Shedding Light on Dark Matter Through Gravitational Lensing

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Abstract

Dark matter comprises a larger fraction of the universe's mass than ordinary matter, but it's practically invisible because it doesn't emit or absorb electromagnetic radiation. However, we are able to observe its effects in space through gravitational lensing. Gravitational lensing is the bending of light caused by a massive object that creates distorted images of what an observer would otherwise see with a telescope. Using data analytical techniques in Python, we are able to create simulations placing clumps of dark matter on gravitationally lensed images and observe effects on those images. The focus of this particular project is the data cube, which is a three-dimensional array of panels, called velocity channels, of the gas at different line of sight velocities in the galaxy we are observing. Using residual maps, we are able to determine the range of masses and positions of clumps of dark matter that can be detected in gravitationally lensed images. To find the lowest possible mass that can be detected, we decreased the Einstein radius, which is directly proportional to the clump's mass, by factors of 10 and placed the clumps directly on the foreground galaxy and placed the clumps near the foreground galaxy. The results of this research increase our understanding of dark matter and gravitational lensing by allowing us to detect more cases of dark matter lensing objects in observations. Using high angular resolution data for our images will make the detection of minimal amounts of dark matter through gravitational lensing more accurate.

Background

Gravitational lensing is the bending of light caused by a massive object that creates distorted images of what an observer would otherwise see with a telescope.

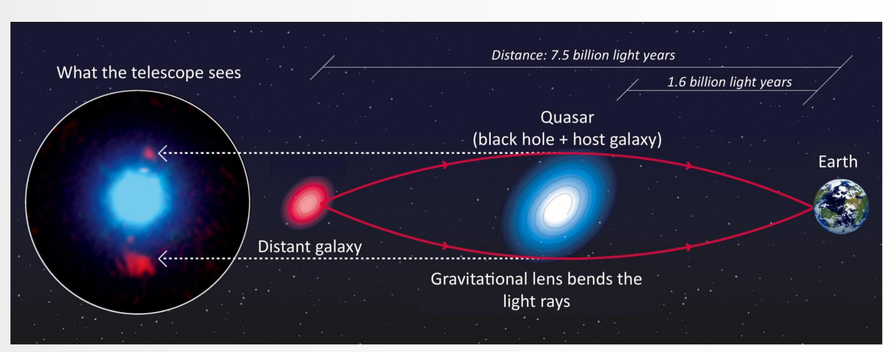


Image credit: G. Djorgovski

Figure 1: Diagram of how gravitational lensing works. In this cartoon, light from a distant galaxy (left) is bent by the gravitational lens (middle), so that it appears two places on the sky (i.e., images) from the point of view of an observer on or near the Earth (right).

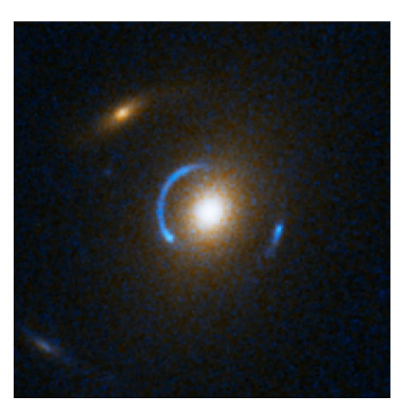


Image credit: NASA, ESA, A.Nierenberg, & T. Treu

Figure 3: Hubble Space Telescope image of a nearly complete Einstein ring, which is produced by the gravitational lensing of a distant source by a lens that is almost exactly along our line of sight to it.

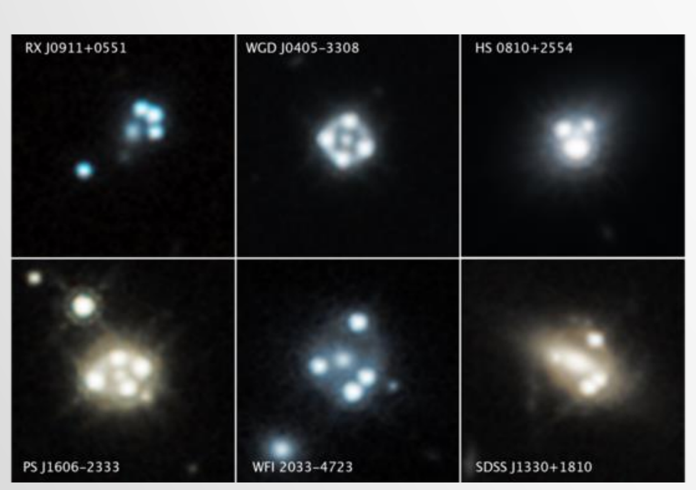


Image credit: NASA, ESA, A. Bolton, & SLACS team

Figure 2: Hubble Space Telescope images of lensed quasars. Gravitational lensing can sometimes produce double or even quadruple images of a single source.

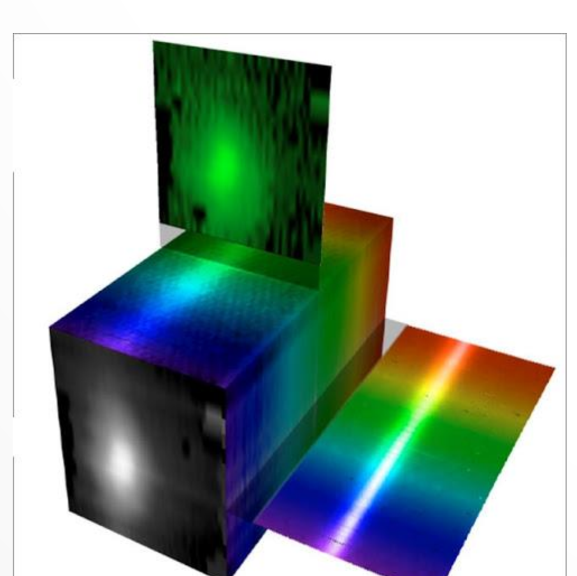


Image credit: IPSEO/University of Strasbourg

Figure 4: Diagram of a data cube with spatial axes x and y, and a third velocity axis. The velocity tells us if material is moving towards or away from the observer and is measured from the changing wavelength (or frequency) of the emission.

Methods

The data cubes used in this project were simulated to reproduce observations of a rotating gas disk (with fixed parameters), before being artificially lensed by a main lens and (sometimes) an additional clump with different properties. The resulting lensed data cubes were then convolved (blurred) to represent possible point spread functions.

All the Figure As are the simulated lens models with parameters (b,x0,y0,ec,es,s). b is the Einstein radius of the lens model which is directly proportional to the lens's mass. x0 and y0 are the coordinates of the center of the lens. ec and es describe the ellipticity of the lens. s is the core radius of the lens. The only difference between each A figure is the value of the full width half max (FWHM) that affects the blurriness of the model. Figure 5A is a relatively clear picture with a FWHM value of 0 arcsec, Figure 6A has a FWHM value of 0.25 arcsec, and Figure 7A has a FWHM value of 0.5 arcsec.

All the Figure Bs are simulated lens models with a clump of dark matter. The clump has the same set of parameters with the addition of parameter a. Parameter a is the truncation radius of the clump. When making the titles of the various figures we used the terms bullseye and offset to represent the position of the clump. Bullseye means that it is near or directly on one of the lensed images and offset meaning far from any lensed image.

All the Figure Cs are residual cubes, which show the difference between the lens model without a clump and with a clump. This is the most effective way to see the effect of dark matter.

The unlensed model used to produce these figures is a rotating gas disk observed in CO(1-0) emission at z = 2.5, with half-light radius 1.645 kiloparsec, maximum rotation velocity 150 km/s, velocity dispersion 30 km/s, and inclination 45 degrees.

Figure 5 (A,B,C)

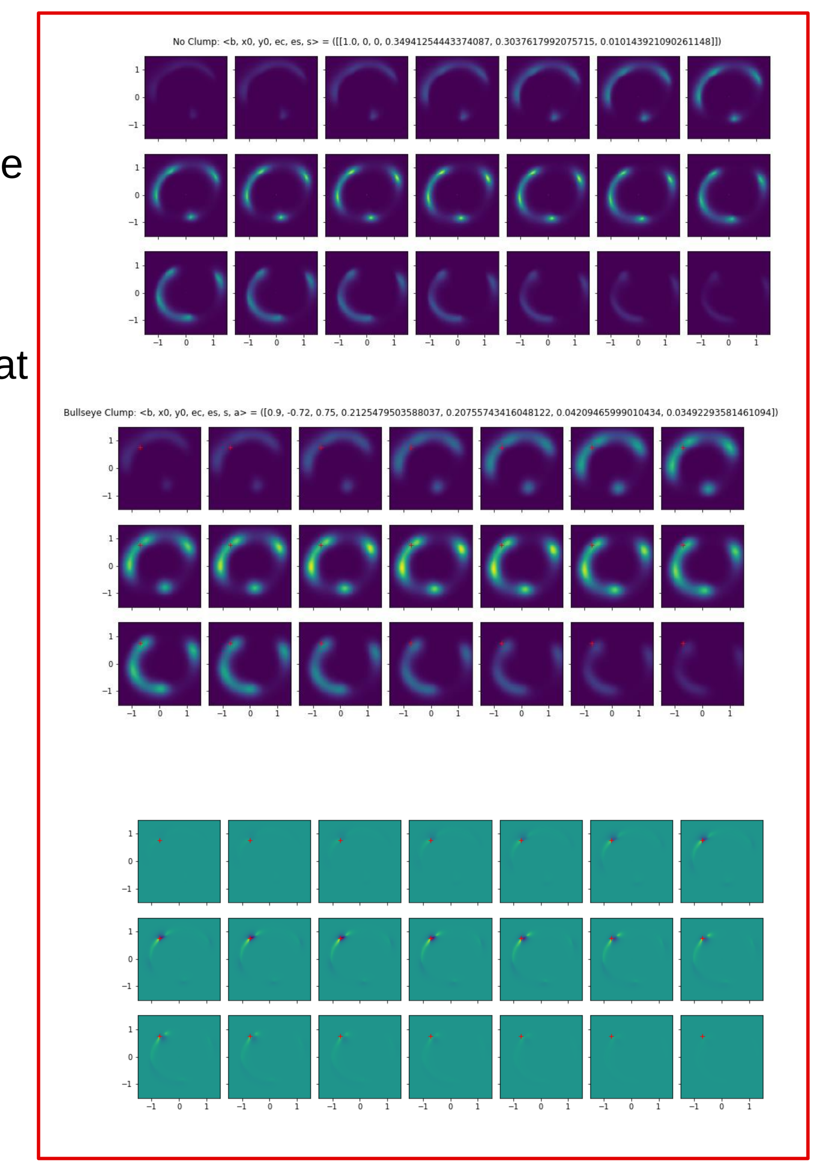


Figure 6 (A,B,C)

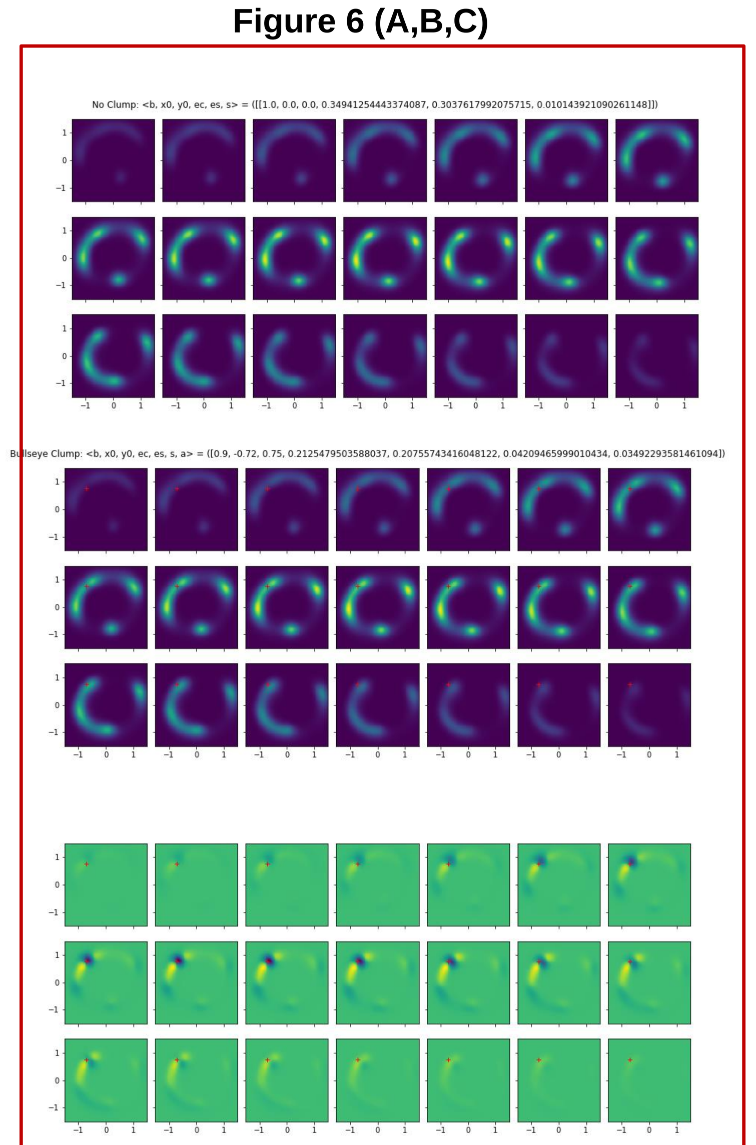
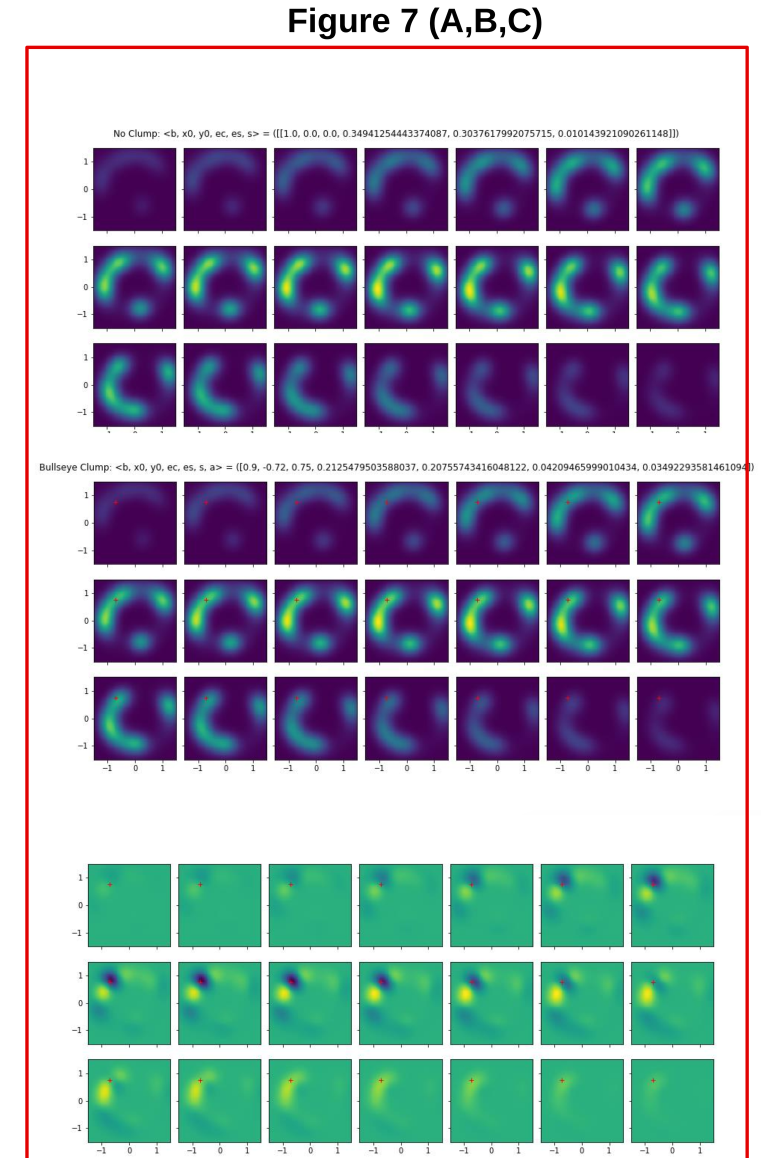


Figure 7 (A,B,C)



Results

The smallest Einstein radius for a clump to be detected when the image is unblurred, slightly blurred (FWHM = 0.25 arcsec), and highly blurred (FWHM = 0.5 arcsec) is b =0.00000001 arcsec where the Einstein radius of the main lens is 1 arcsec. The same is also true for clumps that are far away but the effect of lensing varies with position. Detectability of clumps will also be affected by image noise, not considered here.

Figure 8 (A,B,C)

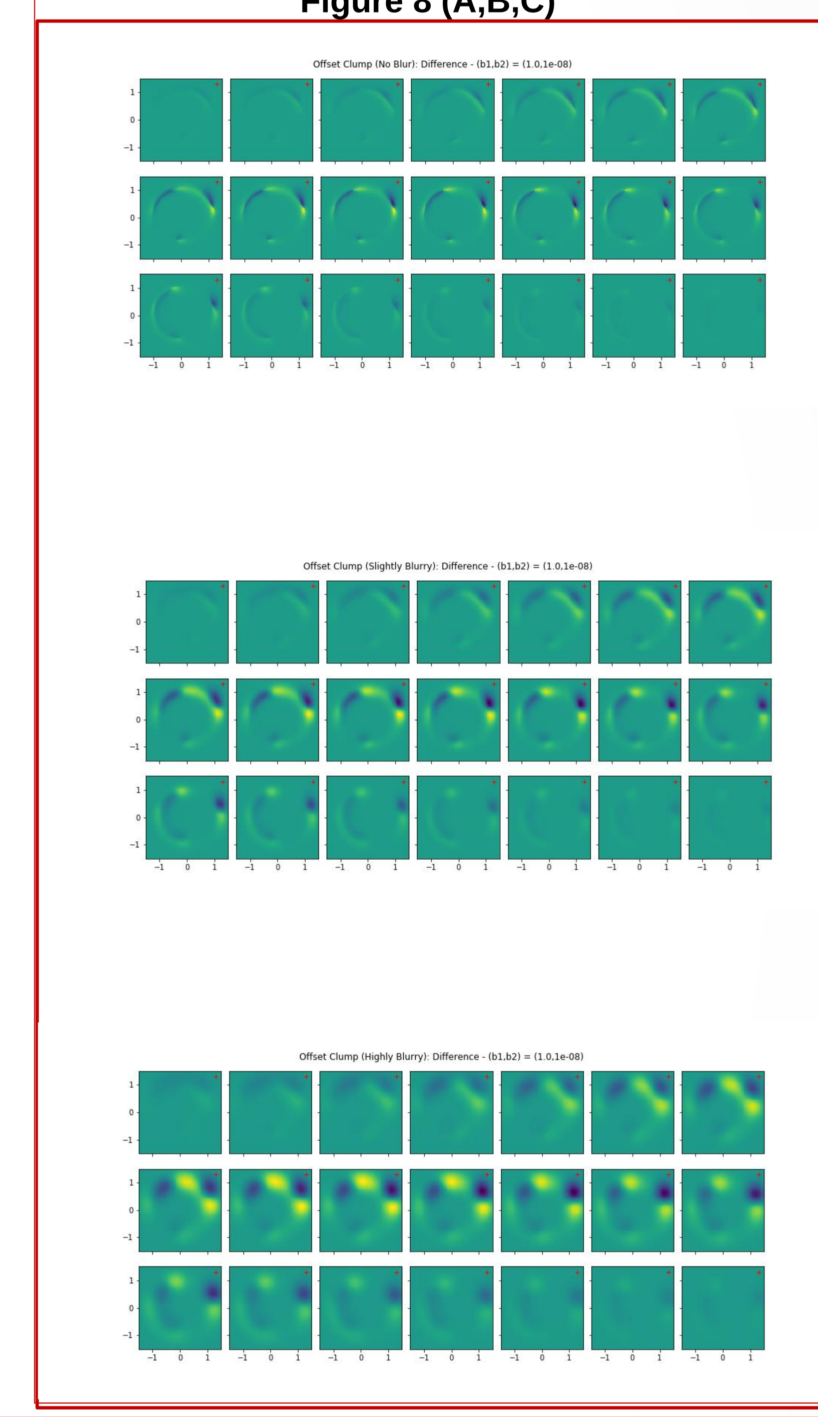
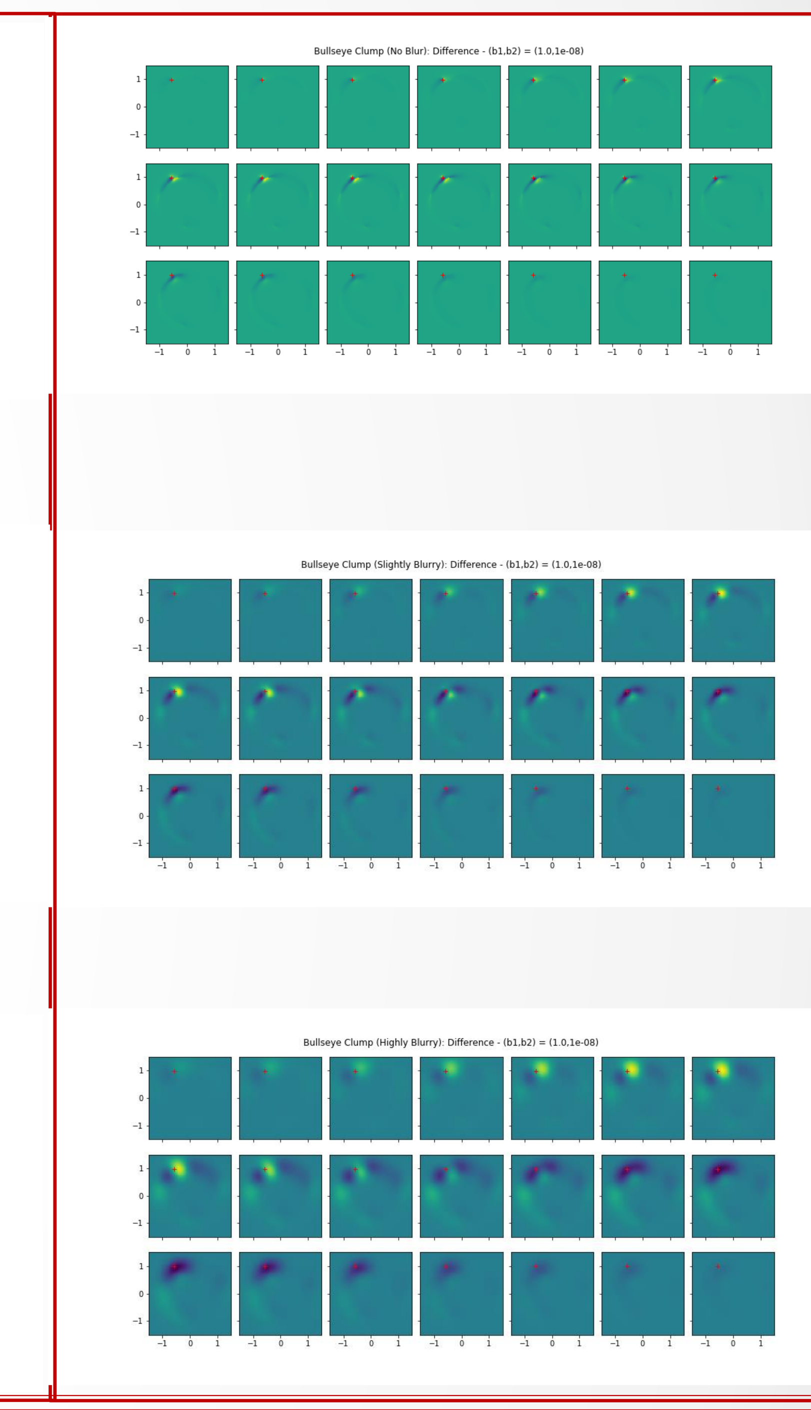


Figure 9 (A,B,C)



Conclusion

The detection of a clump of dark matter is directly proportional to the mass of the clump and inversely proportional to the blur (i.e., point spread function) and distance of the clump in projection from a lensed image.

Future Direction

Future questions to explore include, "How would the range of masses and positions of detectability change if there were multiple clumps?" and "Would a massive clump have the same effect as multiple smaller clumps. To address those questions I would have to run simulations of multiple smaller masses and compare them to results for a single clump with the mass of the sum of the smaller masses. The position of the massive clump would be found through trial and error so its residual cube will look similar if not identical to the previous result. It would also be helpful to explore the effects of image noise on detectability.

Acknowledgments

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