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Determining the Sources of the Zodiacal Cloud Using Relative Velocities of Dust Particles From High-Resolution Spectroscopy

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Introduction

The zodiacal cloud is large debris disk of interplanetary dust that orbits the Sun and within which the Earth's orbit is embedded. The zodiacal light can be seen with the naked eye and is best observed during dusk and dawn. The zodiacal light we see is sunlight that reflects off of the particles that make up the cloud. This light will be Doppler shifted by the moving dust particles, with the shift depending on the velocity of the particles and direction in which they are traveling relative to the Earth. When the sunlight is reflected off of particles that appear to be moving towards us, the light is blue shifted, meaning that the light that we detect is bluer than it would be if the source was not moving relative to us. When the sunlight is reflected off of particles that appear to be moving away from us, the light is red shifted, meaning that the detected light is redder than it would be if the source was not moving relative to us. The faster that these particles are moving relative to us, the more they are either blue or red shifted. By measuring the velocities of these moving dust particles, we can put constraints on their orbits and the source bodies that are producing this dust.

Though comets, asteroids, and, to some extent, interstellar dust make up the primary sources of the dust, the relative contributions of each of the sources are unknown. However, it can be estimated that interstellar sources of dust only make up a very low percentage of the relative contribution, leaving comets and asteroids as the primary sources of the dust cloud. Determining the content, structure, and sources of the dust particles in the zodiacal cloud is important to understanding the nature and evolution of the zodiacal cloud, putting the cloud in context with other debris disks, and yielding source information of collected and catalogued interplanetary dust particles. It will also allow us to more accurately determine the danger posed by interplanetary dust particles to probes and ships in near-Earth space. By observing the spectra of sunlight scattered off of the orbiting dust particles, we can use the resulting Doppler-shifted spectral lines to put constraints on the orbits of the dust. These constraints can then be used to determine the source distribution of the dust particles because asteroidal and cometary particles are expected to have different orbital elements. For example, cometary particles will be more inclined and have more eccentric orbits compared to asteroidal particles, which are expected have more circular orbits with lower inclinations.

In 2004, Reynolds et al. executed a proof of concept study which provided evidence that observing spectral lines and comparing them to synthetic spectra could yield information about dust sources. The proof of concept included only a few nights of observations and was based on work done by Hirshi and Beard (1987). Their work yielded a code that could be used to create synthetic spectra to be compared with observed spectra to help determine particle sources. Both projects used a single solar magnesium Fraunhofer line as the basis for the Doppler shift. The Ipatov code was written in Fortran 77 and makes use of the Swift subroutine package (Levison, Duncan, 1993). The subroutine package includes multiple functions for reading in data, coordinate transformations, and integrations over a given time period to track the evolution of orbits. The Swift package also includes multiple different methods for integration depending on what data is given and what the goal of the integration is

Our work here deviates from previous attempts, i.e., Reynolds and Ipatov, to determine the sources of interplanetary dust particles in the zodiacal cloud in several ways. The first deviation is that our observations will last significantly longer than previous surveys; the team will observe the zodiacal cloud over the course of three years. The long baseline of observations will eventually allow us to determine not only seasonal effects, such as the azimuthal asymmetries of the cloud which define its structure, but also start to differentiate temporal variations over the solar cycle, which will allow us to ascertain the relatively low contribution of interstellar source particles. The second deviation is that two magnesium lines will be observed instead of only one. This project will make use of the Wisconsin Hydrogen Alpha Mapper (WHAM), a specialized Fabry-Perot spectrometer at a remote facility currently located at the Cerro Tololo Interamerican Observatory in Chile. Since the scattered zodiacal light is only able to be seen during a small window during dawn and dusk, these observations will make use of otherwise underused time slots. We will compare observed spectra with synthetic spectra created using an altered version of the Ipatov et al. (2008) code, as well as previous dynamical models of orbital evolution of interplanetary dust particles. By modifying the Ipatov code so that we can use our own more sophisticated orbital population models.

Methods

The Ipatov et al. (2008) code was written in Fortran 77, which requires a compiler to read and run the program. The compiler used was CodeBlocks and the Fortran package used was MinGW. After downloading the compiler and Fortran, the code was analyzed line by line in order to gain an understanding of how it worked. This required me to learn Fortran syntax and functions as I went through the code. As I analyzed the program, I realized that there were several unique functions that were not a part of base Fortran 77 and were created by a separate author. At first, it appeared that these functions were a part of Swifter, a subroutine package written in the mid 2000's. However, it quickly became apparent that this was not the case, as most of the used functions in the Ipatov code had different inputs and the subroutine package was written in an updated version of Fortran, Fortran 90. These functions were actually a part of Swift, an older subroutine package developed by Hal Levison and Martin Duncan that models orbital evolutions of dust particles. Swifter is an updated version of Swift, containing more accurate formulas and based on more contemporary literature. While analyzing the code, a variable dictionary was created in order to keep track of each variable, its type, whether it was a single number or an array, what it represented, and how it was used in the code. Many variables were not defined in the code and were instead defined within the various subroutines and additional files that the program used from the Swift package. These variables are read in from the subroutines and are often times data from input files. The code creates several files as outputs for the manipulated data, including files to be used for graphing.

Results

The code requires four inputs, the first of which is the relative intensity of Doppler shifted wavelengths of one magnesium I Fraunhofer line. This file is directly used in the code and its data is used extensively. The other three are arguments in three Swift subroutines and contain planetary orbital parameters (such as distance from the Sun and their J2 and J4 oblateness numbers), parameters for the dust particles (such as minimum and maximum distances considered and time over which the orbit is integrated), and parameters for test particles. The latter three of these documents thus need to be obtained from the Swift archives. However, what the data is can be determined through analyzing the variables that are being read in by the subroutines. Many of these variables are known quantities, such as masses and radii of the planets, as well as their J numbers. The data for the test particles include masses and positions in heliocentric coordinates. Most of the variables can be renamed and altered so that Dr. Kehoe's outputs from her dynamical evolution model can be used as inputs here.

Discussion

My work on this project reveals that significant revisions to the Ipatov code will need to be done in order to obtain the necessary synthetic spectra. The first major revisions will be to include the missing values from a pair of .inc files that the code and certain subroutines call, as well as pre- allocating the necessary variables that are not defined in the code itself. Every manipulation done to the single line of magnesium I will have to be copied and altered so that the additional line can be manipulated within the code. This is because the second line has a different wavelength and will look graphically different than the line that was previously used. It was not determined if the Swift subroutines used take into account radiation pressures and other effects in their integration. This is important to determine because effects of radiation on small particles will drastically affect their orbits, leading to potentially differing synthetic spectra than what was created by Ipatov et al.

While we made significant progress in understanding and running this approximately 1500 line code, there is still work that needs to be done in order to use this code to produce synthetic observations. As we continue this work, we will use the synthetic observations to compare directly with the WHAM observations that are now starting to be taken. Comparing these real and synthetic observations will allow us to begin to differentiate sources of the dust producing the zodiacal cloud.

An overview of this work was presented at the American Astronomical Society's Division of Planetary Sciences' meeting as "Determining the Sources of the Zodiacal Cloud Using Relative Velocities of Dust Particles from High-Resolution Spectroscopy" and will also be presented at the fall and spring Student Research Symposiums.

References

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