

# ***BALLISTIC MISSILE DEFENSE IN AN IDEAL WORLD***

Presented at the Washington DC joint *Marshall Institute – American Foreign Policy Council* Missile Defense Roundtable by *Dr. Lowell Wood* (University of California Lawrence Livermore National Laboratory and Hoover Institution, Stanford University); 13 July 2005.

Opinions expressed are those of the author only.





# PROLOGUE: THE PAST

- ◆ 61 years: Nazis militarize space with ~3000 V-2 attacks
- ◆ 22.4 years: Reagan's SDI speech
- ◆ 17 years: Reagan takes *Brilliant Pebble* briefing
  - {17-ε} years: First-ever Republican Presidential veto of a Defense Authorization Act
    - Thereby preserving R&D on space-based missile interceptors
- ◆ 14.5 years: GHW Bush's **State of the Union** speech announces *Global Protection Against Limited Strikes*
- ◆ 14.3 years: *Pebbles* selected as “*most mature...first to deploy*” GPALS Segment by Cheney Defense Secretariat
  - Following 10 months of *ad hoc* POTUS, SecDef,.... reviews
- ◆ 11.4 years: *Clementine* demonstrates all-but-one *Brilliant Pebbles* technologies in deep-space operations; first-ever high-resolution off-planet mapping performed
  - *ASTRID* concurrently demonstrates agile, high mass-fraction rocket propulsion, thus completing all *Pebbles* tech-base demos
- ◆ 6.8 years: *Missile Defense Act of 1998* becomes law
  - Following Rumsfeld I Commission Report and North Korean Taepo Dong II and Iranian Shehab-3 flight-tests
- ◆ 3.6 years: U.S. departure from the ABM Treaty















**The LUNAR MODULE**

The Lunar Module (LM) was the only part of the Apollo spacecraft that landed on the Moon. It was designed to carry two astronauts from the Command Module (CM) to the lunar surface and back. The LM consisted of two main parts: the Descent Stage, which landed on the Moon, and the Ascent Stage, which carried the astronauts back to the CM. The LM was the largest man-made object ever to land on the Moon.

**The LUNAR SURFACE**

The lunar surface is a desolate and rocky landscape. It is covered in craters of various sizes, from small pebbles to large basins. The surface is also covered in a layer of fine dust and regolith. The Apollo 11 mission was the first to land humans on the Moon, and it was the only time that humans have walked on the lunar surface.

**Earth and Moon over the Moon**



**The Moon, Sun, and Planets**



**Earth & Moon**



**View of a Full Earth**



**Albedo Map of the Moon**



**Equator**



**North Pole**



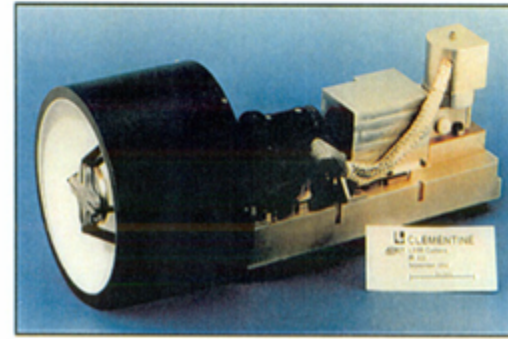
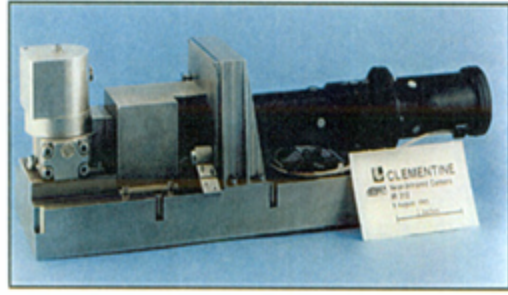
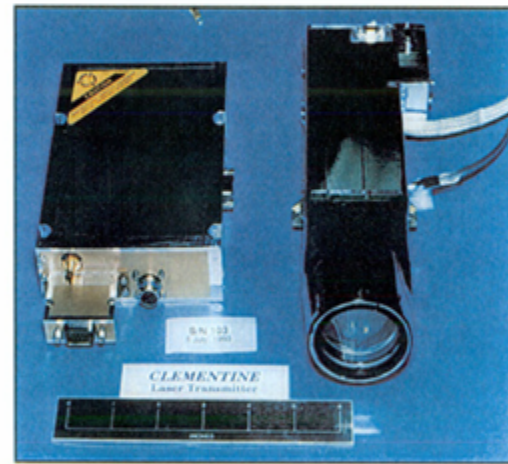
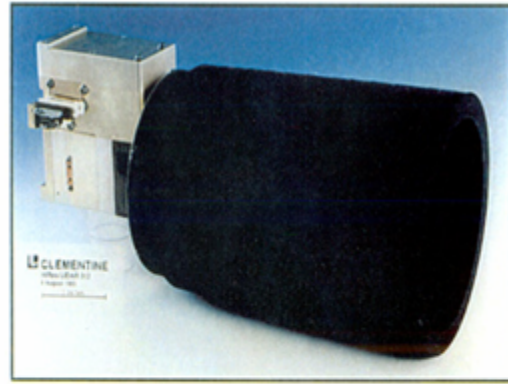
**South Pole**



FOOD SERVICES  
The Wright Place  
McDonald's

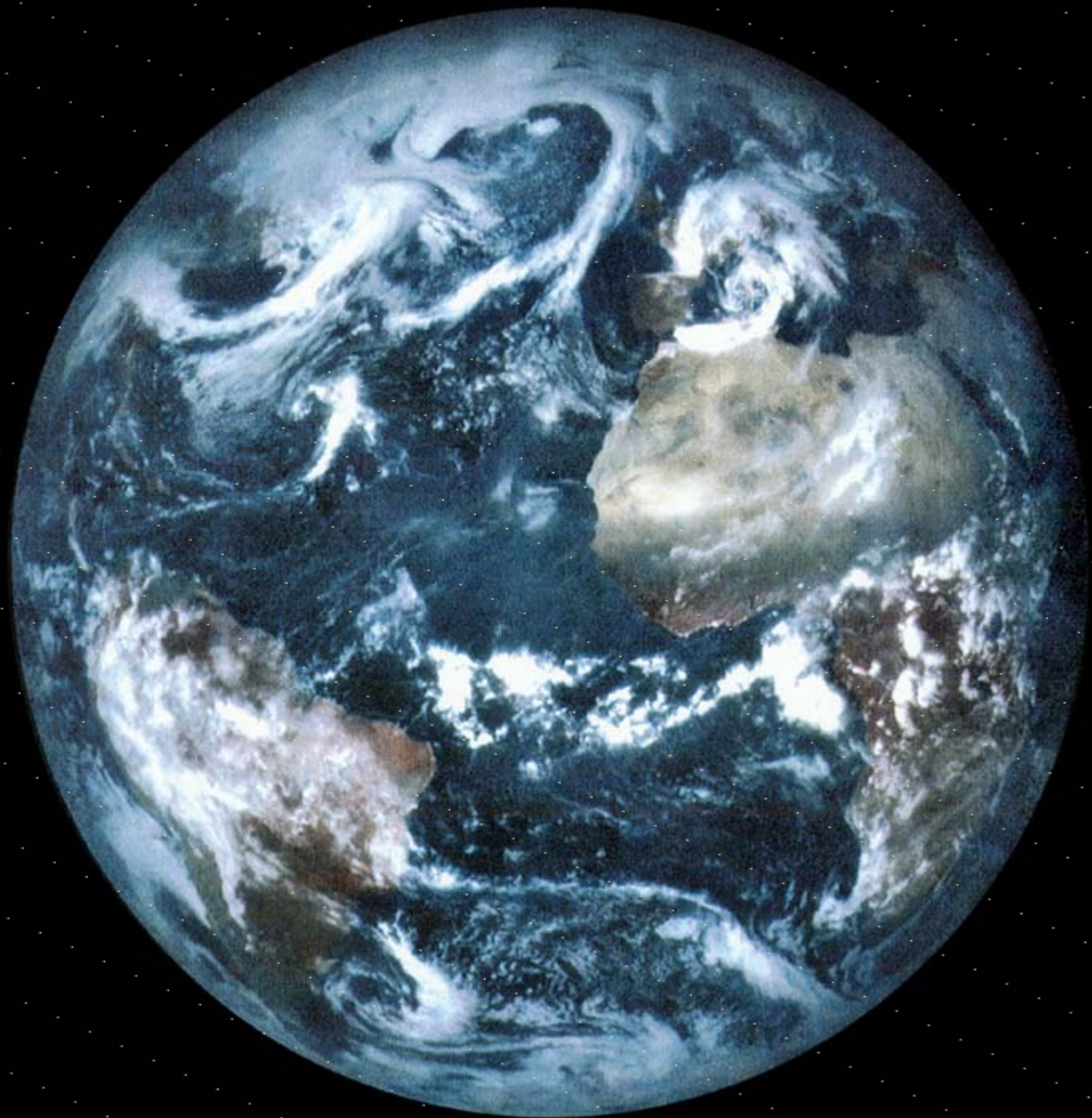


# Clementine Sensor Suite



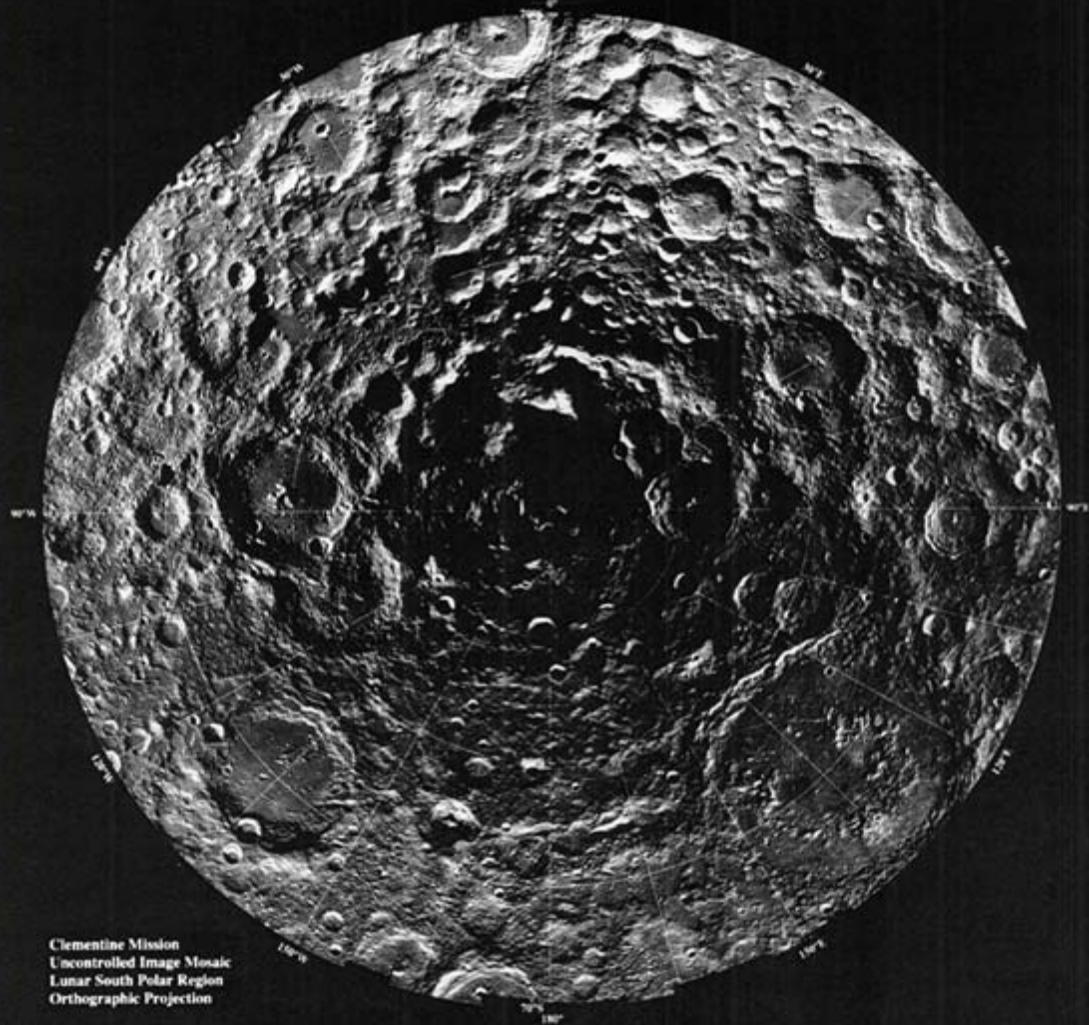
ATP-1293-02475-LDP  
HC.097-01





JE.045-04





Clementine Mission  
Uncontrolled Image Mosaic  
Lunar South Polar Region  
Orthographic Projection





**LLNL's pump-fed hydrazine rocket, ASTRID, ascends the launch rail on February 4, 1994 at Vandenberg. The 4 thrust chambers are glowing but the plume is invisible.**



# LEITMOTIF

*“And there went out a champion out of the camp of the Philistines, named Goliath, of Gath, whose height was six cubits and a span. And he had an helmet of brass upon his head, and he was armed with a coat of mail, and the weight of the coat was five thousand shekels of brass. And he had greaves of brass upon his legs, and a target of brass between his shoulders. And the staff of his spear was like a weaver’s beam; and his spear’s head weighed six hundred shekels of iron; and one bearing a shield went before him.”*

*“And David put his hand in his bag, and took then a stone, and slang it, and smote the Philistine in his forehead, that the stone sunk into his forehead; and he fell upon his face to the earth. So David prevailed over the Philistine with a sling and with a stone, and smote the Philistine, and slew him; but there was no sword in the hand of David.”*

*1 Samuel 17, 4-7; 49-50 (KJV)*

## ◆ **Early instance of highly asymmetric warfare**

- Key role played by novel ballistic missile usage
  - Nothing-to-lose, ‘incredible’ protagonist’s surprise attack “won the day”

## ◆ **Innovation, daring and opportunism enabled a “grossly inferior” player to triumph definitively over “the guy who had everything”**

- Cf. SS-18 (“Satan”) ICBM vs. *Brilliant Pebble*





# WHY WORRY ABOUT DEFENSES AGAINST BALLISTIC MISSILES?

## ◆ An ‘ultimate’ terror-weapon

- “Death falling from the heavens”
  - No-notice “mass destruction from space”
    - From one side of the world to the other in 30-40 minutes: ‘negative perigee’ orbits
  - Seemingly unstoppable – implacable death-from-afar
    - “*Your* life is forever in *my* hands – at a moment’s notice. Never forget it!”
- Pioneered by the Nazis for just such (terrorist-)purposes
  - Nearly 6000 V-2s launched during WWII, most targeted on English cities
    - “...would have prevented the [staging for the] Normandy invasion, if developed a half-year earlier.” – Gen. Dwight Eisenhower
    - A-9 – for attacking New York from Europe – planned for 1947 combat-use

## ◆ “WMD in long-range ballistic missiles is the only thing that can kill the U.S. tonight.” – Gen. Colin Powell

## ◆ ‘Typical’ ICBM packs roughly 1,000 times greater ‘damage expectancy’ than that of a typical “suitcase bomb”

- E.g., CSS-4 at optimum HOB vs. ‘standard’ suitcase-bomb
  - SS-18, ~3.4 times more
- *A priori* estimations-of-relative-likelihoods of unprecedented attacks may represent a classic “Blue-preferred Red threats” syndrome
  - “*My* specialized capabilities as *your* means-of-salvation”





# BASIC FEATURES OF AN IDEAL BALLISTIC MISSILE DEFENSE

## ◆ **The Nitze-Reagan Criteria**

- *Militarily effective* in (all) credible circumstances
  - “Works – against the worst threat that any attacker can pose!”
- *Cost-exchange advantaged* at the margin (in worst case)
  - Defense ‘unit’ always cheaper than the corresponding offense ‘unit’
    - Attacker can’t plausibly “scale his way out” of the defense’s challenge
- *Robust* in (all) plausible military environments
  - Attacker can’t win by “playing dirty” – or “hard”, or “surprise”, ...

## ◆ **Comparable defense extended to friends-&-allies**

- “*A friend in need is a friend indeed!*” vs. “*I’m alright, Jack – too bad about you!*”
  - Alliance-enhancing (vs. alliance-degrading/splitting)

## ◆ **“Firebreak ” for all others e.g., Bush I GPALS**

- E.g., would the U.S. be likely to survive unscathed a Russian-Chinese nuclear exchange?





# DYSFEATURES TO BE ESCHEWED

## ◆ **Attack-saturable defenses**

- Smart attacker builds, masses-in-space, focuses-in-time—classic gambits

## ◆ **“Deployed when-&-where we need them” defenses**

- Illusory – almost never ‘there’ when-&-where you *really* need them
  - Attacker has the keenest motivations to “get to the apple orchard first”
    - ‘Emergency’ deployments as a ‘provocation’? – cf. *Patriots* to S. Korea in ‘94
  - Also, attacks come from ‘odd’ directions against ‘unexpected’ targets
- And what are the BMD analogs of the attacker’s war games?
  - First-time-ever (e.g., defensive) performances are seldom highly competent
  - ‘Practice’ against “Blue-preferred Red threats” usually is self-deceiving

## ◆ **Flimsy-&-readily countermeasured defenses**

- Attacker’s “*qualitative* proliferation” is strongly incentivized

## ◆ **Too-costly defenses**

- Encourages offense to buy more missiles, warheads, penetration-aids, etc.
  - “Perverse incentives” – unit-of-attack becomes ever-cheaper
  - Offense’s geopolitical mind-set becomes ‘poorly’ oriented – e.g., USSR, PRC,...

## ◆ **“We’ll *eventually* grow up to the offense” defenses**

- Essentially never happens – this is the *Real* World!
  - Attacker has *already* fielded his top talent—“low goals” defense will never catch up!
    - Defensive programs can’t enlist top talent to pursue ‘lowbrow’ goals
      - Talent can *smell* seriousness-of-purpose (and the lack thereof)
      - Instead, a “money incinerator” results, e.g., “A’s hire A’s; B’s hire C’s”

## ◆ **I.e., the lessons of the past half-century of BMD efforts**





# MILITARY PRINCIPLES TO BE RECALLED

- ◆ **Attacker's basic advantages**
  - Surprise
  - Mass
  - Choice of place-&-time
- ◆ **Defender's fundamental advantages**
  - Advance preparations and pre-positioning
  - Comparatively short LOCs
  - Battle fought on familiar territory
- ◆ **Defender is “doomed to win” – *unless* very stupid or greatly out-numbered**
  - *Several*-fold quantitative advantage is typically required by offense to likely-prevail
  - Objective lessons of history





# PHYSICAL FACTS TO BE RESPECTED I.

- ◆ **Longer-range ballistic missiles attack from space**
  - “Nitze-Reagan Criteria” defenses will be conducted there
    - ‘Terminal phase’ endo-atmospheric defenses are “goal-line stands”
      - Very costly to conduct over wide areas – especially, *intensively*
        - Defended-area “footprints” are small – and ‘battery’ costs are high
      - “Purchase price” of any defended target is well-known-in-advance
    - Defensive pre-positioning requires assets *there* – pre-attack
      - Early-time defenses impose fundamental uncertainties on attacker
- ◆ **Ballistic missile fly fast – several hundred km/minute**
  - Attack ‘lasts’ 5-30 minutes – 300-1500 seconds – end-to-end
  - Effective defenses will have a highly-automated character
    - All basic decisions must be taken well in advance of any attack
    - “Political consultations” demands come only from ignoramuses
      - Ditto re “military strategy” conferences – illusions of centuries-gone-by
      - ‘Permission to engage’ must come in dozens – not hundreds – of *seconds*
  - “Man-in-the-loop” will be a permission-giving top-level overseer
    - Hordes of joystick-juggling junior officers are “sci-fi fantasies”
      - Never, ever happens, out in the Real World
        - Off-duty, slow, panicked, imprecise, overwhelmed, mistake-prone, ..



# PHYSICAL FACTS TO BE RESPECTED II.

- ◆ **‘Midcourse’ is where *everything* flies ballistically**
  - All objects ‘fly’ *remarkably* similarly to all others
    - Regardless of their particular nature, composition, density, mass, ...
  - Penetration aids – ‘penaids’ – leverage this *ferociously*
    - The offense has only to ‘fool’ once – while the defense has to ‘win’ the very first time that it ever *really* ‘sees’ the offense
      - *Intrinsically* highly asymmetric ‘game’ – with a very predictable outcome
      - Midcourse defenses have been “highly problematic” for 4+ decades
      - Smart guys choose to play for the midcourse *offense*, not the *defense*
  - Offense’s telling advantages of *great distances, high closing-rates, short times-of-engagement, “target-rich environments”* (random crud), *poking-sticks-in-eyes*, etc.
    - A half-century of efforts by tens of thousands of talented folks
  - Only exceptionally ‘robust’ midcourse ways-&-means win at all reliably for the defense
    - I.e., “sky-clearing” technologies – e.g., the Russian approach
- ◆ **Ballistic missiles are *remarkably* delicate objects**
  - E.g., running into a sheet-of-paper in space is ruinous
    - Defensive operations need only be *precise* in order to be effective

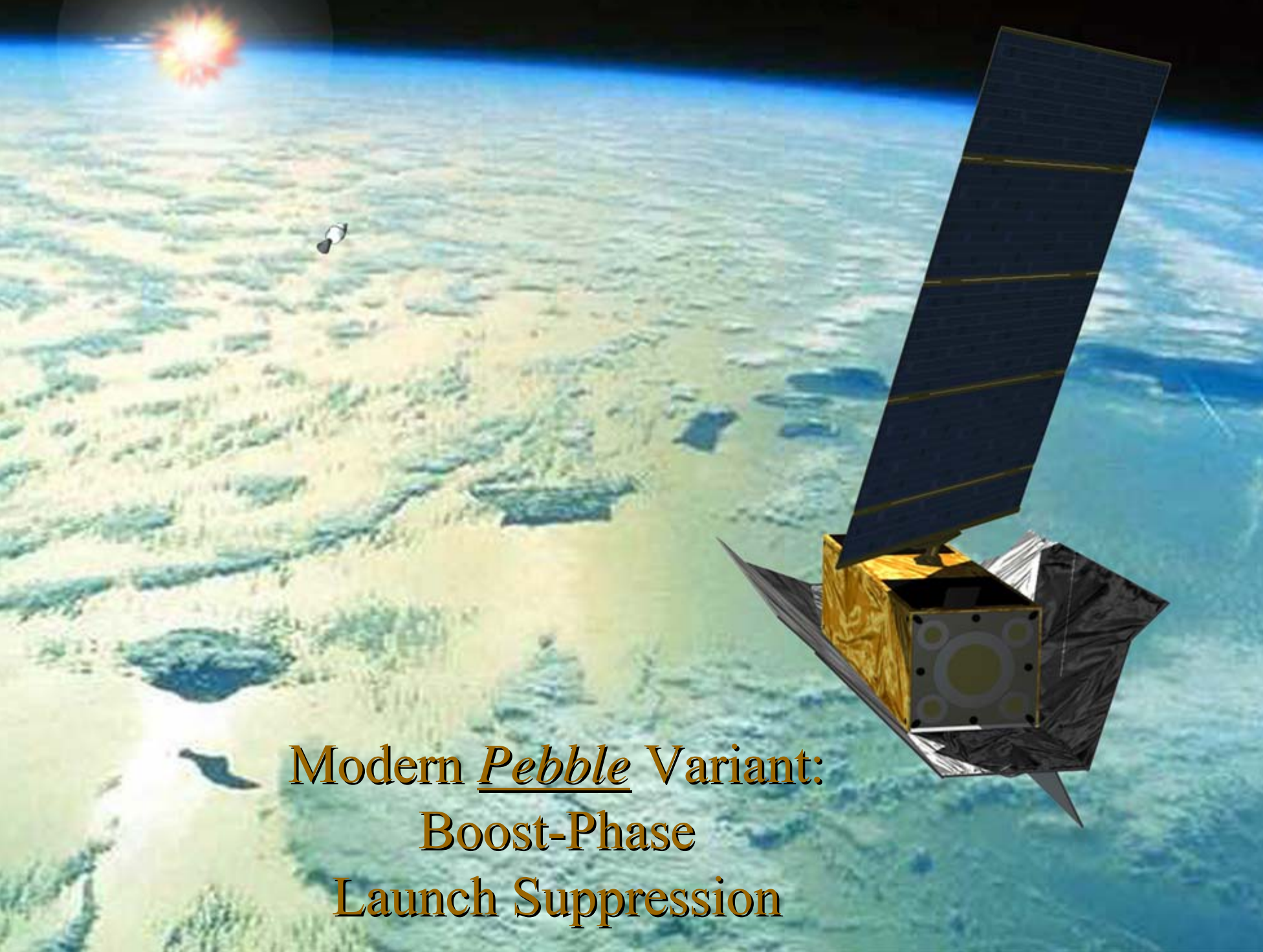
# TECHNOLOGICAL FACTS TO BE RESPECTED

- ◆ **Ballistic missiles represent mature technology**
  - Not qualitatively different from Nazi V-2s: warheads perched on top of big fuel tanks, with rocket engines ‘at the bottom’
    - Nazis built-&-flew more ballistic missiles than everyone else since!
  - Ditto MIRV buses & reentry vehicles: not changed much in 4 decades
- ◆ **‘Serious’ WMD comes packaged in large-ish containers**
  - H-bombs, ‘serious’ bio-agent dispensers, etc.
- ◆ **Inescapable consequence: Longer-range ballistic missiles *invariably* have launch-masses of 20-100 tons**
- ◆ **Ballistic missile defenses can leverage *modern technology-sets***
  - E.g., 1 gram of patterned-silicon suffices for all data-processing and sensor needs of a modern BMD interceptor
    - Brilliant Pebbles-demonstrated; Clementine performance-validated
  - Minimal interceptor masses can be *exceptionally* small
    - ~0.00001 tons of colliding-mass can destroy a ballistic missile, MIRV bus, or warhead in space: *hyper-speed collision physics*
- ◆ **Long-term *intrinsic* advantage goes to the defense**
  - “Small is beautiful” – and is entirely BMD-sufficient
  - Costs-at-the-margin of space systems are always by-the-pound
  - “*Hmm...defensive grams stop offensive tons—is this a trick question?*”



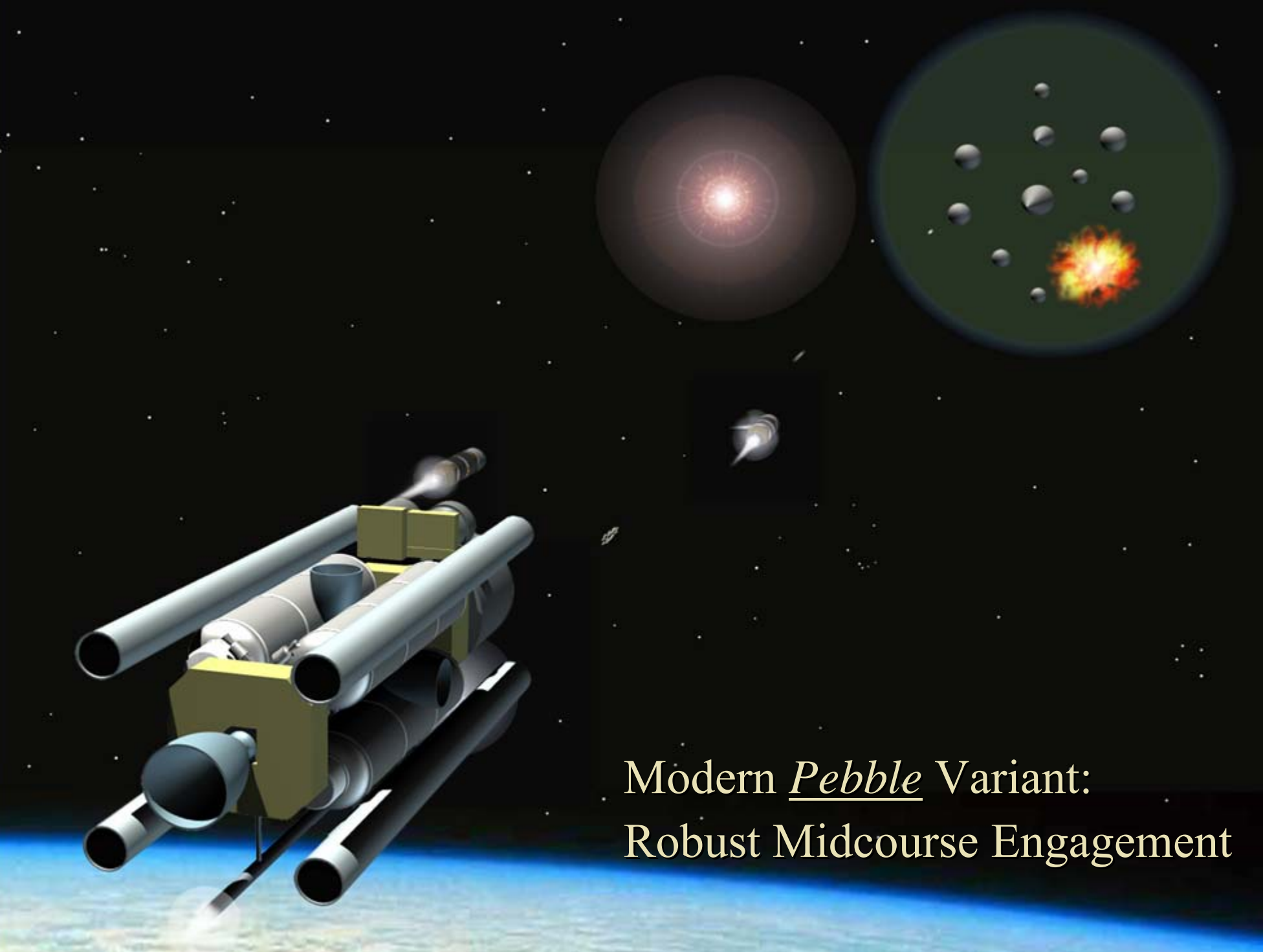
# AND SO??

- ◆ **Do defensive operations primarily in boost-phase**
  - Boosters: self-illuminated, fragile, non-penaid-ed targets...
  - ...coming from more-or-less known launch-locations...
  - ...with very limited maneuverability...
  - ...and relatively few in number – no ‘fractionation’ feasible
  - But ‘absentee-ism’ of defenses is formidable
    - Typically,  $\geq 90\%$  of defensive assets “don’t play” – too far away during a “salvo launch” – though richly available for later taskings
- ◆ **With ‘mopping up’ in post-boost phase defense**
  - Defensive operations against the MIRV-dispensing buses
    - Still good-size, fragile, bright, non-penaided, thruster-marked targets
- ◆ **‘Leisurely’ operations against not-robustly-penaided targets – ‘leakers’ – in midcourse defense**
  - E.g., leveraging self-defense assets; “*Genius Sand*;” ...
- ◆ **“Goalie” operations in high-endo terminal defense**
  - Still-ballistic RVs now atmospherically-stripped of penaid



Modern *Pebble* Variant:  
Boost-Phase  
Launch Suppression





Modern Pebble Variant:  
Robust Midcourse Engagement



# High Endo-Atmospheric Re-Entering Brilliant Pebble Interdicts Penaid-Stripped Soviet Warhead Over U.S. ICBM Field



AIT-0191-00528B-LLW  
JE.051-04



# AND SO WHY NOT?

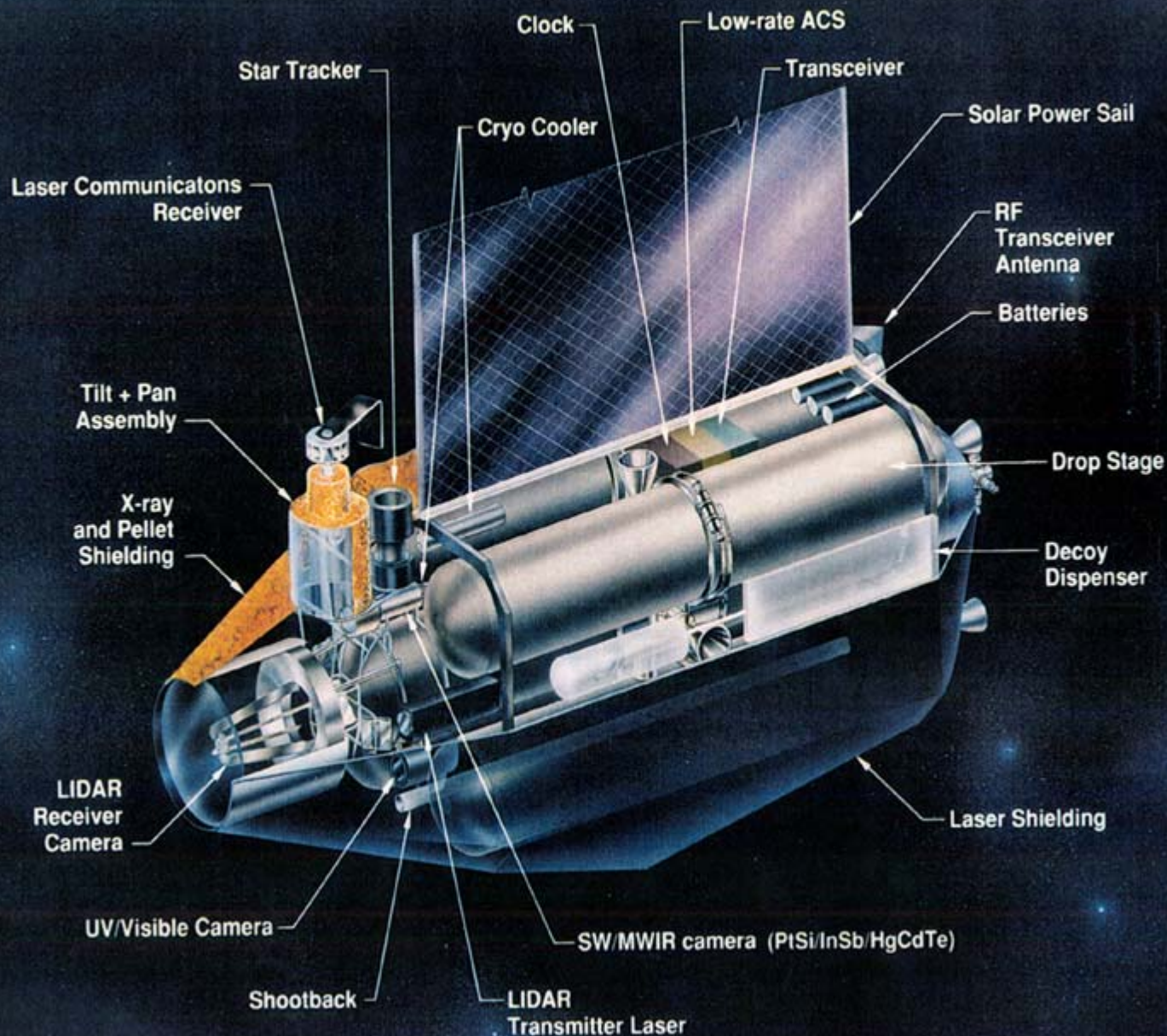
- ◆ **Defensive assets must be pre-positioned in low Earth orbit in order to be boost-phase defense-effective...**
  - Especially for “everywhere-&-all the time” defenses
  - Though countries that are “all border” and have defense-cooperating neighbors *might* have their attacks effectively blocked by ground-based boost-phase defenses...
    - E.g., North Korea, *if* the Russians and Chinese both cooperate, both “in advance” (deployment) and “in time of need” (defensive operations)
- ◆ **...and some folks believe ferverently that only attackers should be allowed to use space for military operations**
  - Diplomats of some foreign countries assert that they believe likewise – but their governments’ undoubted (covert) actions belie their words...
- ◆ **Feasible-in-principle to deploy defenses-in-space only in “time of deep crisis”**
  - But, here-as-elsewhere, “Haste makes waste”...
    - ...and “practice makes perfect” advantages are entirely foregone
    - ...and defensive system crisis-launches become “lucrative targets”
  - Primary intrinsic advantages of the Defense are largely ‘thrown away’
- ◆ **Not technically feasible to deploy-under-attack**

# BUT ISN'T THE COST TOO HIGH?

- ◆ **“Total life-cycle cost to the Nation to own” the Brilliant Pebbles defensive system was \$11 B ('89 \$)**
  - CAIG-validated, DoD-certified-to-Congress cost estimate
    - Tight consensus of 3 “from the bottom up” cost-estimation projects
  - All RDT&E, all production-&-deployment; 2 decades ops
  - Total deployed constellation of 2000 Pebbles
    - Worst-case GPALS threat: Typhoon salvo-launching off Bermuda
    - Clearly met Reagan’s “..*impotent and obsolete*..” spec for the SDI
  - Higher “cost estimates” come from critics-&-opponents
    - Manifestly, professional naïfs – “Will you believe this?!?”
- ◆ **Scheduled for deployment-commencement in '96, -completion in '98, retirement in '18**
  - Pres. GHW Bush, SecDef RB Cheney chose in Winter '90 as “technologically most mature, and thus first-to-deploy”
    - After year of POTUS-ordered intensive ‘scrubbing’ (~300 FTEs)
  - Program cancelled by SecDef Les Aspin in May '93
  - Clementine & ASTRID flight-proved full technology-set ('94)



# CURRENT BP CONCEPT





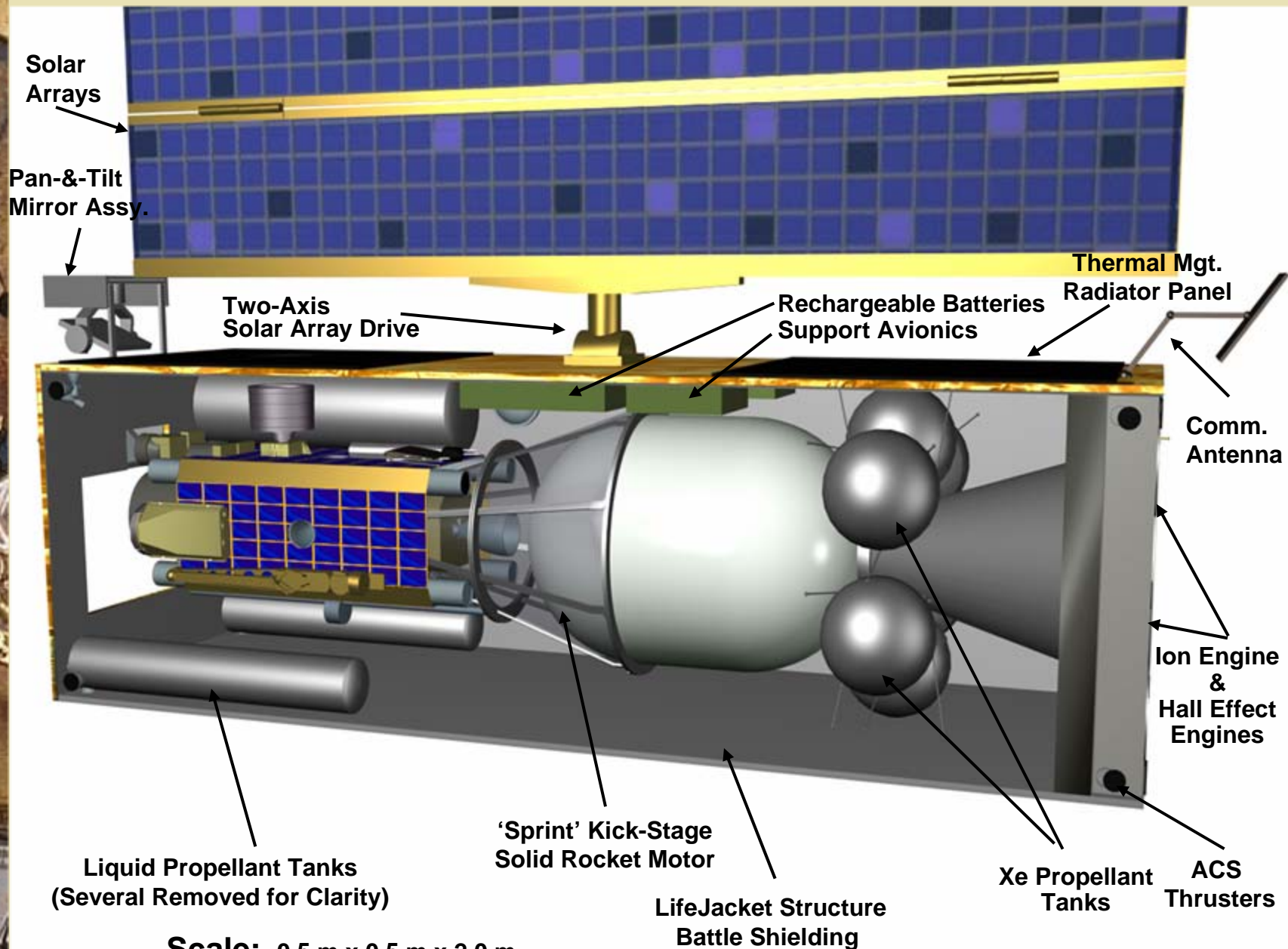


# AND WHAT ABOUT SHORT-RANGE MISSILE THREATS?

- ◆ **E.g., in the Middle East? in South Asia? NE Asia?**
  - Boost-phase  $\Delta t$  of 1-3 minutes (*No Dong 1,2; Shehab 3,5*)
- ◆ **Address with the ‘high flyout acceleration’ variant of Brilliant Pebbles**
  - One of the ‘modernized’ forms that gains unusually-high flyout speeds in  $\sim 10$  sec., vs. slower-speeds in  $>60$  sec.
  - Peregrine falcon-like ‘stooping’ on short-range ballistic missile targets ‘down in the mesosphere’
  - Missions flown over great distances – facilitates effectiveness of small-sized defensive constellations
- ◆ **‘Incidentally’ obviates “fast-burn booster” issues**
  - SCUDs are the ultimate ‘fast-burn booster’
  - No long-range ballistic missile can burn even as fast
    - Atmospheric heating ( $v^3$ ), dynamic pressure ( $v^2$ ) limitations



# 'High-Flyout' Pebble In LifeJacket (Cutaway)

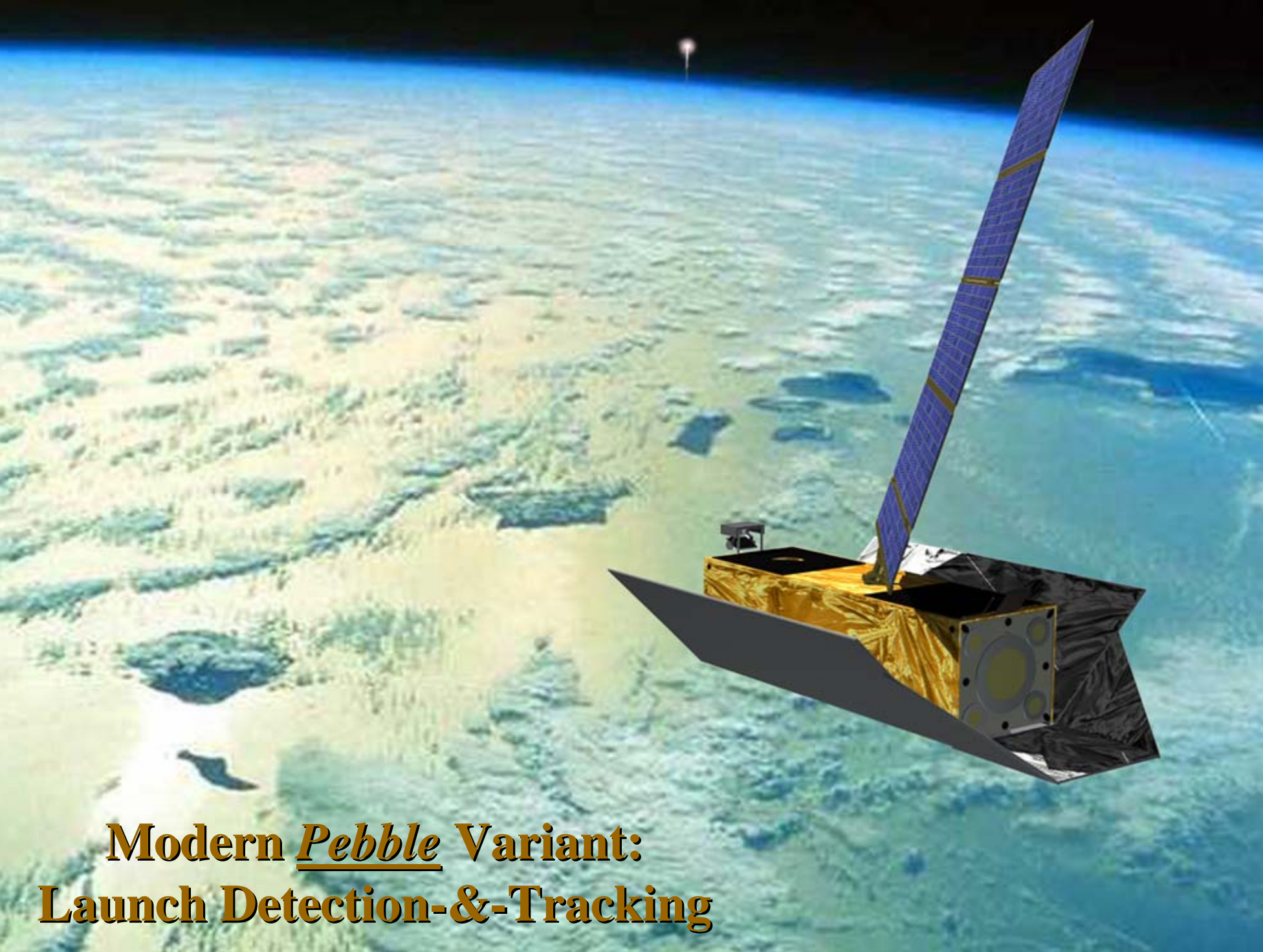


**Scale:** 0.5 m x 0.5 m x 2.0 m  
20" x 20" x 80"

# PRICES TO BE PAID

- ◆ **What's the cost of a significantly more “ideal world?”**
  - I.e., what buys a workable degree of political consensus on the Hill re *space-basing of defenses* against ballistic *missile attacks-from-space*?
- ◆ **Internationalization of space-based missile defenses?**
  - Suppose no one could launch anything into space without a permit from a *multi-national/international* authority
    - That operated the one-&-only space-based defensive constellation..
    - ...and was chartered-&-mandated to allow any *single* launch on the part of anyone along an *orbital trajectory*...
      - ...but to interdict all *sub-orbital* launches and all *multiple* launches...
      - ...and to do so *completely* “*automatically*,” without discussion-or-debate
- ◆ **Why shouldn't the U.S. *rationaly* favor creation-&-operation of such a “space access control” system?**
  - Indeed, why shouldn't the U.S. build, pay for and donate such a system??
    - ~3% of one year's DoD budget, to obviate the ‘Powell Threat’
    - Think about it....





**Modern Pebble Variant:  
Launch Detection-&-Tracking**

# SUMMARY

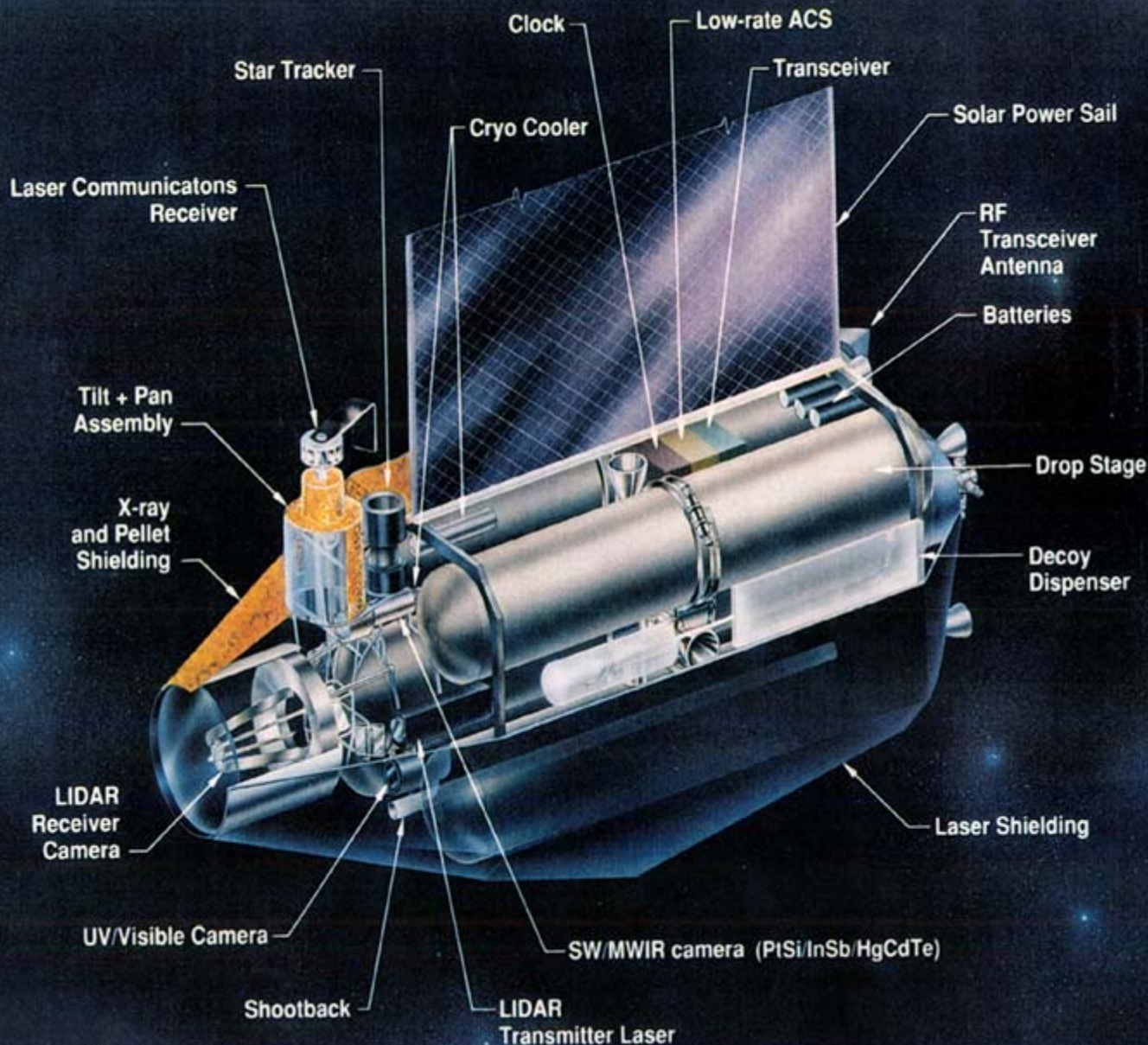
- ◆ **Basic features of an “ideal world” BMD system**
  - Defends every-one, -where, -time: universally trusted
    - Reliably, against all-but-the-heaviest (e.g., Soviet) missile attacks
      - E.g., *continually* detection-tested against all rocket-launches
      - E.g., lots of engineered-near-miss ‘practice shots’ against missile tests
    - Against transnational missiles of all ranges: ~300-15,000 km
  - Robust against all plausible countermeasures: relied upon
    - Including spoofing, harassment, shoot-down, FBBs, etc.
  - Highly cost-exchange-effective “at the margin”: durable
    - Irrational for even a wealthy offense to “over-build” against it
      - Cheaply-&-quickly extensible defenses, in event of ‘irrationality’
    - ‘Tied’ to swiftly-advancing technology: sustained growth potential
    - Economic to supplement-as-needed, to exercise extensively,...
      - E.g., ‘escorting’ of objectively-suspicious “space launches”
- ◆ **We know how to do all this – *in detail***
  - GHW Bush, RB Cheney, et al: *Bush I GPALS*
  - We were only a half-decade away from *having* it, in early ’93
  - It’s remarkably inexpensive – ~\$16 B (FY’04 \$), end-to-end
    - “...*Pebbles* were the most cost-effective component of GPALS, by far.” – Bush I SDIO Director (HF Cooper), writing to SASC Chair John Warner
- ◆ **RF’s Yeltsin government ‘bought off’ on it – if done jointly**



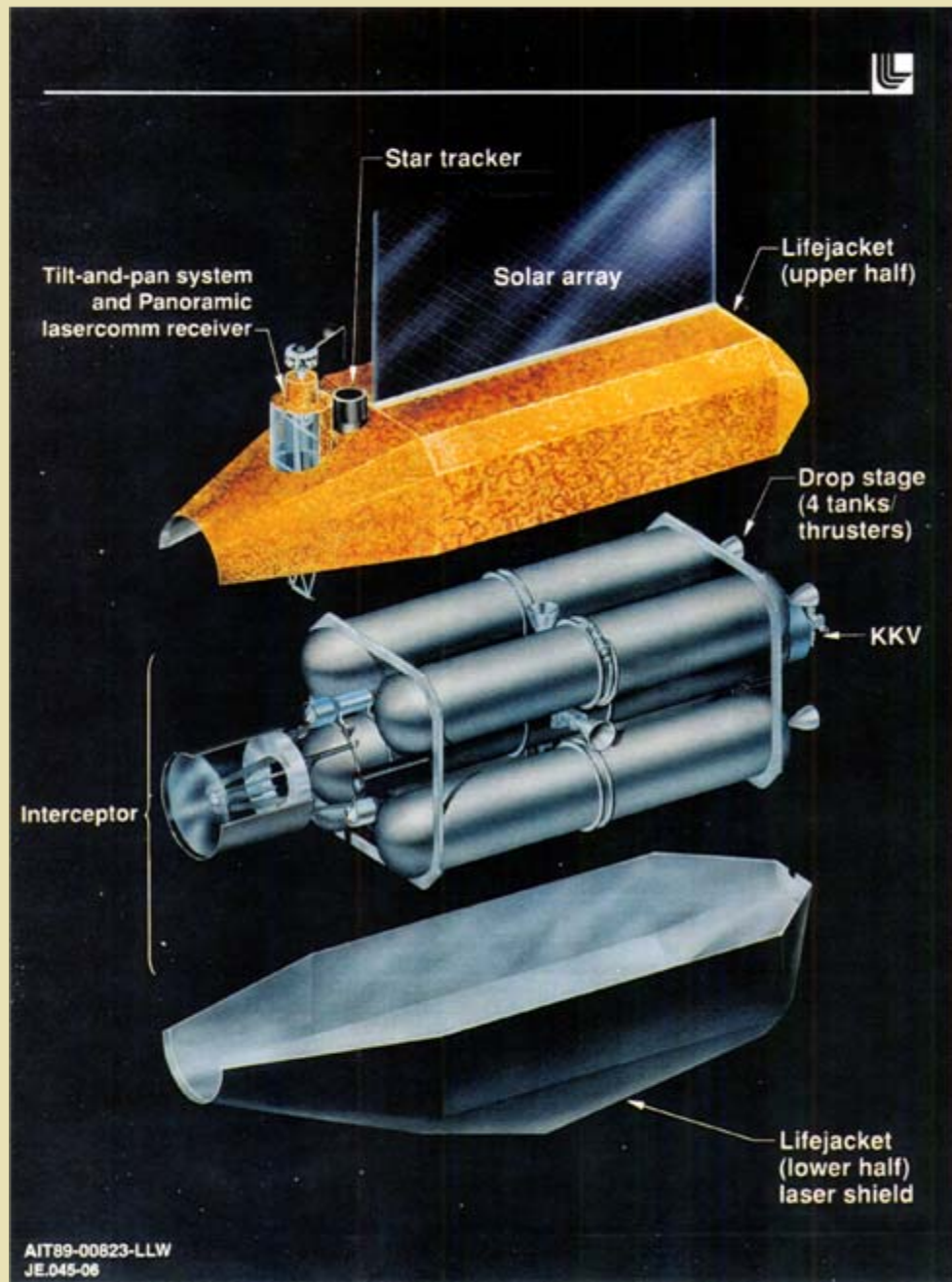


# SUPPLEMENTAL MATERIAL

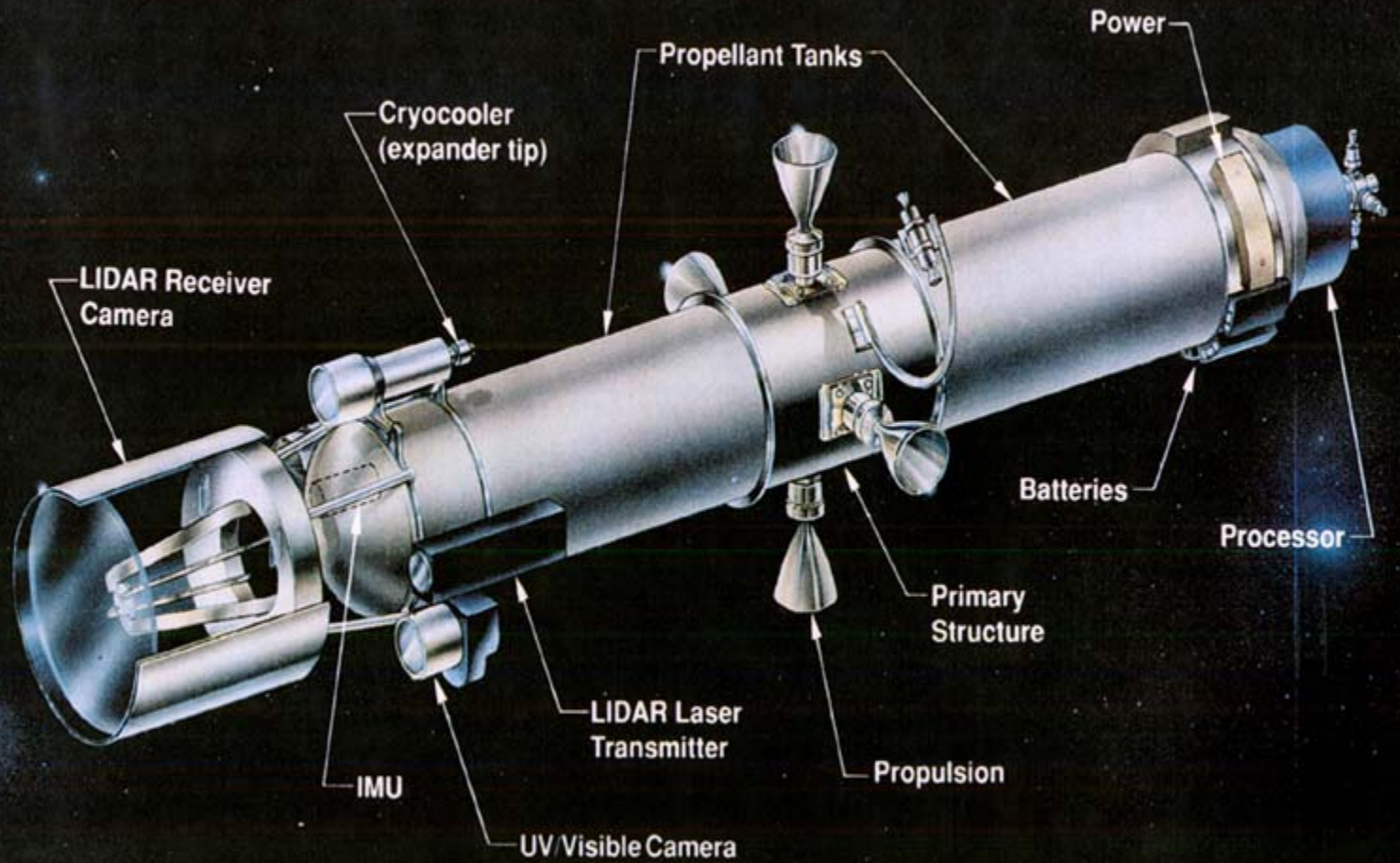
# CURRENT BP CONCEPT



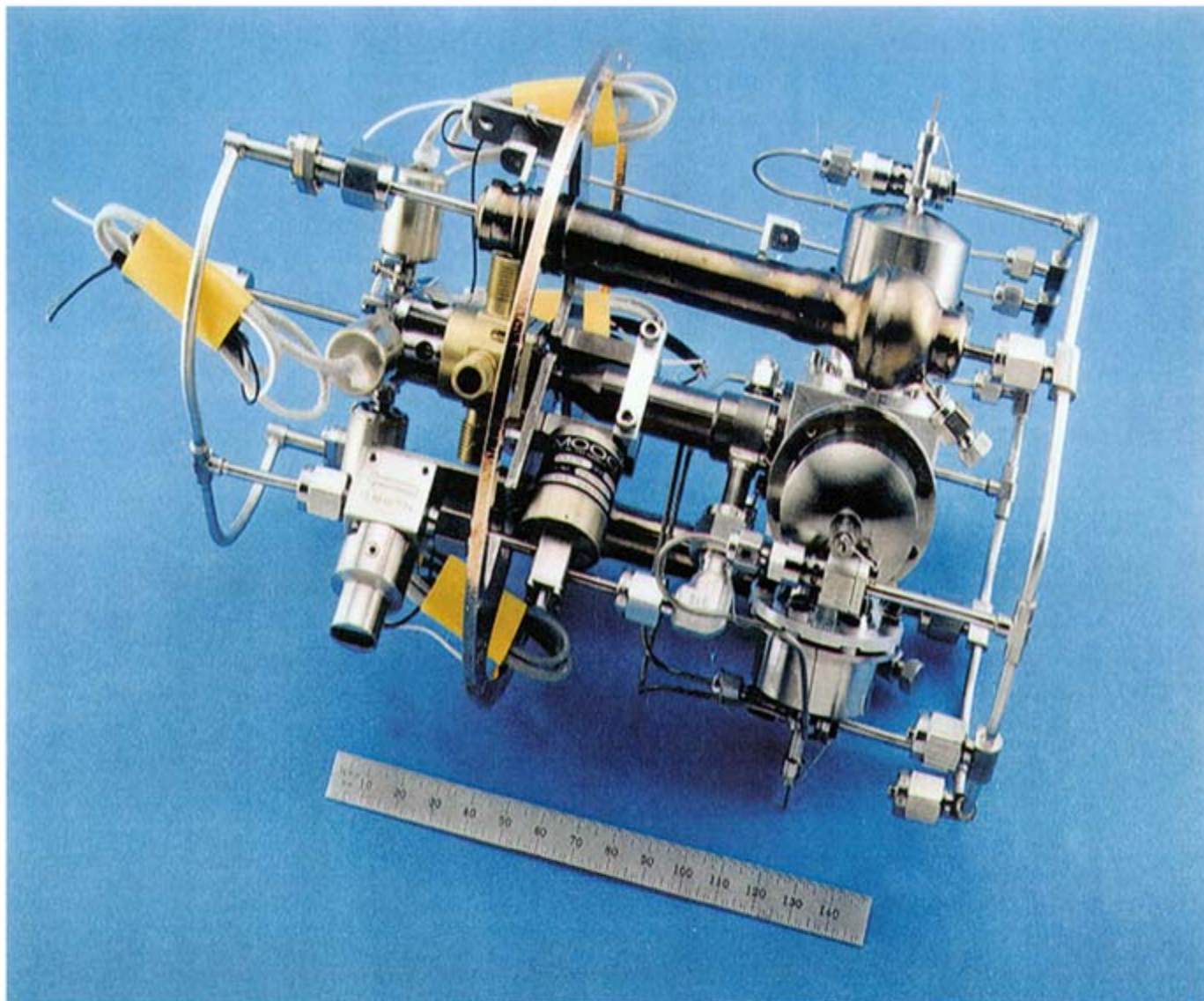












**Propulsion subassembly for a monopropellant axial stage has quad piston pumps, a central propellant filter manifold, and a 4-channel thrust control valve. The dual gas generators which power the pumps receive hydrazine from the side branch on the filter manifold, through a pressure regulator and the system on-off valve.**

ANSS-1193-00346-NJC  
HA.051-03/JCW

JCW-1193-001



# Modern Pebble Variant: On-Orbit LifeJacket-ed Configuration

Solar Arrays

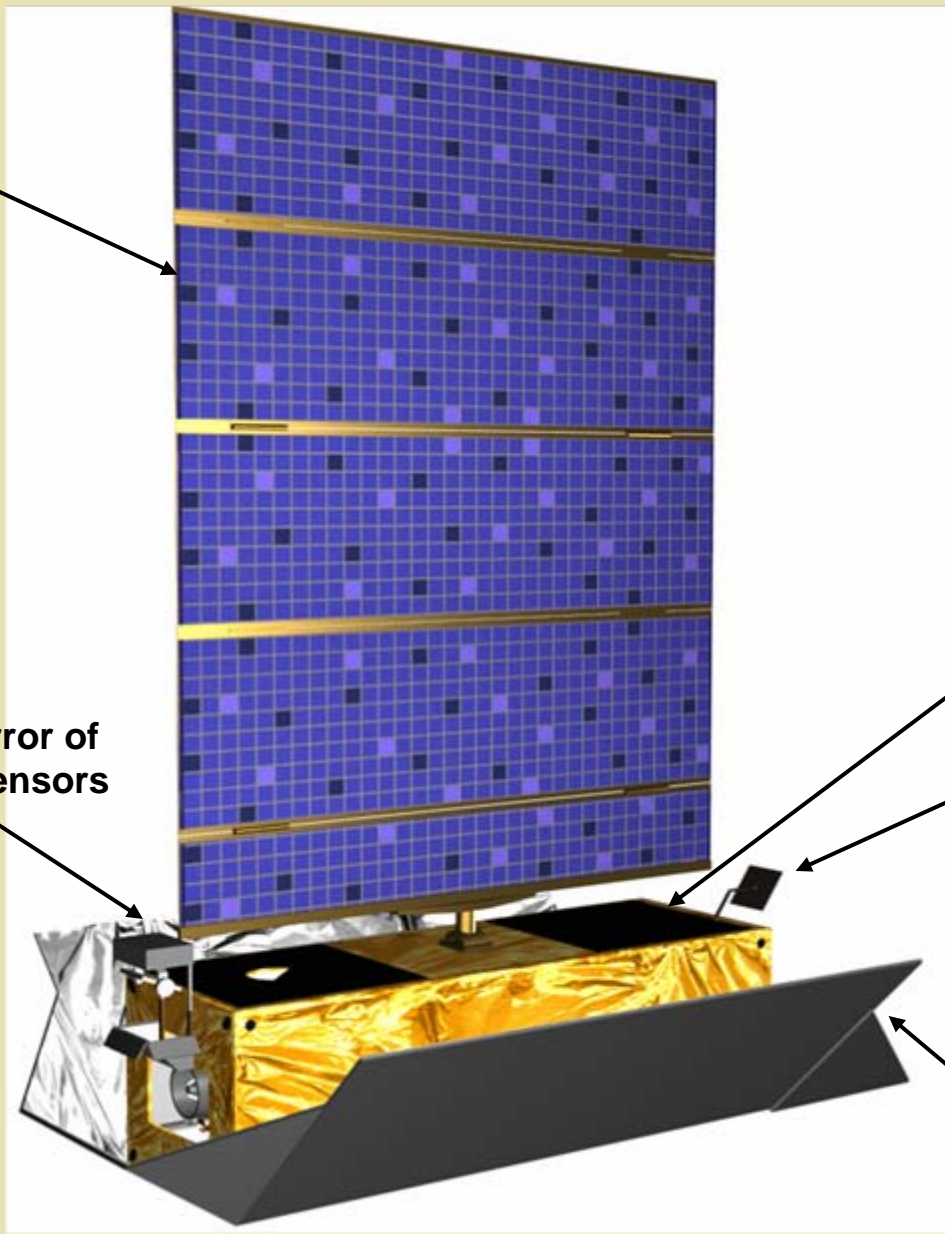
Scale: 0.5 m x 0.5 m x 2.0 m  
20" x 20" x 80"

Pan-&-Tilt Mirror of  
Monitoring Sensors

Radiator Panels

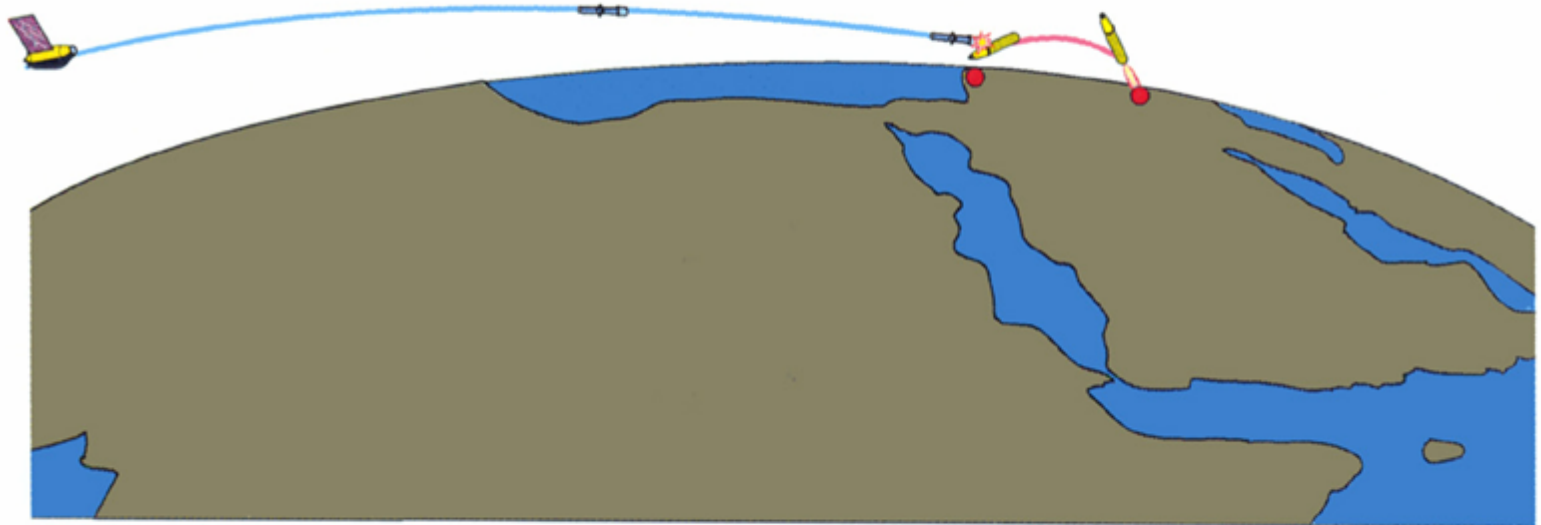
Communications  
Transceiver Antenna

Battle Shielding





**Brilliant Pebbles Are Exceptionally Effective Because They Have Such High Velocity They Can Fly Great Distances To Intercept Their Slower-Moving Targets**



**(Trajectories Drawn to Scale)**