Computer Programming to Advance Gravitational Lensing

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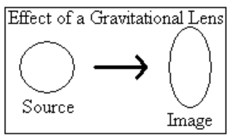
1. Abstract

My purpose this summer was to write a computer code that will numerically test a Poisson equation developed by Dr. Kling and Bryan Campbell. My computer code applies this new equation to simulated data, generated by the program. The code performs numerical analysis of the resulting data.

2. Gravitational Lensing Basics

General Relativity predicts that the path of light is bent by the gravity of massive objects. It has been observed that a galaxy cluster will behave approximately as a thin lens. The result is apparent elliptical stretching of objects far behind the galaxy cluster.



The amount of elliptical stretching is the observable quantity in gravitational lensing. Our equation relates the mass distribution of a galaxy cluster to the ellipticity of background objects.

3. The Poisson Equation

The point of this project is to test the effectiveness of this new equation at finding the mass distribution of a galaxy cluster.

$$\frac{\partial^2\kappa}{\partial x^2}+\frac{\partial^2\kappa}{\partial y^2}=\frac{\partial^2\gamma_1}{\partial x^2}-\frac{\partial^2\gamma_1}{\partial y^2}+2\frac{\partial^2\gamma_2}{\partial xy}$$

κ is mass density and γ_1, and γ_2. are related to the shapes of the galaxies. We solved this equation for κ by using second order Taylor expansions of κ, γ_1, and γ_2.

$$\kappa(x,y)=\frac{1}{4}[\kappa(x+h,y)+\kappa(x-h,y)+\kappa(x,y+h)+\kappa(x,y-h)-F]$$

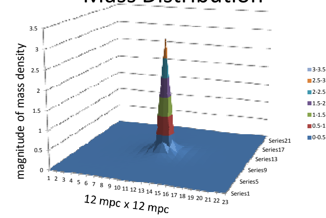
$$F\equiv\gamma_1(x+h,y)+\gamma_1(x-h,y)-\gamma_1(x,y+h)-\gamma_1(x,y-h)$$
$$+\frac{1}{2}[\gamma_2(x+h,y+h)+\gamma_2(x-h,y-h)-\gamma_2(x+h,y-h)-\gamma_2(x-h,y+h)]$$

If we know the values for γ_1 and γ_2, then we can repeatedly apply this equation to our data until it converges.

4. Simulating Data

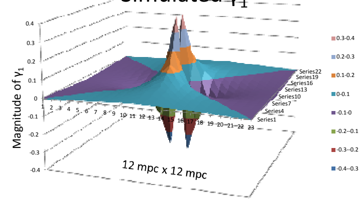
Our program will calculate the mass distribution of a simulated galaxy cluster lens. In a way, our simulation starts where our calculation will finish. We first create a mass distribution that a typical lens galaxy cluster would have.

Mass Distribution

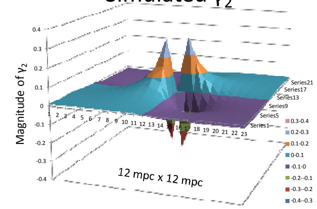


From our simulated mass distribution, we then calculate two quantities that would normally be obtained from the observed shapes of the background galaxies in a telescope image.

Simulated γ_1

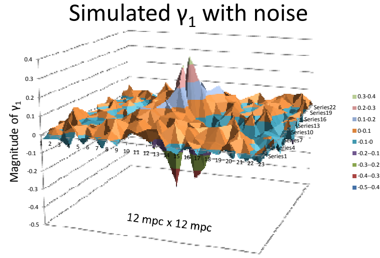


Simulated γ_2

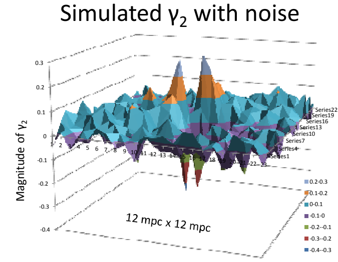


We then add realistic noise to these two observable quantity matrices.

Simulated γ_1 with noise

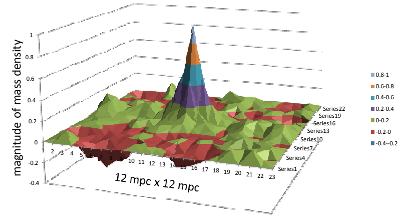


Simulated γ_2 with noise



Mass Distribution

Finally, we apply our Poisson equation to the noisy observable data shown above.

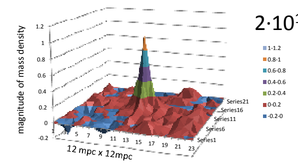


In this example, we were able to accurately recover the mass distribution from the noisy data.

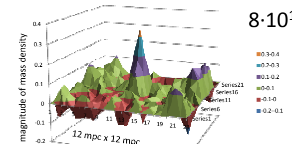
5. Results of Testing

In our universe, galaxy clusters of 10^{14} $M_\odot$ to 10^{15} $M_\odot$ are common. We tested how low we could make the total mass of our simulation and still detect a galaxy cluster.

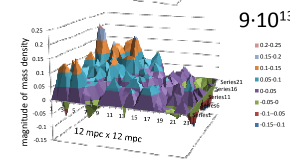
Mass Distributions



$2\cdot10^{15}$ $M_\odot$



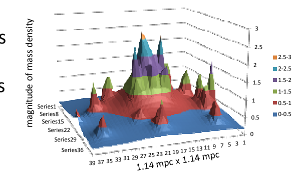
$8\cdot10^{14}$ $M_\odot$

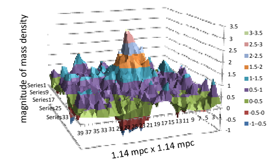


$9\cdot10^{13}$ $M_\odot$

We discovered that our lower limit is at about $5\cdot10^{14}$ $M_\odot$.

Galaxy clusters are made of smaller groups of galaxies.





We were able to recover some of the substructure.

6. Appreciation

Thank you ATP program for generously funding my research, Dr. Kling for his mentorship, and the research students and professors who kindly gave advice.

7. References

Kling, Thomas P., and Bryan Campbell. "Poisson equation for weak gravitational lensing." Physical Review D 77 24 June (2008). Print.
Schneider, P. 2005, in: *Kochanek, C.S., Schneider, P., Wambsganss, J.: Gravitational Lensing: Strong, Weak & Micro. G. Meylan,* P. Jetzer & P. North (eds.), Springer-Verlag: Berlin, p.273