Draft version October 12, 2018
Preprint typeset using LaTeX style emulateapj v. 5/2/11

THE LOW-SPIN BLACK HOLE IN LMC X–3

James F. Steiner[1†], Jeffrey E. McClintock[1], Jerome A. Orosz[2], Ronald A. Remillard[3], Charles D. Bailyn[4], Mari Kolehmainen[5], Odele Straub[6]

Draft version October 12, 2018

ABSTRACT

Building upon a new dynamical model for the X-ray binary LMC X–3, we measure the spin of its black hole primary via the continuum-fitting method. We consider over one thousand thermal-state *RXTE* X-ray spectra of LMC X–3. Using a large subset of these spectra, we constrain the spin parameter of the black hole to be $a_* = 0.21^{+0.18}_{-0.22}$ (90% confidence). Our estimate of the uncertainty in a_* takes into account a wide range of systematic errors. The low spin and low mass of the black hole further align LMC X–3 with the class of Roche-lobe overflowing, transient black-hole systems. We discuss evidence for a correlation between a black hole's spin and the complexity of its X-ray spectrum.

Subject headings: accretion, accretion disks — black hole physics — stars: individual (LMC X–3) — X-rays: binaries

1. INTRODUCTION

Leong et al. (1971) discovered LMC X–3 during the first year of the *Uhuru* mission. In 1983, Cowley et al. (1983) showed via dynamical observations that the compact X-ray source in this 1.7-day binary is a black hole. In Orosz et al. (2014) we use new optical data to derive a much-improved dynamical model of the system, which contains a B-type secondary. Of chief importance, Orosz et al. report tight constraints on the orbital inclination angle of the binary, $i = 69.6 \pm 0.6$ deg, and the mass of the black hole, $M = 6.95 \pm 0.33$ $M_\odot$.

LMC X–3 is unusual compared to the full assemblage of black-hole binary systems: On the one hand, like the transient systems, its X-ray intensity is highly variable because the black hole is fed by Roche-lobe overflow. On the other hand, however, the system almost continually maintains itself in an X-ray bright mode like the persistent (wind-fed) systems (McClintock et al. 2013; Soria et al. 2001).

Transient versus persistent black holes are further set apart by the properties of their black hole primaries: the transient black hole masses are low and tightly distributed (7.8 $M_\odot$ ± 1.2 $M_\odot$), while the masses of the persistent black holes are appreciably higher ($\gtrsim 11$ $M_\odot$; Özel et al. 2010). Meanwhile, the spins of the transients are widely distributed ($a_* \approx 0 - 1$), while the three persistent black holes with spin measurements are all high ($a_* \gtrsim 0.85$). The mode of mass transfer firmly identifies LMC X–3 as belonging to the class of transient black hole binaries. The low mass of LMC X–3's primary and its low spin (reported herein) are perfectly congruent with this classification.

Despite strong variations in X-ray brightness (> 3 orders of magnitude), the X-ray spectrum of LMC X–3 is nearly always in a thermal, disk-dominated state (ideal for measuring spin via the continuum-fitting method), except during occasional prolonged excursions into a low-intensity hard state (e.g., Smale & Boyd 2012; Wilms et al. 2001). Because the X-ray spectrum is strongly disk-dominated, relatively featureless, and minimally affected by interstellar absorption, LMC X–3 is a touchstone for testing spectral models of black-hole accretion disks (e.g., Kubota et al. 2010; Straub et al. 2011). In a precursor to this work, we fitted all archival X-ray spectra with reliable flux calibration to a relativistic model of a thin accretion disk. For hundreds of Rossi X-ray Timing Explorer (*RXTE*) spectra, we showed that the inner radius of the disk is constant to within ≈ 2% over a span of 14 years despite the gross variability of the source. Furthermore, for an ensemble of eight X-ray missions spanning 26 years, we showed that the radius is constant to better than ≈ 6%, despite the uncertainties associated with cross-calibrating the various detectors. This result is the strongest observational evidence to date that spin can be reliably inferred by measuring the inner-disk radius.

The elegant simplicity of a black hole is encapsulated in the famous "no-hair theorem", which tells us that an astrophysical black hole is *completely* described by just its mass and spin angular momentum (the third parameter, electrical charge, being effectively neutral in astrophysical settings). A spinning black hole is an enormous capacitor of angular momentum, with the spin as a ready energy source that can be tapped mechanically in a black hole's ergosphere. Spin has long been proposed as the likely energy source behind the enormously energetic jets emitted from black holes (e.g., Blandford & Znajek 1977). This assumption has gained recent support both theoretically (e.g., Tchekhovskoy et al. 2011), and observation-

jsteiner@cfa.harvard.edu
[1] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138.
[2] Department of Astronomy, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182.
[3] MIT Kavli Institute for Astrophysics and Space Research, MIT, 70 Vassar Street, Cambridge, MA 02139.
[4] Astronomy Department, Yale University, P.O. Box 208101, New Haven, CT 06520.
[5] Astrophysics, Department of Physics, University of Oxford, Keble Road, Oxford OX1 3RH, UK.
[6] LUTH, Observatoire de Paris, CNRS, Universite Paris Diderot, 5 place Jules Janssen, 92190 Meudon, France.
[†] Hubble Fellow.