FACULTAD DE
INGENIERÍA Y CIENCIAS
udp

NÚCLEO DE
ASTRONOMÍA udp

STUDY PLAN
DOCTORATE IN ASTROPHYSICS

Year 2018

I. BACKGROUND OF THE PROGRAM

Name:	Doctorate in Astrophysics
Abbreviation:	DAF01.0_2019
Faculty:	Faculty of Engineering and Sciences
Degree granted:	Doctor in Astrophysics
Intermediate degree/certification	Master in Astrophysics
Director of the program:	Lucas A. Cieza
Year of creation of the program	2018
First year admission:	2019
Duration:	8 semesters
Student's dedication:	Full days, 4 years
Working day:	Daytime
Modality:	Classroom/live
Chronological hours in person (face to face):	616

Total amount of chronological hours (in person + independent work)	7200
Total credits:	240
Date of approval of the Faculty Council:	June 27, 2018
Date of approval of the Academic Council:	October 29, 2018
Date of approval of Superior Council:	October 30, 2018

II. DESCRIPTION OF THE ACADEMIC PROJECT.

2.1. Basics

The UDP Astronomy Nucleus was created in 2013 with the aim of forming a high-level international research group that can capitalize on the enormous comparative advantages that Chile has for the development of observational astronomy. Currently, Chile hosts the largest collection of telescopes in the world. Considering the new generation of mega-telescopes under construction that will be installed in the country (E-ELT, GMT, and LSST), the Chilean territory will concentrate nearly 70% of the terrestrial astronomical infrastructure worldwide. These cutting-edge astronomical facilities represent a unique opportunity for Chilean universities able to can successfully compete for the 10% of the observing time reserved for the host country in each telescope.

Despite its short history and modest size, the UDP Astronomy Nucleus has managed to establish itself as an extremely productive group, measured in terms of the average number of ISI / WoS publications of its scholars. In this context, the creation of a PhD program is essential for the consolidation of the UDP Astronomy Nucleus as a group of international recognition, understanding that:

1) The training of new researchers is an unavoidable responsibility of already established researchers and universities that develop high level research

2) The UDP PhD program will be a valuable contribution to the development of national astronomy, expanding the existing offer in this level of training.

3) Direct doctoral thesis projects are a fundamental aspect of the professional development of scientists, and of astronomers in particular, and thus a doctoral program is necessary to attract and retain scholars and researchers of the best international level.

4) The quality of doctorate programs provides global projection to your university, multiplying the impact of the institution through its graduates.

2.2. Lines of research

1) **Astrophysics of Planetary Systems:** planetary formation, protoplanetary discs, extra-solar planets, cosmic dust laboratory.
2) **Star and Galactic Astrophysics:** stellar evolution, stellar populations and abundances, galactic dynamics, galactic archeology, galactic transients.
3) **Extragalactic Astrophysics:** galactic evolution through cosmic time, extragalactic transients, active galactic nuclei, supermassive black holes

2.3. Applicants and their profiles.

The program is aimed at postulants who hold a bachelor's degree or master's degree in astronomy or related sciences (physics, planetary sciences, etc.). It is expected that the candidates have excellent qualifications in their previous careers, some experience in research projects and a very high level of motivation for research in astronomy. Applicants must also handle the English language (reading comprehension is essential and highly desirable oral and written expression) and be able to devote full time to the doctoral program.

2.4. **Admission requirements and selection criteria**

The formal requirements for admission are: Bachelor's degree or master's degree in astronomy or related sciences (physics, planetary sciences, etc.) and academic suitability of the applicant, which will be evaluated based on the following background.:

1) Cover letter explaining their motivation for entering the PhD and their research interests.
2) Curriculum Vitae
3) Certificate of undergraduate and graduate degrees (if applicable)
4) Certificate of degree or letter from the university specifying the expected date of obtaining degree
5) A minimum of two and a maximum of three letters of recommendation.

The preselected applicants will be called to interview with members of the academic committee of the program. The criteria and weights used to evaluate the background of the applicants will be the following:

Previous training, rankings, grades and proficiency level of the English language (40%)
Research experience based on the CV (20%)
Motivation and potential to become a successful doctoral student based on the letter of intent and interview (20%)
The potential of the candidate to obtain the degree according to the strengths and weaknesses mentioned by the letters of recommendation (20%)

The aforementioned weights will serve as a guide during the admission process, based on which the Program Committee will generate a ranking of the applicants from which the available vacancies will be filled. However, beyond these percentage weights, each application will be evaluated and discussed individually. Although the level of English will be considered as part of the admission process, this will not be an exclusive requirement. Exceptional candidates with deficiencies in their level of English (oral and / or written) may be admitted, but must take remedial courses to a satisfactory level (measured in terms of their oral presentations and written work in the courses).

During the admission process, the interests declared by the applicants will also be taken into account in terms of research areas, and the balance of research areas of the registered students, taking care that no member of the faculty is overburdened with their responsibilities as director of thesis.

2.5. Program objectives.

1) Contribute to the training of researchers in astrophysics, one of the areas of science where Chile has the capacity to become a world leader.

2) To form a group of academics with high scientific productivity, outstanding students and postdoctoral researchers, that enhance the impact of the research carried out by the UDP Astronomy Nucleus in the areas of Astrophysics of Planetary Systems, Stellar and Galactic Astrophysics, and Extragalactic Astrophysics, and his contribution as an internationally relevant actor within the discipline.

2.6. Graduate's profile

The Doctors in Astrophysics from UDP will be able to develop original and independent research, contributing to the advancement of the discipline by publishing its results in journals and specialized conferences.

They will have a solid formation in physical processes and its manifestation in astronomical phenomena, and the capacity of learning new tools -such as observation techniques, data management, analysis methods, numerical simulations- that will allow them to stay at the cutting-edge of their expertise, be it astrophysics of planetary systems, stellar and galactic astrophysics or extragalactic astrophysics.

At the same time, the students will have developed critical thinking skills and capacities to work collaboratively, enabling them to insert themselves in international research networks and grow in demanding and competitive academic and professional contexts. Thus, doctoral graduates in UDP astrophysics will be able to work in purely academic environments, such as universities, or more technical, such as astronomical observatories.

2.7. Curriculum structure

The doctoral program consists of an initial school year, a candidacy exam based on a thesis project, a final thesis development cycle, and a thesis defense.

The initial academic cycle will last for 3 semesters and will consist of a mesh of general courses, specialized courses, colloquiums, and autonomous research projects. The final cycle lasts for 5 semesters and culminates with the thesis defense after the eighth semester of the doctorate.

Curriculum

Initial lecture cycle			
1° semester	**2° semester**	**3° semester**	QUALIFICATION EXAM
Star and Galactic Astrophysics (8 credits)	Astrophysics of Planetary Systems or optional course (8 credits)	Extragalactic Astrophysics or optional course (8 credits)	
Research project I (16 credits)	Research project II (16 credits)	Thesis project (16 credits)	
Topics of Astrophysics I (colloquium/astro-ph) (6 credits)	Topics of Astrophysics II (colloquium/astro-ph) (6 credits)	Topics of Astrophysics III (colloquium/astro-ph) (6 credits)	

Thesis Project cycle					
4° semester	**5° semester**	**6° semester**	**7° semester**	**8° semester**	THESIS DEFENSE
Doctoral Thesis I (30 credits)	Doctoral Thesis II (30 credits)	Doctoral Thesis III (30 credits)	Doctoral Thesis IV (30 credits)	Doctoral Thesis V (30 credits)	

Initial cycle

The PhD program will have a strong emphasis on research, and students are expected to identify their research areas and their thesis directors during the first two semesters. In cases that the Thesis Director is identified from the beginning of the program, it is expected that the doctoral student will begin his research work under her/his direction (Research papers I and II of the curriculum). In the event that the Thesis Director is not identified at the beginning of the program, the Program Director will assign an advising professor, in dialogue with the PhD student and the members of the Program Committee. The advising professor will help the student to select the elective courses and will be her/his point of contact with the program until the student identifies a Thesis Director and Project, which must be presented during the third semester.

The initial school year is designed to provide comprehensive training in the field of astrophysics. Each of the main courses (of 8 credits) of the mesh (**Astrophysics of Planetary Systems, Stellar and Galactic Astrophysics, and Extragalactic Astrophysics**) will be offered once every 3 semesters. These courses are designed to provide an overview of the three major areas of the doctoral program, and may be taken in any order. The course of Stellar and Galactic Astrophysics is mandatory for all students since it is fundamental for all the research lines of the doctorate, from the planetary systems to the extragalactic astronomy. At the suggestion of the guide professor, the courses of Astrophysics of Planetary Systems and Extragalactic Astrophysics can be replaced by specialized elective courses (also 8 credits) that are more in line with the interests and / or academic needs of the student.

The strategy of evaluation of the courses will be defined by each teacher and must be clearly indicated in the syllabus of the subject. However, **each course of 8 credits** will generally have a minimum of two assessments, which allow the student to progressively understand what is expected of him and what the corresponding requirements are for each course. The approval criteria will be specified in the program (in terms of grade, score or other indicator); In addition, a minimum of 70% attendance or more will be required, in the case that is expressly indicated in the program.

The "**Research Projects I and II**" (16 credits each) of the curriculum will allow students to familiarize themselves with the different dimensions of astronomical research: bibliographical study, identification of unsolved problems and ways of approaching them, development of proposals for observation, techniques and tools for data analysis, analysis and critical discussion of results, and presentation of results in specialized journals and oral presentations. It is also expected that the Research Projects developed during the first semesters will help students identify and define their thesis projects. The evaluation of these modules will be based on a written report of the research activities and an oral presentation that will be developed during a seminar at the end of the semester where all the students of the program (both of the initial and final cycle) will present their last advances in research.

The modules "**Topics of Astrophysics I, II, and III**" (6 credits each) will provide a broad view of modern astrophysics based on the discussion of recent literature and the presentations of guest speakers at the UDP astronomy colloquia, and at the same time, they will help students develop relevant academic skills, such as the ability to participate in scientific discussions and the ability to orally present their work. The evaluation will be based on the students' presentations and the discussions during the meetings. Written reports on the topics presented in the colloquia organized by the UDP Astronomy Nucleus will also be evaluated.

The module "**Thesis Project**" (of 16 credits) is designed so that the doctoral student, under the guidance of his Thesis Director, prepares her/his thesis project, which will be the **Qualification Exam**.

The **Thesis Project** will be a written document in English and must include the following elements:

a) Definition of the problem, hypothesis or questions to solve.
b) Critical review of the specialized literature, theoretical framework and state of the art in the area of study.
c) Research methodology.
d) Schedule of activities, with special emphasis on important milestones such as obtaining data and publishing results.

The **evaluation of the thesis project** will consist of the analysis of the written thesis document and a subsequent oral defense by the student. After the oral defense, also in English, the thesis committee will decide by simple majority if the exam is approved or rejected. In case of failing, the student will have a second chance to render it within a period of 6 months.

Once the qualification exam is passed, the student will enter the final thesis development cycle as a "**doctor candidate**".

Final cycle

The final thesis development cycle lasts for 5 semesters and culminates with the thesis defense in the eighth semester. The thesis work is mostly autonomous, but includes regular meetings with the Thesis Director. As part of the Doctoral Thesis modules (I, II, III, IV and V, of 30 credits each), the doctoral student must submit semiannual written reports detailing the progress of their thesis project. The written reports will be shared with all the members of the Defense Committee to evaluate the progress in the thesis work and send their assessments and suggestions to the student and the Thesis Director. The doctoral student must also present their progress orally during the seminar dedicated for this purpose that will be carried out at the end of each semester. It is also expected that, during the final cycle, the doctoral student will expand their international networks through internships abroad, presentations at international meetings and / or collaborations with foreign researchers during the development of their research projects.

The **PhD thesis** must be an original research work that contributes to the development of the discipline. The tenor of this work is expected to be equivalent to 2 first author articles published in specialized ISI / WoS journals. That is, that the content of the thesis can be published in 2 ISI articles of first author, regardless of whether these articles have been published, accepted, sent or are very close to being submitted. The elements of the thesis work should be clearly related to each other, and should consider an initial summary, a section of introduction to the whole of the thesis work and a section of general conclusions. At least one of the articles of the thesis must be accepted for publication at the time of graduation.

Thesis Project Evaluation: The thesis will be evaluated by a Defense Committee that will consist of 5 members (including the Thesis Director) all of them with the degree of doctor and experts in the subject of the doctoral thesis or in part of it. The Defense Committee will be constituted within 3 months of the approval of the thesis project and it is expected that it will meet at least once a year with the student, to evaluate the progress of their work. During the eighth semester, the doctoral student will send the doctoral thesis to the Defense Committee. The defense of the thesis work will be an oral presentation in English by the doctoral student followed by a questioning session by the members of the Defense Committee.

2.8. Graduation requirements and final grade

The **graduation requirements** are as follows:

a) Have approved (or validated) all the elements of the current mesh
b) Pass the qualification exam
c) Approve the two components of the thesis defense: written work and oral presentation.
d) Have at least one article by the first author published or accepted in a specialized international journal.

The **final grade of doctor degree** will only consider the thesis and will be calculated as follows:
• 50% Thesis Report note (DAFINFTE1)
• 50% oral defense note (DAFDEFTE1)

2.9. Magíster en Astrofísica

Students will be eligible for the intermediate certification of Master in Astrophysics, once the initial cycle of the program has ended. To receive the Master's degree, the student must meet the following requirements:

1. To approve all the curricular activities of the initial cycle, with the exception of the qualification exam. That is, having accumulated a total of 90 credits based on courses, seminars and research projects.
2. Present the results of their Research Projects developed during the first 3 semesters, in a written report that will have the format of Master's Thesis. This report must be approved or rejected by a simple majority of the Academic Committee of the Program.

III. . Table of assignments or modules

Semester 1							
Code	Course name or activity	Requirements	Type	Duration (Weeks)	Total Attendance (Hours)	Credits	Evaluation scale
DAF0001	Stellar and galactic astrophysics	*N/R*	*Mandatory*	*18*	36	8	*Approved/disapproved*
DAF0002	*Astrophysics Topics I*	*N/R*	*Mandatory*	*18*	*36*	*6*	*Approved/disapproved*
DAF0003	*Research Project I*	*N/R*	*Mandatory*	*18*	*72*	*16*	*Approved/disapproved*
				Total:	***144***	***30***	

Semestre 2							
Code	Course name or activity	Requirements	Type	Duration (Weeks)	Total Attendance (Hours)	Credits	Evaluation scale
DAF0004	*Astrophysics of planetary systems*	*N/R*	*Elective*	*18*	*36*	*8*	*Approved/disapproved*
	Elective 8-credit course		*Elective*	*18*	*36*	*8*	*Approved/disapproved*
DAF0005	*Astrophysics Topics II*	*DAF0002*	*Mandatory*	*18*	*36*	*6*	*Approved/disapproved*
DAF0006	*Research Project II*	*DAF0003*	*Mandatory*	*18*	*72*	*16*	*Approved/disapproved*
				Total:	***144***	***30***	

Semester 3							
Code	Course name or activity	Requirements	Type	Duration (Weeks)	Total Attendance (Hours)	Credits	Evaluation scale
DAF0007	*Extragalactic Astrophysics*	*N/R*	*Elective*	*18*	*36*	*8*	*Approved/disapproved*
	Elective 8-credit course		*Elective*	*18*	*36*	*8*	*Approved/disapproved*
DAF0008	*Topics of strophysics III*	*DAF0005*	*Mandatory*	*18*	*36*	*6*	*Approved/disapproved*
DAF0009	*Thesis project*	*DAF0006*	*Mandatory*	*18*	*72*	*16*	*Approved/disapproved*
DAFEXCAL1	*Qualify exam*	*90 credits*	*Mandatory*	*1*	*2*	*0*	*Approved/disapproved*
				Total:	***146***	***30***	

Semester 4							
Code	Course name or activity	Requirements	Type	Duration (Weeks)	Total Attendance (Hours)	Credits	Evaluation scale
DAF0010	PhD thesis I	*DAFEXCAL1*	*Mandatory*	*18*	*36*	*30*	*Approved/disapproved*
				Total:	***36***	***30***	

Semester 5							
Code	Course name or activity	Requirements	Type	Duration (Weeks)	Total Attendance (Hours)	Credits	Evaluation scale
DAF0011	PhD thesis II	*DAF0010*	*Mandatory*	*18*	*36*	*30*	*Approved/disapproved*
				Total:	***36***	***30***	

Semester 6							
Code	Course name or activity	Requirements	Type	Duration (Weeks)	Total Attendance (Hours)	Credits	Evaluation scale
DAF0012	PhD thesis III	*DAF0011*	*Mandatory*	18	36	30	*Approved/disapproved*
				Total:	***36***	***30***	

Semester 7							
Code	Course name or activity	Requirements	Type	Duration (Weeks)	Total Attendance (Hours)	Credits	Evaluation scale
DAF0013	PhD thesis IV	*DAF0012*	*Mandatory*	*18*	*36*	*30*	*Approved/disapproved*
				Total:	***36***	***30***	

Semester 8							
Code	Course name or activity	Requirements	Type	Duration (Weeks)	Total Attendance (Hours)	Credits	Evaluation scale
DAF0014	PhD thesis V	*DAF0013*	*Mandatory*	*18*	*36*	*30*	*Approved/disapproved*
DAFINFTE1	Thesis report	*DAF0014*	*Mandatory*	*0*	*0*	*0*	*1 a 7 (minimum 4)*
DAFDEFTE1	Thesis defense	*DAFINFTE1*	*Mandatory*	*1*	*2*	*0*	*1 a 7 (minimum 4)*
				Total:	***38***	***30***	

IV. FOLLOW UP ON THE IMPLEMENTATION OF THE STUDY PLAN

The present study plan will be subject to a permanent process of monitoring and eventual revision. There will be semester meetings of the faculty members to discuss the possible modifications that the different subjects or the curriculum mesh as a whole. These meetings will be held preferably at the end of each semester (during the months of December / January and July / August).

For purposes of monitoring and self-regulation, the Academic Committee will collect the following information:

a) Results of student surveys (Opinion of students in Teacher Evaluation Survey, DAI Surveys, etc.).
b) Samples of student's work (course evaluations, research papers, semi-annual seminars presentations, etc.).
c) Review of the Thesis Projects and analysis of the results of the candidacy exam.
d) Follow-up to the work plan of each student and semiannual report of advances in the thesis (prepared by the students as part of the thesis modules).
e) Thesis papers that have been sent for evaluation to the Defense Committee.
f) Reports of the Defense Committee on the theses presented.

The Director (eventually with all or some members of the Academic Committee) will meet with the students every six months to discuss the progress of the courses and collect their concerns and suggestions regarding specific courses and the general design of the program.

V. COURSE PROGRAMS.

Name of the course/ module: **Stellar and galactic astrophysics, 8 credits** (Jofré and/or Prieto)
Brief description of the course / module: General course designed for all students of the program, since stellar astrophysics is fundamental for all lines of doctoral research, from planetary systems to extragalactic astronomy. This course will be offered at least once every 3 semesters.
Learning objectives: To learn about the theoretical framework of the nature and conditions of the life of a star, from its birth to its death. This theoretical framework will be complemented with the observational sources that are available today to advance with the theoretical aspects not yet solved. Become familiar with the texts and fundamental equations of the subject. Familiarize yourself with all the types of stars that are known today in the Universe.
Contents: · The HR diagram and the different types of stars · Theory of star formation · Stellar structure and evolution theory · Theory of atmospheric structure · Binary stars and their interaction · Death of stars
Methodology and evaluation: The course will be a combination of face-to-face classes with development of equations and discussion of historical and avant-garde results. Assessments will be based on past course material, in addition to written and oral presentations about a particular topic that will be investigated throughout the semester. Course grades will be passed / failed.
Bibliography: · "Stellar Structure and Evolution", R. Kippenhahn, A. Weigert, & A. Weiss, Springer, 2nd. Edition, 2012 · "Theory of Stellar Atmospheres", I. Hubeny & D. Mihalas, Princeton University Press, 2015 · "Understanding Stellar Evolution", H. Lamers & E. Levesque, IOP Publishing, 2017 · "An Introduction to Close Binary Stars", R. Hilditch, Cambridge University Press, 2001

Name of the course / module: **Astrophysics of Planetary Systems, 8 credits** (Cieza y / o Zurlo)

Brief description of the course / module: Course designed to provide the general contents of the area of Planetary Systems Astrophysics. The course is designed for all students interested in developing their PhD thesis in this area, regardless of the sub-area of specialization. This course will be offered at least once every 3 semesters.

Learning objectives: To learn the theoretical framework and the fundamental problems in the area of planetary systems astrophysics, both from a theoretical and observational point of view. Unlike the advanced courses of the various sub-areas, more emphasis will be placed on the general aspects of the Astrophysics of Planetary Systems, than on the specialized problems of each sub-area.

Contents:

· The Solar System and its components.
· The formation of low mass stars and their protoplanetary disks.
· Model of nucleated accretion and gravitational instability.
· Theoretical and observational studies of protoplanetary disks and debris disks
· Detection techniques of extra-solar planets (radial speeds, transits, gravitational lenses and direct detection)
· The characterization of extra-solar planets
· The demography of planetary systems in the Galaxy.
· The evolution of planetary systems.

Methodology and evaluation: The methodology of the course will be a combination of face-to-face classes and discussion meetings. Evaluation will be based on the discussion meetings, written works and oral presentations by the students. Course grades will be passed / failed.

Bibliography: The following books and "review articles", among others

· "Planetary Sciences", de Pater, I. & J. Lissauer, J. Cambridge University Press.
· "Astrophysics of Planet Formation", Armitage, P. Cambridge University Press
· "Protostars and Planets VI", Henrik Beuther, Ralf S. Klessen, Cornelis P. Dullemond, and Thomas Henning (eds.), University of Arizona Press, Tucson
· "Planet Formation", Lisauer, J. 1993, ARA&A, 31, 129
· "Theory of Giant Planets", Hubbard, W., Burrows, A. & Lunine, J. 2002, ARA&A, 40, 103
· "Protoplanetary Disks and Their Evolution", Williams, J. & Cieza, L. 2011, ARA&A, 49, 67
· "The Occurrence and Architecture of Exoplanetary Systems", Winn, J & Fabrycky, D. 2015, ARA&A, 43, 409
· "Implications of Extrasolar Planets for Understanding Planet Formation", Bodenheimer, P. & Lin, D. 2002, ARE&PS, 30, 131

Name of course / module: **Extragalactic Astrophysics, 8 credits** (Aravena, Assef, and / or Ricci)

Brief description of the course / module: This general course will present a contemporary perspective of extragalactic astrophysics, focused on the current challenges in this area. The basic elements of galactic structure and formation will be discussed from an observational perspective, with a solid theoretical base. This course will be offered at least once every 3 semesters.

Learning objectives: This course aims to present the current paradigms in the investigation of the formation and evolution of galaxies. Different topics of observational extragalactic astrophysics will be discussed, with a theoretical background, trying to address the evolution of galaxies from their formation to their final passive stage.

Contents:

- Formation of the Milky Way
- Formation of spheroids and discs
- Galaxies in the near and distant Universe
- Evolution of Galaxies
- Active Nuclei of Galaxies (AGN) and accretion.
- Large scale structure growth
- Gravitational lenses

Methodology and evaluation: The methodology of the course will be based on face-to-face classes, readings and discussion of relevant scientific articles. The evaluations will consist of traditional exams, discussion and presentation of articles. Course grades will be passed / failed.

Bibliography:

· Galaxy Formation and Evolution, H. Mo, F. Van den Bosch, S. White, Cambridge Univ. Press 2010
· Extragalactic Astronomy and Cosmology: An Introduction, P. Schneider, Springer 2014
· Galaxies and Cosmology, F. Combes, P. Boissé, A. Mazure, A. Blanchard, Springer 2001

Name of the course / module: **Topics of Astrophysics I, II and III, 6 credits each** (faculty member)

Brief description of the course / module: Course based on the participation of the students in the discussions of e-prints (available at https://arxiv.org/archive/astro-ph before their publication in their respective journals) and in the colloquia organized by the UDP Astronomy Nucleus. The course is designed for all PhD students and has instances of interaction with postdoctoral researchers, academics and guest speakers. This course is repeated during the three semesters of the initial school year.

Learning objectives: Develop the abilities to analyze in detail the most recent articles of the literature of a variety of topics in astrophysics. To obtain a comprehensive vision of modern astrophysics based on the discussions of recent literature and the presentations of invited speakers to the UDP astronomy colloquiums. Improve capacities to present lectures, lead discussions, and prepare answers to questions about various topics in current astrophysics (mainly in English).

Contents:
· Planetary systems
· Galactic Archeology
· Star evolution
· Transient objects
· The interstellar medium of Galaxies
· Active Nuclei of Galaxies
· Evolution of Galaxies
· Cosmology

Methodology and evaluation: Evaluation will be based on student presentations and questions / discussion during astro-ph meetings. Written reports on the topics presented in the colloquiums organized by the UDP Astronomy Nucleus will also be evaluated. Course grades will be passed / failed.

Bibliography:

· Recent E-prints available at https://arxiv.org/archive/astro-ph

· Literatures contained in the presentations of guest speakers.

Name of the course / module: **Research project I and II, 16 credits each** (faculty member, collaborator or visitor)
Brief description of the course / module: Course based on the development of a research project guided by a faculty member, collaborator or visitor. The work can be a self-contained project or part of a more extensive study. The project can be biannual or extend up to 2 semesters. The course is designed for all PhD students and is repeated during the first 2 semesters of the initial school year. The course is designed to deliver tools and develop skills that facilitate the formulation and execution of a thesis.
Learning objectives: Familiarize with the different dimensions of astronomical research: bibliographic study, identification of unresolved problems and ways of approaching them, development of observation proposals, techniques and tools for data analysis, analysis and critical discussion of the results, presentation of the results in specialized journals and oral presentations.
Contents: The contents will be defined by the professor and the student at the beginning of a semester, through the preparation of a semester work plan (contemplating the possibility of an extension in future semesters, if applicable).
Methodology and evaluation: The work is mostly autonomous but includes weekly meetings with the professor. The evaluation will be based on a written report of the research activities and an oral presentation that will be developed during a seminar at the end of the semester. Course grades will be passed / failed.
Bibliography: · The bibliography will be defined according to the research project

Name of the course / module: **Thesis Project** (Thesis Director)

Brief description of the course / module: module for the development of the Thesis Project (normally) during the third semester. Both the written document and the oral presentation will be prepared during the defense of the project.

Learning objectives: development of the thesis project. It must be taken into account that the PhD thesis must be an original research work that contributes to the development of the discipline, whose scope is equivalent to 2 first author articles published in specialized ISI / WoS journals. The PhD thesis must demonstrate the PhD's ability to carry out original and autonomous research and generate new knowledge in the field of astrophysics.

Contents:

The thesis project will be a written work in English and must contain the following elements:

a) Definition of the problem, hypothesis or questions to solve.
b) Critical review of the specialized literature, theoretical framework and state of the art in the area of study.
c) Research methodology.
d) Schedule of activities, with special emphasis on important milestones such as obtaining data and publishing results.

Methodology and evaluation: The work is mostly autonomous but includes weekly meetings with the thesis supervisor. The evaluation of the module is based on the Qualification Exam and will consist of the analysis of the written project (in English) and a subsequent oral defense by the student. After the oral defense, also in English, the Thesis Committee will decide by simple majority if the exam is approved or rejected.

Bibliography:

· The bibliography will be defined according to the research project

Name of the course / module: **Doctoral Thesis I to V** (Thesis Director)
Brief description of the course / module: module for the development of the thesis work. The module is repeated during the 5 semesters of the final cycle of the doctoral program. The work is mostly autonomous but includes periodic meetings (preferably weekly) with the thesis director.
Learning objectives: develop thesis work. The PhD thesis must be an original research work that contributes to the development of the discipline, whose tenor is equivalent to 2 articles of first author published in specialized ISI / WoS journals. The PhD thesis must demonstrate the PhD's ability to carry out original and autonomous research and generate new knowledge in the field of astrophysics.
Contents: the contents of the module will be defined by the guide professor and the student at the beginning of a semester, through the preparation of a semester work plan (contemplating the possibility of an extension in future semesters, if applicable).
Methodology and evaluation: The evaluation will be based on a written report of the research activities of the semester and an oral presentation that will be developed during a seminar at the end of the semester. The written report will be shared with all members of the Defense Committee to evaluate the progress of the thesis work and send their comments and suggestions to the student and thesis supervisor. The module qualifications will be approved / disapproved.
Bibliography: · The bibliography will be defined according to the research project

OPTIONAL COURSES THAT THE PROGRAM CAN OFFER

Name of the course / module: **Radiative Processes, 8 credits** (Assef)
Brief description of the course / module: Optional course where the main concepts about radiative processes will be covered with an emphasis on astrophysical applications.
Learning objectives: To provide students with an in-depth review of the fundamentals related to radiative processes in astronomical objects. This course may be useful for all students, regardless of their area of expertise.
Contents: · Fundamentals of Radiative Transfer · Review of Maxwell's equations and polarization · Free-Free Radiation (Bremsstrahlung) · Synchrotron radiation · Compton Scattering · Atomic and molecular emission and absorption processes
Methodology and evaluation: The methodology of the course will be based on face-to-face classes, readings and discussion meetings. The assessments will consist of traditional exams and assignments. Course grades will be passed / failed.
Bibliography: · “Radiative Processes in Astrophysics”, G.B. Rybicki & Alan P. Lightman, editorial Wiley-VCH, 2004 · “Physics of the Interstellar and Intergalactic Medium”, B.T. Draine, editorial Princeton University Press, 2011

Name of course / module: **Astrophysics of high energies, 8 credits** (Ricci)

Brief description of the course / module: Optional and specialized course where the main concepts on astrophysics of high energies will be covered, from X-rays to gamma rays.

Learning objectives: To provide students with a deep understanding of the current status of high energy astrophysics (X and gamma rays). The course will cover the X / gamma emission of sources in the solar system, stars, galaxies, black holes and group of galaxies, and may be useful for all students, regardless of their area of expertise.

Contents:
- Optics in X-rays / Gamma
- X-ray / Gamma detectors
- Analysis of data in X-ray / gamma
- Principles of statistics for the analysis of data in X-rays / gamma
- X-ray / gamma sources: from the solar system to the furthest galaxies
- X-ray spectroscopy

Methodology and evaluation: The methodology of the course will be based on face-to-face classes, readings and discussion meetings. The assessments will consist of traditional exams and assignments. Course grades will be passed / failed.

Bibliography:

· "Handbook of X-ray Astronomy", Keith Arnaud, Randall Smith, Aneta Siemiginowska, Cambridge Observing Handbooks for Research Astronomers, 2011.

· "Gamma-Ray Astrophysics: New Insight Into the Universe", Carl E. Fichtel, Jacob I. Trombka, editorial NASA Goddard Space Flight Center 2015.

Name of the course / module: **Radio astronomy (8 credits)** (Aravena)
Brief description of the course / module: This elective course will cover the fundamental concepts of radio astronomy and interferometry, and the astrophysical phenomena generally observed in radio frequencies. Emphasis will be placed on an observational approach, and on data processing with radio telescopes.
Learning objectives: A general overview of the main concepts related to radio astronomy, including concepts and theory of radio antennas and interferometry, will be provided. The radiative processes observed in radio frequencies with emphasis on astrophysical phenomena will be reviewed. In addition, tools for the processing of data obtained with radio telescopes in general and ALMA in particular will be delivered.
Contents: - Fundamentals of Radiation - Basic concepts of Radioastronomy - Radio Telescopes - Radio Interferometry - Free-Free and Synchrotron Radiation - Pulsars, Spectral Lines and Cosmic Dust - Data processing
Methodology and evaluation: The methodology of the course will be based on face-to-face classes, projects, readings and discussion meetings. The evaluations will consist of traditional exams and works related to astronomical data processing of contemporary radio observatories. Course grades will be passed / failed.
Bibliography: · Essential Radio Astronomy, J. Condon & S. M. Ransom, Princeton University Press · Tools of Radio Astronomy, T. Wilson, K. Rohlfs, S. Huettemeister, Springer 2009 · Fundamentals of Radio Astronomy, J. M. Marr, R. Snell, S. Kurtz, CRC Press 2016 · Synthesis Imaging in Radio Astronomy II, G. B. Taylor, C. L. Carilli & R. A. Perley · Interferometry and Synthesis in Radio Astronomy, A. R. Thompson, J. M. Moran and G. W. Swenson Jr., Springer Open 2017 · An Introduction to Radio Astronomy, B. F. Burke and F. Graham-Smith, Cambridge University Press 2010 · "Radiative Processes in Astrophysics", G.B. Rybicki & Alan P. Lightman, editorial Wiley-VCH, 2004 · "Physics of the Interstellar and Intergalactic Medium", B.T. Draine, editorial Princeton University Press, 2011

Name of the course / module: **Astronomical techniques and planetary detection, 8 credits** (Zurlo)

Brief description of the course / module: Optional course where the main concepts on astronomical techniques in the optical and near infrared will be covered, with special emphasis on search and study techniques of extrasolar planets. The course will be useful for students who want to do their thesis in the area of extrasolar planets or in other areas that use observations in nearby optical and infrared wavelengths.

Learning objectives: A general overview of the main observational techniques in the optical and infrared wavelengths will be provided. Students will share knowledge about exoplanets, search and study methods, instruments installed on land and in space dedicated to the search for exoplanets.

Contents:
- Fundamentals of photometry and spectroscopy
- Infrared and visible instrumentation, data analysis.
- Transits
- Radial Speeds
- Gravitational lenses
- Direct Images
- Astrometry
- The demography of extasolar planets

Methodology and evaluation: The methodology of the course will be based on face-to-face classes, projects, readings and discussion meetings. The assessments will consist of traditional exams and assignments. Course grades will be passed / failed.

Bibliography:

- “Exoplanets”, S. Seager, University of Arizona Press, 2010
- “Planetary Sciences”, I. de Pater & J. Lissauer, Cambridge University Press, 2016

Name of the course / module: **Planetary Formation, 8 credits** (Cieza)

Brief description of the course / module: Optional and specialized course designed for students who consider developing their PhD thesis in the area of planetary system formation.

Learning objectives: To learn about the theoretical framework and the border problems in the area of planetary formation, both from the theoretical and observational point of view. Familiarize with the most recent literature in the area. Help identifying possible thesis projects.

Contents:

· The formation of low mass stars and their protoplanetary disks
· Nuclear accretion model
· Gravitational instability model
· The evolution of protoplanetary disks
· Observational studies of protoplanetary discs
· Theoretical models of protoplanetary disks
· Debris disks
· Connections with studies of the Solar System
· Connections with the study of extra-solar planets

Methodology and evaluation: The methodology of the course will be a combination of face-to-face classes and discussion meetings. Evaluation will be based on the discussion meetings, written works and oral presentations by the students. Course grades will be passed / failed.

Bibliography: Recent publications of the area in specialized magazines and the following books and "review articles", among others:

- "Astrophysics of Planet Formation", Armitage, P. Cambridge University Press.
- "Protostars and Planets VI", Henrik Beuther, Ralf S. Klessen, Cornelis P. Dullemond, and Thomas Henning (eds.), University of Arizona Press, Tucson
- "Planet Formation", Lisauer, J. 1993, ARA&A, 31, 129
- "Theory of Giant Planets", Hubbard, W., Burrows, A. & Lunine, J. 2002, ARA&A,
- 40, 103
- "Protoplanetary Disks and Their Evolution", Williams, J. & Cieza, L. 2011, ARA&A, 49, 67
- "The Occurrence and Architecture of Exoplanetary Systems", Winn, J & Fabrycky, D. 2015, ARA&A, 43, 409

Name of the course / module: **Infrared and submillimeter laboratory spectrometry for astrophysics, 8 credits** (Roberto Lavín)

Brief description of the course / module: Optional and specialized course. This course is designed for students who want to do their doctoral thesis using the Cosmic Dust Laboratory of the UDP. The course will focus mainly on the theoretical foundations and the main experimental laboratory techniques of infrared spectrometry.

Learning objectives: To know in depth the theoretical foundations and the experimental techniques of infrared and submillimeter spectrometry with emphasis on astronomy and planetary sciences. Become familiar with the operations of the Bruker Vertex 80V spectrometer and the laboratory sample preparation techniques.

Contents:

· Fundamentals of spectrometry and radiation
· Theoretical aspects of infrared spectrometry
· Experimental techniques of infrared spectrometry
· Types of spectrometers and scopes of the characterization with infrared spectrometry
· Infrared spectrometry in astronomy: applications in proto-planetary disks, planetary systems and meteorites
· Methods of preparation and characterization of samples for infrared laboratory spectrometry
· Other experimental techniques and their scope in astronomy: Raman spectrometry, X-ray, UV-VIS, electron microscopy, etc.

Methodology and evaluation: The course will consist of face-to-face classes, laboratory experiences (developed by the students), seminars, discussions and readings. The assessments will measure the theoretical and experimental knowledge of the students through written assignments and laboratory work. The course grades will be passed / failed.

Bibliography:

· “Infrared Spectroscopy: Fundamentals and Applications”, Stuart, Wiley, 2005.
· “Dust in the Galactic Environment”, D. Whittet, IOP Publishing, 2003.
· “Protoplanetary Dust: Astrophysical and Cosmochemical Perspectives”, D. Apal & D. Lauretta, Cambridge, 2010.
· “Dust from collisions: A way to probe the composition of exo-planets?”, A. Morlok et al, Icarus 239 (2014) 1–14.
· “Mid-infrared spectroscopy of components in chondrites: Search for processed materials in young Solar Systems and comets”, A. Morlok et al, Icarus 231 (2014) 338–355.
· “Mid-infrared spectra of differentiated meteorites (achondrites): Comparison with astronomical observations of dust in protoplanetary and debris disks”, A. Morlok et al, Icarus 219 (2012) 48–56.
· “Transmission infrared spectra (2-25 mm) of carbonaceous chondrites (CI, CM, CV-CK, CR, C2 ungrouped): Mineralogy, water, and asteroidal processes”, P. Beck et al, Icarus 229 (2014) 263–267.

Course name / module: **Galactic Archeology, 8 credits** (Jofré)

Brief description of the course / module: Optional and specialized course designed for students who consider developing their doctoral thesis in subjects where the knowledge of the Milky Way is fundamental, either in studies of evolution and structure of spiral galaxies, or in studies of evolution chemistry and / or evolution and stellar structure.

Learning objectives: To learn about the theoretical framework of all the galactic components, considering not only their spatial and dynamic distribution but also their formation and evolution. This theoretical framework will be complemented with the sources observations that are available today to advance with the theoretical aspects not yet solved. In that sense, it is important to treat the chemical aspect as a fundamental ingredient, for which emphasis will be given to learn the methods of determination of chemical abundances in stars and the theory of nucleosynthesis. It is intended to emphasize certain stellar types depending on the direction you want to take in the thesis.

Contents

· Introduction to the different galactic components
· Formation and evolution of the Milky Way from a cosmological point
· Galactic structure from a dynamic point
· Evolution of chemical elements
· Spectral analysis of low mass stars

Methodology and evaluation:

The course will be a combination of face-to-face classes with development of equations and discussion of historical and avant-garde results. Assessments will be based on the material in progress, in addition to written and oral presentations about a particular topic that will be investigated throughout the semester. Course grades will be passed / failed.

Bibliography:

· Galactic Dynamics, Binney and Tremaine, IBSN: 978-0691130279, Princeton Series

· Galactic Astronomy, Binney, IBSN: 978-0691025650, Princeton Series

· The observation and analysis of stellar photospheres, Gray, IBSN: 978-0521066815, Cambridge

· Nucleosynthesis and chemical evolution of Galaxies, Pagel, IBSN: 978-0521840309, Cambridge

· Galaxy Formation and evolution, Ho, van den Boesch, White, IBSN: 978-0521857932, Cambridge

Name of the course / module: Transients, 8 credits (Prieto)

Brief description of the course / module: Optional and specialized course designed for students who consider developing their doctoral thesis in the area of supernovas and other energy transient objects observed in galaxies.

Learning objectives: To know the theoretical and observational framework of a wide range of transient energy objects in galaxies, including supernova explosions, intermediate transients between novae and supernovae, star disruptions by supermassive black holes, gamma-ray bursts, normal star fusions , and electromagnetic sources connected with emission of gravitational waves. Familiarize yourself with recent literature.

Contents:

· Thermonuclear supernovas
· Gravitational collapse supernovas
· Intermediate transients between novae and supernovas
· Super-bright supernovas
· Gamma ray bursts
· Transients related to the fusion of normal stars and compact stars
· Disruptions of stars by supermassive black holes

Methodology and evaluation: The methodology of the course will be a combination of face-to-face classes and discussion meetings. Evaluation will be based on the discussion meetings, written works and oral presentations by the students. Course grades will be passed / failed.

Bibliography: It will be based on recent books and articles of literature (original and review)

· "Supernova Explosions", D. Branch & J. Craig Wheeler, Springer, 2017

· "Supernovae and Nucleosynthesis", D. Arnett, Princeton University Press., 1996

· "Gravitation", C. Misner, K. Thorne & J. Wheeler, Princeton University Press., 2017

· "Handbook of Supernovae", Ed. A. Alsabti, P. Murdin, Springer, 2017

· "The evolution and explosion of massive stars", S. Woosley, A. Heger, & T. Weaver, Reviews of Modern Physics, 2002, 74, 1015

· "The Supernva Gamma-Ray Burst Connection", S. Woosley & J. Bloom, Annual Review of Astronomy & Astrophysics, 2006, 55, 507

· "Type Ia Supernova Explosion Models", W. Hillenbrandt & J. Neimeyer, Annual Review of Astronomy & Astrophysics, 2000, 38, 191

· "Observational Clues to the Progenitors of Type Ia Supernovae", D. Maoz, F. Mannucci, & G. Nelemans, Annual Review of Astronomy & Astrophysics, 2014, 52, 107

· "Kilonovae", B. Metzger, Living Reviews in Relativity, 2017, 20, 3

· "The disruption of stars by supermassive black holes: Status of observations", S. Komossa, Journal of High Energy Physics, 2015, 7, 148

Name of the course / module: **Active Galaxies Nuclei (AGN), 8 credits** (Assef and / or Ricci)

Brief description of the course / module: Optional and specialized course where the physical and observational foundations on the Active Galaxies Nucleus, better known as AGN for its acronym in English, will be covered, as well as the theories and recent discoveries of its properties.

Learning objectives: To provide students with a thorough review of the physical processes associated with AGN and their observational properties.

Contents:

- Properties and Observational Classifications of AGN
- Supermassive Black Holes and Accretion Discs
- Structure of an AGN and emission mechanisms through the electromagnetic spectrum
- Regions of broad and thin emission lines
- Formation and Evolution of AGN and its relationship with host galaxies

Methodology and evaluation: The methodology of the course will be based on face-to-face classes, readings and discussion meetings. The assessments will consist of traditional exams and assignments. Course grades will be passed / failed.

Bibliography:

· "The Physics and Evolution of Active Galactic Nuclei", H. Netzer, editorial Cambridge, 2013

· "Active Galactic Nuclei", B.M. Peterson, editorial Cambridge, 1997

· "Active Galactic Nuclei", J.H. Krolik, editorial Princeton University Press, 1999

· "Black Hole Astrophysics", D.L. Meier, editorial Springer, 2012

Name of the course / module: **General Relativity, gravity and black holes. 8 credits** (González and / or Maedler)

Brief description of the course / module: This optional course will present a perspective of General Relativity with astrophysical application. The focal points of the course are the properties of the black holes and gravitational waves. The course will mainly deal with theoretical aspects, but also some observational ones.

Learning objectives: This course aims to present the bases of General Relativity that are necessary for the investigation and study of contemporary scientific articles. The theoretical foundations of space-time in astrophysically relevant contexts will be discussed, with an emphasis on black holes and gravitational waves.

Contents:

· Basic introduction to the tools of Differential Geometry
· Spacetime of Newton, Minkowski and Einstein
· Black hole properties of Schwarzschild and Kerr-Newman
· Black Hole Solutions in the Theory of General Relativity.
· Movement of particles in the vicinity of a Black Hole. .
· Gravitational waves in the linear approach and its electromagnetic-magnetic analog
· Propagation of fields in the background of a Black Hole. Quasi-normal modes.
· Thermodynamics of Black Holes.
· Alternative Theories of Gravitation.

Methodology and evaluation: The methodology of the course will be based on face-to-face classes, readings and discussion meetings. The evaluations will consist of tasks and tests. The qualification of the course will be approved or disapproved.

Bibliography:

· Gravitation, C Misner, K Thorne, A Wheeler, H.W. Freeman & Company, 1972
· General Relativity, R. Wald, The University of Chicago Press, 1984
· Numerical Relativity, T. Baumgarte, S. Shapiro, Cambridge Univ. Press 2010
· Introducing Einstein's Relativity, R. d'Inverno, Carendon Press Oxford, 199
· "The Mathematical Theory of Black Holes", S Chandrasekhar, Oxford Science Publications, 1992.
· "Gravitation", Misner, Thorne and Wheeler, Princeton University Press, 2017.

Course name / module: **Cosmology 8 credits** (Maedler)
Brief description of the course / module: This elective course will present an introduction to contemporary cosmology. A focus of the course are the observational aspects of cosmological models and how to distinguish between different models based on invariant observables. Another focus of the course is the theory of cosmological perturbations of General Relativity and its relation to microwave background radiation.
Learning objectives: This course aims to present the basic ideas of Cosmology that are necessary for the investigation and study of the scientific articles of the area. In the course the physical foundations are presented to establish a cosmological model based on the understanding of space-time, thermodynamics, electromagnetism and quantum physics. The mathematical tools are also introduced to analyze the observations of the microwave background radiation spectrum.
Contents: · Introduction to the necessary tools of Differential Geometry · Cosmology in Newton's Spacetime and in Einstein's · Properties of the Lemaitre-Friedmann-Robertson-Walker models · Rung of cosmological distances · Extensions of General Relativity and its cosmological implications · Theory of cosmological perturbations and microwave background radiation · Theory of inflation and numerical models by Cosmology
Methodology and evaluation: The methodology of the course will be based on face-to-face classes, readings and discussion meetings. The evaluations will consist of tasks and tests. The course grades will be approved or disapproved.
Bibliography: · Gravitation, C Misner, K Thorne, A Wheeler, H.W. Freeman & Company, 1972 · Cosmolocial Physics, J. Peacock, Cambridge Univ. Press 1998 · Principles of Physical Cosmology, J. Peebles, Princeton Univ. Press 1993 · Physical Foundation of Cosmology, V. Mukhanov, Cambridge Univ. Press 2005