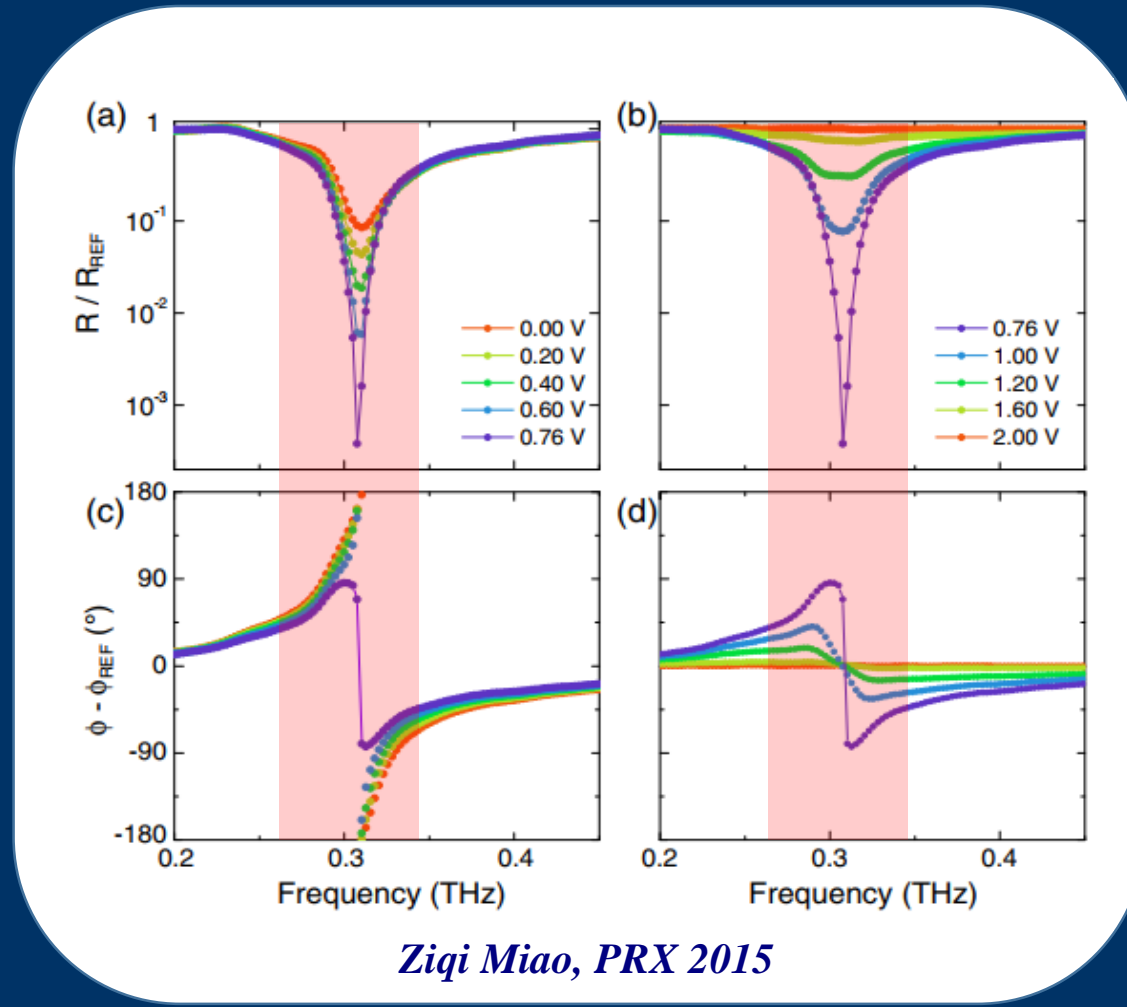
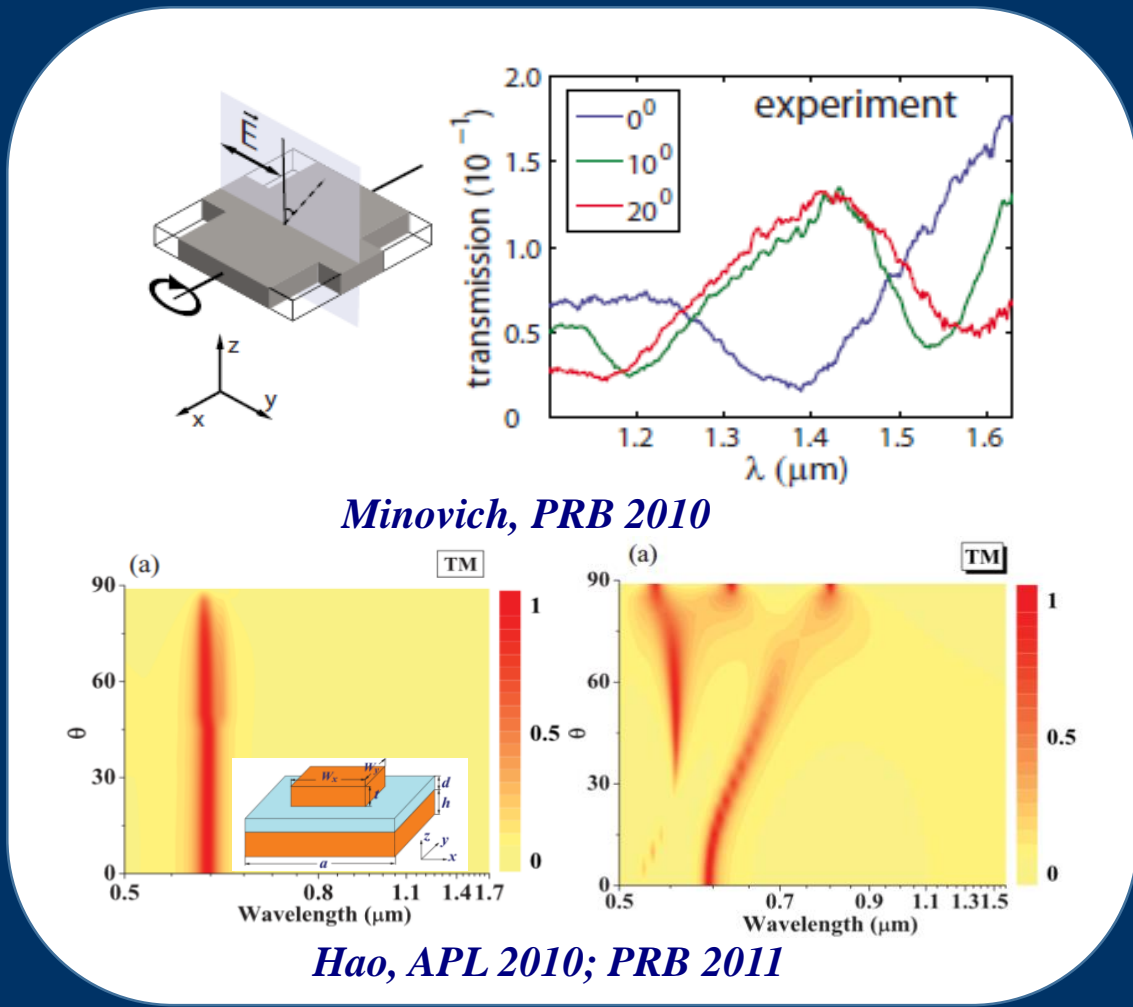


Metasurfaces with complex meta-atoms: Role of coupling between bright and dark modes

Tong Liu¹, Haoyang Zhou¹, Qiong He¹, Shiyi Xiao^{2,*}, Lei Zhou^{1,*}

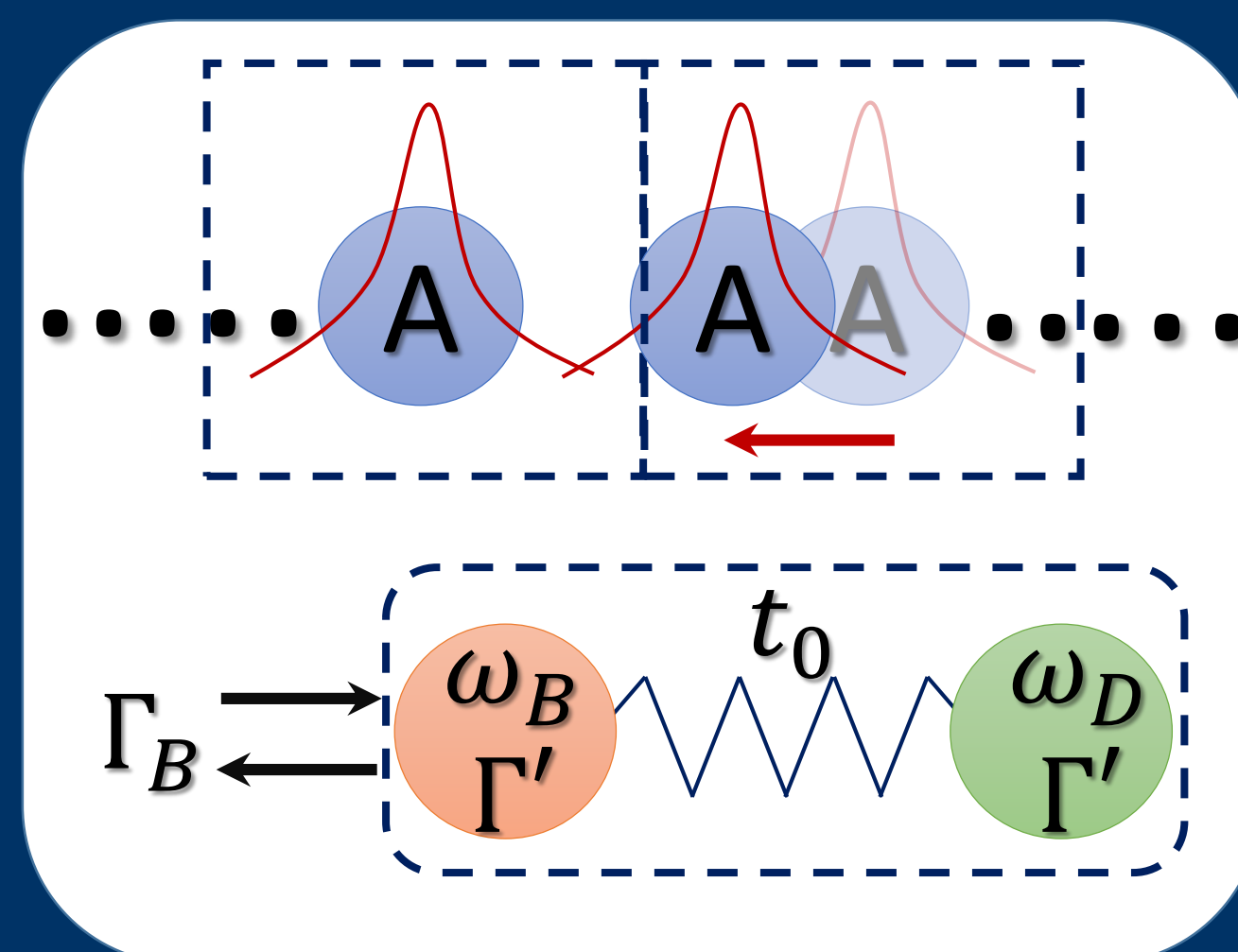
• Backgrounds



• Intrinsic limitations of metasurfaces built with single-mode meta-atoms:

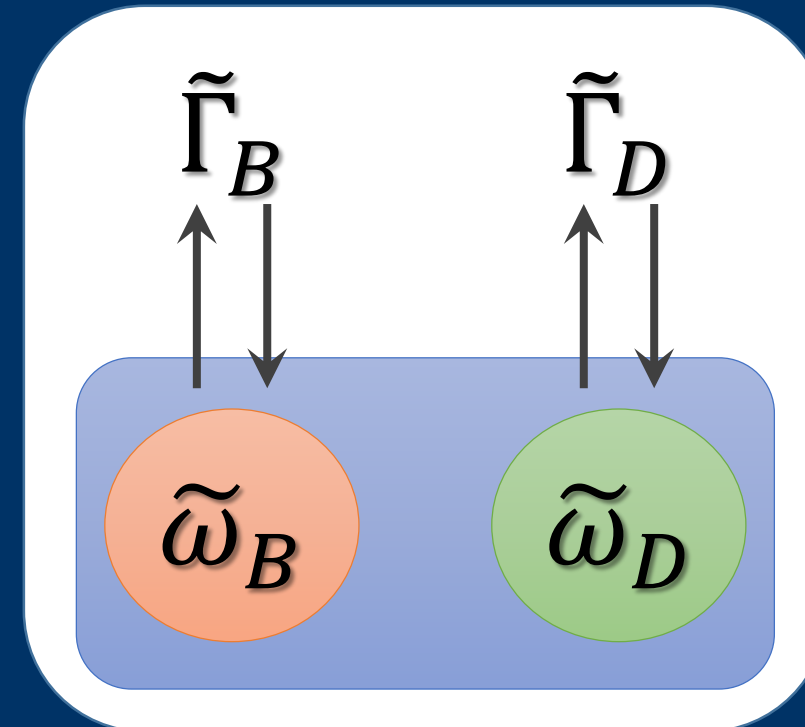
1. Uncontrollable angular dispersions (AD)
2. Strongly correlated amplitude & phase due to frequency dispersion (FD)

• Basic idea: New DOF by breaking symmetry



What can we control ?

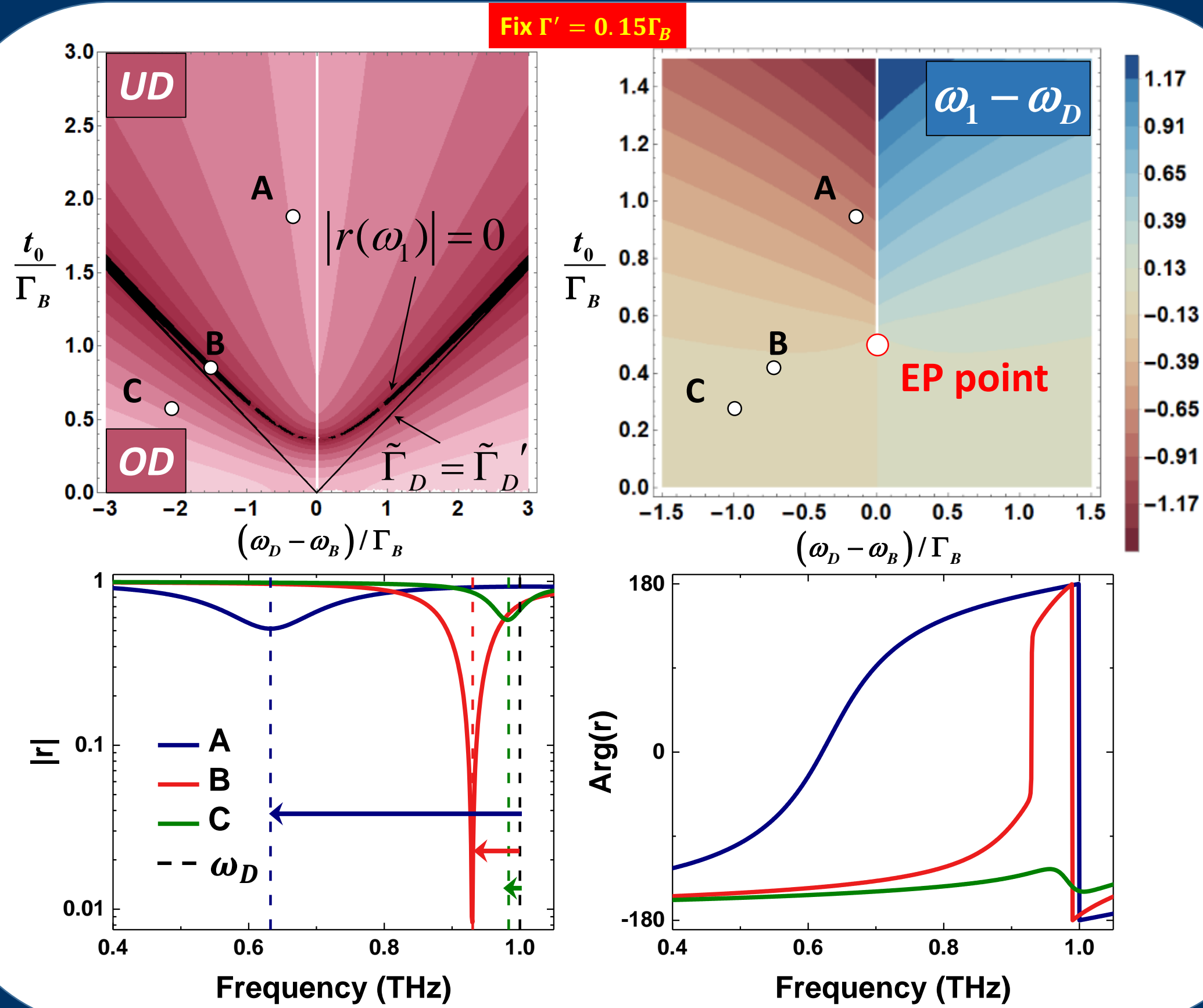
- ① Detuning: $\frac{\omega_D - \omega_B}{\Gamma_B}$
- ② Coupling: $\frac{t_0}{\Gamma_B}$
- ③ Intrinsic loss: $\frac{\Gamma'}{\Gamma_B}$



Modulation on dressed modes

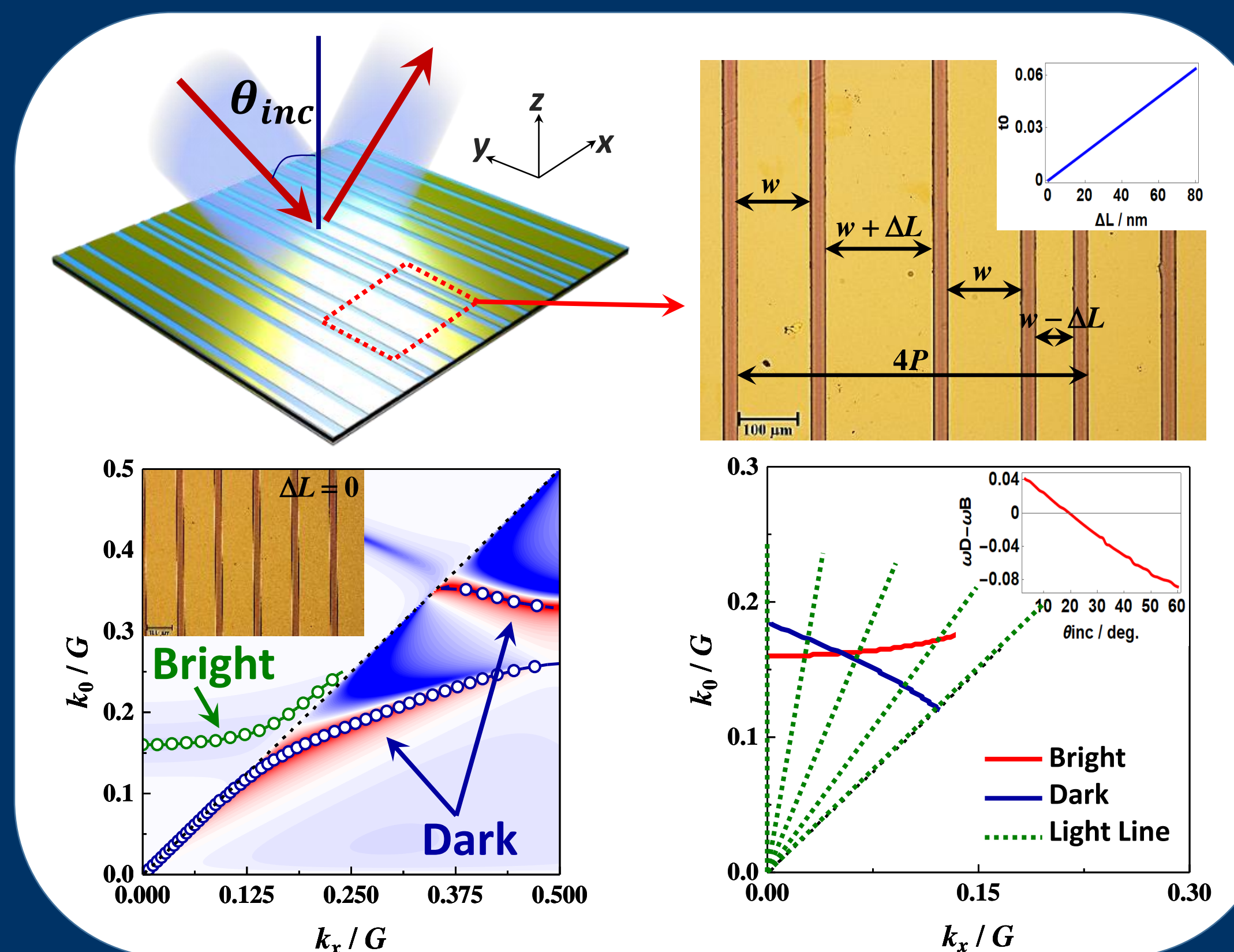
$$\begin{cases} \tilde{\omega}_B = \bar{\omega}_0 - \kappa \\ \tilde{\omega}_D = \bar{\omega}_0 + \kappa \\ \tilde{\Gamma}_B = \frac{\Gamma_B \cdot \Delta\omega^2}{\Delta\omega^2 + t_0^2} \\ \tilde{\Gamma}_D = \frac{\Gamma_D \cdot t_0^2}{\Delta\omega^2 + t_0^2} \end{cases}$$

• A generic phase diagram



- Fascinating yet distinct optical properties of the dressed modes are shown in different phase regions, generated by interplays between three important parameters.

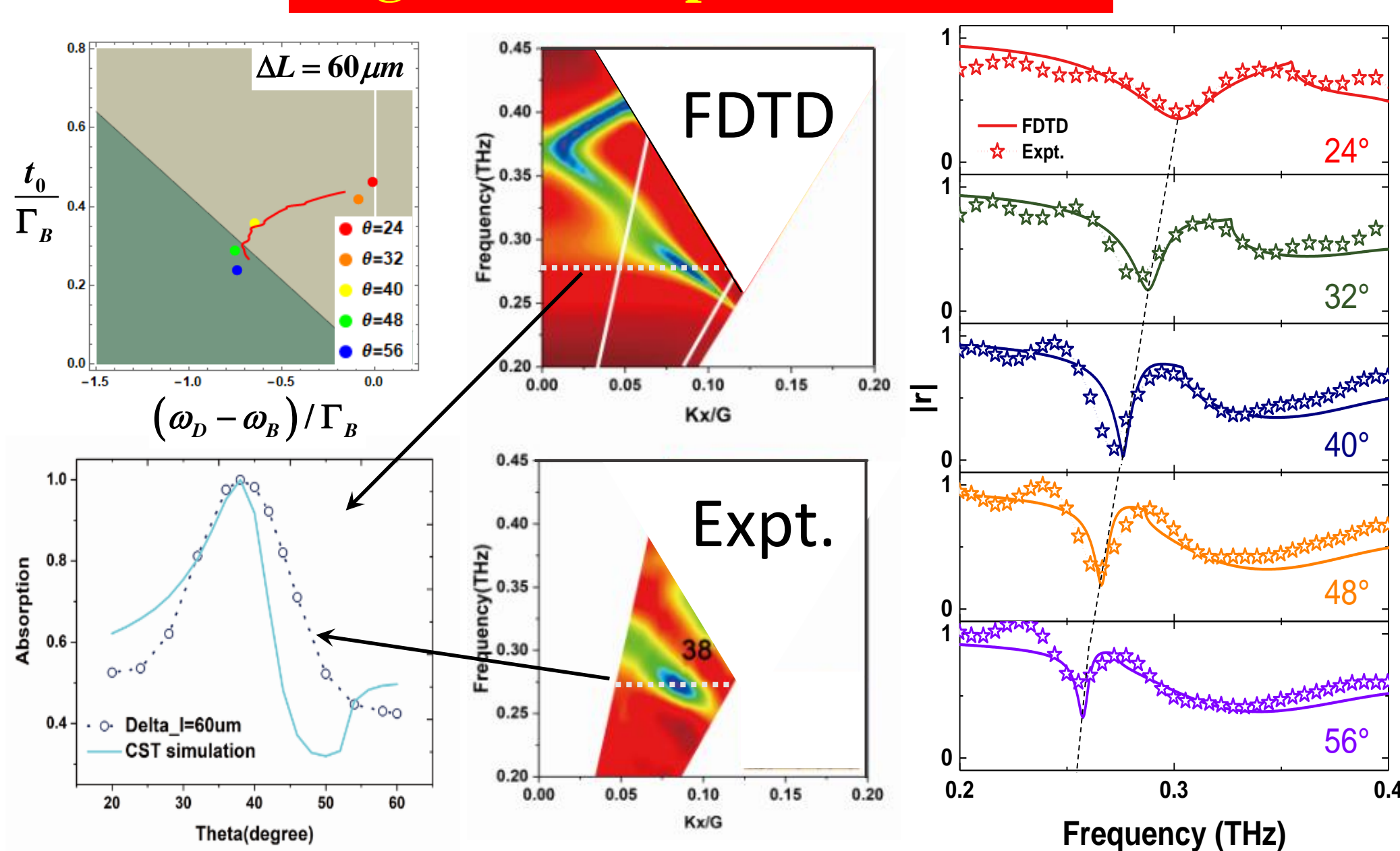
• Correlate lumped parameter with θ_{inc} & ΔL



- Such a generic phase diagram, together with the established relations, offers an excellent platform to guide researchers to design meta-atoms exhibiting freely controlled FD & AD.

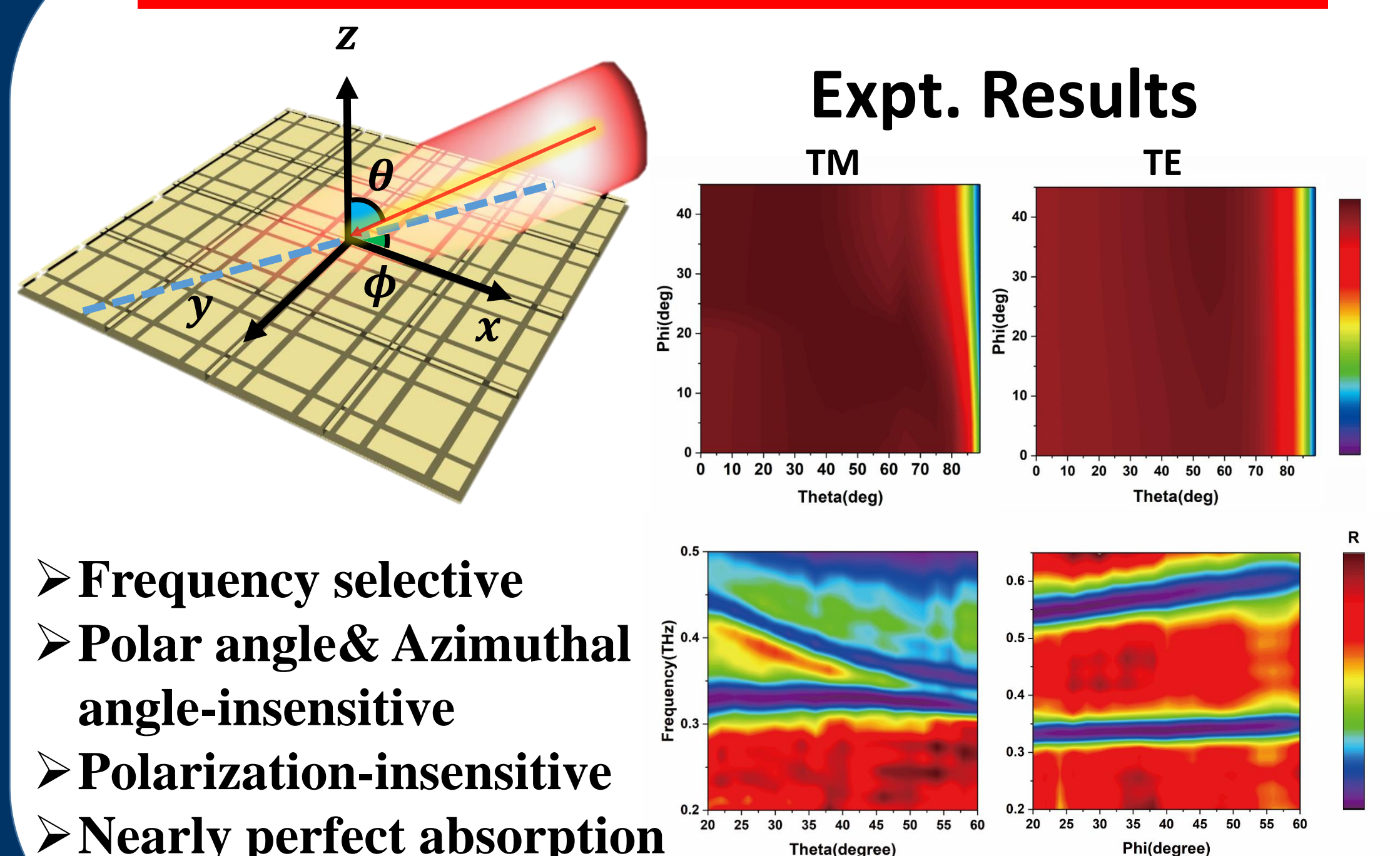
• THz experimental verification

Angle-selective perfect absorber



- We can further achieve perfect absorption at steerable critical angle by other samples with different ΔL .

All-angle polarization-insensitive perfect absorber



- Frequency selective
- Polar angle & Azimuthal angle-insensitive
- Polarization-insensitive
- Nearly perfect absorption

- **Summary:** we show that composite meta-atom, involving a bright mode coupled with a dark mode in a controllable way, provides an ideal platform to overcome the above issues for single-mode meta-atoms. Our discoveries open a new door to freely control EM waves based on metasurfaces, laying a solid basis for realizing functional and tunable devices in different frequency regimes.