SISYPHUS VICTORIOUS

ASTEROID PROJECT

Planetary defense test & a feasible (flexible) next giant leap for human exploration beyond LEO

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California Institute of Technology, Pasadena
December 6th, 2010

« Early in the next decade, a set of crewed flights will test and prove the systems required for exploration beyond low Earth orbit. And **by 2025, we expect new spacecraft designed for long journeys to allow us to begin the first-ever crewed missions beyond the Moon into deep space**. So **we'll start by sending astronauts to an asteroid for the first time in history**. By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth. And a landing on Mars will follow. And I expect to be around to see it.

Now, I understand that some believe that we should attempt a return to the surface of the Moon first, as previously planned. But I just have to say pretty bluntly here: We've been there before. Buzz has been there. There's a lot more of space to explore, and a lot more to learn when we do. So I believe it's more important to ramp up our capabilities to reach -- and operate at -- **a series of increasingly demanding targets, while advancing our technological capabilities with each step forward**. And that's what this strategy does. And that's how we will ensure that our leadership in space is even stronger in this new century than it was in the last. »

In his speech at Kennedy Space Center (April 15, 2010), President Obama clearly laid out his goals and a timetable for NASA:

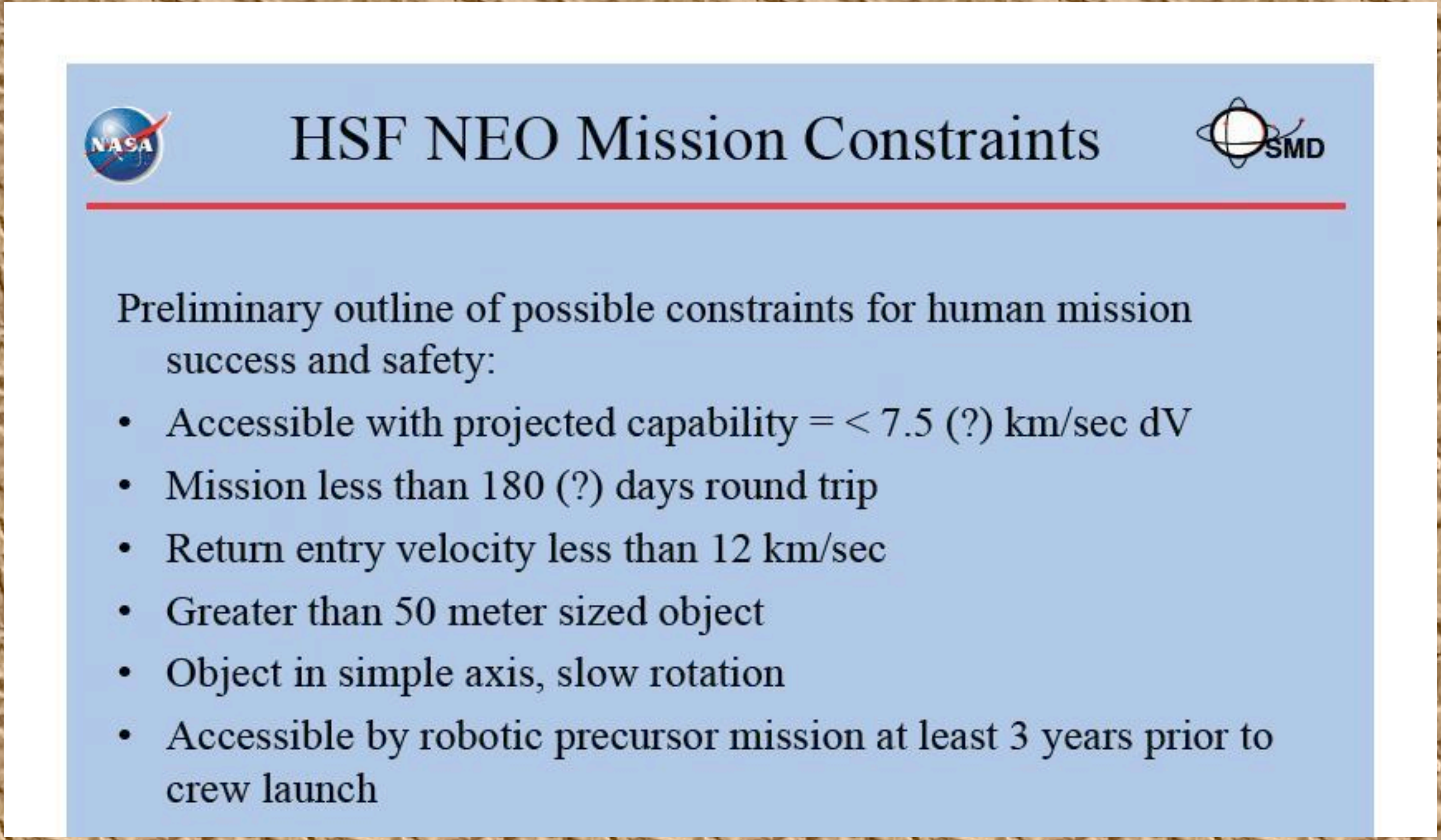
By 2015 – Finalize a heavy-lift launcher design and begin to build it.

By 2025 – Begin the first crewed missions beyond the Moon and into deep space. The final choice of destination is not immediately made, but will depend on technology advances. A near-Earth asteroid is a possible choice, with increasingly demanding targets to follow.

By mid-2030s – Send humans to orbit Mars and return them safely to Earth.

Cape Canaveral, April 15, 2010

Current Framework

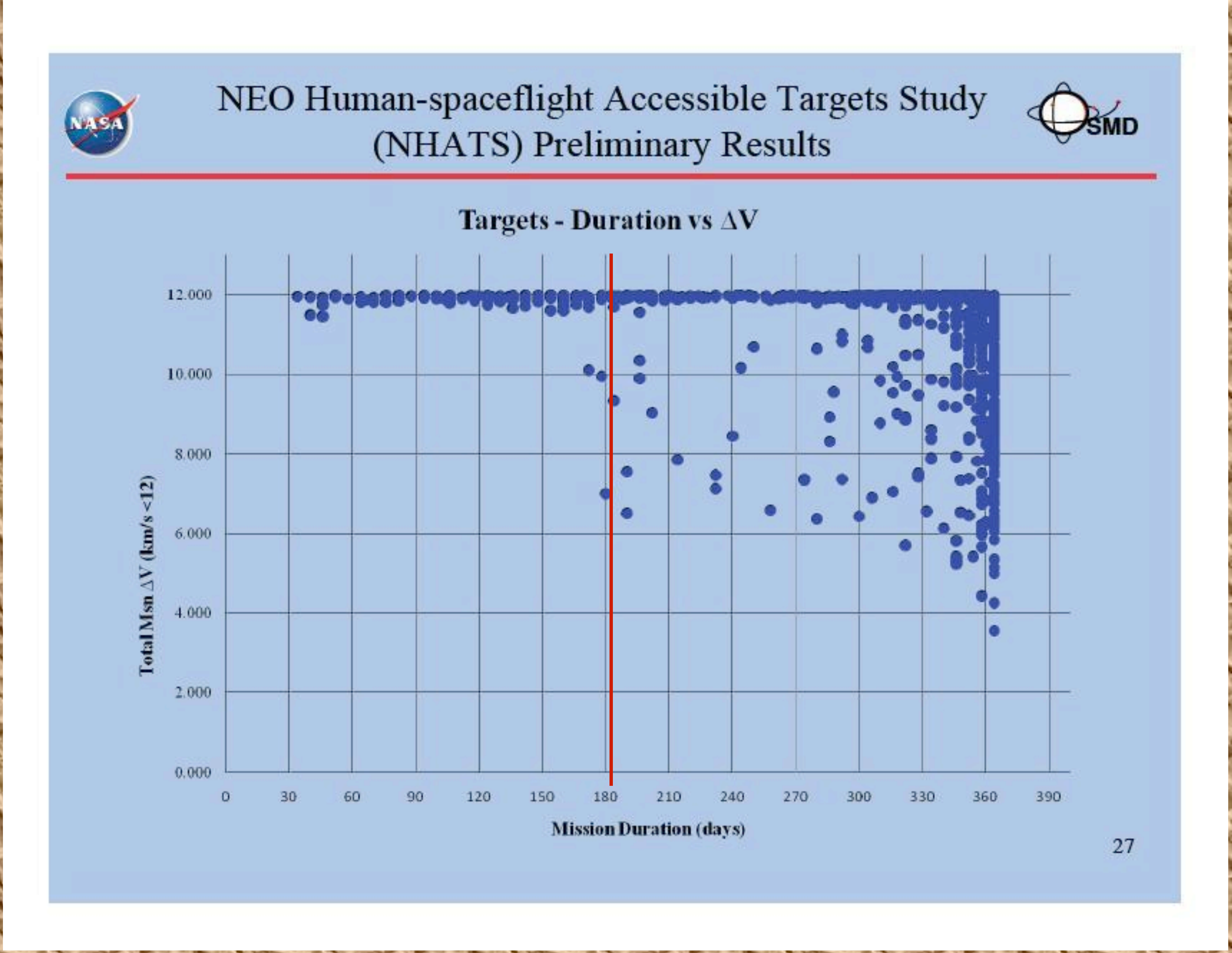


HSF NEO Mission Constraints

Preliminary outline of possible constraints for human mission success and safety:

- Accessible with projected capability = < 7.5 (?) km/sec dV
- Mission less than 180 (?) days round trip
- Return entry velocity less than 12 km/sec
- Greater than 50 meter sized object
- Object in simple axis, slow rotation
- Accessible by robotic precursor mission at least 3 years prior to crew launch

Credit: Lindley Johnson, NASA HQ, 2010



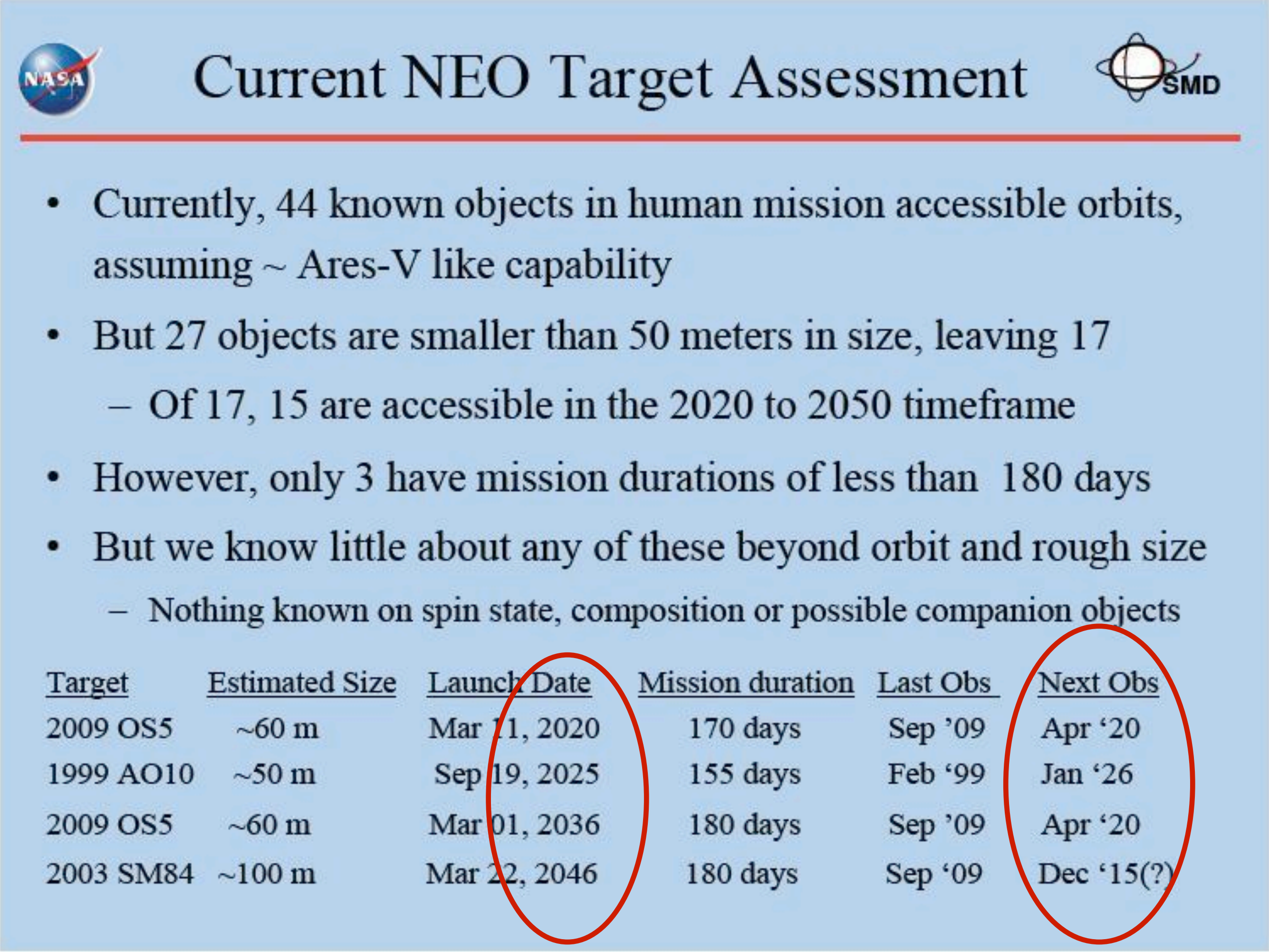
NEO Human-spaceflight Accessible Targets Study (NHATS) Preliminary Results

SMD

Targets - Duration vs ΔV

27

Credit: Lindley Johnson, NASA HQ, 2010



Current NEO Target Assessment

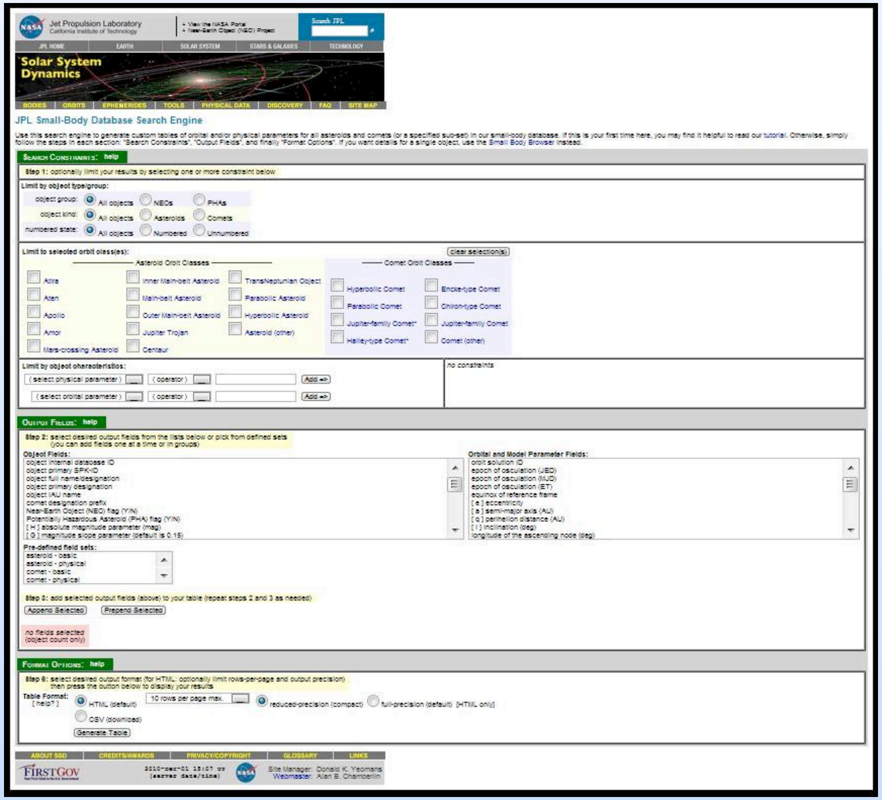
- Currently, 44 known objects in human mission accessible orbits, assuming ~ Ares-V like capability
- But 27 objects are smaller than 50 meters in size, leaving 17
  - Of 17, 15 are accessible in the 2020 to 2050 timeframe
- However, only 3 have mission durations of less than 180 days
- But we know little about any of these beyond orbit and rough size
  - Nothing known on spin state, composition or possible companion objects

Target	Estimated Size	Launch Date	Mission duration	Last Obs	Next Obs
2009 OS5	~60 m	Mar 11, 2020	170 days	Sep '09	Apr '20
1999 AO10	~50 m	Sep 19, 2025	155 days	Feb '99	Jan '26
2009 OS5	~60 m	Mar 01, 2036	180 days	Sep '09	Apr '20
2003 SM84	~100 m	Mar 22, 2046	180 days	Sep '09	Dec '15(?)

Credit: Lindley Johnson, NASA HQ, 2010

Some meteoroids discovered and tracked up to December 6th, 2010

2007 UN12 (H = 28.7, 6 m wide)
2008 HU4 (H = 28.2, 8 m wide)
2008 EA9 (H = 27.7, 10 m wide)
2010 UE (H = 29.6, 4 m wide)
2008 UA202 (H = 29.4, 4 m wide)
2009 BD (H = 28.4, 7 m wide)
2008TS10 (H = 28.8, 6 m wide)
2000 LG6 (H = 29.0 , 5 m wide)
2008 EL68 (H = 27.7, 10 m wide)
2010 JW34 (H = 28.1, 9 m wide)
2009 VT1 (H = 29.6, 4 m wide)
2008 JL24 (H = 29.6, 4 m wide)
2008 WO2 (H = 29.8, 4 m wide)
2008 VM (H = 30.2, 3 m wide)



JPL Small-Body Database Search Engine

Use this search engine to generate custom tables of orbital and/or physical parameters for all asteroids and comets (or a specified sub-set) in our small-body database. If this is your first time here, you may find it helpful to read our tutorial. Otherwise, simply follow the steps in each section: "Search Constraints", "Output Fields", and finally "Format Options". If you want details for a single object, use the Small Body Browser instead.

SEARCH CONSTRAINTS: help

Step 1: optionally limit your results by selecting one or more constraint below

Limit by object type/group:
object group: ● All objects ○ NEOs ○ PHAs
object kind: ● All objects ○ Asteroids ○ Comets
numbered state: ● All objects ○ Numbered ○ Unnumbered

Limit to selected orbit class(es):

Asteroid Orbit Classes
☐ Atira
☐ Aten
☐ Apollo
☐ Amor
☐ Mars-crossing Asteroid
☐ Inner Main-belt Asteroid
☐ Main-belt Asteroid
☐ Outer Main-belt Asteroid
☐ Jupiter Trojan
☐ Centaur
☐ TransNeptunian Object
☐ Parabolic Asteroid
☐ Hyperbolic Asteroid
☐ Asteroid (other)

Comet Orbit Classes
☐ Hyperbolic Comet
☐ Parabolic Comet
☐ Jupiter-family Comet*
☐ Halley-type Comet*
☐ Encke-type Comet
☐ Chiron-type Comet
☐ Jupiter-family Comet
☐ Comet (other)

Limit by object characteristics:
(select physical parameter) (operator)
(select orbital parameter) (operator)
no constraints

OUTPUT FIELDS: help

Step 2: select desired output fields from the lists below or pick from defined sets
(you can add fields one at a time or in groups)

Object Fields:
object internal database ID
object primary SPK-ID
object full name/designation
object primary designation
object IAU name
comet designation prefix
Near-Earth Object (NEO) flag (Y/N)
Potentially Hazardous Asteroid (PHA) flag (Y/N)
[H] absolute magnitude parameter (mag)
[G] magnitude slope parameter (default is 0.15)

Orbital and Model Parameter Fields:
orbit solution ID
epoch of osculation (JED)
epoch of osculation (MJD)
epoch of osculation (ET)
equinox of reference frame
[e] eccentricity
[a] semi-major axis (AU)
[q] perihelion distance (AU)
[i] inclination (deg)
longitude of the ascending node (deg)

Pre-defined field sets:
asteroid - basic
asteroid - physical
comet - basic
comet - physical

Step 3: add selected output fields (above) to your table (repeat steps 2 and 3 as needed)

no fields selected
(object count only)

FORMAT OPTIONS: help

Step 4: select desired output format (for HTML: optionally limit rows-per-page and output precision)
then press the button below to display your results

Table Format: [help?]
● HTML (default) 10 rows per page max. ● reduced-precision (compact) ○ full-precision (default) [HTML only]
○ CSV (download)

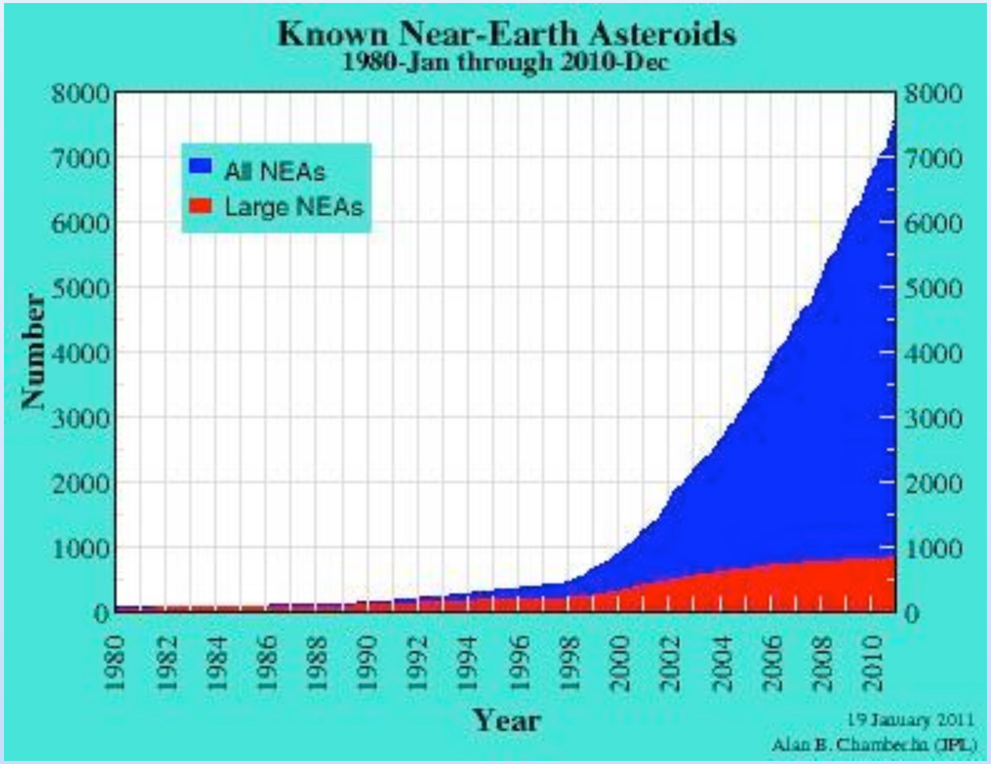
2010-Dec-01 15:07 UT
[server date/time]

Site Manager: Donald K. Yeomans
Webmaster: Alan B. Chamberlin

Small-Body Search Engine <http://ssd.jpl.nasa.gov/sbdb_query.cgi

Meteoroids discovered and tracked: December 6th - March 25th (H ≥ 27.5)

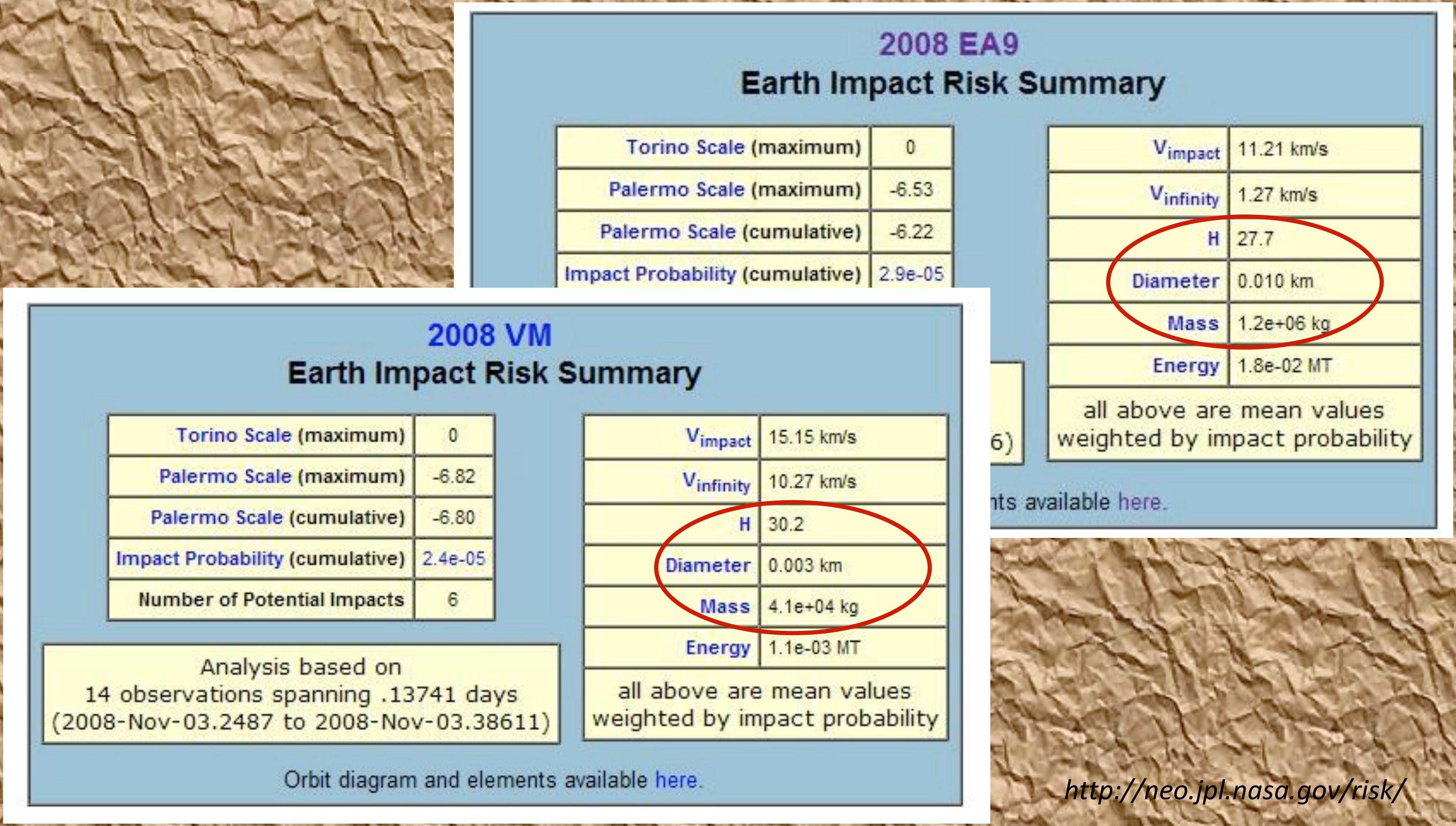
2010 XG64 (H = 27.9)
2011 AN1 (H = 27.7)
2011 AE3 (H = 27.5)
2011 AZ22 (H = 28.6)
2011 AM37 (H = 29.7)
2011 AN52 (H = 28.5)
2011 BW11 (H = 28.3)
2011 BQ50 (H = 28.3)
2011 CQ1 (H = 32.0)
2011 CA7 (H = 30.3)
2011 CF22 (H = 30.9)
2011 CH22 (H = 29.0)
2011 CL50 (H = 27.6)
2011 EN11 (H = 27.9)
2011 EY11 (H = 28.6)
2011 EM40 (H = 28.0)
2011 EV 73 (H = 28.4)



Credit: Alan B. Chamberlin, NASA JPL, 19 January 2011

slide added in March 2011

SISYPHUS VICTORIOUS approach: example



2008 EA9
Earth Impact Risk Summary

Torino Scale (maximum)	0
Palermo Scale (maximum)	-6.53
Palermo Scale (cumulative)	-6.22
Impact Probability (cumulative)	2.9e-05

V_{impact}	11.21 km/s
$V_{infinity}$	1.27 km/s
H	27.7
Diameter	0.010 km
Mass	1.2e+06 kg
Energy	1.8e-02 MT
all above are mean values weighted by impact probability	

6)

ts available here.

2008 VM
Earth Impact Risk Summary

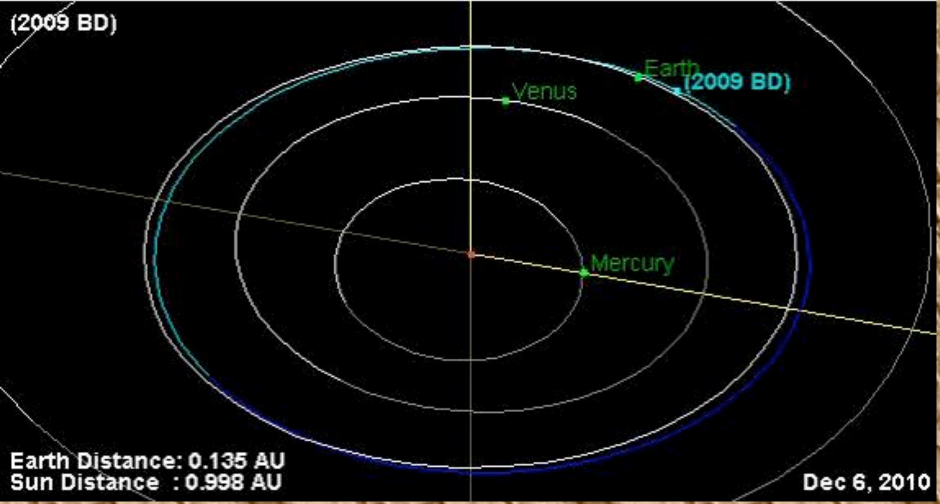
Torino Scale (maximum)	0
Palermo Scale (maximum)	-6.82
Palermo Scale (cumulative)	-6.80
Impact Probability (cumulative)	2.4e-05
Number of Potential Impacts	6

Analysis based on
14 observations spanning .13741 days
(2008-Nov-03.2487 to 2008-Nov-03.38611)

V_{impact}	15.15 km/s
$V_{infinity}$	10.27 km/s
H	30.2
Diameter	0.003 km
Mass	4.1e+04 kg
Energy	1.1e-03 MT
all above are mean values weighted by impact probability	

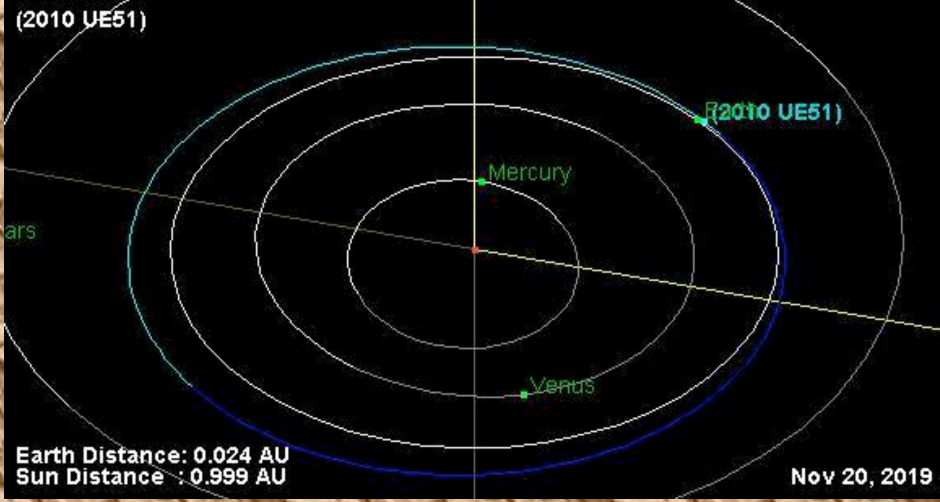
Orbit diagram and elements available here.

http://neo.jpl.nasa.gov/risk/



Earth Distance: 0.135 AU
Sun Distance : 0.998 AU

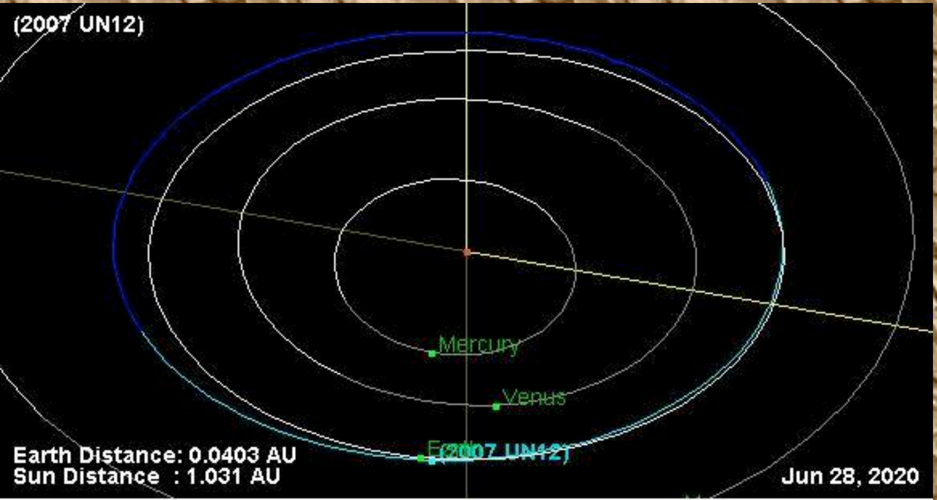
Dec 6, 2010



Earth Distance: 0.024 AU
Sun Distance : 0.999 AU

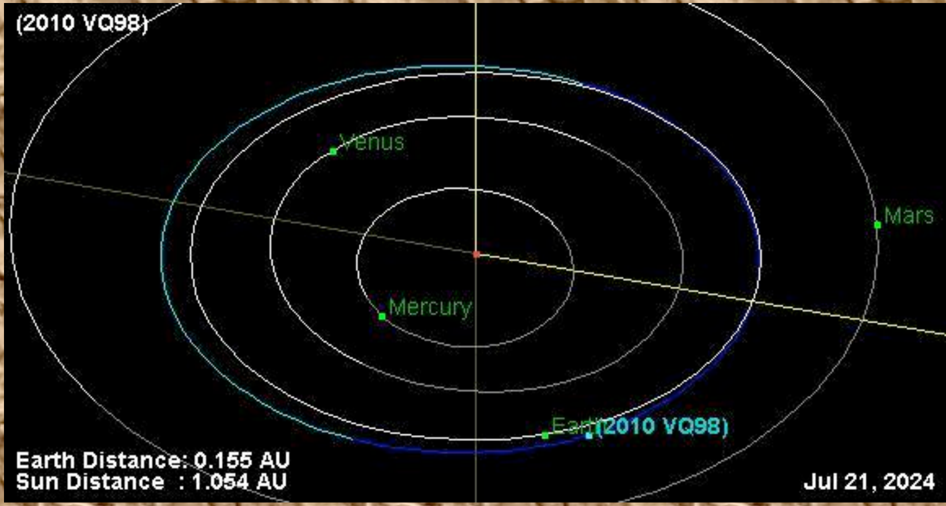
Nov 20, 2019

http://ssd.jpl.nasa.gov/



Earth Distance: 0.0403 AU
Sun Distance : 1.031 AU

Jun 28, 2020



Earth Distance: 0.155 AU
Sun Distance : 1.054 AU

Jul 21, 2024

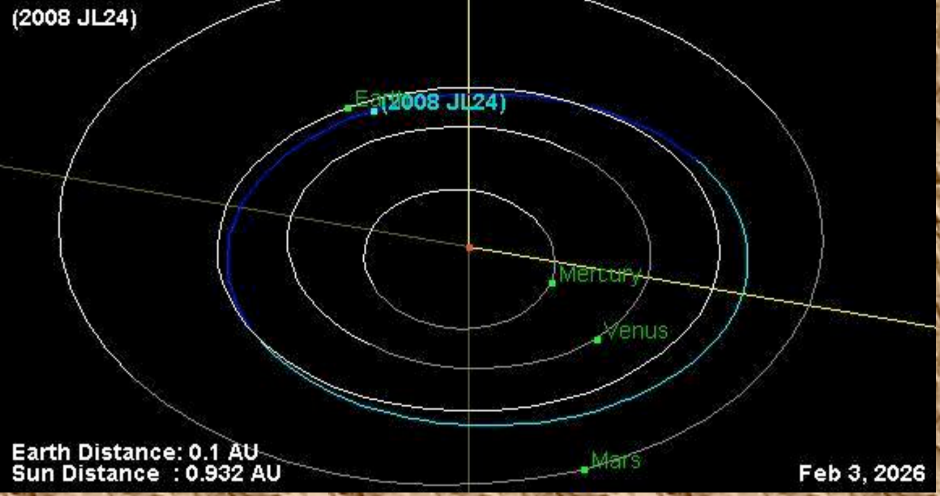
2009 BD: June 14, 2011
Earth distance: 0.0091 AU

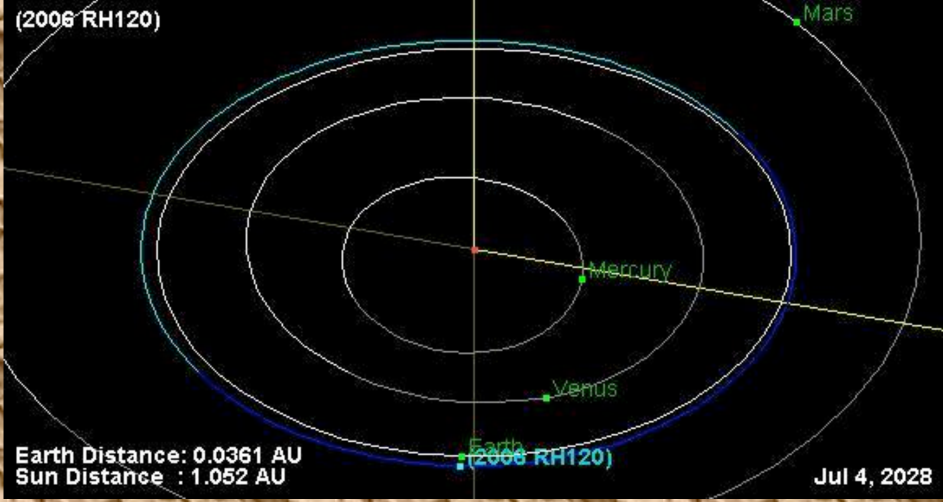
Note

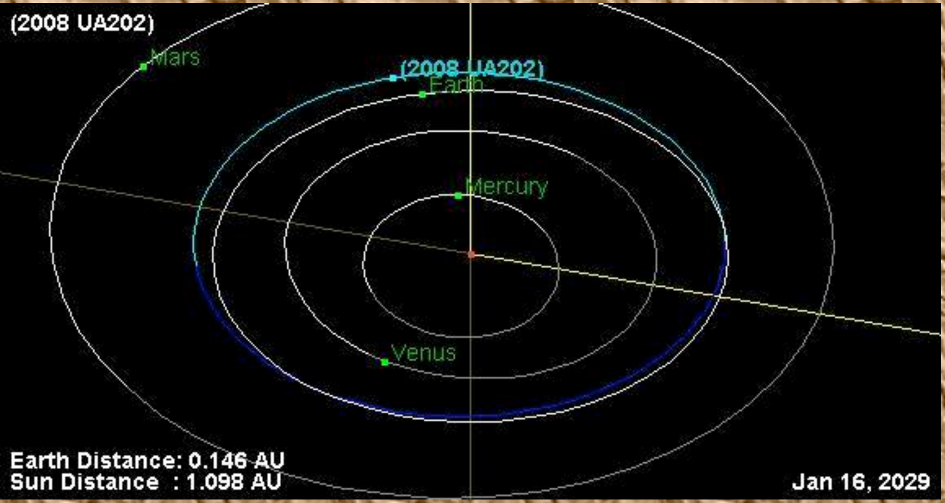
SE L1/L2 → 0.01 AU from Earth
EM L1/L2 → 0.0004 AU from Earth

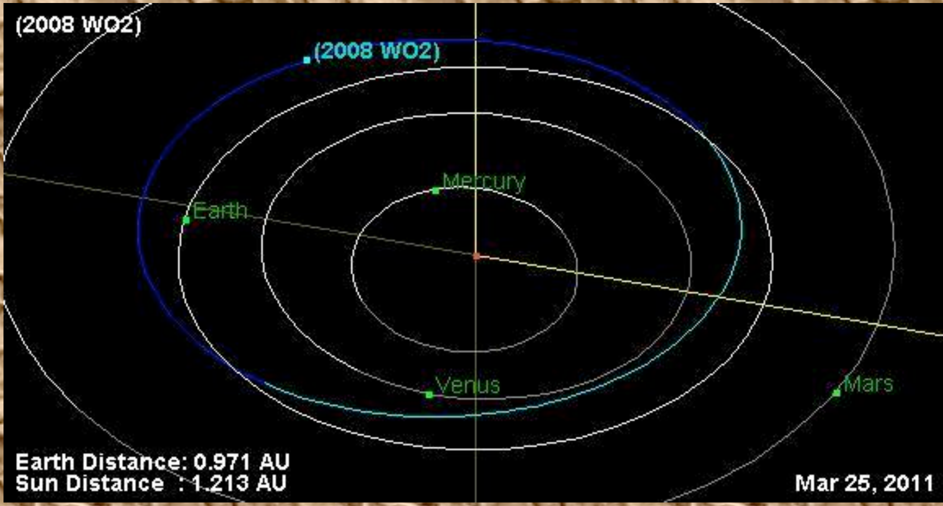
SISYPHUS VICTORIOUS

Planetary defense test & human exploration beyond LEO





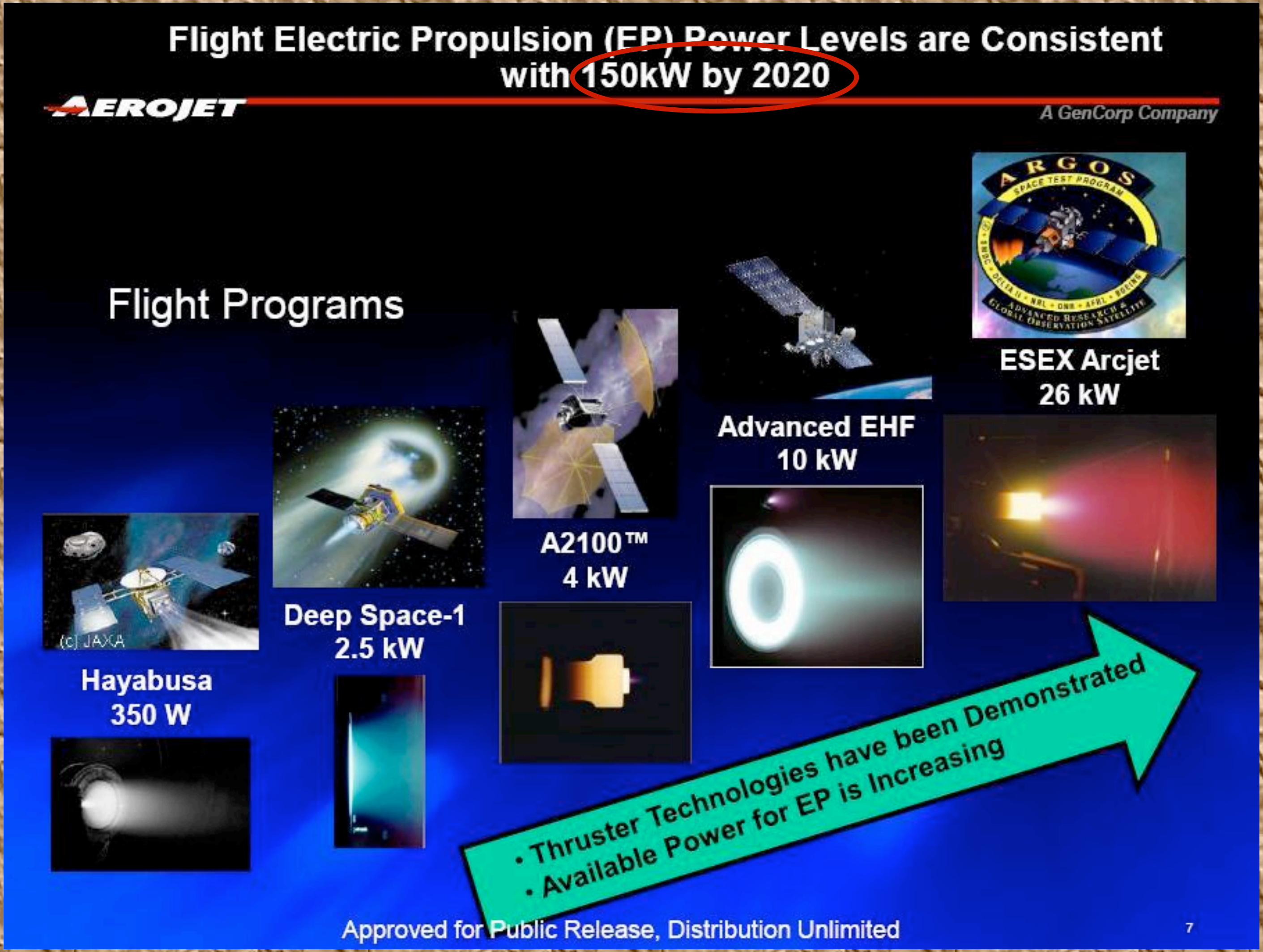




http://ssd.jpl.nasa.gov/

SISYPHUS VICTORIOUS

Planetary defense test & human exploration beyond LEO



Flight Electric Propulsion (EP) Power Levels are Consistent with 150kW by 2020

AEROJET

A GenCorp Company

Flight Programs

(c) JAXA

Hayabusa
350 W

Deep Space-1
2.5 kW

A2100™
4 kW

Advanced EHF
10 kW

ESEX Arcjet
26 kW

- Thruster Technologies have been Demonstrated
- Available Power for EP is Increasing

Approved for Public Release, Distribution Unlimited

7

Credit: Joseph Cassady, Aerojet, 2010

Solar Electric Propulsion (SEP)

Based on current technology: 50 mN/kW

Example:

SEP: **150 kW**, Isp = 3000 s, T = 7.5 N, Fuel mass one year: **8.0 tons**

2008 VM (3 m) Mass: **41 tons**

Acceleration: 1.82 x 10^{-4} m/s^2
DeltaV after one year: **5772.7 m/s**

2000 LG6 (5 m) Mass: 200 tons

Acceleration: 3.75 x 10^{-5} m/s^2
DeltaV after one year: 1183.4 m/s

2007 UN12 (6 m) Mass: 300 tons

Acceleration: 2.50 x 10^{-5} m/s^2
DeltaV after one year: 788.5 m/s

2008 EA9 (10 m) Mass: **1200 tons**

Acceleration: 6.25 x 10^{-6} m/s^2
DeltaV after one year: **197.2 m/s**

Use SEP combined with the Invariant Manifolds (SE and EM)

Solar Electric Propulsion (SEP)

Based on current technology: 50 mN/kW

Example:

SEP: **100 kW**, Isp = 3000 s, T = 5 N, Fuel mass one year: **5.3 tons**

2008 VM (3 m) Mass: **41 tons**

Acceleration: 1.21 x 10^{-4} m/s^2
DeltaV after one year: **3848.5 m/s**

2000 LG6 (5 m) Mass: 200 tons

Acceleration: 2.50 x 10^{-5} m/s^2
DeltaV after one year: 788.9 m/s

2007 UN12 (6 m) Mass: 300 tons

Acceleration: 1.66 x 10^{-5} m/s^2
DeltaV after one year: 525.9 m/s

2008 EA9 (10 m) Mass: **1200 tons**

Acceleration: 4.16 x 10^{-6} m/s^2
DeltaV after one year: **131.5 m/s**

Use SEP combined with the Invariant Manifolds (SE and EM)

Solar Electric Propulsion (SEP)

Based on current technology: 50 mN/kW

Example:

SEP: **50 kW**, Isp = 3000 s, T = 2.5 N, Fuel mass one year: **2.6 tons**

2008 VM (3 m) Mass: **41 tons**

Acceleration: 6.09 x 10^{-5} m/s^2
DeltaV after one year: **1924.2 m/s**

2000 LG6 (5 m) Mass: 200 tons

Acceleration: 1.25 x 10^{-5} m/s^2
DeltaV after one year: 394.4 m/s

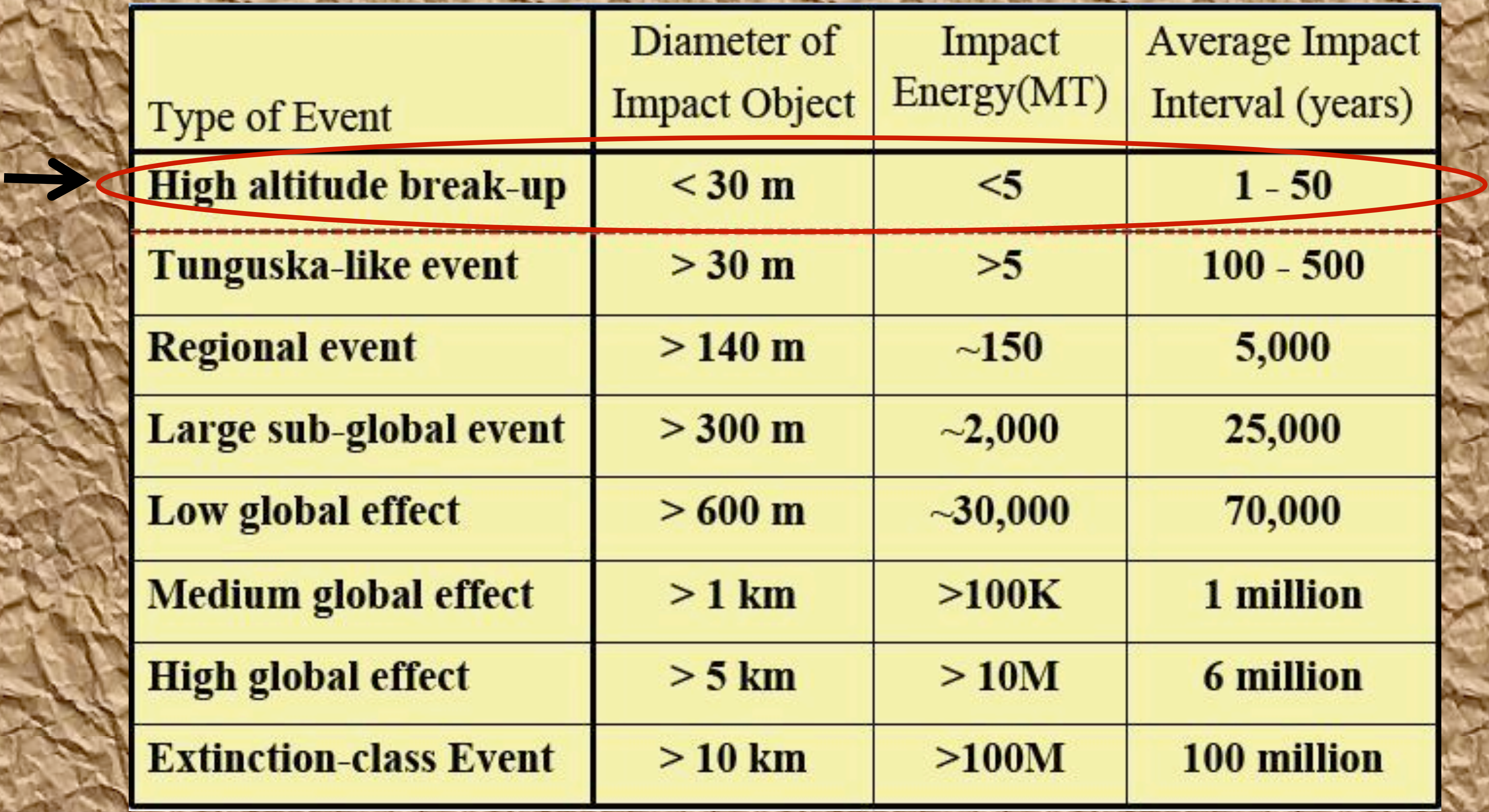
2007 UN12 (6 m) Mass: 300 tons

Acceleration: 8.33 x 10^{-6} m/s^2
DeltaV after one year: 262.9 m/s

2008 EA9 (10 m) Mass: **1200 tons**

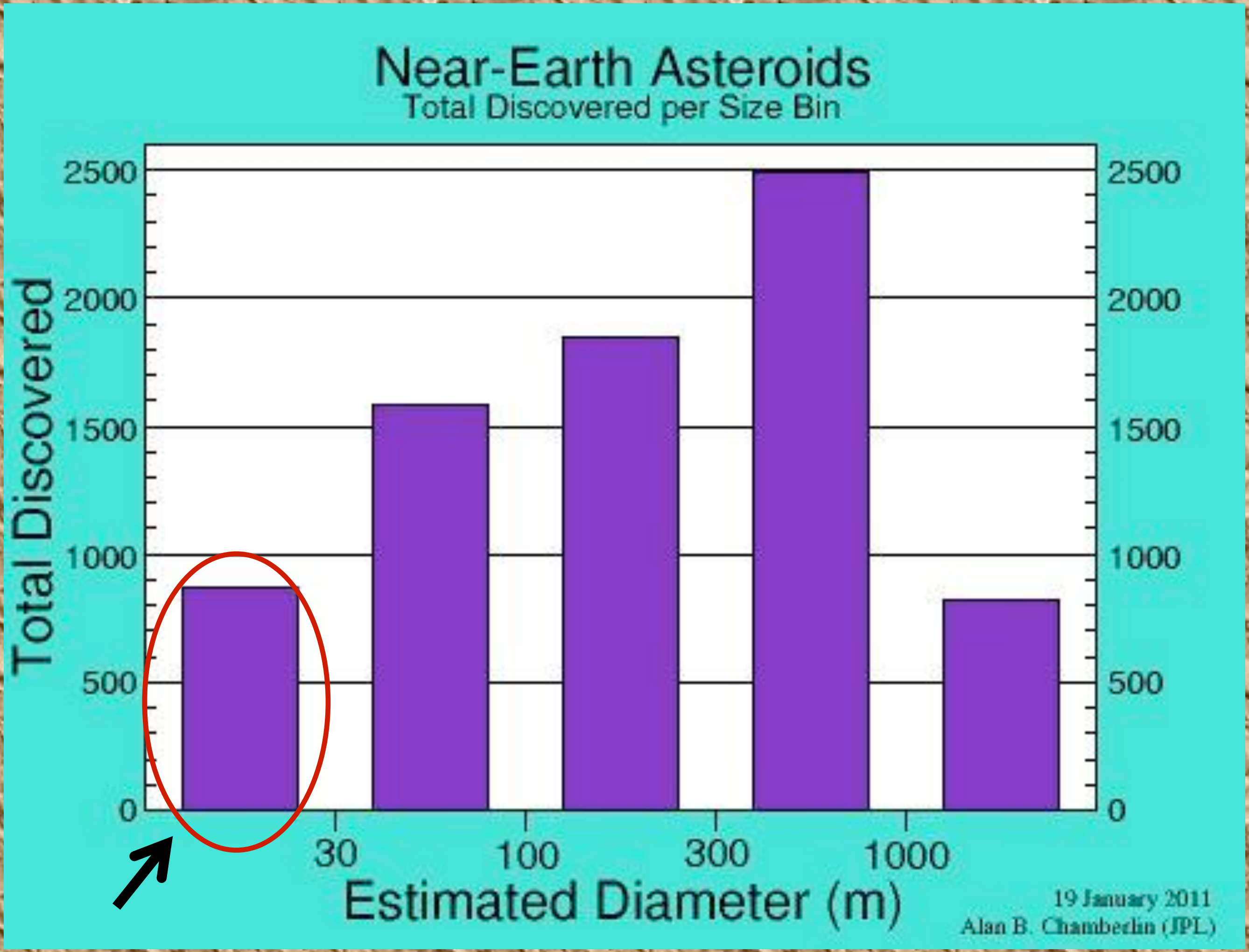
Acceleration: 2.08 x 10^{-6} m/s^2
DeltaV after one year: **65.7 m/s**

Use SEP combined with the Invariant Manifolds (SE and EM)



Type of Event	Diameter of Impact Object	Impact Energy(MT)	Average Impact Interval (years)
High altitude break-up	**< 30 m**	**<5**	**1 - 50**
Tunguska-like event	**> 30 m**	**>5**	**100 - 500**
Regional event	**> 140 m**	**~150**	**5,000**
Large sub-global event	**> 300 m**	**~2,000**	**25,000**
Low global effect	**> 600 m**	**~30,000**	**70,000**
Medium global effect	**> 1 km**	**>100K**	**1 million**
High global effect	**> 5 km**	**> 10M**	**6 million**
Extinction-class Event	**> 10 km**	**>100M**	**100 million**

Credit: Lindley Johnson, NASA HQ, 2010



Credit: Alan B. Chamberlin, NASA JPL, 19 January 2011

SISYPHUS VICTORIOUS FLEXIBLE APPROACH: SV is a robotic mission!

Planetary defense and human exploration through milestones (2015-2025)

(1) Robotic mission to a < 10 m NEO, tug, SEP + Invariant Manifolds, NEO moved in EM L1/L2, station-keeping performed through SV thrusters.
Milestones: **Planetary defense test, celestial object moved using SEP + natural (low energy) dynamics, station-keeping on a natural object.**

(2) Manned Mission to NEO in EM L1/L2, direct (fast) transfer: 4 days cruise + few hours on the NEO + 4 days cruise back to Earth.
Milestones: **First human mission to a Lagrange point and to a NEO.**

(3) Manned Mission to NEO in EM L1/L2, indirect (long cruise and low energy) transfer: up to 180 days for the mission duration. SV refueled.
Milestones: **Long cruise test in a safe environment (in case of main failure, astronauts can be taken back to Earth in a few days), first low energy transfer trajectory for a manned mission, spacecraft refueled in-space.**

(4) SV-NEO moved from EM L1/L2 to SE L2 through Invariant Manifolds (heteroclinic connections).
Milestones: **Natural object moved from a Lagrange point to a Lagrange point through natural dynamics, station-keeping in SE L2.**

(5) Manned Mission to NEO in SE L2, direct (/indirect: low energy) transfer: 1 month + 1 day + 1 month (/3 months + 1 day + 3 months).
Milestones: **First human mission to SE Lagrange point, first human mission to deep space, technology tested an ready for deeper space.**

Note: for manned missions to NEO, no landing nor docking, but parking the spacecraft near the NEO + EVA: no walk, but terrific science and exploration!

In case of loss of NEO:

- when in EM L1/L2, either to deep space, or hit the Moon
- when in SE L2, either to deep space, or burn into the upper atmosphere (it happens naturally many times every year) → NO DANGER!

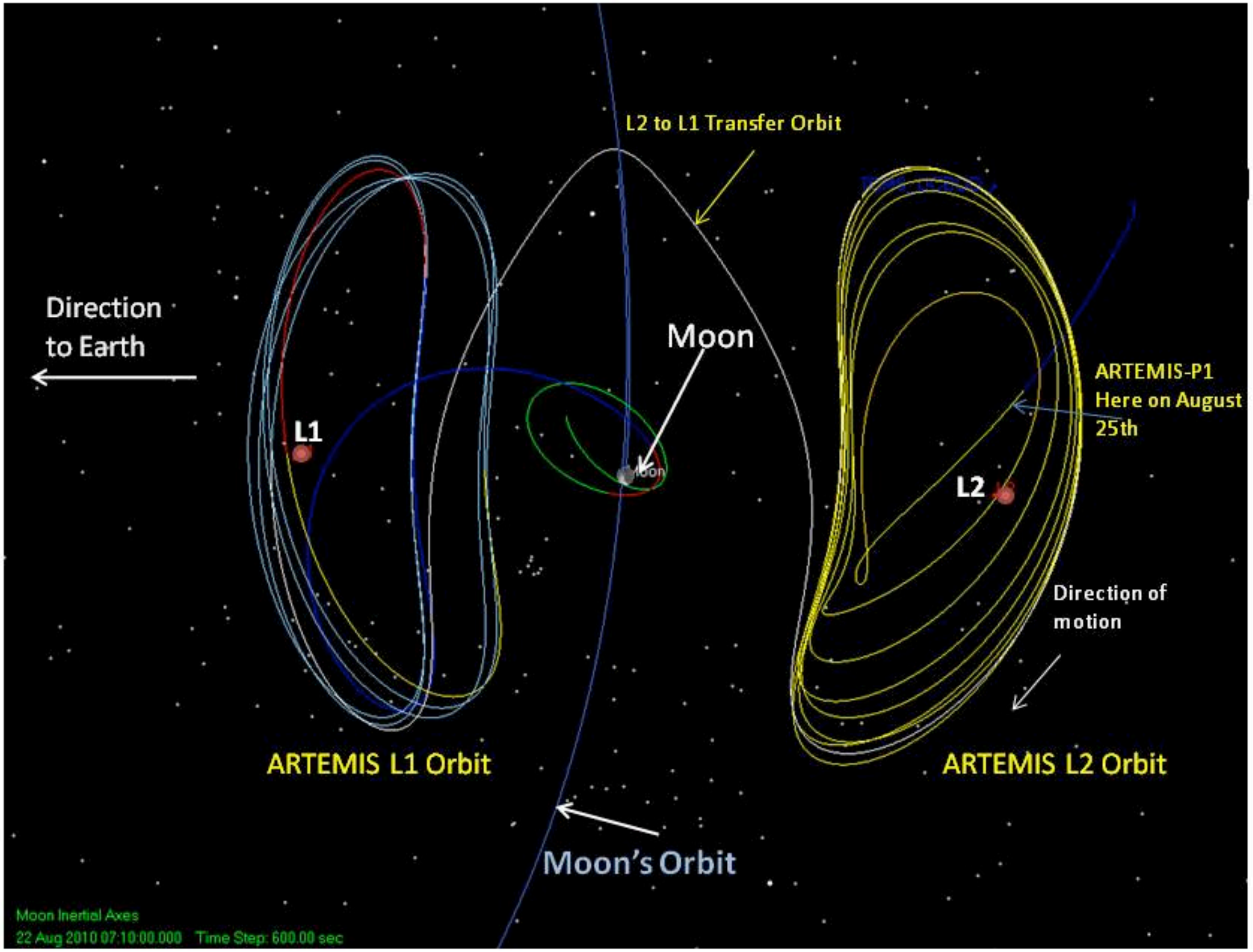
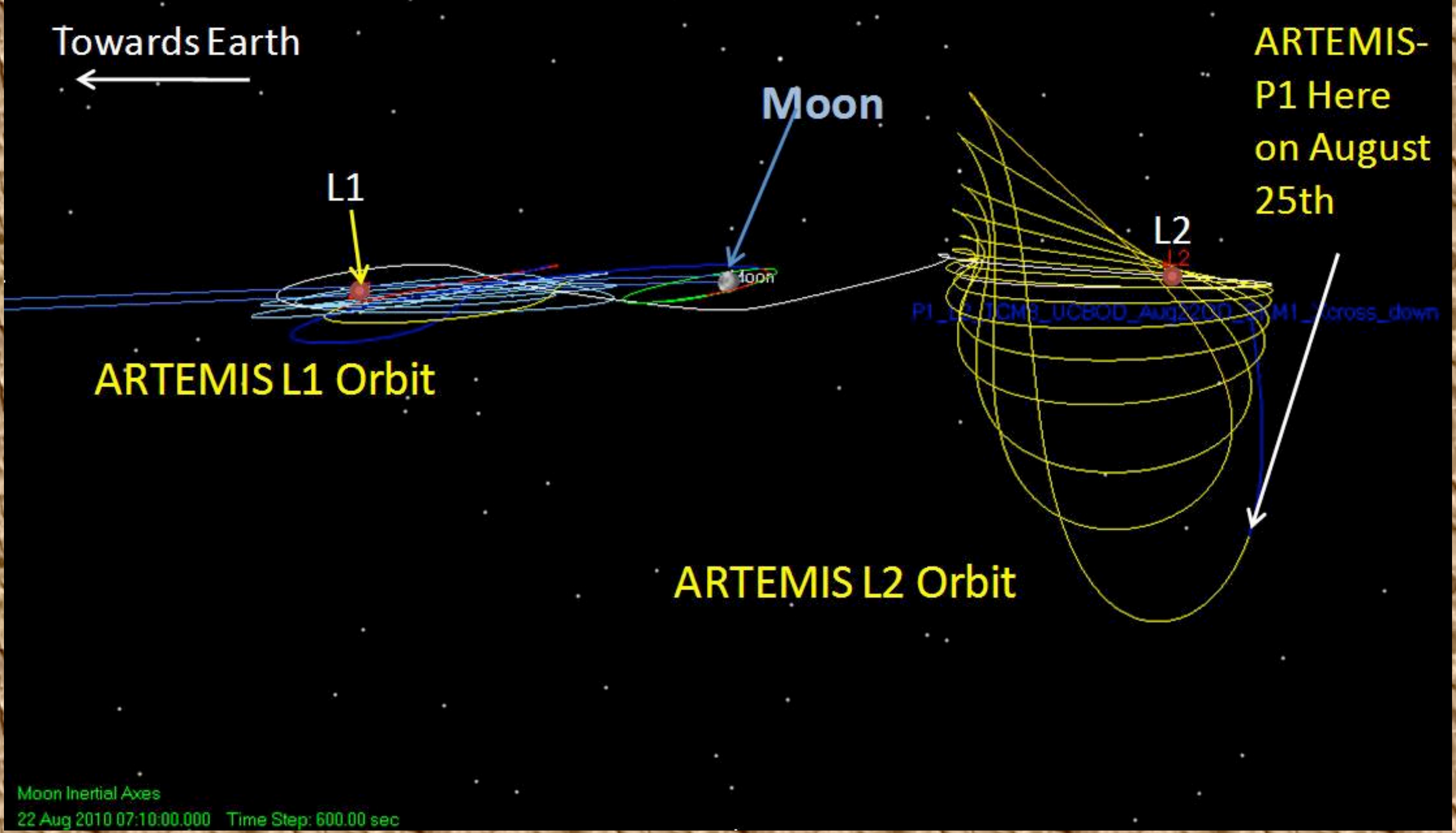


Illustration of ARTEMIS-P1 Librations Orbits Credit: NASA GSFC

ARTEMIS-P1 Spacecraft's Orbit – Side View



Credit: NASA GSFC

SISYPHUS VICTORIOUS

Planetary defense test & human exploration beyond LEO

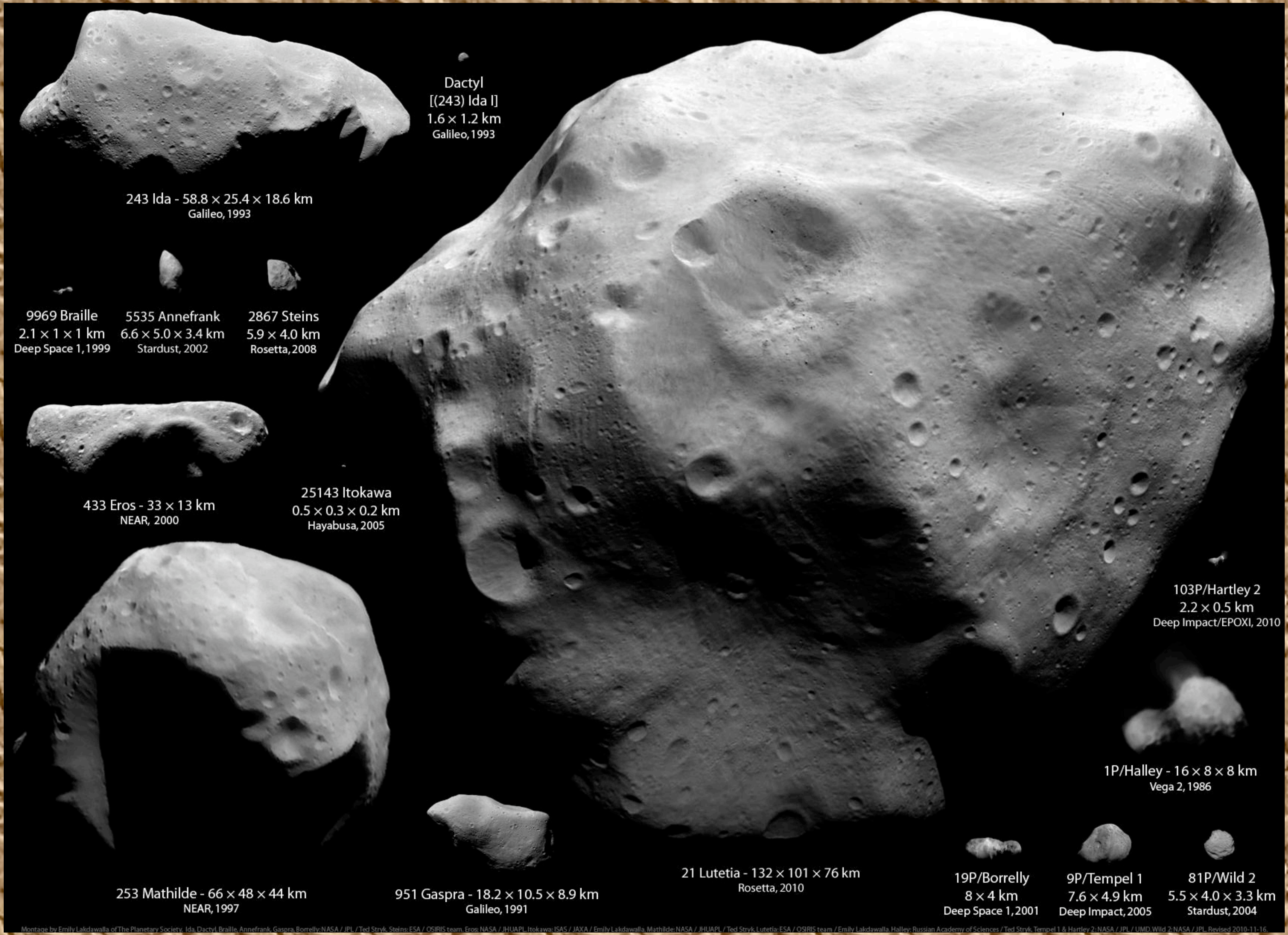
(1b/4b)

- Bring additional NEOs into EM L1/L2 or SE L2. The manned mission could then visit and sample multiple NEOs

- Instead of EM L1/L2, bring the NEO to EM L4/L5: no manifolds, thus parking manoeuvre required, but no station-keeping needed

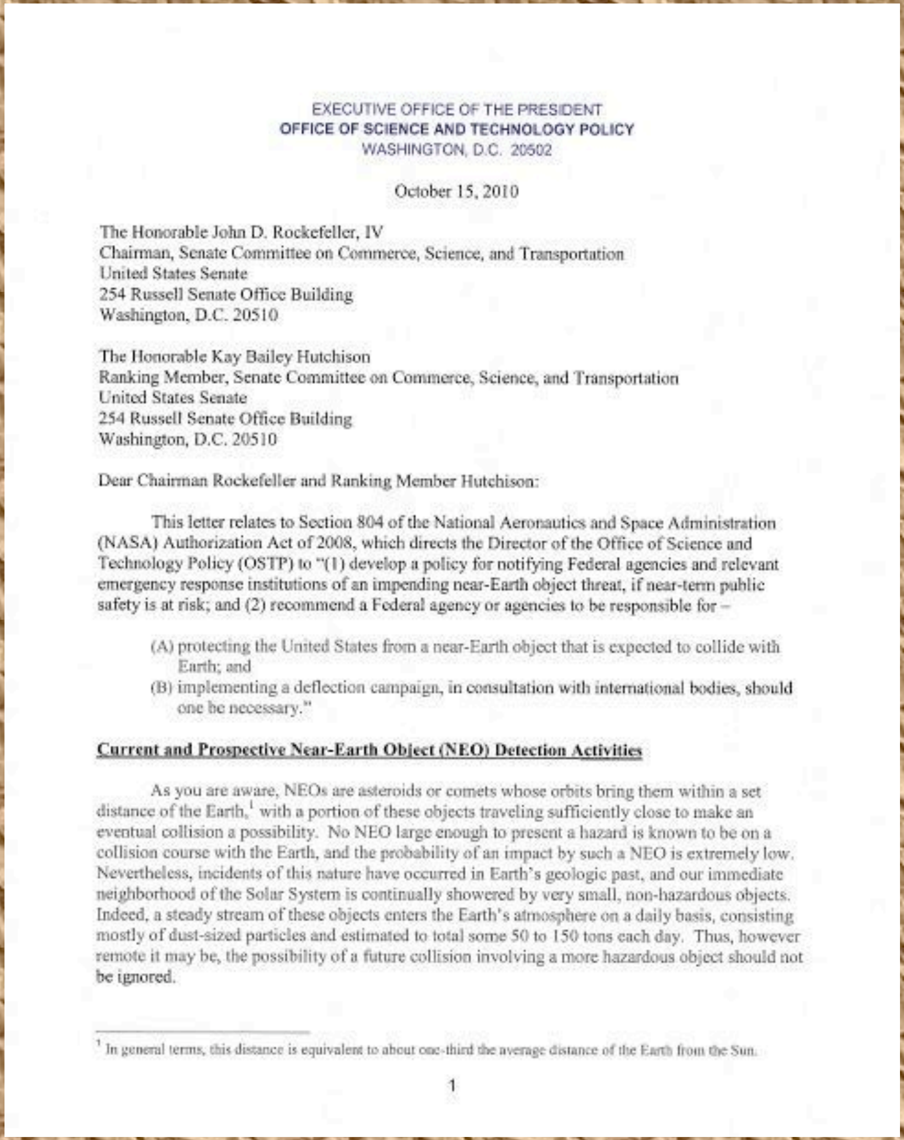
(1c)

- Forget about the Moon and bring the NEO straight to SE L2: indeed, it looks that if you use the invariant manifolds (+SEP), you have to pass first through SE L2 to reach EM L1/L2



Montage by Emily Lakdawalla of The Planetary Society. Ida, Dactyl, Braille, Annefrank, Gaspra, Borrelly: NASA / JPL / Ted Stryk. Steins: ESA / OSIRIS team. Eros: NASA / JHUAPL. Itokawa: ISAS / JAXA / Emily Lakdawalla. Mathilde: NASA / JHUAPL / Ted Stryk. Lutetia: ESA / OSIRIS team / Emily Lakdawalla. Halley: Russian Academy of Sciences / Ted Stryk. Tempel 1 & Hartley 2: NASA / JPL / UMD. Wild 2: NASA / JPL. Revised 2010-11-16.

Credit: Emily Lakdawalla, The Planetary Society, 2010



EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20502

October 15, 2010

The Honorable John D. Rockefeller, IV
Chairman, Senate Committee on Commerce, Science, and Transportation
United States Senate
254 Russell Senate Office Building
Washington, D.C. 20510

The Honorable Kay Bailey Hutchison
Ranking Member, Senate Committee on Commerce, Science, and Transportation
United States Senate
254 Russell Senate Office Building
Washington, D.C. 20510

Dear Chairman Rockefeller and Ranking Member Hutchison:

This letter relates to Section 804 of the National Aeronautics and Space Administration (NASA) Authorization Act of 2008, which directs the Director of the Office of Science and Technology Policy (OSTP) to "(1) develop a policy for notifying Federal agencies and relevant emergency response institutions of an impending near-Earth object threat, if near-term public safety is at risk; and (2) recommend a Federal agency or agencies to be responsible for –

(A) protecting the United States from a near-Earth object that is expected to collide with Earth; and
(B) implementing a deflection campaign, in consultation with international bodies, should one be necessary."

Current and Prospective Near-Earth Object (NEO) Detection Activities

As you are aware, NEOs are asteroids or comets whose orbits bring them within a set distance of the Earth,[1] with a portion of these objects traveling sufficiently close to make an eventual collision a possibility. No NEO large enough to present a hazard is known to be on a collision course with the Earth, and the probability of an impact by such a NEO is extremely low. Nevertheless, incidents of this nature have occurred in Earth's geologic past, and our immediate neighborhood of the Solar System is continually showered by very small, non-hazardous objects. Indeed, a steady stream of these objects enters the Earth's atmosphere on a daily basis, consisting mostly of dust-sized particles and estimated to total some 50 to 150 tons each day. Thus, however remote it may be, the possibility of a future collision involving a more hazardous object should not be ignored.

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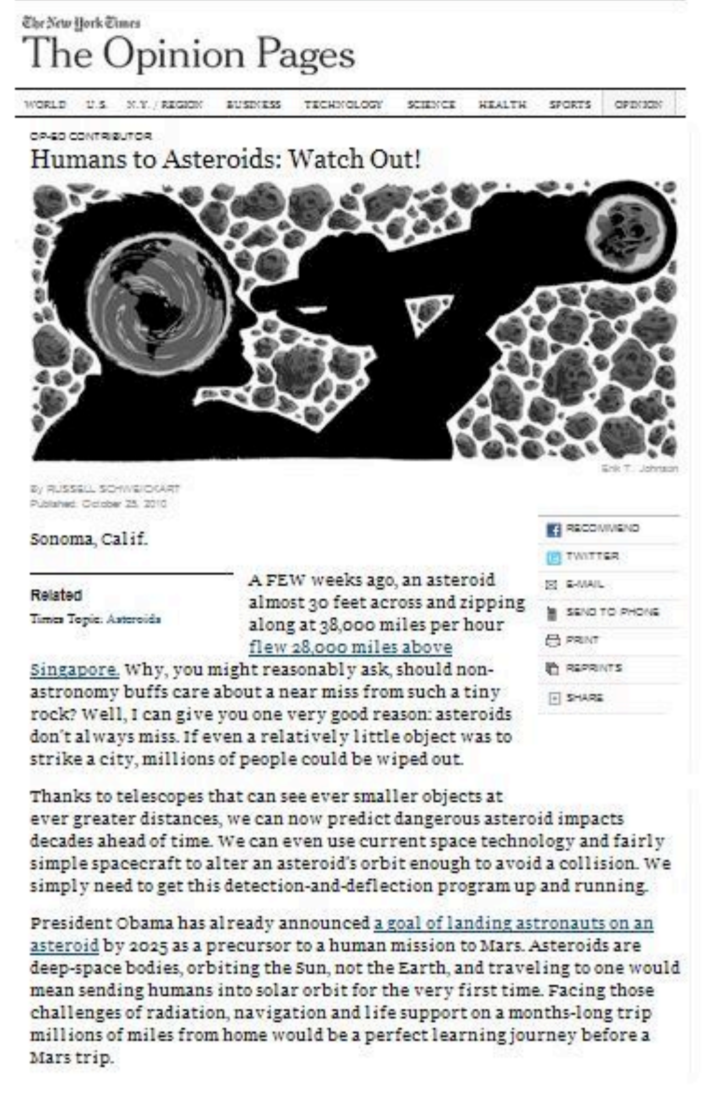
[1] In general terms, this distance is equivalent to about one-third the average distance of the Earth from the Sun.

1

John Holdren, OSTP ,October 15, 2010



The New York Times
The Opinion Pages

OP-ED CONTRIBUTOR

Humans to Asteroids: Watch Out!

Erik T. Johnson

By RUSSELL SCHWEICKART
Published: October 25, 2010

Sonoma, Calif.

Related
Times Topic: Asteroids

A FEW weeks ago, an asteroid almost 30 feet across and zipping along at 38,000 miles per hour flew 28,000 miles above Singapore. Why, you might reasonably ask, should non-astronomy buffs care about a near miss from such a tiny rock? Well, I can give you one very good reason: asteroids don't always miss. If even a relatively little object was to strike a city, millions of people could be wiped out.

Thanks to telescopes that can see ever smaller objects at ever greater distances, we can now predict dangerous asteroid impacts decades ahead of time. We can even use current space technology and fairly simple spacecraft to alter an asteroid's orbit enough to avoid a collision. We simply need to get this detection-and-deflection program up and running.

President Obama has already announced a goal of landing astronauts on an asteroid by 2025 as a precursor to a human mission to Mars. Asteroids are deep-space bodies, orbiting the Sun, not the Earth, and traveling to one would mean sending humans into solar orbit for the very first time. Facing those challenges of radiation, navigation and life support on a months-long trip millions of miles from home would be a perfect learning journey before a Mars trip.

Rusty Schweickart, NYTimes Op-Ed, October 25, 2010

Planetary defense test & human exploration beyond LEO

S.3729 NASA Authorization Act of 2010

(1) The extension of the **human presence** from LEO to other regions of space **beyond LEO** will enable missions to the surface of the **Moon** and missions to deep space destinations such as **near-Earth asteroids** and **Mars**.

(2) The regions of cis-lunar space are accessible to other national and commercial launch capabilities, and such access raises a host of national security concerns and economic implications that international human space endeavors can help to address.

(3) The ability to support human missions in regions beyond low-Earth orbit and on the surface of the Moon can also drive developments in emerging areas of space infrastructure and technology.

(4) Developments in space infrastructure and technology can stimulate and enable increased space applications, such as in-space servicing, propellant resupply and transfer, and in situ resource utilization, and open opportunities for additional users of space, whether national, commercial, or international.

(5) A long term objective for human exploration of space should be the eventual **international** exploration of Mars.

(6) Future international missions beyond LEO should be designed to incorporate capability development and availability, affordability, and international contributions.

(7) Human space flight and future exploration beyond low-Earth orbit should be based around a **pay-as-you-go approach**. Requirements in new launch and crew systems authorized in this Act should be scaled to the minimum necessary to meet the core national mission capability needed to conduct cis-lunar missions. **These initial missions, along with the development of new technologies and in space capabilities can form the foundation for missions to other destinations. These initial missions also should provide operational experience prior to the further human expansion into space**.

Sisyphus Victorious approach is so flexible that it meets also S.3729 framework → higher probability to have NASA support, whatever the next "new direction" is!

Low Thrust trajectory design: approach

2BP
(Sun + NEO)

Initial point: NEO in its natural orbit

Final point: NEO coinciding with Earth

a) Time optimal (thrust always ON)
→ optimize varying departure date, direction of thrust

b) Fuel optimal (Thrust-Coast-Thrust)
→ optimize varying departure date, thrust ON/OFF, direction of thrust, arrival date

Coupled 3BP
(Sun + Earth+ NEO)
(Earth + Moon + NEO)

Initial point: NEO in its natural orbit

Final point: NEO in EM L1/L2 or SE L2

a) Time optimal
there is no time optimal in 3BP: the manifolds are used to save fuel, not to save the time of flight

b) Fuel optimal (Thrust-Coast-Thrust)
→ optimize varying departure date, thrust ON/OFF, direction of thrust, injection point and date on the manifold

Tug options

(1) "Netting"-"hugging" mechanism

(2) Laser drilling:

10 kW, COIL or Fiber laser,
0.85 m/min

SV & NEO one body:

(a) Moving the NEO

(b) Station-keeping (in Earth-Moon L1/L2: ~ 10 m/s per year needed)

(c) Moving NEO from Earth-Moon L1/L2 to Sun-Earth L2 through heteroclinic connections of Invariant Manifolds

SPE International
Society of Petroleum Engineers

SPE 49259

StarWars Laser Technology Applied to Drilling and Completing Gas Wells

R.M. Graves, SPE, Colorado School of Mines; and D.G. O'Brien, PE, SPE, Solutions Engineering

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Abstract

This paper describes results of the first phase of a Gas Research Institute (GRI) funded research program. The overall purpose of this research is to advance a fundamental change in the method currently used to drill and complete natural gas wells applying the U.S. Defense Department's StarWars laser technology. Results of tests conducted at the U.S. Air Force and the U.S. Army's high power laser research facilities are presented.

Initial testing on reservoir rocks conducted with the **M**id **I**nfrared **A**dvanced **C**hemical **L**aser (MIRACL) at the U.S. Army's High Energy Laser Systems Test Facility at White Sands, New Mexico, showed the potential for laser drilling. The laser beam drilled at a speed that indicates penetration could be increased by more than 100 times current rates.

Planned testing for the next phase of this research is to use the **C**hemical **O**xygen-**I**odine **L**aser (COIL) high powered laser invented in 1977 by the U.S. Air Force Research Laboratory in Albuquerque, New Mexico, for air-to-air defense. COIL has gained notoriety as an airborne laser tactical weapon capable of tracking and destroying missiles.

An annotated bibliography was developed for the GRI that comprehensively reviews published laser-rock interaction, current drilling research, and technical data related to laser applications in non-reservoir rocks.[1] Developing commercial applications of StarWars laser technologies has commenced not only in the U.S., but also in Russia and the former Soviet Union.

Introduction

Advances in laser-rock-fluid interactions appear to have been largely ignored in petroleum literature. A search of the SPE Image Library, which contains more than 28,000 papers, listed only two laser references, both of which were more than 25 years old.[2,3] Basic research on high power laser-rock-fluid interactions is being undertaken in order to determine which laser(s) have the required power, portability, reliability, durability, safety and environmental impacts for economically drilling and completing natural gas wells.

Tremendous advances have occurred in laser power generation, efficiency and transmission capabilities that are now being made available for use by the petroleum industry through a U.S. Congressional mandate.[4] The possibility exists to revolutionize drilling for natural gas resources by:

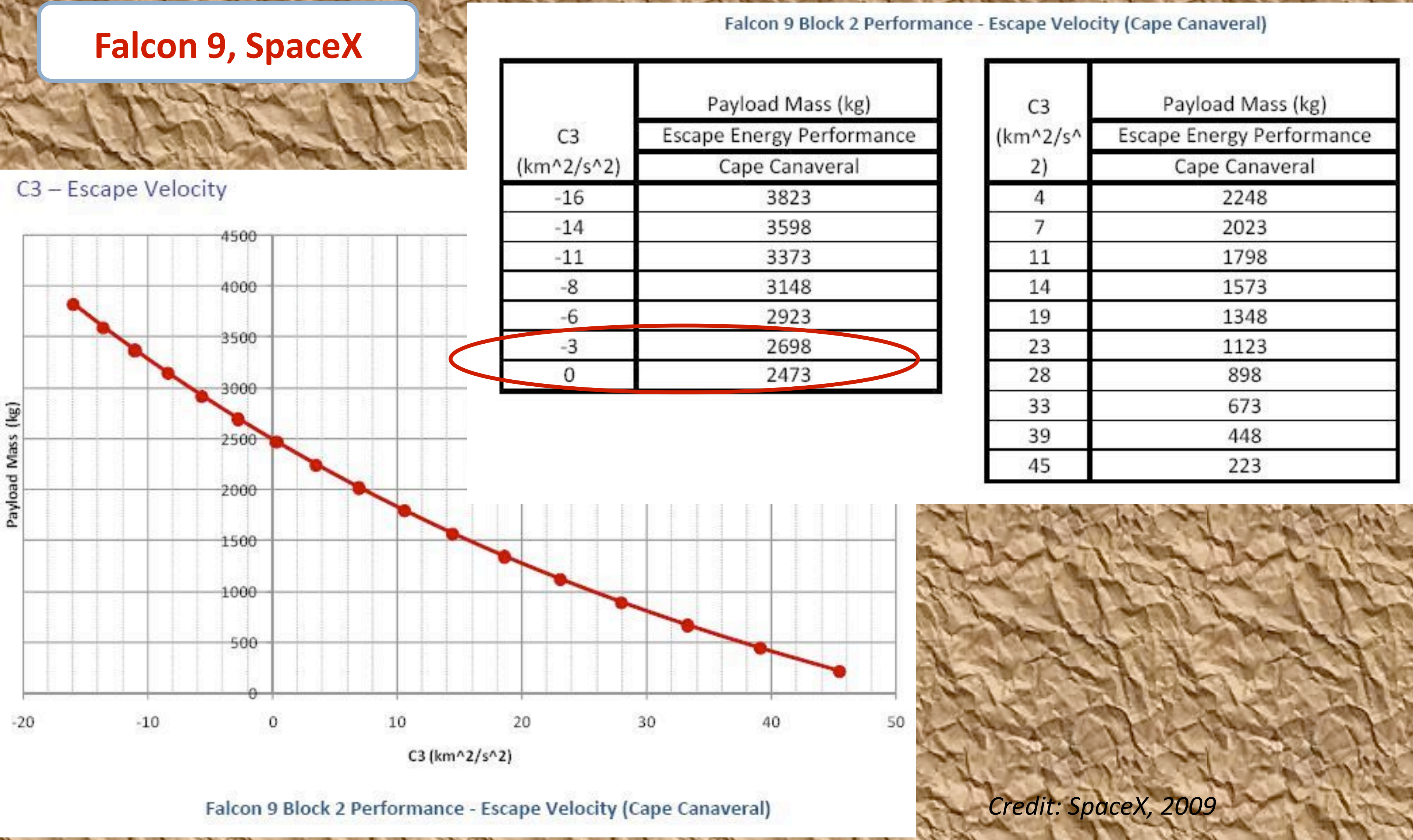
1. Significantly increasing the rate of penetration (ROP)
2. Reducing or eliminating rig day rate, casing requirements, bit life and trip time
3. Providing enhanced well control, perforating and side-tracking capabilities
4. Achieving these breakthroughs with environmentally attractive, safe and cost effective technology.

Laser is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. Albert Einstein[5] predicted stimulated emission (generation of photons or discrete bundles of energy via transition between atomic or molecular energy levels) in 1917 but it wasn't until the early 1960's that the first laser was invented. Lasers are basically devices that convert energy of one form to photons (electromagnetic radiation). For example, chemical lasers convert chemical energy to light energy which can be focused into intense laser beams that can in turn be used to spall (fragment), fuse (melt) or vaporize rock depending on input power.

The dissenting and contradictory views towards laser drilling advocated by some people in the petroleum industry are based on limited laboratory studies and experiments that were conducted over 25 years ago when lasers were in their infancy. These early studies were directed at enhancing tunneling machines used in the mining industry. The lasers used in these studies had very low power (less than a kilowatt), created relatively large wavelengths (therefore were difficult to focus), were incapable of transmitting power to the

761

Falcon 9, SpaceX



Falcon 9 Block 2 Performance - Escape Velocity (Cape Canaveral)

C3 (km^2/s^2)	Payload Mass (kg)
	Escape Energy Performance
	Cape Canaveral
-16	3823
-14	3598
-11	3373
-8	3148
-6	2923
-3	2698
0	2473

C3 (km^2/s^2)	Payload Mass (kg)
	Escape Energy Performance
	Cape Canaveral
4	2248
7	2023
11	1798
14	1573
19	1348
23	1123
28	898
33	673
39	448
45	223

C3 – Escape Velocity

Falcon 9 Block 2 Performance - Escape Velocity (Cape Canaveral)

Credit: SpaceX, 2009

SISYPHUS VICTORIOUS

Planetary defense test & human exploration beyond LEO

Sisyphus Victorious robotic spacecraft can be launched on Falcon 9 Heavy (or another launcher of the same class).

Falcon 9 throw mass to EM L1/L2 – SE L2 is not sufficient to launch a crew mission directly, but Falcon 9 Heavy could throw a Dragon-based system towards EM L1/L2 – SE L2.

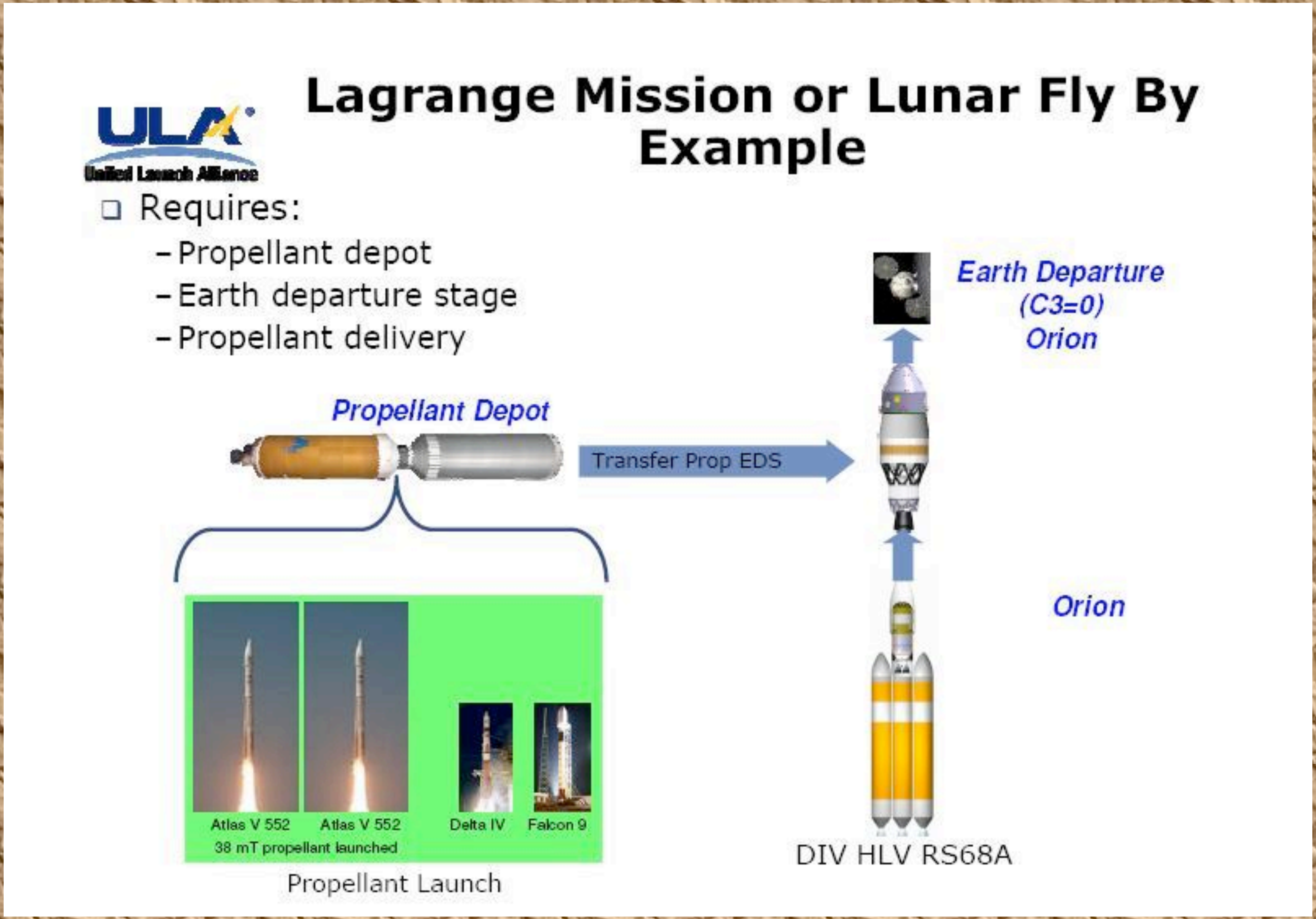
Doing a crew rendezvous in LEO would allow to launch the crew on a likely already human-rated Falcon 9 (non-heavy), rather than potentially having to human-rate the F9H within the scope of this program.

→ In-space propulsion system launched on an F9H prior to the F9 (non-heavy) crew launch; a LEO rendezvous; then injection to EM L1/L2 – SE L2.

Either F9H second stage or the in-space propulsion stage could provide the ~3 km/s transfer orbit injection towards EM L1/L2 – SE L2. The F9H second stage would not provide the ~1 km/s injection into EM L1/L2 – SE L2: the stage lifetime is not that long. Additionally, Dragon-integrated propulsion likely will not be able to provide that much delta-V.

→ In-space propulsion module needed to perform the EM L1/L2 – SE L2 capture burn as well as the Earth-return burn.

Credit: Jamie Hadden, SpaceX, 2010



United Launch Alliance

Lagrange Mission or Lunar Fly By Example

- Requires:
  - Propellant depot
  - Earth departure stage
  - Propellant delivery

Propellant Depot

Transfer Prop EDS

Earth Departure
(C3=0)
Orion

Orion

Atlas V 552 Atlas V 552
38 mT propellant launched

Delta IV Falcon 9

Propellant Launch

DIV HLV RS68A

Credit: Bernard Kutter, ULA, 2010

Differences EM L1/L2 – SE L2 in terms of manned missions from Earth

Earth-Moon L1

ΔV1 = 3.0661 km/s
ΔV2 = 0.8859 km/s
ΔVtot = **3.9520 km/s**
transfer = 3.8543 days

Earth-Moon L2

ΔV1 = 3.0966 km/s
ΔV2 = 0.7819 km/s
ΔVtot = **3.8786 km/s**
transfer = 6.2016 days

Sun-Earth L2

ΔV1 = 3.1537 km/s
ΔV2 = ***0.4666 km/s***
ΔVtot = **3.6203 km/s**
transfer = 37.6611 days

Mission Duration

Earth-Moon L1: ~ 9 days
Earth-Moon L2: ~ 13 days
Sun-Earth L2: **~ 76 days**

Assumption: Hohmann-like transfer from LEO (h = 400 km)

Some things to be addressed during the research program

a) NEO targets: define, list, rank, plan observations (size, composition, spin rate, junk?)

b) Trajectory design: Earth – NEA & s/c+NEA – target destination

c) SV-NEO attitude control and station-keeping

d) Engineering: SEP, spacecraft design, TUG mechanism

e) Experiments to be done once in EM L1/L2 and/or SE L2

a) Study in detail manned missions to EM L1/L2 and SE L2

Work in progress: **Gerard Gómez, Josep J. Masdemont, Yuan Ren, Marco Tantardini**

Strategy to select and move a small NEO from its natural orbit to Sun-Earth L2, matching SEP with Invariant Manifolds.

Step 1) From the Gauss planetary equations, get the optimal direction of thrust that can maximize/minimize "quickly" the semi-major axis, eccentricity or inclination. Keeping these optimal thrust directions, 2BP, and propagating backward from the Earth, get the range of semi-major axis, eccentricity and inclination respectively.

Varying the mass, the ranges of semi-major axis, eccentricity and inclination that can be reached have been computed, propagating for 5/10 years.

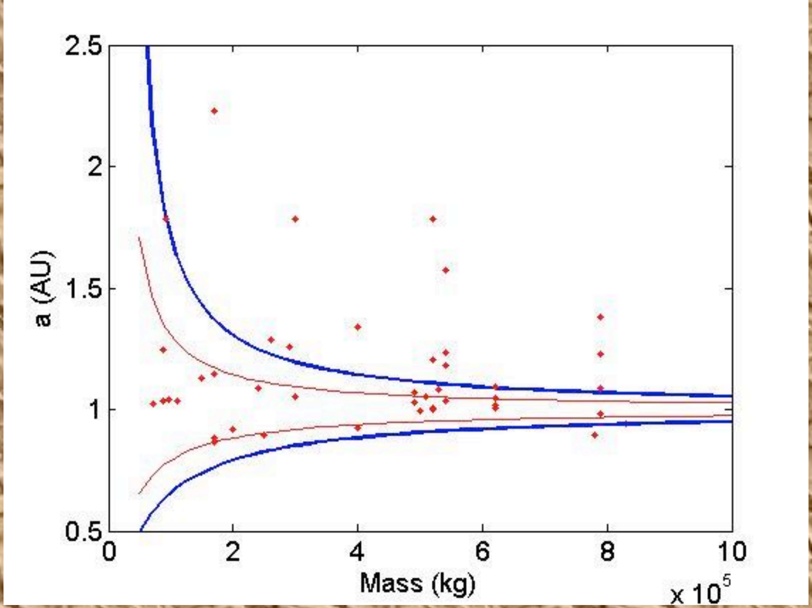
NEOs that satisfy all three constraints can be considered as possible targets to be moved to Sun-Earth L2 with SEP, Isp = 3000 s and T = 2.5 N.

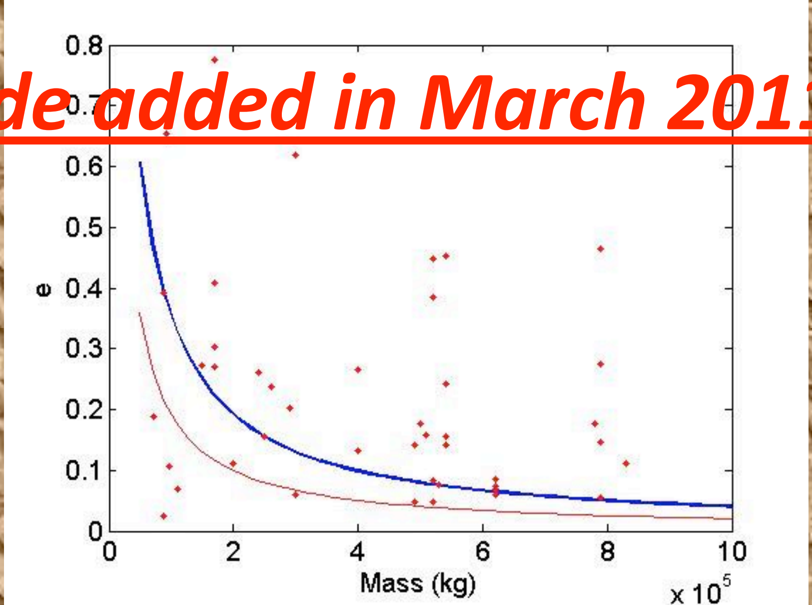
Identify candidates and keep the list up-to-date.

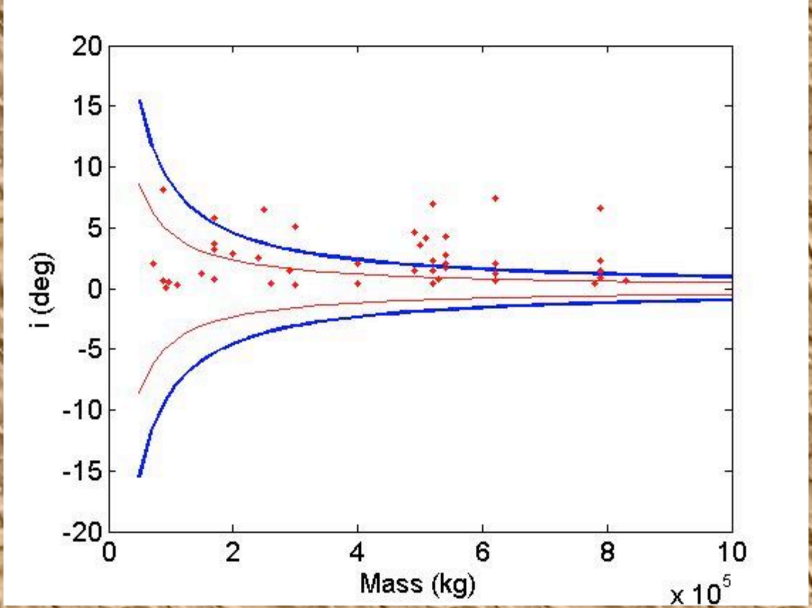
Once few targets are identified, then optimize Earth - NEO leg and NEO - SE L2 leg, looking for windows.

slide added in March 2011

slide added in March 2011







Up to March 25, 2011, we have already found **10** (**5**) small NEOs that could be moved to the vicinity of the Earth in 10 (5) years with SEP, Isp = 3000 s and T = 2.5 N

Pruning from 164 to 10 (5) elements (NASA current framework has only 3 possible NEO targets): more targets will be discovered in the next few years

Good news!

slide added in Feb 2011

Technical Development Solicitation

Full solicitation information

Letters of Intent Due: March 15, 2011

Proposals Due: April 15, 2011

2011 Study Programs Announced

- Asteroid Return Mission Study
- Digging Deeper: Algorithms for Computationally-Limited Searches in Astronomy
- Next Generation UV Instrument Technologies Enabling Missions in Astrophysics, Cosmology and Planetary Sciences
- Monitoring of Geoengineering Effects and their Natural and Anthropogenic Analogues
- xTerramechanics - Integrated Simulation of Planetary Surface Missions

2011 Student-led Mini Programs Announced

- High Altitude Ballooning for Space and Atmospheric Observation
- Caltech Space Challenge

Watch a **video** about the KISS funded research.

Read the article **Quantifying Martian Stratigraphy - Chronology, Composition and Morphology**.

Generously supported by **W.M. Keck Foundation**

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References

(1) Opportunities for Near-Earth Object Exploration, NASA HQ, Lindley Johnson

(2) Falcon 9 Launch Vehicle: Payload User’s Guide, SpaceX

(3) Innovation In-Space Transportation for Servicing Applications, Aerojet, Joseph Cassady

(4) Propellant Depots Made Simple, United Launch Alliance, Bernard Kutter

International collaboration?

Hopefully, more soon...