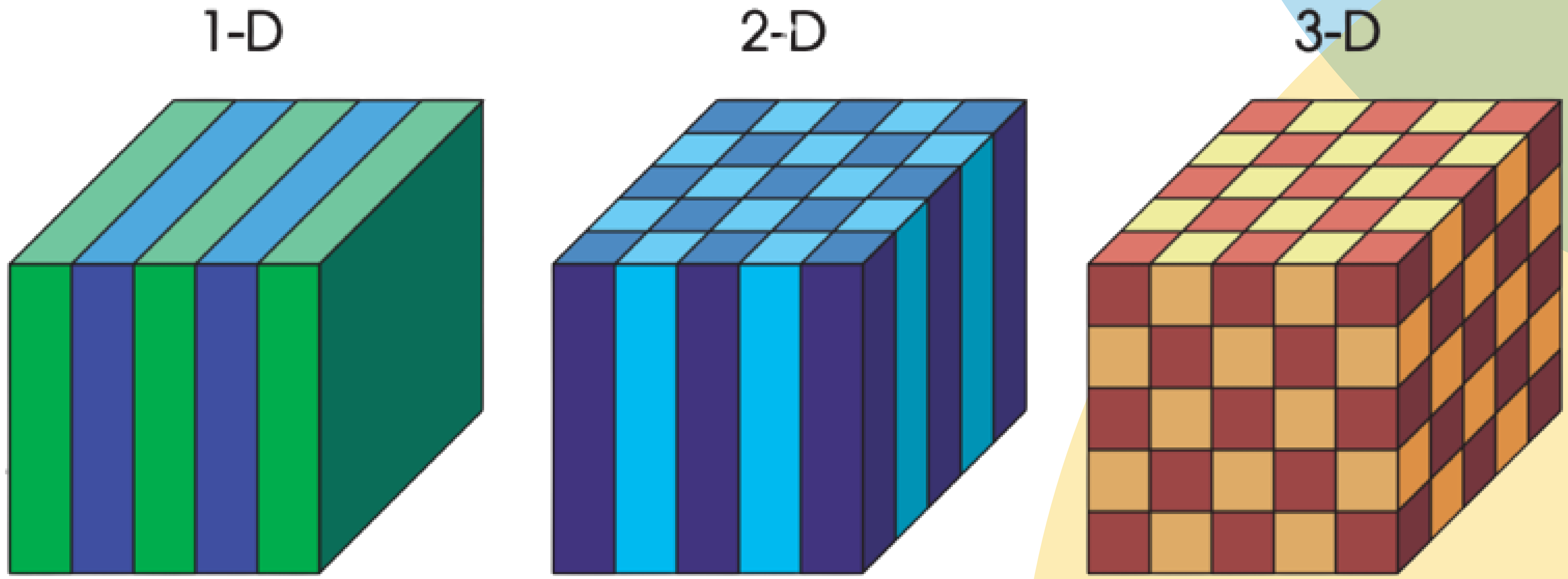
JORGE MARIO ESCOBAR, BRAYAN FERNANDO DÍAZ, JESÚS MARÍA CALERO

PHOTONIC CRYSTALS WITH SUPERCONDUCTORS

A STUDY OF THEIR REFLECTANCE IN ANNULAR TERNARY SYSTEMS

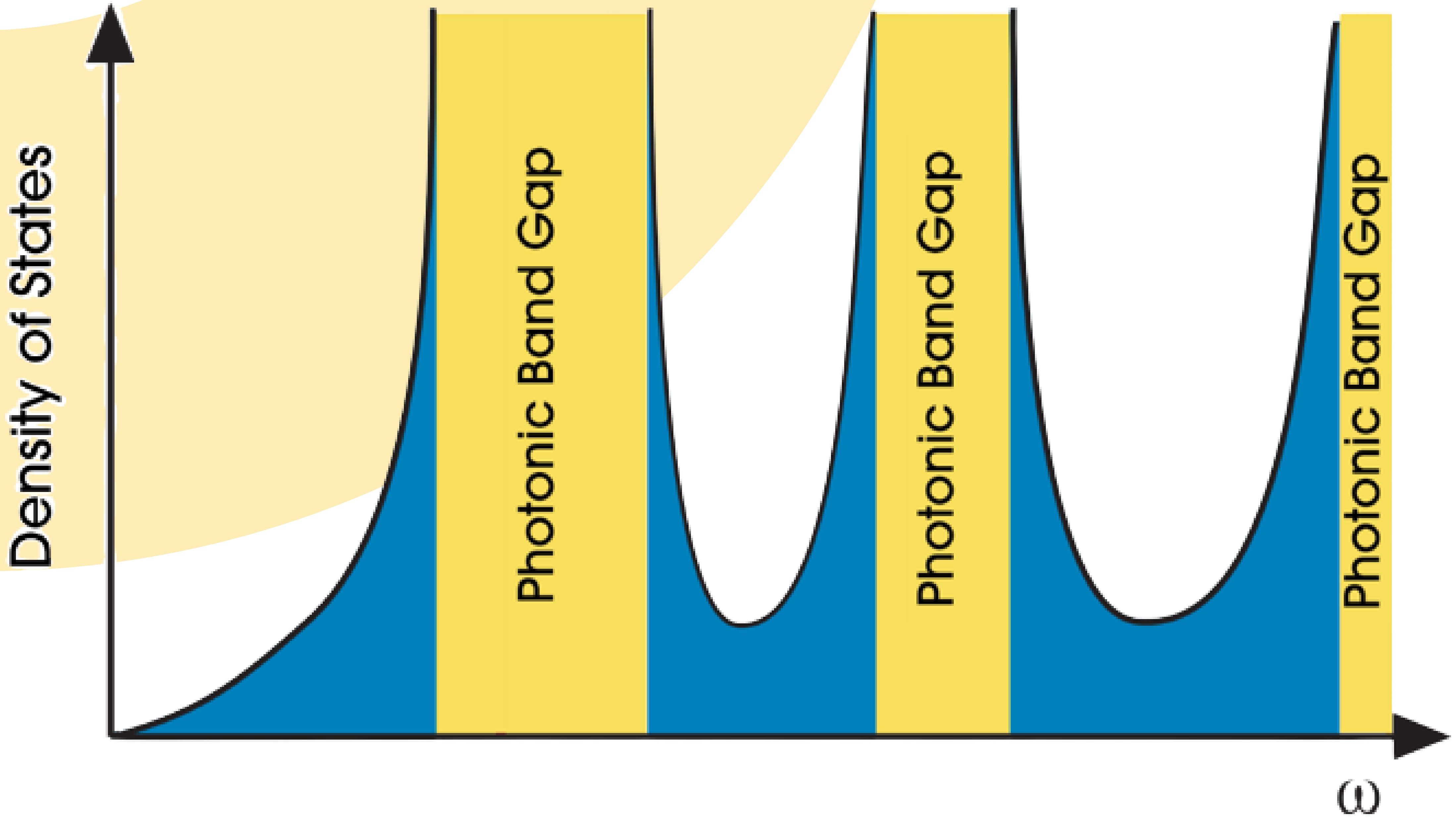
THEORETICAL SOLID STATE PHYSICS GROUP
DEPARTMENT OF PHYSICS
UNIVERSIDAD DEL VALLE
COLOMBIA

PHOTONIC CRYSTALS



J. D. Joannopoulos, *Photonic Crystals*, Princeton Universtiy Press, (2008).

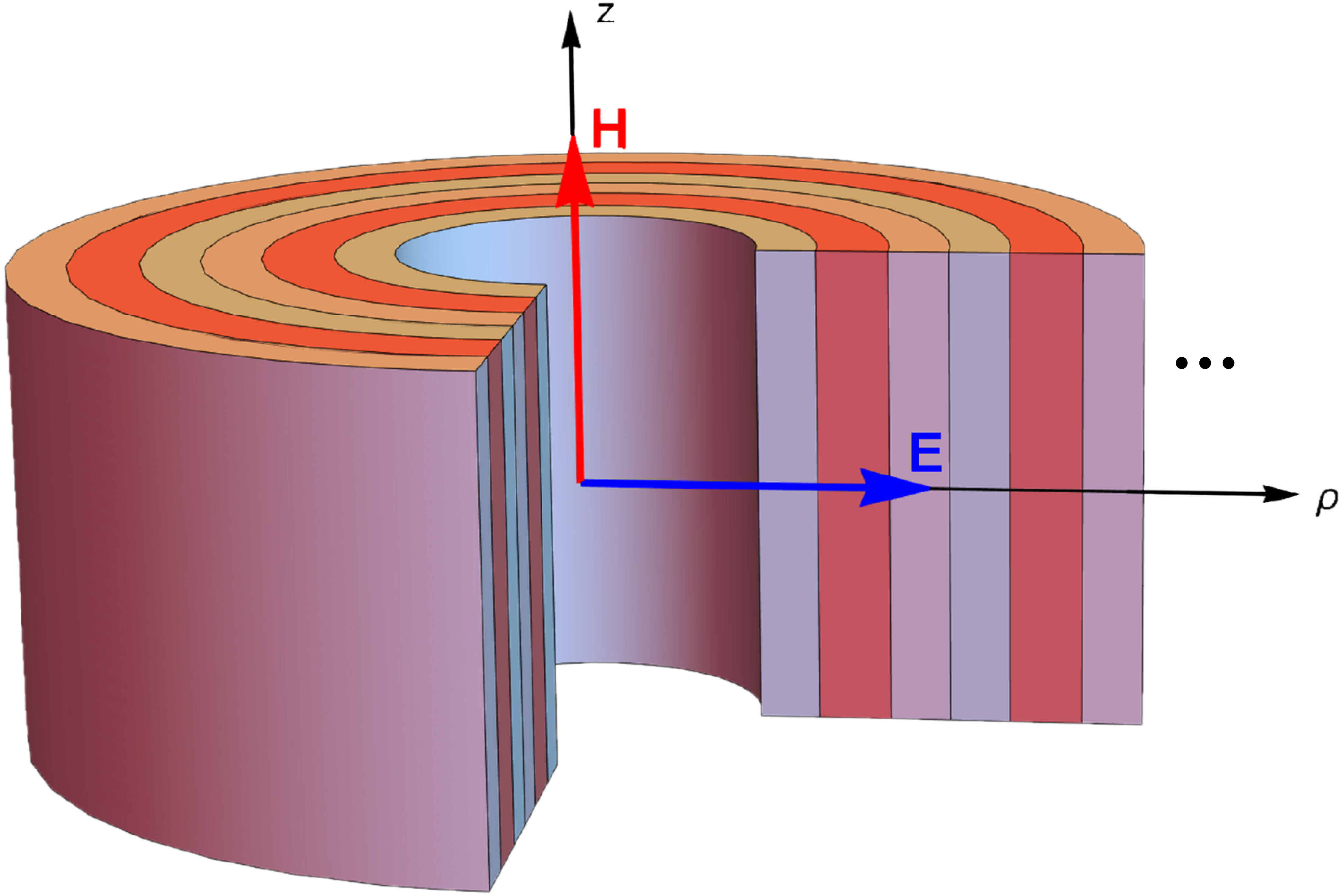
PHOTONIC BAND GAPS



THESE PHOTONIC BAND GAPS ALLOW US TO DESIGN FILTERS AND REFLECTORS FOR ELECTROMAGNETIC WAVES.

J. D. Joannopoulos, *Photonic Crystals*, Princeton Universtiy Press, (2008).
M. S. Chen *et al.*, Solid State Communications, 149, 1888–1893 (2009).
V. V. Nikolaev *et al.*, Fiz. Tekh. Poluprovodn., 33, 174–179 (1999).

ANNULAR TERNARY SYSTEM

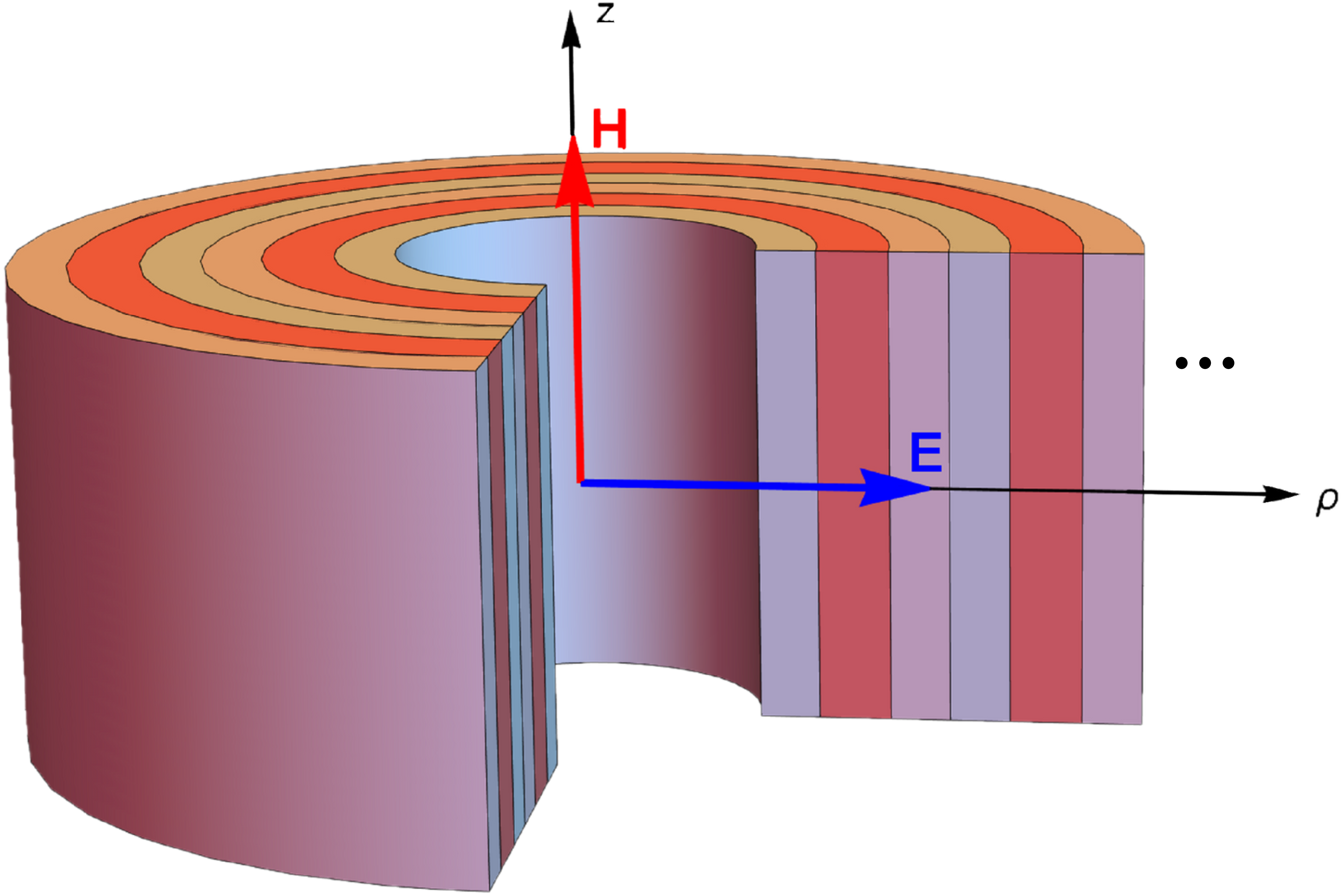


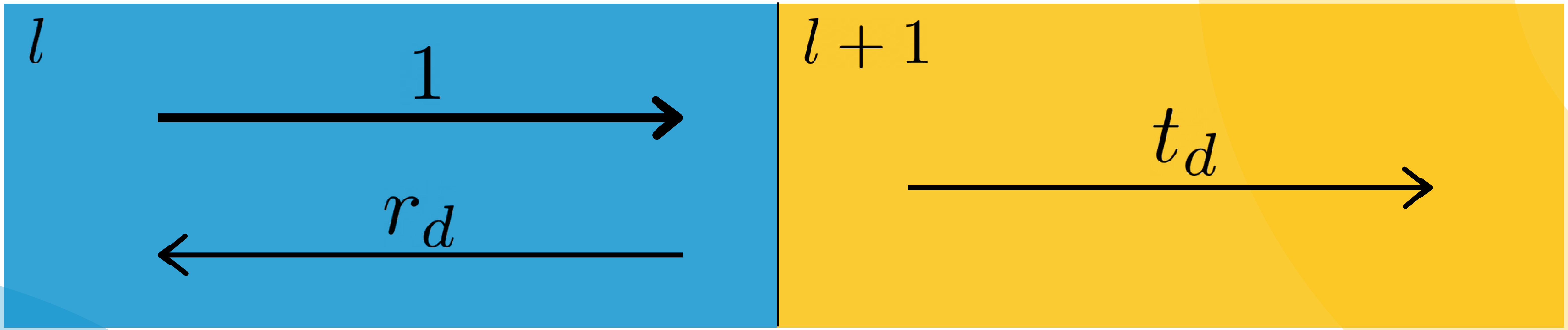
ANNULAR TERNARY SYSTEM

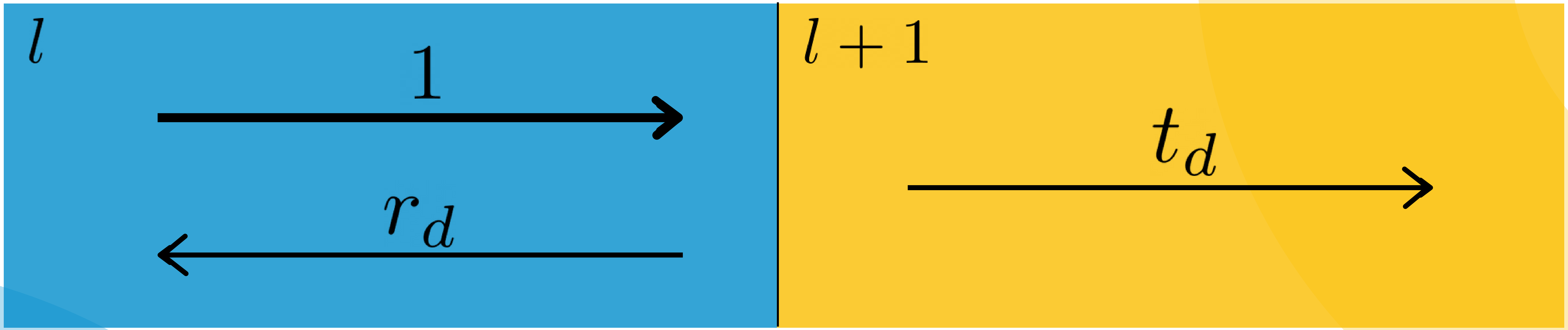
WE WILL ANALYZE THE OPTICAL RESPONSE OF THE SYSTEM IN TM POLARIZATION.

$$\mathbf{H} = H_z \hat{\mathbf{e}}_z$$

$$\mathbf{E} = E_\rho \hat{\mathbf{e}}_\rho + E_\phi \hat{\mathbf{e}}_\phi$$

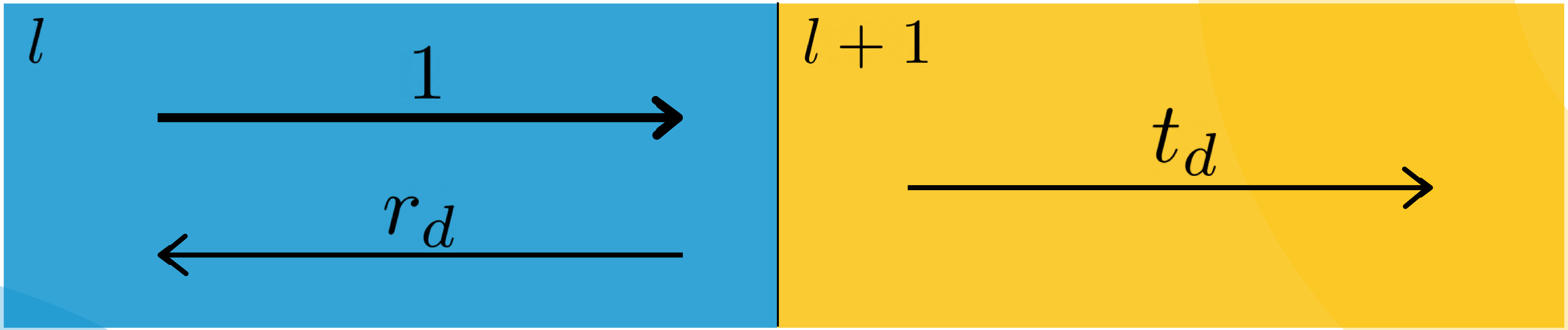



l
1
r_d
$l+1$
t_d



$$\begin{pmatrix}\text{EM}\\ \text{wave}\end{pmatrix}_{l} \longrightarrow \begin{pmatrix}\text{EM}\\ \text{wave}\end{pmatrix}_{l+1}$$

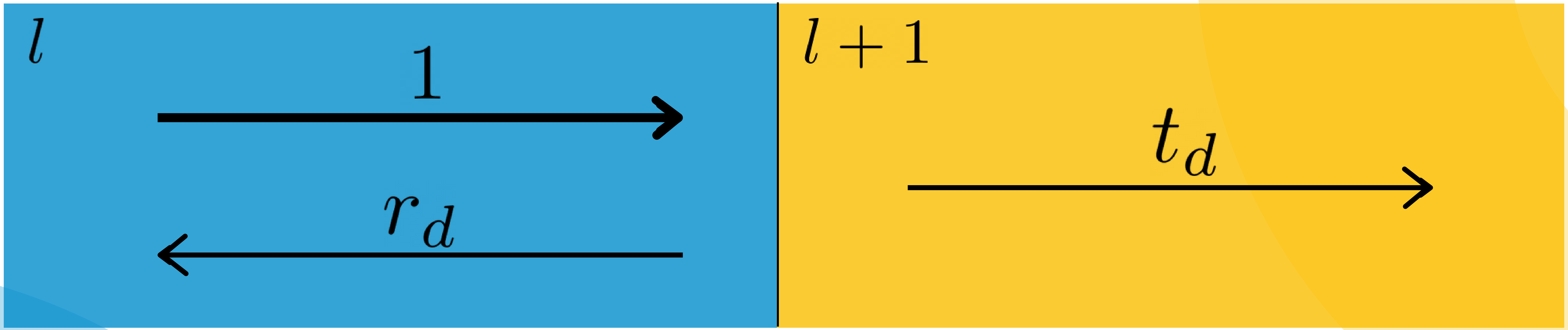
TRANSFER MATRIX METHOD



$$\hat{\mathfrak{M}}_l \begin{pmatrix} \text{EM} \\ \text{wave} \end{pmatrix}_l = \begin{pmatrix} \text{EM} \\ \text{wave} \end{pmatrix}_{l+1}$$

M. Born, E. Wolf, *Principles of Optics*, P. 77, Moscow, (1970).

TRANSFER MATRIX METHOD



$$\hat{\mathfrak{M}}_l \begin{pmatrix}\text{EM}\\ \text{wave}\end{pmatrix}_l = \begin{pmatrix}\text{EM}\\ \text{wave}\end{pmatrix}_{l+1}$$

$$t_d = \frac{|\hat{\mathfrak{M}}_l|}{\mathfrak{M}_l^{22}} \quad \text{y} \quad r_d = -\frac{\mathfrak{M}_l^{21}}{\mathfrak{M}_l^{22}} \longrightarrow R_d = \left|\frac{\mathfrak{M}_l^{21}}{\mathfrak{M}_l^{22}}\right|^2, \quad \text{con } R_d = \boxed{R_d(\lambda)}$$

M. Born, E. Wolf, *Principles of Optics*, P. 77, Moscow, (1970).
P. Markos, C. M. Soukoulis, *Wave Propagation*, Princeton University Press, (2008).

THEORETICAL TREATMENT

MASTER EQUATION

$$\nabla \times \left[\frac{1}{\epsilon(\mathbf{r},\omega)}\nabla \times \mathbf{H}(\mathbf{r})\right] = \left(\frac{\omega}{c}\right)^2 \mathbf{H}(\mathbf{r})$$

J. D. Joannopoulos, *Photonic Crystals,* Princeton Universtiy Press, (2008).

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Description in cylindrical coordinates

BESSEL PARTIAL DIFFERENTIAL EQUATION

$$\left[\frac{1}{\rho^2}\frac{\partial}{\partial\phi}\left(\frac{1}{\epsilon(\mathbf{r},\omega)}\frac{\partial}{\partial\phi}\right) + \frac{1}{\rho}\frac{\partial}{\partial\rho}\left(\rho\frac{1}{\epsilon(\mathbf{r},\omega)}\frac{\partial}{\partial\rho}\right)\right] H_z(\mathbf{r}) = -\left(\frac{\omega}{c}\right)^2 H_z(\mathbf{r})$$

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C. A. Hu *et al.*, Optics Communications, 291, 424–434, (2013).

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Solutions in traveling wave basis

$$\begin{cases} H_z^{\pm} = A H_m^{\binom{1}{2}}(k\rho)e^{im\phi} \\ E_\phi^{\pm} = ipA\frac{\partial}{\partial(k\rho)} H_m^{\binom{1}{2}}(k\rho)e^{im\phi} \end{cases}$$

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THEORETICAL TREATMENT

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Description in cylindrical coordinates

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Apply boundary conditions to build the matrix

TRANSFER MATRIX

$$\hat{\mathfrak{M}}_l = \begin{pmatrix} H_m^{(1)}(k_l\rho_l) & H_m^{(2)}(k_l\rho_l) \\ \frac{1}{k_l}H_m'^{(1)}(k_l\rho_l) & \frac{1}{k_l}H_m'^{(2)}(k_l\rho_l) \end{pmatrix}$$

J. D. Joannopoulos, *Photonic Crystals*, Princeton Universtiy Press, (2008).

C. A. Hu *et al.*, Optics Communications, 291, 424–434, (2013).

SUPERCONDUCTOR REFRACTIVE INDEX

$$n(\lambda, T) = \sqrt{1 - \left(\frac{\lambda}{2\pi\lambda_L(T)}\right)^2}$$

TWO FLUIDS MODEL

LONDON PENETRATION DEPTH

$$\lambda_L(T) = \frac{\lambda_0}{\sqrt{1 - \left(\frac{T}{T_c}\right)^4}}$$

K. P. Sreejith, V. Mathew, Journal of Superconductivity and Novel Magnetis, 32:2397, (2019).

C. P. Poole Jr. *et al*, *Superconductivity*, Elsevier (2007).

SUPERCONDUCTOR REFRACTIVE INDEX

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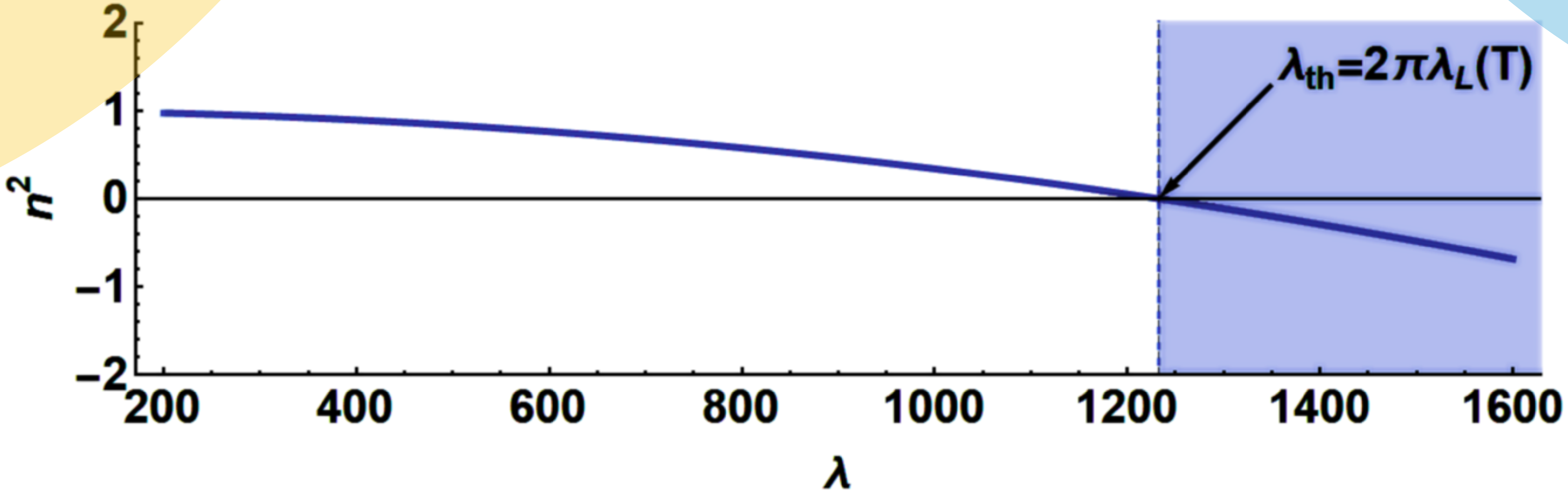
AT FIXED TEMPERATURE



K. P. Sreejith, V. Mathew, Journal of Superconductivity and Novel Magnetis, 32:2397, (2019).
C. P. Poole Jr. *et al*, *Superconductivity*, Elsevier (2007).

OUR SYSTEM

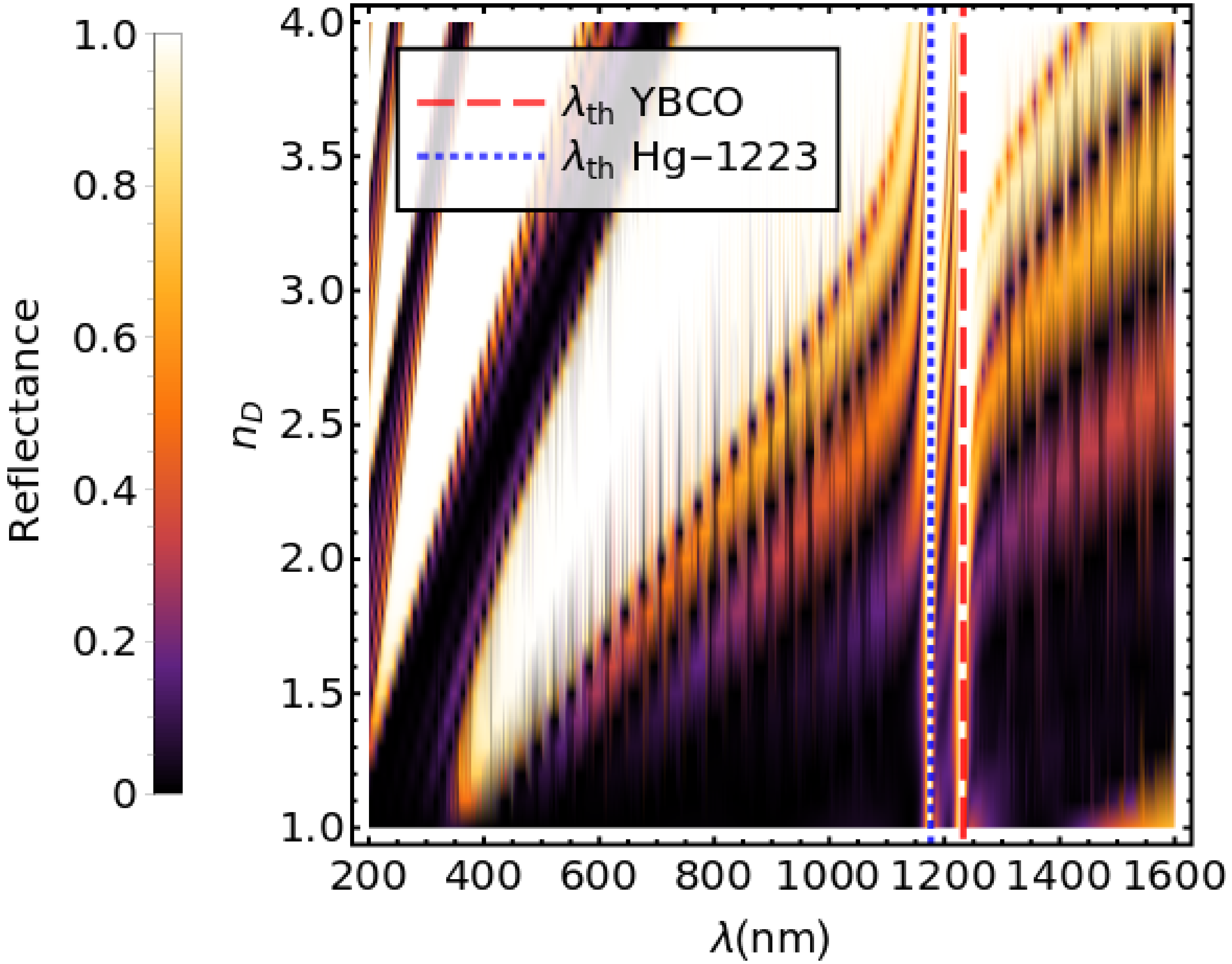
Superconductor
$YBa_2Cu_3O_7$
(YBCO)
T_C=92K

Dielectric
SrTiO
n_D=2.437

Superconductor
$HgBa_2Ca_2Cu_3O_{10}$
(Hg-1223)
T_C=135K

RESULTS

Dielectric refractive index variation



$$T = 77K$$

Superconductor refractive index

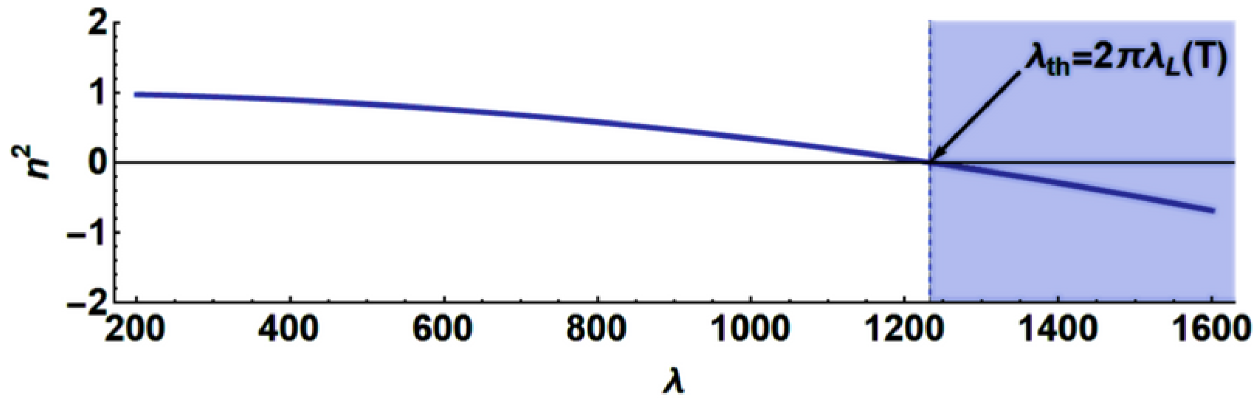
$$n(\lambda, T) = \sqrt{1 - \left(\frac{\lambda}{2\pi\lambda_L(T)}\right)^2}$$

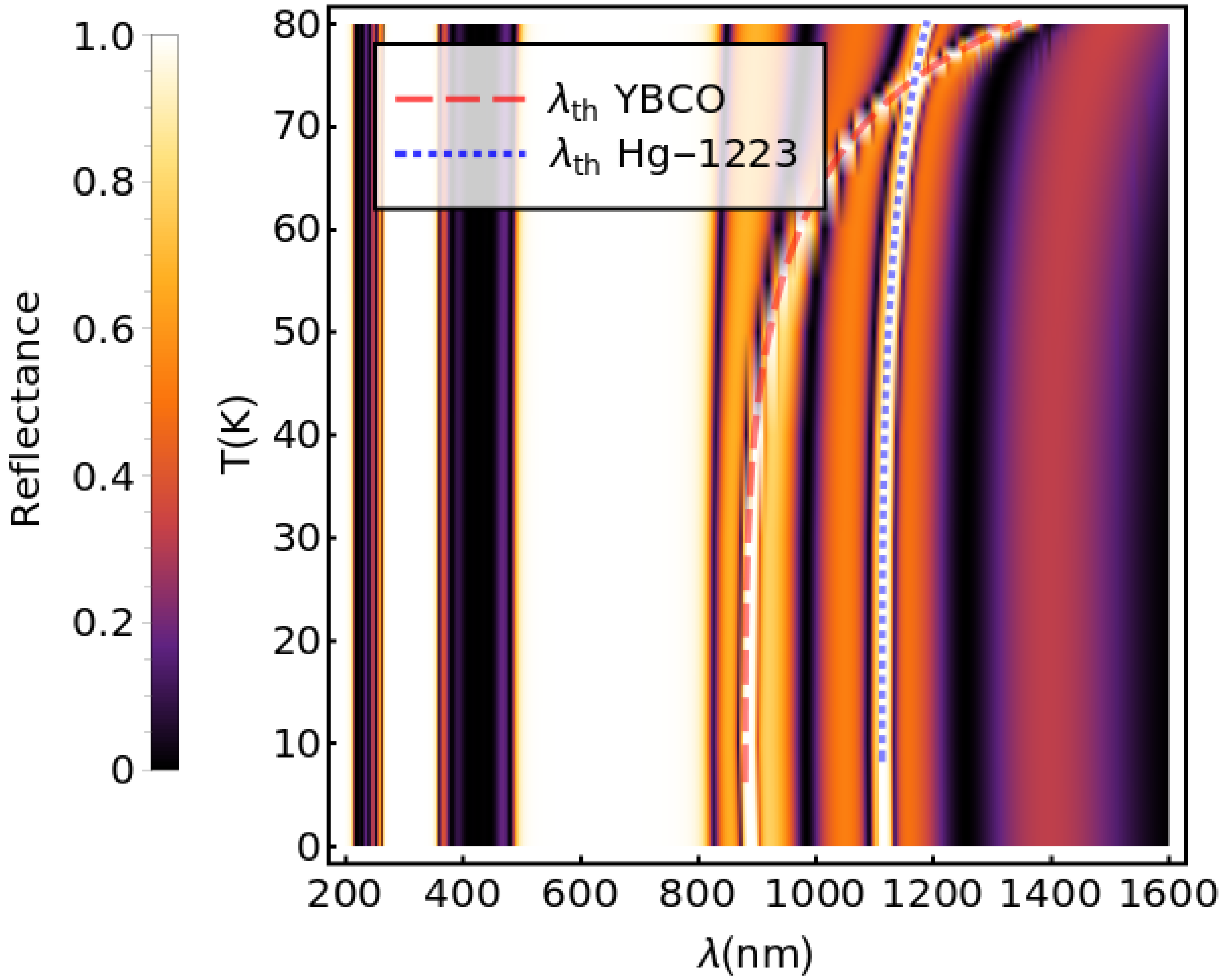
RESULTS
Temperature variation

$$n_D = 2.437$$

Superconducting threshold

$$\lambda_{th} = 2\pi\lambda_L(T) = 2\pi \frac{\lambda_0}{\sqrt{1-\left(\frac{T}{T_c}\right)^4}}$$





CONCLUSIONS

- Characterizing the optical response allows us to control the propagation of electromagnetic waves in the crystal.
- Introducing superconductors into the system produces new gaps, presenting new technological applications such as thermal sensors.

PERSPECTIVES

- It is possible to study the optical response of the system to variations of other parameters such as crystal radius or layer thickness.
- Other combinations of materials can be proposed and even alternate the order in which the superconductors are configured.

THANK YOU

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