

In the article we present the first experimental demonstration of cloaking an event in the time domain. Our temporal cloaking scheme is based on the time-space duality and novel split time-lenses (STL) composed of two half time-lenses connected at the tips. In this document we first present the full configuration of a STL, its spectral response and the phase imposed by it on the probe beam for opening a 20-ps gap. We also present in details our numerical model for simulating the probe as it propagates through the setup.

A space-time schematic of a single STL is presented in supplementary Fig. 1(a). The split time-lens focuses light to the edges of the time window rather than to the center so that after propagating through a medium with normal GVD, part of the probe light is delayed in time while the other part is advanced. This is realized by imposing a parabolic phase shift with a discontinuity in the middle as presented in supplementary Fig. 1(b). To obtain such a STL, we utilize Bragg scattering via four-wave mixing process with two pump waves at frequencies denoted by ω_1 and ω_2 . This parametric process shifts the frequency of the probe beam by the frequency difference between the two pumps, as

$$\omega_1 - \omega_2 = \omega_i - \omega_s, \quad (1)$$

where ω_s and ω_i are the signal and idler frequencies, respectively. The energy diagram for this process is presented in supplementary Fig. 1(c). In our case the beam at ω_1 is continuous wave (CW) while that at ω_2 is chirped. Since the signal wave is CW, the resulting idler wave is chirped. Due to the phase matching conditions, the chirp is opposite to that of the ω_2 pump wave. With such a four-wave mixing process it is possible to impose a phase shift as large as 4000π on the idler with respect to the signal wave.

The full configuration of one STL is presented in supplementary Fig. 2. A short pulse splits into two paths, each with bandpass filters. One filter has a 0.18 nm bandwidth so that the pulse becomes 20-ps long, while the other has a 10-nm bandwidth so that the pulse duration is shorter than 0.4 ps. Supplementary Fig. 2(a) presents the wavelength as a function of time for the narrowband pulse and supplementary Fig. 2(b) for the broadband pulse. Next, 120 m of single mode fiber (SMF) with a total dispersion of 2.2 ps/nm is exploited to chirp the short pulse into 20-ps long pulse such that the wavelength as a function of time is presented in supplementary Fig. 2(c). Using a diffraction grating we spectrally spread the chirped pulse

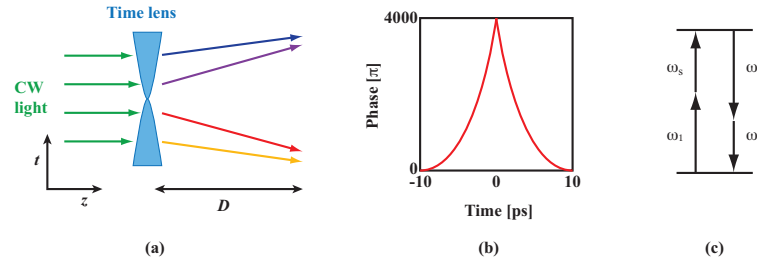


Fig. 1. Split time-lens (STL) composed of two halves of a regular time-lens which are connected at the tips. Inset (a) presents the space-time schematics of the STL; inset (b) presents the phase as a function of time imposed by the STL; Inset (c) presents the energy diagram of the Bragg scattering process.

and reflect the light back into the fiber with two mirrors, one for the longer wavelengths and one for the shorter wavelengths. The two mirrors are displaced by 3 mm so as to obtain a delay of 20 ps between the short wavelengths and the long wavelengths, as presented in supplementary Fig. 2(d). Finally, we combine the two pulses, as presented in Fig. 2(e). The combined pulses are coupled to the probe laser by a wavelength division multiplexer (WDM) to serve as pump pulses for the STL. The pump and the probe laser are sent through 20 m of highly nonlinear fiber (HNLF) where the four-wave mixing process between the two pumps and the probe beam shifts the wavelength of the probe beam according to the frequency difference between the two pumps. Therefore, the resulting wavelength as a function of time after the time-lens is linearly spread with a discontinuity in the middle, as presented in supplementary Fig. 2(f).

To characterize the STL, we measure the spectrum before and after the nonlinear fiber. The results are presented in supplementary Fig. 3. The dashed (blue) curve denotes the spectrum of the two pump beams and the probing light before the nonlinear fiber. The solid (red) curve denotes the spectrum after the nonlinear fiber. The four-wave mixing process transforms part of the light in the probe beam to form pedestal. We operate the pumps with different power levels such that the two curves will not overlap and will be clearly observed in the figure. We note that both STL's operate with identical pump pulses and are synchronized. In order for the second STL to completely undo the temporal focusing of the first one, adjustment of the relative phase between the pump waves of the second STL and the signal wave is necessary.

We numerically simulate the STL using the standard nonlinear propagation equation with dispersion under the slowly varying envelope approximation. We model the pump field $E_p(t)$ as the sum of a short CW field and a rectangularly dispersed pulse. The dispersed pulse is calculated by multiplying the FFT array with the dispersion operator $\exp(iD\omega^2)$. Half of the

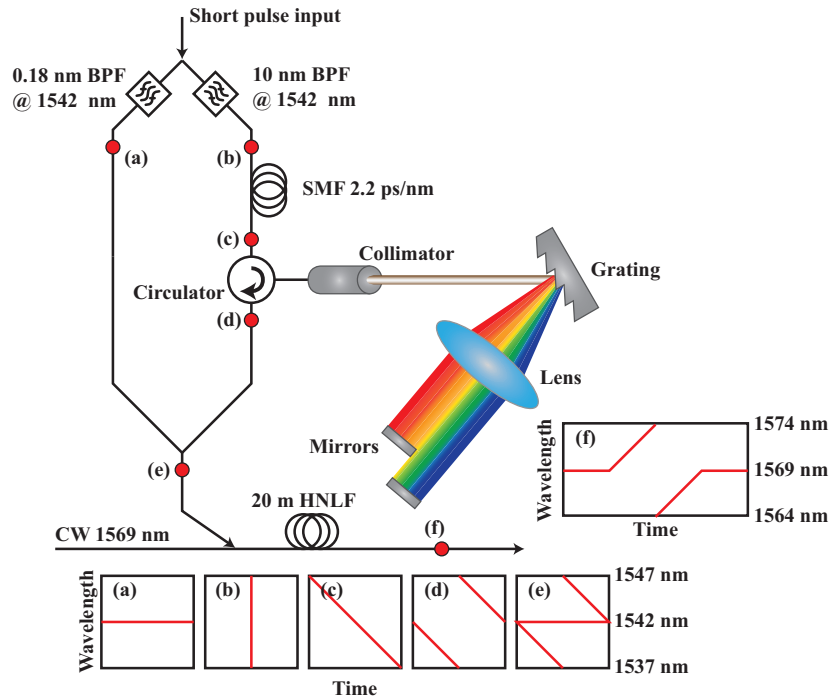


Fig. 2. Experimental configuration of a single time-lens. Insets (a)-(e) present the wavelength of the pump as a function of time at five different points in the configuration; inset (f) presents the wavelength of the probe beam as a function of time after the split time-lens. BPF - band pass filter; DCF - dispersion compensating fiber; HNLF - highly nonlinear fiber.

spectrum of the pump is then delayed with respect to the other to create the split time-lens. Next, we obtain the time-lens process by multiplying a constant probe with $\exp(i\gamma|E_p(t)|^2)$, and propagating the probe through the dispersive material such that the dispersion operator $\exp(iD\omega^2)$ is applied on the resulting field.

To simulate the event, we solve the nonlinear interaction between the probe at the focus and a short pulse of light. The result from this interaction yields the perturbed field that is used to detect the event. To obtain the amplitude of the perturbed field as a function of the pump power (Fig. 5 solid curve), we perform the simulation for different values of γ , i.e. different pump power and took into account the noise level of the detector. We also calculate the spectrogram of the probe beam before and after the first STL, at the focus, and before and after the second STL. These results are presented in the article in Figs. 2(a)-2(e).

To conclude, in this supplementary method we present in experimental and numerical details the STL used for temporal cloaking. This setup also enable us to realize other time-lenses with more complicated designs.

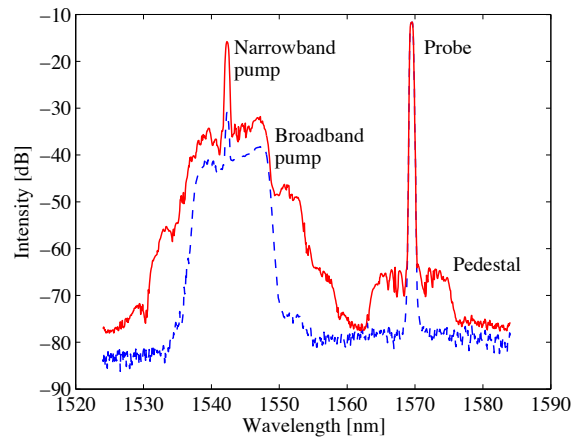


Fig. 3. Spectrum of the light before and after the highly nonlinear fiber. The dashed (blue) curve denotes the spectrum of the two pumps and the probe beam before the nonlinear fiber. The solid (red) curve denotes the spectrum after the nonlinear fiber. After the nonlinear fiber, the pedestal around the probe beam are clearly observed, indicating that the wavelength of part of the light from the probe is shifted. We operated the pumps with different power levels such that the two curves will not overlap and will be clearly observed in the figure.