Optical Lens Activity
Cosmology Crash Course

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This activity requires an optical lens that simulates the gravitational lensing of a point mass, graciously lent to us by Bhuvnesh Jain.
See http://www.hep.upenn.edu/~bjain/harrison/setup.html

The glass lens is your own personal black hole to play with for the next 15 minutes. (Not really, but it bends light like there's a small, very dense, point mass at its center.)

Look at a dot on a sheet of paper. Close one eye and observe the dot when you put the lens near or in front of the dot. See how the image of the dot changes as you move the observer and the lens both in redshift (closer or further away from the dot) and in postion on the sky (In general, you will see 3 kinds of images: (1) a nearly undistored dot (2) two distorted images of the dot (3) an Einstein ring (looks like the dot is smeared into a circle)

A) What is the relative angular position of the dot and the black hole when you see an Einstein ring?

B) How does the apparent size of the Einstein ring change as you vary D_L (keeping D_S constant)? What if you vary D_S (keeping D_L constant)?

C) When do you see two distorted images of the dot?

   a) Describe the shapes of these two images.

   b) If you open your other eye, you can see the (approximate) actual position of the dot as well as its lensed images. Describe the angular position of these images relative to the actual angular position of the source and the angular position of the lens.

   c) What do you notice about the sizes of these two images? How do their relative sizes change as you increase the angular separation between the source and the lens?

D) When the angular separation between the source and the lens is small, does the image cover more solid angle or less solid angle than the unlensed source?

E) Now pass the lens over the Hubble Deep Field image. How does it tend to distort the image? If you were given an image that was strongly lensed by a black hole, how might you try to guess where the black hole is? (Note: we are cheating here; really all the galaxies should be at different redshifts, not on a sheet of paper.)

F) Write your own question(s), and experiment to find the answer!

G) (Bonus) Estimate the mass of the black-hole gravitational lens that would produce the same effect as the optical lens. The Einstein radius is given by

$$\theta_E = \sqrt{\frac{D_{LS}}{D_L D_S}\frac{4GM}{c^2}}$$