Astrophysics Questions (DRAFT)

February 14, 2001

1. How did the Greeks determine the size of the Earth and the distance to the Moon?

2. How did Copernicus determine the distance to Jupiter (in units of the AU)?

3. What kind of objects would you guess the following were?

HD 128 220	Abell 426	QSO 1015 +277
α Crucis	3C 234	W51
Mk 509	NGC 2808	M3
PSR 0950+08	BD +61^o 1211	1983 TB

4. Briefly describe the following famous astronomical objects:

The Crab	M87	Cyg X-1	Boötes void
3C 273	SS 433	Orion	Virgo
Cyg A	LMC	M31	h and χ Persei

5. How far away are the following objects: the sun, the Hyades, the Orion nebula, M13, M31, the Virgo Cluster, the Coma Cluster, 3C 273? How large and massive are they?

6. What are the brightest extra-solar system sources in the sky at the following wavelengths: $10\,\mathrm{cm}$, $10^{-1}\,\mathrm{cm}$, $10^{-3}\,\mathrm{cm}$, $10^{-5}\,\mathrm{cm}$, $10^{-7}\,\mathrm{cm}$, $10^{-9}\,\mathrm{cm}$? Is the source distribution isotropic at any of these wavelengths?

7. What are the strongest spectral lines seen in each of the following: the integrated starlight from a typical galaxy; a quasar; a $100\,\mathrm{km\,s^{-1}}$ interstellar shock wave; a giant molecular cloud?

8. Is atmospheric "seeing" better at a wavelength of $1\,\mu\mathrm{m}$, $10\,\mu\mathrm{m}$ or $100\,\mathrm{m}$? Why?

9. Briefly describe the following kinds of astronomical instruments and their purpose: Schmidt camera, echelle spectrograph, CCD, III aJ emulsion, proportional counter, H maser, aperature synthesis telescope, laser interferometer, tank of cleaning fluid.

10. Briefly describe the main objectives and capabilities of the following astronomical satellites: Voyager, Einstein, IRAS, HST, COBE, Compton GRO, Rossi XTE, AXAF.

11. Explain how a radio interferometer manages to produce sub-arcsecond images when none of the constituent dishes has an angular resolution of better than 1 arcminute.

12. How does an X-ray telescope image? Why is it necessary to have the reflection take place at grazing angles of incidence?

13. How is the astronomical unit measured in modern astronomy, and with what accuracy?

14. Describe the difference between stellar parallax and stellar aberration. Why does the latter not interfere with measurements of the former when it results in a much larger angular displacement?

15. What is the moving cluster method of determining distances, and how does it work?

16. What is spectroscopic parallax? How would you use this method to determine the distance to a globular cluster?

17. What are "apparent magnitude," "absolute magnitude," and "bolometric magnitude"? What are U, B, and V colors?

18. What is "brightness temperature"? What are typical brightness temperatures of (a) an H II region at 5 GHz; (b) a radio pulsar at 1 GHz; (c) a compact extragalactic radio source at 5 GHz; (d) the sun at 100 MHz; (e) a Citizen's Band radio?

19. Explain the steps you would take to show that both the orbital period and the total energy of a Keplerian orbit depend only on the semimajor axis and not on the orbital eccentricity.

20. What is the "mass function" of a binary star system and how is it determined?

21. Describe the physics involved in the Earth–Moon interaction whereby the Earth's rotation rate is slowing and the orbital separation is increasing.

22. Describe qualitatively the standard model for the formation of the solar system, and discuss the observational evidence supporting this model.

23. Describe Oort's theory of the origin of comets.

24. What is the 3:2 resonance involving Neptune and Pluto? And that involving the day and year on Mercury?

25. Calculate the approximate distance to the heliopause. Does the local interstellar medium begin at this boundary? Explain

26. Discuss the observational status of searches for planets outside our own solar system.

27. What is the MHD approximation? What are the MHD equations for continuity, momentum conservation, and energy conservation?

28. What are the three types of MHD waves in a magnetized plasma? Are magnetic fields important in the propagation of waves in the interstellar medium? In a star?

29. What is meant by "temperature"? What is the "pressure tensor" for a plasma? What is meant by the term "temperature anisotropy"?

30. What is the physical significance of the plasma frequency? What is the dispersion relation for electromagnetic waves in a plasma?

31. What is "Faraday rotation"? How is it used in astronomy?

32. What is the "ideal Ohm's law" for a plasma? What does "frozen-in" mean?

33. Describe the spectral classification scheme for stars: O,B,A,F,G,K,M. What are the characteristic effective temperatures of stars of each class? What are the characteristic luminosities for main-sequence stars of each class?

34. From a physics perspective, how does the quantity (B-V) help to determine a star's effective (surface) temperature?

35. Two stars are observed to have the same color and brightness. One of them is a giant at a greater distance than the other which is a main-sequence star. How could these be distinguished from spectroscopic measurements?

36. If you are given an HR diagram, how would you go about constructing lines of constant stellar radius on the diagram?

37. Sketch the HR diagram for a typical globular cluster and open cluster. Identify the various observed populations and interpret them on the basis of stellar evolution theory.

38. What is the Saha equation and how is it used in stellar structure calculations?

39. Explain, from a statistical mechanics point of view, why the Balmer lines are most prominent in A stars with an effective temperature of $\sim 10,000\,\mathrm{K}$.

40. Write down the four basic equations of stellar structure.

41. Make a dimensional analysis of the equation of hydrostatic equilibrium using a polytropic equation of state to find a general mass-radius relation for spherically symmetric, self-gravitating bodies. For which two polytropic indices is the configuration unstable?

42. Make a dimensional analysis of the equation of radiative diffusion in stars to show that the luminosity of a star scales as its mass cubed, if the opacity is taken to be a constant.

43. Write down the basic equations of the p–p chain that provides the Sun's nuclear power.

44. Describe the internal structure of the sun. How old is the sun?

45. How does the CNO cycle work?

46. Describe the prominent neutrino producing reactions in the sun, and the experiments that are designed to detect them. What is the solar neutrino problem? What are neutrino oscillations and how might they solve the problem?

47. What is the Schwarzschild criterion for convective instability? What is the entropy distribution in a convective envelope?

48. Derive the equation for the radiative energy flux in a stellar envelope and show how the Rosseland mean opacity is introduced.

49. What is meant by "free-free" absorption? How is this different from electron scattering?

50. What is the dominant absorption mechanism in the Sun's atmosphere that leads to the production of the Fraunhofer spectrum?

51. Describe the various evolutionary phases of a low-mass star ($\sim 1\,M_\odot$), and those of a high-mass star (e.g., $12\,M_\odot$). Show the corresponding evolutionary tracks on an HR diagram.

52. Use the known luminosity and mass of the Sun to estimate its nuclear lifetime.

53. Describe the Weber-Davis model for stellar spin down (angular momemtum loss through the effects of magnetic torques). Why are magnetic torques an effective way to shed angular momentum, for a given rate of mass loss?

54. Describe the types of stellar evolution that lead to type Ia, type Ib, and type II supernovae. What are the observational differences among these?

55. How much energy is typically released in a type II supernova? What fractions of that energy are in the form of neutrinos, visible light, gas kinetic energy, and gravitational radiation?

56. What was the approximate flux in neutrinos on Earth due to SN 1987A? If nineteen SN 1987A neutrinos were detected by manmade experiments, what was the total cross section of all those experiments to $\sim 10\,\mathrm{MeV}$ neutrinos?

57. It is believed that most stars leave a collapsed remnant at the end of their evolution. What stars leave (i) white dwarfs, (ii) neutron stars, or (iii) black holes?

58. What is a white dwarf star? Why is the radius of a white dwarf a decreasing function of its mass? What is the basic physics that leads to the upper limit on the mass of a white dwarf (i.e., the Chandrasekhar limit)?

59. What is a "cataclysmic variable"? What are nova explosions, and what is the basic physics underlying these events?

60. What is a neutron star? What assumptions and inputs go into determining the upper mass limit for a neutron star? What is the approximate ratio of neutrons to protons (and electrons) in the interior of a neutron star?

61. A double neutron star system in M31 merges. What is the approximate energy emitted in gravitational radiation and what is the corresponding amplitude (strain) h observed here on Earth? Would LIGO be able to detect it?

62. Approximately how many binary systems in the Galaxy are thought to contain a black hole? What is the evidence for this?

63. How does the orbital frequency of the innermost stable orbit around a black hole scale with its mass?

64. What is Lense-Thirring precession, how might we observe it, and what evidence is there that we have?

65. What is the gravitational redshift from the surface of a neutron star?

66. Explain the basic physics underlying type I X-ray bursts on neutron stars. Explain why very little mass is ejected during such a burst. Compare this phenomenon with recurrent novae.

67. Explain why you might expect most of the emission of an accreting neutron star to be in the form of X-rays. How does an X-ray pulsar pulse?

68. How much rotational kinetic energy can be stored in a neutron star? How does this help resolve the "energy budget" for the Crab nebula?

69. How are the magnetic fields of neutron stars estimated in (i) X-ray binaries and (ii) radio pulsars.

70. What is the Eddington limit and how is it manifested in (i) ordinary stars and (ii) accreting X-ray sources?

71. How would you calculate the magnetospheric radius of an accreting neutron star?
72. What is the significance of the Hulse-Taylor binary radio pulsar to physics?
73. What is a “millisecond pulsar”? What is the shortest spin period known for such an object? Estimate a lower bound to its mean density.
74. What is the “Shapiro time delay”?
75. Derive a plausible relation between the luminosity of an X-ray pulsar and its spin-up rate.
76. What are the “anomalous” X-ray pulsars, and why are they anomalous?
77. What are “magnetars”, and what evidence do we have that they exist?
78. If the kHz QPO seen in (some) low-mass X-ray binaries in fact reflect the Keplerian frequency at the inner edge of the accretion disk, then how can this be used to constrain the neutron star mass-radius relation?
79. How would you explain the detection in a globular cluster of an isolated radio pulsar whose spin period appears to be getting shorter with time?
80. Why are more X-ray binaries and radio pulsars found in globular clusters (per unit mass) than in other parts of the Galaxy?
81. What is the Roche potential in a binary system? Describe carefully the assumptions that go into deriving it. Define the Roche limit.
82. What is the Shakura-Sunyaev model (alpha-disk model) for accretion disks? What are the assumptions that go into its derivation?
83. Show from a simple dimensional analysis how the effective temperature of an accretion disk depends on accretion rate and distance from the central object.
84. What evidence is there for “superluminal” jets in binary systems containing black holes, and how does one explain the superluminal motion?
85. Describe a scenario whereby a neutron star can be formed in a binary system and have the system remain bound.
86. What is a Cepheid variable? Explain the underlying stellar physics involved. What role do Cepheids play as distance indicators?
87. What are RR Lyrae stars, and how to they differ from Cepheids?
88. What is a P Cygni line profile, and what does it signify?
89. What are HH objects? T Tauri stars? Bipolar flows? OH masers? Where are they all found?

90. Explain how interstellar dust grains can result in linear polarization of transmitted starlight. How is the direction of polarization related to the average direction of the interstellar magnetic field (as projected on the plane of the sky)?

91. If a typical interstellar dust grain is 0.2 micron in size, and starlight suffers an extinction of 1 magnitude per kpc, estimate the space density of dust grains.

92. Why is the gas in the interstellar medium largely transparent at visible wavelengths?

93. Discuss the various "phases" of the gas in the interstellar medium. Are these phases in pressure equilibrium?

94. Sketch a typical cooling function $\Lambda(T)$ for diffuse interstellar gas and identify its prominent features. Overplot a hypothetical heating curve and show how to identify points of thermal equilibrium and their stability.

95. Explain the physics of 21 cm radio emission from neutral hydrogen atoms.

96. What are the Einstein A and B coefficients for a spectral line, and what are the relationships among them?

97. Explain quantitatively why stimulated emission is important and spontaneous emission is usually ignored in the radio domain, whereas the reverse is true in the optical domain. Given a thermal spectrum at some temperature T, at what frequency would the two emission rates be equal?

98. Name five molecules found in the interstellar medium and comment on how they are detected.

99. What is an H II region? Estimate how the Strömgren radius scales with the luminosity of the ionizing source and with the ambient density.

100. What is a planetary nebula? What is our current understanding of the formation of planetary nebulae? What effects limit the lifetime of a planetary nebula?

101. Write down the Jeans equation for a disturbance propagating in a self-gravitating medium. From this show how to find the critical wavenumber for propagating modes. What is the Jeans mass?

102. Write down the fluid equations for conservation of mass and momentum that would describe a spherically symmetric, expanding supernova remnant. How would you derive the "jump conditions" for a strong adiabatic shock?

103. Describe the various stages of evolution of a supernova remnant. What are the relevant physical processes during each phase? Explain why in the Sedov-Taylor phase of a supernova remnant, the radius expands as $t^{2/5}$.

104. X-ray emission from a nearby supernova remnant is observed to peak at $\sim 0.5\,\mathrm{keV}$. Estimate the velocity with which the blast wave is propagating through the interstellar medium.

105. Explain what bremsstrahlung radiation is. From what kinds of astrophysical objects is such radiation observed?

106. Make a simple classical argument to show that the spectrum of radiation from monoenergetic electrons with a speed v impinging on ions at an impact parameter b would be roughly flat up to a frequency $\sim v/b$.

107. What is synchrotron radiation? From what kinds of astrophysical objects is such radiation observed?

108. What is the spectrum of radiation from a single ultra-relativistic electron in a magnetic field? What is the spectrum of radiation from an ensemble of such electrons with energy spectrum $\propto E^{-\gamma}$ for $E_1 < E < E_2$?

109. Make a sketch of the Galaxy to scale (top and side views), and indicate its various features and properties.

110. What are stellar populations? Give several examples of Pop. I and Pop. II objects in our Galaxy.

111. How many globular clusters does our Galaxy contain? How are they distributed in space? What fraction of the total mass of the Galaxy do they contain?

112. How are gas and dust distributed in our Galaxy? Why are they distributed differently from the stars?

113. Sketch the rotation curve of our Galaxy, with approximate scales on the axes. How can information about the rotation curve be determined from 21 cm radio observations?

114. What evidence do galaxy rotation curves provide for dark matter? How are galaxy rotation curves measured?

115. What are the Oort A and B coefficients and what basic information about the Galaxy can be determined from them?

116. What is the Oort limit and how is it determined? How much dark matter in the solar neighborhood is inferred from the Oort limit?

117. Derive an equation whose solution gives the vertical density profile for an isothermal, self-gravitating (galactic) disk.

118. Why do some galaxies have prominent spiral structure and others do not? Briefly describe the density wave theory of spiral structure.

119. What is the density profile of a self-gravitating isothermal gas sphere? What is the corresponding phase space distribution function?

120. What is the radial Jeans equation in spherical coordinates for a spherically symmetric system, keeping terms associated with an anisotropic velocity dispersion tensor? How is it used to measure masses for galaxies and clusters?

121. Define the following simple "laws" and "profiles" for stellar systems: Hubble, King, de Vaucouleurs, exponential.

122. What is the "fundamental plane" for elliptical galaxies?

123. What is the difference between a "tube" orbit and a "box" orbit and how are the latter helpful in building galaxies?

124. What is violent relaxation? How does the phase space distribution function it produces differ from that of an isothermal gas?

125. A globular cluster at a distance of 10 kpc, containing 10^6 stars, subtends an angle of 1/3 arc minute. Estimate the velocity dispersion among its stars.

126. What is two-body relaxation? For a self-gravitating cluster of N objects each of mass m, with velocity dispersion σ, what is the relaxation time? How long does it take a massive object ($M \gg m$) to sink to the bottom of a cluster potential well?

127. What is meant by the "gravothermal collapse" of a globular cluster, and what can save the cluster from complete collapse?

128. What is gravitational microlensing, what do we learn from it, and how are various experiments studying this phenomenon?

129. What is the "Local Group"?

130. Describe Hubble's classification scheme for galaxies and explain why it is useful.

131. What fraction of all galaxies are spirals? Ellipticals? SOs? How are these ratios different in loose and dense clusters of galaxies? Why? Give several possible explanations.

132. What are cD galaxies and where are they found? How might they be formed?

133. What is the "Schechter luminosity function"? What is the luminosity of a typical bright galaxy?

134. What is the "Faber-Jackson law"? Give a plausible derivation.

135. What is the “Tully-Fisher method”? Can it be used to determine H_0? How about q_0?

136. What do we know about the masses of galaxies and clusters of galaxies and how do we know it?

137. What minimum mass is required for a black hole powering a quasar of luminosity 10^{12} $L_\odot$? What accretion rate is required?

138. Sketch the frequency distribution of the emission of a typical QSO from radio to X-ray frequencies.

139. Describe in detail a large extragalactic radio source such as Cygnus A.

140. What is the “inverse-Compton catastrophe” in compact extra-galactic radio sources?

141. The spectra of non-thermal radio sources frequently show a “break”, i.e., a change of slope of the flux density vs. frequency curve. The frequency at which the break occurs (never well defined) is used to estimate the “age” of the source. Describe how this is done.

142. What is the “equipartition energy” of a synchrotron source? Why is this energy interesting?

143. What is the meaning and purpose of a $\log N - \log S$ curve? Explain the current interpretation of this curve for gamma-ray bursts.

144. Describe the basic features of the “fireball” model of gamma-ray burst afterglows. What is the emission mechanism? What inputs are required?

145. What kinds of sources are detected at TeV energies? How far from the Milky Way can they be observed, and why?

146. Explain at least two different ways of determining the cosmic ray energy density in an external galaxy.

147. What are current explanations for the X-ray background? Discuss the ~ 3 keV, the ~ 1 MeV and the $\sim$ GeV portions of the spectrum quantitatively.

148. Specify (at least) six stages in the standard method of determining the extragalactic distance scale.

149. Summarize the observational evidence in favor of the standard “Big Bang” model of the universe.

150. What fraction of each of the following is composed of “dark matter”: a) the disk of the Milky Way; b) the Milky Way; c) the Coma cluster of galaxies; d) the universe? How are each of these estimates arrived at?

151. What is the baryonic contribution to the cosmological mass density and how is it determined?

152. What volume of the universe do the following surveys sample: CfA, LCRS (Las Campanas Redshift Survey), 2dF (2 degree Field), SDSS (Sloan Digital Sky Survey)? How many galaxy redshifts do these catalogues have? What can we learn from them?

153. What is the "Lyman limit", and how does it relate to observations of high-redshift galaxies?

154. What is the "Hubble deep field"? What have we learned from it?

155. What is the Hubble constant? Explain at least three independent methods to measure it. How does it relate to the age of the universe?

156. How can the age of the universe be estimated empirically? Do the current estimates agree with that obtained from the Hubble constant?

157. What is the "cosmological constant"?

158. What is the Robertson-Walker metric? What are the Friedmann equations? How does the universe expand if it is (i) radiation dominated, (ii) matter dominated with $\Omega \ll 1$, $\Omega = 1$, $\Omega \gg 1$, and (iii) dominated by a cosmological constant?

159. What is the parametric solution (in terms of an "eccentric anomaly") for the evolution of the radius of curvature and age in a dust-only universe?

160. Describe the synthesis of light elements in the Big Bang. Why can their abundances constrain Ω_b? Does the microwave background play a role in Big Bang nucleosynthesis?

161. How does the average density of luminous matter in the universe compare with that inferred from gravity? With the amount inferred from primordial nucleosynthesis? Is this enough to close the universe?

162. What was the temperature of the universe at recombination, and why did recombination occur then?

163. How did the particle content of the universe evolve? What is the most abundant particle in the universe today?

164. What mass should a neutrino have to close the universe? Compare it with current upper bounds (or detections).

165. When (or at what redshift) did the universe become (i) matter dominated, (ii) optically thin to electron scattering (and what was the temperature of the CMB at this time)? What significance did these events have for the CMB?

166. Is most of the hydrogen in the universe neutral or ionized? What is the Ly α forest? Why are cosmologists interested in it?

167. Explain how the apparent magnitudes of distant supernovae can be used to distinguish between cosmological models. What is the apparent magnitude difference, for a supernova at redshift $z \sim 1$, between a model with $\Omega_m = 1, \Omega_\Lambda = 0$ and one with $\Omega_m = 0.3, \Omega_\Lambda = 0.7$. Is $\Omega_\Lambda \simeq 0.7$ a "natural" value from the particle physics point of view?

168. What are the anisotropies in the CMB? Do their amplitudes depend on angular scale?

169. What range of physical scales are being probed by current and future CMB experiments? Are the anisotropies related to galaxy formation? What is the current observational status?

170. What is the "Doppler peak" in the CMB power spectrum? What does its location tell us?

171. What are the main sources of foreground emission that CMB experiments have to contend with?

172. What is the galaxy correlation function? How do the correlation functions of galaxies and clusters of galaxies differ? What are "Lyman break" galaxies? Are they clustered?

173. What is the "Press-Schechter theory" and why is it wrong?

174. What is "biased galaxy formation"?

175. What is the "spherical top hat" model for the formation of galaxies and clusters? What is the significance of the number $18\pi^2$?

176. Why are voids spherical?

177. What are the thermal and kinetic Sunyaev-Zel'dovich effects?

178. How does a gravitational lens work? Explain what needs to be measured to use a gravitational lens system to measure the Hubble constant. What is the current status of these determinations of H_0?

179. What is the "weak lensing effect"? Explain how it can be used to measure the masses of clusters of galaxies. What other ways are there to estimate the masses of clusters? Compare the different methods.

180. What are the "flatness problem" and the "isotropy problem" in standard Big Bang cosmology? How does the inflationary model resolve these problems?