In-Situ Wind, Temperature, and Pressure Data at 50-100 km Altitudes

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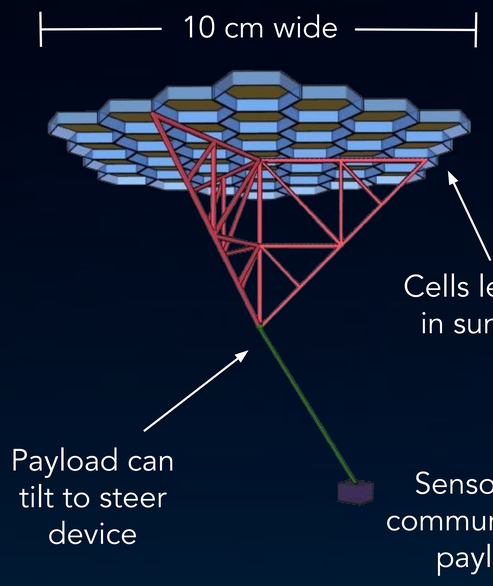
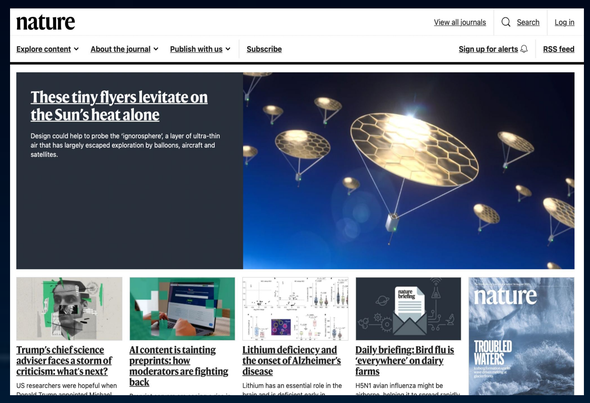
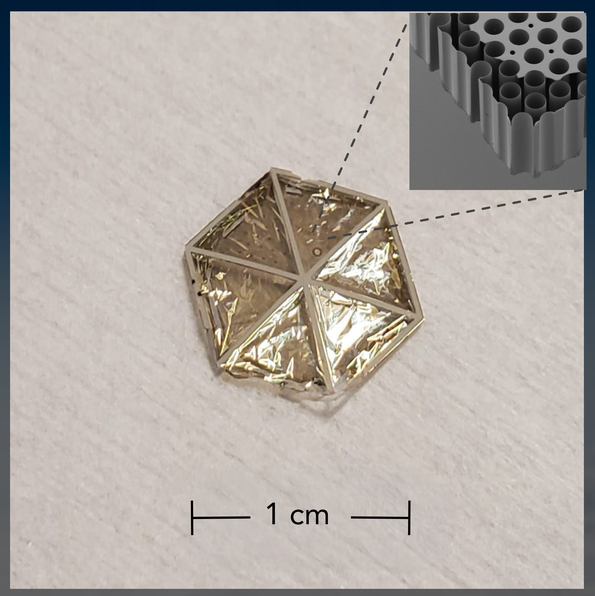
Photophoresis is a phenomenon that occurs when an object surrounded by a low-pressure gas is illuminated. An asymmetry in the object's temperature or accommodation coefficient (AC) causes the gas to transfer more momentum to one side, resulting in a force [1]. This explains why a radiometer spins when illuminated and how aerosol layers remain aloft in the stratosphere and mesosphere (20–100 km altitudes) [2]. Our recent work showed, for the first time, that lightweight devices with engineered surfaces generate sufficient photophoretic lift to sustain near-space flight when illuminated by sunlight [3,4].

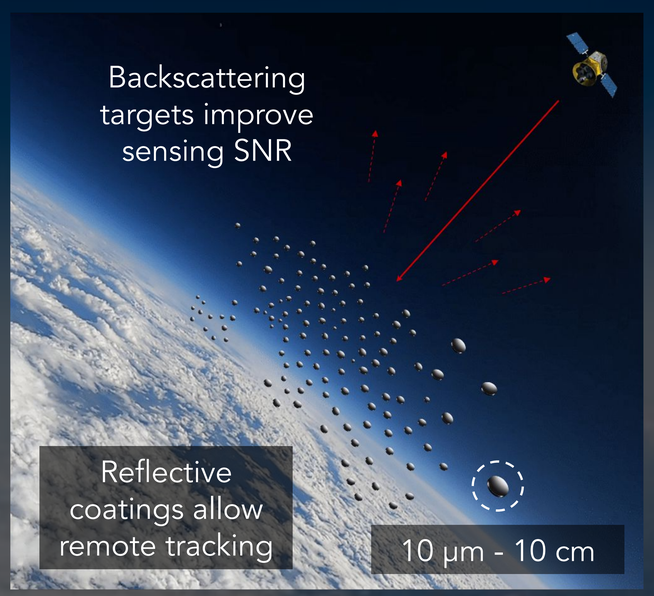


Photophoresis enables new observational capabilities:

- Flyers can remain aloft for days to months, depending on size and altitudes.
- Devices can be deployed by stratospheric balloons or rocketsondes.
- Low-cost flyers without payloads can be fabricated today, and near-term scaling can enable >100 mg payloads within 5 years.
- Passive tracers can be remotely tracked from the ground or from space to measure local wind vectors, while photophoretic force models estimate ambient pressure and temperature. Tracer material degradation can provide information on UV flux, ion flux, and atomic oxygen concentration.
- Active payloads could enable directional control and station-keeping, allowing flyers to remain at fixed locations under favorable wind conditions. A 10 mg payload, achievable with current fabrication methods, could support data transmission of ~10 Mb/s from 70 km altitude.
- Large ensembles of flyers could form phased arrays with Gb/s-scale aggregate data rates, comparable to some LEO constellation capabilities.
- Coatings can be tuned for radio and IR interaction, creating opportunities for persistent relays or countermeasures.
- At end of life, tracers disintegrate into non-toxic mineral dust, minimizing long-term environmental burden.







Top: A 10 cm-wide photophoretically levitating devices could loft payloads greater than 100 mg in the mesosphere. Here, the payload is hung below the photophoretic portion of the device. By changing the hanging angle of the payload using MEMS actuators, the entire structure can be steered. **Bottom Left:** A 1 cm-wide prototype device containing microscale perforations through which rarefied gas flows to generate upward thrust. The perforations can be tuned to change the flight performance (e.g., flight altitude, persistence, payload capacity, etc.) **Bottom Right:** We are currently fabricating photophoretic devices without payloads to be used as atmospheric tracers to collect wind, temperature and pressure data between 30-100 km altitudes. Tracers would be deployed via a high-altitude balloon and tracked with satellite-based lidar or radar.

References: 1. Horvath, H. *KONA Powder Part. J.* 31, 181–199 (2014) 2. Cheremisin, A. A. *J. Aerosol Sci.* 136, 15–35 (2019). 3. Schafer, B. C., Kim, J.-h., Sharipov, F., Hwang, G. S., Vlassak, J. J., Keith, D. W. *Nature* 644, 362–369 (2025). 4. Sharipov, F. & Schafer, B. C. Radiometric forces exerted on a perforated membrane. Phys. Fluids 36, 117155 (2024).