The AGNIFS survey: distribution and excitation of the hot molecular and ionised gas in the inner kpc of nearby AGN hosts

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Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

We use the Gemini NIFS instrument to map the H$_2$ 2.1218 µm and Br$_γ$ flux distributions in the inner 0.04–2 kpc of a sample of 36 nearby active galaxies (0.001 ≲ z ≲ 0.056) at spatial resolutions from 4 to 250 pc. We find extended emission in 34 galaxies. In ~55% of them, the emission in both lines is most extended along the galaxy major axis, while in the other 45% the extent follows a distinct orientation. The H$_2$ emission is less concentrated than that of Br$_γ$, presenting a radius that contains half of the flux 60% greater, on average. The H$_2$ is less concentrated than that of Br$_γ$, presenting a radius that contains half of the flux 60% greater, on average. The H$_2$ emission is driven by thermal processes – X-ray heating and shocks – at most locations for all galaxies, where 0.4 < H$_2$/Br$_γ$ < 6. For regions where H$_2$/Br$_γ$ > 6 (seen in 40% of the galaxies), shocks are the main H$_2$ excitation mechanism, while in regions with H$_2$/Br$_γ$ < 0.4 (25% of the sample) the H$_2$ emission is produced by fluorescence. The only difference we found between type 1 and type 2 AGN was in the nuclear emission-line equivalent widths, that are smaller in type 1 than in type 2 due to a larger contribution to the continuum from the hot dusty torus in the former. The gas masses in the inner 125 pc radius are in the range $10^1$ – $10^4$ M$_☉$ for the hot H$_2$ and $10^4$ – $10^6$ M$_☉$ for the ionised gas and would be enough to power the AGN in our sample for $10^5$ – $10^8$ yr at their current accretion rates.

Key words: galaxies: active – galaxies: Seyfert – galaxies: ISM – techniques: imaging spectroscopy

1 INTRODUCTION

The presence of a gas reservoir in the inner few tens of parsecs of galaxies is a necessary requirement to trigger an Active Galactic Nucleus (AGN) and/or a nuclear starburst. Understanding the origin of the gas emission at these scales is critical to investigate the role of AGN and star formation (SF) feedback in galaxy evolution. The cold molecular gas is the raw fuel of star formation in the central region of galaxies and AGN, while the ionised gas is usually observed as...
a consequence of star formation and nuclear activity. The ionised gas is easier to trace, since the strongest emission lines are observed in the optical region. These emission lines are good tracers of many galactic components, such as disks, outflows and AGN (e.g. Ricci et al. 2014). However, there are no strong emission lines of molecular gas in the optical. For this reason, most studies of molecular hydrogen distribution and kinematics usually use other molecules as its tracer, such as the CO emission at sub-millimeter wavelengths. These studies have found that there are two main classes of galaxies regarding their molecular gas distribution: a starburst one, where the molecular gas distribution is very compact with short consumption times ($10^7$–$10^8$ yr), and a quiescent one, with the gas distributed in extended disks and longer consumption times ($\sim 10^9$ yr) (Daddi et al. 2010; Genzel et al. 2010; Sargent et al. 2014; Silverman et al. 2015). In order to properly compare ionised and molecular gas distributions, however, it is ideal that they are observed in the same wavelength range and with the same spatial resolution. In the near-infrared (hereafter near-IR) both gas phases, hot molecular and ionised, can be observed simultaneously. In particular, the K-band spectra of galaxies include ro-vibrational emission lines from the $H_2$, tracing the hot total molecular gas, and the hydrogen recombination line Br$\gamma$, a tracer of the ionised gas (e.g Riffel et al. 2006). Physically motivated models (Hopkins & Quataert 2010) show that the relevant feeding processes occur within the inner kiloparsec, which can only be resolved in nearby galaxies. Near-IR integral field spectroscopy (IFS) on 8–10-m telescopes is a unique tool to investigate the distribution and kinematics of the molecular and ionised gas at spatial resolutions of 10–100 pc providing observational constraints to better understand the AGN feeding and feedback processes. Such constraints are fundamental ingredients of theoretical models and numerical simulations of galaxy evolution aimed to understand the co-evolution of AGN and their host galaxies (Kormendy & Ho 2013; Heckman & Best 2014; Harrison 2017; Harrison et al. 2018; Storchi-Bergmann & Schnorr-Müller 2019).

The near-IR emission of molecular and ionised gas have been investigated over the years using both long slit spectroscopy (e.g. Rodríguez-Ardila et al. 2004, 2005; Riffel et al. 2006, 2013a; Lamperti et al. 2017) and spatially resolved observations (e.g. Riffel et al. 2009, 2020; Dutse et al. 2009; Hicks et al. 2009; Storchi-Bergmann et al. 2009; Mazzalay et al. 2013; Scharwächter et al. 2013; Barbosa et al. 2014; Durrê & Mould 2014; Schönell et al. 2014, 2017; Durrê & Mould 2018; Diniz et al. 2015; Fischer et al. 2017; Husemann et al. 2019; Shimizu et al. 2019; Rosario et al. 2019). In most cases, the hot molecular and ionised gas show distinct flux distributions and kinematics, with the $H_2$ more restricted to the galaxy plane following circular rotation and the ionised gas showing more collimated emission and contribution of non-circular motions. However, in few cases, hot molecular outflows are also observed (e.g. Davies et al. 2014; Fischer et al. 2017; Guilka et al. 2020; May & Steiner 2017; May et al. 2020; Riffel et al. 2020). These results, combined with the fact that the ionised gas is usually associated with higher temperatures when compared to the molecular gas, has led Storchi-Bergmann et al. (2009) to suggest that the molecular gas is a better tracer of AGN feeding, whereas the ionised gas is a better tracer of AGN feedback. While the studies above have addressed the origin, morphology and amount of molecular gas in individual sources, it is now necessary to trace a more complete picture of the subject from a statistical point of view. This will allow us to detect common points and differences in order to advance on the knowledge of the origin and black hole feeding mechanisms in AGN and galaxies overall.

A few studies using near-IR IFS on larger samples have also been carried out, as for example those of the AGNIFS (AGN Integral Field Spectroscopy) survey (Riffel et al. 2017, 2018; Schönell et al. 2019), the Local Luminous AGN with Matched Analogs (LLAMA) survey (Davies et al. 2015; Lin et al. 2018; Caglar et al. 2020) and the Keck OSIRIS Nearby AGN (KONA) survey (Müller-Sánchez et al. 2018b). But so far, the studies based on these surveys were aimed to describe the sample, map its stellar kinematics and nuclear properties of the galaxies, while the origin, amount and distribution of the hot molecular hydrogen in the inner kiloparsec of nearby AGN are still not properly covered and mapped.

In the present work, we use K-band IFS of a sample of 36 AGN of the local Universe, observed with the Gemini Near-infrared Integral Field Spectrograph (NIFS), to map their molecular and ionised gas flux distributions at resolutions ranging from a few pc to $\approx 250$ pc. We investigate the origin of the $H_2$ emission, derive the $H_2$ excitation temperature and mass of hot molecular and ionised gas, available to feed the central AGN and star formation. This paper is organized as follows: Section 2 presents the sample, observations and data reduction procedure, Sec. 3 presents the results, which are discussed in Sec. 4. We present our conclusions in Sec. 5. We use a $h = 0.7, \Omega_m = 0.3, \Omega_\Lambda = 0.7$ cosmology throughout this paper.

## 2 THE SAMPLE AND DATA

### 2.1 The sample

We used the catalog of hard X-ray (14–195 keV) sources detected in the first 105 months of observations of the Swift Burst Alert Telescope (BAT) survey (Oh et al. 2018) to select our parent sample of AGN. The hard X-ray measures direct emission from the AGN and is much less sensitive to obscuration along the line-of-sight than softer X-ray and optical observations (see Davies et al. 2015, for a discussion about the advantages of using BAT catalogue to select AGN). This sample was cross-correlated with the Gemini Science archive looking for data obtained with the Near-Infrared Integral Field Spectrograph (NIFS) in the K band. We emphasize that just like any other AGN selection method (e.g. based on optical emission lines), our selection criteria may not include all AGN available in the Gemini database. As the aim of this work is to study the hot molecular hydrogen emission from AGN hosts, we limit our search to redshifts $z < 0.12$, for which the $H_2$ 2.128$\mu$m is still accessible in the K band.

We have found NIFS data for 36 galaxies obtained using the K and $K_{long}$ gratings, most of them observed as part of the Brazilian Large Gemini Program NIFS survey.
of feeding and feedback processes in nearby active galaxies (Riffel et al. 2018). The central wavelengths of the K and K$_{\text{long}}$ gratings are 2.0 and 2.30 μm, respectively. For both gratings, the bandwidth is ~4000 Å and the spectral bin is ~2.13 Å. Table 1 lists the galaxies of our sample, as well as their morphologies, nuclear activity types, redshifts, hard X-ray luminosities ($L_{\text{X}}$) obtained from the Swift BAT survey (Oh et al. 2018), Gemini Program ID, exposure time and the full width at half maximum (FWHM) of the Point Spread Function (PSF) measured from the flux distribution of the telluric standard stars for the type 2 AGN and from the flux distribution of the broad Brγ emission line for the observed type 1 AGN. Although our redshift limit is $z < 0.12$, the most distant galaxy (Cygnus A) we have found in the archive obeying all our criteria has $z = 0.056$. Except NGC 1052, all galaxies in our sample are classified as hosting Seyfert nuclei. The nature of LINERs is still not well understood, as similar line ratios can be produced by distinct mechanisms.
(e.g. AGN, hot low-mass evolved stars and shocks). However, NGC1052 undoubtedly presents an AGN as indicated by its optical emission lines (Heckman 1980; Ho et al. 1997; Dahmer-Hahn et al. 2019b), by the detection of a hidden broad line region seen in polarized light that shows a broad Hα component (Barth et al. 1999) and by its high hard X-ray luminosity, comparable to the luminosities in Seyfert nuclei (Table 1). We divide the sample into type 1 (1 to 1.5) and type 2 (1.9 and 2), according to the classification in the 105 month BAT catalogue (Oh et al. 2018). The type 1 and type 2 sub-samples have the same number (18) of objects.

In Figure 1 we show the X-ray luminosity and redshift distribution of the galaxies of our sample. We divide the sample into type 1 (blue-dashed line) and type 2 (red-continuous line) as in the Table 1. To test whether the distributions for the type 1 and type 2 are drawn from the same underlying distribution, we use the Kolmogorov-Smirnov (K-S) test and compute the probability of the null hypothesis ($P_{KS}$). $P_{KS} < 0.05$ implies that the null hypothesis, that the two distributions are drawn from the same underlying distribution, is rejected at a confidence level of 95 per cent. We find high values of $P_{KS}$ for both $L_X$ ($P_{KS} = 0.75$) and $z$ ($P_{KS} = 0.24$) distributions, meaning that the type 1 and type 2 AGN in our sample most likely follow similar distributions in these two parameters. As type 1 and 2 AGN follow the same distributions in terms of X-ray luminosity and redshift, we compare these sub-samples in terms of other physical properties in the following sections.

### 2.2 Observations, Data Reduction and Measurements

The observations were carried out with the NIFS instrument (McGregor et al. 2003) on the Gemini North Telescope from 2006 to 2019. NIFS has a square field of view of $3\arcsec \times 3\arcsec$, divided into 29 slices with an angular sampling of $0\arcsec.05 \times 0\arcsec.042$. At the distances of the galaxies of our sample, the NIFS field of view varies from 60$\times$60 pc$^2$ to 3.5$\times$3.5 kpc$^2$. Most of the observations (34/36) used Adaptive Optics (AO) by coupling NIFS with the ALTitude conjugate Adaptive optics for the InfraRed (ALTAIR) system. Only NGC1125 and ESO578-G009 were observed without AO.

The resulting angular resolutions are shown in Table 1 and are in the range $0\arcsec.11$–$0\arcsec.14$. Distinct observational strategies were used during the observations, which include the use of K or K$_{long}$ gratings and spatial dithering, resulting in different spatial and spectral coverage among galaxies. The spectral resolving power of NIFS in the K band is $R \approx 5290$. Telluric standard stars were observed just before and/or after the observations of each galaxy.

The data reduction followed the standard procedures (e.g., Riffel et al. 2017) using the gemini iraf package, including the trimming of the images, flat-fielding, cosmic ray rejection, sky subtraction, wavelength and s-distortion calibrations, removal of the telluric absorptions using the spectra of the telluric standard star and flux calibration by interpolating a black body function to the spectrum of the telluric standard. Finally, the data cubes were created at an angular sampling of $0\arcsec.05 \times 0\arcsec.05$ for each individual exposure and median combined using a sigma clipping algorithm to eliminate bad pixels and remaining cosmic rays and using the peak of the continuum emission of the galaxy as reference to perform the astrometry among the individual data cubes.

Results on gas emission properties of individual sources have already been published for 22 galaxies of our sample based on the K-band data used here. The references to these studies are shown in Tab. 1. The K-band spectra of nearby active galaxies show plenty of H$_2$ emission lines and usually also present strong Brγ emission (e.g. Riffel et al. 2006). To obtain the emission-line flux distributions, we integrated the fluxes within a spectral window of 1500 km s$^{-1}$ width centred at each emission line, after subtraction of the contribution of the underlying continuum fitted by a third order polynomial, similarly to the procedure adopted in Storchi-Bergmann et al. (2009). Our spectral window choice is very conservative, as the near-IR line widths in nearby galaxies are commonly much narrower than 1500 km s$^{-1}$ and so our choice warrants that we are computing the total line fluxes. To minimize the effect of noise, we followed Liu et al. (2013) and first fitted each emission line by a combination of three Gaussian curves and the continuum by a linear equation using the ifscube code...
(Ruschel-Dutra 2020). For type 1 AGN, we included an additional Gaussian to account for the broad Brγ component. Before computing the fluxes of Brγ in type 1 objects, we subtracted the contribution of this component and thus all measurements presented in this paper are for the narrow line components.

The fitting routine starts by modeling the spaxel corresponding to the peak of the continuum emission, using initial guesses for the centroid velocity and velocity dispersion of each component provided by the user. Then the irscube code performs the fitting of the neighboring spaxels following a spiral loop and using the parameters from spaxels located at distances smaller than 0.′′25 from the fitted spaxel as optimized guesses (as defined by the refit parameter). As mentioned above, we allow up to three Gaussian components to fit each line profile (4 for the Brγ line in Sy 1), but the code finds the minimum number of Gaussians to reproduce the profiles by setting the initial guesses for the amplitudes of the unnecessary Gaussian functions to zero. The fit of multi Gaussians has no physical motivation, it merely adjusts the initial guesses for the amplitudes of the unnecessary Gaussian functions to zero. The fit of multi Gaussians has no physical motivation, it merely reproduces the profiles by setting the initial guesses for the amplitudes of the unnecessary Gaussian functions to zero. The fit of multi Gaussians has no physical motivation, it merely reproduces the profiles by setting the initial guesses for the amplitudes of the unnecessary Gaussian functions to zero. The fit of multi Gaussians has no physical motivation, it merely reproduces the profiles by setting the initial guesses for the amplitudes of the unnecessary Gaussian functions to zero.

3 RESULTS

3.1 Emission-line flux distributions and line-ratio maps

In Figures 2 and 3 we present examples of maps constructed from the Gemini NIFS data measurements, comprising: the continuum, H2 2.1218 μm and Brγ flux distributions, the H2 2.1218 μm/Brγ ratio map and Brγ equivalent width (EqW) map for selected type 2 and type 1 AGN, respectively. The maps for the other galaxies are shown in Figures A1 and A2 of the Appendix. We masked out regions where the amplitude of the line profile was smaller than three times the standard deviation of the continuum next to each line profile. The galaxies NGC 3393 (Sy 2) and Mrk 352 (Sy 1) do not present extended line emission and thus we do not show their corresponding maps. All other galaxies show extended emission in both H2 and Brγ emission lines. The only exception is NGC 3516, for which the Brγ emission is seen only from the unresolved nucleus.

3.1.1 Flux distributions

The emission-line flux distributions present a wide variety of structures in both Brγ and H2 emission. In most galaxies, the H2 emission is more extended than the Brγ and the peak emission of both lines is observed at the galaxy nucleus. Other structures observed in the gas distribution comprise: nuclear spirals seen in molecular gas (e.g. Mrk 79); galaxies in which both H2 and Brγ emission are seen mainly along the major axis of the large scale disk (e.g. NGC 4235); galaxies in which the H2 and Brγ emission are distributed along distinct orientations (e.g. NGC 4388); ring-like structures (e.g. Mrk 1044); galaxies with elongated H2 emission and round Brγ flux distribution (e.g. Mrk 766), among other emission structures. There is no clear difference between the emission-line flux distributions of type 1 and type 2 AGN. A qualitative inspection of the H2 and Brγ flux maps in each object (Figs. 2, 3, A1 and A2) shows that the Brγ usually traces a more collimated emission, while the H2 emission spreads more over the whole field of view. This result is consistent with previous studies where the H2 and ionised gas have been shown to present distinct flux distributions and kinematics (Riffel et al. 2018; Schönell et al. 2019).

We compute the radii that contain 50% of the total flux (R50) of H2 2.1218 μm and Brγ emission lines. Although this parameter can be affected by projection effects if the H2 and Brγ emission originate from distinct spatial locations in individual targets, the R50 is useful to compare the H2 and Brγ emission in the whole sample. The corresponding R50 values for H2 and Brγ are shown in Table 2 and Figure 4 shows the comparison between R50H2 and R50Brγ. The Brγ flux distribution is more concentrated than that of H2 and the R50 for the H2 is on average 56% larger than that of Brγ.

We use the cv2.moments python package to compute the moments and orientation of the H2 and Brγ flux distributions. The orientations are shown as the continuous lines in the flux maps of Figs. 2, 3, A1 and A2. The position angles (PAs) are listed in Table 2, together with the orientation of the major axis of the galaxy obtained from the Hyperleda database (Paturel et al. 2003), measured from the 25 mag arcsec−2 isophote in a B-band image. We performed Monte Carlo simulations with 100 iterations each to compute the uncertainties, by adding random noise with amplitude of the 20th percentile flux value of the corresponding map. The listed uncertainties in Tab. 2 correspond to the standard deviation of the mean of the simulations.

We have compared the PA offset (∆PA) between the major axis of the large scale disk and the orientation of the Brγ and H2 flux distributions. Although the orientations of both flux distributions vary, the K-S test (P = 0.97) indicates the distributions of the corresponding ∆PA for Brγ and H2 are not distinct. ∆PA > 30° is usually used as a threshold to determine whether the stellar and gas disks are misaligned (Jin et al. 2016). We find that ∆PA larger than this value in 15 galaxies (42%) for the Brγ and in 16 galaxies (44%) for H2. These fractions are higher than those between the kinematic position angle of the stellar velocity field in the inner 3′′ × 3′′ and the major axis of the large scale disk, of ∼18% (Riffel et al. 2017), suggesting an origin in non-circular motions in the gas. The distributions of the ∆PA between the orientation of the H2 and Brγ flux distributions (PAH2−PABrγ) for type 1 and type 2 AGN are similar. We find ∆PA > 30° for 15 galaxies (45%). 3 galaxies (NGC 1275, NGC 5548 and Mrk 766) of these show ∆PA > 60°, for which the H2 emission is observed mainly along the major axis of the galaxy.

3.1.2 Line ratios

The H2 2.1218 μm/Brγ emission-line ratio is commonly used to investigate the main source of the H2 excitation (Reunanen et al. 2002; Rodríguez-Ardila et al. 2004, 2005; Storchi-Bergmann et al. 2009; Riffel et al. 2010a, 2014, 2013a; Riffel et al. 2018; Schönell et al. 2019; Dahmer-Hahn et al. 2019b; Fazeli et al. 2020). Small values
regions (SF: H\(_{\alpha}\) < 0.4), low excitation AGN (AGN\(_{LE}\): 0.4 ≤ H\(_{\alpha}\)/Br\(_{\gamma}\) < 2) and high excitation AGN (AGN\(_{HE}\): 2 ≤ H\(_{\alpha}\)/Br\(_{\gamma}\) < 6) and shock-dominated objects (Shock: H\(_{\alpha}\)/Br\(_{\gamma}\) > 6). In each row, the name of the galaxy is identified in the continuum image, the filled circle corresponds to the angular resolution, the spatial scale is shown in the bottom-left corner of the continuum image and the cross marks the position of the peak of the continuum emission. The dashed line indicates the orientation of the galaxy major axis obtained from the Hyperleda database. The continuous line on the flux maps shows the orientation of the emission-line flux distributions. The continuous line on the excitation map shows the orientation of the Br\(_{\gamma}\) emission. The gray regions indicate locations where emission lines are not detected above 3 times the continuum noise amplitude (3\(\sigma\)).

For all galaxies, north is up and east is to the left.

(H\(_{\alpha}\)/Br\(_{\gamma}\) < 0.4) are usually observed in H\(_{II}\) regions and star forming galaxies, while AGN present 0.4 ≤ H\(_{\alpha}\)/Br\(_{\gamma}\) ≤ 6.0 and higher values are usually observed in LINERs and shock-dominated regions (e.g. Riffel et al. 2013a; Colina et al. 2015; Riffel et al. 2021). In the near-IR the line ratio limits are empirical and their excitation mechanisms are less understood than those of the optical lines (e.g. Rodríguez-Ardila et al. 2004, 2005). However, it is worth mentioning that the H\(_{\alpha}\)/Br\(_{\gamma}\) line ratio can be affected by the geometry of the H\(_{II}\) region (Puxley et al. 1990) and the velocity of the shock (Wilgenbus et al. 2000). Both properties affect the dissociation of the H\(_2\) molecule, making the fraction of H\(_2\) and the H\(_2\)/Br\(_{\gamma}\) ratio, to change. The H\(_2\)/Br\(_{\gamma}\) maps for our sample (Figs. 2, 3, A1 and A2) show values ranging from nearly zero, as seen in the rings of star forming regions of Mrk 1044 and for NGC 4151 – in which the H\(_2\) emission decreases due to the dissociation of the molecule by the strong AGN radiation field (e.g. Storchi-Bergmann et al. 2009) – to values of up to H\(_{\alpha}/Br\(_{\gamma}\) ~ 30 for NGC 1275, where the H\(_2\) emission originates in shocks produced by AGN winds (Riffel 2020a).

We build excitation maps (fifth column of Figs. 2, 3, A1 and A2) to spatially locate the regions where different excitation mechanisms may be occurring. All galaxies present spaxels dominated by AGN excitation (0.4 < H\(_{\alpha}/Br\(_{\gamma}\) < 6), and in order to map the variation of this excitation, we have divided the AGN regions into low (0.4 ≤ H\(_{\alpha}/Br\(_{\gamma}\) < 2) and high excitation (2 ≤ H\(_{\alpha}/Br\(_{\gamma}\) < 6). This separation allows us to further investigate the origin of the H\(_2\) emission in the AGN. A similar separation was done in Riffel et al. (2020) to split the high line ratio region in the H\(_{\alpha}/Br\(_{\gamma}\) vs. [Fe\(_{II}\)]1.2570 \(\mu\)m/Pa\(_{\alpha}\) diagnostic diagram.

Table 3 presents the median H\(_{\alpha}/Br\(_{\gamma}\) ratio over the whole FoV (H\(_{\alpha}/Br\(_{\gamma}\)\_MED) for each galaxy of our sample, the median value within \(r < 125 \, pc\) (H\(_{\alpha}/Br\(_{\gamma}\)\_MED\_extra), the nuclear ratio, computed using an aperture with radius equal to the angular resolution of the data for each galaxy (H\(_{\alpha}/Br\(_{\gamma}\)\_nuc), and the extra-nuclear line ratio, measured as the median value of spaxels located at distances from the galaxy nucleus larger than the angular resolution (H\(_{\alpha}/Br\(_{\gamma}\)\_extra). The median values of H\(_{\alpha}/Br\(_{\gamma}\) are within the AGN range for 31 (91\%) galaxies of our sample. The exceptions are NGC 6240, NGC 1275 and Mrk 3 that show H\(_{\alpha}/Br\(_{\gamma}\) median values of 11.76, 11.10 and 0.17, respectively. The high H\(_{\alpha}/Br\(_{\gamma}\)\_MED values are consistent with shocks as the dominant H\(_{\alpha}\) excitation mechanism (Ilha et al. 2016; Müller-Sánchez et al. 2018a; Riffel 2020a). The low ratios observed for Mrk 3, NGC 5506 and NGC 4151 may be explained by the dissociation of the H\(_2\) molecule by the AGN radiation field in these galaxies as proposed by previous works (Guinla et al. 2020; Storchi-Bergmann et al. 2009). As seen in Tab. 3, type 1 and type 2 AGN show similar values of H\(_{\alpha}/Br\(_{\gamma}\) median values.

We use K-S statistics to test whether the distributions of H\(_{\alpha}/Br\(_{\gamma}\)\_MED for type 1 and type 2 AGN are distinct. We find \(K_{KS} = 0.96\), meaning that likely the H\(_{\alpha}/Br\(_{\gamma}\)\_MED distributions of type 1 and type 2 AGN are drawn from
Table 2. (1) Galaxy name, (2) position angle of the large scale disk from Hyperleda database, (3) H$_2$ and (4) Br$\gamma$ position flux distribution position angles, (5) and (6) radii that contain half of the total flux of H$_2$ 2.1218\mu m and Br$\gamma$. All angles are measured east of north.

| Galaxy     | $\Phi_0$ (deg) | $PA_{H_2}$ (deg) | $PA_{Br\gamma}$ (deg) | $R_{H2}$ (pc) | $R_{Br\gamma}$ (pc) |
|------------|----------------|------------------|------------------------|---------------|---------------------|
| type 2     |                |                  |                        |               |                     |
| NGC788     | 108.1          | 39.8 $\pm$ 1.6  | 89.4 $\pm$ 3.2         | 254 $\pm$ 42  | 296 $\pm$ 42        |
| NGC1052    | 112.7          | 44.0 $\pm$ 1.8  | 162.0 $\pm$ 7.7        | 62 $\pm$ 15   | 46 $\pm$ 15         |
| NGC1068    | 72.7           | 68.3 $\pm$ 1.2  | 28.8 $\pm$ 0.6         | 106 $\pm$ 11  | 71 $\pm$ 11         |
| NGC1125    | 53.5           | 46.5 $\pm$ 1.4  | 56.7 $\pm$ 1.2         | 137 $\pm$ 34  | 102 $\pm$ 34        |
| NGC1241    | 147.7          | 157.7 $\pm$ 4.6 | 46.9 $\pm$ 0.7         | 126 $\pm$ 42  | 126 $\pm$ 42        |
| NGC2110    | 175.1          | 143.4 $\pm$ 2.2 | 152.5 $\pm$ 0.9        | 145 $\pm$ 24  | 121 $\pm$ 24        |
| NGC4258    | 150.0          | 20.3 $\pm$ 2.6  | 13.7 $\pm$ 5.5         | 32 $\pm$ 4    | 28 $\pm$ 4          |
| NGC4388    | 91.1           | 85.6 $\pm$ 1.0  | 54.3 $\pm$ 0.8         | 183 $\pm$ 26  | 183 $\pm$ 26        |
| NGC5506    | 88.7           | 94.9 $\pm$ 1.3  | 92.8 $\pm$ 4.3         | 96 $\pm$ 19   | 57 $\pm$ 19         |
| NGC619     | 20.8           | 10.3 $\pm$ 1.0  | 170.7 $\pm$ 1.7        | 80 $\pm$ 26   | 80 $\pm$ 26         |
| NGC6240    | 12.2           | 0.9 $\pm$ 0.7   | 178.5 $\pm$ 0.8        | 610 $\pm$ 76  | 458 $\pm$ 76        |
| Mrk3       | 15.0           | 73.7 $\pm$ 1.3  | 80.9 $\pm$ 1.2         | 210 $\pm$ 42  | 168 $\pm$ 42        |
| Mrk348     | 87.0           | 160.8 $\pm$ 2.2 | 7.5 $\pm$ 5.9          | 186 $\pm$ 46  | 93 $\pm$ 46         |
| Mrk607     | 137.3          | 134.8 $\pm$ 1.2 | 140.6 $\pm$ 2.2        | 110 $\pm$ 27  | 55 $\pm$ 27         |
| Mrk1066    | 112.3          | 118.8 $\pm$ 1.5 | 126.0 $\pm$ 0.3        | 224 $\pm$ 37  | 186 $\pm$ 37        |
| ESO378-G009| 27.6           | 29.9 $\pm$ 0.6  | 29.3 $\pm$ 0.7         | 1199 $\pm$ 109| 654 $\pm$ 109       |
| CygnusA    | 151.0          | 176.1 $\pm$ 1.8 | 140.6 $\pm$ 1.0        | 1049 $\pm$ 174| 1049 $\pm$ 174      |
| type 1     |                |                  |                        |               |                     |
| NGC1275    | 110.0          | 42.2 $\pm$ 6.1  | 137.9 $\pm$ 2.2        | 164 $\pm$ 54  | 109 $\pm$ 54        |
| NGC3227    | 156.0          | 128.8 $\pm$ 3.1 | 153.1 $\pm$ 2.2        | 60 $\pm$ 12   | 36 $\pm$ 12         |
| NGC3516    | 55.0           | 138.0 $\pm$ 4.0 | $\pm$ 27               | 27 $\pm$ 27   |                     |
| NGC4051    | 139.4          | 96.9 $\pm$ 1.5  | 117.4 $\pm$ 4.6        | 35 $\pm$ 7    | 14 $\pm$ 7          |
| NGC4151    | 56.0           | 100.0 $\pm$ 1.0 | 57.5 $\pm$ 0.4         | 61 $\pm$ 10   | 51 $\pm$ 10         |
| NGC4235    | 49.0           | 44.4 $\pm$ 0.5  | 42.6 $\pm$ 0.6         | 224 $\pm$ 24  | 224 $\pm$ 24        |
| NGC4395    | 127.8          | 106.4 $\pm$ 3.2 | 104.3 $\pm$ 5.2        | 10 $\pm$ 4    | 10 $\pm$ 4          |
| NGC5548    | 118.2          | 146.0 $\pm$ 3.8 | 46.2 $\pm$ 2.3         | 160 $\pm$ 53  | 160 $\pm$ 53        |
| NGC6814    | 107.6          | 121.2 $\pm$ 1.3 | 153.2 $\pm$ 1.3        | 48 $\pm$ 16   | 48 $\pm$ 16         |
| Mrk79      | 73.0           | 76.2 $\pm$ 3.9  | 171.9 $\pm$ 3.5        | 276 $\pm$ 69  | 207 $\pm$ 69        |
| Mrk509     | 80.0           | 139.4 $\pm$ 5.1 | 96.3 $\pm$ 4.3         | 536 $\pm$ 107 | 428 $\pm$ 107       |
| Mrk618     | 85.0           | 34.9 $\pm$ 2.2  | 24.8 $\pm$ 0.9         | 442 $\pm$ 110 | 221 $\pm$ 110       |
| Mrk766     | 73.1           | 62.0 $\pm$ 1.4  | 135.1 $\pm$ 1.1        | 160 $\pm$ 40  | 120 $\pm$ 40        |
| Mrk926     | 104.1          | 71.7 $\pm$ 1.4  | 104.0 $\pm$ 2.9        | 730 $\pm$ 146 | 438 $\pm$ 146       |
| Mrk1044    | 177.5          | 169.2 $\pm$ 2.2 | 6.5 $\pm$ 7.9          | 359 $\pm$ 51  | 102 $\pm$ 51        |
| MCG-08-11-01| 80.3           | 135.4 $\pm$ 1.5 | 167.4 $\pm$ 3.0        | 536 $\pm$ 134 | 536 $\pm$ 134       |
the same underlying distribution. However, our observations cover spatial scales from a few tens of pc to a few kpc, and so, for the most distant objects the H$_2$/Br$\gamma$MED is dominated by the extra-nuclear regions, while in the closest galaxies, the contribution of the nuclear emission is higher. In order to avoid this problem, we compute the H$_2$/Br$\gamma$ within the inner 125 pc radius for all objects. This aperture corresponds to the lowest spatial resolution in our sample (for ESO578-G009). For three galaxies (NGC4258, NGC4051 and type 2 AGN. Finally, we test whether H$_2$/Br$\gamma$ (median, within 125 pc radius and nuclear) and the hard X-ray luminosity are correlated using the Pearson test, resulting that the distributions of the galaxies of our sample.

3.2 Br$\gamma$ Equivalent width maps

The fifth column of Figs. 2, 3, A1 and A2 shows the Br$\gamma$ equivalent width (EqW$_{Br\gamma}$) maps. The emission structures are better seen in the EqW$_{Br\gamma}$ than in the flux distribution maps, as the former measure the emission relative to the continuum. For example, in Mrk3 (Fig. A1) the EqW$_{Br\gamma}$ map shows knots of emission not easily observed in the Br$\gamma$ flux map. Young (<10 Myr) stellar populations present EqW$_{Br\gamma} \gtrsim 50$ Å, as predicted by evolutionary photoionisation models (Dors et al. 2008; Riffel et al. 2009a). All galaxies of our sample clearly show smaller values (EqW$_{Br\gamma} \lesssim 30$ Å) than those predicted for young stellar population models. Even galaxies with known active star-formation, as NGC6240 (e.g. Keel 1990; Lutz et al. 2003; Pasquali et al. 2004) and NGC3227 (Gonzalez Delgado & Perez 1997; Schinnerer et al. 2000), present low EqW$_{Br\gamma}$ values, which suggest the near-infrared continuum is dominated by the contribution of old stellar populations and the AGN featureless continuum in the nucleus.

Differently from the Br$\gamma$ flux distributions, which usually present the emission peak at the nucleus, the highest values of EqW$_{Br\gamma}$ are seen away from the nucleus in most galaxies of our sample. In addition, a visual inspection of the EqW$_{Br\gamma}$ maps shows a drop in the EqW$_{Br\gamma}$ values at the nucleus. This drop is more prominent in type 1 AGN than in type 2, possibly due to a stronger dilution of the Br$\gamma$ emission by the nuclear continuum.

We measure the EqW$_{Br\gamma}$ values for the nucleus of each galaxy within an aperture corresponding to the angular resolution of the data for each galaxy) for type 1 and type 2 AGN. Finally, we test whether H$_2$/Br$\gamma$ (median, within 125 pc radius and nuclear) and the hard X-ray luminosity are correlated using the Pearson test, resulting that these parameters do not present a statistically significant correlation.

Figure 5 shows the only distinct distributions we found: the H$_2$/Br$\gamma$$_{\text{nuc}}$ and H$_2$/Br$\gamma$$_{\text{extra}}$ ones. Using the K-S test we obtain $P_{\text{KS}} = 0.045$ indicating that the distributions are distinct: on average, the nucleus presents lower H$_2$/Br$\gamma$ ratios than the extra-nuclear regions.
Table 3. \( H_2/Br\gamma \) line ratio: (1) galaxy name, (2) median values of the line ratio for the whole FoV (\( H_2/Br\gamma_{MED} \)), (3) in the inner \( r < 125 \) pc (\( H_2/Br\gamma_{<125pc} \)), (4) within the central angular resolution element (\( H_2/Br\gamma_{nuc} \)) and (5) for spaxels at distances larger than the angular resolution radius (\( H_2/Br\gamma_{extra} \)).

| Galaxy       | \( H_2/Br\gamma_{MED} \) | \( H_2/Br\gamma_{<125pc} \) | \( H_2/Br\gamma_{nuc} \) | \( H_2/Br\gamma_{extra} \) |
|--------------|---------------------------|-----------------------------|---------------------------|-------------------------------|
| NGC788       | 0.96±0.91                 | 0.82±0.35                   | 0.53±0.05                 | 0.96±0.91                     |
| NGC1052      | 2.32±1.07                 | 2.32±0.77                   | 2.15±0.27                 | 2.36±1.09                     |
| NGC1068      | 1.78±3.18                 | 1.30±3.72                   | 0.54±0.10                 | 1.79±3.18                     |
| NGC1125      | 0.78±0.62                 | 0.39±0.06                   | 0.38±0.04                 | 0.88±0.62                     |
| NGC1241      | 3.11±2.21                 | 3.21±1.58                   | 2.67±0.09                 | 3.18±2.24                     |
| NGC2110      | 3.61±1.57                 | 3.15±1.57                   | 1.36±0.38                 | 3.65±1.55                     |
| NGC2458      | 1.84±0.90                 | 1.84±0.90                   | 2.59±1.47                 | 1.81±0.85                     |
| NGC4388      | 1.25±1.16                 | 1.31±0.38                   | 1.15±0.16                 | 1.26±1.17                     |
| NGC5506      | 0.51±0.68                 | 0.43±0.45                   | 0.09±0.02                 | 0.51±0.68                     |
| NGC5509      | 4.35±1.43                 | 4.27±4.38                   | 2.40±0.13                 | 4.41±4.15                     |
| NGC6240      | 11.78±7.49                | 8.55±4.70                   | 8.65±2.96                 | 11.95±7.86                    |
| Mrk3         | 0.17±0.15                 | 0.07±0.04                   | 0.04±0.01                 | 0.18±0.15                     |
| Mrk348       | 1.30±0.84                 | 0.89±0.28                   | 0.56±0.09                 | 1.34±0.83                     |
| Mrk607       | 1.06±0.69                 | 0.93±0.37                   | 0.51±0.06                 | 1.08±0.69                     |
| Mrk1066      | 1.39±1.51                 | 1.41±0.55                   | 1.41±0.16                 | 1.39±1.51                     |
| ESOS578-G009 | 1.60±1.77                 | 2.97±0.77                   | 2.17±1.17                 | 1.59±1.79                     |
| CygnovaA     | 2.06±1.75                 | 1.92±0.14                   | 1.93±0.27                 | 2.08±1.76                     |
| Mean         | 2.35±2.58                 | 2.10±1.96                   | 1.71±1.94                 | 2.38±2.62                     |

Figure 6. Nuclear Br\gamma equivalent width distributions for the type 1 (dashed-blue lines) and type 2 (continuous-red lines) AGN in our sample. The equivalent widths are measured within apertures corresponding to the angular resolution of the data.

3.3 Masses of hot molecular and ionised hydrogen

We use the fluxes of the \( H_2\) 2.12 \( \mu m \) and Br\gamma emission lines to compute the mass of hot molecular (\( M_{H_2} \)) and ionised (\( M_{H11} \)) hydrogen. The mass of hot molecular gas (\( M_{H_2} \)) can be estimated, under the assumptions of local thermal equilibrium and excitation temperature of 2000 K, by (e.g. Scoville et al. 1982; Riffel et al. 2014):

\[
\left( \frac{M_{H_2}}{M_\odot} \right) = 5.0776 \times 10^{13} \left( \frac{F_{H_2\lambda 2.1218 \, erg \, cm^{-2} \, s^{-1}}}{D \, Mpc} \right)^2 ,
\]

where \( F_{H_2\lambda 2.1218} \) is the \( H_2 \) 2.1218\( \mu m \) emission-line flux and \( D \) is the distance to the galaxy.

Following Osterbrock & Ferland (2006) and Storchi-Bergmann et al. (2009), we estimate the mass of ionised gas \( M_{H11} \) by:

\[
\left( \frac{M_{H11}}{M_\odot} \right) = 3 \times 10^{19} \left( \frac{F_{Br\gamma \lambda 2.572 \, erg \, cm^{-2} \, s^{-1}}}{D \, Mpc} \right)^2 \left( \frac{N_e}{cm^{-3}} \right)^{-1} ,
\]

where \( F_{Br\gamma} \) is the Br\gamma flux (summing the fluxes of all spaxels) and \( N_e \) is the electron density. Recent studies find that...
the electron densities in ionised outflows are underestimated using the [S ii] line ratio (Baron & Netzer 2019; Davies et al. 2020). However, most of the Brγ emission in the inner kpc of nearby Seyfert galaxies originate from gas rotating in the plane of the disk (e.g. Riffel et al. 2018; Schönen et al. 2019), and thus we adopt \( N_e = 500 \text{ cm}^{-3} \), which is a typical value measured in AGN from the [S ii]λ6717,6731 lines (e.g. Dors et al. 2014, 2020; Brum et al. 2017; Freitas et al. 2018; Kakkad et al. 2018). The distances to the galaxies adopted here are based on the galaxy redshift (Table 1) for all targets.

Table 4 shows the mass of hot H\(_2\) and ionised hydrogen for the galaxies of our sample computed in the whole NIFS FoV (\( M_{\text{H}_2 \text{FoV}} \) and \( M_{\text{H}^+ \text{FoV}} \)) and within the inner 125 pc (\( M_{\text{H}_2 \text{r}<125pc} \) and \( M_{\text{H}^+ \text{r}<125pc} \)). The corresponding distributions are shown in Fig. 7. For three galaxies (NGC 4258, NGC 4041 and NGC 4395) the FoV is smaller than 250 pc and so, we do not calculate the mass within the inner 125 pc radius. We do not find statistically significant differences between the masses of ionised and molecular gas of type 1 and type 2 AGN.

### 3.4 \( \text{H}_2 \) vibrational and rotational temperatures

The \( \text{H}_2 \) 1–0 S(1) 2.1218 \( \mu \)m/1–0 S(2) 2.2477 \( \mu \)m and 1–0 S(1) 2.0338 \( \mu \)m/1–0 S(0) 2.2235 \( \mu \)m line ratios can be used to estimate the vibrational and rotational temperatures of \( \text{H}_2 \). Using \( N_i/g_i = F_i/\lambda_i A(g_i) = \lambda_i [N_i/(k_i T_{\text{exc}})] \), where \( N_i \) are the column densities in the upper level, \( g_i \) the statistical weights, \( F_i \) and \( \lambda_i \) are the line fluxes and wavelengths, \( A_i \) are the transition probabilities, \( E_i \) are the energies of the upper level, \( T_{\text{exc}} \) is the excitation temperature and \( k_B \) is the Boltzmann constant. Using

```latex
| Galaxy        | \( M_{\text{H}_2 \text{r}<125pc} \) (10\(^3\) M\(_\odot\)) | \( M_{\text{H}^+ \text{r}<125pc} \) (10\(^3\) M\(_\odot\)) | \( M_{\text{H}_2 \text{FoV}} \) (10\(^4\) M\(_\odot\)) | \( M_{\text{H}^+ \text{FoV}} \) (10\(^4\) M\(_\odot\)) | \( T_{\text{vib}} \) (K) | \( T_{\text{rot}} \) (K) |
|--------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|----------------|----------------|
| NGC1275      | 1170.3±5.3                      | 150.6±8.5                       | 2327.5±56.7                     | 229.8±20.5                      | 2309±12        | 1021±356      |
| NGC3277      | 52.1±1.3                        | 11.5±1.2                        | 53.7±1.5                        | 11.8±1.3                        | 2906±27        | 1909±358      |
| NGC3516      | 8.7±2.2                         | 2.0±0.3                         | 16.2±2.7                        | 2.1±1.9                         | 3583±374       |               |
| NGC4051      | 36.9±1.3                        | 54.7±1.6                        | 37.8±1.8                        | 56.8±2.3                        | 2495±45         | 1365±778     |
| NGC4151      | 40.0±4.0                        | 0.2±0.1                         | 13.7±1.2                        | 1.9±0.5                         | 5055±145        |               |
| NGC4395      | 33.3±5.5                        | 32.1±6.8                        | 79.7±28.5                       | 71.2±32.8                       | –               |               |
| NGC5548      | 7.8±0.8                         | 1.4±0.4                         | 8.6±1.4                         | 1.4±0.6                         | 3093±115        | 1811±812     |
| NGC6814      | 52.9±2.1                        | 23.9±2.5                        | 195.6±12.1                      | 61.4±6.7                        | 3392±95        |               |
| Mrk79        | 8.2±0.1                         | 21.0±9.3                        | 213.8±26.0                      | 226.9±22.3                      | 3593±320        |               |
| Mrk618       | 62.5±8.3                        | 162.8±10.4                      | 507.1±58.0                      | 538.0±82.7                      | 4090±291        | 752±703      |
| Mrk766       | 23.3±2.0                        | 112.2±3.7                       | 60.5±7.3                        | 166.5±17.7                      | 3278±164        |               |
| Mrk926       | 79.3±12.5                       | 54.7±15.2                       | 1340.8±106.5                    | 507.2±53.0                      | 3388±173        | 1498±732     |
| Mrk1048      | 0.1±0.1                         | 53.5±4.9                        | 11.5±3.1                        | 81.7±14.1                       | –               |               |
| MCG+08-11-01 | 117.6±18.5                      | 138.2±19.7                      | 1080.3±56.8                     | 424.8±44.4                      | 2560±44         | 1212±675     |
| Mean         | 99.3±269.6                      | 49.0±54.8                       | 386.8±622.2                     | 158.6±179.5                     | 3298±791        | 1254±570     |
```
the transition probabilities from Turner et al. (1977), the rotational temperature is given by:

\[ T_{\text{rot}} \approx \frac{1113}{\ln \left( \frac{0.323 \, F_{H_2}}{F_{H_2} \pm 2.235} \right)} \]  

(3)

and the vibrational temperature by

\[ T_{\text{vib}} \approx \frac{5594}{\ln \left( \frac{1.355 \, F_{H_2} \pm 2.235 \pm 2.2477}{} \right)} \]  

(4)

We were able to estimate the H$_2$ vibrational temperature for 32 galaxies. For NGC 5548 and Mrk 1044 at least one of the H$_2$ emission lines used to determine $T_{\text{vib}}$ is not detected in our NIFS data with an amplitude larger than twice the standard deviation of the adjacent continuum. We estimate the H$_2$ rotational temperature for 21 galaxies. 11 galaxies of our sample were observed using the K$_{\text{long}}$ grating (Tab. 1), for which the spectral range does not include the H$_2$ 2.0338 $\mu$m emission line, needed to estimate the H$_2$ rotational temperature. In addition, this line is not detected for NGC 3516 and NGC 4235. In Figures A3 and A4 we show the maps of $T_{\text{rot}}$ and $T_{\text{vib}}$ for the type 2 and type 1 AGN and in Figure A5 we show the $T_{\text{vib}}$ maps for the objects where the spectral range does not include the 1–0 S(2) line. Table 4 shows the median temperatures for each galaxy. The median values of the vibrational temperature are in the range from $\sim$2100 to $\sim$4300 K, while the rotational temperatures are in the range $\sim$450–1900 K. There is no difference between the mean temperatures in type 1 and type 2 AGN.

4 DISCUSSION

4.1 Type 1 vs. type 2 AGN

According to the AGN Unification Model (Antonucci 1993; Urry & Padovani 1995), type 1 and type 2 AGN represent the same class of objects seen at distinct viewing angles. However, some recent results suggest these two classes may be intrinsically distinct objects (e.g., Elitzur 2012; Elitzur et al. 2014; Villarroel & Korn 2014; Prieto et al. 2014; Audibert et al. 2017), the tori of type 2 AGN having on average smaller opening angles and more clouds along the line of sight than for type 1 (Ramos Almeida et al. 2011).

Our sample presents the same number of type 1 and type 2 AGN and they follow similar luminosity and redshift distributions (Fig. 1), thus we can compare both AGN types in terms of the emission-line properties. We find the type 1 and type 2 AGN of our sample present similar H$_2$/Br$\gamma$ line ratios, ionised and hot molecular gas masses and H$_2$ excitation temperature distributions. They also present no difference in terms of the $\Delta$PA between the Br$\gamma$ and H$_2$ flux distributions and between the orientation of the major axis of the hosts and the emission-line flux distributions. These results support the unification scenario.

We find a statistically significant difference between type 1 and type 2 AGN only for the emission line equivalent widths at the nucleus (Fig. 6). Seyfert 1 nuclei show smaller equivalent widths than Seyfert 2 nuclei. The K-band continuum of AGN can present a strong contribution of hot dust emission from the inner border of the torus (e.g. Riffel et al. 2009c; Dumont et al. 2020). This component is present in about 90 per cent of Seyfert 1 nuclei, while only about 25 per cent of Seyfert 2 nuclei present this component (Riffel et al. 2009b). Thus, the smaller values of equivalent widths we observe in type 1 AGN may be due to stronger contributions of hot dust emission to the underlying continuum than those in type 2 AGN. Similar results are found for CO absorption-band heads at $\sim$2.3 $\mu$m, which can be diluted by the hot dust emission (Riffel et al. 2009b; Burtscher et al. 2015; Müller-Sánchez et al. 2018b). We find a decrease in the nuclear $EqW_{Br\gamma}$ in 88% (15 objects) of Type 1 AGN, and in 47% (8 objects) of the type 2 AGN, as compared to the extra-nuclear $EqW_{Br\gamma}$ values. The mean values of the ratio between the mean value of the nuclear $EqW_{Br\gamma}$ (computed using an aperture with radius equal to the angular resolution of the data for each galaxy) and the mean extra-nuclear $EqW_{Br\gamma}$ (computed using spaxels at distances larger than the angular resolution) is $1.35\pm0.27$ and $0.58\pm0.14$ for the type 2 and type 1 AGN in our sample, respectively. Considering only the galaxies that show a nuclear decrease in $EqW_{Br\gamma}$, the mean ratios between the nuclear and extra-nuclear $EqW_{Br\gamma}$ are $0.52\pm0.11$ and $0.39\pm0.07$ for type 2 and type 1 AGN, respectively.

The difference in the equivalent widths in type 1 and type 2 AGN can be reconciled with the AGN unification model, as in type 1 AGN we observe directly the contribution of the inner and hotter region of the dusty torus, while...
The black dashed curve corresponds to the ratios for an isothermal and uniform density gas distribution for temperatures ranging from 1000 (left) to 4000 K (right) – the open circles identify the ratios in steps of 1000 K. The orange polygon represents the region occupied by the non-thermal UV excitation models of Black & van Dishoeck (1987) and the pink polygons cover the region of the photoionisation models of Dors et al. (2012). The blue rectangle covers the locus of the thermal UV excitation models of Sternberg & Dalgarno (1989), as computed by Mouri (1994) for gas densities \( n_t \) of \( 10^5 \) and \( 10^6 \) cm\(^{-3}\) and UV scaling factors relative to the local interstellar radiation field \( \chi \) from \( 10^2 \) to \( 10^4 \). The filled blue squares are the UV thermal models from Davies et al. (2003) for \( 10^3 < n_t < 10^6 \) cm\(^{-3}\) and \( 10^2 < \chi < 10^3 \), while the open blue square is from Sternberg & Dalgarno (1989) for \( n_t = 10^6 \) cm\(^{-3}\) and \( \chi = 10^2 \). The brown stars are from the thermal X-ray models of Draine & Woods (1990), the gray open diamond is from the shock model of Kwan et al. (1977) and the gray filled diamonds represent the shock models from Smith (1995). The AGN photoionisation from Riffel et al. (2013a) span a wide range in both axes \((0 \lesssim H_2 2–1 S(1)/1–0 S(0) \lesssim 0.6 \text{ and } 0.5 \lesssim 1–0 S(2)/1–0 S(0) \lesssim 2.5)\) and therefore is not shown in the figure. The right panels show the \( H_2 2.1218 \mu m \) luminosity distributions for the spaxels used in the left panels, in logarithmic units of ergs s\(^{-1}\).

### 4.2 The origin of the \( H_2 \) emission

The origin of the \( H_2 \) near-IR emission lines in active galaxies has been investigated in several theoretical and observational studies (e.g. Black & van Dishoeck 1987; Hollenbach & McKee 1989; Draine & Woods 1990; Maloney et al. 1996; Rodríguez-Ardila et al. 2004, 2005; Lamperti et al. 2017), but it is still not clear which is the main excitation mechanism – if there is a dominant – of the \( H_2 \) molecule. In summary, three main processes can produce the \( H_2 \) emission: (i) fluorescent excitation by the absorption of soft-UV photons \((912–1108 \AA)\) in the Lyman and Werner bands (Black & van Dishoeck 1987), (ii) excitation by shocks (Hollenbach & McKee 1989) and (iii) excitation by X-ray illumination (Maloney et al. 1996). The first process is usually referred as non-thermal, while the latter two are commonly reported as thermal processes, where the \( H_2 \) emitting gas is in local thermodynamic equilibrium (LTE). In some cases, thermal and non-thermal processes are observed simultaneously with the \( H_2 1–0 \) transitions in LTE, while the higher energy ones...
(H2 2–1 and H2 3–2) being due to fluorescent excitation of the dense gas (Davies et al. 2003, 2005).

In thermal processes, the rotational and vibrational temperatures are similar, as the gas is in LTE, while for fluorescent excitation the vibrational temperature is high (T_vib ~5000 K) and the rotational temperature is about a tenth of T_vib, as the highest energy levels are overpopulated due to non-local UV photons compared to the prediction for a Maxwell-Boltzmann population (Sterberg & Dalgarno 1989; Rodríguez-Ardila et al. 2004). As shown in Table 4, for all galaxies, but NGC788, the median values of the rotational temperature are larger than 10 per cent of the vibrational temperatures. On average, we find $T_{\text{rot}}/T_{\text{vib}} = 0.48 \pm 0.31$. This value is consistent with measurements based on single aperture spectra of AGN (e.g. Rodríguez-Ardila et al. 2005; Riffel et al. 2013a).

The H2/Brγ line ratio is useful in the investigation of the origin of the H2 emission. In star-forming regions and starburst galaxies, this ratio is usually smaller than 0.4, while AGN present 0.4 < H2/Brγ < 6.0 and larger values are usually associated to shocks (Riffel et al. 2013a). We find the median values of H2/Brγ in our sample are within the range observed in AGN, but there is a trend of higher ratios being observed at larger distances from the nucleus for most galaxies, as seen in Tab. 3 and Figs. 2, 3, A1 and A2. Since the H2 line intensity generally decreases with distance from the nucleus, an explanation for the higher values of the H2/Brγ away from the nucleus is that the Brγ decreases faster with radius, i.e. it is enhanced very close around the AGN (excited primarily by the AGN) while the H2 is excited by processes that operate on more extended spatial scales such as shocks.

In order to further investigate the H2 emission origin, we construct the H2 2–1 S(1)/1–0 S(1) vs. 1–0 S(2)/1–0 S(0) diagnostic diagrams shown in Figure 8. The density plots show the observed line ratios for all spaxels where we were able to detect all H2 emission lines. We separate the data into four diagrams, according to the H2/Brγ presented in the excitation maps (see Figs. 2, 3, A1, A2): H2 > 6.0 – indicative of shocks (top left panel), 2.0 < H2/Brγ < 6.0 – high excitation AGN (top right panel), 0.4 < H2/Brγ < 2.0 – low excitation AGN (bottom left panel) and H2/Brγ < 0.4 – typical value of starbursts (bottom right panel). The number of points in each plot is shown in the top-left corner of the corresponding panel.

The observed H2 2–1 S(1)/1–0 S(1) and 1–0 S(2)/1–0 S(0) line ratio distributions for H2/Brγ > 0.4 lie close to the region predicted by photoionisation (pink polygons) and shock models (gray symbols) suggesting thermal processes dominate the H2 excitation. This result is in good agreement with previous works using single aperture measurements of the H2 line fluxes (e.g. Rodríguez-Ardila et al. 2004, 2005; Riffel et al. 2013a). Here, we show not only the nuclear emission originates from thermal processes but that also the emission from locations furthest from the nucleus, as the vast majority (96 per cent) of the spaxels in our sample present H2/Brγ >0.4.

Although the peak of the distributions of H2 2–1 S(1)/1–0 S(1) and 1–0 S(2)/1–0 S(0) is observed nearly at the same location for both spaxels with 0.4 < H2/Brγ < 2.0, 2.0 < H2/Brγ < 6.0 and H2/Brγ > 6.0, the distributions are distinct. For the 0.4 < H2/Brγ < 2.0 (low excitation AGN) and 2.0 < H2/Brγ < 6.0 (high excitation AGN) the luminosity distribution of the H2 2.1218 µm is very similar and both H2 2–1 S(1)/1–0 S(1) and 1–0 S(2)/1–0 S(0) spread over a larger region in the diagnostic diagram. The peak in the diagnostic diagrams lie close to both the photoionisation model (pink polygons) and to the UV thermal models (filled blue squares) indicating that heating due to the AGN may be the cause of the gas excitation. Also, the fact that the points on the diagram are not distributed along the isothermal line indicates that the gas is not in LTE. For the typical AGN line ratio, 0.4 < H2/Brγ < 6.0, the H2 emission can either be produced by shocks (gray symbols) or by the AGN radiation field.

The H2/Brγ > 6.0 shows a more concentrated distribution in the diagnostic diagram and is particularly elongated towards higher values of 1–0 S(2)/1–0 S(0). The H2 2.1218 µm distribution is concentrated towards higher values, indicating the higher ratios is due to the higher H2 luminosity. This line ratio is more sensitive to shocks, as seen from the wider range of values predicted by distinct shock models for this ratio than for the 2–1 S(1)/1–0 S(1) (Kwan et al. 1977; Smith 1995). Thus, the H2 emission from locations with H2/Brγ > 6.0 likely originates from heating of the gas by shocks, as those produced by AGN winds (e.g. Riffel 2020a).

For H2/Brγ < 0.4, typical of star-forming regions, the median values of 2–1 S(1)/1–0 S(1) and 1–0 S(2)/1–0 S(0) – 0.39 and 1.09, respectively – are close to the predicted values by the models of Black & van Dishoeck (1987) (orange polygon) for fluorescent excitation. The peak of the observed distribution of ratios is shifted to slightly lower values of 2–1 S(1)/1–0 S(1) than predicted by the models, but a large scatter is seen in both axes. This shift can be understood as a contamination of thermal excitation plus the dissociation of part of the H2 molecules by the AGN radiation field, as seen in some objects (Storchi-Bergmann et al. 2009; Riffel et al. 2010a; Guilka et al. 2020).

### 4.3 Mass reservoir in the central region and AGN feeding

The galaxies of our sample present masses of hot molecular gas ranging from a few tens of solar masses to $10^4$ M☉ and of ionised gas in the range $10^5$–$10^7$ M☉ within the inner 125 pc radius (Tab. 4). We can compare these masses with the mass accretion rate ($\dot{m}$) necessary to power the AGN, which is given by:

$$\dot{m} = \frac{L_{\text{bol}}}{c^2 \eta},$$

where $c$ is the light speed, $\eta$ is the efficiency of conversion of the rest mass energy of the accreted material into radiation assumed to be 0.1 (Frank et al. 2002) and $L_{\text{bol}}$ is the AGN bolometric luminosity, which can be estimated from the hard X-ray (14-195 keV) luminosities ($L_X$) listed in Tab. 1, by Ichihara et al. (2017):

$$\log L_{\text{bol}} = 0.0378 (\log L_X)^2 - 2.03 \log L_X + 61.6.$$
the inner 125 pc. We find the mass of ionised gas alone can feed the central AGN for $10^3$–$10^6$ yr at the current accretion rates. The mass of hot molecular gas is on average 3 orders of magnitude smaller than that of ionised gas. We emphasize that the feeding times estimated above should be treated as an upper limit, as they are based on the total line fluxes and we do not separate the components associated to non-circular motions (e.g. due to inflows and outflows).

The hot molecular and ionised gas masses represent only the "tip of the iceberg" of the total gas mass in the center of galaxies. Dempsey & Zakamska (2018) find the mass of the NLR, measured from emission-line fluxes of the ionised gas, is underestimated because the gas behind the ionisation front is invisible in ionised transitions. This gas may be in the molecular phase, dominated by cold molecular gas, and we now know that the mass of cold molecular gas correlates with the H$_2$ 2.1218 $\mu$m luminosity – and thus with the hot H$_2$ mass (Dale et al. 2005; Müller Sánchez et al. 2006; Mazzalay et al. 2013). These studies found that the amount of cold molecular gas is $10^5$–$10^8$ times that of hot H$_2$. Thus, the cold molecular gas could provide fuel necessary to power the AGN for an activity cycle of $10^5$ to $10^6$ yr (e.g. Novak et al. 2011) and still remain available to form new stars in the nuclear region.

5 CONCLUSIONS

We have used Gemini NIFS K-band observations to map the H$_2$ and Br$\gamma$ emission distribution within the inner 0.04–2 kpc of a sample of 36 active galaxies with $z \lesssim 0.056$ and hard X-ray luminosities in the range 41 $\lesssim \log L_{2-10 keV}$ (erg s$^{-1}$) $\lesssim 45$. The spatial resolutions at the galaxies range from 6 to 250 pc and the field of view covers from the inner $75\times 75$ pc$^2$ to $3.6\times 3.6$ kpc$^2$. The main conclusions of this work are:

- Extended H$_2$ 2.1218 $\mu$m and Br$\gamma$ emission is observed in 34/36 galaxies of our sample. There is no statistically significant difference between the orientation of the H$_2$ and Br$\gamma$ flux distributions relative to the orientation of the major axis of the host galaxy ($\Delta$PA). We find $\Delta$PA larger than 30$^\circ$ in 15 galaxies (42%) for the Br$\gamma$ and in 16 galaxies (44%) for H$_2$.
- The H$_2$ emission is usually more spread over the field of view, while the Br$\gamma$ shows a more collimated flux distribution in most cases and a steeper flux gradient, decreasing with the distance from the nucleus. We find offsets larger than 30$^\circ$ between the orientations of the H$_2$ 2.1218$\mu$m and Br$\gamma$ flux distributions in 45% of our sample. On average, the radius that contains 50 per cent of the total H$_2$ emission is $\sim 60$ per cent larger than that for Br$\gamma$.
- We derive the H$_2$ rotational and vibrational temperatures based on the observed H$_2$ 2–1 S(1)/1–0 S(1) vs. 1–0 S(2)/1–0 S(0) diagram in regions with H$_2$/Br$\gamma$ > 0.4 (96% of all spaxels with flux measurements) are consistent with predictions of photoionisation and shock models, confirming that the main excitation mechanism of the H$_2$ molecule are thermal processes, not only at the nucleus but also in the extranuclear regions.
- The Br$\gamma$ excitation usually increases outwards with H$_2$/Br$\gamma$ values increasing from < 2 in the nucleus to values up to 6 outwards.
- In locations with H$_2$/Br$\gamma$ > 6.0, the most likely H$_2$ excitation mechanism are shocks, as indicated by the H$_2$ 2–1 S(1)/1–0 S(1) and 1–0 S(2)/1–0 S(0) line ratios. This is observed mostly in locations away from the nucleus, for $\sim 40$ per cent of the galaxies.
- Most of the regions with H$_2$/Br$\gamma$ < 0.4 (4% of the spaxels with flux measurements) are consistent with fluorescent excitation of the H$_2$ but dissociation of the H$_2$ molecule by the AGN radiation cannot be ruled out in galaxies with small H$_2$/Br$\gamma$ nuclear values. This is observed in $\sim 25$ per cent of the sample.
- The mass of hot molecular and ionised gas in the inner 125 pc radius are in the ranges $10^4$ – $10^6$ M$_\odot$ and $10^4$ – $10^6$ M$_\odot$, respectively. The masses computed for the whole NIFS field of view are about one order of magnitude larger.
- The mass of ionised gas within the inner 125 pc radius alone is more than enough to power the AGN in our sample for a duty cycle of $10^6$ yr at their current accretion rates.

ACKNOWLEDGEMENTS

RAR acknowledges financial support from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPQ – 202582/2018-3, 304927/2017-1, 400352/2016-8 and 312036/2019-1) and Fundação de Amparo à pesquisa do Estado do Rio Grande do Sul (FAPERGS – 17/2551-0001144-
REFERENCES

Antonucci, R., 1993, ARA&A, 31, 473
Audibert A., Riffel R., Sales D. A., Pastoriza M. G., Ruschel-Dutra D., 2017, MNRAS, 464, 2129
Barbosa F. K. B., Storchi-Bergmann T., McGregor P., Vale T. B., Rogemar Riffel A., 2014, MNRAS, 445, 2353
Baron D., Netzer H., 2019, MNRAS, 486, 4290
Black J. H., van Dishoeck E. F., 1987, ApJ, 322, 412
Blum C., et al., 2019, MNRAS, 486, 691
Boroson T. E., Green R. F., 1992, ApJ, 386, 50
Brunner R. J., et al., 2011, ApJ, 725, L10
Burtscher L., et al., 2015, A&A, 578, A47
Cuglar T., et al., 2020, A&A, 634, A154
Dahmer-Hahn L. G., et al., 2019a, MNRAS, 482, 5211
Dahmer-Hahn L. G., et al., 2019b, MNRAS, 489, 5653
Dale D. A., Sheth K., Helou G., Regan M. W., Hüttemeister S., 2005, AJ, 129, 2197
Davies R. I., Sternberg A., Lehner M., Tacconi-Garman L. E., 2003, ApJ, 597, 907
Davies R. I., Sternberg A., Lehner M. D., Tacconi-Garman L. E., 2005, ApJ, 633, 105
Davies R. I., Maciejewski W., Hicks E. K., Sales D. A., Genzel R., Engel H., 2009, ApJ, 702, 114
Davies R. I., et al., 2014, ApJ, 792, 101
Davies R. I., et al., 2015, ApJ, 806, 127
Davies R. I., et al., 2020, MNRAS, 496, 836
Dempsey R., Zakamska N. L., 2018, MNRAS, 477, 4615
Diniz M. R., Riffel R. A., Storchi-Bergmann T., Winge C., 2015, MNRAS, 453, 1727
Diniz M. R., Riffel R. A., Dors O. L., 2018, Research Notes of the American Astronomical Society, 2, 3
Dorn O. L. J., Storchi-Bergmann T., Riffel R. A., Schimdt A. A., 2008, A&A, 482, 59
Dors O. L. J., Riffel R. A., Cardaci M. V., Hägele G. F., Krabbe A. C., Pérez-Montero E., Rodrigues I., 2012, MNRAS, 422, 252
Dors O. L., Cardaci M. V., Hägele G. F., Krabbe A. C., Pérez-Montero E., Arma M., 2020, MNRAS, 496, 836
Dreher D. A., Storchi-Bergmann T., Ferrari F., Cappellari M., Riffel R. A., 2015, MNRAS, 450, 128
Dumont A., Seth A. C., Strader J., Greene J. E., Burtscher L., Neumayer N., 2020, ApJ, 888, 19
Durré M., Mould J., 2014, ApJ, 784, 79
Elitzur M., 2012, ApJ, 747, L33
Elitzur M., Ho L. C., Trump J. R., 2014, MNRAS, 438, 3340
Fazzel N., Eckart A., Busch G., Yütenem G., Combes F., Misspina P., Straubmeier C., 2020, A&A, 638, A36
Fischer T. C., et al., 2017, ApJ, 834, 30
Frank J., King A., Raine D. J., 2002, Accretion Power in Astrophysics: Third Edition
Freitas I. C., et al., 2018, MNRAS, 476, 2760
Genzel R., et al., 2010, MNRAS, 407, 2091
Gnäk C. L., et al., 2020, ApJ, 893, 30
Gonzalez Delgado R. M., Perez E., 1997, MNRAS, 284, 931
Harrison C. M., 2017, Nature Astronomy, 1, 0165
Harrison C. M., Costa T., Tadhunter C. N., Flütsch A., Kakad D., Perna M., Vieiti G., 2018, Nature Astronomy, 2, 198
Heckman T. M., 1980, A&A, 500, 187
Heckman T. M., Best P. N., 2014, ARA&A, 52, 589
Hicks E. K. S., Davies R. I., Filippenko A. V., Genzel R., Tacconi L. J., Müller Sánchez F., Sternberg A. , 2009, ApJ, 696, 488
Ho L. C., Filippenko A. V., Sargent W. L. W., Peng C. Y., 1997, ApJS, 112, 391
Hollenbach D., McKee C. F., 1989, ApJ, 342, 306
Hopkins P. F., Quataert E., 2010, MNRAS, 407, 1529
Husemann B., et al., 2019, A&A, 627, A53
Ichikawa K., Ricci C., Ueda Y., Matsuoka K., Toba Y., Kawamuro T., Trakshenbrot B., Kos M. J., 2017, ApJ, 835, 74
Ilha G. d. S., Bianchi M., Riffel R. A., 2016, Ap&SS, 361, 178
Jan Y., et al., 2016, MNRAS, 463, 913
Kaidad D., et al., 2018, A&A, 618, A6
Keel W. C., 1990, AJ, 100, 356
Kormendy J., Ho L. C., 2013, ARA&A, 51, 511
Kwan J. H., Gatley I., Merrill K. M., Probst R., Weintraub D. A., 1998, ApJ, 500, 187
Lamperti I., et al., 2017, MNRAS, 467, 540
Lee M.-Y., et al., 2018, MNRAS, 473, 4582
Liu G., Zakamska N. L., Greene J. E., Nesvadba N. P. H., Liu X., 2013, MNRAS, 436, 2576
Lutz D., Sturm E., Genzel R., Spoon H. W. W., Moorwood A. F. M., Netzer H., Sternberg A., 2003, A&A, 409, 867
Maloney P. R., Hollenbach D. J., Tielens A. G. G. M., 1996, ApJ, 466, 561
May D., Steiner J. E., 2017, MNRAS, 469, 994
May D., Steiner J. E., Menezes R. B., Williams D. R. A., Wang J., 2020, MNRAS, 496, 1488
Mazzalay X., et al., 2013, MNRAS, 428, 3839
McGregor P. J., et al., 2003, Gemini near-infrared integral field spectrograph (NIFS). Proceedings of the SPIE, pp 1581–1591, doi:10.1117/12.459448
Mouriri H., 1994, ApJ, 427, 777
Müller Sánchez F., Davies R. I., Eisenharder F., Tacconi L. J., Genzel R., Sternberg A., 2006, A&A, 454, 481
Müller-Sánchez F., Nevin R., Comerford J. M., Davies R. I., Privon G. C., Treister E., 2018a, *Nature*, 556, 345
Müller-Sánchez F., Hicks E. K. S., Malkan M., Davies R., Yu P. C., Shaver S., Davis B., 2018b, *ApJ*, 858, 48
Novak G. S., Ostriker J. P., Ciotti L., 2011, *ApJ*, 737, 26
Oh K., et al., 2018, *ApJS*, 235, 4
Osterbrock D. E., Ferland G. J., 2006, *Astrophysics of gaseous nebulae and active galactic nuclei*. University Science Books
Pasquali A., Gallagher J. S., de Grijs R., 2004, *A&A*, 415, 103
Paturel G., Petit C., Prugniel P., Theureau G., Rousseau J., Brouty M., Dubois P., Cambrésy L., 2003, *A&A*, 412, 45
Prieto M. A., Mezcua M., Fernández-Ontiveros J. A., Schartmann M., 2014, *MNRAS*, 442, 2145
Puxley P. J., Hawarden T. G., Mountain C. M., 1990, *ApJ*, 364, 77
Ramos Almeida C., et al., 2011, *ApJ*, 731, 92
Reunanen J., Kotilainen J. K., Prieto M. A., 2002, *MNRAS*, 331, 154
Ricci T. V., Steiner J. E., Menezes R. B., 2014, *MNRAS*, 440, 2419
Riffel R. A., 2020a, *MNRAS*, 494, 2004
Riffel R. A., 2020b, *MNRAS*, 494, 2004
Riffel R., Rodríguez-Ardila A., Pastoriza M. G., 2006, *A&A*, 457, 61
Riffel R. A., Storchi-Bergmann T., Winge C., McGregor P. J., Beck T., Schmitt H., 2008, *MNRAS*, 385, 1129
Riffel R. A., Storchi-Bergmann T., Dors O. L., Winge C., 2009a, *MNRAS*, 393, 783
Riffel R., Pastoriza M. G., Rodríguez-Ardila A., Bonatto C., 2009b, *MNRAS*, 400, 273
Riffel R. A., Storchi-Bergmann T., McGregor P. J., 2009c, *ApJ*, 698, 1767
Riffel R. A., Storchi-Bergmann T., Nagar N. M., 2010a, *MNRAS*, 404, 166
Riffel R. A., Storchi-Bergmann T., Riffel R., Pastoriza M. G., 2010b, *ApJ*, 713, 469
Riffel R., Rodríguez-Ardila A., Aleman I., Brotherton M. S., Pastoriza M. G., Bonatto C., Dors O. L., 2015a, *MNRAS*, 430, 2002
Riffel R. A., Storchi-Bergmann T., Winge C., 2013b, *MNRAS*, 430, 2249
Riffel R. A., Vale T. B., Storchi-Bergmann T., McGregor P. J., 2014, *MNRAS*, 442, 656
Riffel R. A., Storchi-Bergmann T., Riffel R., Dahmer-Hahn L. G., Diniz M. R., Schönell A. J., Dametto N. Z., 2017, *MNRAS*, 470, 992
Riffel R. A., et al., 2018, *MNRAS*, 474, 1374
Riffel R. A., Storchi-Bergmann T., Zakamska N. L., Riffel R., 2020, *MNRAS*, 496, 4857
Riffel R. A., Bianchin M., Riffel R., Storchi-Bergmann T., Schönell A. J., Dahmer-Hahn L. G., Dametto N. Z., Diniz M. R., 2021, *MNRAS*, 414, 1041
Rosario D. J., Togi A., Burtscher L., Davies R. I., Shimizu T. T., Lutz D., 2019, *ApJ*, 875, L8
Ruschel-Dutra D., 2020, danielrd6/ifscube v1.0, doi:10.5281/zenodo.3945237, https://doi.org/10.5281/zenodo.3945237
Sargent M. T., et al., 2014, *ApJ*, 793, 19
Scharwächter J., McGregor P. J., Dopita M. A., Beck T. L., 2013, *MNRAS*, 429, 2315
Schinnerer E., Eckart A., Tacconi L. J., 2000, *ApJ*, 533, 826
Schönell A. J., Riffel R. A., Storchi-Bergmann T., Winge C., 2014, *MNRAS*, 445, 414
Schönell Astor J. J., Storchi-Bergmann T., Riffel R. A., Riffel R., 2017, *MNRAS*, 464, 1771
Schönell A. J., Storchi-Bergmann T., Riffel R. A., Riffel R., Bianchin M., Dahmer-Hahn L. G., Diniz M. R., Dametto N. Z., 2019, *MNRAS*, 485, 2054
Scoville N. Z., Hall D. N. B., Ridgway S. T., Kleinmann S. G., 1982, *ApJ*, 253, 136
Shimizu T. T., et al., 2019, *MNRAS*, 490, 5860
Silverman J. D., et al., 2015, *ApJ*, 812, L23
Smith M. D., 1995, *A&A*, 296, 789
Sternberg A., Dalgaro A., 1989, *ApJ*, 338, 197
Storchi-Bergmann T., Schnorr-Müller A., 2019, *Nature Astronomy*, 3, 48
Storchi-Bergmann T., McGregor P. J., Riffel R. A., Simões Lopes R., Beck T., Dopita M., 2009, *MNRAS*, 394, 1148
Turner J., Kirby-Docken K., Dalgaro A., 1977, *ApJS*, 35, 281
Urry C. M., Padovani P., 1995, *PASP*, 107, 803
Villarroel B., Korn A. J., 2014, *Nature Physics*, 10, 417
Wilgenbus D., Cabriot S., Pineau des Forêts G., Flower D. R., 2000, *A&A*, 356, 1010
de Vaucouleurs G., de Vaucouleurs A., Corwin Herold G. J., Buta R. J., Paturel G., Fouque P., 1991, Third Reference Catalogue of Bright Galaxies

**APPENDIX A: GEMINI NIFS MEASUREMENTS**

This paper has been typeset from a TeX/LaTeX file prepared by the author.
Figure A1. Maps for type 2 AGN. From left to right: K-band continuum obtained within a spectral window of 100Å centred at 2.14 µm, H$_2$ 2.1218 µm flux distribution, Brγ flux distribution, H$_2$/Brγ ratio map, Brγ equivalent width map and excitation map. The color bars show the continuum in units of erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$ spaxel$^{-1}$, the emission-line fluxes in erg s$^{-1}$ cm$^{-2}$ spaxel$^{-1}$ and the Brγ equivalent width in Å. The excitation map identifies the regions with typical H$_2$/Brγ values for star forming galaxies (SF: H$_2$/Brγ < 0.4), AGN with low excitation (AGN$_{LE}$: 0.4 ≤ H$_2$/Brγ < 2) and high excitation (AGN$_{HE}$: 2 ≤ H$_2$/Brγ < 6) and higher line ratios, usually observed in shock dominated objects (Shock: H$_2$/Brγ > 6). In each row, the name of the galaxy is identified in the continuum image, the filled circle corresponds to the angular resolution of the data, the spatial scale is shown in the bottom-left corner of the continuum image and the cross marks the position of the peak of the continuum emission. The dashed line indicates the orientation of the galaxy major axis obtained from the Hyperleda database. The continuous line on the flux maps shows the orientation of the emission-line flux distributions. The continuous line on the excitation map shows the orientation of the Brγ emission. The gray regions indicate locations where the emission lines are not detected within 2σ above the continuum noise.

For all galaxies, north is up and east is to the left.
Figure A1. continued.

Figure A2. Maps for type 1 AGN. Same as Fig. A1, but for type 1 AGN.
Figure A2. continued.
Figure A2. continued.

Figure A3. \( \text{H}_2 \) rotational and vibrational temperatures for type 2 in our sample calculated according to Eqs. 3 and 4. The gray regions indicate locations where at least one of the \( \text{H}_2 \) emission lines is not detected within 2\( \sigma \) above the continuum noise. The colorbar shows the temperatures in logarithmic scale in units of K.
Figure A4. Same as A3, but for type 1 AGN.

Figure A5. H$_2$ vibrational for objects where the H$_2$ 1–0 S(2) line is not detected.