Mathematics, more than the fundamental language and underlying analytical structure of science and technology, is a formal way of thinking—an art that ties together the abstract structure of reason and the formal development of the logic that defines the scientific method. From the study of just how arguments and theories are formed in language and technology to the framework of quantitative and qualitative models of the natural and social sciences, mathematics is based upon the development of precise expressions, logical arguments, and the search for and exposure of pattern and structure.

The undergraduate program in the Department of Mathematics is intended both for students interested in attaining the proper preparation for graduate study and research in pure mathematics, and for students interested in using mathematics to define, properly pose, and solve problems in the sciences, engineering, and other areas. With either purpose, the focus of the program is to help those who wish to understand further the logical content, geometric meaning, and abstract reasoning of mathematics itself. A flexible program involving a broad selection of courses is a department tradition. The program begins by introducing students to the basics of algebra and mathematical analysis and then gives them the choice of exploring topics in theoretical mathematics or studying applications to physics, economics, engineering, computer science, probability, statistics, or mechanics.

The graduate program is designed primarily to prepare students for research and teaching in mathematics. It is naturally centered around the research areas of the faculty, which include algebraic geometry, algebraic number theory, differential geometry, partial differential equations, topology, several complex variables, algebraic groups, and representation theory. The program can be supplemented in applied directions by courses in theoretical physics, computer science, mechanics, probability, and statistics offered in other departments of the Krieger School of Arts and Sciences and in the Department of Applied Mathematics in the Whiting School of Engineering.

Facilities
The Mathematics Department resides in Krieger Hall on the Keyser Quad of Homewood. Adjacent to Krieger Hall, The University’s Milton S. Eisenhower Library has an unusually extensive collection of mathematics literature, including all the major research journals, almost all of which are accessible electronically. The stacks are open to students. The department also has a useful reference library, the Philip Hartman Library. Graduate students share departmental offices, and study space can also be reserved in the university library. Graduate students may access the department’s Linux and Windows servers, as well as computers in graduate student offices. The department also hosts numerous research seminars, special lectures, and conferences throughout the academic year.

Math Course Placement and Sequencing for All Students
There are three different versions of single variable calculus offered by the Mathematics Department, including 2 versions of semester courses in Calculus I and II, roughly equivalent to Calculus AB and BC in the College Board's Advanced Placement (AP) system, and a single semester honors version encompassing both Calculus I and II. Students should select their first course in mathematics at JHU based on their intended areas of study, prior experience and training in mathematics, and the results of an advisory Placement Exam offered to incoming freshmen. Students intending to major in mathematics, the natural sciences, or engineering, or who are interested in studying mathematics beyond a year of single variable calculus are strongly encouraged to begin with the AS.110.108 Calculus I - AS.110.109 Calculus II (For Physical Sciences and Engineering) sequence or AS.110.113 Honors Single Variable Calculus. Students majoring in other subjects, or who do not intend to continue taking mathematics courses beyond a year of calculus, may wish to take the sequence AS.110.106 Calculus I (Biology and Social Sciences) - AS.110.107 Calculus II (For Biological and Social Science). This latter sequence relates the methods of calculus to the biological and social sciences. A one-semester pre-calculus course (AS.110.105 Precalculus) is a pre-calculus course offered for students who would benefit from additional preparation in the basic tools (algebra, trigonometry and the properties of functions) used in calculus.

Entering students may receive course credit for Calculus I or Calculus I and II on the basis of the performance level on either the (AP) or International Baccalaureate (IB) exams (http://e-catalog.jhu.edu/undergrad-students/academic-policies/external-credit/#examcredittext). All students, regardless of completion of advanced placement exams previously, must take a departmental placement exam to determine their appropriate first course in mathematics. Additional placement information can be found here (http://mathematics.jhu.edu/undergraduate/placement-exams).

After completing a full year of calculus, the courses AS.110.201 Linear Algebra, AS.110.202 Calculus III, or AS.110.302 Differential Equations and Applications may be taken in any order. The department offers honors courses of the former 2; AS.110.212 Honors Linear Algebra and AS.110.211 Honors Multivariable Calculus.

Requirements for the B.A. Degree
In addition to the Requirements for a Bachelor's Degree (http://e-catalog.jhu.edu/undergrad-students/academic-policies/requirements-for-a-bachelors-degree), a candidate for the Bachelor of Arts Degree in Mathematics is required to have completed the major requirements listed below. All courses used to meet these requirements must be completed with a grade of C- or better and may not be taken satisfactory/unsatisfactory (S/U) grading scheme.

AS.110.106 or AS.110.108 Calculus I (Biology and Social Sciences) 4
or AS.110.107 or AS.110.109 Calculus II (For Biological and Social Science) 4
or AS.110.113 Honors Single Variable Calculus

AS.110.202 or AS.110.211 Calculus III 4
or AS.110.212 Honors Multivariable Calculus

AS.110.201 or AS.110.212 Linear Algebra 4

AS.110.401 Introduction to Abstract Algebra 4
or AS.110.411 Honors Algebra I

One Additional Algebra Course From List: 4
AS.110.304 Elementary Number Theory 4
or AS.110.411 Honors Algebra II
or AS.110.411 Introduction To Topology
or AS.110.421 Representation Theory
or AS.110.435 Introduction to Algebraic Geometry

or AS.110.415 Honors Analysis I

One Additional Analysis Course From List: 4

AS.110.311 Methods of Complex Analysis
or AS.110.406 Real Analysis II
or AS.110.415 Honors Complex Analysis
or AS.110.411 Introduction To Topology
or AS.110.416 Honors Analysis II
or AS.110.421 Dynamical Systems
or AS.110.413 Introduction To Topology
or AS.110.44 Calculus on Manifolds
or AS.110.44 Fourier Analysis

One 300-level or higher math course 4

Two courses in any one of the approved applications of mathematics or other courses approved by the Director of Undergraduate Studies ** 8

Total Credits 44

* Majors are encouraged but not required to take honors variant.

** See table below for approved application courses.

*** AS.110.413 Introduction to Topology cannot be used for more than one requirement.

**** Honors Single Variable is a single 4 credit course that will count toward the major or minor in mathematics as both Calculus I and Calculus II.

Sample Program of Study

The following chart is one example of how a student might progress through the mathematics major. As potential math majors enter JHU with a wide range of prior math abilities, students should begin courses at their current level of knowledge.

Freshman

Fall Credits Spring Credits
AS.110.108 Calculus I 4 AS.110.109 Calculus II (For Physical Sciences and Engineering)
4

Sophomore

Fall Credits Spring Credits
AS.110.202 Calculus III or 211 4 AS.110.201 Linear Algebra or 212 4

Math application course 3-4

Junior

Fall Credits Spring Credits
AS.110.405 Real Analysis I or 415 4 AS.110.406 Real Analysis II or 416 4

Math application course 3-4

7-8

Senior

Fall Credits Spring Credits
AS.110.401 Introduction to Abstract Algebra 4 AS.110.304 Elementary Number Theory 4

Math application course 3-4

4

Total Credits: 42-44

Requirements for a Minor in Mathematics

All courses used to meet the mathematics minor requirements must be completed with a grade of C- or better and may not be taken using the S/U grading scheme. One course in the Applied Mathematics and Statistics Department (at the 300-level or above) may be substituted for one of the elective courses for the minor.

AS.110.106 Calculus I (Biology and Social Sciences) or AS.110.108 Calculus I

AS.110.107 Calculus II (For Biological and Social Science) or AS.110.109 Calculus II (For Physical Sciences and Engineering) or AS.110.113 Honors Single Variable Calculus

AS.110.202 Calculus III 4

One 200-level or above math course (excluding AS.110.202) 4

Three 300-level or above math courses 12

Total Credits 28
Honors Program in Mathematics

As a general guideline, departmental honors are awarded to recipients of the B.A. degree who have completed AS.110.411 Honors Algebra I, as well as AS.110.412 Honors Algebra II, AS.110.415 Honors Analysis I AS.110.416 Honors Analysis II, AS.110.407 Honors Complex Analysis and one more course at the 400-level or above with a combined grade point average of at least 3.6/4.0.

J.J. Sylvester Prize

The J.J. Sylvester Prize in Mathematics, which carries a cash award, is given each year to the one of two top-performing graduating seniors majoring in mathematics for outstanding achievement.

The B.A./M.A. Program

By applying some courses simultaneously toward the requirements for the Bachelor of Arts degree and a Master of Arts degree, an advanced student can qualify for both degrees during the four years of undergraduate study. Admission to the BAMA Program is by the standard graduate application form, completed during a student’s junior year of study. A current GPA of at least 3.0/4.0 is required in the 400-level mathematics courses taken while resident at the university, and at the time of application, a student must be a candidate for honors in the undergraduate degree. Students may contact the graduate program assistant for further information.

Undergraduate Teaching Assistantships

The department awards many upper-level undergraduates the opportunity to act as recitation instructors to our freshman courses. This award enables a student to practice the art of teaching and communicating mathematics in an environment where they are hired as a formal instructor to aid the professor of a regular curriculum course as a Teaching Assistant (TA). Undergraduate TAs are fully mentored and monitored, and the position provides a valuable credential and experience.

Graduate Programs

Admission

Admission to the Ph.D. program is based on academic records, letters of recommendation, a statement of purpose, an optional personal statement, and Graduate Record Examination scores.

Basic Program

Graduate study is centered around three core areas:

Analysis

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Advisor</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.605</td>
<td>Real Variables</td>
<td>NA</td>
</tr>
<tr>
<td>AS.110.607</td>
<td>Complex Variables</td>
<td>NA</td>
</tr>
<tr>
<td>AS.110.608</td>
<td>Riemann Surfaces</td>
<td>NA</td>
</tr>
<tr>
<td>AS.110.631</td>
<td>Partial Differential Equations I</td>
<td>NA</td>
</tr>
<tr>
<td>&amp; AS.110.632</td>
<td>Partial Differential Equations II</td>
<td>NA</td>
</tr>
<tr>
<td>AS.110.645</td>
<td>Riemannian Geometry</td>
<td>NA</td>
</tr>
</tbody>
</table>

Algebra

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Advisor</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.601</td>
<td>Algebra</td>
<td>NA</td>
</tr>
<tr>
<td>&amp; AS.110.602</td>
<td>Algebra</td>
<td></td>
</tr>
<tr>
<td>AS.110.617</td>
<td>Number Theory</td>
<td>NA</td>
</tr>
<tr>
<td>AS.110.619</td>
<td>Lie Groups and Lie Algebras</td>
<td>NA</td>
</tr>
<tr>
<td>AS.110.643</td>
<td>Algebraic Geometry</td>
<td>NA</td>
</tr>
<tr>
<td>&amp; AS.110.644</td>
<td>Algebraic Geometry</td>
<td>NA</td>
</tr>
</tbody>
</table>

Topology

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Advisor</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.615 &amp; AS.110.616</td>
<td>Algebraic Topology and Algebraic Topology</td>
<td></td>
</tr>
</tbody>
</table>

These 600-level graduate courses are preliminary to research upon the foundations of an undergraduate math major.

The 700-level courses are designed to bring students abreast of recent developments and to prepare them for research in the area of their choice.

Requirements for the M.A. Degree

Although the Mathematics Department does not admit students seeking a terminal M.A. degree, students in the Ph.D. program may earn an M.A. degree. Advanced undergraduate students may also apply to be admitted to the accelerated B.A./M.A. program.

M.A. candidates must complete:

• Four graduate courses given by the Johns Hopkins Mathematics Department;
• Two additional courses at the graduate or 400-level, other than AS.110.401, AS.110.405, and AS.110.415, given by the Johns Hopkins Mathematics Department, or, with the permission of the graduate program director, graduate mathematics courses given by other departments or universities.

All courses used to satisfy the requirements must be completed with a grade of B- or better. (Advanced graduate courses completed with a grade of P can also be used to satisfy the requirements.)

Requirements for the Ph.D. Degree

The departmental requirements for the Ph.D. degree are:

1. Candidates must show satisfactory work in Algebra (AS.110.601-AS.110.602), Real Variables (AS.110.605), Complex Variables (AS.110.607), Algebraic Topology (AS.110.615), and one additional mathematics graduate course in their first year. The seminars and qualifying exam preparation course cannot be used to fulfill this requirement. The algebra and analysis requirements can be satisfied by passing the corresponding written qualifying exam in September of the first year; these students must complete at least two courses each semester. Students having sufficient background in topology can substitute an advanced topology course for AS.110.615, with the permission of the instructor.

2. Candidates must pass written qualifying exams by the beginning of their second year in Analysis (Real and Complex) and in Algebra. Exams are scheduled for September and May of each academic year.

3. Candidates must show satisfactory work in at least two mathematics graduate courses each semester of their second year, and, if they have not passed their oral qualifying exam, in the first semester of their third year.

4. Candidates must pass a departmental oral qualifying examination in the student’s chosen area of research by April 8th of the third year. The topic of the exam is chosen in consultation with the faculty member who has agreed (provisionally) to be the student’s thesis advisor, who will also be involved in administering the exam.

5. There is no longer a Mathematics Department foreign language requirement. With the vast majority of articles written in English, the importance of having the capability of reading another language has diminished. However, important earlier literature in certain areas of mathematics may be written in French, German, or Russian. Moreover, some articles are still being written in French. It is now at
the discretion of the student’s thesis advisor whether to impose a language requirement.

6. Candidates must produce a dissertation based upon independent and original research.

7. Candidates will gain teaching experience in mathematics as a teaching assistant for undergraduate courses. The student will be under the supervision of both the faculty member teaching the course and the director of undergraduate studies. First year students are given a reduced TA workload in the spring semester (this is related to item #2).

8. After completion of the thesis research the student will defend their dissertation by means of the Graduate Board Oral Exam. The exam must be held at least three weeks before the Graduate Board deadline the candidate wishes to meet.

Financial Aid
Students admitted to the Ph.D. program receive teaching assistantships and full tuition fellowships. Exceptional applicants become candidates for one of the university’s George E. Owen Fellowships.

William Kelso Morrill Award
The William Kelso Morrill Award for excellence in the teaching of mathematics is awarded every spring to the graduate student who best exemplifies the traits of Kelso Morrill: a love of mathematics, a love of teaching, and a concern for students.

Excellence in Teaching Awards
Three awards are given each year to a junior faculty member and graduate student teaching assistants who have demonstrated exceptional ability and commitment to undergraduate education.

For current faculty and contact information go to http://www.mathematics.jhu.edu/people/

Faculty
Chair
David Savitt
Number theory, Galois representations.

Professors
Caterina Consani
Arithmetic geometry, number theory, and non-commutative geometry.

Nitu Kitchloo
Symplectic geometry, topology of Kac-Moody groups, classical algebraic topology

Hans Lindblad
Harmonic analysis, PDE, fluid dynamics, relativity.

Chikako Mese
Geometric analysis.

Mauro Maggioni

Yiannis Sakellaridis
Number theory, automorphic representations

Vyacheslav V. Shokurov
Algebraic geometry.

Yannick Sire
Harmonic analysis, real geometry, complex geometry.

Christopher Sogge
J.J. Sylvester Professor; Fourier analysis, partial differential equations.

Joel Spruck
J.J. Sylvester Professor; Partial differential equations, geometric analysis.

W. Stephen Wilson
Algebraic topology, homotopy theory.

Steven Zucker
Hodge theory, algebraic geometry.

Associate Professors
Jacob Bernstein
Minimal surface theory, mean curvature flow.

Ben Dodson
Partial differential equations, harmonic analysis.

Assistant Professors
Fei Lu
Malliavin Calculus and stochastic partial differential equations, data-driven model reduction and data assimilation.

Emily Riehl
Homotopy theory.

Yi Wang
Geometric analysis, nonlinear partial differential equations

Associate Teaching Professor
Richard Brown
Director of Undergraduate Studies; Dynamical systems, low-dimensional topology.

Emeriti
J. Michael Boardman
Differential topology, algebraic topology.

Jack Morava
Algebraic topology, mathematical physics.

Takashi Ono
Algebra, number theory, algebraic groups.

Bernard Shiffman

J.J. Sylvester Assistant Professor
Christian Gavrus
Partial differential equations, harmonic analysis

Jingjun Han
Algebraic geometry

Alexander Mramor
Geometric analysis

Aurélien Sagnier
Arithmetic, tropical, and non-commutative geometries

Joel Specter
Number theory
Liming Sun
Geometric analysis, partial differential equations

Valentin Zakharevich
Algebraic topology, quantum field theory

**Associate Research Scientist/Lecturer**
Jian Kong
IT Senior Lecturer; Algebraic geometry.

**Assistant Research Professor**
Marie Jose Kuffner
Harmonic analysis, mathematics for data science

Sui Tang
Applied harmonic analysis, mathematical signal processing.

**Joint Appointments**
Gregory Eyink
Professor (Applied Mathematics); Mathematical physics, fluid mechanics, turbulence, dynamical systems.

For current course information and registration go to https://sis.jhu.edu/classes/

### Courses

**AS.110.105. Precalculus. 4.0 Credits.**
This course starts from scratch and provides students with all the background necessary for the study of calculus. It includes a review of algebra, trigonometry, exponential and logarithmic functions, coordinates and graphs. Each of these tools will be introduced in its cultural and historical context. The concept of the rate of change of a function will be introduced. Not open to students who have studied calculus in high school.

**Prerequisites: NA**
**Corequisites: NA**
Instructor(s): J. Cutrone
Area: Quantitative and Mathematical Sciences
NA.

**AS.110.106. Calculus I (Biology and Social Sciences). 4.0 Credits.**
Differential and integral calculus. Includes analytic geometry, functions, limits, integrals and derivatives, introduction to differential equations, functions of several variables, linear systems, applications for systems of linear differential equations, probability distributions. Many applications to the biological and social sciences will be discussed.

**Prerequisites: NA**
**Corequisites: NA**
Instructor(s): C. Sogge
Area: Quantitative and Mathematical Sciences
NA.

**AS.110.107. Calculus II (For Biological and Social Science). 4.0 Credits.**
Differential and integral Calculus. Includes analytic geometry, functions, limits, integrals and derivatives, introduction to differential equations, functions of several variables, linear systems, applications for systems of linear differential equations, probability distributions. Applications to the biological and social sciences will be discussed, and the courses are designed to meet the needs of students in these disciplines.

**Prerequisites: NA**
**Corequisites: NA**
Instructor(s): M. Zhong
Area: Quantitative and Mathematical Sciences
NA.

**AS.110.108. Calculus I. 4.0 Credits.**
Differential and integral calculus. Includes analytic geometry, functions, limits, integrals and derivatives, polar coordinates, parametric equations, Taylor’s theorem and applications, infinite sequences and series. Some applications to the physical sciences and engineering will be discussed, and the courses are designed to meet the needs of students in these disciplines.

**Prerequisites: NA**
**Corequisites: NA**
Instructor(s): J. Cutrone; J. Spruck
Area: Quantitative and Mathematical Sciences
NA.

**AS.110.109. Calculus II (For Physical Sciences and Engineering). 4.0 Credits.**
Differential and integral calculus. Includes analytic geometry, functions, limits, integrals and derivatives, polar coordinates, parametric equations, Taylor’s theorem and applications, infinite sequences and series. Some applications to the physical sciences and engineering will be discussed, and the courses are designed to meet the needs of students in these disciplines.

**Prerequisites: NA**
**Corequisites: NA**
Instructor(s): J. Cutrone; V. Zakharevich; Y. Wang
Area: Quantitative and Mathematical Sciences
NA.

**AS.110.113. Honors Single Variable Calculus. 4.0 Credits.**
This is an honors alternative to the Calculus sequences AS.110.106-AS.110.107 or AS.110.108-AS.110.109 and meets the general requirement for both Calculus I and Calculus II (although the credit hours count for only one course). It is a more theoretical treatment of one variable differential and integral calculus and is based on our modern understanding of the real number system as explained by Cantor, Dedekind, and Weierstrass. Students who want to know the "why's and how/s" of Calculus will find this course rewarding. Previous background in Calculus is not assumed. Students will learn differential Calculus (derivatives, differentiation, chain rule, optimization, related rates, etc), the theory of integration, the fundamental theorem(s) of Calculus, applications of integration, and Taylor series. Students should have a strong ability to learn mathematics quickly and on a higher level than that of the regular Calculus sequences.

**Prerequisites: NA**
**Corequisites: NA**
Instructor(s): J. Cutrone; V. Zakharevich; Y. Wang
Area: Quantitative and Mathematical Sciences
NA.

**AS.110.201. Linear Algebra. 4.0 Credits.**

**Prerequisites: Grade of C- or better in AS.110.107 or AS.110.109 or AS.110.113 or AS.110.202 or AS.110.302, or a 5 on the AP BC exam.**
**Corequisites: NA**
Instructor(s): J. Cutrone; J. Han
Area: Quantitative and Mathematical Sciences
NA.
AS.110.202. Calculus III. 4.0 Credits.
Calculus of functions of more than one variable: partial derivatives, and applications; multiple integrals, line and surface integrals; Green's Theorem, Stokes' Theorem, and Gauss' Divergence Theorem.
Prerequisites: Grade of C- or better in AS.110.107 OR AS.110.109 OR AS.110.113 OR AS.110.201 OR AS.110.212 OR AS.110.302, or a 5 or better on the AP BC exam.
Corequisites: NA
Instructor(s): J. Cutrone; R. Brown
Area: Quantitative and Mathematical Sciences
NA.

AS.110.211. Honors Multivariable Calculus. 4.0 Credits.
This course includes the material in AS.110.202 with some additional applications and theory. Recommended for mathematically able students majoring in physical science, engineering, or especially mathematics. AS.110.211-AS.110.212 used to be an integrated yearlong course, but now the two are independent courses and can be taken in either order.
Prerequisites: Grade of C- or better in (AS.110.201 or AS.110.212)
Corequisites: NA
Instructor(s): R. Brown
Area: Quantitative and Mathematical Sciences
NA.

AS.110.212. Honors Linear Algebra. 4.0 Credits.
This course includes the material in AS.110.201 with additional applications and theory, and is recommended only for mathematically able students majoring in physical science, engineering, or mathematics who are interested in a proof-based version of linear algebra. This course can serve as an Introduction to Proofs (IP) course. Prerequisites: Grade of B+ or better in 110.107 or 110.109 or 110.113, or a 5 on the AP BC exam.
Area: Quantitative and Mathematical Sciences.
Prerequisites: Grade of B+ or better in AS.110.107 or AS.110.109 or AS.110.113 or AS.110.202, or AS.110.302, or a 5 on the AP BC exam.
Corequisites: NA
Instructor(s): W. Wilson
Area: Quantitative and Mathematical Sciences
NA.

AS.110.225. Problem Solving Lab. 2.0 Credits.
This course is an introduction to mathematical reason and formalism in the context of mathematical problem solving, such as induction, invariants, inequalities and generating functions. This course does not satisfy any major requirement, and may be taken more than once for credit It is primarily used as training for the William Lowell Putnam Mathematics Competition. Area: Quantitative and Mathematical Sciences.
Prerequisites: NA
Corequisites: NA
Instructor(s): L. Sun
Area: Quantitative and Mathematical Sciences
NA.

AS.110.301. Introduction to Proofs. 4.0 Credits.
This course will provide a practical introduction to mathematical proofs with the aim of developing fluency in the language of mathematics, which itself is often described as "the language of the universe." Along with a library of proof techniques, we shall tour propositional logic, set theory, cardinal arithmetic, and metric topology and explore "proof relevant" mathematics by interacting with a computer proof assistant. This course on the construction of mathematical proof will conclude with a deconstruction of mathematical proof, interrogating the extent to which proof serves as a means to discover universal truths and assessing the mechanisms by which the mathematical community achieves consensus regarding whether a claimed result has been proven.
Prerequisites: NA
Corequisites: NA
Instructor(s): E. Riehl
Area: Quantitative and Mathematical Sciences
NA.

AS.110.302. Differential Equations and Applications. 4.0 Credits.
This is a course in ordinary differential equations (ODEs), equations involving an unknown function of one independent variable and some of its derivatives, and is primarily a course in the study of the structure of and techniques for solving ODEs as mathematical models. Specific topics include first and second ODEs of various types, systems of linear differential equations, autonomous systems, and the qualitative and quantitative analysis of nonlinear systems of first-order ODEs. Laplace transforms, series solutions and the basics of numerical solutions are included as extra topics. Prerequisites: Grade of C- or better in 110.107 or 110.109 or 110.113, or a 5 on the AP BC exam. Area: Quantitative and Mathematical Sciences.
Prerequisites: Grade of C- or better in AS.110.107 or AS.110.109 or AS.110.113 or AS.110.201 or AS.110.202 or AS.110.211 or AS.110.212, or a 5 on the AP BC exam.
Corequisites: NA
Instructor(s): J. Cutrone
Area: Quantitative and Mathematical Sciences
NA.

AS.110.304. Elementary Number Theory. 4.0 Credits.
The student is provided with many historical examples of topics, each of which serves as an illustration of and provides a background for many years of current research in number theory. Primes and prime factorization, congruences, Euler's function, quadratic reciprocity, primitive roots, solutions to polynomial congruences (Chevalley's theorem), Diophantine equations including the Pythagorean and Pell equations, Gaussian integers, Dirichlet's theorem on primes.
Prerequisites: Grade of C- or better in (AS.110.201 or AS.110.212)
Corequisites: NA
Instructor(s): J. Kong
Area: Quantitative and Mathematical Sciences
NA.
AS.110.311. Methods of Complex Analysis. 4.0 Credits.
This course is an introduction to the theory of functions of one complex variable. Its emphasis is on techniques and applications, and it serves as a basis for more advanced courses. Functions of a complex variable and their derivatives; power series and Laurent expansions; Cauchy integral theorem and formula; calculus of residues and contour integrals; harmonic functions.
Prerequisites: Grade of C- or better in 110.202 or 110.211
Corequisites: NA
Instructor(s): B. Dodson
Area: Quantitative and Mathematical Sciences

AS.110.328. Non-Euclidean Geometry. 4.0 Credits.
For 2,000 years, Euclidean geometry was the geometry. In the 19th century, new, equally consistent but very different geometries were discovered. This course will delve into these geometries on an elementary but mathematically rigorous level.
Prerequisites: NA
Corequisites: NA

AS.110.401. Introduction to Abstract Algebra. 4.0 Credits.
An introduction to the basic notions of modern abstract algebra and can serve as as Introduction to Proofs (IP) course. This course is an introduction to group theory, with an emphasis on concrete examples, and especially on geometric symmetry groups. The course will introduce basic notions (groups, subgroups, homomorphisms, quotients) and prove foundational results (Lagrange's theorem, Cauchy’s theorem, orbit-counting techniques, the classification of finite abelian groups). Examples to be discussed include permutation groups, dihedral groups, matrix groups, and finite rotation groups, culminating in the classification of the wallpaper groups. Prerequisites: Grade of C- or better in 110.201 or 110.212 Area: Quantitative and Mathematical Sciences.
Prerequisites: Grade of C- or better in (AS.110.201 or AS.110.212)
Corequisites: NA
Instructor(s): A. Sagnier
Area: Quantitative and Mathematical Sciences

AS.110.405. Real Analysis I. 4.0 Credits.
This course is designed to give a firm grounding in the basic tools of analysis. It is recommended as preparation (but may not be a prerequisite) for other advanced analysis courses and may be taken as an Introduction to Proofs (IP) course. Topics include the formal properties of real and complex number systems, topology of metric spaces, limits, continuity, infinite sequences and series, differentiation, Riemann-Stieltjes integration. Prerequisites: Grade of C- or better in 110.201 or 110.212 and 110.202 or 110.211
Prerequisites: Grade of C- or better in (AS.110.201 OR AS.110.212) AND (AS.110.202 OR AS.110.211)
Corequisites: NA
Instructor(s): J. Bernstein
Area: Quantitative and Mathematical Sciences

AS.110.406. Real Analysis II. 4.0 Credits.
This course continues AS.110.405 with an emphasis on the fundamental notions of modern analysis. Sequences and series of functions, Fourier series, equicontinuity and the Arzela-Ascoli theorem, the Stone-Weierstrass theorem, functions of several variables, the inverse and implicit function theorems, introduction to the Lebesgue integral.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Spruck
Area: Quantitative and Mathematical Sciences

AS.110.407. Honors Complex Analysis. 4.0 Credits.
AS.110.407. Honors Complex Analysis. 4.00 Credits. This course is an introduction to the theory of functions of one complex variable for honors students. Its emphasis is on techniques and applications, and can serve as an Introduction to Proofs (IP) course. Topics will include functions of a complex variable and their derivatives; power series and Laurent expansions; Cauchy integral theorem and formula; calculus of residues and contour integrals; harmonic functions, as well as applications to number theory and harmonic analysis. Area: Quantitative and Mathematical Sciences. This is not an Introduction to Proofs course (IP) and may not be taken as a first proof-based mathematics course except at the discretion of the instructor. This course satisfies a core requirement of the mathematics major as a second analysis course, and is a core requirement for honors in the major.
Prerequisites: AS.110.405 OR AS.110.415
Corequisites: NA
Instructor(s): C. Gavrus
Area: Quantitative and Mathematical Sciences

AS.110.411. Honors Algebra I. 4.0 Credits.
An introduction to the basic notions of modern algebra for students with some prior acquaintance with abstract mathematics. Elements of group theory: groups, subgroups, normal subgroups, quotients, homomorphisms. Generators and relations, free groups, products, abelian groups, finite groups. Groups acting on sets, the Sylow theorems. Definition and examples of rings and ideals.
Prerequisites: Grade of C- or better in AS.110.212 OR AS.110.304 OR AS.110.113 OR AS.110.405 OR AS.110.415 OR AS.110.407 OR AS.110.413 OR AS.110.421
Corequisites: NA
Instructor(s): E. Riehl
Area: Quantitative and Mathematical Sciences

AS.110.412. Honors Algebra II. 4.0 Credits.
This is a continuation of 110.411 Honors Algebra I. Topics studies include principal ideal domains, structure of finitely generated modules over them. Introduction to field theory. Linear algebra over a field. Field extensions, constructible polygons, non-trisectability. Splitting field of a polynomial, algebraic closure of a field. Galois theory: correspondence between subgroups and subfields. Solvability of polynomial equations by radicals. Prerequisites: Grade of C- or better in 110.201 or 110.212 Area: Quantitative and Mathematical Sciences.
Prerequisites: C- or better in AS.110.411
Corequisites: NA
Instructor(s): C. Consani
Area: Quantitative and Mathematical Sciences

NA.
AS.110.413. Introduction To Topology. 4.0 Credits.
Topological spaces, connectedness, compactness, quotient spaces, metric spaces, function spaces. An introduction to algebraic topology: covering spaces, the fundamental group, and other topics as time permits.
Prerequisites: Grade of C- or better in (AS.110.202 OR AS.110.211)
Corequisites: NA
Instructor(s): W. Wilson
Area: Quantitative and Mathematical Sciences
NA.

AS.110.415. Honors Analysis I. 4.0 Credits.
This highly theoretical sequence in analysis is reserved for the most able students. The sequence covers the real number system, metric spaces, basic functional analysis, the Lebesgue integral, and other topics.
Prerequisites: NA
Corequisites: NA
Instructor(s): F. Lu
Area: Quantitative and Mathematical Sciences
NA.

AS.110.416. Honors Analysis II. 4.0 Credits.
Prerequisites: Grade of C- or better in AS.110.415
Corequisites: NA
Instructor(s): L. Sun
Area: Quantitative and Mathematical Sciences
NA.

AS.110.417. Partial Differential Equations. 4.0 Credits.
Characteristics. classification of second order equations, well-posed problems. separation of variables and expansions of solutions. The wave equation: Cauchy problem, Poisson’s solution, energy inequalities, domains of influence and dependence. Laplace’s equation: Poisson’s formula, maximum principles, Green’s functions, potential theory Dirichlet and Neumann problems, eigenvalue problems. The heat equation: fundamental solutions, maximum principles. Recommended Course Background: AS.110.405 or AS.110.415
Prerequisites: NA
Corequisites: NA
Instructor(s): F. Lu
Area: Quantitative and Mathematical Sciences
NA.

AS.110.421. Dynamical Systems. 4.0 Credits.
This is a course in the modern theory of Dynamical Systems. Topic include both discrete (iterated maps) and continuous (differential equations) dynamical systems and focuses on the qualitative structure of the system in developing properties of solutions. Topics include contractions, interval and planar maps, linear and nonlinear ODE systems including bifurcation theory, recurrence, transitivity and mixing, phase volume preservation as well as chaos theory, fractional dimension and topological entropy. May be taken as an Introduction to Proofs (IP) course. Prerequisites: Grade of C- or better in 110.201 or 110.212 OR 110.202 or 110.211 and 110.302 Area: Quantitative and Mathematical Sciences
Prerequisites: Grade of C- or better in (AS.110.201 OR AS.110.212) AND (AS.110.202 or AS.110.211) AND 110.302
Corequisites: NA
Instructor(s): R. Brown
Area: Quantitative and Mathematical Sciences
NA.

AS.110.422. Representation Theory. 4.0 Credits.
This course will focus on the basic theory of representations of finite groups in characteristic zero: Schur’s Lemma, Mashcke’s Theorem and complete reducibility, character tables and orthogonality, direct sums and tensor products. The main examples we will try to understand are the representation theory of the symmetric group and the general linear group over a finite field. If time permits, the theory of Brauer characters and modular representations will be introduced.
Prerequisites: Grade of C- or better in (AS.110.201 OR AS.110.212) AND (AS.110.401 OR AS.110.411)
Corequisites: NA
Instructor(s): J. Specter
Area: Quantitative and Mathematical Sciences
NA.

AS.110.433. Introduction to Harmonic Analysis and Its Applications. 4.0 Credits.
The course is an introduction to methods in harmonic analysis, in particular Fourier series, Fourier integrals, and wavelets. These methods will be introduced rigorously, together with their motivations and applications to the analysis of basic partial differential equations and integral kernels, signal processing, inverse problems, and statistical/machine learning.
Prerequisites: (AS.110.201 OR AS.110.212 OR EN.550.291 OR EN.553.291) AND (AS.110.202 OR AS.110.211) AND (AS.110.405 OR AS.110.415)
Corequisites: NA
Instructor(s): M. Maggioni
Area: Quantitative and Mathematical Sciences
NA.

AS.110.435. Introduction to Algebraic Geometry. 4.0 Credits.
Algebraic geometry studies zeros of polynomials in several variables and is based on the use of abstract algebraic techniques, mainly from commutative algebra, for solving geometric problems about these sets of zeros. The fundamental objects of study are algebraic varieties which are the geometric manifestations of solutions of systems of polynomial equations. Algebraic geometry occupies a central place in modern mathematics and has multiple conceptual connections with diverse fields such as complex analysis, topology and number theory. This course aims to provide an undergraduate student majoring in mathematics the fundamental background to approach the study of algebraic geometry by providing the needed abstract knowledge also complemented by several examples and applications.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Consani
Area: Quantitative and Mathematical Sciences
NA.

AS.110.439. Introduction To Differential Geometry. 4.0 Credits.
Theory of curves and surfaces in Euclidean space: Frenet equations, fundamental forms, curvatures of a surface, theorems of Gauss and Mainardi-Codazzi, curves on a surface: introduction to tensor analysis and Riemannian geometry; theorema egregium; elementary global theorems.
Prerequisites: Grade of C- or better in (AS.110.201 or AS.110.212) and (AS.110.202 or AS.110.211)
Corequisites: NA
Instructor(s): Staff
Area: Quantitative and Mathematical Sciences
NA.
AS.110.441. Calculus on Manifolds. 4.0 Credits.
This course provides the tools for classical three-dimensional physics and mechanics. This course extends these techniques to the general locally Euclidean spaces (manifolds) needed for an understanding of such things as Maxwell's equations or optimization in higher dimensional contexts, e.g., in economics. The course will cover the theory of differential forms and integration. Specific topics include Maxwell's equations in terms of 4D Lorentz geometry, vector (in particular, tangent) bundles, an introduction to de Rham theory, and Sard's theorem on the density of regular values of smooth functions. The course is intended to be useful to mathematics students interested in analysis, differential geometry, and topology, as well as to students in physics and economics.
Prerequisites: NA
Corequisites: NA
Instructor(s): H. Xu
Area: Quantitative and Mathematical Sciences
NA.

AS.110.443. Fourier Analysis. 4.0 Credits.
Prerequisites: Grade of C- or better in (AS.110.201 OR AS.110.212 ) AND ( AS.110.202 OR AS.110.211)
Corequisites: NA
Instructor(s): S. Tang
Area: Quantitative and Mathematical Sciences
NA.

AS.110.446. Introduction to Statistical Learning, Data Analysis and Signal Processing. 4.0 Credits.
Introduction to high dimensional data sets: key problems in statistical and machine learning. Geometric aspects. Principal component analysis, linear dimension reduction, random projections. Concentration phenomena: examples and basic inequalities. Metric spaces and embeddings thereof. Kernel methods. Nonlinear dimension reduction, manifold models. Regression. Vector spaces of functions, linear operators, projections. Orthonormal bases; Fourier and wavelet bases, and their use in signal processing and time series analysis. Basic approximation theory. Linear models, least squares. Bias and variance tradeoffs, regularization. Sparsity and compressed sensing. Multiscale methods. Graphs and networks. Random walks on graphs, diffusions, page rank. Block models. Spectral clustering, classification, semi-supervised learning. Algorithmic and computational aspects of the above will be consistently in focus, as will be computational experiments on synthetic and real data. Linear algebra will be used throughout the course, as will multivariable calculus and basic probability (discrete random variables). Basic experience in programming in C or MATLAB or R or Octave. 7Recommended Course Background: More than basic programming experience in Matlab or R; some more advanced probability (e.g. continuous random variables), some signal processing (e.g. Fourier transform, discrete and continuous). Co-listed with EN.553.416
Prerequisites: AS.110.201
Corequisites: NA
Instructor(s): M. Maggioni
Area: Quantitative and Mathematical Sciences
NA.

AS.110.503. Undergraduate Research in Mathematics. 0.0 - 4.0 Credits.
NA
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

AS.110.586. Independent Study. 0.0 - 4.0 Credits.
NA
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

AS.110.587. DRP Independent Study. 1.0 Credit.
Directed Reading Program (DRP) Independent Study.
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: Quantitative and Mathematical Sciences
NA.

AS.110.595. Internship. 1.0 Credit.
NA
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: Quantitative and Mathematical Sciences
NA.

AS.110.599. Independent Study. 0.0 - 3.0 Credits.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Luehrmann
Area: Quantitative and Mathematical Sciences
NA.

AS.110.601. Algebra. NA Credit.
An introductory graduate course on fundamental topics in algebra to provide the student with the foundations for number theory, algebraic geometry, and other advanced courses. Topics include group theory, commutative algebra, Noetherian rings, local rings, modules, rudiments of category theory, homological algebra, field theory, Galois theory, and non-commutative algebras.
Prerequisites: NA
Corequisites: NA
Instructor(s): V. Shokurov
Area: Quantitative and Mathematical Sciences
NA.
AS.110.602. Algebra. NA Credit.
An introductory graduate course on fundamental topics in algebra to provide the student with the foundations for Number Theory, Algebraic Geometry, and other advanced courses. Topics include group theory, commutative algebra, Noetherian rings, local rings, modules, and rudiments of category theory, homological algebra, field theory, Galois theory, and non-commutative algebras. Recommended Course Background: AS.110.401-AS.110.402
Prerequisites: NA
Corequisites: NA
Instructor(s): V. Shokurov
Area: Quantitative and Mathematical Sciences NA.

AS.110.605. Real Variables. NA Credit.
Measure and integration on abstract and locally compact spaces (extension of measures, decompositions of measures, product measures, the Lebesgue integral, differentiation, Lp-spaces); introduction to functional analysis; integration on groups; Fourier transforms.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Bernstein
Area: Quantitative and Mathematical Sciences NA.

AS.110.607. Complex Variables. NA Credit.
Analytic functions of one complex variable. Topics include Mittag-Leffler Theorem, Weierstrass factorization theorem, elliptic functions, Riemann-Roch theorem, Picard theorem, and Nevanlinna theory. Recommended Course Background: AS.110.311, AS.110.405
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Spruck
Area: NA

AS.110.608. Riemann Surfaces. NA Credit.
Abstract Riemann surfaces. Examples: algebraic curves, elliptic curves and functions on them. Holomorphic and meromorphic functions and differential forms, divisors and the Mittag-Leffler problem. The analytic genus. Bezout's theorem and applications. Introduction to sheaf theory, with applications to constructing linear series of meromorphic functions. Serre duality, the existence of meromorphic functions on Riemann surfaces, the equality of the topological and analytic genera, the equivalence of algebraic curves and compact Riemann surfaces, the Riemann-Roch theorem. Period matrices and the Abel-Jacobi mapping, Jacobi inversion, the Torelli theorem. Uniformization (time permitting).
Prerequisites: NA
Corequisites: NA
Instructor(s): H. Xu
Area: NA

AS.110.615. Algebraic Topology. NA Credit.
Polyhedra, simplicial and singular homology theory, Lefschetz fixed-point theorem, cohomology and products, homological algebra, Künneth and universal coefficient theorems, Poincaré and Alexander duality theorems.
Prerequisites: NA
Corequisites: NA
Instructor(s): N. Kitchloo
Area: NA

AS.110.616. Algebraic Topology. NA Credit.
Polyhedra, simplicial and singular homology theory, Lefschetz fixed-point theorem, cohomology and products, homological algebra, Künneth and universal coefficient theorems, Poincaré and Alexander duality theorems.
Prerequisites: NA
Corequisites: NA
Instructor(s): N. Kitchloo
Area: Quantitative and Mathematical Sciences NA.

AS.110.617. Number Theory. NA Credit.
Topics in advanced algebra and number theory, including local fields and adeles, Iwasawa-Tate theory of zeta functions and connections with Hecke's treatment, semi-simple algebras over local and number fields, adeles geometry.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Consani
Area: Quantitative and Mathematical Sciences NA.

AS.110.618. Number Theory. NA Credit.
Topics in advanced algebra and number theory, including local fields and adeles, Iwasawa-Tate theory of zeta-functions and connections with Hecke's treatment, semi-simple algebras over local and number fields, adele geometry.
Prerequisites: NA
Corequisites: NA
Instructor(s): D. Savitt
Area: NA

AS.110.619. Lie Groups and Lie Algebras. NA Credit.
Lie groups and Lie algebras, classification of complex semi-simple Lie algebras, compact forms, representations and Weyl formulas, symmetric Riemannian spaces.
Prerequisites: NA
Corequisites: NA
Instructor(s): X. Zheng
Area: Quantitative and Mathematical Sciences NA.

AS.110.631. Partial Differential Equations I. NA Credit.
An introductory graduate course in partial differential equations. Classical topics include first order equations and characteristics, the Cauchy-Kowalewski theorem, Laplace's equations, heat equation, wave equation, fundamental solutions, weak solutions, Sobolev spaces, maximum principles.
Prerequisites: Grade of C- or better in AS.110.605
Corequisites: NA
Instructor(s): Y. Wang
Area: NA
AS.110.632. Partial Differential Equations II. NA Credit.
An introductory graduate course in partial differential equations. Classical topics include first order equations and characteristics, the Cauchy-Kowalevski theorem, Laplace’s equation, heat equation, wave equation, fundamental solutions, weak solutions, Sobolev spaces, maximum principles. The second term focuses on special topics such as second order elliptic theory.
Prerequisites: NA
Corequisites: NA
Instructor(s): Y. Sire
Area: NA
NA.

AS.110.633. Harmonic Analysis. NA Credit.
Fourier multipliers, oscillatory integrals, restriction theorems, Fourier integral operators, pseudodifferential operators, eigenfunctions. Undergrads need instructor’s permission.
Prerequisites: NA
Corequisites: NA
Instructor(s): H. Lindblad
Area: Quantitative and Mathematical Sciences
NA.

AS.110.635. Microlocal Analysis. NA Credit.
Microlocal analysis is the geometric study of singularities of solutions of partial differential equations. The course will begin by introducing the geometric theory of (Schwartz) distributions: Fourier transform and Sobolev spaces, pseudo-differential operators, wave front set of a distribution, elliptic operators, Lagrangean distributions, oscillatory integrals, method of stationary phase, Fourier integral operators. The second semester will develop the theory and apply it to special topics such as asymptotics of eigenvalues/eigenfunctions of the Laplace operator on a Riemann manifold, linear and non-linear wave equation asymptotics of quantum systems, Bochner-Riesz means, maximal theorems.
Prerequisites: NA
Corequisites: NA
Instructor(s): H. Lindblad
Area: Quantitative and Mathematical Sciences
NA.

AS.110.637. Functional Analysis. NA Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): B. Dodson
Area: NA
NA.

AS.110.643. Algebraic Geometry. NA Credit.
Affine varieties and commutative algebra. Hilbert’s theorems about polynomials in several variables with their connections to geometry. General varieties and projective geometry. Dimension theory and smooth varieties. Sheaf theory and cohomology. Applications of sheaves to geometry; e.g., the Riemann-Roch Theorem. Other topics may include Jacobian varieties, resolution of singularities, geometry on surfaces, connections with complex analytic geometry and topology, schemes.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Han
Area: NA
NA.

AS.110.644. Algebraic Geometry. NA Credit.
Affine varieties and commutative algebra. Hilbert’s theorems about polynomials in several variables with their connections to geometry. General varieties and projective geometry. Dimension theory and smooth varieties. Sheaf theory and cohomology. Applications of sheaves to geometry; e.g., the Riemann-Roch Theorem. Other topics may include Jacobian varieties, resolution of singularities, geometry on surfaces, schemes, connections with complex analytic geometry and topology.
Prerequisites: NA
Corequisites: NA
Instructor(s): X. Zheng
Area: Quantitative and Mathematical Sciences
NA.

AS.110.645. Riemannian Geometry. NA Credit.
Differential manifolds, vector fields, flows, Frobenius’ theorem. Differential forms, deRham’s theorem, vector bundles, connections, curvature, Chern classes, Cartan structure equations. Riemannian manifolds, Bianchi identities, geodesics, exponential maps. Geometry of submanifolds, hypersurfaces in Euclidean space. Other topics as time permits, e.g., harmonic forms and Hodge theorem, Jacobi equation, variation of arc length and area, Chern-Gauss-Bonnet theorems.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Mese
Area: NA
NA.

AS.110.646. Riemannian Geometry. NA Credit.
The goal is to give a self-contained course on mean curvature flow, starting with the basic linear heat equation in Euclidean space and – hopefully – getting to topics of current research. Mean curvature flow is a geometric heat equation that shares many properties with Ricci flow, harmonic map heat flow, Yang-Mills flow and the Navier-Stokes equations. Recommended Course Background: AS.110.605 and an undergraduate course in differential geometry; AS.110.645 and AS.110.631
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Mese
Area: NA
NA.
AS.110.675. High-Dimensional Approximation, Probability, and Statistical Learning. NA Credit.
The course covers fundamental mathematical ideas for certain approximation and statistical learning problems in high dimensions. We start with basic approximation theory in low-dimensions, in particular linear and nonlinear approximation by Fourier and wavelets in classical smoothness spaces, and discuss applications in imaging, inverse problems and PDE’s. We then introduce notions of complexity of function spaces, which will be important in statistical learning. We then move to basic problems in statistical learning, such as regression and density estimation. The interplay between randomness and approximation theory is introduced, as well as fundamental tools such as concentration inequalities, basic random matrix theory, and various estimators are constructed in detail, in particular multi scale estimators. At all times we consider the geometric aspects and interpretations, and will discuss concentration of measure phenomena, embedding of metric spaces, optimal transportation distances, and their applications to problems in machine learning such as manifold learning and dictionary learning for signal processing.

Prerequisites: NA
Corequisites: NA
Instructor(s): M. Maggioni
Area: Quantitative and Mathematical Sciences

AS.110.707. Functional Analysis. NA Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): B. Dodson
Area: NA

AS.110.711. Topics in Topos Theory. NA Credit.
Reading course to discuss Topics in Topos Theory
Prerequisites: NA
Corequisites: NA
Instructor(s): E. Riehl
Area: NA

AS.110.712. Topics in Mathematical Physics. NA Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): H. Lindblad
Area: NA

AS.110.722. Topics in Homotopy Theory. NA Credit.
The course will focus on recent developments in homotopy theory, such as Galois theory for E_n (n \geq 2) ring-spectra, and on connections with number theory; in particular, work of Bhatt, Hesselholt, Lurie, Scholze and others on topological Hochschild homology and its applications to geometry over the p-adic complex numbers.

Prerequisites: NA
Corequisites: NA
Instructor(s): E. Riehl
Area: Quantitative and Mathematical Sciences

AS.110.724. Topics in Arithmetic Geometry. NA Credit.
Topics around the subject of Arithmetic Geometry will be covered in this course.
Prerequisites: NA
Corequisites: NA
Instructor(s): B. Smithling
Area: Quantitative and Mathematical Sciences

AS.110.726. Topics in Analysis. NA Credit.
The topics covered will involve the theory of calculus of Functors applied to Geometric problems like Embedding theory. Other related areas will be covered depending on the interest of the audience.

Prerequisites: NA
Corequisites: NA
Instructor(s): L. Sun
Area: Quantitative and Mathematical Sciences

AS.110.727. Topics in Algebraic Topology. NA Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): N. Kitchloo
Area: NA

AS.110.728. Topics in Algebraic Topology. NA Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): N. Kitchloo
Area: NA

AS.110.731. Topics in Geometric Analysis. NA Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): Y. Wang
Area: NA

AS.110.733. Topics In Alg Num Theory. NA Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): D. Savitt
Area: NA

AS.110.735. Topics In Hodge Theory. NA Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Mese; R. Brown; S. Zucker
Area: NA

AS.110.737. Topics Algebraic Geometry. NA Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): V. Shokurov
Area: NA
AS.110.738. Topics Algebraic Geometry. NA Credit.
Introduction to toric varieties. This class is a general introduction to toric varieties. Toric varieties are special kinds of algebraic varieties which can be described by lattices and convex sets. They provide a rich source of concrete examples in complex geometry or mathematical physics. If time permits, we discuss in the end the stability of toric embeddings. Students should know basic notions of algebraic geometry (schemes, sheaves, linear systems), as covered in AS.110.643.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Mese; R. Brown; V. Shokurov
Area: Quantitative and Mathematical Sciences
NA.

AS.110.741. Topics: Partial Differential Equations. NA Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): H. Lindblad
Area: NA
NA.

AS.110.742. Topics in Partial Differential Equations. NA Credit.
In this course we will be discussing some dispersive evolution equations, primarily the nonlinear Schrödinger equation. Topics will include well-posedness theory, conservation laws, and scattering. The course will be accessible to students who have not taken graduate partial differential equations or functional analysis.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Spruck
Area: NA
NA.

AS.110.749. Topics in Differential Geometry. NA Credit.
In this class, we will study Aaron Naber and Jeff Cheeger’s recent result on proving codimension four conjecture. We plan to talk about some early results of the structure on manifolds with lower Ricci bound by Cheeger and Colding. We will prove quantitative splitting theorem, volume convergence theorem, and the result that almost volume cone implies almost metric cone. Then we will discuss regularity of Einstein manifolds and the codimension four conjecture.
Prerequisites: NA
Corequisites: NA
Instructor(s): Y. Wang
Area: Quantitative and Mathematical Sciences
NA.

AS.110.750. Topics in Representation Theory. NA Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: Quantitative and Mathematical Sciences
NA.

AS.110.756. Topics in Algebra. NA Credit.
This will be a course in commutative algebra. Topics may include: Noetherian rings and modules, the Nullstellensatz, Hilbert basis theorem, localization, integrality, Noether normalization, primary decomposition, DVRs, Dedekind domains, dimension theory, smoothness and regularity, and homological methods.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Consani
Area: Quantitative and Mathematical Sciences
NA.

AS.110.757. Topics in Stochastic Dynamical Systems. NA Credit.
The course will present an introduction to stochastic dynamical systems and some applications in model reduction and data assimilation. The main focus will be on stability and ergodicity of stochastic dynamical systems, including stochastic differential equations driven by white and fractional noise, and their numerical approximations. We will then discuss model reduction, focusing on Mori-Zwanzig formalism and approximation of the generalized Langevin equation, and methods on the parametric inference of related stochastic systems. Data assimilation and stochastic control will also be briefly introduced.
Prerequisites: NA
Corequisites: NA
Instructor(s): F. Lu
Area: Quantitative and Mathematical Sciences
NA.

AS.110.790. Seminar in Complex Geometry. NA Credit.
Presentations of current research papers by faculty, graduate students and invited guest speakers. For graduate students only.
Prerequisites: NA
Corequisites: NA
Instructor(s): B. Shiffman
Area: Quantitative and Mathematical Sciences
NA.

Presentations of current research papers by faculty, graduate students and invited guest speakers. For graduate students only.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Bernstein
Area: Quantitative and Mathematical Sciences
NA.

AS.110.793. Seminar in Topology. NA Credit.
For graduate students only. Presentations of current research papers by faculty, graduate students and invited guest speakers.
Prerequisites: NA
Corequisites: NA
Instructor(s): N. Kitchloo
Area: Quantitative and Mathematical Sciences
NA.

AS.110.794. Seminar in Category Theory. NA Credit.
Presentations of current research papers by faculty, graduate students and invited guest speakers. For graduate students only.
Prerequisites: NA
Corequisites: NA
Instructor(s): E. Riehl
Area: Quantitative and Mathematical Sciences
NA.
AS.110.795. Data Science Seminar. NA Credit.  
Presentations of current research papers by faculty, graduate students and invited guest speakers. For graduate students only.  
Prerequisites: NA  
Corequisites: NA  
Instructor(s): M. Maggioni  
Area: Quantitative and Mathematical Sciences  
NA.

AS.110.798. Seminar in Number Theory. NA Credit.  
Presentations of current research papers by faculty, graduate students and invited guest speakers. For graduate students only.  
Prerequisites: NA  
Corequisites: NA  
Instructor(s): B. Smithling  
Area: NA  
NA.

AS.110.799. Seminar in Algebraic Geometry. NA Credit.  
For graduate students only. Presentations of current research papers by faculty, graduate students and invited guest speakers.  
Prerequisites: NA  
Corequisites: NA  
Instructor(s): X. Zheng  
Area: NA  
NA.

AS.110.800. Independent Study-Graduates. NA Credit.  
NA  
Prerequisites: NA  
Corequisites: NA  
Instructor(s): M. Maggioni  
Area: Quantitative and Mathematical Sciences  
NA.

AS.110.801. Thesis Research. NA Credit.  
NA  
Prerequisites: NA  
Corequisites: NA  
Instructor(s): Staff  
Area: NA  
NA.

Cross Listed Courses  
Applied Mathematics Statistics  
EN.553.738. High-Dimensional Approximation, Probability, and Statistical Learning. 3.0 Credits.  
The course covers fundamental mathematical ideas for certain approximation and statistical learning problems in high dimensions. We start with basic approximation theory in low-dimensions, in particular linear and nonlinear approximation by Fourier and wavelets in classical smoothness spaces, and discuss applications in imaging, inverse problems and PDE's. We then introduce notions of complexity of function spaces, which will be important in statistical learning. We then move to basic problems in statistical learning, such as regression and density estimation. The interplay between randomness and approximation theory is introduced, as well as fundamental tools such as concentration inequalities, basic random matrix theory, and various estimators are constructed in detail, in particular multi scale estimators. At all times we consider the geometric aspects and interpretations, and will discuss concentration of measure phenomena, embedding of metric spaces, optimal transportation distances, and their applications to problems in machine learning such as manifold learning and dictionary learning for signal processing.  
Prerequisites: NA  
Corequisites: NA  
Instructor(s): M. Maggioni  
Area: NA  
NA.