Astronomy 501: Radiative Processes

Lecture 1

Aug 22, 2022

Announcements:

- Welcome!
- Please leave your camera on if at all possible
- Syllabus posted
- Questions? I can talk outside after class

Today's Agenda

⋆ Overview and Appetizer

⋆ Course Mechanics

⋆ Cosmic Messengers

Welcome! ...and Introductions

Radiative Processes: Overview

radiative processes: tools to address fundamental questions

⋆ *given an astrophysical system, how will it look?*

⋆ *given how an observed astronomical object looks*

i.e., given an image *and/or* spectrum

what is the nature of the physical system?

radiative processes *link*

astrophysical systems with **astronomical observables**

so: we'll spend the semester at

the heart of astronomy and astrophysics!

Academic New Year's Resolution: Astrophysical Workout

this is a "**tools**" course

$\rightarrow$ builds *astro-muscles*: *intuition, estimation, analysis*

all are crucial for our line of work

$\rightarrow$ you want to finish this course "radiatively buff"

can show off at the beach or at summer conferences

of course: to get fit, need to sweat a little!

adopt and keep a consistent workout regime

$\rightarrow$ lots of exercises = problem sets

But wait! There's more!

bonus: getting fit pays off

- conceptual depth and technical ability:
  skills to play the game well
- looks good and shows value to advisors,
  collaborators, search committees

bonus: radiative processes is a beautiful subject!

- combines much of physics and astrophysics
  E&M, quantum mechanics, statistical mechanics, relativity ...
  ...and a lot of astronomy
- excellent opportunity to learn/review, synthesize these topics
- radiation inherently relativistic = cool
- pretty pictures also are data, encode a wealth of information!
- now also: multimessenger radiative processes *Q: whazzat?*

Methods to the Madness

My goals: you will come away knowing:

- ⋆ how to assess what a system will look like spatially and across the EM spectrum

- ⋆ the physics and astrophysics of the underlying emission, absorption, scattering processes

- ⋆ the detailed spectra arising from idealized examples of radiating systems, and how these arise

- ⋆ how to calculate spectra for realistic systems

- ⋆ how to interpret and analyze spectra and to infer underlying physical properties

Appetizer: The Multiwavelength Sky

More Than a Pretty Picture: JWST

JWST: space telescope, huge collecting area
sensitive mostly to infrared

successful launch Dec 2021, first images summer 2022

`www: JWST Southern Helix Nebula`
NIRCam: near-IR, 0.6 to 5 μm $= (0.6 - 5) \times 10^{-6}$ m
MIRI: mid-IR, 5 to 28 μm

Q: what do you notice? gross features, details?
Q: what is the source of the light we see?
Q: what in the image is resolved? what isn't?
Q: how are the images similar? different? lessons?

Q: what is the object? lessons?

The Big Picture: All-Sky Views

observational astronomy: map the sky (at great cost)
in different bandpasses/lines

course goal: understand qualitatively and quantitatively

- what are the main sources of emission?
  i.e., what object(s) are emitting? by what mechanism(s)?
- why does the image look the way it does?

`www: optical, infrared, X-ray, 511 keV`

Q: what's making the light? gross features? lessons?

Decoding and Diagnosing Spectra

⋆ a Sun-like star

`www:` Hα `around 6563`$\mathring{A}$

`www: Calcium D double around 5890`$\mathring{A}$

Q: what does this say about hydrogen and calcuim in the Sun?

⋆ a planetary nebula: Ring

Q: what's that? optical spectrum?

⋆ mystery spectra

Q: what are the sources?

Syllabus

Course Mechanics

Homework 70% of course grade
to build and keep your radiative muscles
need regular workouts

- 11 problem sets, drop lowest score
- collaboration fine, but...
  you must write and fully understand you own answers!

Midterm 10% of course grade

- "fitness test"
- **not** collaborative!

Final Exam 15% of course grade
to encourage you to synthesize entire course material

- comprehensive, but weighted to post-midterm
- **not** collaborative!

Q: what's missing?

Class Participation 5% of course grade

Science is collaborative! Communication is essential!

I like to ask many Socratic questions

- to receive full credit, *I need to hear from you* in class about $\sim 1/N_{\rm students}$ of the time
- "participation" counts both answers to my questions, but also questions of yours
- correctness not required, engagement is

Course Format hybrid, but likely largely online

you are welcome to view lectures in Kaler Classroom!

participation all the more important!

I don't do this lightly, and I truly appreciate your patience

Prerequisites

Formally: ASTR 404, Stellar Astrophysics
includes most of the physics and astronomy we'll need

Really: we will develop most of the course from
"*first-ish* principles," so you just need the principles

you need to have seen (or come up to speed on)

- E&M, including comfort with Maxwell's equations
- elementary quantum mechanics, e.g., Bohr hydrogen atom, basics of wavefunctions, distinction between fermions and bosons
- basic thermal physics: e.g., Thermodynamic Laws 0 thru 3, Boltzmann distribution
- basic special relativity: e.g., Lorentz transformations

I know most of you and know you are good to go
If you are unsure/nervous about the prerequisites
please talk to me after class!

Course Texts

Bruce Draine

The Physics of Interstellar Matter, Princeton (2011)

Required.

> "I wish I'd bought a copy when I took 501."
> – Advanced Grad Student

George Rybicki and Alan Lightman

Radiative Processes in Astrophysics, Wiley (1979, reprinted 2004)

"*Recommended.*"

Free (personal use) pdf posted on Compass

Cosmic Messengers

CSI: Cosmos

Astronomy is (mostly) a "forensic" science

- usually: "can look but can't touch"
  Q: exceptions?
- usually: can't repeat the experiment (big bang in lab?)

Astronomy is also expensive! And publicly funded!
to get taxpayers money's worth, need to extract all possible info from the signals that arrive in our detectors

Q: very broadly, what is (are) the messenger(s)?
Q: what is (are) the signal(s)?

Astronomical Messengers

Solar System

can (sometimes!) bring matter into lab!

e.g.: terrestrial, lunar (and Martian?) rocks; meteorites

also solar wind and interplanetary dust return missions

and deep-ocean/lunar samples from recent nearby supernovae! ^{60}Fe!

- gives precise, detailed information on composition, age
- but lab samples unavailable even for most of Solar System

the rest of the Universe

must catch and decode particles arriving from afar

- *EM radiation* – the vast bulk of available signal
- but EM is not all! other "messengers" now accessible!

cosmic rays, neutrinos, gravity waves

...and perhaps dark matter?

Warmup: Electromagnetic Radiation

want to define terms and try to be clear about assumptions

What is light?

classically: electromagnetic waves

- move at speed c in vacuum
- monochromatic wavelength and frequency related by $\lambda\nu = c$
- visible band roughly $\lambda_{\rm vis} \sim 400 - 700$ nm

quantum mechanically: photons

- electromagnetic quanta: massless, spin-1 particles
- Planck: energy $E_\gamma = h\nu = hc/\lambda$
- but Einstein: $E^2 - (cp)^2 = (mc^2)^2$, and here $m_\gamma = 0$, so momentum $p_\gamma = E_\gamma/c = h/\lambda$

$\rightarrow$ particle/wave duality
Q: when is each description appropriate?