ASTRONOMY 288C

Special Projects in Astronomy:
Astronomy Research Techniques

ASTR 288C – Lecture 1, Part 1

Introduction and Overview

About the Class

- Time and Place: Monday 3:30-5:15, CSS 1220
- Instructors: Dr. Tracy Huard (CSS 0231) and Dr. Mike Loewenstein (CSS 0245)
- Contact: thuard@astro.umd.edu, 301-405-2059; mloewenstein@astro.umd.edu, 301-286-3615
- Office hours: Mondays 2:00-3:00, or by appointment
- Textbook: none, Exams: none
- Class website: http://www.astro.umd.edu/academics/instructorpages.html (under construction)
- Your feedback during the semester is encouraged!

Course Description

- 1st 12 Classes consist of lecture and lab sections

- Topics to be covered include

✓ the scientific method and ethics
✓ databases, data archives, catalogs, data formats
✓ statistics and signal detection
✓ detector characteristics
✓ science communication and literature searches
✓ data and error analysis
✓ multiwavelength studies

	SCHEDULE – subject to minor revision/reshuffling
August 30	Introduction and Overview, Astronomy Basics
September 6	Labor Day: No Class
September 13	Optical/Infrared Databases, Archives, Catalogs, and Data Formats
September 20	High Energy Databases, Archives, Catalogs, and Data Formats
September 27	Statistics, Source Detection, Noise and Background in the Optical/IR
October 4	Statistics, Source Detection, Noise and Background at High Energies
October 11	Signal transmission, Resolution, Detectors
October 18	Science Communication, Literature Searches, Latex Documents
October 25	Data Analysis I: Optical/IR
November 1	Data Analysis II: High Energy
November 8	Data Analysis III: Optical/IR
November 15	Data Analysis IV: X-ray Spectroscopy
November 22	Multiwavelength Studies, The Future, Wrap-Up
November 29	Dedicated Time for Research Projects
December 6	Dedicated Time for Research Projects
Finals Week	Project presentations

Course Aims and Composition

- Lectures: introduce basic concepts, and present examples -- often from our own research experience
- Labs: illustrate these with hands-on applications
- Homework: address the material in more depth and detail
- Research project: put it all together by carrying out a project from the analysis stage all the way through to the presentation of results

Course Aims and Requirements

- By the end of the semester, students should have a good idea of what astronomical research is, how its done, and whether it is something you might wish to further pursue.
- Students should be familiar with first-year mathematics and physics, basic astronomical concepts and computer skills.

Student Evaluation

- Final Grade Breakdown:

  Homework -- 50%

  Final project – 40% (20% written report, 20% oral presentation)

  Class Participation – 10%
- Students are expected to attend class. No more than one absence is permitted.
- Late homework may be turned in, but with a penalty of 20% each day. Under no circumstance will homework be accepted more than 3 days late. BUT, each student has one “free pass”: the lowest of homework grades will be dropped, allowing one homework to be skipped without adversely affecting the final grade.

Class Research Project

- The instructors design the projects.
- The projects will have written and oral components, and will be done in pairs.
- These projects will require extensive analysis over a significant part of the semester, and should begin after the October 4th class.
- A written report *draft* is due on the last day of the semester (Friday December 10, by 5:00 pm).
- The written report is due on finals week.
- The oral presentations will be delivered during finals week.
- The final two lecture periods are reserved for projects, with the instructors available for consultation and feedback.
- Some details TBA…

Academic Integrity

Students must be fully familiar and comply with the University Code of Academic Integrity, as detailed at

http://www.studenthonorcouncil.umd.edu/code.html

There is a zero tolerance policy with respect to incidents of academic dishonesty, including cheating, fabrication, facilitation, and plagiarism.

Scientific Ethics and Standards

- For research to contribute to the advancement of science, results must be repeatable and original.
- The integrity of scientists, and the scientific enterprise, is founded on the principle that research is conducted honestly, and reported fully and truthfully.
- Due credit should be given to all contributors and previous work.

Scientific Ethics and Standards

- One must not falsify data, deliberately misrepresent results, plagiarize the work of others, etc.
- Researchers are ultimately responsible for the integrity of their results, but there are also cultural safeguards (repeatability and consistency, peer review).
- Research results become part of accepted scientific knowledge when published in peer-reviewed professional journals. That is, experts in the field must assure that the work meets professional standards in terms of honesty, methodology, originality, significance, reference to previous work, and clarity of presentation.

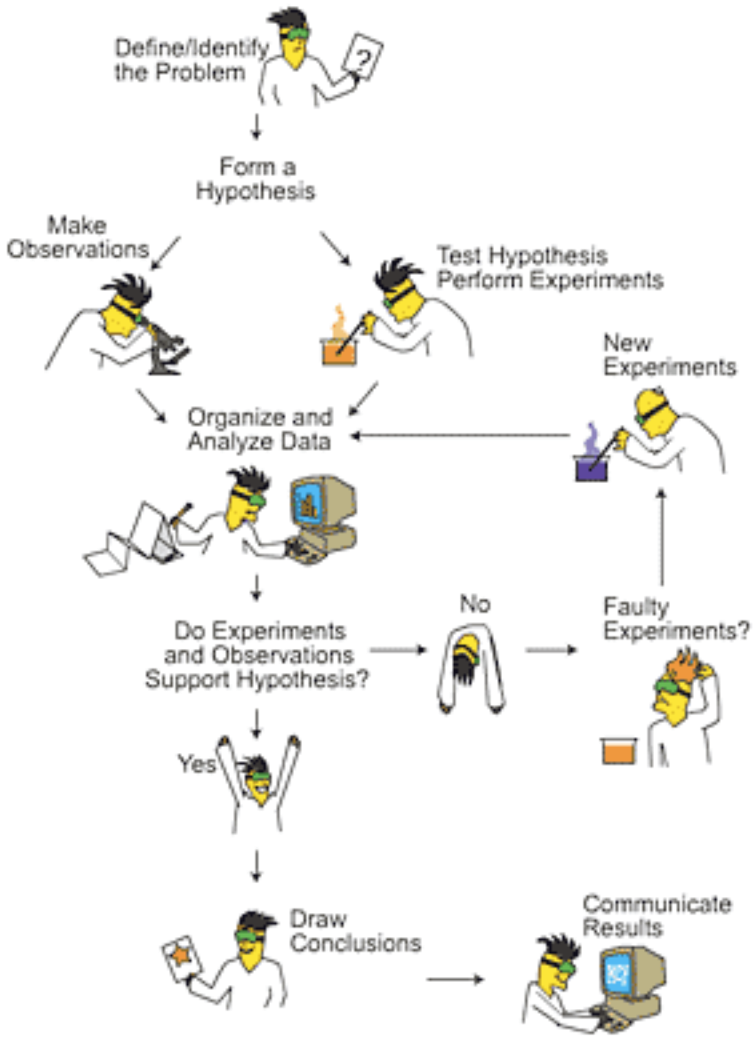
The Scientific Method

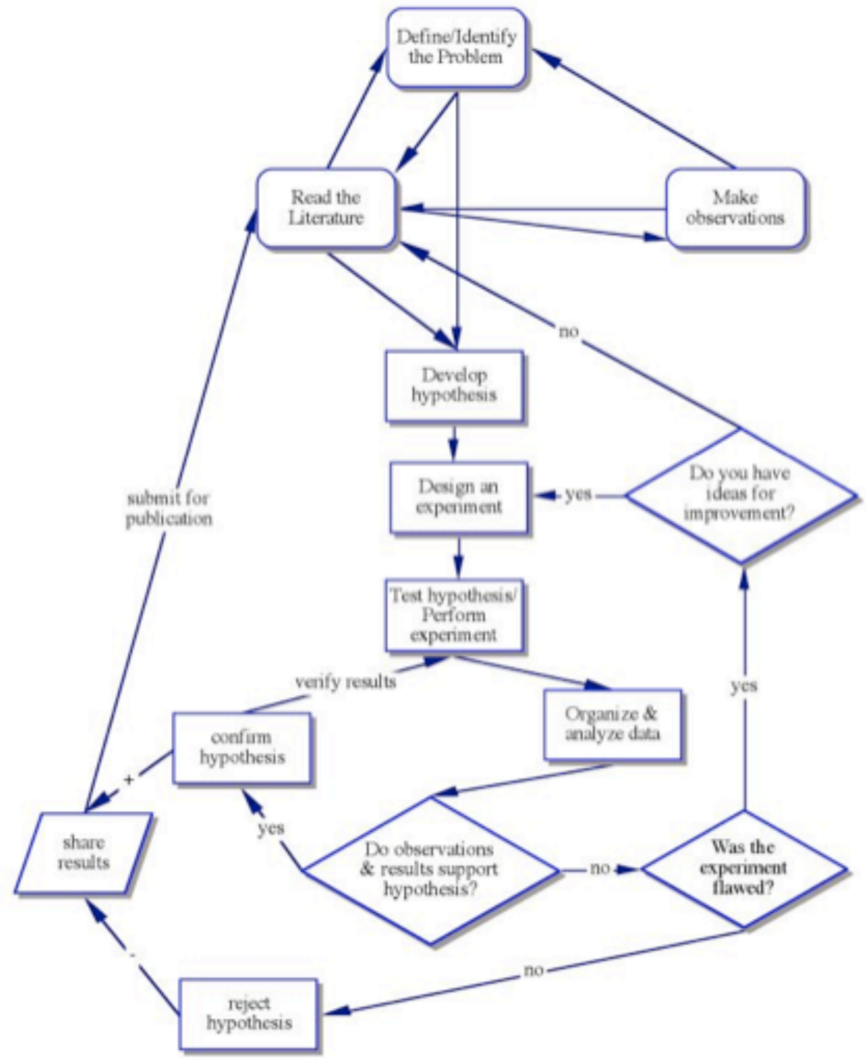
- Models of the physical world are tested and revised based on empirical evidence – experiments/observations and their analysis that must be repeatable.
- The "scientific method" is a formulation of how this is done in principle and in practice.

The Scientific Method

- An iterative and objective methodology for investigating, and expanding our knowledge of, physical phenomena using the experimental (observational) testing of hypotheses.
- Normal science resembles a cycle (or spiral) of hypothesis formulation, experimental testing, and the formulation of new hypotheses – all within some larger theoretical framework.

Scientific Method Flow Charts





The Scientific Method

1) Define the problem (within some theoretical context)
2) Gather background information
3) Construct hypothesis
4) Collect experimental/observational data
5) Analyze data
6) Interpret analysis – does it confirm (☑) or refute (☒) the hypotheses, or is inconclusive (☐)?
7) Next steps…
    a) Report results
    b) Go to (3) or (4) [or (5)] [or 6)]

The Scientific Method – An Example

1) What is the dark matter (DM)?
2) A particular dark matter candidate decays into a neutrino and an X-ray.
3) We can observe X-rays from decaying dark matter in places of high dark matter concentration.
4) Observe dwarf spheroidal (dSph) galaxies in X-rays.
5) Analyze dSph spectra; look for a dark matter line feature. None seen.
6) Constrain the parameters (e.g., abundance) of this DM candidate (including it doesn't exist).
7) (a) Publish results in Astrophysical Journal (ApJ).

   (b) Look at more dSphs – i.e., back to (4).
5) Detect weak evidence for a line in analysis of new target (Willman 1).
6) Calculate the parameters if the detection is real.
7) (a) Publish results ApJ

   (b) Look at W1 again with a different (more sensitive) X-ray telescope.

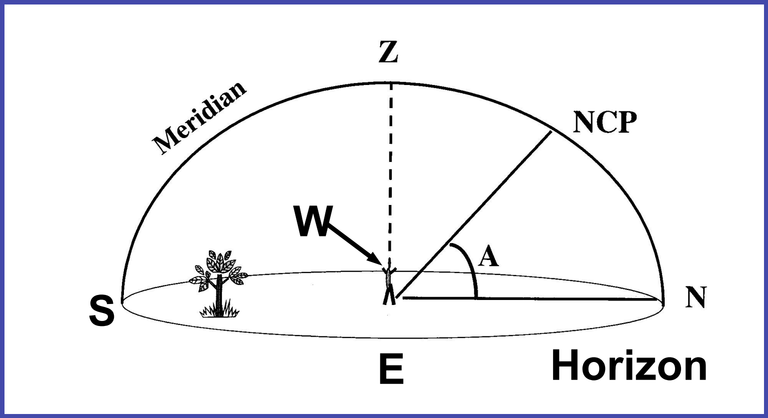
The Celestial Coordinate System

Astronomical Coordinate Systems

- Horizontal (altitude and azimuth)
- Equatorial (right ascension and declination)
- Galactic (galactic latitude and longitude)
- Ecliptic (ecliptic latitude and longitude)

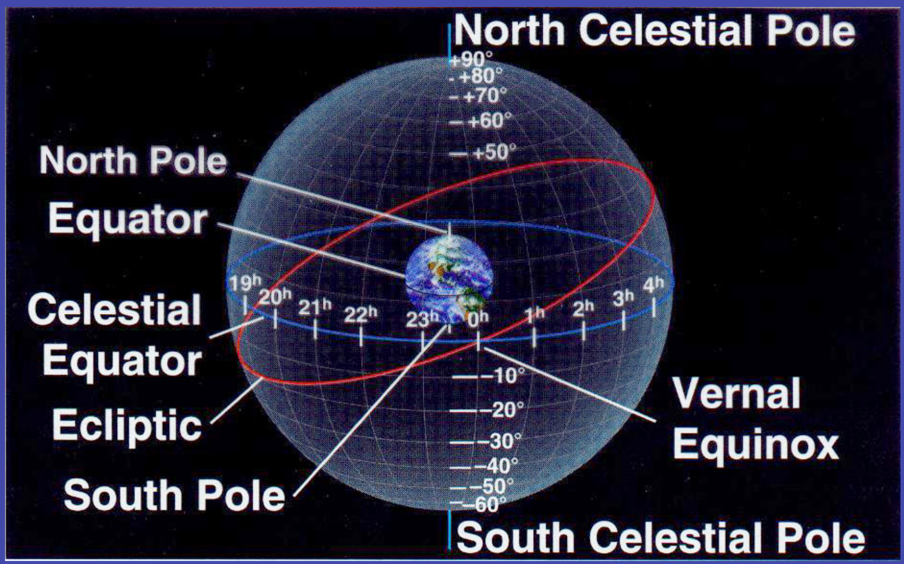
Equatorial System

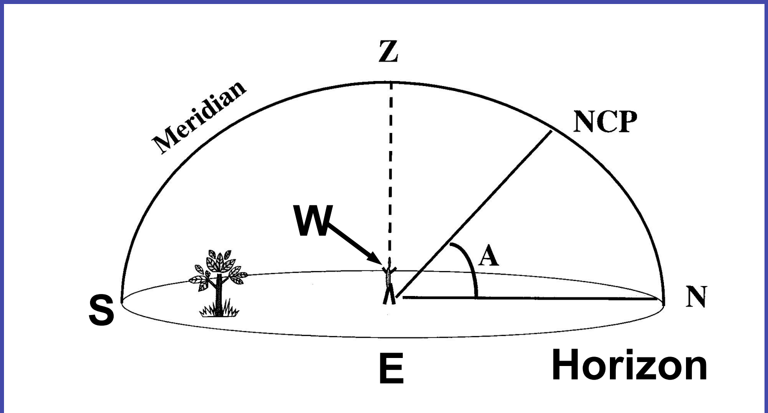
…as seen from an observer.



The Celestial Coordinate System

Equatorial System





Right Ascension ("longitude")

Hours: Minutes: Seconds

$1^h = 60^m = 3600^s$

RA = α = 18:36:56.34 = $18^h\ 36^m\ 56^s.34$

Declination ("latitude")

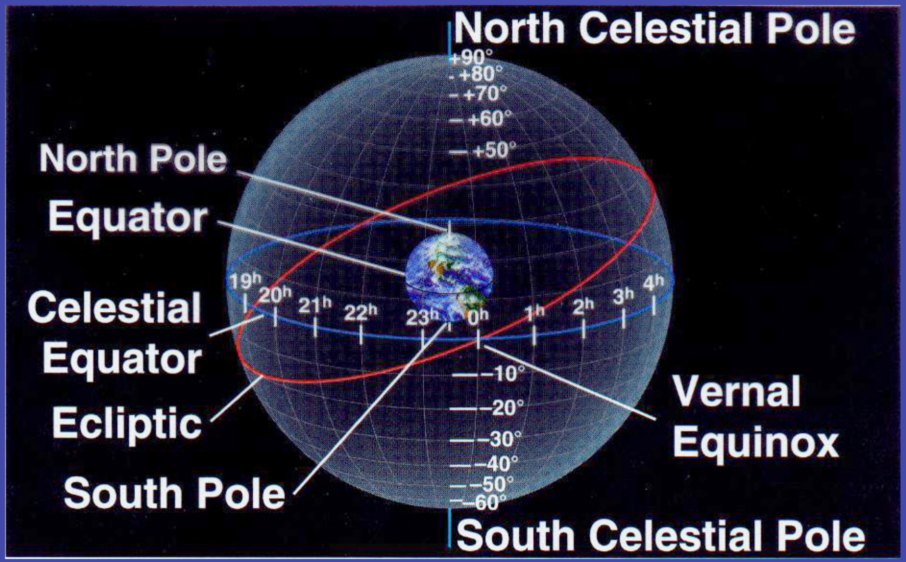
Degrees: Arcminutes: Arcseconds

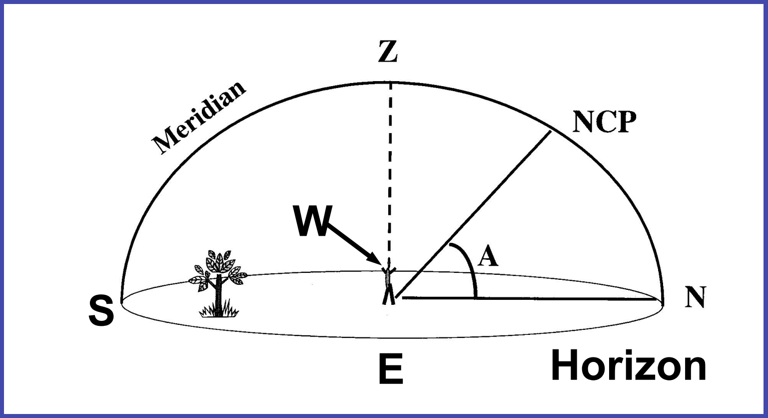
$1° = 60' = 3600''$

Dec. = δ = +38:47:01.3 = $+38°\ 47'\ 01.3''$

The Celestial Coordinate System

Equatorial System





$24^h = 360°$ (only along celestial equator!)

$24^h = 360° \cos\delta$ (otherwise)

Right Ascension (“longitude”)

Hours: Minutes: Seconds

$1^h = 60^m = 3600^s$

RA = α = 18:36:56.34 = $18^h\ 36^m\ 56^s.34$

Declination (“latitude”)

Degrees: Arcminutes: Arcseconds

$1° = 60' = 3600''$

Dec. = δ = +38:47:01.3 = $+38°\ 47'\ 01.3''$

The Celestial Coordinate System

Declination ↑

← **Right Ascension (increases toward East)**

Electra

$\alpha_1 = 03^h\ 44^m\ 52.54^s$

$\delta_1 = +24°\ 06'\ 48.0''$

Atlas

$\alpha_2 = 03^h\ 49^m\ 09.74^s$

$\delta_2 = +24°\ 03'\ 12.3''$

Convert coordinates to decimal degrees:

$\alpha_1 = 3.74793 \text{ hours} = 56.21892°$

$\delta_1 = 24.11333°$

$\alpha_2 = 3.81937 \text{ hours} = 57.29058°$

$\delta_2 = 24.05342°$

Use equation for angular separation:

$\theta = 0.98021° = 58.81'$

Angular separation between points on Celestial Sphere:

$$\theta = \sqrt{[(\alpha_1 - \alpha_2)\cos\bar{\delta}\,]^2 + (\delta_1 - \delta_2)^2}$$

The Magnitude System

Logarithmic scale

Apparent magnitude, m_λ, at waveband λ defined as:

$$m_\lambda = 2.5 \log (I_\lambda / I_{0,\lambda})$$

I_λ = intensity, or flux density at λ

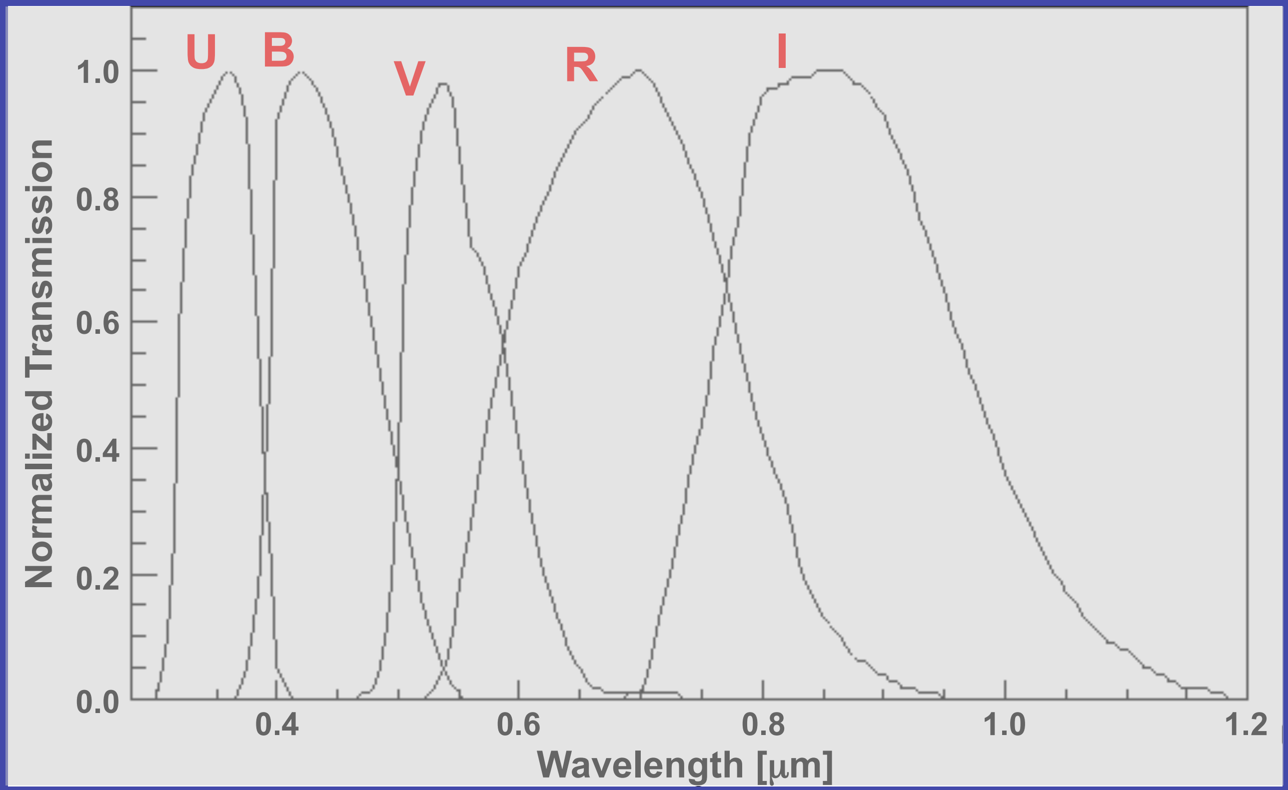
$I_{0,\lambda}$ = zero point at λ

Fainter sources have greater magnitudes

Human eye typically can see sources with $m_V \leq 6$

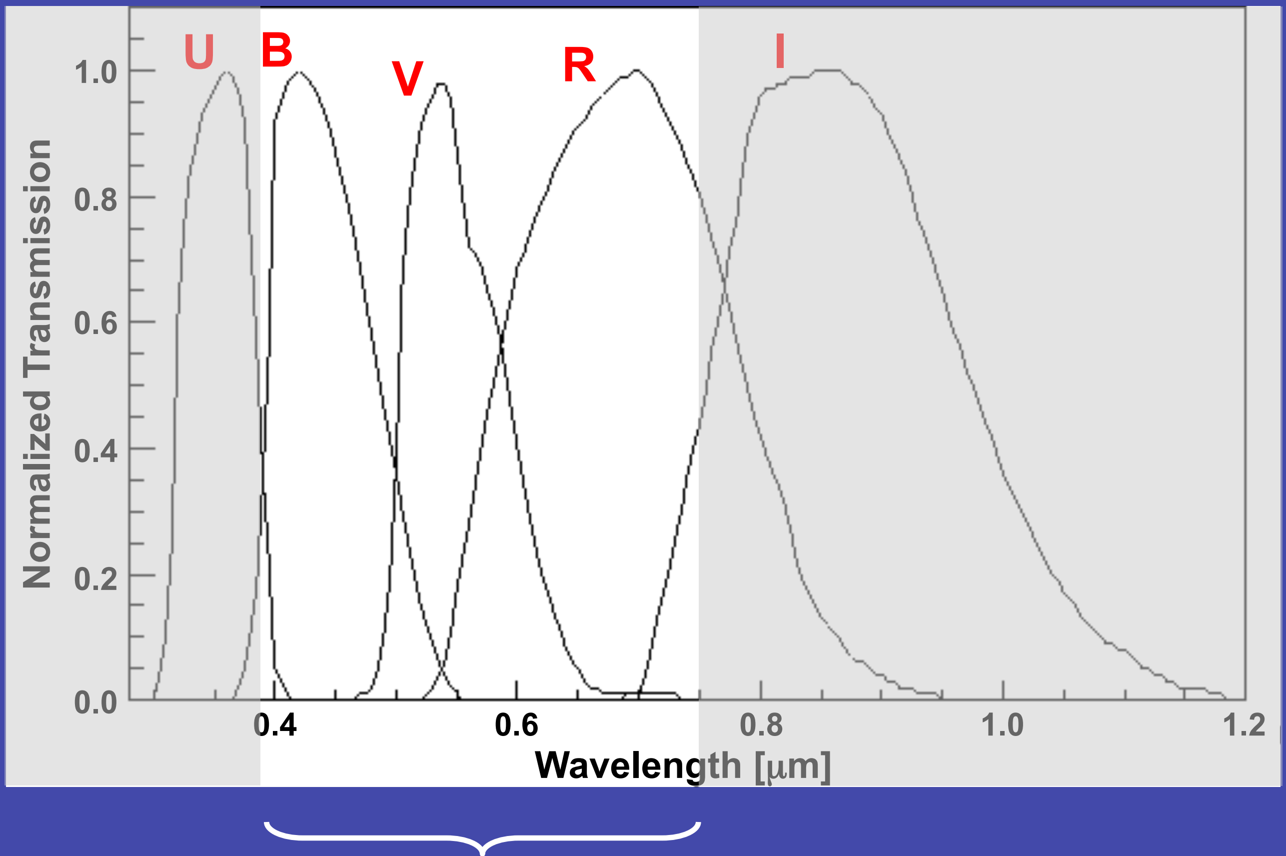
The Magnitude System

Johnson Optical Broadband Filter System



The Magnitude System

Johnson Optical Broadband Filter System



Human eye sensitive to 0.39 - 0.75 μm

The Magnitude System

Waveband λ	λ_{eff} [μm]	$\Delta\lambda/\lambda$	$I_{0,\lambda}$ [Jy]	
U	0.36	0.15	1810	Johnson (Bessel 1979)
B	0.44	0.22	4260	
V	0.55	0.16	3640	
R	0.64	0.23	3080	
I	0.79	0.19	2550	
J	1.235	0.162	1594	2MASS (Cohen et al. 2003)
H	1.662	0.251	1024	
K_s	2.159	0.262	667	

Zero points have been historically defined such that α Lyra (A0V star) has $m_\lambda = 0$ at all λ

The Magnitude System

Apparent magnitude depends on:

distance, intrinsic brightness

Absolute magnitude, M_λ, at wavelength λ defined as:

$$M_\lambda = m_\lambda - 5 \log (d / 10 \text{ pc})$$

d = distance

The Magnitude System

Apparent magnitude depends on:
distance, intrinsic brightness

Absolute magnitude, M_λ, at wavelength λ defined as:

$$M_\lambda = m_\lambda - 5 \log (d / 10 \text{ pc})$$

d = distance

A word about distances in astronomy…

$1 \text{ pc} = 3.09 \times 10^{16} \text{ m}$

$1 \text{ AU} = 1.50 \times 10^{11} \text{ m}$

The Magnitude System

What is the distance between the sun and earth (AU) in miles?

$$1 \text{ mile} = 1610 \text{ m} \quad \Rightarrow \quad 1 = \frac{1 \text{ mile}}{1610 \text{ m}}$$

$$1 \text{ AU} = 1.50 \times 10^{11} \text{ m} \quad \times \quad 1$$

$$= 1.50 \times 10^{11} \text{ m} \quad \times \quad \frac{1 \text{ mile}}{1610 \text{ m}} = 9.32 \times 10^{7} \text{ miles}$$

A word about distances in astronomy…

$1 \text{ pc} = 3.09 \times 10^{16} \text{ m}$

$1 \text{ AU} = 1.50 \times 10^{11} \text{ m}$

The Magnitude System

Apparent magnitude depends on:
distance, intrinsic brightness

Absolute magnitude, M_λ, at wavelength λ defined as:

$$M_\lambda = m_\lambda - 5 \log (d / 10 \text{ pc})$$

d = distance

A word about distances in astronomy…

$1 \text{ pc} = 3.09 \times 10^{16} \text{ m}$

$1 \text{ AU} = 1.50 \times 10^{11} \text{ m}$

The Magnitude System

Apparent magnitude depends on:

distance, intrinsic brightness

Absolute magnitude, M_λ, at wavelength λ defined as:

$$M_\lambda = m_\lambda - 5 \log (d / 10 \text{ pc})$$

d = distance

Absolute magnitude depends on only intrinsic brightness