On the appearance of asteroid Arrokoth

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Abstract

Bi-lobed Kuiper belt asteroid Arrokoth is shown to consist of two hexagonal pyramids connected with a stretched neck. Their formation is accounted for by fission of a larger body in a landslide manner. The simple rationale permits to restore a view of the precursor as well as provides consistent rationalization of Arrokoth's features. Its density is amended to be twice less than previously proposed.

1. Introduction

On January 1, 2019 NASA's New Horizons spacecraft flew by Kuiper belt asteroid (486958) Arrokoth, formerly informally known as 2014 MU69 Ultima Thule. The icy object located in the far reaches of the solar system belongs to dynamically stable subdivision of the belt, which is commonly believed to contain the primordial remnant bodies since the system's accretion formation. The bulk of information acquired by seven scientific instruments of the spacecraft has already been received while the remainder will be transmitting till this autumn. Several months ago three articles devoted to Arrokoth's properties and likely multistage scenarios of its formation were simultaneously published by New Horizons Team[1,2,3] .

It is written[2] that "Arrokoth is a contact binary consisting of two distinct lobes, connected by a narrow neck". The large and small lobes are found there to be flattened and oval shaped with sizes 20.6x19.9x9.4km and 15.4x13.8x9.8km. The main conclusion[2,3] is that the observations fully support accretion anticipations and the asteroid resulted from slow gravitational fusion of two smaller planetesimals previously originated in the same pristine pebble cloud.

Contrary, in the following we establish and confirm simple fission origin of the asteroid from a larger precursor body. Firstly, we scrutinize raw approach images acquired by the spacecraft. Secondly, we reconcile the results of the analysis to consistently explain Arrokoth's properties and compose a view of its ancestor.

2. Problems of Arrokoth's visualization

Before the start of image analyses let us make up geometry of the close encounter. At the approach era the Sun illuminates mostly Arrokoth's southern part because the obliquity of the asteroid rotational pole to its orbit is 99º, the pole direction deviates approx. 28º from the Sun-asteroid line and approx. 39º from the spacecraft approach vector[2]. Thus the spacecraft telescopes are to fix propeller-like rotation of the object which permanently changes faces of its parts.

New Horizon's primary telescope is the Long-Range Reconnaissance Imager (LORRI) of reflective Ritchey-Chrétien design with 20.8 cm aperture[4]. It is black-and-white narrow angle camera with effective focal length of 2,63m, square 0.29º field of view, and 1024x1024 (13x13mm frame) charge coupled device (CCD). Fused to CCD refractive silica lenses are used for field flattening because the focal plane curvature over the flat CCD would have limited imaging performance without them. The closest encounter with the asteroid at the distance of three and half thousand kilometers allows LORRI provide images with the resolutions of several tens of meters.

It is known that only the lens with focal length around the size of its frame reproduces a field of view that appears "natural" to a human eye (see e.g. https://en.wikipedia.org/wiki/Normal_lens_photography). Others produce perspective distortion, which is a warping or transformation of an object from what the object would look like due to relative scale of nearby and distant features. For images of the same field size depth shrinkage and extension result from angles of view narrower or wider than normal (longer or shorter focal lengths), respectively. Narrow angle instruments may introduce drastic compression distortion - the viewer cannot discern relative distances along the line of view. The remedy occasionally is to see a scene in normal perspective if one adjusts the viewing distance. It is impractically close to the image for wide angle photographs and further away for narrow ones (see e.g https://en.wikipedia.org/wiki/Perspective_distortion_photography).

Thus for Arrokoth images interrelations of its features are expected to be distorted due to perspective deviations from reality. Special perspectives may highlight details and their mutual relations. Meaningful features are to appear and disappear in different images. Besides, when assessing shapes of objects human vision judge their relations to vertical line (gravity asymmetry) and interpret views depending on their distinctive angles relative to horizon. As a consequence, our visual intuition is not supposed to work well for raw images of the asteroid.

3. Fresh look at the raw data

Two dozens of low resolution snapshots of the New Horizon's flyby sequence are accessible now. These views are shown in fig.1 where the image sequence covers 13 of 15.92 hours of the asteroid rotational period. Common sense and logic advices us to analyze images sequentially to progressively follow Arrokoth's growth in size while approach from lower resolutions up. To get overall impression of the shapes let us scan the left column of fig.1 where image 11 marks the half of the rotation period, and image 21 – two thirds of it.

Propeller-like rotation implies that the longest size of the whole asteroid should be seen perpendicular to the line of sight. Therefore measured sizes of approx. vertical images in fig.1 underestimate the real size or are close to it. One can see that returning to vertical position does not mean simple view inversion due to distortions (cf. images 1, 2 and 9-13). The comparison of scale marks of images 1 and 11 in right columns also proves that.

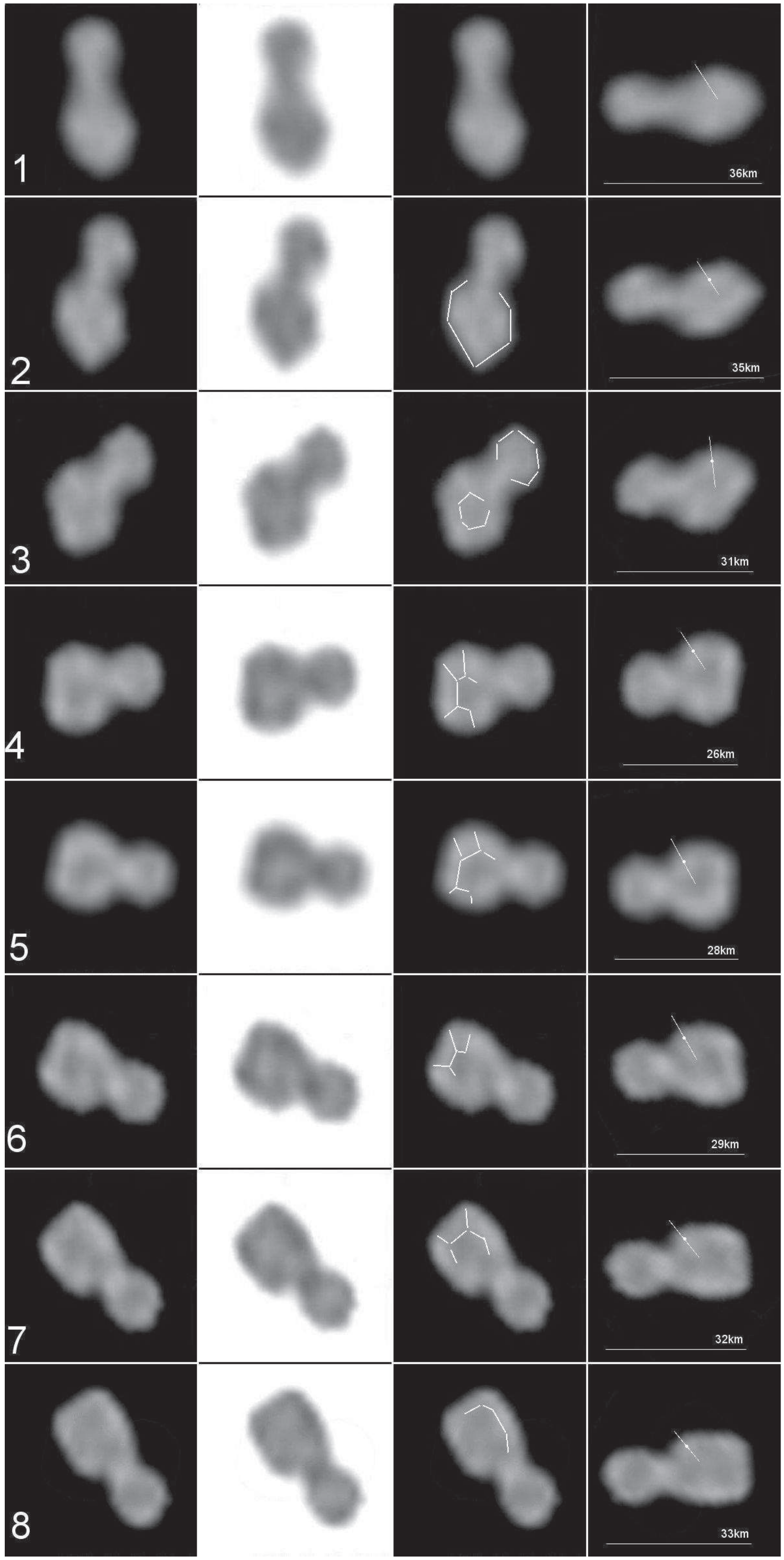
The obvious conclusion of the scan is that Arrokoth consists of the large and small lobes connected with a stretched neck. As for the its length it is clearly about 10% of the largest asteroid dimension and is, so to say, sizeable insertion between the lobes (e.g. see image 9). The neck looks brighter in all images akin other smaller brighter areas located on the lobes' surfaces.

Now let us have a look at image 2 (fig1, third column). The clear angular borders of the large lobe left no doubts that it is hexagonal. Other images of the third column with some edges marked with lines also prove the point. The same holds for the small lobe which in several images looks very angular (e.g. image 3). Therefore, if the lobes look rounder in other images it results from special perspectives, illumination conditions, or visual distortions.

Let us remember that in all images we see the southern part of Arrokoth that turns a bit and distorts from image to image (e.g. cf. images of the right column). The former means that in different images different edges of its angular shapes are discernable. The latter suggests changing interrelations of edge lines and areas restricted by them. According to the said above, images with maximal perspective distortions are the shortest ones. In the left column they are close to those horizontal (e.g. 19-21). The examination of all images shows, that majority of shape edges stay direct but often disappear. We marked some of them with lines in the third column the way that one may follow their consistency from image to image while keeping the shape integrity in mind.

The large lobe contains several white spots which are lined in chain. The spots and the chain direction are shown in fig.1 (right column) with points and lines, respectively. The upper part of the small lobe, which is a hexagonal crater informally named Maryland, also contains two white spots lined along the diagonal of its perimeter hexagon (e.g. fig.1, image 23). This diagonal ends with a concave relief feature (see also fig.3, right). Direction of the chain line on the large lobe is also diagonal which as well ends with the concavity. It is shown in image 9 (fig.1, third column) with the black angle (cf. fig.3, right).

Now we are quite experienced to discern hexagons in fig 2. Two long scale lines there (fig.2, middle) prove that the base of the small lobe coincides in size to the upper plane of the large lobe and short scale line gives the measure of the neck. Notice, that bright spots inside Maryland and on the upper side of the large lobe look obscure and somewhat whiter (fig.2, left) or darker (fig.2, middle, right) than their surroundings.



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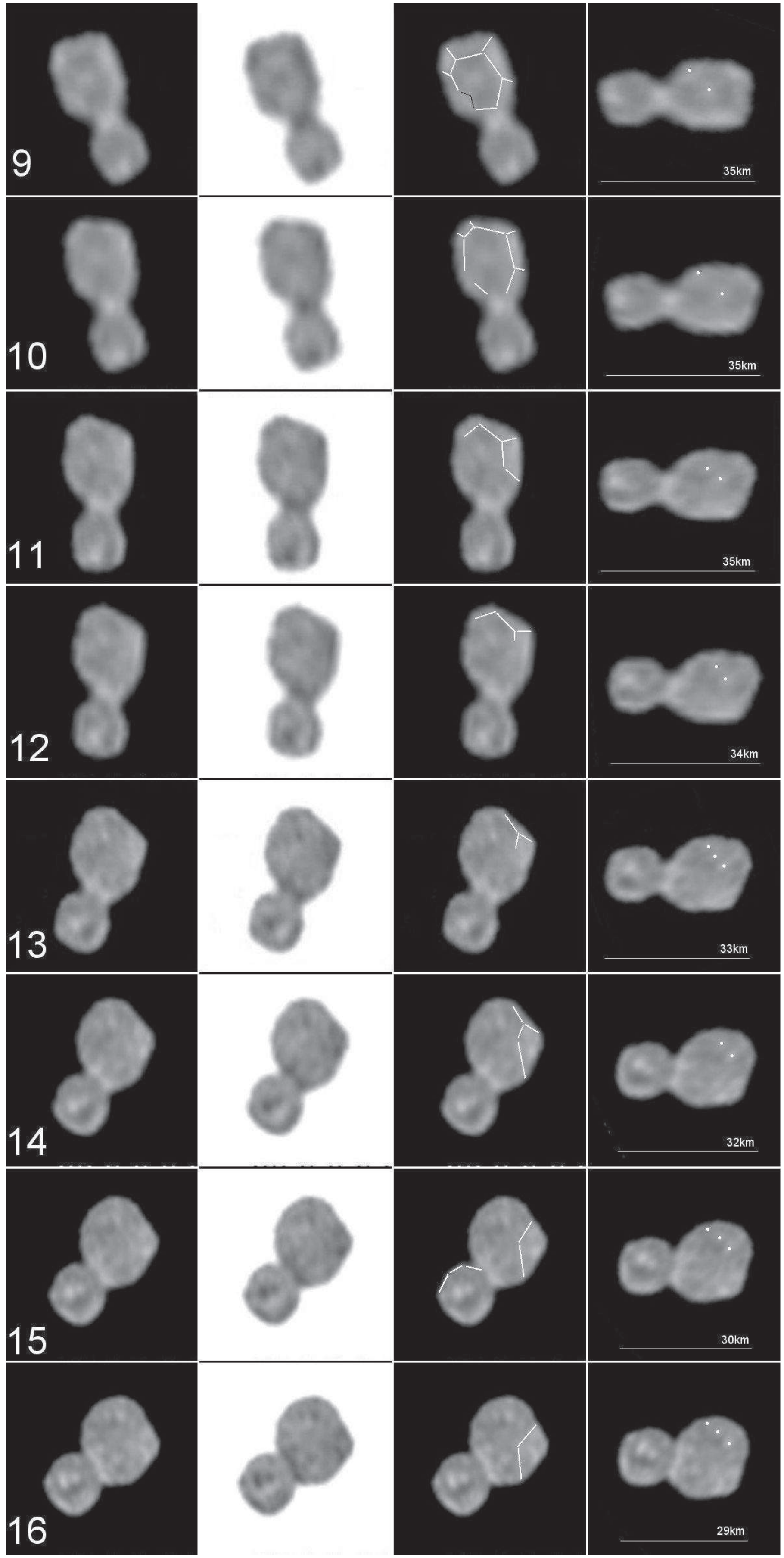
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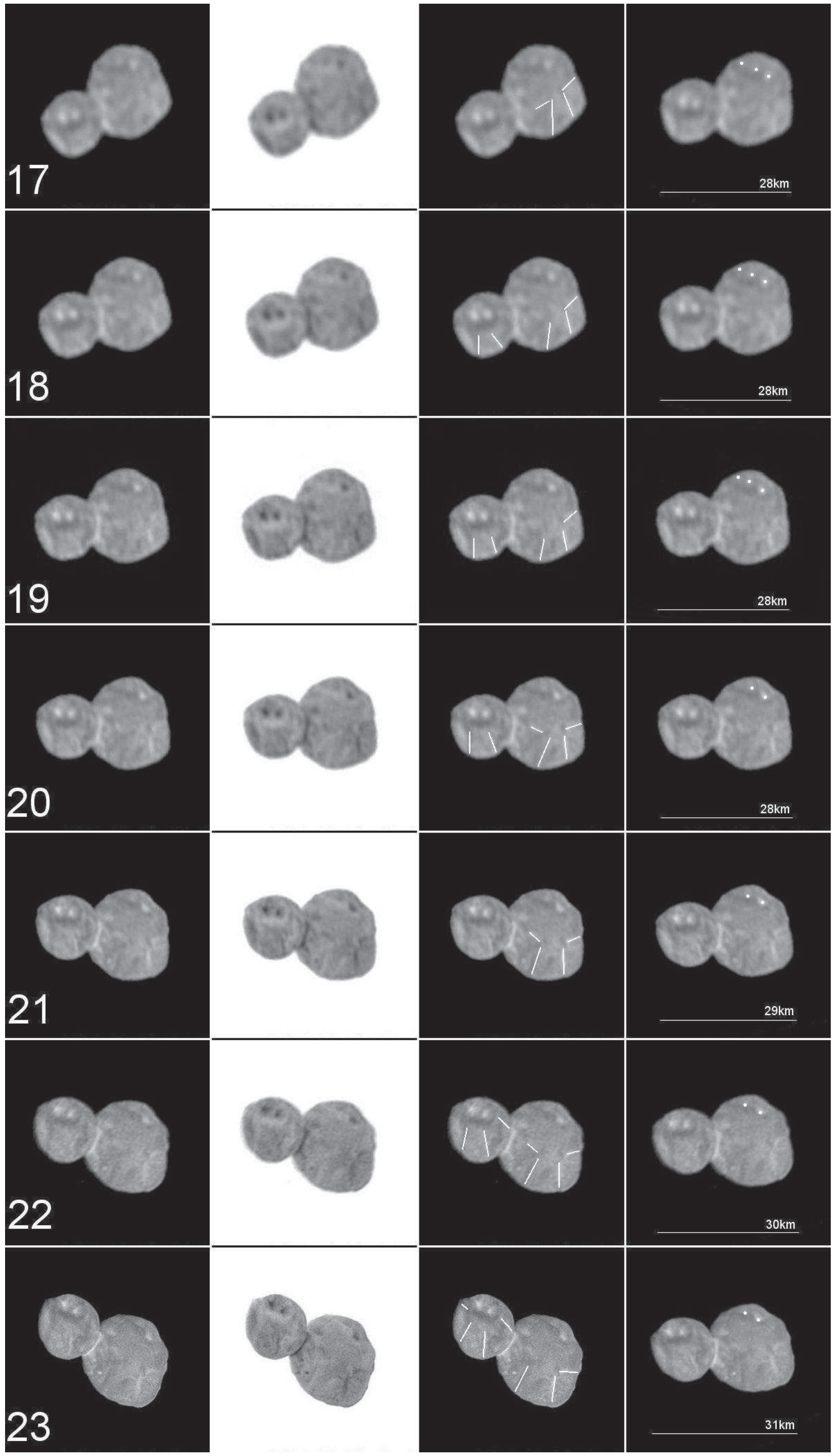

Fig.1. Flyby image sequence acquired by LORRI before and after the close encounter. Left column contains numbered original images, white column – their negatives, the third column – original images with some edges of both lobes marked with lines. Right column consists of original images with scales. They were rotated to alleviate their visual analyses as horizontal ones. White lines and points of right column images direct and mark bright spots diagonally crossing the top side of the large lobe (upper cutting plane of the lobe's hexagonal pyramid).

*This figure with equally scaled by us images combines data from two sources. The first is image gif file (*296x296pix *frame sequence) released by NASA's site on January15, 2019 and showing propeller-like rotation of Arrokoth in the nine hours (http://pluto.jhuapl.edu/Galleries/Featured-Images/image.php?page=&gallery_id=2&image_id=581), (file: approachrot2_montage). We used the file frames as images 5, 8, 10, 12, 14-18, 20-21. The second source is fi*g.*4 in article*[2]*. 2020), which contains some* 150x150pix crops of *"deconvolved LORRI approach images of Arrokoth scaled to a constant frame size of 44x44km". Images 1-4, 6, 7, 9, 11, 13, 19 were cropped from fig.4 and rescaled to* 296x296pix. *In result, images 1-10 were acquired 31.12.2019 at 15-58, 17-00, 18-13, 19-23, 20-00, 20-38, 21-28, 22-01, 22-46, 23-26, images 11-23 – 01.01.2019 at 00-07, 00-29, 01-12, 01-33, 01-55, 02-16, 02-45, 03-08, 03-26, 03-43, 04-04, 04-22, 05-01, respectively. All images are inside 44x44km frames. Credit: NASA/Johns Hopkins University Applied Physics Lab/Southwest Research Institute/National Optical Astronomy Observatory*

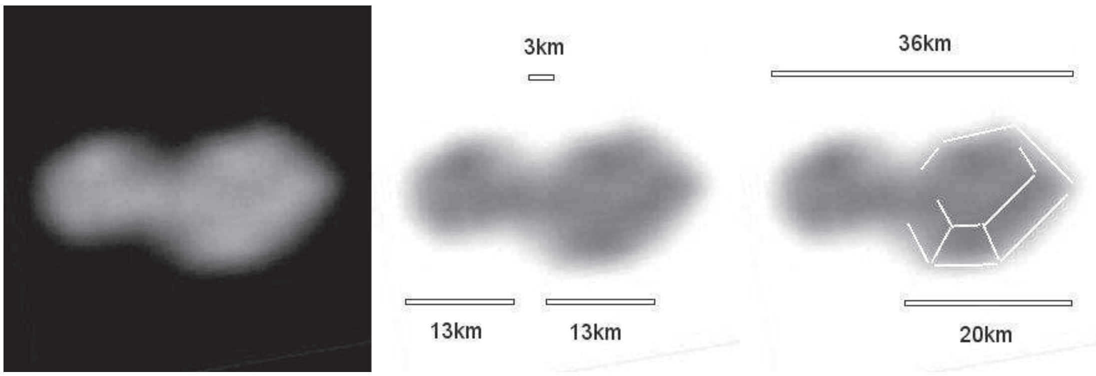

Fig.2. Left: image 2 from fig.1 (right column). Middle: the left one inverted with scale marks. Right: the middle one with scale marks and white lines sketching edges of the hexagonal large lobe. Credit: NASA/Johns Hopkins University Applied Physics Lab/Southwest Research Institute/National Optical Astronomy Observatory

An example of high resolution image of the asteroid is shown in fig.3 (right). The similarity of relief features of both lobes there is striking. Their spectra are also very similar which implies the same material properties[1]. It is said in article[5] that "the lobes have similar normal reflectance distributions: both are approx. Gaussian, at 610 nm, and range from 0.10 – 0.40, which is consistent with co-formation and co-evolution of the two lobes".

As a result we conclude that the lobes appeared due to the landslide-like separation of a larger pyramid. It is their geological freshness that allows us to restore the appearance of the ancestor pyramid in fig.3 (left, middle). The relief and geometric consistency of the pyramid sides is apparent there, thus providing crucial support to our approach. Smoothness of the large lobe at the scale larger than 30m, and no evidence of impact deformation of both lobes[2] also prove the landslide-like fission scenario.

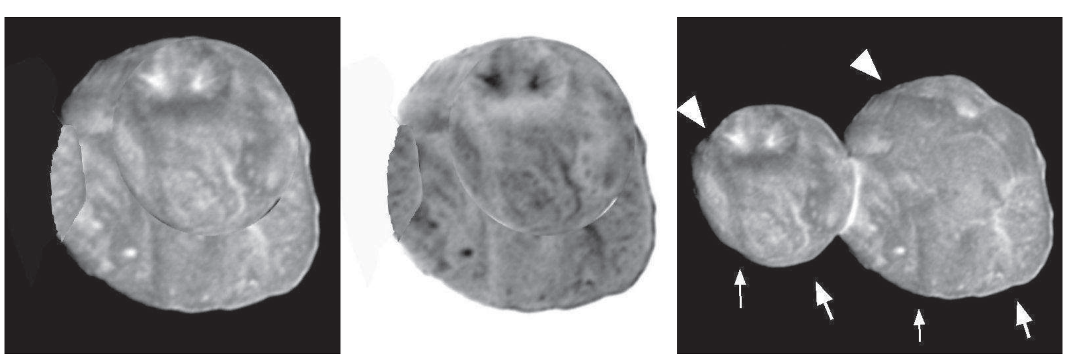

Fig.3. Right: A rotated crop (right half) from LORRI image acquired at 5.26 on January 1, 2019 from distance 6600 km and released on March 7, 2019. (http://pluto.jhuapl.edu/Galleries/Featured-Images/image.php?page=1&gallery_id=2&image_id=599),(fileUT_Stereo_parallel_030619.png). White arrows show the positions and directions of coincident relief features (pyramid edges) of the small and large lobes of Arrokoth. White triangles nail their coincident concave features. Left: The large lobe coherently superposed by the small one. Both lobes were cropped from the right image and the neck region of the large lobe was patched by its own crop. Middle: The negative of the right image. To vividly confirm shape and relief self-consistency of the resulted frustum the reader is highly recommended to look at the image from a distance or diminish its screen size. Credit: NASA/Johns Hopkins University Applied Physics Lab/Southwest Research Institute/National Optical Astronomy Observatory.

4. Discussion

The above considerations result in some amendments to Arrokoth's physical parameters. The lobes' pyramid geometry implies interdependency of their dimensions. Those are simple relations but it is not clear to us which size is to be taken as the most reliably measured. At least, we are to point out that the volume ratio of the lobes is ca. three. The same is their mass ratio, provided the density equality.

As for the latter it is not directly measured and several indirect assessments are constrained it [2,3]. Mean gravity slope of Arrokoth's gives density about 250 g/c.c being average of broad minimum 200-300 g/c.c. Besides, it is said[2] that "if the neck of Arrokoth is assumed to have no tensile strength, the density must be >290 g/c.c., or the rotation would overcome the mutual gravity of the two lobes, causing them to separate". Thus in [2,3] the density of the asteroid was concluded to be about comet-like 500 g/c.c. The angular momentum evaluation proves that the lobes are to lose it before accretion contact because contemporary rotational period would match the spin-synchronous orbit period for barely touching lobes for densities about twice less [3]. This is one of stumbling blocks of the fusion scenario. Our fission rationale removes the discrepancies. Slow rotational divergence with the neck in tension makes all density constraints consistent for the value about. 250 g/c.c.

The neck of several kilometers in length puts fusion ideas into question because such sizeable part of the asteroid could appear only after reverse movement of already contacted bodies. That suggests an addition of extra stages into the complex accretion scenario. Opposite, the slow fission may explain both the neck sizes and its comparative brightness which means freshness. If the neck results from plastic elongation it appears to contain icy materials of smaller grain sizes.

References

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