Ph.D. Qualifying Examination
Department of Astronomy
June 15, 2010
8:30 a.m. — 1:30 p.m.

Name: ___________________________

Student Number: _________________

The exam sheets are inside this envelope and are not fastened together. When you are finished, please put the questions and your answer sheets back in the envelope in the correct order. **Be sure the student number given to you by the proctor is on every page of your answers.**

Astronomy Program students **MUST** do the **FIRST TWO** problems and **SIX** more problems from the remaining **EIGHT**.

Astrophysics Program students **MUST** do **ONE** of the **FIRST TWO** problems and **FOUR** more problems from the remaining **EIGHT**. Astrophysics students must finish by **12:00 p.m.** (3.5 hours).

M.A. students must do **ONE** of the **FIRST TWO** problems and **THREE** more problems from the remaining **EIGHT**. M.A. students must finish by **11:00 a.m.** (2.5 hours).

Physical Constants

$c = 3.00 \times 10^{10}$ cm/s
$G = 6.67 \times 10^{-8}$ dyn cm^2/g^2
$h = 6.63 \times 10^{-27}$ erg s
$k = 1.38 \times 10^{-16}$ erg/K
$m_p = 1.67 \times 10^{-24}$ g
$a = 7.56 \times 10^{-15}$ erg cm^{-3} K^{-4}
$e = 4.80 \times 10^{-10}$ esu
$m_e = 9.11 \times 10^{-28}$ g
$\sigma = 5.67 \times 10^{-5}$ erg cm^{-2} K^{-4} s^{-1}
$\sigma_T = 6.65 \times 10^{-25}$ cm^2
1 eV = 1.6×10^{-12} erg

$R_\odot = 6.96 \times 10^{10}$ cm
$M_\odot = 1.99 \times 10^{33}$ g
$L_\odot = 3.90 \times 10^{33}$ erg/s
A.U. = 1.50×10^{13} cm
1 year = 3.16×10^7 s
1 parsec = 3.09×10^{18} cm
$M_{V\odot} = 4.83$ mag
$B.C._\odot = -0.07$ mag
$(B-V)_\odot = 0.64$ mag
$T_{eff,\odot} = 5770$ K
$M_E = 5.97 \times 10^{27}$ g
$R_E = 6.38 \times 10^8$ cm

REQUIRED: Question 1: Equilibrium

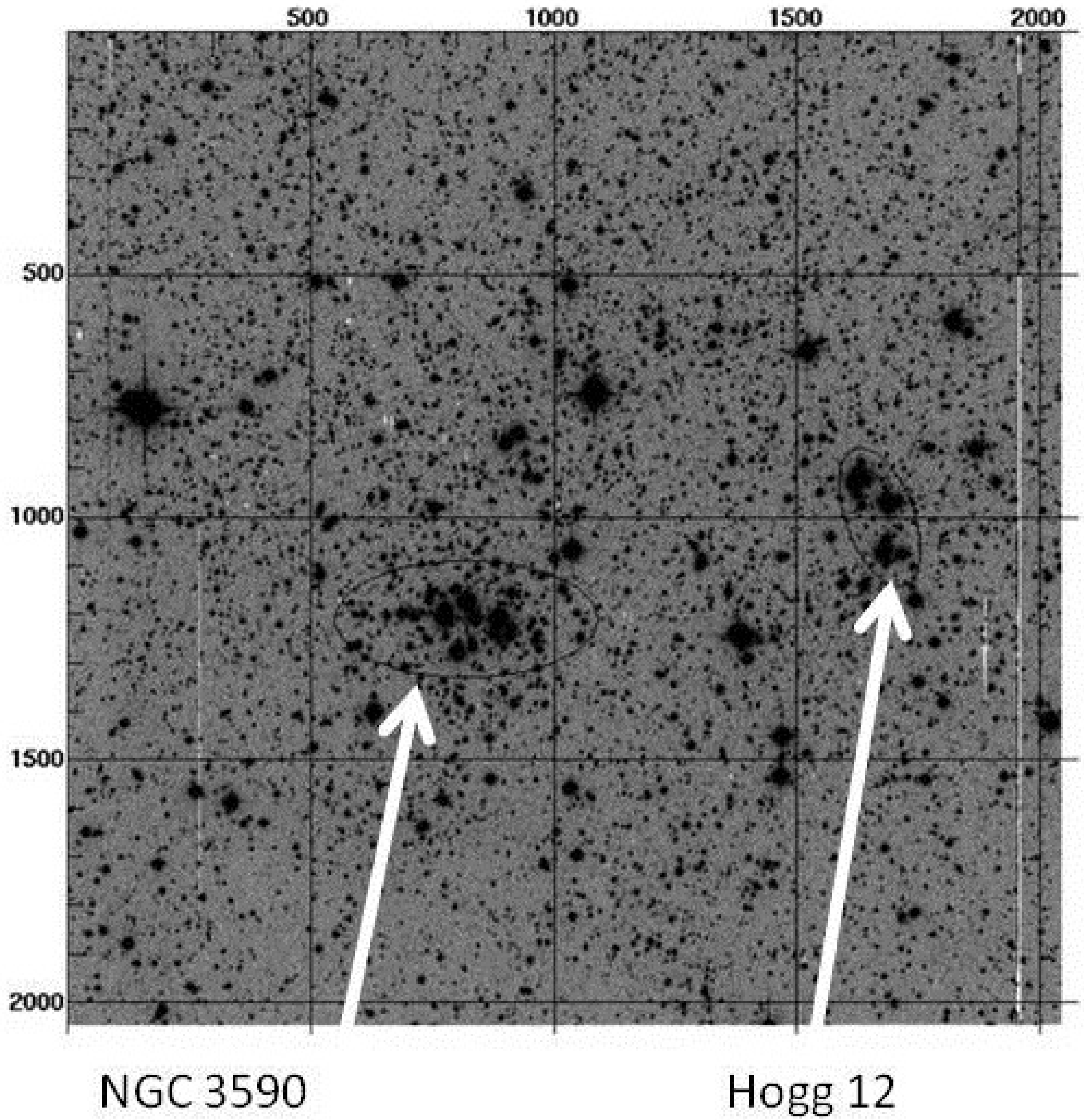
The concept of a physical process or processes being in “equilibrium” is central for understanding astrophysical systems. Choose any one major form of equilibrium that has applications to the theory of the interstellar medium or to the theory of stellar interiors and evolution and answer the following questions.

a) What is meant in general by the concept of “equilibrium”? (10 pts)

b) Name and explain the general type of equilibrium you wish to consider. Write down and derive (if possible) an equation that describes this type of equilibrium for some generic application. Be sure to explain any special assumptions or restrictions you are assuming. (60 pts)

c) Carefully describe a specific application (example) where the type of equilibrium you discuss in part (b) yields multiple solutions, not all of which are stable. (30 pts)

REQUIRED: Question 2: Star Clusters NGC 3590 and Hogg 12

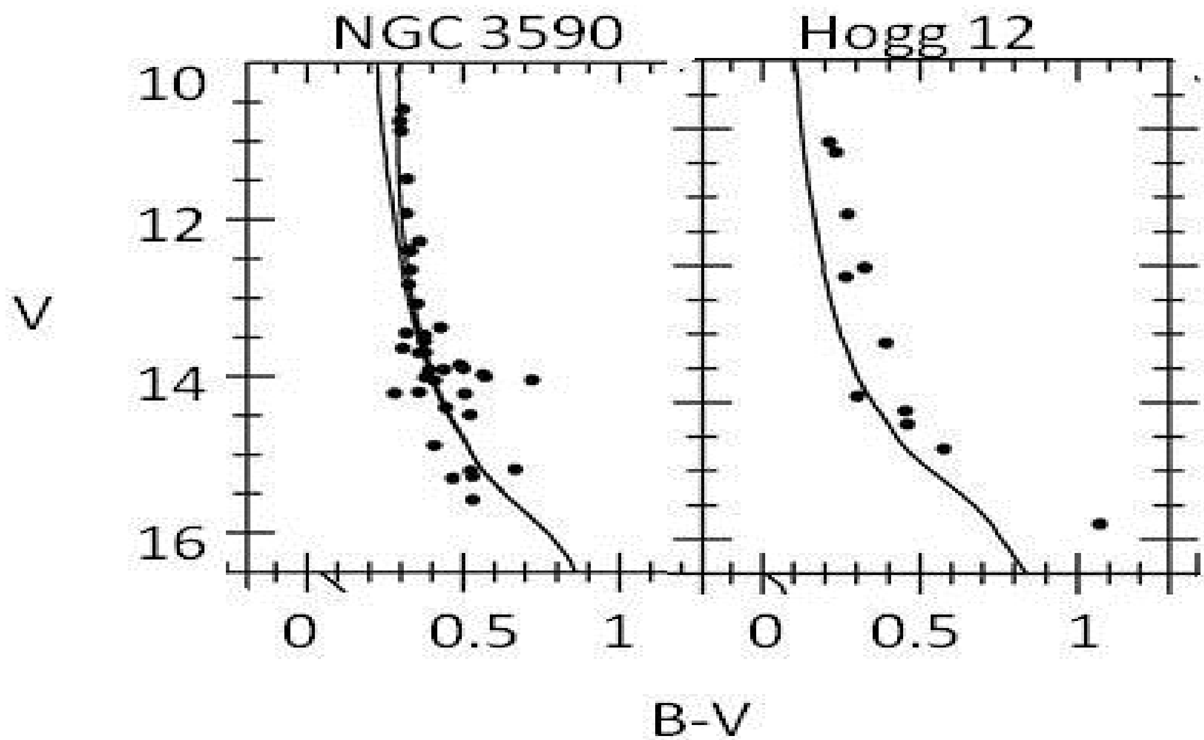


This question uses data from a recent paper by Piatti et al. 2010 (PASP, 122, 516).

The image above is a region of the sky observed with the 0.9-m telescope at CTIO. Coordinates are in pixels, with east to the left and north up. The plate scale is 0.4" pixel^{-1}. Two star clusters are circled, NGC 3590 and Hogg 12.

Cleaned color-magnitude diagrams for each cluster are shown in the figures below. For both clusters, a ZAMS is fit to the main sequence to determine the reddening, distance, and age. The CMD for NGC 3590 also shows an isochrone for log t =7.5 (30 Myr).

Question 2 (continued):



a) From the color magnitude diagrams, estimate the reddening E(B-V), the V band distance modulus, and the distance in kpc to each cluster. (40 pts)

b) Estimate the diameters and minimum physical separation of the two clusters in parsecs. Comment on the size of these clusters compared to typical young clusters. (20 pts)

c) Assuming that each cluster includes a mass of 10^3 solar masses and that they are gravitationally bound together, compute the orbital period of the clusters around their common center of mass. (20 pts)

d) Compare the orbital period and the age of the cluster and comment on the probable future of this double cluster system. (20 pts)

Question 3: Cosmological Principle

a) State the Cosmological Principle. (20 pts)

b) What evidence is there that the Cosmological Principle is valid within our Hubble sphere? (30 pts)

c) What is the Hubble sphere? Can we see beyond the Hubble sphere, or is the radius of the Hubble sphere equal to the radius of our observable universe? Explain. (30 pts)

d) Clearly the Cosmological Principle is not valid on solar system length scales. At what length scale does the Cosmological Principle appear to be valid? Explain. (20 pts)

Question 4: UBV Photometry

a) Sketch the filter bandpasses for the three filters of the Johnson UBV photometric system. Plot relative transmission vs. wavelength. Label each filter and give the central wavelength and width, in Angstroms. The vertical scaling is fairly unimportant, but try to get the wavelength locations and widths approximately correct. (20 pts)

b) Draw again the outline of the filters from part (a), but now sketch on top of them the approximate spectral energy distribution for: (i) an O star, (ii) an A star, and (iii) an M star. You don't need to sketch the detailed absorption features in the stellar spectra; just give the approximate shape of the flux distribution to show where flux of the star lies, relative to the locations of the UBV filters. Label your plot and supplement it with words / short descriptions as you see fit. (20 pts)

c) UBV photometry can be used in a variety of applications to derive important information about stars. Describe in as much detail as you can how UBV photometry is used to measure the following quantities: (i) stellar surface temperature; (ii) metal abundance (define/describe what is meant by UV excess); (iii) interstellar reddening (describe/define what is meant by color excess); (iv) ages of star clusters. The use of diagrams is encouraged. (25 pts)

d) Photometry (with UBV filters, or some other filter set) can be a powerful and efficient tool for gaining physical insight into stars and stellar populations. Furthermore, obtaining *accurate* photometry is important to many astronomical applications. Using what you know about astronomical magnitudes and error analysis, show that a 1% error on flux leads to a magnitude error of 0.01 magnitude. (15 pts)

e) Explain briefly the difference between absolute photometry and differential photometry. What sort of accuracy (in magnitudes) is achievable using each of these techniques? Which method leads to more accurate magnitude values, and why? (20 pts)

Question 5 : Galaxy Scaling Relations

There are a number of "scaling relations" which describe global trends in galaxy properties such as luminosity, mass, metallicity, and dominant stellar population. For the following questions, consider one of **either** (A) the Tully-Fisher relation or (B) the Faber-Jackson relation.

a) Provide a brief description (in words) of your choice of scaling relation and sketch the expected correlation between the galaxy properties. Be sure to label your axes clearly and with representative values. (25 pts)

b) Describe the observations needed to discover such trends. At minimum, your description should indicate the sample selection, wavelength, observation type, depth/sensitivity, and preferred telescope(s) for the project. (60 pts)

c) Describe potential observational biases of the data collected in (b) above. (15 pts)

Question 6: Accretion onto a White Dwarf Star

Consider cold pure hydrogen gas accreting steadily in spherical symmetric free-fall onto a white dwarf with a mass and radius of 0.4 $M_\odot$ and 0.01 $R_\odot$, respectively. Assume that a collisional shock forms above (but near) the surface of the white dwarf due to this accretion flow. Answer the following questions.

a) Assume the shock is a strong adiabatic shock. Explain what this means. Then use the free-fall velocity at the surface of the white dwarf to estimate the post-shock temperature of the infalling shocked gas, for the case where all the gas is characterized by a single temperature. Explain what you are doing. (35 pts)

b) If the total mass infall rate is 10^{-8} $M_\odot$ yr $^{-1}$, estimate the post-shock mass density of the gas. Again, assume the shock is strong and adiabatic. (30 pts)

c) Assume the post-shock region is optically thin and that the magnetic field of the white dwarf is negligible. Based on your answer to (a) and what you know about collisional cooling mechanisms in diffuse gas, what would be the dominant radiative cooling mechanism operating in the post-shock region? What would the spectrum look like and what part of the electromagnetic spectrum would it be in? [Hint: It *may* help if you convert kT from part (a) to electron volts.] (20 pts)

d) It is actually possible for the temperatures of the post-shock electrons and protons to be different. Explain what is meant by the “equipartition time” and how it relates to the time scales on which electrons and protons separately relax to a Maxwell Boltzmann distribution. (15 pts)

Question 7: Galaxy Structure

The equations for the de Vaucouleur ($r^{1/4}$) and exponential surface brightness distributions that describe the light profiles exhibited by galaxies are:

$$I_b(r) = I_e\, 10^{(-3.33[(r/r_e)^{1/4}-1])},$$

$$I_d(r) = I_o \exp(-r/r_d),$$

where I_e is the surface brightness at the effective radius r_e, I_o is the central surface brightness of the exponential disk, and r_d is the disk scale length. Note that for this problem we are associating the $r^{1/4}$ profile with a galactic bulge (subscript b) and the exponential profile with the disk (subscript d).

a) Describe or define, in words, the meanings of I_e, r_e, I_o, and r_d. (20 pts)

b) Derive the corresponding formulae for the surface brightness in magnitude units for both profiles ($\mu_b(r)$ and $\mu_d(r)$). Be sure to define all relevant terms. In particular, you will need to express the profiles in terms of μ_e, the surface brightness in magnitude units at the effective radius r_e, and μ_o, the central surface brightness of the exponential disk in magnitude units. (40 pts)

c) Let μ_e = 19.50 magnitudes/sq. arcsec, μ_o = 17.00 magnitudes/sq. arcsec, and $r_d = 0.75r_e$. Compute and tabulate both $\mu_b(r)$ and $\mu_d(r)$ at r = 0, r_e, $2r_e$, $3r_e$, and $4r_e$. Sketch a graph of both together on the same plot, with the correct relative scale. Based on your calculations/plot, which profile will dominate the surface brightness of the galaxy at large r (say $r = 10r_e$)? Justify your answer. (40 pts)

Question 8: 51 Peg and NLTT 54007

This question uses data from a recent paper by Mamajek 2010 (arXiv: 1004.4700).

Greaves (2006, arXiv: 1003.3032) suggested that three faint red stars with proper motions similar to 51 Peg's may be co-moving with that famous planet host. While proper motion data are available for the putative co-movers, parallax data are not, so the distances to these faint stars are unknown.

Answer the following questions about 51 Peg and the co-mover NLTT 54007 using the data below.

a) Given an angular separation between NLTT 54007 and 51 Peg of 8.4 degrees, estimate the physical separation between the stars in AU if they are co-distant. (10 pts)

b) Comment on whether 51 Peg and NLTT 54007 (if co-distant) are likely to be gravitationally bound. (20 pts)

c) Develop a plausible, quantitative argument as to whether Greaves' hypothesis is reasonable for the star NLTT 54007. (70 pts)

Star Data	51 Peg	NLTT 54007
Spectral Type	G2.5IV or G4-5V	"late type"
V	5.49	14.91
K	3.91	10.69
Parallax	64 mas	unknown
Distance	15.6 pc	unknown

Table of Spectral Types for Question 8

Sp. Type	Mv	(B-V)	(V-K)	Sp. Type	Mv	(B-V)	(V-K)
B0.0	-4.0	-0.30	-0.97	G2.0	4.7	0.63	1.26
B6.0	-0.9	-0.14	-0.64	G5.0	5.1	0.68	1.32
A0.0	0.6	-0.01	-0.17	G8.0	5.5	0.74	1.47
A4.0	1.7	0.12	0.08	K0.0	5.9	0.81	1.74
A8.0	2.4	0.27	0.36	K2.0	6.4	0.92	2.06
F0.0	2.7	0.32	0.52	K5.0	7.4	1.15	2.66
F5.0	3.6	0.45	0.89	K7.0	8.1	1.33	3.01
F8.0	4.0	0.53	1.03	M0.0	8.8	1.37	3.29
G0.0	4.4	0.60	1.14	M3.0	10.4	1.50	3.83
G2.0	4.7	0.63	1.26	M4.0	11.3	1.52	3.98

Question 9: Stellar Populations over time

a) Explain the age-metallicity degeneracy for the optical broadband colors of galaxies. Your answer should include a detailed discussion of the direction and magnitude by which colors are affected by changes in metallicity and a clear description of the physical processes that cause these changes in color. (40 pts)

b) A simple flat-universe cosmological model (no cosmological constant) yields the following equation for the age of the universe:

$$\frac{t(z)}{t_H} = \frac{2}{3}\frac{1}{(1+z)^{3/2}}$$

Adopting this simplified cosmology, what is the maximum age of the dominant stellar population of a galaxy at a redshift of 3.0? (10 pts)

c) If all of the stars in a z=3.0 galaxy formed in a single burst at t=0, approximately what spectral class of stars are now (at z=3.0) evolving off the main sequence? What mass are these stars? Be sure to indicate clearly any assumptions you may need to make to derive the stellar mass and spectral classification. (20 pts)

d) Using the concept of simple stellar population models, describe an observational program to distinguish between a galaxy with an "old" stellar population and one dominated by a young stellar population at a redshift of 3.0. Cite specific spectral features that can distinguish these populations and the expected (redshifted) wavelengths. Finally, either identify, or describe the process you would use to identify, appropriate telescopes/instruments/facilities to carry out your observations that are designed to distinguish the dominant stellar populations for z=3.0 galaxies. (30 pts)

Question 10: Dark Matter

Observations of the Universe on various size scales seem to suggest the presence of "dark matter." Its existence is inferred by the gravitational influence it appears to exert on luminous matter.

a) Describe **TWO** ways in which the existence of dark matter has been suggested by observations. Clearly and thoroughly explain and illustrate the type of observation involved and the characteristic of the observed quantity that implies that dark matter is present. **Include equations and figures in your explanation wherever possible.** (40 pts each)

b) Describe **ONE** type of dark matter (i.e., a so-called “dark matter candidate”) and discuss what its properties are, how it might be detected, and what are its advantages and disadvantages as a proposed explanation for some or all of the dark matter in the Universe. (20 pts)