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Star Formation Characteristics of Galaxies Hosting AGN

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Abstract

We present an analysis of the ultra-violet (UV) observations of two Seyfert type active galactic nuclei (AGN), namely NGC 4051 and NGC 4151. These observations aimed at studying the star formation in the hosts of these AGN were carried out with the ultra-violet imaging telescope on board *AstroSat* in far-UV. A total of 193 and 328 star-forming regions (SF) were identified using SExtractor in NGC 4051 and NGC 4151, respectively. Using aperture photometry of the identified SF regions, we estimated the star formation rates (SFRs). We found NGC 4051 to have the lowest SFR with a median value of $3.16 \times 10^{-5} M_\odot\,\mathrm{yr}^{-1}$ while for NGC 4151, we found a median SFR of $0.012 M_\odot\,\mathrm{yr}^{-1}$.

Keywords: galaxies: active – galaxies: Seyfert – stars: formation – ultraviolet: galaxies

1. Introduction

All massive galaxies host supermassive black holes (SMBHs) at their centers (Kormendy and Ho, 2013). These SMBHs power active galactic nuclei (AGN) via accretion and are believed to play an important role in the co-evolution of SMBHs and their host galaxies. This belief is based on the observed relation between SMBH mass (M_{BH}) and bulge mass (Magorrian et al., 1998), M_{BH} and bulge luminosity (Marconi and Hunt, 2003) and M_{BH} and stellar velocity dispersion (Gebhardt et al., 2000; Ferrarese and Merritt, 2000). A mechanism that is invoked to understand the co-evolutionary scenario in AGN is by feedback processes (Fabian, 2012). Therefore, finding observational signatures of AGN feedback is very important in enhancing our understanding of the effect of AGN on the evolution of their host galaxies. This triggers studies of star formation rate (SFR) in galaxies hosting AGN. This is because, the connection between AGN and star formation (SF) activity in their hosts arises naturally as both the processes are fed by the same gas reservoir.

It is still poorly understood how AGN activity impacts star formation in their host galaxies. However, there are evidences of both positive and negative feedback in AGN. Negative feedback

Table 1: Details of the galaxies studied here. The α, δ, z and morphology are taken from NED; $M_{\rm BH}$ for NGC 4051 and NGC 4151 are from Denney et al. (2009) and Bentz et al. (2022).

Name	α(2000)	δ(2000)	z	Morphology	$M_{\rm BH}/M_{\odot}$
NGC 4051	12:03:09.64	+44:31:52.80	0.00234	SAB(rs)bc	$1.73^{+0.55}_{-0.52} \times 10^6$
NGC 4151	12:10:32.58	+39:24:20.63	0.00333	SAB(rs)ab	$1.66^{+0.48}_{-0.34} \times 10^7$

Table 2: Log of observations.

Name	Dates of Observation	Filter	Exposure time
NGC 4051	08/06/2016, 11/02/2018	F172M	26444 s
NGC 4151	22/02/2017, 17/03/2017, 04/01/2018, 02/05/2018	F154W	67547 s

is when AGN emission is found to suppress SF and is known in few systems (Maiolino et al., 2012). Alternatively, in sources with radio jets, there are evidences of the jets inducing SF, a case of positive feedback (Nesvadba et al., 2020; Maiolino et al., 2017). Also, studies of a few systems have revealed the co-existence of both positive and negative feedback on SF (Shin et al., 2019; García-Bernete et al., 2021) pointing to the complicated nature of AGN feedback.

Studies available in the literature have addressed the issue of SF around AGN (Davies et al. 2007 and references therein). Of those, ones that investigated the SF characteristics close to the central SMBH on scales of a few hundred parsecs have focussed on Seyfert galaxies as they are the closest to us. Moreover, one needs to probe different spatial scales to understand this connection better. This is because, AGN and SF phenomena occur on different spatial scales and time scales. The connection between AGN and SF can exist at smaller scales; however, at much larger scales, it is unlikely to find a connection as those regions are too far to be influenced by the AGN. Therefore, to firmly understand the connection, if any, between AGN and SF, one needs to probe the SF characteristics of AGN host galaxies at different spatial scales using different probes. We have been involved in a systematic investigation of a sample of Seyfert type AGN as part of an observational effort to characterize the SF in galaxies hosting AGN using data acquired in the ultra-violet band, with the Ultra-Violet Imaging Telescope (UVIT; Tandon et al. 2017, 2020) onboard *AstroSat*, India's multi-wavelength astronomical observatory (Agrawal, 2006). Here, we present our preliminary results on two sources based on UVIT observations. Observations of these two sources in optical Hα were recently acquired with the Devasthal optical telescope (Sagar et al., 2019), the results of which will be presented elsewhere.

2. Observation and Data Reduction

We observed NGC 4051 and NGC 4151 using UVIT. The details of the sources are given in Table 1. The observations were done in both far-UV (FUV; 1300–1800 Å) and near-UV (NUV; 2000–3000 Å) bands. However, to characterize SFR, we used observations acquired in FUV, the details of which are given in Table 2.

We downloaded the Level 2 (L2) science ready images from the Indian Space Science

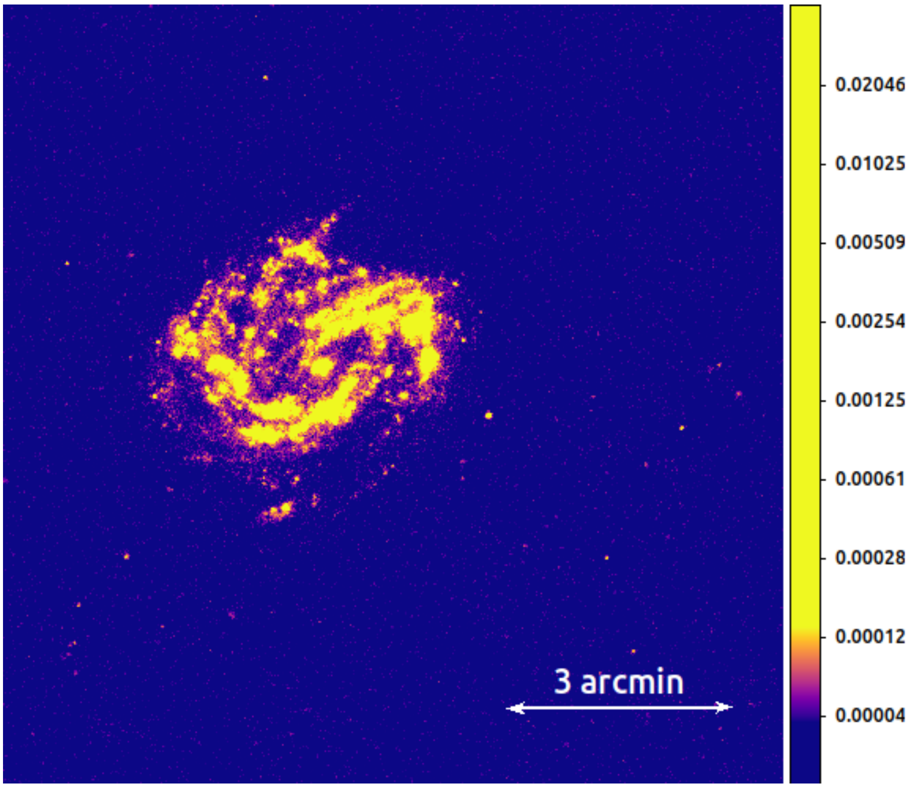

Figure 1: FUV image of NGC 4051. The brightness in counts per second is shown in the bar.

Data Center (ISSDC). These images were processed by the UVIT-Payload Operations Center at the Indian Institute of Astrophysics using the official L2 pipeline (Ghosh et al., 2022) and transferred to ISSDC for archival and dissemination. We redid astrometry on the L2 images using stars available on the image frames with their (α, δ) values taken from *Gaia-DR3* (Gaia Collaboration et al., 2023). These images, with new astrometry were used for further analysis. The final FUV image of NGC 4051 and NGC 4151 is shown in Fig. 1 and Fig. 2, respectively.

3. Analysis and Results

For all analysis in this work, we used the final image in F172M and F154M filters. To identify SF regions, we used the Source Extractor Software (SExtractor; Bertin and Arnouts 1996) by adopting parameter values DETECT_THRESH = 5σ, DETECT_MINAREA = 11 and DEBLEND_THRESHOLD = 32. We identified 193 SF regions in NGC 4051 and 328 SF regions in NGC 4151. We calculated the fluxes of the identified SF regions using the technique of aperture photometry for which we used PhotUtils (Bradley et al., 2020), after subtracting the background. To determine the background, we calculated the median count rate in square boxes of 50×50 pixels placed in ten random regions devoid of any UV sources. The median of these ten measurements was taken as the background value per pixel which was then subtracted from each of the pixels used to derive the fluxes of the SF regions. We note here that while doing photometry of SF regions, we did not consider SF regions with overlapping apertures.

We corrected the derived magnitudes of the SF regions for extinction in UV following

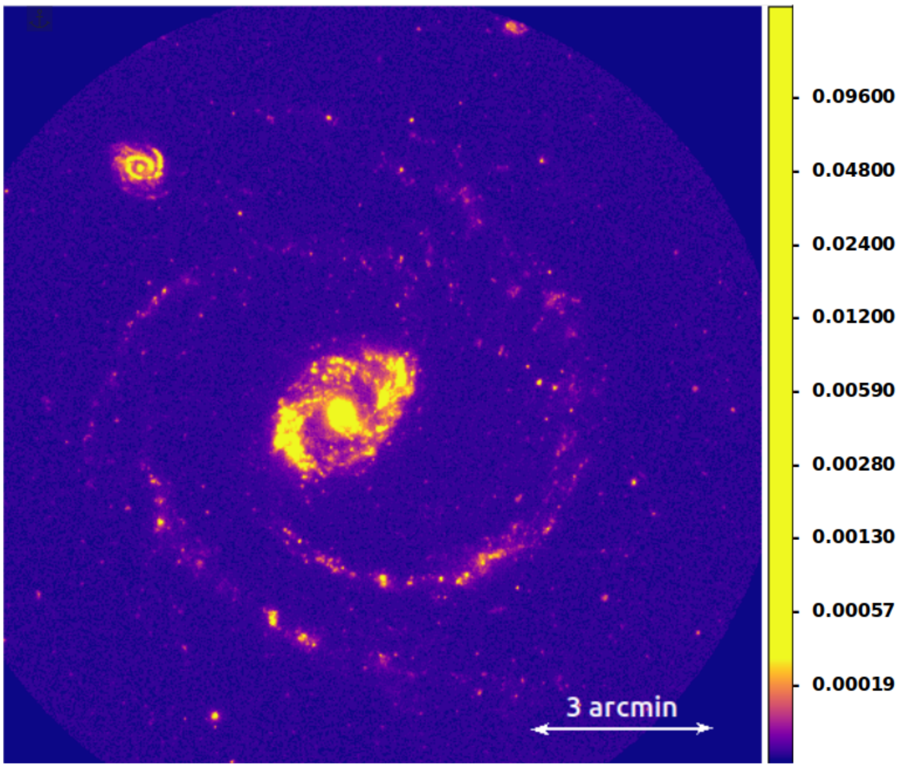

Figure 2: FUV image of NGC 4151. The brightness in counts per second is shown in the bar.

Cardelli et al. (1989)

$$\langle A(\lambda)/A(V)\rangle = a(x) + b(x)/R(V) \tag{1}$$

We adopted the Galactic extinction of $A(V) = 0.036$ mag and 0.074 mag in the V-band for NGC 4051 and NGC 4151, respectively, from NED (https://ned.ipac.caltech.edu). In Eq. (1), x is the wave number and we calculated $a(x)$ and $b(x)$ following Cardelli et al. (1989). Similarly, to correct the Galactic extinction corrected magnitudes for internal extinction, we used the β method following the details outlined in Nandi et al. (2023). From the extinction corrected magnitudes, we calculated SFR as follows (Salim et al., 2007).

$$\log(\mathrm{SFR_{FUV}}/M_{\odot}yr^{-1}) = \log(L_{\mathrm{FUV}}/(\mathrm{W\,Hz^{-1}})) - 21.16 \tag{2}$$

The SFR distributions for NGC 4051 and NGC 4151 are shown in Fig. 3. Galaxies hosting AGN are known to have higher SFR relative to those that do not host AGN. A possible interpretation of the higher star formation activity in AGN hosts could be due to positive feedback processes caused by AGN activity (Santini et al., 2012). However, the relation between AGN and star formation is complex and various factors need to be considered for a quantitative comparison of the SFR in galaxies with and without AGN (Mountrichas et al., 2023). The feedback process that might be at play in NGC 4051 and NGC 4151 is being investigated (Nandi et al., in preparation).

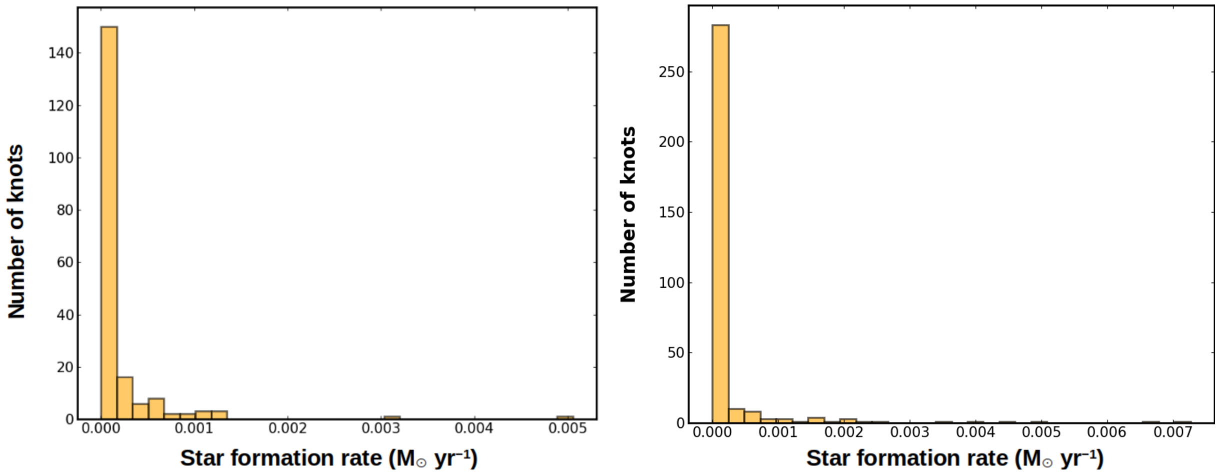

Figure 3: SFR distributions in NGC 4051 (*left*) and NGC 4151 (*right*).

4. Conclusion

Here, we studied the star formation rates of two Seyfert galaxies, namely NGC 4051 and NGC 4151. The results of this study can be summarized as follows:

1. we identified 193 and 328 star-forming regions in NGC 4051 and NGC 4151, respectively;
2. for NGC 4051, we found that the star formation rate lies between 2.534×10^{-7} and $50.55 \times 10^{-4}\,M_\odot\,\mathrm{yr}^{-1}$ with a median value of $3.16 \times 10^{-5}\,M_\odot\,\mathrm{yr}^{-1}$;
3. for NGC 4151, we found that the star formation rate lies between 4.35×10^{-4} and $31.32 \times 10^{-2}\,M_\odot\,\mathrm{yr}^{-1}$ with a median value of $1.188 \times 10^{-2}\,M_\odot\,\mathrm{yr}^{-1}$.

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Further Information

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Author contributions

The first author reduced and analyzed the data. She wrote the first draft of the manuscript. The second author contributed to the finalisation of the results and the manuscript.

Conflicts of interest

This manuscript is an outcome of an independent work. It does not conflict with others' ideas or results.

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