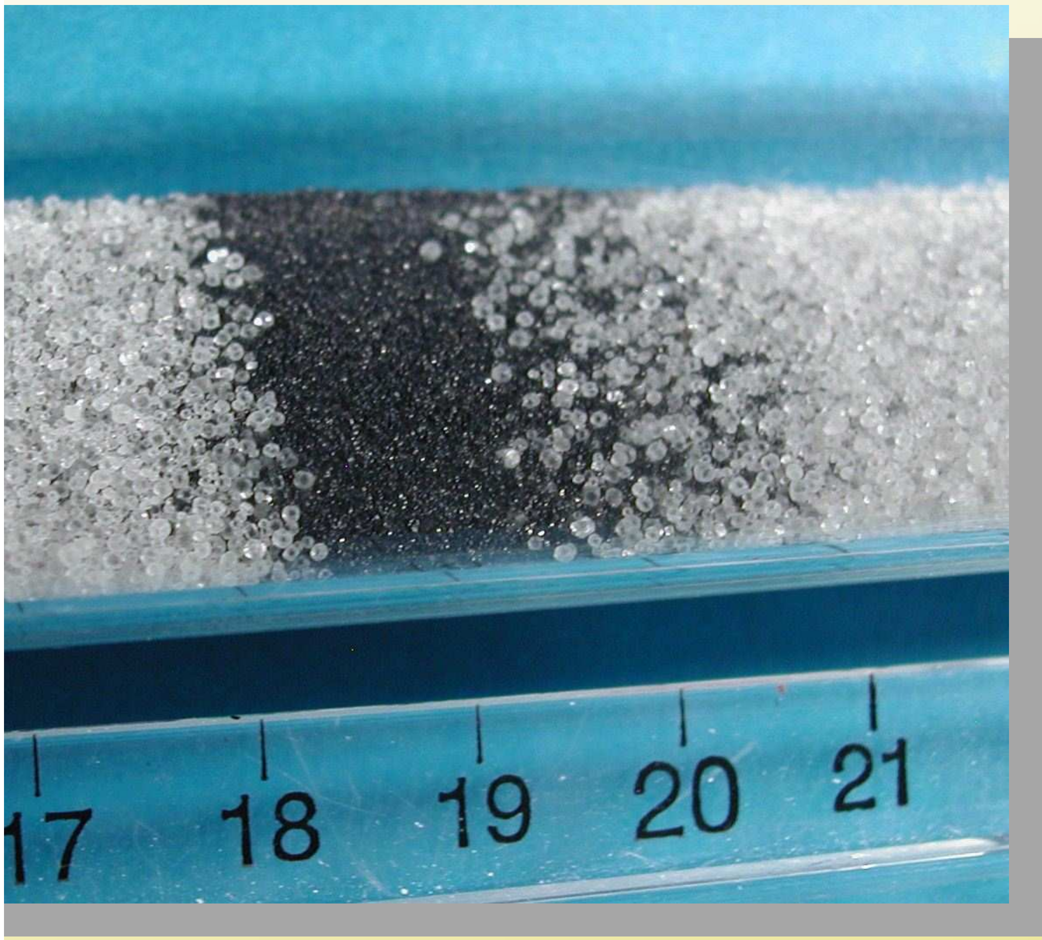
Subdiffusion in granular segregation experiments



- Zeina Khan
- Wayne Tokaruk
- Kiam Choo
- *Stephen Morris*

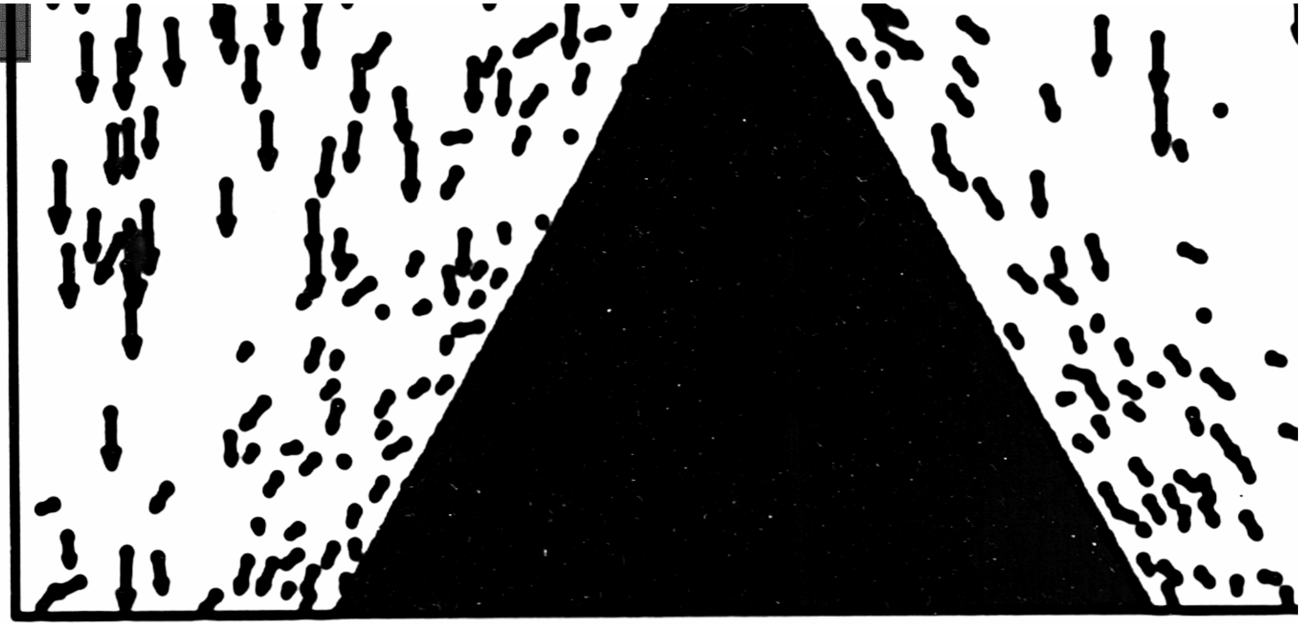

systems
Consist of discrete macroscop


systems
Stress chains in a
2D shear experiment
D. Howell and R. B. Behringer
Phys. Rev. Lett. 82, 5241 (1999).
Collective continuum behaviour is not captured by
any single well-agreed-upon differential equation.

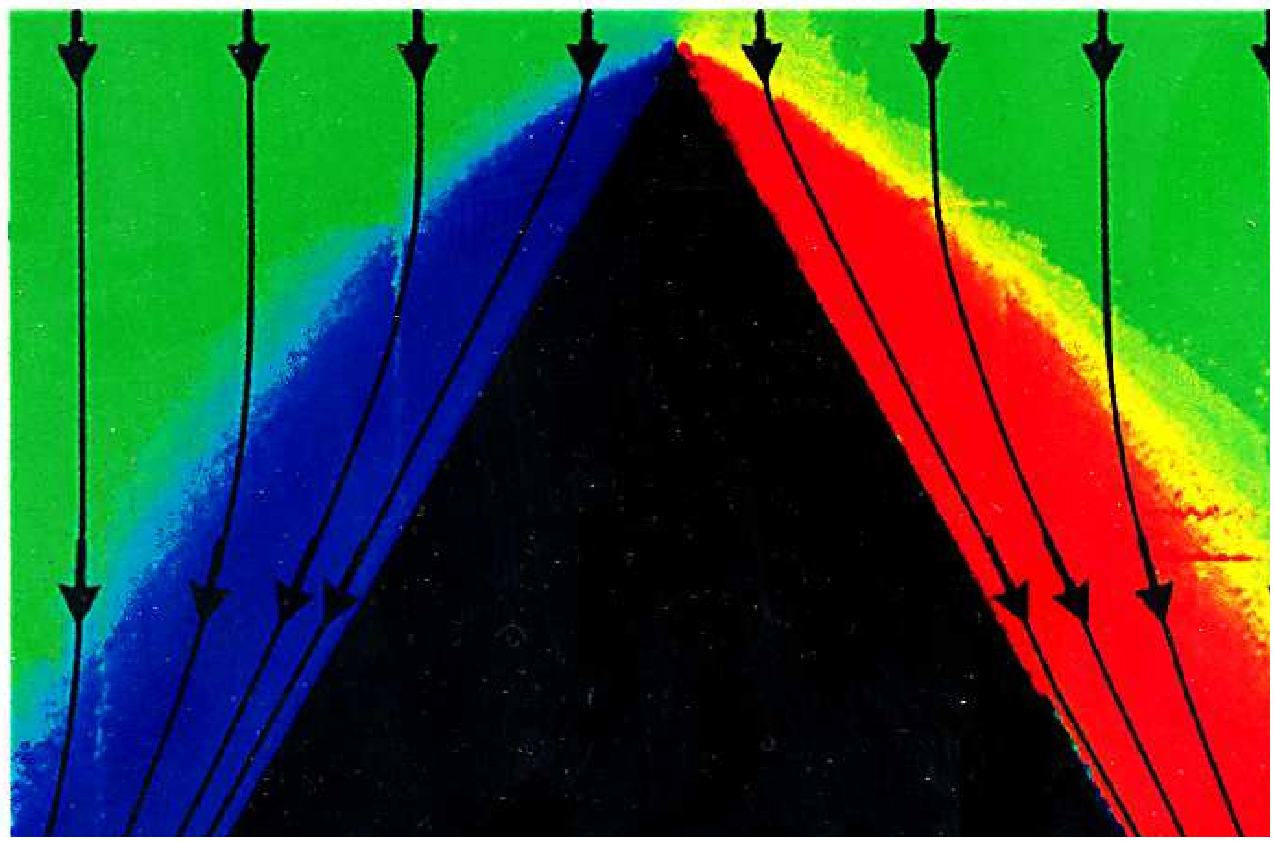
Granular systems

highly
ed" flows are
y
uilibrium,
ense gas
, shocks etc.

richa, C. Bizon, M.
k and H. L. Swinney,
ev. Lett. 88, 014302
(2002).



Time Averaged Horizontal Velocity Field



Granular systems

nelastic
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stering in
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gases

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, coefficient of
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dhirsch and G.
Phys. Rev. Lett.
1619 (1993)

systems

lar layers
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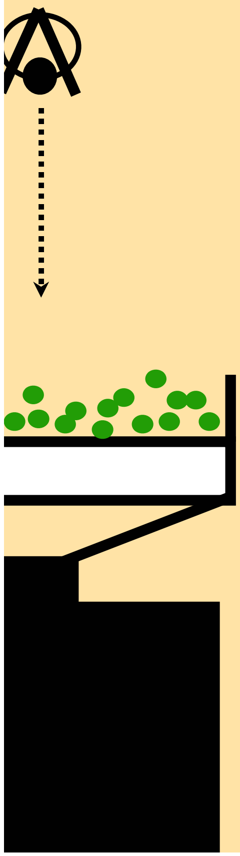
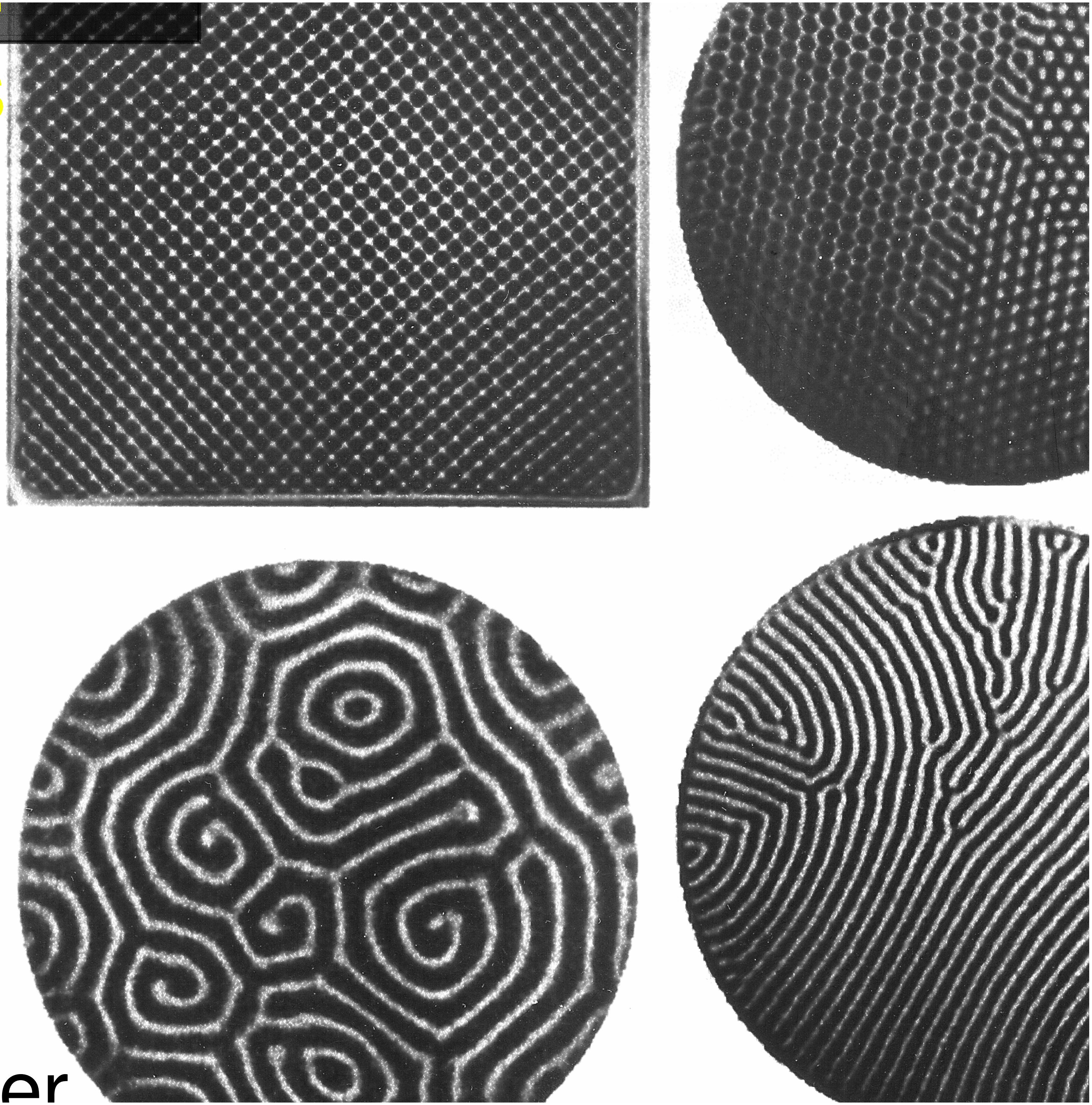
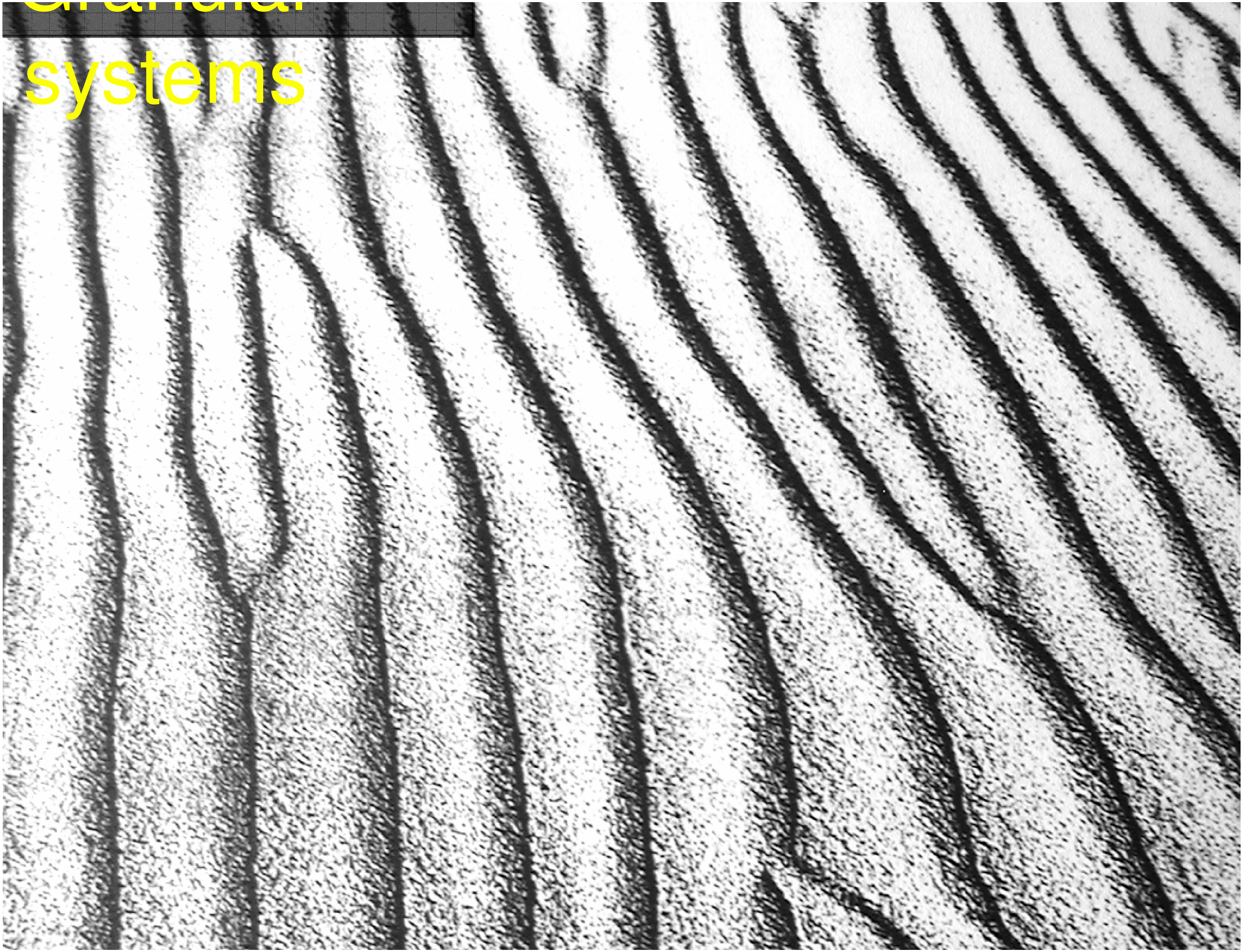


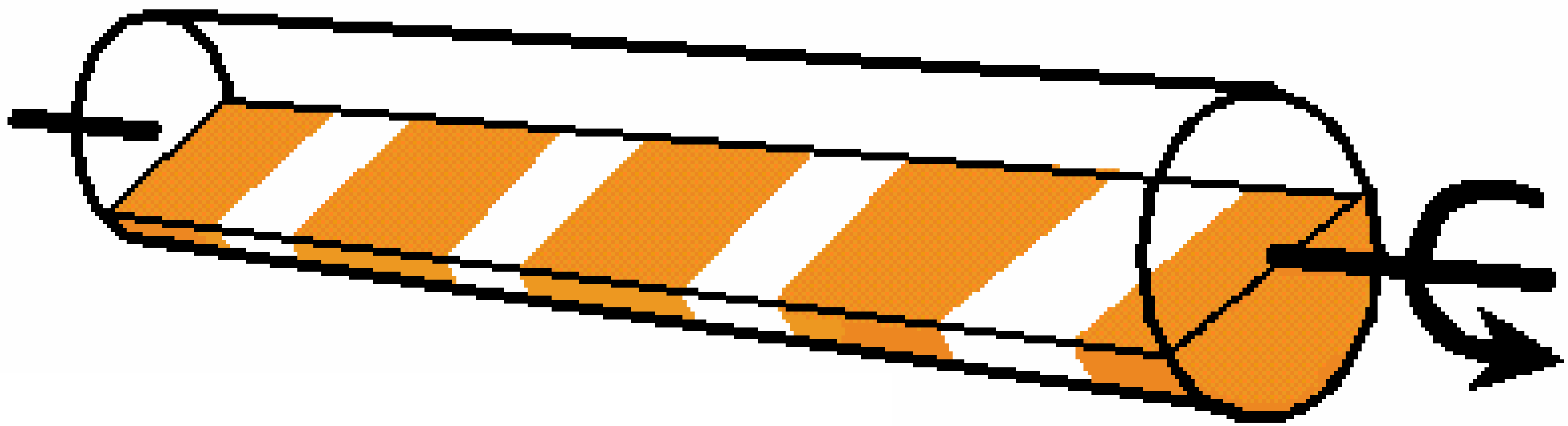
shaker




systems

Granular systems

ize segregation in a long" drum mixe



grains = white *(table salt or glass spheres*

m

ll grains = **black** *(hobby sand)* ~ 0.2mm

ω = rotation frequency $\sim 2\pi/1s$

η = filled volume fraction $\sim 1/3$

Φ = composition fraction

Movie of axial segregation with random premixed initial conditions

QuickTime™ and a
None decompressor
are needed to see this picture.

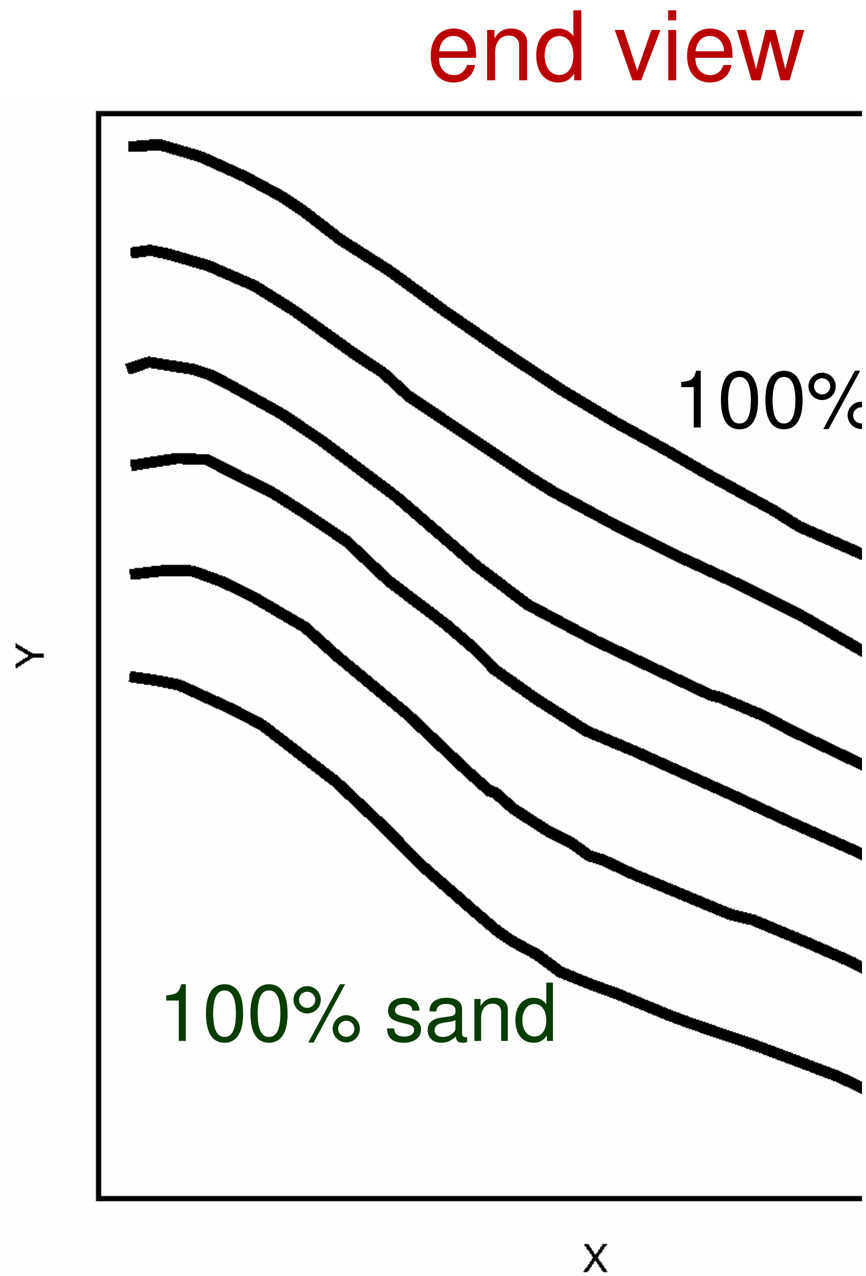
Speeded up 60 X real time

ʼerfectly premixed initial conditions are difficult to ›roduce. We use a long U channel which is otated in the tube to gently deposit premixed

ial segregation
des axial. Smaller
les move toward axis of
on.

aming surface shapes
erent concentrations
fferent. S-P. Breton.

y ideas tried to explain
segregation with a
ive effective axial



with random premixed initial

conditions

rve rather

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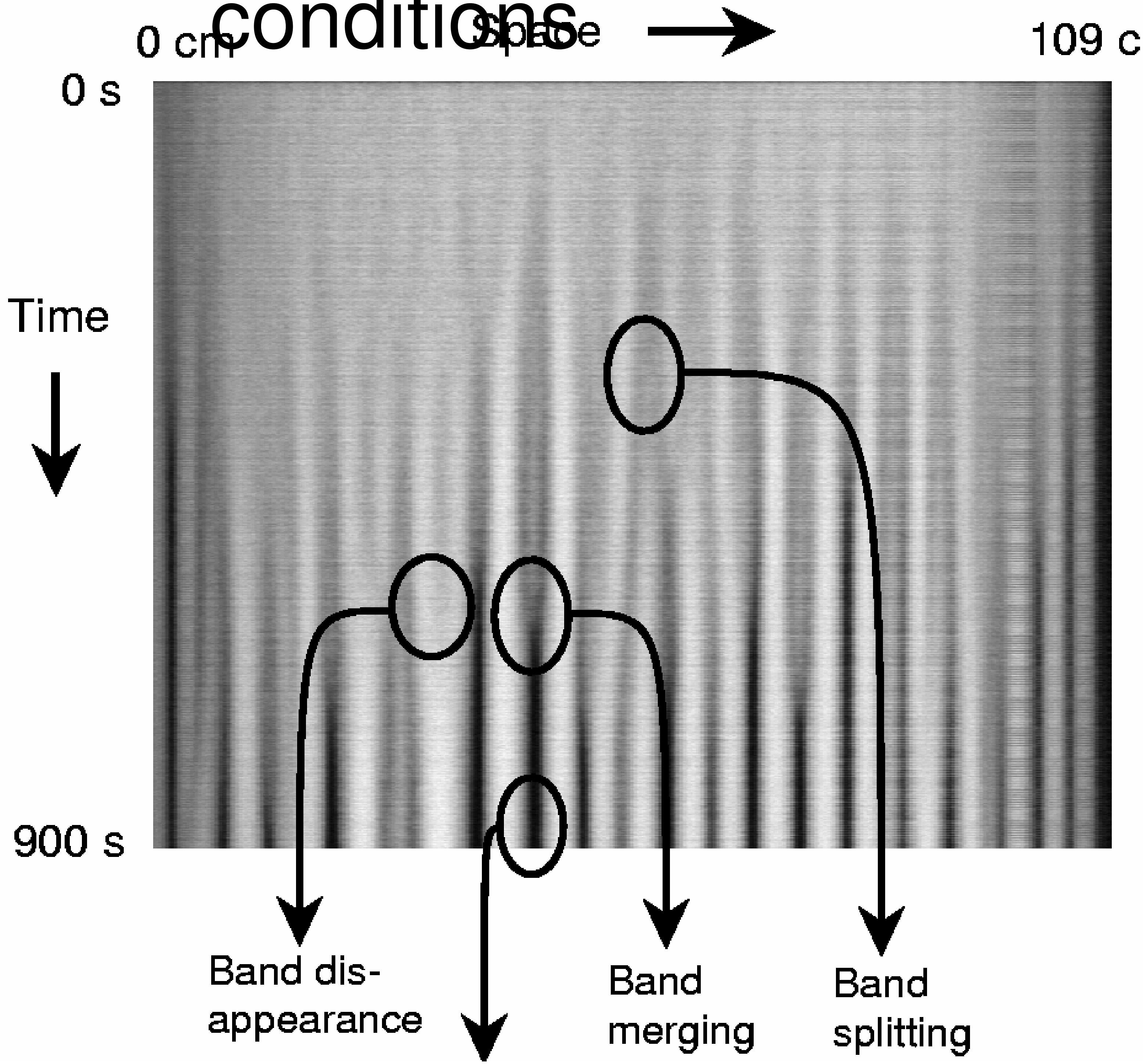
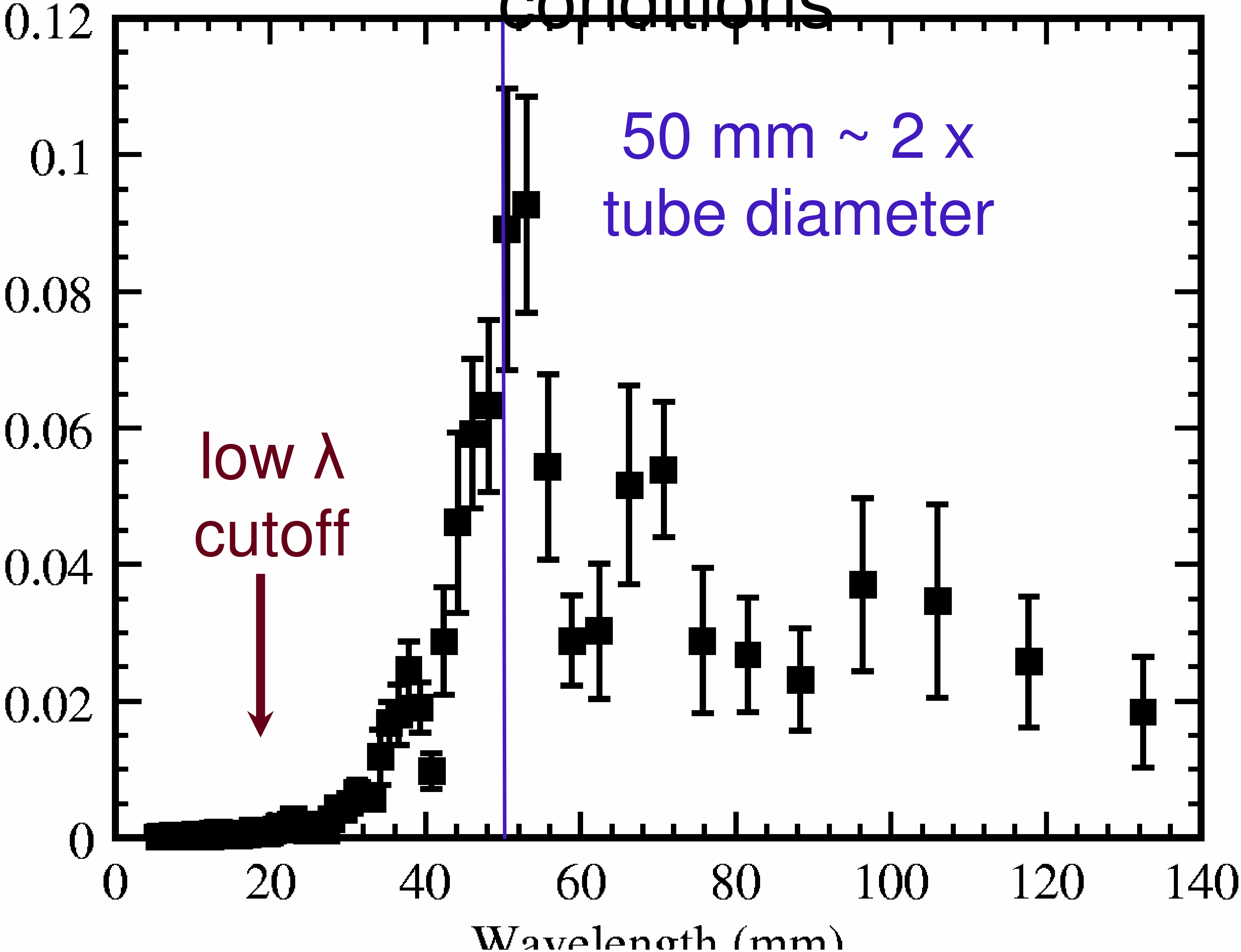
= 0.5



bands with random premixed initial conditions



with random premixed initial conditions

= 0.66

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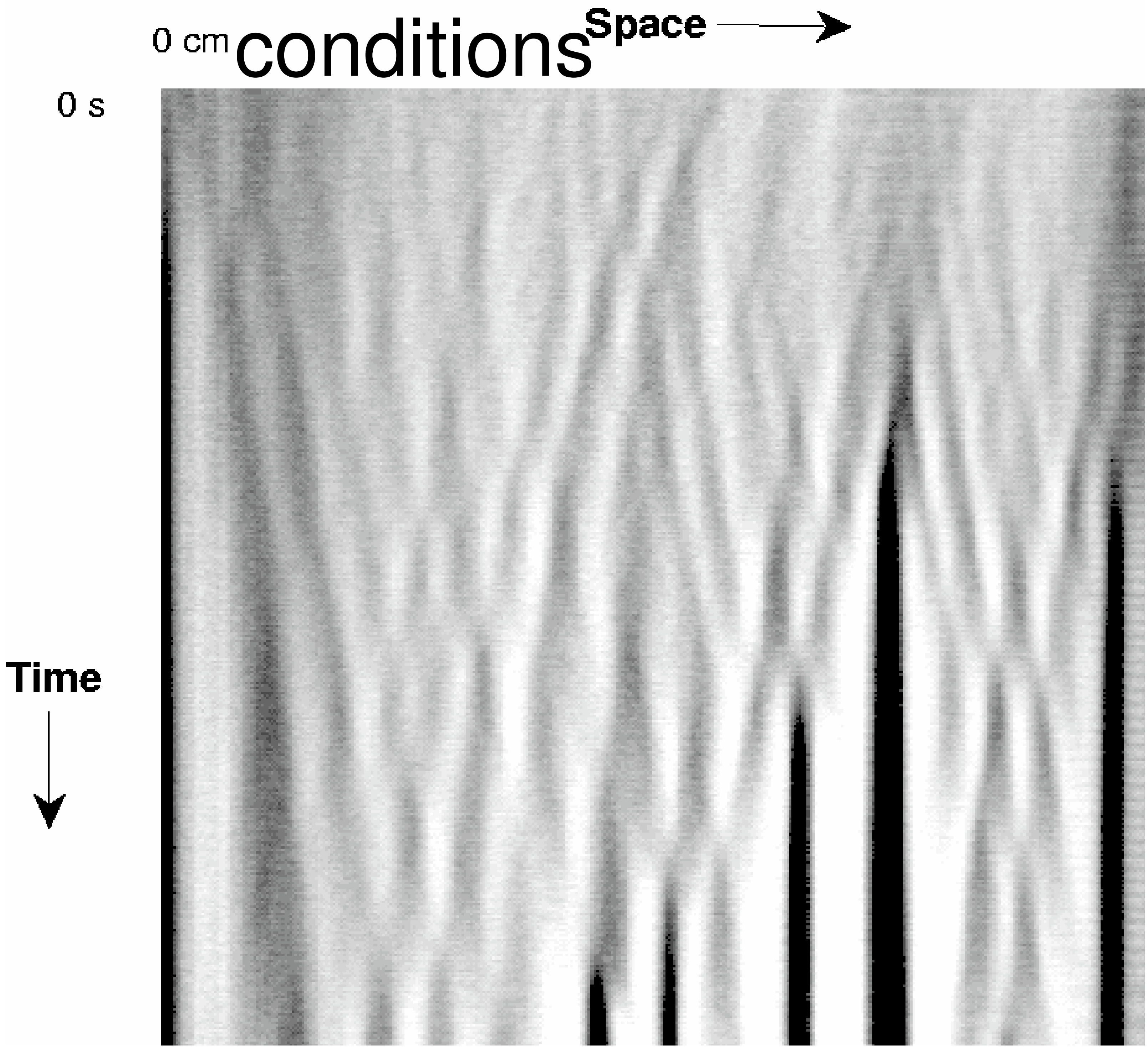
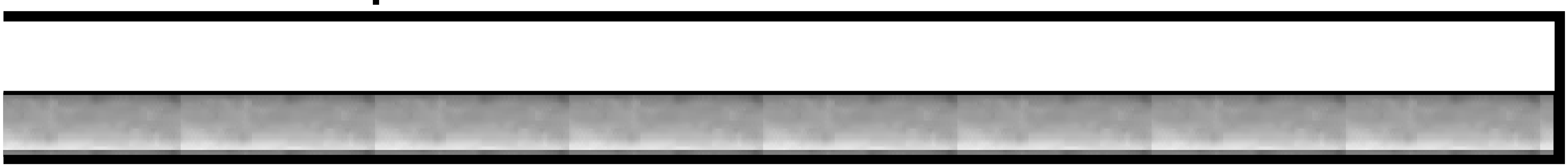


premixed initial conditions

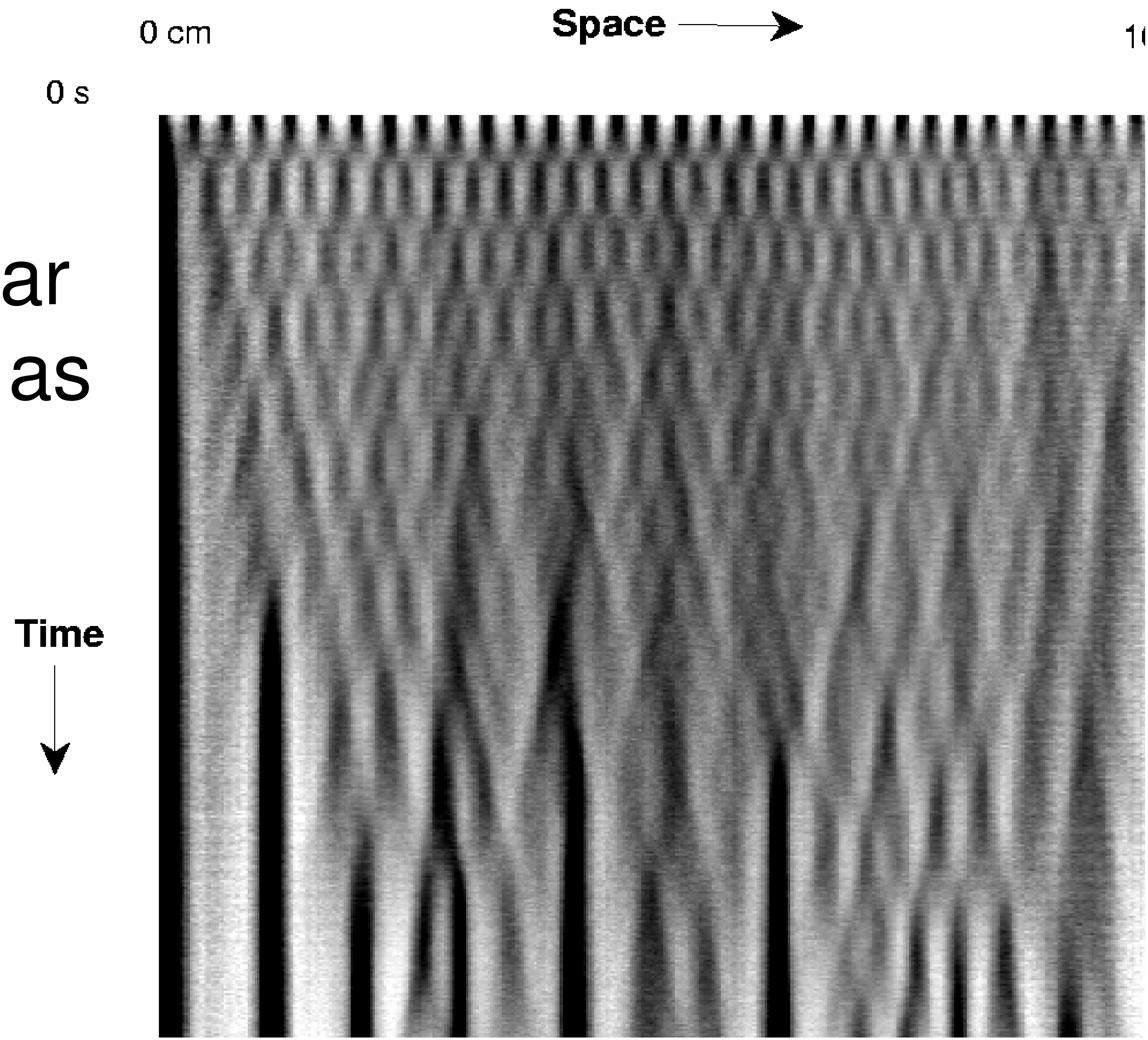
nstability amplifies fluctuations in the initia
entration distribution so the transient dyna
eproducible. Solution: use presegregated
itions.

premixed with fluctuations



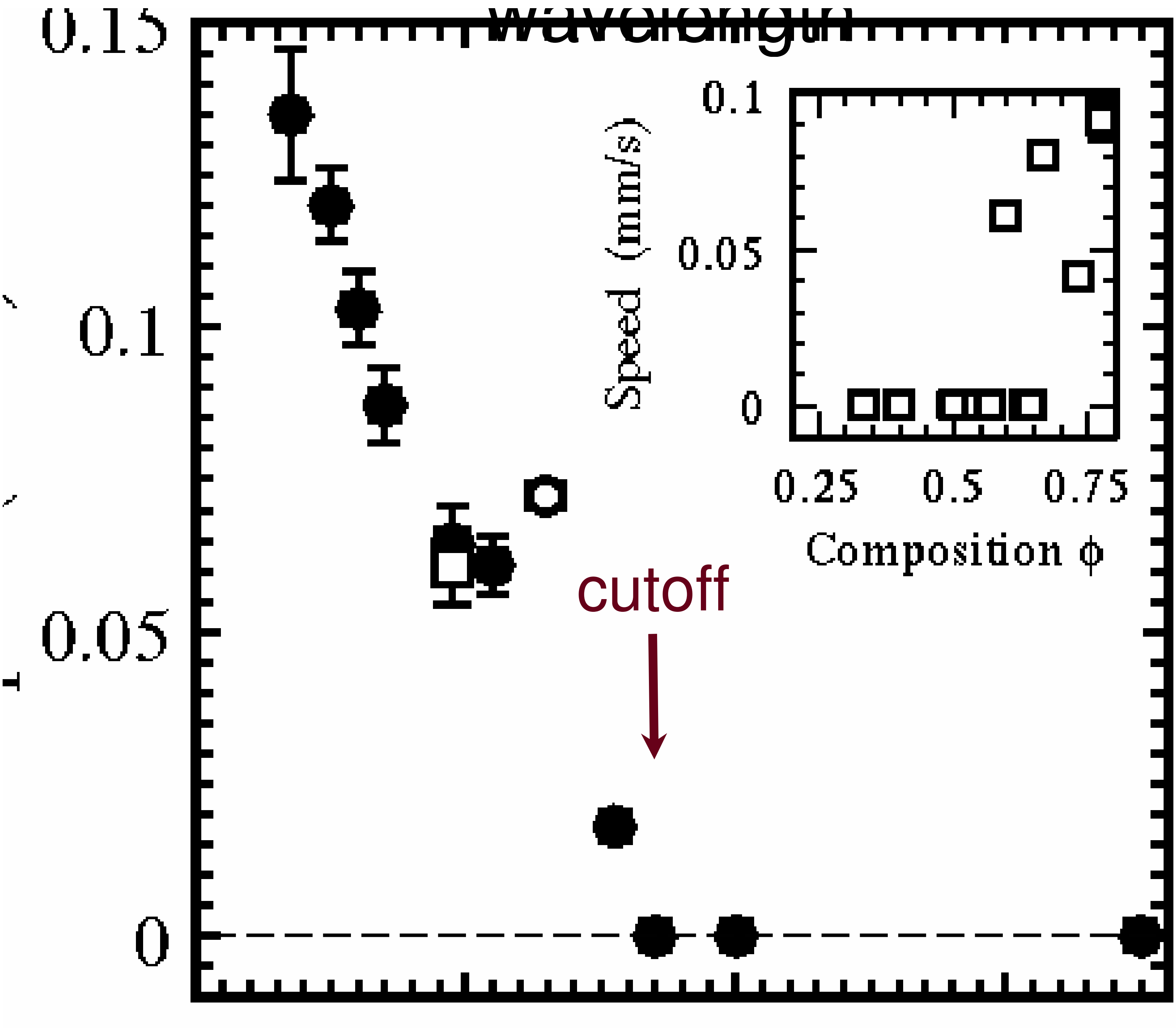
presegregated with fixed Φ and λ

with *presegregated* initial conditions



see a clear
ng wave as
lecaying
ansient

= 0.66



wavelength
0.15
0.1
0.05
0
cutoff
Speed (mm/s)
0.1
0.05
0
0.25
0.5
0.75
Composition φ

ve a coupled diffusion process between
concentration $c(z)$ and the local streaming
e

$$= -\frac{\partial}{\partial z}\Big[- D\frac{\partial c}{\partial z} + g(c)\frac{\partial \theta}{\partial z}\Big]$$

Fick diffusion

axial slope gradient flux

$g(c) \sim 1 - c^2$

$$\alpha\big[\Omega - \theta + f(c)\big] + D_\theta \frac{\partial^2 \theta}{\partial z^2} + \gamma$$

rotation rate and concentration dependent source of slope

slope diffusion

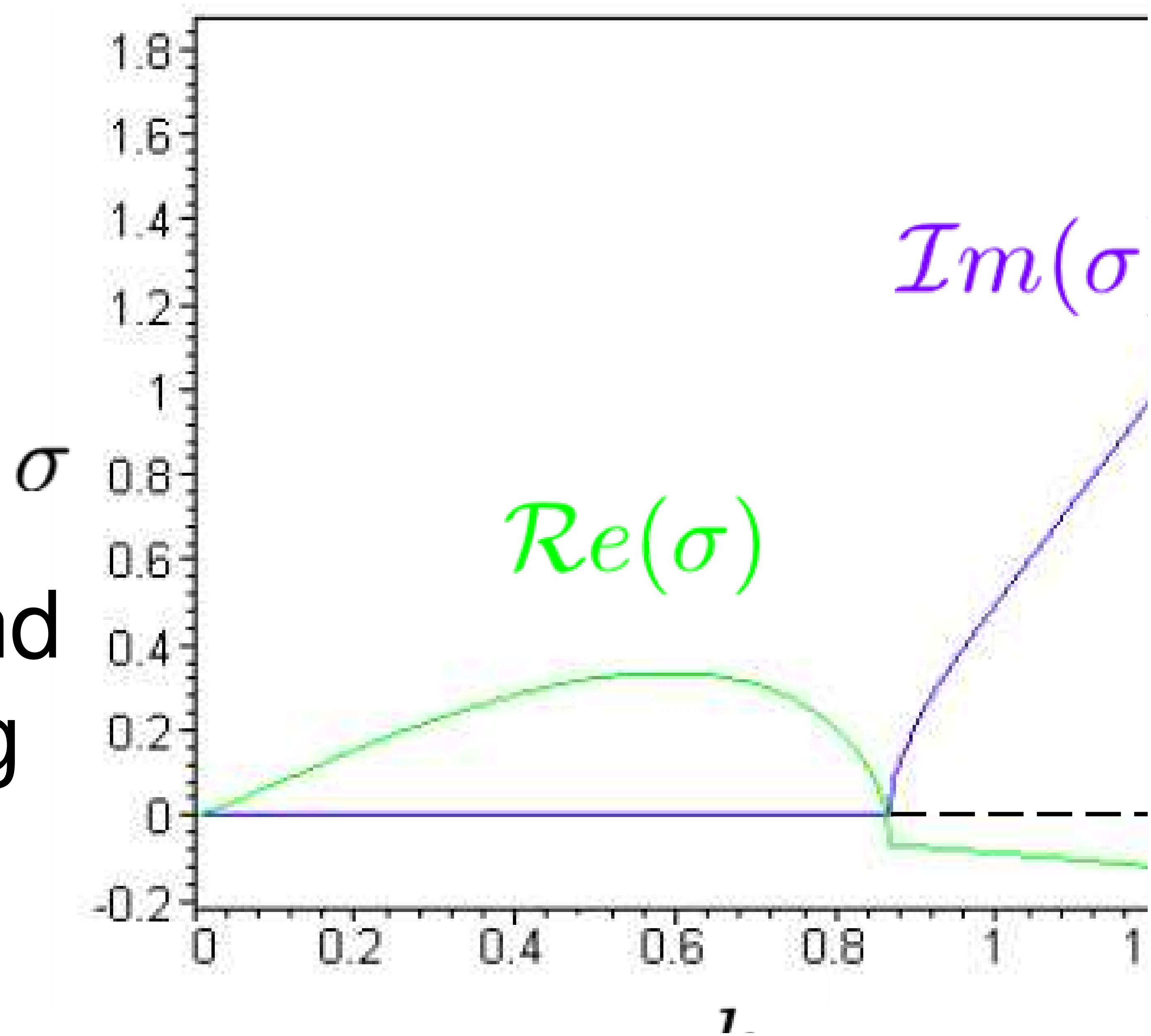
cou
allov

Uniform state: $c = c_o$, $\theta_o = \Omega + f(c_o)$

$c_o + Ae^{\sigma t+ikz}$

$\theta_o + Be^{\sigma t+ikz}$

rowing non-
atory modes
' a cutoff *k*, and
atory decaying
s above.



waves

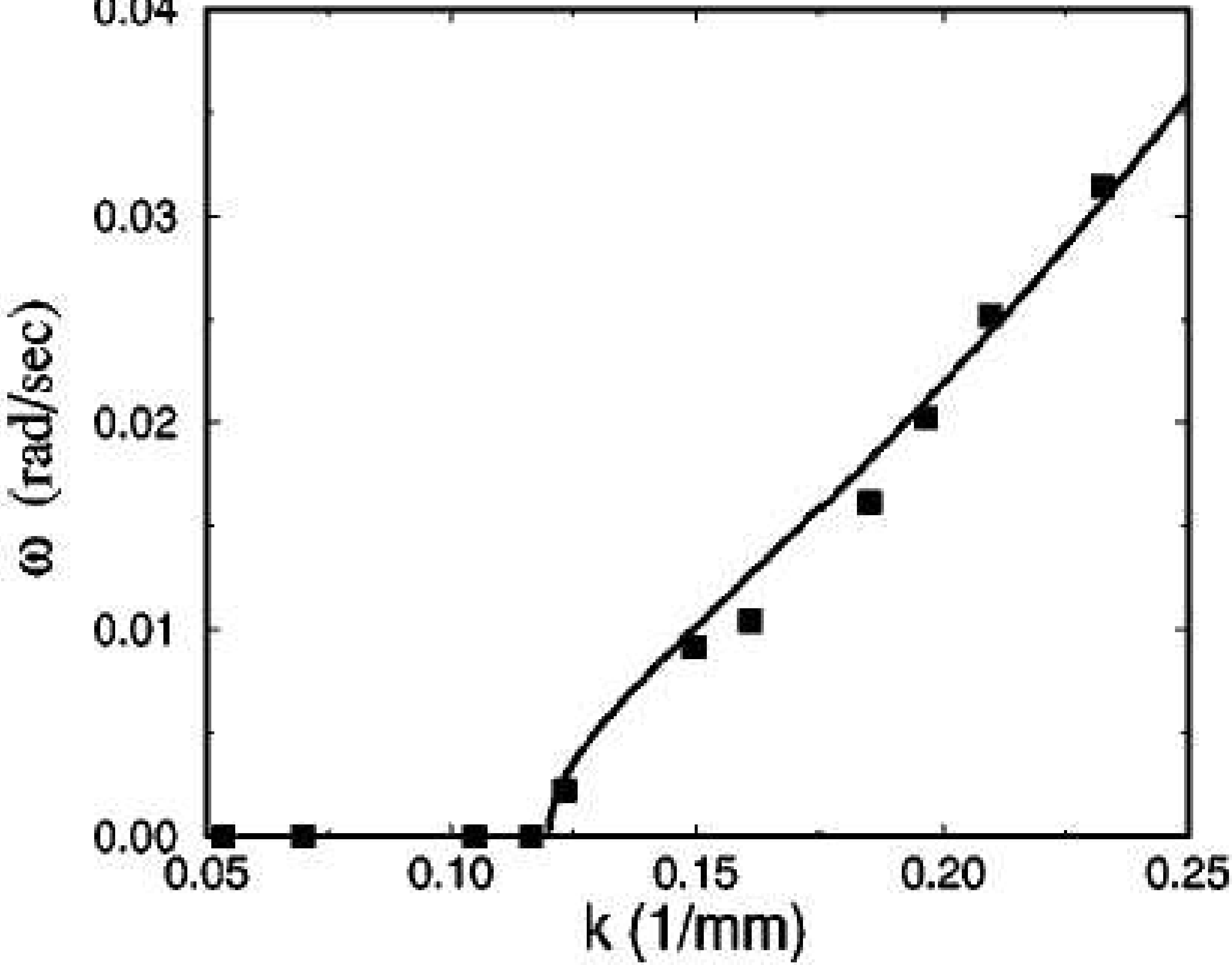
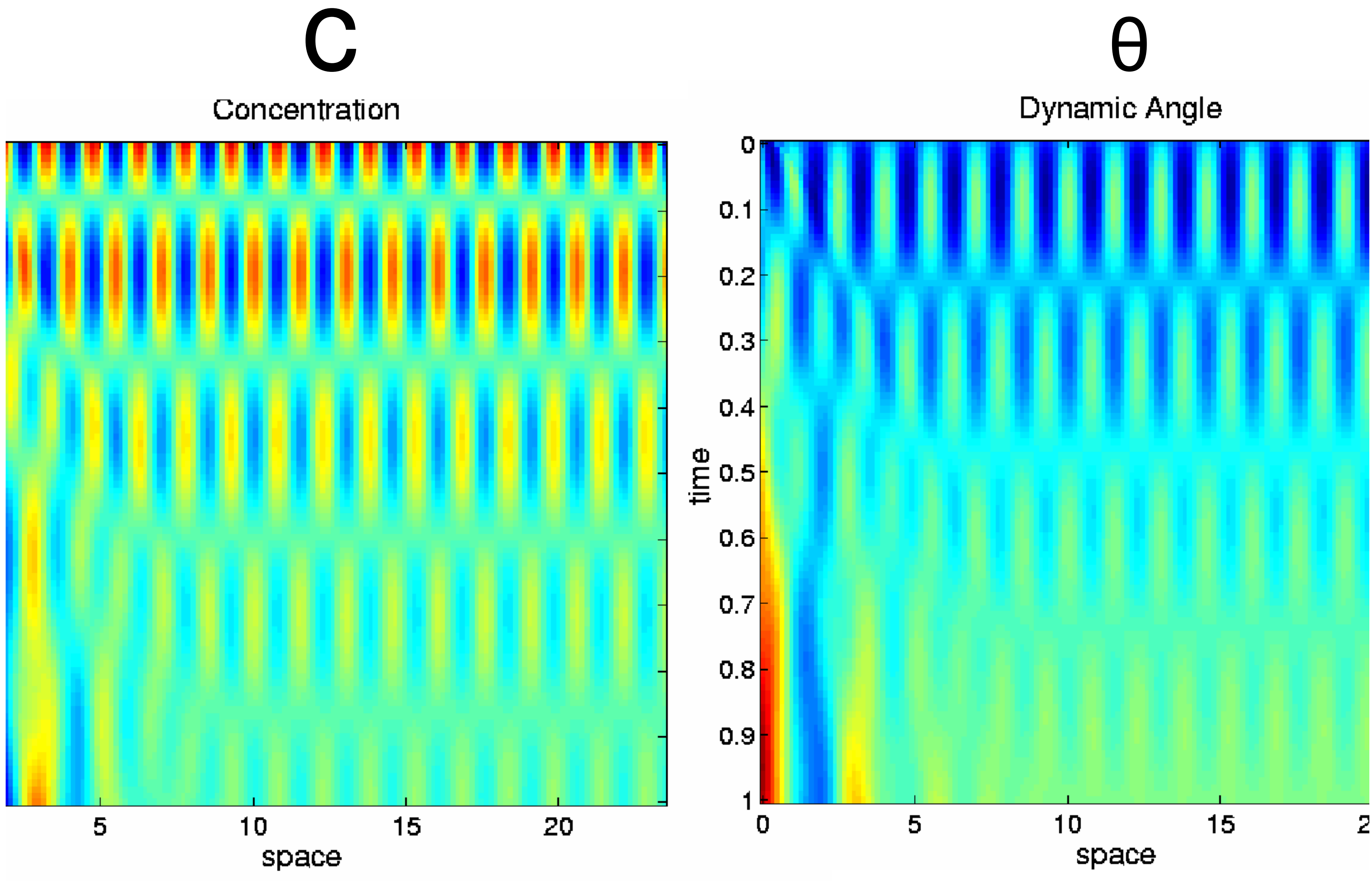
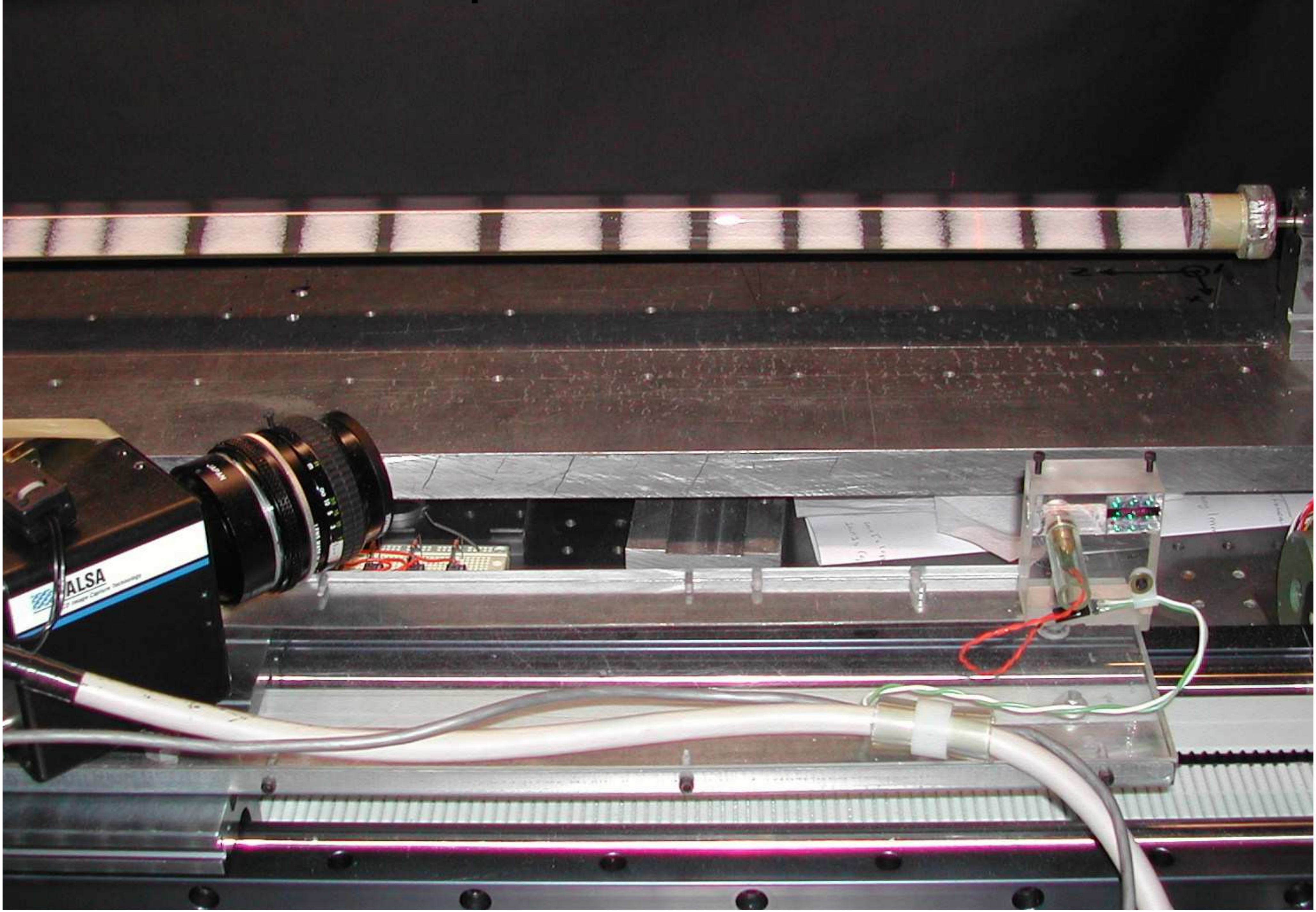


FIG. 3. Comparison of theoretical results ω vs k (solid line) with experimental data of Ref. [6] (squares). The values of parameters

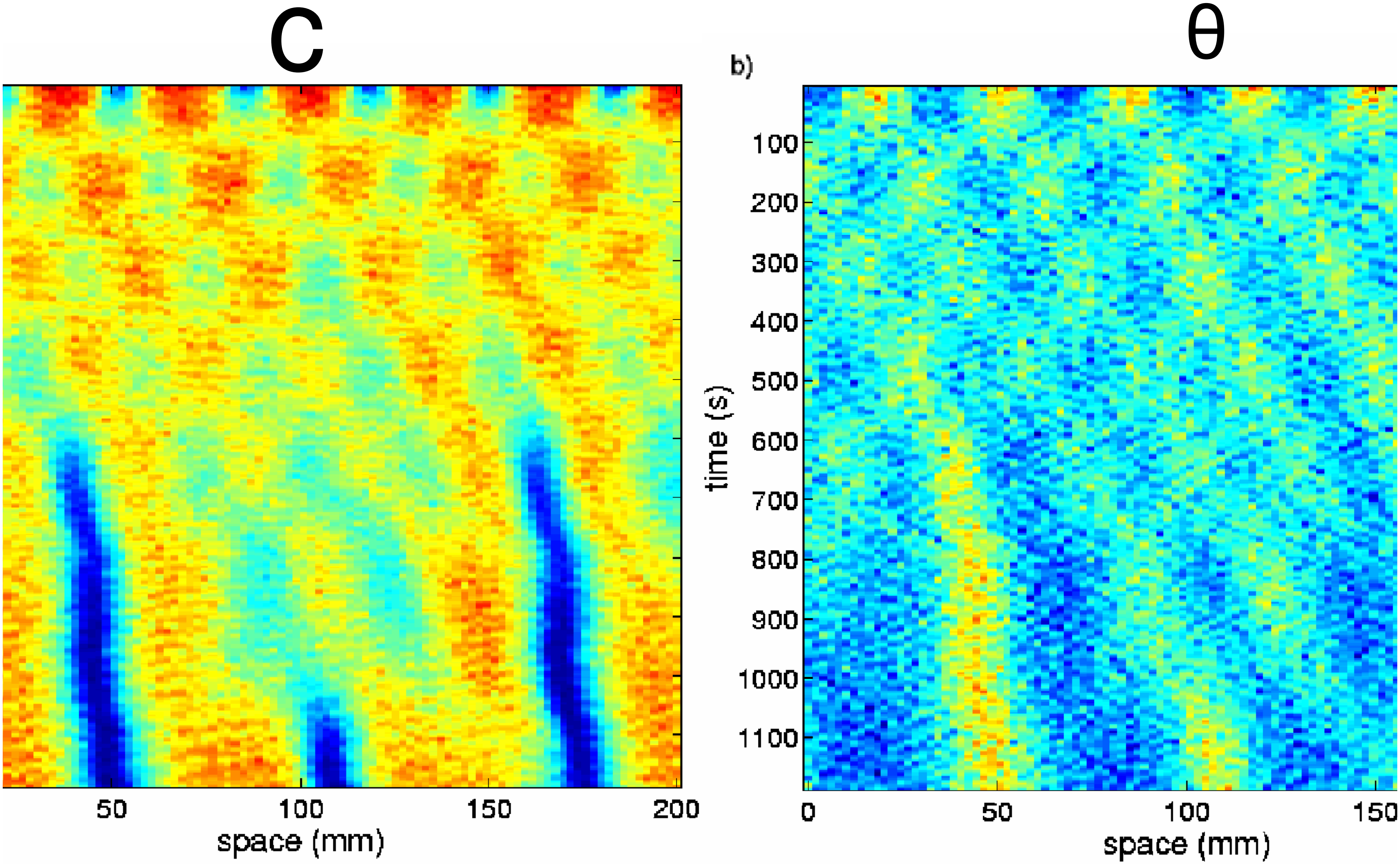


c and θ are π/2 out of phase at early

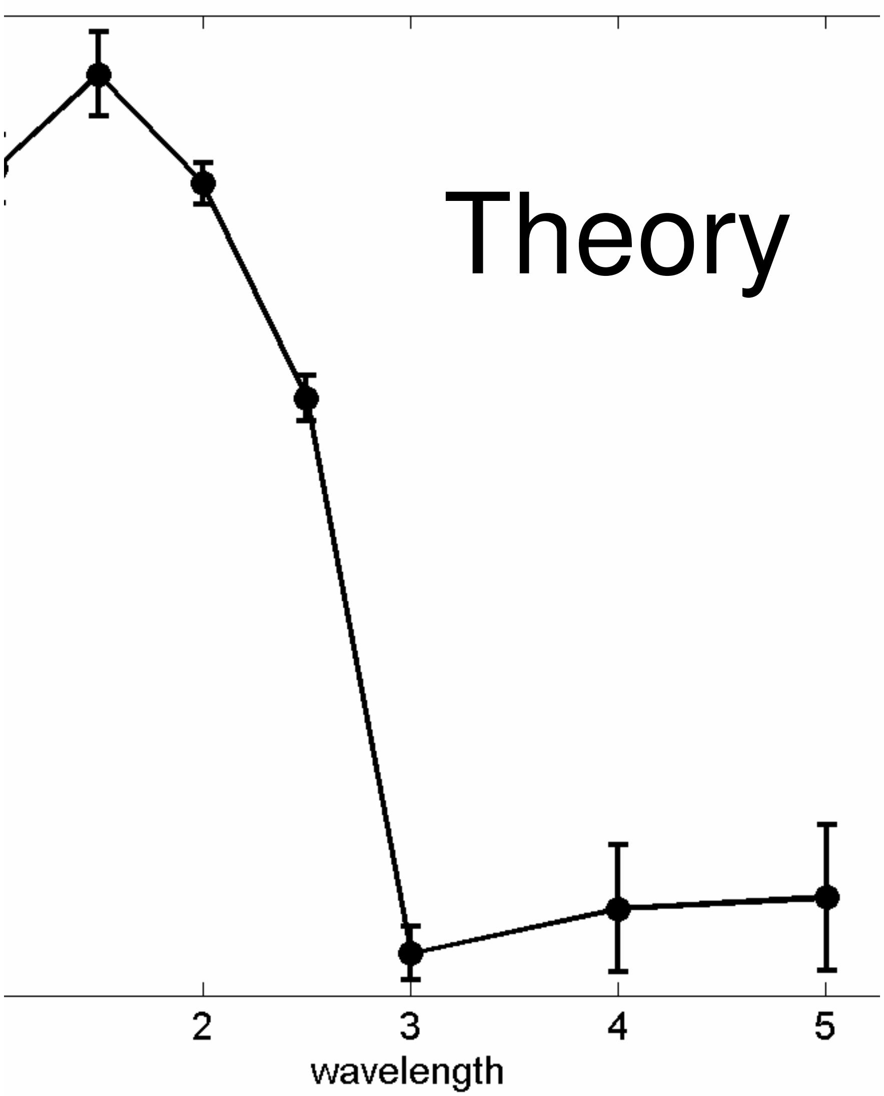
profilometer

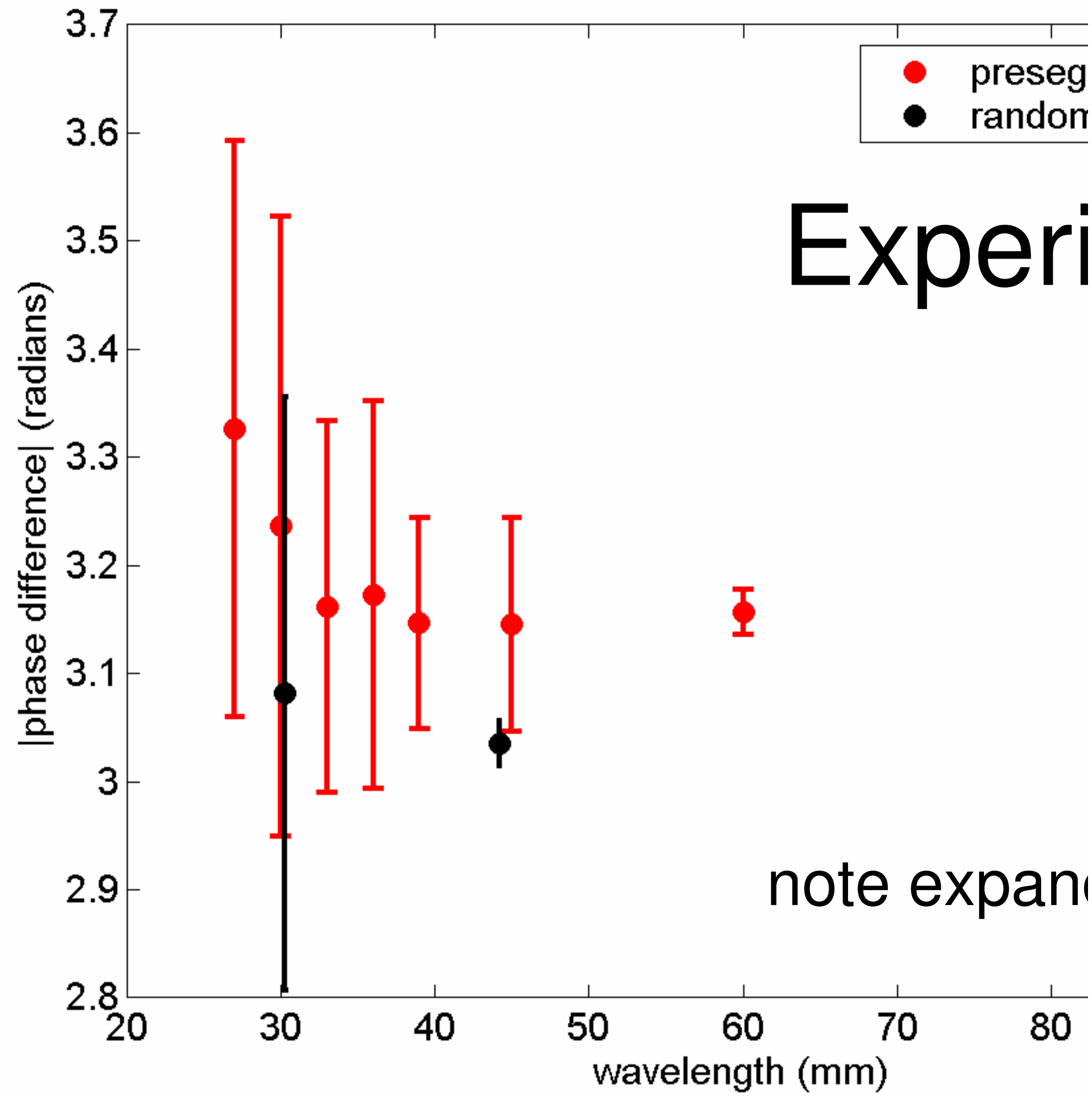


measurements contradict ATV theory



measurements contradict ATV theory





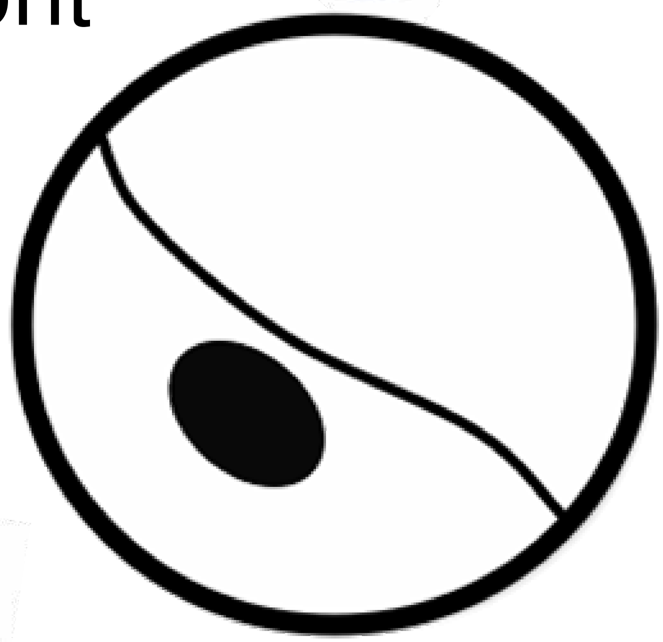
This shows that surface slope is *not*

segregated core?

ɔs the buried core of small particles is dynamicall
ıging material with the surface and playing the ro

ca

ate between front
ack lighting



See the shadov
dark subsurfac

projection movies

front view

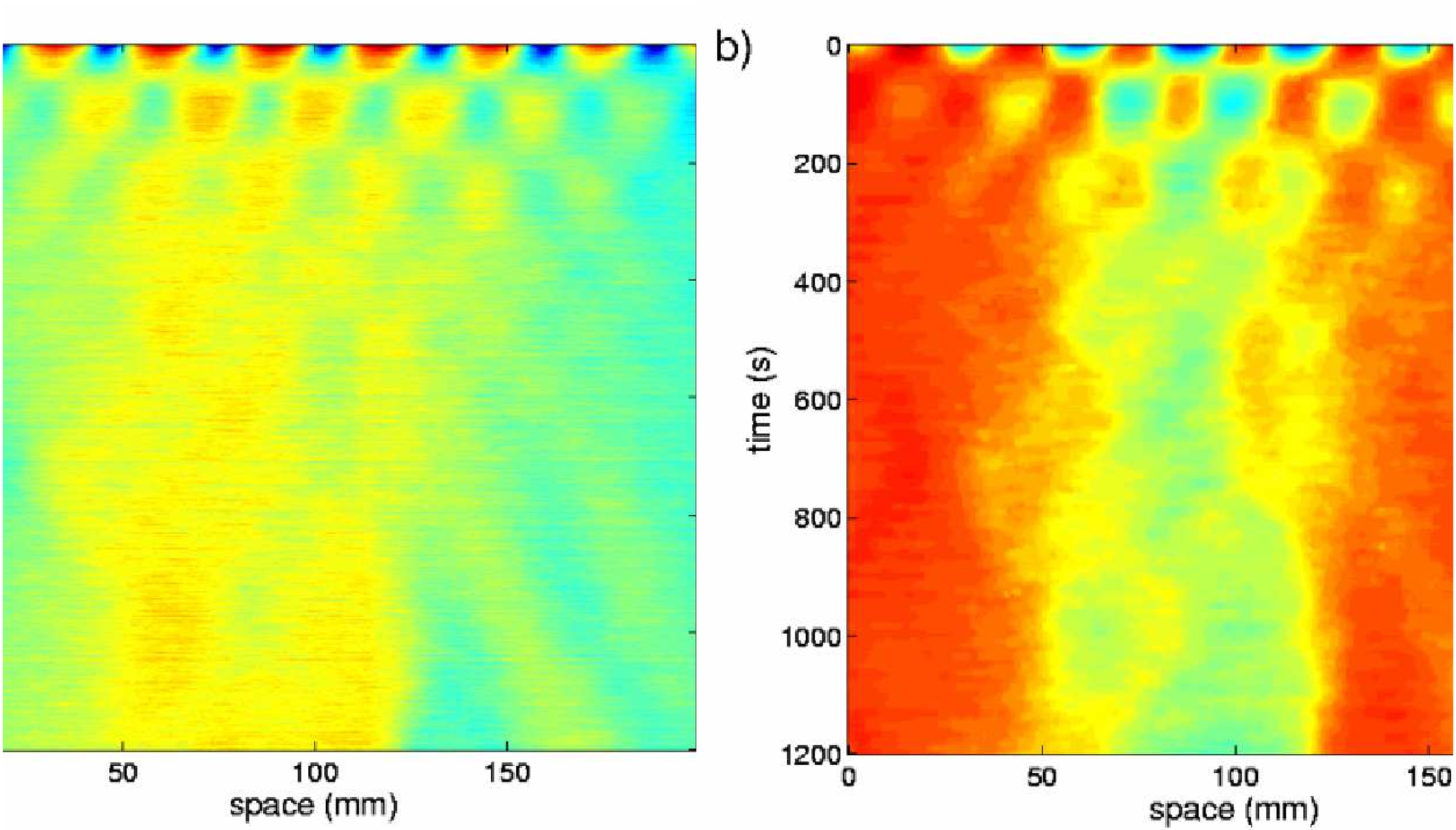
QuickTime™ and a
None decompressor
are needed to see this picture.

projection view

QuickTime™ and a
None decompressor
are needed to see this picture.

Spacetime view of surface and core projections

c core width



Oscillatory axial segregation remains a mystery!

- Segregation looks like an oscillatory
nstability of the radial core.

- We have not identified an out-of-phase
eld analogous to θ in ATV theory.

- Subtle charge effects *etc.* seem to have
een eliminated.

- Return to simplest questions about axial
ansport in the tube.

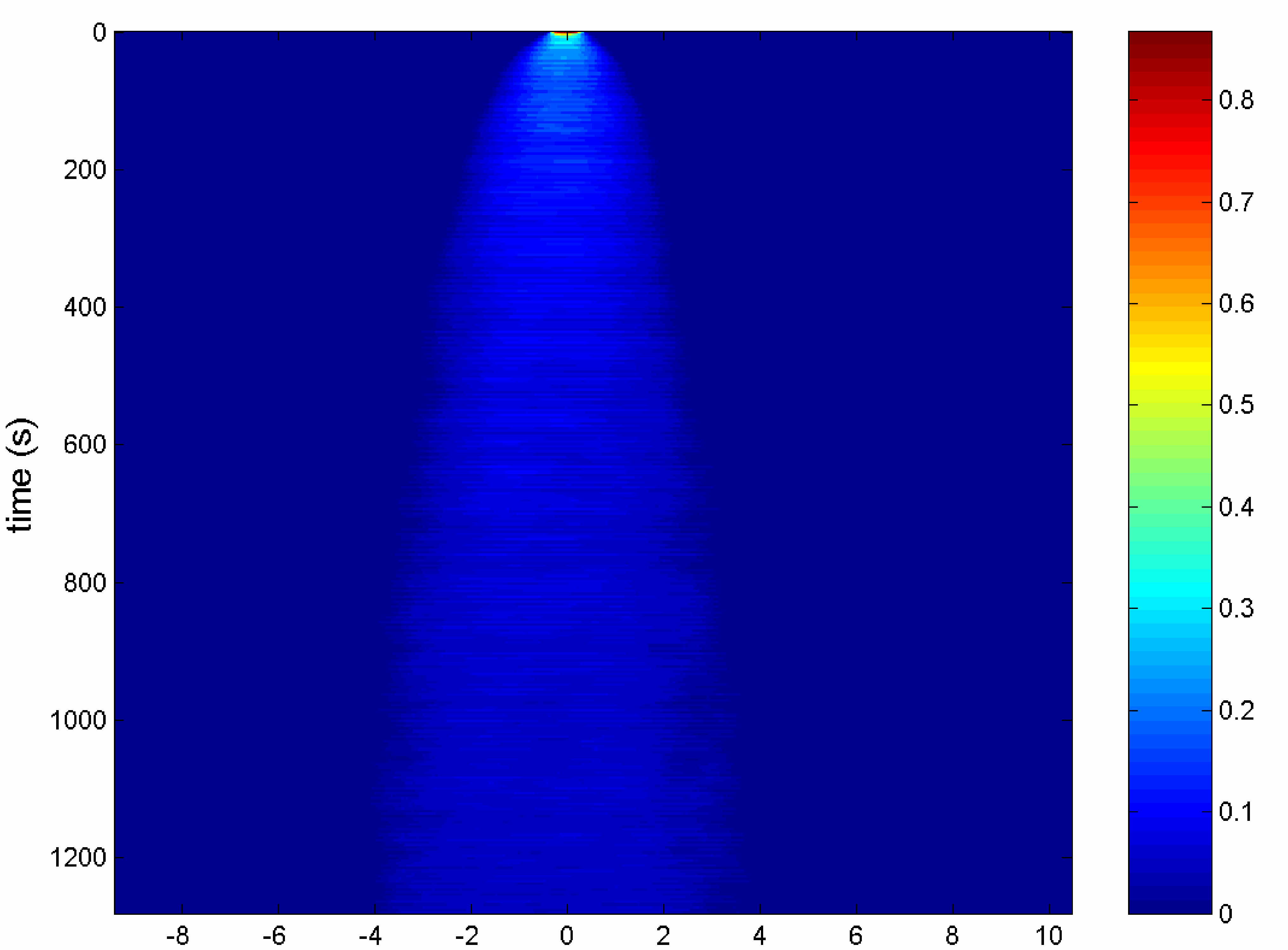
condition

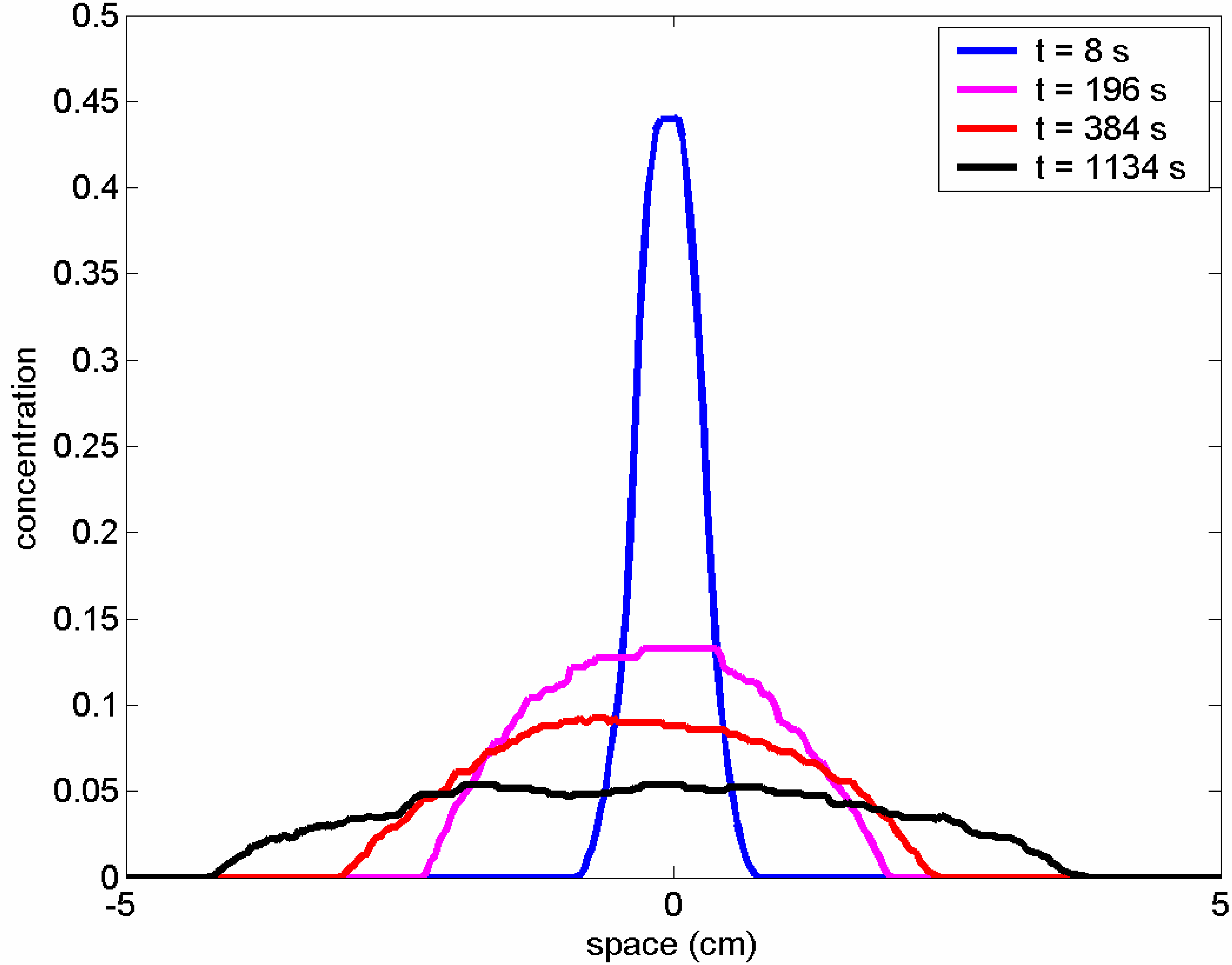
projection view

QuickTime™ and a
decompressor
are needed to see this picture.

ulse quickly moves to axis of rotation and become surface. It then expands slowly along the axis of tube.

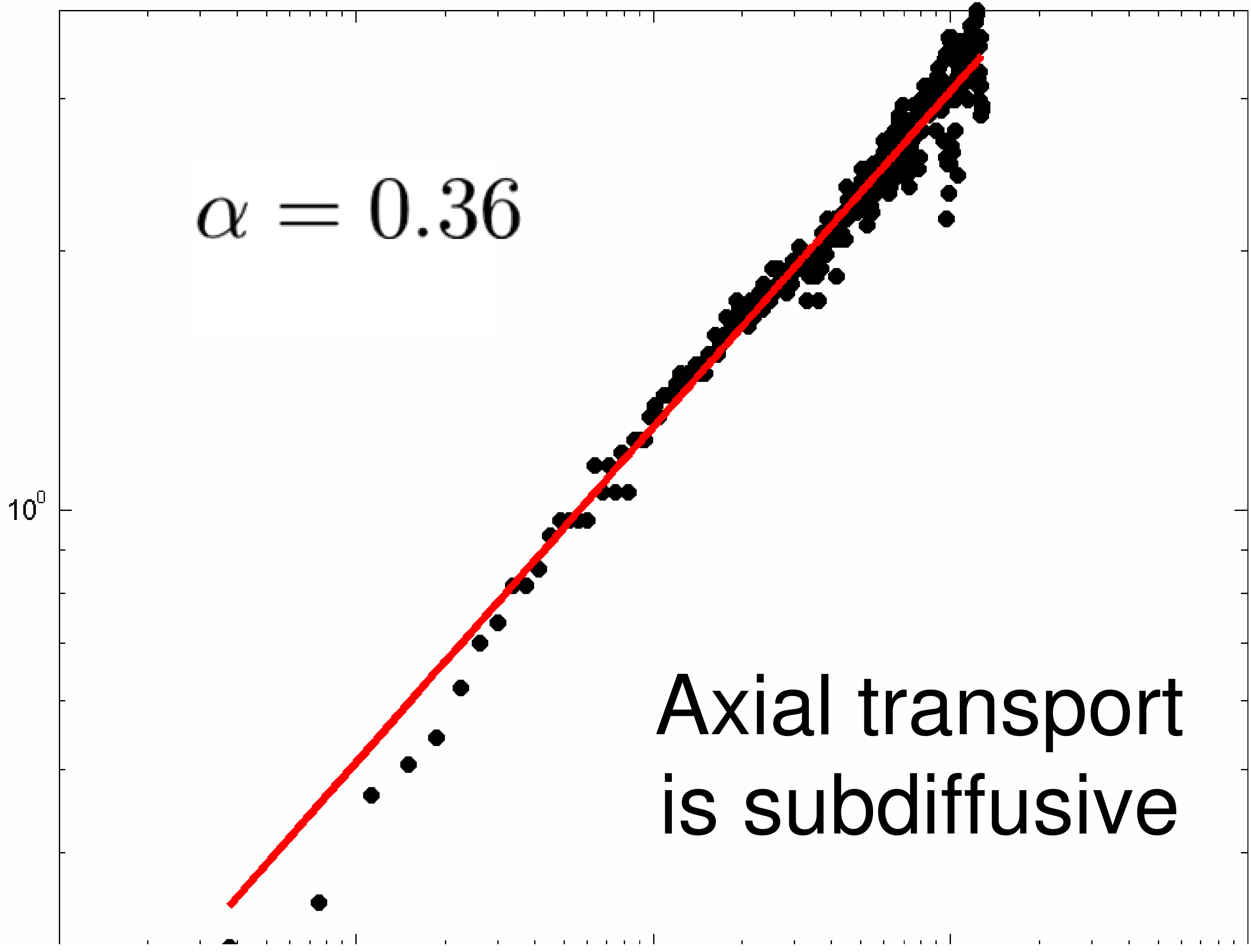
Is this regular diffusion?


time (s)
0
200
400
600
800
1000
1200
-8
-6
-4
-2
0
2
4
6
8
10
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0



studied the growth of the width of this distribution

time. For normal diffusion, we expect

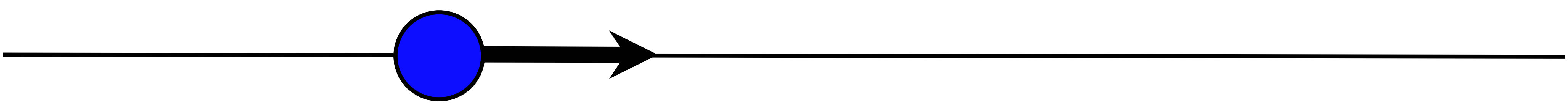


10^0
$\alpha = 0.36$
Axial transport
is subdiffusive

Fractional diffusion equation

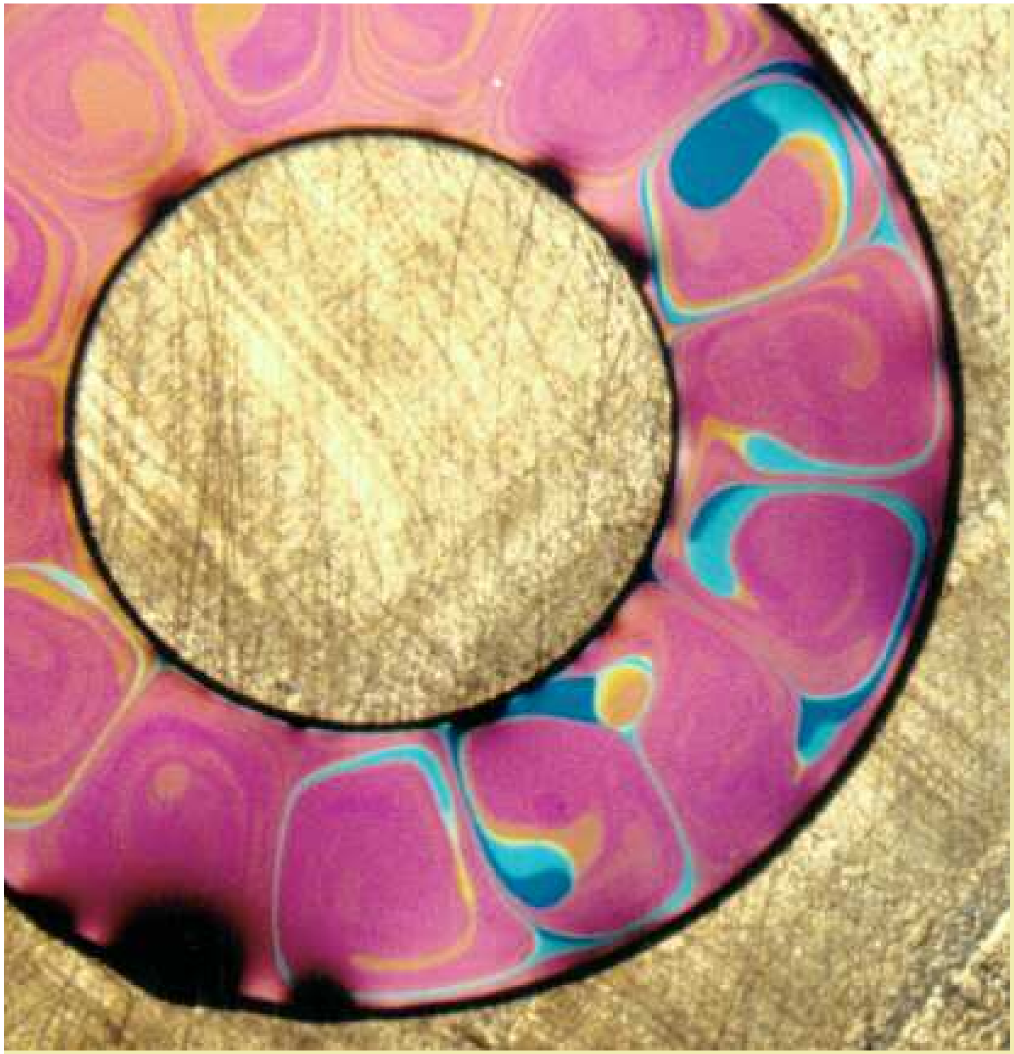
$$\frac{\partial^\beta C}{\partial t^\beta} = D \frac{\partial^2 C}{\partial z^2}$$

$\beta = 2\alpha, \quad \alpha = 1/2$ for normal diffusion



A 1D random walker with equal spatial steps taken at time intervals Δt such that $\langle \Delta t \rangle \to \infty$

find α ~ independent of tube rotation frequency.



You are invited to
the nonlinear phy
group lab!

Sunday at 1:00p
Monday at 1:00p

or anytime by appointm
smorris@physics.utoron

St. George St., Room 090 (north
sement). Go out the back door of Fields
d past the big smokestack...