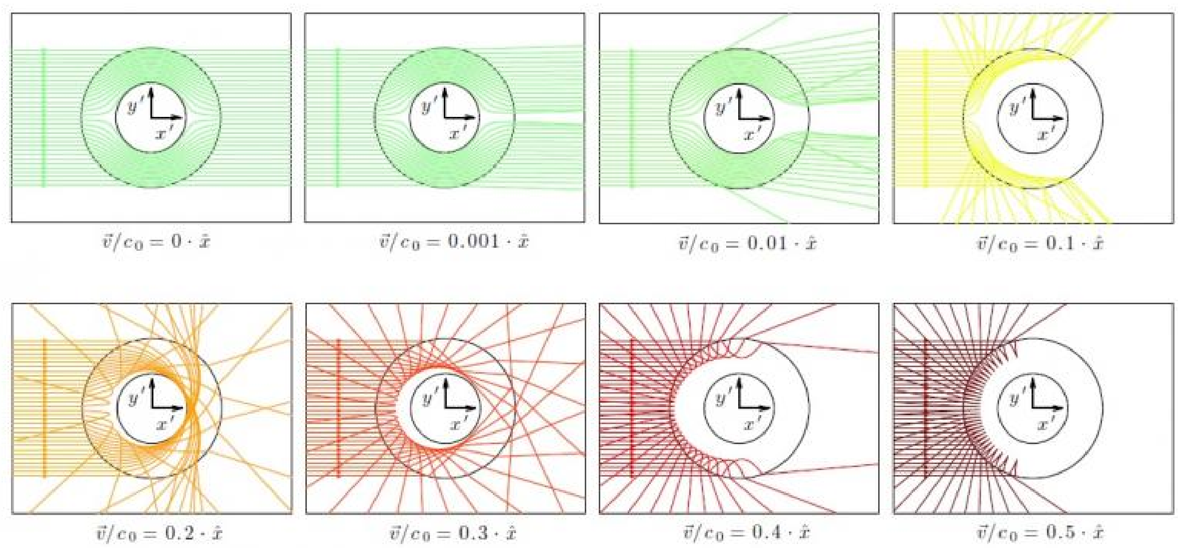
PHYS.ORG

Fast-moving invisibility cloaks become visible

January 28 2016, by Lisa Zyga



A cylindrical invisibility cloak is perfectly invisible when not in motion (top left) because the incoming light rays have the same frequency as the cloak's operational frequency. As the cloak's velocity increases, the frequency of the light changes so that it no longer matches the operational frequency, creating image distortions that cause the cloak to become visible. (Colors correspond to the light's frequency.) Credit: Halimeh, et al. ©2016 American Physical Society

(Phys.org)—Physicists have found that invisibility cloaks that can achieve perfect invisibility when not in motion will become visible when moving at speeds of around thousands of meters per second. This is because invisibility cloaks appear invisible only to light at a certain frequency called the cloak's "operational frequency." When the cloak is moving at high speeds with respect to an observer, relativistic effects shift the frequency of the light arriving at the cloak so that the light is no longer at the operational frequency. In addition, the light emerging from the cloak undergoes a change in direction that produces a further frequency shift, causing further image distortions for a stationary observer watching the cloak zoom by.

The scientists, Jad C. Halimeh, et al., have published a paper on invisibility cloaks moving at relativistic velocities in a recent issue of *Physical Review A*.

Although the work shows that high speeds can be detrimental for invisibility cloaks, the physicists also showed that, for light with the right frequency moving in the right direction, the harmful relativistic effects will cancel out, and perfect cloaking can still be achieved. However, this cloaking is now inherently "non-reciprocal," meaning an observer inside the invisibility cloak would be able to see people on the outside.

"The non-reciprocal cloaking is actually quite an interesting feature, as people have been investigating it for quite some time in the context of transformation optics. Here, this effect just came about from the physics – we didn't really design it," Halimeh, a physicist at the Ludwig Maximilian University of Munich, told *Phys.org*.

This is the first time that relativistic invisibility cloaks have been investigated, although there has been a great deal of research on other objects moving at relativistic velocities. In general, two unusual phenomena occur in these situations: length contraction (the moving object appears compressed to a stationary observer) and time dilation (time slows down for the moving object compared to a stationary observer). These effects have been well-documented for fast-moving particles, and time dilation has even been measured for astronauts, who age a fraction of a second slower aboard the fast-orbiting International

Space Station than they would on Earth.

In the new study, the scientists found that length contraction and time dilation also contribute to making an invisibility cloak visible when moving at relativistic speeds. Length contraction and time dilation help create a relativistic Doppler effect, which is similar to the regular Doppler effect that causes a siren to sound higher-pitched (wavelengths are compressed) as it comes closer and lower-pitched (wavelengths are extended) as it moves away. Although the relativistic Doppler effect is more complicated than the regular Doppler effect, in both cases the frequency shift is caused by the relative motion of the source and the observer. Even small frequency shifts as perceived by the cloak cause distortions, technically called "aberrations," that can interfere with the cloak's invisibility. As the cloak's velocity increases, the aberrations become more pronounced.

Yet no matter how fast the cloak is moving, the researchers showed that it's always possible to find a way to restore invisibility at that specific velocity.

"This is achieved by giving light of some frequency the right direction such that the Doppler shift is canceled," Halimeh said. "The relativistic Doppler shift can be seen as an admixture of a longitudinal Doppler red-shift and a transverse Doppler-blue shift. For a given frequency, you can tune the direction such that these two shifts cancel each other out and the cloak ends up seeing the light as having its operational frequency, thereby cloaking it."

Using this strategy, the researchers show that there are infinitely many combinations of light frequency and direction that can be cloaked at any given relativistic velocity. The results will help scientists better understand the abilities and limitations of invisibility cloaks.

"We are interested in such research for two reasons," Halimeh said. "First, it allows us to further investigate whether or not these invisibility cloaks are electromagnetically equivalent to vacuum. Second, it allows us to better understand the limitations of these cloaks when it comes to a relativistic world, where we have fast-moving objects that we need to cloak or cloak ourselves from, or in case we are in a strong gravitational field, for example, and we wish to have a cloak that works there as well."

As coauthor Dr. Robert Thompson at the University of Otago in New Zealand added, the results go beyond cloaking.

"Scientists around the world are using cloaking as a testbed for the design and construction of new light-controlling technologies that could have a big impact on everything from communications to medical devices, and fully understanding the kinds of effects we're studying is crucial for making the most of these new technologies," Thompson said.

More information: Jad C. Halimeh, et al. "Invisibility cloaks in relativistic motion." *Physical Review A*. DOI: 10.1103/PhysRevA.93.013850 . Also at arXiv:1510.06144 [physics.optics]