Research Project

The Potential of Dark Matter and Gas Dynamics in Dwarf Spheroidal Galaxies

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Advisor: Dr. Gustavo A. Lanfranchi
Center for Astrophysics

São Paulo, April 2024

Summary

SUMMARY

A characteristic common to all classical Dwarf Spheroidal Galaxies, however still The total absence of neutral gas, not satisfactorily explained, is its removal. The gaseous content could have been caused by internal mechanisms (*feedback* stellar or of an intermediate-mass black hole), external (drag pressure, tidal force), or a combination of both. This work will investigate the evolution of gaseous content of dwarf spheroidal galaxies, taking into account different distributions of dark matter in these systems, the *stellar feedback* and the *outflow* of a black hole intermediate mass. The effects of the different formulations proposed for the potential of Dark matter in the dynamical evolution of the gaseous content of these galaxies will be analyzed. with the help of hydrodynamic simulation codes. Initially, the following will be analyzed. different proposals existing in the literature for the potential of the dark matter halo in dwarf spheroidal shapes. These formulations will then be adopted into a three-dimensional code. hydrodynamically adjusted model for the spheroidal galaxy Ursa Minor, which will be simulated within a computational box with sides twice the tidal radius of the galaxy during 3 Ganos. Based on these simulations, the pattern of the following will be analyzed as a function of time: density, temperature, pressure, and velocity of the gas in the galaxy up to its radius of tide.

1. Introduction

The Dwarf Spheroidal Galaxies (dSph) of the Local Group (LG) are relatively small systems. Simple, yet with a complex evolution. They do not exhibit any distinctive structure. (core, spiral arms, bulge, rods, etc.), have low mass (on the order of $10^{5\text{-}7} M_{\odot}$- (approximately 1 million times smaller than the mass of our Galaxy), small rays (~1 kpc compared to ~30 kpc of the Milky Way), are poorly enriched (~10-100 times smaller than the Sun) and contains, for the most part, ancient stellar populations (with ages greater than 10 Gans), but with some systems also featuring stars of varying ages. intermediate (between 10 and 3 Ganos) and new stars (with ages~1 Gano) (Matthew 98, Tolstoy, Hill & Tosi 2009, McConnachie 2012, Molero et al. 2021, Aguado et al. 2021). However, several recent studies indicate that the evolution of these galaxies is much more... more complex than its properties suggest.

Star formation in dSph, for example, exhibits different characteristics from a system to another. While galaxies like Ursa Minor and Draco formed stars in a single episode between approximately 9 and 13 years ago (Dolphin et al. 2005), Fornax and Carina, on the other hand, show evidence of several episodes of star formation. or even continuous star formation occurring until recent times (Hurley-Keller, Mateo & Nemec 1998, de Boer et al. 2012a, 2012b). What mechanisms would be responsible? The reason for these differences is still unknown. On the other hand, a common characteristic is... What is surprising about these galaxies is the total absence of neutral gas in their interstellar medium. Grcevich & Putman (2009) investigated the environment and the HI (hydrogen) content. neutral) in all dSph galaxies of the LG using available data from HIPASS (Barnes et al. 2001) and LAB (Kalberla et al. 2005) and did not detect any signs of neutral gas in virtually none of the galaxies. The authors did not reach a definitive conclusion. Regarding what would be the main mechanism responsible for removing interstellar gas from these... galaxies, although external mechanisms such as drag pressure and tidal forces have been favored (Emerick et al. 2016).

On the other hand, internal physical processes should not be disregarded. Several studies theoretical (Mac Low & Ferrara 1999, Grebel, Gallagher & Harbeck 2003, Fragile et al. 2003, Ruiz et al. 2013, Recchi 2014, Caproni et al. 2015, 2017) point out that a high fraction (above 90%, depending on initial conditions) of the gaseous medium of a galaxy dSph can be removed by galactic winds originating from supernova explosions.

(SNe). Another internal mechanism, not yet explored in studies of dwarf galaxies, and the *outflow* of an intermediate-mass black hole ($M \sim 10^4 M_\odot$-$10^6 M_\odot$ no center of the galaxy. In spiral galaxies, both observational and theoretical work they seek to estimate the contribution of *feedback* of a supermassive central black hole (SMBH) ($M > 10^6 M_\odot$) for the removal of gas from the host galaxy (Aalto et al. 2012, Cicone et al. 2014, Genzel et al. 2014; Tombesi et al. 2015, Melioli & de Gouveia Dal Pino 2015). While observations indicate intense mass loss, Melioli & de Gouveia Dal Pino (2015) argue that the jet alone is not capable of causing intense gas loss. But it can sporadically accelerate material that is exiting the galaxy. In galaxies Dwarf stars are expected to have an intermediate-mass black hole at their center. (Maccarone et al. 2005, Lora et al. 2009, Nucita et al. 2013, Manni et al. 2015), which, Thus, as in the case of SMBH, it should affect the interstellar medium of the system.

2 Objectives

The objectives of this work are:

1) to study the different proposals for the potential of dark matter in galaxies-dwarf pheroids of the Local Group and their effects on the chemical evolution of these galaxies, in especially important is the occurrence or non-occurrence of galactic winds, and the consequences for parameters. such as metallicity distribution and chemical abundance ratios;

2) Apply the results of the chemical evolution models and the different proposals for the dark matter in hydrodynamic simulation codes in order to analyze its effects on internal dynamics of these systems.

3) Based on the results obtained with the chemical evolution codes and simulations By comparing hydrodynamic data with observed data, we will seek to link which scenario to The distribution of dark matter is best suited to this type of galaxy.

3 Theoretical Framework

Among dwarf galaxies, the least luminous and least massive known are the galaxies dSph, both the classics (Sculptor, Fornax, Ursa Minor, Lei I, Leo II, Draco, Sextans, Carina and Sagittarius) as for the so-called *ultra-faint*, recently discovered in analyses of deep multi-color photometry from the Sloan Digital Sky Survey (SDSS) (Willman et al. 2005A, 2005B, Zucker et al. 2006A, 2006B, Belokurov et al. 2006, Belokurov et al. 2007, Irwin et al. al. 2007, Walsh et al. 2007, Belokurov et al. 2008, Belokurov et al. 2009, Grillmair 2009, (Watkins et al. 2009, Belokurov et al. 2010). Classical dSph systems are small systems. (radius of *core*: r_W~0,3-1 *kpc* when compared to spiral or elliptical galaxies, relatively simple (without striking structures), with low surface luminosity ($M_V > -14\,mag$), low total mass and baryonic (~$10^7 M_\odot$), poorly enriched (with average metallicities on the order of 1/10 - 1/100 of the solar value), with a stellar population ancient (and some traces of populations with intermediate ages), dominated by matter dark (M/L ratios of ~100 up to ~3000 in some *ultra-faint*), with complete absence of detectable neutral gas in its central region and a variety of stories of star formation (Mateo 98, Tolstoy, Hill & Tosi 2009, McConnachie 2012).

In addition to these properties, in recent years a series of studies related to dSph have been conducted. They analyzed everything from chemical abundances (Molero et al. 2021, Aguado et al. 2021, Lemasle et al. 2014, Hendricks et al. 2014, Letarte et al. 2006, 2010, Larsen et al. 2012, Kirby et al. 2010, 2011) up to the histories of star formation (de Boer et al. 2012a, 2012b, Dolphin et al. 2005), going through the study of stellar populations, removal mechanisms of gas, among other topics. However, the mechanisms that govern the evolution of these Galaxies are not yet fully understood, and several hypotheses have already been put forward. A striking characteristic of this type of galaxy, and one that certainly had an influence on...

Its evolution is characterized by the complete absence of neutral gas (Grcevich & Putman 2009, Spekkens).
et al. 2014), not yet satisfactorily explained. Models of chemical evolution are capable of reproducing a series of observed data from classical dSph and *ultra-faint* na-
Naturally, if low star formation efficiency and the occurrence are considered...
intense galactic winds capable of removing a large fraction of the gas from the inter-
restellar (Lanfranchi & Matteucci 2003, 2004, 2010, Vicenzo et al. 2014). In these models,
Galactic wind occurs when the kinetic energy of the interstellar gas equals or exceeds the binding energy of the galaxy. The kinetic energy of the gas is strongly dependent-
tooth of the fraction of thermal energy released by stars (in supernova explosions) or stellar winds) which is converted into kinetic energy, while binding energy depends of the galaxy's total mass (luminous matter plus dark matter) and its distribution.
The hypothesis that the energy resulting from stellar explosions is capable of removing the
The gaseous content of the galaxy still generates debate in the literature. Several studies based on
Numerical models suggest that galactic winds triggered by star formation do not
They are capable of completely removing ISM gas from dSph, a fact that is possible so-
mind for systems with masses up to $\sim 5 \times 10^6 M_\odot$ (Mc Low & Ferrara 1999, Fragile et al. 2003, Revaz et al. 2009, Revaz & Jablonka 2012). It should be emphasized, however, that, for systems with mass in the same range as those observed in dSph, a good fraction (up to ~75% of the gas could be lost, including almost all of the enriched hot gas.
acid and injected into the ISM by supernova explosions (SNe). However, these conclusions
They depend heavily on the adopted star formation history (Ruiz et al. 2013): a
Intense star formation with a high rate of supernova explosions facilitates the loss of gas.
from the ISM, while a low SNe rate is not sufficient for significant removal.
of the gas in the middle.

Despite this, in the specific case of Ursa Minor, Caproni et al. (2015, 2017) argue-
so that only the *feedback* SNe is not able to explain the almost complete absence of

Gas in the central region of the galaxy: in some cases up to approximately 30% of the content. The gaseous medium remains in the system after 3 Gans (simulation duration time). Another factor not analyzed in these studies, and which may play an important role... A key factor in the almost complete removal of the gaseous content from dSph would be the presence of a The central black hole in the galaxy. Both the radiation emitted by matter falling into the black hole as black as the particle jet typical of active galactic nuclei (AGN) can Removing gas from the central region of the galaxy generates a galactic wind, as they suggest. observational evidence. Tombesi et al. (2015), for example, based on observations of molecular winds in ultraluminous galaxies in the infrared, they claim that the wind The accretion disk of a black hole can transfer energy in an efficient way. for the ISM of the host galaxy removing gas from the central region of the galaxy, making its observable core. A similar phenomenon could have occurred in dwarf galaxies and disem- played an important role in its evolution, removing the gas that feeds the formation. of stars, decreasing their intensity or ceasing it completely and affecting, therefore In this way, the evolution of this type of galaxy.

The quantity and distribution of dark matter in dSph directly influence am- Both scenarios proposed for the removal of interstellar gas. Both internal mechanisms External factors must have enough energy to overcome the binding potential energy. of galaxies, which depends on the total mass of these systems. Since in these dwarf galaxies it is It is suggested that dynamic mass is up to 100 times greater than luminous mass, that is... first, which will almost completely define the binding energy of the galaxy. Furthermore, Knowing whether the potential well is deep or not, whether it is concentrated or extended, influences the... The dynamics of interstellar gas and determines whether it is possible for this gaseous content to be... whether or not to remove it, or what fraction can be removed.

Dwarf galaxies are believed to be the type of galaxy that, proportionally, possesses the largest amount of dark matter in relation to luminous matter (Walker et (al. 2010). In some local galaxies, the estimated mass-to-luminosity ratio reaches to be greater than 100 in the case of classic dSph and above 1000 in the case of *Ultra Faint Dwarfs* ((UfD). The way this matter is distributed in these galaxies, however, is still unknown. It is a subject of discussion, known as the problem. *cusp-core*: if in an extensive halo and with approximately constant density in the inner regions of the galaxy or if in a potential with high power-law behavior (see De Blok 2010 for (a review). To analyze, therefore, all these scenarios and their influence on the evolution of these Systems are of paramount importance in the quest to understand how these galaxies are structured. They formed and evolved. The effects of dark matter on the dynamic and chemical evolution of Local spheroidal curves can be tested using theoretical models adopting the following scenarios. proposed in the literature for the dark matter potentials in these objects.

4 Methodology

As part of this research project, the evolution of spheroidal galaxies will be analyzed. local dwarfs, in particular the effects of the dark matter halo on the dynamics of their content gaseous and its chemical properties. The scenario for removing the gas through Galactic winds will be tested with different formulations for distribution and quantity. of dark matter present in these objects.

Studies on the presence and distribution of dark matter in dwarf galaxies (Vera- (Ciro et al. 2012, Governato et al. 2012, Walker 2013 and references), with a broader perspective. detailed information on this subject provides important links to characterize this type. Galaxy simulations. The different proposals for the distribution of dark matter. in these galaxies, as shown in these and other works, data will be collected and analyzed for to be subsequently included in chemical evolution models and simulation code. hydrodynamics. From there, the gas dynamics will be analyzed, as well as the occurrence and intensity The phenomena of galactic winds and their consequences on chemical properties will be investigated.

of these systems analyzed.

4.1 Dark Matter in dSph Galaxies

In 1933, Zwicky discovered that luminous matter is responsible for only one fraction of the mass of the Universe. Calculating the radial velocity of 8 galaxies in the cluster- In the Coma radar experiment, he found a much higher dispersion velocity than expected. Based on these speeds, the mass in the cluster should be 400 times greater. that estimated from luminous matter. The matter that would be missing was He called it dark cold matter, and it would be much more abundant than luminous matter. The same result was subsequently obtained for the Virgo cluster (Smith 1936). and for the Local Group (Kahn & Woltjer 1959). In 1939, the rotational speeds of Objects in the outer regions of M31 were measured, with very high values. The curve of Andromeda's rotation showed that rotational speeds did not follow a pattern. Keplerian: they remained constant between 16 and 30 kpc from the center of the galaxy instead of decay. In other words, the mass of the galaxy in these regions should increase, although the luminosity... decreased. From this it was concluded that M31 should also contain dark matter. in a quantity greater than the luminous amount. The same was observed in all types of galaxies. spiral and elliptical galaxies, where the dynamical mass is inferred from the theorem of viral.

Dwarf galaxies are also characterized by having a dynamic mass greater than their luminous mass. However, on a much larger scale. In classical dSph galaxies of the Local Group, the ratio The estimated mass-luminosity ratio is on the order of 100, or greater, and in UfDs (*Ultra Faint Dwarfs*) It can reach values exceeding 1000 (Mateo 1998, Walker 2009). There is an apparent The relationship between this ratio and the galaxy's luminosity: the lower the luminosity, The greater the ratio (Walker 2013). However, the exact quantity and form of the potential

The exact proportions of dark matter in dSph are not yet known. While models

Cosmological simulations predict the density of dark matter in dwarf galaxies.

It is approximately constant in the central regions of these systems (Navarro et al. 1996,

1997, Diemand et al. 2005), dynamic observations suggest that the matter potential

Darkness in those same galaxies behaves like an intense power law -*cored*-in

scales always exceeding a few hundred parsecs, typical central densities between

10 - 22 Gev/cc and with solid halos -$M_h > 5 \times 10^7 M_\odot$(Gilmore et al. 2007).

4.2 The hydrodynamic code

Non-cosmological three-dimensional hydrodynamic simulations of gas from a typical

Isolated dSph galaxies are being studied to analyze the effects of dark matter potential.

in the gas dynamics of dwarf epheroidal galaxies, using the same code used in

previous work by the group (Caproni et al. 2015, Caproni et al. 2017, Lanfranchi et al.

2021). Assuming an initial baryonic matter-dark matter ratio derived

of the cosmic microwave background radiation and a gravitational potential of matter

Dark static and nuclear, the galactic gas distribution is evolved by 1 Gan taking

taking into consideration *outflow* from a central IMBH and the *feedback* type II supernovae

and of type Ia. The initial simulation configuration is exactly the same as that adopted for

a dSph Ursa Minor (used as a model for a classical dSph galaxy), described in

Details in Lanfranchi et al. (2021). The interstellar medium is initially in equilibrium.

hydrostatic potential of dark matter (as adopted by Mac Low & Ferrara)

(1999)).

The code developed in Caproni et al. (2015, 2017) and Lanfranchi et al. (2021) for

The Ursa Minor galaxy, as used in this project, is based on the code... *Pluto*[1], a code

A fluid dynamics diagram written in the C programming language that uses finite elements to...

[1] http://plutocode.ph.unito.it/

Integrate the system of differential equations in conservative form (Ignone et al. (2007)):

$$\frac{\partial \vec{U}}{\partial t} = -\vec{\nabla} \cdot \vec{T}(\vec{U}) + \vec{S}(\vec{U}) \quad (1)$$

where U represents the conserved physical quantities, T and second-order tensor associated with the flow of quantities U and S represents the source terms associated with the pro- problem.

In the hydrodynamic case, the conserved quantities U are of the form $U = [\rho, m, E]^T$, being ρ the volumetric density, $m = \rho v$, v speed and AND the energy density of a given fluid element.

In this work, as described in Caproni et al. (2015, 2017) and Lanfranchi et al. (2021) observational characteristics of the Ursa Minor galaxy, a dSph, are used. typical classical model, to define the initial conditions of the simulations. The total mass of the halo of Dark matter is estimated from the radius of the nucleus $r_{.0}$=300 pc, the initial speed of sound in the middle c_{s0}=11.5 km.s^{-1} and the circular speed in Ursa Minor v_w=21.1 km.s^{-1} (Irwin & Hatzidimitriou 1995, Strigari et al. 2007), resulting in a value of M_h= $1.51\times10^9 M_\odot$ Based on the WMAP relationship between dark matter and baryonic matter, The estimated initial total mass is $M_{.g0} \sim 2.94\times10^8 M_\odot$ and the initial central density is ρ_0= 3.11×10^{-22} g.cm^{-3}.

The amount of SNe that will be considered in this project and its temporal distribution. are derived from the supernova rate resulting from chemical evolution models that reproduce- They derive the ratios between chemical abundances and various other chemical properties. of dSph galaxies (Lanfranchi & Matteucci 2004, 2007). The injection sites of the energy The energies released in supernova explosions are detailed in Lanfranchi et al. (2024). In am- In both cases, an energy of 10^{51} erg is inserted in the middle when t_{snia} or t_{snii} (scale time for the occurrence of a type Ia supernova and a type II supernova, respectively) is reached. The location where the energy is inserted, however, is different for each type. In

In the case of SNe II cells, the choice of the cell where the energy is injected is made according to the density.

Gas density: the higher the density, the greater the likelihood of the cell being selected.

If there is more than one cell with high density, then the choice between them will be random.

SNe Ia has a much longer timescale for its occurrence (potentially reaching (up to about 1 billion years after the formation of stars) which is why they can explode in locations far from the high-density region where they were formed. In this way, the The choice of the cell where the energy from each SN Ia will be inserted is completely random.

THE*feedback*of an IMBH (M_{BH}~$10^3 10^6 M_{\odot}$) is considered from the creation of one*outflow*of matter exiting from two central cells of the adopted computational box, with an injection density and with an injection speed in the direction of one of the axes of the rectangular coordinate system. The injection values of density and speeds were set within a range corresponding to the estimated mass. observationally for the central black hole and the luminosity values of AGN in dwarf galaxies (Maccarone et al. 2005, Lora et al. 2009, Nucita et al. 2013, Manni et al. al. 2015, Mezcua & Sánchez 2020) and following the results of Lanfranchi et al. (2021).

5. Implementation Schedule

In the first stage, attention will be given to searching for and reading literature specifically-specialized area in order to collect the data necessary for the development of the project. and so that the student becomes familiar with the processes of searching for and collecting scientific data and with the specific content of the work's development area. The data analyzed-Those will be related to the distribution and quantity of dark matter present in dSph galaxies. There is still no consensus on this point and several formulations exist. Several proposals have been made in recent years, taking into account different masses, densities, and profiles. Each of these proposals will be analyzed.

After working with the observed data and having familiarity and experience with

After this, attention will be devoted to the model of chemical evolution. The fundamentals

Theorists of this type of model will be studied and simple models will be developed by the group.

The guidance from the advisor will be used as a learning tool. In this part of the work

the different dark matter formulations found will be applied to the model and the

Results analyzed. However, at this stage, very large differences are not expected.

among the models with different formulations since these models do not take into account

the dynamic part of the system. The effects of dark matter, in this case, will be noticeable.

only in the binding energy of the galaxy and, consequently, in the occurrence of winds.

galactic. These, however, are of vital importance in the evolution of dSph galaxies.

The project will continue in a second phase, when the different distributions...

The guidelines will be applied to hydrodynamic simulations. In this case, the differences will be...

More pronounced and robust results should be obtained.

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Appendix 1: Link to the supervisor's Lattes curriculum.

Prof. Dr. Gustavo A. Lanfranchi
Lattes: http://lattes.cnpq.br/4920024724994011

7 Appendix 2: Supervisor's opinion

DECLARATION

São Paulo, April 18, 2024

I hereby declare for all due purposes that the student Gustavo Mota Macedo, RGM: 30410746, enrolled in the 5th semester of the Computer Science course, is my advisee in the Scientific Initiation program, in the area of Extragalactic Astrophysics, with a research project entitled...*The Potential of Dark Matter and Gas Dynamics in Dwarf Spheroidal Galaxies*.

The research developed by the student is within the project "Application of Theoretical-Computational Models in Astrophysics" within the research line of Galactic and Extragalactic Astrophysics of the Postgraduate Program in Astrophysics and Computational Physics. All the research developed in the aforementioned project has the collaboration of professors and researchers from national and international universities and institutes, highlighting Prof. Dr. Francesca Matteucci from the Università Degli Studi di Trieste (Italy).

It is also important to mention that the candidate has been involved in a scientific initiation internship since February 2024, during which time they have studied general topics in Astronomy as well as specific subjects related to the area of knowledge of the research project to be developed, demonstrating great interest and dedication.

Yours sincerely,

Prof. Dr. Gustavo A. Lanfranchi
Center for Astrophysics, City University of São Paulo

CANDIDATE INFORMATION

Full name: Gustavo Mota Macedo. Link to CNPq Lattes curriculum (optional): Course: Computer Science. Semester: 5th. University: Universidade Cidade de São Paulo.

RGM: 30410746

Period: Daytime Campus: Tatuapé
Overall average grade: 8.35

SUPERVISOR'S INFORMATION

Full name: Gustavo Amaral Lanfranchi

Link to CNPq Lattes curriculum (required): http://lattes.cnpq.br/4920024724994011

Letter of Acceptance for Scientific Initiation Supervision

São Paulo, April 18, 2024

In accordance with the rules of the PIBIC and PIBITI Calls for Proposals from Cruzeiro do Sul University and Cidade de São Paulo University, I declare that I accept to supervise the student. *Gustavo Mota Macedo*, from the Course of*computer Science*, as a scholarship recipient of the Scientific Initiation Program, in the research project entitled:*"The Potential of Dark Matter and Gas Dynamics in Dwarf Spheroidal Galaxies*.

I further declare that the student participated in the development and discussion of the research project, specifically in the following stages:*Introduction, methodology and schedule*The research developed in the aforementioned project has the collaboration of Prof. Dr. Anderson Caproni and Prof. Dr. Pedro Henrique Ribeiro da Silva Moraes, who are also professors in the Postgraduate Program in Astrophysics and Computational Physics.

I confirm that the information above is correct and that I am aware of and agree to the rules established in the PIBIC and PIBITI Manuals of Cruzeiro do Sul University and Cidade de São Paulo University.

Yours sincerely,

Prof. Dr. Gustavo A. Lanfranchi

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Decree No. 757, of July 20, 2016, Official Gazette No. 139, of July 21, 2016, Section 1, Page 55

SCHOOL RECORD

STUDENT INFORMATION

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CPF:07441242550**Identification Document:**2042253294**Issuing state:**BA

ENTRY DETAILS

Access method: Enem**Date:**16/03/2022

COURSE DETAILS

e-MEC Code:20041**Course:**Computer Science (Bachelor's Degree)

Legal Act: Decree No. 919, of December 27, 2018, Official Gazette No. 249, of December 28, 2018, Section 1

Discipline	Period	C/Schedule	Average	Situation	Teacher / Qualification
6831 - APPLICATIONS FOR INTERNET	**2022/1**	60	9.0	Approved	CARLOS ALBERTO MAJER - Specialization
8607 - LANGUAGE Brazilian Sign Language	****	40	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10534 - LOGIC COMPUTATIONAL	**2022/1**	60	8.5	Approved	RODRIGO RODRIGUES - Master's degree
6836 - MATHEMATICS APPLIED	**2022/1**	80	7.0	Approved	VINICIUS AZEVEDO BORGES - Master's Degree
10233 - ORGANIZATION AND ARCHITECTURE OF COMPUTERS	**2022/1**	60	9.5	Approved	SERGIO RICARDO MASTER PENEDO - Master's degree
10554 - THOUGHT COMPUTATIONAL	**2022/1**	60	8.0	Approved	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10531 - PROGRAMMING OF COMPUTERS	**2022/1**	60	8.0	Approved	FRANCIS OF ASSISI CAVALLARO - PhD
10573 - CIRCUITS LOGICAL	**2022/2**	40	9.0	Approved	RAIMUNDO NONATO DA ROCHA FILHO - Master's degree

Discipline	Period	C/Schedule	Average	Situation	Teacher / Qualification
10572 - CALCULATION DIFFERENTIAL AND INTEGRAL I	**2022/2**	80	8.5	Approved	CLAUDIO MARCIO RIBEIRO MAGALHAES - PhD
6845 - INTERFACE HUMAN-COMPUTER	**2022/2**	40	8.5	Approved	CLAUDIO BENOSSI - Master's degree
10574 - LABORATORY OF DEVELOPMENT OF ALGORITHMS	**2022/2**	60	7.0	Approved	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10575 - WEB PROGRAMMING	**2022/2**	60	9.5	Approved	CARLOS ALBERTO MAJER - Specialization
10235 - DEVELOPMENT TECHNIQUES OF ALGORITHMS	**2022/2**	60	8.5	Approved	SERGIO RICARDO MASTER PENEDO - Master's degree
10576 - CALCULATION DIFFERENTIAL AND INTEGRAL II	**2023/1**	80	9.5	Approved	CLAUDIO MARCIO RIBEIRO MAGALHAES - PhD
10577 - STRUCTURES DATA I	**2023/1**	60	7.0	Approved	JULIANO RATUSZNEI - Master's degree
10578 - MATHEMATICS DISCREET	**2023/1**	60	8.5	Approved	FRANCIS OF ASSISI CAVALLARO - PhD
8683 - MODELING OF DATA	**2023/1**	80	7.5	Approved	JESSICA BARBARA DA SILVA RIBAS - Master's Degree
10579 - SCHEDULE OBJECT-ORIENTED	**2023/1**	60	9.0	Approved	TATIANA DA SILVA HORTELANO VIECO - Master's degree
6871 - NETWORKS OF COMPUTERS	**2023/1**	60	7.5	Approved	CLEBER SILVA FERREIRA DA LUZ - PhD
10546 - SYSTEMS ANALYSIS AND DESIGN	**2023/2**	60	7.5	Approved	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10544 - ENGINEERING SOFTWARE	**2023/2**	80	9.0	Approved	VINICIUS HELTAI PACHECO - PhD
10545 - STRUCTURES DATA II	**2023/2**	60	8.0	Approved	JULIANO RATUSZNEI - Master's degree
8807 - PROBABILITY AND STATISTICS	**2023/2**	80	9.5	Approved	LUCIANO DE OLIVEIRA SOURCES - Specialization
10248 - SYSTEMS OPERATIONS	**2023/2**	60	8.0	Approved	FRANCIS OF ASSISI CAVALLARO - PhD

Discipline	Period	C/Schedule	Average	Situation	Teacher / Qualification
10224 - BANK OF DATA	**2024/1**	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
8105 - CALCULATION NUMERIC	**2024/1**	80	******	Pending	FRANCISCO AGUSTIN ECHALAR AXE - PhD
12755 - LANGUAGE ENGLISH: BASIC	**2024/1**	80	******	Pending	JOCELMO CASSIO DE ARAUJO LEITE - PhD
10115 - OPTIONAL	****	80	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10547 - PROCESSING IMAGES	**2024/1**	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10548 - SYSTEMS CLIENT/SERVER	**2024/1**	60	******	Pending	CLEBER SILVA FERREIRA DA LUZ - PhD
8947 - THEORY OF GRAPHS	**2024/1**	60	******	Pending	JULIANO RATUSZNEI - Master's degree
7862 - ARCHITECTURE OF SYSTEMS DISTRIBUTED	****	40	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10535 - COMPUTABILITY AND COMPLEXITY OF ALGORITHMS	****	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
7088 - COMPUTING GRAPHICS	****	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
7089 - COMPUTING PARALLEL AND DISTRIBUTED	****	80	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10253 - OPTIONAL	****	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10537 - PROGRAMMING FOR MOBILE DEVICES	****	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
7863 - BIG DATA	****	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
7864 - FUNDAMENTALS INTELLIGENCE ARTIFICIAL	****	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree

Discipline	Period	C/Schedule	Average	Situation	Teacher / Qualification
10536 - LANGUAGES FORMAL AND AUTOMATA	****	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10247 - QUALITY OF SOFTWARE	****	40	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
8985 - WORK OF GRADUATION INTERDISCIPLINARY I	****	140	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
12100 - TOPICS ADVANCED IN SYSTEMS INFORMATION I	****	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
7865 - SCIENCE OF DATA AND LEARNING MACHINE	****	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10549 - COMPUTING IN THE CLOUD	****	80	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
12840 - LABORATORY FROM DATABASE ADVANCED	****	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
10508 - PROJECT OF LANGUAGES OF SCHEDULE	****	60	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
8986 - WORK OF GRADUATION INTERDISCIPLINARY II	****	140	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree
6604 - GENERAL ETHICS AND CITIZENSHIP	****	40	******	Pending	TATIANA DA SILVA HORTELANO VIECO - Master's degree

Complementary Activities

Teaching, Research and Outreach	274	TATIANA DA SILVA HORTELANO VIECO - Master's degree

Subtitles

A -Approved**S -**Satisfactory**I -**Unsatisfactory***** **-**Credit transfer

Additional Data

Estimated Workload: 3200 hours
Completed Course Load: 1634 hours
Enade/2022: Student ineligible for the Enade exam due to the evaluation cycle calendar or the nature of the course's pedagogical project.

Additional Information

Global average: 8.35