Imaging at the speed of light

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Progress in the design and development of arrays of single photon avalanche diodes (SPAD) has led to the first SPAD cameras that are paving the way for a series of applications ranging from enhanced time-of-flight imaging to fluorescence life-time microscopy.
These SPAD cameras also allow imaging of light at the single photon level and, when operated in "time-correlated single photon counting" (TCPSC) mode, give a temporal resolution that can be of the order of 100 ps. Light propagates by only 3 cm in 100 ps – such a temporal resolution thus allows to effectively freeze light in motion and obtain images and videos of "light in flight". As an example, the figure below shows a few snap-shots from a full video in which we observe a pulse propagating in air and bouncing of several mirrors. The 500 ps (15 cm long) laser pulse with a wavelength of 532 nm is propagating in free space, i.e. air. Although "light in flight" measurements have been performed before, these all required intercepting the light pulse with a white screen (and the reflection of light from screen was measured) or, more recently, an additional scattering agent e.g. mist (in air) or nanoparticles (in water). These methods produce a large amount of scattered photons that can thus be detected by the imaging device (typically a standard CCD or streak camera). Conversely, the single photon sensitivity of the SPAD camera allows for the first time to observe light in flight without any additional scattering agent, i.e. by simply collecting the few photons scattered by air molecules. As a further example we performed direct light in flight measurements of an intense laser pulse creating a filament in air and thus generating a plasma filament. The high temporal resolution allows to clearly observe the dynamics of the pulse propagation and plasma evolution.
SPAD arrays may be used for a variety of applications beyond light-in-flight diagnostics. For example, the weak light imaging capability enables imaging of objects hidden from view. The camera can be used in two modalities: (i) it can visualize objects hidden from the direct line of sight by multiple scattering of a laser beam that allows to circumvent the obstacles blocking the line of sight; (ii) it can be used to image directly through the obstacle or wall by capturing even extremely weak (single photon level) ballistic photons.
We will discuss these ideas that address both fundamental questions regarding the fundamental nature of the propagation of light and novel applications of light for range finding and tracking objects.

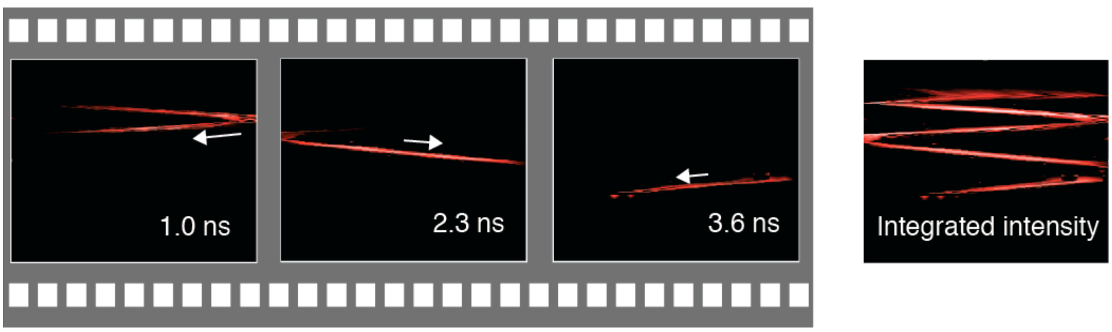

Figure 1. Frames from a light-in-flight movie of a pulse of light propagating in free space. Each frame is separated by 1.3 ns. The arrows indicate the propagation direction of the laser pulse. The integrated intensity shows the total path of the light.