

# Determining Whether Dark Matter is Entirely Primordial Black Holes with a Direct Detection DECam Microlensing Survey

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With LIGO's recent discovery of 30 solar mass ( $M_{\odot}$ ) black holes<sup>1</sup> and new theoretical arguments<sup>2</sup>, we are now motivated to consider a dark matter candidate consisting entirely of primordial intermediate mass black holes formed less than one second after the Big Bang (IM MACHOs;  $15-10^4 M_{\odot}$ ). Previous MACHO searches during the 1990's constrained the MACHO content of the universe for MACHO masses below  $15 M_{\odot}$  (Figure 1). Meanwhile, the original CMB<sup>3</sup> and wide-binary<sup>4</sup> constraints from the 2000's appeared to rule out black hole dark matter above  $2M_{\odot}$ ; however, these constraints were reliant on complex and poorly constrained astrophysical assumptions. As these assumptions were explored in more detail<sup>5,6</sup>, the window reopened between  $30 < M_{\text{dark matter}} \lesssim 200 M_{\odot}$  but still with "order-of-magnitude" uncertainty due to necessary assumptions. The latest astrophysical constraint based on the stellar profile in dwarf galaxies<sup>7</sup>, that presumably rules out black hole dark matter  $> 20 M_{\odot}$ , is also reliant on several astrophysical assumptions (a delta function MACHO mass function, no central massive black hole, and that the Eridanus II star cluster is at the center of the dwarf galaxy) which may be incorrect<sup>8,9,10</sup>, and would cause the mass window to reopen.

Rather than attempt to address the various complex assumptions and associated systematics with these astrophysical probes, we propose to carry-out direct detection microlensing measurements of the intermediate mass MACHO population to determine if they comprise all of the dark matter.

Previous microlensing surveys were limited by image quality, analysis methods, and computational resources. Modern telescopes, instruments, and computing enable our parallactic microlensing detection method, which is ideal for the multi-year microlensing event timescales of intermediate mass MACHOs<sup>1</sup>. We have proven this on data from a recently detected  $9.6M_{\odot}$  black hole<sup>11</sup>. By combining the parallactic<sup>12</sup> and astrometric<sup>13</sup> microlensing signals we can break the lensing mass-geometry degeneracy and make a precise measurement of individual black hole masses<sup>14</sup>. Thus, if primordial black holes make up dark matter, we will be measuring their "particle" properties, and the distribution of their masses will provide insight into the fundamental physics of the early universe. Furthermore, the parallactic microlensing signal enables dark matter mass constraints irrespective of the Einstein radius crossing time (i.e. mass), thus we can constrain all mass ranges  $> 10 M_{\odot}$ .

We propose a 5 year, 700 sq. deg., multi-band survey of the Galactic bulge with DECam (4 nights/month, 8 months/year, resulting in  $\sim 60$  measurements/year of  $\sim 500$  million stars). With this survey, we expect  $\sim 100$  microlensing events by IM MACHOs. Importantly, this will also act as a bridge to the start of the LSST survey. LSST has potential to be the ideal survey for this science (with  $\sim 1000$  expected microlensing events); however, microlensing is currently outside its purview. Additionally, current survey plan options, which only observe the Milky Way in the first year, will unnecessarily preclude microlensing dark matter science. It is pressing that we begin this effort now while there is still time to influence the LSST survey strategy.

By leveraging existing DOE investments in DECam & LSST ( $\sim \$225M$ ), LLNL & FNAL computing (including an ongoing reduction effort of archival DECam data), and LLNL LDRD staff support ( $\$150k$  one year LLNL feasibility study), this survey can be carried out with minimal additional investment by DOE. In particular, funds are needed to support 2.5 postdoc FTE, two graduate students, one professor's summer salary, and travel for DECam survey observing runs to Chile.

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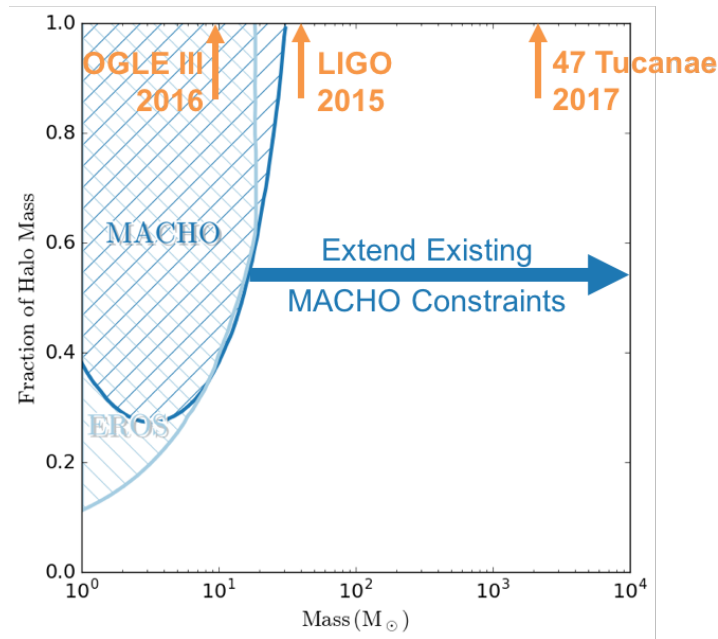


Figure 1: Existing constraints on the fraction of the mass in the MW halo that can be composed of IM MACHO dark matter. We seek to extend the existing MACHO microlensing constraint to higher masses. The masses of detected black holes are indicated in orange<sup>1,9,11</sup>.

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<sup>2</sup>Chapline, George F, and Paul H Frampton. 2016. “A New Direction for Dark Matter Research: Intermediate-Mass Compact Halo Objects.” *Journal of Cosmology and Astroparticle Physics* 2016, 11, 042–042

<sup>3</sup>Ricotti, Massimo, Jeremiah P Ostriker, and Katherine J Mack. 2008. “Effect of Primordial Black Holes on the Cosmic Microwave Background and Cosmological Parameter Estimates.” *The Astrophysical Journal*, 680, 829–45

<sup>4</sup>Yoo, Jaiyul, Julio Chanamé, and Andrew Gould. 2004. “The End of the MACHO Era: Limits on Halo Dark Matter From Stellar Halo Wide Binaries.” *The Astrophysical Journal* 601, 311–18

<sup>5</sup>Quinn, D P, M I Wilkinson, M J Irwin, J Marshall, A Koch, and V Belokurov. 2009. “On the Reported Death of the MACHO Era.” *Monthly Notices of the Royal Astronomical Society: Letters* 396, L11–L15

<sup>6</sup>Ali-Haïmoud, Yacine, and Marc Kamionkowski. 2016. “Cosmic Microwave Background Limits on Accreting Primordial Black Holes.” *arXiv:1612.05644v2*

<sup>7</sup>Brandt, Timothy D. 2016. “Constraints on MACHO Dark Matter From Compact Stellar Systems in Ultra-Faint Dwarf Galaxies.” *The Astrophysical Journal Letters* 824, L31

<sup>8</sup>Li, T S, J D Simon, A Drlica-Wagner, K Bechtol, M Y Wang, J García-Bellido, J Frieman, et al. 2016. “Farthest Neighbor: the Distant Milky Way Satellite Eridanus II.” *arXiv:1611.05052v2*

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<sup>10</sup>Crnojević, D, D J Sand, D Zaritsky, K Spekkens, B. Willman, and J R Hargis. 2016. “Deep Imaging of Eridanus II and Its Lone Star Cluster.” *The Astrophysical Journal Letters* 824, L14

<sup>11</sup>Wyrzykowski, L, Z Kostrzewa-Rutkowska, J Skowron, K A Rybicki, P Mróz, S Kozłowski, A Udalski, et al. 2016. “Black Hole, Neutron Star and White Dwarf Candidates From Microlensing with OGLE-III.” *MNRAS* 458, 3012–26

<sup>12</sup>Alcock, C, R A Allsman, D Alves, T S Axelrod, D P Bennett, K. H. Cook, K C Freeman, et al. 1995. “First Observation of Parallax in a Gravitational Microlensing Event.” *Astrophysical Journal Letters* 454, L125

<sup>13</sup>Lu, J R, E Sinukoff, E O Ofek, A Udalski, and S Kozłowski. 2016. “A Search for Stellar-Mass Black Holes via Astrometric Microlensing.” *Astrophysical Journal* 830, 41

<sup>14</sup>Yee, Jennifer C. 2015. “Lens Masses and Distances From Microlens Parallax and Flux.” *The Astrophysical Journal Letters* 814, L11