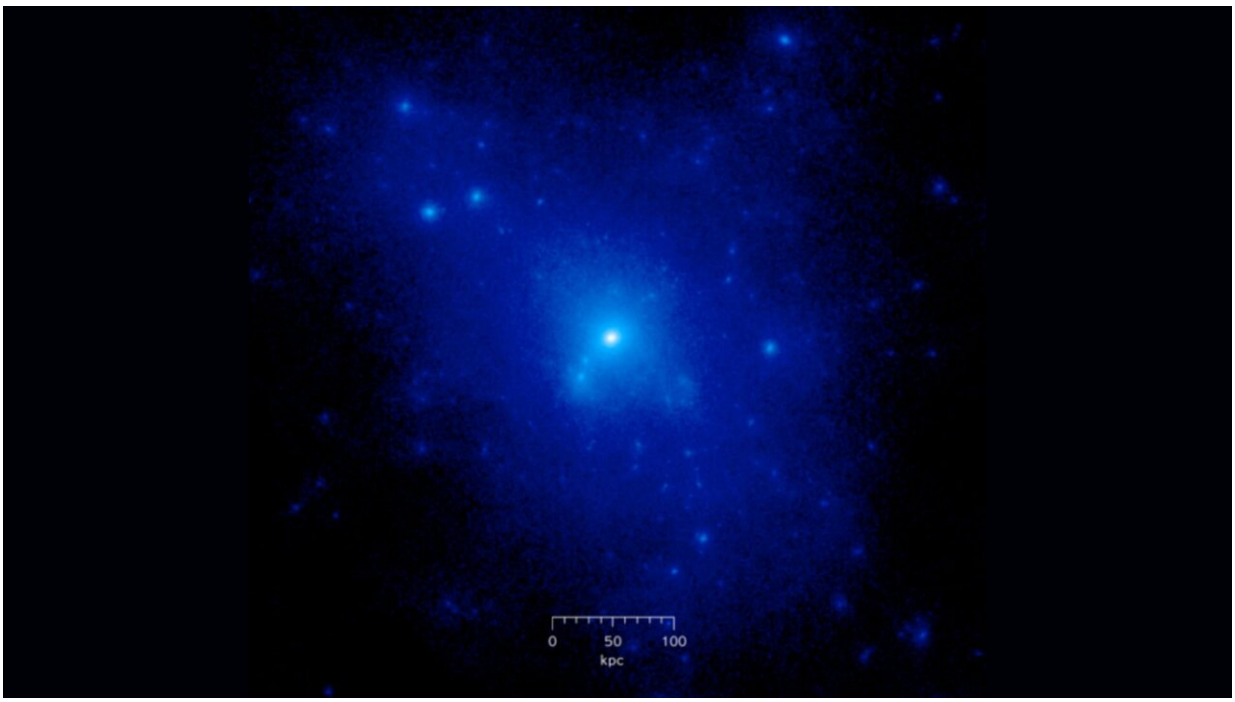
First detection of cross-correlation between cosmic shear and X-ray background enhances baryonic matter understanding

September 5 2024, by Tejasri Gururaj



Dark matter halo from a cosmological N-body simulation. Credit: Cosmo0/Wikimedia Commons. https://en.wikipedia.org/wiki/User:Cosmo0.

A new study in *Physical Review Letters* offers the first detection of the cross-correlation between cosmic shear and diffuse X-ray background, helping to understand the distribution of baryonic matter in the universe.

Making up around 5% of the universe, baryonic matter—comprising protons and neutrons—plays a crucial role in the creation of cosmological structures such as stars, planets, and galaxies. It contains valuable information for understanding large-scale structures in the universe.

Baryonic matter is drawn into concentrated regions of dark matter, called dark matter halos, by the gravitational pull of dark matter. Within these halos, baryonic matter exists in either concentrated forms (such as stars and galaxies) or in diffuse forms (such as hot gas).

Detecting baryonic matter in both forms is difficult due to the complex interactions of the diffused gas and the effects of dark matter.

Dr. Tassia Ferreira and colleagues from the University of Oxford investigated the influence of baryonic physics on cosmological measurements in their PRL study. For this, they focused on combining data from two observational sources.

Dr. Ferreira spoke to Phys.org about probing the nature of baryonic matter. "I have always had a passion for studying the universe through an observational perspective," Dr. Ferreira said.

"I have worked with cosmic shear for most of my research career and, at Oxford, I found experts in cross-correlations using weak lensing data. It thus made sense to push cross-correlations to combine effects that intuitively should be connected but had not yet been detected."

Baryonic matter distribution

For cosmic shear measurements, which give information about the concentrated baryonic matter, the researchers relied on The Dark Energy Survey Year 3 (DES Y3) data release.

This data contains images and measurements of galaxies, galaxy clusters, and other cosmic structures.

The gravitational pull of dark matter can cause the shape of background galaxies to be distorted. Cosmic shear measures the distribution of dark matter indirectly by observing how it distorts the shapes of background galaxies.

It does not give direct insights into baryonic matter but is useful for inferring the influence of dark matter on it.

The baryonic matter in hot gas in dark matter halos gets heated by gravitational forces, emitting X-ray radiation. This X-ray data can be used to trace the distribution of the baryonic matter in the form of hot gas.

The researchers obtained the data through The ROSAT All-Sky Survey (RASS). Conducted by the ROSAT satellite over 1990 and 1991, this survey provides a broad X-ray view of the entire sky.

The 'halfway' mass

The cross-relation of the two data sets offers several advantages. Dr. Ferreira explained, "The X-ray emission of the hot gas in dark matter halos is governed by the gas temperature and density."

"This dependence makes it ideal for tracing how the gas is distributed. Since cosmic shear is most sensitive to the mis-modeling of baryonic effects, the cross-correlation offers a consistent way of breaking degeneracies."

Additionally, the cross-correlation signal is sourced by the collective emission of all large-scale structures, making it less sensitive to errors in

modeling individual objects.

Using a hydrodynamical model developed from earlier research, the researchers modeled how mass and gas are allocated in halos. Cold dark matter, gravity-bound gas, ejected gas, and stars are all considered in this model.

Dr. Ferreira said, "According to X-ray observations, the fraction of bound gas can be parametrized by the cosmic baryon fraction (the number of baryons related to the total matter content of the universe), the total mass of the halo, the 'halfway mass' and the slope of the hot-gas suppression towards small halo masses."

"X-ray observations are ideal for probing this quantity since they trace the bound gas."

The halfway mass of a dark matter halo is where half of the gas that was originally in the halo has been expelled. This value measures the extent of gas loss attributable to processes such as star formation or black hole.

The study's constraint of the halfway mass is a major contribution to understanding how cosmic structures lose gas over time and how this loss affects the structure of the universe.

High-significance and future work

The datasets' cross-correlation highlighted a significant correlation between cosmic shear and the diffuse X-ray background.

The 23σ (sigma) significance indicates that this correlation is highly statistically significant, suggesting a strong relationship between the two datasets. This result leaves little doubt about the robustness of their findings.

The researchers estimated the halfway mass of dark matter halos to be around 115 trillion solar masses.

In addition to the halfway mass, the researchers were also able to constrain the polytropic index, which measures the relationship between the temperature and density of hot gas in dark matter halos.

The estimated polytropic index value showed good agreement with past studies. The new constraints are tighter and more precise when compared to earlier cosmic shear and X-ray data.

In addition to giving a clearer view of matter distribution in the universe, the study also provides a new method for assessing theories related to dark matter and dark energy.

Dr. Ferreira said, "The procedure developed is a starting point for a more rigorous analysis using cross-correlations between cosmic shear and maps of the diffuse X-ray background. This is particularly relevant to future weak lensing surveys, such as the Vera Rubin Observatory and Euclid with ongoing X-ray missions, like eROSITA, which seek to obtain more precise cosmological constraints from large-scale structure data."

Looking ahead, Dr. Ferreira sees numerous possibilities for building upon their findings, particularly validating the theoretical model before the methodology developed can be used in cosmological analyses.

"Additionally, residual degeneracy between cosmological and hydrodynamical parameters could be broken by including cross-correlation with Sunyaev-Zel'dovich Compton-y maps, given their complementary sensitivity to gas density and temperature," she concluded.

More information: Tassia Ferreira et al, X-Ray–Cosmic-Shear Cross-Correlations: First Detection and Constraints on Baryonic Effects, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.133.051001.

Citation: First detection of cross-correlation between cosmic shear and X-ray background enhances baryonic matter understanding (2024, September 5) retrieved 5 September 2024 from https://phys.org/news/2024-09-cosmic-ray-background-baryonic.html