

Helicity With a Twist: Complete Control of Polarization, Divergence, and Vortex Charge of Attosecond, Extreme Ultraviolet Vortices via Spin-Orbit Coupled High Harmonic Generation

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ABSTRACT

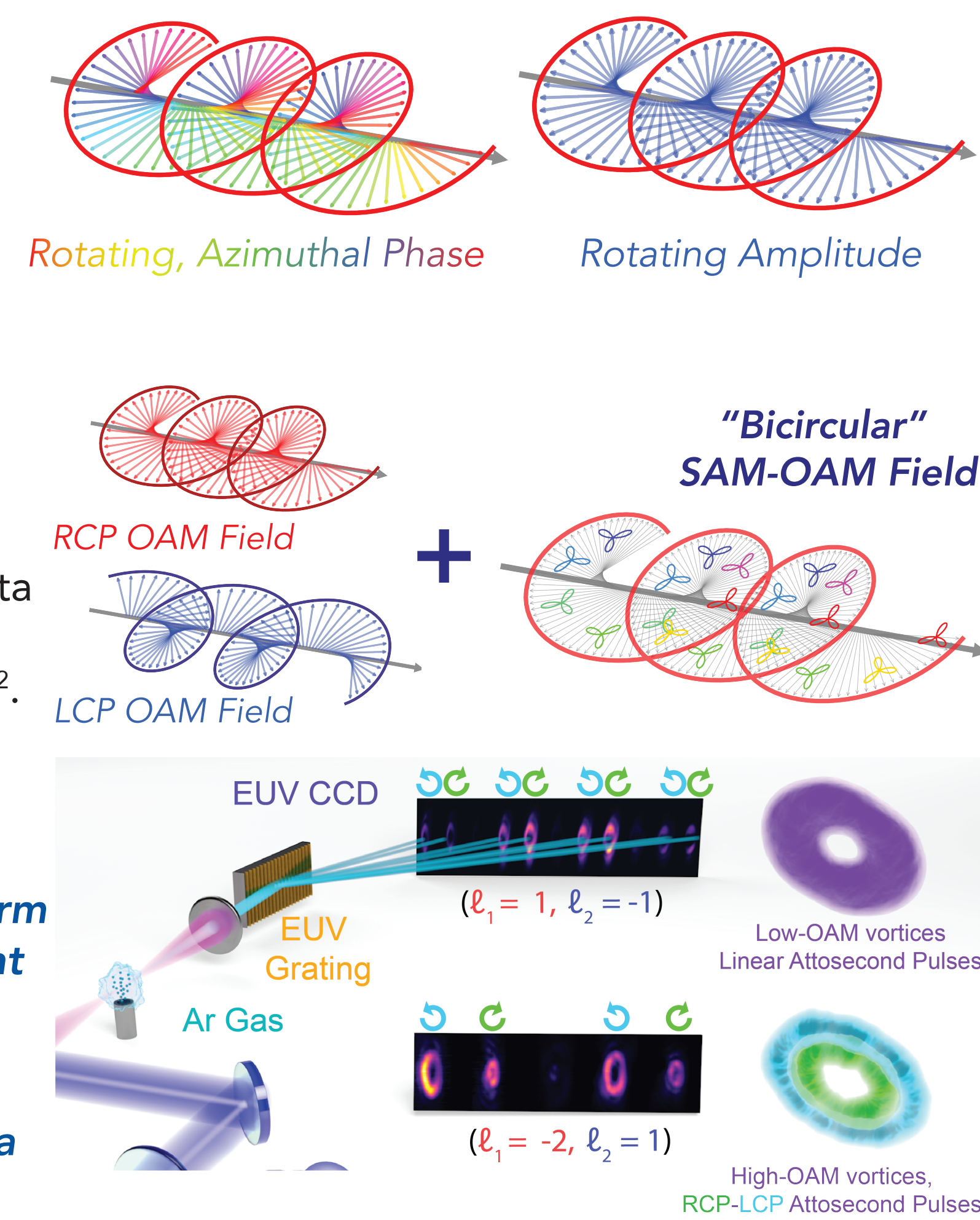
MOTIVATION - Spin-orbit (SO) coupling is a fundamental property of small, particle-like systems that has recently been observed in photonic systems¹. All-optical SO coupling shows great promise for quantum and optical spectroscopies and metrologies; however, initial demonstrations have been limited to the low-intensity and visible regimes.

EXPERIMENT - Attosecond, circularly polarized extreme ultraviolet (EUV) vortices are produced via high-harmonic generation (HHG) with a bicircular vortex driver. The emitted EUV vortices exhibit coupled spin and orbital momenta (SAM and OAM), enabling full control of the polarization, vortex charge, and propagation properties of the EUV beams².

RESULTS -

1. The HHG process entwines the angular momenta of the bicircular and EUV vortices, *yielding an entirely new form of optical SO coupling in high-intensity, non-linear light matter interactions*.
2. We exploit this non-linear SO coupling to generate *coherent EUV vortices with designer angular momenta for EUV chiral spectroscopies*.

OAM Light Field SAM Light Field



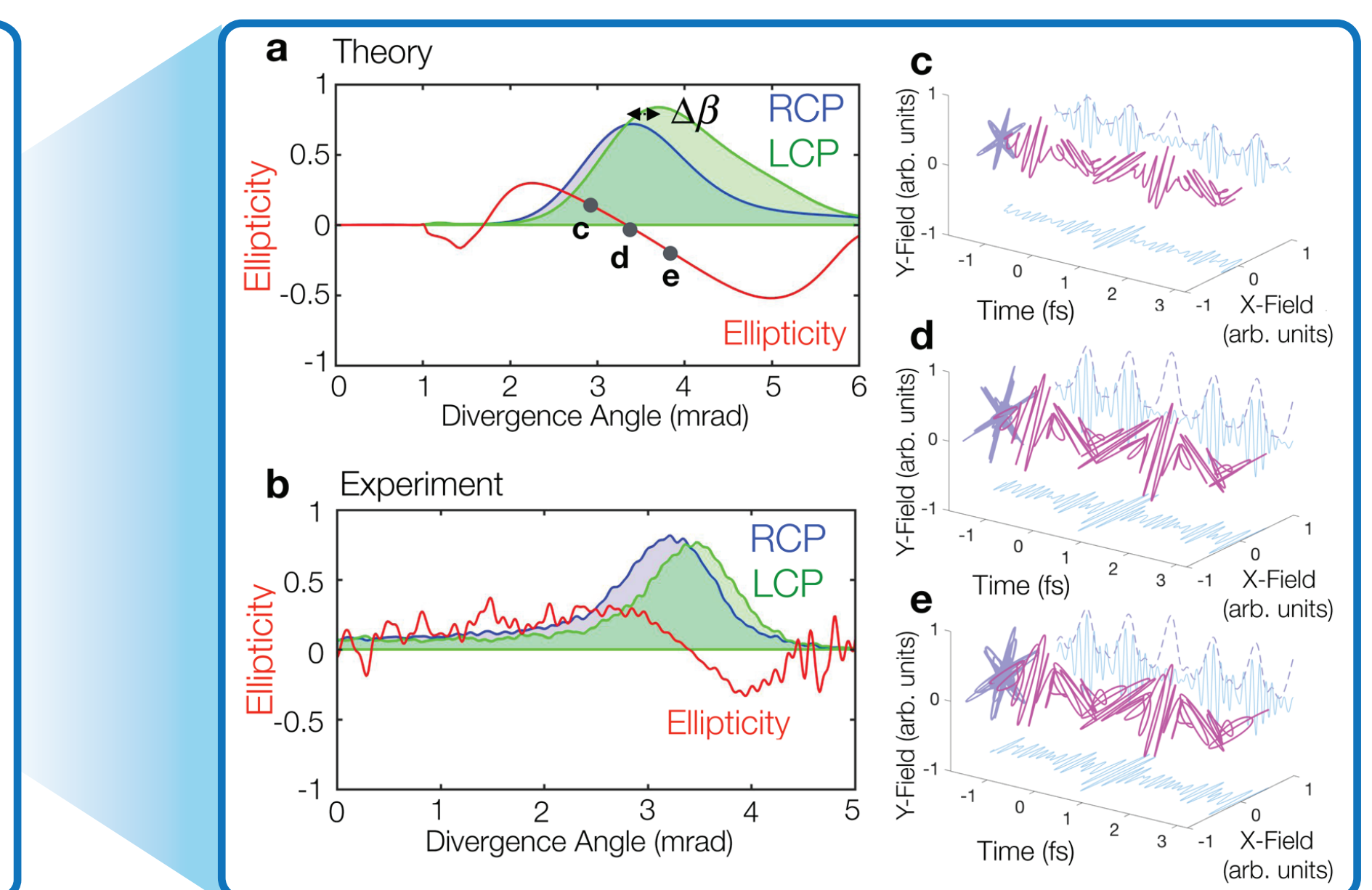
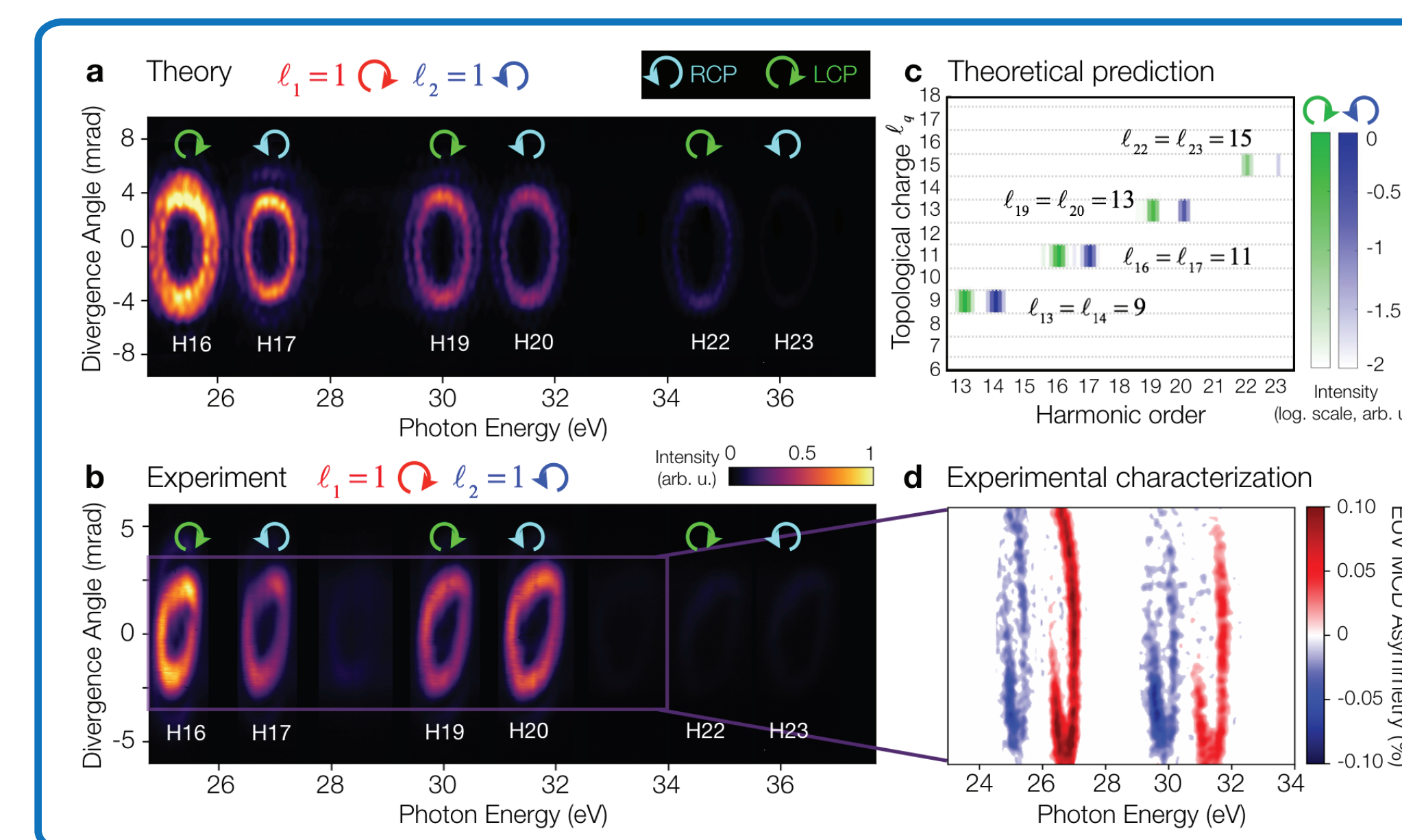
HIGH HARMONIC GENERATION IN THE PRESENCE OF SPIN-ORBIT COUPLING: A NEW REGIME OF ALL-OPTICAL, NONLINEAR, SPIN-ORBIT INTERACTIONS

SO Coupling in SAM-OAM HHG^{2,3}

All-optical control of OAM and divergence, $\Delta\beta$, of EUV vortices by the visible driving lasers!

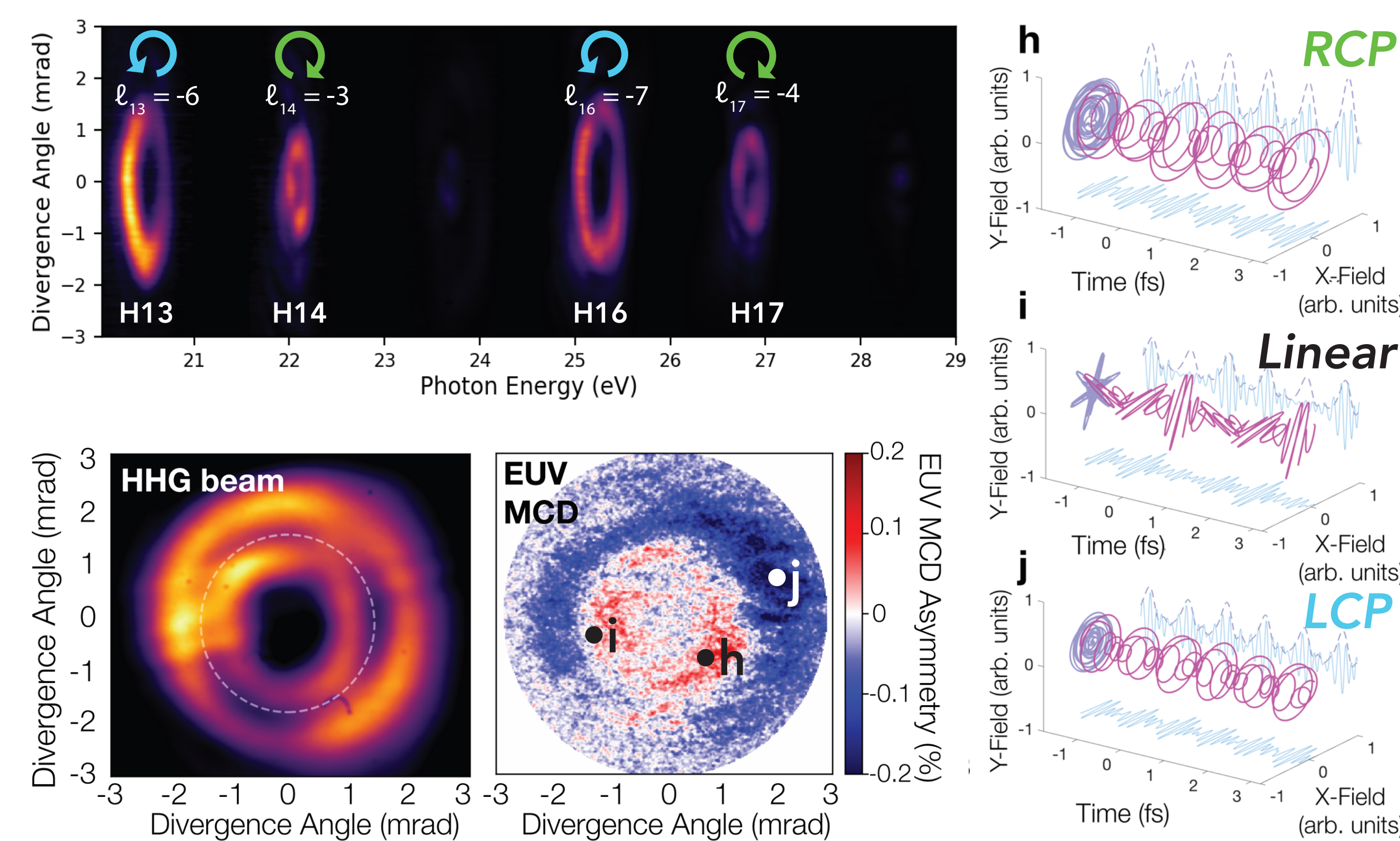
$$\ell_{q,q+1} = \frac{q + 2\sigma_q \sigma_{1,2} (\ell_1 + \ell_2)}{3} - \sigma_q \sigma_{1,2} \ell_{2,1}$$

$$\Delta\beta \propto (\ell_1 - 2\ell_2) \frac{|\ell_1 + \ell_2|}{\ell_1 + \ell_2}$$

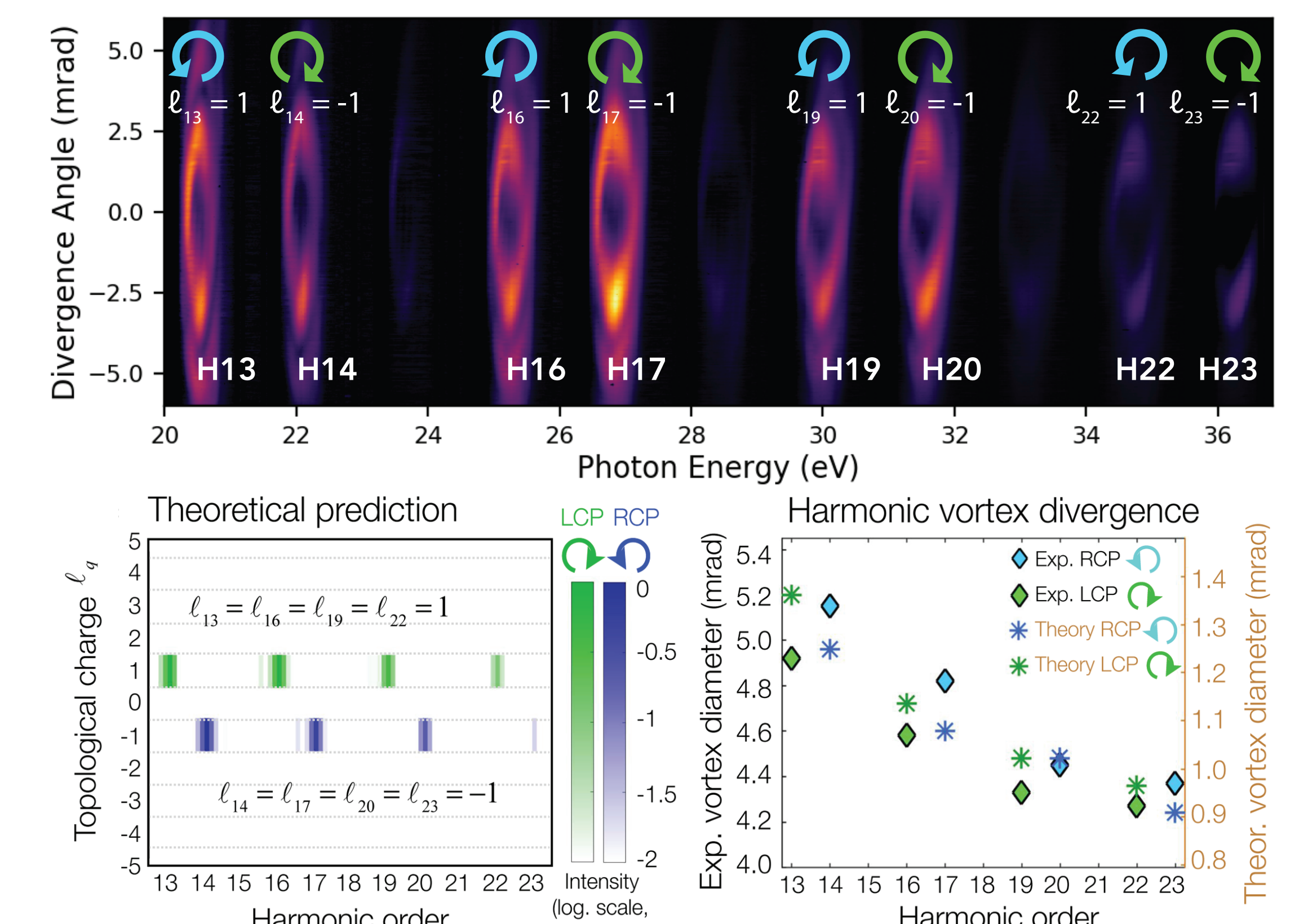


HARNESSING SO COUPLING IN SAM-OAM HHG: ATTOSECOND, EUV VORTICES WITH DESIGNER SAM AND OAM

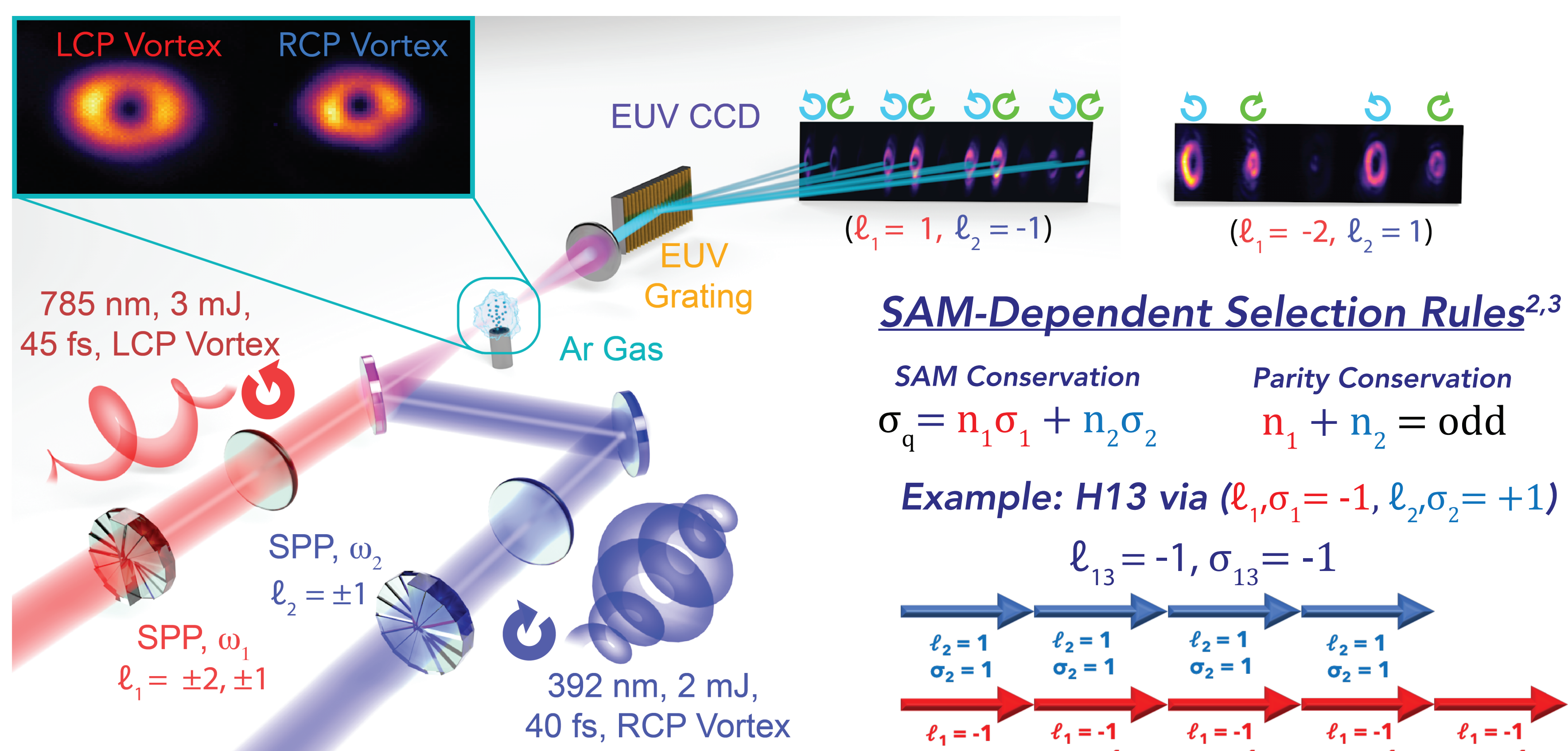
EUV SAM Control: Spatially Isolated Attosecond Vortices of Opposite Circular Polarization



EUV OAM Control: High-Energy, Low Topological Charge Vortices



SPIN-ORBIT COUPLED HHG VIA BICIRCULAR VORTEX BEAMS



REFERENCES

- ¹Cardano, F., Marrucci, L. Spin-orbit photonics. Nat. Photonics **9**, 776-778 (2015).
- ²Dorney, K. M. et al. Helicity in a twist: Controlling the polarization divergence and vortex charge of attosecond high harmonic beams via optical spin-orbit coupling. Nat. Photonics. **Submitted**. (2018)
- ³Rego, L. et al. Nonperturbative twist in the generation of extreme-ultraviolet vortex beams. Phys. Rev. Lett. **117**, 163202 (2016).

CONCLUSIONS AND OUTLOOK

- We generate, for the first time, *EUV vortex beams with fully controlled SAM and OAM and discover an entirely new form of nonlinear SO coupling*.
- This work paves the way for *extending SAM and OAM chiral spectroscopies and metrologies to the nanometer spatial, and attosecond temporal scales*.
- Future work is aimed at *generating isolated EUV vortices of pure circular polarization and using these designer vortices for ultrafast, EUV chiral spectroscopies*.

