AN INTERSTELLAR CARBONACEOUS TWINKIE IN ASTEROID RYUGU? C. Kraver¹, L. R. Nittler¹, J. Barosch², R. M. Stroud¹, I. Karrouch¹, and J. Wang², ¹School of Earth and Space Exploration, Arizona State University, Mail Code 6004, Tempe AZ, 85287, ckraver@asu.edu, ²Earth and Planets Laboratory, Carnegie Institution of Washington, 5241 Broad Branch Rd NW, Washington DC 20015.

Introduction: Initial analysis (IA) of samples of C-type asteroid Ryugu returned by JAXA’s Hayabusa2 mission has revealed them to be closely similar to Ivuna-type (CI) carbonaceous chondrite meteorites [1]. Organic C, both in the form of a wide range of soluble molecules [2] and in macromolecular material [3] makes up ~3 wt% of the samples. Coordinated microscale measurements have found the macromolecular material to be primarily in the form of chemically and morphologically heterogeneous sub-µm particles [3-6]. NanoSIMS measurements revealed macromolecular material to be enriched in D and 15N, with a small fraction (“outliers”) of the organic particles showing extreme deviations from the average H, C, and/or N isotopic composition [6, 7]. We report here the results of a NanoSIMS study of two additional Ryugu particles collected during Hayabusa2’s first touchdown, including the discovery of a highly unusual isotopically anomalous, tubular-shaped organic grain enclosing phyllosilicate material.

Samples and Methods: Two Ryugu particles – A0079 and A0169 – were allocated to us during the 1st International AO. The two particles were selected based on curatorial bulk infrared measurements indicating different degrees of aqueous alteration, with A0079 exhibiting a shallower OH feature at 2.7 µm (Fig. 1). Small fragments (tens of µms in size) of each were broken off, transferred to Au mounts and pressed flat with clean quartz disks. We first imaged the fragments in a JEOL 6500F SEM and then used the Carnegie Institution’s NanoSIMS 50L to map the C, and N isotopic ratios of 27 fragments and H isotopes in 22 of these. We then imaged the fragments in a JEOL 6500F SEM and then used the Carnegie Institution’s NanoSIMS 50L to map the C, and N isotopic ratios of 27 fragments and H isotopes in 22 of these. Methods were identical to our previous work during the Hayabusa2 Initial Analysis [6, 7]. Following NanoSIMS measurements, we extracted two ultrathin sections of one fragment with a Helios G5 UX (ThermoScientific) SEM-FIB and analyzed them by scanning transmission electron microscopy (STEM) with a JEOL ARM200F, equipped with an Oxford Aztec energy dispersive X-ray spectroscopy (EDS) system.

Results: A total of ~11,000 µm² and ~5,000 µm² of A0079 and A0169 were analyzed, respectively. As in previous work, we found ubiquitous sub-µm organic particles dispersed in the analyzed grains, which otherwise were dominated by phyllosilicates, sulfides, and magnetite. One 30-µm fragment appears to be pure organic matter with isotopically normal H, C, and N; this is most likely contamination introduced during sample mounting. Most of the organic particles show H, C, and N isotopes consistent with average values identical to prior work (δD~+500‰, δ15N~+40‰, δ13C~–15‰). Outliers (“hotspots” and “coldspots”) show similar isotopic distributions to those seen in prior Ryugu studies and carbonaceous chondrites (δD up to 13,000‰, δ15N up to ≈1500‰). There are no significant isotopic differences between the organic particles in A0079 and A0169 despite the apparent difference in degree of aqueous alteration.

Although most of the organic particles are at most a few 100 nm across, the images revealed several larger C-rich grains as well. The most interesting thus far (Fig. 2) appeared as an elongated 4.5×1µm whisker-shaped grain in the ion images, found to be highly isotopically anomalous in both H and N: δD=10,870±570‰, δ15N=760±20‰.
The pre-NanoSIMS SE image of this object showed lighter contrast in its interior (Fig. 2B) suggesting that it is not homogeneously enriched in C. STEM high angle annular dark field (HAADF) and bright field (BF) images of one FIB section across this object are shown in Figure 3. They reveal a 200-nm thick semi-circular rind around fine-grained phyllosilicate material at the location of the particle in the section with very little C remaining at the top, where the SIMS measurement was made. We infer that the rind originally went all the way around (inset cartoon on top panel), but the top material was removed by the extensive NanoSIMS sputtering. This, along with the original SEM image, suggests that this particle was originally tubular in shape, filled with phyllosilicates (cartoon in bottom panel), analogous to a cream-filled cake or “twinkie.” STEM-based EDS measurements (Fig. 4) reveal that the phyllosilicates (point 2) within the carbonaceous rind (#3) or tube are chemically distinct from the surrounding matrix (#1), specifically showing a higher Mg/Fe ratio.

**Discussion:** Overall, the NanoSIMS results broadly agree with prior measurements on other Ryugu samples, showing similar ranges of H, C, and N isotopes among sub-μm organic grains. There are no obvious substantial differences in macromolecular organic composition between the two particles, despite their showing differences in bulk infrared spectra. Future TEM analyses will further investigate how these spectral differences are reflected at the nanoscale.

We are unaware of previous reports of μm-sized isotopically anomalous tubular-shaped organic grains similar to the one identified here in any extraterrestrial materials. The origin of this unusual object is unclear. The extreme D and 15N enrichments point toward a low-T origin in the Sun’s parental molecular cloud or outer reaches of the protoplanetary disk [8]. This and the distinct silicate compositions inside and outside the grain argue against parent-body formation and indicate it existed as a distinct object in space prior to the accretion of Ryugu’s parent asteroid. We suggest that this object originated as an organic-rich ice coating on an elongated aggregate of interstellar silicates that was further polymerized to form the macromolecular “tube.” During the aqueous alteration of Ryugu’s parent body, fluids penetrated the grain and altered the original silicates to phyllosilicates (and perhaps affected the organic matter as well, though if so, without substantially altering its unusual isotopic composition). Planned EELS and STXM measurements should allow us to compare this unusual grain’s organic composition to other Ryugu organic matter and help answer the question of its origin.