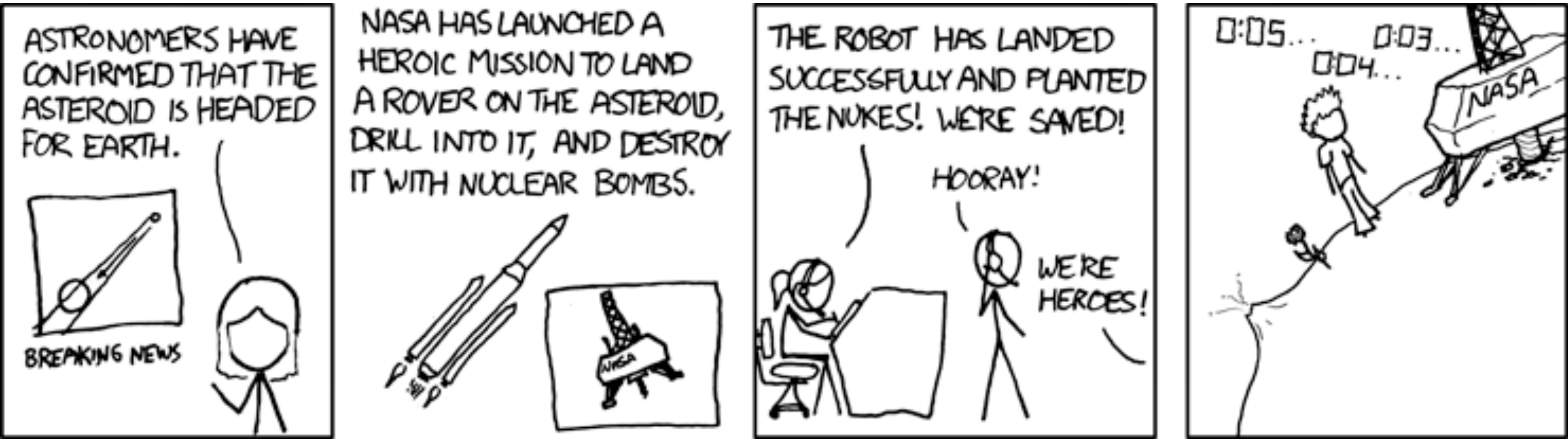
ASTR 150



- Homework 3 due tonight
- Night Observing starts next week
- Last time: Finding Impactors
- Today: Mitigation

Music: *Chiron Beta Prime*– Jonathan Coulton

Earth is in a cosmic shooting gallery!

A Ride With The Earth

An animation centered on Earth showing the known objects that have approached to within 20 million km between July 2007 and June 2008. See the Animations Page on the MPC website for a description of the symbols used in this animation.

Earth is in a shooting gallery...

i>clicker poll

Right now, the US Government is spending money on finding PHAs (potential hazardous asteroids). How much money should we be spending on this issue?

A. $0 per year -- we’ve got bigger problems to worry about.

B. Few million $ per year -- get some people working on it, and this cost is a drop in the bucket compared to e.g. DoD.

C. Few billion $ per year -- given the consequences, this requires lots of resources.

D. Few trillion $ per year -- Holy Crap, this should be our top priority!

Larger asteroids would not necessarily cause a mass-extinction but would probably wipe out millions to billions of people and decimate civilization
the chance of an asteroid doing this in the next few thousand years is remote…. But if it comes, it would be a big problem!
A more immediate problem are the smaller asteroids that cause Tunguska like events. On a city they’d cause thousands to millions of deaths, but civilization would not be destroyed. Something like this could very well happen within the next hundred years…. Or it might not…

What Do We Know About the Impact Hazard?

WE KNOW THIS…

Very Well
- **How many asteroids and comets** there are of various sizes in Earth-approaching orbits (hence, impact frequencies are known).

Very Well
- **How much energy** is delivered by an impact (e.g. the TNT equivalence, size of resulting crater).

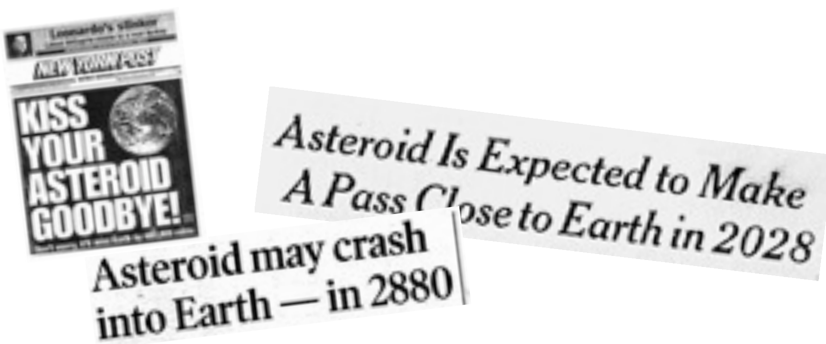
Somewhat
- How much dust is raised into the stratosphere and other **environmental consequences**.

Poorly
- **Biosphere response** (agriculture, forests, human beings, ocean life) to environmental shock.

Very Poorly
- Response of human **psychology, sociology, political systems, and economies** to such a catastrophe.

Secondary Consequences from Small, Likely Events

OVER IRAN? ISRAEL? KASHMIR?
HOW WOULD GOVERNMENTS RESPOND?



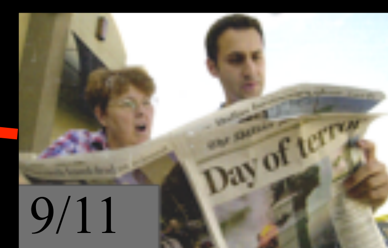
- Public and government freakout after 9/11 (e.g. stock market volatility, homeland security overreaction) could be replicated by a modest, unexpected impact disaster.
- An otherwise harmless but brilliant bolide (fireball) could be mistaken for an atomic attack, causing a dangerous response.
- Even sensational journalism or a mistaken prediction about a possible future impact could be disruptive.

Lifetime Chances?

Clark R. Chapman
Southwest Research Institute

Cause of Death	Chance: 1 in
Motor vehicle accident	90
Suicide	120
Homicide	185
Falls	250
Terrorism (Middle East)	1,000
Fire or smoke	1,100
Electrocution	5,000
Drowning	9,000
Flood	27,000
Airplane crash	30,000
Lightning strike	43,000
Asteroid impact (global)	**75,000**
Terrorism (non Mid-East)	80,000
Insect bite or sting	100,000
Natural tsunami	100,000
Earthquake	130,000
Asteroid impact (regional)	**1,600,000**
Food poisoning (botulism)	3,000,000
Asteroid impact (local)	**5,700,000**
Shark attack	8,000,000





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This is hard to understand as there is very little chance that anyone in your lifetime will die from an impact. BUT, if a global impact occurs within the next 100 million years, billions of people will die, so the average per year is still relevant. Low chance, but high risk events!

The impact threat is real, even if it is small

Earth has suffered many impacts in its past

It will suffer more in the future

The questions are:

- When will the next one happen?
- What can we do about it?

Last class, we looked at some of the threats to Earth, and we know about NASA's program to find 90% of NEAs less than 140 m across by 2020.
It is currently believed that there are approximately 20,000 objects capable of crossing Earth's orbit and large enough (140 meters or larger) to warrant concern. On the average, one of these will collide with Earth each 5,000 years, unless preventative measures are undertaken.

What do we do?

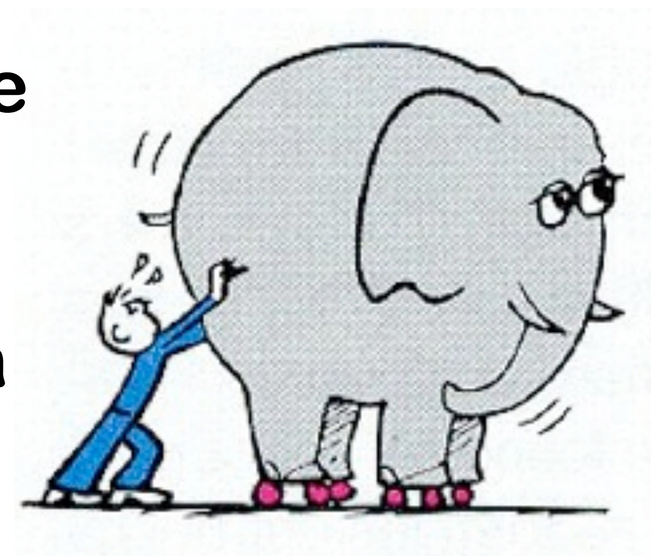
Early Detection is Key

The earlier we can detect a threat, the easier it is to mitigate the danger.

A very small change in velocity (speed or direction) can make a huge difference in months.

Remember inertia (the resistance of mass to change motion), and these things are massive.

Key issue: warning time



http://sol.sci.uop.edu/~jfalward/physics17/chapter2/chapter2.html

iClicker Poll
Asteroid vs Comet Threat

Consider two large impactors of the same size not already discovered

- an asteroid whose orbit has a small eccentricity
- a comet whose orbit has a large eccentricity

Which is likely to be detected with the least warning time before impact?

A. the asteroid

B. the comet

C. equal likelihood to detect both

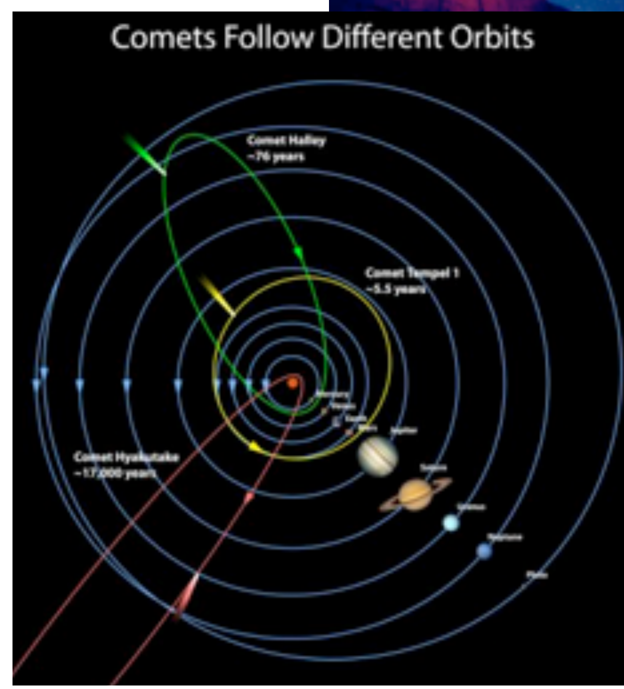
Asteroid vs Comets: Warning Time

Near-earth asteroids mostly have small eccentricities

- distances from Sun similar to us
- and distances from Sun do not change much
- from year to year, have similar brightness
- detection chances always about the same
- can detect years before impact

Comets have large eccentricities

- most of orbit spent far away from Sun
- most of time, too dim to see
- detectable only a few months before impact!
- dangerously small warning time



Comets are "wildcards"

- biggest "surprise attack" threat
- especially Oort cloud comets

So How to Mitigate?

Two main options:

Destroy

- Can be problematic
- Fragment into many pieces (all in the same orbit).. Have to track hundreds or thousands of objects now!

Delay

- Earth is moving 30 km/s, or 1 Earth diameter every 7 minutes.

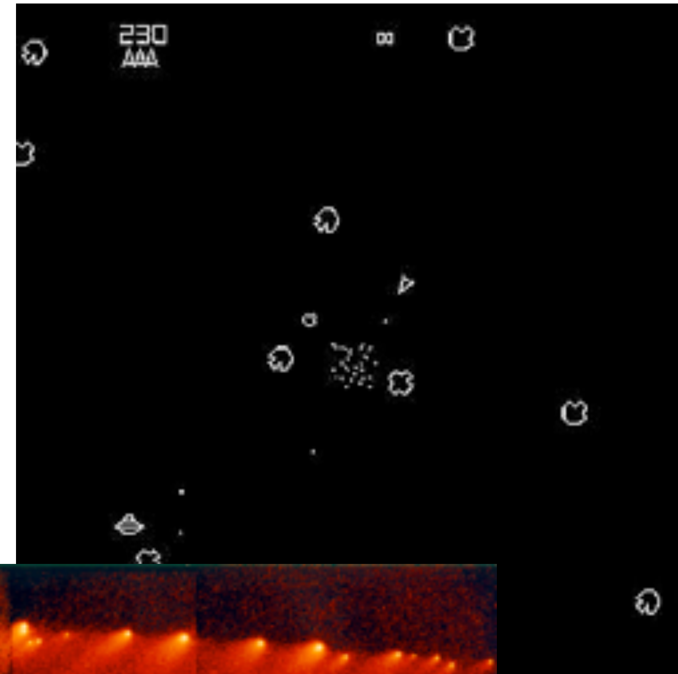
Blow the Mother Up!

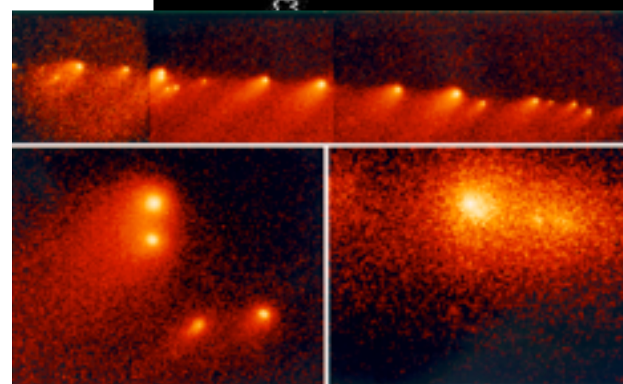
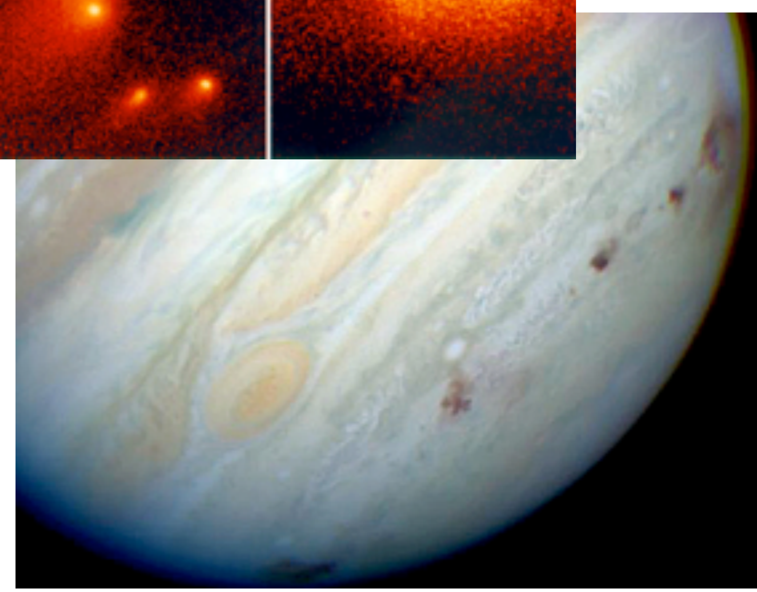
Typical option discussed is nuclear explosion.

- Might work, vaporizes or at least reduce mass.
- Last resort--possibly the only option if impactor found with very little warning

But, need to make sure not to fragment into many still dangerous pieces.

- Imagine twenty-five 50m pieces in the same orbit, would be hard to stop!
- Comet Shoemaker-Levy 9 had broken up into 20+ fragments, but still resulted in major impacts on Jupiter!



i>clicker question

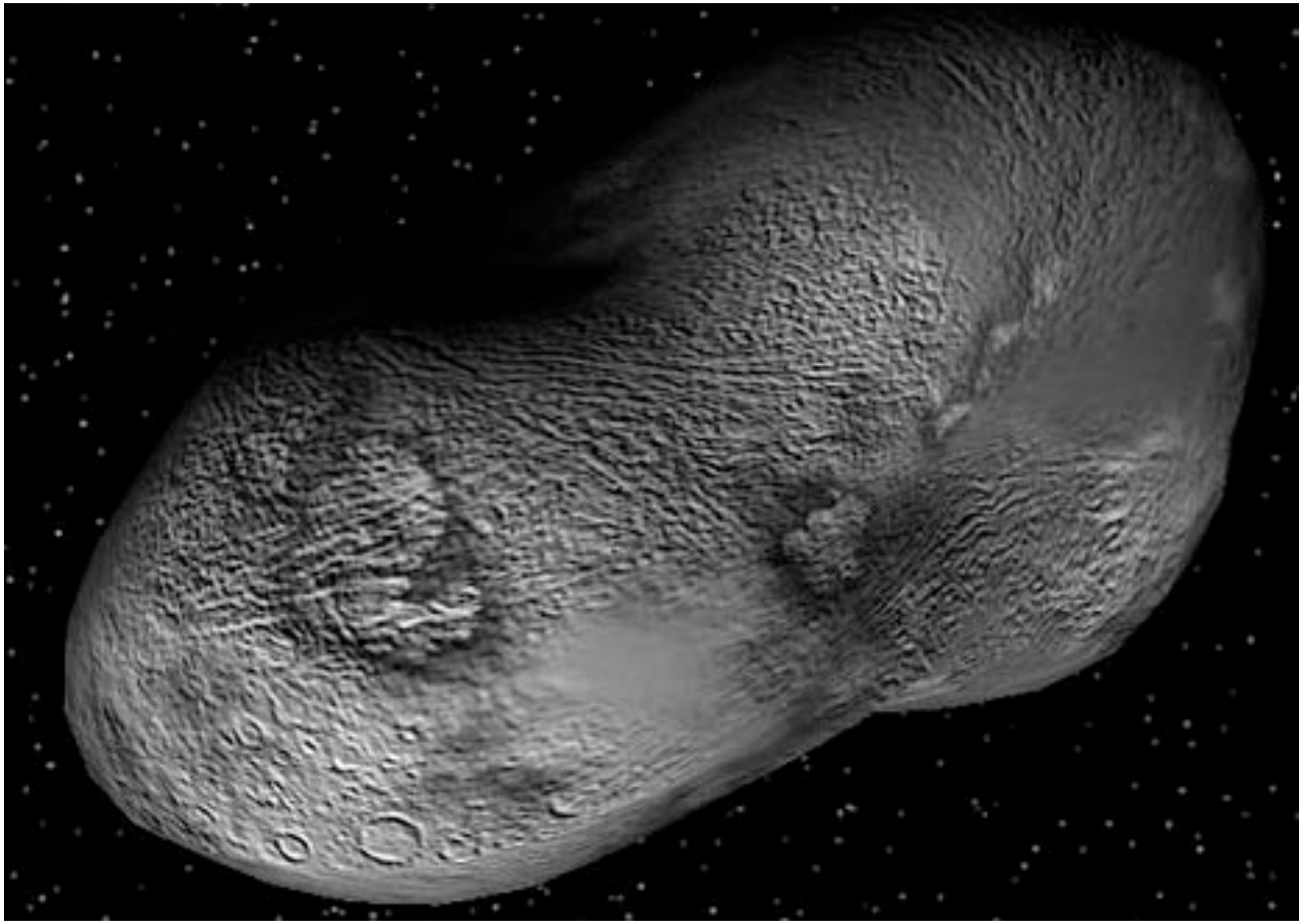
How many 50 meter fragments could be made by blowing up a single Apophis-sized asteroid (i.e., 250 meters across)?

Just guess…

A. 2
B. 5
C. 25
D. 125
E. 1250

Assuming all the fragments came out the same size (not realistic of course)
Answer D

That is 125 bigger than Tunguska fragments!



A single 250 meter asteroid like Apophis has enough material to make **over a hundred** 50 meter (i.e., Tunguska impactor sized) fragments!

So, do we trade a single massive impact for dozens of Tunguska-sized blasts?

Two delay types of mitigation options

Quick-Jolt Options

- Nuclear Deflection
- Kinetic Impact Deflection

Slow-Push Options

- Rockets/Mass Drivers
- Space Mirrors
- Yarkovsky effect
- Lasers/Particle Beams
- Gravity Tractor

Nuclear Deflection

Blow up a nuclear weapon near the asteroid/comet

- But not too near to fragment it
- Optimal height: 15-20 km

Imparted energy changes velocity by ~2 cm/sec

Is that enough?

Yes! If there is enough time!

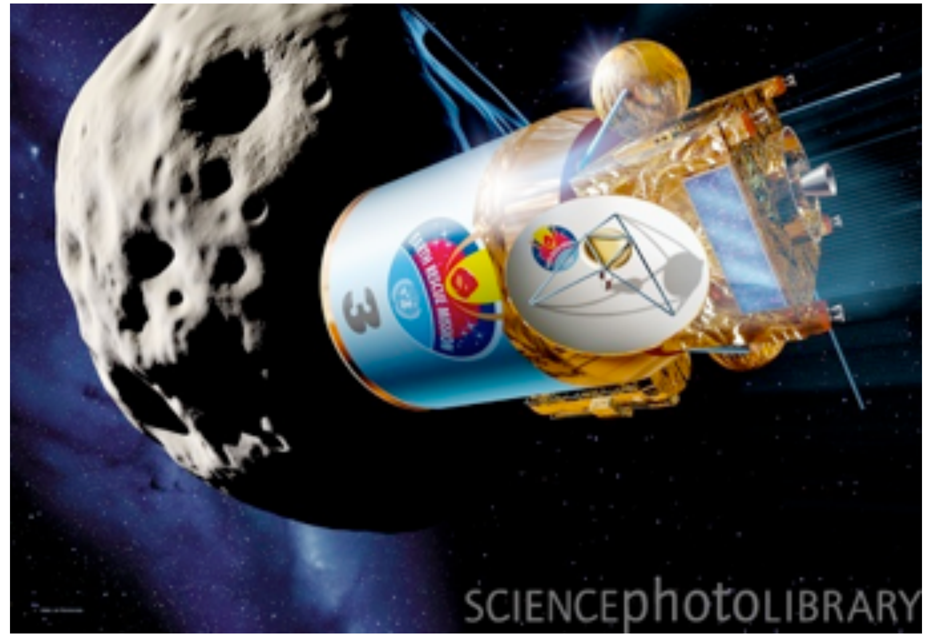
- If 10 years warning, change asteroids path by distance

$$\begin{aligned} d_{\text{deflect}} &= v_{\text{deflect}} \times t \\ &= (2\ \text{cm/s}) \times (10\ \text{years}) \\ &= 6 \times 10^8\ \text{cm} = R_{\text{earth}} \end{aligned}$$

A nuclear weapon exploded next to an asteroid could alter its trajectory

Kinetic Impact

- Hit the impactor with a projectile
- Change in speed mostly from the ejecta of the impact
- 1-ton spacecraft hitting at 10 km/sec = 0.01% energy of nuclear bomb
- Smaller change in speed

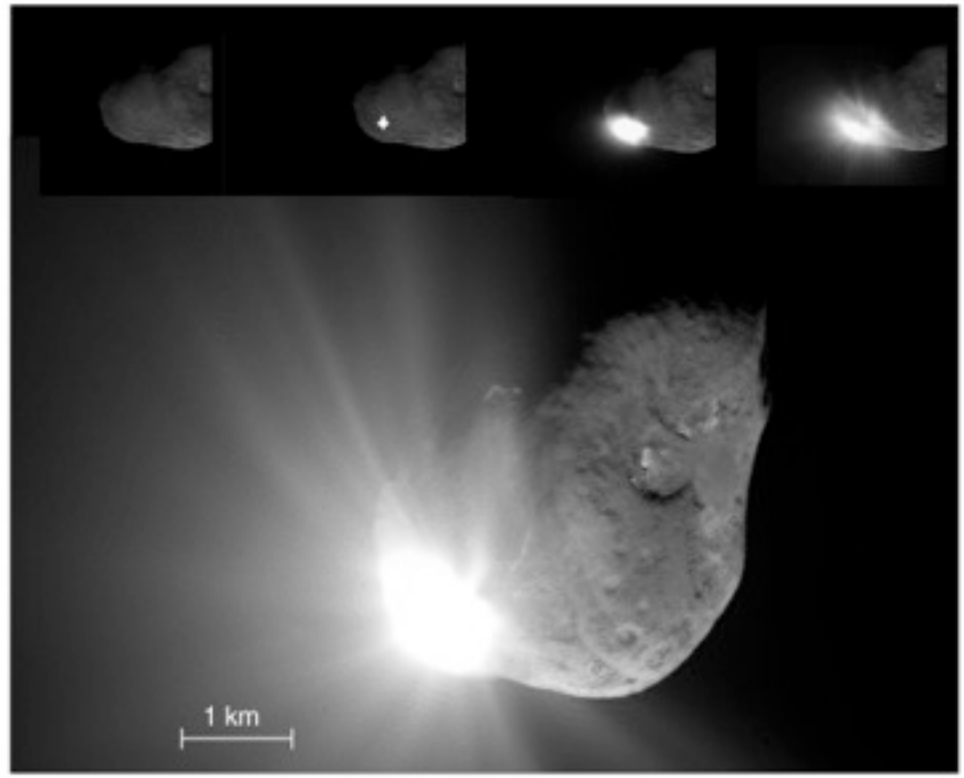


The spacecraft will collide with the asteroid to deflect the asteroid away from an Earth-bound trajectory

This is the one technique we've actually done – not to move a threatening object, but for science!

Deep Impact

- 7/4/05: Deep Impact probe collided with Comet Tempel 1
- Projectile weighed 370 kg (816 lbs)
- 15-30 million kg of material outgassed from impact site!
- Outgassing lasted for 13 days!



Initial results were surprising. The material excavated by the impact contained more dust and less ice than had been expected. In addition, the material was finer than expected; scientists likened it to talcum powder rather than sand.
Analysis of data from the Swift X-ray telescope showed that the comet continued outgassing from the impact for 13 days, with a peak five days after impact.
Outgassing changed the comets trajectory

Attaching rockets to an asteroid

Rocket thrust nudges the asteroid from an Earth-bound trajectory

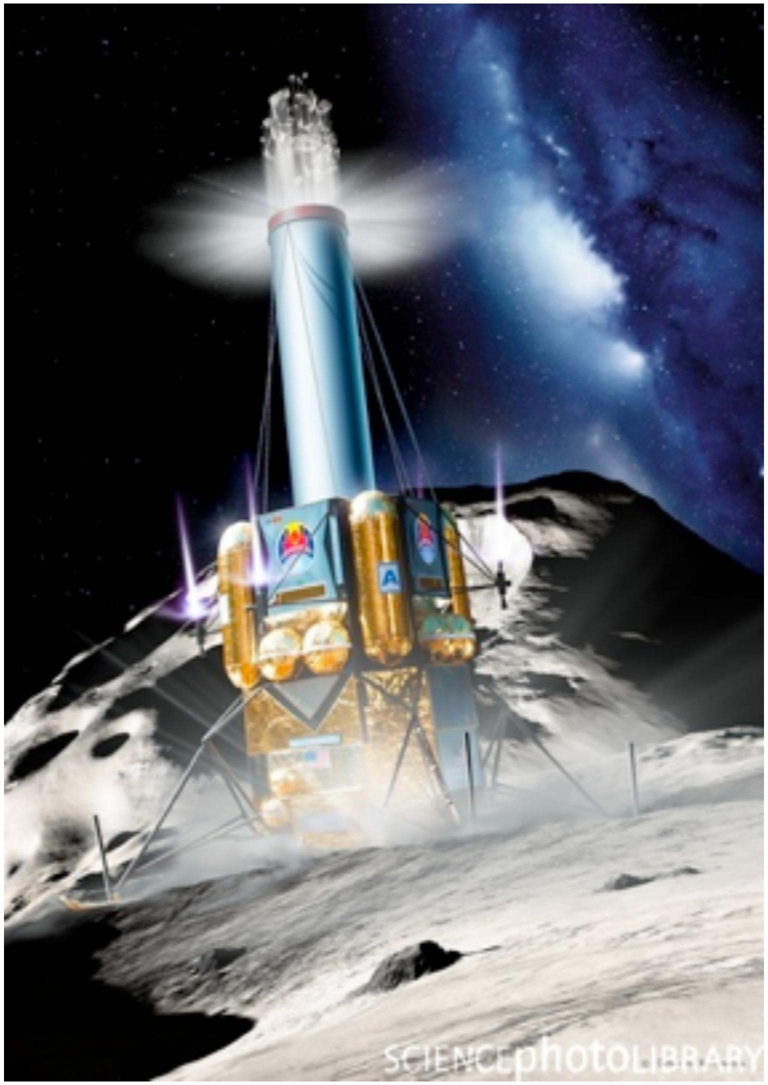
The main shuttle engine could, in theory, deflect a 1 km asteroid, with enough warning (~30 years from impact)

Rockets firing from the surface of a near-Earth asteroid

Newton's 3rd Law: for every action there is an equal and opposite reaction!
One problem with rockets – we must bring the fuel for the rockets to the asteroid

Mass-drivers

- Robot drills into the asteroid and electromagnetically catapults material into space
- Ejecting material creates thrust
  - like a rocket
  - but fuel is asteroid material
- Slowly nudges asteroid away from an Earth-bound orbit
- Newton’s 3rd Law!



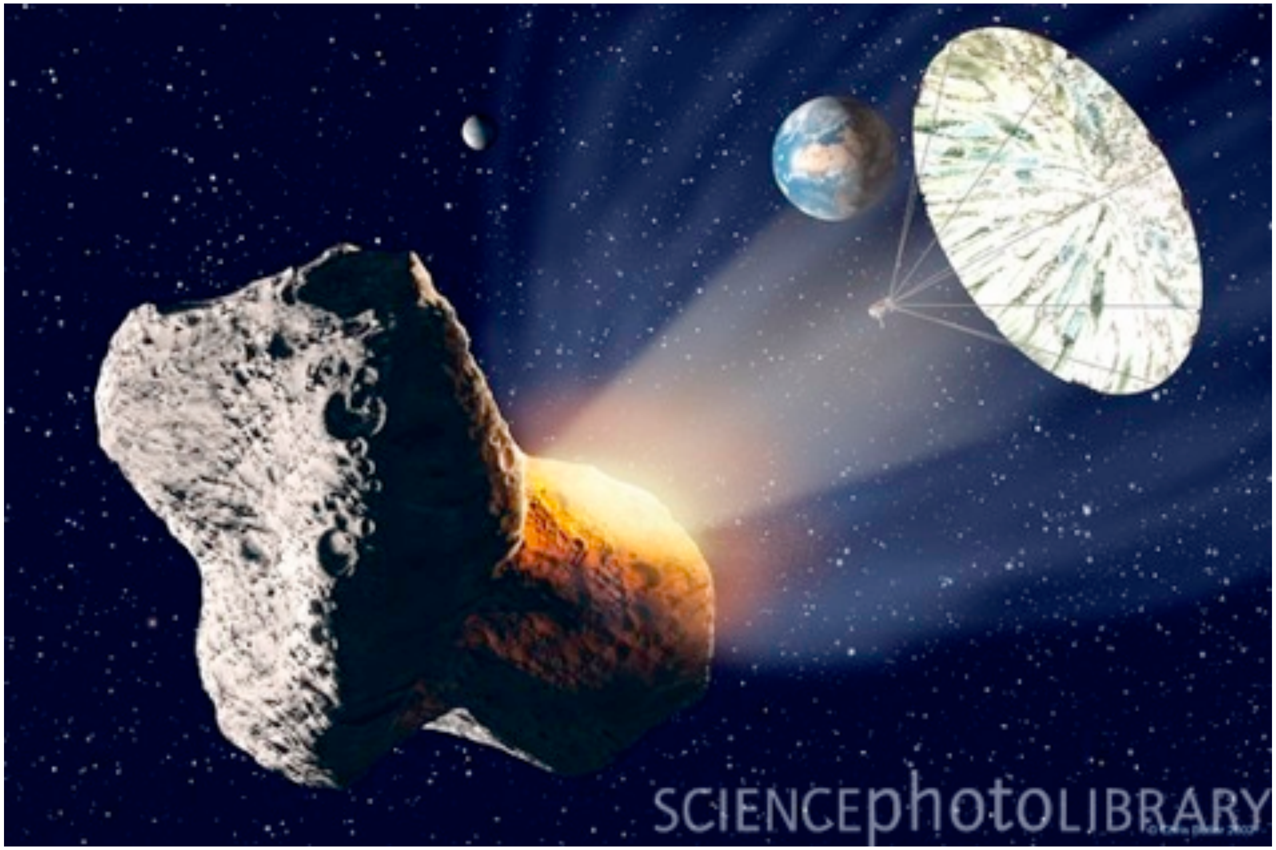
So, no fuel problem, but now we are sending a complicated robot to the asteroid
It must quarry, load, and catapult the material – and be completely automated!

Another issue: Asteroids ‘tumble’

How do you ensure the thrust is in the right direction?

How do you ensure the thrust is in the right direction from a body tumbling in space?

Space Mirrors



Use the Sun to melt the asteroid surface

This removes material and creates a jet

A parabolic reflector focuses sunlight on the asteroid, heating the surface and vaporizing ice or dust. The stream of heated material produces thrust, just as a rocket does, and alters the course of the asteroid. An experimental solar mirror called Znamia was deployed in February 1993 from a Russian Progress spacecraft. It was 20 metres in diameter. A system capable of deflecting an asteroid would have to be much larger, perhaps kilometres across.

Space Mirrors

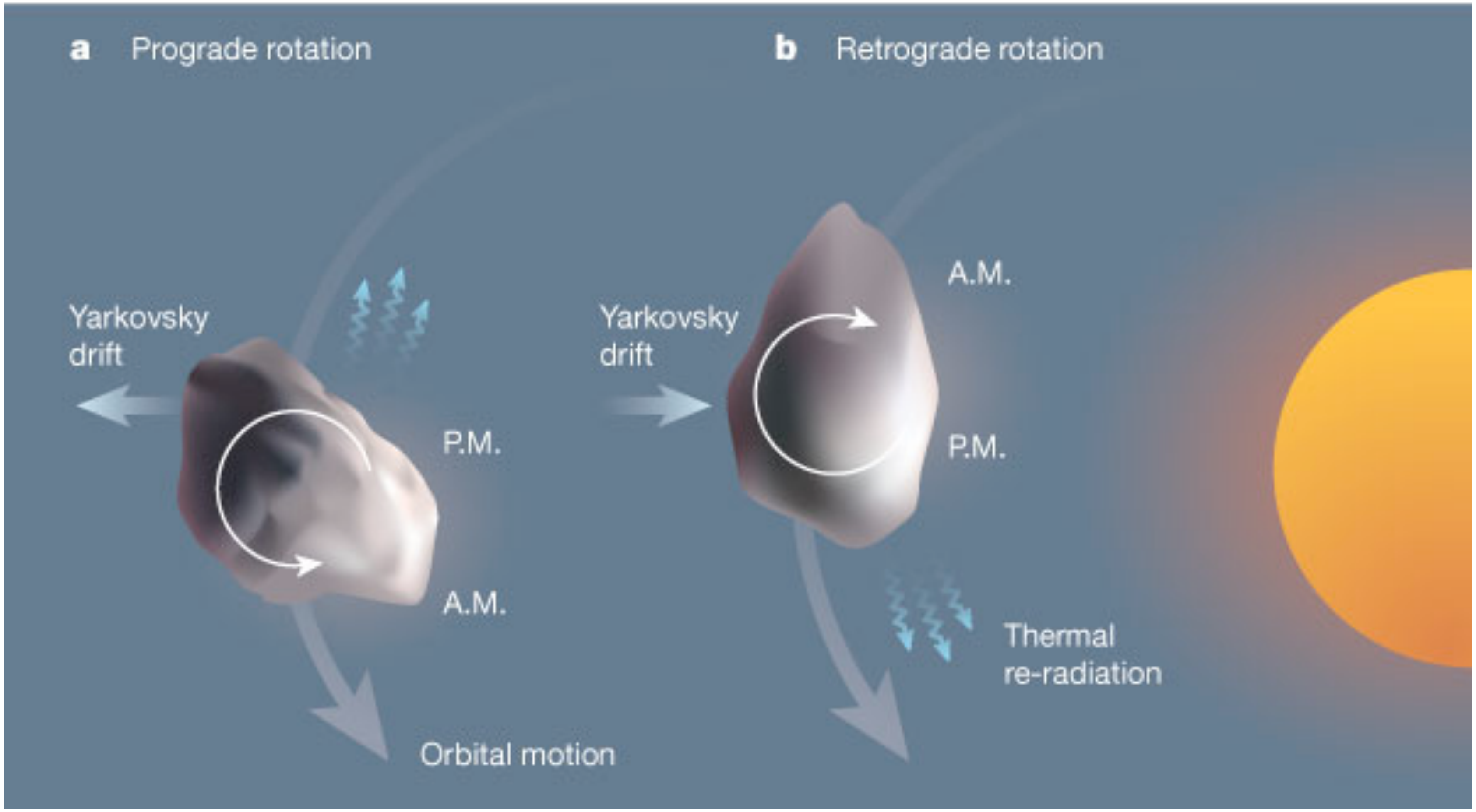
Lasers/Particle Beams

- Use a laser to heat the surface of an asteroid or comet
- Gas jets are emitted
- Jets act as rockets to propel the object off its impact course
- Works best on comets or water-bearing asteroids

Water or other volatile compounds vaporize easier
A hunk of iron/nickel would not vaporize easy,

Lasers/Particle Beams

Yarkovsky Effect



- A spinning body is hottest on its afternoon side including the Earth!
- The release of infrared heat radiation slightly pushes on the asteroid, changing its orbit

The Yarkovsky Effect is an acceleration that is produced when an asteroid's surface is heated by the sun during the day, and then cools off during the night. The asteroid tends to emit more heat from its afternoon side, just as the evening twilight on Earth is warmer than than morning twilight. This unbalanced thermal radiation produces a net acceleration.
Over time an asteroid rotating in the same sense as its motion around the Sun is gradually accelerated and pushed into a wider orbit. Conversely, a retrograde spinner is doomed to spiral inward toward the Sun.

Using the Yarkovsky Effect

- If we change the asteroid's reflectivity (color)
  - then we change its ability to absorb heat
  - and so we change its Yarkovsky drift
- Change reflectivity by
  - Deep Impact-type mission excavates brighter ejecta to the surface
  - Paint the surface white!

Spraying white paint onto the side of an asteroid can alter its trajectory!

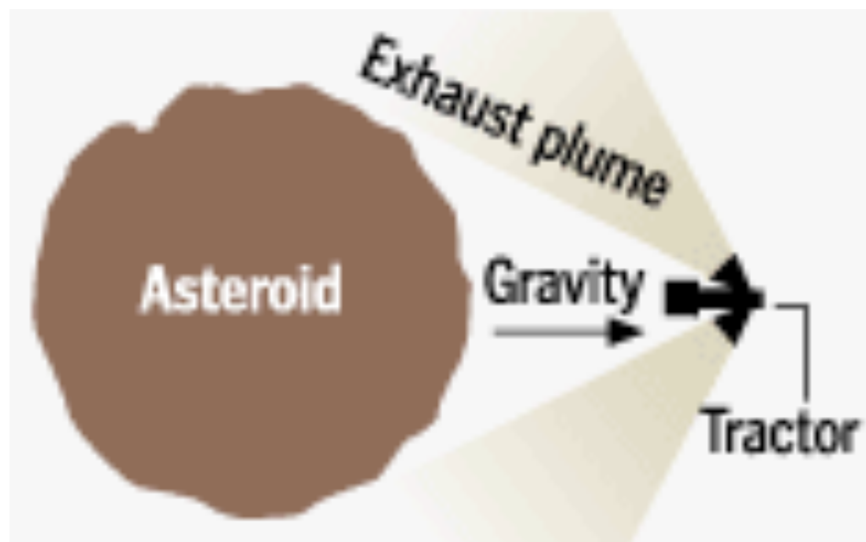
Gravity Tractor

Park a large spacecraft close to the asteroid

- each object exerts equal and opposite gravity force on the other

Fire spacecraft engines for months (or more) - long continuous thrust

Aim engines so thrust doesn't hit the asteroid!



Gravity Tractor: The most elegant technique

Gravity acts as a towline connecting the asteroid/ comet and spacecraft

The method is slow

But unaffected by object composition or spin rate

Also allows precise control of object trajectory

The spacecraft effectively tows the asteroid along with it by using gravity as the towline. If you only need to nudge a football-field- size impactor out of a keyhole pass, a spacecraft with the mass of just a few metric tons (comparable to a typical communications satellite) could do the job with a few months of thrusting. You might alter the asteroid's speed by only a fraction of a millimeter per second, but that's all it might take to miss a small keyhole 25 years later

i>clicker question

We do know of an asteroid that has a 1 in 300 chance of hitting us in 2880. What should we do?

A. Blow it up into smaller pieces that will dissipate over the next 800 years.
B. Send a Deep Impact-style spacecraft to impact the asteroid.
C. Coat it in white paint as soon as possible.
D. Construct a giant laser on the Moon (e.g. Alan Parsons Project) to deflect the asteroid.
E. Nothing; we can't reliably predict asteroid orbits more than ~20 years in advance.

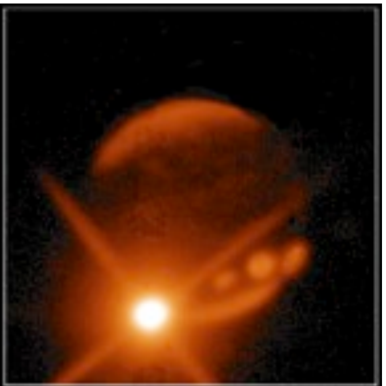
Answer E

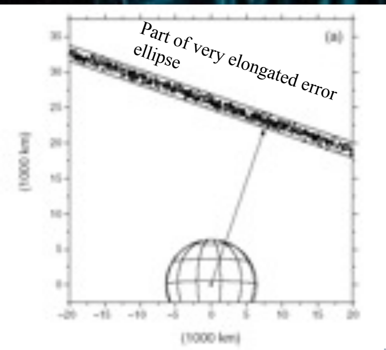
Early Detection is Key

- The earlier we can detect a threat, the easier it is to mitigate the danger
- A very small change in an object's velocity can make a huge difference over long periods of time

An example of detecting the impactor too late!

Common Misperceptions





- **Long waiting time until next impact**
  - **Instead, we should think of <u>chances</u> of disaster and our responsibilities "on our watch"**
- **Judging consequences quantitatively**
  - **Civilization-ending impact vs. K/T mass-extinction**
  - **"one death" vs. 100 deaths/yr vs. 3000 9/11 dead vs. we will <u>all</u> die in next 100 years (what are our values?)**
  - **Shoemaker-Levy 9 Jupiter impacts overshadowed the Rwanda genocide in the news (July 1994)**
- **"Blow it up" on the way in**
  - **Movies misrepresent reality of decades lead-time**
- **NEA is "on an impact course with Earth"**
  - **NEA discovery process, error ellipses, NEA orbits the Sun many times before impact: <u>not intuitive</u>!**

Asteroids are Not Likely to Destroy our World…

…but we can contemplate the NEO hazard as the most extreme environmental disaster, and put the lesser, more likely ones into context…

…and distinguish between societal issues like global warming and true, sudden catastrophes.

Many threats to society and our lives (flu, war, famine…global warming) are here today.

Asteroids <u>are</u> in our future…as places to travel to, as fuel stations for a spacefaring civilization …let's hope they don't come to us first!

Imagine

Walking to class next week, you notice that you suddenly have two shadows.

You turn quickly, and it looks like there are two Suns, but one of them is moving toward the horizon!

Very Fast!

As it meets the horizon, there is a incredible bright flash, and you can feel the heat!

Imagine

An earthquake throws you to the ground, and you get a little worried as you notice that the trees in the distance have burst into flames.

A sound wave bears down on you at 700 mph!

Like a mighty thunderclap, it sweeps over you, pulverizing all the nearby buildings…

As your body disintegrates, you wonder what Leslie was going to lecture on today.

Asteroids are the number one astronomical threat, but not the only one!