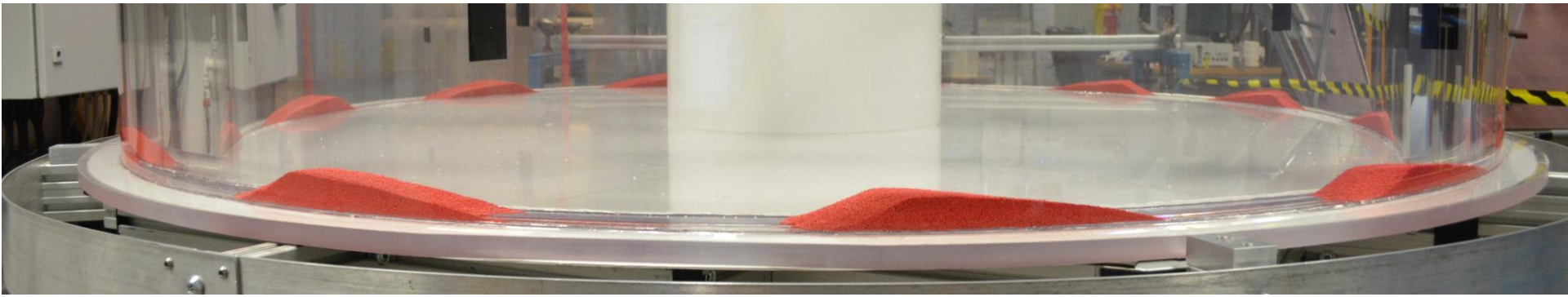
On the formation and pattern coarsening of subaqueous ripples and dunes



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  - Karol Bacik (PhD-student: 2017 – 2021)

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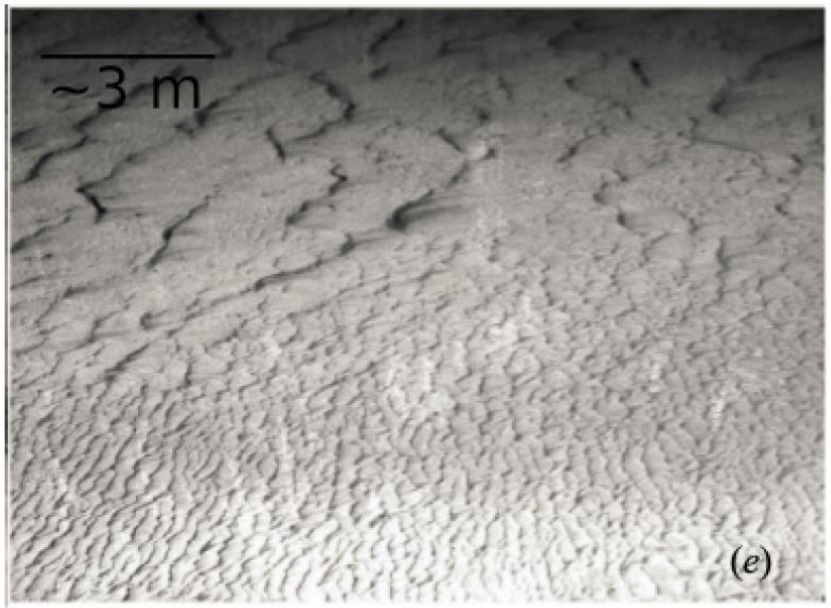
  - David Page-Croft, Paul Mitton, John Milton
  - Stuart Dalziel

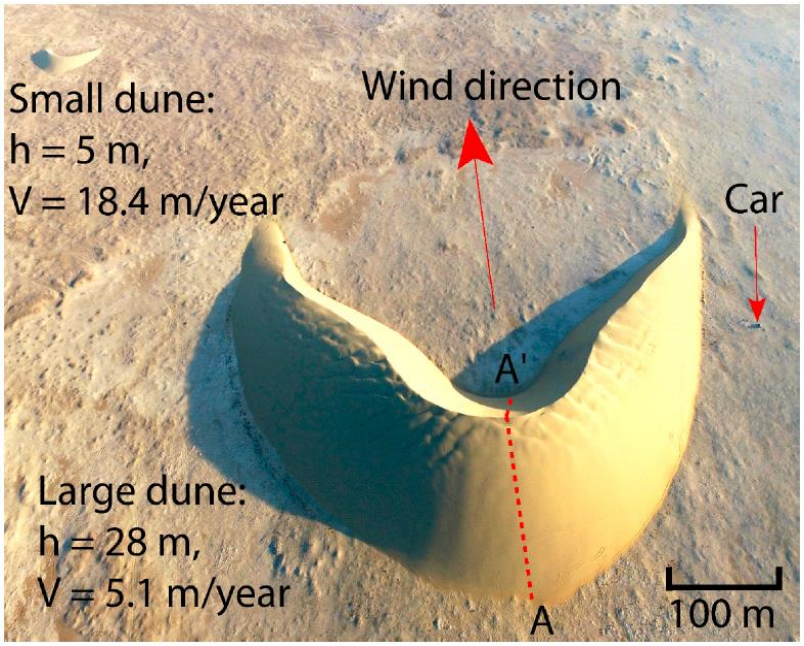
Motivation: bedform morphology

- Transverse aqueous dunes:
  - Plentiful sand supply
  - Unidirectional flow
  - Amplitudes & wavelengths



(Fourriere et al., 2010, JFM)

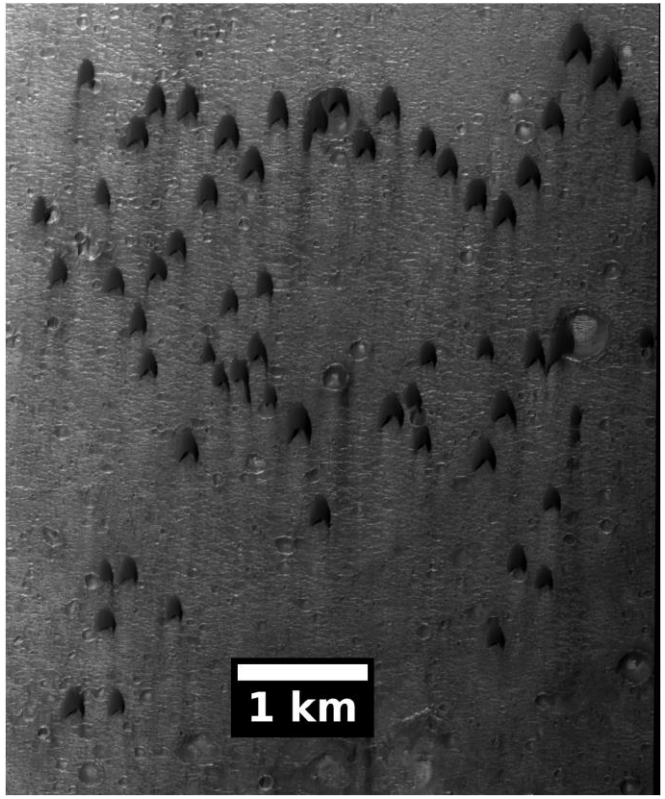
(credit: Sylvain Michel, Cambridge)



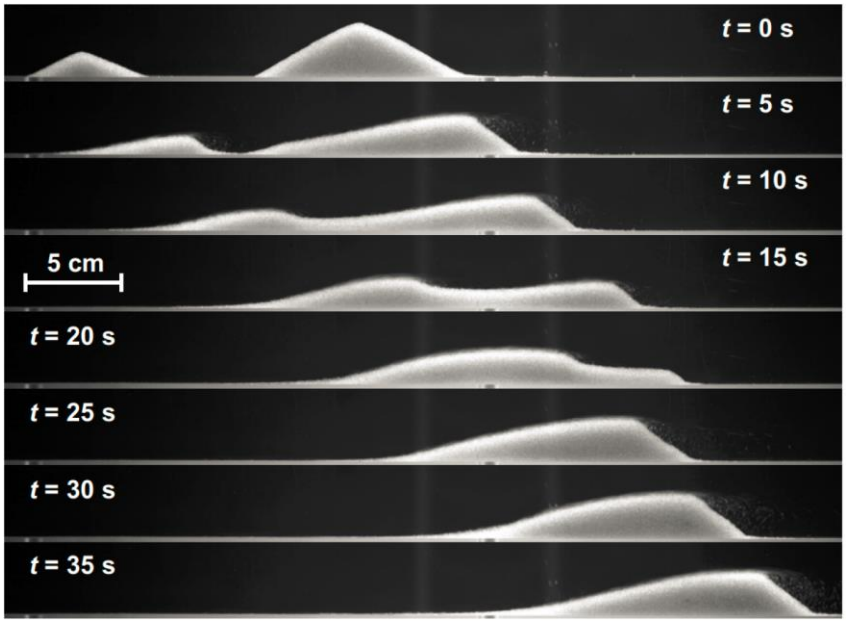
- Barchan aeolian dunes:
  - Limited sand supply
  - Unidirectional flow
  - Heights & scatter

Motivation: bedform morphology (2)

- Martian dune field (HiRISE)
  - 3D dune interactions



(Credit: NASA/JPL/University of Arizona)

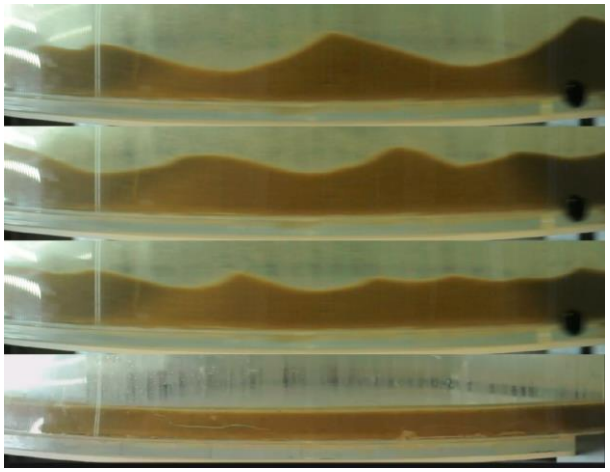


(Groh et al., 2009, New J. Phys. 11)

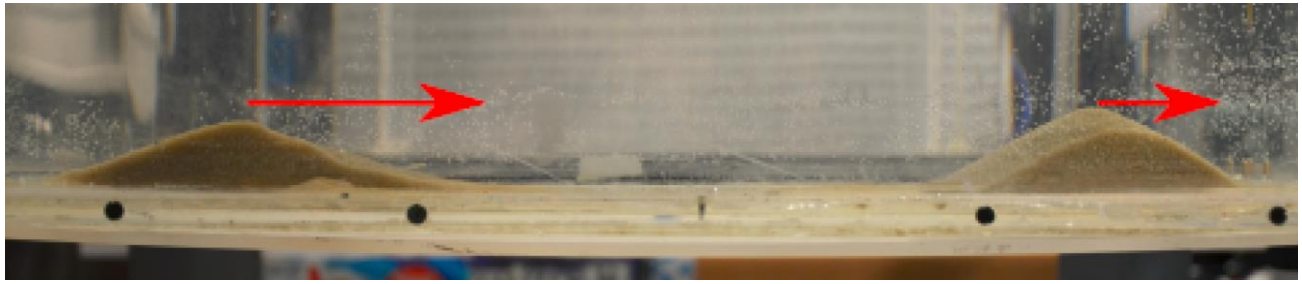
- Laboratory 1D dune:
  - Migration velocity c ~ 1/H
  - Differential velocities
  - Dune collisions

Central questions of interest

- Linear stability on a flat bed:
  - Initial conditions…
  - Limits of linear regime?
  - Wavelength distribution, growth rate?
  - Start of pattern coarsening?

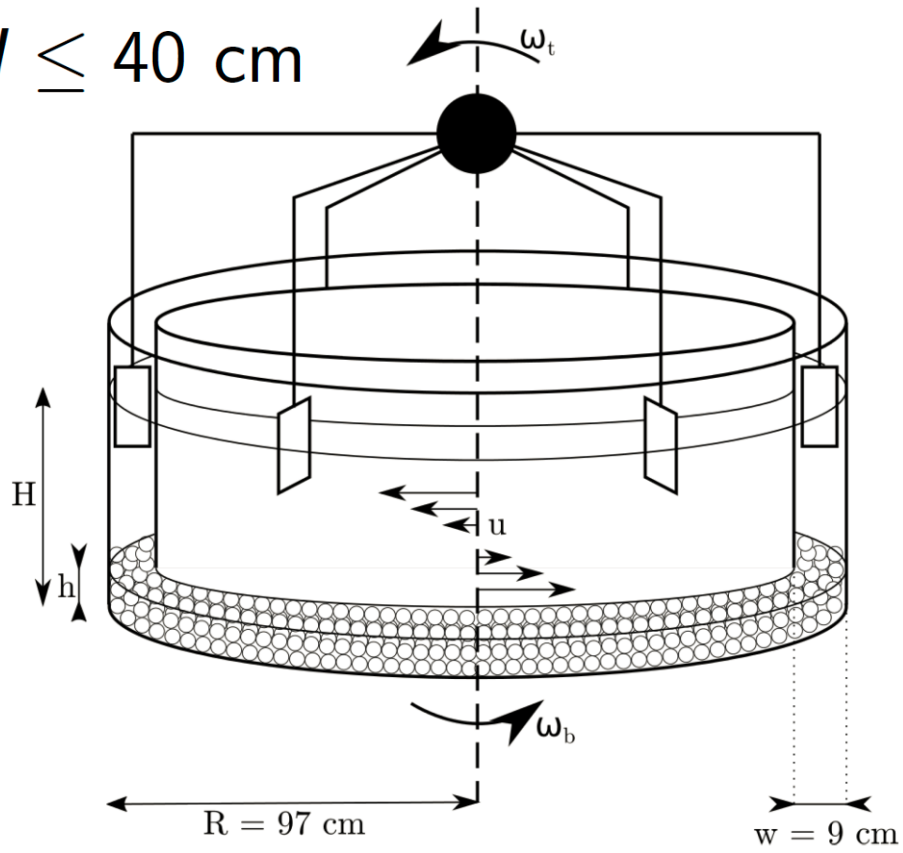


- Non-linear pattern coarsening:
  - Interaction potentials for two colliding bedforms?
  - Controls on coarsening of dune field?
  - Steady-state solution in a periodic domain?



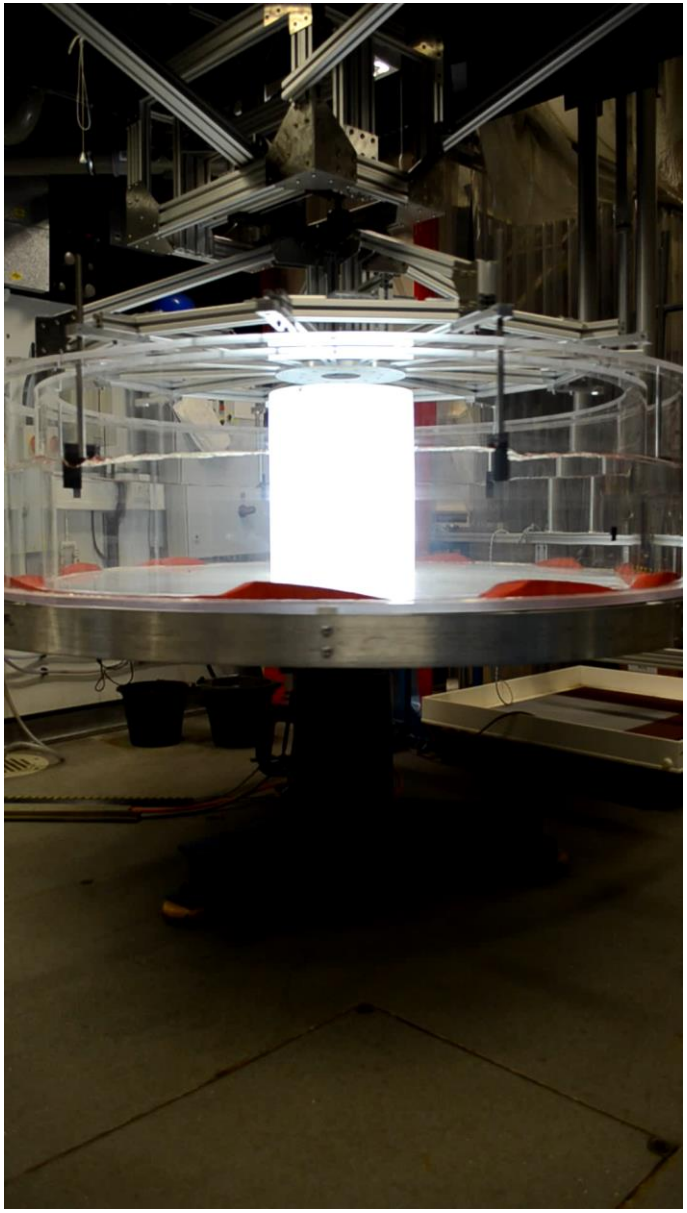
Experimental set-up

$H \leq 40$ cm



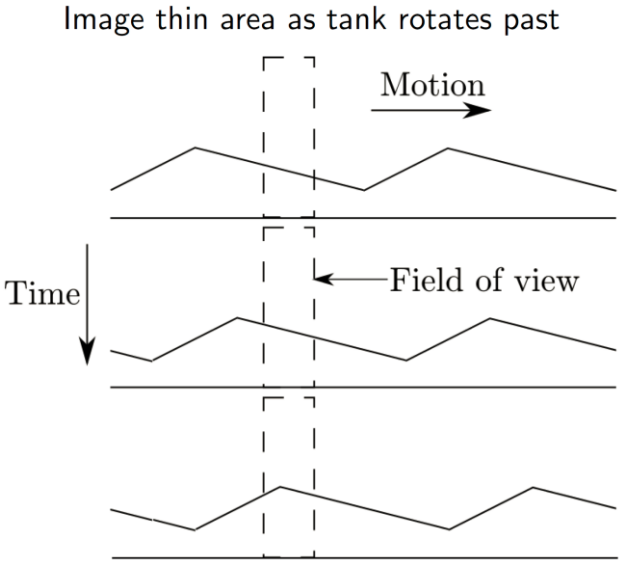
$$\Omega = |\omega_t| + |\omega_b| \leq 14 \text{ rpm}$$

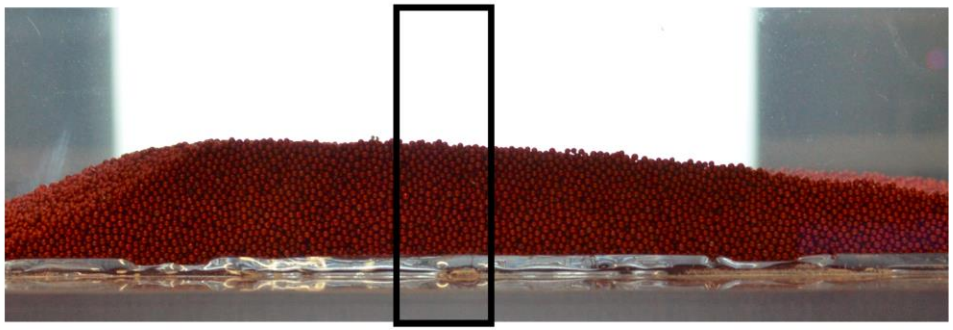
$$U = R\Omega \leq 1.47 \text{ m s}^{-1}$$



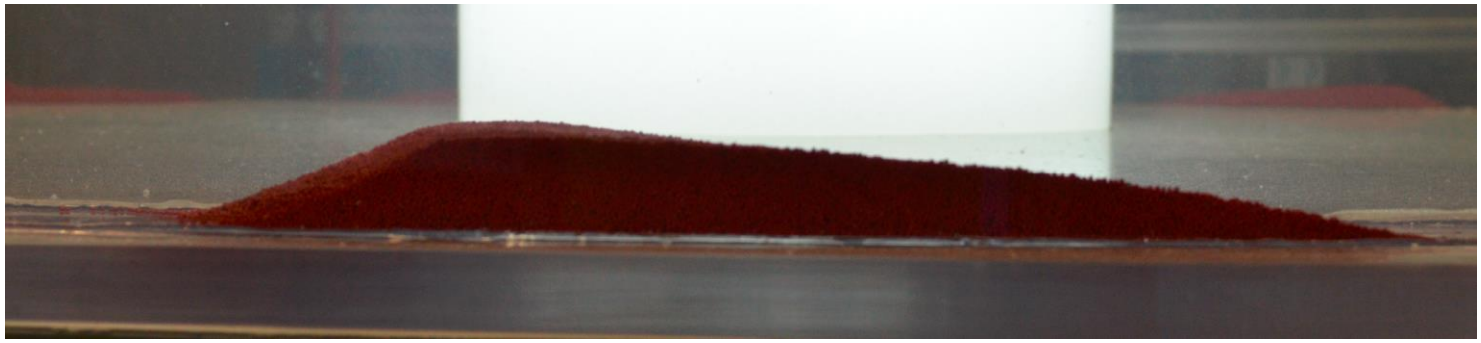
Experimental parameters

- First set of initial conditions:
  - Flow velocity up to: U = 1.4 m/s
  - Flow depth: H = 20, 30, 40 cm
  - Initial bed thickness: h = 1, 2, 4 cm
  - Particle size diameter: d = 1 mm
- Non-dimensionless numbers:
  - Flow Reynolds: Re ~ 10^5
  - Particle Reynolds: Re_p ~ 10^3 - 10^4
  - Froude: Fr ~ 1
- Resolution:
  - Spatial → covering
  - Time → 1 rotation





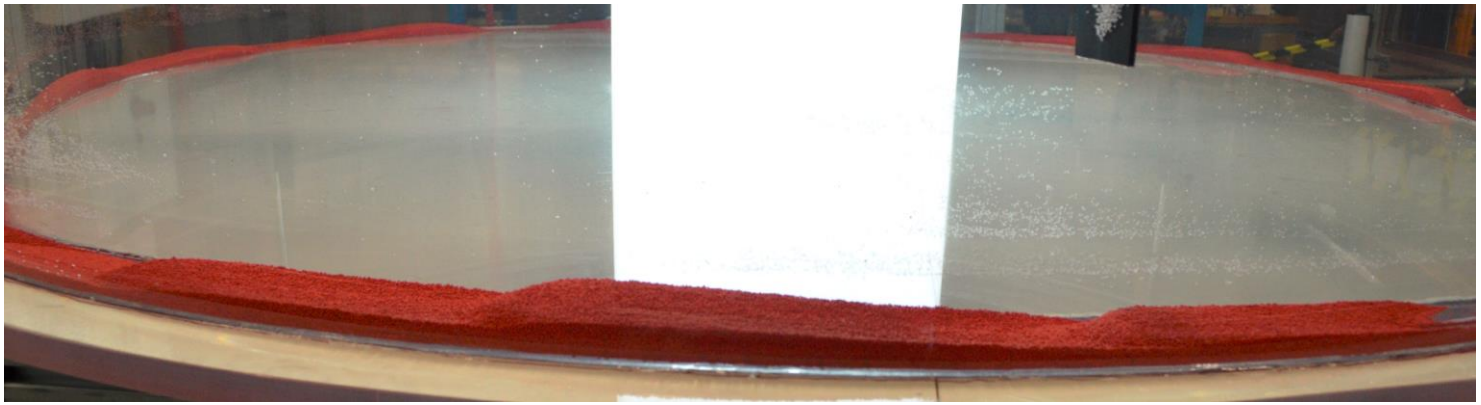
Results: bedform stages



Barchan dunes

↑

Transverse dunes



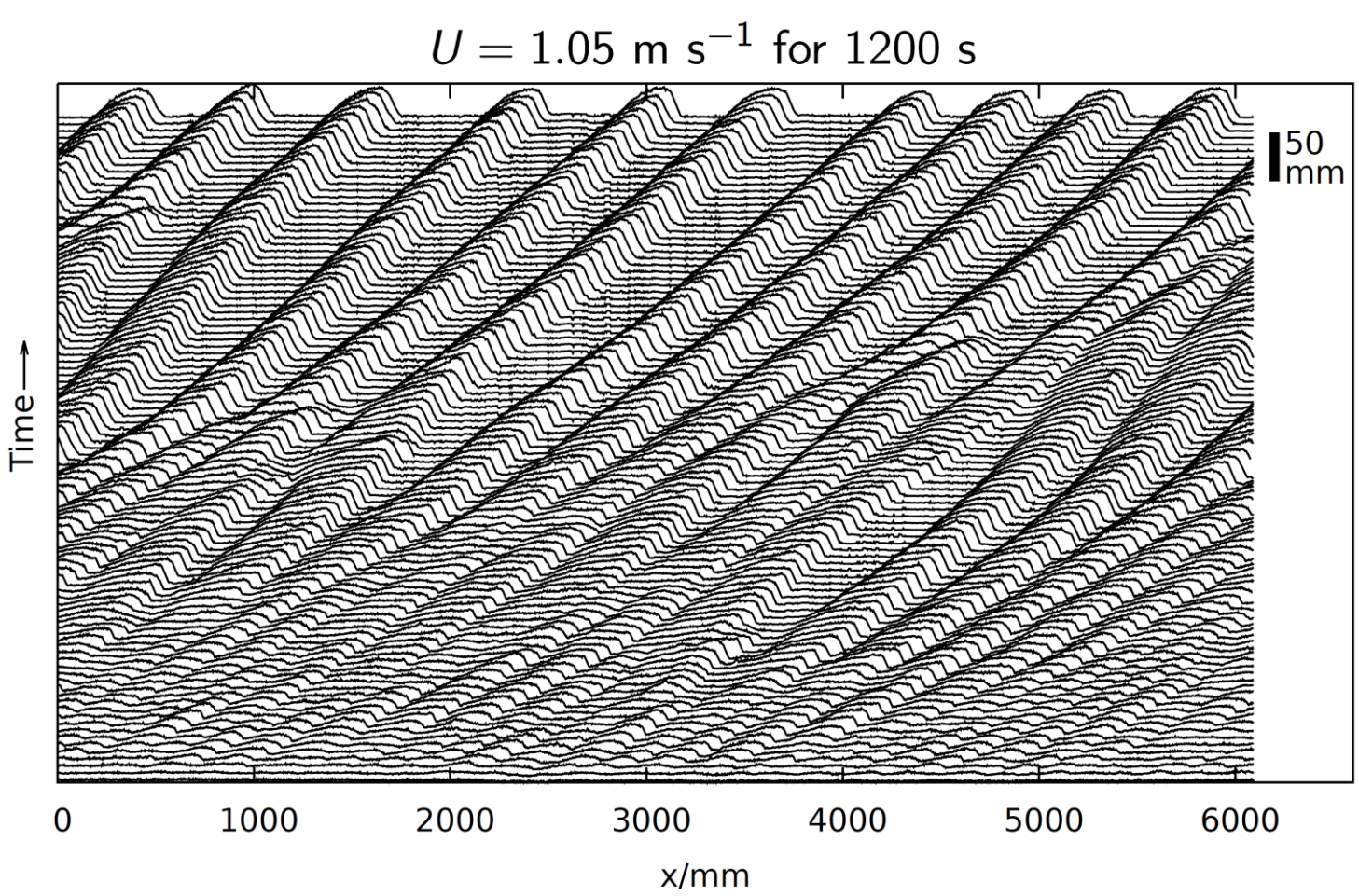
↑

Irregular amplitude and wavelength

↑

Initially flat bed

Results: bed evolution



Barchan dunes

↑

Transverse dunes

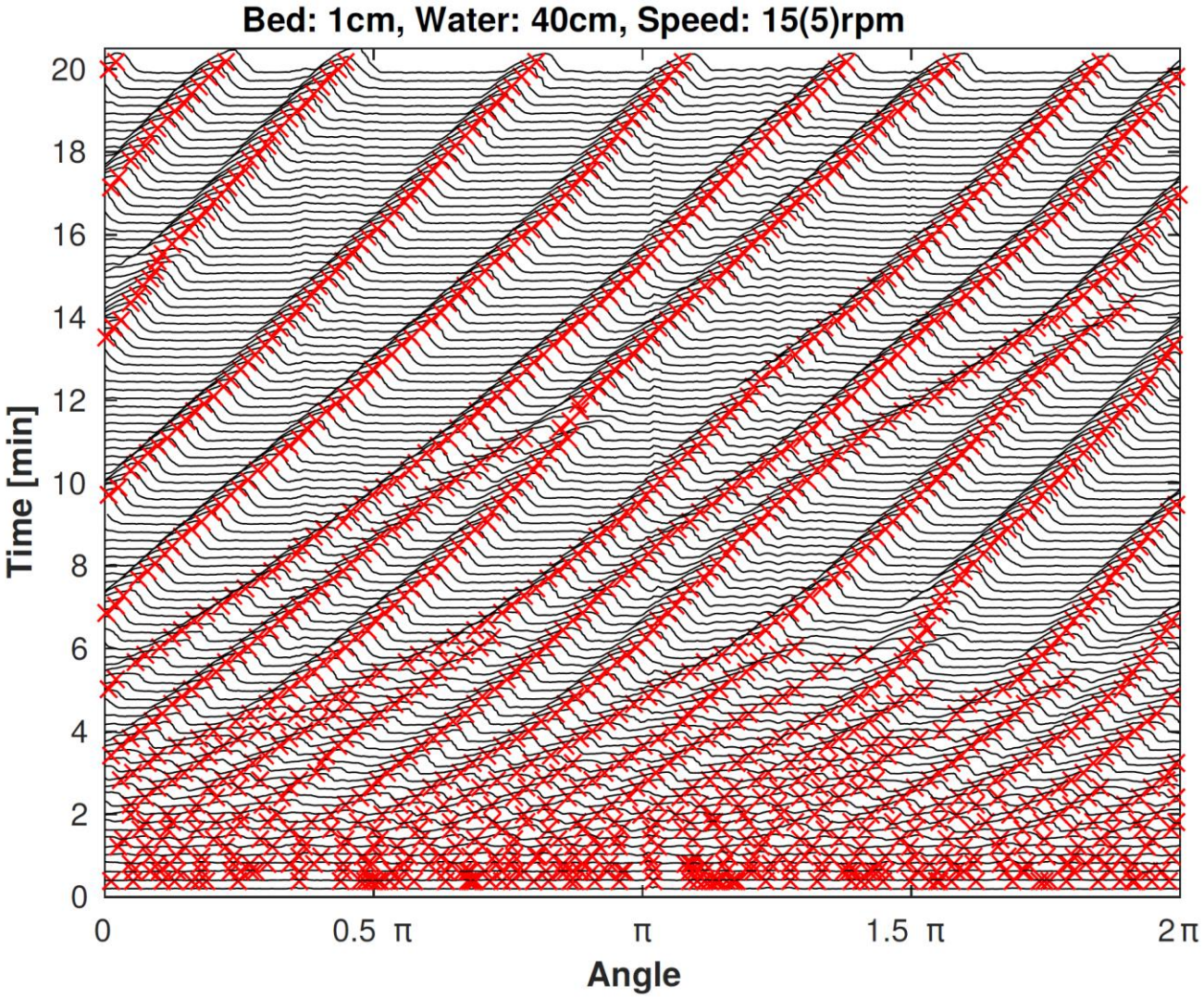
↑

Irregular amplitude and wavelength

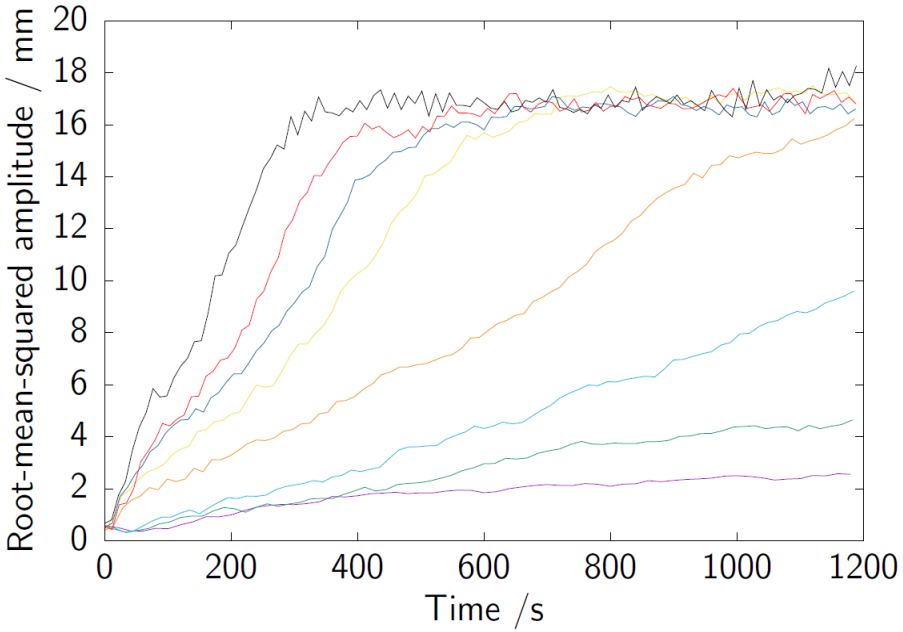
↑

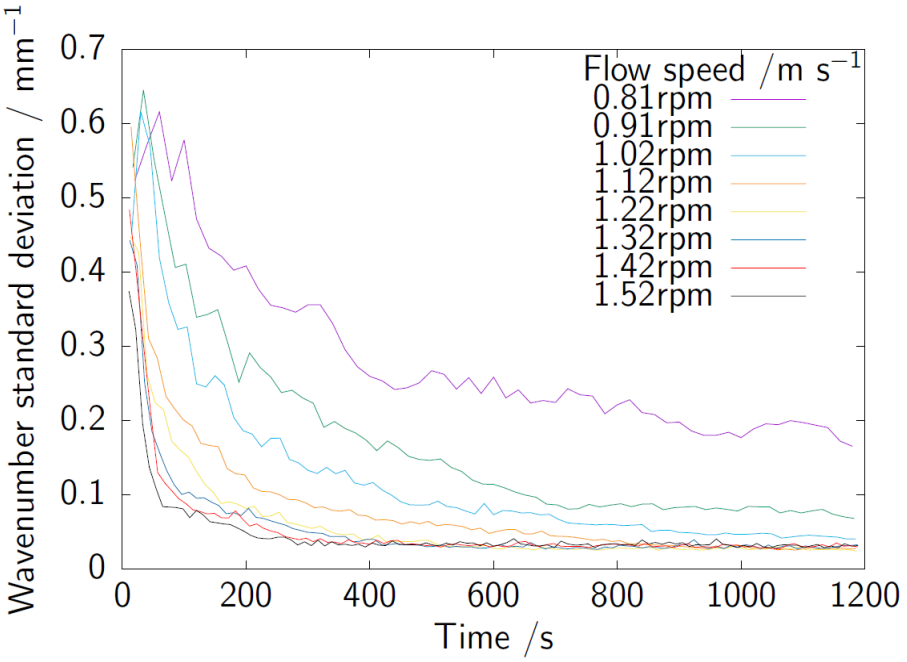
Initially flat bed

Results: peak-finding algorithm



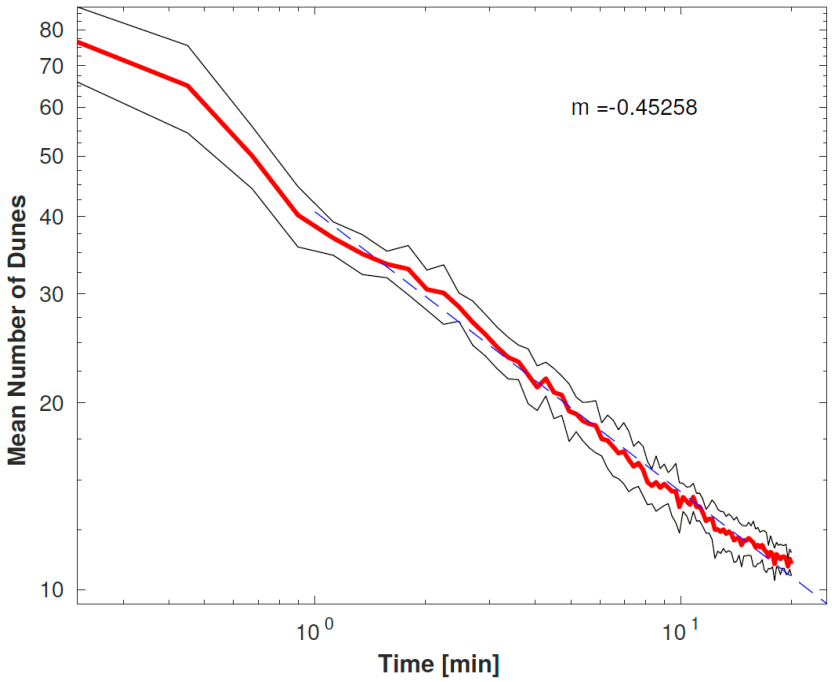
Results: coarsening at H = 30cm, h = 2 cm

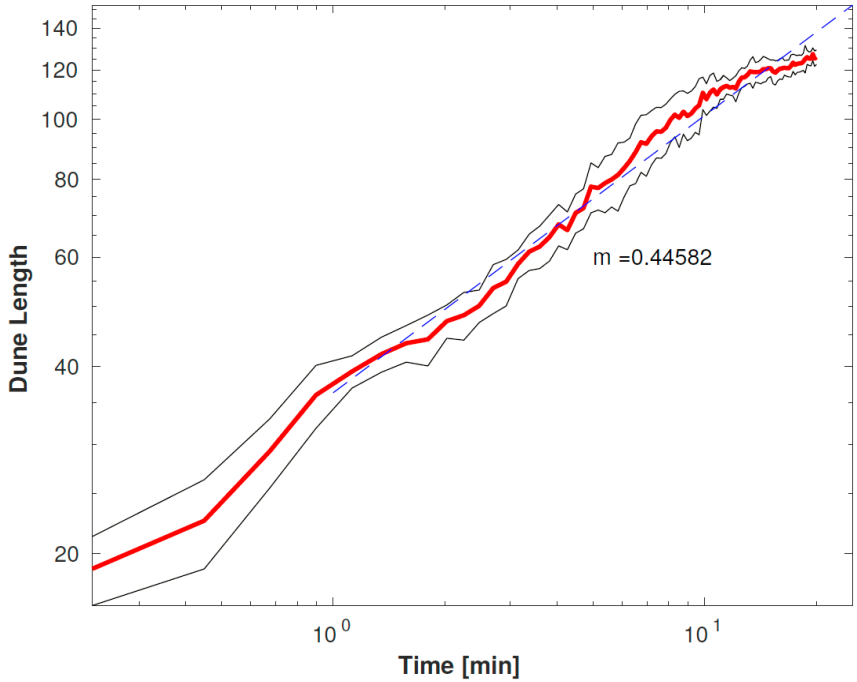




- Saturation at 20 min for fastest 4 rotation speeds:
  - Amplitude & wavelength ↑ with time → until saturation
  - Rate of growth rate ↑ with time
  - Wavelength distribution ↓ with time → smoothing of spacing

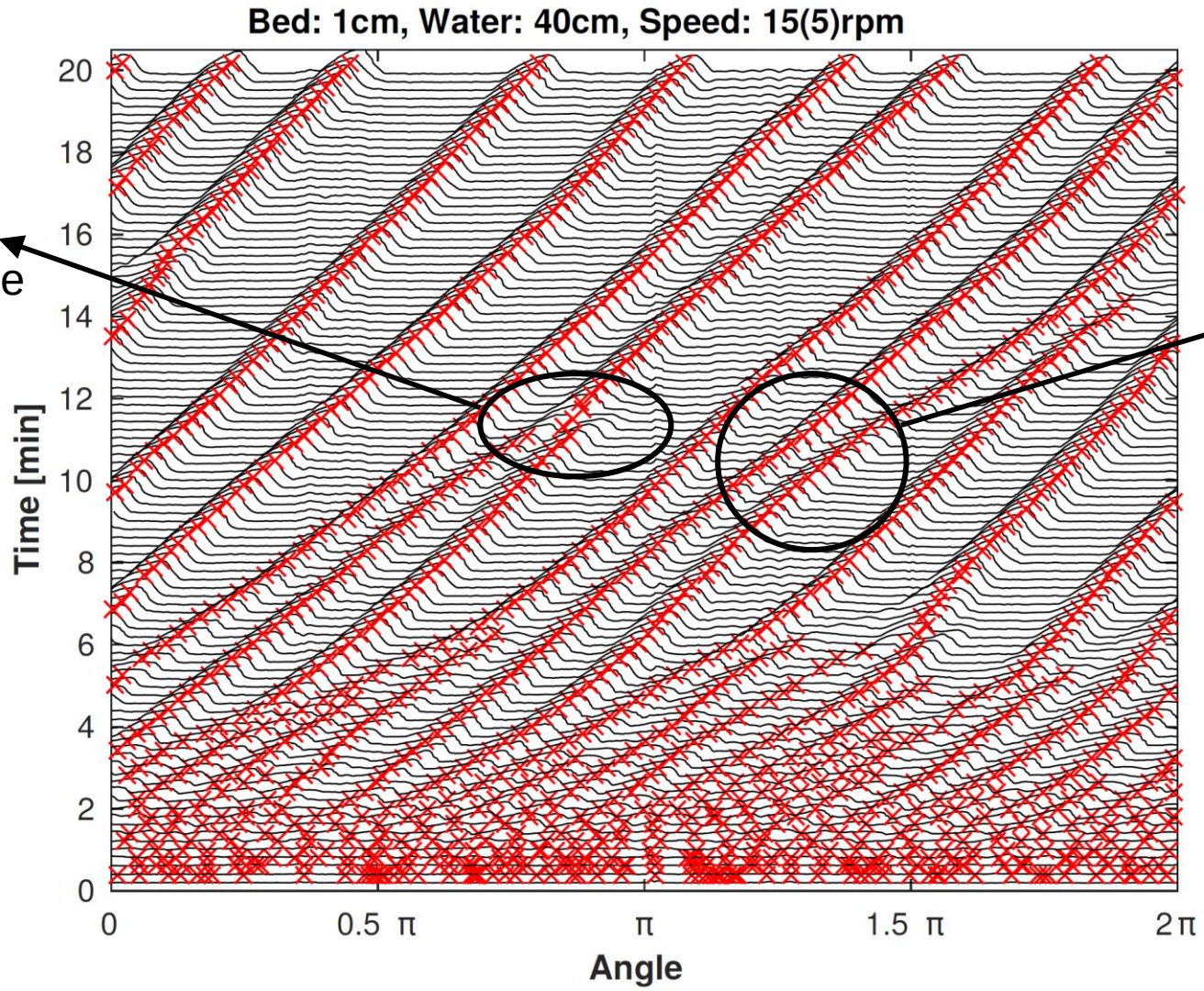
Results: 10 repeats at H =40 cm, h = 2 cm





- Long-term time predictions:
  - Power-law behavior? Tail off around 20min (saturation?)
  - One megadune after 2d, 17h?

Results: interactions between dunes

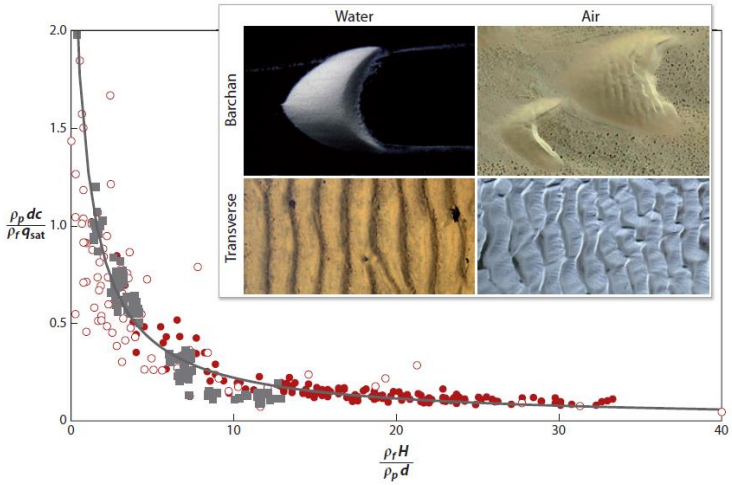


Merging = coalescence

Interaction = ejection

Dune interaction potentials

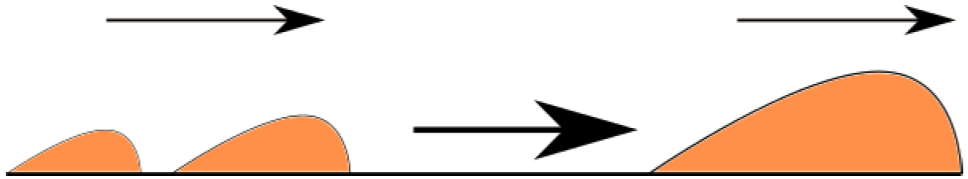
From: Charru et al., Ann. Review of Fluid Mech., 2013



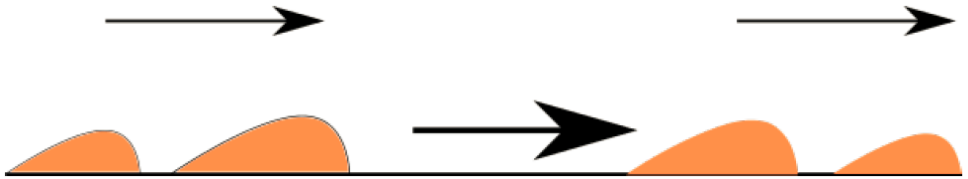
- Migration velocity and height:
  - Smaller dunes → faster
  - Larger dunes → slower

$$\mathbf{v}_d = \frac{q_b}{\rho H}$$

- Coalescence:
  - Smaller upstream, big downstream

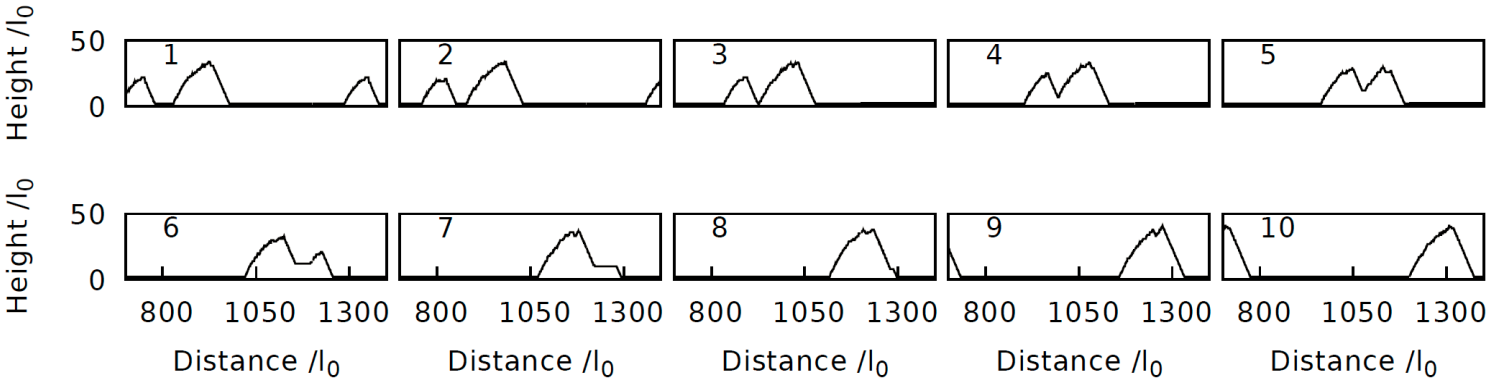


- Ejection:
  - Slightly bigger upstream big downstream

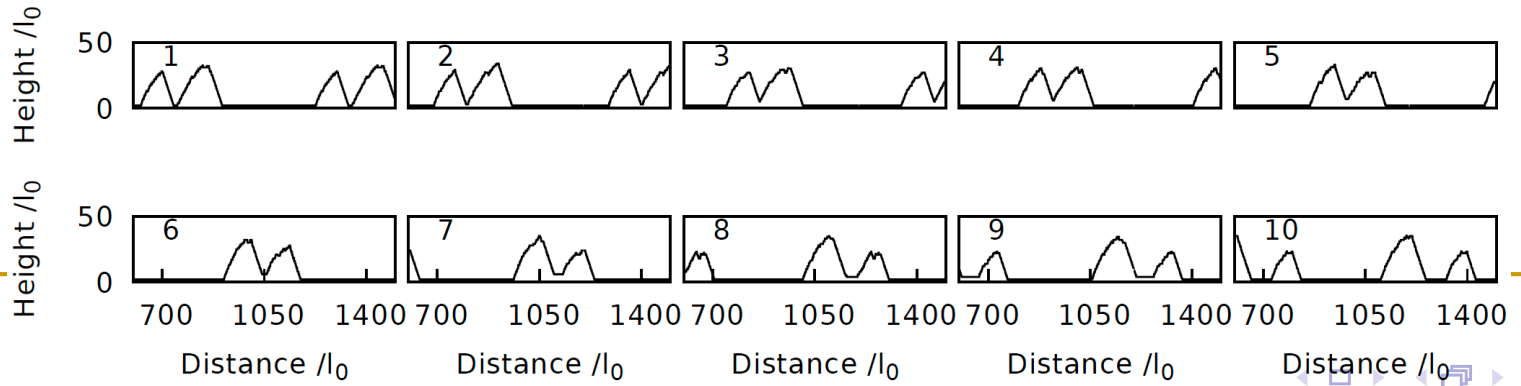


Dune collision simulations

- Collaboration: Clement Narteau & Olivier Rozier, IPGP
- Use of cellular automaton model (ReSCAL)
- Coalescence:

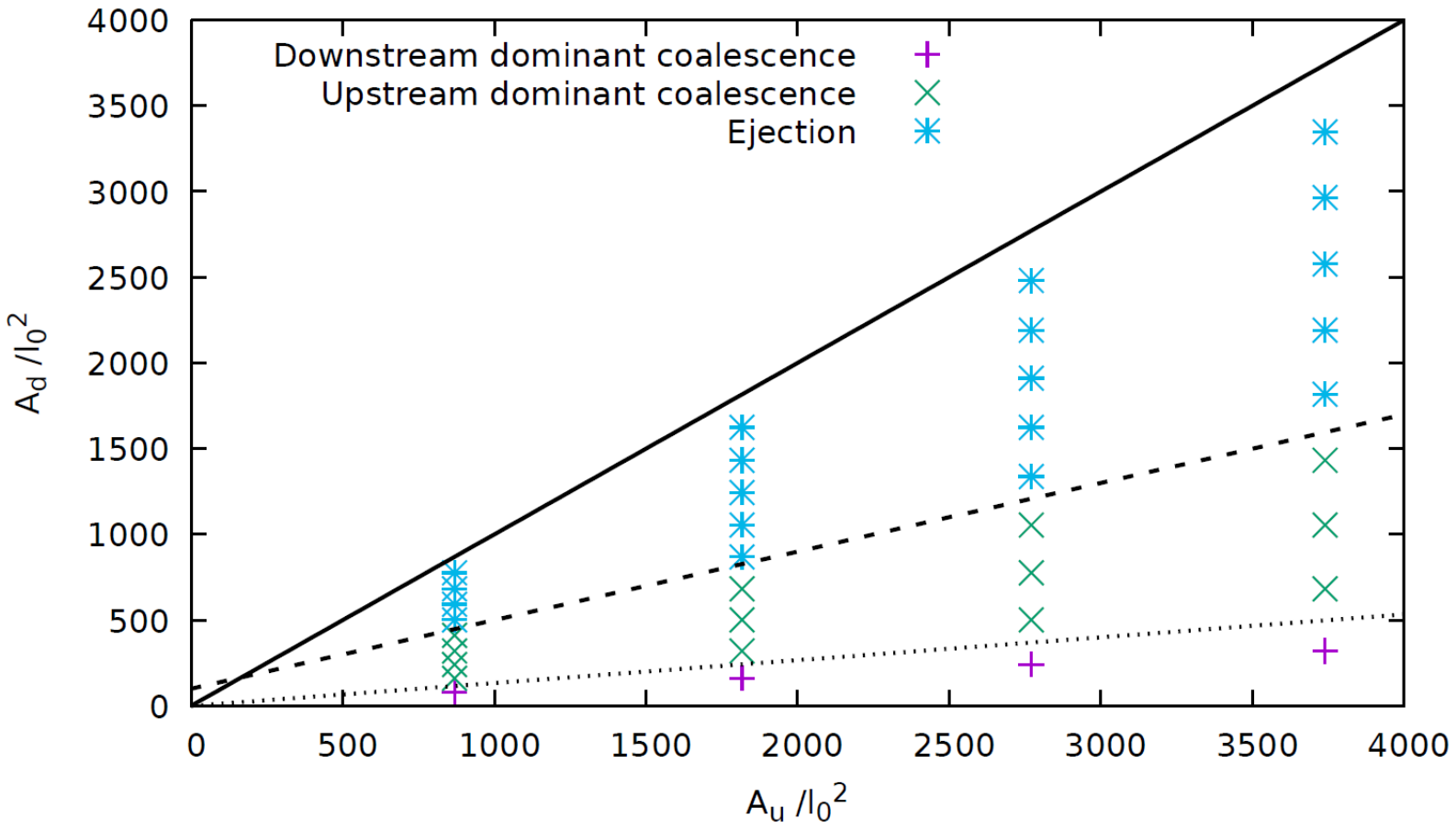


- Ejection:



Dune collision simulations (2)

- Phase space interaction potentials



Conclusions, discussion, future work

- Bedform formation and morphodynamics from flat bed
  - Initial formation and bedform coarsening
  - Quantify dune amplitude, wavelength and total number
  - Bedform interaction: dune ejection and coalescence

- Future work on interaction potentials:
  - Two individual bedforms of different sizes
  - Phase space map of outcomes

- Future work on initial formation:
  - Co-rotating camera to increase time resolution
  - Exploration of linear regime


Questions?
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