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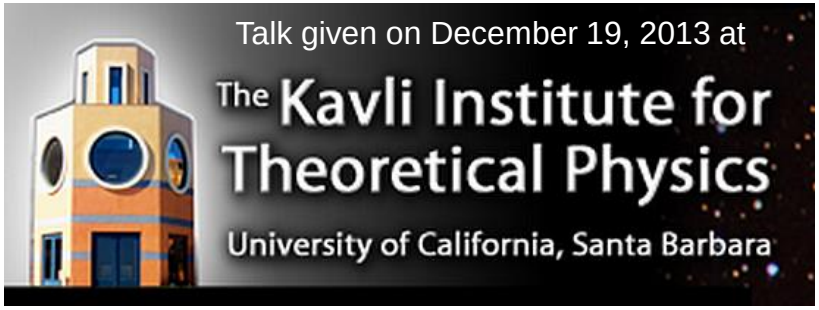


Hochschule Karlsruhe
Technik und Wirtschaft
UNIVERSITY OF APPLIED SCIENCES

# Where to Dig for Gold?
# Density Segregation inside Migrating Dunes

C. Groh[1], I. Rehberg[1], and C. A. Krülle[1,2]

[1]Experimentalphysik V, Universität Bayreuth, Germany
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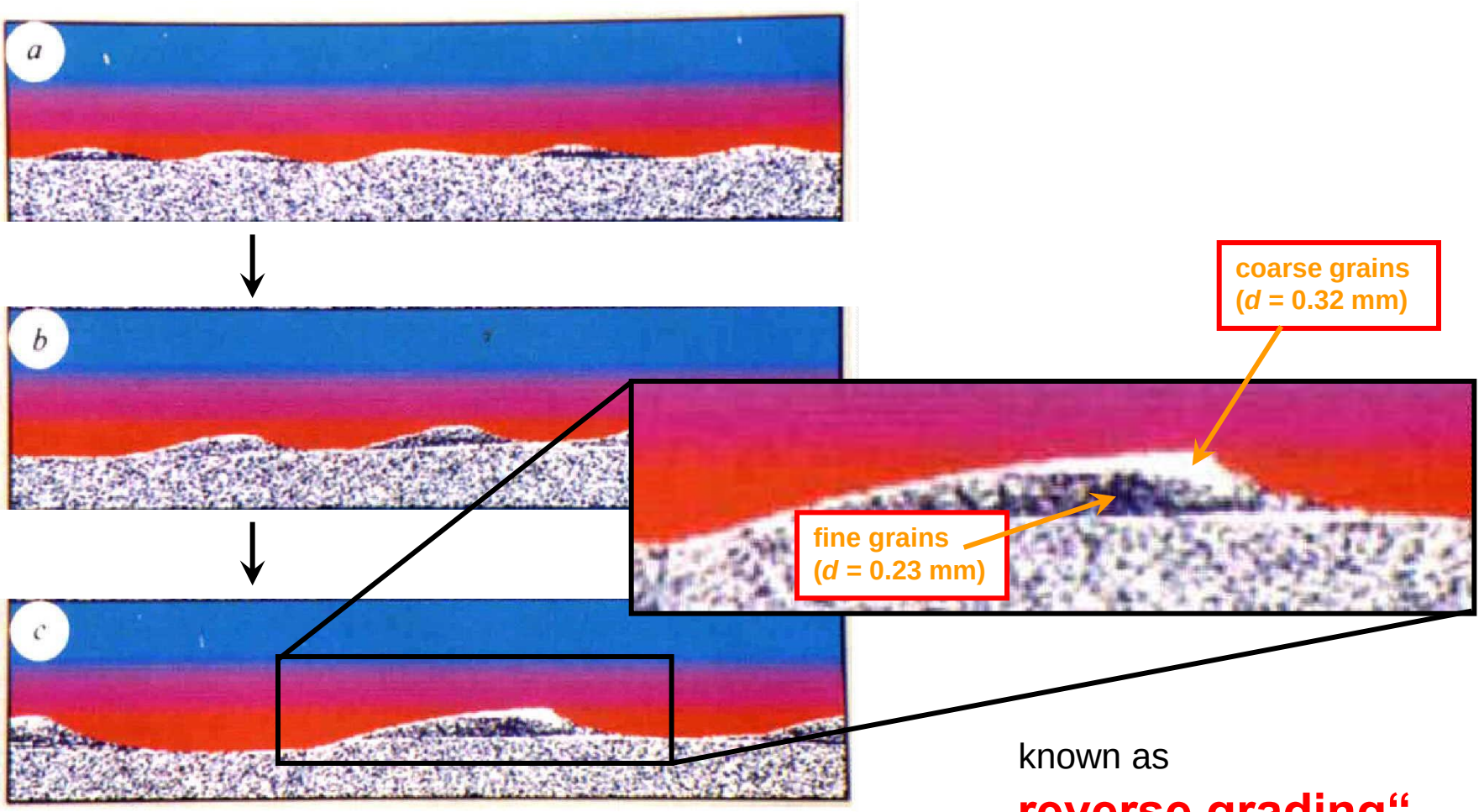
I. Introduction
II. Segregation phenomena
III. Dunes in the laboratory
IV. Migration velocity
V. Conclusions

# Grain sorting phenomena discussed so far …

**1.** Grain **size** segregation: large particles on top of smaller ones




**cellular automaton** modelling

known as

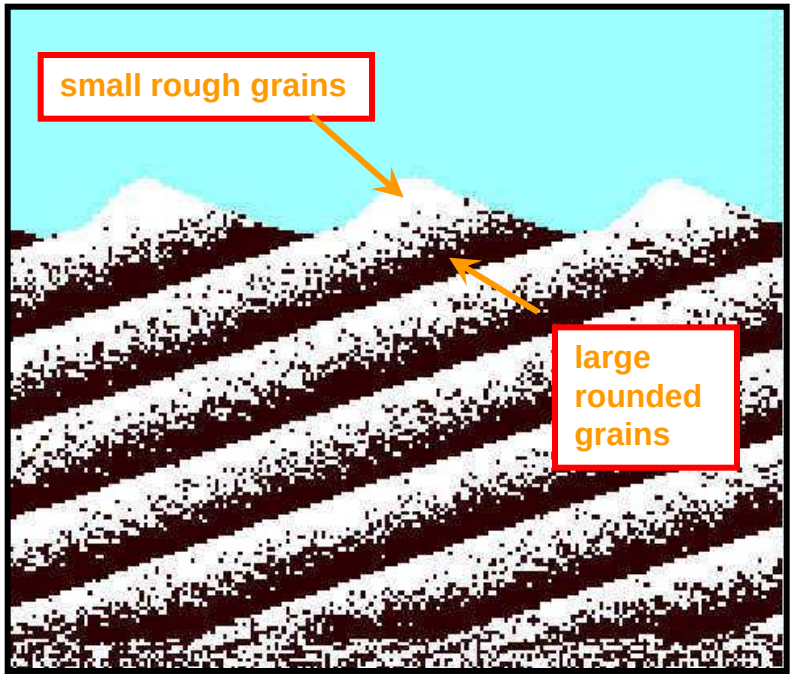
**„reverse grading“**

R.S. Anderson & K. L. Bunas, *Grain size segregation and statigraphy in aeolian ripples …*, Nature 365, 740 (1993).

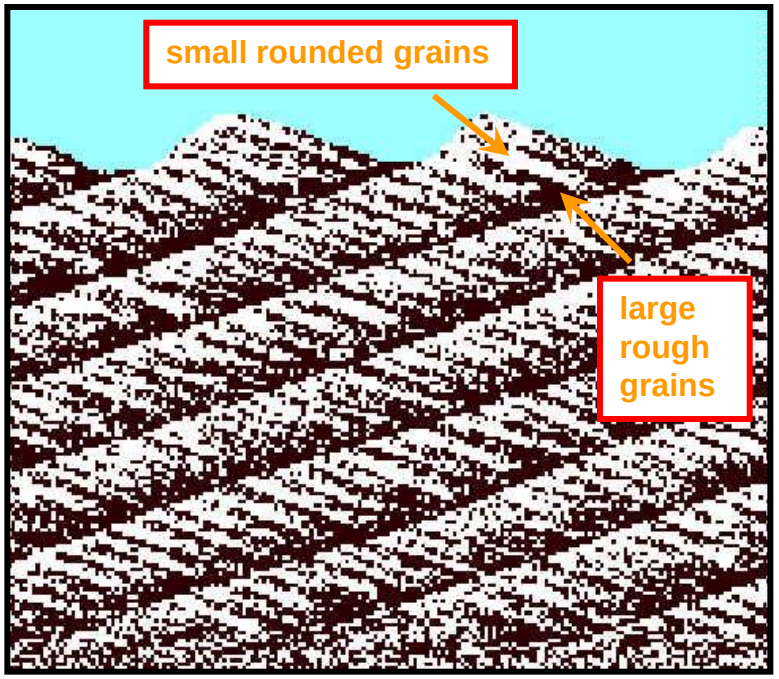
# Grain sorting phenomena discussed so far …

## **2.** Grain **shape** segregation:

**normal graded lamination**




**cross-stratification**

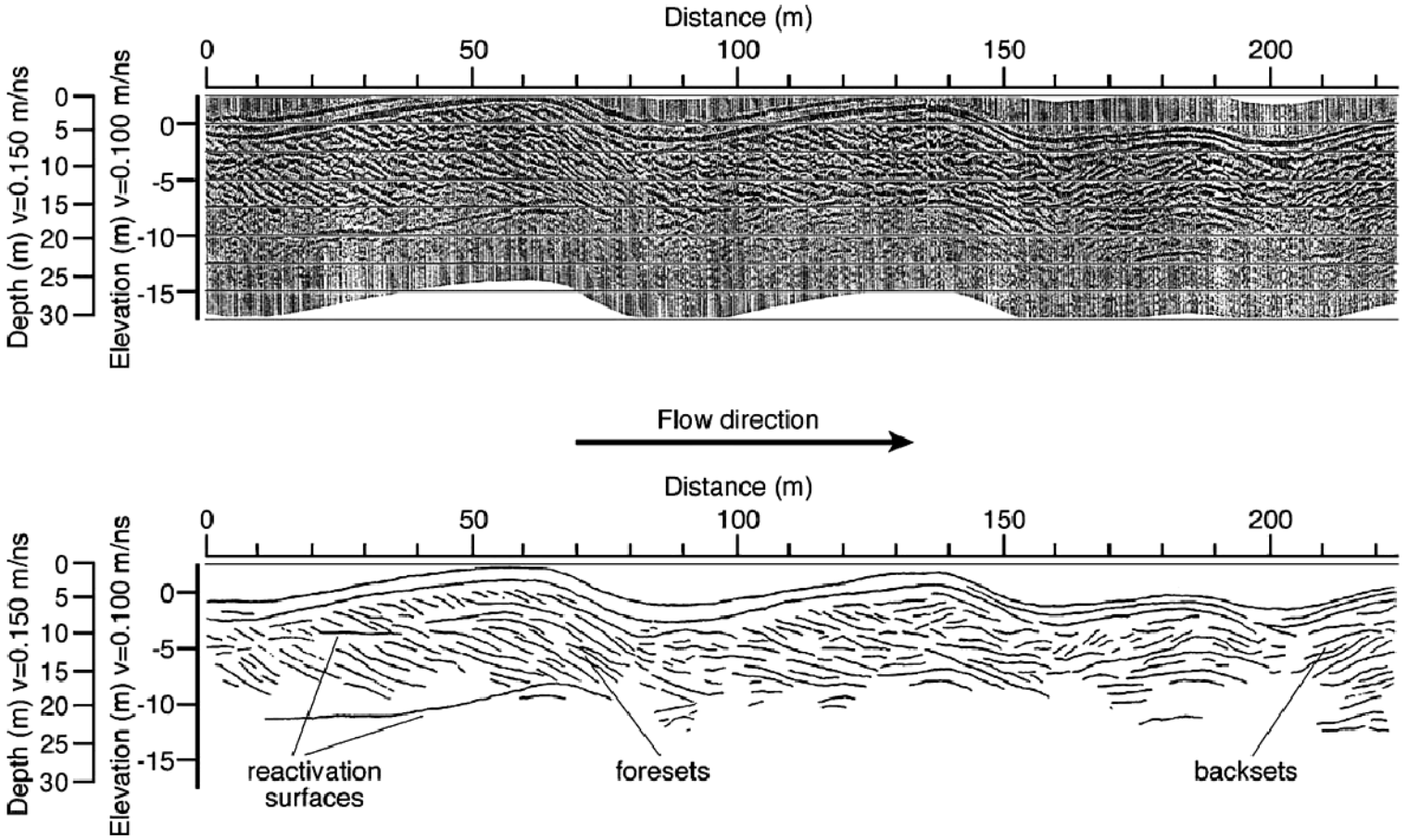



**continuous modelling** with convective-diffusion equations

H.A. Makse, *Grain segregation mechanism in aeolian sand ripples*, The European Physical Journal E 1, 127 (2000).

# Grain sorting phenomena discussed so far …

## 3. Grain **density** segregation:



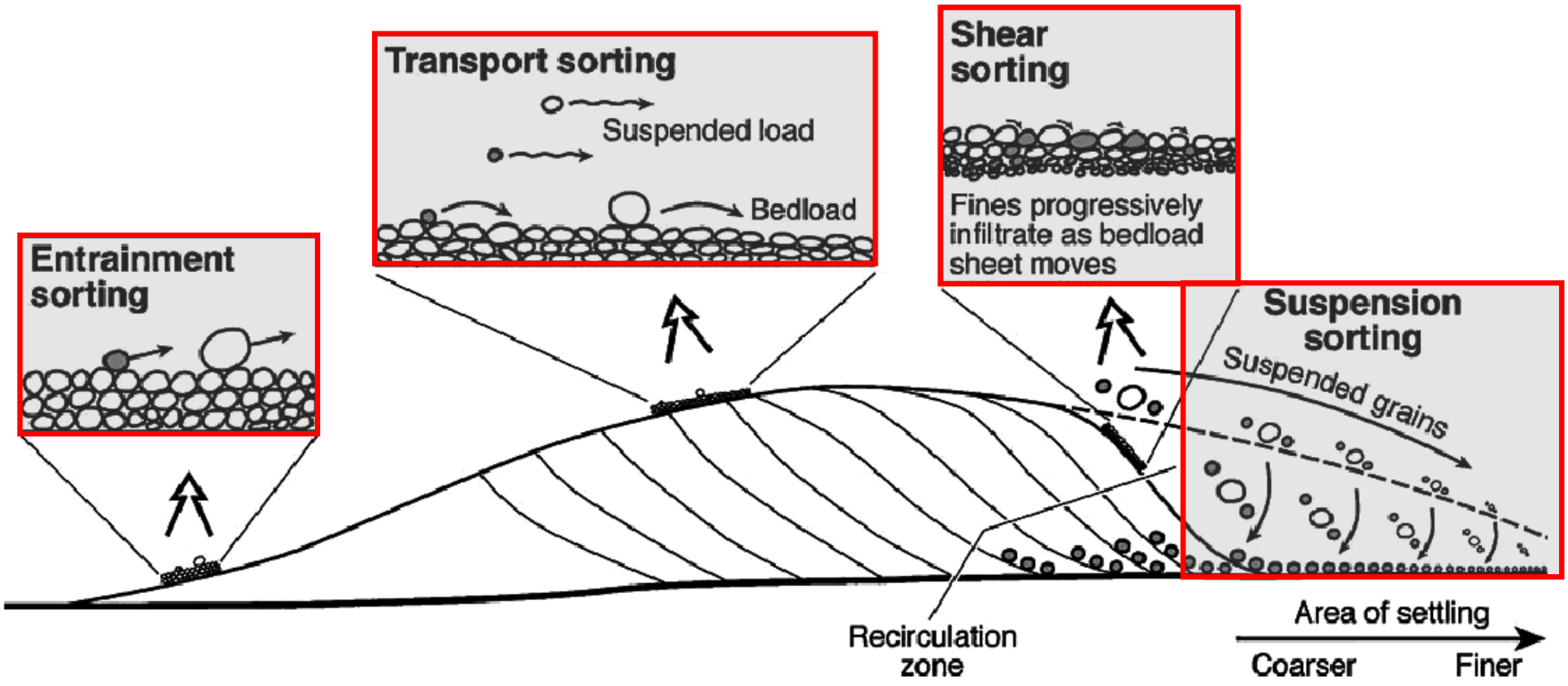

**G**round **P**enetrating **R**adar **profiling**

P. Huggenberger et al., *GPR as a tool to elucidate the depositional processes of giant gravel dunes …*, (1998).

P.A. Carling & R.M.D. Breakspear, *Placer formation in gravel-bedded rivers*, Ore Geology Reviews 28, 377 (2006).

# Grain sorting phenomena discussed so far …

## 3. Grain **density** segregation:



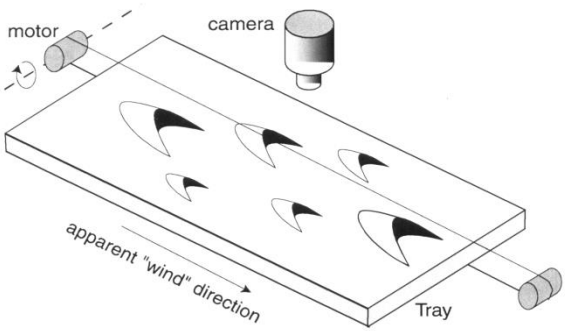

all four mechanisms **occur simultaneously** …

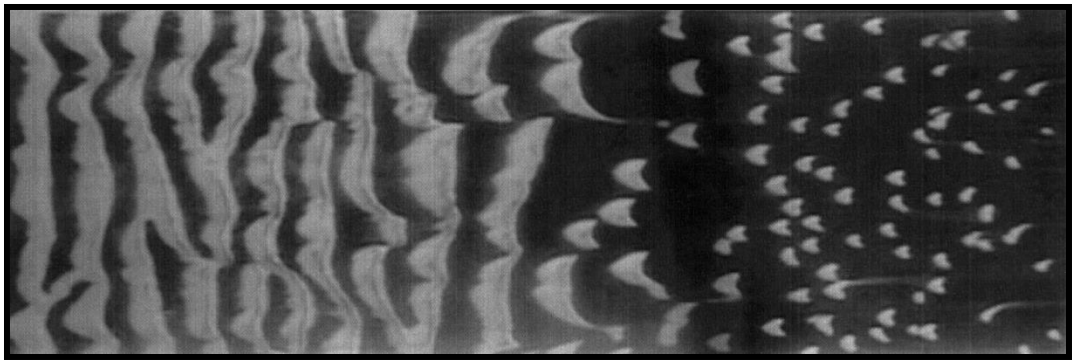

L.L. Brady & H.E. Jobson, *An Experimental Study of Heavy-Mineral Segregation …*, Geol. Surv. Prof. Paper 562-K (1973).

R. Slingerland, *Role of hydraulic sorting in the origin of fluvial placers*, Journal of Sedimentary Petrology 54, 137 (1984).

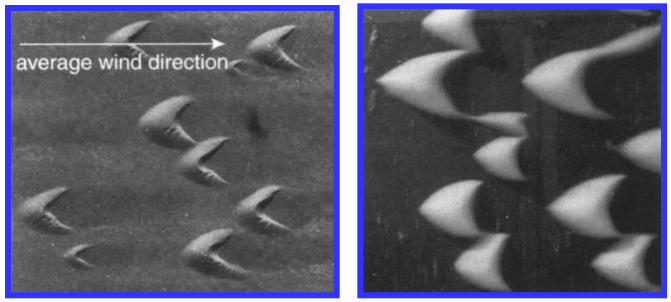
P.A. Carling & R.M.D. Breakspear, *Placer formation in gravel-bedded rivers*, Ore Geology Reviews 28, 377 (2006).

# Barchan dunes in the laboratory



Endo, Kubo & Sunamura, Earth Surf. Process. Landf. (2004)




Hersen, Douady & Andreotti, PRL (2002)

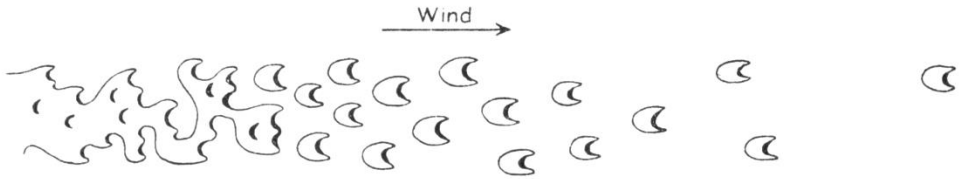
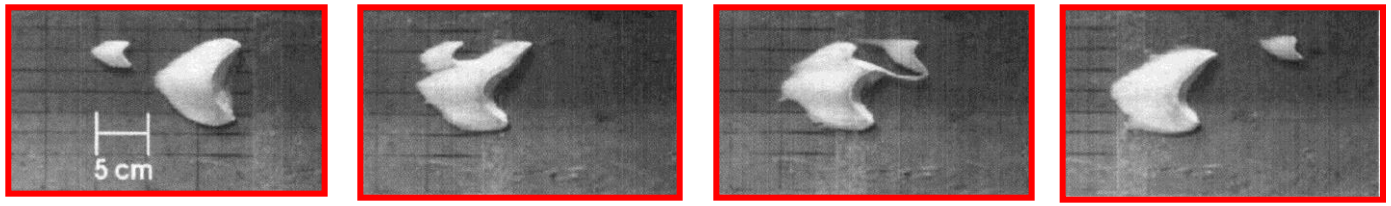



FIG. 77.—A TYPICAL BELT OF BARCHANS (NOT TO SCALE)

R. A. Bagnold, *The Physics of Blown Sand and Desert Dunes* (1941)




Katsuki *et al.*,
J. Phys. Soc. Jpn. (2005)

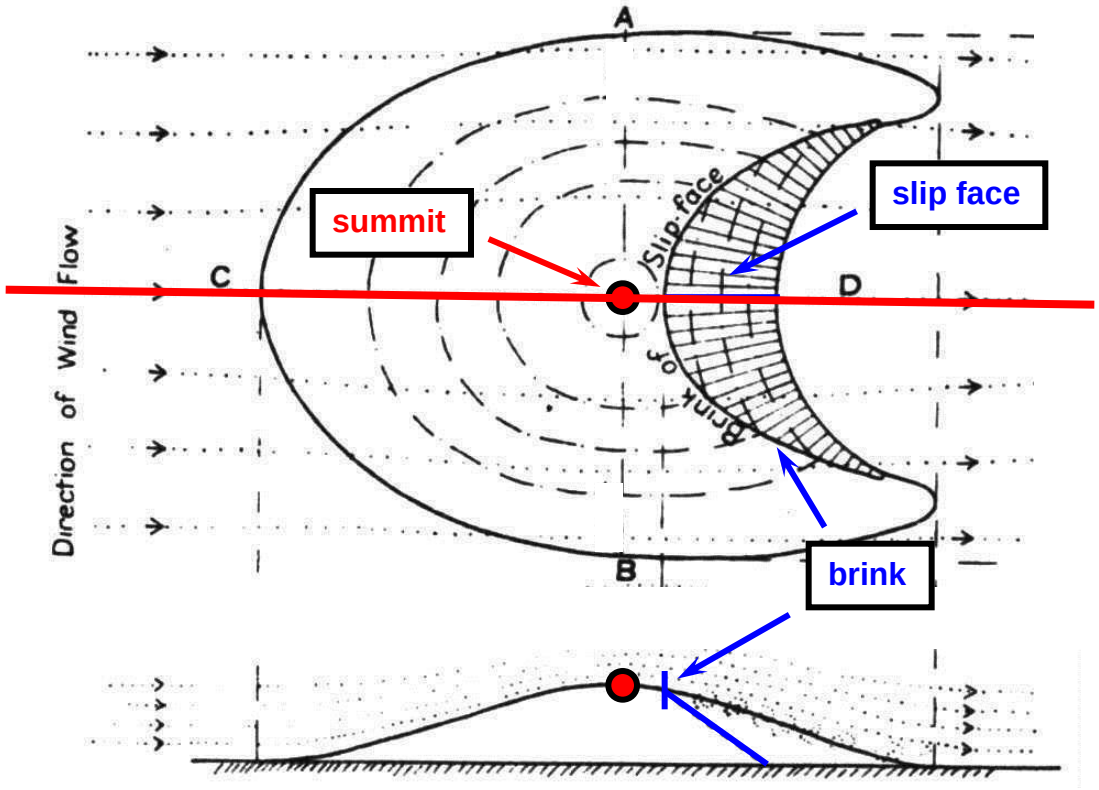
Time ⟶

**Driven by water!** ⇨ **shorter length and time scales**

# Two-dimensional barchan dune slice

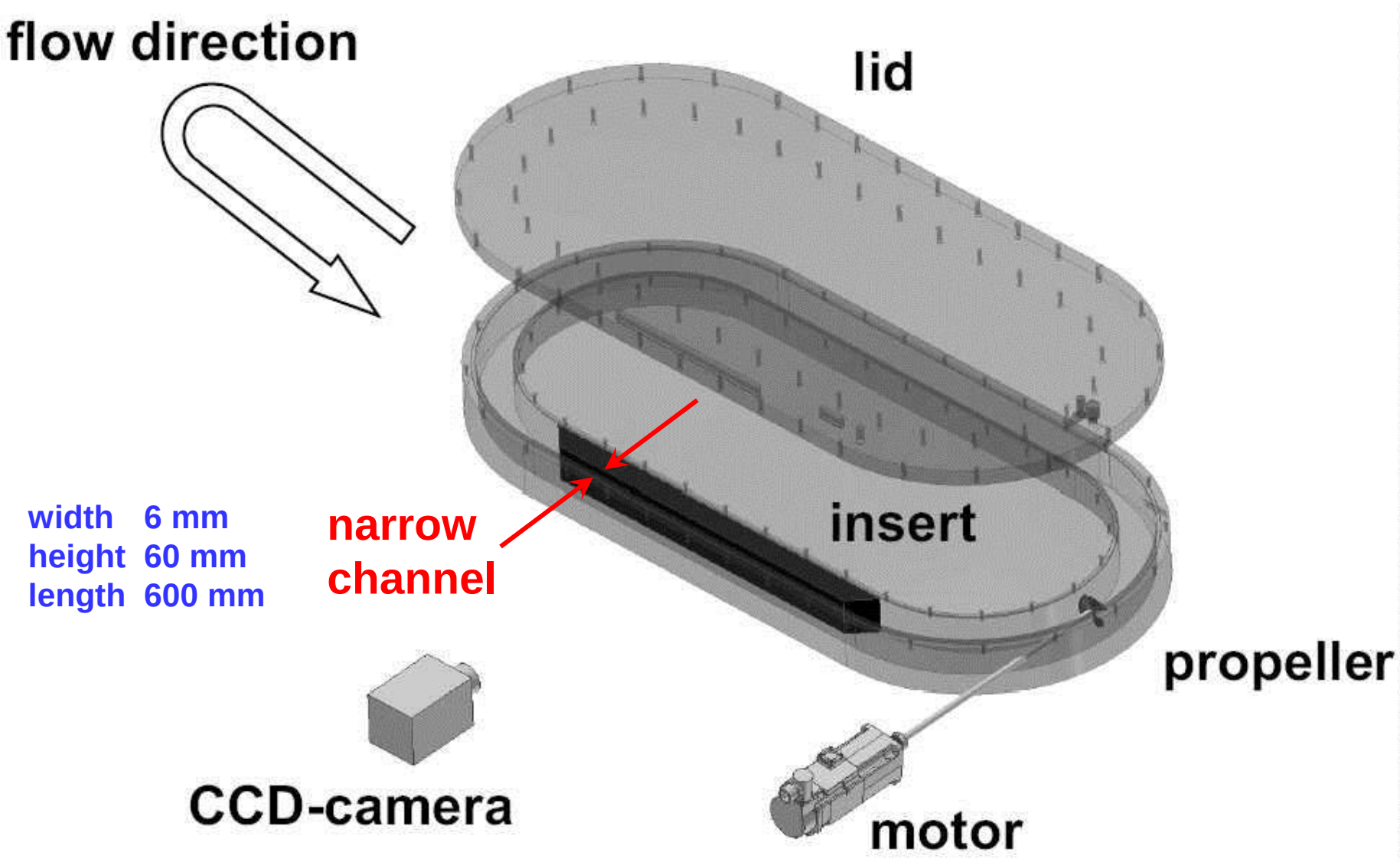
**Problem:** How can we **look inside** the dune?

**Solution:** Realize a **2D slice** in a transparent narrow channel.

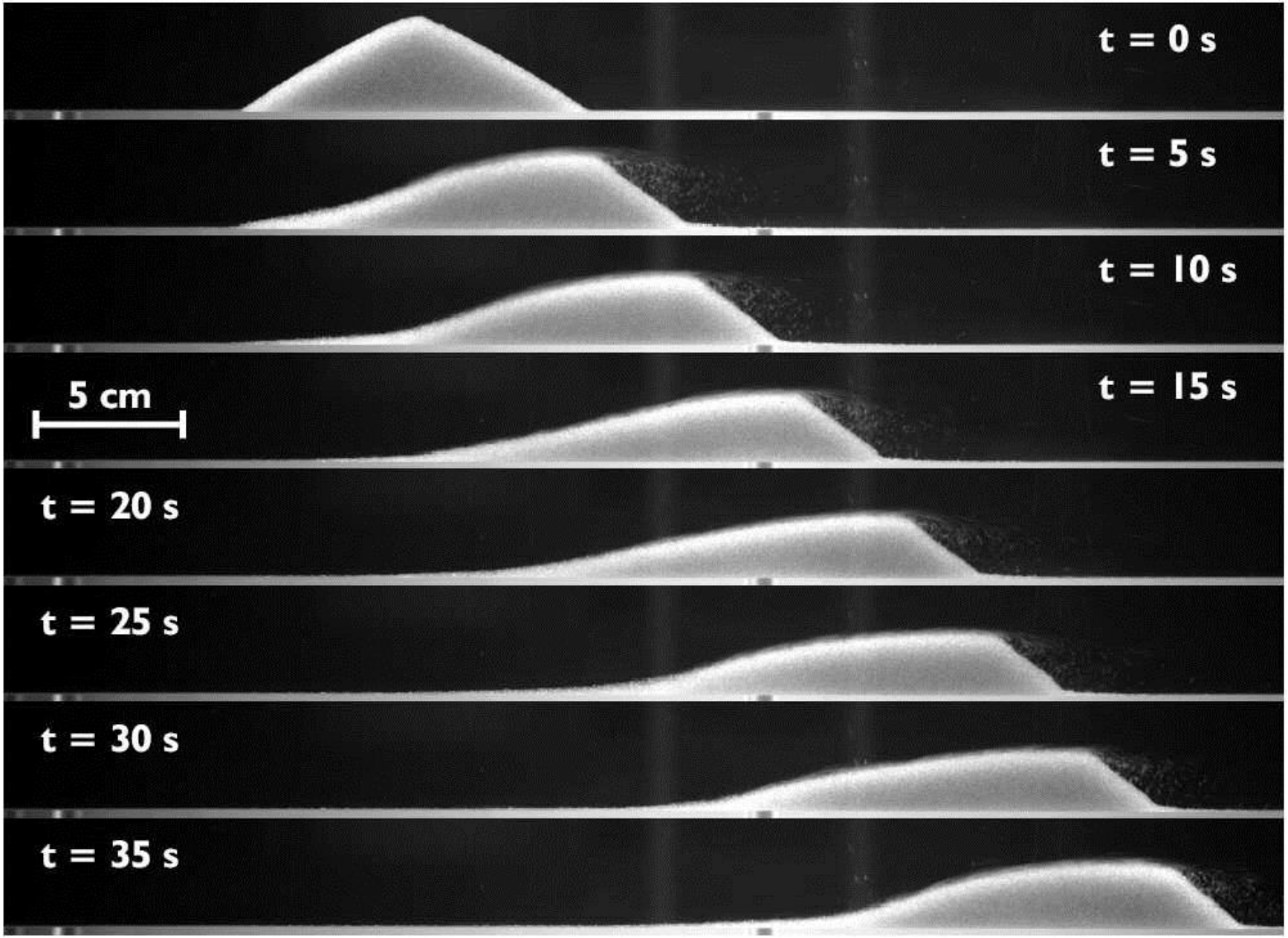


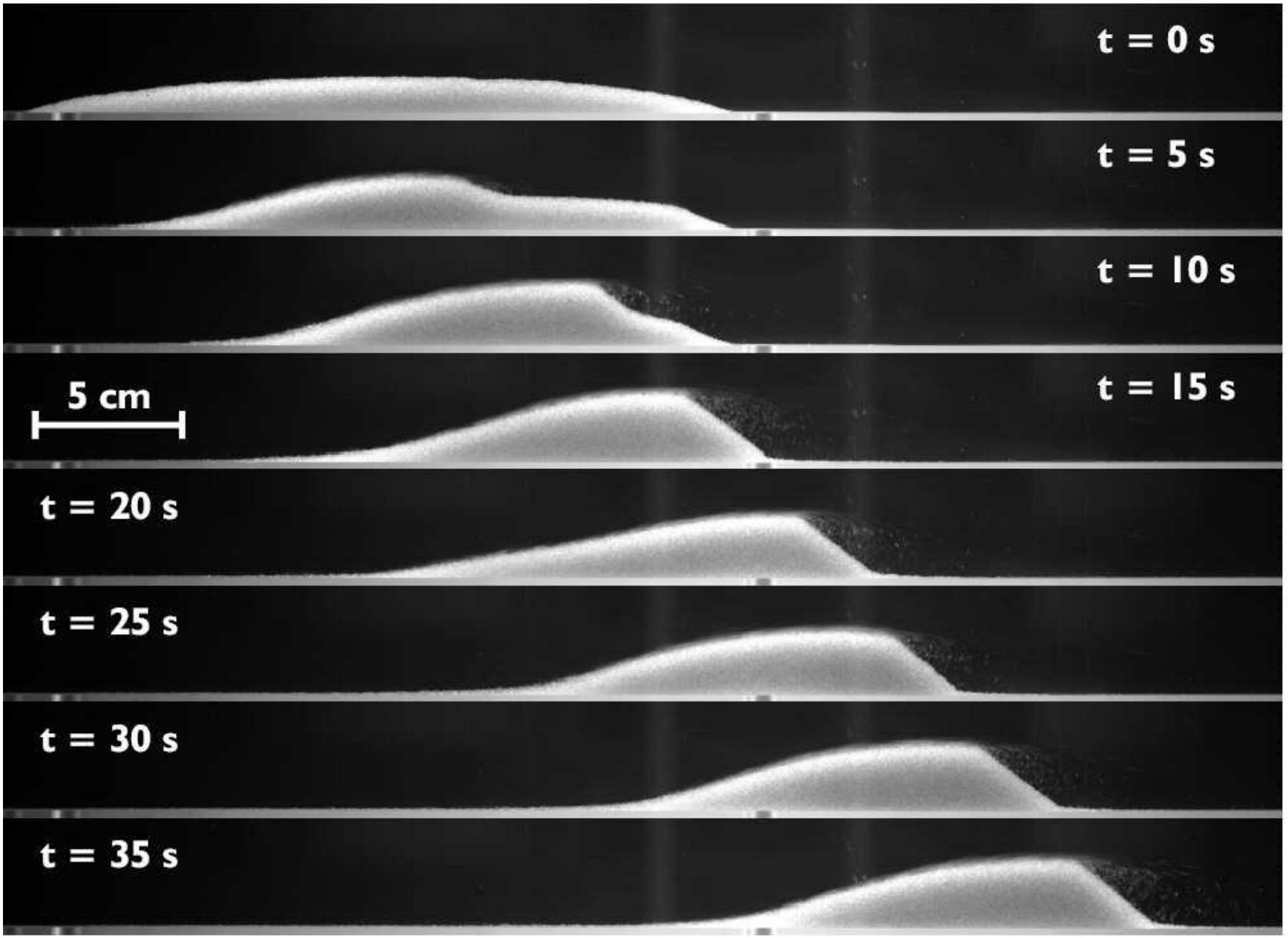

R. A. Bagnold, *The Physics of Blown Sand and Desert Dunes* (1941)

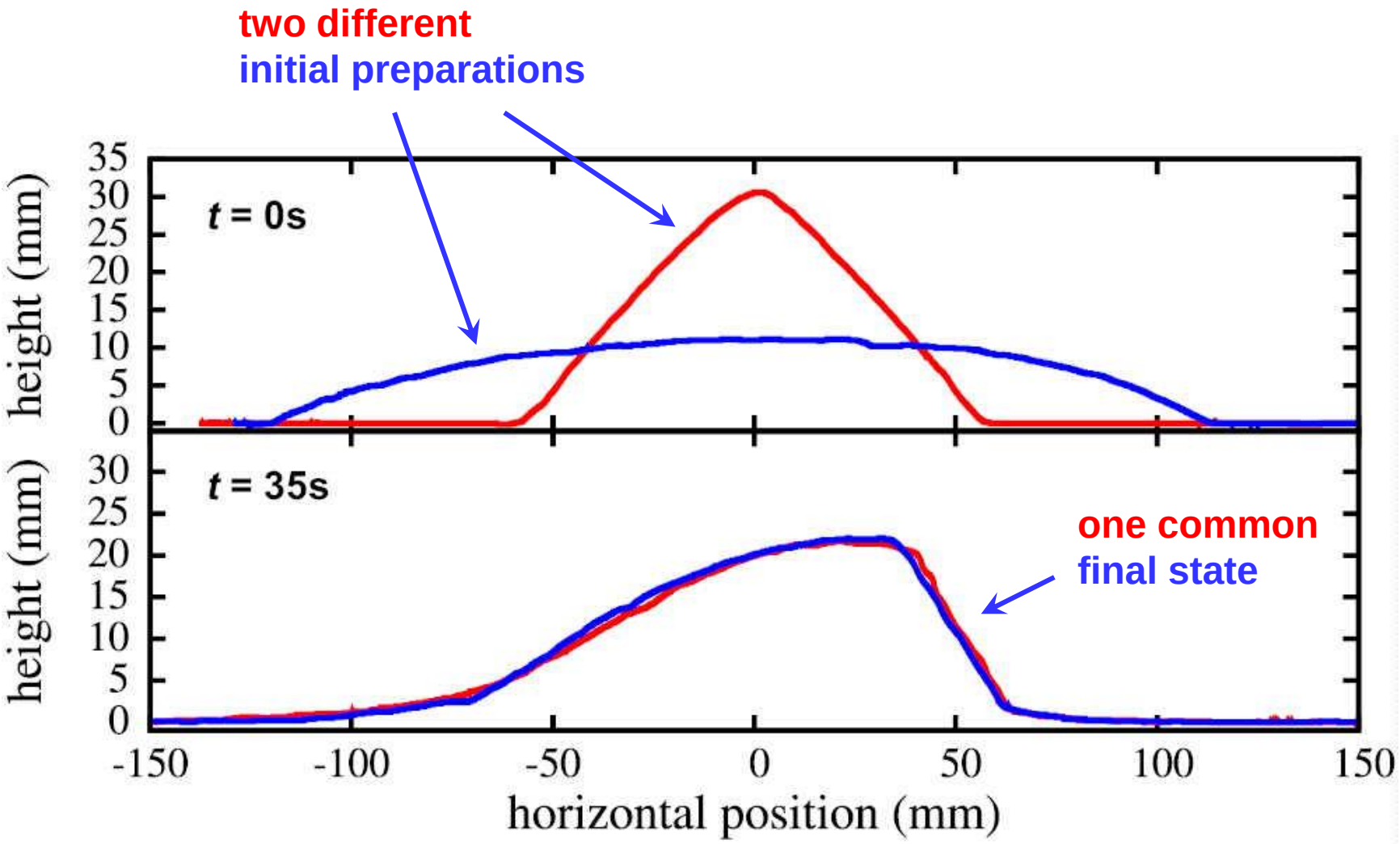
# Our new experimental setup



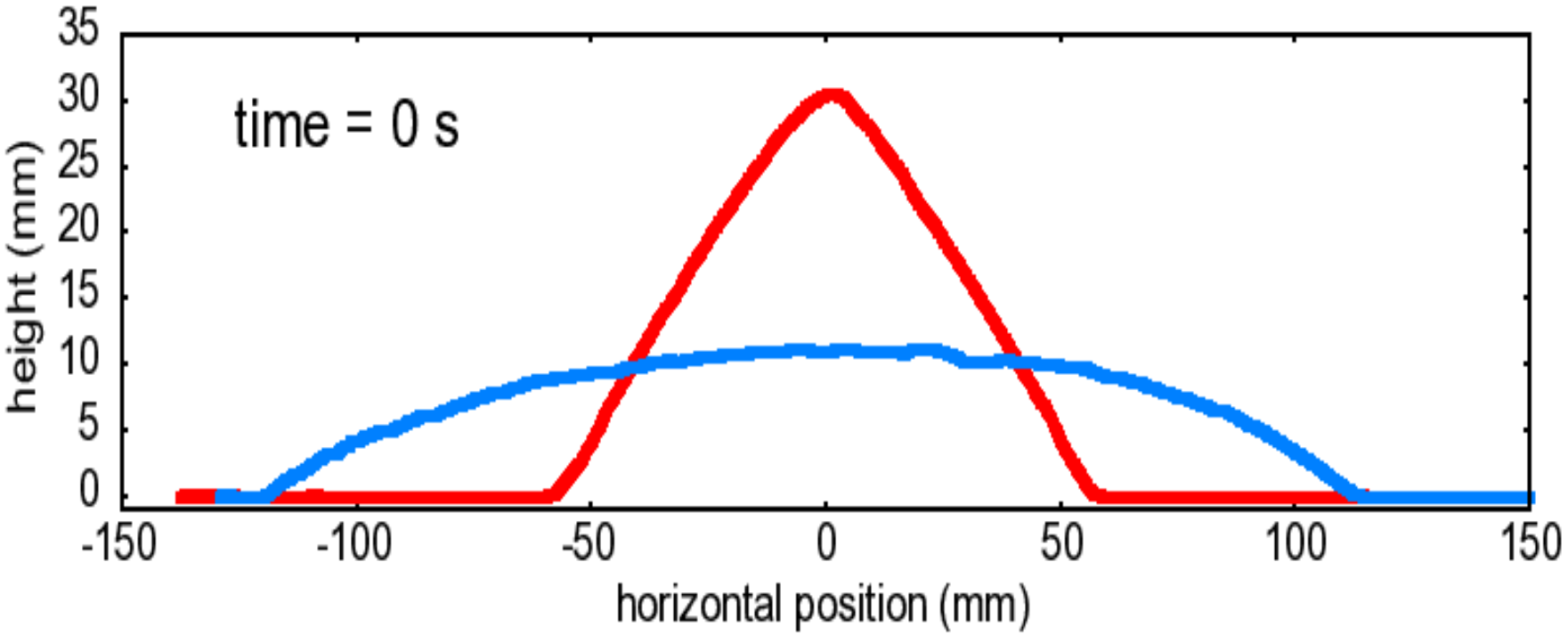

C. Groh, I. Rehberg, and C. A. Kruelle, *How attractive is a barchan dune?*, New Journal of Physics 11, 023014 (2009).


t = 0 s
t = 5 s
t = 10 s
t = 15 s
5 cm
t = 20 s
t = 25 s
t = 30 s
t = 35 s

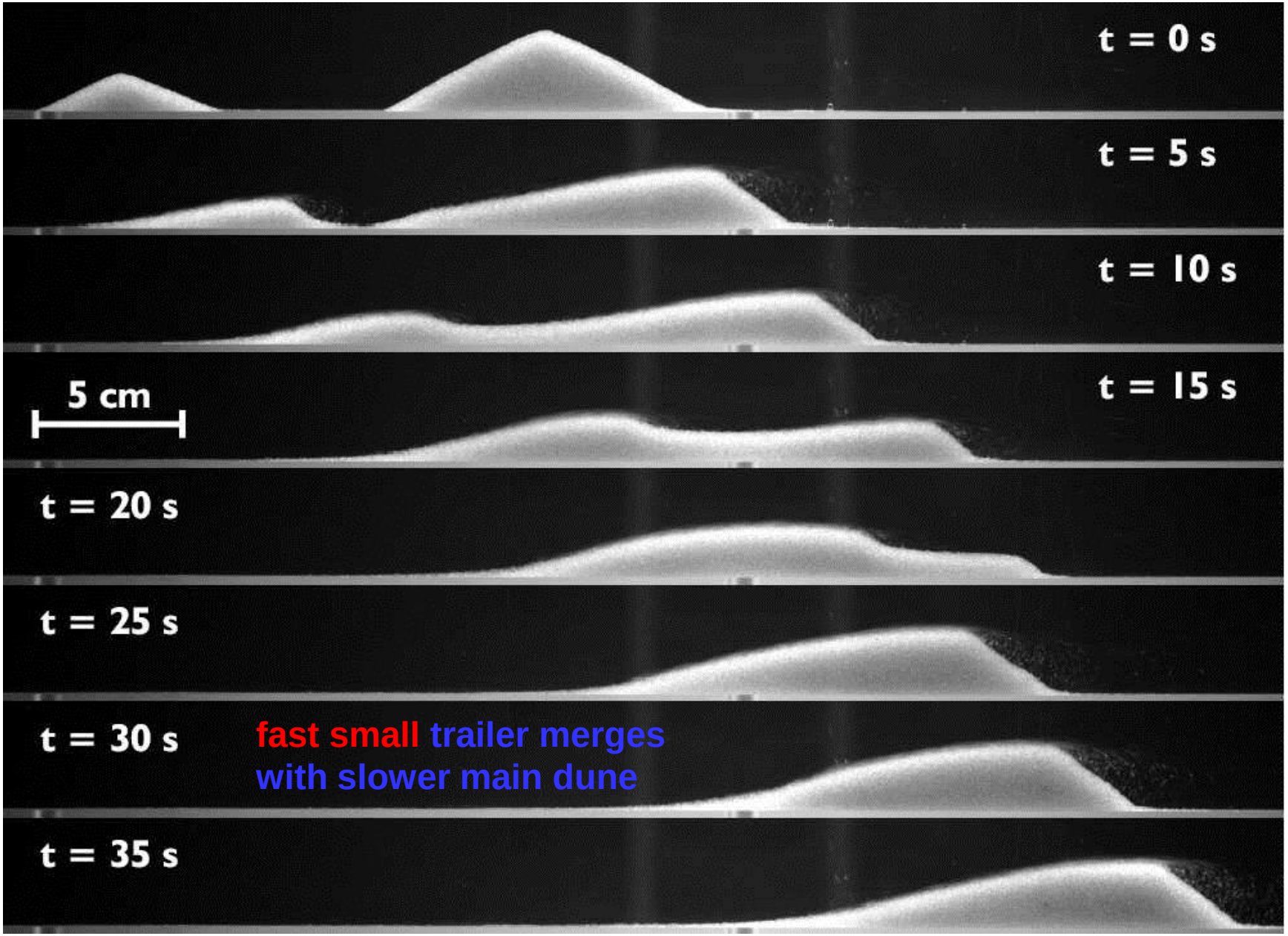

t = 0 s
t = 5 s
t = 10 s
t = 15 s
5 cm
t = 20 s
t = 25 s
t = 30 s
t = 35 s



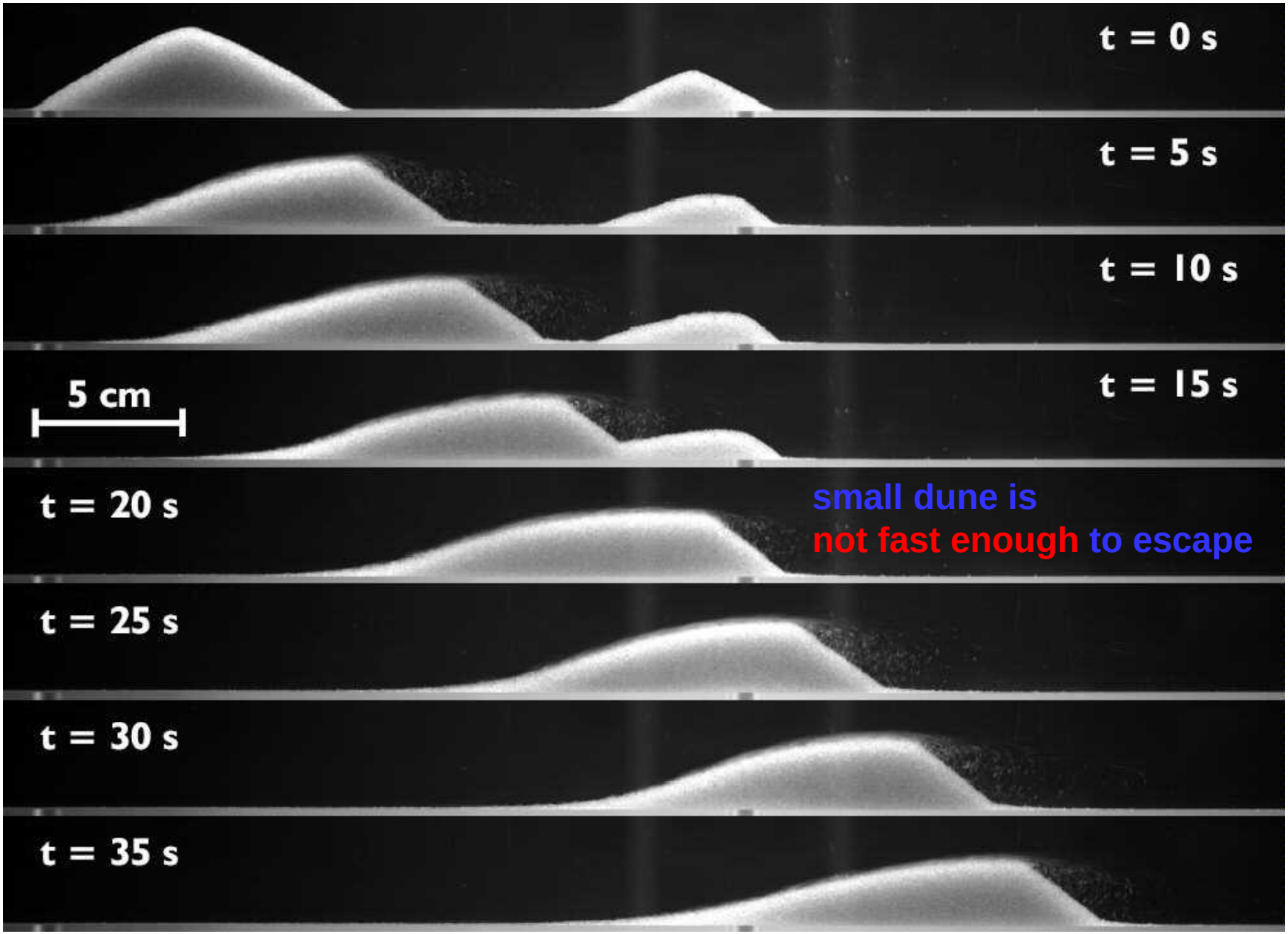

C. Groh, I. Rehberg, and C. A. Kruelle, *How attractive is a barchan dune?*, New Journal of Physics 11, 023014 (2009).

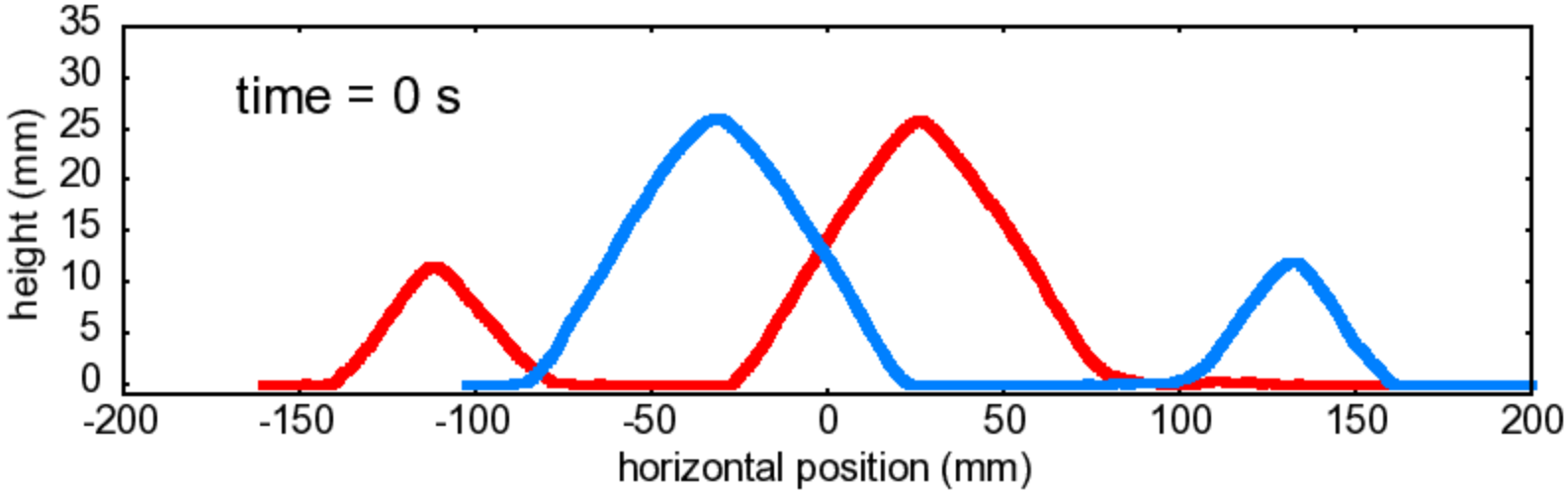

time = 0 s
height (mm)
35
30
25
20
15
10
5
0
-150
-100
-50
0
50
100
150
horizontal position (mm)

# What will happen here?

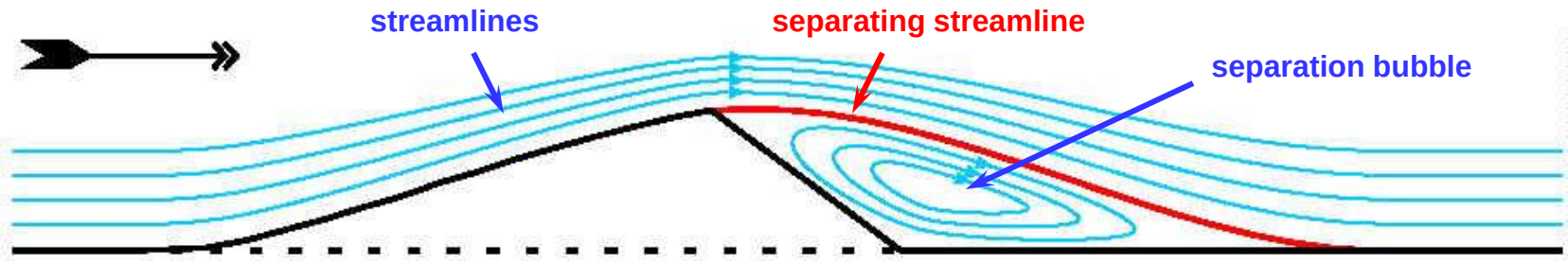

t = 0 s
t = 5 s
t = 10 s
t = 15 s
5 cm
t = 20 s
t = 25 s
t = 30 s
fast small trailer merges
with slower main dune
t = 35 s

## And here?


t = 0 s
t = 5 s
t = 10 s
t = 15 s
5 cm
t = 20 s
small dune is
not fast enough to escape
t = 25 s
t = 30 s
t = 35 s

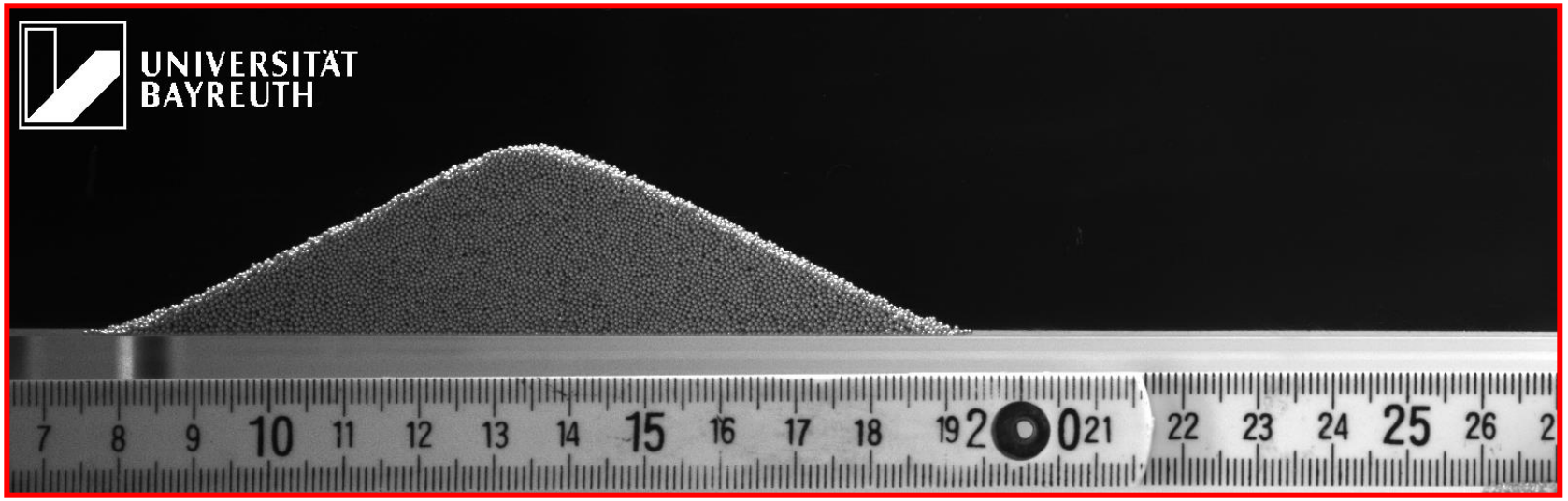

time = 0 s
height (mm)
35
30
25
20
15
10
5
0
-200
-150
-100
-50
0
50
100
150
200
horizontal position (mm)

# Flow separation …




## … seen behind barchan dune slice

**(realtime movie, 24 fps)**




**e.g. silver coated glass beads**

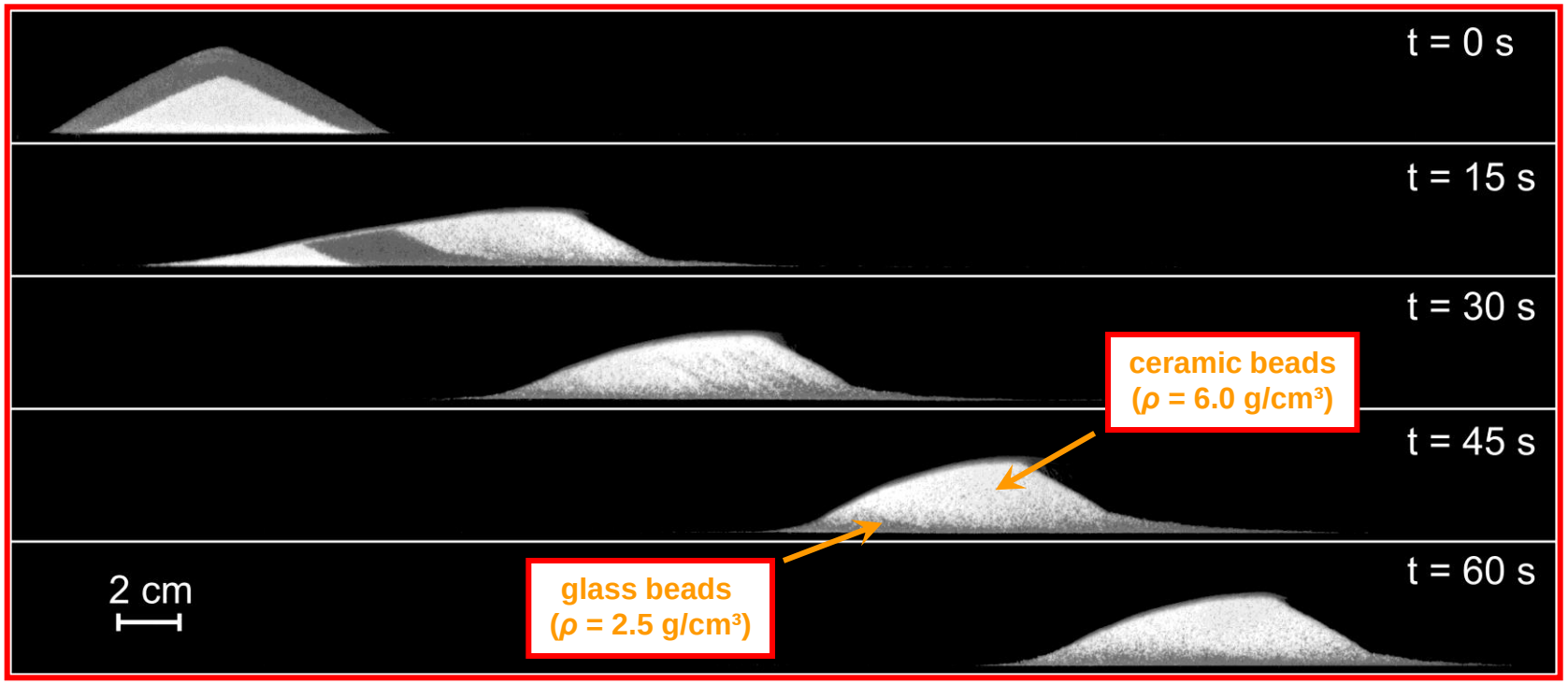
- $d$ = 560 - 600 µm
- $\rho$ = 2.5 g/cm³
- dune mass $m$ = 13 g

**water flow** 45 cm/s

Re = 27000

# Direct observation and monitoring of …

… grain **density** segregation: **heavy particles on top of lighter ones**

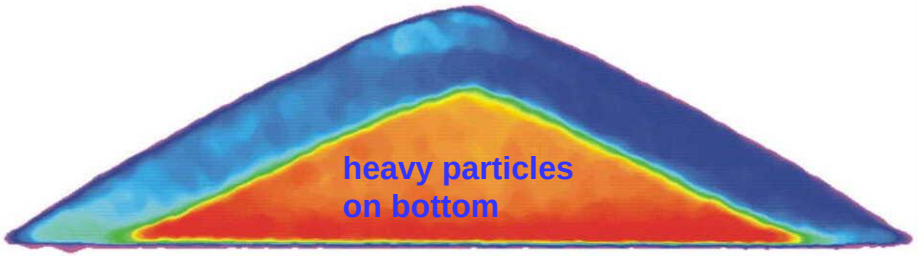



**(false-color time-lapse movie)**

**laboratory** experiments + digital **image processing**


**C. Groh, I. Rehberg, and C. A. Kruelle, *Observation of density segregation inside migrating dunes*, Physical Review E 84, 050301(R) (2011)**

# Dependence on initial starting conditions



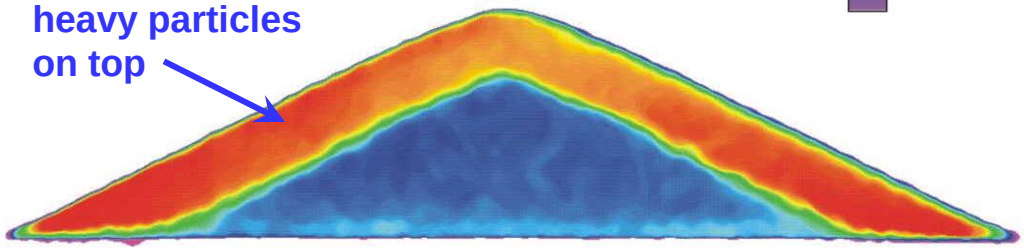

$\rho$ = 6.0 g/cm³

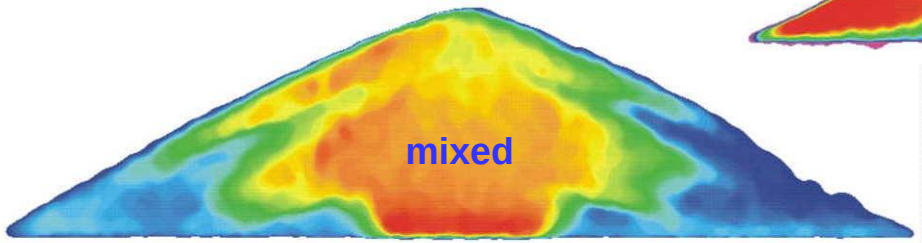
ceramic

$\rho$ = 2.5 g/cm³

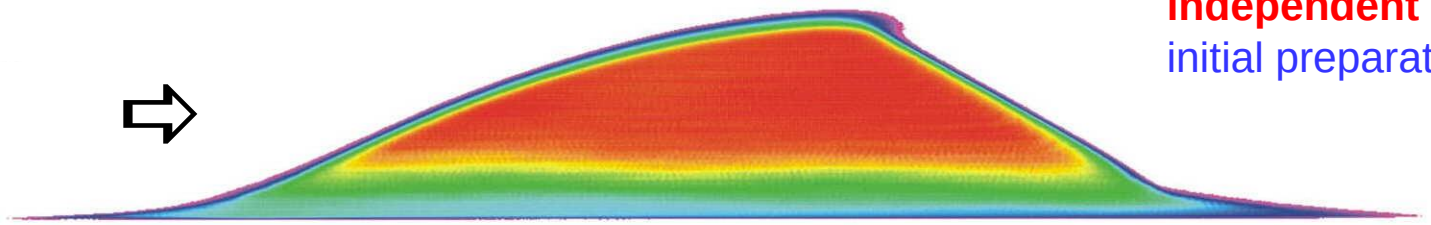
glass

heavy particles
on top



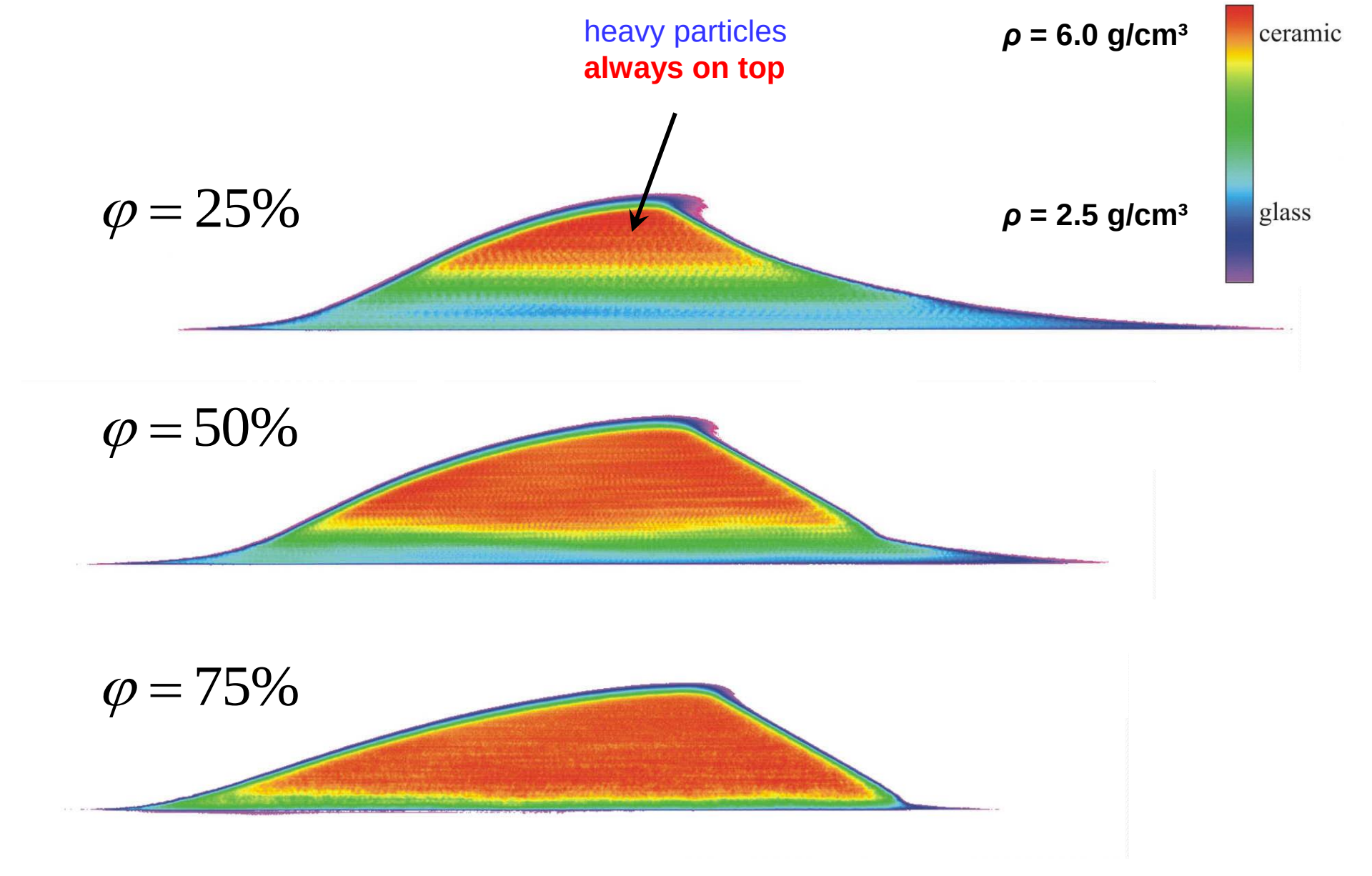



final state is
**independent** on
initial preparation !

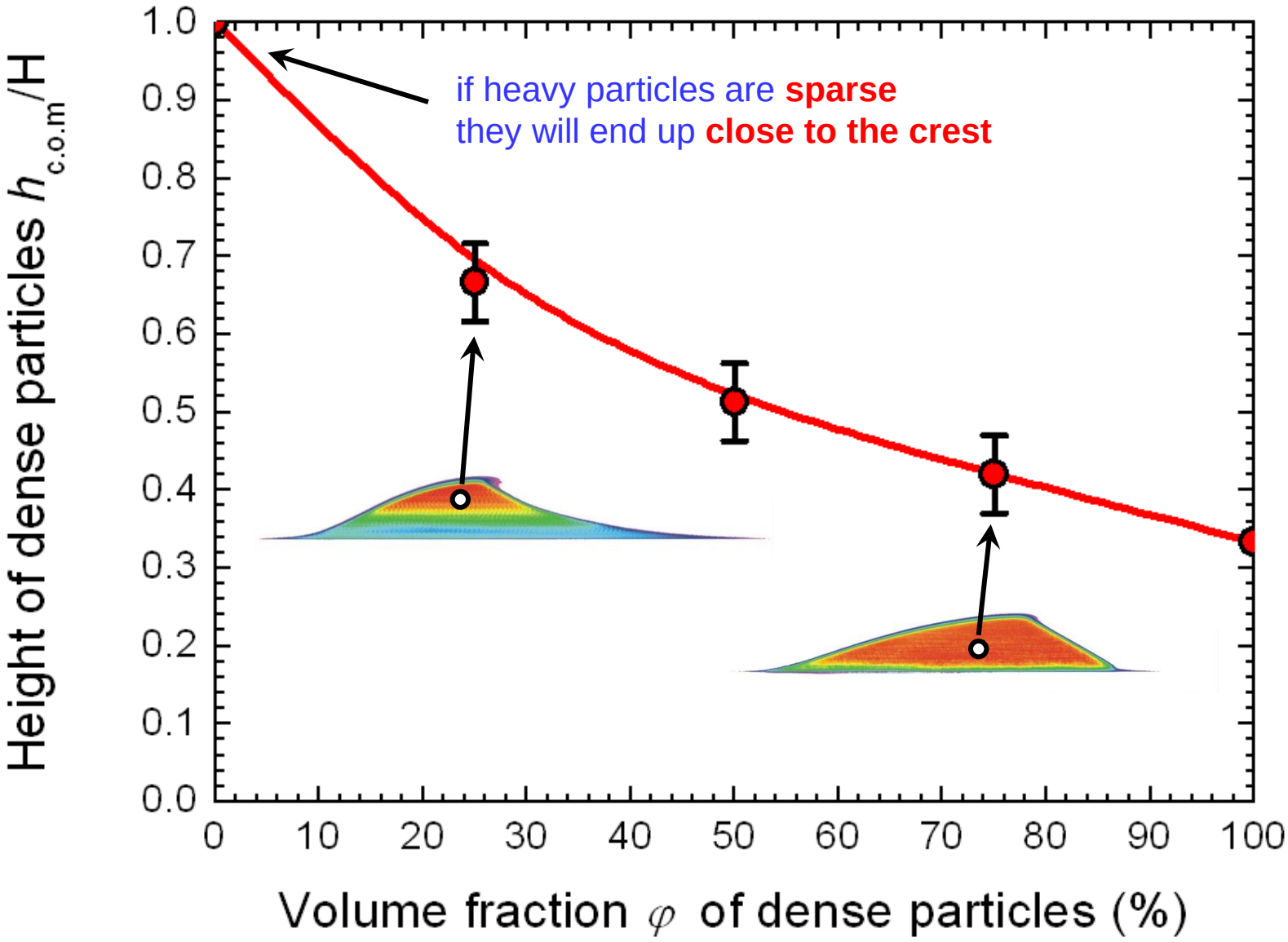


common segregated state

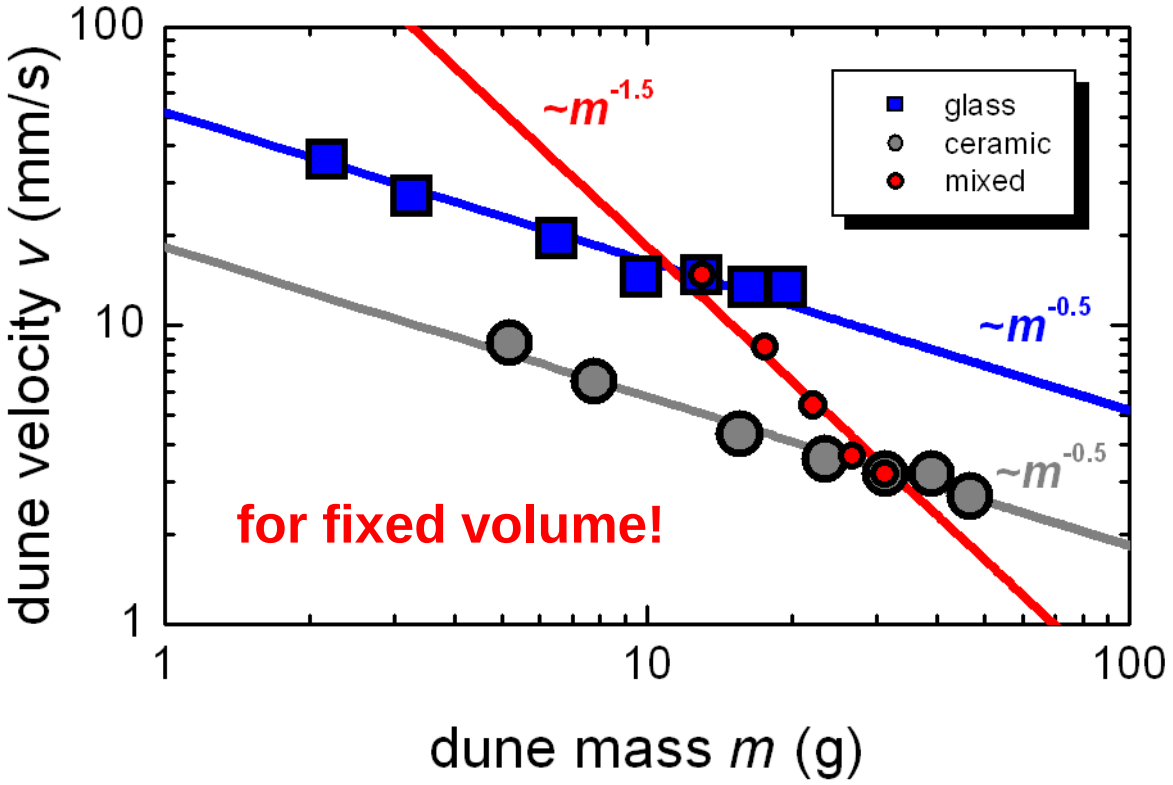
# Dependence on volume ratio of dense particles



# Center-of-mass height of dense particles



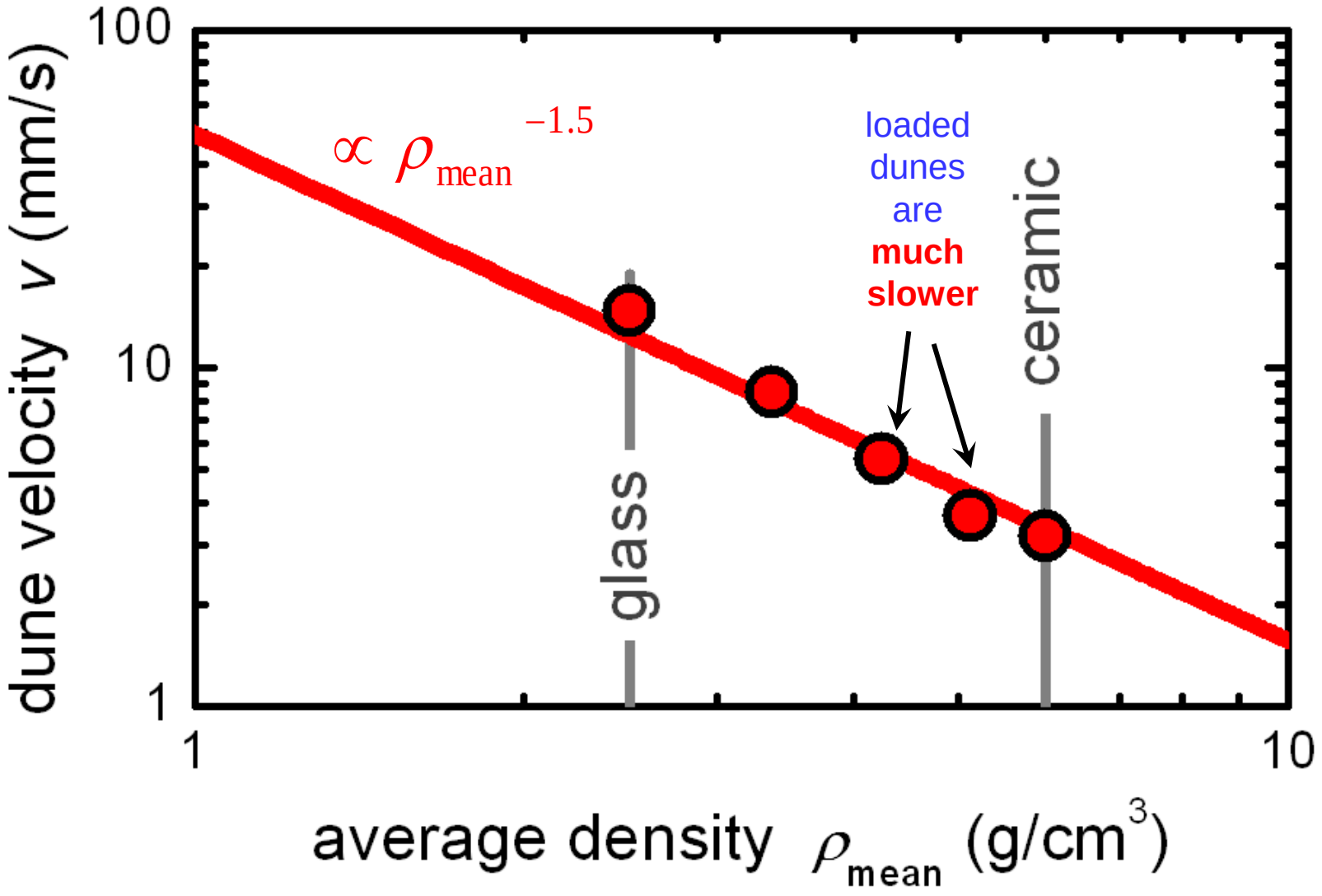
# Scaling behavior of the migration velocity




prediction by Bagnold (1941): $v \propto \rho_{\text{mean}}^{-1} \cdot m^{-0.5} \Rightarrow v \propto m^{-1.5}$

and since $m \propto \rho_{\text{mean}} \Rightarrow v \propto \rho_{\text{mean}}^{-1.5}$

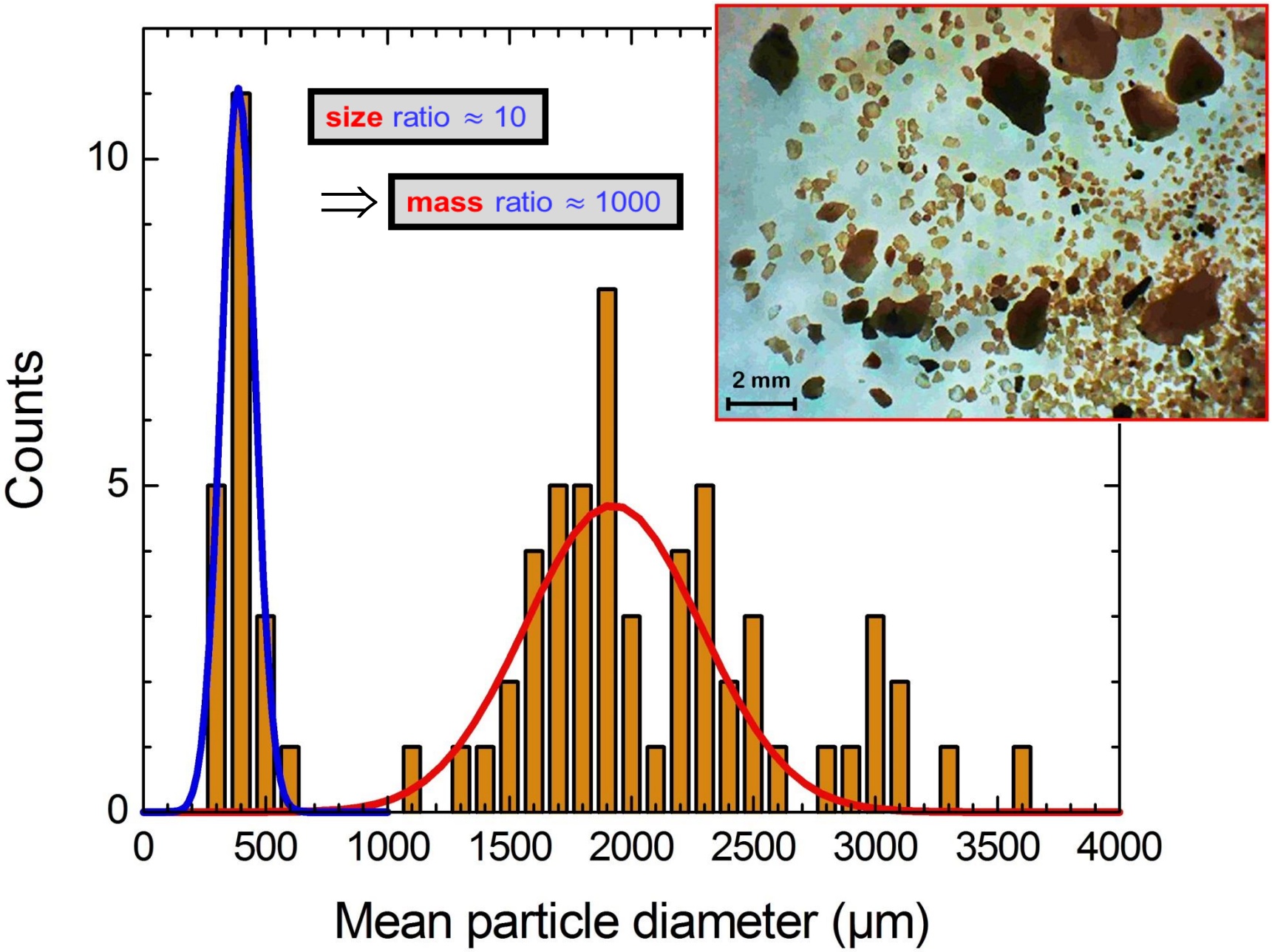
# Scaling behavior of the migration velocity



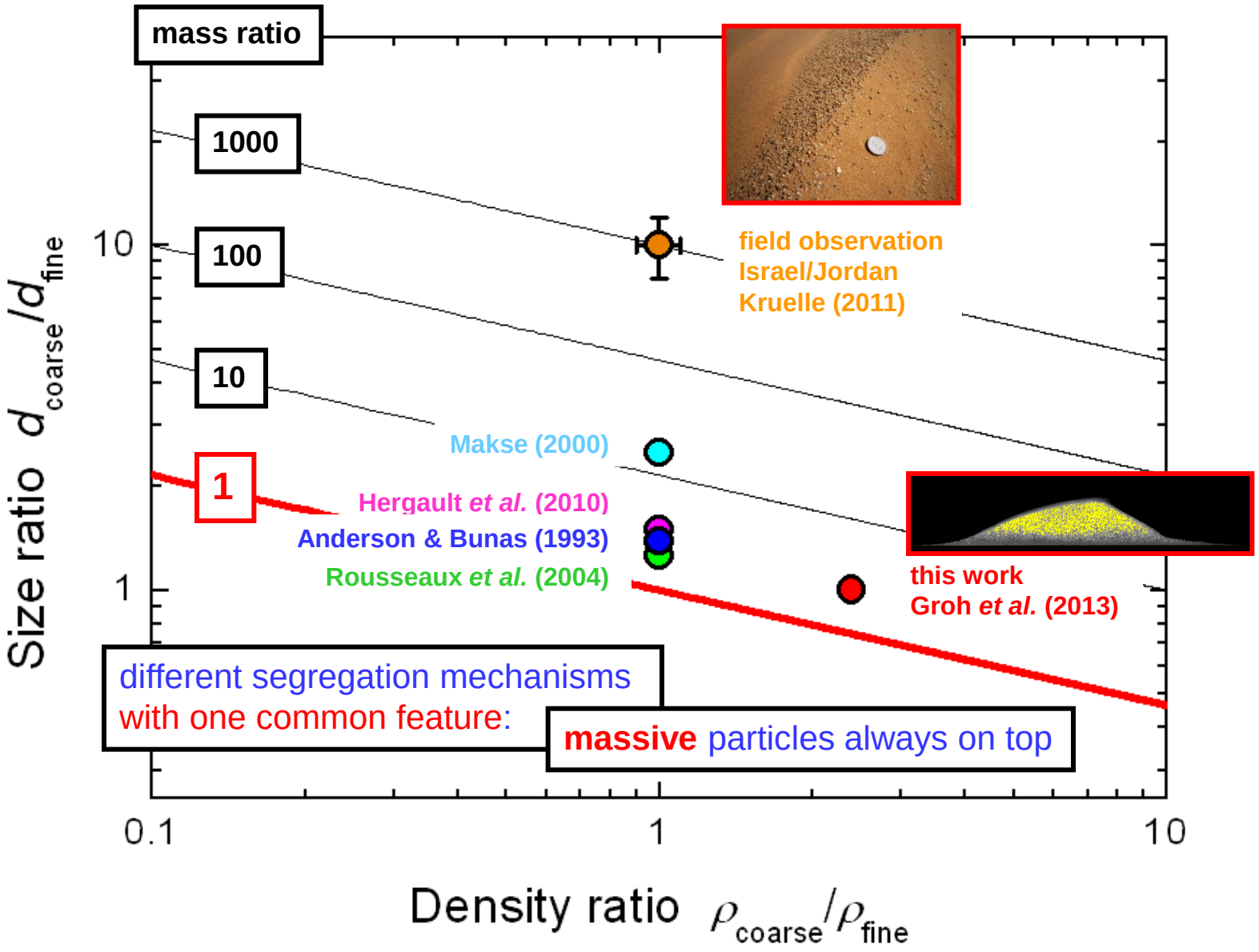
# Megaripples in the Arava valley (Israel-Jordan border)

2 mm sized gravel
on top of
300 µm sand

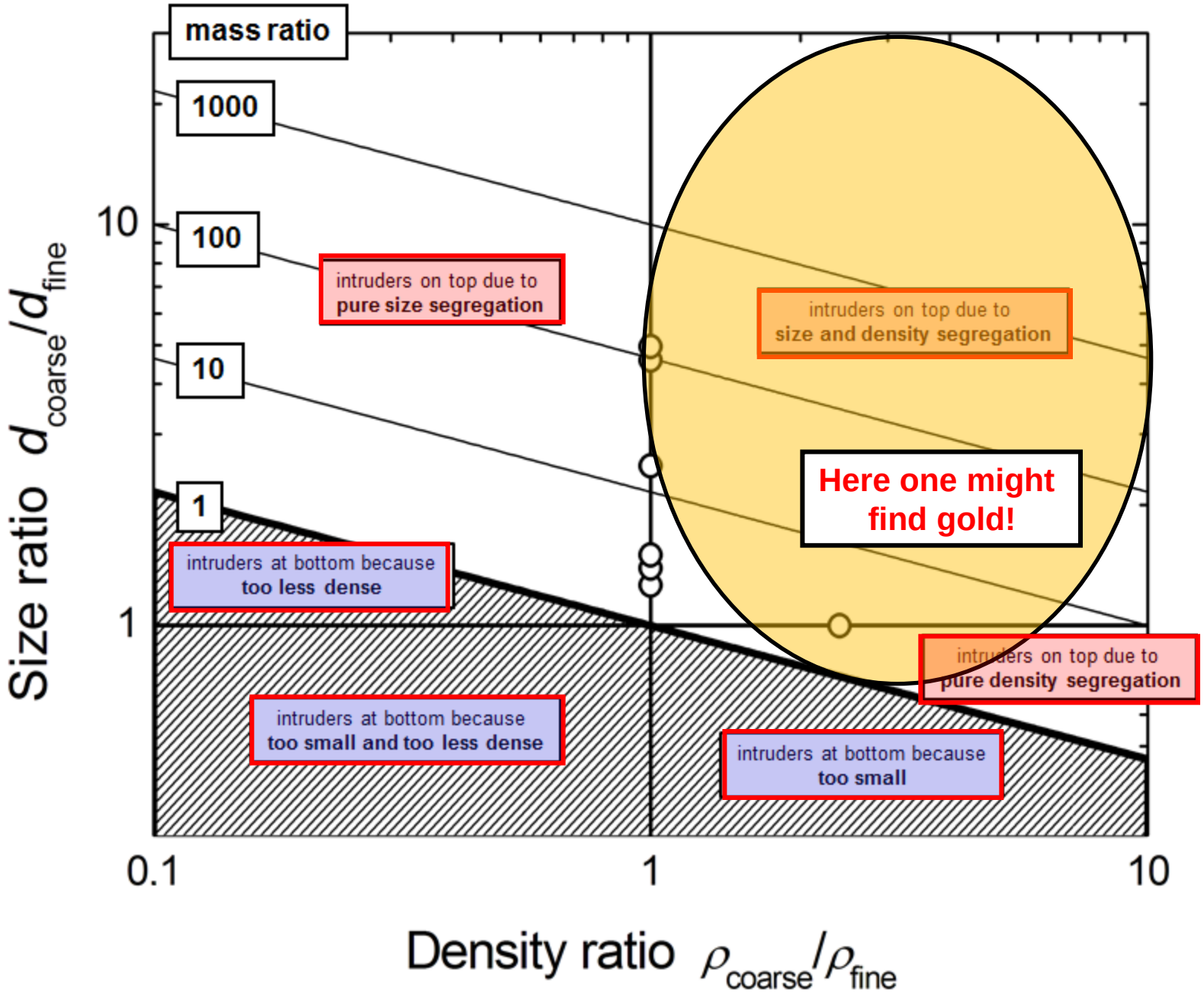
# Grain size distribution



# Survey of the parameter space explored so far …




C. Groh, I. Rehberg, and C. A. Kruelle, *Where to dig for gold? - Observation of density segregation inside migrating dunes*, Powders & Grains 2013, Sydney, 8 – 12 July 2013, AIP Conf. Proc. 1542, 1047 (2013).


mass ratio
1000
100
10
1
10
1
0.1
1
10
Size ratio $d_{coarse}/d_{fine}$
Density ratio $\rho_{coarse}/\rho_{fine}$
intruders on top due to
pure size segregation
intruders on top due to
size and density segregation
Here one might
find gold!
intruders at bottom because
too less dense
intruders on top due to
pure density segregation
intruders at bottom because
too small and too less dense
intruders at bottom because
too small

# A simple conclusion …

**Knowing this …**

**… where would you dig for gold here?**

Answer:

Choose a dune, **which migrates slower** than equally sized neighbors …

… and dig close to the surface **at its crest**.

# Thank you ...


Simon Fischer
Christopher Groh
Tobias Lang
Ingo Rehberg

Experimentalphysik V,
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Tobias Edtbauer
Matthias Jurke
Andreas Karolewski
Mustapha Rouijaa
Andreas Wierschem

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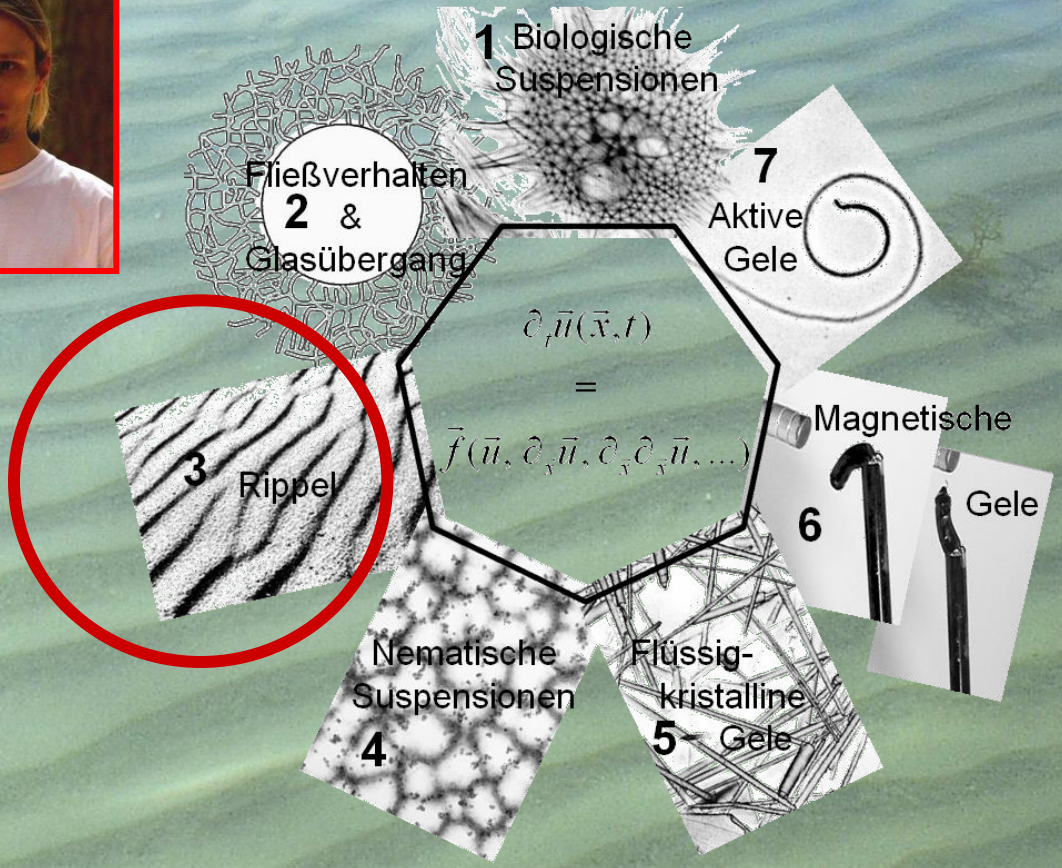


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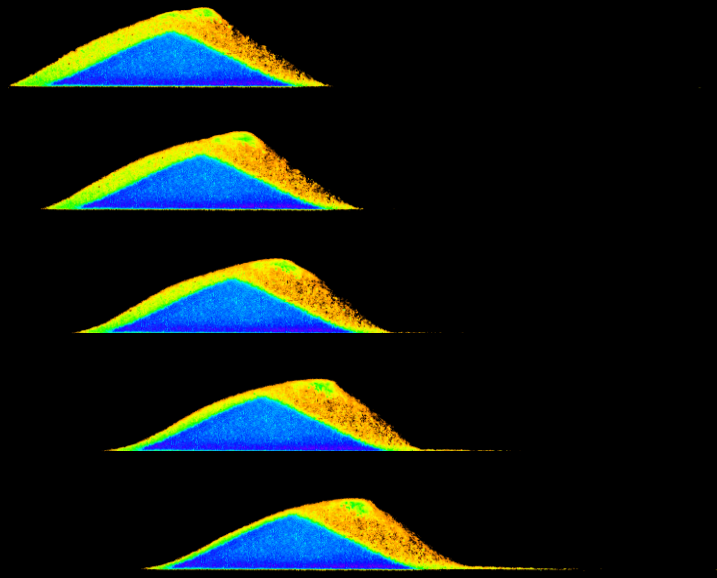

Thank you for your attention!