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Astronomy

Hot gas around the Galaxy

Amiel Sternberg

An extended system of highly ionized gas clouds that surrounds the Milky Way has been detected. This gas may be part of the original matter from which our Galaxy and its nearest neighbours formed.

How did galaxies form? Astronomical observations and theory suggest that the process began with the collapse of density perturbations in an originally smooth distribution of cosmic 'dark matter'. Baryonic matter, the ordinary visible matter that can be incorporated into stars, was then pulled into the growing condensations of dark matter. Eventually the baryons settled into the disks and elliptical structures observable today as galaxies. On the basis of data from the Far Ultraviolet Spectroscopic Explorer satellite (FUSE), Nicastro *et al.* (page 719 of this issue[1]) present evidence for the existence of a large reservoir of baryons around the Milky Way — which, they argue, may be a relic of the original matter that formed our Galaxy and its nearest neighbours.

The total baryon content of the Universe is a key cosmological parameter. Observations of the cosmic deuterium-to-hydrogen abundance ratio, a quantity that was fixed by nucleosynthesis in the hot Big Bang, imply that baryons constitute 4% of the total 'mass-energy' density of the Universe[2]. Remarkably, the same percentage is inferred from studies of the 'acoustic' oscillations in the primordial plasma, evident today as fluctuations in the cosmic microwave background radiation[3].

Observations of intergalactic atomic hydrogen in clouds that existed when the Universe was about a tenth of its current age, the epoch when galaxy formation began, reveal a cosmologically expected baryon content. At that time, most of the baryons were distributed in a diffuse intergalactic medium, which was photoionized and heated to a temperature of around 10^4 K by the first stars and quasars. But in the present-day Universe, the baryon budget comes up short. Observations of stars, galaxies, clouds in the intergalactic medium and very hot (10^8 K) X-ray-emitting plasma in galaxy clusters account for only a third of the expected cosmological baryon density[4].

So where are the 'missing' baryons? One possibility is that they are contained in massive astrophysical compact halo objects (MACHOs), a collective term for objects such as isolated neutron stars, brown dwarfs or planetary masses that are faint and hard to detect. Alternatively, they could be hiding as dilute 'warm–hot' ionized clouds at temperatures of 10^5–10^7 K. Such gas would be difficult to detect by conventional methods: it would be too highly ionized to allow it to be identified by observations of atomic hydrogen, yet too cool to be evident as thermally emitting X-ray plasma.

Hydrodynamic simulations[5] of galaxy formation suggest that much of the baryonic mass today could indeed be present in a warm–hot intergalactic medium (WHIM) at 10^5–10^7 K. In this picture, WHIM is produced by the shock waves that inevitably occur as gas falls out of the much cooler, diffuse intergalactic medium and into the collapsing filamentary web of 'over-dense' regions where galaxies form. The shocked gas cannot cool efficiently because the WHIM densities are low, and as much as half of the primordial baryonic material is predicted to survive as WHIM, rather than condense into stars and galaxies.

Can the WHIM be detected? One possibility would be to detect the absorption-line signatures of highly ionized trace 'metals' (elements heavier than helium) that may be present[6–8]. The oxygen ions O^{5+}, O^{6+} and O^{7+} — designated O VI, O VII and O VIII by astronomers — are particularly important candidates for this purpose. The available spectroscopic line transitions of the oxygen ions occur at ultraviolet and X-ray wavelengths, however, meaning that observations must be carried out above the Earth's atmosphere. This is now possible with the revolutionary spectroscopic capabilities of the FUSE satellite, and the Chandra and XMM-Newton orbiting X-ray observatories. Distant quasars serve as (point-like) sources of ultraviolet and X-ray radiation, and clouds are detected as intervening oxygen-line absorbers along the lines of sight.

Indeed, one of the spectacular results of the FUSE mission has been the detection of many discrete O VI absorbers, distributed all over the sky[9,10]. They probably represent a heterogeneous collection of clouds that are at widely varying distances and have widely different origins. Some absorption probably originates in ionized gas close to, or within, the interstellar medium of the disk itself; some, however, may occur in clouds located well outside the Milky Way.

The 'radial velocities' of the O VI clouds, as determined by the Doppler shifts of the absorption lines, provide clues to their origin and location. Nicastro *et al.*[1], and, independently, Sembach *et al.*[10], have analysed high-velocity O VI absorbers, with absolute radial velocities in excess of 100 km s^{-1}, and as high as 550 km s^{-1}. Such velocities are larger than would be expected for motions confined to the Galactic disk. Nicastro *et al.* show that the kinematic properties of this ensemble may imply that most of the high-velocity O VI absorbers are distributed in a volume encompassing the entire Local Group of galaxies, consisting of the Milky Way, Andromeda and 30 or more less-massive galaxies. They note that an extended distribution of hot gas is consistent with very low gas densities inferred from X-ray absorption-line detections of O VII and O VIII. For such an extended distribution, the total mass of hot ionized gas is comparable to the dynamical mass of the Local Group, and the hot gas represents a major reservoir of baryons.

Is the extended distribution of high-velocity O VI absorbers the original WHIM? Nicastro *et al.* argue that it is. Given the uncertainties in the distance estimates, however, the clouds could also be reprocessed, metal-enriched gas that was ejected from the Milky Way (or its neighbours) by supernova explosions. Measurements of the metal abundances in the hot clouds will help to clarify this issue. ■

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