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

The DIVING3D project: Deep IFS View of Nuclei of Galaxies

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The project is moving towards its end. We are very happy and fortunate with the amount and quality of the data we obtained, and very thankful to the NTAC for the support.

With respect to the report from the NTAC we would like to strongly disagree at least in the many aspects in which it is completely wrong. Bellow we comment on this:

T*he NTAC found that the links given in the report to the data reduction and analysis software (http://www.astro.iag.usp.br/~pcatomography) as well as the reduced data in the VO (Bravo) server (http:// www.iag.usp.br/diving3d) either did not contain the reported information or not to be functional by 10 May 2017*.

Our response:
1 - The software page is operational since 2009 and was **never** interrupted.
2 - The reduced data are being offered to the Brazilian community and were interrupted for significant period in the transition from the Cloud/USP to the BRAVO. However on the day mentioned in the report it was operational. The NTAC could not have consulted the site as it requires a password that was not requested. The NTAC can now consult the site using:

Username: ntac
Password: ntac#%

Third, the report lists 8 papers that were published with data from the LP. However, it appears that only one of these papers is related to data from the LP, as the other 7 make use of data from 2008AB, 2011A, 2012B, and 2013A (the LP started in 2014A).

Our response:
3 - Our report mentions that 8 papers were published with data from the DIVING3D survey, regardless of the semester in which the data were obtained. It also mentions that only one paper was published with data from semester 2014A on. This is wrong. Two papers were published with these data: on the galaxies NGC 3621 and NGC 1313 and an additional one submitted on NGC 1556. From now on, we will separate the DIVING3D papers with data obtained before and after 2014A.

Fourth, one of the most important questions from the previous report was to quantify the need for the requested LP extension in terms of what science goals cannot be achieved without such extension. The answer to this question was found to be seriously shortcoming: The report answered this question by stating the percentages of completeness of the various samples (ETGs: 100%, B<11: 98%, MW twins: 91%, spirals: ~60%), while they should have addressed the question in terms of the scientific impact of these varying degrees of incompleteness.

Our response

4 – The project has a fundamental statistical aspect and this seems difficult to be understood by some people. For this reason we are observing a statistically complete sample. The reason is that we want to derive statistical parameters such as luminosity functions, black hole mass function as well as define percentages of activity as a function of morphology and mass. We are particularly focusing the low-luminosity end of the luminosity function of the AGN. There is only one way of doing this: by observing the full sample.

We have been publishing papers on individual galaxies along the project. This has never been the purpose of the project and this was stated very clearly since the beginning. Although our group has been quite productive in this period, we never could address the main issues and the main goals that we proposed to achieve. Until recently we did not have any complete data set to perform the statistical analysis.

Recently we obtained the data for the last ETG with the SOAR Telescope. Although it is only one object, it represents a fundamental progress to the project. We hope to get an additional object in early October with the SOAR Telescope, so we finally can analyze also the mini-DIVING3D.

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 was 78% completed. Additional time is requested for 2018A to observe 6 galaxies to bring the degree of completion to 85%.

We have adopted a new strategy for concluding the project: We will observe the brightest remaining galaxies with the SOAR Telescope. In 2018A we propose to observe 5 Sa+Sb galaxies (with bright bulges/nuclei) with the SIFS spectrograph that will be offered in shared risk mode. We propose to observe 6 Sc+Sd galaxies (with faint bulges/nuclei) with the Gemini telescope. **This will conclude the whole project for the A semesters.** Additional B semesters will still be necessary (see bellow).

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. We propose to perform statistical analysis such as luminosity function, black hole mass function and percentages of AGN as a function of morphology, mass etc. For this statistical analysis it is absolutely necessary to observe a statistically complete sample.

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 1 galaxy is missing (NGC 1232), and is proposed to be observed in a Science Verification run in early October/2017.

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 five are being written; among them the first three papers 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. To remove it 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).

To date, 10 papers were published containing data from the DIVING3D galaxies (see list in item 6, bellow). 7 of these papers were based on observations made before 2014A when the program formally started as an LLP. Three papers were published on galaxies observed after 2014A. Three additional papers have been submitted or are ready to be submitted for publication. Three other 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 three cases (NGC 613, NGC 908 and NGC 1187) we see double central bulges. Associated with this there is strong indication of stellar population with less than 1 Gyear. Two papers on these objects are being submitted.
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.

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 published:
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, is:

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	22	14	36
4 – Milky Way twins	21	2	23
5 – Late type (Sc-Sd) spiral galaxies	28	21	49
Total	***133***	***37***	***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
2017A	17 hs	14	2

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.
A total of 14 galaxies were observed in 2017A. Two were not.

The proposed objects for the remaining semesters are:

2018A - (11 galaxies)
Gemini (Sc and Sd galaxies): NGC 6118, NGC 4504, NGC 5584, NGC 5161, NGC 3513, NGC 7713.
SOAR (Sa and Sb galaxies): NGC 6753, NGC 5530, NGC 7723, NGC 7496 and NGC 7083

2018B - 16.00h (15 galaxies)
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

2019B - 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 degree of completion, per subsample, by the end of the semesters 2016A, 2016B, 2017A, 2017B and 2018A are:

Priority	***Completion degree***				
	16A	16B	17A	17B	18A
1 – High –mass ETGs	100%	100%	100%	100%	100%
2 – Bright (B<11.0) Mini-DIVING^{3D}	93%	98%	98%	100%	100%
3 – Low-mass ETGs	80%	97%	100%	100%	100%
4 – Milky Way twins	74%	89%	91%	91%	91%
5 – Early type spirals	33%	39%	61%	61%	75%
6 – Late type spirals	45%	51%	57%	57%	67%
Total	***63%***	***70%***	***78%***	***78%***	***85%***

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 with all spectra:
- Removal of high frequency spatial noise with Butterworth filter
- Fingerprint removed

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

In order to consult the site, a username and a password are required. The NTAC can consult the site using:

Username: ntac
Password: ntac#%

The "Mini-DIVING3D" is now complete except for one object: NGC 1232, not yet observed. All data have been reduced and treated and are located in site above.

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 spiral 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 galaxies of the DIVING3D project:

A – DIVING3D objects observed before 2014A (the beginning of the LLP):

1 - 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

2 - 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

3 - 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

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

5 - 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.

6 - 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

7 - Suzi I.F. Diniz, Miriani G. Pastoriza, Jose A. Hernandez-Jimenez, Rogerio Riffel1, Tiago V. Ricci, J. E. Steiner, Rogemar A. Riffel – 2017 MNRAS 469, 994
Integral Field Unit Spectroscopy of the inner 1 kpc of the galaxy NGC 5044

B – DIVING3D objects observed after 2014A:

1 - 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

2 - 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.

3 - Patrícia da Silva, J. E Steiner & R. B Menezes – 2017 MNRAS 470, 1703
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.**

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

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

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

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

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

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

7 - 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

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

9 - 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

10 - 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.

11 - 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

12 - May, D. & Steiner, J. E 2017 MNRAS 469, 994
A two-stage outflow in NGC 1068

13 - Menezes, R. B, da Silva, Patrícia & Steiner, J. E. – accepted for publication in 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 are writing 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.

Three other papers on individual galaxies have been completed and are submitted or will be submitted soon.

- **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