Brazilian Large and Long Program (BrLLP) LP002
Progress Report - September 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.

In 2016A we were awarded 15hrs to observe three galaxies in project GN-2016A-Q-6: NGC3227, NGC4235, J-band NGC4388 and NGC4939, but received only **59%** of the awarded time, comprising observations of **NGC3227** and **NGC4235**.

Present semester:

We were awarded 15hrs more to observe three galaxies in project GN-2016B-Q-26: NGC1125, NGC2992 and NGC3081. We received the following remark regarding this project: "This program is in band 1 and has been accepted for rollover into semesters 17A and 17B if not completed in 16B."

Assessment of the data:

We have reduced all the data received until July 2016: J and K-bands observations of NGC3516, NGC5506, NGC788, J-band observations of NGC2110, J and K-band observations of NGC3227 and NGC4235. 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 both from previous and new proposed observations. The student Luis Gabriel Hahn is leading this effort and had a proposal to IRTF (InfraRed Telescope Facility, NASA, Hawaii) approved 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.

Data analysis:

(1) We have been a Butterworth filter to reduce the noise in the data.

(2) 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. One example of the measurements we have been obtaining from the data using PROFIT is shown in Fig. 1.

(3) 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).

(4) Stellar kinematics: We have obtained the stellar line-of-sight velocity distribution (LOSVD) of each galaxy by fitting the spectra within the range ~2.26–2.40 μm (rest wavelengths), which includes the CO absorption band-heads from ~2.29 to ~2.40 μm (Winge, Riffel & Storchi-Bergmann 2009). This spectral range includes also weaker absorption lines from Mgi and CaI at 2.26–2.28μm. The fitting of the spectra was performed using the penalized Pixel-Fitting pPxf method (Cappellari & Emsellem 2004), that finds the best fit to a galaxy spectrum by convolving template stellar spectra with a given LOSVD, under the assumption that this distribution is well represented by a Gauss-Hermite series. Preliminary results from this analysis is shown in Fig. 2 below, and a paper - led by Rogemar Riffel, is beeing written with these results.

(5) We are modelling the stellar and emission line kinematics. In the case of the gas kinematics, we fit rotation models that, when subtracted from the measured kinematics, allows the isolation of non-circular motions, where we investigate the signatures of feeding (via inflows) and feedback (via outflows)>

Software development:

Dr. Rogério Riffel and his students have developed 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 as well as the stellar 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 were presented by Thaisa Storchi-Bergmann in an invited talk at the conference "The Interplay between local and global processes in galaxies", that took place in Cozumel, Mexico, in April 11-15, 2016.

3. Recent results

Emission lines flux distributions, ratios and gas kinematics:

We have obtained the gas flux distributions, excitation and kinematics in the J- and K-band emission lines for all galaxies observed and reduced, using the PROFIT routine to fit Gauss-Hermite polynomials to the emission lines. This is illustrated in Fig. 1 below for NGC3227, and has already been obtained for all the galaxies observed in the LLP. It will be part of a paper being prepared by the PhD student Astor Schoenell on the gas emission, excitation and kinematics of the sample.

Table 1 bellow shows a compilation of the derived masses of ionized and molecular gas from the line fluxes, as well as the corresponding surface mass densities within the FoV of 3"x 3" for all the galaxies analyzed so far, by the PhD student Astor Schönell, and will be the subject of his Thesis, under the supervision of Thaisa Storchi Bergmann.

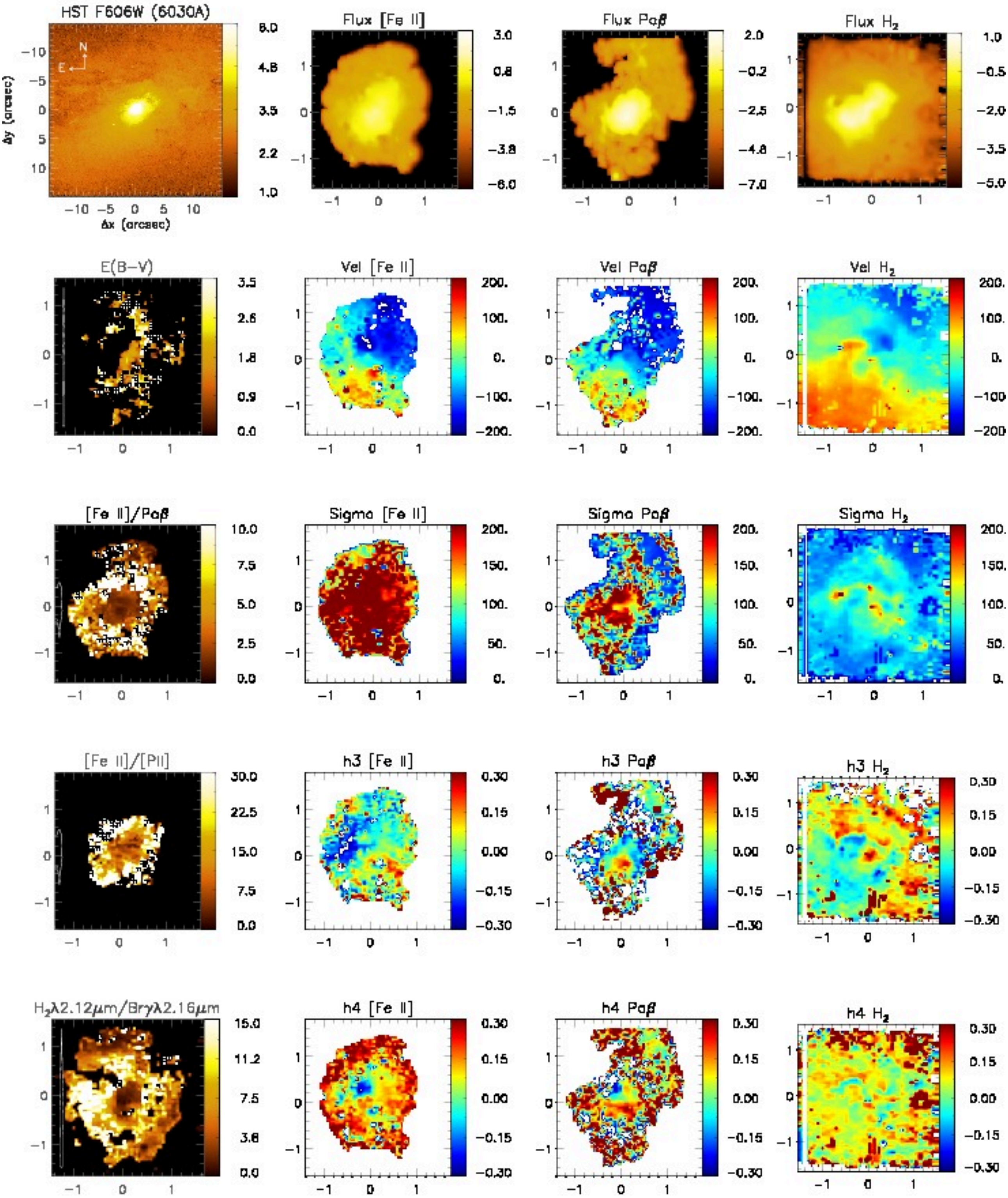

Figure 1: Flux distributions in the [FeII]1.257µm, Paβ and H_2 2.122µm emission lines, emission-line ratios and the corresponding gas kinematics. The flux distributions are shown in logatithmic units of 10^{-17} erg cm^{-2} s^{-1}. The LOSVD (Vel) and velocity dispersion (sigma) are shown in units of km s^{-1}. h3 and h4 are Gauss-Hermitte moments.

Table 1 - Column (1): identification of the galaxies (including 5 galaxies from the LLP plus data from previous NIFS observations); (2) the area corresponding to the emission of molecular hydrogen (in pc^2);(3) the area corresponding to the emission of ionized hydrogen (in pc^2); (4) mass of hot molecular gas (in solar masses);(5) mass of cold molecular gas (in solar masses); (6) mass of ionized gas (in solar masses); (7) mass surface density of hot molecular gas (in solar masses per pc^2); (8) mass surface density of cold molecular gas (in solar masses per pc^2); (9) mass surface density of the ionized gas (in solar masses per pc^2).

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
NGC5506	$1.4x10^5$	$1.2x10^5$	$1.4x10^3$	$1x10^9$	$3.2x10^7$	$9.7x10^{-3}$	7951	244
NGC3516	$8x10^4$	$6x10^4$	517	$3.7x10^8$	$3x10^5$	$6.4x10^{-3}$	6168	5
NGC788	$6.2x10^5$	$5.5x10^5$	1012	$7.3x10^8$	$4.8x10^6$	$1.6x10^{-3}$	1319	8.8
NGC3227	$8.8x10^4$	$4.4x10^4$	1274	$9.2x10^8$	$1.7x10^6$	$1.4x10^{-2}$	20682	39
NGC5899	$1.9x10^5$	$8.7x10^4$	559	$4x10^8$	$4.2x10^5$	$2.9x10^{-3}$	4624	4.8
MRK607	$5.9x10^4$	$2.3x10^4$	182	$1.3x10^8$	$1.1x10^6$	$3x10^{-3}$	5710	48

Stellar kinematics:

In an effort led by Rogemar Riffel, we have measured and analysed the stellar kinematics of the 16 galaxies listed in Table 1 via the analysis of the spectra using the program pPxf (Cappellari & Emsellem 2004), that finds the best fit to a spectrum by convolving template stellar spectra with a given LOSVD, under the assumption that this distribution is well represented by a Gauss-Hermite series. Results from these measurements as well as from the fit of a circular rotation model and its subtraction from the LOSVD is shown in Fig. 2 for the galaxy NGC788. A paper is being written with the presentation and analysis of these results.

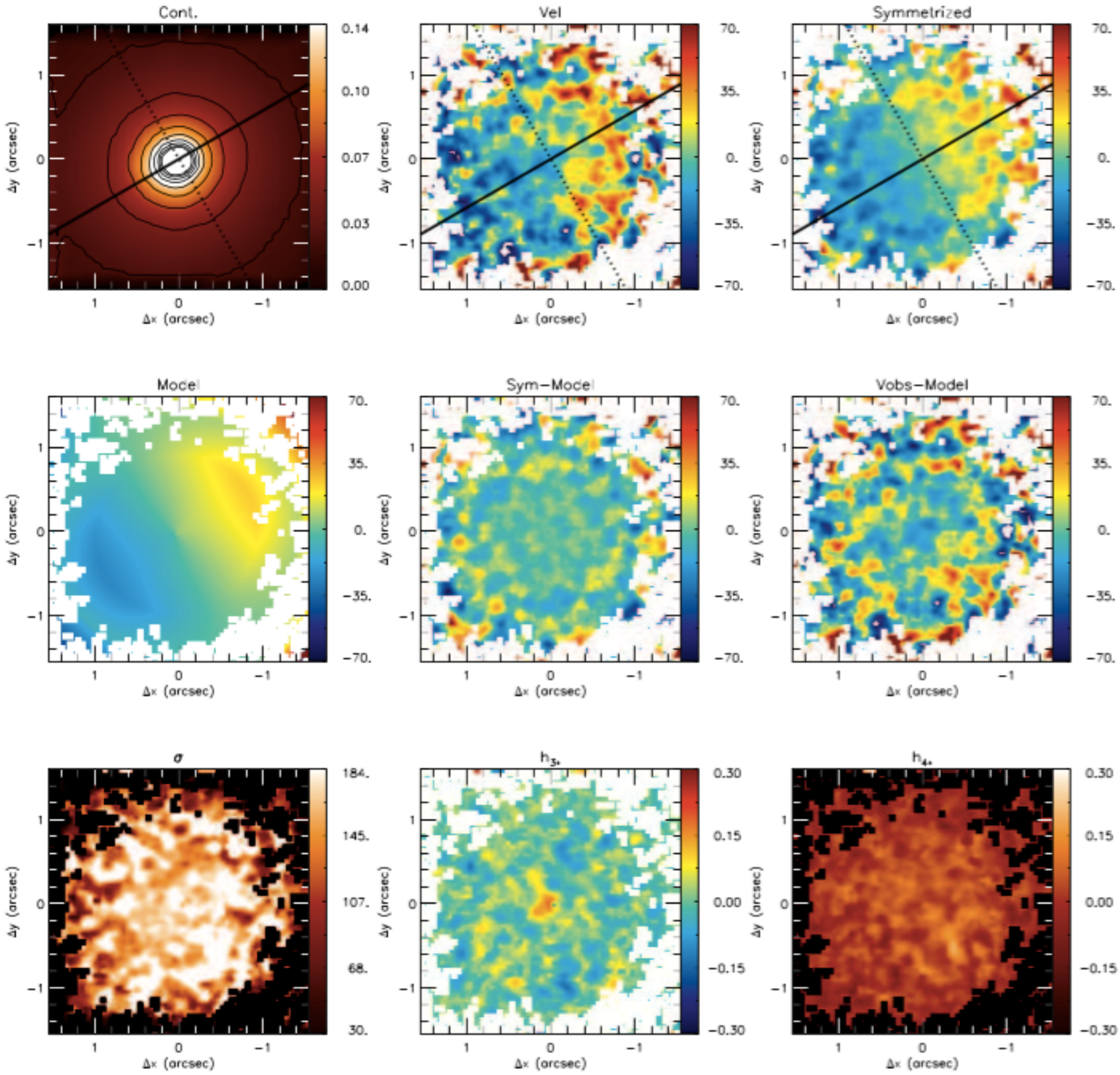

Figure 2. Stellar kinematics of the inner 3"x 3" of NGC 788: Top-left: K-band continuum image obtained by averaging the spectra, with the color bar shown in units of 10^{-17}erg cm^{-2} s^{-1}; top-middle: stellar velocity field; top-right: symmetrized velocity field; middle-left: rotating disk model; middle-middle: residual map for the symmetrized velocity field; middle-right: residual map for the observed velocity field; bottom-left: stellar velocity dispersion; bottom-middle: h3 Gauss-Hermite moment and bottom-right: h4 Gauss-Hermite moment. White regions (and black regions in σ and h4 maps) are masked locations and correspond to regions where the signal-to-noise ratio of the spectra was not high enough to allow reliable fits. The continuous line identifies the orientation of the line of nodes and the dotted line marks the orientation of the minor axis of the galaxy. North is up and East to the left in all maps. The color bar for velocity, model, residual maps and σ show the velocities in units of km s^{-1} and the systemic velocity of the galaxy was subtracted from the observed velocities.

Stellar Population

The stellar population is being analized by the PhD students Marlon Diniz under the supervision of Rogemar Riffel and by Luis Gabriel D. Hahn under the supervision of Rogério Riffel. While Marlon is focusing on the NIFS data only, Luis Gabriel is combining NIFS and GMOS data (when available for the same galaxies) to perform a panchromatic study of the stellar population. NIFS 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..

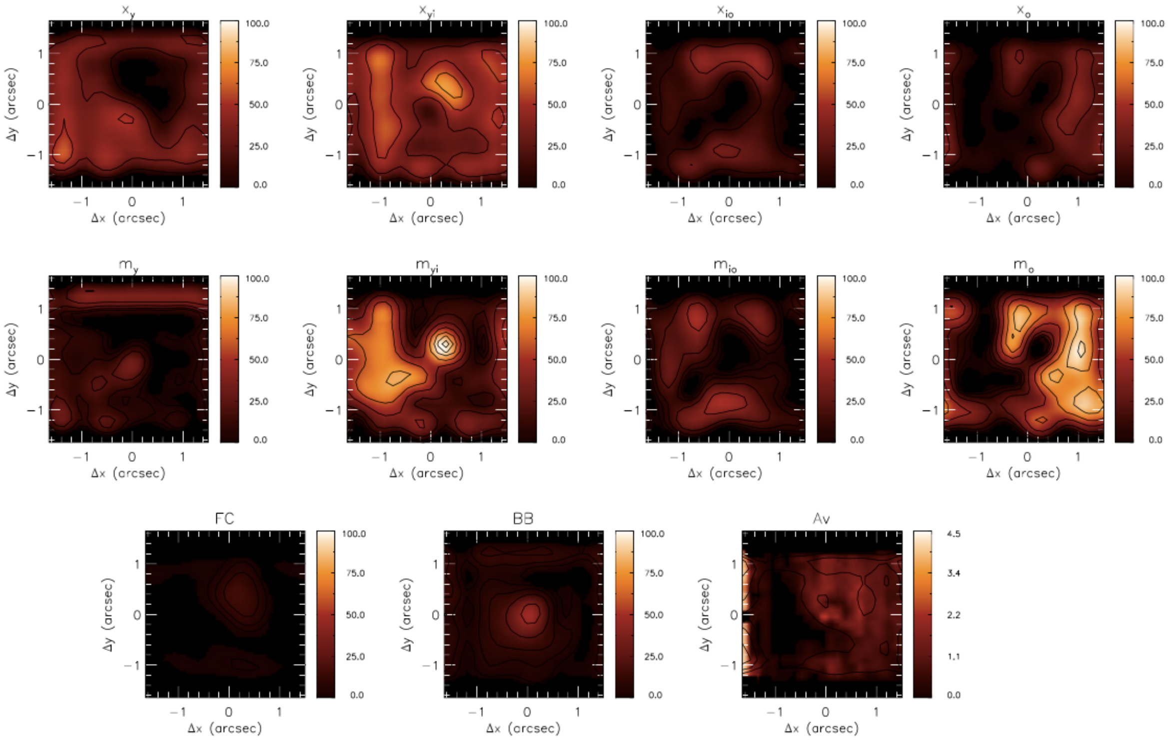

Fig. 6: NGC3516: Results of the spectral synthesis, where x_y, x_{yi}, x_{io} and x_o represent the percent contribution to the continuum at 2.2μm for the age bins in yrs 1E3-1E8, 1.01E8-7E8, 7.01E8-2E9, 2.01E9-15E9, respectively.
In the second row of Fig. 6 we show the percent contribution of the each 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

We are now in the fourth semester of the LLP (2016B), and this report thus corresponds to tthree semesters of observations (2015A, 2015B and 2016A).

The efficiency of data collection has been ~ 50-60%: we should have by now 9 galaxies observed until September 2016, but we have only 5 observed so far, plus the J-band for NGC2110.

We have contacted Gemini about this, and learned that LLPs should have rollover status, and we thank the TAC for giving us this status, that we hope will warrant that we obtain at least most of the data we need for a successful conclusion of our project.

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 analysis of the calibration between the J and K bands, using cross-dispersed data from IRTF, helping with the development of the Megacube tasks and now beginning to perform also panchromatic spectral synthesis using combined data cubes GMOS-IFU + NIFS.

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 five galaxies so far: NGC788, NGC3516, NGC5506, NGC3227 and NGC4235. We thus still need to observe 11 more galaxies. If we are successful in observing 3 galaxies in 2016B, as requested, we will have 9 more galaxies to observe. If we do get 3 galaxies per semester, we need three more semesters to complete the observations: 2017A, 2017B and 2018A.

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 - 1	J and K bands observed. Data reduced and analysis on-going.
NGC1125	Sy2	0.56"	16B - 1	Current semester
NGC1194	Sy1	Sy1	17B - 1	
NGC2110	Sy2	done	15B - 2	J band: observed in Feb. 16, reduced. K-band observed in a previous proposal and results published in Diniz+2015.
Mrk9	Sy1	Sy1	17B - 2	Not observed in 15B. Proposed for 17B
NGC2992	Sy2	0.64"	16B - 2	Current semester
NGC3035	Sy1	Sy1	17B - 3	
NGC3081	Sy2	0.55"	16B - 3	Current semester
NGC3227	Sy1.5	Sy1	16A - 1	Observed in 16A. Data reduced, analysis on-going
NGC3393	Sy2	0.72"	17A - 1	
NGC3516	Sy1.5	done	15A - 1	Observed May-July 2015: Data reduced, analysis on-going.
NGC3786	Sy1.8	0.70"	18A - 1	
NGC4235	Sy1	0.47"	16A - 2	Observed in 16A. Data reduced, analysis on-going
NGC4388	Sy2	partially done	16A -> 17A - 2	Only 800s in 15A, proposed again for next semester
NGC4939	Sy1	0.68"	16A -> 18A - 2	Not observed, being proposed for other semester
NGC5506	Sy1.9	done	15A - 2	Observed May-July 2015: Data reduced, analysis on-going.
NGC5728	Sy2	-	17A - 3	

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 - the first contains data from the LLP while the others are from the same project but based on data that have been observed in previous runs:

Schoenell, A. et al., in preparation: Gemini NIFS survey of feeding and feedback processes in nearby Active Galaxies: II - Gas excitation and kinematics

Riffel, Rogemar et al., in preparation: Gemini NIFS survey of feeding and feedback processes in nearby Active Galaxies: I - Stellar kinematics

Diniz et al. 2016, being revised by collaborators: 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, tmp 1370S: 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 and Thesis: 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. His Thesis should be presented in 2017A.

7. Response to NTAC questions

Ultimo parecer da NTAC:
"O projeto tem considerável impacto e está sendo recomendado com alto

ranking e no status rollover. É liderado por pesquisadora que possui grande experiência na área. O projeto sem duvida precisar ser levado adiante, mas preocupa a eficiência na obtenção dos dados. O projeto teve 82.5 horas para observar 26 galáxias, mas só observaram 10 e agora solicitam mais 82.5 horas para observar 16. O status de rollover deve amenizar este problema. Além disso, o comitê chama a atenção para a necessidade de disponibilizacão dos dados reduzidos no prazo especificado, dando assim maior visibilidade aos dados."

Esclarecimento:
Na verdade a amostra de 26 galáxias inclui objetos anteriormente observados. Dentro da LLP, pedimos para observar 16 galáxias nas bandas J e K (5 horas por galáxia), mais uma galáxia - NGC2110, na banda J (+2.5 horas), perfazendo um total de 82.5 horas. Nosso plano seria observar 3 galáxias por semestre, em média, o que estimamos tomaria cerca de 6 semestres, mas frente aos problemas com o NIFS (Laser), temos conseguido menos do que 3 galáxias por semestre e agora estimamos termos o projeto se estendendo a 2018A.