THE FEMTOSPACECRAFT ASTEROID IMPACT MISSION (FAIM): A LOW COST MISSION TO MONITOR THE DART IMPACT ON THE DIDYMOON

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Introduction: 63803 Didymos is a binary near-Earth asteroid which will make a close approach to Earth in early October, 2022. Observations show that the Didymos primary is roughly spherical with a diameter of $\sim 800$ m [1, 2, 3], while the secondary, the “Didymoon”, is roughly 150 m in diameter with an orbital period of $\sim 11.9$ hours and an orbital radius of 1.18 km.

The ESA Asteroid Impact Monitoring (AIM) mission [4] was intended to rendezvous with the Didymos system as one component of the Asteroid Impact & Deflection Assessment (AIDA), mission, a planetary defense test [5]. The other AIDA component, the NASA Double Asteroid Redirection Test (DART) [6], is intended to impact the Didymos in October, 2022, demonstrating the effectiveness of kinetic impactors for asteroid deflection. The DART impact is expected to change the Didymoon velocity by $0.3 \beta$ mm s$^{-1}$, where $\beta$ is a scale factor between the momentum of DART and the Didymoon post-impact momentum change. $\beta$ is expected to be $> 1$ due to the effects of impact ejecta; determining the impact $\beta$ is a primary goal of the AIDA mission.

On December 2, 2016, ESA announced that funding was not approved for the AIM mission; shortly thereafter NASA announced that work was continuing on the DART impact mission. While the combined AIDA mission was designed so that the DART planetary defense test could go forward even without AIM, there is no question that the goals of AIDA would be enhanced by having in situ observation of the results of the impact.

Here, we show that the core programmatic goals of AIM can be met with a relatively low cost Femtospacecraft Asteroid Impact Mission (FAIM), a 6-U “Bradbury” CubeSat deploying a swarm of dozens of 50-gm “Pixie” femtospacecraft. FAIM would also provide scientific information about the Didymos system, and an opportunity to expand the technological readiness of small spacecraft for asteroid exploration and mining.

The Pixie Femtospacecraft: The exploration of the Solar System can be enhanced by the use of femtospacecraft, small autonomous units which can be used to provide multiple observation points or in hazardous environments (such as near the DART impact) where there is a risk of loss of individual nodes. The first femtospacecraft sent into space (in 2013) were the “KickSats” developed at Cornell University [7]. These KickSats were stateless, having no battery, long-term memory or ability to receive commands, and reviving in a default configuration every time sufficient solar power was available.

In order to meet the more demanding requirements of operation in deep space and to create true spacecraft swarms to meet various operational goals, Asteroid Initiatives LLC is developing the Pixie femtospacecraft (see Figure 1). A Pixie is 80 x 40 x 9 mm with a mass $< 50$ grams, includes a battery and a variety of instruments, and is intended to operate in a swarm with other spacecraft nodes (Pixies or otherwise) within communication range.

The assumption for FAIM is that the requirements of AIDA would require swarms of femtospacecraft, accepting the risk that a substantial fraction may be lost at deployment (due to failure to land on the Didymoon surface) or during the DART impact phase (when nodes might be buried by debris or even ejected from Didymoon surface).

In order to operate as a single unit spacecraft swarms must be able to perform data fusion and ideally distributed information processing, and in many cases may need to perform internal swarm positioning and external communication fusion as well. To act as a Swarm, the Pixies must collectively:

- Aggregate: Determine which swarm members are within reach and establish an ad-hoc communications network encompassing them.
- Observe: Collect and share data from the aggregated swarm.
- Distill: Convert the analyzed data into a higher-level summary.
- Communicate: Report the high level data summaries to Earth.

The FAIM femtospacecraft deployment would advance the technology of such sensor networks for asteroid spectrums, would test innovative means of networked communication over the surface of an asteroid, would provide fine-grained information about the surface properties of the secondary, and would provide important insight into the reaction of the secondary to the DART impact.

Scientific and Planetary Defense Objectives: The Didymos primary appears to have been spun up by Yarkovsky-O’Keefe-Radzievskii-Paddack (YORP) radiative torques [8], with the primary currently rotating near the predicted rotational disruption spin rate, and the secondary presumably resulting from material disrupted from the primary. The Didymoon is thus highly
unlikely to be monolithic, but instead can expected to a poorly consolidated “rubble-pile” [9], which will complicate its response to the DART impact.

The small asteroids explored by spacecraft and radar to date largely have surfaces with very few impact craters, presumably smoothed out by seismic shaking after a large impact [10]. Recent work [11] indicates that seismic shaking from impacts can be more severe than previously indicated; characterizing this shaking, and material transport associated with it, are important goals of FAIM.

In the proposed mission, the Bradbury CubeSat would be a femtospacecraft carrier with propulsion by either a solar or an electric sail. After rendezvousing with Didymos, this CubeSat would deploy its Pixie femtospacecraft near the Didymoon L1 or L2 Lagrange points, where there is a high probability of low velocity deployments impacting the Didymoon surface [12]. The Bradbury would then proceed to leave the Didymos system and observe the DART impact remotely.

Scientific and planetary defense goals for FAIM include

**Approach:** The Bradbury would take pre-deployment images both for optical navigation and to provide pre-impact geological context of both Didymos and the Didymoon.

**Descent:** Deployment by ballistic descent would take at least an hour, providing an opportunity to estimate the mass of the secondary through mutual tracking of the femtospacecraft swarm. The scientific goal of this phase is the measurement of the mass of the secondary to ~1% or better, limited by measurement accuracy and solar radiation pressure on the femtospacecraft.

**Surface Anchoring:** The experience with the bouncing of the Philae lander shows the difficulty with landing spacecraft in a microgravity environment. We propose the use of a Microgravity Electromagnetic Anchoring System (MEMAS) system [13] to attach the Pixie femtospacecraft to the surface of the Didymoon, and to validate this anchoring technology for further use in microgravity.

**Pre- and Post-Impact Rotational Dynamics:** If the Didymoon is an synchronously rotating ellipsoid then it may undergo forced librations due to orbital perturbations [14] and the DART impact is likely to excite free librations in either latitude or longitude, depending on the location of the impact and the angular momentum carried by impact ejecta. A scientific goal of FAIM is the measurement of rotation rate with a precision better than 1 deg/hour.

**Post Impact Seismology:** The seismic shaking after the DART impact might last for 1 or 2 hours [10]. A scientific goal of FAIM is to measure this shaking at multiple locations with accelerometers with an accuracy of $10^{-3}$ m s$^{-2}$ / $\sqrt{Hz}$ or better.

**Pixie Astrometry:** At the time of the DART impact Pixie transmissions could be used as a source for differential Very Long Baseline Interferometry (VLBI) observations from Earth. The scientific goal would be to provide astrometry good to 10 m in transverse position, sufficient to determine the velocity $\beta$ at the 10% level within 3 days of the DART impact.

**References:**