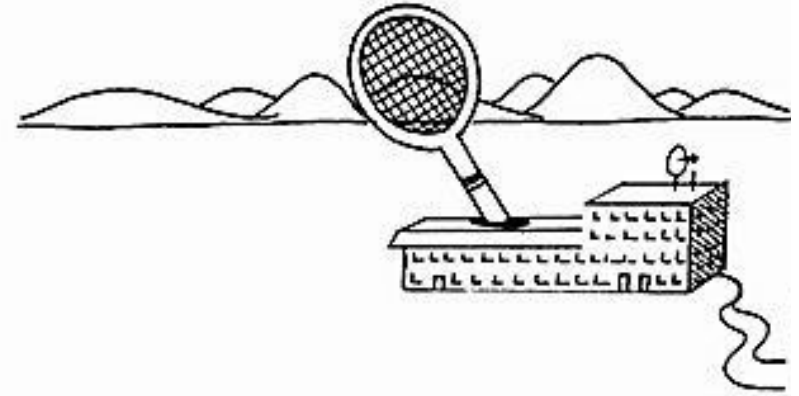


# ASTR 150

- ▶ **Homework 3** due next Monday (Sept 30th)
- ▶ No lecture next Wed/Fri
  - ▶ Good time to finish asteroid lab
- ▶ Last time: Impacts and the Earth
- ▶ Today: Finding Impactor



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*Music: Until the End of the World– U2*



## **If an asteroid hits the ocean, it will create a tsunami**

oceans cover about 75% of the Earth's surface, so it is likely the asteroid will hit an ocean. The amount of water in the ocean is nowhere near large enough to "cushion" the asteroid. The asteroid will push the water aside and hit the ocean floor to create a large crater. The water pushed aside will form a huge tidal wave, a tsunami.

# How tall would the tsunami wave be?

- ▶ Depends on distance from impact site

Distance	Height
300 km	1.3 km
1,000 km	550 m
3,000 km	250 m
10,000 km	100 m



300 km = 200 miles  
1000 km = 600 miles  
3000 km = 2000 miles  
10000 km = 6000 miles



## **Material ejected from the impact reenters the atmosphere, setting fires around the Earth!**

4

The material ejected from the impact through the hole in the atmosphere will re-enter all over the globe and heat up. For 30 minutes to an hour after the impact, "the entire sky was like a big, glowing sheet of rock," "Imagine the effects of a thousand shooting stars suddenly entering the atmosphere and ablating at an altitude above 60 km. The sky would turn from its normal transparent blue to a brilliant red sheet of glowing lava," The shooting stars wouldn't have hit you; they stop at 60 km or so above the ground. But there's so many of them that you're standing there in this radiation bath, hot enough to set paper on fire. Global fires will put about  $7 \times 10^{10}$  tons of soot into the air.

# Acid Rain

Heat from the impact **cooks the atmosphere**

- ▶ produces nitric and nitrous acids

Creates a worldwide deluge of **acid rain**:

- ▶ Damage to foliage
- ▶ Kills upper ocean organisms

Nitrates set off chemical reactions that destroy the ozone layer

- ▶ removes shielding from Sun's UV rays



**Acid rain would cause additional devastation**

Shells of ocean organisms will dissolve in the acid water. That along with the "impact winter" kills off about 90% of all marine nanoplankton species.

Note: A majority of the free oxygen from photosynthesis on the Earth is made by nanoplankton.

The ozone layer is destroyed by O<sub>3</sub> reacting with NO. The amount of ultraviolet light hitting the surface increases, killing small organisms and plants (key parts of the food chain).

# Climate Change: Impact Winter

Within a day, dust and soot from fires would **block out the Sun**

Plunging the world into darkness for as long as a year

Temperatures drop, greater than during the Ice Age

Cool period may last a decade



**Without sunlight, the Earth would freeze after the impact**

# Climate Change: Global Warming?

Burning of plants and killing of plankton releases large amount of CO<sub>2</sub> gas

After the impact winter, a warming period may follow

Temperatures rise for about 100 years

GLOBAL  
WARMING



Temperatures would rise for up to a century, Toon conjectures. "Temperatures don't just go back to normal after the global cooling but rise considerably higher," notes Sharpton. "There's a shift in temperature and it stresses the heck out of things. You might just be getting used to the cold and all of a sudden you've got this hot dry spell."

# i>clicker question

**The impact of a 10-km-diameter asteroid on the surface of the Earth would very likely**

- A. disrupt the global ecology and cause the extinction of a large percentage of all species living on the Earth.**
- B. create significant damage near the impact site but have relatively little lasting worldwide effect.**
- C. shatter the Earth into fragments.**
- D. completely destroy life on the Earth.**



# i>clicker question

**Suppose there had been no major impact in the last 65 million years. What might Earth be like today?**

- A. Mammals would have evolved differently; humans might not be here.**
- B. Humans would be directly competing with dinosaurs for food.**
- C. Dinosaurs would have evolved into humans.**



**A very profound statement  
for humanity's existence**

**Life on Earth started long ago, but the path that led to us had to go through several catastrophic events that almost wiped out everything on Earth. Our ancestors survived by adapting quickly enough.**

Furthermore, the species that's going to dominate Earth millions of years from now will not necessarily be us....

# Last word: Neil de Grasse Tyson



<http://www.youtube.com/watch?v=H6XbRtEREd0>

**On the bright side, it could be worse...**



[http://www.youtube.com/watch?v=zc4HL\\_-VT2Y](http://www.youtube.com/watch?v=zc4HL_-VT2Y)



**If something like Tunguska happens every ~100 years, how come we haven't heard about it? Why haven't more people been killed by asteroid impacts in the past?**

- **Before the 20th Century, human population was much lower, so likelihood of someone being affected is lower.**
- **If someone did see a Tunguska, less likelihood of word getting around -- news didn't disperse as easily back then.**

Crater is 1 km in diameter.

Impact was 20 megatons

Privately owned National Landmark.

# Witness to Disaster?

**Impact cratering is an important process in the history of Earth and other planets**

**Have humans ever seen a large impact?**



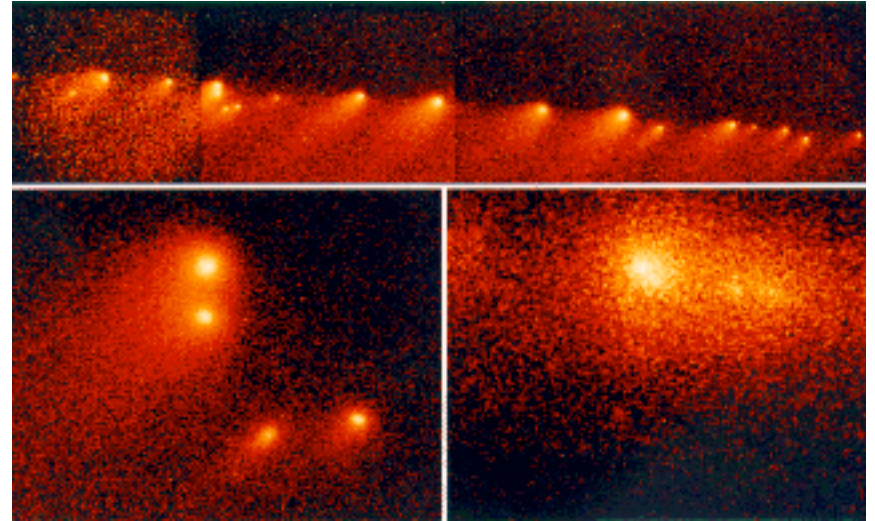
**YES, we have seen a major impact...on  
Jupiter:**

In 1994, Comet Shoemaker-Levy 9 (5km!) -- already broken up into fragments -- collided with Jupiter. Each fragment impacted, reminding us that catastrophic collisions can and do happen.

# The sequence of events

The collision of the comet with Jupiter occurred over several days, 16-22 July 1994  
It was the first collision of two solar system bodies ever observed

- ▶ At least 20 fragments hit Jupiter
- ▶ at speeds of 60 km/second  
= 130,000 mph



<http://www2.jpl.nasa.gov/sl9/background.html>

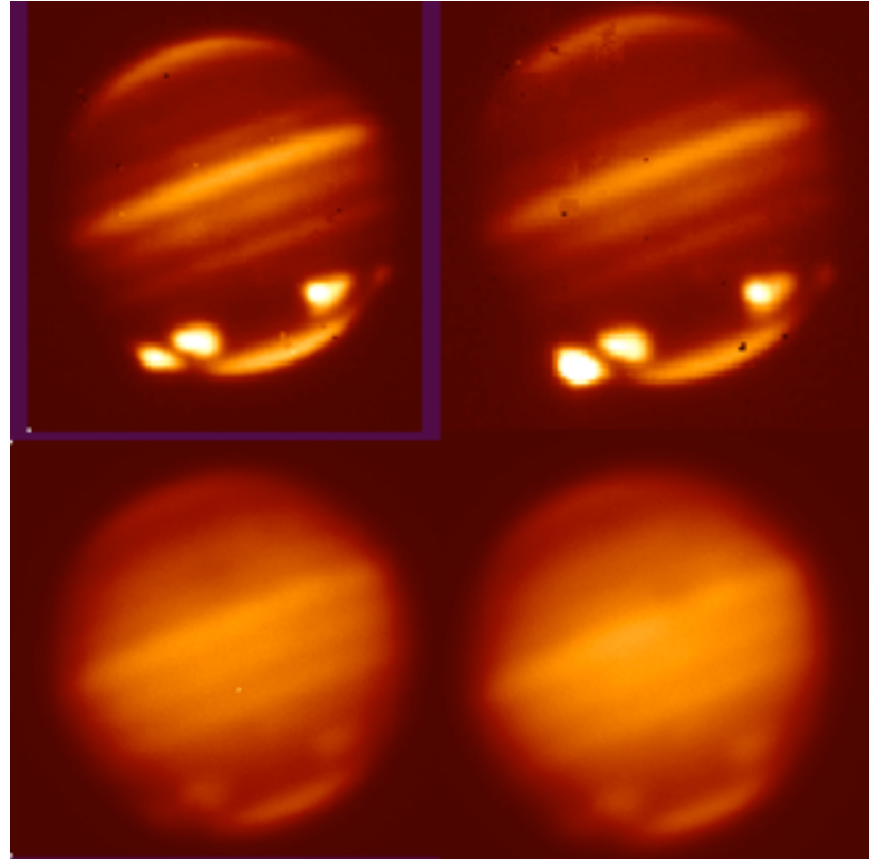


# Sizes of fragments

The largest fragments were about 2 km in diameter

Huge plumes thousands of km high were generated

Comparisons can be made with the Cretaceous-Tertiary (KT) extinction event– Dino Killer



<http://www.as.utexas.edu/mcdonald/comet/jul21.gif>

# *Stop Giggling?*



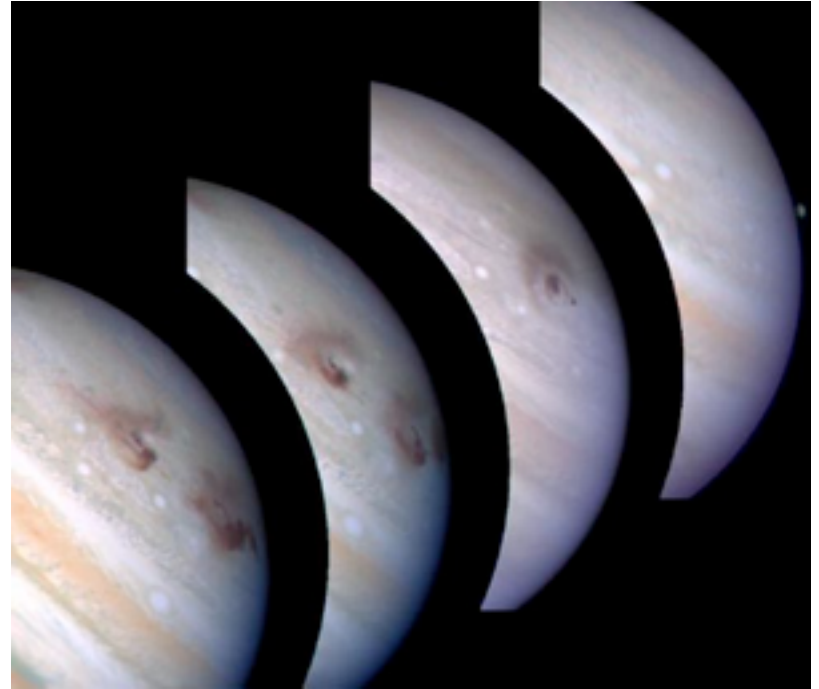
<http://www.youtube.com/watch?v=16AIt36-whc>

# Energies

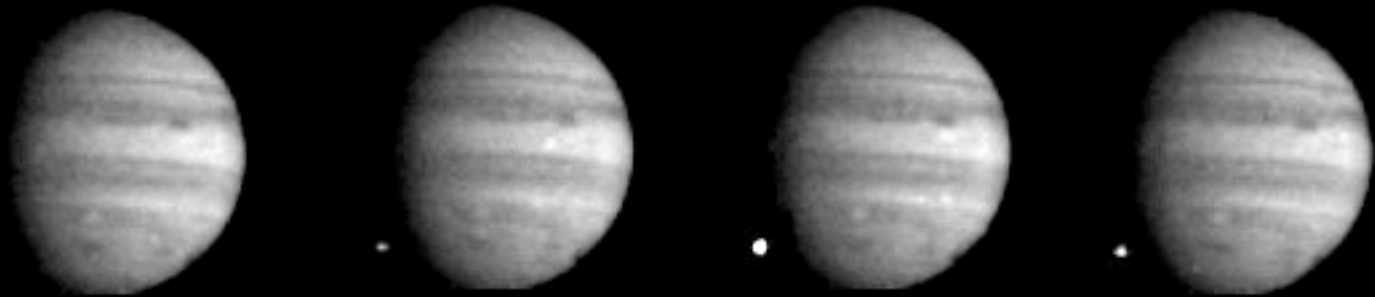
**Fragment A struck with energy equivalent to 225,000 megatons of TNT, the plume rising to 1000 km**

**Fragment G was the biggie, with 6,000,000 megatons TNT energy and a plume rising to 3,000 km**

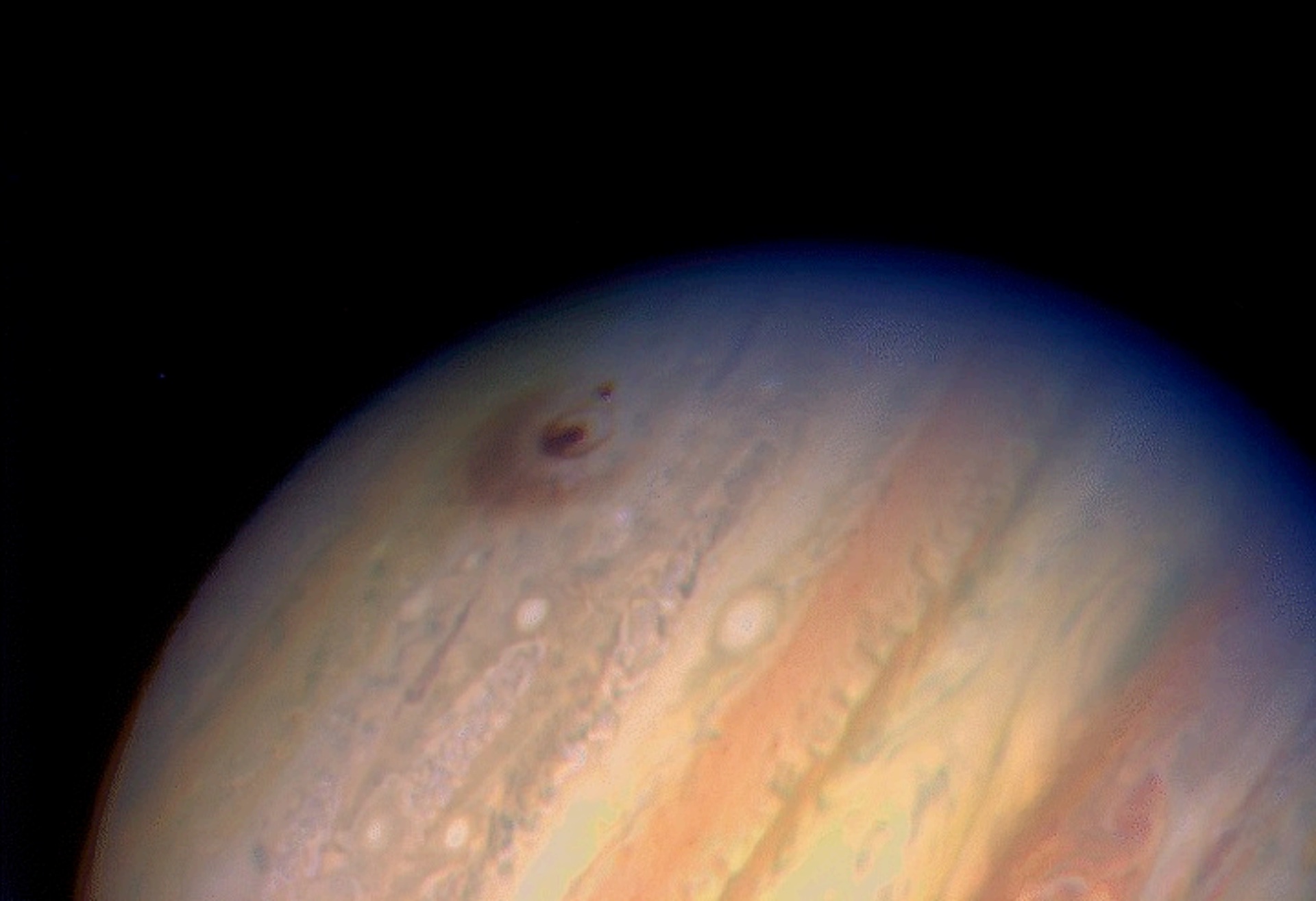
**Fragment G (and K, L) created dark impact sites whose diameters were at least that of Earth's radius**

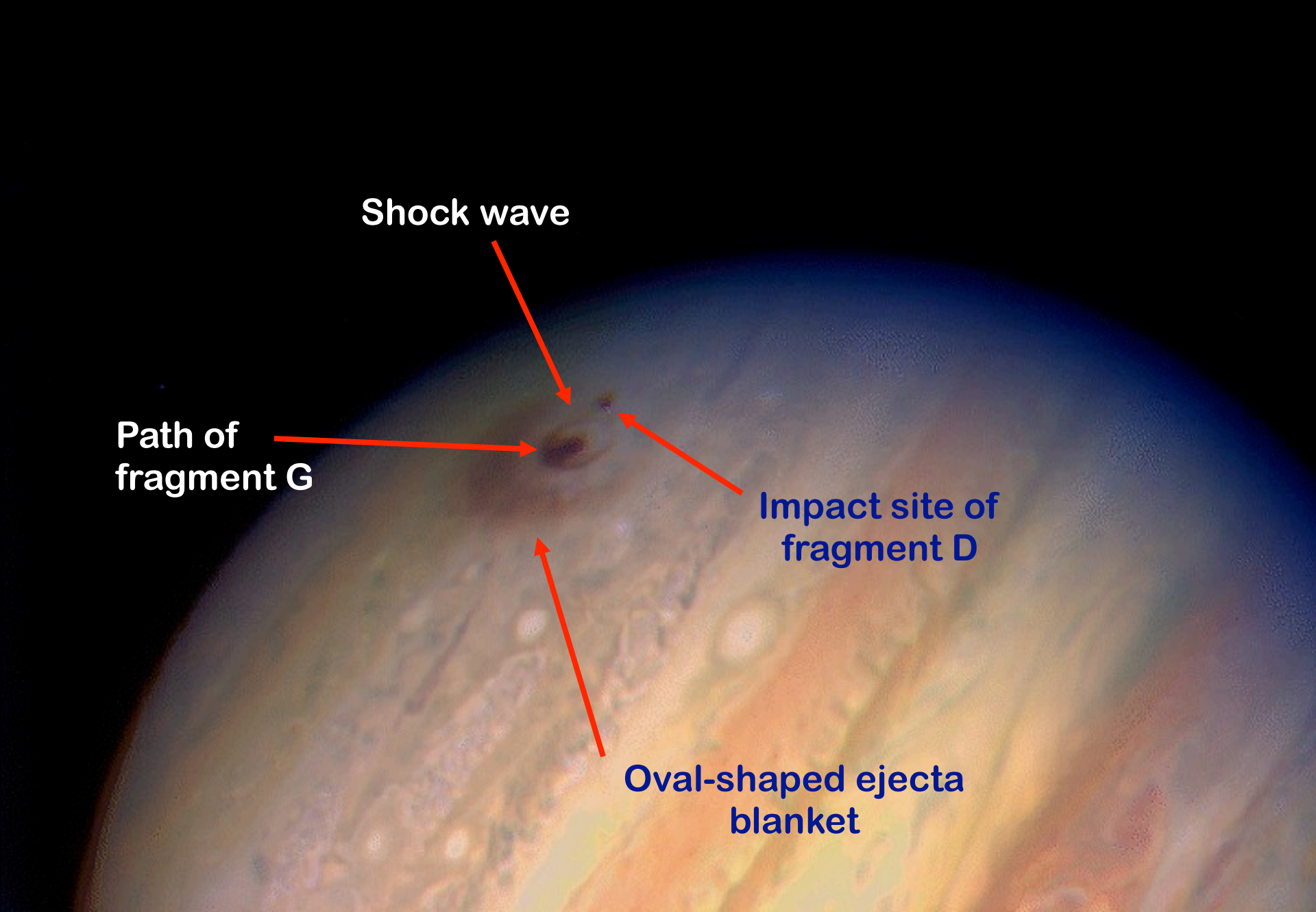


[http://www.sai.msu.su/apod/image/9808/sl9gevol\\_hst.jpg](http://www.sai.msu.su/apod/image/9808/sl9gevol_hst.jpg)



Images of Jupiter catch the fireball of fragment G. Amazing!



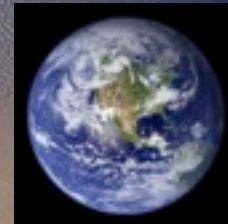


**Shock wave**

**Path of  
fragment G**

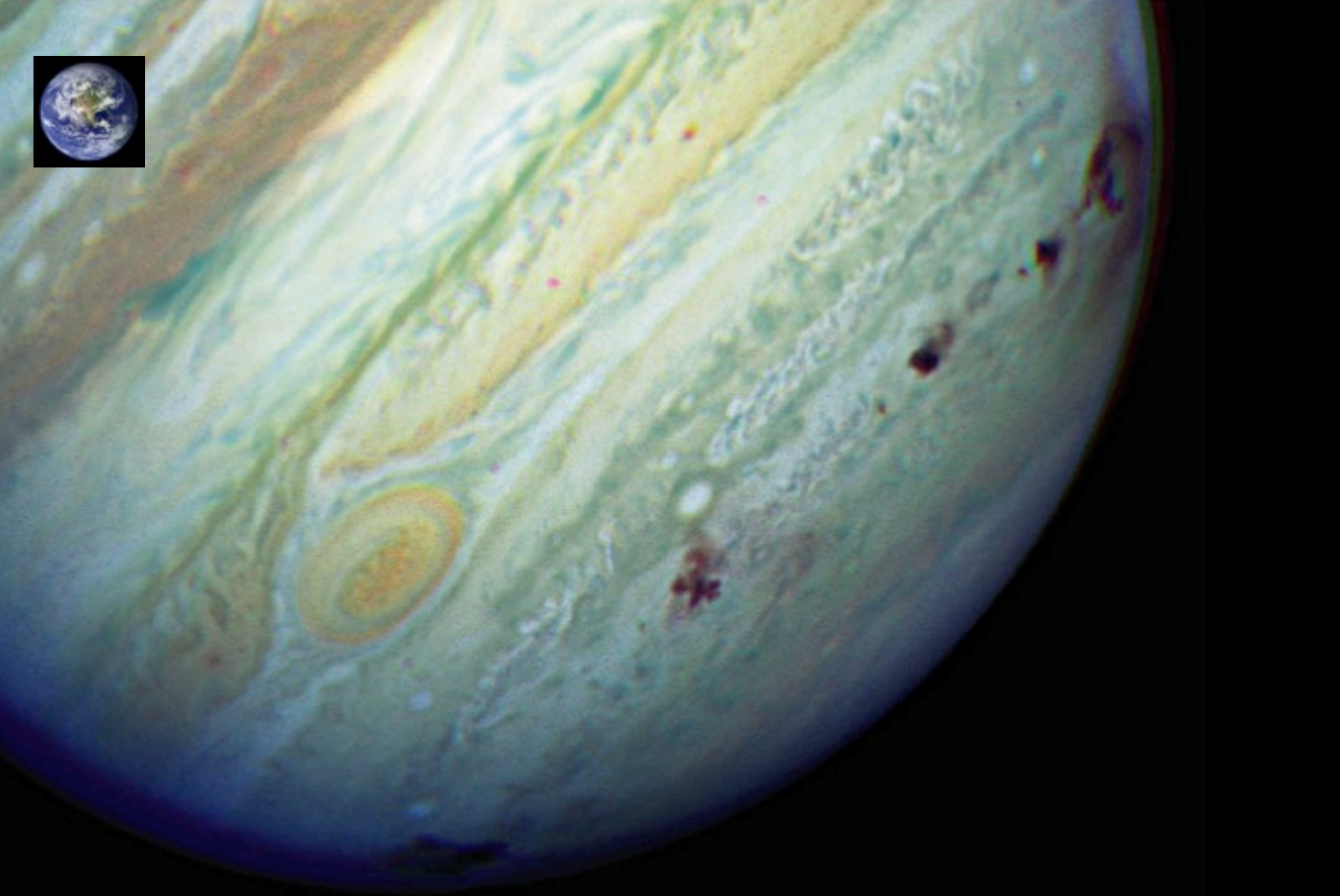
**Impact site of  
fragment D**

**Oval-shaped ejecta  
blanket**



## **Dusty debris at an impact site -- it's as big as Earth!**

Though note that this is debris on the top of Jupiter's atmosphere.  
The comet exploded in the atmosphere & didn't hit ground.



Several impact sites



# Even More Recently: July 19, 2009

Anthony Wesley, a 44-year-old computer programmer from Australia, made the discovery using his 14.5 inch telescope.

Earth-sized impact scar on Jupiter, but:

- ▶ we didn't see the impactor!
- ▶ we didn't see the collision!

Probably a comet impact, but we don't know.



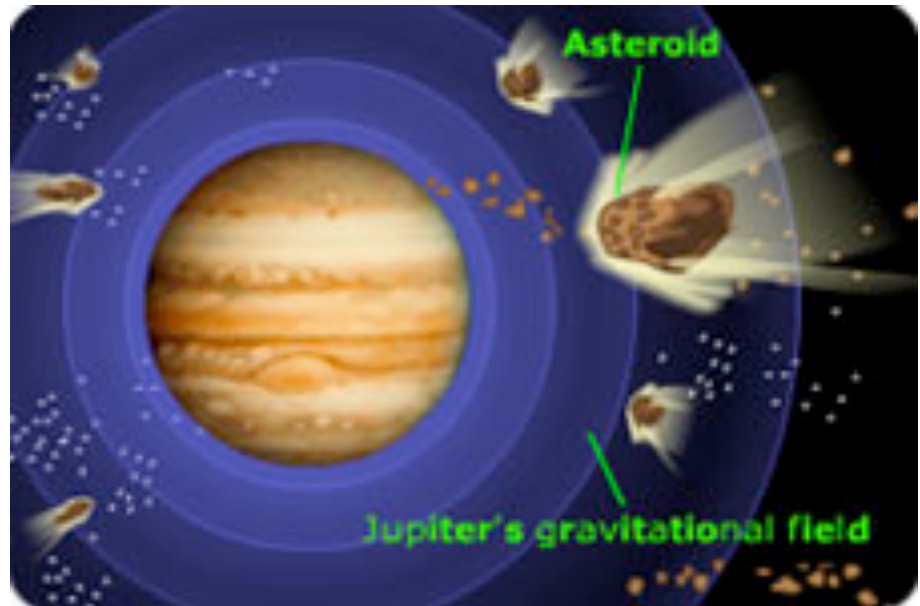
<http://jupiter.samba.org/>

# Jupiter: The Vacuum Cleaner

**Strong gravitational influence, so many small comets and asteroid impacts.**

**Estimate that rate of impacts is 2000 to 8000 higher than the rate on Earth!**

**Without Jupiter, the probability of asteroid impacts with the Solar System's inner planets would be greater.**

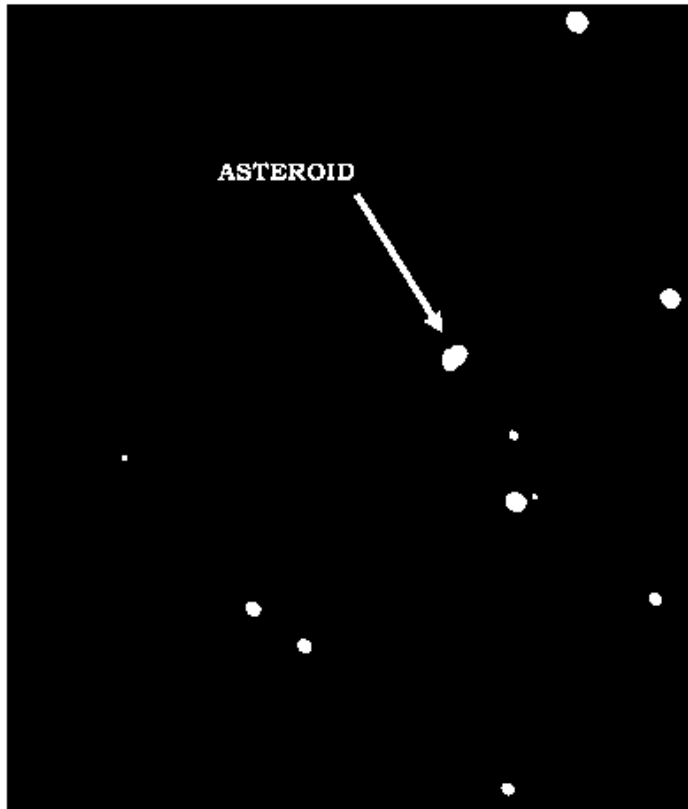


[http://www.bnsc.gov.uk/assets/channels/education/se/jupiter\\_3.jpg](http://www.bnsc.gov.uk/assets/channels/education/se/jupiter_3.jpg)

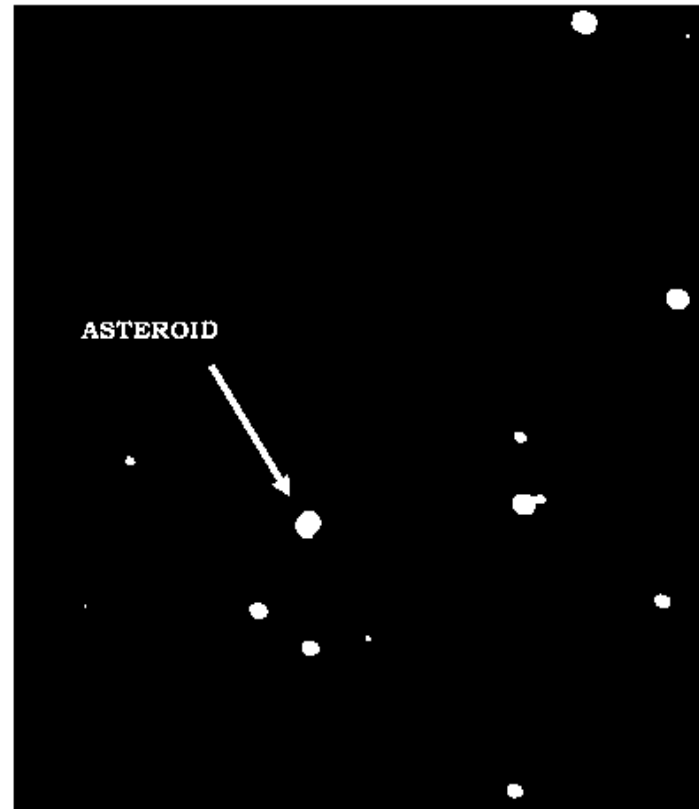
# GLOBAL DEFENSE I: FINDING THE THREAT



# How do we find asteroids?



**IMAGE NUMBER 1**



**IMAGE NUMBER 2  
(25 minutes later)**

**In two pictures of the sky a few minutes apart, the stars will not move with respect to one another, but an asteroid will**

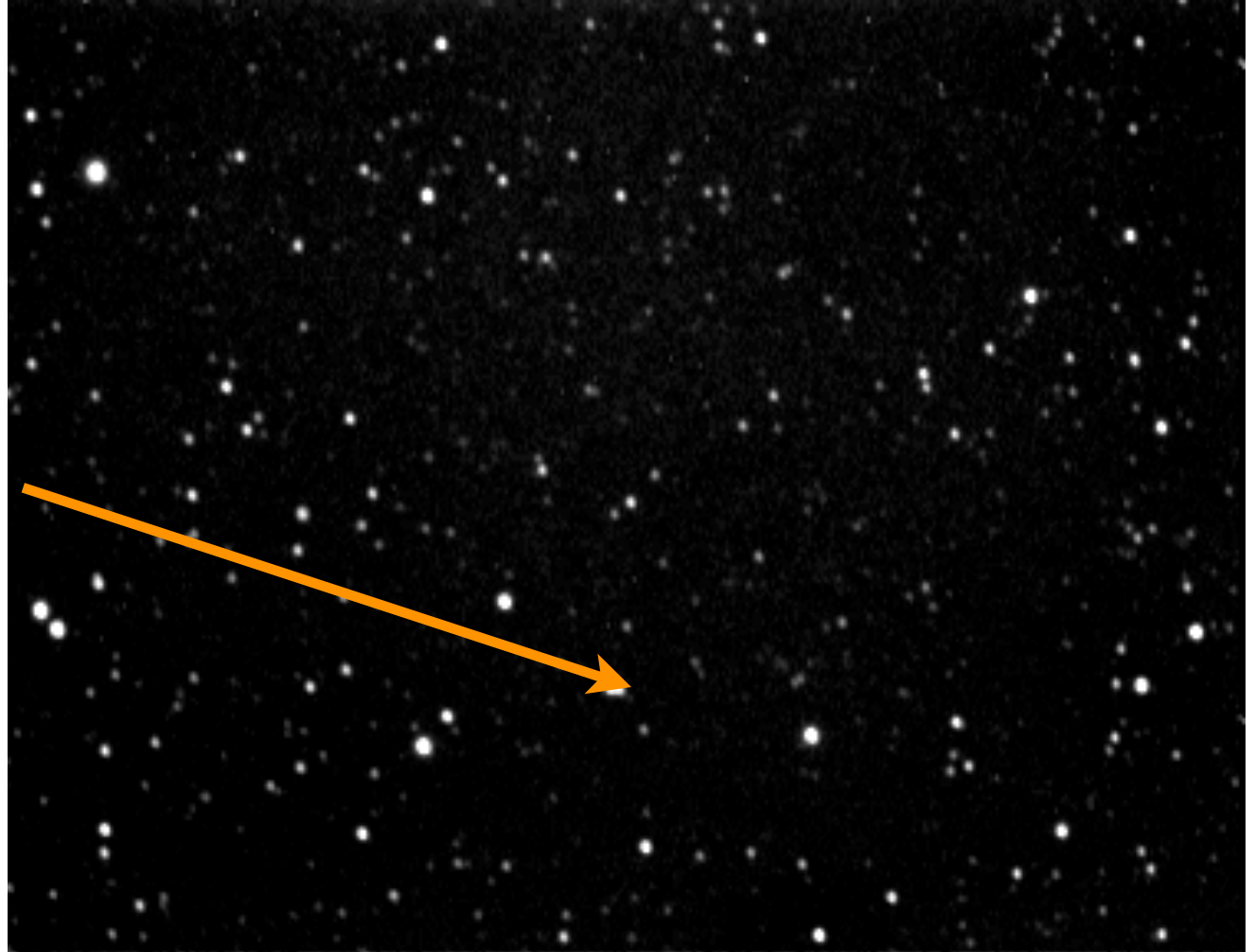
Most asteroids are only a few kilometers in size, often even less. Like the planets, they reflect sunlight, but because they are so small, they appear only as points of light on images of the sky. How then can we tell which point of light on an image is an asteroid, and which points are stars?

The key to recognizing asteroids is to note that asteroids move noticeably against the background of the stars because an asteroid is orbiting the sun.

If you take two pictures of the sky a few minutes apart, the stars will not have moved with respect to one another, but an asteroid will have moved.

- ▶ In the blink technique, quickly switch between two images of the same part of the sky
- ▶ Any asteroids in the image will appear to “jump”

**Can you spot  
the asteroid?**



Often there are so many stars on a picture that you can't easily remember the pattern when you look at another image, and therefore you can't easily tell which dot of light has moved. You can load and display simultaneously two images of the sky that were previously taken with a telescope. You then switch the display quickly back and forth from one image to another, a technique called blinking. The only object that will change will be the asteroid, which will appear to jump, making it easy to spot.

## DISCOVERY OF THE PLANET PLUTO



January 23, 1930



January 29, 1930

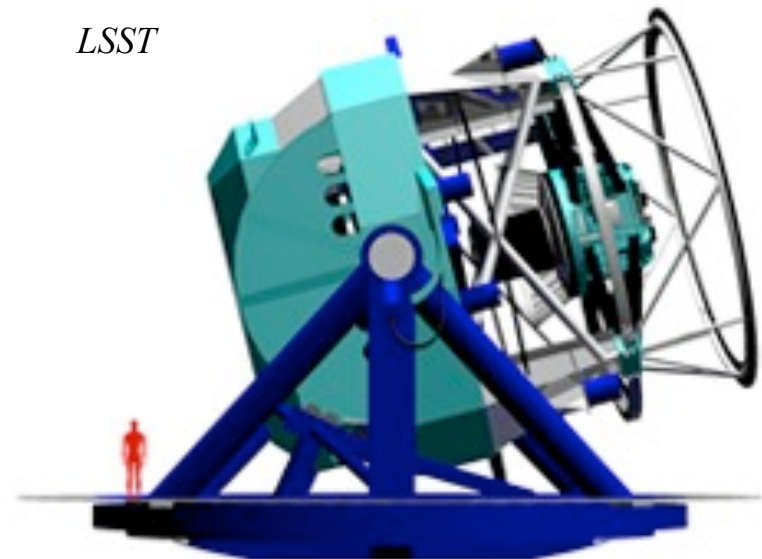
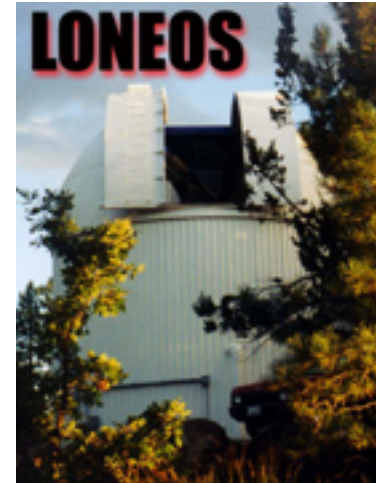
**The blink technique was used to discover the planet Pluto!**

# Near Earth Object Program

<http://neo.jpl.nasa.gov/>

Survey: 1998 to 2009, found  
>90% of NEOs >1 km  
diameter (Near Earth  
Objects)

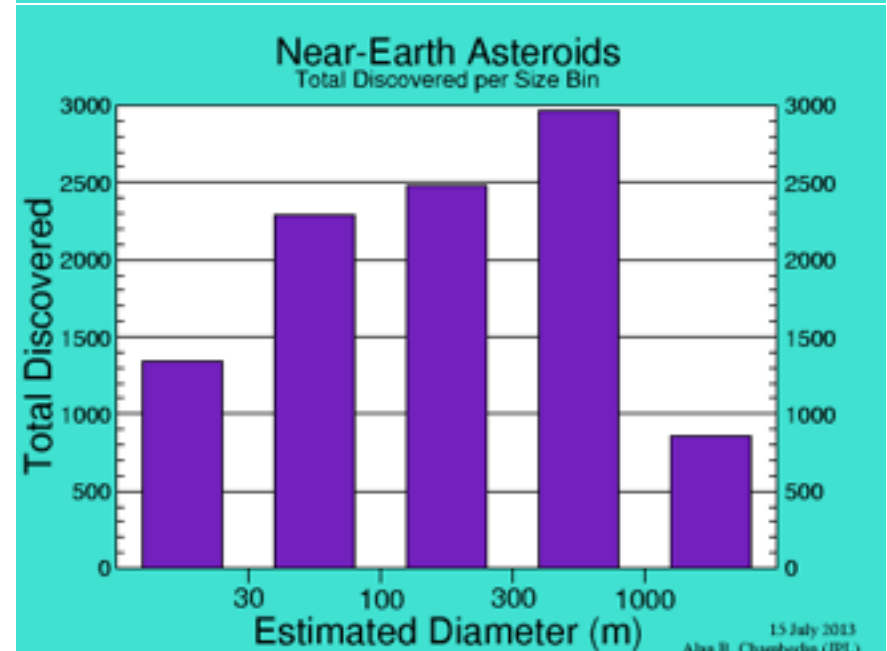
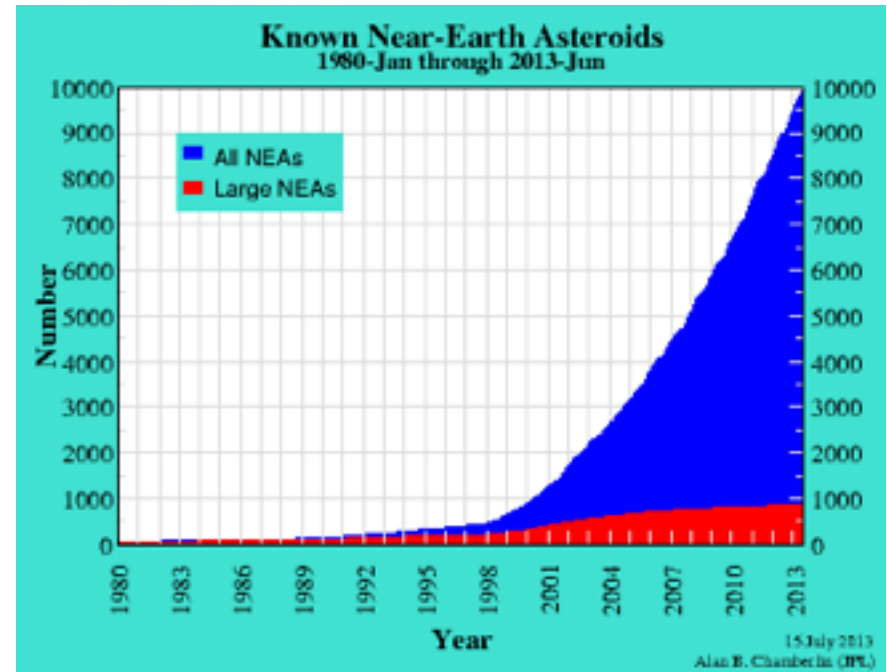
Congress ordered NASA to  
find 90% of NEOs >140 m by  
2020



# Killer Asteroids

- ✳ As of Sept 15, 2013, **10218 Near-Earth Asteroids (NEAs)** are known
- ✳ **859** of these are **>1km**
- ✳ **1424** of these are classified as **PHAs: Potentially Hazardous Asteroids**

<http://neo.jpl.nasa.gov/faq/>  
<http://neo.jpl.nasa.gov/stats/>





# Killer Asteroids

The most dangerous currently known is 1950 DA (~1.2km),

0.33% chance of collision in March 2880

Would be a 100,000 MT impact event

But... can't reliably predict asteroid orbits more than ~20 years in advance

*Asteroid may crash into Earth — in 2880*



Radar image of asteroid  
1950DA

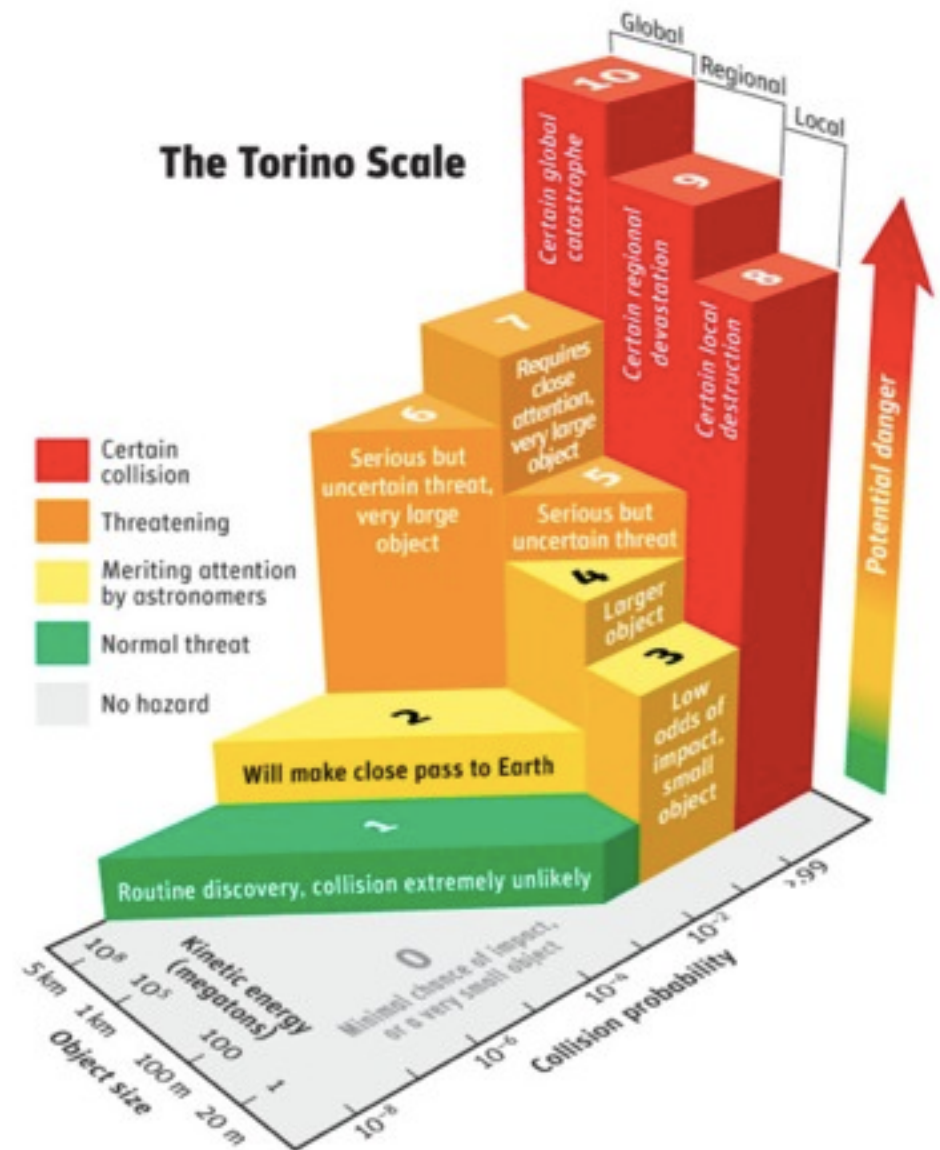
# Scale It! - The Torino Scale

Based on

- ▶ Probability of impact
- ▶ Potential for damage

Scale from 0 to 10

- ▶ 0: minimal chance of impact OR too small to cause damage
- ▶ 10: certain impact, global devastation



Currently, 1950DA is a 1 on the Torino Scale  
One other object is listed as "1" - all others are 0s

# Also color coded!

White - no hazard

Green - normal threat (routine discovery)

Yellow - Meriting attention by astronomers

Orange - Threatening

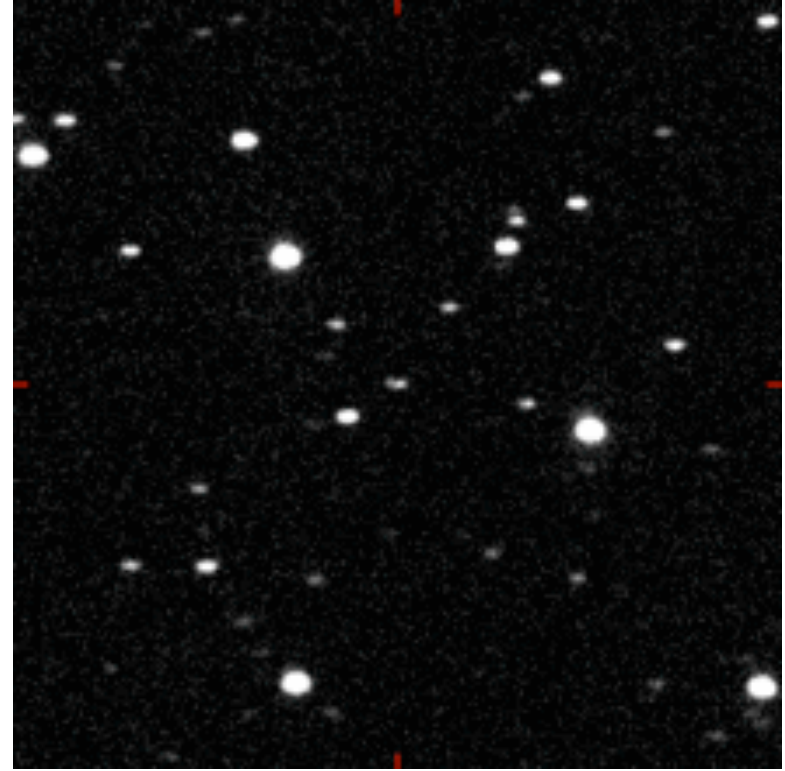
Red - Certain Collision

## THE TORINO SCALE

0	ZERO OR VIRTUALLY ZERO CHANCE OF IMPACT
1	IMPACT EXTREMELY UNLIKELY, MERITS MONITORING
2	IMPACT VERY UNLIKELY
3	CLOSE ENCOUNTER WITH AT LEAST 1% CHANCE OF LOCAL DESTRUCTION
4	CLOSE ENCOUNTER WITH AT LEAST 1% CHANCE OF REGIONAL DESTRUCTION
5	CLOSE ENCOUNTER WITH SIGNIFICANT THREAT OF REGIONAL DESTRUCTION
6	CLOSE ENCOUNTER WITH SIGNIFICANT THREAT OF GLOBAL CATASTROPHE
7	CLOSE ENCOUNTER WITH EXTREMELY SIGNIFICANT THREAT OF GLOBAL CATASTROPHE
8	CERTAIN COLLISION WITH LOCAL DESTRUCTION
9	CERTAIN COLLISION WITH REGIONAL DEVASTATION
10	CERTAIN COLLISION CAUSING GLOBAL CLIMATIC CATASTROPHE

# The Asteroid with Our Name on It: The Deadly Impactor

**We haven't seen it yet.  
But we want to find all the  
potentially hazardous  
asteroids, to be sure  
nothing's coming soon....  
Though statistics are on  
our side.**



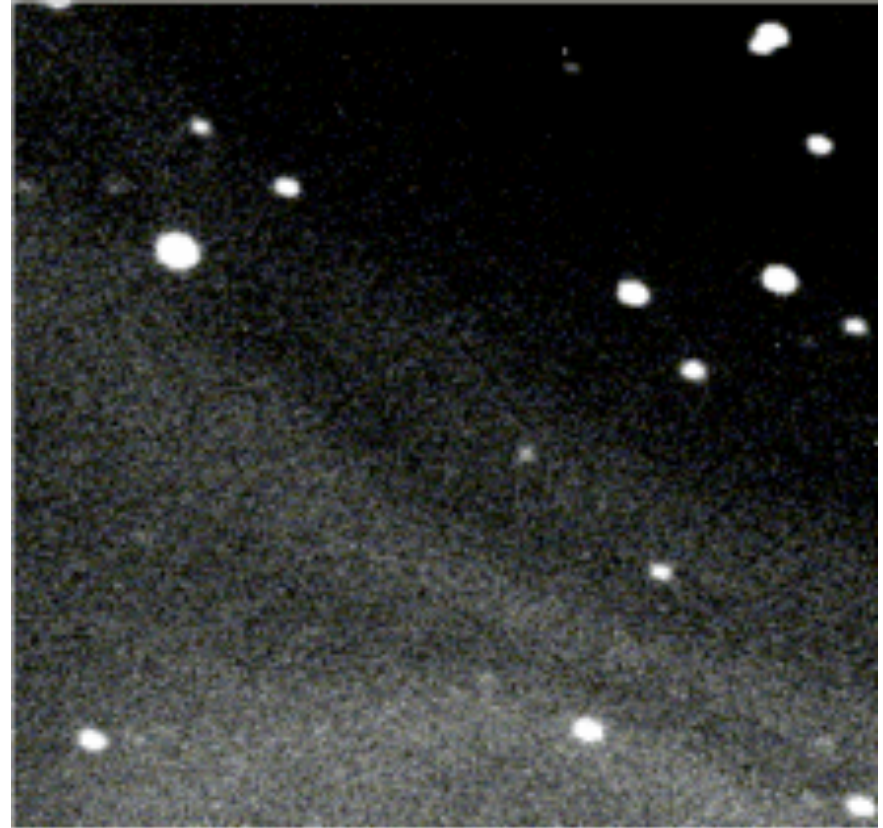
**2004 FH (30 meter)  
passing 10% the Earth-  
Moon distance**

<http://antwrrp.gsfc.nasa.gov/apod/ap040322.html>

Asteroid 2004 FH. 30 meters in diameter. About 1 Megaton of TNT energy in an Earth impact! Passed within 7 Earth radii of Earth. Hiroshima was 15 kilotons.

## Most famous “close call”: Asteroid Apophis

At one time, the chance  
of a hit was estimated at  
1 in 37 for 2029, now 0%  
In 2036, chance is  
currently 1 in 250,000  
Highest Ever Ranked  
NEA on the Torino Scale  
(for a time)



Asteroid Apophis

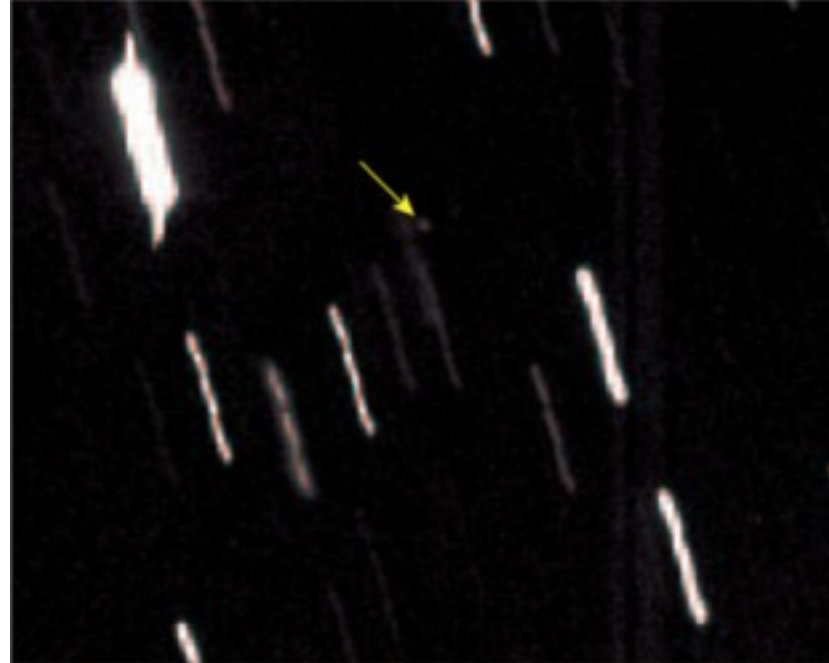
# 99942 Apophis

**Discovered June 19, 2004**

- ▶ Initial designation 2004 MN<sub>4</sub>
- ▶ Permanent name 99942 Apophis

**Near-Earth Asteroid**

- ▶ ~270m in diameter
- ▶ ~30 million metric tons



The discovery image of  
asteroid Apophis

# Apophis Impact Score

**12/23/04: NASA  
announces 1 in 200  
chance Apophis will hit  
Earth on 04/13/29**

**12/25-12/27: chance goes  
up to 1 in 37!**

**Potential Impact (at the  
time):**

- ▶ 1200 MT of energy
- ▶ 7.7 magnitude quake
- ▶ 3.4 km crater
- ▶ Torino Scale: 4!



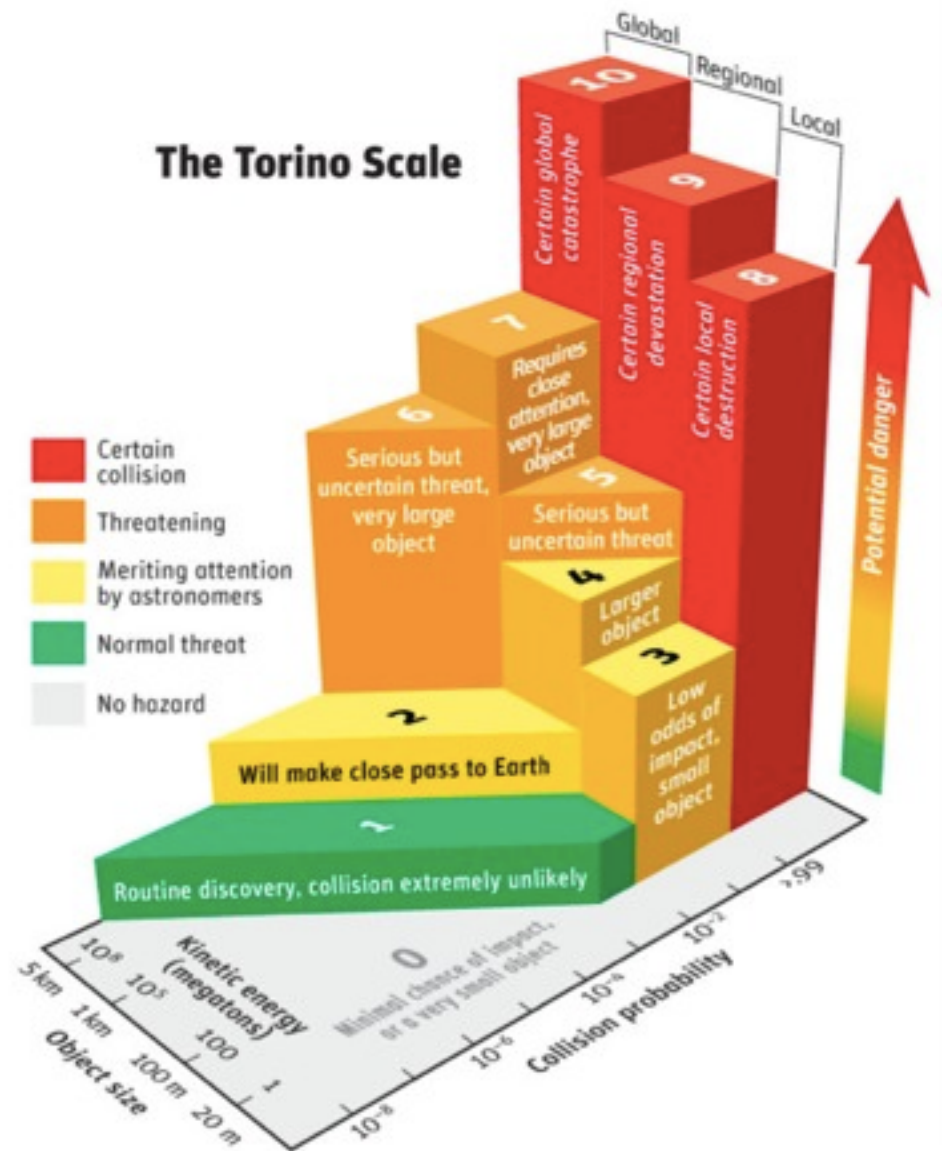
Observations predicted a  
2.7% chance Apophis would  
hit Earth in 2029

# Apophis on the Torino Scale

Initially ranked a **2**  
1 in 37 chance of collision increased ranking to a **4**!

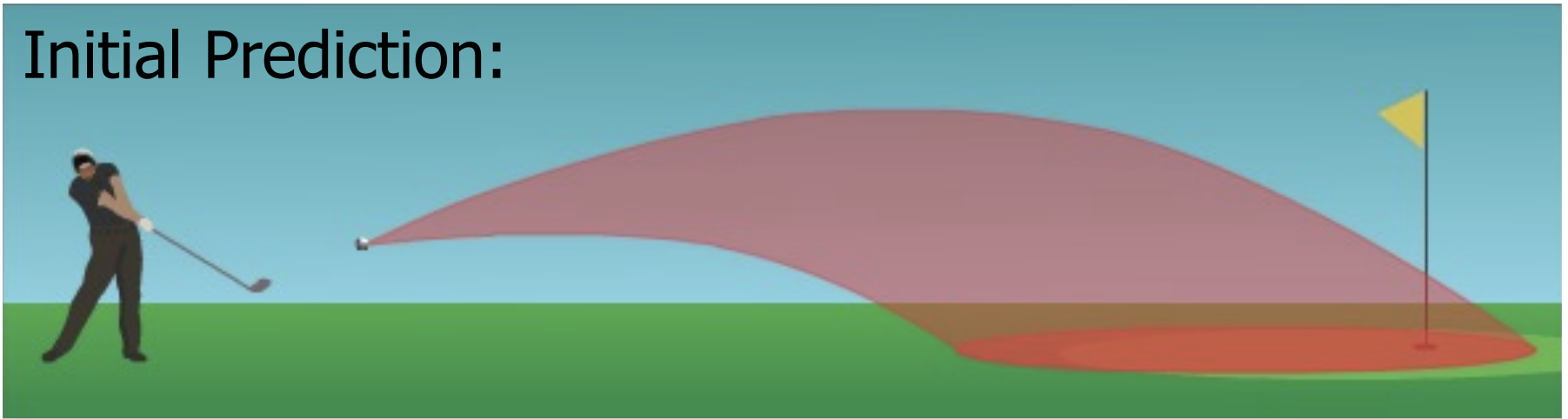
▶ Highest rank ever!

As a better fit of its orbit was found, it dropped to a **1**

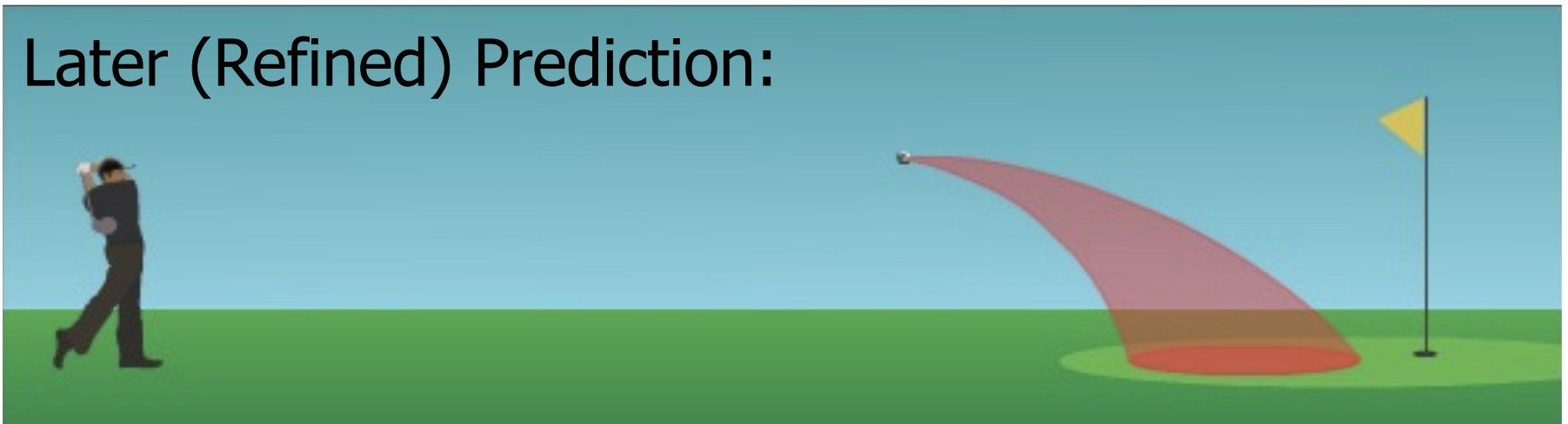




Initial Prediction:

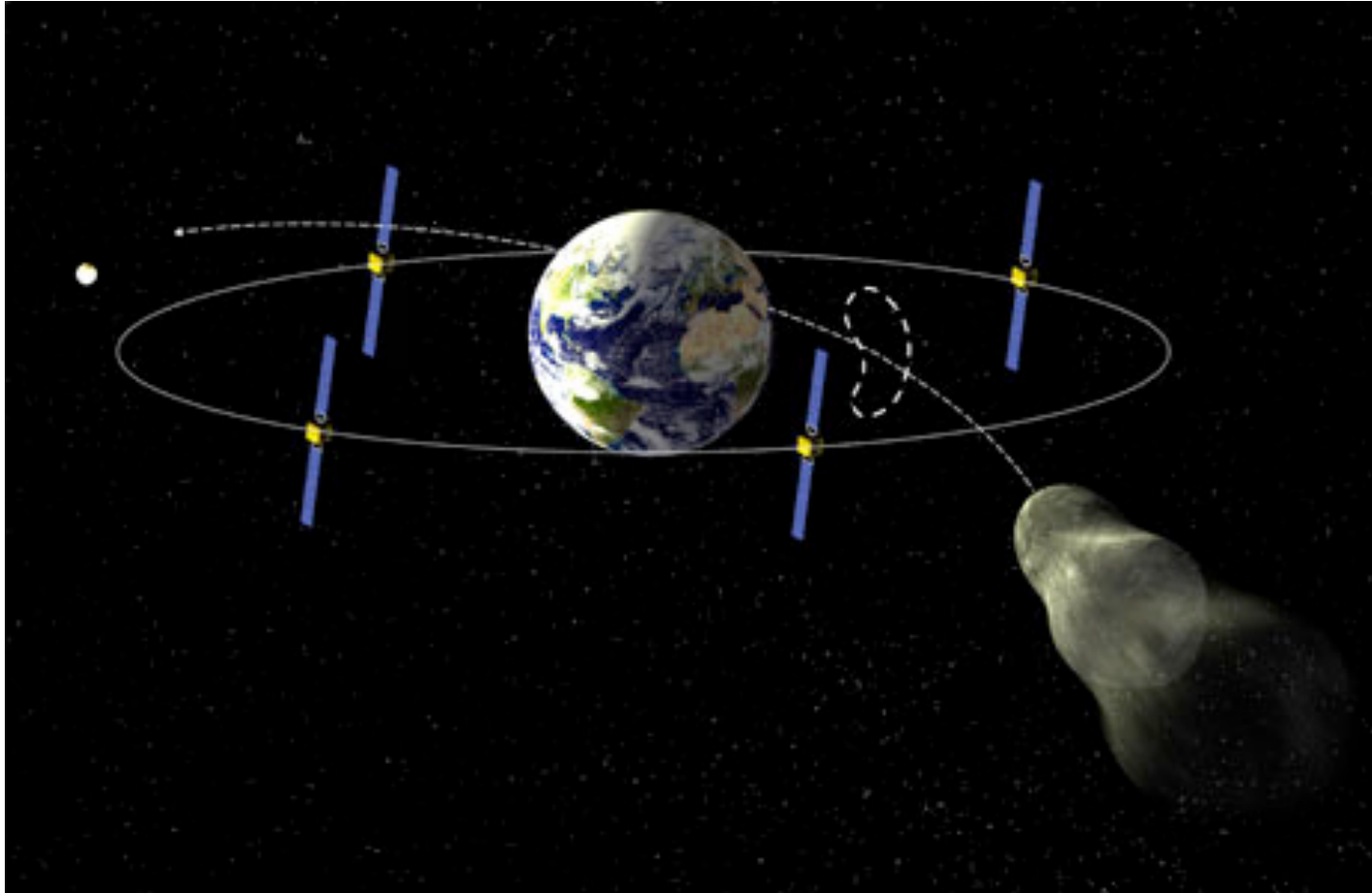


Later (Refined) Prediction:



Additional observations refine impact probabilities - similar to refining predictions of where the golf ball will land as we observe its trajectory

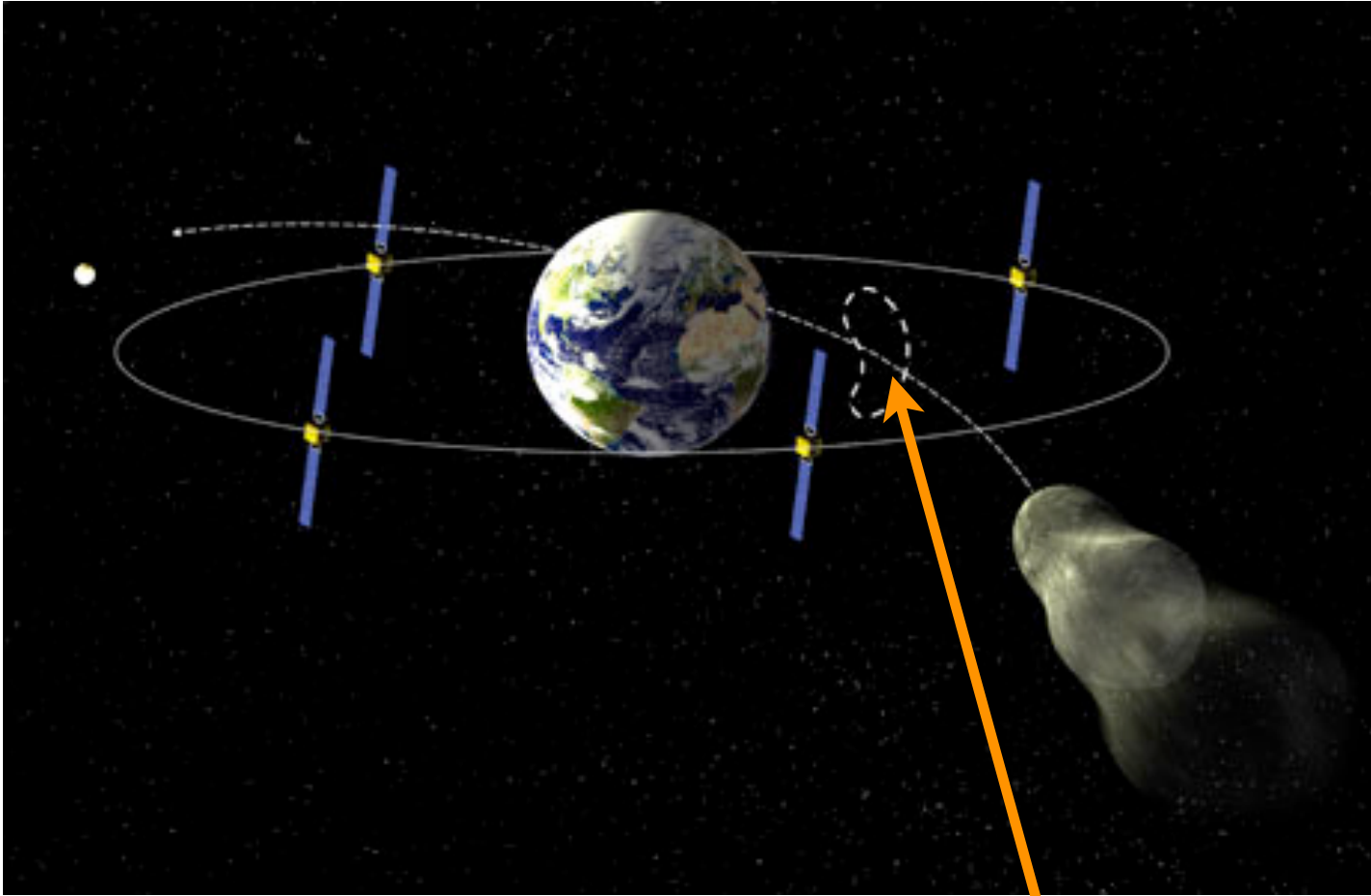
# No impact in 2029, but...



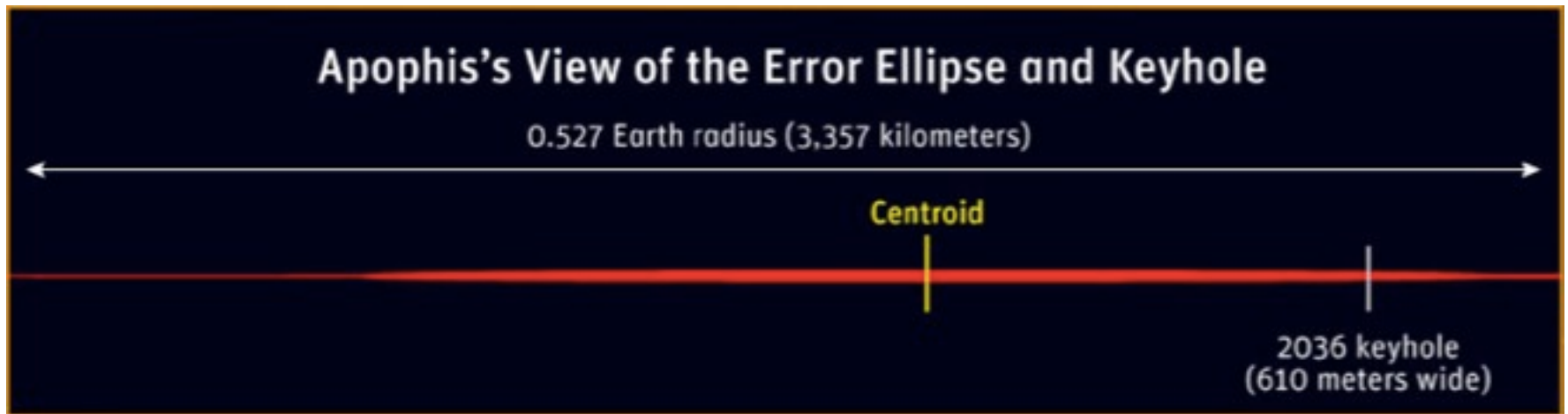
- ▶ Apophis will miss Earth by just 5 Earth radii!
- ▶ Under the orbits of communications satellites!

Earlier images found (unlikely!) and analyzed: it will miss by 5 Earth diameters  
Month later, Arecibo radar shows that positions are wrong: Apophis will miss by just 5 Earth radii, under the orbits of geosynchronous communications satellites

# No impact in 2029, but...



**Apophis may pass through a “keyhole” in 2029**



- ▶ 2036 keyhole only **~600 meters** wide
- ▶ Apophis' error ellipse = **uncertainty** in trajectory prediction **~3000 km** in diameter
- ▶ Chance of Apophis hitting keyhole: **1 in 250,000**

# What Might Happen?

[http://www.youtube.com/watch?v=xaW4013\\_M1o](http://www.youtube.com/watch?v=xaW4013_M1o)

# i>clicker poll

**Should possible impacts like Apophis be announced as soon as they are found, or should we wait until it is confirmed?**

- A. Wait until better than 90% sure.**
- B. Give us info immediately, then update.**