Mapping All the Mass in the Universe (with Weak Gravitational Lensing)

Spencer Everett

Office of Science, Science Undergraduate Laboratory
Internship (SULI) Program

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(with Weak Gravitational Lensing)

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SLAC National Accelerator Laboratory

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Abstract:

Recent discoveries have shown that most of the universe is made of an exotic dark matter that behaves much differently than the normal matter that we experience in everyday life. As we cannot detect dark matter directly, we must infer its location in the universe by indirect effects, such as the distortion of light from distant galaxies as it travels through large clouds of dark matter. While the degree of distortion should be proportional to the amount of dark matter present, we don't know the original shape of the galaxy so the distortion is difficult to quantify. If we had a model of how dark matter is linked to galaxies, and thus be able predict the amount of distortion that should occur, we could apply the model to galaxy surveys to map out the dark matter in our universe. In this research, I attach a spherical 'halo' of dark matter to each galaxy in a simulated universe to approximate its known complex dark matter structure. I then predict how the halos distort the light from distant galaxies generated behind the halos. As the data is simulated, the true distortion of the light is known which is compared to the halo-predicted distortion. I find that, on average, the model under-predicts the degree of distortion on all scales and fails to capture distortions from large-scale dark matter structure. These issues are likely due to missing features in the model, as the halo model is a greatly simplified version of the actual distribution of dark matter. Potential improvements to the model for future work are discussed.

A visualization of the cosmic web, showing a complex network of dark matter filaments and galaxy clusters. The background is a deep purple, with bright yellow and orange points representing galaxies and star-forming regions. The filaments are thin, branching structures that connect the larger clusters.

Where is the dark matter?

How can we model the dark matter distribution?

How accurate is the model?

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Where is the Dark Matter?

- Dark matter cannot be detected directly as it does not absorb or emit light
- Galaxies *should* trace out the distribution of dark matter
- Simulations and observations have supported this claim

Dark Matter Halos

- The simplest model is to attach a dark matter 'halo' to each galaxy
- From this we know the location of the dark matter, but not the mass

Gravitational Lensing

- Light from distant 'background' galaxies is bent when travelling through massive 'foreground' galaxies
- The degree of lensing is proportional to the amount of dark matter

There are two types of gravitational lensing effects:

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Galaxy Cluster Abell 2218

Weak Gravitational Lensing

- Strong lenses are rare
 - only ~200 currently known
- *All* galaxies are weakly lensed!
 - Usually 1%-5% shape distortion
- Can be detected statistically

Unlensed

X = lens

Lensed

Weak Gravitational Lensing

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How accurate is the model?

The Pangloss Model

Background Galaxy

The Pangloss Model

Background Galaxy

The Pangloss Model

The Pangloss Model

The Millennium Simulation (MS)

- We aren't testing the model on observational data, as we don't know the intrinsic shapes of the background galaxies
- The model is applied to the latest Millennium Simulation, where the 'true' lensing has already been calculated

Foreground galaxies:

Foreground galaxies:

Convergence:

Shear:

Background galaxies:

Intrinsic:

Foreground galaxies:

Convergence:

Shear:

Background galaxies:

Intrinsic:

Foreground galaxies:

Convergence:

Shear:

Background galaxies:

Intrinsic: — (blue)

Observed: — (green)

Foreground galaxies:

Convergence:

Shear: — (red)

Background galaxies:

Intrinsic:

Observed:

Foreground galaxies:

Convergence:

Shear:

Galaxy:

Background galaxies:

Intrinsic:

Observed:

Predicted:

Foreground galaxies:

Convergence:

Shear:

Galaxy:

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Testing Pangloss - Correlation Functions

- The orientation of galaxies *should* be randomly distributed in the sky
- After lensing, galaxies near a dark matter halo are lensed in a similar way and should be correlated
- The average correlation as a function of separation distance is called the correlation function

?

Correlation Function at Various Galaxy Orientations:

Map of Unlensed Galaxies

Correlation of Unlensed Galaxies

Map of Lensed Galaxies

Correlation of Lensed Galaxies

Waiting for Pangloss code ...

Waiting for Pangloss code ...

Ellipticity - Ellipticity Correlation

Ellipticity - Ellipticity Correlation

Ellipticity - Ellipticity Correlation

Not accounting
for voids or
filaments

Pangloss only
attaches halos to
individual
galaxies, not
clusters or
superclusters

Systematic
under-prediction
of shear power

Not capturing large-
scale dark matter
structure

Galaxy - Galaxy Correlation

Galaxy - Galaxy Correlation

Galaxy - Galaxy Correlation

Issues with the Pangloss Model

- There is a systematic under-prediction of shear power in the ε - ε correlation function
 - Missing filaments?
 - Missing voids?
- Only galaxies receive halos - not clusters or superclusters
- Strong lensing is not accounted for

- Much too slow!

Moving Forward

- Pick only most “important” galaxies for lightcones
 - Increase shear power
 - Lower CPU time
- Optimize Pangloss code (profiling, lookup tables, etc)
- Possible filament and void correction

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Conclusions

- We have implemented a simple halo model to approximate the dark matter mass distribution of the matter in the MS to predict weak lensing effects
- Summary statistics show an under-prediction of shear power - implies missing features in the model
- With improvements, Pangloss could be applied to sky survey data to make dark matter maps of our own universe