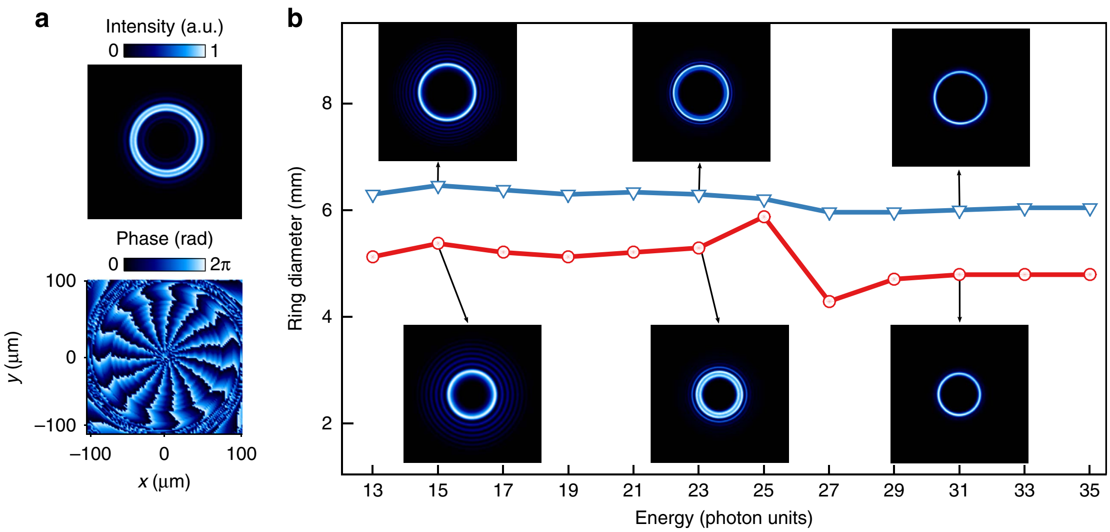

Figure 1 | Calculation of high-order harmonic profiles generated with a driving laser carrying OAM. (**a**) Intensity and phase transverse profiles of harmonic 15 close to focus when the driving laser carries $\ell_1=1$. We observe a well-defined ring-shaped distribution for the intensity (top panel) and a phase profile linearly increasing by $15\times\ell_1\times 2\pi$ along a circle centred on the beam axis (bottom panel). (**b**) Diameter of the harmonic rings in the far field for $\ell_1=1$ (red circles) and $\ell_1=2$ (blue triangles), which present a constant diameter proportional to $\sqrt{|\ell_1|}$. Insets: corresponding intensity profiles for a selection of harmonics.

driving beams[27]. The scaling of the divergence is however very different from the usual Gaussian case, for which the harmonic divergence noticeably changes with harmonic order[28]. When doubling the OAM carried by the driving field ℓ_1, the harmonic diameter increases by a factor of $1.4 \simeq \sqrt{2}$, consistent with the predicted $\sqrt{|\ell_1|}$ scaling law.

Generation of attosecond light vortices. The numerical results reported in Fig. 1 were tested experimentally on the LUCA laser facility at CEA Saclay using the experimental set-up described in Fig. 2a. A spiral phase plate (SPP) is inserted to imprint a spiral staircase phase profile on this incoming beam, which is either one, two or three times 2π per round. Focusing such a phase-shaped beam leads to a distribution of light about the focal point very close to a LG mode carrying, respectively, $\ell_1=\pm 1$, ± 2 or ± 3 units of OAM, the sign being determined by the orientation of the phase mask[29]. This is illustrated by the intensity profile reported in Fig. 2b and accurately measured in Supplementary Note 3. XUV harmonic spectra obtained using an infrared driving field with $\ell_1=1$, 2 or 3 are displayed in Fig. 2c. For each harmonic order and all OAM values of ℓ_1, we observe a clear ring shape pinched in the horizontal dimension by the dispersion of the grating. The divergence of the harmonics, seen in the vertical dimension, appears to be constant throughout the whole spectrum, as predicted.

We measured the average ring diameters to be 1.01 ± 0.02, 1.33 ± 0.04 and 1.61 ± 0.01 mm for $\ell_1=1$, 2 and 3, respectively, in agreement within 5% with the anticipated $\sqrt{|\ell_1|}$ dependency. We note that we observe only one ring. This is probably because of the selection through phase matching of only the short quantum trajectory. Interestingly, we also note that the harmonics are mostly constituted of one single LG mode. The evidence here is that they show a single ring pattern both at focus (where their shape necessarily mimics that of the driving infrared) and in the far field, where they were measured. The diameter of the rings being constant throughout the spectrum, the momentum is conserved and the OAM is multiplied by the harmonic order. Here the highest value is obtained when using $\ell_1=3$, for which $\ell_{19}=57$. We also carried out this experiment in Neon, allowing

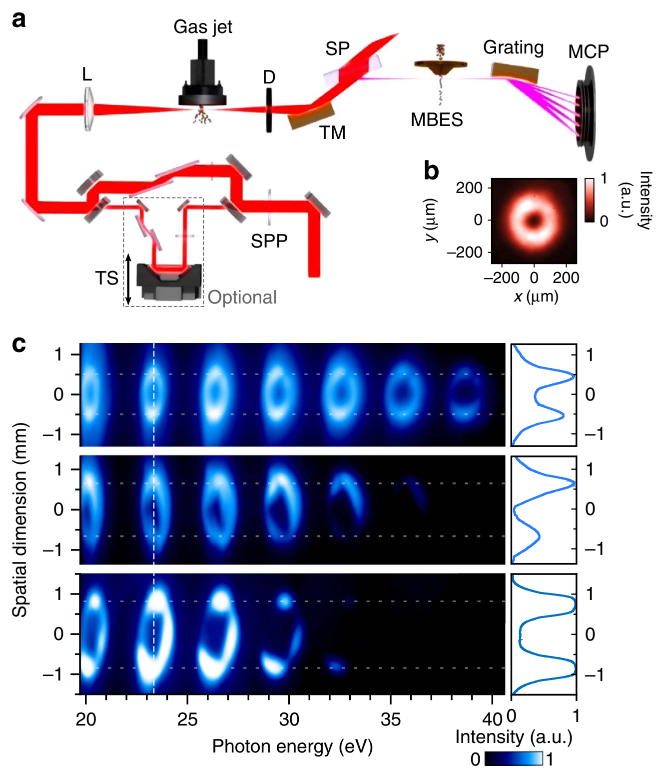

Figure 2 | Experimental observation of HHG spectra carrying OAM. (**a**) Experimental set-up. It has two operation modes, corresponding to the imaging of HHG light spectra and to the characterization of EWP. The close to Gaussian Ti:Sapphire laser beam is passed through a SPP and used to generate harmonics. They can be either directly imaged using a photon spectrometer or focused inside a MBES, where an extra infrared beam can be added with a delay controlled by a translation stage (TS), allowing to perform RABBIT measurements (Methods). (**b**) Intensity profile of the laser beam at focus close to the HHG gas inlet. (**c**) Normalized intensity of harmonic orders 15th to 27th generated in argon and observed in the far field, using $\ell_1=1$ (top row), $\ell_1=2$ (middle row) and $\ell_1=3$ (bottom row).