Ast 622: The Interstellar Medium

Overview of the course
Mondays and Wednesdays 2:00-3:20 pm  Fern Room
Jan 11th - May 4th

Course website:
www.ifa.hawaii.edu/users/jpw/ism

No course book!
- see website for lecture handouts
- (but website pdf is a poor substitute for class attendance)
Physical Processes in the Interstellar Medium

Ralf S. Klessen and Simon C. O. Glover

Abstract

Interstellar space is filled with a dilute mixture of charged particles, atoms, molecules and dust grains, called the interstellar medium (ISM). Understanding its physical properties and dynamical behavior is of pivotal importance to many areas of astronomy and astrophysics. Galaxy formation and evolution, the formation of stars, cosmic nucleosynthesis, the origin of large complex, prebiotic molecules and the abundance, structure and growth of dust grains which constitute the fundamental building blocks of planets, all these processes are intimately coupled to the physics of the interstellar medium.

However, despite its importance, its structure and evolution is still not fully understood. Observations reveal that the interstellar medium is highly turbulent, consists of different chemical phases, and is characterized by complex structure on all resolvable spatial and temporal scales. Our current numerical and theoretical models describe it as a strongly coupled system that is far from equilibrium and where the different components are intricately linked together by complex feedback loops. Describing the interstellar medium is truly a multi-scale and multi-physics problem. In these lecture notes we introduce the microphysics necessary to better understand the interstellar medium. We review the relations between large-scale and small-scale dynamics, we consider turbulence as one of the key drivers of galactic evolution, and we review the physical processes that lead to the formation of dense molecular clouds and that govern stellar birth in their interiors.
Lectures

- Few derivations, mostly applications
- Goal is to understand concepts, develop physical intuition
- Some “flipping the classroom”
Discussions

- Blackboard problem solving by students
- Go through homework assignments
- Review of assigned papers / topics
Research project

• Each student will carry out an individual, independent research project

• Analysis of reduced dataset(s) and/or numerical calculation, generally mimicking a published paper

• Timeline:
  • preliminary review April 11th
  • “submit” (to me) an ApJ Letter style paper by April 27th
  • Pecha kucha presentations May 2nd & 4th
Research project

• See course webpage for project descriptions
• Discussion with me during the semester is welcome and encouraged
• I expect the work effort to be \( \approx 2-4 \) weeks depending on your proficiency but do not leave it until the last week!
Grading

• 60% on homeworks & classroom discussions
  (with additional credit for asking good questions/finding mistakes in lectures or handouts, and discussing applications of classwork in colloquia, astro-ph, arXiv talks!)

• 40% on research project (paper & talk)
So what is the ISM?
Early indications of the ISM

- Dark clouds
- Bright nebulae
- Absorption lines
- Interstellar reddening
Early indications of the ISM and the birth radio astronomy

- HI 21cm line
  http://www.nrao.edu/archives/Ewen/ewen.shtml

- Millimeter rotational lines
ALMA and EVLA
Space observatories
and the explosion of multi-wavelength astronomy
The vacuum of space

\[ M_{\text{ISM}} \approx 7 \times 10^9 \text{ Msun} \]
\[ R_{\text{Gal}} \approx 10 \text{ kpc} \]
\[ H_{\text{ISM}} \approx 250 \text{ pc} \]

\[ \Rightarrow \rho = \frac{M}{2\pi R^2 H} \approx 10^{-24} \text{ g/cm}^3 \]
\[ \Rightarrow n_H \approx 1 \text{ cm}^{-3} \]

What is the density of molecules in this room?

What is the density of the Universe?
Syllabus

- Dust
- Ionized regions
- Atomic regions
- Heating and Cooling
- Molecules
- Dynamics
- The circumstellar medium
Dust

- Reddening and extinction
- Mie theory
- Grain size, growth, composition
- Gas-to-dust ratio
HII regions

Ionized gas (HII = H\(^+\))
OB stars
⇒ recent star formation

\(n_H = 10-10^4 \text{ cm}^{-3}\)
\(T = 8000 \text{ K}\)

The Stromgren sphere

Optical recombination and collisional lines, infrared dust emission, radio free-free emission

Measuring densities, temperatures, abundances

Super star clusters
HI regions

Atomic gas (HI = neutral H)

\[ n_H = 1 \times 10^2 \text{ cm}^{-3} \]
\[ T = 80 - 8000 \text{ K} \]

21cm line, [CII] 157\(\mu\)m line
optical absorption lines (equivalent width ⇒ abundances)
Heating and cooling

Absorption of radiation, shocks
⇒ heating

Collisions and escape of radiation
⇒ loss of kinetic energy from medium
⇒ cooling

Pressure balance
⇒ 2-phase atomic medium
+ supernovae shocks
⇒ 3-phase medium

Extragalactic context - is the WHIM the source of the missing baryons?
Molecular clouds are the densest parts of the ISM and the sites of star formation

\[ n_H = 1 \times 10^6 \text{ cm}^{-3} \]
\[ T = 10 \text{ - } 1000 \text{ K} \]

- Molecular vibrational and rotational lines
- Astrochemistry
- PDRs
- Extragalactic context
Dynamics

- Expanding HII regions
- Expanding SN remnants
- Bonnor-Ebert sphere  
  - star formation
- Magnetic fields
The circumstellar medium

- Disk formation and evolution
  - *planet formation*
Order of magnitude estimates

• There are many large uncertainties in determining physical quantities in the ISM (and astronomy in general)
  • distance
  • geometry
  • “invisible” matter
  • poor statistics, incompleteness (unknown unknowns)

• BUT most physical processes are sufficiently different that an order of magnitude estimate is sufficient

• Do NOT be alarmed at how approximate some of the calculations are - they are still good enough to draw profound conclusions about the way the Universe works!

• And they are an essential skill for a successful researcher (and successful grad student to pass thequals...)