AST 541 – FALL 2012
Seminar in Theoretical Astrophysics: Star Formation

I. Instructor

Prof. Eve Ostriker
Office: 136 Peyton Hall
Phone: 609-258-7240
email: eco@astro.princeton.edu
Office hours: by appointment

II. Class Meetings

Tu 4:30-5:50, Peyton 145

III. Web Page

`http://www.astro.princeton.edu/~eco/AST541/index.html`

IV. Course Description

The study of star formation lies at the nexus of modern astrophysics, with connections to a wide range of other fields ranging from galactic structure and evolution to physics of the interstellar medium to formation of planetary systems. Observational studies of star formation draw on essentially all astronomical wavelengths, from radio to X-rays, and current facilities including *HST, Spitzer, Herschel,* and *ALMA* are providing increasingly rich and detailed views of star formation phenomena from scales of giant molecular clouds and above to circumstellar disks and below.

Many paradigmatic theoretical problems involving gravitational collapse, turbulence, accretion flows, radiation hydrodynamics, and other fundamental astrophysical processes were first investigated in the context of star formation, and modeling the complex interplay of these effects is central to forefront numerical work in the field.

In this course, we will review a range of topics in star formation, primarily concentrating on theory but also including the observations that motivate and constrain these studies. Each week will have a theme and two student presentations. The presentations will draw on papers in the astrophysical literature, including both classic works, reviews, and reports of the most recent advances.

Each presentation will be 30 minutes long, followed by 10 minutes for questions and discussion. Presentations should include relevant observational background. Papers to be covered by presenters will be posted in advance, and everyone should read the papers and come to the seminar prepared to ask questions and contribute to the discussion after the talk. After the presentation, everyone in the seminar will be asked to provide (anonymous) constructive feedback to the speaker. Each student speaks once per semester, and should set up a meeting with the instructor (Eve) to go over the plan for the talk in the week prior to the date of the presentation. Grading for the course is on a P/F basis.

V. General References

A recent comprehensive review, including many references to journal articles, is *Theory of Star Formation*, by C. F. McKee and E. C. Ostriker, 2007, ARAA, 45, 565-687.

The following books are available either from the course reserve area in Lewis Library, or electronically via a link from the university's Main Catalog:

A. Texts/monographs

Principles of star formation, by Peter Bodenheimer, 2011, Springer (available online)

An Introduction to Star Formation, by Derek Ward-Thompson and Anthony Whitworth, 2011, Cambridge University Press

The Formation of Stars, by Steven W. Stahler and Francesco Palla, 2008, Wiley

Accretion Processes in Star Formation, by Lee Hartmann, 2009, Cambridge U. Press

Handbook of Star Forming Regions, by Bo Reipurth, 2008, ASP Press

B. Review Volumes & Conference Proceedings

Protostars and Planets V, Eds. B. Reipurth et al, 2007, U. Arizona Press

Computational Star Formation, Eds. J. Alves et al, 2011, Cambridge U. Press (available online)

Massive Star Formation: Observations Confront Theory, Eds. H. Beuther et al, 2008, ASP Press (available online)

Turbulence and Magnetic Fields in Astrophysics, Eds. E. Falgarone & T. Passot, Springer (available online)

VI. Topics for Presentations

Below is a list of topics (and detailed issues) drawn from current research in star formation studies. Some of these topics are larger and can be split into two presentations. In addition, presentations on other topics not listed here is permitted, provided that there is a strong connection to the star formation theme for this semester. Topics will be allocated based on student preferences, to the extent possible. We will follow the approximate order below, with some adjustments.

- **Giant Molecular Clouds (GMCs) – structure and turbulent properties**

Cloud properties and observed scaling laws
MHD turbulence – power spectra of **v** and **B** from simulations
Turbulent dissipation and driving
Density structure – PDFs and correlations
Observational diagnostics of turbulence and magnetic fields in GMCs

- **GMCs – microphysics**

Heating and cooling processes for gas and grains
Molecule formation and dissociation
PDR solutions
Radio and IR diagnostics
Ambipolar diffusion, C shocks

- **Low-mass prestellar and protostellar cores – formation and structure**

Identification of cores in molecular-line and continuum surveys; inferring ages
Formation mechanisms and connection to environment
Bonnor-Ebert spheres
Magnetized equilibria; ambipolar diffusion

- **Collapse of low-mass cores**

Isothermal unmagnetized collapse: Larson-Penston solution, Shu solution, generalized solutions
Observational diagnostics of collapse
Effects of magnetic fields
Effects of rotation
Disk formation and magnetic braking

- **Protostars and pre-main sequence stellar evolution**

First hydrostatic core
Deuterium burning
Stellar birthline
Hayashi and Henyey tracks

- **T Tauri systems – radiation diagnostics**

Spectral Energy Distributions (SEDs): star, disk, and envelope contributions
Inferred vertical structure of disks
Accretion shock diagnostics
Disk diagnostics from line emission

- **Winds, jets, and outflows from Young Stellar Objects (YSOs)**

Magnetohydrodynamic (MHD) winds: disk winds, X-winds; acceleration and collimation
Magnetosphere-disk interactions and flow onto the star
Molecular outflows from wind/ambient interactions
Herbig-Haro objects

- **Protostellar disks – accretion processes**

Thermal/ionization structure of disks; dead zones and layered accretion
Magnetorotational instability (MRI) in partially-ionized disks – resistivity, Hall effect, ambipolar diffusion
Angular momentum transport via self-gravitating instabilities
Spatially-variable accretion rates and the FU Ori outburst phenomenon
Evolutionary models

- **Binary star formation**

Formation via capture
Formation via fragmentation of rotating core or disk
Accretion in binary systems

- **Protostellar disks – gas/grain dynamics**

Regimes of grain/gas aerodynamic drag laws
Vertical settling of dust
Differential mass loading and Kelvin-Helmholz instabilities
Gravitational instabilities in dust-loaded layers (Goldreich/Ward)
Gas-dust streaming instability
Particle concentration in gas disk structures (pressure maxima, vortices)

- **Planet formation – overview in the star formation context**

Planetisimal formation – collisional agglomeration of > meter-sized bodies
Runaway growth and oligarchic growth stages
Gas giants – core accretion vs. gravitational instability models
Planet migration – Type I and Type II
Planet-planet scattering

- **Disk clearing around low-mass stars**

Photoevaporation by external radiation (EUV)
Photoevaporation by a central object (FUV, X-ray)
Gap opening and evolution to transition disks

- **The Initial Mass Function (IMF)**

Relation between the observed IMFs and Core Mass Functions (CMFs)
Winds/outflows and core-to-star conversion efficiency
Theories of gravoturbulent fragmentation of GMCs into cores – physical dependence, numerical simulations
Competitive accretion theories

- **Star cluster formation**

Fragmentation of massive, turbulent cores
Feedback effects in clustered environments
Stellar mass segregation
Small-N dynamical interactions; sub-cluster merging
Gas expulsion and post-expulsion dynamical relaxation

- **High-mass star formation**

IRDCs; progenitor structures for high-mass stars
Effects of radiation pressure on dusty envelopes/accretion flows
Outflows from high-mass stars
Compact HII regions

- **Destruction of GMCs**

HII region expansion – classical solutions
Blister HII regions and champagne flows
Effects of radiation pressure, stellar winds, supernovae
Cloud lifetimes

- **Star formation on galactic scales**

Kennicutt-Schmidt and other empirical laws
GMC formation mechanisms – collisional agglomeration, self-gravitating instability, effects of spiral structure
Star formation efficiency in GMCs
Self-regulation of star formation via feedback – ISM equilibrium models

- **Primordial star formation**

H2 formation under high-z conditions
Cooling of metal-free and metal-poor gas
Stages of evolution for primordial prestellar "cores"
Feedback effects in primordial star formation
Fragmentation in primordial star formation