Challenges of Reaching an ISO

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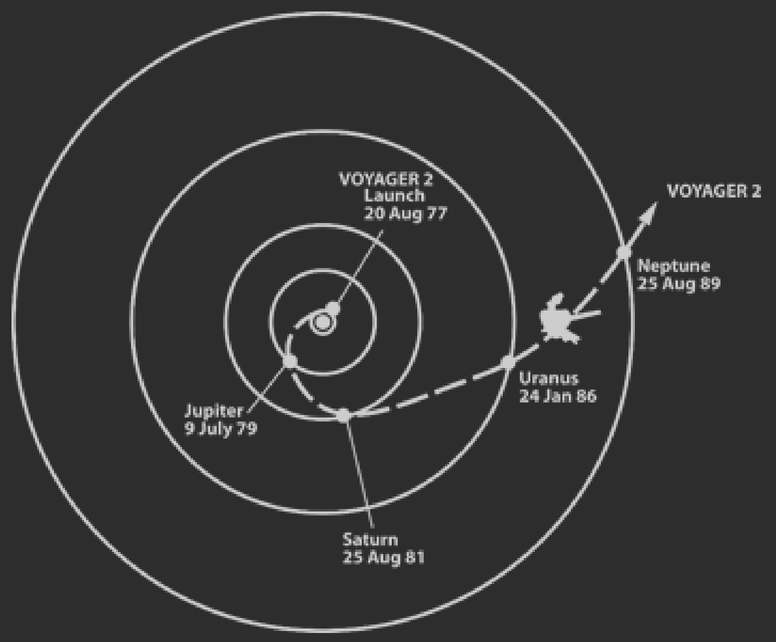
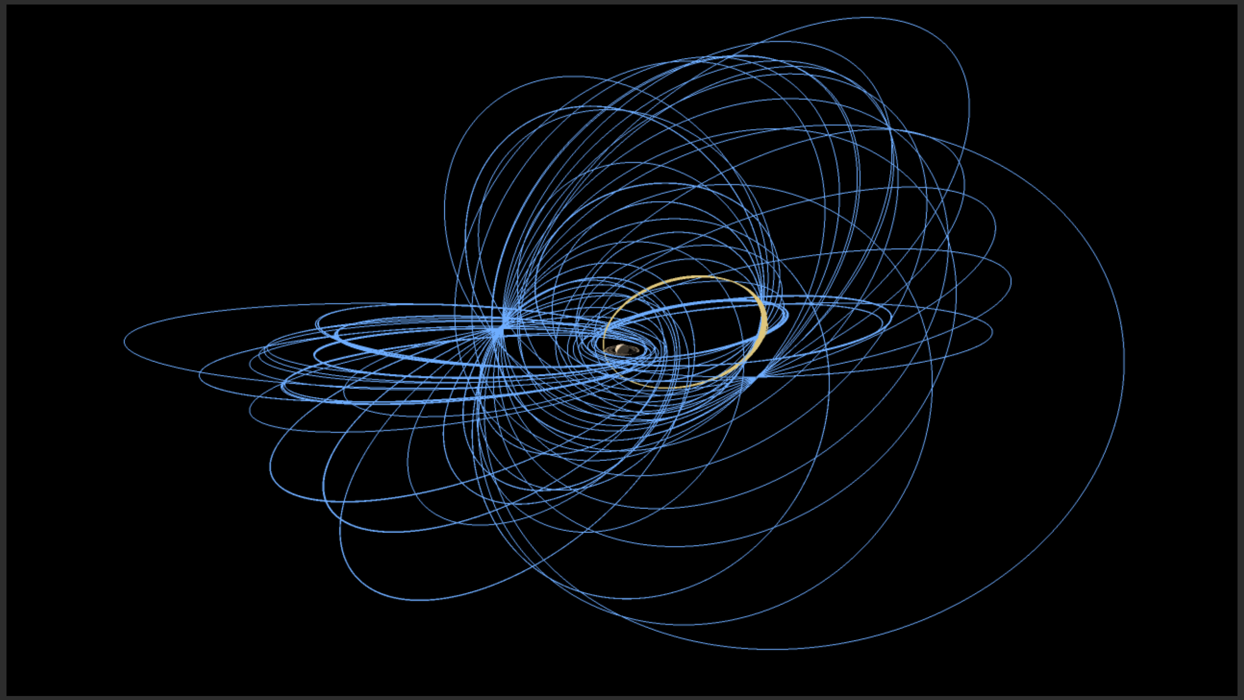
Traditional Missions, Voyager and Cassini, use Flybys



Voyager

Flybys require planning and alignment



Cassini

Challenges

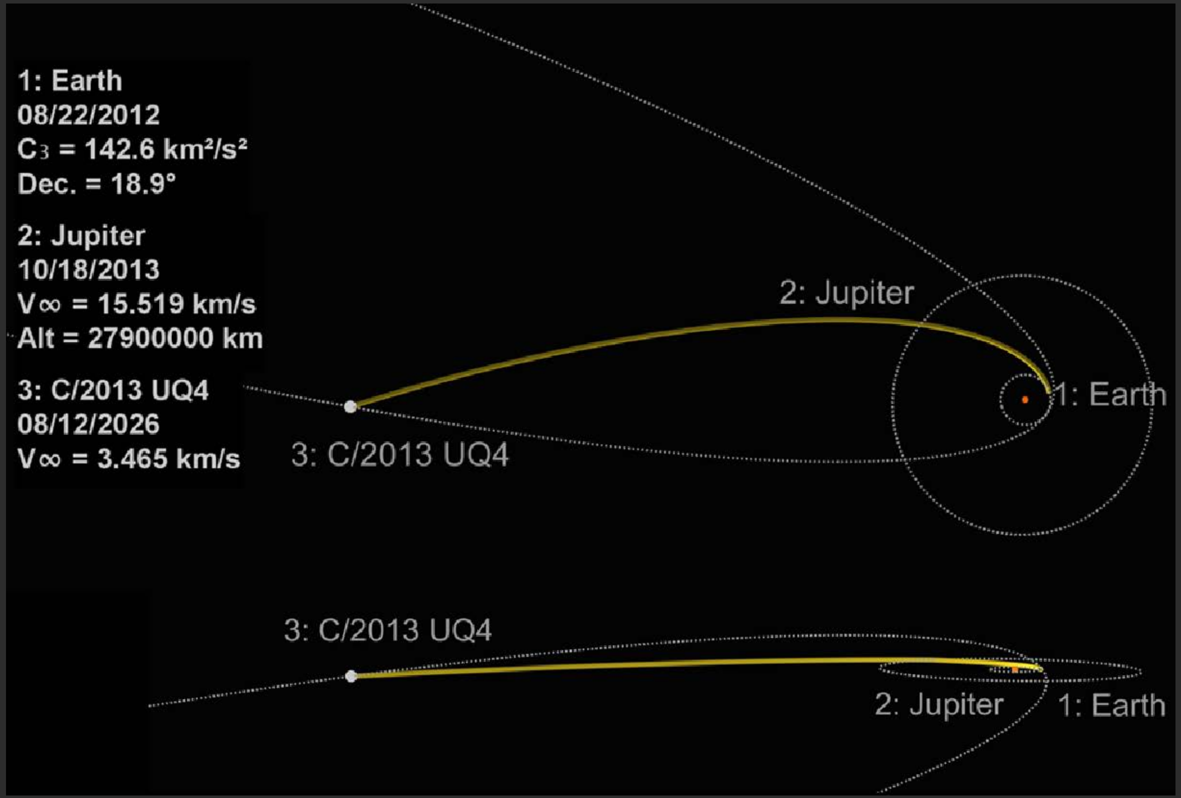
- Engelhardt Suggested that there may be one ISO present within 1 AU at any given time
    - Large Synoptic Survey Telescope will find at least 1 new ISO per year.
- ISO have high Heliocentric velocity, JPL KISS Study (Castillo-Rogez 2019)
    - ‘Oumuamua’s relative velocity to the Sun was 36-50 km/s at the times of observation CFHT 2013/05/10-13 -v
    - Very short observation window (< 2 weeks)
- Orbital properties are not known in advance and can span a broad range of inclinations
    - Due to their expected small sizes, dark albedo (from space weathering), they are hard to detect with sufficient lead time to launch a mission from Earth
- Flyby of Jupiter hard to plan for
- More intensive volatile and dust activity at long period comets

Halley Comet 1986

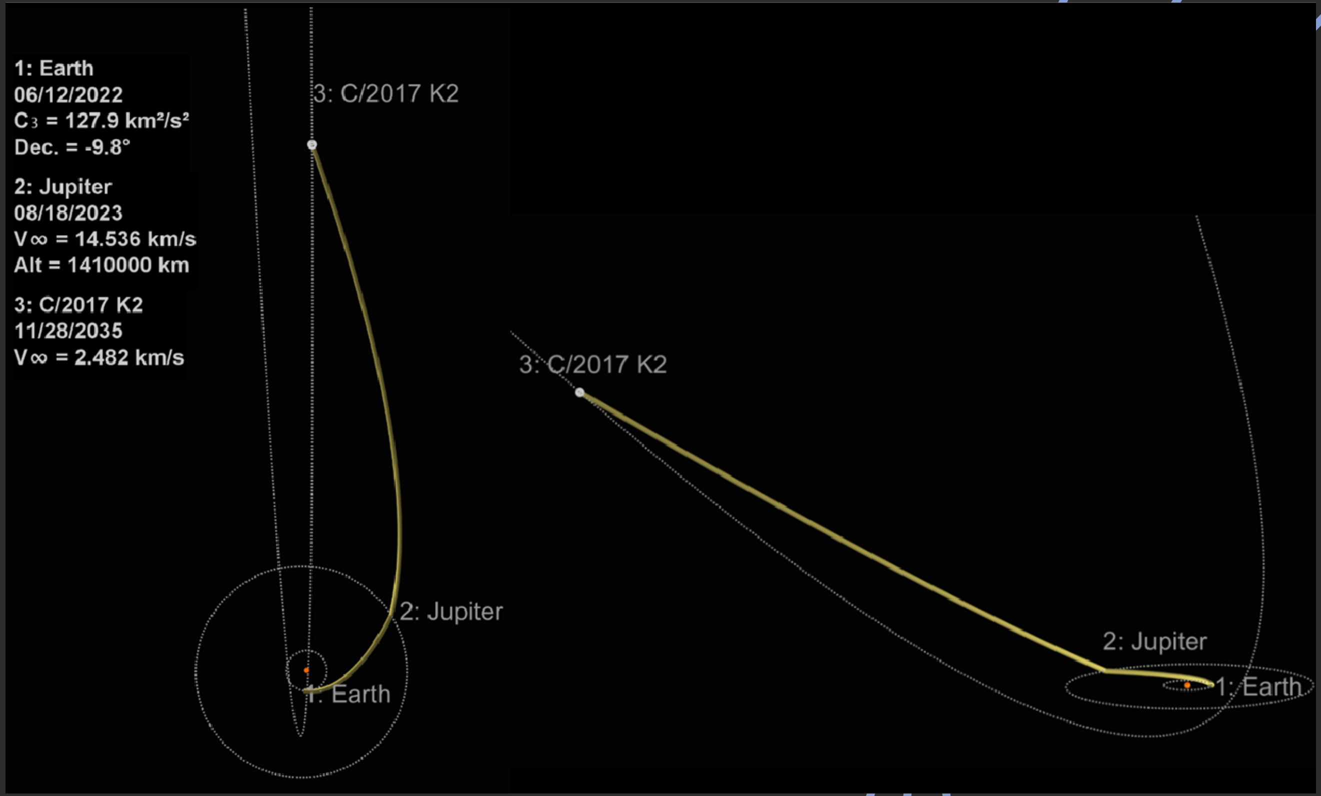
- Long-Period Comet (LPC) pose similar difficulties as ISO
- Halley comet is an example of LPC encounter 1986
  - Encounters occurred at a relative velocity of up to 79 km/s.
    - (Julie C. Castillo-Rogez, 2019)
- Six spacecraft were sent by different space agencies:
  - NASA, ESA, Roskosmos (USSR), and JAXA (its first space mission)

Traditional Trajectories, KISS Study

LPO Flyby Trajectory



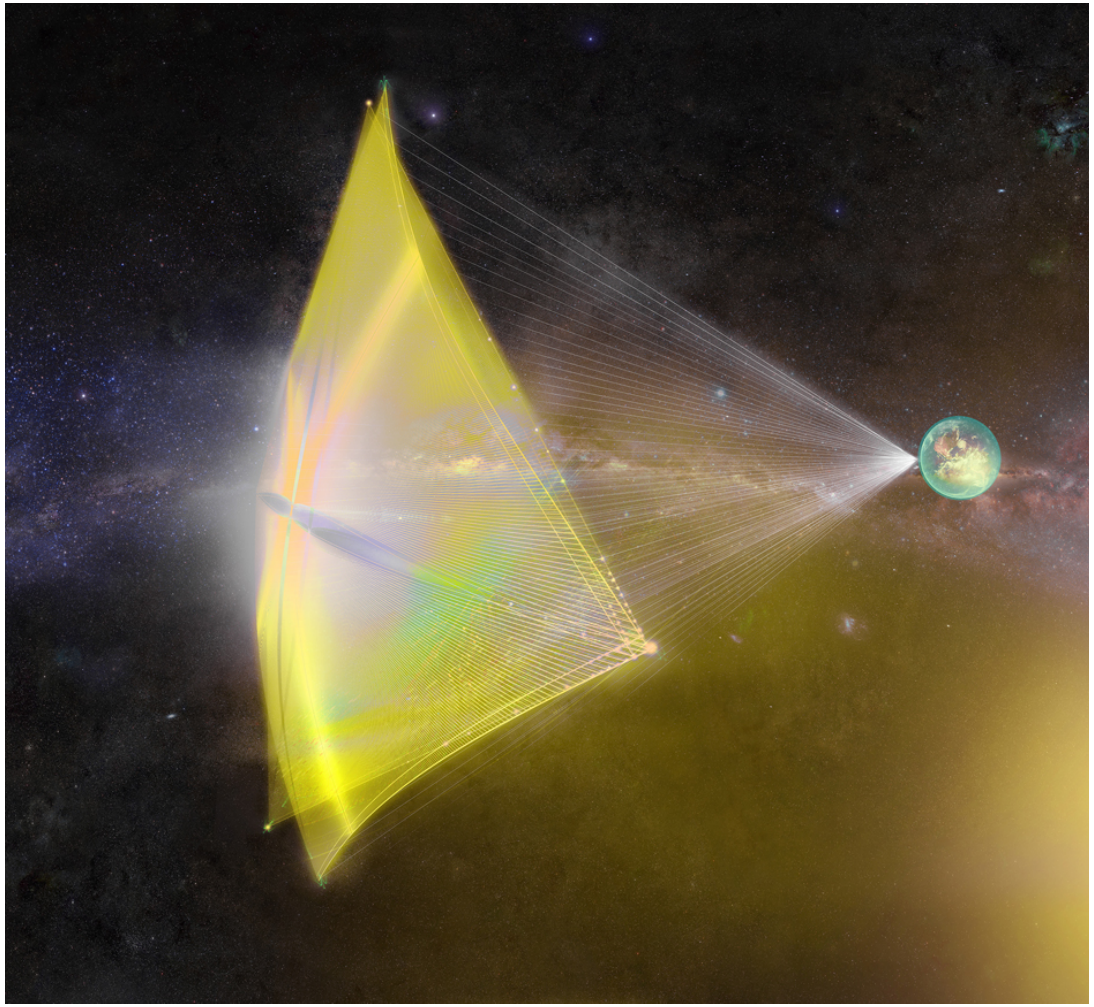
LPO Fly-by Trajectory, Jupiter Flyby



Images from Julie C. Castillo-Rogez 2019

Starshot Breakthrough Initiative

- Using combination of Lasers and aggressive material design
  - Ground to space laser illumination of a solar sail for DeltaV
  - Can achieve high heliocentric velocities
- Material are very exotic but theoretically possible
  - Atwater, Harry A., et al. "Materials challenges for the Starshot lightsail."



Electrostatic Sail Propulsion

- Unproven but promising
- Heliocentric velocities of (>10 AU/yr)

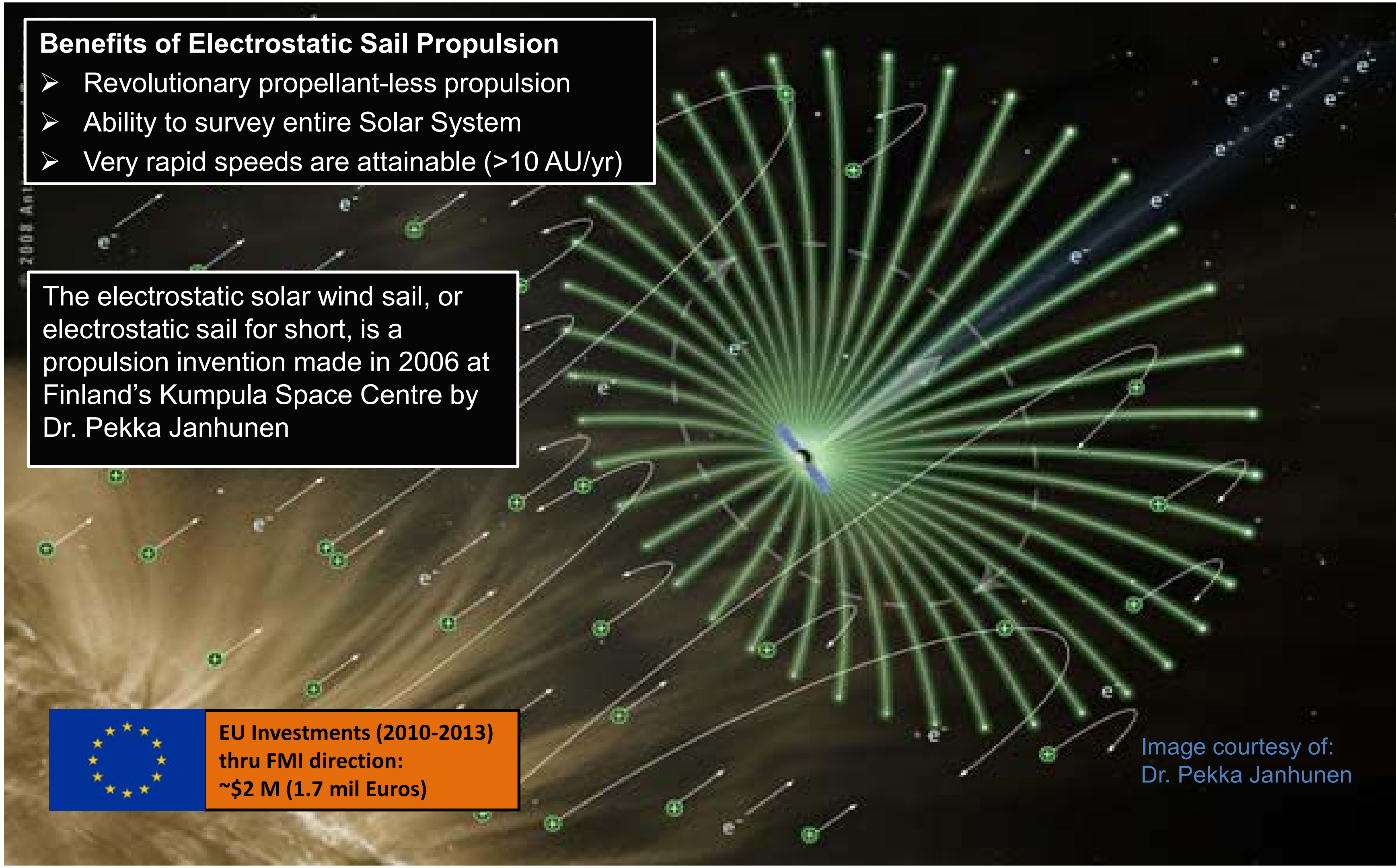
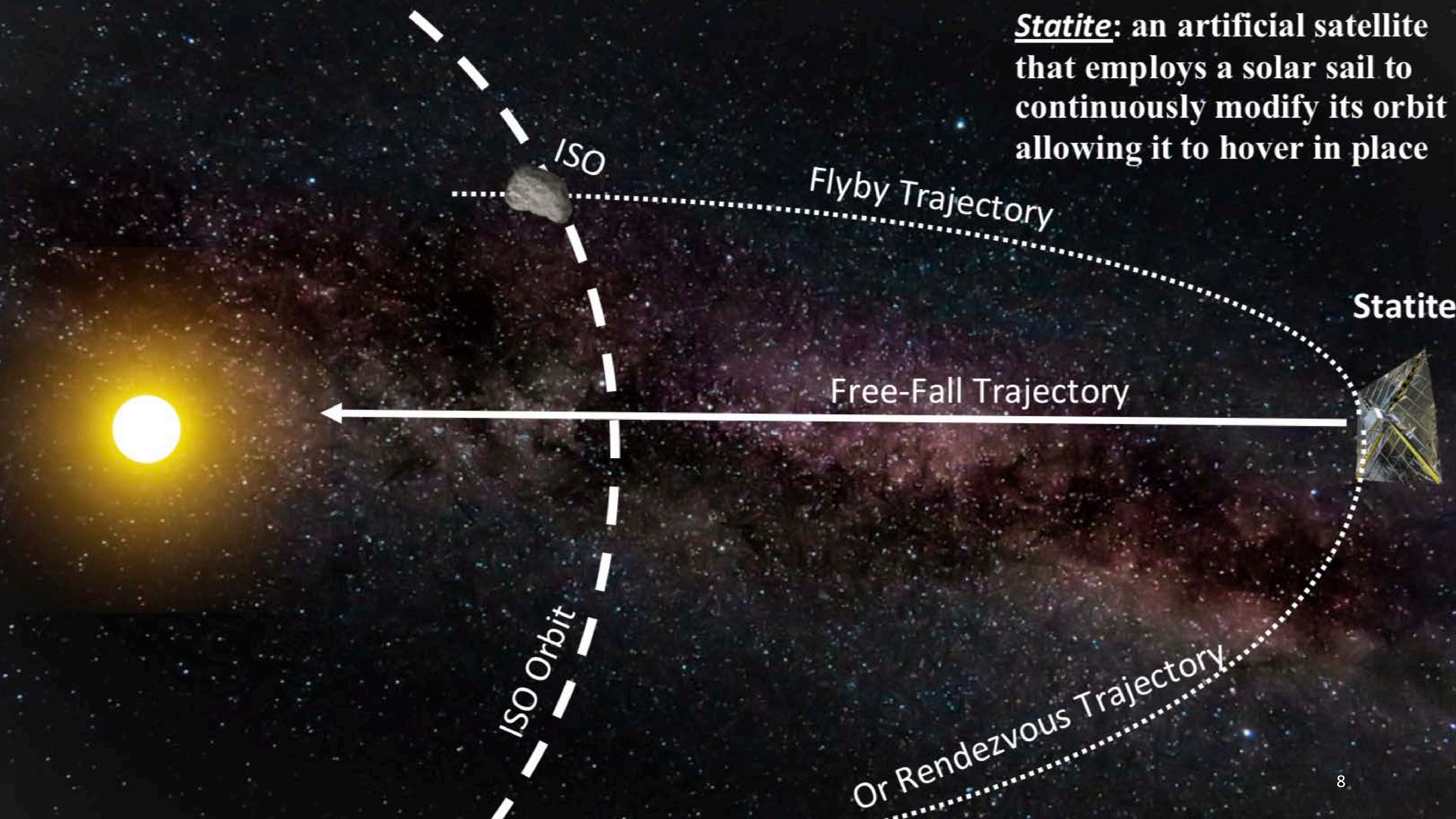


Image courtesy of: Dr. Pekka Janhunen


Statite: **an artificial satellite that employs a solar sail to continuously modify its orbit allowing it to hover in place**
ISO
Flyby Trajectory
Statite
Free-Fall Trajectory
ISO Orbit
Or Rendezvous Trajectory

Statites Concept

- Statites use solar sail technology to “cancel” out the gravitational acceleration from the Sun

$$F = \frac{GM_{Sun}m}{R^2} = 2\frac{A}{C}\frac{L}{4\pi R^2} \rightarrow \boxed{\frac{m}{A} = \frac{L}{2\pi c G M_{Sun}}}$$

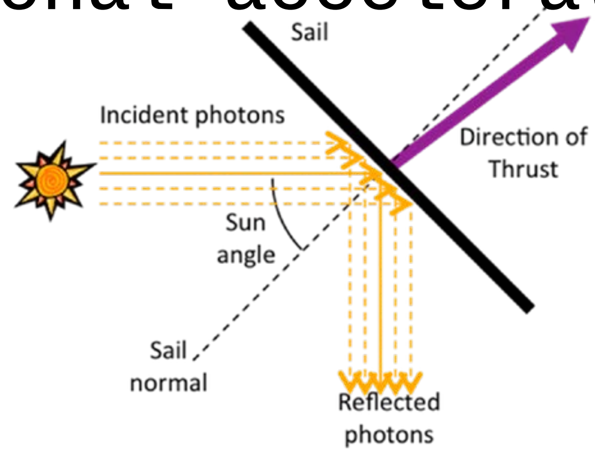
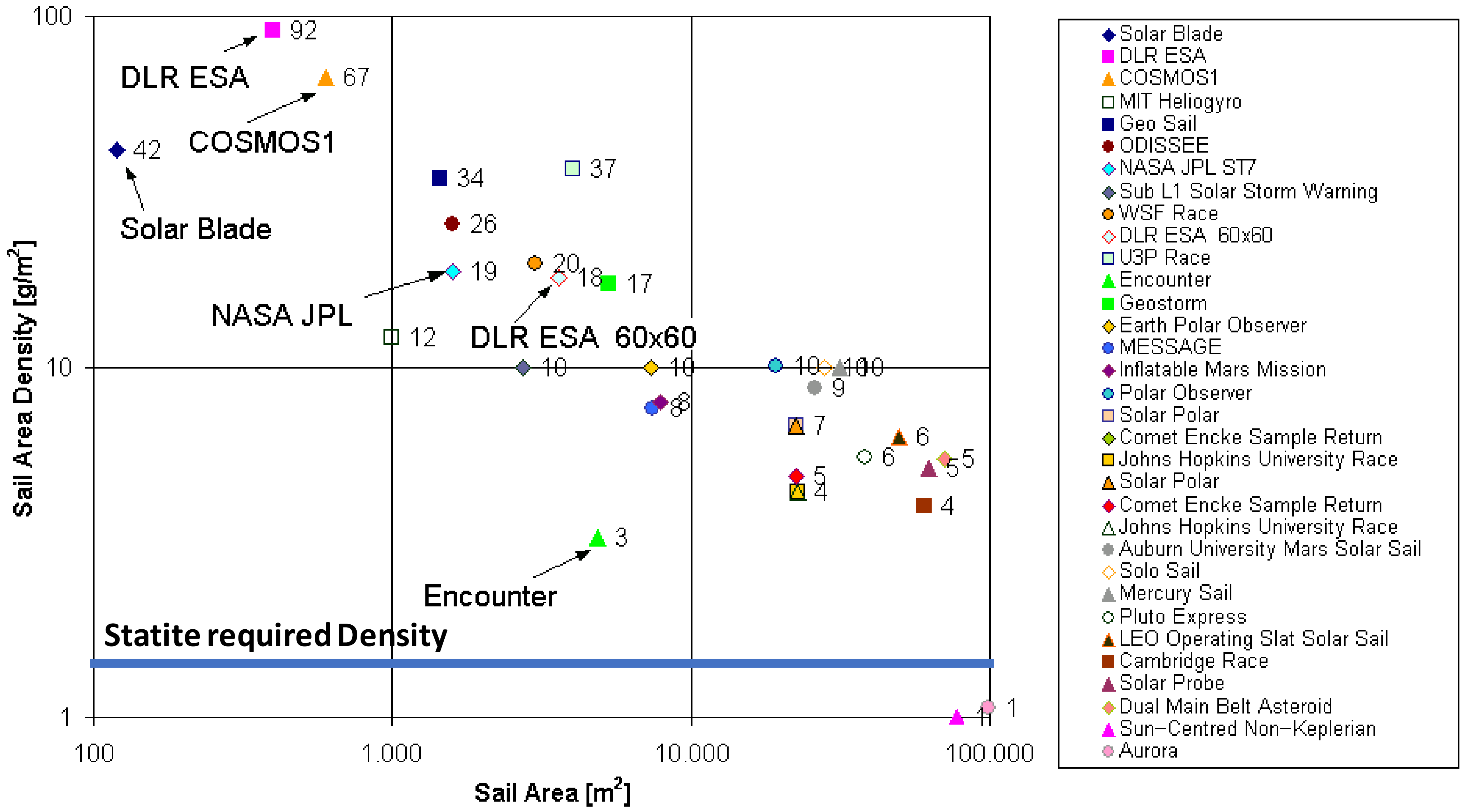


Figure 3: Solar Sail Reflection Geometry (credit www.deorbitsail.com).

  - Area-to-mass ratio is 0.625 m^2/g
  - These values are potentially achievable with exotic materials (SnS).



Herbeck, Lars, et al. "Solar sail hardware developments." European Conference on Spacecraft Structures, 2002.

Release Trajectories

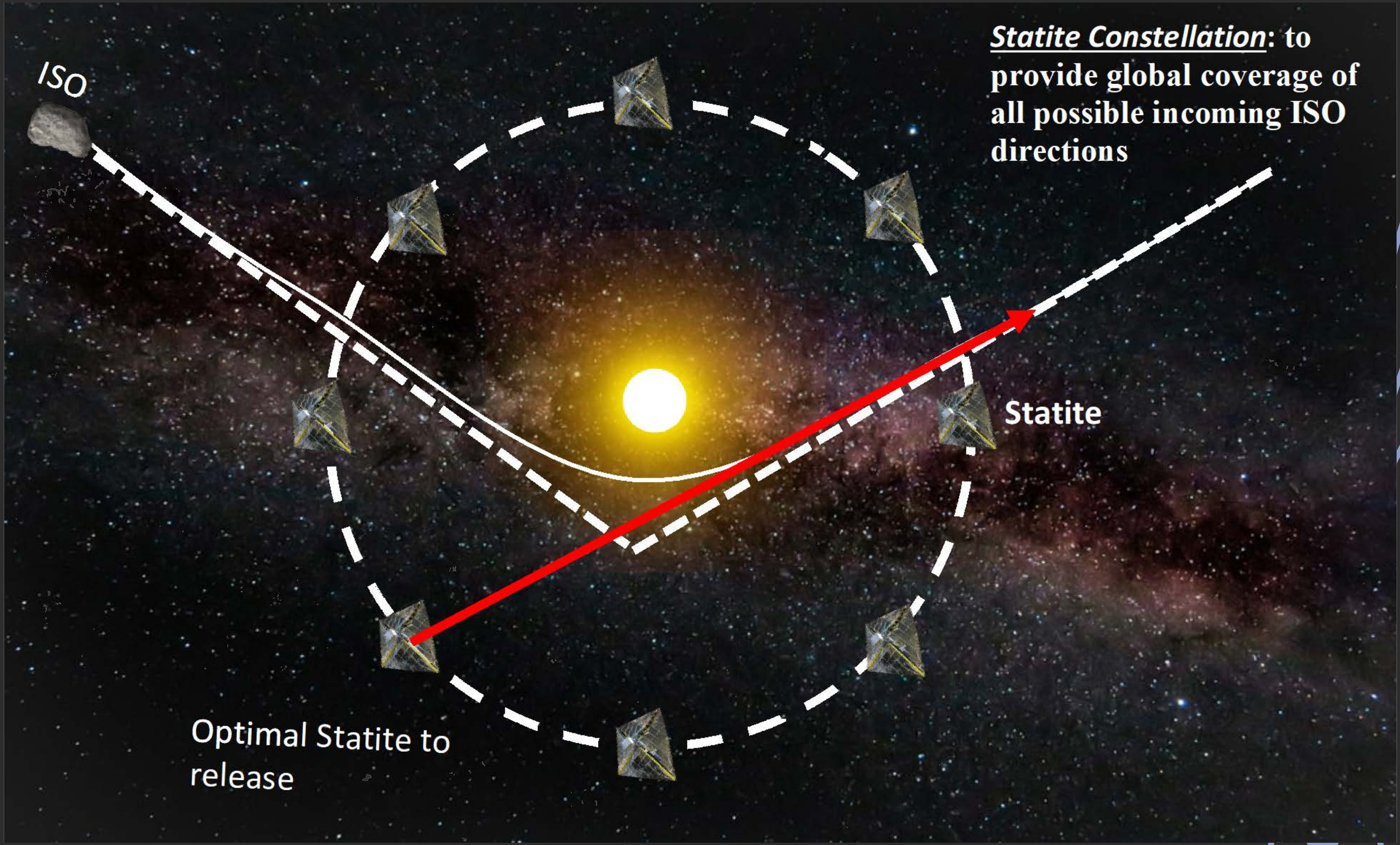
- Additionally, since the solar sail is levitating or hovering, its velocity is zero and therefore if it is rel ... t wit

$$\underbrace{E=-\frac{\mu}{r}+\frac{v^2}{2}}_{\text{Energy}}=-\frac{\overbrace{2\mu_{sun}}^{\text{Semi-major axis}}}{a}\rightarrow a=\frac{r}{2}\rightarrow \underbrace{\frac{T}{2}}_{\text{Orbital Period}}=\frac{1}{2}2\pi\sqrt{\frac{r^3}{8\mu_{sun}}}=\pi\sqrt{\frac{(1\,AU)^2}{8*4\pi^2}}=0.1768\ years$$

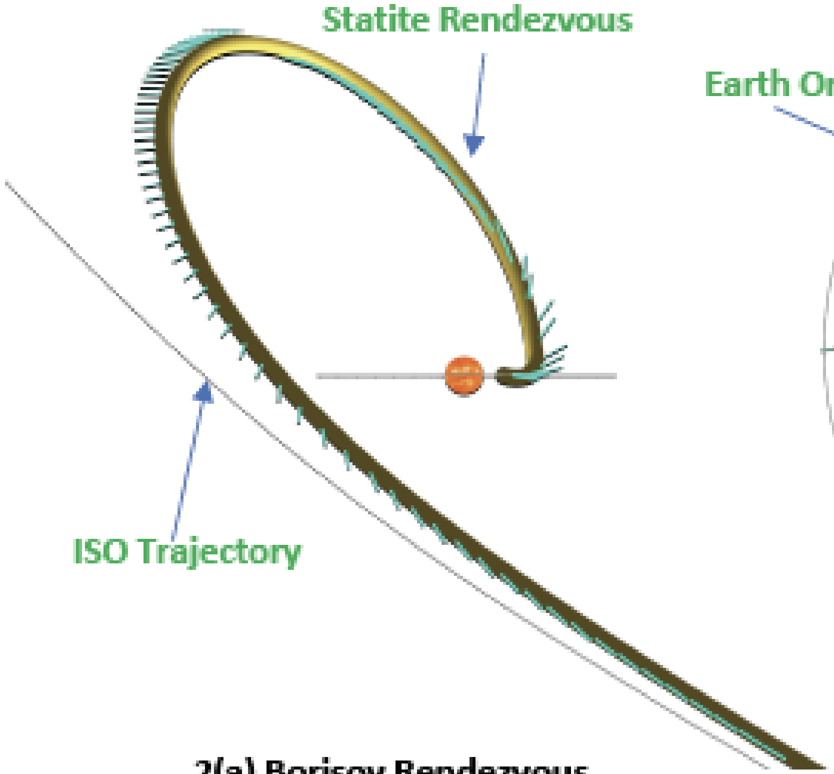
Orbital Period @ 1 AU

- This relationship shows that a statite at 1 AU has a free-fall trajectory of about 64 days.
- This fast response time to a potential ISO can be thought of as a slingshot effect, since the solar sail is used to “store energy” that is released when desired.

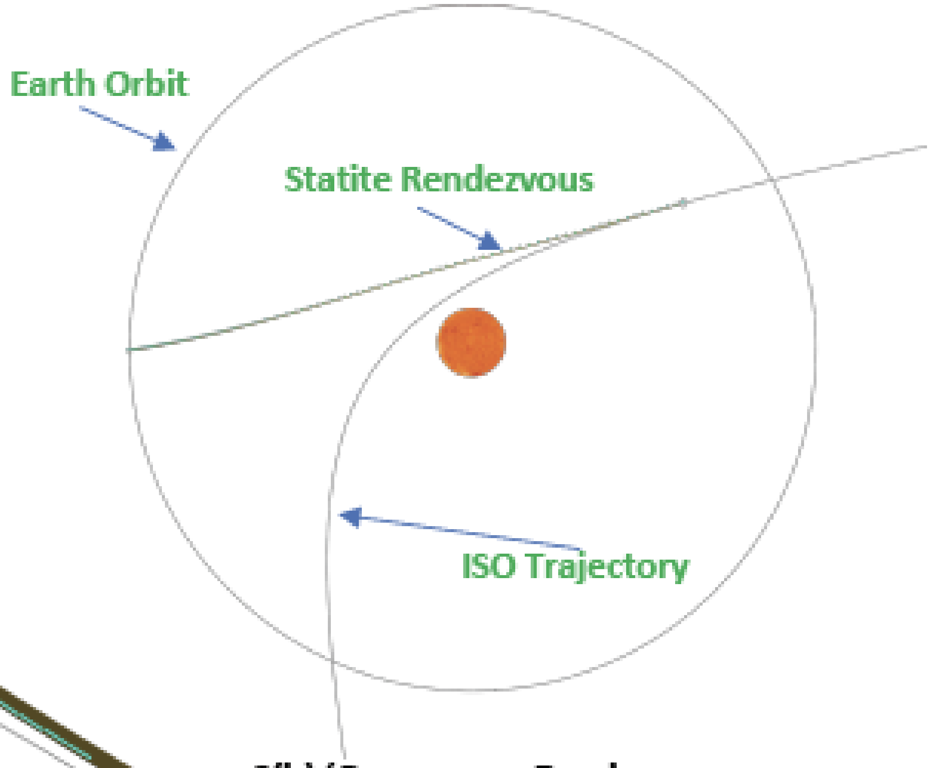
Release Trajectories



Initial Results



2(a) Borisov Rendezvous

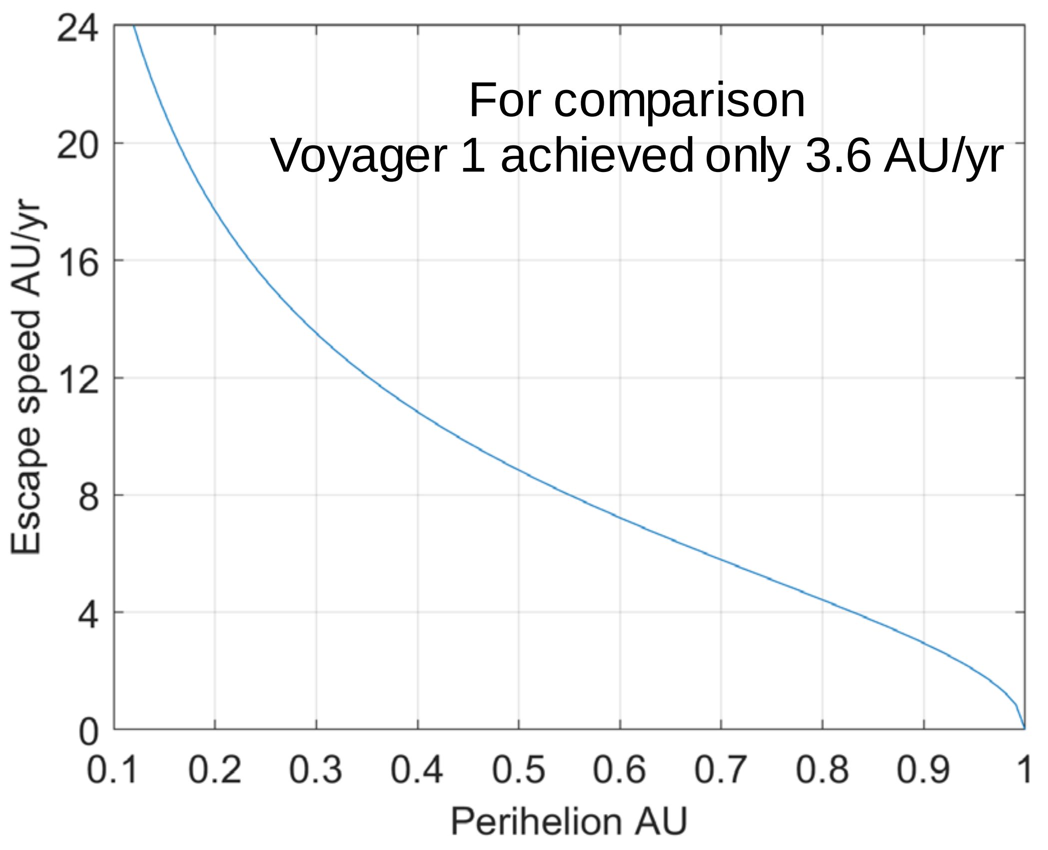


2(b) ‘Oumuamua Rendezvous

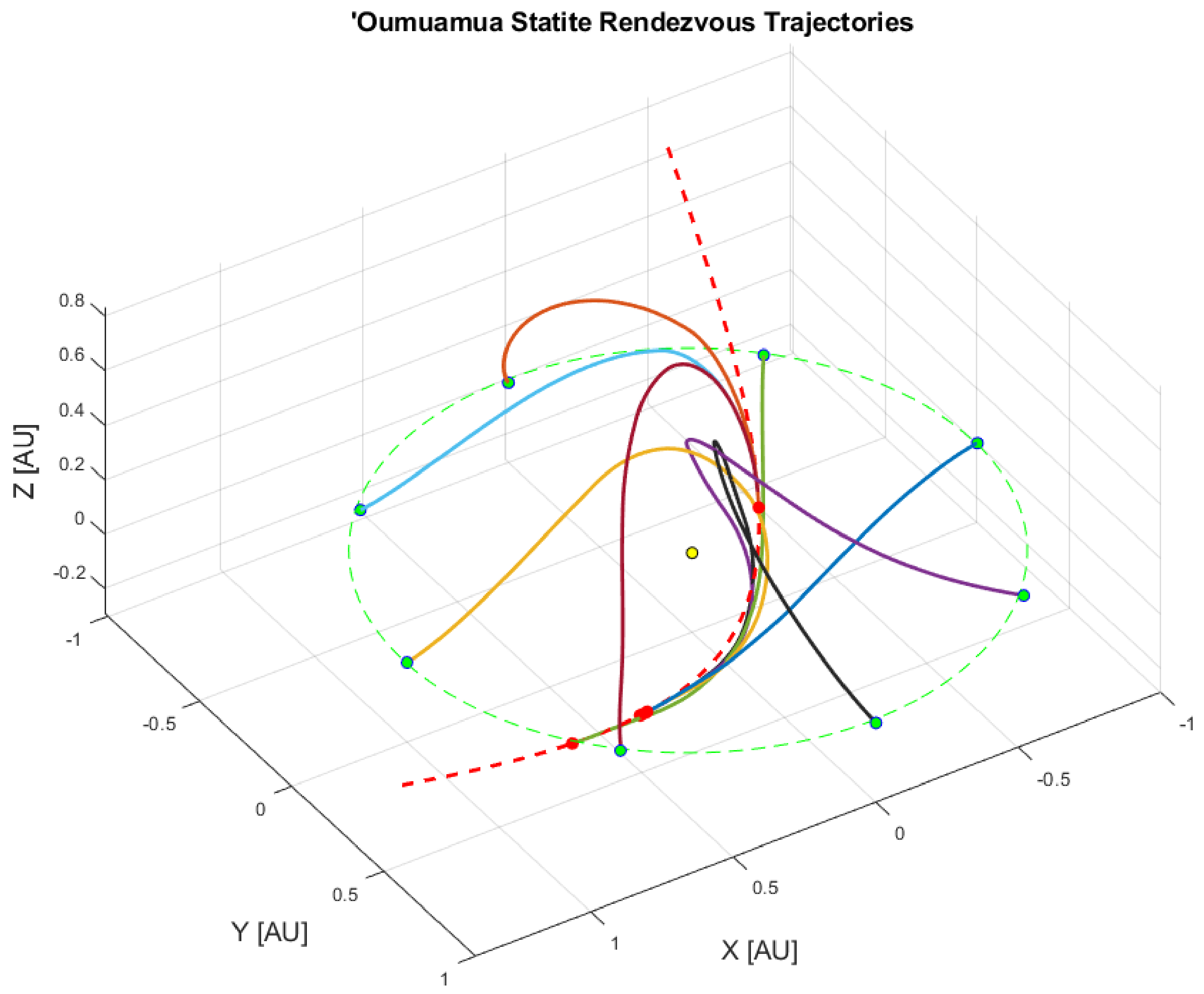
Target	Objective	Depart	Rendezvous	DeltaV
ISO1/‘Oumuamua	Max. departure	June/25/2017	Oct/01/2017	104 km/s
ISO2/ Borisov	Min. flight time	Dec/29/2016	Feb/24/2024	145 km/s

ISO Coverage

Figure shows “back of the envelope” calculation



Solar System Escape trajectories for Statites.



Conclusion

- The existence of ISOs offer us a great scientific opportunity to develop a detail understanding of the formation and history of other star systems.
- However, due to their high heliocentric velocities and relatively short lead time, this may be extremely difficult with current satellite propulsion systems.
- The proposed approach can respond to a newly detected ISO within 2-3 month to perform a flyby.
- The proposed approach also allows for rapid response rendezvous missions.