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KINEMATICS IN SEYFERT AND NON-ACTIVE GALAXIES

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Abstract. We investigate the kinematic properties of the stars and ionised gas in the circumnuclear regions of a matched sample of Seyfert and non-active galaxies, using the SAURON Integral-Field Unit (IFU) on the William Herschel Telescope (WHT). The stellar velocity fields present regular rotation patterns. After removal of the non-gravitational components due to e.g. AGN-driven outflows, the ionised gas kinematics are dominated by rotation. The non-active galaxies present global alignment between stellar and gaseous components while a majority of the Seyfert galaxies present strong kinematic misalignments. A more refined analysis of our two-dimensional kinematic maps reveal evidence for deviations from axial-symmetry in the gaseous velocity fields, these deviations being stronger in the case of Seyfert galaxies than the associated non-active galaxies. This suggests the presence of weak dynamical perturbations in the circumnuclear regions of Seyfert galaxies and provides a tentative link between host galaxy dynamics in these regions and the nuclear activity.

1 Introduction

Most of bulge-dominated galaxies host a supermassive black hole and yet ongoing nuclear activity is observed in only ∼5% of nearby galaxies. Re-ignition of dormant black holes via accretion of material in the central parts of these galaxies is therefore required and a key unanswered question is whether the ignition mechanism is related to the galaxy host properties, in particular the fuel transportation mechanisms. Numerical simulations predict efficient gas radial inflows in non-axisymmetric gravitational potential related to galaxy interaction or to the presence of large scale stellar bars. In particular, high-distant quasars are found preferentially in galaxies in interaction. However, most of all optical/IR imaging studies failed to find any differences between low-luminosity AGN hosts (such as Seyfert galaxies) and inactive galaxy morphology, on a range of spatial scales that encompass galactic interaction, stellar bars and nuclear bars and spirals. In contrast, recent results e.g. from Hunt & Malkan (2004) and Simões Lopes et al. (2007), could suggest the presence of identifiable dynamical differences between Seyfert and inactive galaxies in the central kpc region.

Probing the dynamics of Seyfert galaxies requires spectroscopic data. Single aperture and long-slit spectroscopy are clearly inadequate to investigate the complex structures observed in the central kpc of Seyfert galaxies. Integral-field spectroscopy (IFS) allows to obtain two-dimensional kinematic maps of both the stars and the ionised gas in the circumnuclear regions of nearby galaxies. Moreover, in order to constrain the fuelling mechanisms in Seyfert galaxies from the outskirts of the galaxies down to the circumnuclear regions, data on larger scales are required in addition to IFS data in the circumnuclear regions. Neutral hydrogen (HI) is often the most spatially extended component of the galactic disk. It is then very sensitive to galaxy interactions and mergers and is also a potential tracer of non-axisymmetric gravitational potential (e.g. bar, spiral arms). Therefore, HI synthesis imaging provides unique information on the global mass distribution and dynamics of the galactic disk at large radii and a long-term dynamical history of the galaxy via kinematic features, on spatial scales larger than ∼15". Then optical IFS and HI observations are complementary and allow to map the kinematics and morphology of the large scale gaseous disk properties as well as the circumnuclear regions.

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A project was therefore designed to conduct a comprehensive study of the kinematics and morphology of the neutral gas, ionised gas and stars of nearby active and inactive galaxies, using the VLA and the SAURON IFU on the WHT. Consequently, the first statistically-significant investigation of the circumnuclear regions and the outer disk of the host galaxy was initiated. This project aims to compare the morphological and kinematic properties of active and inactive galaxies. A sample of 28 Seyfert galaxies was selected from the RSA catalogue, and each Seyfert galaxy was paired with a control inactive galaxy with carefully matched optical properties, as described in Mundell et al. (2007). We then conducted the first multi-wavelength observation campaign to investigate the host galaxy structure and kinematics on spatial scales from the outer disk to the inner regions ($\sim$ 100 pc) via two observational surveys:

1. The VHIKINGS survey (VLA Hydrogen Imaging and Kinematics of INactive Galaxies and Seyferts survey, PI: Carole Mundell), aiming to quantify the properties of the atomic gas in the Seyfert and inactive galaxies of the master sample.

2. The SAURON/Seyfert survey (PI: Carole Mundell) extends the study of structures and kinematics to the inner 100 pc of a subsample of galaxies selected from the VHIKINGS sample. In particular, the galactic potential of the host galaxies are probed by comparing the properties of both the ionised gas and stellar components in the circumnuclear regions of Seyfert and inactive galaxies, with the ultimate aim of connecting the large scales properties traced by the neutral hydrogen with the circumnuclear regions.

In the following, the first results from the SAURON/Seyfert survey are presented. Sect. 2 presents the survey and the stellar and gaseous maps obtained. Then a first kinematic analysis of the stellar and gaseous velocity fields is discussed in Sect. 3. Finally, Sect. 4 presents our conclusions and the perspectives of this study.

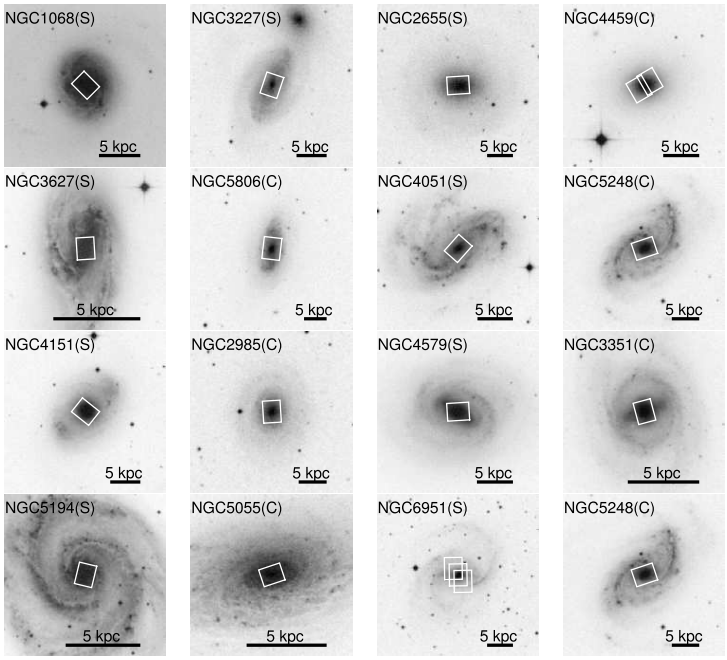

Fig. 1. R-band Digital Sky Survey images of the SAURON/Seyfert sample galaxies. The '(S)' or '(C)' on the right of the object names stand for Seyfert or Control galaxy, respectively. Each Seyfert galaxy is displayed on the left of its associated non-active galaxy, except for NGC 1068 and NGC 3227 (first two panels) for which no control galaxy has been observed. The orientation is such that North is up and East is left. The bar located at the bottom right corner of each panel corresponds to 5 kpc. Overplotted on each image is the position of the SAURON field-of-view for that galaxy.

2 SAURON/Seyfert survey

2.1 The sample

A restricted subsample of active and inactive galaxies (15 pairs of Seyfert and inactive galaxies with $V_{sys} < 1600$ km s^{-1}) has been selected from the master sample, to be observed with the SAURON IFU on the WHT. The limit of the systemic velocity of the targets is required in order to retrieve reliable stellar kinematics. The available field of view ensures that we observe ionised gas and the stellar component under the influence of the galactic potential, the spatial sampling allowing us to probe the AGN-related emission in the inner parts, from the central few kpc down to the inner 1" $\sim$ 50 pc (at 10 Mpc). 15 galaxies of the SAURON/Seyfert sample has been already observed: 7 pairs of Seyfert and inactive galaxies and two well known Seyfert galaxies (NGC 1068 and 3227) with no control galaxy data. NGC 1068 has been included for completeness, while weather constraints prevented the observations of the control galaxy for NGC 3227. Fig. 1 presents the DSS images of the observed galaxies.

All the maps and results of this study discussed briefly here, can be found in Dumas et al. (2007).

2.2 The maps

The four left columns of Fig. 2 presents the stellar and gaseous intensity maps for a few galaxies of the SAURON/Seyfert sample. These maps reveal various and complex structures such as stellar circumnuclear rings (e.g. NGC 3351) or gaseous nuclear spiral (e.g. NGC 4579).

Examples of stellar and gaseous velocity fields obtained from our data are shown in Fig. 2, four right columns. The stellar velocity fields present regular rotation patterns for both inactive and Seyfert galaxies, in broad agreement with previous studies (Barbosa et al., 2006). Gaseous kinematics are also dominated by global rotation motions for Seyfert and non-active galaxies. However kinematic perturbations, such as twists of the zero-velocity lines (e.g. NGC 1068, NGC 4579) or misalignments between the stellar and gaseous kinematic major axis (e.g. NGC 2655, NGC 4579) are observed in gaseous velocity fields . Such perturbations may hint for the presence of streaming or radial flows, which could be related to the fuelling mechanisms. In order to investigate these perturbations, the stellar and gaseous kinematics of the Seyfert and inactive galaxies of our sample have been quantitatively analysed.

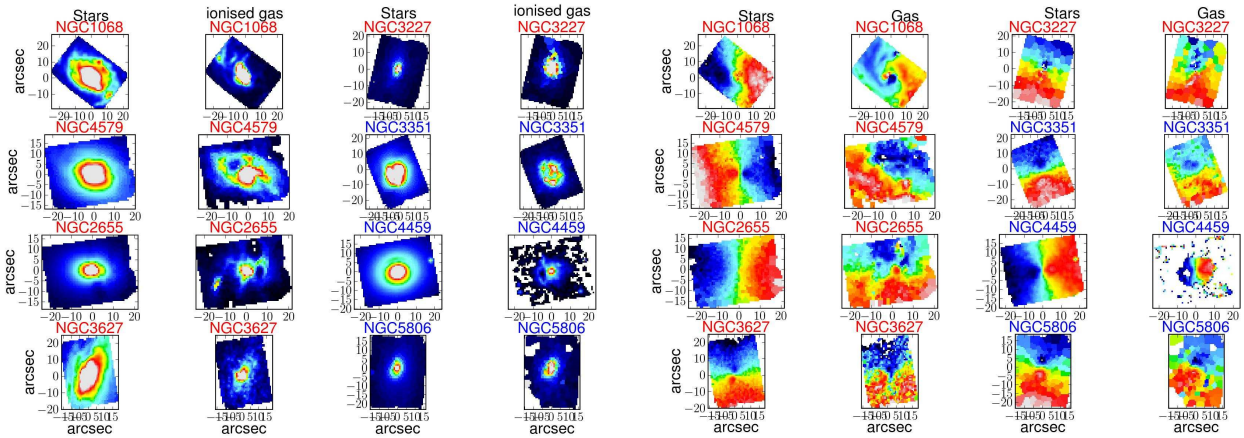

Fig. 2. Reconstructed stellar continuum and ionised gas intensity maps (four left panels) and stellar and gaseous velocity fields (four right panels) for 3 pairs of galaxies and two Seyfert galaxies NGC 1068 and 3227. Each Seyfert galaxy is displayed on the left of its associated non-active galaxy, except for the first row showing NGC 1068 and NGC 3227. For each galaxy, the stellar continuum (respectively velocity field) and ionised gas intensity (respectively velocity field) are presented in the first and second panel, respectively.

3 Kinematic Analysis

3.1 Kinematic misalignments

First, misalignments between the kinematic major-axis of the stellar and ionised gas may reveal the presence of non-axisymmetric structures. Therefore the global position angle (PA) of the kinematic major-axis were determined for both the stellar and ionised gas velocity fields, using the method developed by Krajnović et al (2006). The differences between the stellar and gaseous kinematic PAs, corresponding to the kinematic misalignments, are shown in fig. 4. The ionised gas is generally co-rotating with respect to the stars: the global stellar and gaseous kinematic PAs is aligned for all the non-active galaxies within 20 °. In comparison, about half of the Seyfert galaxies (5/7, without counting NGC 1068 and 3227 which do not have associated non-active galaxies) present kinematic misalignments larger than 25 ° (Dumas et al. (2007)).

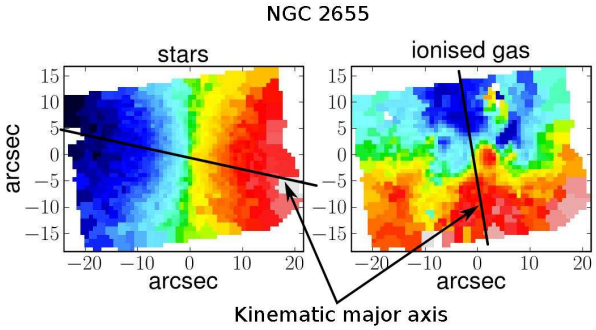

Fig. 3. Stellar (left panel) and gaseous (right panel) velocity fields of the Seyfert 2 galaxy NGC 2655. The lines displayed on the velocity fields correspond to the stellar and gaseous kinematic major axis, derived from the symmetrization method of Krajnović et al (2006).

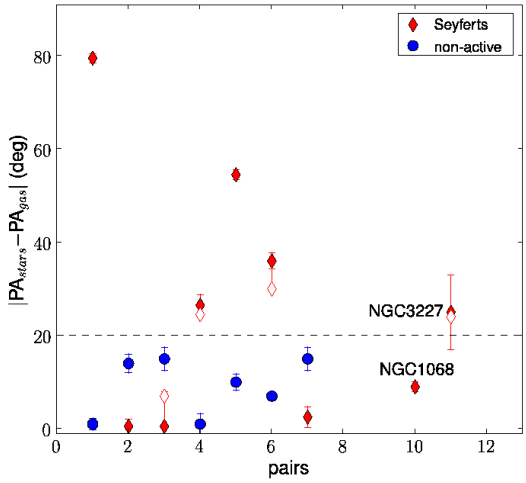

Fig. 4. Kinematic misalignments between stars and ionised gas. The distribution of differences of global kinematic PAs of stars and gas PA_{stars}-PA_{gas} for Seyfert (red diamonds) and non-active (blue circles) is shown. The non-filled diamonds correspond to the PA derived by masking the BLR of the Seyfert 1 galaxies (NGC 3227, 4051 and 4151) and the outflow bubble of NGC 5194. The dashed black horizontal line corresponds to a kinematic misalignment of 20 °

3.2 Radial variations of the kinematic parameters

In addition to kinematic misalignments between the stellar and gaseous components, our kinematic maps reveal some disturbances in the gaseous velocity fields, which may be evidence for deviations from axisymmetry, independent from non-gravitational motions induced by the AGN. These perturbations in the kinematics of the ionised gas may hint for the presence of streaming or radial flows, which could be related to fuelling mechanisms. We developed a dedicated kinematic tool, using a tilted-ring algorithm, to analyse the radial variations of the kinematic PAs of the gaseous and stellar velocity fields. We start from circular rotation motions in a two-dimensional thin disk and fit the circular velocity and the PA as a function of the radius. Fig. 5 presents the amplitude of the radial variations of the kinematic PA of the stellar and gaseous components for both the Seyfert and their associated non-active galaxies. The radial variations of the stellar and gaseous PAs in the central kpc of the Seyfert galaxies are 2.5 times greater than those of the inactive galaxies (Dumas et al. (2007)). We conclude that the increased incidence of disturbed ionised gas in the circumnuclear regions of the Seyfert galaxies (100 to 10 pc) supports a close link between nuclear hosts dynamics and relevant dynamical and activity timescales.

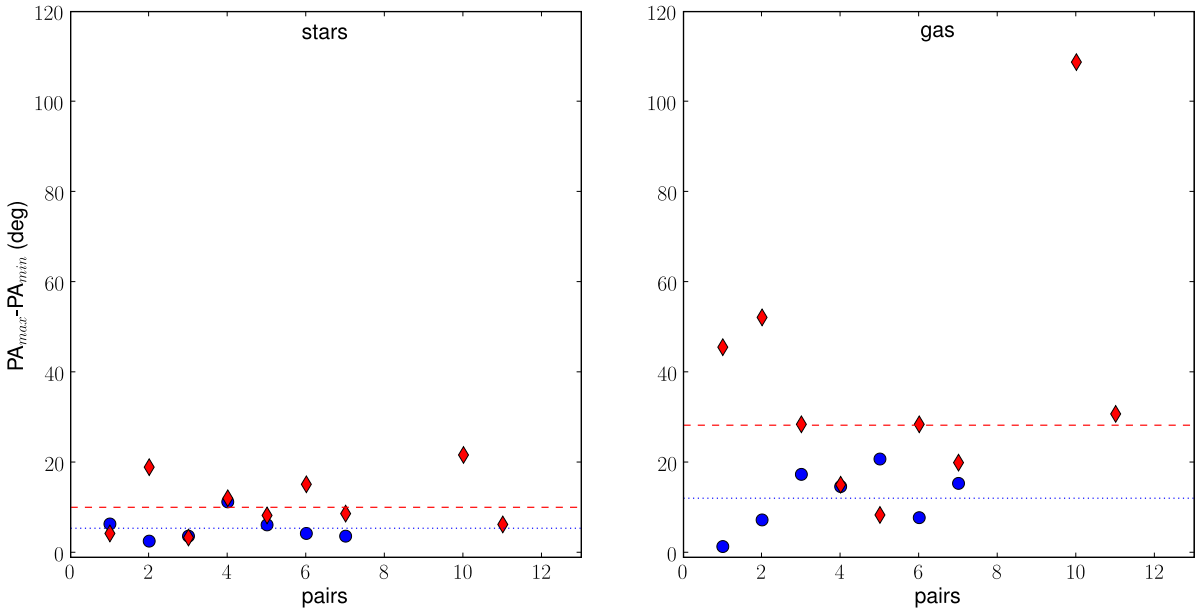

Fig. 5. Distribution of the amplitudes of the radial variations of the stellar (left panel) and gaseous (right panel) kinematic PAs (PA$_{max}$-PA$_{min}$). Active and non-active galaxies are shown as filled red diamond and filled blue circles, respectively. The blue dotted and red dashed lines correspond to the mean value of PA$_{max}$-PA$_{min}$ for the non-active and Seyfert galaxies, respectively, for the stars (left panel) and the ionised gas (right panel)

4 Conclusions and perspectives

In this study we obtained two-dimensional distribution and kinematic maps in the circumnuclear regions of a well-matched sample of Seyfert and non-active galaxies, using the SAURON spectrograph. The gaseous velocity fields reveal kinematic perturbations, and a first quantitative analysis of these kinematic maps indicate that these perturbations are larger and more frequent in Seyfert galaxies than in their associated non-active galaxies. This result provides evidence of the presence of weak dynamical structures in the circumnuclear regions of the Seyfert galaxies, which could be related to fuelling mechanisms.

In order to further investigate the dynamics of the host galaxy and in particular to identify the dynamic structures in the central kpc and constrain the fuelling mechanisms in Seyfert galaxies, a more refined analysis is required. Harmonic analysis of the velocity fields has been proved to be efficient to investigate the observed non-circular motions and to quantitatively interpret the underlying dynamic structures, as shown in Schoenmakers, Franx, & de Zeeuw (1997) and Wong, Blitz, & Bosma (2004). Such an analysis is underway on our SAURON and HI kinematic data. Connecting the large-scale disk and circumnuclear regions will allow to constrain the galactic dynamics from the outskirt of the galaxy down to about 20 pc, then identify or eliminate potential AGN fuelling mechanisms.

Finally, the physics of the innermost regions must play an important role in the fuelling of the AGN. Investigating the physical condition of the gas would then probe the fuelling mechanisms in the close vicinity of the SMBH. Our neutral and ionised gas data, combined with molecular gas data, from the NUGA survey (García-Burillo et al., 2003), would provide for the first time unique information of various gaseous components at different spatial scales, allowing therefore a quantitative study of the physics of the gas in the galaxy and its link with the AGN fuelling.

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