RoadMap

Workshop

Wind-driven Dust and Sand transport. Merrison (AU)

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"Wind-driven Dust and Sand transport"

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

Greeley and Iversen
Wind as a Geological process
(1985)

Pye and Tsoar
Aeolian sand and sand dunes
(1990)

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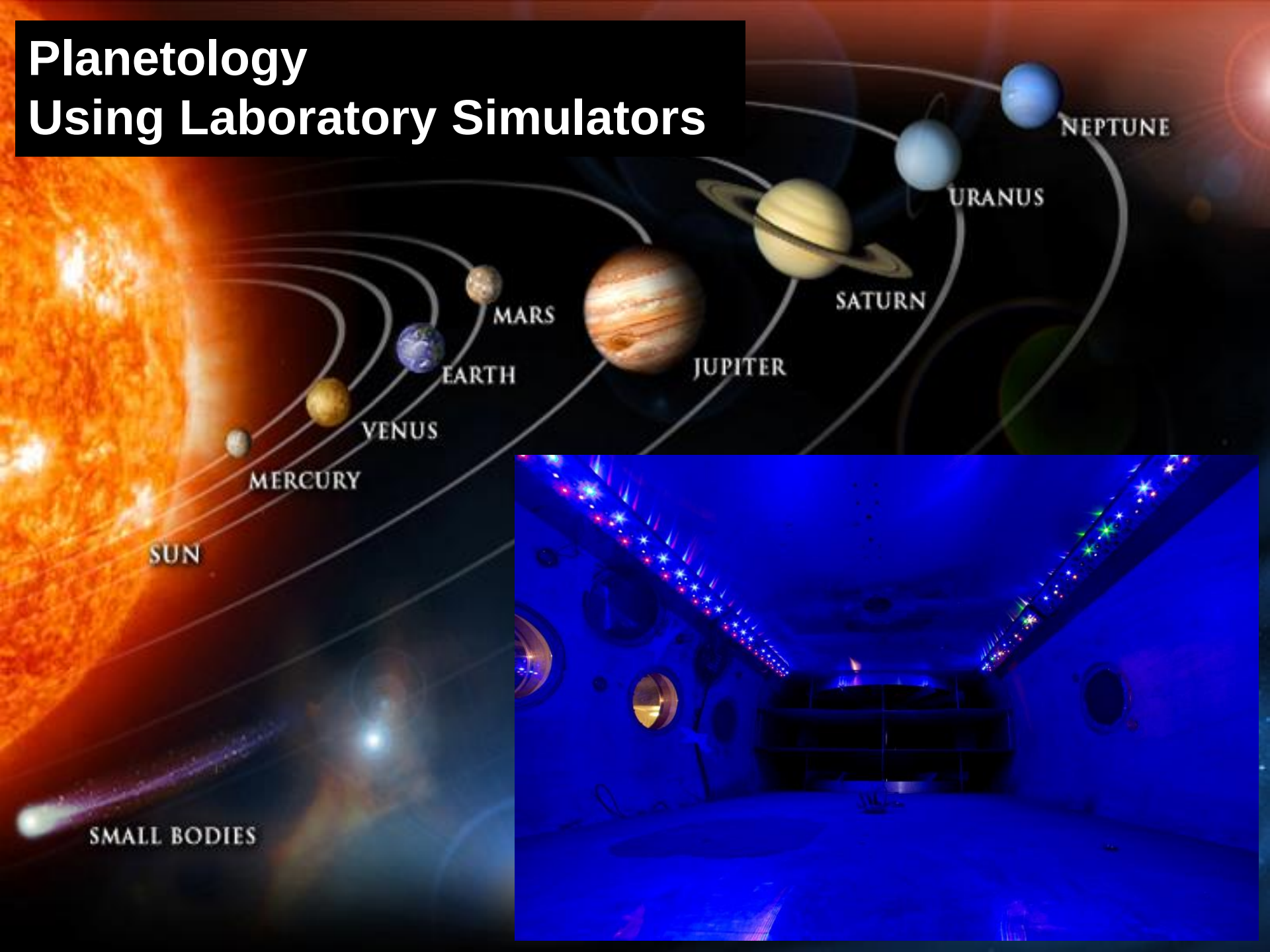
Planetology
Using Laboratory Simulators

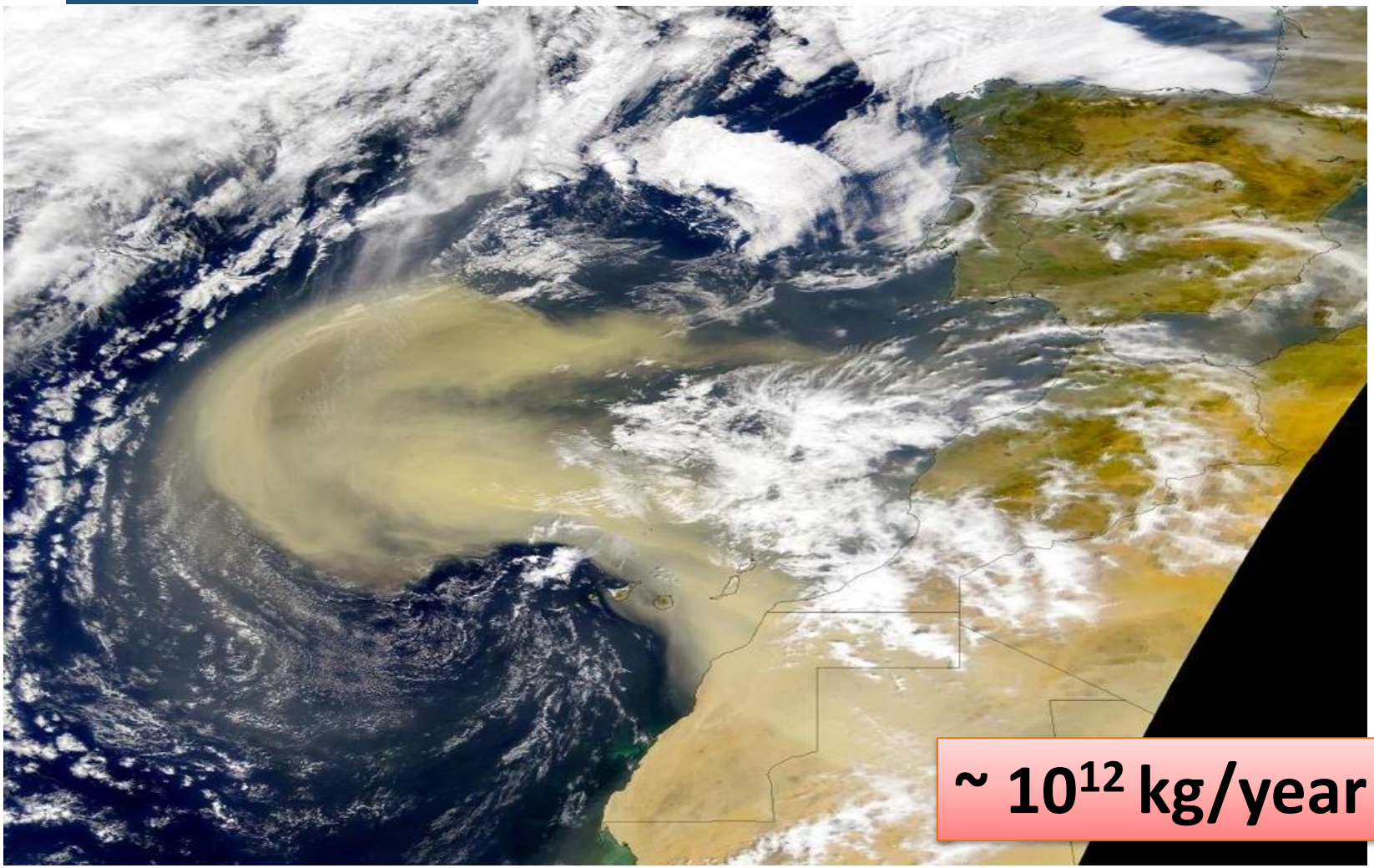


Terrestial type environments (comparative planetology)

Earth, Mars, Venus, and Titan (Surface – Atmosphere)

Comparative Planetology; Dust Aerosols.

Courtesy NASA/JPL-Caltech



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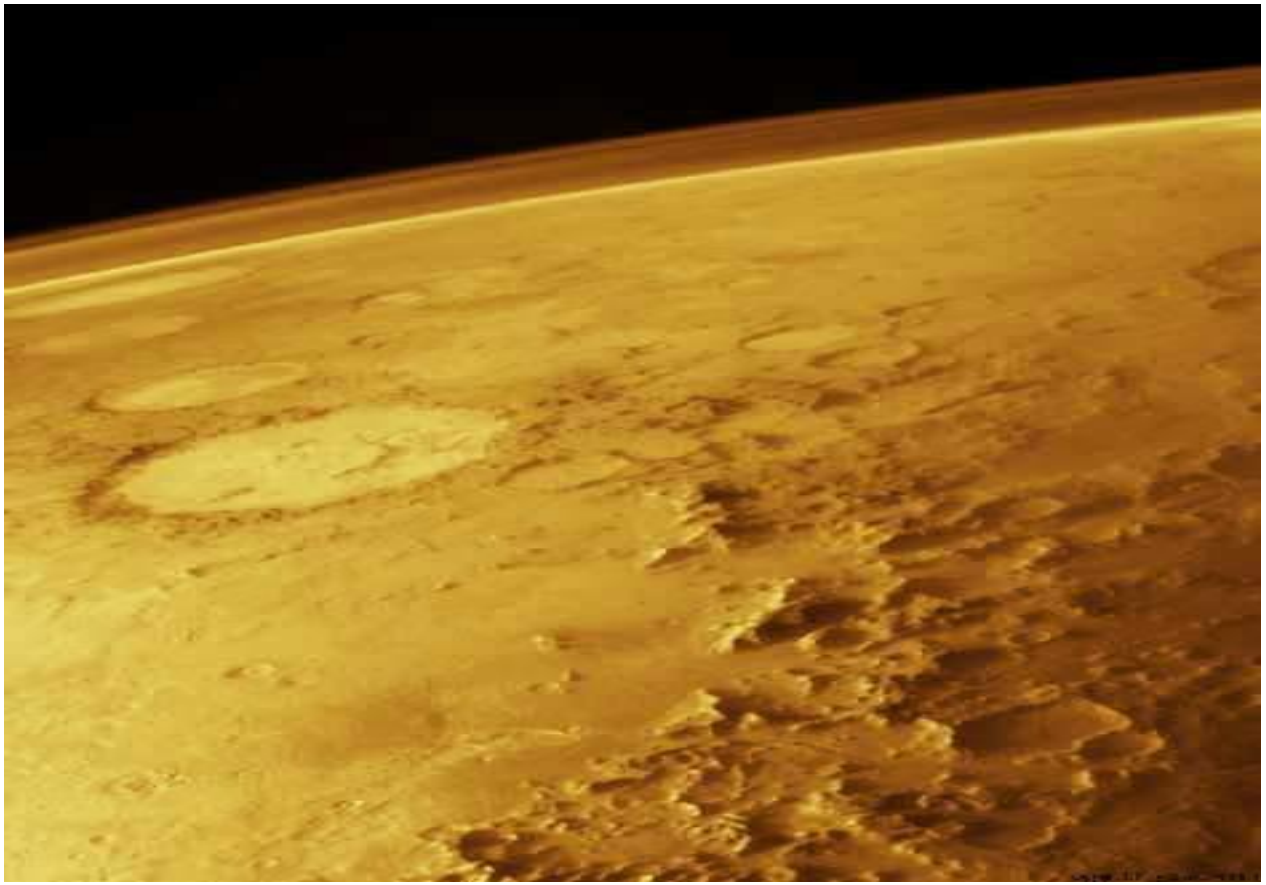
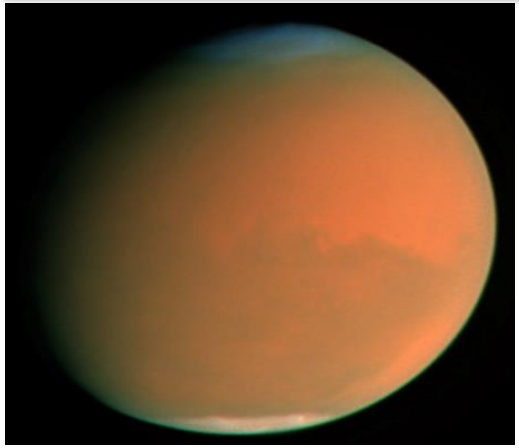
Martian dust transport





Most dynamic factor affecting the surface/atmosphere

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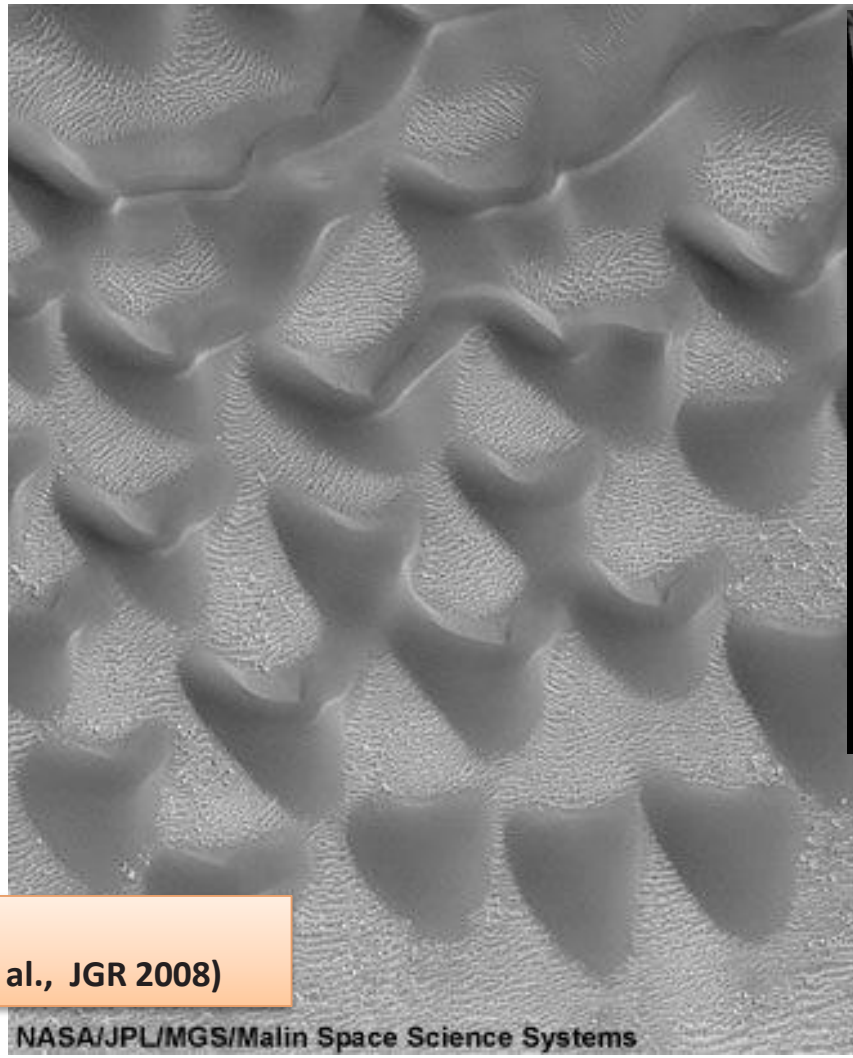
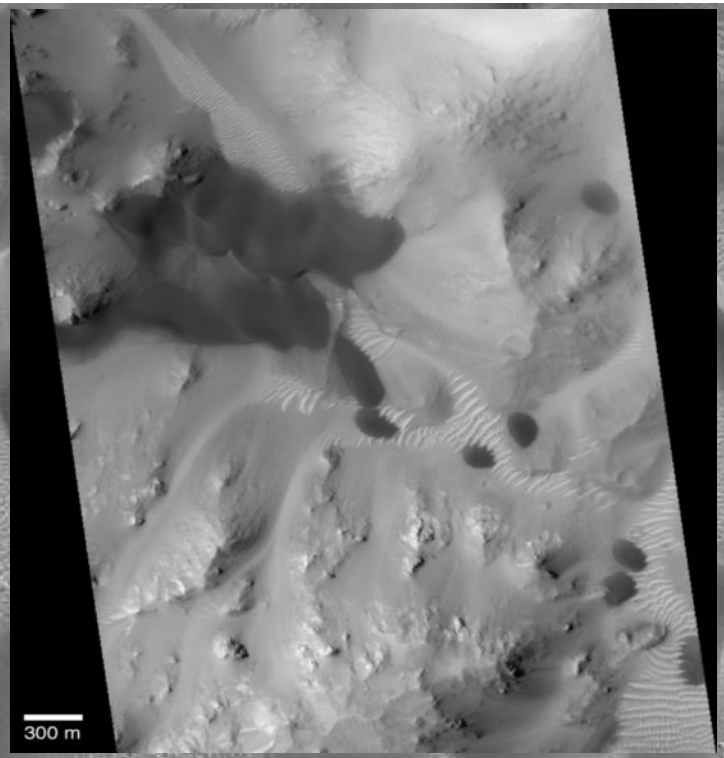
Sand Dunes on Mars (ancient)





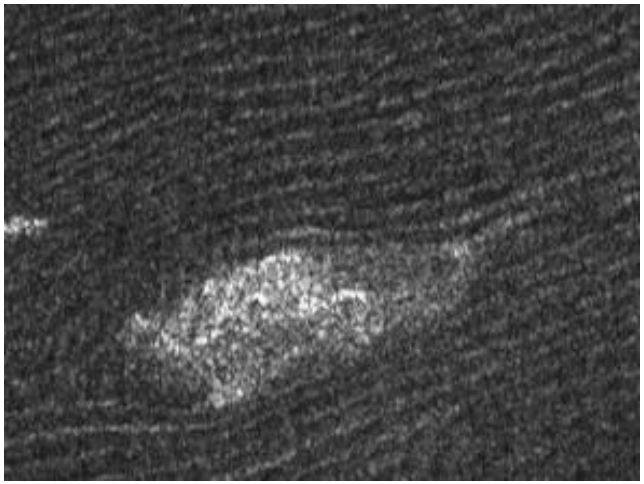
Sand Transport
(Sullivan , R.J. et al., JGR 2008)

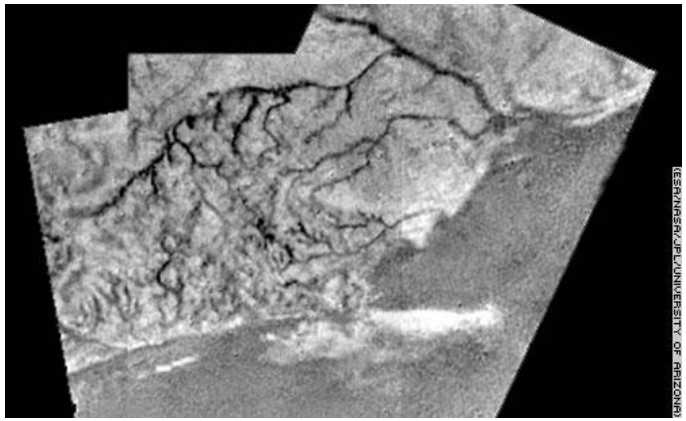
Sporadic / Localized Sand transport on Mars!!!

Titan

Casini / Huygens (ESA/NASA)

Ice sand dunes





Rivers, lakes, seas, rain, mud etc..

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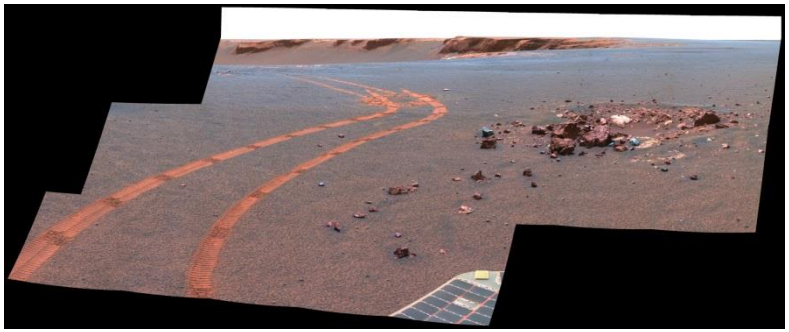
Wind driven Ash transport



Martian surface =
volcanic sand /dust
+ Aeolain transport

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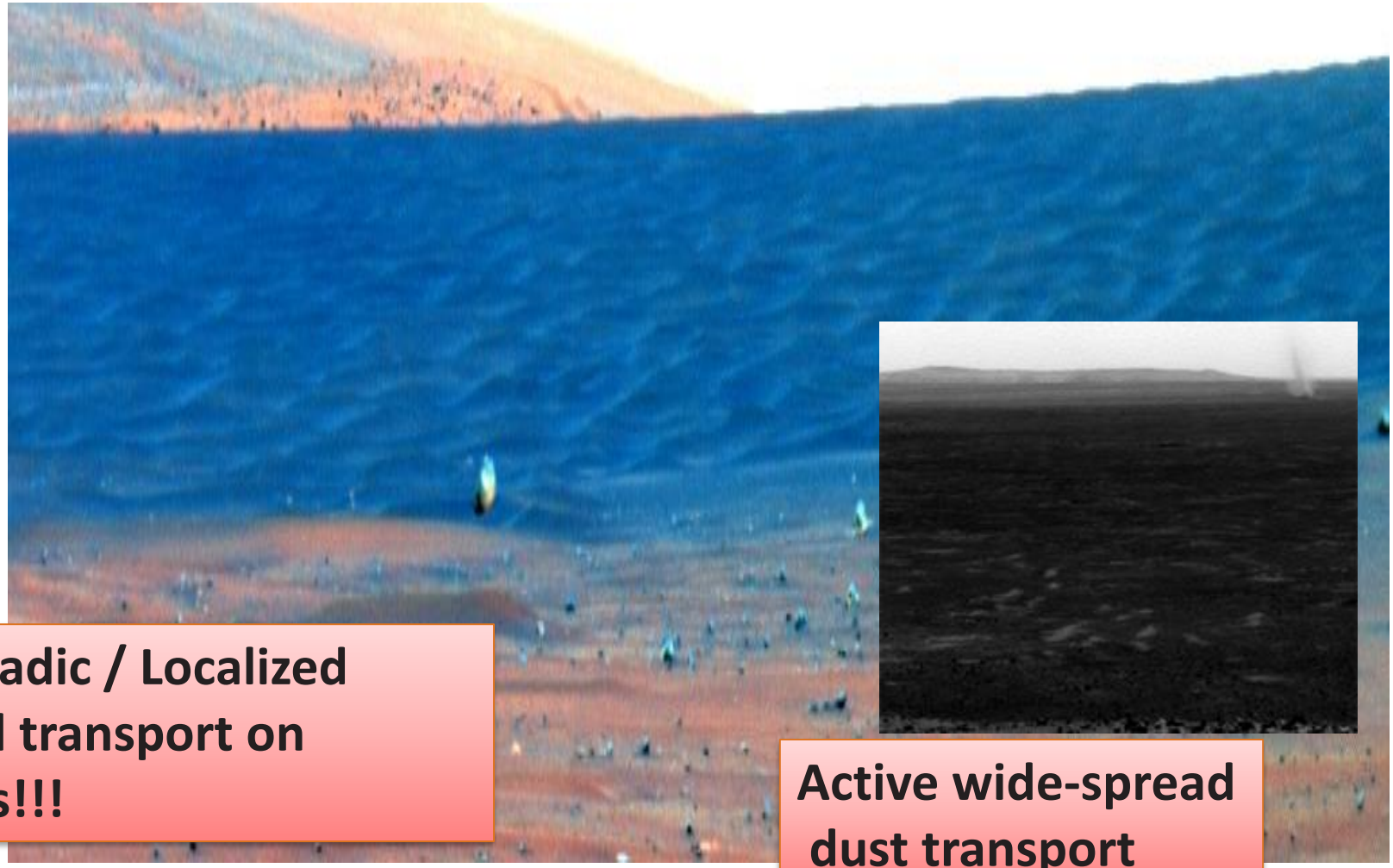
Mars: Current Aeolian (Erosion) Activity)



Sporadic / Localized Sand transport on Mars!!!

Active wide-spread dust transport

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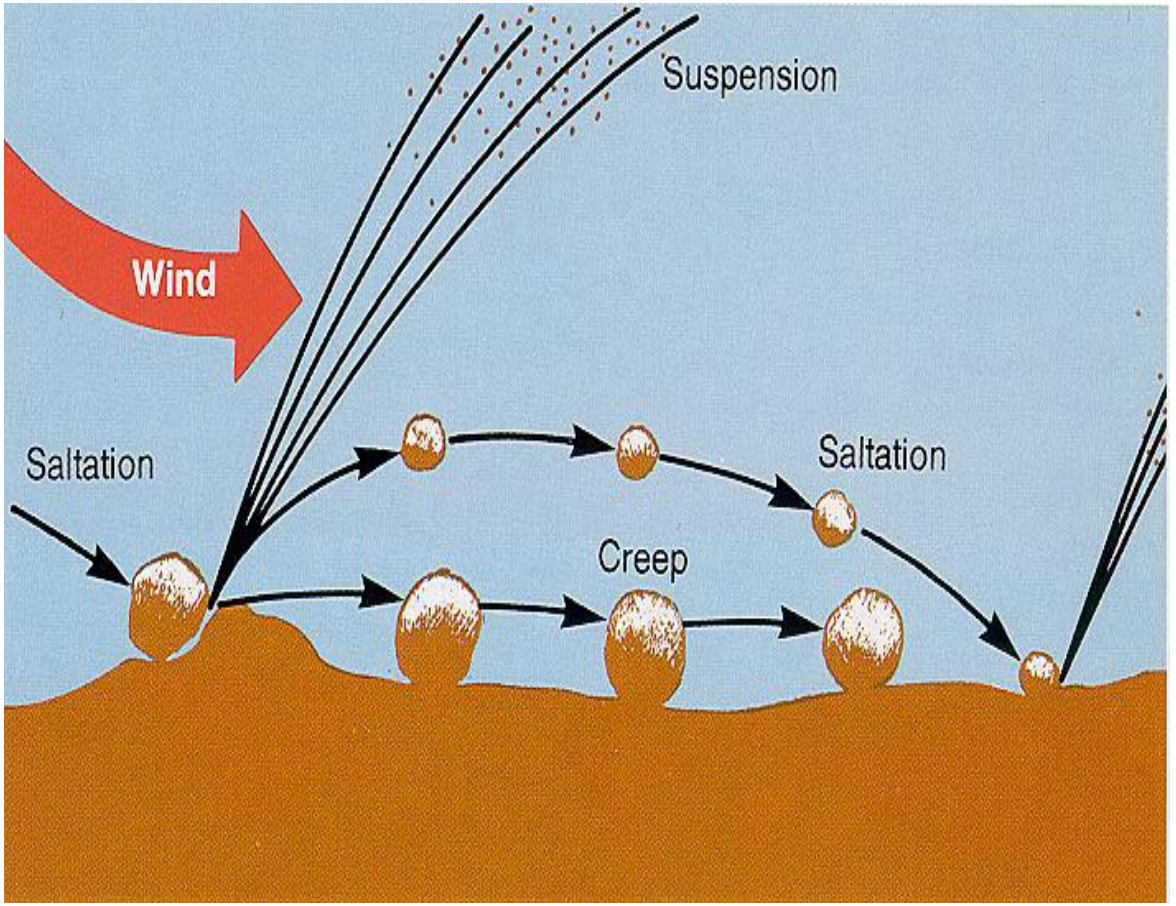
Wind driven processes; saltating sand:

Ripples, Dunes, Abrasion (ventifacts), dust transport



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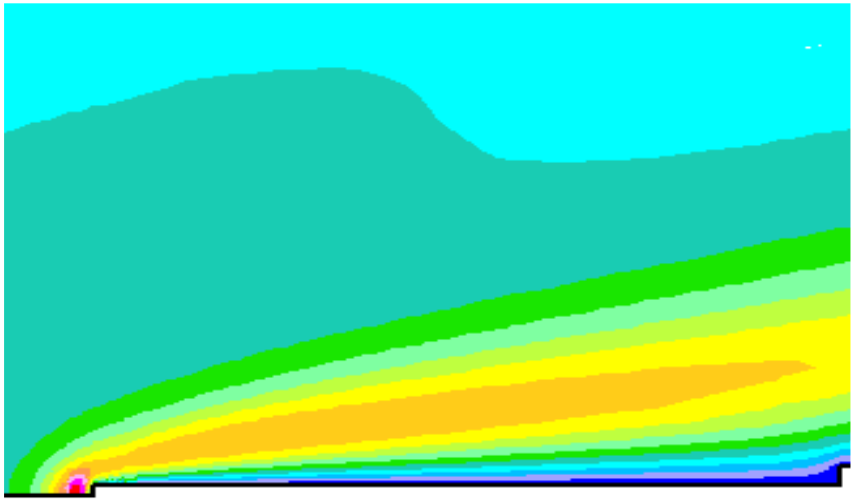
Conventional Boundary Layer Model

Surface Shear Stress = F/A = ρU_*^2

U_* = Friction Velocity

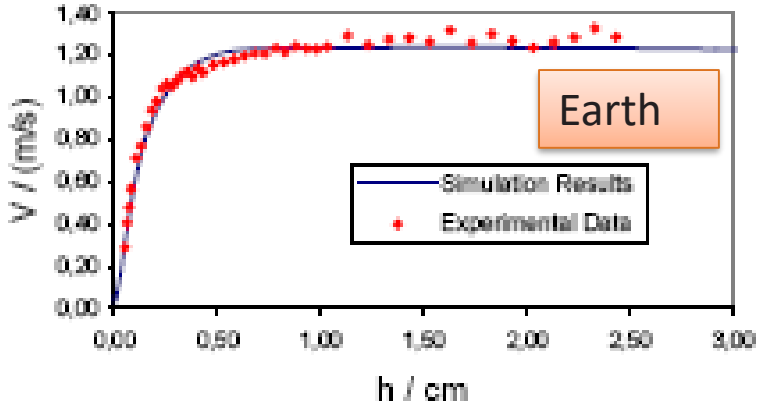


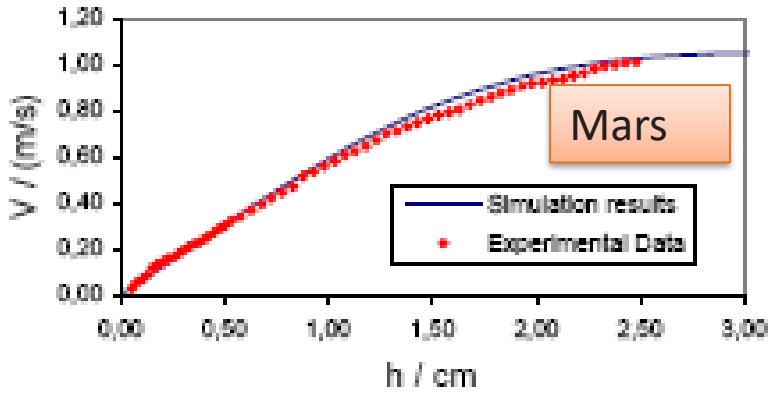
Turbulent Boundary (sub) Layer

$$U = 2.5U_* \ln\left(\frac{\rho U_*^2}{\mu} Z\right) + 5.1U_*$$

Viscous Boundary (sub) Layer

$$U = \frac{\rho U_*^2}{\mu} Z$$





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Computational Fluid Dynamic: CFD Modeling

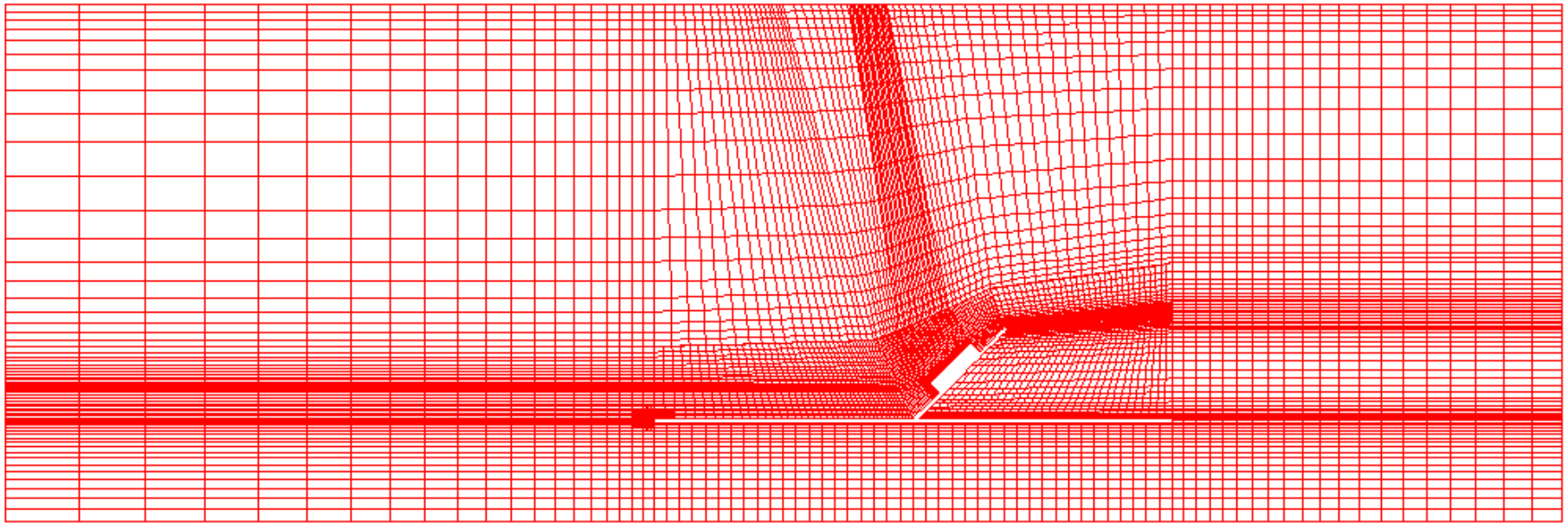
Finite Element Analysis (Computational Grid)

Navier-Stokes Equations
(momentum conservation i.e. Newtons 2nd law [moving gas parcel, ideal gas law]

$$\frac{Dv}{Dt} = -\frac{1}{\rho}\nabla P + g_p + \nu_v \nabla^2 v$$

$$\frac{D\rho}{Dt} = -\rho \nabla . v$$

+ Conservation E and mass;



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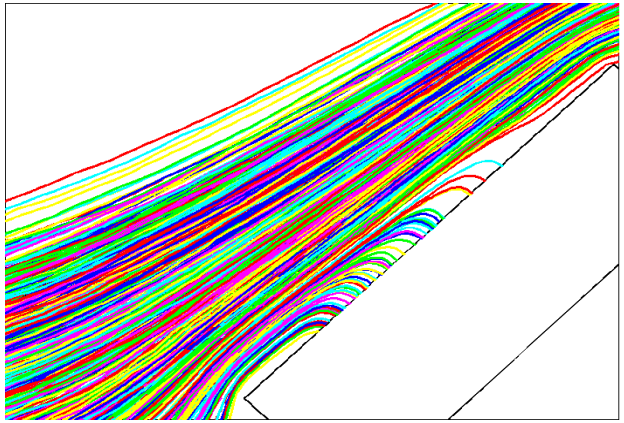
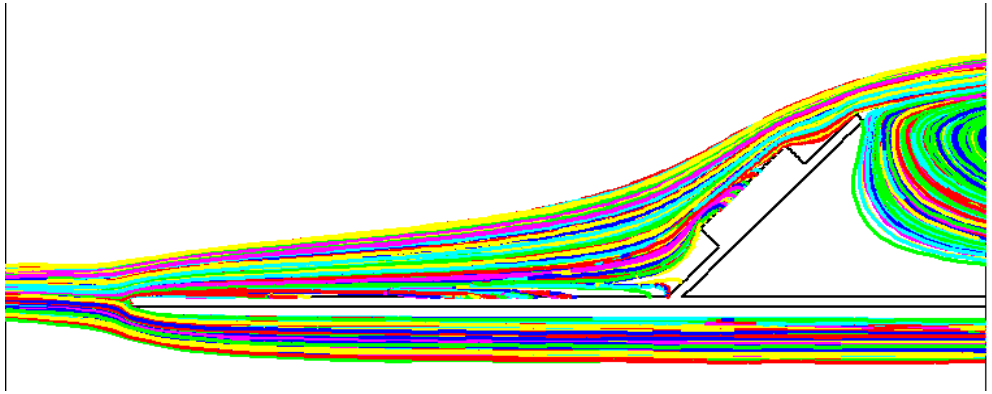
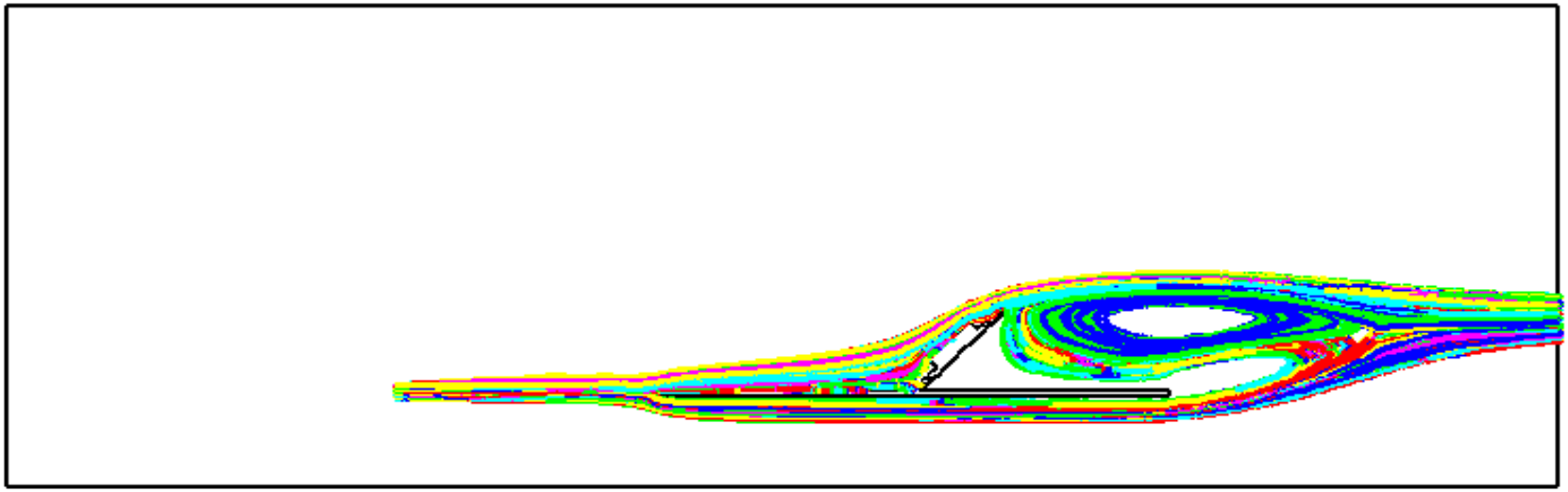
Computational Fluid Dynamic: CFD Modeling

Injecting individual dust grains







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Aerodynamic Drag

Sand Transport

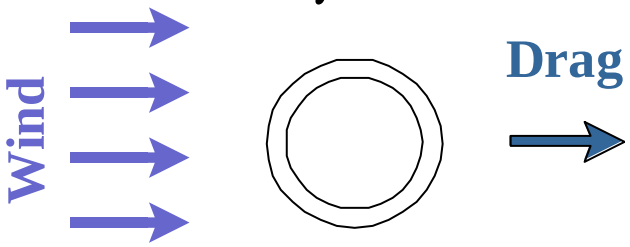
Dust Transport

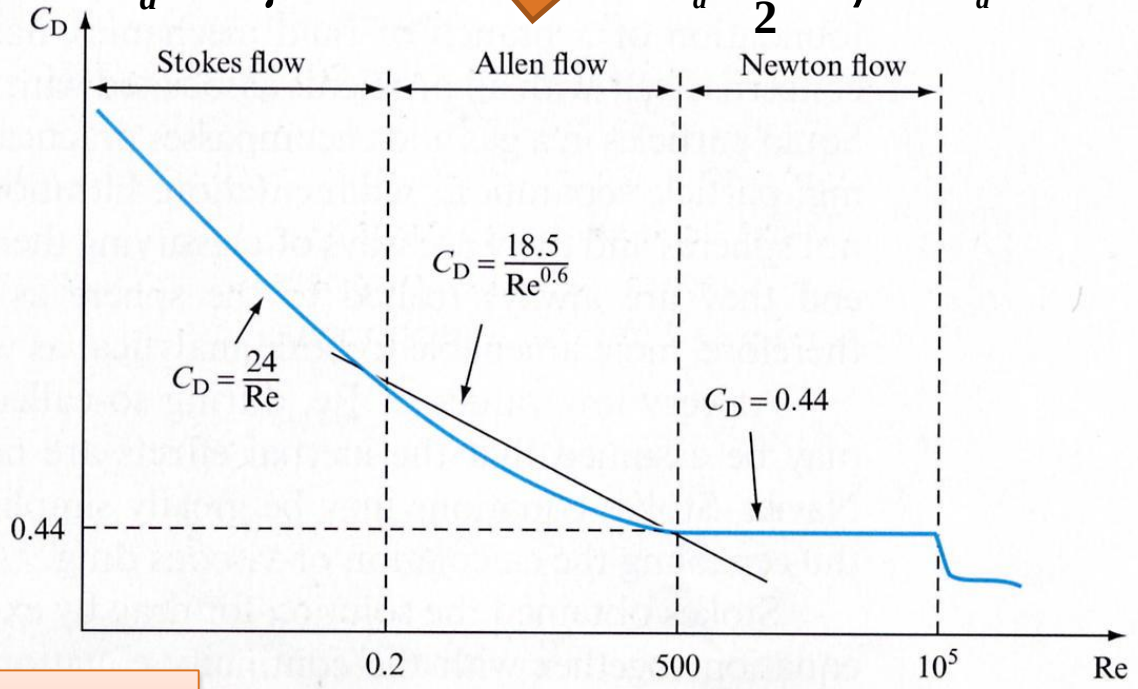
$$F_d = 6\pi\mu r U$$

$$F_d = \frac{1}{2}\pi r^2 \rho U^2 C_d$$

Reynolds Number

$$R = \frac{\rho \cdot U \cdot d}{\mu}$$





$$F_d = \frac{4\pi}{3}\delta\rho\bar{c}r^2 U$$

For Very Small Kn=λ/r Molecular drag [Epstein 1924]

$$F_d = \frac{6\pi\mu r U}{1 + Kn\left(\alpha + \beta \exp\left(-\frac{\gamma}{Kn}\right)\right)}$$

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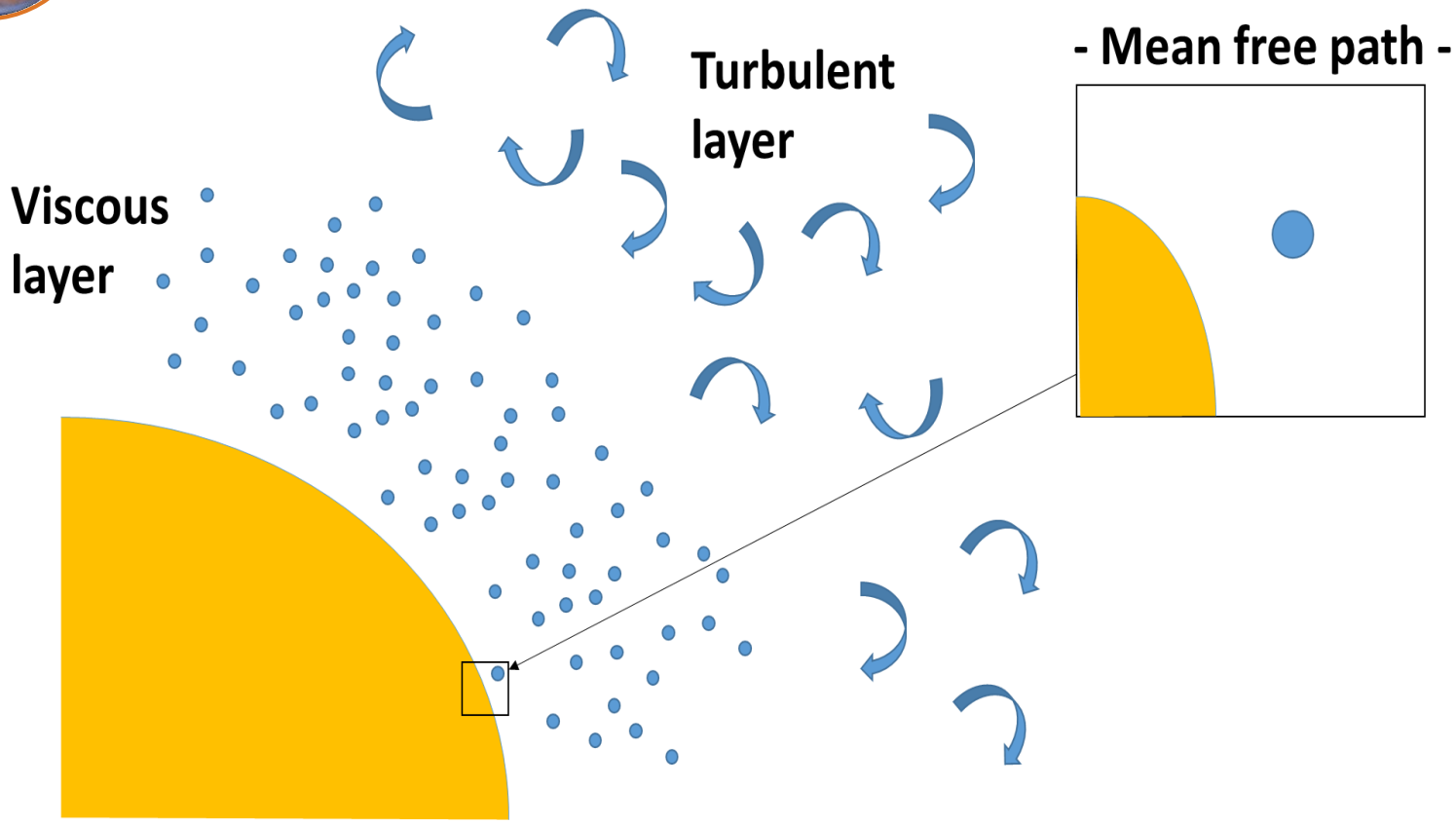
Aerodynamic drag



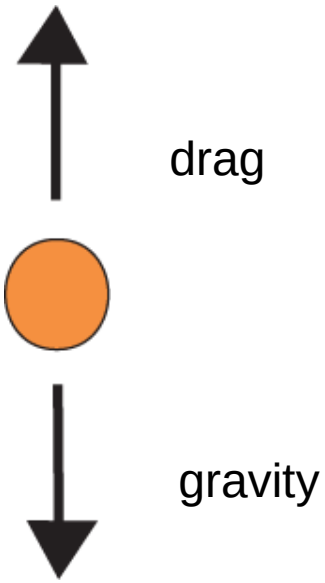
DUST; definition .....

Turbulence:

$$U_{rms} = \sum \sqrt{(u - u_{mean})^2}$$

Terminal velocity

$$U_T = \frac{2}{9\mu} \rho_g r^2 g$$



Grains remain suspended when:
$U_{rms} > U_T$

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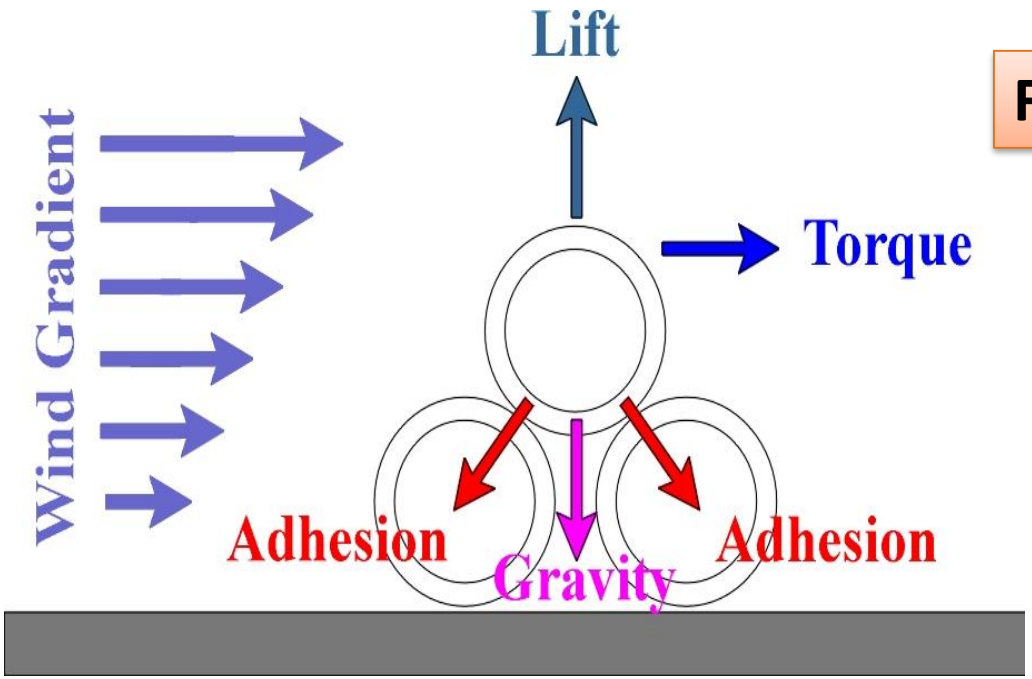
Detachment Threshold: Force Balance Equation

Drag : Lift and Torque



$$F_{lift} + F_{Torque} = F_g + F_{adh}$$

Gravity:	Not easily independently varied in the lab.
Drag lift and Torque:	Empirically determined, poorly defined (power law fit)
Adhesion:	Not known

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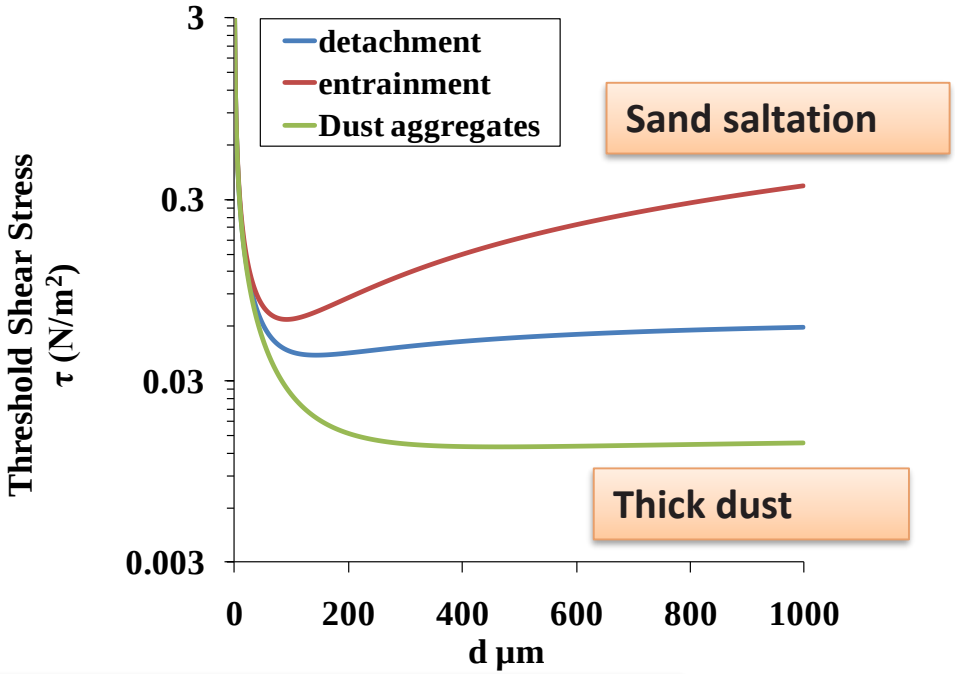
dust/sand wind threshold

Force Balance

$$\rho U_*^2 = \frac{\frac{\pi}{6} g \rho_g d^3 + C_{adh} d}{C_L d^2}$$

Shao and Lu 2000

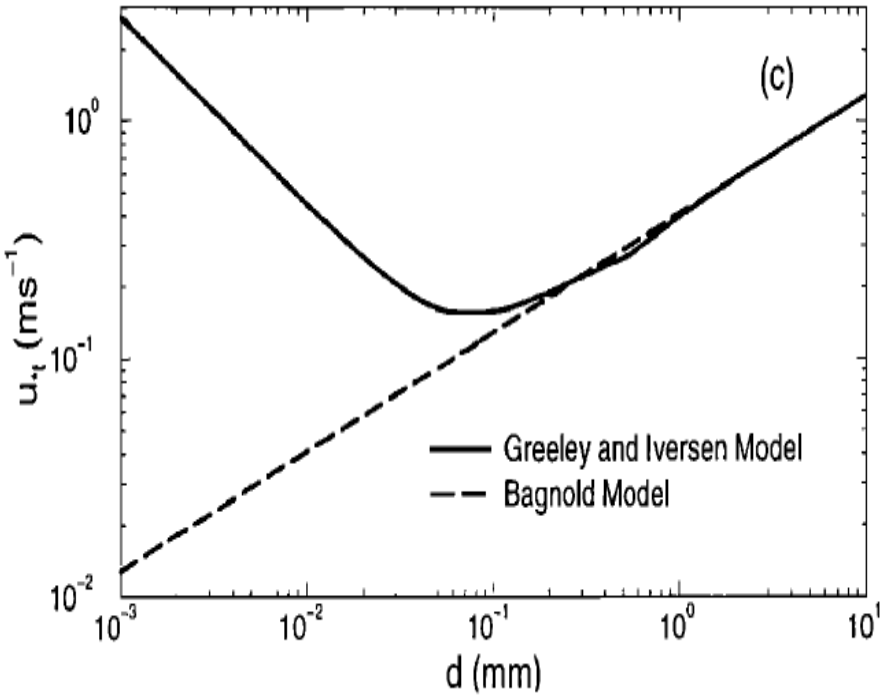
$$u_{*t} = \sqrt{Y_1 d + \frac{Y_2}{d}}$$



Sand saltation

Thick dust

Merrison et al., ICARUS, 2007
Holstein-Rahtlou et al. 2010



Greeley and Iversen 1985

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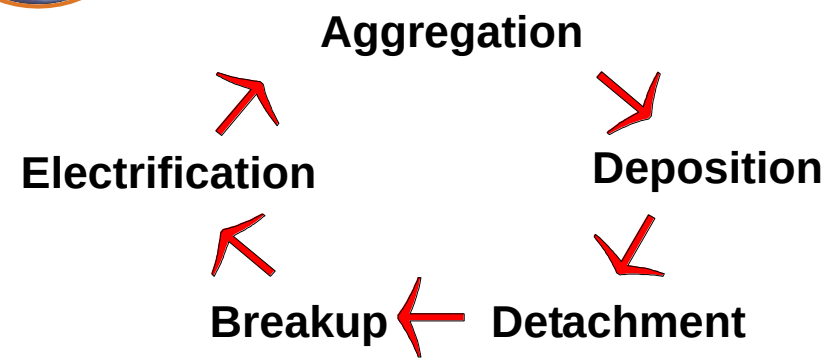
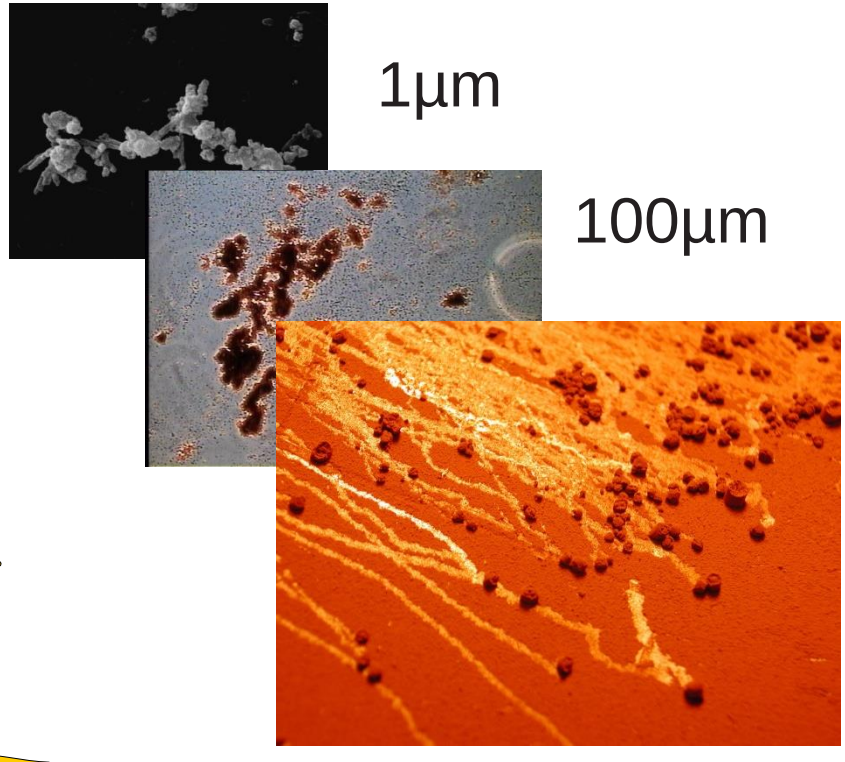
Dust Aggregates

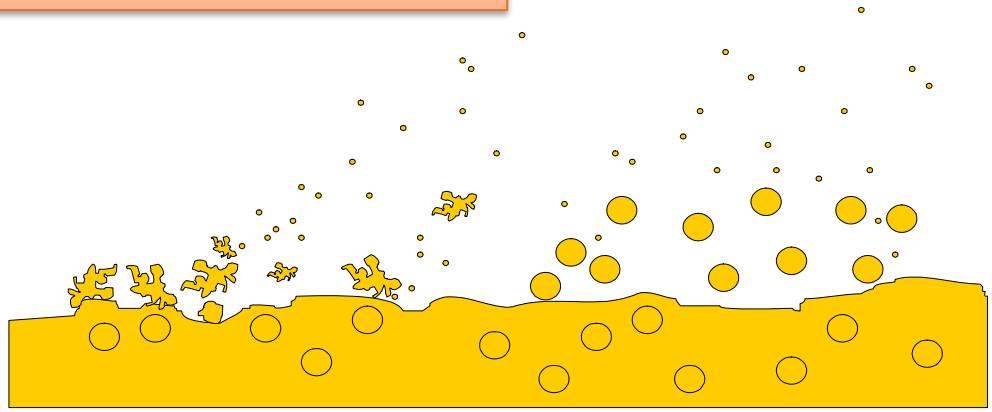


Dust Transport



Dust >10m/s,
(shear stress = 0.01Pa)

Sand >25m/s



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Saltation (sand)

Old models

Analytical, Dimensionless analysis;

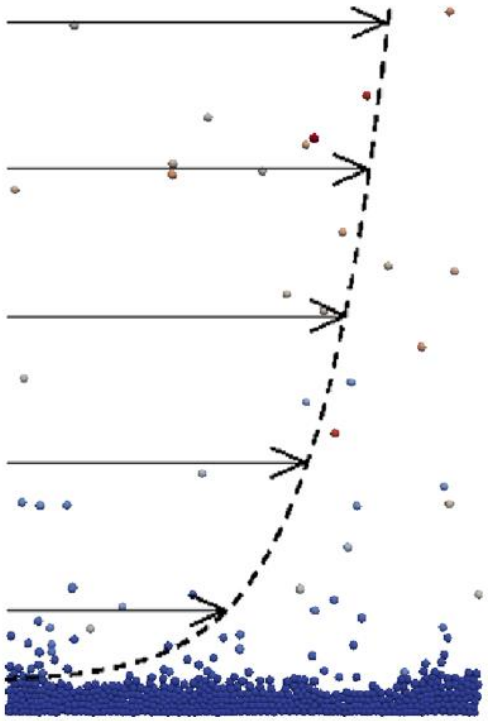
Feedback Layer

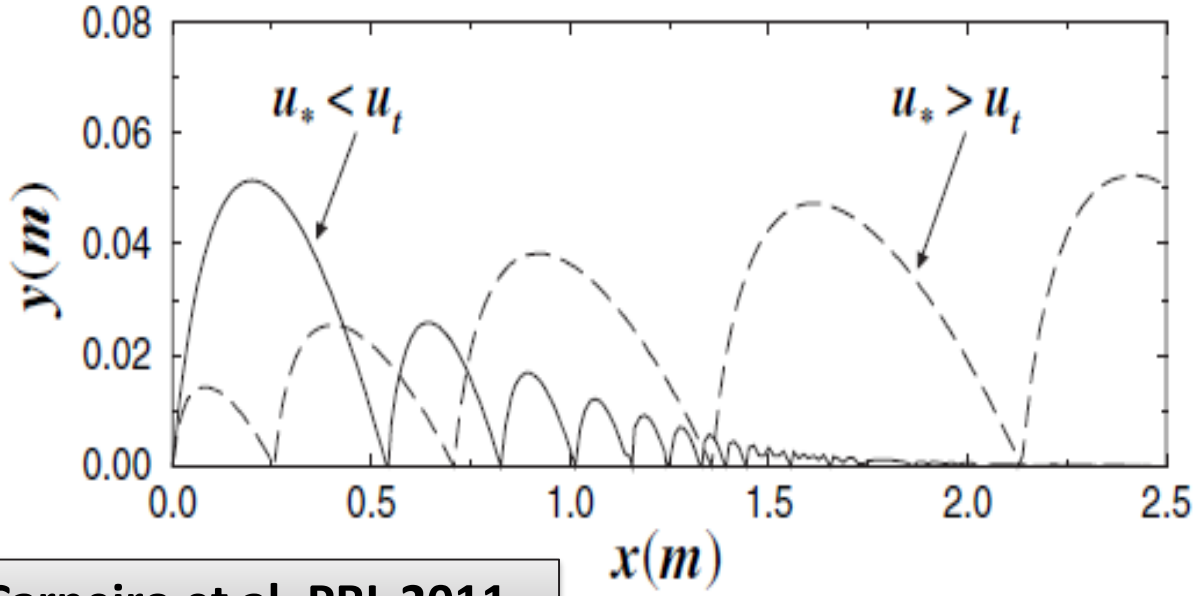
Modern ideas

Computational (CFD, Stochastics)

Transport rates, Trajectories

Threshold (do we need one???)





Carneiro et al. PRL 2011

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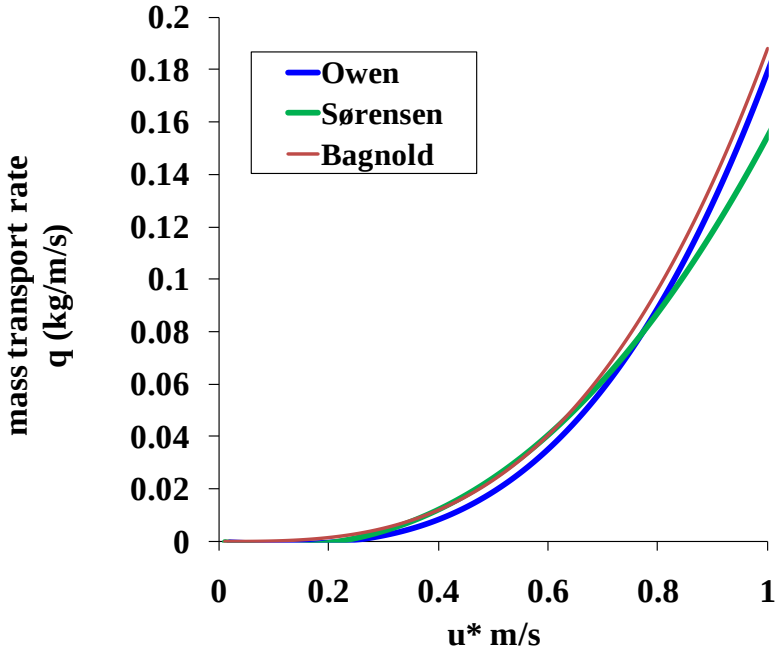
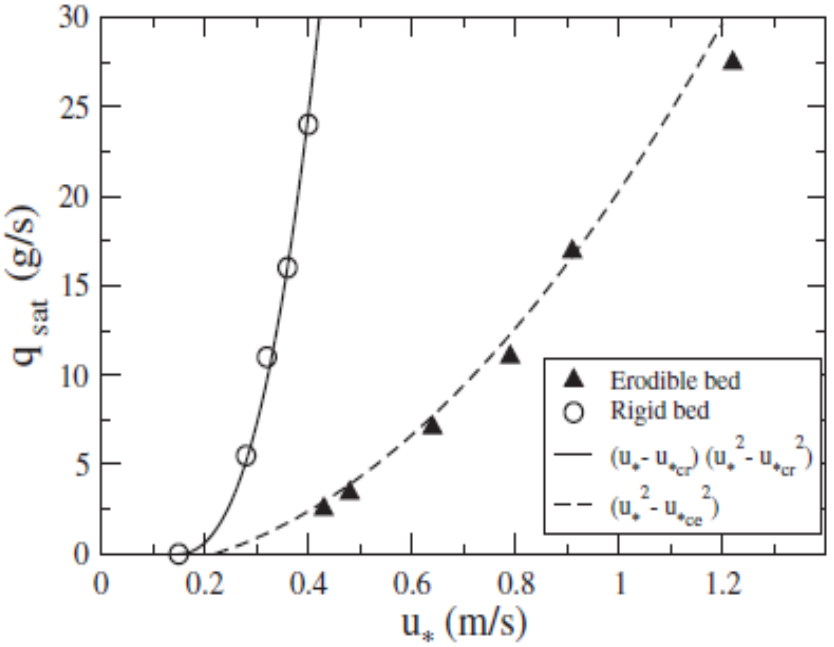
Saltation Transport Rate

Non-Erodable bed



Erodable bed



Rate ~ $(\tau - \tau_{th})U_* \sim (U^2)U \sim U^3$
(lift rate).(horizontal speed)

Rate α (U^2)

Ho et al. 2011 PRL

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Saltating grain trajectories; high speed imaging

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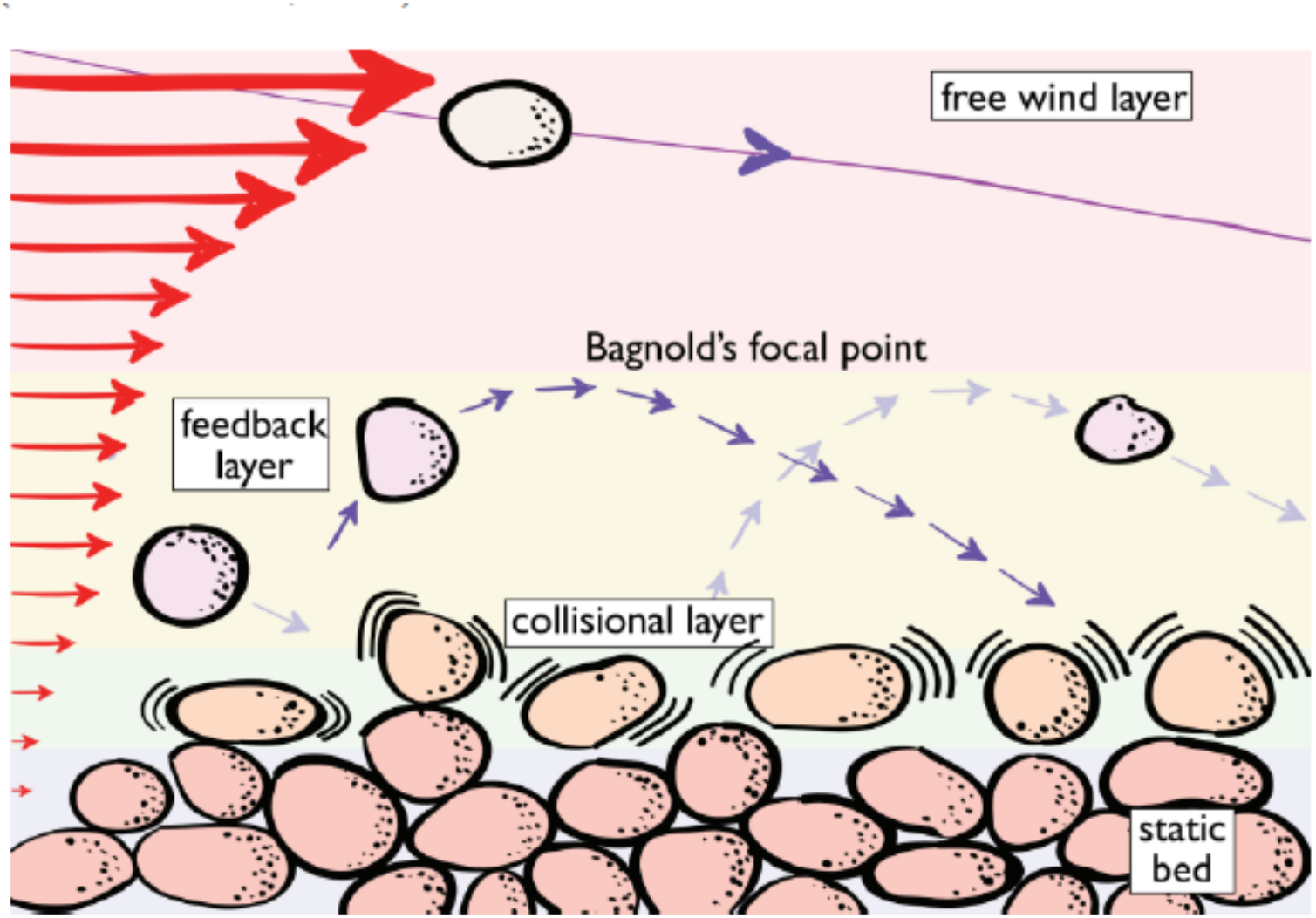
Saltation – new models



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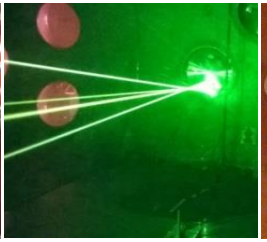
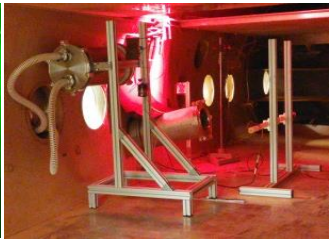
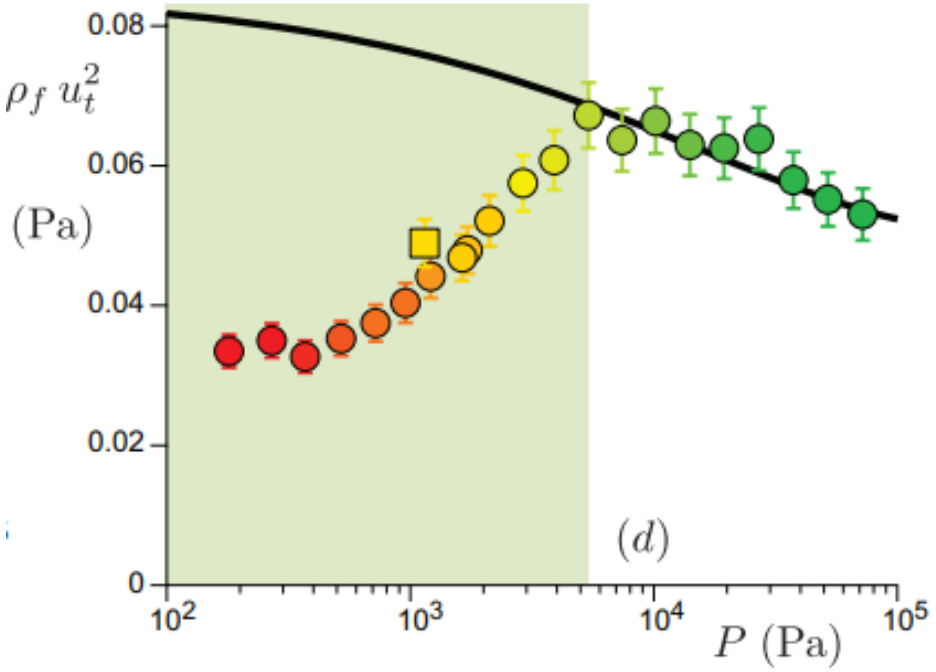
Saltation – new measurements





Not fitting the model at low pressure – new regime of transport on Mars!!!

Andreotti et al. PNAS 2021, LPS Paris, France

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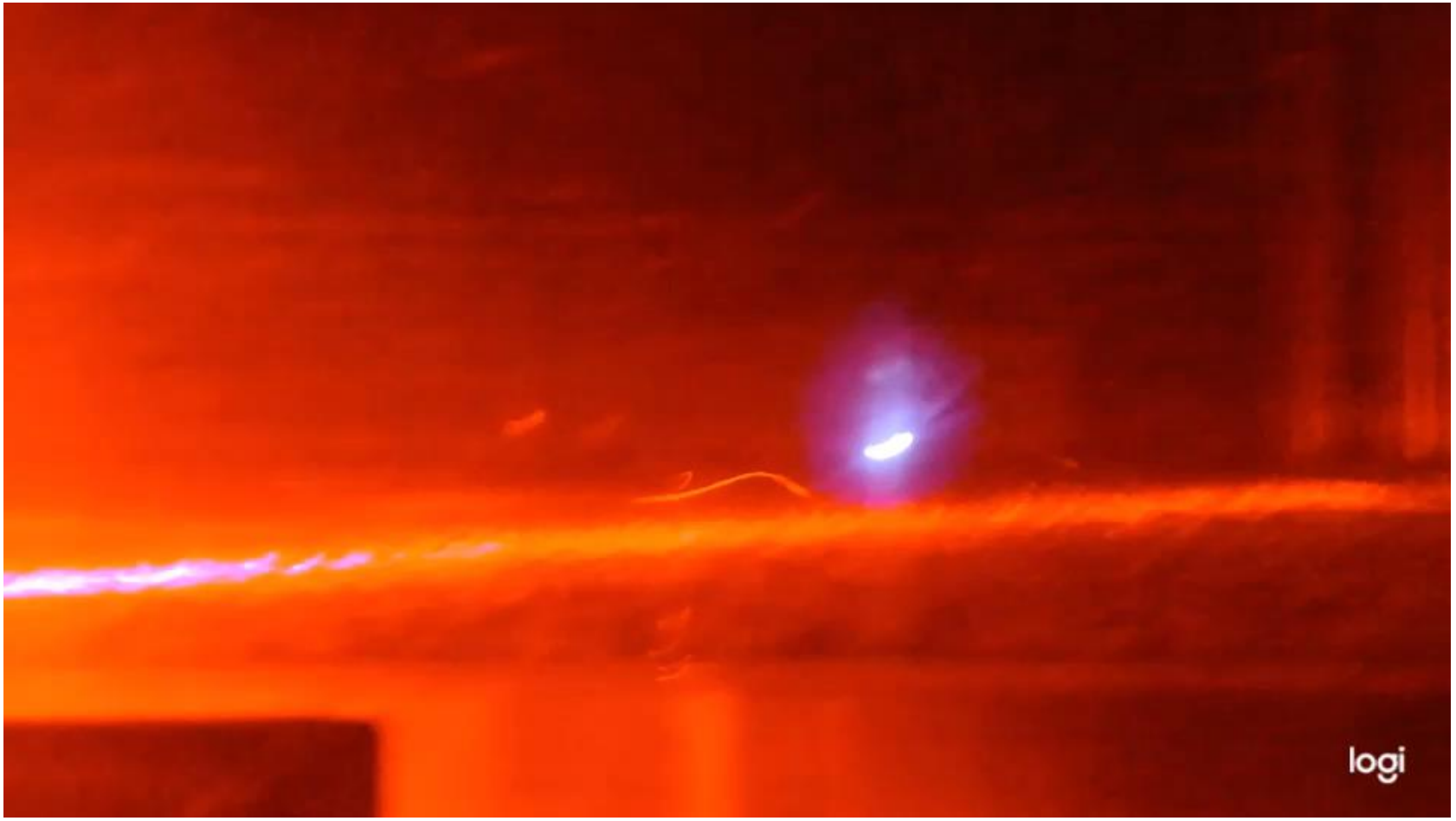
Saltation threshold; laser sheet + microscope



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Ripple migration; time lapse

Ripple length and speed do fit the model

Ripple migration; microscope time lapse

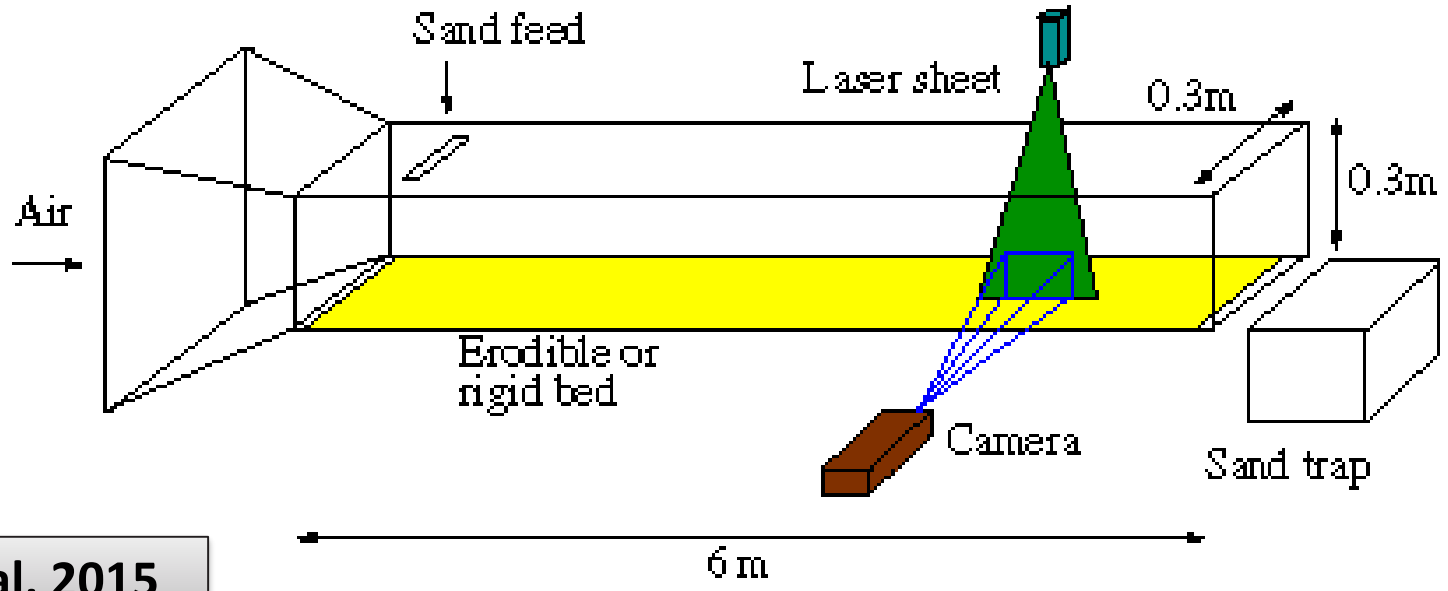
Lab work (wind tunnels)

Old technology

Sensors = traps, pitot tubes

Modern technology

Sensors = PIV, LDV, high speed cams, lasers



Rasmussen et al. 2015

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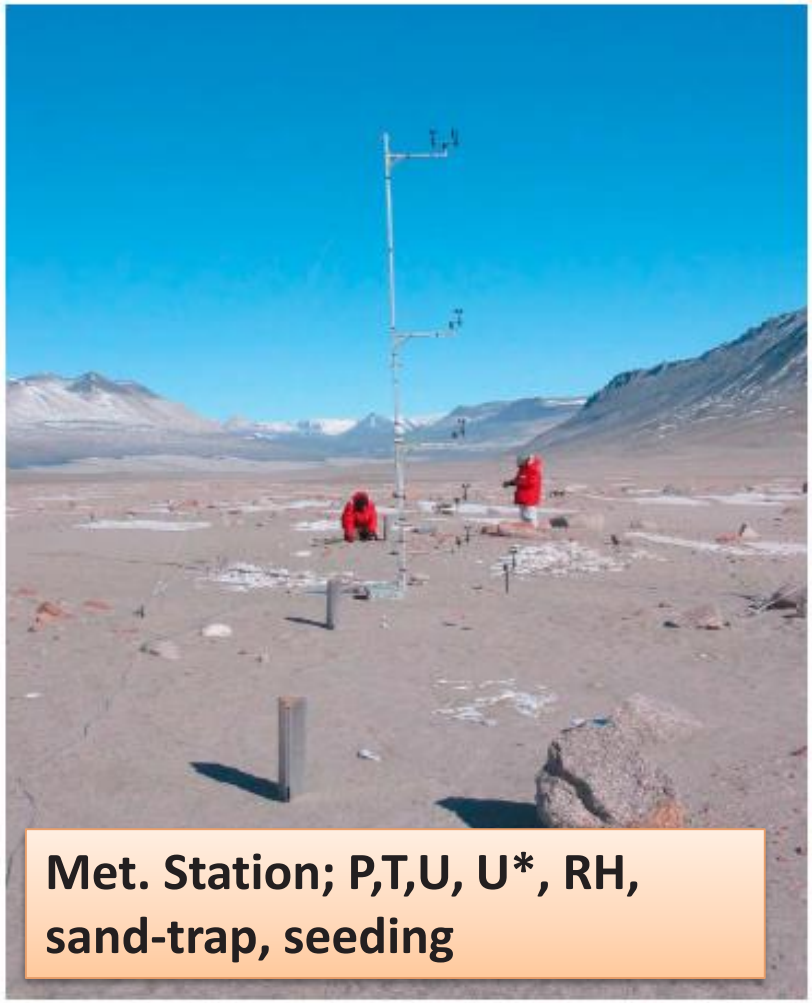
Field Experiments

Lancaster et al. 2010 JGR

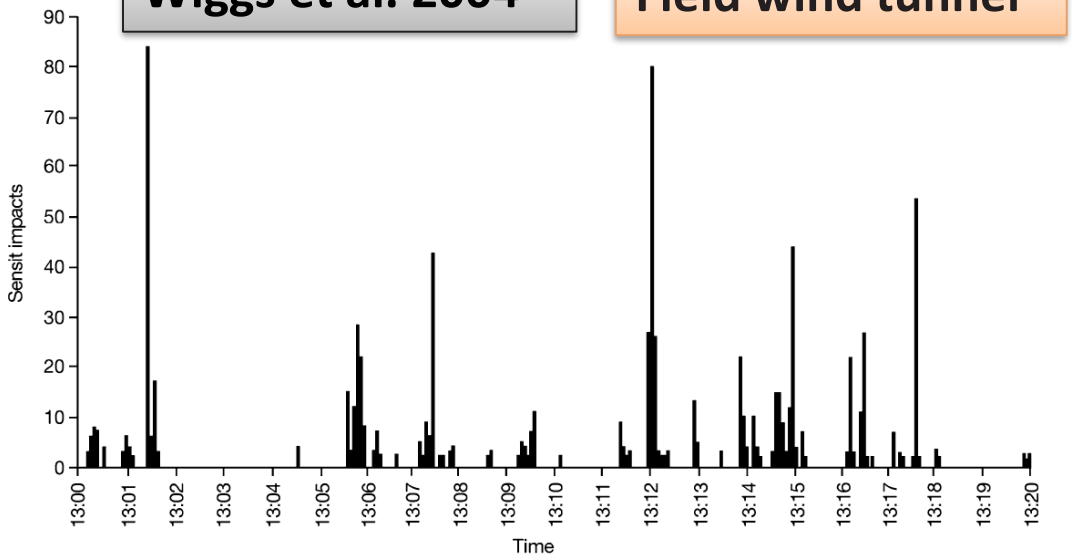


Met. Station; P,T,U, U*, RH, sand-trap, seeding

Pye and Tsoar 1990, Aeolian sand and sand dunes

Wiggs et al. 2004

Field wind tunnel



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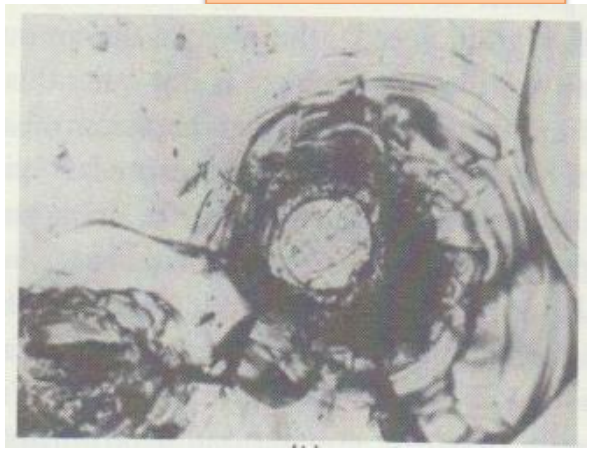
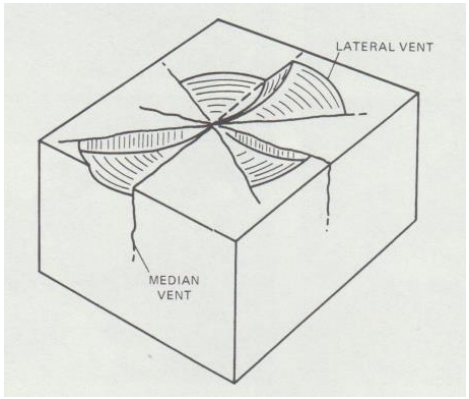
Abrasion

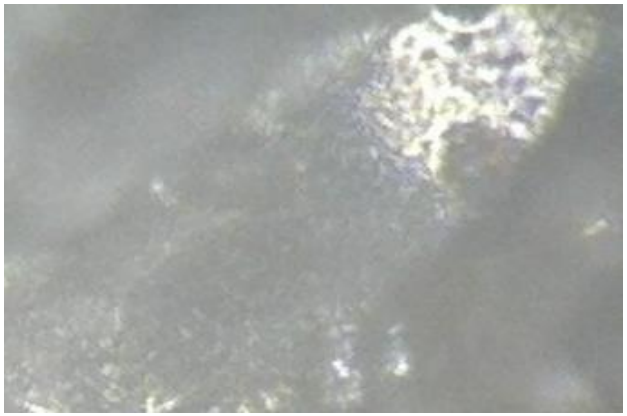
U >10m/s





Greeley and Iversen 1985

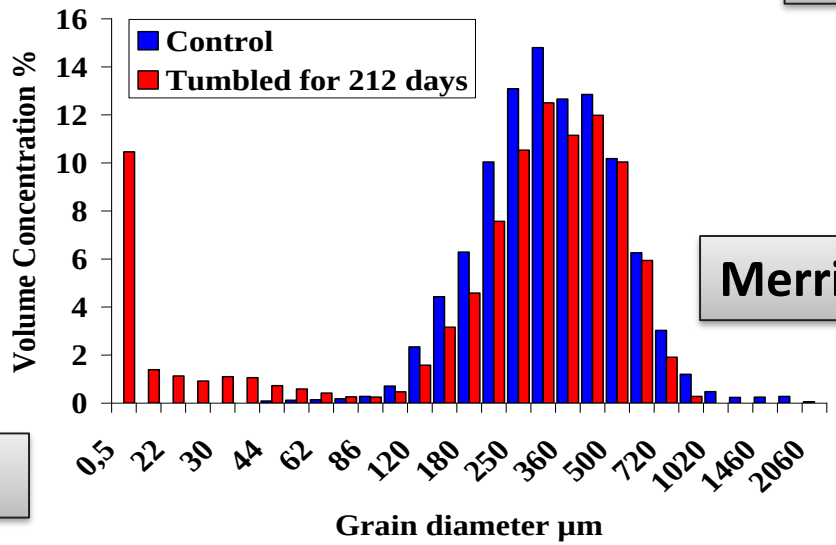
U ~ 1m/s)



U <0.3 m/s

NO EROSION

det Vet et al. 2015



Merrison et al. 2009

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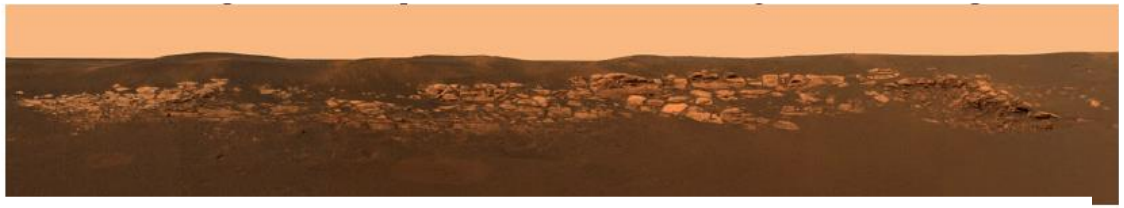
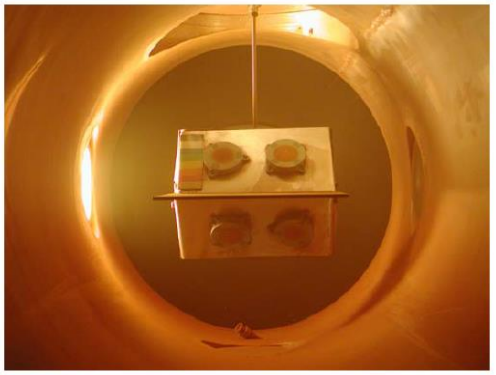
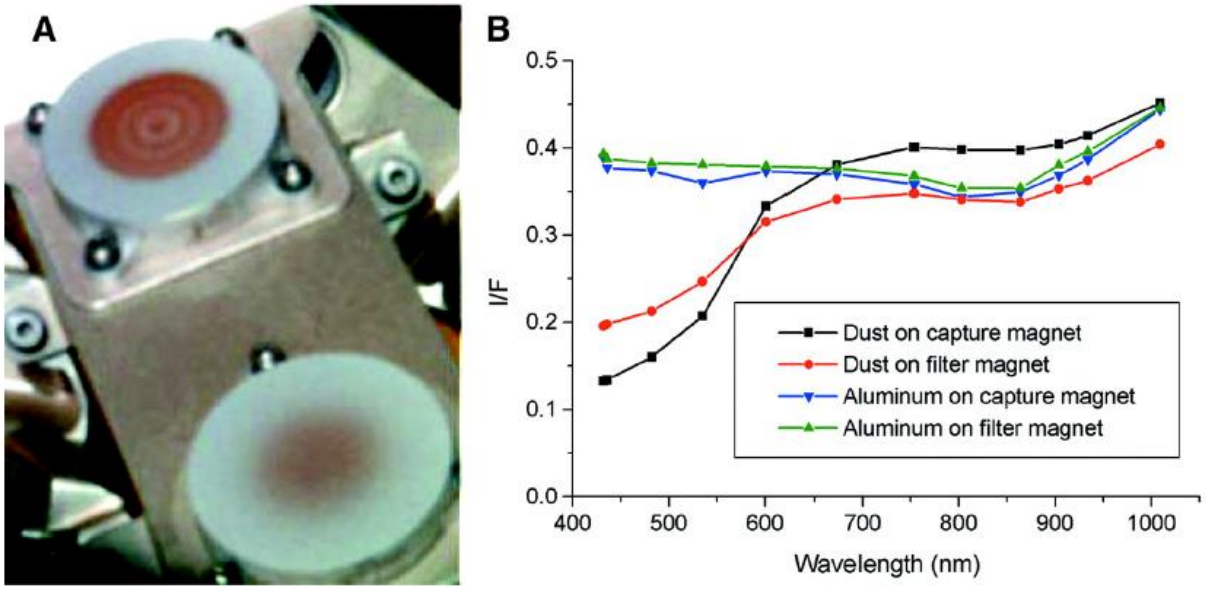
Why Mars is red ....







- Optical spectroscopy
- Mossbauer spectroscopy
- X-ray scattering

Figure 3-31: *Pancam image of the Spirit Capture and Filter magnets and optical reflectance spectra from the two magnets. [5]*

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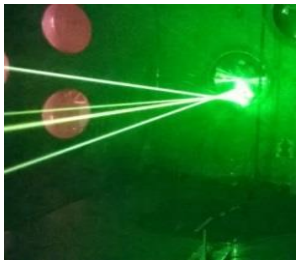
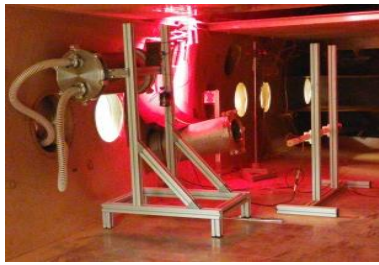
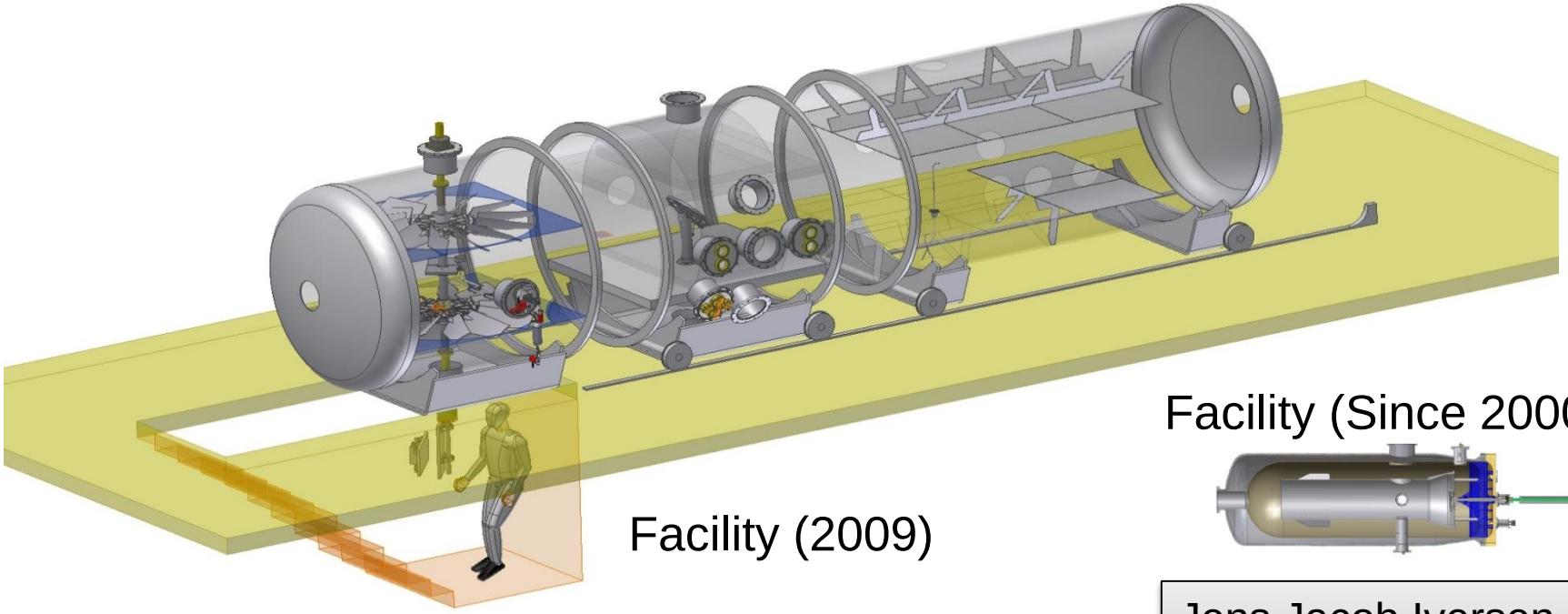
Planetary Environmental Simulator(s)





Facility (2009)

Facility (Since 2000)

Jens Jacob Iversen
Jon Merrison
Keld R Rasmussun

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Planetary Environmental Simulator(s)

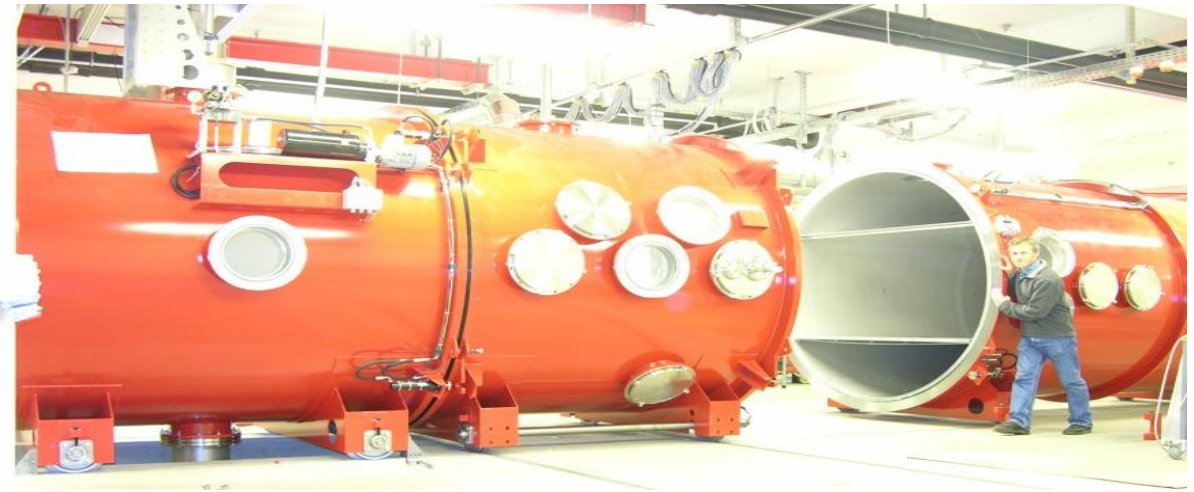
Pressure 0.02-1000 mbar (Mars 10mbar),
Gas (Air, CO_2, N_2,)

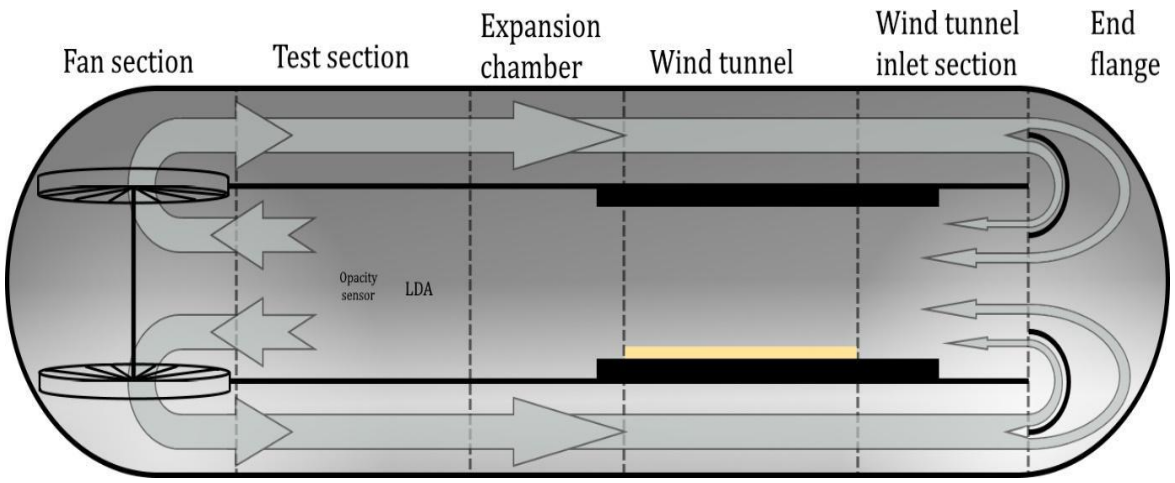
Temperature (100K – 350K)
[Humidity control]

Wind speed 1 - 40m/s

Dust aerosol ≈ 1-1000 cm^{-3}
Sand transport

Vol. (2m x 8m x 1m)





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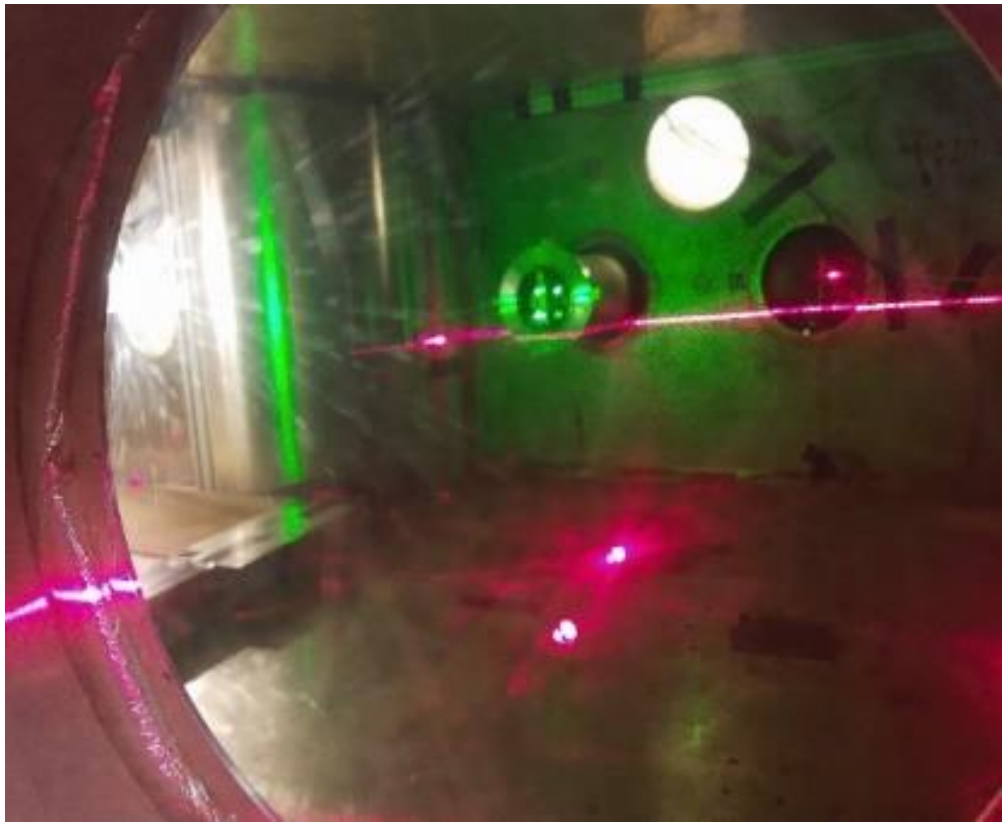
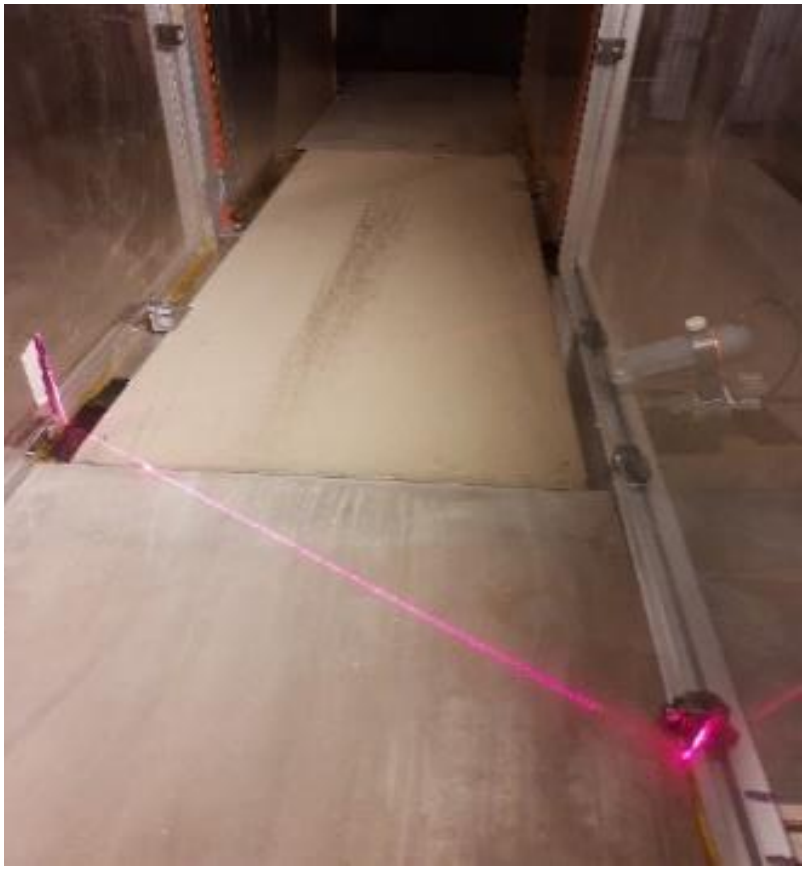
Dust Aerosolization; Opacity sensor + LDV

ROADMAP project – wind tunnel studies
Dust remobilization

DOWNWIND Resuspension
LDV, opacity



UPWIND: Dust Removal
(web cameras)



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ROADMAP project – wind tunnel studies
A 'wind tunnel' on Mars

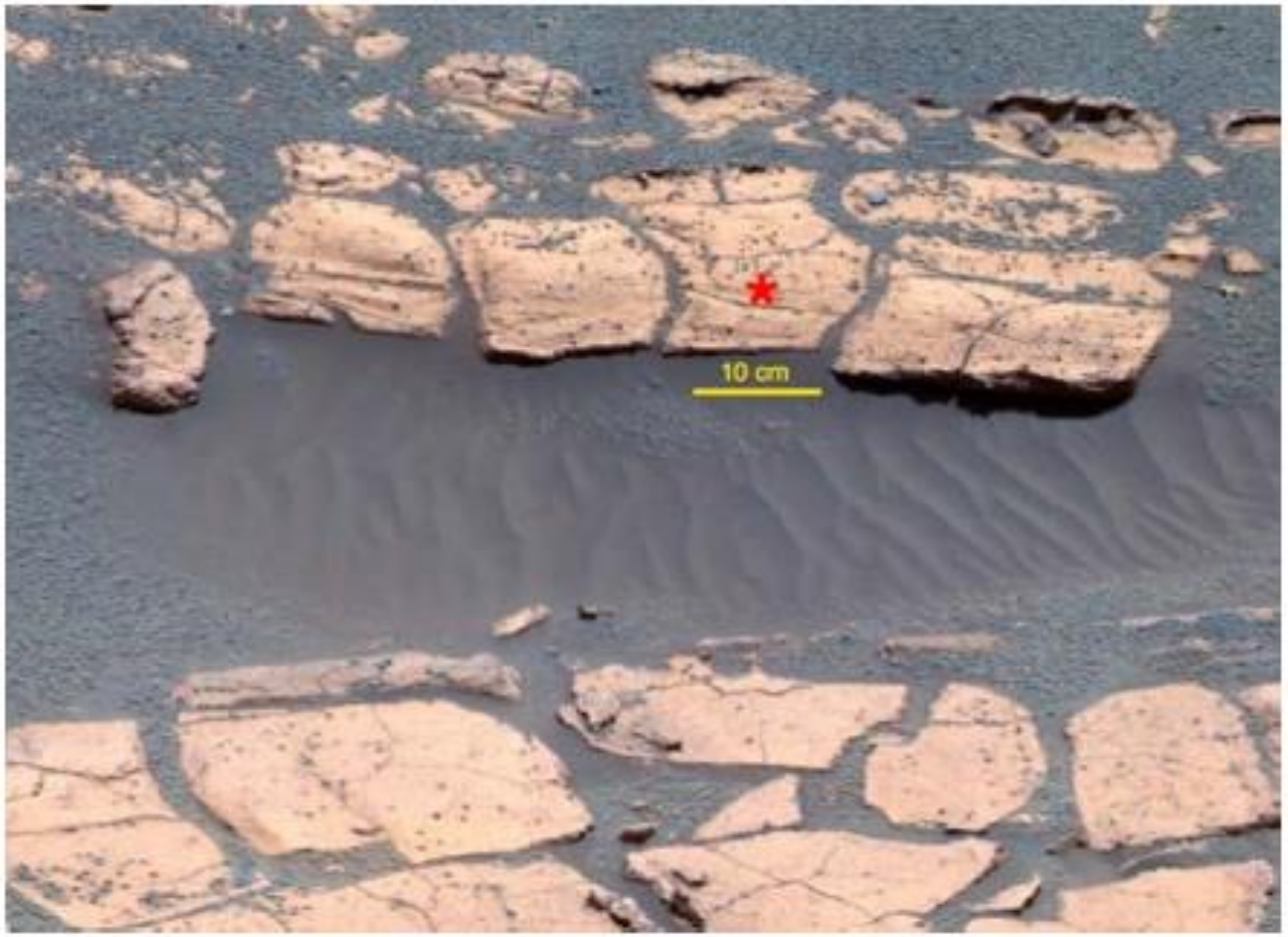

Photo from NASA opportunity rover

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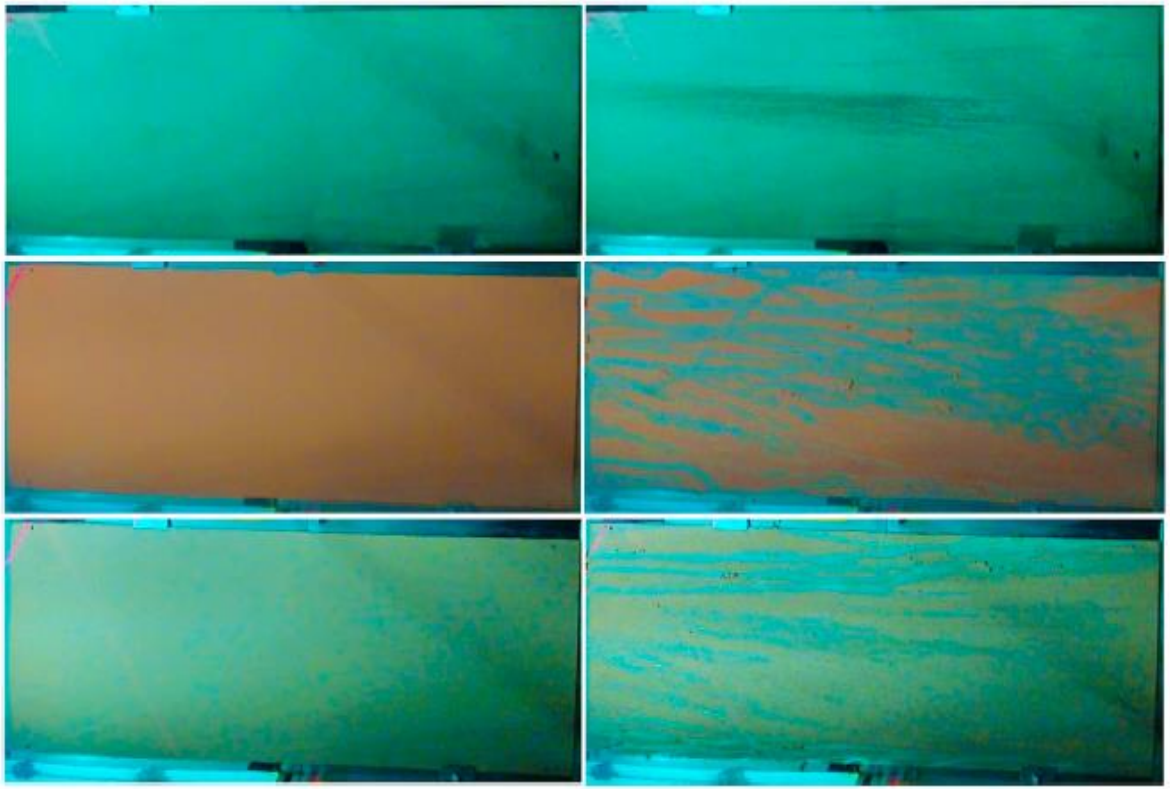
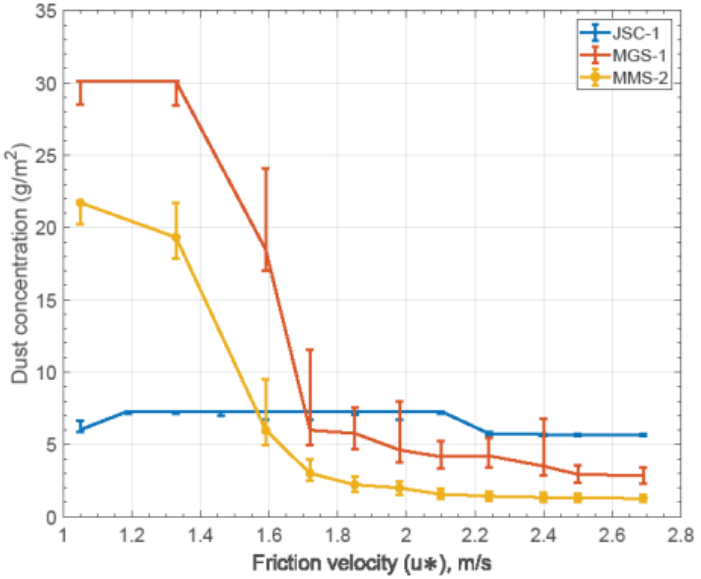
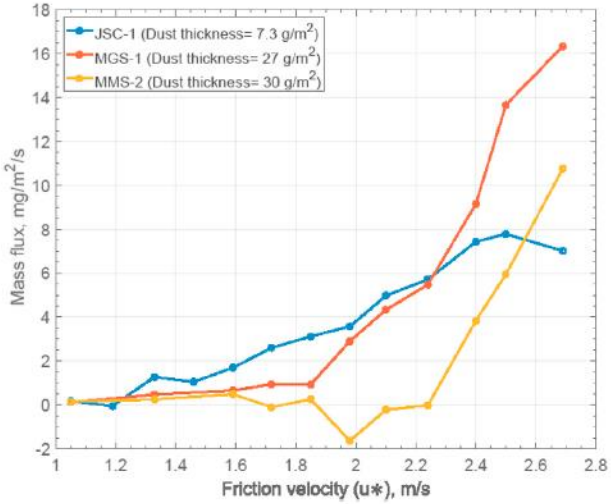
ROADMAP project – direct dust remobilization







- **Cannot remove thin dust layer !!!!!**
- **Direct Remobilization / Resuspension**
- **Threshold / flux(u*)**

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ROADMAP project – direct dust (analogue) remobilization

Direct Dust Remobilization (MMS-2, Martian conditions)

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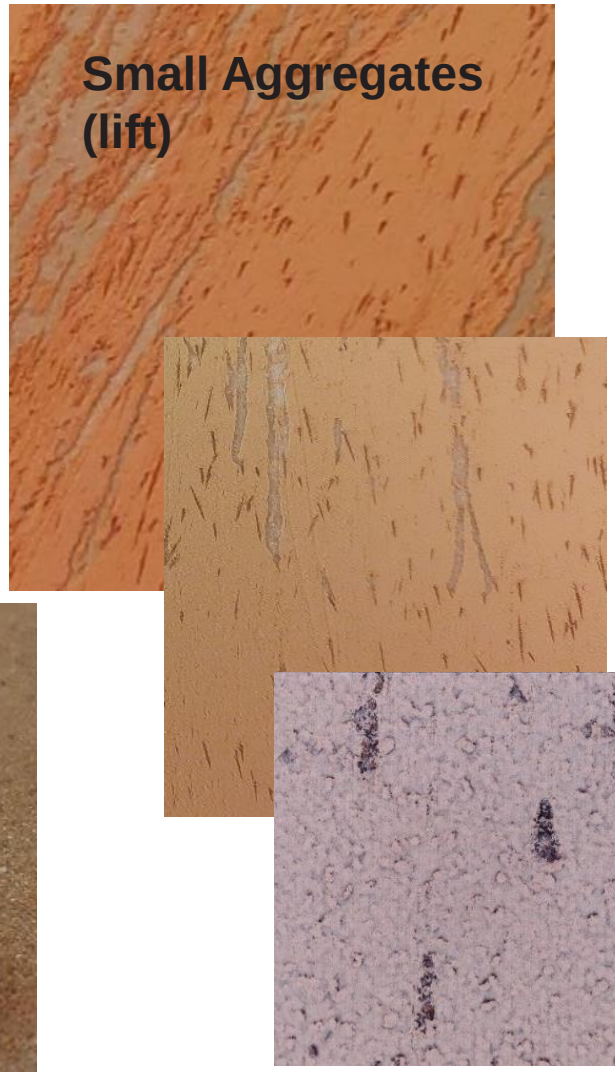
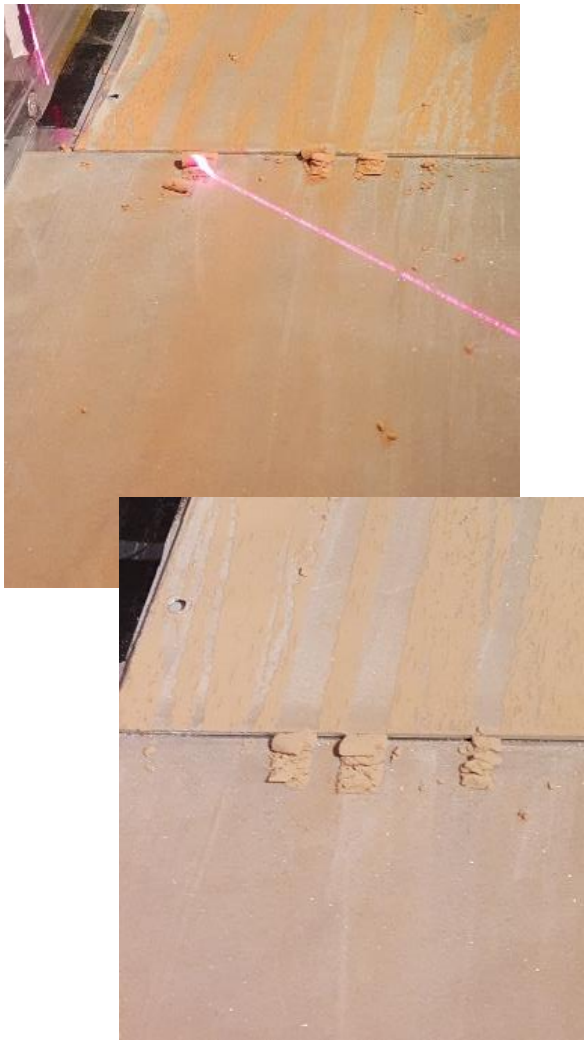
ROADMAP project – first direct dust remobilization

Big Aggregates (roll)

Small Aggregates (lift)



Breakup+redeposition



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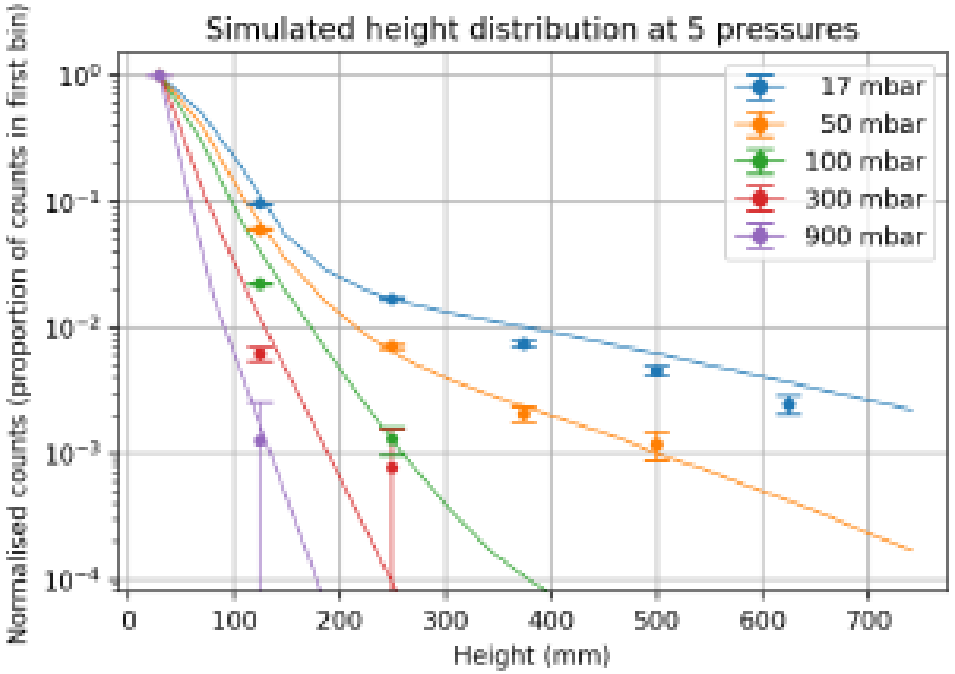
ROADMAP project – saltation induced dust remobilization

Low pressure Saltation – sand suspension !!!

Simple modelling – monte-carlo single particle tracking



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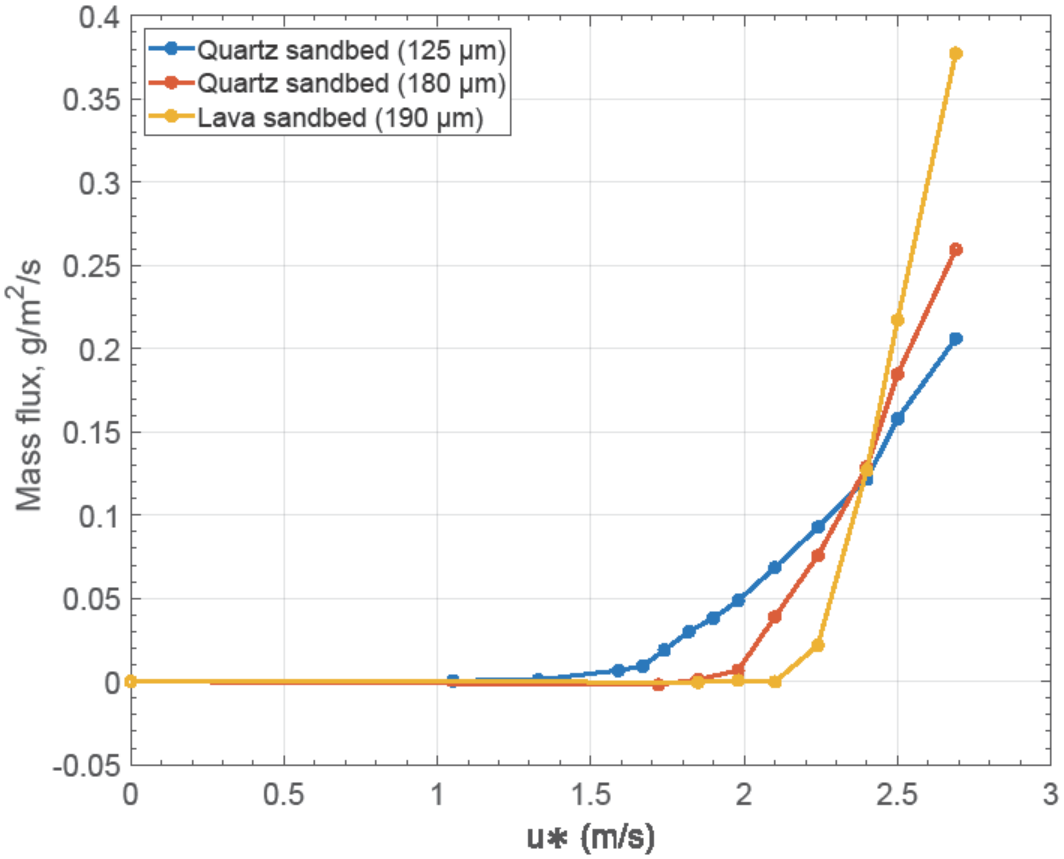
ROADMAP project – saltation abrasion generated dust

First saltation induced abrasion observed (in windtunnel)



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ROADMAP project – followup

Future

- New saltation Experiments (several groups)
- New dust resuspension Experiments (few groups)
- Experiments Relating tansport rates to abrasion rates (dust generation)

- Computational models (CFD, Monte Carlo, etc..)
- Turbulent models (stochastics)
- New physical models (less empirical)

Co-funded by the Horizon 2020 programme of the European Union

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THANK YOU!
MORE INFO?

roadmap.aeronomie.be

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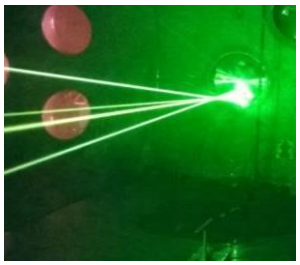
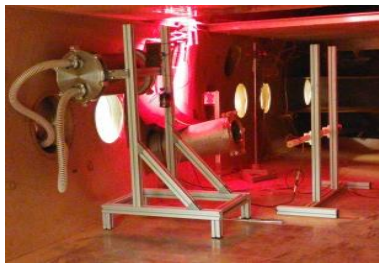
End

AU Team



AU Team

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Task 2.2: Dust resuspension/Aerosolization

Task 2.3: Aerosol dynamics (electrification)

Task 2.4: Aerosol deposition

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