# Resonator sensors

## Simulating 'whispering gallery modes' in micro-resonators.

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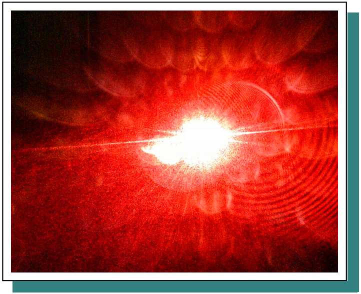

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## IONS-KOALA 2014, 23-28 November, Adelaide SA

# Sensing with light

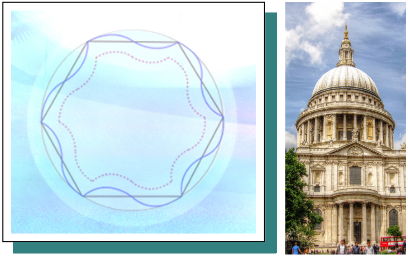
- Light can resonate inside microscopic devices: spheres, disks or shells.
- **What for?** Resonators act as detectors of nearby macro-molecules, such as viruses, bacteria or DNA.
- **How?** Resonators of a certain size (diam: 5-30 $\mu$m) can support special resonant 'whispering gallery modes'.

  $\rightarrow$ We can fabricate these resonators (e.g. polystyrene). Let's investigate the quality of a resonator.

Illustration of a resonator. Polystyrene microspheres have been shown to **lase**.

# ‘Whispering gallery modes’

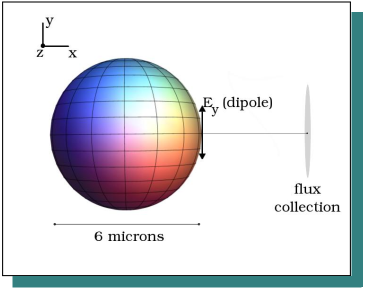
- Electromagnetic waves at the boundary of a sphere or disk can be reflected around the surface.
- These resonant ‘bound’ whispering gallery modes correspond to the number of surface nodes, and radial nodes. The are also narrow (‘high $Q$’) and trackable.
- At the material/medium interface, an ‘evanescent field’ extends outward, which is sensitive to the external environment.



Whispering galleries

# Simulation methods

- To test the viability of a resonator cost-effectively, we have developed a simulation tool (based on 'FDTD').
- In FDTD, a volume is discretised into a 4-d lattice.
- Field equations are solved at each step in time, making transient or emergent optical effects accessible.



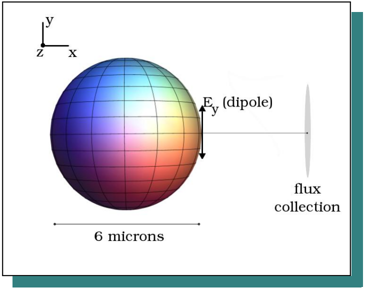

Collecting flux from a microsphere.

# Simulation methods

- We choose the source type, wavelength, and resonator size, and measure the radiation through a flux area, $A$.
- The profile of the power spectrum tells us about the mode structure, calculated from

$$P(\lambda) = \int (\mathbf{E} \times \mathbf{H}^*) \cdot \hat{\mathbf{n}} \, \mathrm{d}A.$$

- Spheres, shells and odd-shape configurations are permitted, including inhomogeneous materials.




Collecting flux from a microsphere.

# Tools of the trade

- Pro: FDTD is easy to customise- straightforward to incorporate changes to geometry, source distribution, index, and material inhomogeneities.
- Pro: FDTD can compute arbitrary flux regions/collection times to simulate realistic coupling scenarios.
- Con: FDTD is computationally intensive, especially for fine-detail, as waves across the whole volume must be simulated uniformly.
- Pro: Systematic effects from discretisation can be quantified using complementary Analytic models, and thus incorporated into the uncertainty estimate.

# Tools of the trade

Computing resources required for a three-dimensional FDTD simulation of a 6 $\mu$m diameter sphere excited by a dipole source with a central wavelength of 0.6 $\mu$m. The Tizard machine at eResearchSA is used in these simulations, which uses AMD 6238, 2.6 GHz CPUs.

| $\Delta x$(nm) | $\Delta\lambda$(nm) | CPUs | RAM(GB) | VM(GB) | WT(hrs:mins) |
|---|---|---|---|---|---|
| 33 | 0.62 | 24 | 28.45 | 34.82 | 15 : 08 |
| 30 | 0.62 | 24 | 36.73 | 43.00 | 26 : 12 |
| 29 | 0.62 | 24 | 41.44 | 47.75 | 27 : 19 |
| 27 | 0.62 | 24 | 46.57 | 52.77 | 30 : 09 |
| 26 | 0.62 | 24 | 53.33 | 59.61 | 37 : 31 |
| 25 | 0.62 | 24 | 59.31 | 65.62 | 43 : 12 |
| 22 | 0.31 | 32 | 100.19 | 108.02 | 90 : 37 |

# Tools of the trade

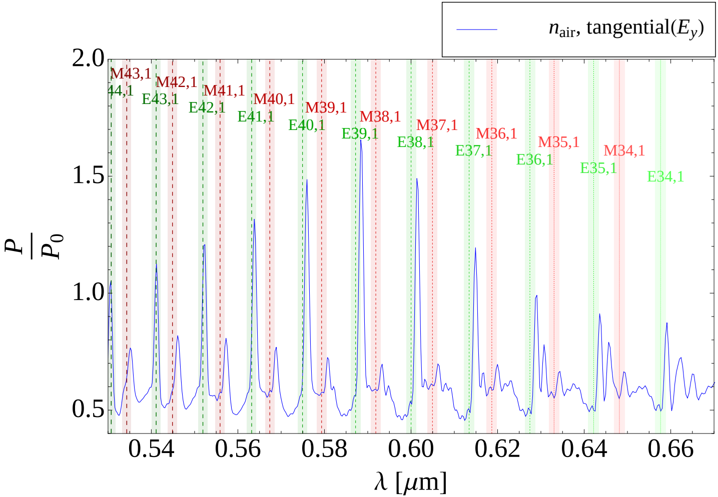
- FDTD is good for 'higher index-contrast' scenarios, where *diameter ÷ wavelength* is not too large.

- Analytic models (Mie Scattering/Shell-model) are good for 'lower index-contrast' scenarios, when *diameter ÷ wavelength* becomes large.

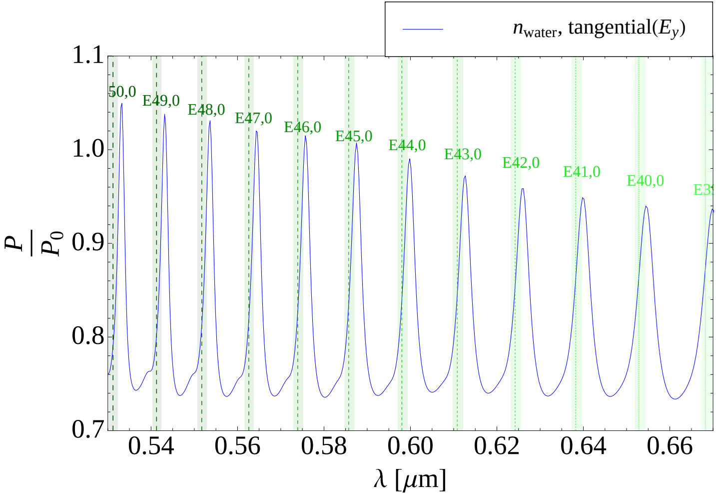
  BUT:
- If we have high index-contrast, and a large diameter compared to wavelength, modes are so narrow and closely-spaced we can't track them!

# Results

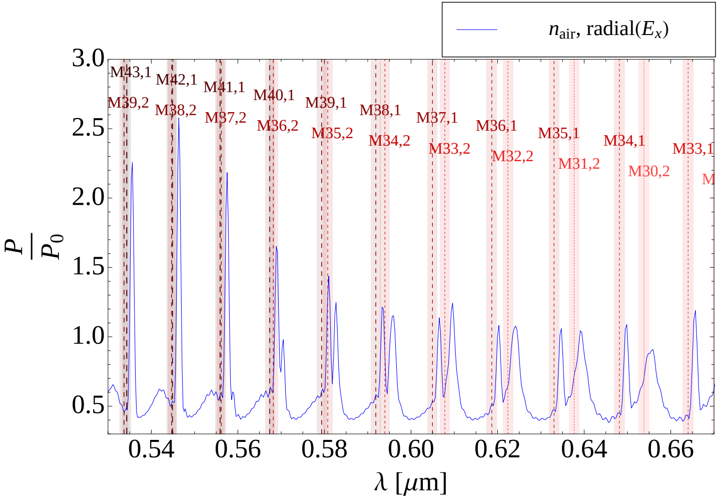
# Wavelength spectrum



# Wavelength spectrum



# Wavelength spectrum



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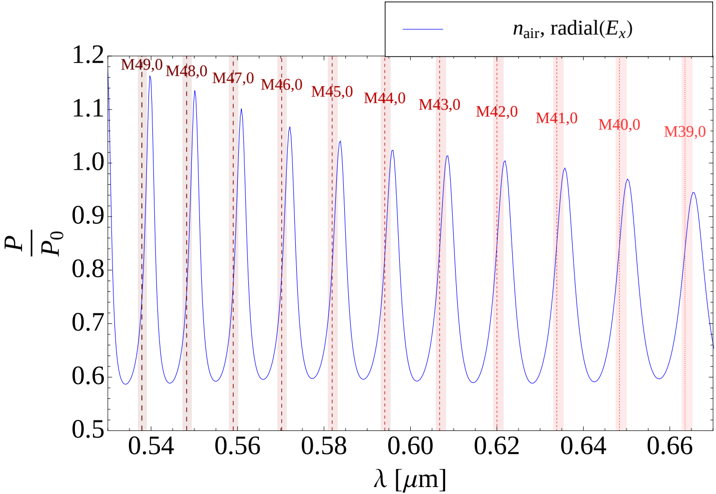

# Radiation distribution

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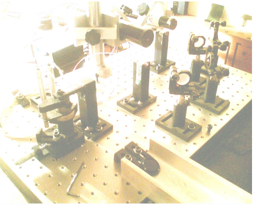
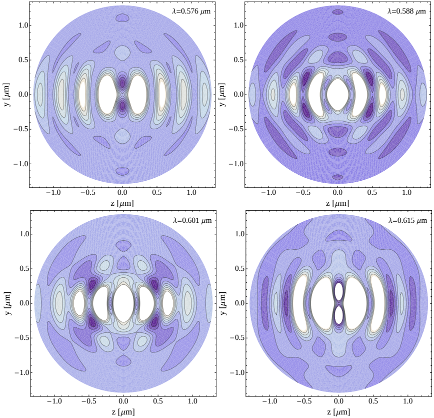
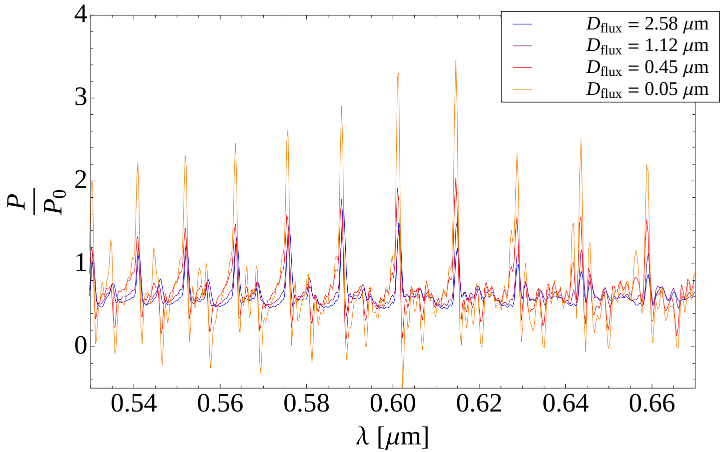
- We can also measure how the power is distributed, e.g. as seen by a fibre.
- More concentrated modes (smaller angular distribution) are less sensitive to changes in large collection apertures.



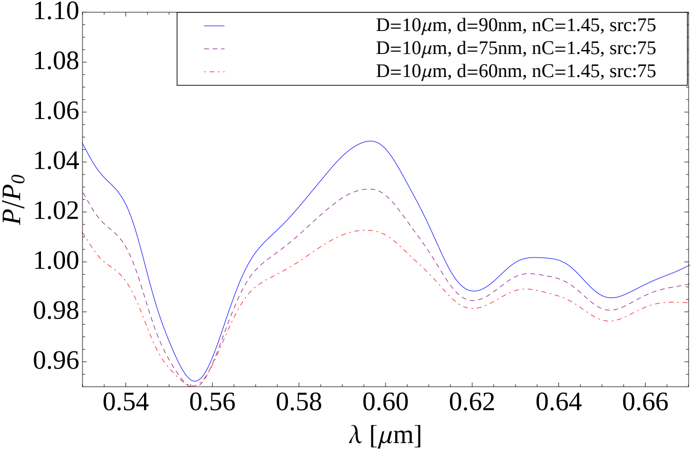



Power distribution for four different modes (wavelengths).

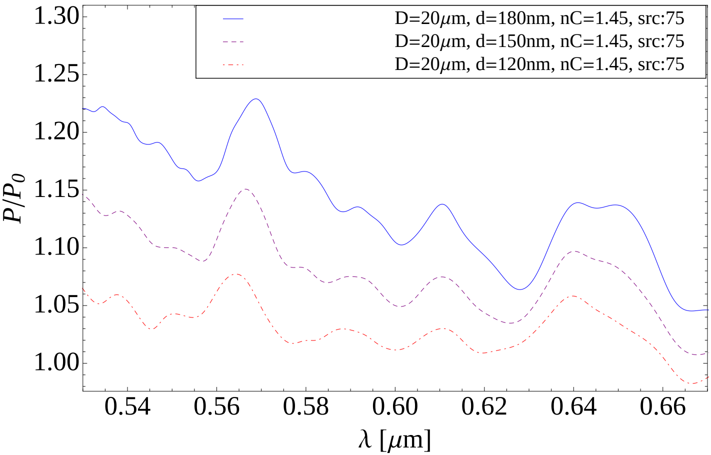
# Radiation distribution



# Fluorescent micro-shell simulation

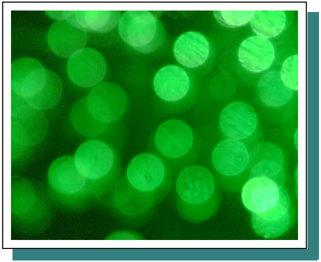


# Fluorescent micro-shell simulation



# Plan for the future

- We are mapping out resonator configurations suitable for bio-sensing.
- Realistic structural imperfections are incorporated.
- **What next:**
  Optimal design solutions will be checked against a fabricated analogue of the resonator.
- Configurations that match viable design solutions will be sent for experiment.



Sensing technology of the future?