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# The birth of an AGN: NGC 4111

**Gabriel R. H. Roier and Thaisa Storchi-Bergmann**

Instituto de Física, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves 9500, 91501-970, Porto Alegre, RS, Brazil
email: gabrielrhroier@gmail.com

**Abstract.** We have used near-infrared and optical Integral Field Spectroscopy along with optical images to study the inner 100 pc of NGC 4111 in a project to investigate the stellar and gas kinematics in the surroundings of Supermassive Black Holes in nearby galaxies. We have compared the inner stellar and gas kinematics with data of the outer regions of the galaxy. We found larger scale hot ionized gas and warm molecular gas within the inner 100 pc that is in counter-rotation relative to the stellar kinematics, a sign of inflowing material that is probably triggering an Active Galactic Nucleus. This is supported by the nuclear X-ray emission which is heating the molecular gas and causing it to emit. The presence of large amounts of dust in a polar ring suggests that this is a fairly recent event probably due to the capture of a dwarf galaxy.

**Keywords.** galaxies: active, galaxies: individual: NGC 4111, galaxies: kinematics and dynamics

## 1. Introduction

NGC 4111 is an S0 edge-on galaxy from the Ursa Major galaxy group, at a distance of 15 Mpc, has 4 companion galaxies located within a distance of 250 kpc (Pak *et al.* 2014) and seems to have suffered a merger with a companion dwarf galaxy. Hubble Space Telescope (HST) optical images show an extended dust-rich polar ring – perpendicular to the galactic plane – which is also associated with H I filaments probably originating in tidal-stripping gas from nearby galaxies (Pak *et al.* 2014). Chandra X-ray data (González-Martín *et al.* 2009) shows that NGC 4111 has an extended soft X-ray ($0.5-2.0$ keV) emission along the galaxy plane due to stellar contribution and a hard X-ray ($2.0-10.0$ keV) emission located at the nucleus due to supermassive black hole activity. Our and previous data suggest that NGC 4111 has a fairly extincted Active Galactic Nucleus (AGN) embedded in the dusty polar ring. Further evidence for this is given by its classification as a LINER in diagnostic diagrams.

To investigate the inner 100 pc kinematics, we used the Gemini North Near-Infrared Integral Field Spectrometer (NIFS) data in the K-band, which has a Field-of-View (FOV) of $3'' \times 3''$, that corresponds to 219 pc $\times$ 219 pc at the galaxy. The near infrared spectra shows abundance of $H_2$ emission lines and an absence of the Br$\gamma$ recombination line. To further explain the nature of these emissions, we also used HST F475W and F814W images and data from the Spectrographic Areal Unit for Research on Optical Nebulae survey (SAURON) to study the gas and stellar kinematics of the outer regions of the galaxy and see how it links to the central region small scale kinematics. We also investigate the physical properties of the gas in these small and large scales.

## 2. Results

Figure 1 shows a HST composite image in the visible with the NIFS FOV as a white dashed box. The right panels show the stellar (upper panels) and the $H_2$ gas (lower panels) kinematics from NIFS. The right panels show that the molecular gas is counter

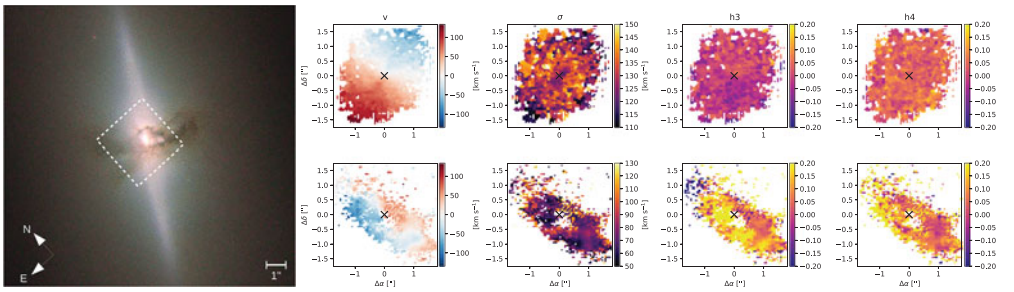


**Figure 1. Left:** HST composite image with the NIFS FOV shown as a white dashed box. **Right:** Stellar and Gas kinematics obtained from NIFS.

rotating with respect to the stellar component of the galaxy, and it is located in a ring-like structure not centered in the nucleus which is associated with the dusty polar ring. For further analysis, we created channel maps to investigate the 3D geometry of this molecular ring in search for inflows and/or outflows. The stellar kinematics shows a $\sigma$ drop in the nuclear region, which may be due to young stellar population which hasn't entered the same velocity field of the older stars yet. SAURON data confirms the presence of a young stellar population in the central region, that may be due to inflowing gas from the dusty polar ring.

The HST F475W and F814W images show the presence of a dusty polar ring which has an extension of 458 pc and 129 pc width. SAURON data shows the outer gas kinematics follows a rotation-like pattern along the polar ring, but the subtraction of the stellar velocity field from that of the gas shows a spiral-like pattern in the gas kinematics with the central portion similar to the NIFS gas kinematics, and comparison with the channel maps show consistent signs of inflowing material.

Therefore, we conclude that the polar ring structure is inflowing towards the nucleus and then forming new stars on the way in and fueling the central black hole, also causing the hard X-ray emission seen at the nucleus. However, as the dust polar ring is still present, it suggests that the nuclear activity is fairly recent, as there wasn't enough time to heat the medium enough to sublimate the dust. The measured temperature of the $H_2$ gas is 2704K (following Wilman, Edge & Johnstone 2005) and the molecular emission is caused by thermal processes, as shown by the $H_2$ $\lambda$2.2477 $\mu$m/$H_2$ $\lambda$2.1218 $\mu$m line ratio (Storchi-Bergmann *et al.* 2009). We believe it is been heated by the embedded X-ray emission, which is consistent with the absence of the Br$\gamma$ line in the spectrum, as it isn't caused by stellar ionization.

## References

González-Martín, O., Masegosa, J., Márquez, I., *et al.*2009, *A&A*, 506, 1107
Pak, M., Rey, S.-C., Lisker, T., *et al.* 2014, *MNRAS*, 445, 630
Storchi-Bergmann, T., McGregor, P. J., Riffel, R. A., *et al.*2009, *MNRAS*, 394, 1148
Wilman, R. J., Edge, A. C., & Johnstone, R. M. 2005, *MNRAS*, 359, 755

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