Astronomy 142 — Recitation 10

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Formulas to remember

Leavitt's Law

Classical Cepheid variables

$$\overline{M_V} = -2.77 \log \Pi - 1.69$$

$$\overline{m_V} - \overline{M_V} = 5 \log\left(\frac{d}{10\text{ pc}}\right)$$

Hubble's Law

Galaxies in the uniform Universal expansion

$$v_r = H_0 d \qquad H_0 = 73.04\text{ km s}^{-1}\text{ Mpc}^{-1} = 22.4\text{ km s}^{-1}\text{ Mly}^{-1} \tag{1}$$

Redshift

$$z = \frac{\lambda - \lambda_0}{\lambda_0} \tag{2}$$

SN Ia magnitude

Dereddened

$$m_V^0 = M_V^0 + 5\log\left(\frac{d}{1\text{ Mpc}}\right) + 25 \qquad M_V^0 = -19.14 \tag{3}$$

Black hole accretion

$$L = \frac{dE}{dt} = \eta c^2 \frac{dm}{dt} \qquad \eta \approx 0.1 \tag{4}$$

Workshop problems

Remember! The workshop problems that you will do in groups in Recitation are a crucial part of the process of building up your command of the concepts important in ASTR 142 and subsequent courses. Do not, therefore, do your work on scratch paper and discard it. Better for each of you to keep your own account of each problem in some sort of bound notebook.

1. **(Group discussion)** A type Ia supernova happens when the mass of a white dwarf, accreting material from a close-by normal or giant stellar companion, approaches the Stoner-Anderson-Chandrasekhar mass, $M = 1.44M_\odot$.
    (a) If mass is added to a white dwarf, does its radius get larger, smaller, or stay the same? Is this different from what happens when mass is added to an ordinary nondegenerate star?

(b) If *heat* is suddenly added to a white dwarf — for example, along with the accreted mass — does its radius get larger, smaller, or stay the same? Is this different from what happens when heat is suddenly added to an ordinary nondegenerate star?

(c) In white dwarfs, electrons are degenerate, but nuclei behave as an ideal gas. What happens to the temperature and density of the gas of nuclei as the white dwarf accretes mass and (because of energy conservation) heat?

(d) Suppose that during this process, *additional* heat (besides that accreted) is generated within the star — for instance, by thermonuclear fusion of the nuclei. What happens to the temperature and density of the gas of nuclei? Is this different from what happens to the temperature and density when heat is created within an ordinary nondegenerate star?

(e) As a result: why does mass accretion by white dwarfs near the Chandrasekhar limit result in runaway thermonuclear deflagration and explosion, rather than stable, slow fusion power generation as in ordinary stars?

Learn your way around the sky, lesson 10. (A feature *exclusive* of ASTR 142 recitations.) You may find the lab's celestial globes and the program Stellarium useful in answering these questions about the celestial sphere and the constellations.

2. **Secant ZA.** If you want to measure stellar magnitudes accurately while the stars rise from low altitude to high and then set back to low altitude again, you must correct for atmospheric extinction. This correction will have to be made in the RR Lyrae observing project for this class. Fortunately, this is easier than correcting for interstellar extinction:

   Suppose that the atmosphere is an infinite plane-parallel which we can assume to be uniform in density. Suppose further that the flux we would measure from a star at the zenith is f_0 in the absence of the atmosphere. Then the flux with the atmosphere in place is $f = f_0 e^{-\tau_0}$, where τ_0 is the extinction of the atmosphere toward the zenith (expressed as an optical depth).

   (a) Suppose that the star has moved over to a zenith angle of ZA. If the thickness of the atmosphere is d, what is the length of the path through the atmosphere for the line of sight toward the star?

   (b) If the optical depth is proportional to path length through the atmosphere, what is the atmospheric optical depth toward the star with zenith angle ZA?

   (c) If the sky is clear and dry, the extinction must be fairly small, since we can see the stars well as they rise and set, not just when they are close to zenith. Make a first-order approximation and derive a simple formula for the flux f received from a star at zenith angle ZA in terms of the unextinguished flux f_0 and the minimum atmospheric optical depth τ_0.

   (d) Describe how you could, therefore, measure f_0 and τ_0, assuming these quantities to be constant throughout the night.

Intro to Python, lesson 10. (A feature *exclusive* of ASTR 142 recitations.)

3. In Problem Set 6, you measured the distances to two open clusters by main-sequence fitting. These clusters were chosen because each of them has at least one classical Cepheid variable as a member: there are nine in all.

Name	Cluster	$\log \Pi$ [days]	$\overline{m_V}$
DL Cas	NGC 129	0.9031	8.92
SZ Tau	NGC 1647	0.4980	6.76
V Cen	NGC 5662	0.7399	6.89
QZ Nor	NGC 6067	0.5783	8.84
V340 Nor	NGC 6067	1.0526	8.20
S Nor	NGC 6087	0.9892	6.31
CEb Cas	NGC 7790	0.6512	10.39
CF Cas	NGC 7790	0.6880	10.62
CEa Cas	NGC 7790	0.7111	10.30

(a) Consult with your classmates who measured the clusters you did not, collect all the distances and extinction values that you are missing, and compare your results to those by classmates who chose the same clusters as you. Then use these distances, visual extinctions, and the average apparent magnitudes given above to calculate the extinction-corrected average absolute V magnitudes of the nine classical Cepheids. (Since the calculations are repetitive, it is easiest to use either Excel or Python.)

(b) Plot the average absolute V magnitude as a function of $\log \Pi$. Then determine the parameters of a linear best fit line to the data. Compare your results with the Leavitt Law ($\overline{M_V} - \log \Pi$ relation) for classical Cepheids; comment on the agreement or lack thereof.

(c) If all has gone well, you will notice that three of the points — those from NGC 7790 — seem to differ somewhat from the trend of the rest. Look back at the main sequence fits to this cluster and speculate on the origin of this difference.