Review comments by Randolph Kirk on

**Proposal about reference frames and mapping schemes of comet 67P/C-G for common use within the Rosetta project and for approval by the IAU**

General Philosophy of the Review

The proposal consists of 3 parts, A) definition of the reference frame and rotational parematers; B) division of the body into subsets; and C) proposed mapping approach for the global body and subsets.

This data set is a bounding case. The technical issues are novel and complex because the nucleus of 67P is highly irregular in shape, therefore also possibly irregular in its rotational behavior in the short run, and is also subject to physical changes on relatively short time scales that affect both the intrinsic dynamics and the definition of mapping parameters. Dealing with this review in a thoughtful way is essential because it will likely set precedent for multiple future investigations.

I view the review of part A) of the proposal as critical. The PDS has a requirement that archived data sets conform to the standards of the IAU Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE), of which I am currently a member. The “normal” flow of approval is for rotational and cartographic constants to be published in the peer-reviewed literature, after which they will be incorporated into one of the triennial reports of the WGCCRE (or an interim report, e.g., by web) and then considered acceptable by the PDS. More recently, the WGCCRE has recognized archiving with the PDS as an acceptable “publication” of coordinate system data. This creates the possibility of circular logic as to what is acceptable. To solve this problem the onus is on the review group convened by the PDS prior to abstract submission. They must provide both the usual scientific peer review of the coordinate results, an evaluation whether the results and presentation are consistent with IAU WGCCRE recommendations/requirements, and the usual input of a PDS review on the completeness and usability of data and how they can be improved.

For parts B) and C) of the proposal, there are no such rigorous standards; the issue of dividing a body for multiple map projections has never arisen before and the choice of map projections is not subject to formal requirements. I will approach these aspects of the proposal as for any other PDS review, focusing on the clarity and usability of the archive.

A high-level summary of my conclusions (with which the other reviewers concur) is that the coordinate system proposal is IAU compliant and the overall proposal can be improved mainly by providing additional data and additional information about the design process for the archive to help future users.

**A) Definition of the C-G reference frame and rotational parameters**

The information in this section is extremely important and for the most part very clearly presented. I see no conflicts between the rationale for the rotational elements, longitude definition, and shape model and IAU recommendations on these topics. However, the section could be made clearer and more useful by adding some discussion and minor amounts of additional data.

1. The IAU definition of a coordinate system as “the combination of the way positions are measured in the reference frame (the SPICE definition), a defined origin and the reference frame itself” (PDS Management Council, Draft Policy on Acceptable Body-Fixed Coordinate Systems). The proposal for 67P describes the definition of the coordinate axis directions relative to the surface of the nucleus and their orientation in inertial space but does not discuss the origin at all. This is important because there could be significant uncertainty in locating this origin in the future. For most bodies, the origin of models based on remote sensing is the center of mass (COM) because the relative motion of spacecraft and target is tracked. I have a potential concern that the COM may be rather poorly known for 67P because of the small size and hence weak gravitational acceleration of the body. If the COM was assumed as origin this uncertainty should be discussed. An alternate approach would be to place the origin at the center of figure (COF); if this was done, even more discussion would be needed. How was COF defined for such a complex figure? How was the unseen portion of the surface accounted for and how sensitive is the origin location to topography in these areas?
2. The proposal discusses and gives parameters for the precession as well as spin of 67P. The statement near the top of p. 2 appears to say that the spin (angular velocity) vector precesses on a cone of half-angle 0.2° in inertial space (the herpolhode), which is about 5 m in radius at the surface. Rigid body dynamics tells us that the angular velocity vector will also move (along a different path called the polhode) relative to the body itself. This subtly different effect is not discussed; the coordinate axes are fixed by definition in the body and the Z axis is equated with the spin axis. This raises the issue that the Z axis ought properly to be taken as the long-term average of the rotation axis rather than an instantaneous location, and also potentially complicates the equations to transform from inertial to body-fixed coordinates. On a practical level, it would be good to provide an estimate of the size of the polhode (e.g., from dynamical considerations if it was not directly observed in the rotation modeling) and hopefully show that it is so small (even smaller than the herpolhode) that it is not significant for cartography. Alternatively, the axes might be tied to the principal moments of inertia of the nucleus, if these were observed. This topic is not addressed in the proposal so I don’t know if these moments were determined from gravity at some accuracy, from figure at some other accuracy, or were considered in establishing the coordinate system at all. NOTE that I really have my fingers crossed that the polhode effect is NOT significant, so that all that is needed is a short discussion stating why it could be ignored. If it is significant then I’m not asking for a new and more complex definition of the rotation and axis definitions, but there would be a need to state clearly how the axis directions were chosen and that the Z axis is not exactly equivalent to the spin axis.
3. Rotational parameters are given on p. 2 in what is presumably a NAIF format, and again on p. 5 where the ellipsoid shape parameters are added. Probably only one table is needed. Use of a NAIF convention to present the data is not required but it is certainly acceptable and practical. However, the reference given [A7] is a personal communication. Because these parameters are so important, it is equally important that how to use them be extremely clear. Therefore the NAIF documentation describing this set of parameters should be cited. I didn’t manage to find this in a brief search before the review, but Chuck Acton was able to supply it.
4. The use of more than one feature to define the coordinate system is an extension of using a single surface feature to define longitude (when the pole is obtained from simple and precisely measured rotational dynamics) is novel and is highly laudible. There are several reasons one might want to use three or more points:
   1. To deal with the fact that the rotation axis is not strictly fixed on the body as described above, so some other way of specifying Z is needed;
   2. In case the chosen features are subject to change;
   3. In case the whole body is subject to change, e.g., by non-rigid motion of the lobes;
   4. To define the location of the origin as well as the coordinate directions, if this is not addressed in another way; and
   5. To provide redundant observations to improve the precision of the coordinate specification.

Because there are so *many* such effects at work, it would be desirable to provide more than the minimum number (3) of surface features to which to tie the coordinate system. The features in Figs. 1-2 could still have a primary definitional status but it would be useful to give a reference to the full SPG control network data set, with features defined in image space and calculated ground coordinates. Then if later workers discover that the 3 prime features or the rotation axis have moved relative to the body as a whole, this would allow relatively graceful recovery of an updated version of the coordinate system.

**B) Definition of C-G body subsets**

This topic is novel because of the extreme irregularity of the shape of 67P and the approach used is probably specific to that shape rather than general. It makes sense to me. There are a couple of minor issues that could be clarified to help users.

1. Table 1 gives only the center coordinates, not the other parameters of the best-fit ellipsoids. Reading between the lines, I surmise that this is because the only intended function of the ellipsoids is to determine the most appropriate center point for each section, which is then mapped using a sphere. Nevertheless, the axes and orientations of these ellipsoids could be quite interesting for some sorts of research and the values are known to the authors, so it would be easy and good to add the information to the table. Adding a sentence saying that the “function” of the ellipsoids is as I said (or something else, if I have misinterpreted it) would also be helpful.
2. I agree strongly with rationale for using a spherical reference surface for mapping the segments. The rationale for the sizes of the spheres used is not discussed and would be useful to know. Is it based on the sizes of the best-fit ellipsoids? The values appear to have been rounded off rather drastically, which may be a good idea but the rationale (simplicity and stability) should be described.
3. It would be very useful to readers to have an idea of how much the shape model departs from the ellipsoids, and from the reference spheres.
4. The nucleus is so irregular that there is a possibility that the surface is multivalued with respect to latitude and longitude, certainly for the global coordinate system and maybe even for the segments. It would be very useful to have an indication of how extensive this problem is. A starting point would be simple statistics (“X% of the surface shares the same latitude-longitude values as two (or more?) other locations.”). A map of the regions affected, e.g., shaded relief colored green where lat-lon is single valued and red where it is multi-valued would be even more helpful.
5. The authors are essentially providing up to 4 separate systems for specifying the location of a feature (global and the 3 segments, though any given feature would only fall within 3 of these) and the lat-lon coordinates could be multi-valued even within one of these. Perhaps they should explicitly make a suggestion about how future researchers should best use the systems to describe a feature of interest. This could be global lat-lon-radius or local lat-lon (if the sections turn out to be single valued) or even global Cartesian coordinates, which are unique.
6. I found Figs. 3 and 4 a bit unclear, perhaps partly because of their small size. Fig. 3 is described as a view of the global shape model but all I see apart from the shape model is the axes. Fig. 4 appears to show the axes through the origins of the segments and shows the “cuts” implicitly by removing the neck region. The view on the right doesn’t show the neck anyway, so this is not too useful. Perhaps the figures could be revised to show the global ellipsoid (Fig. 3) and the 3 local spheres (Fig. 4) as transparent surfaces superimposed on the shape model?

**A) Definition of C-G standard map parameters**

I agree strongly with the opening paragraph. My main suggestion is that it should be made clear that this is a *de*scription of how the mission is planning to present their data in map form, rather than a *pre*scription to limit the acceptable presentations. Other types of projection might be quite useful. For example, Batson advocated orthographic projections based on the detailed shape model for Phobos, and the authors of this proposal must agree for at least some applications, because they present Figs. 3 and 4 in this form!

PDS 3 documentation includes “equidistant” in a list of admitted map projections but its meaning is not documented; there are equidistant cylindrical and equidistant azimuthal projections. As a result, several recent missions have adopted the term “equirectangular” for the simple cylindrical projection generalized to allow different grid spacing in latitude and longitude. I recommend the Rosetta team follow this terminology.

In the 3rd paragraph of p 8, “non star-like shape” should presumably be “non sphere-like shape”.

There is a long history of choosing grid spacings with 2^n pixels/degree for PDS archives, and I used to advocate strongly for this. More recently there are an increasing number of archives with round numbers of meters/pixel as proposed here, and I think this is also acceptable. It would be useful to point out that the nominal “scale” applies on the reference sphere for the projection, and thus the true scale at most points on the surface is different.

The maps for the “big lobe” are centered at 140°, 230°, etc. which is 40° offset from the default of 0°, 90°, 180°, 270°. There is no objection to this but it would be worthwhile to add a sentence explaining that this is done to place the end of the lobe in the center of the map. Similar remarks apply to the equatorial aspect maps of the neck region.

It might be especially useful to have a map of the neck region in transverse equirectangular projection with the “transverse equator” running down the centerline of the region, i.e., roughly 60° to 240°E.