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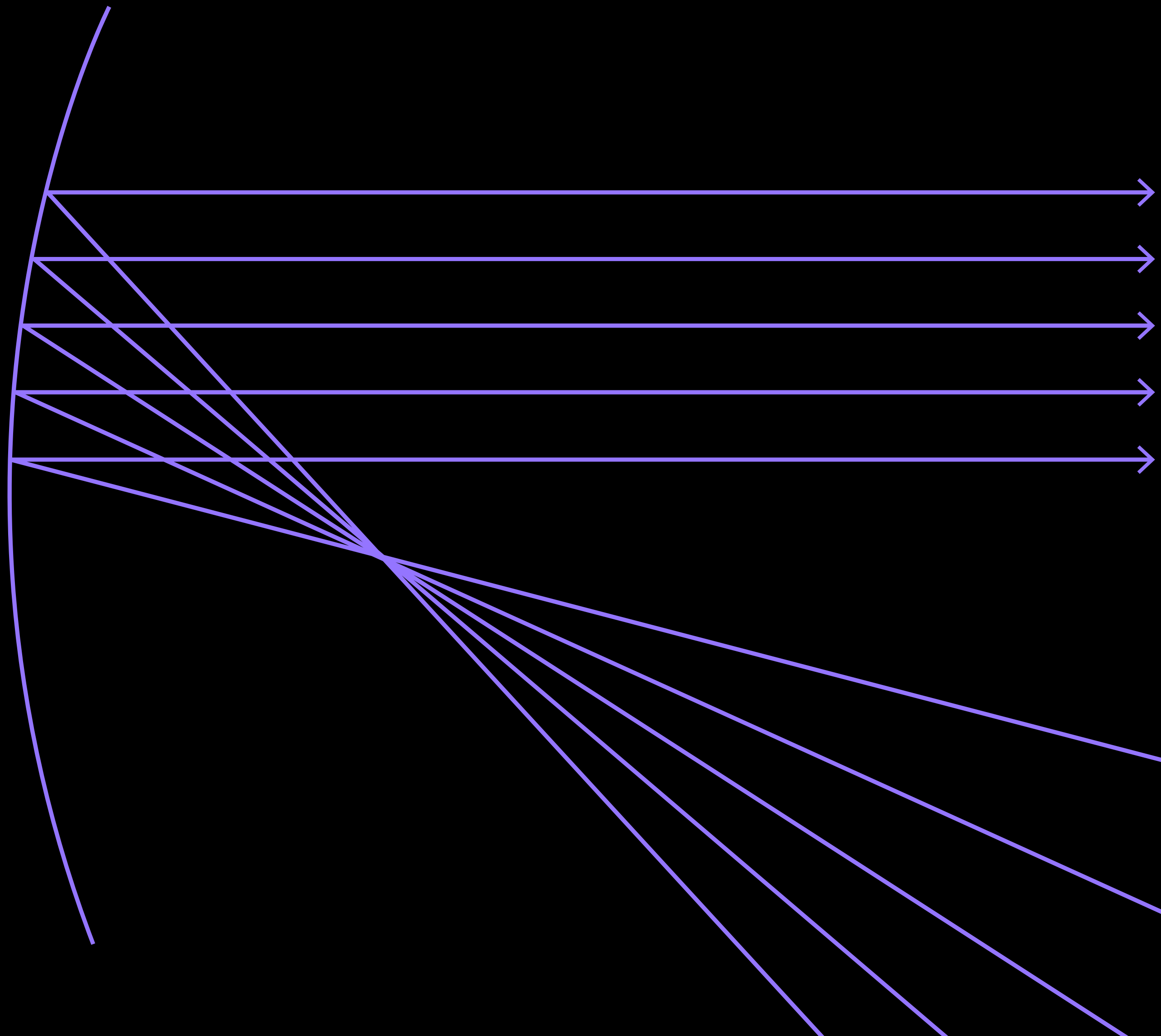

All in a Spin: Rotating Trapped Microspheres

Featuring Kishan Dholakia University of Adelaide, University of St. Andrews

09 February 2023

A Quick Zoom Tutorial

- Submit a question by clicking on “Q&A”
- Like a question that’s been submitted?
  Click the “thumbs up” icon to vote for it.
- Share your feedback in the survey.

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All in a spin: Rotating, Trapped Microparticles: Optical Trapping and Manipulation in Molecular and Cellular Biology (BT) Webinar

Kishan Dholakia
Centre of Light for Life, University of Adelaide, Australia and
School of Physics and Astronomy
University of St Andrews, Scotland

@OpticManip

http://opticalmanipulationgroup.wp.st-andrews.ac.uk

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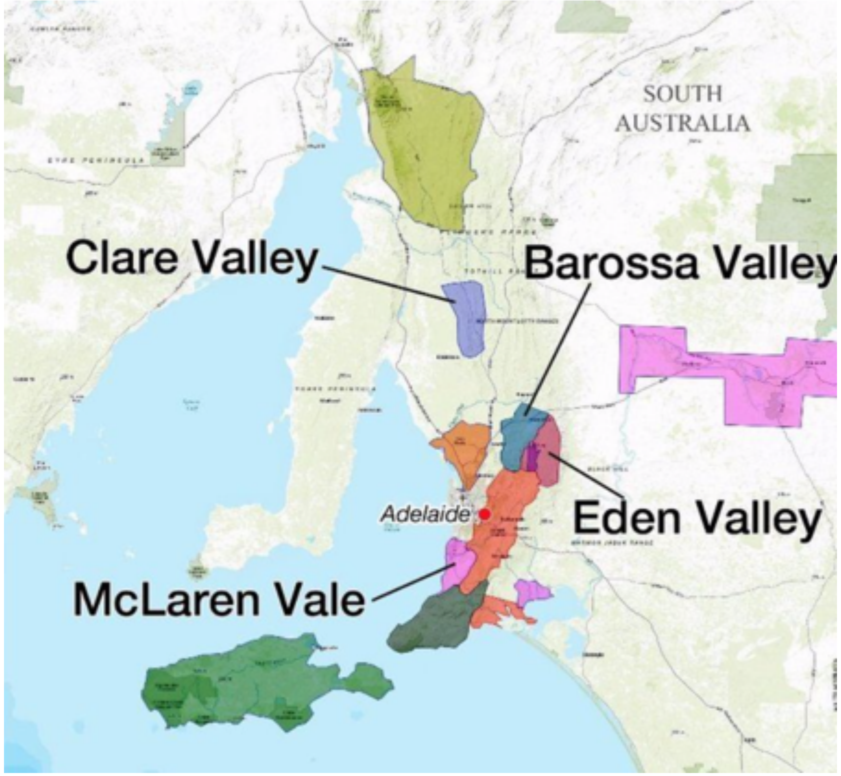
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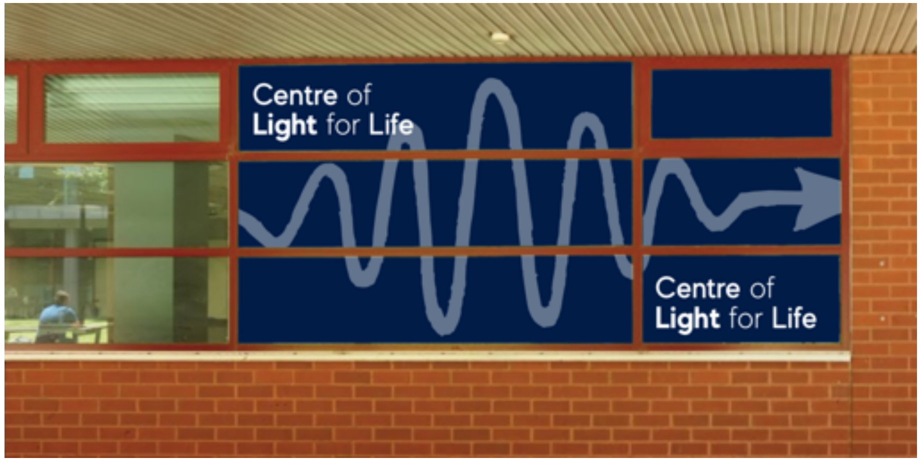
Selection Report: Discovery Projects 2022

Secured over A$8M in funding since 2021

500m² lab and office space for 20 people

THE UNIVERSITY *of* ADELAIDE



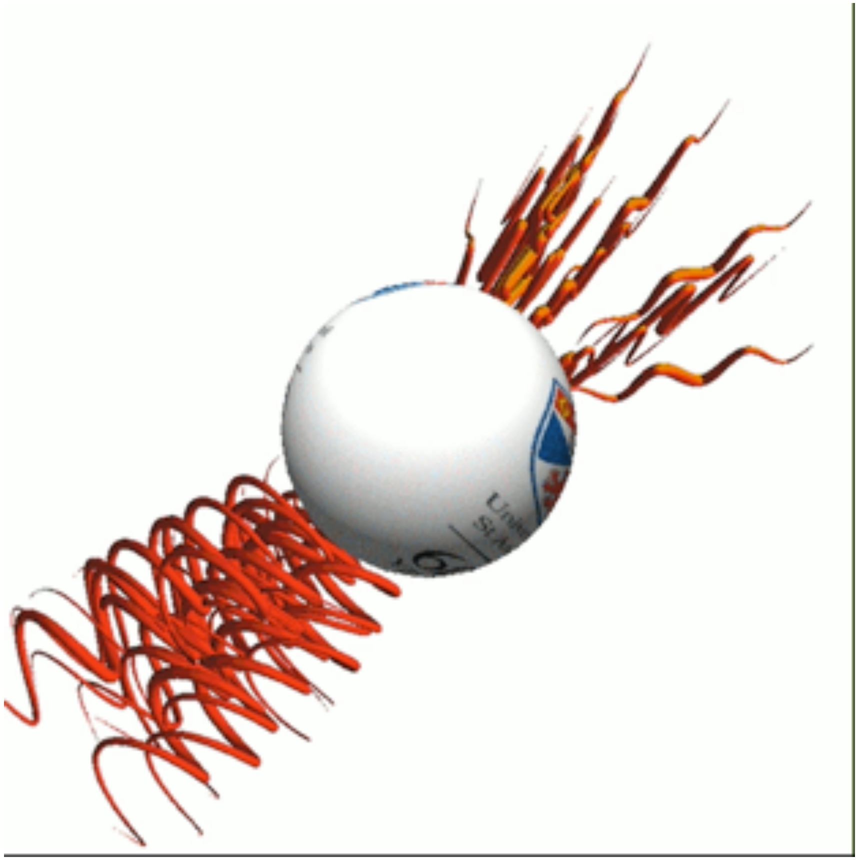
TOPICS

IMAGING AT DEPTH
MANIPULATION AND LEVITATED OPTOMECHANICS
QUANTUM INSPIRED BIOPHOTONICS
HEALTH: IVF IMPROVEMENT, EARLY DIAGNOSIS

Group of 18 (Jan 2023).

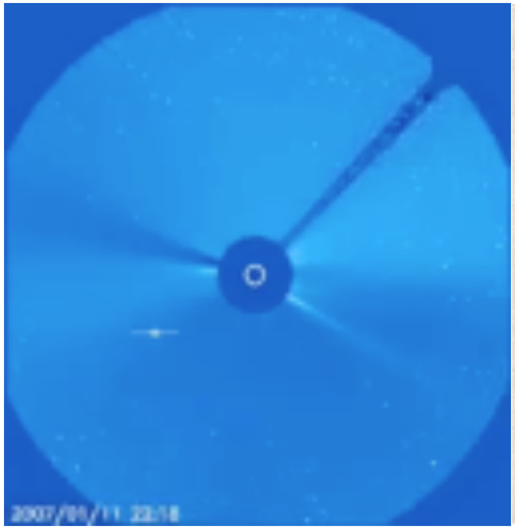
Several PDRA and PhD positions (incl joint with St Andrews) - please get in touch!

Rotation in optical traps

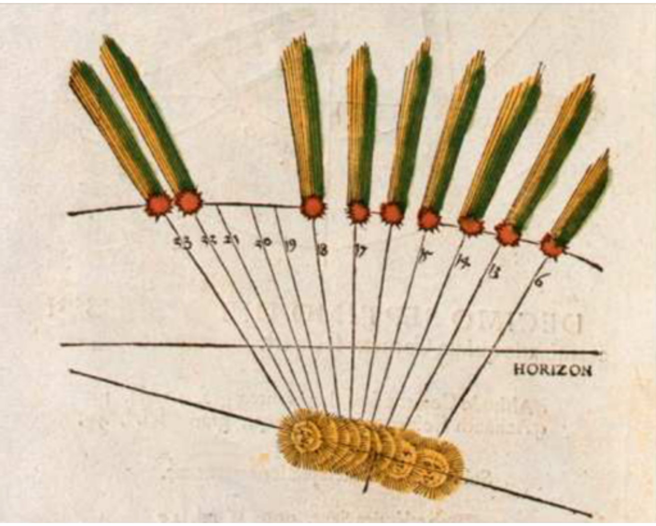


The Tail of a Comet

Pen & Ink Rendition of Engraved Frontispiece from "The Tome of Hevelius," 1668



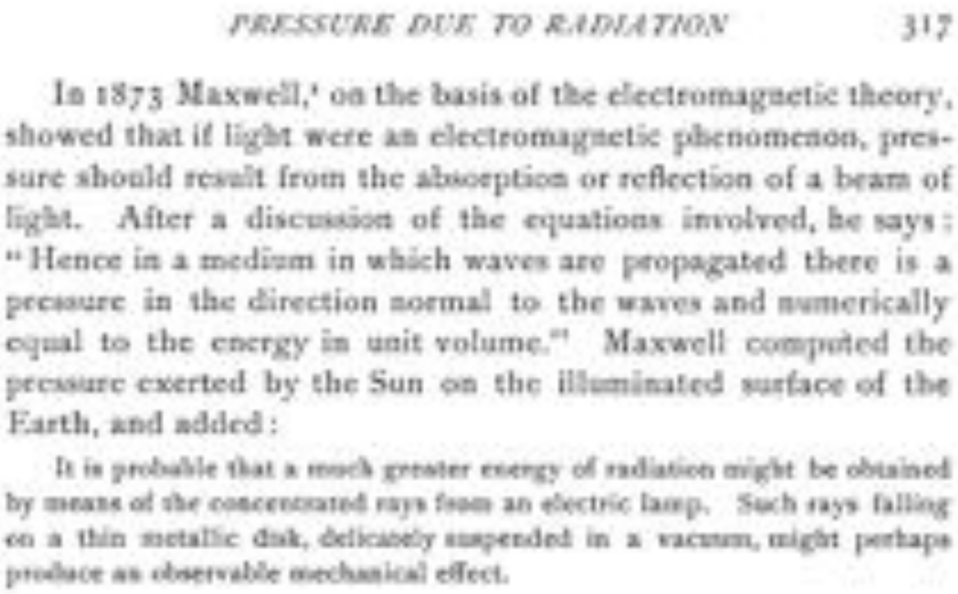
http://sohowww.nascom.nasa.gov/hotshots/



Peter Arpian « Astronomicum Caesareum » (1577)

***Kepler (1619)**: 'The direct rays of the Sun strike upon it [the comet], penetrate its substance, draw away with them a portion of this matter, and issue thence to form the track of light we call the tail . . . In this manner the comet is consumed by breathing out is own tail.'*

The search for the correct form: On the title page of Cometographia by Johannes Hevelius, Aristotle (left), Johannes Kepler (right) and the author discuss the trajectories of comets [Credit: © Max Planck Society]



PRESSURE DUE TO RADIATION 317

In 1873 Maxwell,[1] on the basis of the electromagnetic theory, showed that if light were an electromagnetic phenomenon, pressure should result from the absorption or reflection of a beam of light. After a discussion of the equations involved, he says: "Hence in a medium in which waves are propagated there is a pressure in the direction normal to the waves and numerically equal to the energy in unit volume."[1] Maxwell computed the pressure exerted by the Sun on the illuminated surface of the Earth, and added:

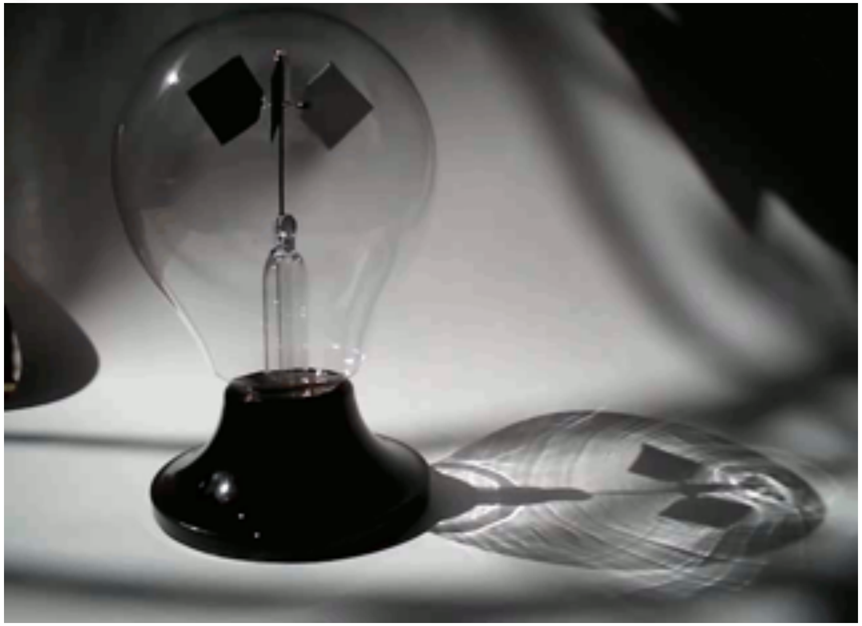
> It is probable that a much greater energy of radiation might be obtained by means of the concentrated rays from an electric lamp. Such rays falling on a thin metallic disk, delicately suspended in a vacuum, might perhaps produce an observable mechanical effect.

BBC NEWS

James Clerk Maxwell celebrated at final resting place in Parton

10 March 2020

James Clerk Maxwell is being celebrated in the village where he is buried

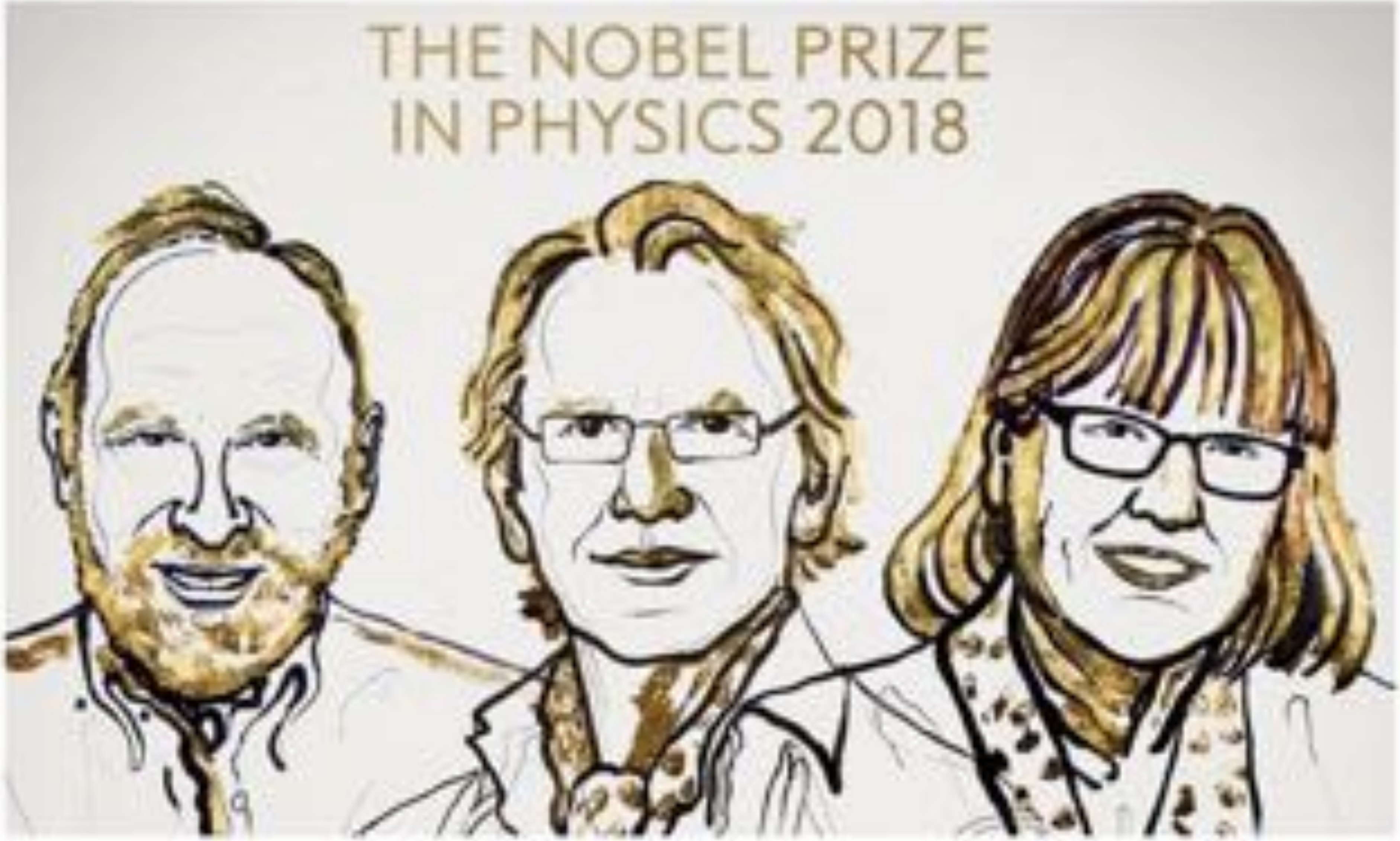


THE PRESSURE DUE TO RADIATION.[1]

By E. F. NICHOLS and G. F. HULL.

ASTROPHYSICAL JOURNAL

VOLUME XVII JUNE 1903 NUMBER 5

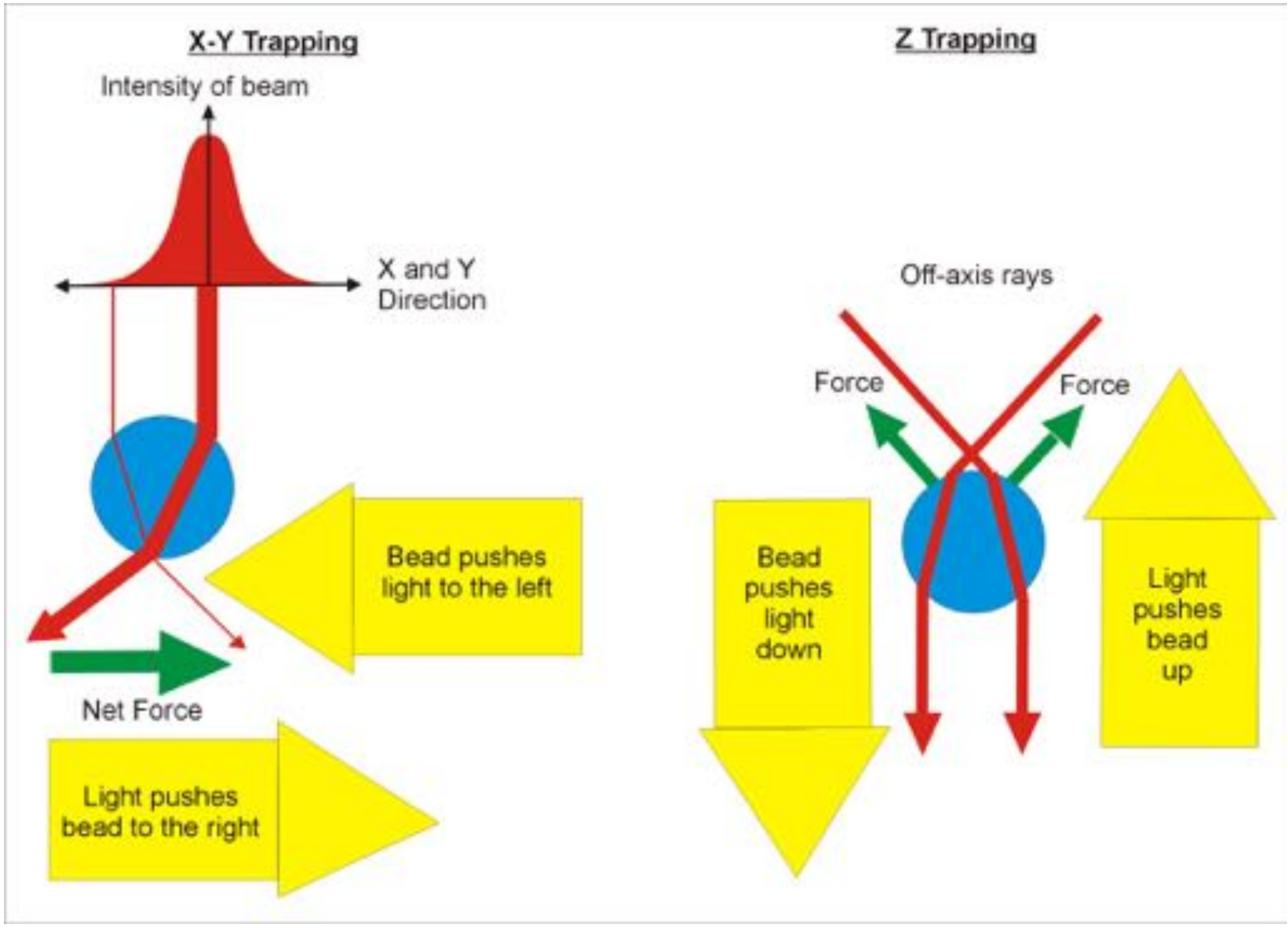


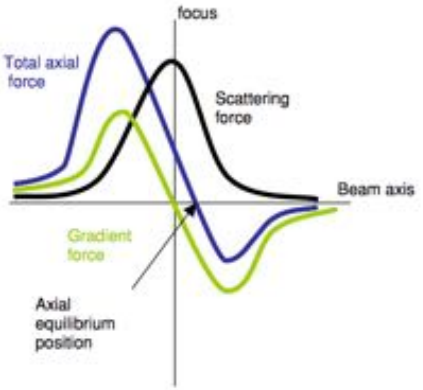
▲ Arthur Ashkin, Gérard Mourou and Donna Strickland, 2018's Nobel laureates in physics. Photograph: Nobel Assembly

Optical Tweezers

SINGLE BEAM GRADIENT TRAP: Ashkin et al, Opt Lett 11, 288 (1986)

Co-recipient of the Nobel Prize 2018

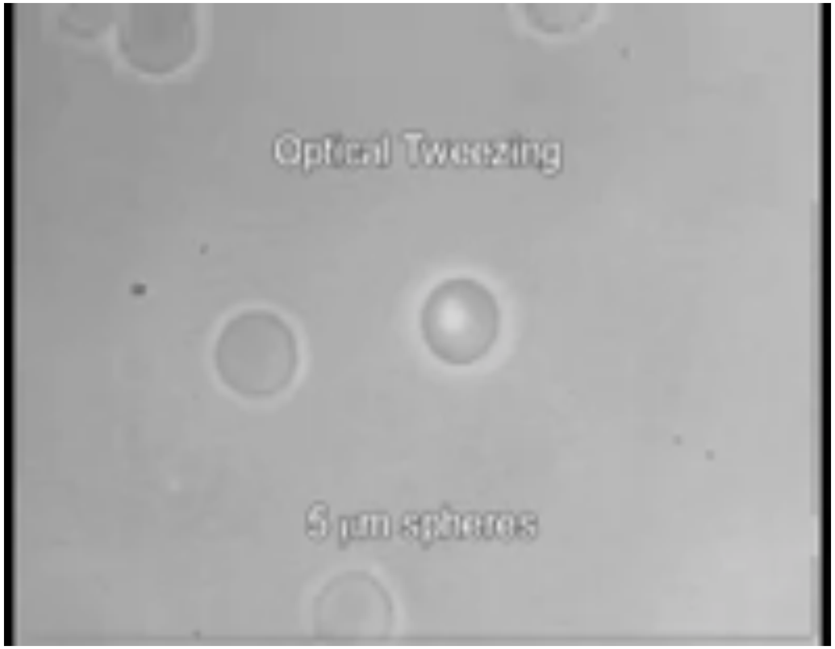


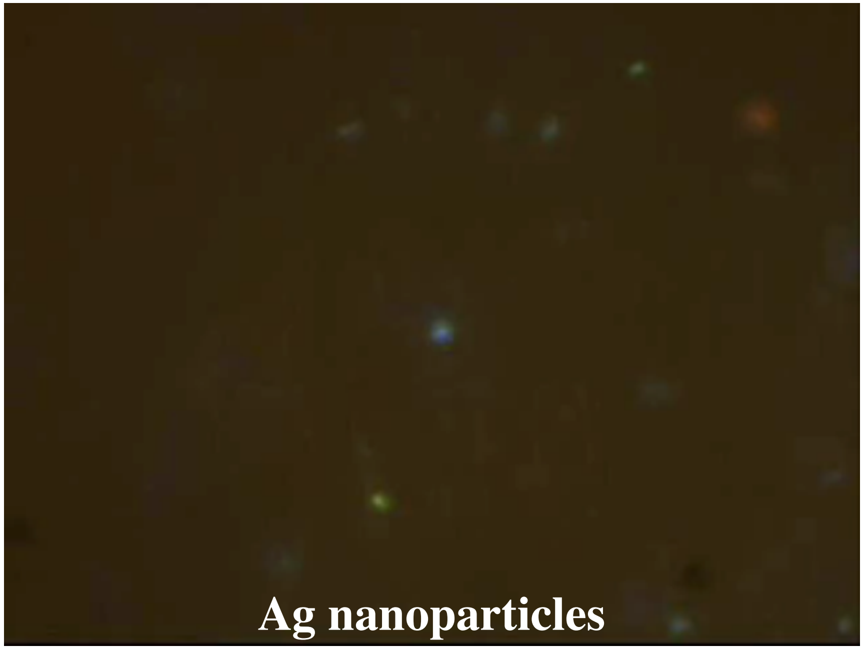


$$F_{gradient} \propto \alpha \nabla I$$

$$F_{scattering} \propto I$$

Microscale to the Nanoscale



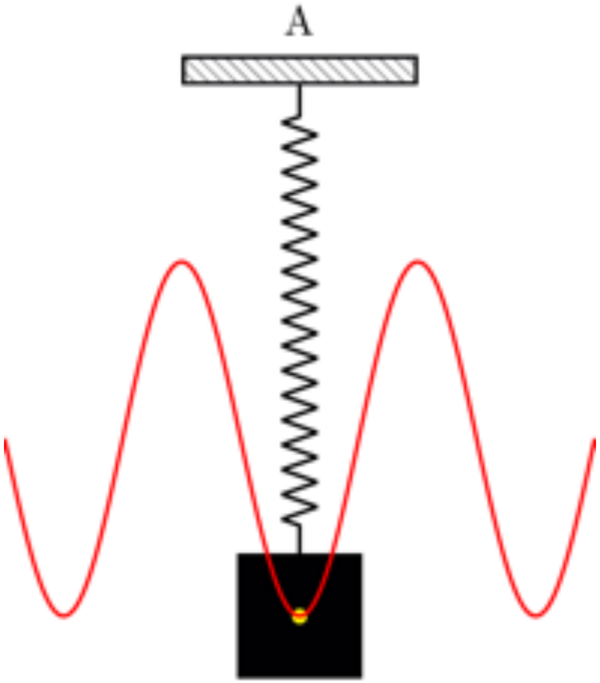


Care must be taken with heating! (trap light used from 700nm-1100nm)
Particle polarisability is key, as are field gradients

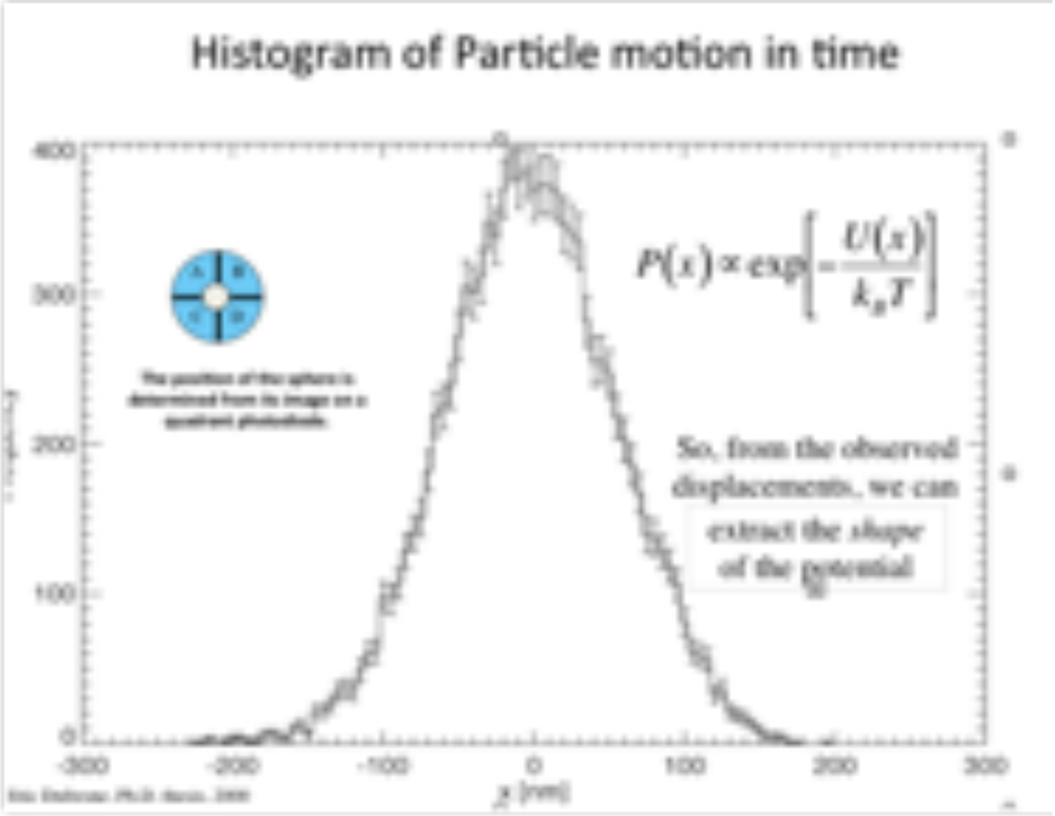
$$F_{\mathrm{grad}} \propto \alpha . \nabla I(r) \longrightarrow$$

Reason why we go to plasmonics, nanoapertures, waveguides etc

Optical tweezers:
the World's most elegant example of a Hookean spring?



$$F_{\text{trap}} = -\kappa x$$


Histogram of Particle motion in time

$P(x) \propto \exp\left[-\frac{U(x)}{k_B T}\right]$

The position of the sphere is determined from its image on a quadrant photodiode

So, from the observed displacements, we can extract the *shape* of the potential

Optical tweezers has revolutionised single molecule motion: e.g. kinesin steps on microtubules …8nm..

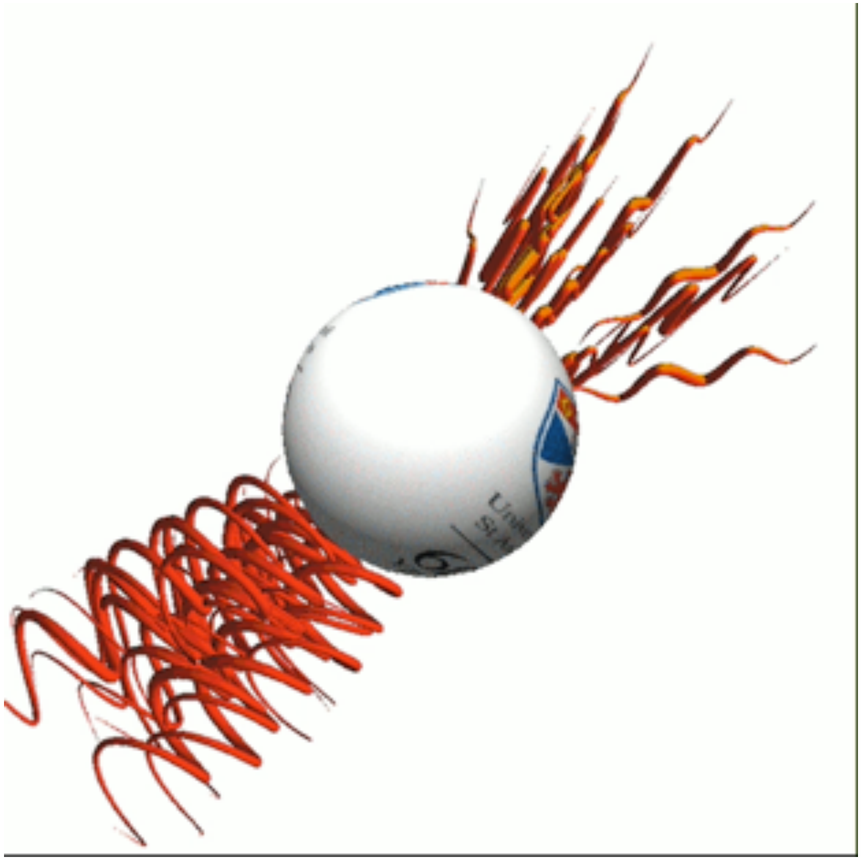
https://imgur.com/t/Science_and_Tech/s64ax

How do we cause particles to rotate in optical traps?

Two main methods:

Asymmetric
Rotating light patterns that cause objects to align (e.g. form birefringence)

Transfer of optical angular momentum: spin and orbital



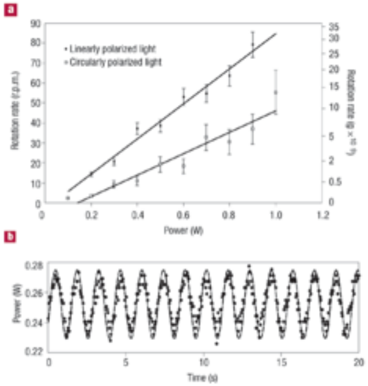
LETTERS

All-optical control of microfluidic components using form birefringence

STEVEN L. NEALE*, MICHAEL P. MACDONALD, KISHAN DHOLAKIA AND THOMAS F. KRAUSS
School of Physics and Astronomy, St Andrews University, St Andrews, Fife, KY16 9SS, UK
*e-mail: sln2@st-and.ac.uk

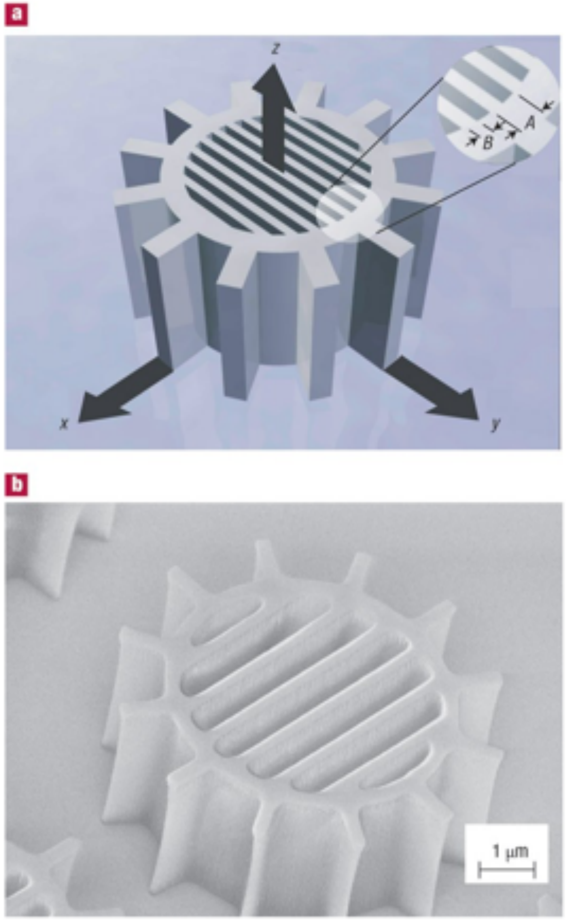
Nature Materials **4**, 530–533 (2005)

Figure 4: Rotation results.



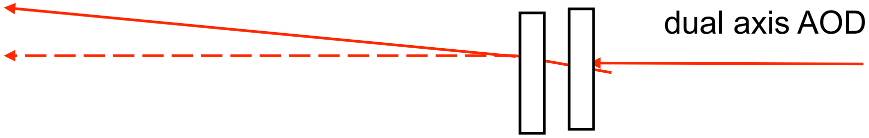
a, Maximum rotation rates with increasing power for both linearly and circularly polarized light. **b**, Light transmitted through the microgear that has been analysed by passing it through a polarizer. The amplitude of the power variation indicates the magnitude of the birefringence, and the rotation rate can be gained from the period. The error bars represent the deviation from the mean rotation rate when averaging over 12 revolutions of the microgear.

Figure 1: Form birefringent microgears.



a, Diagram of a form birefringent microgear. *A* is the pitch of the photonic lattice, *B* is the rib width and the fill factor is *B*/*A*. **b**, SEM micrograph of an actual microgear before release from the substrate.

Creating multiple traps: time sharing



Acousto-Optic Deflectors (AODs) can be scanned at *hundreds* of kHz

(video in collaboration with I Poberaj group).

A microfluidic pump made from glass beads the size of a heart valve. (DM Marr et al. Science 2002)

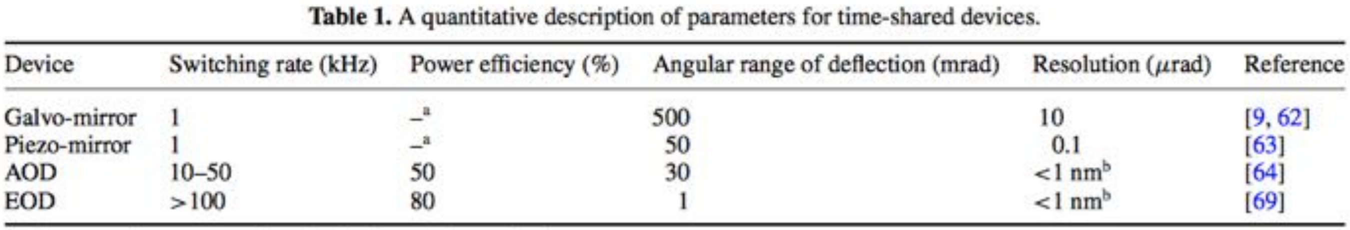


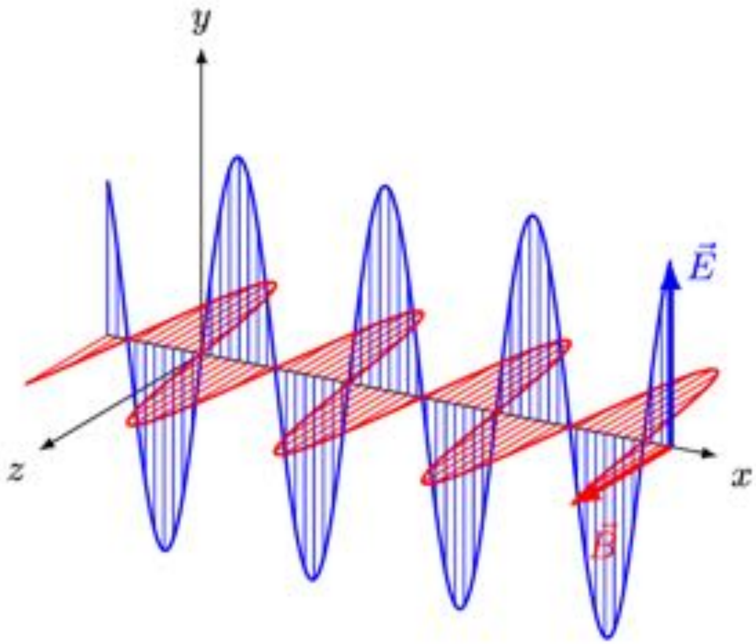
Table 1. A quantitative description of parameters for time-shared devices.

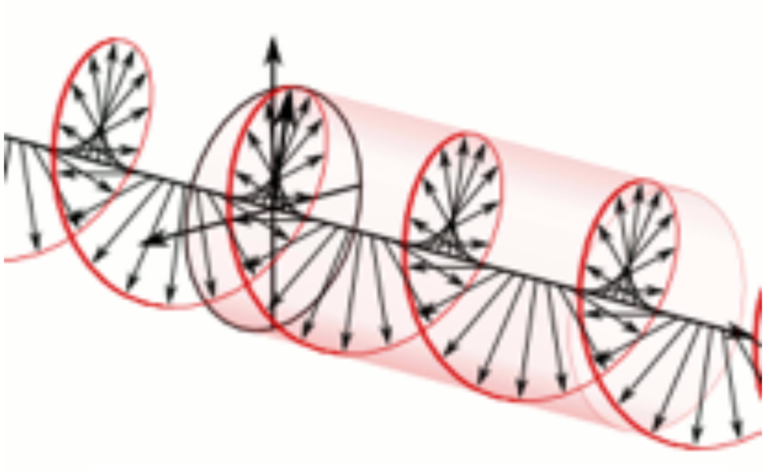
Device	Switching rate (kHz)	Power efficiency (%)	Angular range of deflection (mrad)	Resolution (μrad)	Reference
Galvo-mirror	1	–[a]	500	10	[9, 62]
Piezo-mirror	1	–[a]	50	0.1	[63]
AOD	10–50	50	30	<1 nm[b]	[64]
EOD	>100	80	1	<1 nm[b]	[69]

J. Phys. B: At. Mol. Opt. Phys. **43** (2010) 102001

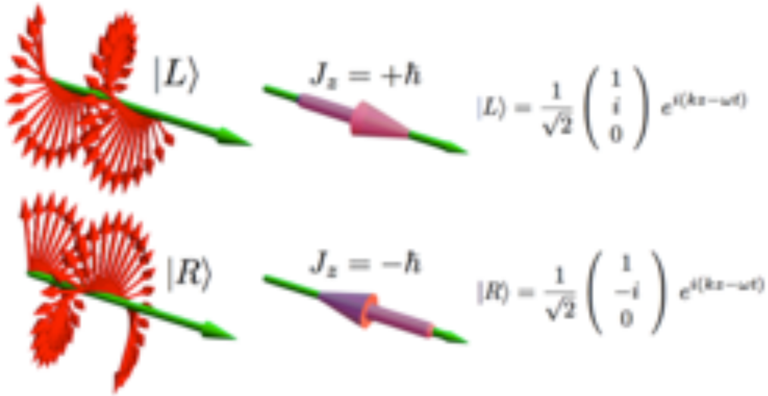
Light is a transverse electromagnetic wave

The E-field can oscillate up and down (linear polarization) or rotate (circular polarization – spin angular momentum)





±ħ per photon



Structured light can possess angular momentum: rotation

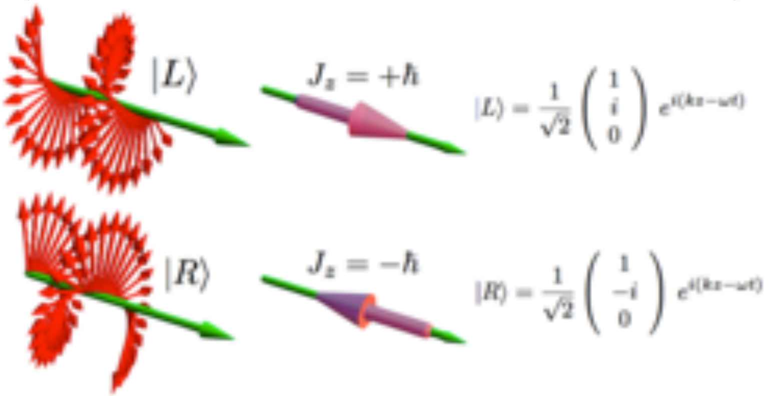
$$j = \varepsilon_o \left[r \times \langle E \times B \rangle \right]$$

Allen et al Phys Rev A (1992)

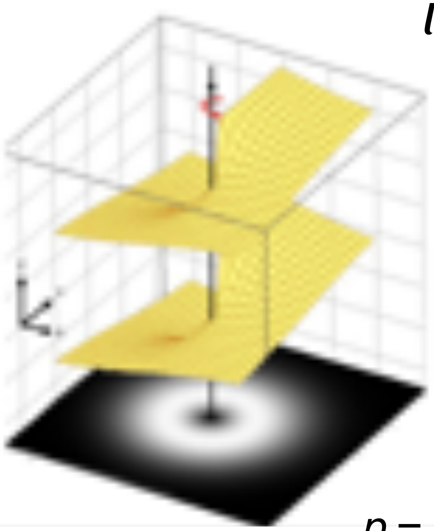
Spin: due to polarisation state (rotating E-field)

Orbital: due to inclined wavefronts

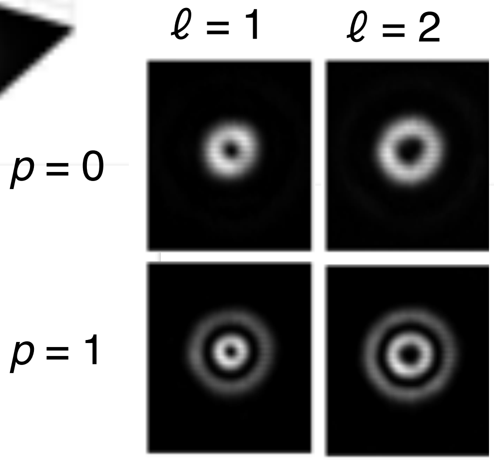
±ħ per photon



lħ per photon



Laguerre-Gaussian (LG) beam



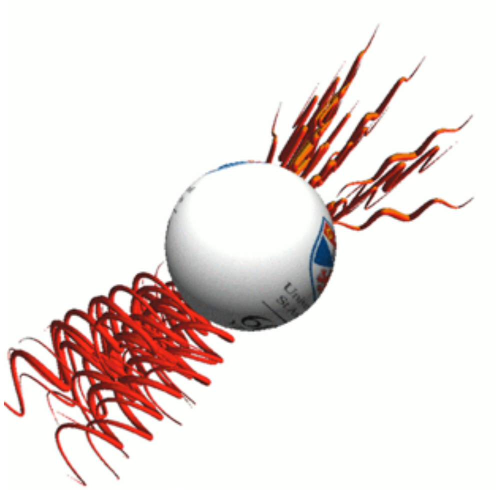
LG modes

$$\mathbf{S} = \epsilon_0 \int (\mathbf{E} \times \mathbf{A})\, d^3\mathbf{r}.$$

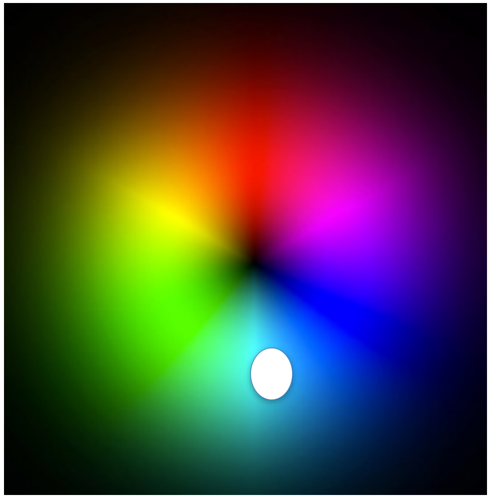
$$\Rightarrow \quad \mathbf{S} = \frac{\epsilon_0}{2i\omega} \int (\mathbf{E}^* \times \mathbf{E})\, d^3\mathbf{r}.$$

$$\mathbf{S}_z = \pm\hbar.$$

Transfer of angular momentum to trapped particles



SPIN



ORBITAL

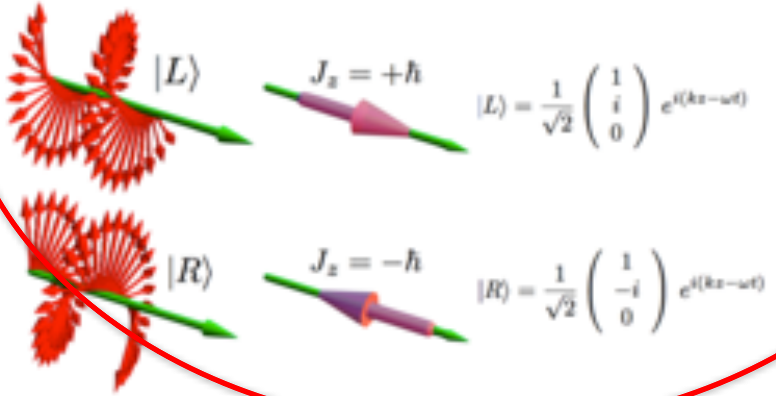
Structured light can possess angular momentum: rotation

$$j = \varepsilon_0 \left[r \times \langle E \times B \rangle \right]$$

Allen et al Phys Rev A (1992)

Spin: due to polarisation state (rotating E-field)

±ℏ per photon

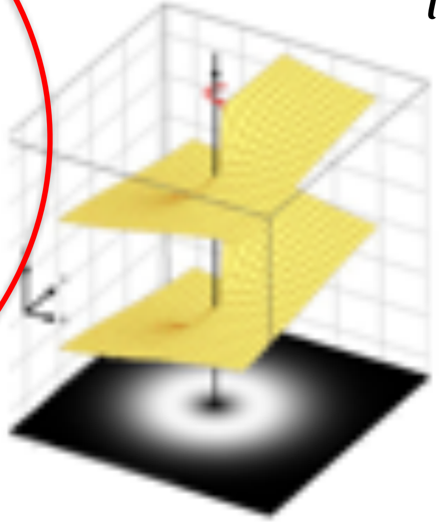


$$\mathbf{S} = \epsilon_0 \int (\mathbf{E} \times \mathbf{A})\, d^3\mathbf{r}$$

➡ $$\mathbf{S} = \frac{\epsilon_0}{2i\omega} \int (\mathbf{E}^* \times \mathbf{E})\, d^3\mathbf{r}.$$

Orbital: due to inclined wavefronts

lℏ per photon



Laguerre-Gaussian (LG) beam

$$\mathbf{S} = \sum_{\mathbf{k}} \hbar \mathbf{u}_{\mathbf{k}} \left(\hat{a}^\dagger_{\mathbf{k},L} \hat{a}_{\mathbf{k},L} - \hat{a}^\dagger_{\mathbf{k},R} \hat{a}_{\mathbf{k},R} \right)$$

$$\mathbf{S}_z = \pm\hbar.$$

Demonstration of spin angular momentum:
R. Beth, 1936, Princeton

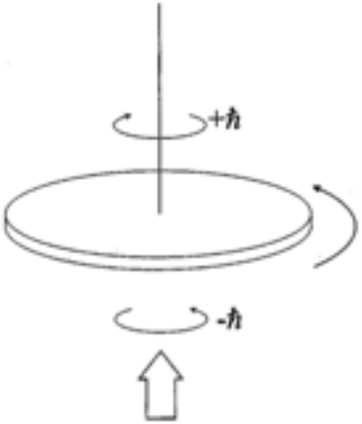
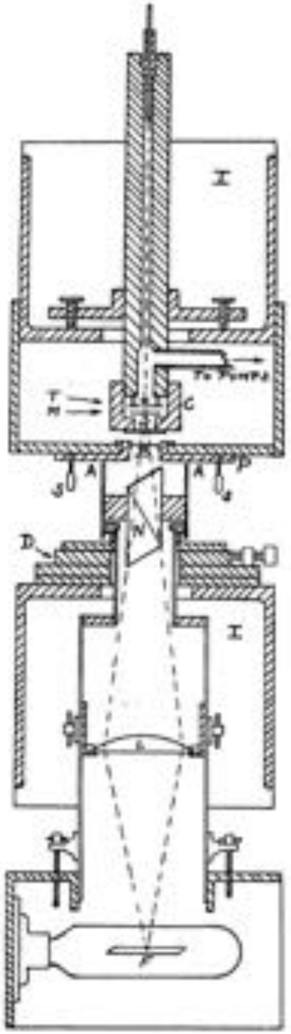


Fig. 1. Beth's experiment from 1936 (Ref. 2) was based on measuring the torque as circularly polarized light passed through a suspended quarter-wave plate.



Experimental setup of Beth’s experiment

Experimental proof of that theoretical prediction was done by R. Beth in 1936 in Princeton. As Beth announces in his paper (R. A. Beth, *Mechanical Detection and Measurement of the Angular Momentum of Light*, Physical Review, v. 50, July 15, 1936) he had several discussions about the experiment with Einstein.

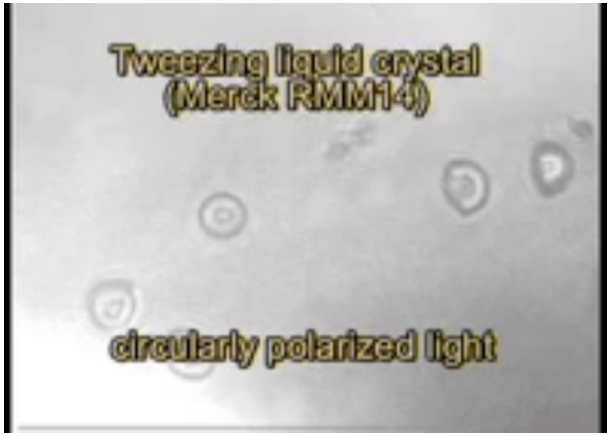
In this experiment Beth showed that when linearly polarized light is converted to circularly polarized one by doubly refracting slab, the slab experiences a reaction torque.

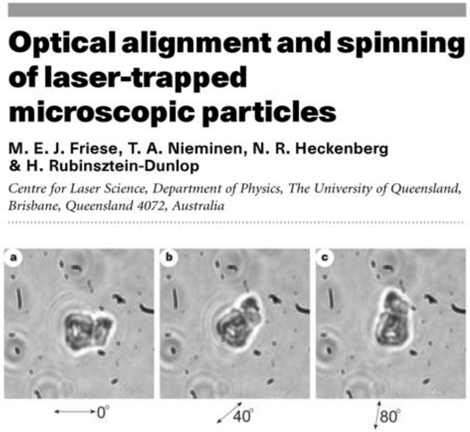
Rotation using birefringence

Right handed circularly polarised light

Left handed circularly polarised light

Trapped birefringent microsphere ('golf ball')





Optical alignment and spinning of laser-trapped microscopic particles

M. E. J. Friese, T. A. Nieminen, N. R. Heckenberg & H. Rubinsztein-Dunlop

Centre for Laser Science, Department of Physics, The University of Queensland, Brisbane, Queensland 4072, Australia

Friese et al
Nature 1998

$2\hbar$ **Per photon transferred**

$$\phi = \frac{2\pi}{\lambda}(n_e - n_o)d$$

$$\tau_{\text{Optical}} = \frac{\Delta L}{\Delta t} = (\eta\Delta\sigma)\left(\frac{P}{h\omega}\right)$$

and for a spherical particle:

$$\tau_{\text{drag}} = 8\pi\eta\Omega R^3$$

$$\eta_{\text{local}} = \frac{\Delta\sigma P}{8\pi R^3\Omega\omega}$$

Nanofabricated quartz cylinders for angular trapping: DNA supercoiling torque detection

Christopher Deufel[1], Scott Forth[1],
Chad R Simmons[1,2], Siavash Dejgosha[1] &
Michelle D Wang[1]

NATURE METHODS | VOL.4 NO.3 | MARCH 2007

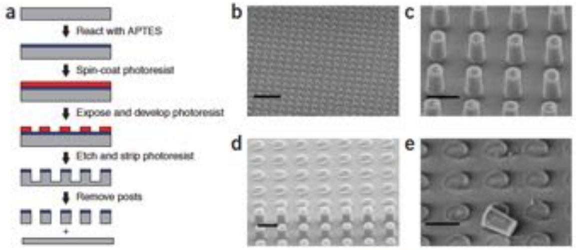
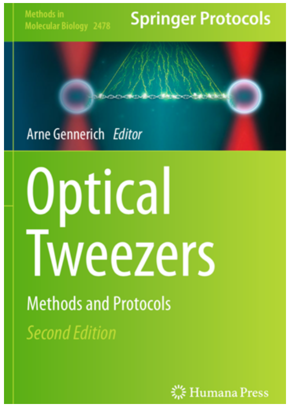


Figure 2 | Nanofabrication of quartz cylinders. (**a**) Schematic outline of the nanofabrication protocol. (**b–e**) Scanning electron micrographs of nanofabricated cylinders. Nanofabricated cylindrical posts on the wafer (**b**,**c**). The cylinders were 1.1 µm high and 0.53 µm in diameter. Quartz substrate after a portion of the posts was removed from the wafer (**d**). The quartz posts fractured evenly at their bases in a consistent manner. A single quartz cylinder after mechanical removal (**e**). Scale bars, 5 µm in **b** and 1 µm in **c–e**.



Methods in Molecular Biology 2478

Springer Protocols

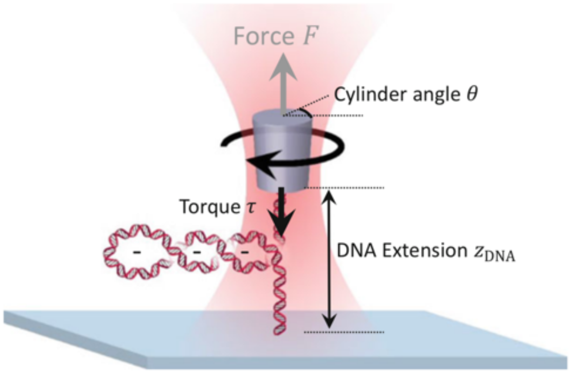
Arne Gennerich *Editor*

Optical Tweezers

Methods and Protocols

Second Edition

Humana Press



As twist was introduced to a DNA molecule, torque increased essentially linearly until the DNA buckled to form a plectoneme, after which the torque plateaued. Vertical dashed lines: buckling transitions

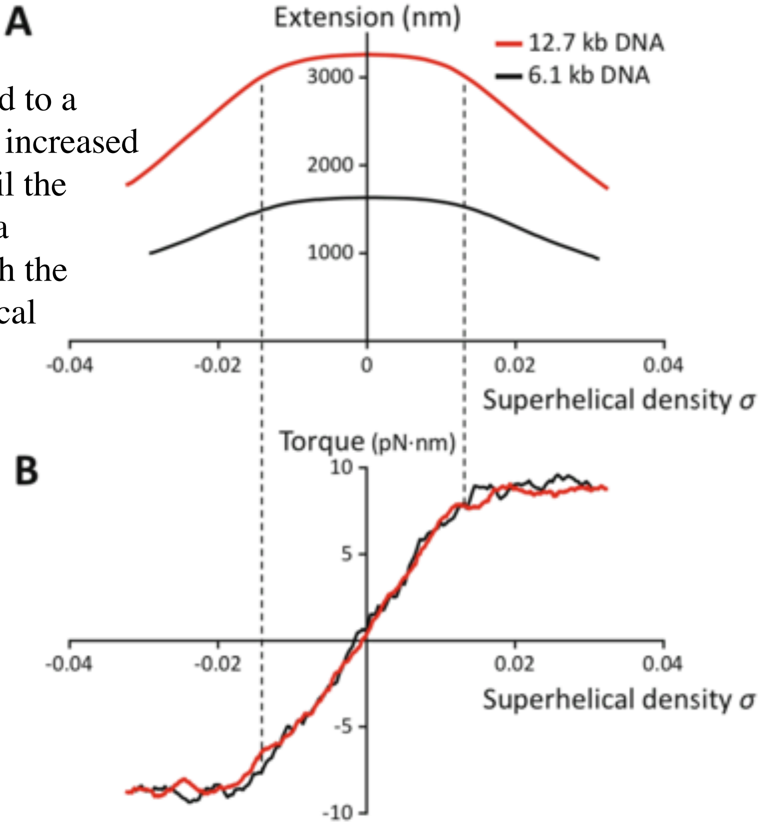
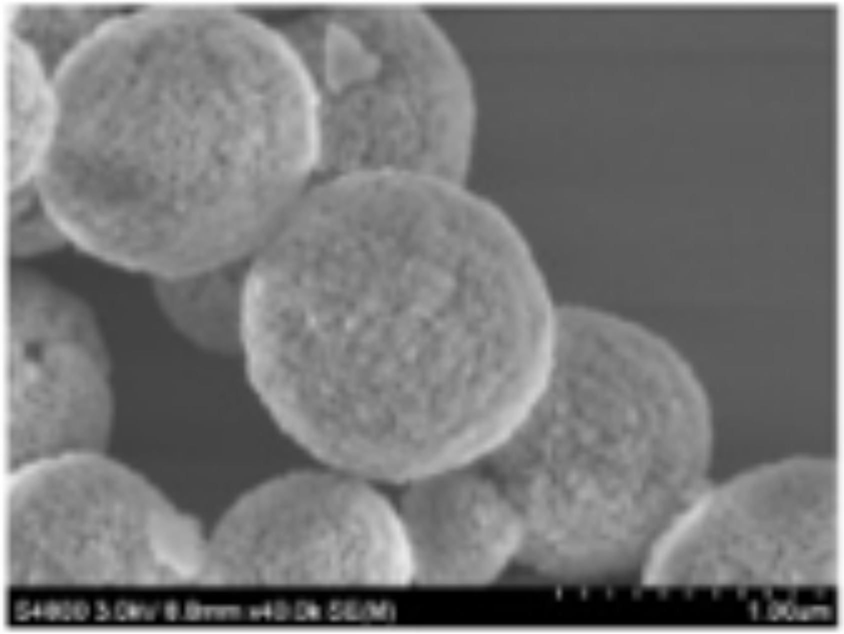


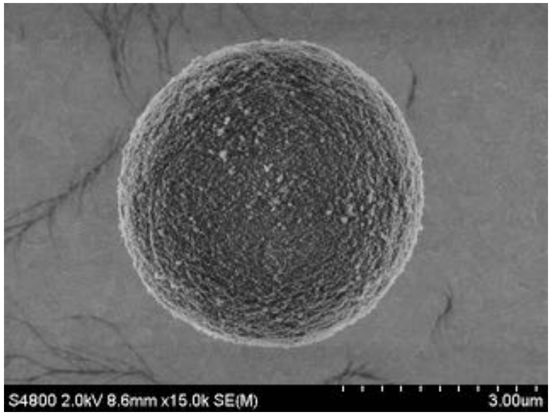
Fig. 14 Measured torque and extension of DNA molecules with different lengths. Extension (**a**) and torque (**b**) measurements for naked DNA molecules of 12.7 kbp (red) and 6.1 kbp (black) in length are shown. The

1. Le TT, et al., . Cell 179(3):619–631.e615 (2019)

Birefringent spheres: synthesis of vaterite and nanovaterite



The nucleation and growth rate of the vaterite spheres is determined by the supersaturation level of the dissolved amorphous $CaCO_3$.



4.4um vaterite (see later)

A key issue is avoidance of rapid recrystallisation into the calcite phase, which can occur due to the enhanced solubility of the particles as the particle size decreases.

To avoid this, ethylene glycol was added to the water used as the solvent for this reaction.

SEM for nanovaterite at St Andrews

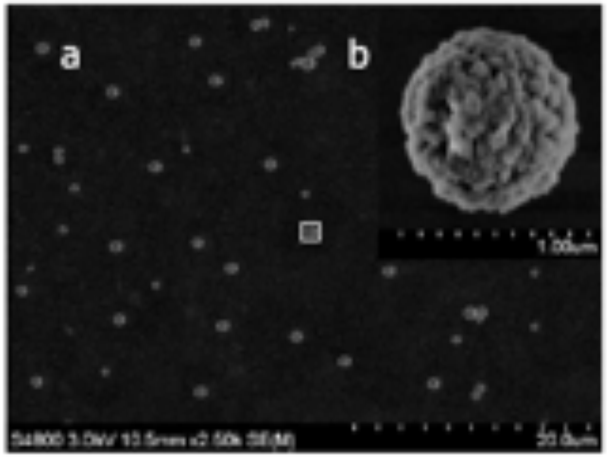


Fig. 2. SEM image of nanovaterite particles produced via the co-precipitation method in 83% ethylene glycol solvent. Mean particle size was found to be 846 nm.

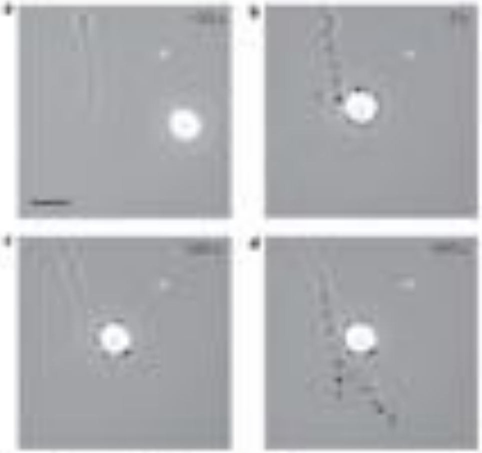
Optical forces and torques can direct the growth of neurons

A photon-driven micromotor can direct nerve fibre growth

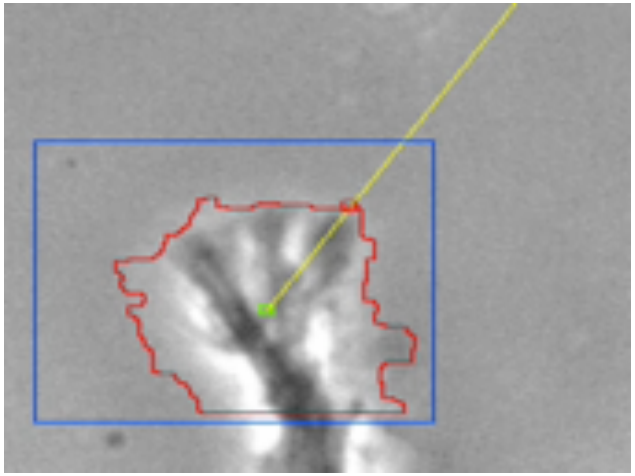
Tao Wu, Timo A. Nieminen, Samarendra Mohanty, Jill Miotke, Ronald L. Meyer, Halina Rubinsztein-Dunlop & Michael W. Berns

Nature Photonics **6**, 62–67 (2012) | doi:10.1038/nphoton.2011.287

Figure 1: Time-lapse images when a vaterite particle is rotated anticlockwise and positioned to the left of the axon defined by the growth direction of the axon (dashed arrow 1).



a, Before the trapped vaterite particle was moved near the axon. b, The vaterite particle was moved to the left of the axon and rotated anticlockwise at ~1 Hz. c, After 340 s, the axonal growth cone had already turned to a new direction...



Carnegie, D. J., Stevenson, D. J., Mazilu, M., Gunn-Moore, F. & Dholakia, K. Guided neuronal growth using optical line traps. *Opt. Express* **16**, 10507–10517 (2008).

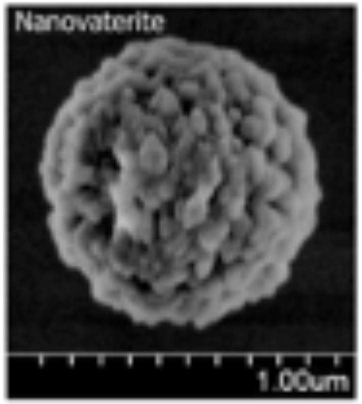
original paper:

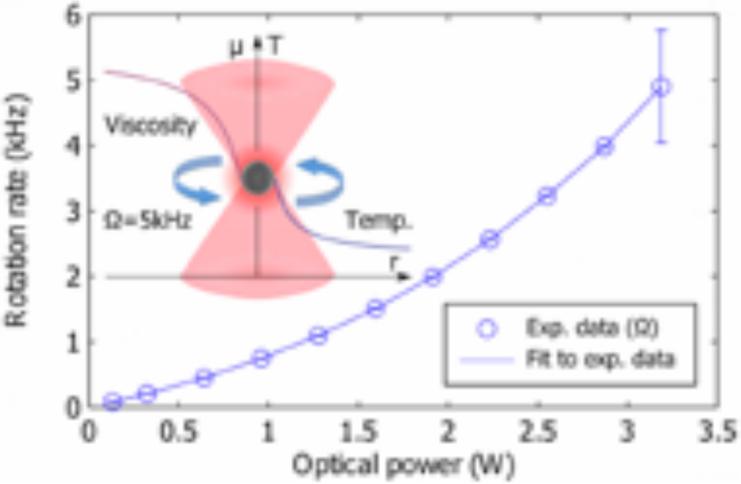
Ehrlicher, A. *et al.* Guiding neuronal growth with light. *Proc. Natl Acad. Sci. USA* **99**, 16024–16028 (2002).

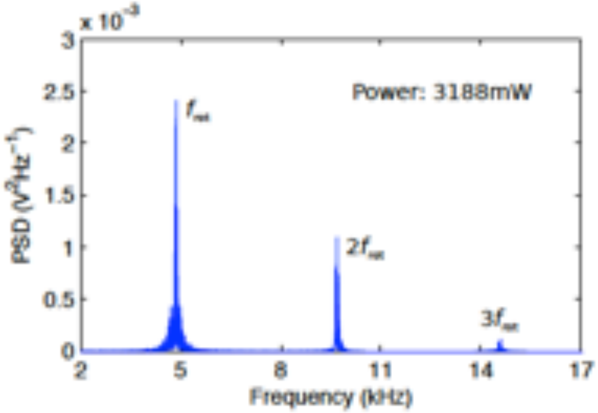
Optical trapping and rotation of nanovaterite particles

Nanovaterite trapped by a 532nm circularly polarised beam in D_2O.

➔ No heating to the medium $< 0.1\,{}^\circ\mathrm{C}\,\mathrm{W}^{-1}$







See also Schmidt group work, e.g. 8mK/mW (1064nm) – dominated by fluid
Biophysical Journal 84, 1308 (2002) using normal water

Previous vaterite study: Parkin, S. J. et al., Phys. Rev. E 2007, 76, 041507: For vaterite crystals, a temperature increase of 66 $\mathrm{C}\,\mathrm{W}^{-1}$ was inferred @ 1064nm

Rings, D.; Chakraborty, D.; Kroy, K. *New J. Phys.* **2012**, *14*, 053012.

Our study isolates thermal effects in the microsphere

Determining properties of nanovaterite

A laminar Navier-Stokes model is used which can then deliver the overall drag torque or force for the rotational and translational motion of the nanoparticle.

Finite element method (implemented in COMSOL) to calculate the overall drag torque or drag force for different residual optical absorption powers.

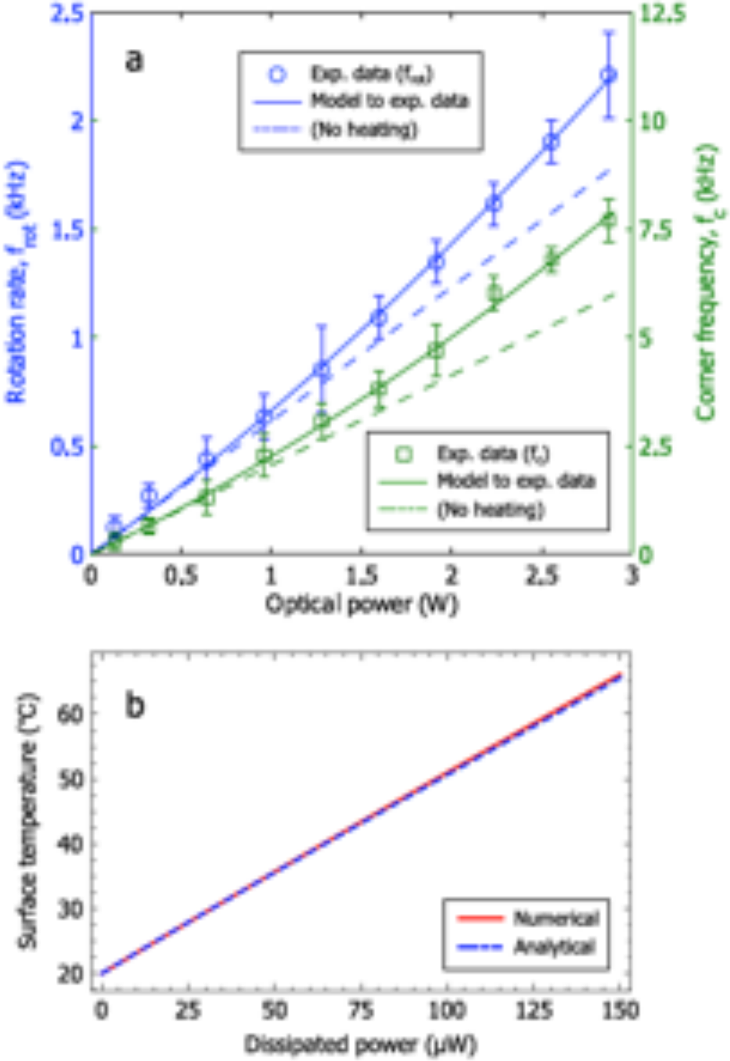
$$\tau = x/v = 6\pi\mu r/\kappa.$$

$$f_c = \tau^{-1} = \kappa/6\pi\mu r \propto P.$$

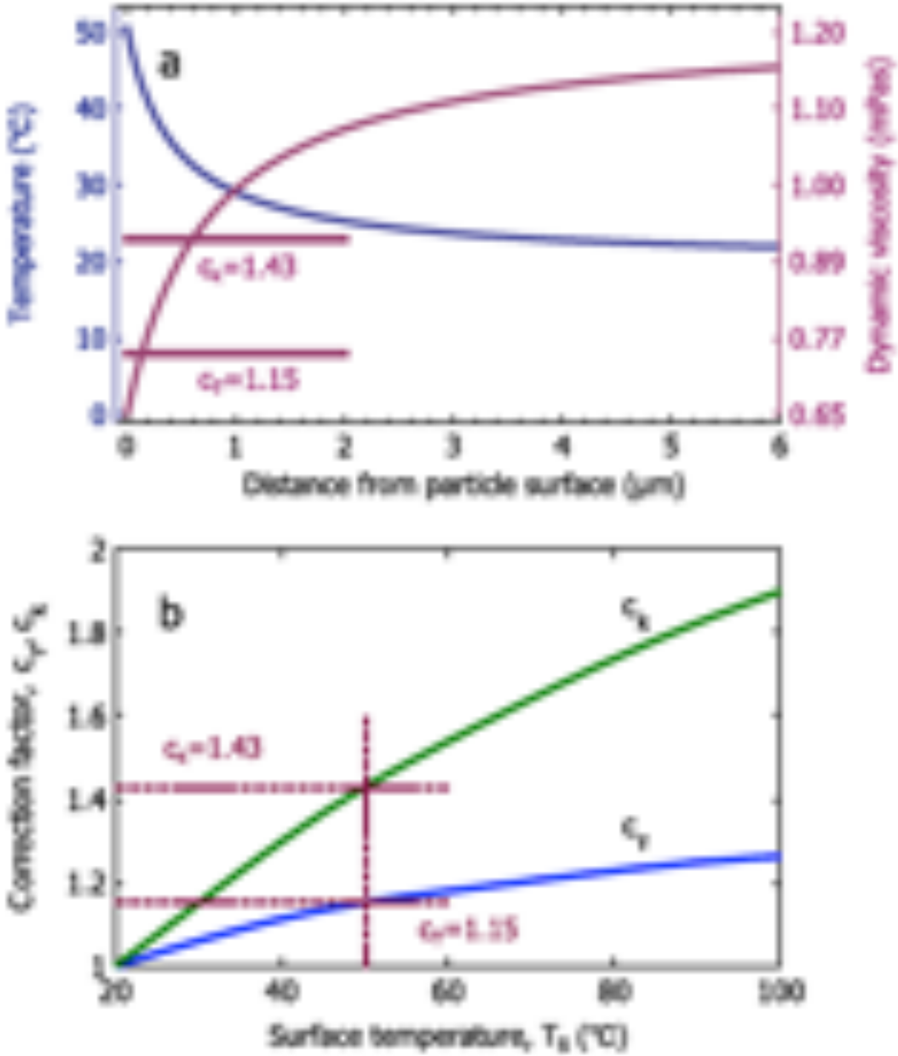
$$T_s = \frac{Q_{\mathrm{abs}}}{4\pi r k(T_s)}$$

absorption coefficient of $1{:}59 \times 10^{-5}$ for nanovaterite

i.e. for an incident beam with a power of 1W, the nanoparticle dissipates 15.9 μW, which leads to the surface temperature of 25:6 C.



Optical trapping and rotation of nanovaterite particles



Temperature dependent dynamic viscosity correction factor.

(a) Radial temperature profile and the corresponding dynamic viscosity of heavy water surrounding a nanoparticle dissipating 100 μW.

(b) Viscosity correction factors for rotational (blue solid line) and translational (green solid line) motion of the nanoparticle (radius of 423nm) as a function of its surface temperature.

$$
\begin{aligned}
\tau_{drag} &= c_\tau(T_s)8\pi\mu(T_s)r^3\Omega, \\
F_{drag} &= c_k(T_s)6\pi\mu(T_s)rv,
\end{aligned}
$$

Arita et al., ACS Nano 10, 11505 (2016)

rotational/translational motion differs

Rings, D.; Chakraborty, D.; Kroy, K. *New J. Phys.* **2012**, *14*, 053012.

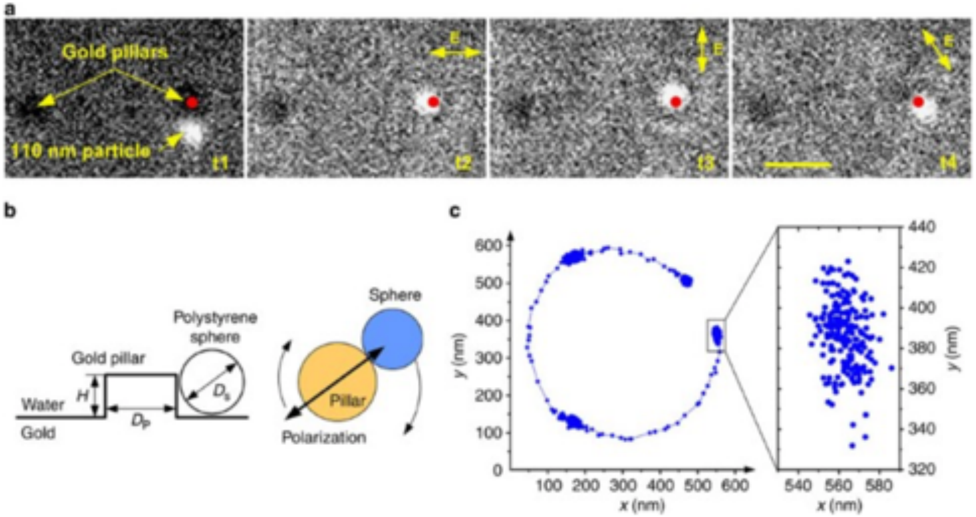
Published: 13 September 2011

Trapping and rotating nanoparticles using a plasmonic nano-tweezer with an integrated heat sink

Kai Wang, Ethan Schonbrun, Paul Steinvurzel & Kenneth B. Crozier

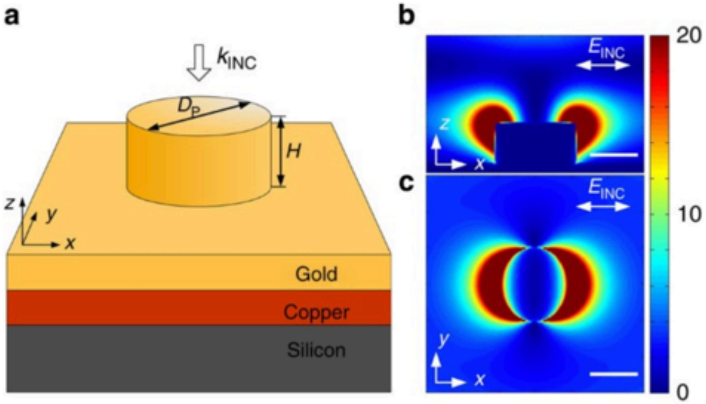
Nature Communications **2**, Article number: 469 (2011) | Cite this article

Figure 3: Trapping and manual rotation of polystyrene nanospheres by gold nanopillars.



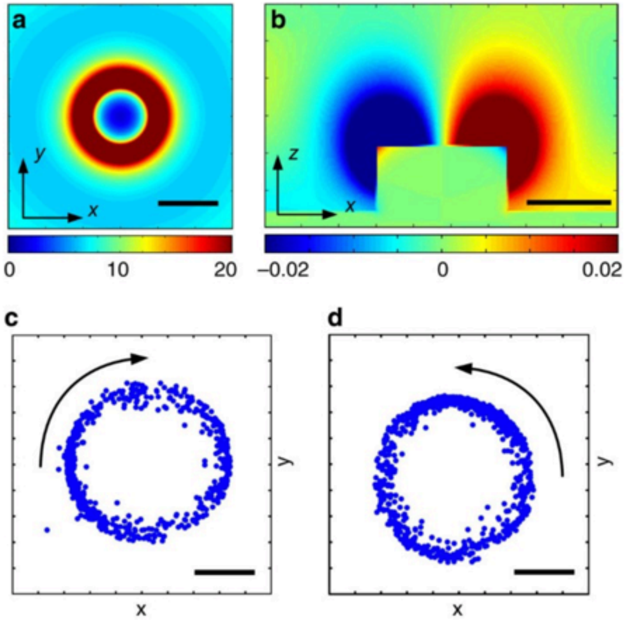
(**a**) Fluorescence images, obtained at successive times, of trapping and rotating 110 nm diameter polystyrene sphere by gold nanopillar. At time t1, sphere is close to nanopillar, but not trapped. At

Figure 1: Gold nanopillar tweezer.

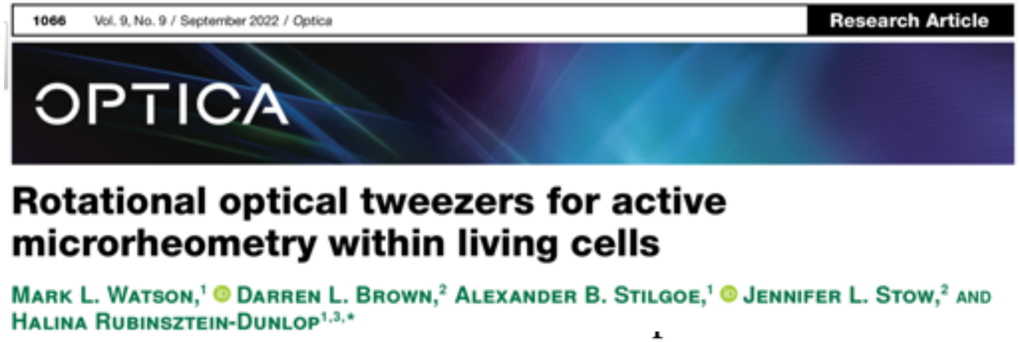


(**a**) Plasmonic nano-tweezer comprising nanopillar formed on gold film. Underlying copper film and silicon substrate act as heat sink, conducting heat from nanopillar to substrate, thereby minimizing water heating. Nanopillar diameter D_P is 280 nm, and height H is 130 nm. (**b**,**c**) FDTD calculation of the electric field intensity distribution resulting from normal incidence plane wave illumination polarized along x-axis (E_{inc}) at λ=974 nm. Intensity enhancement, that is, intensity normalized to incident intensity $|E|^2/|E_{INC}|^2$, is plotted. Peak intensity enhancement is 490 times, although upper limit of colourscale is chosen to be 20 times for visualization. Scale bars, 200 nm.

Figure 4: Passive rotation of polystyrene spheres by gold nanopillar.



(**a**) FDTD calculation of electrical field intensity enhancement $|E|^2/|E_{INC}|^2$ distribution resulting from circularly polarized illumination at λ=974 nm. (**b**) FDTD calculation of y-component of Poynting

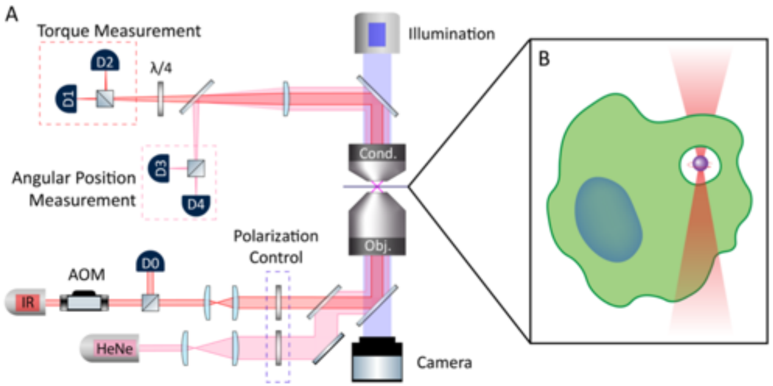

1066 Vol. 9, No. 9 / September 2022 / Optica **Research Article**

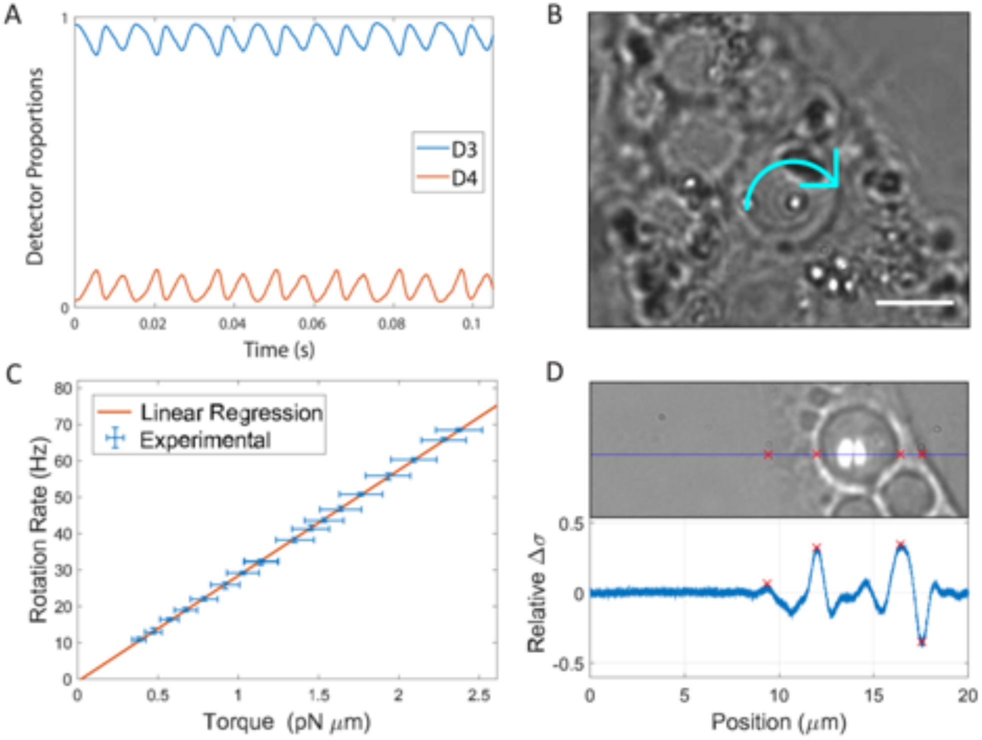
OPTICA

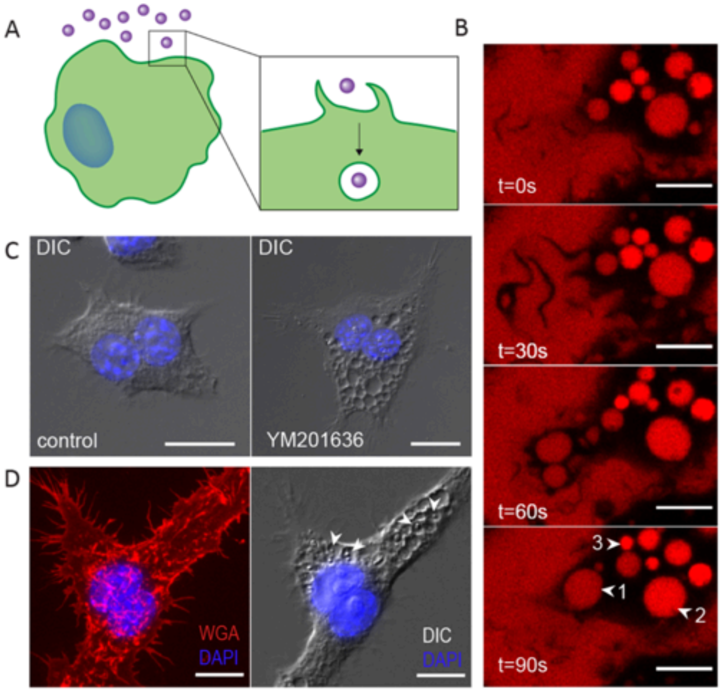
Rotational optical tweezers for active microrheometry within living cells

Mark L. Watson,[1] Darren L. Brown,[2] Alexander B. Stilgoe,[1] Jennifer L. Stow,[2] and Halina Rubinsztein-Dunlop[1,3,*]

$$(D1 - D2)/(D1 + D2)$$







Advantage over translational motion: microrheology centred on one particle. Potential reduction of boundary effects

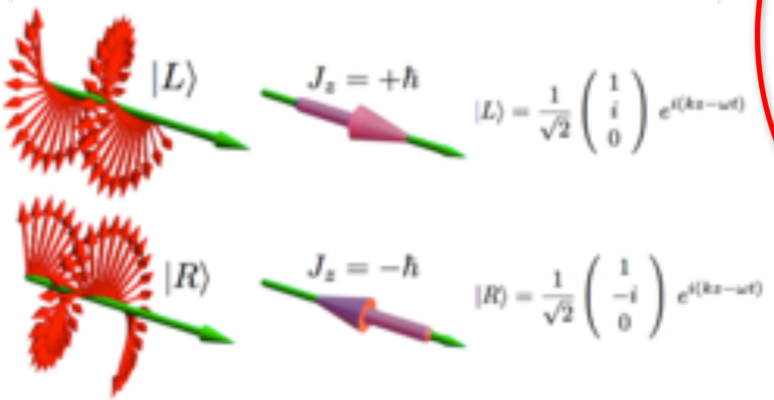
Structured light can possess angular momentum: rotation

$$j = \varepsilon_o \left[r \times \langle E \times B \rangle \right]$$

Allen et al Phys Rev A (1992)

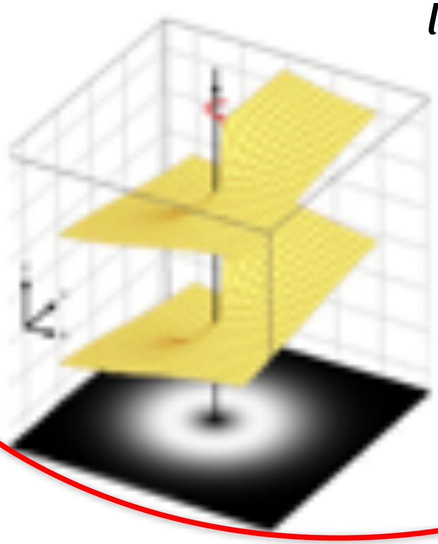
Spin: due to polarisation state (rotating E-field)

±ħ per photon



Orbital: due to inclined wavefronts

lħ per photon



Laguerre-Gaussian (LG) beam

$$\mathbf{S} = \epsilon_0 \int (\mathbf{E} \times \mathbf{A})\, d^3\mathbf{r}$$

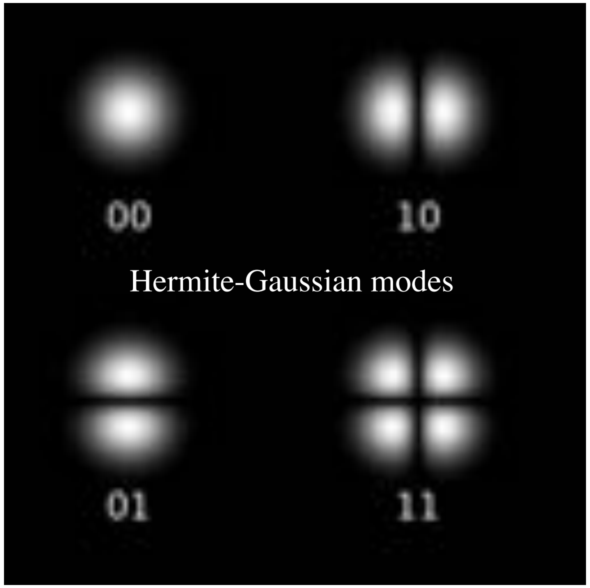
$$\Rightarrow \quad \mathbf{S} = \frac{\epsilon_0}{2i\omega} \int (\mathbf{E}^* \times \mathbf{E})\, d^3\mathbf{r}.$$

$$\mathbf{S} = \sum_{\mathbf{k}} \hbar \mathbf{u}_{\mathbf{k}} \left(\hat{a}^\dagger_{\mathbf{k},L} \hat{a}_{\mathbf{k},L} - \hat{a}^\dagger_{\mathbf{k},R} \hat{a}_{\mathbf{k},R} \right)$$

$$\mathbf{S}_z = \pm\hbar.$$

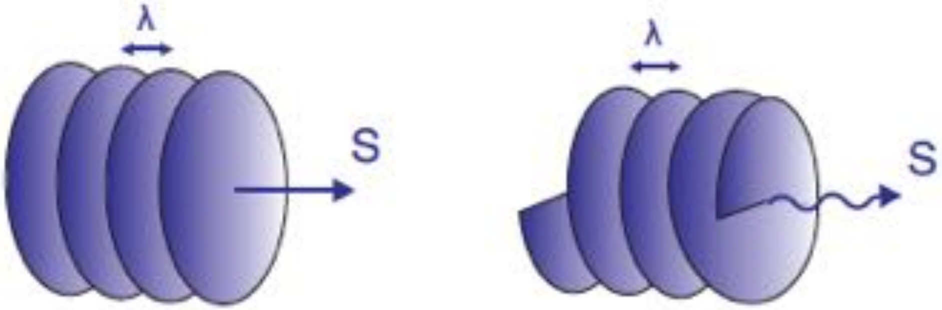
Laguerre-Gaussian modes

L. Allen et al., Physical Review A **45**, 8185 (1992)

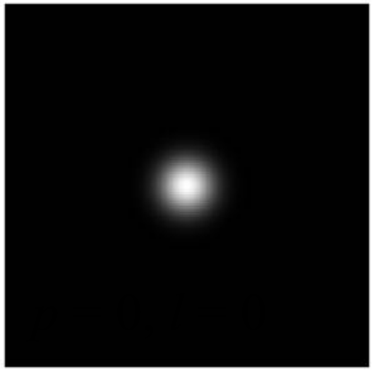


Hermite-Gaussian modes

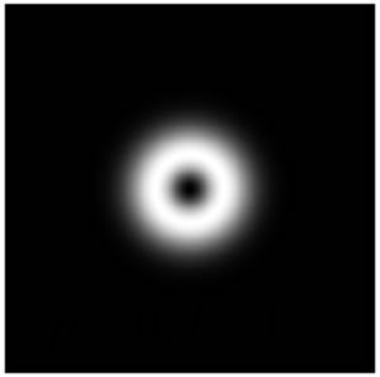
- **radial mode index *p*** **(determines radial structure)**
- **azimuthal mode index *l*** **(determines helicity)**



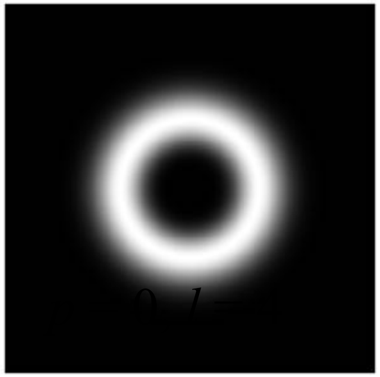
lħ per photon



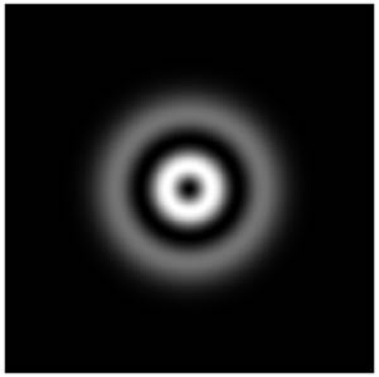
$p = 0, l = 0$



$p = 0, l = 1$

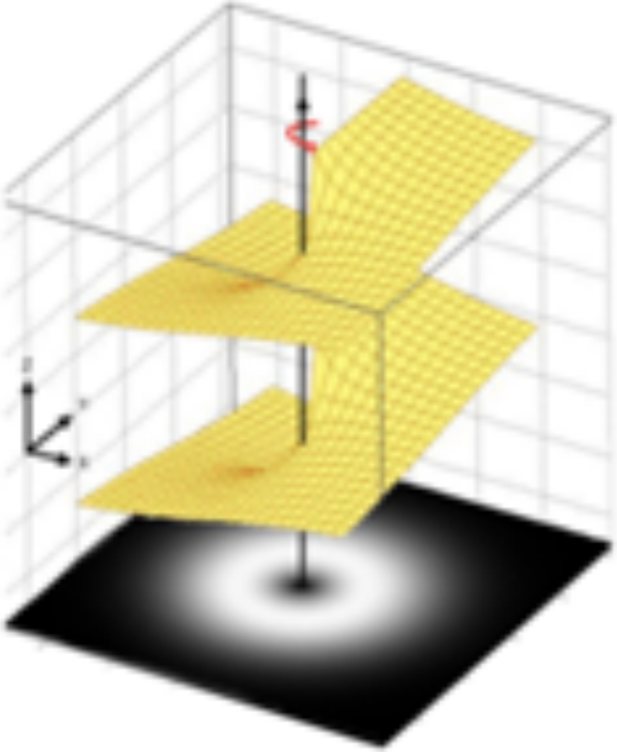


$p = 0, l = 3$



$p = 1, l = 1$

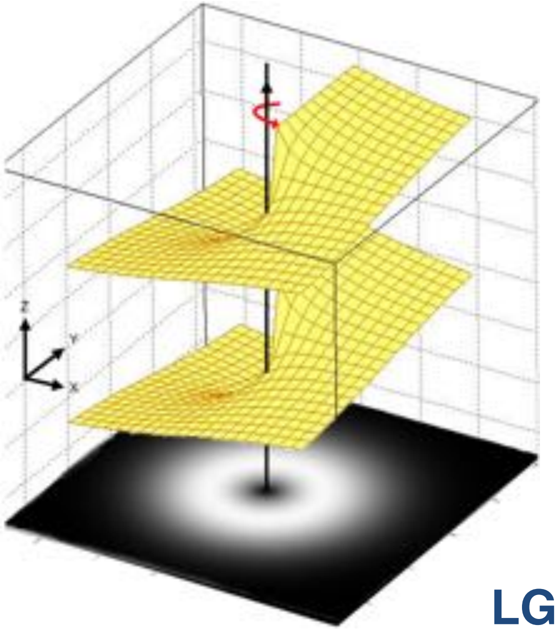
Laguerre-Gaussian modes have orbital angular momentum – due to inclined wavefronts



Laguerre-Gaussian (LG) beams
Allen et al., Phys Rev A 1992

Light for rotation: orbital angular momentum transfer

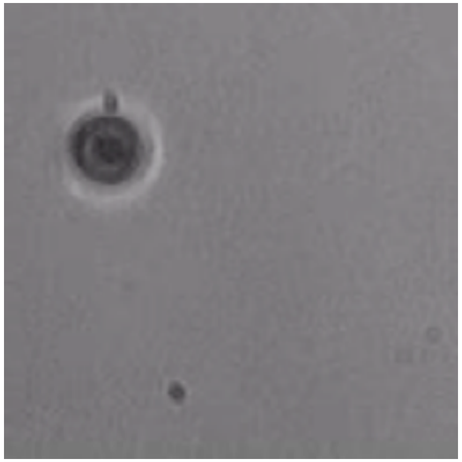
Orbital angular momentum (**OAM**) transfer by inclined wavefronts via light scattering



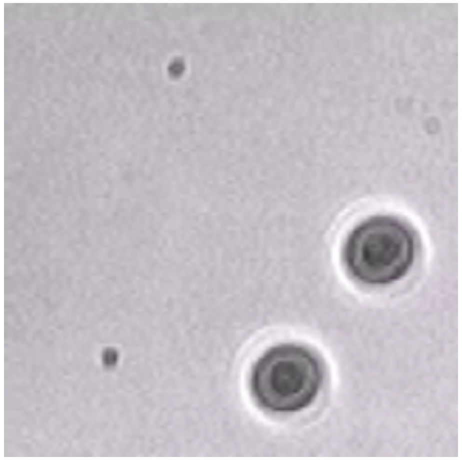
LG beam
(ℓ=1, p=0)

$\ell\hbar$ per photon

Silica
(3μm)

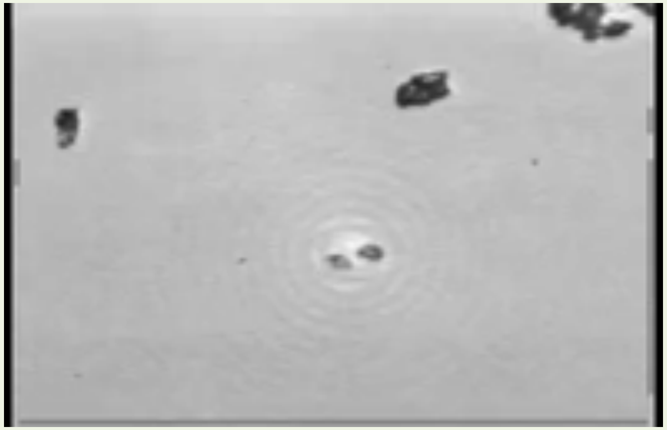


ℓ=10

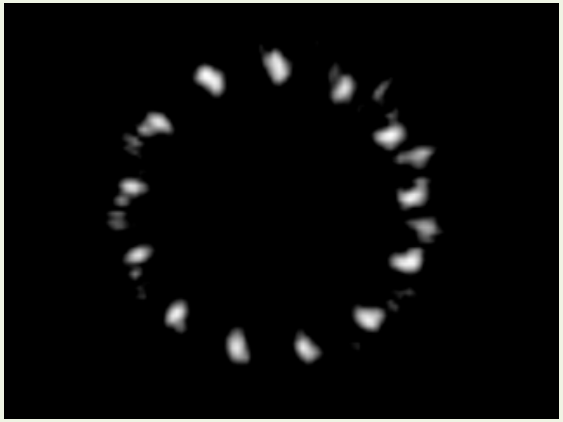


ℓ=-10

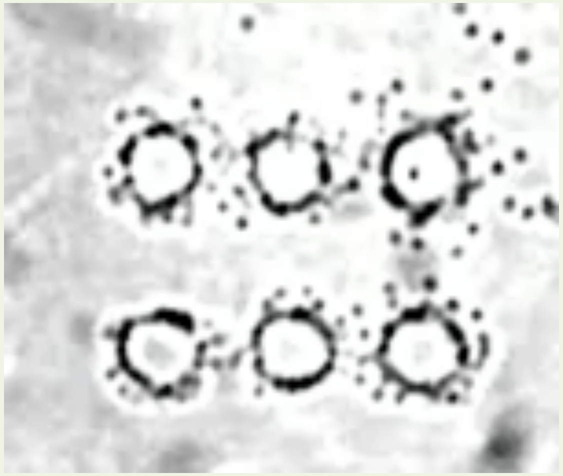
Orbital angular momentum transfer to trapped particles



Garces-Chavez et al., Physical Review Letters (2003)
O'Neil et al., Physical Review Letters (2002)



Chen et al. Optics Letters (2013)



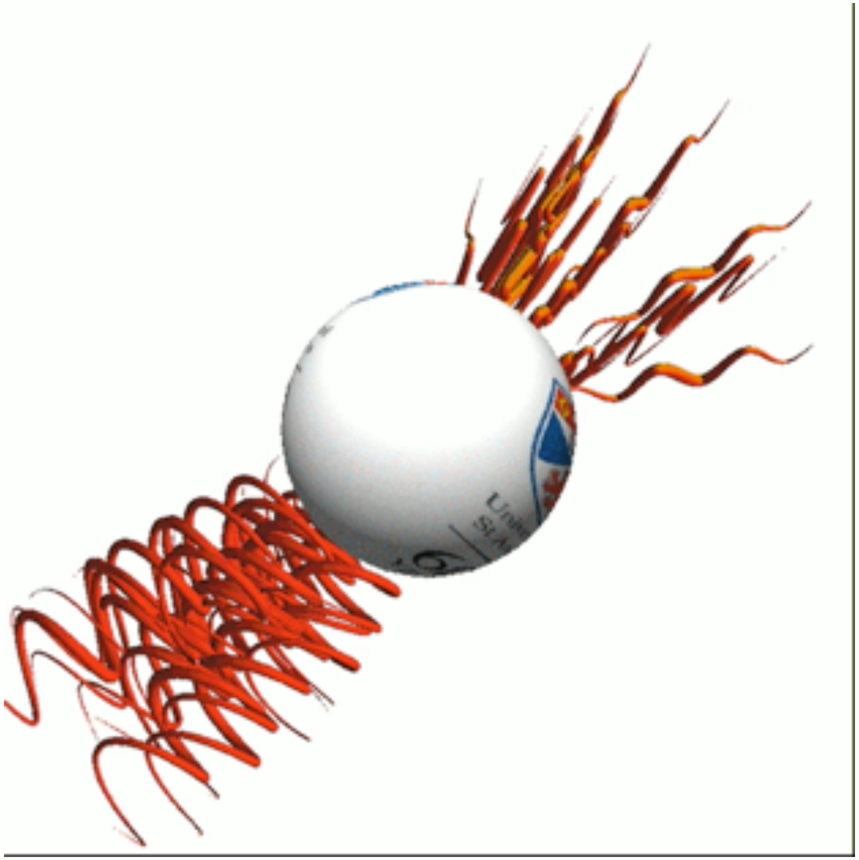
New concepts to look at
spin-orbit coupling
negative torque

This video from Kosta Ladavac and David Grier, "Microoptomechanical pumps assembled and driven by holographic optical vortex arrays," Opt. Express **12**, 1144-1149 (2004)

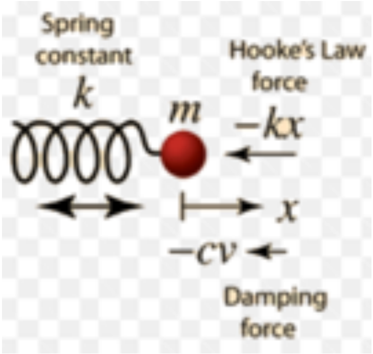
see also related work by other groups, including:

Ristch-Marte group, Innsbruck, Austria
Padgett Group, University of Glasgow, UK
Rubensztein-Dunlop group,Brisbane (did first work on rotation - based on absorption of CuO particles (He et al PRL, 1995)

Rotation in optical traps in vacuum



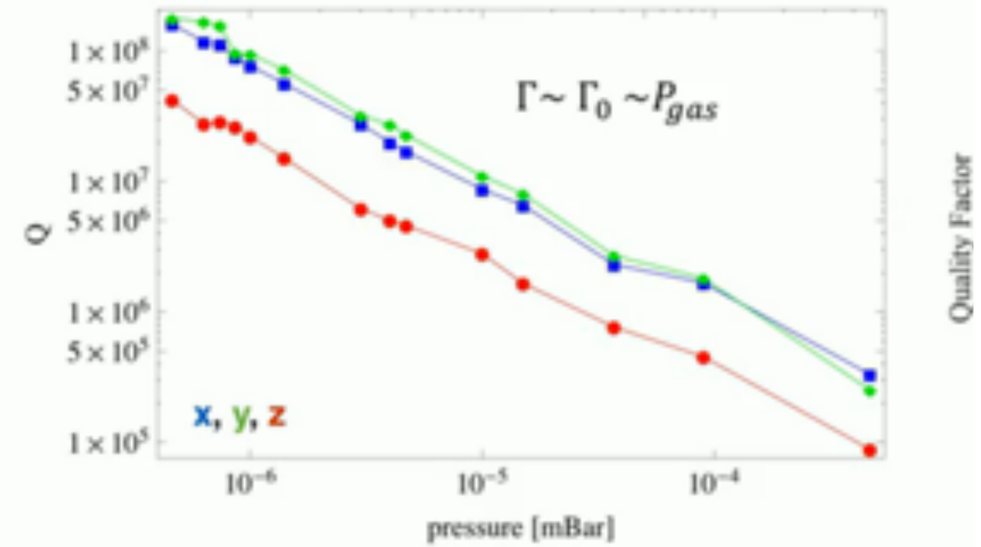
Trap in vacuum? Why?

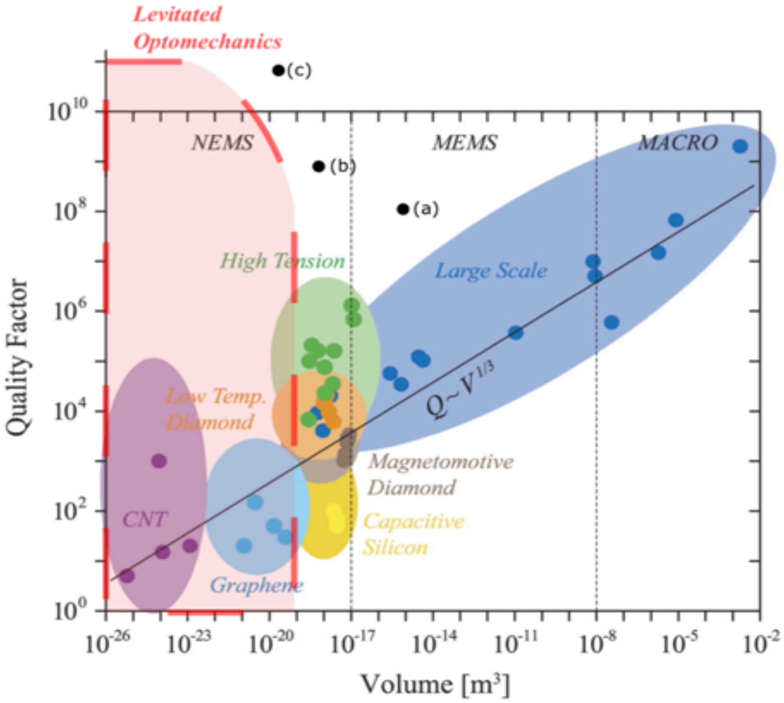


$$F \propto \frac{1}{\sqrt{Q}}$$

$$\langle n \rangle = k_B T_{\mathrm{cm}} \,/\, (\hbar\, \Omega_0)$$

Optical levitation of a trapped sphere offers:
high vibrational frequencies, record rotational speeds, and mechanical Q factors exceeding 10^{12} suggested.
Geraci group: zeptonewton force sensing. St Andrews has shown Q ~10^8 (Science Advances,(2020))

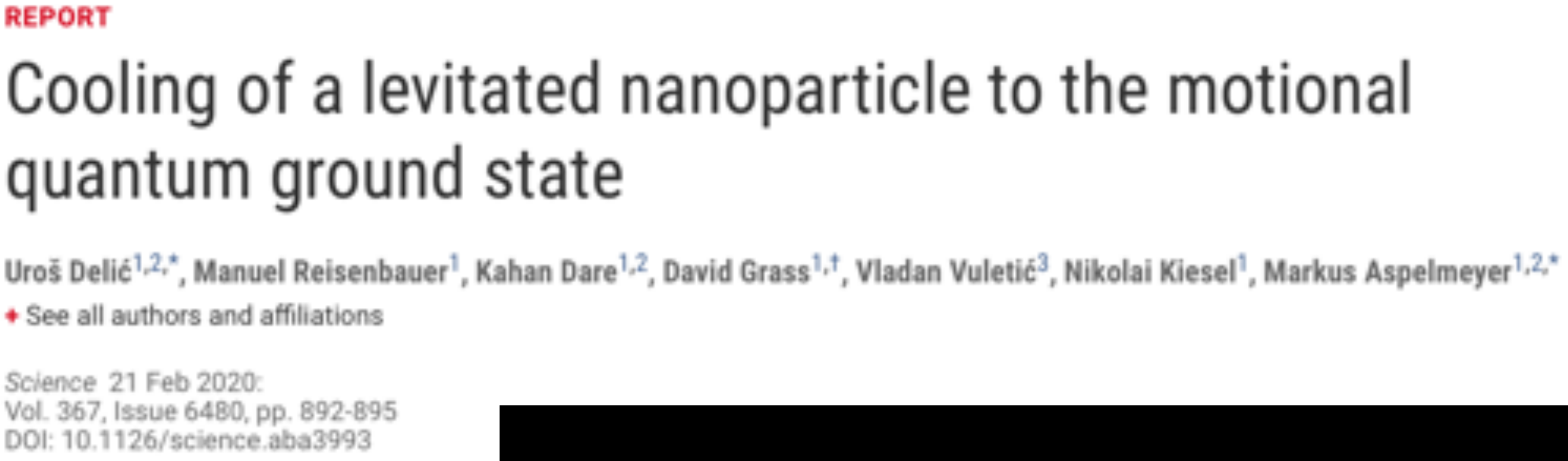




Optomechanics with levitated particles

Rep. Prog. Phys. **83** (2020) 026401 (36pp)

J. Gieseler, B. Deutsch, R. Quidant, L. Novotny, Phys. Rev. Lett. **109**, 103603 (2012)



REPORT

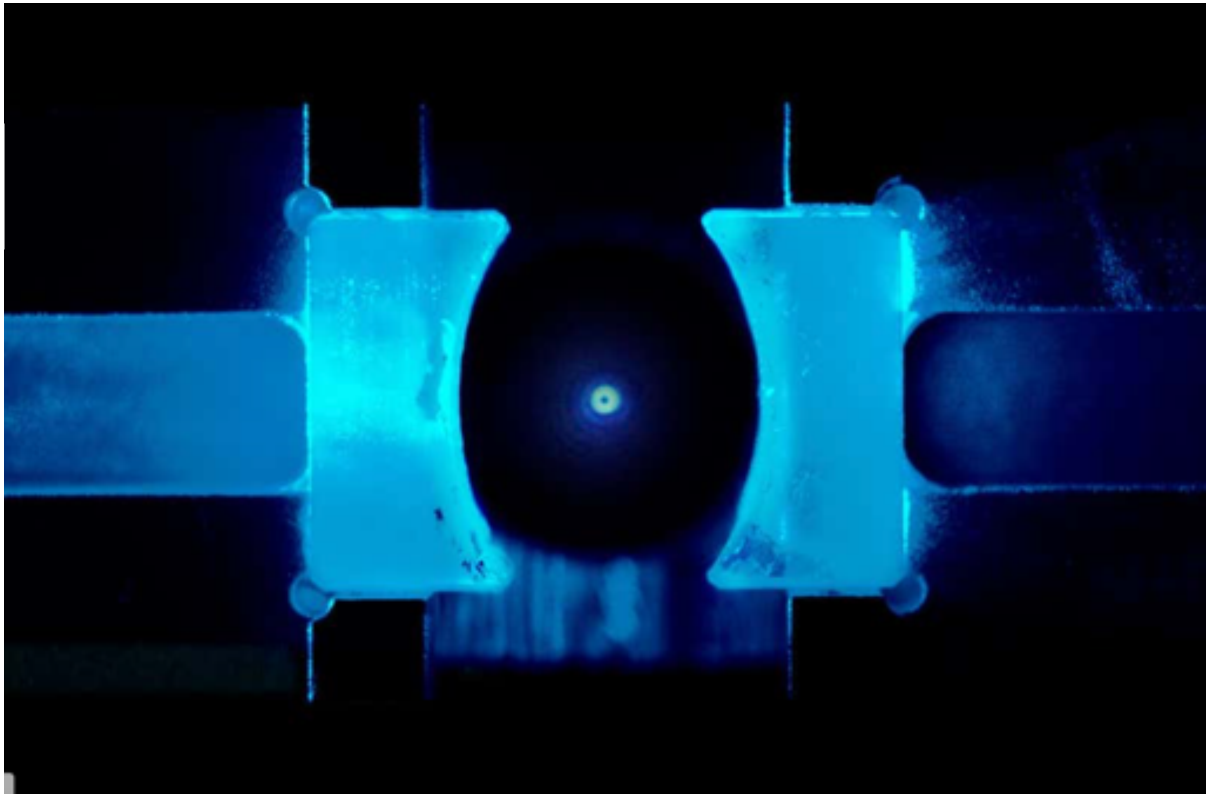
Cooling of a levitated nanoparticle to the motional quantum ground state

Uroš Delić[1,2,*], Manuel Reisenbauer[1], Kahan Dare[1,2], David Grass[1,†], Vladan Vuletić[3], Nikolai Kiesel[1], Markus Aspelmeyer[1,2,*]

✦ See all authors and affiliations

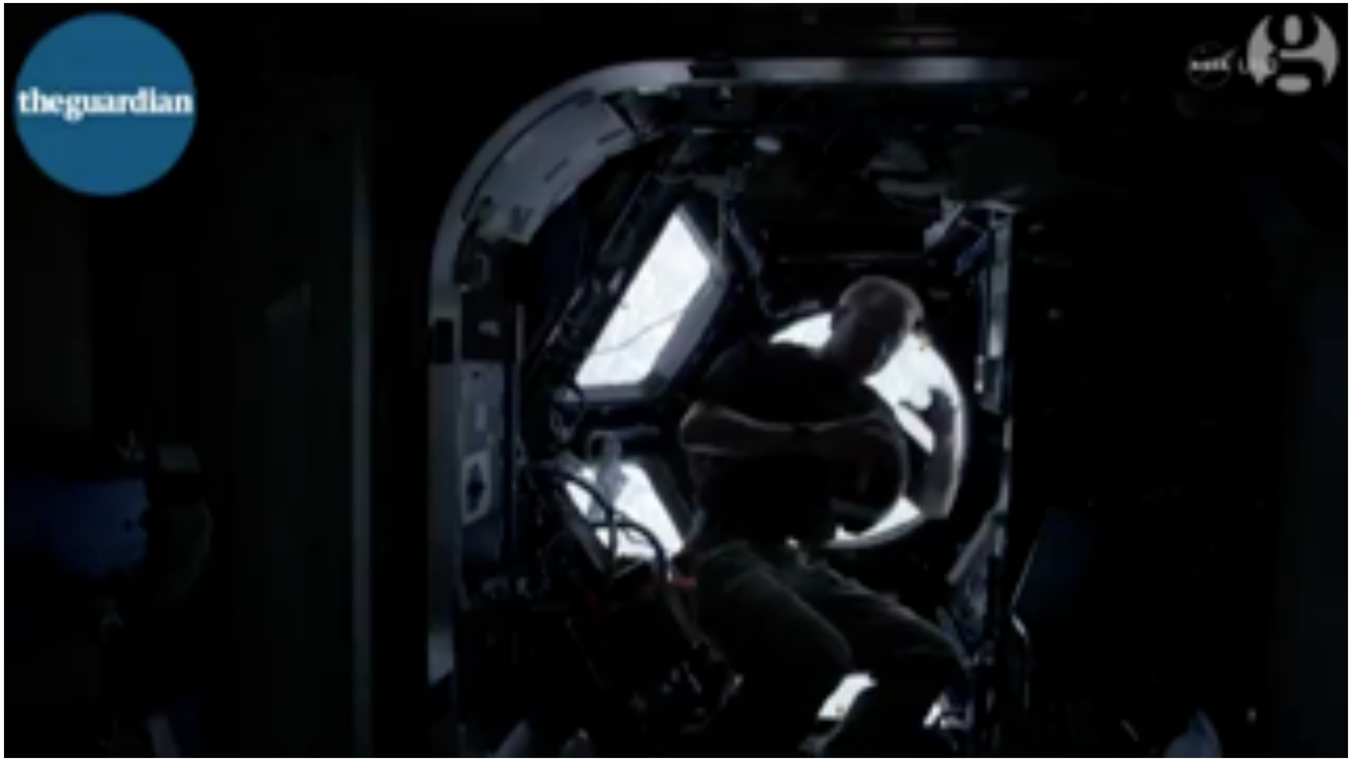
Science 21 Feb 2020:
Vol. 367, Issue 6480, pp. 892-895
DOI: 10.1126/science.aba3993

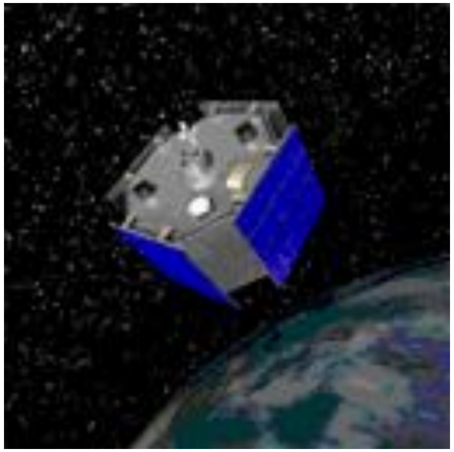
NewScientist

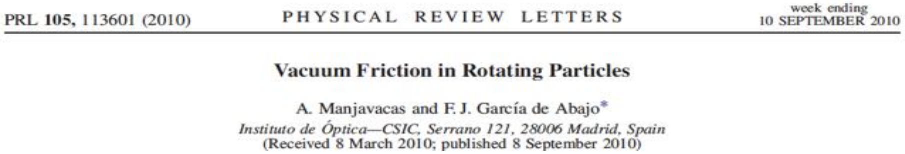


This tiny glass bead has been quantum chilled to near absolute zero

Rotational levitated optomechanics: all in a spin







PRL **105,** 113601 (2010) PHYSICAL REVIEW LETTERS week ending 10 SEPTEMBER 2010

Vacuum Friction in Rotating Particles

A. Manjavacas and F. J. García de Abajo*

Instituto de Óptica—CSIC, Serrano 121, 28006 Madrid, Spain

(Received 8 March 2010; published 8 September 2010)

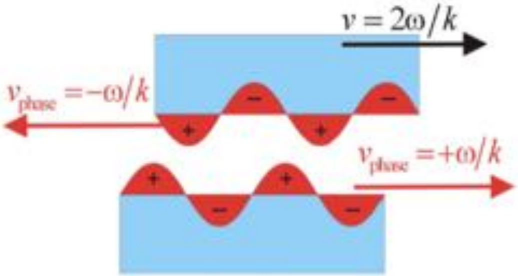
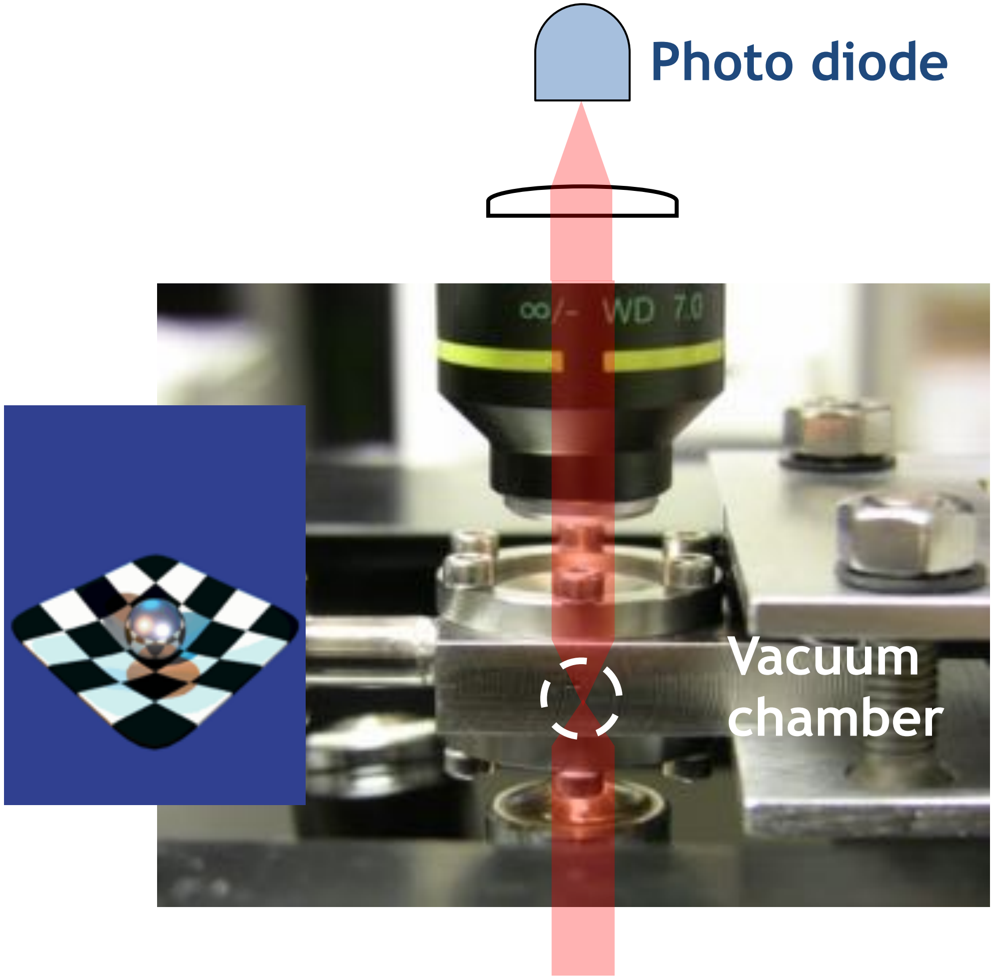


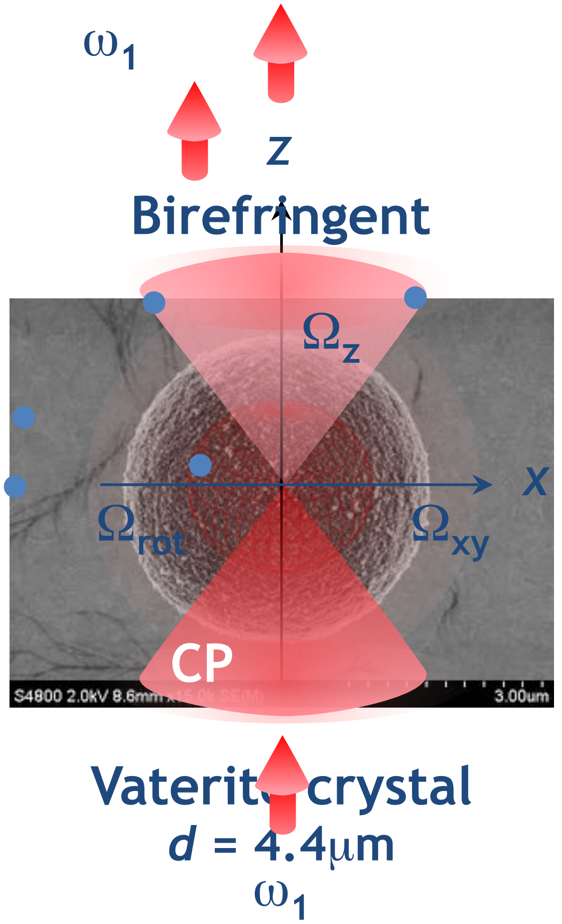
Figure adapted from: Pendry J B, *Quantum friction- fact or fiction?, New J. Phys.,(2010)*)

Experiment: trap and rotate in air or vacuum



Circularly polarised (CP) trapping beam (1070nm)

$\omega_2 = \omega_1 \pm 2\Omega_{rot}$



Vaterite crystal
d = 4.4μm

Rotation versus pressure for the microgryoscope

28 August 2013 Last updated at 16:27

University of St Andrews scientists create 'fastest man-made spinning object'

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Ten hurt as gas blast flattens homes

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The dodo skeleton and other strange objects

Cow v camel

Scientists create fastest-spinning man-made object ever

Tia Ghose, LiveScience

Aug. 29, 2013 at 12:39 PM ET

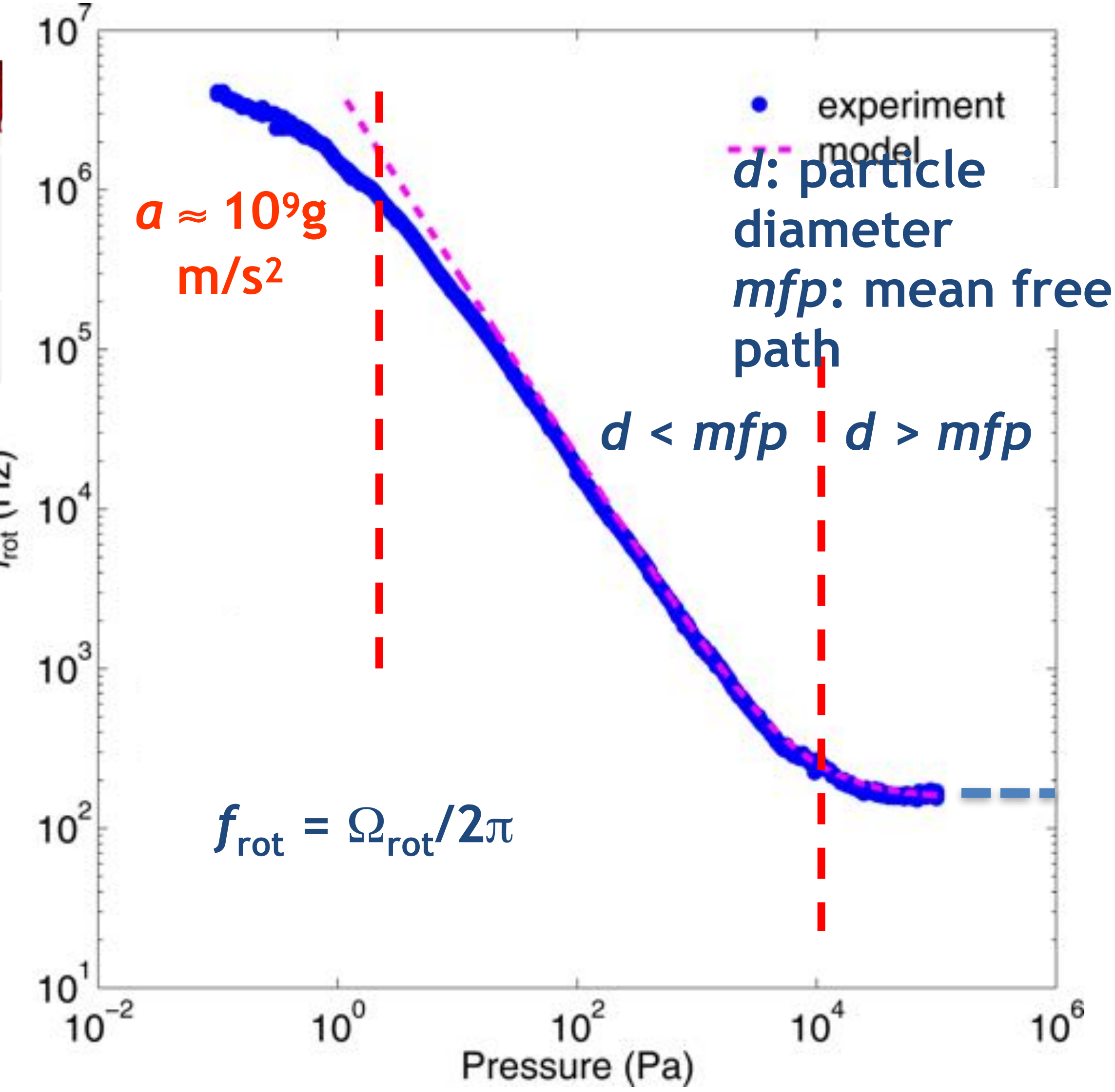
Scientists have created a microscopic sphere and set it awhirl at a blistering 600 million rotations per minute.

The sphere, which rotates 500,000 times faster than the average washing machine, is the fastest-spinning object ever made.

Scientists create fastest-spinning man-made object ever

How Ground Zero's supertower rose above New York's 9/11 nightmare

Arita et al. Nature Comm 4, 2374 (2013)



$a \approx 10^9$g m/s²

d: particle diameter

mfp: mean free path

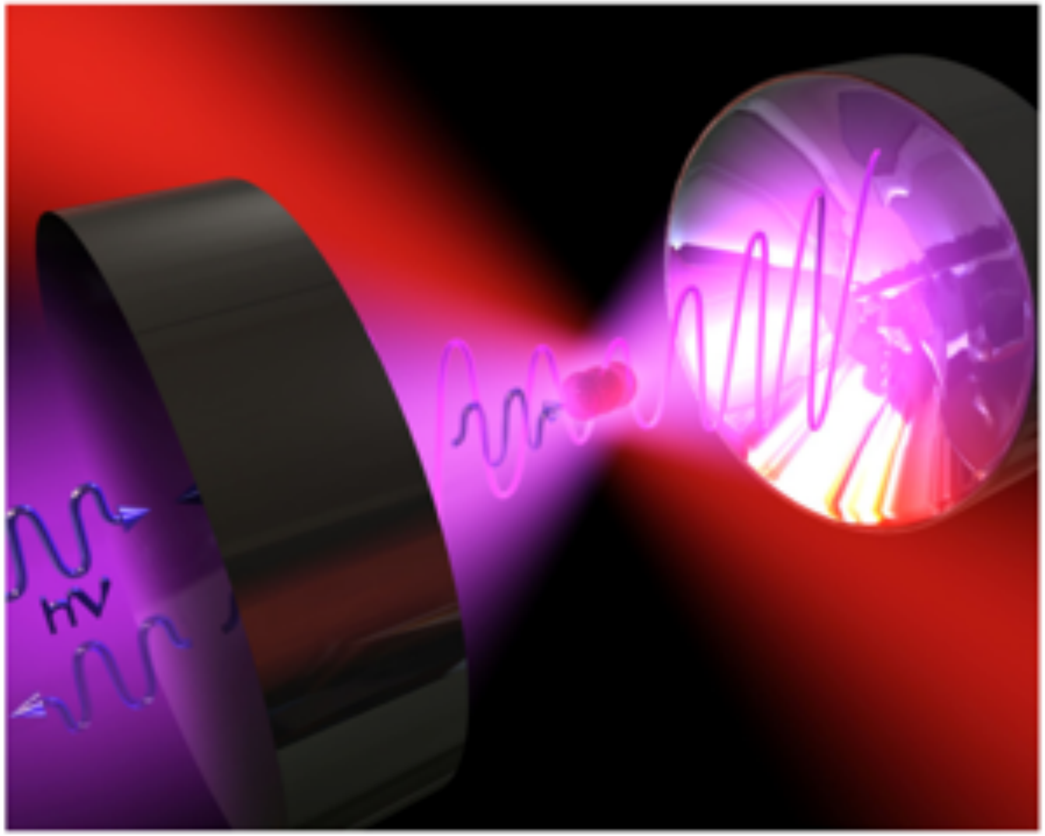
d < *mfp*

d > *mfp*

$f_{rot} = \Omega_{rot}/2\pi$

OFFICIALLY AMAZING

Guinness book of world records 2015 (fastest man-made rotation)



Common influenza viruses, with a size of ~ 100 nm, can be stored for several weeks in vacuum down to 10−4 torr.

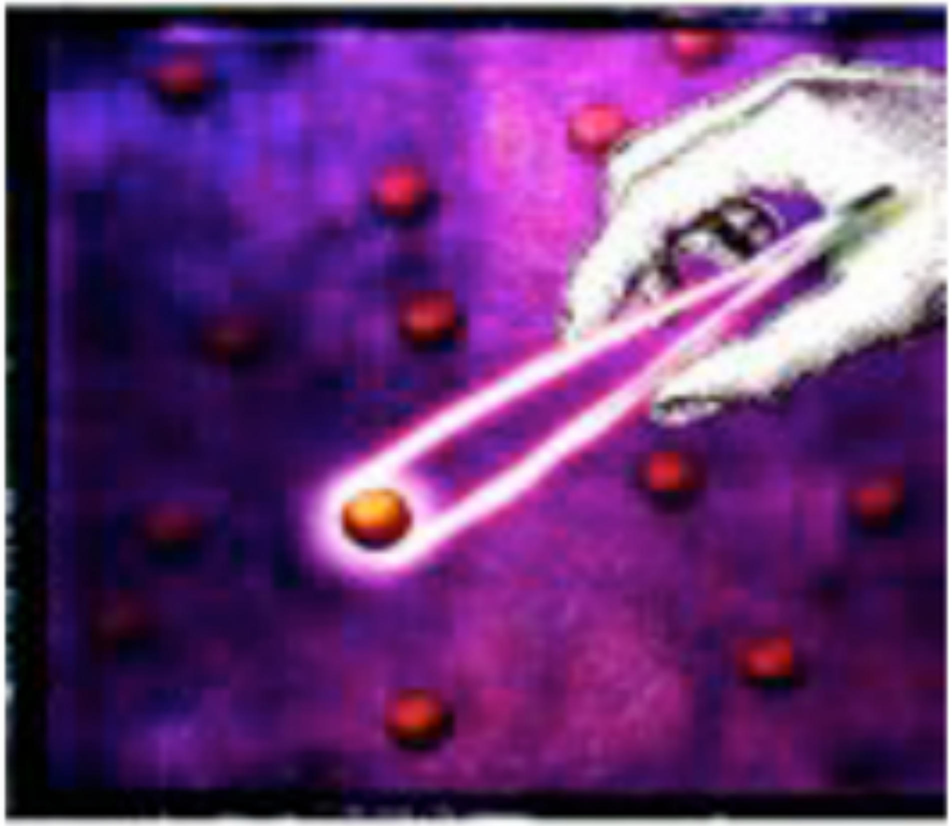
Due to their structure (e.g. lipid bilayer, nucleocapsid protein and DNA), viruses present a transparency window at the optical wavelength which yields relatively low bulk temperatures

Figure 3. Quantum superposition of living organisms. Illustration of the protocol to create quantum superposition states applied to living organisms, such as viruses, trapped in a high-finesse optical cavity by optical tweezers.

Toward quantum superposition of living organisms

To cite this article: Oriol Romero-Isart *et al* 2010 *New J. Phys.* **12** 033015

“When I described catching living things with light people said: ‘Don’t exaggerate Ashkin’.”



OE Magazine, SPIE 2013

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Veneranda Garces-Chavez

THE UNIVERSITY
of ADELAIDE

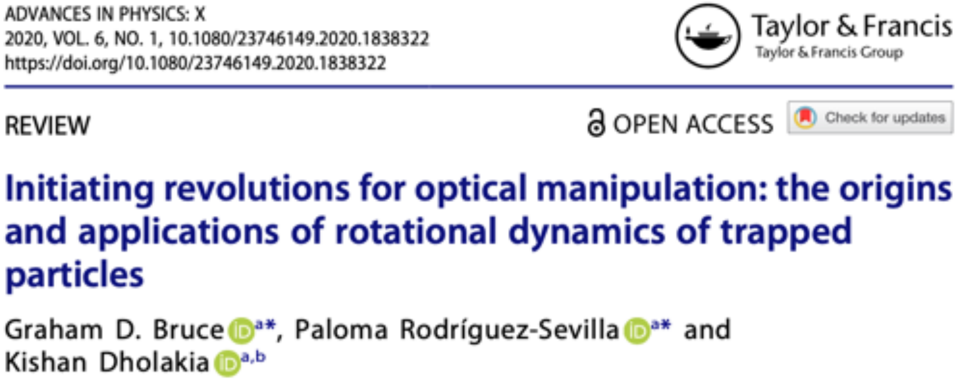
EPSRC
Pioneering research
and skills

Australian Government
Australian Research Council

Theory collaborators
Ewan Wright
Pavel Zemanek
Stephen Simpson

University of
St Andrews
FOUNDED
1413

Early work on rotation with Michael Mazilu



ADVANCES IN PHYSICS: X
2020, VOL. 6, NO. 1, 10.1080/23746149.2020.1838322
https://doi.org/10.1080/23746149.2020.1838322

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REVIEW

OPEN ACCESS Check for updates

Initiating revolutions for optical manipulation: the origins and applications of rotational dynamics of trapped particles

Graham D. Bruce[a*], Paloma Rodríguez-Sevilla[a*] and Kishan Dholakia[a,b]