

# Topological robustness of quantum skyrmions in complex media

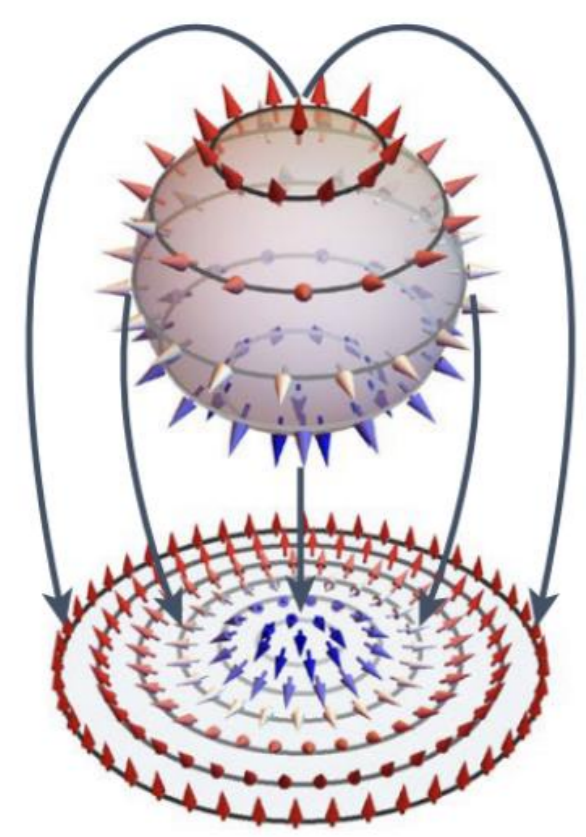
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We report that **quantum skyrmions** preserve their **topological structure** under turbulence, enabling **robust quantum information transmission** without error correction.

## Optical skyrmions

Skyrmions: quasiparticle carrying a topologically stable vector texture

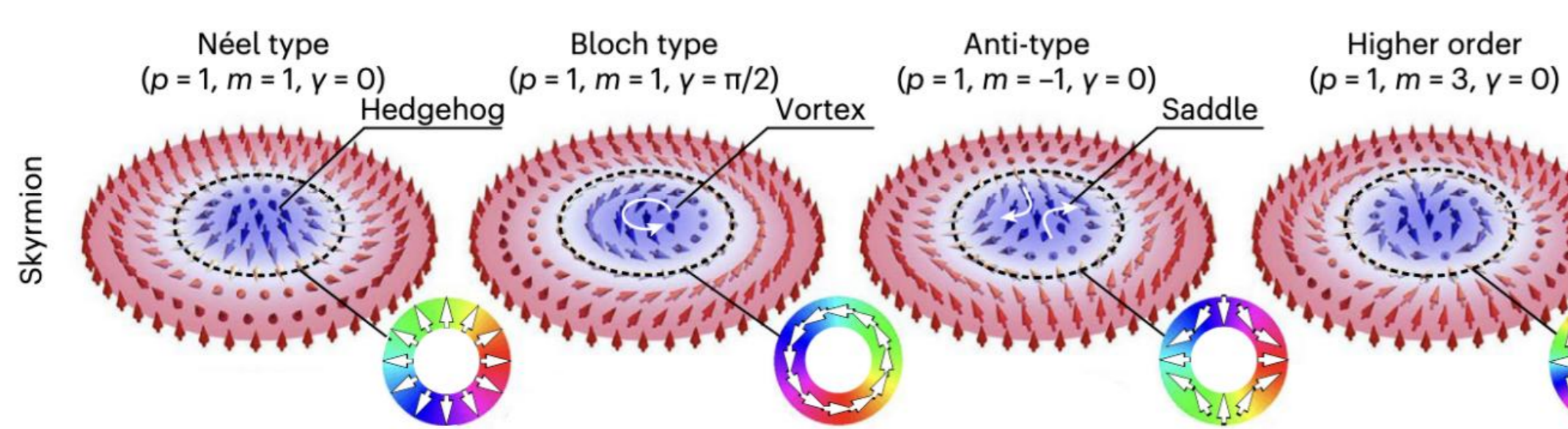


Topological number  $N$ :

$$N = \frac{1}{4\pi} \iint_{\sigma} \mathbf{S} \cdot \left( \frac{\partial \mathbf{S}}{\partial x} \times \frac{\partial \mathbf{S}}{\partial y} \right) dx dy$$

$$= \frac{1}{4\pi} [\cos \beta(r)]_{r=0}^{r=r_{\sigma}} [\alpha(\phi)]_{\phi=0}^{\phi=2\pi} = p \cdot m$$

$\alpha(\phi) = m\phi + \gamma \rightarrow$  helicity    polarity    vorticity



[Nat. Photon. 18(1), 15–25 (2024)]

## Quantum skyrmions

Quantum skyrmions are constructed by entanglement between OAM and polarization

$$|\Psi\rangle = \lambda_1 |l_1\rangle_A |H\rangle_B + \lambda_2 |l_2\rangle_A |V\rangle_B$$

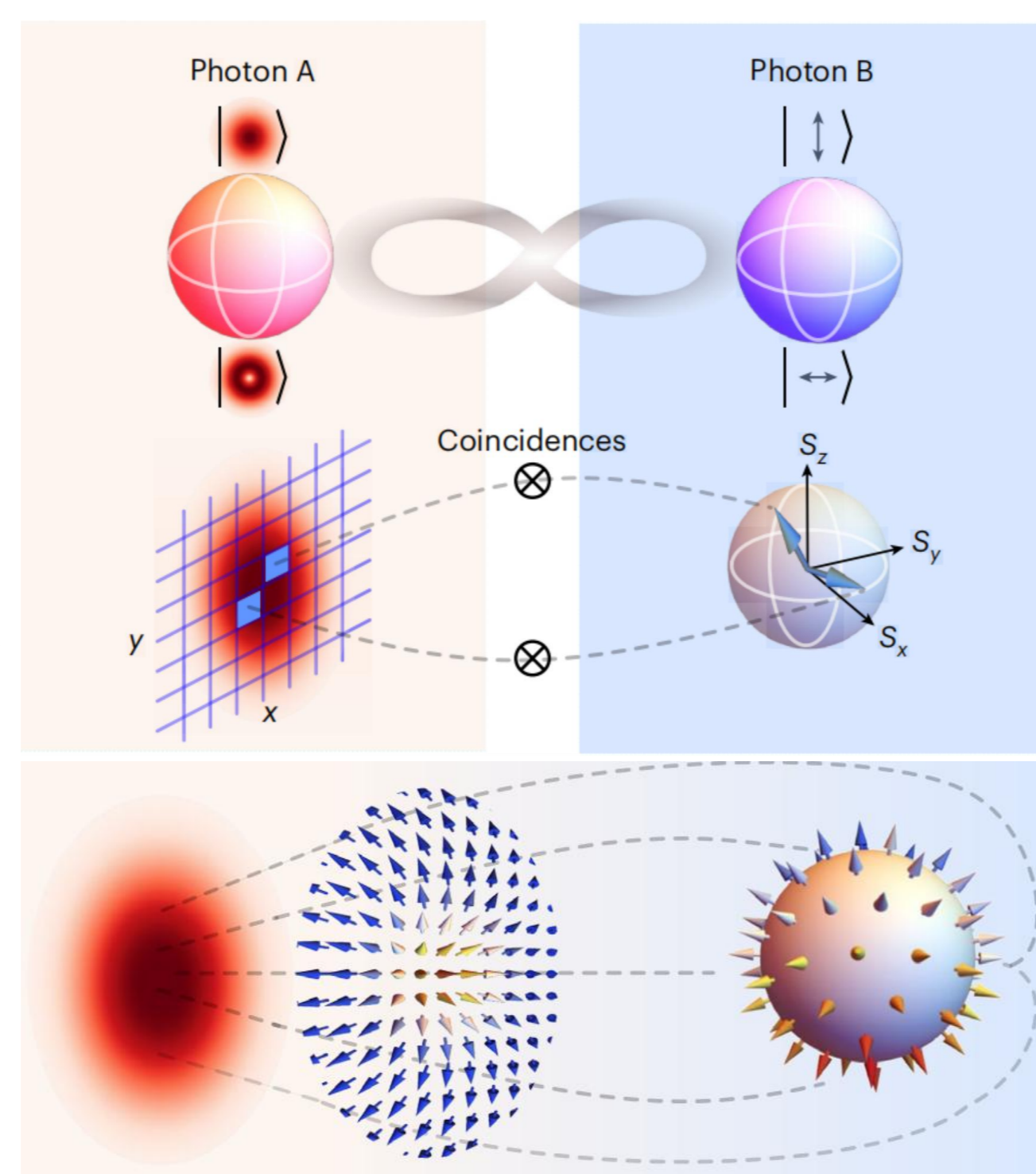
Quantum skyrmion number  $N$ :

$$N = \frac{1}{\sqrt{2}} \int_{R^2} \epsilon_{ijk} S_i \frac{\partial S_j}{\partial x} \frac{\partial S_k}{\partial y} dx dy$$

$$= n |l_1 l_2|$$

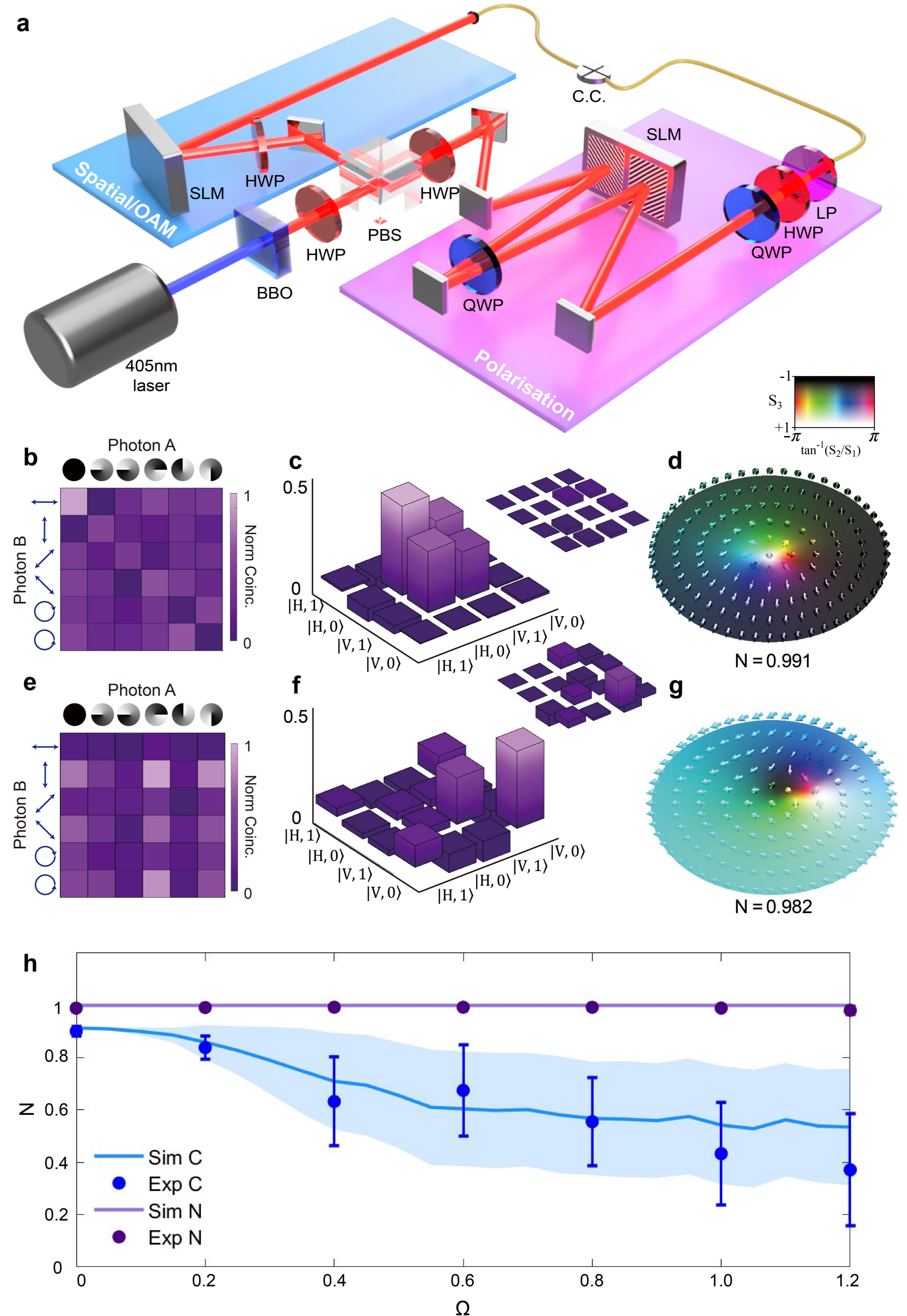
Turbulence causes OAM states to disperse into other states

$$|l\rangle \rightarrow \sum_{l'} \alpha_{l'} |l'\rangle$$



[Nat. Photon. 18(3), 258–266 (2024)]

## Results



Quantum Experimental Results

(a) Experimental setup

(b)–(d) Present the joint measurement data

The reconstructed density matrices, and the corresponding spin-textured fields in the absence of turbulence.

(e)–(g) Experimental tomography results, reconstructed density matrices, and corresponding spin-textured fields

(h) Evolution of skyrmion number  $N$  and concurrence  $C$  versus turbulence

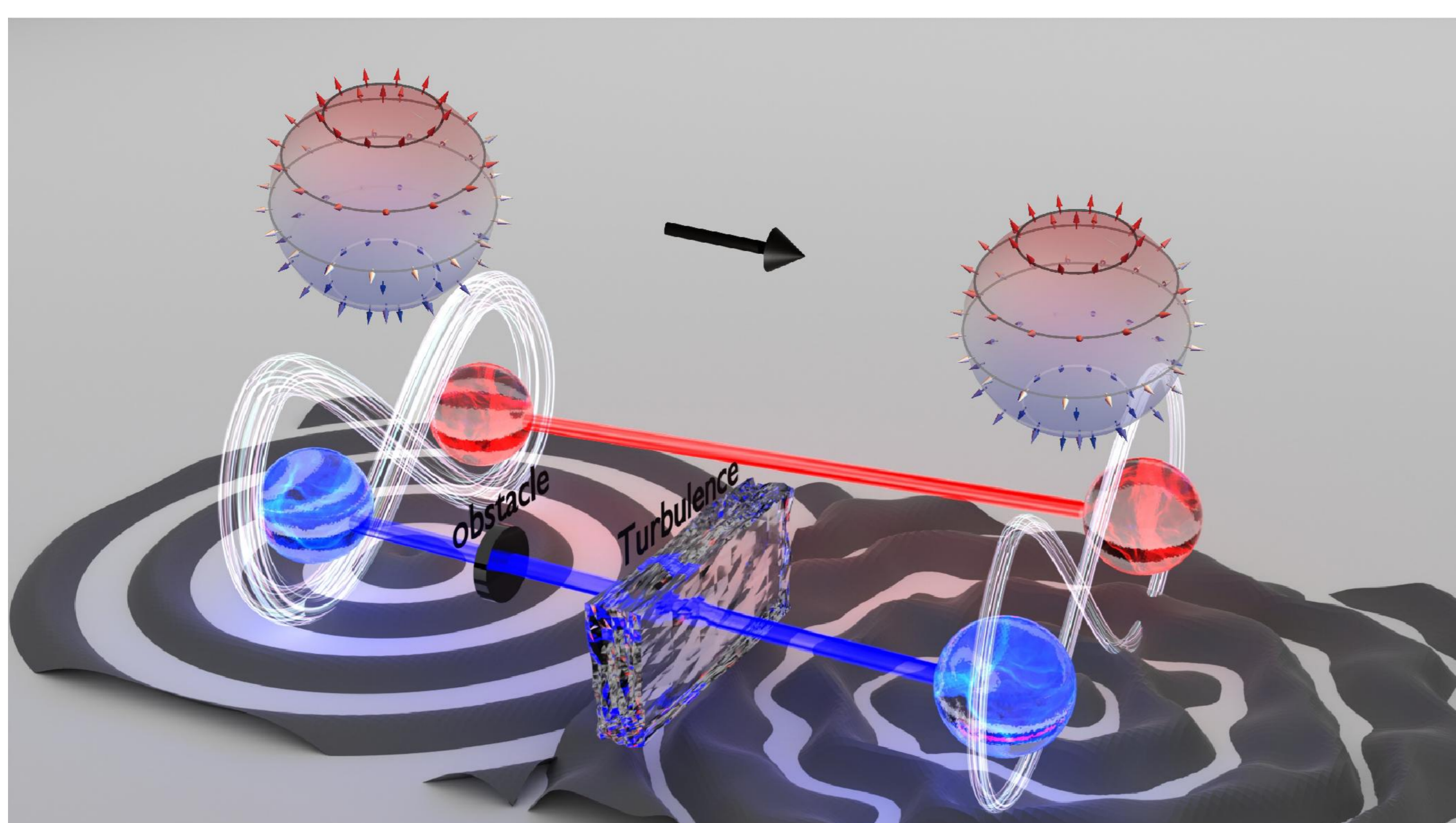
The solid curve denotes theoretical predictions, and the blue shaded region indicates the error range from 200 independent simulations.

## Conclusions

Quantum skyrmions act as **turbulence-resistant information carriers**: while their **entanglement degrades** under turbulence, their **topological structure remains conserved**.

**Topological protection** suggests broad applications across **topological photonics** and **quantum information science**.

## Quantum Skyrmions under Turbulence



### Schematic of quantum skyrmions in complex media

Photon A carries OAM and photon B encodes polarization. Despite turbulence degrading entanglement or correlations, the skyrmion number remains conserved.