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# ASTR 621

## Planet Formation Theory

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### Overview

The physical processes involved in planetary system formation are addressed. Specific foci include molecular cloud collapse, disk processes, and competing theories of planet formation within disks. Additional topics to be discussed may include: the solar wind, planetary magnetic fields, planetary ring processes, and mineralogy.

### Goals

After taking this course, the student should have quantitative command of our current understanding of the processes that shape the formation of planetary systems. The course will cover all phases of planet formation, from a theoretical perspective, guided by the most modern observational constraints.

### Requirements

The course is restricted to astronomy graduate students.

### Course notes

The lecture notes will be posted on Canvas, but students are encouraged to take their own hand-written notes to better follow the material. The notes will be complemented with slides, images, and videos when appropriate.

### Textbooks

The lecture notes will be complemented by the textbook “Astrophysics of Planet Formation” by Phil Armitage. You do not necessarily need to buy the book, since very similar notes are available in the arxiv (astro-ph/0701485).

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**Spring 2020**

Tue/Thu 12:00–1:15pm, Astronomy 119

**Professor: Dr Wladimir Lyra**

E-Mail: wlyra@nmsu.edu

Phone: 575-646-1400

Office: Astronomy 202A

Office Hours: TBD.

**Preferred communication method: email.**

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### Materials

- Scientific calculation (or computer).
- NMSU Canvas will be used for lecture notes, assignments, and grades.



Since the theory of planet formation is an active and rapidly evolving field of research, the book and arxiv notes will be complemented with scientific articles and reviews on an ad hoc basis.

If you choose to buy the book, I strongly recommend the 2nd edition. The 1st edition is from 2009 and a lot has happened in planet formation since then. Problem is, the 2nd edition costs \$80, and you will not find a cheaper used copy: the 2nd edition is from 2020; it is fresh off the press.

## Grading

This course is divided in modules (see “Topics”, below); each module will have an associated homework assignment that involves conceptual, analytical, and/or computational exercises. Each assignment is worth 100 points. The homework grade is  $(\sum_{i=1,n} HW^i)/n$ , where  $HW^i$  is an individual homework assignment and  $n$  the number of assignments. There will be no make-ups. Late homework will be accepted at 5% penalty per day of lateness. If you foresee an extraordinary circumstance that will require you to turn in the homework late, please communicate so to me as soon as you know it, to avoid the penalty. Re-dos of the homework will be allowed, worth 90% of the original grade. Homework comprise 80% of the grade. Quizzes will be given regularly, comprising 20% of the final grade.

A note on collaboration: I strongly encourage you to work with other students on the problem sets. You will find it very helpful to discuss the course material with your classmates, reviewing the overall concepts together, or discussing in general terms how to approach tricky aspects of a derivation or coding exercise. However, anything that you submit for course credit with only your name on it must be your original work and reflect your own thinking. If your solutions draw any inspiration from your classmates or group work, then please note whom you worked with.

The final grade will range from 0 to 100, and then converted to letter format. I will determine the mapping from numerical to letter grades at the end of the semester.

## Topics to be covered

This is a **PRELIMINARY** list of the topics that will be covered. The list is **DYNAMIC** and **WILL** be updated as the course goes, based on how in-depth we decide to go on some topics, as well as on the interest of the class.

Class #	Date	Topics	Subtopic	Reading (Armitage)
1	01/23	Observations of planetary systems	Solar System planets, exoplanets.	Book: Ch 1 Notes: I
2	01/28		Nebular hypothesis, cluster disk fraction, infrared observations, disk classification.	
3	01/30		Sub-mm observations.	
4	02/04	Molecular Cloud Collapse	Star formation, Jeans criterion, Jeans mass and Jeans length.	Class notes (TBD)
5	02/06		Bonnor-Ebert mass, Circumstellar disks, angular momentum problem.	
6	02/11	Protoplanetary Disk Structure	Minimum Mass Solar Nebula. Vertical structure, disk scale height.	Book: Ch 2 Notes: II A, B
7	02/13		Centrifugal equilibrium.	

8	02/18		Temperature. Flared disks.	
9	02/20		Disk opacity, condensation sequence, ionization state of disks.	
10	02/25	Protoplanetary Disk Evolution	Viscous spreading. The 1D viscous evolution equation and solution.	Book: Ch 3 Notes: II C, D, E
11	02/27		Sources of viscosity. The Shakura-Sunyaev model. Angular momentum transport.	
12	03/03		Rayleigh criterion and hydrodynamical turbulence, magneto-rotational instability.	
13	03/05		Dead zones, photoevaporation, disk winds.	
14	03/10	Planetesimal Formation	Aerodynamics. Regimes of drag (Epstein, Stokes, and quadratic).	Book: Ch 4 Notes: III A
15	03/12		Dust settling, radial drift, Smoluchowski equation.	
16	03/17		Goldreich-Ward mechanism, streaming instability.	
17	03/19		Disk vortices.	
18	03/31	Terrestrial Planet Formation	Gravitational focusing, pebble accretion.	Book: Ch 5 Notes: III B
19	04/02		Growth rates, isolation mass.	
20	04/07		Coagulation and Dynamical friction.	
21	04/09		Oligarchic growth, planet synthesis models.	
22	04/14	Giant Planet Formation	Core accretion, critical core mass, runaway gas accretion.	Book: Ch 6 Notes: III C
23	04/16		Gravitational instability.	
24	04/21		Preventing GI. Convection and opacity in disks.	
25	04/23		Comparison to observations, HR8799, Jupiter.	
26	04/28	Planet migration and planetary system architecture.	Disk torques. Type I migration. The timescale problem.	Book: Ch 7 Notes: IV
27	04/30		Gap opening, type II migration.	
28	05/05		Corotational torques, resonant migration.	
29	05/07		Planetesimal disk migration, Nice model.	

## Office hours

The office hours will be defined in the first week of class. A poll will be sent to find the time most suitable to everyone. If a student cannot make it in the chosen time, contact me so we can find a time that fits both our schedules. If you are able to phrase/illustrate your doubt in a clear way in writing, you are welcome to do so instead of scheduling an in-person meeting.

## Student Responsibility

You are responsible, as the student, for all material presented in class and in assignments, and for any announcements made during class time (which may include changes to the schedule), whether you are present or absent. It is your responsibility to attend and keep up with the rhythm of the class. Changes to assignments may happen, in which case I will communicate the change via Canvas. It is the student's responsibility to check Canvas periodically for these updates.

Class attendance is essential for the understanding of the material. If you should decide to drop the class, you must do so before the deadline listed in the schedule of classes, or a grade will be assigned. Dropping the class is the student's responsibility, not the instructor's.

Due diligence is defined as a measure of prudence, activity, assiduity, effort, expediency, and/or disclosure, as is properly to be expected from, and ordinarily exercised by, a reasonable and prudent person under the particular circumstances. If you exercise due diligence with respect to your responsibilities in this course, you will find that I am very sympathetic and will work very hard to resolve any problems that come up to our mutual satisfaction.

What you can expect from me: I love astronomy. If you don't get excited about anything we study this semester I will consider it a failure on my part. I will do my best to be respectful of your time and effort. I will strive to make every reading, class session, and homework assignment as useful to your learning as possible. I will listen to and respectfully consider any comments or suggestions you have about any aspect of this course. I will be respectful of any protected status recognized by the university, as well as many that are not, assuming that you are duly diligent in alerting me to any possible issues before or as they arise. I will not tolerate harassment or bullying.

## Use of Laptop Computers & Mobile Phones

You may use a laptop computer in the classroom only for class purposes. You may not surf the web, play games, or engage in any activity, which I would consider disruptive to you, or students around you. Smartphones and tablets must be silent and turned to airplane mode, and can only be used to participate in class.

## Use of Listening, Video, or Other Recording Device

The use of any electronic listening, or recording devices by anyone in class are not permitted. If you need to use a recording device as an authorized disability accommodation, you must provide me with verification from the Student Accessibility Services (SAS) prior to the use. The SAS office is located at Corbett Center, Rm. 208 Phone: (575) 646-6840 E-mail: [sas@nmsu.edu](mailto:sas@nmsu.edu) Website: <http://sas.nmsu.edu/>

## Academic Misconduct

**Academic and non-academic misconduct:** The Student Code of Conduct defines academic misconduct, non-academic misconduct and the consequences or penalties for each. The Student Code of Conduct is available in the NMSU Student Handbook online:

<http://studenthandbook.nmsu.edu/>

Academic misconduct is explained here:

<http://studenthandbook.nmsu.edu/student-code-of-conduct/academic-misconduct/>

## Discrimination and Disability Accommodation

Section 504 of the Rehabilitation Act of 1973 and the Americans with Disabilities Act Amendments Act (ADA) covers issues relating to disability and accommodations. If a student has questions or needs an accommodation in the classroom (all medical information is treated confidentially), contact:

### Main Campus

Student Accessibility Services (SAS)  
Corbett Center Student Union Room 208  
Trudy Luken, Director  
575-646-6840  
[sas@nmsu.edu](mailto:sas@nmsu.edu)

New Mexico State University, in compliance with applicable laws and in furtherance of its commitment to fostering an environment that welcomes and embraces diversity, does not discriminate on the basis of age, ancestry, color, disability, gender identity, genetic information, national origin, race, religion, retaliation, serious medical condition, sex (including pregnancy), sexual orientation, spousal affiliation, or protected veteran status in its programs and activities, including employment, admissions, and educational programs and activities. Inquiries may be directed to the Laura Castille, Executive Director, Title IX and Section 504 Coordinator, Office of Institutional Equity, P.O. Box 30001, E. 1130 University Avenue, Las Cruces, NM 88003; 575.646.3635; 575-646-7802 (TTY); [equity@nmsu.edu](mailto:equity@nmsu.edu).

Title IX prohibits sex harassment, sexual assault, intimate partner violence, stalking and retaliation. For more information on discrimination or Title IX, or to file a complaint contact:

Laura Castille, Executive Director and Title IX Coordinator  
Office of Institutional Equity (OIE) - O'Loughlin House, 1130 University Avenue  
Phone: (575) 646-3635 E-mail: [equity@nmsu.edu](mailto:equity@nmsu.edu)  
Website: <http://equity.nmsu.edu/>

## Other NMSU Resources

NMSU Police Department:	(575) 646-3311	<a href="http://www.nmsupolice.com">www.nmsupolice.com</a>
NMSU Police Victim Services:	(575) 646-3424	
NMSU Counseling Center:	(575) 646-2731	
NMSU Dean of Students:	(575) 646-1722	

For Any On-campus Emergencies:	911	
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## Special Accommodation

Section 504 of the Rehabilitation Act of 1973 and the Americans with Disabilities Act Amendments Act (ADAAA) covers issues relating to disability and accommodations. If a student has questions or needs an accommodation in the classroom (all medical information is treated confidentially), contact:

Trudy Luken, Director  
 Student Accessibility Services (SAS) - Corbett Center, Rm. 208  
 Phone: (575) 646-6840 E-mail: [sas@nmsu.edu](mailto:sas@nmsu.edu)  
 Website: <http://sas.nmsu.edu/>

## Discrimination

NMSU policy prohibits discrimination on the basis of age, ancestry, color, disability, gender identity, genetic information, national origin, race, religion, retaliation, serious medical condition, sex, sexual orientation, spousal affiliation and protected veterans status. Furthermore, Title IX prohibits sex discrimination to include sexual misconduct: sexual violence (sexual assault, rape), sexual harassment and retaliation. For more information on discrimination issues, Title IX, Campus SaVE Act, NMSU Policy Chapter 3.25, NMSU's complaint process, or to file a complaint contact:

Laura Castille, Title IX Coordinator  
 Agustin Diaz, Title IX Deputy Coordinator  
 Office of Institutional Equity (OIE) - O'Loughlin House, 1130 University Avenue  
 Phone: (575) 646-3635  
 E-mail: [equity@nmsu.edu](mailto:equity@nmsu.edu)  
 Website: <http://eeo.nmsu.edu/>

**This syllabus may be subject to change**