PI
Terminal Planetary Defense
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arxiv.org/abs/2110.07559
www.scientificamerican.com/article/planetary-defense-is-good-but-is-planetary-offense-better
Terminal Defense Appears Feasible

- Up to 1km class can be mitigated
- Ex: 100m diameter with 1 day prior to impact
- Technique – “slice and dice” – penetrator array
- Conclusion: low residual damage from:
  - Acoustic (Blast Wave)
  - Optical Flash
  - Explored secondary issues such:
    - dust (nuclear winter) – negligible
    - EMP – negligible
- Technology is here now
- US can begin now to develop practical PD
The Problem – Impacts are Real

→ No Current Defense ←

Chelyabinsk, Russia (0.5 Mt)
February 15th, 2013

Tunguska, Russia 3-30 Mt
June 30th, 1908

Asteroid/comet air bursts are similar to nuclear blasts in total energy. Common impact energies are comparable to strategic NED-class nuclear warheads, while less common larger impact energies can exceed significant fractions of the global nuclear arsenal.
Relative threat level per Lifetime

C.R. Chapman & D. Morrison, 1994, Nature 367, 33-40 (roughly all humanity dies every 100 million years)

\[ \frac{10^{10}}{10^8} = 100 \text{ people/yr} = 10^4 \text{ people per human lifetime} \sim 10^{-6} \text{ chance of a person dying per lifetime} \]

- Motor vehicle accident = 1 in 100
- Homicide = 1 in 300
- Fire = 1 in 800
- Firearms accident = 1 in 2,500
- Electrocution = 1 in 5,000
- Passenger aircraft crash = 1 in 20,000
- Flood = 1 in 30,000
- Tornado = 1 in 60,000
- Venomous bite or sting = 1 in 100,000
- **Asteroid/comet impact** = ~1 in 200,000+ (but Episodic!)
- Fireworks accident = 1 in 1 million
- Food poisoning by botulism = 1 in 3 million
- Drinking water EPA limit of tricholoethylene = 1 in 10 million
- Stress from writing proposals = unity
The Scale of the Problem

34,513 Noted Points of impact - Last 4000 years
On a typical non eventful day >100 Tons hits
We Have Yet to Detect Many Threats

A Near-Earth Asteroid Census
Each image represents 100 objects

- Known Asteroids
- New Predicted Total (WISE)
- Old Predicted Total (pre-WISE)

- > 1000 m
- 500–1000 m
- 300–500 m
- 100–300 m
- < 100 m
Recent Hits – From CNEOS Infrasound Data

Large circle is 2013 Chelyabinsk Event (0.5MT)

Approx. 20yrs of data shown
Time Between Asteroid Hit vs Yield (MT)

10 KT event/yr – 1 MT event/lifetime

Near Earth Asteroid (NEA) and Potentially Hazardous Asteroid (PHA) orbits

PHA < 8MKm from Earth
Daily Drive-by Shootings – 100 ton/day
Previous Mitigation Ideas

• “Duck and Cover”
• Impactor to “bump” – change orbit to miss
• Gravity Tractor – change orbit
• Ion deflection – change orbit
• Laser Ablation – change orbit (UCSB)
• NED deflection – change orbit
The Solution \( \pi \) – Pulverize It

- **Accept the hit** – atmosphere is your “bullet proof vest”
  - BUT disassemble to \( \sim 10m \) (or less) diameter fragments
- **Use Earth’s atmosphere to absorb & disperse the energy**
  - Analogous to body armor
- **Use asteroid’s speed** (typ. 20km/s) against itself
- **Place penetrator array** “in front of asteroid”
- **Penetrators disassemble asteroid** (typ. 20km/s)
- **Temporally de-correlate acoustic blast waves**
  - Fragments are typ. <10m diameter
  - **SUM of fragment blast waves do little harm**
  - **SUM of fragment optical pulses do little harm**
The Solution

Kinetic impactor array “slices and dices” target. Earth’s atmosphere is our body armor – absorbs fragments. Spatially distribute energy to de-correlate blast waves.

(1) Launch vehicle carries compact penetrator array to intercept location. Safe intercept times and choice of launch vehicle vary depending on target size.

(2) Penetrator array is deployed and expands into conical distribution. Individual penetrators may be passive kinetic impactors or active explosives.

(3) Target strikes array of penetrators, outer layers of target “peeled” off. Subsequent penetrator waves ultimately reduce target to cloud of <10m fragments.

(4) Fragments enter atmosphere and burst at ~30km altitude. Fragment cloud spatially and temporally distributes energy of impact, which de-correlates blast waves and vastly reduces danger.
The Earth Can Take It
Why This System Works

Single impactor generates extremely large blast wave and optical pulse which causes damage on a vast scale.

VS.

Multiple fragments distribute total impact energy into spatially and temporally decorrelated blast waves which greatly mitigates risk of damage.

Earth’s atmosphere acts as a “bullet proof vest,” while the asteroid disassembly converts a single “bullet” into a “buckshot.”
Two Primary Damage Modes

Air burst – never allow for ground hit

Relevant Asteroid energy is similar to large NED
- 20m Chelyabinsk – 0.5 MT
  • Similar to strategic NED
- 50m Tunguska – 10 MT
  • comparable to largest US NED test

1. Acoustic Signature – blast wave destruction
- Can lead to significant building and personnel effects
- If peak pressure exceeds 10 kPa → residential damage
- Keep peak pressure below 2 kPa to avoid glass damage

2. Optical Signature – combustion concern
- Combustion danger if > 0.2 MJ/m²

B61 thermonuclear bomb, max yield 0.4MT, similar to total energy of Chelyabinsk event.

Building and window damage after Chelyabinsk event.
Two Primary Damage Modes in Air burst
Acoustic and Optical Pulses – Dust is Minimal

1) Optical flash 
2) Acoustic shockwave 
3) Dust production

System is designed to mitigate all of the above.
Why Does This Work – Acoustic de-correlation

Shockwaves from individual fragments arrive at different times for any arbitrary observer due to varying slant distances and differing burst times for each fragment.
Solution – Keep fragments below ~10m to mitigate blast wave damage.

10kPa: wooden frame building damage threshold

1kPa: window damage threshold

Window damage after ~20m meteor air burst over Chelyabinsk, Russia.

KEY: 10m stony asteroid fragments stay below window damage threshold based on data from nuclear tests and small asteroid impacts. Smaller fragments are better if feasible.
Fragmenting to 10m scale results in vastly reduced blast pressure
10m fragment shown – pressures well below window damage threshold can be achieved.
Simulation Logic Diagram

- Threat detection and trajectory analysis
  - Determine parent object parameters
  - Determine optimal intercept parameters
  - Determine fragment properties

- Determine pressure from fragment acoustical pulses
- Determine optical pulse from each fragment

- Peak acoustic pressure < 2 kPa?
  - Total acoustic pressure < 2 kPa?
    - Total optical energy flux < 0.2 MJ/m²?

- Increase $\tau \times v_{avg}$

- Conclude analysis
Summary

- Intercept time vs diam
  - Red dots
- Product of $\tau \cdot v_{\text{disruption}}$ is key metric
  - Can trade $\tau$ and $v_{\text{disruption}}$
  - Allows even fast response IF needed
- 10m/s for 15, 20m 100 s intercept
- 1m/s for 15, 20m 15 min intercept
- 1m/s for all others
- Observer Optical pulse <0.2MJ/m$^2$
  - Orange dots
- Observer Acoustic pulse <1 Kpa
  - Blue dots
- Worst Acoustic pulses under fragments <2 Kpa
  - Magenta dots
- Zero time intercept for 20m
  - 100 sec shown for 15, 20m
  - Zero time works for $\leq$ 20m
  - Burst altitude dispersion with fragment diameter variation allows zero time for $\leq$ 20m
Asteroids CAN be Disassembled

Disassembly energy required is very modest

(left) Asteroid self-disassembly thresholds for various inter-particle cohesion values $c$ and rotational periods $T$.

(left) Image taken by the OSIRIS-REx spacecraft of the loosely bound, rubble pile-like surface of the asteroid Bennu (~500m). (right) Image taken by the Hayabusa spacecraft of a similar composition found on the surface of the asteroid Ryugu (~900m).

Asteroid KE comparison to existing/past NED’s

Even smaller asteroids impact with energies comparable to strategic nuclear weapons.

B61 thermonuclear bomb, max yield 0.4MT.

B83 thermonuclear bomb, max yield 1.2MT.

Falcon 9, ~70m

Starship, ~120m

Tasar Bomba, 50/100MT, largest nuclear weapon ever detonated.

Apophis, 370m

4GT, ½ world arsenal
Response times can be remarkably short
Intercept Distance vs Time – Zero Time Intercept Possible for \( \leq 20\) m Diameter

Intercept Distance vs Time Prior to Impact

**Lunar Distances (LD)**

- \(10^0\)
- \(10^1\)
- \(10^2\)
- \(10^3\)

**Intercept Time Prior to Impact (days)**

- \(10\)
- \(100\)
- \(1000\)

Mean Lunar Distance = 380,000 km

\(1\) AU = 1.5\times10^8\) km

**GEO**

(~36,000 km)

**LEO**

**MEO**

**HEO**

**Lunar Distance**

(1 LD \(\approx\) 380,000 km)

- 15m
- 20m

100s intercept possible!
Short Term Response Scenarios

• 20m (0.5 MT) – fragment into 20 pieces
  – 1-10m/s disruption - ~ 200 kg TNT equivalent KE
  – 1-15 min prior to impact intercept (Inside GEO)!

• 50m (10 MT) – fragment into 100 pieces
  – 1m/s disruption - ~ 30 kg TNT equivalent KE
  – 5 hour prior to impact intercept (One LD~ 10xGEO)

• 100m (100 MT) – fragment into 1000 pieces
  – 1m/s disruption - ~ 250 kg TNT equivalent KE
  – 1 day prior to impact intercept (3x LD)

• Apophis 370m (4 GT) – fragment into 30000 pieces
  – >1/2 World arsenal
  – 1m/s disruption - ~ 10 ton TNT equivalent KE
  – 10 day prior to impact intercept (30x LD)
# Short Term Response Scenarios

Note that Penetrator KE is energy NOT mass

20 km/s asteroid $\rightarrow$ 1 t penetrator mass $\sim$ 50t TNT

All building blocks exist already – no miracles required.

Starship, $\sim$120m

Falcon 9, $\sim$70m

<table>
<thead>
<tr>
<th>Target size</th>
<th>20m</th>
<th>50m</th>
<th>100m</th>
<th>Apophis (370m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetrator KE (kg TNT*)</td>
<td>200 (4 kg mass) (for 10m/s disruption)</td>
<td>30 (&lt;1 kg mass) (for 1m/s disruption)</td>
<td>250 (5 kg mass) (for 1m/s disruption)</td>
<td>10,000 (200 kg mass) (for 1m/s disruption)</td>
</tr>
<tr>
<td>Intercept time</td>
<td>&lt;15 minutes</td>
<td>5 hours</td>
<td>1 day</td>
<td>10 days</td>
</tr>
<tr>
<td>Capable launch vehicles (conservative)</td>
<td>ICBM interceptor New small booster</td>
<td>New small booster Falcon 9 Delta IV SLS</td>
<td>New small booster Falcon 9 Starship SLS</td>
<td>Starship SLS</td>
</tr>
</tbody>
</table>

*Minimum equivalent mass TNT required for disassembly $\rightarrow$ 1 t penetrator mass $\sim$ 50 t TNT @ 20km/s asteroid

Depending on coupling efficiency the interceptor could be very small in all cases shown
### Solid Booster- Minuteman III- Interceptor

3rd stage removed

Lunar, GEO, MEO, LEO Basing Option

<table>
<thead>
<tr>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Payload(kg)</th>
<th>Stage 1 Delta_v (km/s) vs payload</th>
<th>Stage 2 Delta_v (km/s)</th>
<th>Total delta_v (km/s) No grav vs payload</th>
<th>C₃ (km/s)² vs payload</th>
<th>Lunar Surface Launch Speed far from Moon w/Earth grav (km/s) vs payload</th>
<th>Earth Geosync Launch Speed far from Earth (km/s) vs payload</th>
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</thead>
<tbody>
<tr>
<td>Thiokol</td>
<td>Aerojet</td>
<td>Thiokol Tu-122 SR19</td>
<td>I₀sp (s)</td>
<td>I₀sp (s)</td>
<td>m_begin (kg)</td>
<td>m_begin (kg)</td>
<td>Thrust 792 kN (sea level)</td>
<td>Burn 60 sec</td>
</tr>
<tr>
<td>262 (vac)</td>
<td>288 (vac)</td>
<td>500</td>
<td>2.92</td>
<td>5.02</td>
<td>7.94</td>
<td>-62.5</td>
<td>7.43</td>
<td>6.64</td>
</tr>
<tr>
<td>237 (sea level)</td>
<td></td>
<td>1000</td>
<td>2.84</td>
<td>4.26</td>
<td>7.10</td>
<td>-75.1</td>
<td>6.53</td>
<td>5.61</td>
</tr>
<tr>
<td>Stage 1 Alpha</td>
<td>Stage 2 Alpha</td>
<td>1500</td>
<td>2.75</td>
<td>3.73</td>
<td>6.49</td>
<td>-83.4</td>
<td>5.86</td>
<td>4.81</td>
</tr>
<tr>
<td>0.099</td>
<td>0.11</td>
<td>2000</td>
<td>2.68</td>
<td>3.33</td>
<td>6.01</td>
<td>-89.3</td>
<td>5.33</td>
<td>4.15</td>
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<tr>
<td>3000</td>
<td></td>
<td></td>
<td>2.54</td>
<td>2.76</td>
<td>5.30</td>
<td>-97.4</td>
<td>4.51</td>
<td>3.03</td>
</tr>
<tr>
<td>Stage 1 m_begin (kg)</td>
<td>Stage 2 m_begin (kg)</td>
<td>4000</td>
<td>2.41</td>
<td>2.36</td>
<td>4.78</td>
<td>-102.6</td>
<td>3.88</td>
<td>1.98</td>
</tr>
<tr>
<td>23077</td>
<td>7032</td>
<td>5000</td>
<td>2.30</td>
<td>2.07</td>
<td>4.38</td>
<td>-106.3</td>
<td>3.37</td>
<td>0.49</td>
</tr>
</tbody>
</table>
Penetrator Mass - KE to Disrupt

The Coupling Efficiency is Important to Understand – Explosive Filled Penetrators May Help

At 20 km/s 1 kg mass penetrator = 48 kg TNT equivalent energy (1 ton mass = 48 t TNT)

Penetrator Mass Required for Disassembly
Includes Grav Binding Energy which is Minimal Here
\( \rho = 2.6 \text{g/cc} \)

Fragment Energy Including Grav Binding
\[ E = \left( \frac{\pi d^3}{6} \right) \cdot \frac{\rho v^2}{2} + 2.19 \times 10^{-11} \rho^2 d^5 \]

Intercept (closing) KE Speed \( v_{\text{int}} \)
\[ E_{\text{imp}} = \frac{mv_{\text{int}}^2}{2} \]
\[ E_{\text{imp}} = E \rightarrow m = E / (v_{\text{int}}^2 / 2) \]
Next Steps Needed

- **Design and Optimize penetrator array/ system** *(AFRL/RW/DOE labs (LANL, LLNL))*
  - Extended hypervelocity (HV) penetrator 4D simulations *(UNM, APL, Ames)*
  - Ground testing of HV penetrator w/wo explosives
    - Low cost – rapid feedback
    - Test against asteroid “mockup” – (concrete + rocks…)
    - Feedback into modeling to validate/ models and 4D super computer simulations
    - Simulation and testing of small explosive penetrators – cluster bomb approach
    - Simulation and testing of surface contact explosives/ “balls” – successive erosion approach

- **Work on spacecraft – interceptor deployment** *(AFRL/RV, SSC/ Development Core)*
  - Trajectory and mission design
  - Explore existing and upcoming booster options – are they sufficient?

- **Ground and space testing on asteroid simulators/ real asteroids** *(US Space Command)*
  - Lots of space opportunities

- **Explore terminal defense small detection/tracking** *(AFRL/RV, MDA, Space Command, USSF (Space Force), NorthCom and StratCom)*
  - Possible lunar synergy
    - Explore lunar based/ component of PD system
    - **Infrared telescope for active and passive detection and tracking**
    - LIDAR – laser based active illumination

- **Explore in space targets for disassembly/ full sys testing** *(Space Command/ NASA)*
Observations suggest that virtually all asteroids larger than 100m in diameter are gravitationally bound.

This offers an opportunity to fabricate loosely bound asteroid simulants to use as targets for prototype penetrators.

Envisioned ground testing program:

- Fabrication of high aspect ratio asteroid simulant targets (ex. 100m x 3m x 3m).
- Rail guns, gas guns, or rockets are viable options for propulsion of penetrator prototypes.
- Terrestrial experiments provide opportunity to explore passive and explosive penetrator designs.

Ground testing is fundamentally limited by atmospheric and propulsive constraints. Penetrator designs informed by ground experiments will require in-situ testing and demonstration, such as during future known asteroid close approaches.
Individual fragment impacts are distributed over large fractions of the Earth’s surface.
Blast Wave Significant but Drops Rapidly with Distance

Chelyabinsk ~ 1 MT NED (at 50% NED yield to shockwave conversion)

Problem: Must Keep Blast Wave Pressure Below 1-2 kPa to avoid glass breakage

1 KT Nuclear Standard Air Blast

\[ p_n = 3.11 \times 10^{11}, \quad p_f = 1.8 \times 10^7, \quad \alpha_n = -2.95, \quad \alpha_f = -1.13 \]

1 KT test data from 0.03 to 8 km distance
Other data from meteor and asteroid air bursts

\[ \eta = \text{distance from 1 kt nuclear blast standard yield} \]
\[ r = \text{distance from yield of energy E generally given in E(kt)} \]
\[ \eta(r) = \text{scaled distance of 1 kt standard for detonation of yield E(kt) = r/r_s}^{3/2} \]
\[ p(r) = p_n \eta(r)^{\alpha_n} + p_f \eta(r)^{\alpha_f} \] (assume power laws)

For arbitrary yield:
\[ p(r) = p_n \left( r/r_s \right)^{3/2} + p_f \left( r/r_s \right)^{1/2} \]
Blast Wave Speed

Shock Start Highly Supersonic Then Rapidly Decay to Near Mach 1

Air Burst
Shock to Sound Speed Ratio vs Slant Distance

\[ p_n = 3.11 \times 10^{11}, \quad p_f = 1.8 \times 10^7, \quad \alpha_n = -2.95, \quad \alpha_f = -1.13 \]
Measured Bolide Optical Signature
~4-15% of Blast Energy goes into Optical Pulse

Bolide Emitted Optical Power and Energy
June 6, 2002 event - estimated bolide total energy 26 kt

Problem: Must Keep Optical Flash Below 0.2 MJ/m²
Acoustic Signature

Even in extremely short-term interdiction scenarios, few fragments cause any window damage.

20m (15min@1m/s or 100s@10m/s disruption)

Window damage after ~20m meteor air burst over Chelyabinsk, Russia.

In either case, very few fragments create blast waves with pressures great enough to damage windows. Further confidence can be gained by ensuring that no fragments are larger than 10m.
Two Examples – Acoustic Signature
100m (1 day) and Apophis (10 day)

Blast Wave Peak Pressure vs Arrival Time
100K sec (1.2 day) Intercept Time, 100m Parent Asteroid
20 km/s-2.6 g/cc -1m/s Disruption-100km radius ring
$\sigma_{\text{diam}} = 10\text{m}$, $\sigma_{\text{rad-v}} = 0.3\text{m/s}$, $\sigma_{\text{long-v}} = 0.3\text{m/s}$, $\sigma_{\text{rho}} = 0.3\text{g/cc}$
1000 Fragments-Observer at x=100km, y=0
Observer right under ring edge (worst position)

Apophis - Blast Wave Peak Pressure vs Arrival Time
10 Day Intercept Time, 370m Parent Asteroid
4.1 GT exo-atmosphere impact energy - Approx world nuclear arsenal
20 km/s-2.6 g/cc -1m/s Disruption
30000 Fragments (12m ave diam) -Observer at x=1000km, y=0
Observer Right Under Fragment Ring (worst place)
Blast Waves Rarely Correlate Due to Long Travel Time

100m (1 day) Blast Wave De-Correlation

Blast Wave Pressure vs Time

- 100K sec Intercept Time, 100m Parent Asteroid
- 20 km/s-2.6 g/cc -1m/s Disruption-100km radius ring
- 1000 Fragments-Observer at x=100km, y=0
  Observer right under ring edge

\[ P(t) = P_0 e^{-\frac{t}{t_1}}(1 - \frac{t}{t_1}) \]

- \( P_0 \): peak over pressure at \( t=\)initial arrival time
- \( t_1 \): time when crosses zero \( P(t_1) = 0 \) (ambient)
- \( t_1 = 1 \) sec here
Fragmentation Design so that Optical Pulse Will Not Causes Fires

(forest, building, not even paper)

Advise to stay indoors or wear dark glasses

Optical Signature

100m (1 day) and Apophis (10 day)

Keep observer optical energy below 0.2 MJ/m² to avoid combustion

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Observer Fragment Optical Energy Flux vs θ, φ
1 day Intercept Time, 100m Parent Asteroid
20 km/s-2.6 g/cc -1m/s Disruption
σ_diam=4m, σ_rad=0.3m/s, σ_long=0.3m/s, σ_rot=0.3g/cc
1000 Fragments-Observer at x=0, y=0
Atmos Included-Observer in center of ring - 600 km horizon range cut

Integrated Optical Energy Flux at Obs (No proj)= 0.04 MJ/m²@10% Blast Conversion

Observer Fragment Optical Energy Flux vs θ, φ
10 day Intercept Time, Apophis
20 km/s-2.6 g/cc -1m/s Disruption
σ_diam=4m, σ_rad=0.3m/s, σ_long=0.3m/s, σ_rot=0.3g/cc
30,000 Fragments-Observer at x=1000km, y=0
Atmos Included-Observer right under ring - 600 km horizon range cut

Integrated Optical Energy Flux at Obs (No proj)= 51 KJ/m²@10% Blast Conversion
Dust production from air burst events
Comparison to volcanic dust production

Mt. St. Helens eruption
May 19th, 1980
Approximately 540 million metric tons of ash and dust were released into the atmosphere.

Krakatoa eruption
May 20th, 1883
Approximately 45 km$^3$ (~100 billion metric tons at 3 g/cm$^3$) of volcanic ash released into atmosphere.

Worst case scenario: Apophis (370m) intercept results in its entire volume, ~0.026 km$^3$, being converted to atmospheric dust upon air bursting. For a density of 2.6 g/cm$^3$, this amounts to approximately 68 million tons of material, only 0.1% the mass of material released by Krakatoa and 13% of the Mt. St. Helens eruption.

Conclusion: even in cases where the entirety of the impactor’s mass is converted to atmospheric dust, the amount of dust produced by air burst events is small compared to that produced by volcanic eruptions.
Electromagnetic Pulse (EMP)

High altitude detonation of nuclear devices are known to sometimes cause severe electromagnetic signatures known as EMP’s, some of which can be strong enough to disrupt communications and power systems.

Since asteroid air bursts do not possess a radiative component (i.e. they do not produce high energy photons like a nuclear device), they will not produce “classic” EMP’s as illustrated below.

However, the air around the object is ionized during atmospheric entry before the air burst, which can produce small EM effects similar to lightning. Since these effects are not coherent, unlike the case for a nuclear device. No EMP damage is expected from fragmented bodies.
Proposed Apophis Intercept Demonstration Mission (2029/2036)

370m asteroid, avg. orbital speed 30km/s.

April 13th, 2029: Apophis extremely close approach, within GEO orbits.
March 27th, 2036: Apophis close approach, ~0.3AU.

Instrumented kinetic penetrator experiment (single or set of multiple penetrators) to study asteroid interior composition, inform penetrator design, and demonstrate payload delivery to desired depth.

Additional future close approaches in 2051 and 2066 offer potential opportunities to mitigate threat entirely by pro-actively destroying the asteroid.

Apophis orbit around Sun and 2029 close approach.

Apophis 2029 close approach relative to Earth-Moon plane.

[Images of Apophis orbit and close approach]

Data source: HORIZONS System, JPL, NASA

https://en.wikipedia.org/wiki/99942_Apophis
Conclusions

• New mitigation approach makes planetary defense feasible
• General purpose but also allow very rapid response if needed
• No technological “show stoppers” – no miracles needed
• Synergy with current generation of launch vehicles
• Allows for a logical roadmap to a robust PD system
• Proactive vs passive approach to PD
  – Consider mitigating threats before they are a real threat (ex. Apophis)
  – Many threats come close to Earth in orbits prior to impact
• Synergy with long range asteroid detection
• Options for lunar operations, intercept+detection (IR, LIDAR)
• Options for LEO, MEO, GEO deployment
• Long term program with long term consequences