Brazilian Large and Long Programs (BrLLP)
Progress Report – 2018A

The DIVING3D project: Deep IFS View of Nuclei of Galaxies

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1. Executive summary

The DIVING3D project - Deep IFS View of Nuclei of Galaxies – is one of the two Brazilian LLPs. By the end of 2018A, 85% will be completed, depending on the results of two nights of observations at the SOAR Telescope that will be made in May, 2018.
If the run is successful, we will have completed all objects of the DIVING3D project for semester A. Additional time will be requested for the SOAR Telescope for the brightest of the remaining galaxies.

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.

We have now in hands all galaxies with B<11.2. We are preparing one paper for this subsample, called Mini-DIVING3D.

So far we have published 8 papers on individual or small samples of galaxies from DIVING3D observed previous to 2014A. Three papers on objects observed after 2014A were published and two papers more have been submitted.

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

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 three 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.

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 2017B, 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 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<11.2) 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

So far 4 objects have been requested by community members.

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

The "Mini-DIVING3D" is now complete to B=11.2. 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

8 - Ricci, T. V.; Steiner, J. E.; May, D.; Garcia-Rissmann, A.; Menezes, R. B.
2018 MNRAS 473, 5334
Optical and near-infrared IFU spectroscopy of the nuclear region of the AGN-starburst galaxy NGC 7582

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

4 – R.B Menezes & J.E. Steiner
Double nuclei in NGC 908 and NGC 1187
2018 - Submitted to the Astrophysical Journal

5- Patrícia da Silva, J. E. Steiner, R. B. Menezzes
2018 - MNRAS – submitted.
NGC 6744- A nearby Milky Way morphological twin with a very low luminosity AGN.

- 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.
2018 MNRAS 473, 2198
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 as well as 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<11.2 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