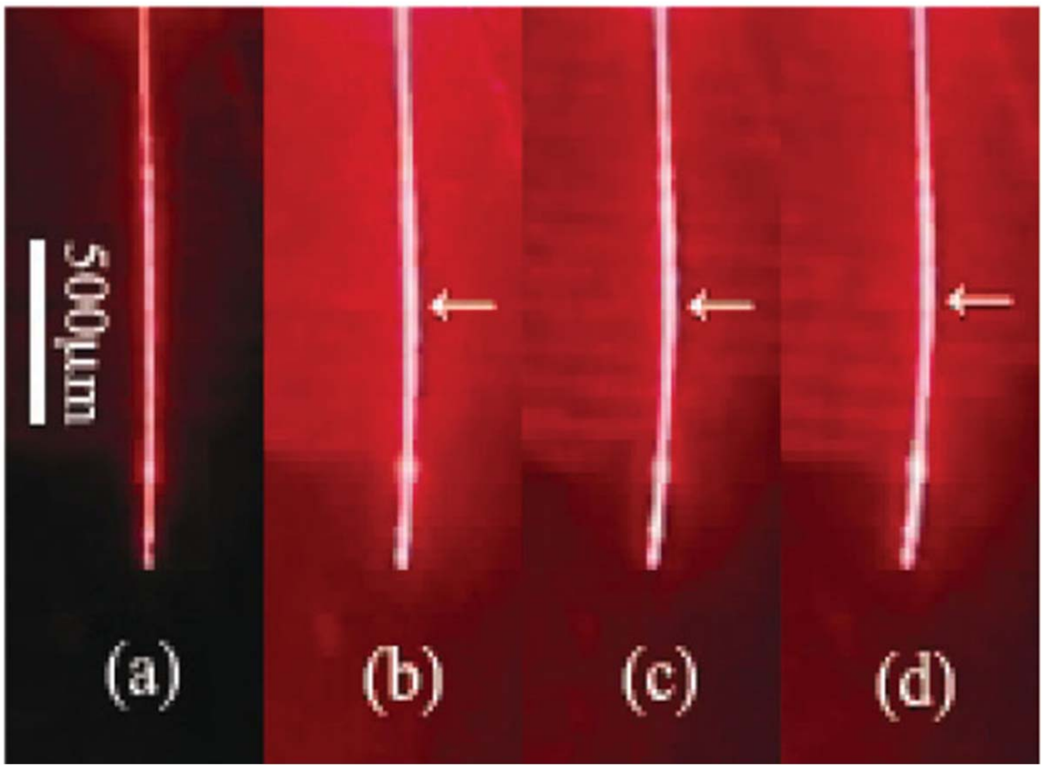
# Momentum of Light in a Dielectric

## Group 9

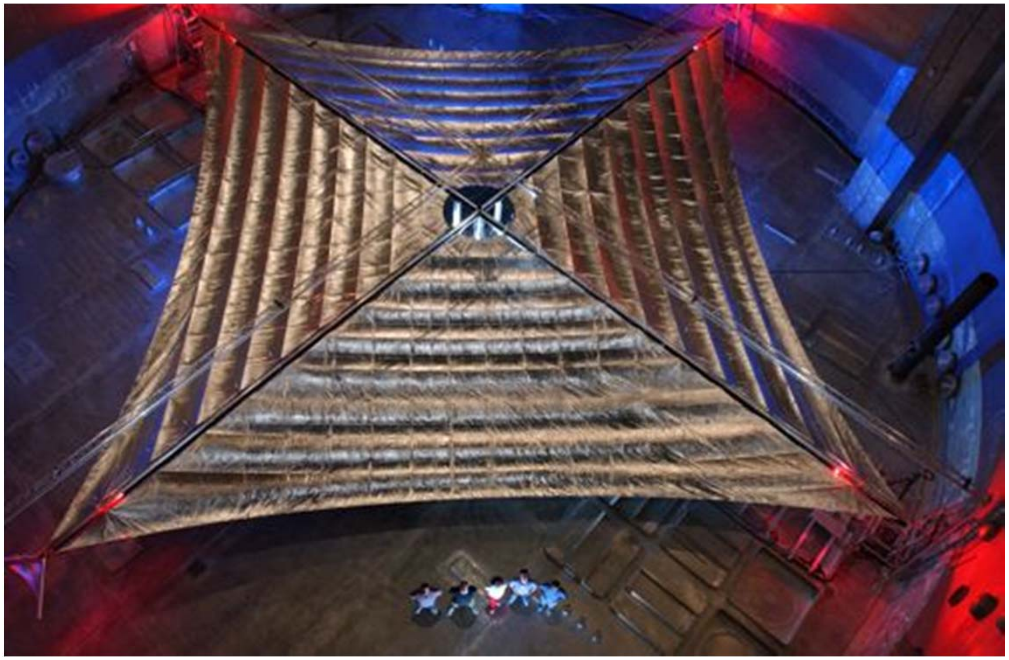
Chi, Bill, Greg and Sarvagya




*Phenomenon observed in She's experiment. The filament is bent to the right as pointed by the white arrows, and moves left-upward at the end point. Figure from:*
***Observation of a Push Force on the End Face of a Nanometer Silica Filament Exerted by Outgoing Light, Physical Review Letters (2008) 101, 243601.***

# The Abraham-Minkowski Controversy over the Momentum of Light in a Dielectric

- It's known that light carries momentum and has been used in practical applications (Solar Sails)
- The two rival theories predict precisely the opposite effects
- There is scientific evidence in support of both theories, the debate puts fundamental physics at stake.



*Solar sail by L'Garde, Incorporated, proposed for NASA's ST9*

***Picture courtesy : www.nasa.gov***

## Abraham

- Light loses momentum

- Velocity of light decreases in a dielectric ⇒ Momentum must also decrease ($p = \frac{h}{n\lambda}$)

- Classically sound argument

## Minkowski

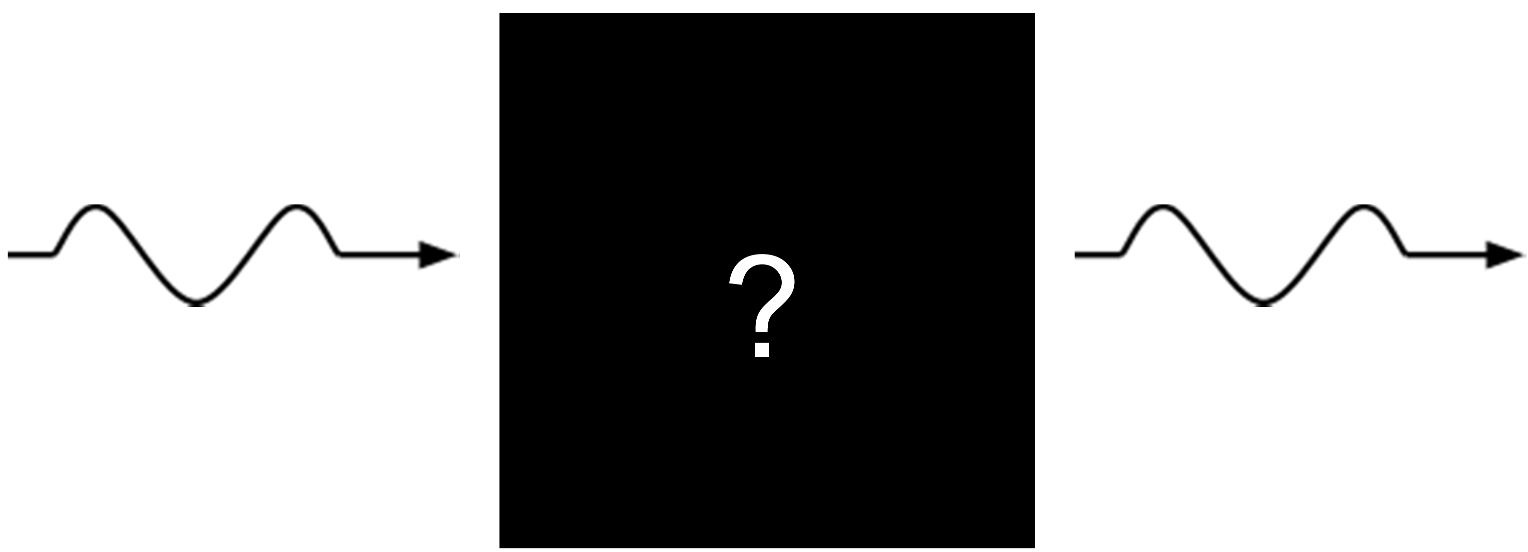
- Light gains momentum

- Wavelength decreases by a factor of refractive index ⇒ Momentum must increase ($p = \frac{nh}{\lambda}$)

- Quantum mechanically sound argument

# Experimental tests prove difficult

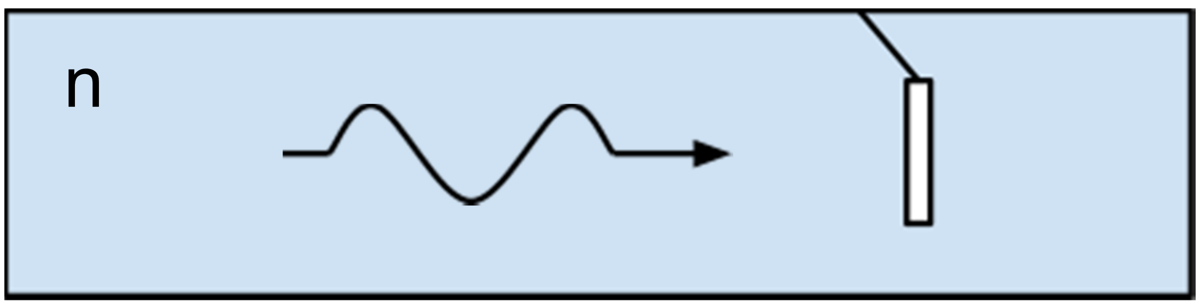
- How do you observe the momentum of a photon while it is INSIDE a dielectric?
- Where does the momentum reside? With the photon? Within the body of the dielectric?
- Are any observed forces due solely to photon momentum?



# How does radiation pressure change in a dielectric?

- Light exerts pressure on matter, especially reflective materials.

- Suppose a mirror is placed in a liquid dielectric and exposed to light.




- Abraham (p~1/n) claims that any deflection should be lesser. Minkowski (p~n) claims that any deflection should be greater.

# Minkowski Takes the Lead

- Jones and Richards (1954) demonstrate that the deflection increases in direct proportion with the index of refraction.
- Jones and Leslie (1978) repeat the experiment using lasers and arrive at the same conclusion.

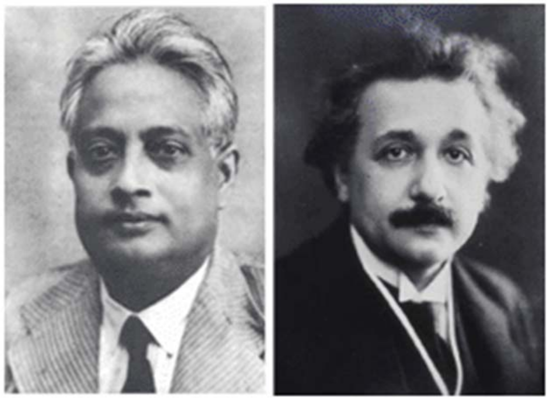
# Dielectric Interface distortions provide another point for Minkowski.

- Any change in photon momentum across a dielectric boundary must be compensated by a force exerted on the dielectric.

- Ashkin and Dziedzic (1974) observe that a dielectric surface bulges outward as a photon enters or leaves, thus supporting Minkowski.

# Bose-Einstein Condensate experiments also support Minkowski

- Bose-Einstein Condensates are dense enough to be treated as dielectrics.
- G. K. Campbell et al (2005) demonstrate that atoms within a BEC recoil as if struck by photons of greater momentum.
- Is Minkowski the clear winner?



http://archiveweb.epfl.ch/latsis2008.epfl.ch/page21377.html

# Abraham stages a comeback

- Detailed calculations for single photon pulses demonstrate that Abraham's model may agree with the mirror deflection.

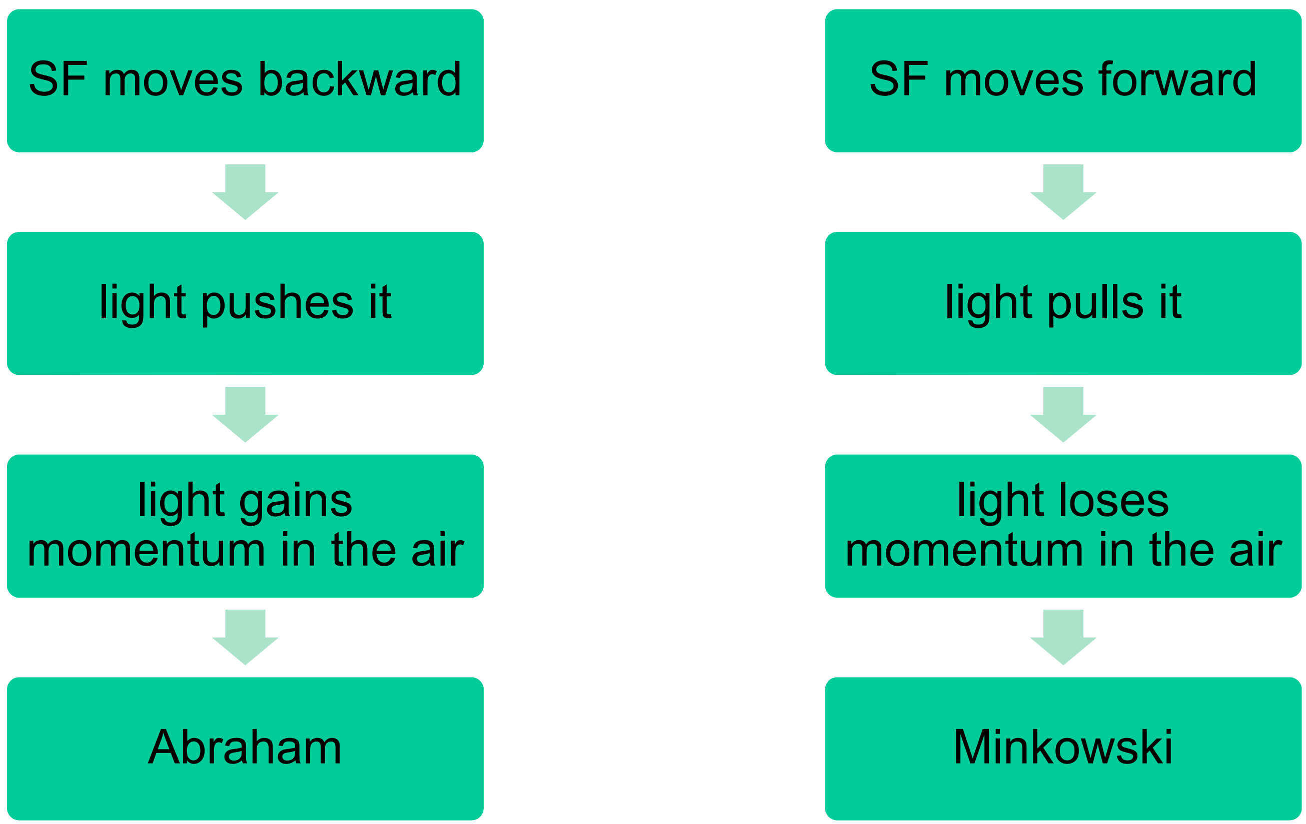
- A non-uniform beam intensity would induce lateral forces on a dielectric surface, thus confusing the results.

# Experiment by She’s group supports Abraham

- In 2008, Weilong She’s group, at Zhongshan University China, reported to have observed a push force on the end face of a nanometer silica filament exerted by outgoing light and concluded that the Abraham momentum was correct.

# Description of She's Experiment (1)

- Replace the water-air surface in Ashkin and Dziedzic's experiment with a nanometer silica filament (SF)



# Description of She's Experiment (2)

- Equipment
  - Silica filament: diameter=450nm, length=1.5mm
  - Light source: 650 nm laser, fiber connector, 4/15 sec pulse & 1/5 sec dead time
  - Chamber: hermetic, glass
  - Camera: video mode, 15 frames/sec

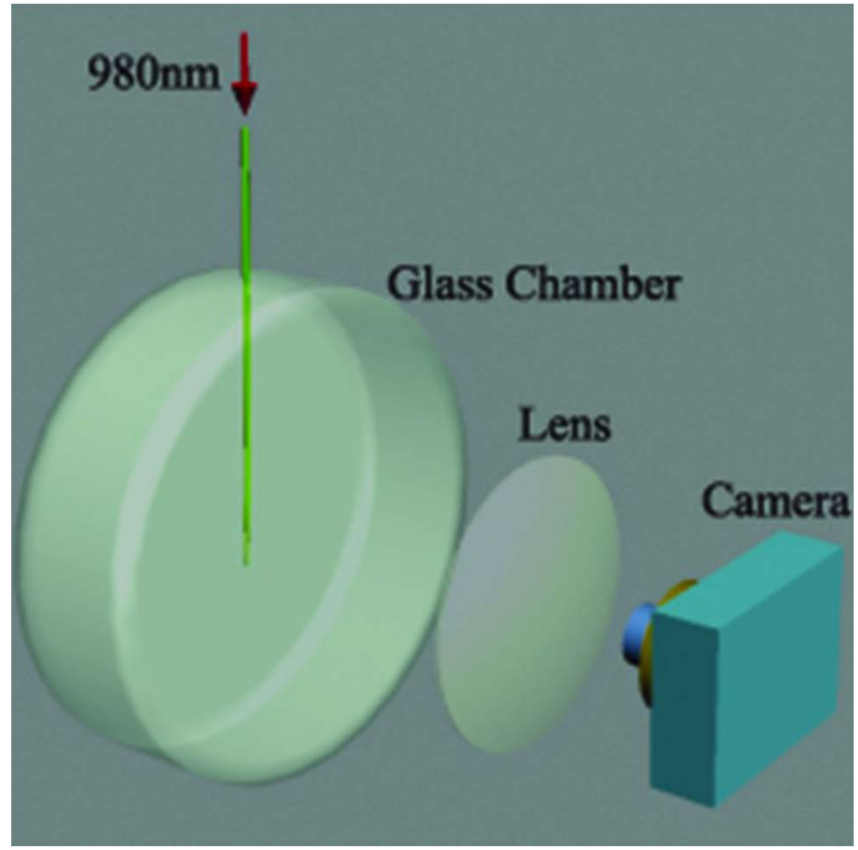
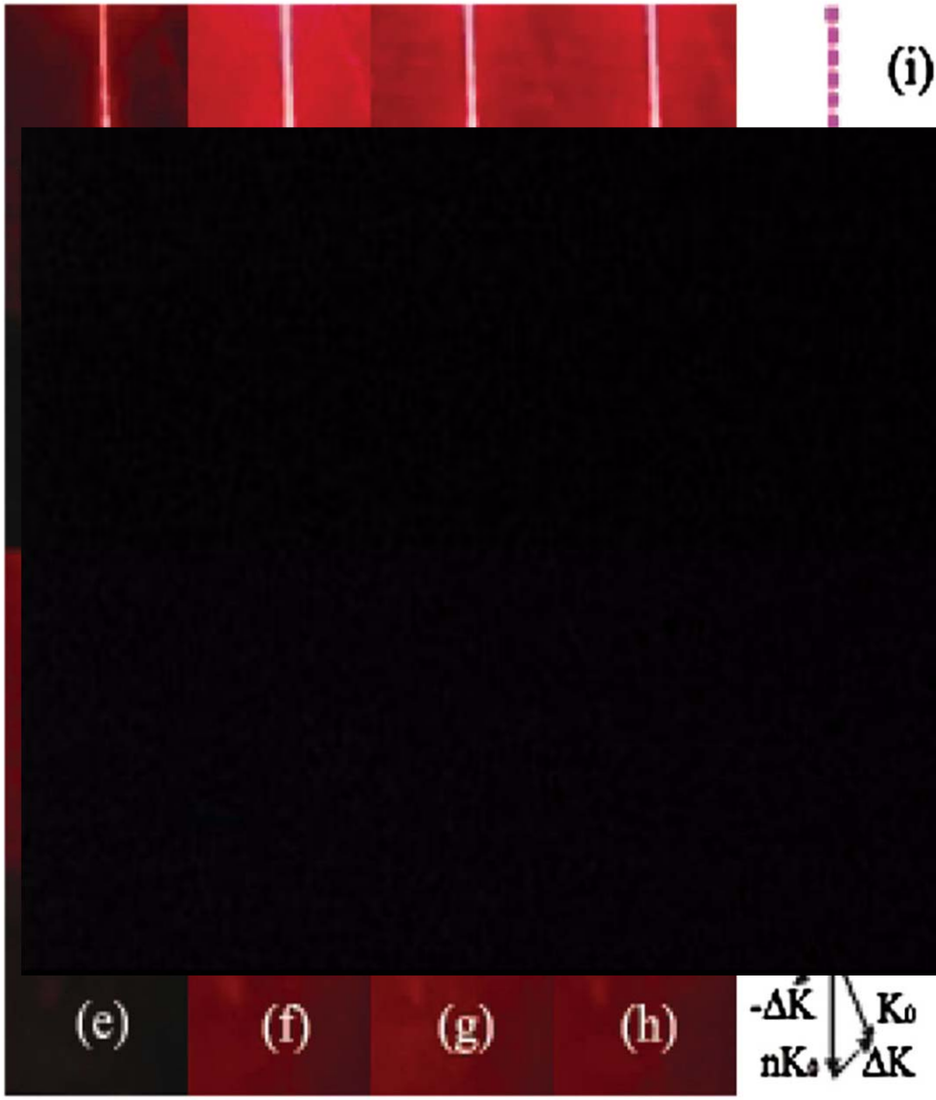



**Figure**: Equipment in She's experiment. (http://www.opfocus.org/content/v4/s4/opfocus_v4_s4.pdf)

# Description of She's Experiment (3)




[redacted]

- Result and analysis by the authors
  - Out-going light exerts inward force on the SF
  - Light gains momentum when emerges to the air
  - Abraham momentum is correct

[redacted]**ure**: Phenomenon observed in [redacted]'s experiment. The filament is [redacted]t to the right as pointed by the [redacted]e arrows, and moves left-upward at the end point. (Taken from She's paper)

# Description of She's Experiment (4)

## Supplementary experiments (i)

- Scattering of the filament contributes only 0.7%, and cannot lead to a movement like that in the experiment.
- Deformation due to thermal effect is less than 0.2 μm. (Temperature is far lower than 300 °C. )

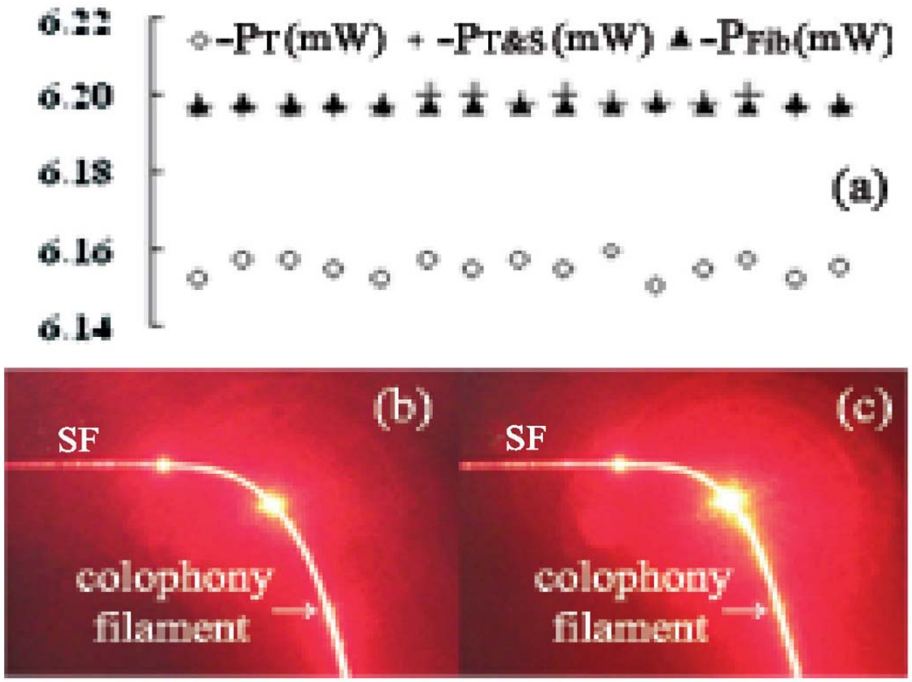



**Figure**: Phenomenon observed in two supplementary experiments. (a) Transmissions of the SF and the fibre are measured. (b) and (c), A colophony filament is connected to the silica filament. (b) 1 min after turning on the light source. (c) 60 min after turning on the light source. (Taken from She’s paper)

# Description of She's Experiment (5)

Supplementary experiments (ii)

- Air or electrostatic field do not affect the phenomena.

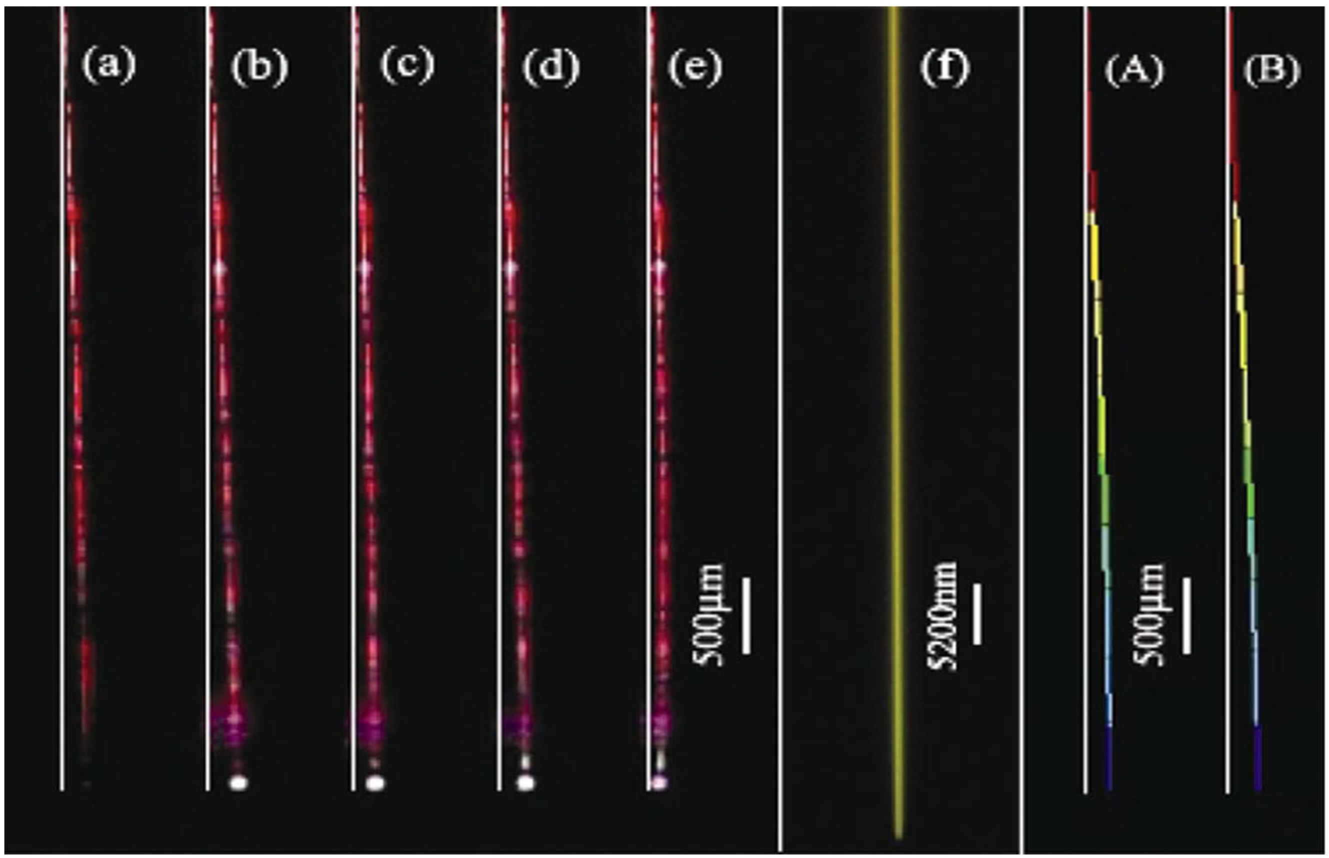
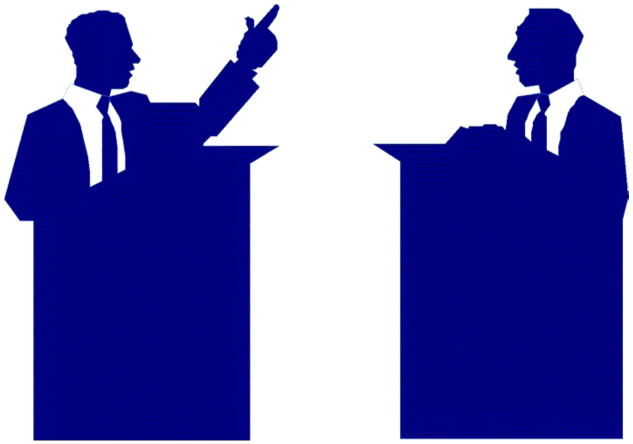



**Figure**: Phenomenon observed in a third supplementary experiment. The silica filament is located in vacuum and a electrostatic shield. (a) shows the static position of the filament. (b) – (e) show the motion when light arrives. The filament bends. (Taken from She’s paper)

# The Debate Goes On

- She's paper has been cited 33 times by other articles
- She's paper is typically used as one evidence point in favor of Abraham's momentum ($p = \frac{h}{n\lambda}$)
- Still no resolution to Abraham-Minkowsky controversy
- Two PRL comments offer critiques of She's experiment and analysis



http://bellarminenews.com/?p=639

# Mansuripur challenges She's analysis

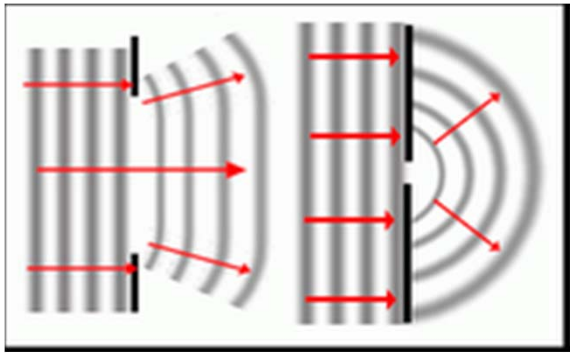
- M. Mansuripur, Phys. Rev. Lett. **103**, 019301 (2009).

- Diffraction broadening will reduce momentum and occurs when light pulse diameter ($d{\sim}500nm$) is less than or comparable to wavelength ($\lambda_1 = 650nm$, $\lambda_2 = 980nm$)

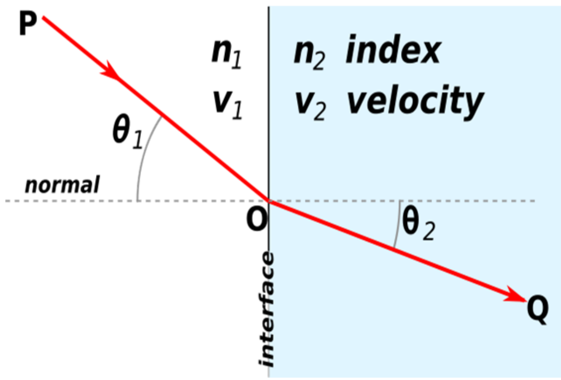
- Abraham momentum equation uses group index of refraction ($n_g = c/v_g$), but W. She used phase index ($n_\varphi = c/v_\varphi$) for calculations

- She's paper ignores the effect of mechanical momentum of particles inside the dielectric ($p_{tot} = p_{EM} + p_{mech}$)

http://innovativescience.blogspot.com/2011/02/diffraction.html



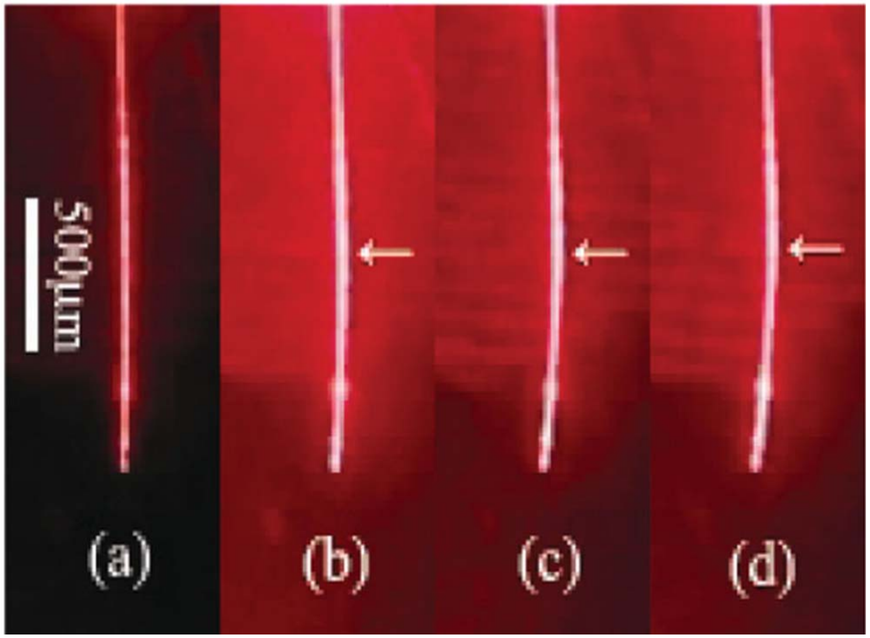
Diffraction patterns for large and small diameter waves




http://en.wikipedia.org/wiki/Refractive_index

# In Summary

- She's paper presents a clear hypothesis and a well-defined experimental result
- Theoretical analysis of results has some flaws
- Want to know She's response to Mansuripur's critiques
- Strong impact on a currently hot topic
- Your questions?




Observation of a Push Force on the End Face of a Nanometer Silica Filament Exerted by Outgoing Light, Physical Review Letters (2008) 101, 243601.