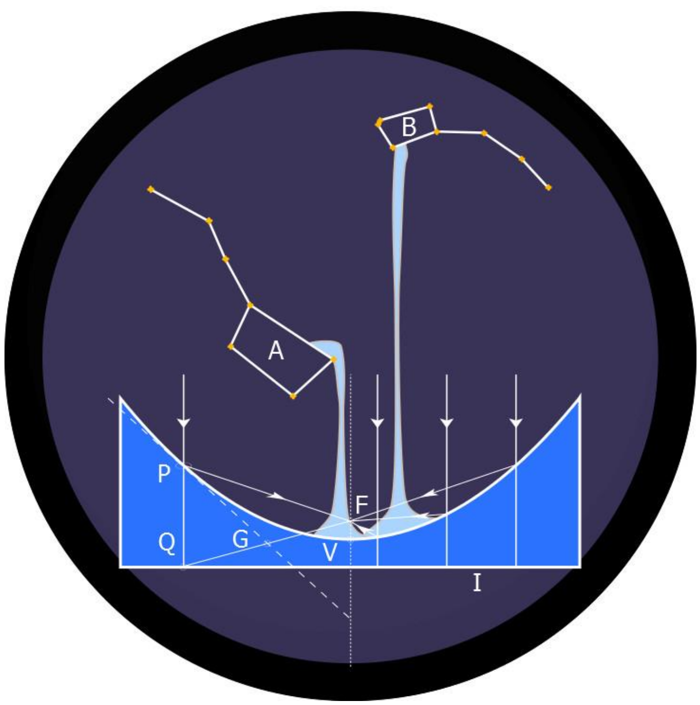
MAG Laboratory

Light Sight

First Technical Report



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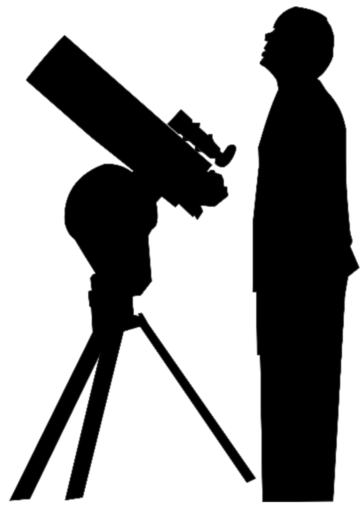

Light Sight's goal is to explore the creation of a lower cost alternative to traditional glass mirrors for telescopes that are used in activities such as the discovery of asteroids. Because the majority of asteroids are small objects in celestial terms, that are moving extremely fast and reflecting very little of the Sun's light back through Earth's atmosphere to its surface, the mirrors used to discover asteroids have to collect as much of that light as possible and effectively reflect that scarce light exactly where it is needed. Traditionally, this kind of mirror is made from large, glass plates that have a surface ground down until it has the required geometry for a reflecting mirror. While this time honed process produces incredibly effective mirrors, the time and costs associated with this technique makes these mirrors relatively expensive. This high cost reduces the number of amateur astronomers who are able to participate in sophisticated activities such as surveying for asteroids.

We want to reduce the cost of the mirrors in these telescopes so that more astronomers are able to afford telescopes that have the capacity to assist with asteroid discovery. In order to achieve this goal, we are utilizing the developing technology of spin-casting epoxy mirrors.

The technology of spin-casting epoxy mirrors hinges on the phenomena that centripetal acceleration of a fluid around a stable axis that is perpendicular to a strong gravity field leads to a naturally smooth, parabolic shape. The discovery of this phenomena and its application to astronomy is not at all new. One of the most common applications of this technology with astronomy is in the creation of what are called liquid mirror, zenith telescopes. have been used to great effect. Most of these types of telescopes such as the Large Zenith Telescope in British Columbia utilize a giant spinning pool of liquid mercury to create a mirror surface. While extremely effective within a narrow range of uses, one major setback with liquid mirrors is that the axis of rotation must be kept perpendicular to the ground. This means that a zenith telescope is essentially limited to only being useful to seeing things that are directly straight up above it. This is not a very effective configuration for the discovery of asteroids.

Spun epoxy mirrors are being explored because whereas the mercury stays liquid, epoxy cures and becomes a solid, usually with an insignificant change in volume. After the epoxy has cured, the epoxy mirror base can be vacuum metalized with aluminum coating for a mirror perfect finish, just like glass typically is. Once the shape has solidified, the mirror no longer has to be kept parallel to the ground and so the telescope becomes a lot more useful because it can be pointed at almost anywhere in the night sky.

In order to most effectively approach this uniquely challenging goal that has a common benefit for everyone, Light Sight is a completely open source project. This makes it easier to join in for anyone who is interested in collaborating, no matter their current skill level.

The Team

Kevin Salvini: Mechanical Design Lead

Malak Salmo: Web Development

Jacob Christ: Electrical Design Lead

Trenton Wilson: Production Lead

Rod Reil: Bookkeeper and Fabrication

Kevin Hsu: Project Web Diplomat

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A Special Thanks to:

Lisa Brodhacker, Dave Rowe, Russ Genet, Paul Hickson, Gerald Lapuz at Polymer Composites, numerous people who stopped to watch us work and pitch in, the great team at SpaceGAMBIT for making this happen, DARPA for additional financial support, loved ones and friends for bearing with our absences, and Isaac Newton

The Affiliated Hackerspace

Makers, Artists and Gadgeteers Laboratory or “MAG Lab”, located in Pomona, California is a hackerspace that formally opened its doors to the public in 2012. Membership is primarily made up of students and professors from nearby colleges as well as local business owners, engineering professionals and retirees who still love to make things. Primarily oriented towards fabrication of physical hardware, members take advantage of tools such a space owned mills, lathes, laser cutters, welding equipment, soldering irons, oscilloscopes and hand tools to work on personal or team projects. Additionally, MAG Lab regularly hosts events such as technology themed parties, hackathons, music shows, robot battles and quadcopter competitions.

The Current State of the Art in the Field of Spun Epoxy Mirrors

Scientists and Engineers have been exploring the potential of spin cast epoxy mirrors for many decades. Over the years, as the goal has passed from team to team, the technology has developed a great deal and the quality of the produced mirrors has steadily increased. However, the level of precision necessary in order to achieve the optical quality required for the discovery of new asteroids cannot be overstated. Lisa Brodhacker, a foremost expert in the field, has been making great progress with her team in recent years. She was able to help the Light Sight team narrow in our limited resources on some particular challenges to tackle in our mission to harness this technology towards our goal of helping amateur astronomers discover new asteroids. It is important to note that regardless if the challenge is singled out below or not, the making of telescope mirrors of the required tolerances is always going to be an exacting challenge whatever material or process is selected.

Primary Existing Challenges

Material Strength:

The great thing about spun epoxy mirrors are not liquid. It is this fact which makes it possible to tilt the mirrors toward almost any direction in the sky. However while cured epoxy may be solid, it is still not remarkably strong. This is why epoxy is most commonly found in composite materials and is not instead applied on its own very frequently. Other materials such as glass or carbon fibers are typically added to give composite materials their great strength.

Even the smallest deflection caused by uneven strain will make the mirrors useless for asteroid detection. One of our major challenges is that because high quality optical mirrors demand such an incredibly smooth surface and that they be made of such highly homogenous material, the actual chemical reaction that occurs during curing must be very carefully controlled in order to achieve the maximum length of molecular bonding. Ensuring the longest possible polymer chains will give the produced mirrors a lot more strength and therefore help prevent distortions that are caused by gravity that would normally occur if the mirror is tilted in any direction or moved very quickly.

CTE:

Managing CTE, or the Coefficient of Thermal Expansion, is certainly one of the most typical concerns when it comes to telescope design and it is no exception with our own effort. Different materials expand and contract in different ways in response to the same changes in environmental temperature. This means that in order to help ensure that our mirrors undergo as close to zero surface distortion as possible, we have to be very careful and deliberate when it comes to selecting our support material and any structural elements that are added to our mirror in order to attach it to the larger telescope assembly.

Design Process

In response to these challenges, it became clear that we were going to have to narrow in on three primary areas of development in order to have any hope of meeting our project deadlines. Those areas were:

- Tight control of our research and fabrication environment
- Thoughtful design engineering of an adaptable test rig for fabricating our mirrors
- Very careful chemical design of our desired mirror base.

Work Environment Design

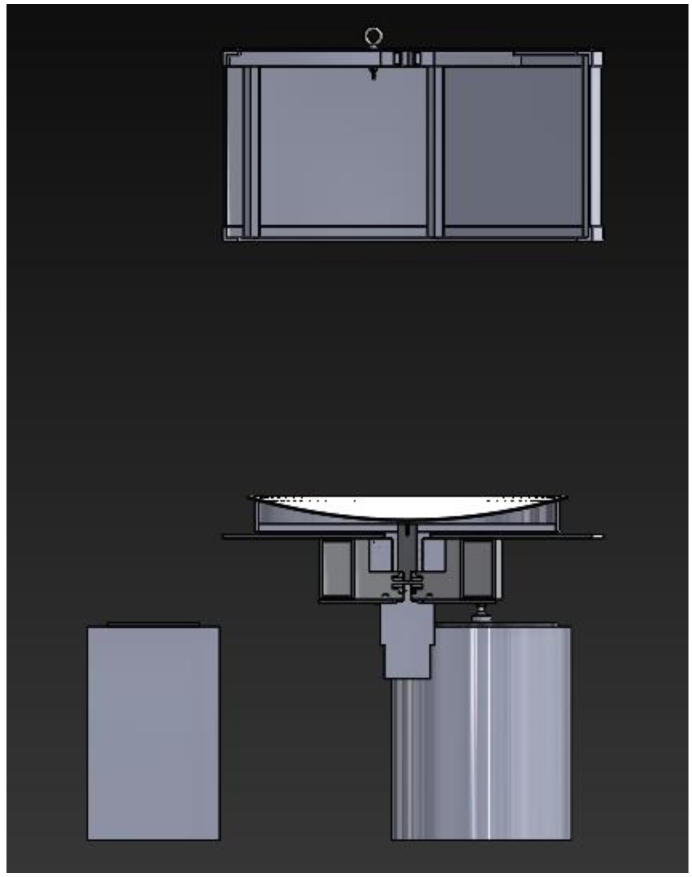
Numerous factors come into play when it becomes necessary to employ very strict control over a production process. In our own case, a cramped, busy, industrial fabrication shop, especially one that sees such a wide variety of use as MAG Laboratory does, could not possibly be a less ideal location for the production of world class optical components. On any given day someone at MAG Lab could be doing any number of different kinds of things such as; doing wood work, welding and cutting, grinding or melting down metal, or spray painting a pumpkin just to name a few things, all within about a 1,200 square feet area. This is all very disruptive to the kind of high precision work that we have been undertaking with this project. For example, the presence of even a few loose Silone molecules from spraying something like WD-40 a few weeks earlier can wreak havoc on precision epoxy processes of this nature.

Our major response to these kind of issues was the development of a side project aimed towards creating a simple, low cost clean room that can be easily assembled and disassembled as needed. So far, this includes using portable HEPA air filter systems to create positive displacement within a large plastic structure. This also includes a changing room and airlock system for dawning masks and bunny suits before entering. This all done in order to minimize the likelihood of outside particles and chemicals disturbing the epoxy curing process.

Work on the clean room is ongoing. As further developments are made in this area they will be shared on Light Sight's blog.

Machine Design

The mirror making machine is the last and most important point where the outside environment must only be allowed to interact with our curing process in exactly the way that we need to insure the best possible quality in our product.



One of the most significant forms of undesired environmental disturbance comes in the form of vibrational energy. In order to minimize outside vibrations our machine rests on three large, independent pillars make up of concrete with a vibration dampening layer of epoxy on top. The machine itself is designed to be extremely rigid. Lastly, the turntable upon which the mirror base is spun is rotated within an air bearing by a shaft that is isolated from a high precision, high torque electrical motor by a magnetic coupler. As a spin off project, a kind of affordable, quick to make, vibration sensor and data logger was developed using an Arduino and a triple-axis accelerometer board was developed in order to help assess the effects of the team's vibration dampening efforts. Separate documentation will be provided for this side project once time allows.

The curing is designed to occur within a chamber that has very carefully controlled temperature essentially, a custom designed, precision controlled oven. This is done so that we are able to maintain as close to an ideal temperature at which the curing process occurs within. This in turn helps to yield the longest possible polymer chains.

One currently unrealized project goal is making so that we are able to pump down the curing chamber in order to facilitate the dissolving out of volatiles from the curing epoxy as well as to help minimize wind shear caused by the discontinuity at the location where the spinning epoxy interfaces with the outside air.

In all, the fundamental design philosophy that we have embraced has been to design and make our mirror making machine in such a way that it is relatively easy to change what we want to do with it. This is because the world still doesn't know what the appropriate process is for making these kinds of mirrors. In order to help our chances of discovering the ideal method, we must be able to change our process many times without driving our project costs beyond our means.

All machine design documentation as well as any relevant bills of material and process descriptions are hosted on the project's website and will be continually developed and updated as we move forward.

Mirror Base Design

The actual fabricated mirror is of course the desired end-product of all this and yet it also remains the aspect of this project that harbors the most unresolved design mysteries. Because we are still in the process of designing and fabricating our prototype mirror making machine, we have not yet been able to test out any of our ideas regarding how the mirror itself should be best designed. As of now, a basic formulation for our epoxy mix has been developed with the assistance of Polymer Composites, a well-regarded local, polymer design and manufacturing company.

Shallow, precision-turned aluminum bowls were designed and fabricated to work as the mirrors super-structure and point of attachment to a larger telescope assembly. However, issues caused by CTE differences are very likely to be encountered. Once again, we will not be able to begin to address these anticipated issues until the mirror making machine is completed. We will then be capable of experimenting with different design ideas.

Documentation of the exploration of these ideas will be hosted on Light Sight's website as we conduct those studies in the future.

The Current State of the Project

Light Sight's project goals are admittedly ambitious by any measure. Mirrors for telescopes that can do asteroid discovery are some of the more sophisticated "simple" artifacts that humanity can make. The required levels of precision are hard to compare to everyday demands. The fact that we are attempting to fabricate these mirrors using an unproven technology only makes this goal all the more difficult to tackle. Given this, achieving all of the critical project milestones within SpaceGAMBIT's reporting timeline would have required a near perfect confluence of events. Unfortunately but perhaps understandably, setbacks have occurred. As our team is made completely of volunteers, talented though they may all may be, there have been times that outside life interfered and team members have been at times unable to fulfill some obligations by the dates required. All of this has stretched the project out. Still even if things are not proceeding according to the original schedule, they are still progressing smoothly on their own timeline and the project remains on budget as expected. Really as has been seen with many other open source projects, the only truly scarce resource ends up being time.

Currently, machine fabrication is on hold in order to allow for some affordable precision machining of a few critical components. Focus over the next month will shift towards a more detailed design and review of our open source cleanroom system. After we finish fabrication of our machine, we will begin the fabrication of our first test mirrors. All remaining funds will be allocated towards the development of prototype mirrors and the fabrication of a beta version of our mirror making machine after additional data has been collected regarding our alpha version's performance.

At the current rate of project progress, an adjusted project time line has the projects expected budget to be exhausted sometime by July of 2015.

Additional Project Outcomes to Date

We believe that one of the most valuable things to come out of this project is the incredible education many of the project's participants have received so far in the fields of optical design and composites. For many, this was the first time that they had ever seriously considered telescope design or working with polymers. Now, many of the team are conversant with terminology at a much higher level. Also, many members of the team have gained some first time experience with processes such as precision machining and systems design.

Also notable, there have already been a few "spin-off" technologies that have come out of our experiences so far. Two examples of this are the open source cleanroom and vibration monitor projects. These projects as well as all similar such side projects that develop in the future will be documented on Light Sight's website.

The Plan Going Forward

To reiterate and elaborate, the plan right now is to use the remaining budget to finish our prototype machine so that we can begin the fabrication of some mirror bases. These bases will need to be vacuum metalized by offsite experts. Then the completed mirrors will be tested and measure against the desired performance specifications. As production issues are identified, solutions will be developed and the appropriate changes to our process or equipment will be made. Further outside experts will be sought out for consultation when solutions are not forthcoming. The current internal project deadline for the successful production of an affordable and reliable mirror with the desire performance specifications is the end of July, 2015. This mirror will then be incorporated into an appropriate telescope as new funding becomes available.

Predicting Future Challenges

One possible but relatively drastic design change at some point will be shifting the mirror's design in order to make it function with an open source active-optics system. This change may be necessary if we end up butting up against some real material limitations. However, such changes are beyond the project's financial capacity at this time.

Additionally, it may be necessary to put even more focus on developing the chemistry of the process than is now anticipated. Should this prove to be the case, an additional teammate with more professional experience in working with polymers will be sought out.