Brazilian Large and Long Program (BrLLP) LP002
Progress Report - March 2016

Title: AGNIFS - NIFS survey of feeding and feedback processes in nearby Active Galaxies

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1. Executive summary

We have been awarded 82.5 hours (spread over 6 semesters: 2015A-2017B) to complete NIFS+ALTAIR observations in the J and K bands of the inner few hundred parsecs of a distance limited sample of 26 nearby Seyfert galaxies drawn from the Swift-BAT 60-month catalogue and selected to have 14-195 keV luminosities larger than $10^{41.5}$ erg/s, redshifts z<0.015 and being accessible to NIFS (-30°<δ<73°). Our goal is to map the ionized and hot molecular gas distributions and kinematics, as well as the stellar population and kinematics in order to answer the following questions: (i) How much mass is available for accretion, what mechanisms bring gas to the environs of the SMBH and what are the mass inflow rates? (ii) How do outflows interact with the interstellar medium, what are the mass outflow rates and kinetic power? Can the outflows strip the ISM away from around the BH? (iii) What is the role of star formation in the process? Can we find signatures of recent star formation in the vicinity of the AGN -- a signature of co-evolution of the bulge and SMBH?

In order to complete the observations of the sample of 26 nearby Seyfert galaxies, we need to observe 16 galaxies in the J and K bands plus one galaxy, NGC2110, only in the J band, as we have previous NIFS observations of 10 galaxies of the BAT sample. We have estimated we need 5 hours per galaxy, thus a total of 82.5 hours for the completion of the observations. The first semester of observations was 2015A, the last is now expected to be 2017B.

2. Work progress

Summary of previous semesters:

In 2015A we received only ~60% of the approved observations. The project was awarded 20 hours: 15 hours in Band 1 under the project GN-2015-Q-3 and 5 hours in Band 2 under project GN-2015A-Q35. We received 11.5 hours for the observations of the galaxies NGC3516 and NGC5506 in both the J and K bands, 1.5hrs more than requested because they had difficulty in the acquisition of NGC5506. We received also 2 (0.2 hrs) of 10 requested exposures for NGC4388 and no data for NGC4939.

In 2015B we received ~50% of the approved observations. We were awarded a total of 15hrs in project GN-2015B-Q-29: 2.5hs to observe NGC2110 in the J-band, 10 hours to observe J and K bands of Mrk9 and NGC788, and 2.5hrs to observe the K-band of NGC3081, but only observations in the J-band for NGC2110 and in the J and K bands of NGC788 were obtained. We did not receive any data for Mrk9 and NGC3081.

Present semester:

We were awarded 15hrs to observe three galaxies in project GN-2016A-Q-6: NGC3227, NGC4235, NGC4939, plus NGC4388 (we have reduced a bit the time of the brightest galaxies to include this last galaxy that was not observed in 2015A, as requested). The observations have just begun (26% executed, according to Gemini).

Assessment of the data: From the beginning of 2015B until the present date we have reduced all the data: J and K-bands observations of NGC3516, NGC5506 and NGC788 and J-band observations of NGC2110. Rogemar Riffel is leading this effort.

Calibrations: The data has good quality, but we have a few problems with calibrations when there are observations of the same target in two different nights. We have been solving these problems via calibrated long-slit cross-dispersed spectra from previous observations. The student Luis Gabriel Hahn is leading this effort and is now submitting a proposal to IRTF (InfraRed Telescope Facility, NASA, Hawaii) to observe the galaxies of the LLP for which we do not have previous cross-dispersed spectra to improve our cross-calibrations between the J and K bands. An illustration of the process is shown in Fig. 1 below.

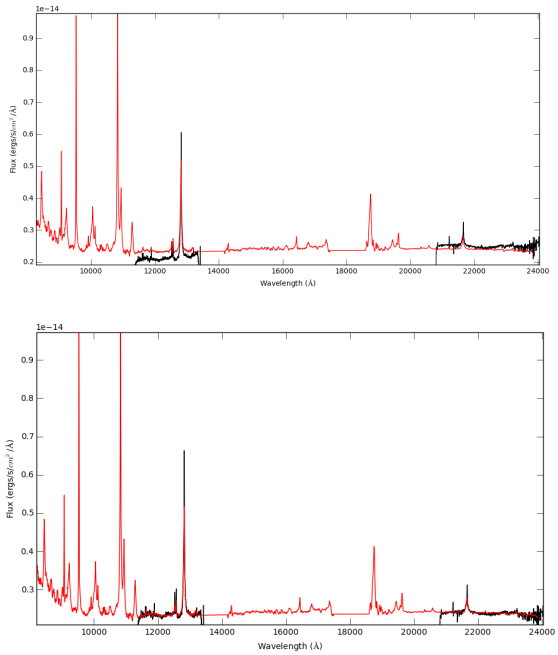

Fig. 1 – Red: Cross-dispersed spectrum of NGC5506 obtained with IRTF. Black: NIFS integrated spectra within the same area of IRTF slit. Top panel: NIFS J and K-band spectra before normalization; bottom panel: NIFS spectra after normalization to the IRTF spectrum.

Data analysis: We have been using the program PROFIT (Rogemar Riffel) for the measurement of the emission lines via the fit of one or more Gaussians or Gauss-Hermite polinomials. We are using the program Starlight (Cid Fernandes 2004) adapted for observations in the near-IR by Rogério Riffel for the study of the stellar population, as well as black body components (to account for the contribution from the dusty torus) and a power-law continuum (to account for the AGN continuum). We have been using also a Butterworth filter to reduce the noise in the data. We have modelled the emission line kinematics and when the data allows (high signal-to-noise ratio in the continuum), also the stellar kinematics. In general we use rotation models that, when subtracted from the gas kinematics, allows the isolation of non-circular motions.

Software development: Dr. Rogério Riffel and his students are developing a tool, called "MEGACUBE", with an initial goal to fit the continuum via spectral synthesis over the whole data cube (using different stellar population bases, continua and varying fitting parameters) to produce

maps of the star formation history, mean ages, mean metallicities in a uniform way for all the datacubes obtained in the LLP. These maps will be stored in the Megacube together with the reduced data. A recent development is to include also in the Megacube maps for the gas flux distribution and kinematics.

Collaborations: We are collaborating with the group of Dr. Richard Davies from the Max Planck Institute for Extraterrestrial Physik, in the analysis of some X-Shooter data for a similar sample of nearby AGN as well as of a control sample. The control sample is important mainly for the analysis of the stellar population, and he agreed to collaborate with us allowing us to use their control sample.

Conferences: some of the results shown below as well as those from previous targets from the BAT sample will be presented by Thaisa Storchi-Bergmann in an invited talk at the conference "The Interplay between local and global processes in galaxies", to take place in Cozumel, Mexico, in April 11-15, 2016.

3. Recent results

We show some preliminary results for the ionized and molecular gas distribution and kinematics in the inner 3"x3" for the galaxies NGC3516 and NGC5506. Particularly interesting are the large extents of the molecular gas distribution and the kinematics suggesting rotation. We show also some preliminary results from the analysis of the stellar population in the same regions.

Emission lines:

We have fitted the J- and K-band emission lines of the central region of the galaxies NGC3516 and NGC5506 using the PROFIT routine, and results for the gas flux distributions and kinematics are shown in Figs. 1 - 4 below. This work is being led by the PhD student Astor Schönell, under the supervision of Thaisa Storchi Bergmann.

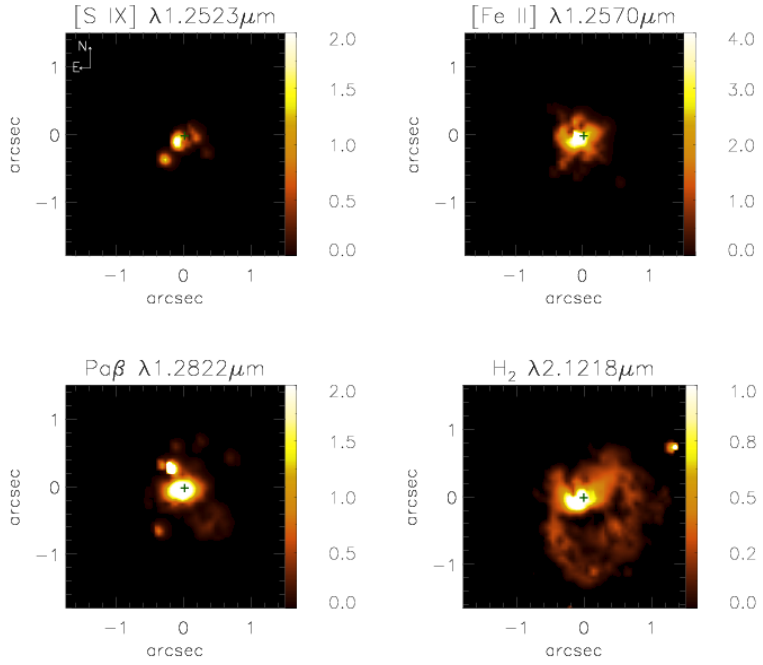

Fig. 2 - NGC3516: Flux distributions in the strongest emission lines of the J and K bands of the inner 3"x3". Flux units are 10^{-17} erg/cm^2/s.

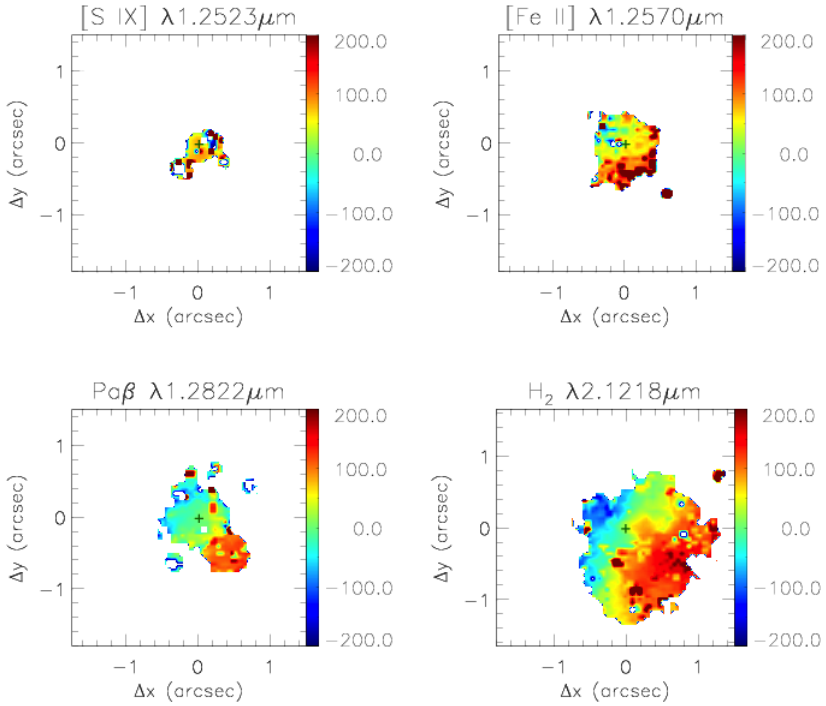

Fig. 3: NGC3516: Gas kinematics for the same emission lines of Fig. 2. Velocities are shown in km/s.

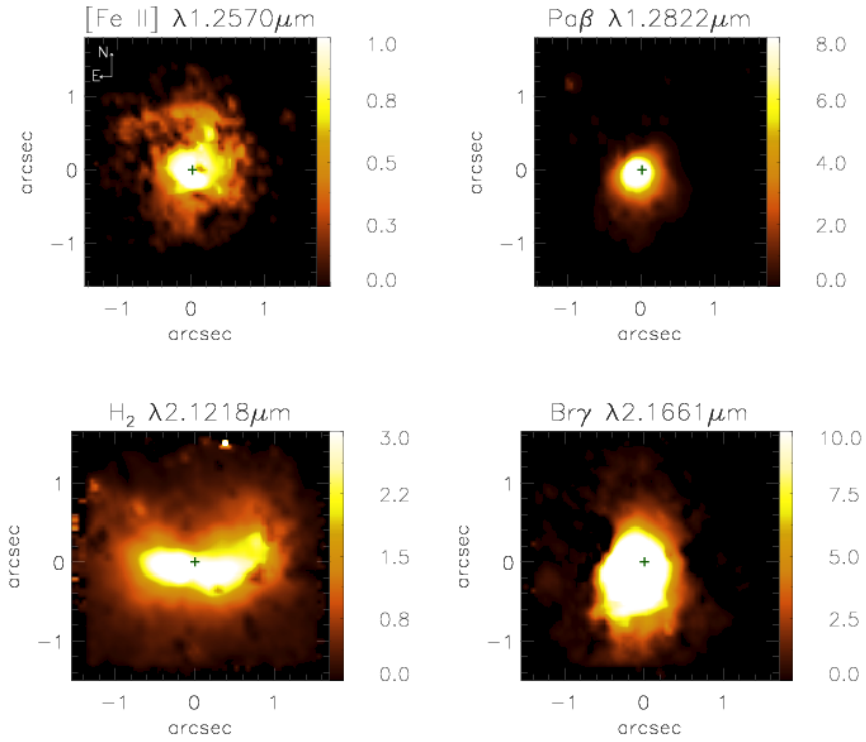

Fig. 4: NGC5506: Flux distributions in the strongest emission lines in the J and K bands. Flux units are 10^{-16}erg/cm^2/s in the J-band and 10^{-17} erg/cm^2/s in the K-band.

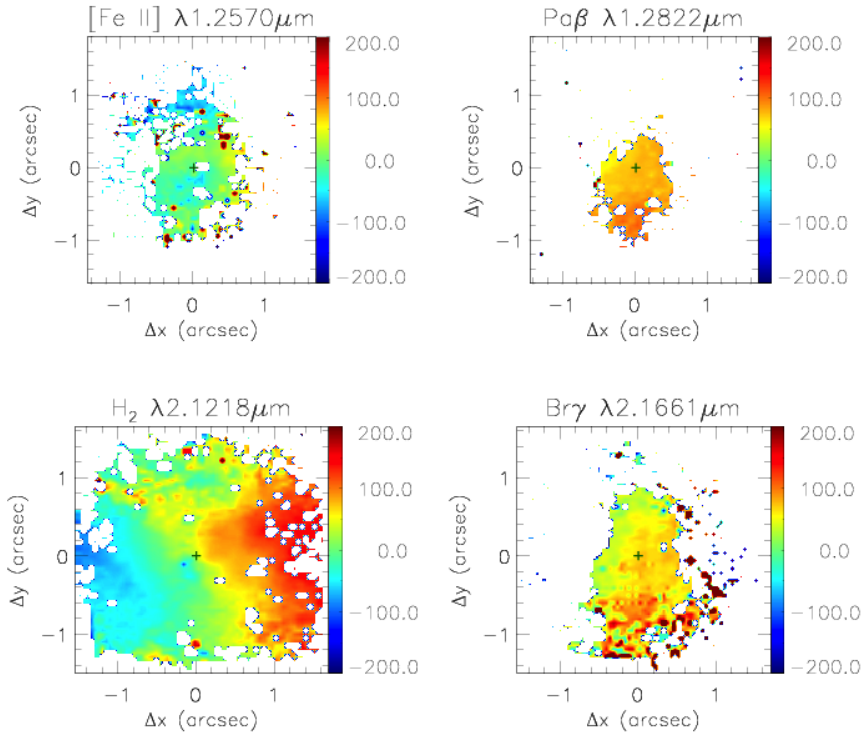

Fig. 5: NGC5506: Gas kinematics in the same emission lines of Fig. 4. Velocities are in km/s.

Stellar Population

The stellar population is being analized by the PhD student Marlon Diniz under the supervision of Rogemar Riffel. Preliminary maps for the stellar population distribution as well as that of a Featureless Continuum and Black Body contribution attributed to a dusty torus are shown in Fig. 6 for NGC3516..

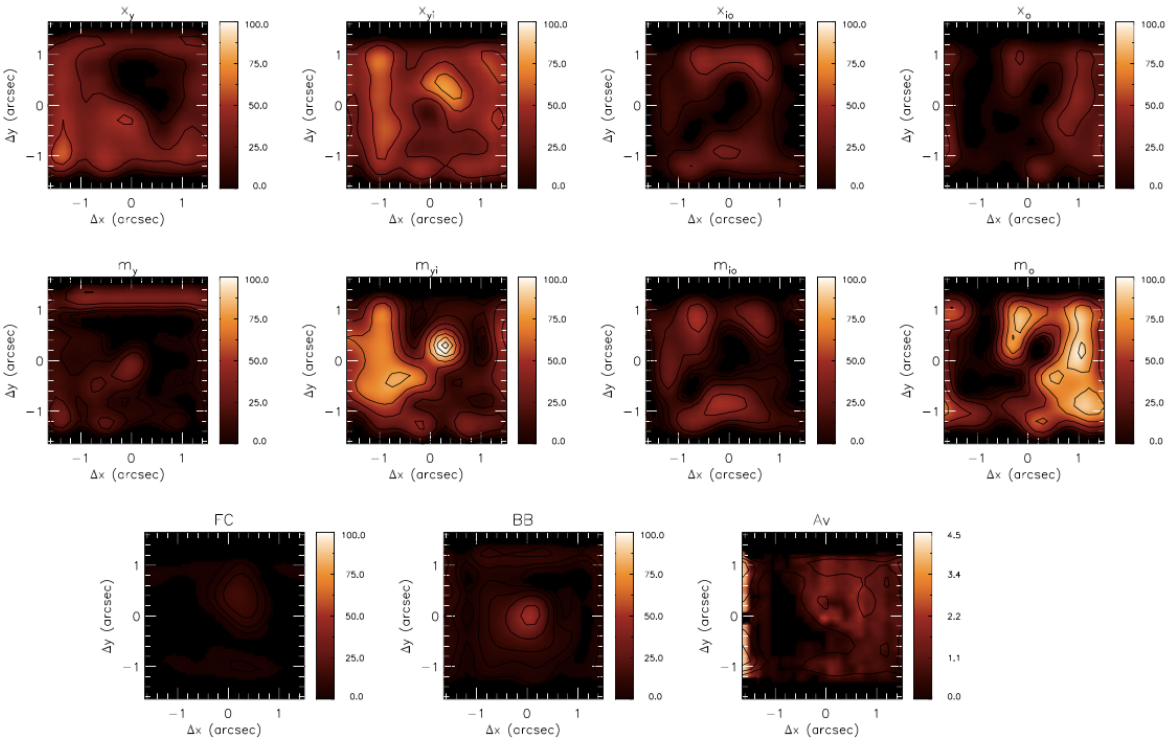

Fig. 6: NGC3516: Results of the spectral synthesis, where x_y, x_{yi}, x_{io} and x_o represent the percent contribution to the

continuum at 2.2μm for the age bins in yrs 1E3-1E8, 1.01E8-7E8, 7.01E8-2E9, 2.01E9-15E9, respectively. In the second row of Fig. 6 we show the percent contribution of the each age bin in mass. The bottom row shows, from left to right, the percent contribution of the featureless continuum FC, the black body components (with temperature T~1000K to account for the torus contribution) and the reddening affecting the stellar population.

4. Overall status

Considering that our third semester of the LLP is just beginning (2016A), this report corresponds to two semesters of observations (2015A and 2015B).

The efficiency of data collection has been ~ 50-60%: we should have by now 6 galaxies observed until February 2016, but we have only 3 observed so far, plus the J-band for NGC2110.

We have contacted Gemini about this, and learned that LLPs should have rollover status, and ours does not have. This fact is particularly critical for NIFS + ALTAIR observations: as the instrument is not very frequently in the telescope, the absence of rollover status is harming our project. We would like to ask the TAC to attribute rollover status to our proposal to increase the success rate of the observations.

We have also received the information that it is important that the proposal is highly ranked as compared with GMOS proposals, for example. This is again due to the fact that NIFS+ATAIR is at the telescope usually only twice per semester, while GMOS is always in the telescope. A proposal similarly ranked (and even ranked lower) for GMOS has much higher chance of being executed than a proposal for NIFS+ALTAIR.

We presently have 4 PhD students working in the project: (1) Astor Schönell is in charge of the analysis of the gas flux and mass distributions, excitation and kinematics; (2) Marlon Diniz is in charge of the analysis of the stellar population; (3) Natacha Dametto is so far using additional data in the comparison of stellar population synthesis results between the optical and near-infrared and investigation of the best stellar population templates for the synthesis and (4) Luis D. Hahn is working in the analsys of the calibration between the J and K bands, using cross-dispersed data from IRTF and helping with the development of the Megacube tasks.

Reduction of data is being done quickly now, as well as the fits of the emission lines. Most "protocols" for data analysis and reduction are getting ready, including MEGACUBE.

5. Observing plan and data release

With our LLP we aim at completing NIFS+ALTAIR observations of a distance-limited sample of 26 Active Galaxies: 10 already observed via previous proposals plus 16 to be observed in this LLP (plus J-band observations of NGC2110, just obtained). Besides this NGC2110 data we have J and K-band data for three galaxies so far: NGC788, NGC3516 and NGC5506. We thus still need to observe 13 more galaxies. If we are successful in observing 4 galaxies in 2016A, as requested, we will need three more semesters to complete the observations: 2016B, 2017A and 2017B.

Our effort with the MEGACUBE has the goal of storing the reduced data, together with the measurements of flux distributions and kinematic maps in each emission line, as well as the results of the spectral synthesis as extensions of the same cube. In the case of the spectral synthesis we plan to save maps of the percent contribution of each stellar population template, featureless continuum and black body (torus) contribution, as well as the reddening map. The MEGACUBE will then be made available in a data release by the end of our analysis of the data. The reduced datacubes will be made available for the Brazilian astronomical community 18 months after receiving the data: e.g. Jan. 2017 for the galaxies NGC3516 and NGC5506.

The Table 1 below shows our progress so far as well as the planned semesters for the forthcoming observations.

Galaxy	**Activity**	**FWHM** **F606W**	**Semester**	**Status**
NGC788	Sy2	done	15B	J and K bands observed. Data reduced and analysis on-going.
NGC1125	Sy2	0.56"	16B	Being proposed for next semester
NGC1194	Sy1	Sy1	17B	
NGC2110	Sy2	done	15B*	J band: just observed (Feb. 16). K-band observed in a previous proposal and results published in Diniz+2015.
Mrk9	Sy1	Sy1	17B	Not observed in 15B. Proposed for 17B
NGC2992	Sy2	0.64"	16B	Being proposed for next semester
NGC3035	Sy1	Sy1	17B	
NGC3081	Sy2	0.55"	16B	Not observed in 15B. Being proposed for next semester.
NGC3227	Sy1.5	Sy1	16A	Current semester
NGC3393	Sy2	0.72"	17A	
NGC3516	Sy1.5	done	15A	Observed May-July 2015: Data reduced, analysis on-going, preliminary results in Figs. 2,3 and 6
NGC3786	Sy1.8	0.70"	17A	
NGC4235	Sy1	0.47"	16A	Current semester
NGC4388	Sy2	partially done	16A	Only 800s in 15A, proposed again for current semester
NGC4939	Sy1	0.68"	16A	Current semester
NGC5506	Sy1.9	done	15A	Observed May-July 2015: Data reduced, analysis on-going, preliminary results shown in Figs. 4 and 5.
NGC5728	Sy2	-	17A	

As requested by the NTAC, we investigated the availability of tip-tild guiding for the targets that have not been observed yet. We have been guiding in the galaxy nucleus, what is not a problem for Seyfert 1 galaxies, that have a point source at the nucleus. We have used HST (Hubble Space Telescope) F606W images of the galaxies, when available, to calculate the FWHM of the nuclear source and list this value in arcseconds for each galaxy (that has not been observed yet) in the third column of the Table, showing that they have compact nuclear sources. The typical magnitudes of the nuclear sources in F606W range between 17 and 16 mag. We also have checked all galaxies in the Gemini Observing Tool and they are accepted as NIFS targets with no warning. Further information on the nuclear sources of these galaxies can be found in the paper by Malkan et al. 1998, ApJS, 117, 25.

6. Publications

During the years 2015 and 2016, we have finalized and published the following papers using data from the galaxies of the BAT-AGN sample - thus from the same project although not yet from the LLP proposal - that have been observed in previous runs:

Diniz et al. 2016, paper almost ready for submission: Correlations of young/intermediate-age stellar populations with the molecular gas distribution and low-stellar velocity dispersion rings: the cases of Mrk3 and Mrk573.

Schönell, A. J., Storchi-Bergmann, T., Riffel, R. A. & Riffel, R. 2016, MNRAS, submitted: Feeding versus feedback in AGN from near-infrared integral-field spectroscopy XII: NGC5548

Diniz, Marlon R.; Riffel, Rogemar A.; Storchi-Bergmann, Thaisa; Winge, Claudia, 2015, MNRAS, 453, 1727: Feeding versus feedback in AGN from near-infrared IFU observations XI: NGC 2110

Riffel, Rogemar A., Storchi-Bergmann, T., Riffel, R. 2015, MNRAS, 451, 3587: Feeding versus feedback in active galactic nuclei from near-infrared integral field spectroscopy - X. NGC 5929

Storchi Bergmann, Thaisa, IAU General Assembly, Meeting #29, #2286157: Active Galactic Nuclei in 3D: feeding and feedback processes

Colina, Luis; Piqueras López, Javier; Arribas, Santiago; Riffel, Rogério; Riffel, Rogemar A.; Rodriguez-Ardila, Alberto; Pastoriza, Miriani; Storchi-Bergmann, Thaisa; Alonso-Herrero, Almudena; Sales, Dinalva 2015, A&A, 578, 48: Understanding the two-dimensional ionization structure in luminous infrared galaxies. A near-IR integral field spectroscopy perspective

Riffel, Rogemar A.; Storchi-Bergmann, Thaisa; Riffel, Rogério, 2015, IAU Symp. 309, 339: Near-IR Integral Field Spectroscopy of the central region of NGC 5929

Riffel, R.; Pastoriza, M. G.; Rodríguez-Ardila, A.; Dametto, N. Z.; Ruschel-Dutra, D.; Riffel, R. A.; Storchi-Bergmann, T.; Martins, L. P.; Mason, R.; Ho, L. C., 2015, ASPC, 497, 459: Models Constraints from Observations of Active Galaxies

Alf Drehmer, Daniel; Storchi-Bergmann, Thaisa; Ferrari, Fabricio; Cappellari, Michele; Riffel, Rogemar A. 2015, MNRAS, 450, 128: The benchmark black hole in NGC 4258: dynamical models from high-resolution two-dimensional stellar kinematics

PhD exam: The student Astor Schönell presented his PhD exam in 2015B, where he collected relevant measurements for all the galaxies of the BAT sample such as: gas masses and surface mass densities - ionized and molecular, mass outflow and inflow rates, geometry, extent, velocities and power of the outflows. He will continue to collect these measurements to present a joint analysis and investigate correlations among these properties and between these properties and

the power of the active nucleus. The table below shows some of the collected quantities for the sample; we are preparing a paper on the sample and these measurements.

Galaxies	A (H_2)	A (HII)	M $(H_2)_h$	M $(H_2)_c$	M (HII)	μ $(H_2)_h$	μ $(H_2)_c$	μ (HII)
MRK 1157	$2.8x10^5$	$1.8x10^5$	$2.3x10^3$	$1.6x10^9$	$5.4x10^6$	$8.2x10^{-3}$	5714	45
NGC 1068	$5.2x10^4$	$1.5x10^4$	29	$2x10^7$	$2.2x10^4$	$5.6x10^{-4}$	384	1.4
MRK 1066	$2.5x10^5$	$1.9x10^5$	$3.3x10^3$	$2.4x10^9$	$1.7x10^7$	$1.3x10^{-2}$	9600	89
NGC 2110	$1.1x10^5$	$7x10^4$	$1.4x10^3$	$9.9x10^8$	$1.7x10^6$	$1.3x10^{-2}$	9000	24
MRK 79	$9.8x10^5$	$7.8x10^5$	$3x10^3$	$2.2x10^9$	$7x10^6$	$3.1x10^{-3}$	2245	9
NGC4051	$1.3x10^4$	$1.4x10^4$	66	$4.7x10^7$	$1.4x10^5$	$5.3x10^{-3}$	3760	9.8
NGC4151	$2.4x10^4$	$1.9x10^4$	240	$1.7x10^8$	$2.4x10^6$	$1.8x10^{-2}$	7083	125
MRK766	$3x10^5$	$2.7x10^5$	$1.3x10^3$	$9.8x10^8$	$7.6x10^6$	$4.3x10^{-3}$	3266	29
NGC5548	$1.7x10^5$	$6.7x10^5$	$2.3x10^2$	$1.7x10^8$	$2.2x10^6$	$6.6x10^{-3}$	3473	7.2
NGC5929	$1.2x10^5$	$7x10^4$	471	$3.5x10^8$	$1..3x10^6$	$3.9x10^{-3}$	2966	18

In the Table 2 above, the area A covered by the flux distributions is in units of pc^2, the masses M are in units of solar masses and the surface mass densities μ are in units of solar masses per pc^2.

7. Response to NTAC questions

We have completed the present report taking into account the requests made by the NTAC in their analysis of our last report. A few additional responses follow below.

One of the requests was for us to talk with Gemini directly about the low efficiency in the completion of the observations (~50-60%). We have discussed this with Gemini and I reproduce here the response of Marie Lemoine-Busserolle, from Gemini:

"Actually it looks like you programs are normal queue programs and not Large Programs (LP). I don't remember if Brazil is participating to the LP but if yes that will actually help to reach 100% completion. Also you got some time in band 2 and most importantly all your band 1 programs were not ''rollover''. Past experience shows that getting rollover status make a huge difference with LGS programs. The reason is that there is few LGS runs and once there are spoiled by bad weather it is very difficult to complete them. Do you know why your programs do not have rollover status?"

I clarified to Marie that it is a "Brazilian only LP", but, as Marie explained and as I wrote previously in the report, it is important that it is classified for Band 1 and has rollover status. I hope the NTAC can warrant this so that we can reach our goals. We need just three more semesters to complete our observations.

Another request by the NTAC was the verification of the availability of tip-tilt guiding for all the galaxies. We are guiding at the nucleus of the galaxies, and have included in Table 1 the FWHM of the nuclear sources as determined from F606W HST images of the sample galaxies. As discussed at the bottom of the Table, these nuclear sources have F606W magnitudes in the range 16.5 -17.5 mag at 600nm and should allow tip-tilt guiding, what is also confirmed via the Observing Tool.