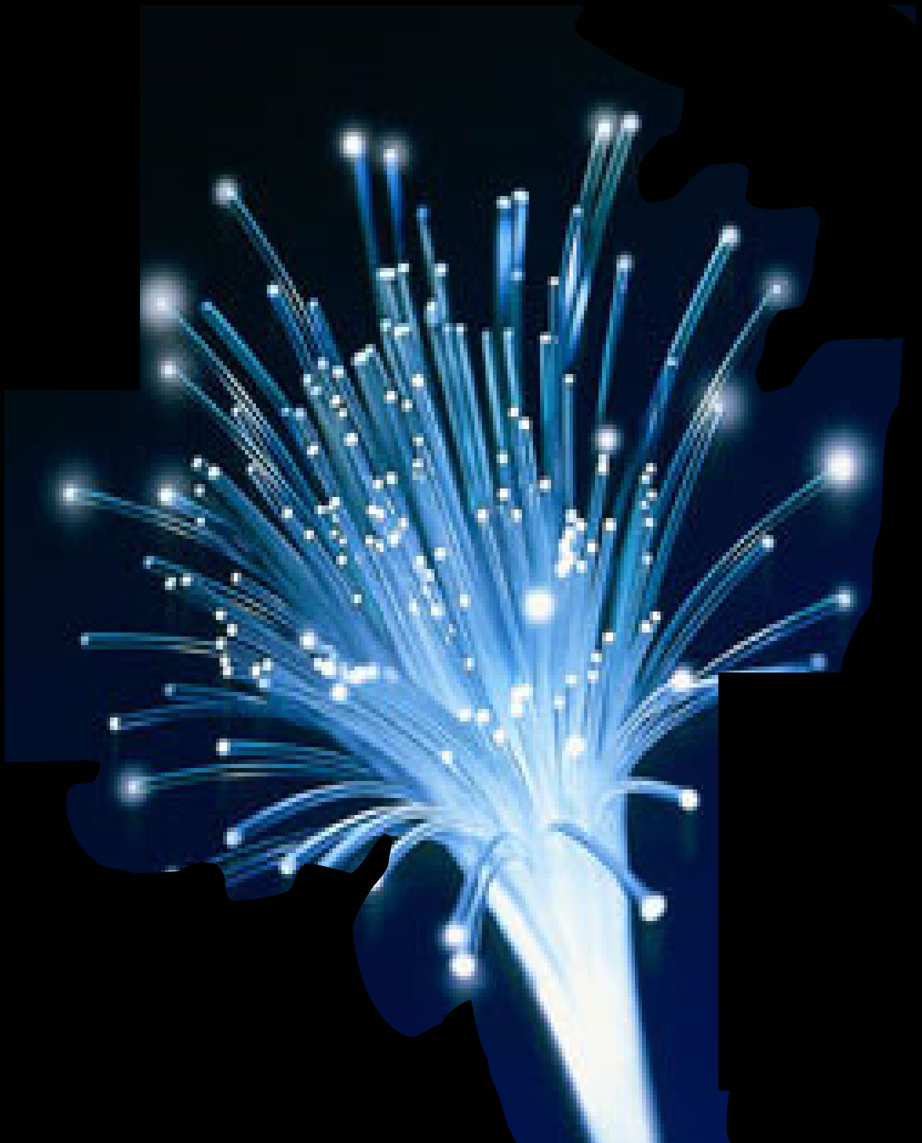
Microfibres for Quantum Optics

Dr Síle Nic Chormaic
Quantum Optics Group



Motivation

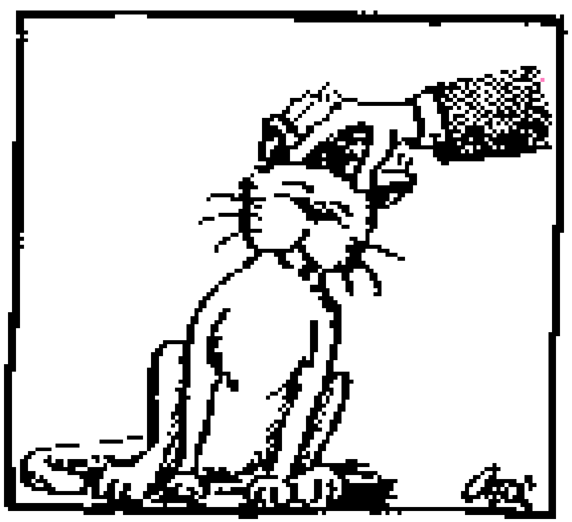
Strong need to engineer atoms and photons for the development of new technologies… "*quantum technologies*"

Future advances in nanotechnology, communications, cryptography, information processing, computing all rely on these developments.

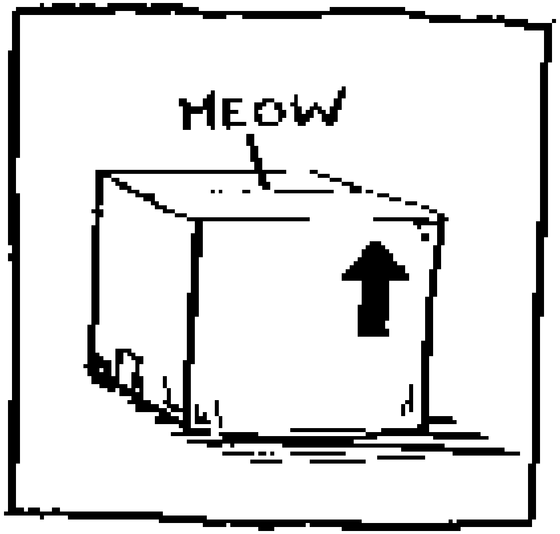
Explore techniques to control and manipulate internal and external properties of particles (atoms, photons,…) in a manner that would have been *impossible* 10-20 years ago.

What is Quantum Optics?

A field of research in physics, dealing with applying quantum mechanics to phenomena involving light and its interactions with matter.



Theoretician's Cat



Experimentalist's Cat

Research Activities

- Design and testing of novel microcavity light sources from UV to near IR, including lasing devices at 1560 nm.

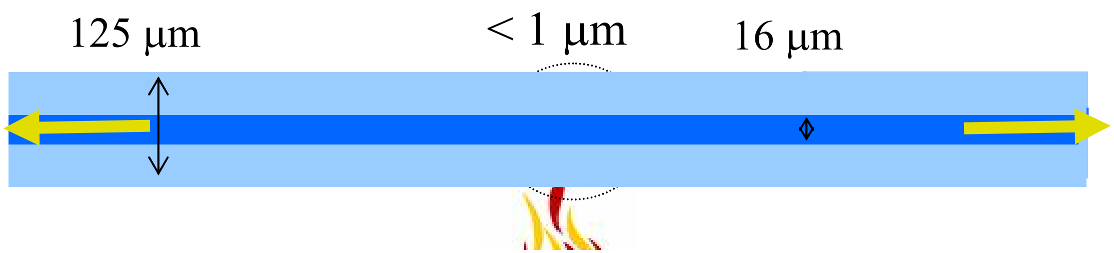
- Development of atom optics elements for cold atoms (diffraction gratings, waveguides,…) to manipulate and control the centre-of-mass motion using light and/or magnetic fields → enables **atom+light interaction** studies.

The microfibre is the common element in all our work…

Research Laboratory

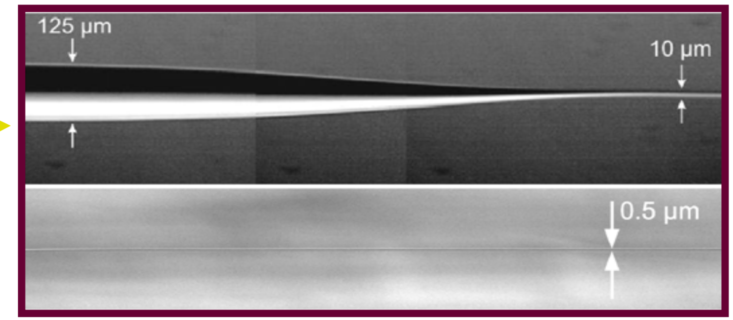
Based in Tyndall National Institute

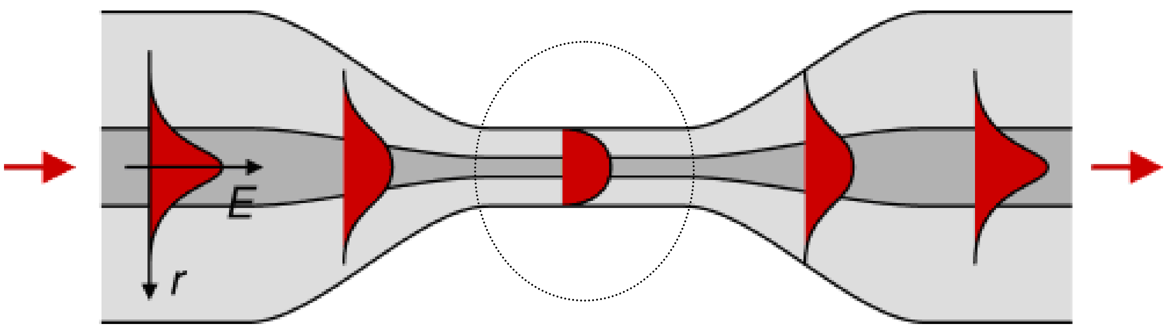
Microfibres



Single mode fibre

Taper region: Cladding becomes core, vacuum becomes cladding

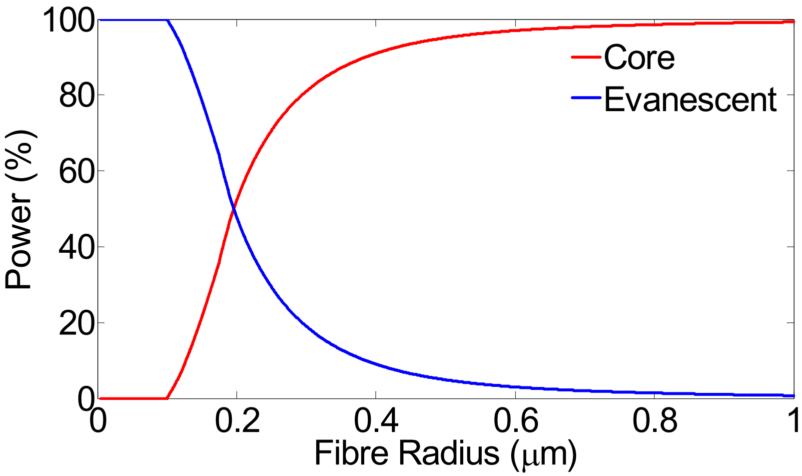


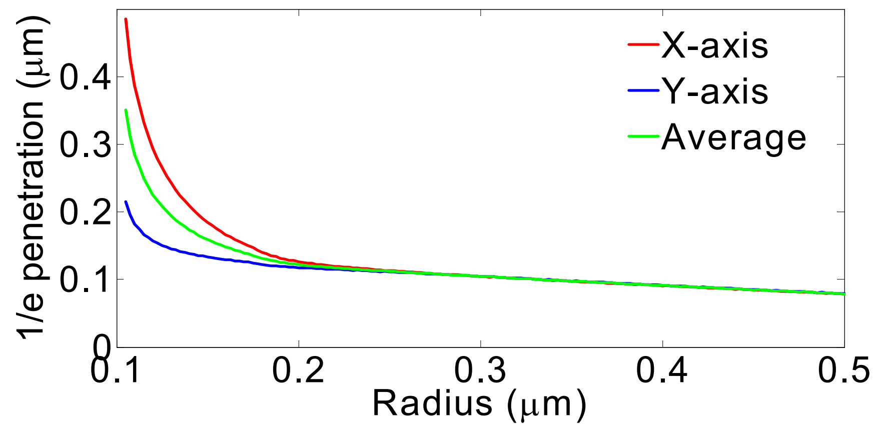


Evanescent field component in tapered region extends beyond fibre surface: very high intensities achieved

1 micron fibre versus 100 micron hair

Evanescent field

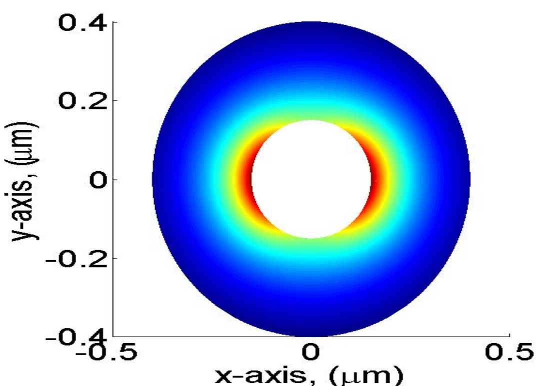




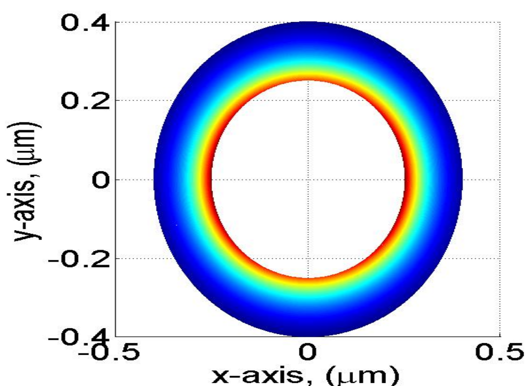
a = 0.5 μm, *Ev* = 5%
a = 0.3 μm, *Ev* = 20%
a = 0.1 μm, *Ev* = 100%, but unguided!!

Decay length ~ 100 nm

r = 0.15 μm



r = 0.25 μm

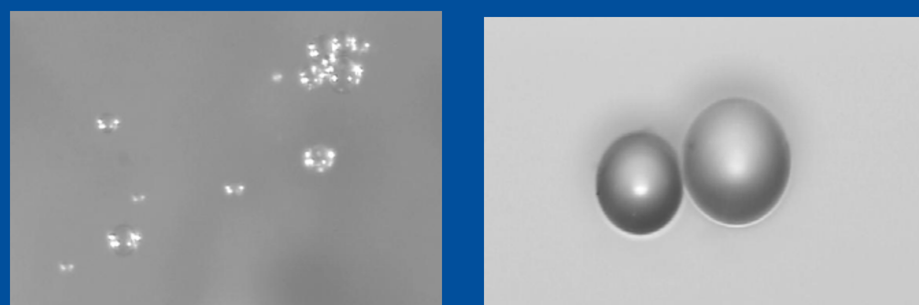


Variation in the power distribution of the evanescent field for two fibres of different radii.

Microfibres for Microcavity Light Sources

- Characterisation of light emissions from solid laser glass spheres, diameter ~50-80 micron.

- Use erbium-doped novel fluorides (ZBNA, ZBLAN, ZBLALiP) and erbium/ytterbium co-doped commercial phosphate (IOG2) glass.

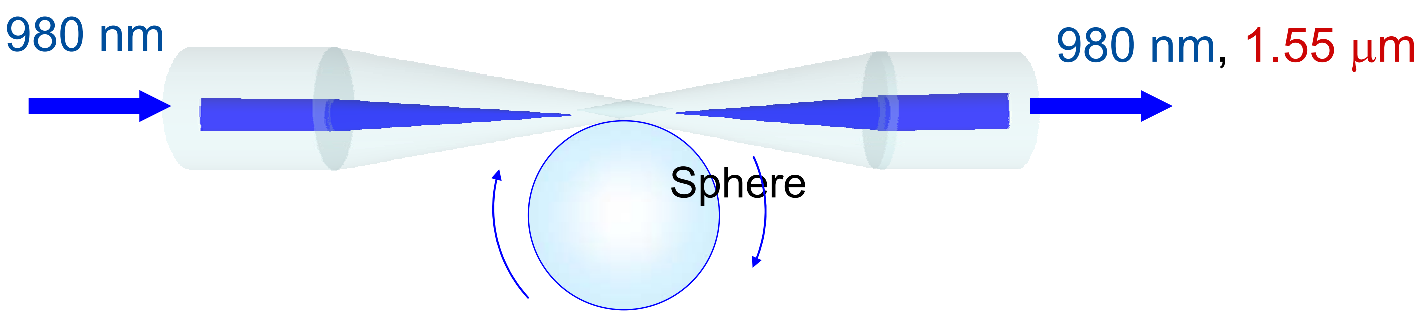


Images of our Er:ZBNA microspheres

- Microspheres fabricated in ENSSAT (France) by dropping glass powder through a microwave plasma torch. Surface tension produces spheres with ~10^{-3} eccentricity.

Mode Matching for Light Coupling

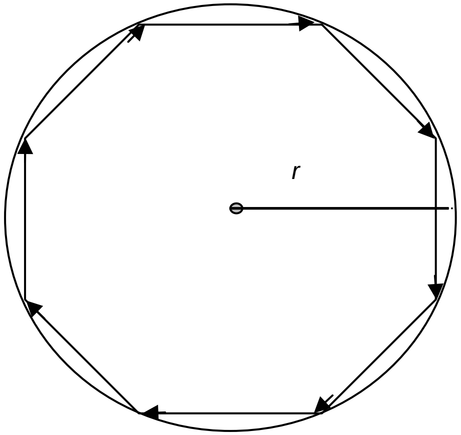
- Couple 980 nm pump light into sphere using tapered optical fibre with waist ~ 1 micron → evanescent field coupling.

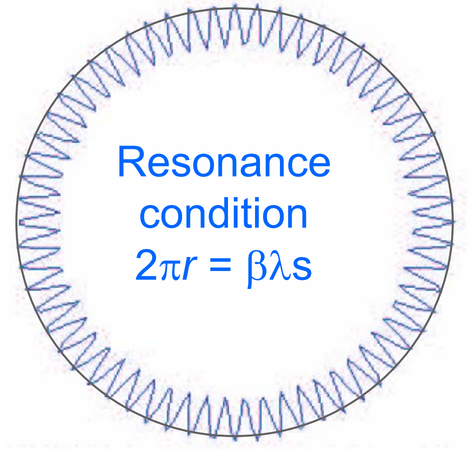


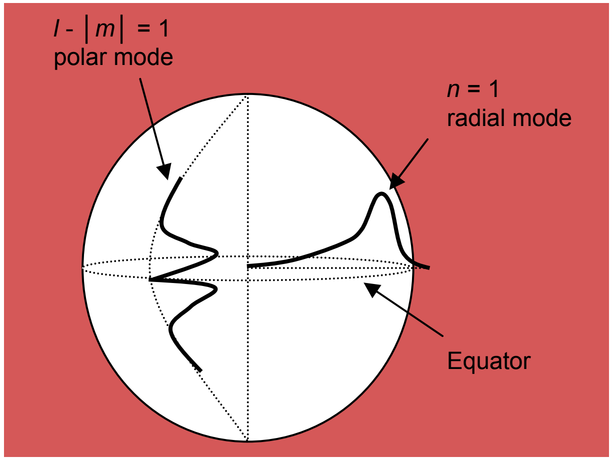
Whispering gallery modes. Strong green emissions at 520 nm and 540 nm are characteristic of erbium doping due to upconversion of 980 nm pump.

Whispering Gallery Modes

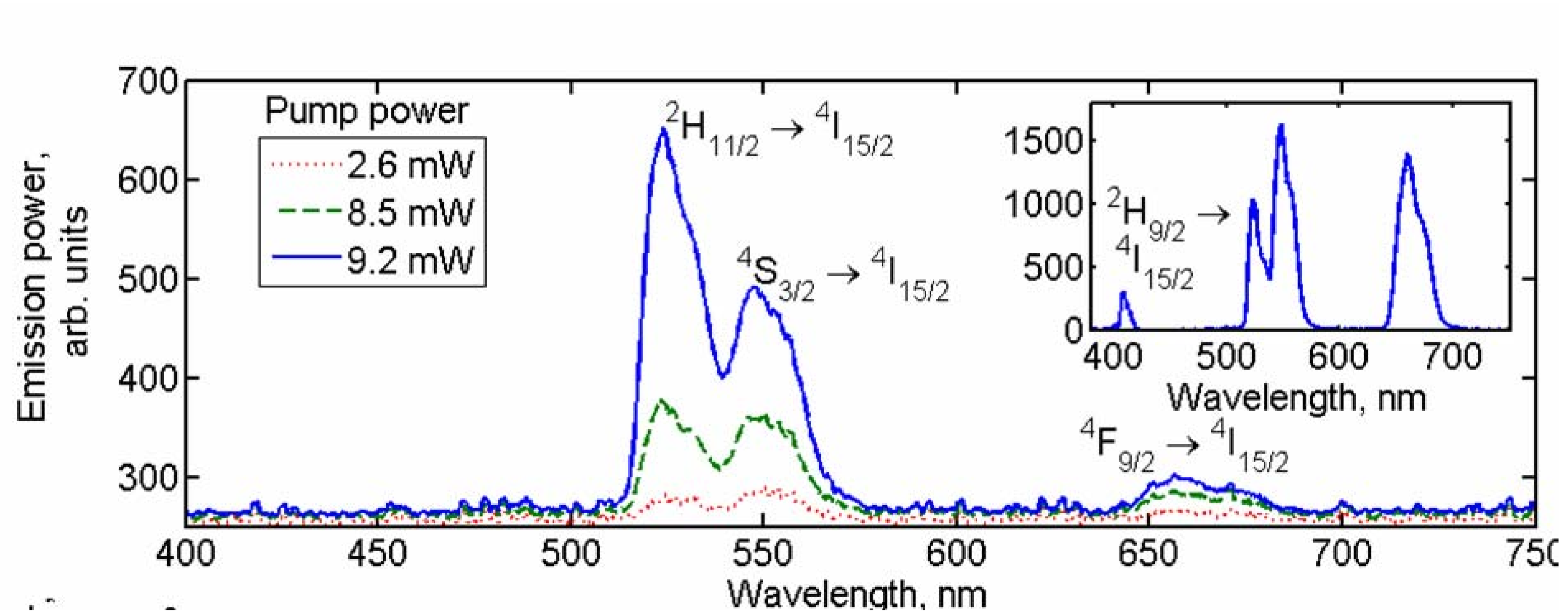
Light travelling inside sphere, strikes glass-air interface. Total internal reflection occurs. If sphere is of good quality light undergoes multiple reflections … leads to long photon storage lifetimes, high Q factor and low mode volume







Example: Temperature Sensing

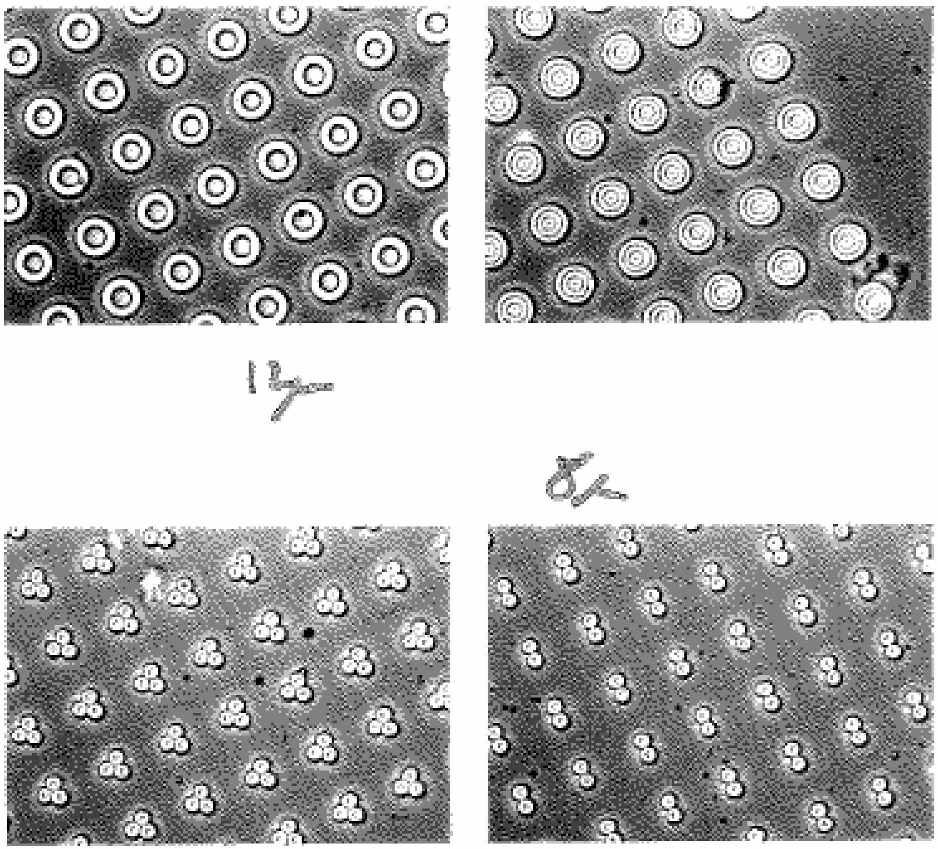


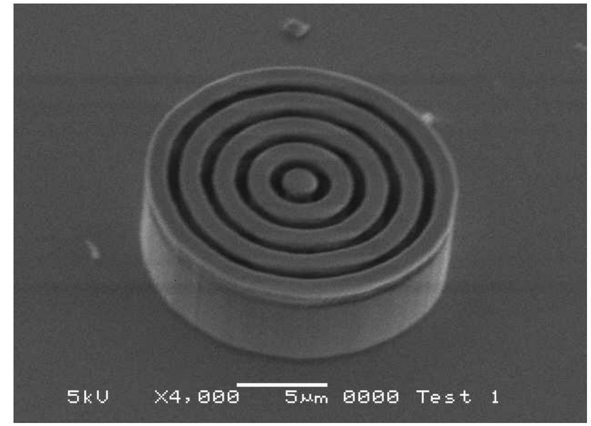
Ratio of emissions between 520 nm and 540 nm lets us estimate temperature of environment.

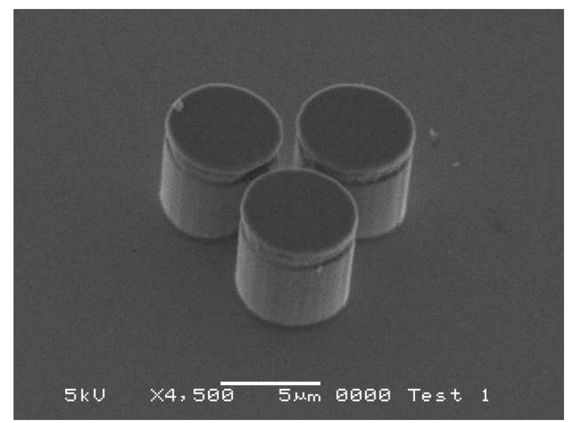
Equivalently, increasing intensity of pump light coupled into sphere, changes its temperature and changes its size (monitor green ratio to see effect).

By changing the size, can tune the cavity to be resonant with any wavelength that we need (e.g. atomic transitions)!!!!

Example: Quantum Dot Devices

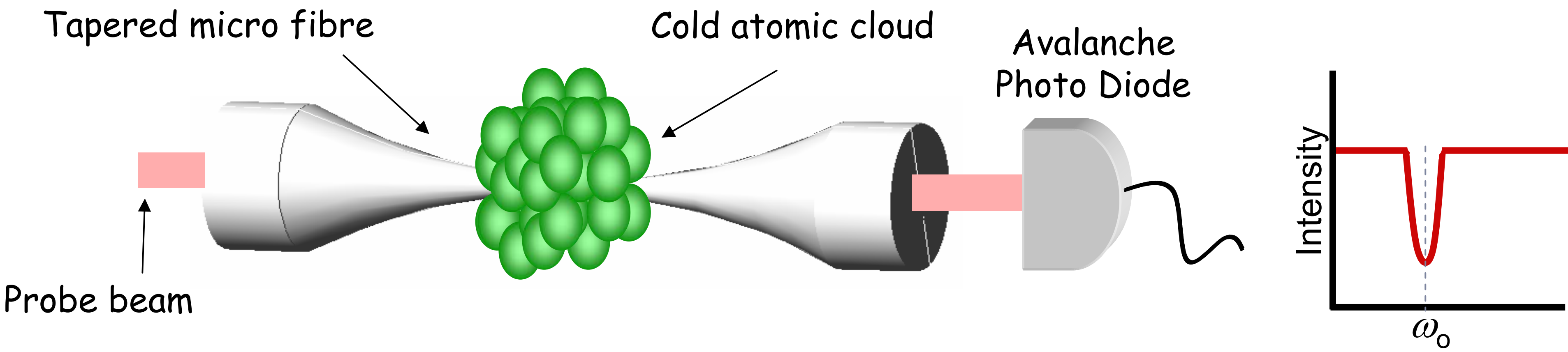




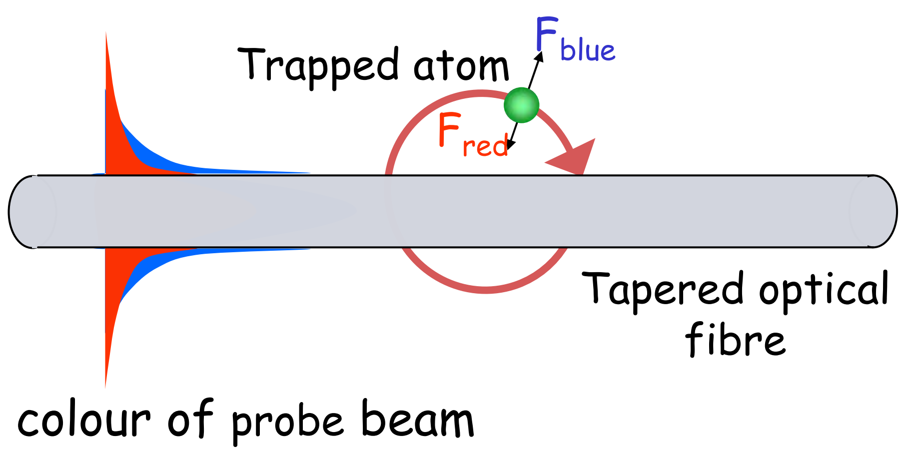


Micro-cylinder resonators with quantum dots embedded in GaAs structures. Ground state emission at 1.28 μm.

Microfibres for Cold Rubidium Atoms



When probe beam resonant with atoms, light is absorbed and a dip in the transmitted intensity is noted. Note: only about 10 atoms interact with photons in evanescent field!!



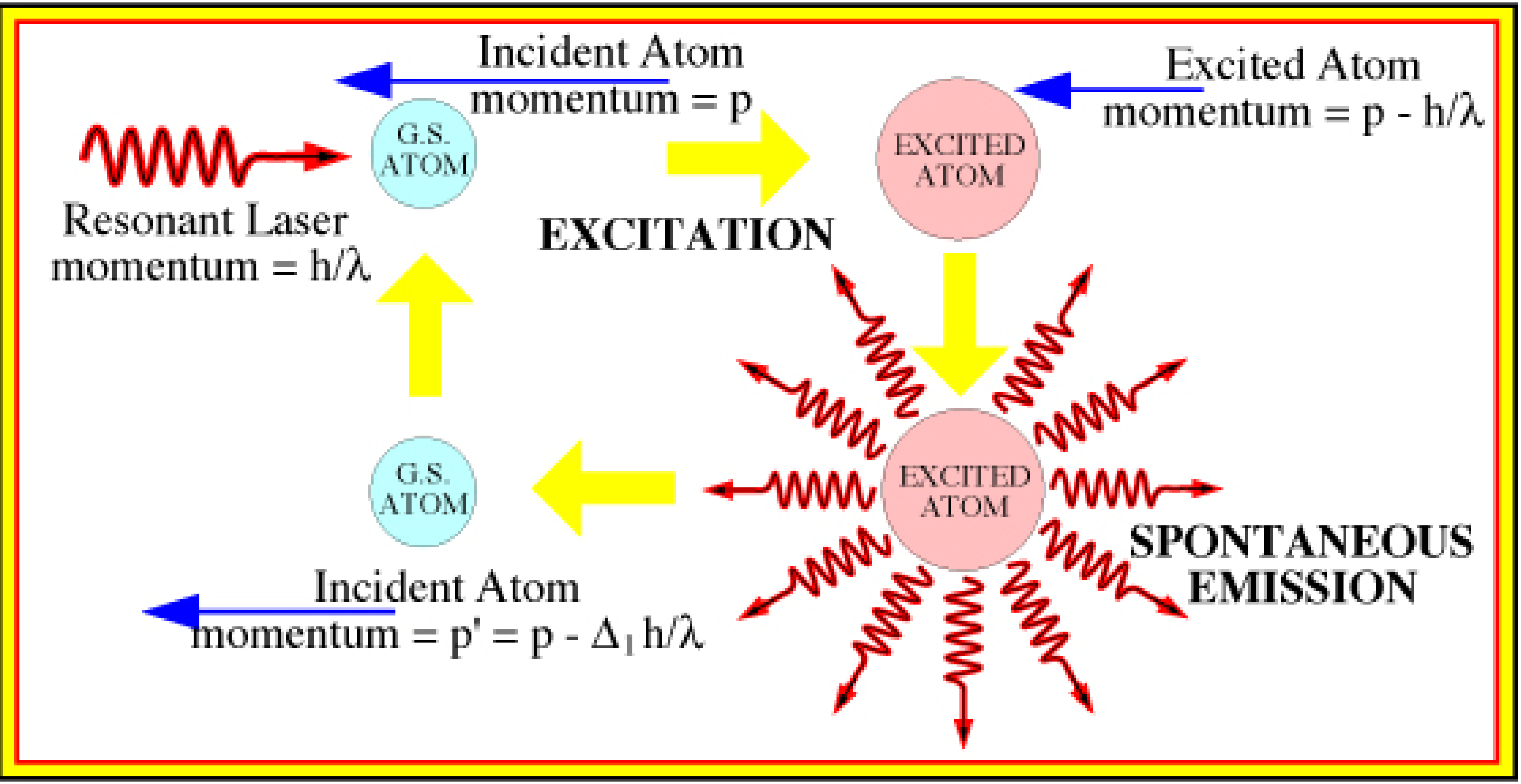
Blue detuning (shorter λ): Repulsive force

Red detuning (longer λ): Attractive force

Combination: Optical trapping of atoms ???

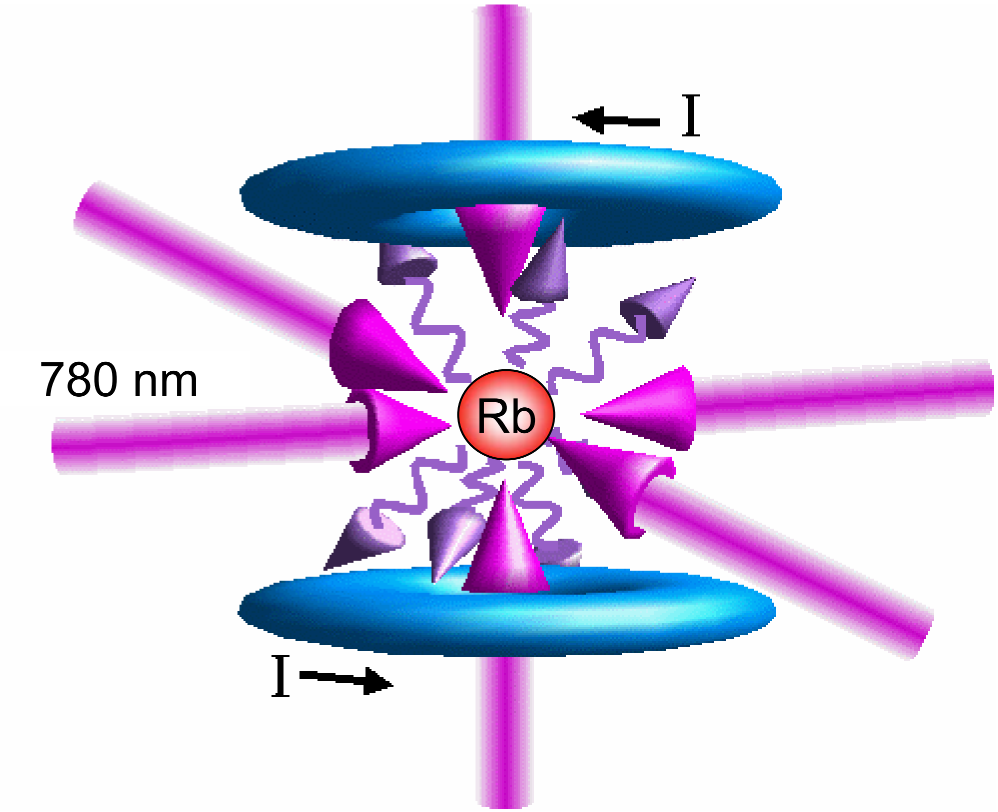
Cold Atom Source – the MOT

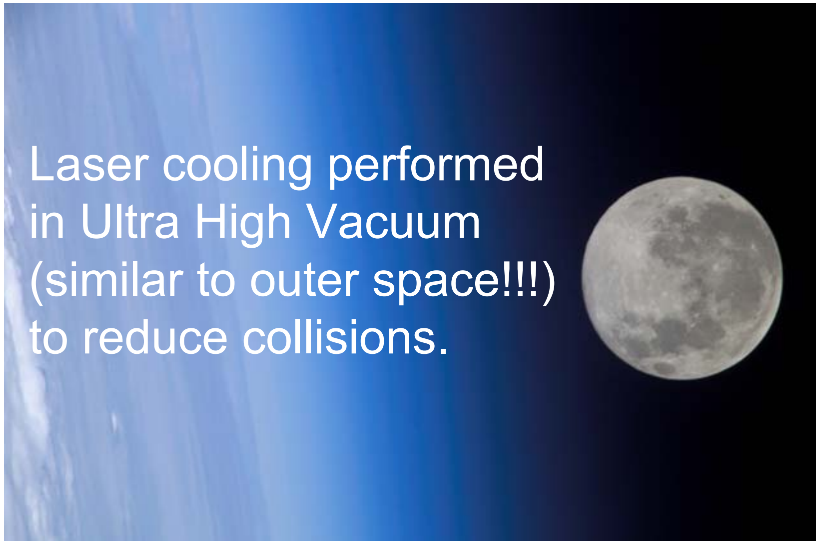
Temperature of atoms related to their velocity: $\frac{1}{2}mv^2 = k_BT \quad \rightarrow \quad v = \sqrt{\frac{2k_BT}{m}}$



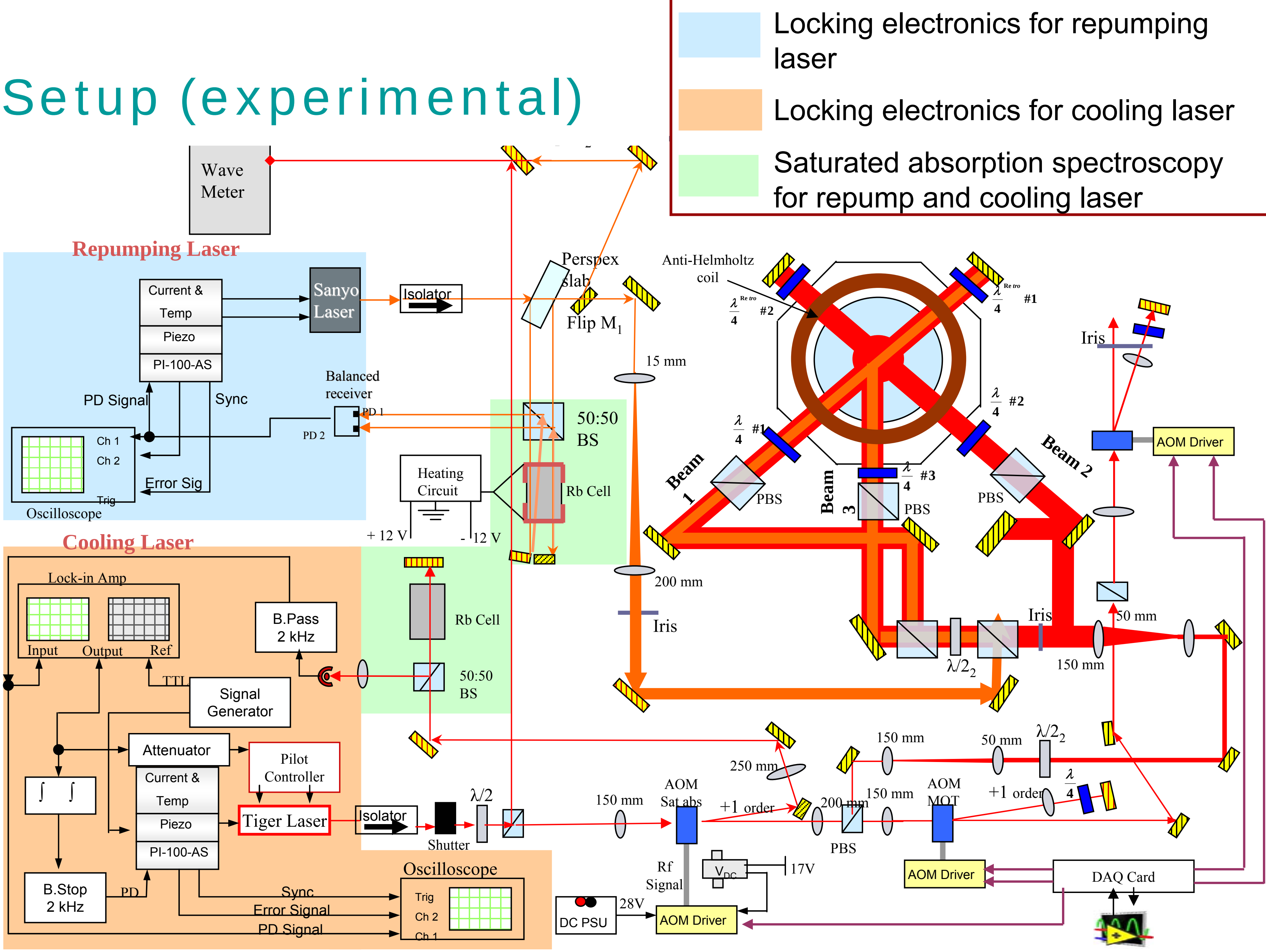
Magneto-Optical Trapping

A magnetic field added to laser arrangement to form a zero field region in the centre – the atom trap. Atoms pushed towards centre since they are "low-field seekers".



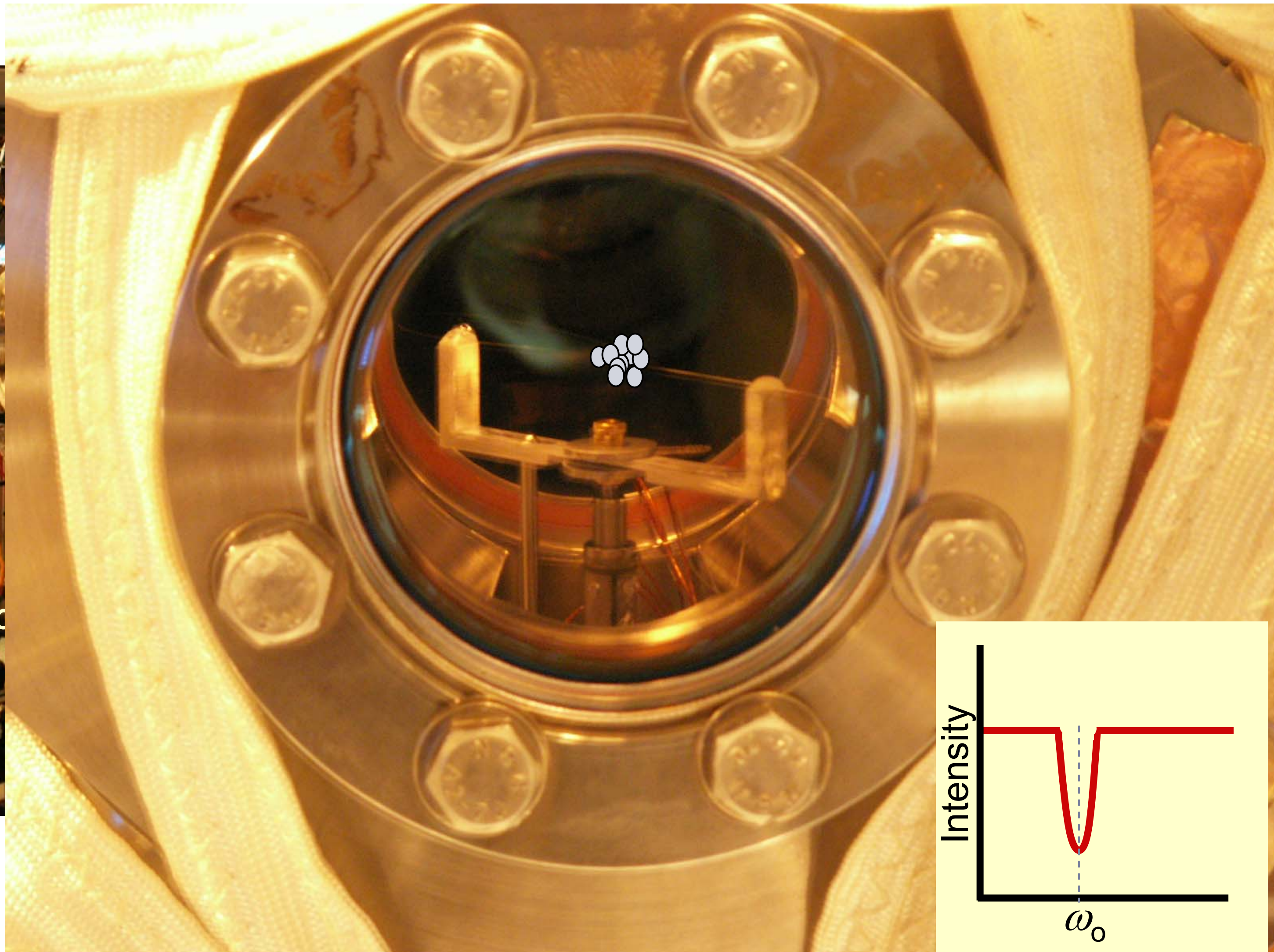


Setup (experimental)



Setup (theoretical)

Setup (experimental)



s achieved:

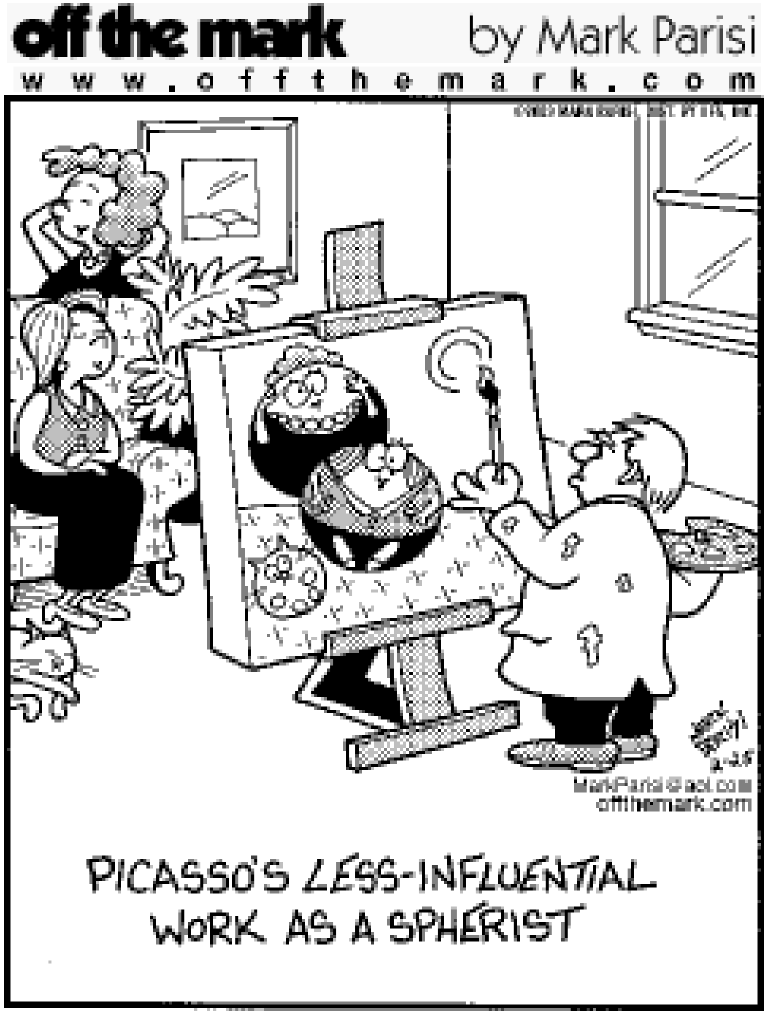
10^{-10} mbar

e: ~100 μK

ns: ~ 10^7

~ 1 mm

Projects...



Possible 4th year projects:

- Optical Tweezers for Manipulating and Trapping Particles (biophysics interest)
- Microdisk Resonators with Quantum Dot Coatings (photonics interest)
- Narrow Linewidth Laser for Rb Spectroscopy and Atom Cooling (quantum, atom, optics interest)

If curious, office 215d
www.physics.ucc.ie/nicchormaic

For podcasts on quantum engineering: http://physics.nist.gov/Mp4s/

Group Members

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