

## Measurement of a superluminal ionization front

Ilya Alexeev, K.Y. Kim, and H.M. Milchberg

*Institute for Physical Science and Technology  
University of Maryland, College Park, MD 20742*

It is well known that a sufficiently intense laser beam focused in a gas can produce ionization as it propagates. Focused beams are usually produced by conventional lenses or mirrors and the ionization front (the boundary between ionized and not-yet-ionized gas) co-propagates with the laser pulse at approximately its group velocity, which is less than  $c$ , the speed of light in vacuum. However, there is an interesting class of electromagnetic waves called Bessel beams, whose peak electric field can move at greater than light speed. Such beams can be produced using phase masks or from cones in reflection or transmission. In the form of a transmitting glass cone, this element is called an axicon. Geometrically, when the laser beam is sent through the flat base of the axicon, it refracts from the conical surface and forms a high intensity focal zone which propagates away from the cone apex at a speed faster than  $c$ . The particular speed of the focus propagation depends on the details like the axicon cone angles, axicon material, and ambient material (such as gas type and density), but it is *always* greater than  $c$ . By using a sufficiently powerful laser pulse, ionization can be generated by the propagating focus, and this ionization front should travel at faster than  $c$ . The figure shows measurement of the ionization front in argon gas from a 70 femtosecond Bessel beam pulse using two methods. In the first method, an absolutely synchronized, transversely directed femtosecond probe pulse passes through the interaction region, and the scattered light from the plasma is imaged, showing the ionization front. By delaying the probe beam with known time delays, the front can be ‘strobed’ at successive downstream locations, and the speed is determined to be 1.1 times faster than  $c$ . The second method involves longitudinally co-propagating a chirped, frequency doubled probe pulse along the ionization front, and sending this pulse to a spectrometer that images along the entrance slit direction. The time-dependent transverse refraction of the probe pulse gives rise to an image with a Cerenkov-like scattering cone whose angle also verifies the superluminal ionization front speed. It is important to note that the distinct front images were made possible by the use of intense femtosecond pulses: longer pulses would have resulted in reduced contrast of the ionization front.

**Contact:** Ilya Alexeev  
Institute for Physical Science and Technology  
University of Maryland, College Park, MD 20742  
(301) 405-4847  
[ilya@ipst.umd.edu](mailto:ilya@ipst.umd.edu)

**Figure caption:**

Setup showing measurement of superluminal ionization front, using time-resolved transverse imaging of scattered femtosecond probe light, and spatio-spectral imaging of longitudinally propagating chirped second harmonic probe light. The circular inset shows the generation of the Bessel beam in the axicon focal region.

