Introduction to Astrophysics I

Craig Sarazin
ASTR 2110
Fall 2014

Centaurus A in X-rays
Introduction to Astrophysics I

MWF 11-11:50
Chem. 305

Discussion Session
F 3-3:50
Clark G004

Sched. #s
10382 and 10383
Instructor

Craig Sarazin
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Phone: 924-4903
Office hours:
MWF 1:30-2:30 or by appointment or any time

At a scientific meeting in Hawaii
Should you be here?

Quantitative (mathematical) & physical introduction to astrophysics

Primarily for people majoring in a science or engineering (astronomy or astrophysics majors)

Prerequisites: MATH 1210 or 1310, PHYS 1610 or 1425, or permission of instructor

Very strong high school calculus and physics
Basic Outline

Quantitative, physical introduction to astrophysics

ASTR 2110 – fall semester:
  Introduction
  Physics
  Stars

ASTR 2120 – spring semester:
  Galaxies and Cosmology
  Solar System
Organization

Class Webpage

Class Syllabus

Text: Ryden and Peterson
Foundations of Astrophysics
Lectures: different emphasis, material on recent
developments in astronomy
Attendance very important
Course Work

Weekly Problem Sets: Passed out Monday, due next Monday. Must be done on time, or credit reduced to 50%.

Reinforce material in class

Graded mainly on effort

Do the homeworks!

Note: first HW due Monday, September 8
Grading

Homeworks: 25%
2 in class tests: 20% each
Final exam: 35%

Possible dates for 2 tests in syllabus
Teaching Assistant

Andrew Burkhardt
Office: ASTR 267
E-mail: amb3au@virginia.edu
Phone: 924-0686
Office hours:
Friday 2-3 pm or by appointment
Discussion Session

Friday, 3-4 pm

Clark G004

Led by Teaching Assistant

Discussion of lectures, reading, class work, but particularly help with problems sets

Time OK?

First Discussion Session Friday, September 5
| I.  | Introduction [Preface]                     |
| II. | Coordinates, Time, and Telescopes [Chapts. 1 & 6] |
| III. | Motion and Gravity [Chapts. 2 & 3]         |
| IV. | Electromagnetism and Light [Chapt. 5]      |
| V.  | Basic Stellar Properties [Chapt. 13, pp. 307-321] |
| VI. | Binary Stars [Chapt. 13, pp. 322-335]       |
| VII. | Atomic Physics and Spectra of Stars [Chapts. 5 & 14] |
| VIII. | The Sun [Chapt. 7]                         |
| IX. | Stellar Structure [Chapt. 15]              |
| X.  | Stellar Evolution [Chapt. 17, pp. 398-408]   |
| XI. | The Death of Stars and Stellar Corpses [Chapt. 18] |
The Unit Police

SI or Die?
Units in Astronomy

Astronomy units (e.g., AU)

“Right Sized”

Introduce during semester

Astronomers mainly use CGS units, not SI (MKS)

Unless specified in problem, problem sets and exams can be done in CGS or SI

I will use CGS and Astronomy units

Text uses SI (mainly) and Astronomy

Only big difference is electromagnetism, CGS easier
# CGS UNITS

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Rationalized MKSA (SI)</th>
<th>CGS (Gaussian)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>$m$</td>
<td>1 kg</td>
<td>$10^3$ gm</td>
</tr>
<tr>
<td>Length</td>
<td>$l$</td>
<td>1 m</td>
<td>$10^2$ cm</td>
</tr>
<tr>
<td>Time</td>
<td>$t$</td>
<td>1 sec</td>
<td>1 sec</td>
</tr>
<tr>
<td>Frequency</td>
<td>$\nu$</td>
<td>1 Hz = 1 sec$^{-1}$</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Force</td>
<td>$F$</td>
<td>1 newton</td>
<td>$10^4$ dynes</td>
</tr>
<tr>
<td>Energy</td>
<td>$E$</td>
<td>1 joule</td>
<td>$10^7$ ergs</td>
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<tr>
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<td>$P$</td>
<td>1 watt</td>
<td>$10^7$ ergs/s</td>
</tr>
<tr>
<td>Charge</td>
<td>$q$</td>
<td>1 coulomb</td>
<td>$3 \times 10^9$ statcoulombs</td>
</tr>
<tr>
<td>Current</td>
<td>$I$</td>
<td>1 amp</td>
<td>$3 \times 10^9$ statamperes</td>
</tr>
<tr>
<td>Potential</td>
<td>$V$</td>
<td>1 volt</td>
<td>1/300 statvolts</td>
</tr>
<tr>
<td>Electric Field</td>
<td>$\vec{E}$</td>
<td>1 volt/m</td>
<td>$1/3 \times 10^{-4}$ statvolts/cm</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>$\vec{B}$</td>
<td>1 tesla/m</td>
<td>$10^4$ gauss</td>
</tr>
</tbody>
</table>

Coulomb’s Law for Electrostatic Forces

\[
F = \frac{q_1 q_2}{d^2}
\]
Gamma Ray Bursts: An Astronomical Mystery Story
Accidental Discovery

Limited Nuclear Test Ban Treaty 1963

Need to Verify
Accidental Discovery (Cont.)

- Discovered by accident in 1969 by Vela satellites looking for illegal nuclear testing on Earth or in space
- Looked for gamma rays
- Satellites had no ability to tell where gamma rays came from
- Found huge bursts of gamma-rays lasting 10’s of second
Accidental Discovery (Cont.)

- Were the Russians cheating?!
- Nervous time in Defense Department
Accidental Discovery (Cont.)

- No. Satellites on opposite sides of Earth see the same burst.
- Must be coming from Up not Down!
Accidental Discovery (Cont.)

- Velas found 73 GRBs 1969-1979
- Existence classified top secret until 1973
- Lack of information even after declassified
- So bright, mess up electronics on satellites throughout Solar System
- December 27, 2004 burst significantly inflated the outer atmosphere of Earth.
Compton Gamma Ray Observatory
Burst Profiles
Burst Profiles (cont.)
Types of Bursts

Initially, all mixed together, but now

- Soft Gamma Repeaters
- Gamma Ray Bursts
  - Long, soft bursts (> 2 seconds long)
  - Short, hard bursts (< 2 seconds long)
March 5, 1979 SGR

Big burst (2 sec), long tail, 8 sec pulsation
SGRs - Repeating Bursts

![Graphs showing events per half-month for SGR 1806-20, SGR 0526-66, and SGR 1900+14 over the years 1975 to 2000.](image)
Localized by time of arrival

Relative positions of spacecraft during Aug. 27, 1998 burst by SGR 1900+14

Ulysses (below plane of ecliptic)

Near Earth Asteroid Rendezvous

Sun
Earth
ASCA
Beppo SAX
RXTE
Wind
DMSP, NOAA

Galactic center (~33,000 L.Y.)
SGR 1900+14 (~20,000 L.Y.)
Within Supernova Remnant (N49) in LMC

X-ray picture of supernova remnant
Locations of SGR and AXPs

Known magnetar candidates

- SGR
- AXPs
Magnetar
Gamma Ray Bursts

• What are they?
• Long vs. short?
• Where are they located?
Compton Gamma Ray Observatory
Spatial distribution

2512 BATSE Gamma-Ray Bursts

Fluence, 50-300 keV (ergs cm$^{-2}$)
Spatial distribution (cont.)

Distribution of Gamma-Ray Bursts on the Sky

Expected

Observed

Must be at cosmological distances

Very luminous $10^{54}$ ergs !! (beaming?)
Accurate locations = BeppoSAX satellite

Long bursts have X-ray afterglows
Accurate locations = BeppoSAX satellite
Location = galaxies at far end of Universe
Galaxies with lots of massive young stars and supernovae
Model: Long Bursts = Hypernovae = Supernova Due to Jets from a Black Hole
Model: Long Bursts = Hypernovae = Supernova Due to Jets from a Black Hole

- Core of massive star (50 $M_\odot$) collapses, forms black hole
- Rotating material from star falls onto BH
- Black holes shoots out jets of gas at 0.99995 c
- Jets blast through star, blowing it up
- If jets point in our direction, we see a gamma-ray burst
Model: Long Bursts = Hypernovae = Supernova Due to Jets from a Black Hole
What are Short, Hard Bursts?

Weak, short lived afterglows, so have to be caught quickly to be localized
Swift Satellite
Swift Satellite

Can turn in seconds to catch an X-ray afterglow

Short bursts: May 9, 2005, July 24, 2005
Large Elliptical Galaxies
E Galaxy Host: Not Like Long Bursts

• Long burst hosts:
  subluminous, blue, star-forming galaxies, mainly at high redshift

• Short burst hosts:
  very luminous, red, non-star-forming galaxy
Model: Neutron Star Mergers to Form a Black Hole?
Neutron Star – Neutron Star Merger
Neutron Star – Black Hole Merger
Neutron Star – Black Hole Merger
An Astronomical Mystery Solved: Gamma Ray Bursts = Birth Screams of Black Holes