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Controlled Light-Driven Levitation of Macroscopic Plates

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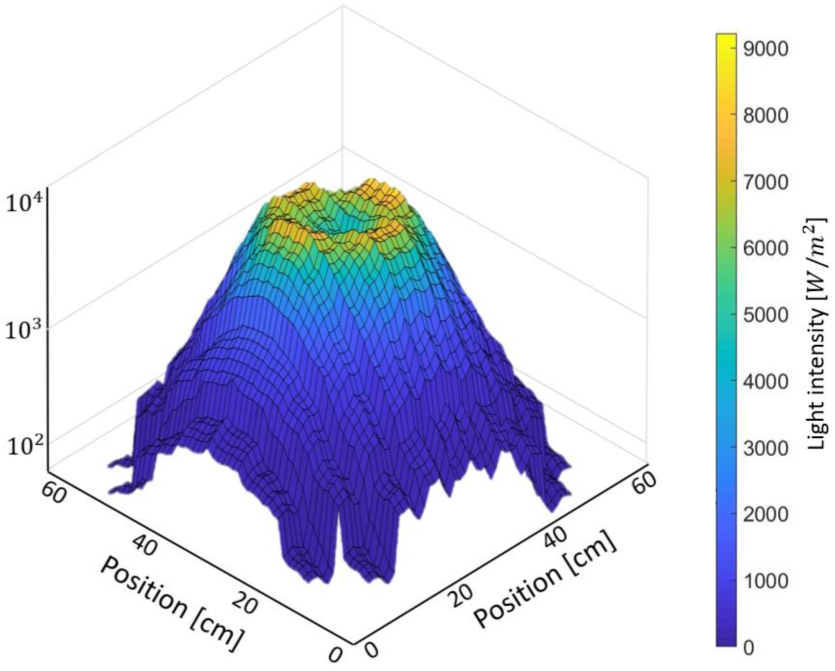
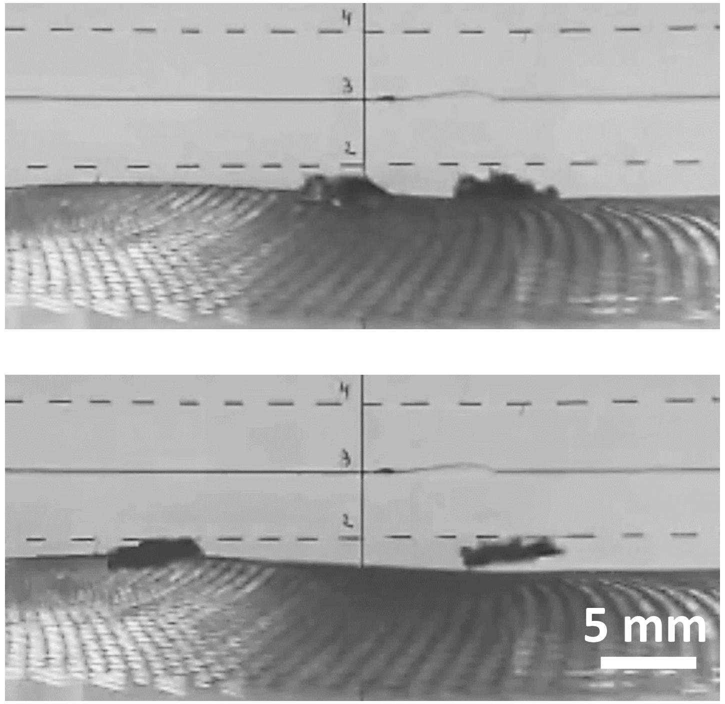
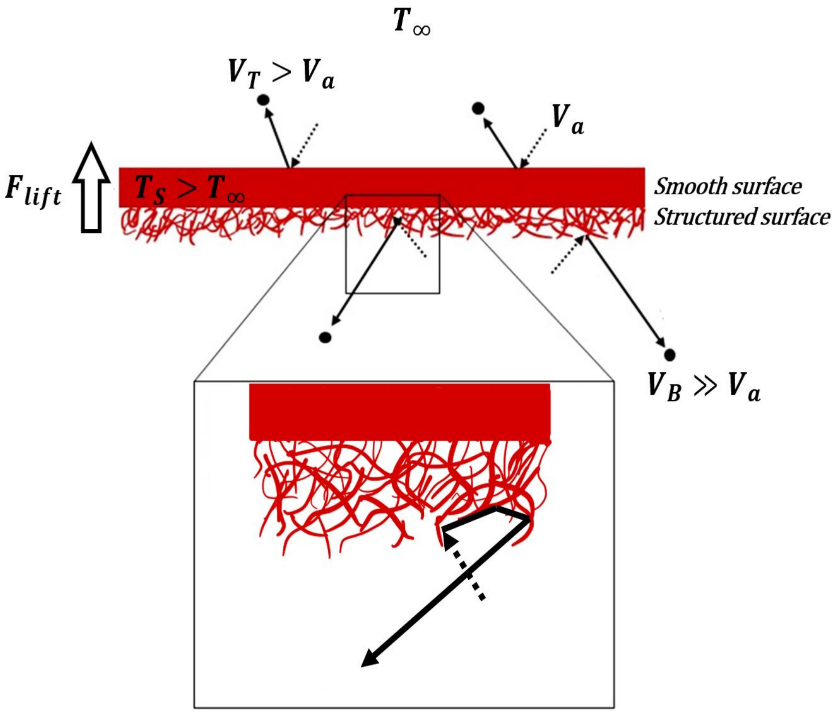






Controlled Light-Driven Levitation of Macroscopic Plates

We report light-driven levitation of 0.5-um thick mylar samples that have been modified by depositing a 300-nm-thick layer of carbon nanotubes (CNTs) on a single side. The CNT layer serves three key purposes: 1) It acts as a lightweight light absorber, absorbing ~ 90% of the incident light and elevating the temperature of the sample. 2) It increases the structural rigidity of the mylar film, allowing cm-scale discs with submicron thicknesses to hold their shape. 3) It creates a structured porous surface that traps impinging gas molecules, which results in an accommodation coefficient difference between the top and bottom surfaces for gas-surface interactions. Air molecules that rebound from the CNT-coated side have on average higher velocities than those departing from the opposing uncoated mylar surface. We show that the net force thus created can be used to levitate the mylar films. Moreover, we will demonstrate our ability to manipulate a light field in order to control the flight of levitating samples for extended periods of time.

Keywords: Photophoresis, light-driven motion, near-space flight

M. Azadi, G. A. Popov, Z. Lu, A. G. Eskenazi, A. J. W. Bang, M. F. Campbell, H. Hu and I. Bargatin, *Controlled levitation of nanostructured thin films for sun-powered near-space flight* Sci Adv 7 (7), eabe1127. DOI: 10.1126/sciadv.abe1127

A new way to fly!

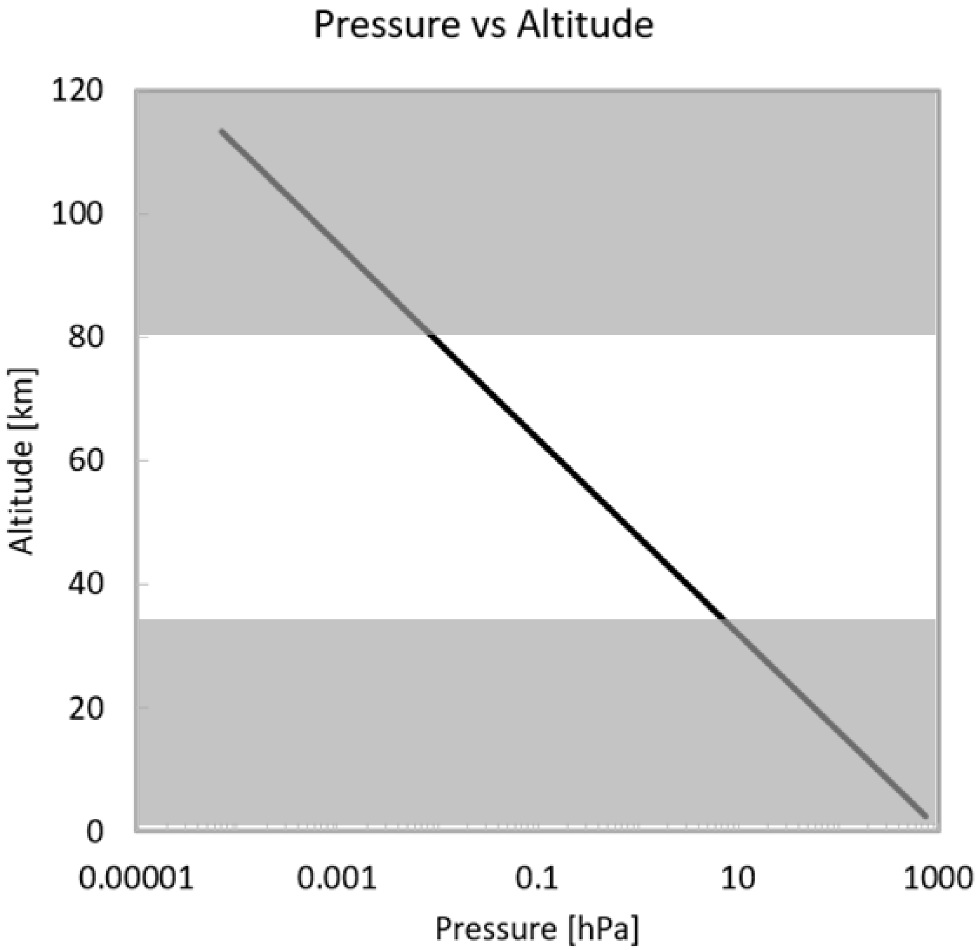
Micromachines Conference April 2021

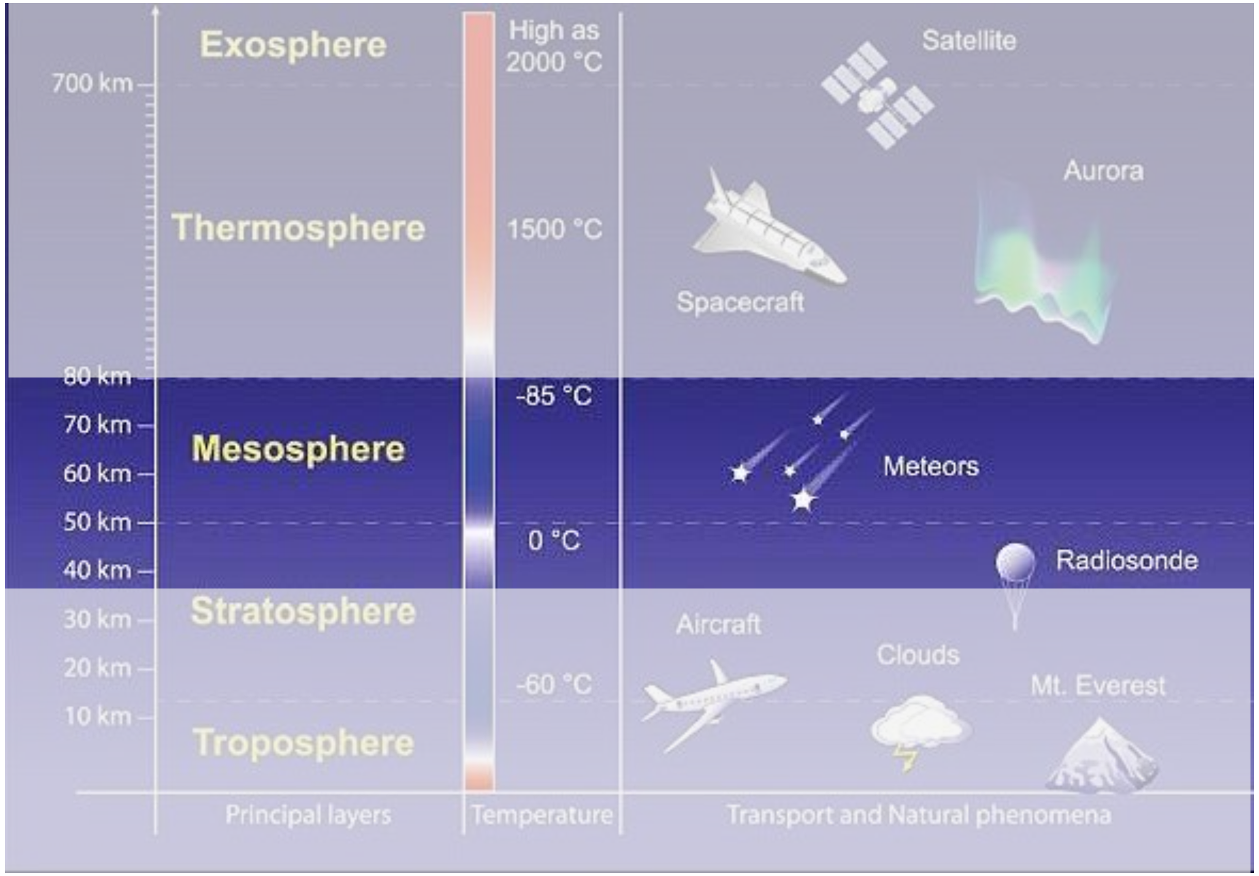
Controlled flight of a 1cm disc
over a large light trap
60 Pa environment

Bargatin Group – University of Pennsylvania

Motivation

Inaccessible regions of the Earth's atmosphere





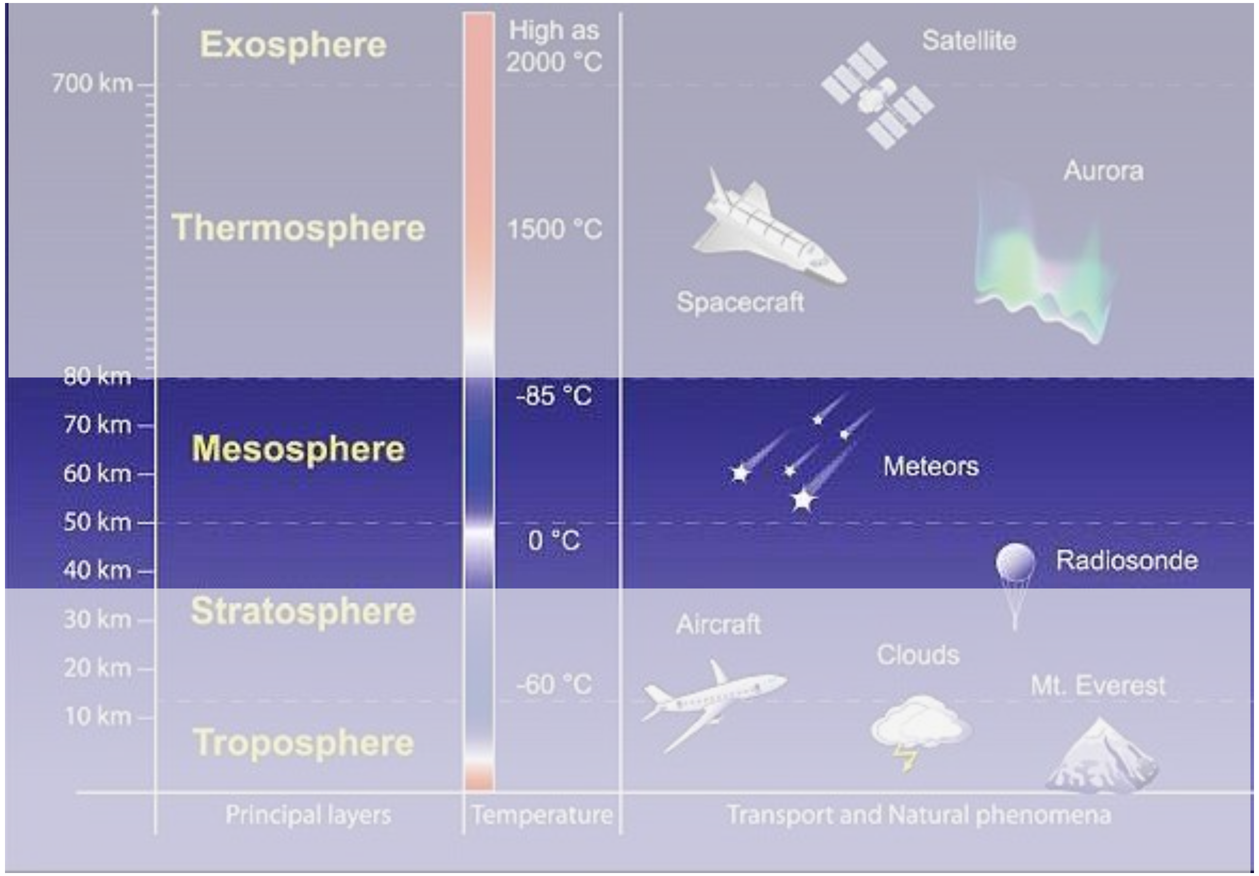
https://newbreweress.weebly.com/stratospheric-ozone.html

Motivation

Inaccessible regions of the Earth's atmosphere

- No flight mechanisms available
- Important for weather, sensing, surveillance, etc.

Low ambient pressure for aircraft and balloons, high pressures for satellites causing high drag force.



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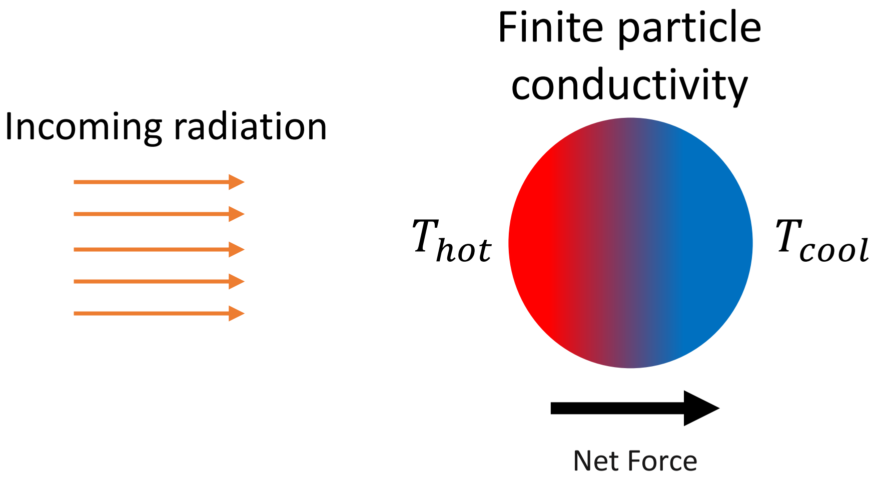
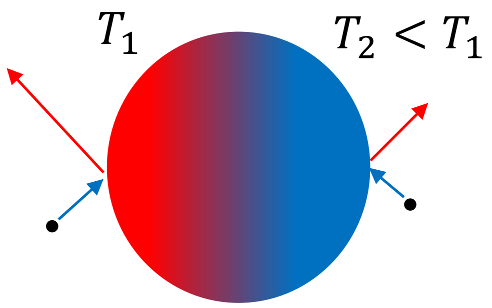
Photophoresis: light-driven flow → Photophoretic force: Force due to light-driven flow

Photophoresis on microscopic particles:

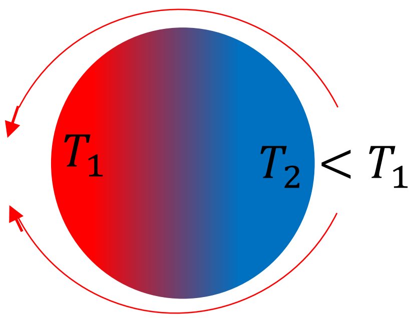


Free Molecular Regime



Kn > 10

Slip Flow Regime



Kn < 0.5

We eliminated the need for internal temperature gradient

We capitalized on $T_{avg.\,sample} - T_{amb}$.

Concept – low pressure

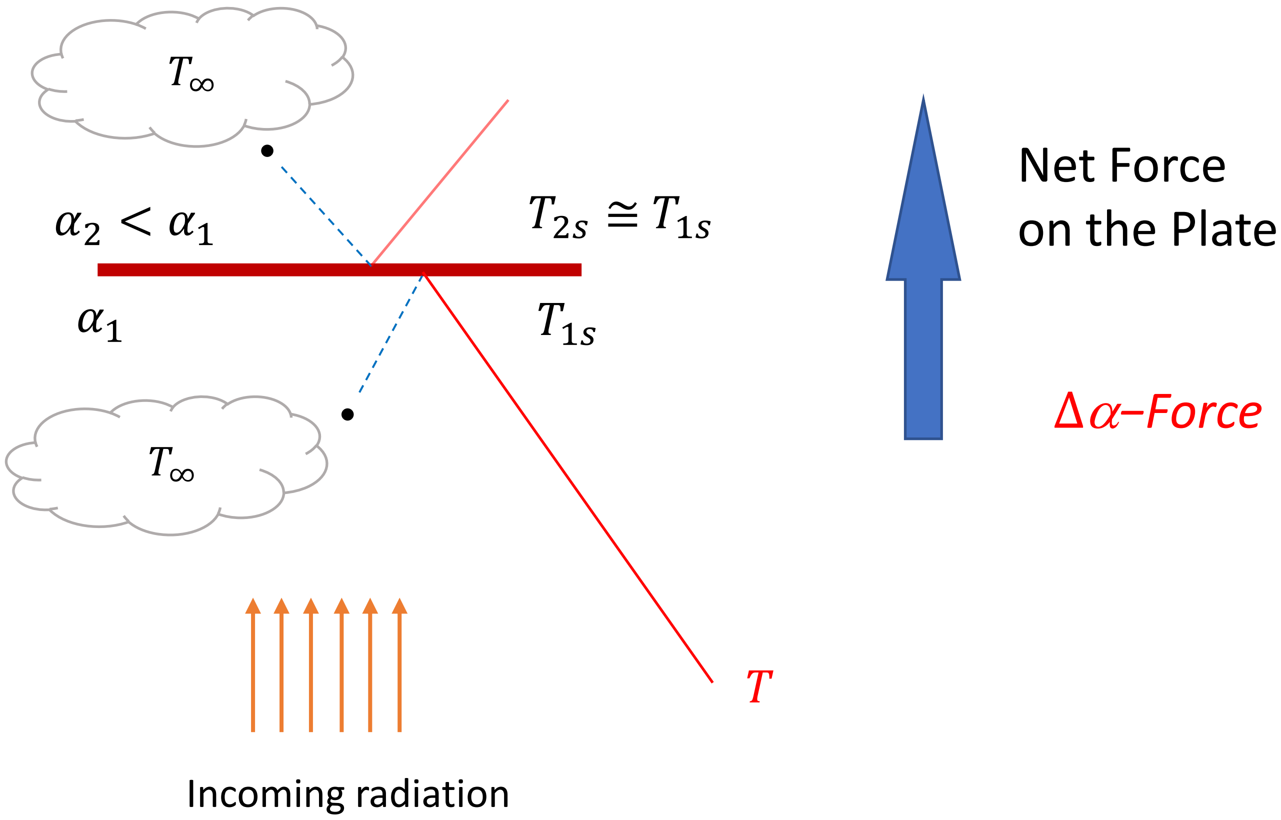
Assume we have a uniformly heated sample: thin disk

Consider a very thin plate in a low-pressure gas where intermolecular collisions don't happen.

$$\alpha = \frac{T - T_\infty}{T_s - T_\infty}$$

Thermal accommodation coeff.: α

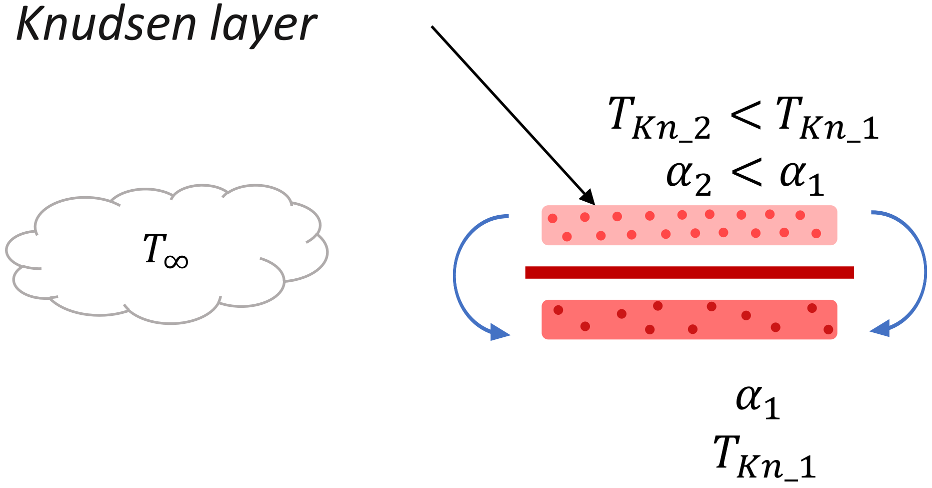
Indicator of thermal interaction between gas molecules and surface



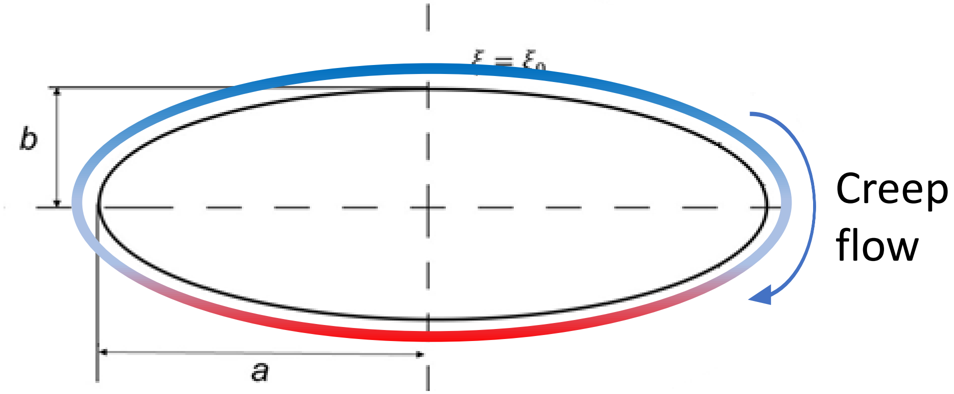
Concept – high pressure

Slip flow regime; physics:

$$\alpha = \frac{T - T_\infty}{T_s - T_\infty}$$

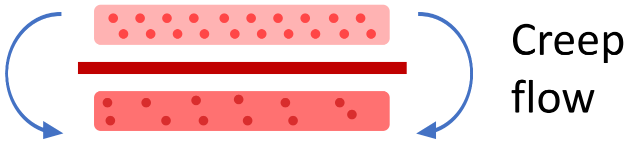


Slip flow regime; Formulation: Avoiding discontinuity



uniform surface temperature
different α on each side

$$\lim_{\frac{b}{a} \to 0}$$



Sample Fabrication

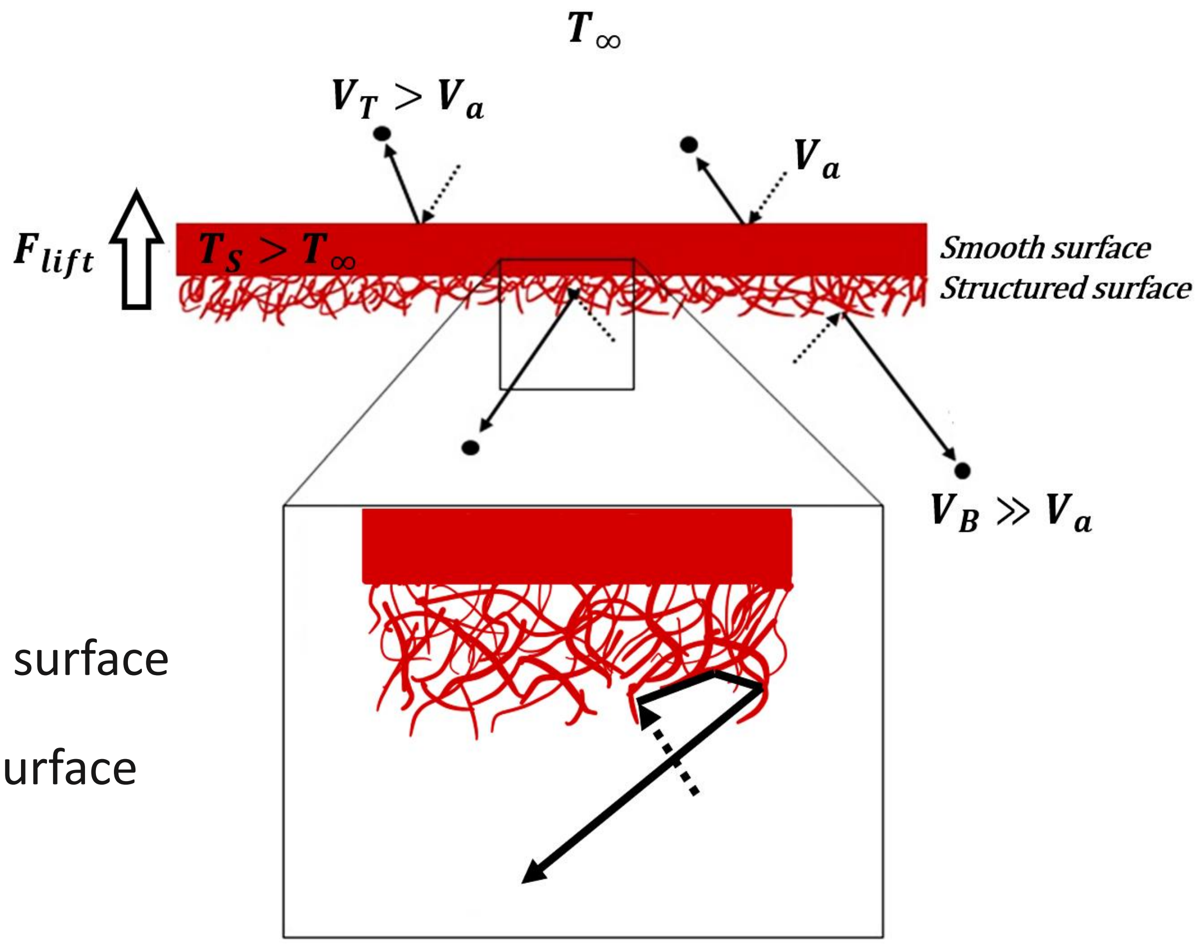
Cheap, fast, easy to make samples:

What we MUST have: *$\Delta\alpha$ between the two sides*

$$\alpha = \frac{T - T_\infty}{T_s - T_\infty} \sim \text{how much energy the molecule absorbs from the surface}$$

Easy ways to change α :

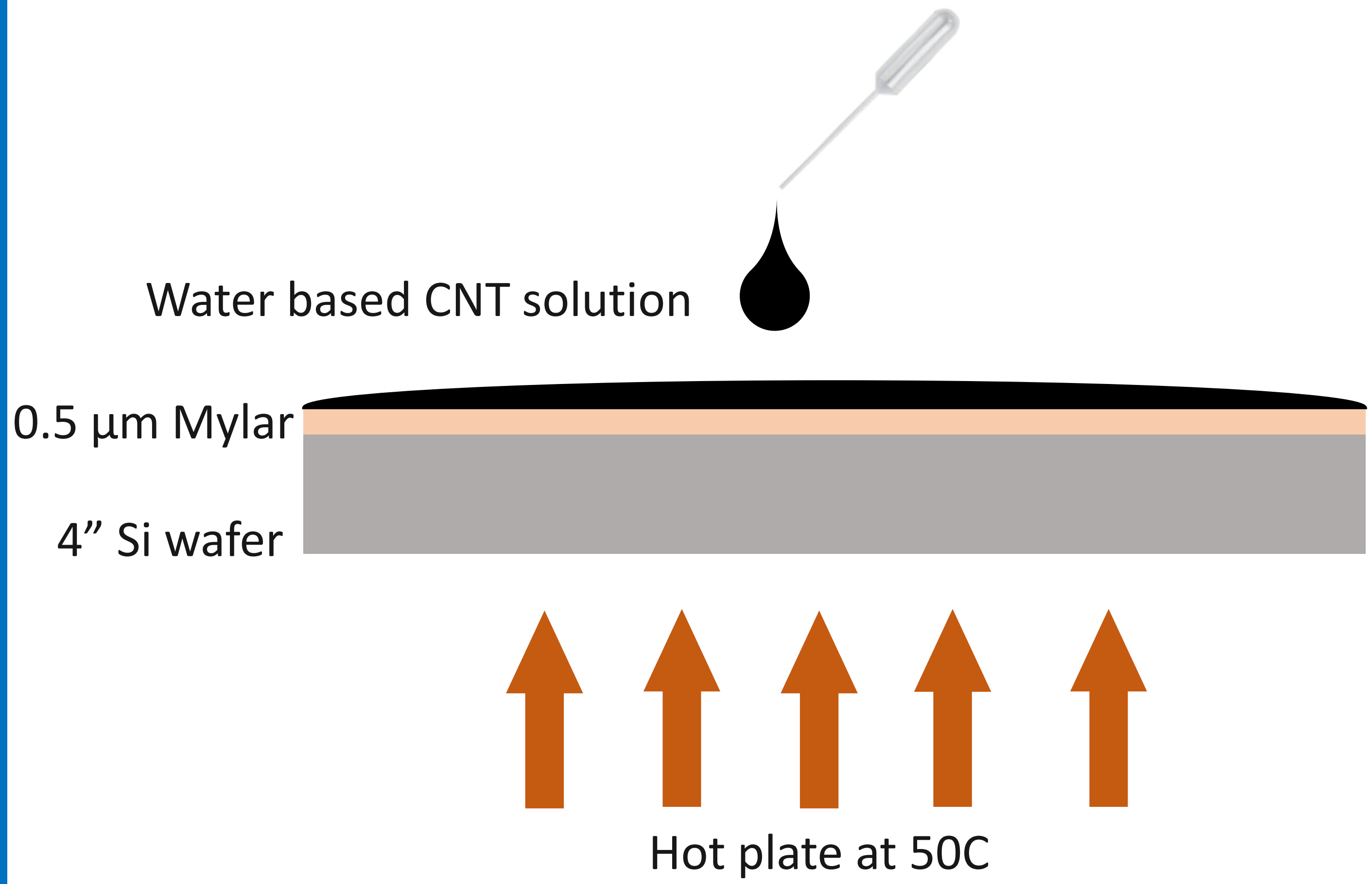
- Change the interaction time between gas molecule and surface
- Increase number of collisions each molecule has with surface before returning to ambient



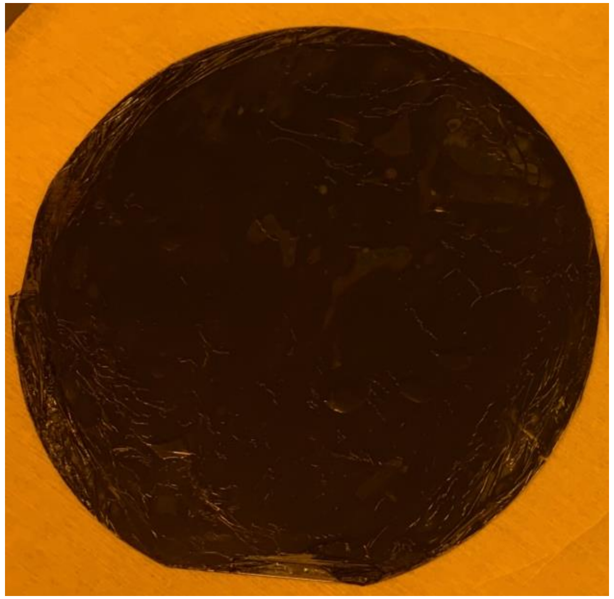
Creating a trap

Sample Fabrication

Cheap, fast, easy to make samples: *Creating a trap*



4“ wafer after evaporation of the water:



Bonus point:

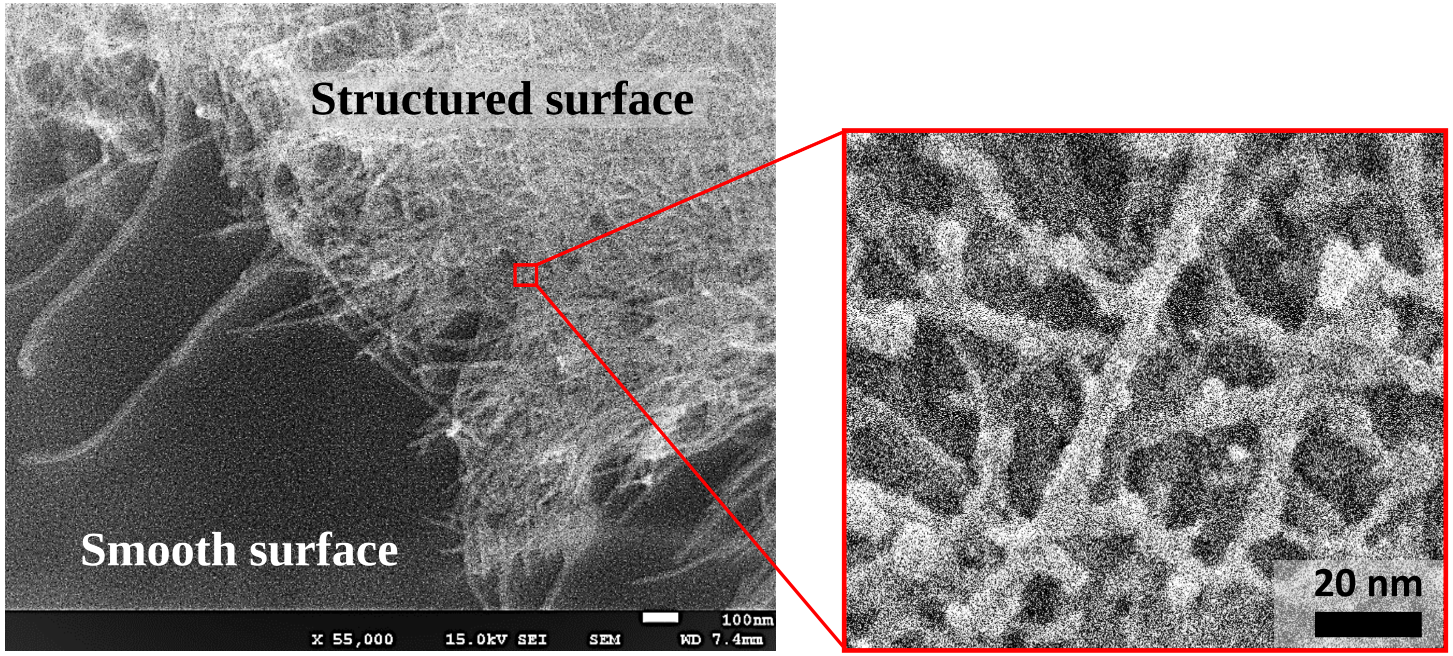
- *CNT layer absorbs light*
- *CNT layer increases structural rigidity*

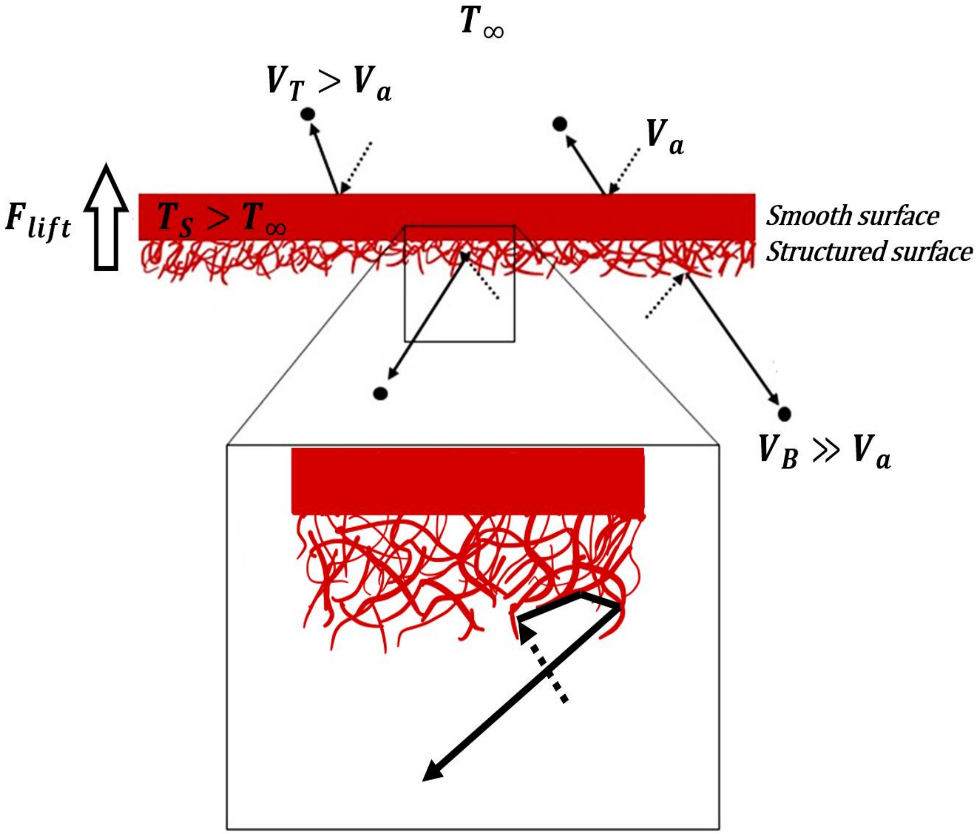
Areal density: 1 $\boldsymbol{g/m^2}$

Sample Fabrication

Cheap, fast, easy to make samples:

Creating a trap

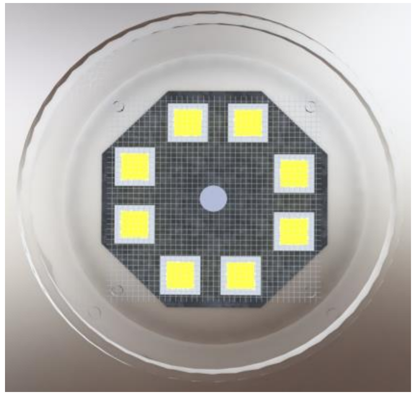


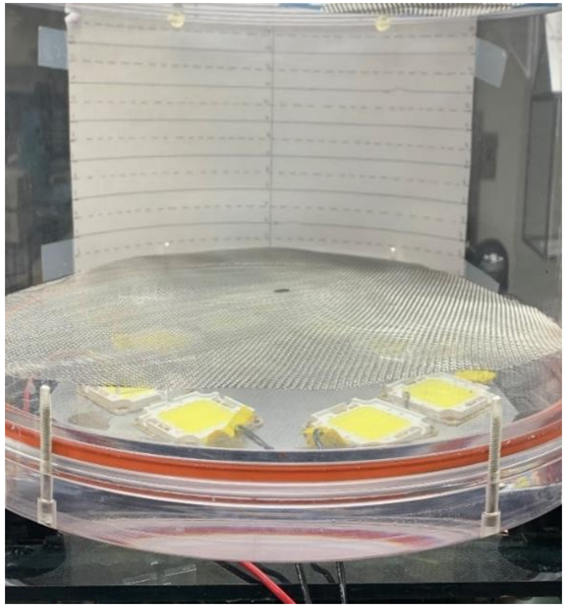


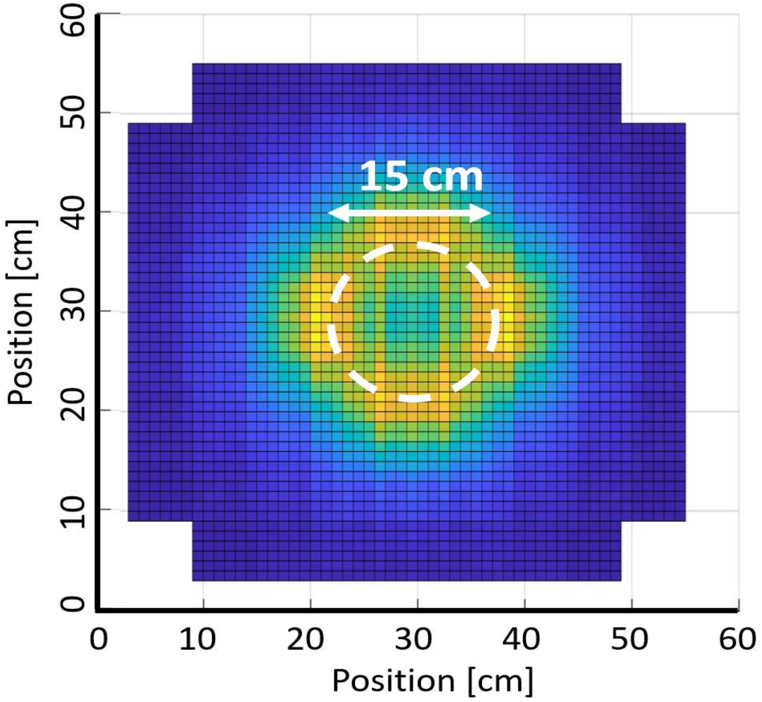
Light field

Creating a light trap and the experimental setup:

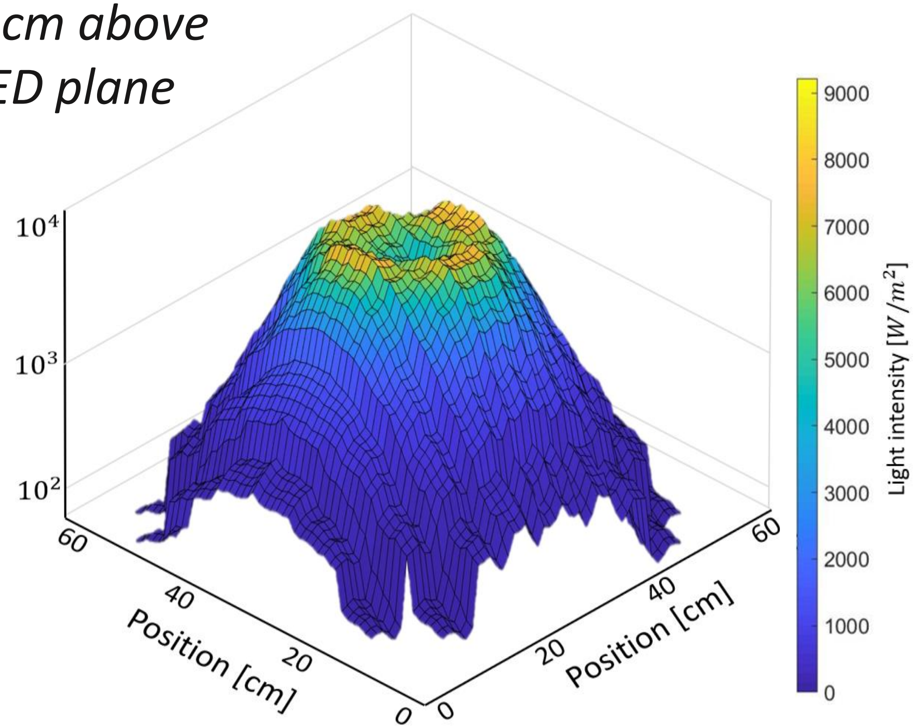
- *8 LED setup for a light ring – up to 10 suns in intensity of the center of the ring.*
- *Transparent metallic mesh (74%) as launch pad*
- *Clear acrylic chamber for video capturing*



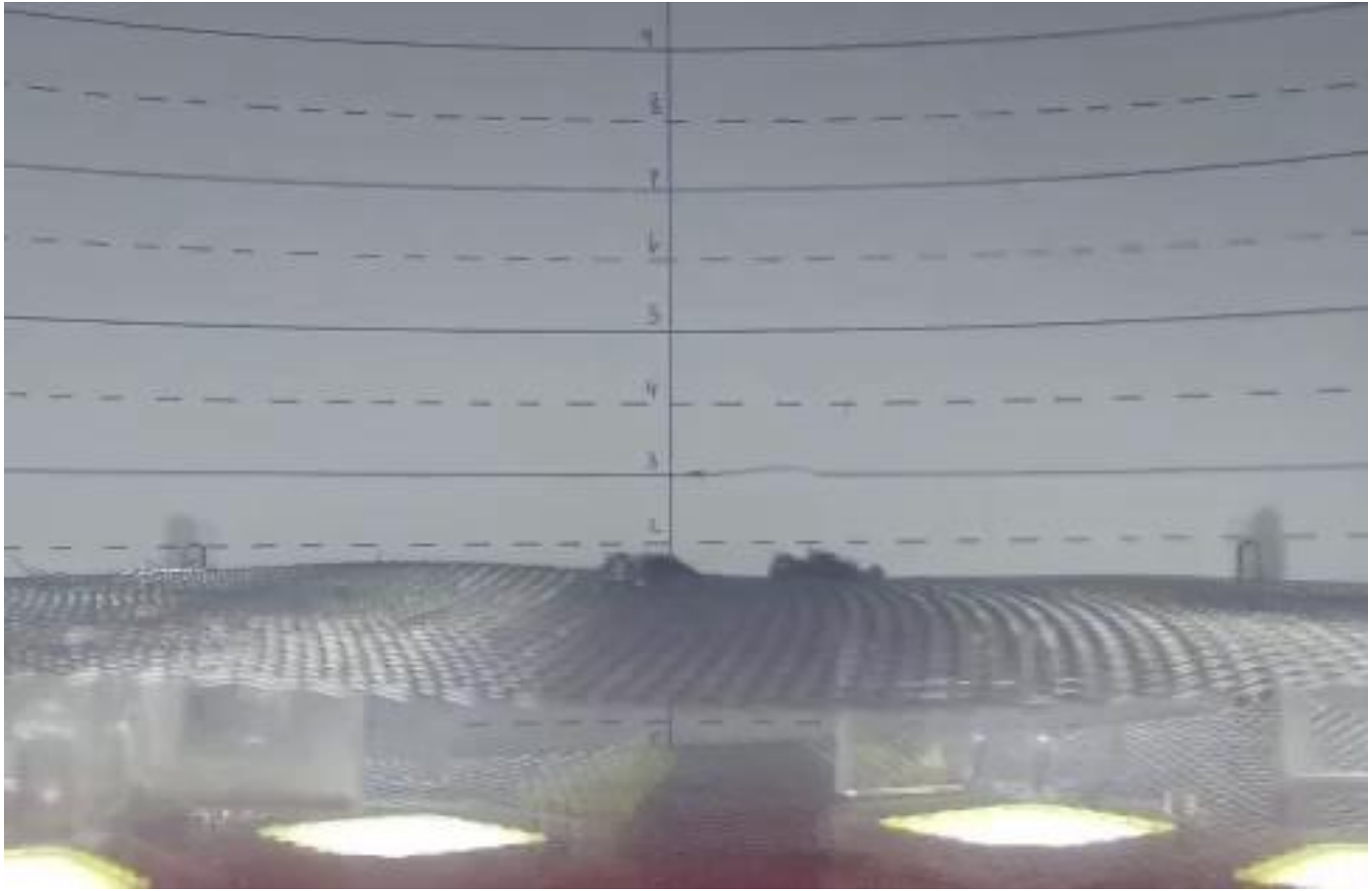




7 cm above LED plane

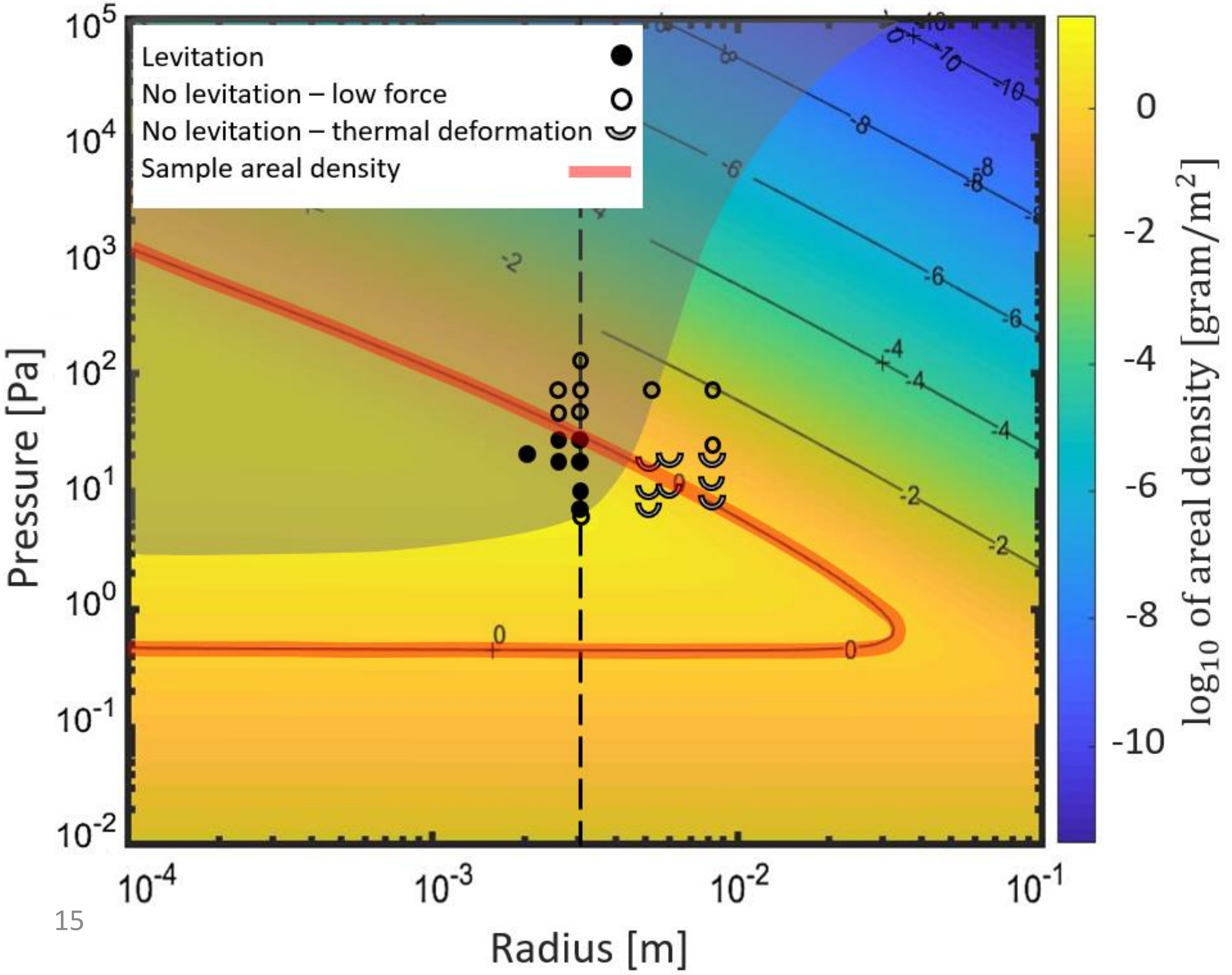


Experimental results



Experimental results

We also tested scenarios that the theory says they shouldn't work:



Experimental results

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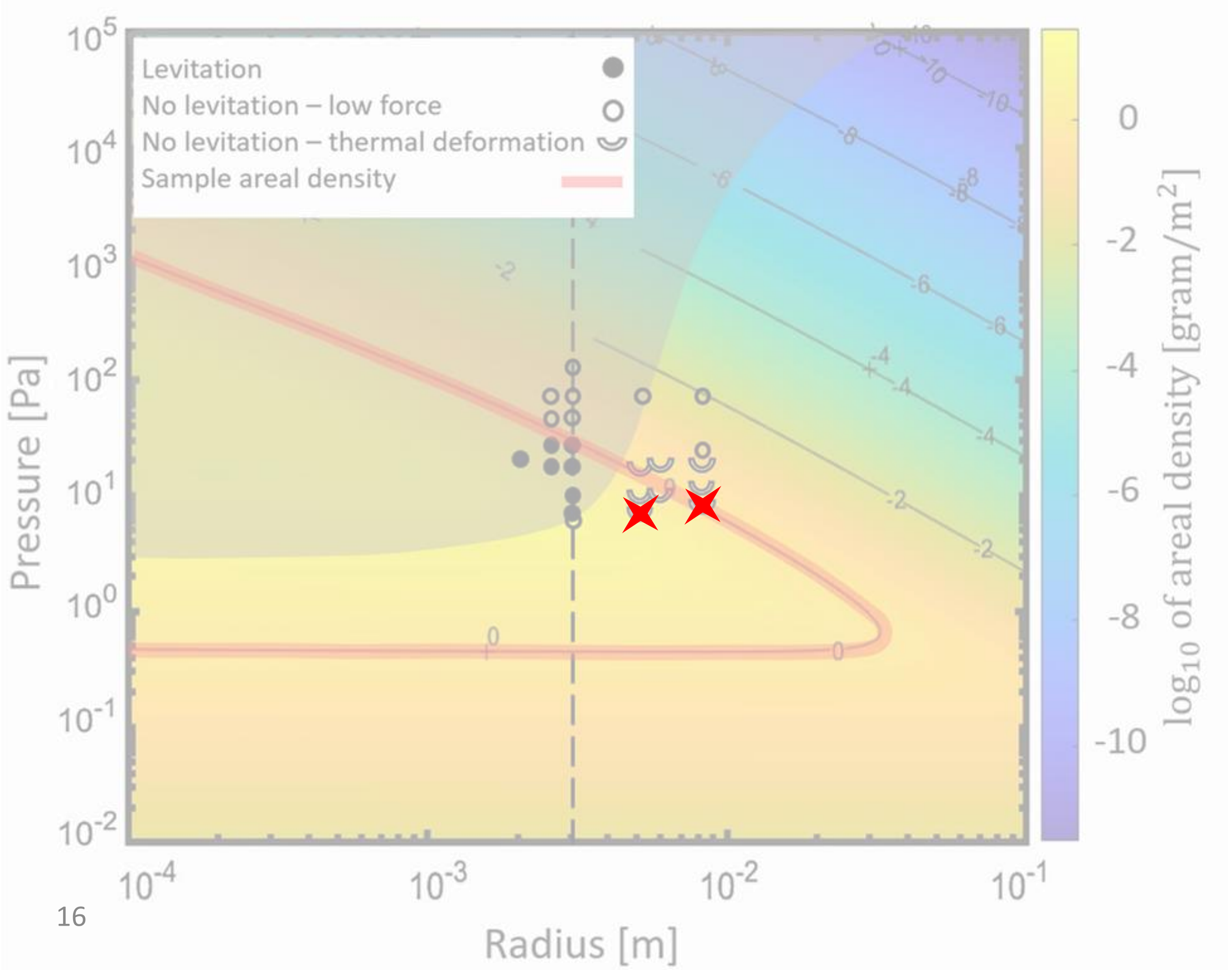
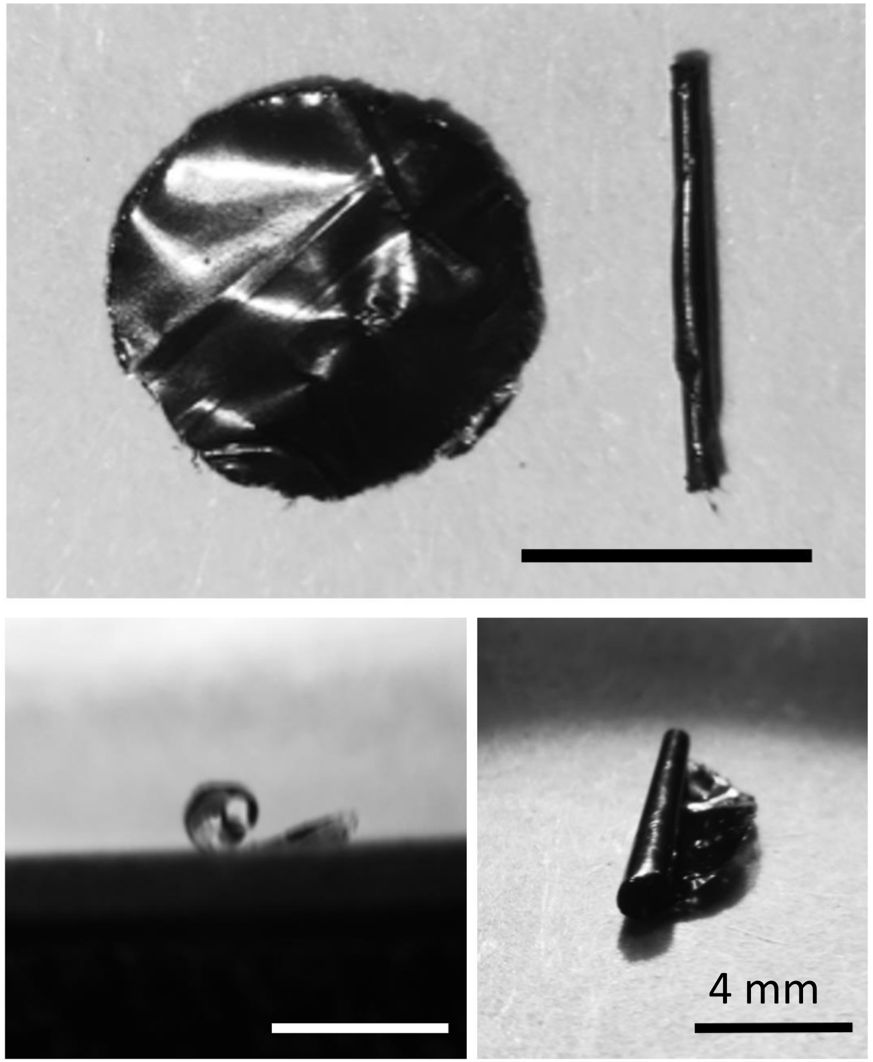
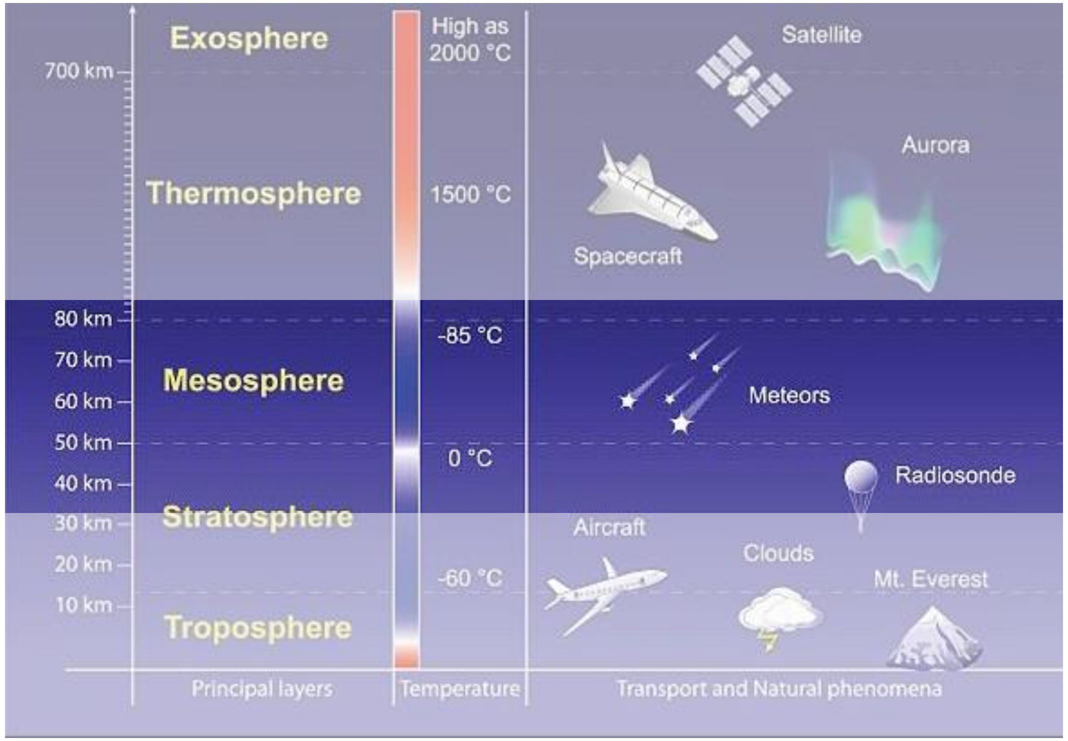




Theoretical prediction

Earth's upper atmosphere:



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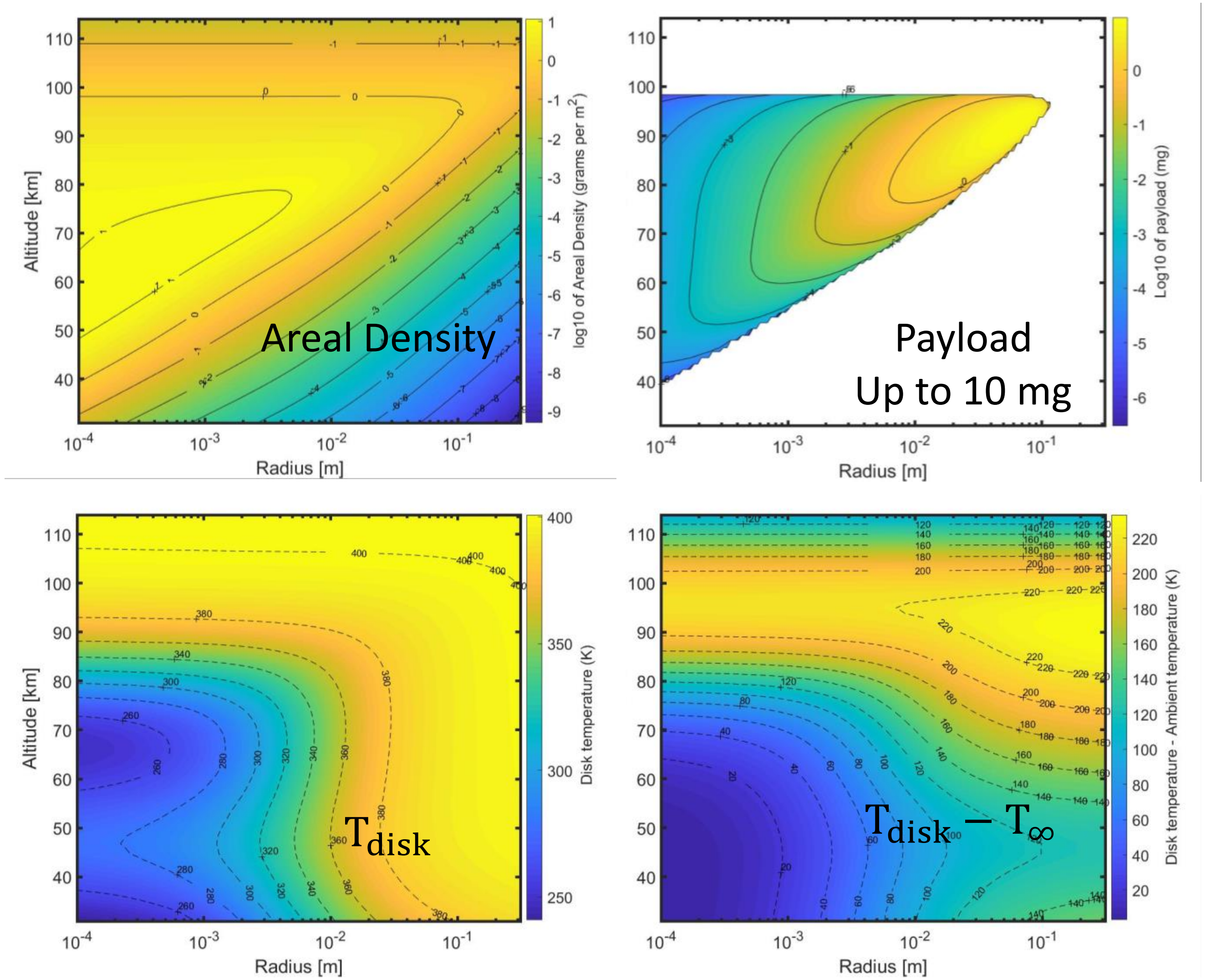
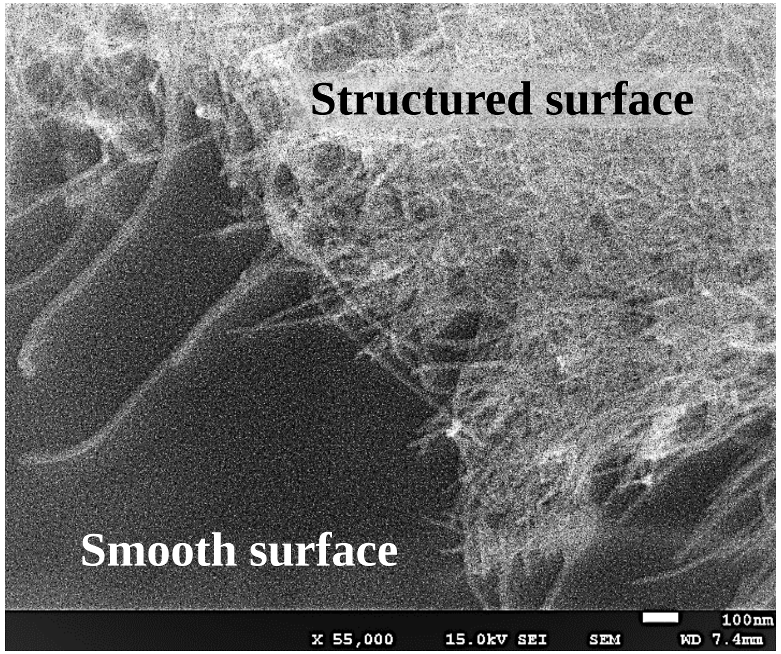
Optimized values of $\Delta\alpha$=0.5 and emissivity= 0.5 under natural sunlight

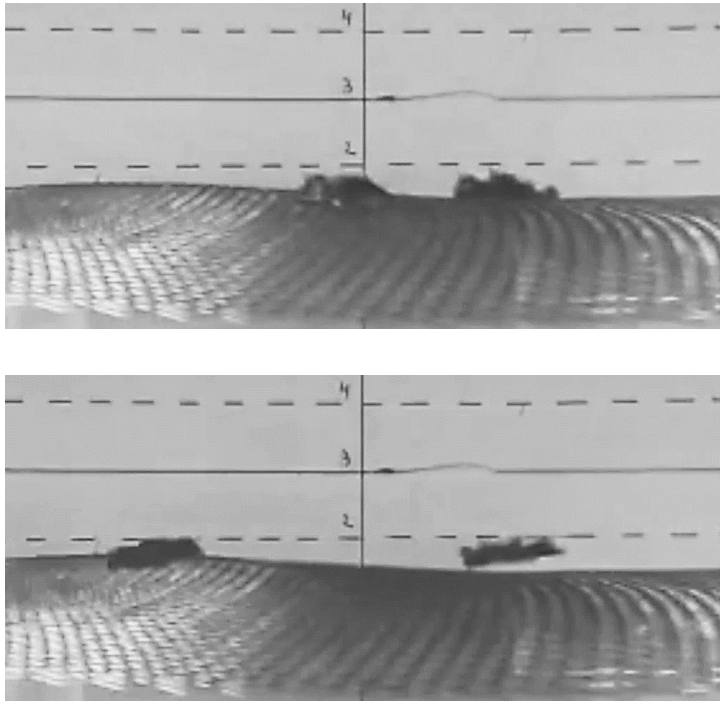


Conclusion

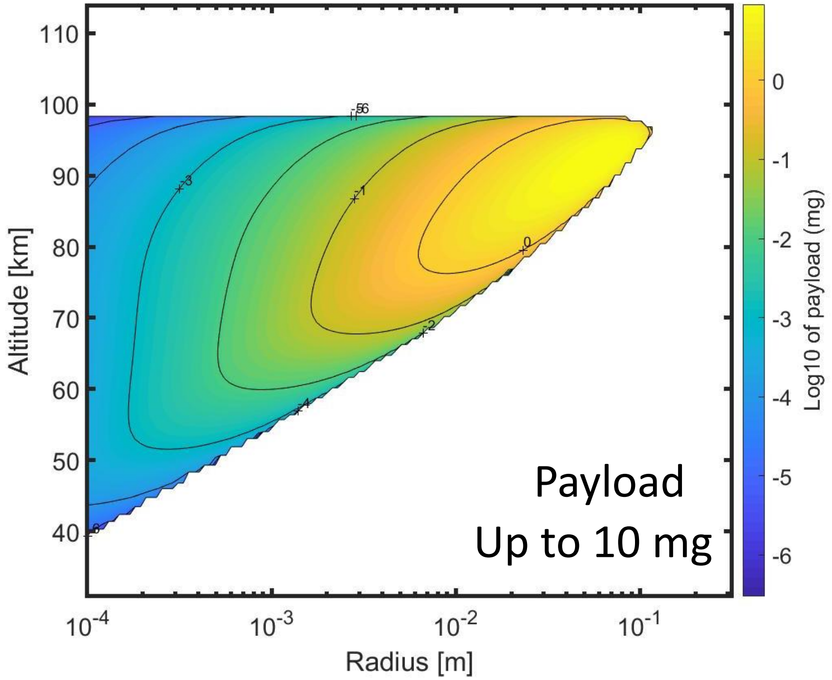
Cheap and fast Sample fabrication, with structured surface



Controlled flight at low pressures



Optimized high altitude levitation with payload



Acknowledgment

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Thank you!