National Aeronautics and Space Administration

Low-cost Paul trap to test reflective granular media to enable future astrophysics

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Program: Spontaneous Concepts

Project Objective:

Typically, the cost of a space-borne imaging system is driven by the size and mass of the primary aperture. The solution that we propose is the Granular Imager (GI): a self-assembled, self-organized granular medium suspension of reflective/refractive material that operates as a scalable, low mass, self-healing, disposable/replenishable imaging system in the visible or microwave bands. Recent work funded by NIAC (now closed) investigated the feasibility of a GI system, concluding that such a system could be built and controlled in orbit, and would lead to a significant reduction of overall mass and cost. This effort is aligned with the 2018 JPL Strategic Plan: "…JPL develops autonomous robotic systems to image distant objects with new telescopes". The GI presents an attractive alternative with its low mass payload and flexible aperture size to provide useful astronomical observations, and has the potential to bring new opportunities for NASA imaging technology for astrophysics, remote sensing, and DoD surveillance and reconnaissance.

Part of our very preliminary experimental work confirmed the feasibility of capturing an image from a reflective granular medium, and provided valuable insight into the process of suspending a stable cloudlet. This initial work was done with a toy small trap that could be used on a desktop with no safety requirements, but this trap has insufficient power to do meaningful optical reflection tests with larger particles. We need to build and test a more capable device with sufficient trapping capability in order to demo the imaging system concept, retire the perceived risk associated with this innovative idea, and strengthen the science pull we need to be able to move forward to the next step in GI technology maturation. This work is new, is not incremental, and represents a critical step to move forward.

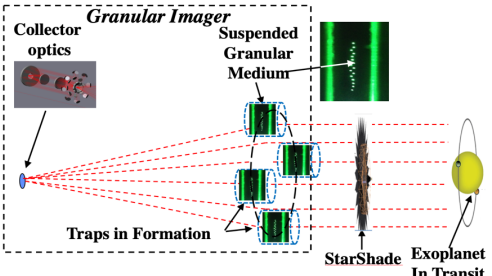
The objective of this task was to build and demo a larger, low-cost table-top electrostatic ring trap (Paul trap) that stably suspends reflective metallic granular medium a few centimeters in diameter. A collimated laser is used to probe the confined medium and reflected light is measured. This demo trap will subsequently be used for optical tests of sizeable reflective apertures.

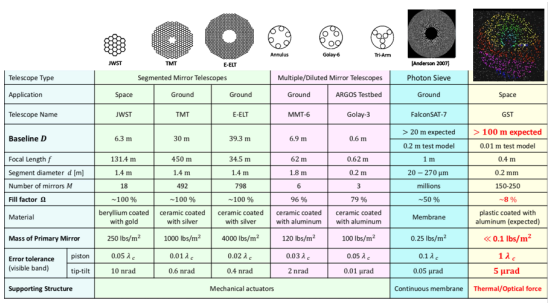
Benefits to NASA and JPL:

- Enable detection of habitable worlds from Sun-Earth L2, in the near IR to visible (0.5 to 2 micron), with an array of apertures scalable to 100m class low-fill factor distributed primary.
- Scalable (modular) apertures of several tens of m based on the GI would enable remote observations of earth from GEO at spatial and temporal resolution sufficient to resolve the evolution of several processes related to weather and the water cycle.

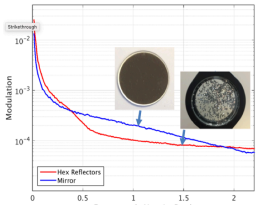
The Granular Imager is an array of a disaggregated collection of granular reflectors that are externally shaped into a primary surface, scalable to km-size apertures.

The Granular Imager could be used to detect and spectroscopically characterize habitable worlds from Sun-Earth L2, in the near IR to visible (0.5 to 2 micron) .



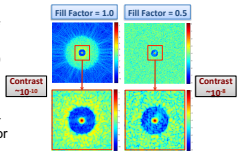


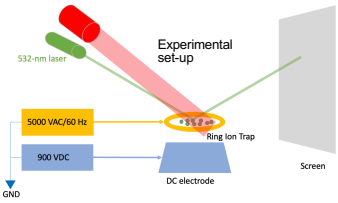
Telescope Type	Segmented Mirror Telescopes			Multiple/Diluted Mirror Telescopes		Photon Sieve	
Application	Space	Ground	Ground	Ground	ARGOS Testbed	Ground	Space
Telescope Name	JWST	TMT	E-ELT	MMT-6	Golay-3	FalconSAT-7	GST
Baseline D	6.3 m	30 m	39.3 m	6.9 m	0.6 m	> 20 m expected	> 100 m expected
						0.2 m test model	0.01 m test model
Focal Length f	131.4 m	450 m	34.5 m	62 m	0.62 m	1 m	0.4 m
Segment diameter d [m]	1.4 m	1.4 m	1.4 m	1.8 m	0.2 m	20 – 270 μm	0.2 mm
Number of mirrors M	18	492	798	6	3	millions	150-250
Fill factor Ω	~100 %	~100 %	~100 %	96 %	79 %	~50 %	~8 %
Material	beryllium coated with gold	ceramic coated with silver	ceramic coated with silver	ceramic coated with aluminum	ceramic coated with aluminum	Membrane	plastic coated with aluminum (expected)
Mass of Primary Mirror	250 lbs/m^2	1000 lbs/m^2	4000 lbs/m^2	120 lbs/m^2	100 lbs/m^2	0.25 lbs/m^2	≪ 0.1 lbs/m^2
Error tolerance (visible band) piston	0.05 λ_c	0.01 λ_c	0.02 λ_c	0.03 λ_c	0.05 λ_c	0.1 λ_c	1 λ_c
tip-tilt	10 nrad	0.6 nrad	0.4 nrad	2 nrad	0.01 μrad	0.05 μrad	5 μrad
Supporting Structure	Mechanical actuators					Continuous membrane	Thermal/Optical force



(Left) Comparison to the state of the art. (Right) Experimentally obtained Modulation Transfer Function of granular lens compared to monolithic mirror.

(Right) Comparison of WFIRST contrast (10^{-10}) with attainable contrast of equivalent granular mirror at 50% fill factor (10^{-8}).





Approach:

A low-cost Paul trap was fabricated that operates at 60Hz and leads to a stable suspension (cloudlet) of charged reflective sub-mm particles. It included a 5-10 kV AC high voltage power supply, a double copper ring arrangement, the necessary (safe) voltage control electronics, but at this stage is not under vacuum, and was placed inside an enclosure to avoid disturbances due to air convection.

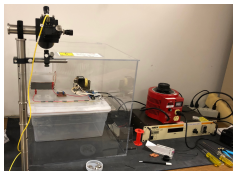
FY19 Results:

- Multiple traps were fabricated and tested
- Conducted numerical simulation in support of design of multi-electrode trap
- Tested efficiency of multi-electrode trap for focusing

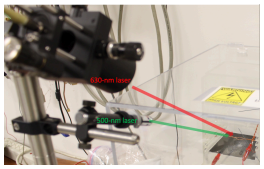
Conclusions:

- The trap stably suspends the granular medium and confines the particles within a flat volume
- Gravity biases the equilibrium and makes tests with the multi-electrode trap challenging
- Conducted preliminary reflection tests of light scattered by the granular medium onto screen and stored images for subsequent analyses.

Future work: Multiple frames of reflected light can be deconvolved to estimate the object under observation

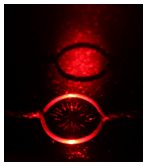


- Experimental set-up

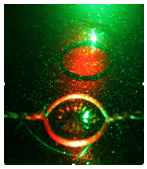


- Trapped ions are illuminated by the red and green lasers.

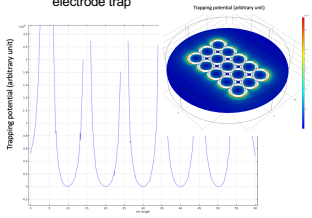
- Trapped ions are illuminated by the red laser.
- VAC = 100 V (Variac), VDC =950 V.

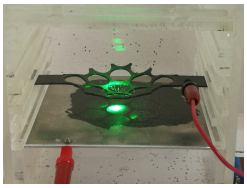


- The green laser only illuminates a small portion of the trapped grains.



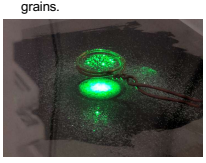
- Numerical analysis of the multi-electrode trap



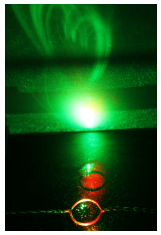


- One of the multi-electrode traps that were tested

- The reflection of the green laser light. The bright green lines are the reflections from the trapped grains.



- A repeatable pattern is observed, and will be analyzed to form images in the next phase.



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