A close look at Seyfert 2 nuclei

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Abstract. We present SINFONI adaptive optics assisted and seeing limited NIR integral field spectroscopy of the central hundreds of pc of ten z < 0.01 Seyfert 2 galaxies. The main goal of this study is to assess the significance of star formation and extinction in the circumnuclear region of Seyfert 2s. The immediate surroundings of the nuclei are resolved at linear scales of about 50-100 parsecs for most of the observed sources. The intensity and line-of-sight velocity distribution of different species is derived from the 3D SINFONI data by calculating the higher order moments of the emission lines. As part of this work in progress, the resulting maps are currently analyzed following the approach of generalized surface photometry, which allows us to identify the multiple kinematical components in the circumnuclear region of Seyfert 2s.

1. Introduction
If most galaxies harbor a central massive black hole, why are the nuclei of some galaxies more active than others? Probably, the main difference is in the available amount of fuel and the efficiency of feeding of the central engine (cf. [1], [2]). Bars or disturbed morphologies are supposed to be efficiently fuelling the nuclear region with gas from the outskirts of the galaxy. L. K. Hunt and M. A. Malkan [3] investigate the detailed circumnuclear morphologies of Seyfert 1, Seyfert 2, LINER, and starburst galaxies using HST/NICMOS. They report that H II/starburst galaxies show the strongest deviations from smooth elliptical isophotes, while the normal galaxies and LINERs have the least disturbed morphology. The Seyfert 2s have significantly more twisted isophotes than any other category, and the early-type Seyfert 2s are significantly more disturbed than the early-type Seyfert 1s, which cannot be explained by pure orientation effects. However, even the near-infrared (NIR) can be affected by dust extinction, which has to be taken into account (e.g. [4]).

On 0.1–1 kpc scales circumnuclear star formation is an important process in all types of AGN. In particular, empirical population synthesis of Seyfert 2 nuclei ([5], [6]) reveals evidence for recent (< 1 Gyr) star formation within a few hundred parsecs of the nuclei in about 40% of Seyfert 2s. Star formation models have begun to consider star formation within the torus ([7], [8]) which is proposed by the unification scheme, and it has shown that the contribution of dust is a key component in the nuclear region of such active galaxies.

It has been found that Seyfert 2 galaxies exhibit a higher contribution of star formation to the nuclear emission than Seyfert 1 galaxies, challenging the simple unified scheme ([9]). However, when compared to the well-known Kennicutt-Schmidt law, the star formation in the circumnuclear regions of Seyfert galaxies appears to be suppressed, emphasizing the importance.
of AGN feedback ([10]). In this context, the analysis of the velocity distribution in the circumnuclear region is of key interest (c.f. NuGa consortium work). Only a thorough decomposition of the different kinematical components in the vicinity of the AGN can help us in understanding the mechanisms behind the feeding of the central supermassive black hole.

2. The data

2.1. The sample

We obtained SINFONI $H+K$ imaging spectroscopy of the central 400 pc of 10 nearby $V^{\text{mag}} < 14$ Seyfert 2 galaxies - based on the VCV catalog ([11]). Since the analysis of circumnuclear star formation and extinction is our main interest in this study, we selected only sources, where high resolution optical HST images are available. Apart from being optically classified as Seyfert 2 galaxies, no selection on the base of morphology has been imposed. Fig. 1 shows large scale visible HST images of the sample sources.

![Figure 1. HST F606W images of the observed Seyfert 2 galaxies. The size of each image is approximately 3.25' × 2.75'. North is up, East is to the left. Note that the SINFONI field of view only covers the immediate circumnuclear region of 3'' × 3'' (centered on the nucleus).](image)

2.2. Reduction and analysis

If possible, SINFONI was operated in AO mode using the 100mas scale and guiding was always performed on the nucleus itself. Here, the central 700 pc can be resolved up to linear scales of about 50-100 pc. Due to weather constraints, the performance of the AO system was limited to a PSF of approximately 0.4'' (derived from the K-band continuum). For some galaxies, weather prevented the AO to close the loop and it was only possible to operate SINFONI in seeing-limited mode, where we chose the 250mas in order to compensate for the loss in spatial resolution. Telluric standards were observed prior and following the science targets and basic data reduction was applied using the ESO SINFONI pipeline.

Our analysis of one of these galaxies, NGC 7172, has recently been published in [4]. For the first time, we were able to identify broad recombination lines at the center of this extremely
edge on galaxy. Our results suggest that in this case, significant galactic extinction might prohibit a detection of the Seyfert 1 core region at visible wavelengths, making even polarimetric measurements of reflected broad emission difficult.

As shown exemplary in Fig. 2, the core regions of our Seyfert 2 galaxies show a plentitude of emission lines such as recombination and molecular Hydrogen lines and, in certain cases, also the coronal line [SiVI]. In order to handle this analysis in a very systematic approach, we are developing an IDL analysis tool for 3D-data in general that extracts emission line maps together with the line-of-sight (LOS) velocity field and a map of the LOS velocity dispersion (Fig. 2). These information are derived from the 3D data cubes by calculation of the zeroth, first and second order moments of the respective emission line. The calculation of the higher order moments is, in particular for low S/N spectral regions, significantly more robust than an e.g. Gaussian fit to the emission line. However, since the noise in the resulting moment map increases with the order of the moment, we introduced a S/N clipping on the base of the zero order moment, i.e. the line has to be detected with a minimum of 3–5 sigma above the continuum noise. Resulting moment maps are shown in Fig. 3 for two different circumnuclear Seyfert 2 regions. Additional output of our tool yields error propagation for the three moments.

![Figure 2](image_url)

**Figure 2.** Dialog of the 3D-data analysis tool developed to create emission line and maps of the line-of-sight velocity field and the velocity dispersion. These maps are created by calculating higher order moments. As an example, the central spectrum is plotted in the top left window, with continuum regions defined close to the Brγ emission line and the continuum subtracted residuum on bottom left. The 3-sigma continuum noise is indicated in green. Several additional emission lines such as molecular Hydrogen can be seen in the spectrum together with prominent stellar CO absorption features. The different maps display the (currently selected) channel map, the emission line map (0th-order), and the LOS velocity map (1st order, from top to bottom right). On the bottom of the window, various adjustments to the definition of the extraction can be made. The maps can be created interactively or in a scripted way.
Figure 3. K-band continuum, Brγ zero-order (i.e. emission line) and first order (i.e. line-of-sight velocity) maps for two selected sample galaxies. The maps show the central 4 × 4 arcsecs, which represents the central 500 pc. The spatial resolution derived from the K-band continuum is, in both cases, of the order of 0.4 arcsecs (despite AO in use, weather limited its performance). Prominent star formation regions and structures suggesting a mini spiral can be identified.

3. Outlook

We are reporting preliminary results on the NIR study of the central hundreds of parsecs of a sample of Seyfert 2 galaxies. As the morphology of the recombination-line emission already implies (Fig. 3), we are able to spatially resolve different circumnuclear star formation regions. In addition to line ratios in these prominent emission line regions, which are giving us insight into the excitation mechanisms and the possible influence of the AGN (e.g. [12], [13]), the kinematic information contained in the higher order maps of the LOS velocity distribution are currently under investigation.

Similar to what is described in [14], the analysis of the different moment maps following the approach of a generalized surface photometry allows us to detect multiple co- and counter rotating components. In contrast to the recombination lines, the extended molecular hydrogen emission can in most cases be described by a single disc component. In a next step, these results have to be compared to extinction maps derived from a multi-component continuum decomposition together with the high resolution visible data, because especially when dealing with Seyfert 2 nuclear regions, extinction can play an important role. In addition, the different regions will be modeled using starburst models such that eventually, a thorough model of the circumnuclear environment of each of the Seyfert 2 nuclei will be obtained.

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