Ice Particle Mass- and Area-dimension Expressions for Cirrus Clouds: A Proposed Strategy

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Proposed Strategy for Developing m-D and A-D Expressions for Cirrus Clouds

1. m-D & A-D power laws differ between small and relatively large ice particles having the same ice particle shape; a power law cannot describe this relationship across all sizes. Therefore size-resolved measurements of m and A are needed to determine the general form of m-D & A-D expressions.

2. To address the smallest sizes, use 2D-S probe size-resolved measurements of number, area and mass concentration, where mass is estimated from the Baker-Lawson m-A power law. These measurements can be combined to generate m-D & A-D expressions for 10 μm < D < 1280 μm.

3. Test the 2DS m-D expression for -40°C < T < -20°C against size-resolved ice particle mass measurements for the same temperature regime.

Proposed Strategy for Developing m-D and A-D Expressions for Cirrus Clouds - Continued

4. If the agreement regarding (3) is good, then assume that the 2DS mass estimates for T < -40°C are adequate provided PSD area ratios for T < -40°C are not much different than for -40°C < T < -20°C.
    a. This appears true for -55°C < T < -40°C, but not for T < -55°.
    b. Direct measurements of single ice particle mass are needed for T < -55°C. Until an instrument has been developed to address this need, the best option may be to use mass estimates from the Baker-Lawson m-A power law.

5. Assume that m-D & A-D uncertainties measured for -40°C < T < -20°C also apply at colder temperatures.

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

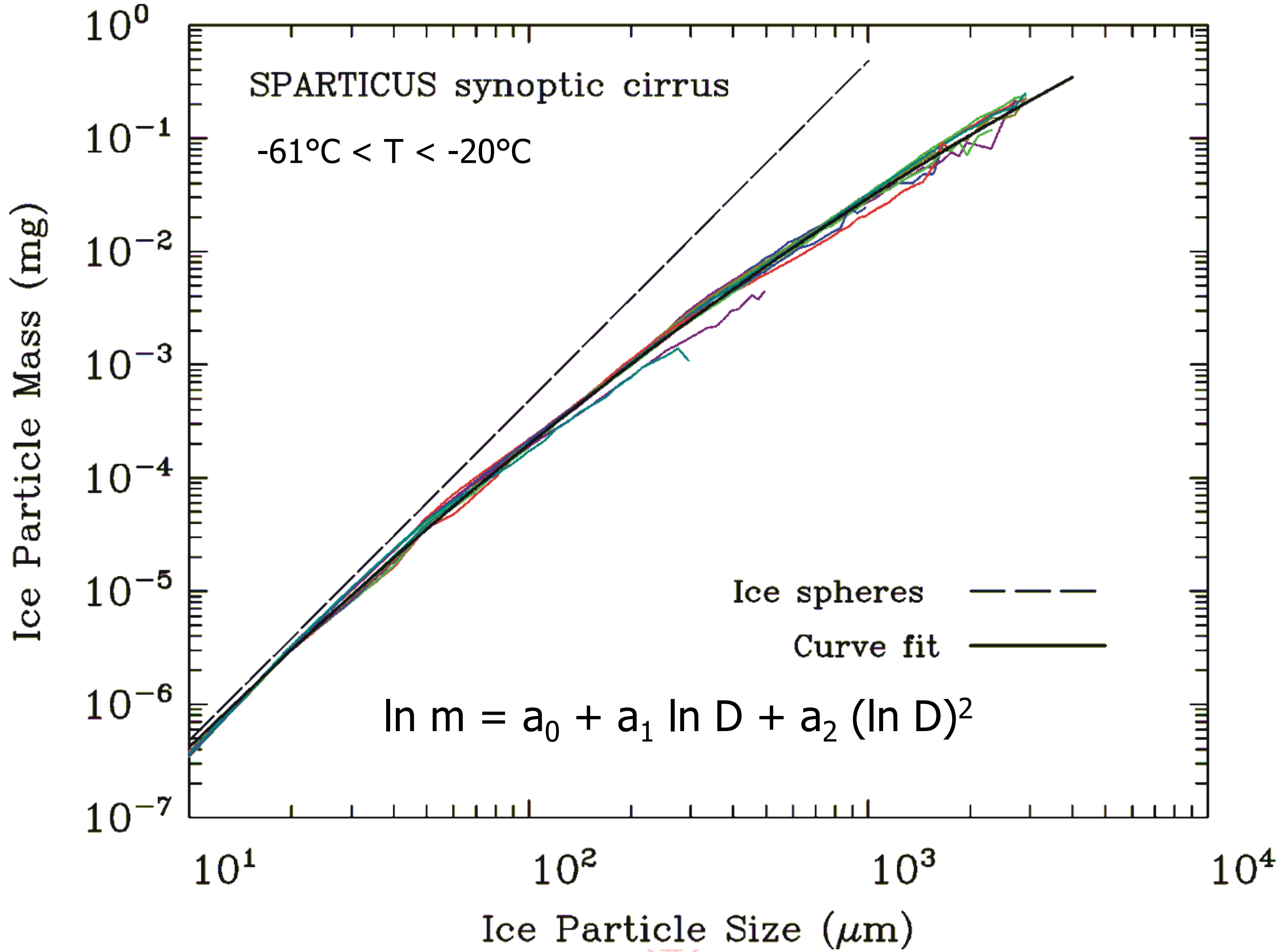
$$m = M/N$$

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.

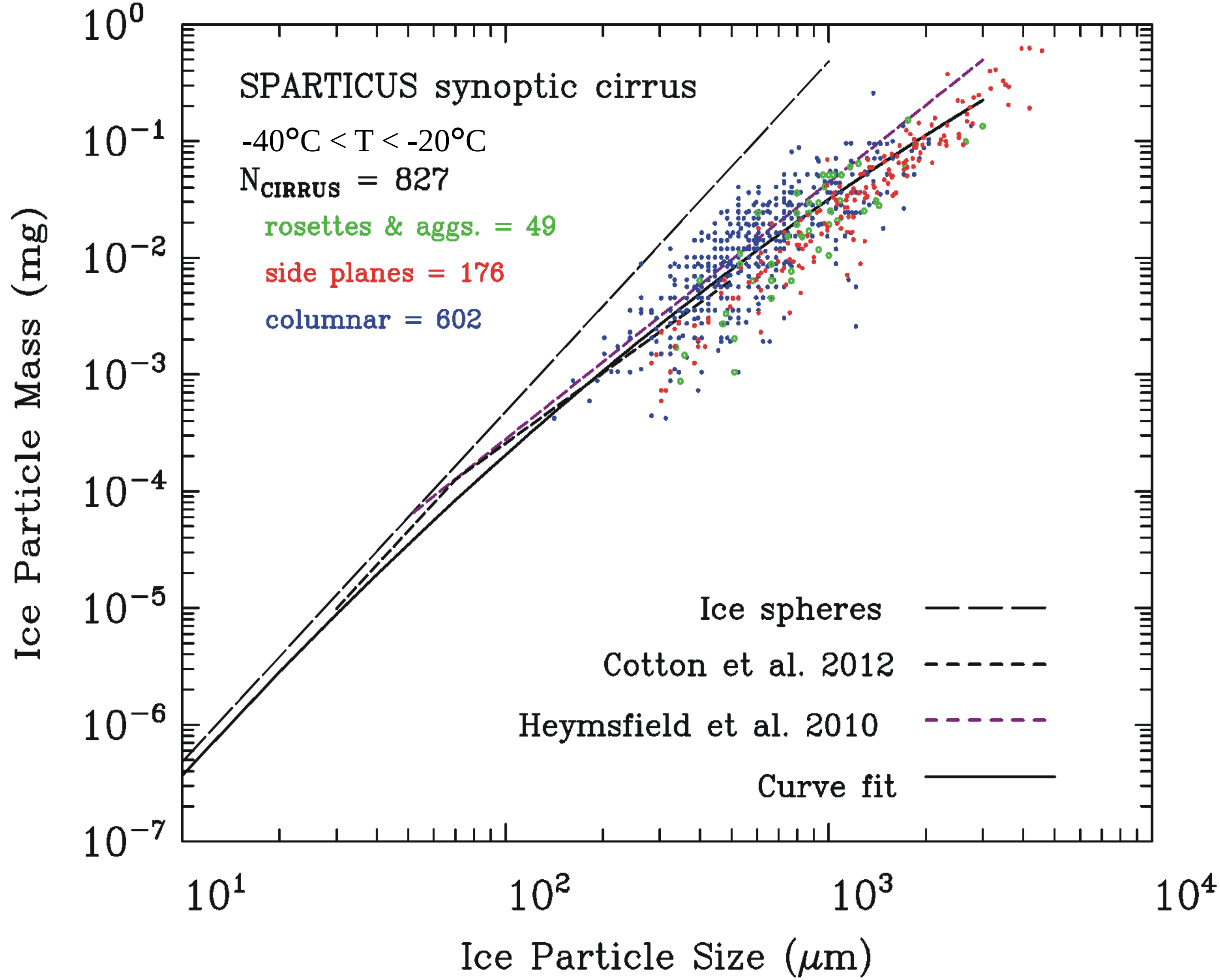
A mean PSD was produced for each 5°C T-interval that reduces scatter while focusing the curve fit. Temperature categories were identified where m-D & A-D curves were similar. A single m-D or A-D curve fit was produced per T-category.

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).

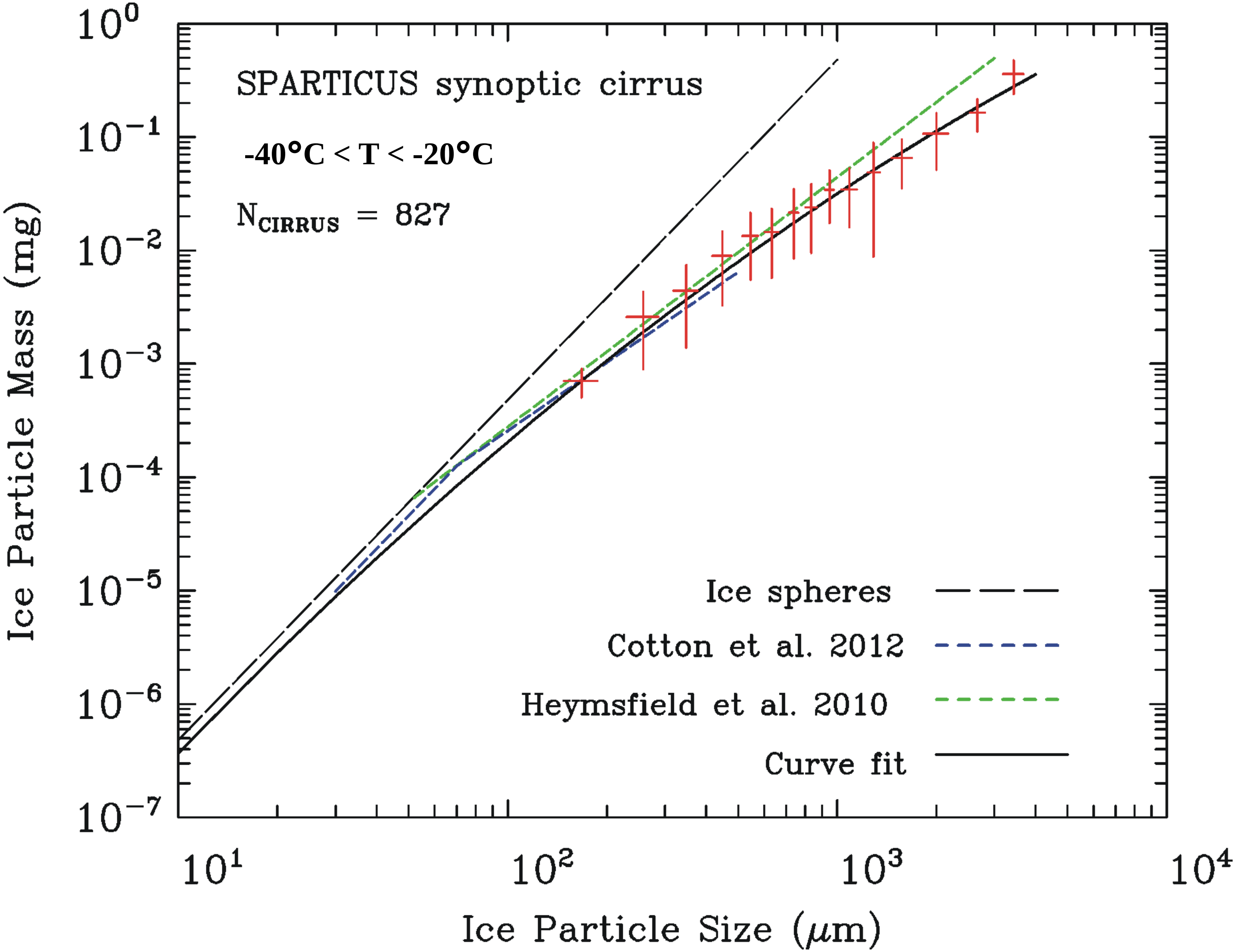
Dependence of log(m) on log(D) is not linear



Comparing a 2DS m-D expression with size-resolved ice particle mass measurements and other studies



Mean uncertainty = ± 54.4%



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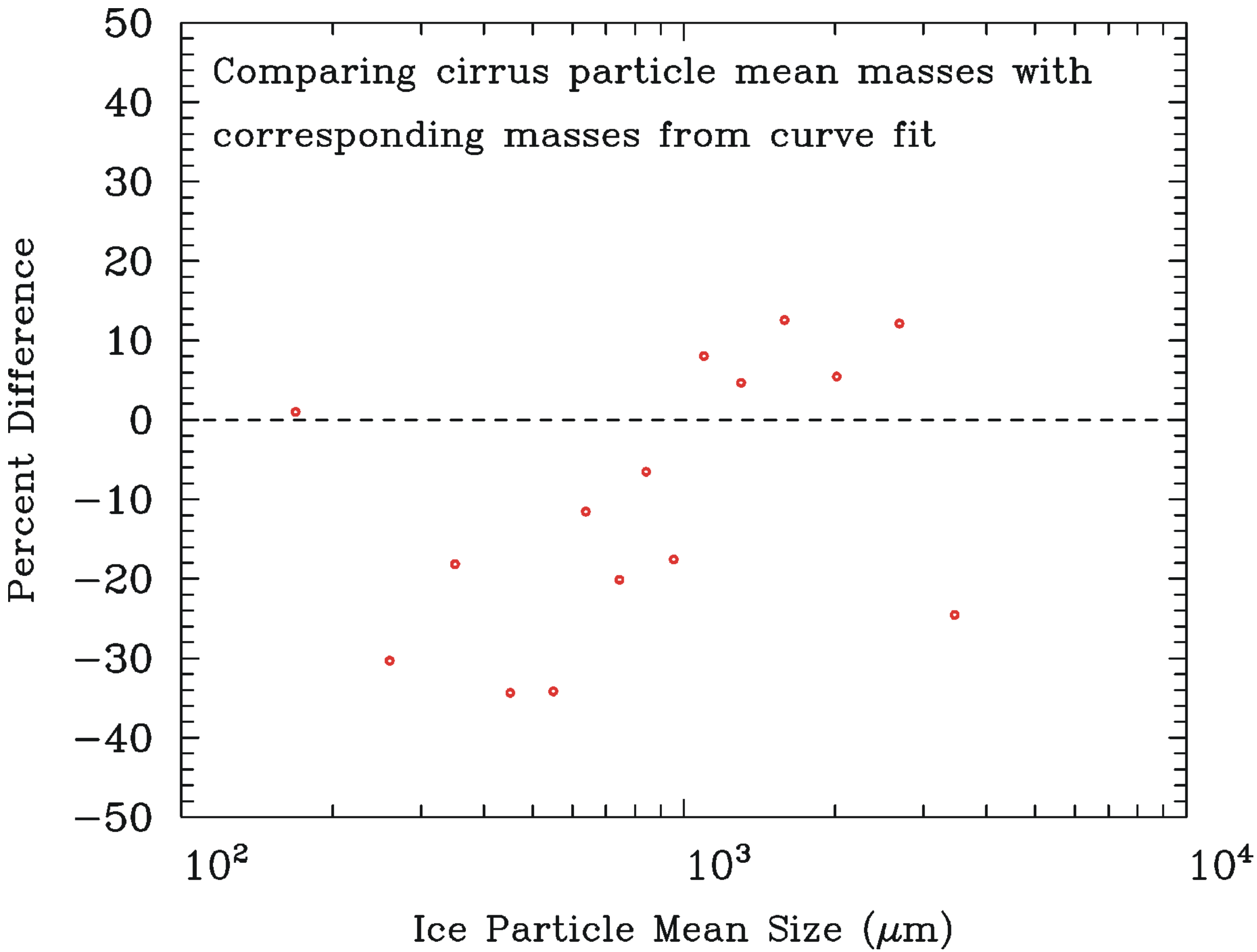
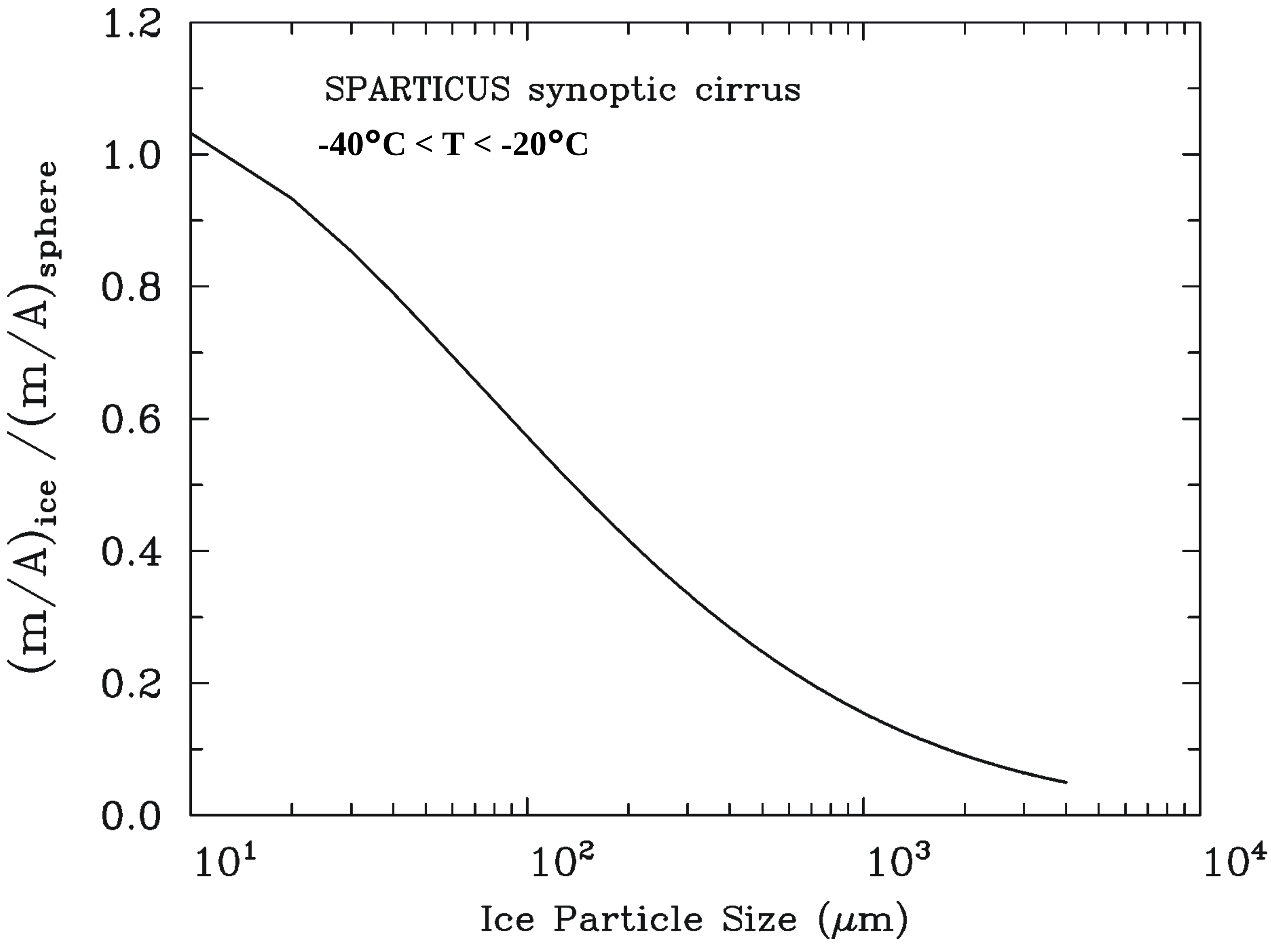


Comparing cirrus particle mean masses with
corresponding masses from curve fit
Percent Difference
50
40
30
20
10
0
−10
−20
−30
−40
−50
10^2
10^3
10^4
Ice Particle Mean Size (μm)

Testing for self-consistency and physical realism

(using 2D-S curve fits for m & A)



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

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

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
	Power β			
$-40 < T \leq -10°C$	2.632	2.368	2.079	1.814
$-55 < T \leq -40°C$	2.564	2.280	1.968	1.684
$-65 < T \leq -55°C$	2.477	2.057	1.597	----
Mean β	2.558	2.235	1.881	1.749
Standard deviation of β	0.064	0.131	0.206	----

Mean uncertainty for β as $100 \times \sigma/$ mean value : 6.4%

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.

Summary and Conclusions

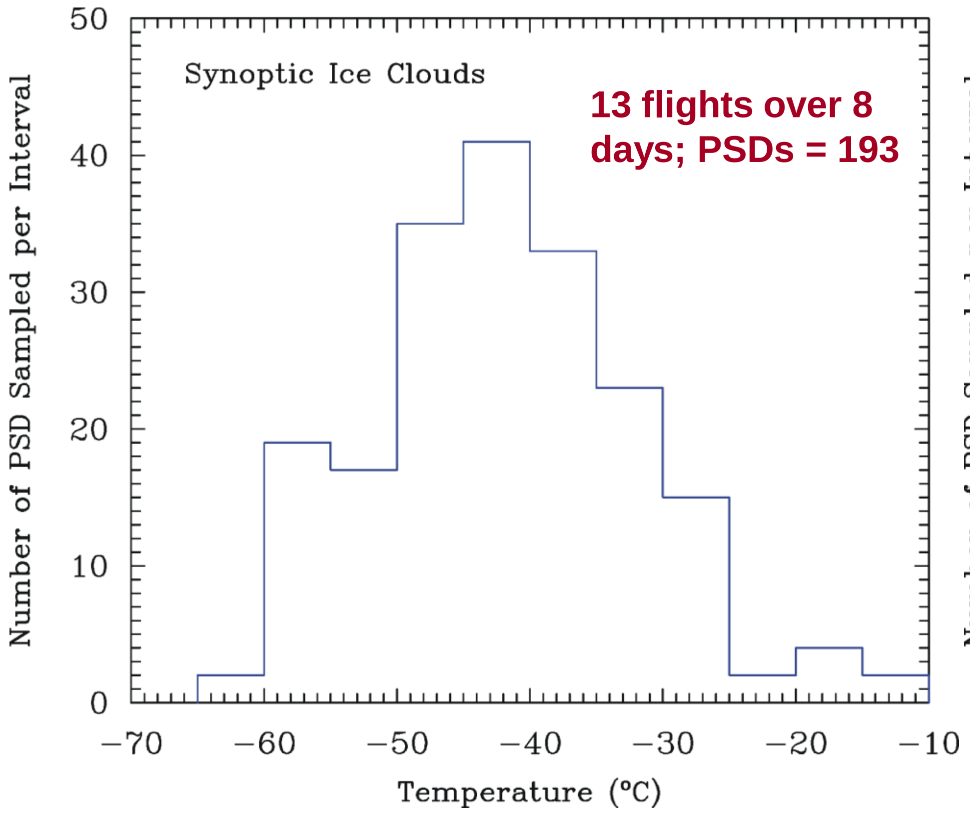
1. When considering all sizes, ice particle mass and projected area are better estimated by 2nd order polynomial fits than by power laws.

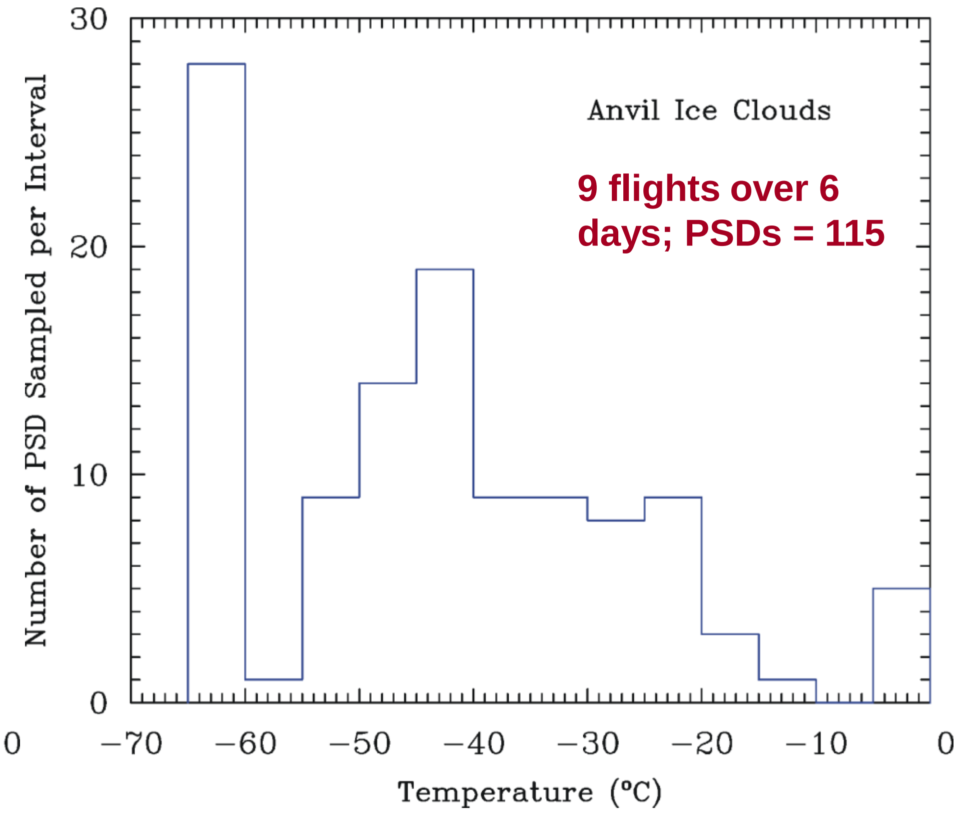
2. Method's accuracy for -40°C < T< -20°C is evident through comparisons with two recent studies and m-D measurements.

3. The greatest m-D & A-D uncertainties (σ) appear to be associated with the prefactor of the m-D and A-D power laws.
   - This should be useful for estimating σ of cloud retrievals.

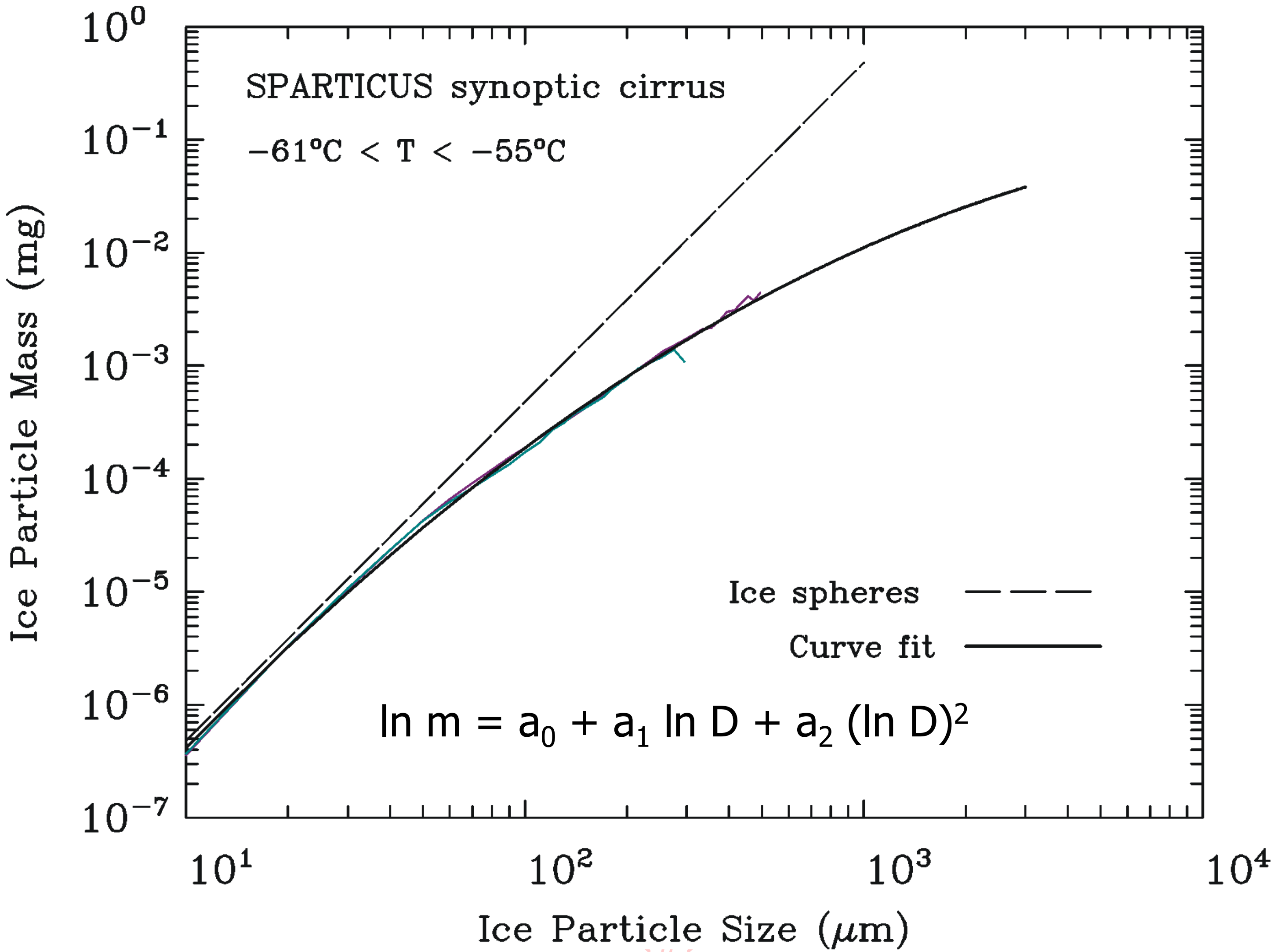
4. A means of obtaining accurate m-D and A-D power laws for modeling ice clouds was developed, thus avoiding major changes to model architecture.

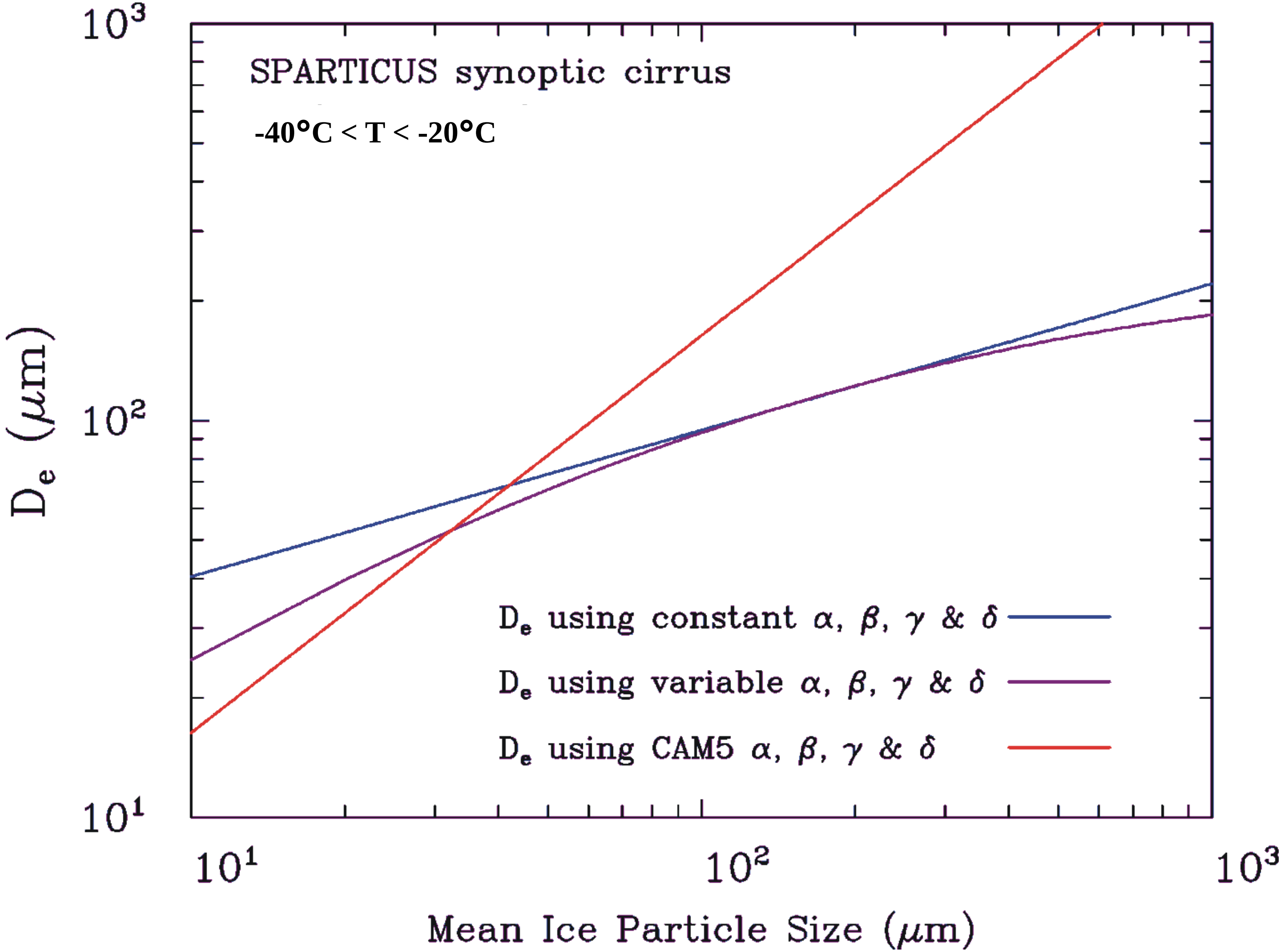
SPARTICUS PSD SAMPLING FOR SELECTED SYNOPTIC AND ANVIL CIRRUS CLOUDS



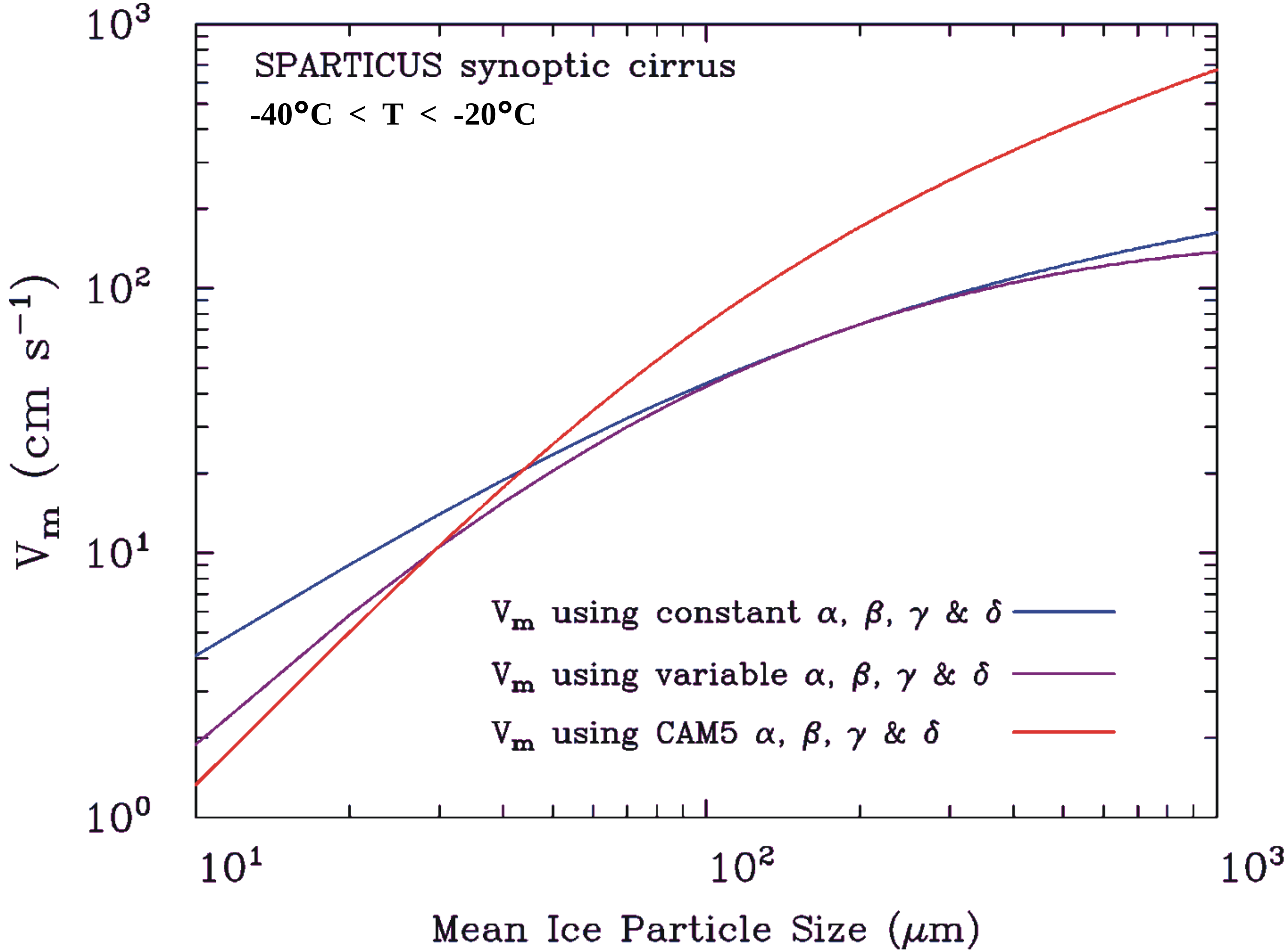


Data was grouped into 3 temperature-categories for synoptic and anvil cirrus, with a m-D and A-D curve fit for each category





SPARTICUS synoptic cirrus
-40°C < T < -20°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


SPARTICUS synoptic cirrus
-40°C < T < -20°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)
Mean Ice Particle Size (μm)
10^0
10^1
10^2
10^3