Here it is. The primary goal of this is to get you thinking about how we go about doing the kinds of research that we do. Along the way you will learn something about observing and, hopefully, a lot about the Kuiper Belt. This project is in between the usual “paper” that you might have to write in some classes and a simulated research project that you might encounter in other classes. Work in groups, ask questions, dig into the literature, and have fun!

Astronomy advances with new instrumentation. People are continuously trying to build something bigger, better, and faster than what was built before. Whenever we do this, however, there must be a justification. It is up to the proponents of a new instrument to say how it will advance the science it is designed to do. What you have in this assignment is an instrument and the task of thinking about how to use that instrument to learn something about the Kuiper Belt. There are a number of references at the end of this document for your reading pleasure. I would suggest the review article by Jane Luu and David Jewitt for starters. We will also go over some of this in class.

Your first task is to design a survey for Kuiper Belt objects using the One Degree Imager to be deployed on the WIYN 3.5m telescope in 2010. As the name suggests the instrument has an instantaneous field of view of 1 square degree on the sky. The WIYN telescope has a 3.5m diameter primary mirror. You may assume that 100% of the photons hitting the Earth’s atmosphere make it all the way to the detector (not really true, but let’s run with it anyway). The full description of ODI can be found at http://www.noao.edu/wiyn/ODI/jacoby_spie2002.pdf. The salient features are its size and the expected median image quality of 0.52”, 0.43”, and 0.35” in the R, I, and Z bands respectively. The limiting magnitude in 1 hour will be 25.9 in R, 25.5 in I, and 25 in Z.

Although a survey of the Kuiper Belt is not the primary science driver for ODI, the instrument will be capable of making significant advances in the field. Your job is to describe what those advances might be and how ODI can be used to make them. Other telescopes are also working on similar surveys.

Our goal is to explore the contents of the outer solar system. To date we know of something like 1000 KBOs with radii larger than 50km and in orbits with semi-major axes between 35 and 150 AU (Luu & Jewitt 2002, Bernstein et al. 2003). Luu & Jewitt (2002) estimate that the vertical scale height (height over which the density of KBOs decreases by a factor of e) is something like 20-30 degrees. There are suggestions of two different size distribution power laws, one for objects with radii > 10 km and one for objects with radii < 1 km. The “break radius” has important implications for the dynamical history of the outer solar system.

The first task is to estimate how many KBOs you can detect per night (assume 10 hours of observing time per night) in a single filter using ODI under two different types of surveys. The first will be a deep survey where you point the telescope at the same spot all night long. The second will be a shallow survey done using 20 minute exposures for a total coverage of 30 square degrees in one night.
1. Make a plot of the number of KBOs you expect to detect per night as a function of their intrinsic brightness for each of these surveys, assuming you are observing at (roughly) the same part of the sky.

Now, there are a lot of assumptions (guesses?) you will need to make. I’m going to leave it up to you to figure out what it is you need to know and then go about trying to find that information. Come see me if/when you get stuck. To get you started you will certainly need to think about how the sizes, spatial distribution, color, and intrinsic brightness of KBOs will affect your survey. Your group should try at least two different models for the spatial distribution of KBOs. Realistically, we aren’t going to get much farther than 150 AU for the brightest KBOs.

2. Explicitly state and justify the assumptions that led you to the plot you are showing in part 1. Anyone reading your paper should be able to recreate what you have done and get the same result.

Part of the point of the project is to get you doing some type of research that resembles what we typically do. Some recommended sources include the journals Icarus, The Astronomical Journal, The Astrophysical Journal, and Nature. To give you a target, one estimate is that ODI will detect ~150 KBOs per night. You should probably get to within a factor of 2-3 of this target depending on your initial assumptions.

3. What volume of the Kuiper Belt have you sampled in each of these one night initial surveys? The best way to express this might be to think about the volume sampled for a given range of intrinsic brightness.

4. Estimate the mean number density of KBOs per cubic AU. Does this number make sense given your initial assumptions? Do you get a different answer depending on which observational approach you take?

5. Based on what you’ve done so far, design the observational program using ODI on WIYN whose goal is to accurately determine the break radius in the size distribution of KBOs that have semi-major axes between 35 and 100 AU. To “accurately determine” something means that you need to understand the errors in your measurement. Assume for the moment that your errors are purely statistical. The important part is how you justify the observing program.

Part 2.

The orbital properties of KBOs are the keys to understanding their origin and the dynamical evolution of the outer solar system. The distribution of KBOs is believed to largely be the result of scattering by Neptune and, therefore, KBOs occupy preferred regions of the orbital parameter phase space. Jones et al. (2006) give an example of what one would expect if all of the KBOs had a semi-major axis of 44 AU, a fixed inclination of 2 degrees, and a range of eccentricities (0.01, 0.1, 0.2, 0.3). Let’s call these models 1a, 1b, 1c, and 1d. These are appropriate for a survey at opposition. You may end up with small numbers, but that’s ok. This will tell you how much observing you really need to do to distinguish between different models of the distribution of KBOs.
1. **Make a histogram of the number of KBOs you will detect in your two surveys (part 1, question 1) as a function of distance for models 1a, 1b, 1c, and 1d. Assume a uniform distribution of all the other orbital parameters (e.g. the various angles). It should look something like Figure 5 in Jones et al.**

2. **Are you better off doing the deep single pointing or the 30 square degree shallow survey?**

3. **Now assume a uniform distribution of eccentricities (equal numbers of objects with eccentricities of 0.01, 0.1, 0.2, and 0.3). Make a histogram of the number of objects detected as a function of distance using whichever survey method you picked in question 2.**

4. **Now let’s assume some other model. Assume that 2/3 of the KBOs are at 48 AU and 1/3 are at a= 40 AU. Redo question 3.**

5. **What happens to your plot of number vs distance if there is a population of KBOs that are uniformly distributed between 50 and 60 AU. Assume this population is equal in number to the population between 40 and 48 AU and their eccentricities are uniformly distributed in the 4 bins we used in problem 3.**

**Part 3.**

Everybody loves dwarf planets (Brown, Trujillo, & Rabinowitz 2005). Or at least it’s a quick way to get your name in the paper. There are estimates that there are something like 10-20 Pluto sized things in the Kuiper Belt. But people haven’t searched a huge volume yet.

1. **What would an Earth-sized “dwarf planet” look like (brightness) in your one night WIYN survey if it had a semi-major axis of 100 AU, 200 AU, 500 AU, and 1000 AU? Would you have detected such a beast in the survey you did in Part 1, question 5?**

2. **In its infinite wisdom the WIYN Time Allocation Committee awards your team 50 nights of telescope time a year for 5 years using ODI. You must use the time to observationally determine how many Pluto-sized dwarf planets exist between 35-250 AU. How would you do it? Again, it’s the justification that matters. Keep in mind that it is highly unlikely that you would really be able to search every cubic AU in that range.**

**References**


