AY 5, Summer Session I, 2008: History of the Universe

Due in class, Wednesday, July 16th

Draft: July 3, 2008

Name:
Name(s) of collaborator(s):

Please feel free to ask for hints and/or clarification. Group work is strongly encouraged, but please identify who your collaborators are; each group member must submit the assignment copied in his/her own writing. Please put circles around final numerical answers. Homework must be legible, neat, and stapled. **Show your work**; the more work you show the more points you can accumulate even if the final answer is incorrect.

1. The temperature of the cosmic microwave background (CMB) today is $T_{CMB,now} = 2.73\,\mathrm{K}$. What is the cosmological redshift at which the temperature of the CMB was $T_{CMB,then} = 3000\,\mathrm{K}$? The redshift z is defined as: $z = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}}$,
where λ_{obs} is the observed (on Earth) wavelength of light and λ_{em} is the wavelength of light emitted by the object.

2. 'The Big Bang was like X H-bombs!' Determine X.

   (a) The critical density ρ_{crit} is the mass-energy density of the Universe necessary to prevent the "Big Crunch," where gravitational attraction would overcome the expansion of the Universe and cause everything to collapse into a singularity. Compute the critical density in kg/m^3:
   $\rho_{crit} = \frac{3H_0^2}{8\pi G}$,
   where H_0 is today's Hubble constant and G is the gravitational constant. State what values you use for H_0 and G, and *check you units!*

   (b) What is the volume (in m^3) contained within our observable Universe?

   (c) Assume that the mass-energy density of the Universe is equal to the critical density ρ_{crit}. What is the energy contained within our observable Universe? (1 Joule (J) = 1 kg m^2 s^{-2} = 6.242×10^{18} eV.)

   (d) To how many hydrogen bombs is this energy equivalent? Please cite the value of and the source for the energy released by one H-bomb.

   (e) Why can we *not* actually say how much energy was *released* by the Big Bang?

3. Measuring Hubble's Law (with great thanks to the University of Washington Astronomy Department).

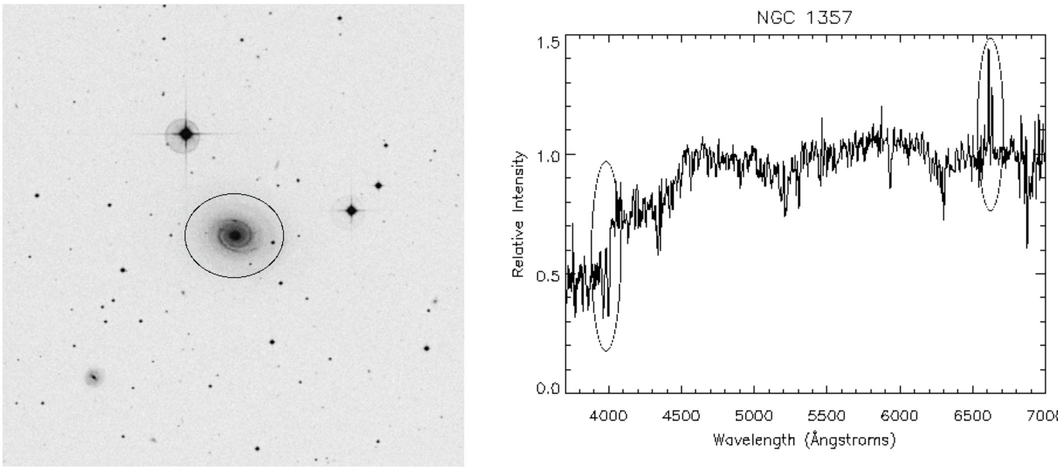

Figure 1: You will be presented with an image like the one shown on the left (the first galaxy NGC1357). In this *inverted* image (or negative), the light portions are dark and dark portions light. You will click on two places of the image online in order to measure the size of the galaxy in milliradians (mrad; 1 radian = $180/\pi$ degrees). I have drawn the bounds I would place on the galaxy (*left*). The full spectrum of NGC1357 is shown (*right*) with the absorption features calcium-H and K (Ca H and K) circled on the left and the emission feature hydrogen-alpha (Hα) circled on the right.

(a) Follow steps #1–14 on this online worksheet:
http://astro.wku.edu/astr106/HubbleLaw.html
The worksheet and graph paper are provided. The graph must be plotted *by hand*, and please label the points with the NGC numbers of the objects. Additional instructions are provided here.

(b) You will find that some of the galaxies are *not* symmetric; you could measure very different sizes, which would result in very different distances to the galaxy. **Question**: which size do you use and why? Think back to the galaxy inquiry; talk to a person who investigated"shape" if you aren't one.

(c) Though we know Hubble's constant already, **do not** fudge your answers to exactly match Hubble's constant. If it makes you feel any better, I measured $H_0 = 66.2 \pm 18.4$ km/s/Mpc.

(d) There are two lines on the worksheet (D) for the age of the Universe. The second line is for a question from another variant of the online worksheet (http://www.astro.washington.edu/labs/clearinghouse/labs/HubbleLawShort/lab.html): "The 'expansion' age of the universe is $t = 1/H_0$. This is a very simple model for the expansion of the Universe. A better model would account for the deceleration caused by gravity. Models like this predict the age of the universe to be $t = 2/(3H_0)$. Re-calculate the age using this relation."

(e) To be clear, here are the **questions**/prompts you must answer *in addition* to filling in the complete worksheet and making the plot.

- When the galaxy is not symmetric, with one direction larger than another, which size do you use? Why?

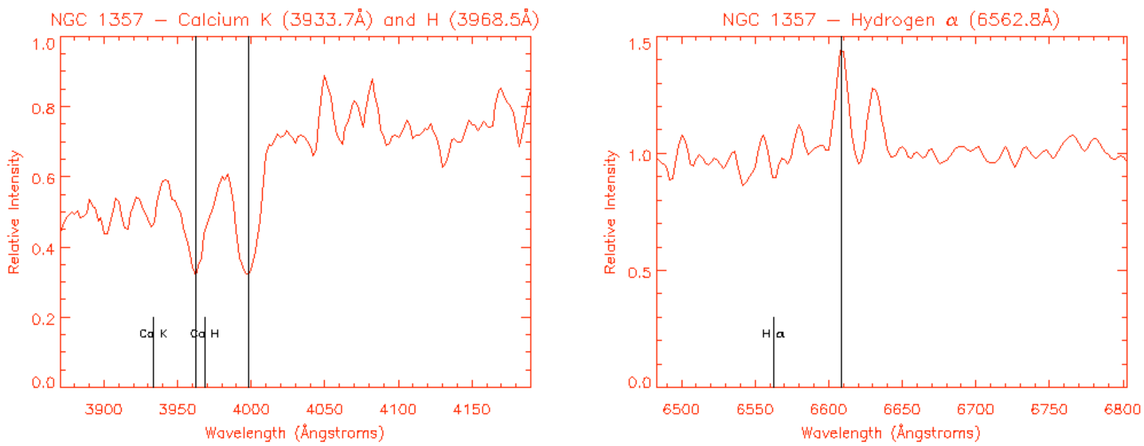

Figure 2: Next you will measure the redshift of the galaxy from its spectrum. You will click on the center of each of the absorption lines Ca H and K. I have shown where I would mark the center for both lines (*left*). The emission line Hα is located between two other emission lines (N[II]), and I have also shown where I would mark its center (*right*). Typically, the "center of the line" is where the relative intensity is at a minimum (for absorption lines) or at a maximum (for emission lines), but you'll find at least one case where this is not appropriate.

- From the online instruction #11, "clearly and concisely explain why this [best fit] line must pass through the origin (the 0,0 point)."
- The age of the Sun is 4.57 Gyr. Fill out line E on the worksheet.

(f) **Extra Credit**: Answer #15 (about oldest globular clusters) and #16 (dark energy). *Cite all sources consulted.*

Note: Courtesy of Astronomy Department, University of Washington.

4. Energetics of nucleosynthesis:

Particle	Mass		
	(kg)	(u)	(MeV/c^2)
Electron (e^-)	9.109×10^{-31}	5.486×10^{-4}	0.5109991
Proton (p^+)	1.672×10^{-27}	1.0073	938.2723
Neutron (n^0)	1.675×10^{-27}	1.0087	939.5656
Deuterium (D)	3.344×10^{-27}	2.0136	1875.6134
Helium-4 (^{4}He)	6.645×10^{-27}	4.0015	3727.3803

Constants and Conversion Factors:

$1 \text{ eV} = 1.602 \times 10^{-19}$ J

$1 \text{ u} = 931.5 \text{ MeV/c}^2$

Boltzmann constant $k = 1.381 \times 10^{-23}$ J/K $= 8.617 \times 10^{-5}$ eV/K

Planck's constant $h = 6.626 \times 10^{-34}$ J $\cdot$ s $= 4.136 \times 10^{-15}$ eV $\cdot$ s

Anti-particles have the same mass as their partner particles (*e.g.*, an anti-electron or *positron*, e^+, has a mass of 0.511 MeV/c^2).

(a) How much energy is there in one atom of ^{4}He?

(b) How much energy is released when two p^+ and two n^0 fuse to make one atom of ^{4}He?

(c) If all of the energy released above were emitted as a photon, what would its wavelength be? What part of the electromagnetic spectrum describes this wavelength (*e.g.*, visible)?

(d) What was the temperature of the Universe when p^+-p^- production could take place?

(e) What wavelength corresponds to this temperature? What part of the electromagnetic spectrum describes this wavelength?

Note: Conversion factors and particle mass data from *Modern Physics, 2nd Ed.* by Kenneth Krane.