WHY WE SHOULD, AND SHOULD NOT, VISIT APOPHIS. A. S. Rivkin[1] [1]JHU/APL (Laurel, MD, USA, andy.rivkin@jhuapl.edu)

Introduction: The asteroid (99942) Apophis will make a very close approach to the Earth in 2029, as is well-known by asteroid scientists, planetary defenders, and others. This upcoming close approach provides an obvious impetus for considering missions to Apophis, and an obvious urgency for making decisions. Close approaches by objects the size of Apophis are thought to happen infrequently—this will be the closest recorded approach of an object this large, and we might expect to go 1000-2000 years between such approaches.

However, the existence of an opportunity is not by itself sufficient reason to pursue that opportunity. Given the limited resources typically made available for planetary exploration by the world's space agencies, the infrequent cadence of mission selections, and competing priorities of other planetary science communities, advocates of an Apophis mission will need to identify three things:

1. What community priorities can *only or best* be accomplished via an Apophis mission?
2. What community priorities *cannot be or are poorly* accomplished via an Apophis mission?
3. What community priorities *could but maybe shouldn't* be accomplished via an Apophis mission?

Agreement among advocates about these points will naturally lead to the form and goals of an Apophis mission, and greatly improve the chances of such a mission taking place.

Group I: What Can Be Done: While the US planetary science community is beginning to reconsider its community priorities via our Decadal Survey process, we can still identify what an Apophis mission can most effectively accomplish, at least in theory:

1. Detailed dynamics: The position of Apophis is of obvious interest to scientists (and humanity), and it spends long periods at small solar elongations (over 93% of the period from 2000-2040 is spent at solar elongations < 90°) and difficult to observe. Furthermore, it is not in principal-axis rotation and its rotation rate could change as a result of the Earth encounter in 2029, though the degree of change is not well understood [1,2]. A transponder or transponder network (or equivalent) could provide positional data both for "space situational awareness" and also plausibly could provide rotational data to improve understanding of how NEO spins, and tumbling asteroids, evolve.
2. Detailed remote sensing: Given its status as one of the most hazardous asteroids, there may be justification for an initial reconnaissance for purposes of understanding it in case mitigation is deemed necessary in the future, or merely as an exercise to consider how an object like Apophis might best and most safely be deflected. Such reconnaissance would likely look a lot like the NEAR Shoemaker, OSIRIS-REx, or Hayabusa 1 or 2 mission operations, excepting the sample return aspect of the latter missions. Shape, mass/density, and surface rock fraction all have direct relevance to mitigation issues [3,4].
3. "Comparative asteroidology": Apophis is roughly the same size as Itokawa, and both have spectra indicating similar ordinary chondritic (OC) compositions [5-7]. The DART and Hera missions to the Didymos system will provide in-depth information about additional OC objects that bracket Apophis in size. Itokawa, Didymos, and Apophis are all potentially-hazardous asteroids (PHAs), and comparison of their surfaces and surface processes will be important as we try to understand which aspects of asteroid evolution are deterministic and which are more random.

Group II: What Can't Be Done: In contrast, an Apophis mission will provide no progress, or effectively no progress, toward answering other questions about asteroid science. For instance, Apophis is likely to be generally volatile-poor, making Apophis of limited interest for addressing volatile-related questions (like those under Objective 1.3 of the Small Bodies Assessment Group Science Goals Document: [8]). Rather than enumerate the long list of what can't be done at Apophis, I merely note that compelling Apophis mission concepts will not overreach and try to be all things to all people.

Of particular note, however, are proposals to study large-scale resurfacing of Apophis caused by Earth's gravity during the 2029 encounter. In theory, such studies fall into the category of "what can be done", but the current state of the necessary instrumentation suggests that the tidal forces experienced during the encounter may lead to seismic signals below the detection level of the type of payloads typically under consideration [2,9], and that any resurfacing may be limited in extent [10] with YORP or thermal degradation playing a larger role in asteroid resurfacing than tidal forces [11,12].

Group III: What Shouldn't Be Done: Perhaps the most fraught category, and the one where the most care must be taken, is that of investigations that *could* be done at Apophis, but are ill-advised. A cursory consideration of those investigations suggest they include the following, among others:

1. Mitigation demonstrations: We must, in the spirit of the Hippocratic Oath, first do no harm. All evidence suggests that while Apophis is among the most threatening known asteroids, it does not actually cross the threshold to being dangerous in an absolute sense. We know it will miss the Earth in 2029, and attempting to change its orbit prior to that safe passage would be considered in PR terms reckless at a scale that is unprecedented in human history. *This would be true even if the proposers could "guarantee" that the experiment wouldn't lead to an impact.* This would include missions that carried out the gravity tractor technique, or that incidentally carried out the gravity tractor technique during a period of extended operations. Given the nature of the "keyhole" resonances in the vicinity of Apophis' orbit, any gratuitous orbit changes subsequent to the Earth encounter might also cause general alarm.
2. Similarly, anything that might be thought of as possibly changing the orbit of Apophis whether or not it was done as a mitigation demonstration is also a certain "non-starter" in PR terms. This could include active seismic experiments, and could even be seen as including surface sampling if selecting officials and/or the public are sufficiently skittish.

We must similarly be aware that those UN-related entities relevant to NEO issues (the Office for Outer Space Affairs, Committee on the Peaceful Uses of Outer Space, Space Mission Planning Advisory Group, etc.) may find an Apophis mission of particular concern. Understanding the relevant legal issues and political sensitivities ahead of time would lower the likelihood of roadblocks to an Apophis mission.

Implications: The best-motivated Apophis missions will draw their investigation goals from Group I above, while not diluting their work with items from Group II and staying far from Group III. This seems straightforward, but mission concepts might run afoul of these suggestions by proposing to include elements that stray into Group III while attempting to address Group II goals. For instance, if the tidal forces during the 2029 encounter are insufficiently strong to allow detections on an Apophis-wide sensor network, there may be a temptation to use active sources to obtain the desired data. Similarly, it might be tempting to include a Hayabusa-2-style impactor on a mission with a goal of studying resurfacing by tidal forces, again just in case those tidal forces are insufficiently strong to do the job unaided. I would argue that in both of these cases we are better served by visiting a completely different asteroid and carrying out those active experiments.

Summary: The upcoming close pass of Apophis provides an impetus for a mission. For such a mission to be compelling, it must focus on goals that are uniquely or best achieved at Apophis and serve to reduce anxiety about asteroid impacts rather than increase that anxiety.

References:

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