RADIATION PRESSURE FORCES AND BLOW-OUT SIZES FOR PARTICLES IN DEBRIS DISKS. 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]School of Natural Sciences, Far Eastern Federal University, 8 Sukhanova Street, Vladivostok 690950, Russia

Introduction: Debris disks are a type of circumstellar disk that contain dust generated by collisions and disruptions of protoplanets and/or planetesimals. These planetesimals are analogous to asteroids and comets in our own solar system. We seek to determine the composition of the material within these extrasolar systems in order to better understand the planet formation process. At visible and near-infrared wavelengths, dust within debris disks is detected via light from the host star scattered by grains. To interpret scattered light observations of debris disks, it is useful to compare modeled grain size minimums to radiation pressure blow-out sizes. One convenient parameter is the ratio of radiation pressure to gravitational forces (β) acting on a dust grain, which depends on grain composition, size, and structure. Typically, β is calculated using the assumption of compact, spherical particles or accounting for porosity via the Maxwell-Garnett mixing rule [e.g. 1, 2]. Calculations of radiation pressure balance for porous, irregular dust grains have been carried out for a handful of cases [3-5] using the discrete dipole approximation (DDA) method [e.g. 6]. However, due to computational considerations, these focused on submicron particles that only require a small number of dipoles (N<=2048) to model, but may be below the blow-out size of some systems.

Here we present comparisons between Mie, Maxwell-Garnett, and DDA calculations of β for micron-sized grains using different stellar effective temperatures and luminosities and grain compositions. The grain shapes and DDA implementation used to generate scattering and absorption efficiencies are similar to [7]. Stellar properties were chosen to correspond to stars known to host debris disks.

DDA calculations and model dust grains: We use our own implementation of a DDA code [8] to calculate the light-scattering properties of irregularly shaped agglomerated dust grains (Fig 1). 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: $m = n + i\kappa$. The number of and spacing between the dipoles are constrained by the condition $|m|kd < 1.0$ [8], where d is the lattice spacing and $k = {2\pi}/{\lambda}$ is the wavenumber.

The agglomerate shape 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 placed in random orientations relative to the direction of incidence. More particles are added as necessary until addition of new particles changes the average scattering properties by less than 1%.

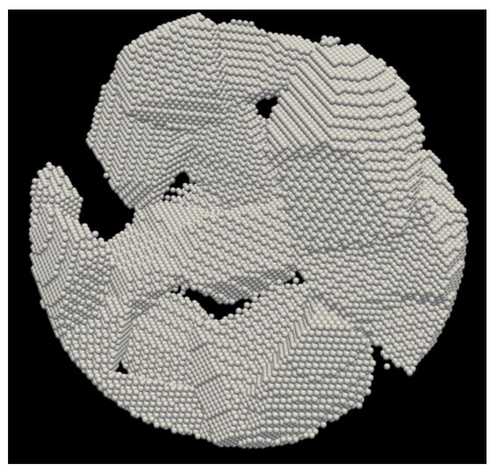

Fig 1: Example of an agglomerated dust grain composed of dipoles within a 3D lattice.

Dust grain blow-out size: When the force of radiation pressure exceeds gravity the dust grain becomes unbound from the system on an orbital timescale.

The ratio of these forces is often expressed as $\beta = \frac{\sigma\langle Q_{pr}\rangle L_*}{4\pi G m c M_*}$, where σ is the grain cross-sectional area, $\langle Q_{pr}\rangle$ is the average scattering efficiency over the stellar spectrum, G is the gravitational constant m is the grain mass, c is the speed of light, and L_* and M_* refer to the luminosity and mass of the host star, respectively [e.g. 2]. $\langle Q_{pr}\rangle = Q_{abs} + (1 - g)Q_{sca}$.

For a given grain porosity, this parameter can be used to determine the effective radius below which grains will not stay in the system.

To represent debris disk dust grain compositions we use optical constants of astro-silicate [9] and amorphous carbon [10]. For each grain composition three different grain models are compared: 1) Compact spheres where $\langle Q_{pr} \rangle$ is calculated using Mie theory, 2) porous spheres where the Mie theory $\langle Q_{pr} \rangle$ is modified by the Bruggeman mixing rule and 3) irregular grains where $\langle Q_{pr} \rangle$ is calculated via DDA as described in the previous section (Fig 2, 3). Because the algorithm used to generate irregular agglomerated dust grains yields roughly 70-80% porosity [11], we compare these results to Mie-Bruggeman calculations with 75% porosity. The Mie-Bruggeman approximation uses Mie theory from a homogeneous sphere that has optical properties given by the Bruggeman approximation for a heterogeneous system. Table 1 gives the stellar properties used in Figs 2 and 3.

Host star	HD 32297	AU Mic
Spectral type	A0	M1
L_* (L_{sun})	3.33	0.13
T_* (K)	6450	3500
M_* (M_{sun})	1.84	0.5
Age (Myr)	30	20

Table 1: Stellar properties used to calculate β_{pr} for Fig 2 and 3.

Implications: For HD 32297, the irregular agglomerated dust particles behave similarly to Mie-Bruggeman particles of 75% porosity when composed of amorphous carbon, but not silicate. Although the estimated blow-out size for irregular carbon grains around AU Mic is similar to 75% porosity spheres, the overall behavior of β vs. grain size is quite different. For both test cases, the maximum silicate β occurs at a different grain radius for the irregular dust agglomerates vs. both compact and porous spheres. This modeling suggests that the grain shape can have an effect on the blow-out size, and must be taken into account in such calculations.

DDA calculations of the large grain sizes needed to approach the blow-out size of an A-type star such as HD 32297 would require prohibitively long computation times. However, it can be inferred from the slope of the computed points that the blow-out sizes are larger than previously inferred assuming compact spheres.

Actual debris disk dust grains are composed of intimate mixtures of silicate, carbon and ice and would be expected to have sensitivity to radiation pressure intermediate to the endmembers shown here.

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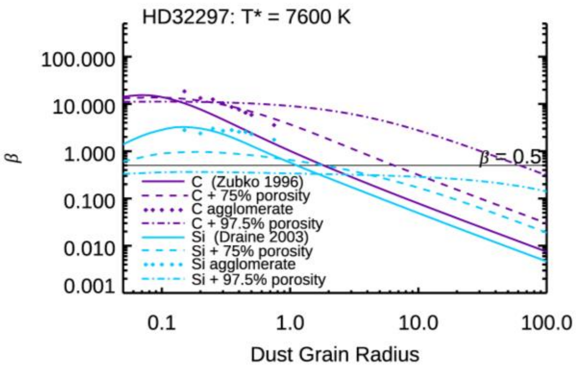

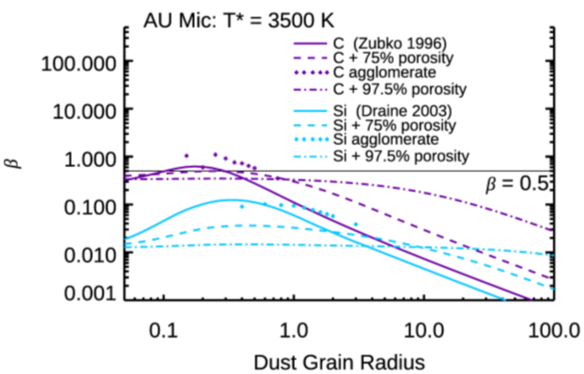

Fig 2: HD 32297 (top) and **Fig 3:** AU Microscopii (bottom). β as a function of dust grain radius for carbon (purple) and silicate (blue). Compact spheres (solid lines), Mie-Bruggeman porous spheres (75% dashed lines, 97.5% dash-dotted lines), agglomerates (+ markers).