National Centre for Radio Astrophysics
TATA INSTITUTE OF FUNDAMENTAL RESEARCH
PUNE UNIVERSITY CAMPUS, GANESHKHIND, PUNE 411007, INDIA

Guidelines for Graduate Studies by Research Scholars

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Contents

1 Introduction

The Graduate Programme at NCRA, Pune, involves both course work and research work in the areas of observational and theoretical astrophysics, with an emphasis on radio astronomy. There are also courses on basic physics and mathematical methods relevant for astronomy and astrophysics.

The normal duration of the Programme, including the doctoral research, is five years for Regular Ph.D. students and six years for Integrated Ph.D. ("Int-Ph.D.") students, within which the student is expected to submit a thesis for a Ph.D. degree to the Tata Institute of Fundamental Research (TIFR), a deemed University, or any other University/Institution with whom NCRA has a formal arrangement. Details regarding the requirements of the University/Institution can be obtained from the Faculty Office at NCRA.

The Graduate Programme is monitored by the Academic Affairs Committee (AAC). The Convenor of this committee has the overall responsibility for the programme. The academic activities of all Ph.D. students are monitored by the AAC, who will work in co-ordination with the Ph.D. supervisor and the Ph.D. Advisory Committee which is set up for each student. The student's supervisor will be a member of his/her Ph.D. Advisory Committee, along with one member of the AAC, and one member of the NCRA faculty.

Policies and guidelines concerning various aspects of the Graduate Programme are described below. Further information and recent updates are available on the NCRA (`http://www.ncra.tifr.res.in`) and TIFR (`http://www.tifr.res.in`) web pages.

2 Admission to the Graduate Programme

2.1 Normal Procedure

The normal procedure for admission to NCRA's Graduate Programme is via one of the TIFR GS written test, the IUCAA-NCRA Admission Test (INAT) and the Joint Entrance Screening Test (JEST). These are announced through advertisements placed in several national newspapers and the NCRA web page, as well as notifications sent to different educational/research institutions. Based on their performance in the written test and assessment of their academic abilities, candidates are invited for interviews. Candidates short-listed via INAT are interviewed at Pune jointly with the Inter-University Centre for Astronomy and Astrophysics (IUCAA) while those short-listed via the TIFR written test and JEST are interviewed at TIFR, Colaba, Mumbai. Candidates who clear these interviews are selected to join NCRA's Graduate Programme as Research Scholars, in either the Regular Ph.D. or Int-Ph.D. programmes (see below). INAT candidates may also be pre-selected to join NCRA after completion of their current programme. Students who are interviewed in TIFR, and opt to join NCRA from the time of induction, will join the IUCAA-NCRA Graduate School at the outset. Research Scholars may also be pre-selected for the Ph.D. programme from the Visiting Students' Research Programme (VSRP), conducted each summer at NCRA. Students may apply for the VSRP directly to NCRA, via an online application portal which is open from around mid-January to mid-February every year. Students who are entering the final year of an M.Sc., Int.-M.Sc., B.E., B.Tech. or four-year-B.Sc. programme are eligible for the VSRP. Selected VSRP students spend about two months during the summer working on a project at NCRA. Based on their performance during the VSRP, which includes a project seminar and interviews, students may be pre-selected to join NCRA's Graduate Programme after they satisfactorily complete their M.Sc., Int.-M.Sc., B.E., B.Tech. or four-year-B.Sc. course.

Depending on the nature and the duration of the qualifying degree, students would be admitted to the Ph.D. or Int-Ph.D. courses. Table 1 summarizes the various possibilities:

The category of a student who does not clearly belong to one of the above categories will be determined by the NCRA Faculty. Note that "Int.-M.Sc." is used here to refer to all 5-year integrated Master's of Science programmes, including the "B.S.-M.S." degree.

For brevity, Int-Ph.D. students who are required to complete 100 credits during their course work will be referred to henceforth as "Int-Ph.D. (100 credits)", while those who are required to complete 80 credits will be referred to as "Int-Ph.D. (80 credits)".

Before joining NCRA		Programme in NCRA		
Previous degree	**Years**	**Name of the programme**	**Number of credits in the course work**	**Degree(s) awarded**
B.Sc. (Physics, Maths, Astronomy)	3	Int-Ph.D.	100	M.Sc. in Physics + Ph.D. in Physics
B.E./B.Tech. (any subject *except Engineering Physics*)	4	Int-Ph.D.	100	M.Sc. in Physics + Ph.D. in Physics
B.Sc./B.S. (Physics, Maths, Astronomy)	4	Int-Ph.D.	80	M.Sc. in Physics + Ph.D. in Physics
B.E./B.Tech. (Engineering Physics)	4	Int-Ph.D.	80	M.Sc. in Physics + Ph.D. in Physics
M.Sc. (Physics, Maths, Astronomy)	2	Ph.D.	60	Ph.D. in Physics
Int.-M.Sc. (Physics, Maths, Astronomy)	5	Ph.D.	60	Ph.D. in Physics

Table 1: Summary of the eligibility criteria, credit requirements, and awarded degrees at NCRA.

2.2 Exceptional Case for Research Scholars: Applicants from Abroad

An exception to the requirements described above for admission of Research Scholars to the NCRA Graduate Programme may be made for applicants who are not in India and are therefore unable to appear for the standard tests and interviews. This procedure will be used sparingly and only in exceptional cases. Details of this procedure are described in Appendix 1.

3 Elements of the Graduate School

The Graduate School in NCRA consists of different types of courses and research projects. Their description, along with the grading procedures, are given below.

3.1 IUCAA-NCRA Graduate School

- **Description:** The IUCAA-NCRA Graduate School consists of 14 courses distributed over four terms with each term lasting for about 8 weeks. During the Graduate School, Research Scholars are taught a set of basic courses in Physics and Mathematics and are also introduced to courses in Astronomy and Astrophysics.

- **Structure:** The structure of the Graduate School along with the teaching hours and credit structure is given in Table 2.

  The detailed syllabi of the courses are listed in Appendix 2. Note that it is possible that the ordering of the courses in the Graduate School may be altered (with formal approval from the Dean, NCRA), in rare and unavoidable circumstances. The students will be notified well in advance in case such a situation arises. A course may be given as a reading course if there are only one or two students taking the course.

- **Evaluation and performance requirements:** The performance of the students in the courses will be evaluated on the basis of a combination of written test(s), home assignments, classroom discussions and/or seminars. For every course, the instructor would give each student a numerical grade between 0% and 100%, depending on his/her performance in the course. A student must score $\geq 40\%$ to pass a course. Students are normally expected to clear all the courses at the first attempt. However, in case the

Structure of the IUCAA-NCRA Graduate School			
Sl	Course	Teaching hours	Credits
Semester I, Term I: Early August to end-September			
01	Methods of Mathematical Physics I	21	3
02	Introduction to Astronomy and Astrophysics I	14	2
03	Electrodynamics and Radiative Processes I	14	2
04	Quantum and Statistical Mechanics I	14	2
Semester I, Term II: Mid-October to mid-December			
05	Methods of Mathematical Physics II	14	3
06	Introduction to Astronomy and Astrophysics II	14	2
07	Electrodynamics and Radiative Processes II	14	2
08	Quantum and Statistical Mechanics II	14	2
Semester II, Term I: Early January to early March			
09	Astronomical Techniques I	14	3
10	Galaxies : Structure, Dynamics and Evolution	21	3
11	Extragalactic Astronomy I	21	3
Semester II, Term II: Mid-March to mid-May			
12	Astronomical Techniques II	14	3
13	Interstellar Medium	14	3
14	Extragalactic Astronomy II	14	3
	Total Credits		36

Table 2: The structure of the IUCAA-NCRA Graduate School

student fails in one or more courses at the first attempt, he/she will be given a second chance to clear the courses in the subsequent year(s). The AAC would guide the student(s) regarding this.

- **Exemption:** Normally, no student will be exempted from completing the course requirements. However, if a student feels that he/she is thoroughly familiar with the material in a particular course in the IUCAA-NCRA Graduate School, he/she may request the lecturer to exempt him/her from attending the lectures and to evaluate him/her directly. It is up to the lecturer to decide whether such an exemption should be granted.

- **Feedback:** At the end of each semester in the IUCAA-NCRA Graduate School, students will be given an opportunity to anonymously evaluate the courses and course instructors in a prescribed form. All students of a given year should put their *unsigned* feedback forms into a single envelope, seal the envelope, and then sign across the seal. Even if a student does not wish to fill out the feedback form, s/he should sign across the seal of the envelope; this is to preserve confidentiality in the evaluation. The evaluation forms will be sent to the Directors of IUCAA and NCRA and will be treated as confidential.

3.2 Courses Outside NCRA

- **Description:** The Int-Ph.D. (100 credits) students will do the first year of courses at the Physics Department, Savitribai Phule Pune University (hereafter, the Physics Dept.), or at the Indian Institute of Science Education and Research (hereafter, IISER-Pune).

- **Structure:** The details of the Int-Ph.D. (100 credits) courses are given in Table 3.

- **Evaluation and performance requirements:** It is the responsibility of the students to satisfy the requirements for passing the courses (e.g., attendance, registering for the examinations on time, payment of fees, etc.), as applicable at either the Physics Dept. or IISER-Pune. The evaluation for these courses

Structure of Courses Outside NCRA			
Sl	Course	Teaching hours	Credits
Semester - I: Mid-July to early December			
01	Mathematical Methods in Physics	~ 40	4
02	Classical Mechanics	~ 40	4
03	Quantum Mechanics I	~ 40	4
04	Electronics	~ 40	3
05	General Laboratory I / Computer Laboratory	~ 40	3
Semester - II: Early January to early May			
06	Quantum Mechanics II	~ 40	4
07	Statistical Mechanics	~ 40	4
08	Electrodynamics I	~ 40	4
09	Atoms, Molecules and Solids	~ 40	3
10	Computer Laboratory / General Laboratory I	~ 40	3
	Total Credits		36

[1]The listed courses are based on the 2017 programme at the University of Pune; the exact courses may vary at both the University of Pune and at IISER-Pune, but the broad structure would be similar. If there are any changes in the course structure, the students should convey this to the AAC.

Table 3: The structure of external courses (at the Physics Dept.), that are required for Int-Ph.D. (100 credits) students.

Schedule for the Advanced Courses				
Course	Start date	End date	Teaching hours	Credits
Advanced Course I	February 15	May 15	~ 25	6
Advanced Course II	February 15	May 15	~ 25	6
Total Credits				12

Table 4: The schedule for the Advanced Courses, which are required for Int-Ph.D. (80 credits) students.

will be done entirely by the institution running the courses, i.e. by the Physics Dept. or IISER-Pune, based on their rules and regulations. The resulting marks will be forwarded to NCRA at the end of each semester. A student must score $\geq 40\%$ to pass a course. Students are normally expected to clear all the courses at the first attempt. However, in case a student fails in one or more courses at the first attempt, s/he will be given a second chance to clear the courses in the subsequent year(s). The AAC would guide the student(s) regarding this.

3.3 Advanced Courses

- **Description:** The NCRA Graduate School also offers Advanced Courses covering various topics in Astronomy and Astrophysics. These are primarily meant for students of the Int-Ph.D. (80 credits) programme. Such students will be allowed to choose two courses from a set of eight courses described in Appendix 3. It is possible that some of the courses may not be offered in a particular year due to the non-availability of instructors. In such a situation, the AAC will advise the students on possible alternatives.

- **Structure:** The details of the Advanced Courses are provided in Table 4. Depending on the number of students attending, the instructor may decide to offer the course as a reading course.

Details of the 3-month Research Projects				
Project	Project start date	Project end date	Deadline for seminar and report	Credits
Project I	June 15	September 15	September 30	12
Project II	October 15	January 15	January 31	12
Project-A	February 15	May 15	May 31	12
Project III	June 1	August 31	September 15	8
Project-B	October 1	December 31	January 15	8

*Project-A provides a safety net for doctoral students who have either failed in one of Projects I or II, or not obtained the minimum average grade in Projects I and II.

†Project III and Project-B are only for Int-Ph.D. (80 credits) students.

‡Project-B provides a safety net for an Int-Ph.D. (80 credits) student who has failed to obtain the minimum required grade of 60% in Project III.

Table 5: Details of the 3-month Research Projects

- **Evaluation and performance requirements:** The grading procedure will be decided by the instructor, on the basis of assignments, tests, seminars, classroom discussions, etc. The final grade will be a number between 0% and 100%. A student must score $\geq 40\%$ to pass a course. In case a student fails one of the Advanced Courses, s/he would be allowed to take a third Advanced Course, also of 3-month duration, over the period July 1–October 1 of the same year. This third course should not be a repeat of either of the two earlier courses.

3.4 3-month Research Projects

- **Description:** Every NCRA doctoral student is required to do at least two 3-month research projects with different NCRA faculty members, as part of the Graduate School, in order to allow them to explore different research areas before choosing a Ph.D. topic. One of these projects must be based on the observational or instrumentation facilities operated by NCRA, i.e. the Giant Metrewave Radio Telescope, the Ooty Radio Telescope, the 15-m telescope, new hardware, or facilities in the Radio Physics Laboratory, etc. The project may include analysis of GMRT, ORT or 15-m data, as well development of software tools or hardware instrumentation for the different facilities.

- **Structure:** The schedule of these projects are as follows:

- **Evaluation and Performance requirements:** Students will have to give a seminar at the end of each project and submit a formal project report. If the project seminar and report are not submitted by the stipulated date, the student will be deemed to have failed the course.

  For each of the projects, students will be given a grade that is the average of the grades on their seminar (graded by members of the NCRA faculty) and their performance during the project (graded by the project supervisor). Students must score $\geq 40\%$ to pass Projects I and II, and $\geq 60\%$ to pass Project III. In addition, the average grade over Projects I and II must be $\geq 60\%$.

  If a doctoral student fails in either of Projects I or II, but clears the other one, or if his/her average grade over Projects I and II is $< 60\%$, s/he will be allowed to carry out an additional 3-month project ("Project-A"), allowing an additional chance to satisfy the Graduate School requirements. This extra project may not be a continuation of either of the earlier two projects and should be done with a faculty member different from those supervising Projects I and II. In such circumstances, the student's grade on the research projects will be computed based on the two highest grades obtained in the three projects.

  If an Int-Ph.D. (80 credits) student fails to get the minimum grade of 60% in Project III, s/he will be allowed to carry out an additional 3-month project (Project-B) to satisfy the Graduate School requirements. Again, her/his extra project may not be a continuation of the student's earlier projects.

- **Assigning the projects:** Students are encouraged to approach faculty members for prospective projects well in advance. A faculty member who intends to provide a project must give a brief description of the scope and content of the project to the AAC by May 15, for Projects I and II (which begin in June and October of the year). The AAC will collect and circulate these abstracts to the students who will then be asked to convey back their choices within a given deadline.

  In the case of Project-A (where there will often not be much time between the end of the previous project and the beginning of the new one), the supervisor should provide a brief description of the scope and content of the project to the AAC by February 7 (for a project beginning on February 15 of that year).

  Finally, in the case of Project III, the supervisor must provide a brief description of the scope and contents of the project to the AAC by May 1 (for projects beginning on June 1 of that year), while, in the case of Project-B, the supervisor should provide this description to the AAC by September 22 (i.e. a week before the beginning of the project).

3.5 RPL or Experimental/Reading Project

- **Description:** All Int-Ph.D. (100 credits) students will carry out either a short project in the Radio Physics Laboratory (RPL), NCRA, or an experimental or reading project with an NCRA faculty member, during the summer of their first year. The content of the project will be decided by the supervisor; a brief description of the project should be provided by the supervisor to the AAC by May 1 (i.e. 2 weeks before the beginning of the project).

- **Structure:** The project will run for ~ 6 weeks between mid-May and mid-July; the exact dates can be tuned to match the convenience of the supervisor and the student(s). This project will carry 4 credits.

- **Evaluation and performance requirements:** The grading procedure for this project will be decided by the supervisor. Students must score $\geq 40\%$ to pass the project. In case an Int-Ph.D. (100 credits) student fails this project, s/he must repeat it either in the next summer, or after completing the other requirements of the Graduate School. This will be done under the supervision of the AAC.

4 The NCRA Graduate School Structure

Research Scholars in the Ph.D. programme are normally required to join the Institute on or before August 1 every year, while Research Scholars in the Int-Ph.D. programme are normally required to join the Institute on or before July 15 every year.

- *The Int-Ph.D. students who are required to complete 100 credits* would undergo one year of coursework at the Physics Dept. or at IISER-Pune, followed by a short summer project and then another year of courses in the IUCAA-NCRA Graduate School. These students would also have to carry out two 3-month research projects in the first half of their third year.

- *The Int-Ph.D. students who are required to complete 80 credits* would do one year of courses in the IUCAA-NCRA Graduate School, followed by two 3-month research projects in the first half of their second year. In the second half of their second year, these students will be required to take two advanced courses and, finally, carry out one more research project.

- *The Regular Ph.D. students who are required to complete 60 credits* would do one year of courses in the IUCAA-NCRA Graduate School, followed by two 3-month research projects in the first half of their second year.

A summary of the detailed course and project structure for each of the above three programmes (essentially, combining Tables 2, 3, and 5), is provided in Appendix 1.

Research Scholars are allowed to register for a Ph.D. degree with the TIFR (Mumbai) Deemed University once they successfully clear all requirements of the NCRA Graduate School concerning the courses and the research projects. These requirements are detailed in Section 5.2.

The broad structure of the programme for the different categories of students is indicated below. It should be kept in mind that the actual duration of a semester may vary based on whether the student is doing courses or projects. Also, if a student is unable to clear the usual courses, he/she will have to spend additional time repeating them; however, the total duration of the Ph.D. or Int-Ph.D. programme will remain unchanged.

5 Evaluation in the Graduate School

5.1 Cumulative Performance Index (CPI)

Evaluation in the NCRA Graduate School is based on the Cumulative Performance Index (CPI), which is calculated from the marks obtained in the courses and research projects as follows:

$$\text{CPI} = \frac{\sum_i \text{ credits for course } i \times \text{ percentage marks obtained in course } i}{\sum_i \text{ credits for course } i} \ ,$$

where the sum over i runs over all courses and research projects under consideration.

5.2 Graduate School Performance Requirements

A student must satisfy the following conditions in order to satisfactorily complete the requirements of the NCRA Graduate School. If a student fails to satisfy the above criteria at the end of the course work (i.e., at the end of two years for Regular Ph.D. students and at the end of three years for Int-Ph.D. students), s/he would be asked to leave NCRA.

- The student should pass all courses, i.e., s/he should score $\geq 40\%$ in all courses (both courses and research projects), within the period of his/her coursework (two years for Regular Ph.D. students and three years for Int-Ph.D. students).
- The student must get a aggregate CPI of $\geq 60\%$ over all courses, including advanced courses.
- The student must get a CPI of $\geq 60\%$ in the two research projects, i.e. an average grade of $\geq 60\%$ in the research projects.
- Int-Ph.D. (80 credits) students must score $\geq 60\%$ in their third research project.

Students would be required to leave NCRA under the following circumstances:

1. If a student fails to meet the three performance criteria listed above at the end of the Graduate School, he/she would be required to leave NCRA.
2. If a student fails to achieve an aggregate CPI of $\geq 60\%$ at the end of each semester (whether or not s/he has failed some courses), s/he would be required to leave NCRA.
3. If a student fails in more than three courses (i.e. in four or more courses) at any point in the course work, s/he would be required to leave NCRA.
4. If a student obtains a grade $< 40\%$ in both of the initial 3-month research projects, s/he would be required to leave NCRA.
5. If a Int-Ph.D. (80 credits) student obtains a grade of $< 60\%$ in the third 3-month research project, s/he would be required to leave NCRA.

The following safety nets have been provided for students failing to clear the requirements of the Graduate School at the first attempt:

- If a Regular Ph.D. student has a CPI of $\geq 60\%$ at the end of each semester, but has failed in one or more, but fewer than four, courses, s/he will be given another chance to clear these courses in the second year. At the end of the second year, the student should satisfy all the three criteria listed above, otherwise s/he will have to leave NCRA.
- Int-Ph.D. students have to maintain a CPI $\geq 60\%$ at the end of each semester. A student may fail at most three courses during the entire two year duration of the course work. Students who have failed in four or more courses will have to leave the Graduate School. Students who have failed one or more courses will have to clear these courses by the end of their third year in the programme. At the end of the third year, the student should satisfy all the three criteria listed above, else s/he would have to leave NCRA.
- In case a student scores $< 40\%$ in one of the research projects or if his/her average CPI on the two research projects is $< 60\%$, he/she would be allowed to carry out an additional 3-month project to satisfy the Graduate School requirements. This extra project may not be a continuation of either of the earlier two projects and will run from January 16 to April 15; the seminar must be completed and the project report submitted by April 30. If a student is required to carry out a third project, the CPI on the research projects will be computed based on the two highest grades obtained in the three projects.

6 Requirements for Ph.D. Registration

Research Scholars may register for a Ph.D. after successful completion of their Graduate School (i.e. courses and the research projects). Note that the stipend of a Regular Ph.D. and an Int-Ph.D. students would be raised after two and three years, respectively, provided her/his Graduate School studies have been completed satisfactorily, her/his progress is assessed to be satisfactory, and s/he has registered for the Ph.D. degree.

6.1 M.Sc. Degree for B.Sc./B.E./B.Tech. students

Students in the Int-Ph.D. (80 credit) or Int-Ph.D. (100 credit) programmes should register for an M.Sc. degree with the TIFR Deemed University after joining NCRA as Research Scholars. The additional credits obtained by these students (20 and 40 extra credits, respectively) are considered by the TIFR Deemed University to be equivalent to the course requirements of an M.Sc. degree. Such students would be granted their M.Sc. degrees along with the Ph.D. degrees, based on the NCRA Graduate School requirements, *unless they leave NCRA without completing a Ph.D. degree*. If an Int-Ph.D. student wishes to leave NCRA after completion of the NCRA Graduate School requirements, but before completion of the Ph.D. degree, s/he would be required to carry out an additional 6-month research project with an NCRA faculty member, in order to obtain an M.Sc. degree from the TIFR Deemed University.

6.2 Thesis Advisor Selection for Research Scholars

Registration for a Ph.D. degree requires the identification of a thesis supervisor (an academic member of NCRA with the rank of Fellow or higher) for the candidate. Keeping this in mind, students are encouraged to get acquainted with the research areas at NCRA as early as possible and to interact personally with Faculty members to find out their research interests and availability as guides. Finding an advisor who is willing to supervise the work of a student is solely the responsibility of the student. However, s/he will be advised and assisted by the AAC, whenever required.

Ideally, the student should have identified a supervisor by the end of the Graduate School. In case a student fails to identify an advisor by then, s/he will be allowed until the end of the academic year (which would correspond to the end of the second year in NCRA for Regular Ph.D. students and the end of the third year for

Int-Ph.D. students). If the student is still unable to find an advisor at this time, his/her Research Scholarship would be terminated.

The name of the supervisor and the broad area of research must be provided to the NCRA Faculty Office before a student is allowed to register for a Ph.D.. In addition, a written outline of the Ph.D. project, signed by both the supervisor and the student, should be submitted to the Faculty Office, for submission to the TIFR Deemed University.

6.3 Ph.D. Advisory Committee (PAC)

Each Ph.D. student will have a Ph.D. Advisory Committee (PAC), consisting of at least three faculty members, to monitor her/his progress until the completion of the Ph.D.. The PAC will consist of the student's supervisor, a member of the AAC, and an additional NCRA Faculty member. The PAC will monitor the performance of the student at least once every year, typically in May/June, and make recommendations concerning the renewal or termination of the student's Research Scholarship. Students should feel free to approach members of their PAC for advice during the year, in case of any problems.

6.4 Premature Exit Options

Any student in the Ph.D. or Int-Ph.D. programme can at any time resign his/her position, obtain a 'No Dues' certificate and leave NCRA without a degree. A resigning student who wishes to obtain a degree against time spent in NCRA can avail of one of the options decided by the TIFR Physics Subject Board, the details of which can be found at `http://www.tifr.res.in/~sbp/new2015/exitoption.htm`. The students who wish to resign are also encouraged to discuss their options with the AAC and/or the Dean, NCRA.

7 Stay in NCRA

7.1 Monitoring the Progress of a Student

The appointment of a Research Scholar is for one year at a time, with an extension every year subject to satisfactory performance. The progress of all Research Scholars is reviewed by their respective PACs every year, typically in May or June. The review is based on:

- A detailed report by the student summarizing the work carried out since the previous review, as well as plans for the future. This should include details of projects, publications, proposals, work-related travel, plans for the timeline of the Ph.D., and anything else that the student or supervisor feel is relevant to her/his research performance.
- An open seminar (of duration $50 - 60$ minutes) given by the student and graded by NCRA faculty members, in which s/he describes the work done since the previous review. The student may also choose to describe proposals, publications, and plans for the future in the talk.
- A discussion with the PAC on the work done and the student's plans for the future; this would usually take place just after the above review seminar.

The review seminar will be evaluated by the NCRA faculty members who attend the talk. This evaluation will be based on a range of factors, such as the quantity and the quality of the work, the clarity of the presentation of the talk, the understanding of the field, the quality of the slides or presentation materials, the handling of questions during and after the talk, etc. Each faculty member will provide a mark on the talk on a scale of $1-10$, with a higher number indicating a better talk, and a mark of 6 indicating a marginal talk. Faculty members may provide comments on areas where they feel that the student might improve and also areas where they feel that the student has done well. The marks of all faculty members who evaluate the talk will be averaged together to obtain the final seminar grade, out of 10.

The PAC will then separately evaluate the student based on the submitted report, any issues arising from the seminar, inputs from the guide, and a discussion with the student. The evaluation will be based on a number of factors, such as the quality and quantity of work done since the previous review, the number of successful proposals and published papers led by the student, motivation, conscientiousness, and commitment shown by the student, etc. The PAC may also discuss with the student the comments of the faculty members on the talk, to try to help the student improve on her/his work and presentation skills. Any problems that the student might have faced during the review period should also be brought up, so that these can be discussed; the PAC will attempt to come up with solutions or suggestions. The PAC members will then provide individual evaluations of the student's performance over the year, again on a scale of $1-10$, with a higher number indicating better performance and a mark of 6 indicating marginal performance. These will be averaged together to obtain the final PAC grade. The final review grade will be the arithmetic mean of the final seminar grade and the final PAC grade.

Based on all these inputs, the PAC will recommend an extension of the Research Scholarship , or a termination of the student's Research Scholarship. In normal circumstances, the PAC will recommend an extension of one year when the final review grade is significantly higher than 6 out of 10. The PAC may recommend a six-month extension followed by a mid-term review in cases where closer monitoring is felt to be necessary, either because the review grade is marginal, or for any other reason. A final review grade significantly lower than 6/10 is likely to result in a recommendation for termination of the Research Scholarship, unless the PAC feels that there are extenuating circumstances that warrant an extension.

While the student reviews are held once a year, it is strongly recommended that the student or supervisor should bring any problems in the student's progress (either apparent or envisaged, and including any interpersonal problems that are affecting the work) to the attention of the PAC as early as possible so that these, along with possible solutions, can be discussed. If needed these discussions could include the AAC or the Dean (NF). The students are especially advised to not wait until the annual review to take up such issues, but to bring them up as soon as possible.

The minutes of the review will be provided to the student within ≈ 2 weeks of the review. If a student feels for any reason that the minutes are not a fair representation of what transpired during the seminar or review, or feels that the review process has not been fair, s/he should discuss the matter with the advisor and/or the PAC, and may request another meeting with the PAC. If the student is not satisfied with the outcome of this meeting, s/he may make a representation to the Dean (NF) or the Centre Director (in cases where the Dean(NF) is a member of the PAC).

7.2 Salary, Travel Grant, and Contingency Grant

Prog (Credits)	**Int-Ph.D. (100 & 80)**		**Ph.D. (60)**	
Years	**Monthly Salary (INR)**	**Annual Contingency (INR)**	**Monthly Salary (INR)**	**Annual Contingency (INR)**
I	21,000	25,000	31,000	40,000
II	31,000	40,000	31,000*	40,000
III	31,000*	40,000	35,000	40,000
IV	35,000	40,000	35,000	40,000
V	35,000	40,000	35,000	40,000
VI	35,000	40,000	17,500	–
VII	17,500	–	–	–

*: Fellowship amount increases to Rs. 35,000/- p.m. after Ph.D. registration

Table 6: Salary and Contingency grant for the Ph.D. and Int-Ph.D. programmes.

All NCRA Ph.D. and Int-Ph.D. students are provided a scholarship to support them during their Ph.D.

research, as well as an annual contingency grant. The details of the scholarship and contingency grant at present (August 2019) are given in Table 6. We emphasize that all scholarships and grants are subject to revision by the Department of Atomic Energy and TIFR from time to time.

The items covered by the grant are scientific and reference books (including dictionaries and encyclopedias), science journal subscriptions, memberships of professional societies, laptops, electronic storage media (e.g. USB memory devices, hard drives, RAM, etc), software items, telescopes, Ph.D. Registration/Thesis fees. The purchase of other items required for research purposes may also be permitted, based on the recommendations of the guide or, for students who have not yet registered for the Ph.D., by the Convenor of the AAC.

The contingency grant is maintained on the basis of the academic year, i.e. August to July, and is non-cumulative. However, if a specific item (e.g. a laptop) costs more than the total annual contingency grant, students may be permitted, based on the recommendations of the guide or, for students who have not yet registered for the Ph.D., the Convenor of the AAC, and as per the TIFR norms, to combine the grants from two or more years in order to purchase the item.

In addition, Regular Ph.D. and Int-Ph.D. students will be provided with a research and travel support grant (INR 2.25 lakhs during the course of the Ph.D., as of December 2018) to enable them to attend international research conferences, workshops, or schools, carry out international research collaborations, travel for observations or experiments with international research facilities, etc. Formal approval of the supervisor (or of the Convenor of the AAC for students who have not yet registered for a Ph.D.) for such travel should be obtained when submitting the relevant application forms (to be obtained from the Faculty Office). The final permission for such travel must in all cases be obtained from the Centre Director, NCRA.

7.3 Leave of Absence for Research Scholars

During the courses of the Graduate School, students will not be allowed to take leave from NCRA except in circumstances such as illness or emergencies. In any event, absence from the Programme during the Graduate School period will be permitted only with the consent of the Convenor of the AAC.

Students attending Graduate School courses are generally not expected to go out of station to attend scientific conferences or workshops, or to go on deputation. An exception to this norm must be recommended by the AAC, and then discussed and approved by the Dean, NCRA.

Research Scholars are not permitted to go on vacation while their courses are in progress. Vacation can be taken only during the breaks in the Graduate School.

Once the courses are over, students are entitled to seventy days of leave in a year, provided the leave is taken during the vacation period (October 1 to October 31, December 16 to January 14, and March 1 to June 30). Further details of leave can be obtained from the Faculty Office. All requests for leave must be approved in advance by the Ph.D. supervisor or, for students who have not yet registered for a Ph.D., the Convenor of the AAC.

7.4 Support Activities

All Research Scholars are strongly encouraged to take part in support activities, especially in the observatory, to enrich their experience and learning, and also to contribute to the Centre. These support activities include Science Day activities, GMRT test and upgrade activities, acting as a teaching assistant in a lecture course, etc..

7.5 Seminars and other Academic Activities

Research Scholars are expected to participate in academic activities, such as seminars, colloquia, informal discussion meetings, etc. Besides the annual review seminar, every Research Scholar is required to give an additional talk, typically at the NCRA Academic Day(s), during each academic year. Research Scholars are also strongly encouraged to give more seminars, both at NCRA and at other institutes.

Programme (Credits)		Duration											
	Years	I		II		III		IV		V		VI	
	Semesters	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Int-Ph.D. (100)		C*	C*	C	C	C	R	R	R	R	R	R	T
Int-Ph.D. (80)		C	C	C	C	R	R	R	R	R	R	R	T
Ph.D. (60)		C	C	C	R	R	R	R	R	R	T		

C*: Course work (outside NCRA)
C: Course work (including research projects) in NCRA
R: Research work
T: Thesis preparation

Table 7: The overall structure of the Ph.D. and Int-Ph.D. programmes.

7.6 National Eligibility Test (NET)

It is strongly recommended that NCRA Research Scholars pass the CSIR/UGC National Eligibility Test (NET) at the earliest opportunity. While this test is not required by NCRA or the TIFR Deemed University, it is an important qualifier for faculty positions at Indian universities and experience has shown that it is far easier to clear this test when candidates have recently cleared the M.Sc. examination.

8 Requirements and Procedures for a Ph.D. Degree

The year-by-year structure of the programmes for Int-Ph.D. (100 credits), Int-Ph.D. (80 credits), and Regular Ph.D. students is summarized in Table 7.

8.1 Duration of Ph.D. Programme

A Regular Ph.D. student is expected to submit his/her Ph.D. thesis to the TIFR Deemed University or the University at which s/he is registered within five years of the date of joining the NCRA Ph.D. Programme (i.e. including the Graduate School). The corresponding limit for Int-Ph.D. students is six years. Research Scholars who fail to complete their work within these periods will have to request an extension. In such cases, the student's Ph.D. Advisory Committee would refer the matter to the NCRA Faculty, along with a justification for the extension. The Faculty will review the case and recommend an extension, if felt appropriate, to the NCRA and TIFR Directors. In general, such extensions will be granted for less than six months at a time and would not exceed a total of one year. It should be emphasized that such extensions are not guaranteed and require the approval of the TIFR Director. Including such extensions, the total duration of the thesis should not be more than six years for Regular Ph.D. students and seven years for Int-Ph.D. students. Extensions beyond these limits will be allowed only in rare and exceptional cases, based on a written application from the advisor.

It should be noted that the monthly salary of the student is expected to be reduced during the period of the extension (based on the TIFR norms). The contingency grant will not be available during this period.

8.2 Basic Requirements for a Ph.D. Thesis

The requirements for a Ph.D. thesis at the TIFR Deemed University are set by the TIFR Subject Board of Physics. Essentially, the thesis must demonstrate that the candidate has done a significant amount of original work in the chosen subject. A necessary criterion for this is that at least some part of the thesis, where the candidate has made a significant contribution, should be published or accepted for publication in a peer-reviewed journal, at the time of the submission of the synopsis. Further details are provided at the website of the TIFR Subject Board of Physics `http://www.tifr.res.in/~sbp/new2015/thesis.htm`.

8.3 Synopsis Seminar

When the student has completed his/her research work to the satisfaction of the supervisor, s/he is required to give a "synopsis seminar" on the work on which the thesis is based. The NCRA Faculty Office will make arrangements for this synopsis seminar. The Dean, NCRA, will (usually in consultation with the supervisor and the Convenor of the AAC) set up an evaluation committee for the student, including one external member.

The synopsis is a PDF document, of length not fewer than 10 pages and not more than 15 pages, legibly typed on A4-size pages in 12-pt. font size, with 1.5 pt. spacing and with 1 inch margins. Apart from text, it may contain figures, tables, sections of computer code and a short bibliography. A copy of the synopsis must be submitted to the Faculty office for circulation to the evaluation committee at least one week before the synopsis seminar.

The synopsis and the synopsis seminar will be evaluated by the evaluation committee, and the grades given by members of the evaluation committee will be recorded in the file of the candidate. If the average grade of the committee is lower than 60%, the thesis will not be forwarded to the TIFR Deemed University. The committee's recommendations should be taken into account by the student, and the synopsis (and possibly, the thesis) revised accordingly before the final submission.

8.4 Synopsis and Thesis Submission

After the synopsis and the synopsis seminar have been approved by the evaluation committee, the student may submit the final synopsis of her/his Ph.D. thesis to the TIFR Deemed University. The procedure for this may be obtained from the NCRA Faculty Office. Finally, the Ph.D. thesis may be submitted to the NCRA Faculty office (for forwarding to the TIFR Deemed University) at any time following the submission of the synopsis, up to a maximum of six months from the date of submission of the synopsis.

8.5 Visiting Fellowship After Submission of Thesis

A Regular Ph.D. student who has submitted his/her thesis within a maximum period of six years (within seven years for Int-Ph.D. students) will, *on application*, be offered a short-term Visiting Fellowship (typically for 6 months) at NCRA to allow completion of the thesis evaluation formalities as well as ongoing research projects. Students exceeding this maximum period are very unlikely to be offered a Visiting Fellowship without a clear justification and a strong recommendation from the Ph.D. Advisory Committee. Each such case will be discussed in detail in the NCRA Faculty. Regular Ph.D. students requiring more than six years (seven years for Int-Ph.D. students) to complete a thesis will not be offered such a Visiting Fellowship.

9 Students or Guides Affiliated to Other Institutions

9.1 Students working at NCRA

Students affiliated to an institution other than TIFR but desirous of working at NCRA for extended periods must have a guide and a research problem clearly identified in their parent institution. Such a collaborative effort, in which an NCRA staff member is interested in partially supervising the student, would contribute to increasing academic activities at NCRA. However, the following norms should be followed:

1. The NCRA staff member with whom the student is working, and who is responsible for the student, should be clearly identified.

2. The total duration of such visits by one student should not exceed six months in a calendar year. In exceptional circumstances, this could be extended to at most nine months, with approval of the NCRA Faculty.

3. The total number of such external students at NCRA at any given time should in general not exceed five.

4. Such visits should be mentioned in the NCRA Faculty meetings as an informational item. The students should also be encouraged to give a talk at the end of each visit.

5. The students are expected to be financially supported by their parent institute or their own research grants. However, efforts will be made to provide logistical support. Students from India and abroad will be treated at par.

6. Accomodation in the NCRA hostel will be provided to such students depending on availability, and following the hostel norms.

9.2 NCRA Members Guiding Students Working Elsewhere

Occasionally, an NCRA member may be requested to be the Ph.D. guide of a student who intends to carry out doctoral work at another institution. NCRA imposes no constraints on this activity, except that the thesis may not be submitted through NCRA. The doctoral research of such students will be governed entirely by the rules and regulations of his/her institution. However, the NCRA Faculty Office should be informed about such cases.

Appendix 1: Summary of the course and project structure for the three NCRA Ph.D. and Int-Ph.D. programmes

Course Outline for Regular Ph.D. Students (60 Credits)			
Sl	Course	Teaching hours	Credits
Semester I, Term I: Early August to end-September			
01	Methods of Mathematical Physics I	21	3
02	Introduction to Astronomy and Astrophysics I	14	2
03	Electrodynamics and Radiative Processes I	14	2
04	Quantum and Statistical Mechanics I	14	2
Semester I, Term II: Mid-October to mid-December			
05	Methods of Mathematical Physics II	14	3
06	Introduction to Astronomy and Astrophysics II	14	2
07	Electrodynamics and Radiative Processes II	14	2
08	Quantum and Statistical Mechanics II	14	2
Semester II, Term I: Early January to mid-March			
09	Astronomical Techniques I	14	3
10	Galaxies : Structure, Dynamics and Evolution	21	3
11	Extragalactic Astronomy I	21	3
Semester II, Term II: Mid-March to mid-May			
12	Astronomical Techniques II	14	3
13	Interstellar Medium	14	3
14	Extragalactic Astronomy II	14	3
Semester III, Term I: Mid-June to mid-September			
15	Research Project I	–	12
Semester III, Term II: Mid-October to mid-January			
16	Research Project II	–	12
	Total Credits		60

Table 8: Courses and Projects for Regular Ph.D. Students

Course Outline for Integrated Ph.D. Students (80 Credits)			
Sl	Course	Teaching hours	Credits
Semester I, Term I: Early August to end-September			
01	Methods of Mathematical Physics I	21	3
02	Introduction to Astronomy and Astrophysics I	14	2
03	Electrodynamics and Radiative Processes I	14	2
04	Quantum and Statistical Mechanics I	14	2
Semester I, Term II: Mid-October to mid-December			
05	Methods of Mathematical Physics II	14	3
06	Introduction to Astronomy and Astrophysics II	14	2
07	Electrodynamics and Radiative Processes II	14	2
08	Quantum and Statistical Mechanics II	14	2
Semester II, Term I: Early January to mid-March			
09	Astronomical Techniques I	14	3
10	Galaxies : Structure, Dynamics and Evolution	21	3
11	Extragalactic Astronomy I	21	3
Semester II, Term II: Mid-March to mid-May			
12	Astronomical Techniques II	14	3
13	Interstellar Medium	14	3
14	Extragalactic Astronomy II	14	3
Semester III, Term I: Mid-June to mid-September			
15	Research Project I	–	12
Semester III, Term II: Mid-October to mid-January			
16	Research Project II	–	12
Semester IV, Term I: Mid-February to mid-May			
17	Advanced Course I	~ 25	6
18	Advanced Course II	~ 25	6
Semester IV, Term II: Early-June to end-August			
19	Research Project III	–	8
	Total Credits		80

Table 9: Courses and Projects for Integrated Ph.D. Students (80 Credits)

Course Outline for Integrated Ph.D. Students (100 Credits)			
Sl	Course	Teaching hours	Credits
Semester - I: Early August to early December (IISER/Physics Dept.)[1]			
01	Mathematical Methods in Physics	~ 40	4
02	Classical Mechanics	~ 40	4
03	Quantum Mechanics I	~ 40	4
04	Electronics	~ 40	3
05	General Laboratory I / Computer Laboratory	~ 40	3
Semester - II: Early January to early May (IISER/Physics Dept.)[1]			
06	Quantum Mechanics II	~ 40	4
07	Statistical Mechanics	~ 40	4
08	Electrodynamics I	~ 40	4
09	Atoms, Molecules and Solids	~ 40	3
10	Computer Laboratory / General Laboratory I	~ 40	3
Summer Project: Mid-May to mid-July (NCRA)			
11	RPL or Experimental/Reading Project	–	4
Semester - III, Term - I: Early August to end-September (IUCAA/NCRA)			
12	Methods of Mathematical Physics I	21	3
13	Introduction to Astronomy and Astrophysics I	14	2
14	Electrodynamics and Radiative Processes I	14	2
15	Quantum and Statistical Mechanics I	14	2
Semester III, Term II: Mid-October to mid-December (IUCAA/NCRA)			
16	Methods of Mathematical Physics II	14	3
17	Introduction to Astronomy and Astrophysics II	14	2
18	Electrodynamics and Radiative Processes II	14	2
19	Quantum and Statistical Mechanics II	14	2
Semester - IV, Term - I: Early January to mid-March (IUCAA/NCRA)			
20	Astronomical Techniques I	14	3
21	Galaxies : Structure, Dynamics and Evolution	21	3
22	Extragalactic Astronomy I	21	3
Semester - IV, Term - II: Mid-March to mid-May (IUCAA/NCRA)			
23	Astronomical Techniques II	14	3
24	Interstellar Medium	14	3
25	Extragalactic Astronomy II	14	3
Semester V, Term I: Mid-June to mid-September (NCRA)			
26	Research Project I	–	12
Semester V, Term II: Mid-October to mid-January (NCRA)			
27	Research Project II	–	12
	Total Credits		100

[1]These courses are listed according to the curriculum followed in 2017 at the Physics Dept.; the exact listing of courses may vary at both the Physics Dept. and IISER-Pune.

Table 10: Courses and Projects for Integrated Ph.D. Students (80 Credits)

Appendix 2: Research Scholar Applications from Abroad

The procedure for Research Scholar applications from persons residing outside India who are unable to participate in the Regular selection procedure is described below;

Such candidates should write to the Dean, NCRA or the chairperson of the AAC, either of whom may then propose the case at a meeting of the AAC. The AAC should examine such cases carefully and satisfy itself that the applicant is genuinely unable to appear for the test and interviews. In such cases, every effort should be made to interview the candidate over telephone/video conferencing/Skype if possible. The AAC should also assess the candidate's qualifications and aptitude; this assessment may be based on reference letters, publications, and any other available information.

If the AAC is convinced that the candidate should be admitted to the Graduate Programme, it should make a clear recommendation to this effect to the Director or Dean, NCRA. The AAC may also bring the matter up for discussion at the NCRA Faculty, if it finds this necessary, before making a recommendation to the Director or Dean. The recommendation must explain why the candidate is unable to undergo the normal selection procedures, and must state the academic grounds on which admission of the candidate is being recommended.

The final decision will be made by the Director or the Dean, NCRA and communicated to the applicant.

An applicant who is offered admission in this way should be aware that the normal duration of the NCRA Ph.D. programme is five years. This is important for foreign students who may have restrictions on their period of absence from their home country. The applicant should also be made aware of the fees payable to the University, the type of visa required and any other regulations that may be in force.

Candidates selected through this procedure will in all other respects be subjected to the same rules and requirements as those selected through the normal procedure.

Appendix 3: Syllabus for the IUCAA - NCRA Graduate School Courses

(a) The courses are designed so as to emphasize aspects that are directly relevant to Astronomy and Astrophysics and to avoid unnecessary repetition of material already taught in M.Sc. syllabi. While selecting students for the IUCAA/NCRA Graduate School, we try to ensure that the student is familiar with physics at the M.Sc. level, so that there is no need for routine material to be repeated in the graduate-level course.

(b) The syllabus provides enough avenues for topics which are of "local interest" to be included in the Graduate School. This is necessary so that graduate students coming out of IUCAA/NCRA not only have a comprehensive grasp of astronomy and astrophysics but are also aware of the key research areas in which these two institutions are concentrating at present.

01. Methods of Mathematical Physics I

[The emphasis will be on practical aspects of using mathematics to solve problems rather than on formal mathematical proofs. Emphasize on Green's functions, and Fourier analysis].

Sturm-Liouville problem and its connection with special functions - Partial differential equations (inhomogeneous and homogeneous wave equations, diffusion equation, Green functions) - WKB and other approximation methods, series expansions, saddle-point, etc. - Fourier analysis.

02. Introduction to Astronomy and Astrophysics I

[All these topics will come up for detailed study later; the aim of this course will be to connect physics with astrophysics at an order-of-magnitude level and to introduce conventions and jargon of astronomy and astrophysics to a physics student].

Earth-solar system - The Sun as a star - Stellar structure and evolution - The HR diagram - Colours, magnitudes, Spectral classification - White dwarfs, neutron stars, black holes - Binaries - ISM - Structure of Milky Way - Stellar population and galactic structure - Cosmology - Brief description of Galaxy morphology and evolution - Active Galaxies - Clusters of Galaxies.

03. Electrodynamics and Radiative Processes I

Review of Maxwell's equations, and M.Sc. level electrodynamics - Motion of charged particle in E, B fields Electromagnetic waves - Polarization and geometrical optics - Radiation of electromagnetic waves - Scattering of radiation (Thomson and Compton) - Bremsstrahlung and synchrotron radiation.

04. Quantum and Statistical Mechanics I (Quantum Mechanics)

[The Course will emphasize the functionality of QM rather than its mathematical or conceptual structure].

Overview of M.Sc. level quantum mechanics - Solution of Schrödinger equation in 1 d and potential motion - Quasi classical case, WKB - Hydrogen atom and the structure of periodic table - Perturbation theory - Fine structure and hyperfine structure (21 cm) - Quantum theory of radiation - Energy levels of atoms, and molecules and selection rules.

05. Methods of Mathematical Physics II (General Relativity)

Physical basis for GR - Tensor analysis - Geodesics, connection and curvature - Einstein equations - Schwarzschild metric (orbits and classical tests of GR) - Black holes - Gravitational waves - FRW spacetime.

06. Introduction to Astronomy and Astrophysics II (Stellar Physics)

Observational data on stars (types of stars, spectral classification, regions of HR diagram) - Basics of nuclear energy generation - Sources of opacity - Steady state stellar models (homologous models and multilayered configurations) - Stellar evolution (simple analytical estimates and summary of numerical results) - Supernova and SNR - End stages of stellar evolution (white dwarfs, neutron stars and black holes) - Pulsars - Evolution of binary star systems - Star formation (including brown dwarfs) - Star cluster.

07. Electrodynamics and Radiative Processes II (Astrophysical Processes : Fluid dynamics, Radiative processes and Plasmas)

Basics of fluid dynamics - Hydrostatic equilibrium, with applications to self gravitating bodies - Instabilities - Accretion and winds - Shocks - Turbulence - Basics of plasma physics - MHD - Dynamos - Radiative processes in astrophysical systems: Bremsstrahlung, synchrotron radiation, Compton and inverse Compton processes -

Macroscopic description of radiation field - Moments of radiative transfer equations and simple approximate solutions - Ionisation and recombination processes.

08. Quantum and Statistical Mechanics II (Statistical Mechanics)

Overview of M.Sc. level statistical physics - Basics of statistical mechanics and thermodynamics - Boltzmann, Bose, Fermi distributions - Applications to classical gases, electron degeneracy in white dwarfs - Photons Bose condensation and superfluidity - Ionisation and pair creation equilibria - Phase transitions - Elementary introduction to stochastic processes.

09. Astronomical Techniques I (Incoherent Detection)

Time and coordinate measurements - Atmospheric effects (absorption, seeing,) - Basics of telescopes - Noise and statistics - Photon detectors - Basics of photometry - Spectroscopy and polarimetry.

10. Galaxies : Structure, Dynamics and Evolution

Galaxies as self gravitating objects, virial equilibrium - Estimates of collision times - Collisionless Boltzmann equation and some steady state solutions - Globular clusters - stability - Spiral structure, bars and disc dynamics - Ellipticals - Galaxy morphology - Chemical evolution - Galaxy formation and evolution.

11. Extragalactic Astronomy I (Cosmology)

Friedmann models (geometrical and physical aspects) - Thermal history of the universe from T = 1 GeV to T = 900 K - Linear growth of perturbations - Anisotropies in CMBR and comparison with observations - Nonlinear evolution of perturbations (Zeldovich approximation, spherical top hat, basic idea of simulation results) - Segregation of baryons and dark matter- Very early universe and inflation - Clusters and superclusters - Overall structure of IGM-Gunn-Peterson effect - Quasar absorption systems - High redshift galaxies.

12. Astronomical Techniques II (Coherent Detection)

Partial coherence - Aperture synthesis and image reconstruction High angular resolution techniques and astrometry - Databases in astronomy.

13. Interstellar Medium

Extinction and reddening of star light, dust - 21 cm, galaxy rotation curves, HI distribution - Ionised gas, pulsar DM - HII regions - Cooling and heating - Shocks - Supernovae remnants - Phases of the ISM - Magnetic field and Faraday rotation - Cosmic rays - Molecular clouds and star formation.

14. Extragalactic Astronomy II (Radio Galaxies and Quasars)

Phenomenology of AGNs (Seyferts, Quasars, Radio Galaxies, LINERS, BL Lacs) with a survey of continuum, emission and absorption features of spectra - Black hole and accretion disc models for AGNs - Emission line regions (BLR, NLR) - Physics of jets and hot spots.

Appendix 4: Syllabus for the Advanced Courses

The syllabi for the Advanced Courses offered to the Int-Ph.D. (80 credits) students are as follows:

01. Advanced Radio Astronomy

1. Wide-field, wide-band imaging
2. Data pre-processing and calibration
3. Propagation effects
4. Construction of sky models
5. Beam formation techniques
6. De-dispersion techniques
7. Pulsar search algorithms.

02. Radio Instrumentation

1. Types of antennas and feeds in radio astronomy, and their radiation patterns.
2. Signal amplification, transmission, and related analogue electronics:
   (a) Low noise radio frequency amplifiers and their design characteristics,
   (b) Working and design of a Superheterodyne radio receiver system (including the local oscillator, IF amplifier and baseband receiver).
3. Basics of fibre optics communication and servo systems.
4. Digital correlators: design principles and their implementation using both hardware- and software-based signal correlation.
5. Hands-on experiment with any two of the above 4 modules.

03. Cosmology and Structure Formation

1. Review of basic cosmology.
2. Cosmological perturbations.
3. Anisotropies in the Cosmic Microwave Background.
4. Gravitational collapse and formation of dark matter haloes.
5. Statistical properties of the cosmic density field.
6. Models of galaxy formation.
7. Numerical simulations.
8. The intergalactic medium.
9. The epoch of Reionization.
10. Dark energy.

04. Advanced Interstellar Medium

1. The distribution of neutral atomic hydrogen in the Milky Way
2. Dust models and emission processes
3. Polycyclic aromatic hydrocarbons
4. The hot ionized medium
5. Multi-phase models of the interstellar medium
6. Diffuse and dense molecular gas
7. The CO-to-H2 conversion factor
8. Determining physical conditions in the interstellar medium
9. Magnetic fields in the Milky Way and external galaxies
10. The interstellar medium in external galaxies.

05. Advanced course on Galaxies: Their structure, formation and evolution

1. The first galaxies
    (a) Collapse of density fluctuations
    (b) The role of cooling in galaxies and clusters
    (c) Major and minor mergers
2. Probing large-scale structure using galaxy tracers
    (a) Measurements of galaxy clustering and large-scale structure
    (b) Redshift surveys
    (c) Evolution of clustering
3. Galaxy properties
    (a) Modern view of the Hubble Sequence
    (b) Stellar populations.
    (c) Galaxy luminosity and mass functions
    (d) Properties of spiral, elliptical and dwarf galaxies.
    (e) Fundamental correlations and scaling relations.
    (f) Galaxy clusters.
    (g) High redshift galaxies.
4. Galaxy Evolution
    (a) Basic processes: secular and environment-dependent.
    (b) Deep galaxy surveys and selection effects.
    (c) Star formation and stellar mass.
    (d) Extragalactic Background Light.
    (e) Chemical evolution of galaxies.
    (f) Feedback processes.

06. Advanced Course on Pulsars

1. Introduction to Pulsars and Neutron stars.
2. Origin and evolution of pulsars.
3. Classes of Pulsars and Neutron Stars.
4. Observational properties of pulsars.
5. Instrumentation for pulsar observations.
6. Pulsar data analysis techniques: Searches, timing, imaging.
7. Pulsar emission mechanisms: theory and probes.
8. Pulsars as probes of the interstellar medium.
9. Binary and millisecond pulsars
10. Pulsars as probes of gravity
11. The equation of state of pulsars
12. Pulsars and their environments: Supernova remnnants, pulsar wind nebulae.
13. Pulsars in globular clusters.

07. Solar and Heliospheric Physics

1. Introduction to the Sun and the Heliosphere.
2. Electromagnetic emission from the Sun.
3. Solar radio emission mechanisms.
4. Solar flares.
5. Coronal mass ejections.
6. Coronal heating

7. Magnetic reconnection in the corona
8. Probes of the heliosphere.
9. The impact of the Sun on the Earth and Space Weather

08. Advanced Course on Active Galactic Nuclei

1. Active Galactic Nuclei (AGNs) across the electromagnetic spectrum.
    (a) Emission Mechanisms at different observing bands.
    (b) Spectral Modelling of AGNs.
2. The physics of black hole accretion.
3. The Broad and Narrow Line Regions:
    (a) Types of spectral lines and kinematics.
    (b) Determination of the black hole mass.
    (c) Reverberation mapping.
4. AGN Classification and Unification schemes.
5. Formation and evolution of AGNs.
6. AGN feedback and the AGN-Starburst connection.
7. Jets in AGNs: theoretical models and observational signatures.
8. The Black Hole - Disk - Jet connection in AGNs.
    (a) The Fundamental Plane.
    (b) The Quasar-Microquasar connection.
9. AGNs and Cosmology.
10. Open questions in AGN studies.

Appendix 5: Norms for NCRA staff members doing a Ph.D.

The norms for NCRA staff members who would like to register for a Ph.D. under TIFR Deemed University are as follows:

1. The research ability of the candidate will be tested in an interview by an NCRA faculty committee before he/she begins graduate school studies. This interview could cover the technical skills of the candidate, his/her understanding of projects that have been done in the past as well as the area proposed for doctoral research, and his/her understanding of basic physics. The committee for this purpose will be constituted by the NCRA Dean.

2. The academic requirements for obtaining the Ph.D. degree should be the same as for Regular Ph.D. students in NCRA. Specifically, the staff member should complete all the required graduate school courses and research projects. The points worth noting are (i) the staff members will be allowed two attempts at clearing each Graduate School course and (ii) staff members will have the same CPI requirements for courses and projects as those for Regular students of the NCRA Graduate School. The CPI for the staff members will be computed at the end of every 18 credits, which roughly corresponds to the number of credits per semester of the Graduate School. The detailed norms are outlined in Sections 3, 4 and 5 of this document.

3. However, bearing in mind the fact that the staff members will have parallel observatory duties, they would be allowed to complete the graduate school requirements in 5 years (as opposed to 2 years for Regular Ph.D. students).

4. Also, staff members will be allowed a maximum of 6 months in which to complete each "3 month" research project.

5. It is possible that the staff members may not be able to attend classroom lectures for some or most of the graduate school courses, due to observatory duties at GMRT. Hence the staff member be allowed to take the required courses as reading courses, if deemed necessary by the review committee. The review committee should decide which courses should be taken as reading and classroom courses. For reading courses, all courses should not be taken under the guidance of a single faculty member; preferably, not more than 2-3 courses should be taken under a single faculty member. The performance in the reading courses should be evaluated as per the standard graduate school norms, i.e. a combination of assignments, tests, seminars, and discussions, as deemed appropriate by the advisor. The member can also try to attend the lecture courses via video link.

6. A review committee should be set up for the Ph.D. candidate, similar to the Ph.D. Advisory Committees of NCRA Ph.D. students. This committee should consist of the guide, a member of the AAC, and the candidate's reporting officer. In case the reporting officer is also the guide, the NCRA Dean should nominate an NCRA faculty member to be on the review committee.

7. There will be a review of the candidate's performance every year, similar to the reviews of other NCRA Ph.D. students.