Ice crystal aggregation

Paul Field

Met Office

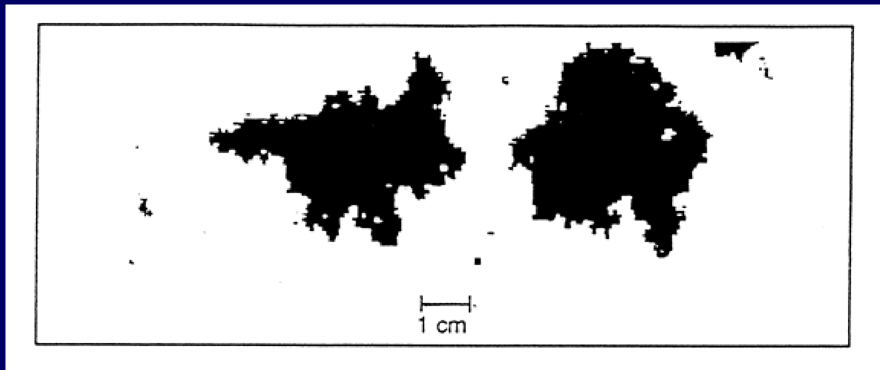
Chris Westbrook & Robin Ball

Univ. Warwick

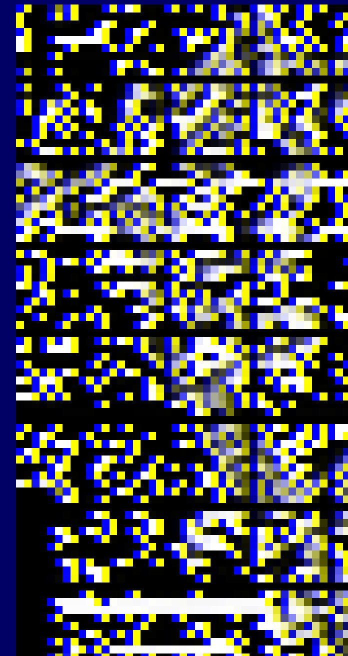
Andrew Heymsfield

NCAR

http://www.its.caltech.edu/~atomic/snowcrystals/

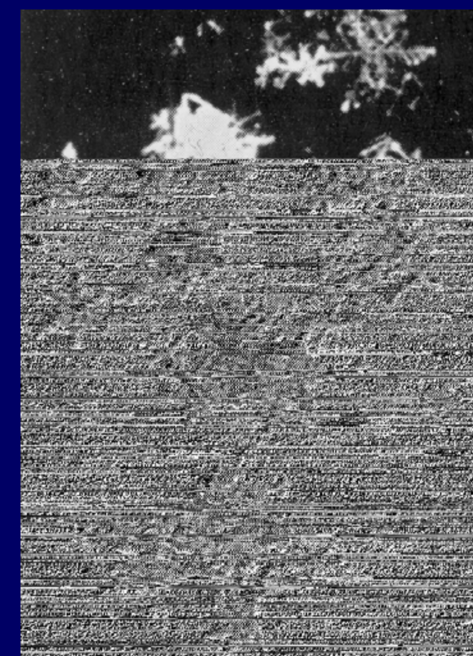


Paul Lawson, JAS'99



Field & Heymsfield '03

Emerald2
Paul Connolly
UMIST

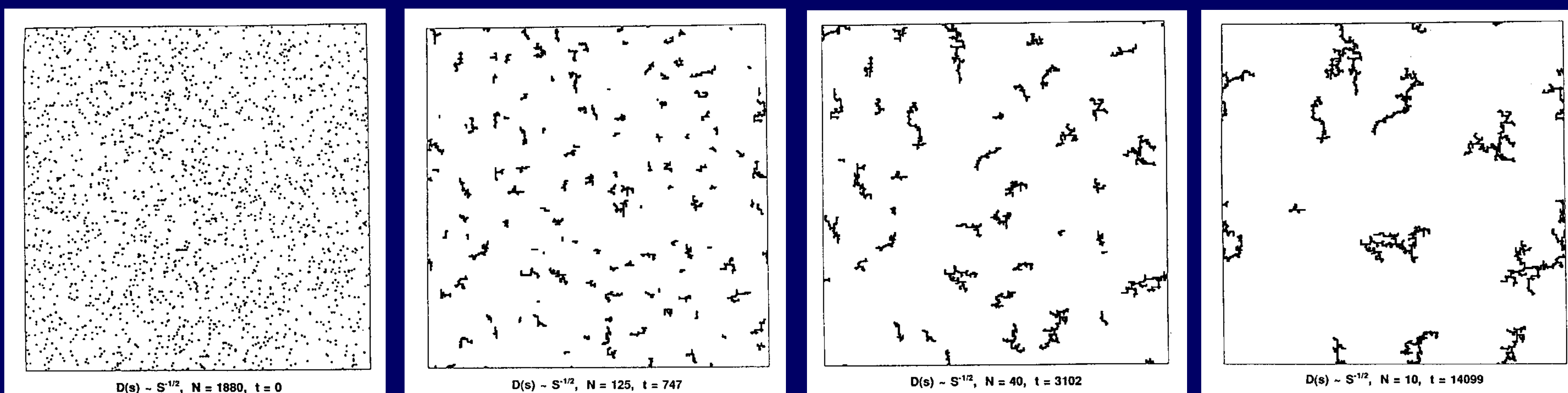


Mason
POC

Motivation

- Ice crystal aggregates appear to have an immense number of geometrical permutations
- Can we predict ice crystal aggregate properties (e.g. mass or cross sectional area) from a simple model of aggregation?
- Improve ice aggregate representation in numerical weather and climate models

Simulated aggregation



Increasing time →

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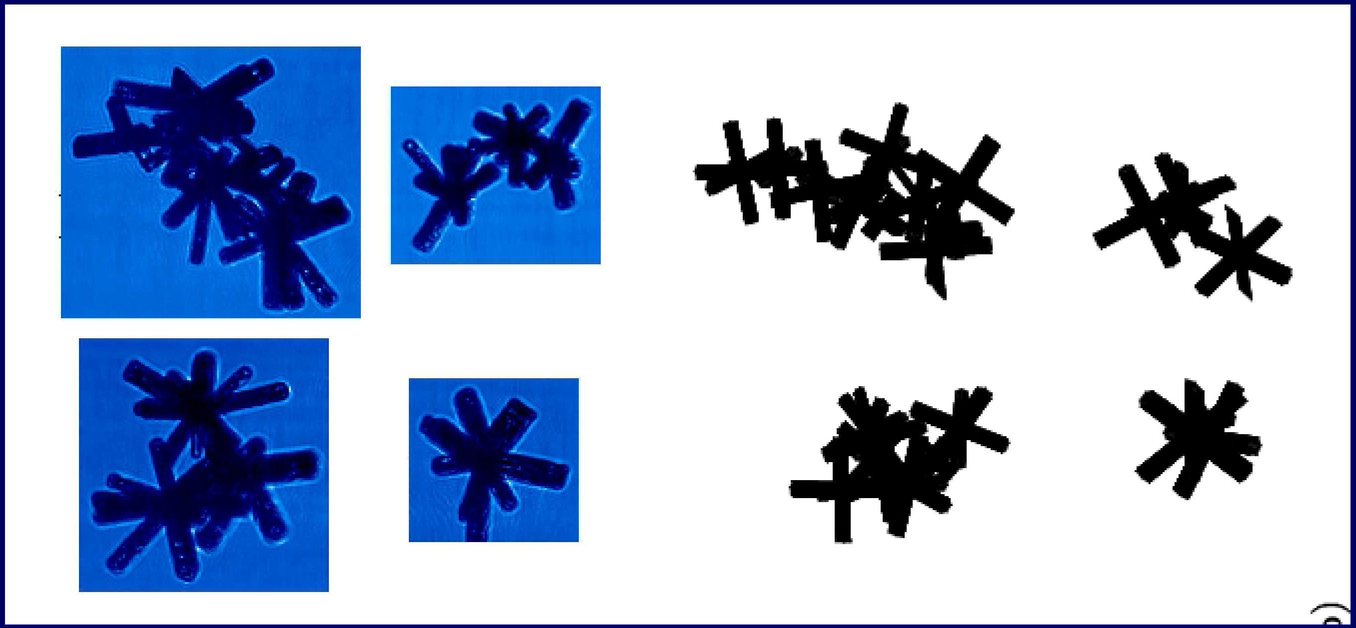
Modelling aggregation

- Start off with narrow distribution of monomers
- Pick pairs of particles from list based on probability computed from collection kernel $\sim E(D_1+D_2)^2|v_1-v_2|$
- Place selected particles in a volume and fire one towards the other
- If they contact – make the joint rigid and return new particle to list

Real and modelled aggregates

CPI

Model



500 μm

T=-46°C

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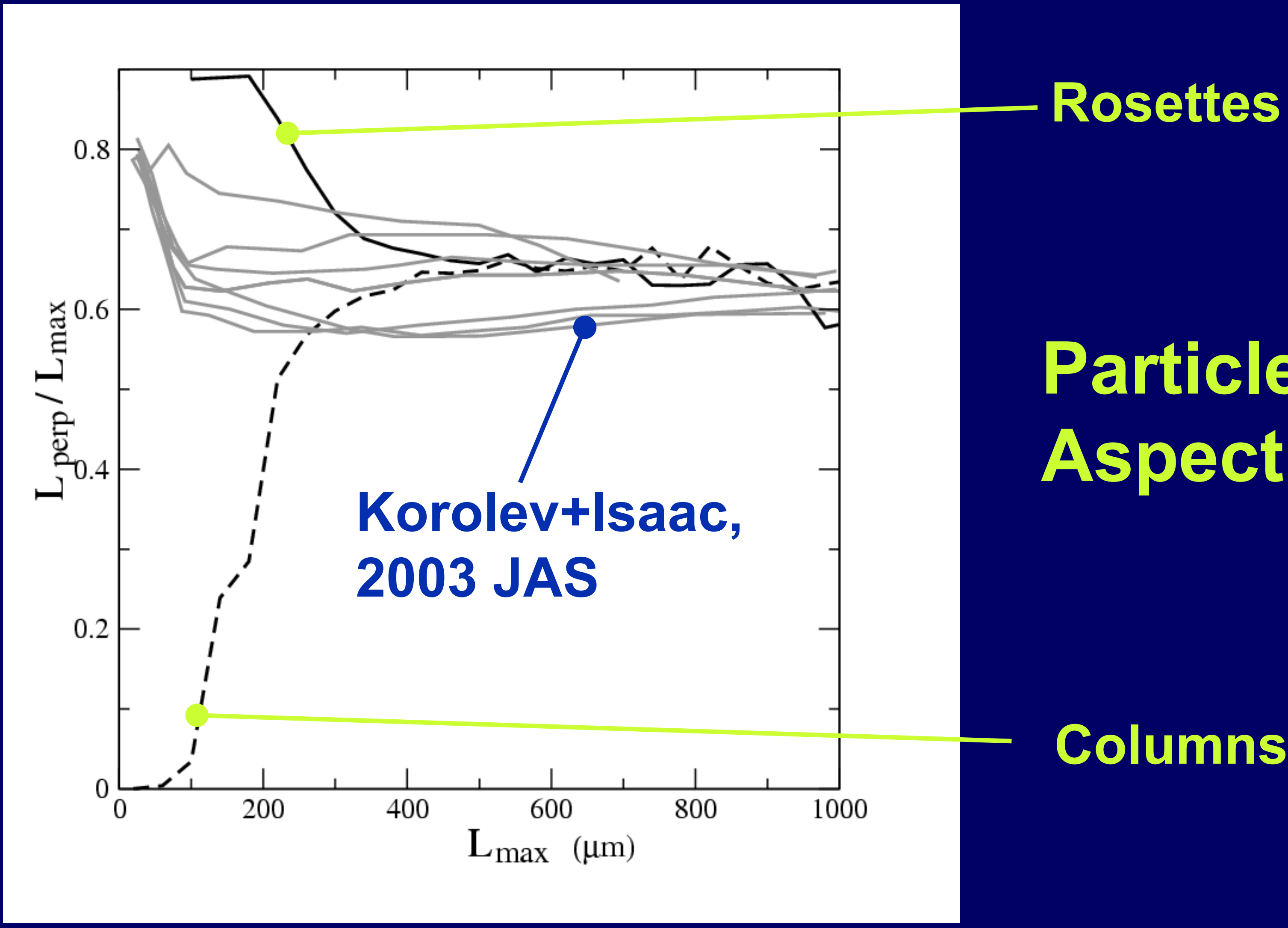

Particle Mean Aspect Ratio

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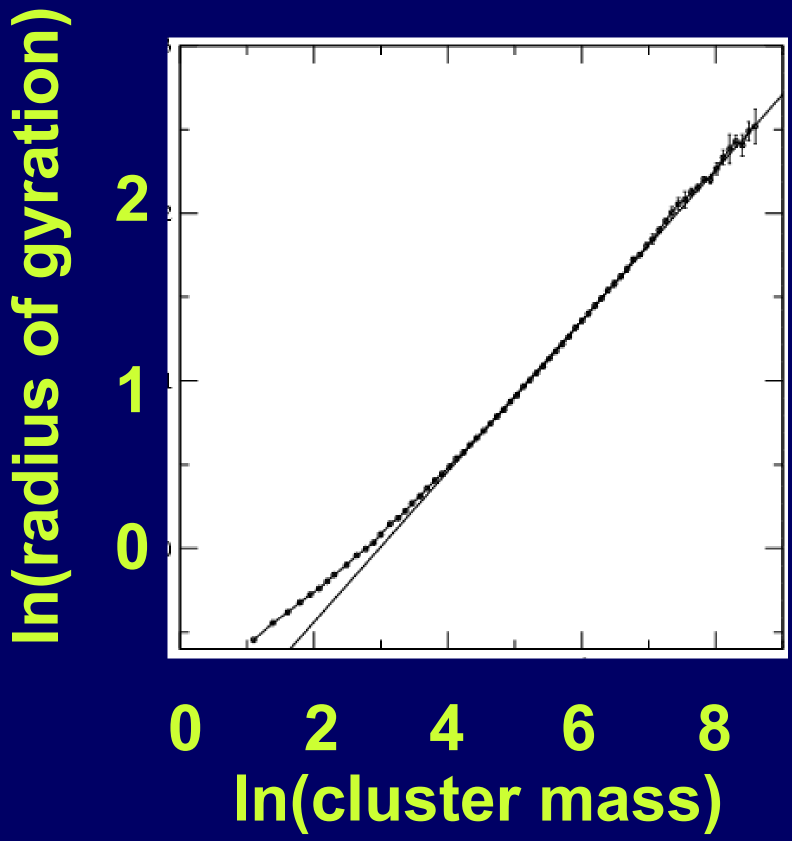
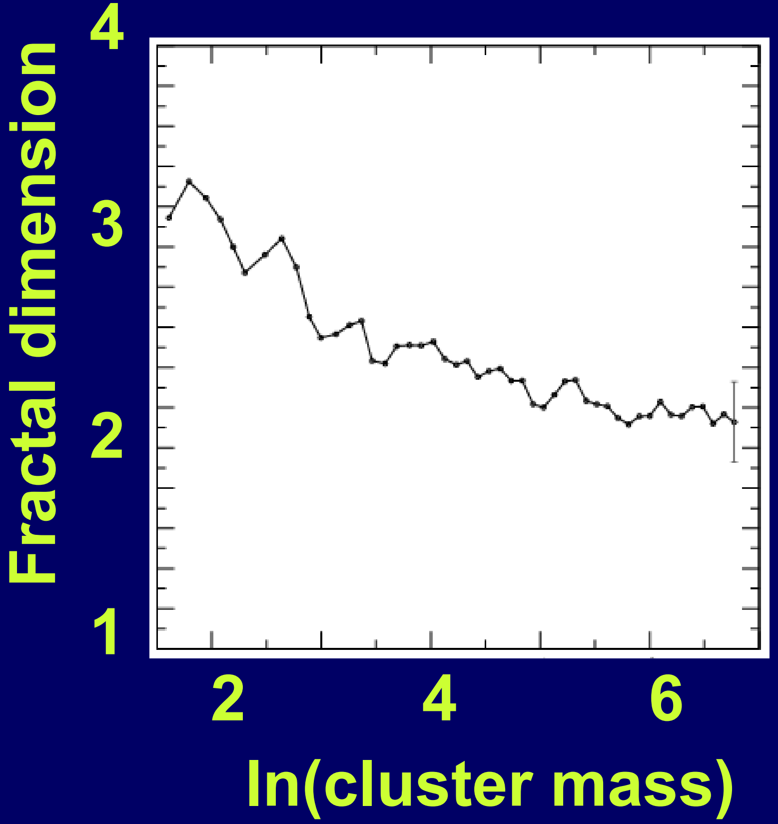
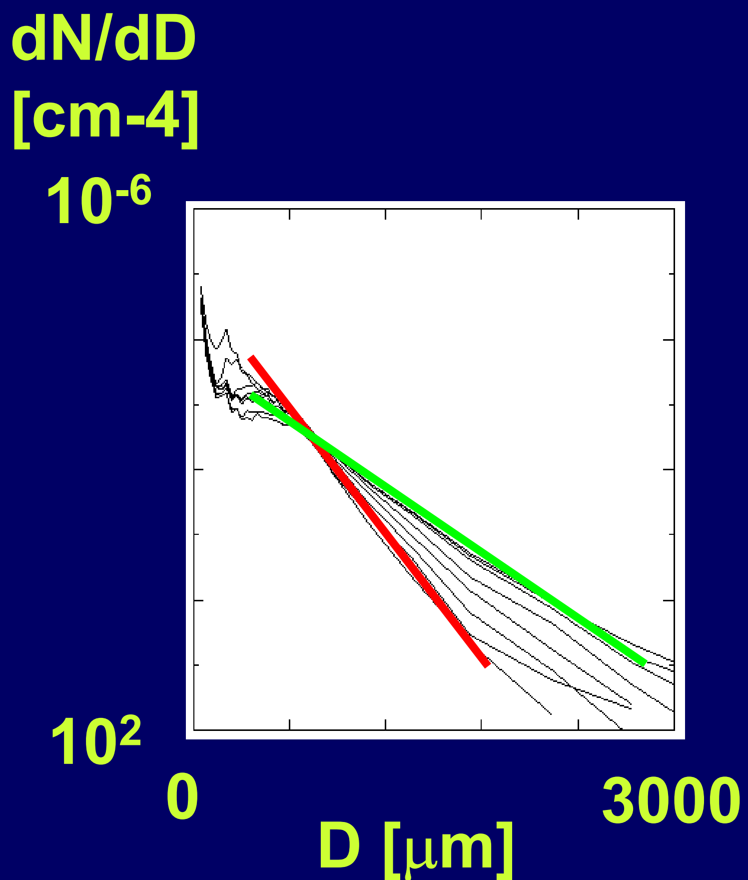

ln(radius of gyration)
2
1
0
0
2
4
6
8
ln(cluster mass)

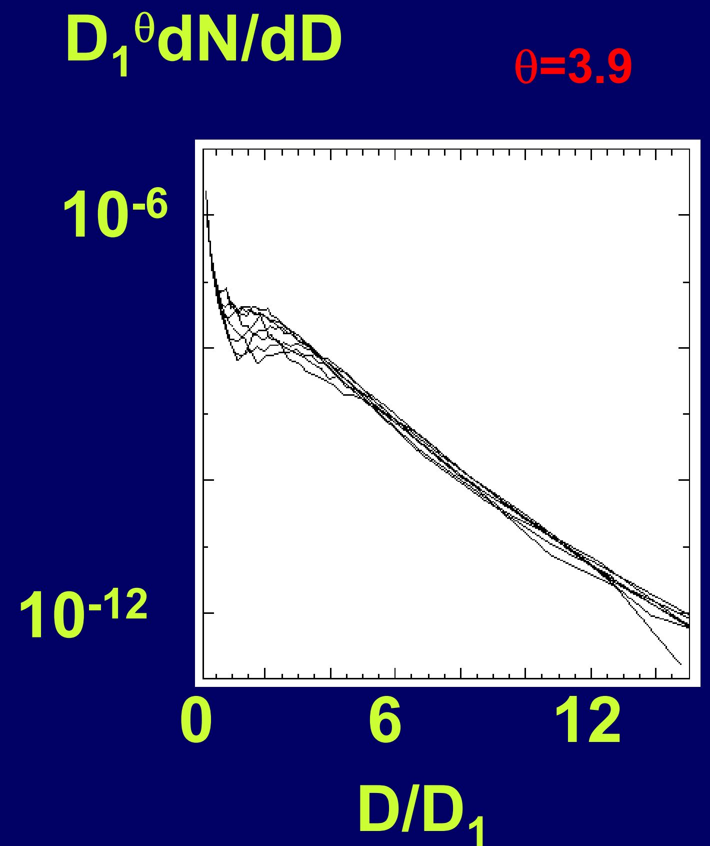

Fractal dimension
4
3
2
1
2
4
6
ln(cluster mass)

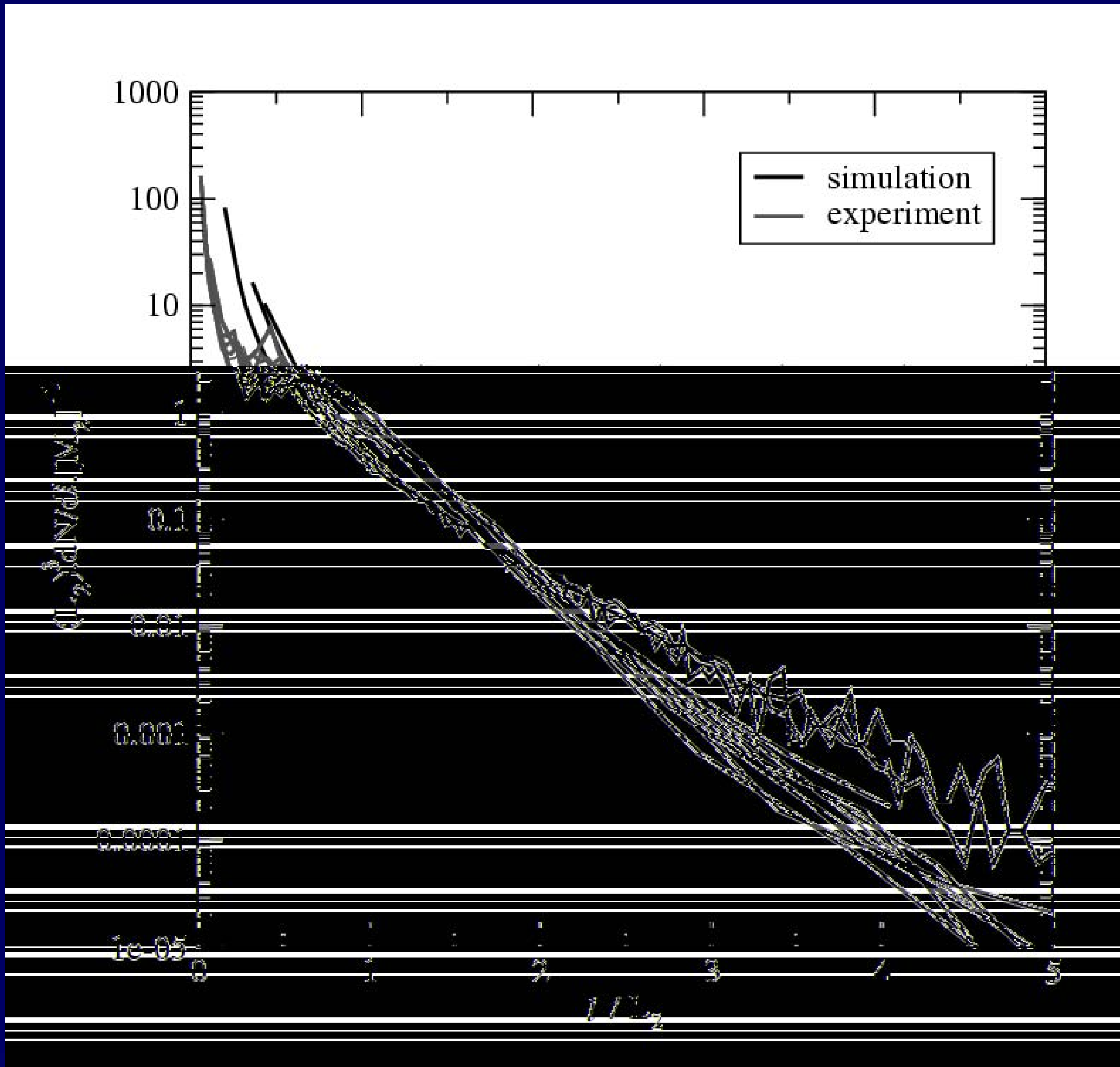
- Aggregation controls the geometry of the particles
- Aggregation controls the evolution of the particle size distribution

Scaling of the PSD

$$\frac{\mathrm{d}N}{\mathrm{d}D} = D_1(t)^{-\theta}\, g\left(\frac{D}{D_1(t)}\right)$$


dN/dD
[cm-4]
10^{-6}
10^{2}
0
3000
D [μm]


$D_1^{\theta}dN/dD$
θ=3.9
10^{-6}
10^{-12}
0
6
12
D/D_1


1000
100
10
1
0.1
0.01
0.001
0.0001
1e-05
simulation
experiment
0
1
2
3
4
5

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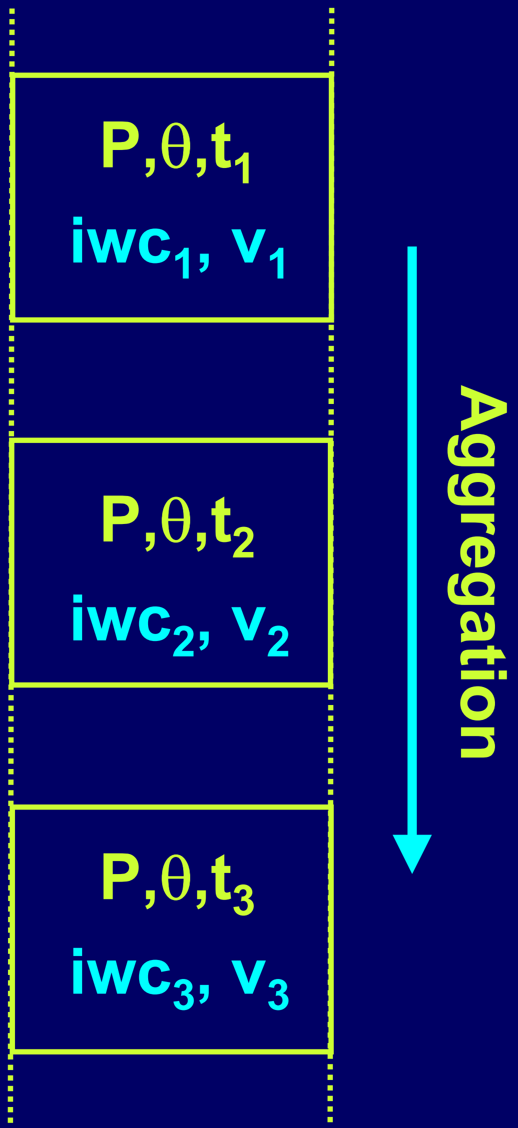
Idealised 'aggregation-only' cloud

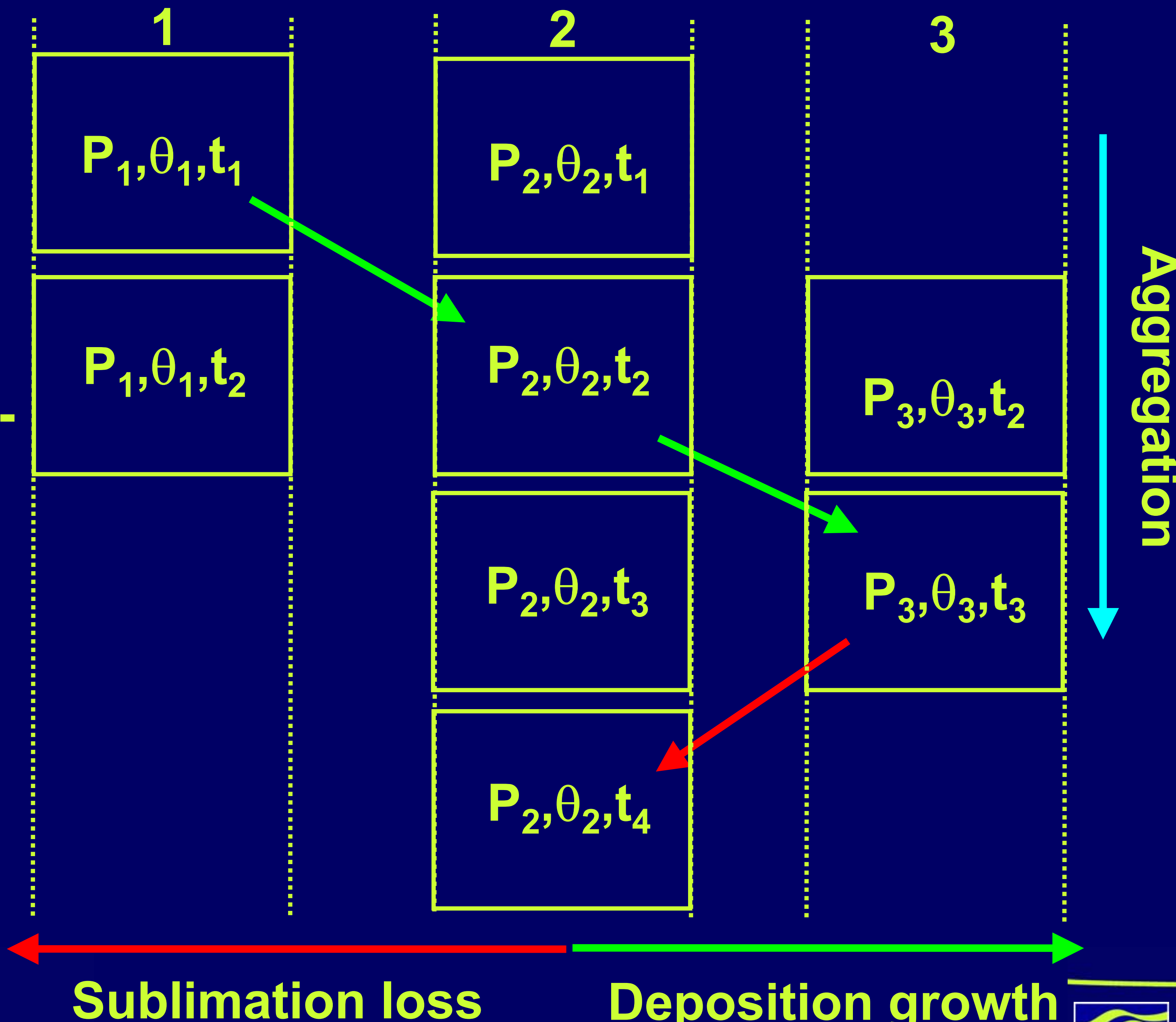
$iwc_1 > iwc_2 > iwc_3$

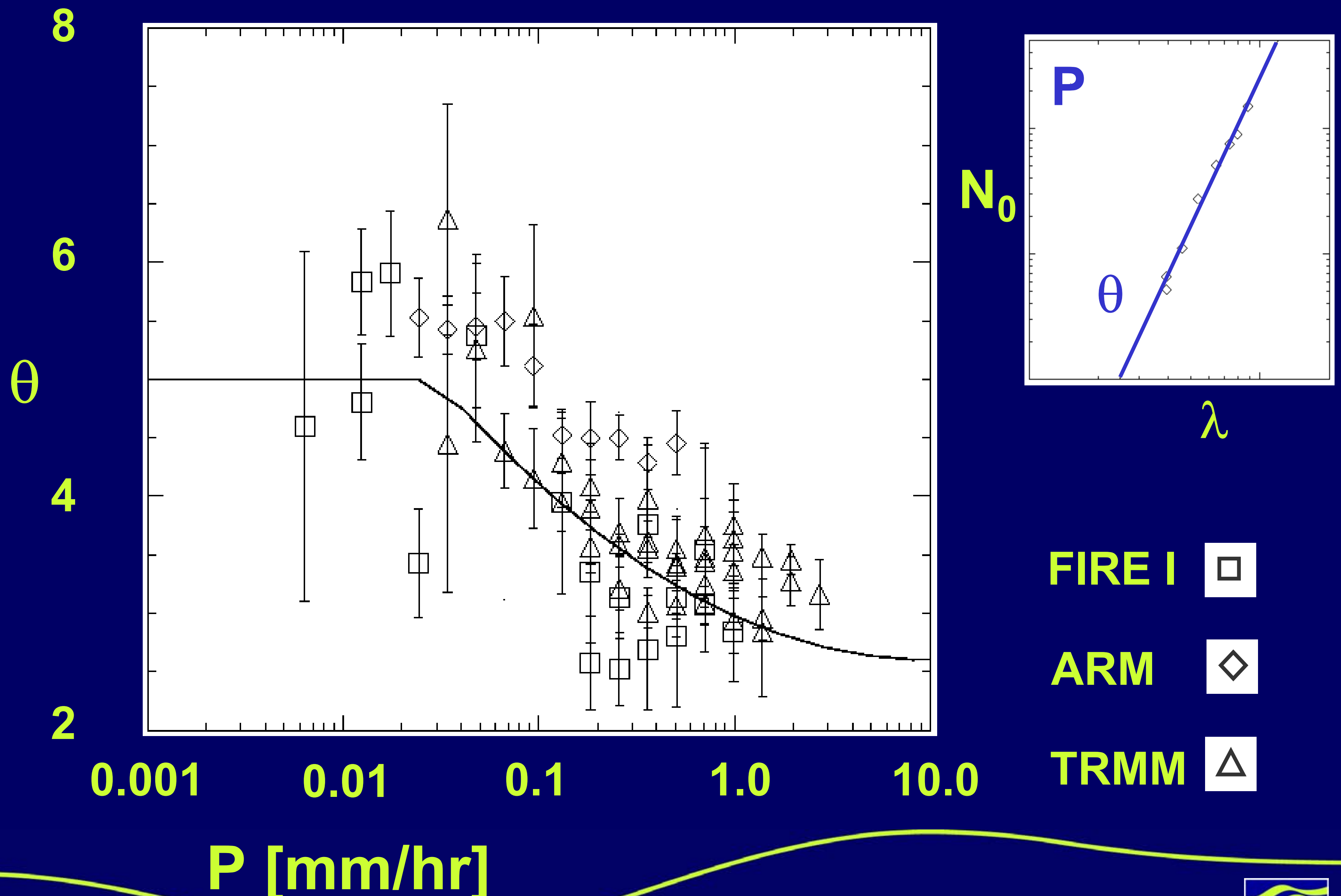
$v_1 < v_2 < v_3$

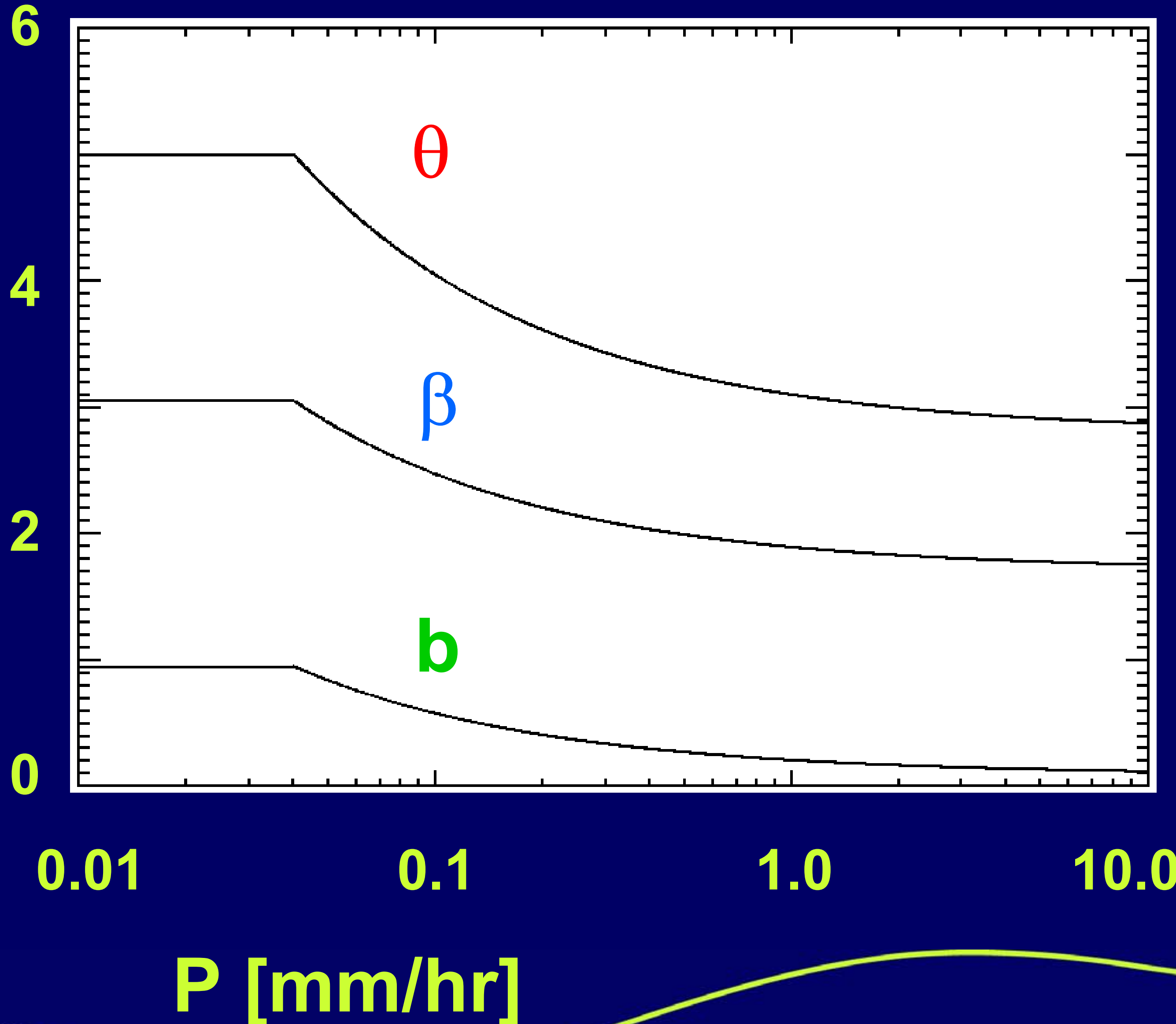


3 idealised 'aggregation-only' clouds

$P_1<P_2<P_3$




8
6
4
2
θ
0.001
0.01
0.1
1.0
10.0
P [mm/hr]
P
N_0
θ
λ
FIRE I
ARM
TRMM

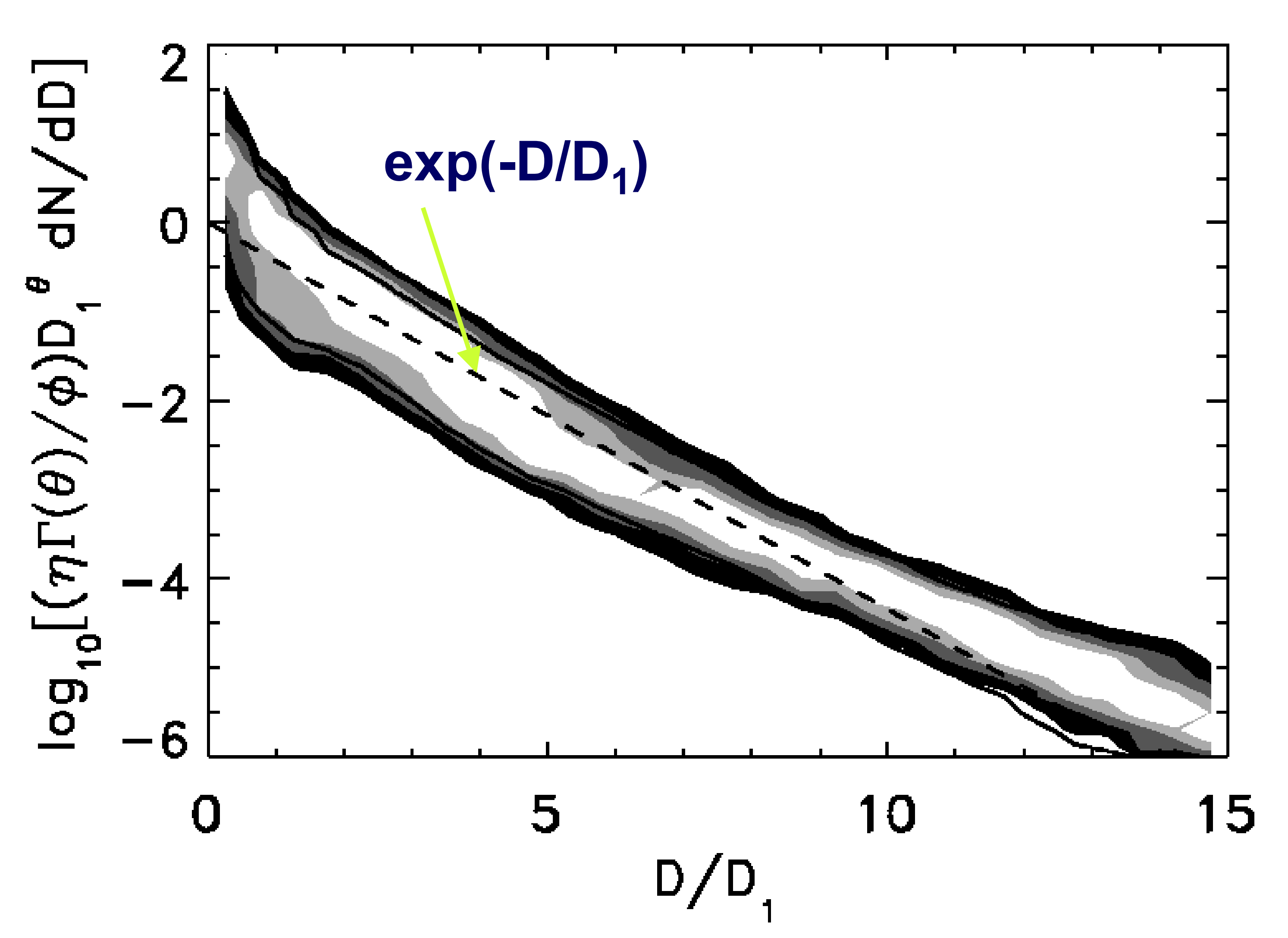


$m = \alpha D^{\beta}$

$V_t = aD^{b}$

PSD scaling

~2500 1km particle size distributions from FIRE I, ARM and TRMM



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Summary

- Aggregation model predicts $\beta \rightarrow 2$ and aspect ratio ~0.7
- $\theta \rightarrow 3$; $\beta \rightarrow$ **2; b**$\rightarrow 0$ when precip. rate becomes large
- Same scaling behaviour for TRMM, FIRE, ARM and model data
- Scaled PSD is exponential to at least $9D_1$

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