Real Time Visualization of Debris Disks in Scattered Light and Thermal Radiation

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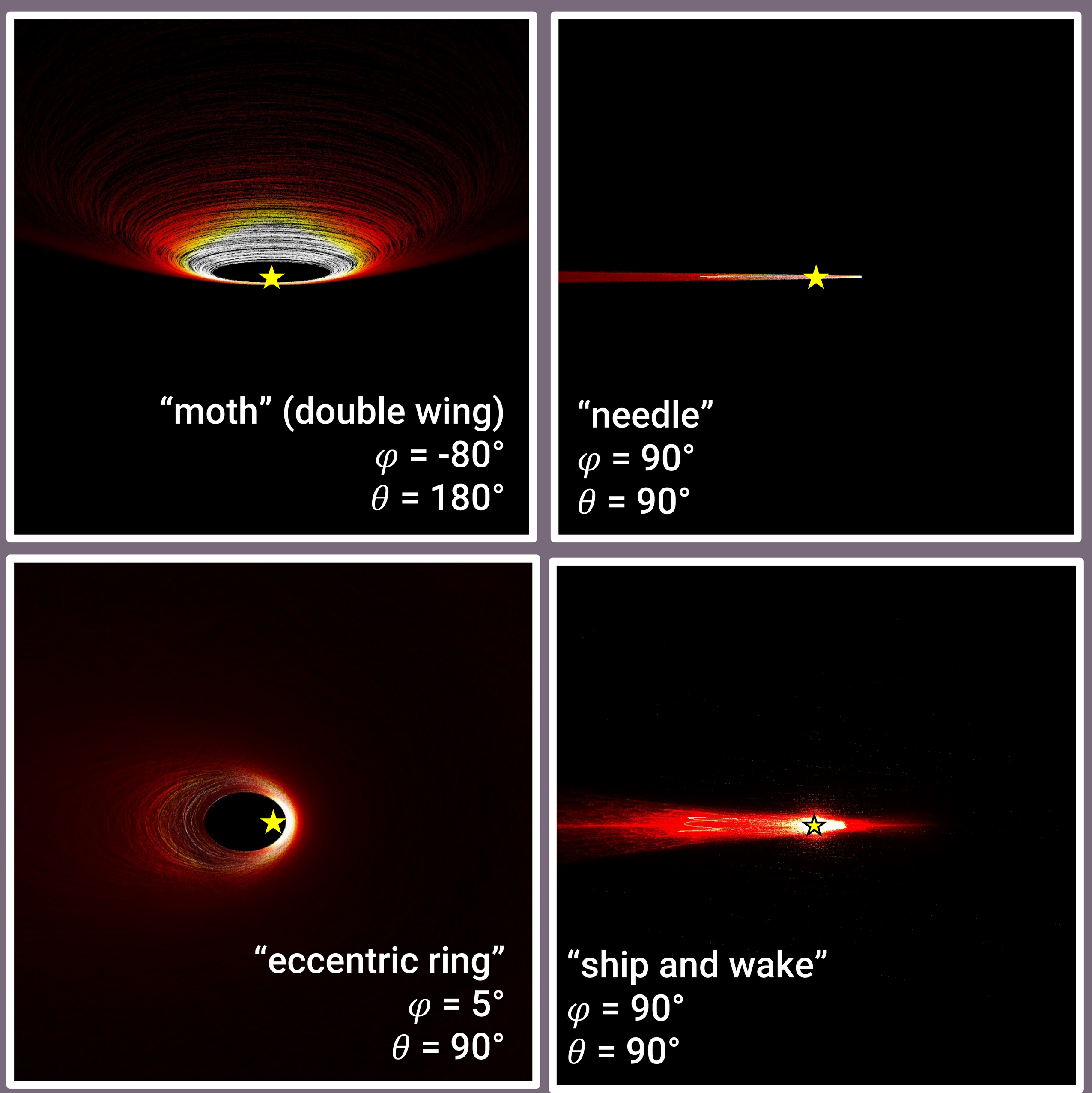
DEBRIS DISKS

A debris disk is a collection of dust particles orbiting a solar system older than 10Myrs. These dust particles are the remnants of planetesimal collisions within the solar system, collisions that lead to planet formation according to the core accretion model.

Since the debris are the results of planet formation, and since the dust particles are gravitationally secluded by the solar system, analyzing a debris disk can give crucial information on the presence of exoplanets within the system.

In 2016, Lee & Chiang published a primer on relating the morphology of a debris disk to the orbits of the exoplanets within a solar system. They saw that the viewing angle of the disk along with the properties of the system's planets' orbits were creating specific shapes; "moths", "eccentric rings", "needles" and even "ship and wake".



The morphology of a disk is caused by the viewing angle and the system's orbits. At the top, a system with planet eccentricity of 0.25, at the bottom, a system with eccentricity 0.7.

THE MODEL

Following up on the work of Lee & Chiang, this project presents a real-time visualization tool to simulate a debris disk in 3D in thermal radiation and scattered light. Only solar systems composed of a single planet on a possibly eccentric orbit are simulated.

The model starts from parent bodies, simulating their collisions to produce dust particles.

1000 parental orbits are computed in a uniformly distributed narrow ring located just outside the planet's elliptical orbit and apsidally aligned with it. Then, the parental orbits are uniformly divided to instantiate 100 parent particles along each orbits. For every parent particles, a dust orbit is created, which orbital Keplerian parameters depend on the parent body orbit, and on radiation, the ratio of the force of stellar radiation pressure to that of stellar gravity.

THE RENDERING

1000 dust particles, uniformly distributed along each dust orbits, are drawn. This results in a total of 10^8 drawn particles. Every particle is mapped to a pixel grid, which size depends on the desired resolution.

The intensity of every dust particle is computed, and then mapped to a 1D colormap. Every particles in a pixel contribute to 10% of alpha blending, to simulate the transparency of each grain.

The rendering is performed in a real time environment, with user input controlling the position of the observer and the observed wavelength.

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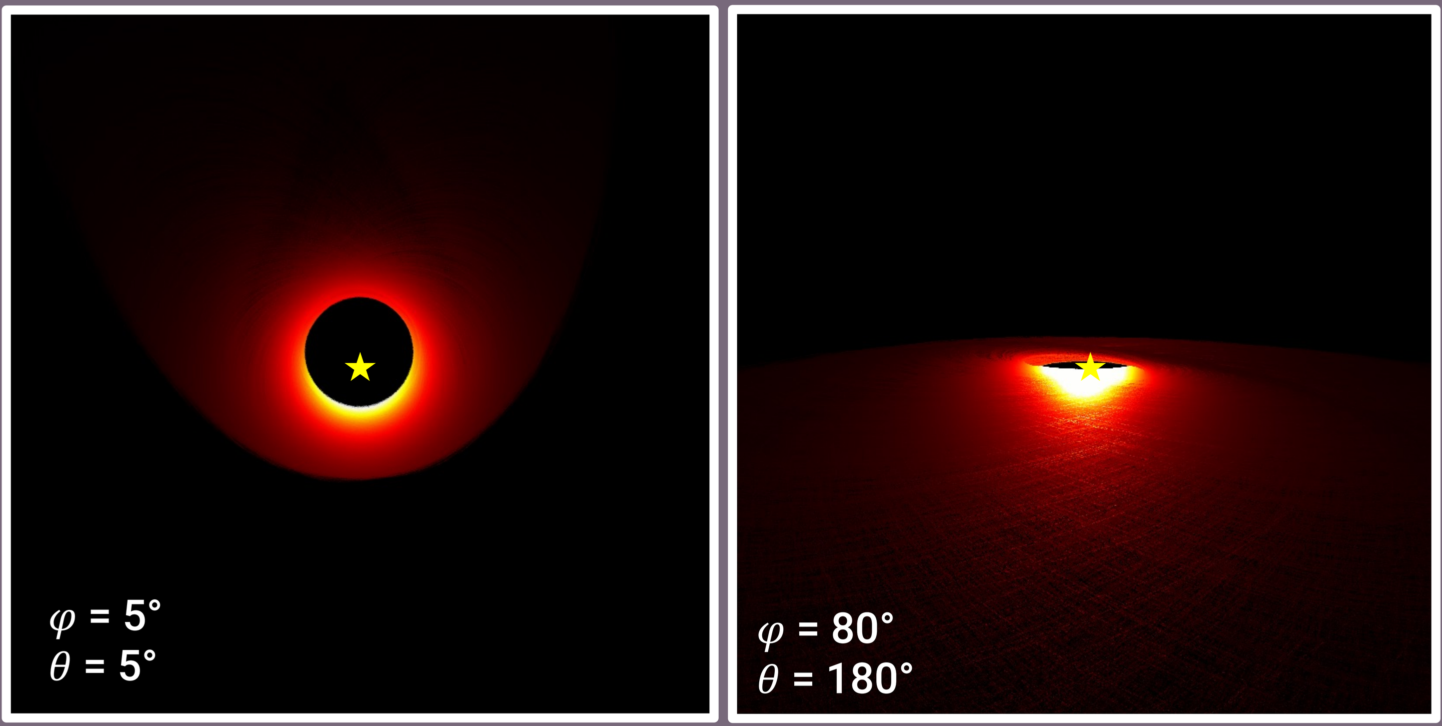
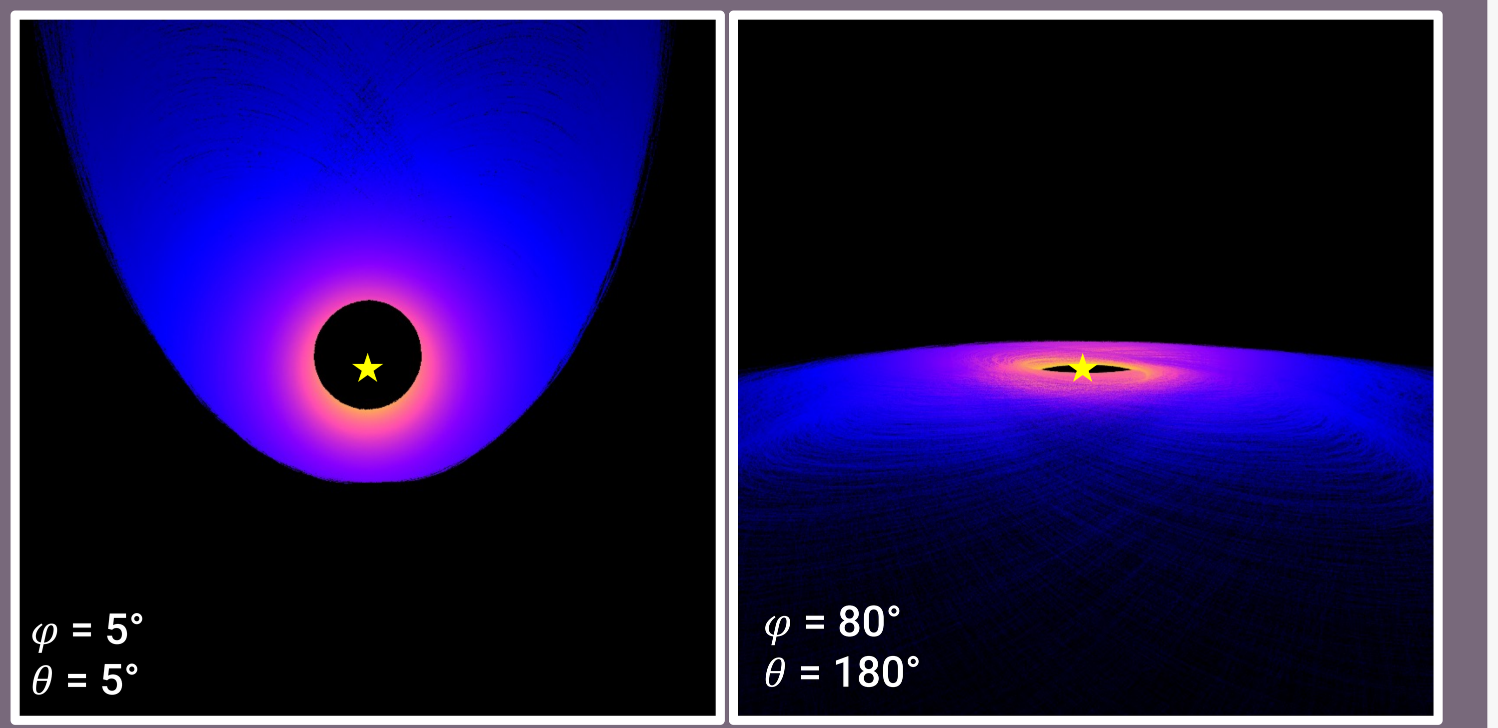


Disk with a single inner planet and fixed radiation equal to 0.35, shown at various angles in scattered light.



Identical disk but in thermal radiation. It shows that thermal radiation allows for a larger probing of dust population.

SCATTERED LIGHT

To simulate scattered light, so a wavelength in the visible range, the intensity of a dust particle is computed proportionally to the scattering phase function, and inversely proportionally to the square of radiation and distance from the observer.

For the phase function, a linear combination of three Henyey Greenstein functions is chosen.

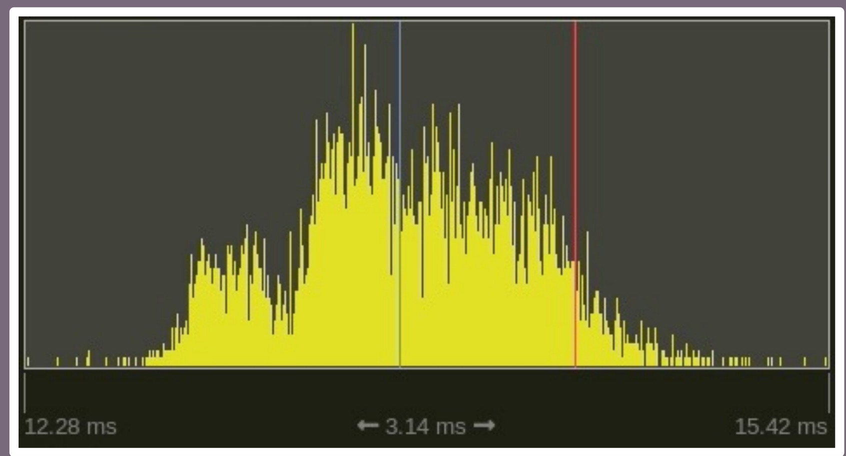
THERMAL RADIATION

To visualize the disk thermal radiation, so simulating a wavelength in the militer range, the intensity is computed proportionally to the thermal emission of each grain.

The thermal emission of each grain is proportional to its surface density, opacity and Planck function. The grain is approximated as a blackbody, whose temperature depends on the thermal radiation of the star.

RESULTS & PERFORMANCES

The model is successful at analyzing disk morphologies and categorizing them according to their viewing angle and planet properties. A high planet orbit inclination variation will result in a "ship and wake" when seen edge on. For systems with low inclination variation, it will result in a "needle". When viewed faced on, an eccentric planet orbit will result in a "eccentric ring" disk. When almost edge on, it will be a "moth". Viewing the disk at different wavelengths allows to probe different dust populations and can help classifying its morphology.



The simulation runs in a real-time environment at 14.37ms per frames in average for 10^7 particles, as shown in the frame versus time histogram. Converting the dust orbitals to drawable particles in cartesian coordinates is the bottleneck and was optimized from an average of 7.32s to 1.26s using multithreading. This totals in 2.16s of loading time at launch. The time complexity is O(n), with n the number of particles.