Concept Study of Comet Halley Revisiting Missions

Naoya Ozaki (JAXA/ISAS)

G. Murakami, K. Yoshioka, Y. Shinnaka, H. Kobayashi, S. Bonardi, R. Hyodo, D.A. Dei Tos, Y. Takao, H. Kawakita, S. Kasahara, S. Kameda, R. Funase, M. Fujimoto

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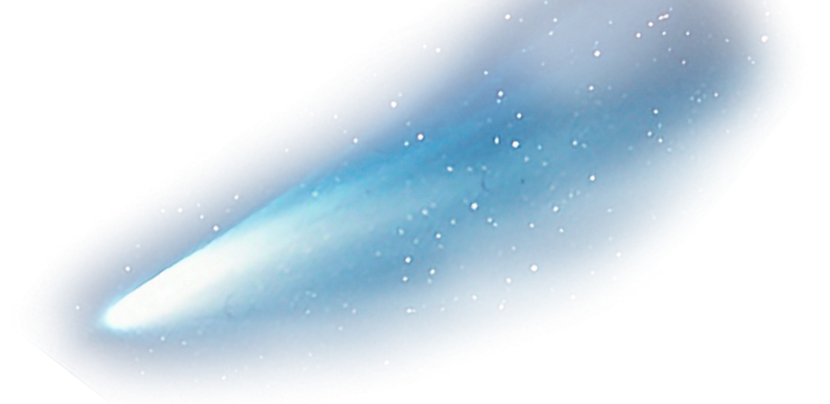
Comet Halley will return in 2061

1P/Halley



Characteristics

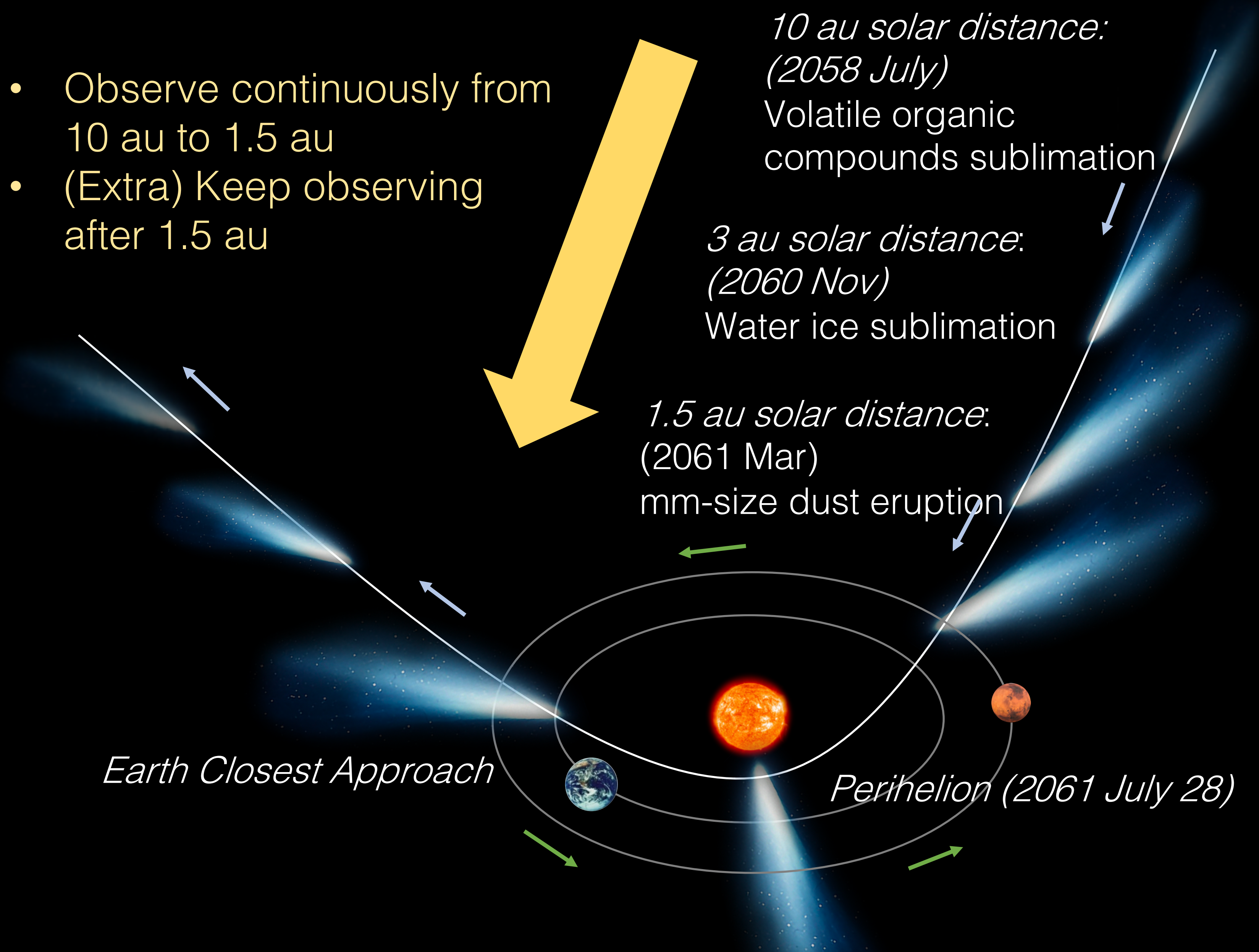
- Short-period comet (75.32 years)
- Belonging to Halley-Family Comets originated in the Oort cloud
  ⇔ Jupiter-Family Comets (e.g. 67P/Churyumov–Gerasimenko) originated in Kuiper belt object (and/or Scattered disk)
- Dimensions: 15 km x 8 km
- Orbital Property: Perihelion 0.586 au, Aphelion 35.082 au,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

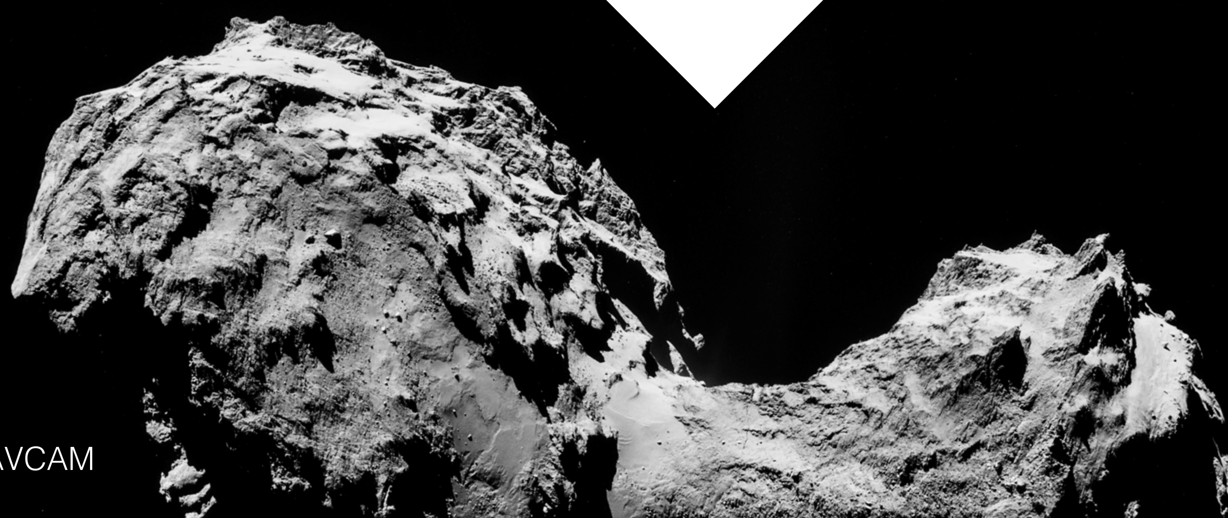
- Observe continuously from 10 au to 1.5 au
- (Extra) Keep observing after 1.5 au



Science Requirement

Time-wise Observation
(Solar Distance = Temperature)

Space-wise Observation



Science Requirement

Time-wise Observation
(Solar Distance = Temperature)

Space-wise Observation

Multiple Spacecraft
(International Collaboration is Important!!)

Science Requirement

Orbiter

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

Dynamical Measurement
- Gravity
- Porosity
- Dust Trail

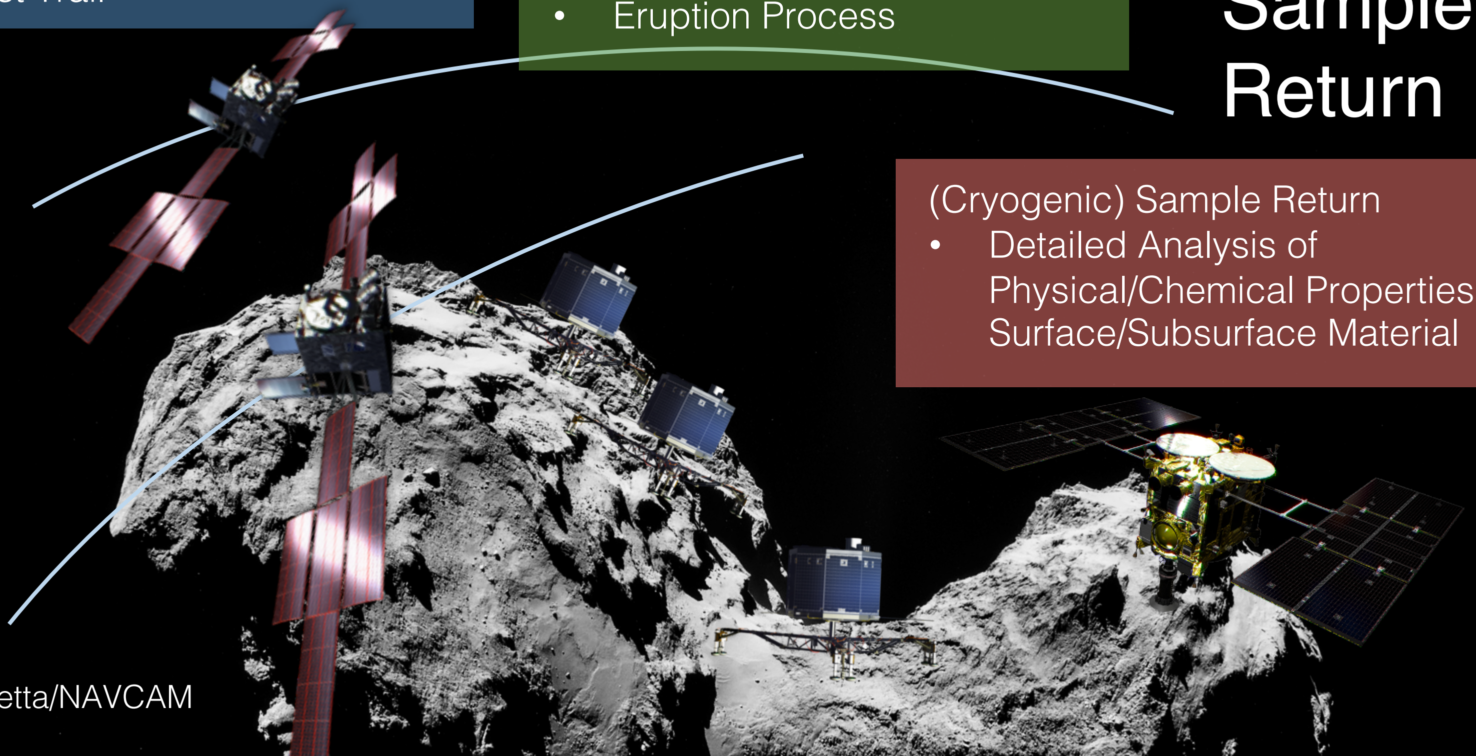
Surface Probe

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

Subsurface Exploration
- Primordial Ice Property
- Eruption Process

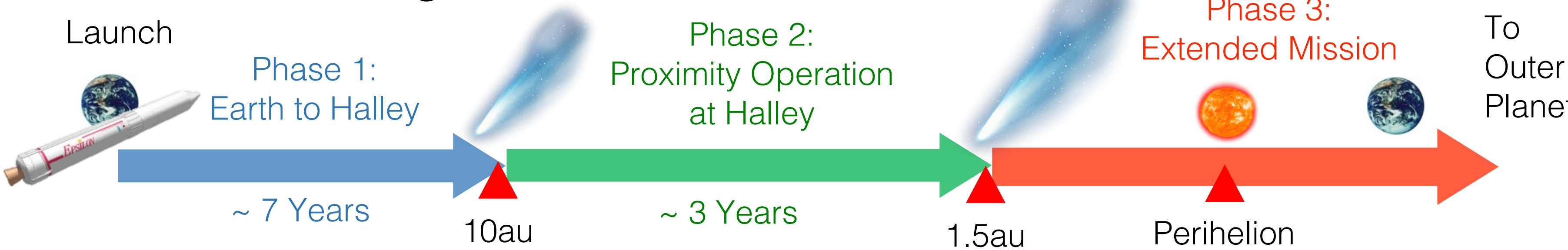
Sample-Return

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

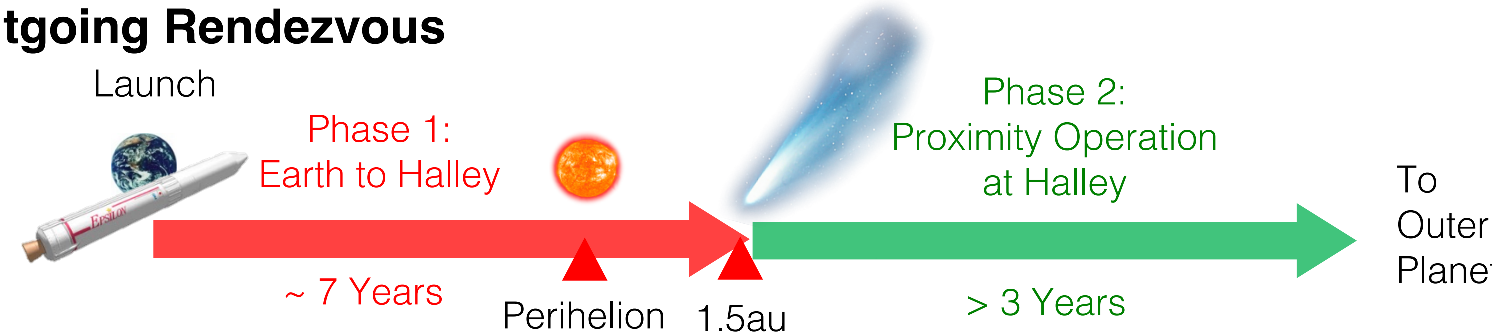


Mission Scenarios

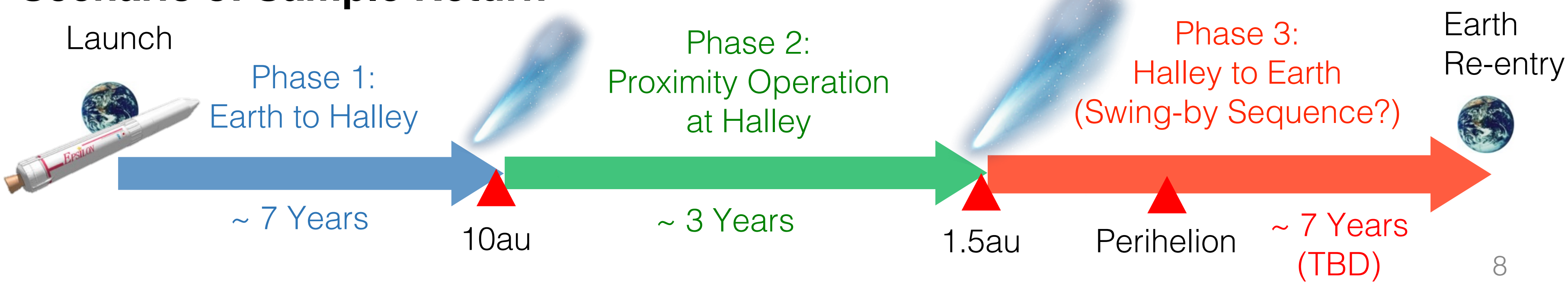
Scenario 1: Incoming Rendezvous



Scenario 2: Outgoing Rendezvous

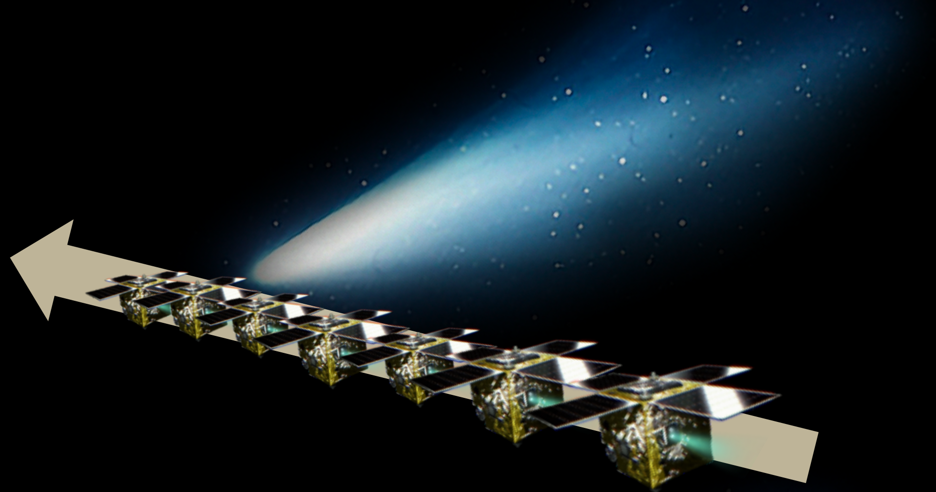


Scenario 3: Sample Return



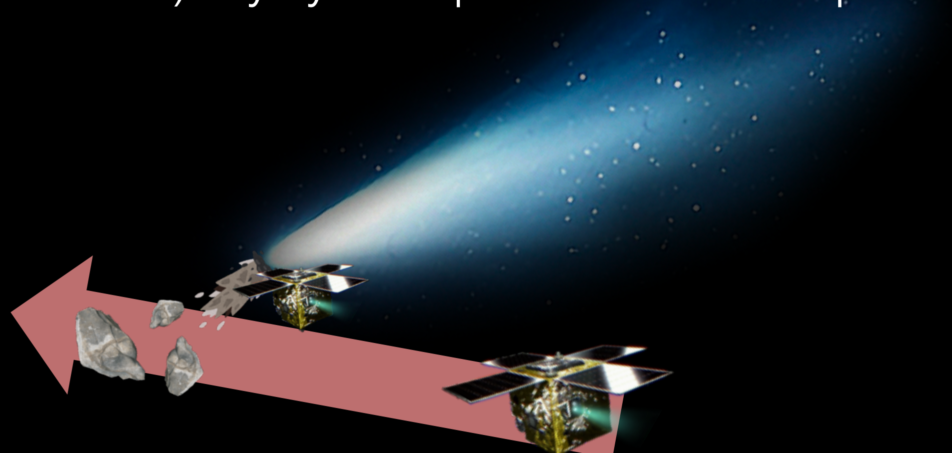
Alternative Scenarios…

a) Massive Cluster Flyby



c) Hitchhike

b) Flyby Sample Return or Impactor



Let Us Find Innovative/Crazy Exploration Style!!

Example Scenario: Incoming Rendezvous

Mission Sequence

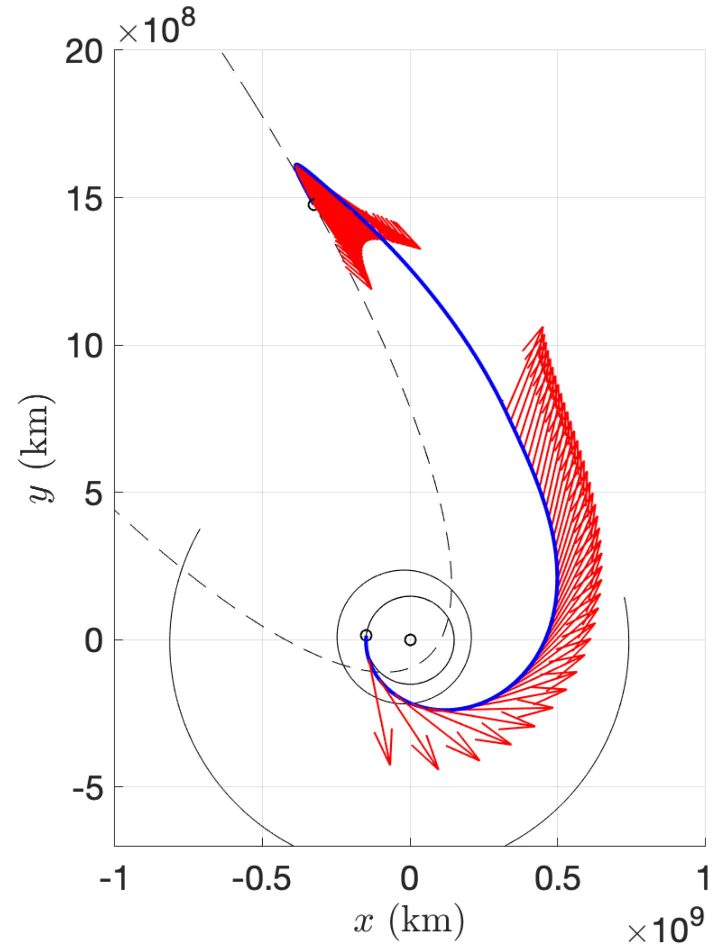
❖ 2051 Mar 16: Earth Departure
(Departure V-infinity = 5.0km/s)
Ion Engine Start (1st Thrust Arc)

❖ 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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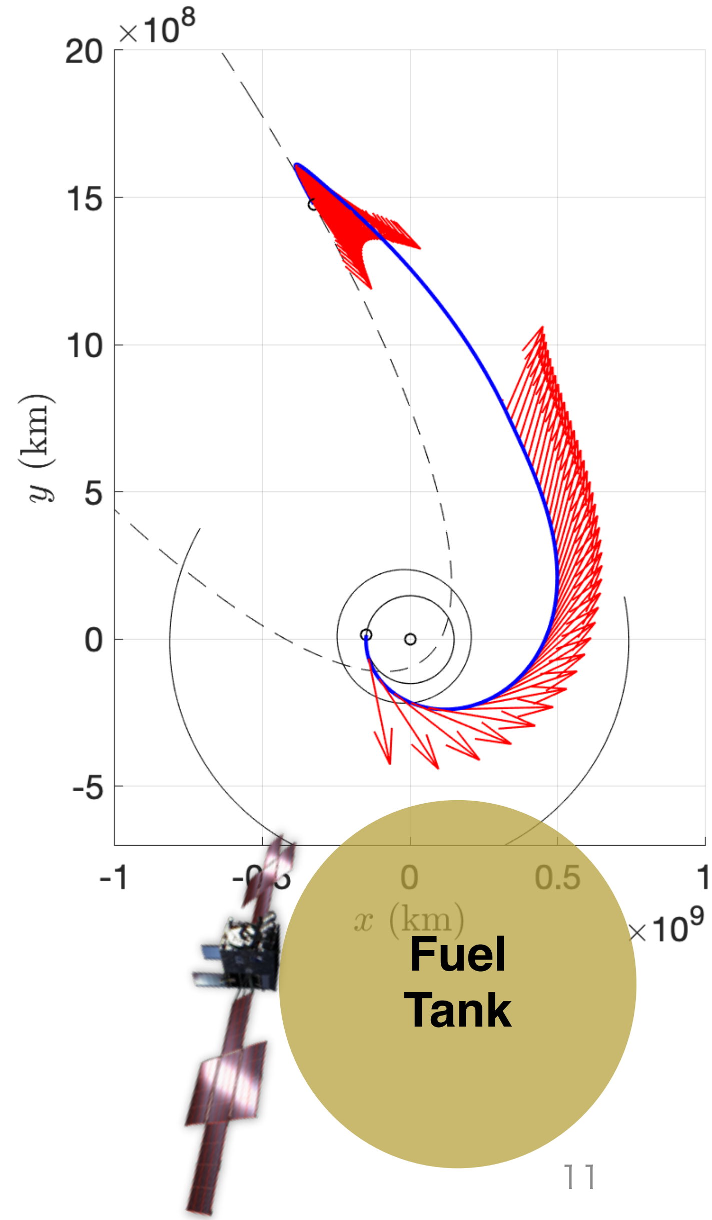


Surface Probe (Lander/Rover)

- 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

Modular Robot

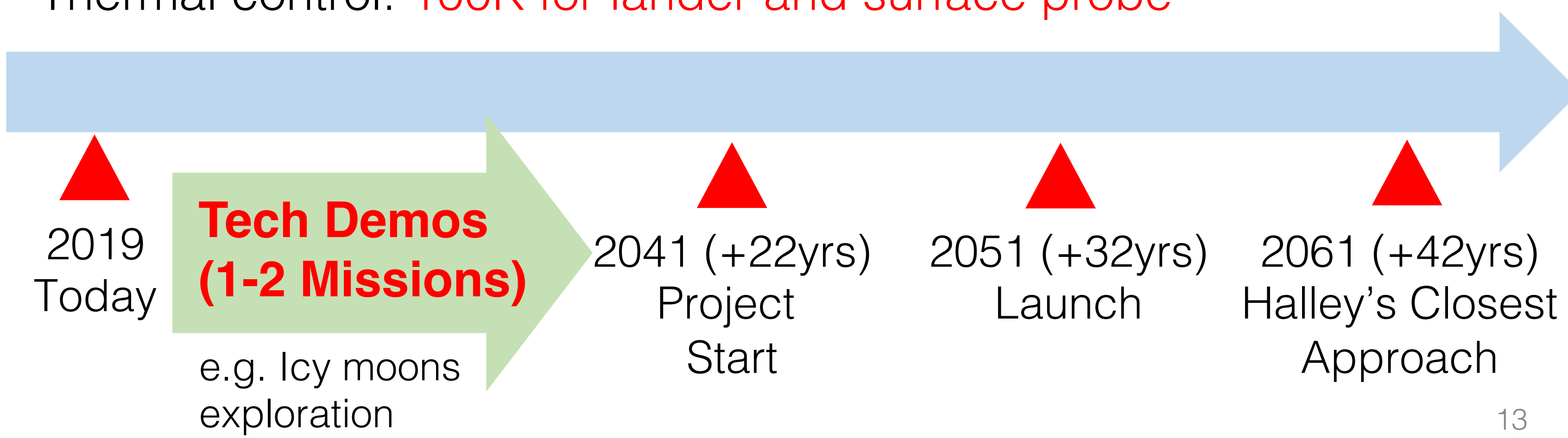
Will be presented
by Dr. Stephane Bonardi

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
  - Solar electric sail: will be presented by Dr.Osamu Mori
- 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



Related Missions

- Active Asteroids Exploration
  - Comparing them with Halley is scientifically interesting
  - DESTINY+ mission will explore (3200) Phaethon
- Kuiper Belt Object (KBO) Exploration / Inner Bound of Oort Cloud Exploration
  - Comparing them with Halley is scientifically interesting
  - Similar technologies (power/thermal) are needed
- Dynamically New Comet Exploration
  - Comparing them with Halley is scientifically interesting
  - Comet Interceptor mission in 2028 is the first step
  - 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
- International collaboration is a key factor to succeed the exploration
  - Let us start discussing the mission architecture!!

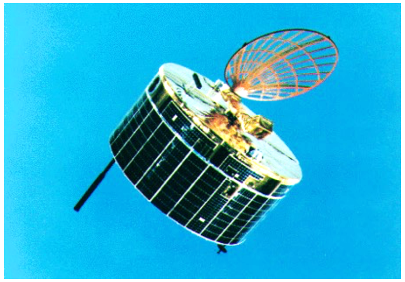
Next Closest Approach to the Sun

41 Years 10 Months 16 Days

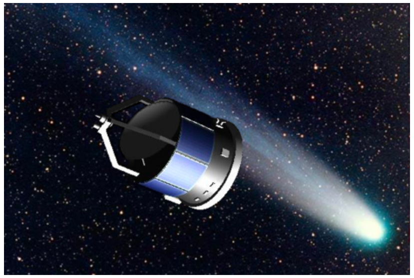
Supplemental Material

Review of Previous Comet Exploration

- ICE (ISEE-3) in 1978
  - First mission to comet (21P/Giacobini–Zinner)
- Sakigake&Suisei, Giotto, etc… in 1984-85
  - World's collaboration to explore 1P/Halley
  - Sakigake is the Japanese first deep space mission
- Stardust in 1999
  - First (flyby) sample return from comet
- Rosetta in 2004
  - First rendezvous mission to comet (67P/Churyumov–Gerasimenko)
- Comet Interceptor in 2028
  - Exploration to Dynamically New Comets



Sakigake & Suisei (ISAS)



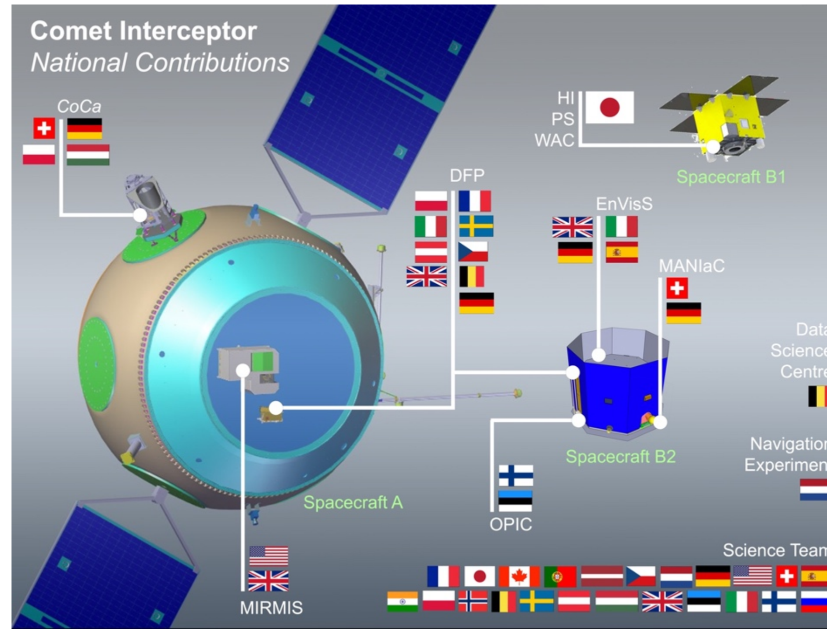
Giotto (ESA)

Rosetta (ESA)

Comet Interceptor Mission

(selected as a new ESA's F-class mission, and will be launched in 2028 with Ariel spacecraft to Sun-Earth L2)

Comet interceptor mission explores dynamically new comets (DNC) by flyby. JAXA will contribute by developing one of the daughter spacecraft.



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