

**VERY SHORT REACTION TIME,  
LOW  $\Delta V$ , NON-NUCLEAR  
MITIGATION OF SOME NEOS:  
A CASE STUDY**

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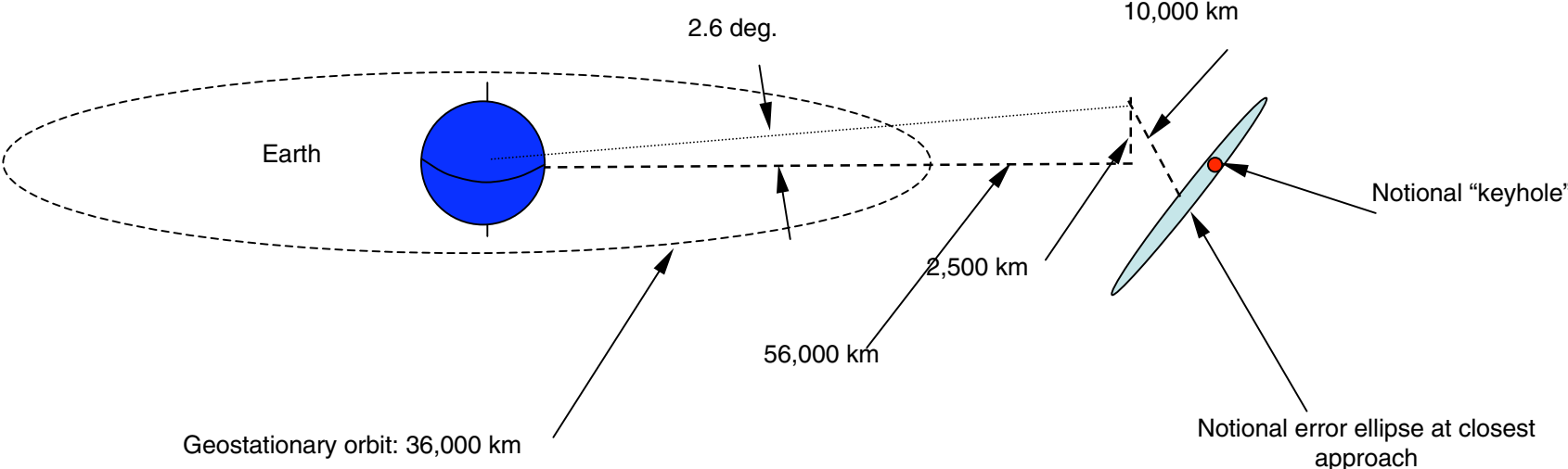
## CONVENTIONAL INTERCEPTION

- Intercepts a NEO far out in space, years-to-decades before Earth impact
- This keeps the  $\Delta V$  low, but the spacecraft is large and complex
- Decades of warning time needed

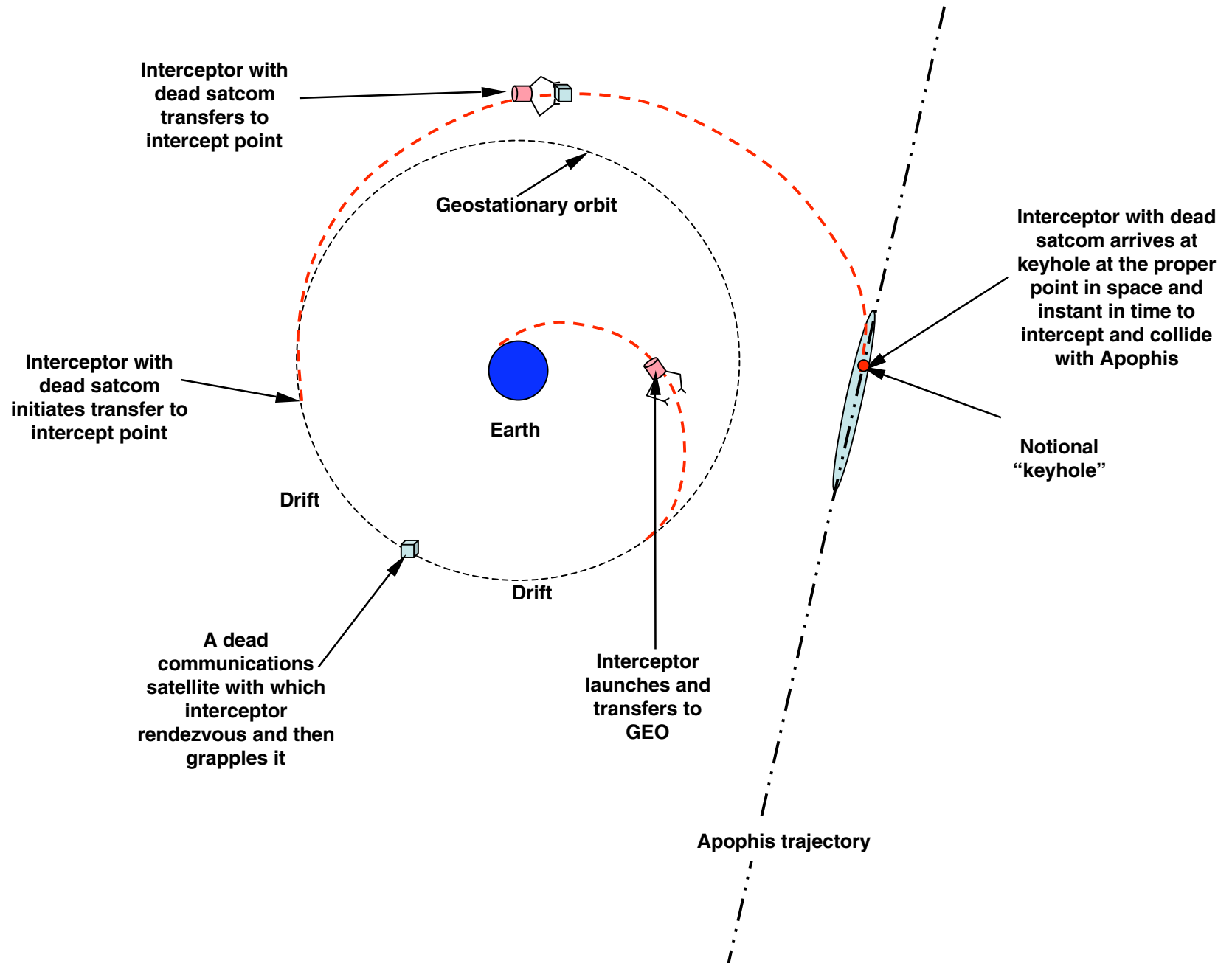
## NEW STRATEGY

- Applies to NEOs which have, or will have, resonant returns to Earth
- Intercepts in the ‘keyhole’, which is close to Earth
- Spacecraft is small. Uses dead GEO communications satellite as “free” mass
- Kinetic collision deflects NEO to prevent Earth collisions in resonant returns

# CLOSEST APPROACH OF APOPHIS TO EARTH, April 13, 2029 (numbers approximate)



# KEYHOLE INTERCEPTION MISSION PROFILE



# MASS AND $\Delta V$ REQUIRED

## • $\Delta V$ needed

- Transfer from 36,000 km orbit to 56,000 km apogee requires 345 m/s
- Plane change of 2.6 degrees at GEO altitude requires 167 m/s
- Double that to account for the ascending node being non-optimum at epoch = 334 m/s
- **Total  $\Delta V$  needed = 334 + 345 = 679 m/s**

## • Mass required

- Dead communications satellite is 2000 kg
- Interceptor bus = 300 kg dry mass. Hydrazine propulsion system
- Rocket equation dictates Initial/Final mass = 1.25 for Hohmann transfer to 56,000 km
- The total propellant load required is 575 kg of hydrazine
- **Thus the interceptor weighs 2,875 kg fully fueled**
- This is well within capability of current launch vehicles

# APPROXIMATE MAXIMUM TIMELINE FOR AOPHIS INTERCEPT

	Store on ground	Store docked in GEO
•Launch from ground	0	--
•Transfer to GEO	6 hrs	--
•Checkout in GEO	12 hrs	12 hrs
•Transfer to rendezvous with dead satcom	30 days	30 days
•Rendezvous and grappling	1 day	1 day
•Checkout stack	6 hrs	6 hrs
•Transfer to intercept node	30 days	30 days
•Vernier phasing	1 day	1 day
•Hohmann transfer to intercept a point in space at an instant in time	13.6 hrs	13.6 hrs
•Total time to intercept	63.56 days	63.31 days

These times could be as low as a few days with faster drifts and properly chosen launch date

# CONCLUSIONS

- New strategy applies to all NEOs which have, or will have, resonant returns to Earth
- Kinetic collision with the NEO in its keyhole passage has fundamental advantages
- For the example case study of Apophis:
  - Imparts 1 cm/sec  $V$  to Apophis during its 4/13/2029 keyhole passage
  - Prevents Earth impacts in 2034, 2035, 2036, and probably other resonant returns
  - Interception occurs only 2-8 weeks after launch
  - Uses “free” collision mass by grappling a dead GEO communications satellite
  - Uses mostly current technology stage and current launch vehicles
  - Low  $\Delta V$  required for interception vehicle--less than 1,000 m/s
  - Energy/mass is low enough to prevent fragmentation, but even if it does occur the fragments will also mostly miss the Earth
- This is the only non-nuclear mitigation technique that needs only a few weeks warning time