Parameterizing Ice Particle Mass and Area in Ice Clouds: Towards a Self-consistent Treatment of Ice Microphysics and Radiation

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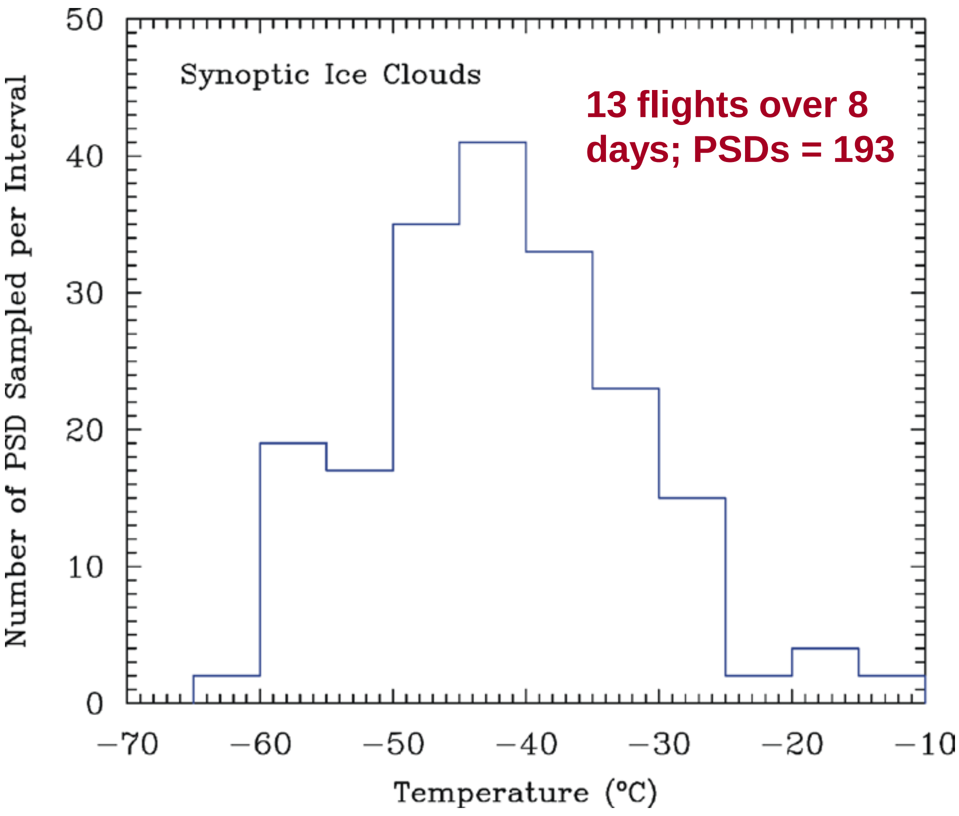
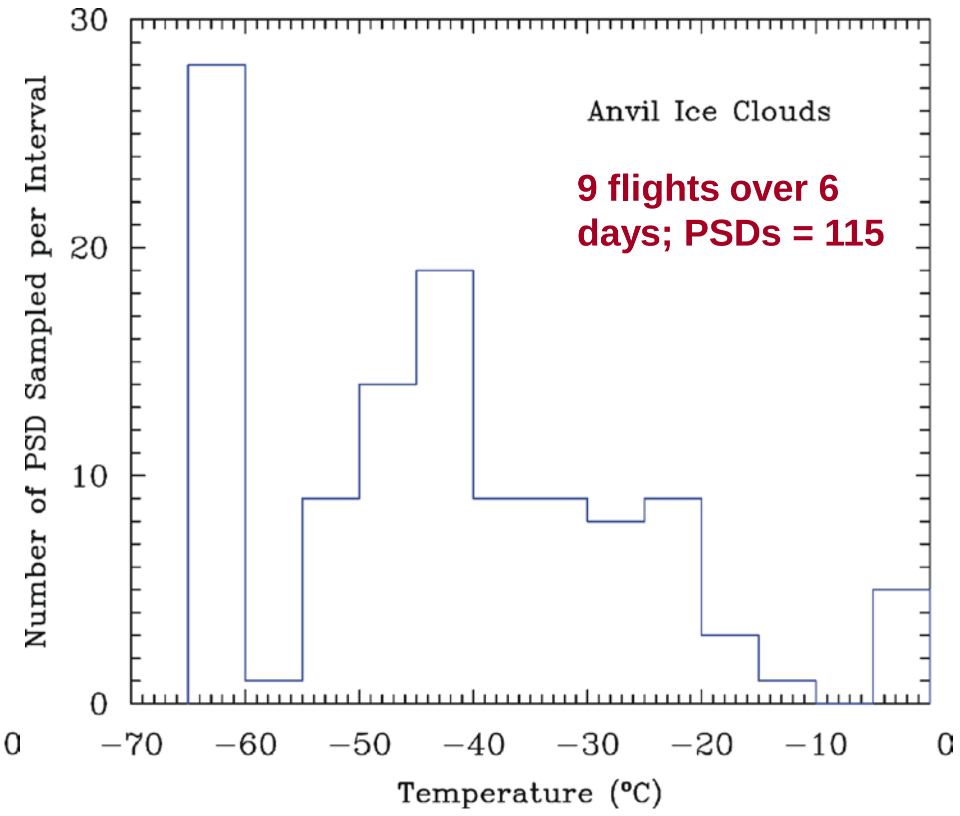
ASR
Atmospheric
System Research

ARM

DRI
Desert Research Institute

SPARTICUS PSD SAMPLING FOR SELECTED SYNOPTIC AND ANVIL CIRRUS CLOUDS





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

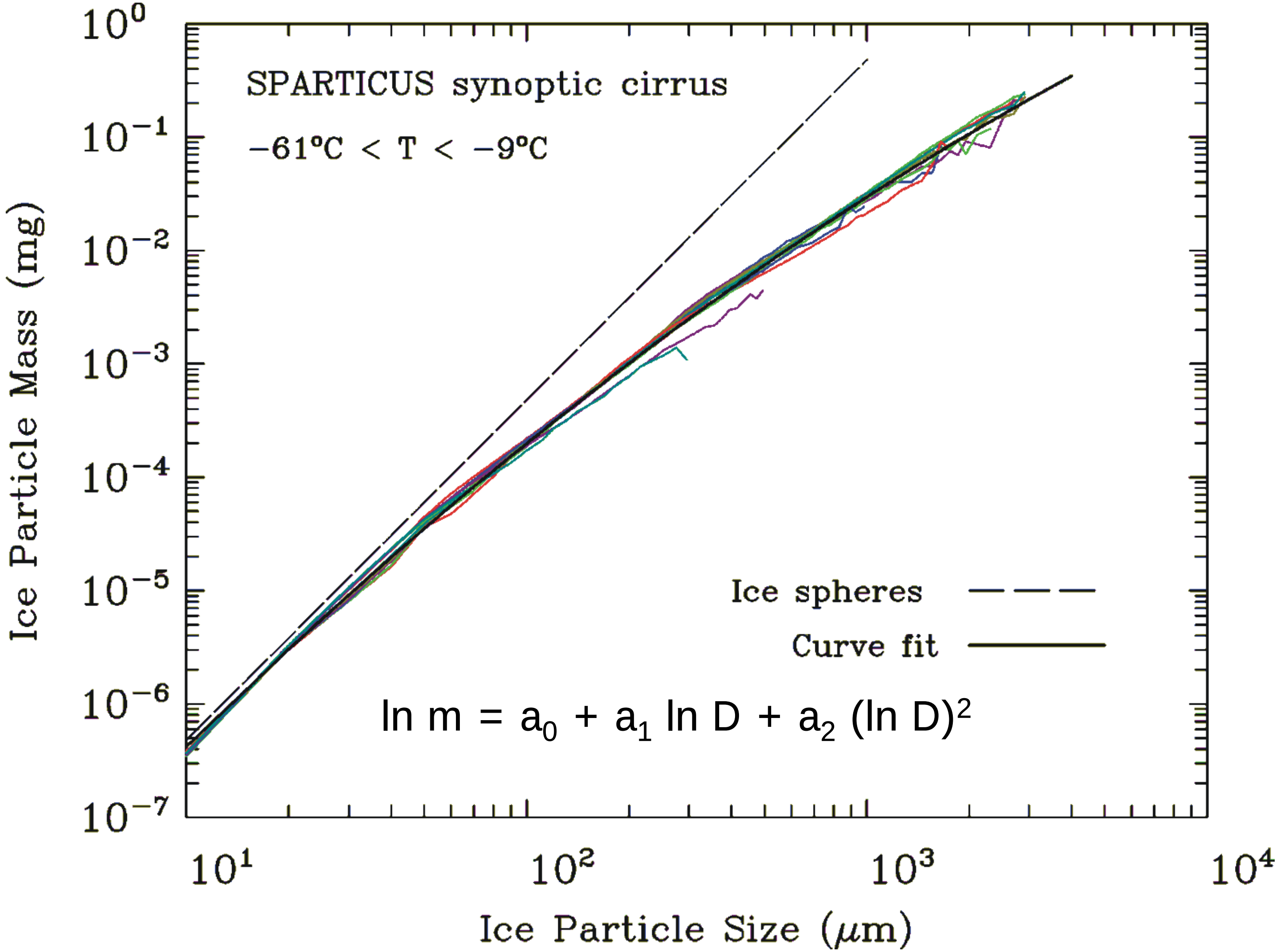
$$m = M/N$$

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.

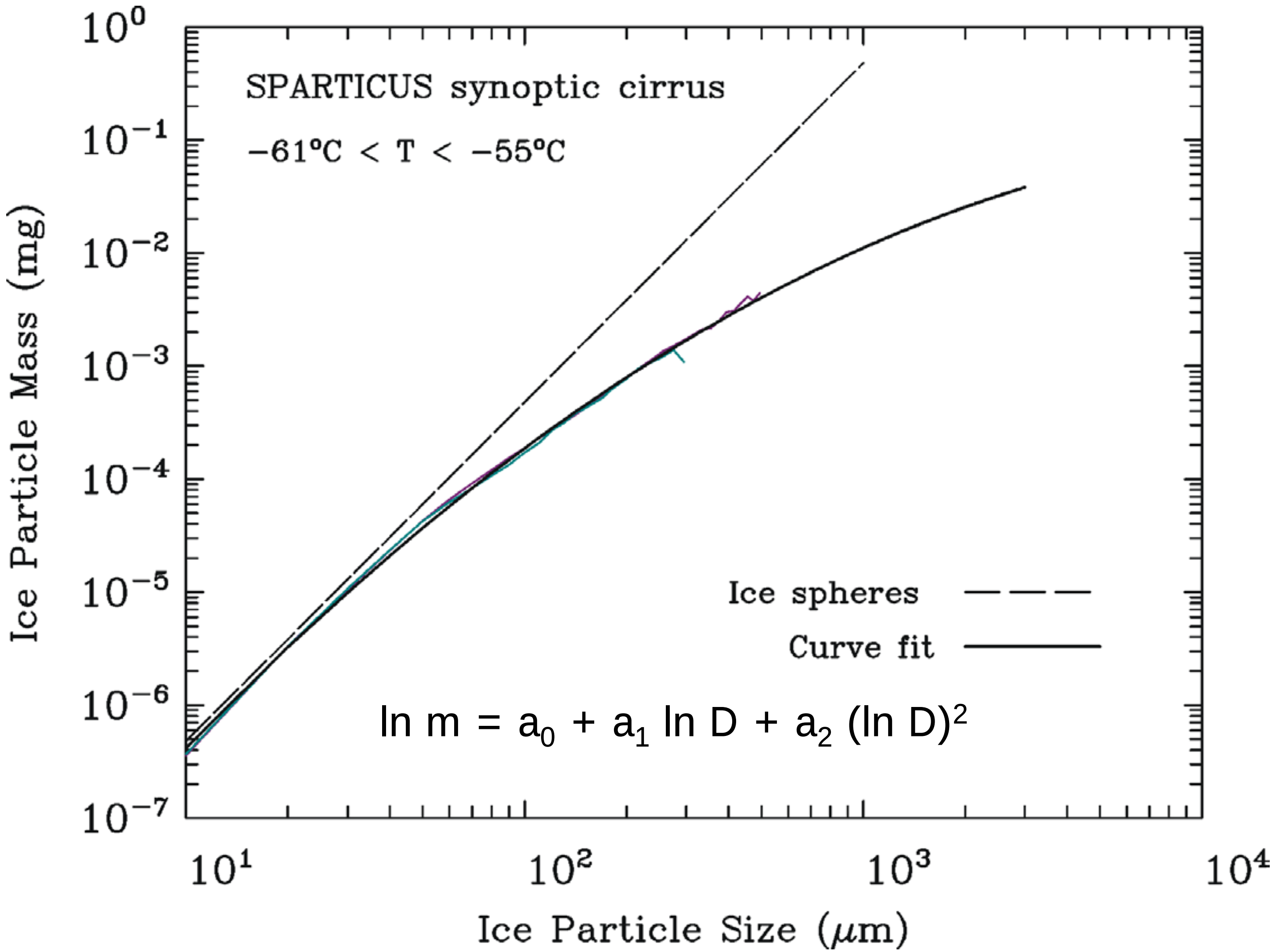
A mean PSD was produced for each 5°C T-interval that reduces scatter while focusing the curve fit. Temperature categories were identified where m-D & A-D curves were similar. A single m-D or A-D curve fit was produced per T-category.

A key 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).

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

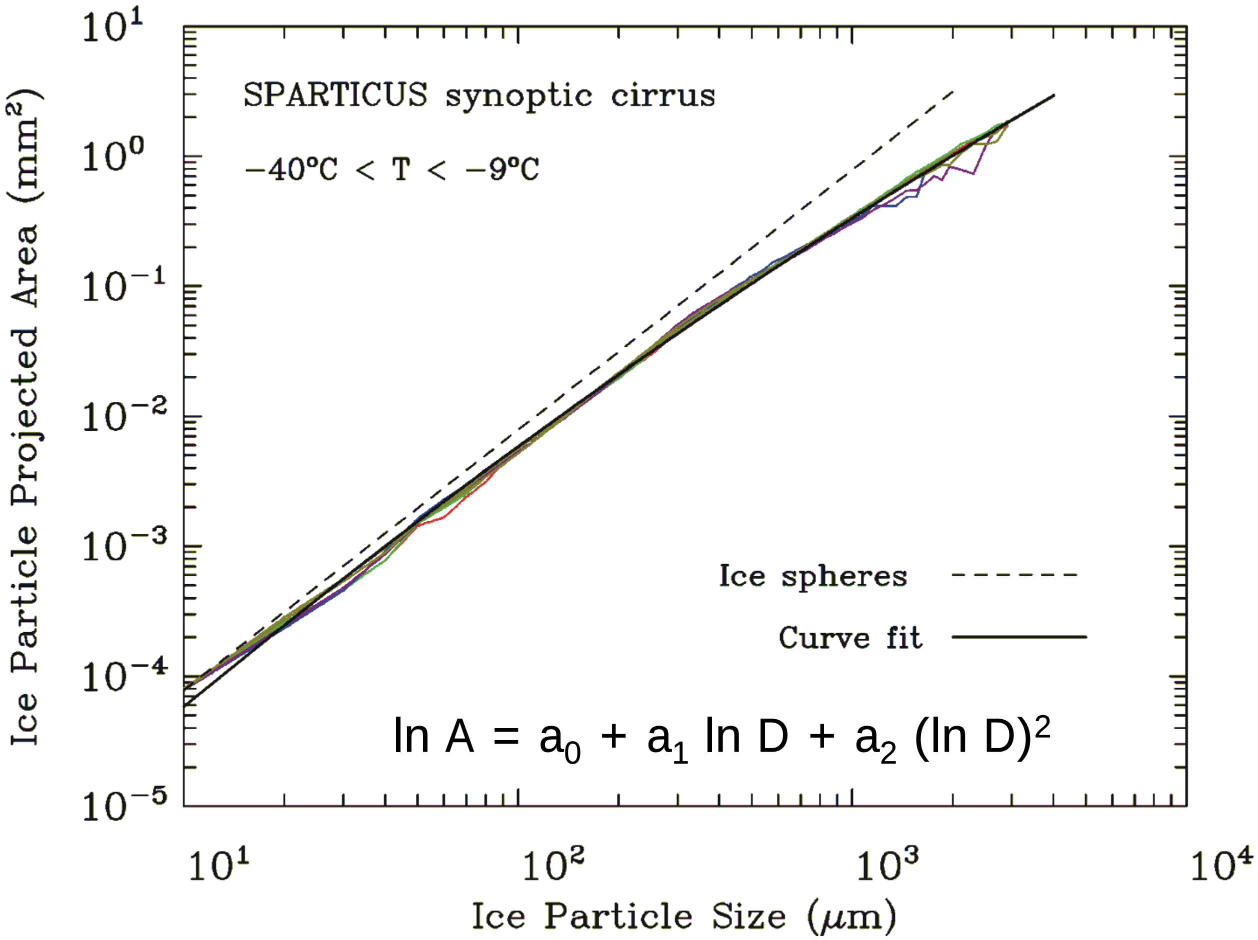


Data was grouped into 3 temperature-categories for synoptic and anvil cirrus, with a m-D and A-D curve fit for each category

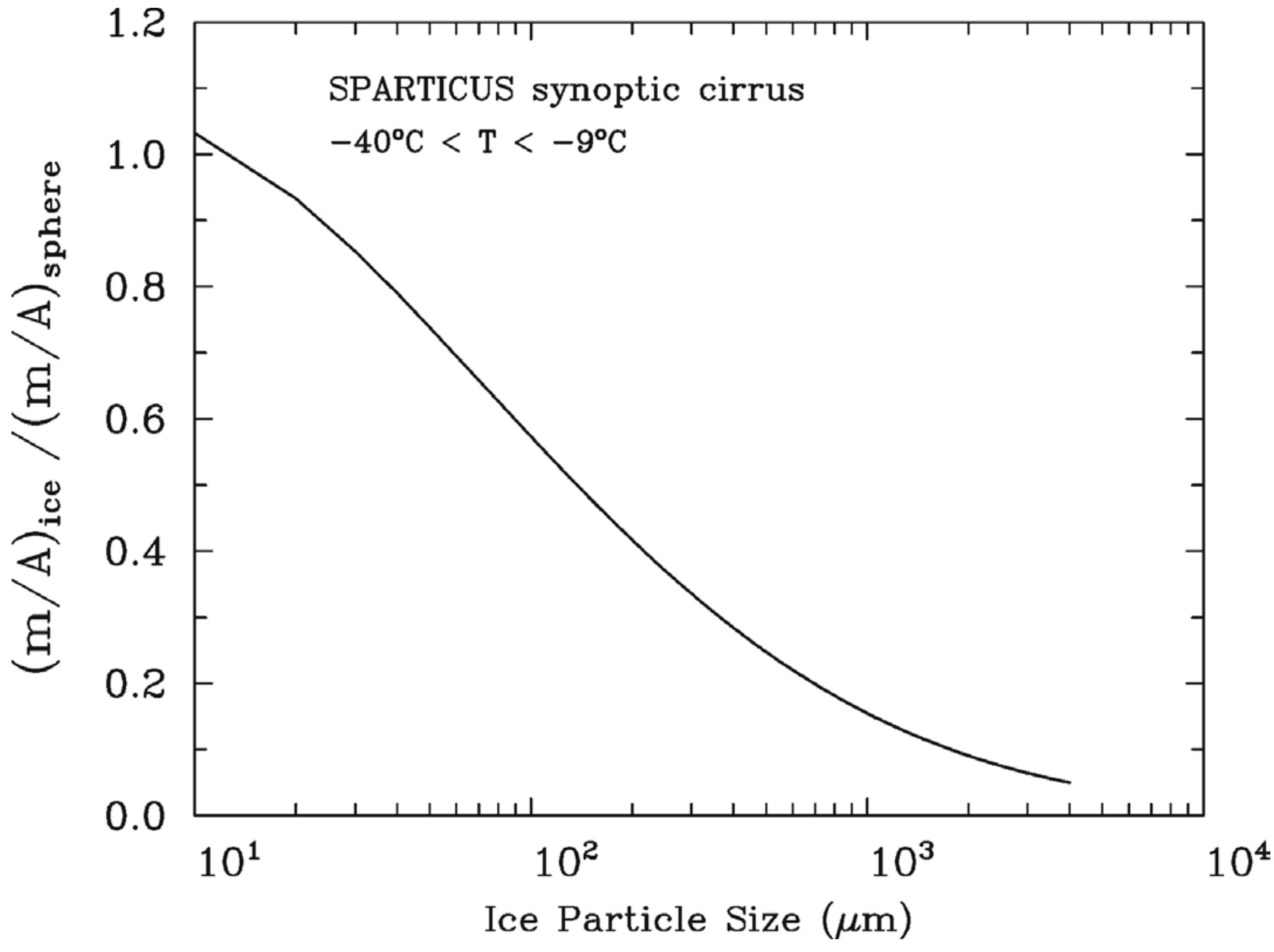


$$\ln m = a_0 + a_1 \ln D + a_2 (\ln D)^2$$

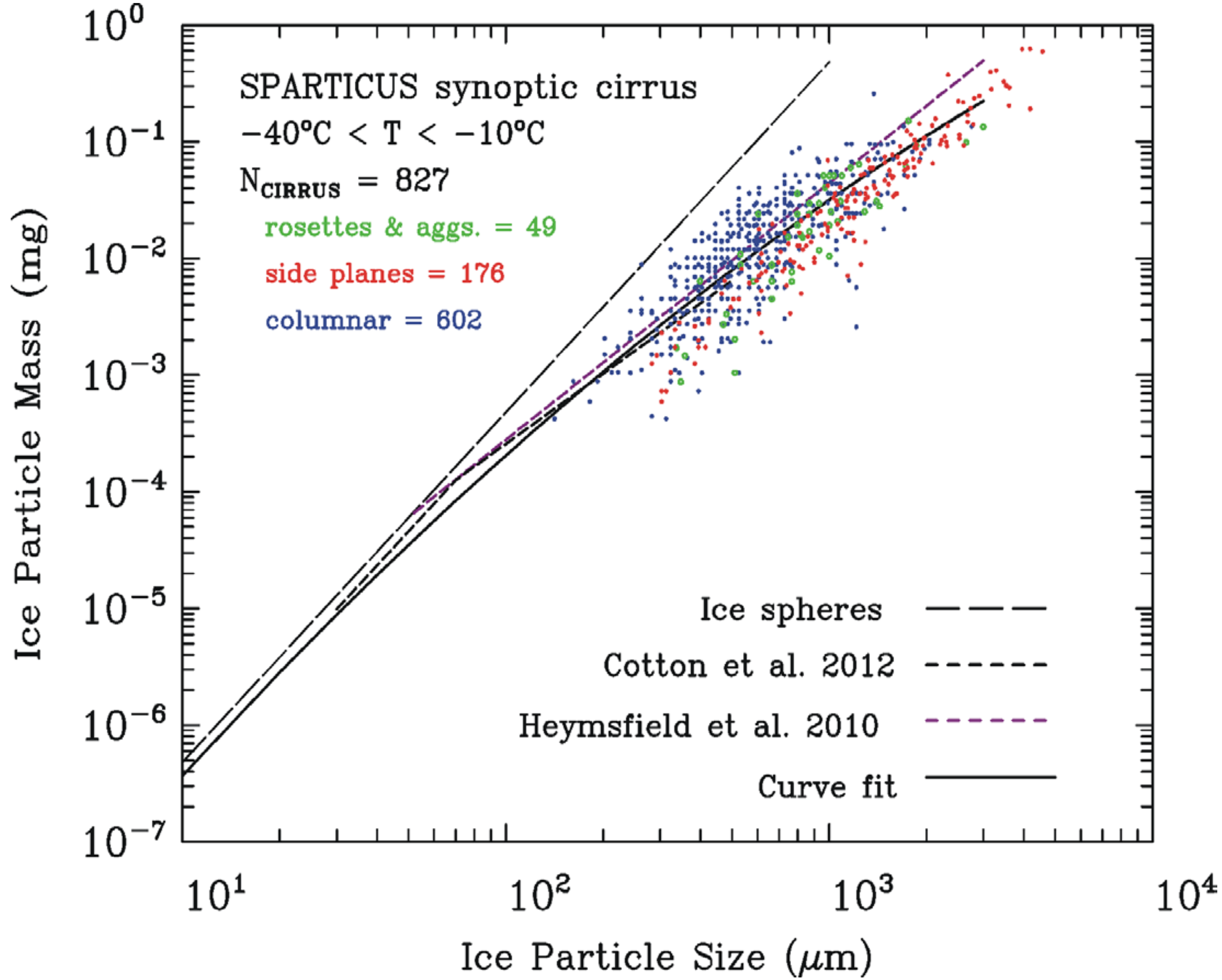
Example of A-D Curve Fit



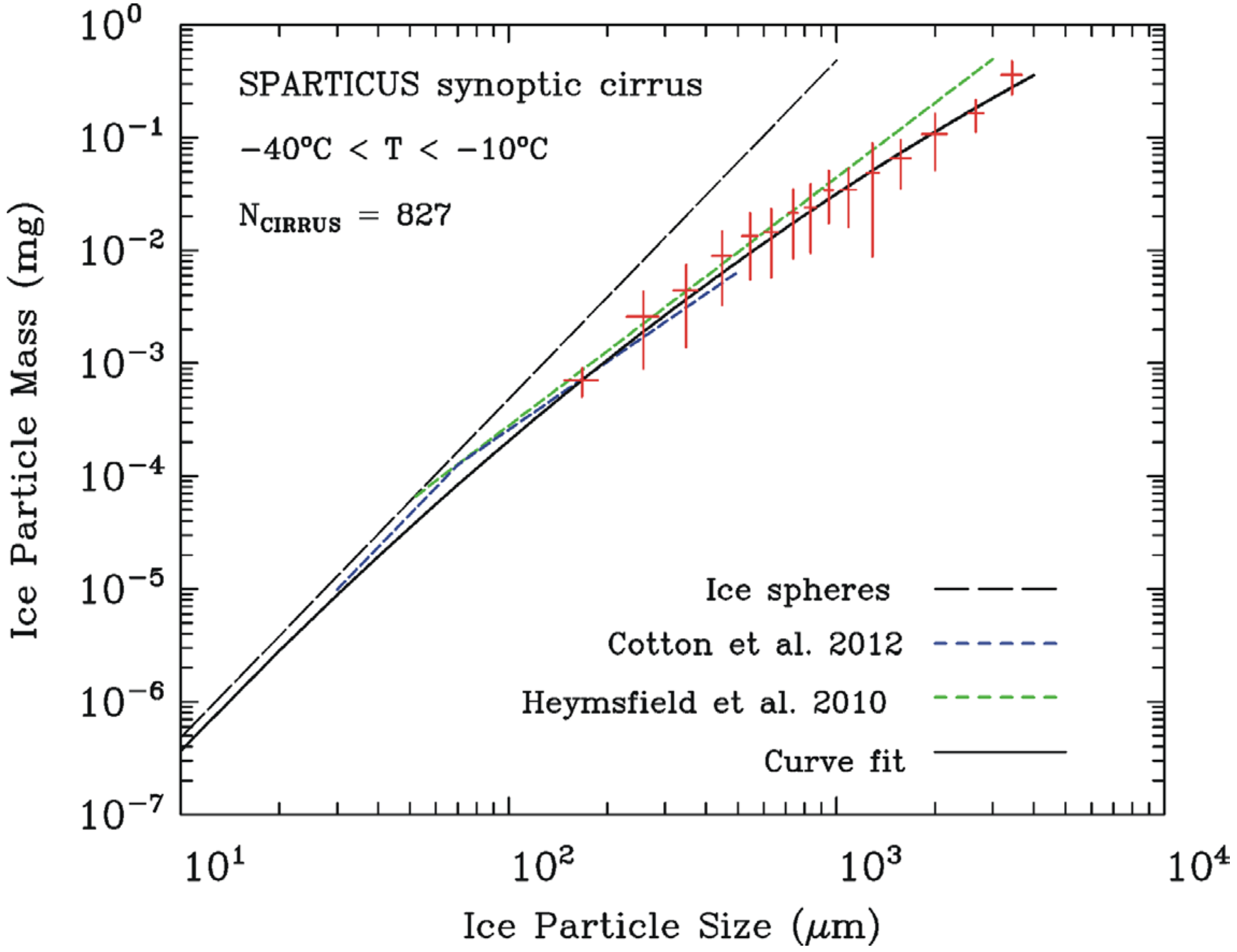
Testing for self-consistency and physical realism

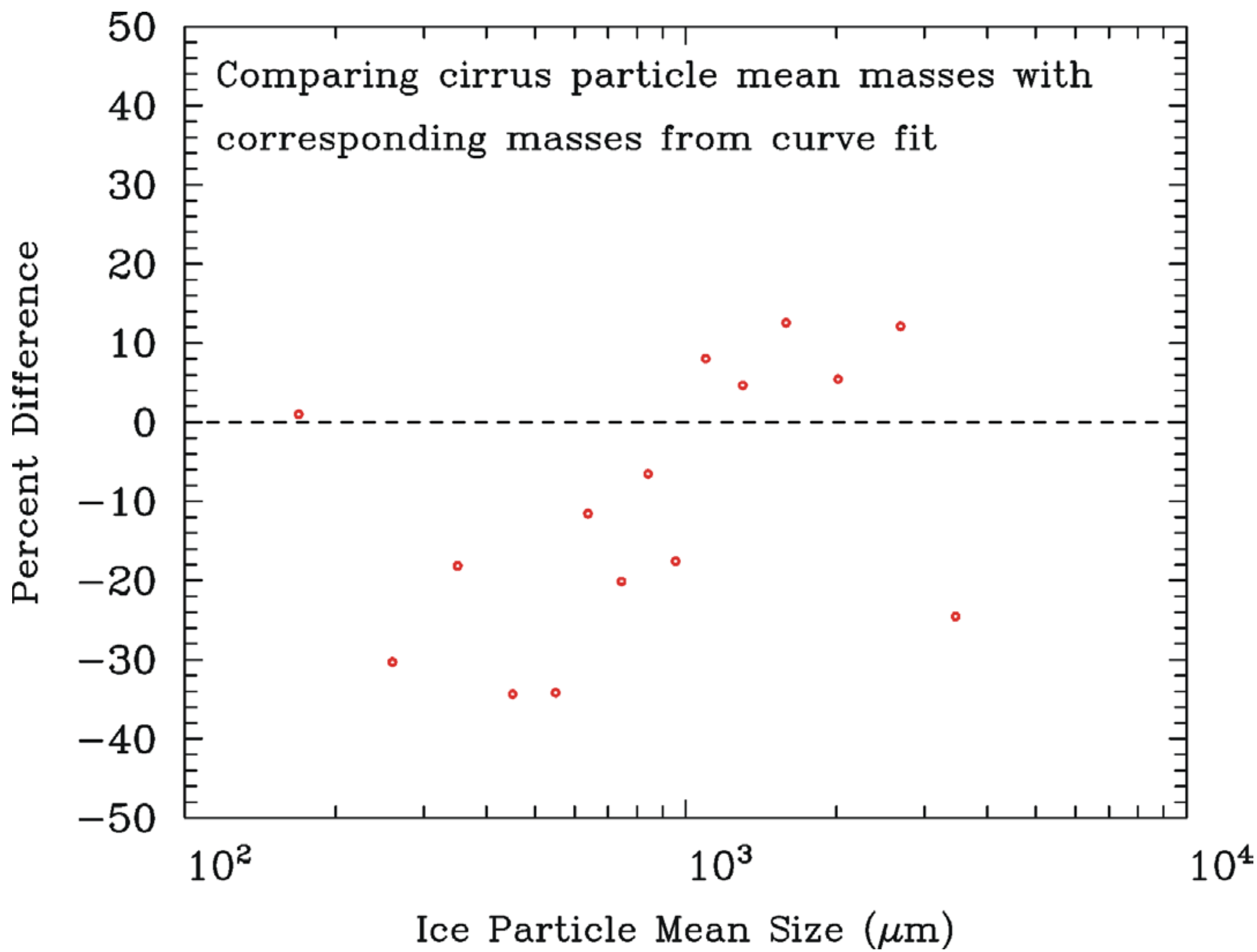


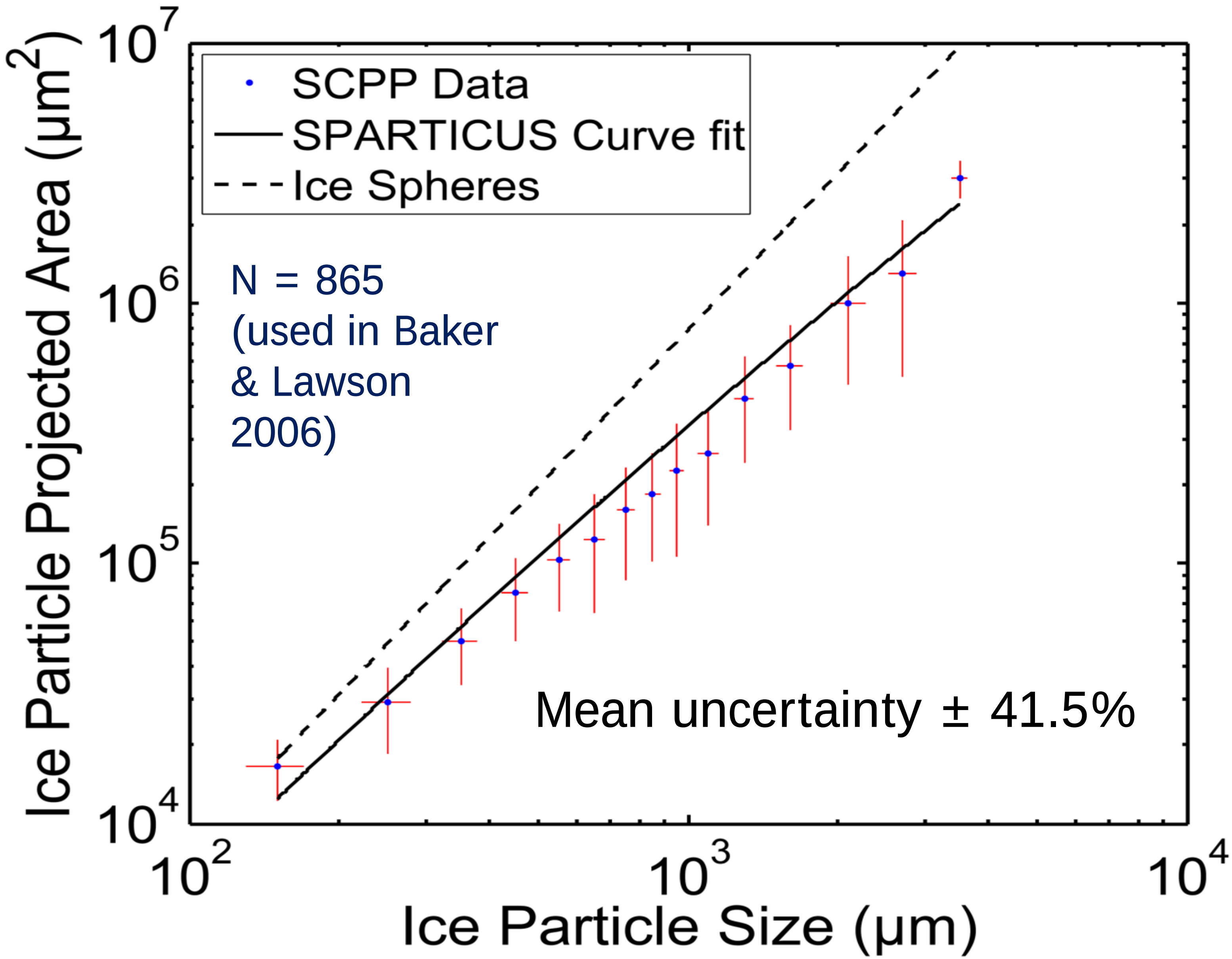
Comparisons with other field data and other studies



Mean uncertainty = ± 54.4%




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)
10^7
10^6
10^5
10^4
10^2
10^3
10^4

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

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

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

Temperature Range	Ice particle size (μm): 50	150	500	1500	4500
	Power β				
-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

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

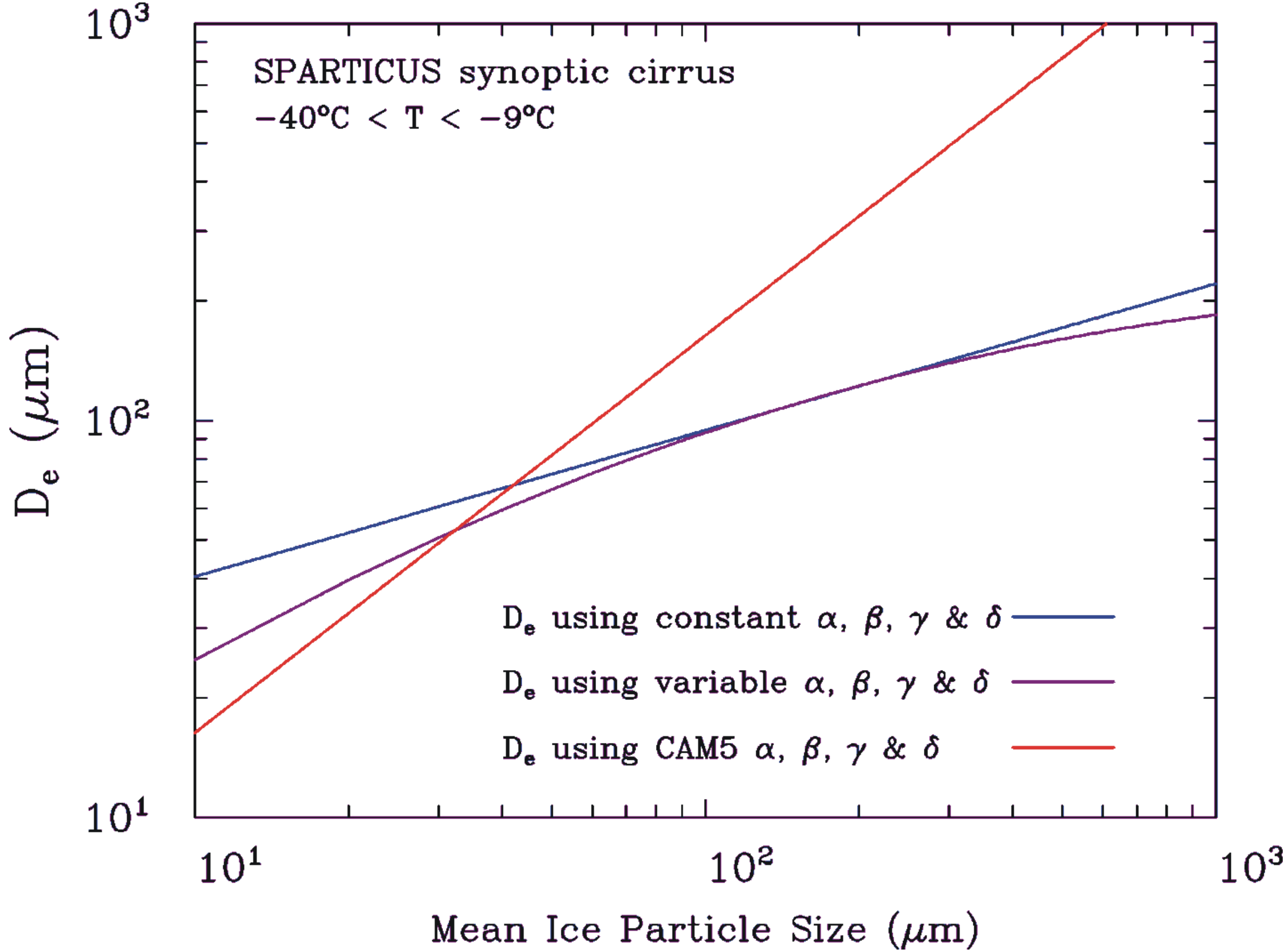
$$\lambda = \left(\frac{\alpha\, \Gamma(\beta+\nu+1)\, N}{\Gamma(\nu+1)\, IWC} \right)^{1/\beta}$$

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:

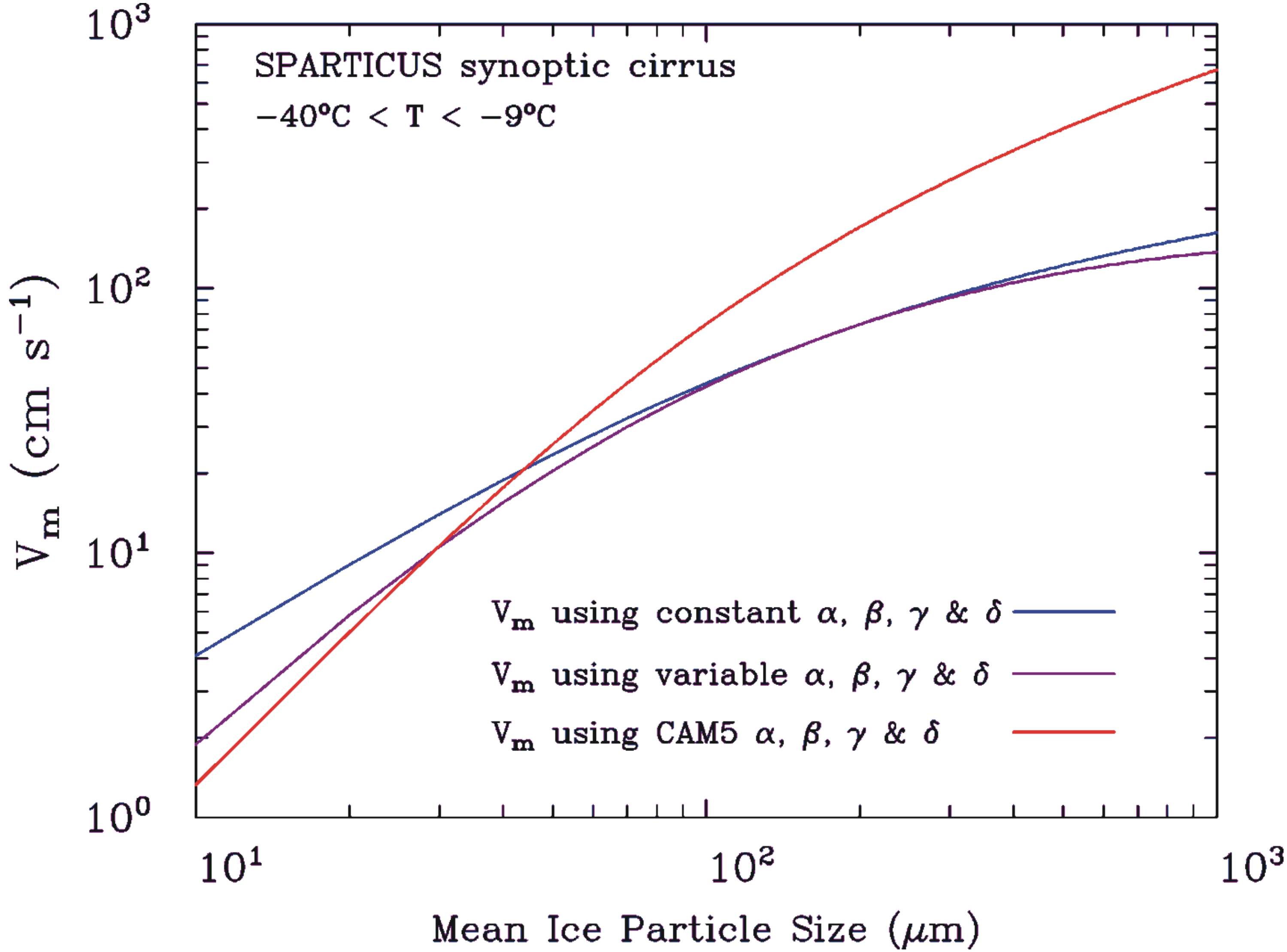
$D_N = (\nu + 0.67)/\lambda$	Median number conc. dimension
$D_a = (\delta + \nu + 0.67)/\lambda$	Median area dimension
$D_m = (\beta + \nu + 0.67)/\lambda$	Median mass dimension
$D_Z = (2\beta + \nu + 0.67)/\lambda$	Median radar reflectivity dimension

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

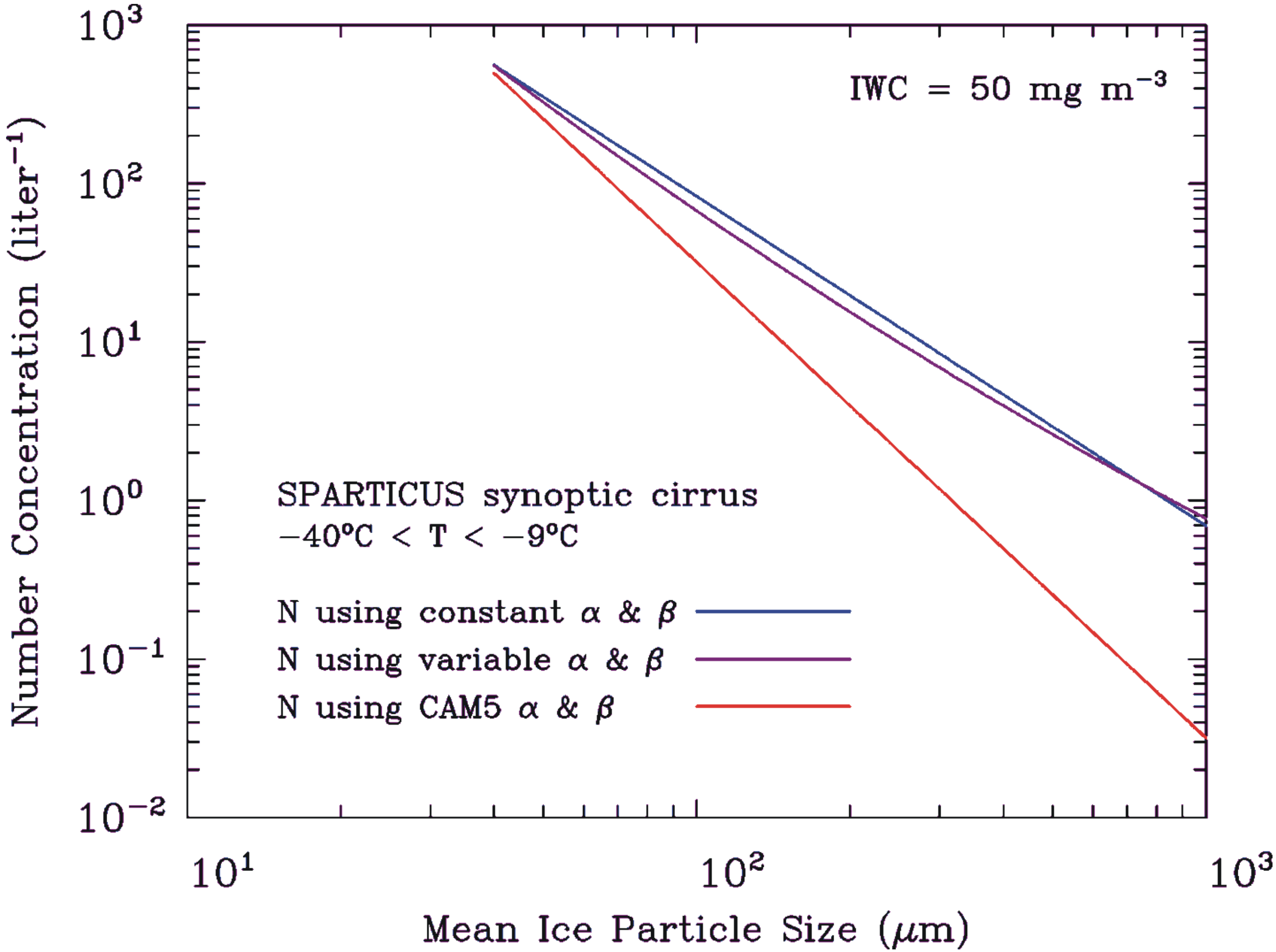

SPARTICUS synoptic cirrus
−40°C < T < −9°C
D_e using constant α, β, γ & δ
D_e using variable α, β, γ & δ
D_e using CAM5 α, β, γ & δ
D_e (μm)
Mean Ice Particle Size (μm)
10^1
10^2
10^3

Summary and Conclusions

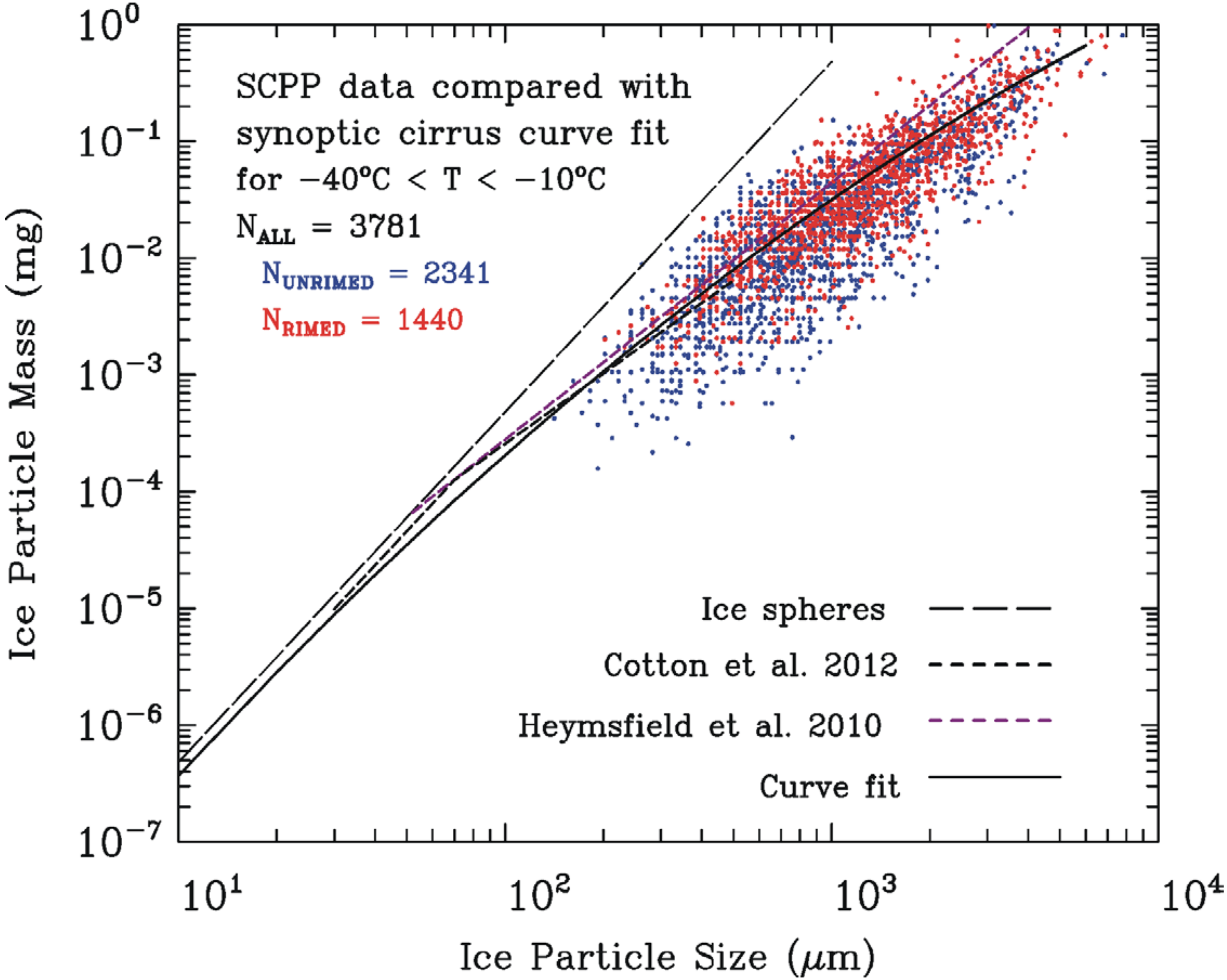
1. When considering all sizes, ice particle mass and projected area are better estimated by 2nd order polynomial fits than by power laws.
2. Method's accuracy is evident through comparisons with two recent studies and ground field measurements.
3. To a 1st approximation, the uncertainties (σ) measured can be attributed to the prefactor of the m-D and A-D power laws.
   - This should be useful for estimating σ of cloud retrievals.
4. A means of obtaining accurate m-D and A-D power laws for modeling ice clouds was developed, thus avoiding major changes to model architecture.
5. This treatment of m-D/A-D relationships can be used in CAM5 to achieve consistency between the ice cloud microphysical and optical properties.

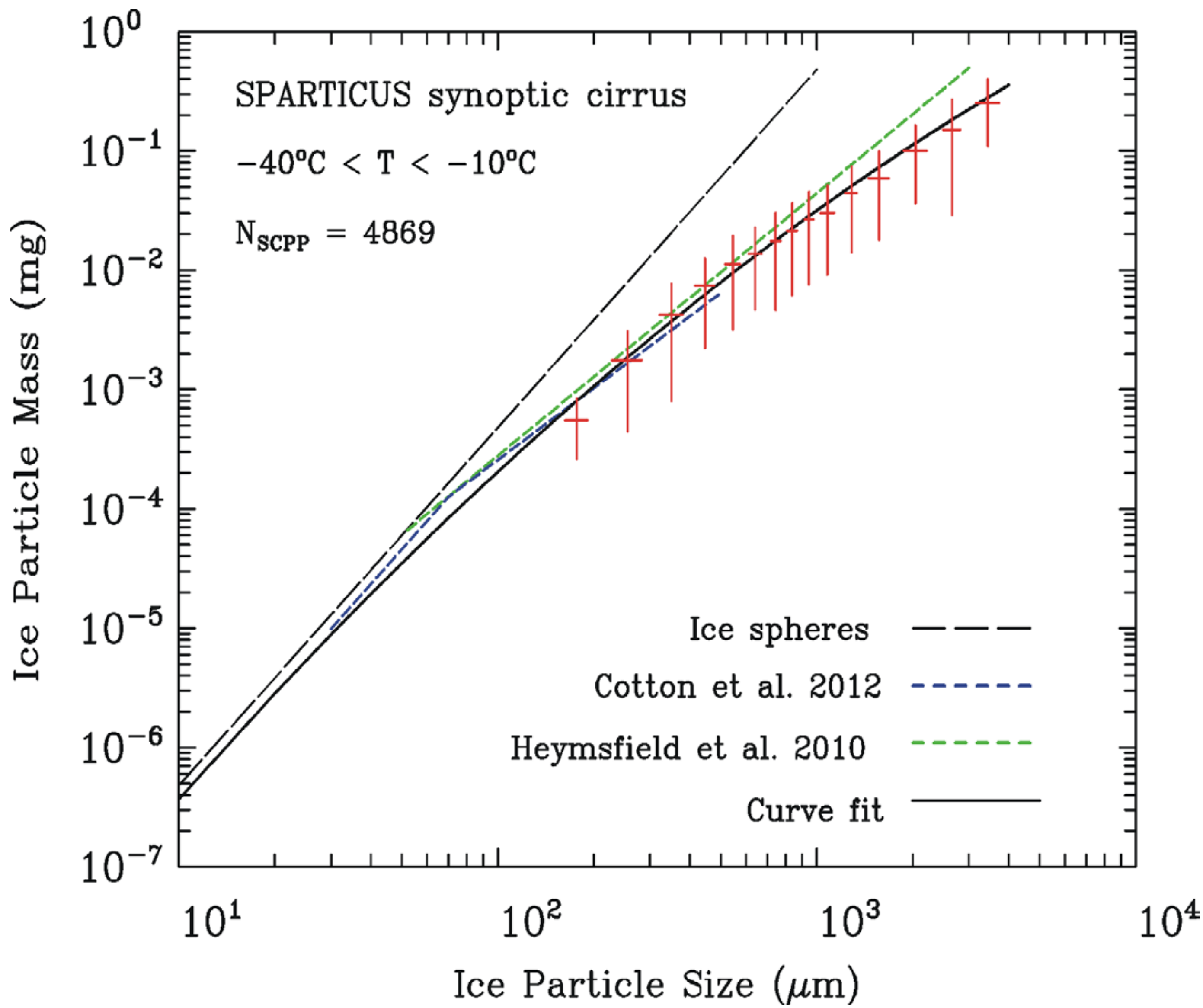


SPARTICUS synoptic cirrus
−40°C < T < −9°C
V_m using constant α, β, γ & δ
V_m using variable α, β, γ & δ
V_m using CAM5 α, β, γ & δ
V_m (cm s^{-1})
10^0
10^1
10^2
10^3
10^1
10^2
10^3
Mean Ice Particle Size (μm)

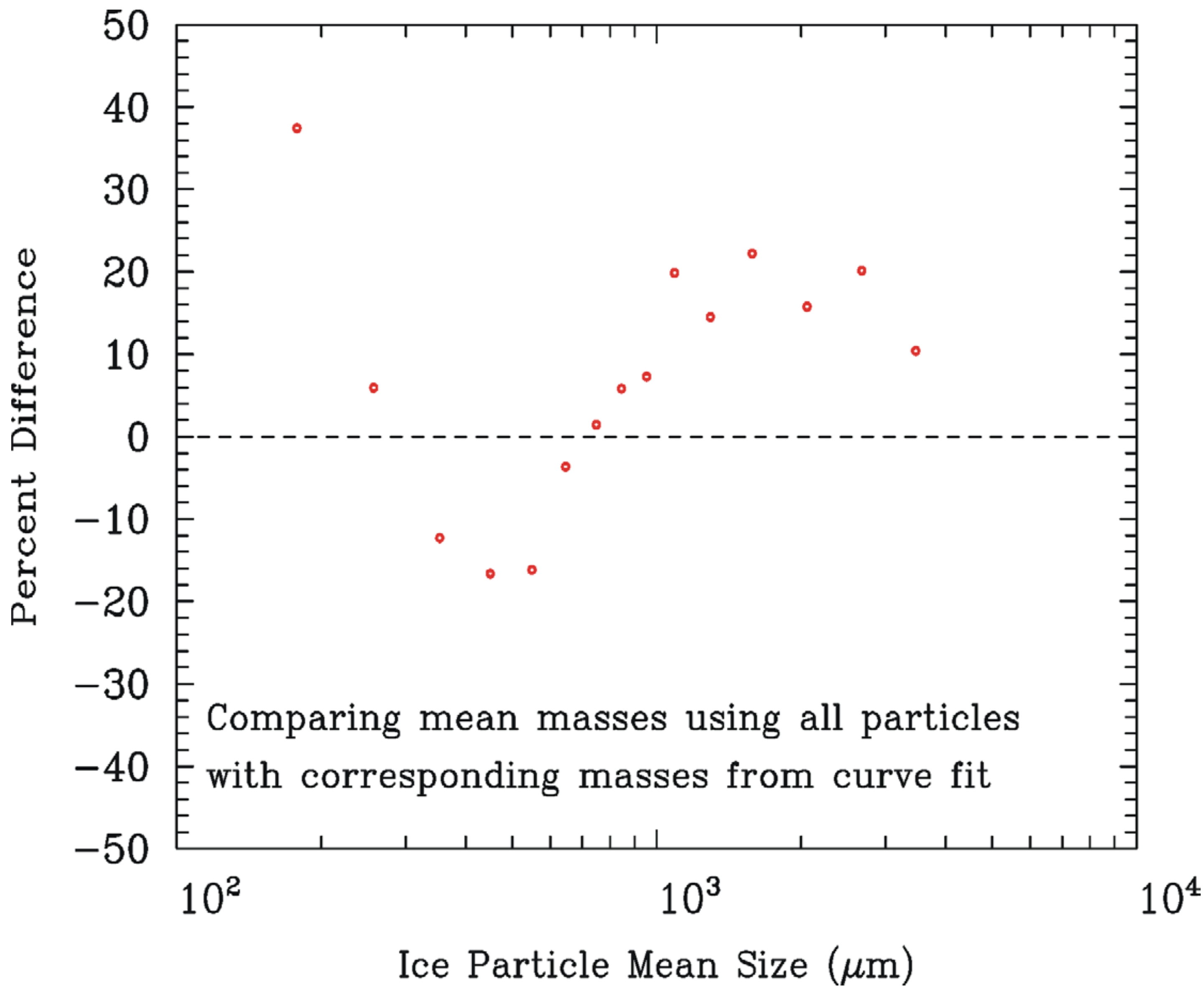


IWC = 50 mg m^{-3}
SPARTICUS synoptic cirrus
−40°C < T < −9°C
N using constant α & β
N using variable α & β
N using CAM5 α & β
Number Concentration (liter^{-1})
Mean Ice Particle Size (μm)
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{1}
10^{2}
10^{3}


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)



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)