GELATO: A JPL PSSS COMET SURFACE SAMPLE RETURN MISSION CONCEPT. M. J. Kinczyk[1], L. M. Aaron[2], S. Boone[3], C. E. Buffo[4], A. J. Flom[5], E. S. Frizzell[6], C. Govinda Raj[4], C. D. K. Harris[7], A. Hyder[8], B. Idini[9], V. C. Jayanetti[10], S. Kasapis[11], B. S. McCann[12], E. Millman[13], A. Ngo[14], M. F. Ringwood[15], L. E. Rodriguez[7,16], A. Rudolph[17], K. L. Mitchell[7], A. E. Nash[7], and L. Lowes[7], [1]Johns Hopkins Applied Physics Laboratory, [2]Johns Hopkins, [3]UC Boulder, [4]Georgia Tech, [5]U. Hawaii at Manoa, [6]U of Maryland College Park, [7]JPL/CalTech, [8]NMSU, [9]UC Santa Cruz, [10]USC, [11]U of Michigan, [12]Embry-Riddle, [13]Wash. U. in St. Louis, [14]Oklahoma State U., [15]UC Santa Barbara, [16]LPI/USRA, [17]Purdue

Introduction: Comets are often thought of as time capsules of early Solar System (SS) formation. Traditionally, these objects were thought to have formed in the cold outer reaches of the SS [1], preserving some of its most primordial materials. It wasn't until dedicated spacecraft were sent to observe and analyze comet materials at close range that a more complex picture of the comet lifecycle and its role in SS evolution was realized [2-4]. Comet science has progressed in the last several decades from being derived from primarily telescopic observations prior to the 1980s, to flyby observations such as that of the International Cometary Explorer (ICE) which performed the first cometary flyby in 1985 [5]. Since then, multiple spacecraft have performed in-situ and return sample analysis of coma materials. The next step in advancing the fundamental aspects of comet science is acquiring and returning a comet nucleus sample for Earth-based laboratory analysis through a comet surface sample return mission (CSSR).

Mission Overview: Gelato, a CSSR mission concept targeting the previously visited comet, 67P/Churyumov-Gerasimenko (67P), was derived through the 2022 NASA Jet Propulsion Laboratory's Planetary Science Summer School (PSSS). Here we briefly describe the science objectives that address the 2022 Planetary Decadal Survey (DS) priority science questions [6] (**Table 1**), payload, and concept of operations for the mission.

Goal DSQ	Science Objectives: "Determine whether.."	Physical Parameters
#1 DSQ 1,2,3	• reservoirs of radio-nuclides in the proto-planetary disk were (H1) homogenous or (H2) heterogenous	**1.1 Age & Abundance** • Mg:24,25,26,27 & Al:26,27 **1.2 Age & Date Alter.** • Cr:50,52,53,54 & Mn:53,55 **1.3 Absolute Age** • Pb:204,206,207 & U:235,238
#2 DSQ 3,10	• volatile delivery to early Earth by 67P-like comets was (H1) significant, (H2) minor, (H3) insignificant	**2.1** Water (H: 1, 2) **2.2** NH_3 & N_2 (N:14,15) **2.3** Xe (128,132,136) **2.4** Kr (82,84,86) **2.5** Ar (36,38)
# 3 DSQ 1,9, 10	• 67P has organics, • organics w/ee, & • if they originated due to (H1) interstellar / outer solar nebula chemistry, (H2) inner solar nebula chemistry or (H3) parent-body processes.	**3.1 ID organics** • AAs/HAs/NHs/ sugars/FAs **3.2 Organic Isotopes** • δD,15N,13C,18O **3.3 Coord. of organics w/** • PSG, Fe/Ni, volatiles, minerals **3.4 Organic chirality** • ee of AAs, HAs, Sugars

Table 1. Gelato science objectives to be achieved. DSQ = Decadal Survey Question; H = hypothesis; Alter. = alteration; coord = coordinated analysis; AAs/HAs/NHs/FAs = amino acids/ hydroxy acids/N-heterocycles/fatty acids; ee = enantiomeric excess.

Objective #1: This objective aims to measure both short- and long-lived radionuclide isotopes in the comet nucleus sample to determine whether early compositional reservoirs were homogenous between the inner and outer SS. Radionuclide age dating often assumes a homogeneous initial distribution of 26Al/27Al between the inner and outer disk. However, some samples point toward small heterogeneities and there is no consensus on the compositional distribution in the protoplanetary disk [7]. Retrieving a nucleus sample of sufficient size could enable both detection of $^{26}Al/^{27}Mg$ decay products as well as Pb-Pb absolute age dating [8] which can help resolve this discrepancy.

Objective #2: The high bulk water abundance observed at comets has made them central to past theories of water delivery to Earth. Measurements of cometary D/H have revealed a range of values for different comets [9], only some of which are consistent with terrestrial water. However, these ratios have been determined from cometary comae rather than direct measurements from the nucleus. Water D/H along with N, Ar, Kr, and Xe isotopic ratios [10] from a returned nucleus sample would elucidate the connection between surface and coma isotopic ratios and would enable better constraints on theories of comet volatile delivery.

Objective #3: Meteorite studies have shown that biological building blocks, including those with enantiomeric excess (ee), could have been exogenously delivered to early Earth [11]. A sample from the cometary nucleus, which likely hosts the most pristine organic content from the early SS would help delineate which biologically-relevant molecules comets could have delivered to Earth and their origins (interstellar medium/outer solar nebula, inner solar nebula, or parent-body processes) [12]. This in turn would elucidate how geochemical activity on planetary bodies (e.g. asteroids/early Earth) influence the availability of these molecules for origins of life events.

Payload: The reconnaissance instruments proposed for Gelato were a *Near-/Mid-IR Hyperspectral Imager* and a single *Medium-Angle 3-color pushbroom camera* based on previously flown analogs [13, 14].

The hyperspectral imager would be used to identify minerals in the visible-to-mid-infrared range (0.8-4.5 μm) on the surface of 67P. This wavelength range allows for identification of refractory minerals (e.g., pyroxene), H_2O and CO_2 ices, and organics [e.g.,15-16]. The instrument would have a spectral resolution of ~3 nm/channel with a ground sampling distance (GSD) of 7.5 m. The 3-color pushbroom camera would acquire high-resolution images to provide morphologic context for the compositional data provided by the hyperspectral imager. The GSD of the camera would be 0.225 m allowing for features <0.5 m to be clearly identified. Collectively, the data from these two instruments would be used during the Gelato orbital phases to monitor for any changes across 67P since the Rosetta mission.

Sampling mechanism: A BiBlade sampling chain [17] via a touch-and-go maneuver (**Figure 2**) would be used to acquire the nucleus sample. The mechanism utilizes a two-shovel blade design that quickly fires into a surface, surrounds the sample, and retracts to remove and contain the sample. The BiBlade has been validated to TRL 6 and can collect at least 250g of sample (more than the 133.25g derived from science requirements). Approximately 75g of sample can be taken from below 4 cm of the surface.

Mission Design: *Comet selection:* 67P is by far the most studied Jupiter-family comet due to the success of the Rosetta mission [18]. As a result, surface feature maps [19] with corresponding compositional data [20] are available, reducing the amount of reconnaissance necessary for sample site selection and therefore driving down cost. Furthermore, Rosetta's observations of the coma and surface are highly relevant to our science objectives, namely whether the coma composition is representative of the surface composition. This body of existing data would provide valuable context for the mission and subsequent laboratory analysis.

Sample site selection: Minimal sample alteration would be required to achieve science closure for each objective and much effort was put into delineating the sample handling requirements for this reason. The rough terrains (e.g., cliffs and talus deposits) mapped by ESA's Rosetta mission are more likely to expose primitive surface materials [19]. We therefore chose to target the cliff regions because they are the most likely to expose the least modified material. We also built in additional time to the mapping phase to conduct a proper risk assessment.

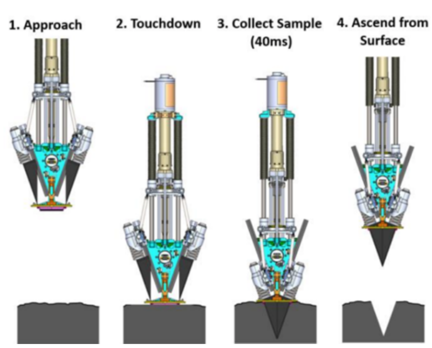

Figure 2. BiBlade sampling mechanism. Figure from validation study [17].

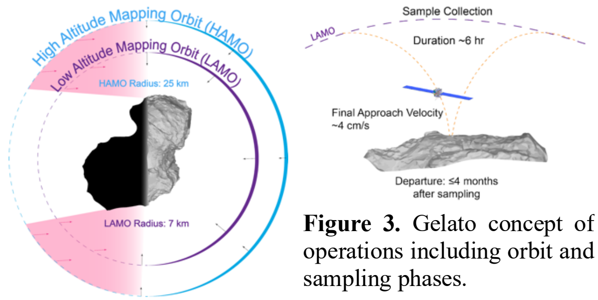

Figure 3. Gelato concept of operations including orbit and sampling phases.

Sample storage: We treated the Sample Return Container (SRC) as a black box due to time constraints. However, we proposed the following requirements for the SRC that would have been achievable based on technologies used on current or previous sample return missions (OSIRIS-REx and Hayabusa 2): hermetic seal; temperature control at 0°C; and, separate volatiles containment. While these requirements would not result in the ideal cryogenic sample return which was recently studied as part of the DS [21], it was determined that keeping the samples frozen and volatiles isolated would be adequate for preventing aqueous alteration and achieving Gelato's science objectives.

Concept of Operations: After its six-year cruise, Gelato would enter a High-Altitude Mapping Orbit (radius 25km) around 67P to conduct a reconnaissance phase during which time sample site selection and context mapping would be conducted (**Figure 3**). It would remain in this orbit for eight months after which point it would enter a Low-Altitude Mapping Orbit (radius 7km) for four months to conduct high resolution mapping of candidate sample sites. During a final 12-month sampling phase, the vehicle would perform two sample collection rehearsals and the sample collection event itself using the BiBlade. Gelato would then depart 67P for its five-year return to Earth.

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