Brazilian Large and Long Programs (BrLLP)
Progress Report – 2017A

The DIVING3D project: Deep IFS View of Nuclei of Galaxies

J. E. Steiner[1], R. Cid Fernandes[2], P. Coelho[1], N. Vale Asari[2], R. B. Menezes[1], T. V. Ricci[3], A. L. Amorim[2], D. May[1], Patricia da Silva[1], Inaiara Andrade[1] & Maiara S. Carvalho[2]

Theses: Patricia da Silva[1], Inaiara Andrade[1] & Maiara S. Carvalho[2]

[1]Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, Rua do Matão 1226, Cidade Universitária, São Paulo, SP CEP 05508-090, Brazil
[2]Departamento de Física, Universidade Federal de Santa Catarina, PO Box 476, 88040-900, Florianópolis, SC, Brazil
[3]Universidade Federal da Fronteira Sul – Rua Jacob Reinaldo Haupenthal, 1580, sala 111, Cerro Largo RS, CEP 97900-000

1. Executive summary

The DIVING3D project - Deep IFS View of Nuclei of Galaxies – is one of the two Brazilian LLPs. By the end of 2017A it will be 79% completed. Additional time is requested for 2017B to bring the degree of completion to 89%.

The main goals of this survey are to perform a study of the a) nuclear and b) circumnuclear emission of a complete sample of all galaxies brighter than B=12.0 in the southern hemisphere. As a by-product we will also obtain stellar c) kinematics and d) archaeology.

Although the El Nino phenomenon has affected badly the operations of Gemini South and 15 galaxies of the program were not observed in the semesters 2015B and 2016A, the sample of ETGs is now completed. The last galaxy, NGC 4856, that was not observable by Gemini, has just been observed in March/2017 with the SIFS IFU spectrograph, the SOAR equivalent to the GMOS.

For the mini-DIVING3D, only 2 galaxies were missing in 2016B but only one of them was observed. The last one, NGC 1232, is proposed to be observed in 2017B.

We are now (after the observation with the SOAR telescope in March/2017) in the situation of publishing the first paper with statistical analysis on the ETGs. After NGC 1232 is observed in 2017B, we will publish the first paper on the Mini-DIVING3D.

So far we have published 8 papers on individual or small samples of galaxies from DIVING3D. Two more papers have been submitted and three are being written, with global analysis.

Out of the 170 objects initially proposed for this LLP, there are still 35 objects to be observed. 25 of them were scheduled in previous semesters and not observed for various reasons related to the Gemini Observatory or the El Niño phenomenon.

For 2017B we propose to observe 16 objects. The remaining objects will be proposed to 2018A (9 objects) and 2018B (10 objects).

2. Work progress

Here, a detailed description of the work done in the semester related to LLP activities such as:

The data quality is, in general, very good. Although all data cubes have instrumental fingerprints, we have been able to remove them. The change of CCDs in Gemini South made the fingerprint extremely complex. Its removal process has consumed a lot of time but we have been able, after painful work, to always remove it.

The signal-to-noise obtained for the emission line analysis is very good. For the stellar component of the central bulge it is quite appropriate. In two cases, at the edges of the FOV, we had deficit of s/n for

analysing the stellar component, but this has not been a problem, given our objectives.
The wavelength calibration has been made very accurately. The flux calibration is not better then ~30%.

All data cubes are submitted to the following procedures:

- Bias subtraction and flat-field correction
- Cosmic ray removal
- Wavelength calibration
- Sky subtraction
- Flux calibration
- Telluric absorption removal
- Correction for the differential atmospheric refraction (DAR).
- High frequency spatial noise removal with Butterworth filter
- Fingerprint removal
- Richardson-Lucy deconvolution

The data analysis is done with the following techniques:

- PCA Tomography
- Starlight spectral synthesis
- pPXF kinematic analysis, obtaining the Gauss-Hermite momenta

Software development

All software developed by our group in IDL is available in the site:

www.astro.iag.usp.br/~pcatomography

3. Recent results

Among the ETGs, only one object, NGC 4856, was not observed with the Gemini Telescope because of lack of guiding star. Fortunately, we have obtained 6 exposures (6x20 minutes) with the SIFS IFU spectrograph on the SOAR telescope, during an engineering run. The data have already been reduced and look very good (see Figure 1).

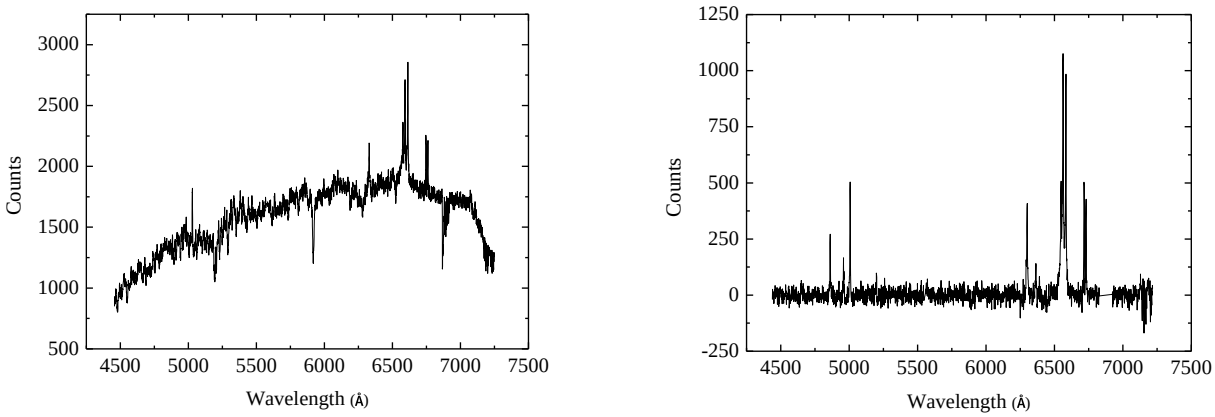

Figure 1 – The spectrum of the nucleus of NGC 4856, observed with the SIFS spectrograph on the SOAR Telescope (left); after the subtraction of the stellar component (right). This is one data cube of 20 minutes integration (we have 5 more).

To date, 8 papers were published containing data from the DIVING3D project (see list in item 6, bellow). Two additional papers have been submitted to the MNRAS. Three papers are in preparation (listed in item 6.)

One of the main surprises of the data reduced so far is the frequency in which we find indications of past mergers:

a) At least in two cases we see double or well elongated central bulges. Associated with this there is strong indication of stellar population with 1 Gyear.
b) In two cases we see double AGN (~1" separation). In one case it is associated with a double central bulge.
c) In one case there is a suggestion of a triple AGN (within 0.7")
d) In two cases we see off-centered AGN. Perhaps this indicates the ejection of the central black hole, as a consequence of black hole merger.

The fact that this is an IFU survey with unprecedented resolution and signal-to-noise, such unprecedented findings are not surprising.

In a recent observation we have observed that the galaxy NGC 1365 has suffered a transmutation from Seyfert 1.8 to a NLS1 (Narrow Line Seyfert 1 Galaxy). It is not clear what exactly this means but it should give some insight of the nature of such classes.

The galaxy NGC 1398 has revealed a compact stellar disc around the central black hole with a very high radial velocity (~300 km/s). This suggests that we can, for the first time for this object and for the first time with data obtained with the GMOS, calculate the mass of the central black hole.

4. Overall status

The current membership of the project is:
Joao Steiner: Coordinator
Roberto Menezes: reduction, data processing and analysis. Emission line properties of the mini-DIVING3D.
Tiago Ricci: reduction and data processing and analysis. Priority on ETG galaxies.
Roberto Cid Fernandes, Natália do Vale e André Amorin: Spectral synthesis and stellar archaeology.
Paula Coelho: Spectral libraries; alfa enhancement.

Theses:
Patricia da Silva: the master thesis was concluded and she has started her PhD thesis, following the work on Sbc galaxies (Milky Way twins).
Inaiara Andrade: her PhD thesis focuses on IFU spectroscopy of nuclei of S0 galaxies.
Maiara S. Carvalho: her master thesis focuses on stellar archaeology of the mini-DIVING3D.

External collaboration:

One paper in collaboration with the Porto Alegre group was submitted:
Integral Field Unit Spectroscopy of the inner 1 kpc of the galaxy NGC 5044
Suzi I.F. Diniz, Miriani G. Pastoriza, Jose A. Hernandez-Jimenez, Rogerio Riffel,Tiago V. Ricci, J. E. Steiner, Rogemar A. Riffel

An additional paper is being prepared with Gabriel Hahn, Rogério Riffel and Rogemar Riffel in which the GMOS data of the galaxy NGC 1052 will be combined with their NIFS data.

One additional paper is being prepared in collaboration with Alberto Ardilla (LNA) on the Coronal Line Seyfert galaxy NGC 5643.

5. Observing plan and data release

The current observing strategy is to observe sub-samples as listed below.

Observational strategy

Sub-samples

The observational status of the subsamples, by the end of semester 2017A, will be:

Sub-sample	***Obs***	***Unobs***	***Total***
1 – High-mass (σ>200 km/s) ETGs	32	0	32
2 – Low-mass (σ<200 km/s) ETGs	30	0	30
3 – Early type (Sa-Sb) spiral galaxies	23	13	36
4 – Milky Way twins	21	2	23
5 – Late type (Sc-Sd) spiral galaxies	29	20	49
Total	***135***	***35***	***170***

It is very important to notice that the two semesters B were not completed, as shown in the following table. The program DIVING3D was approved in Nov/2013 and the time allocated by semester was:

Semester	time	observed	not observed
2014A	8.5hs	7	0
2014B	17hs	9	7
2015A	21hs	20	0
2015B	21.6	12	8
2016A	17hs	8	7
2016B	17hs	13	3

In the semester 2014B, 7 galaxies were not observed due to an operational mistake by the Gemini Observatory. In 2015B, 8 galaxies were not observed because of the bad weather due to the strong El Niño phenomenon. In the semester 2016A, 7 galaxies were not observed due to the El Nino phenomenon.
In the semester 2016B the following three galaxies where no observed: NGC 1232, NGC 1084 e NGC 1421, for unknown reason.
The proposed objects for the remaining semesters are:

2017A – 12 galaxies have been observed by march/2017. Four remain to be observed and we hope they still will:
NGC 7496 , NGC 7083, IC 5273, NGC 7552

2017B - 17.00h (16 galaxies)
NGC 1232, NGC 1084, NGC 1421, IC 5332, NGC 1448, NGC 1512, NGC 1350, NGC 578, NGC 1042, NGC 1371, NGC 1637, NGC 1532, NGC 7727, NGC 1425, NGC 1964, NGC 210

2018A - 9.63h (9 galaxies)
NGC 6118, NGC 4504, NGC 6753, NGC 5584, NGC 5161, NGC 5530, NGC 3513, NGC 7713, NGC 7723

2018B - 10.65h (10 galaxies)
NGC 1385, NGC 1744, NGC 150, NGC 986, NGC 1249, NGC 1493, NGC 2090, NGC 779, NGC 685, NGC 1087

The Legacy strategy

Our commitment is to deliver the data to the Brazilian Astronomical Community. The idea is to give access to our community not only to the raw data (available after 1 year anyway) but also the reduced and the processed data. For this reason we will deliver three data cubes for each galaxy:

A – The original data cube

- Wavelength calibrated
- Flux calibrated
- Corrected for the differential atmospheric refraction (DAR).

B – One data cube treated with the following procedures:
- Removal of high frequency spatial noise with Butterworth filter
- Fingerprint removal

C – One additional cube will be available to the community with the additional data processing:
- Richardson-Lucy deconvolution

The data are located in the VO (Bravo) server at IAG.
The address is:

www.iag.usp.br/diving3d

It has a mirror in the LNA server.

The "Mini-DIVING3D" is now complete except for one object: NGC 1232. All data have been reduced and treated and are located in site above.

The next release will be in 2017A for the subsample "Low-mass ETGs".

6. Publications

We believe that a significant number of papers on individual objects will be published. The main goal, however, is, at the end, publish statistical analysis on:
- The ETGs
- Early-type galaxies
- Milky Way Twins
- Late-type galaxies

Our perspective is that in all cases we will address:
- Nuclear emission line properties
- Circumnuclear emission line properties
- Stellar archaeology
- Stellar kinematics

List of papers published with data from the Dinving3D project:

Menezes, R. B., Steiner, J. E., Ricci, T. V. 2013 Ap J 765, L40
Collimation and Scattering of the Active Galactic Nucleus Emission in the Sombrero Galaxy

Ricci, T. V., Steiner, J. E. & Menezes, R. B. 2014 MNRAS 440, 2429 – Paper I
Integral field unit spectroscopy of 10 early-type galactic nuclei - I. Principal component analysis Tomography and nuclear activity

Ricci, T. V., Steiner, J. E. & Menezes, R. B. 2014 MNRAS 440, 2442 – Paper II
IFU spectroscopy of 10 early-type galactic nuclei - II. Nuclear emission line properties

Menezes, R. B., Steiner, J. E. & Ricci, T. V. 2014 Ap J Lett 796, L13
An off-centered active galactic nucleus in NGC 3115

Ricci, T. V.; Steiner, J. E.; Menezes, R. B. 2015 MNRAS 451, 3728

IFU spectroscopy of 10 early-type galactic nuclei - III. Properties of the circumnuclear gas emission.

R. B. Menezes, J. E. Steiner and Patrícia da Silva 2016, Astrophysical Journal 817, 150
The off-centered Seyfert-like compact emission in the nuclear region of NGC 3621

Ricci, T. V., Steiner, J. E. & Menezes, R. B. 2016 MNRAS, 643, 3860
IFU spectroscopy of 10 early-type galactic nuclei - IV. Properties of the circumnuclear stellar kinematics

Menezes, R. B. and Steiner, J. E. 2017 MNRAS, 466, 749
The emission-line regions in the nucleus of NGC 1313 probed with GMOS-IFU: Wolf-Rayet stars and a B[e]/LBV candidate.

The following papers are submitted for publication:

Suzi I.F. Diniz, Miriani G. Pastoriza, Jose A. Hernandez-Jimenez, Rogerio Riffel1, Tiago V. Ricci, J. E. Steiner, Rogemar A. Riffel – submited to MNRAS.
Integral Field Unit Spectroscopy of the inner 1 kpc of the galaxy NGC 5044

Patrícia da Silva, J. E Steiner & R. B Menezes – submited to the MNRAS
NGC 1566: analysis of the nuclear region from optical and NIR Integral Field Unit spectroscopy

- Separately, papers published by the group, which are related to the LLP (at least in terms of IFU methodology) and that did not make use of the LLP data.

Steiner, J. E.; Menezes, R. B.; Ricci, T. V.; Oliveira, A. S. Mapping low- and high-density clouds in astrophysical nebulae by imaging forbidden line emission 2009 MNRAS.396, 788

Steiner, J. E.; Menezes, R. B.; Ricci, T. V.; Oliveira, A. S. PCA Tomography: how to extract information from data cubes 2009 MNRAS 39, 64

Oliveira, A. S.; Steiner, J. E.; Ricci, T. V.; Menezes, R. B.; Borges, B. W. Optical identification of the transient supersoft X-ray source RX J0527.8-6954, in the LMC 2010 A&A 517, L5

Ricci, T. V.; Steiner, J. E.; Menezes, R. B. NGC 7097: The Active Galactic Nucleus and its Mirror, Revealed by Principal Component Analysis Tomography 2011 ApJ 734 L10

Steiner, J. E.; Menezes, R. B.; Amorim, Daniel Identification of a high-velocity compact nebular filament 2.2 arcsec south of the Galactic Centre 2013 MNRAS 431, 2789

Menezes, R. B.; Steiner, J. E.; Ricci, T. V. Discovery of an Hα Emitting Disk around the Supermassive Black Hole of M31 2013 ApJ 762 L29

Menezes, R. B., Steiner, J. E. & Ricci, T. V. 2014, MNRAS 438, 2597
A treatment procedure for Gemini North/NIFS data cubes: application to NGC 4151

Ricci, T. V.; Steiner, J. E.; Giansante, L. 2015 A&A 576, 58
A hot bubble at the centre of M81

Menezes, R.B., da Silva, P., Ricci, T.V., Steiner, J. E. & May, D., 2015 MNRAS 450, 369
A treatment procedure for VLT/SINFONI data cubes: application to NGC 5643

Menezes, R. B. & Steiner, J. E. 2015 Astrophysical Journal 808, 27
The molecular H2 emission and the stellar kinematics of the nuclear region of the Sombrero Galaxy.

May, D., Steiner, J. E., Ricci, T.V., Menezes, R.B, & Andrade, I.S. 2016 MNRAS 457, 949

Digging process in NGC 6951: the molecular disc bumped by the jet

May, D. & Steiner, J. E submitted to MNRAS
Winds and bubbles in NGC 1068: a two-stage outflow

Menezes, R. B, da Silva, Patrícia & Steiner, J. E. - submitted to the MNRAS
The molecular H2 and stellar discs in the nuclear region of NGC 4258

All publications up to now have treated individual or small (~10 objects) samples. Now that the ETGs have been observed (and soon the mini-DIVING3D), we plan the first three statistical papers:

Paper I: The DIVING3D Project: sample definition, strategy and early results.
Paper II: The DIVING3D Project: nuclear emission line properties of Early Type Galaxies.
Paper III: The DIVING3D project: Statistical analysis of the complete sample of B<11.0 galaxies.

- **Theses or dissertation works finished that are related to the LLP.**

Roberto Menezes (2012): Methodology development for the program
Tiago Ricci (2013): 10 early type galaxy studies, including some from the DIVING3D
Patrícia da Silva (April 2016): Analysis of 4 SBsc galaxies (Milky Way twins).
Suzi Diniz (2016): Analysis of the galaxy NGC 6868

7. Response to NTAC questions

The authors mention that thee papers including statistical results are in preparation by the group. The NTAC recommends that if these papers are not submitted at the time of the new report that the authors includes a better description of the works being done related to these studies.

We will show two preliminary statistics that illustrate our preliminary results. The first one is about the classification of the massive ETGs, when compared to the Palomar Survey. The second is the diagnostic diagram for half of the Mini-DIVING3D, showing the expected dichotomy in the ionization mechanism.

Considering the central source, we can make a preliminary statistics and compare it to the Palomar survey. The result shows that we are looking much deeper and finding significantly more AGNs.

Preliminary comparison with the Palomar Survey for massive ETGs (σ>200 km/s):

Type	Palomar Survey		DIVING3D	
	Nr	%	Nr	%
No Em.	19	33%	3	9%
L1.9	6	11%	10	31%
Lb?	0	0%	6	19%
S1.5	1	2%	2	6%
T1.9:	1	2%	0	0%
S2	0	0%	0	0%
S2:	1	2%		
L2	8	14%	4	13%
L2::	6	11%	7	22%
T2	2	4%		
T2:	7	12%		
H:	1	2%	0	0%
T2/L2-S2:	4	7%		
S2/L2	1	2%		
Total	57	100%	32	100%

No Em.	19	33%	3	9%
L b/Sy b	8	14%	18	56%
S2/L2/T2	29	51%	11	34%
HII	1	2%	0	0%

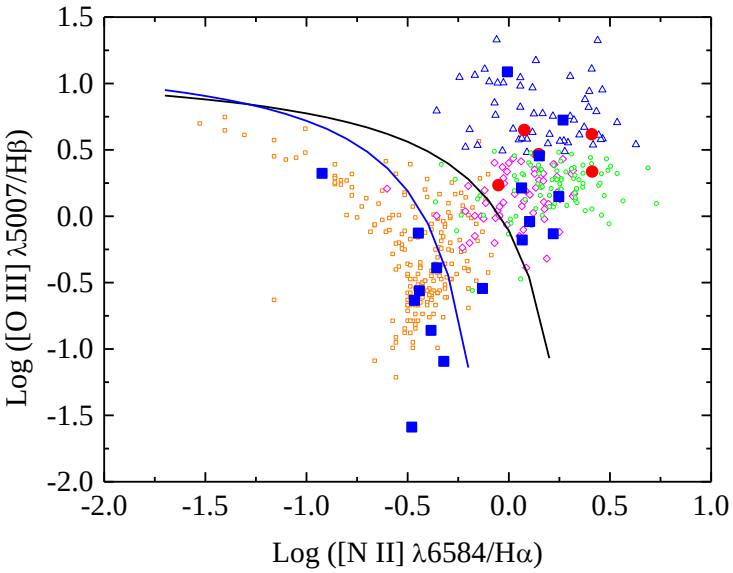

Figure 2 – Diagnostic diagram for [O III] λ5007/Hβ x [N II] λ6584/Hα of the brightest DIVING3D galaxies. Red circles are ETGs, blue squares are late type spirals (from Sbc to Sd). In the same diagram we show the galaxies from the Palomar Survey (Ho et al, 1997); objects in orange are HII regions, red are transition objects, green are LINERs and blue are Seyferts. Only one object is in the transition zone. This is an important consequence of the IFU data: the dichotomy AGN x HII emission appears more clearly because of the better spatial resolution and separation.

As the project has not been totally executed during previous semesters, the authors asked for additional time to complete the observations of all galaxies.

The NTAC asks to include a very detailed description of the scientific impacts in case they do not get the additional time to conclude the observations.

The impact can be summarized in the table bellow.
The degree of completion, per subsample, by the end of the semesters 2016A, 2016B and 2017A will be:

Priority	***Completion degree***			
	16A	16B	17A	17B
1 – High –mass ETGs	100%	100%	100%	100%
2 – Bright (B<11.0) Mini-DIVING^{3D}	93%	98%	98%	100%
3 – Low-mass ETGs	80%	97%	100%	100%
4 – Milky Way twins	74%	89%	91%	96%
5 – Early type spirals	33%	39%	64%	86%
6 – Late type spirals	45%	51%	59%	73%
Total	***63%***	***70%***	***79%***	***89%***

This means that, by the end of 2017A, we will have a degree of completion of 100% for the sub-samples High-mas ETGs, Low-mass ETGs. This will allow a statistical analysis of the full sample of ETGs.

For the Mini-DIVING 3D, the one missing object will make the degree of completion to be 98%. For the Milky Way Twins, the 2 missing objects will leave the sample 91% completed. We badly need these three objects for the completion of the two sub-samples.

For the subsamples of early type galaxies and Late type galaxies the degree of completion is 64% and 59% respectively. If the project is not approved for 2017B the scientific impact will be evidently enormous. The basic conclusion is that the scientific goals will be achieved for ETGs but not at all for Spiral Galaxies.

Although the authors mention that the data will be made available for the Brazilian community it is not clear how this will be done. For the next report, we ask that they include in a very clear way their plan to make the data cubes available. We also recommend that they include the original data cubes in the data release, without the Butterworth filtering procedure.

We are absolutely committed in releasing the data to the Brazilian community. The first release (massive ETGs) was already done. In April/2017 the Mini-DIVING3D will be released (with one object missing). In June/2017 the low-mass ETGs will be released. We would like to make it clear that these two new releases will be made before the group has the proper time for completing the publication, as an answer to the NTAC pressure.

All released data are in:

www.iag.usp.br/diving3d