Please work on this problem set by yourself. It will be used as part of your grade.

1) Suppose you are doing a survey to find objects of luminosity $L_s$ with an imaging array that covers a solid angle $\Omega_a$ on the sky (with many pixels). The imaging array has a flux limit given by

$$f_i = f_o (t / t_o)^{-1/2}$$

Where $t$ is the array exposure time on a given field, and $f_o$ and $t_o$ are a reference flux and exposure time respectively. Suppose the space density of the sources is $n_s$ and space is Euclidean. Let $N$ be the total number of sources found in a total survey time $t_{sur}$. The total survey time is fixed (as assigned by the TAC – Time Allocation Committee). Your desire is to find as many sources as possible your allocated time.

a) Derive an expression for the total number of sources you expect given the parameters above. Make sure you cast this in a form that lets you see how the number of sources detected varies with exposure time.

b) What is better for your survey, depth or breadth?

c) What might happen if you make your exposure time too short?

2) Let us look at the problem of the formation of large black holes. A star initially collapses to form a 10 solar mass black hole.

a) Estimate the (minimum) time for this initial black hole to grow to $10^6$, $10^7$, $10^8$, and $10^9$ solar masses through accretion.

b) Given that quasars have been detected to $z \sim 6.5$. Do we have a timescale problem with forming black holes of this size?

c) If there is a problem, what might be a solution? If there is not a problem, explain why not.
3) We wish to investigate the emission from dust in galaxies. In particular this problem investigates some of the differences between dust heated by a distributed set of stars (as in a starburst galaxy) and by a central engine, and how these differences affect the perceived visual and infrared luminosities.

Consider an idealized galaxy consisting of a uniform spherical distribution of stars and dust. The galaxy is of radius, $R$, the effective emissivity of the stars is $j_\nu$, and the optical depth of the dust (assumed independent of wavelength) through the center of the sphere is $\tau_d$. The dust is purely absorbing, that is, we will neglect scattering.

![Diagram of a galaxy with intensity $I_\nu$ and impact parameter $b$.]

a) Find the intensity, $I_\nu(b)$, where $b$ is the impact parameter, from the galaxy. See figure above. Ignore self-absorption by the stars.

b) Assuming the galaxy is a distance $d$ away; derive an expression for the observed flux $f_\nu$ (ergs/cm$^2$/s/Hz). Show that as $\tau_d \to 0$ the correct limit is achieved.

c) The dust absorbs the optical and UV photons radiated by the stars and reemits them in the infrared. If the luminosity of the stars (without dust) is $L$, what is the observed optical luminosity? What is the infrared luminosity?

d) Suppose a central engine dominates the luminosity, $L$. Give expressions for the visual (optical) and infrared luminosities assuming the total dust optical depth through the entire sphere is $\tau_d$.

e) In part a) self-absorption by the stars was ignored, that is, we assumed that the probability that a photon emitted by one star did not terminate on the surface of another one. Taking $10^9$ stars contained in 1 kpc and a stellar radius equal to $R_\odot$, show that this probability (the total optical depth) is indeed very small.
4) You will be assigned an object from the list below of potential AGN and/or starburst objects. You will give a short presentation (< 10 minutes, < 5 transparencies) in class on the object (on the due date).

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<th>NGC 1052</th>
<th>NGC 5506</th>
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<td>BL-Lae</td>
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Search the web and/or literature for information on the assigned object. The information you need to gather is:

a) Optical and/or radio images plus others (UV, etc) as appropriate. Some note should be made of the size scale (either in arcseconds or kpc) on each image.

b) The broadband spectral energy distribution (radio to x-rays), preferably $\nu F_\nu$.

c) Sample spectra showing typical narrow and broad line widths, as appropriate.

d) Sample light curve(s) as appropriate.

e) Identify the type of object and include distance (or redshift), and luminosity information.

f) Include references and web links for the data.

g) Please deposit the appropriate images, spectra, etc. at ftp site given below (you will be given the password in class). My preference is for JPEG or GIF images, but postscript will do if necessary. (This data may be useful for future discussions of AGN.)

You will likely find the ADS, NED, and ASTRO-PH websites useful. You might also find www.google.com is useful too. Ftp instructions are below:

machine: tpc.astro.cornell.edu

login: a590

directory: agn_data (create subdirectory for your object, e.g. ngc1275)