Draft version July 13, 2023
Typeset using LaTeX default style in AASTeX631

Spectroscopic Follow-Up of Two Star-Forming Objects in the M101 Field*

Ray Garner, III,[1] Steven Janowiecki,[2] and J. Christopher Mihos[1]

[1] Department of Astronomy, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, OH, 44106, USA
[2] Hobby-Eberly Telescope, McDonald Observatory, University of Texas at Austin, Austin, TX, 78712, USA

ABSTRACT

We present the spectra of two faint star-forming objects originally identified in our deep narrowband survey of the M101 Group. One is an isolated H II region near the M101 Group galaxy NGC 5474, and the other is projected close to the background galaxy NGC 5486. Both are spectroscopically confirmed to be physically associated with their nearby host. We estimate the oxygen abundances for each system using strong-line methods. For the source near NGC 5474, we use *GALEX* UV photometry to estimate an age of ∼200 Myr and suggest a connection to the M101-NGC 5474 interaction.

1. INTRODUCTION

Understanding star formation (SF) and the variety of locales in which it takes place is key to understanding galaxy formation and evolution. However, SF in low-density environments is not well understood, whether that be in low-luminosity dwarf galaxies (e.g. Lee et al. 2007, 2009) or outlying, intragroup H II regions (e.g. Ryan-Weber et al. 2004; Werk et al. 2010). In our previous search for outlying, intragroup H II regions in the M101 Group environment (Garner et al. 2021), we found two interesting sources. One source (N5474-3-1) was near the the M101 Group galaxy NGC 5474 was detected in all three narrowband emission-line images used (Hα, Hβ, [O III]), and had photometric and structural properties consistent with H II regions. The other source (N5486-2-1) was near the background galaxy NGC 5486 and was detected in only two of the three emission-lines (Hα, [O III]), and has many properties similar to local dwarf galaxies.

In order to know for certain the physical nature of these objects and their association with their nearby galaxies, we obtained follow-up spectroscopy in Spring 2023 totaling 1.75 h to measure redshifted emission lines using the Low Resolution Spectrograph 2 (Chonis et al. 2016) on the Hobby-Eberly Telescope. The collected spectra were reduced and processed with the standard `Panacea`[1] processing software. In what follows, we show preliminary results for both objects, confirming that both are located near their respective nearby galaxies.

2. ANALYSIS OF N5474-3-1

The top panel of Figure 1 shows the flux-calibrated spectrum for N5474-3-1. We identified the strongest emission-lines by eye, namely Hα, Hβ, [O III]$\lambda\lambda$4959,5007, and [O II]$\lambda\lambda$3726,3729, and measured their redshifted wavelengths using `astropy`'s `SpecUtils` package. Using these strong emission-lines, we were able to measure a corrected, heliocentric velocity of $266.4 \pm 5.0\,\mathrm{km\,s^{-1}}$ or a redshift of $z = 0.000\,89 \pm 0.000\,02$. The heliocentric velocity of NGC 5474 is $262 \pm 1\,\mathrm{km\,s^{-1}}$ or a redshift of $z = 0.000\,874 \pm 0.000\,003$ (Epinat et al. 2008). Thus, we confirm that N5474-3-1 is physically near NGC 5474 albeit at a projected distance of 8.9 kpc or $1.8R_{25}$.

We also estimated the oxygen abundance of N5474-3-1 to compare this H II region's abundance to that of our previous work (Garner et al. 2022). We use the strong-line method of R_{23} (Pagel et al. 1979) and the calibration of Kobulnicky & Kewley (2004). To determine the branch of the R_{23}-O/H relation this object lies on, we use the [N II]/[O II] to break the degeneracy (Kewley & Ellison 2008). This object's log([N II]/[O II]) $= -1.1 \pm 0.2$ ratio puts its abundance in the turn-around region with $12 + \log(\mathrm{O/H}) = 8.47 \pm 0.07$. This only mildly flattens our reported gradient for NGC 5474 to $12 + \log(\mathrm{O/H}) = (8.62 \pm 0.02) - (0.006 \pm 0.007)(R/\mathrm{kpc})$ and does not change any of our original conclusions about the chemical evolution of NGC 5474 (Garner et al. 2022).

* Based on observations obtained with the Hobby-Eberly Telescope (HET), which is a joint project of the University of Texas at Austin, the Pennsylvania State University, Ludwig-Maximillians-Universitaet Muenchen, and Georg-August Universitaet Goettingen.

[1] https://github.com/grzeimann/Panacea

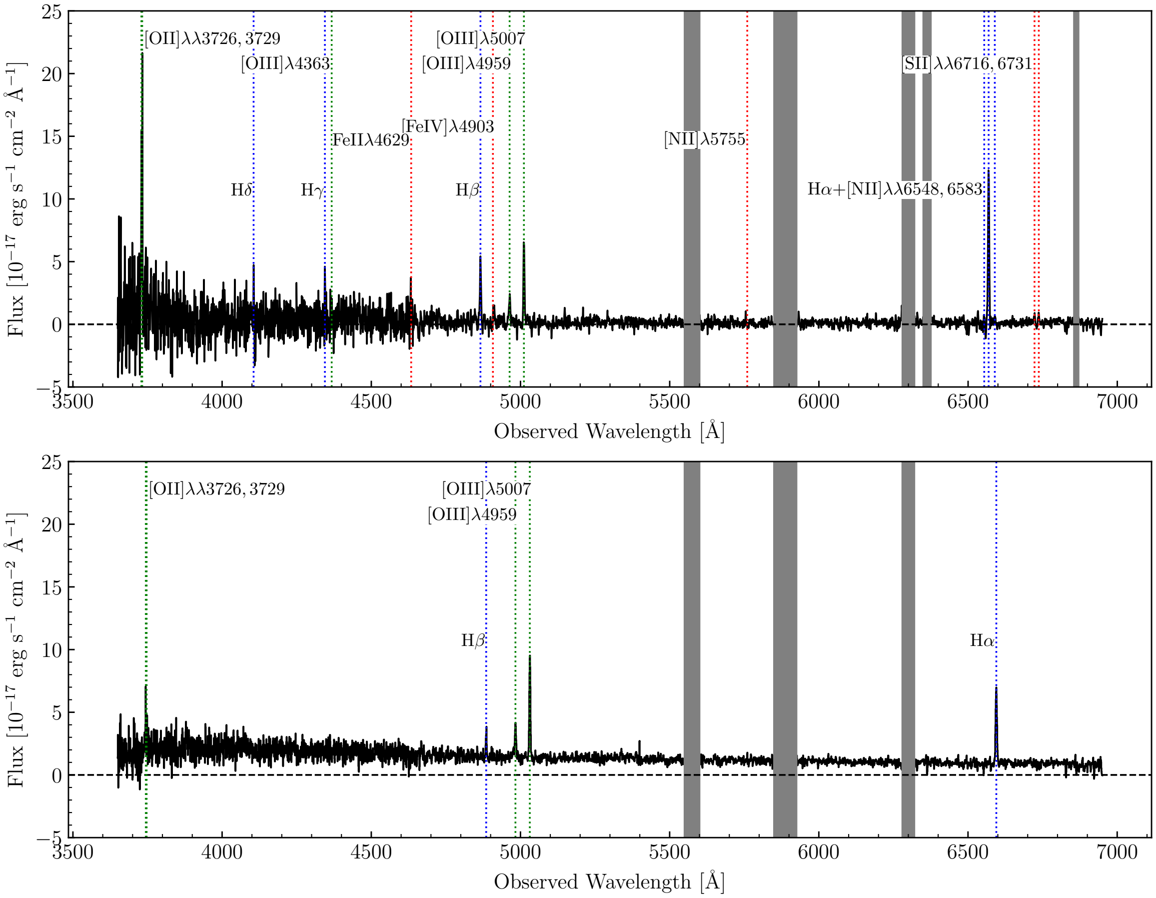

Figure 1. Top: the spectrum of N5474-3-1. Bottom: the spectrum of N5486-2-1. In both panels, several lines are identified. The gray areas show the masked parts of the spectra, i.e., those areas affected by sky residuals.

This object's distance from NGC 5474 is strikingly odd. Despite NGC 5474 having a Type 1 extended-UV disk (Thilker et al. 2007), this object lies visually beyond the edge of that disk. Its $FUV - NUV \sim 0.3$ color in *GALEX* images (Clark et al. 2018) suggests a relatively young age of ∼200 Myr, based on the SSP modeling of Bianchi (2011). This object does appear to be in the outer H I disk of NGC 5474 (van der Hulst & Huchtmeier 1979). Given its approximate age and location, this hints at a possible origin in the M101-NGC 5474 interaction that happened ∼300 Myr ago (Linden & Mihos 2022). Perhaps this is one instance of tidally-induced SF in the outer H I disk of NGC 5474?

3. ANALYSIS OF N5486-2-1

The bottom panel of Figure 1 shows the flux-calibrated spectrum for N5486-2-1. Again, identifying the strongest emission-lines by eye, we measured their redshifted wavelengths. The corrected, heliocentric velocity of N5486-2-1 is $1453.5 \pm 6.1\,\mathrm{km\,s^{-1}}$ or a redshift of $z = 0.004\,85 \pm 0.000\,02$. The heliocentric velocity of NGC 5486 is $1368 \pm 5\,\mathrm{km\,s^{-1}}$ or a redshift of $z = 0.004\,563 \pm 0.000\,016$ (van Driel et al. 2016). This is a $\sim 100\,\mathrm{km\,s^{-1}}$ difference between the radial velocities of the object and galaxy. However, NGC 5486 has a dynamical H I line width of about $200\,\mathrm{km\,s^{-1}}$ centered around $\sim 1400\,\mathrm{km\,s^{-1}}$ (van Driel et al. 2016). Thus, our redshift determination, combined with the H I dynamics of NGC 5486, does support the conclusion that N5486-2-1 is a dwarf companion of NGC 5486.

Our spectrum of N5486-2-1 lacks detection of any auroral lines, so we again estimate its oxygen abundance using the same strong-line method as before. Just as before, we run into the issue of what branch of the R_{23}-O/H relation to associate with this object. However, in this case the upper branch and lower branch solutions are within 1σ of each other, requiring us to adopt the average of the two solutions as the oxygen abundance (Moustakas et al. 2010). Thus, N5486-2-1 has an abundance in the turn-around region of $12 + \log(\mathrm{O/H}) = 8.45 \pm 0.24$. With $M_V = -13.5$ (Garner et al. 2021) and assuming 1 $M_\odot\, L_\odot{}^{-1}$, this object falls on the mass-metallicity relation as expected (Kewley & Ellison 2008).

This work was supported in part by a Towson Memorial Scholarship to RG. Based on observations obtained with the Hobby-Eberly Telescope (HET), which is a joint project of the University of Texas at Austin, the Pennsylvania State University, Ludwig-Maximillians-Universitaet Muenchen, and Georg-August Universitaet Goettingen. The HET is named in honor of its principal benefactors, William P. Hobby and Robert E. Eberly. The Low Resolution Spectrograph 2 (LRS2) was developed and funded by the University of Texas at Austin McDonald Observatory and Department of Astronomy, and by Pennsylvania State University. We thank the Leibniz-Institut fur Astrophysik Potsdam (AIP) and the Institut fur Astrophysik Goettingen (IAG) for their contributions to the construction of the integral field units.

Facility: HET

Software: `Astropy` (Astropy Collaboration et al. 2022), `Matplotlib` (Hunter 2007), `NumPy` (Harris et al. 2020)

REFERENCES

Astropy Collaboration, Price-Whelan, A. M., Lim, P. L., et al. 2022, ApJ, 935, 167, doi: 10.3847/1538-4357/ac7c74

Bianchi, L. 2011, Ap&SS, 335, 51, doi: 10.1007/978-94-007-2573-7_7

Chonis, T. S., Hill, G. J., Lee, H., et al. 2016, SPIE, 9908, 99084C, doi: 10.1117/12.2232209

Clark, C. J. R., Verstocken, S., Bianchi, S., et al. 2018, A&A, 609, A37, doi: 10.1051/0004-6361/201731419

Epinat, B., Amram, P., Marcelin, M., et al. 2008, MNRAS, 388, 500, doi: 10.1111/j.1365-2966.2008.13422.x

Garner, R., Mihos, J. C., Harding, P., & Watkins, A. E. 2021, ApJ, 915, 57, doi: 10.3847/1538-4357/ac0055

Garner, R., Mihos, J. C., Harding, P., Watkins, A. E., & McGaugh, S. S. 2022, ApJ, 941, 182, doi: 10.3847/1538-4357/aca27a

Harris, C. R., Millman, K. J., van der Walt, S. J., et al. 2020, Nature, 585, 357, doi: 10.1038/s41586-020-2649-2

Hunter, J. D. 2007, CSE, 9, 90, doi: 10.1109/MCSE.2007.55

Kewley, L. J., & Ellison, S. L. 2008, ApJ, 681, 1183, doi: 10.1086/587500

Kobulnicky, H. A., & Kewley, L. J. 2004, ApJ, 617, 240, doi: 10.1086/425299

Lee, J. C., Kennicutt, R. C., Funes, J. G., Sakai, S., & Akiyama, S. 2007, ApJ, 671, L113, doi: 10.1086/526341

Lee, J. C., Gil de Paz, A., Tremonti, C., et al. 2009, ApJ, 706, 599, doi: 10.1088/0004-637x/706/1/599

Linden, S. T., & Mihos, J. C. 2022, ApJ, 933, L33, doi: 10.3847/2041-8213/ac7c06

Moustakas, J., Kennicutt, R. C., Tremonti, C. A., et al. 2010, ApJS, 190, 233, doi: 10.1088/0067-0049/190/2/233

Pagel, B. E. J., Edmunds, M. G., Blackwell, D. E., Chun, M. S., & Smith, G. 1979, MNRAS, 189, 95, doi: 10.1093/mnras/189.1.95

Ryan-Weber, E. V., Meurer, G. R., Freeman, K. C., et al. 2004, AJ, 127, 1431, doi: 10.1086/381905

Thilker, D. A., Bianchi, L., Meurer, G., et al. 2007, ApJS, 173, 538, doi: 10.1086/523853

van der Hulst, J. M., & Huchtmeier, W. K. 1979, A&A, 78, 82

van Driel, W., Butcher, Z., Schneider, S., et al. 2016, A&A, 595, A118, doi: 10.1051/0004-6361/201528048

Werk, J. K., Putman, M. E., Meurer, G. R., et al. 2010, AJ, 139, 279, doi: 10.1088/0004-6256/139/1/279