Massively Degenerate Coherent Perfect Absorber for Arbitrary Wavefronts

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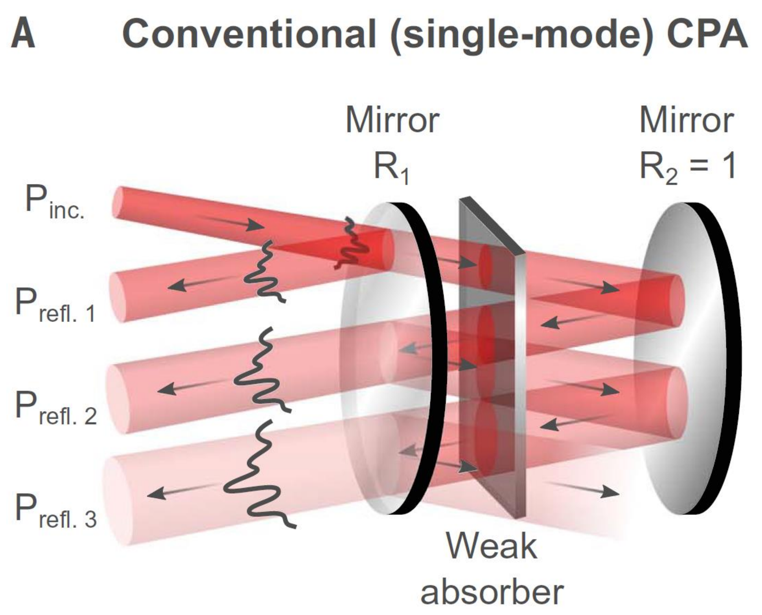
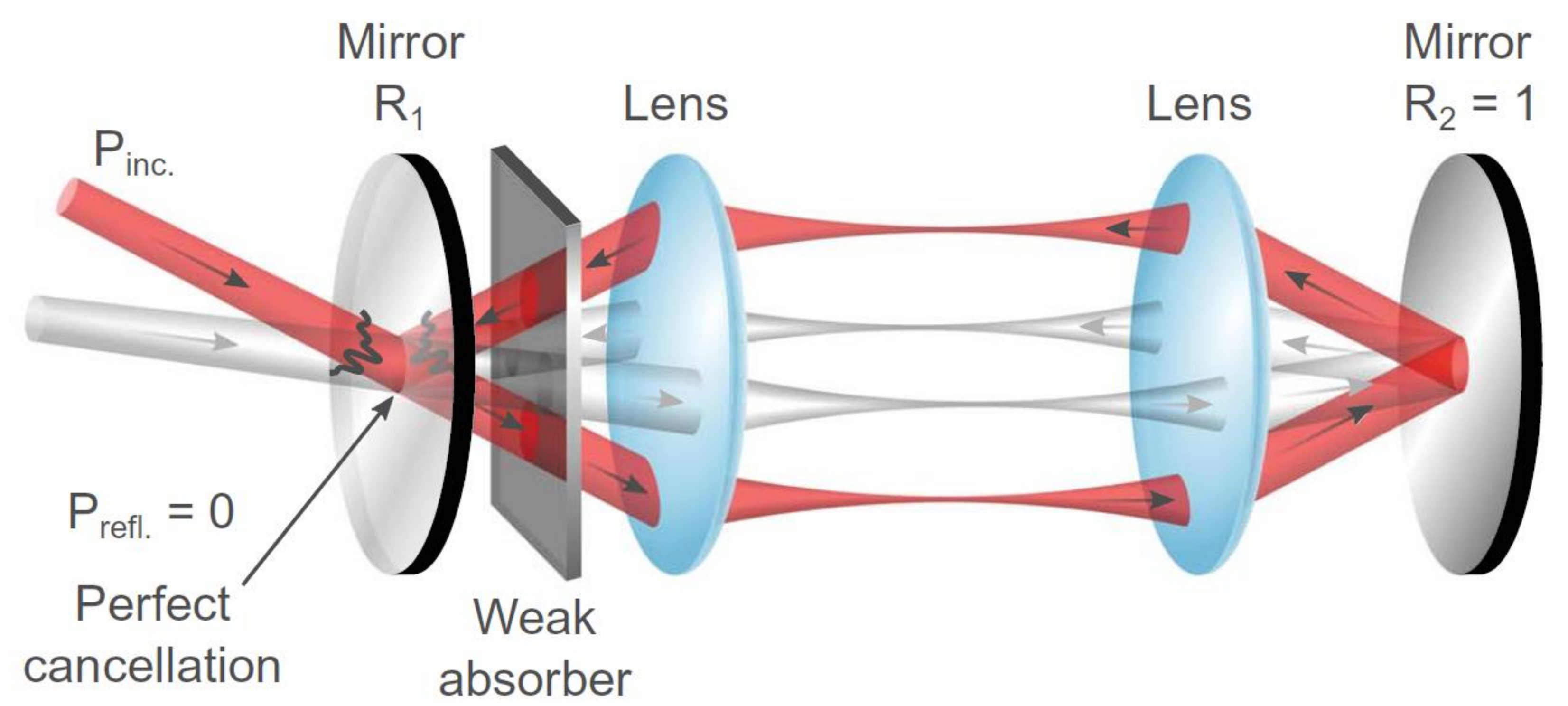
Motivation and Basics

- A laser can be operated in reverse to realize a coherent perfect absorber (CPA): lasing condition becomes critical absorption condition
- Thin and weakly absorbing media can be made strongly absorbing by putting them into such a resonant CPA structure
- Previous work[1,2]: CPAs are limited to a single, judiciously shaped wavefront or mode
- Example (see figure): a CPA that works for axis-parallel incident light does not work for tilted incident light beams



Massively Degenerate CPA (MAD-CPA)[3]

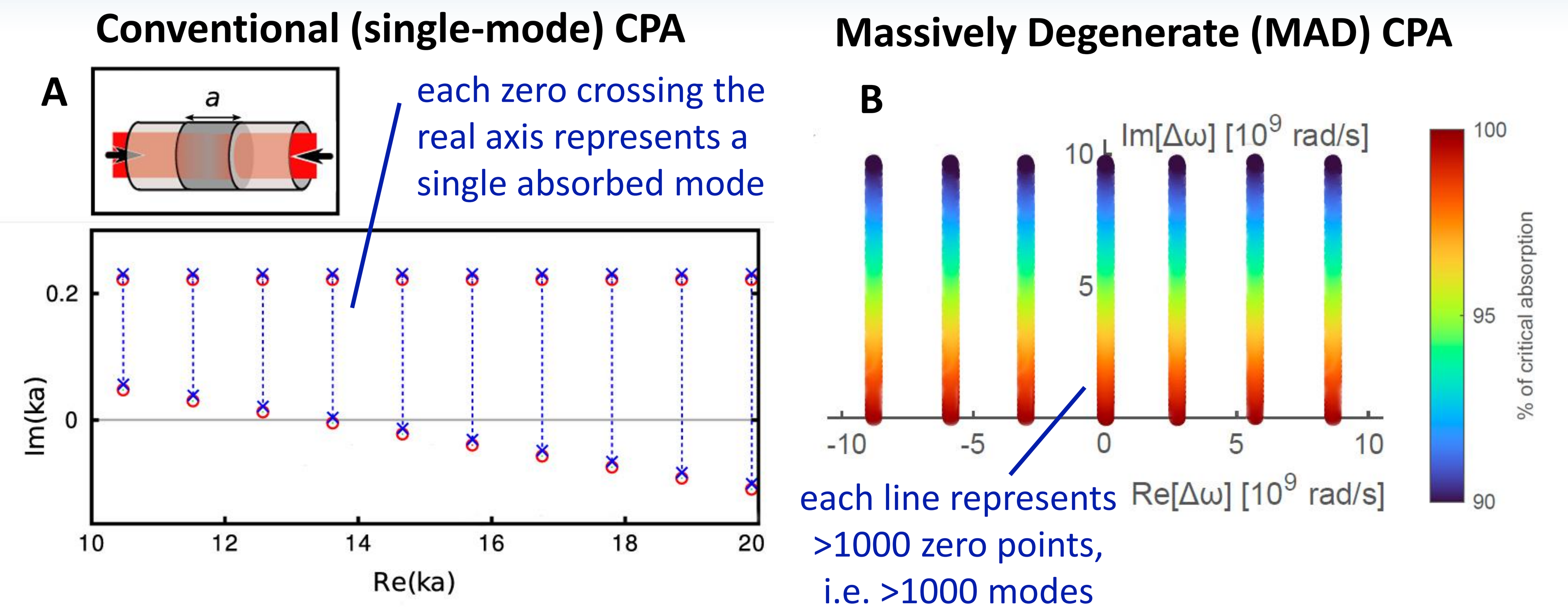
- We overcome this limitation by time-reversing a degenerate laser cavity (like a 4f-cavity), which self-images any incident light field onto itself.
- A weak, critically coupled absorber in this cavity absorbs any incoming wavefront with close to perfect efficiency.



Numerical Simulation[3]

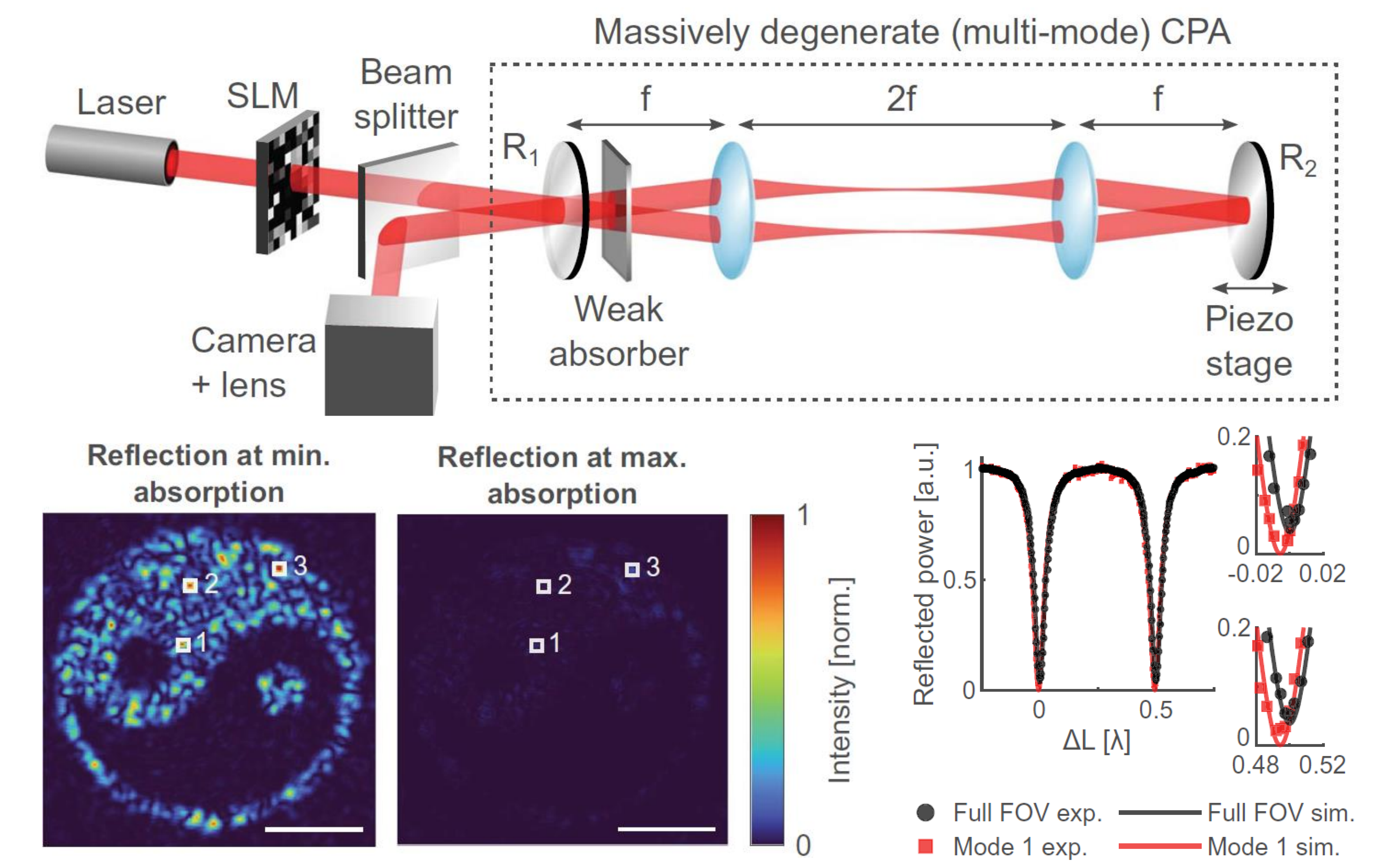
- **Basic Method: Scalar Fourier Optics using Transmission Matrices** *(Fast, but cannot simulate residual reflection on lenses)*
  - Each optical element and the propagation in-between is expressed by *Transmission Matrices* T_i
  - Simulation of a *single* roundtrip through cavity: $T_{\text{srt}} = \prod_i T_i$
  - Cavity's Reflection Matrix is calculated by the geometric series formula (in matrix form): $R_{\text{cav}} = r_1 \mathbb{1} + t_1^2 T_{\text{srt}} (\mathbb{1} - r_1 T_{\text{srt}})^{-1}$
- **Refined Method: Scalar Fourier Optics using Scattering Matrices** *(expensive, but can simulate residual reflection on lenses)*
  - Each optical element and the propagation in-between is expressed by *Scattering Matrices* S_i
  - Each S_i can be converted into a corresponding *Transfer Matrix* M_i. The whole cavity can then be expressed as $M_{\text{cav}} = \prod_i M_i$
  - After back-converting M_{cav} into S_{cav}, the cavity's Reflection Matrix is obtained by extracting the according sub-matrix from S_{cav}

Simulation: Conventional CPA vs. MAD-CPA



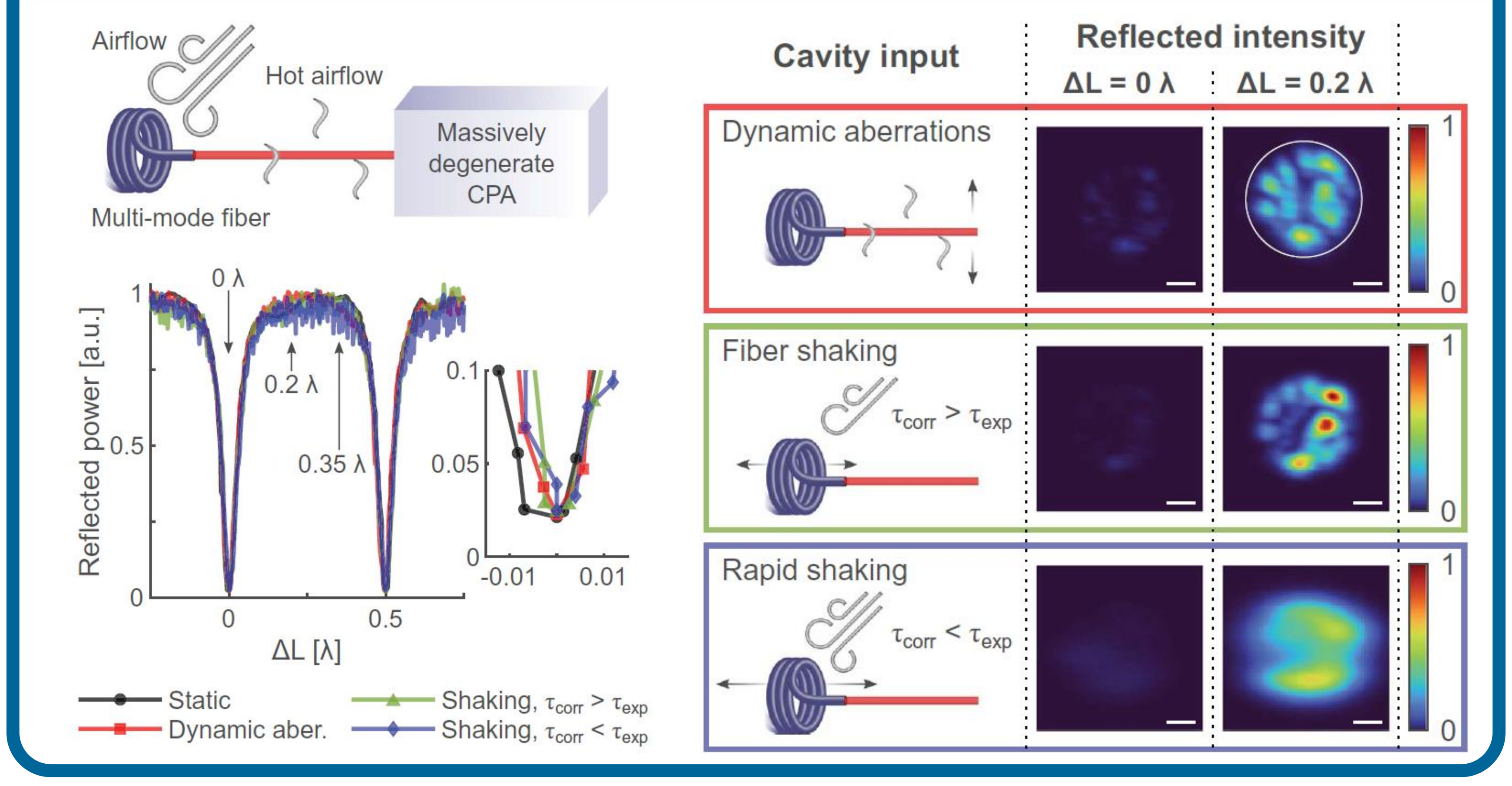
(A) Simple CPA: Only one zero-point per real frequency is crossing the real axis, representing only one transverse mode each (from: [1])
(B) MAD-CPA: R_{cav} has more than 1000 zeros (i.e. >1000 transverse modes) per real frequency hitting the real axis simultaneously.

Setup and Experimental Results[3]



$R_1 = 70\%, R_2 = 99.9\%, f = 75\text{mm}$. Absorber: 0.6mm, $T = 85.2\%$
Yin-yang symbol composed of >1000 modes. Wavelength: λ=633nm

MAD-CPA also Works for Rapidly Varying Fields[3]



References

[1] Y. Chong, L. Ge, H. Cao, A. Stone, *Phys. Rev. Lett.* **105**, 053901 (2010)
[2] W. Wan, Y. Chong, L. Ge *et al.*, *Science* **331**, 889–892 (2011)
[3] Y. Slobodkin, G. Weinberg, H. Hörner *et al.*, *Science* **377**, 995-998 (2022)