The importance & challenges of rapid response

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(Pre-decisional information -- for planning & discussion purposes only)
The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.
Missions to NEOs, ISOs, & LPCs

- Proposal timelines
- Target detection
- Rapid response concepts
- Challenges & Outlook
Traditional mission planning sequence

Detection
Design
Build
Launch

Project milestones

Donitz et al. (2020). *Blue Sky Study Report, JPL Internal, Available upon request.*
Example: NASA Juno Mission (Jupiter)

Prehistoric times

1980’s +
Selected 2004

2004 onwards

2011

Proposal timelines - NASA

- Discovery or New Frontiers (up to $1 Billion USD):
  - New mission selected every 2 to 5 years
  - Launch dates 5-10 years post-selection
  → Overall: 10 - 15 years +
Proposal timelines - NASA

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- SmallSat missions: ~$55-100 M USD
  - Ride-alongs for Discovery, New Frontiers
  - No dedicated launch vehicle!
  → Risk: launch delay for Psyche → smallsat EscaPADE delayed by yrs
Proposal timelines

ESA – Rosetta (9 yrs approval → launch)

- 1970’s – first Rosetta mission concepts
- 1986 – Comet Haley global campaign
- 1993 – Mission approved
- 2004 – Launch
Proposal timelines

**ESA – Rosetta** (9 yrs approval → launch)
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**JAXA – Hayabusa2** (7 yrs)
- 2007 – study began for follow-up to Hayabusa
- 2009 – Hayabusa2 mission concept
- 2010 – JAXA approves mission
- 2014 – Launch
Proposal timelines

ESA – Rosetta (9 yrs approval → launch)
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JAXA – Hayabusa2 (7 yrs)
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+ Frequent collaborations between ESA, JAXA, & NASA. (instruments, data, etc)
Traditional mission planning sequence

Detection

Design

Build

Launch

Project milestones

1I/'Oumuamua
Detection: Oct 2017
Perihelion: Sept 2017
(detected after perihelion)

2I/Borisov
Detection: Aug 2019
Perihelion: Dec 2019

Comet C/2017 K2
June 26, 2017
HST WFC3/UVIS F350LP
Detection: May 2017
Perihelion: Dec 2022

Missed Opportunities?

Meech et al. (2017); "MPEC 2019-S72 : 2I/Borisov = C/2019 Q4 (Borisov)"
"MPEC 2017-N26 : COMET C/2017 K2 (PANSTARRS)"
NEOs / potentially hazardous asteroids
Near miss?

Asteroid 2019 OK
Discovered day before perihelion
0.00048 AU (1/5 distance to moon)
How far in advance can we detect NEOs, ISOs, & LPCs?
Some sky survey telescopes

PanSTARRS 1 & 2

- Hawaii, 2008-present
- Discovers >50% of new NEOs, comets (IfA)
- Apparent magnitude 24

Vera C. Rubin Observatory

- Chile, estimated 2023
- Will catalog 61% of all NEOs that are > 140m
- Apparent magnitude ~24 (single), 27 (stacked)
Brightness impacts detectability

Active comets – brighter, long tail

More asteroidal – dimmer, lower albedo
Detecting NEOs, ISOs, and LPCs

- LPC’s (Wilman Jr, 1995; Castillo-Rogez+, 2018)

3-5 yr detection window before perihelion
Detecting NEOs, ISOs, and LPCs

- LPCs: several per year, 3-5yrs before perihelion

- ISO's: 1-2 per year with the Vera C. Rubin Observatory (Trilling + 2017; Hoover + 2022)
Detecting NEOs, ISOs, and LPCs

- LPCs: several per year, 3-5yrs before perihelion
- ISO’s: 1-2 per year with the Vera C. Rubin Observatory (Trilling + 2017; Hoover + 2022)
- NEO’s:
Traditional mission planning sequence

Detection

Design

Build

Launch

PROBLEM

Project milestones

Solution:
Rapid response missions
Changing the paradigm

Detection

Design

Build

Launch

Rapid response architectures and Concept Studies

A. Ground storage
  Launch on detection
“Bridge” concept (2019 Planetary Science Summer Seminar)

1st flyby of a yet-to-be discovered ISO

Approach: Main spacecraft + autonomous impactor
Wait in ground storage until target detection

Science: Chemical & isotopic composition incl. organics, & geologic morphology

Payload: Camera, impactor, near-IR, mid-IR, UV point spectrometers

Preliminary cost estimate by JPL Team-X between Discovery- and NF-class

Moore et al. (2021). Planetary & Space Science
Rapid response architectures and Concept Studies

A. Ground storage
Launch on detection
e.g. BRIDGE concept

B. Parking orbit
Launch then wait
e.g. Comet Interceptor

Design
+ ground storage
Detection
Launch

Build
(parking orbit)
Detection
Comet Interceptor (ESA/JAXA)

1st encounter with a dynamically new LPC or ISO

Approach: Main spacecraft + 2 smaller probes
Parking orbit (Sun-Earth L2).
Short period comet as backup after 3yr

Science: 3D profile of surface & coma composition, shape, & structure

Payload: multiple cameras, spectrometers, dust, and plasma instruments

Developed under ESA’s Fast-Class program — cost ~roughly equivalent to Discovery

Rapid response architectures and Concept Studies

A. Ground storage
   Launch on detection
   e.g. BRIDGE concept

B. Parking orbit
   Launch then wait
   e.g. Comet Interceptor

C. Build on detection
   e.g. Xenia concept
SmallSats: *Xenia* concept to Comet K2 (FY19 JPL study)

1st in situ exploration of an Oort Cloud Comet

**Approach:** Twin smallsats (block redundancy)

*Build, test, & launch in < 2yrs!*

**Science:** Protoplanetary disk temperature

Nucleus jet activity

**Payload:** UV spectrometer (isotopes) +

High-res camera

Consistent w/ increased SIMPLEx cap, but required dedicated, large launch vehicle

Donitz et al. (2020). *IEEE Aerospace Conference Proceedings*
Rapid response missions to ISOs, LPCs, and NEOs are feasible. How can we enable them over the coming decade?
Programmatic

Challenges:

○ LPCs, ISOs, & NEOs are only discoverable shortly before perihelion
○ Current opportunities are too restrictive (cadence, LV, regulations)

Approach: Rapid response architectures
Programmatic

Challenges:
- LPCs, ISOs, & NEOs are only discoverable shortly before perihelion
- Current opportunities are too restrictive (cadence, LV, regulations)

Approach: Rapid response architectures

Recommendations:
- Evaluate implications of proposals with unspecified targets & dedicated LVs
- Assess procurement for dedicated vehicles & long lead items – “pool of parts”
Engineering

Challenges:

- Rapid spacecraft development, certification, and launch
  - NASA: Long Phase A/B - each mission mostly re-designed from scratch
Engineering

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Recommendations:
- Spacecraft standardization - e.g. modular bus, interfaces & software blocks
- Multi-functional components (low TRL)
- Fast but reliable testing approach
Technology

Challenges:
- Navigation at NEOs, LPCs, and ISOs is very challenging
- Smallsats can assist, but have intrinsic limitations (e.g. propulsion)

Approach:
- Multi-spacecraft architectures → increase science return
- Autonomy → improve navigation & decrease risk
Technology

Challenges:
○ Navigation at NEOs, LPCs, and ISOs is very challenging
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Approach:
○ Multi-spacecraft architectures → increase science return
○ Autonomy → improve navigation & decrease risk

Recommendations:
○ Concept studies to de-risk multi-spacecraft architectures
○ Technology maturation (autonomy, navigation, manufacturing)
2023-2032 Planetary Science & Astrobiology Decadal Survey

Coordinated white paper campaign (Donitz et al., Meech et al., Moore et al., +)
Achieved policy success!

"Recommendation: In the coming decade, NASA should develop an approach for a rapid response, flyby characterization of emerging, short-warning-time (< 3 years) threats and science opportunities"

Recommended: 50% increase in cost cap for small sats
Increased investment in autonomy tech
Outlook

NEOs, ISOs, and LPCs are high-value targets

- Require a rapid response architecture
- Mission concept studies demonstrate feasibility at a range of cost caps

BUT current programmatic constraints create challenges

Coordinated effort by the scientific community can make these missions a reality.
Questions?