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Introduction to Optofluidics

1 - 5 June 2009

Use of spatial light modulators (SLM) for beam shaping and optical tweezers

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ICTP

Use of spatial light modulators (SLM) for beam shaping and optical tweezers

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Part One

- Holographic Optical Tweezers
  - Tweezers human interface, the “optical nano-hand”

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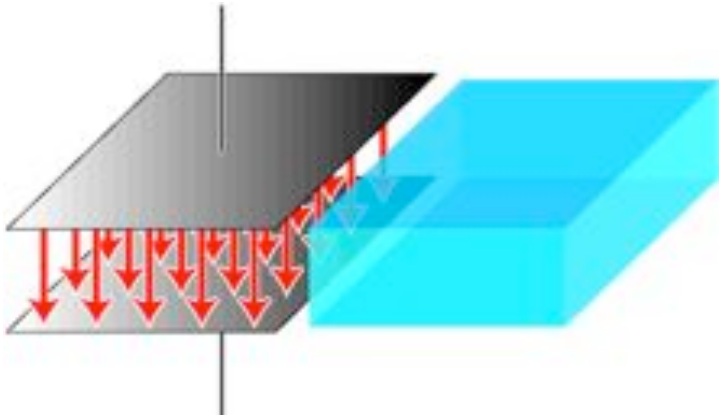
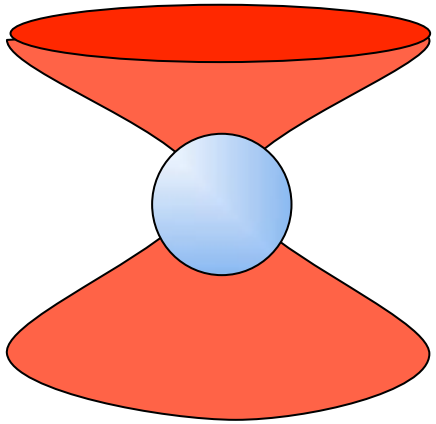
Optical Tweezers: the trapping force



- The charged capacitor
  - "gradient force" acts on dielectric
  - Draws dielectric into region of high field



- The focused laser
  - "gradient force" acts on dielectric
  - Draws dielectric into region of high field
  - But need to immerse in fluid to damp motion

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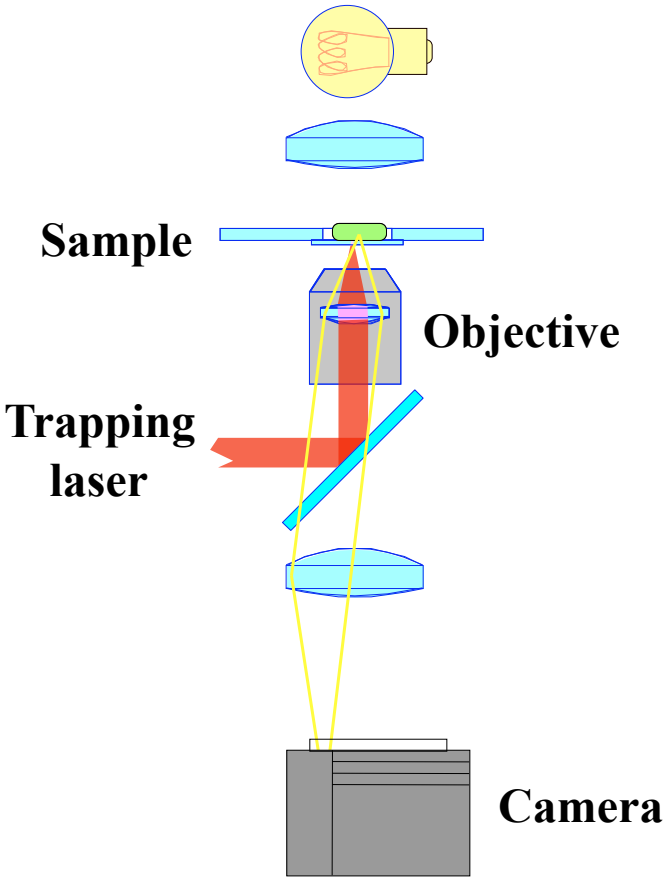
Optical Tweezers: two problems to overcome

- Two Problems
  - Making the laser beam small enough to hit the object
  - See what's going on
- Solution
  - Use a microscope to do both
  - Inverted geometry allows ease of access



Ashkin *et al.* Opt. Lett. 11, 288, 1986

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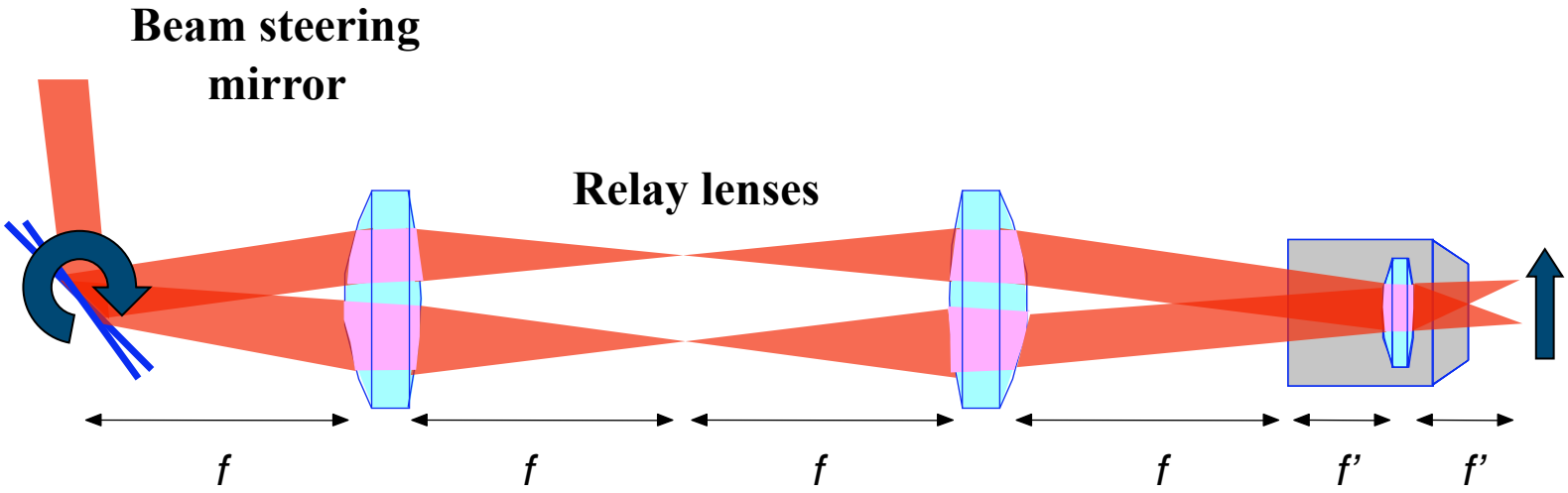
Moving objects around



- Angular deflection at mirror gives lateral shift of trap

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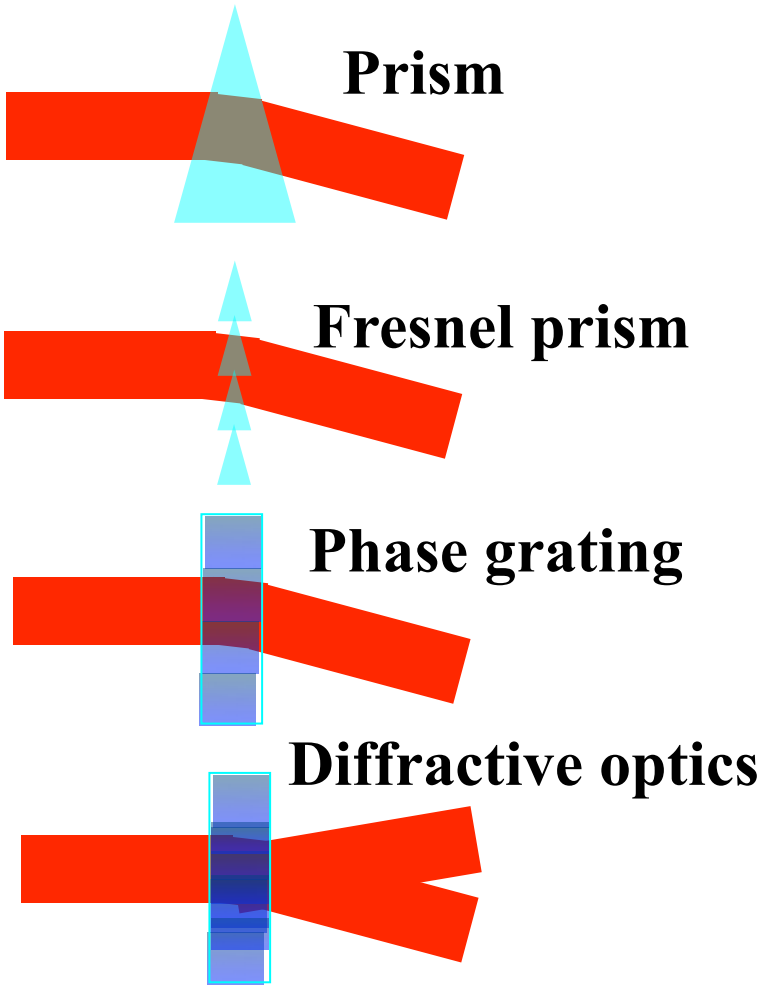
Holographic optical tweezers

- Create traps and steer them around
- Ways of deflecting a beam
  - Prism
  - Fresnel prism
  - Phase grating (ϕ=0-2π)
  - Diffractive optics



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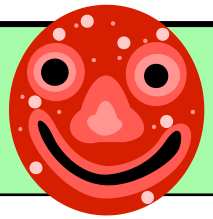
Moving objects around in optical tweezers

Technology	Positives 	Negatives 
Acousto-optic modulator	Precise lateral shift (≈nm) Fast multiplexing (kHz)	No axial shift
Galvo-mirror	Large dynamic range (>100μm)	No axial shift Limited multi-plexing (<10)
SLM	Axial AND lateral shift (>10's μm's) Multi-trap	Slow (nematic ≈10Hz, ferro ≈100Hz) Limited dynamic range
Deformable mirror	Fast (kHz)	Only axial shift Limited range (≈μm)

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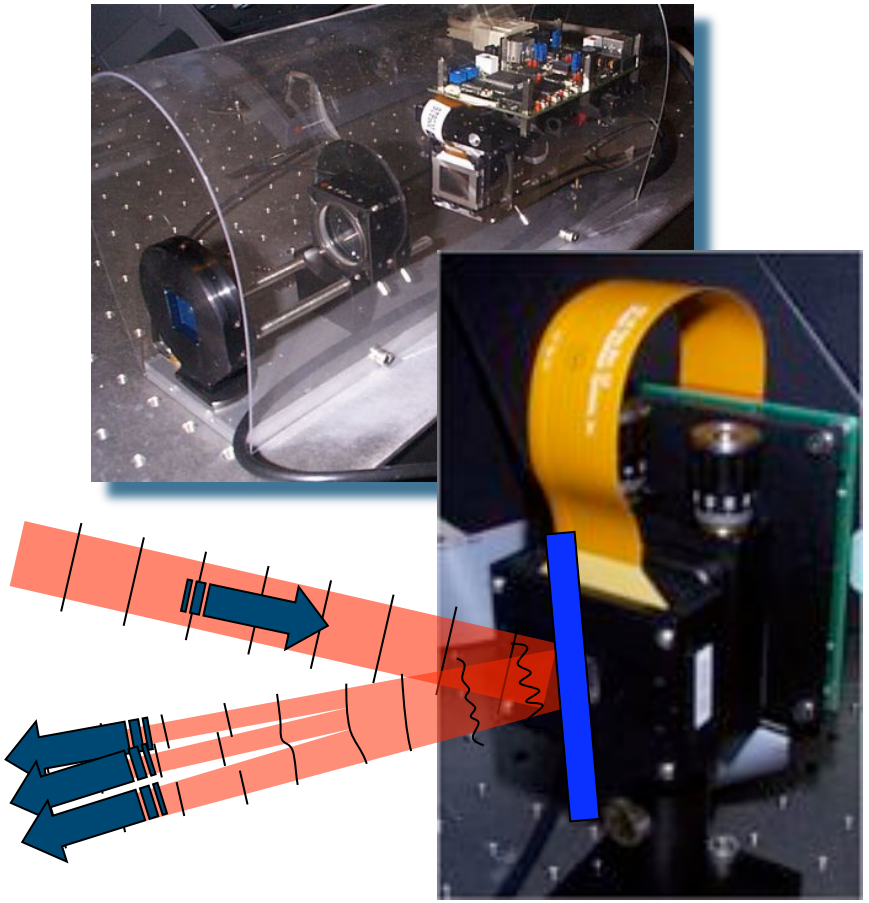
Spatial Light Modulators: what are they?

- Diffractive optics, e.g.
  - Diffraction grating
  - Fresnel lens
  - Hologram!
- Make reconfigurable with “data projector” technology
- Calculate pattern to get desired diffraction
  - Computer generated hologram



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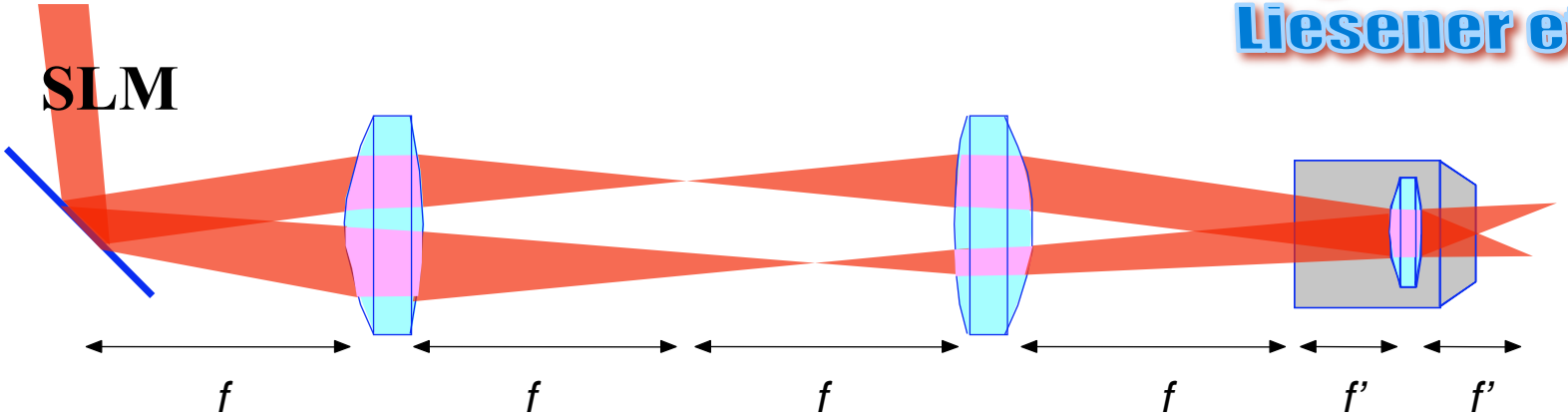
Moving objects around

Precursor work by
Fournier et al
Hayasaki et al
Liesener et al.



- Angular deflection at mirror gives lateral shift of trap
- Wavefront curvature gives axial shift of trap
- Splitting the beam gives multiple traps

Curtis *et al.* Opt. Commun 207, 169, 2002

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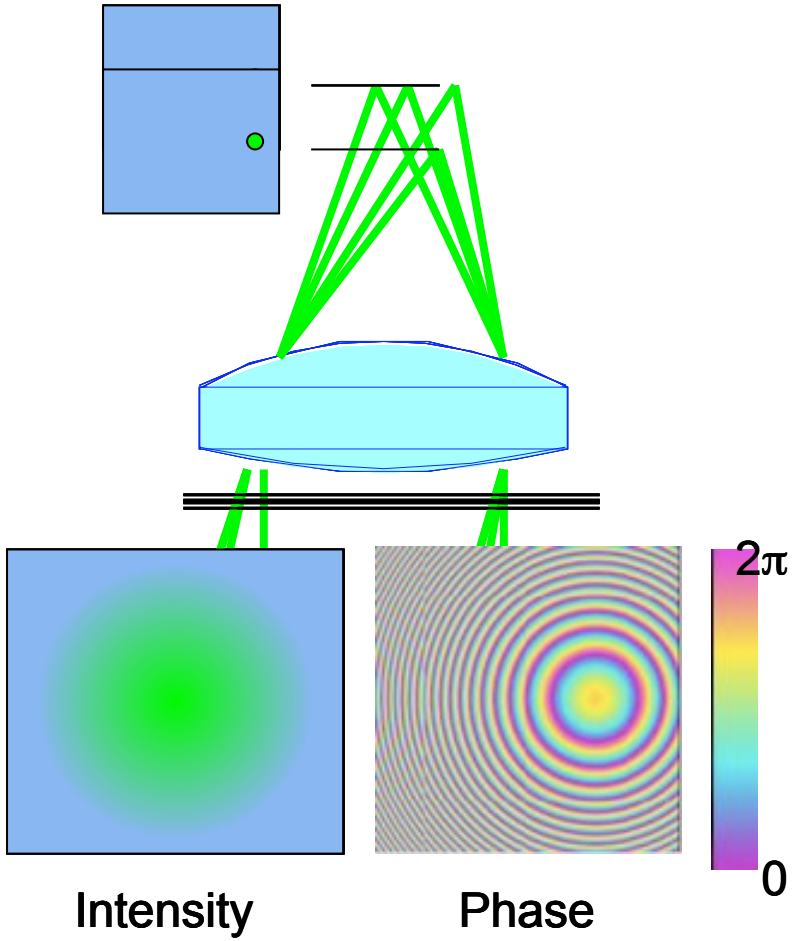
Consider Holograms as back projections

- Consider a point of light positioned at the trap
- What does it look like back in just behind the lens?



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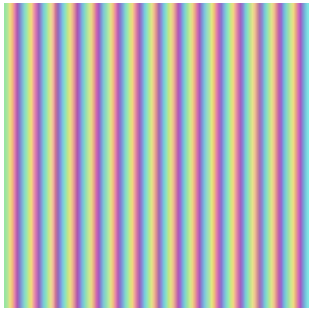
We've just designed a hologram

Grating

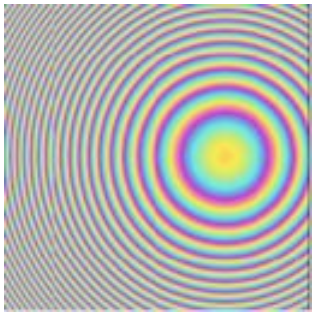


+

Modulo 2π

Lens

=



SLM

Reimage SLM to lens

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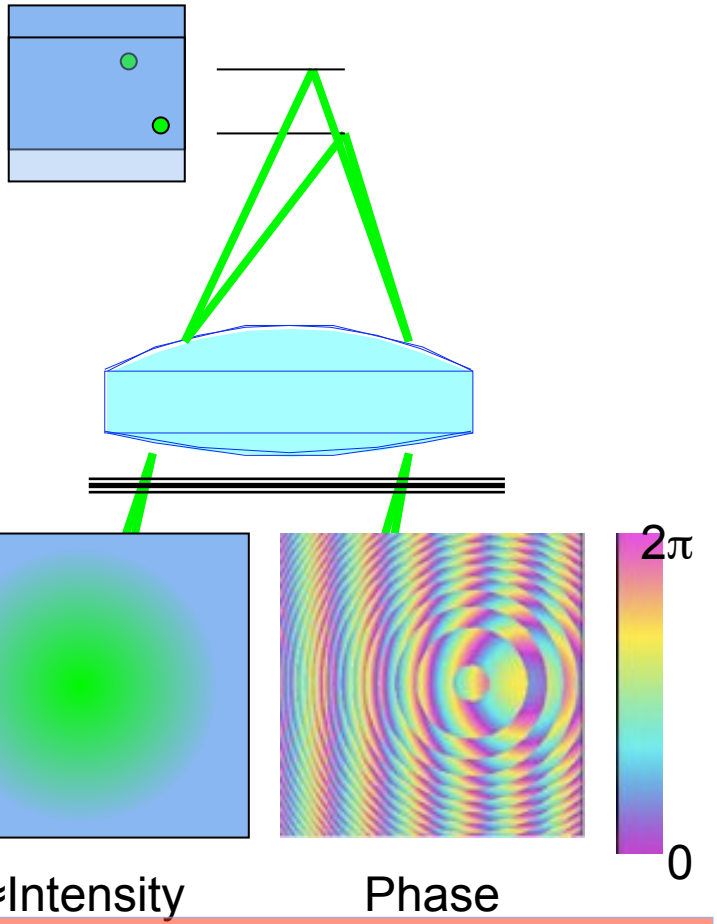
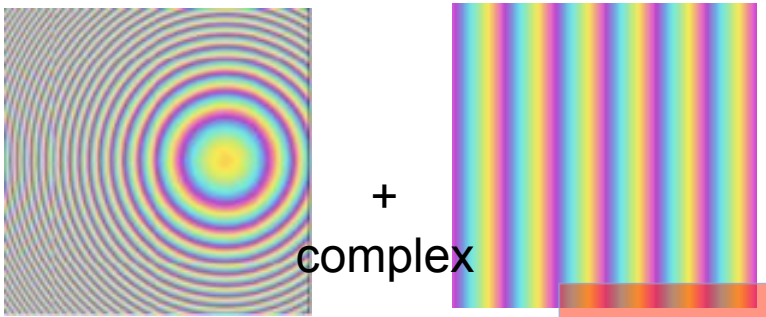
Adding traps, gratings and lenses

- Consider a second point of light positioned at the trap
- For equal intensity the interference pattern is simply the sum of the two phase distributions



$\exp(i\theta_1)$ + complex $\exp(i\theta_2)$



Reicherter *et al.* Opt. Lett. 24, 608, 1999

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Software for driving SLMs

- Software for hologram design and drive of SLMs
  - http://www.physics.gla.ac.uk/Optics/projects/tweezers/slmcontrol/

Click Here!

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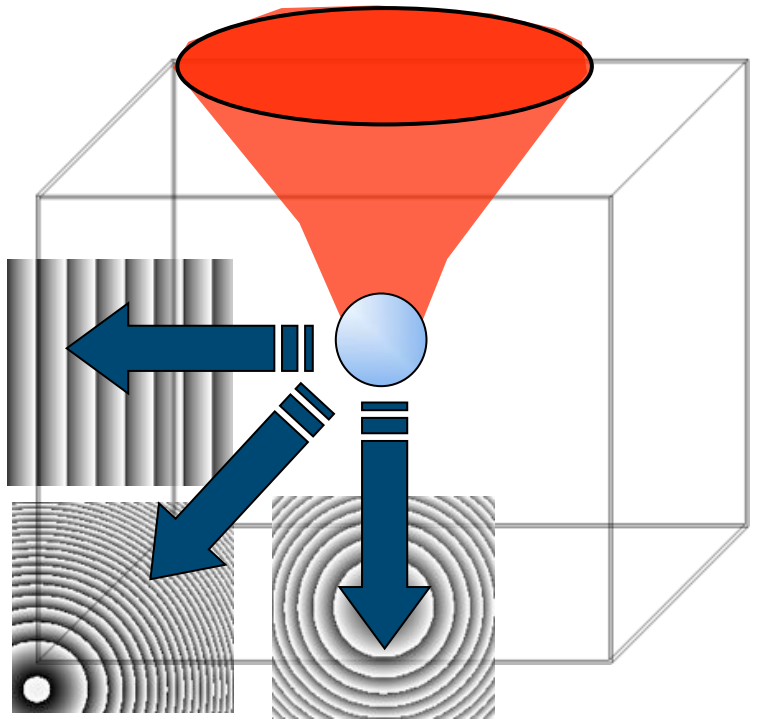
The range of SLM manipulation

- Lateral shift limited by spatial resolution of SLM
  - +/- 40μm
  - cf fov 190μm
- Axial shift also limited by spherical aberrations of objective lens
  - +/- 25μm
  - Aberration correction, improves trap by≈ 20%



Sinclair *et al.* J Mod. Opt. 51, 409, 2004

Wulff *et al.* Opt. Express 14, 4170, 2006

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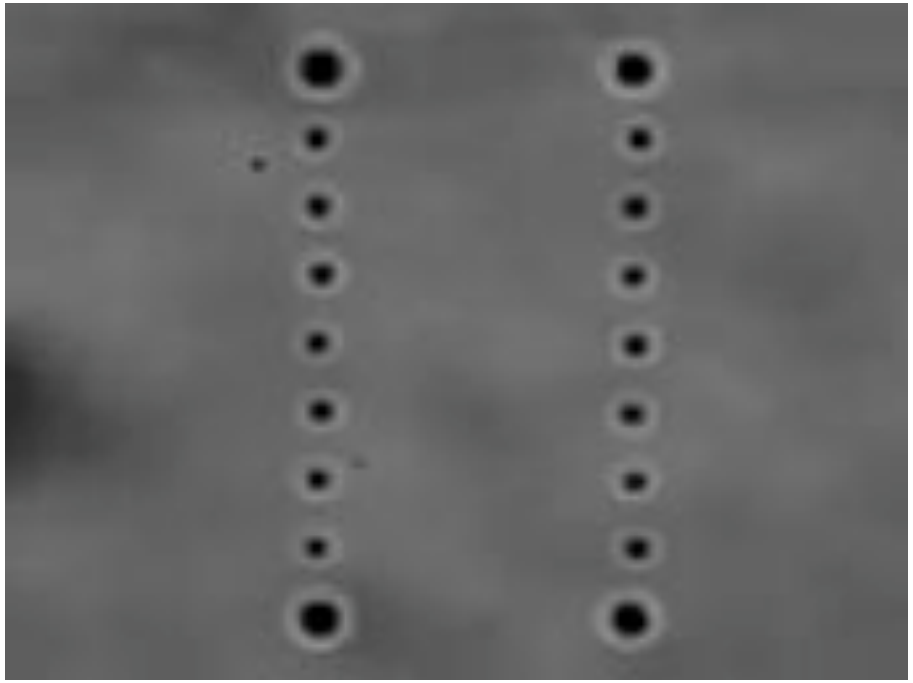

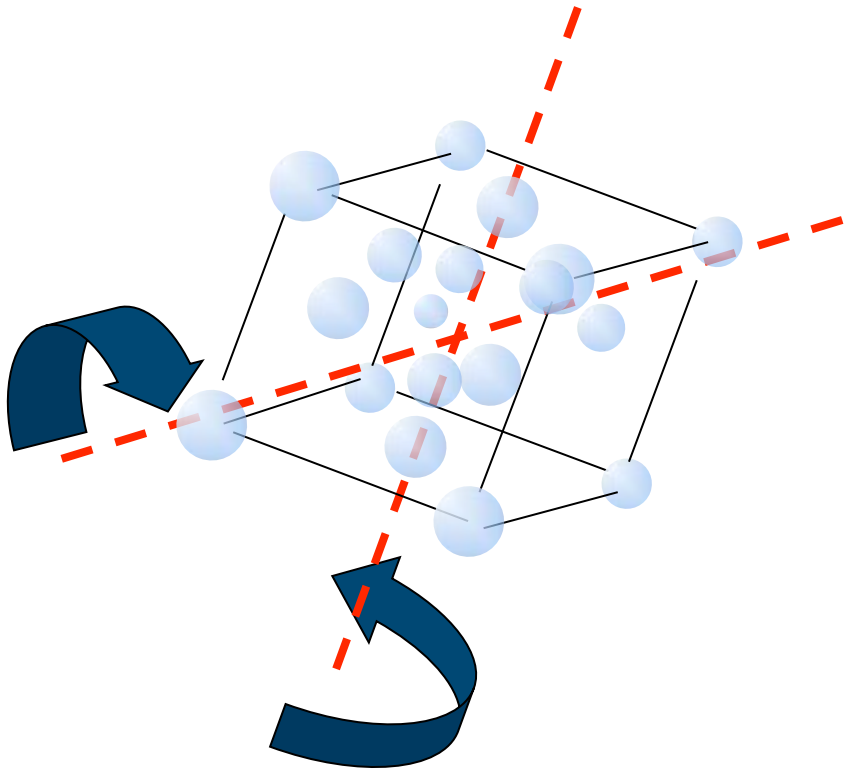

- 18 beads in 5 planes

Sinclair *et al.* Opt. Express 12, 5475, 2004

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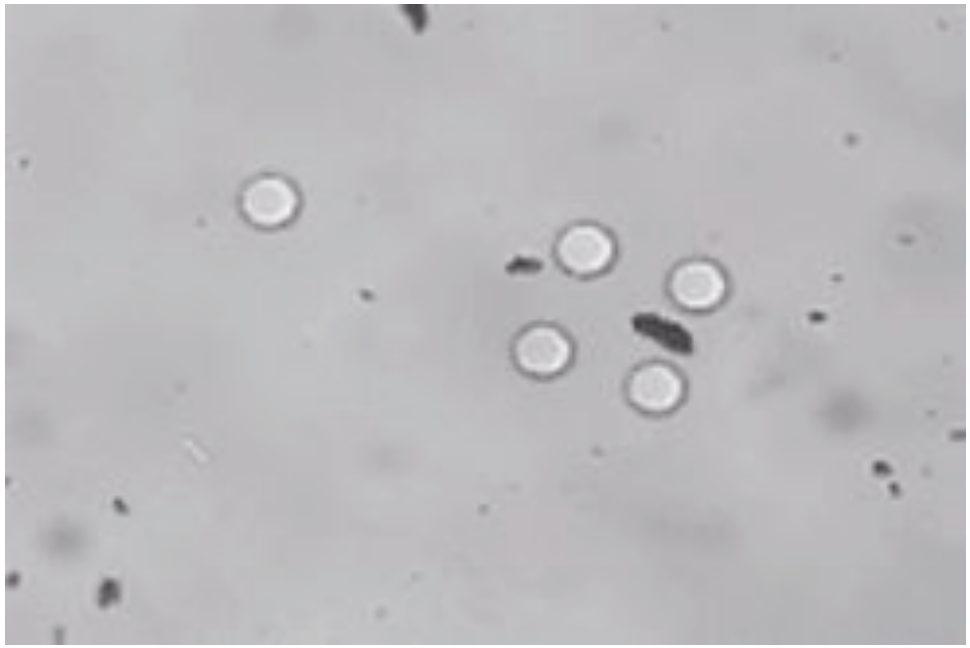
The Gripper at work….



4 x 5micron dia. trapped silica beads, gripping and moving a metal particle

Gibson *et al.* New J. Phys. 9, 14, 2007

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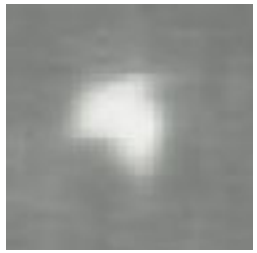
Aberration correction

- We aberrations in optical systems using additional holograms
  - Important for <1micorn particles
- Wulf *et al.* Aberration correction in holographic optical tweezers,

Hologram 

Uncorrected spot 

Corrected spot 

Wulf *et al.* Opt. Express 14, 4170, 2006

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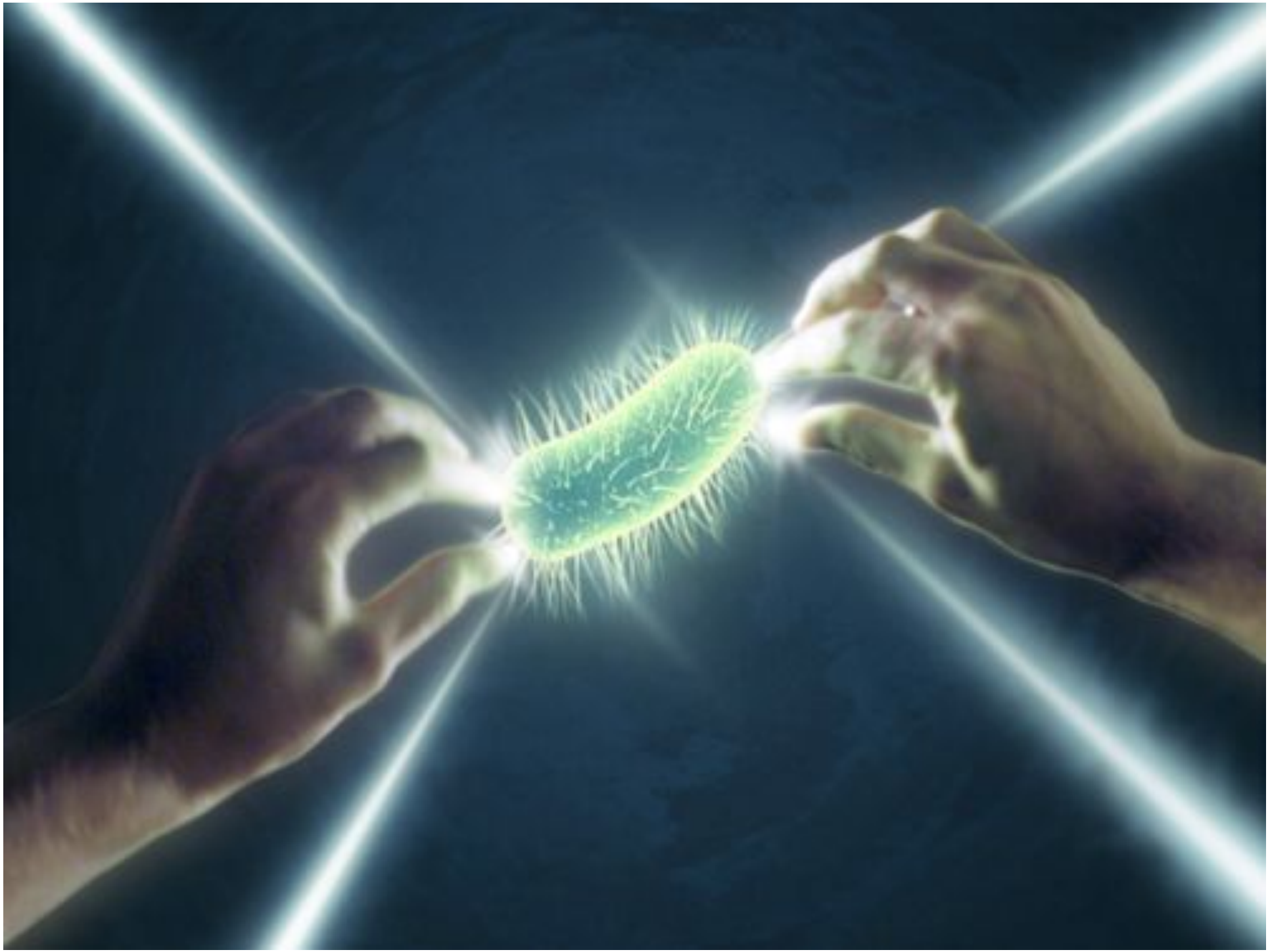
The microhand workstation



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Controlling a Micro-Hand

Whyte *et al.* Opt. Express 14, 12497, 2006

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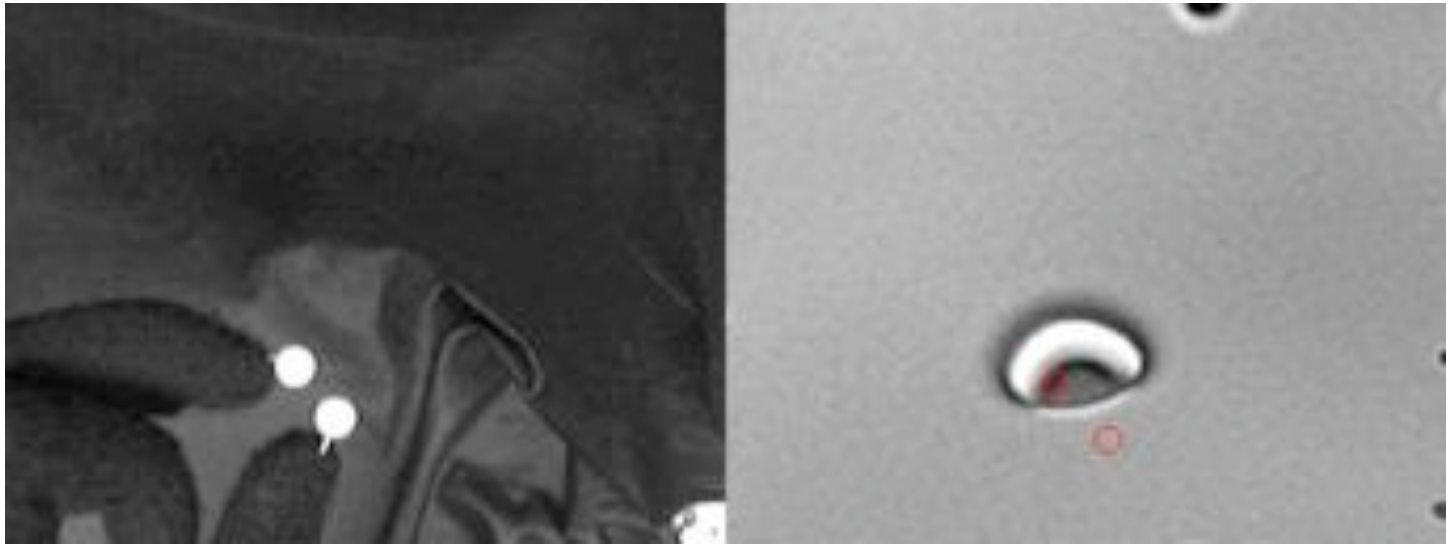
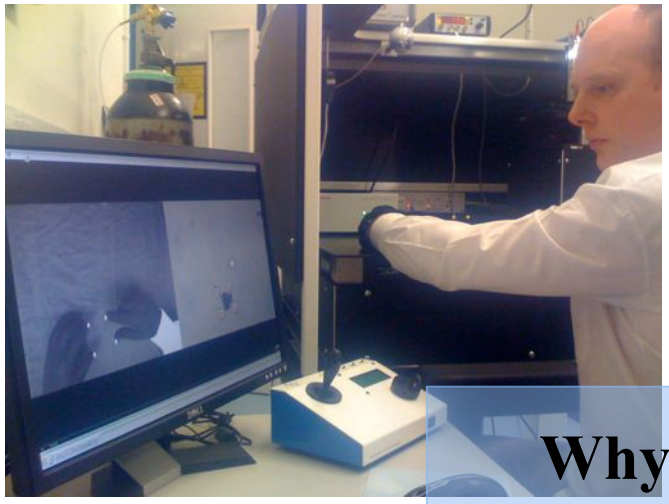
The nano hand (collab. Miles, Bristol)





Whyte *et al.* Opt. Express 14, 12497, 2006

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The multi touch screen

- The world's largest iPhone!

Grieve *et al.* Opt. Express 147, 3595, 2009

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iTweezers!

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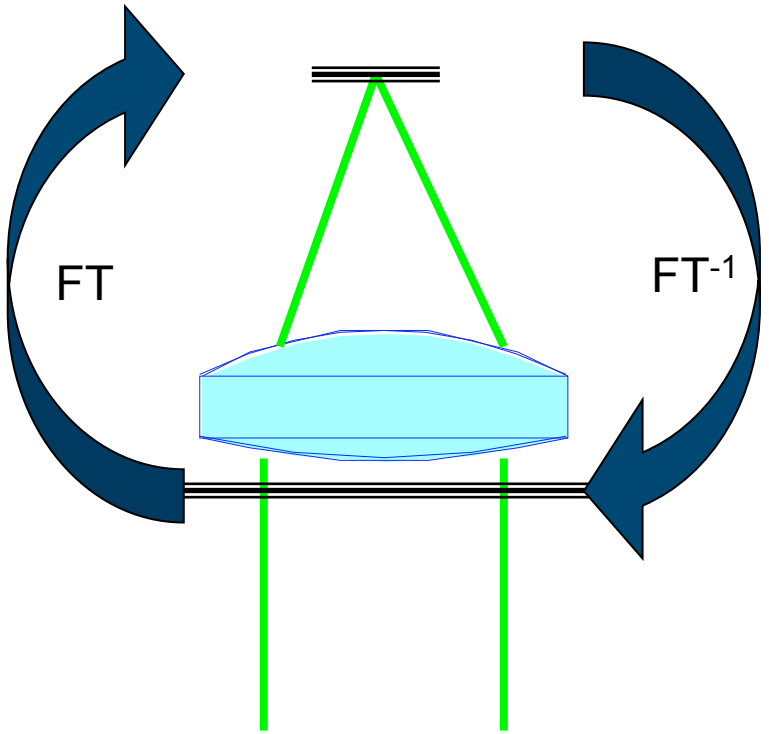
Gerchberg Saxton

- But what what more complicated patterns (not points)
- The trapping plane and the lens plane are transformed as Fourier-Transforms



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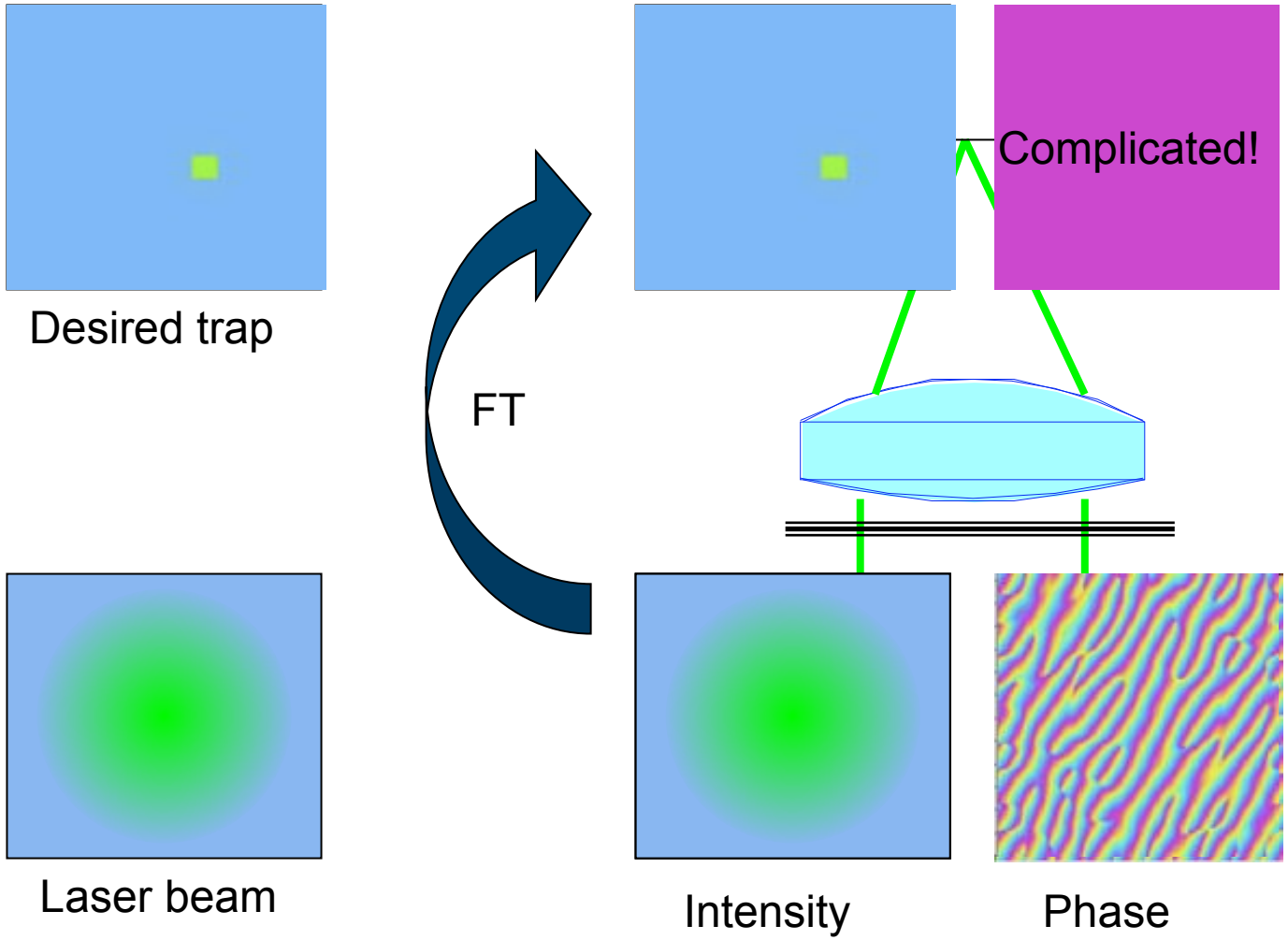
Gerchberg Saxton



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Software for driving SLMs

- Software for hologram design and drive of SLMs
  - http://www.physics.gla.ac.uk/Optics/projects/tweezers/slmcontrol/

Leach *et al.* Appl. Opt. 45, 897, 2006

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www.physics.gla.ac.uk/Optics