Boletim da Sociedade Astronômica Brasileira, **34**, no. 1, 175-176

Study of the physical conditions of coronal gas in the Circinus Galaxy and IC 5063

M. A. Fonseca-Faria[1,2,⋆], A. Rodríguez-Ardila[1,2], & M. Contini[3]

[1] Laboratório Nacional de Astrofísica, Rua dos Estados Unidos, 154, Itajubá, MG, Brazil.
[2] Instituto Nacional de Pesquisas Espaciais, Av. dos Astronautas, 1758, São José dos Campos, SP, Brazil
[3] School of Physics and Astronomy, Tel Aviv University, Tel Aviv 69978, Israel

Abstract. This work aims to characterize the outflows of ionized gas in the Circinus galaxy and IC 5063, based on VLT/MUSE data. Using a proprietary code, written in PYTHON, it was possible to detect outflows of highly ionized gas, traced by the coronal lines [Fe VII] λ6087 and [Fe X] λ6375, extending to a distance of hundreds of parsecs from the nucleus. This region is characterized by a temperature of up to 18000 K and a gas density of ne >10^2 cm^{-3}. The SUMA code was used to model the contribution of photoionization by the central source and by shocks, being identified that in the regions traced mainly by [Fe VII] emission there is strong evidence of the coupled effect of these two photoionization mechanisms. Our results indicate that the kinematic feedback, even in objects with low power jets, is not negligible, being a component that must be taken into account in the calculation of the AGN feedback.

Resumo. Este trabalho visa caracterizar o escoamento de gás ionizado nas galáxias Circinus e IC 5063, com base nos dados do VLT/MUSE. Utilizando um código próprio, escrito em PYTHON, foi possível detectar os escoamentos de gás altamente ionizado, traçados pelas linhas coronais [Fe VII] λ6087 e [Fe X] λ6375, estendendo-se a uma distância de centenas de parsecs do núcleo. Esta região é caracterizada por temperaturas de até 18000 K e densidade de gás de ne >10^2 cm^{-3}. Adicionamento foi utilizado o código SUMA para modelar a contribuição da fotoionização pela fonte central e por choques. Foi identificado que nas regiões com emissão de [Fe VII] existe fortes evidências do efeito acoplado desses dois mecanismos de fotoionização. Nossos resultados indicam que o *feedback* cinemático, mesmo em objetos com jatos de baixa potência, não é desprezível, sendo uma componente que deve ser levada em consideração no cálculo de *feedback* em AGN.

Keywords. Active galactic nuclei – high ionization lines – modeling

1. Introduction

The study of the feedback from the active galactic nucleus (AGN) indicates that it proves to be an important driver of galactic evolution (Fabian 2012). In this context, it is widely accepted that gas in outflows, on galactic scales, are present in most AGN. However, AGNs with moderate luminosity ($L_{\rm bol} < 10^{44}$ erg/s, where $L_{\rm bol}$ is the bolometric luminosity) and jets of low power ($P < 10^{23}$ W Hz^{-1}) have been neglected, although they represent a large fraction of the AGNs detected in surveys.

In order to better understand the outflow region, we use two classic seyferts 2, Circinus and IC 5063. In particular Circinus the gas kinematics reveal an expanding bubble structure with velocities of a few hundred kms^{-1} spatially coincident with the prominent emission of hard X-rays detected by Chandra Rodríguez-Ardila & Fonseca-Faria (2020); Fonseca-Faria & Rodríguez-Ardila (2021); Smith & Wilson (2001). IC 5063 shows a radio-emitting jet extending 0.5 kpc to either side of the galaxy Morganti et al. (2019). The structure exhibits a cocoon shape to the east and west of the galaxy's core, being traced by an emission at 8 GHz Morganti et al. (1998) and X-ray Gómez-Guijarro et al. (2017). Both structures of these galaxies are associated with their respective ouflows.

2. Detection of ionized gas outflow and physical properties

In this section we will present the maximum extent of coronal emission from Circinus and IC 5063. In addition we present the maps of physical information (temperature and density) of the extended region in these galaxies. In the Figure 2 the upper panels show the flux maps of [Fe VII] λ6087 for galaxies Circinus (left panel) and IC 5063 (right panel). In the lower panels are shown the flux maps of [[Fe X] λ6375 for galaxies Circinus (left panel) and IC 5063 (right panel). In all maps the maximum emission has been observed using integration in a gray circle, above each panel is the spectrum after integration in the region of the circle.

It was possible to calculate the electron density (n_e), (using the ratio between the doublet [S II] $\lambda\lambda$6716, 6731 Å) and the temperature (using the lines of [S III] λ6312 and [S III] λ9069). In Figure 2 are presented the maps of density (upper panels) and temperature (lower panels) of the gas, calculated for Circinus (left column) and IC 5063 (right column). In all cases, the emission contours of [Fe VII] λ6087 are shown in red.

3. Photoinization Models

In this section, the SUMA code Contini & Viegas (2001) was applied to model the contribution of photoionization by the central source and by shocks. For this, 10 regions of the IC 5063 galaxy were selected to focus the analyzes on the region close to the ionization cone. Figure 3 shows the flux ratio map [O III] λ5007/Hβ, for ten regions numbered from R1 to R10.

4. Analysis and discussion

– We present here, for the first time in the literature, the detection of coronal emission from IC 5063 at a distance of

⋆ e-mail: marcosfonsecafaria@gmail.com

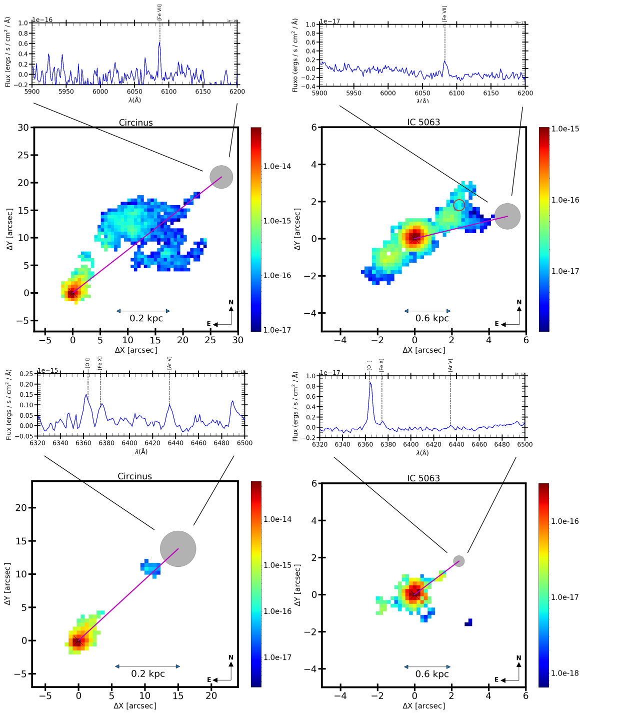

Figure 1. Flux maps of [Fe VII] $\lambda6087$ (top panels) and [Fe X] $\lambda6375$ (lower panels) for galaxies Circinus (left panel) and IC 5063 (right panel). In all maps the maximum emission has been observed using integration in a gray circle, above each panel is the spectrum after integration in the region of the circle.

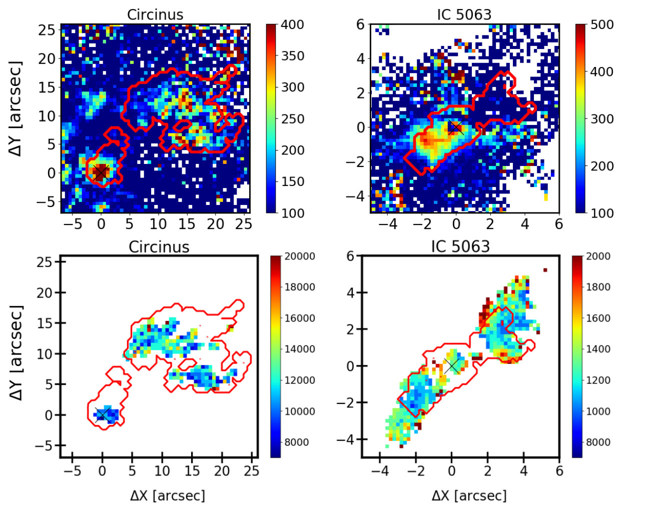

Figure 2. Maps of density (upper panels) and temperature (lower panels) and emission contours of [Fe VII] $\lambda6087$ are shown in red.

1200 pc from the central source. We also emphasize the maximum detection of coronal emission in Circinus, located 700 pc from the central source, a result that is presented in detail.

– In Figure 2, an association can be seen between regions with high temperature values (> 12000 K) and high density values (> 400 cm^{-3}) in regions that are associated with radio and X-ray emission. These results indicate the possible effects of shocks in these regions.

– We produced photoionization models using the SUMA code in order to characterize the photoionization mechanisms in the outflow. Figure 3 presents the main results for IC 5063. The modeling for Circinus can be seen in Fonseca-Faria et al. (2021). In both results we observed that there is a need for shocks to reproduce the line ratios found in these galaxies, mainly in the most distant regions of the AGN and co-spatial to the coronal gas.

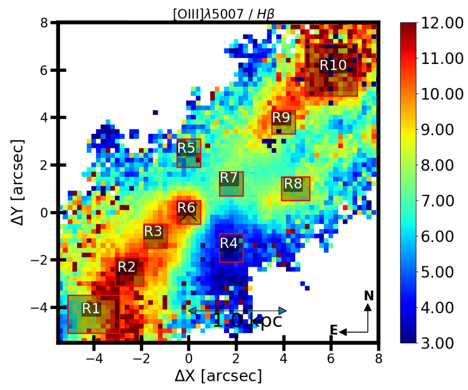

Figure 3. Flux ratio map [O III] $\lambda5007$/Hβ, for ten regions numbered from R1 to R10.

	R3o	R3c	R6o	R6c	R7o	R7c	R8o	R8c	R10o	R10c
[O III]5007	9.94	9.4	10.27	9.6	7.40	7.23	8.10	8.4	9.88	10.0
[Fe VII]6087	0.033	0.013	0.1	0.15	0.02	0.012	0.07	0.06	-	0.01
[O I]6300	0.32	0.26	0.3	0.02	0.35	0.7	0.15	0.02	0.14	0.23
[S III] 6312	0.04	0.036	0.04	0.04	0.12	0.3	0.05	0.05	-	0.04
[O I] 6360	0.1	0.1	0.10	0.01	0.03	0.03	0.05	0.01	0.09	0.08
[Fe X] 6375	-	-	0.04	0.04	-	-	-	0.016	-	0.002
Hα6563	3.09	2.9	3.12	2.93	3.11	2.9	3.16	2.9	3.14	2.9
[N II] 6583	2.32	2.0	1.96	1.7	2.37	2.4	1.9	1.8	1.31	1.50
[S II] 6718	0.85	0.72	0.65	0.4	1.19	1.18	0.92	0.7	0.67	0.71
[O II] 7320	0.06	0.08	0.07	0.13	0.08	0.11	-	0.13	-	0.11
[S III] 9402	0.45	0.6	0.38	0.6	0.40	0.70	0.46	1.1	0.23	0.8
Hβ [1]	-	0.043	-	0.002	-	0.07	-	0.011	-	0.055
V_s [2]	-	380	-	450	-	600	-	450	-	400
n_0 [3]	-	140	-	170	-	150	-	170	-	150
D [4]	-	2.9	-	0.85	-	3.6	-	0.95	-	2.7
F [5]	-	2.6	-	0.7	-	5.3	-	1	-	3.
(N/H) [6]	-	0.9	-	0.7	-	1.0	-	0.7	-	0.6
(O/H) [6]	-	6.4	-	6.3	-	6.2	-	6.6	-	6.2
(S/H) [6]	-	0.16	-	0.10	-	0.16	-	0.16	-	0.16
(Fe/H) [6]	-	0.42	-	0.15	-	0.42	-	0.32	-	0.32

[1] (erg cm^{-2} s^{-1}) ; [2] (km s^{-1}) ; [3] (cm^{-3}) ; [4] (10^{16} cm) ; [5] (10^{10} photons cm^{-2} s^{-1} eV^{-1}); [6] (10^{-4})

Figure 4. Emission line flux ratios (relative to Hβ) calculated using the SUMA code and observed ratios for regions R3, R6, R7, R8 and R10. The suffix ’o’ and ’c’ refer to observed and calculated values.

Acknowledgements. The authors thank the Brazilian Agencies: Agency of Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

References

Contini M., Viegas S. M., 2001, ApJS, 132, 211
Fabian A. C., 2012, ARA&A, 50, 455
Fonseca-Faria M. A., Rodríguez-Ardila A., 2021, in Storchi Bergmann T., Forman W., Overzier R., Riffel R., eds, Vol. 359, Galaxy Evolution and Feedback across Different Environments. pp 272–273, doi:10.1017/S1743921320002082
Fonseca-Faria M. A., Rodríguez-Ardila A., Contini M., Reynaldi V., 2021, MNRAS, 506, 3831
Gómez-Guijarro C., González-Martín O., Ramos Almeida C., Rodríguez-Espinosa J. M., Gallego J., 2017, MNRAS, 469, 2720
Morganti R., Oosterloo T., Tsvetanov Z., 1998, AJ, 115, 915
Morganti R., Schulz R., Nyland K., Paragi Z., Oosterloo T., Mahony E., Murthy S., 2019, arXiv e-prints, p. arXiv:1901.01446
Rodríguez-Ardila A., Fonseca-Faria M. A., 2020, ApJ, 895, L9
Smith D. A., Wilson A. S., 2001, ApJ, 557, 180