Computing Lensing Deflection Angle Maps for Simulated Large-Scale Structures

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Introduction

- **Gravitational Lensing**: the deflection and distortion of light rays emanating from distant galaxies due to mass distributions curving spacetime
  - Can act as cosmic telescopes that magnify distant galaxies
- **Deflection Angle**: the angle by which an incoming light ray is bent
  - Deflection angles at a range of positions can be arranged into a map
- **Large-Scale Structure (LSS)**: a "cosmic web" of dark and baryonic matter formed by gravity, connecting galaxies and galaxy clusters

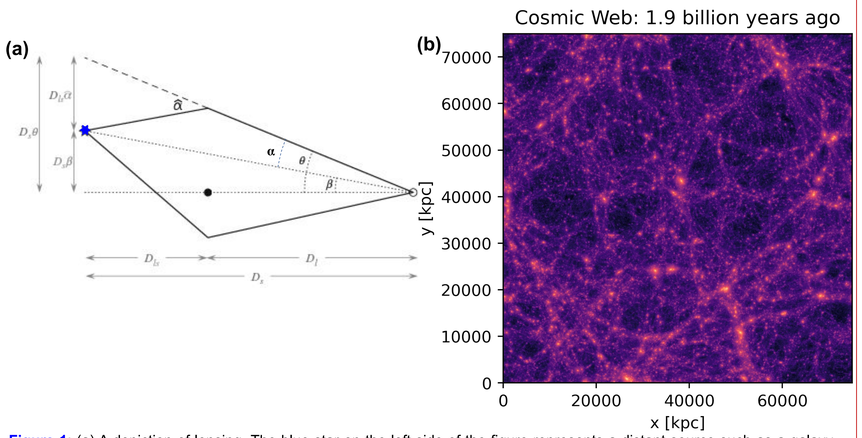

Figure 1: (a) A depiction of lensing. The blue star on the left side of the figure represents a distant source such as a galaxy. The solid, black dot in the middle of the figure represents a lensing mass. The hollow dot represents the observer. (Keeton 2014) (b) Density plot of the large-scale structure obtained using the TNG100-3 simulation. Brighter dots represent galaxy clusters. Mass between galaxy clusters are pulled towards the clusters producing long filaments.

Background

- Current lensing calculations assume a uniform density outside the lens
  - Implies that a light ray bends only at a lens
- Existence of LSS creates fluctuations in this density - acting as lenses
- **Goal**: Use simulations of LSS to obtain deflection angle maps.

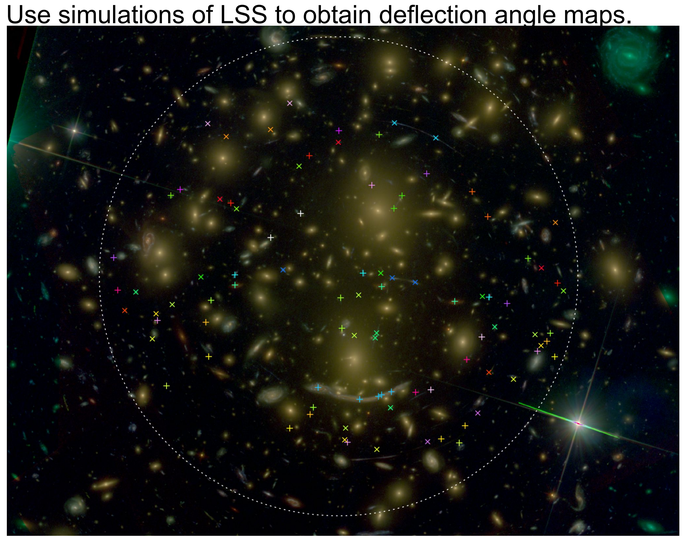

Figure 2: Abell 370 galaxy cluster. The background is an RGB image of the cluster taken by the Hubble Space Telescope. Shapes of the same color refer to different images of the same source galaxy. This image is adapted from Figure 7 of Raney et al. (2020). The circle spans roughly 1 arcminute in radius (full moon is roughly 30').

Materials and Methods

Our work is divided into two stages (1) Code Development, (2) Using Simulation Data

The Simulation

IllustrisTNG Project[2, 3, 4, 5, 6]

- 18 simulations of galaxy formation and evolution
  - Our interest: TNG300-3
    - Largest simulation box: ~ 300 Mpc along each side
  - Currently using TNG100 for testing.

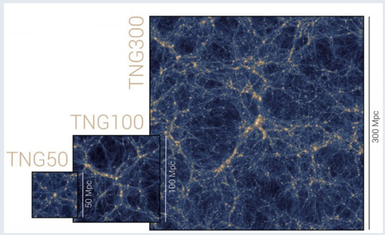

Figure 3: A comparison of three simulations that are a part of the IllustrisTNG project. While our testing is done using TNG100 (smaller file sizes), our future analyses will be derived from TNG300

Stage 1

- Our research group updates pygravlens[7]
  - Performs a variety of lensing calculations, including calculating lensing potentials and deflection angle maps
  - Can also be used to solve the lens equation for new lensing models (obtained via the simulations)

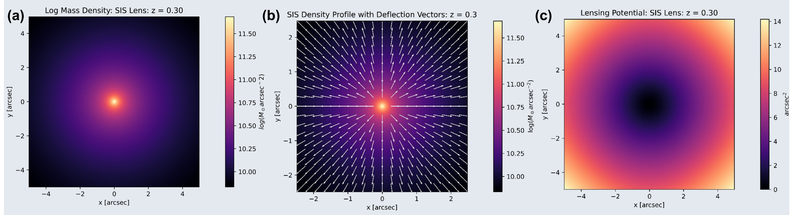

Figure 4: (a) Log mass density profile for a simple standard model galaxy (singular isothermal sphere - SIS). (b) Log mass density profile overlaid with deflection vectors computed using pygravlens. (c) A plot of the lensing potential for the density profile obtained using our code.

Stage 2

- We begin working with the TNG100-3 simulation
  - We need the masses and coordinates of dark matter, gas, and star particles
    - Unfortunately, we do not have enough storage available to extract this information at once
      - We focus on the gas and star particles first, and obtain the density map for these particles. Then, we repeat with dark matter. We add the two density maps afterwards and use it with pygravlens.

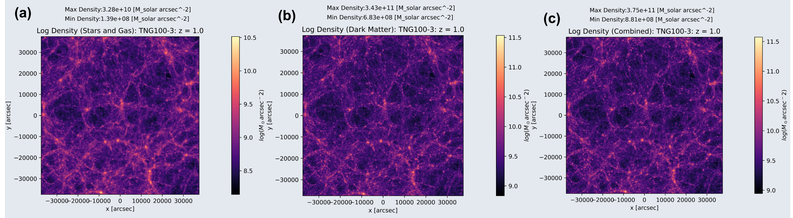

Figure 5: (a) A map of the surface log density for stellar and gas particles in the LSS at redshift 0.15. (b) A map of the surface log density for dark matter particles in the LSS at the same redshift. (c) Map of the surface log density for all three particles combined.

Results

We present the log surface densities, and deflection maps for various redshifts.

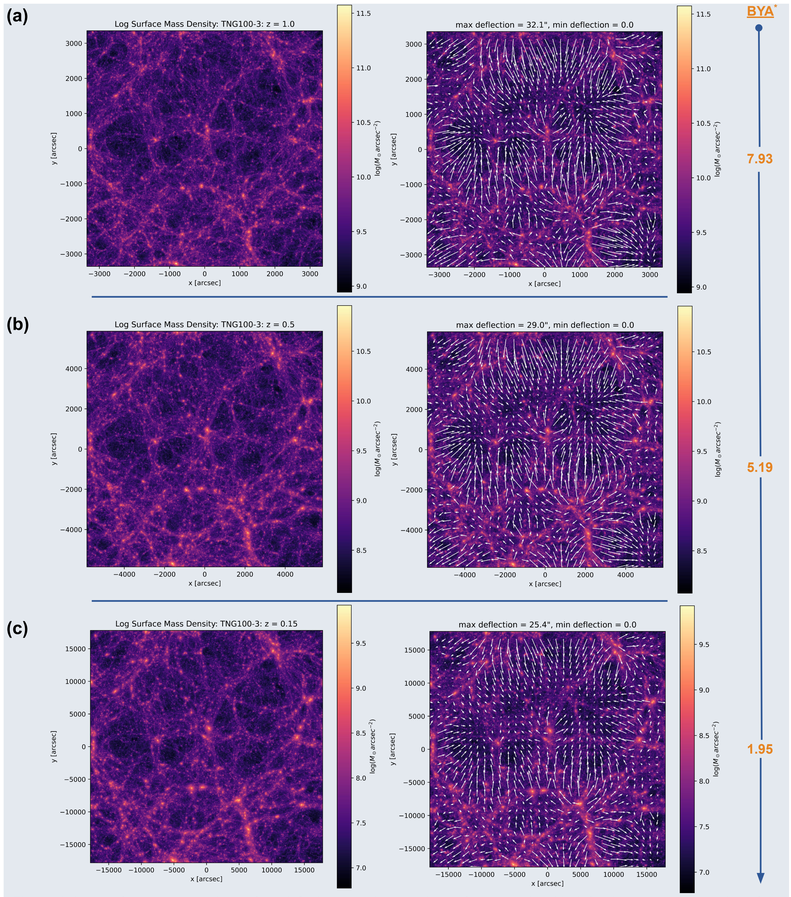

Figure 6: Log surface mass density profiles (left plots) and log density profiles overlaid with deflection vectors (right plots) for various redshifts along the LOS. (a) z = 1.0. (b) z = 0.50. (c) z = 0.15. *: Billion Years Ago (BYA)

Future Direction

- Repeat the analysis for the TNG300 simulation
  - Drive a statistical analysis on the effect of LSS on light deflection
    - How variable are the deflection angles for nearby line-of-sights?
      - If significantly variable, we need to incorporate this into our lensing models as a new parameter
    - Will be used to refine interpretations of the Hubble Frontier Field Observations.

Citations

1. https://frontierfields.org/
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4. Marinacci, F., Vogelsberger, M., Pakmor, R., Torrey, P., Springel, V., Hernquist, L., Nelson, D., Weinberger, R., Pillepich, A., Naiman, J., & Genel, S. (2018). First results from the IllustrisTNG simulations: radio haloes and magnetic fields. *|mnras, 480(4), 5113-5139.*
5. Pillepich, A., Nelson, D., Hernquist, L., Springel, V., Pakmor, R., Torrey, P., Weinberger, R., Genel, S., Naiman, J., Marinacci, F., & Vogelsberger, M. (2018). First results from the IllustrisTNG simulations: the stellar mass content of groups and clusters of galaxies. *\mnras, 475(1), 648-675.*
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7. https://github.com/chuckkeeton/pygravlens

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