



# On the use of conserved electromagnetic field quantities in radio studies of space

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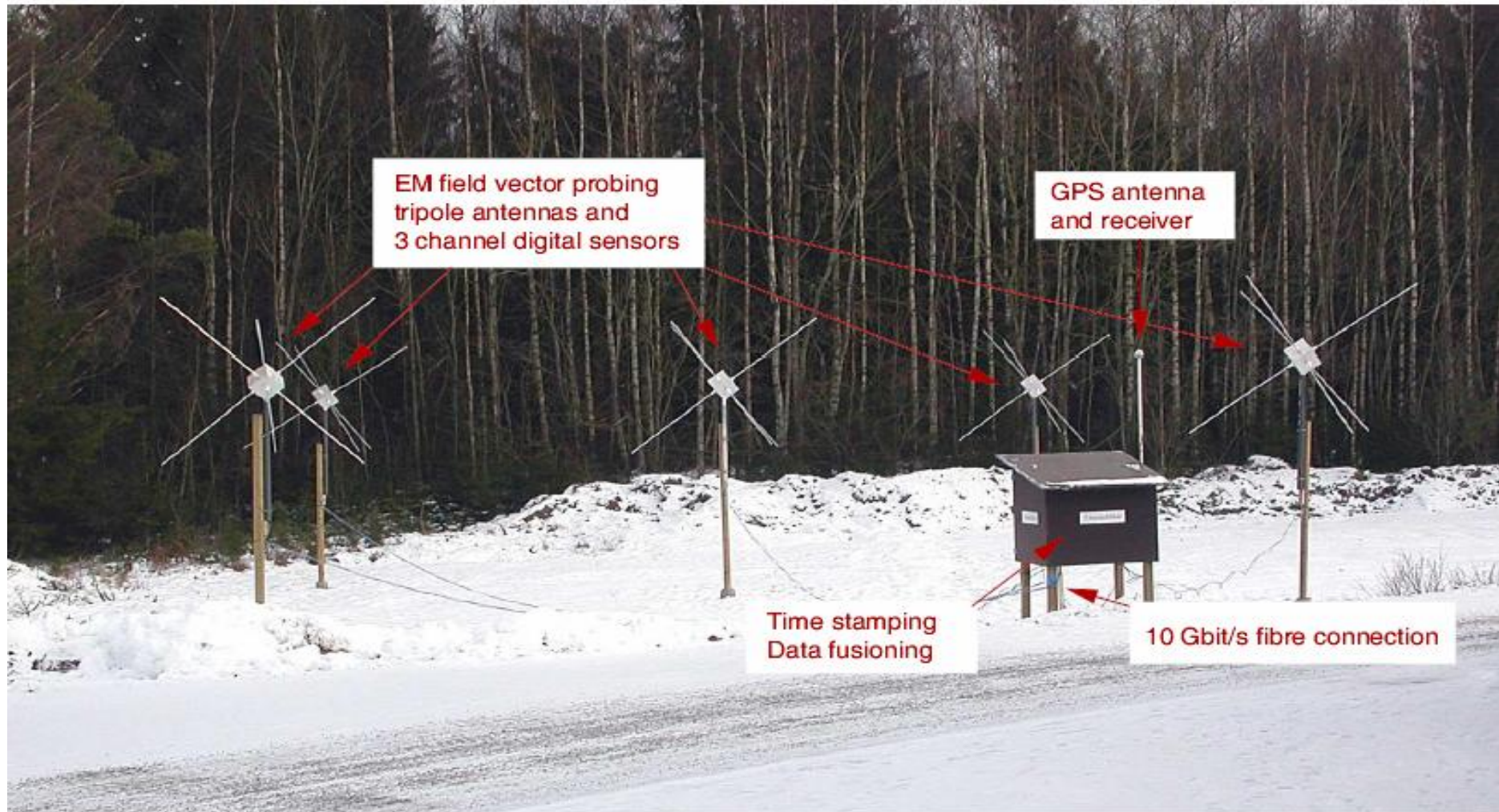
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Three orthogonal linear dipole antennas probe the 3D electric field vectors

## LOIS Test Station, the Risinge site, Växjö, Sweden

January, 2005 (after the hurricane)



Three orthogonal  
loop antennas  
probe the 3D  
magnetic field  
vectors



From the *total* E-field and B-field vectors one can determine a number of constants of motion

- Total energy

$$H = \frac{1}{2} \sum_i m_i v_i^2 + \frac{\epsilon_0}{2} \int d^3x (\mathbf{E}^2 + c^2 \mathbf{B}^2)$$

- Total linear momentum

$$\mathbf{p} = \sum_i m_i \mathbf{v}_i + \epsilon_0 \int d^3x (\mathbf{E} \times \mathbf{B})$$

- Total angular momentum (including spin/polarisation/helicity)

$$\mathbf{J} = \mathbf{L} + \mathbf{S} = \sum_i \mathbf{x}_i \times m_i \mathbf{v}_i + \epsilon_0 \int d^3x (\mathbf{x} - \mathbf{x}_0) \times (\mathbf{E} \times \mathbf{B})$$

- Energy centre of the EM field

$$\mathbf{C} = \int d^2x \left[ \frac{\epsilon_0}{2} (\mathbf{x} - \mathbf{x}_0) (\mathbf{E}^2 + c^2 \mathbf{B}^2) - (t - t_0) (\mathbf{E} \times \mathbf{B}) \right]$$

The EM parts of these conserved (and other) quantities are transported by the EM field (radio beam) and carry additional information on the intrinsic dynamic state of the electromechanical system under study (ionosphere, magnetosphere, solar corona, CME, transition layer ...)

See G. Molina-Terriza *et al.*, Phys. Rev. Lett., **88**, 013601 (2002).

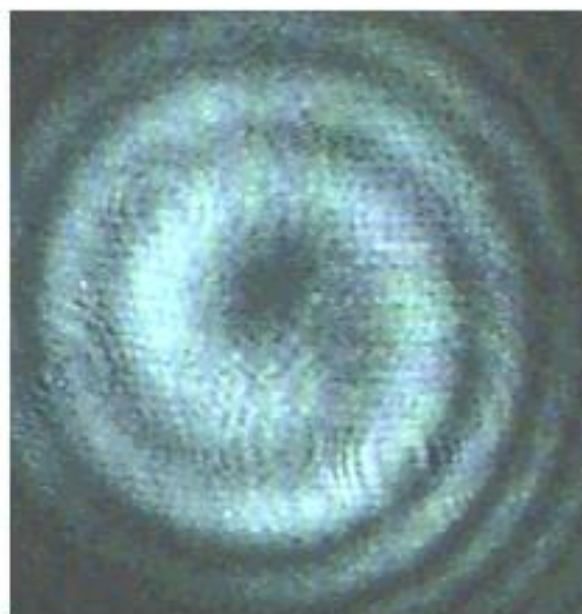
**Angular momentum** conserved both in mechanical systems and in EM fields (wave bundles/rays, Laguerre-Gaussian beams *etc.*).

- Includes **orbital angular momentum** and **spin angular momentum/polarisation**.
- Gives rise to a **rotational Doppler shift**
- Underutilised quantity in space physics (rapid development in optics/laser physics)
- High potential for new discoveries, in particular for turbulent plasma

## Breaking Free of Bits

Quantum communication schemes using light normally rely on the two types of photon polarization to encode information a bit at a time. But if researchers could efficiently measure a photon's orbital angular momentum, which can take an infinite number of different values, they could conceivably pack much more information into a light beam. Now, in the 24 June print issue of *PRL*, a team reports a way of sorting individual photons according to their orbital angular momentum, which could allow them to make use of all that extra data.

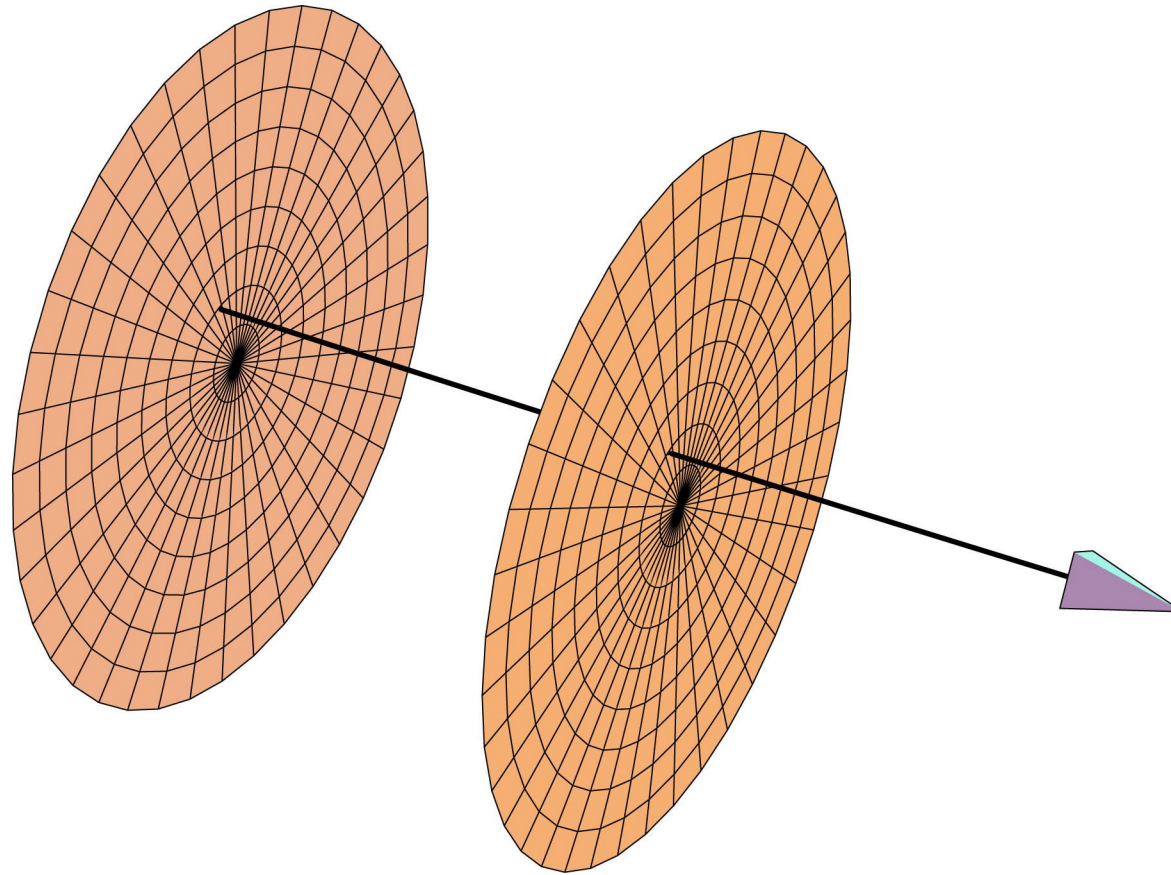
Photons have two spin states, which correspond to the two types of circular polarization for a light beam: the electric field rotates either clockwise or counterclockwise. A cross-section



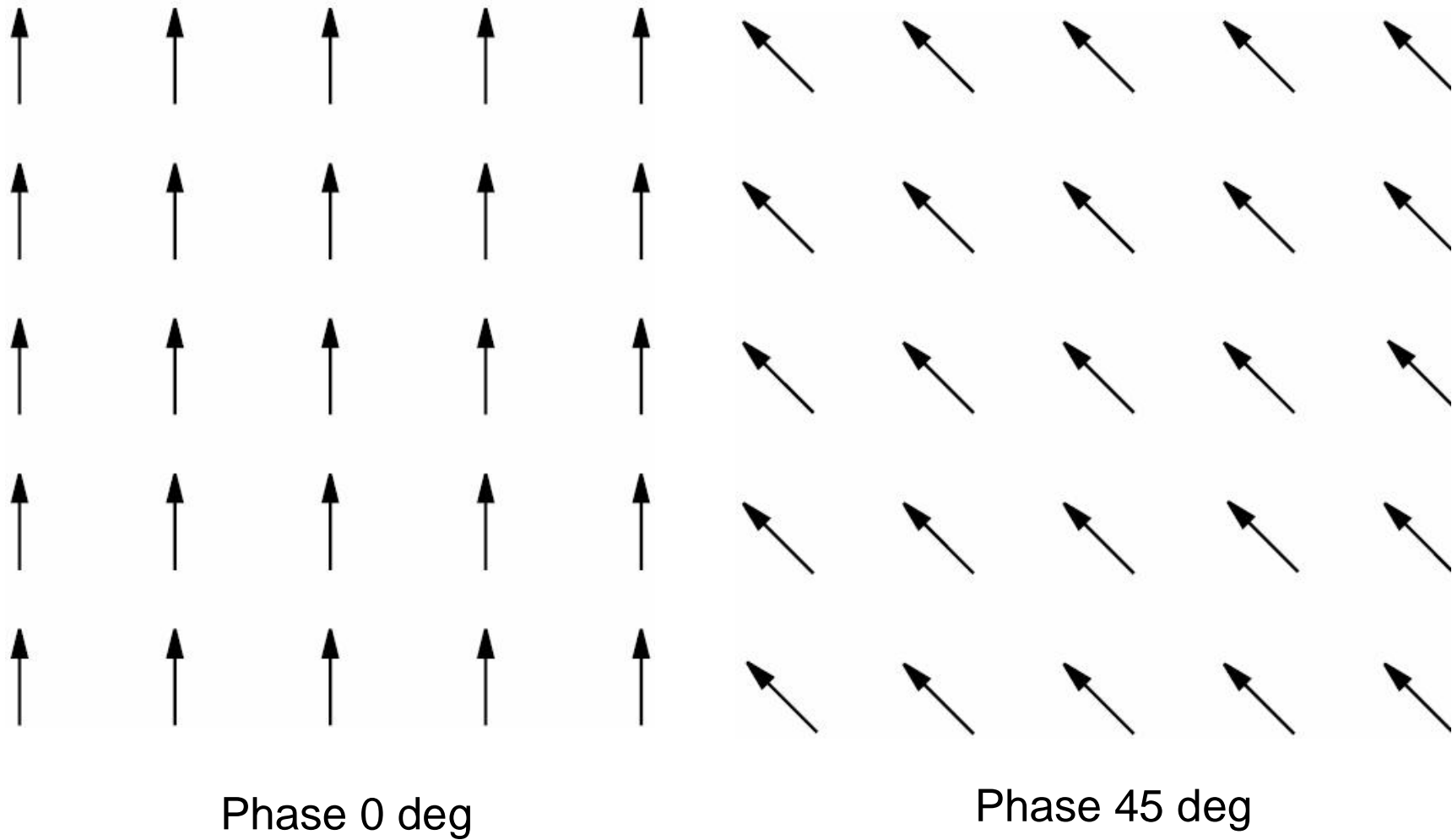
E. Galvez/Colgate Univ.

**Caught in Orbit.** A light beam with orbital angular momentum can generate a spiral-shaped interference pattern. Sorting photons by this property could allow researchers to extract increased amounts of information from such beams.

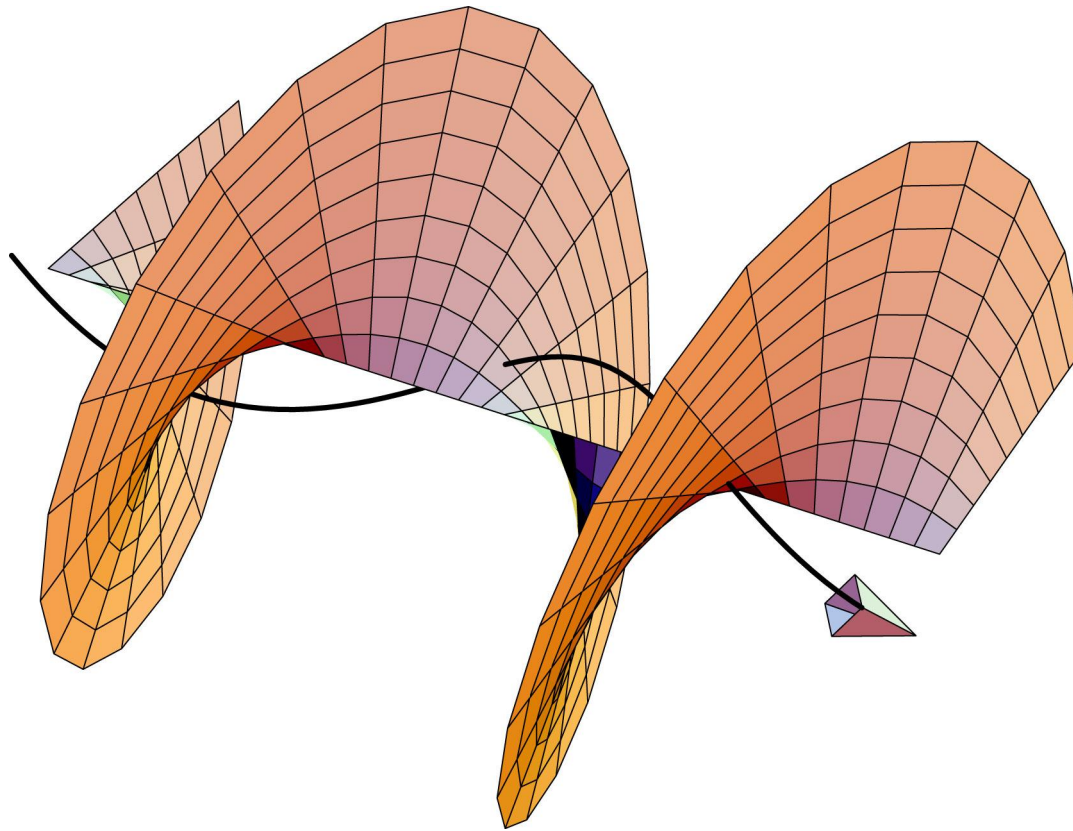
Beam with spin (circular polarisation)  
no orbital angular momentum



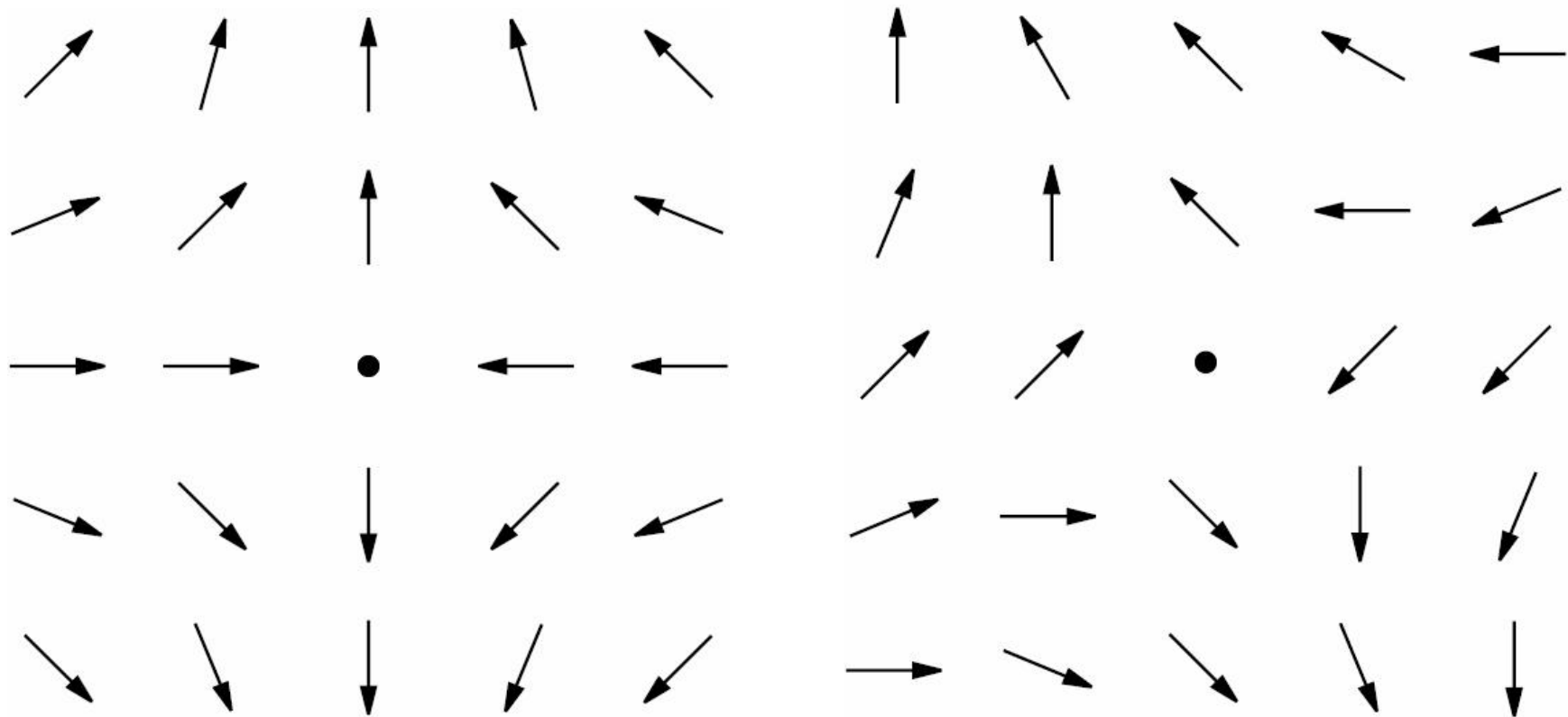
# Field vectors across antenna array for beam with spin



# Beam with orbital angular momentum ( $l=+1$ )



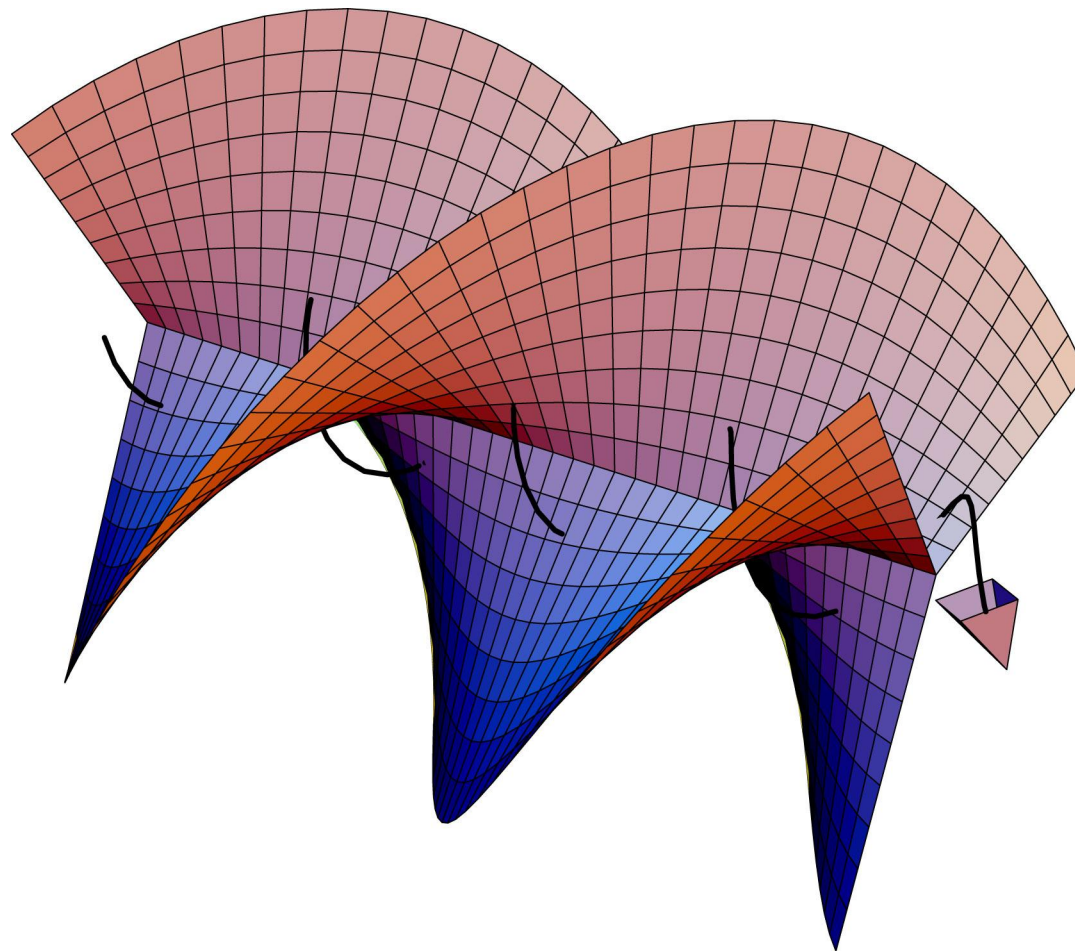
# Field vectors across antenna array for beam with OAM



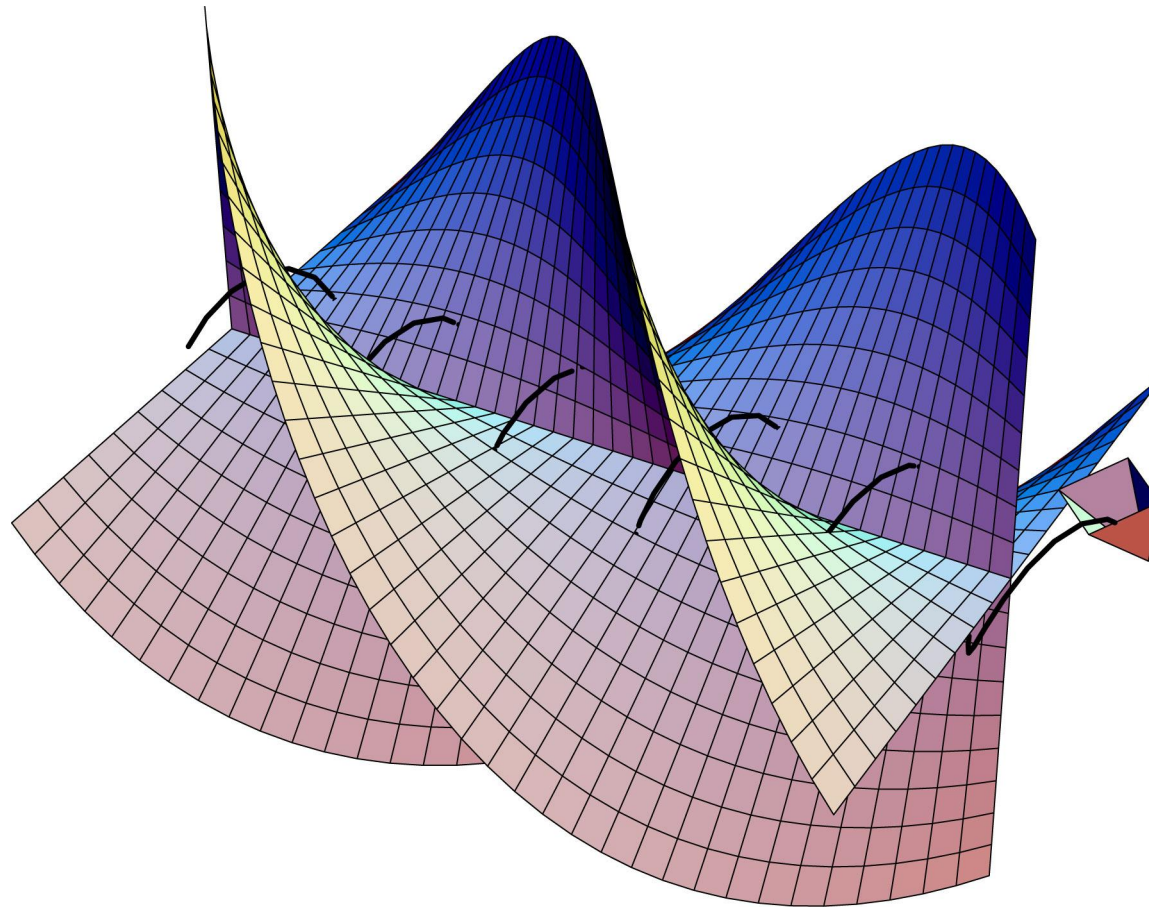
Phase 0 deg

Phase 45 deg

# Beam with orbital angular momentum ( $l=+3$ )



# Beam with orbital angular momentum ( $l = -4$ )



# A helical radio beam carrying orbital angular momentum

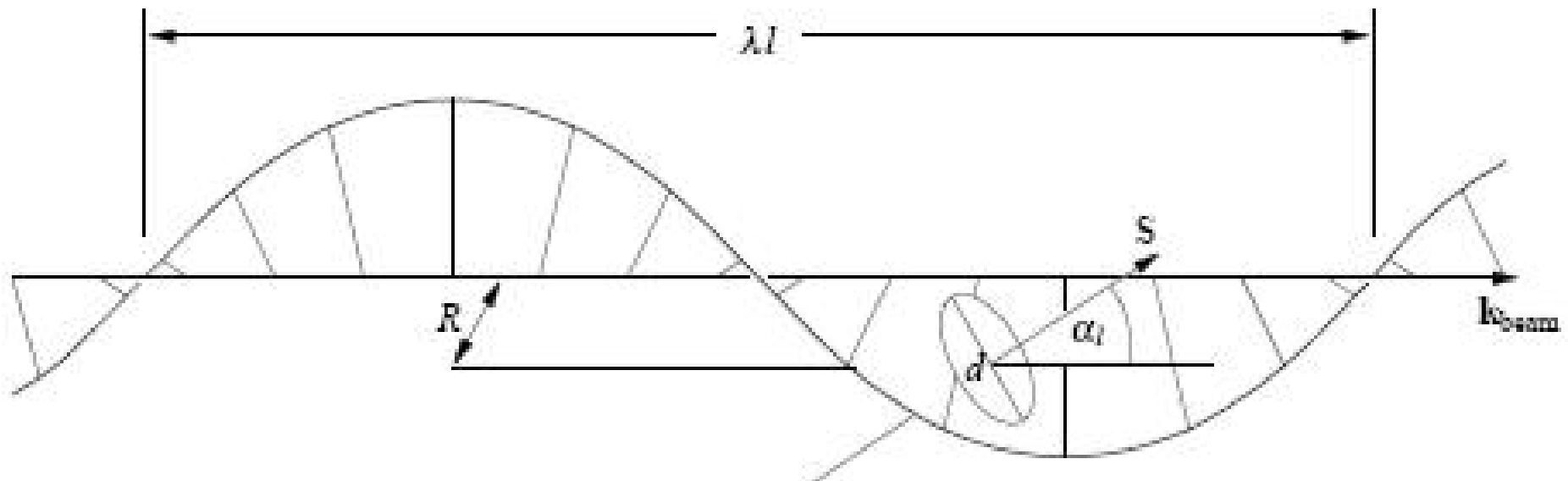


Figure 3: A radio beam with orbital angular momentum is helical. For a beam of waves with wavelength  $\lambda$  and angular momentum  $l$ , an antenna array with a diameter  $d$  and offset from the beam axis by a distance  $R$  will observe a Poynting vector  $S$  which is tilted an angle  $\alpha_l = \arctan(\lambda l / 2\pi R)$  with respect to the beam axis.

## Atmospheric Turbulence and Orbital Angular Momentum of Single Photons for Optical Communication

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The effects of propagation through random aberrations on coherence for single-photon communication systems based on orbital angular momentum states are quantified. A rotational coherence function is derived which leads to scattering equations for azimuthal modes of different orbital angular momentum states. The effect on a single-photon communication system is quantified using the channel capacity. The work shows that the decoherence effect of atmospheric turbulence on such systems is important even for weak turbulence.

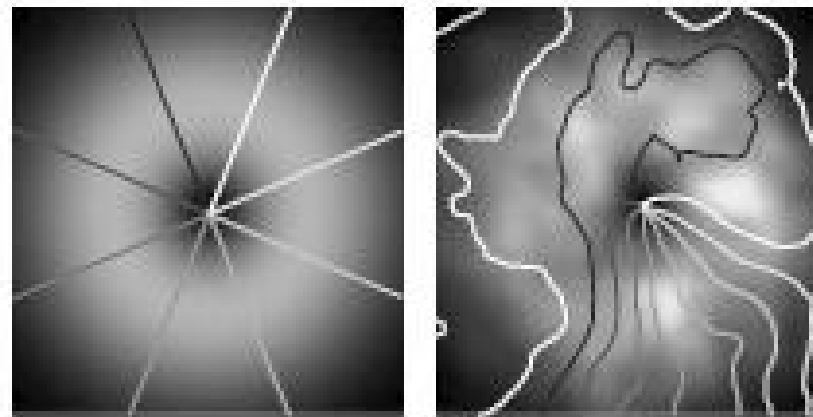


FIG. 1. Example intensity (gray scale) and phase map ( $\pi/4$ -spaced contours) of a pure  $LG_0^0$  beam (left) and the same beam with aberrations caused by propagation through Kolmogorov turbulence (right).