SHIELD

A Comprehensive Earth-Protection System

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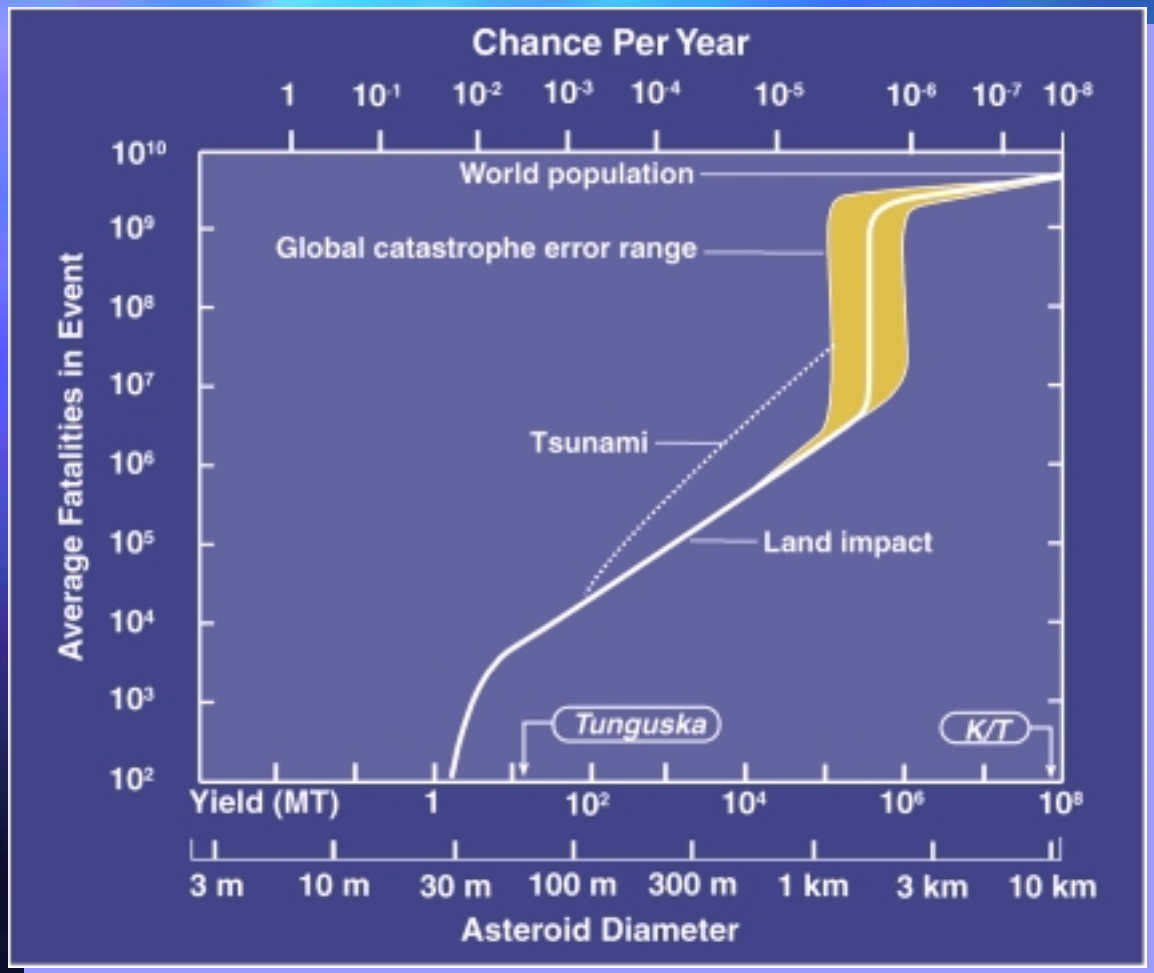
Earth Impact Fatalities



Average mortality from impacts as a function of energy for the current population of the Earth.

Historical Fatalities from Worst Disasters by Type

Epidemic	75 million
Famine	9-13 million
Flood	900,000
Earthquake	830,000
Cyclone	>300,000
Conflagration	140,000
Landslide	>100,000
Tsunami	36,000
Volcano	30,000
Avalanche	20,000

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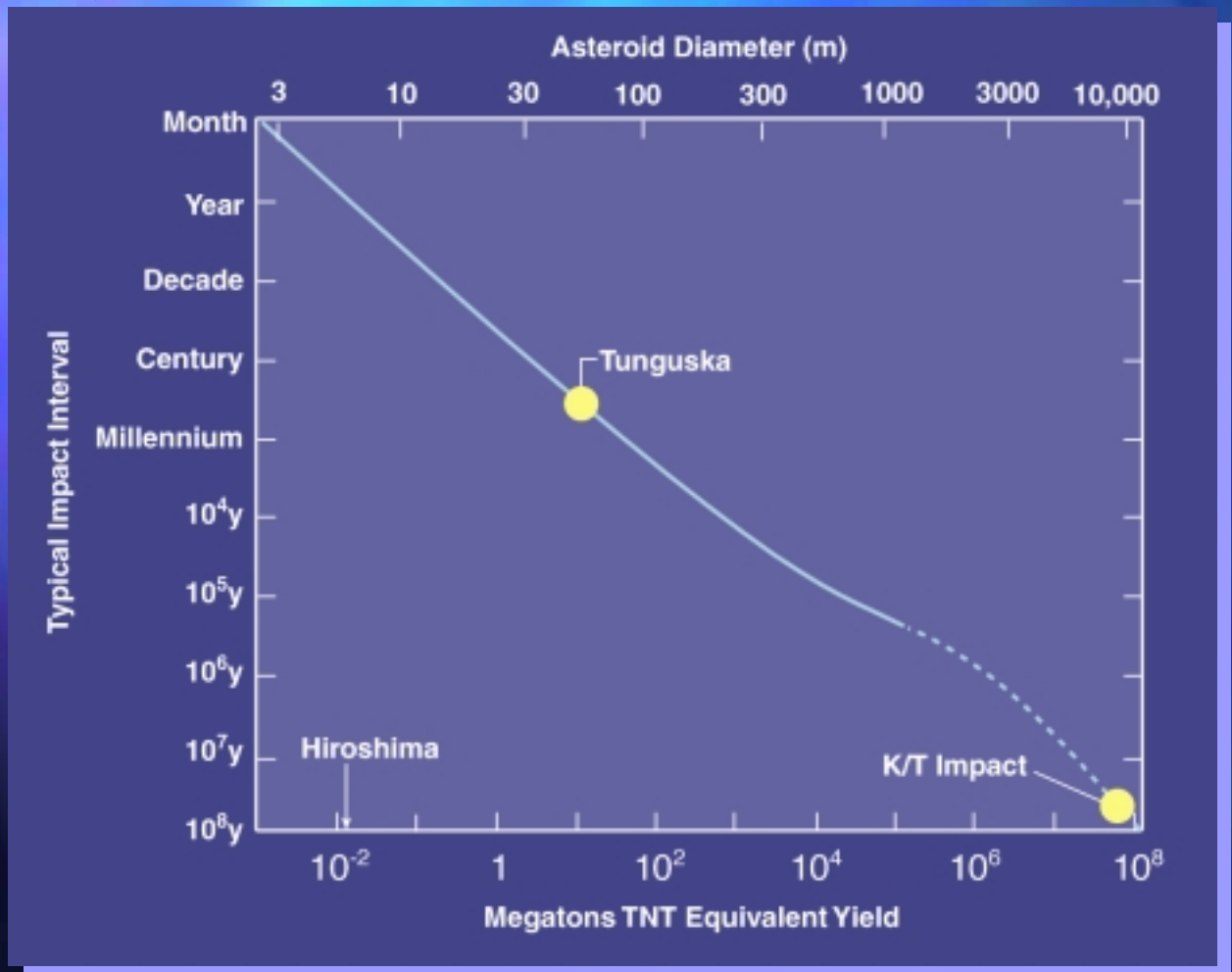
How Big, How Often, How Bad



- Impact speed = 20 km/s
- $\rho = 3$ g/cm^3
- From Shoemaker (1983)

Cumulative energy-frequency curve for impacts on the Earth.

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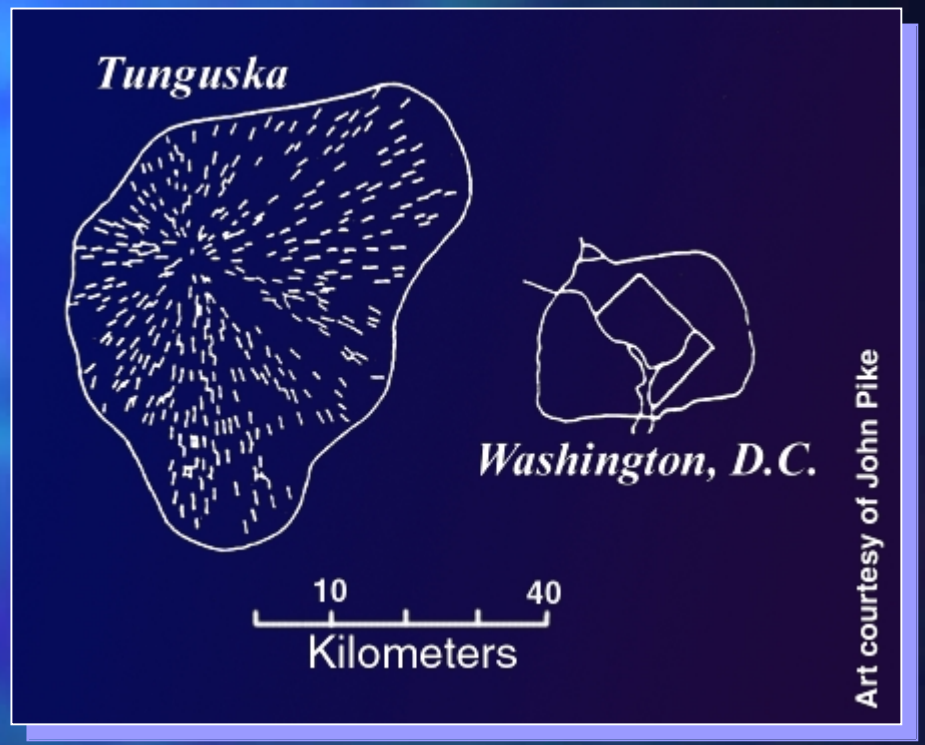
Tunguska Blast, Siberia 1908



Tunguska in perspective

Annual probability is 1 in 300.

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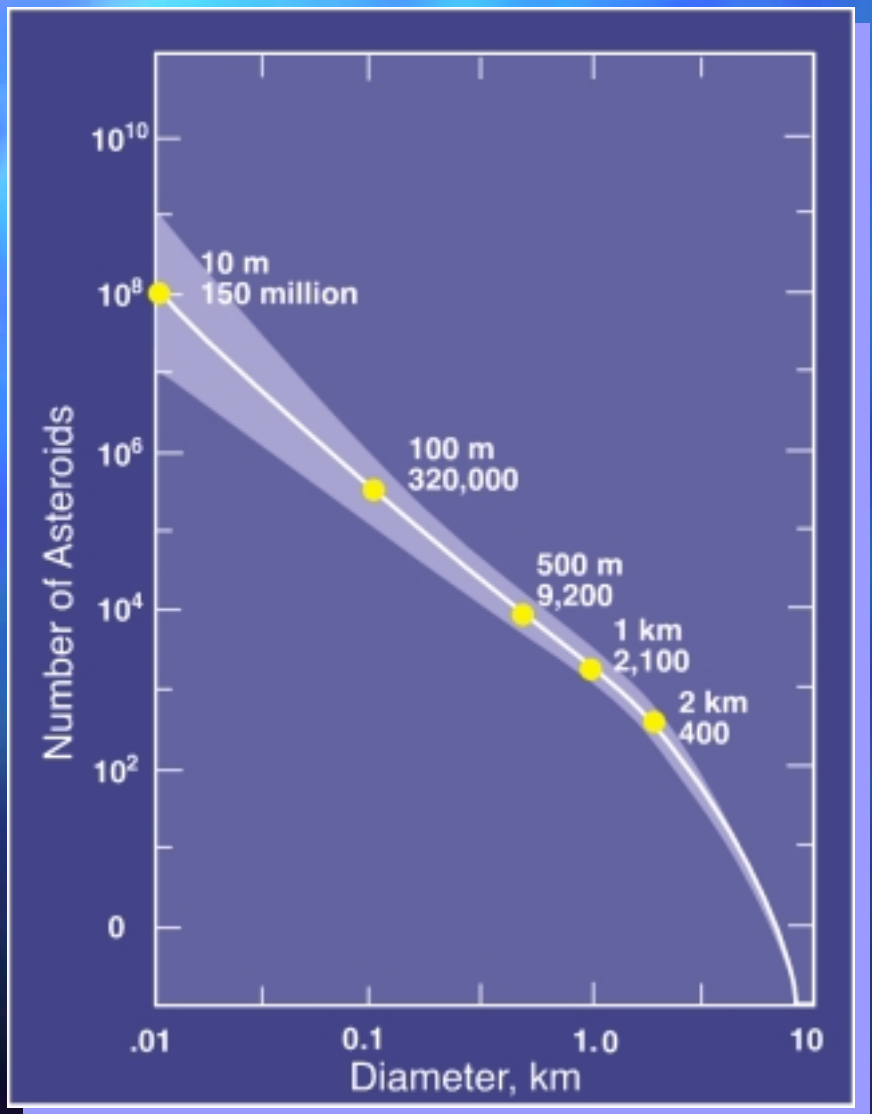
Size of the Threat



- **D**istribution of Earth-crossing asteroids from the Spaceguard survey (Morrison 1992)
- ~10% of 1-km asteroids have been discovered

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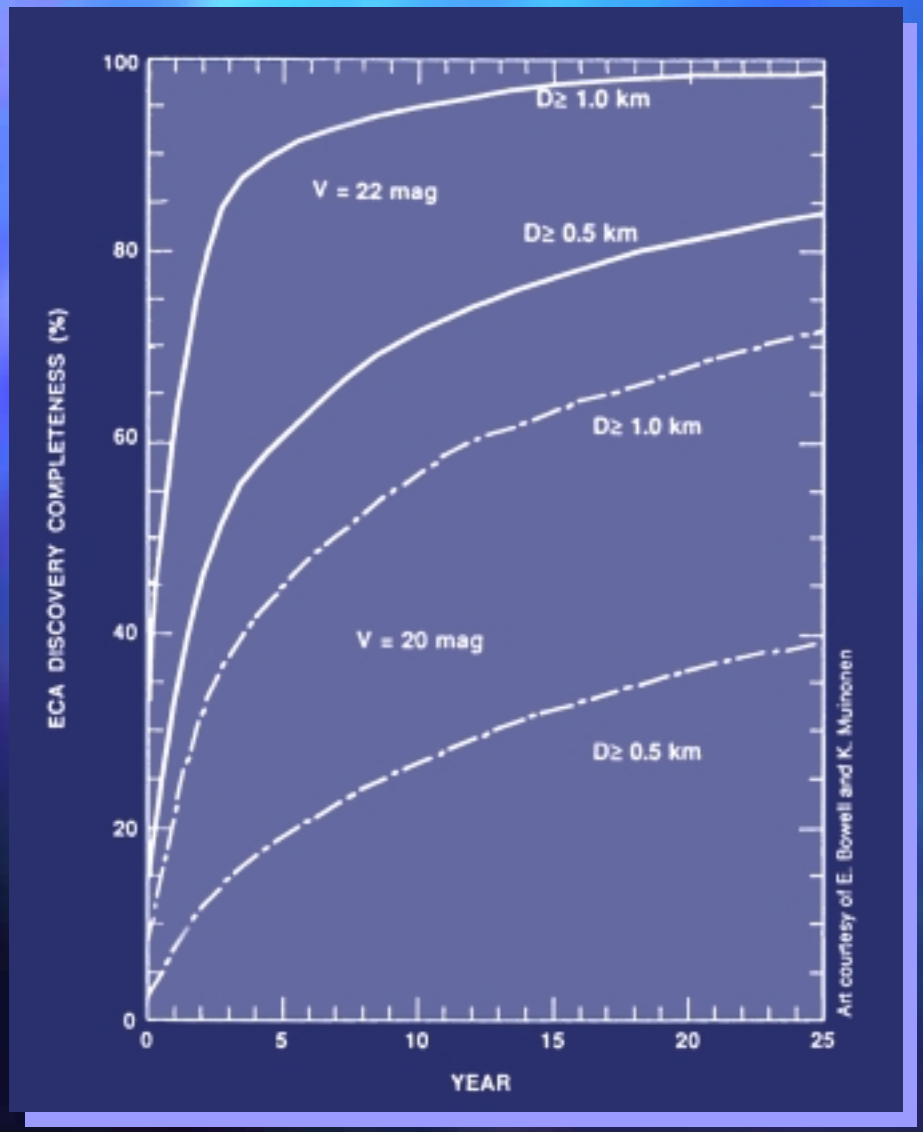
Inadequate Earth-Based Discovery Rate



- Worldwide search effort has fewer than 100 people.
- Nearly 1/3 of all NEOs are discovered at their closest approach to Earth.

Discovery completeness of Earth-crossing asteroids resulting from whole-sky surveys.

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Bimodal Threat: Comets vs. Asteroids

Parameter	*Long Period Comets*	*Asteroids*
Impact velocity	~58 km/sec	~20 km/sec
Warning time	Typically 2 months to 2 years	Decades after survey complete. Days to decades before.
Orbit inclinations	Often high inclination or retrograde orbits which are difficult to reach.	Typically low inclination,prograde orbits.
Mitigation techniques	Rendezvous difficult due to high velocity. Limited to flyby or impact methods. Require very accurate terminal guidance.	Rendezvous, flyby, or impact methods.

Note: LPCs constitute 5 to 10% of the Earth impactors and 25 to 50% of the craters larger than 20 km in diameter.

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A Few Points to Remember

- $KE = \frac{1}{2} mv^2$
- Mass of 1 km diameter asteroid is ~ 1.7×10^9 tons.
- Energy of an asteroid impacting at 3 km/sec is equivalent to the energy of the same mass of TNT.
- Typical asteroid impact velocity is 20 km/sec. Energy equals 44 times the mass of TNT.
- Typical comet impact velocity is 58 km/sec. Energy equals 374 times the mass of TNT.

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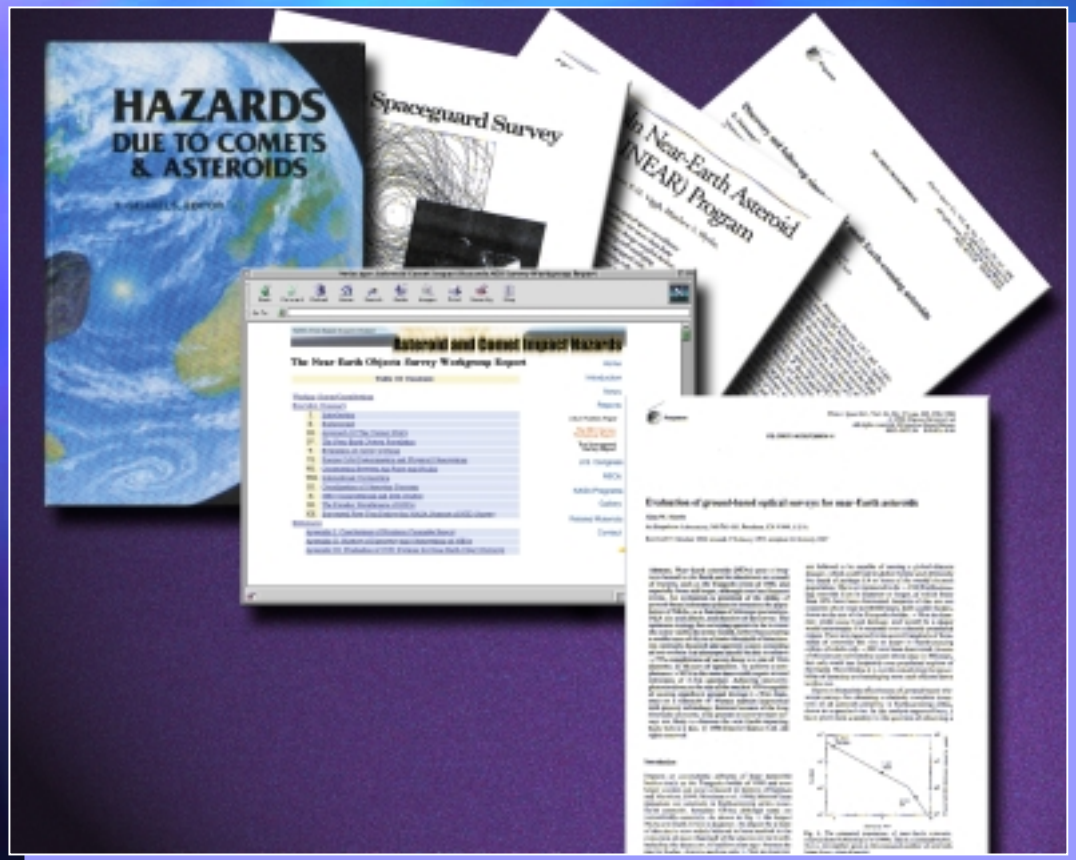
Shield Acknowledgements



- Excellent work exists on individual aspects of Earth protection.
- SHIELD extends it to an overall Earth protection system.
  - Detection
  - Command and control
  - Multi-tiered defensive system

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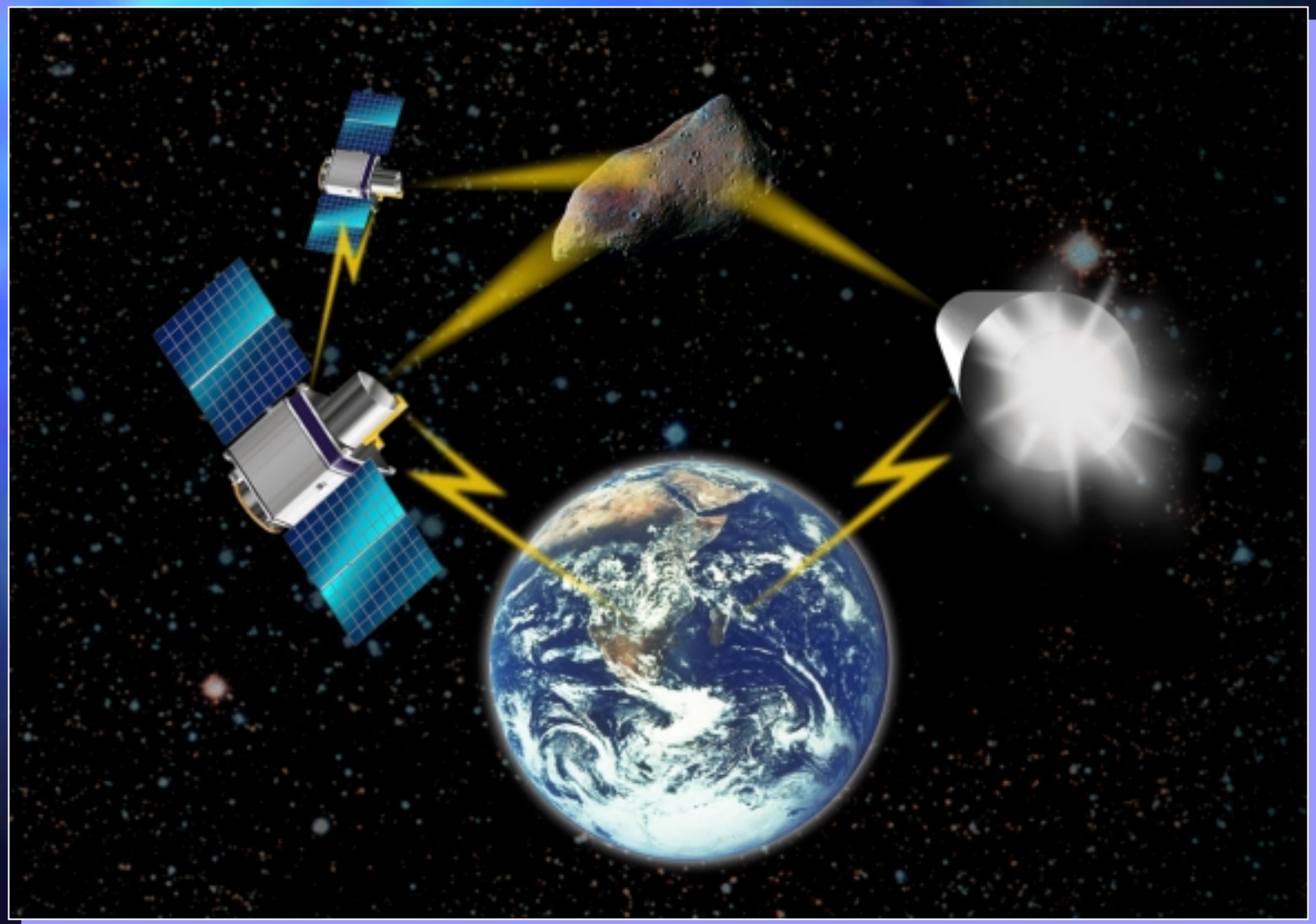
Total System Concept



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Need For Space-Based Detection

- **Advantages**
  - Optimal location
  - Observing time
  - Sensitivity
- **Results**
  - Detection of Aten asteroids not observable from Earth
  - Increased warning time for long period comets
    - From days or months to years
    - Ability to view comets approaching from the opposite side of the Sun
  - Increased observing time by ≥ 4
  - Greater areal coverage
  - Better limiting magnitude
  - Reduced time to complete catalog

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Sentry Instruments

- 1-2 meter diameter telescope
- 10,000 x 10,000 pixel charge coupled device (CCD)
- Computing power
  - 1 PC-equivalent processor for image processing
  - 1/2 of a PC-equivalent processor for orbit calculations
  - < 10 MB (RAM)
  - 100 GB digital storage
    - 90 GB storage for images
    - <10 GB storage for catalog, star charts, etc
- Communications
  - RF or newer technology at 1024 bps to ground
  - Optical cross link for sentry-to-sentry communications at 1024 bps

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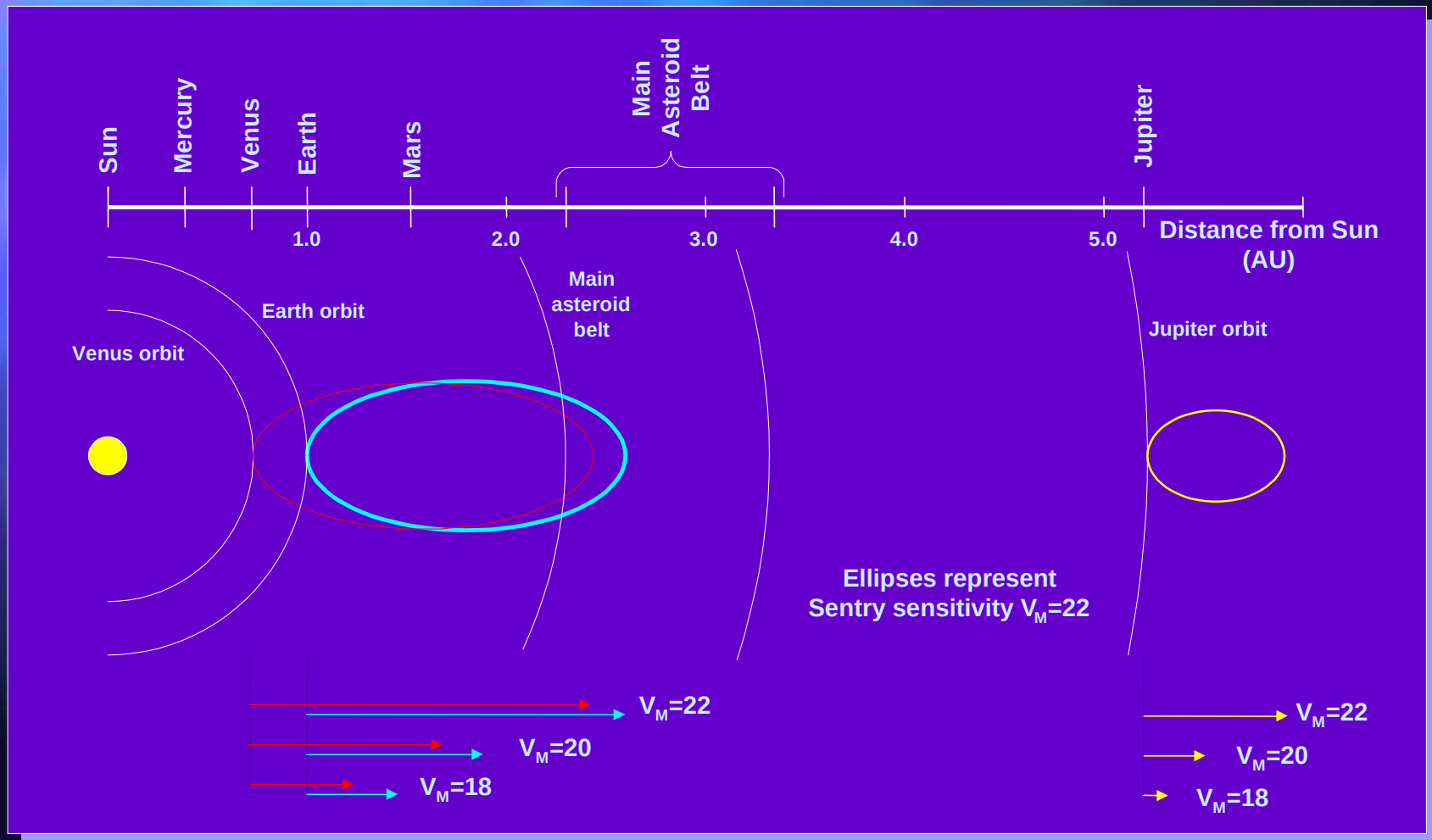
Detection Distance from Venus, Earth and Jupiter Orbits (1-km object, V_m = 22, 20, and 18)



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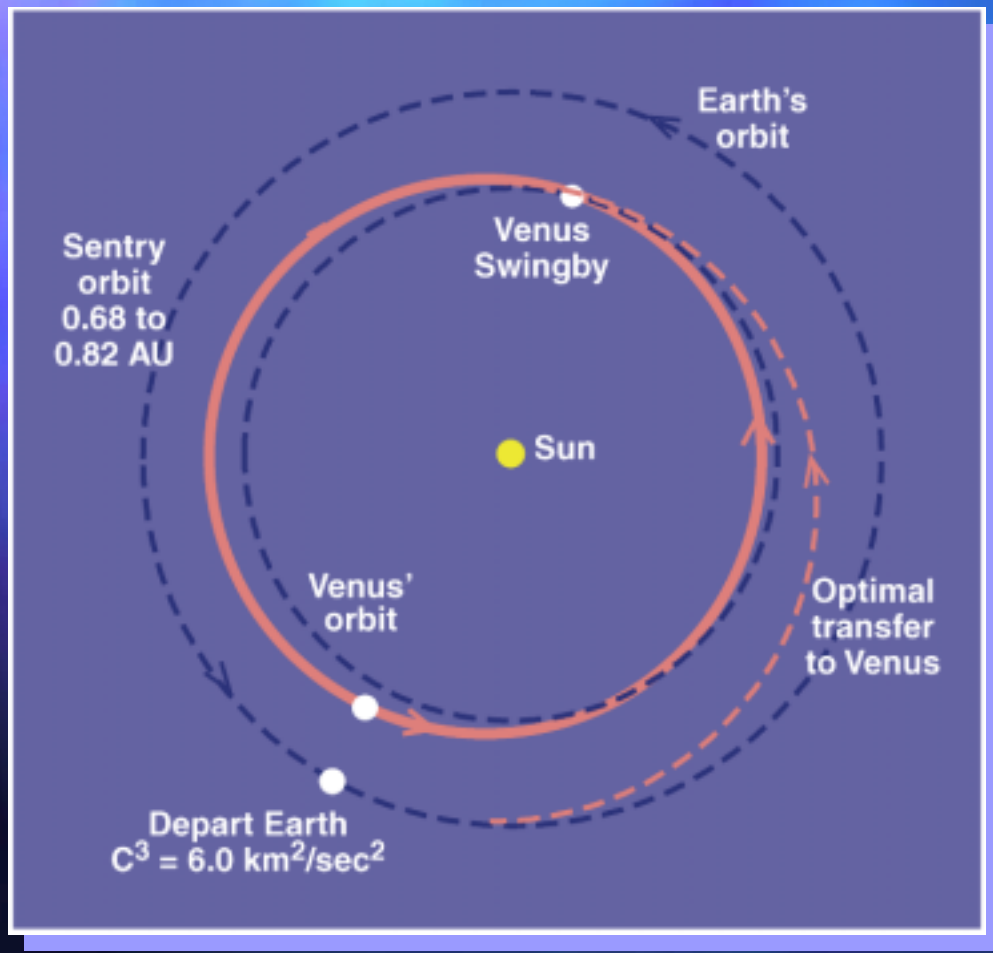
Location and Number of Sentries



- Orbits entirely within Earth's are necessary to find all Atens
- Venus swingby is most cost-effective to achieve such orbits
- All asteroids that cross Earth's orbit can be found
- Need 4 to 6 Sentries for complete sky coverage (for faster asteroid survey and long-period comets)
- Orbital period about 240 days for faster sky coverage than is possible from Earth
- Can launch every 19 months
- 5-month transfer to Venus

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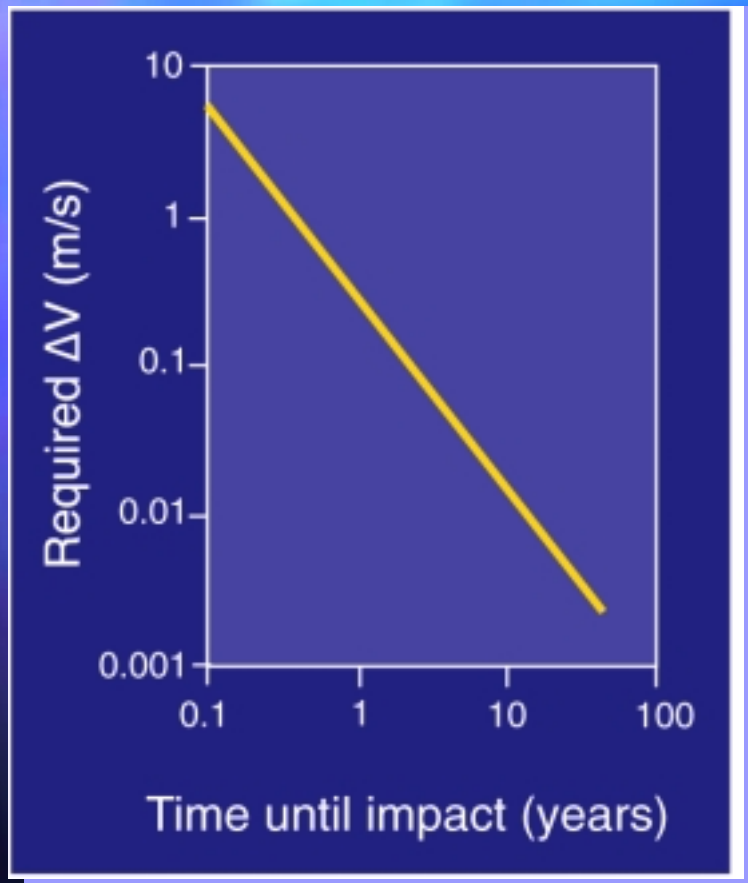
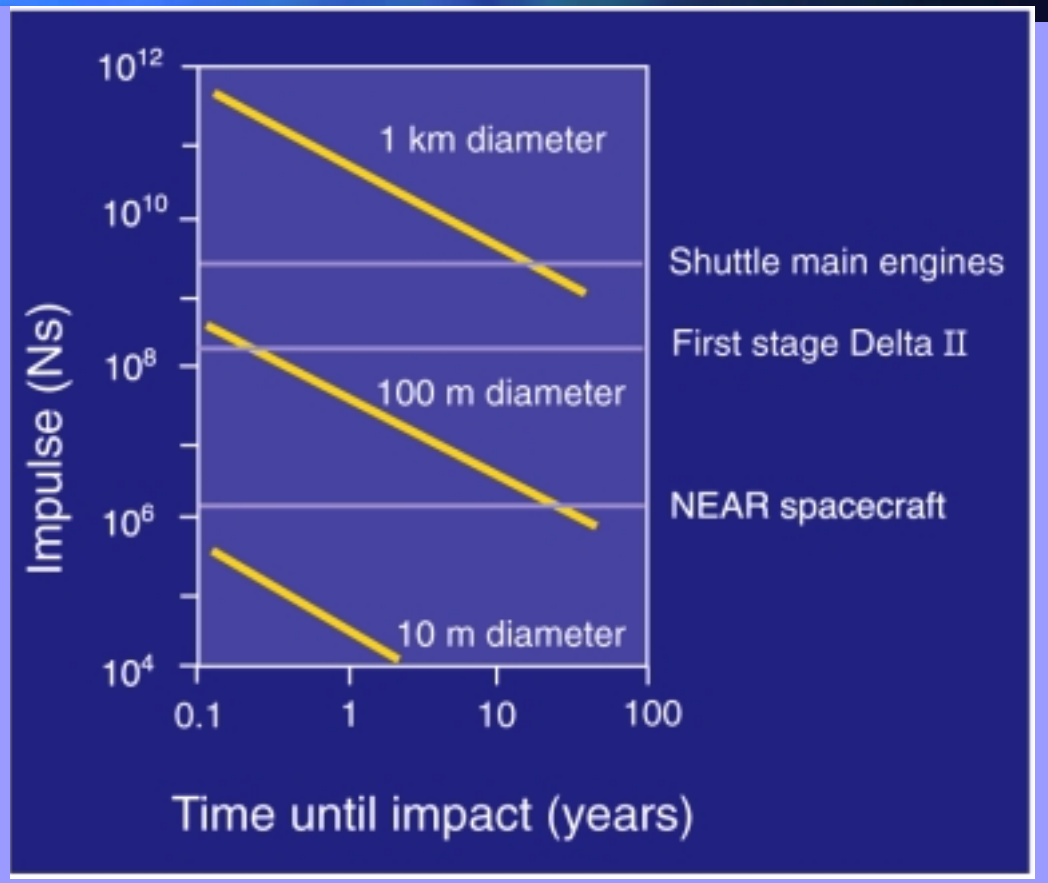
Deflection Simplifies With Lead Time





- Only small velocity change required
- Deflection much easier decades ahead

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Deflection Techniques

- **Kinetic Energy**
  - Impact the asteroid at high speeds
- **Propulsive** (chemical, electrical, nuclear, solar sails, mass drivers)
  - Dock a thrusting device to asteroid
- **Directed Energy** (laser, solar collector)
  - Vaporize asteroid material to form a jet
- **Nuclear Detonation** (standoff, surface, buried)
  - Deflect from blast impulse or ejected matter, or fragment asteroid

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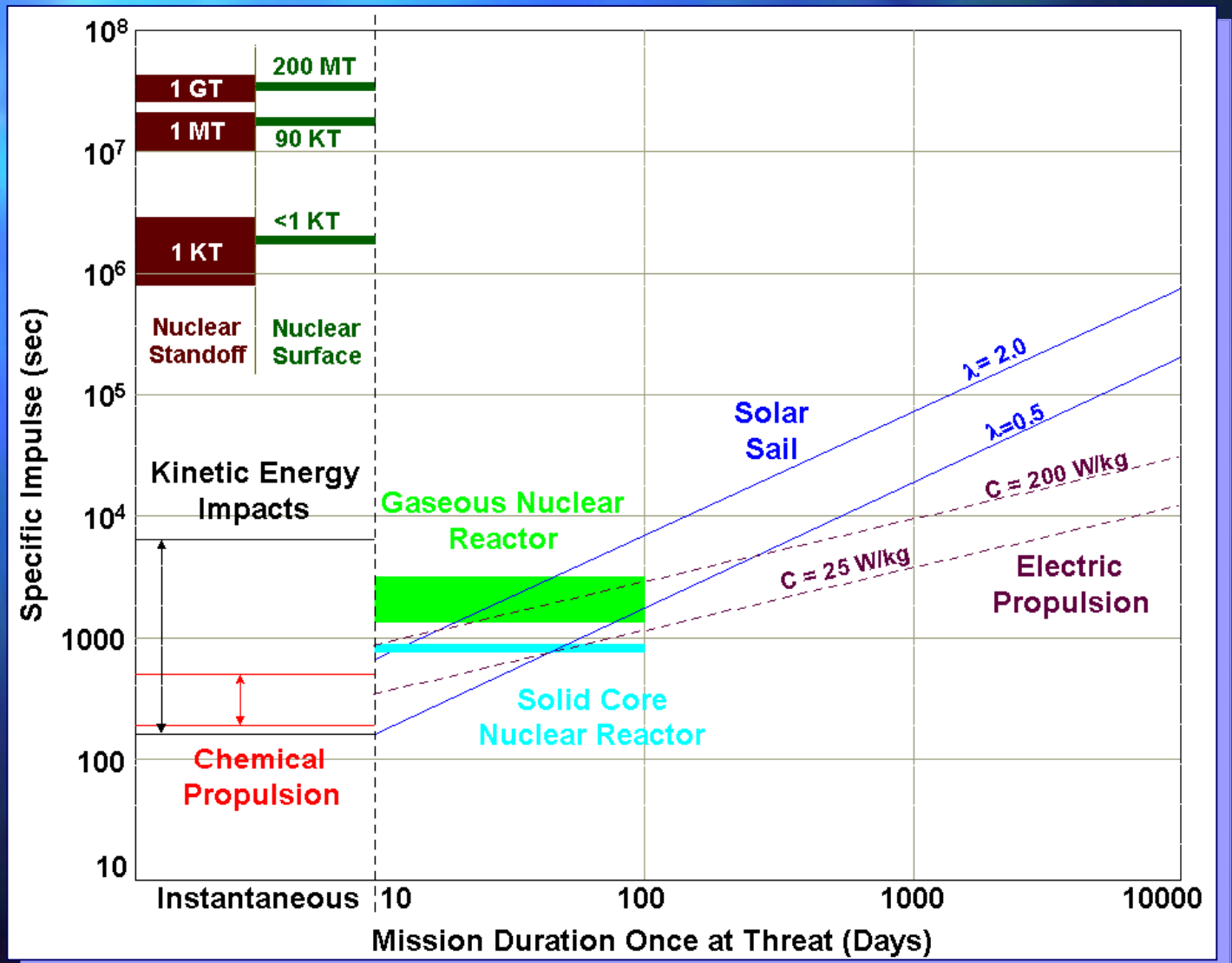
Technique Efficiencies



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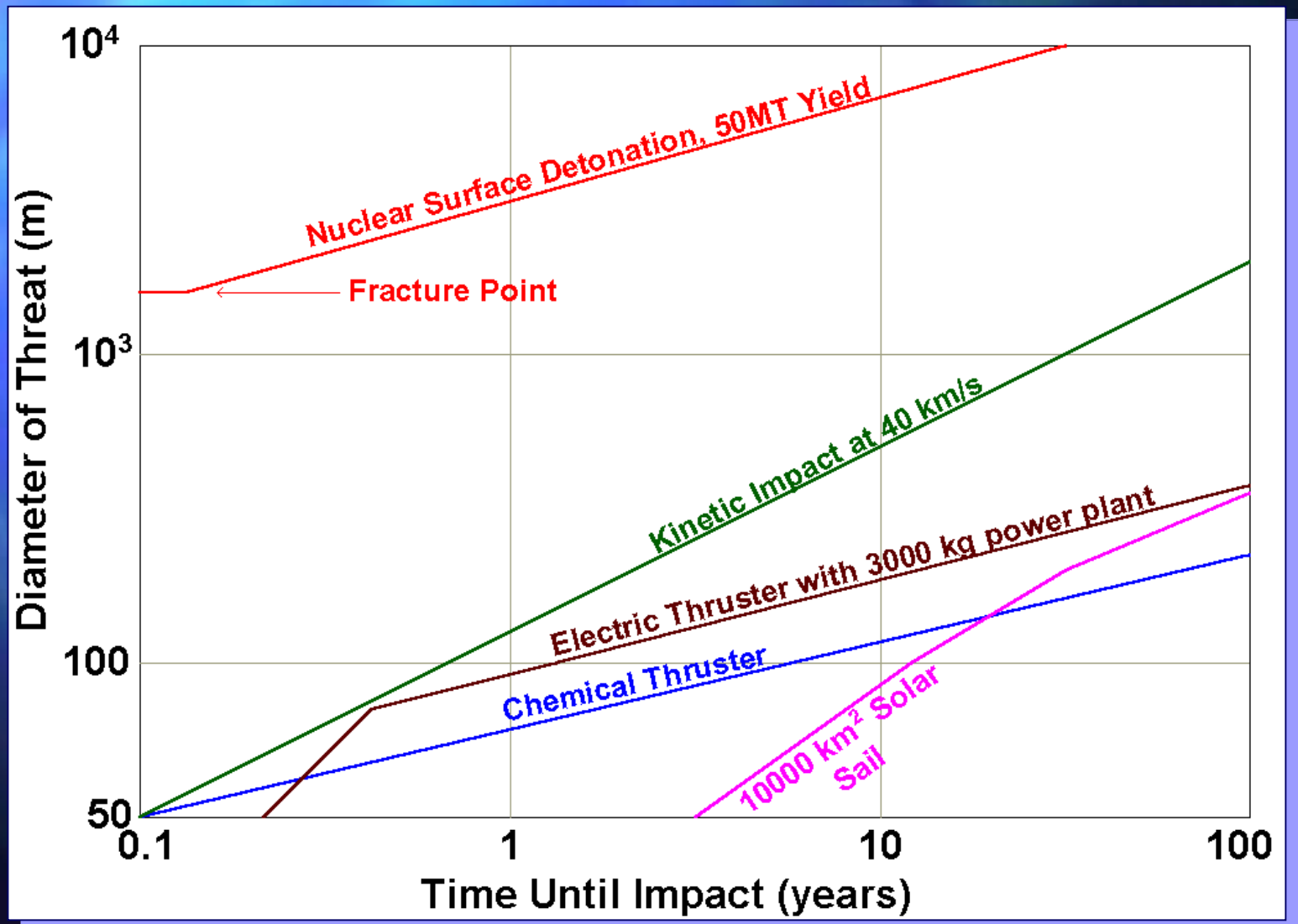
How Big, How Soon



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Deflection Technologies and Efficiencies

- **Efficiency**
  - Nuclear surface detonation
  - Solar sail
  - Kinetic energy
- **Near-Term Technologies**
  - Chemical thrusters
  - Nuclear detonations
  - Kinetic energy
- **Future Technologies**
  - Solar sails, directed energy, and mass drivers have enormous potential
  - State-of-the-art electric thrusters are too weak
- **Nuclear systems face political and social problems**

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Soldier Summary I

- **Soldier functions**
  - Survey target
    - Characterize physical properties, rotation, composition, strength
  - Modify asteroid orbit; prevent Earth intercept
    - Dock, grapple, intercept
    - Impart ΔV to asteroid
- **Scenarios: Rendezvous vs Intercept**
  - **Rendezvous**: All-in-one soldier (chemical rocket, electric propulsion)
    - Scouts asteroid from orbit
    - Docks and diverts
  - **Intercept**: Scout / Soldier pair (impactor, nuclear deflection)
    - Dedicated Scout precedes Soldier
    - Soldier carries guidance control for targeting

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Soldier Summary II

- **Scouting Instrument Complement**
  - Imager/spectrometer (composition/regolith)
  - Ground-penetrating radar (structure/regolith)
  - Seismic network (structure/composition)
  - Data processing and communications packages
- **Pushing Equipment (Rendezvous)**
  - Anchors - couple soldier to surface
  - Gimbals - alter orientation to provide thrust in proper direction
  - Electronics/communications; sector firing, thruster control
  - Power systems
- **Pushing Equipment (Intercept)**
  - Inert mass (kinetic)/warhead (nuclear)
  - Guidance and control and targeting computers and thrusters

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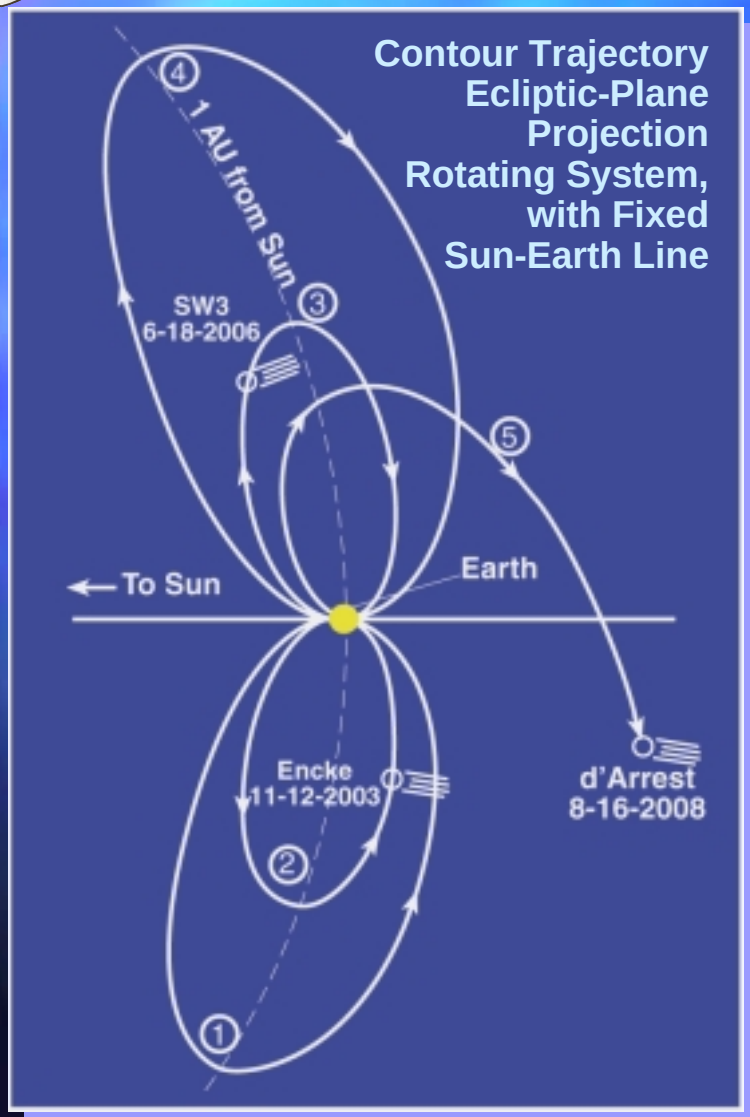
Location and Number of Soldiers



- Should have 6 or more soldiers
- 4 or more in Venus-return orbits for good coverage
- High-energy Venus-return orbits, like Contour's Earth-return orbits, shown at left
- 2 or more launch-on-demand from Earth for quick response, flexibility
- Some comets reached from Mars, Jupiter, but periods long
- Rendezvous usually requires large low-thrust system, Jupiter gravity assist

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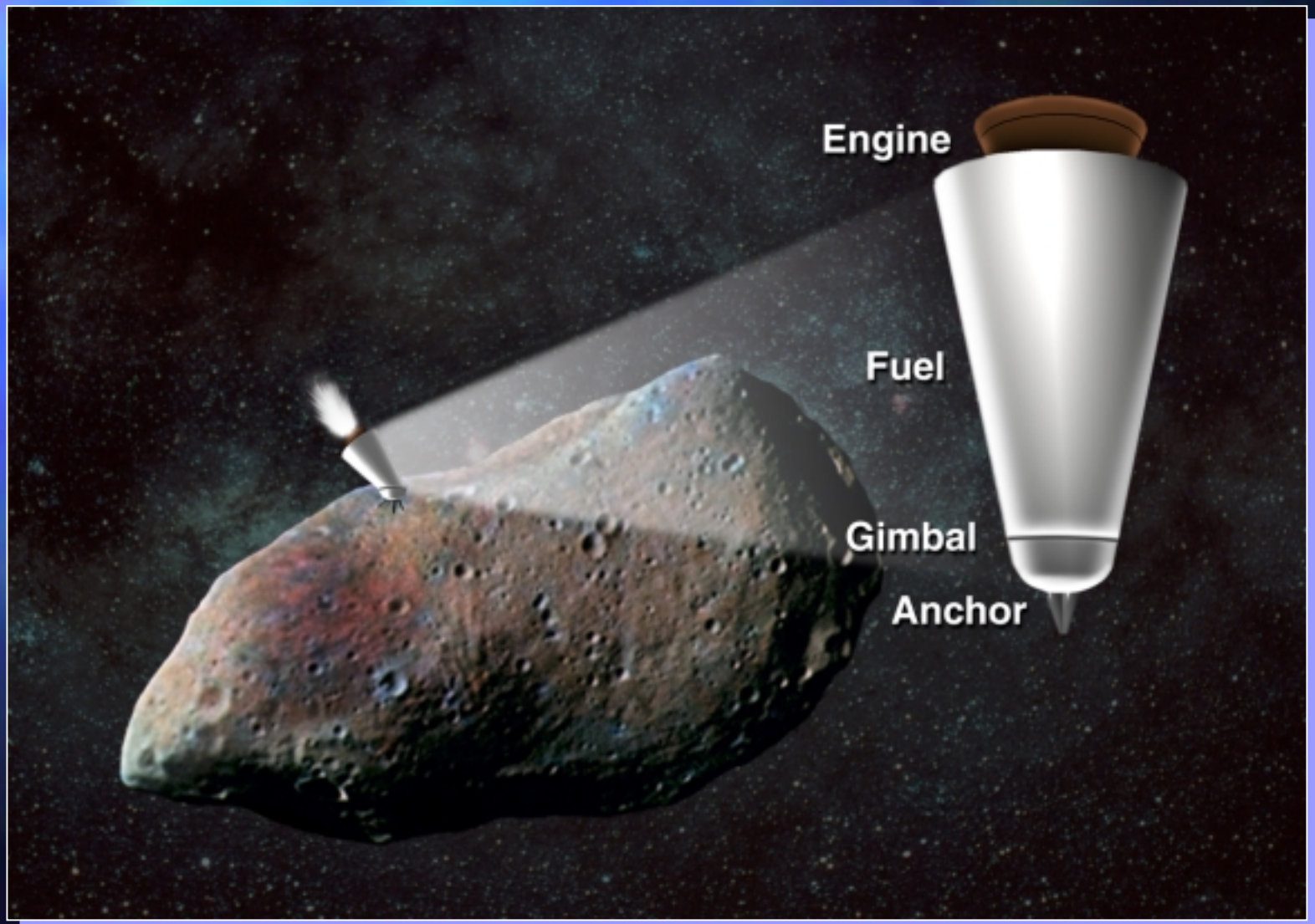
Soldier Description



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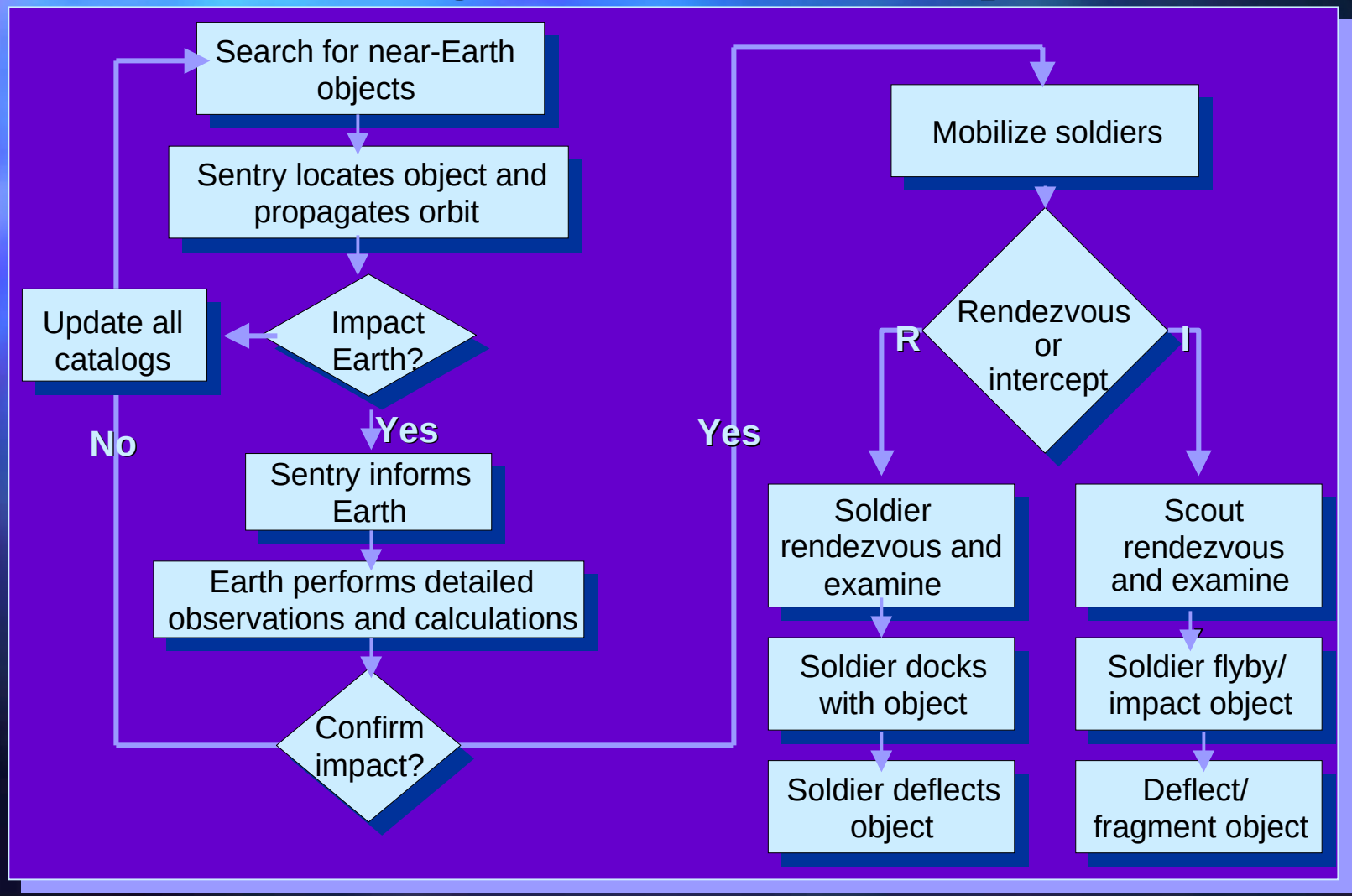
Flowchart of SHIELD Detection and Mitigation of an Earth Impactor



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We Can Start Today

- Sentry can be MIDEX
- 1-m telescopes exist
- Mid-size Explorers have been proposed with pointing, etc.
- Electronics and computing exist

It is time to extend the asteroid catalog.

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Summary

"All I'm saying is <u>now</u> is the time to develop the technology to deflect the asteroid."

(*The New Yorker*, 1998)