RETRIEVING DUST PROPERTIES OF THE AU MIC DEBRIS DISK, A POSSIBLE FORMING PLANETARY SYSTEM. J. A. Arnold[1], A. J. Weinberger[1], G. Videen[2], E. Zubko[3], [1]Department of Terrestrial Magnetism, Carnegie Institution for Science, 5421 Broad Branch Rd. Washington, DC 20015, USA (jarnold@carnegiescience.edu), [2]Space Science Institute, 4750 Walnut Street, Boulder Suite 205, CO 80301, USA, [3]Kyung Hee University, 1732, Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do 17104, Republic of Korea

Introduction: Debris disks are dusty circumstellar disks analogous to our solar system's Kuiper belt, asteroid belt, and zodiacal cloud [1]. The dust in these disks is produced by the destruction of comets, asteroids, and protoplanets. Understanding the composition of the material within these extrasolar systems may provide insight into the planet formation process. At visible and near-infrared (VNIR) wavelengths, dust within debris disks is detected via light from the host star scattered by these dust grains. As debris disks are typically too cold to produce key identifying silicate spectral features in thermal emission near 10 μm [2], scattered light in the VNIR wavelength range is important for making compositional determinations. To interpret scattered light observations of debris disks we need to model the light scattering properties of the constituent dust, which depend on grain composition, size, and structure. Often these models assume compact, spherical particles [e.g. 3], although other grain shapes such as ellipsoids and distributed hollow spheres have been considered [e.g. 4]. We use the discrete dipole approximation (DDA) method [5,6] to calculate scattering efficiencies for realistic grain shapes [6] and use these to model the optically thin disk surrounding AU Microscopii (AU Mic). AU Mic hosts a pair of candidate Jovian exoplanets, that require follow-up and confirmation [7].

Light scattering calculations: AU Mic's debris disk (Fig. 1) has been spatially resolved across a wide range of wavelength regimes, including optical to near-IR scattered light, optical polarized scattered light, as well as far-IR, sub-mm, and mm emission [e.g. 8,9,10].

In scattered light, the AU Mic debris disk shows a change in color with separation from the central star [8]. The light-scattering response is dependent on the shape of the dust particles, their optical properties, and their orientation with respect to the star and the observer. Hence, we need a model that can determine if these spectroscopic changes are due to the sampling of different portions of the light scattering phase function (Fig. 2) or changes in the size or composition of the dust grains themselves. Thus far, spherical grains have not been able to provide an independently consistent match to both VNIR scattered light and thermal infrared emission data of debris disks [11].

We use the Zubko et al. 2005 [6] implementation of the discrete dipole approximation (DDA) method to calculate the light-scattering properties of irregularly shaped agglomerated dust grains. In the DDA code, targets are generated by placing electric dipoles within a 3D lattice of points. Each dipole has a specified index of refraction: $m = n + i\kappa$, representing the chemical composition. The number of and spacing between the dipoles are constrained by the condition $|m|kd < 1.0$ [6], where d is the lattice spacing and $k = 2\pi/\lambda$ is the wavenumber.

The agglomerate shape (Fig. 3) is generated by confining the lattice points to a sphere and filling the remaining points as follows. The upper 0.5% of the sphere radius is designated as a surface layer. Below the surface layer, 21 points are randomly chosen as seeds for material while another 20 are randomly chosen as seeds for void space. Within the surface layer, a further 100 points are selected as void space. Each lattice point is assigned the properties of the nearest seed particle, whether it is a material or empty space. It is possible to split the 21 material seeds between multiple compositions. Scattering properties are averaged over at least 500 such randomly generated particles in order to achieve orientation-averaged properties. More particles are added as necessary until addition of new particles changes the average scattering properties by less than 1%.

Retrieving dust properties: To apply these calculations to the debris disk spectra we generate a lookup table of the scattering properties as a function of grain size and refractive index. We then use a Markov chain Monte Carlo (MCMC) model [12] to fit the scattered light spectra using these lookup tables. We also generated a table over the same range of properties for spherical grains to compare with the agglomerated debris particles.

We define the disk shape using the inner and outer edge, opening angle, and surface density profile derived from Atacama Large Millimeter Array (ALMA) data [9]. We then calculate the phase angle for each parcel of the disk. We also assume the disk is optically thin.

We then use a Python MCMC package [12] to search for fits to the grain size parameters (minimum radius and grain size distribution power law slope) and compositional parameters. Composition is parameterized as the volume fraction of each component based on the wavelength-dependent complex refractive index and includes astronomical

silicate, amorphous carbon, water ice, tholin, and metallic iron. The disk is then projected in 2-D so that spectra generated from a given set of parameters can be extracted and compared to the measured flux ratio.

Implications: We have found that a small minimum grain size (0.1 – 0.3 um) is necessary to fit the blue slope observed by Lomax et al. [8] in the inner disk. This is consistent with the fact that radiation pressure is not expected be effective at removing dust from the system. We have also found that we may have to assume a component with a different surface density profile for the portion of the disk exterior to 40 AU that extends past the ALMA emission detection (see Fig. 1).

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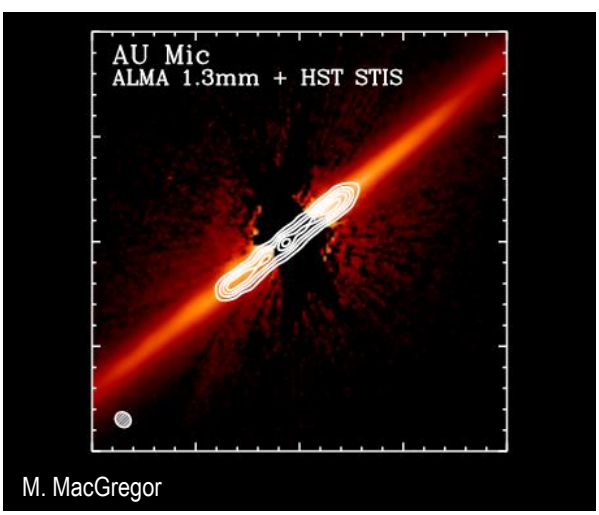

Fig. 1: ALMA 1.3 mm contours overlaid on an HST STIS image of the AU Microscopii debris disk. The ALMA beam spot size is shown in the lower left.

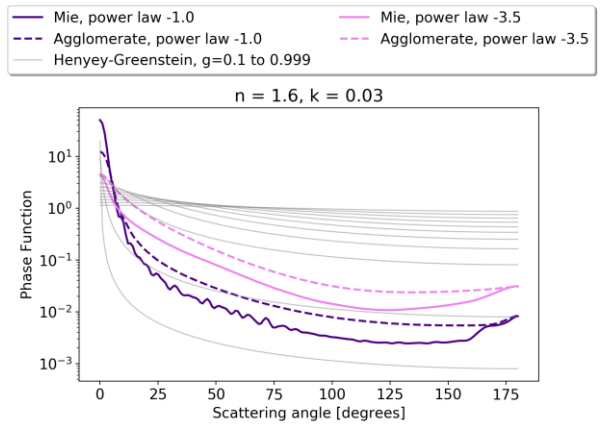

Fig. 2: Scattering phase function for two different power law grain size distributions p=-1 (purple), p=-3.5 (pink) and grain types spheres (solid) and agglomerated debris particles (dashed).

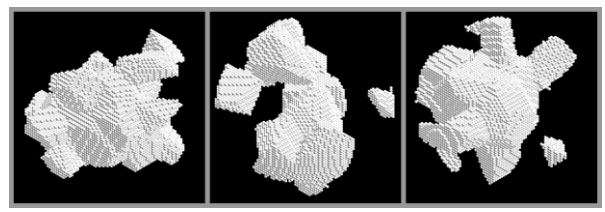

Fig. 3: We use the Zubko et al. (2005) implementation of the discrete dipole approximation (DDA) method to calculate the light scattering properties of irregularly shaped agglomerated dust grains. Seed grains are introduced into a cubic lattice representing the dipoles. Each lattice point then takes on the properties of the nearest seed.