The Eccentricity Distribution of Long-Period Brown Dwarf Companions
Keywords: brown dwarfs, direct imaging, radial velocity

Abstract:

I propose to measure the eccentricity distribution of long-period (1-500 yr) brown dwarfs. I will accomplish this measurement by modifying the Orbits for the Impatient algorithm and applying it to calculating posterior eccentricity probability density functions (PDFs) for a statistically large sample of long-period brown dwarfs. I will then aggregate these PDFs to determine the underlying eccentricity distribution of long-period brown dwarf companions. These results will allow direct comparison with the empirical distribution of exoplanets discovered by radial velocity and direct imaging, allowing insights about planetary formation, and will provide opportunities for statistical inferences about individual systems.

Background and Motivation:

Whether brown dwarfs form like large planets or small stars is key to understanding the process of exoplanet formation. Brown dwarf eccentricities can provide insight into formation scenarios, since brown dwarfs with high eccentricities are likely to have experienced close encounters with other orbiting objects early in their lifetimes (Morbidelli 2014), but in spite of this, little analysis has been done to characterize the eccentricities of individual brown dwarfs, let alone the population of brown dwarfs at a wide range of orbital separations. In order to study the formation scenarios of brown dwarfs and make statistical inferences about the population of brown dwarfs with respect to the population of giant exoplanets, it is therefore necessary to have accurate eccentricity measurements from a large sample of brown dwarfs orbiting stars.

Fortunately, several long-period brown dwarfs have already been observed with both the radial velocity and direct imaging methods, but few orbital fits intended to characterize their orbital eccentricities have been attempted, in many cases due to their long orbital periods, for which only short orbital arcs have been observed. In order to provide these empirical constraints, I propose to use the NSF Graduate Research Fellowship to compute eccentricity PDFs for each of a statistically large sample of long-period brown dwarfs using our novel Bayesian technique, Orbits for the Impatient (OFTI; Blunt et al 2016). Since many systems will only have observations covering a fraction of a full orbital period, the uncertainty on the eccentricity of any given system will be relatively large, but with a large sample of systems, the underlying eccentricity distribution of the population can be measured to much higher precision than for any one object. I will combine the eccentricity PDFs to compute the physical distribution of the eccentricities of brown dwarfs, and determine whether this distribution is consistent with or qualitatively different from that for long-period giant planets.

Methods:

Combining data from radial velocity and direct imaging measurements can result in precise determinations of orbital eccentricities (Nielsen et al 2016), so the first step in my analysis will be to modify the OFTI algorithm, which produces orbital element PDFs from direct imaging data, to fit orbits to data sets composed of both radial velocity and direct imaging measurements. Once I'm prepared with this necessary tool, I will compile radial velocity and direct imaging data on >40 brown dwarf companions from the literature, and supplement these by reducing and analyzing unpublished data. Stanford is ideally suited for accomplishing this work, since there are many individuals at Stanford and in the Gemini Planet Imager Collaboration (including GPI PI Bruce Macintosh, and collaboration members at Stanford and nearby institutions Eric Nielsen, James Graham, Robert De Rosa, and Jason Wang) who are experienced with reduction of both radial velocity and direct imaging data, and since Stanford has access to the high-performance computing resources necessary for robust and efficient data reduction.

Once I have compiled reduced direct imaging and radial velocity data for a sufficient number of brown dwarfs, I will run the modified version of OFTI on each data set to produce a posterior PDF in eccentricity for each brown dwarf. I will then aggregate these posterior PDFs to obtain the physical probability distribution of long-period brown dwarfs, testing the effectiveness of several functional models at reproducing this distribution, and so determine for the first time the functional form of the long-period brown dwarf eccentricity distribution.

Anticipated Results:

The most direct application of the calculation of the physical eccentricity distribution of long-period brown dwarfs will be a comparison with the eccentricity distribution of exoplanets detected by the radial velocity method (Nielsen et al 2010), and corresponding analysis to determine the probability that the two empirically determined distributions are the same. Additionally, the orbit fits to the selected brown dwarfs will in many cases be the first measurements of eccentricity, semi-major axis, and relative inclinations of these systems, which will be useful for understanding interactions between the substellar companions and circumstellar disks (e.g. Rameau et al. 2016). Orbit fits can also be used to calculate the probabilities of the existence or absence of additional bound exoplanets or brown dwarfs orbiting a given star (e.g. Bryan et al 2016), and guide future observations of these systems.

Proposed Timeline:

<u>Year 1</u>: Modify OFTI and compile brown dwarf astrometric and RV data.
<u>Year 2</u>: Publish early results for individual systems and finish fitting orbits to remaining systems.
<u>Year 3</u>: Produce eccentricity distribution of long-period brown dwarfs, publish comparison to planet population.

References:

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