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SFB1242

Topology in Plasmonic Fields Analyzed Using Vector Polarimetry

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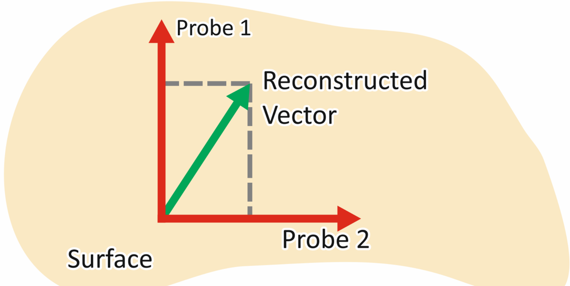
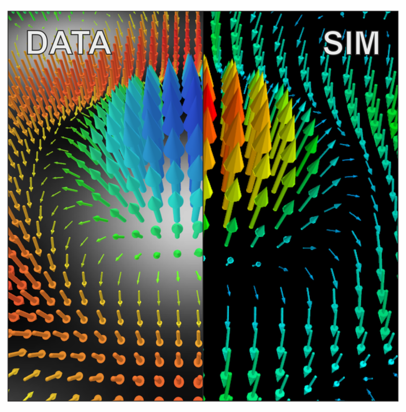
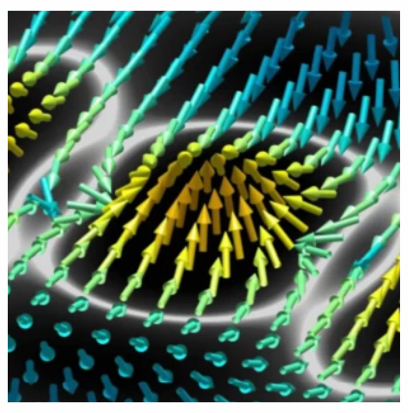
Introduction

- Investigating near fields of Surface Plasmon Polaritons (SPPs) with sub-wavelength resolution on a femtosecond timescale is challenging.
- Time-resolved two-photon photoemission microscopy measures the projection of the SPP field onto a probing laser pulse.
- Performing the experiment with different probe polarizations allows reconstructing the SPP's electric field vector in time and space.





T. Davis et al.,Science **368**, eaba6415 (2020)

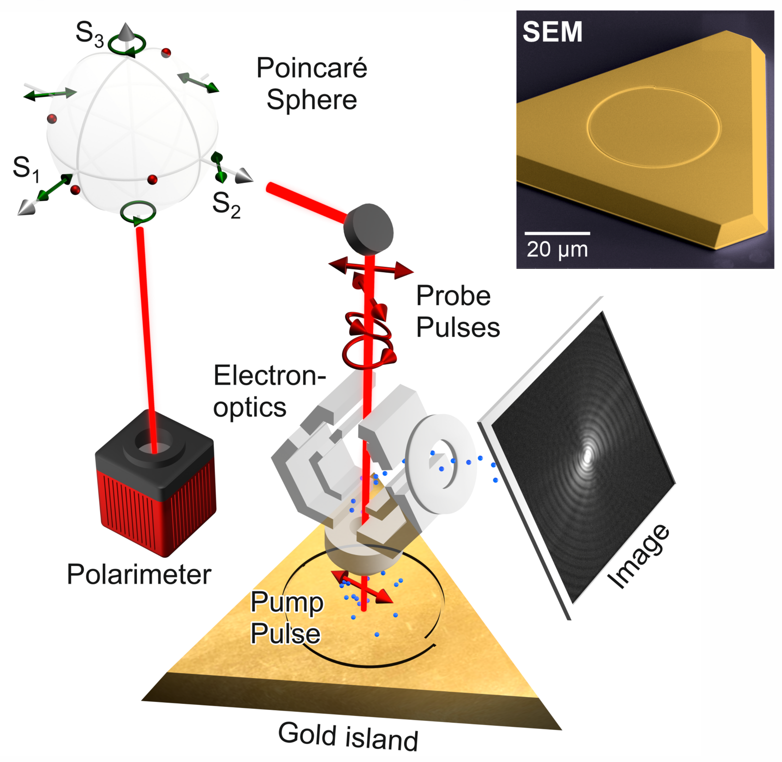


Y. Dai et al., Nature **588**, 616 (2020)

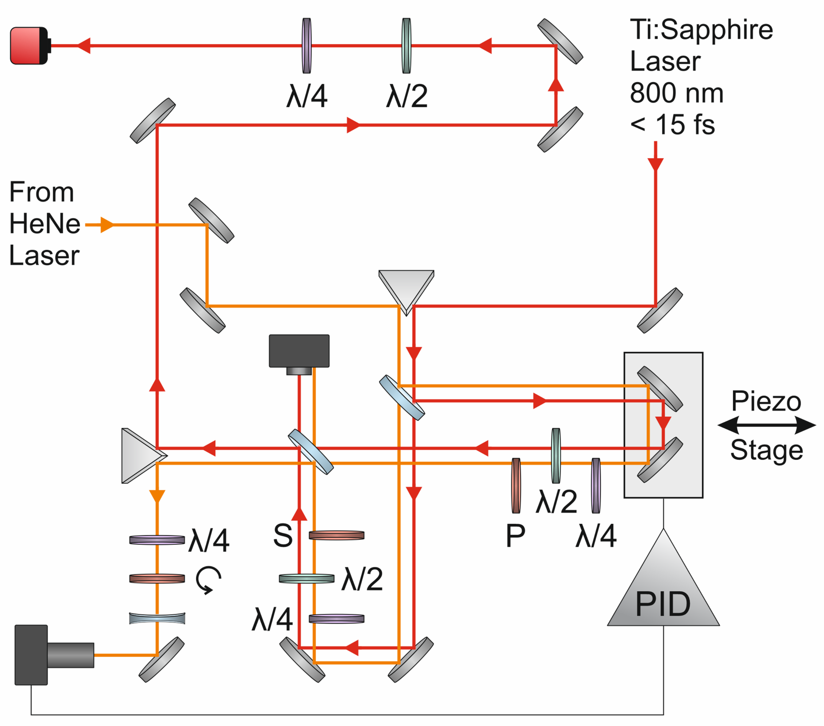
- Recent work: Reconstruction of a SPP skyrmion lattice by vector microscopy.
- Here: Determination of the electric field vectors of topological SPP fields by vector polarimetry. Analysis of the spin angular momentum using topological concepts.

Experimental Details & General Idea

Experimental Setup



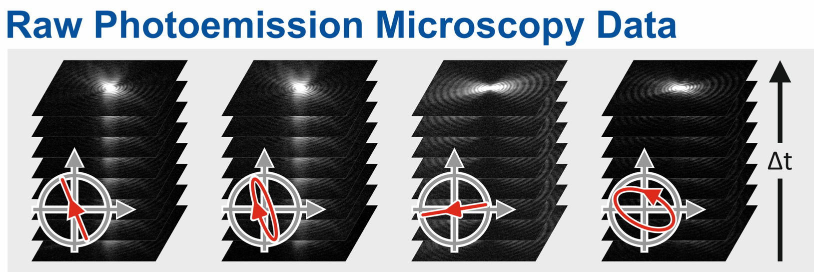
- Femtosecond laser pulses of controlled polarisation impinge on an atomically flat Gold island.
- SPPs are excited at grooves in the shape of Archimedean spirals that are cut into the island using focused ion beam milling.
- Photoemitted electrons are imaged in an ELMITEC Low Energy Electron Microscope upgraded with a TVIPS F216 detector.



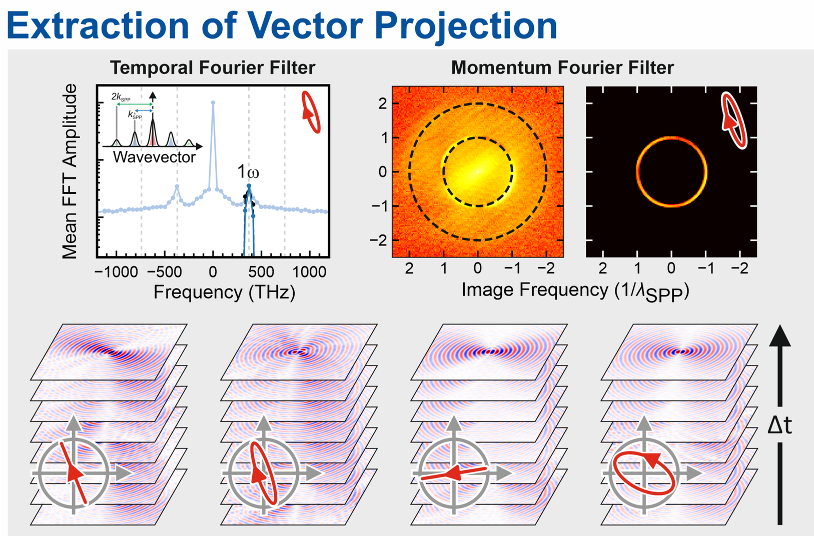
- Time-resolution well below one femtosecond is achieved in a pump-probe setup using a Pancharatnam's phase-stabilized Mach-Zehnder interferometer.
- By inserting wave plates into the two interferometer arms, different polarization states for pump- and probe- pulses are prepared.
- All polarizations are verified using a polarimeter in an equivalent sample plane.

Vector Polarimetry Data Pipeline

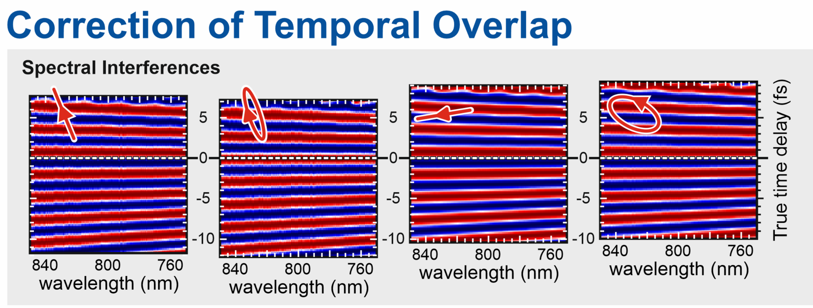
Raw Photoemission Microscopy Data



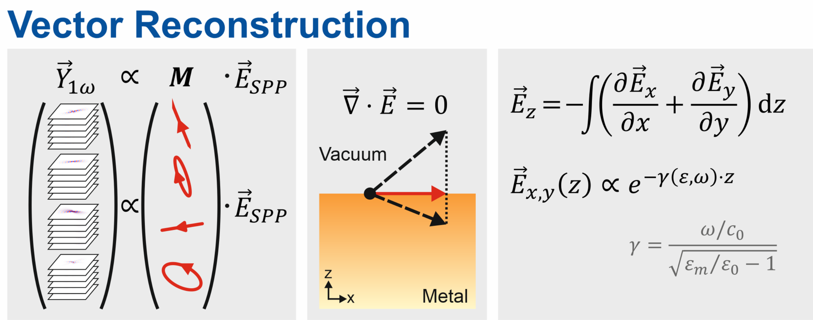
Extraction of Vector Projection



Correction of Temporal Overlap



Vector Reconstruction



$$\vec{Y}_{1\omega} \propto M \cdot \vec{E}_{SPP}$$

$$\vec\nabla \cdot \vec E = 0$$

$$E_z = -\int\left(\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y}\right)dz$$

$$E_{x,y}(z) \propto e^{-\gamma(\varepsilon,\omega)\cdot z}$$

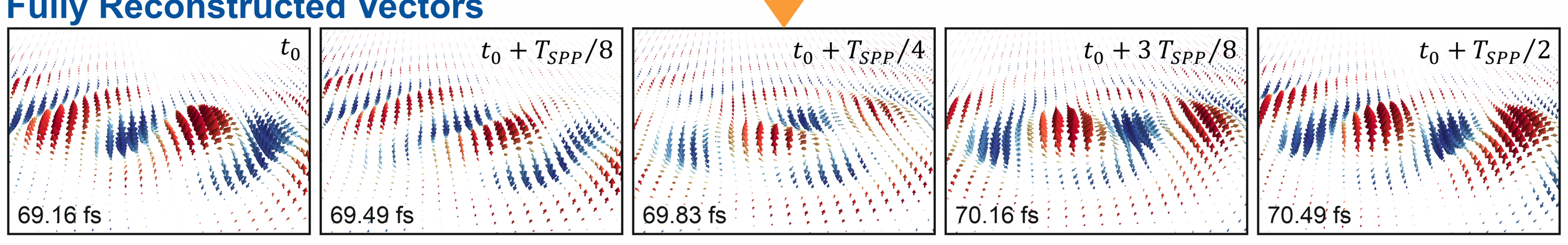
$$\gamma = \frac{\omega/c_0}{\sqrt{\varepsilon_m/\varepsilon_0 - 1}}$$

- A time-resolved PEEM dataset is recorded for the same pump- but for different probe-polarizations.
- The contrast in the images is rather complex. The average electron emission rate is described by

$$\Gamma_{2PPE} \propto |\vec E_{SPP}(\vec r)|^4 + |\vec E_L(\vec r)|^4 + 4|\vec E_L|^2|\vec E_{SPP}|^2 + 4|\vec E_L|^2 Re\{\vec E_L^* \cdot \vec E_{SPP} \cdot e^{-i\omega t + i\vec k_{SPP}\cdot\vec r}\} + 4|\vec E_{SPP}|^2 Re\{\vec E_L^* \cdot \vec E_{SPP} \cdot e^{-i\omega t + i\vec k_{SPP}\cdot\vec r}\} + 2\, Re\{\vec E_L^* \cdot \vec E_{SPP} \cdot e^{-2i\omega t + 2i\vec k_{SPP}\cdot\vec r}\}$$

- Fourier-filtering to the 1ω and the $1|k|$ component produces a signal that is linear in $\vec E_{SPP}$, as long as $\vec E_{SPP}$ is weak compared to $\vec E_L$.
- Changing the probe-polarization in the interferometer affects the relative time-delay.
- Spectral interferences provide the phase of the Jones-vector of the probe pulses.
- The in-plane component of the field vectors can then be calculated from the data.
- The z-component of the field vector can be reconstructed (above the surface) using the Maxwell equation $\vec\nabla \cdot \vec E = 0$. The numerical integration is easily possible since the SPP is an evanescent wave.
- The result is a full vector reconstruction with sub-wavelength spatial and sub-femtosecond temporal resolution.

Fully Reconstructed Vectors

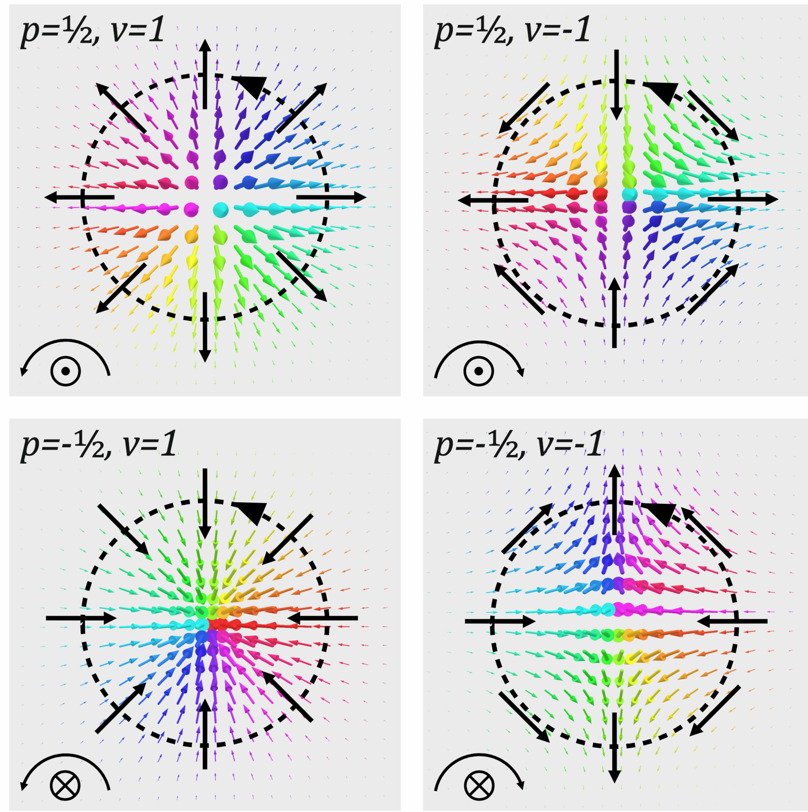


Analysis of Topological Fields

- Nanoplasmonic topology can be described by C-points and L-lines in the spin-angular momentum density

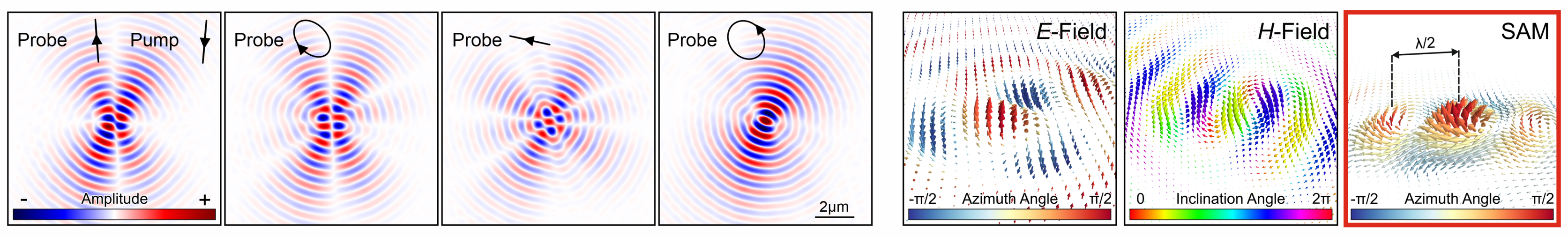
$$\vec S = \frac{1}{2\omega}\cdot \mathrm{Im}\left(\varepsilon \vec E^* \times \vec E + \mu \vec H^* \times \vec H\right)$$

- C-points are isolated locations where $\vec S$ points directly into (p=-½) or out of the surface (p=+½).
- L-lines are closed loops whereon $\vec S$ lies within the surface plane.
- The vorticity v depends on how often and with what handedness $\vec S$ rotates along an L-line. The vorticity is connected to the C-points within the region.
- The Chern number $C = p\,v$ follows from both polarity and vorticity.

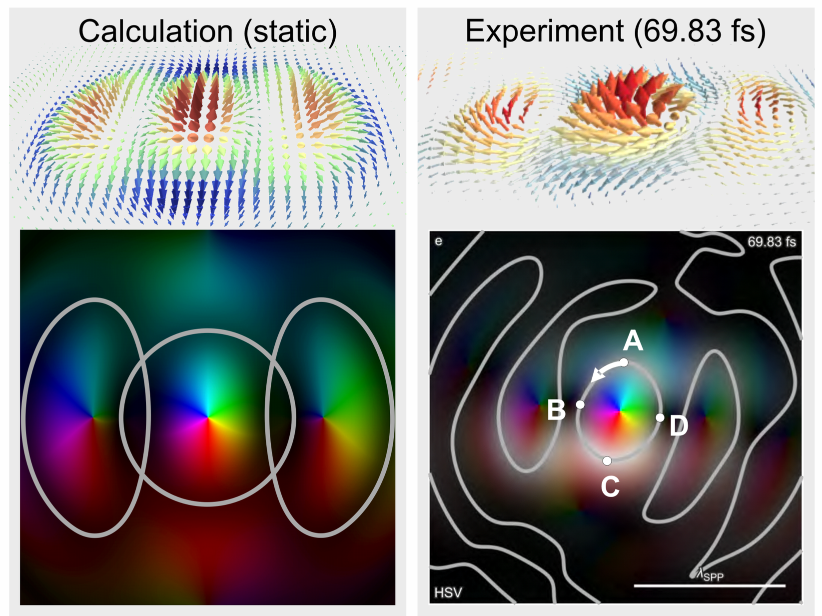


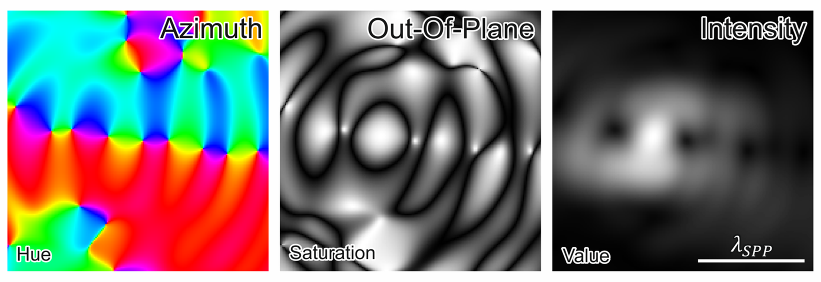
Plasmonic Meron

- Exciting an L=2 Archimedean spiral with linear polarized light yields a SPP Meron.
- 1ω-filtering of data recorded with different probe polarizations yields the projection of the SPP on the probe pulse.
- Polarimetry reconstructs the electric and magnetic fields and the spin angular momentum density.
- Here, the reconstruction is shown at a delay-time of 69.83 fs.

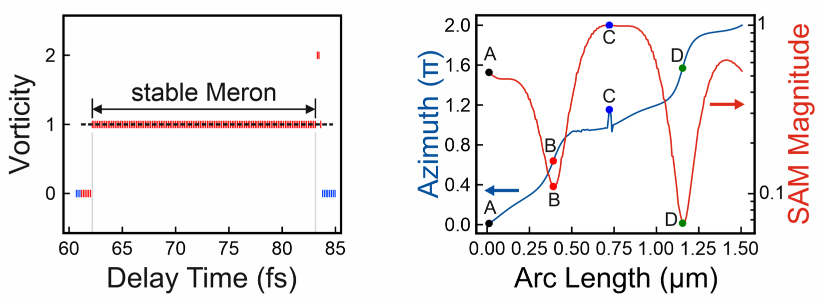


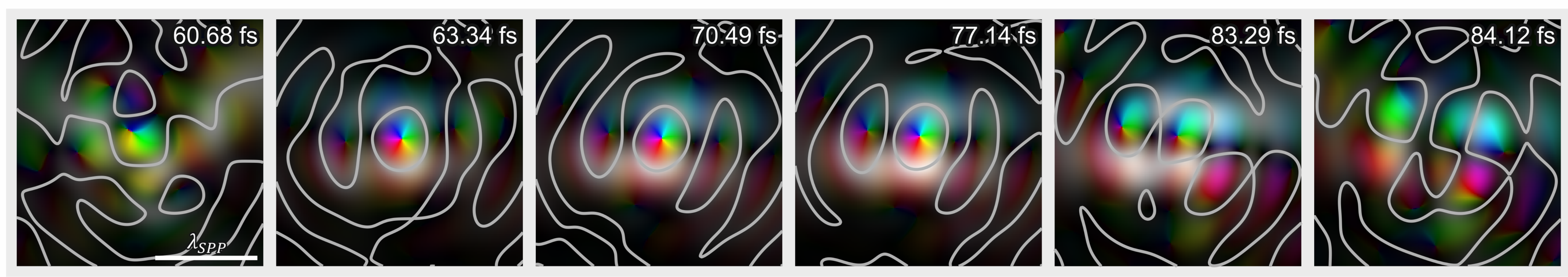
- To visualize the topology, $\vec S$ is plotted in a HSV color scale:
- H: azimuth angle of $\vec S$
- S: sine of polar angle ($|\vec S_\perp| / |\vec S|$)
- V: relative length $|\vec S|$





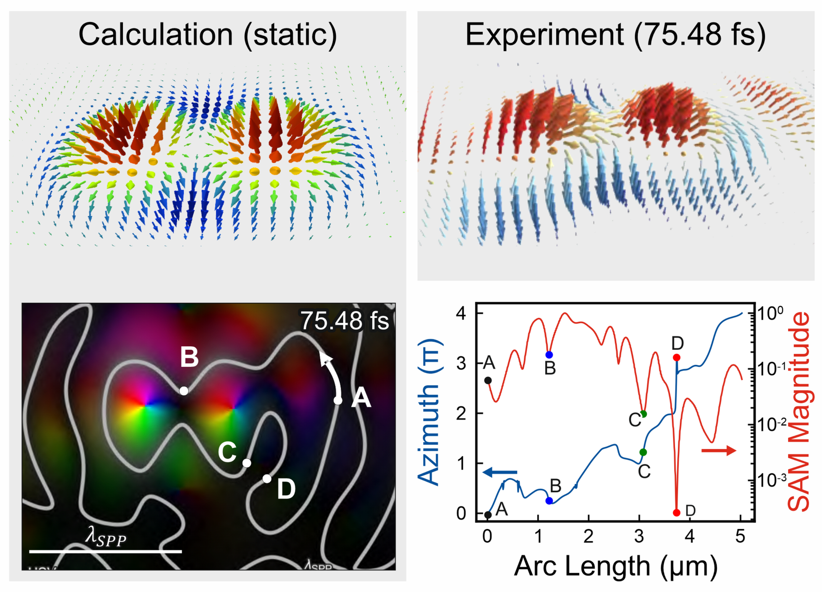
- C-points, L-lines and the relative azimuth of $\vec S$ can be determined experimentally.
- With a polarity p=+½ and a vorticity v=1 the Meron's Chern number is C=0.5.
- The Meron is stable for more than 20 fs.

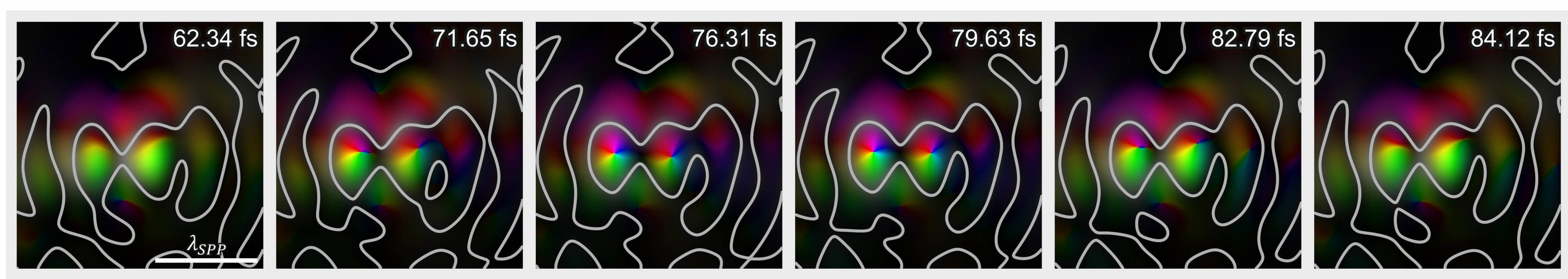




Plasmonic Meron Pair

- The same analysis can be applied to a SPP Meron pair, where two Merons with the same polarity and vorticity are next to each other.
- Such Meron pair can be created by exciting an L=1 spiral with linearly polarized light.
- The polarity is p=+½ for both Merons comprising the Meron pair.
- The total vorticity is v=2 resulting in C=1.
- The Meron pair is stable for more than 10 fs.





Conclusion

- Vector polarimetry is an excellent tool to reconstruct the electric and magnetic field of SPPs.
- Using vector polarimetry it is possible to measure the spin angular momentum of an SPP even in complex field situations with femtosecond time and deep-subwavelength spatial resolution.
- After calculating the spin angular momentum it is possible to determine L-lines and C-points for SPP Merons and Meron pairs and verify experimentally that they are topologically different.