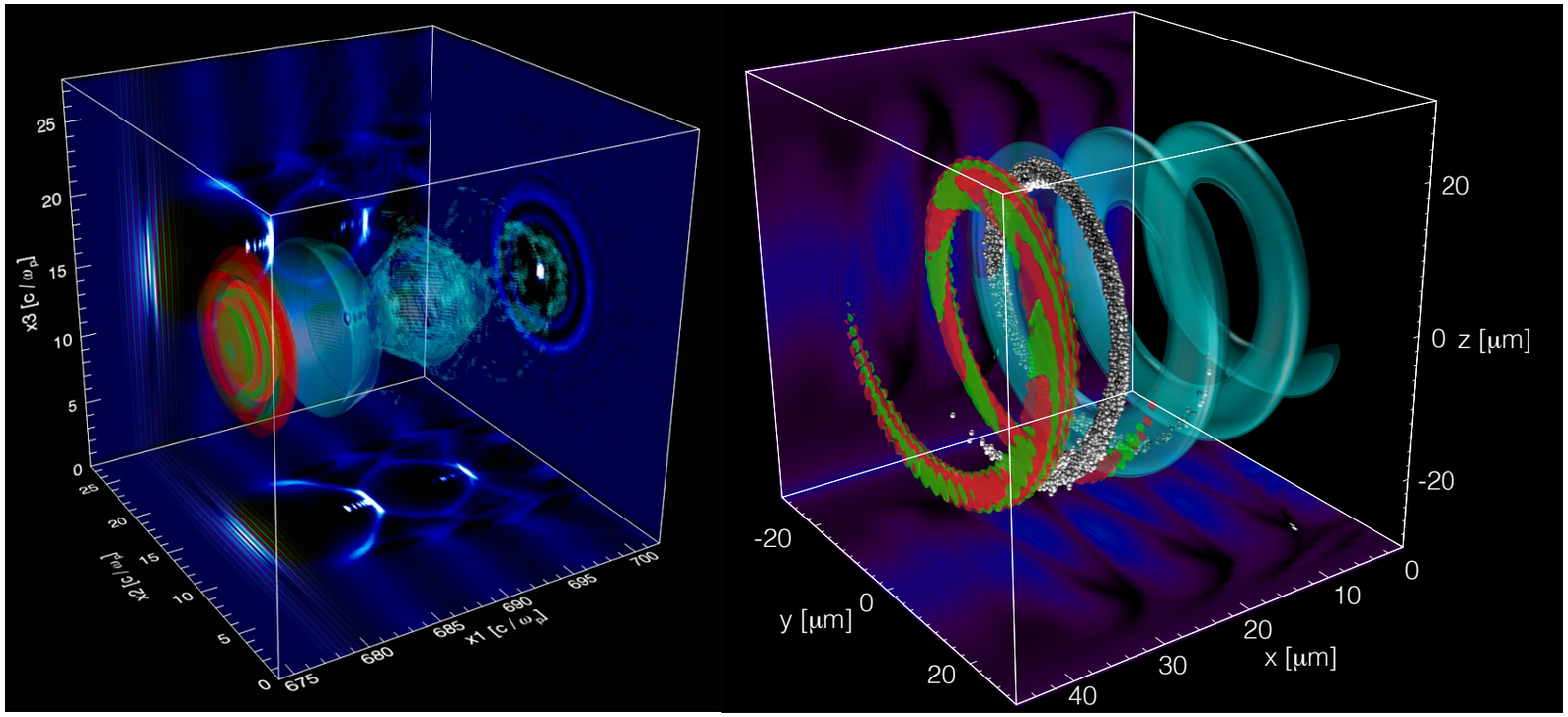
Laser light with orbital angular momentum and its applications

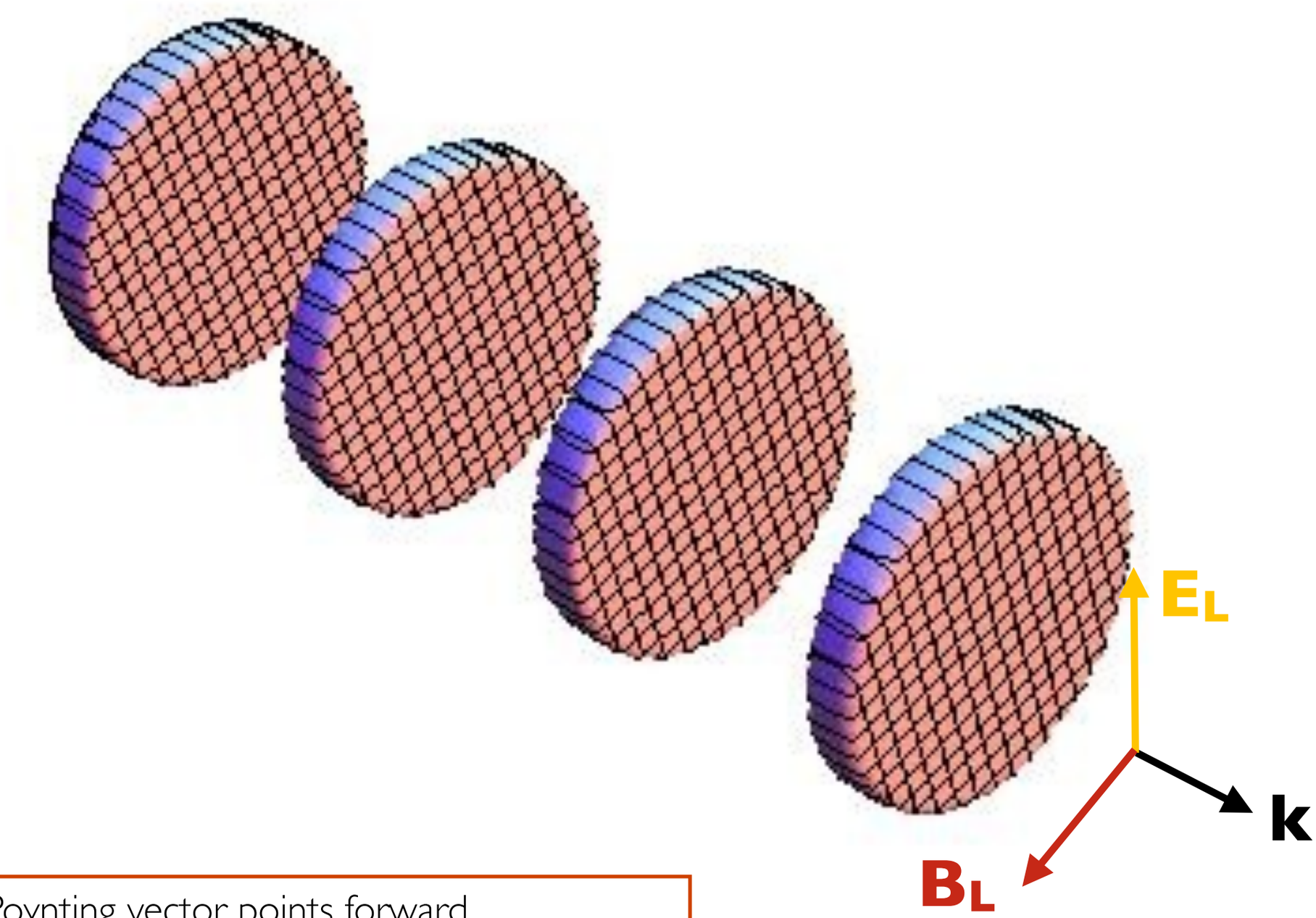
Jorge Vieira
GoLP / IPFN, Instituto Superior Técnico, Lisbon, Portugal



The orbital angular momentum of light

The Orbital Angular Momentum (OAM) of light

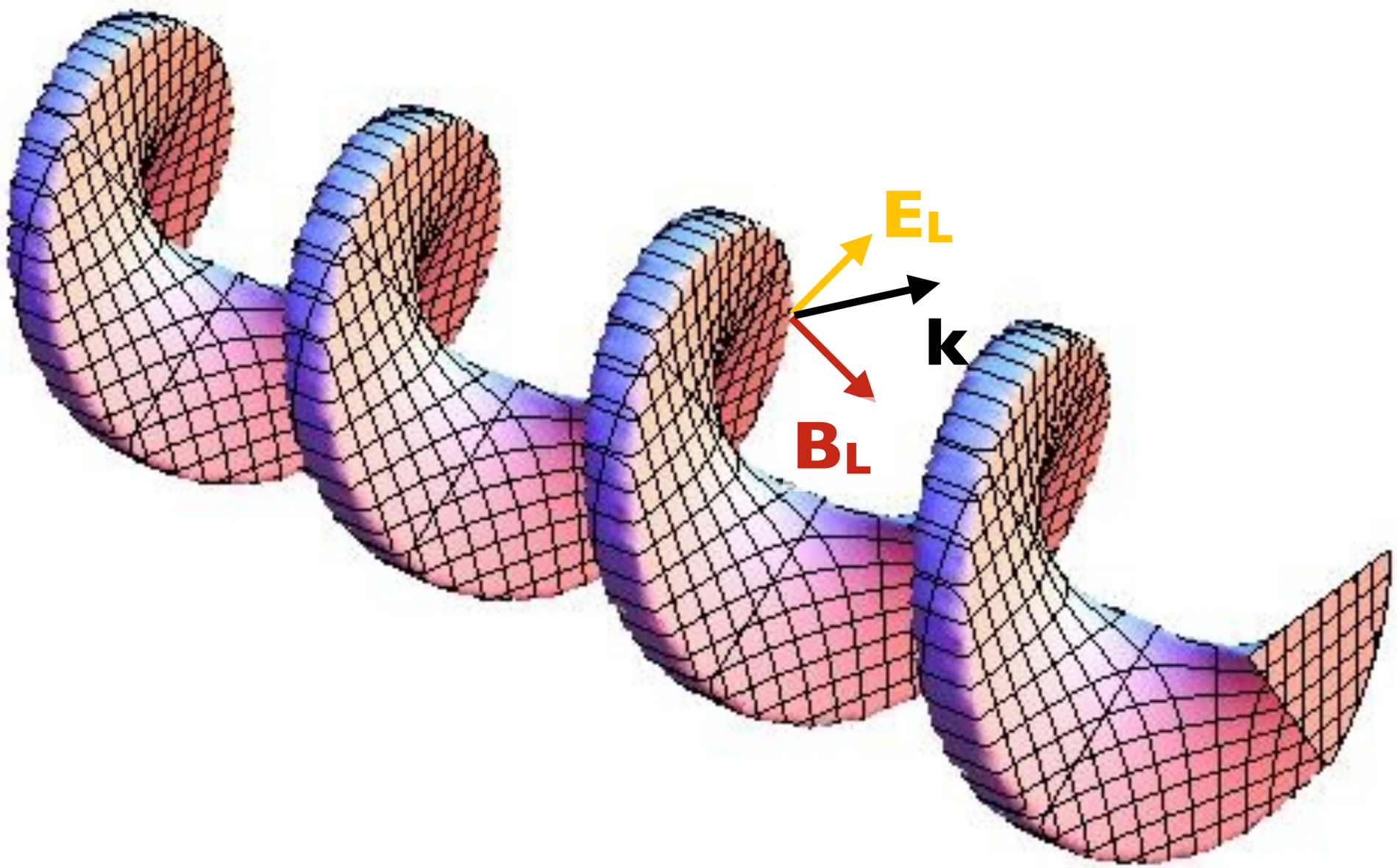
representation of a *plane* wave



Poynting vector points forward
Transfer *linear* momentum to matter: **optical tweezers**

The Orbital Angular Momentum (OAM) of light

Representation of a wavefront of a Laguerre Gaussian mode



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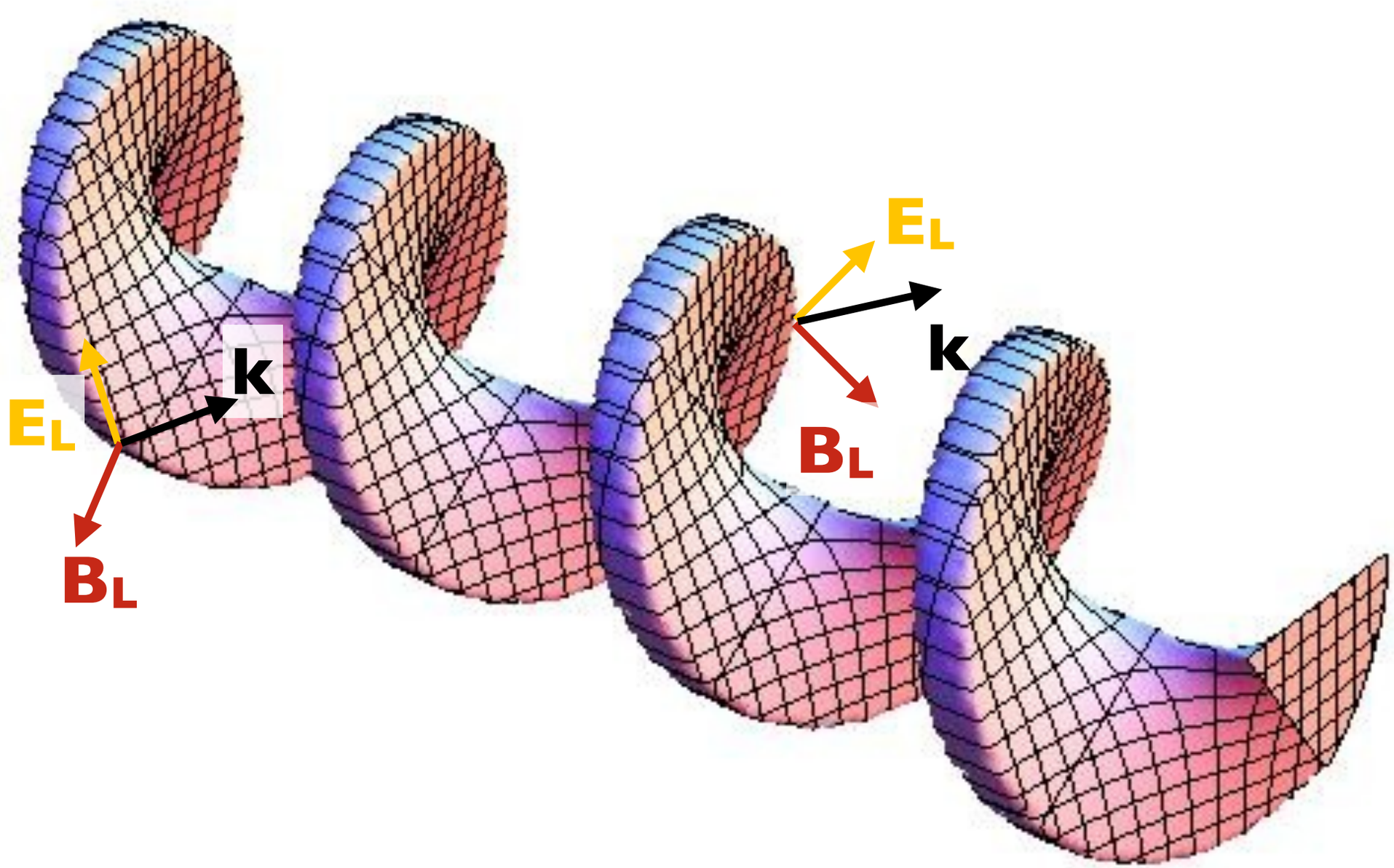

Poynting vector spirals around laser

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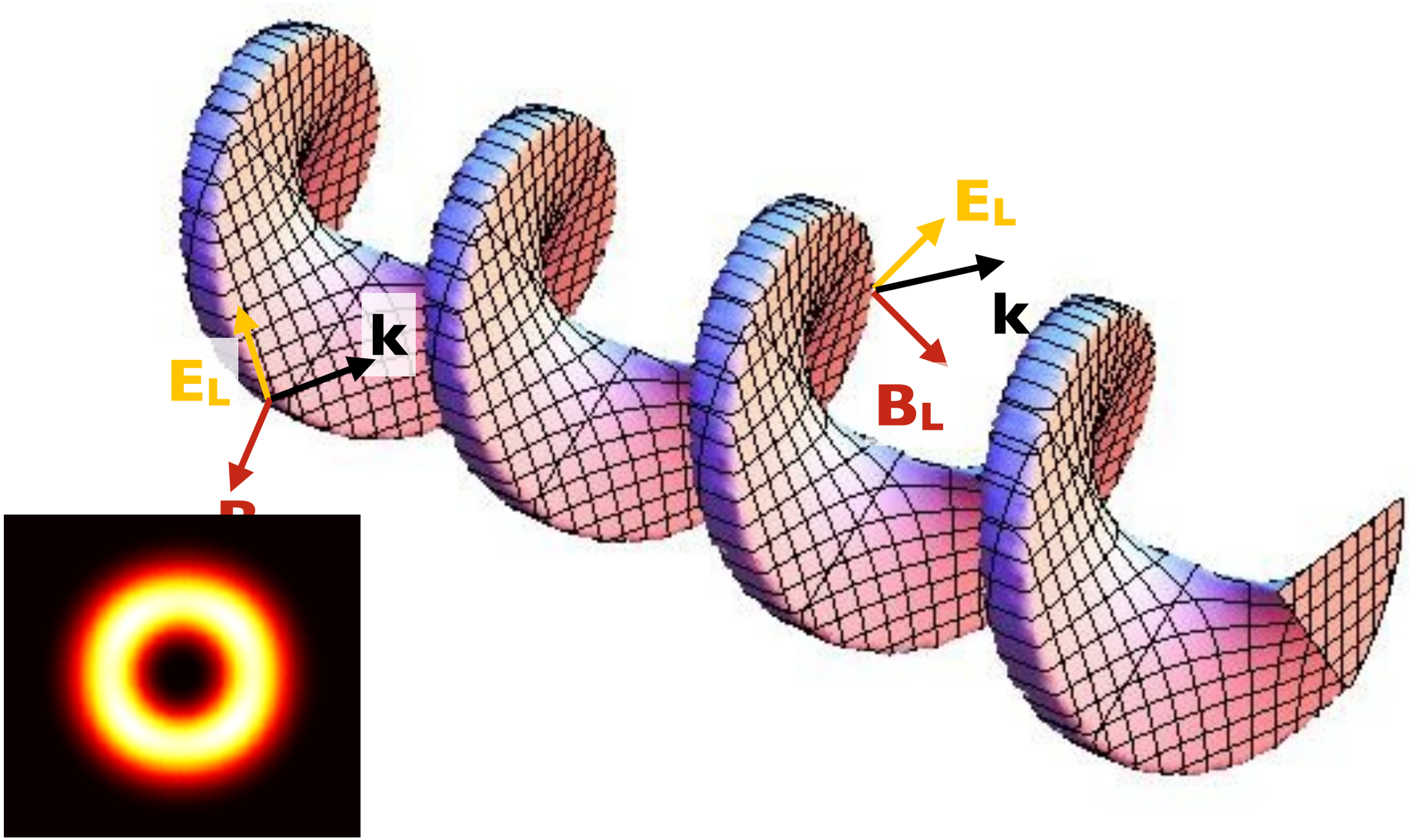
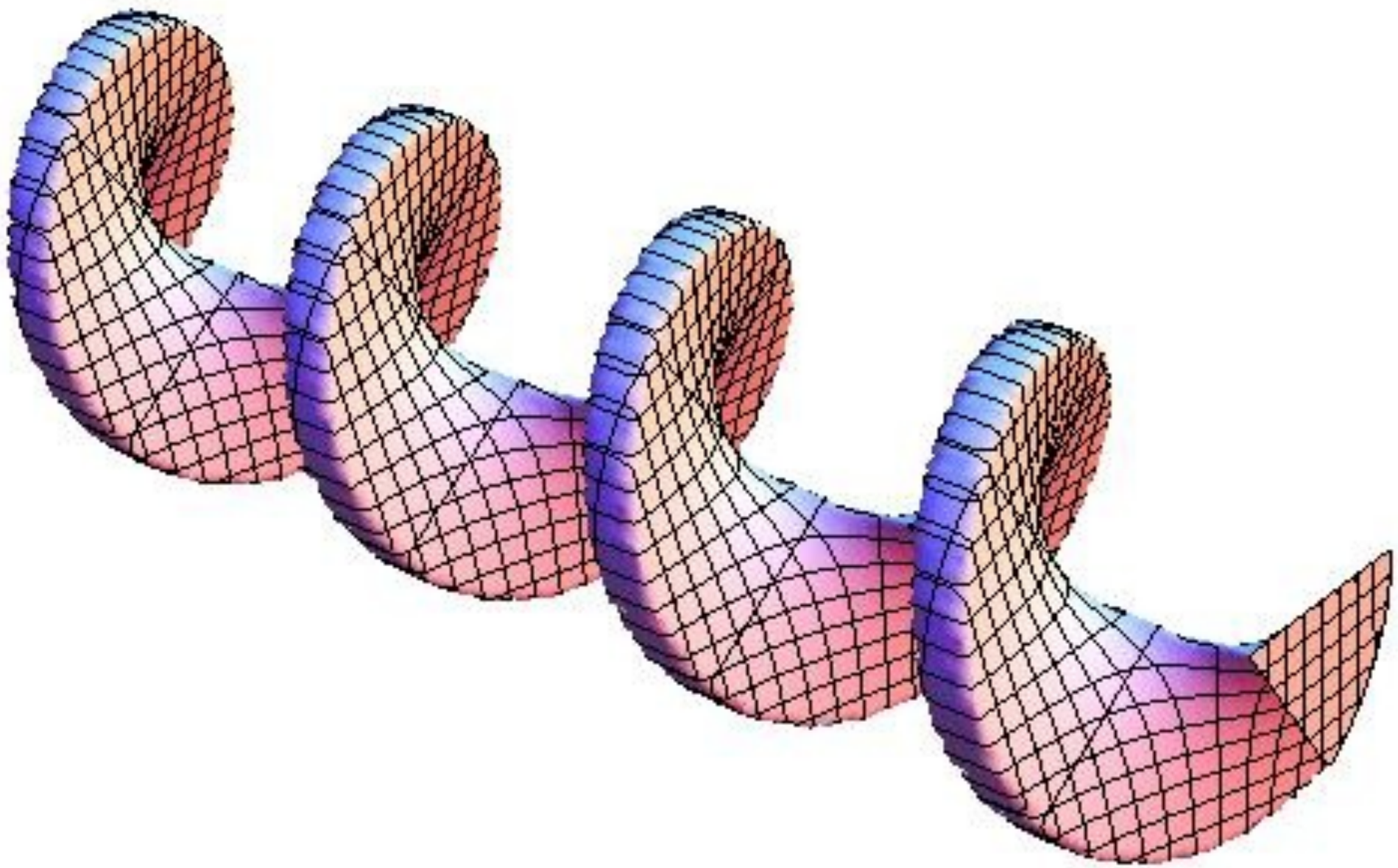


Phase singularity on axis

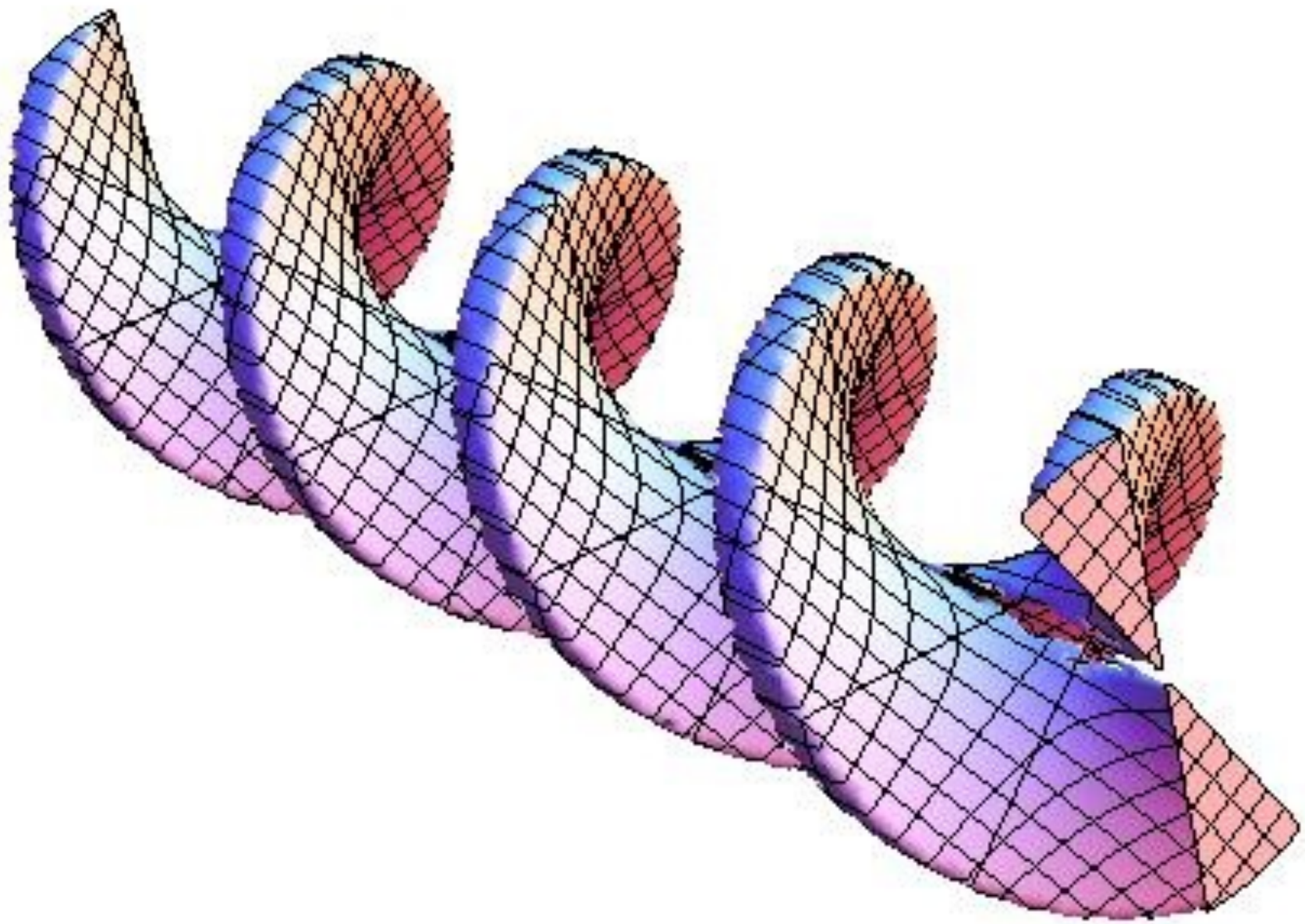
The Orbital Angular Momentum (OAM) of light

single helix - OAM (ℓ) is 1



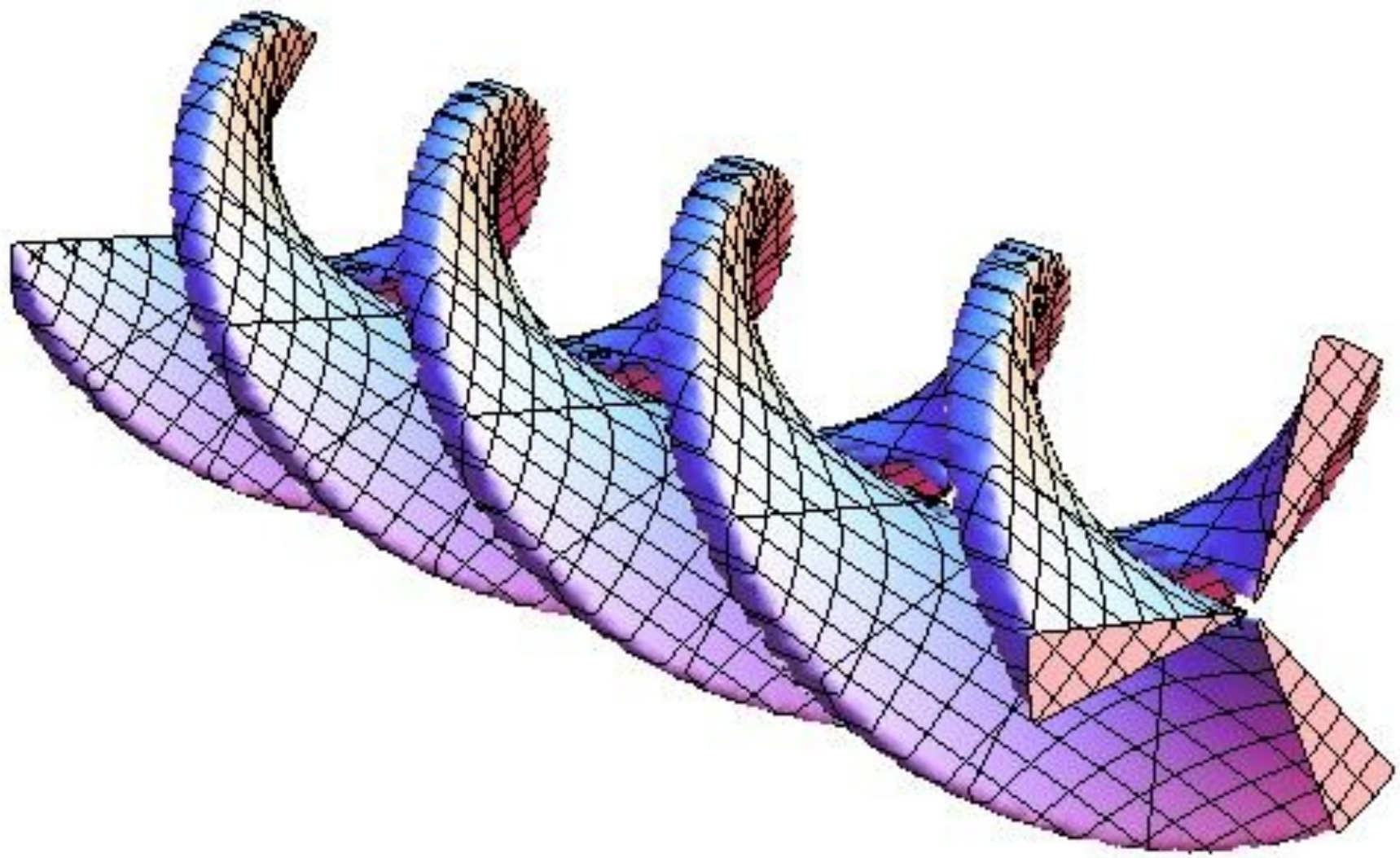
The Orbital Angular Momentum (OAM) of light

double helix - OAM (ℓ) is 2



The Orbital Angular Momentum (OAM) of light

triple helix - OAM (ℓ) is 3

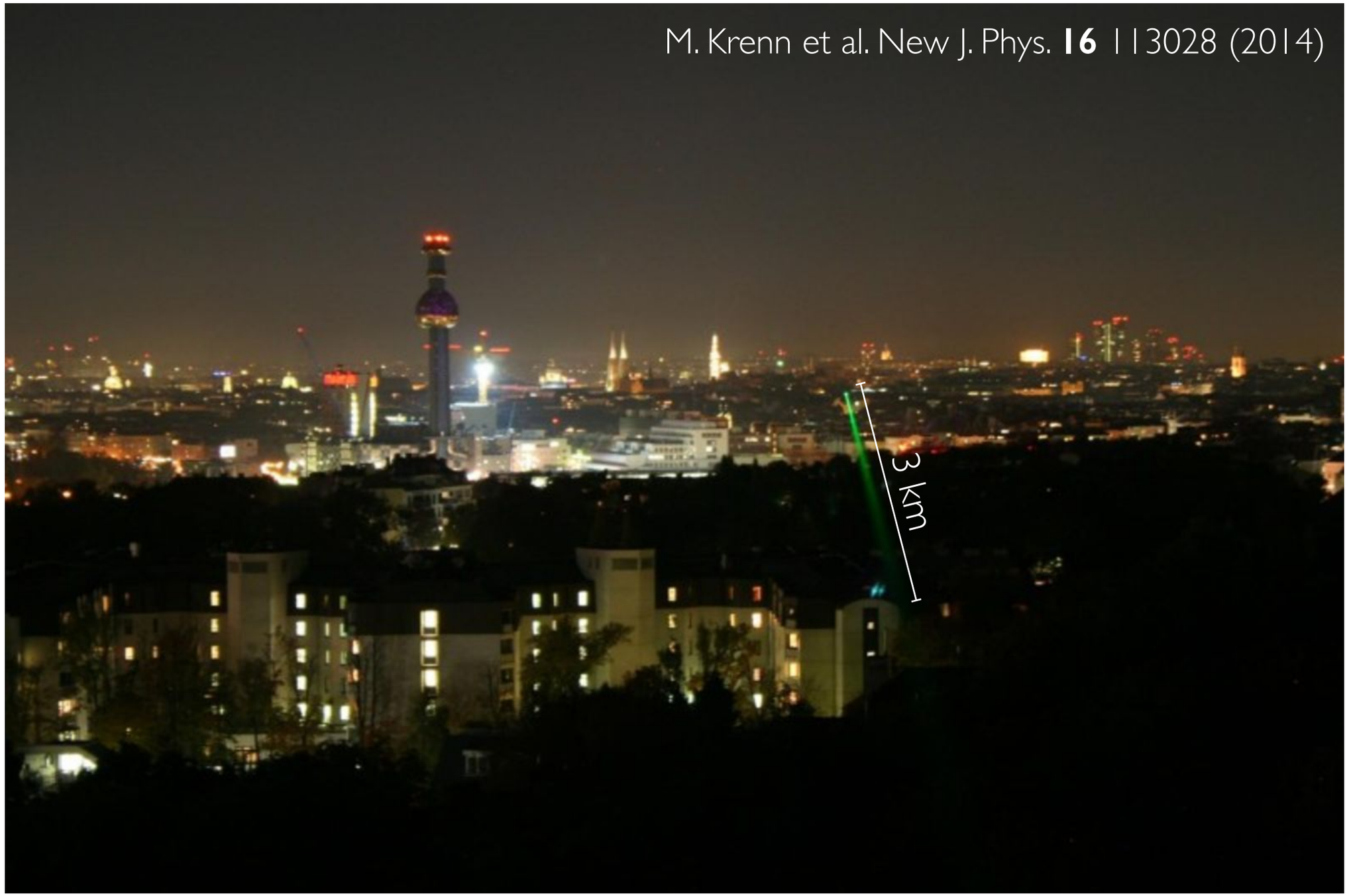


Optical communications

Optical communications

Twisted light data encoding in free space

Topological protected states enabled stable transmission over 3km across Vienna



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M. Krenn et al. New J. Phys. **16** 113028 (2014)

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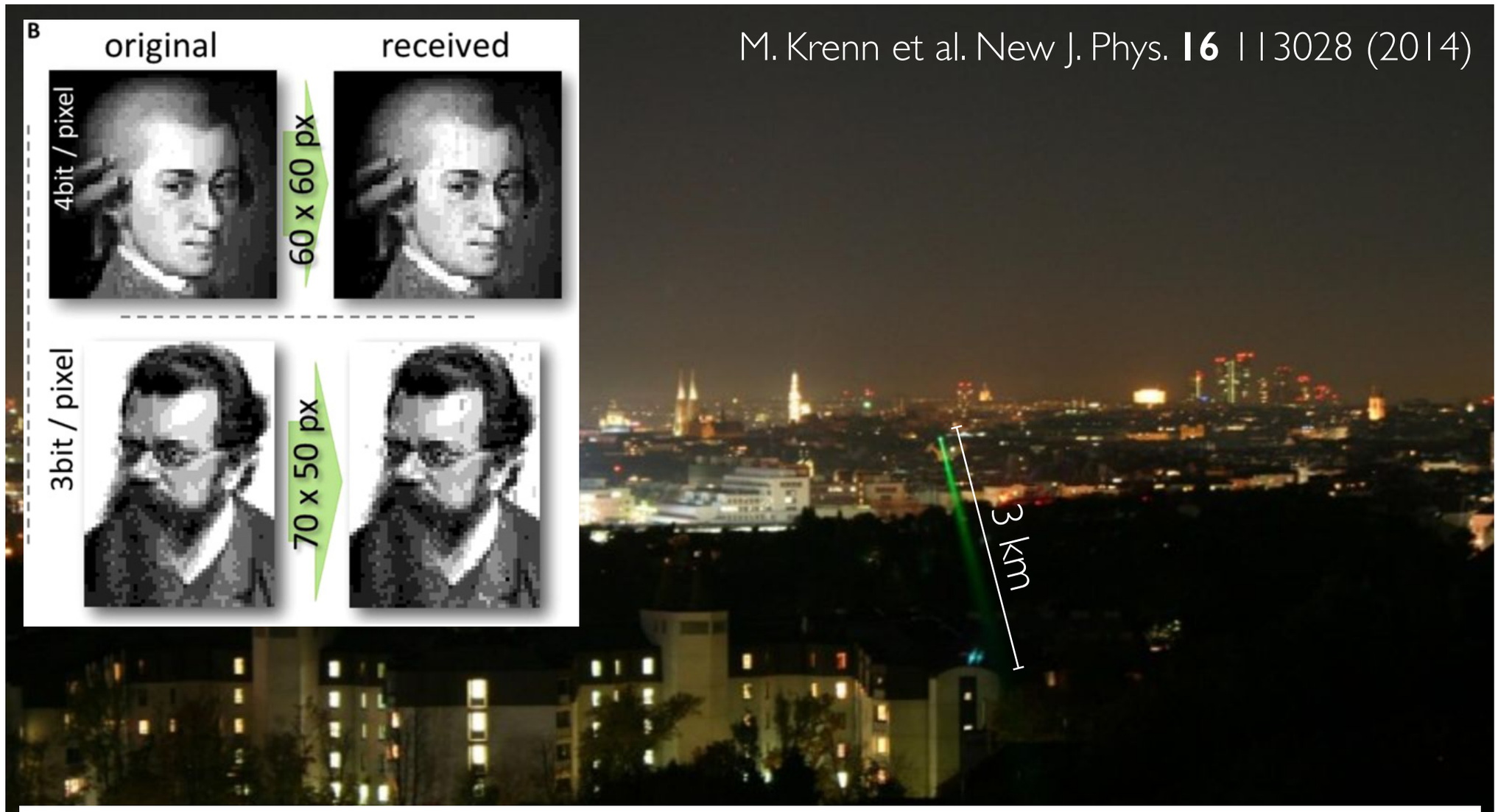

M. Krenn et al. New J. Phys. **16** 113028 (2014)

Terabit free-space data transmission employing orbital angular momentum multiplexing

J. Wang et al. Nat. Phot. 6, 488–496 (2012)

Astrophysics

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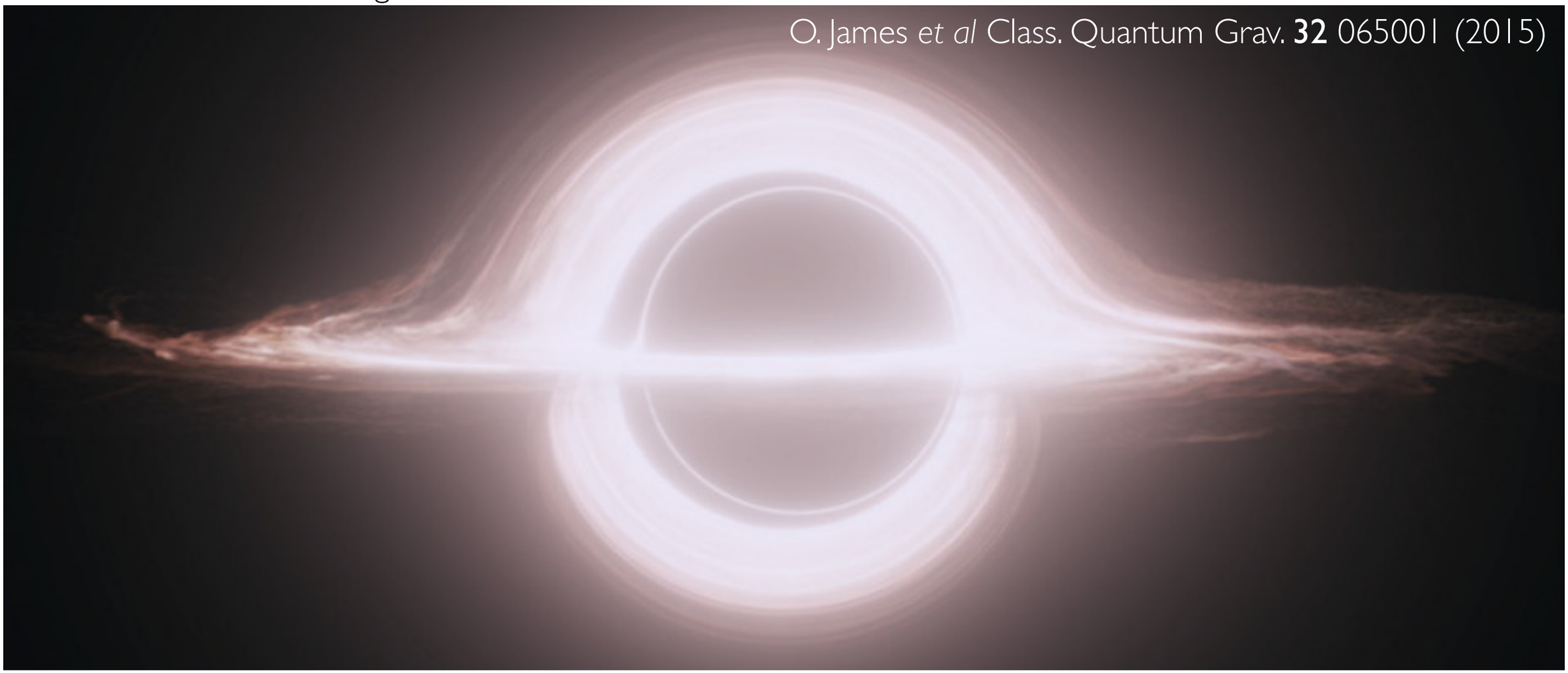
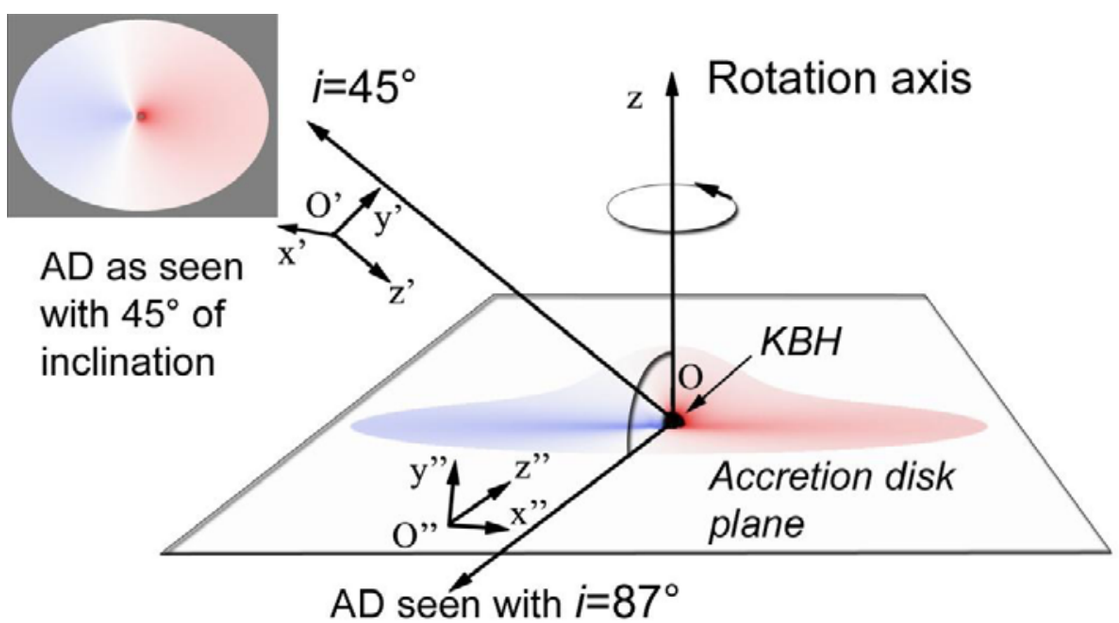
Accretion disk of a rotating black hole



Astrophysics

Detection of rotating black-holes



F. Tamburini et al Nat. Phys. **7**, 195–197 (2011)

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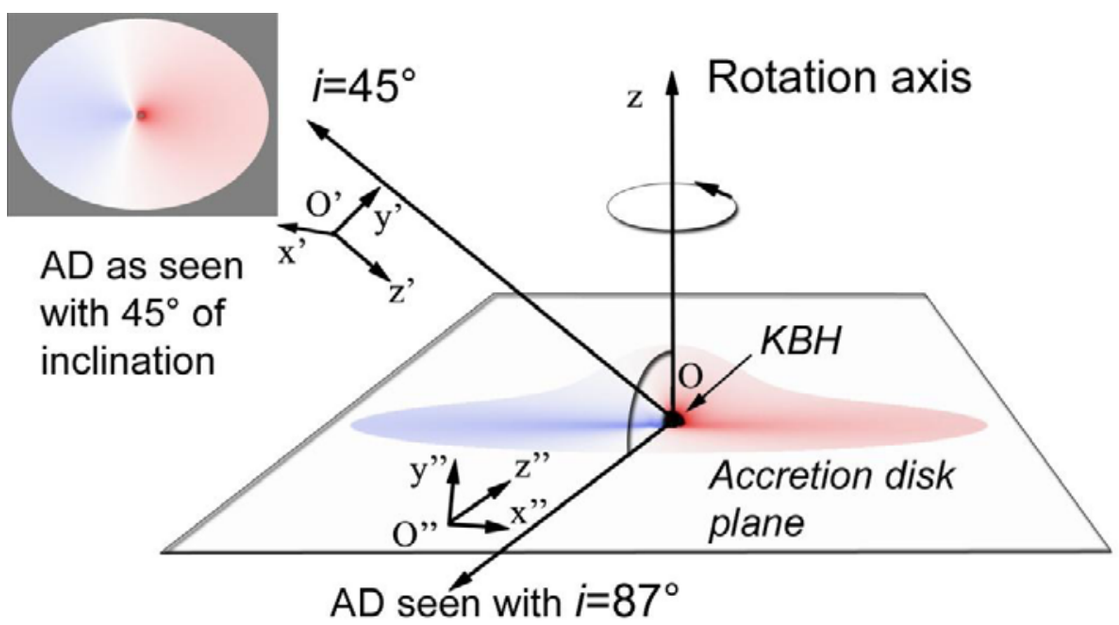

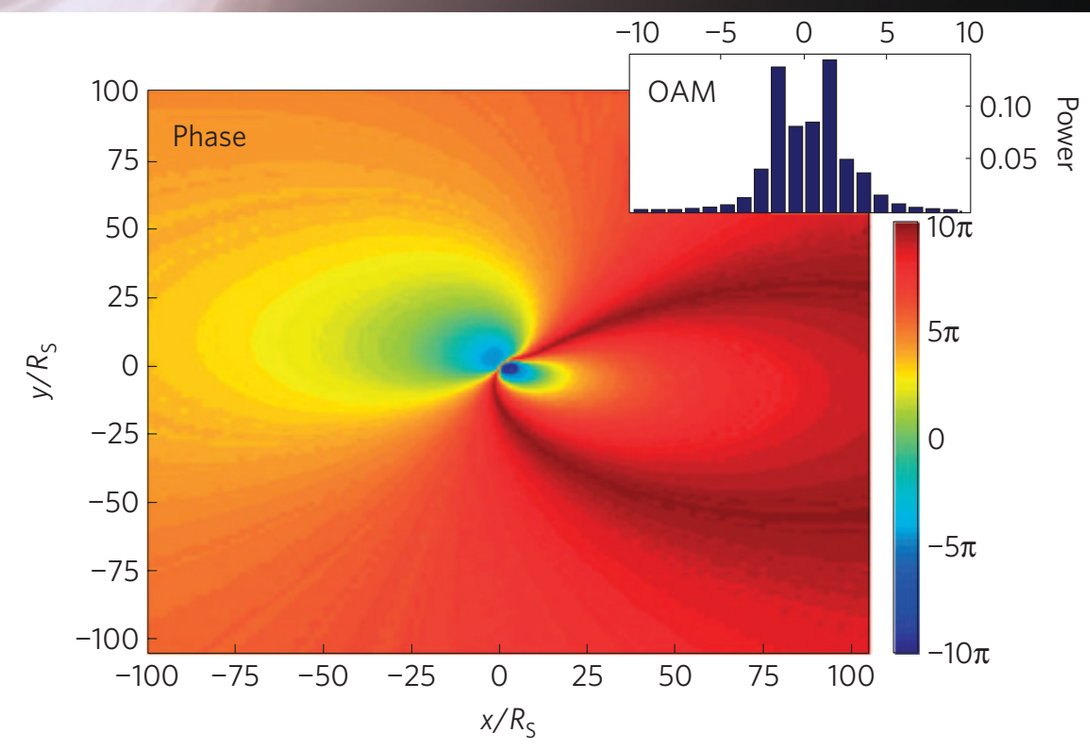

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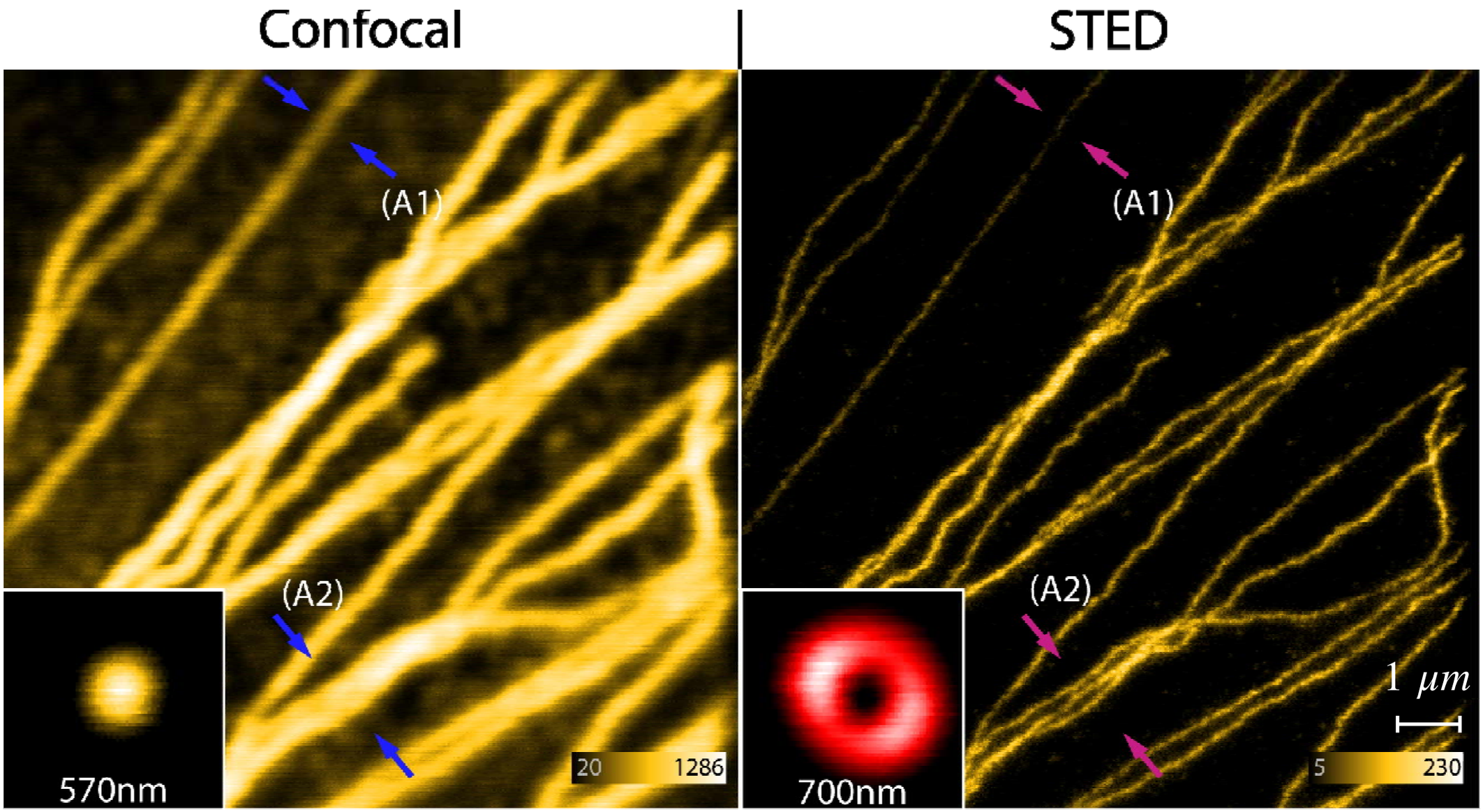
Microscopy

Visualising the nano-world

Super-resolution microscopy

Stefan W. Hell and Jan Wichmann, Optics Lett. **19** 780 (1994).



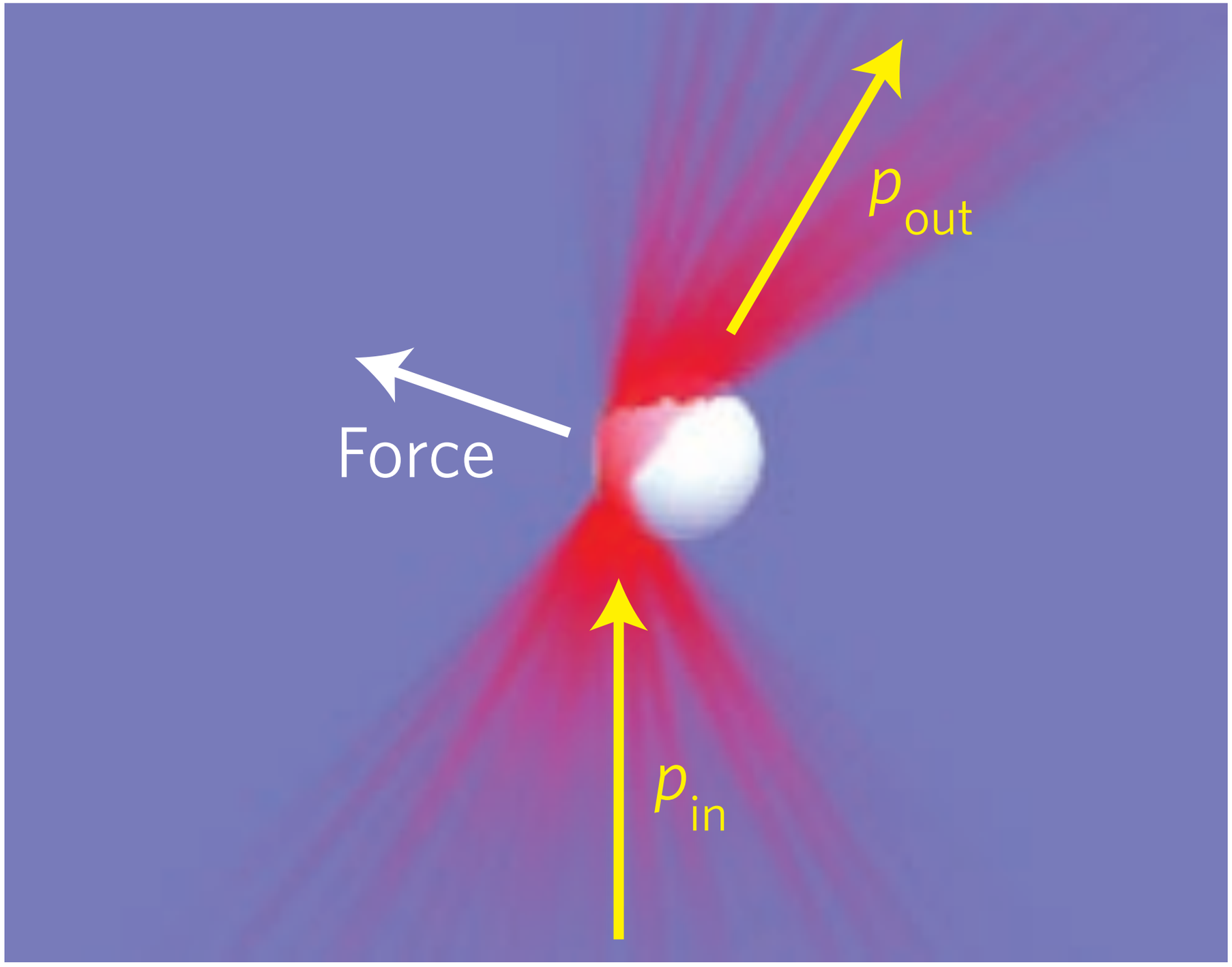
D. Wildanger et al. Opt. Exp. **16**, 9614 (2008).

Optical tweezers

Controlling the motion of nano-particles

Optical tweezers with a twist

M. Padgett and R. Bowman, Nat. Photonics **5**, 343–348 (2011)



Controlling the motion of nano-particles

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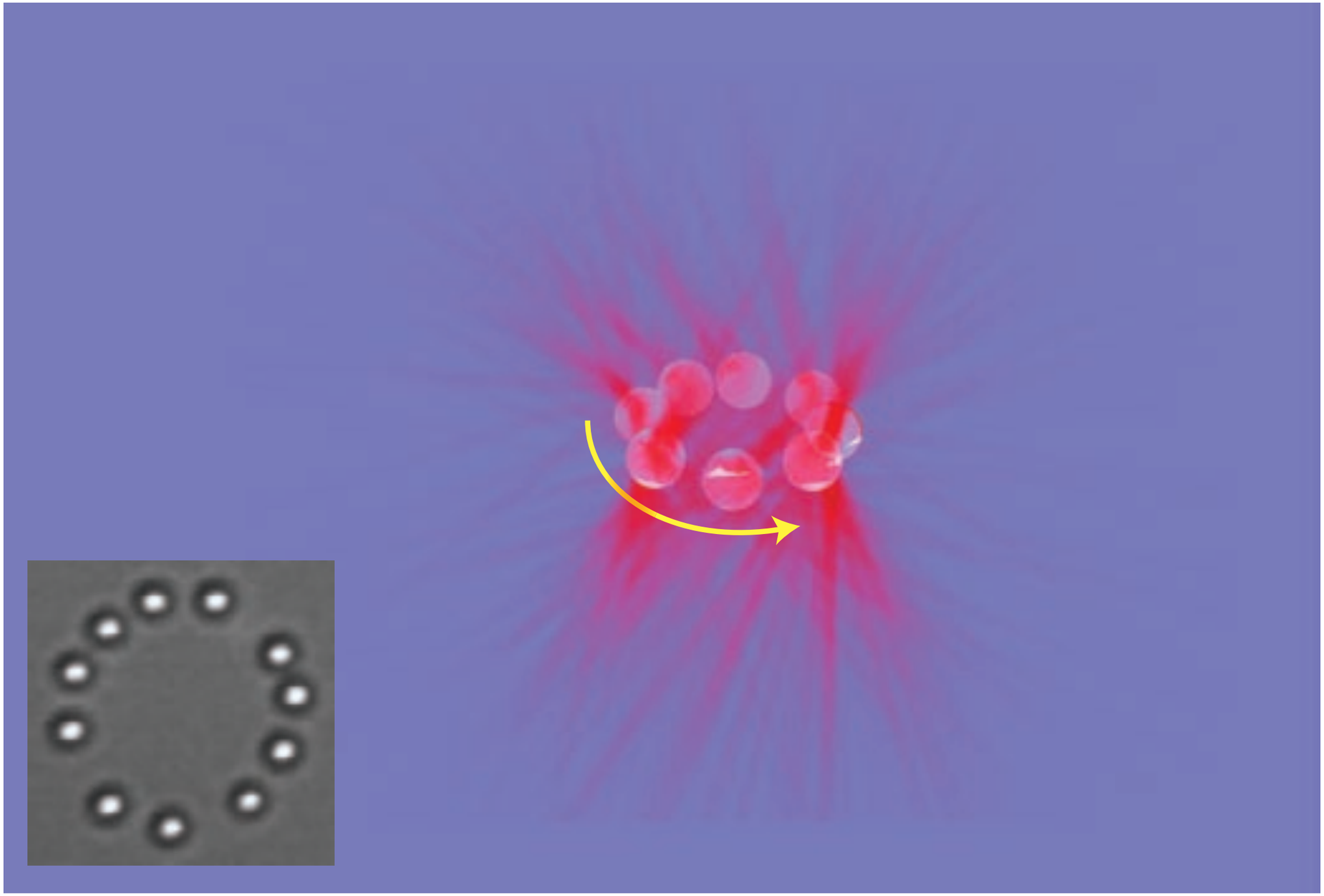

Laser plasma accelerators

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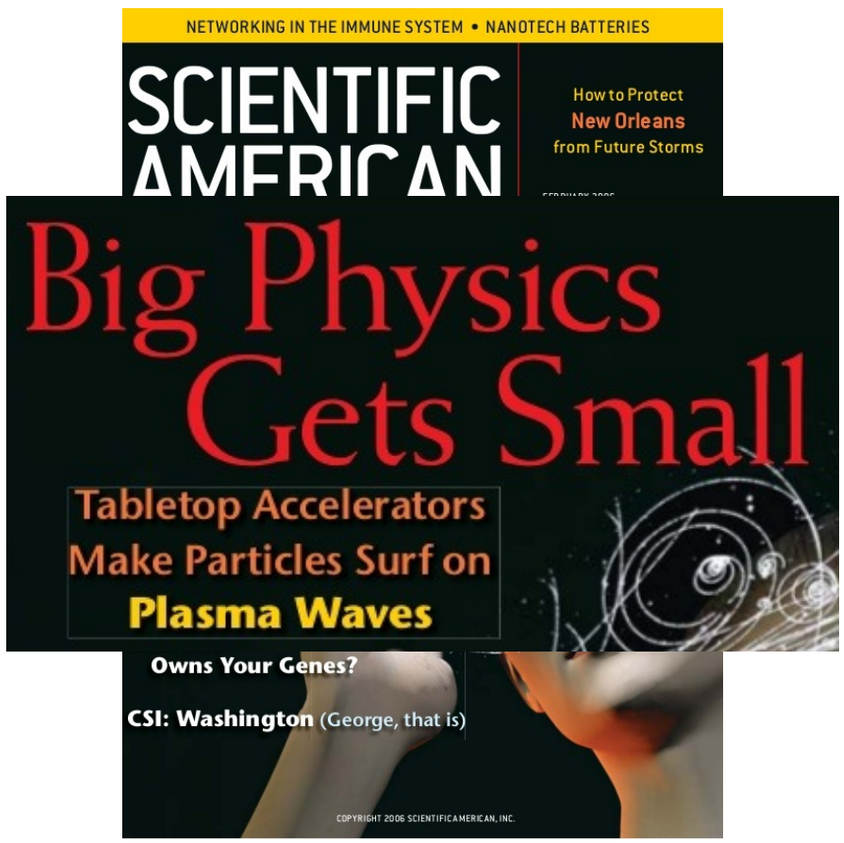
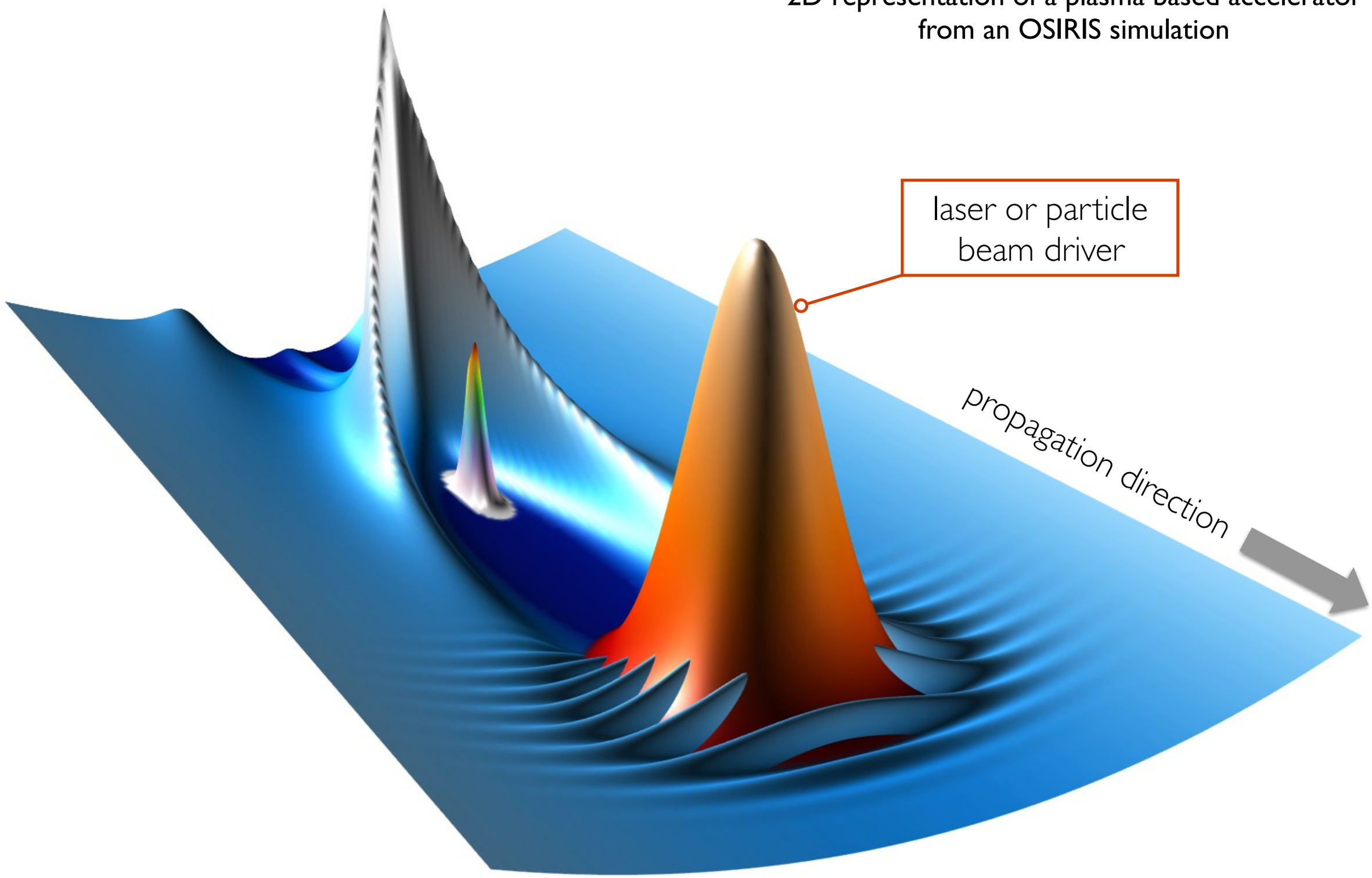


1000x smaller

How do plasma accelerators work?

2D representation of a plasma based accelerator from an OSIRIS simulation



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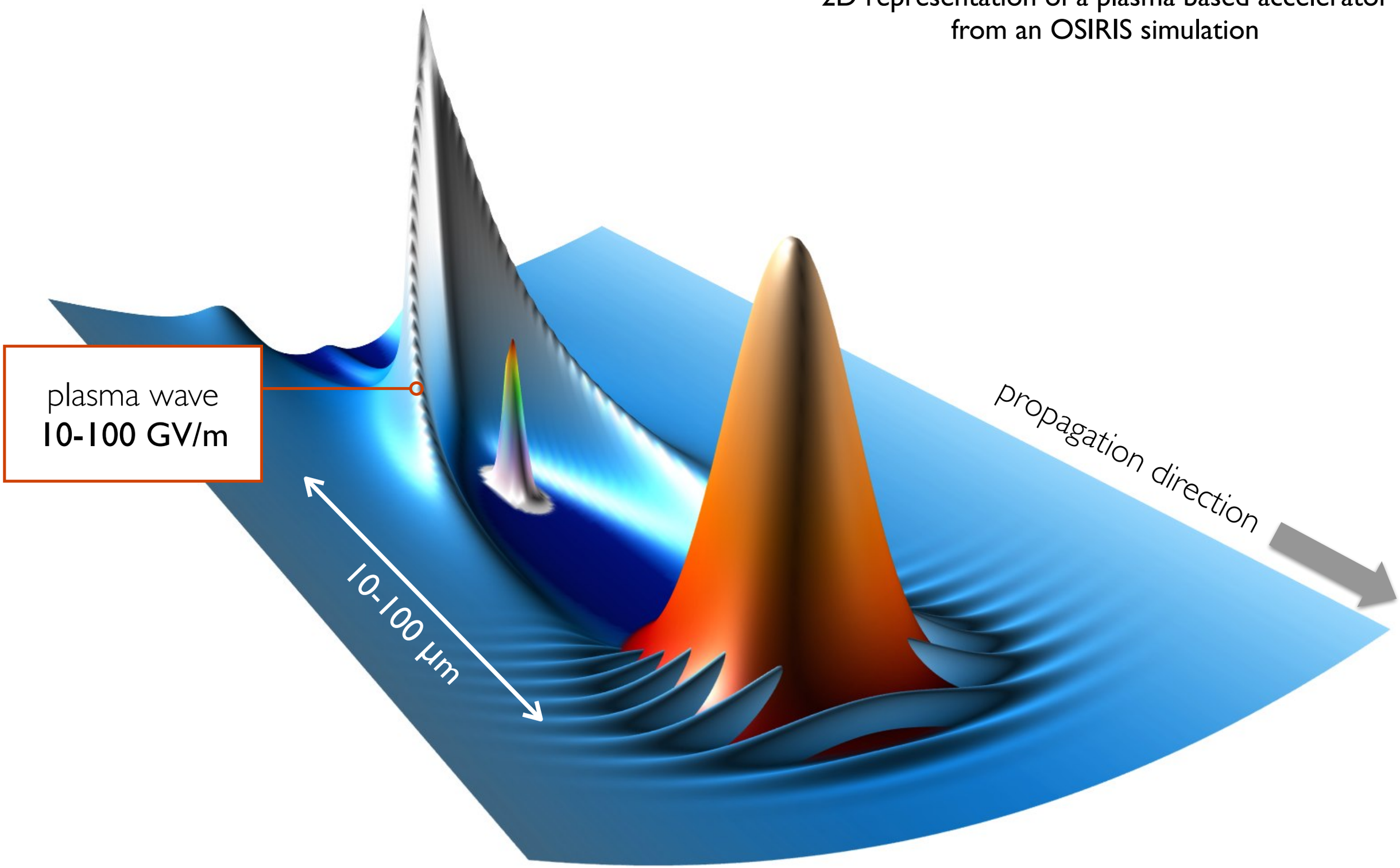

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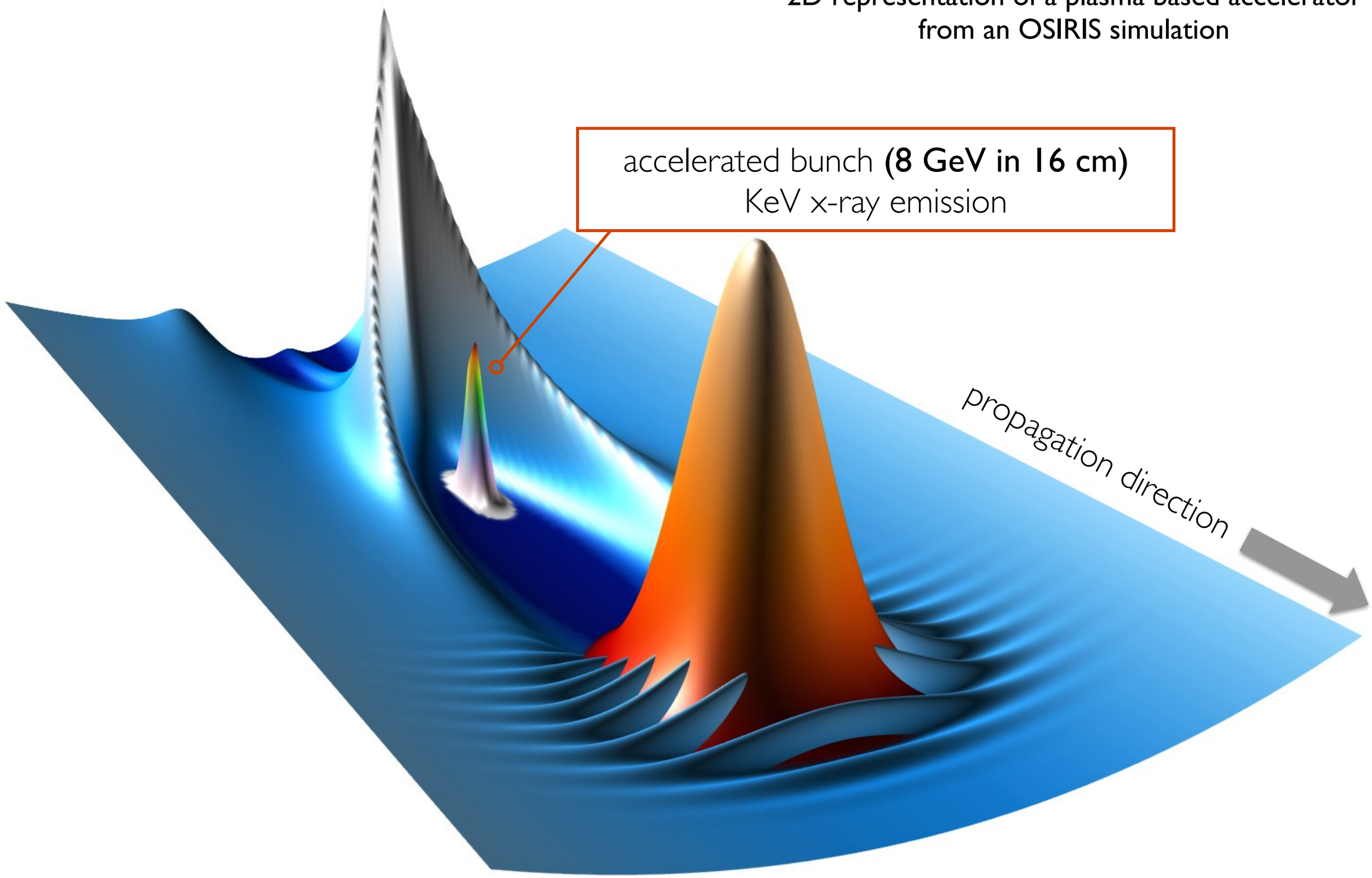
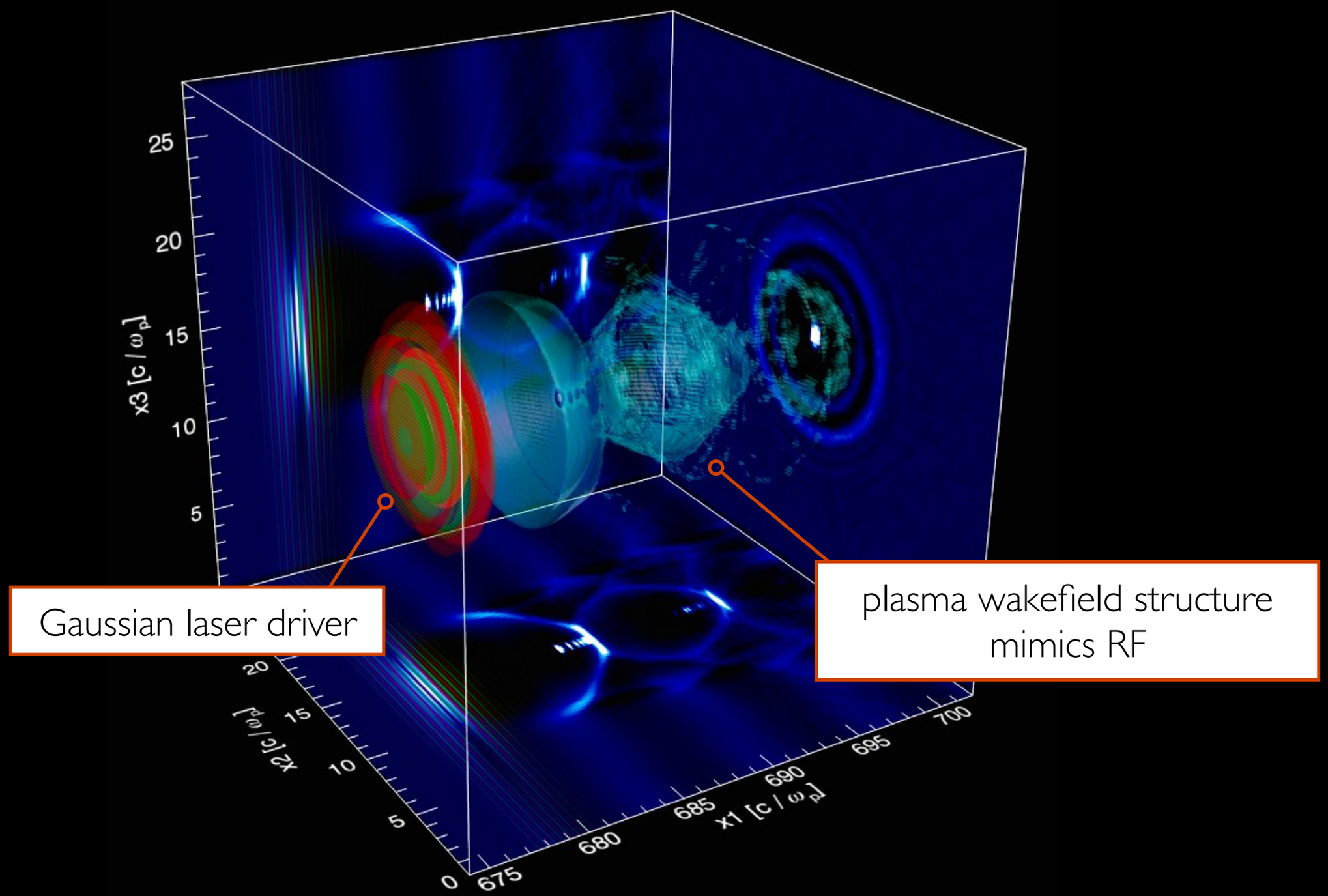


Conventional approach

Exploiting compactness: mimicking wakefield structure from RF cavities



C. Murphy *et al.*, PoP '05, W. Lu *et al.*, PRSTAB '11

The topological dimension of plasma accelerators

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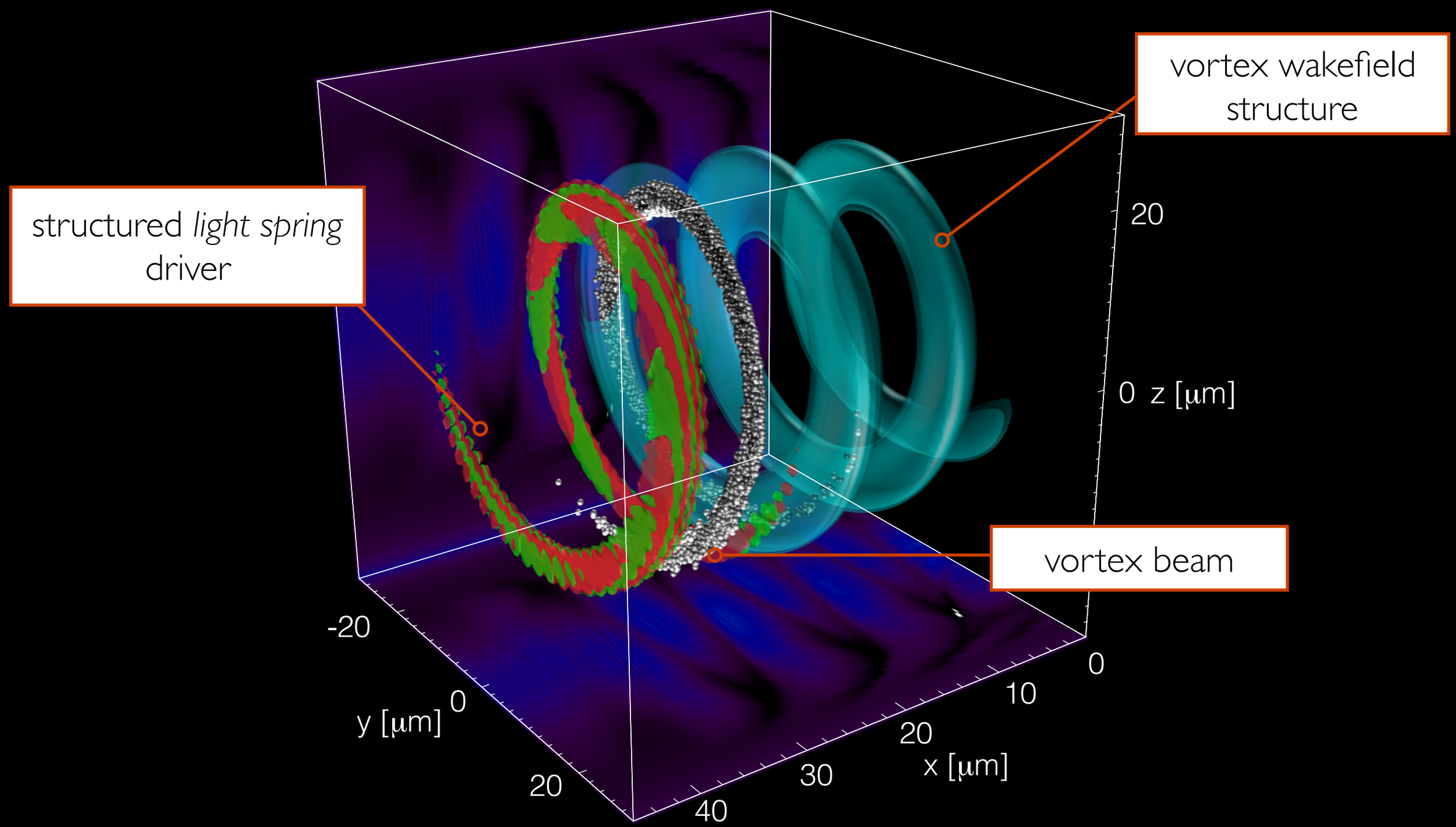
Topological acceleration - *pushing the limits for relativistic beam phase-space manipulation*



J. Vieira, J.T. Mendonça, F. Quéré Phys. Rev. Lett. 121, 054801 (2018)

Vortex beams have quantised OAM levels

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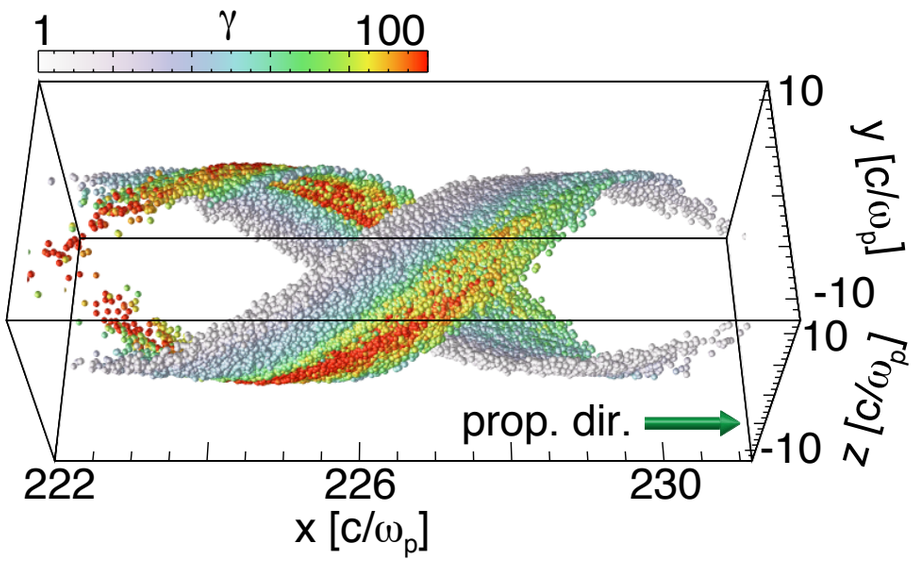
Vortex particle beam

Vortex electron beam with ℓ = 2



Ratio of angular momentum flux to energy flux for vortex electron beams

$$\frac{\Delta L_x}{E} = \frac{\ell}{\omega_p}$$

Vortex beams have quantised OAM levels

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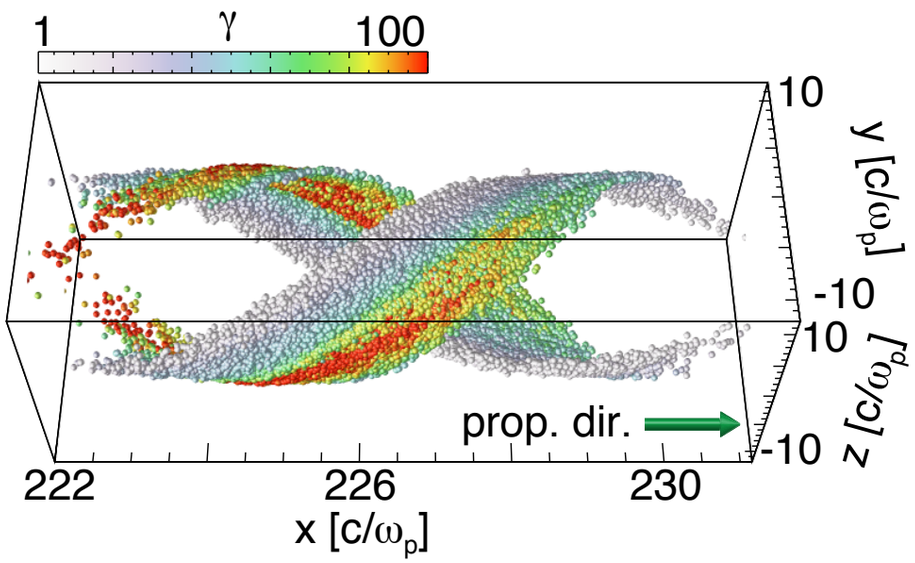
Vortex particle beam

Vortex electron beam with ℓ = 2



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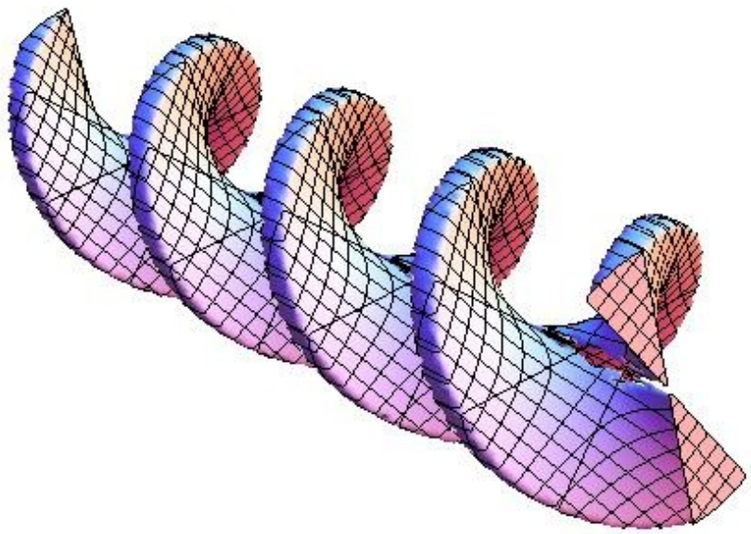
Vortex light beam

OAM light beam with ℓ = 2



PHYSICAL REVIEW A VOLUME 45, NUMBER 11 1 JUNE 1992

Orbital angular momentum of light and the transformation of Laguerre-Gaussian laser modes

L. Allen, M. W. Beijersbergen, R. J. C. Spreeuw, and J. P. Woerdman
Huygens Laboratory, Leiden University, P.O. Box 9504, 2300 RA Leiden, The Netherlands
(Received 6 January 1992)

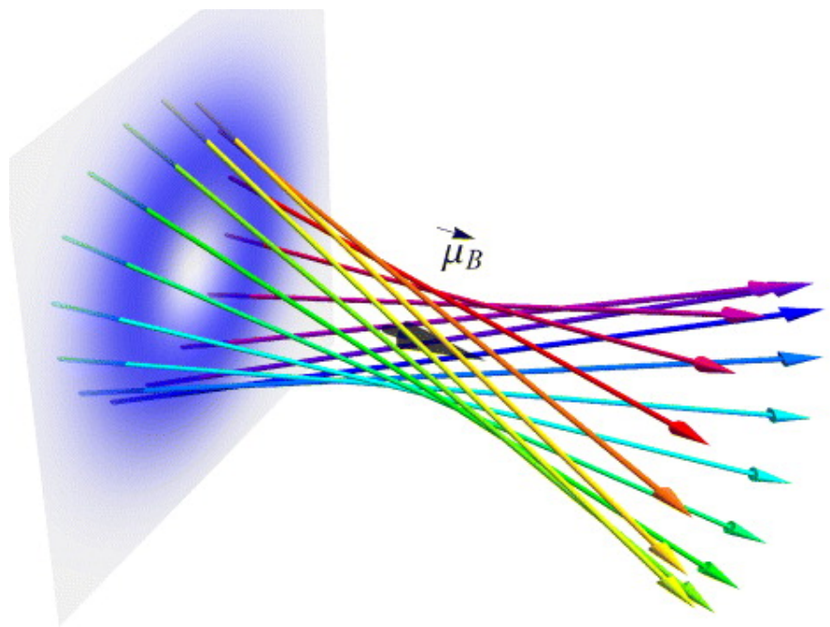
Ratio of angular momentum flux to energy flux for OAM light beams

$$\frac{\mathbf{J}}{c\mathbf{P}} = \frac{\ell}{\omega_0}$$

Vortex quantum electron wave-packets

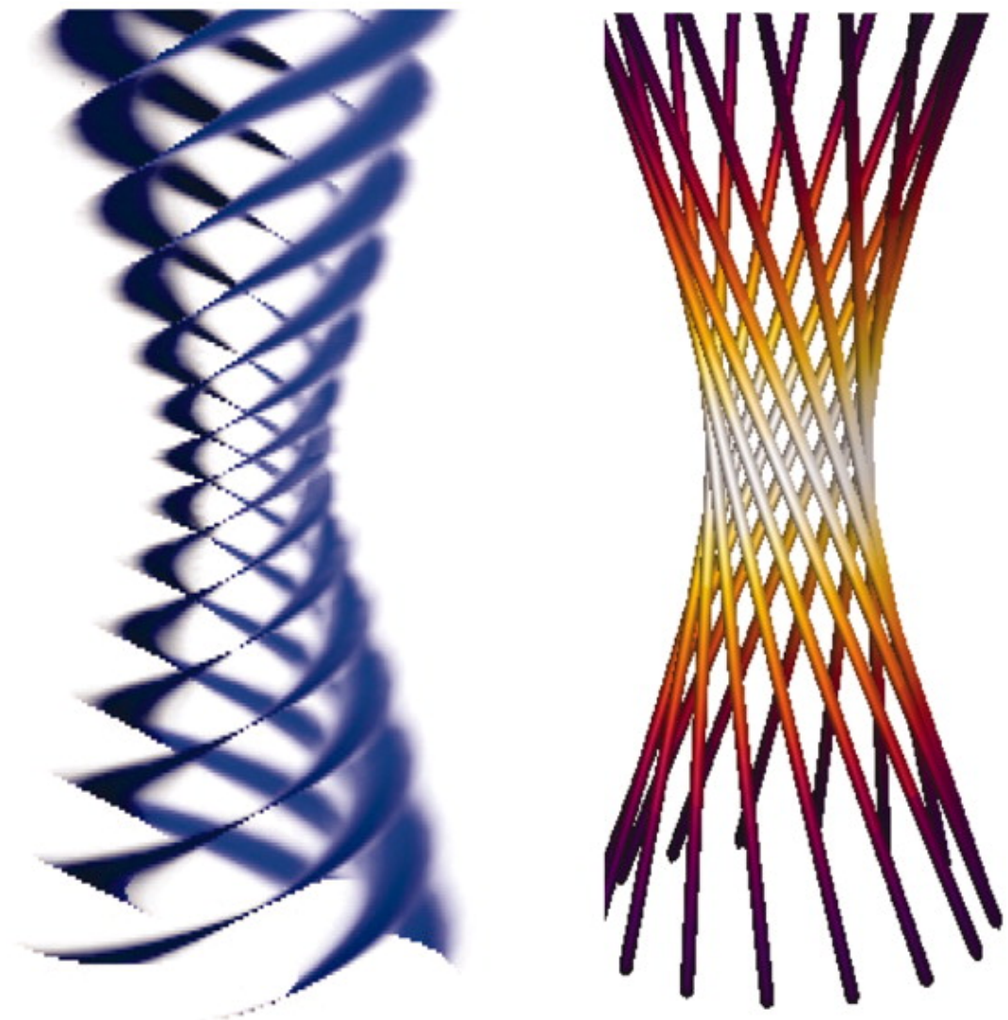
Opening new research avenues in hadronic physics

Produced at non-relativistic velocities but were never accelerated.



Ratio of angular momentum flux to longitudinal momentum

$$\frac{L_z}{p_z} = \frac{\ell}{k_z}$$



wave function and phase-fronts of a vortex electron beam
B. J. McMorran *et al.,* Science '11; K. Bliokh et al., Phys. Rep. '17.

Conclusions and future perspectives

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Twisted light is a major research topic in optics and photonics

Multiple applications include optical communications, astrophysics, microscopy, matter manipulation, quantum computing and now plasma acceleration

OAM light beams are promising drivers for plasma accelerators

Enable to exploit a new and distinctive feature of plasma accelerators: the topological freedom on the acceleration structures

Generation of relativistic beams with new properties

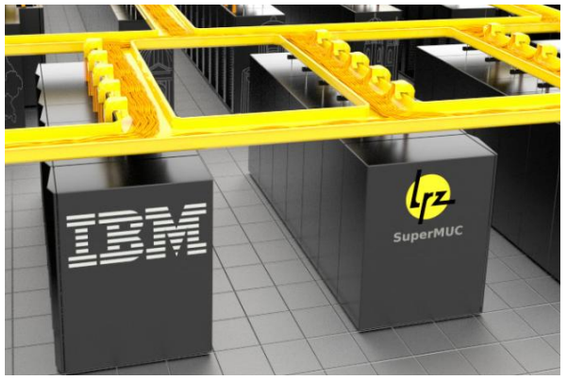
Electrons with angular momentum positron acceleration. Opportunities for radiation?

Acknowledgments

Work in collaboration with:

J. T. Mendonça (IST); **F. Quéré** (CEA);

Simulation results obtained at the SuperMUC supercomputer in Garching, Germany.



Thank you!

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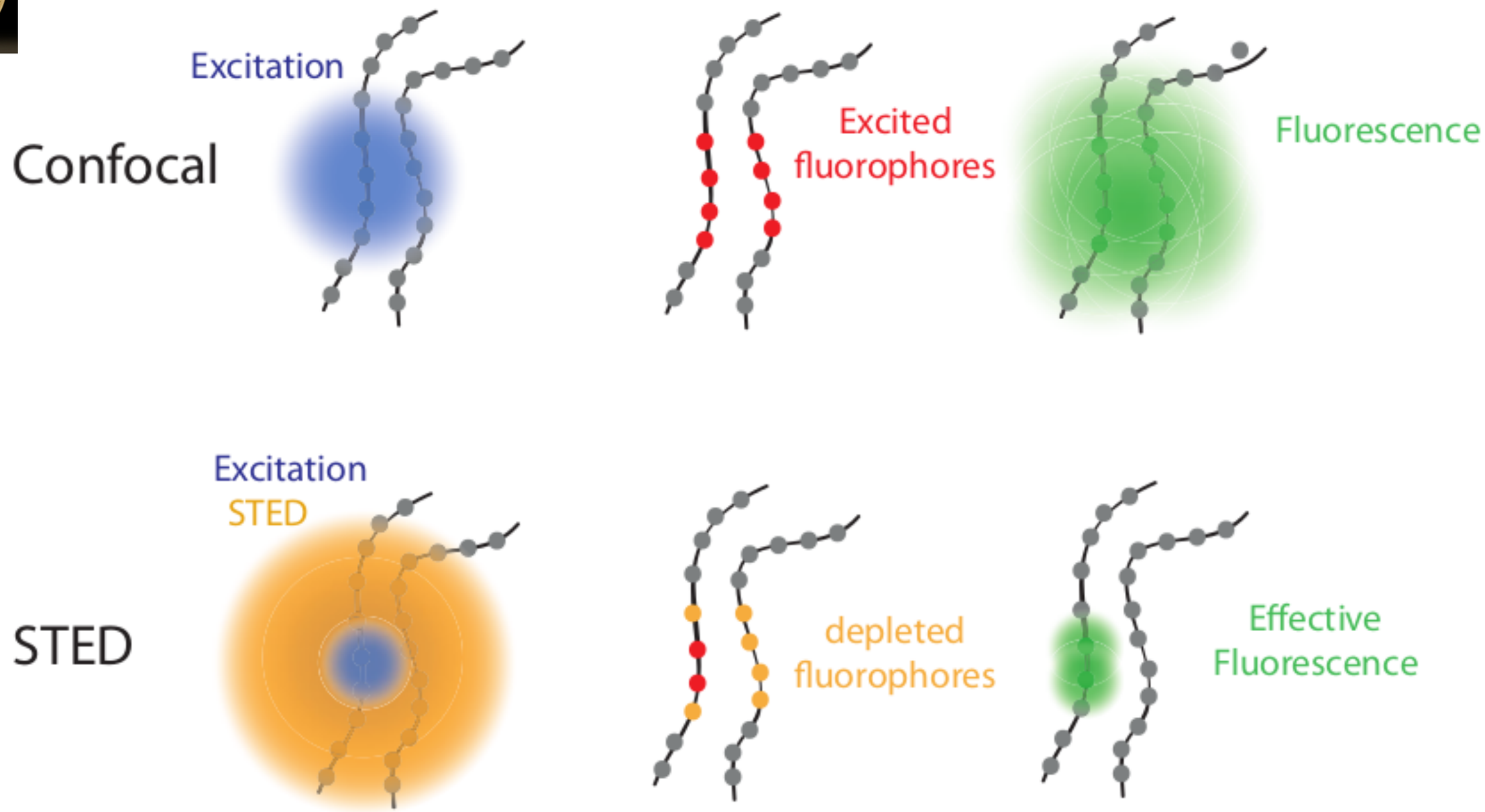

Image taken from: https://svi.nl/STEDMicroscopy

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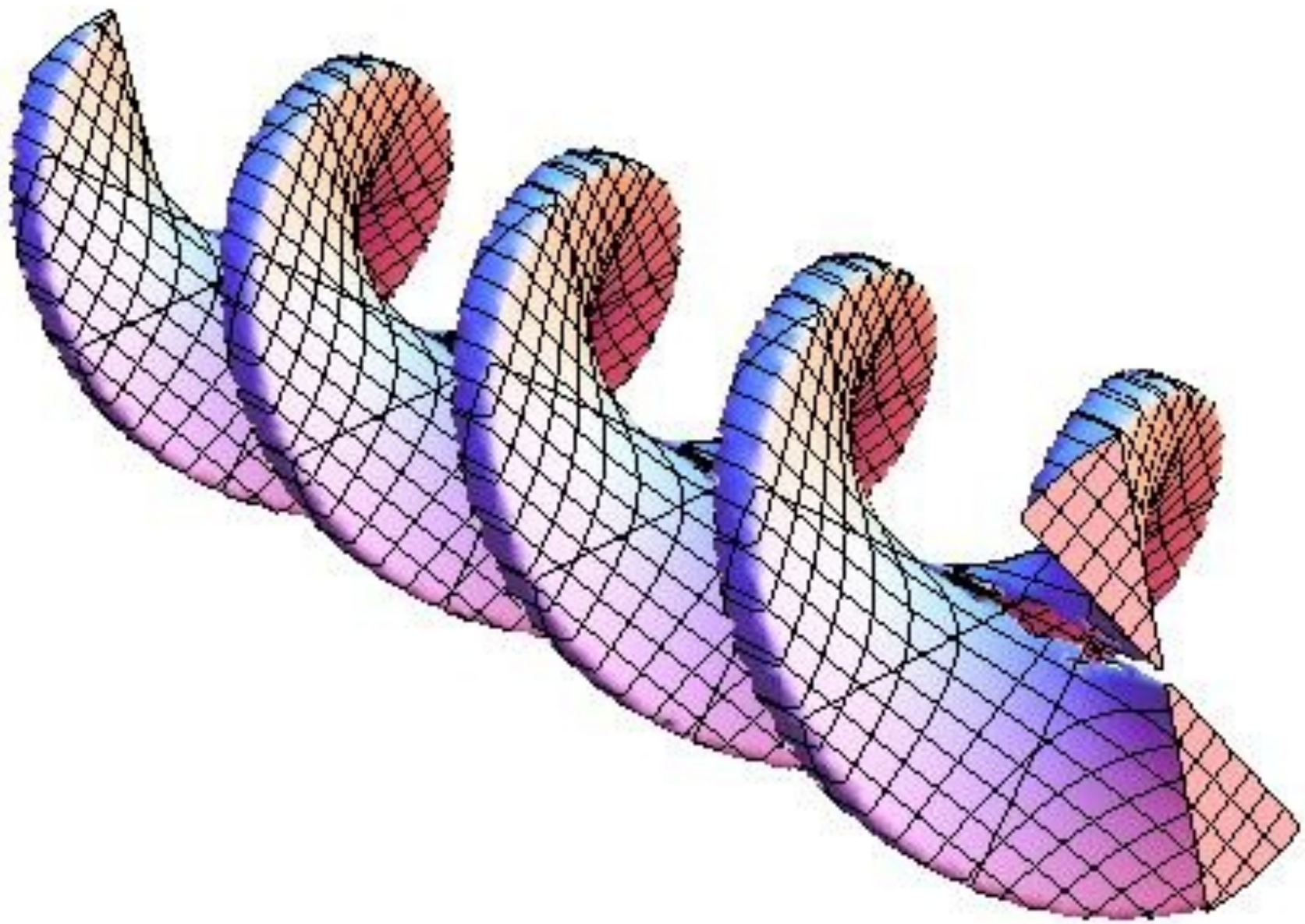
double helix - OAM (ℓ) is 2



Interesting examples of double helixes

adapted from M. Padgett *et al.*

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