Measuring the mass of a brown dwarf orbiting HD 206893

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Dynamical mass of a brown dwarf

A low-mass companion orbiting the star HD 206893 was directly imaged[1] using the VLT/SPHERE in 2017. Milli, et al. declared that the companion would be a "very attractive" system for further research, and I aim to measure the mass of this low-mass compainion. Currently, brown dwarf masses are measured using the dwarf's luminosity and measured age, which is based on poorly calibrated models. Since the brown dwarf I am observing orbits around HD 206893 within the star's debris disk, I will use the inner ring of the debris disk to place dynamical constraints on the brown dwarf's mass. As this is only the second star discovered to have a brown dwarf orbiting within a resolvable debris disk, this research should allow the current model of brown dwarf mass measurement to be adjusted.

Thanks to ALMA (Atacama Large Millimeter/submillimeter Array), we have resolved the inner radius of the debris disk around the star, whose outer radius was previously resolved at infrared wavelengths. This measurement allows us to place dynamical constraints upon the mass of the brown dwarf within the star's debris disk. As of now, I have received one set of data and am awaiting the arrival of two more sets of data.

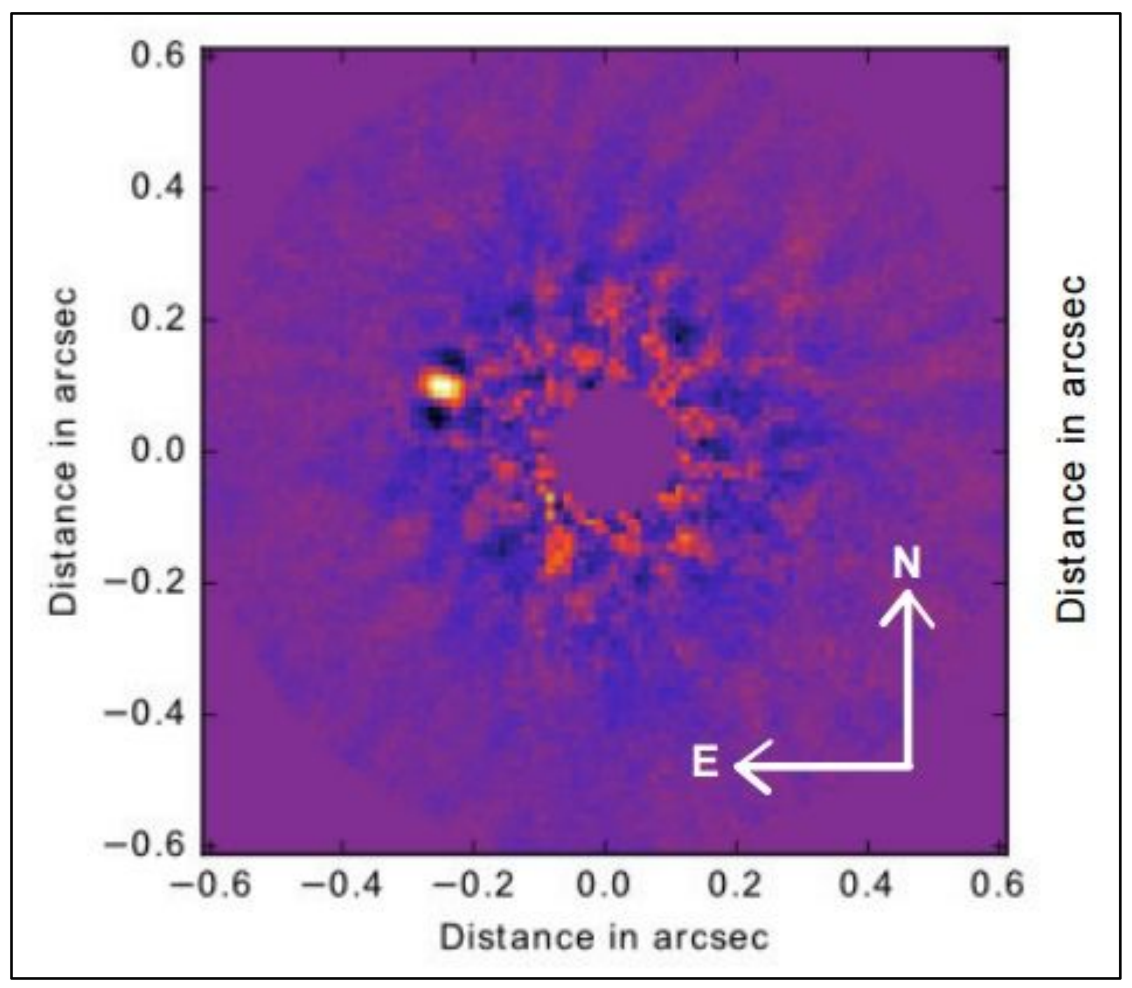
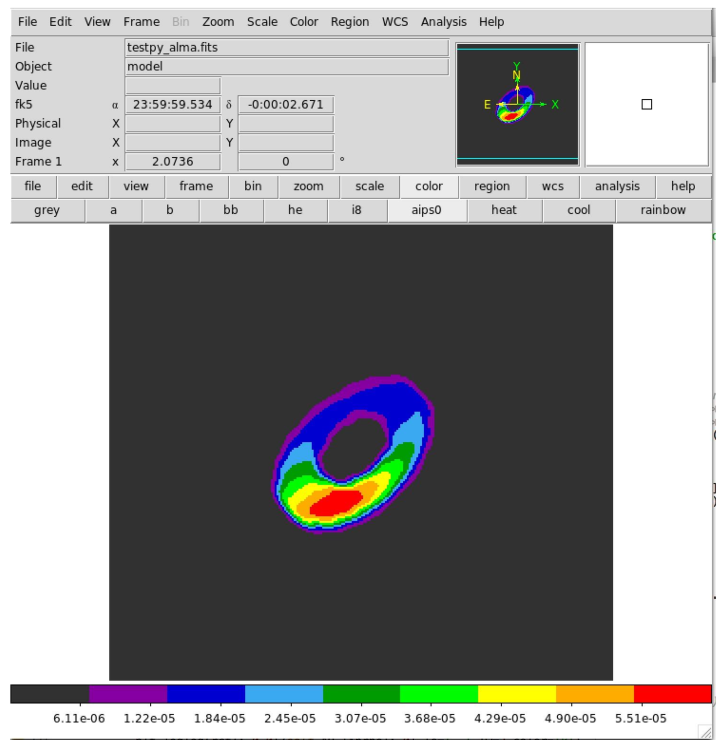
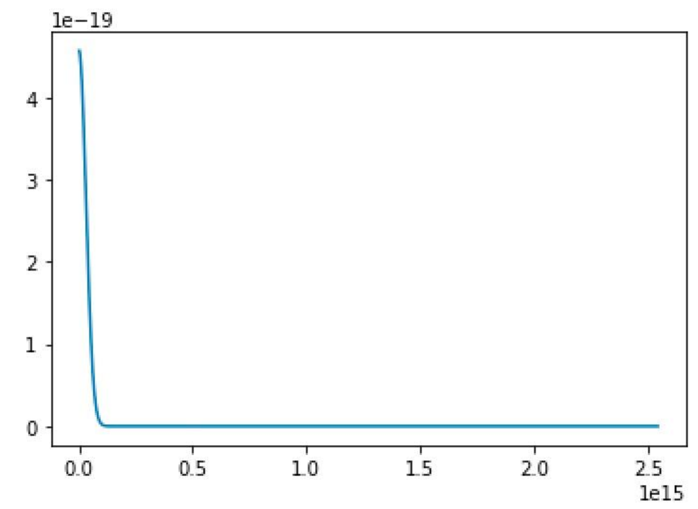


Figure 1: VLT/SPHERE image of the brown dwarf companion to HD 206893 (Milli, et al. 2017)

Current models





```
9.3966843543e-19
0.00040973053153
disk init took 53.152482 seconds

In [5]: runfile('/Network/Servers/vimes.astro.wesleyan.edu/Volumes/users/dvizgan/code/disk_model/debris_disk_ecc.py', wdir='/Network/Servers/vimes.astro.wesleyan.edu/Volumes/users/dvizgan/code/disk_model')

In [6]: runfile('/Network/Servers/vimes.astro.wesleyan.edu/Volumes/users/dvizgan/rhosho.py', wdir='/Network/Servers/vimes.astro.wesleyan.edu/Volumes/users/dvizgan')
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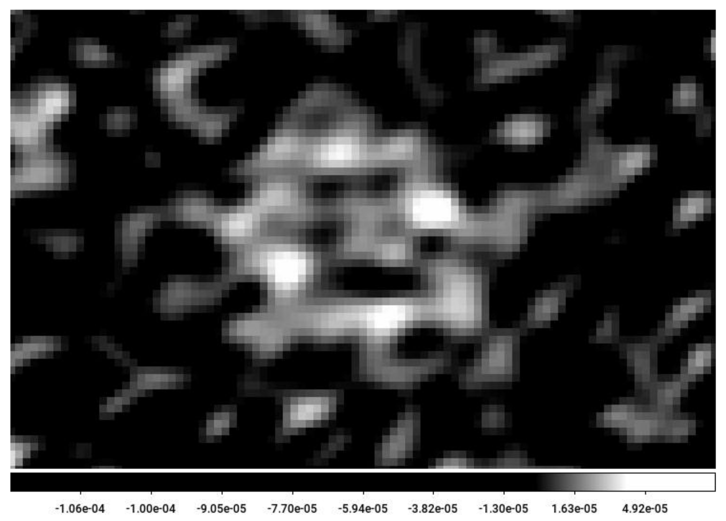
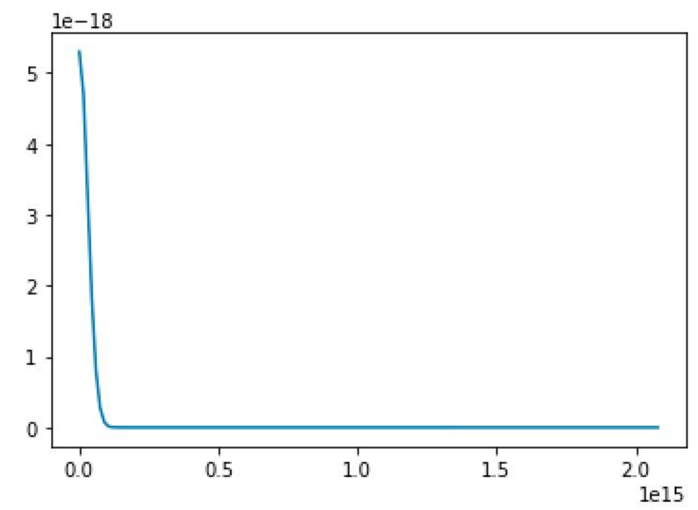




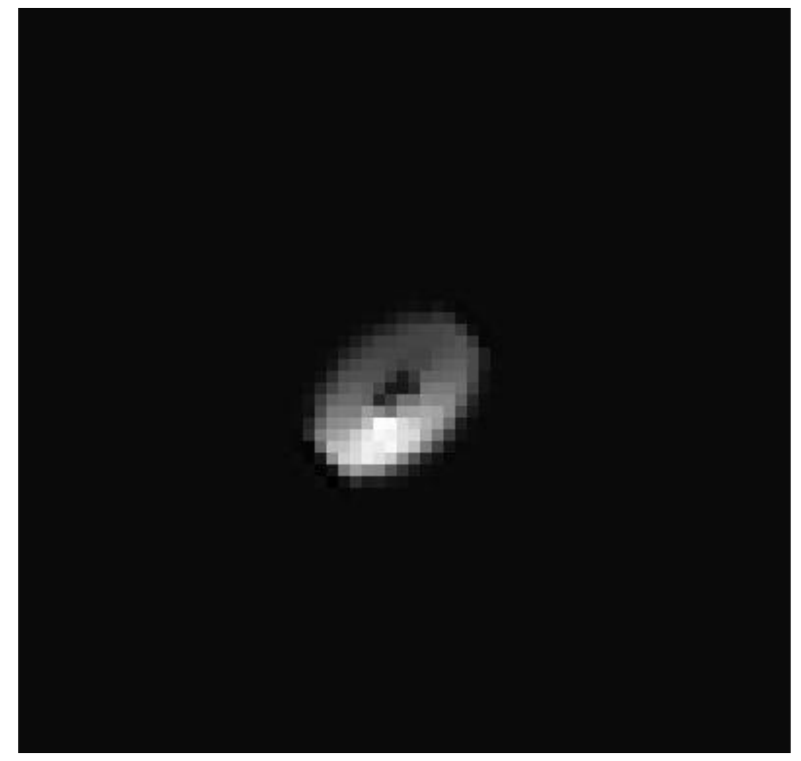
As I await for some data to arrive from ALMA, I have been modifying a computer model created by Flaherty, et al. 2015. Kevin Flaherty, former post-doc in the department, created this program to model circular protoplanetary disks. Modifications by Sam Factor (BA '14, MA '15) enabled modeling of eccentric protoplanetary disks, while modifications by Evan Carter (MA '18) adjusted the temperature and density structure of the circular disk code to be consistent with debris disks. Debris disks are vertically isothermal because they are optically thin, unlike protoplanetary disks, which are hotter on the surface due to being optically thick. Debris disks are also gas-poor, unlike the gas-rich protoplanetary disk, and are better modelled using a Gaussian in height above and below the midplane of the disk, as opposed to protoplanetary disks, whose vertical density structures rely on hydrostatic equilibrium.

My project this summer required me to "Frankenstein" the edits made by Factor and Carter to yield a working modelling program for eccentric debris disks, and to ensure that my modifications were all self-consistent.

Specifically, I took the program within Kevin's code base that models eccentric protoplanetary disks and modified density and temperature structures of the code so that it would model an eccentric dust disk. You can see some of these adjustments on the graphs here -- the top graph is a pyplot of the disk's volume density as a function of the vertical direction, and I used the same parameters and formula to test the shape of the function by making the plot outside of Kevin's code. There is a discrepancy in the y-axis due to "theta dependence" -- essentially, an eccentric debris disk is most dense at its apocenter, or the point furthest from the star, and that is the red glow you see in the top left picture. Thus these graphs were one of several tests that were used to ensure that the program was working properly.

Normalizing the mass: a problem

The final check I am working on is ensuring that the mass of the disk is conserved while it is modelled. As of Tuesday, the disk loses about 80% of its mass while the surface density is distributed radially across the disk. We are working on understanding whether the problem is a consequence of an improper mass normalization, a problem with the gridding, or something else.



In addition, there is a problem with how the axes of the model are utilized within the program, creating several errors whenever I try to load up the disk model. Once I solve these two issues, I will work on a data pipeline that will load ALMA's measurements into the disk modelling program and that will eventually give me a measurement of the disk's inner ring, a measurement which will ultimately be used to place dynamical constraints on the mass of the brown dwarf orbiting HD 206893.

Some acknowledgements

Special thanks to Meredith for her incredible advice and guidance, and to Kevin Flaherty for walking me through his original modelling program. Special thanks to ALMA for taking measurements of HD 206893.

This research made use of Astropy, a community-developed core Python package for Astronomy (Astropy Collaboration, 2013).

This research also utilized the Python packages numpy, pyplot, and matplotlib.

References:

1. Milli, et al. 2017, Astronomy and Astrophysics Letters, 597, 2
2. Flaherty, et al. 2015, The Astrophysical Journal, 813, 2, 99
3. Astropy Collaboration (2013)
4. Van der Walt and Colbert 2011, Computing in Science & Engineering 13, 22.