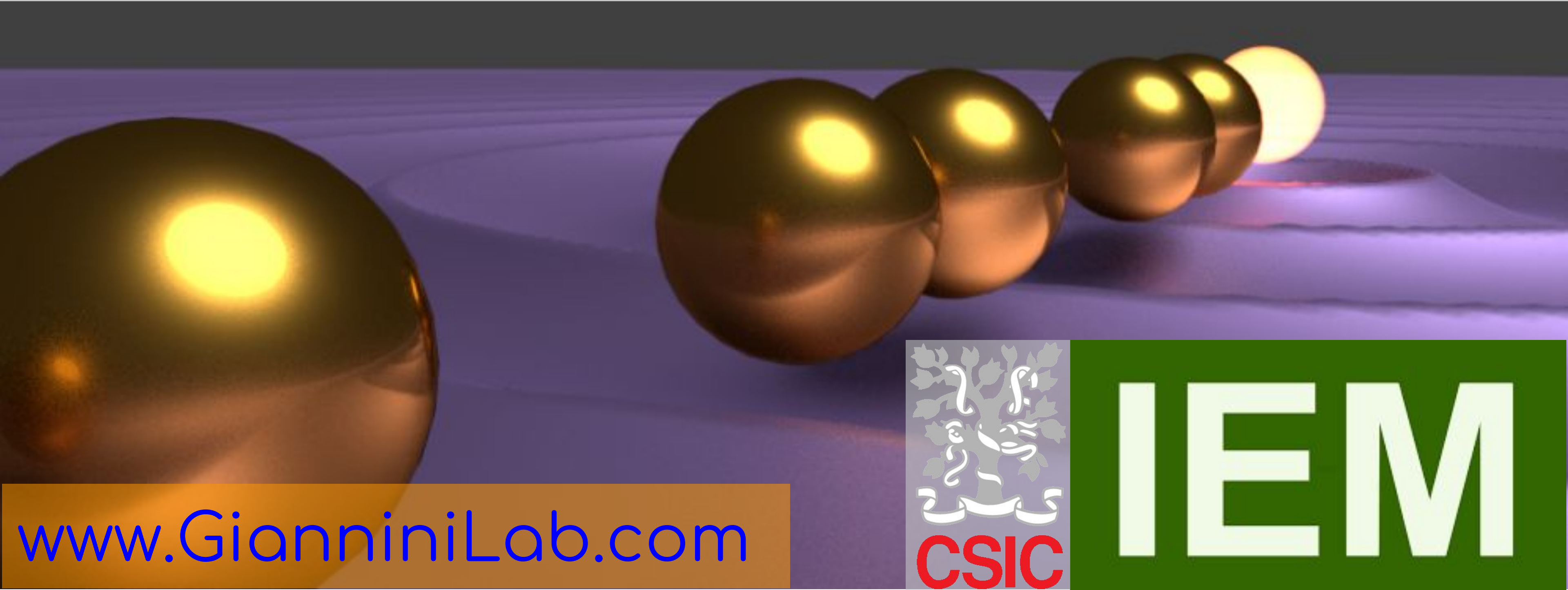
Topological NanoPhotonics

Vincenzo Giannini



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ACKNOWLEDGMENTS

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Peter Haynes

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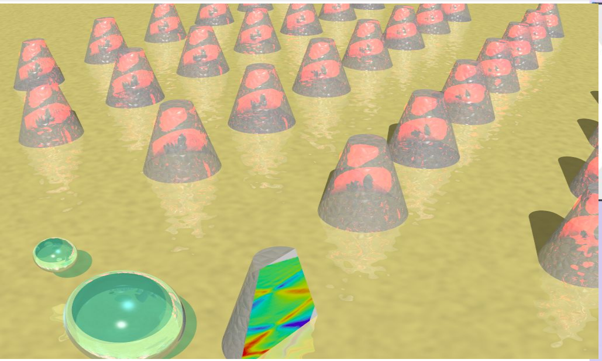
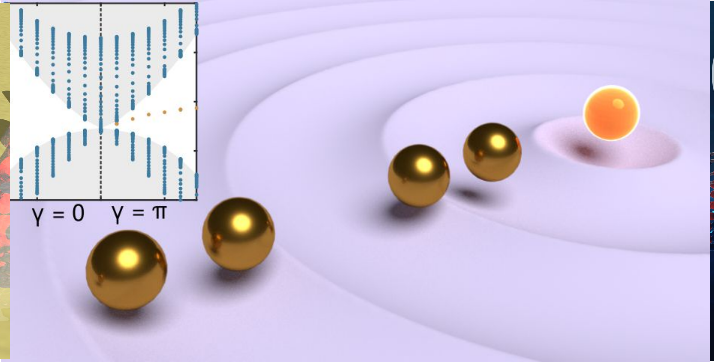
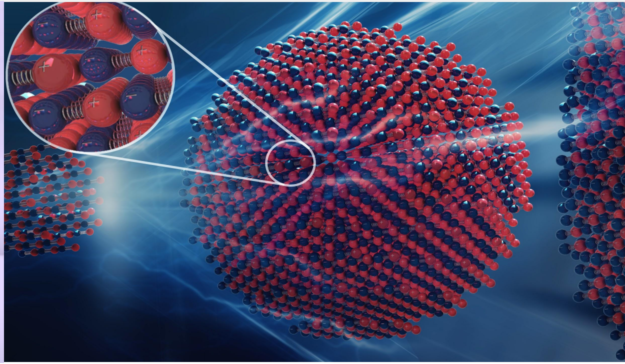
My Interests



Phonon Polaritons



Topological Nanophotonics

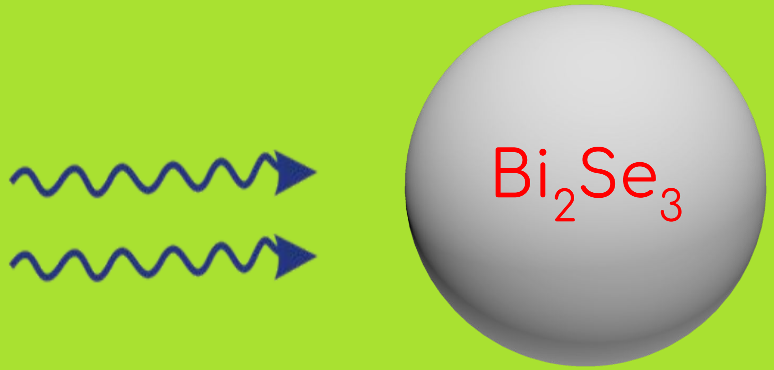


Quantum Plasmonics

Condensed Matter Theory

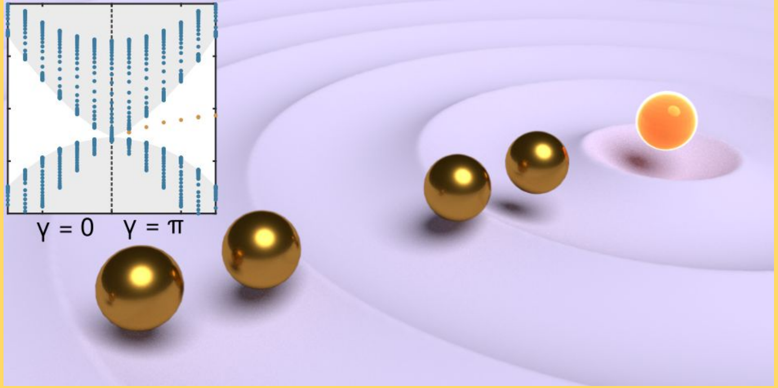
Topological Nanophotonics

Topological Quantum Dots



Experimental evidences

Topological Plasmonic Chain



Protected Hot-Spots

Motivations

Robustness of subwavelength modes against:

1. Unidirectional light propagation
2. Low threshold lasing
3. No scattering from sharp bending
4. Disordered domain

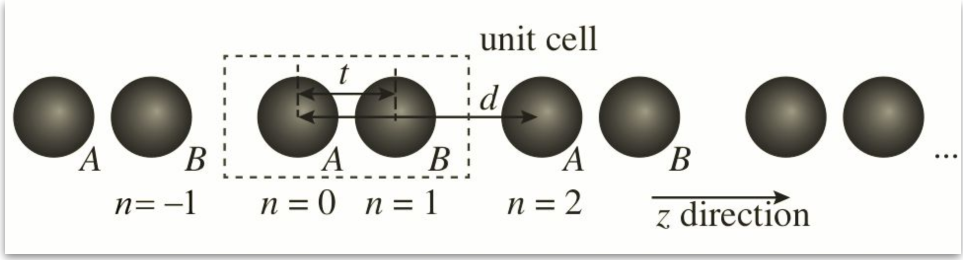
Journal of Applied Physics

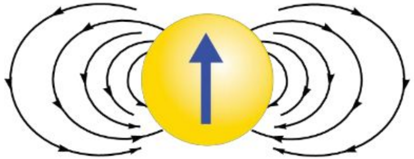
PERSPECTIVE

scitation.org/journal/jap

A perspective on topological nanophotonics: Current status and future challenges

Topological Plasmonic Chain...





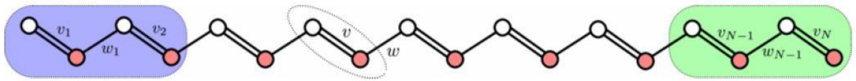
$$\frac{1}{\alpha(\omega)}\mathbf{p}_n = \sum_{j=1}^{N} \mathrm{G}(\mathbf{r}_n, \mathbf{r}_j)\mathbf{p}_j$$

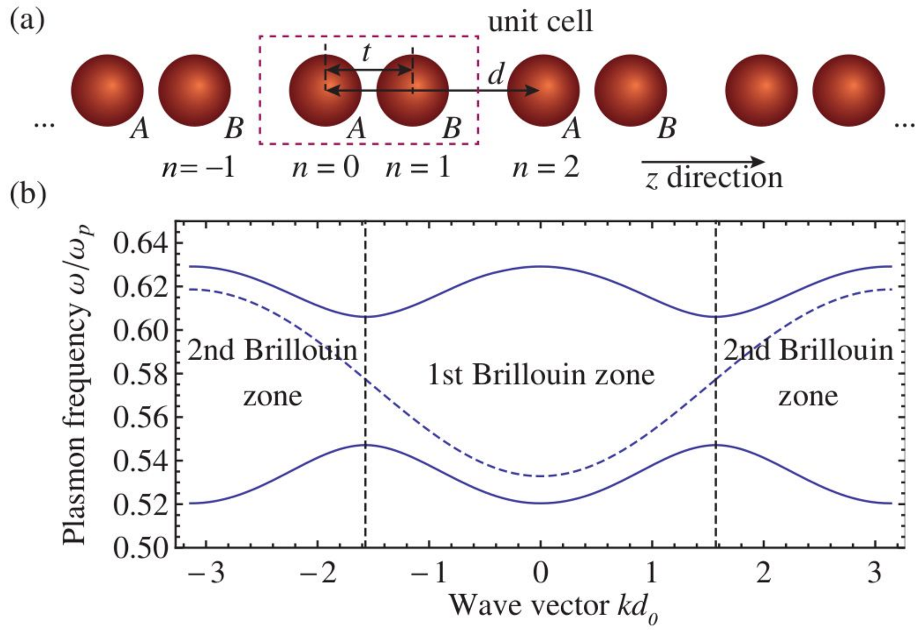
$$G_{\text{long}}(r_{nj}, \omega) = \frac{2e^{ikr_{nj}}}{4\pi\epsilon_0}\left(\frac{1}{r_{nj}^3} - \frac{ik}{r_{nj}^2}\right)$$

$$G_{\text{trans}}(r_{nj}, \omega) = \frac{-e^{ikr_{nj}}}{4\pi\epsilon_0}\left(\frac{1}{r_{nj}^3} - \frac{ik}{r_{nj}^2} - \frac{k^2}{r_{nj}}\right)$$

SSH Model: Plasmonic Chain

Su-Schrieffer-Heeger



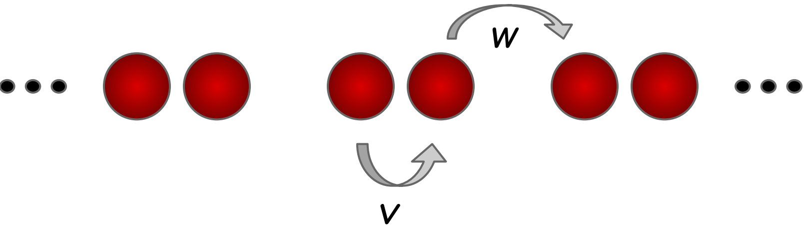


$$\alpha^{-1}p_n = \begin{cases} \dfrac{2}{4\pi\varepsilon_0}\left[\dfrac{p_{n-1}}{(d-t)^3} + \dfrac{p_{n+1}}{t^3}\right], & \text{for } n \text{ is even} \\ \dfrac{2}{4\pi\varepsilon_0}\left[\dfrac{p_{n-1}}{t^3} + \dfrac{p_{n+1}}{(d-t)^3}\right], & \text{for } n \text{ is odd} \end{cases}$$

$$p_n(k) = \begin{cases} p_A(k)e^{ik\frac{n}{2}d}, \\ p_B(k)e^{ik\left(\frac{n-1}{2}d\right)} \end{cases}$$

CW Ling et al., Opt. Express 23, 2021 (2015)

SSH Model: Plasmonic Chain



$$|m,\alpha\rangle \to |m\rangle \otimes |\alpha\rangle \in \mathscr{H}_{\text{external}} \otimes \mathscr{H}_{\text{internal}}$$

Chiral Symmetry

$$\sigma_z H \sigma_z^{-1} = -H$$

$$\sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

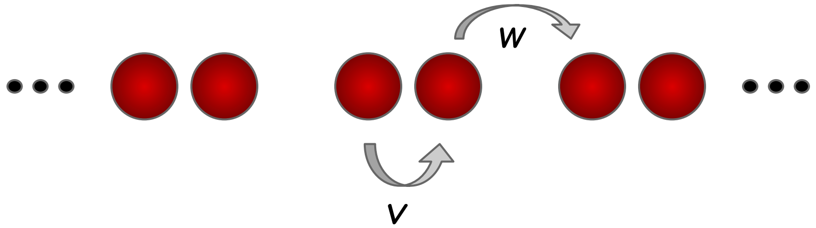
$$\begin{bmatrix} p_A \\ p_B \end{bmatrix}$$ Eigenvector with eigenvalue *E*

$$\begin{bmatrix} p_A \\ -p_B \end{bmatrix}$$ Eigenvector with eigenvalue -*E*

SSH Model: Plasmonic Chain

Edge states

$$H = \begin{pmatrix} 0 & v & 0 & 0 & 0 & 0 & 0 & 0 \\ v & 0 & w & 0 & 0 & 0 & 0 & 0 \\ 0 & w & 0 & v & 0 & 0 & 0 & 0 \\ 0 & 0 & v & 0 & w & 0 & 0 & 0 \\ 0 & 0 & 0 & w & 0 & v & 0 & 0 \\ 0 & 0 & 0 & 0 & v & 0 & w & 0 \\ 0 & 0 & 0 & 0 & 0 & w & 0 & v \\ 0 & 0 & 0 & 0 & 0 & 0 & v & 0 \end{pmatrix}$$



Chiral Symmetry

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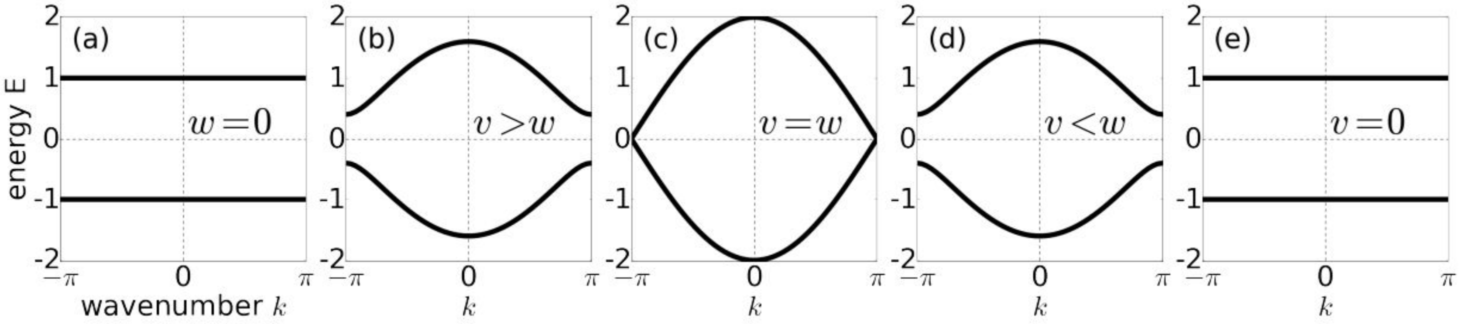


Topological Plasmonic Chain

ACS Photonics
ACS AuthorChoice
Article
Cite This: ACS Photonics 2018, 5, 2271–2279

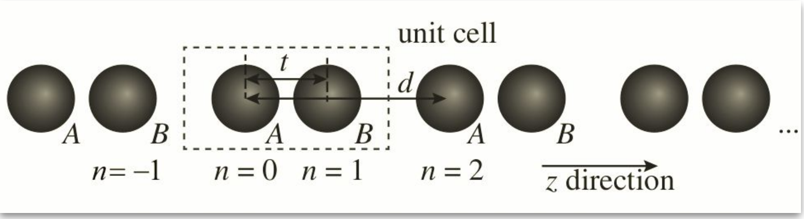
Topological Plasmonic Chain with Retardation and Radiative Effects

Simon R. Pocock,[*,†] Xiaofei Xiao,[†] Paloma A. Huidobro,[†] and Vincenzo Giannini[†,‡,§]

- TE and TM are different
- Long range interaction break the chiral symmetry
- Not Hermitian Hamiltonian
- Band are complex
- *Retardation Induced Phase Transitions*

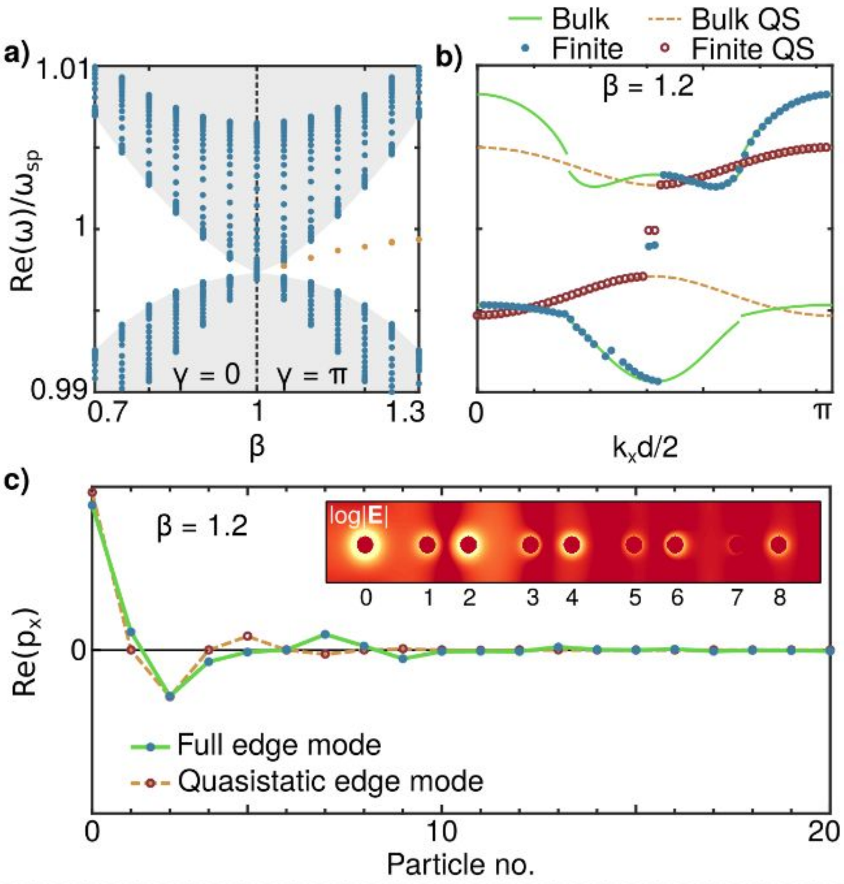
Topological Plasmonic Chain

$$t = \beta\frac{d}{2}$$

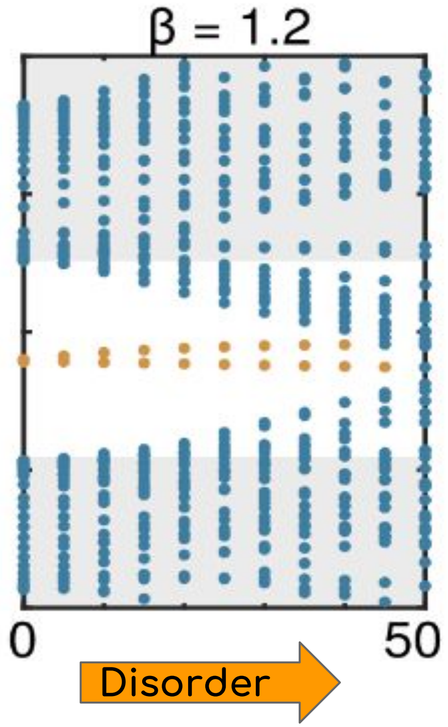


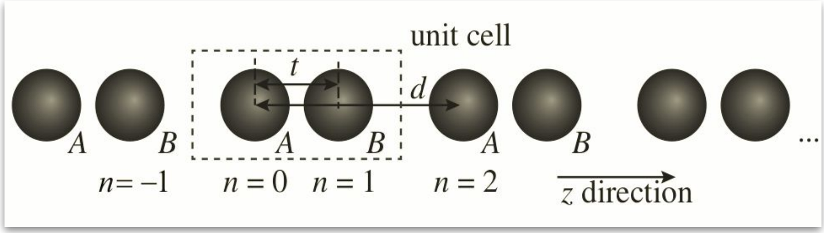
Pocock et al., ACS Phot. 5, 2271 (2018)

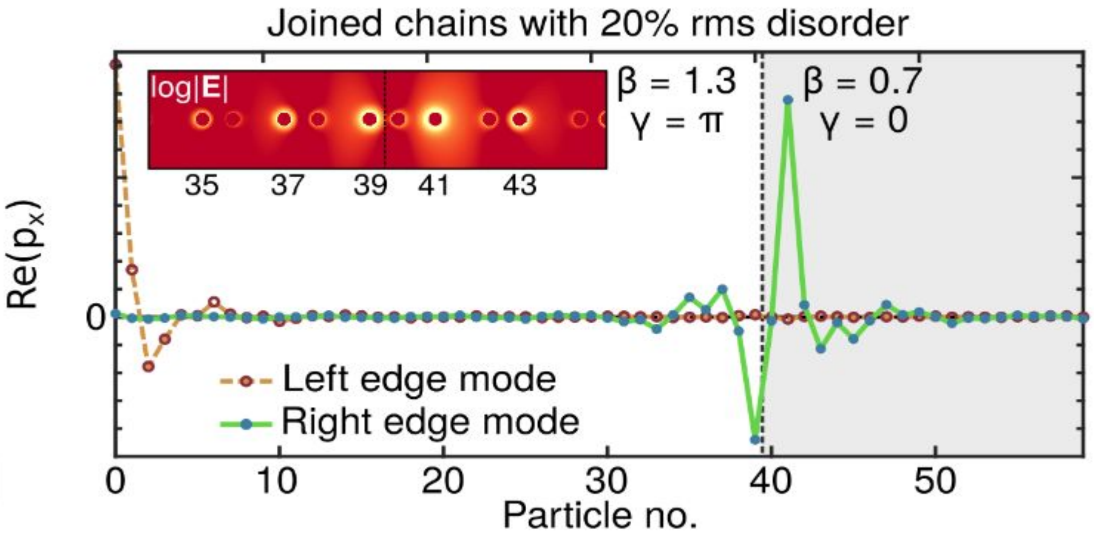
Longitudinal finite 60 particle chains, d = 250nm, a = 20nm



Topological Plasmonic Chain







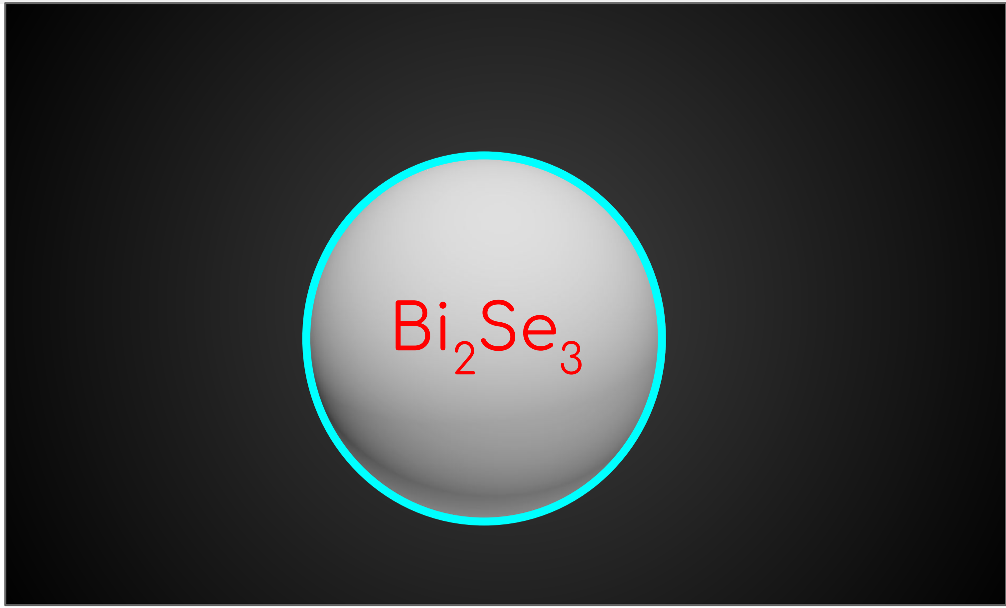
Pocock et al., ACS Phot. 5, 2271 (2018)

Plasmonics with Topological Insulators

Light

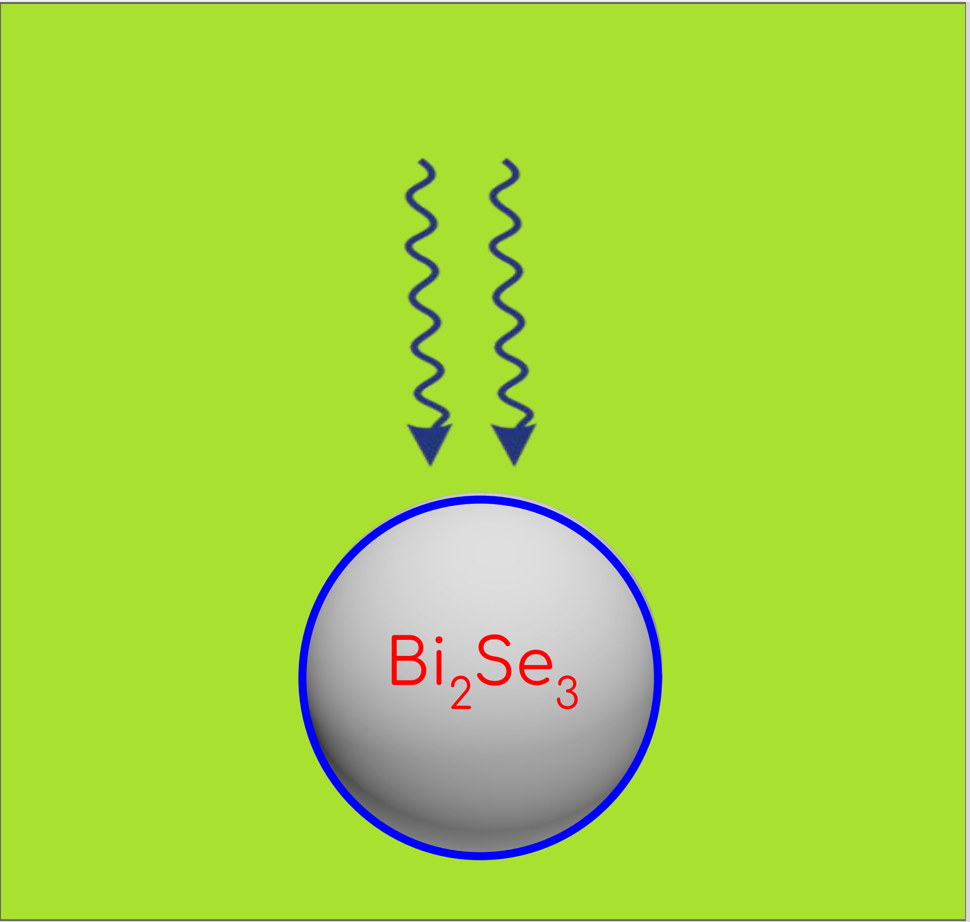
+

Topological Insulator Nanoparticle



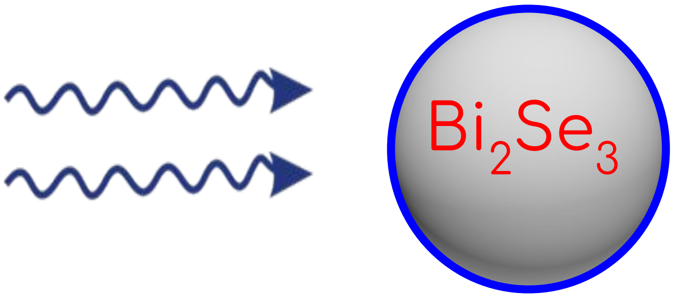
- Bulk insulator
- Topological protected conducting states on the surface

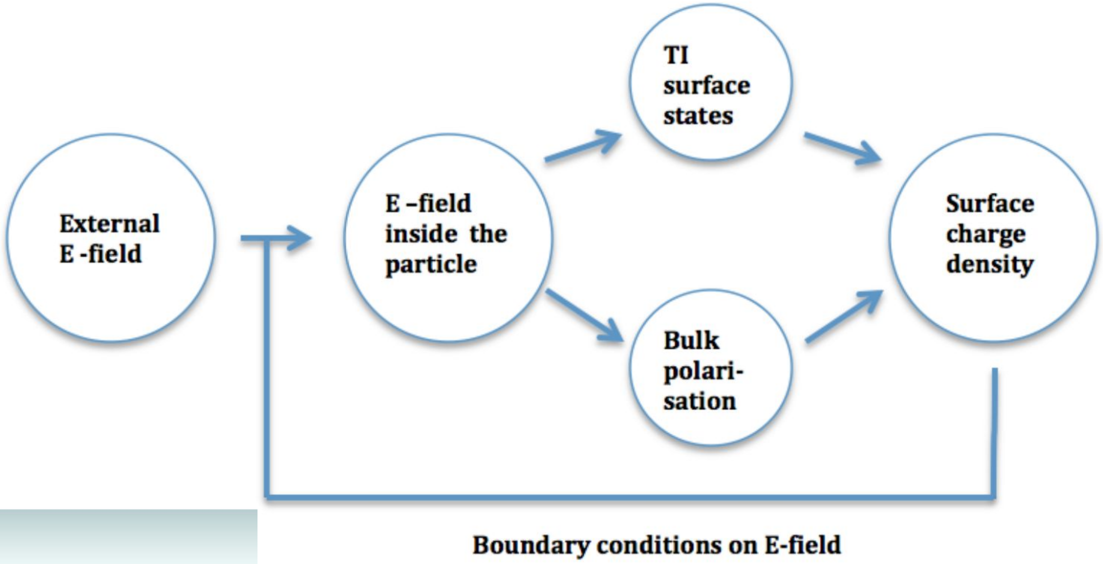
What Do We Expect...



- Strong THz EM enhancements
- Protected particle plasmons
- Nano-sources for non-local and non-dipolar transitions
- Topological Quantum dot

Light + Topological Insulator Nanoparticle





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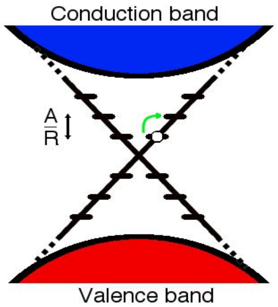
OPEN

Single-electron induced surface plasmons on a topological nanoparticle

G. Siroki[1], D.K.K. Lee[1], P.D. Haynes[1,2] & V. Giannini[1]

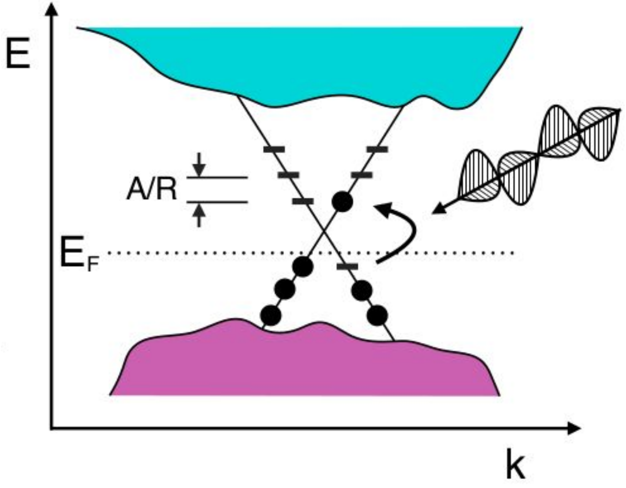


Light + Topological Insulator Nanoparticle

...the perturbation (light) **induces a time dependent surface charge density!**

$$\sigma_{abs} = 4\pi R^3 \frac{2\pi}{\lambda} Im\left(\frac{\varepsilon_{in} + \delta_R - 1}{\varepsilon_{in} + \delta_R + 2}\right)$$

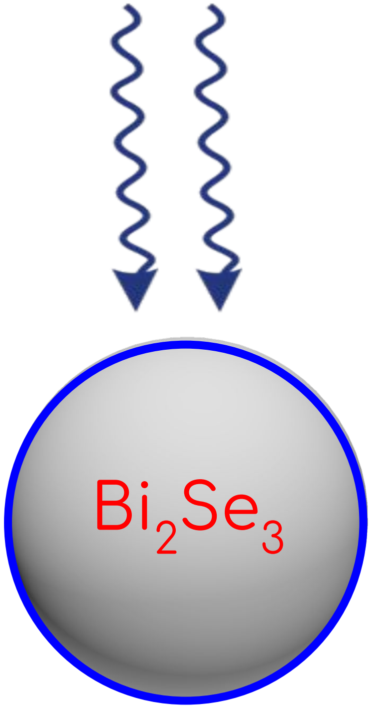
$$\delta_R = \frac{e^2}{6\pi\epsilon_0}\left(\frac{1}{A - \hbar\omega R} + \frac{1}{A + \hbar\omega R}\right)$$

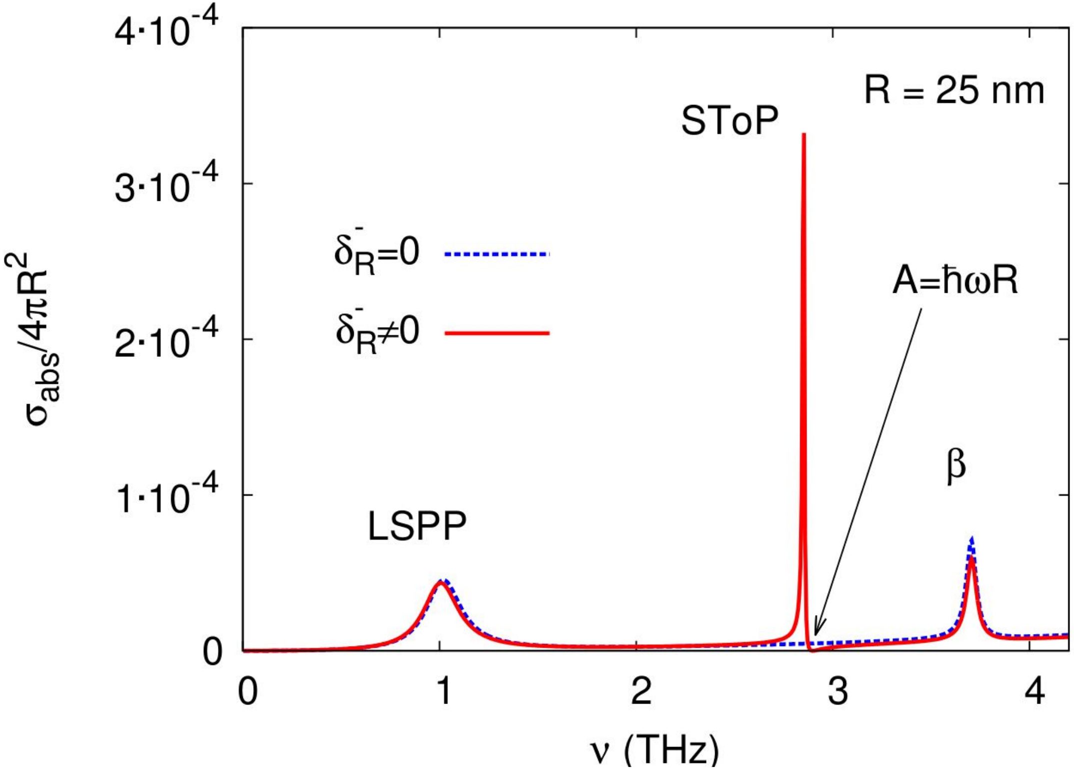


Fermi Energy and Radius dependence

Siroki et al., Nature Comms., 12375, (2016)

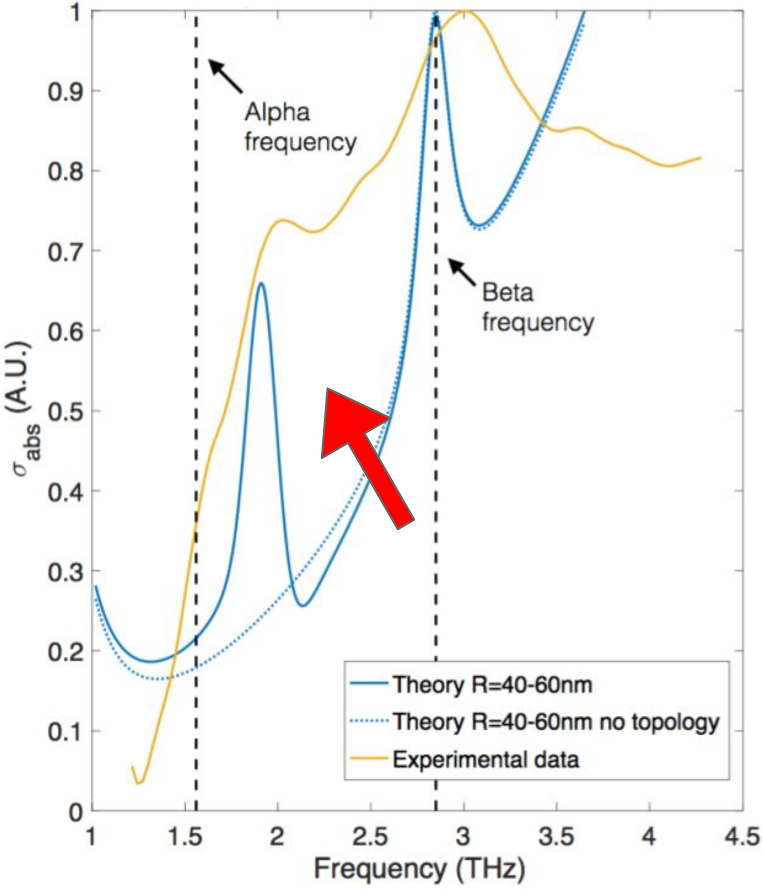
Surface Topological Polariton

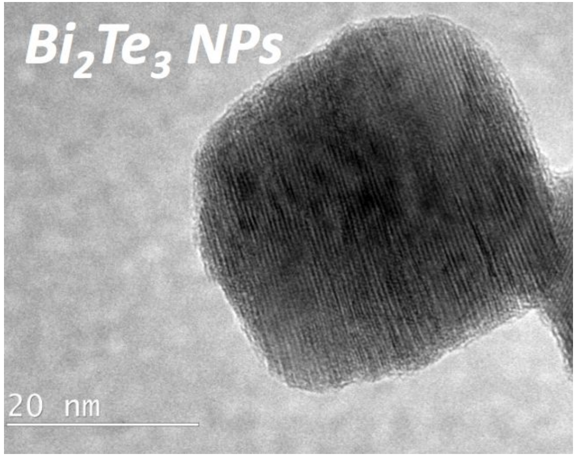




Siroki et al., Nature Comms., 12375, (2016)

Experimental Evidence of SToP Modes





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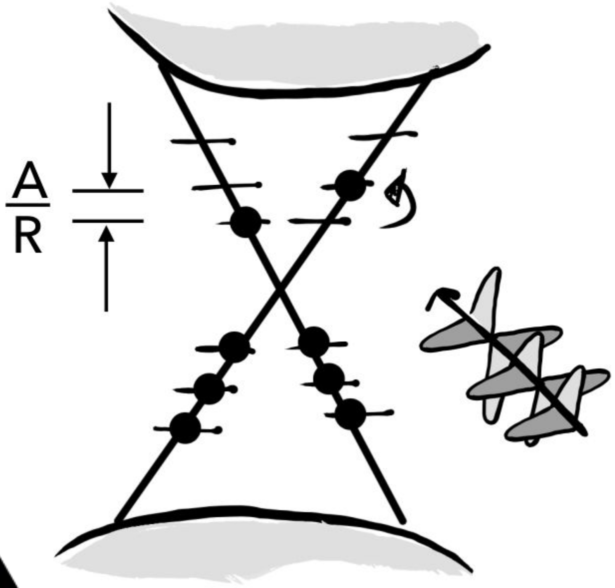
Cecilia Mattevi,

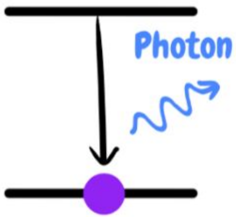
Imperial College London

Under Review

Topological Nanoparticle Lesing

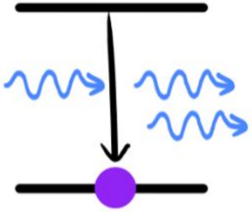


SPONTANEOUS EMISSION



$$\Gamma_{fi}^{spon} = \frac{4\alpha\omega_{fi}^3}{3c^2}|\langle f|\mathbf{x}|i\rangle|^2$$

STIMULATED EMISSION



$$\Gamma_{fi}^{stim} = \frac{4\pi^2\alpha I(\omega_{fi})}{\hbar}|\langle f|\varepsilon\cdot\mathbf{x}|i\rangle|^2$$

Conclusions

- Retardation Induced Transitions Phase
- Plasmonic Chain: Protected Hotspots
- Topological Quantum Dots
- Topological Photonics: Rich Physics

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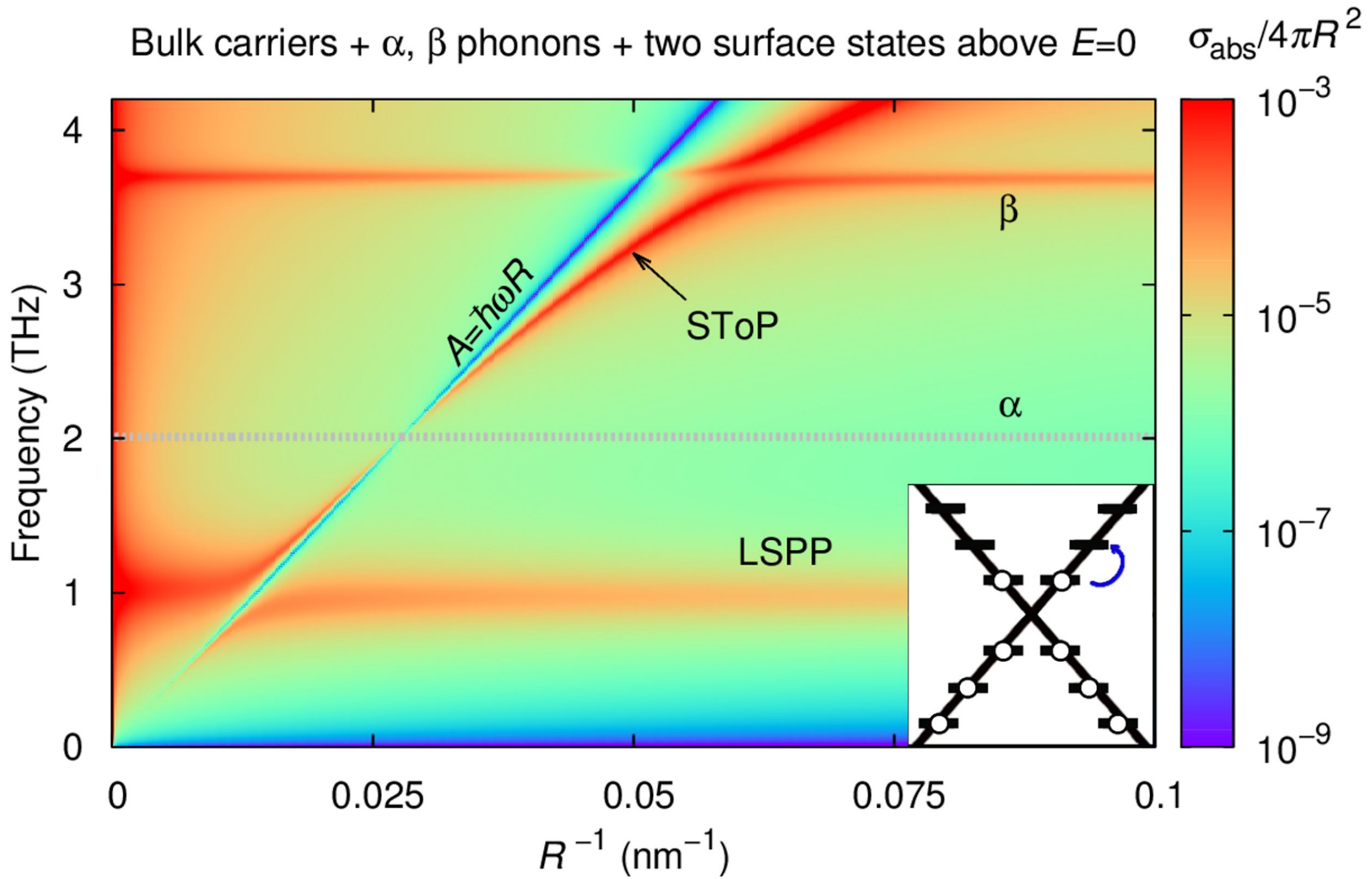
Topological Quantum Dots (SToP Mode)



Topological Nanoparticles

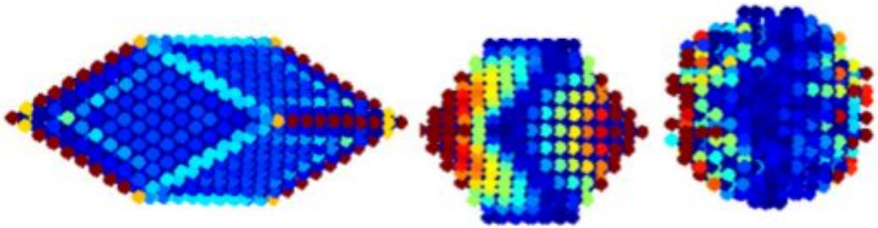
- Topological surfaces states are a bulk property!

Do we have enough bulk in a nanoparticle?

PHYSICAL REVIEW MATERIALS **1**, 024201 (2017)

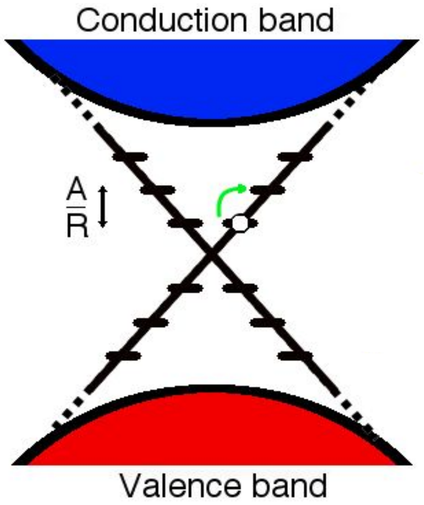
Protection of surface states in topological nanoparticles

Gleb Siroki,[1,*] Peter D. Haynes,[1,2] Derek K. K. Lee,[1] and Vincenzo Giannini[1,3]



Quantized Bands

A is a constant entering surface Dirac equation that determines the energy spacing of surface states



PHYSICAL REVIEW B **86**, 081303(R) (2012)

Surface states of topological insulators

Fan Zhang,* C. L. Kane, and E. J. Mele

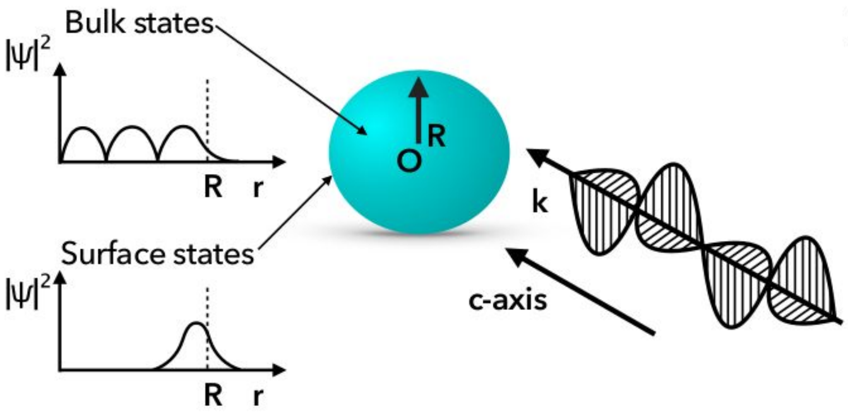
PHYSICAL REVIEW B **86**, 235119 (2012)

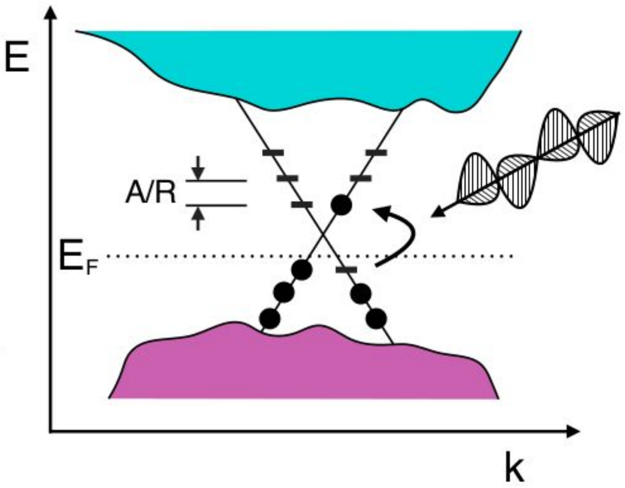
Spherical topological insulator

Ken-Ichiro Imura,[1] Yukinori Yoshimura,[1] Yositake Takane,[1] and Takahiro Fukui[2]

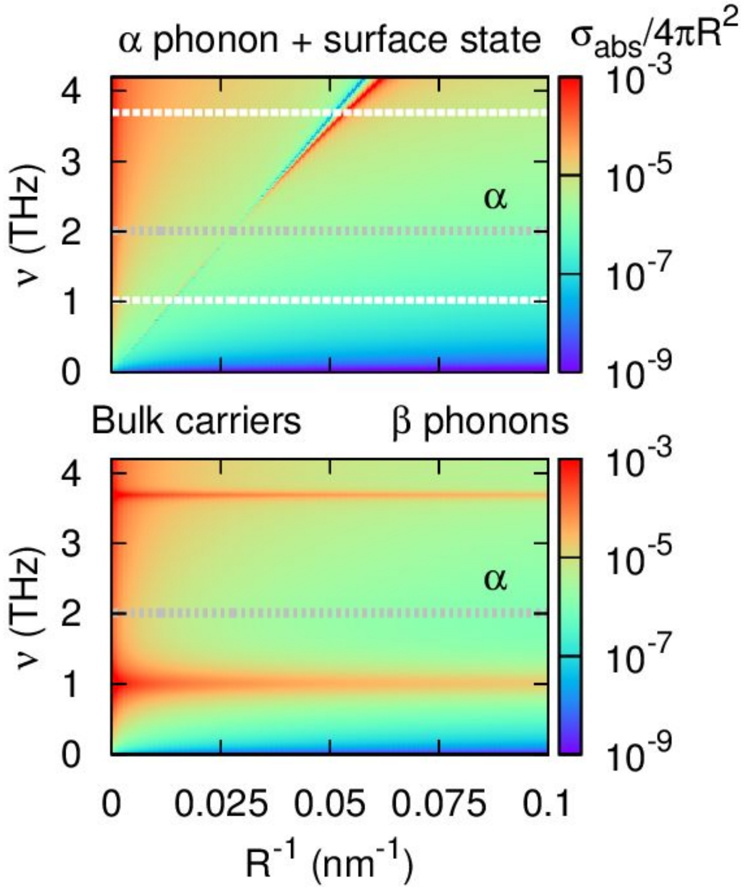
...+Light

- A simple system (Sphere, Bi_2Se_3)
- A simple perturbation (circularly polarized light)
- Time dependent Perturbation Theory to the Imura simplified four-band Hamiltonian of Bi_2Se_3





Surface Topological Polariton (SToP Mode)

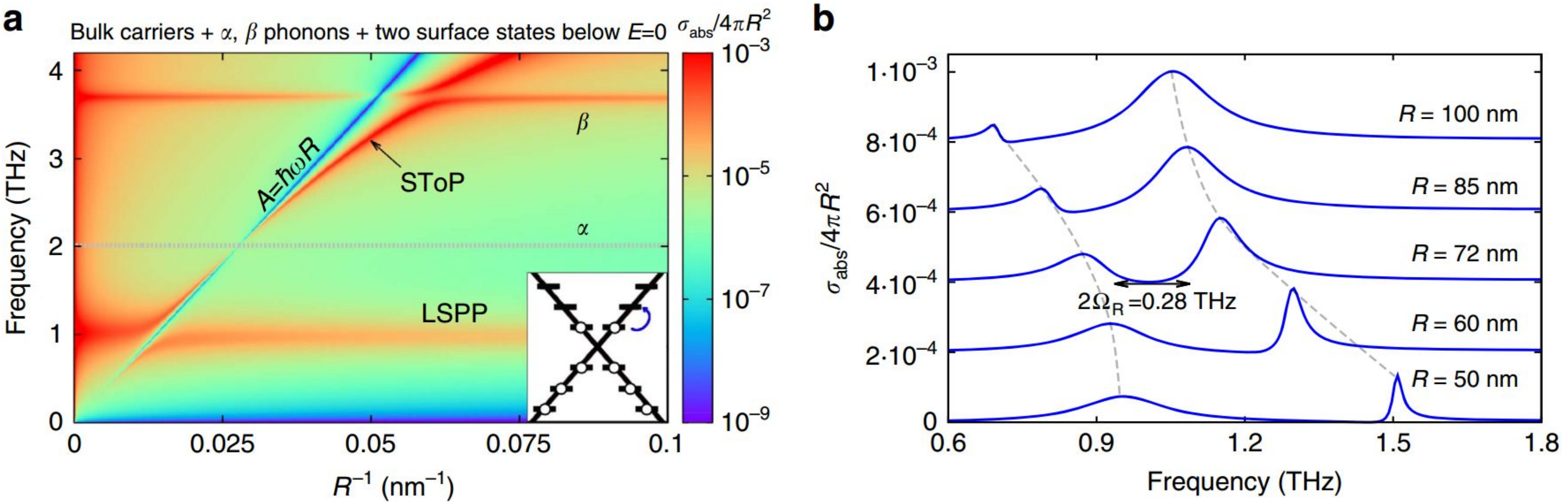


SToP mode:

Interaction of α phonon and surface states

Siroki et al., Nature Comms., 12375, (2016)

Surface Topological Polariton (SToP Mode)



- Rabi Splitting (g>0.1)
- Total Screening
- Quantum behaviour at room temperature... ???

Siroki et al., Nature Comms., 12375, (2016)