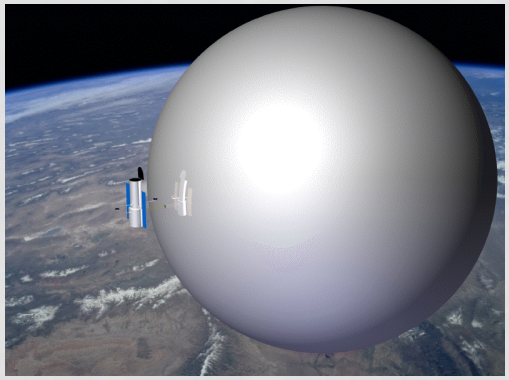
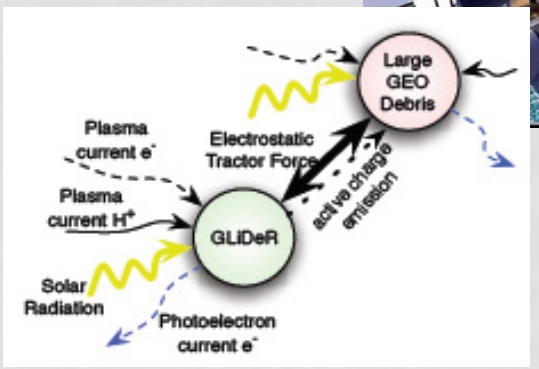
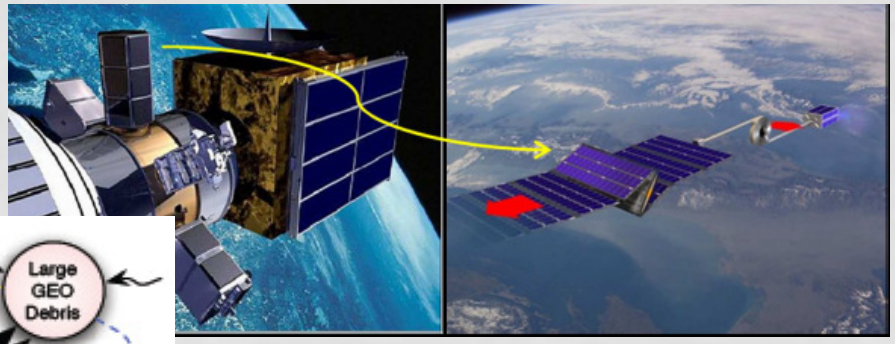






US ACTIVE DEBRIS REMOVAL (ADR) EFFORTS

DR. DARREN MCKNIGHT

VIENNA UN COPUOS FEBRUARY 2013

DISCLAIMER

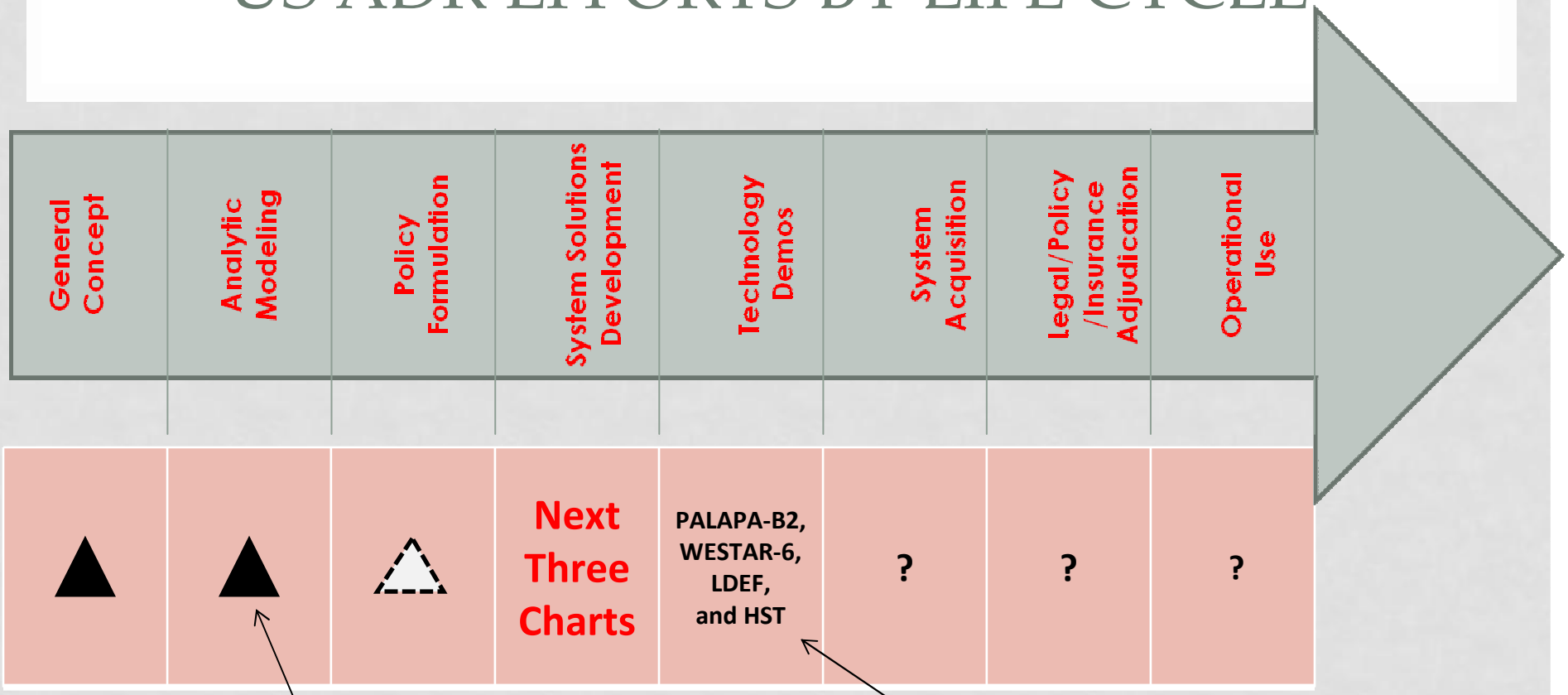
- This presentation solely represents the opinions of the author and should not be construed as being endorsed or validated by the US Government.
  - This information reflects efforts that have been conducted and does not address planned future US investments.

BACKGROUND

- **USG National Space Policy (June 2010) called for NASA and DoD to pursue R&D on ADR, reducing hazards, and increasing understanding of debris environment.**
  - NASA
    - Centralized funding and policy implementation through NASA/HQ.
    - Johnson Space Center is center of excellence for orbital debris mitigation.
      - Several other centers and Office of Chief Technologist have unique contributions.
    - Space Technology Program applying resources for concept exploration and technology development.
  - DoD
    - ADR activities performed largely in labs (NRL, APL, AFRL, etc.) and the Defense Advanced Research Programs Agency (DARPA).

- Regular (at least annual) NASA/DoD OD Working Group meetings cover a full range of OD efforts to include ADR.

US ADR EFFORTS BY LIFE CYCLE



Foundational research papers by Johnson and Liou on ADR, 2009 and 2011

Rendezvous, grappling, and retrieval/servicing missions

EVALUATION OF POSSIBLE ADR METHODS

2009 CONFERENCE IN US - CATALYST TO DISCUSSIONS

Debris object class	Removal method	Orbit	Feasible physics	Encounter velocity	Anti-collision maneuver?	Units needed	Acceptable	Issues
Large	**Propulsive tug**	Any	Yes	Near 0	Yes	< 10	Yes	Large amounts of delta-v, object capture, rotating objects
Large	**Inflatable drag device**	LEO	Yes	NA	No	10s per year	No	Collision with active or other large debris
Large	**Solar sail**	GEO	Maybe	NA	No	10s per year	No	Low mass object capture mechanism
Large	**Electrodynamic tether**	LEO	Maybe	TBD	Maybe	< 10	No	Complex control, dynamic stability, debris object capture method
Large	**Momentum tether**	Any	Maybe	TBD	Maybe	< 10	No	control, dynamic stability, object capture method
Large, Medum	**Ground based laser**	LEO	No	NA			No	Engagement geometry, laser physics, detection & tracking
Large, Medum	**Space based laser**	LEO	No		NA	< 10	No	Engagement geometry, laser physics, detection & tracking
Medium	**Passive sweeper**	LEO	Yes	Up to 11 km/s	No	45,000	No	Infrequent debris encounters, collision with active or other large debris
Medium	**Active sweeper**	LEO	Yes	Up to 11 km/s	Yes	100	No	Need large numbers, large delta-v, advanced sensors
Medium	**Liquid, Gas, Particulate cloud**	LEO	Yes	Up to 11 km/s	No	10,000s	No	Need large numbers, effect on operational spacecraft
Medium	**Electromagnetic**	Any	Maybe	Up to 11 km/s	Yes	100s to 1,000s	No	Massive device, complex encounter geometry, detection & tracking, object composition

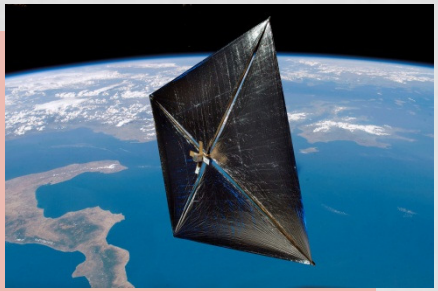
Scores and metrics are outdated

FOUR "MAINSTREAM" AREAS

- **EDDE (ElectroDynamic Debris Eliminator)**
- E-tether uses Earth's magnetic field to create propulsive force
- Use force to both rendezvous for grappling and to move derelict
- Some partially successful testing in the past

- **GOLD (Gossamer Orbit Lowering Device)**
- Inflatable
- Simple, effective
- Better long-term collision risk than any ADR system except for propulsive tug

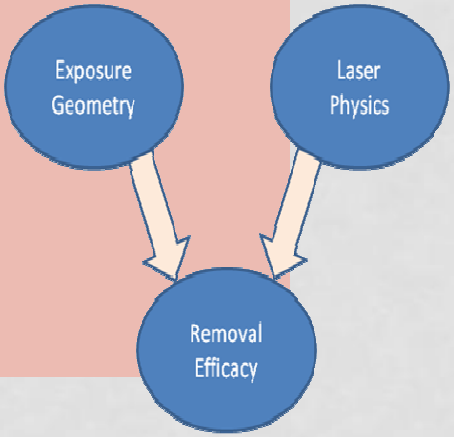
- **Solar Sail**
- Uses solar photon pressure to move derelicts
- Similar systems deployed previously but not for operational ADR applications
- Fragile and slow process



- **Propulsive Tug**
- Traditional propulsion system still the most mature capability
- High impulse and controllability for reentry risk mitigation
- Exemplar for several satellite servicing initiatives

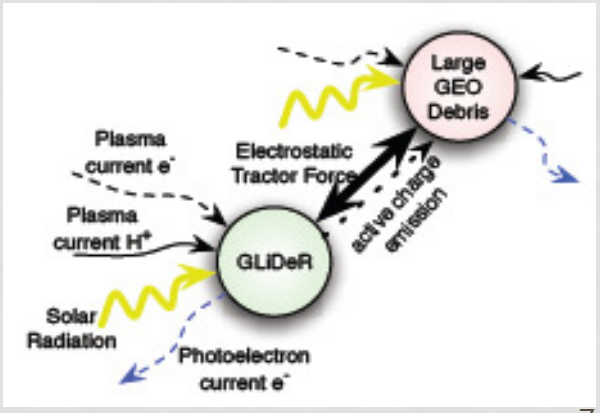
THREE "NICHE" EFFORTS

- **Laser Removal from ground or space**
- No need to detumble or even go to space for groundbased version
- Physics of dwell time and laser interaction are unproven
- Feasibility for ADR unclear



- **Geosynchronous Large Debris Reorbiter (GLiDeR)**
- Contactless-coupling plus ion thrusters in GEO only
- No need to detumble
- Unproven, limited applications
- Deposit in GEO graveyard, not deorbit

- **Tungsten Dust**
- Remove derelicts by depositing tons of dust in space to "wash out" medium-large debris
- Significant effects on operational spacecraft
- Feasible only for "start over" mode



ORGANIZING ADR OPTIONS

- Orbital solution creates potential risk to create more orbital debris vice ballistic (i.e. sub-orbital) system
- Options viable for certain orbital regions: LEO, GTO, and/or GEO
- Needing propellant to rendezvous adds cost/weight
- Needing propellant to remove adds cost/weight
- It is important to be able to control deorbiting to minimize risk to people on the ground
- Technology readiness level (TRL) provides measure of programmatic risk and potential investment needed to make operational
- Cost per object removed determines financial efficacy of approach
- Cost per collision prevented is a broader metric that may motivate examination of "other" approaches… such as just-in-time collision avoidance (JCA)

ADR-RELATED OBSERVATIONS
PERSONAL THOUGHTS

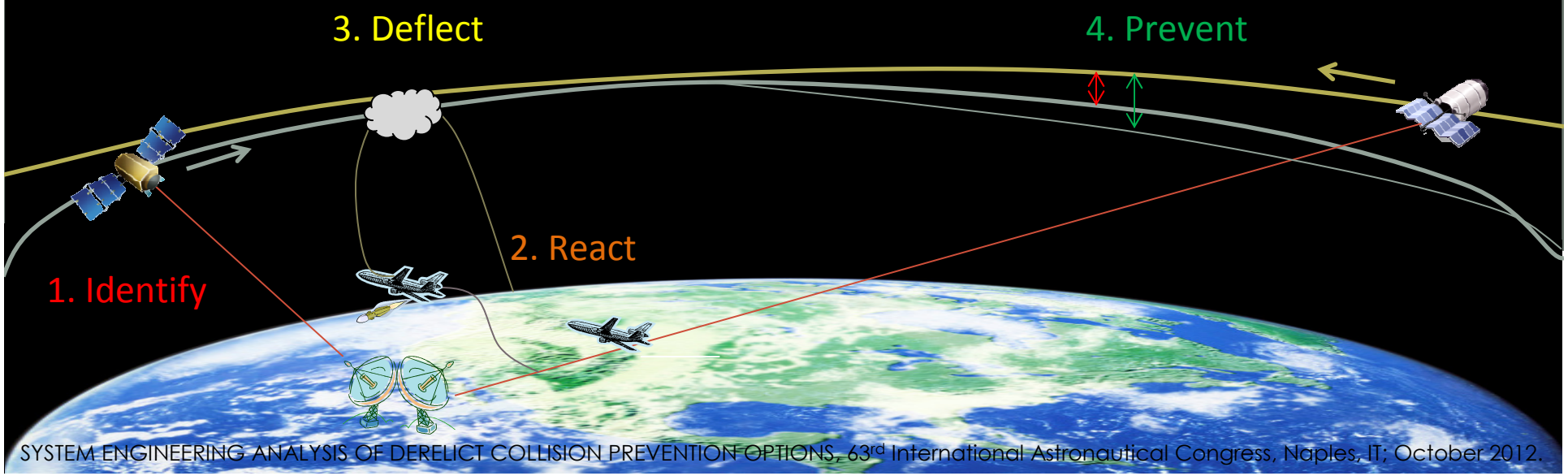
- 1. Need to examine **metric for success for ADR** for large derelict objects
  - Environmental stability is the common factor discussed but reduction in satellite operational lifetimes from collisions with nontrackable/lethal debris fragments might be more relevant
- 2. **Detumbling** of derelicts is often overlooked
  - May be significant component of solution

- 3. Include Just-in-Time Collision Avoidance (JCA) with ADR for **"derelict collision prevention"** mission space

JCA Operations:
Prevent imminent orbital collision w/o going into orbit

1. Identify: Ground and orbital systems detect imminent collision.
2. React: Air-launch system is mobilized with JCA system on board.
3. Deflect: JCA system is deployed to induce a slight change in the orbit of one of the objects involved by deploying cloud of high density gas.
4. Prevent: If the object's orbit is changed enough the collision will be prevented.

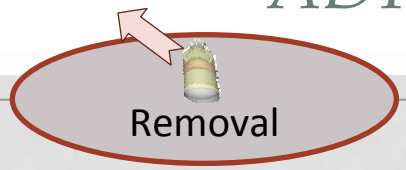
Original Orbit
Ground Detection
Aircraft Trajectory
Launch Vehicle Trajectory
New Orbit



SYSTEM ENGINEERING ANALYSIS OF DERELICT COLLISION PREVENTION OPTIONS, 63rd International Astronautical Congress, Naples, IT; October 2012.

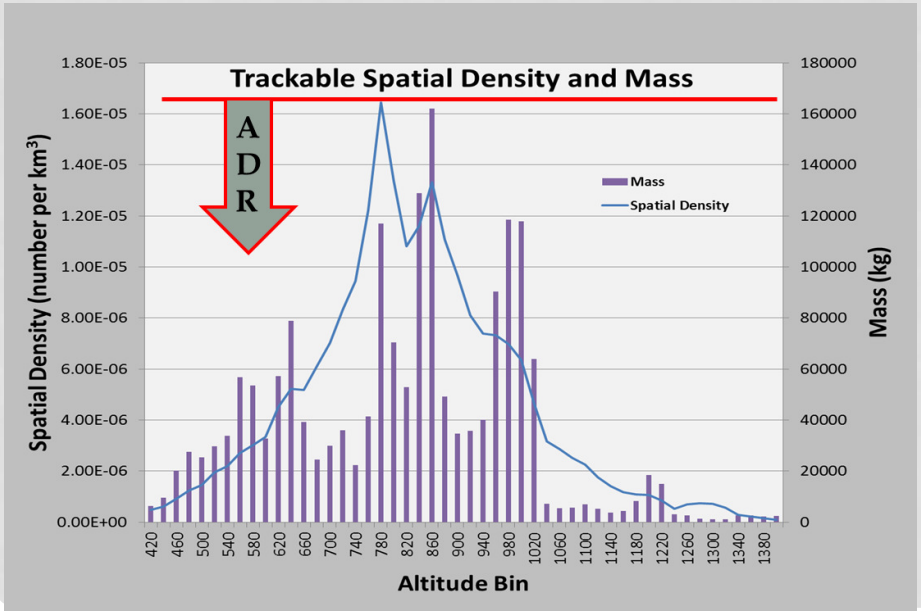
PREVENTING DERELICT COLLISIONS

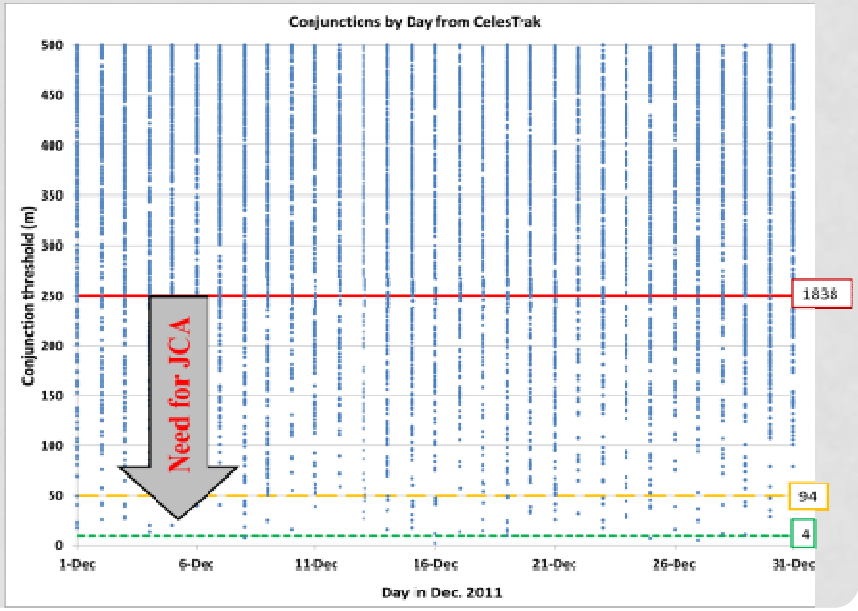
ADR AND JCA



Active Debris Removal (ADR)
-Requires many launches
-Requires grapple/detumble
-Execute over decades
-Manage reentry risk
STRATEGIC - Statistical

Just-In-Time CA (JCA)
-Want low false alarms
-Need enhanced el set accuracy
-Hourly/daily response
-No reentry risk
TACTICAL - Deterministic





ADR AND JCA

BOTH ARE DIFFICULT AND EXPENSIVE

	ADR	JCA
Number of objects moved/removed per collision prevented	~30-50	~5-3,000
Costs per collision prevented	~$100M's-$B's	~$10M's-$10B's
Game Changer(s) Needed	**10s-100s of derelicts removed per launch**	**Improve el set accuracy by 25x (250m→10m) and ballistic launch less than $1M**

PARTING THOUGHT

"PAY ME NOW OR PAY ME MORE LATER"

- **Timing for ADR…**

  1) research and development;
  2) demonstrations;
  3) industry scale-up;
  4) legal/policy evolution and codification;
  5) operations and maintenance; and
  6) accrued benefits

  are uncertain.

  - Tradeoff between acting too soon or acting too late needs to be examined.