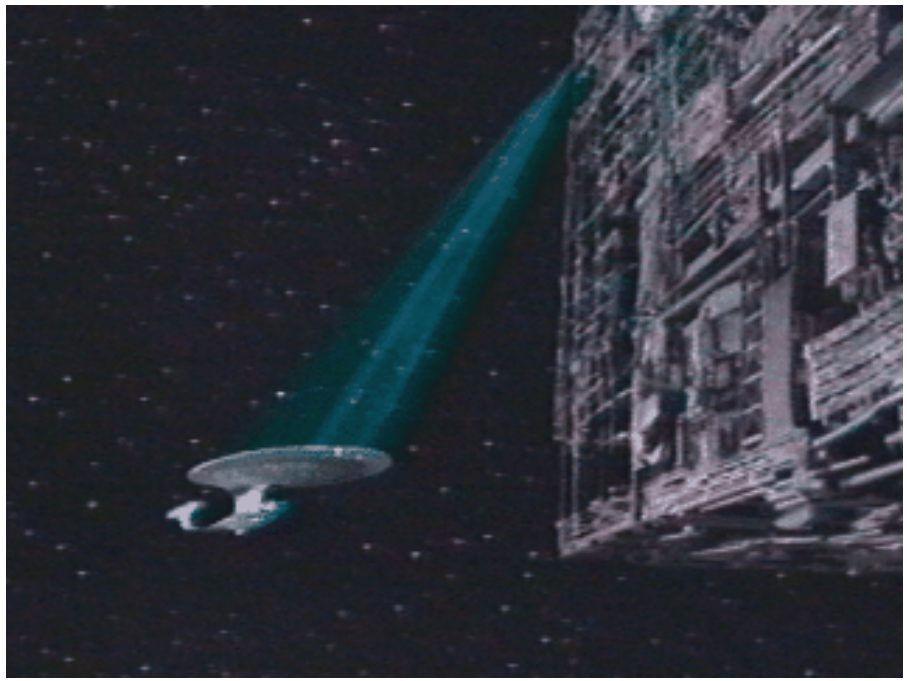
optical tweezers

tractor beams

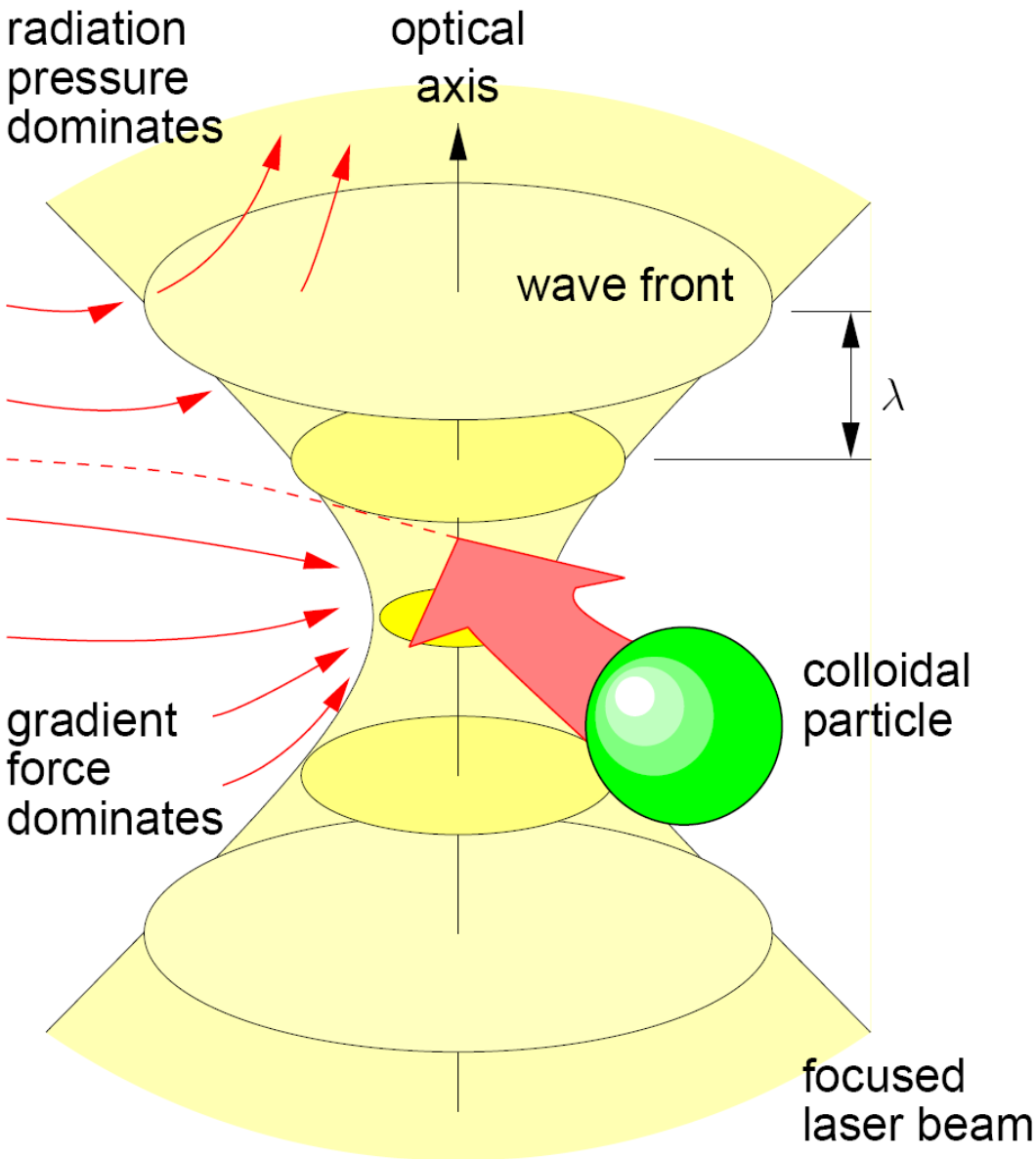


outline

What it is, how it works, how to make it

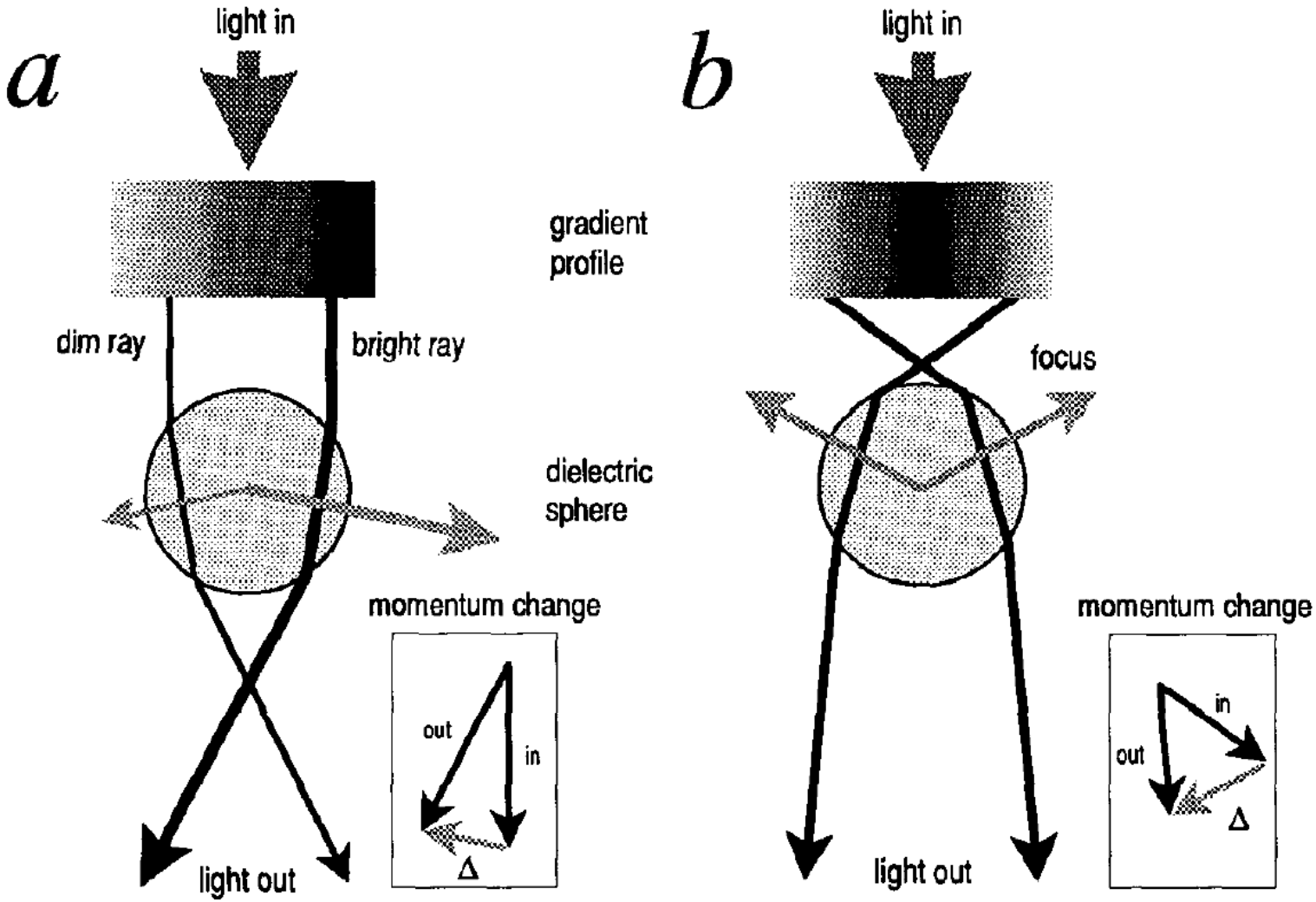
My favourite setup… holograms.

Why care? applications etc. Movies!



A. Ashkin, J. M. Dziedzic, J. E. Bjorkholm, and S. Chu, *Opt. Lett.* **11**, 288–290 (1986)

ray optics a ›› λ

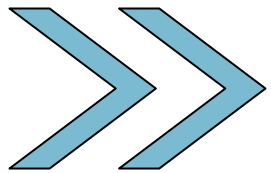


K. Svoboda and S. M. Block, *Ann Rev Biophys Biomol Struct* **23**, 247–285 (1994).

Rayleigh a ‹‹ λ

gradient force

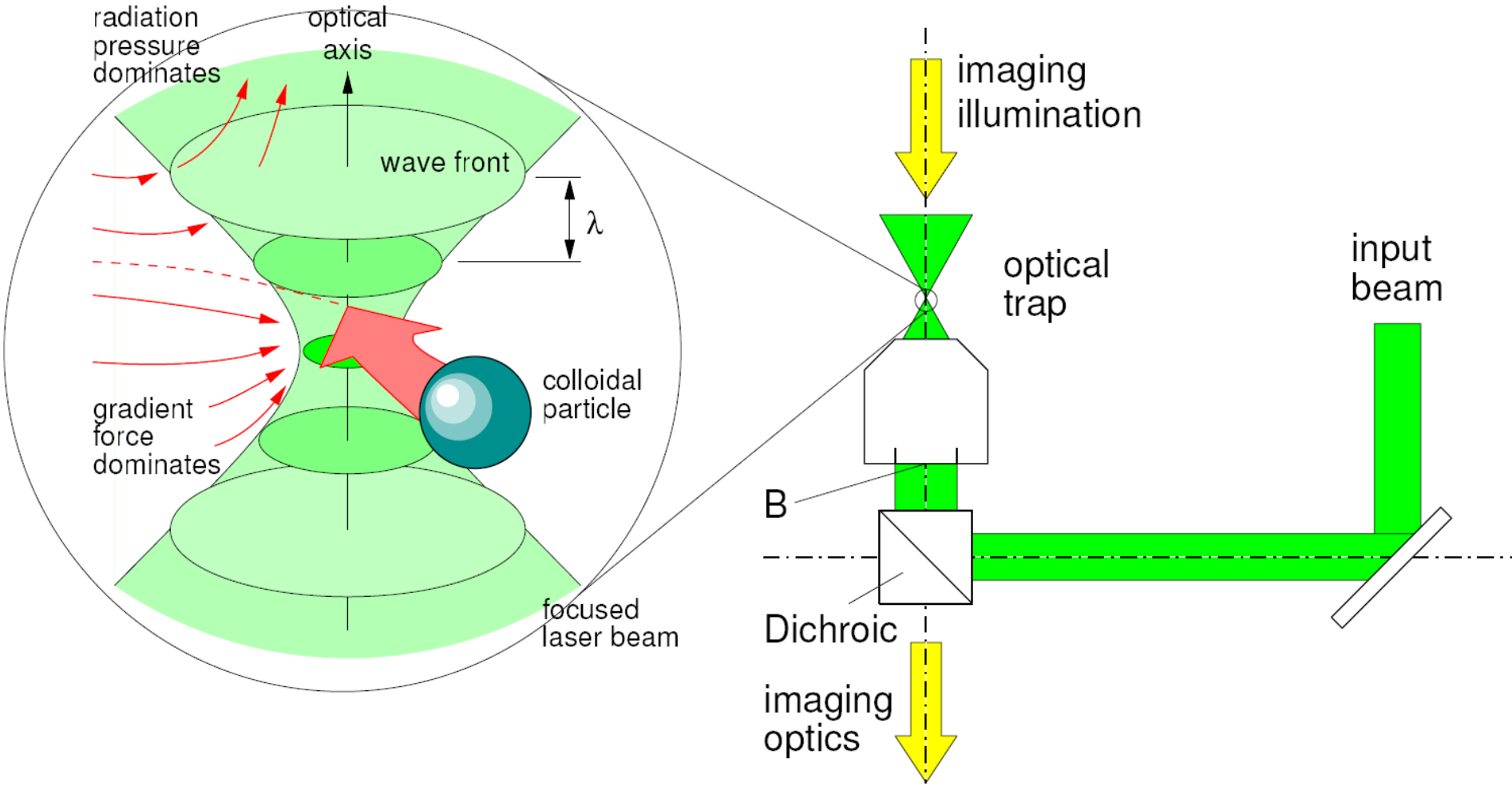
$$\mathbf{F}_{\mathrm{grad}} = \frac{2\pi}{c}\, a^3 \left(\frac{\epsilon_1 - \epsilon_2}{\epsilon_1 + 2\epsilon_2} \right) \nabla |\mathbf{S}| \,.$$



radiation pressure

$$\mathbf{F}_{\mathrm{scat}} = \frac{8\pi}{3} k^4 a^6 \frac{\sqrt{\epsilon_2}}{c} \left(\frac{\epsilon_1 - \epsilon_2}{\epsilon_1 + 2\epsilon_2} \right)^2 \mathbf{S} \,,$$

how to make one

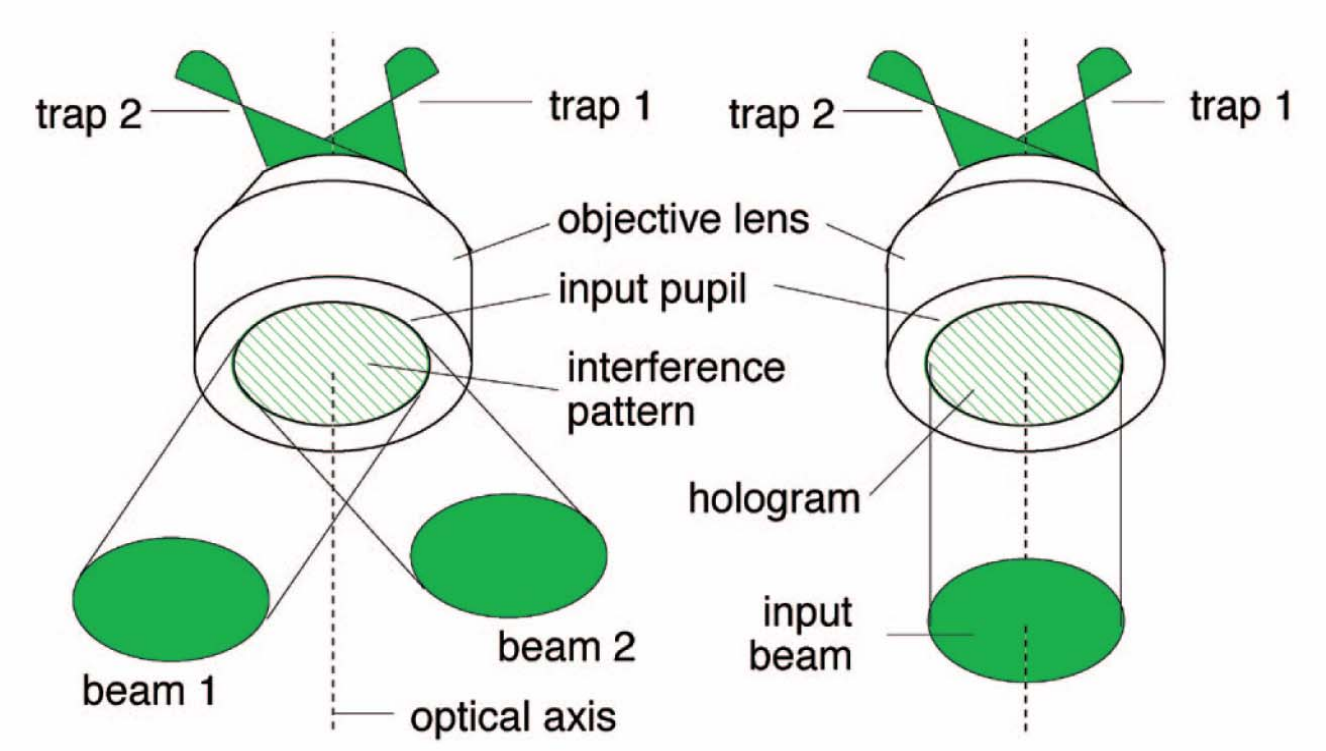


how to make many

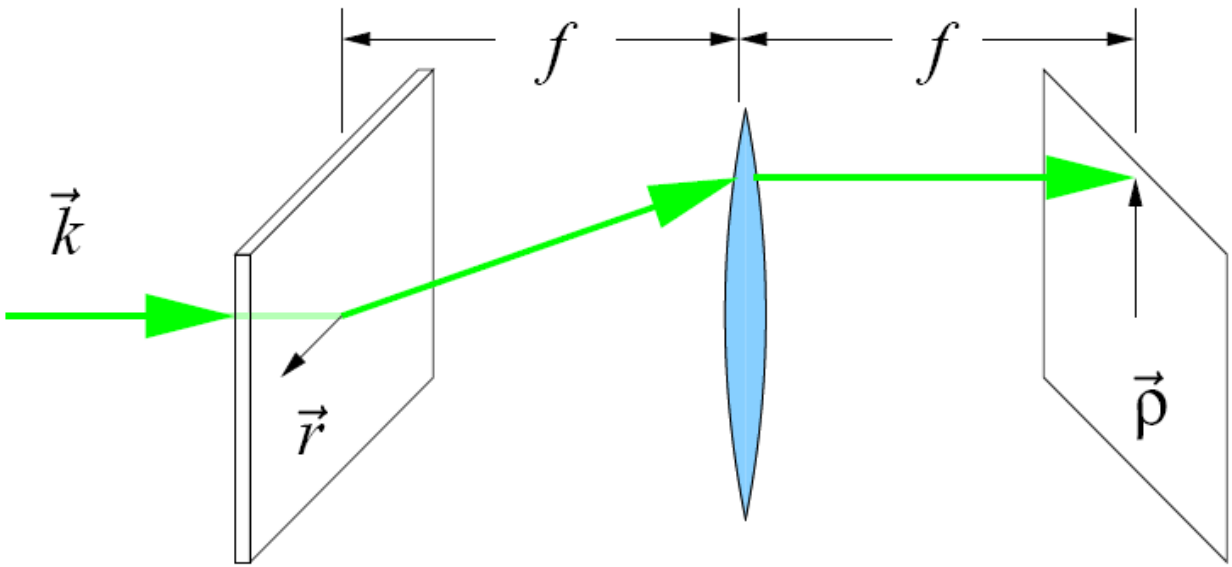
Beam splitting

Time sharing (2D)

DOE – HOT



diffraction in action



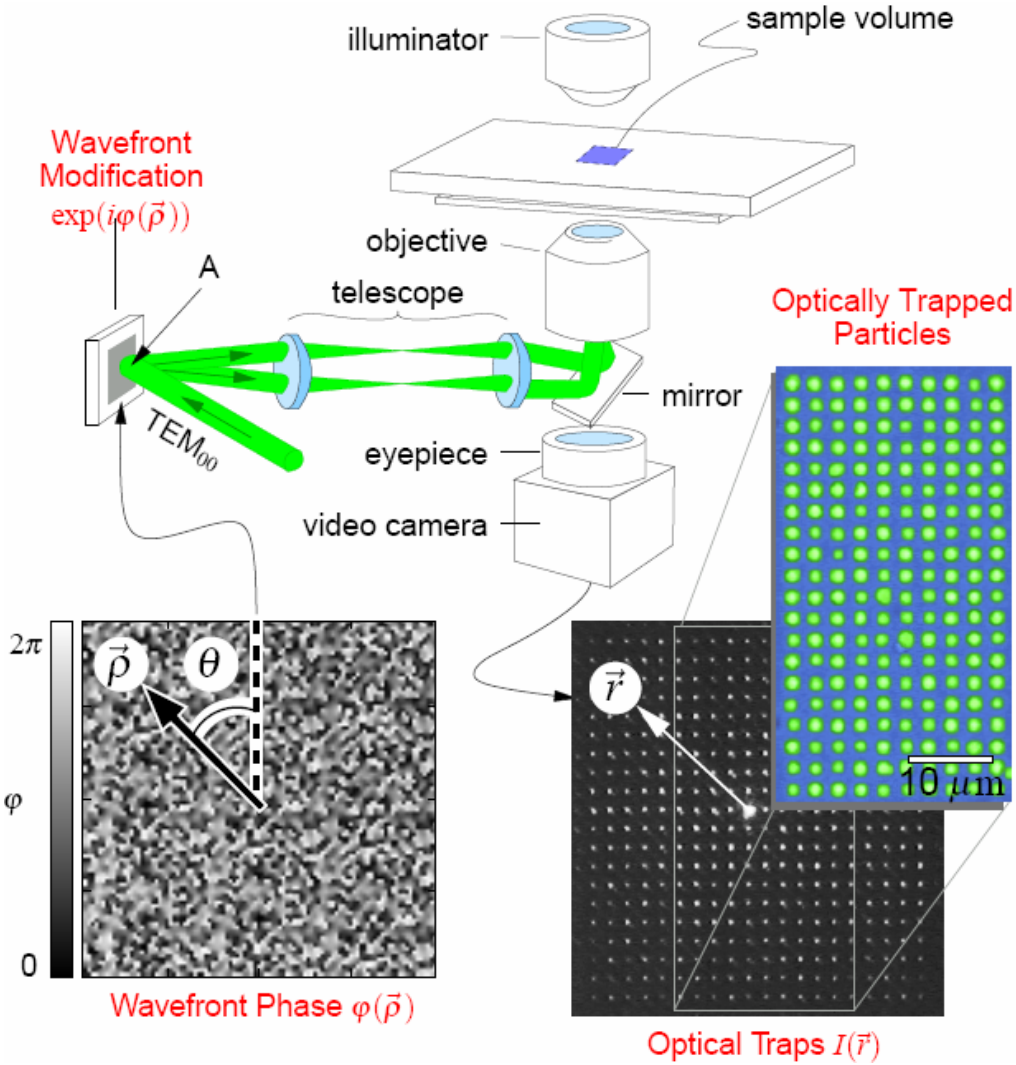
$$E(\vec{r}) = A_0(\vec{r})\, e^{i\phi(\vec{r})}$$

$$\mathcal{E}(\vec{\rho}) = \mathcal{A}(\vec{\rho})\, e^{i\varphi(\vec{\rho})}$$

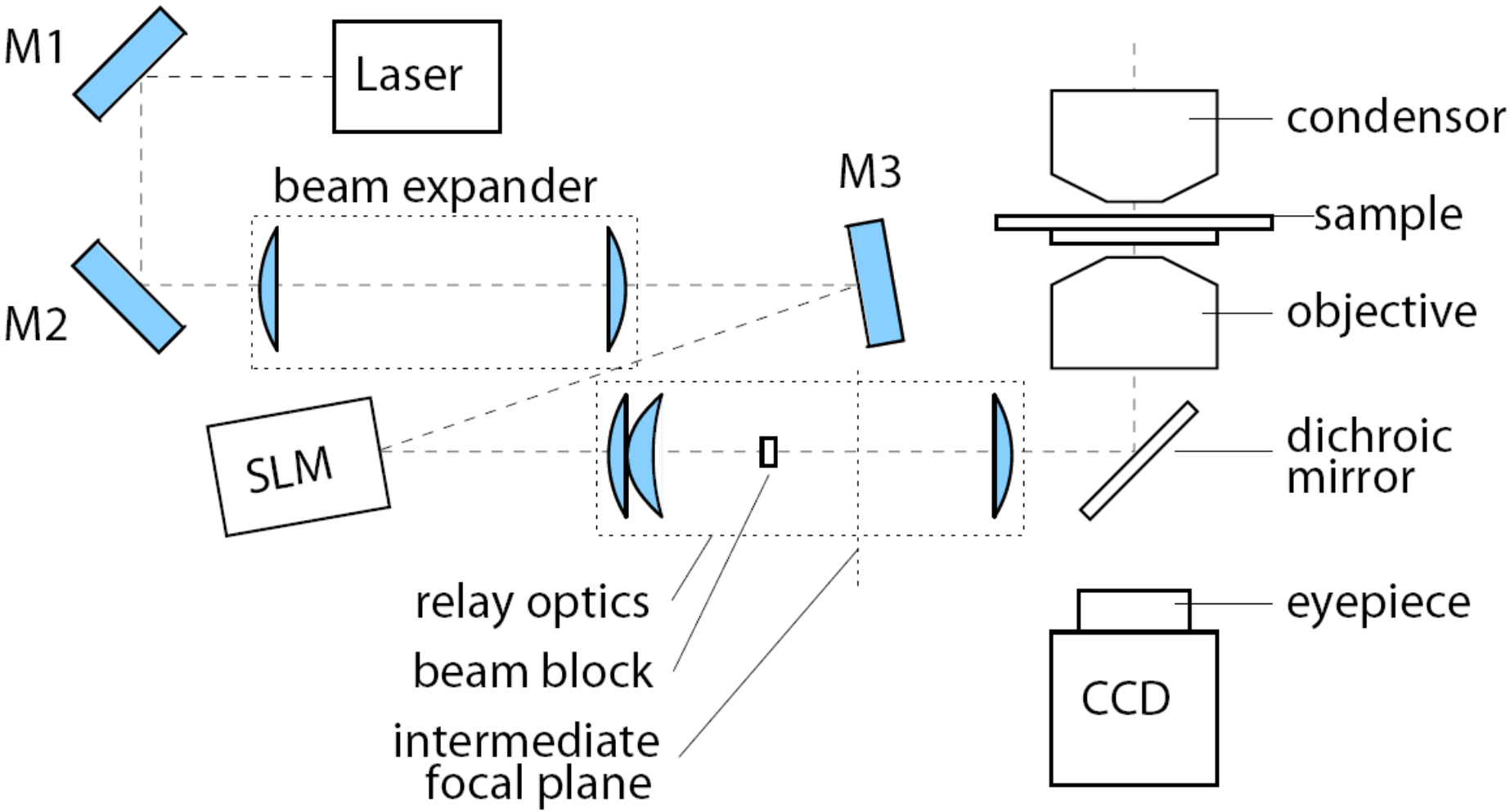
Input (DOE) | Lens | Output (Tweezer Array)

E. R. Dufresne and D. G. Grier, *Rev. Sci. Instrum.* **69**, 1974–1977 (1998).

holographic optical tweezers (HOT)

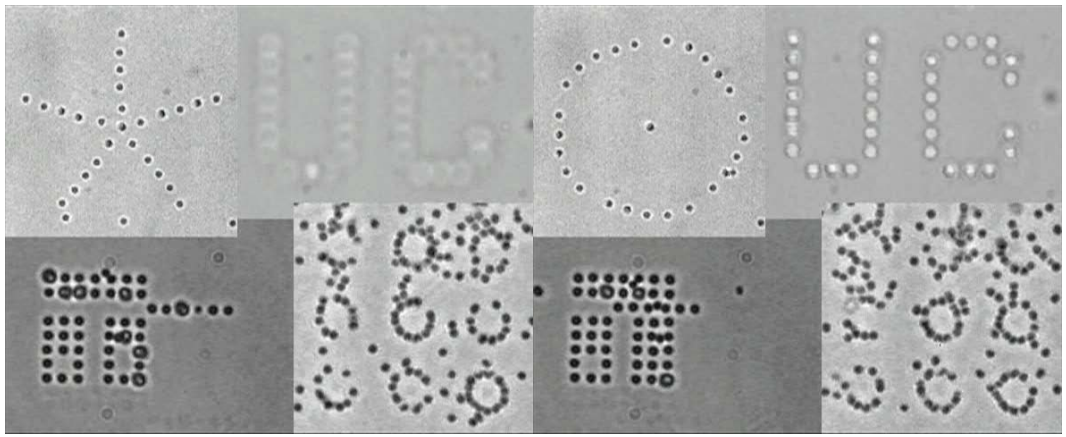


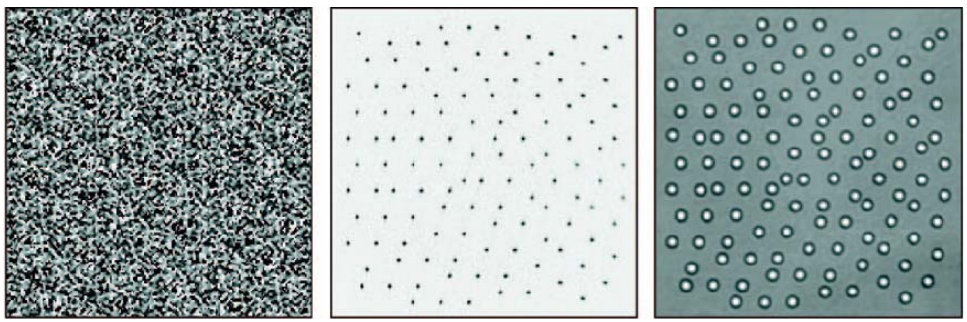
setup (HOT)


M1
Laser
beam expander
M3
condensor
sample
M2
objective
SLM
dichroic mirror
relay optics
beam block
intermediate focal plane
eyepiece
CCD

showtime (HOT)

pre-calculated holograms





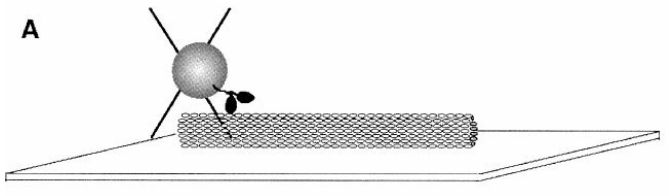
griergroup @ nyu

find (calc) trap (calc) sort

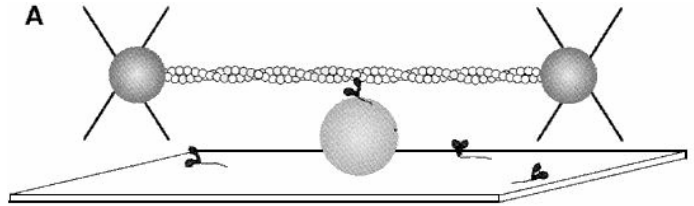
Dufresne group @ yale

movie

applications – bio



K. Svoboda, C. F. Schmidt, B. J. Schnapp, S. M. Block, *Science* **365**, 721 (1993).



J. T. Finer, R. M. Simmons, J. A. Spudich, *Science* **368**, 113 (1994).

DNA elasticity (stretch – release; force/extension)

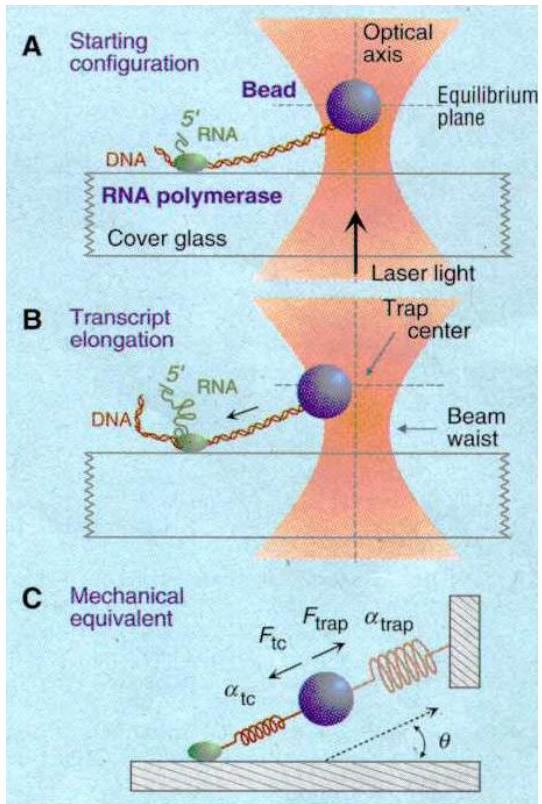
cell membrane mech props

molecular motors (kinesin stepping on microtubules)

In vitro fertilization; sperm cell motility

optical scissors (chromosomes dissection + manipulation)

In vivo..?



Yin, H. et al. (1995), Science 270, 1653–1657

applications – colloids

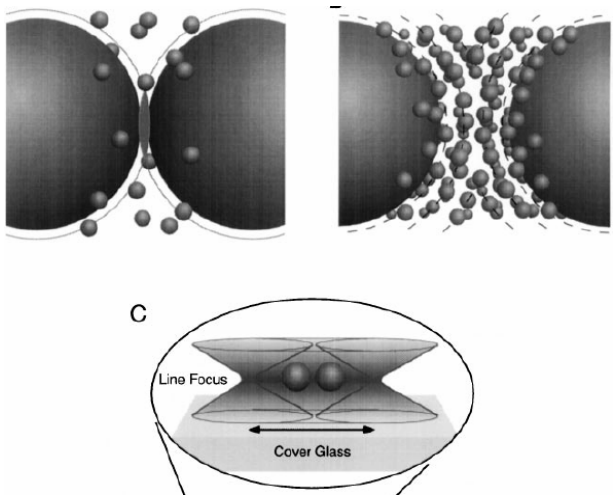
Direct measurements of colloidal interactions:

-- electrostatic: Like charges attraction etc. (hold two and release crocker grier 94 dlvo ok, in confinement 96 attraction…)

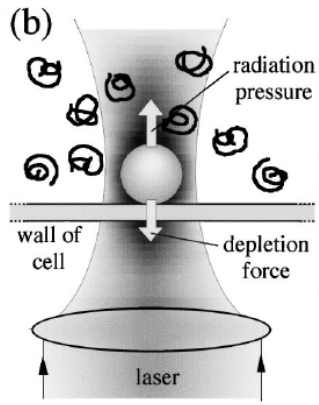
-- hydrodynamic (Quake ’99 two ptcles, Polin ’06 10ptcles) (close to wall(s) Dufresne PhD)

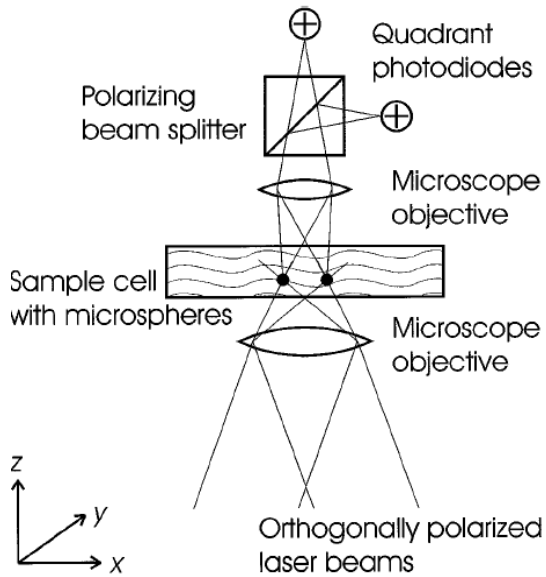
-- entropic (blow away = depletion force; line tweezer;)

-- optical



Ohshima *et al*. *Phys. Rev. Lett.* **78**, 3963–3966 (1997).



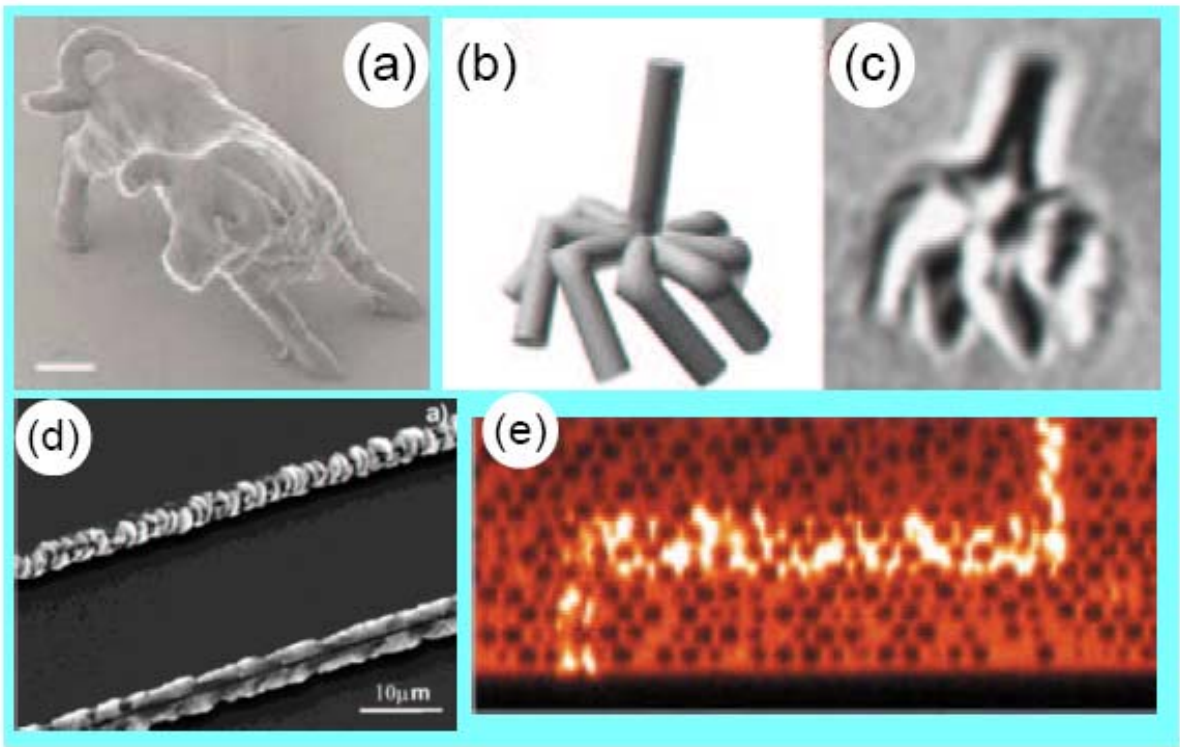


Crocker, J. C., Matteo, J. A., Dinsmore, A. D., and Yodh, A. G. *Phys. Rev. Lett.* **82**, 4352–4355 (1999).

Meiners, J. C. and Quake, S. R., *Phys. Rev. Lett.* **82**, 2211–2214 (1999).

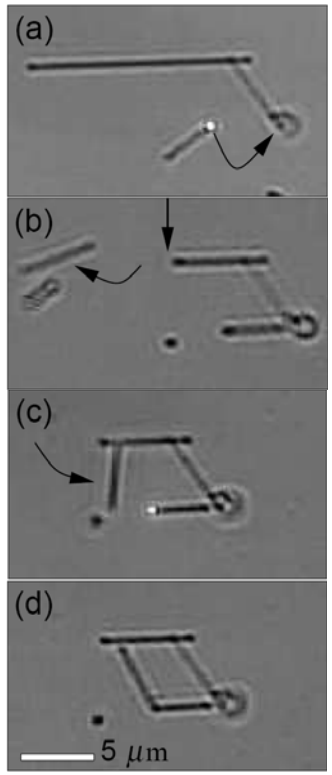
microfabrication

(a,b,c) twophoton photopolymerization, scanned tweezers. (a) 2μ bar
(d) photochemistry salt deposition
(e) photopolymerization, waveguide



D. G. Grier, *Nature* **424**, 810-816 (2003).

nanowires



R. Agarwal *et al*, Optics Express **13**, 8906-8912 (2005)

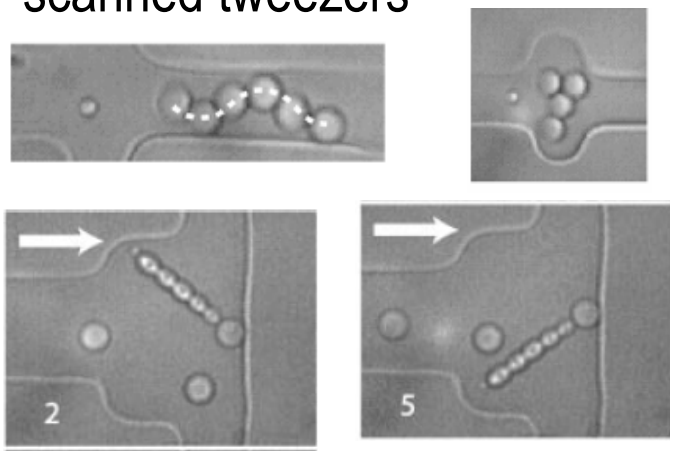
more...

trap in gel + polymerize

controlled seeding of colloidal crystals

MEMS

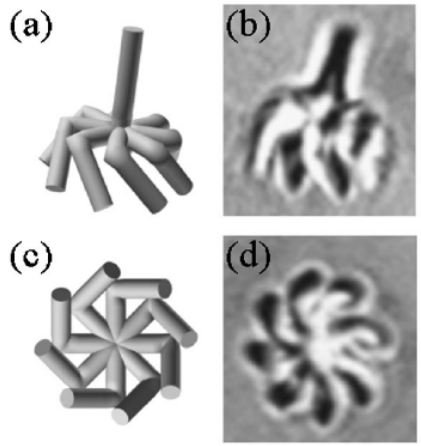
scanned tweezers



movies

Terray, A., Oakey, J. & Marr, D. W. M., *Science* **296**, 1841–1844 (2002).

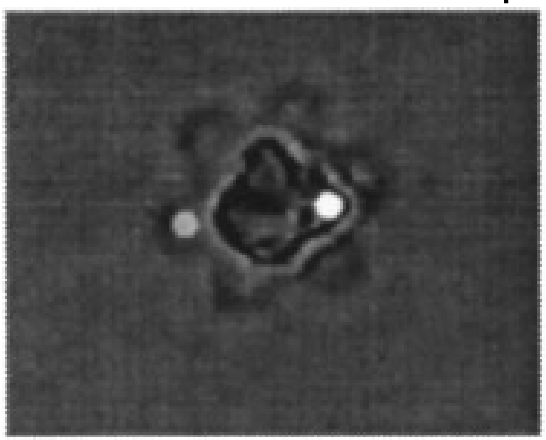
plane polarized + static



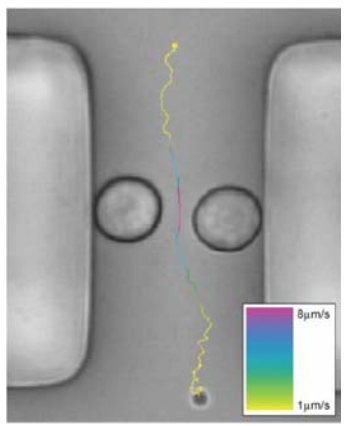
Galajda P. and Ormos P., *Appl Phys Lett,* **78,** 249–251, 2001.

circular polarized

movie



Friese *et al, Appl. Phys. Lett.* **78**, 547–549 (2001).

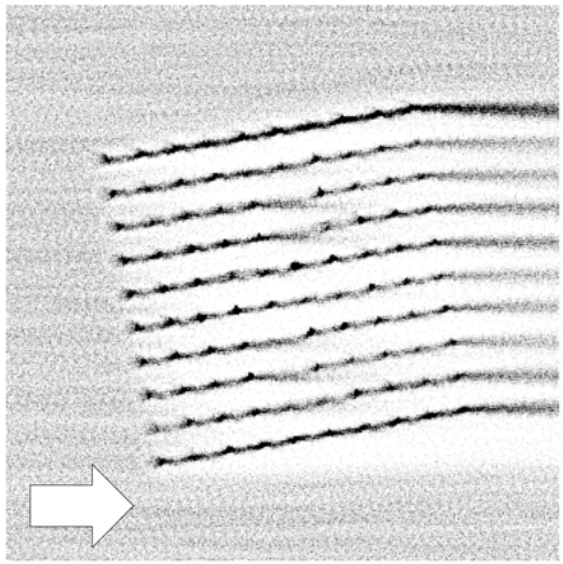


movie

Leach *et al., Lab on a Chip* **6**, 735 - 739, (2006)

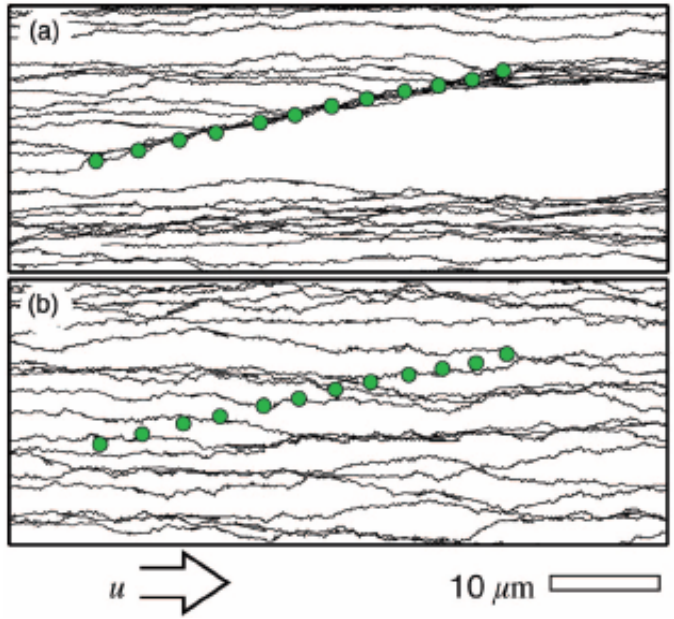
sorting

kinetic lock-in



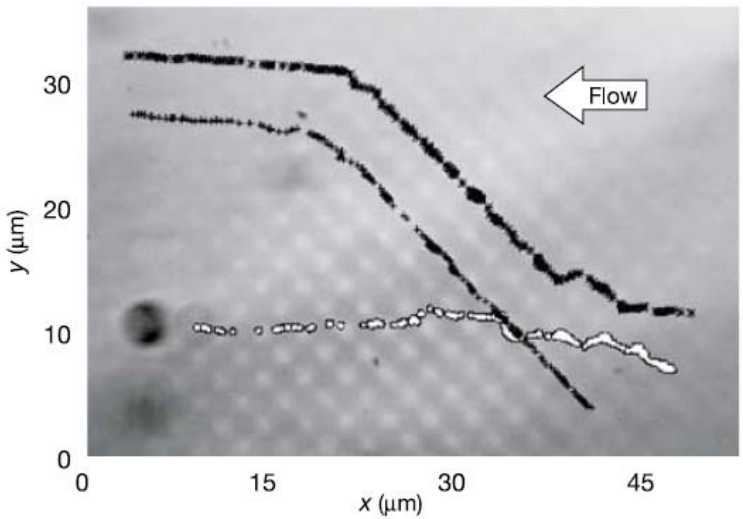
P. T. Korda, M. B. Taylor, and D. G. Grier, *Phys. Rev. Lett.* **89**, 128301 (2002).

colloids (1 and 1.5 μ)



K. Ladavac, K. Kasza and D. G. Grier, *Phys. Rev. E* **70**, 010901(R) (2004).

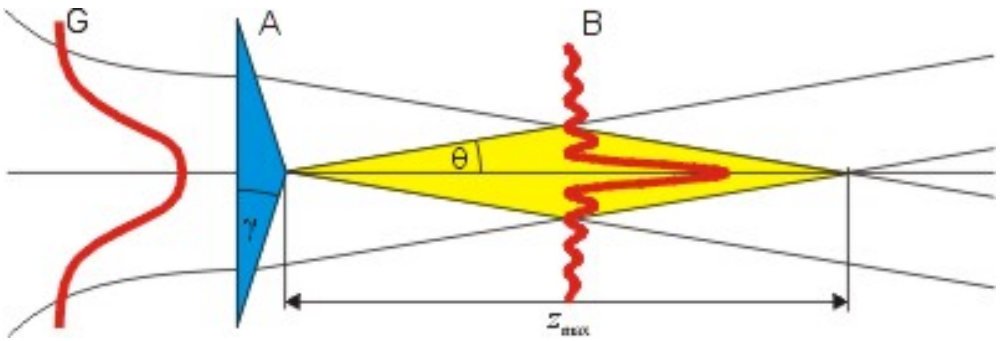
protein capsules (2 and 4 μ)

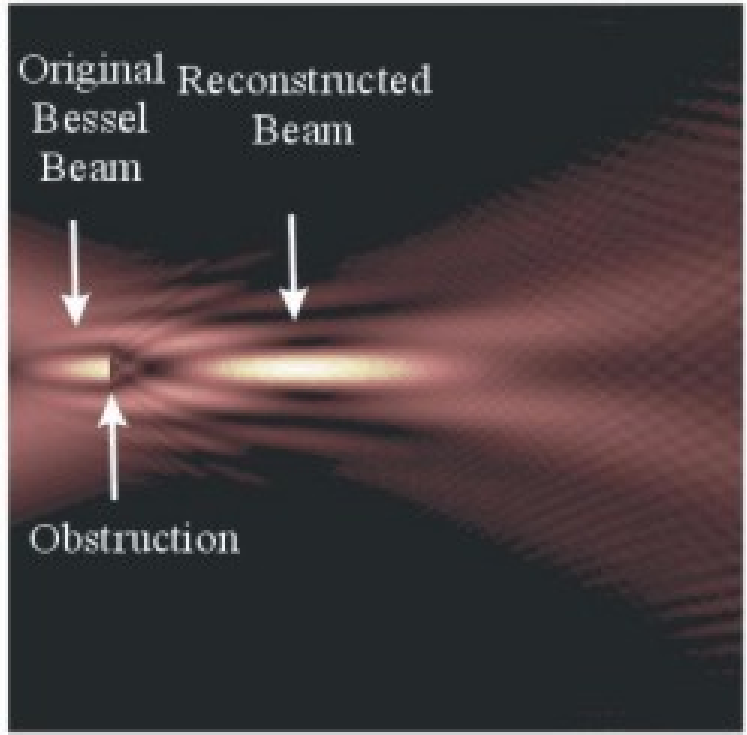


M.P. MacDonald, G.C. Splading and K. Dholakia, *Nature* **426**, 421 (2003)

beyond plane waves
- bessel beams -

$$\varphi(\vec{\rho}) = \gamma\rho$$

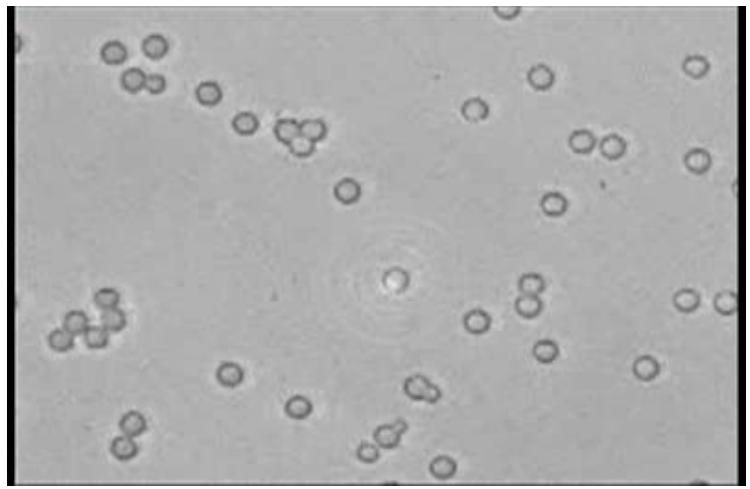




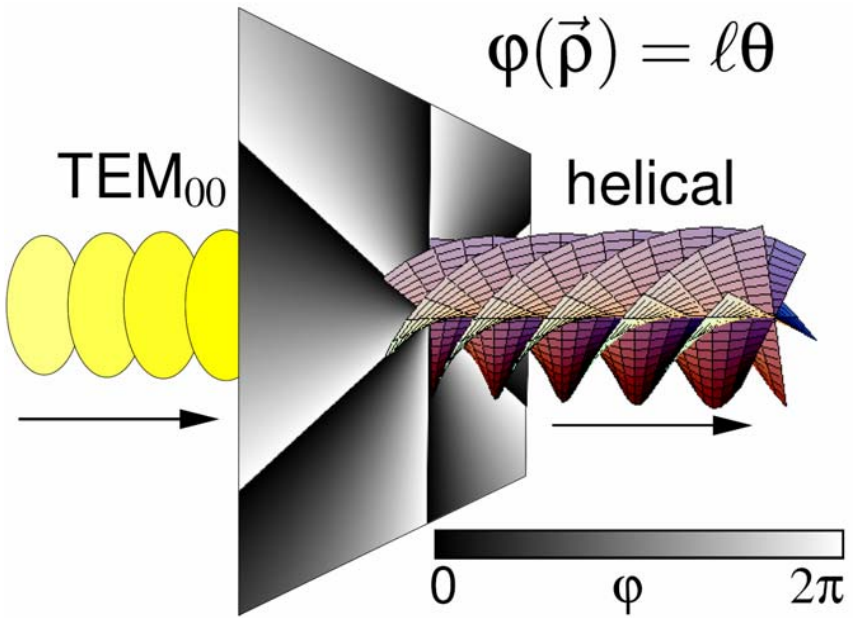
bessel beams – non-diffracting + reconstructing

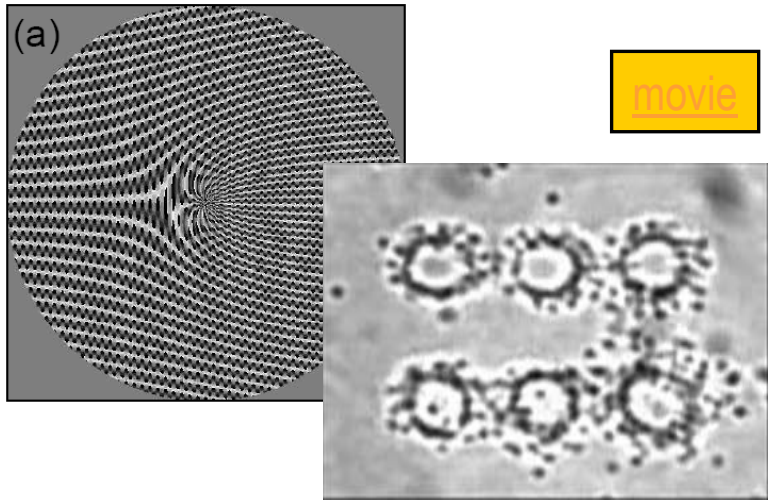
Garces-Chavez, V., McGloin, D., Melville, H., Sibbett, W. & Dholakia, K., *Nature* **419**, 145–147 (2002).

movie

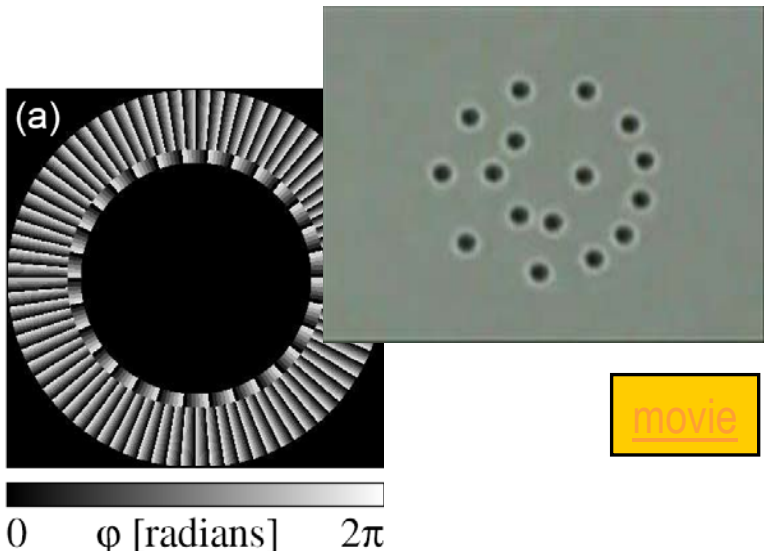


beyond plane waves
- optical vortices -





movie



movie

even more you can do (…via SLM)

- make general patterns of light
- flip holograms – move traps
- correct for aberrations
- 1D amplitude modulation

references

A. Ashkin. “History of optical trapping and manipulation of small-neutral particle, atoms, and molecules.” IEEE Journal on Selected Topics in Quantum Electronics 6, 841–856 (2000).

K. Svoboda and S. M. Block. “Biological applications of optical forces.” Annual Review of Biophysics and Biomolecular Structures 23, 247–285 (1994).

Keir C. Neuman and Steven M. Block, “Optical trapping”, Rev. Sci. Inst. 75 (9), 2787 (2004)

M. Lang and S. Block, Am. J. Phys., Resource Letter on Optical Tweezers

Dholakia group, St. Andrews, great links

Grierlab