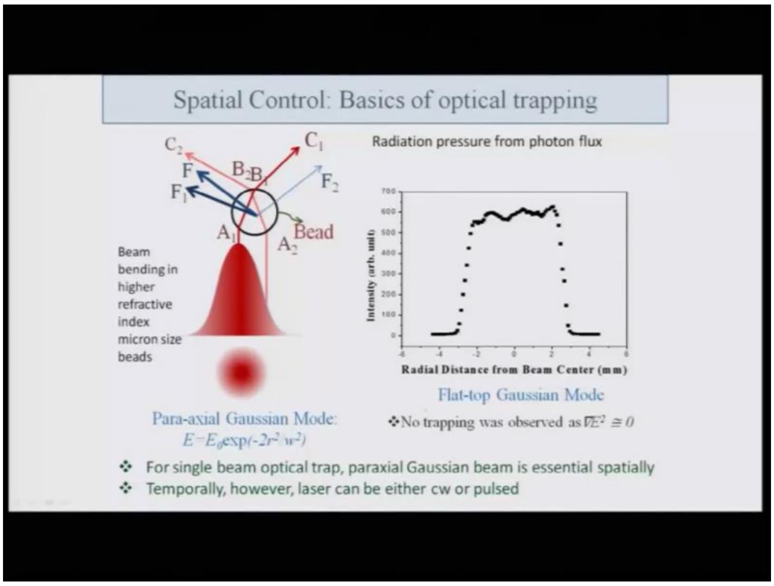
Implementation Aspects of Quantum Computing
Prof. Debabrata Goswami
Department of Chemistry
Indian Institute of Technology, Kanpur

Lecture – 45
Futuristic Aspects in Implementing Quantum Computing – II

We have been looking at the temporal aspects of interaction of light with matter, which is resulted in qubit manipulations and this is the specific part of work that has been going on in our particular area of research and since it relates to all the various different aspects of quantum computing that we have been discussing throughout this course, I thought I will finish it off by looking at the other interaction that also is very important in this particular aspect which is a spatial interaction concept.

(Refer Slide Time: 01:24)



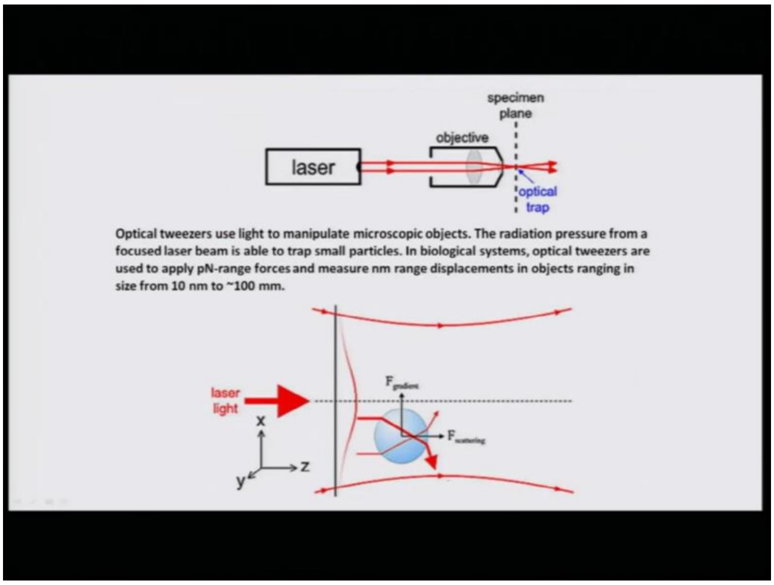
So, as in terms with the ion trapped condition where the spatial interaction part was utilized to make sure that the qubits could interact properly and the gates could be associated in this manner, here also we can do this saying principle by having a spatial modulation being applied by an optical field.

So, in this regard let me show you how this works; in terms of these spatial control the basics of optical trapping is been shown here. The trap essentially is of a particle which happens because of the laser being passing through the particle undergoes bending due to the higher refractive index of the particles, in comparison to the environment it is kept in.

So, typically a bead which is being trapped in a liquid would be having the higher refractive index and are of typical micron sizes are lower and having a Gaussian spatial beam would essentially mean that the beam would interact with the bead in such a way so that it is drawn more towards this focus. So, the radiation pressure from the proton flux is utilized in this process of trapping the particle.

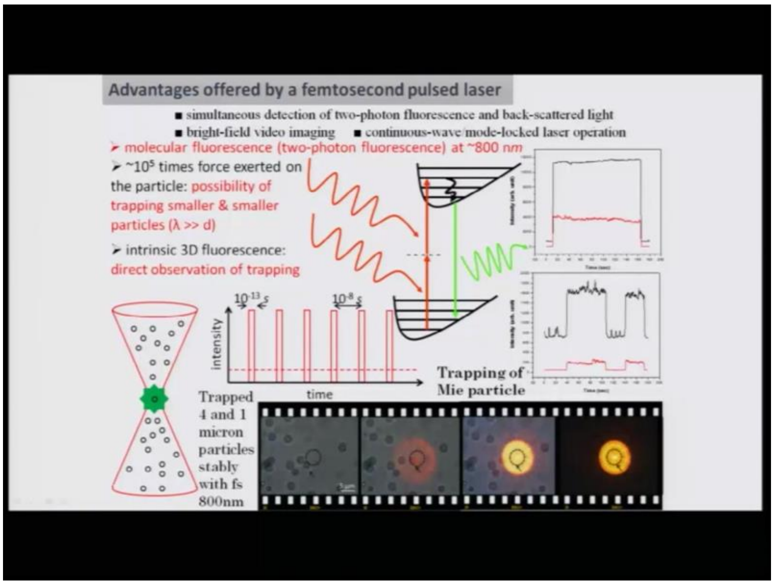
So, this can be thought in terms of the paraxial Gaussian mode, the spatial mode of the beam and if a Gaussian beam is not available in fact, if it is a flat top or a square or a rectangular beam specially, it will not be possible to trap a particular bead in this particular fashion because the gradient of the paraxial beam would not be possible to balance the forces, so for single beam optical trap paraxial Gaussian beam is essential temporarily; however, the laser can be either cw or pulsed.

(Refer Slide Time: 03:22)



Optical tweezers use light to manipulate microscopic objects. The radiation pressure from a focussed laser beam is able to trap small particles in biological systems optical tweezers are used to apply peco Newton range forces and measure nanometre range displacements in objects ranging in size from 10 nano meters to about 100 millimetres.

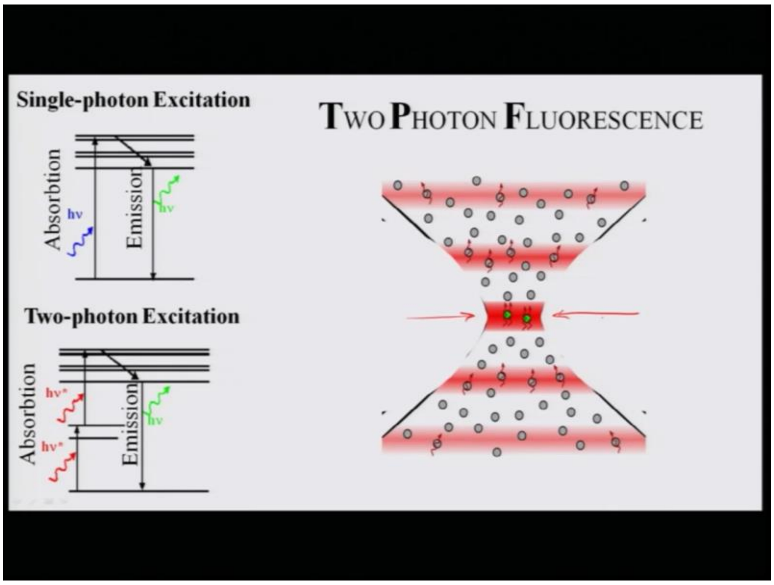
(Refer Slide Time: 03:54)



So this has a lot of influence in many areas of research and in this particular case, we have utilized the femtosecond lasers for certain benefits. One of the benefit is the simultaneous detection of two-photon fluorescence and back scattered light which is possible in this particular case, as long as the beats are coated with the two-photon die, this enables bright field video imaging and it could be used in both continuous wave or mode locked laser wave operations either by looking at this scatter or by looking at the two-photon fluorescence.

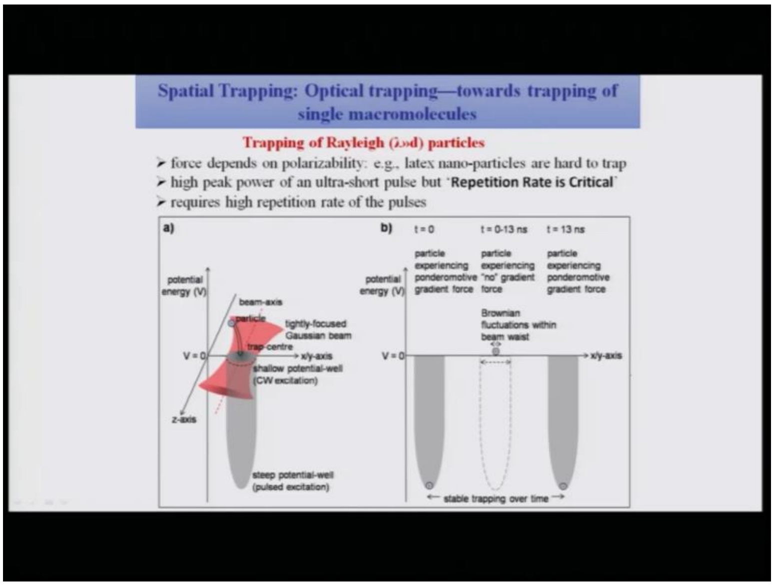
Since the visibility of the system becomes much better because of the fluorescence, it is possible to have better signal to noise of the trap particle and so smaller and smaller particles can be visualized as a result of this particular approach. So, we have managed to show trapping for various range of particles ranging from 4 microns to 100 nanometres quite comfortably.

(Refer Slide Time: 05:22)



Here is a slide picture which shows 4 and 1 micron particles which has stably trapped with femtosecond 800 nanometre lasers and the principle of trapping works easily with the two-photon fluorescence because the fluorescence comes from only the focal point where the intensity is high enough to produce the two-photon fluorescence signal in every other place with photon fluorescence signal is not possible to be generated and so the focal plane where in the particle get trapped is easily detected.

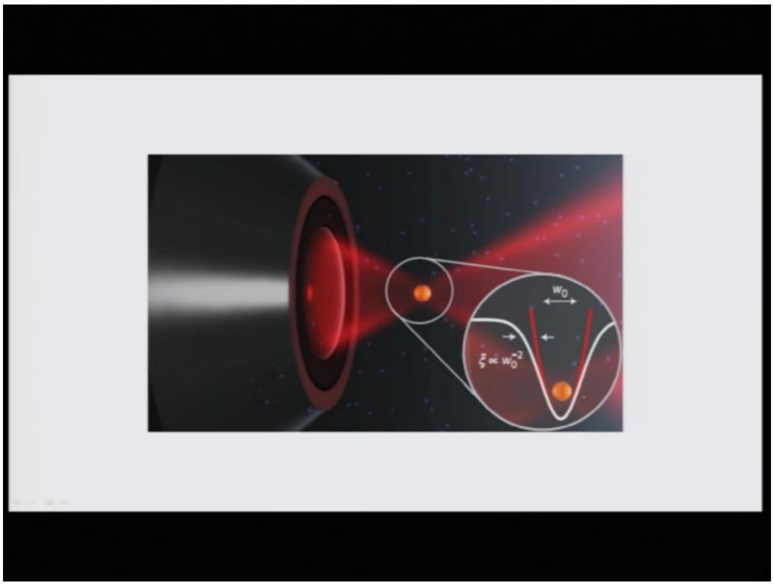
(Refer Slide Time: 05:54)



So, spatial trapping with the help of optical pulses can be utilized towards trapping smaller and smaller particles. So, we have gone to particle sizes which are either in the range of wave length of the light used or even smaller than that under those conditions the force depends on polarizability; for example, latex nano particles are hard to trap. High peak power of an ultra short laser pulse helps; however, the repetition rate is also critically the pulses come after a very long time then the stable trapping time will not be possible to be maintained.

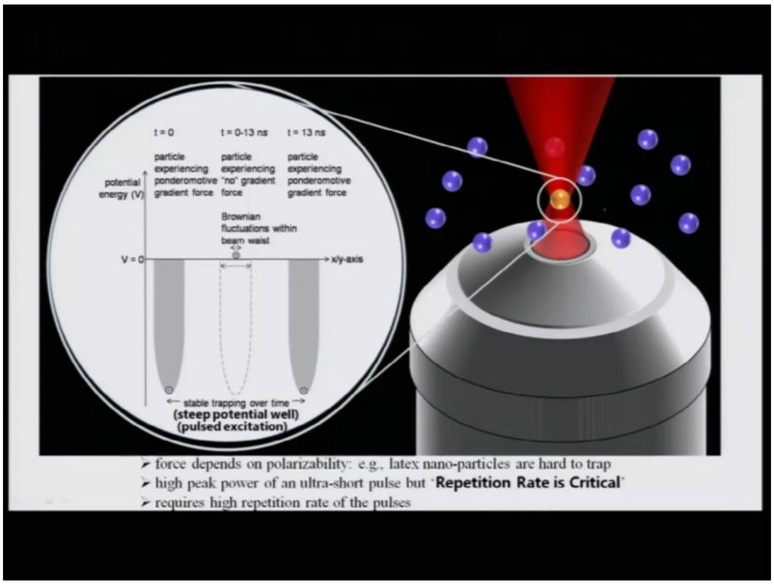
So, here is a cartoon of how these particle trapping works and the particle is basically put into a potential created by the optical field under which the particle gets trapped. When the pulse goes away, particle experiences no gradient force; however, when the pulse is not present the particle experiences no gradient force; however, the Brownian motions or the fluctuations within the beam base continue. As long as the next pulse comes before the Brownian motion takes the particle away from the trapping zone, the particle remains trapped and so that is the reason of the reputation rate of the laser to be sufficiently high to make sure that the particle remains trapped.

(Refer Slide Time: 07:42)



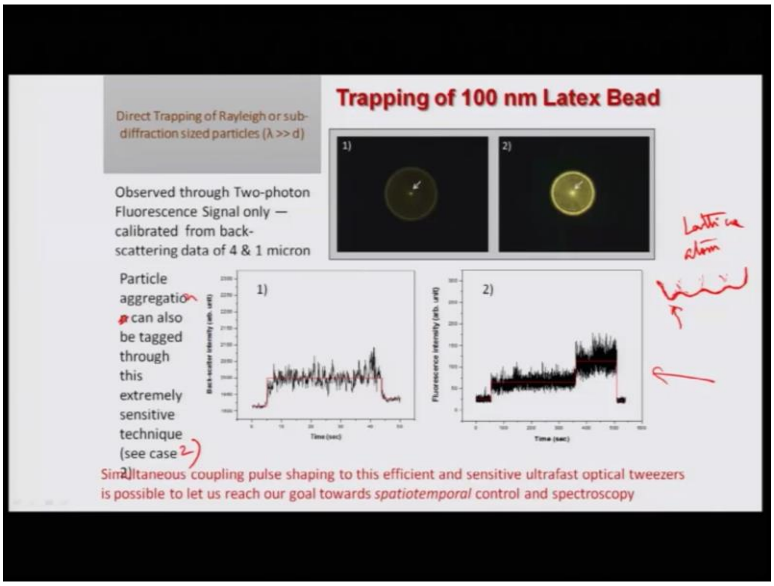
So, here is a cartoon of how a microscope objective essentially traps a particle in its force field and mostly this force field is thought to be a modelled as a harmonic potential where in the particle is sitting and the close to the minima of the harmonic potential; that is how the model is being developed.

(Refer Slide Time: 08:08)



And what we have found is that, it is also possible to have multiple particles come together because as the particle size goes lower. the zone in which the particle trapping can happen can be large enough to accommodate more than one particle and that would enable multiple particle trapping.

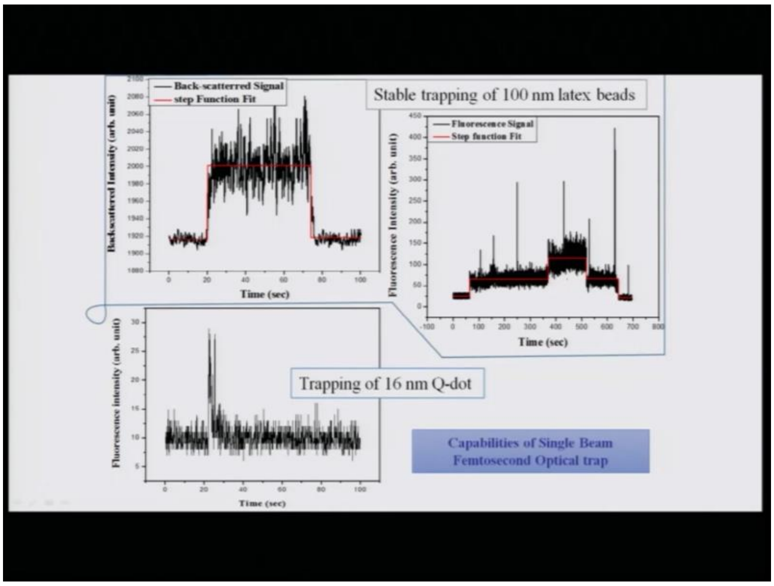
(Refer Slide Time: 08:40)



So, for instance with a 100 nanometre for instance with a 100 nanometre latex bead particle with 800 nanometre wave length laser pulses, we are under the condition where the wave length of light is greater than the diameter of the particle beam looked at. So, it is in some sense better than the diffraction limited condition; this can be observed through two-photon much easily once the system is calibrated by using back scattering data of 4 and 1 micron. The particle aggregation can also be tagged through the extremely sensitive technique and so here is the case where we can see a second particle coming into the trapping zone and seeing a two particle trap. Simultaneous coupling pulse shows that these efficient and sensitive ultrafast optical tweezers is possible to let us reach our goal towards spatial temporal control and spectroscopy.

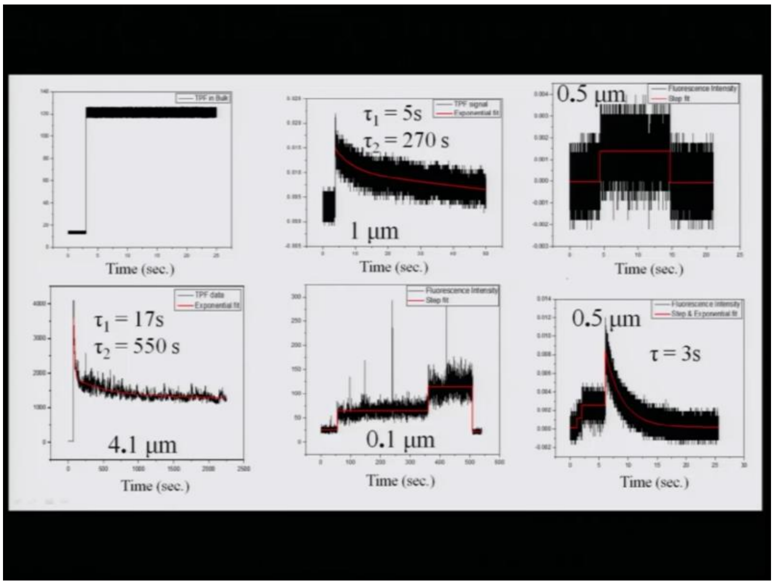
So, that is one of the interesting parts of having a trap which can enable the motion of particles. So, this is in some sense analogous to the condition which we have discussed earlier where we have atoms in lattice. So, we would imagine if you could produce traps where we could put the qubit like objects to be coupled by using optical particles, by using optics such that they could then be made to interact and things. However, at this point of time, atom trapping is not really out of word, is out is reach in terms of the conditions that we are using, but the same principle works for the atom lattice that we have used before or discussed before in our regular lectures for quantum computing here.

(Refer Slide Time: 11:10)



So, the back scattering technique can help us set the problem and then using the two-photon fluorescence coming from the trap particle, if they calibration is made right; it can help us go down to look at smaller and smaller particles. So, that way quantum dots of 16 nanometre particles also been trapped, you can also see multiple trapping as we discussed before, so these are interesting developments which have been utilized.

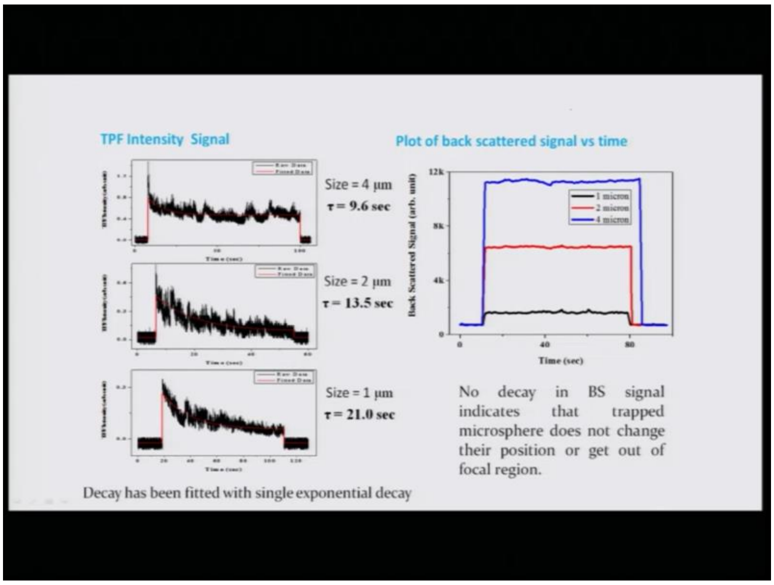
(Refer Slide Time: 11:50)



One of the things which we notice while this particular work has been developed is the fact that the two-photon fluorescence coming from these trapped particles also show a decay property, which is not quite expected and these decay occurred not for the very small particles; for example, the 100 nanometre particle does not show any decay, even when they aggregate.

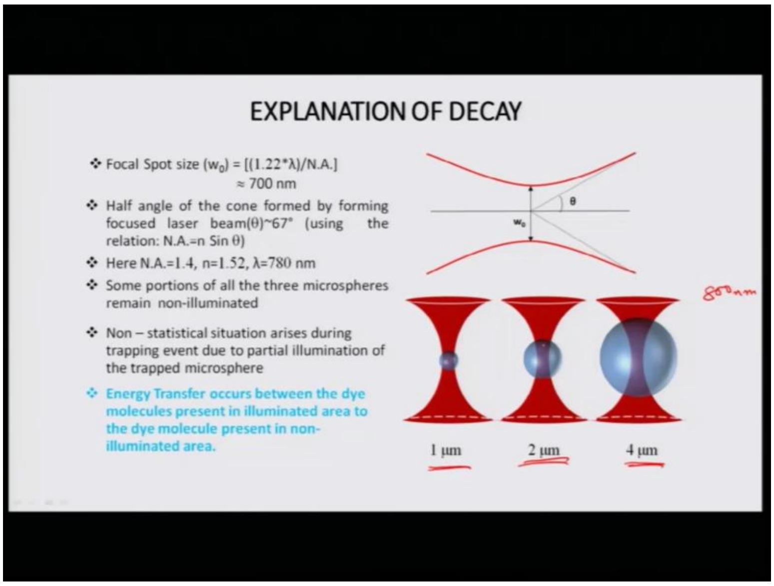
However, the larger particles for example, 1 micron or 4 micron they show decay and once the smaller particle say 500 nanometre particle; individually even if they do not show any decay when they start aggregating, they start showing decay; essentially indicating the fact that as the size of the particle getting trapped is increasing to a size which is beyond certain limit then there is a decay feature which appears in at least the fluorescence signal that we are using.

(Refer Slide Time: 13:09)



So, when we looked at this particular process, so we had to understand as to how this was happening, we did not see any of this kind of a decay feature to appear in the back scattering signal for these kinds of microspheres; however, the decay was always evident from the fluorescence signals.

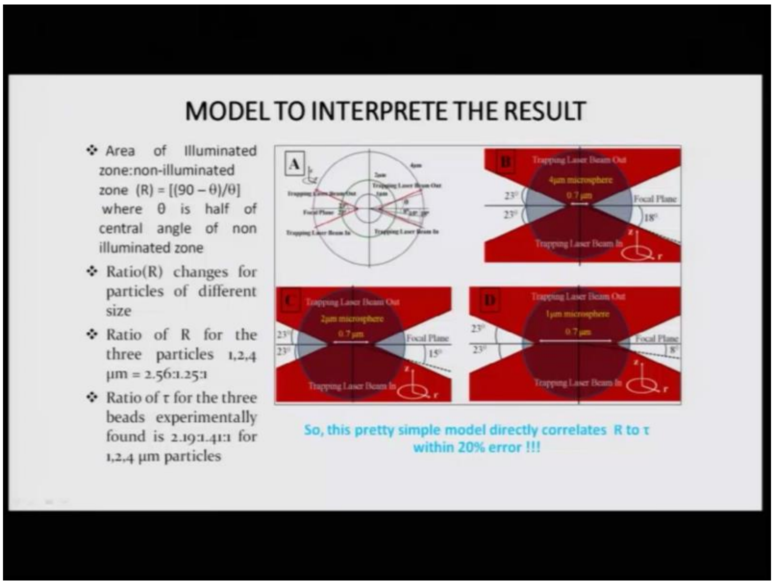
(Refer Slide Time: 13:32)



So, one of the ways that we understood this problem was to realize that these particles are essentially undergoing some sort of energy transfer when they reach a condition, where part of the particle is not able to see all the light because when the particle size is smaller than the particle is always emerged in the photon flux. However, has the particles size gets larger like 1 micron, 2 micron, 4 micron because our; there is a wavelength is 800 nanometre. All of these particles are larger than the zone in which the light is getting focus in terms of diffraction limited conditions and as a result of that, these larger particles are not getting illuminated all through.

That is one of the reasons why this can undergo energy transfer within the illuminated versus the non illuminated zone and that can lead to a decay of the fluorescence that is been observed.

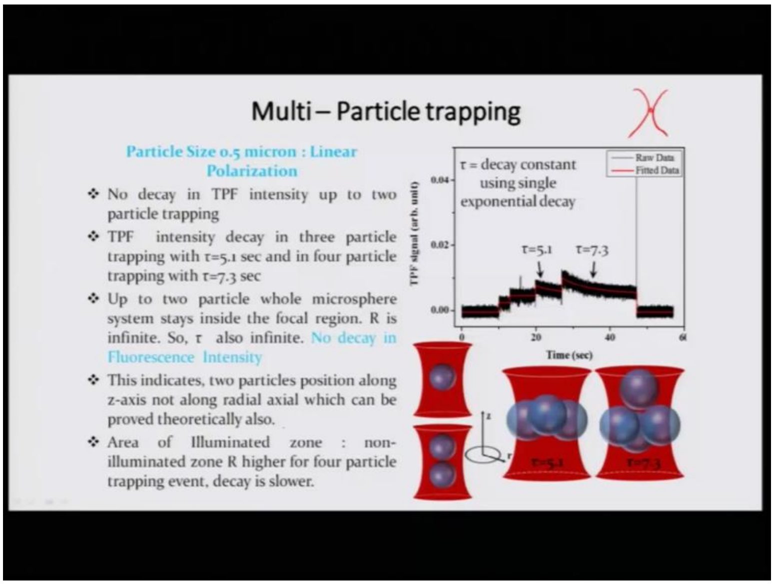
(Refer Slide Time: 14:49)



And we did a very simple model to rectify our conjecture and then it was interesting to note that even with the very simple approach of assuming a cone of the beam coming in and a circle to just represent the size of the bead by just taking the ratio of the illuminated versus the non illuminated part, a simple model could be developed where the decay was quite well correlating to the size of the particle that was being used.

So, we were able to use this idea to easily understand how the size of the bead was affecting the way the trapping was going on.

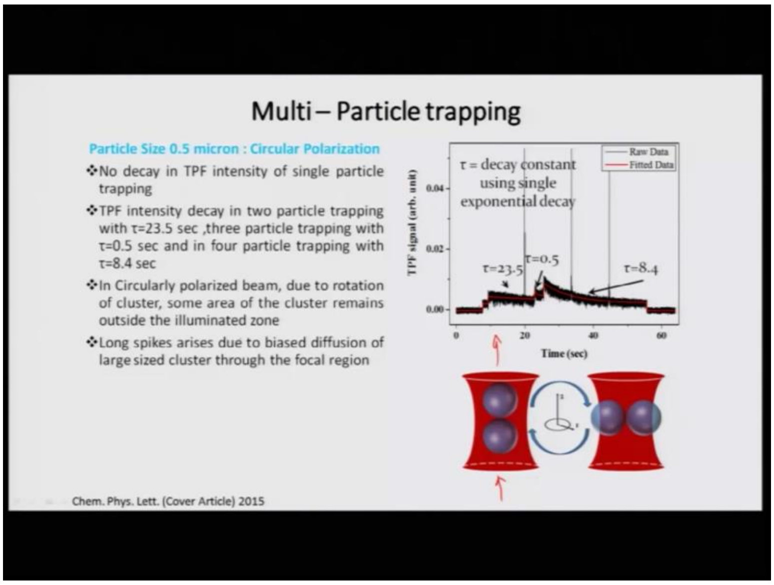
(Refer Slide Time: 15:43)



Once we detected that it will also brought up an interesting concept that as the particle size increased which is what we had noticed earlier that a for a 500 nanometre particle which is embedded within the 800 nanometre wavelength light in the focal spot. As the particle size is increasing because of aggregation, we will also see the same affect that there is decay in the multiple particles fluorescence and this is our observation in terms of linear polarization of light first use, no decay in the TPF signal up to two particle trapping.

TPF intensity decay in three particles with some time scale and four particles with another time scale of decay. Up to two particles the whole microsphere system stays within the focal region, so there is no decay seen. This indicates that the two particles position along the z axis and not along the radial axis and that has been shown earlier with some theoretical studies.

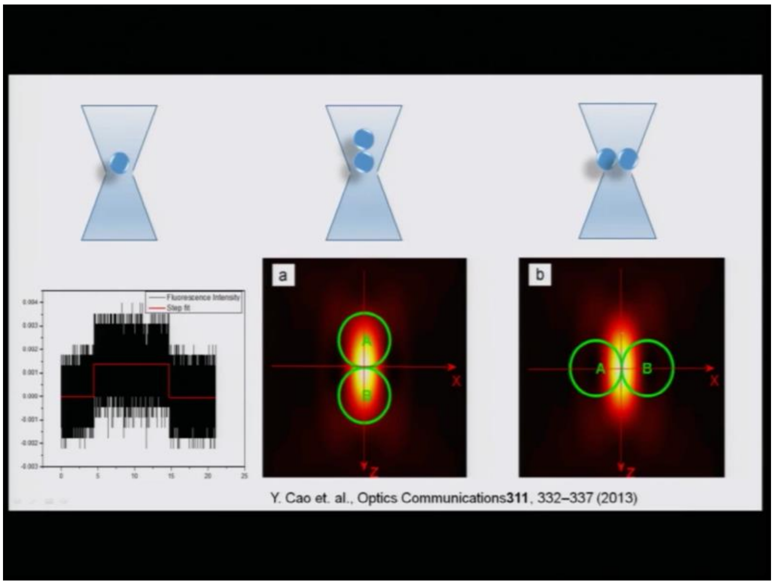
(Refer Slide Time: 17:11)



So, this is one of the interesting experimentally proofs of the fact that the particle essentially is aligned in the direction of the laser beam for the linearly polarized light. However, when circularly polarize light is used for trapping; there is a decay which is again evident for even the two particle case and that is possible because for the circularly polarized light, the dimmer undergoes tumbling motion and as such it could be either aligned along the axis or along the equator.

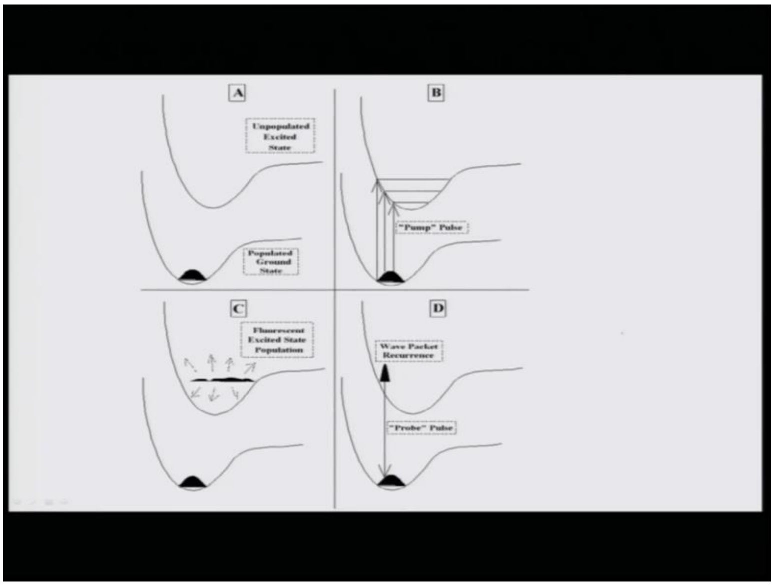
So, in circularly polarized beam due to rotation of the cluster; some area of the cluster remains outside the illuminated zone and so the decay can have. Now the experimental spikes that are often seen in these kinds of trapping experiments are due to the biased diffusion of large size clusters which are experimentally difficulties which happen sometimes and as they go through the focal region these kinds of a spurious features may come, so these can be minimized as the concentration of the system is reduced.

(Refer Slide Time: 18:33)



So, the overall story correlated very well to the theoretical prediction which was earlier done based on the interaction of the laser with dipolar particle assumptions and our experiment essentially proves the fact that when we do have this kind of a scenario where particles are getting trapped and if they lose their symmetry because they are going to become a dimmer then they are going to align along the direction of propagation to laser rather than in perpendicular to a direction of propagation of laser.

(Refer Slide Time: 19:22)



So, we found several different aspects of application of this particular spatio temporal control of systems that we have developed until now. We have been also looking at how interaction in time can change the property of the system that we discussed in the previous studies and one of the ways of development of a quantum computer in this particular aspect will definitely be involving and interaction with both time and space as we have been showing here.

So, with this I would like to actually conclude our understanding and study of quantum computation implementation and other aspects that is we have been dealing with in this course, I have tried my best in explaining all the different aspects which have come into this field over the years of development. Initially the development of this field has been extremely rapid with a lot of input and then there was a period where a lot of questions were raised and lot of understanding needed to be developed.

So, the initial years which were also fuelled by the fact that Feynman realized that quantum systems need quantum computers to have the best results brought in the entire principle of interest in this area of quantum computing. For a while there was a lot of development and because universally t was established by Dovish then after there was a period where a lot of questions were raised on the viability and the error aspects of the problem, which were built on and the first important development came when Shor was able to show the algorithm which works exponentially in speed, which is what is the expectation of this realization of the fact of quantum computing in reality and there after Grover's algorithm and many processes and many other developments has happened. Many important people have; many important developments have made contributions to this field which are very critical and it is still a very growing field.

So, many many aspects that we have discussed here are still being explored and many of it is perhaps going to change over the next few years as we realize much better ways of dealing with these kinds of ideas. So, with that I would expect that this particular kind of course, would need to get upgraded in some years because a lot more new information will come in and a lot more interesting results will be there to be presented in such a evolving developing course. But there is a lot of interest, and I hope you all enjoyed the course and I look forward to having interacting with you in the years to come in the future.

Thank you.