Comments for the Final ARM Report by FAST

by
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The report is very well written with appreciated detailed analysis of the various relevant issues. As you may know, I strongly push for any mission that aims at interacting directly with a small asteroid, either for sampling, performing an impact (in both the high and low speed regimes), deploying a seismic experiment or other packages devoted to the understanding of the mechanics in a low-g environment. Without such direct interactions, our understanding on how small body's surfaces behave, respond to external actions, and evolve will remain based on many assumptions. ARM and its other potential investigations greatly serve this purpose. Plus, its target 2008 EV5 is very intriguing.

I give below some comments and suggestions, in case they can help (you can disregard them at will).

Executive Summary, Section 1. Origin

Page 5 : When it is stated that 2008 EV5 started as part of a much larger parent body and migrated inward, it would be good to specify that it was first extracted from the parent body by its catastrophic disruption and that this extraction process may have formed EV5 as a rubble pile (so that one already introduces the idea that it is a rubble pile, based on various other arguments). One could then say :
« … as part of a much larger parent body that experienced a catastrophic disruption. As a result, 2008 EV5 may have been produced as a re-assembly of ejected fragments, as suggested by numerical simulations of catastrophic disruptions (e.g. Michel et al. 2001, Science 294, 1696-1700) that indicate that most bodies larger than hundred meters produced during such events are not intact fragments but rather rubble piles formed by reaccumulation of smaller pieces due to their mutual attractions. »

Executive Summary, Section 2. Boulder distribution

Page 5, first bold question.
I would put a word of caution, as done for the second bold question, when the difference between EV5 (weaker rocks) and Eros/Itokawa is well indicated. It may be that EV5 contains some microporosity (in addition to macroporosity), which is not the case of Eros and Itokawa, and that its surface responds mechanically in a very different way (with compaction processes at play, due to pore crushing). Thus, the analogy with Eros and Itokawa must be done with this in mind …

Executive Summary, Section 3. Surface geotechnical properties

It is stated that it its likely that the surface should be fairly uniform (in terms of porosity and acting processes). I'm not sure whether by target, you mean the rock to be sampled or the whole asteroid. In the later case, this may not be true. As stated elsewhere, because of its top shape and other dynamical properties, it is possible that the equator is richer in regolith than the pole (at least, that some regions are richer than others), and I don't see any rational for a uniform distribution. Moreover, it is not obvious either that the surface as more porosity than the interior. Suppose that it is made of a few irregular blocks, then it's interior would contain a lot of void space, while the surface, if rich in regolith, may have experienced compaction because of impacts or thermal compactions. In fact, although this is a passionating subject (asteroid geophysics), I don't see where this section is going … All we can say is that it is likey that boulders will be present, and there are good arguments to assume that cohesive forces may be at play, although this deserves more modeling.

Executive summary. Section 4. Boulder physical properties

Page 8: When comparing with meteorite strength data and stating that this data is sparse on a number of important types, another weakness of this comparison should be stated. It would be good to point out that the meteorite collection is very likely to be biased towards the stronger materials that evolve in space. Fragile materials are lost in the atmosphere, and this is probably why most compressive strengths of meteorites (except Tagish lake), in particular primitive ones, are higher than terrestrial rock materials. A good example is 2008 TC3, which lost most than 99% of its mass in the atmosphere (probably the most fragile part. Moreover, the rock that is expected to be taken by ARM is much larger than meteorites, and we have indications that the larger the rock the weaker it is (in the strength regime) due to the highest probability of large fla presence. But in addition to the weakest link approach (at the heart of the Weibull flaw distribution in rock pieces, the biased towards stronger materials in meteorites should be noted, that also justifies that a weaker strength should be assumed.

FAST response to ARRM project questions

Page 17, on the origin

When mentioning the catastrophic disruption event that resulted in a highly fractured or shattered object (rubble pile), this is not enough. In fact a shattered object is not necessarily a rubble pile (maybe you know the debate about Eros …). I would rather say:
" … in a highly fractured or shattered or aggregated object (rubble pile)"
(I prefer "reaccumulted" to "aggregated" but I'm not sure non-expert people would understand; also, for the aggregated/reaccumulated scenario, you can point to my Science paper in 2001, as an example if you want).

Page 21-22, Boulder Distribution

At the end of page 21 (beginning of 22), regarding whether Eros and Itokawa are representative of the asteroid population and that comparisons with Bennu and Ryugu will allow us to verify this, I'm not sure we should conclude too rapidly based on this comparison, or that this is the right way to approach the problem. Bennu and Ryugu are B/C-type objects, while Eros and Itokawa are S-types. So, even if they may be different, this may be because of different material properties due to their different types. So, the literature of Eros and Itokawa may still be extrapolated to other NEAs belong to the S type, even if Bennu and Ryugu are different. We would need to see other S-types to determine whether there's a common trend for these type (for objects of the same size, because the gravitational environment has an important effect, explaining at least part of the differences between Eros and Itokawa).

So, I would rather say that thanks to Hayabusa-2 and OSIRIS-REx, as well as Eros and Itokawa's data, we'll have a more complete picture of asteroid properties for the two main taxonomic types in the NEA population. (without talking about representativity).

Page 23, firs paragraph, there's seem to be a format problem as this is the same paragraph as the one I just talked about (or is it my printer?).

Page 24, last paragraph: here the only source of boulders that is indicated is impact cratering. I would again put a word of caution, as this assumes that ejection speeds are low enough that they fall back, which depends on many things because in principle, due to the low escape speed of the body, it is hard to retain a lot of material (which is an issue for Itokawa etc … although I made a work showing that these boulders may be part of the reacumulation process that formed Itokawa; Michel and Richardson 2013, AA 554, L1-L4). Other mechanisms could also be related to seismic shaking that may trigger the Brazil Nut Effect, leading to the rise of big interior boulders to the surface (under investigation; see e.g. Matsumara et al. 2014. MNRAS 443, 3368-3380). So, this is just to say that the description in this paragraph relies on many non-obvious assumptions.
I would rather just say that: "the distribution of boulders around an irregularly shaped bodies require much more analysis to estimate, as it depends on the processes at their origin and other dynamical considerations."

Surface Geotechnical properties

Page 30, paragraph in the bullet "What is the expected range of surface compaction …"

I have the same remark as in the Executive Summary: I repeated it here. I'm not sure whether by target, you mean the rock to be sampled or the whole asteroid. In the later case, this may not be true. As stated elsewhere, because of its top shape and other dynamical properties, it is possible that the equator is richer in regolith than the pole (at least, that some regions are richer than others), and I don't see any rational for a uniform distribution. Moreover, it is not obvious either that the surface as more porosity than the interior. Suppose that it is made of a few irregular blocks, then it's interior would contain a lot of void space, while the surface, if rich in regolith, may have experienced compaction because of impacts or thermal compactions. In fact, although this is a passionating subject (asteroid geophysics), I don't see where this section is going … All we can say is that it is likey that boulders will be present, and there are good arguments to assume that cohesive forces may be at play, although this deserves more modeling.

Page 31: Caption of Figure 5, there's a typo in Macroporosities. Also, note that I don't think we can rely say that the fraction of porosity is purely at macro-scale. I find a hard time to believe that 60-80% porosity can be sustained by large voids only. As long as we don't have direct measurements of an asteroid internal structure, we cannot certify what kind of porosity is present. I think a paragraph explaining that micoporosity and macroporosity may be present in some asteroids, and explain the difference would be interesting for the reader, specially because it may be relevant for 2008 EV5.

Page 31, first paragraph: it is stated that the cumulative size distribution of coarse and fine regolith is expected to have a power-index of d^-2.8. I would rather give a range of possible power-law exponents. For the same reason as stated above, the material properties of EV5 may be very much different from that of Itokawa, and even under the same processes (impacts, thermal cracking etc), different outcomes may be expected in terms of size distribution from those on Itokawa. We should not rely on only one case, specially when this case has material properties that are already expected to be quite different than those of EV5 …

Page 33, last paragraph: there's a problem with the reference to Figure 6. Also, Figure 6 (and not 5) shows the results of DEM simulations.

Page 37: regarding the effectiveness of thermal processes to break a boulder (first paragraph), in addition to thermal expansion coef., Young's modulus etc … you could also mention the presence of different mineralogies with different thermal expansion coefficients within a rock that also influences the thermal cracking efficiency. In fact, a pure uniform temperature rise will not result in any stress, and the rock may get bigger without breaking. What makes it break is temperature differentials (due to gradients, a variety of thermal expansion coefficients etc …).

Page 38, 39: I like very much the way those issues are explained!

Page 40: the caption of the table is wrong: it should be: Compressive and Tensile Strength of Terretsrial Materials and Chondrite Meteorites. I also send as an annex file a compilation of material properties that I produced for OSIRIS-Rex and others, based on various measurements, including porous materials like gypsum, pumice, whose mechanical properties may be (or not) relevant for porous asteroids.