Limits on Ionized Gas in M81's Globular Clusters

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Observational constraints on the gas in globular star clusters (GCs) are key to understanding GC evolution (Roberts 1988; van Loon et al. 2009, and references therein). As the stars in GCs evolve, they shed gas into the potential wells of the GCs. Rough estimates suggest that about 100 to 1000 $M_{\odot}$ of gas could be accumulated before being purged as the GCs cross the Galactic disk. Searches have failed to detect these amounts of gas in Galactic GCs. Still, observations indicate about 0.1 $M_{\odot}$ of ionized gas in the central few parsecs of 47 Tuc and M15 (Pfahl & Rappaport 2001; Freire et al. 2001) and (tentatively) about 0.3 $M_{\odot}$ of neutral gas in M15 (van Loon et al. 2006). Numerical studies of gas removal between disk crossings suggest a diversity of gas properties among Galactic GCs (Priestley et al. 2011; Pepe & Pellizza 2013; McDonald & Zijlstra 2015; Pepe & Pellizza 2016).

Measurements encompassing the bulk of a GC should offer the most robust constraints on its gas content. This can be problematic for Galactic GCs because they subtend arcminutes. For example, some gas inventories require extrapolations, while others could be affected by discrete sources in front of, within, or behind the GCs, or by the Galactic interstellar medium toward the GCs (e.g., Hills & Klein 1973; Knapp et al. 1996; van Loon et al. 2009). These concerns are mitigated for extragalactic GCs. Their typical half-light radii of 2-3 pc (Brodie & Strader 2006) mean they subtend less than an arcsecond beyond the Local Group, making it easier to encompass the bulk of a GC. Also, the entire GC system of a galaxy can be studied, important given the aforementioned diversity of gas properties.

Here, we re-purpose data from our radio search for the radiative signatures of accretion onto intermediate-mass black holes in probable GCs in M81, a spiral galaxy at a distance of 3.63 Mpc (Wrobel et al. 2016). Among the 214 probable GCs tabulated by Nantais et al. (2011), 40% are spectroscopically confirmed and 60% are good GC candidates due to their colors and sizes. The 214 probable GCs have a median 2D half-light radius of 2.63 pc, derived from individual half-light radii with 40% uncertainties. Our radio search used the NRAO Karl G. Jansky Very Large Array (VLA; Perley et al. 2011) at a wavelength of 5.5 cm and resolution of $1\farcs5$ (26.4 pc). Eight probable GCs fell outside the search region. We achieved 3σ upper limits of between 3×4.3 and 3×51 μJy beam^{-1} for individual GCs and of 3×0.43 μJy beam^{-1} for the weighted-mean image stack of 206 GCs.

We use equation (3) from Knapp et al. (1996) to convert the flux-density upper limit for each GC and the GC stack to an upper limit on the ionized gas mass, $M_{\rm HII}$ and $M_{\rm HII}^{\rm stack}$, respectively. We assume that the gas is optically thin, isothermal with $T_e \sim 10^4$ K, of uniform density, and spherically distributed with a 3D radius that is $\frac{4}{3}$ times the 2D half-light radius (Spitzer 1987). We adopt the median half-light radius rather than the poorly-constrained individual radii. The gas thus subtends $0\farcs4$ arcsec (7 pc), necessitating a 7% correction to the flux-density upper limits. The stellar mass, $M_{\star}$, for each GC was taken from Wrobel et al. (2016). Using their approach, the peak of the GC luminosity function (Nantais et al. 2011) converts to a stellar mass $M_{\star}^{\rm peak} \sim 1.6 \times 10^5 M_{\odot}$.

Figure 1 shows $M_{\rm HII}$ and $M_{\star}$ for the GCs and locates the stack's $M_{\rm HII}^{\rm stack}$ at $M_{\star}^{\rm peak}$. From Figure 1 we find: (1) None of the 206 individual GCs in M81 has ionized gas detected with these radio observations. A typical gas-mass limit is $M_{\rm HII} < 550$ $M_{\odot}$. Gas-mass fractions, $M_{\rm HII}/M_{\star}$, are below about 0.1 at $M_{\star} \sim 10^4$ $M_{\odot}$ and below about 0.0002 at $M_{\star} \sim 3.4 \times 10^6$ $M_{\odot}$. (2) From the stack of 206 GCs, the formal gas-mass limit is about $M_{\rm HII}^{\rm stack} < 150$ $M_{\odot}$. Dividing this by the stellar mass peak for M81's GCs, we infer a formal gas-mass fraction below about 0.0009.

These first-look gas constraints are referenced to the median 2D half-light radius of the GCs. As such, they provide reasonably robust constraints on one possible gas phase among the 206 probable GCs in M81. These constraints can be improved with longer VLA exposures or similar exposures with the next-generation VLA (Carilli et al. 2015), and with more accurate half-light radii for the individual GCs.

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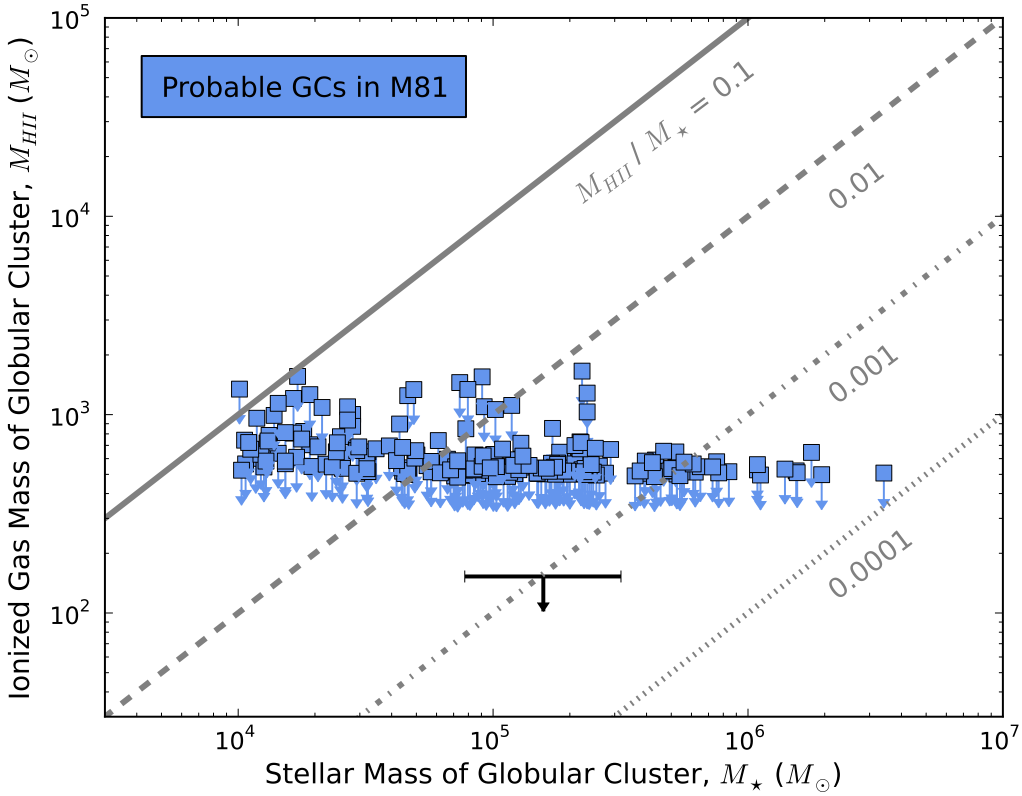

Figure 1. Ionized gas mass, $M_{\rm HII}$, and stellar mass, $M_\star$, for each probable GC in M81. The grey diagonal lines of constant $M_{\rm HII}/M_\star$ convey ionized-gas-mass fractions. For the stack of 206 probable GCs, $M_{\rm HII}^{\rm stack}$ is plotted as a dark line centered at $M_\star^{\rm peak}$. All gas-mass upper limits are at 3σ.

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