Introduction to Astrophysics

PHYS 45400, Spring 2024

Dr. James Hedberg

1. What is this class about?

This is a quantitative look at the universe - from our local solar system to the edges of the universe (if there are edges...). We'll use physics mostly from the level of 207 and 208 and 209 and math from 213. If we need higher level math or physics, we'll take it slow and introduce those concepts and skills as needed. But, make sure you realize this is a upper level physics elective. It's not astro 101.

2. Class Structure

The class needs to be appropriate for all of you: physics majors, future astrophysicists, data scientists, Engineers. So, the one thing you all need to be able to do: communicate complex ideas.

There will be homeworks and a larger project presentation (hopefully involving the planetarium). Some, but not a lot of 'physics problems', but more like research technique challenges. i.e. plotting data, analysis, measurements. Etc.

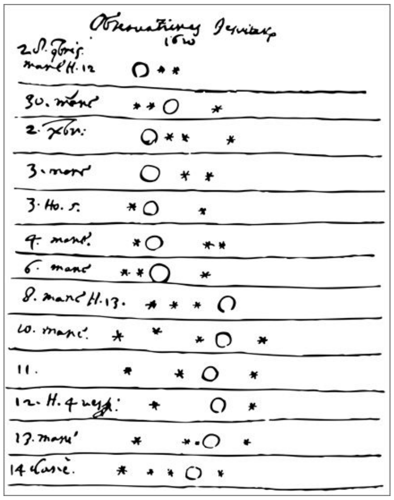
We'll try to schedule an observation night when the weather starts being a little more pleasant.

3. Some Important Observations/events:

3.1 Moons of Jupiter

During the later winter months of 1609/1610, Galileo was able to see 4 objects that were close to Jupiter and whose positions were changing every night. Using basic laws of orbital mechanics, he deduced that they must be moons orbiting Jupiter. This discovery was the first in many ways.

First observation of objects not visible to the naked eye.

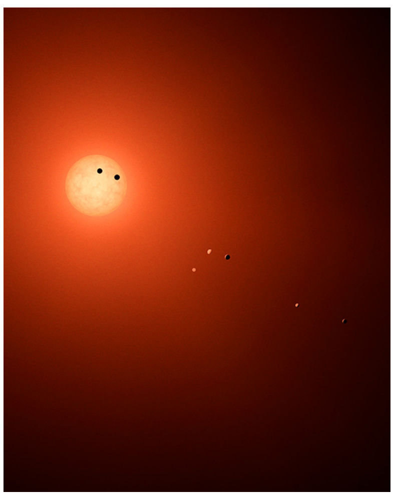


Galileo's Diagrams showing the position of the moons of Jupiter on successive evenings.

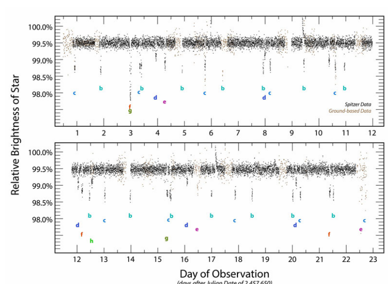
First time another object (Jupiter) was considered the center of an orbit. (except in the context of the sun vs earth debate.)

The geocentric model of the universe begins to unravel.

3.2 Modern Analogue: Exoplanets



An artist's interpretation of the trappist-1 system.



Data from the trappist 1 system showing the relative brightness of the central star.

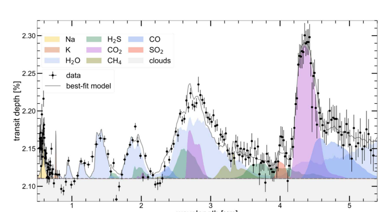
NASA/JPL-Caltech/M. Gillon (Univ. of Lige, Belgium)

As of Jan 2024, there more than 5,569 confirmed planets, in 4,142 planetary systems. This is probably just the beginning.

3.3 Spectroscopy

The dark lines of the solar spectrum as depicted by Fraunhofer

Bestimmung des Brechungs- und Farbenzerstreuung-Vermögens verschiedener Glasarten in Bezug auf die Vervollkommnung achromatischer Fernröhre. [https://onlinelibrary.wiley.com/doi/full/10.1002/andp.201400807]



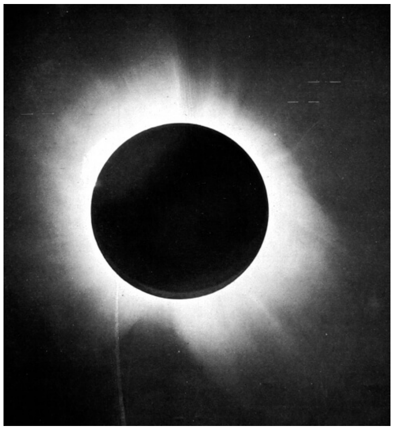
The JWST-PRISM transmission spectrum of WASP-39b with key contributions to the atmospheric spectrum.

https://arxiv.org/pdf/2211.10487.pdf

Black lines in an otherwise normal rainbow! Those where regions of the electromagnetic spectrum where light of particular wavelengths was absorbed.

Now, we can not only just see when these exoplanets pass in front of the sun, we can also make measurements that show what elements and molecules are present in their atmospheres.

3.4 1919 Eclipse

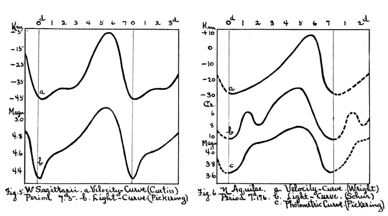


The 1919 eclipse

F. W. Dyson, A. S. Eddington, and C. Davidson (1920). "A Determination of the Deflection of Light by the Sun's Gravitational Field, from Observations Made at the Total Eclipse of May 29, 1919". Philosophical Transactions of the Royal Society A: 332. ISSN 1364-503X.

The total solar eclipse in 1919 was used to confirm (sort of) the recent General Theory of Relativity put forth by Einstein several years earlier (and improved upon by others). Only during an eclipse are the stars near the sun visible. They positions will be slightly shifted due to the gravitational influence of the sun on the photon's path through space.

3.5 Cepheid Variables



Cepheid Variables: The light from theses stars changed - periodically!

https://archive.org/details/popularsciencemo69newy/page/180/mode

How do you know how far away something is? We use parallax, and the works for objects kinda near us, but fails for objects farther away.

If there were two identical lightbulbs in the distance, you could tell which one was farther away by measuring which one was brighter. However, if they are not identical, then you can't be sure. Perhaps one is just dimmer? In 1908, Cepheid Variables were discovered to have a predictable relationship between period and luminosity.

Figuring our how far away things are in space has been a major project since the earliest efforts in astrophysics. We'll spend a lot of time discussing the various methods we have for establishing cosmic distances.

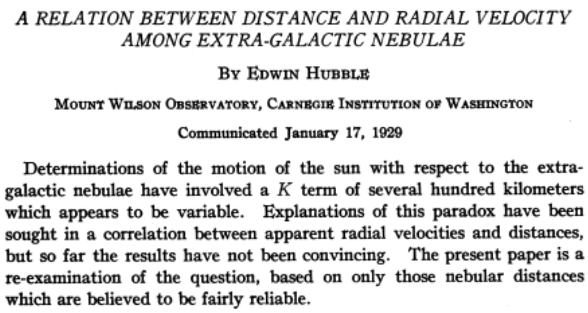
3.6 1930's: Jansky Radio Antenna

Karl Jansky, working at Bell Telephone Laboratories in Holmdel, NJ, used this antenna to detect radio waves coming from the milky way, with the strongest signal coming from the center, in the constellation Sagittarius.

Now, our radio telescopes are much larger and more recognizable.

There are a lot of different types of light. We can see a small portion, but the vast majority of photons out there, are not visible by our wimpy little eyes.

3.7 Expansion of the Universe



A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE

By Edwin Hubble

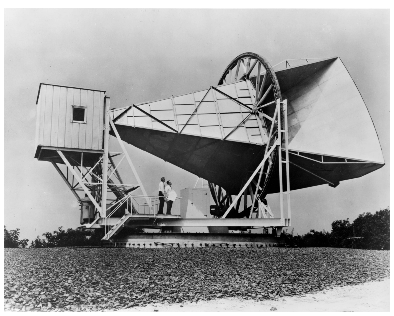
Mount Wilson Observatory, Carnegie Institution of Washington

Communicated January 17, 1929

Determinations of the motion of the sun with respect to the extra-galactic nebulae have involved a K term of several hundred kilometers which appears to be variable. Explanations of this paradox have been sought in a correlation between apparent radial velocities and distances, but so far the results have not been convincing. The present paper is a re-examination of the question, based on only those nebular distances which are believed to be fairly reliable.

Of course, it's interesting to ask not just where something is now, but where it has been in the past and where it will be in the future.

3.8 Cosmic Microwave Background

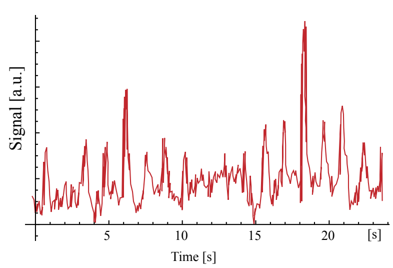


The Holmdel Horn Antenna on which Penzias and Wilson discovered the cosmic microwave background

1964 - Arno Penzias and Robert Wilson.

The first experimental evidence of the big bang was found by accident not too far from here.

3.9 Pulsars



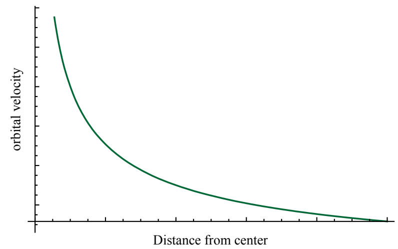
Data from the original discovery of a pulsar.

Data from: [Observation of a Rapidly Pulsating Radio Source](#) A. HEWISH, S. J. BELL, J. D. H. PILKINGTON, P. F. SCOTT & R. A. COLLINS, Nature 217, 709 - 713 (24 February 1968);

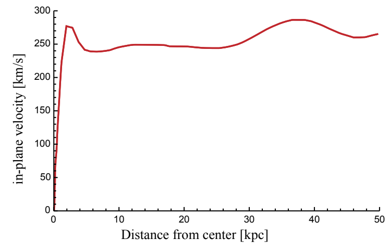
1967 - Jocelyn Bell Burnell and Antony Hewish obtained periodic data from a source in the. The intensity of the radio frequency emission peaked every 1.3373 seconds. Such a signal was completely new and unknown. (they nicknamed the signal LGM-1, for "little green men")

3.10 Dark Matter

60s-70s Vera Rubin and Kent Ford. The Milky Way galaxy was not rotating according to Keplerian orbital mechanics.



The expected velocity of orbiting bodies as a function of position from the center.

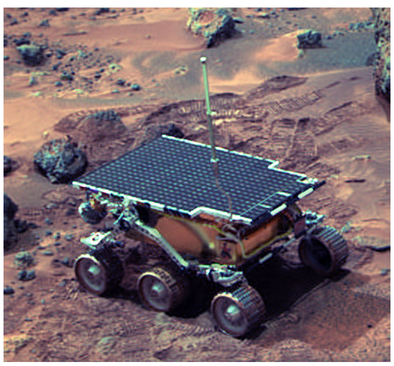


A measured galactic rotation curve shows that the objects further away move about the same speed as the ones close in. uh-oh

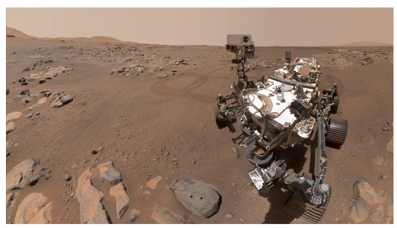
Data from: [Rotational properties of 21 SC galaxies with a large range of luminosities and radii...] Rubin, V. C.; Ford, W. K., Jr.; Thonnard, N. Astrophysical Journal, Part 1, vol. 238, June 1, 1980, p. 471-487

3.11 Missions!

3.12 Mars Rovers



The Sojourner rover.

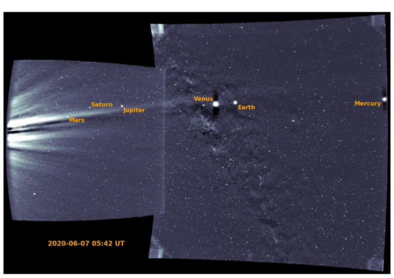


The Perseverance rover landed in Feb 2021

In 1997, the Sojourner rover began a 100 meter march across the surface of mars. It operated for 83 sols and represented a major advancement in our exploration of the solar system.

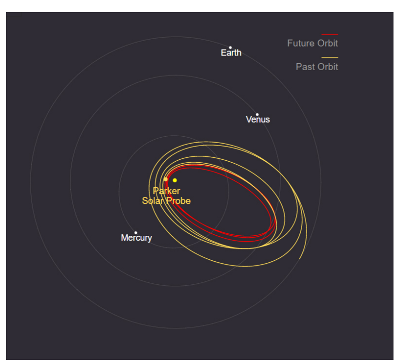
More robots are now on the red planet.

3.13 Solar probe



Parker Solar Probe was making its closest approach to the Sun on June 7, 2020, when its Wide-field Imager for Solar Probe (WISPR) captured the planets Mercury, Venus, Earth, Mars, Jupiter and Saturn in its field of view.

Credit: NASA/Johns Hopkins APL/Naval Research Laboratory/Guillermo Stenborg and Brendan Gallagher



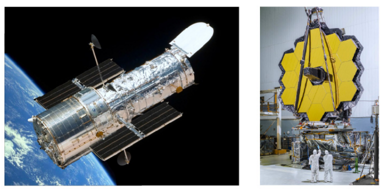
Parker Solar Probe is in the 10th of 24 planned, progressively closer orbits around the Sun. the spacecraft, built and operated at the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland, launched on Aug. 12, 2018.

Credit: NASA/Johns Hopkins APL

3.14 Return to the Moon

There are several missions currently working towards establishing a long term lunar presence. It's much more involved than just trying to plant a flag and then come home.

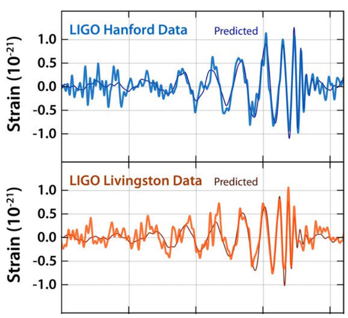
3.15 Instrumentation



Two Space telescopes.

Just over a year ago on Dec 25, 2021, a new Space Telescope was launched. This enormous project has taken decades to complete, and has cost billions of dollars. But, now, there's an amazing instrument out in space. Everyday an entire phone worth of data is sent back to Earth. We'll look at some.

3.16 Gravitational Waves



Data from the first Advanced LIGO detection

Image credit: [LIGO]

These plots show the signals of gravitational waves detected by the twin LIGO observatories at Livingston, Louisiana, and Hanford, Washington. The signals came from two merging black holes, each about 30 times the mass of our sun, lying 1.3 billion light-years away.

The top two plots show data received at Livingston and Hanford, along with the predicted shapes for the waveform. These predicted waveforms show what two merging black holes should look like according to the equations of Albert Einstein's general theory of relativity, along with the instrument's ever-present noise. Time is plotted on the X-axis and strain on the Y-axis. Strain represents the fractional amount by which distances are distorted.

As the plots reveal, the LIGO data very closely match Einstein's predictions.

4. Last bits

Topics:

- History of Astro
- Celestial Mechanics
- Light And Interactions
- Instrumentation
- Stars - inside/evolution/black holes
- Solar System
- Planets,Sun,Earth & moon system
- Galaxies
- Cosmology

To do:

Get a python installation going. This can be done with:

- → Google Colab ←
- Anaconda
- (or more fancy things)