Galaxies - ASTR421 Final
Fall 2014
Dec 20, 2014
10:30 – 12:30 PM
Instructions- 115 total points 30 in sec A, 60 in sec B and 25 in sec C.

The exam consists of sections A, B and C. Section A contains short-answer questions. You should attempt all questions in section A. Section B has 6 longer problems. You may attempt no more than 3 questions from section B for a maximum total of 60 points. Section C has 2 math oriented problems 25 pts each, please answer only 1. Using the mark allocation as guidance, once you have given a sufficient answer, move on quickly.
You may use a calculator.
Do not turn over this question sheet until you have been instructed to begin.
This is not a complete list… there maybe a question on a formula that is not here, but which you should know

Equations Formula etc
Faber-Jackson relation $L\sim\sigma^4$
Eddington ratio $L=1.38\times10^{38}$ergs/sec $M_\odot$
$t^2_{ff}=1/G\rho<(R/c_s)^2=10^8 n^{-1/2}_H$ yrs free fall time
Jeans mass $M_J= 4/3\pi\lambda^3_J\rho=4/3\pi c^3_s\rho^{-1/2}$
Jeans length $\lambda_J=sqrt(\pi c_s^2/G\rho)$
For typical values
$M_{J\ SOLAR\ UNITS}=(T/10k)^{3/2}(n_H/10^5 cm^{-3})^{-1/2}$
In units of surface mass density $\lambda_J=c_s^2/G\Sigma$
c_s= sound speed=$sqrt(dP/d\rho)=sqrt(k_BT/\mu m_H)$ for hydrogen $(c_s=0.3km/sec(T/10k)^{1/2}$
'non-trivial' Jeans eq for a spherical system is
$(1/\rho)d(\rho(v^2)/dr)+2\beta(r)v^2/r=-d\phi/dr$
$\beta(r)$ describes the anisotropy of the orbit
re-write this as $M(R)=-(<v_r^2>r/G)[dln/dlnr+dlnv_r^2/dlnr+2\beta]$

$M(R)=(V^2r/G)+(r\sigma^2_r/G)[-dln\rho/dlnr-dln\sigma^2_r/dlnr-(1-\sigma^2_\theta/\sigma_r^2)-(1-\sigma^2_\phi/\sigma^2_r)]$
where V is the rotation velocity and (σ_r) the radial and σ_θ, σ_ϕ the angular components of the velocity dispersion
1keV=1.17×10^7k
Mass of sun=2×10^{33} gms
Poisson's equation $\nabla^2\phi = 4\pi\rho G$
equation of hydrostatic equilibrium $\nabla\cdot(\mathbf{1/\rho\nabla P)=-\nabla^2\phi =-4\pi G\rho}$
$M(r)=[kT_g(r)/\mu Gm_p)]$ **r** (dlnT/dr+dlnρ_g/dr); mass of a spherically symmetric system in hydrostatic equilibrium; T_g is temperature, ρ_g is gas density
Equations: ϕ is the potential , Σ is the surface density
For motion perpendicular to the disk $\sigma_h^2\sim2\pi G\Sigma_0 z_0$
Scale heights/lengths for spirals $\rho(r)=\rho(0)exp(-R/R_0)\ exp(-z/z_0)$ where R_0 is the radial scale length and z_0 is the scale height of the stars perpendicular to the disk

Escape velocity $v^2_{escape}=-2\phi$; $v^2_{escape}=2v^2_{circular}$

Virial theorem " : $2\langle T\rangle+\langle U\rangle = 0$; T= Kinetic energy; U= potential energy

$U=m\phi(r)$

Singular isothermal sphere $\phi(r)=4\pi\rho(r)Ga^2\ln(r/a)$ where a is the radius of the sphere and $\rho(r)=\rho(0)(r/a)^{-2}$

$t_{relax}/t_{cross}=N/6\ln(N/2)$ where N is the number of stars in the system

Sunyaev-Zeldovich effect:amplitude $\delta T_{SZ}/T_{CMB}\sim\int n_e T_e\, dl$; independent of redshift

$L \sim I(0)\, R^2$

For gravitational lensing $\alpha\sim 4GM/bc^2=2R_s/b$; where α is the angle of deflection, b is the impact parameter and Rx is the Schwarschild radius ($2GM/c^2$)

Section A
Short questions (30pts) ;most are 3 points, 2 are 4 pts (# 4 and #6) and 2 are 2pts (#1 and #7)
1) What is the form of the galaxy luminosity function, what are 2 of the variables that describe it (2pts)
2) Give one difference between type I and type II Seyfert galaxies (Type I or Type II AGN)
3) Describe 2 ways to find AGN and how one distinguishes them from a 'normal' galaxy.
4) What is the Sunyaev-Zeldovich effect and what does it depend on (4pts)
5) What process is responsible for the x-ray emission in clusters of galaxies?
6) What is the Kennicutt-Schmidt law concerning star formation?-what 2 variables does it relate (4pts)
7) What population of stars dominates the light in massive elliptical galaxies? (2pts)
8) Give one example of feedback (relevant to galaxy formation).
9) Give (or draw) a summary of the cosmic star formation rate since z~3.
10) Describe an observational relation between the central supermassive black hole and its host galaxy.

Section B 60 points
Answer ONLY 3 of the following –maximum of 60 points to this part

Question 1 (20pts- 4pts per section) Multi-wavelength view of galaxies
In the multi-wavelength view of galaxies each wavelength (e.g. radio, IR, optical, UV, x-ray, gamma-ray) conveys different information. Please describe in 1-2 sentences what we can learn about galaxy properties (e.g star formation rate, mass, existence of an AGN, age etc etc) from
a) radio b) IR c) optical d) UV e) x-ray/gamma-ray observations. Remember that sometimes a given wavelength band carries multiple pieces of information. It is <u>not</u> necessary that you be complete about the information that a given band carries, only that you correctly identify at least 1 piece of information in each band and describe it succinctly.

Question 2 Local Group (20 pts)
a) Describe the contents of the local group-the types of galaxies and 3 properties of the most massive galaxies. (7pts)
b) What is the eventual fate of M31 and the MW? (3pts)
c) Why do we think the dynamical properties of the local group require dark matter (3pts)
d) How can we use observations of local group galaxies to constrain their star formation history… what about the local group makes this possible?? (7pts)

Question 3. (20 points) Supermassive black holes and nuclear activity in galaxies.
(a) (6 points) Describe the observational evidence for a supermassive black hole at the center of most massive galaxies and sketch the theoretical principles and assumptions that are used to derive the mass of the putative black holes.
(b) (6 points) Why do we need supermassive black holes to explain the properties of active galactic nuclei? You may want to use the concept of the Eddington luminosity as part of your answer.
(c) (7 points) Briefly describe the unified model of AGN. Give 2 properties of each type (I and II) of AGN and how this model can account for these differences between the 2 types.

Question 4 20 pts Galaxy formation 6pts each +1 extra for all correct

a) Describe hiearchical galaxy formation in 2-3 sentences
b) Give one problem with galaxy formation models that just have gravity and no other processes.
c) Briefly describe a possible theoretical scenario for how feedback 'solves' this problem.

Question 5 Elliptical galaxies (20 pts)

(a) (7 points) What is the fundamental plane of elliptical galaxies? Describe 3 of the variables and how they are connected.
(b) (6 points) Describe how you would determine the age of an elliptical galaxy: describe the observational quantities you would need and the theoretical tools you would use. Make sure to mention the assumptions you are making .
(c) (7 points) In the one picture of galaxy formation, elliptical galaxies form early through rapid collapse and mergers. Describe recent observational evidence which measures how much mass ellipticals have gained since z~1 and in what form.

Question 7 (20 pts) Mass in Galaxies

a). Describe the distribution of the 4 components of the mass (supermassive black hole, stars, gas and dark matter) vs radius in either spiral or elliptical galaxies (6 pts)
b) In spiral galaxies describe one method to determine the mass distribution. Write down the relevant observables and estimates of their values (7pts)
c). In elliptical galaxies describe one method to determine the mass distribution. Write down the relevant observables and estimates of their values (7pts)

Section C Answer 1 of 2 25 total points

Question 8 Clusters of galaxies (25 pts)

a) Derive the mass of a cluster of galaxies using the assumption of hydrostatic equilibrium. Assume a temperature of 5 keV, a scale length of 1Mpc (3.08×10^{24}cm) and that the gas is isothermal. Do you get a reasonable number?- (be quantitative). (15 pts)
b) What dynamical observables does one have to determine the mass of clusters of galaxies using the galaxies? What fundamental uncertainties in the mass of the cluster are there from using measurements of only motions of the galaxies, using the relevant equation Please be quantitative. (5pts)
c) Give one technique that can derive the mass of clusters independent of the assumptions of equilibrium and the measurements needed. (5)

Question 9 25 pts Mass of Black Holes

Estimating the mass of black holes from stellar velocities or reverberation analysis.
Let =1000km/sec be the width of a broad line in an AGN (the width can represent a circular velocity); let the time delay, δ, between the continuum and when the line responds be 10 days. Assume $R=c\delta t$ is the size of the emitting region and the viral theorem holds. What is the mass of the black hole??