# Attosecond Extreme Ultraviolet Beams with Time-Varying Orbital Angular Momentum: the Self-Torque of Light

Kevin M. Dorney

*Kapteyn-Murnane Group, JILA–University of Colorado Boulder*

*Postdeadline Session III (JTh5C), CLEO USA 2019*

*May 9th, 2019*

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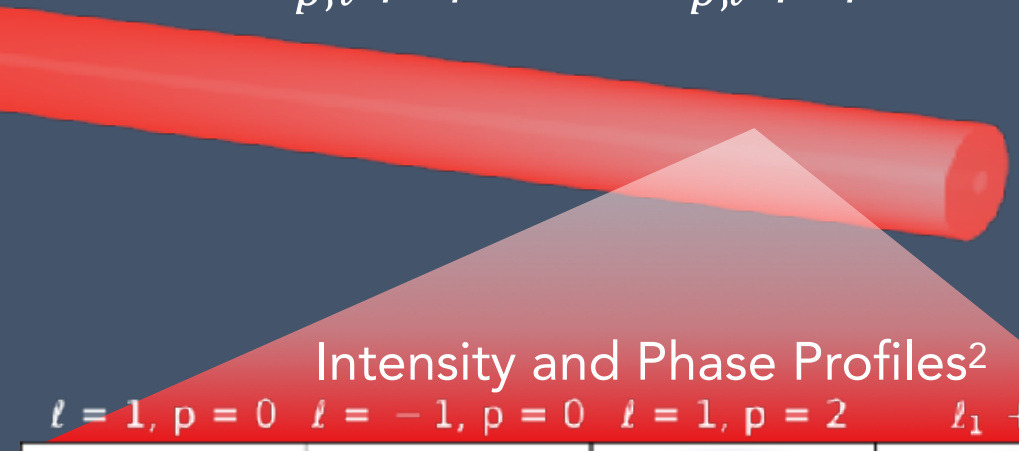

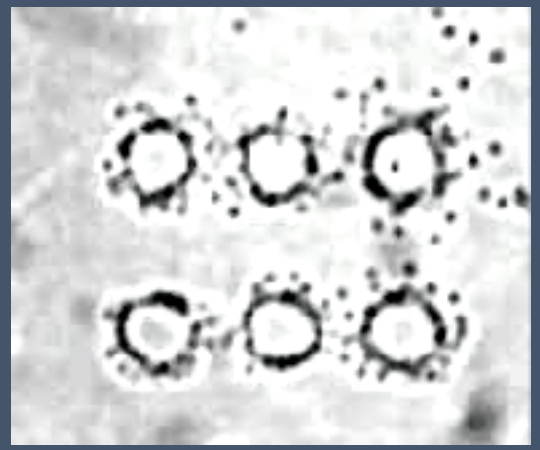

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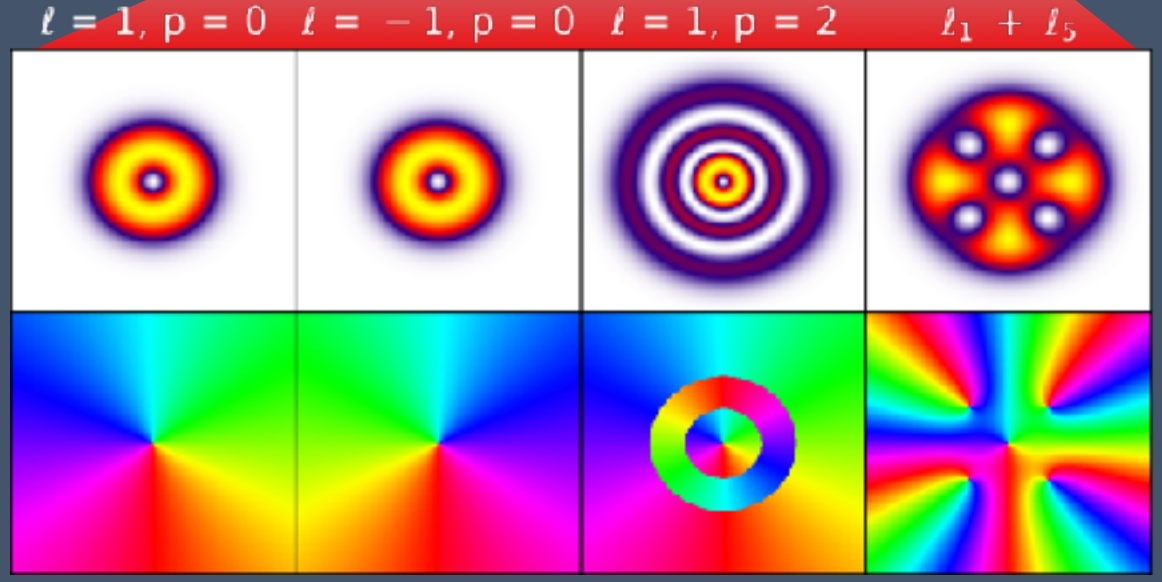


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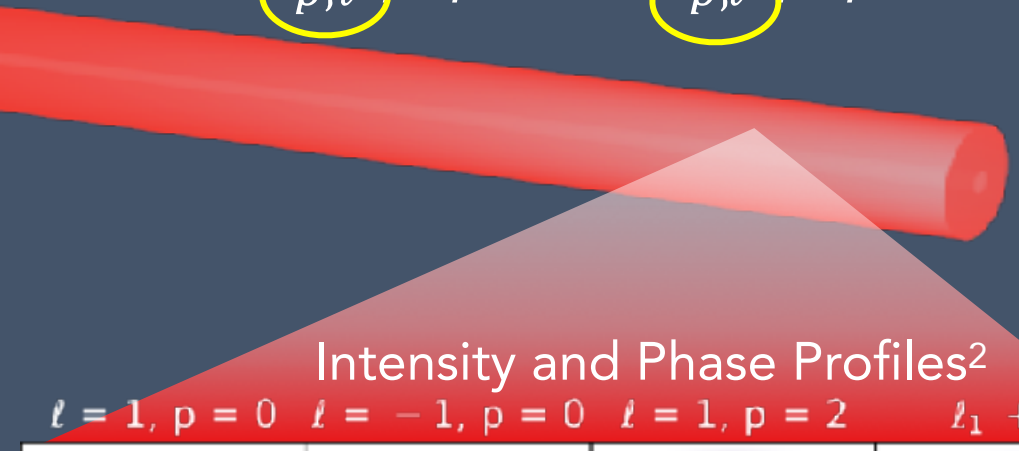

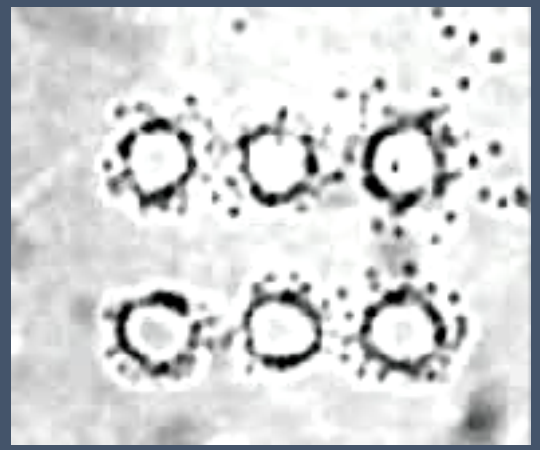

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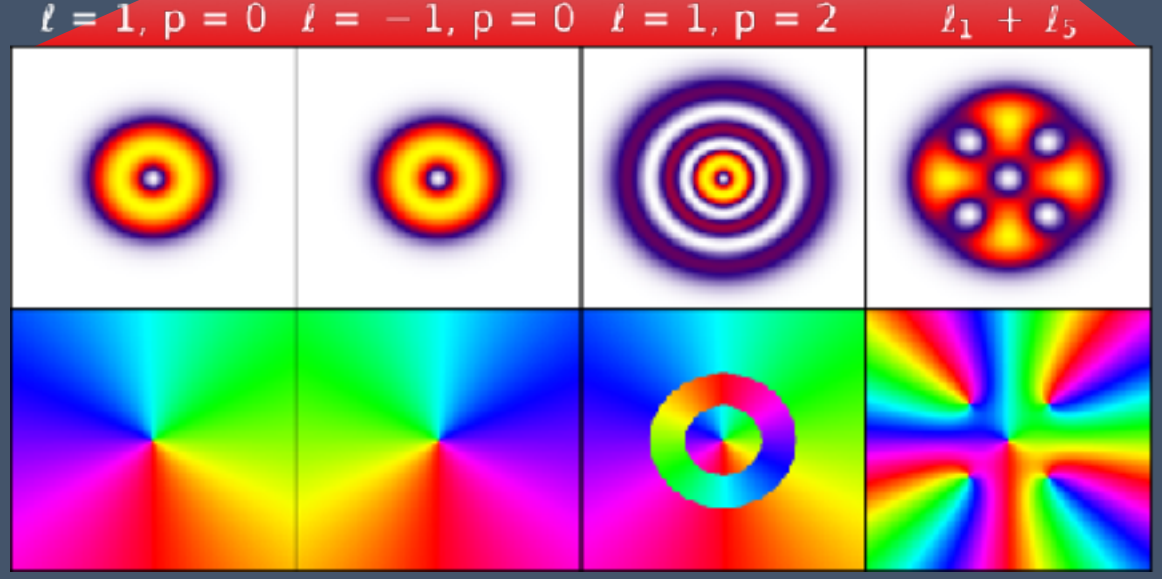


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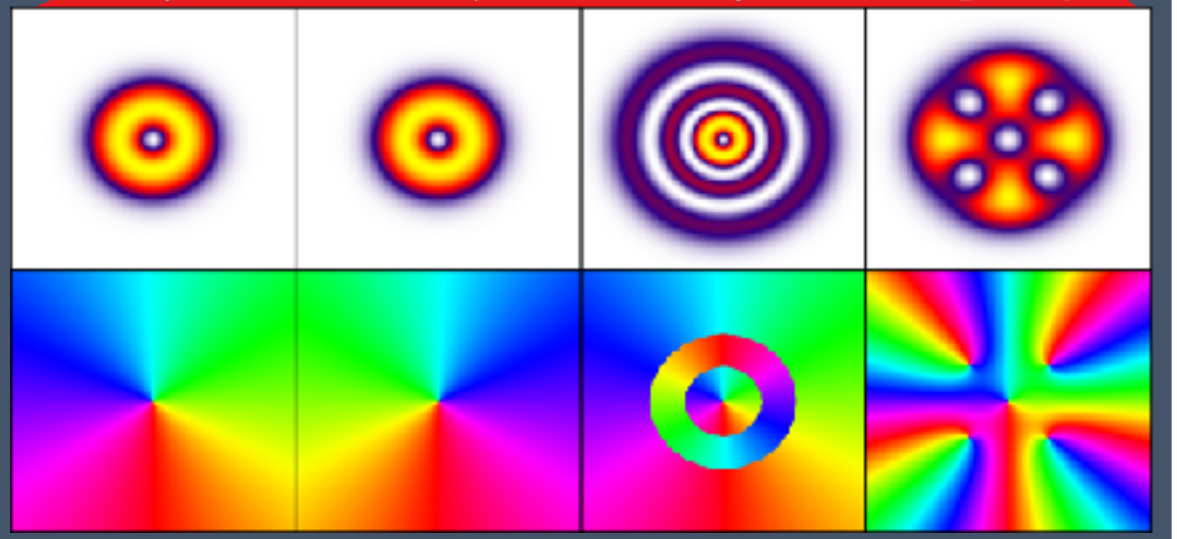


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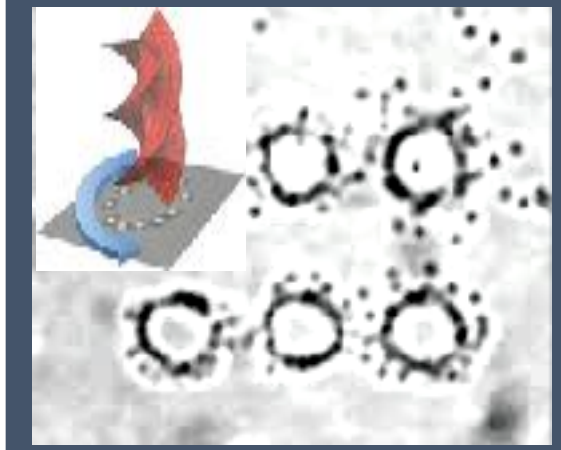
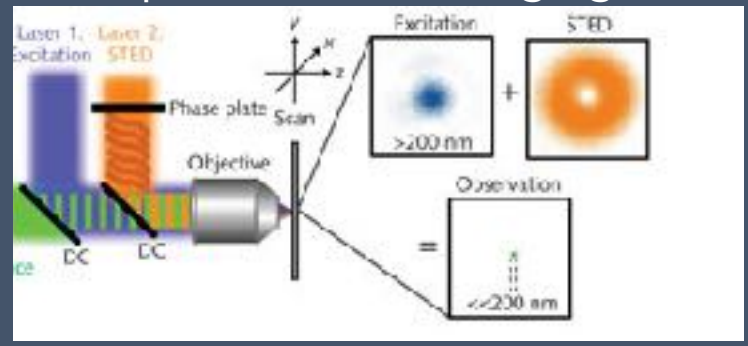


## Superresolution Imaging[4,5]

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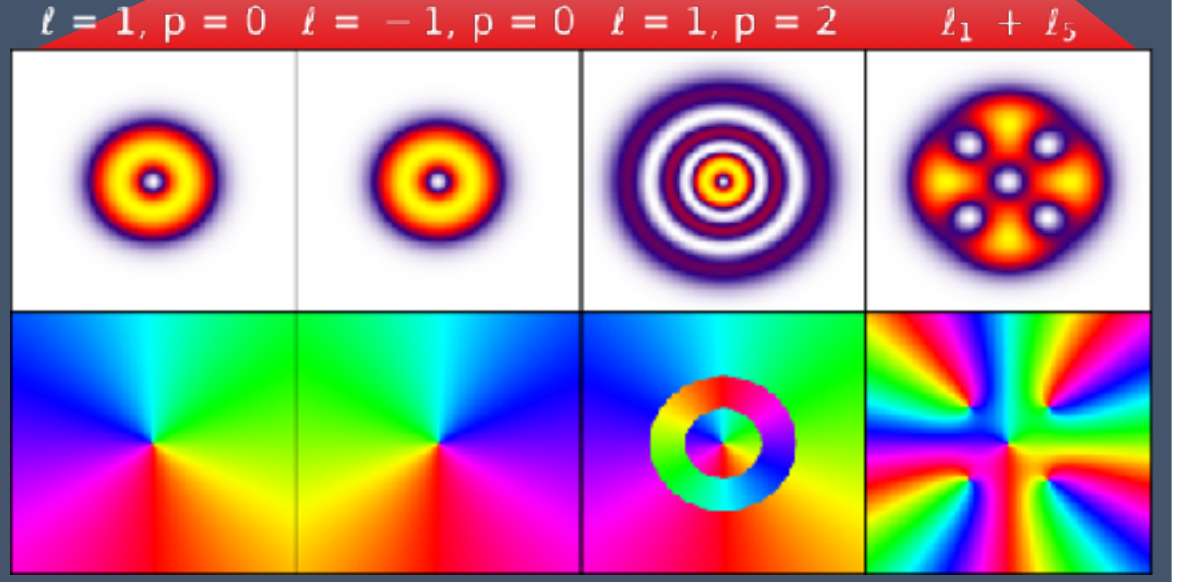


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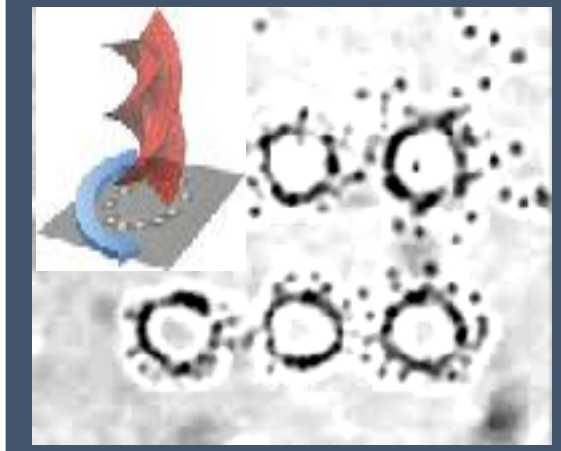

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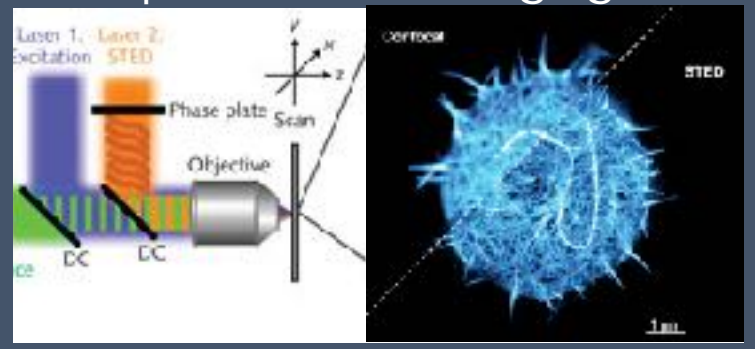


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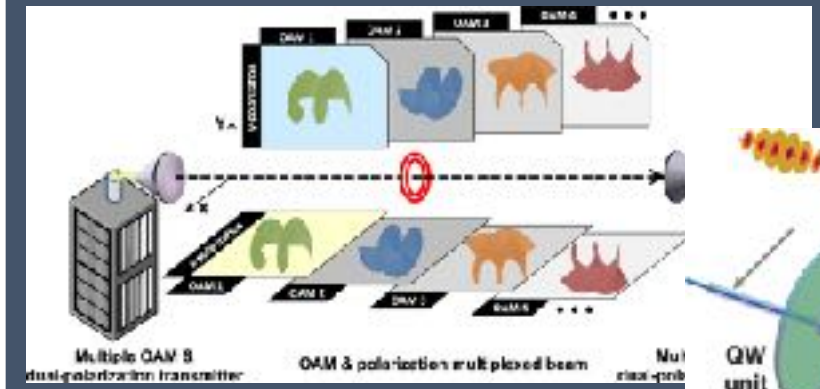
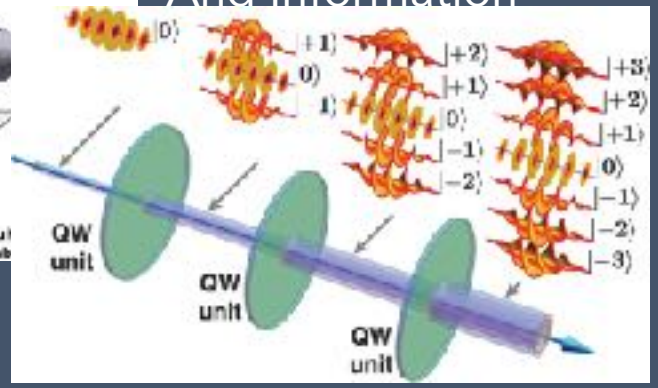


## Quantum Logic And Information[7]

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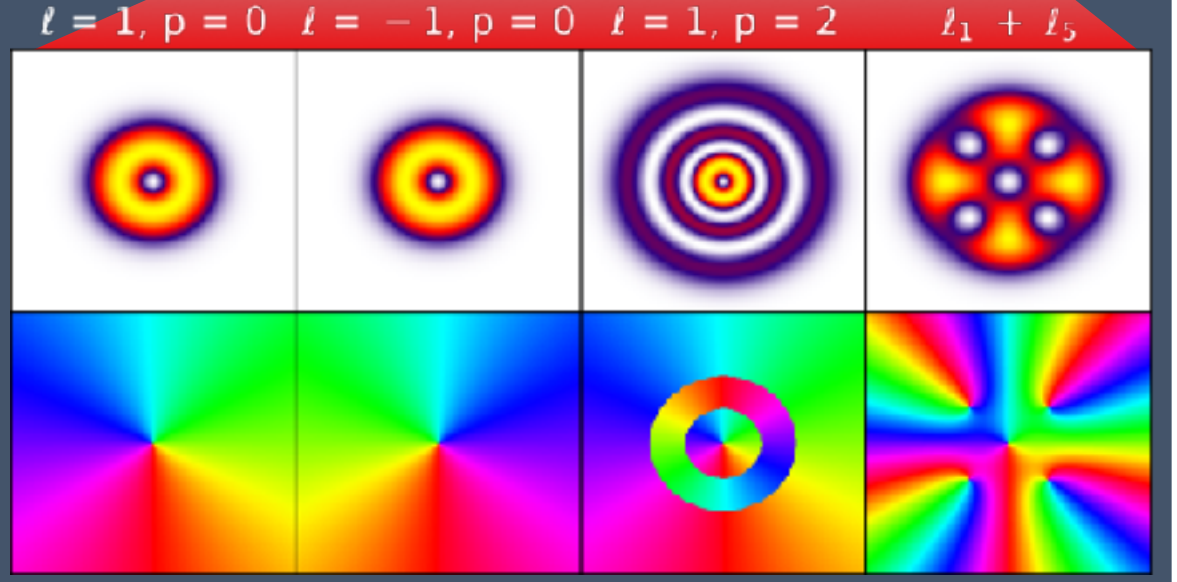


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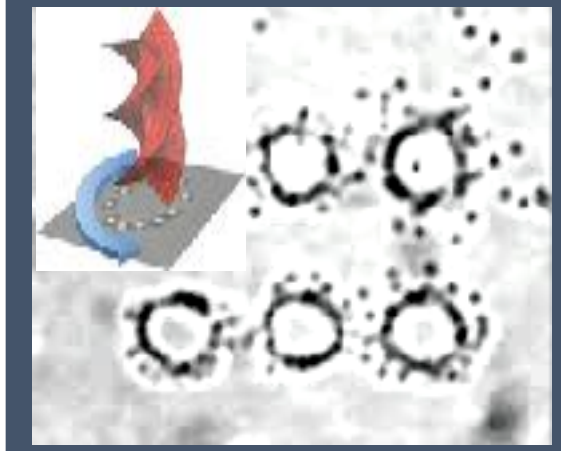

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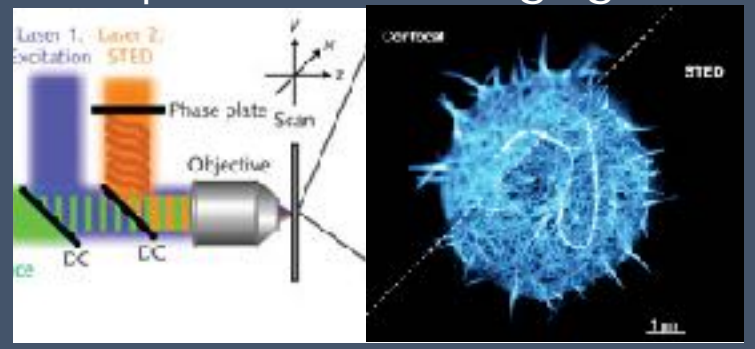


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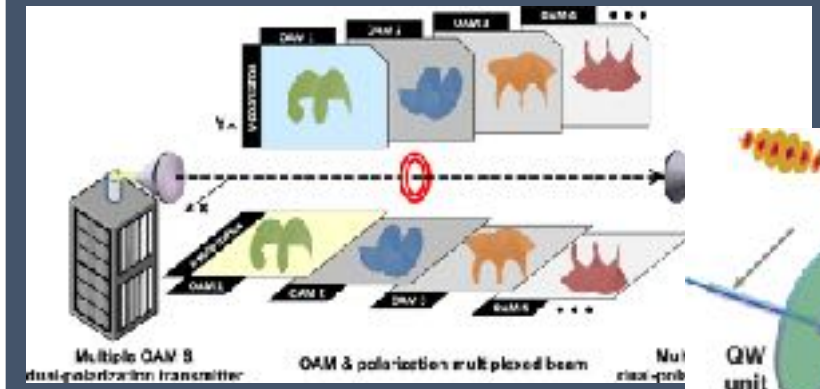

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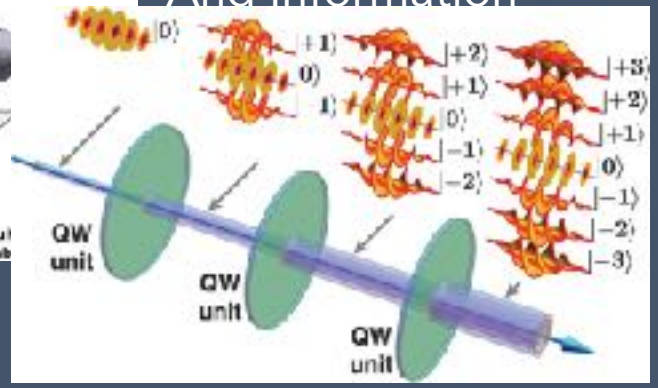


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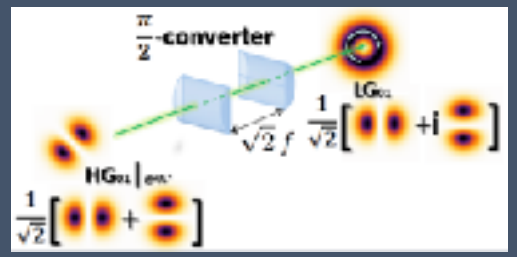


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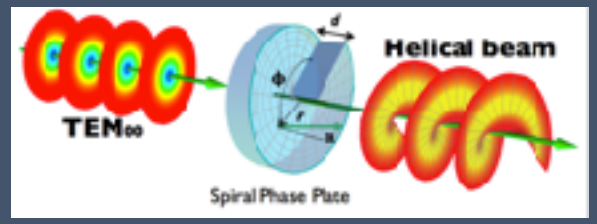


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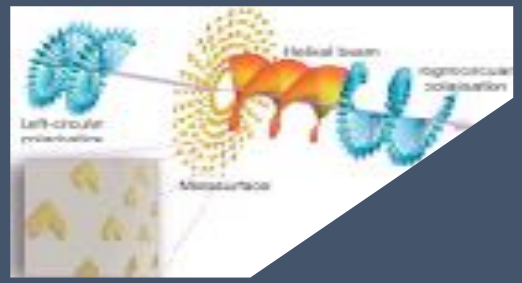

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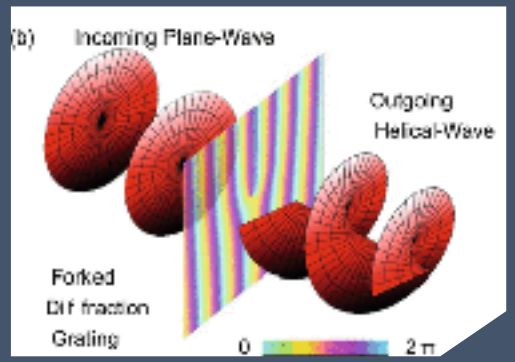


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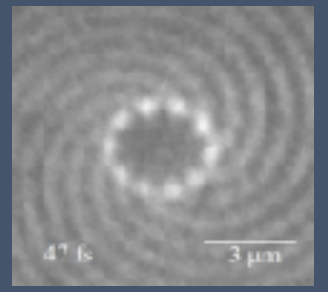

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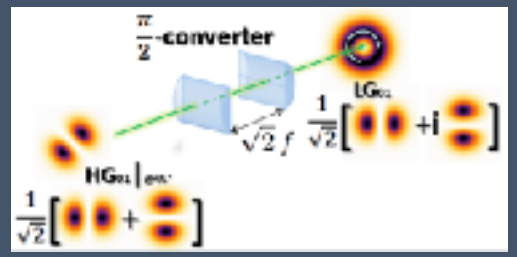


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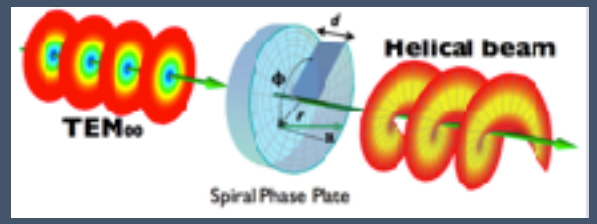


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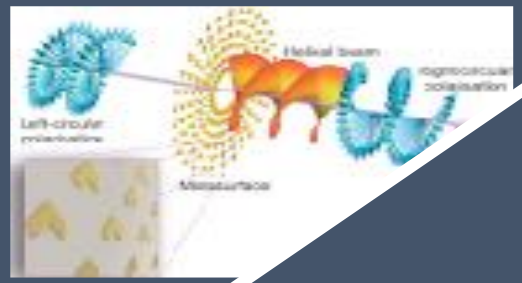

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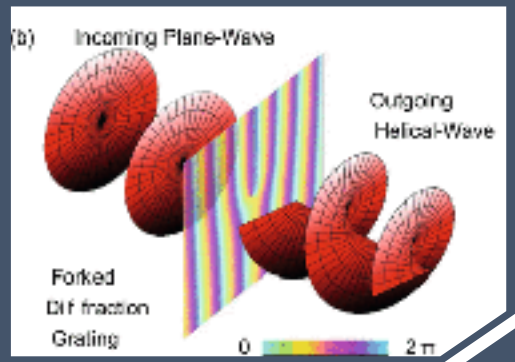


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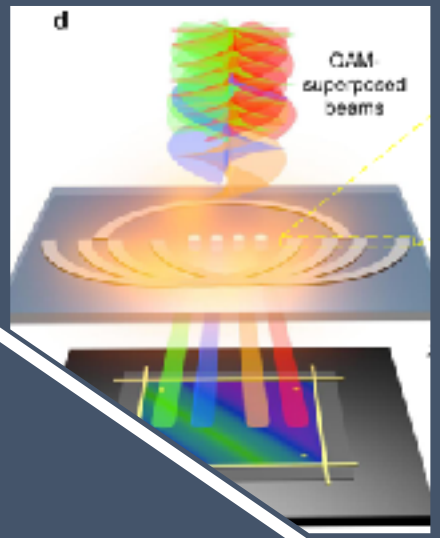


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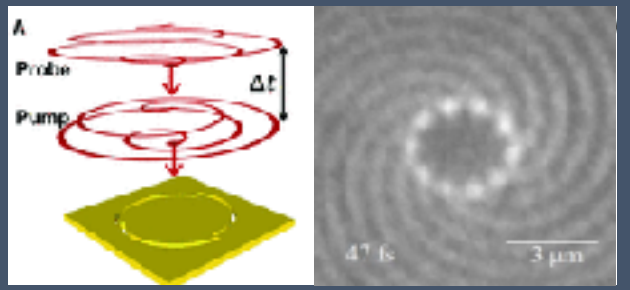

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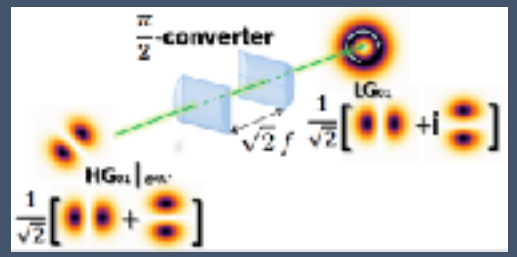


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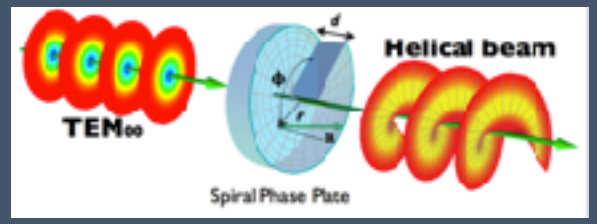


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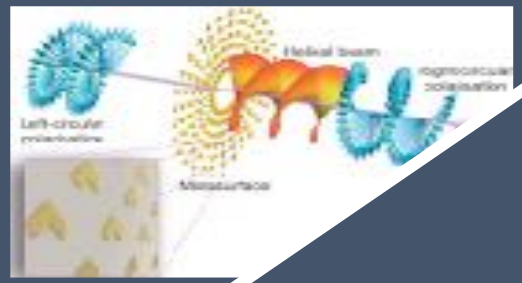

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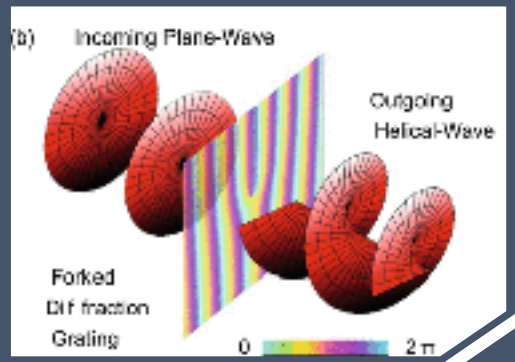


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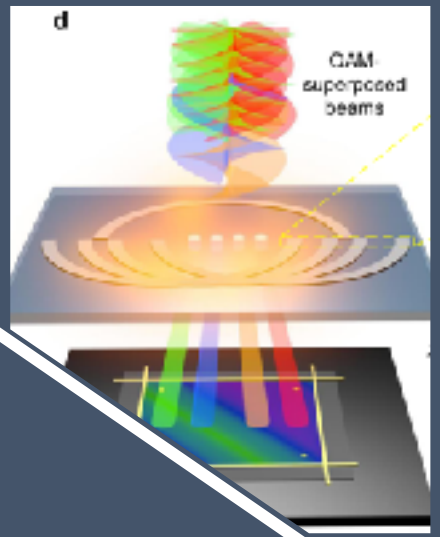


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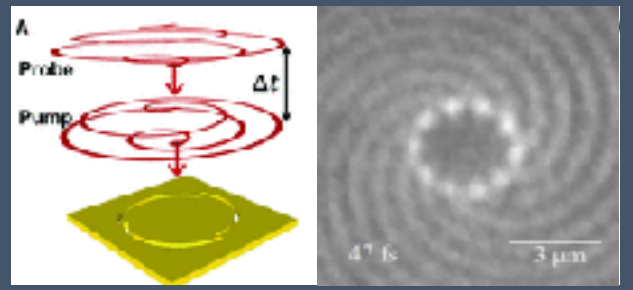


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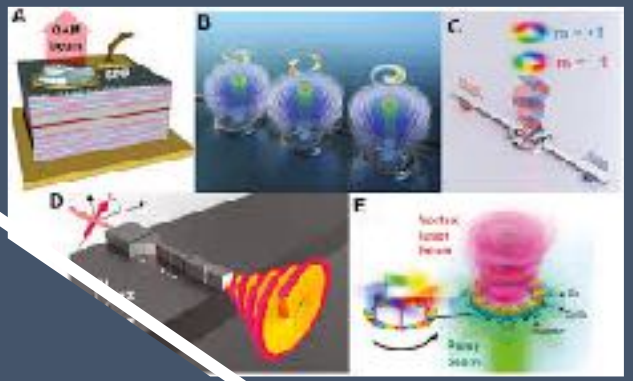

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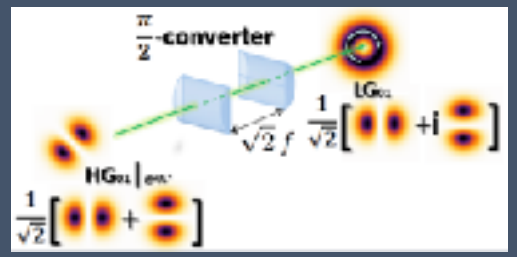


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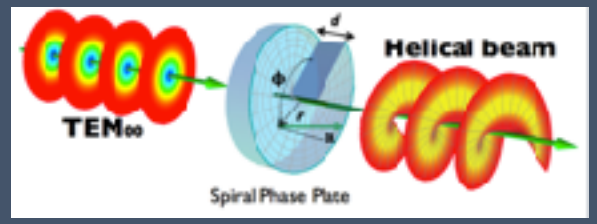


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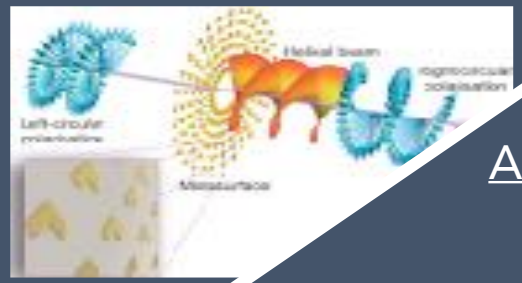

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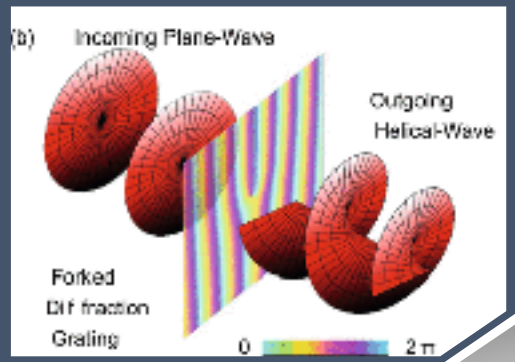


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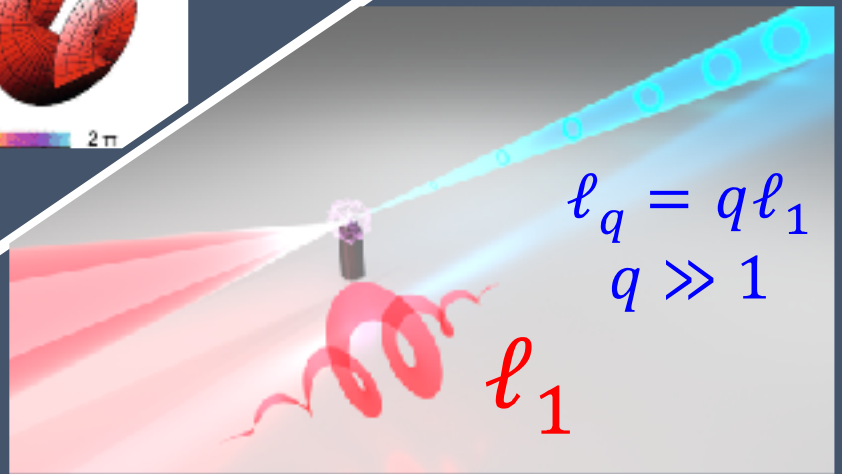


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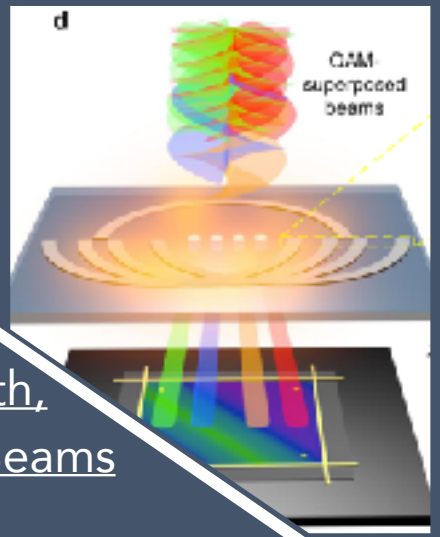


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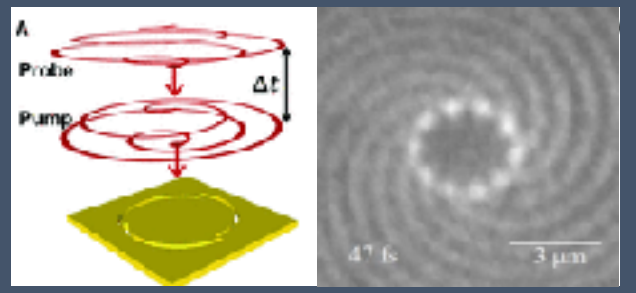


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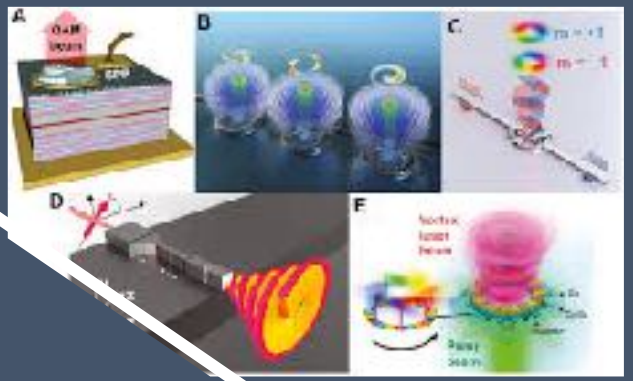

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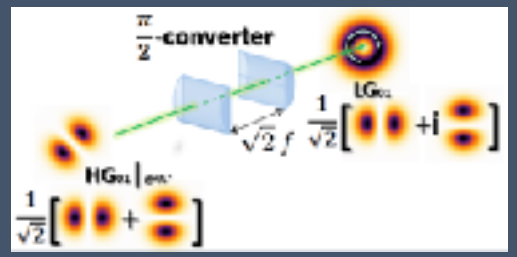


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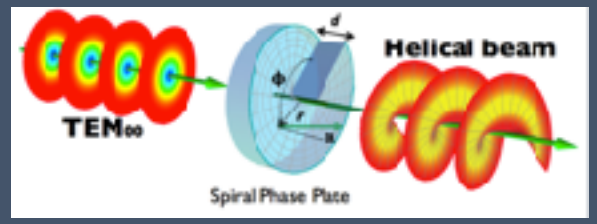


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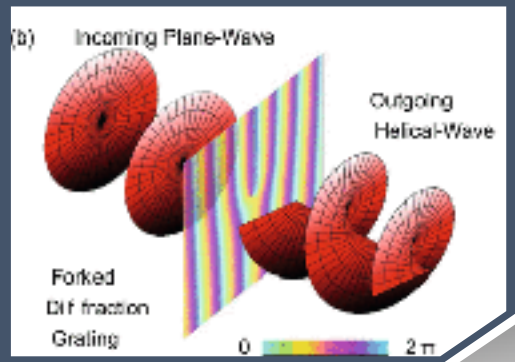


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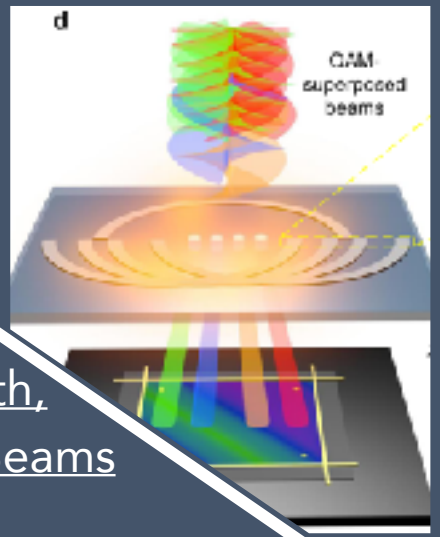


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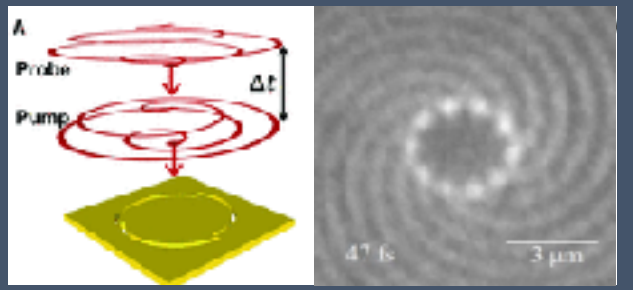


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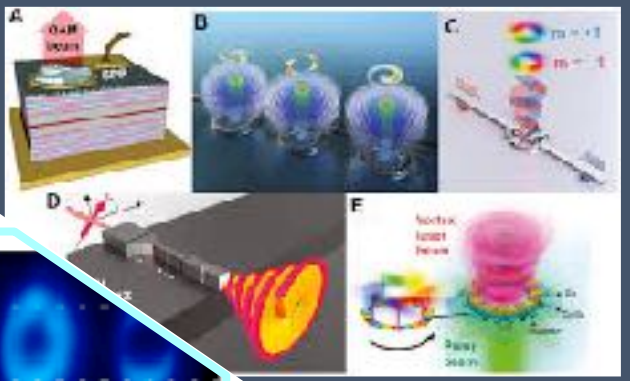


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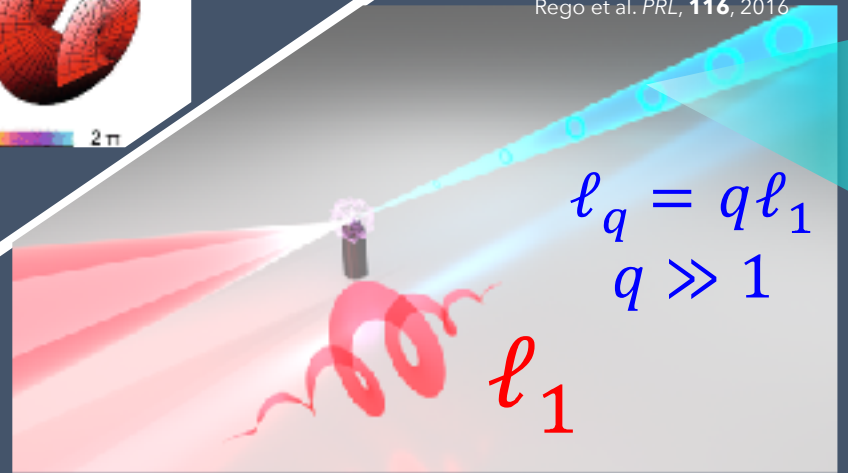

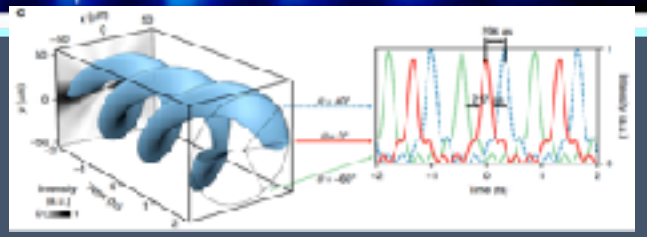

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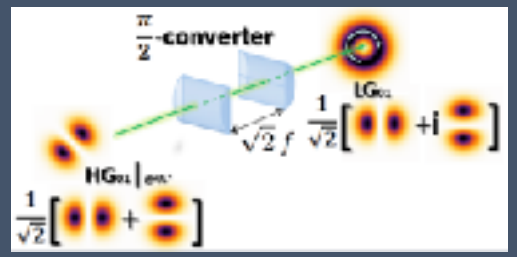


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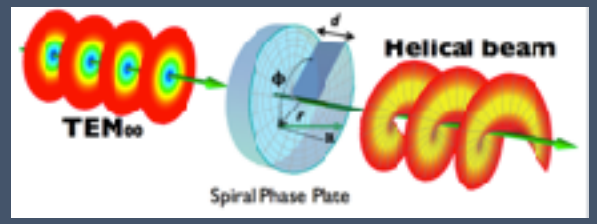


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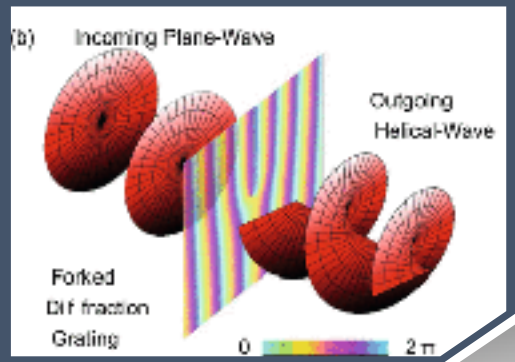


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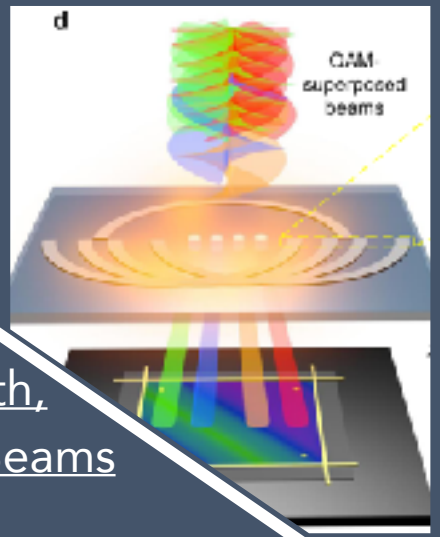


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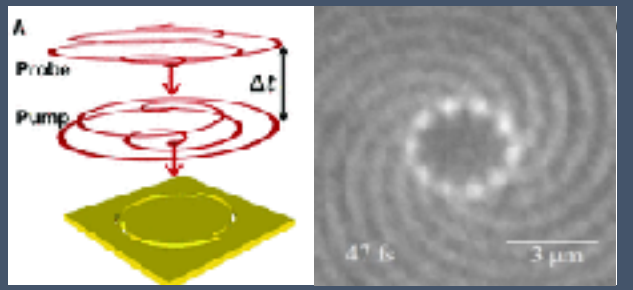


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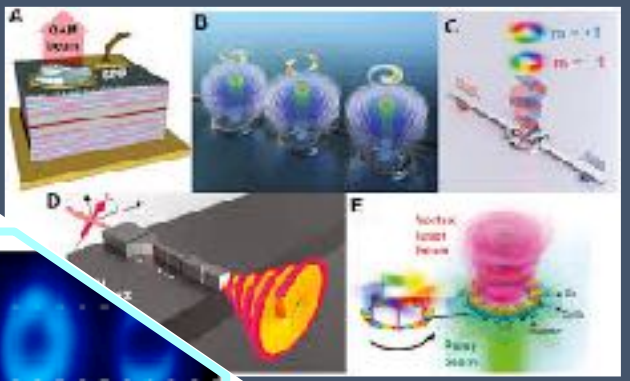


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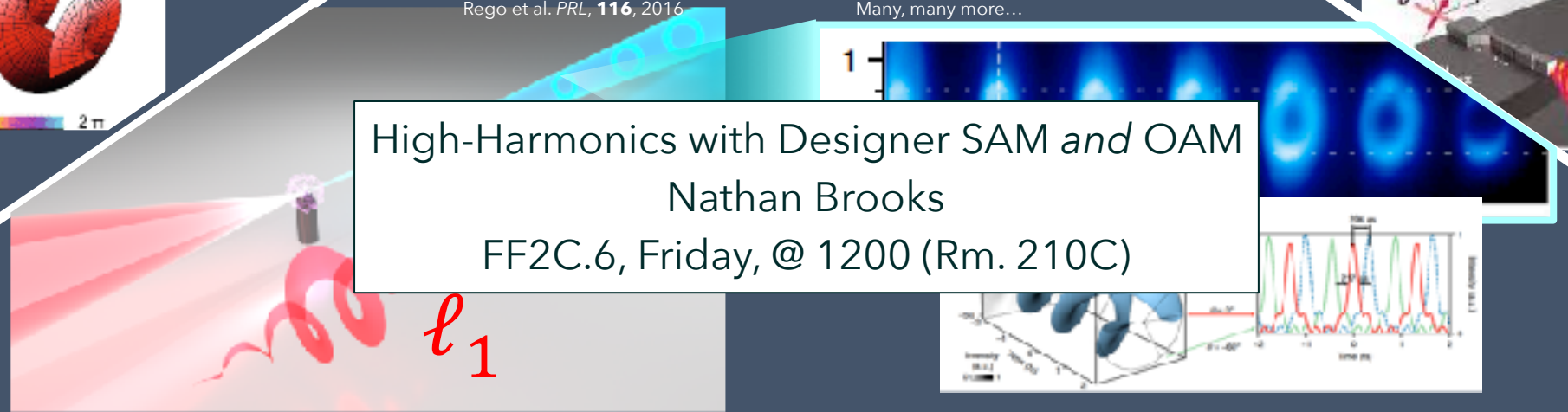


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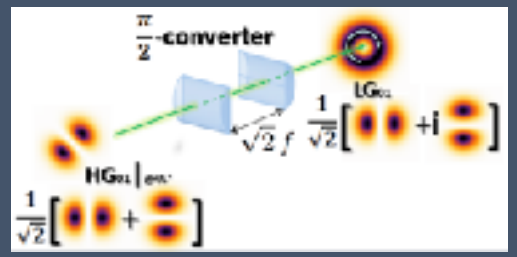


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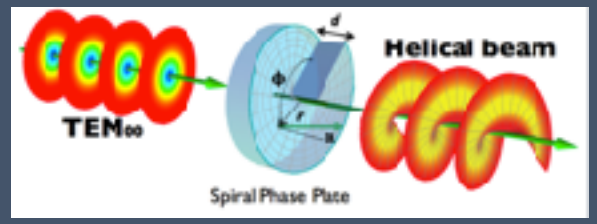


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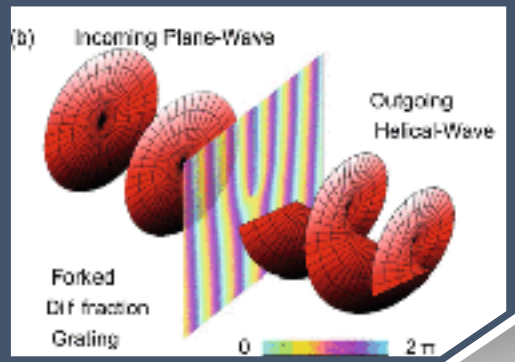


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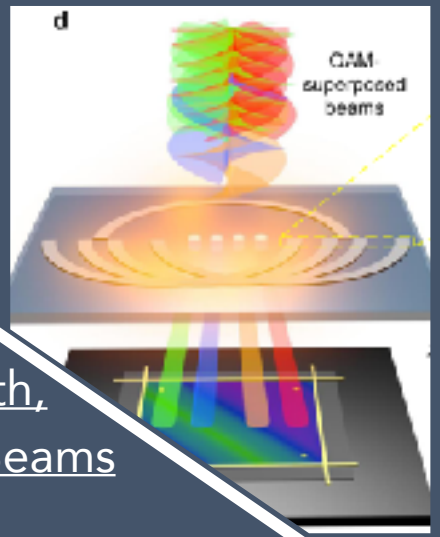


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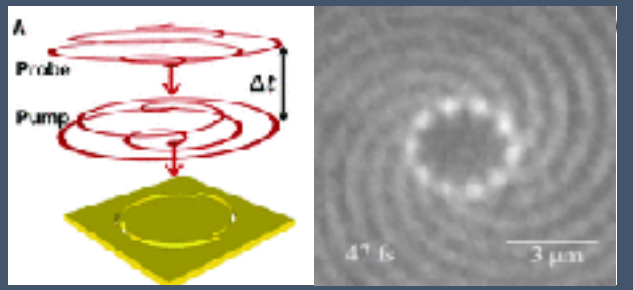


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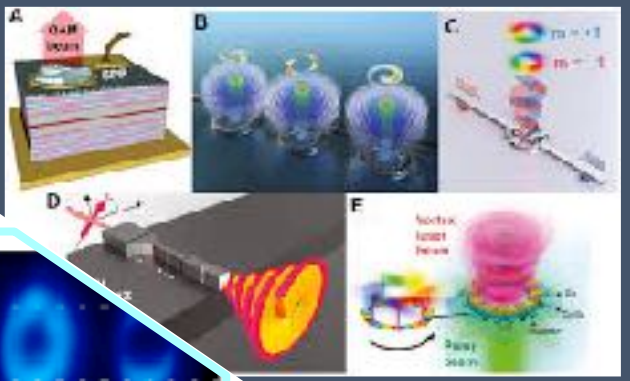


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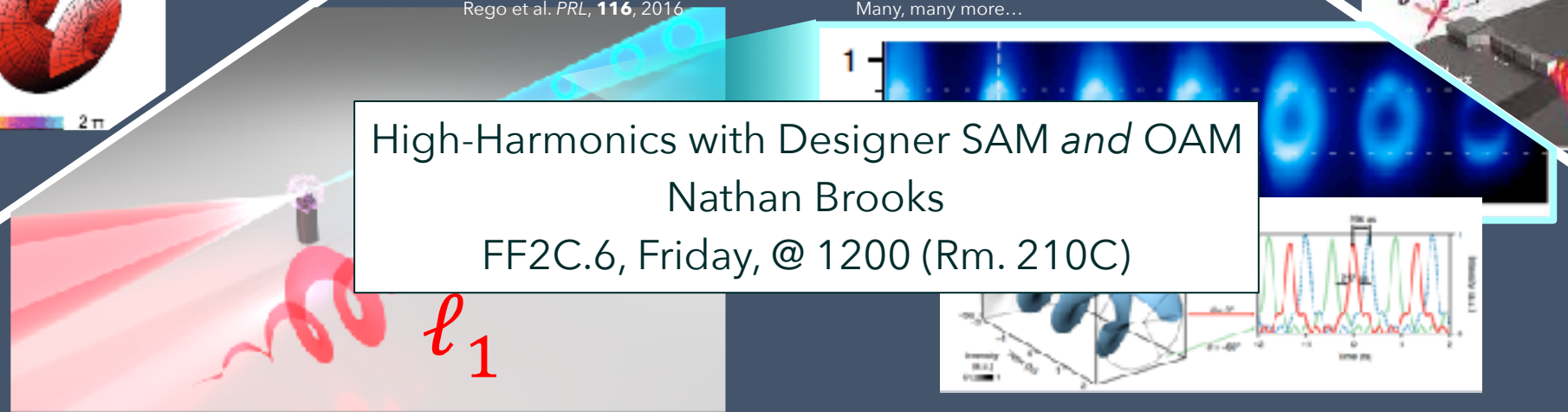


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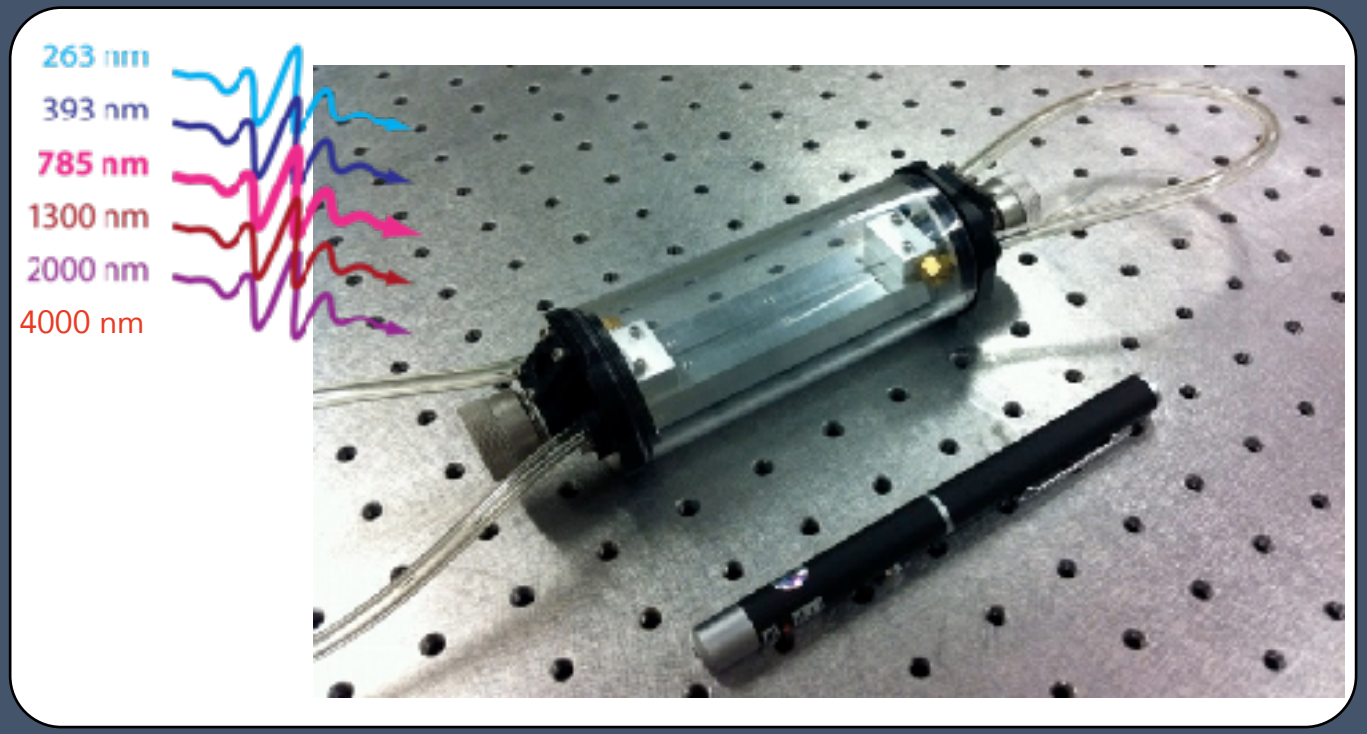


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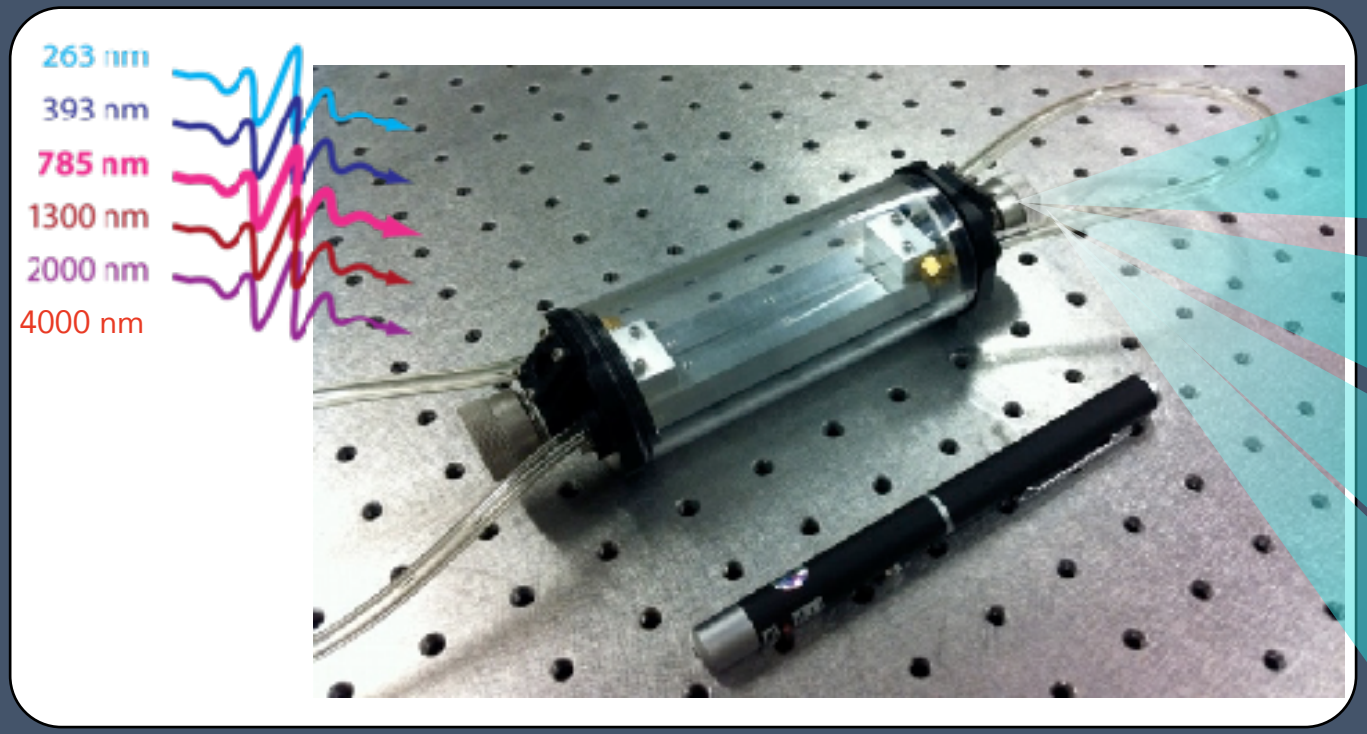
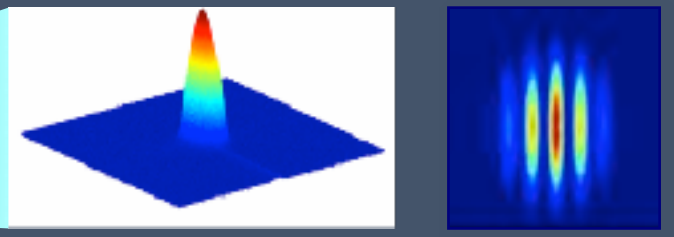



30nm HHG beam (1998/2002)[1,2]



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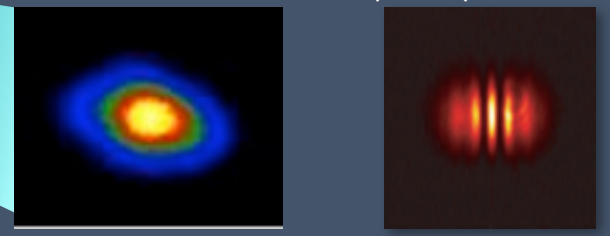

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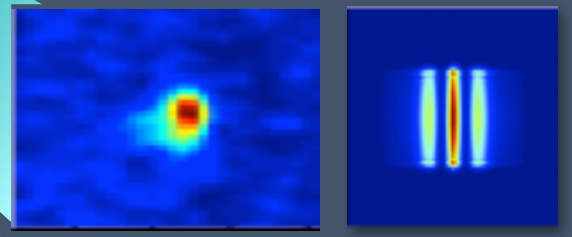
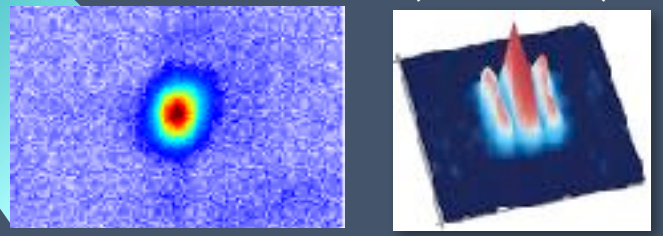


1nm HHG beam (2012/2015)[5,6]



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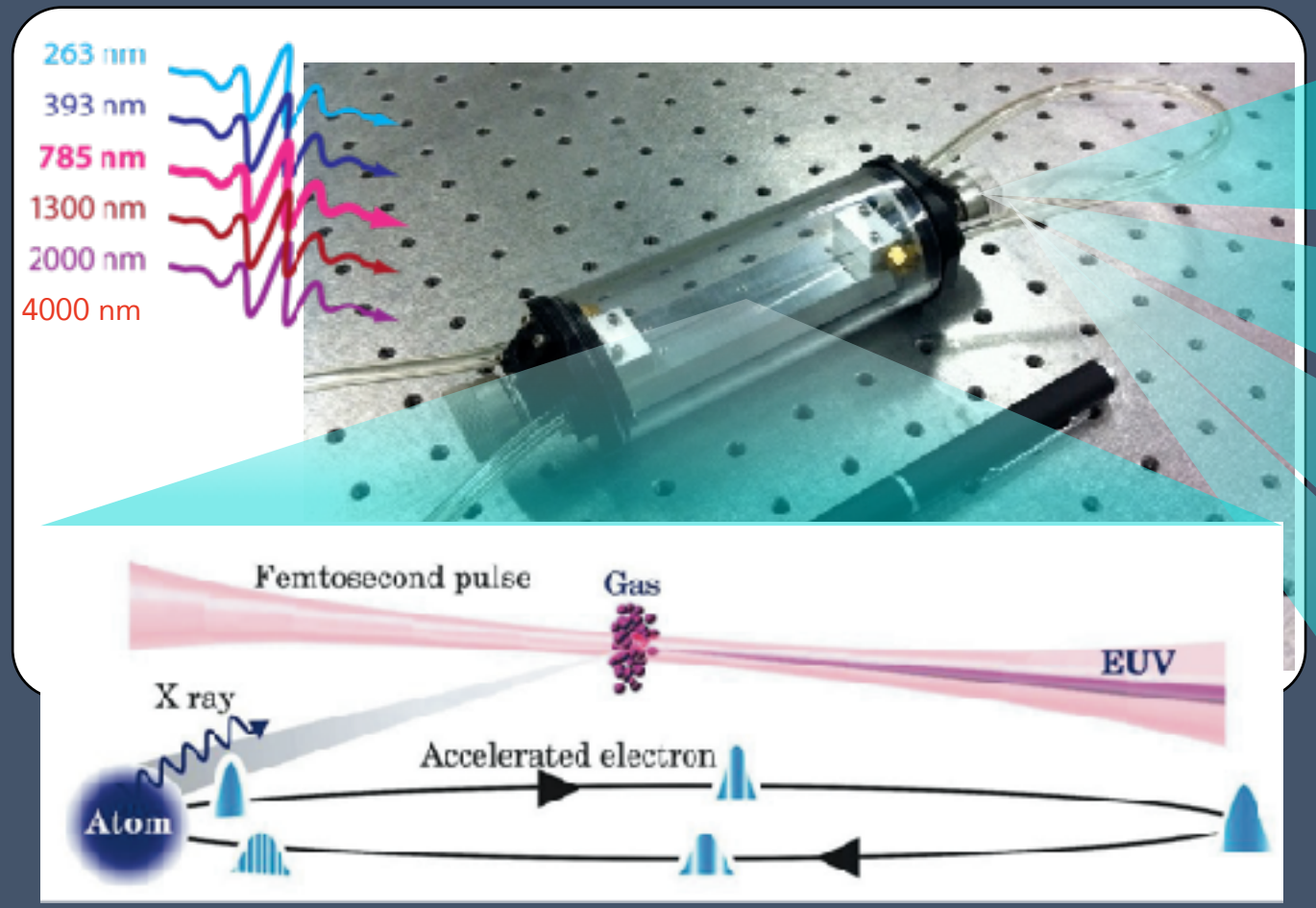


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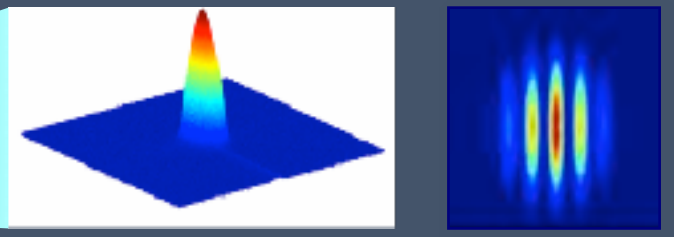

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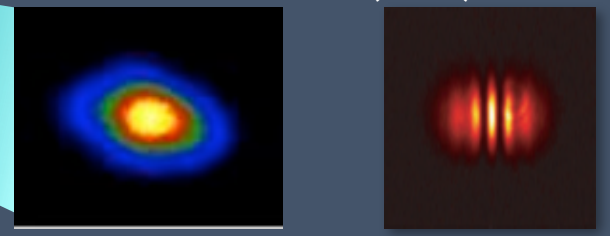

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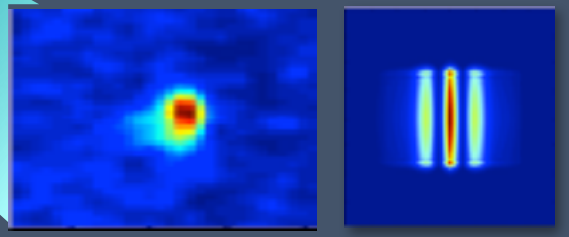

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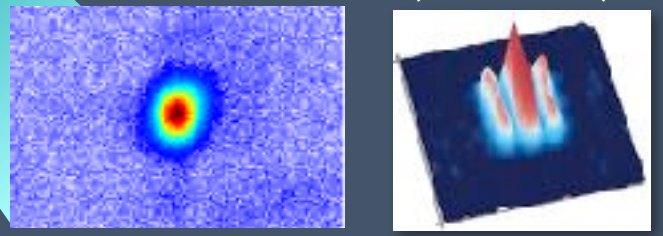

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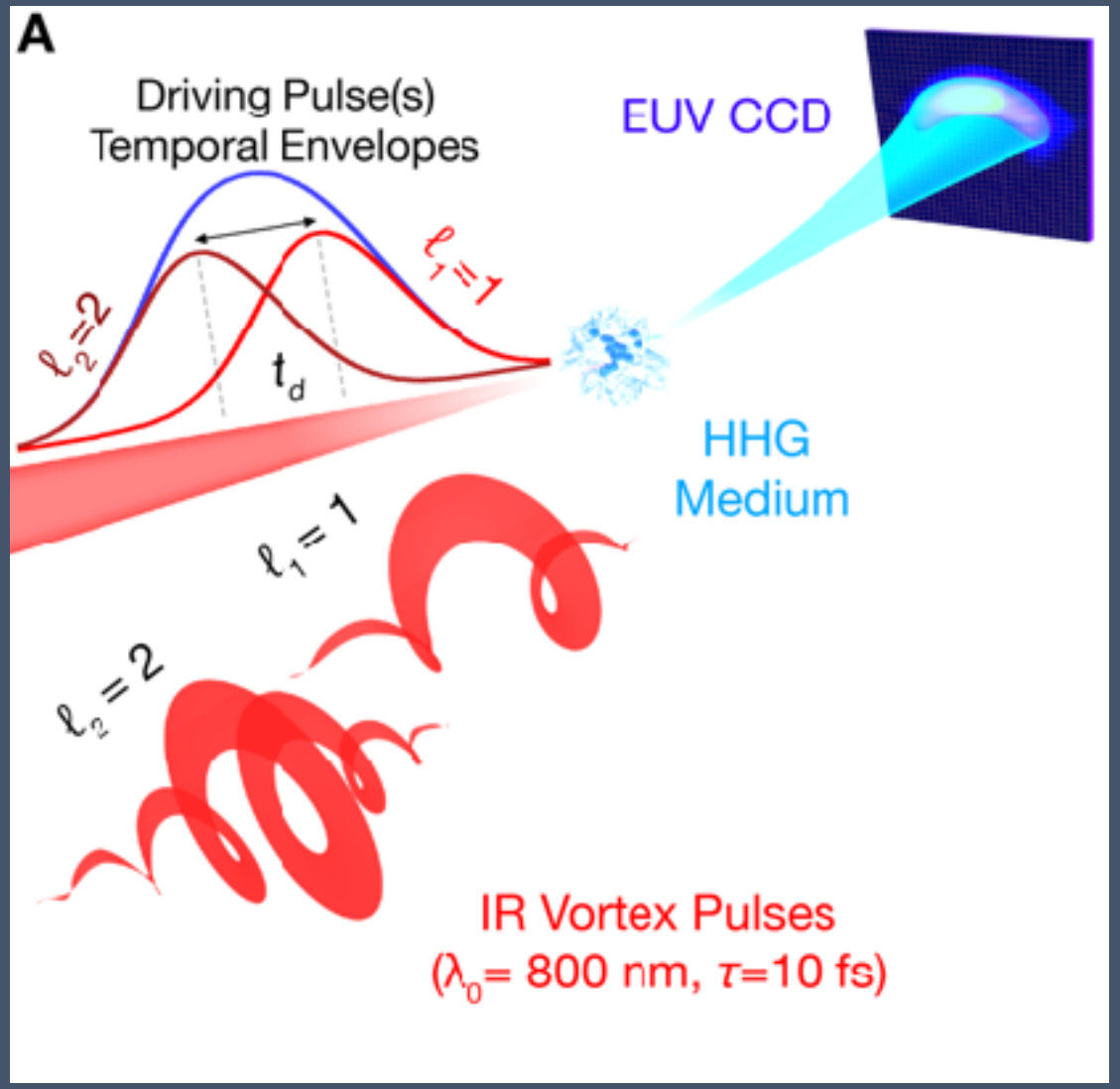


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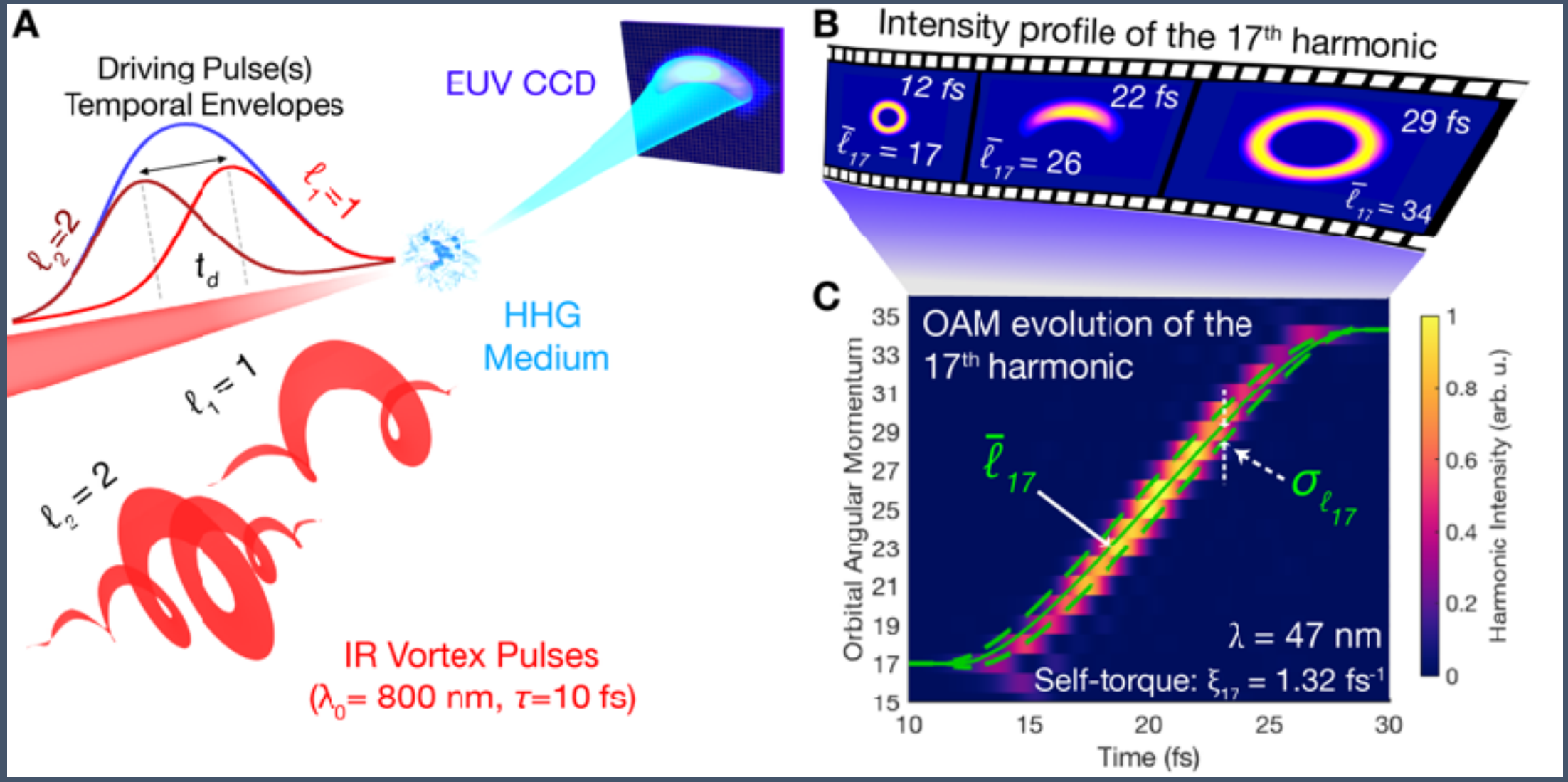


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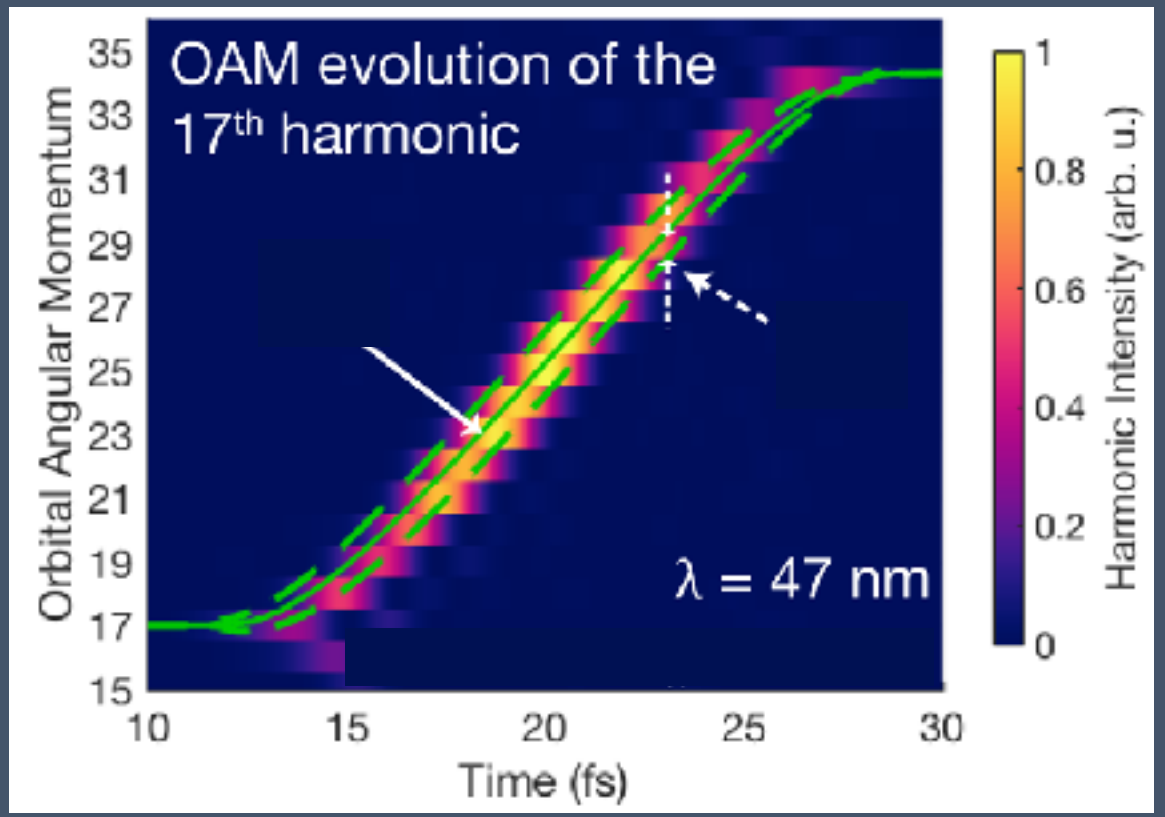
***Smooth, Continuous, Variation of OAM!***

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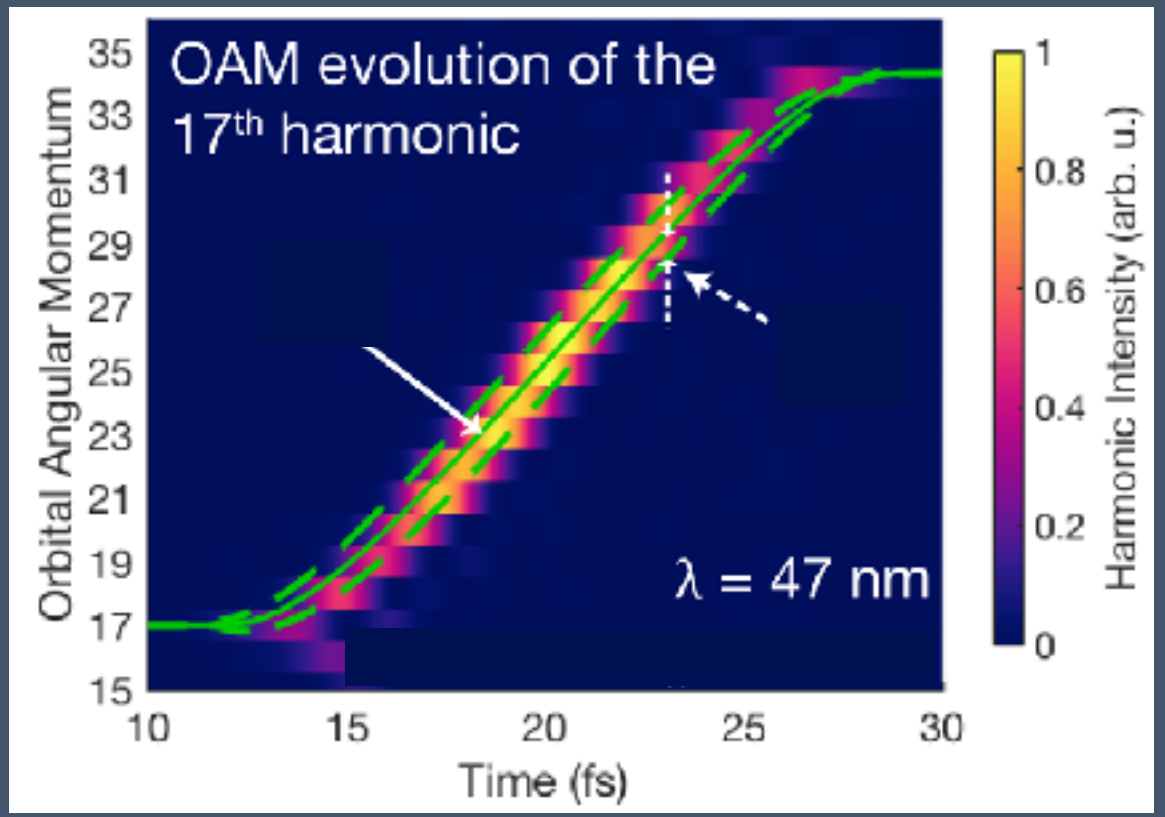


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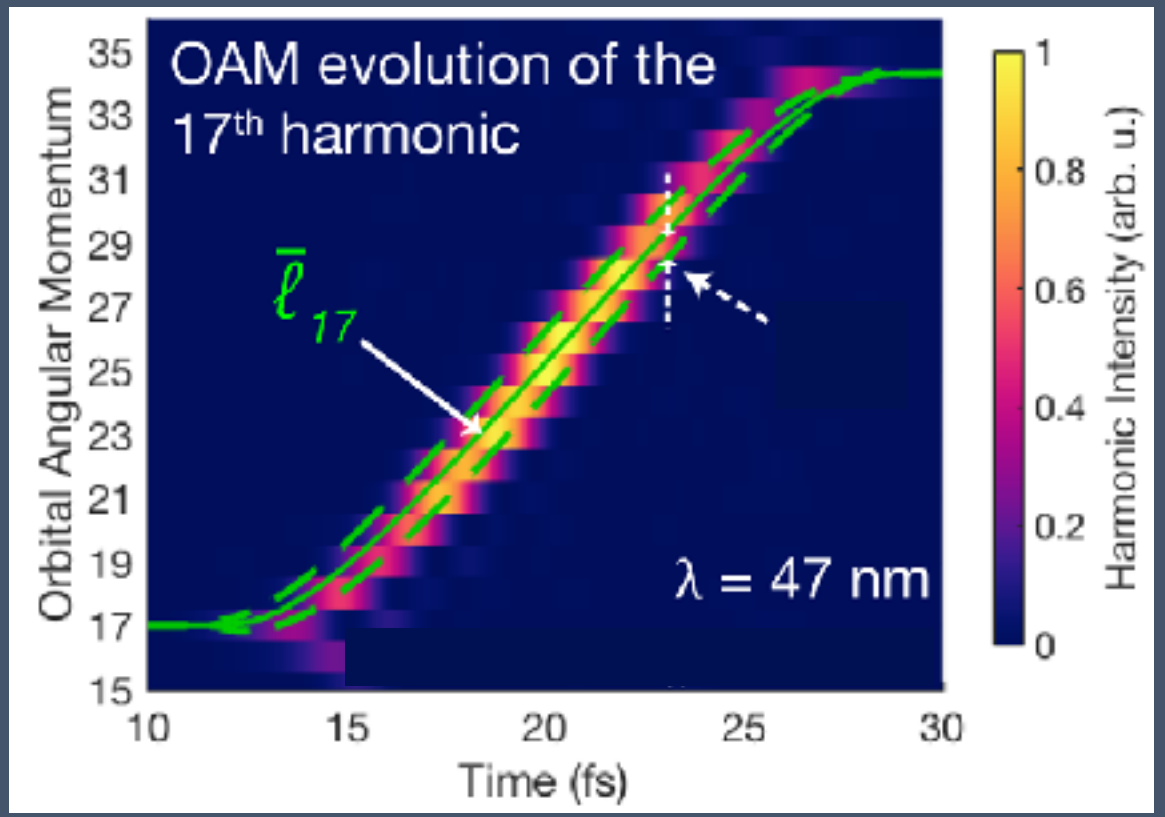


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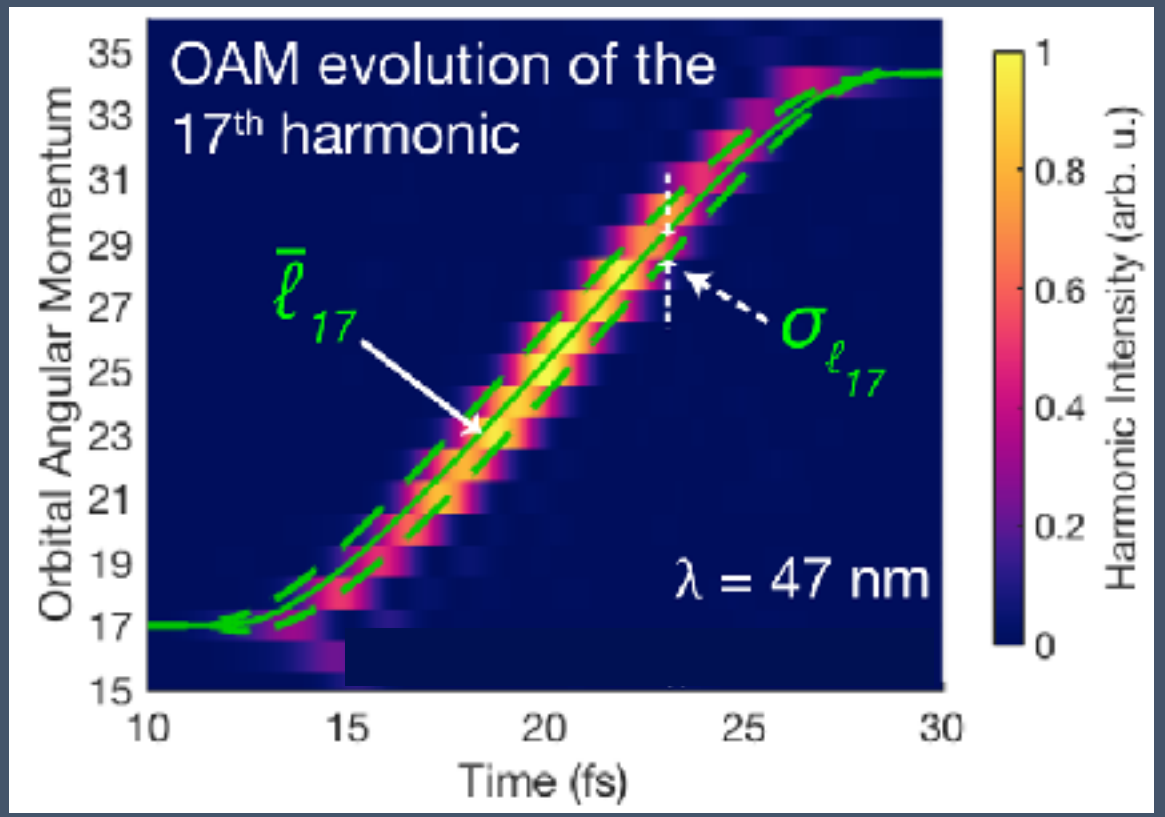


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Width of OAM Spectrum at Time (t)

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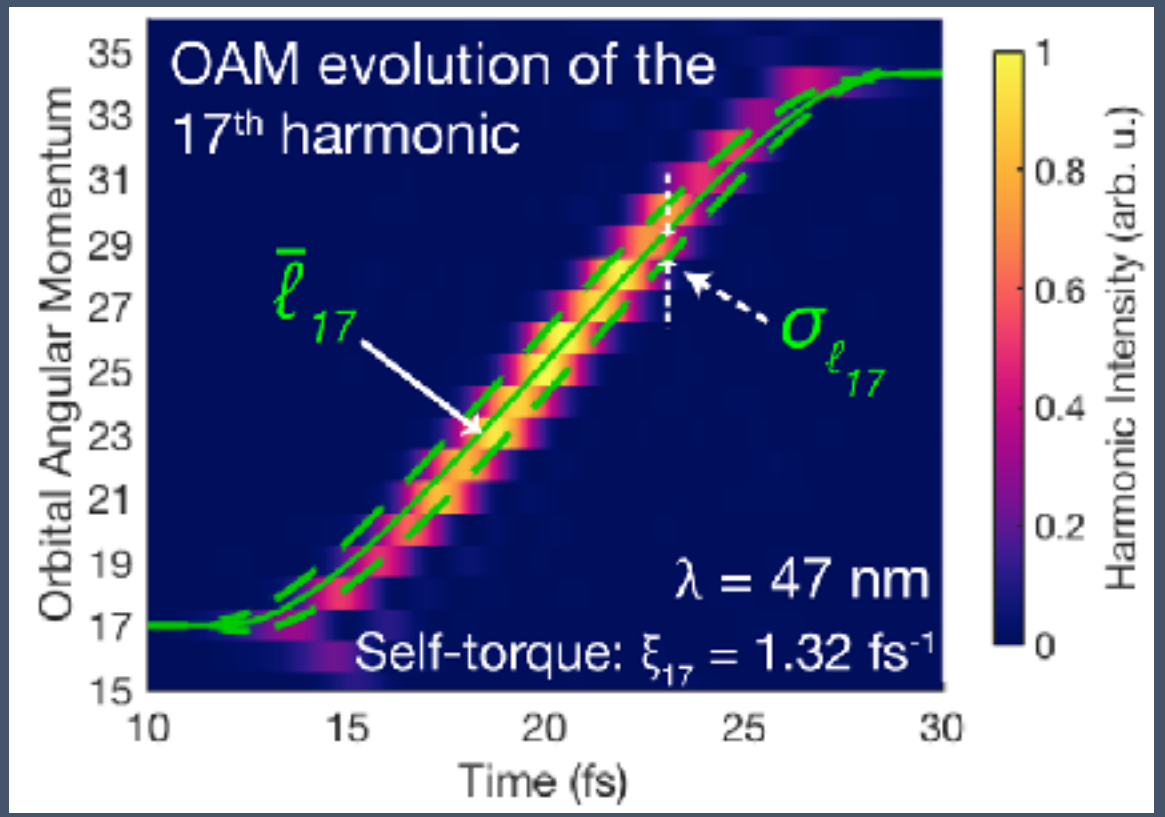


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Width of OAM Spectrum at Time (t)

$$\sigma_{\ell_q} = |\ell_2 - \ell_1|\sqrt{p\bar{\eta}(t)(1-\bar{\eta}(t))}$$

Self-Torque of Light!

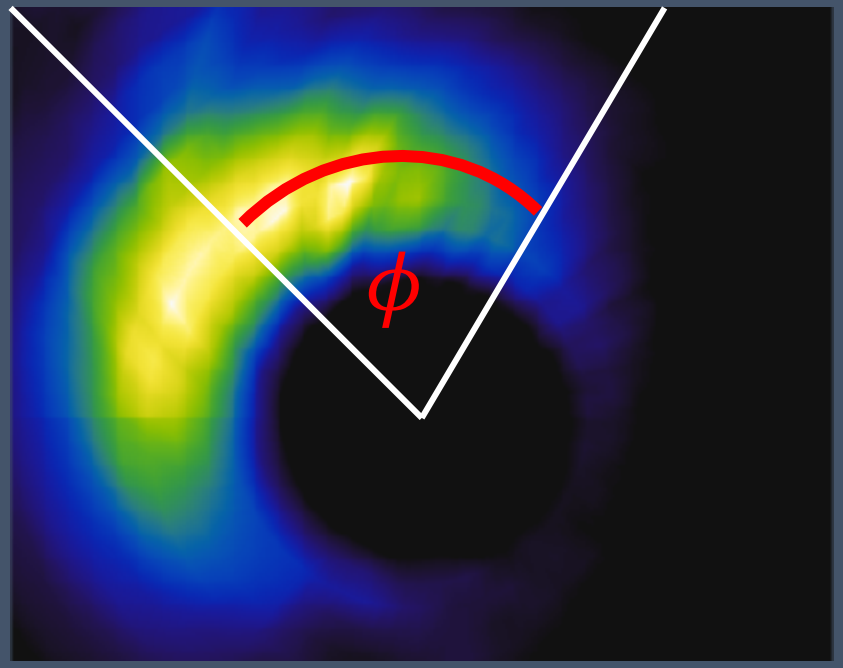
$$\xi_q = d\bar{\ell}_q(t)/dt$$

[1]Rego, et. al. *PRL* **117**, 2016

[2]Rego and **Dorney**, et. al. *Science* 2019 (Accepted)

# Coherent EUV Light Possessing a Self-Torque: Unprecedented Spatiotemporal Optical Topology

## Spatial Profile of Self-Torqued EUV Beam

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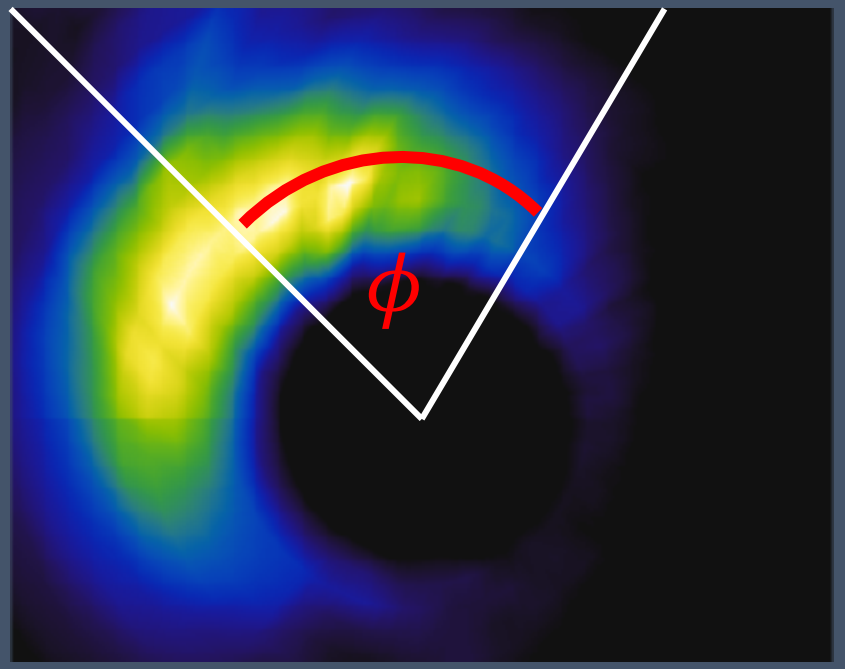


$$d\bar{\ell}_q(t,\phi)\Big/_{dt} = \frac{d\,\varphi_q(\phi,t;\bar{\ell}_q)}{dt} \qquad \omega_q(t,\phi) = \frac{d\,\varphi_q(t,\phi)}{dt}$$

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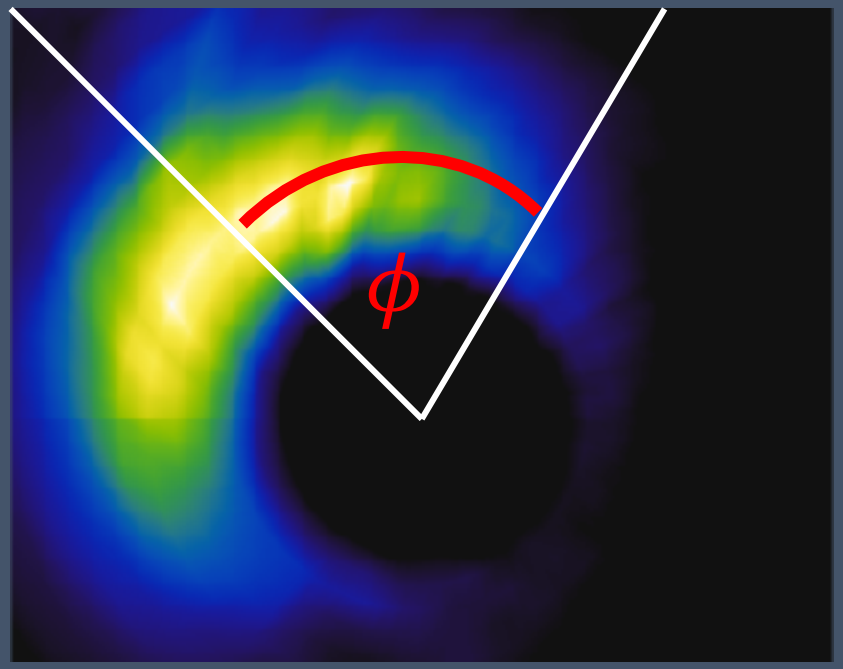


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$$\omega_q(t,\phi) = \frac{d\varphi_q(t,\phi)}{dt} = \omega_q + \frac{d\ell_q(t)}{dt}\phi \approx \omega_q + \xi_q\phi$$

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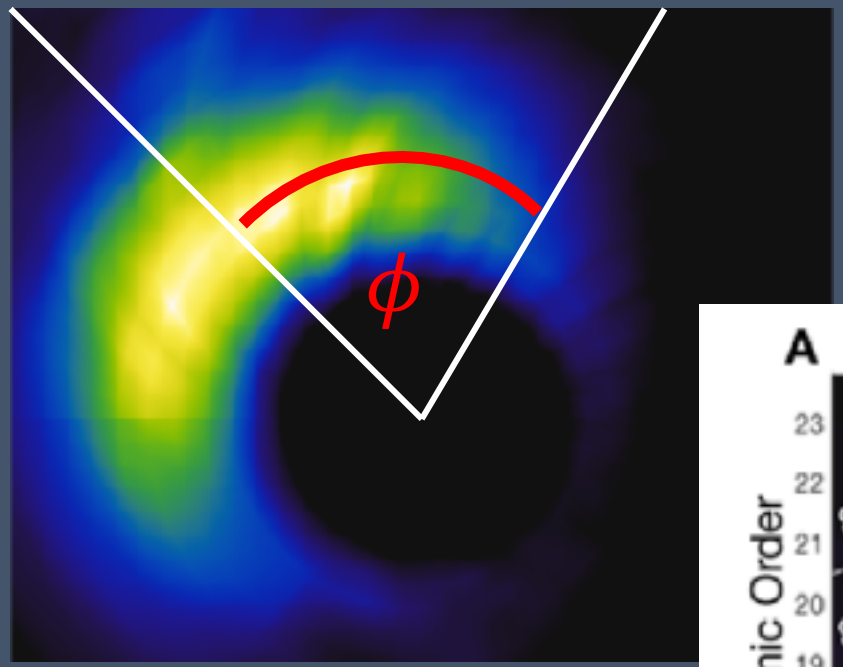


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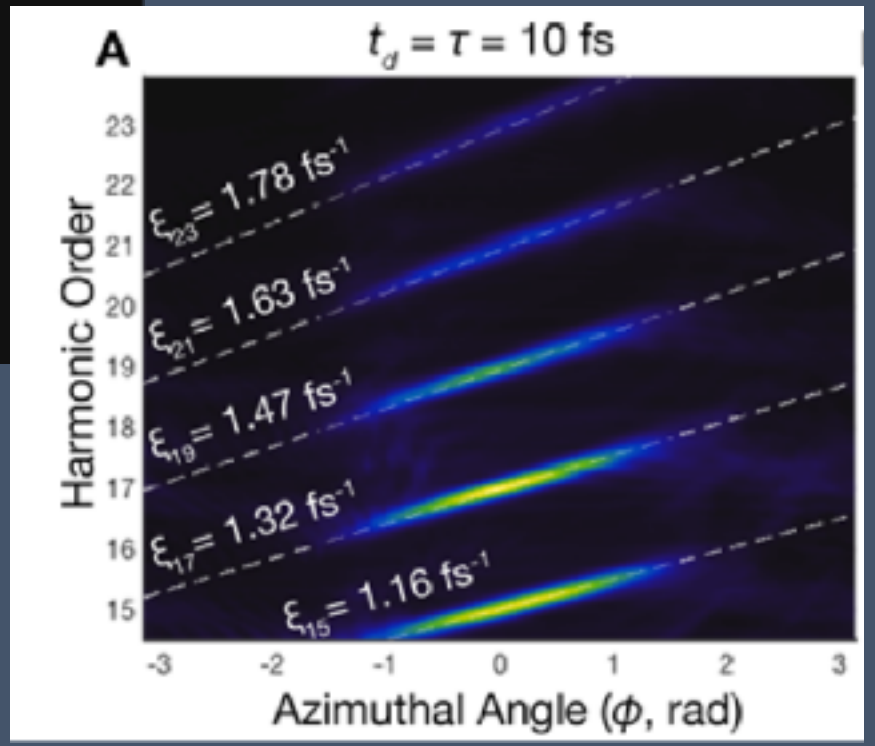


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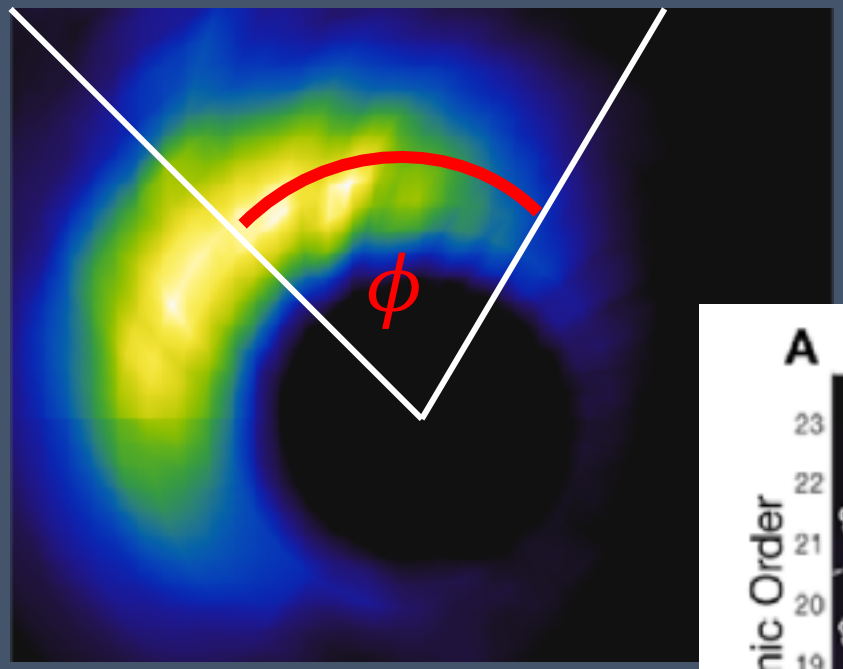


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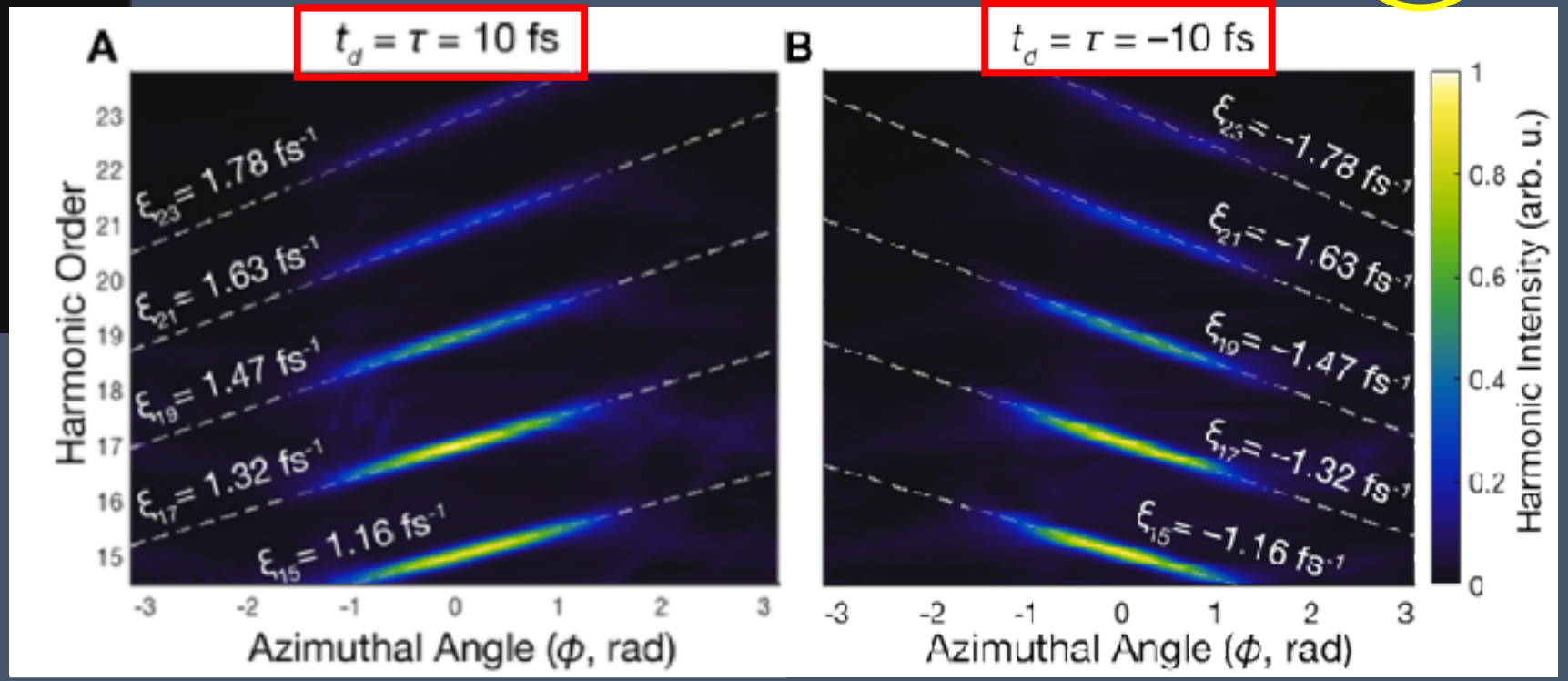


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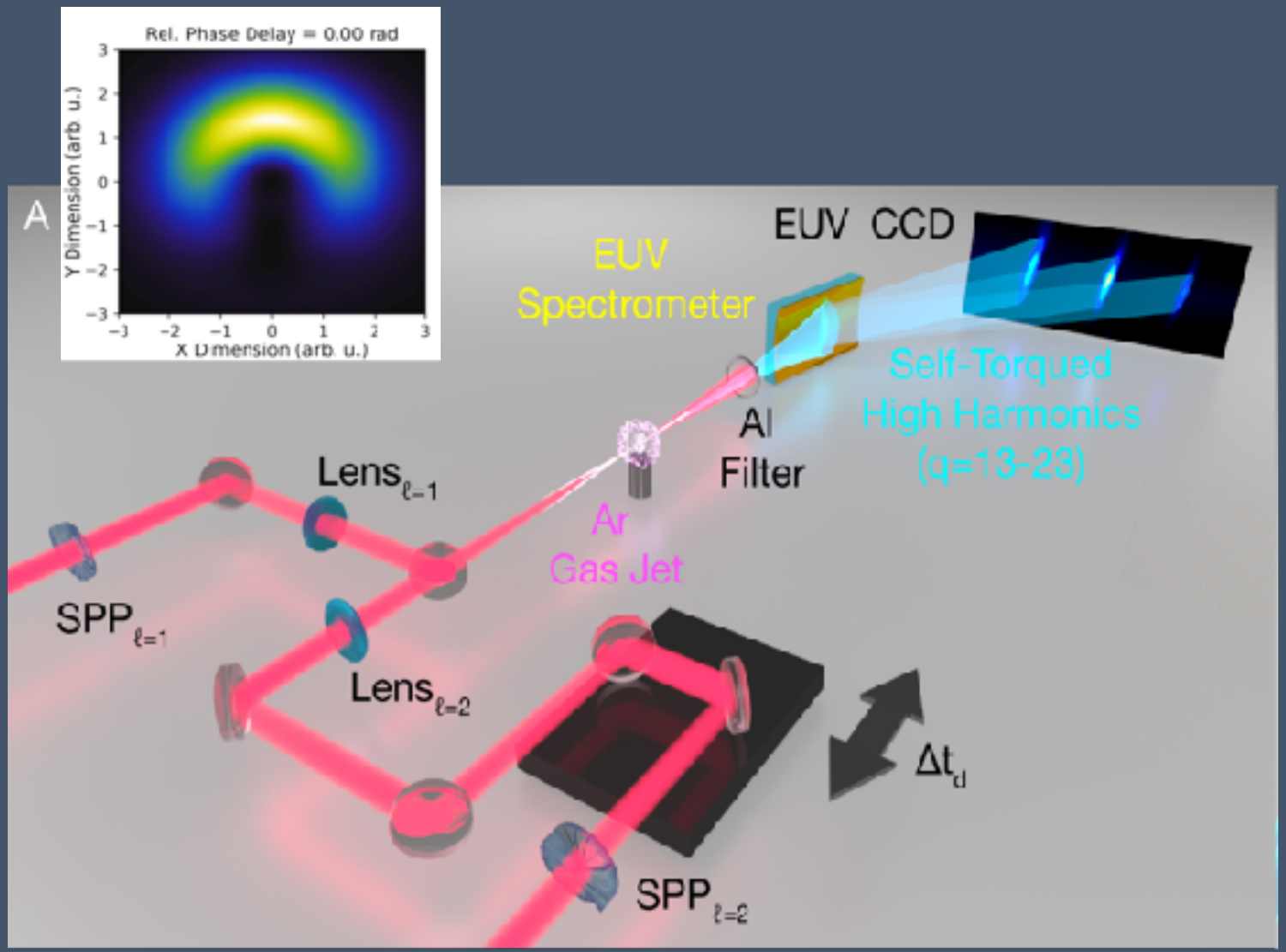


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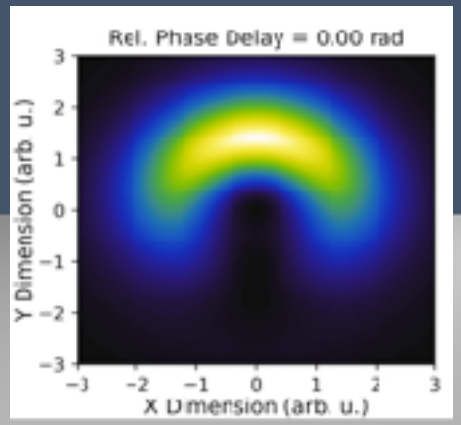


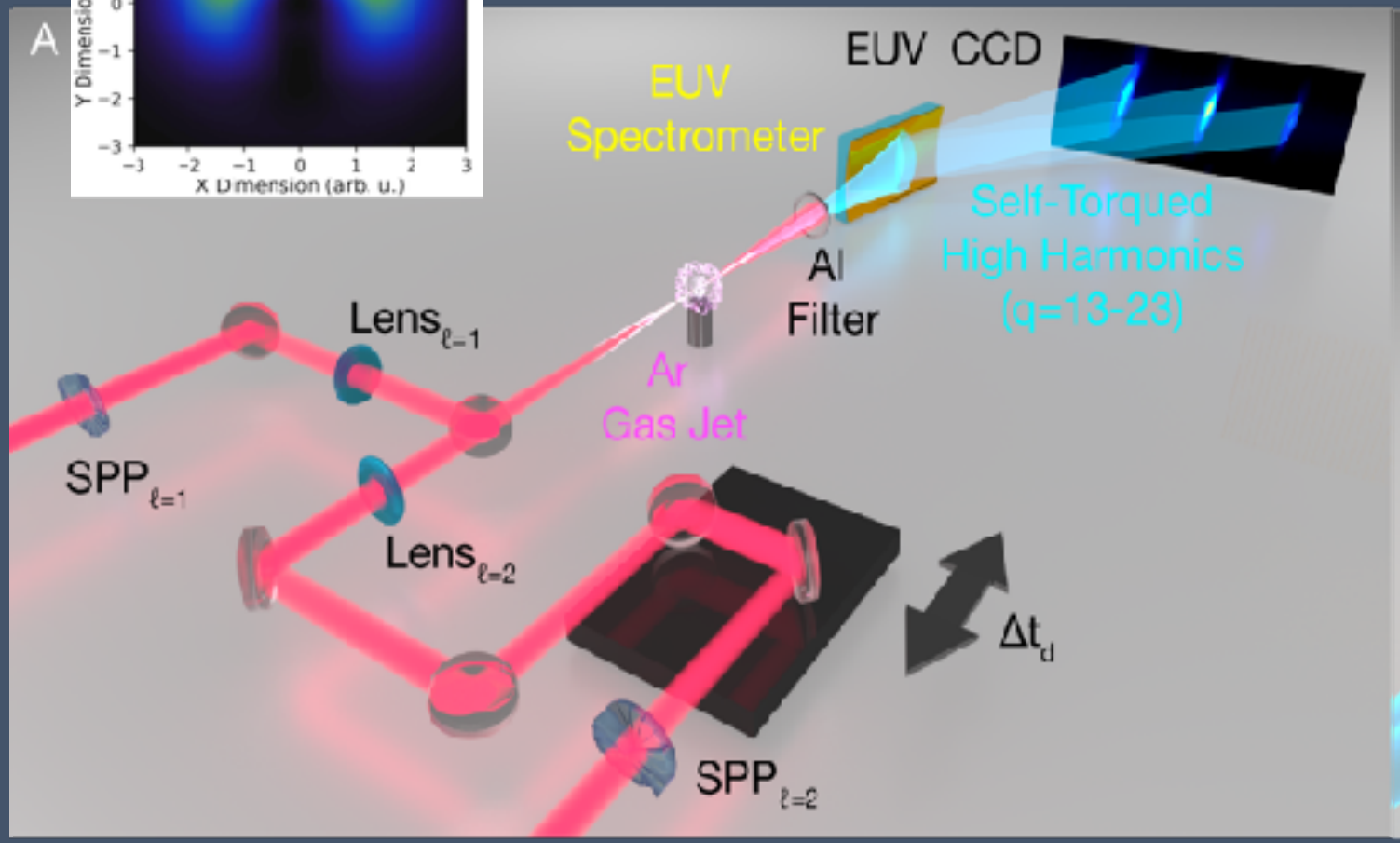


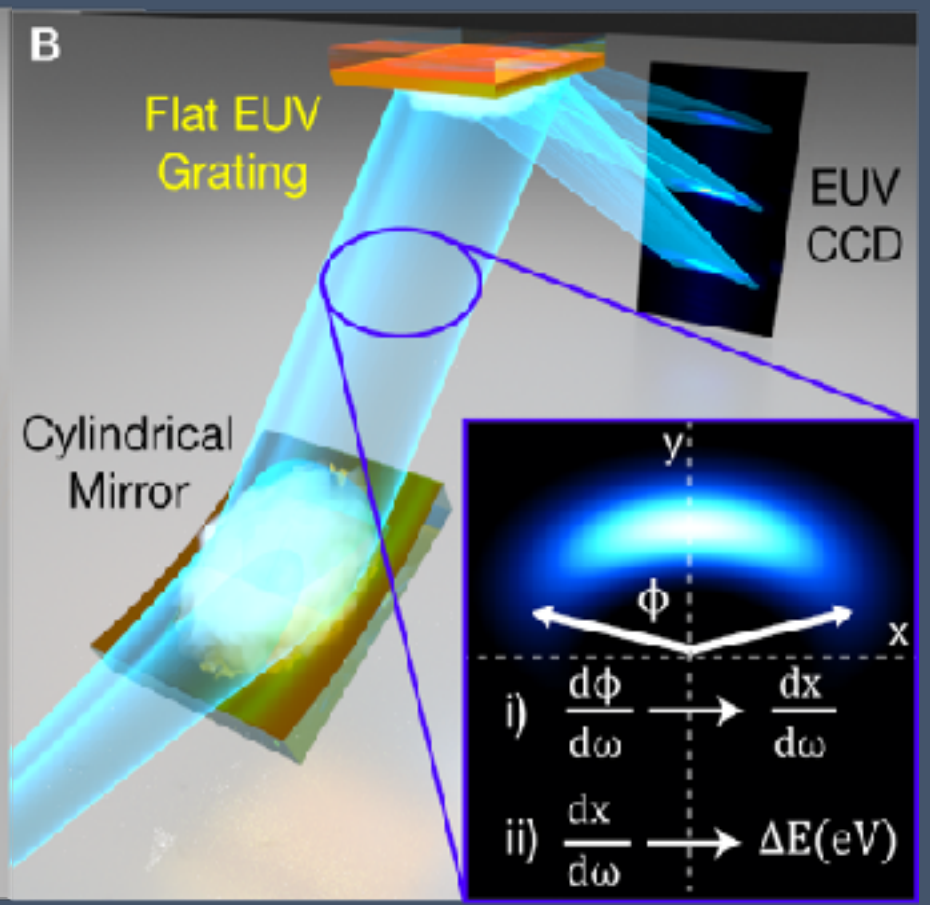


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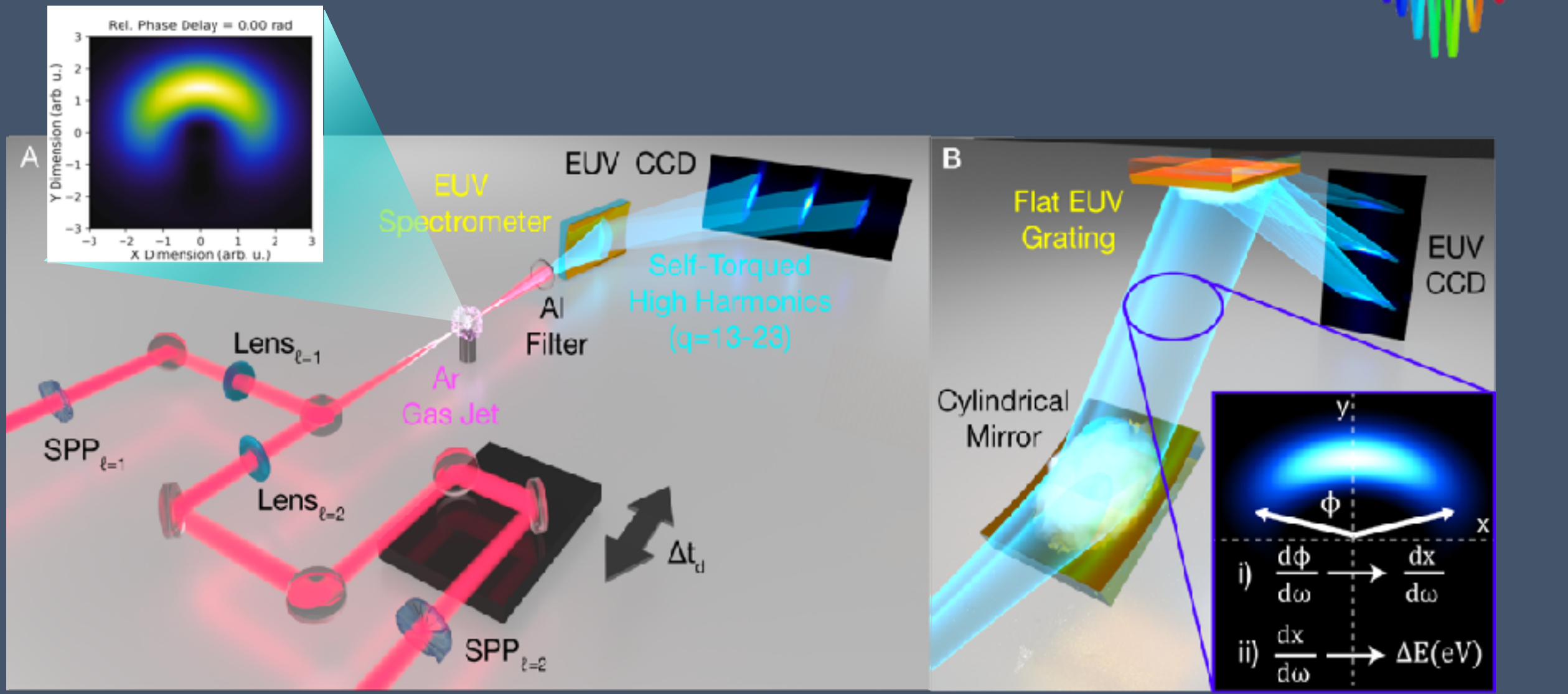


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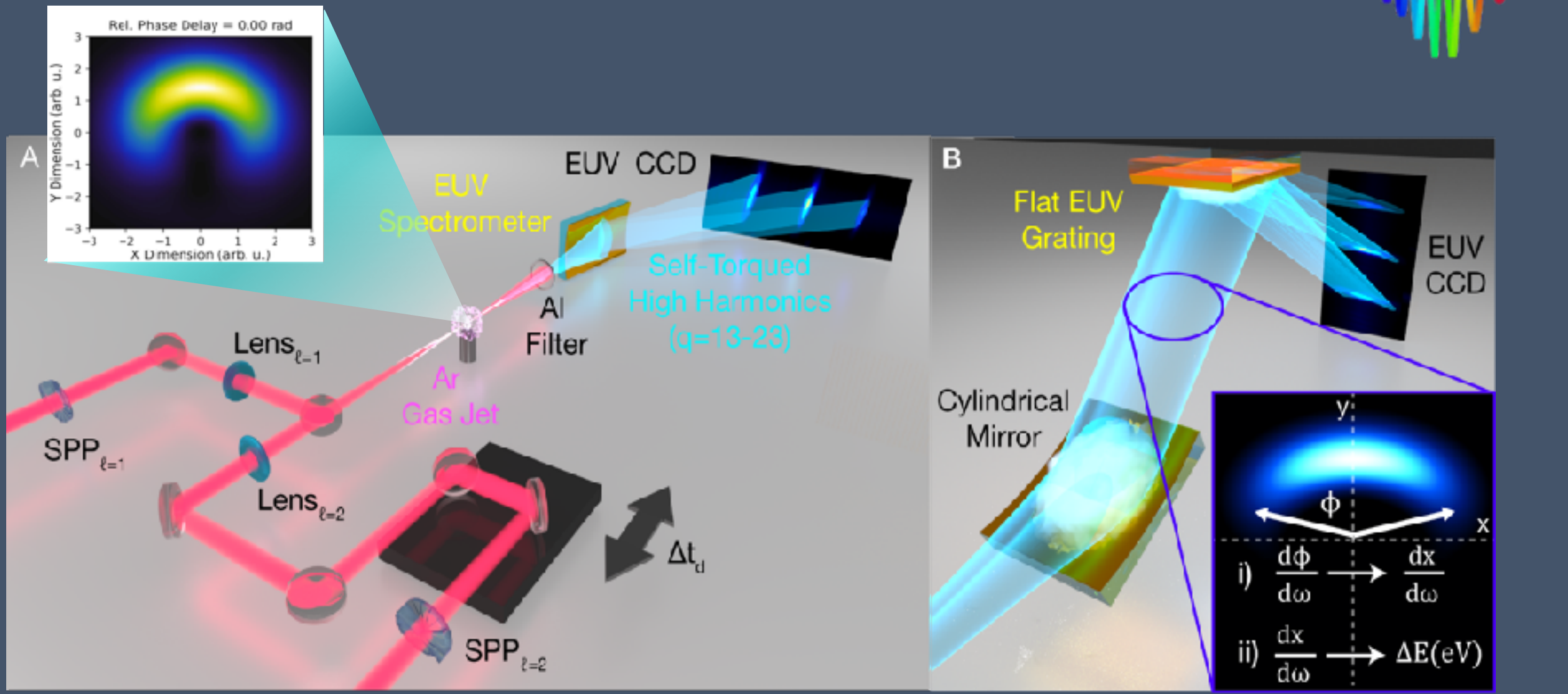


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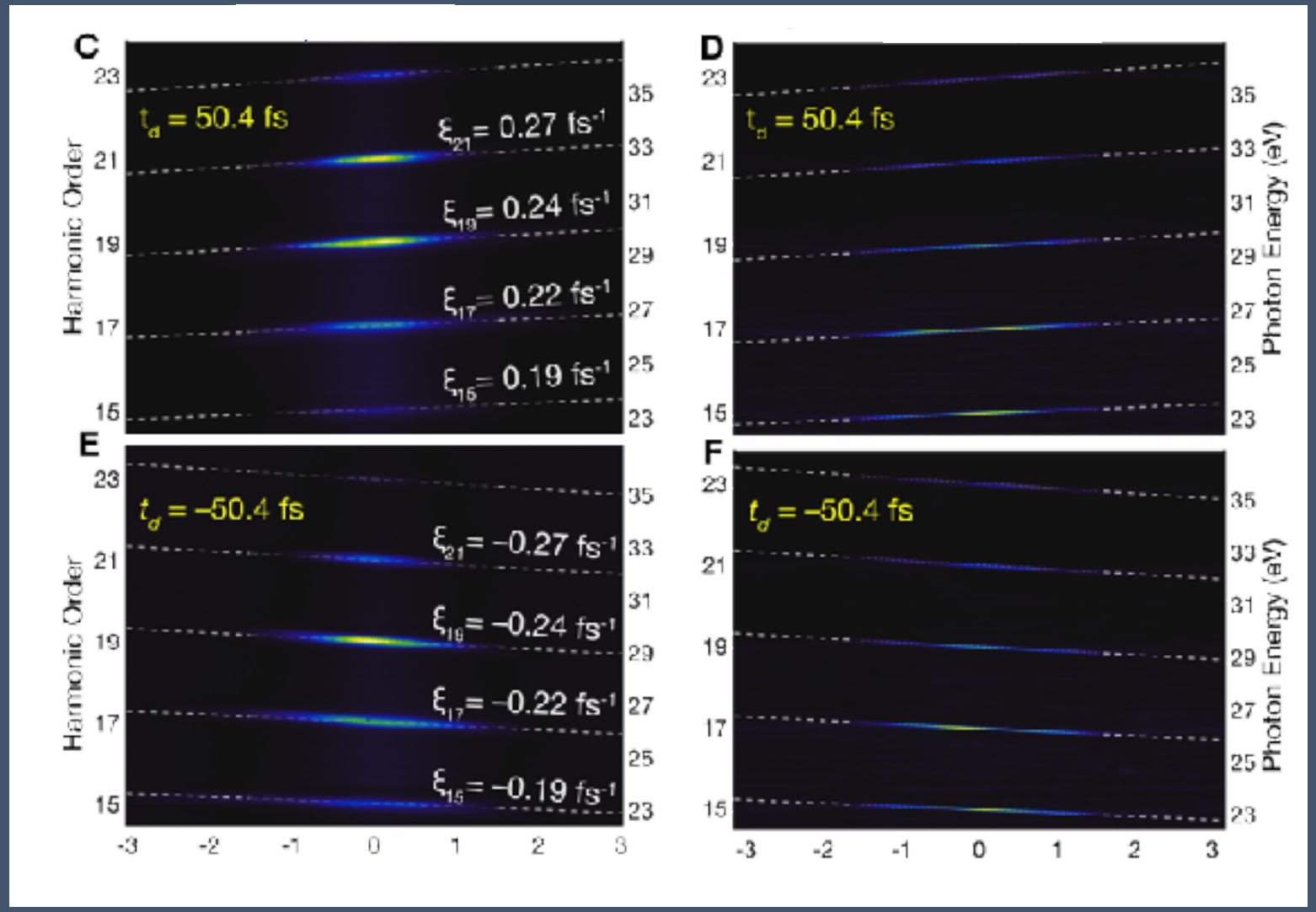


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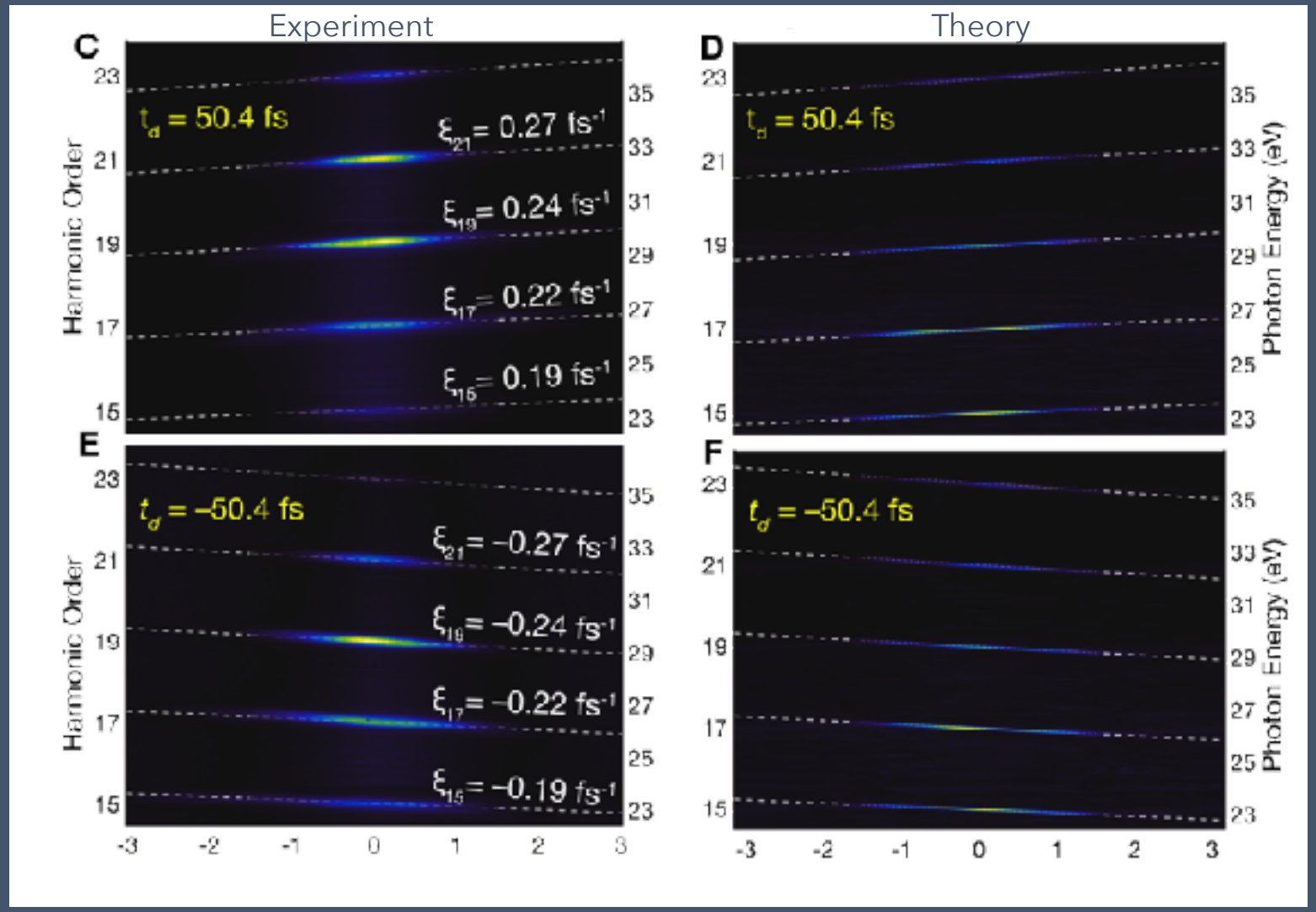


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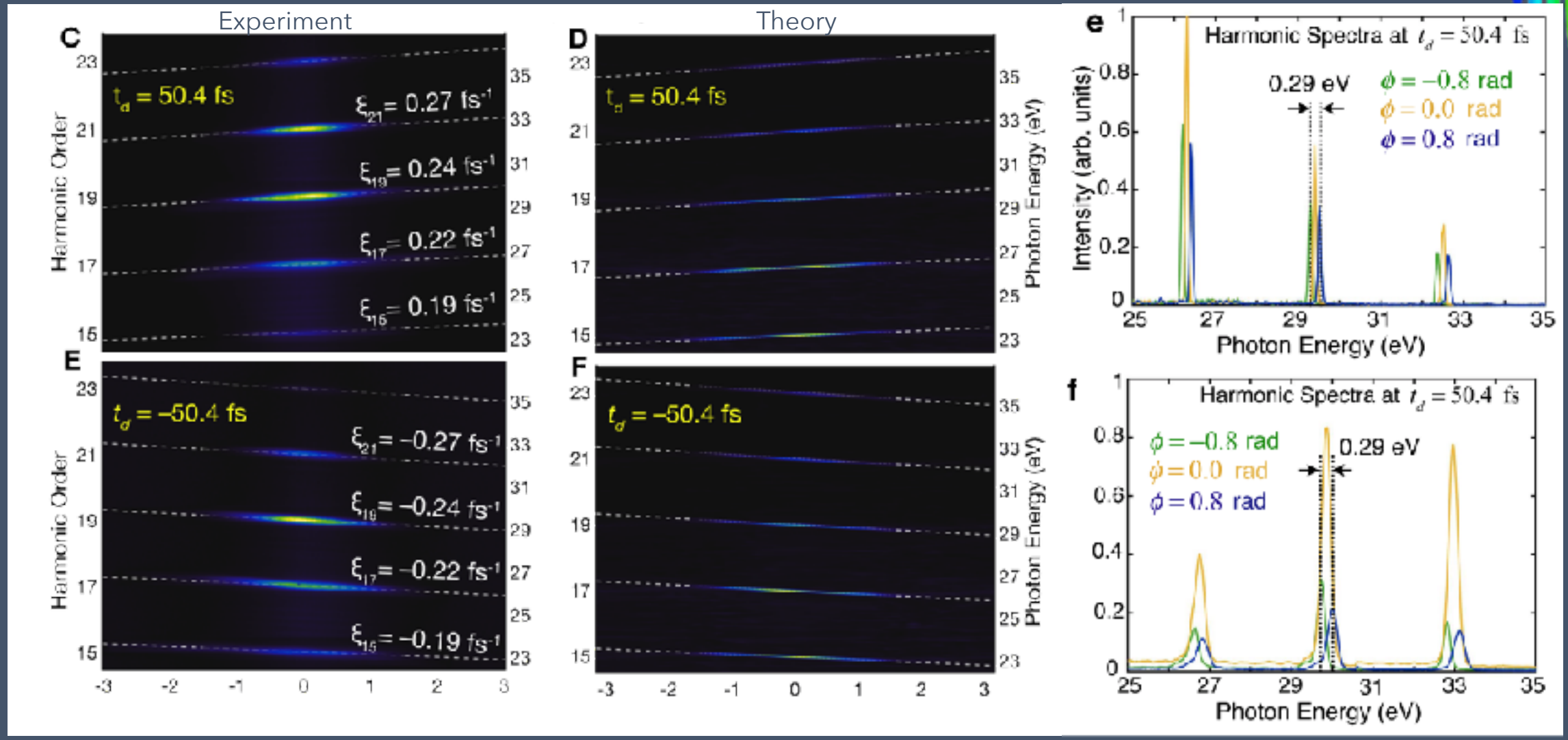


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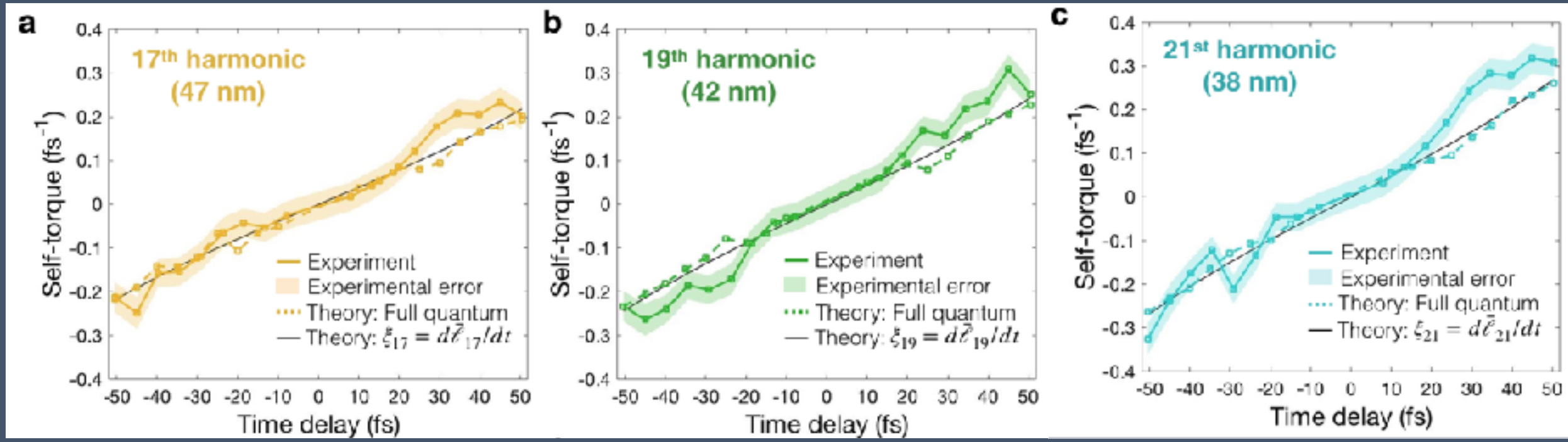


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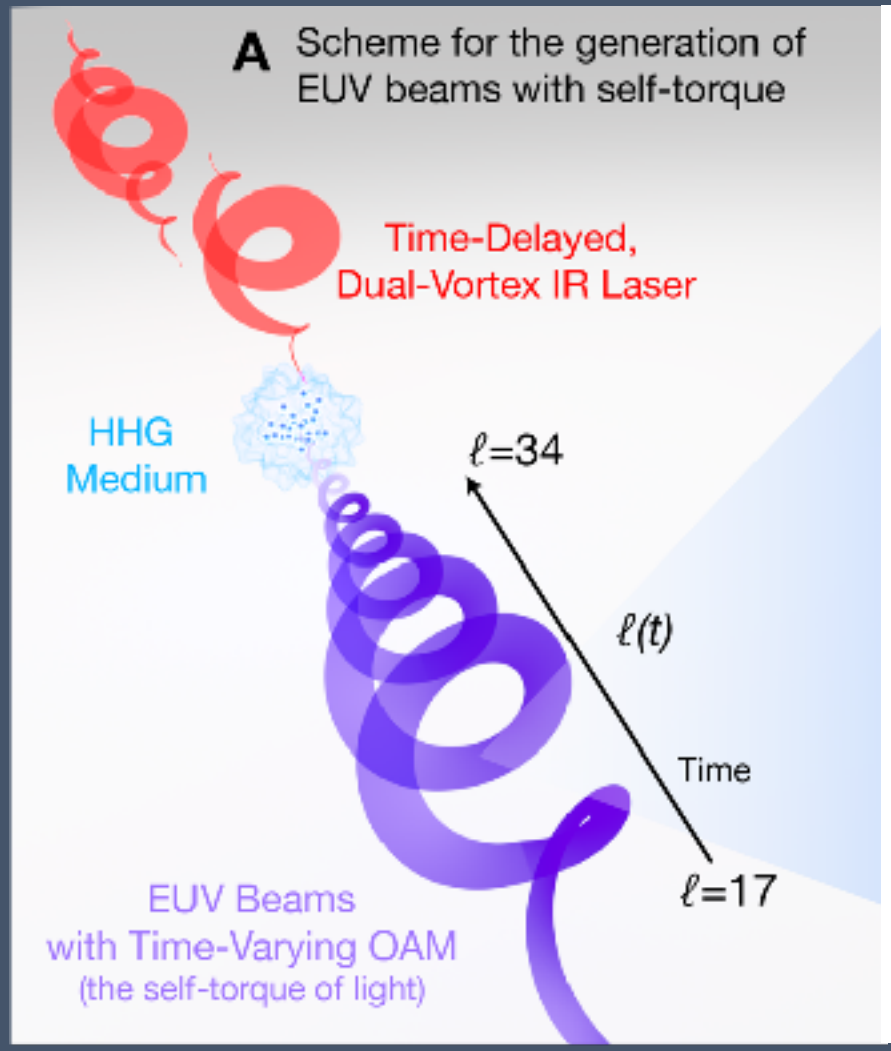
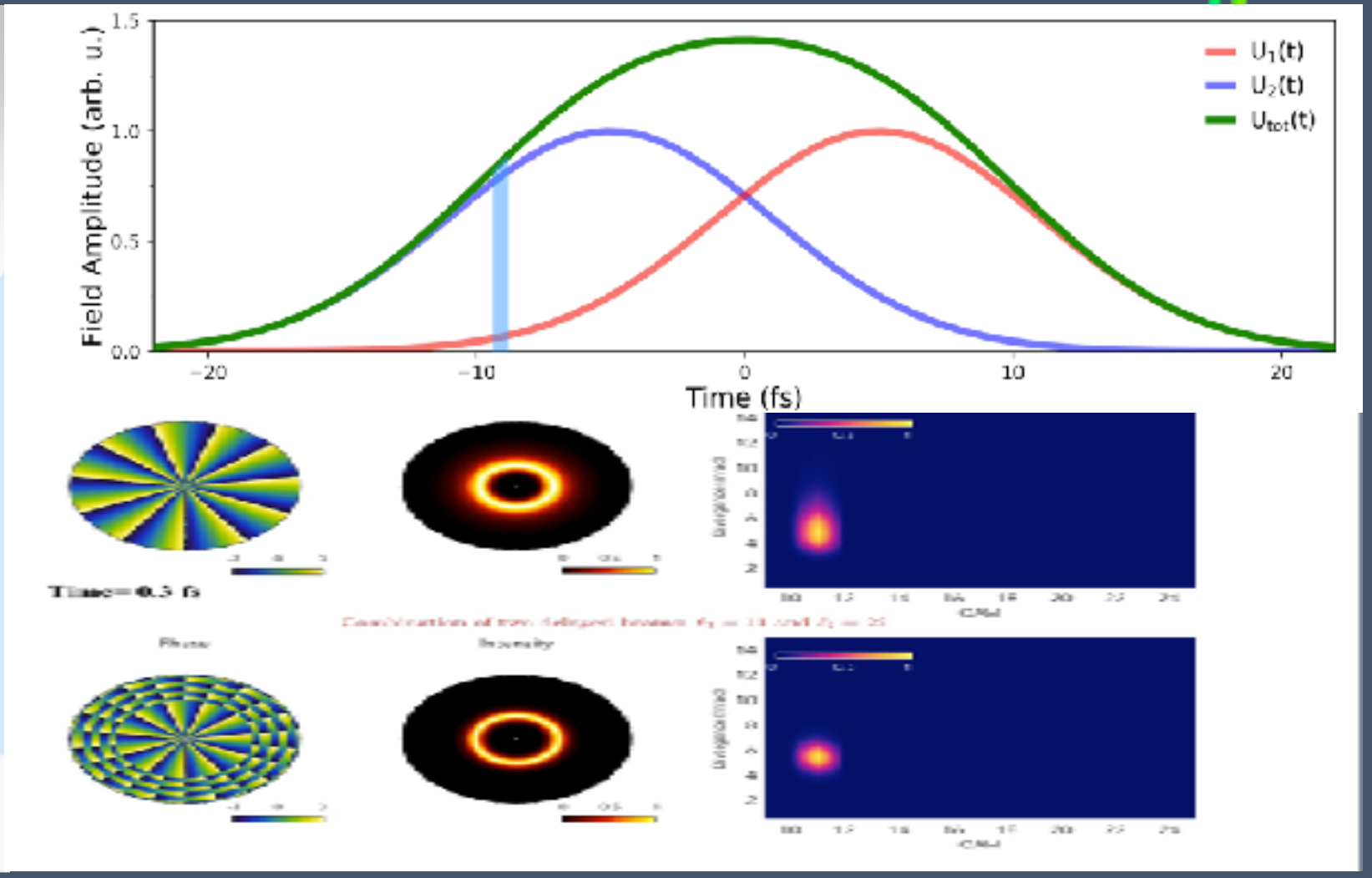
# Mechanism Behind The Creation of Self-Torqued EUV Beams: Peering Into an Attosecond Whirlwind

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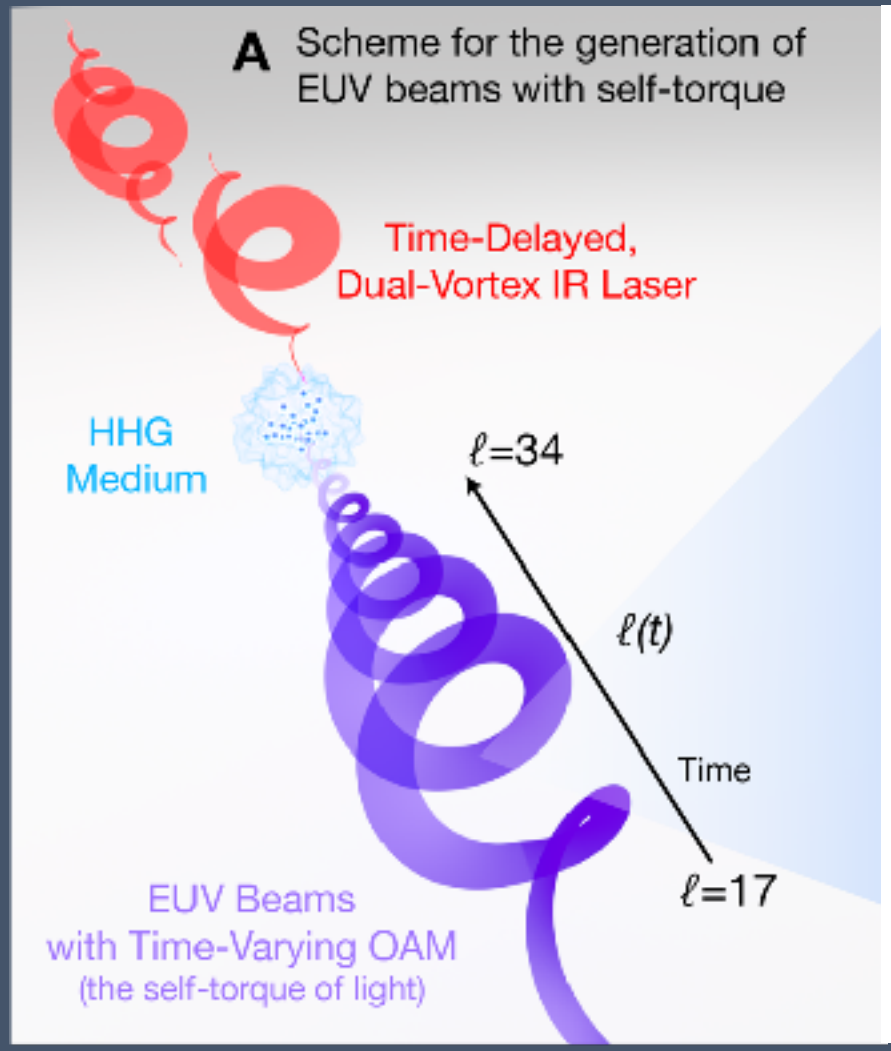


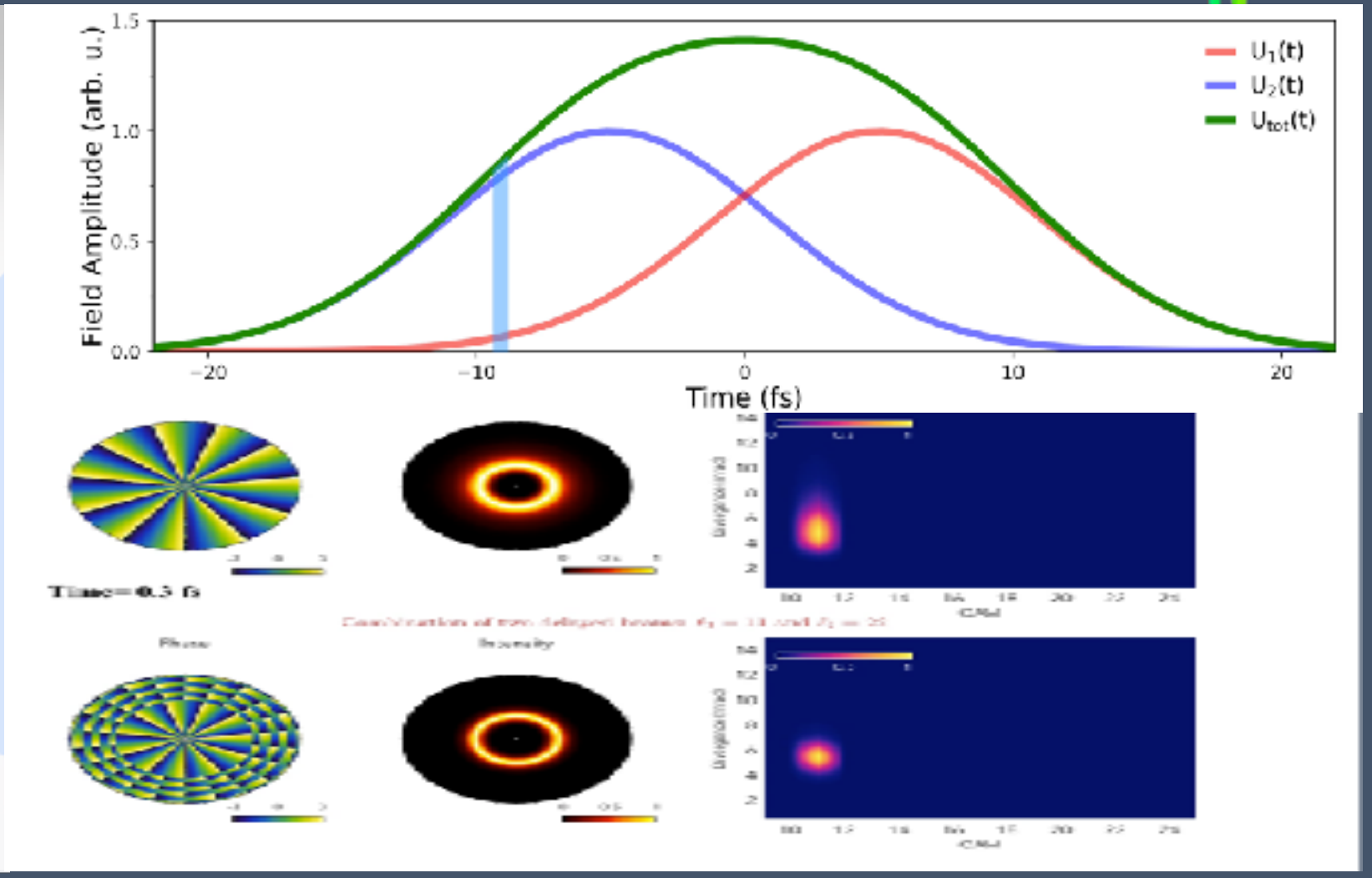


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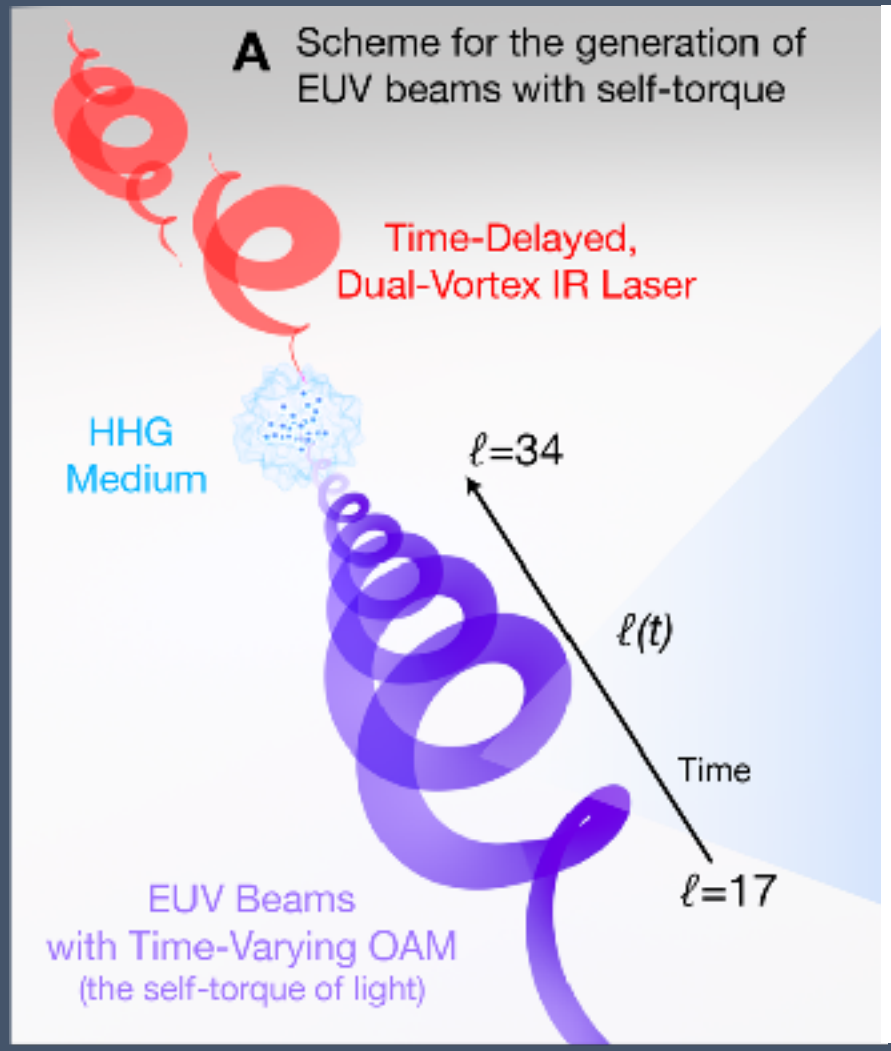


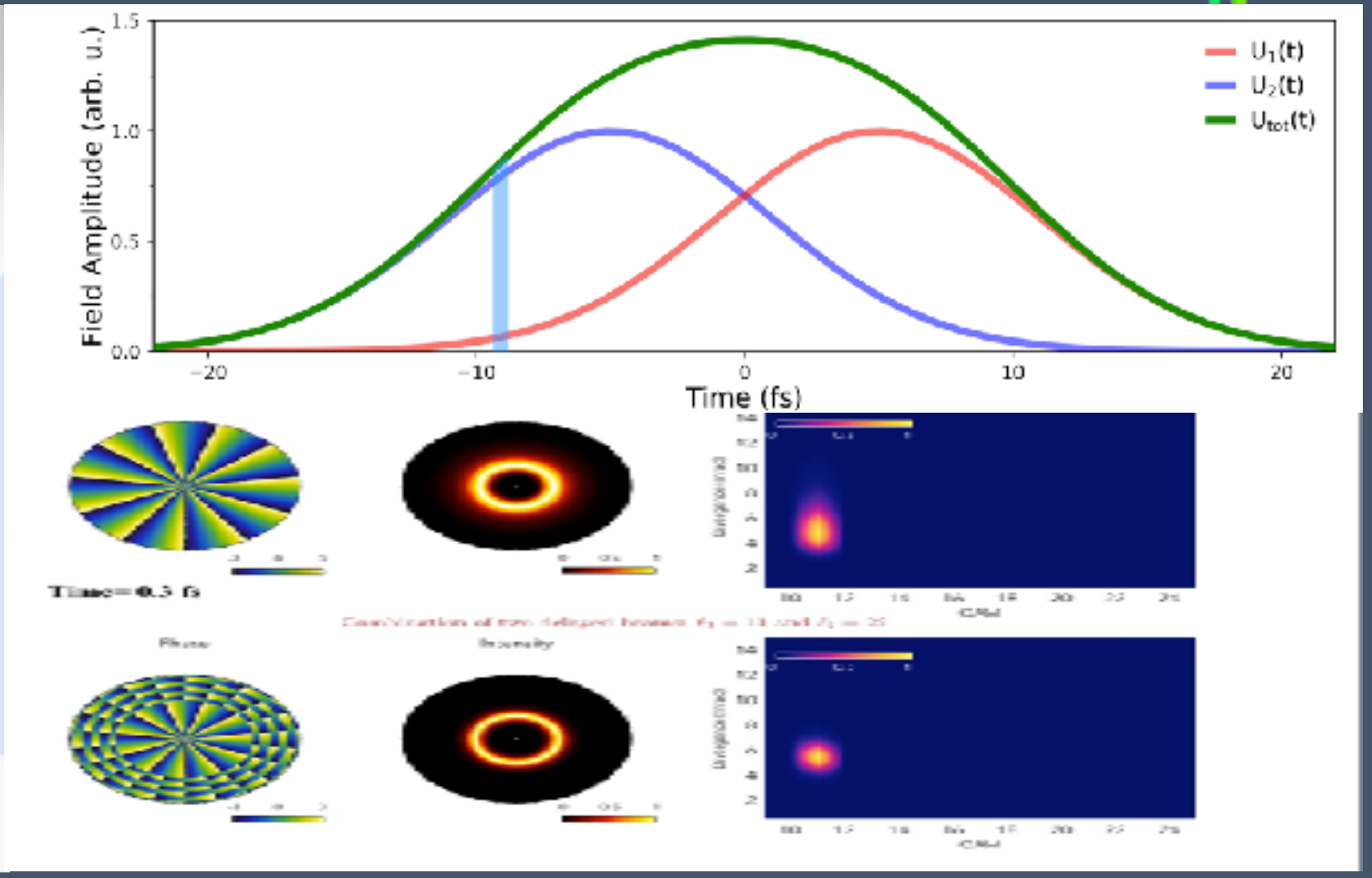


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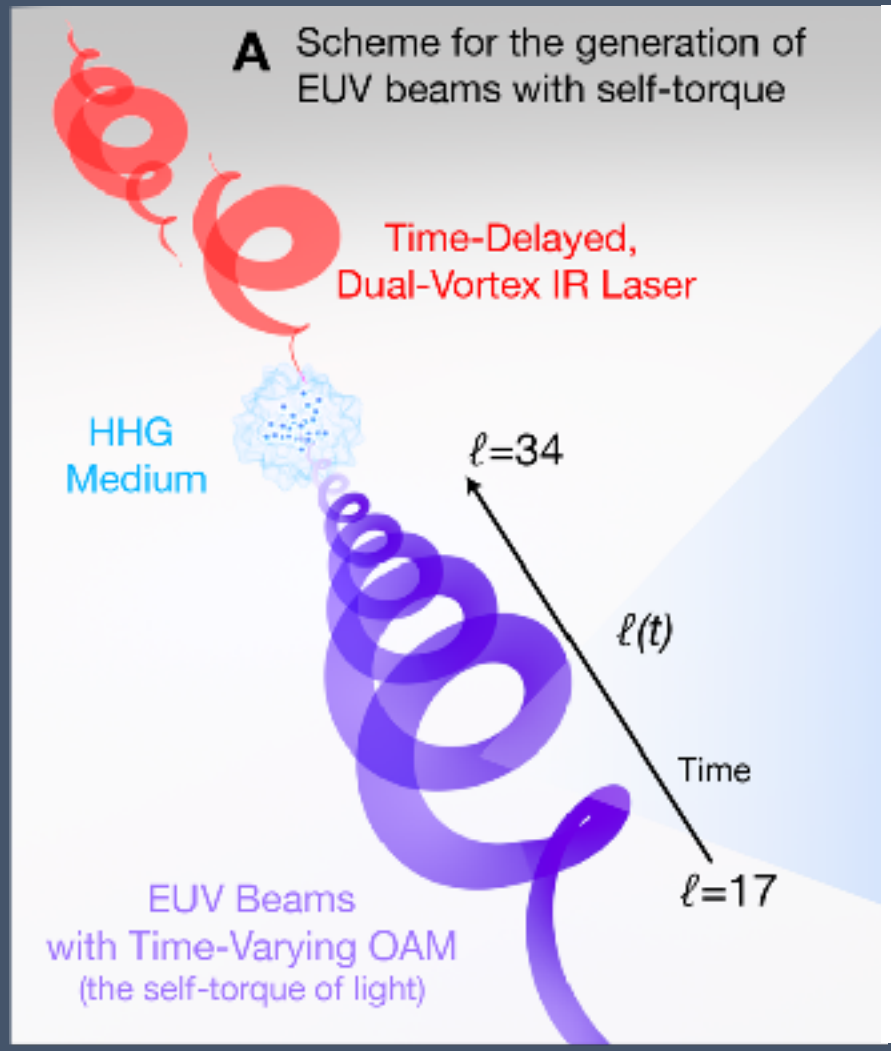


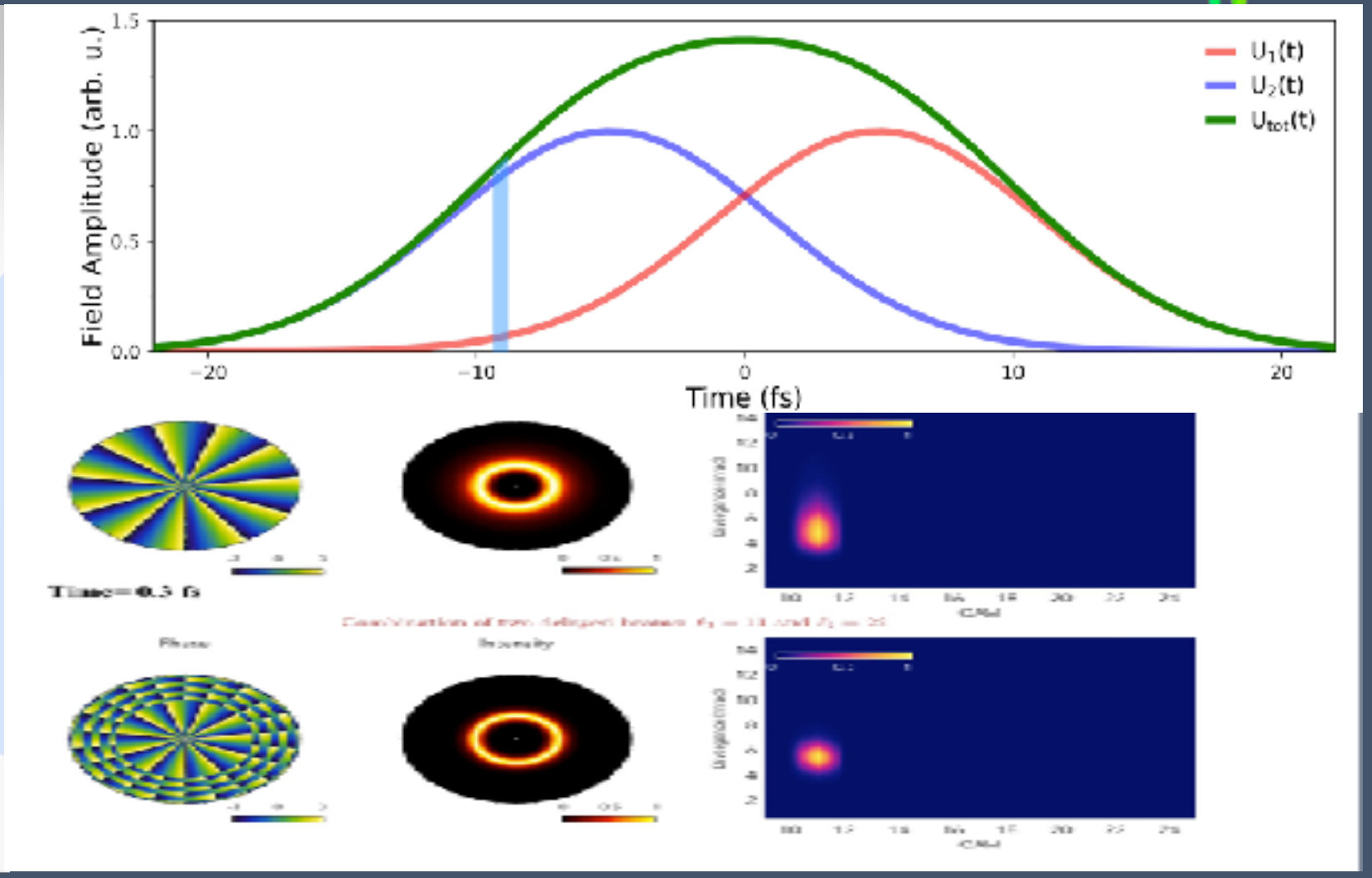


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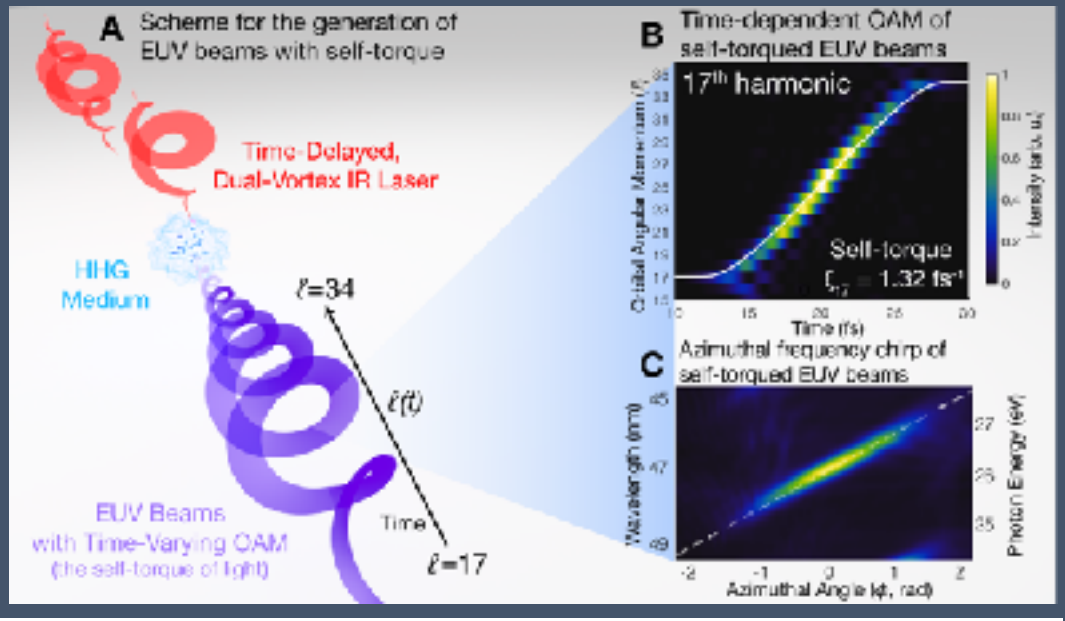
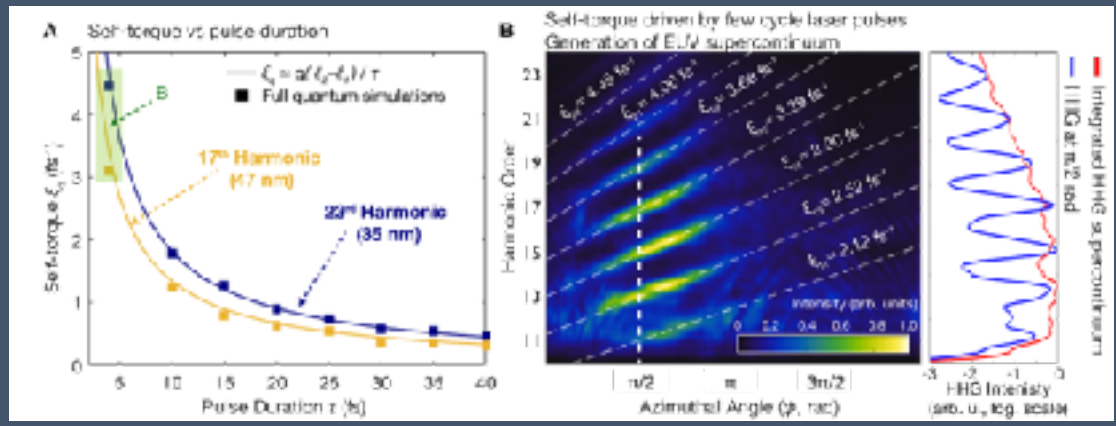
- Prediction and description of a new property of light, self-torque, associated with a time-variation of OAM.
- Self-torque endows unique properties to coherent light forms (time-varying OAM, azimuthal frequency chirp).
- Self-torqued light beams synthesized via HHG, so far the only method for producing self-torqued light.
- Unique light source for controlling quantum and topological matter, OAM dichroism, and resolving ultrafast charge and spin transport.
- Self-torqued beams can yield exotic EUV supercontinua with attosecond variation of the OAM.

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Cornell University

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## Light with a self-torque: extreme-ultraviolet beams with time-varying orbital angular momentum

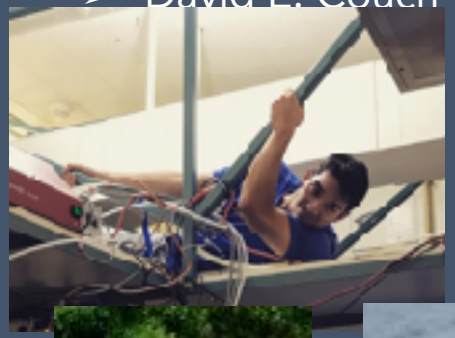
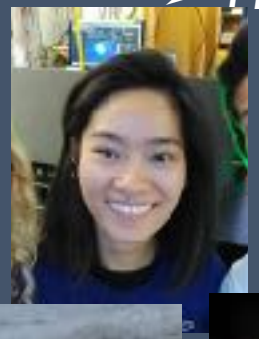
Laura Rego, Kevin M. Dorney, Nathan J. Brooks, Quynh Nguyen, Chen-Ting Liao, Julio San Román, David E. Couch, Allison Liu, Emilio Pisanty, Maciej Lewenstein, Luis Plaja, Henry C. Kapteyn, Margaret M. Murnane, Carlos Hernández-García

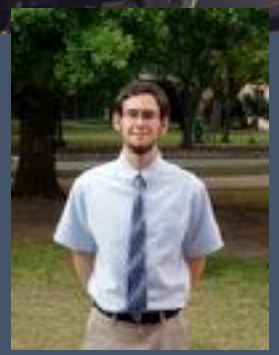
Rego and **Dorney**, et. al. *Science* 2019 (Accepted)

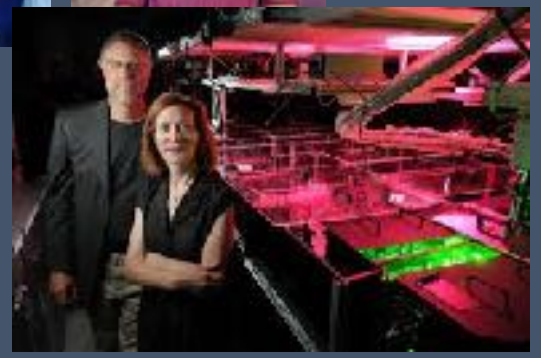
# Excellent Group of Students, Collaborators and Advisors: Both at Home and Abroad!

## JILA/CU Boulder (USA)

- Nathan Brooks
- Quynh L. Nguyen
- Dr. Chen-Ting Laio
- David F. Couch
- Allison Liu
- Michael Tanksalvala
- ***Prof. Henry Kapteyn***
- ***Prof. Margaret Murnane***





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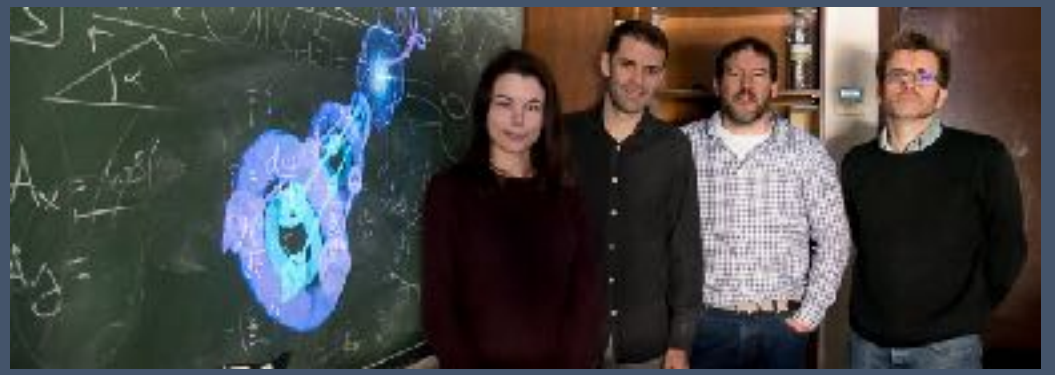
- ***Dr. Carlos Hernández-García***
- ***Prof. Luis Plaja***



## ICFO (ESP)

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- ***Prof. Maciej Lewenstein***

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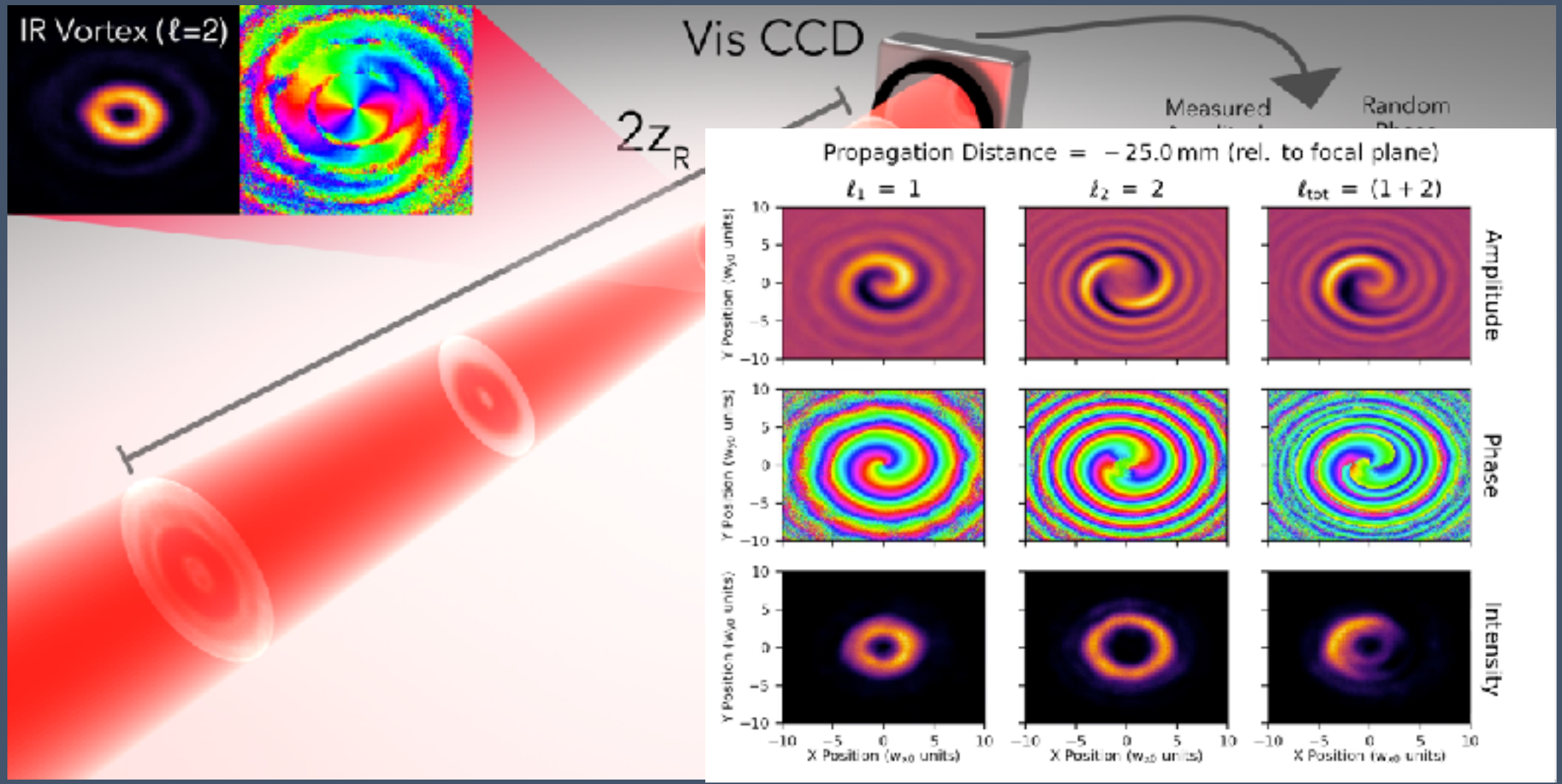
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

# Generating and Quantifying High-Quality, Intense, Mixed OAM Vortex Beams





Fu, et al. *Opt. Lett.* **41**, 2016
Chang, et al. *Opt. Commun.* **405**, 2017
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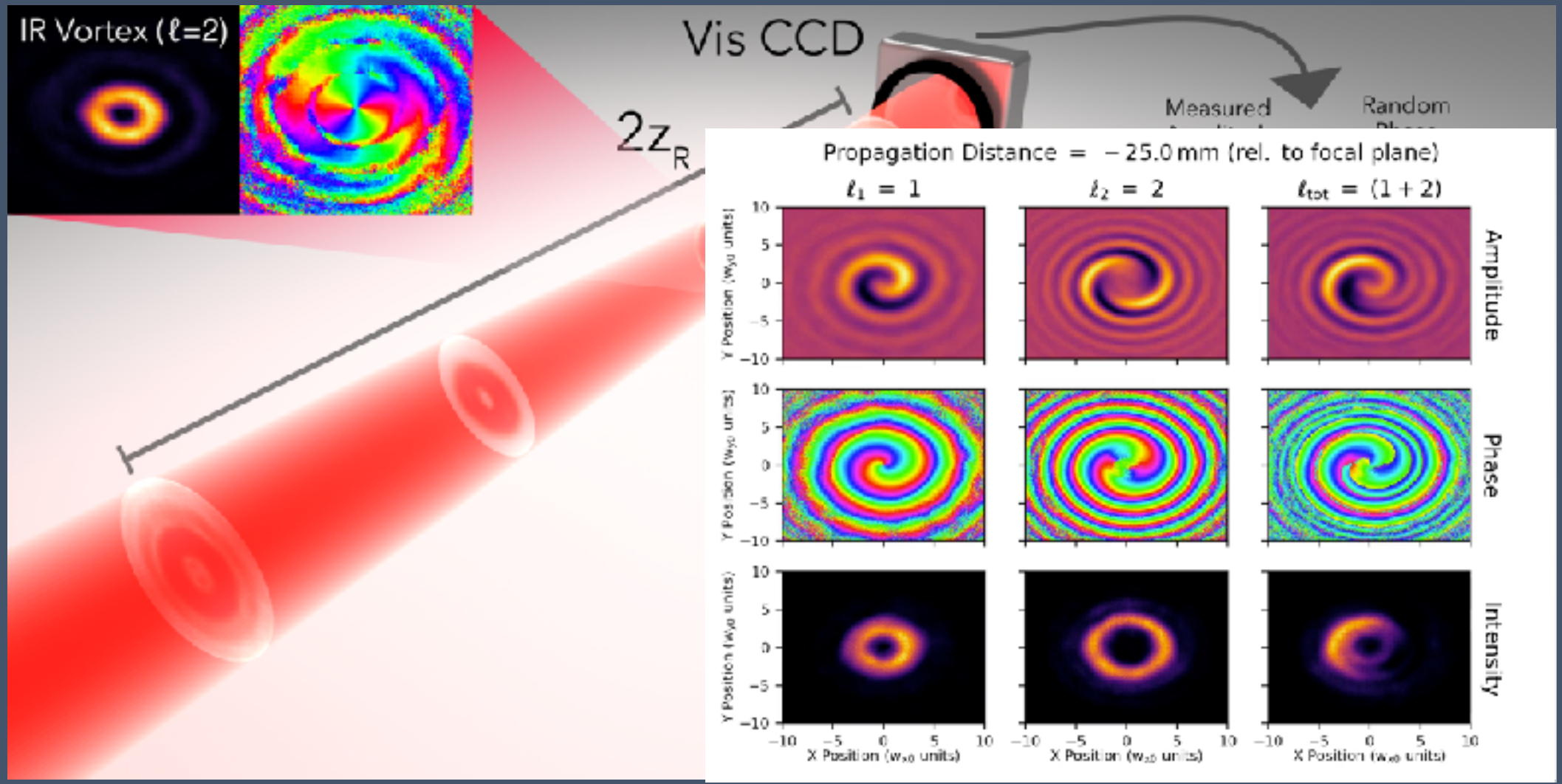



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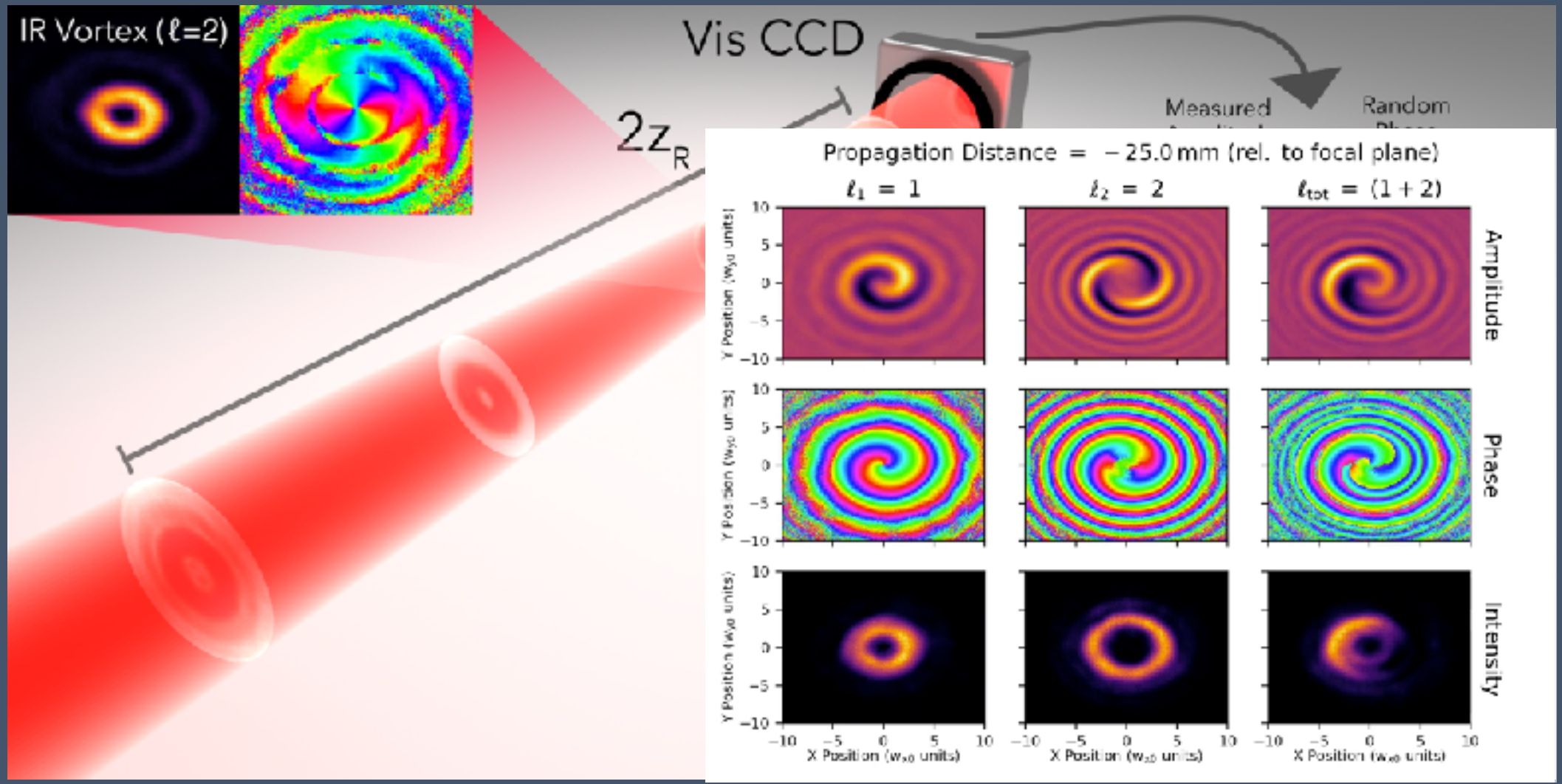



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Yao, Padgett, *Adv. Opt. Photonics*, 2011
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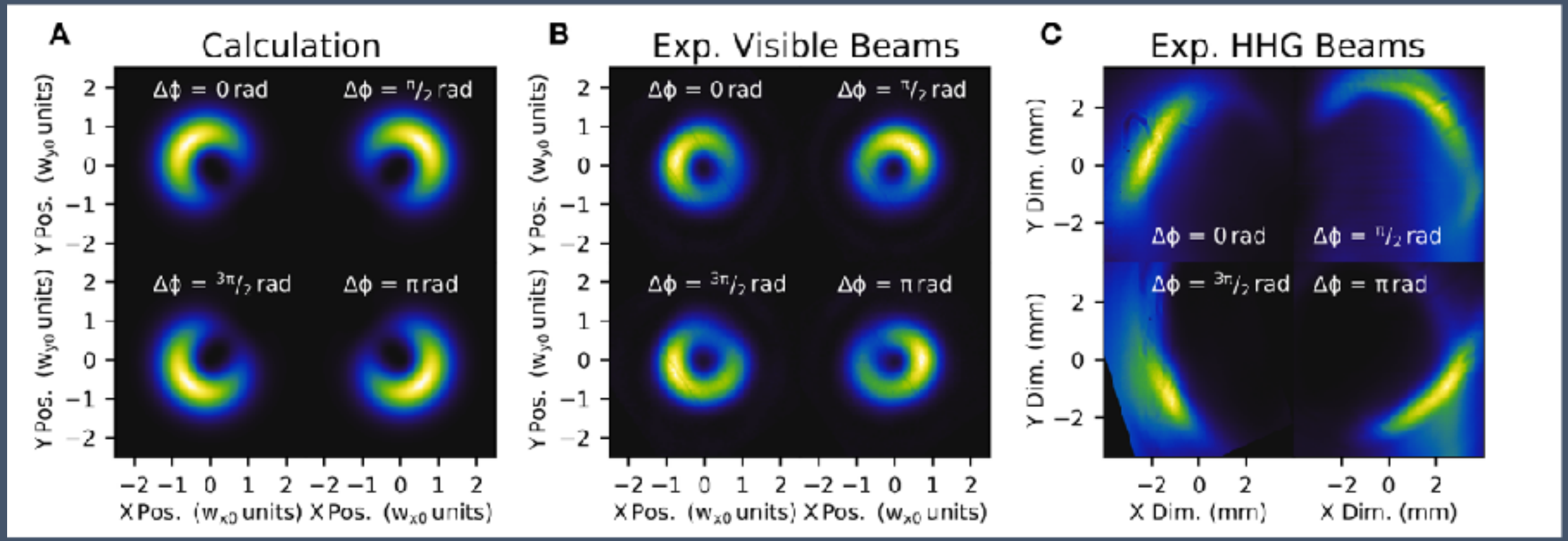


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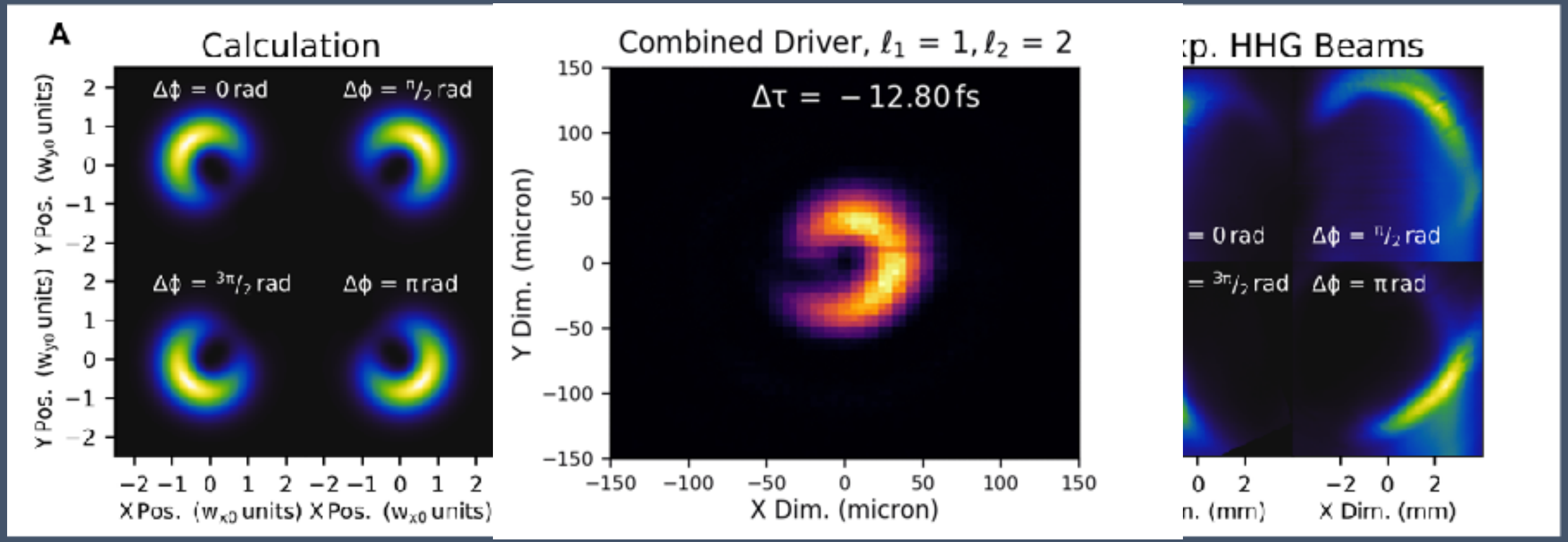


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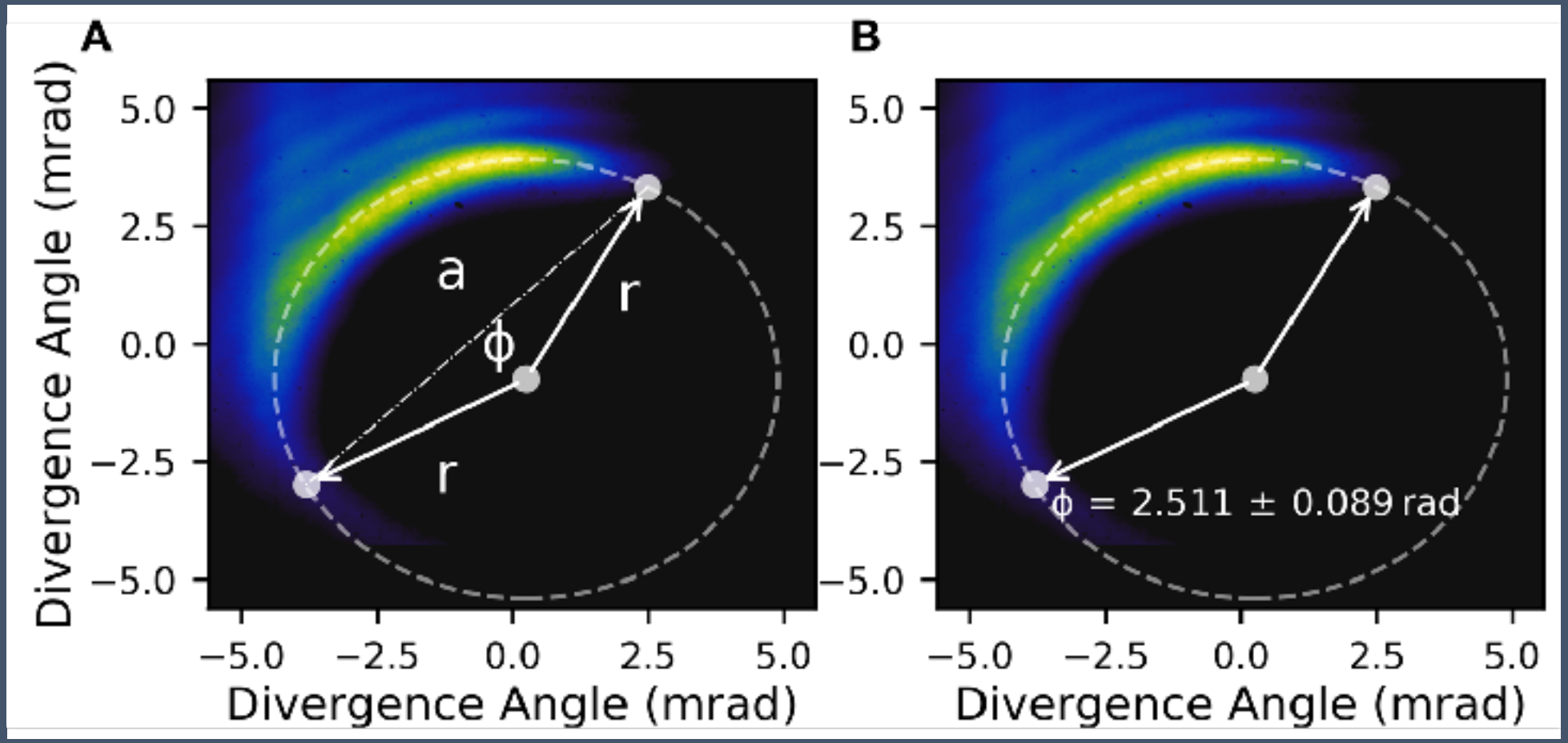
Rego and **Dorney**, et. al. *Science* 2019 (Accepted)

# Extraction of the Azimuthal Extent of the Experimentally Generated Self-Torqued Beams

$$a = 2r\sin\left(\phi/_2\right) \longrightarrow \phi = 2\sin^{-1}\left(a/_{2r}\right)$$

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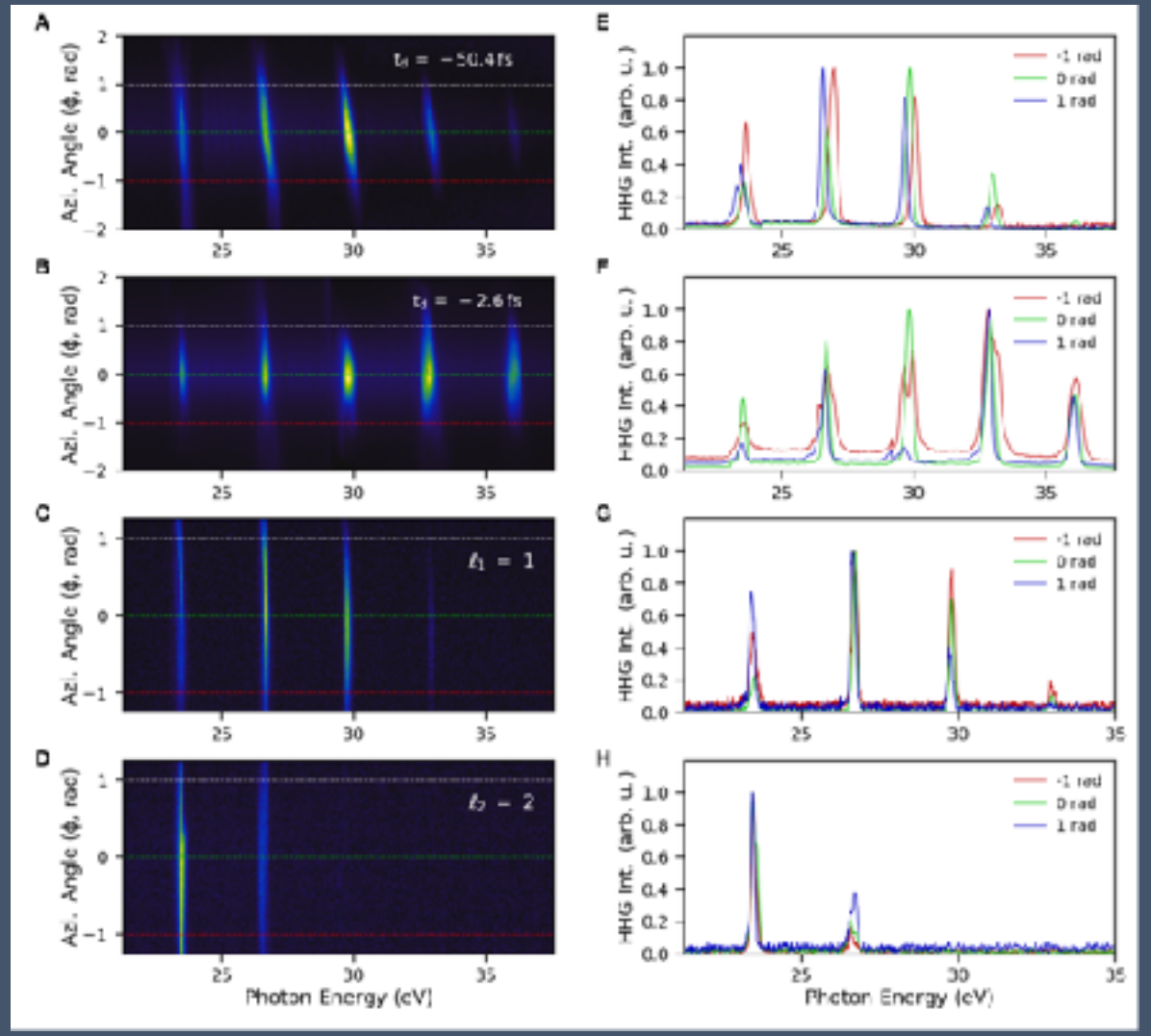
# Confirmation of the Extracted Azimuthal Chirp in Self-Torqued High-Harmonic Beams

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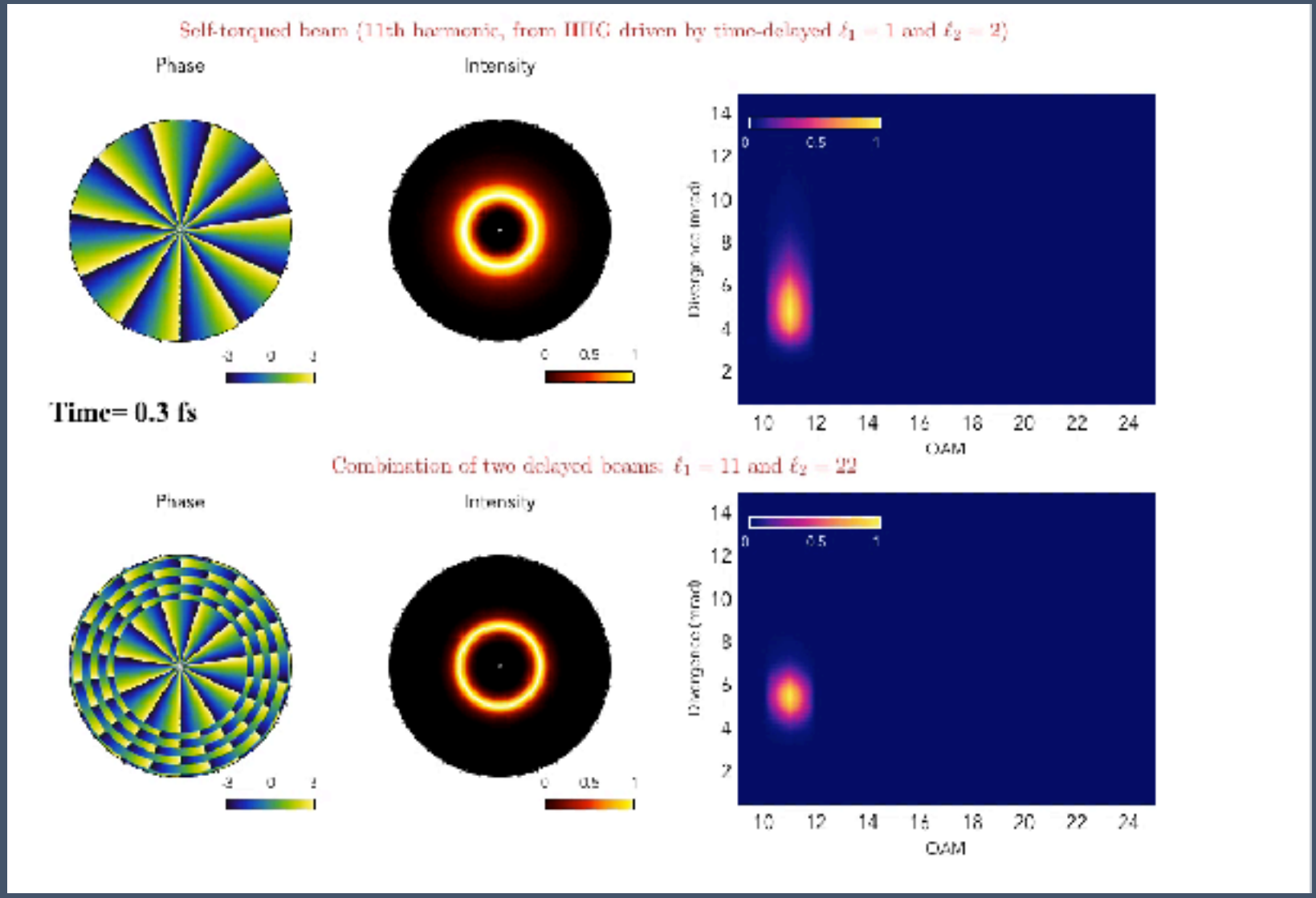
# Self-Torqued Light Beams: Much More Than Time-Dependent Average OAM

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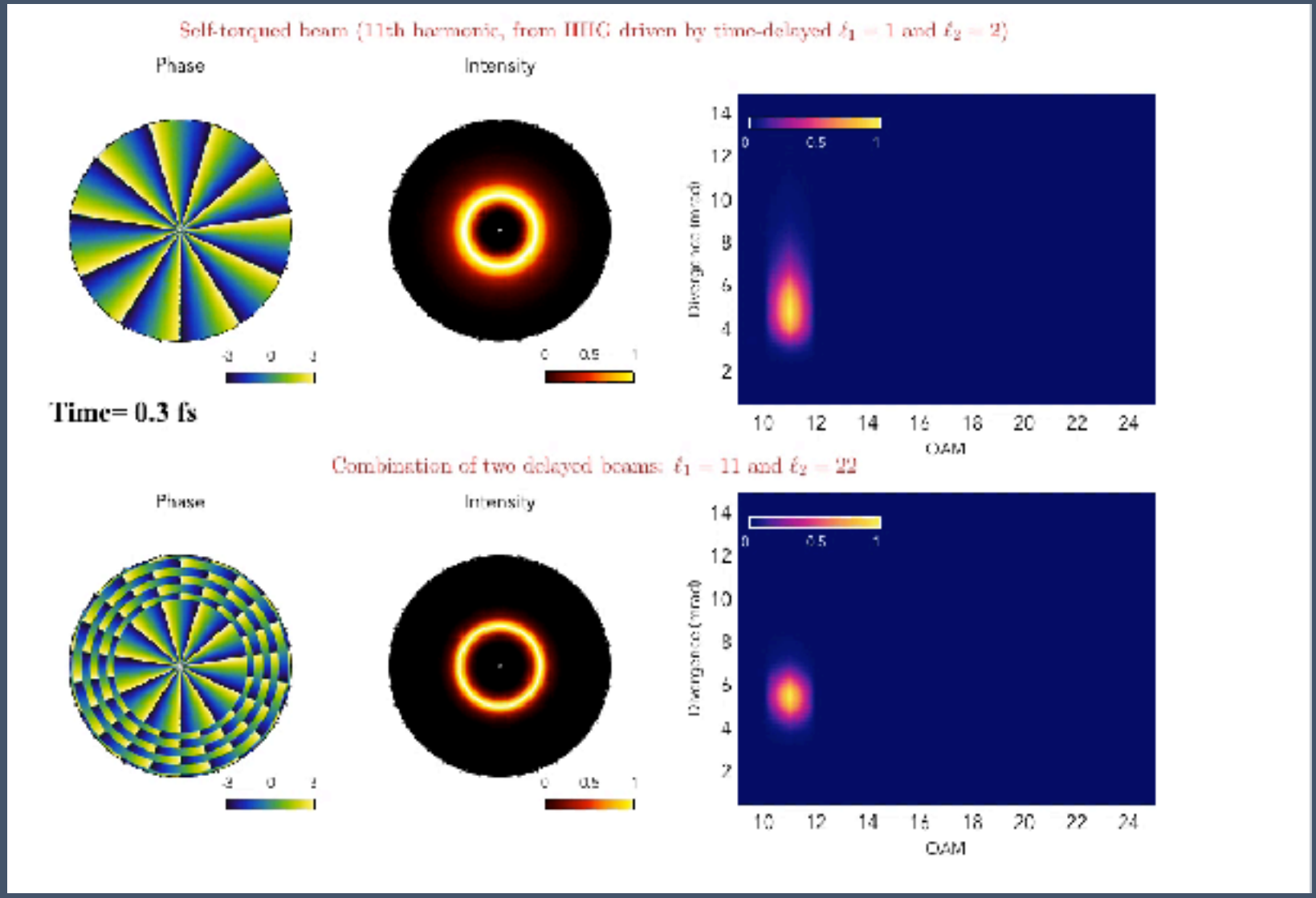


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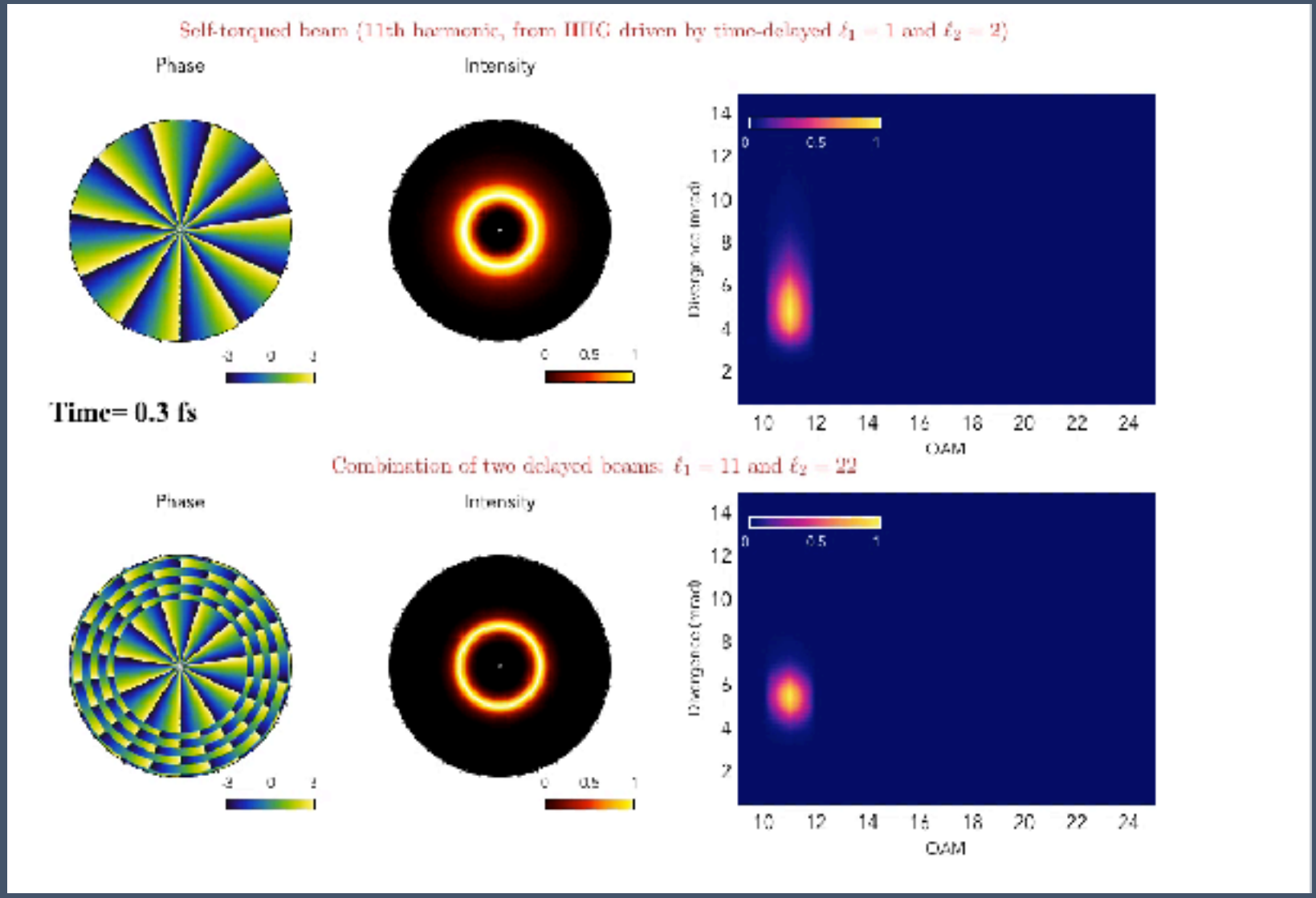
# Self-Torqued Light Beams: Much More Than Time-Dependent Average OAM

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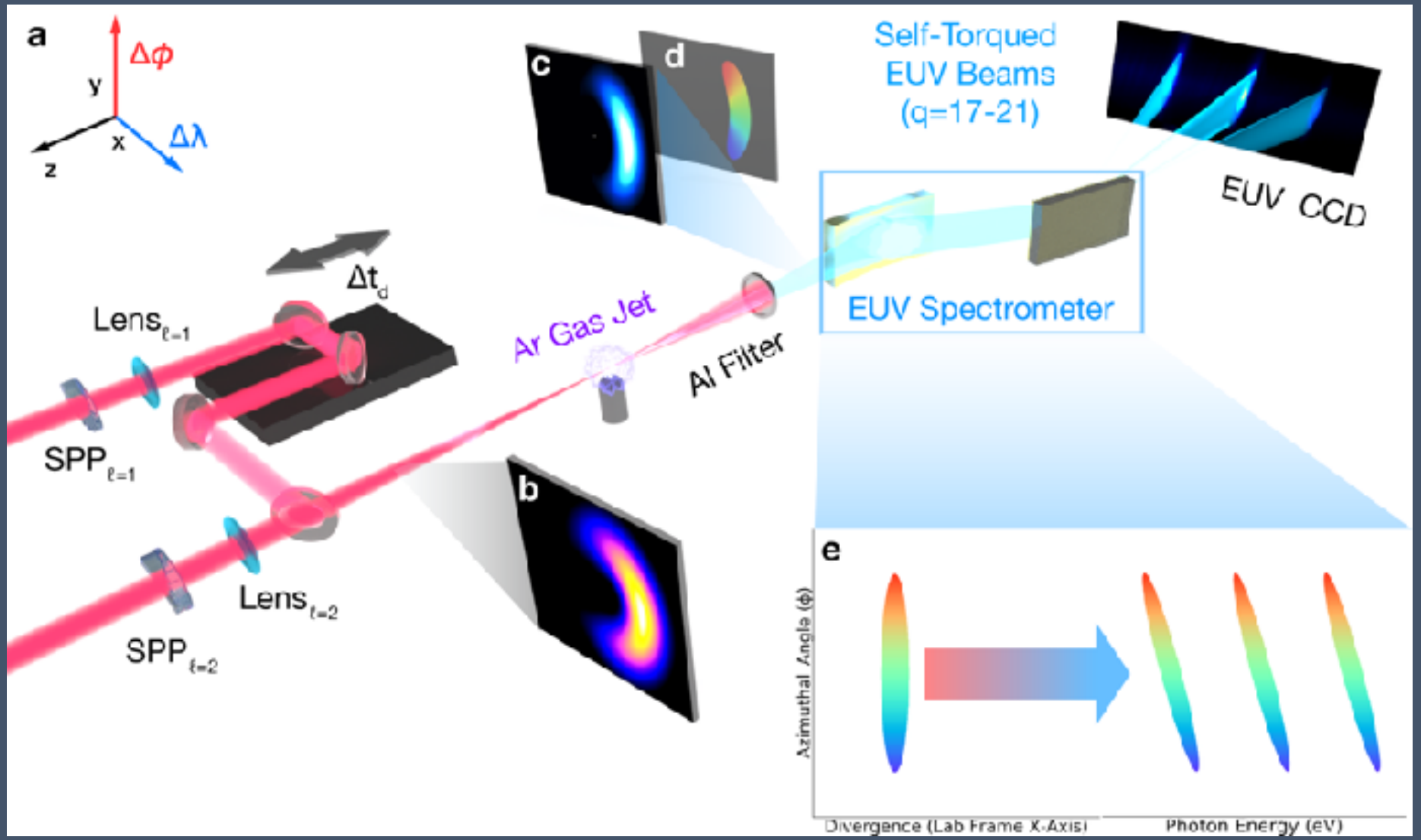
# Experimental Measurement of Azimuthal Frequency Chirp in Self-Torqued EUV Beams

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