intriguing possibility. Mutations in the tumor suppressor gene *VHL* that are associated with qualitatively different tumor predispositions (pheochromocytoma versus clear cell renal carcinoma) appear to be associated with quantitative differences in impairment of HIF regulation (*10–12*). Conceivably, matching of cellular context to a relatively precise, quantitatively restricted, level of HIF activation (that is the consequence of an IDH1 Arg^{132} mutation) is necessary for glioblastoma multiforme predisposition. If true, then alteration of such a balance, through metabolic interventions that target α-KG, might offer a therapeutic or preventive strategy.

Finally, although Zhao *et al.* provide an explanation for dominant mutational inactivation of IDH1, they do not completely explain why the pathogenic effects are restricted to Arg^{132}. Other arginine residues (Arg^{100} and Arg^{109} in human IDH1) are implicated in isocitrate binding (*13*), and in recombinant porcine IDH1, mutations at all these sites are inactivating (*14*). Perhaps the proposed disruption of subunit cooperation is restricted to Arg^{132} mutations, or Arg^{132} mutations in some way favor the heterodimerization that is required for dominant inactivation. Alternatively, Arg^{132} mutations might have some quantitatively specific effect on enzyme inhibition that is necessary for oncogenic predisposition.

On the other hand, could there be a primary genetic explanation? Mutational predisposition at CG dinucleotides can explain the common $Arg^{132} \rightarrow$ His substitution but not all of the other mutations. Moreover, Yan *et al.* recently sequenced the homologous exon of the *IDH2* gene in tumors that did not contain an *IDH1* mutation, and found nine mutations at the equivalent Arg^{172}, a residue that is encoded by a codon not containing the CG dinucleotide (*3*). This mutation was shown to be inactivating, although neither dominant inactivation nor effects on HIF were tested. Further studies to test this and other (non–disease-associated) mutations in the model proposed by Zhao and colleagues should be of great interest.

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APPLIED PHYSICS

Laser Beams Take a Curve

Complex energy flows within laser beams can cause them to curve as they travel.

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The properties usually associated with laser beams are illustrated by laser pointers, which are monochromatic (red or green), coherent (they create speckle patterns), and directional (the beam travels in a straight line). However, the advent of laser sources that emit ultrashort laser pulses has changed this simple picture: These sources are broadband and may maintain coherence for very short times—just for one or a few cycles of the electric field. These sources are so intense that, when traveling through a medium such as air, they can ionize atoms and create plasmas. On page 229 of this issue, Polynkin *et al.* (*1*) exploit linear optical effects of laser beams with complex profiles, as well as nonlinear effects that arise at high intensities, to create laser beams that can form plasma channels whose paths curve as they propagate.

Laser beams with complex profiles (that have multiple maxima and minima and are not a single peak) can curve in part because energy can flow between components within these beams. Polynkin *et al.* use a beam profile based on the Airy function, which has its own history in optics—it was introduced in the study of rainbows. A two-dimensional (2D) Airy beam (*2*, *3*) (see the figure, panel A) can be prepared by inserting an active element such as a matrix of liquid crystals oriented so as to tailor the distribution of phase in the plane perpendicular to the beam. This Airy profile is asymmetrical and its intensity is strongly localized in a main peak on one side of the beam profile.

As the beam propagates, interferences between the phases in different locations in the beam profile impose a curved trajectory to the main peak in the Airy profile. This interference effect is linear—it depends neither on the beam intensity nor on interactions with the propagation medium. Viewed head on, the pulse would appear to swing from the left and back to the right. However, the beam's center of mass still propagates on a straight line (the red line in panel A) because the energy fraction contained in the long trail on the other side of the beam balances the main Airy peak.

A further remarkable property of the Airy beam is that it is "self-healing": If part of the beam hits an opaque object, energy flows from the rest of the beam profile and reconstructs the original asymmetric pattern (*4*). A similar self-healing effect occurs in high-intensity laser beams that form self-guided plasma channels, also called filaments (*5–8*). A dynamic balance develops between the nonlinear optical Kerr effect, which changes the refractive index of its propagation medium to create a virtual converging lens, and diffraction by the self-generated plasma, which creates long plasma channels. If a laser filament impinges on a particle, the scattered light is released into the periphery of the profile, where it contributes to the optical Kerr effect, thereby reconstructing the filament shortly after the interaction (*9*). This self-healing capability may allow high-intensity laser beams to access remote locations and to be transmitted through clouds and turbulence, opening the way to atmospheric applications (*8*, *10*).

Polynkin *et al.* combined the complex profile of an Airy beam with nonlinear optical effects to create plasma channels that can turn and follow the shape (or "caustic") shown in panel A of the figure; the plasma forms only in the high-intensity region of the main peak. A key issue is whether the natural (linear) energy flow (see the figure, panel B) that displaces the transverse beam will dominate the nonlinearly induced energy flow from the optical Kerr effect, which attracts energy toward the plasma filament (see the figure, panel C) and feeds it during its propagation.

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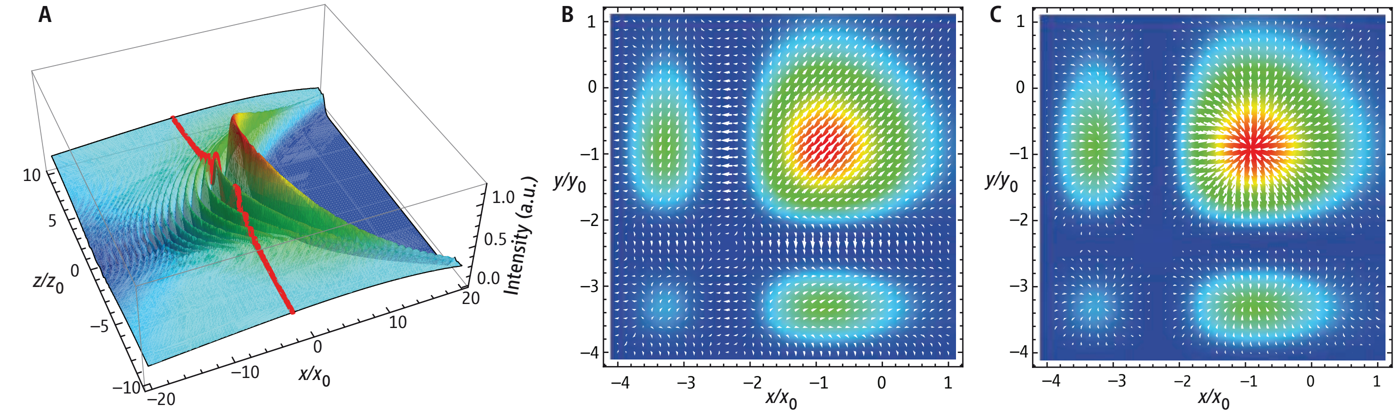

Laser beams taking turns. (**A**) A laser pulse with an Airy profile propagates in the z direction (normalized units). The main peak emerges from an initially broad profile, accelerates toward the exterior of the beam while progressively growing up to $z = 0$, and then loses intensity until it is absorbed in a resurgent broad maximum. The red line is the straight trajectory of the beam's center of gravity. (**B** and **C**) Energy flows in the curving beams of Polynkin *et al*. (B) Linear and (C) nonlinear (Kerr effect) energy flow (white arrows) across the beam profile. The same normalized color scale as in (A) is used to illustrate a 2D Airy beam (damping coefficient $a = 0.1$; $z = 0$). While the linear Airy flow pushes the main peak of the profile toward the top-right corner of the graph, independently from the incident intensity, the Kerr effect tends to attract the energy toward this main peak, with an efficiency proportional to the local intensity. The competition between the two processes causes deformations of the plasma channels generated in Airy beams at high intensity.

At moderate intensities, the transverse energy flux is dominated by the Airy regime, but at higher intensities, the Kerr contribution establishes an attractor at the beam's main peak, and tends to let the beam move straight rather than follow the Airy caustic. However, the curved plasma channels observed by Polynkin *et al.*—both in their experiments and in the numerical integration of the nonlinear Schrödinger equation—show that such a regime is not reached in the filaments in gases, where the intensity ranges from 10^{13} to 10^{14} W/cm^2 (*11*).

Thus, the Airy regime will dominate in most realistic experimental conditions in air. In particular, the observed curved plasma channel compares well to the electron density that would be generated by the intensity of a linearly propagating Airy beam. This density can be estimated as the eighth power of the intensity profile, which takes into account the ionization of oxygen driven by multiple absorption of photons (*11*). However, the longitudinal asymmetry of the curved plasma channel and the bifurcations observed both experimentally and numerically by Polynkin *et al.* show that the Kerr effect cannot be fully neglected at this intensity level.

Because the trajectory of the curved plasma channels roughly follow that of the Airy beam, their length and curvature suffer from the same limitations related to the intensity drop of the main peak along its propagation path. The maximum achievable deviation from a straight path scales linearly with the initial beam size w_0, but the propagation distance required to reach a given deviation scales with w_0^2. Sending a macroscopic Airy beam around a corner thus appears difficult. For example, an Airy beam with a main peak of w_0 = 1-cm width and an optimal value of the confinement factor a (in this case, 0.05) would need to propagate more than 2.8 km before reaching its maximum deviation of only 24 cm.

Nevertheless, Airy beams carrying high intensities provide a wealth of attractive applications at smaller geometrical scales. Self-bent beams could be used to manufacture curved waveguides in transparent bulk media, in a way similar to permanent optical waveguides inscription in fused silica using filaments (*6*). The ability of controlling curvature would allow for the realization of complex guiding structures in three dimensions, with applications such as wavelength division multiplexers, beam splitters, and couplers. A beam main peak of ~10 µm could be deviated by ~25 times its size, meaning that it would have moved off a straight trajectory by 250 µm after less than 3-mm propagation.

A further striking advantage of Airy-driven curved propagation, compared to Kerr-driven propagation, is its applicability in vacuum. A curved beam in vacuum, especially at high intensity, could open new ways of achieving long interaction lengths with particle beams, acceleration of protons and electrons on controlled trajectories, or efficient coupling with beams of x-rays or gamma-rays.

The use of Airy beams in the context of high-power pulses and self-channeling further builds on a recent trend to apply specific beam shapes, such as X-waves (*12*), Bessel beams (*13*), or axially or radially polarized beams (*14*), to exploit their remarkable properties already developed in the linear regime. Depending on the specific beam shape considered, such properties may include nondiffractiveness, self-healing, transverse acceleration, or the generation of a zero electric field at the beam center. When these methods are used with higher-power sources, nonlinear effects such as self-guiding further extend their scope for applications. Examples include tailoring the spectrum of the "white light" generated in the filaments for atmospheric remote sensing, or using filaments and their associate plasma to divert lightning strikes from sensitive targets, such as airports and industrials plants (*15*).

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