Intermediate-Mass Black Holes in Globular Cluster Systems

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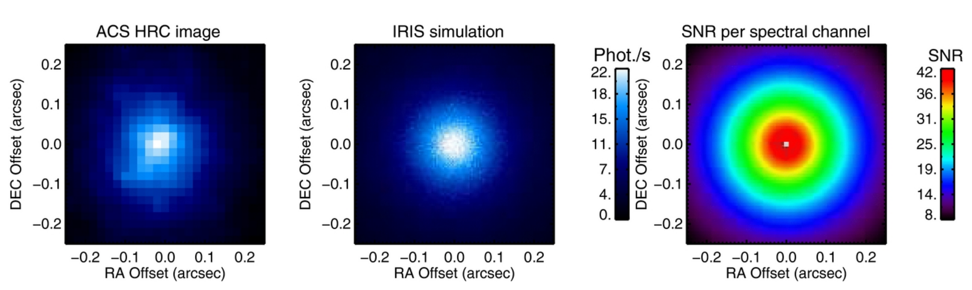
Motivation

A typical galaxy contains several hundred globular clusters (GCs) of stars [1,2]. Theory suggests that GCs can host intermediate-mass black holes (IMBHs) with masses of 100 $M_\odot$ to 100,000 $M_\odot$. Finding IMBHs in GCs could validate a formation channel for seed BHs in the early universe, underpin gravitational wave predictions for space missions, and test scaling relations between stellar systems and the central BHs they host [3,4,5].

A key science driver for extremely large telescopes (ELTs) is to measure, at a distance of 10 Mpc, a BH mass as low as 100,000 $M_\odot$ by spatially resolving its sphere of influence in its GC host [6].

Fig. 1 – Simulation of using an ELT, the Thirty Meter Telescope, to spatially resolve the sphere of influence of an IMBH in an extragalactic GC [6].



It is expected that this ELT approach will eventually yield a sample of IMBHs in extragalactic GCs. Some GCs in the Local Group have been targeted in sphere-of-influence studies, but all these studies are contentious ([7] and references therein). Also, a sphere-of-influence study with an ELT must be done one GC at a time. This makes it expensive to inventory the range of IMBH masses in a galaxy's globular cluster system.

References
[1] Harris+ 2013, ApJ, 772, 82
[2] Harris 2016, AJ, 151, 102
[3] Sakurai+ arXiv 1704.06140
[4] Amaro-Seoane+ arXiv 1702.00786
[5] Graham+ 2015, ApJ, 798, 54
[6] Do+ 2014, AJ, 147, 4
[7] Strader+ 2012, ApJL, 750, L27
[8] Wrobel+ 2015, AJ, 150, 120
[9] Pellegrini 2005, ApJ, 624, 155
[10] Freire+ 2001, ApJL, 557, L105
[11] Plotkin+ 2012, MN, 419, 267
[12] Wrobel+ 2016, AJ, 152, 22
[13] Selina & Murphy 2017, ngVLA Memo # 17

Synchrotron Radio Model

We invoke a semi-empirical model to predict the mass of an IMBH that, if undergoing accretion in the long-lived hard X-ray state, is consistent with a given synchrotron radio luminosity [7,8]. Specifically, we conservatively assume accretion at 3% of the Bondi rate [9] from GC gas at a density of 0.2 particles per cubic centimeter [10]. These parameters predict the hard-state X-ray luminosity. The empirical fundamental-plane of BH activity [11] is then used to predict the synchrotron radio luminosity. The radio emission is predicted to be flat-spectrum, persistent, point-like, and located near the dynamical center of the GC.

Fig. 2 – VLA

Fig. 3a - M81, a spiral galaxy at a distance of 3.6 Mpc. Credit: Astro Pro-Am

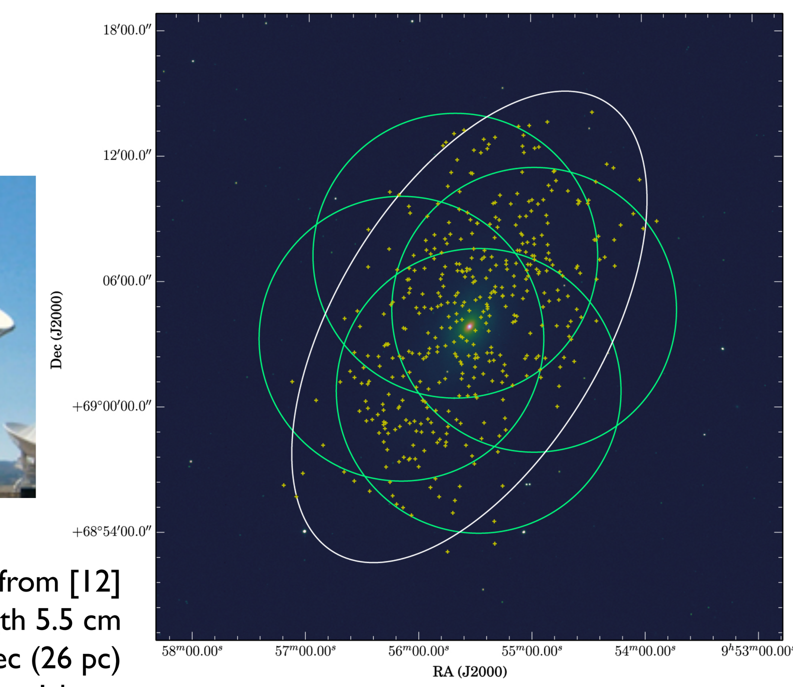


Fig. 3b – Four-pointing mosaic with the VLA from [12]
Observing wavelength 5.5 cm
Spatial resolution 1.5 arcsec (26 pc)
Integration time per pointing 1 hour
Field of view (FOV) per pointing 13.6 arcmin (15.5 kpc)
Green circles convey the four FOVs
White ellipse conveys the galaxy extent in the near IR

Globular Cluster System of M81 with the VLA

We used [12] the Karl G. Jansky Very Large Array (VLA, Fig. 2) to search for the radiative signatures of IMBH accretion from 206 probable GCs in M81 (Fig. 3). None of the individual GCs are detected, nor are weighted-mean image stacks of the 206 GCs and of the 49 GCs with stellar masses of 200,000 solar masses or more (Figs. 4-6). We applied the radio model to predict the IMBH mass that is consistent with a given synchrotron luminosity. The 3σ VLA upper limits imply:

- For 13 individual GCs, the ratios of their IMBH masses to stellar masses appear to be less than 0.03-0.15.
- The stacks correspond to mean IMBH masses of less than 42,000 $M_\odot$ for all 206 GCs and less than 51,000 $M_\odot$ for the 49 massive GCs.

As demonstrated with M81, the VLA is making inroads into the difficult-to-observe regime of IMBHs in extragalactic GCs. To make significant progress, deeper observations are needed for more individual GCs in M81 and other globular cluster systems. Below, we consider the role of the next-generation VLA (ngVLA).

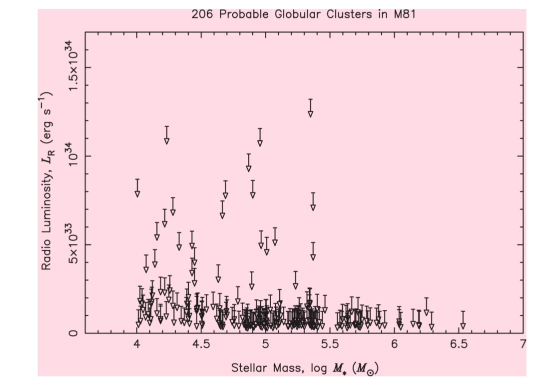


Fig. 4 – 206 GCs

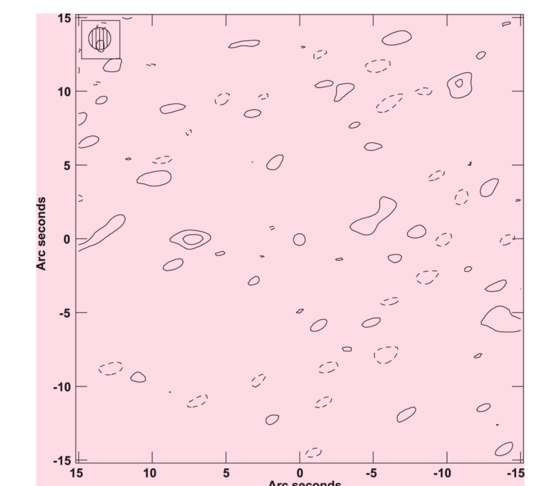


Fig. 5 – Stack 206 GCs 3σ ~ 1 microJy/bm

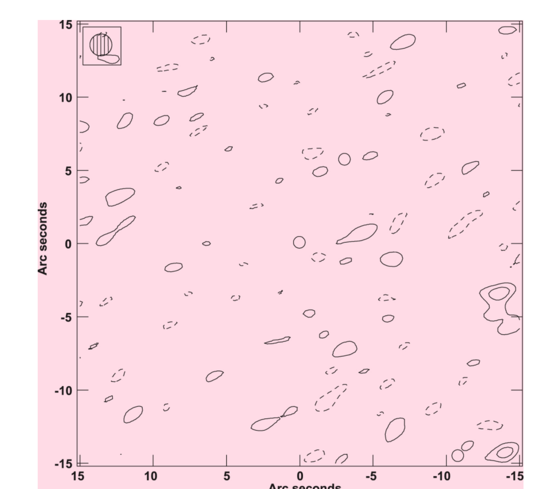


Fig. 6 – Stack 49 GCs 3σ ~ 2 microJy/bm

Globular Cluster Systems with the ngVLA

Globular cluster systems have been studied for 422 galaxies [1,2]. The distribution of the galaxies' distances shows two peaks (Fig. 7). A minor peak contains tens of galaxies with distances out to 10 Mpc. A major peak contains hundreds of galaxies with distances between 10 Mpc and 25 Mpc.

Fig. 8 shows that the ngVLA can be used at 2cm [13] to infer IMBH masses in GCs out to a distance of 25 Mpc. The ngVLA can thus access hundreds of globular cluster systems holding tens of thousands of GCs in total. Specifically:

- At 10 Mpc the radio model predicts a 2cm flux density of 0.35 microJy from an IMBH of 82,000 $M_\odot$ (see ✖). The ngVLA can make a 3σ detection with a 10-hour integration and a robust resolution of 100 mas (5 pc). This resolution matches the half-starlight diameter of a GC. A globular cluster system spans a galactic halo. The FOV of the ngVLA is 3.4 arcmin (10 kpc), so it can encompass the entire globular cluster system in a few FOVs. Each FOV can simultaneously capture many GCs. Undetected GCs can also be stacked. A stacking performance as for M81 can improve the IMBH mass sensitivity by a factor of two.

- At 25 Mpc the radio model predicts a 2cm flux density of 0.35 microJy from an IMBH of 160,000 $M_\odot$ (see ✖). The ngVLA can make a 3σ detection with a 10-hour integration, localize the source to the GC, and encompass the entire globular cluster system in a few FOVs. Each FOV can simultaneously capture many GCs. Stacking can be done too.

Fig. 7

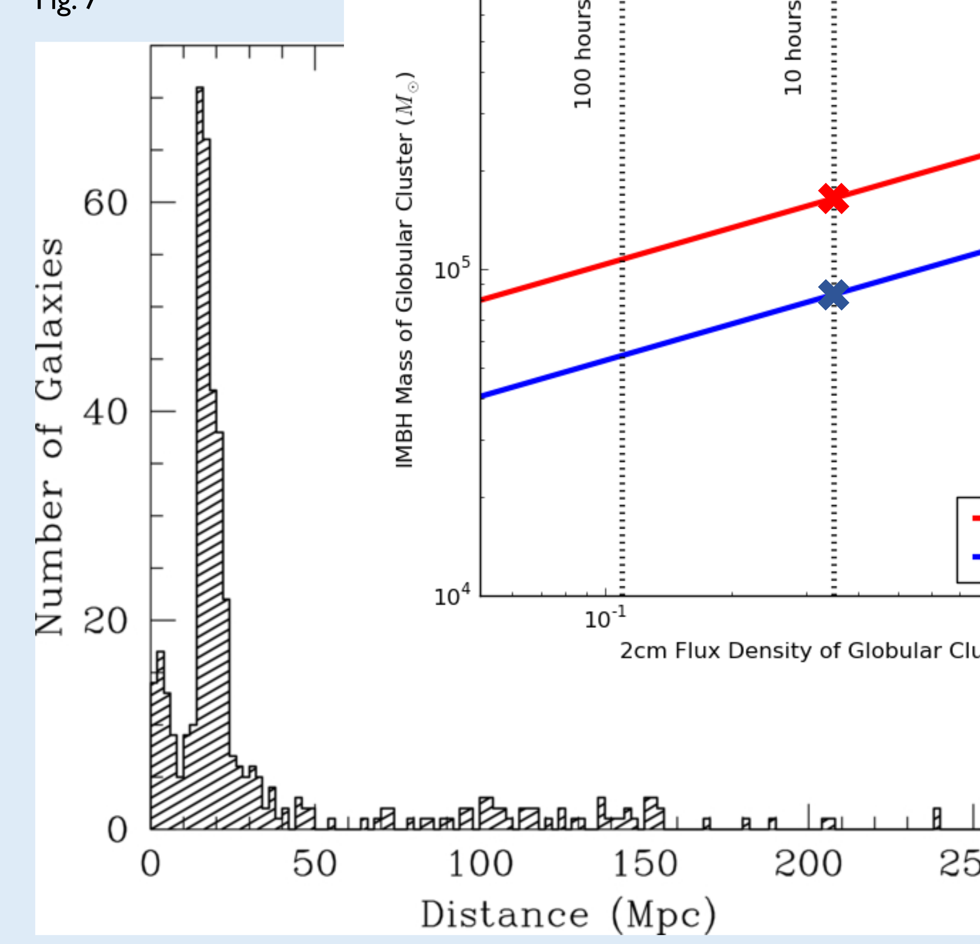


Fig. 8

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