Development of speckle optical tweezers

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1. Light has momentum?

In classical mechanics, momentum p is mass times velocity: $p = mv$. By this definition, a photon shouldn't have any momentum. However, the equation doesn't apply to things moving near or at the speed of light.

So, we turn to Einstein and his famous equation $E = mc^2$. But this is limited to non-zero, stationary masses. The equation's general form is $E^2 = (pc)^2 + (mc^2)^2$. We know that a photon's mass $m = 0$. Substituting, we get:

$$E = pc.$$

Both the left hand side of the equation (a photon's energy) and c (the speed of light) are non-zero values. Thus p, the momentum of a photon, must also be non-zero. I.e., photons get all their energy from their momentum.

2. How speckle tweezers work

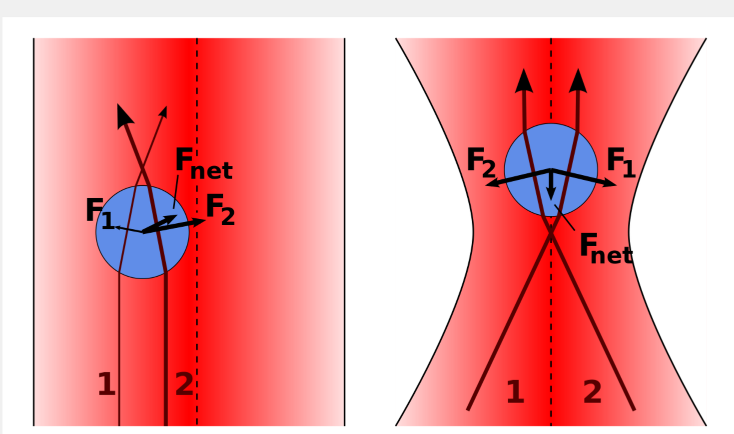

Figure 1. The exchange of momentum from light to a particle (radiation pressure) can trap it at the focus of a beam [1].

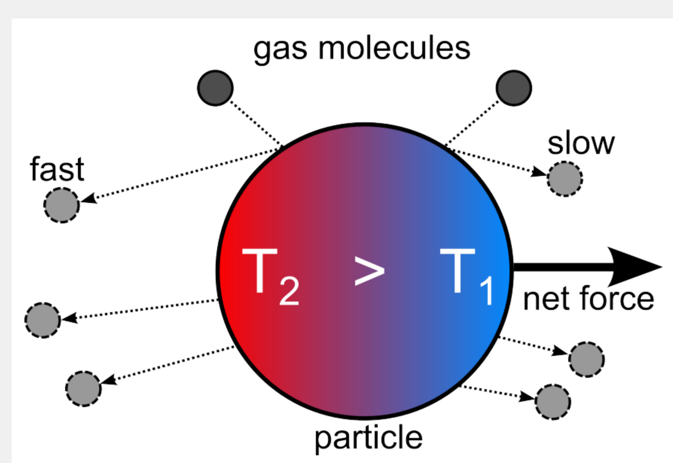

Figure 2. Photophoretic force is caused by a transfer of momentum from gas molecules that bounce off non-uniformly heated particles.

Speckles are a result of scattered light and are generally considered an unwanted imperfection in optics. However, *speckle tweezers* take advantage of these granular patterns (Figure 5). A combination of radiation pressure and photophoretic forces trap particles in "hot spots" of the speckle pattern. A particle's size, refractive index, and other physical characteristics greatly influence the magnitude of the optical forces exerted on it. Thus adjusting the size and intensity of the speckles influences the type of particles trapped.

4. And we have lift off!

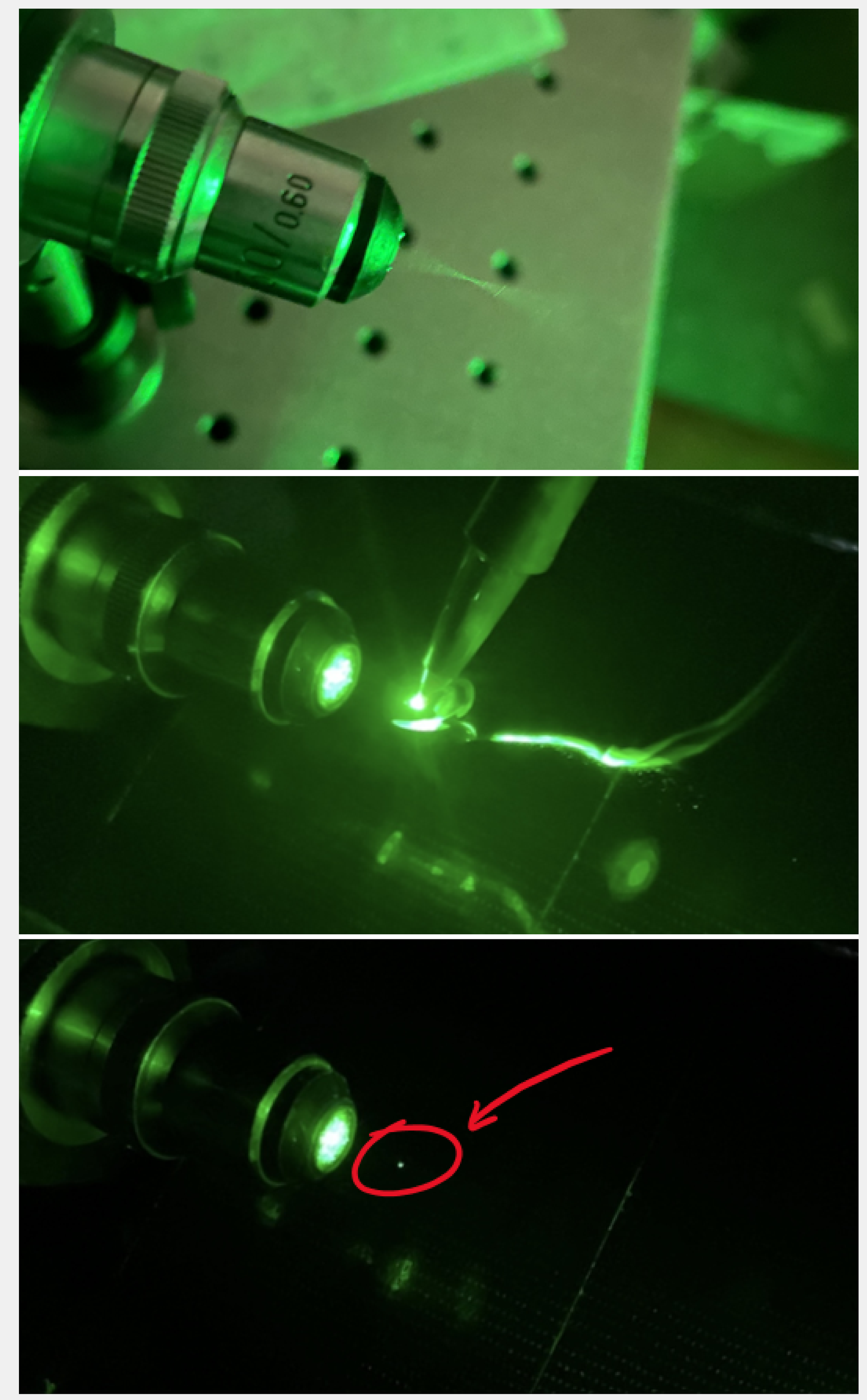

Figure 3. A Paper Mate felt-tip pen was placed at the focus of the laser beam. The ink heated up and produced smoke. As the burned particles crossed the beam, some get trapped in its focus.

5. Long story short...

- Speckles were artificially produced by a multimode fiber. A microscope objective focused the laser to a point where particles were trapped by radiation pressure and photophoretic forces.
- While yeast, lycopodium, and chalk dust were unable to be trapped (most likely because they are too large), the tweezers was able to trap particles forced out of a pen by the steam from ink heated with a laser.
- Particles from the pen were not uniform in size, and it seems only certain particles were trapped. This is possible evidence of selective trapping.

Figure 7. Physical setup in the LTC

6. What's next?

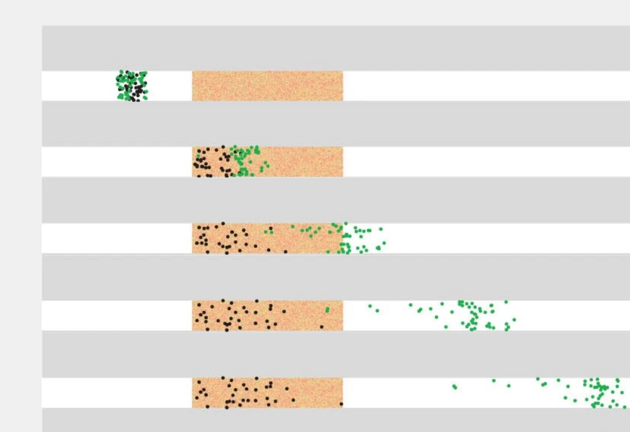

Figure 8. Speckle sieve in action.

- Use speckle tweezers as a *speckle sieve*, trapping particles with similar characteristics while allowing others to pass through (Figure 8).
- Confirmation of if trap is acting like a sieve for the ink particles.
- Better imaging of the trapping area and particle(s).
- Trap multiple particles (or verify if multiple are already being trapped) and trap larger particles (e.g. lycopodium) by modifying speckle pattern.
- **Goal:** Development of system to assist with non-contact collection of space dust and *in situ* analysis of trapped particles using methods such as Raman spectroscopy.

3. The making of the speckle tweezers

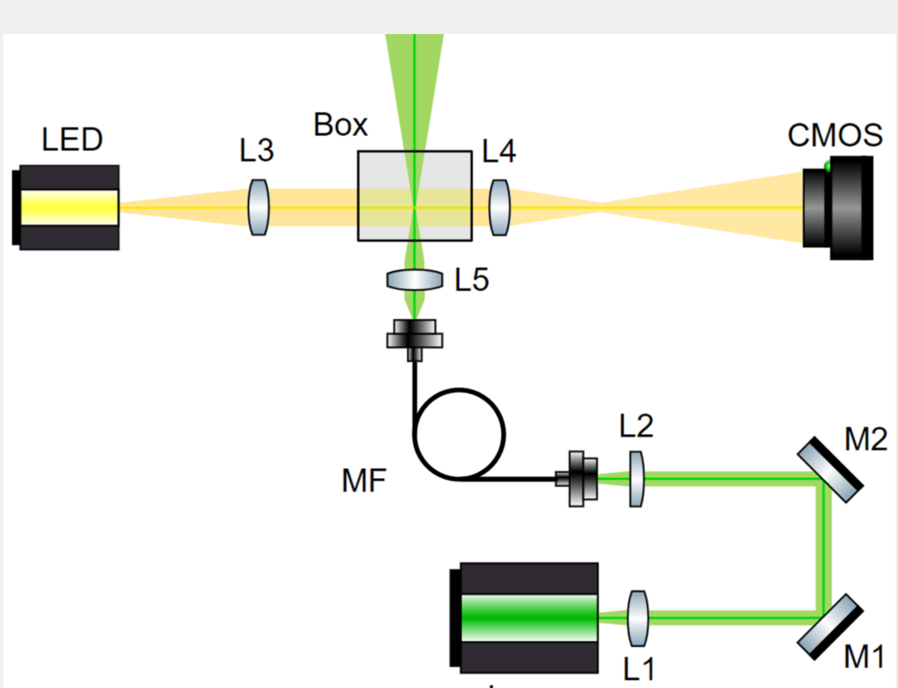

Figure 4. A 532 nm laser was directed into a multimode fiber with a 105 nm core. The light was then pointed into a microscope objective lens. The lens focused the laser into an isolated space for trapping of particles in a box. The box was illuminated by an LED and imaged with a monochrome CMOS camera.

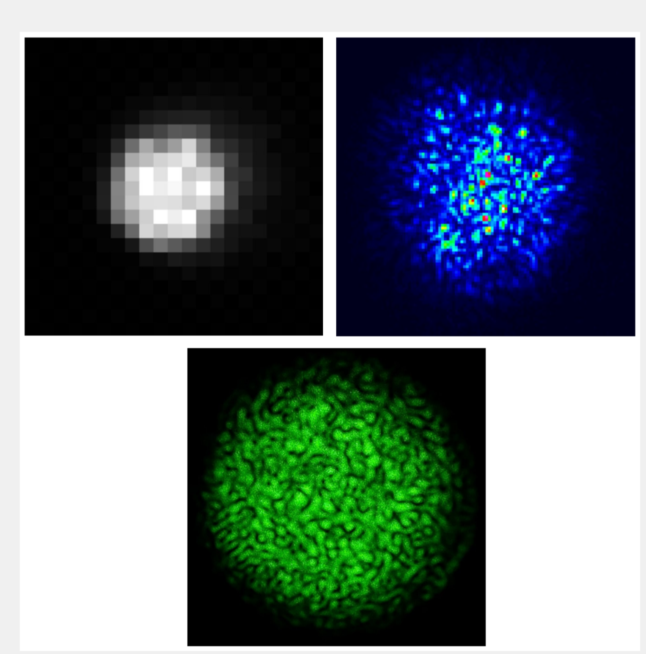

Figure 5. Generated speckle pattern imaged at focus (CMOS Camera), near the focus (Beam Profiler), and when beam hit the wall (iPhone).

Figure 6. Sample particles used for trapping. Left to right: yeast, lycopodium, chalk dust, felt-tip pen.

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References

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