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Topic: Der Weg zu einem umfassenden Verständnis des interstellaren Mediums in der extremen Umgebung von Aktiven Galaxienkernen

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Abstract

This project aimed to provide a better understanding of the fuelling and feedback of Active Galactic Nucleus (AGN) activity by studying the properties of the ISM in the extreme conditions nearby a super-massive black hole. This included observations of the structure and dynamics of the gas and dust on parsec-scales and on circum-nuclear ($\sim$ 50–100 pc) scales as well as improving our theoretical understanding of the gas transport between these scales, and the relation (if any) between the circum-nuclear star formation history and the current accretion activity of the super-massive black hole.

Note 22 months after taking on the project, the PI has assumed a faculty position at the University of Leiden (The Netherlands). The project has therefore not been fully completed, but is being taken on again, (re-)starting in Nov 2017. With the remaining grant money, (part of) a Ph.D. project is sponsored at Leiden University to complete the project, particularly the stellar population synthesis of LLAMA galaxies in the near-infrared.

Report

1. Motivation

Since the discovery of the apparent co-evolution of galaxy properties with their central super-massive black holes, some of the biggest questions in astrophysics include: what causes AGN activity? How are AGNs fed? And how, if at all, do AGN outflows impact the host galaxy's ability to form stars? (for all references for this section, please see the original proposal)

While AGN activity can be triggered by major mergers, most AGN activity cannot easily be traced to environmental or global galaxy properties. This is perhaps not surprising as it has also become clear in recent years, mostly from hydrodynamical simulations that include radiation pressure feedback, that AGN activity must be intermittent. AGNs switch between highly efficient accretion and effective "off" states within timescales much shorter than the dynamical times that regulate the appearance of most of the global galaxy properties. Within the LLAMA (Local Luminous AGN with Matched Analogs) project we have therefore concentrated on the nuclear regions of AGNs (and matched inactive galaxies) where a direct link between the *currently observed* activity and observable stellar properties and gas and dust structures is expected.

The specific aim of this (ISM-SPP supported) project was (and is) to find a possible link between the nuclear star formation history and the activity of the AGN. In some models, outflows from stars in their AGB phase are expected to contribute significantly to the fuelling of "Seyfert"-type AGN, but the observational evidence regarding the link between starburst age and AGN activity is ambiguous. We therefore wanted to test a particular model, in which this link is realised via the formation of a parsec-scale "accretion disk" which resembles (in size and mass) the compact component in a nearby galaxy found with radio and infrared interferometric observations.

In this little note, I summarise relevant results in this context that were created in the last two years and in which the (DFG-funded) PI was either the lead author or a significant co-author. This includes: a re-assessment of the dust-to-gas ratio in the vicinity of active galactic nuclei (Sec. 2.1), development of an analytical model linking inflow and outflow in nuclear regions (and comparison with observational data, Sec. 2.2), stellar population synthesis modelling of a local sample of AGNs (Sec. 2.3) as well as several side projects connected with this sample (Sec. 2.4).

2. Results

2.1 Nuclear dust structures and the relation between nuclear gas and dust properties

As a follow-up to the previously published SINFONI atlas of nearby AGNs (Burtscher+ 2015), we analysed the relation between neutral gas absorption and dust obscuration in a sample of local AGNs (see Fig. 1), using both the best available X-ray absorption values from the Swift-BAT all-sky survey as well as a literature search for historical values. This revealed that, in several cases, the dust-to-gas ratio in local AGNs *can be* close to the local (Milky Way) value (blue band in Fig. 1). Deviations can be explained as "X-ray eclipses" (variable X-ray absorption) in several cases. Thus, there is not necessarily a need to invoke deviant gas-to-dust ratios in the vicinity of AGNs.

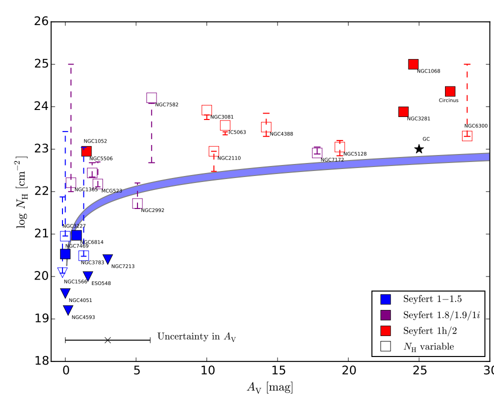

Figure 1: Nuclear gas absorption compared to dust obscuration.

Additionally, a Ph.D. project was supervised to analyse the frequency of non-circular symmetric dust emission on parsec scales in local AGNs. It was found that dust is predominantly found in the polar (outflow) regions of local AGNs in almost all cases where this can be discovered with the existing data (Lopez-Gonzaga, LB et al. 2016). An invited review was written on nuclear, parsec-scale, dust structures, as observed with infrared interferometry (LB et al. 2016). Contributions were made to a new radiative transfer model of parsec-scale dusty warped disks (Jud et al. 2017).

2.2 Revision of the hydrodynamical model linking stellar outflows and nuclear accretion

One of our initial aims was to apply to the Circinus galaxy the hydrodynamical multi-scale model of Schartmann et al. (2010) in which an ageing nuclear star cluster provides low angular momentum fuel from stellar winds to the central accretion flow. That model had proven to be successful in linking the stellar and gas mass properties on ~ 50 pc scales to (sub-)parsec scales, probed by VLBI and infrared interferometry. This model could therefore possibly be seen as a tool to understand gas accretion onto the AGN from circum-nuclear scales. It turned out, however, that a modification of this model to match the properties of the Circinus galaxy on circum-nuclear scales would be unlikely to explain the sub-parsec scale properties of this galaxy.

We therefore instead went on a different path and built a new, fully analytical, model for nuclear gas inflow and outflow. This does not make any assumptions on where the nuclear gas originates (e.g. it could be from stellar winds or secularly accreted gas from the host galaxy), but additionally aims to explain the nuclear gas and dust structure that has become clear in the past years, thanks to e.g. infrared and sub-mm interferometry: a compact disk and an extended outflowing polar component (see Sec. 2.1). The paper describing this model (Vollmer, Schartmann, LB et al.) has been submitted in May 2017 (see Fig. 2) and we are currently working on the referee's report[1].

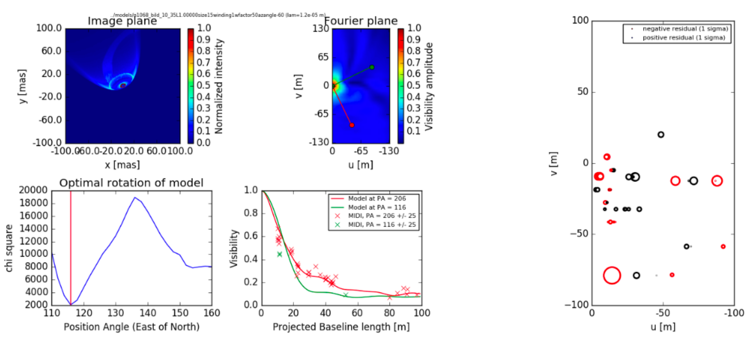

Figure 2: Simple radiative transfer of our new analytical model linking gas in- and outflow and comparison to infrared interferometric data.

Contributions were made to a new hydrodynamical model to explain the life cycle of starbursting circumnuclear gas disks (Schartmann et al. 2017) that is capable of simultaneously explaining the nuclear stellar population as well as the gas distribution.

2.3 The Nuclear Star Formation History of local powerful AGNs and a control sample

Our goal was to derive as robustly as possible the nuclear star formation history of the LLAMA galaxies in order to elucidate observationally the possible link between starburst age and nuclear accretion activity. This part of the project has encountered several challenges, but the first paper is now well underway and with the help of the recently appointed Ph.D. student we hope to complete this part within the next 1-2 years.

[1] The Python module to compare model images with infrared interferometric data, developed for this project, is available at github.com/astroleo/img2vis.

About half of the observations had been taken before the start of the project and the Hydrogen recombination lines of several type 1 AGNs had been analysed in Schnorr-Müller+ 2016. However, the analysis of the much fainter stellar absorption features required a more thorough understanding of the data analysis software (including several bug fixes in the ESO-provided software as well as writing our own calibration tools[2]). We studied the reliability of the commonly used approach of stellar population synthesis, also when compared to using individual lines for age determination (e.g. Hδ-D_{4000} or the Lick indices) as well as the impact of masking emission lines (Fig. 3).

This part of the project is now nearly finished and results will be published next year.

Furthermore we wanted to explore the reliability of the stellar population synthesis across the optical–near-infrared bands. This, again, turned out to be a very challenging project. This is partly because near-infrared spectra taken with X-SHOOTER, and particularly in the pseudo-IFU mode, cannot easily be corrected for atmospheric emission lines. And, on the interpretative side, it turned out that no commonly accepted single stellar population models for the near-infrared exist (such as the widely used, if aged, “BC03” models for the optical). This sub-project is therefore now part of a new Ph.D. student’s work at Leiden University and will be partly funded by this grant.

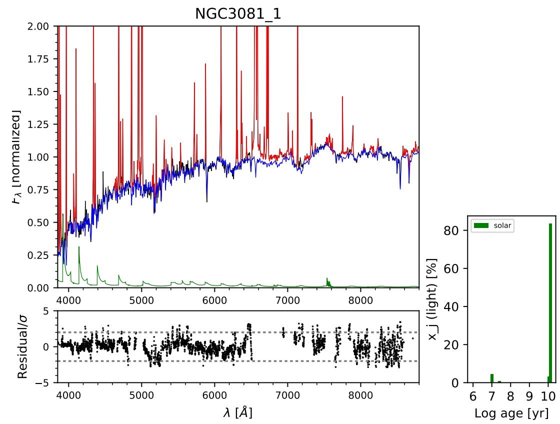

Figure 3: Stellar population synthesis on the active galaxy NGC 3081. We developed an iterative procedure to remove the emission lines (masked, red) while keeping as much information as possible. By applying the same mask to inactive galaxies we verified that the resulting star formation history (lower right panel) does not critically depend on the details of the masking as long as most of the spectrum is unmasked.

2.4 Side projects

Last, but not least, we also studied further properties of the LLAMA sample with a view towards the origin of AGN activity. This included major contributions to a study of the kpc-scale gas properties using APEX (Rosario, LB et al., accepted) and minor contributions to a study of the environmental properties of active and inactive galaxies in the LLAMA sample (Davies et al. 2017).

Furthermore, the possibility of obtaining optical–near-IR imagery using GROND (at the 2.2m MPG/ESO telescope on La Silla) was explored with a precursor programme. This has now led to a full and (accepted) proposal (Jahnke, Burtscher et al.) and a Master project at Leiden university (supervised by LB).

Refereed Publications

Burtscher, L. et al., 2016, A&A, 586, A28; **Burtscher, L.** et al., 2016, SPIE Proceedings, 9907; **Jud, H.** et al., 2017, MNRAS, 465, 248; **Lin, M-Y.** et al., 2017, MNRAS (accepted); Lopez-Gonzaga, N.; **Burtscher, L.** et al., 2016, A&A, 591, A47; Rosario, D. J.; **Burtscher, L.** et al., 2017, MNRAS (accepted); **Schartmann, M.** et al., 2017, MNRAS (accepted); **Shimizu, T.** et al. 2017, ApJ (submitted), Vollmer, B.; Schartmann, M.; **Burtscher, L.** et al. A&A, (submitted)

[2]published at github.com/astroleo/xshtools