Asteroid Research Data Primer:

A Case Study of one Team in the Exploration of the Moon and Asteroids by Secondary Students (ExMASS) Program

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This document is meant to be a starting point for student researchers when it comes to questions and research techniques in asteroid science. This document was written by the Bellaire High School student team leader during the 2014-2015 school year, Jennifer Wang, and the team's teacher, Mr. Jimmy Newland.

Speaking from personal experience – as a high schooler with a limited skill set and even more limited knowledge base – finding a suitable research topic is one of the biggest challenges presented by the ExMASS research program. The dearth of easily attainable data on asteroids only increases the difficulty. The Jet Propulsion Laboratory (JPL) has wonderful data on a large range of asteroids, but this data is incomplete in regards to most asteroids, because not enough studies have been performed, or some points remain controversial. Presented below is an account of how we acquired a topic and the subsequent data for our project - hypothesizing the former existence of a differentiated protoplanet in the 5:2 Kirkwood Gap between Mars and Jupiter.

To start students off, the ExMASS program has several required readings: a general introduction to asteroids, including information about meteorite types, asteroid formation, mineralogy, relation to meteorites and various other properties. Whereas this information is essential to form a basic understanding, it is mostly facts and history – which is nowhere near detailed enough to help find a research topic. Our team felt that we needed more knowledge on the current state of asteroid research – the techniques and mathematical models used, the ongoing debates, the open questions, and most importantly, the data available for student use.

Our advisor, Dr. Maitrayee Bose, suggested mineralogy as a possible topic. It seemed more promising than topics like orbital evolution, which required extensive computer modeling beyond our current skills. We found no easily understandable data base on the mineralogy of asteroids – the Minor Planet Center site was extremely confusing. After much trial and error, we eventually found a general overview on asteroid mineralogy: Gaffey et al.'s 2002 chapter in the book Asteroids III. I highly suggest including this paper/chapter among the readings, as it provides a concise overview on past history, central questions, basic requirements for justification of a hypothesis, reducing data, interpreting taxonomy, techniques for analysis, current characterizations and implications, and future directions.

Most importantly, this chapter had an extensive data chart on properties of a few characterized asteroids, including semi-major axis, diameter, family, and predicted mineralogy. The chart alone didn't magically spark any insights, and we spent a long time (on Google Scholar, ScienceDirect and Researchgate) slogging through as many papers about any asteroid, any mineralogy, any family. Due to a lack of knowledge we often found ourselves looking up about two words in every single sentence. Emotional breakdowns ensued, until one day I came across Fieber et al.'s 2013 paper on plausible parent bodies for a few asteroids in the 3:1 Kirkwood Gap. A single diagram in this paper, showing the expected mineralogy of parent bodies, caught my eye: I noticed that the core, mantle and body of a differentiated parent body corresponded to NiFe, olivine and basaltic mineralogies, or M-, A- and V-type asteroids, respectively. I did not dare to seriously consider this yet, but I thought if one were to find several of these asteroids in the same area, perhaps a hypothesis could be made about the parent body. I immediately went back to the Gaffey chart, and lo and behold, there are several M- and A-type asteroids, all in the 2.6-2.9 AU region. The placement near the 5:2 Kirkwood gap was extremely exciting. Perhaps we could hypothesize about how this parent body was disrupted?

We still needed to find some type of basaltic material corresponding to the crust, but formerly, all V-type asteroids were imagined to be related to 4 Vesta, which was a different parent body far away from the 5:2 Kirkwood Gap. Suddenly I recalled a paper I read around 3 weeks ago, about 1459 Magnya, a V-type asteroid that was hypothesized to NOT originate from Vesta due to orbital distance. I looked up the semimajor axis (~3.14 AU), which was a little far from the original values of around 2.6 to 2.9, but still promising.

But we were far from done.

I had to make sure that this kind of hypothesis was actually reasonable. Imagine my delight when I found a close description of my idea (using M-, A- and V-types to hypothesize about a parent body) from Burbine's (1996) Battered Mantle paper, no less, and also providing an explanation for the dearth of A- and V-type materials due to space weathering.

We needed a more concrete justification than just orbital placement and taxonomy from a paper: I wanted a scientific model to explain and determine mineralogy. Thus I read the Fieber et al. (2013) paper in more detail, and it mentioned the same equations I saw in Gaffey's chapter (2002) – equations relating band center to mineralogy in mafic silicate asteroids, which was exactly what we needed to confirm the composition of V-type asteroids. A bit more trawling through Google scholar revealed that Reddy (2011) had similar equations for olivine- dominated asteroids – also applicable to A-types. By emailing our advisor Dr. Bose, we confirmed these equations were in fact applicable to our situation; much rejoicing ensued. Another paper by Hardensen (2003) confirmed that the M-type asteroids we chose were metallic and anhydrous, allowing them to be core material.

The most crucial challenge: we needed far more data. We only had around three M-types, four A-types, and one V-type that had dubious orbital data. To use the linear calibrations, we needed to find band centers of these asteroids – preferably both Band I and Band II for V-type and at least Band I for A-type (because of absorption features at 0.9 μm and 2.0 μm for pyroxene and 1.0 μm for olivine).

This was where we hit a wall of sorts. There isn't the same volume of asteroid data that is available in the lunar research world. There was no easily accessible database providing band center along with semi-major axis. I had to painstakingly find asteroids of the expected taxonomy within the range we proposed (this is where the JPL database proved insufficient – had to find actual research papers like Harderson's (2003) about 1459 Magnya), and search up related research papers in the hope they contained corrected band center data, since we did not know how to do data reduction directly from asteroid spectra. It was a little bit like searching for a needle in a haystack by throwing individual strands out one by one. Eventually, in addition to the Magnya paper, I found Solontoi et al's 2012 survey, Moskovitz's 1991 study about asteroid 10537, Roig's 2007 paper about the relation of asteroids 21238 and 40521 to Vesta, Burbine's (2008) data about Magnya and asteroid 21238, and various other papers to prove the V-type asteroids used were not related to 4 Vesta (Duffard, 2004 and Moskovitz, 2008). The whole process was extremely frustrating and took around one month; we read ~40 papers in all. Results were mixed – sometimes we found only one band center (in which case I used Burbine's linear calibrations instead of Gaffey's), sometimes none at all; but by and large, what we found confirmed the mineralogy we expected and we were able to continue our research.

More challenges ensued – how to design our poster, how to phrase an abstract, how to explain the current position of these asteroids using the Grand Tack/Nice Model (which, I might add, we originally got wrong, until having one of the judges point it out and reading a chapter about dynamical evolution of the asteroid belt by Morbidelli et al.). All of these challenges would not have been possible to overcome without the extensive advice and mentorship of Dr. Bose, the supervision of our teacher Mr. Newland, the help of our judges and the program managers, and last but not least, my beloved teammate minions.

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Other Useful Asteroid Data Sources

Asteroid Albedos: http://sbn.psi.edu/pds/resource/albedo.html

CALL Asteroid Lightcurve Database:
http://www.minorplanet.info/lightcurvedatabase.html

IAU Minor Planet Center: http://www.minorplanetcenter.net/

NASA Planetary Data System – Small Bodies Node: http://sbn.pds.nasa.gov/

SDSS-based Photometric Taxonomy for asteroids:
http://sbn.psi.edu/pds/resource/sdsstax.html

Sloan Digital Sky Survey - Using SDSS to find asteroids:
http://cas.sdss.org/dr6/en/proj/basic/asteroids/

Vesta Trek: http://vestatrek.jpl.nasa.gov/

References

A more detailed list of references is available upon request; please email exmass@jayfox.net for this list.

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