New light on baryonic matter and gravity on cosmic scales

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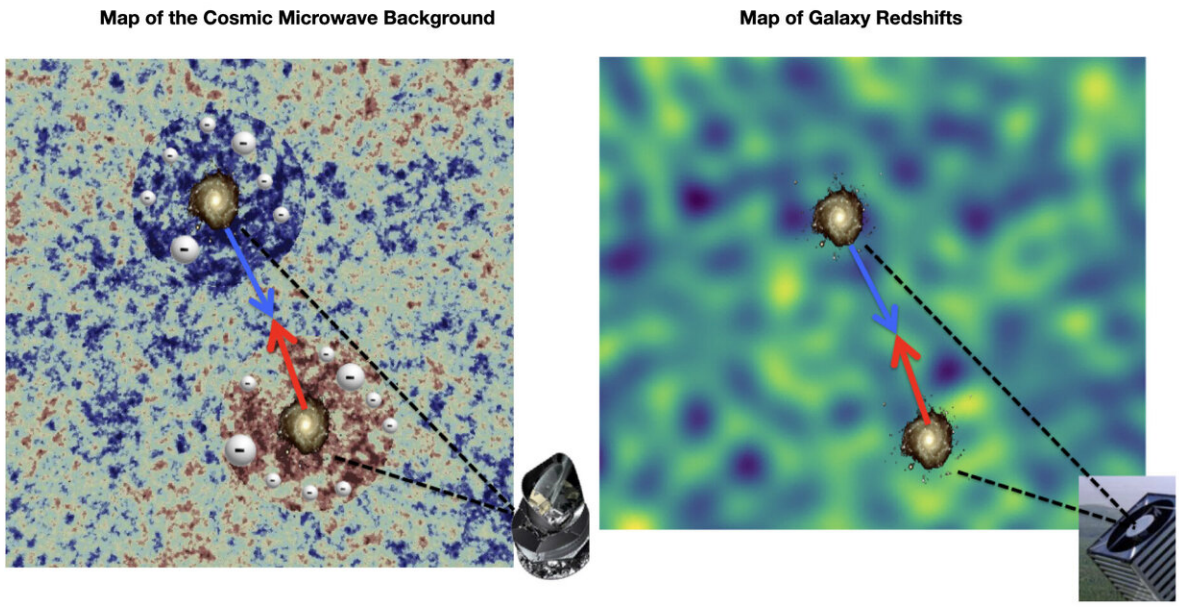

The presence of ionized gas around galaxies with moves with them leaves a trace in the microwave background radiation (left panel) which can be detected knowing the pattern of velocities of the galaxies provided by the map of fluctuations in their redshift (right panel). Credit: Carlos Hernández-Monteagudo (IAC).

Scientists estimate that dark matter and dark energy together are some 95% of the gravitational material in the universe while the remaining 5%

is baryonic matter, which is the "normal" matter composing stars, planets and living beings. However, for decades, almost one-half of this matter has not been found. Now, using a new technique, a team including researchers from the Instituto de Astrofísica de Canarias (IAC) has shown that this "missing" baryonic matter fills the space between galaxies as hot, low-density gas. The same technique also gives a new tool that shows that the gravitational attraction experienced by galaxies is compatible with the theory of general relativity. This research is published today in three articles in the journal *Monthly Notices of the Royal Astronomical Society* (*MNRAS*).

In designing this new technique, the researchers analyzed shifts in the electromagnetic spectrum toward red as galaxies speed away from us. In the universe, the sources that move away show a redder spectrum, and those approaching shift toward blue. This effect provides essential data for modern cosmology. Almost a century ago, Edwin Hubble discovered that the redshifts of galaxies are higher the further away they are, and this was the initial evidence which eventually led to the Big Bang model of the universe. Since then these redshifts have been used to find the distances to the galaxies and to build three dimensional maps of their distribution in the universe.

In the work we are reporting here a new method has been developed, which studies the statistics of the redshifts of galaxies, without converting them to distances. In their first article, the team shows that these maps are sensitive to the gravitational attraction between galaxies on cosmological scales. In a second article, the same team compared the maps with observations of the cosmic microwave background, creating the first complete census of the baryonic matter over 90% of the life of the universe.

"Most of this ordinary matter is invisible to us because it is not sufficiently hot to emit energy. However, by using maps of the redshifts

of the galaxies, we find that all of this matter fills the space between them," explains Jonás Chaves-Montero, a researcher at the Donostia International Physics Center (DIPC) and first author of this article.

Finally, as reported in a third article, the researchers also used the redshift maps of galaxies to study the nature of gravity. "In contrast to previous approaches, our new method is not based on any conversion of redshift to distance, and it is shown to be robust against noise and data impurities. Thanks to that, it allow us to conclude with high accuracy that the observations are compatible with Einstein's theory of gravity," says Carlos Hernández-Monteagudo, an IAC researcher who is the first author on this third article.

More information: Hernandez-Monteagudo, Carlos; Chaves-Montero, Jonas; Angulo, Raul E. "Angular Redshift Fluctuations: a New Cosmological Observable". *MNRAS*: ui.adsabs.harvard.edu/abs/2019 … v191112056H/abstract

Chaves-Montero, Jonas; Hernandez-Monteagudo, Carlos; Angulo, Raul E.; Emberson, J. D. "Measuring the evolution of intergalactic gas from z=0 to 5 using the kinematic Sunyaev-Zel'dovich effect". *MNRAS*: ui.adsabs.harvard.edu/abs/2019 … v191110690C/abstract

Hernández-Monteagudo, Carlos; Chaves-Montero, Jonás; Angulo, Raúl E.; Ariccò, Giovanni. "Tomographic Constraints on Gravity from Angular Redshift Fluctuations in the Late Universe", *MNRAS*: ui.adsabs.harvard.edu/abs/2020 … v200506568H/abstract

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