STAR, INC.

TAI

An Update on EDDE

the ElectroDynamic Delivery Express

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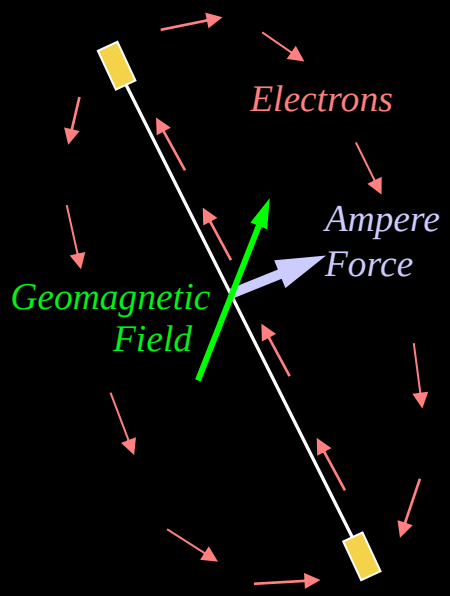
EDDE Concept and Design



Electrodynamic Propulsion

Partly-external current allows net force on EDDE:

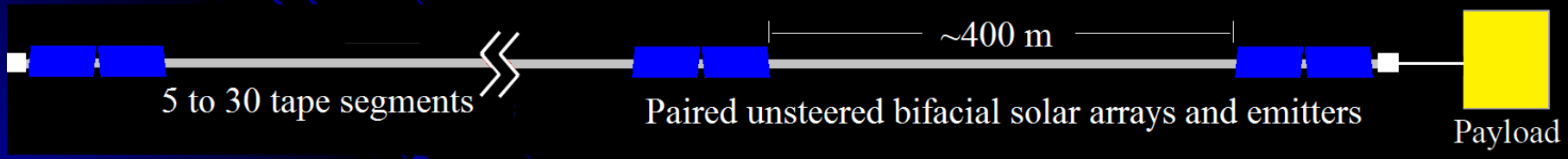
- Current flows in tape, and returns in ionosphere.
- "One-way" tape current in magnetic field causes force.
- Reaction force is in the ionosphere, closing the loop.

EDDE "sails" or "swims" or "glides":

- It maneuvers in near-vacuum, without propellant.
- It swims through and reacts aganst the ionosphere.
- Descent is like gliding: it trades altitude for range.

Key EDDE design features:

1. EDDE turns end-over-end to improve agility & stability.
2. Solar arrays are along length, to reduce peak voltages.
3. Unsteered paired bifacial solar arrays raise power/mass.

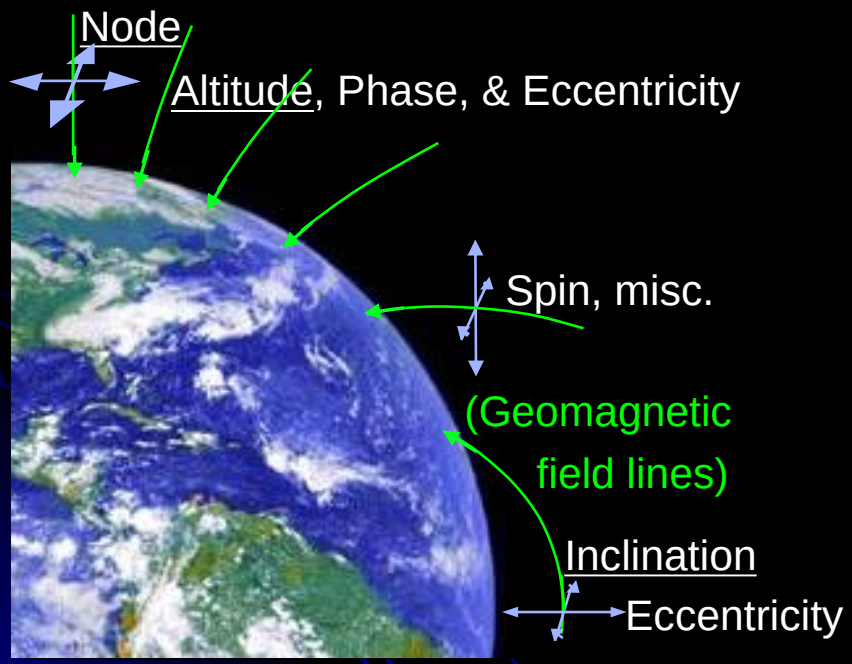


EDDE Layout

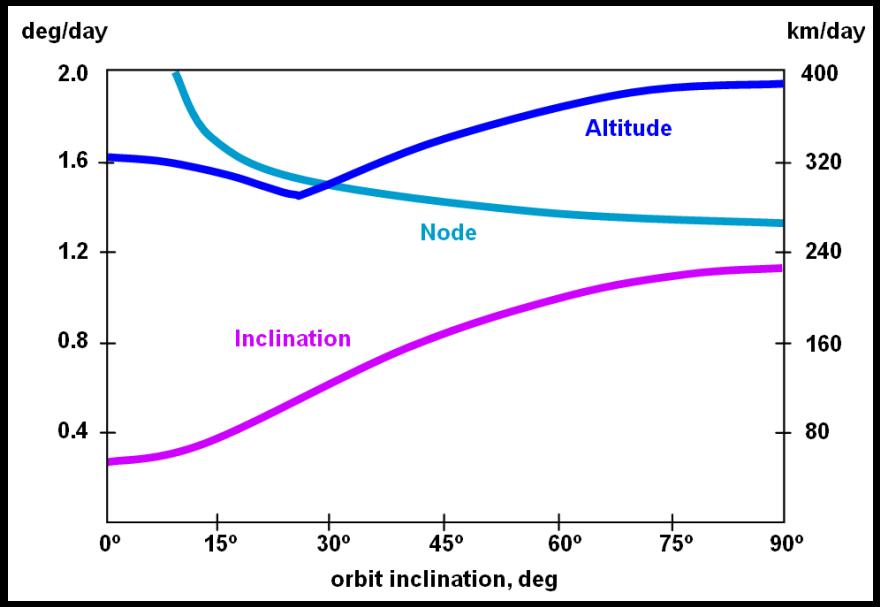
EDDE Maneuver Capability

- 100's of km/day altitude change at ~400-1000 km
- >1°/day orbital plane change (inclination & node)

Orbit elements changed by ED forces:



Elements changed vs. latitude

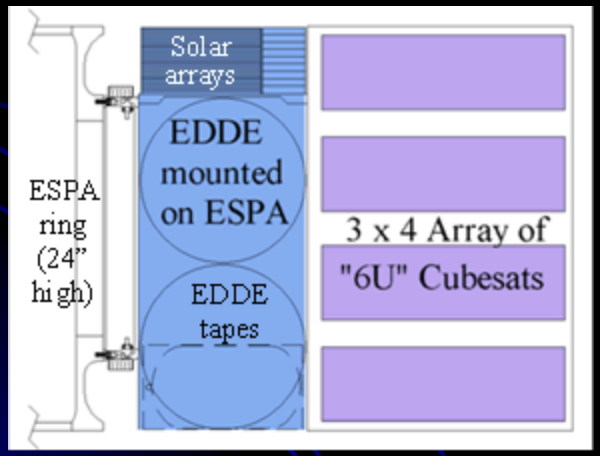


EDDE orbit change rates per amp orbit-average current

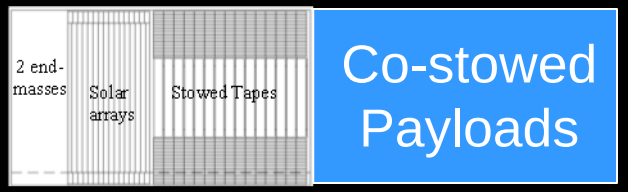
(scale by M_{EDDE}/M_{total})

EDDE Sizing and Packaging

- ESPA can fit an 80 kg EDDE in inner 1/3 of envelope
  - That leaves 100 kg for EDDE payloads in the outer 2/3
  - EDDE can carry and distribute 12 6U CubeSats in that space
  - Or carry 2 EDDEs, or 1 “Big EDDE” to move heavy payloads
- Smallest operational EDDE might be 12U & 30 kg:



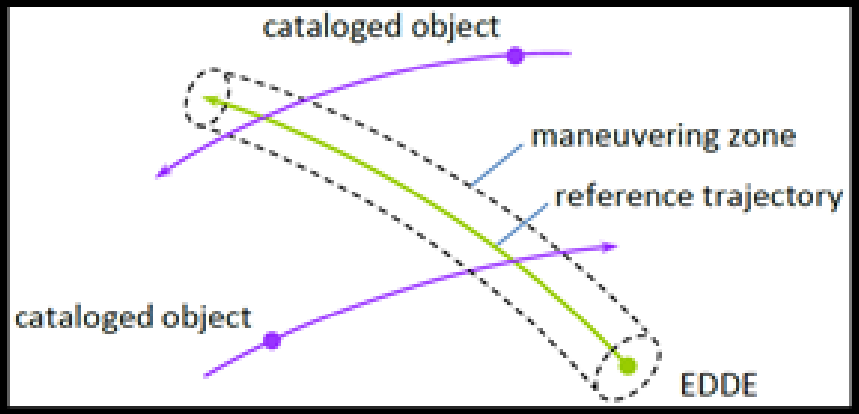
EDDE + CubeSats on ESPA



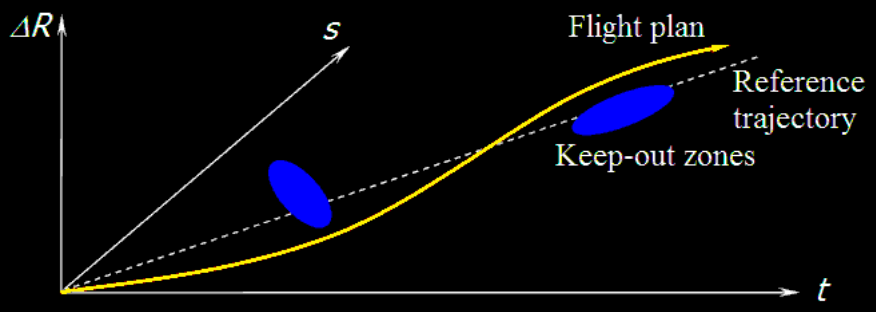
2x2x6U carrier can carry 12U EDDE plus 12U of payloads.

After distributing payloads, this EDDE can do inspections.

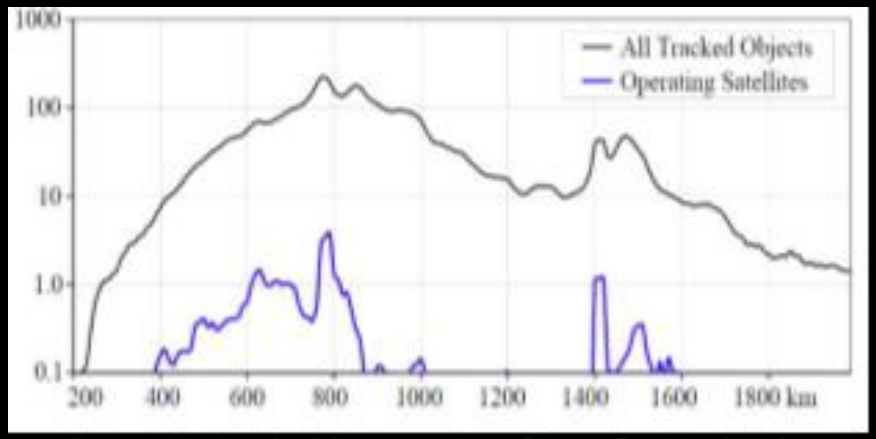
Active Collision Avoidance



EDDE does active avoidance while staying in a specifed moving tube



EDDE maneuvers in phase space



Crossings/day of 30x200 km tube, by operating sats & all tracked objects

EDDE Applications

1. Payload Delivery *(easiest: no rendezvous or capture needed)*
2. LEO Object Inspections *(requires accurate rendezvous)*
3. Satellite Service Support *(requires cooperative captures)*
4. Debris Removal or Collection *(requires captures of debris)*

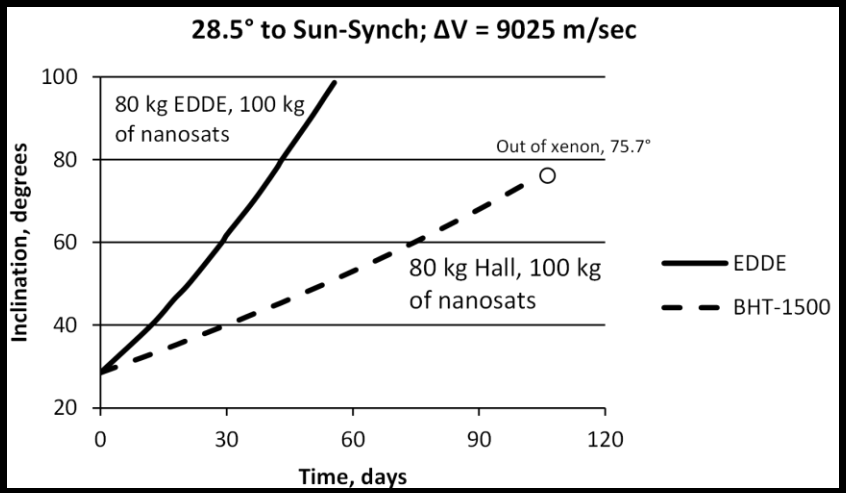
Each EDDE application above has substantial value on its own, and also allows thorough in-space testing for the next application.

Payload Delivery/Distribution

- Distribute multiple secondary payloads into custom orbits in LEO, at costs closer to secondary than dedicated launch.
- After distributing payloads, EDDE can perform space observations
- The key question:
  - How much extra will secondary payloads pay for custom orbits?

Operation	Days	Notes (Mp/MEDDE=3)
400 km circ. boost	8	Power-limited climb
400 km circ.deboost	2	If plasma dense enough
51.6º to 70º orbit	49	Departure day sets node
51.6º to 98º orbit	124	Departure day sets node
Same+ 90º node shift	150	Combined maneuver
Same+180ºnode shift	170	Combined maneuver

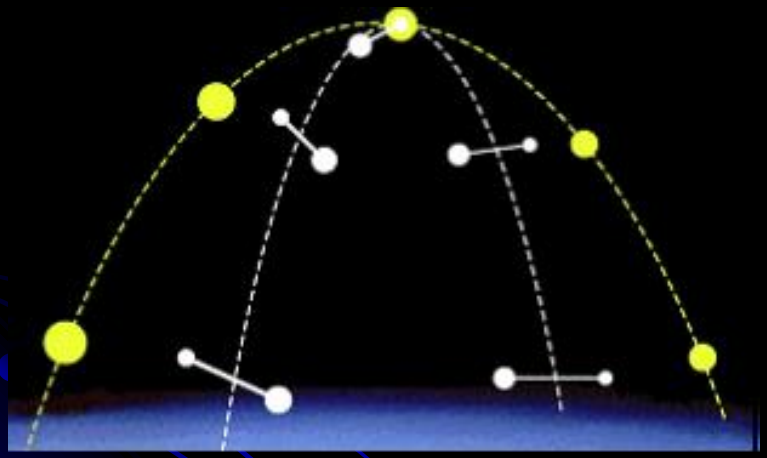
EDDE Nanosat Distribution Times



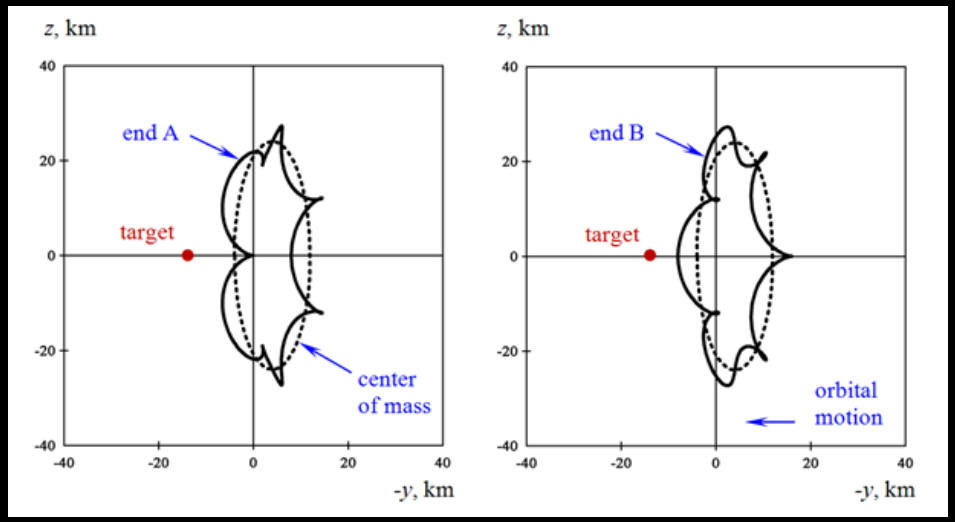
Delivering 100 kg of Nanosats from 28.5º to 97º Inclination

LEO Object Inspection

- EDDE can reach any inclination and node, up to 2000 km altitude
- EDDE does repeated close passes from a “nearly matching” orbit
- Binocular vision from cameras at ends provides accurate ranging



Free-Return Out-of-Plane
“Kiss” Rendezvous



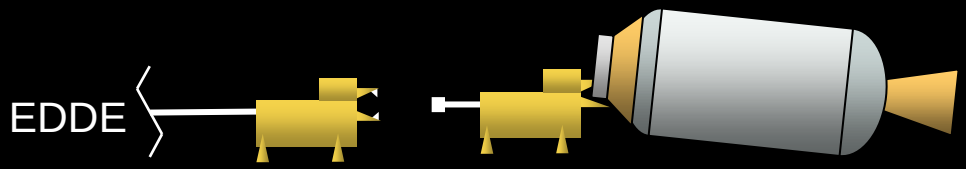
Free return Approach Trajectories

Binocular ranging sensitivity

Satellite Servicing Support

- Servicing is more challenging in LEO than GEO: far higher ΔVs!
- EDDE can deliver service vehicles to each new assignment.
- But it requires repeated EDDE capture of the service vehicle.
- Two-dog capture allows failed satellite delivery to/from ISS.

DARPA Orbital Express + NextSat

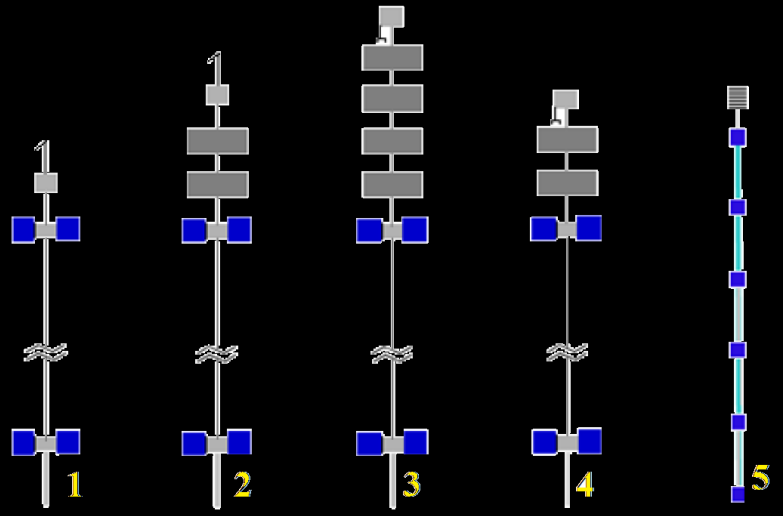


"Two-Dog" capture using a service vehicle can make tethered capture of even passive objects cooperative.

Debris Removal and Collection

Spin up test of hanging bead-chain net

Thrown-Net Capture of Dead Satellite



Debris Collection, Processing,
and Delivery by EDDE

TEPCE, An EDDE Precursor

TEPCE = Tethered Electrodynamic Propulsion CubeSat Experiment

- 1 km conductive tether & stacer spring stow between smart endmasses.
- Collects electrons on ~25mm wide metal “tape measures,” like EDDE.
- Uses enhanced thoriated thermionic electron emitting wires, like EDDE.
- Will test libration, maneuvers, & collision avoidance, as needed by EDDE.
- NRL worked on active avoidance as sub under our NASA STMD program.
- TEPCE is planned to launch on 2nd Falcon Heavy, into an elliptical orbit.

Summary

EDDE has an ordered sequence of 4 major uses in LEO:

- Each step grows in both value and technical challenge.
- Each step also can flight-test EDDE for the next step.

1. Custom Secondary Payload Delivery
   - Stow EDDE with secondary payloads; distribute to custom orbits
2. Affordable Inspection of Many LEO Objects
   - Equip EDDE with camera; do free-return passes to observe
3. Affordable Satellite Servicing
   - Equip EDDE and servicer with cooperative capture interfaces
   - Rendezvous, capture, and deliver servicer to each service job
4. Wholesale LEO Debris Removal or Collection
   - Equip EDDE with expendable nets and net manager
   - Rendezvous, deploy nets, and capture debris
   - Drag below ISS & release, or deliver to recycling facility

LEO Debris Removal by EDDE