Anapole electric dipole modes for a dielectric sphere

S R Ponomareva [1,a)], E A Gurvitz[1,b)], K S Ladutenko[1,2], A M Miroshnichenko[3] and A S Shalin[1]

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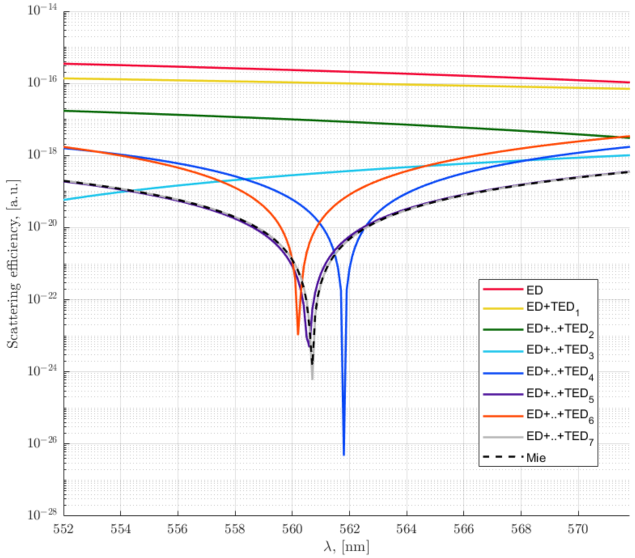
Introduction | Theory | Results | Conclusion

This work is part of our research of resonant anapole states.
It considers the simplest version of the formation of such a state - an electric dipole resonant anapole in a spherical particle.
We obtained values of parameters of the particle for its observation and performed multipole decomposition. It turned out that for the correct description of contribution to the scattering toroidal moments up to the 7th order should be considered.
Also hybrid anapoles of the electric type till the 5th order (electric 32-pole) were found.



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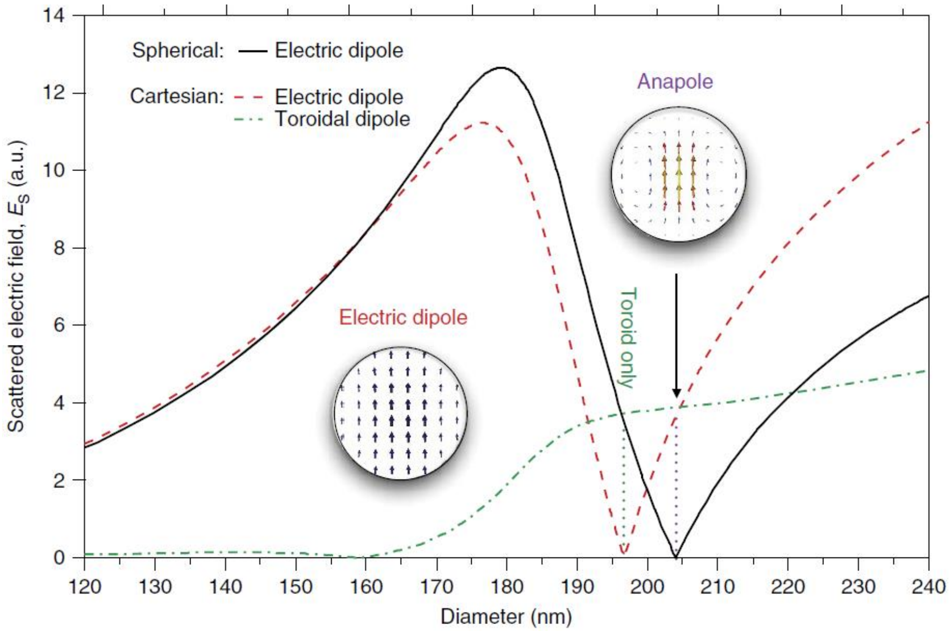
What is an anapole state?



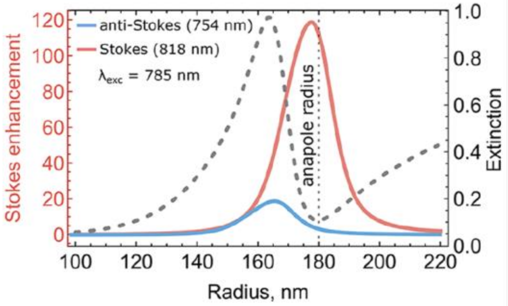
[1]

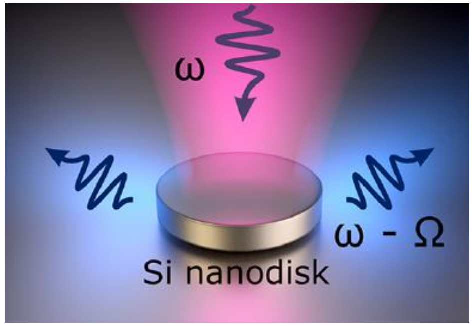
Anapole states are the states in which the scattered power of the particle is strongly suppressed. They can be explained in terms of different multipole expansions. The simplest example [1] of the formation of the anapole state is destructive interference between electric dipole moment and toroidal electric dipole moment in Cartesian multipole expansion. If we consider spherical multipoles, this state corresponds to the minimum contribution of electric dipole in total scattered power in case of nontrivial state.

[1] Andrey E. Miroshnichenko et al, Nonradiating anapole modes in dielectric nanoparticles. Nature communications, 2015

Applications

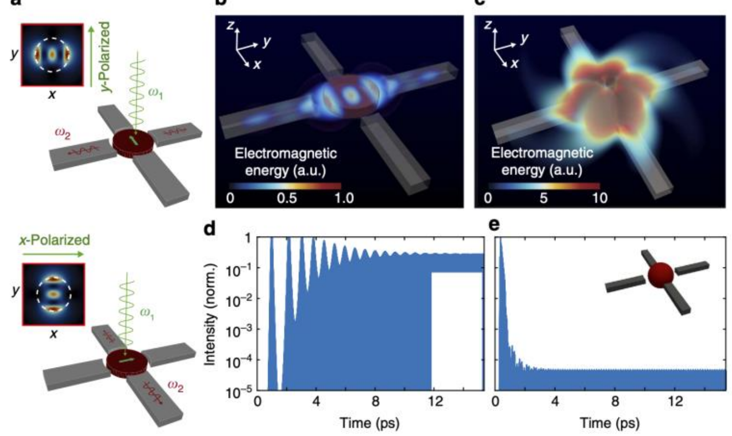
Raman Scattering





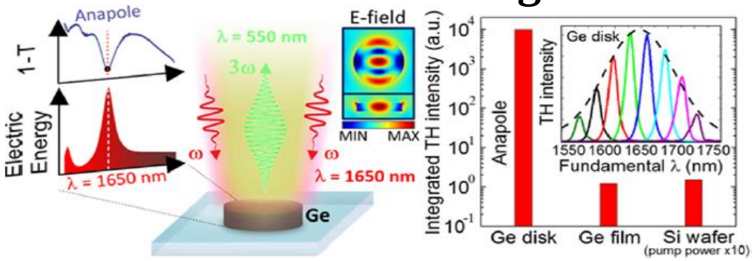
Denis G. Baranov et al
ACS Photonics 2018

Nanolasers



Juan S. Totero Gongora et al (2017) Nature Communications

Third harmonic generation



Grinblat et al. (2016). Nano letters.

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Electric resonances in spherical particles

Most of the works studying anapole states are devoted to the electric dipole, as the first term in the series of electric multipoles. In our work, we investigate the electric dipole resonant anapole.

Electric resonances in spherical particles can be described **[2]** using the phenomenological Fano parameter:

$$q(\rho, l) = \frac{\partial_\rho \chi(\rho, l)}{\partial_\rho \psi(\rho, l)}$$

Where $\rho = kr$ is a size parameter, l is the order of an electric multipole moment, ∂_ρ is a derivative operator over the size parameter, and χ and ψ are Riccati−Bessel functions, as they are introduced in **[2]**.

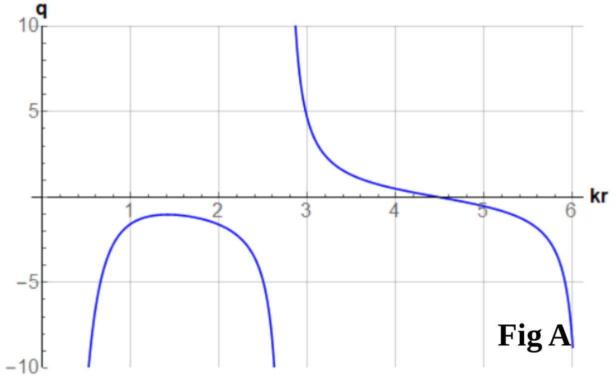


Fig A

The resonant anapole corresponds to q = 0. Solving this equation, we found the size parameter $kr = \rho = 4.482$ for the first electric dipole resonant anapole.

[2] Tribelsky M I et al 2016 Giant in-particle field concentration and Fano resonances at light scattering by high-refractive-index particles *Phys. Rev. A* **93** 1–22

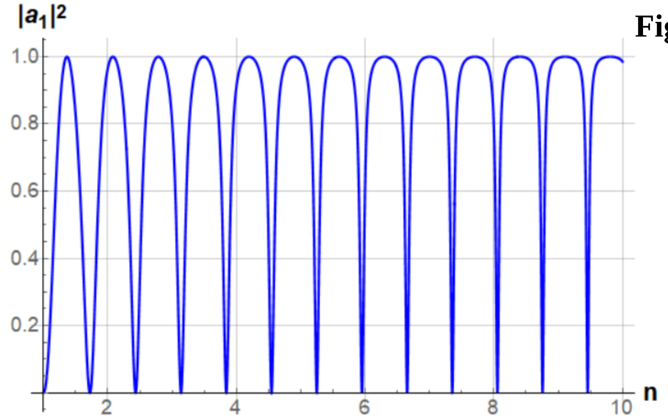
The expression for the Mie coefficient of electric dipole can be written as:

$$a(q, l, n) = \frac{n^2\, \partial_\rho \psi(q, l)\, j(nq, l) - j(q, l)\, \psi(nq, l)}{n^2 \partial_\rho \zeta(q, l)\, j(nq, l) - h^{(1)}(q, l)\, \partial_\rho \psi(nq, l)}$$

Where n is the refractive index of the scatter, $h^{(1)}(q, l)$ is a spherical Hankel function, $j(q, l)$ is spherical Bessel function, and $\zeta(q, l) = \psi(q, l) + i\, \chi(\rho, l)$.

Substituting size parameter $kr = 4.482$ into this expression, we plotted contribution of the electric dipole to scattering power as $|a_1|^2$. Minimums on the graph correspond to the electric dipole resonant anapole states.

Fig B



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Anapole electric dipole modes in a sphere

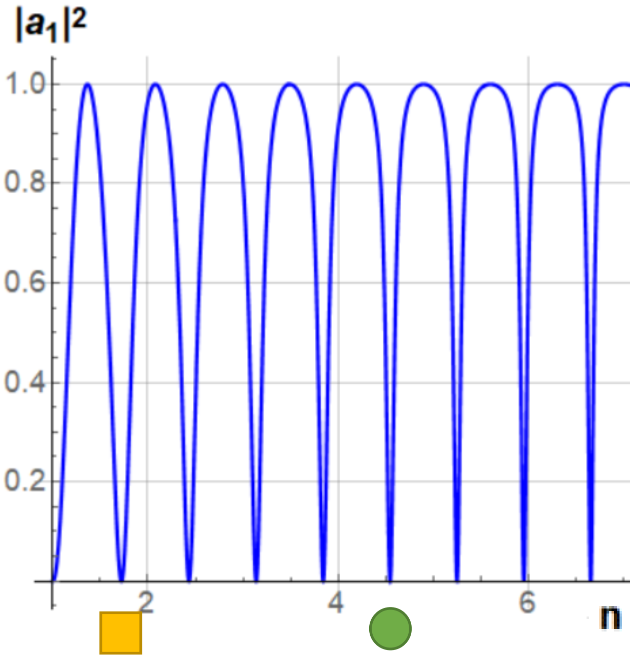


Fig C

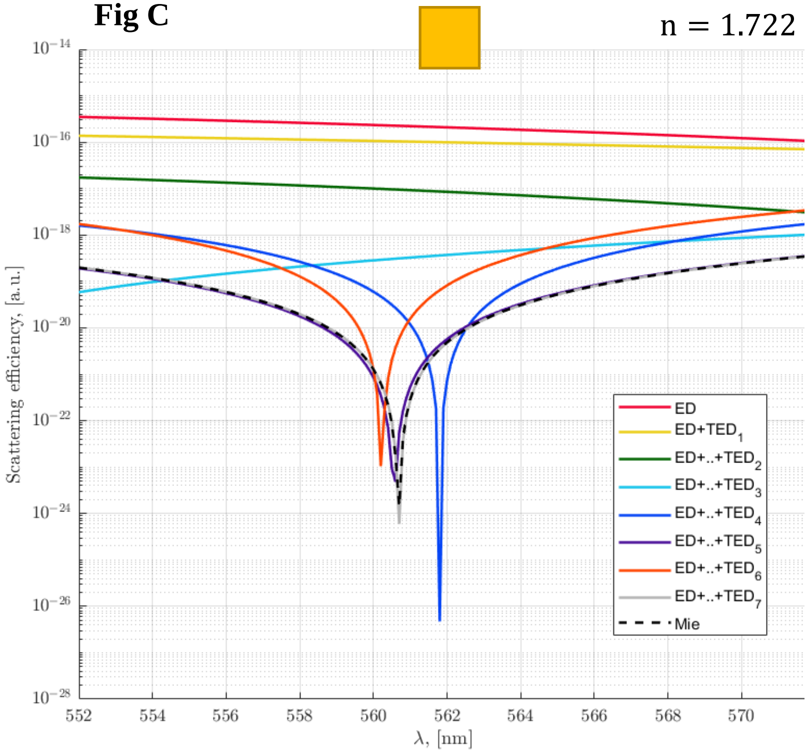
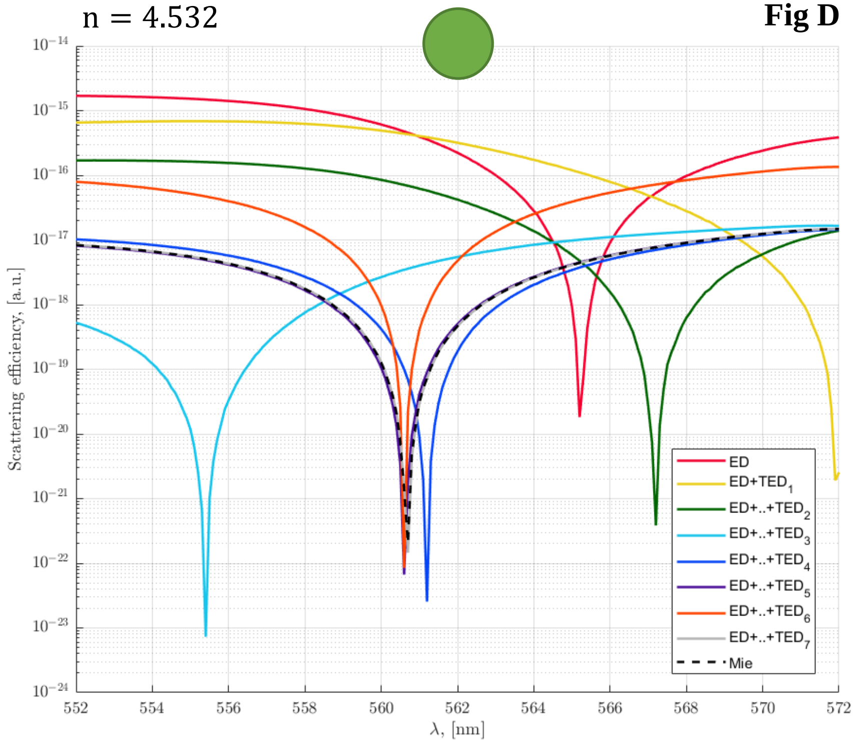


Fig D



There is a whole series of refractive index values which correspond to the resonant anapole mode. From the obtained graphs it is seen that Cartesian multipole decomposition should contain toroidal electric dipole moments at least of 7th order for the correct description of each of such states. Every toroidal term in the expansion in **Fig C, D** seems to be resonant and its dips are localized near the scattering minimum of the resonant electric dipole anapole.

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Hybrid electric type anapole states in spheres

Fig E

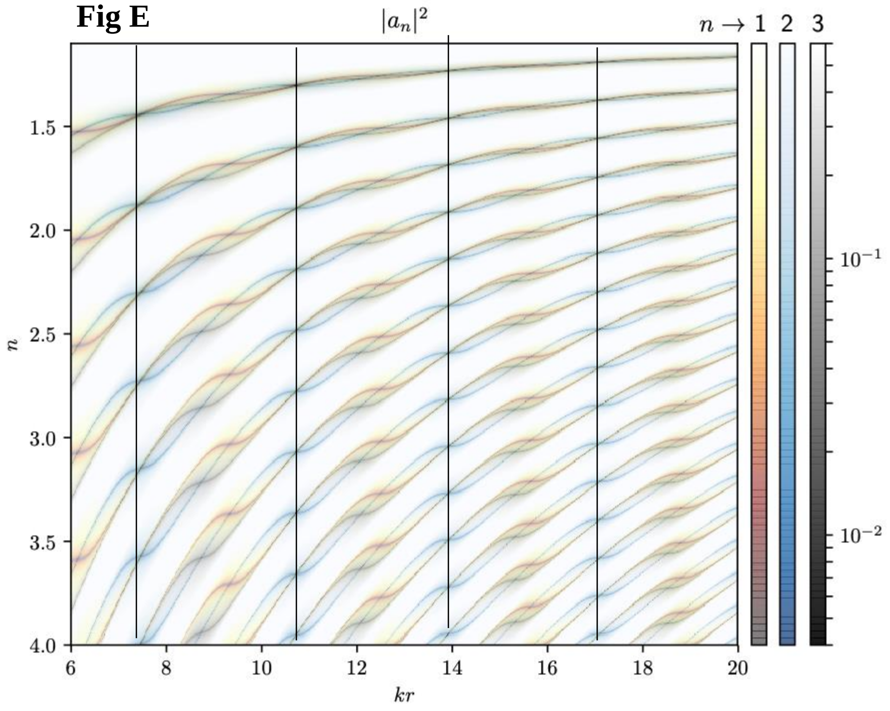

Fig F

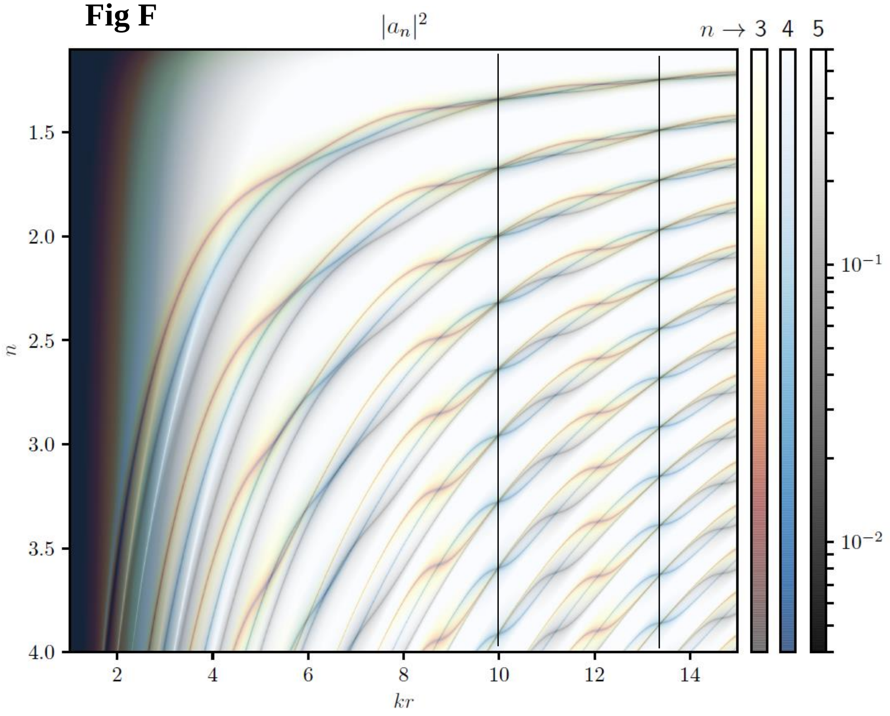

Fig E,F show a part of electric anapole states set in spherical particles. However, they do not result in minima in the total scattering power due to contributions from other multipole moments.

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1. We examined electric dipole resonant anapole states in a dielectric spherical particle and found a set of hybrid anapoles of the electric type till the 5th order (electric 32-pole).
2. Electric dipole resonant anapole states in spheres do not correspond to the total scattering minima because of contributions from other multipoles.
3. Using Cartesian multipole decomposition, we showed that the 1st electric dipole resonant anapole state requires toroidal moments at least of 7th order to correctly describe its contribution to the scattering;