AST 7939: Star Formation

Spring 2021

Instructor:	Prof. Adam Ginsburg	**Time:**	M,W,F — Period 7 (1:55 PM - 2:45 PM)
Email:	adamginsburg@ufl.edu	**Place:**	Rm 3, Bryant Space Science Center, and Zoom
		Office Hours:	by appointment

Timing / Structure:
The course will be taught primarily in person. Class will consist of a mixture of lectures and homework. The course will be taught largely as a classic lecture course so that we can cover a wide range of material. Active learning will be employed when possible, but since this is my first time teaching the course, I may be limited in how much active learning I can incorporate.

Course Pages:

1. https://github.com/keflavich/AST7393_Prostars
2. https://ufl.instructure.com/courses/444877

Communication:
Communication will be via Canvas, Zoom, and Slack.

Office Hours:
Office hours will be primarily virtual and held via Slack, with escalation to Zoom as needed.

Main References:

- Star Formation Notes by Mark Krumholz https://github.com/Open-Astrophysics-Bookshelf/star_formation_notes
- The Formation of Stars by Steven Stahler and Francesco Palla https://ui.adsabs.harvard.edu/abs/2004fost.book.....S/abstract
- Accretion Processes in Star Formation by Lee Hartmann https://ui.adsabs.harvard.edu/abs/1998apsf.book.....H/abstract
- Tom Megeath's "The Secret Lives of Stars" http://astro1.physics.utoledo.edu/~megeath/ph6820/ph6820.html

Objectives: You will learn the fundamentals of star formation, from gravitationl collapse of a molecular cloud to formation of a nuclear burning core.

You will gain experience solving physical problems and developing physical insights. You will learn about physical processes and order-of-magnitude estimation techniques.

This class will fill in the size scales between ISM and stars, and will have some overlap with each.

Course Outline:

Learning goals of the course:

1. Understand the fundamentals of star formation theory and observables
2. Practice formulating, and answering, questions for research
3. Learn key concepts and practice working with them to develop a vocabulary for discussing star formation

Grading Policy:

- Class Assignments and participation, homework (60%)
- Project (30%)
- Exams (10%)*

The late policy is 10% credit lost per day. However, I generally will give extensions if late assignments are well-justified and excused in advance. No credit will be given for the final project if it is late.

*: I do not guarantee that there will be exams; if there are, they will comprise 10% of the grade, otherwise, grades will be based only on projects and class and homework.

More information on UF grading policies is here: https://gradcatalog.ufl.edu/graduate/regulations/#text

Letter grades are:

Letter	Minimum %
A	93
A-	90
B+	87
B	84
B-	80
C+	77
C	74
C-	70
D+	67
D	64
D-	60

I reserve the right to curve the class such that your scores improve if the final score distribution is lower than I expect. This can only help your grades; I will not apply a curve to reduce your score before the raw score.

Attendance

Attendance is required in class. Part of your grade for the semester is based upon class participation during the class sessions. If you feel that you have a situation that may allow for a make-up, contact the professor immediately via email.

Excused absences are consistent with university policies in the graduate catalog (https://catalog.ufl.edu/graduate/regulations/#text) and require appropriate documentation.

Course Communication Policy:

- We will use Canvas for announcements and other digital communication, so you are expected to regularly check Canvas.
- We may use Slack for live communication and office hours.
- Regular attendance on zoom or in person is essential and expected.

Students Requiring Accommodations

Students with disabilities requesting accommodations should first register with the UF Disability Resource Center (352.392.8565) by providing appropriate documentation. Once registered, students will receive an accommodation letter which must be presented to the instructor when requesting accommodations. Students with disabilities should follow this procedure as early as possible in the semester

Course Evaluation

Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and respectful manner is available at https://gatorevals.aa.ufl.edu/students/. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via https://ufl.bluera.com/ufl/. Summaries of course evaluation results are available to students at https://gatorevals.aa.ufl.edu/public-results/.

Health absence / COVID policies

We will have face-to-face instructional sessions to accomplish the student learning objectives of this course.

- You are required to wear approved face coverings at all times during class and within buildings. This requirement may change over the semester.
- If you are experiencing any symptoms of respiratory disease (cold, flu, covid), please do not attend class.
- If you are sick, course materials will be provided to you with an excused absence, and you will be given a reasonable amount of time to make up work. Find more information in the university attendance policies.

Online Teaching Policy

Our class sessions may be audio visually recorded for students in the class to refer back and for enrolled students who are unable to attend live. Students who participate with their camera engaged or utilize a profile image are agreeing to have their video or image recorded. If you are unwilling to consent to have your profile or video image recorded, be sure to keep your camera off and do not use a profile image. Likewise, students who

un-mute during class and participate orally are agreeing to have their voices recorded. If you are not willing to consent to have your voice recorded during class, you will need to keep your mute button activated and communicate exclusively using the "chat" feature, which allows students to type questions and comments live. The chat will not be shared. As in all courses, unauthorized recording and unauthorized sharing of recorded materials is prohibited.

Students are requested, but not required, to keep their video on during Zoom meetings. During breakout sessions and interactive work sessions held on zoom, both audio and video participation will be required. Students must have a functional webcam and microphone.

Class Demeanor (in person)

Students are expected to arrive to class on time and behave in a manner that is respectful to the instructor and to fellow students. Please avoid the use of cell phones and restrict eating to outside of the classroom. Opinions held by other students should be respected in discussion, and conversations that do not contribute to the discussion should be held at minimum, if at all.

Materials and Supplies Fees

There are no additional fees for this course.

University Honesty Policy

UF students are bound by The Honor Pledge which states, '*We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honesty and integrity by abiding by the Student Honor Code. On all work submitted for credit by Students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment."*' The Honor Code (https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TA in this class.

Counseling and Wellness Center

Contact information for the Counseling and Wellness Center: http://www.counseling.ufl.edu/cwc/Default.aspx, 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

Homework Schedule)

Submit via Canvas

1. Problem Set 1: Jan 5 - Jan 24
2. Problem Set 2: Jan 24 - Feb 14
3. Problem Set 3: Feb 14 - Mar 4
4. Problem Set 3: Mar 4 or 14 - Mar 28
5. Problem Set 5: Mar 28 - Apr 20

Preliminary Schedule (subject to change - I don't yet know how long these topics will take)

Dates are Monday of the week; we meet M/W/F

- Week 1 (Jan 5, 7): Syllabus, meta-discussion, gravitational collapse (Krumholz Ch 6)
  Problem Set 1

- Week 2 (Jan 10, 12, 14): Gravitational Collapse: Krumholz Ch 6, Megeath lecture 7
  Problem Set 1
- Week 3 (Jan 19, 21): Protostar Formation: Krumholz ch 16, 17
  Problem Set 1
- Week 4 (Jan 24, 26, 28): Accretion, Core temperature structure
  Problem Set 1 Due
  Problem Set 2
- Week 5 (Jan 31, Feb 2, 4): Protostellar evolution tracks
- Week 6 (Feb 7, 9, 11): Outflows
- Week 7 (Feb 14, 16, 18): Turbulence
  Problem Set 2 due, Problem Set 3
- Week 8 (Feb 21, 23, 25): Flat disks
- Week 9 (Feb 28, Mar 2, 4): Flared disks
  Problem set 3 due (Mar 4)
- Spring break. Problem set 4
- Week 10 (Mar 14, 16, 18): STUDENT LECTURES
- Week 11 (Mar 21, 23, 25): STUDENT LECTURES
- Week 12 (Mar 28, 30, Apr 1): High-mass star formation
  Apr 1: ArXiV presentation day
  Problem set 4 due Mar 28
  Problem set 5
- Week 13 (Apr 4, 6, 8): The IMF
- Week 14 (Apr 11, 13, 15): Clustering
- Week 15 (Apr 18, 20): Binaries
- Week 16 (Finals / Problem Set 5 due)

Presentation topics:

- Makennah Bristow: Planet Formation
  PPVII chapter: "Planet Formation Theory in the era of ALMA and Kepler"
  PPVI chapter "Giant Planet Formation, Evolution, and Internal Structure"

- Jared Cathey: Star formation in molecular clouds
  PPVI chapter: "The Star Formation Rate of Molecular Clouds"
  PPVII chapter: "The Life and Times of Molecular Clouds"

- Nazar Budaiev: Magnetic Fields in Star Formation
  PPVII chapter: "Magnetic Fields in Star Formation: From Clouds to Cores"
  PPVII chapter: "A Revised Paradigm of the Role of Magnetic Fields for Disk Formation and Outflow Driving towards an Understanding of the First Stage of Planet Formation"

- Maria Galloway-Sprietsma: Chemistry & Planet Formation
  PPVII chapter: "Chemical Habitability: Supply and Retention of Life's Essential Elements During Planet Formation."

- Savannah Gramze: Filaments
  PPVII chapter: "From Bubbles and Filaments to Cores and Disks: Gas Gathering and Growth of Structure Leading to the Formation of Solar Systems"

- Alyssa Bulatek: Organic Chemistry in Star Formation
  PPVII chapter: "Organic Chemistry in the First Phases of Solar-Like Protostars."

- Desmond Jeff: Massive star formation (and hot cores)
  PPVI chapter: "Massive star formation"
  Krumholz chapter: "Massive star formation"

- Theo Richardson: Protostellar Evolution & SEDs
  PPVI chapter: "The evolution of protostars: Insights from ten years of infrared surveys with SPITZER and HERSCHEL"
  PPVII chapter: "Accretion Variability as a Guide to Stellar Mass Assembly"

General topics covered

Clouds to Stars:

- Pressure support and spherical collapse
  'Til I collapse / Eminem
  Problem 1: the Bonnor-Ebert sphere

- The Hayashi track, Kelvin-Helmholtz contraction
  The Sun Is A Mass Of Incandescent Gas / They Might Be Giants

- Bondi-Hoyle accretion
  Supermassive Black Hole / Muse

- Turbulence
  All Mixed Up / 311

- The initial mass function
  Breaking the Law / Judas Priest
  alternative: *Wanna Be Startin Something / Michael Jackson*

- Star clustering
  We're all in this together / High School Musical cast

- Triggered star formation
  Winds of Change / Scorpions
- Dust
  Dust in the Wind / Kansas

Disks:

- The Toomre instability
  You Spin Me Round (Like a Record) / Dead or Alive
- Dust growth, protoplanet formation
  When Worlds Collide / Powerman 5000
  Alternate suggestion: *Collide (NOW What's Next!) / EARTHGANG and Tiana Major9*
- Disk heating, passive disks
  Pancake Robot / Parry Gripp

Feedback:

- Accretion and outflow shocks
  Mindfields / Prodigy
- Photoionization, HII regions
  Burnin' for You / Blue Öyster Cult

Additional Presentation topics:

- Collisional formation of massive stars
- Fluid instabilities in the ISM (Kelvin-Helmholtz, Rayleigh-Taylor)
- Turbulence: Any subtopic you like. (statistical characteristics, generation, dissipation, observations)
- Shocks (Rankine-Hugoniot Jump Conditions)
- Dust from clouds to cores to disks

Topics from Tom Megeath's class: **Bold** will be covered here. *Italics* are optional.

- Lecture 1: Introduction to Young Stellar Objects
- Lecture 2: Molecular Clouds: Galactic Context and Observational Methods
- Lecture 3: Molecular Cloud: Properties and Evolution
- Lecture 4: Molecular Cloud: Turbulence and Magnetic Fields
- Lecture 5: **Dense Cores: Observations**
- Lecture 6: **Isothermal and Bonner Ebert Spheres**
- Lecture 7: **The Collapse of Cores and Infall**

- Lecture 8: **Protostars and the Collapse of Rotating Cores**
- Lecture 9: **The Spectral Energy Distributions of Protostars and Disks**
- Lecture 10: **The Spectral Energy Distributions of Disks**
- Lecture 11: *The Evolution of Disks*
- Lecture 12: **The Initial Mass Function**
- Lecture 13: **Clusters and Associations**
- Lecture 14: *Viscous Accretion Disks*
- Lecture 15: *Magnetospheric Accretion*
- Lecture 16: *Outflows*
- Lecture 17: **High Mass Star Formation**
- Lecture 18: **Pre-main Sequence Stars**
- Lecture 19: *The Stellar Birthline*
- Lecture 20: *Deuterium and Hydrogen Burning*
- Lecture 21: Main Sequence Evolution and Leaving the Main Sequence
- Lecture 22: Why Stars Become Red Giants
- Lecture 23: The Helium Flash and Horizontal Branch
- Lecture 24: AGB Stars and Massive Star Evolution
- Lecture 25: Pulsating Stars, Cepheids & RR Lyrae stars
- Lecture 26: Nucleosynthesis I
- Lecture 27: Nucleosynthesis II
- Lecture 28: From AGB stars to Planetary Nebulae
- Lecture 29: The End Stages of Massive Stars and Supernovae

Topics from Mark Krumholz's "Notes on Star Formation": **Bold** will be covered here. *Italics* are optional.

- 1 Observing the Cold Interstellar Medium
- 2 **Observing Young Stars**
- 3 Chemistry and Thermodynamics
- 4 **Gas Flows and Turbulence**
- 5 Magnetic Fields and Magnetized Turbulence

- 6 **Gravitational Instability and Collapse**
- 7 Stellar Feedback
- 8 Giant Molecular Clouds
- 9 *The Star Formation Rate at Galactic Scales: Observations*
- 10 *The Star Formation Rate at Galactic Scales: Theory*
- 11 **Stellar Clustering**
- 12 **The Initial Mass Function: Observations**
- 13 **The Initial Mass Function: Theory**
- 14 **Protostellar Disks and Outflows: Observations**
- 15 **Protostellar Disks and Outflows: Theory**
- 16 **Protostar Formation**
- 17 **Protostellar Evolution**
- 18 **Massive Star Formation**
- 19 *The First Stars*
- 20 *Late-Stage Stars and Disks*
- 21 *The Transition to Planet Formation*

Topics from PPVII reviews: **Bold** will be covered here. *Italics* are optional.
However, these reviews are not yet available! I will try to get ahold of some of them and share them early.

- The Life and Times of Giant Molecular Clouds
- **The Solar Neighborhood in the Age of Gaia**
- **Star formation in the Central Molecular Zone of the Milky Way**
- **OB Associations**
- **Initial Conditions for Star Formation: A Physical Description of the Filamentary ISM**
- *Magnetic Fields in Star Formation: From Clouds to Cores*
- **From Bubbles and Filaments to Cores and Disks: Gas Gathering and Growth of Structure Leading to the Formation of Solar Systems**
- **The Origin and Evolution of Multiple Star Systems**
- **A Revised Paradigm of the Role of Magnetic Fields for Disk Formation and Outflow Driving towards an Understanding of the First Stage of Planet Formation**
- **Accretion Variability as a Guide to Stellar Mass Assembly**

- *Organic Chemistry in the First Phases of Solar-Like Protostars*
- *A Theoretical Perspective of Structured Distribution of the Gas and Solids in Protoplanetary Disks* [Jaehan's review]
- Hydro-, Magnetohydro-, and Dust-Gas Dynamics of Protoplanetary Disks
- Setting the Stage for Planet Formation: Measurements and Implications of the Fundamental Disk Properties
- *Demographics of Young Stars and Their Protoplanetary Disks: Lessons Learned on Disk Evolution and Its Connection to Planet Formation*
- *The Role of Disk Winds in the Evolution and Dispersal of Protoplanetary Disks*
- Near-Infrared View of Planet-Forming Disks and Protoplanets
- Kinematic Structures in Planet-Forming Disks
- Planet-Disk Interactions and Orbital Evolution
- *Planet Formation Theory in the Era of ALMA and Kepler: From Pebbles to Exoplanets*
- Short-Lived Radionuclides in Meteorites and the Sun's Birth Environment
- Direct Imaging and Spectroscopy of Extrasolar Planets
- Exoplanet Science from the Kepler mission
- Architectures of Compact Multi-Planet Systems
- Geophysical Evolution During Rocky Planet Formation
- Giant Planets from the Inside-Out
- Exploration-Based Reconstruction of Planetesimals
- Chemical Habitability: Supply and Retention of Life's Essential Elements During Planet Formation
- The Isotopic Link from the Planet Forming Region to the Solar System