

# Dust: Making a Mess and Cleaning it Up

Surajit Sen

*State University of New York at Buffalo*

[sen@buffalo.edu](mailto:sen@buffalo.edu)

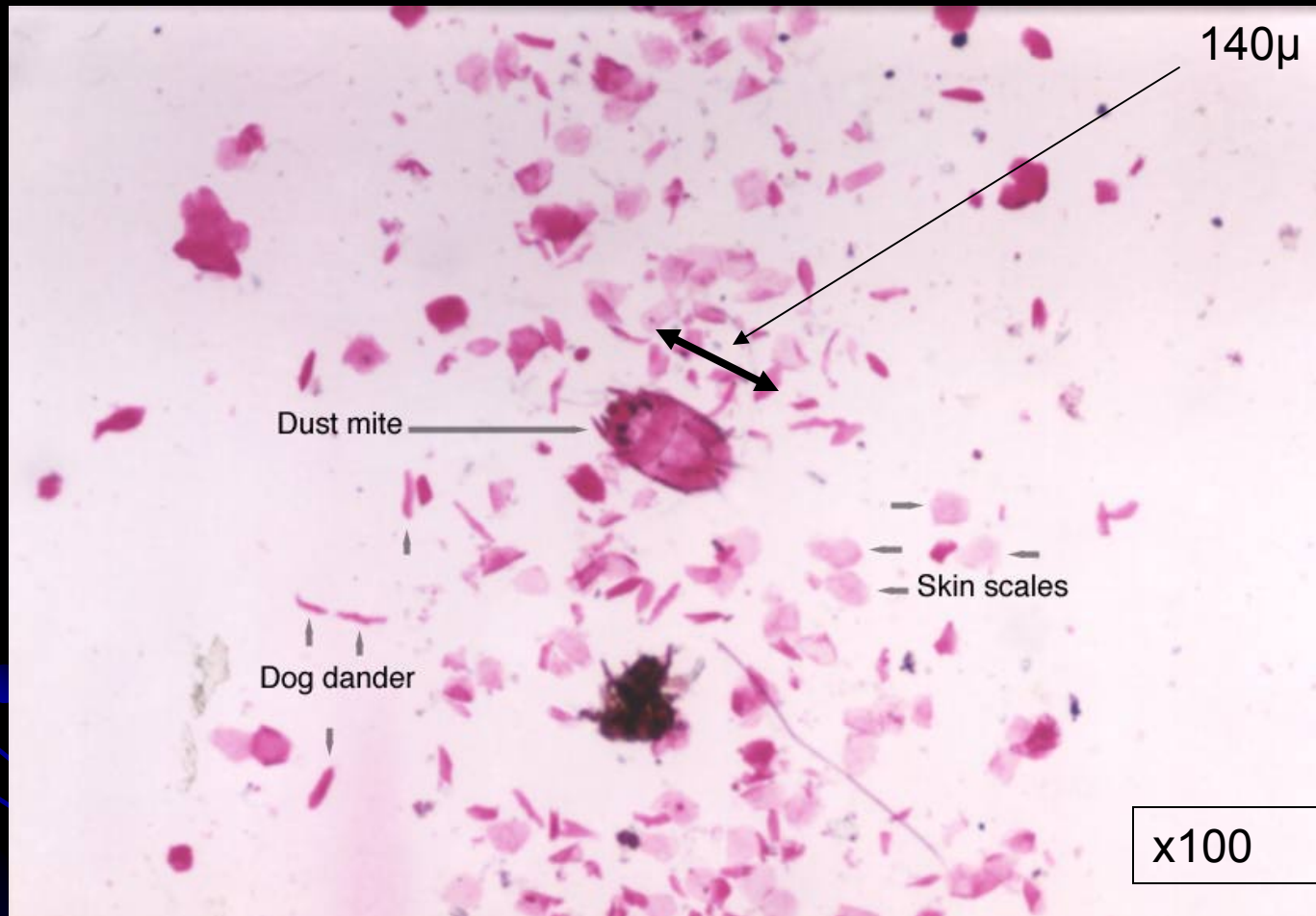
Work done with **T.R. Krishna Mohan** (SUNY-Buffalo and CMMACS-India) and **Adam Sokolow** (UG, SUNY-Buffalo)

Support: NSF

# Outline

1. Portrait of dust (geometry & length scales)
2. How does dust build up (dust bunnies) ?
3. How can one remove dust from the air?
4. A Toy Model and Time Scales
5. Summary

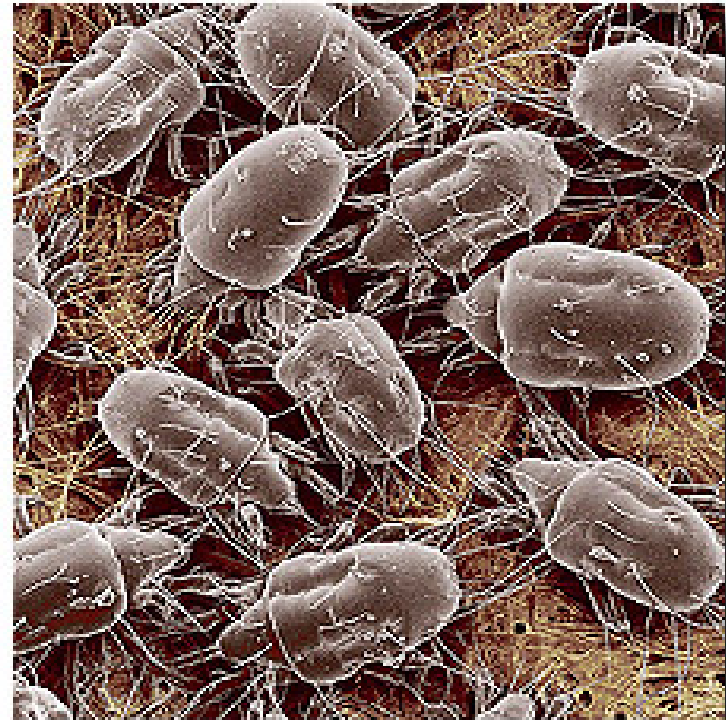
# 1. Portrait of Dust



Observe the lack of sphericity –  
irregular and rod-like shapes

# Four Decades of Length Scales ( $10^{-2}$ - $10^{+2}\mu$ )

Human Hair .....	70 - 100 $\mu$
microns)	
Human Sneeze .....	10 - 100 $\mu$
Pet Dander .....	0.5 - 100 $\mu$
Pollen .....	5 - 100 $\mu$
Spores from Plants .....	6 - 100 $\mu$
Mold.....	2 - 20 $\mu$
Smoke .....	.01 - 1 $\mu$
Dust Mite Debris .....	0.5 - 50 $\mu$
Household Dust .....	.05 - 100 $\mu$
Skin Flakes .....	0.4 - 10 $\mu$
Bacteria.....	0.35 - 10 $\mu$



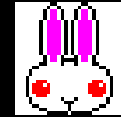
Adult Dust mites are 100 - 600 $\mu$   
(Translucent, No eyes, no antennae or  
mouthparts in front of their bodies)

Almost random walkers?

# Dust mites 101

- Dust mites - prevalent throughout the world.
- Survive in any environment capable of supporting plant or animal life.
- Two most common species found in the US are
  - (a) **dermatophagoides farinae** and (b) **dermatophagoides pteronyssimus**.
- They feed primarily on **dead skin cells of any type of animal, however, the mites do not actively intake water to survive**. Instead, water is absorbed into their bodies directly from the surrounding air
- The dust mite has long hairs extending from the outer margins of the body and shorter hairs on the rest of the body
  - **Hairs aid in the mites ability to freely float in air. In microgravity environments they would almost never settle on the floor.**
- **The female dust mite will lay 66 to 68 eggs singly or in small groups over the course of their lifetime.**
- **To kill mites - (a) Raise temperature to above 140 F or (b) Drop humidity to below 50%.**

## 2. How does dust build up? (making of dust bunnies)



***After sampling some dust collection on a fan grating, there are a few observations that can be made***

- In every dust clump there exists a cotton fiber or some other hair/fur structure
- The various stages of dust collection on a grating subject to constant air flow appear to depend on these fibers
- “Dust” begins to collect on the side of the grating that directly faces the air flow
- “Dust” can travel around completely to the other side to rejoin itself
- Once anchored it streams into long strands that are constantly exposed to the air currents

Courtesy: Adam Sokolow’s  
residential dust lab.

# Getting a sense of things ...

- A strand of hair or fur is much longer than it is wide, and is capable of holding charges.
- Imagine steady air flow past a metal grating. In this air flow are dead skin cell, dust grains, dust mites, hairs, furs, fibers, pollen, etc. Of all of these units to work with, the hairs, furs, and fibers are the largest. While traveling through the air a strand of hair may pick up a charge (positive electrostatic charge due to its excess of protons), this would make a metal grating which due to its conductive nature has an excess of negative charges, a very likely place to 'stick' to
- Also note the force of gravity on a fiber will be considerably lower than that of the electrostatic force
- Assuming this hypothesis is true, if one removes the fibers from the air before they hit the filter, or the gratings then no linking could occur. One possible method would be to bubble the air through a high viscosity fluid hoping to trap most of the fibers before the air is filtered through a conventional HEPA or other styled filter.

# 3. How can one remove dust from the air?

- Perhaps remove the longer “dust” first
- Then remove the finer dust – Filter efficiency (ability to stop progressively smaller dust) should “increase” in time
- **H**igh **E**fficiency **P**articulate **A**rrestance Filters do that ...

## A HEPA filter MUST:

- “be able to handle 99.97% of particles .3 microns in size. They are also very effective on collecting particles less than .3 microns (usually 95% to 98% efficient on less than .3 micron sized particles).”
- “HEPA filters have a high resistance and can not be placed directly in-line in a heating/cooling system. They must be used in conjunction with a separate blower/motor system in a by-pass mode”
- “HEPA filters are known as the most effective filter media for removing the largest percentage, over 99% of most respirable sized particles.”
- “As more dust or airborne particles accumulate on the filter surface, the efficiency or effectiveness of the filter actually increases, but so does the resistance.”

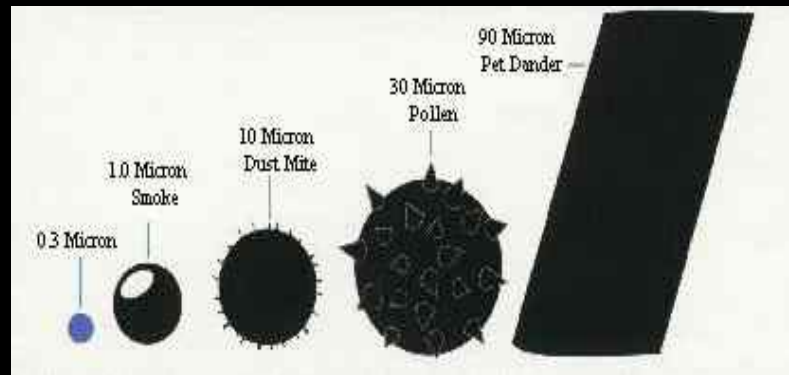
# How clean is clean?

- Dust mites consume dead skin cells and hence act as a natural “cleanser”
- Removing **all** dust mites can lead to an explosion in finer scale dust and hence lead to worse air quality
- “Clean air” can be accomplished by having just **enough dust mites to consume smaller length scale dust**
- Hence filters need only **remove larger length scale dust** – which would mean filters would be efficient and air quality will remain at some “optimum” level

# 4. A Toy Model and Time Scales

We IGNORE the problem of dust self-assembly in this study

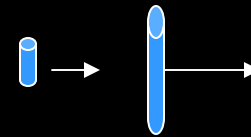
Dust “rods” of GIVEN random sizes come in one at a time and either pass through or get stuck in the filter



←-----→

3 decades of length scales

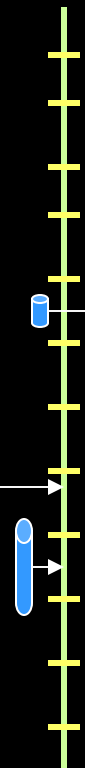
Mean rod size = 5



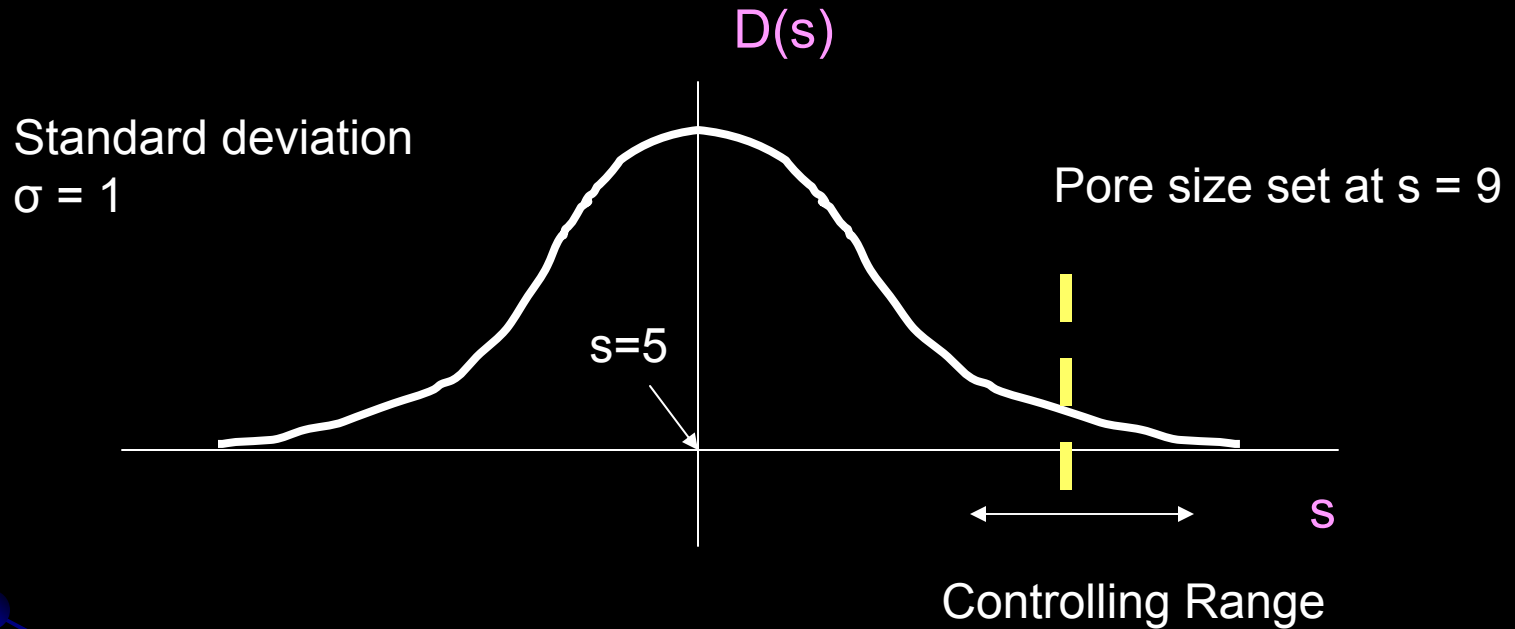
We take between  $10^3 - 10^4$  pores

Pore size = 9

Toy Model Filter



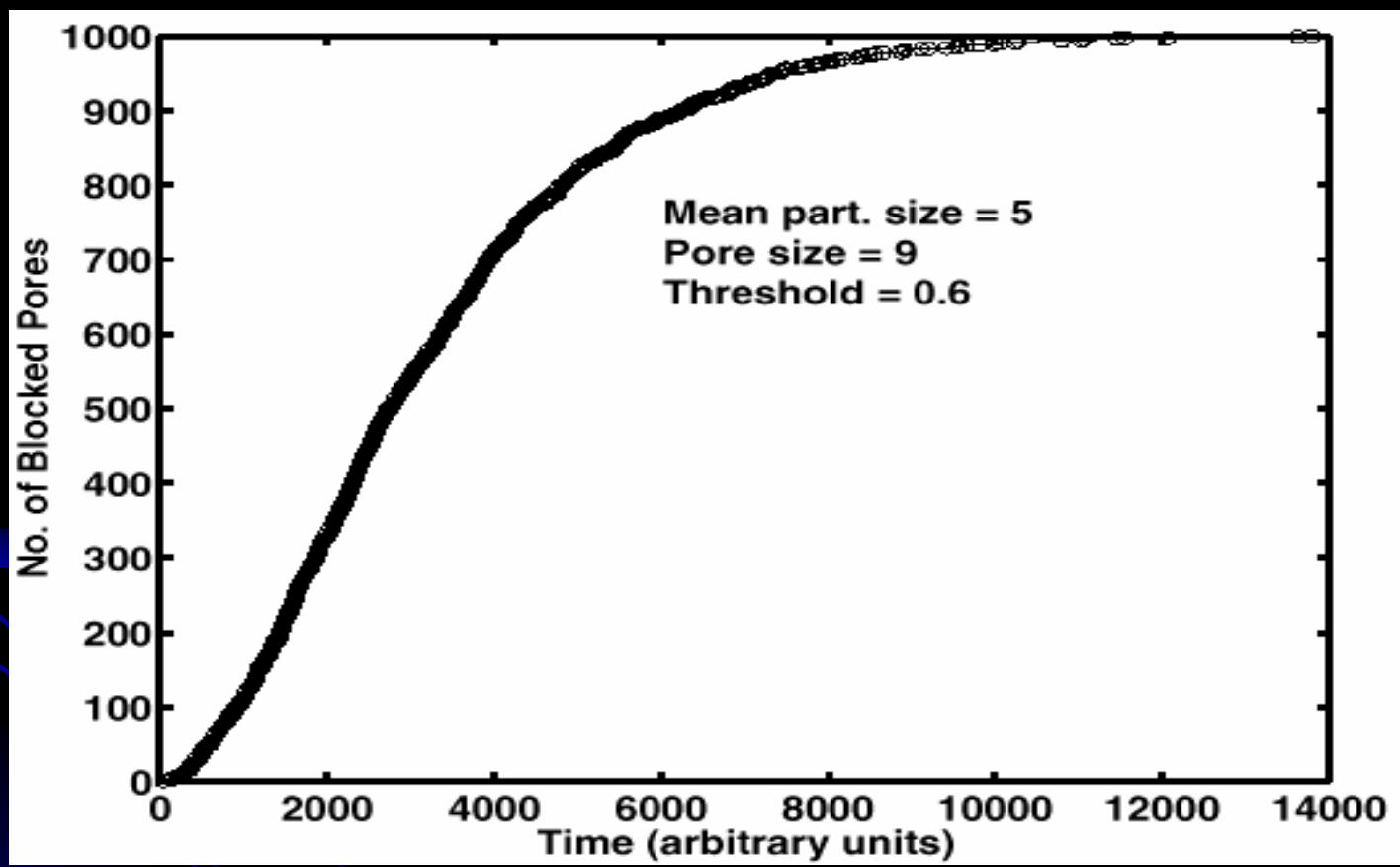
# Dust rod size distribution and sojourn

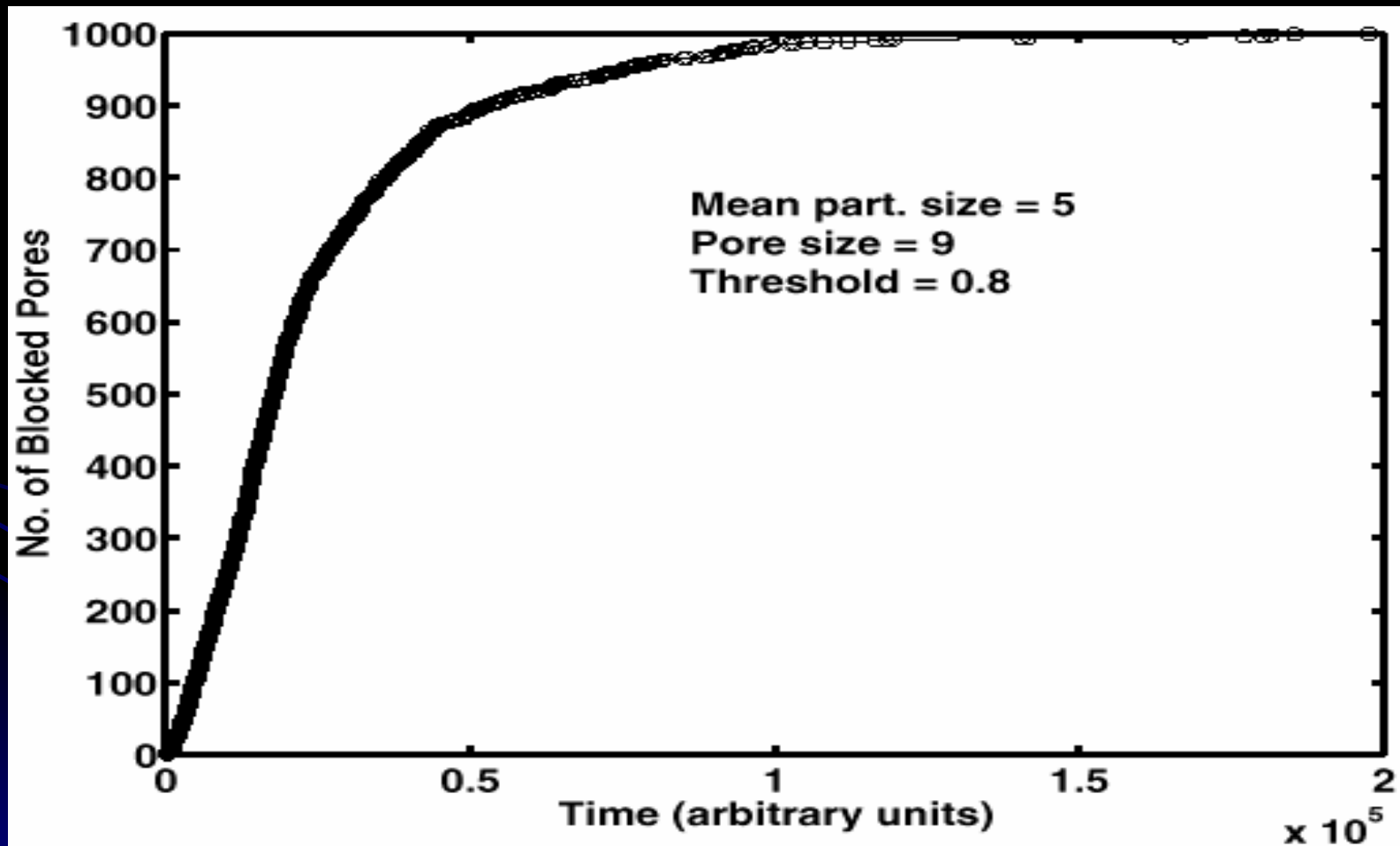


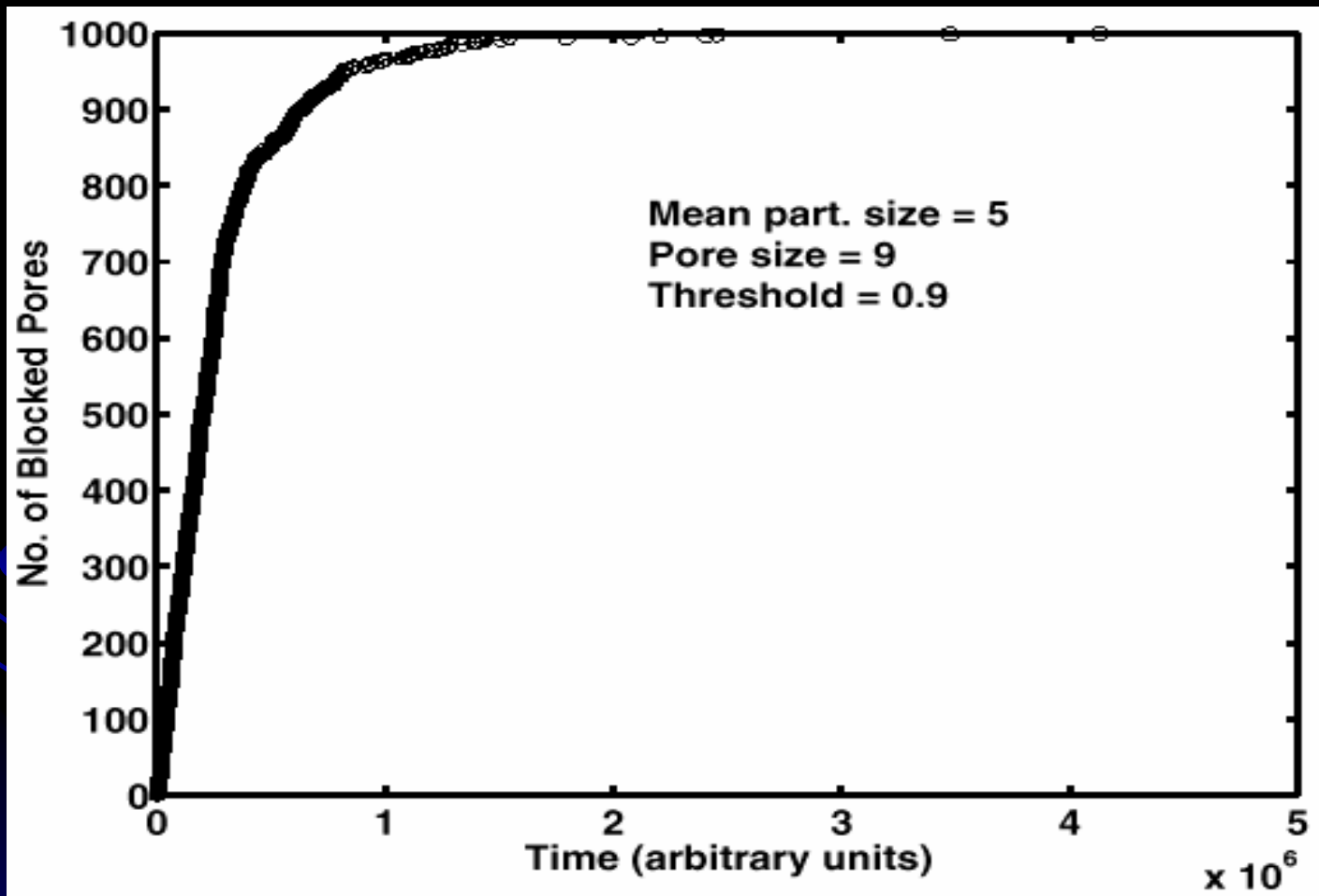
We assume a **Gaussian distribution** of dust rod sizes with the mean at some  $s = 5$

# Model and Method

- Dust rods are chosen randomly from the Gaussian distribution and shot at some random point on the filter one at a time
- Time is measured in units of each shooting event
- Rods  $\ll 9$  go through any pore,
- Rods  $> 9$  get stuck and can block a pore and partially block the next pore (this is done in one direction for the sake of simplicity)
- A Threshold parameter (around 0.8) is introduced to control the rod size that can completely block a pore.
- Threshold allows for (i) sticking events, (ii) for random displacements of rods around a pore, (iii) allows for incremental blocking of the same pore by smaller sized rods
- Rods can get deposited on top of blocked pores

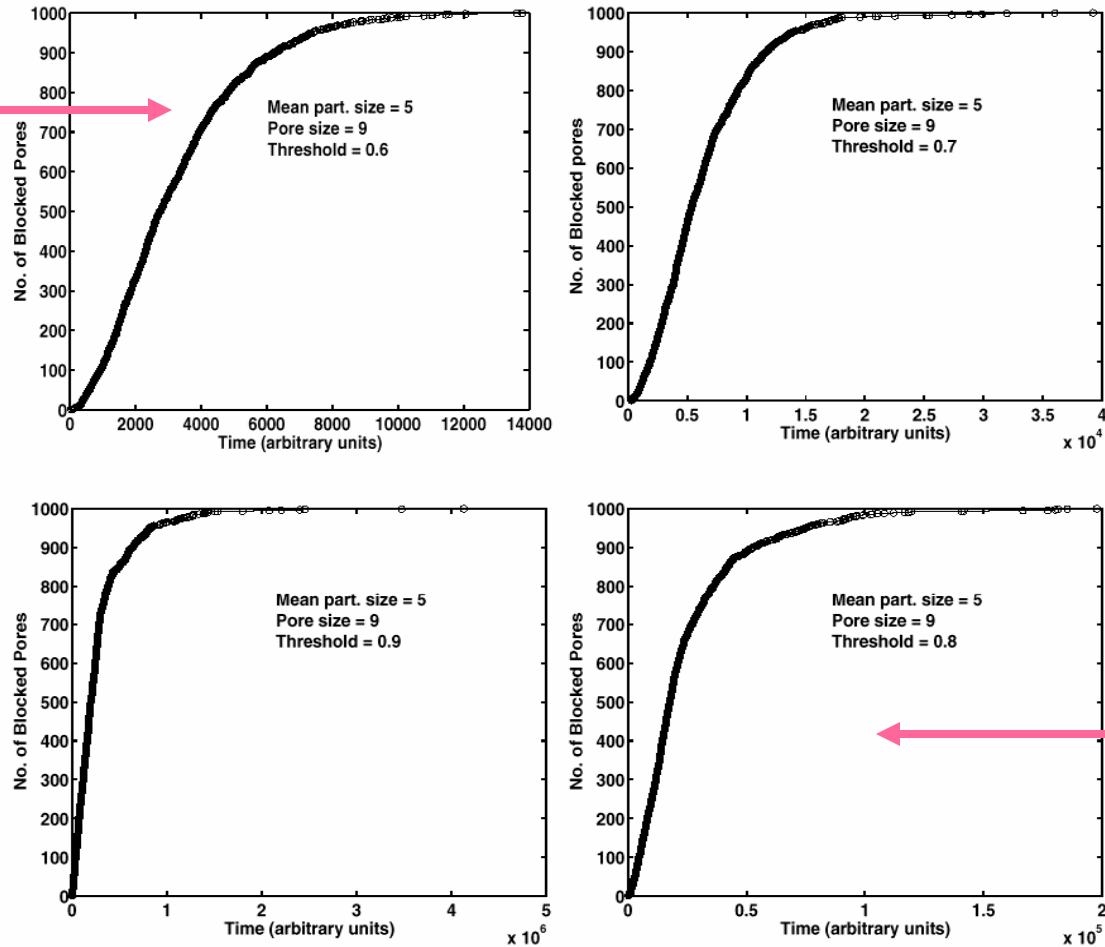






# Results – Low Threshold Filters Block Rapidly

Low  
Threshold  
Filter  
(Sticky)



High  
Threshold  
Filter  
Blocks  
Slowly

FIG. 1: The threshold effect is seen in these diagrams; the threshold increases from 0.6 to 0.9, in units of 0.1, starting at top left, and going anti-clockwise through the diagrams. It is seen that the clogging time, for the same number of pores, increases as we allow only larger particles to stick to an open pore.

# High Threshold filters take long to get blocked

Low  
Threshold

Large  
fraction of  
pores  
blocked

High  
Threshold

Small  
fraction of  
pores  
blocked

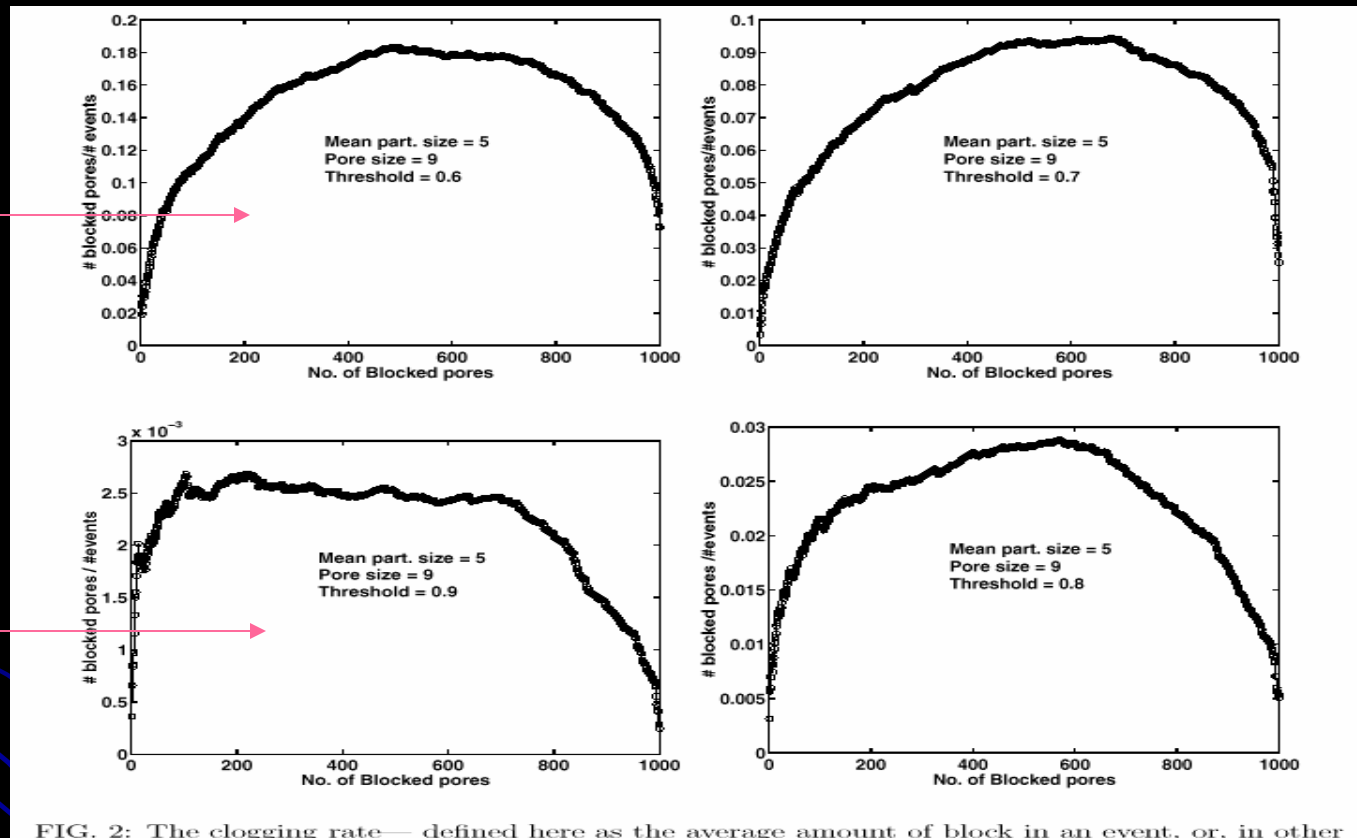
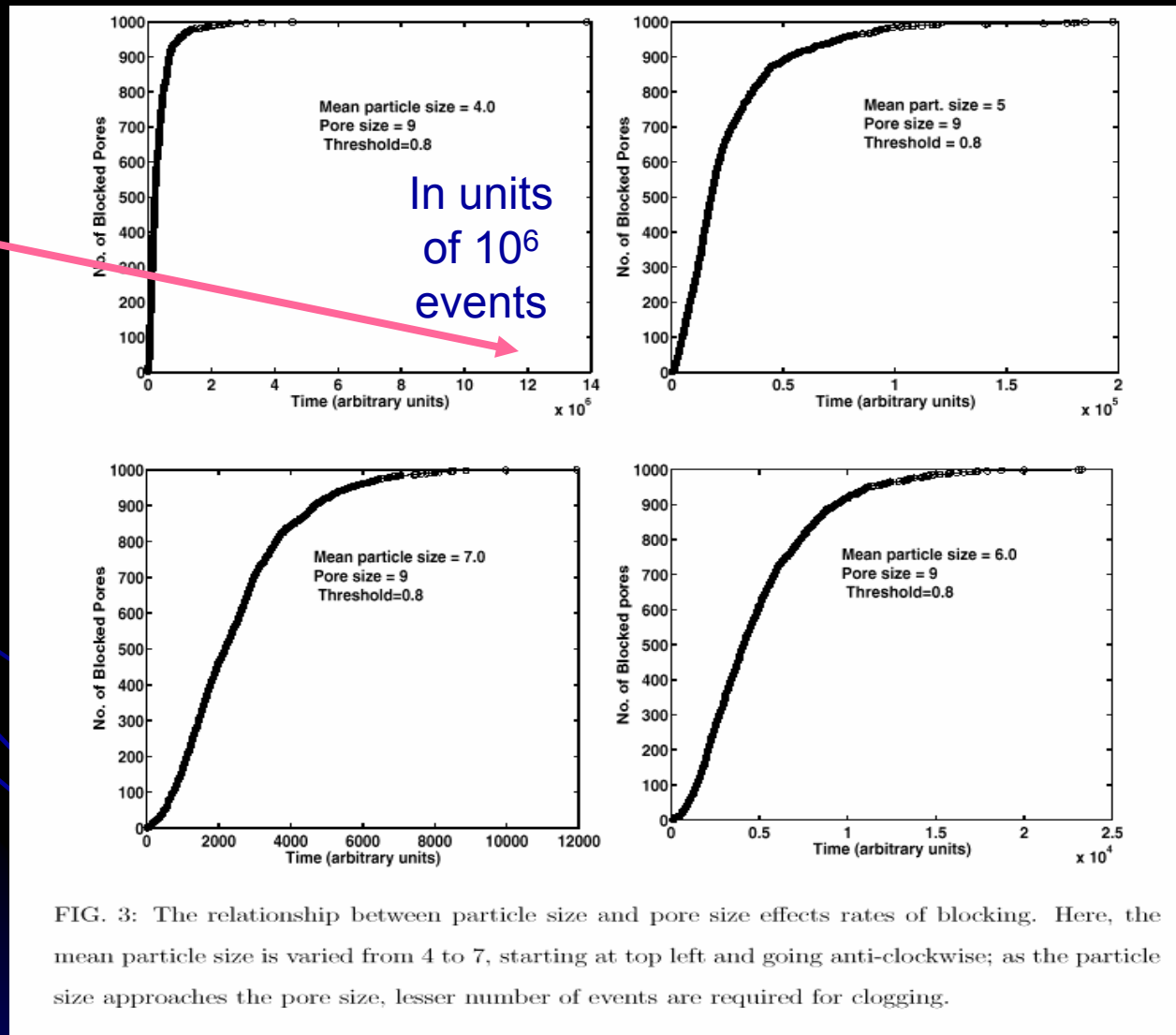


FIG. 2: The clogging rate— defined here as the average amount of block in an event, or, in other words, the fraction of a pore that is blocked in an event— varies as the number of blocked pores increase. It is seen here that, regardless of threshold (increases in units of 0.1, starting at 0.6 at the top left and going anti-clockwise), the form of this variation is the same. However, the rate itself decreases by two orders of magnitude as the threshold increases.

# Particle size vs Pore Size Effects in Blocking

Smaller particles lead to long blocking times



## 5. Summary

- Dust particles are NOT spherical
- Size range  $10^{-2} - 10^2 \mu$
- Dust particles grow in size in time (T, humidity matter)
- Dust bunny formation needs study (?)
- Filter saturation times at least seem to be controlled by
  - (i) Pore size, (ii) Mean size of dust grains,
  - (iii) Threshold

# Open questions on which there is not much refereed literature around

- Dust generation – by human bodies, clothing, ongoing processes, etc.
- Dust removal by mites – what is the optimum rate?
- Structure of dust bunnies – length scales versus formation time, geometrical features versus formation times
- Filters should be such that big rods and small rods will get blocked rapidly and keep the air clean – so pore size, threshold, changing mean size of dust ... should matter
- Dust growth rate must balance filter rate such that dust levels are optimum ...