Bhoonah *et al.* Reply We would like to thank our colleagues Farrar *et al.* [1] for their interest in our work on cold gas cloud calorimetry as a method for dark matter detection. This Reply addresses first relevant gas cloud physics and then the physical parameters used for the bounds set in Refs. [2,3]. Interested readers may also refer to Ref. [3], where a more detailed discussion of these topics can be found.

We begin by reemphasizing an important feature of the calorimetric bounds obtained in Refs. [2,3]. In these papers, it is not assumed that gas clouds are in steady-state thermal equilibrium with their surroundings. This is in contrast to bounds recently proposed by our colleagues Wadekar and Farrar [4], which do assume thermal equilibrium. Instead Refs. [2,3] have pointed out that, for interstellar gas with temperatures $\sim 10^2$ – 10^4 K, cooling occurs primarily via Coulombic scattering excitation and subsequent deexcitation of a few fine structure lines. These few processes cool gas inefficiently compared to cooling processes active above 10^4 K. More crucially, this cooling process decreases monotonically with the temperature of the gas. Therefore, even for the case in which an observed gas cloud is in the process of heating up, it is still possible to set an upper limit on the total cooling rate. From this, a bound on heating from dark matter follows. Otherwise the gas could not have cooled to the temperature observed. (In the case where the cloud is either cooling or in thermal equilibrium, an upper dark matter bound follows trivially from the cooling rate at the cloud's observed temperature.)

A numerical gas cloud calculation we have completed in Ref. [3] has corroborated the analytic cooling rates employed in Ref. [2]. These numerical calculations simulated gas structures large enough to be self-shielding with a realistic ultraviolet and cosmic ray background. Additional heating from shocks and the surrounding hot diffuse gas were not incorporated, as we made the conservative assumption that all heating comes from dark matter interactions. As the cooling rate of the interior of these self-shielding objects is critically determined by the temperature of the gas, these calculations can be used to set an upper limit on the cooling rates of the clouds, even in a non-steady-state scenario. Nevertheless, it is instructive to briefly discuss the entrainment of these gas clouds in a hot outflowing wind, hypothesized in Ref. [5] to account for their distribution near the Galactic Center. While some simulations [6–10] have shown disruption of entrained clouds, these references readily acknowledge the decided lack of disruption in observed clouds. For example McCourt *et al.* [9] note that observations suggest that

the cold component in multiphase gas “appears to be stable, ubiquitous and long-lived, even on small scales.” Resolving relevant cooling lengths and the inclusion of other important factors, like magnetic fields [11] and self-gravity, will likely align the predicted lifetimes of entrained gas clouds with observations in the future.

We thank the authors for pointing out the typographical errors in the gas cloud table and in-line halo profile formula in Ref. [2]. Neither typographical error was reflected in the actual calculations shown in that Letter, and our final results stand as they are presented.

In both papers [2,3], we made use of gas cloud temperature and density parameters as they were reported in Ref. [5]. Farrar *et al.* have suggested that the temperature and density of cloud G1.4 – 1.8 + 87 reported in Ref. [5] may not be correct [1]. However, the bounds in Refs. [2,3] were also obtained using gas clouds G357.8 – 4.7 – 55 and G1.5 + 2.9 + 1.05, whose parameters are not disputed. We look forward to the follow-up observations and analysis of G1.4 – 1.8 + 87 that our colleagues have indicated are forthcoming.

Our choice of gas cloud-halo relative velocity gives us conservative bounds for all of our dark matter models except for the case of a very light vector mediator, as explained at length in Ref. [3]. Even for a very light vector mediator model, matching the velocity to that suggested in the Comment changes the bound on the coupling parameter by less than a factor of 1.2. The Navarro-Frenk-White profile we made use of was conservatively chosen and is commonly used to set dark matter bounds on (for example) dark matter annihilating in the central 3 kpc of the Milky Way. A discussion of different halo profiles drawn from the most recently fit data, and how these alter gas cloud bounds, is given in Ref. [3].

The gas clouds considered in Refs. [2,3] are uniquely suited to set dark matter bounds due to their history and the behavior of their very low cooling rates with respect to their temperatures. Any kind of hydrodynamical system is of course complex, and we welcome all discussion leading to a better understanding of these systems. More detailed modeling of the clouds and their environment will likely produce even stronger bounds, in particular inclusion of heating sources such as the standard astrophysical backgrounds and the hot, diffuse surrounding gas. We once again thank our colleagues for their interest in Refs. [2,3] and look forward to future work on calorimetric dark matter detection using gas clouds.

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