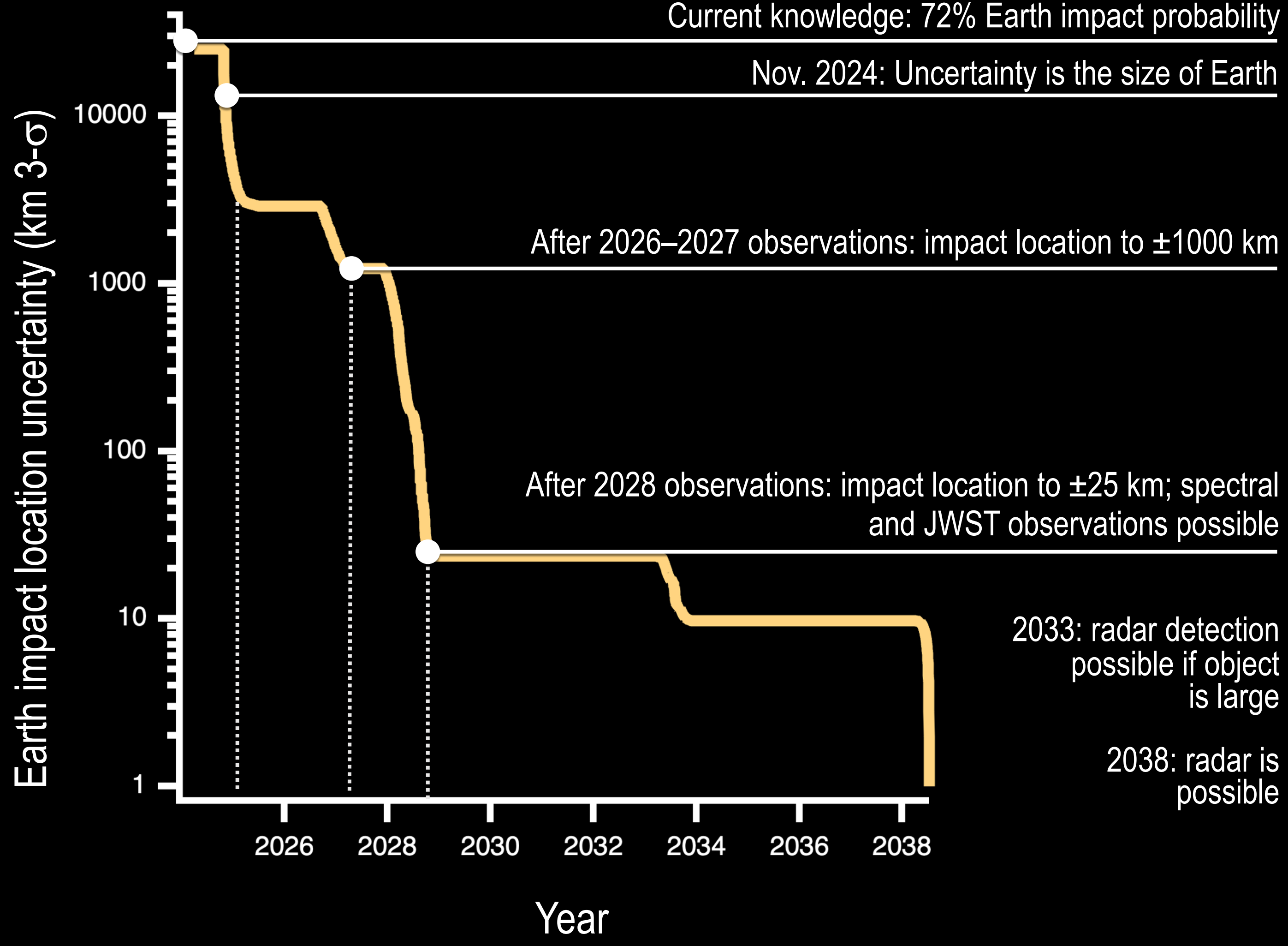
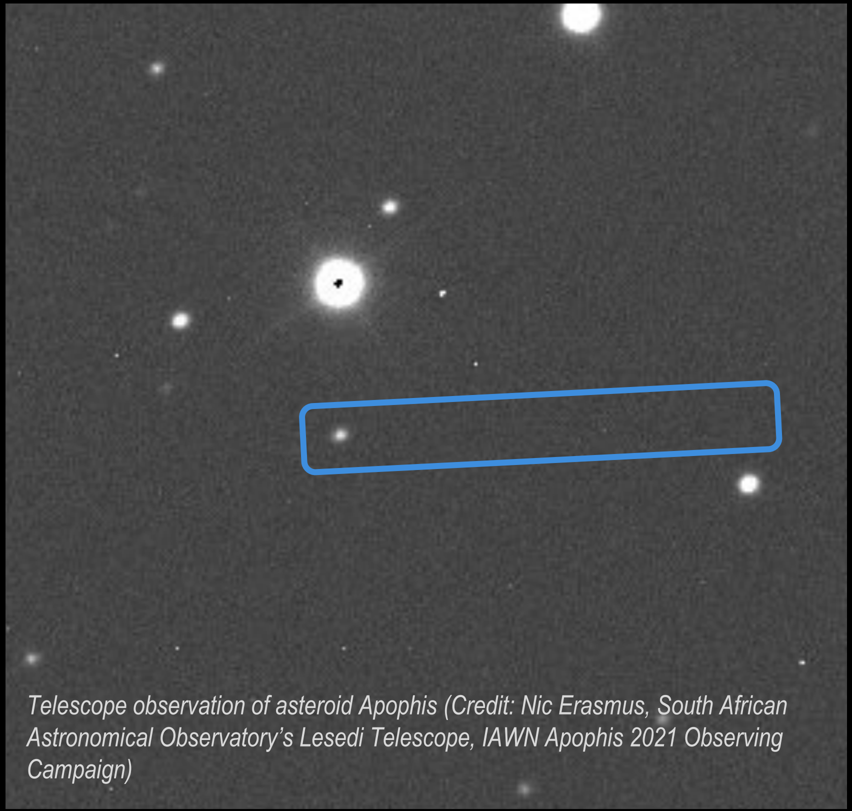
Module 2: Space Mission Options

- Technical briefs
  - Reconnaissance space mission options
  - Impact-prevention space mission options
- Discussion will focus on
  - Current readiness and challenges for a timely and effective in-space response
  - Policy considerations that would come into play
  - International coordination on space mission options
  - Implications of space mission options on emergency preparedness and public messaging

Potential Information from Earth-Based Telescopes




Telescope observation of asteroid Apophis (Credit: Nic Erasmus, South African Astronomical Observatory's Lesedi Telescope, IAWN Apophis 2021 Observing Campaign)

With Earth-based optical telescopes, the asteroid always appears as a single point of light.

Recommended Criteria for Action Have Been Crossed

Action	Warning Time	Impact Probability	Object Size	Threshold Crossed?
Warn	Any	>1%	>10 m or <absolute magnitude 28	✓
Terrestrial preparedness planning	≤20 years	>10%	>20 m or <absolute magnitude 27	✓
Mission options planning	≤50 years	>1%	>50 m or <absolute magnitude 26	✓

Reference: SMPAG Recommended Criteria & Thresholds for Action for Potential NEO Impact Threat (2017)

U.S. benchmarks for considering execution of space missions have also been crossed.	✓

Reference: Report on Near-Earth Object Impact Threat Emergency Protocols (2021)

Reconnaissance Mission Options

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Rylie Bull (Johns Hopkins Applied Physics Laboratory)
Davide Farnocchia (Jet Propulsion Laboratory/Center for Near Earth Object Studies)
Matt Vavrina (NASA Goddard Space Flight Center)

FEMA

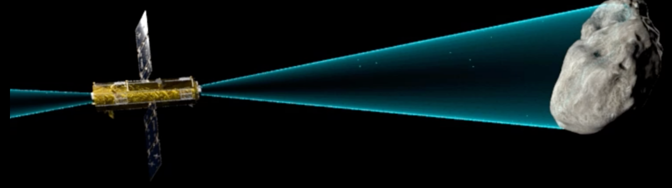
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Ames Research Center

Lawrence Livermore National Laboratory

Asteroid Impacts May Be Preventable

Kinetic Impact



Ion Beam

Nuclear Explosive Devices

Successful impact prevention requires **adequate warning time** and **information about key asteroid properties**.

The Asteroid's Properties Are Highly Uncertain

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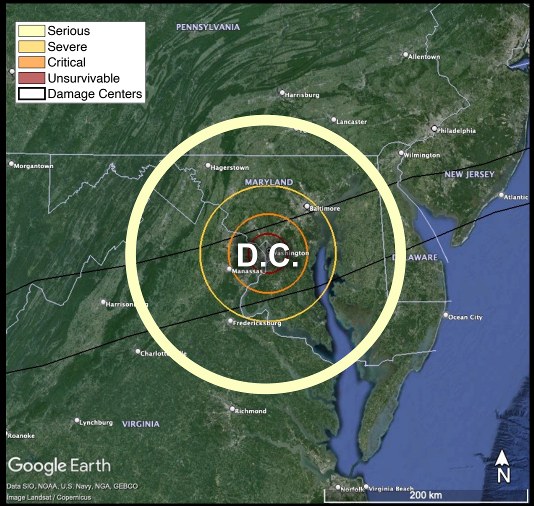
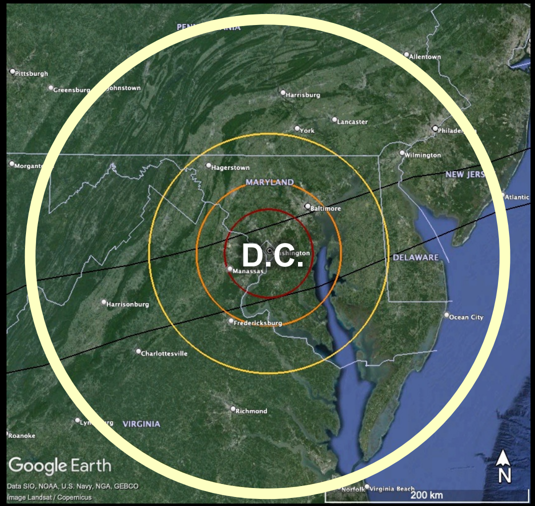
What would emergency management organizations face?

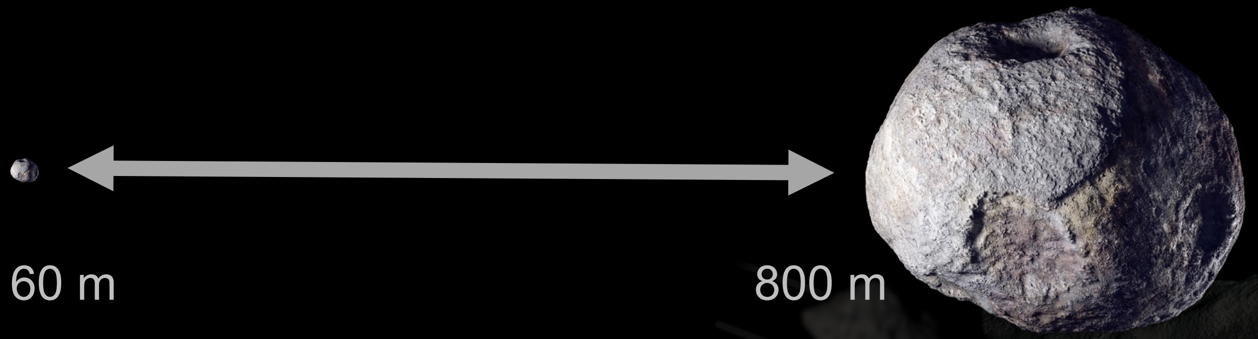
What would impact-prevention mission(s) have to deal with?



50th percentile



95th percentile



60 m

800 m

EXERCISE EXERCISE EXERCISE

PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 5

A Spacecraft Reconnaissance Mission Is the Fastest Way to Reduce These Uncertainties

Flyby Recon

Send a spacecraft to collect data while flying past the asteroid. Typical time from build to launch is **3 years**.

Rendezvous Recon

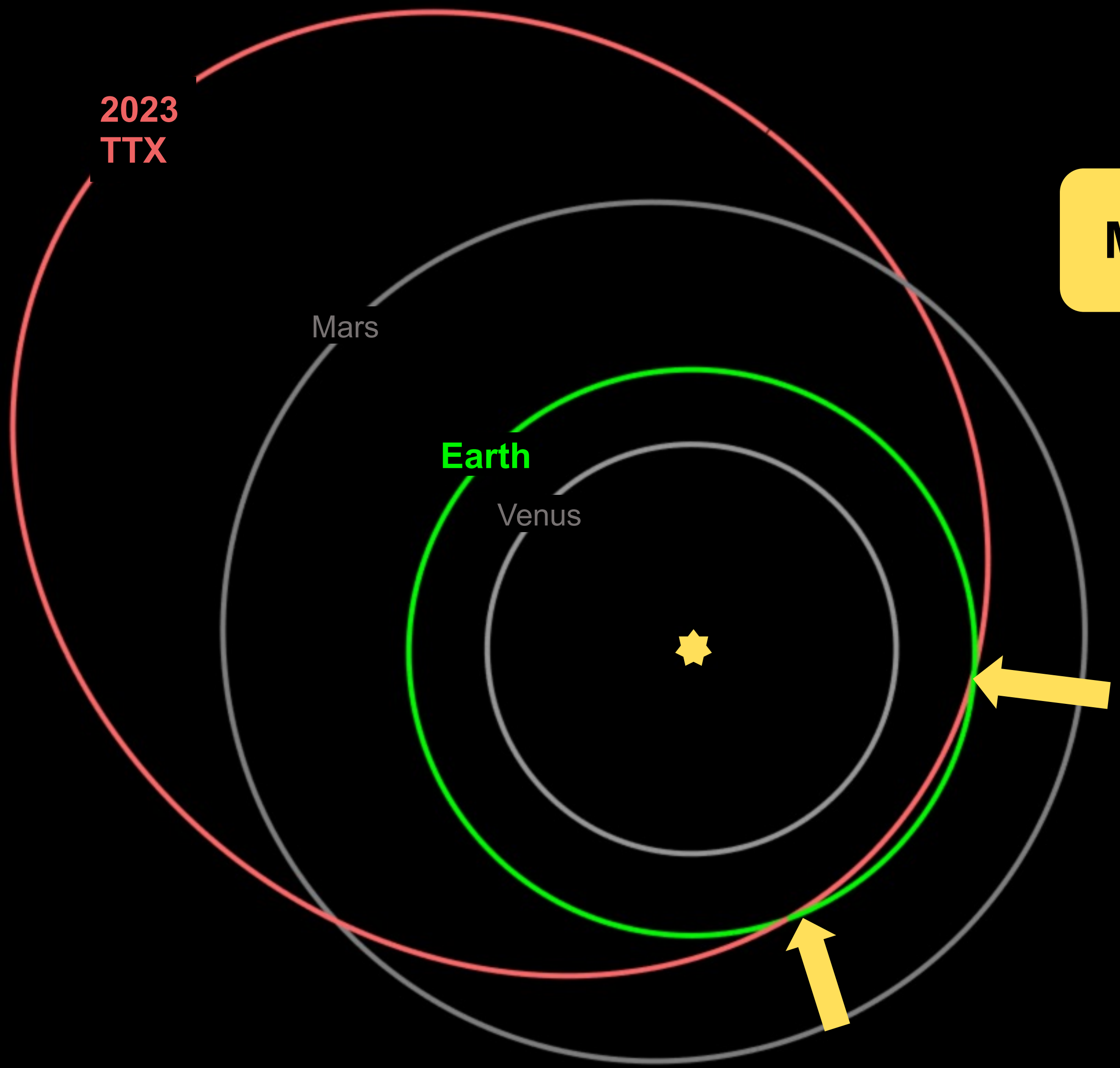
Send a spacecraft to arrive at the asteroid and observe it up close for an extended period of time. Typical time from build to launch is **5 years**.

Design → **Build** → **Test** → **Launch** → Cruise → Encounter → Downlink → Analyze

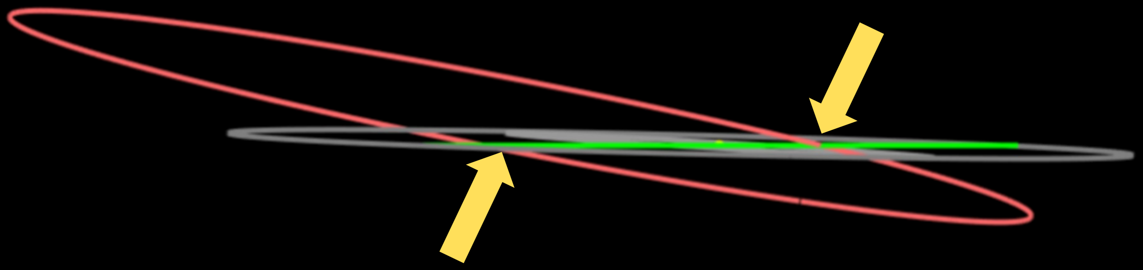
Time for each phase varies depending on the mission; equal block size does not represent equal time.

It is unknown how much these timelines could be compressed in an emergency.

The Asteroid's Orbit Dictates Mission Options

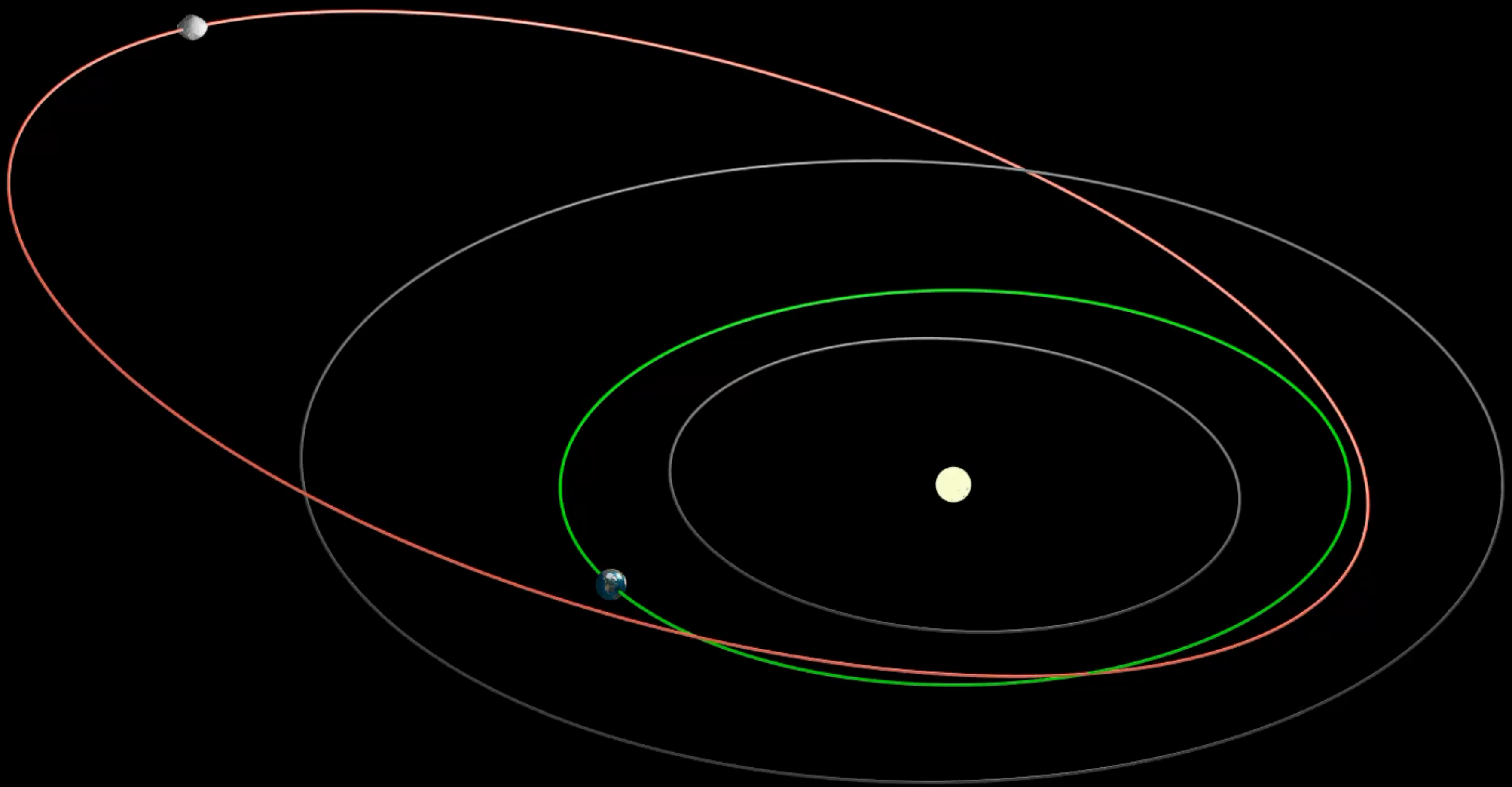


Mission opportunities repeat every ~2.5 years



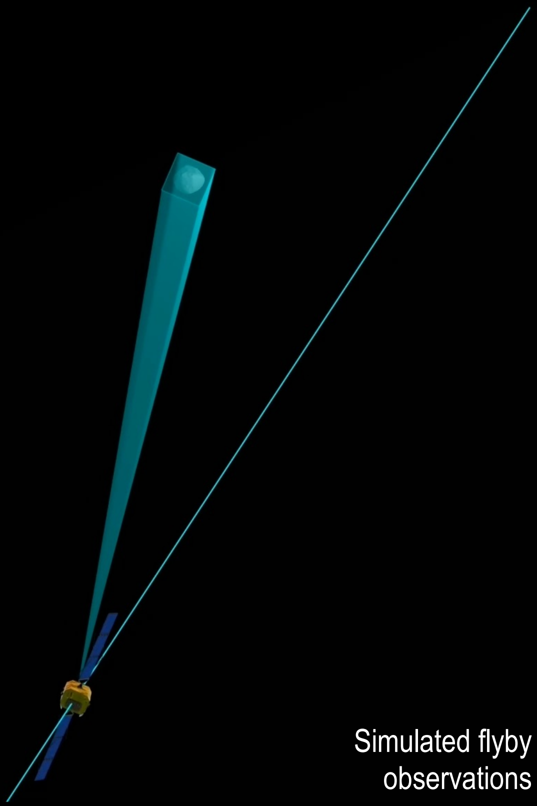
All viable space missions encounter the asteroid near where it crosses Earth's orbit.

Flyby Reconnaissance Example



Flyby Reconnaissance Example

PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 5



Simulated flyby observations

Actual images of comet Hartley 2 from EPOXI mission (2010)

Mission type	Earth impact location uncertainty	Asteroid size uncertainty	Asteroid mass uncertainty	Other asteroid information gained
Flyby recon	~100 km	~10%	~50%	Some surface images and high-level composition classification
Rendezvous recon	<10 km	<1%	<1%	Extensive surface imaging and detailed composition mapping

From analyses of previous planetary defense exercises and data from asteroid missions. Specific information gained would depend on the specific mission.

Flyby Recon Mission Options

Launch Date	Arrival Date	Relative Cost	Launch: Years from April 2024
~~Aug 2024~~	~~Jan 2026~~	~~$$~~	~~0.5~~
Nov 2025	Jul 2027	$$$	1.5
Sep 2027	Jul 2028	$	3.5
May 2029	Jan 2031	$ – $$	5
Jul 2032	Jul 2033	$ – $$	8
Aug 2034	Jan 2036	$	10

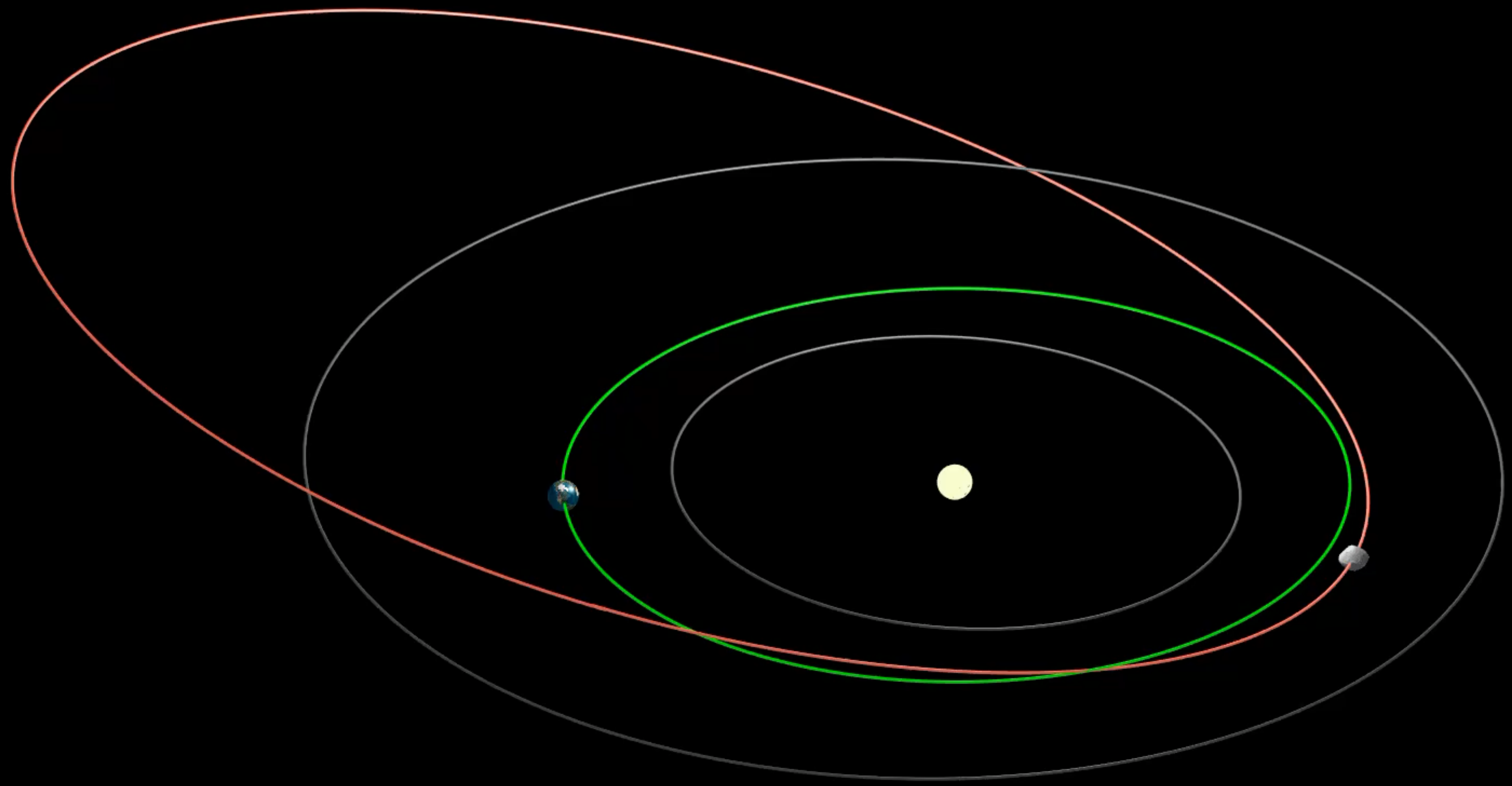
Many flyby options are available for other arrival windows.

← Requires a spacecraft ready to go (Aug 2024)

← Aggressive development schedule (~3 years historically) (Nov 2025)

← Not possible to send a follow-on mitigation mission (Aug 2034)

Rendezvous Reconnaissance Example



Rendezvous Reconnaissance Example

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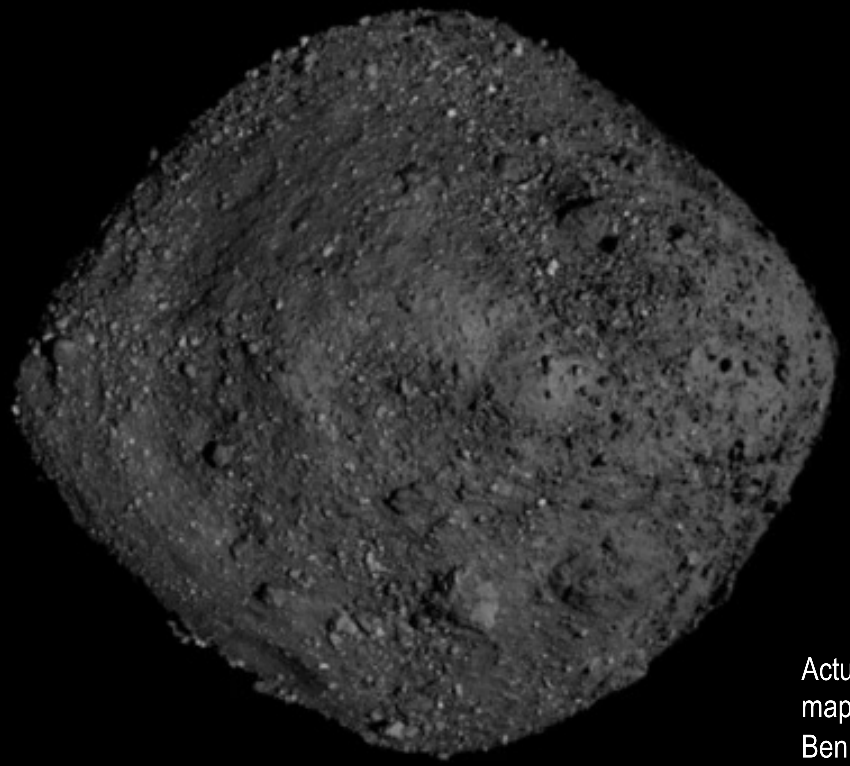
Simulated rendezvous operations



Actual OSIRIS-REx map of asteroid Bennu (2019)

Mission type	Earth impact location uncertainty	Asteroid size uncertainty	Asteroid mass uncertainty	Other asteroid information gained
Flyby recon	~100 km	~10%	~50%	Some surface images and high-level composition classification
Rendezvous recon	<10 km	<1%	<1%	Extensive surface imaging and detailed composition mapping

From analyses of previous planetary defense exercises and data from asteroid missions. Specific information gained would depend on the specific mission.

Rendezvous Reconnaissance Mission Options

Launch Date	Arrival Date	Relative Cost	Launch, Years from April 2024
Jun 2026	May 2028	$$$$	2
Jul 2028	Dec 2030	$$$$	4
Jul 2029	Dec 2032	$$$	5
Jul 2033	Dec 2035	$$$	10

Extremely aggressive development schedule (~5 years historically) ← Jun 2026 option

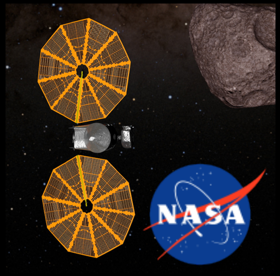
Aggressive development schedule (~5 years historically) ← Jul 2028 option

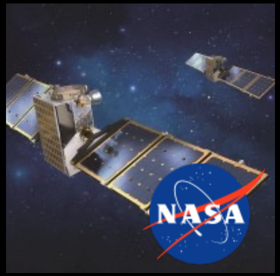
Rendezvous options assume a spacecraft mass and propulsion capabilities similar to NASA's Psyche mission.

Rendezvous requires a more complex spacecraft.

Rendezvous missions could be flown as combined recon and impact prevention missions.

Repurposing Spacecraft for Reconnaissance





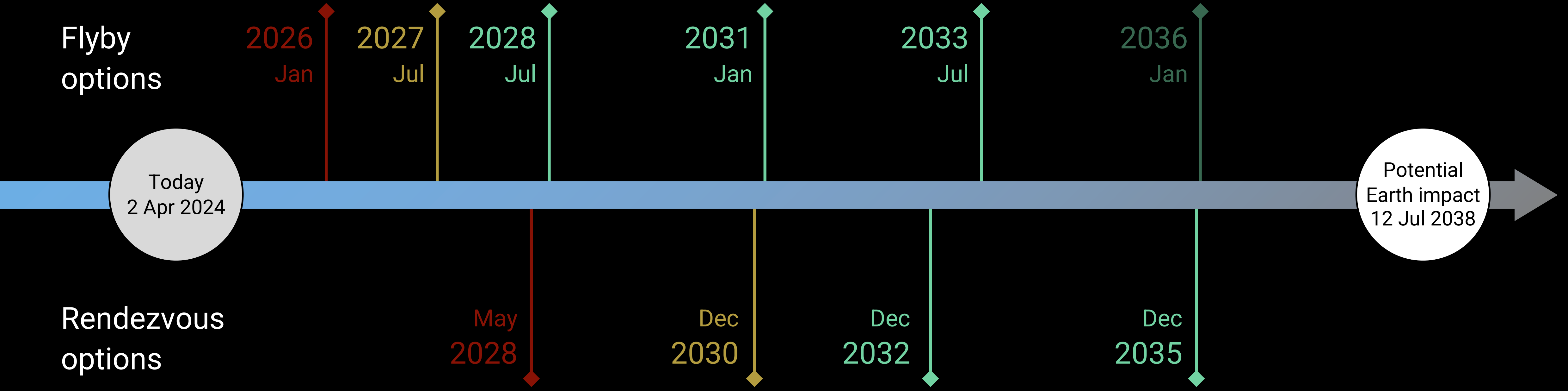
Some currently flying or in-development spacecraft could be rerouted for an asteroid flyby.

HOWEVER:

- A repurposed rendezvous spacecraft has limited navigation and measurement capabilities when applied to a fast flyby.
- The margins for success for a repurposed spacecraft could be much smaller than would be traditionally acceptable, leading to a higher risk of failure than something purpose-built.

Repurposing spacecraft for activities they were not designed for increases the risk that needed measurements will not be successfully acquired.

Reconnaissance Options by Arrival Date



Potential Telescopic Information

Impact location uncertainty is the size of Earth.

Nov 2024

Impact location ±25 km. Spectral and JWST possible. Uncertainties remain in key asteroid properties.

2028

Radar detection is possible if the object is large.

2033

Under standard development schedules, flyby recon data would be available NET **July 2028**. Rendezvous recon data would become available NET **December 2032**.

Spacecraft development schedule, assuming development starts immediately

Red: >2 years faster than standard. Yellow: ~1 year faster than standard. Green: standard schedule is possible.

This slide has been intentionally left blank.

- What pieces of information were most relevant to your role and why?

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- What other information would help in assessing these reconnaissance options?
- What are your thoughts on the pros and cons of these reconnaissance mission options?
  - Are any options an immediate no and why?

- What are your thoughts on current readiness as it relates to these reconnaissance mission options?

- What are your thoughts on current readiness as it relates to these reconnaissance mission options?
- What policy, funding, and resource considerations might emerge for planning and implementation of these reconnaissance missions?

Lunch

PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 5

Recommended Criteria to Consider Impact Prevention Missions Have Been Crossed

Action	Warning Time	Impact Probability	Object Size	Threshold Crossed?
Mission options planning	≤50 years	>1%	>50 m or <absolute magnitude 26	✓

Reference: SMPAG Recommended Criteria & Thresholds for Action for Potential NEO Impact Threat (2017)

Consider executing space-based impact-prevention mission	≤50 years	>10%	>50 m or <absolute magnitude 26	✓
Feasibility benchmarks	• Technically feasible • More likely to decrease impact probability than increase it • Waiting longer to improve confidence in impact prediction would substantially decrease likelihood of successful prevention			
Hazard benchmarks	• Impact would likely result in loss of many lives within the U.S. (of order 100 or more*) **OR** would likely result in U.S. economic cost exceeding the financial cost of prevention			

Reference: Report on Near-Earth Object Impact Threat Emergency Protocols (2021)

** Refers to assessed loss of life that evacuation cannot prevent, either because some cannot evacuate or the risk corridor is too large to organize an effective evacuation.*

Earth Impact Prevention Mission Options

Brent Barbee and Analysis Team
NASA Goddard Space Flight Center

Analysis Team: Justin Atchison (APL), Brent Barbee (NASA/GSFC), Rylie Bull (APL), Mary Burkey (LLNL), Wendy K. Caldwell (LANL), Paul Chodas (JPL/CNEOS), Jessie Dotson (NASA/ARC/ATAP), Davide Farnocchia (JPL/CNEOS), Kathryn Kumamoto (LLNL), Josh Lyzhoft (NASA/GSFC), Catherine Plesko (LANL), Isaiah Santistevan (LLNL), Bruno Sarli (NASA/GSFC), Megan Syal (LLNL), Matt Vavrina (NASA/GSFC)

Key Drivers for Impact Prevention Missions

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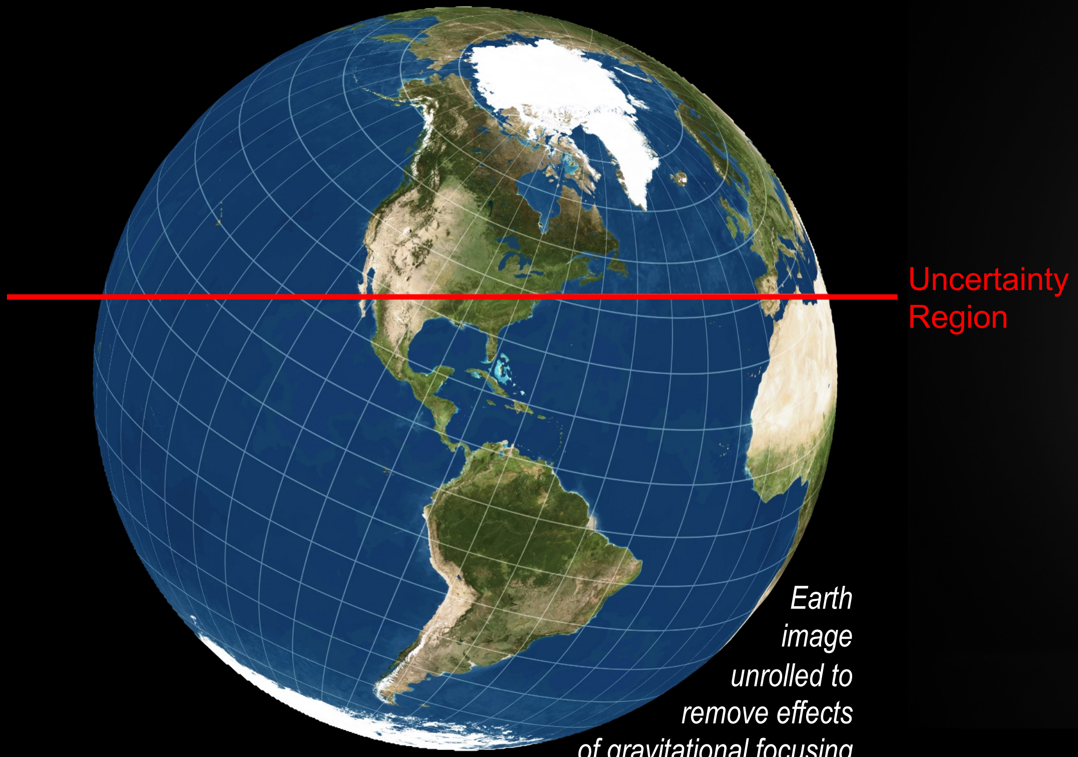


Asteroid mass

Earth impact location

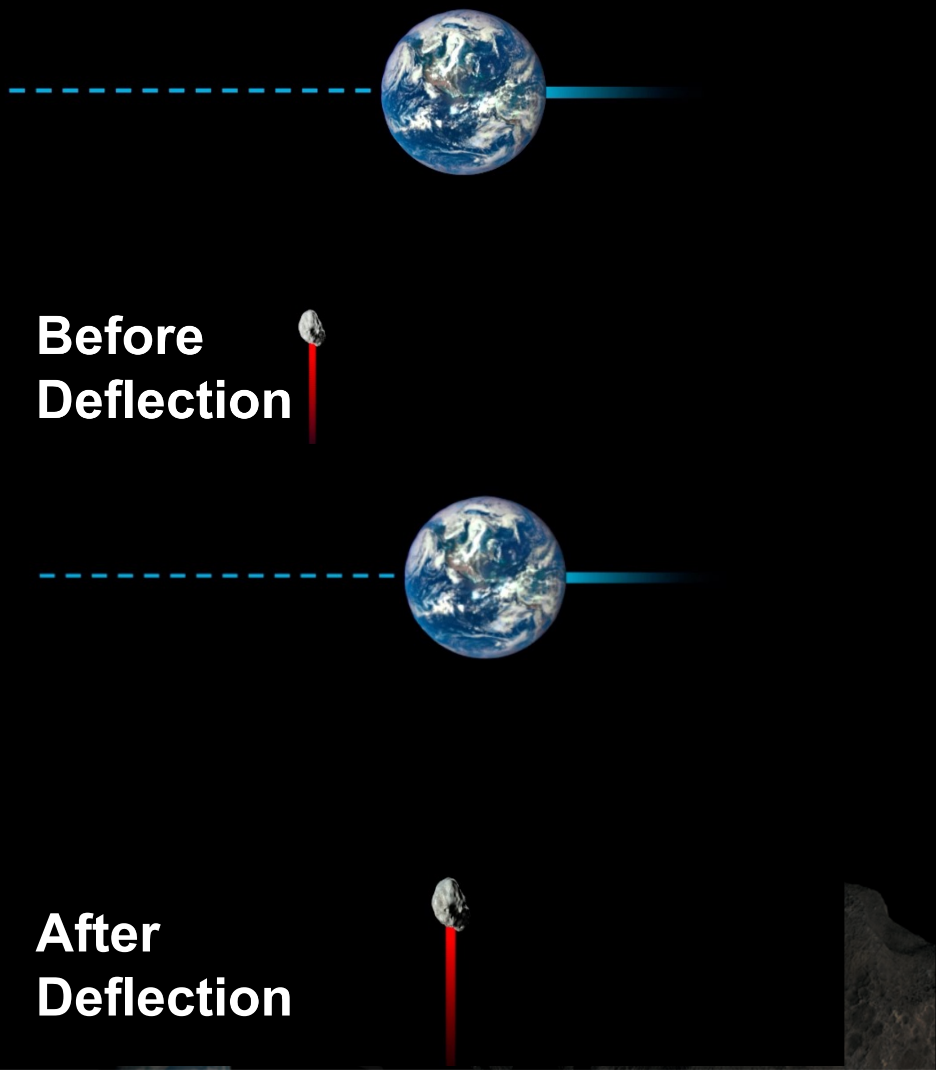
Time to impact

A recon mission could reduce uncertainties in both of these.

The sooner you start, the easier the task

In This Scenario, Deflection Is Preferred

- Given what we know at this time in the scenario, disruption (breaking the asteroid into multiple smaller pieces) is impractical for ~80% of the potential asteroid masses.
- To avoid Earth impact, an asteroid can be **deflected** by changing its speed (slowing it down or speeding it up) but leaving the asteroid largely intact.
- Deflection analysis assumes the **highest deflection energy requirements** and considers up to the **90th-percentile asteroid mass** to provide high probability of mission success.



Kinetic Impact (KI) Deflection

A spacecraft intercepts and rams into the asteroid at high speed, creating ejecta that provides an additional push.

Considerations and technology needs:

- Need to be cautious of disruption. Multiple, smaller impactors co-manifested on a single launch may be needed.
- Larger and faster spacecraft than DART demonstration are useful to achieve deflection.

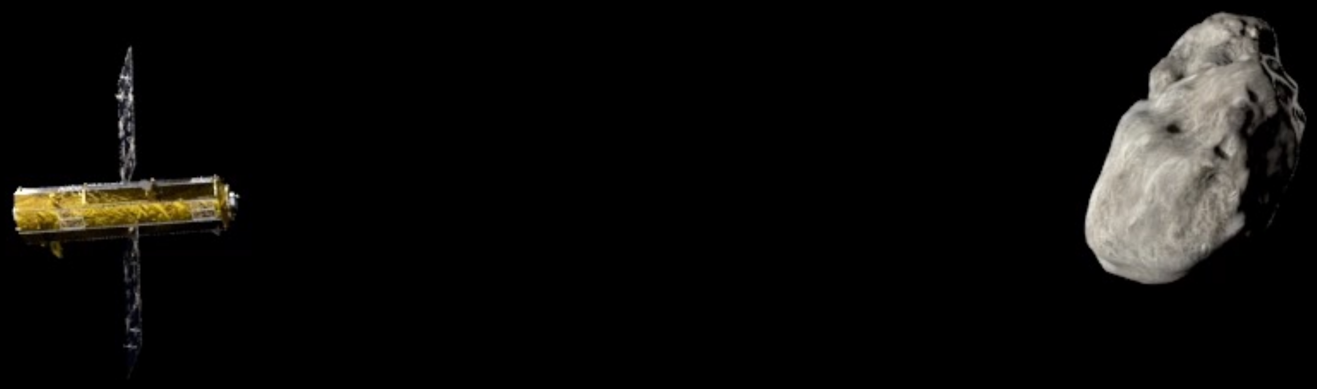
Previous demonstration of asteroid deflection?
Yes – with NASA's DART mission (2022)

Ion Beam (IB) Deflection

Rendezvous spacecraft fires its ion beam engines at the asteroid for many years to slowly push the asteroid.

Considerations and technology needs:

- Higher onboard power
- Development of tightly collimated ion beam emitters
- Precision GNC operations over many years
- In-flight characterization of deflection efficiency



Previous demonstration of asteroid deflection?
No

Nuclear Explosive Device (NED) Deflection

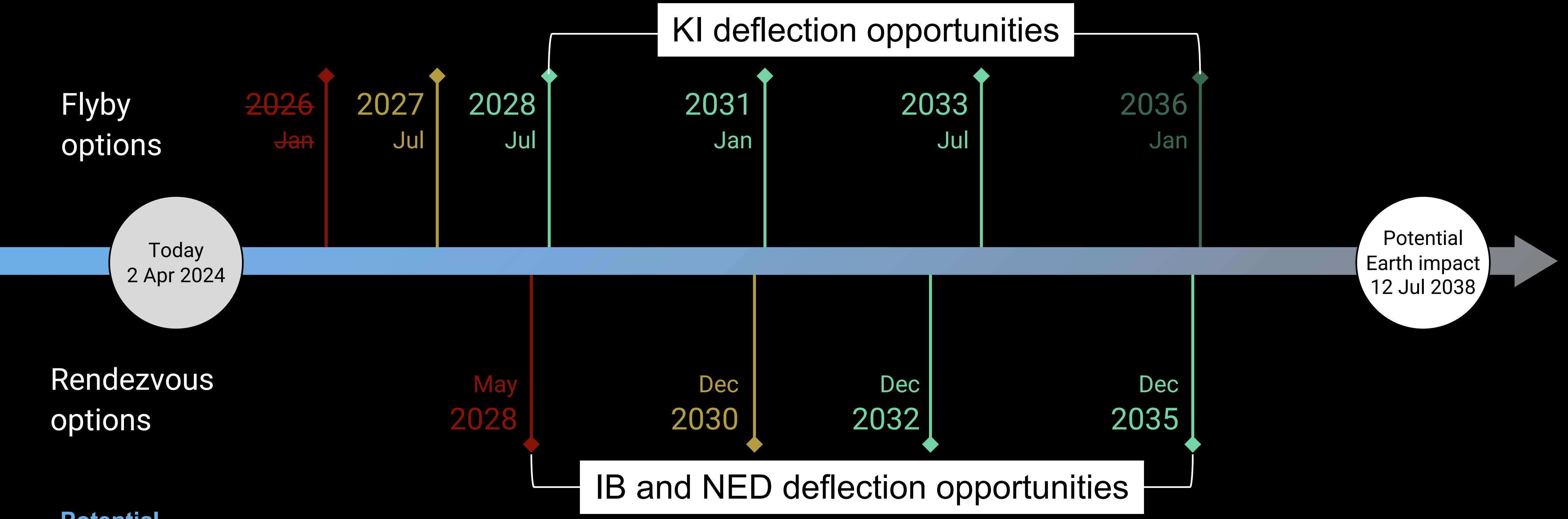
NED is deployed from a rendezvous spacecraft and detonated near the asteroid to vaporize surface material and cause recoil.

Considerations and technology needs:

- NED/spacecraft interfaces and space qualification of hardware
- In-flight characterization of deflection efficiency
- Be cautious of disruption
- Policy and legal considerations

Previous demonstration of asteroid deflection?
No

Deflection Options by Arrival Date



Potential Telescopic Information

Nov 2024: Impact location uncertainty is the size of Earth.

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Spacecraft development schedule, assuming development starts immediately

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Earth Impact Prevention Mission Options

PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 5

Data from recon missions could provide crucial information for planning Earth-impact-prevention missions.

Mission	Time Frame			Date of			# of Launches for Deflection					
							50th Percentile			90th Percentile		
	Launch	Years from April 2024	Arrival	KI Deflection	NED Deflection	IB Deflection	KI	NED	IB	KI	NED	IB
Rendezvous	Jun 2026	2	May 2028	-	Aug 2028	April 2036	-	1	3	-	1	18
Flyby/KI	Sep 2027	3.5	Jul 2028	Jul 2028	-	-	1–2	-	-	7	-	-
Rendezvous	Jul 2028	4	Dec 2030	-	Feb 2031	April 2036	-	1	4	-	1	>20
Flyby/KI	May 2029	5	Jan 2031	Jan 2031	-	-	1–2	-	-	8	-	-
Rendezvous	Jul 2029	5	Dec 2032	-	Aug 2033	April 2036	-	1	11	-	1	>20
Flyby/KI	Jul 2032	8	Jul 2033	Jul 2033	-	-	1–2	-	-	7	-	-
Rendezvous	Jul 2033	9	Dec 2035	-	Feb 2036	*not feasible*	-	1	>20	-	1	>20
Flyby/KI	Aug 2034	10	Jan 2036	Jan 2036	-	-	2	-	-	12	-	-

Spacecraft development schedule, assuming development starts immediately

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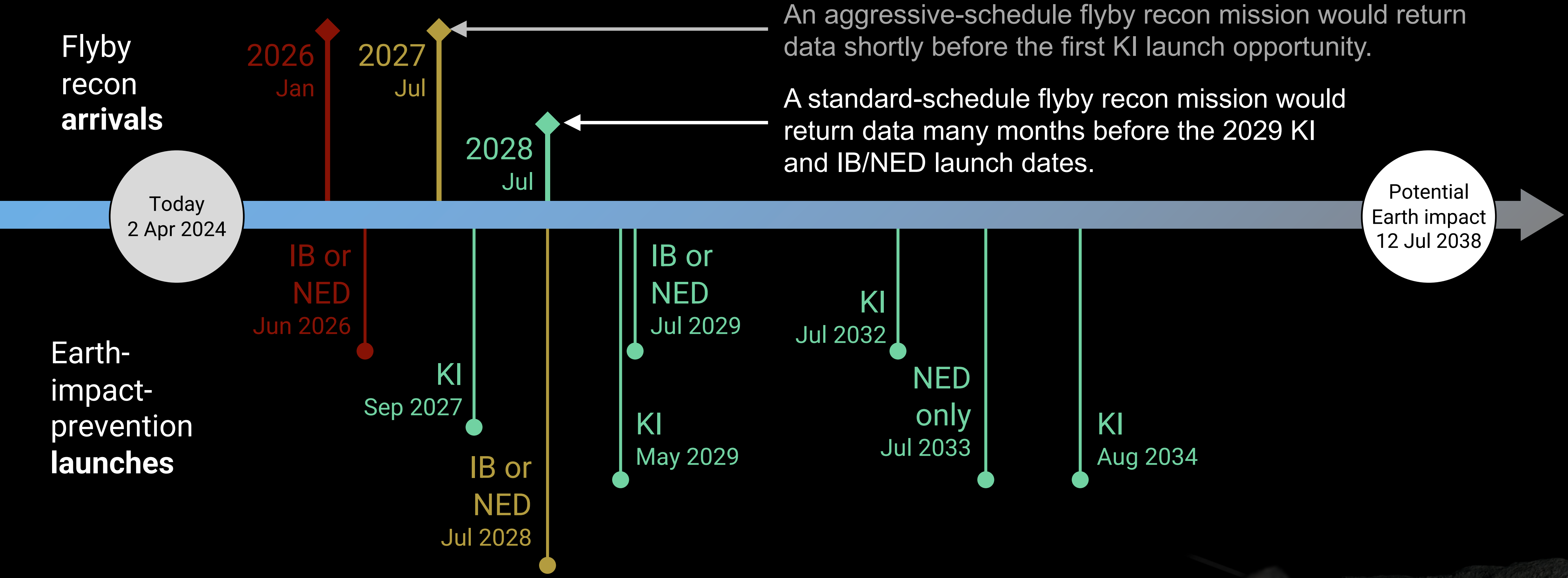
PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 5

Could Flyby Recon Data Inform Earth-Impact-Prevention Missions?



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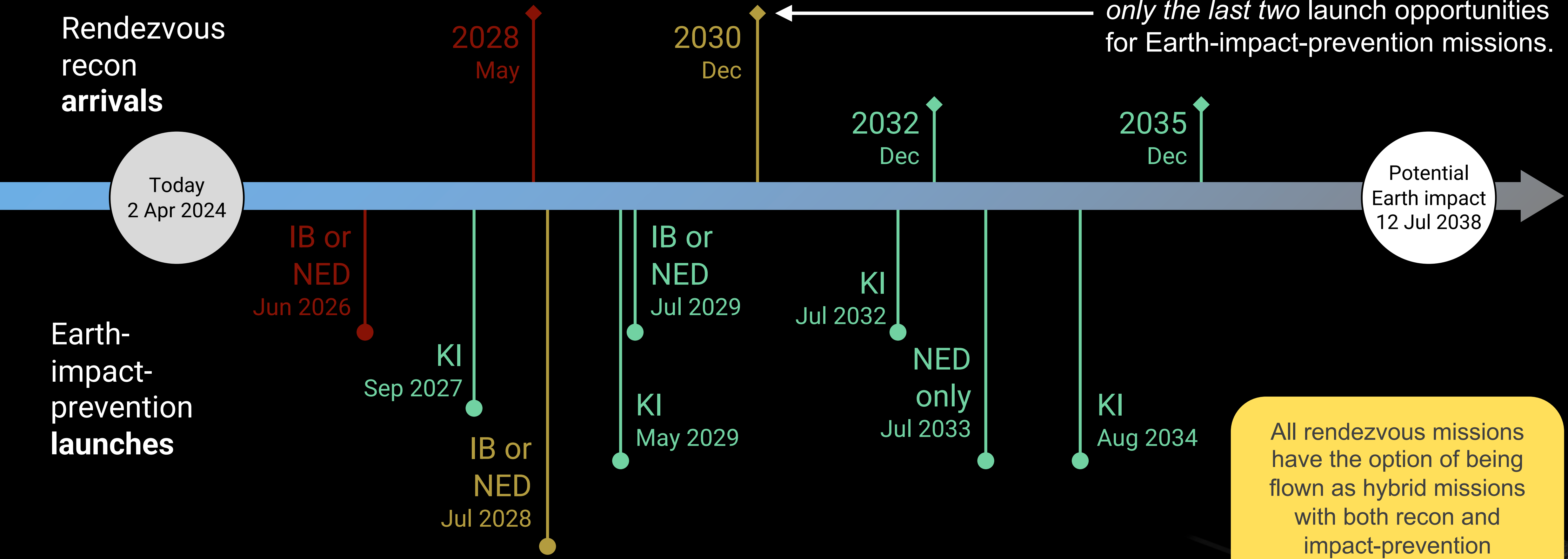
PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 5

Could Rendezvous Recon Data Inform Earth-Impact-Prevention Missions?

Even with an aggressive schedule, rendezvous recon data could inform *only the last two* launch opportunities for Earth-impact-prevention missions.



All rendezvous missions have the option of being flown as hybrid missions with both recon and impact-prevention capabilities.

Spacecraft development schedule, assuming development starts immediately

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Recon Data and Mission Development

July 2028

earliest that flyby recon data would be available **under standard development schedules**

December 2032

earliest that rendezvous recon data would be available **under standard development schedules**

Design → Build → Test → Launch → Cruise → Encounter → Downlink → Analyze

Time for each phase varies depending on the mission; equal block size does not represent equal time.

It would be beneficial to receive recon data early enough in the impact-prevention mission life cycle to make adjustments based on recon data.

It is unknown how late in the development cycle is too late for such a purpose.

This slide has been intentionally left blank.

- What pieces of information were most relevant to your role?

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- What are your thoughts on pros and cons of the Earth impact prevention mission options?
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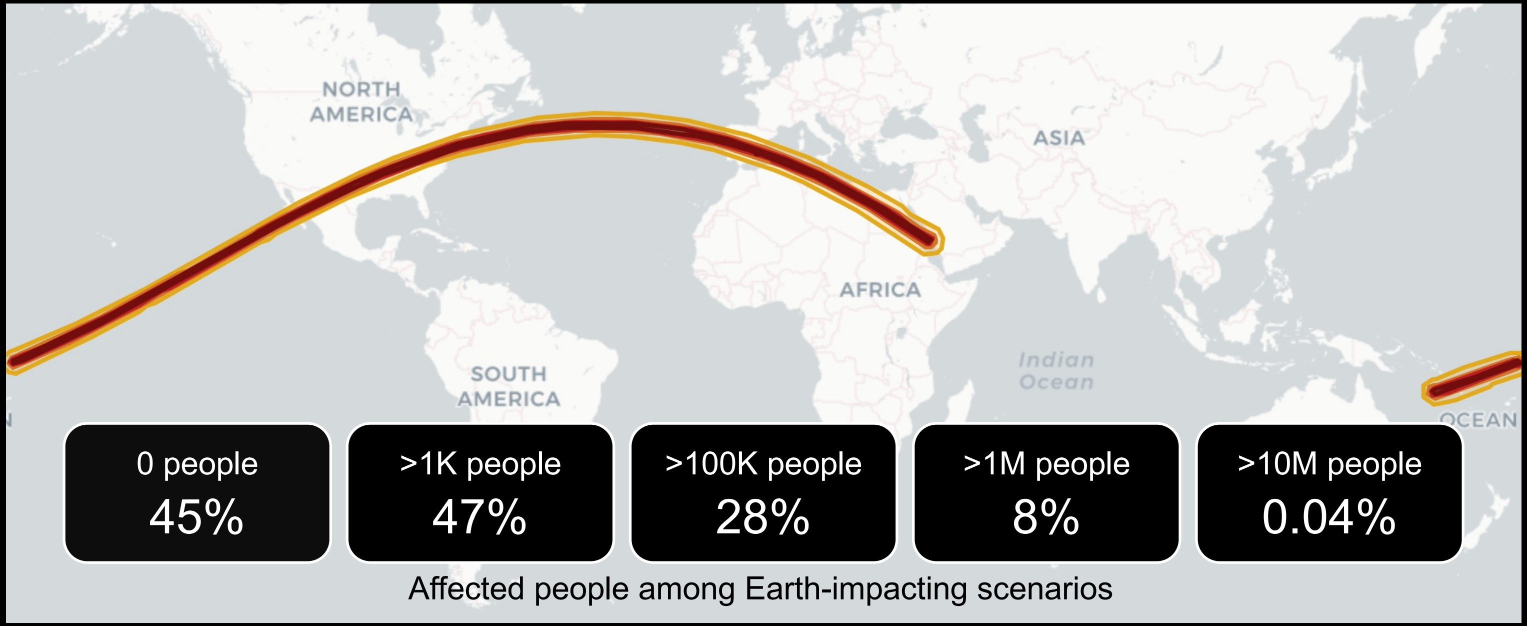
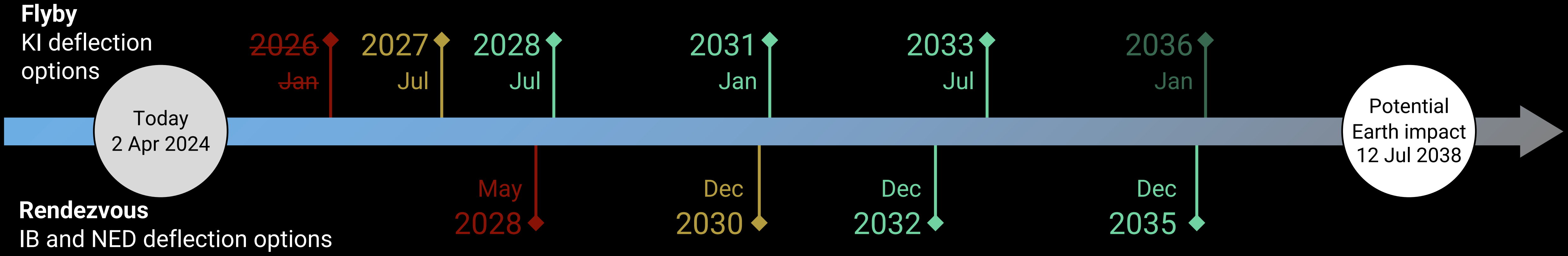
PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 5



72%
probability of Earth impact

14.25 years
from today

Many
uncertainties



Potential Telescopic Information

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2028: Earth impact location ±25 km. Spectral and JWST possible. Uncertainties remain in key asteroid properties.

2033: Radar detection is possible if the object is large.

- What are the thoughts of emergency management organizations after hearing these mission options?

- What are the thoughts of emergency management organizations after hearing these mission options?
- What are the thoughts of public information officers after hearing these mission options?

Hot Wash

- Goal is to gather quick comments and impressions
- One representative from each organization to provide:
  - One lesson learned
  - One best practice
- Two areas of interest for comments:
  1. Preparedness, including policy, technology, or capability gaps
  2. Comments on this exercise: strengths, opportunities, and ideas for future exercises
- Please limit responses to **2–3 minutes** so that many organizations can share
- Remember, you can post comments and responses to comments in the chat, too

Your comments and discussions are the data that will help this TTX culminate in an impactful after-action report.

Participant Feedback Forms

- See link posted in XLeap

PLANETARY DEFENSE
INTERAGENCY
TABLETOP EXERCISE 5

Thank you for participating in the Planetary Defense Tabletop Exercise 5. Your observations, comments, and input are greatly appreciated, and provide invaluable insight that will enable better preparation against asteroid threats. The goal of this written feedback is to ensure we capture the views of all participants. Any comments provided will be treated in a sensitive manner and all personal information will remain confidential.

Your written feedback is an essential part of this exercise and will be used to create an after-action report (AAR). The AAR will capture lessons learned that can then be used to help international planning, preparedness and response to an asteroid threat with >10 years warning time. Please respond to all questions and provide as much detail as possible with specific and constructive comments.

Thank you for your time.

PLANETARY DEFENSE INTERAGENCY TABLETOP EXERCISE 5