Mini-MAGGIE: CubeSat MAGnetism and Gravity Investigation at Europa.
B. Burgett[1], J. Long[1], P. Whaley[1], A. Raz[1], R R. Herrick[1], D, Thorsen[1], P. Delamere[1], [1] University of Alaska: Fairbanks, Fairbanks, AK 99775 (bjburgett@alaska.edu)

Introduction: CubeSats are an evolving technology that promises to enhance planetary missions in the near future at a fraction of the cost of traditional satellites. These micro-satellites can accompany the larger, more expensive primary satellites on their mission and provide extra methods of measuring and returning science data. This document outlines a CubeSat mission to fly with the proposed Europa Clipper mission that will help characterize the magnetic field and gravity around Europa.

Mission Concepts: Our concept study was initiated before NASA settled on the current multiple-flyby concept for the primary mission, and parameters for the concept study allowed placing the CubeSat into Europa orbit and it could be up to 3U in size. Consequently, we considered both orbiting and flyby concepts. We detail the different orbits that are proposed and what technology is required for each situation. The scientific measurements for each of missions do not change but the orbit does affect the amount of data that can be delivered overall.

Orbital Selection: The first and most ambitious orbit is a polar orbit around Europa itself. The Mini-MAGGIE would perform its measurements at approximately 200 km above the surface. In order to insert itself into this orbit, a 2.5 km/s orbit insertion burn would have to be performed. In orbit the satellite would deploy its solar panels and begin monitoring the magnetic field. As the Europa Clipper performs a fly-by, the Mini-MAGGIE will return its magnetic data measurements. Doppler measurements will be made between the Mini-MAGGIE and the Clipper to help determine the gravitational field of Europa. When the Clipper receives the data from the Mini-MAGGIE it will downlink it back to earth for analysis. Of the three mission scenarios, this option provides the most data at the most risk because it constantly measures the magnetic field in proximity to Europa as opposed to the other scenarios where only fly-bys are completed.

The second scenario is a tag-along orbit with the Clipper separated by approximately 1000 km. Around 6 days prior to the desired fly-by with the Mini-MAGGIE, the Clipper will eject the CubeSat in the wake direction 2 m/s slower than its current speed. Once the 1000 km distance is achieved the Mini-MAGGIE will adjust its velocity to maintain its distance. Once the CubeSat is within 8000 km of Europa it will begin taking magnetic field measurements. These measurements are separated spatially and temporally from the Clipper measurements and will help constraining the 3D, time-varying nature of Europa's magnetic field. While the Clipper and Mini-MAGGIE are communicating, Doppler measurements will be made to facilitate the gravity analysis. The gravity measurements require that the Mini-MAGGIE be on the order of hundreds of kilometers from Europa as opposed to the 8000 km when starting the gravity measurements which means that the gravity measurements will only be taken for a small amount of time compared to magnetic field measurements.

The final scenario in similar to the second, only with two 1U CubeSats that will be separated from the clipper at 500 km and 1000 km. All characteristics of this mission are the same as the original fly-by option with the exception that there is an additional CubeSat. This allows more analysis of the variations of the magnetic and gravitation fields with the addition of the new data point provided by the second CubeSat.

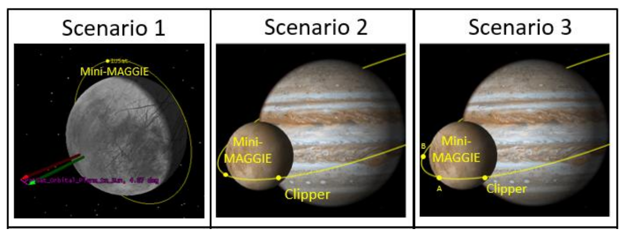

Figure 1: Different Orbits are Proposed with Different Benefits and Requirements

CubeSat Design: As a part of the CubeSat design goals, we wanted to conceptualize a mission that would be run by students and stay in the budget of a university. As such, existing components are heavily relied on to avoid the overhead costs of developing new technologies. Among these are the X-Band transponder developed at Jet Propulsion Laboratory and Magnetometer developed by Imperial College to return the scientific payloads. Figure 1 shows the overall mission architecture of the proposed Mini-MAGGIE.

X-Band Transceiver: The proposed mission requires significant capabilities from the transceiver used. It must have minimal frequency drift and phase noise and be of high enough frequency to give an accurate indication of distance since the precision of the measured distance will be dependent upon the wavelength used. For this purpose it has been determined that the transceivers developed at JPL dubbed the Low Mass Radio Science Transponder (LMRST) [1] and Iris [2] are the top items that will enable the missions.

LMRST is currently in orbit around earth to help calibrate the DSN and is shown to work on current CubeSats. Iris is soon to be on its way to Mars on the upcoming 2020 mission. Both of these systems operate at X-Band, giving high precision distance measurements along with very stable frequencies to support this. In addition to this, Iris is soon to be getting a Ka-Band extension increasing its capabilities even more when it comes to data rates and Doppler measurements. Each of these satellites has been developed for CubeSats, with the LMRST coming in at 1 U and Iris at 0.5 U. These radios are compared in Table 1.

Table 1: Comparison of Radios for the Different Missions

Transceiver	LMRST	Iris V2
Size	1 U	0.5 U
Mass (kg)	0.5	0.5
Bus rails (V)	8	8
Input Power (W)	8	13
RF Output Power (dBm)	20	28

In order to make the gravity measurements, one must be able to account for how the space ship is moving and other offsets to the Doppler data that is obtained from the radio measurements. To facilitate this, both the radios are capable of range finding. To find the orientation of Mini-MAGGIE with respect to the Clipper we propose that a small phased-array antenna be used on the main Clipper spacecraft to determine angle of arrival. This would provide the required angle and distance position to determine where the Mini-MAGGIE is relative to the Clipper.

Magnetometer: The magnetic field in the area around Europa is primarily made up of the induced magnetic field from the time varying field around Jupiter. The ionosphere and atmosphere of Europa also interacts with the magnetospheric plasma to create perturbations in the more steady time varying fields. [3] To measure the magnetic field around Europa, Mini-MAGGIE will require a resolution of less than 10 nT at a rate of 8 vectors per second. Two magnetometers have been identified for the mission with the more suitable component being termed MAGIC from Imperial College. [4] A comparison of the two magnetometers is shown in Table 2. MAGIC is the preferred instrument due to the power and size constraints in the CubeSat environment.

Propulsion: Inserting the CubeSat into orbit is not currently possible with existing technology. The Micro-Electrospray Propulsion [5] may provide enough thrust to enable a tag-along spacecraft to travel with the Clipper for multiple flybys. This comes at the cost of significant power (28 W) and will take up 0.5 U of space.

Table 2: Comparison of the MAGIC and Compact Helium magnetometers.

	MAGIC	**Compact Vector-Helium**
Developer	Imperial College	JPL
Bus rails (V)	3.3, 5, 17	
Power (mW)	425	4000
Mass (g)	104	500
Volume	Sensor head: 10 cm^3, Electronics: 9 cm x 9.6 cm x 2 cm	~10 cm x 10 cm x 5 cm
Resolution (digital)	0.22 nT	
Sensitivity	< 2nT	
Calibrated accuracy	2 nT	
Noise density	150 pT $(Hz)^{1/2}$ at 1 Hz	
Stability		< 10 pT
TRL	flown on CINEMA	manifested on INSPIRE

Conclusions: Scenario 1 is not feasible with the current Clipper mission concept. The second scenario with the tag along CubeSat is perhaps feasible with a propulsion unit to enable multiple flybys. The third scenario would only enable one flyby, but the individual CubeSats could be placed at distances that optimize both the LOS Doppler and magnetic measurements. In each case the Mini-MAGGIE would be designed with radiation hardened components to be able to survive in the harsh environment.

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