A YOUNG MASSIVE STELLAR POPULATION AROUND THE INTERMEDIATE-MASS BLACK HOLE ESO 243-49 HLX-1

S. A. Farrell1,2, M. Servillat3, J. Pförß4,9, T. J. Maccarone3, C. Knigge5, O. Godej6,7, C. Maraston4, N. A. Webb6,7, D. Barret6,7, A. J. Gosling8, R. Belmont6,7, and K. Wiersema2

1 Sydney Institute for Astronomy (SIfA), School of Physics, The University of Sydney, NSW 2006, Australia; sean.farrell@sydney.edu.au
2 Department of Physics and Astronomy, University of Leicester, University Road, LE1 7RH Leicester, UK
3 Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, MS-67, Cambridge, MA 02138, USA
4 Institute of Cosmology and Gravitation, University of Portsmouth, Dennis Sciama Building, Burnaby Road, Portsmouth PO1 3FX, UK
5 School of Physics and Astronomy, University of Southampton, Hampshire SO17 1BJ, UK
6 Université de Toulouse, UPS-OMP, Institut de Recherche en Astrophysique et Planétologie (IRAP), Toulouse, France
7 CNRS, IRAP, 9 Avenue du Colonel Roche, BP 44346, F-31028 Toulouse Cedex 4, France
8 University of Oxford, Department of Physics, Keble Road, Oxford OX1 3RH, UK

Received 2011 October 27; accepted 2011 December 7; published 2012 February 15

ABSTRACT

We present Hubble Space Telescope and simultaneous Swift X-ray Telescope observations of the strongest candidate intermediate-mass black hole (IMBH) ESO 243-49 HLX-1. Fitting the spectral energy distribution from X-ray to near-infrared wavelengths showed that the broadband spectrum is not consistent with simple and irradiated disk models, but is well described by a model comprised of an irradiated accretion disk plus a $\sim 10^6 M_\odot$ stellar population. The age of the population cannot be uniquely constrained, with both young and old stellar populations allowed. However, the old solution requires excessive disk reprocessing and an extremely small disk, so we favor the young solution ($\sim 13$ Myr). In addition, the presence of dust lanes and the lack of any nuclear activity from X-ray observations of the host galaxy suggest that a gas-rich minor merger may have taken place less than $\sim 200$ Myr ago. Such a merger event would explain the presence of the IMBH and the young stellar population.

Key words: accretion, accretion disks – galaxies: interactions – galaxies: star clusters: general – globular clusters: general – X-rays: binaries – X-rays: individual (ESO 243-49 HLX-1)

Online-only material: color figures

1. INTRODUCTION

The formation of stellar-mass black holes (BHs; $\sim 3–80 M_\odot$; Belczynski et al. 2010) through the collapse of massive stars is well accepted, but it is not yet completely clear how the supermassive BHs ($\sim 10^5–10^9 M_\odot$) are formed. They may form through the merger of $\sim 10^2–10^4 M_\odot$ intermediate-mass black holes (IMBHs; Ebisuzaki et al. 2001). IMBHs are thus a crucial missing link between stellar-mass and supermassive BHs, with the existence of IMBHs (Farrell et al. 2009). HLX-1 is located in the halo of the edge-on S0a galaxy ESO 243-49, $0.8$ kpc out of the plane and $\sim 3.3$ kpc away from the nucleus. At the redshift of ESO 243-49 ($z = 0.0223$) the maximum $0.2–10$ keV X-ray luminosity of HLX-1 is $L_X = 1.3 \times 10^{42}$ erg s$^{-1}$ (Godet et al. 2011a), a factor of $\sim 400$ above the theoretical Eddington limit for a $20 M_\odot$ BH. Luminosities up to $L_X = 10^{43}$ erg s$^{-1}$ can be explained by stellar-mass BHs undergoing super-Eddington accretion (Begelman 2002) and/or experiencing significant beaming, which makes them appear to exceed the Eddington limit for isotropic radiation (King 2008; Freeland et al. 2006). However, luminosities above $L_X = 10^{41}$ erg s$^{-1}$ are difficult to explain without a more massive BH. Following the discovery of an optical counterpart by Soria et al. (2010), the distance to HLX-1 was confirmed through the detection of the Hα emission line at a redshift consistent with the host galaxy (Wiersema et al. 2010), confirming the extreme luminosity. Modeling the accretion disk emission using relativistic (Davis et al. 2011) and slim disk (Godet et al. 2011b) models implies a mass between $3000–100,000 M_\odot$, consistent with values obtained by scaling from stellar-mass BH binaries (Servillat et al. 2011).

Long-term monitoring with the Swift observatory has shown that HLX-1 varies in X-ray luminosity by a factor of $\sim 50$ (Godet et al. 2009), with correlated spectral variability reminiscent of that seen in Galactic stellar-mass BHs (Servillat et al. 2011). Since Swift monitoring began in 2009, HLX-1 has been observed to undergo three outbursts, each spaced approximately one year apart (Godet et al. 2011b). The characteristic timescales of the outbursts are inconsistent with the thermal-viscous instability model, and the outburst mechanism could instead be tidal stripping of a companion star in an eccentric orbit (Lasota et al. 2011).

Excess UV emission was detected consistent with HLX-1 with the GALEX and Swift observatories, although this emission could not be resolved from the nucleus of ESO 243-49 (Webb et al. 2010). At least some of the UV excess is likely to be associated with a $z \sim 0.03$ background galaxy (Wiersema et al. 2010; Farrell et al. 2011). Using preliminary UV fluxes obtained...
from the Hubble Space Telescope (HST) data presented in this Letter, Lasota et al. (2011) estimated the age of the stellar environment around HLX-1 to be ~0.3–0.6 Gyr through stellar population synthesis modeling and the assumption of a $5 \times 10^9 M_\odot$ cluster mass and solar metallicities. They therefore concluded that the most likely progenitor of the companion star would be an asymptotic giant branch star with a mass $\sim 2.7–3.5 M_\odot$. However, the contribution from accretion disk emission (in particular, possible irradiation in the outer disk) was not taken into account, and so a more rigorous approach employing broadband modeling is required.

In this Letter we report the results of detailed broadband spectral modeling of HLX-1 using UV, optical, and near-IR observations performed with the HST in conjunction with simultaneous observations performed in X-ray wavelengths with the Swift X-ray Telescope (XRT). The Letter is organized as follows: Section 2 lists the data reduction steps, while Section 3 describes the analysis methods employed and the results obtained. Section 4 discusses the implication of these results and the conclusions that we have drawn.

### 2. DATA REDUCTION

Following the peak of the second outburst we obtained three orbits of observations with the HST on 2010 September 13 and 23 under program 12256 in order to constrain the nature of the environment around HLX-1. During these observations HLX-1 was in the thermally dominated high/soft spectral state. Observations were performed in the far-UV (FUV) band using the Advanced Camera for Surveys (ACS) Solar Blind Camera (SBC), and in the near-UV (NUV), Washington $C$, $V$, $I$, and $H$ bands with the Wide Field Camera 3 (WFC3) UVIS and IR cameras. Table 1 presents the log of the HST observations. We analyzed the final HST images generated by the pipeline (drz files) using the latest calibration data (CALWF3 = 2.1 as of 2010 May 15, and CALACS = 5.1.1 as of 2010 April 27). As part of the pipeline these images were flat-fielded, combined (with cosmic ray rejection) and geometrically corrected using PyDrizzle v6.3.5 (2010 May 19).

We corrected the astrometry of each HST image following a two-step procedure with an intermediate image and using the US Naval Observatory CCD Astrograph Catalog (UCAC3; Zacharias et al. 2010) as an astrometric reference (typical rms error of 0\".1). As the HST WFC3 and ACS fields of view are relatively small and the target is located in a particularly empty field that only contains one or two UCAC3 sources (including the extended source ESO 243-49 itself), we used an intermediate image obtained with the Infrared Side Port Imager (ISPI) at the Cerro Tololo inter-American observatory (CTIO; van der Bieke et al. 2004) on 2009 August 2. This image covers a $10' \times 10'$ region around ESO 243-49 in the J band. We aligned the ISPI image on the UCAC3 catalog using the Starlink/GAIA software and obtained a precision of 0\".13 (rms) using nine reference stars. We then used the ISPI image as a reference to align the WFC3 images. The number of stars used in the process and the resulting absolute position error are given in Table 1 for each band. For the ACS-SBC image (F140LP filter), this process could not be applied because of the lack of detection of ISPI stars in this band. We thus used the WFC3-UVIS near-UV image as a reference, finding four common objects. The precision is also reported in Table 1. The HLX-1 Chandra X-ray position is 0\".3 at 95% confidence (Webb et al. 2010). The HST errors include the UCAC3 absolute error of 0\".05 and the ISPI relative error of 0\".13 (1\sigma). The final position error, adding in quadrature all errors, is thus 0\".5 at 95% confidence level for each HST image. A single counterpart is clearly detected in each band within this error circle (Figure 1), although in the F160W H-band filter image it is difficult by eye to see the counterpart against the strong diffuse emission from the galaxy.

The field of HLX-1 was also observed with the Swift XRT (ObsIDs: 00031287055, 00031287056, 00031287057, 00031287058, and 00031287059) on 2010 September 13, 14, and 23 for a total of 17.5 ks. The data were reduced, and spectra were extracted in the same manner as described in Servillat et al. (2011). The spectra were binned to a minimum of 20 counts per bin in order to use $\chi^2$ statistics for the fitting.

### 3. DATA ANALYSIS AND RESULTS

A single point source was significantly detected in all the HST images within the 95% confidence levels of the combined Chandra and HST astrometry of HLX-1 (see Figure 1). The source is unresolved in all the images. The 0\".08 FWHM of the point-spread function (PSF) in the raw WFC3-UVIS images converts to a diameter upper limit of 40 pc at the distance to HLX-1 (95 Mpc; Wiersema et al. 2010). We extracted the flux of the HLX-1 counterpart using aperture photometry with the astrolib IDL procedure after centering with the centerd procedure. We used extraction radii that encircle at least 90% of the energy from the source (see...
Figure 1. Top panels: HST images from each of the six filters (far-UV, near-UV, Washington C, V, I, and H bands) zoomed in on HLX-1. The circles indicate the X-ray position of HLX-1 with the radii of $0.5''$ indicating the combined HST plus Chandra 95% astrometric error. Bottom: composite HST image constructed from all UV, optical and near-IR images. Prominent dust lanes around the nucleus of ESO 243-49 are evident. The HLX-1 counterpart is indicated by the tick marks. The two sources directly to the west of HLX-1 are a pair of background galaxies. (A color version of this figure is available in the online journal.)

Table 2

| Band | Filter | $\lambda_{pivot}$ (Å) | FWHM (Å) | Aperture Size | Encircled Energy | Magnitude |
|------|--------|------------------------|----------|---------------|------------------|-----------|
|      |        |                        |          | Src Bkg        | Src$^a$ Bkg$^b$  |           |
| FUV  | F140LP | 1527                   | 294.08   | 0.5 0.5–0.6   | 90.5% 1.8%       | 24.11 ± 0.05 |
| NUV  | F300X  | 2829.8                 | 753      | 0.4 0.4–0.5   | 90.4% 1.2%       | 23.96 ± 0.04 |
| C    | F390W  | 3904.6                 | 953      | 0.4 0.4–0.5   | 91.6% 1.2%       | 23.92 ± 0.06 |
| V    | F555W  | 5309.8                 | 1595.1   | 0.4 0.4–0.5   | 92.1% 1.1%       | 23.83 ± 0.08 |
| I    | F775W  | 7733.6                 | 1486     | 0.3 0.2–0.3   | 90.2% 2.1%       | 23.91 ± 0.08 |
| H    | F160W  | 15405.2                | 2878.8   | 0.5 0.5–0.6   | 90.6% 1.2%       | 24.4 ± 0.3  |

Notes.

$^a$ Fraction of encircled energy in the aperture.

$^b$ Fraction of the source energy included in the background annulus.

Table 2). The encircled energy curve was calculated from the Tiny Tim PSF models$^{12}$ (Krist 1995) which consistently match the identified stars in the raw images, degraded with a Gaussian filter to reproduce the effect of image combination with drizzle. We then subtracted the background, estimated in an annulus around the source, and applied aperture corrections (see Table 2) to the net flux to obtain the total flux from the target.

For the WFC3-IR F160W image, the galaxy emission is about 10 times higher than the flux of the counterpart to HLX-1 and the background is not symmetric. We therefore interpolated the extended emission of the galaxy in a 10 pixel radius region around HLX-1 using the procedure grid_tps in IDL, and subtracted it from the image in order to obtain a flat and

$^{12}$ http://www.stsci.edu/hst/observatory/focus/TinyTim
The fluxes were converted into AB magnitudes using the magnitude zero points given in the symmetric background around the source. We then performed the fitting of the broadband spectral energy distribution (SED) constructed from the HST and Swift data was performed using XSPEC v12.6.0q (Arnaud 1996). The Swift XRT data were consistent with both multi-color disk blackbody and power-law models; however, the power-law photon index of $\Gamma = 4.9$ is unphysically steep. We thus assumed a thermal model for the X-ray emission and fitted the SED with an irradiated disk model ($diskir$; Gierliński et al. 2008, 2009), which includes thermal emission from the inner disk, non-thermal contribution from the Compton tail, and reprocessing in the outer disk. Components representing absorption by the neutral hydrogen column (using the $tbabs$ model and the elemental abundances prescribed in Lodders 2003) and dust extinction (using the $redden$ model and the extinction curves in Cardelli et al. 1989) were included.

The upper limit of the age was constrained to be 13.5 Gyr, consistent with the age of the universe minus the light travel time from HLX-1 to Earth.

The upper limit of the age was constrained to be 13.5 Gyr, consistent with the age of the universe minus the light travel time from HLX-1 to Earth.

13 http://www.stsci.edu/hst/wfc3/phot_zp_lbn
14 http://www.stsci.edu/hst/acs/analysis/zeropoints

### Table 3
Best-fit Spectral Parameters for Both the Young and Old Stellar Population Solutions

| Parameter                            | Symbol | Young          | Old            | Units          |
|--------------------------------------|--------|----------------|----------------|---------------|
| Extinction                           | $E(B-V)$ | 0.42$^{+0.06}_{-0.04}$ | 0.2$^{+0.3}_{-0.2}$ | mag           |
| Absorption                           | $N_H$  | 0.1$^{+0.06}_{-0.04}$ | 0.04$^{+0.07}_{-0.04}$ | 10$^{22}$ cm$^{-2}$ |
| Stellar Population Component         |        |                |                |               |
| Metallicity                          | $Z_e$  | 1              | 2              | $Z_\odot$     |
| Age                                  | Log (Age$_e$) | $<7.1$         | 10.1           | yr            |
| Bolometric stellar population luminosity | $L_\ast$ | $1.4 \times 10^{42}$ | $5.5 \times 10^{39}$ | erg s$^{-1}$ |
| Stellar mass                          | $M_\ast$ | $4 \times 10^6$ | $6 \times 10^6$ | $M_\odot$    |
| Irradiated Disk Component             |        |                |                |               |
| Disk temperature                     | $kT_d$ | $0.19^ {+0.03}_{-0.02}$ | $0.21^ {+0.03}_{-0.04}$ | keV           |
| Photon index                         | $\Gamma$ | 2.1           | 2.1            |               |
| High-energy turn over temperature    | $kT_e$ | 100            | 100            | keV           |
| Ratio of Compton tail to disk luminosity | $L_c/L_d$ | $0.09^{+0.01}_{-0.05}$ | $0.13^{+0.1}_{-0.09}$ |               |
| Compton inner disk fraction          | $f_{in}$ | 0              | 0              |               |
| Radius of Compton-illuminated disk   | $r_{ir}$ | 1.001          | 1.001          | $R_\odot$    |
| Fraction of flux thermalized in outer disk | $f_{out}$ | $8 \times 10^{-7}$ | $0.098^{+0.002}_{-0.007}$ |               |
| Outer disk radius                    | Log ($r_{out}$) | 3.4           | 3.4$^{+0.3}_{-0.3}$ | Log ($R_\odot$) |
| Bolometric disk luminosity           | $L_d$  | $1.1 \times 10^{42}$ | $1.1 \times 10^{42}$ | erg s$^{-1}$ |

### Fit statistics

$\chi^2$/dof | 23.38/27 | 24.28/27 | ... |

### Notes

a All errors are quoted at the 90% confidence level.
b These parameters without errors could not be constrained. For example, values as high as $1 \times 10^{-3}$ and 6 are allowed for the $f_{out}$ and $r_{out}$ parameters, respectively, in the young solution.
c Contribution from a Compton component is minimal, so we froze $kT_e = 100$ keV, $\Gamma = 2.1$ (consistent with deeper observations of HLX-1 and stellar-mass BH binaries in the same luminosity state; Servillat et al. 2011; Done et al. 2007); $f_{in} = 0$, and $r_{ir} = 1.001$, setting the Compton illumination component to zero.
et al. 2009). The best-fit outer disk radii in both fits were ∼ of the disk seen by the central BH is > (> unphysically high fractions of reprocessing in the outer disk fraction and an extremely small disk are necessary outcomes or the size and level of irradiation of the disk. In addition, the fact that we can fit the data with two models with such disparate parameter values indicates degeneracies in the fit, particularly between the stellar age and fraction of outer disk irradiation. Nonetheless, using the age, metallicity, and luminosity of the stellar components in each fit, we are able to constrain the stellar-mass to be ∼(4–6) × 10⁵ M⊙. Table 3 lists the parameter values obtained with this fit.

To test for model dependency in the fit, we also generated additive table models using stellar population models based on empirical stellar libraries by Maraston & Strömbäck (2011). In particular, we used the models based on the Pickles (1998) solar metallicity library because of their extended wavelength range. Replacing the theoretical atmosphere models with these empirical stellar library models also obtained fits with both young (χ²/dof = 23.81/28) and old (χ²/dof = 24.52/28) stellar populations.

4. DISCUSSION AND CONCLUSIONS

The detection of a stellar population around HLX-1 provides insights into the origin of and environment around an IMBH. Our SED fitting could not constrain the age of the stellar cluster around HLX-1 other than to show that only young or old populations are allowed. However, the reprocessing fraction in the outer disk required for old solution is ∼10%, which borders on being non-physical (reprocessing fractions >10% require the disk to subtend an unfeasibly large solid angle; Gierliński et al. 2009). In addition, the size of the accretion disk is constrained to be extremely small with an outer radius ∼1000 times the inner disk radius.

Galactic low-mass X-ray binaries in disk-dominated states typically have fractions of reprocessing in the outer disk of f_out ~ 10⁻³ (Gierliński et al. 2009), far lower than the value obtained in the old stellar population solution. The outer disk radius also has a strong effect on the reprocessing fraction. Freezing the outer disk radius at a more likely value of 10⁵R_m (C. Done 2011, private communication), we could not find an acceptable fit solution with an old population (χ²/dof = 225.42/29), indicating that an extremely high reprocessed fraction and an extremely small disk are necessary outcomes with an old star cluster. We therefore favor the young stellar population solution, although without additional data we cannot conclusively rule out an extremely old star cluster. The upper limit of 40 pc derived for the cluster diameter is consistent with either a globular cluster or young massive star cluster, which typically have half-mass radii of ~10 pc (Harris 1996) and <50 pc (Portegies Zwart et al. 2010), respectively.

The presence of a young stellar population is difficult to reconcile with HLX-1 residing in a classical globular cluster (such as those observed in our own Galaxy), which are typically dominated by old stars (e.g., Forbes 2003). However, globular clusters with young stellar populations have been observed around disrupted galaxies such as the Antennae (Bastian et al. 2006) and the Magellanic Clouds (Elson & Fall 1985). The mass

17 In contrast, the poor constraints on the outer disk radius in the young stellar population solution allow for a much larger value up to 10⁷ R_m without an increase in the χ².
of the cluster around HLX-1 (calculated using the derived age and metallicity, the observed luminosity and the model mass-to-light ratio\(^{18}\) is \(\sim 4 \times 10^6 \, M_\odot\), which is at the upper end of the standard classical globular cluster mass range (Maraston et al. 2004).

A young star cluster surrounding HLX-1 could also be explained in the accreted dwarf galaxy scenario (Knierman 2010). Tidally stripping a dwarf galaxy during a merger event could remove a large fraction of the mass from the dwarf galaxy, with star formation triggered as a result of the tidal interactions. This could result in the observed IMBH embedded in the remnant of the nuclear bulge and surrounded by a young, high-metallicity, stellar population. It has been proposed that such accreted dwarf galaxies may explain the origin of some globular clusters, with the remnant cluster appearing more like a classical globular cluster as its stellar population ages (Forbes & Bridges 2010).

A link has been drawn between the presence of prominent dust lanes in early-type galaxies with frequent gas-rich minor mergers, with the host galaxy nuclear BH becoming active within \(< 200\,\text{Myr}\) following the merger event (Shabala et al. 2011). The \textit{HST} images of ESO 243-49 (see Figure 1) reveal pronounced dust lanes and yet no evidence of nuclear activity was detected in \textit{Chandra} X-ray images (Servillat et al. 2011), implying that the merger events that contributed to the formation of the dust lanes took place in the recent past. This is thus consistent with the presence of a young stellar population surrounding HLX-1, where localized star formation would have been triggered as a result of tidal interactions with ESO 243-49 following a recent merger event.

We note that Soria et al. (2011) argue against a young massive stellar population using lower signal-to-noise \textit{UBVR} data from the VLT. However, they do not fit the X-ray and optical data simultaneously and use alternative stellar population models. Additional \textit{HST} observations obtained at different X-ray luminosities are thus required in order to test the competing theories and therefore constrain the disk irradiation and stellar population contributions.

We thank the referee for useful comments and J.-P. Lasota, T. Alexander, C. Done, S. Shabala, F. Grisé, K. Arnaud, and R. Starling for helpful discussions. S.A.F. is the recipient of an ARC Postdoctoral Fellowship, funded by grant DP110102889. S.A.F., T.J.M., A.J.G., and K.W. acknowledge funding from the UK STFC. M.S. acknowledges support from NASA grants DD0-11050X and GO 12256. J.P. and C.M. acknowledge the Marie-Curie Excellence Team grant Unimass, ref. MEXT-CT-2006-042754 of the TMR program financed by the European Community. N.A.W., D.B., and O.G. thank the CNES. Based on observations made with the NASA/ESA \textit{HST}, obtained at the STScI, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. These observations are associated with program 12256. Also based on observations with \textit{Swift}.

\textbf{Facilities:} \textit{HST} (ACS, WFC3), \textit{Swift} (XRT), Blanco

\textbf{REFERENCES}

Abbott, B. P., Abbott, R., Adhikari, R., et al. 2009, \textit{Phys. Rev. D}, 80, 062001
Arnna, K. A. 1996, in \textit{ASP Conf. Ser.} 101, Astronomical Data Analysis Software and Systems V, ed. G. H. Jacoby & J. Barnes (San Francisco, CA: ASP), 17
Bastian, N., Emsellem, E., Kissler-Patig, M., & Maraston, C. 2006, \textit{A&A}, 445, 471
Belgenman, M. C. 2002, \textit{ApJ}, 568, L97
Bolczynski, K., Bulik, T., Fryer, C. L., et al. 2010, \textit{ApJ}, 714, 1217
Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, \textit{ApJ}, 345, 245
Davis, S. W., Narayan, R., Zhu, Y., et al. 2011, \textit{ApJ}, 734, 111
Done, C., Gierlinski, M., & Kubota, A. 2007, \textit{A&AR}, 15, 1
Ebisuzaki, T., Makino, J., Tsaru, T. G., et al. 2001, \textit{ApJ}, 562, L19
Elson, R. A. W., & Fall, S. M. 1985, \textit{ApJ}, 299, 211
Farrell, S. A., Servillat, M., Wiersema, K., et al. 2011, \textit{Astron. Nachr.}, 332, 392
Farrell, S. A., Webb, N. A., Barret, D., Godet, O., & Rodrigues, J. M. 2009, \textit{Nature}, 460, 73
Forbes, D. A. 2003, \textit{RevMexAA Conf. Ser.}, 17, 136
Forbes, D. A., & Bridges, T. 2010, \textit{MNRAS}, 404, 1203
Fornasa, M., & Bertone, G. 2008, \textit{Int. J. Mod. Phys. D}, 17, 1125
Freeland, M., Kuncic, Z., Soria, R., & Bicknell, G. V. 2006, \textit{MNRAS}, 372, 630
Gierlinski, M., Done, C., & Page, K. 2008, \textit{MNRAS}, 388, 753
Gierlinski, M., Done, C., & Page, K. 2009, \textit{MNRAS}, 392, 1106
Godet, O., Barret, D., Webb, N. A., Farrell, S. A., & Gehrels, N. 2009, \textit{ApJ}, 705, L109
Godet, O., Farrell, S., Barret, D., Webb, N., & Servillat, M. 2011a, \textit{ATel}, 3569, 1
Godet, O., Plazolles, B., Kawaguchi, T., et al. 2011b, \textit{ApJ}, submitted
Harris, W. E. 1996, \textit{AJ}, 112, 1487
King, A. R. 2008, \textit{MNRAS}, 385, L113
Knierman, K. A. 2010, in \textit{ASP Conf. Ser.} 423, Galaxy Wars: Stellar Populations and Star Formation in Interacting Galaxies, ed. B. Smith, N. Bastian, S. J. U. Higdon, & J. L. Higdon (San Francisco, CA: ASP), 342
Krist, J. 1995, in \textit{ASP Conf. Ser.} 77, Astronomical Data Analysis Software and Systems IV, ed. R. A. Shaw, H. E. Payne, & J. J. E. Hayes (San Francisco, CA: ASP), 349
Lasota, J.-P., Alexander, T., Dubus, G., et al. 2011, \textit{ApJ}, 735, 89
Lodders, K. 2003, \textit{ApJ}, 591, 1220
Maraston, C. 2005, \textit{MNRAS}, 362, 799
Maraston, C., Bastian, N., Saglia, R. P., et al. 2004, \textit{A&A}, 416, 467
Maraston, C., & Strömbäck, G. 2011, \textit{MNRAS}, 418, 2785
Miller, M. C., & Hamilton, D. P. 2002, \textit{MNRAS}, 330, 232
Pickles, A. J. 1998, \textit{PASP}, 110, 863
Portegies Zwart, S. F., McMillan, S. L. W., & Gieles, M. 2010, \textit{ARA&A}, 48, 431
Ricotti, M., & Ostriker, J. P. 2004, \textit{MNRAS}, 352, 547
Servillat, M., Farrell, S. A., Lin, D., et al. 2011, \textit{ApJ}, in press (arXiv:1108.4405)
Shabala, S. S., Ting, Y. S., Kaviraj, S., et al. 2011, \textit{MNRAS}, submitted (arXiv:1107.5310)
Soria, R., Hakala, P., Hau, G., & Gladstone, J. 2011, \textit{MNRAS}, in press (arXiv:1111.6785)
Soria, R., Hau, G. K. T., Graham, A. W., et al. 2010, \textit{MNRAS}, 405, 870
van der Bliek, N. S., Norman, D., Blum, R. D., et al. 2004, \textit{Proc. SPIE}, 5492, 1582
Webb, N. A., Barret, D., Godet, O., et al. 2010, \textit{ApJ}, 712, L107
Wiersema, K., Farrell, S. A., Webb, N. A., et al. 2010, \textit{ApJ}, 721, L102
Zacharias, N., Finch, C., Girard, T., et al. 2010, \textit{AJ}, 139, 2184

\(^{18}\) See http://www.maraston.eu