



Ion-Beam Deflection Missions for the 2024 PDC25 Scenario

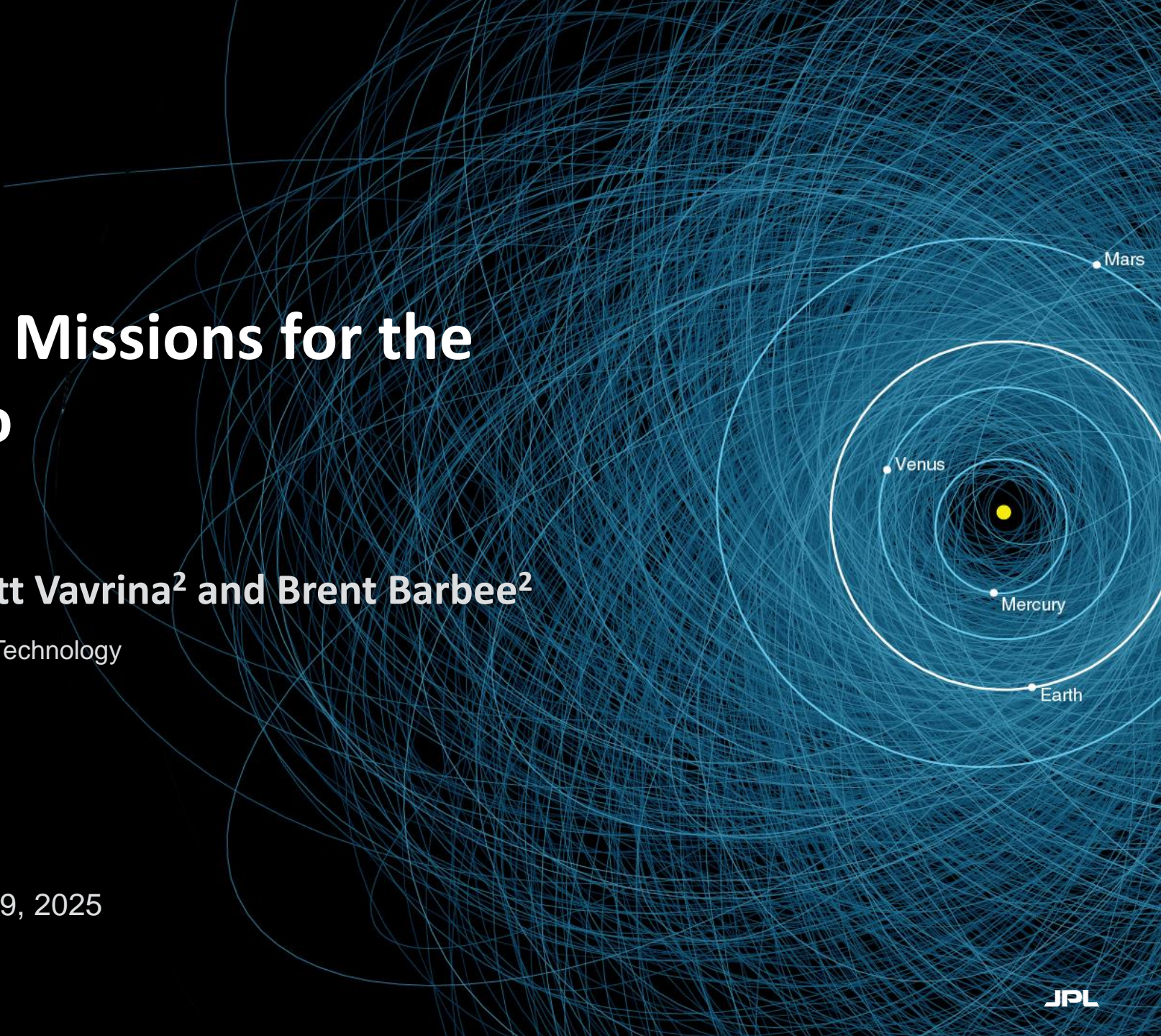
Paul Chodas¹, John Brophy¹, Matt Vavrina² and Brent Barbee²

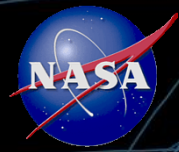
(1) Jet Propulsion Laboratory, California Institute of Technology

(2) NASA Goddard Space Flight Center

9th IAA Planetary Defense Conference,
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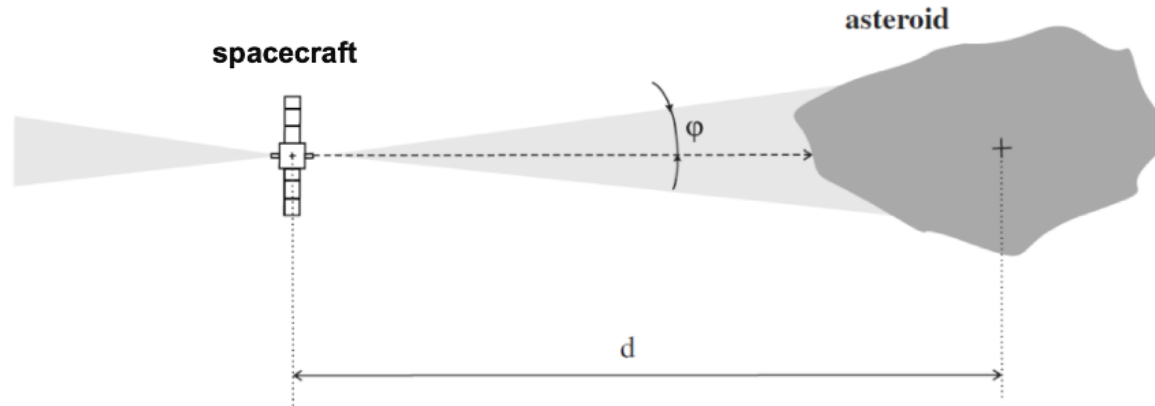
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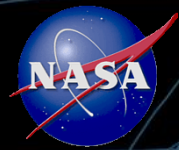
HYPOTHETICAL EXERCISE

Ion-Beam Deflection (IBD) - Overall Concept



- Rendezvous with a high-power SEP spacecraft & a large amount of xenon.
- Hover 3-4 diameters away from the asteroid.
- Continuously fire opposing ion thrusters, one beam directed at the asteroid.
- Momentum of the impinging ions is transferred to the asteroid.
- Over time, a considerable amount of momentum can be imparted to the asteroid without the possibility of disrupting it.

HYPOTHETICAL EXERCISE



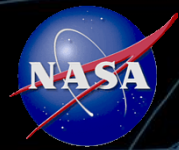
Ion-Beam Deflection - Advantages

- IBD can deflect an asteroid trajectory in either direction
- An IBD spacecraft can be positioned to optimize the deflection
- IBD is highly predictable: its effectiveness does not depend on asteroid physical properties other than mass
 - IBD spacecraft design is largely independent of asteroid physical properties
- IBD does not require a separate rendezvous recon mission or an observer mission to monitor deflection progress
- IBD effectiveness can be amplified via multiple spacecraft operating in parallel



Ion-Beam Deflection - Campaign Strategy

- At Epoch 1 we recommended developing 1-2 modest 22kW IBD spacecraft
- At Epoch 2 we analyzed two higher power IBD spacecraft models:
 - **46kW Purpose-Built IBD** spacecraft modeled on the NASA Asteroid Redirect Robotic Mission (ARRM), modified with 3 pairs of NEXT-C thrusters gridded for low beam divergence (~5 degrees)
 - **Repurposed 60kW Gateway PPE IBD** spacecraft with 7 thrusters total (3x AEPS & 4x BHT-6000) [Not discussed here: see paper for discussion of that option]
- Large amount of extra propellant for deflection, e.g. 2000-5000 kg
- Launches in the April 2029 -- April 2030 timeframe
 - Development time would be only 4.5 - 5.5 years, which could be challenging



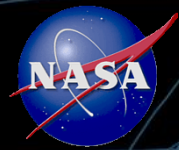
HYPOTHETICAL EXERCISE

Rendezvous Trajectories for 46-kW IBD Spacecraft

Case	Launch Date	Arrival Date	Time of Flight [years]	Launch Mass [kg]	Delivered Mass to Asteroid [kg]	Xenon for Trajectory from Earth to Asteroid [kg]	Estimated Xenon for IBD ops [kg]	Total Estimated Xenon [kg]	Flyby sequence
Early1	2029-04-25	2032-04-27	3.01	10295	8863	1432	5199	6631	Direct
Early2	2029-06-02	2032-06-04	3.01	9235	7855	1380	4191	5571	Direct
Primary	2029-10-03	2032-07-06	2.76	7399	5867	1532	2203	3735	VGA
Backup	2030-04-10	2032-10-01	2.48	6949	6239	710	2575	3285	direct

- Falcon Heavy Expendable launch vehicle
- Choose missions that arrive before the Nov 2032 perihelion
- IBD missions with later launches are possible but not considered here because deflection effectiveness would be reduced by ~40% and the number of required spacecraft would nearly double

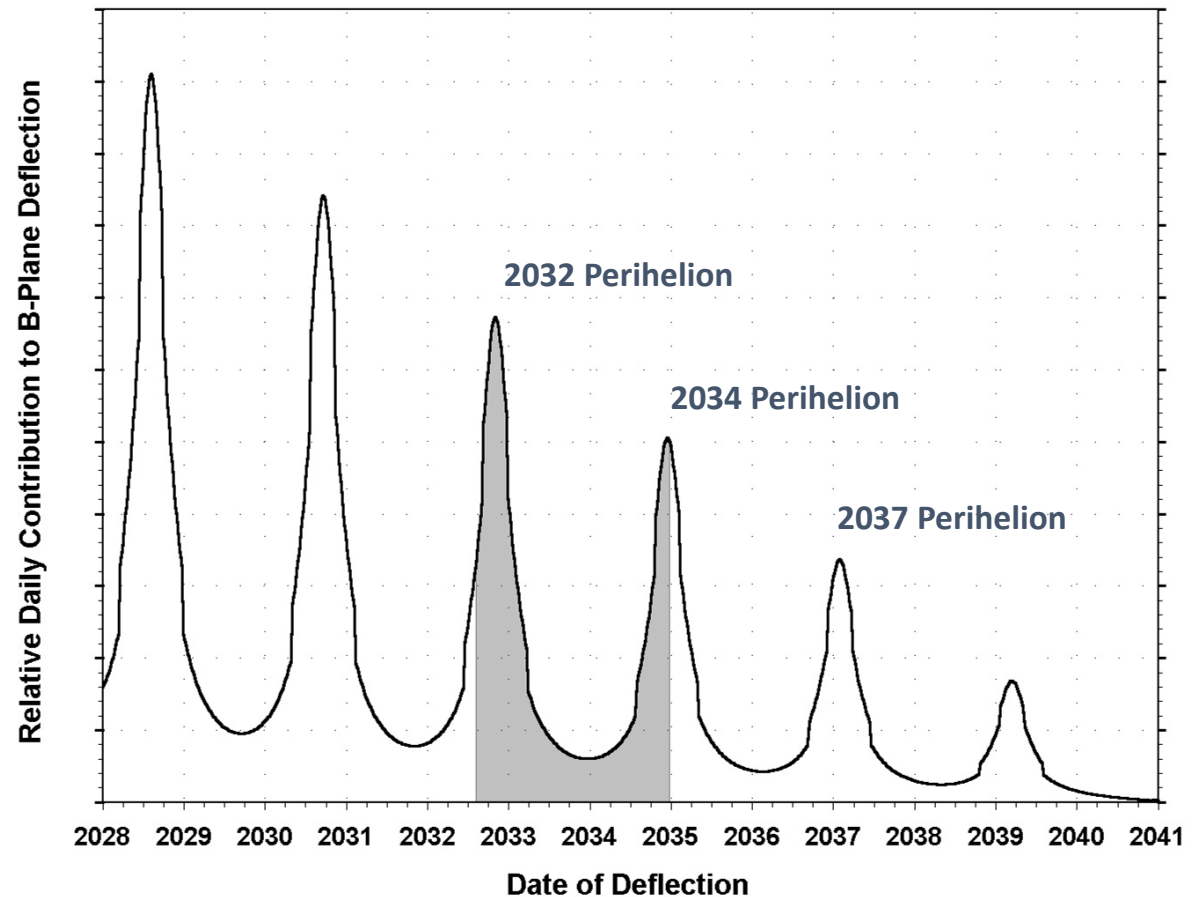
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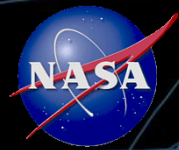


HYPOTHETICAL EXERCISE

Ion-Beam Deflection Efficiency vs. Time for 46kW Spacecraft

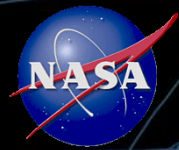
- Plot shows relative daily contribution to p-plane deflection as a function of time
- Peak contributions occur at perihelia, when both power levels and deflection leverage maximize
- This spacecraft design has enough power to continue deflections all the way around the orbit
- The total b-plane deflection is the integral under the curve over the deflection arcs: e.g. the area of the shaded region





Ion-Beam Deflection Simulations - Outline of Results

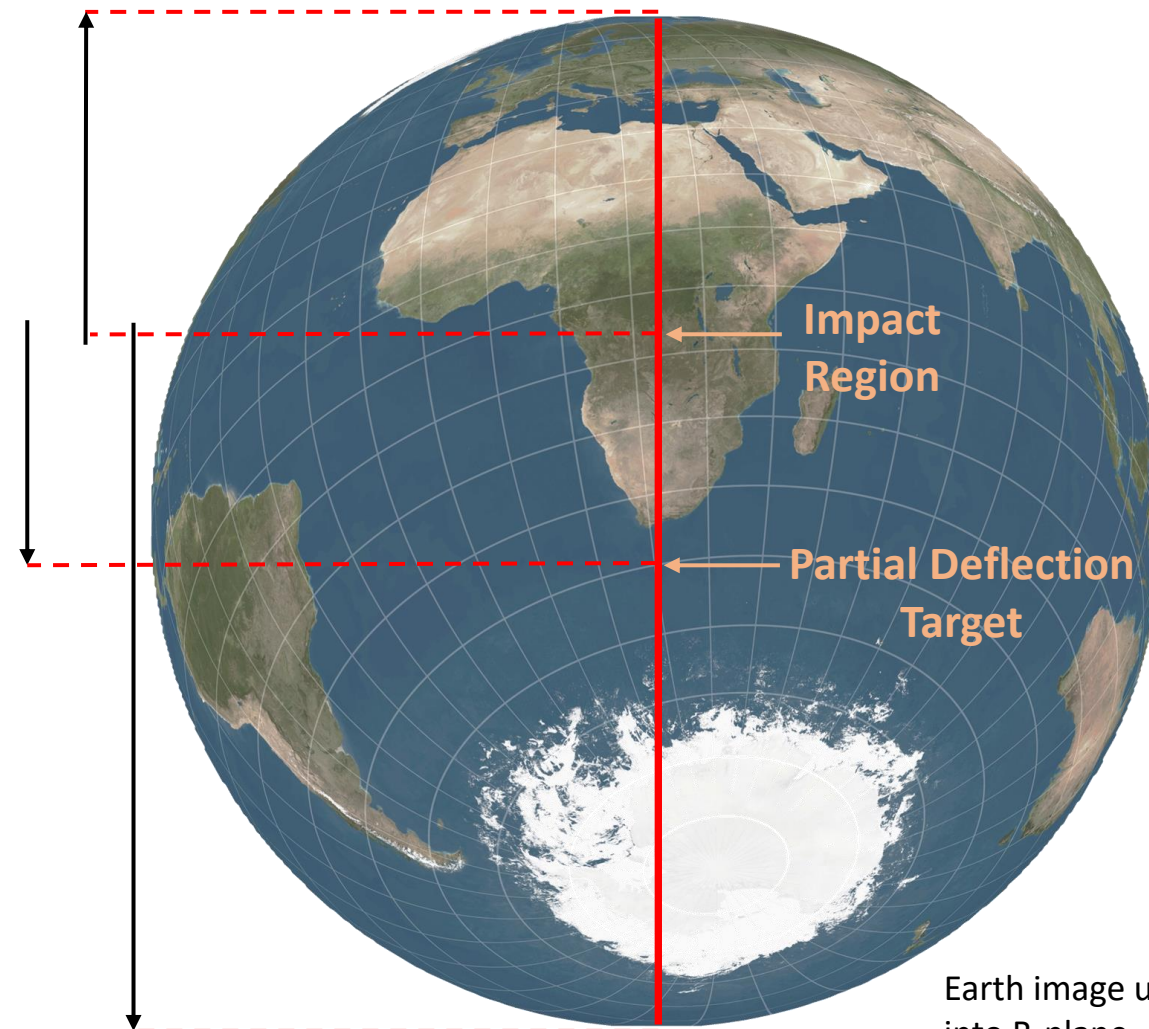
- Simulations run for 3 different deflection goals:
 - **Northward off the Earth**
 - **Southward off the Earth**
 - **Southward Partial Deflection**
- Each simulation calculates the IBD mission's deflection capability, the number of IBD spacecraft and the completion dates
- Deflection thrusting arcs are optimized for early completion.
- Results presented for 3 realizations of the asteroid:
Low Mass, 50th %tile Mass, and High Mass



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2024 PDC25: Three Deflection Goals at Epoch 2

- Northward Deflection:
7370 km
- Partial Southward Deflection:
5046 km
- Full Southward Deflection:
15352 km



HYPOTHETICAL EXERCISE



HYPOTHETICAL EXERCISE

46kW IBD Spacecraft: Results for Northward Deflection

Mission:	Early1	Early2	Primary	Backup
Launch	4/25/2029 <small>(5.5 mo. earlier)</small>	6/2/2029 <small>(4.2 mo. earlier)</small>	10/3/2029	4/10/2030 <small>(6.2 mo. later)</small>
Arrival	4/27/2032	6/4/2032	7/6/2032	10/1/2032
Asteroid Mass %ile:	Required Number of Launches & Completion Dates:			
Low	1 Mar 2034	1 Jun 2034	1 Aug 2034	1 Dec 2034
50th	1 Oct 2036	1 Nov 2036	2 Jun 2034	2 Dec 2034
High	2 Feb 2035	2 Mar 2035	2 Apr 2035	2 Dec 2036

Deflection begins
1 month after arrival

1 or 2 IB spacecraft
could successfully
deflect northwards



HYPOTHETICAL EXERCISE

46kW IBD Spacecraft: Results for Southward Deflection

Mission:	Early1	Early2	Primary	Backup
Launch	4/25/2029 <small>(5.5 mo. earlier)</small>	6/2/2029 <small>(4.2 mo. earlier)</small>	10/3/2029	4/10/2030 <small>(6.2 mo. later)</small>
Arrival	4/27/2032	6/4/2032	7/6/2032	10/1/2032
Asteroid Mass %ile:	Required Number of Launches & Completion Dates:			
Low	1 Feb 2037	1 Mar 2037	2 Sep 2034	2 Jan 2035
50th	2 Dec 2036	2 Jan 2037	3 Dec 2034	3 Jul 2035
High	3 Mar 2037	3 Apr 2037	4 Jul 2035	4 Jan 2037

Deflection begins 1 month after arrival

2-4 IB spacecraft would be needed to successfully deflect southwards



HYPOTHETICAL EXERCISE

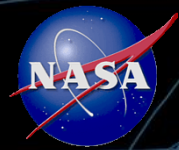
46kW IBD Spacecraft: Results for Partial Southward Deflection

Mission:	Early1	Early2	Primary	Backup
Launch	4/25/2029 <small>(5.5 mo. earlier)</small>	6/2/2029 <small>(4.2 mo. earlier)</small>	10/3/2029	4/10/2030 <small>(6.2 mo. later)</small>
Arrival	4/27/2032	6/4/2032	7/6/2032	10/1/2032
Asteroid Mass %ile:	Required Number of Launches & Completion Dates:			
Low	1 Jan 2033	1 Feb 2033	1 Mar 2033	1 Aug 2034
50th	1 Nov 2034	1 Dec 2034	1 Dec 2034	1 Jun 2035
High	1 Feb 2037	1 Mar 2037	2 Sep 2034	2 Jan 2035

Deflection begins 1 month after arrival

A single early-launch IB spacecraft can achieve a partial southward deflection

In the top 10% of the cases by mass, another spacecraft is required to reach the target



HYPOTHETICAL EXERCISE

IBD for 2024 PDC25: Summary

- A single 46kW IBD spacecraft could achieve the partial southward deflection as long as it is launched early in 2029
- If launched later in 2029, another IBD spacecraft would be needed to reach the partial deflection target if the asteroid was in the top 10% by mass
- Deflecting northward off the Earth would likely require 2-3 IBD spacecraft.
- Deflecting southward off the Earth would likely require 3-4 IBD spacecraft.