MILKY WAY

Gone with the Galactic wind

A Galactic wind blowing from the Milky Way nucleus has swept up a few hundred clouds of atomic gas. New observations reveal dense molecular cores in two of these clouds, indicating a high loss rate of interstellar gas from the Galactic centre.

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Strong, hot winds emanating from the central regions of galaxies are a commonplace occurrence in galaxies undergoing strong bursts of star formation in their centres, as well as in galaxies containing an efficiently accreting central supermassive black hole. Galactic winds in normal, relatively quiet galaxies are harder to study because they exhibit less powerful displays, but our own Milky Way Galaxy provides a unique opportunity to study such winds up close. Recent investigations have shown that the Galactic wind is primarily a hot (~10^6–10^7 K), X-ray-emitting wind[1,2] blowing out from the central few hundred parsecs of the Galaxy into two conical regions above and below the Galactic plane at speeds exceeding 1,000 km s^{-1} (ref. [3]), and that it contains a few hundred slower-moving clumps of cooler gas (100–1,000 K) in neutral atomic form, consisting almost entirely of hydrogen[4–6]. In a recent issue of *Nature*, Enrico Di Teodoro and collaborators report the discovery of dense molecular cores in two of these gas clumps[7], leading to the surprising implication that the total mass of dense gas in the Galactic wind is substantially larger than previously thought. These results defy the theoretical expectation that such gas clumps should have been disrupted and evaporated on timescales shorter than the travel time to their present locations.

The molecular content of two clouds has been examined using the Atacama Pathfinder Experiment (APEX) telescope in Chile to map millimetre-wavelength rotational line emission from carbon monoxide (CO) molecules, which serve as an indirect probe of the total amount of molecular gas, which is mostly in the form of molecular hydrogen (H_2). From this result, it is reasonable to project that many more of the known atomic gas clumps will have a dense molecular core within them. The molecular gas could have originated at the base of the wind, in the Galaxy's Central Molecular Zone (CMZ), a reservoir containing several tens of millions of solar masses of molecular gas[8]. Parcels of this molecular gas could have been ripped off and entrained in the hot Galactic wind, eventually being accelerated to velocities up to around 360 km s^{-1} (ref. [5]). This scenario presents a puzzle, however: how to accelerate relatively massive clumps of dense gas up to high velocities without disrupting them? Disruption should occur by the combined processes of evaporation caused by thermal conduction from the hot medium and dynamical instabilities that occur where a low-density gas pushes into a high-density cloud at highly supersonic speeds.

An interesting possible solution to this puzzle has recently been proposed[9–11]: a cool cloud in the hot wind can actually grow by accumulating mass from the hot wind. When the pressure gradients induced by dynamical instabilities raise the density to high enough values, radiative cooling of the mixed hot/cold medium becomes effective, raising the density even more and finally leading to the entrainment of some of the hot gas within the cold cloud. This clearly complex process couples gas dynamics, radiative transfer, myriad heating and cooling processes, interstellar chemistry,

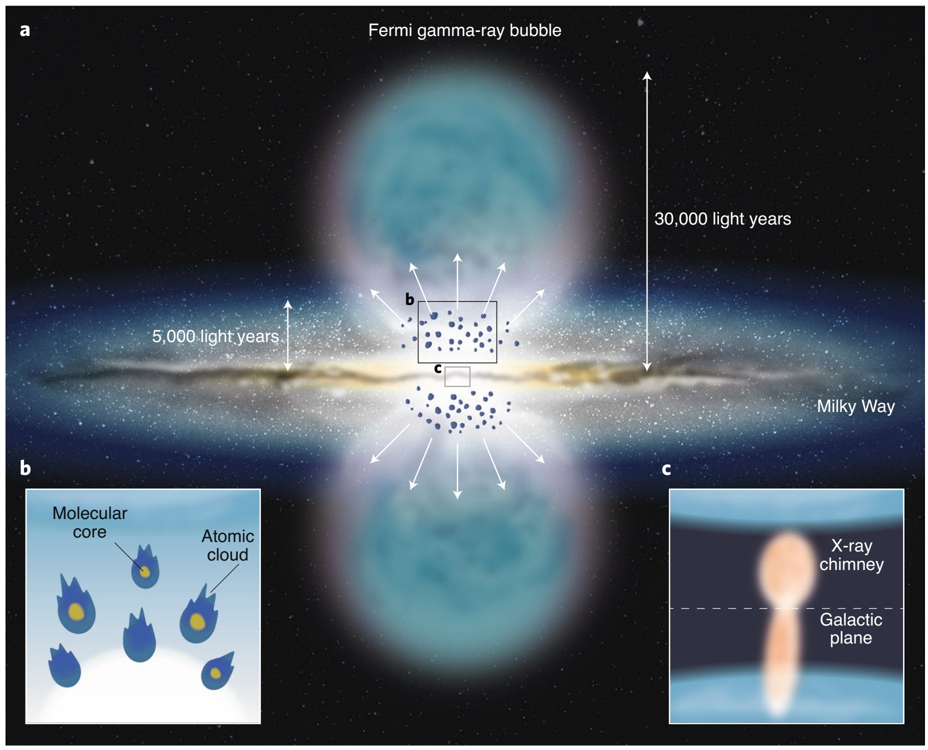

Fig. 1 | Schematic of the Milky Way along with structures observed at different wavelengths in its inner region. a, The Milky Way edge-on, along with the Fermi bubbles seen in gamma rays and the atomic gas clouds entrained in the Galactic flow. **b**, A subset of the atomic gas clouds (blue) containing molecular gas cores (yellow). Their comet-like morphology is due to the clouds being swept up by the faster hot Galactic wind. **c**, The X-ray structures ('chimneys') connecting the centre of the Milky Way to the Fermi bubbles.

and probably magnetic fields. Therefore, three-dimensional magnetohydrodynamic computations embellished with all of this physics are needed to model the evolution of outbound clouds and to thereby constrain the parameter domain in which cloud growth is possible. Observational tests of this hypothesis are also within reach, as the dynamics of the atomic clouds and their molecular cores are spatially well resolved[7]. The observations show, at least in the two observed clouds, a rough-hewn head–tail morphology, as one might expect if they are buffeted by a strong, hot wind that accelerates and shapes them.

Another puzzle is the enormous total mass of cold gas apparently entrained in the Galactic wind. Di Teodoro and collaborators find that the two clouds they have observed contain at least as much molecular gas as atomic mass, and possibly much more, as the abundance ratio of H_2 to CO is not well determined in such an environment, and might be much larger than the minimum they have assumed. If the fraction of molecular gas mass in these two clouds is characteristic of most of the outflowing clouds, then the rate at which gas flows out of the CMZ is at least a few tenths of a solar mass per year, which exceeds the rate at which new stars form in the CMZ. It is often assumed that supernovae resulting from the recent formation of short-lived, massive stars are responsible for driving the Galactic wind, but it is difficult to see how more mass ends up in the wind than goes into star formation, especially considering that only a small fraction of formed stars are massive enough to produce supernovae. This apparent discrepancy therefore implies that frequent bursts of energy from the Galactic supermassive black hole might also be required to drive the wind. Such bursts can be produced by tidal disruptions of stars or extreme gas accretion events. In any case, the gas stripped from the CMZ and transferred to the Galactic halo via the wind is bound to have an important effect on the rate at which stars form at the Galactic centre.

There are other manifestations of the Galactic wind on both smaller and larger scales than the 1,500 pc scale of the outflowing gas clumps. X-ray 'chimneys' were reported last year[2]. These structures probably form the base of the Galactic wind. They are coincident with remarkable 200 pc radio bubbles[12] that might have been formed by the most recent gust, or outburst, in the Galactic wind (Fig. 1). On the much larger scale of ~10,000 pc, one finds the 'Fermi bubbles', gigantic lobes of high-energy gamma-ray emission astride the Galactic centre[13]. Again, there is tension between two models for how the gamma-ray bubbles are powered: supernova-produced cosmic rays that diffuse upward through the hot winds into the Fermi bubbles and interact with ambient gas to produce the gamma rays, or an energetic, accretion-powered outflow from the Galactic black hole? Further study of the dynamics and distribution of the cold clumps being carried by the Galactic wind should provide valuable clues for identifying the origin of the wind, as well as how much mass it carries. An important next step will be to determine what fraction of the abundant gas clumps have dense molecular components. ❐

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