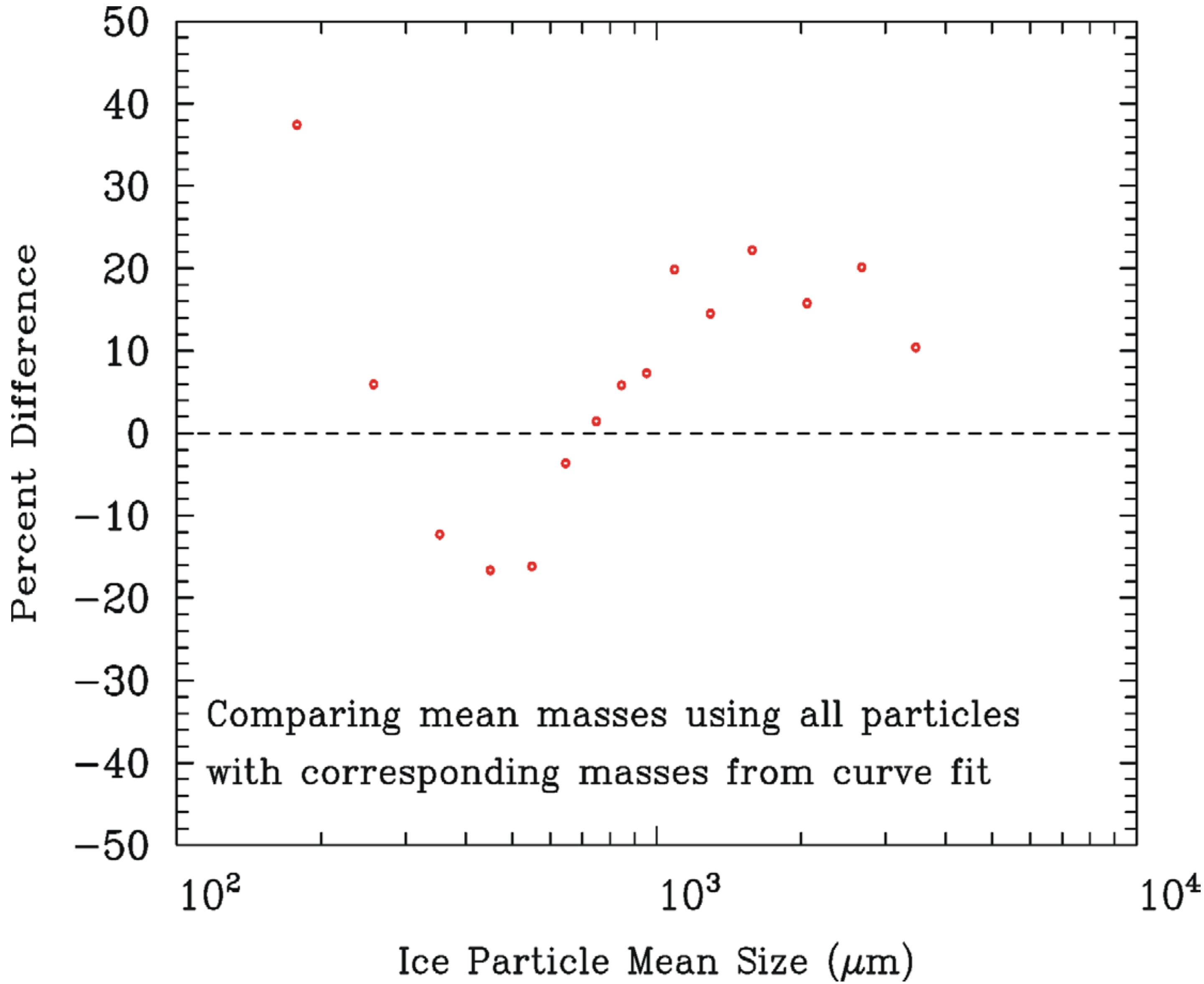

SPARTICUS synoptic cirrus
−40°C < T < −9°C
V_m (cm s^{-1})
10^0
10^1
10^2
10^3
V_m using constant α, β, γ & δ
V_m using variable α, β, γ & δ
V_m using CAM5 α, β, γ & δ
Mean Ice Particle Size (μm)


IWC = 50 mg m^{-3}
SPARTICUS synoptic cirrus
−40°C < T < −9°C
N using constant α & β
N using variable α & β
N using CAM5 α & β
Number Concentration (liter^{-1})
Mean Ice Particle Size (μm)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^1
10^2
10^3


SCPP data compared with
synoptic cirrus curve fit
for −40°C < T < −10°C
N_ALL = 3781
N_UNRIMED = 2341
N_RIMED = 1440
Ice spheres
Cotton et al. 2012
Heymsfield et al. 2010
Curve fit
Ice Particle Mass (mg)
Ice Particle Size (μm)
10^0
10^−1
10^−2
10^−3
10^−4
10^−5
10^−6
10^−7
10^1
10^2
10^3
10^4

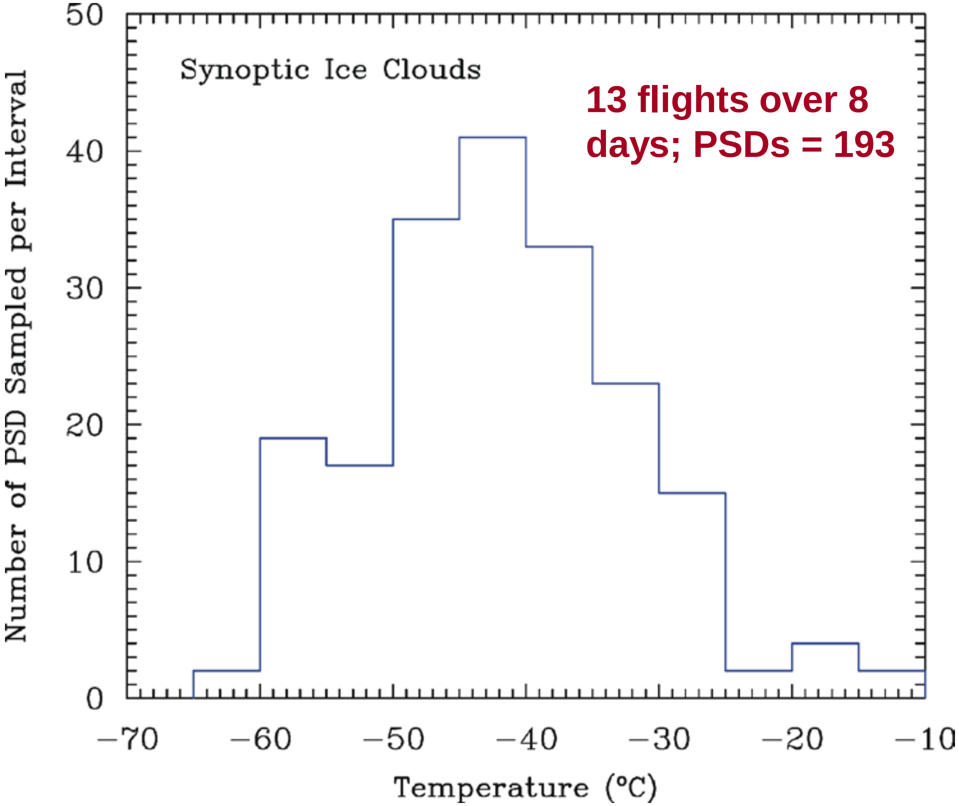


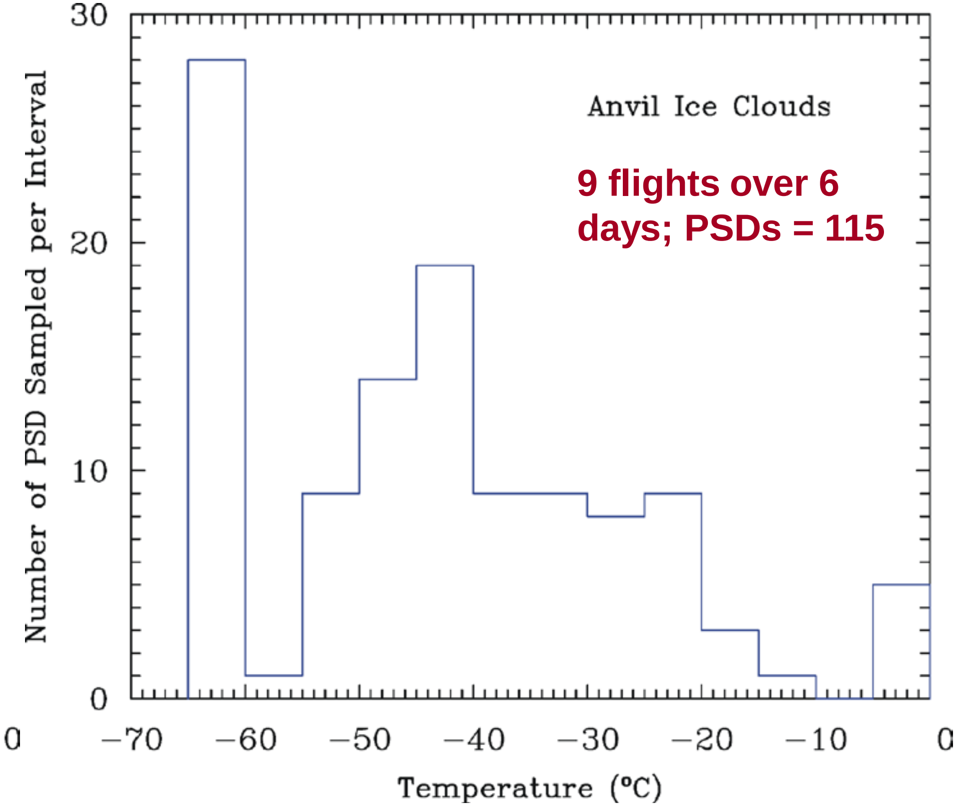
SPARTICUS synoptic cirrus
−40°C < T < −10°C
N_SCPP = 4869
Ice spheres
Cotton et al. 2012
Heymsfield et al. 2010
Curve fit
Ice Particle Mass (mg)
Ice Particle Size (μm)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^1
10^2
10^3
10^4



50
40
30
20
10
0
−10
−20
−30
−40
−50
Percent Difference
Comparing mean masses using all particles
with corresponding masses from curve fit
10^2
10^3
10^4
Ice Particle Mean Size (μm)

SPARTICUS PSD SAMPLING FOR SELECTED SYNOPTIC AND ANVIL CIRRUS CLOUDS





Example of A-D Curve Fit