The correlation between the luminosity of active galactic nuclei and host galaxy parameters

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Abstract

I explore the correlation between the X-ray luminosity of the 13 galaxies selected and values such as the galaxies' inferred stellar mass and its color. The galaxies selected, in the $0.024710 \leq z \leq 0.095000$ range, are all containing an active galactic nucleus, for which I determine the luminosity by using the X-ray luminosity as a proxy. I then plot it against the inferred stellar mass and color of each galaxy. The results show a negative correlation for the X-ray luminosity vs Inferred Stellar Mass plot, and a slight positive for the X-ray luminosity vs Color plot, indicating a connection between the luminosity of an active galactic nucleus and its ability to quench star formation, hence reducing stellar mass and increasing the age of the average of the stars, increasing the color value.

1. Introduction

Active Galactic Nuclei (AGN) are the most energetic phenomena in the observable Universe. They are defined as small regions in the nucleus of galaxies that emit large amounts of radiation in the form of x-ray, radio and gamma rays (Britannica 2019 [6]). E. E. Salpeter (1964 [12]) was the first to propose that supermassive gravitationally collapsed objects (now known as black holes) could accrete matter as a form of growth and release of energy as heat and luminous emissions. Later, one of the earlier connections between such luminous emissions in the nucleus of galaxies and quasars was formulated by LyndebBell (1969 [10]), who hypothesized that those galactic nuclei could have originated from collapsed quasars. Further theorization on the existence of black holes in the center of all galaxies and on their relation to the formation of powerful x-ray and radio emission sources such as Quasars, was formulated by Rees (1984 [11]). In the same decade, studies on the effect of hot wind emission from AGN on the Star Formation Rate (SFR) and the properties of those winds were proposed by Begelman, McKee and Shields (1983 [4]), Begelman (1985 [3]) and Shanbhag and Kembhavi (1988 [13]). These mark the earlier analytical studies regarding the effects that AGN would have on host galaxy evolution. Early century studies relating the mass of AGN and galaxy evolution proved for there to be a significant correlation between the mass of the galaxies' central supermassive black holes (Mbh) and quantities such as the stellar velocity dispersion (Mbh − σ relation, Gebhardt et al. 2000 [8]), showcasing the direct proportionality of the two. More recent studies on the correlations between AGN and host galaxy have shown there to be little correlation between AGN x-ray luminosity and star formation rate at z = 0.2 − 2.5 (Stan et al. 2015 [16]), and there to be significant differences in the galactic evolution depending on the mass of the central

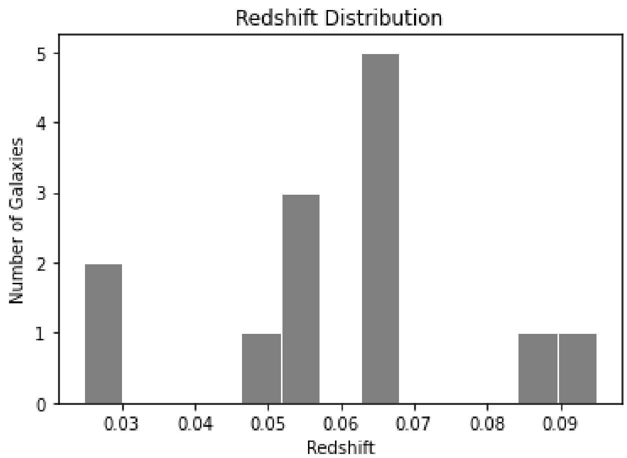

Figure 1: The redshift distribution for all the AGN used. The highest concentration of AGN can be seen in the $0.06 \leq z \leq 0.07$ range.

Supermassive Black Hole (SBH), where the evolution of dwarf galaxies with less massive SBH were shown to have more similar evolutionary paths to those with no SBH than to those with a medium mass SBH and a more massive SBH (Sharma et al. 2020 [14]). Research centered around these correlations are vital for astronomers to understand the effects AGN have on their host galaxies, and are vital for them to understand how feedback (the process by which gas is heated and/or dispersed, disrupting SFR) impacts galaxy evolution. Despite the extensive amount of research conducted in the fields of AGN-Galaxy correlation, there is a lack of studies when it comes to general analyses of correlations between the x-ray luminosity of AGN and the properties of their host galaxies. For this reason I propose the computational analysis of the correlation between the Xray luminosity of the galaxy, which I used as a proxy for the AGN Luminosity, and host

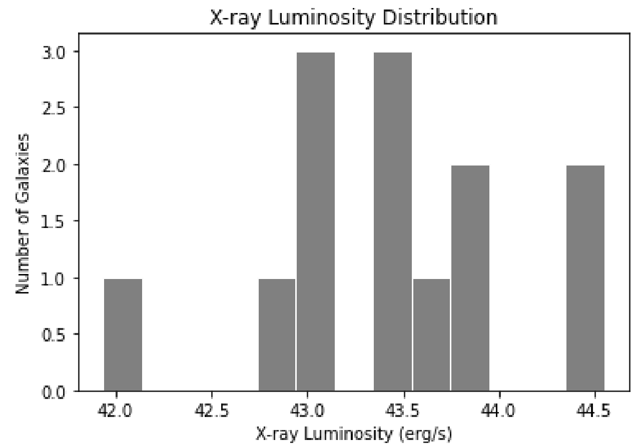

Figure 2: The x-ray luminosity as $Log(L_x)$ distribution.

galaxy properties that include its Inferred Stellar Mass (M∗), and color. I propose a study using AGN found in the 0.024710 ≤ z ≤ 0.095000 range using data from the First Catalog of AGN from the Large Area Telescope (LAT, 1LAC, Abdo et al. 2010 [1]).

2. Data Sample and Selection

For the galaxies I use the 1LAC [1] data. They were selected to represent a range of luminosities and redshifts (0.024710 ≤ z ≤ 0.095000). The redshift distribution can be seen in Figure 1. The values analyzed were all plotted against the xray luminosities. The usage of the X-ray luminosities might have caused a source of error, as sources like hot gas might have interfered in the accuracy of it as a proxy. (Lx, in ergs/s): to calculate the Lx the equation Lx = 4πr2 f, where r is the distance to the galaxy (in cm) and f is the flux (apparent brightness, in ergs/s/cm2). The range Lx distribution can be found in Figure 2. After calculating the Lx in erg/s, I calculated it again using the r-band

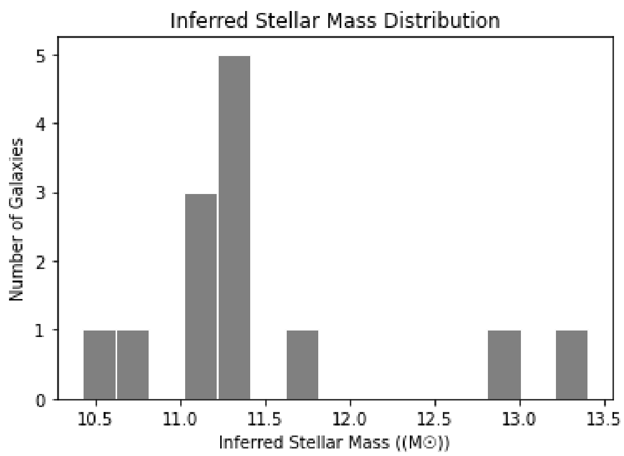

Figure 3: The galaxies' M_* as $Log(M_*)$ distribution.

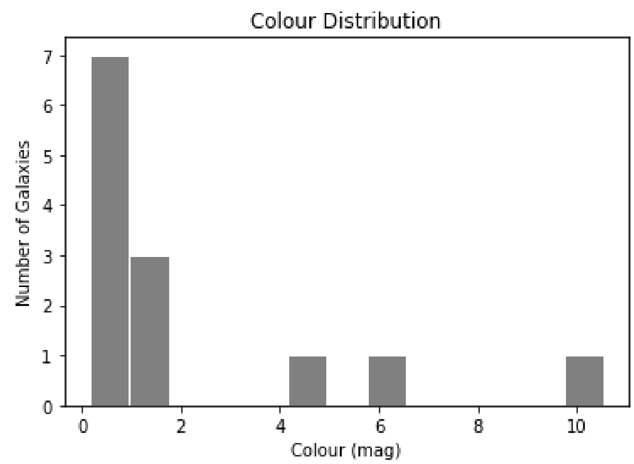

Figure 4: The galaxies' color distribution. Three galaxies present anomalies in color. That is because their photometric values were not taken from the SDSS model as the other ones, as they did not have one.

magnitude, which I got from the SDSS model data (Abdurro'uf et al. 2022 [2]), inputting it and the distance into a Luminosity Calculator (Szyk 2022). This calculator gave us the Luminosity of the galaxy in L☉ which I then multiplied by the static stellar mass-to-light ratio of 3.05 (Bell et al. 2003 [5]). The product is the galaxy's inferred stellar mass (M∗) in M☉; its distribution can be seen in Figure 3. I later calculated the color of the galaxy by subtracting the g-band magnitude to the r-band magnitude or by subtracting the G-band magnitude by the R-band magnitude (g − r or G − R). The color distributions can be seen in Figure 4. The values of the x-ray fluxes, magnitudes and the distances were all taken from the 1LAC survey's data results ([1]). The selection of the AGN and galaxies was based on redshift (so that 0.01 ≤ z ≤ 0.1) and on whether their archival data included apparent brightness and distance: if both weren't included, the AGN was not selected.

3. Graph Analysis

The first property that I plotted against Log(Lx) is the galaxies Log(M∗). The graph can be seen in Figure 5. I show a linear fit to facilitate the showcase of the correlation to the eye, but I make no assumption that this is the accurate line to represent the actual dependency of the M∗ on the AGN Luminosity. The graph shows a negative correlation between the two factors: it shows that as the Lx increases, the M∗ decreases. But why is this? M∗ is very tightly connected to a galaxy's star SFR, as the M∗ is accumulated through the star formation process (Kusakabe et al. 2018 [9]). In fact, the higher a galaxy's SFR, the higher its M∗. This indirect proportionality can then be explained by the activity of luminous AGN and its impact on star formation rate. More

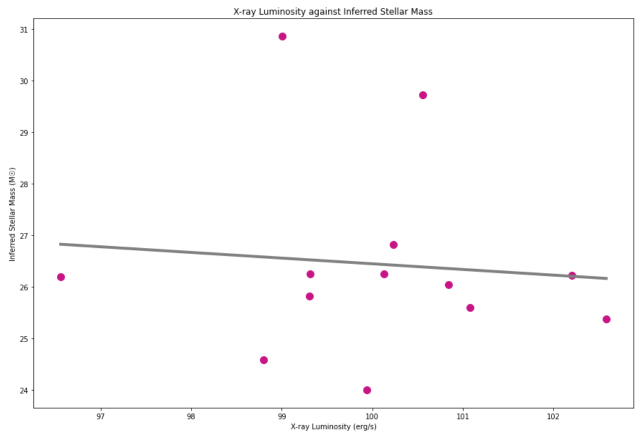

Figure 5: The $Log(L_x)$ against the $Log(M_*)$. A negative correlation can be seen, with the M_* decreasing as the L_x increases. The function used to define the line best fit is $f(x) = 37.45698743453351 - 0.11012438723399873x$, with $f(x) = Log(M_*)$ and $x = Log(L_x)$.

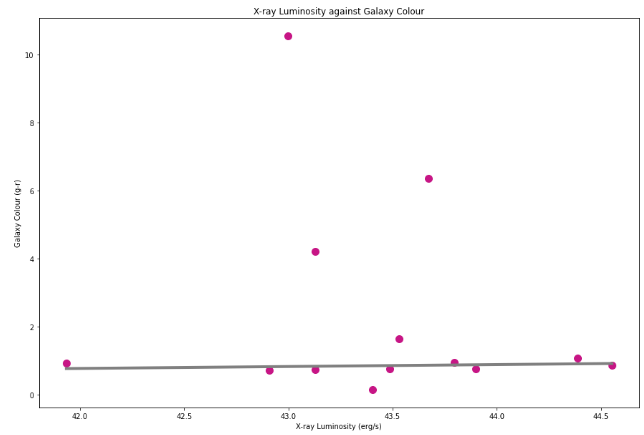

Figure 6: The $Log(L_x)$ against the color of the galaxies. A slight positive trend can be seen, with both increasing as the other does. The function used to define the line best fit is $f(x) = -1.6142727415601743 + 0.024726696883358153x$, with $f(x) = color$ and $x = Log(L_x)$. The three outliers were not taken into consideration for the calculation of the line best fit, as their calculation was made using different photometries than the rest of the values.

active AGN accrete more mass ([12]), hence releasing more energy, increasing their luminosity. A higher accretion of mass increases the amount of mass being integrated into the AGN, increasing the speed at which the mass circulates around the accretion disk: this increase in energy heats up the material and makes it very luminous. Its real impact on the galaxy can be seen when (and if) the gas is released back into the galaxy, heating up existing cold gas, or releasing energetic winds that expel the cold gas from the galaxy (Somerville et al. 2008 [15]). The absence of cold gas in the galaxy causes the SFR to decrease or completely cease to happen: this event being called a quenching. The indirect proportionality of the M∗ and the Lx can be then explained by connecting the higher luminosity with more active AGN, which likely cause quenching in their host galaxy. This quenching, over time, decreases the overall M∗ of the galaxy. This is also observed by Fabian (2012 [7]), who states loss of stellar mass to be the least result of quenching. The second property that I plotted is color. The graph can be seen in Figure 6. As before, I used the fit to help visually only. Differently from the Lx-M∗ relation, this time the graph shows a slight positive correlation, indicating a direct proportionality between the two factors. Galaxies that tend to be bluer, and so have a lower value for color, tend to also be younger galaxies, as younger stars are bluer in color. This high presence of young stars also implies a higher SFR, as more young stars are forming more frequently. On the other hand, galaxies that tend to be redder, and so have a higher value for color, tend to be higher, as older stars are redder in color: this indicates a decrease in SFR in the galaxy or a complete quench of it. As stated earlier, quenched in galaxies are largely caused by more active AGN (Somerville et al. 2008 [15]) This indicates that, as expected from the graph, galaxies with more active nuclei should be redder, as they can likely be quenched, and so appear redder due to the older population rate. This explains the slight positive correlation.

4. Conclusion

To conclude, I compared, plotted and fitted a line to look for correlations between the galaxy's Lx, which I used as a proxy for the AGN's luminosity, and values for the galaxy's M∗ and color. I could note a negative correlation between the Lx and the galaxy's M∗, as explained by the possibility of quenching due to higher activity levels with brighter AGN and its connection with the lowering of a galaxy's M∗(Fabian 2012 [7]). I could also note a slight positive correlation between the Lx and the color of the galaxies, as explained by the fact that younger galaxies tend to have higher SFR, which is connected to a less active AGN. This also is consistent with the fact that the older, redder galaxies tended to have a more luminous AGN, which likely quenched the galaxy (Somerville et al. 2008 [15]). Research surrounding the relationship between AGN properties and galactic properties is extremely important, as it can help scientists make better predictions as to galactic evolution, and also allow them to make better theoretical conclusions through simulations. This result goes to show a support for past research and a confirmation of established theories on galactic evolution and the effect of AGN feedback through quenching, demonstrating the importance of a galaxy's AGN in the evolution of its host.

References

[1] A. A. Abdo, M. Ackermann, M. Ajello, A. Allafort, E. Antolini, W. B. Atwood, M. Axelsson, L. Baldini, J. Ballet, G. Barbiellini, D. Bastieri, B. M. Baughman, K. Bechtol, R. Bellazzini, B. Berenji, R. D. Blandford, E. D. Bloom, J. R. Bogart, E. Bonamente, A. W. Borgland, A. Bouvier, J. Bregeon, A. Brez, M. Brigida, P. Bruel, R. Buehler, T. H. Burnett, S. Buson, G. A. Caliandro, R. A. Cameron, A. Cannon, P. A. Caraveo, S. Carrigan, J. M. Casandjian, E. Cavazzuti, C. Cecchi, O. C¸ elik, A. Celotti, ¨ E. Charles, A. Chekhtman, A. W. Chen, C. C. Cheung, J. Chiang, S. Ciprini, R. Claus, J. CohenTanugi, J. Conrad, L. Costamante, G. Cotter, S. Cutini, V. D'Elia, C. D. Dermer, A. de Angelis, F. de Palma, A. De Rosa, S. W. Digel, E. do Couto e. Silva, P. S. Drell, R. Dubois, D. Dumora, L. Escande, C. Farnier, C. Favuzzi, S. J. Fegan, E. C. Ferrara, W. B. Focke, P. Fortin, M. Frailis, Y. Fukazawa, S. Funk, P. Fusco, F. Gargano, D. Gasparrini, N. Gehrels, S. Germani, B. Giebels, N. Giglietto, P. Giommi, F. Giordano, M. Giroletti, T. Glanzman, G. Godfrey, P. Grandi, I. A. Grenier, M. H. Grondin, J. E. Grove, S. Guiriec, D. Hadasch, A. K. Harding, M. Hayashida, E. Hays, S. E. Healey, A. B. Hill, D. Horan, R. E. Hughes, G. Iafrate, R. Itoh, G. J´ohannesson, A. S. Johnson, R. P. Johnson, T. J. Johnson, W. N. Johnson, T. Kamae, H. Katagiri, J. Kataoka, N. Kawai, M. Kerr, J. Kn¨odlseder, M. Kuss, J. Lande, L. Latronico, C. Lavalley, M. Lemoine-Goumard, M. Llena Garde, F. Longo, F. Loparco, B. Lott, M. N. Lovellette, P. Lubrano, G. M. Madejski, A. Makeev, G. Malaguti, E. Massaro, M. N. Mazziotta, W. McConville, J. E. McEnery, S. McGlynn, P. F. Michelson, W. Mitthumsiri, T. Mizuno, A. A. Moiseev, C. Monte, M. E. Monzani, A. Morselli, I. V. Moskalenko, S. Murgia, P. L. Nolan, J. P. Norris, E. Nuss, M. Ohno, T. Ohsugi, N. Omodei, E. Orlando, J. F. Ormes, M. Ozaki, D. Paneque, J. H. Panetta, D. Parent, V. Pelassa, M. Pepe, M. Pesce-Rollins, S. Piranomonte, F. Piron, T. A. Porter, S. Rain`o, R. Rando, M. Razzano, A. Reimer, O. Reimer, T. Reposeur, J. Ripken, S. Ritz, A. Y. Rodriguez, R. W. Romani, M. Roth, F. Ryde, H. F. W. Sadrozinski, D. Sanchez, A. Sander, P. M. Saz Parkinson, J. D. Scargle, C. Sgr`o, M. S. Shaw, E. J. Siskind, P. D. Smith, G. Spandre, P. Spinelli, J. L. Starck, L. Stawarz, M. S. Strickman, D. J. Suson, H. Tajima, H. Takahashi, T. Takahashi, T. Tanaka, G. B. Taylor, J. B. Thayer, J. G. Thayer, D. J. Thompson, L. Tibaldo, D. F. Torres, G. Tosti, A. Tramacere, P. Ubertini, Y. Uchiyama, T. L. Usher, V. Vasileiou, N. Vilchez, M. Villata, V. Vitale, A. P. Waite, E. Wallace, P. Wang, B. L. Winer, K. S. Wood, Z. Yang, T. Ylinen, and M. Ziegler. The First Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope. , 715(1):429–457, May 2010.

[2] Abdurro'uf, Katherine Accetta, Conny Aerts, V´ıctor Silva Aguirre, Romina Ahumada, Nikhil Ajgaonkar, N. Filiz Ak, Shadab Alam, Carlos 5 Allende Prieto, Andr´es Almeida, Friedrich Anders, Scott F. Anderson, Brett H. Andrews, Borja Anguiano, Erik Aquino-Ort´ız, Alfonso Arag´on-Salamanca, Maria Argudo-Fern´andez, Metin Ata, Marie Aubert, Vladimir Avila-Reese, Carles Badenes, Rodolfo H. Barb´a, Kat Barger, Jorge K. Barrera-Ballesteros, Rachael L. Beaton, Timothy C. Beers, Francesco Belfiore, Chad F. Bender, Mariangela Bernardi, Matthew A. Bershady, Florian Beutler, Christian Moni Bidin, Jonathan C. Bird, Dmitry Bizyaev, Guillermo

A. Blanc, Michael R. Blanton, Nicholas Fraser Boardman, Adam S. Bolton, M´ed´eric Boquien, Jura Borissova, Jo Bovy, W. N. Brandt, Jordan Brown, Joel R. Brownstein, Marcella Brusa, Johannes Buchner, Kevin Bundy, Joseph N. Burchett, Martin Bureau, Adam Burgasser, Tuesday K. Cabang, Stephanie Campbell, Michele Cappellari, Joleen K. Carlberg, F´abio Carneiro Wanderley, Ricardo Carrera, Jennifer Cash, Yan-Ping Chen, Wei-Huai Chen, Brian Cherinka, Cristina Chiappini, Peter Doohyun Choi, S. Drew Chojnowski, Haeun Chung, Nicolas Clerc, Roger E. Cohen, Julia M. Comerford, Johan Comparat, Luiz da Costa, Kevin Covey, Jeffrey D. Crane, Irene Cruz-Gonzalez, Connor Culhane, Katia Cunha, Y. Sophia Dai, Guillermo Damke, Jeremy Darling, Jr. Davidson, James W., Roger Davies, Kyle Dawson, Nathan De Lee, Aleksandar M. Diamond-Stanic, Mariana Cano-D´ıaz, Helena Dom´ınguez S´anchez, John Donor, Chris Duckworth, Tom Dwelly, Daniel J. Eisenstein, Yvonne P. Elsworth, Eric Emsellem, Mike Eracleous, Stephanie Escoffier, Xiaohui Fan, Emily Farr, Shuai Feng, Jos´e G. Fern´andezTrincado, Diane Feuillet, Andreas Filipp, Sean P. Fillingham, Peter M. Frinchaboy, Sebastien Fromenteau, Llu´ıs Galbany, Rafael A. Garc´ıa, D. A. Garc´ıa-Hern´andez, Junqiang Ge, Doug Geisler, Joseph Gelfand, Tobias G´eron, Benjamin J. Gibson, Julian Goddy, Diego Godoy-Rivera, Kathleen Grabowski, Paul J. Green, Michael Greener, Catherine J. Grier, Emily Griffith, Hong Guo, Julien Guy, Massinissa Hadjara, Paul Harding, Sten Hasselquist, Christian R. Hayes, Fred Hearty, Jes´us Hern´andez, Lewis Hill, David W. Hogg, Jon A. Holtzman, Danny Horta, Bau-Ching Hsieh, ChinHao Hsu, Yun-Hsin Hsu, Daniel Huber, Marc Huertas-Company, Brian Hutchinson, Ho Seong Hwang, H´ector J. Ibarra-Medel, Jacob Ider Chitham, Gabriele S. Ilha, Julie Imig, Will Jaekle, Tharindu Jayasinghe, Xihan Ji, Jennifer A. Johnson, Amy Jones, Henrik J¨onsson, Ivan Katkov, Dr. Khalatyan, Arman, Karen Kinemuchi, Shobhit Kisku, Johan H. Knapen, Jean-Paul Kneib, Juna A. Kollmeier, Miranda Kong, Marina Kounkel, Kathryn Kreckel, Dhanesh Krishnarao, Ivan Lacerna, Richard R. Lane, Rachel Langgin, Ramon Lavender, David R. Law, Daniel Lazarz, Henry W. Leung, Ho-Hin Leung, Hannah M. Lewis, Cheng Li, Ran Li, Jianhui Lian, Fu-Heng Liang, Lihwai Lin, YenTing Lin, Sicheng Lin, Chris Lintott, Dan Long, Pen´elope Longa-Pe˜na, Carlos L´opez-Cob´a, Shengdong Lu, Britt F. Lundgren, Yuanze Luo, J. Ted Mackereth, Axel de la Macorra, Suvrath Mahadevan, Steven R. Majewski, Arturo Manchado, Travis Mandeville, Claudia Maraston, Berta Margalef-Bentabol, Thomas Masseron, Karen L. Masters, Savita Mathur, Richard M. 6 McDermid, Myles Mckay, Andrea Merloni, Michael Merrifield, Szabolcs Meszaros, Andrea Miglio, Francesco Di Mille, Dante Minniti, Rebecca Minsley, Antonela Monachesi, Jeongin Moon, Benoit Mosser, John Mulchaey, Demitri Muna, Ricardo R. Mu˜noz, Adam D. Myers, Natalie Myers, Seshadri Nadathur, Preethi Nair, Kirpal Nandra, Justus Neumann, Jeffrey A. Newman, David L. Nidever, Farnik Nikakhtar, Christian Nitschelm, Julia E. O'Connell, Luis Garma-Oehmichen, Gabriel Luan Souza de Oliveira, Richard Olney, Daniel Oravetz, Mario OrtigozaUrdaneta, Yeisson Osorio, Justin Otter, Zachary J. Pace, Nelson Padilla, Kaike Pan, Hsi-An Pan, Taniya Parikh, James Parker, Sebastien Peirani, Karla Pe˜na Ram´ırez, Samantha Penny, Will J. Percival, Ismael Perez-Fournon, Marc Pinsonneault, Fr´ed´erick Poidevin, Vijith Jacob Poovelil, Adrian M. Price-Whelan, Anna B´arbara de Andrade Queiroz, M. Jordan Raddick, Amy Ray, Sandro

Barboza Rembold, Nicole Riddle, Rogemar A. Riffel, Rog´erio Riffel, Hans-Walter Rix, Annie C. Robin, Aldo Rodr´ıguezPuebla, Alexandre Roman-Lopes, Carlos Rom´an-Z´u˜niga, Benjamin Rose, Ashley J. Ross, Graziano Rossi, Kate H. R. Rubin, Mara Salvato, Seb´astian F. S´anchez, Jos´e R. S´anchez-Gallego, Robyn Sanderson, Felipe Antonio Santana Rojas, Edgar Sarceno, Regina Sarmiento, Conor Sayres, Elizaveta Sazonova, Adam L. Schaefer, Ricardo Schiavon, David J. Schlegel, Donald P. Schneider, Mathias Schultheis, Axel Schwope, Aldo Serenelli, Javier Serna, Zhengyi Shao, Griffin Shapiro, Anubhav Sharma, Yue Shen, Matthew Shetrone, Yiping Shu, Joshua D. Simon, M. F. Skrutskie, Rebecca Smethurst, Verne Smith, Jennifer Sobeck, Taylor Spoo, Dani Sprague, David V. Stark, Keivan G. Stassun, Matthias Steinmetz, Dennis Stello, Alexander Stone-Martinez, Thaisa Storchi-Bergmann, Guy S. Stringfellow, Amelia Stutz, Yung-Chau Su, Manuchehr Taghizadeh-Popp, Michael S. Talbot, Jamie Tayar, Eduardo Telles, Johanna Teske, Ani Thakar, Christopher Theissen, Andrew Tkachenko, Daniel Thomas, Rita Tojeiro, Hector Hernandez Toledo, Nicholas W. Troup, Jonathan R. Trump, James Trussler, Jacqueline Turner, Sarah Tuttle, Eduardo Unda-Sanzana, Jos´e Antonio V´azquez-Mata, Marica Valentini, Octavio Valenzuela, Jaime VargasGonz´alez, Mariana Vargas-Maga˜na, Pablo Vera Alfaro, Sandro Villanova, Fiorenzo Vincenzo, David Wake, Jack T. Warfield, Jessica Diane Washington, Benjamin Alan Weaver, Anne-Marie Weijmans, David H. Weinberg, Achim Weiss, Kyle B. Westfall, Vivienne Wild, Matthew C. Wilde, John C. Wilson, Robert F. Wilson, Mikayla Wilson, Julien Wolf, W. M. Wood-Vasey, Renbin Yan, Olga Zamora, Gail Zasowski, Kai Zhang, Cheng Zhao, Zheng Zheng, Zheng Zheng, and Kai Zhu. The Seventeenth Data Release of the Sloan Digital Sky Surveys: Complete Release of MaNGA, MaStar, and APOGEE-2 Data. , 259(2):35, April 2022.

[3] M. C. Begelman. The effects of Xrays from an active galactic nucleus on the interstellar medium of the host galaxy. , 297:492–506, October 1985.

[4] M. C. Begelman and C. F. McKee. Compton heated winds and coronae above accretion disks. II. Radiativetransfer and observable consequences. , 271:89–112, August 1983.

[5] Eric F. Bell, Daniel H. McIntosh, Neal Katz, and Martin D. Weinberg. The Optical and Near-Infrared Properties of Galaxies. I. Luminosity and Stellar Mass Functions. , 149(2):289–312, December 2003.

[6] The editors of the Encyclopaedia. Active Galactic Nuclei. Britannica, March 2019.

[7] A. C. Fabian. Observational Evidence of Active Galactic Nuclei Feedback. , 50:455–489, September 2012.

[8] Karl Gebhardt, Ralf Bender, Gary Bower, Alan Dressler, S. M. Faber, Alexei V. Filippenko, Richard Green, Carl Grillmair, Luis C. Ho, John Kormendy, Tod R. Lauer, John

Magorrian, Jason Pinkney, Douglas Richstone, and Scott Tremaine. A Relationship between Nuclear Black Hole Mass and Galaxy Velocity Dispersion. , 539(1):L13–L16, August 2000.

[9] Haruka Kusakabe, Kazuhiro Shimasaku, Masami Ouchi, Kimihiko Nakajima, Ryosuke Goto, Takuya Hashimoto, Akira Konno, Yuichi Harikane, John D. Silverman, and Peter L. Capak. The stellar mass, star formation rate and dark matter halo properties of LAEs at z ~ 2. , 70(1):4, January 2018.

[10] D. Lynden-Bell. Galactic Nuclei as Collapsed Old Quasars. , 223(5207):690–694, August 1969.

[11] Martin J. Rees. Black Hole Models for Active Galactic Nuclei. , 22:471– 506, January 1984.

[12] E. E. Salpeter. Accretion of Interstellar Matter by Massive Objects. , 140:796–800, August 1964.

[13] Smita Shanbhag and Ajit Kembhavi. QSO Activity and Host Galaxy Evolution. , 334:34, November 1988.

[14] Ray S. Sharma, Alyson M. Brooks, Rachel S. Somerville, Michael Tremmel, Jillian Bellovary, Anna C. Wright, and Thomas R. Quinn. Black Hole Growth and Feedback in Isolated ROMULUS25 Dwarf Galaxies. , 897(1):103, July 2020.

[15] Rachel S. Somerville, Philip F. Hopkins, Thomas J. Cox, Brant E. Robertson, and Lars Hernquist. A semi-analytic model for the coevolution of galaxies, black holes and active galactic nuclei. , 391(2):481– 506, December 2008.

[16] F. Stanley, C. M. Harrison, D. M. Alexander, A. M. Swinbank, J. A. Aird, A. Del Moro, R. C. Hickox, and J. R. Mullaney. A remarkably flat relationship between the average star formation rate and AGN luminosity for distant X-ray AGN. , 453(1):591– 604, October 2015.