SYMPOSIUM ON PLANETARY SCIENCES 2020

Concept Study of Comet Halley Revisiting Missions

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February 18, 2020

Comets have been of interest for thousands of years. JAXA's first interplanetary mission, Sakigake, explored 1P/Halley by flyby observation in 1986, and JAXA opened a door to deep space exploration. This memorial object, Halley's comet, will return and approach the Sun in 2061. 1P/Halley belongs to Halley-family comets, which is in contrast to traditional Jupiter-family comets. The mission toward Halley is not only scientifically beneficial but also technically important as an immovable milestone of technology development. This paper presents the conceptual study of 1P/Halley revisiting missions. Using advanced technologies that will be mature in several decades, we expect to rendezvous Halley, deploy some landers/surface probes, and return its samples to the Earth. Because of its dynamical nature of comets, scientific requirements include not only space-wise observation but also time-wise observation. To observe the sublimating process of volatile organic compounds, the spacecraft is to rendezvous Halley at 10au solar distance in July 2058 and keep observing until 1.5au solar distance in March 2061. An example mission scenario shows that the spacecraft is to be launched in March 2051 and rendezvous Halley via low-thrust transfer by exploiting 30km/s-class DV. The technical challenge includes propulsion systems that can provide 30km/s-class a large amount of DV and lander/surface probe robotics that can survive under a 100-150K cold surface environment. To make "2061: Odyssey" to Halley true, we should start developing the Technology Readiness Levels (TRLs) of such advanced technologies in the 2020s-2030s.

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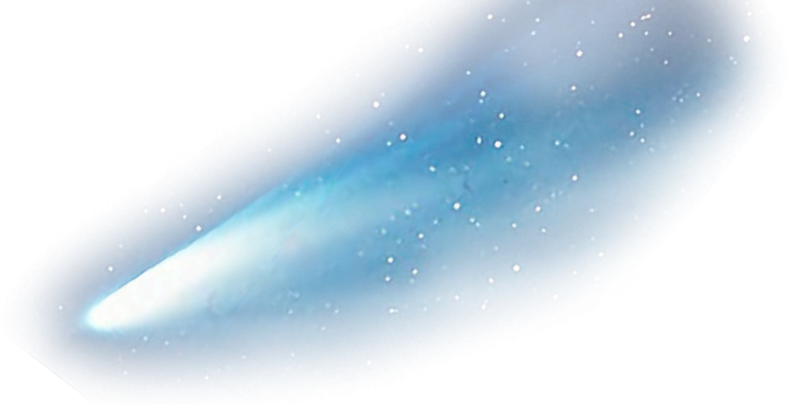
Comet Halley will return in 2061

1P/Halley



Characteristics

- Short-period comet (75.32 years)
- Belonging to Halley-Family Comets originated in the Oort cloud
  ⇔ Jupiter-Family Comets (e.g. 67P/Churyumov–Gerasimenko) originated in Kuiper belt object (and/or Scattered disk)
- Dimensions: 15 km x 8 km
- Orbital Property: Perihelion 0.586 au, Aphelion 35.082 au, Inclination 162.26 deg (**Retrograde Orbit!!**)

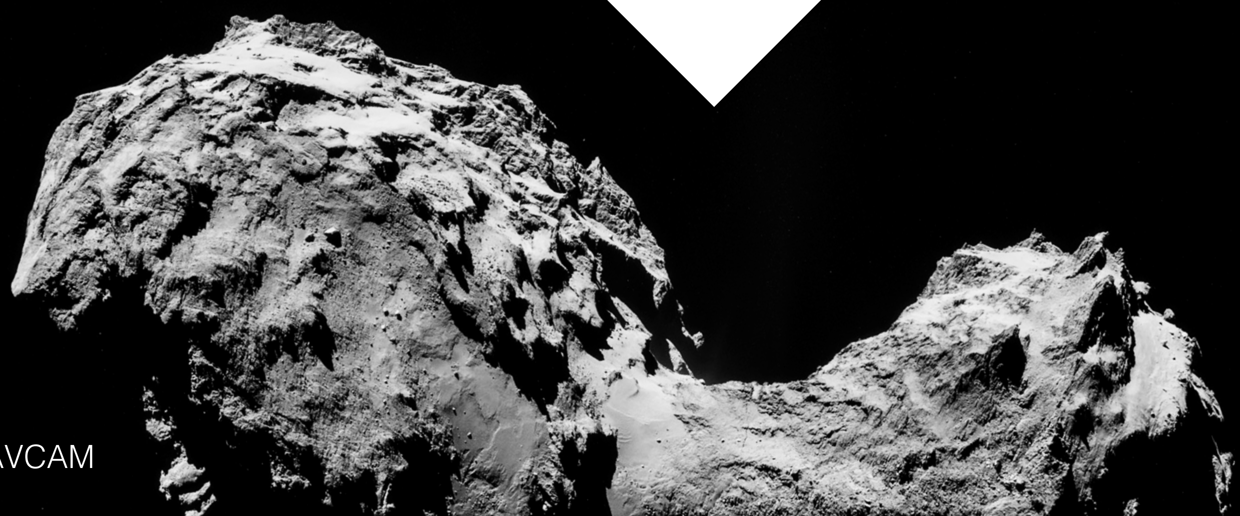
Why 1P/Halley in 2061??

- Halley-Family Comets ⇔ Jupiter-Family Comets
- Geometric condition for ground-based observation is better than one in 1986
  - We can observe Comet Halley simultaneously on ground and in situ
- Still active despite its short period and many apparitions (we can observe Halley's dust as meteor shower)
- Known through ground-based and flyby observation in 1986
- Observable with the naked eye
  - Approaching close to the Earth
  - Relatively large (4 times larger than 67P)

Science Requirement

Time-wise Observation
(Solar Distance = Temperature)

Space-wise Observation



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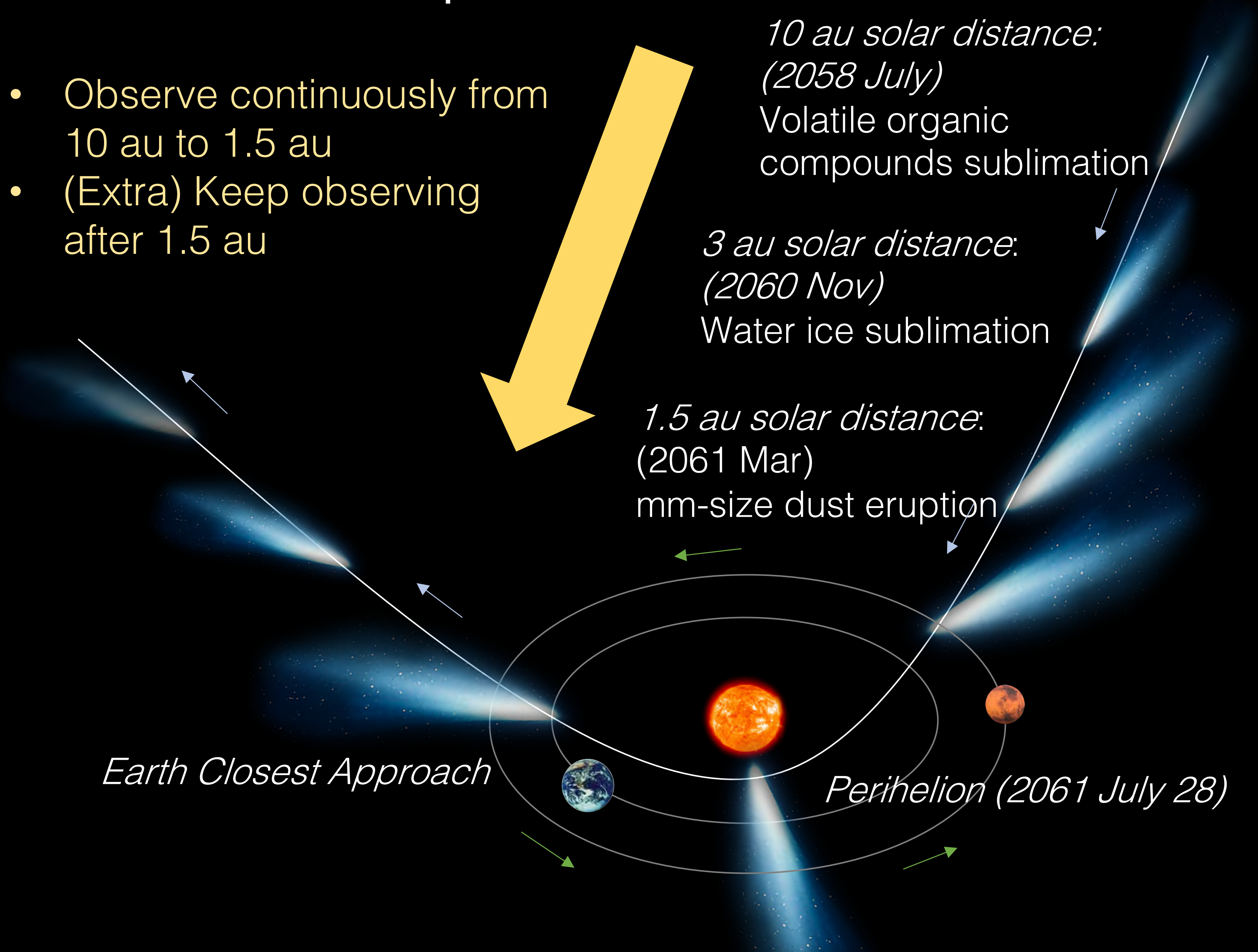
Science Requirement

- Observe continuously from 10 au to 1.5 au
- (Extra) Keep observing after 1.5 au



Science Requirement

Orbiter

Remote Sensing
- Dust Accumulation
- Surface Weathering
- Nucleus hetero/homogeneity

Dynamical Measurement
- Gravity
- Porosity
- Dust Trail

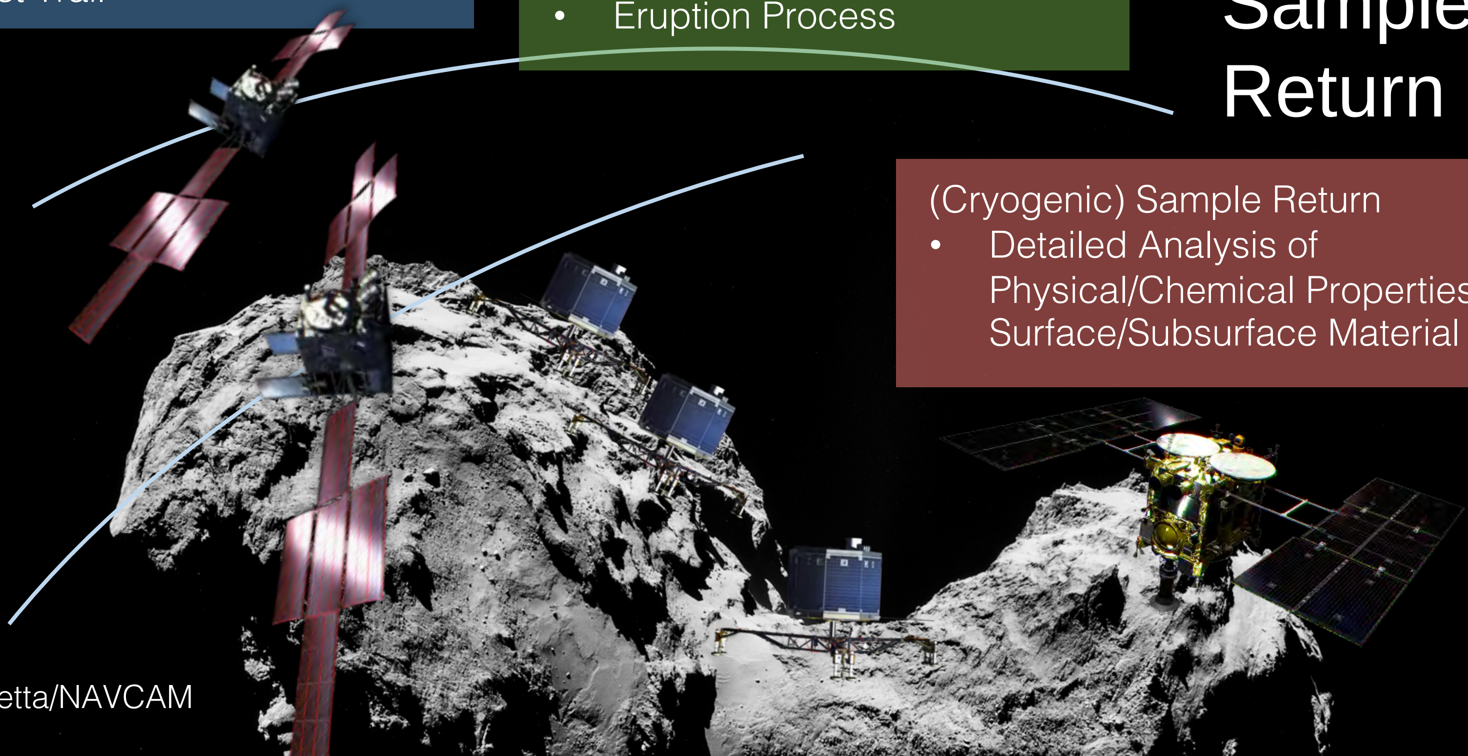
Surface Probe

In Situ Mass Analysis
- Geochronology
- Physical Properties/States of Volatile Organic Compounds

Subsurface Exploration
- Primordial Ice Property
- Eruption Process

Sample-Return

(Cryogenic) Sample Return
- Detailed Analysis of Physical/Chemical Properties of Surface/Subsurface Material



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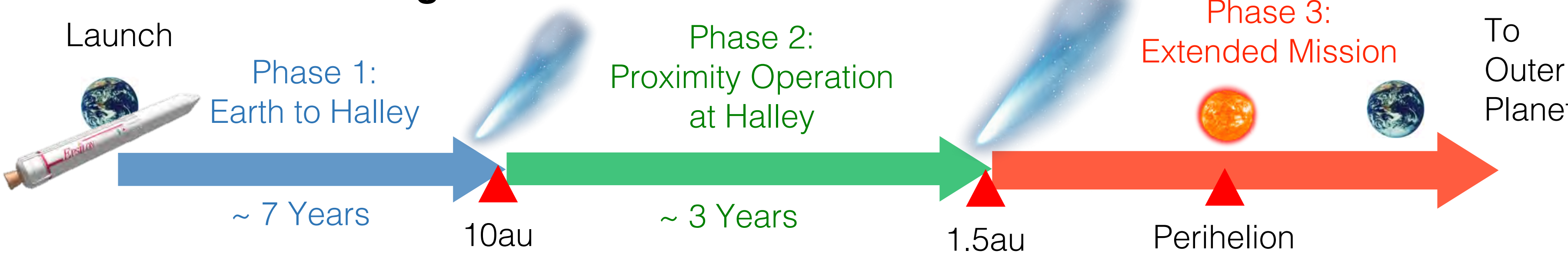
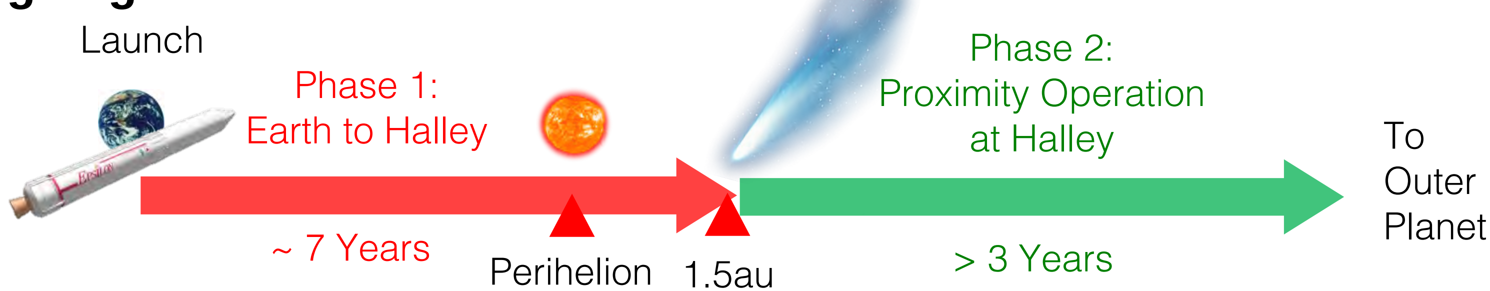
Mission Scenarios

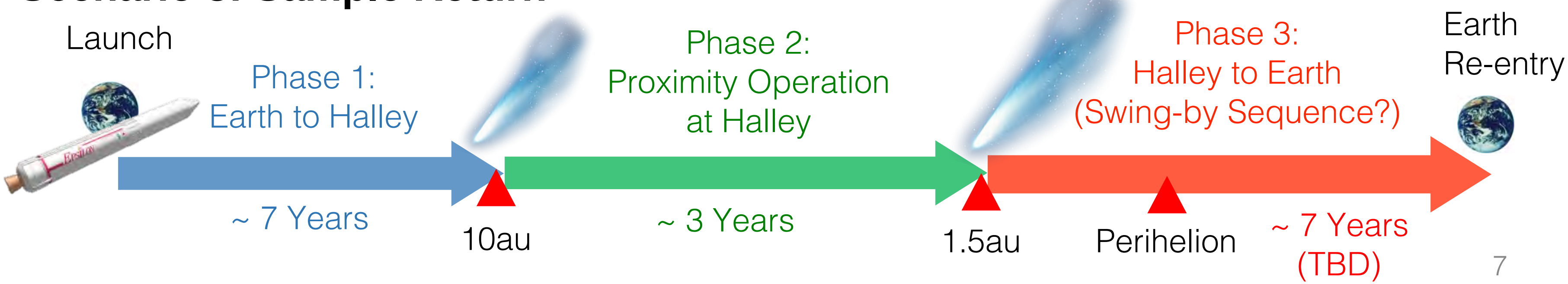
Scenario 1: Incoming Rendezvous



Scenario 2: Outgoing Rendezvous



Scenario 3: Sample Return



Example Scenario: Incoming Rendezvous

Mission Sequence

❖ 2051 Mar 16: Earth Departure
(Departure V-infinity = 5.0km/s)
Ion Engine Start (1st Thrust Arc)

❖ 2054 Jan 29: Ion Engine Stop (1st Thrust Arc)

❖ 2056 Jul 3: Ion Engine Start (2nd Thrust Arc)

❖ 2057 Sep 7: Furthest Solar Distance (11.35 au)

❖ 2058 Jul 26: 1P/Halley Arrival
Ion Engine Stop (2nd Thrust Arc)

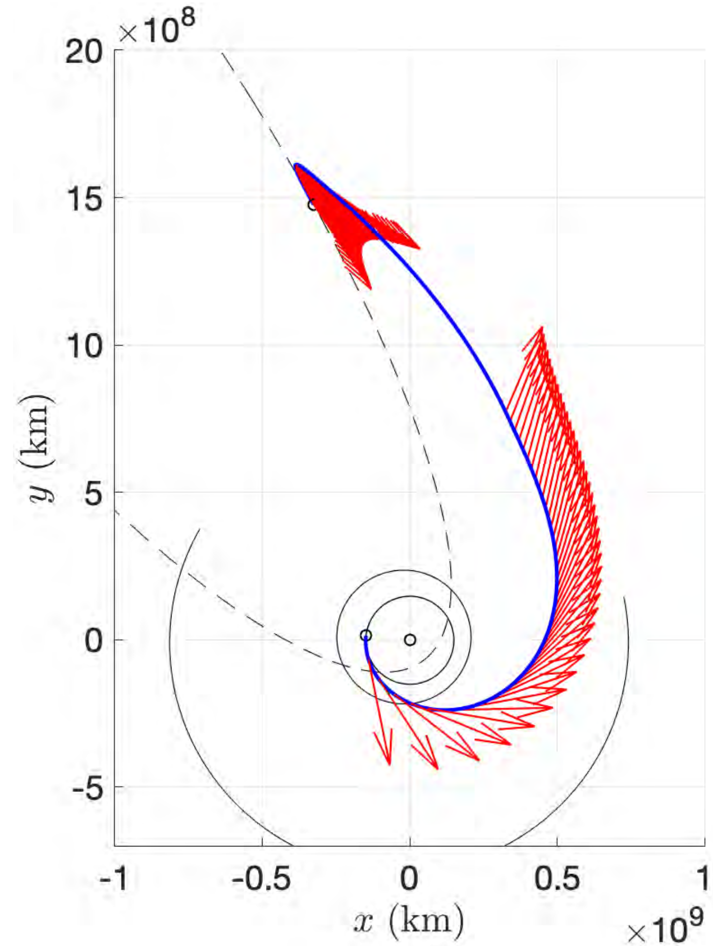
Design Results

Launch Mass: 2780 kg (by JAXA's H-3 Rocket)

Dry Mass: 926 kg (Fuel=1854 kg, ΔV=33.4km/s)

Ion Engine Specification:

- Total Thrust Magnitude: 368 mN
(NSTAR x 4 = 9.2kW)
- Specific Impulse (Isp): 3100 s
- Total Operation Time: 43272 hours



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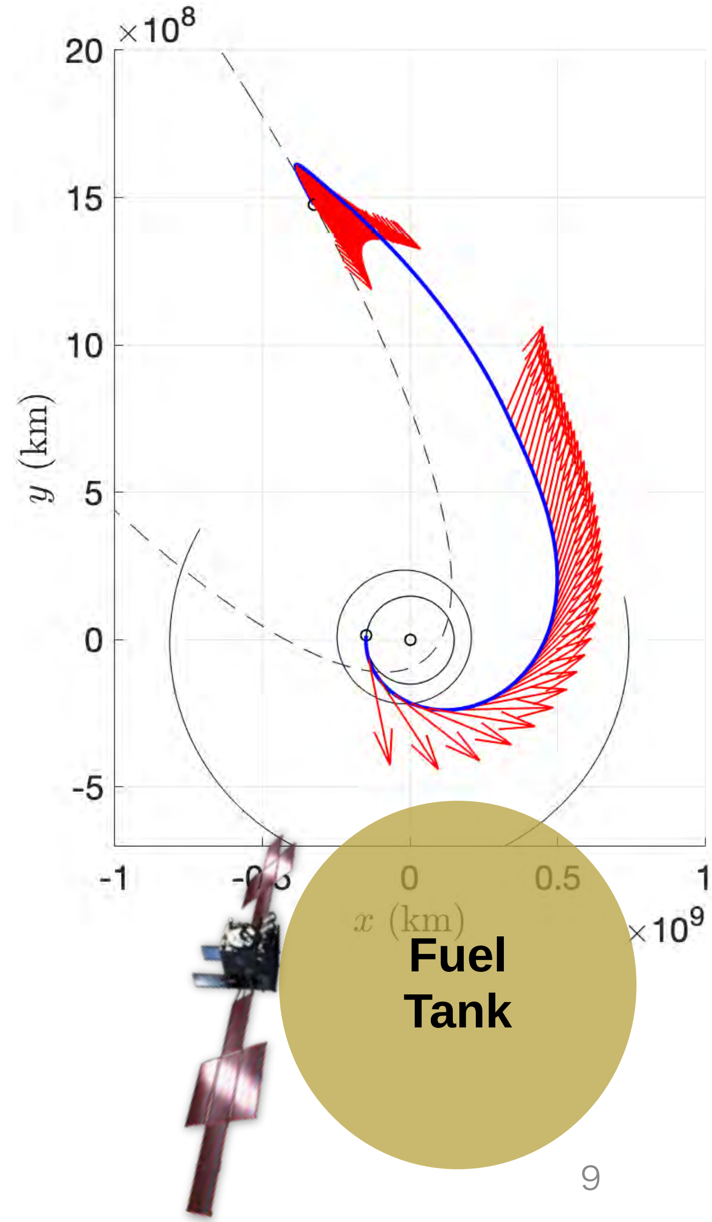
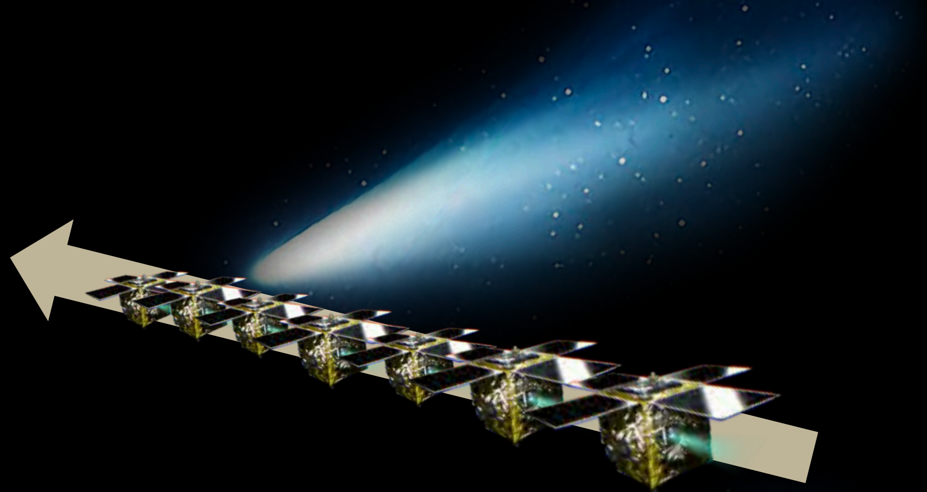


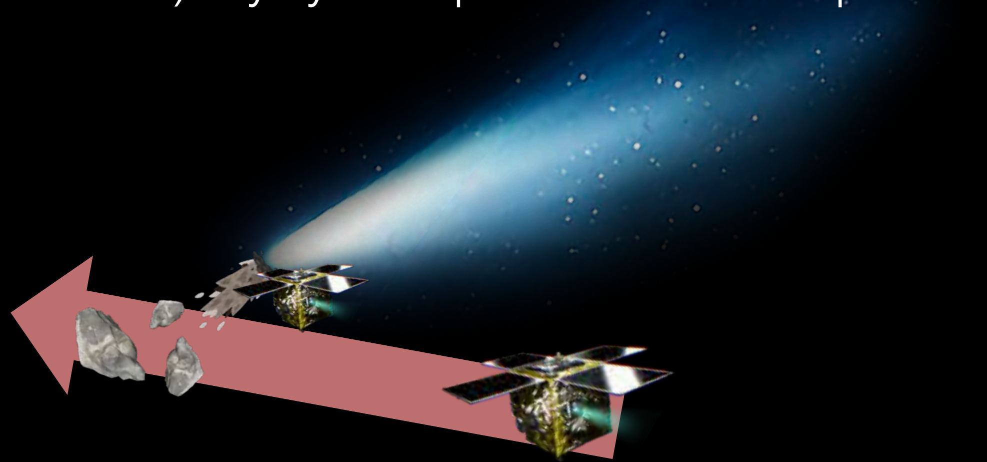
Alternative Scenarios…

a) Massive Cluster Flyby



c) Hitchhike

b) Flyby Sample Return or Impactor

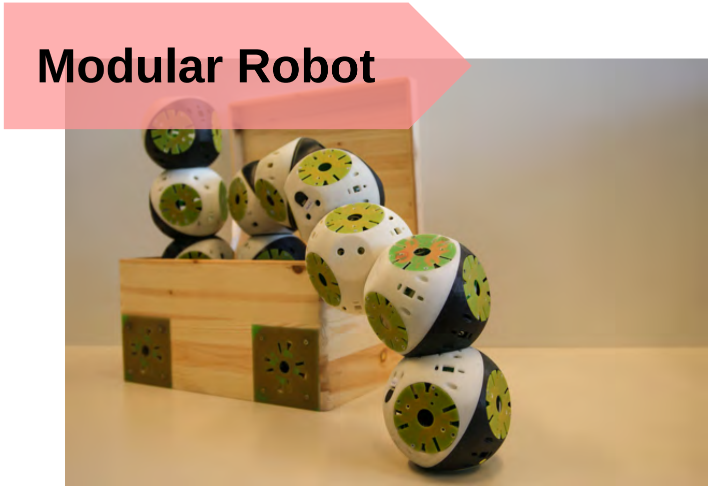


Let Us Find Innovative/Crazy Exploration Style!!

Surface Probe (Lander/Rover)

- Environment
  - Micro-gravity
  - Large uncertainties
  - Very low temperature (100K-150K) at 10 au
- Technical Challenges
  - Power generation
  - Thermal control
  - Mobility on the micro-gravity
  - Sampling mechanism (access to 10m depth subsurface)
  - Sample delivery mechanism to mothership

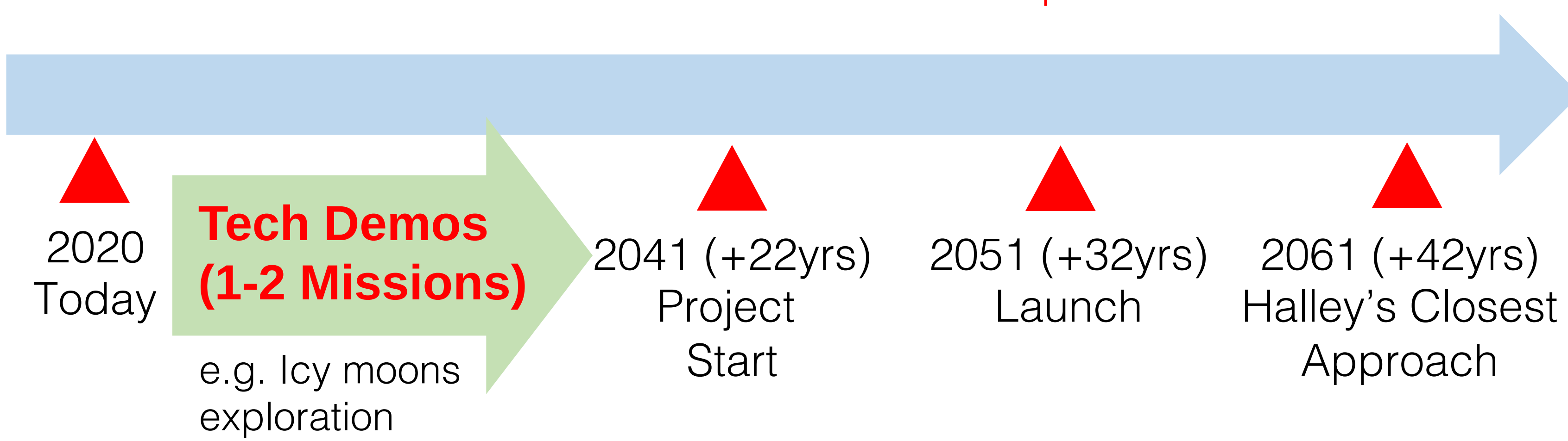
If possible…
keep the surface probe until next
Halley's encounter (76 years later)



Enabling Technology

We must improve TRLs of these technologies until 2040s!!

- Efficient electric propulsion: ~100mN/kW
- Power (radio isotope/solar sail): ~100W/kg @ 10au
- Ultra light structure: Structure mass ~100kg (propellant ~ 2000kg)
- Assembling in space: Integrated and refuel in gateway
- Cryogenic sample return: 150K sample return
- Thermal control: 100K for lander and surface probe



Far Future Mission

Interstellar Object (Rendezvous) Exploration

If an innovation of telescope lets us detect the objects around > 20 au, we could explore dynamical new comets (or extraterrestrial objects such as ‘Oumuamoa) instead of 1P/Halley

Conclusion

- 2061: Odyssey to Halley is not so distant future
  - Project must start at the beginning of 2040s
  - We only have 20 years to prepare and improve TRLs
  - Key technologies
    - Bus (Power, electric propulsion, thermal, structure)
    - Robotics, cryogenic sample return
- The mission toward Halley is not only **scientifically beneficial** but also **technically important as an immovable milestone of technology development**.

Next Closest Approach to the Sun

41 Years 6 Months 12 Days