Extragalactic Astronomy

Topics:

– Milky Way
– Galaxies: types, properties, black holes
– Active galactic nuclei
– Clusters and groups of galaxies
– Cosmology and the expanding universe
– Formation of structure
– Galaxies at high redshift
Cosmic Microwave Background

Small fluctuations are due to sound waves at recombination (when electrons and protons combined to make atoms).
Million Galaxies

Each dot is a galaxy
Varieties of Galaxies
Groups of Galaxies

← Stephane’s Quintet

↓ Coma cluster
Big Questions

– How do different types of galaxies form? What are their properties?
– What is the relation of central supermassive black holes to their host galaxies?
– What is the star formation history of the universe?
– How did we go from fluctuations in a hot plasma to stars and galaxies?
– How was the universe reionized?
Homework

• Combination of easy problems to check reading and harder problems intended to be learning exercises
• Goal of easy problems is to motivate students to read the relevant material before lecture
• Note that lectures will not cover all class material, so reading is essential

• First set due at beginning of next class on Wednesday
• Subsequent sets will typically be due on Mondays or at the start of each new topic
• Students are allowed to work together in small groups, but do try to understand the answer to every problem.
• Open to suggestions about form, frequency, timing, e.g. should the easy and hard problems be split into separate assignments?
Research Project

- An introduction to “big data” astronomy using surveys.
- Two people in each group (or individually if anyone prefers).
- Use the Wide-field Infrared Survey Explorer (WISE) All-Sky Data Release from March 14, 2012.
  - WISE mapped the sky at 3.4, 4.6, 12, and 22 μm.
  - WISE source catalog (864 GB) is on kanawa.physics.uiowa.edu
- Each group (or individual) will get an account.

Choose a project from list on class web site or invent your own.
- Use catalog to select or measure the properties of a class of sources using infrared “colors”.
- Make written and oral presentations including scientific background, motivation for study, procedures, results, discussion.
Electromagnetic spectrum

Describe radiation by wavelength (\(\lambda\)), frequency (\(\nu\)), or photon energy (\(E\)). \(E = h\nu, \lambda = c/\nu\)
Atmospheric Transmission
Spectral energy distribution of a starburst galaxy

Plot shows energy release per decade of wavelength
Radiation from Stars

- Stars make blackbody spectra
- Temperatures of stars range from $\sim1000$ K to $\sim50,000$ K
- Wien Law says spectral peak at $\lambda_{\text{max}} = \frac{2900(\mu\text{m})}{T(\text{K})}$
- Stellar spectra peak at $\sim0.06$ to $\sim3$ $\mu$m
• Classify stars on Hertzsprung-Russell diagram
• Stars spend most of their life on the main sequence.
• Hot stars are more luminous, more massive, have shorter lives, and form more rapidly
• Cool stars are less luminous, less massive, have longer lives, and form more slowly
Lots of hot stars in M82, why does spectrum cut off at 0.3 μm?
Starlight is absorbed and scattered by dust within the galaxy.
This “extinction” is stronger at shorter wavelengths, thus causes the stars to appear redder.
What happens to the scattered or absorbed light?
Which is dominant, scattering or absorption?
Spectral energy distribution of M82

Absorbed star light heats dust clouds that radiate in the IR.
Some galaxies observed by WISE
WISE wavebands

The weighted mean WISE relative spectral response functions after normalizing to a peak value of unity, on a logarithmic scale.

WISE made four images of the whole sky, one each waveband.
Astronomical imaging is obtaining flux measurements in one or more wavebands.

Luminosity can be estimated from flux if distance and extinction are known.

Spectral shape can be estimated from relative fluxes in different bands or “colors”.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Efficiency or Transmission</th>
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<tbody>
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<td>300</td>
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Graph showing efficiency or transmission across different wavelengths for U, B, V, R, and I bands.
Stellar temperatures are measured by determining the brightness in each color band and then comparing ratios of $b_V/b_B$ and $b_B/b_U$.

Hot stars have small $b_V/b_B$ and cool stars have large $b_B/b_U$ ratios.
Magnitudes

Consider two stars, 1 and 2, with apparent magnitudes $m_1$ and $m_2$ and fluxes $F_1$ and $F_2$. The relation between apparent magnitude and flux is:

$$m_1 - m_2 = -2.5 \log_{10} \left( \frac{F_1}{F_2} \right)$$

For $m_2 - m_1 = 5$, $F_1/F_2 = 100$.

The ratio of fluxes in two bands, or color, is then the difference in the magnitudes in those two bands usually written as, e.g. (B-V).

Absolute magnitude, $M$, is corrected for distance

$$M = m - 5 \log_{10} D + 5$$

where $D$ is the distance to the star measured in parsecs. Note that $M = m$ if $D = 10$ parsecs.
Hertzsprung-Russell Diagram

Color-magnitude diagram used to classify stars
WISE color selectes AGN

WISE color W1-W2 selects galaxies with active nuclei (from Stern et al. 2012)
Grading

• Grades will be 50% problem sets and 50% on the data analysis project.
• Students may work together on problem sets, but please write up your own answers.
• Form groups of 2 for the research project.
• There will be both written and oral presentations of the project. During the oral presentation, questions will be asked of individual students.
Questions

• Are people comfortable with magnitudes, RA/DEC, early/late type stars, early/late type galaxies?

• Level of programming expertise, preferred languages, Python?

• Familiar with NASA ADS?

• Everyone introduce themselves, pick groups (today or next class).

• People OK with giving final projects in a public setting? 309 VAN overlapping seminar time
For next class

• The first home work set is available on the class web site and is due at the start of our next class.

• Read chapter 2 in the textbook, sections 2.1-2.3 and 2.6.