EOSC 114 – The Catastrophic Earth, Natural Disasters

29th November 2024

IMPACTS 4

Impacts and Humans: Frequency and Mitigation

Dr Mitch D'Arcy

THE UNIVERSITY OF BRITISH COLUMBIA

Will it happen again?

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IMPACTS MINI-MODULE

1. Biostratigraphy and Geological Time
2. Mass Extinctions
3. Impacts and the Extinction of the Dinosaurs
4. Impacts and Humans: Frequency and Mitigation

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LEARNING GOALS

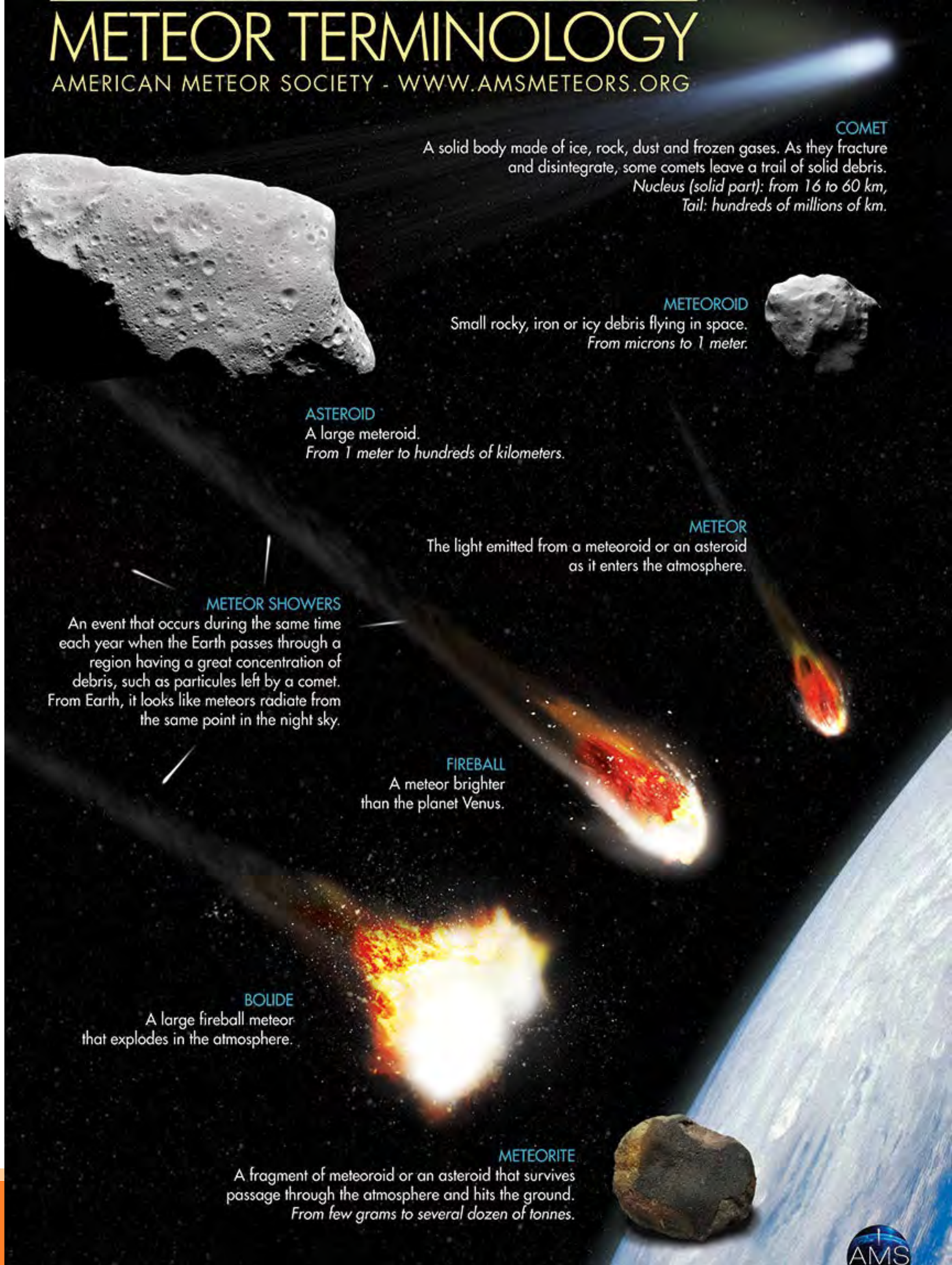
1. Describe the difference between meteoroids, meteors, meteorites, asteroids, comets and bolides
2. Describe the type and source location of potential impactors, and rate of meteoroid influx
3. Explain why impact craters appear rare on Earth compared to the Moon
4. Describe the hypothesis proposed by Raup and Sepkoski
5. List and describe some recent impacts and "near misses"
6. Explain the risk associated with an impact hazard
7. List possible mitigation strategies and appraise their relative effectiveness

METEORS, ASTEROIDS, AND COMETS

Meteoroids:
- Small (< 1 m) rocks
- “Meteors” as they enter Earth’s atmosphere
- “Meteorite” if it survives entry to Earth’s atmosphere as an intact rock
- Bolides – fireballs that explode in the atmosphere

Asteroids:
- Large (> 1 m) meteoroids; smaller than a planet

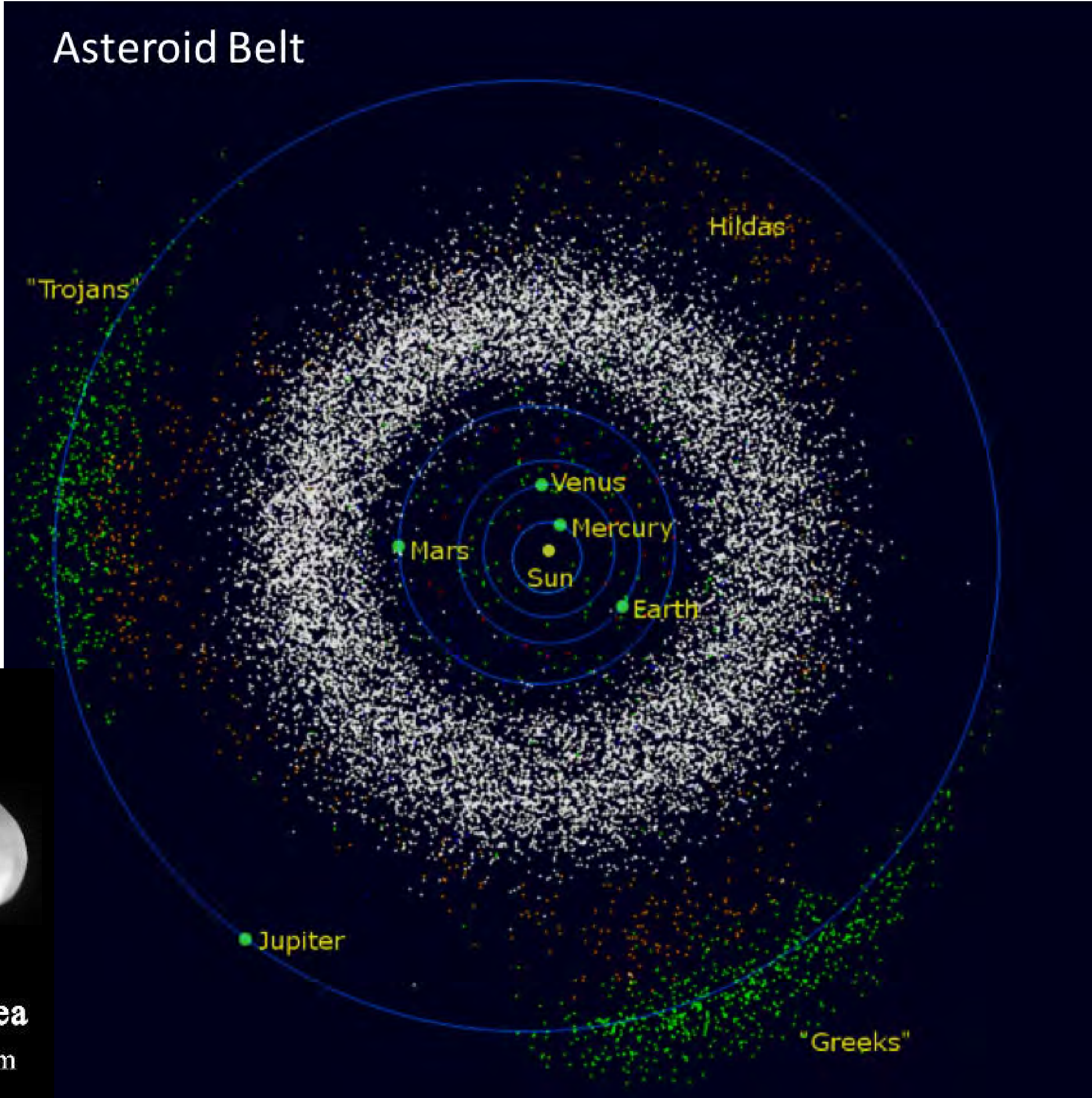
Comets:
- Rock MIXED with ice; leftovers from planet formation
- Near Sun, has a “tail” of gas and dust particles

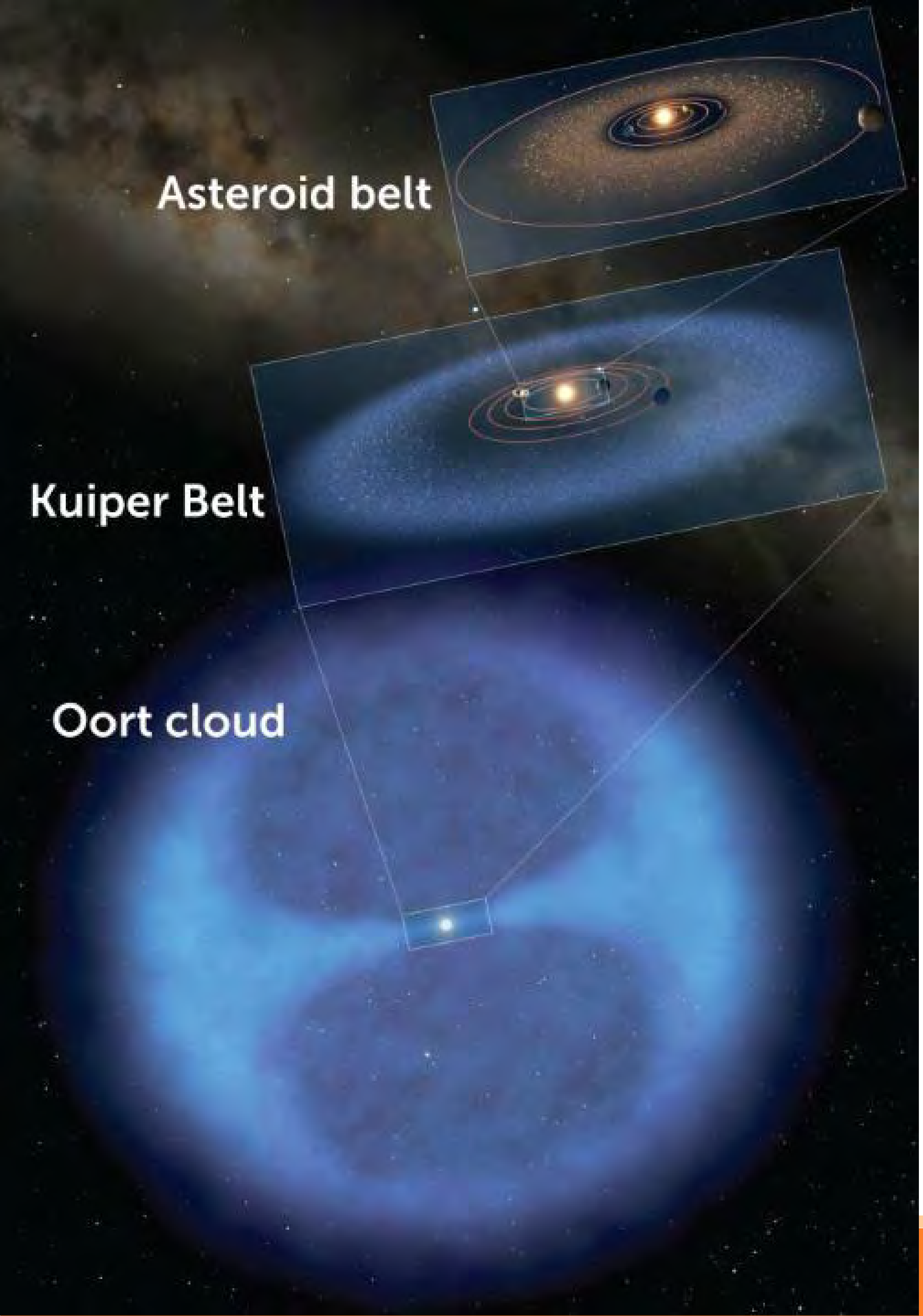


ASTEROID BELT

Meteoroids and asteroids come from the **Asteroid Belt** located between the orbits of planets Mars and Jupiter.

The asteroids are rocky/metallic. Some are **dwarf planets** like Ceres.





COMET ORIGINS

Comets come from two sources farther away:

The Kuiper Belt

- Similar to the asteroid belt, but larger.
- Mostly composed of frozen volatiles like water, methane, and ammonia (called “ices”).
- More dwarf planets, e.g., Pluto. Some of the solar system’s moons are thought to have originated here, e.g., Neptune’s Triton and Saturn’s Phoebe.

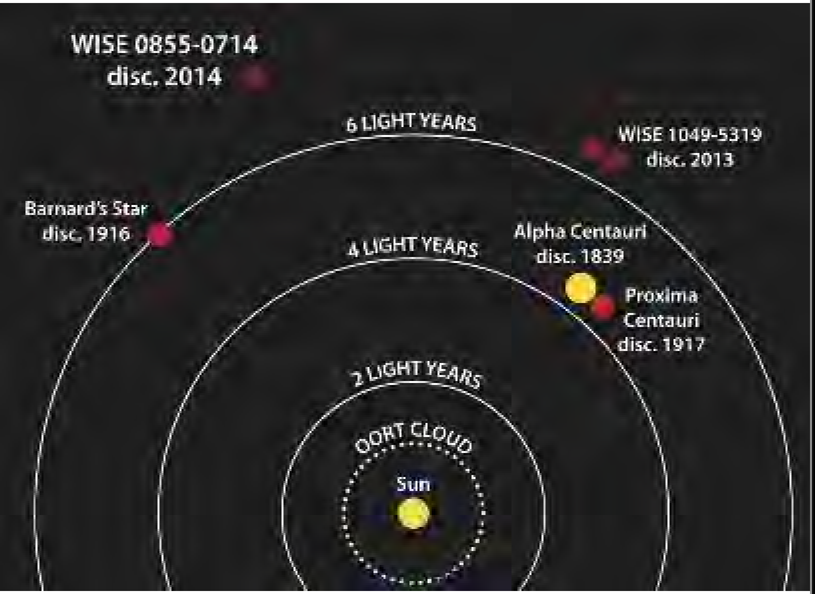
The Oort Cloud

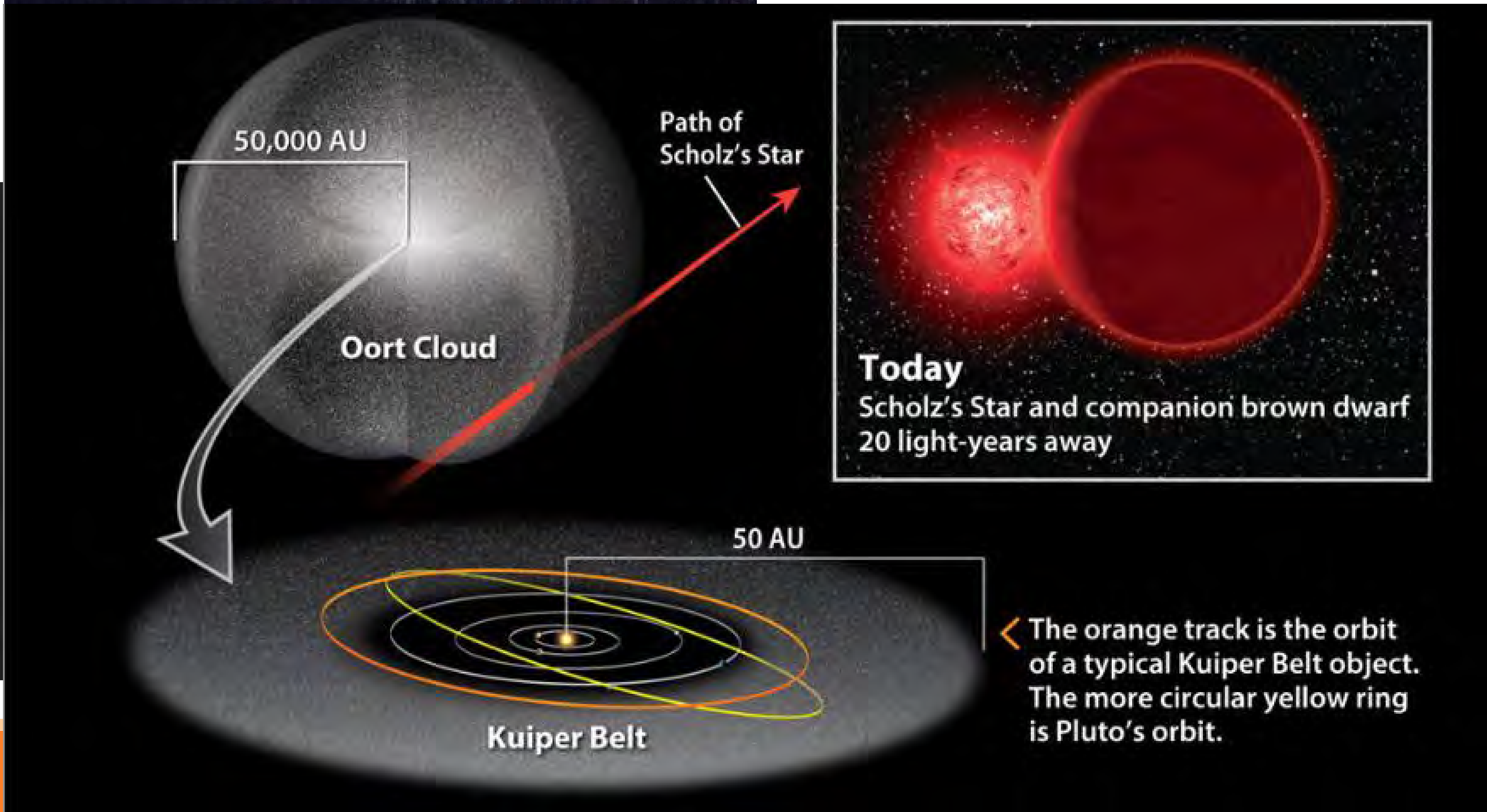
- 1000x farther from the Sun, halfway to Alpha Centauri.
- Defines the edge of the solar system.
- Probably mostly composed of ices.

OORT CLOUD

The Oort Cloud is probably the source of long-period comets like Halley's Comet and Hale-Bopp.

Scholz's Star and its companion brown dwarf moved through the Oort Cloud 70,000 years ago.





OBJECTS FROM OTHER STAR SYSTEMS?

‘Oumuamua passed through our solar system in 2017. It is thought to be an **interstellar object**.

The object is probably rocky or metallic with no volatiles, and has a shape/tumble unlike known solar system objects. It moves extremely fast (~90 km/s) and is now going to the constellation Pegasus.

METEOR INFLUX

About 100 billion **meteroids** enter Earth's atmosphere every day!

This is a **logarithmic graph**. Many natural processes follow logarithmic patterns.

$10^2 = 100$

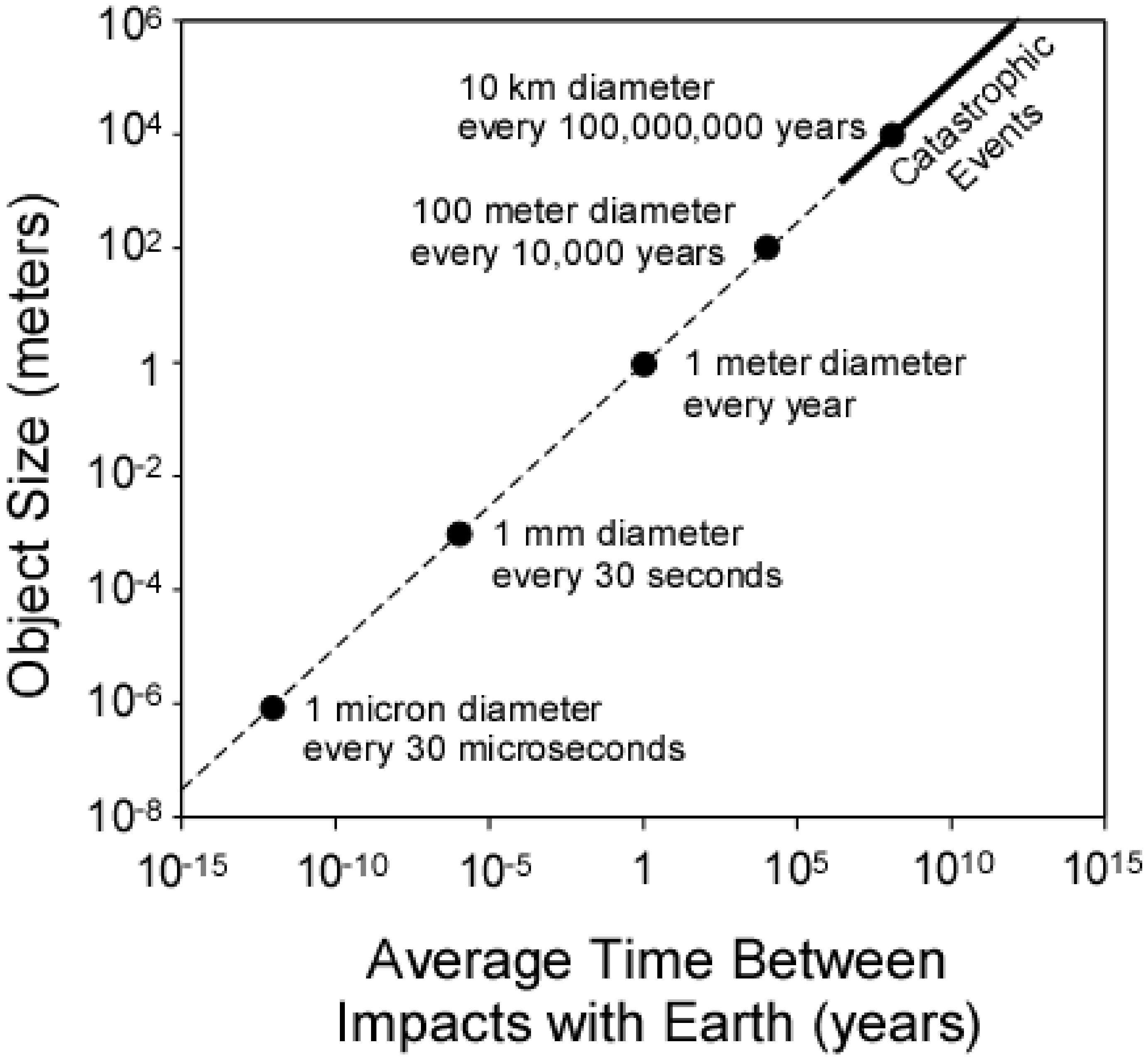
$10^3 = 1000$

$10^4 = 10,000$

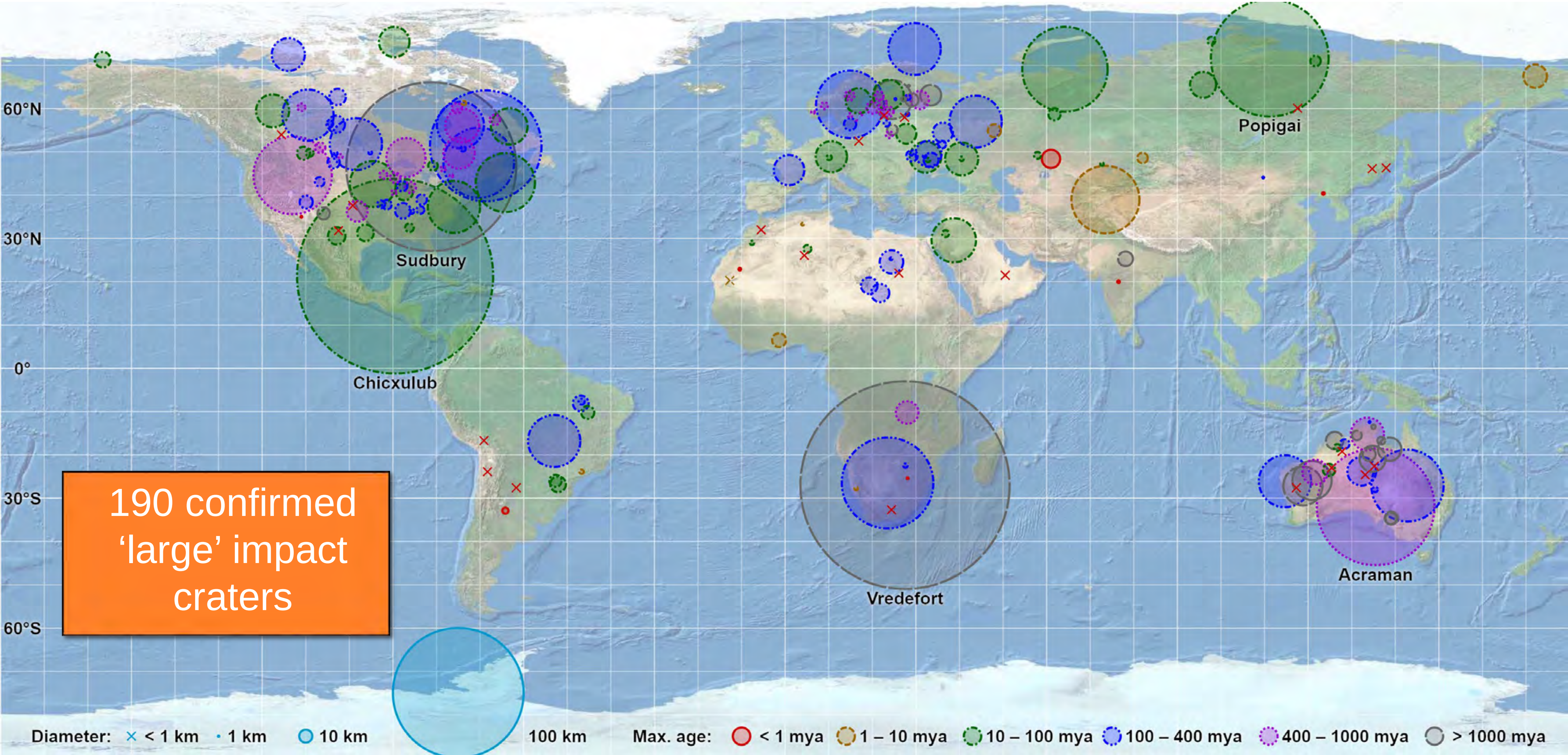
$10^5 = 100,000$

$10^6 = 1,000,000$

We expect a 10 km sized object to hit Earth every 100 Myr **on average.**



KNOWN IMPACT CRATERS ON EARTH



190 confirmed 'large' impact craters

KNOWN IMPACT CRATERS ON THE MOON

9137
recognized
impact craters

SHOEMAKER'S HYPOTHESIS

Until the 1960s, impacts on Earth were considered to be 'improbable' and craters on the moon were thought to be extinct volcanoes.

Shoemaker's Hypotheses:

- Sudden geologic changes can arise from asteroid strikes
- Over geological timescales, asteroid strikes are common
- Impact craters form large, circular structures associated with impact ejecta, shocked quartz, iridium, etc.

Eugene Shoemaker (geologist) and Carolyn Shoemaker (astronomer)

Two of the founders of planetary science

SHOEMAKER'S HYPOTHESIS

Ries Crater, Germany

Eugene Shoemaker studied the **Ries Crater** in Nördlingen, Germany.

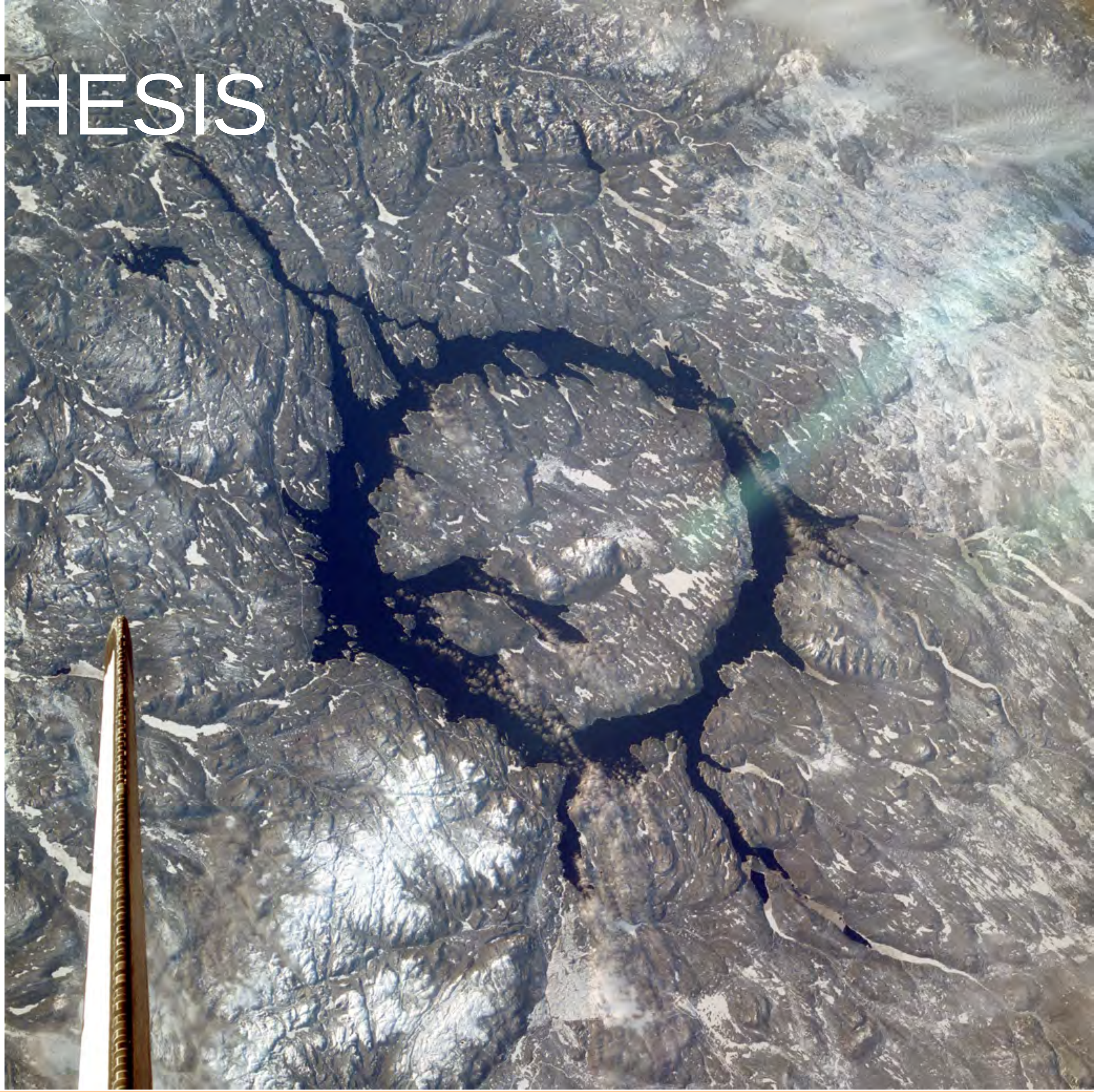
The crater was thought to be volcanic, but Shoemaker noticed the building stone was suevite.

We now know this is a 14 Ma impact crater, created by a 1.5 km-diameter asteroid impacting at ~20 km/s.

SHOEMAKER'S HYPOTHESIS

We have now identified almost 200 other examples of impact craters on Earth.

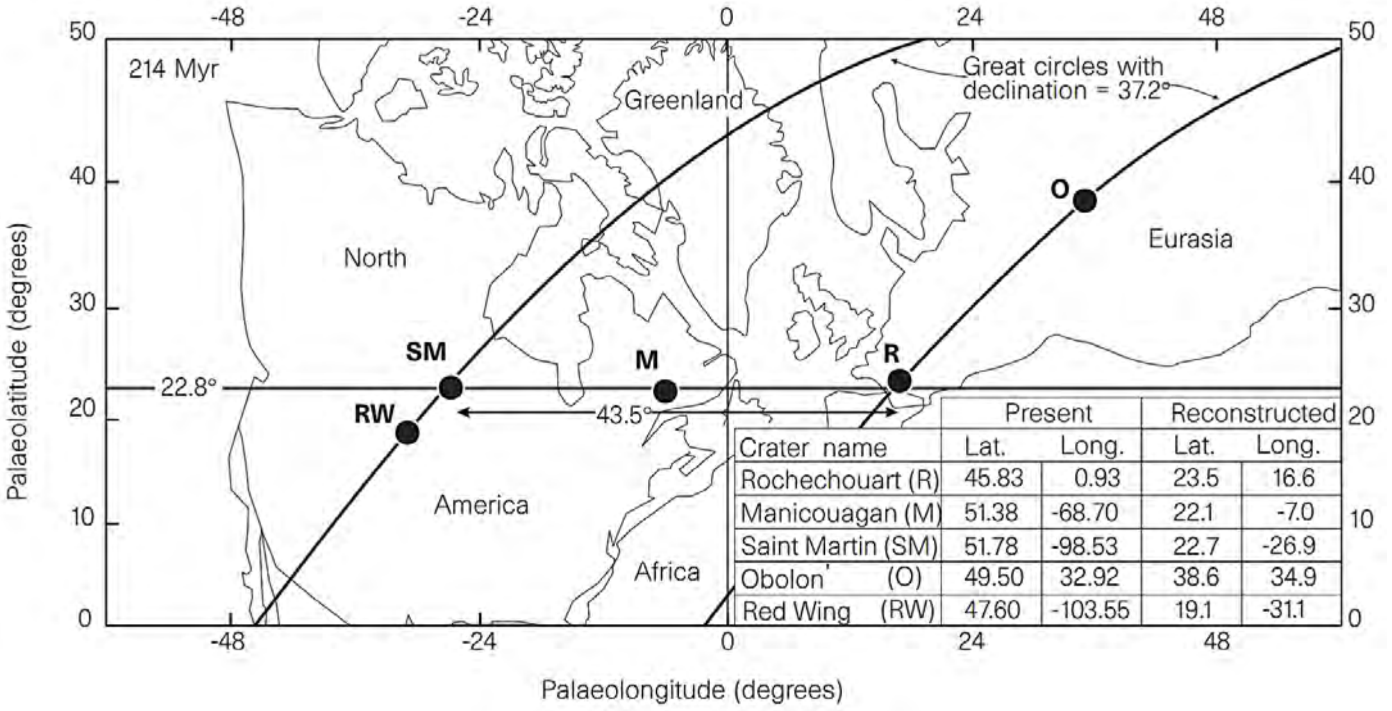
An example in Canada is the Manicouagan Crater in Quebec, which is one of the oldest confirmed impact craters (~214 Ma).



Manicouagan Crater, Northern Quebec

Photographed from the NASA space shuttle in 1983.

END-TRIASSIC MASS EXTINCTION



Crater name	Present Lat.	Present Long.	Reconstructed Lat.	Reconstructed Long.
Rochechouart (R)	45.83	0.93	23.5	16.6
Manicouagan (M)	51.38	-68.70	22.1	-7.0
Saint Martin (SM)	51.78	-98.53	22.7	-26.9
Obolon' (O)	49.50	32.92	38.6	34.9
Red Wing (RW)	47.60	-103.55	19.1	-31.1

In 1998, John Spray at the University of New Brunswick noticed a pattern…

Comet Shoemaker–Levy 9 broke apart in 1992 and collided with Jupiter in 1994.

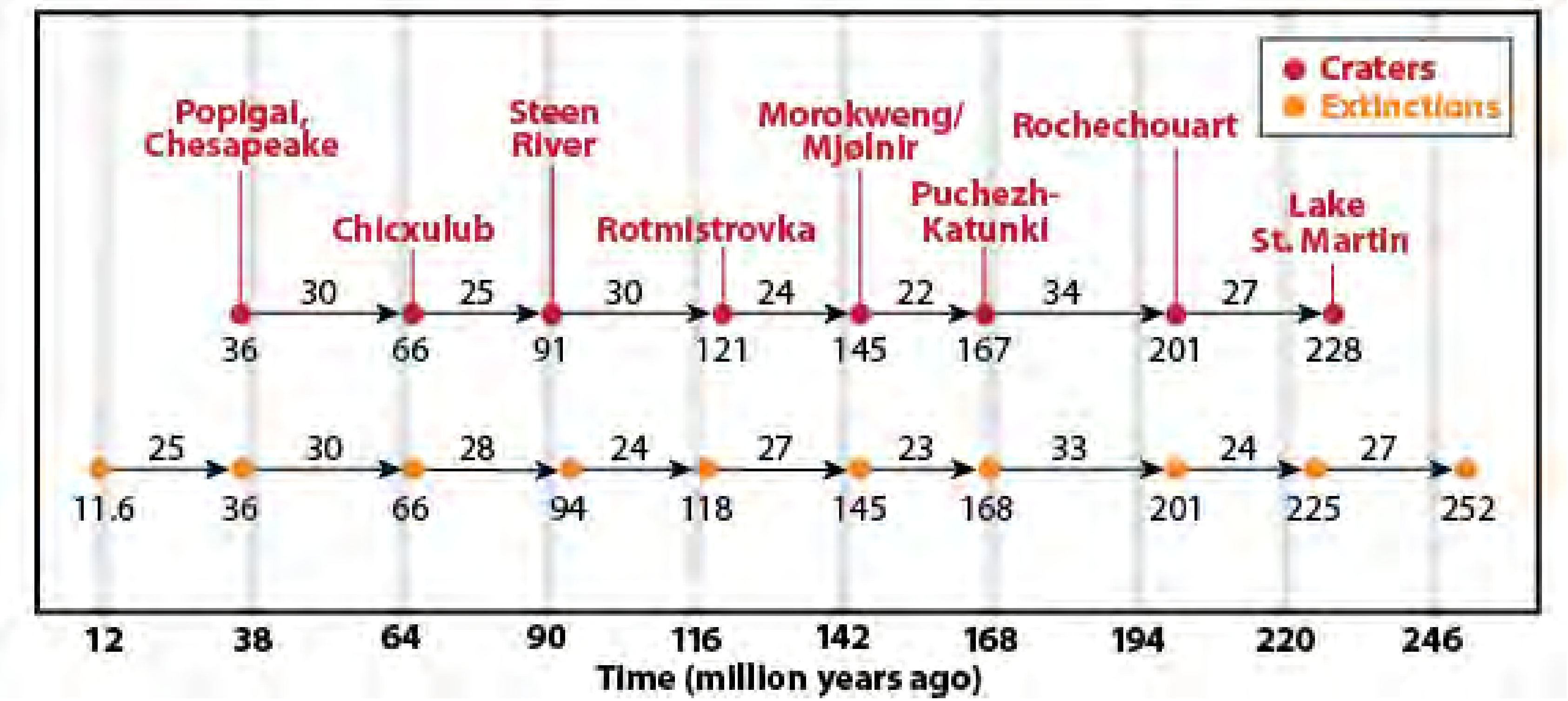
Image from Hubble space telescope.

RAUP & SEPKOSKI'S HYPOTHESIS

In 1984, **David Raup and Jack Sepkoski** suggested that there might be a ~25 Myr cycle in both impacts and extinctions.

This could be due to **gravitational disruption of the Oort Cloud**… but by what?

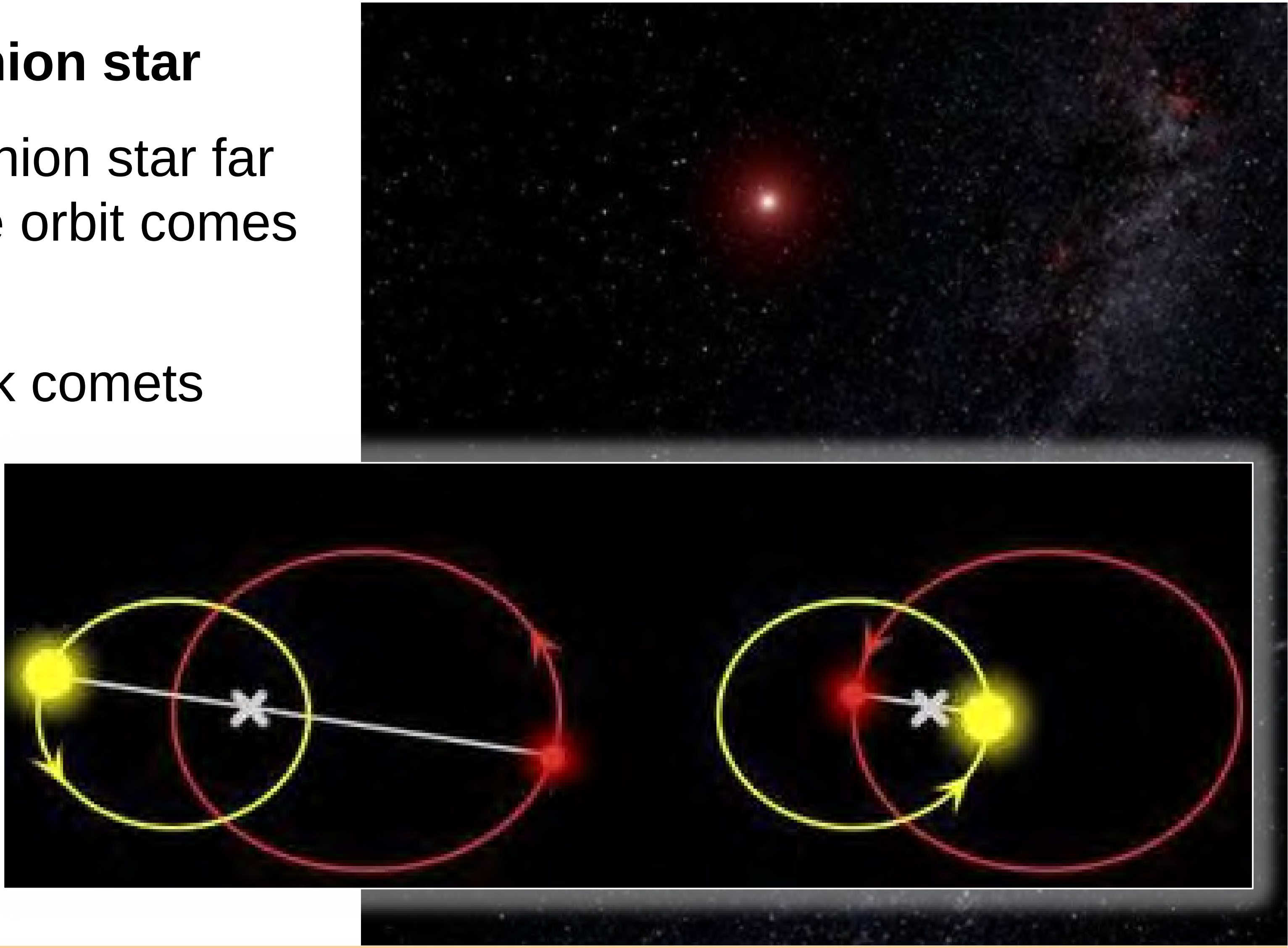
Several ideas have been proposed.



RAUP & SEPKOSKI'S HYPOTHESIS

Option 1: **"Nemesis", a companion star**

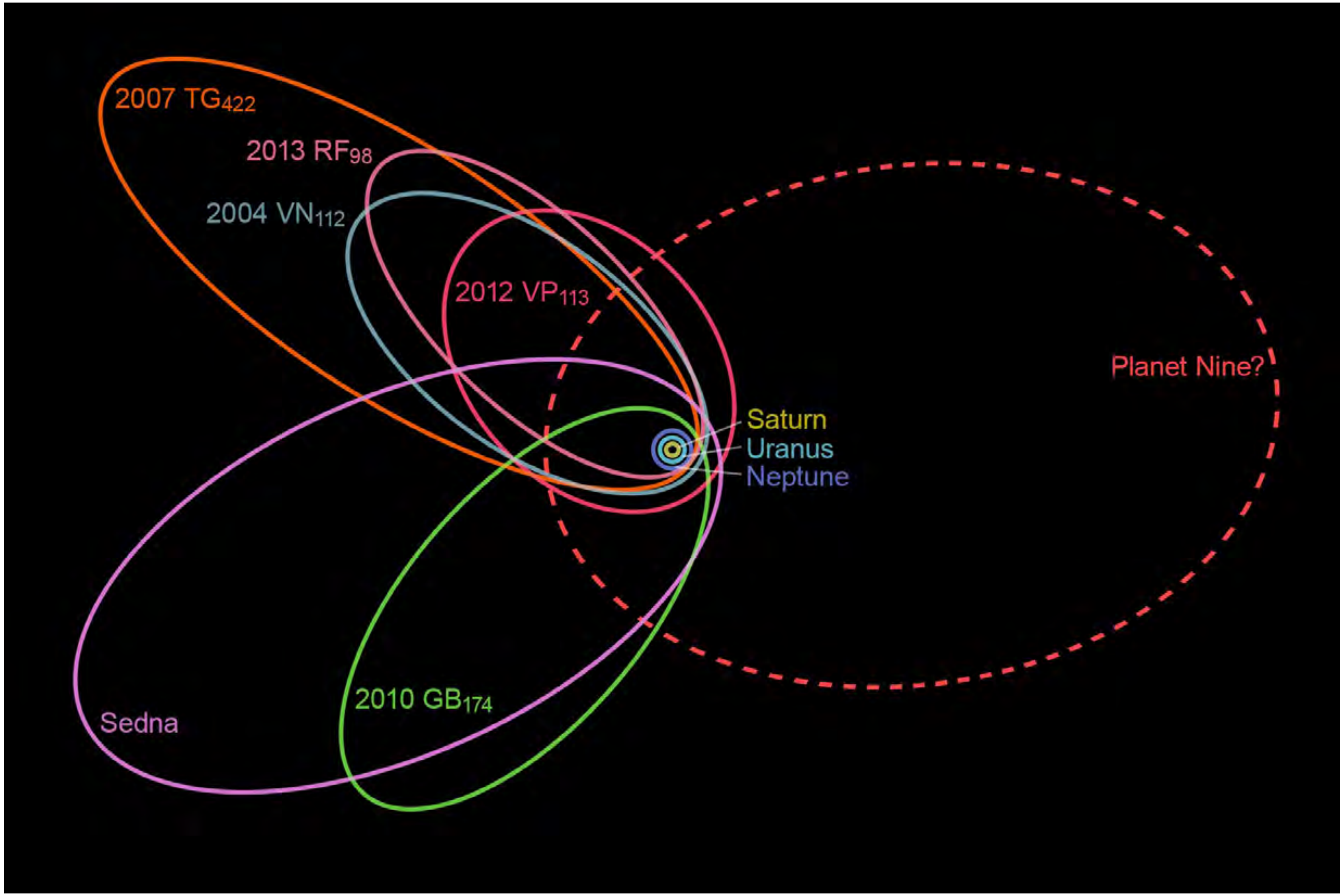
- The Sun would have a companion star far beyond the Oort Cloud, whose orbit comes near to the cloud ever 25 Myr
- Gravitational effects would kick comets into the inner solar system
- If it's a brown dwarf, or even a black hole, it would be difficult to detect
- **No evidence at all so far**



RAUP & SEPKOSKI'S HYPOTHESIS

Option 2: **"Planet 9"**

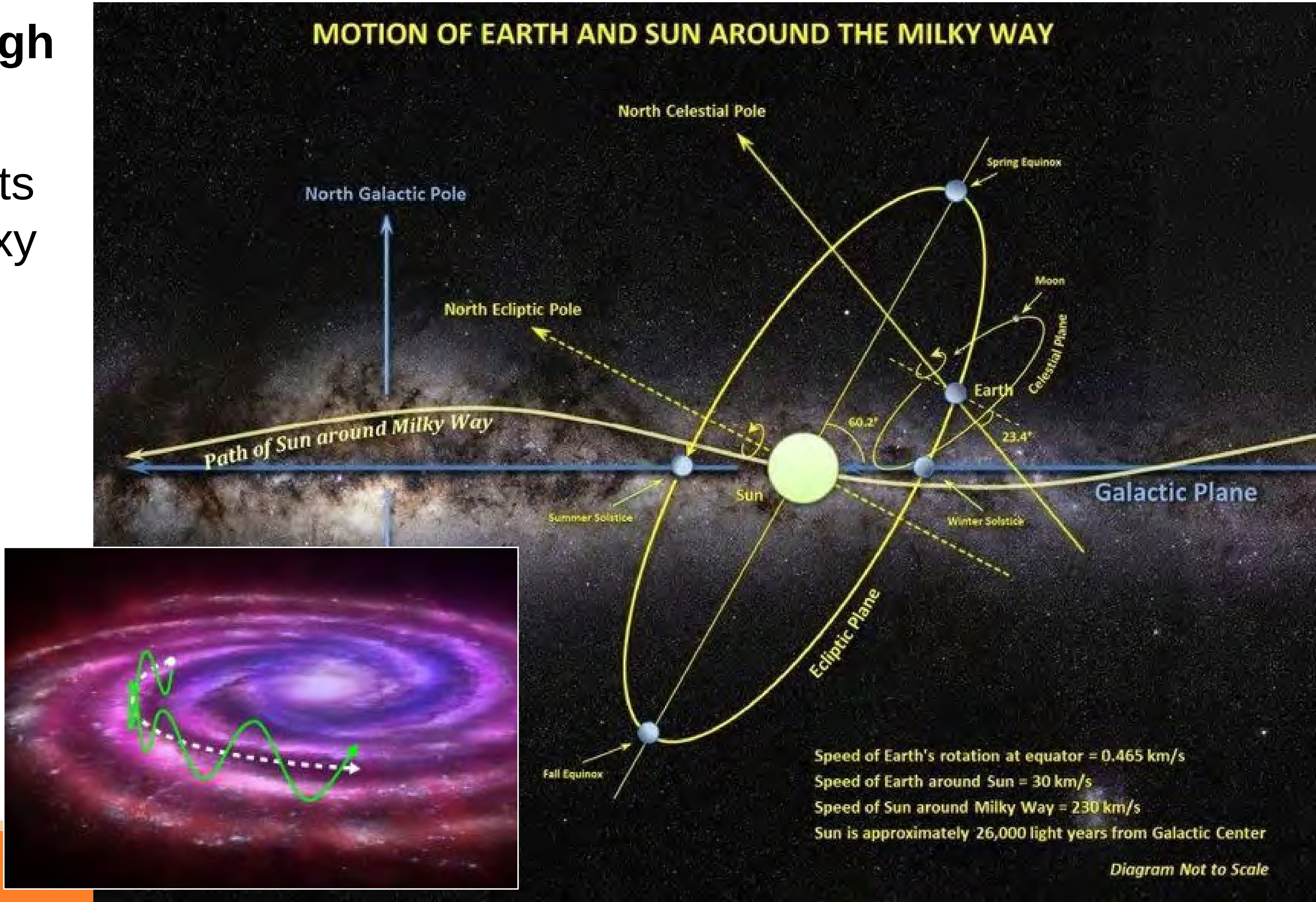
- A distant planet far beyond Neptune could shift the Oort Cloud as it orbits the sun
- The potential planet was proposed by studying the orbits of distant solar system bodies
- **No evidence,** and the astronomical community thinks it's unlikely



RAUP & SEPKOSKI'S HYPOTHESIS

Option 3: **Moving through the Galactic Plane**

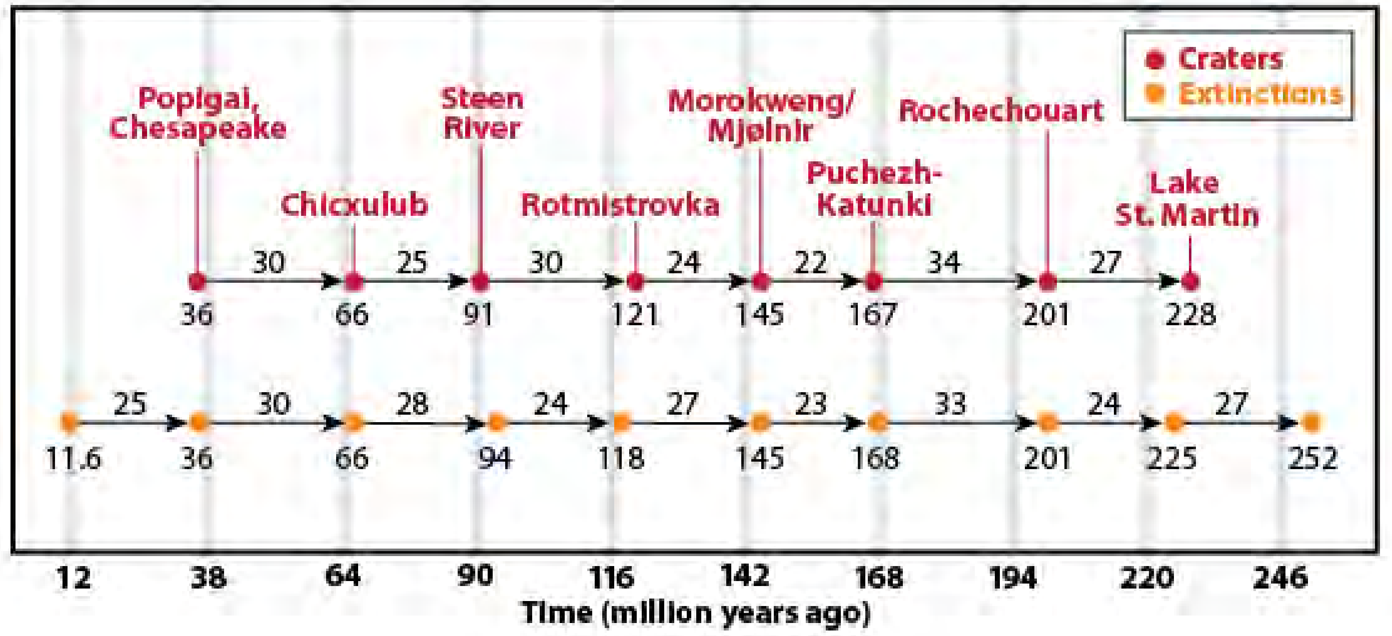
- The solar system orbits the centre of the galaxy
- The galaxy isn't a flat plane, but has a 'thickness' of stars/material
- As we move through the densest part, the Oort Cloud may be disturbed



RAUP & SEPKOSKI'S HYPOTHESIS

Option 4: What if it's just a **coincidence** and there is no 25 Myr cycle?

- The dating of some extinctions and impacts has been challenged
- The spacing is not always consistent
- There have surely been more impacts we don't know about (e.g., into the oceans and subducted)
- We know that other factors also cause extinctions



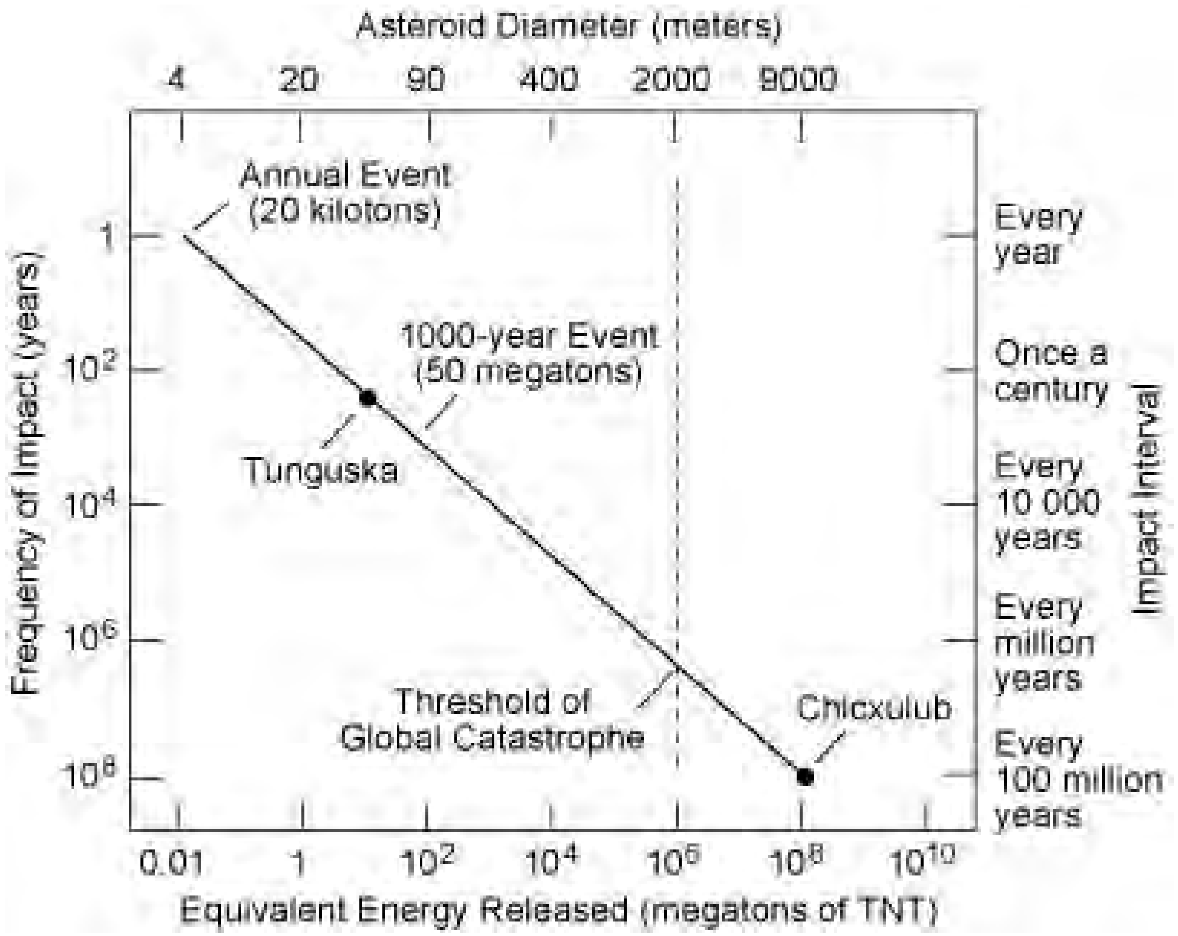
NASA thinks there is no cyclicity in past extinctions, so the Raup-Sepkoski hypothesis is not needed. What do you think?

SHOULD WE BE CONCERNED?

The possibility of global catastrophe is a **concern.**

Civilisation-ending impacts are probably random and happen every ~1 million years.

There have been some surprising historical impacts…



TUNGUSKA, RUSSIA

11:30 am, 30th June 1908.

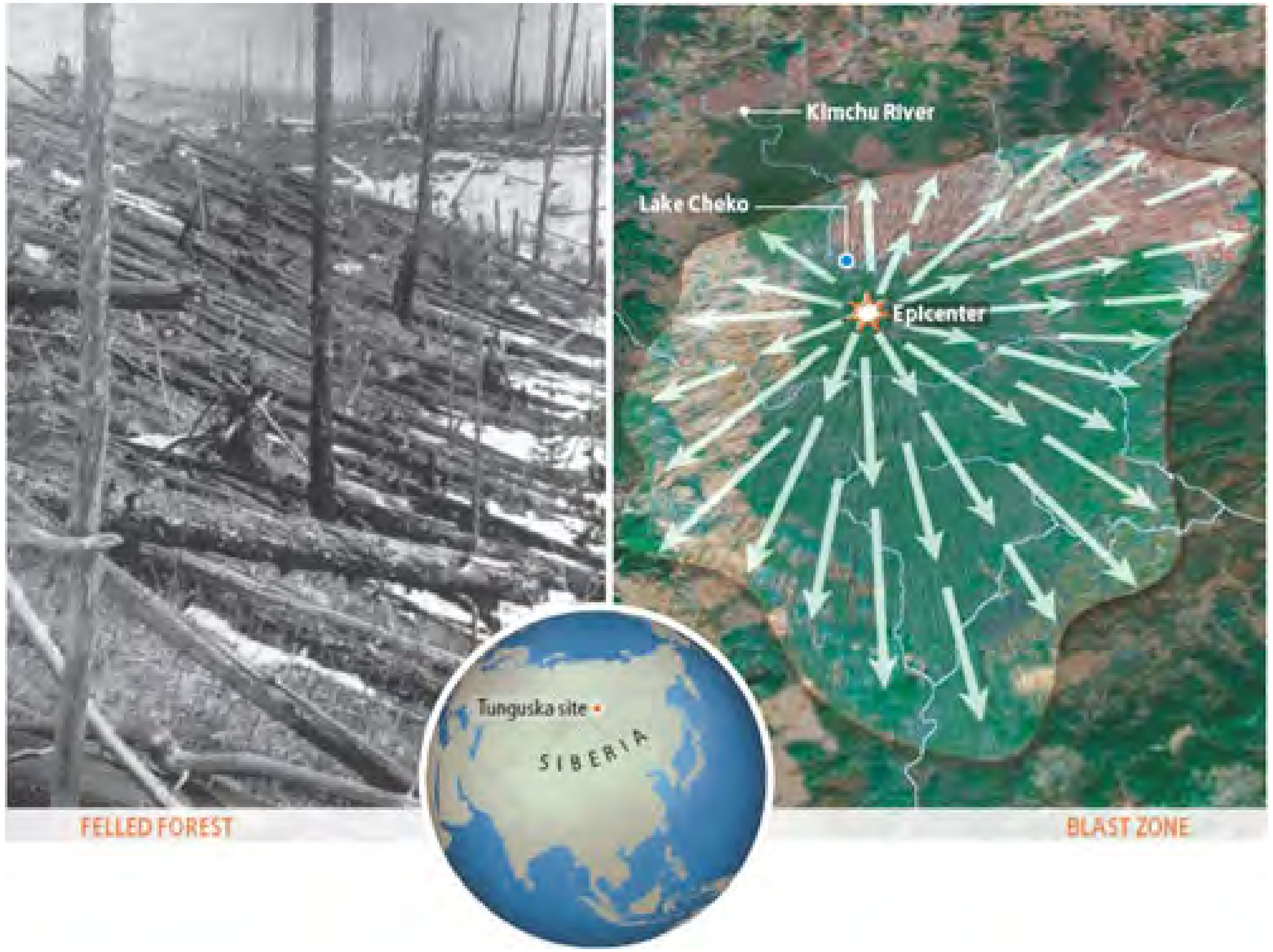
Air blast of something with a diameter ~70 m. Largest historical ‘impact’, which levelled 3100 km^2 of forest and sent a shockwave around the Earth two times.

No impact crater – could have exploded 8 km above ground.

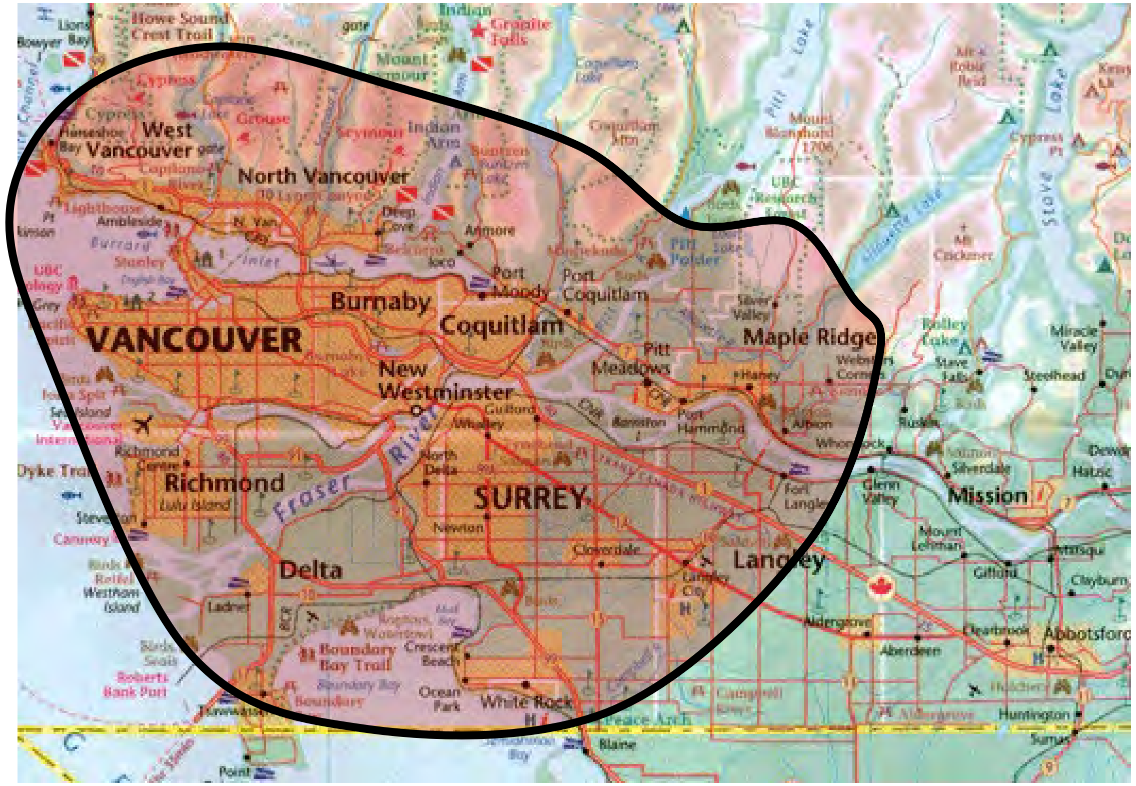
No asteroid material has ever been found on the ground… could have been an icy comet, or an asteroid that bounced back into space.

The object may still be orbiting the sun.

TUNGUSKA, RUSSIA



Whatever happened at Tunguska would flatten most of the Lower Mainland

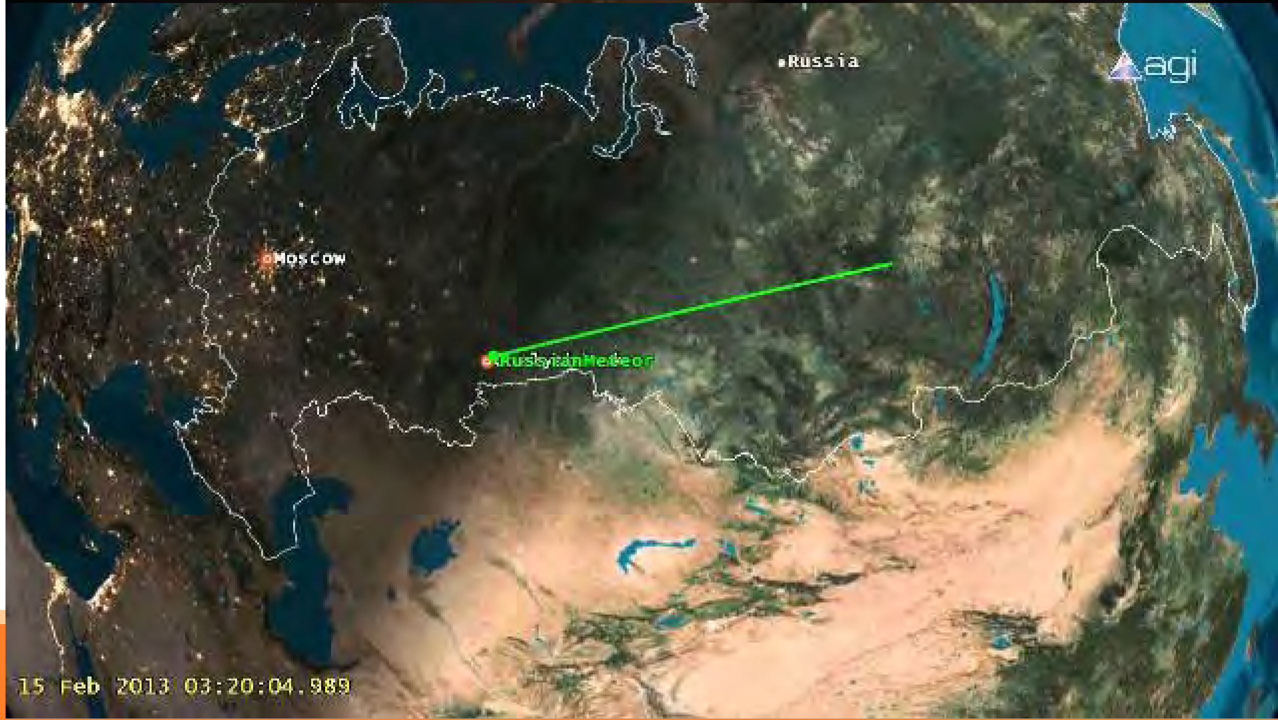


CHELYABINSK, RUSSIA

15th February 2013

20 m diameter meteor that exploded in the atmosphere 30 km above ground – a **bolide**.

Entered the atmosphere at 19 km/s and without warning – it approached from the direction of the sun.



WHAT IS BEING DONE?

The **Torino Scale** communicates the potential threat of impacts on a scale from 0-10.

Near-Earth Objects are assessed for their risk using this scale.

Note: You do NOT need to learn this scale.

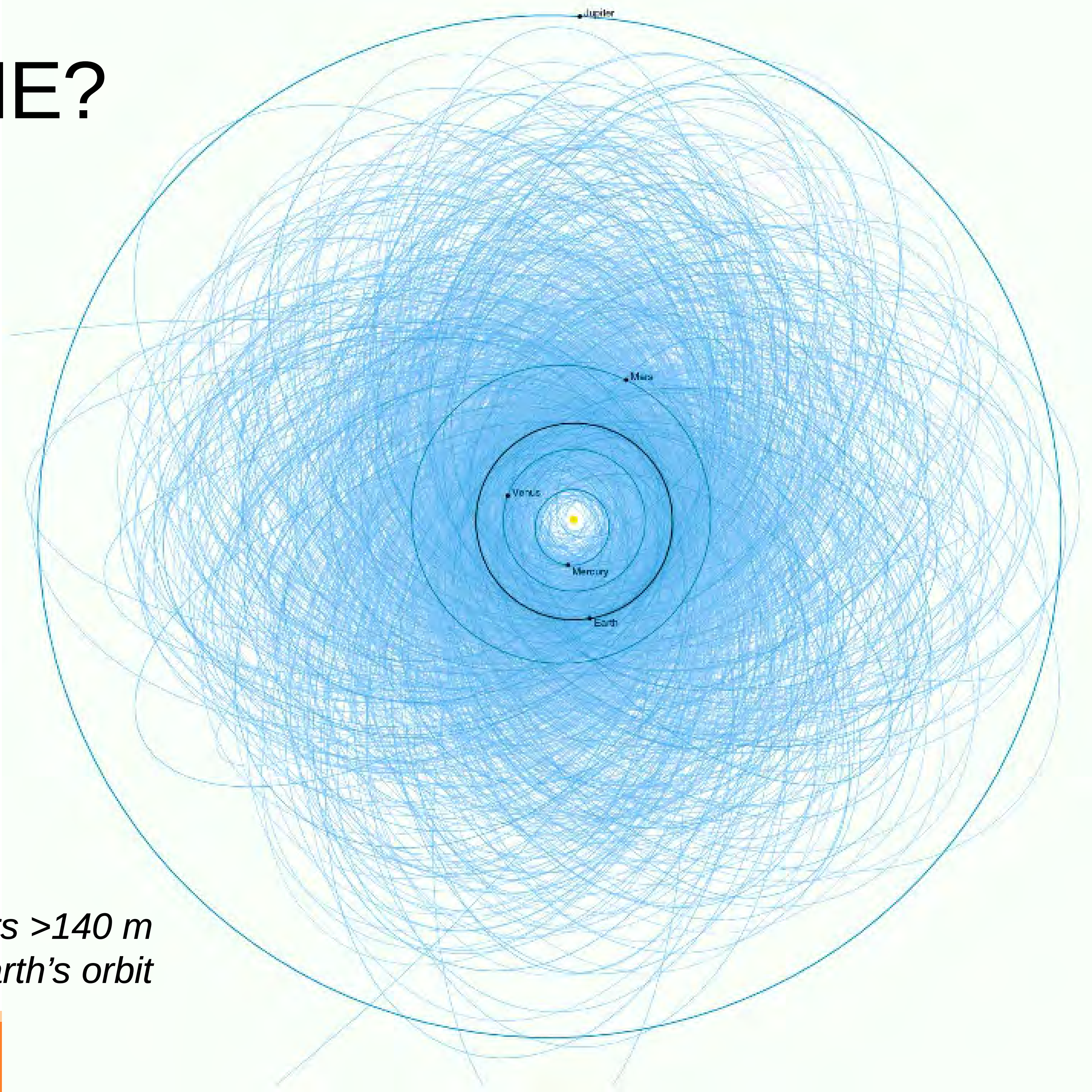
No Hazard	0	The likelihood of collision is zero, or is so low as to be effectively zero. Also applies to small objects such as meteors and bolides that burn up in the atmosphere as well as infrequent meteorite falls that rarely cause damage.
Normal	1	A routine discovery in which a pass near the Earth is predicted that poses no unusual level of danger. Current calculations show the chance of collision is extremely unlikely with no cause for public attention or public concern. New telescopic observations very likely will lead to re-assignment to Level 0.
Meriting Attention by Astronomers	2	A discovery, which may become routine with expanded searches, of an object making a somewhat close but not highly unusual pass near the Earth. While meriting attention by astronomers, there is no cause for public attention or public concern as an actual collision is very unlikely. New telescopic observations very likely will lead to re-assignment to Level 0.
	3	A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of localized destruction. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by the public and by public officials is merited if the encounter is less than a decade away.
	4	A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of regional devastation. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by the public and by public officials is merited if the encounter is less than a decade away.
Threatening	5	A close encounter posing a serious, but still uncertain threat of regional devastation. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than a decade away, governmental contingency planning may be warranted.
	6	A close encounter by a large object posing a serious, but still uncertain threat of a global catastrophe. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than three decades away, governmental contingency planning may be warranted.
	7	A very close encounter by a large object, which if occurring this century, poses an unprecedented but still uncertain threat of a global catastrophe. For such a threat in this century, international contingency planning is warranted, especially to determine urgently and conclusively whether or not a collision will occur.
Certain Collisions	8	A collision is certain, capable of causing localized destruction for an impact over land or possibly a tsunami if close offshore. Such events occur on average between once per 50 years and once per several 1000 years.
	9	A collision is certain, capable of causing unprecedented regional devastation for a land impact or the threat of a major tsunami for an ocean impact. Such events occur on average between once per 10,000 years and once per 100,000 years.
	10	A collision is certain, capable of causing a global climatic catastrophe that may threaten the future of civilization as we know it, whether impacting land or ocean. Such events occur on average once per 100,000 years, or less often.

WHAT IS BEING DONE?

The **Spaceguard Survey** identifies, catalogues, and studies Near-Earth Objects.

All asteroids >1 km are surveyed (in progress).

Large objects (especially those with the potential to cause a mass extinction) are tracked.

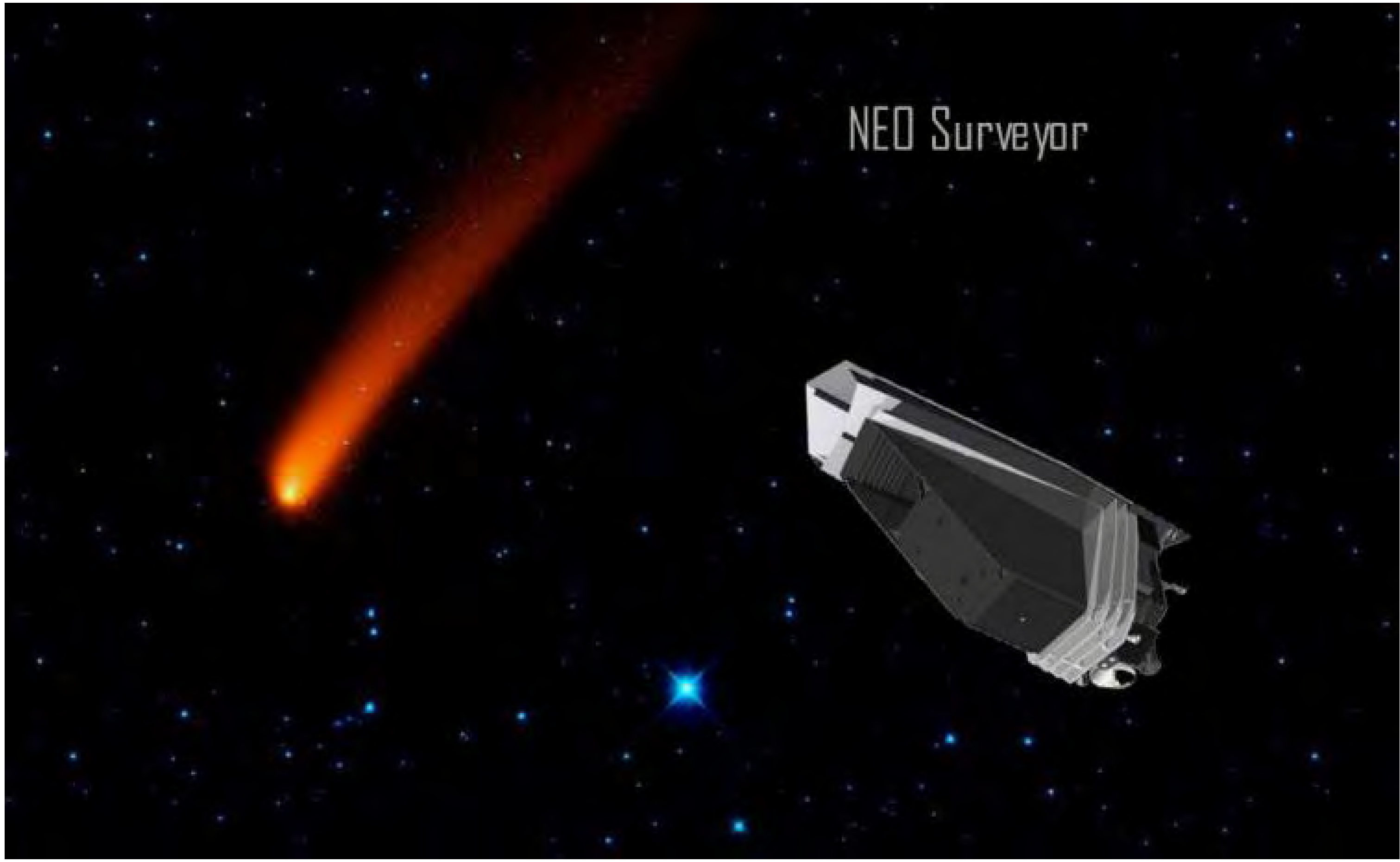


Orbits of known asteroids with diameters >140 m and crossing Earth's orbit

WHAT IS BEING DONE?

The **NEO Surveyor Spacecraft** is a planned space-based infrared telescope that will survey the Solar System for hazardous asteroids.

Authorised in 2019, planned to launch in 2026.



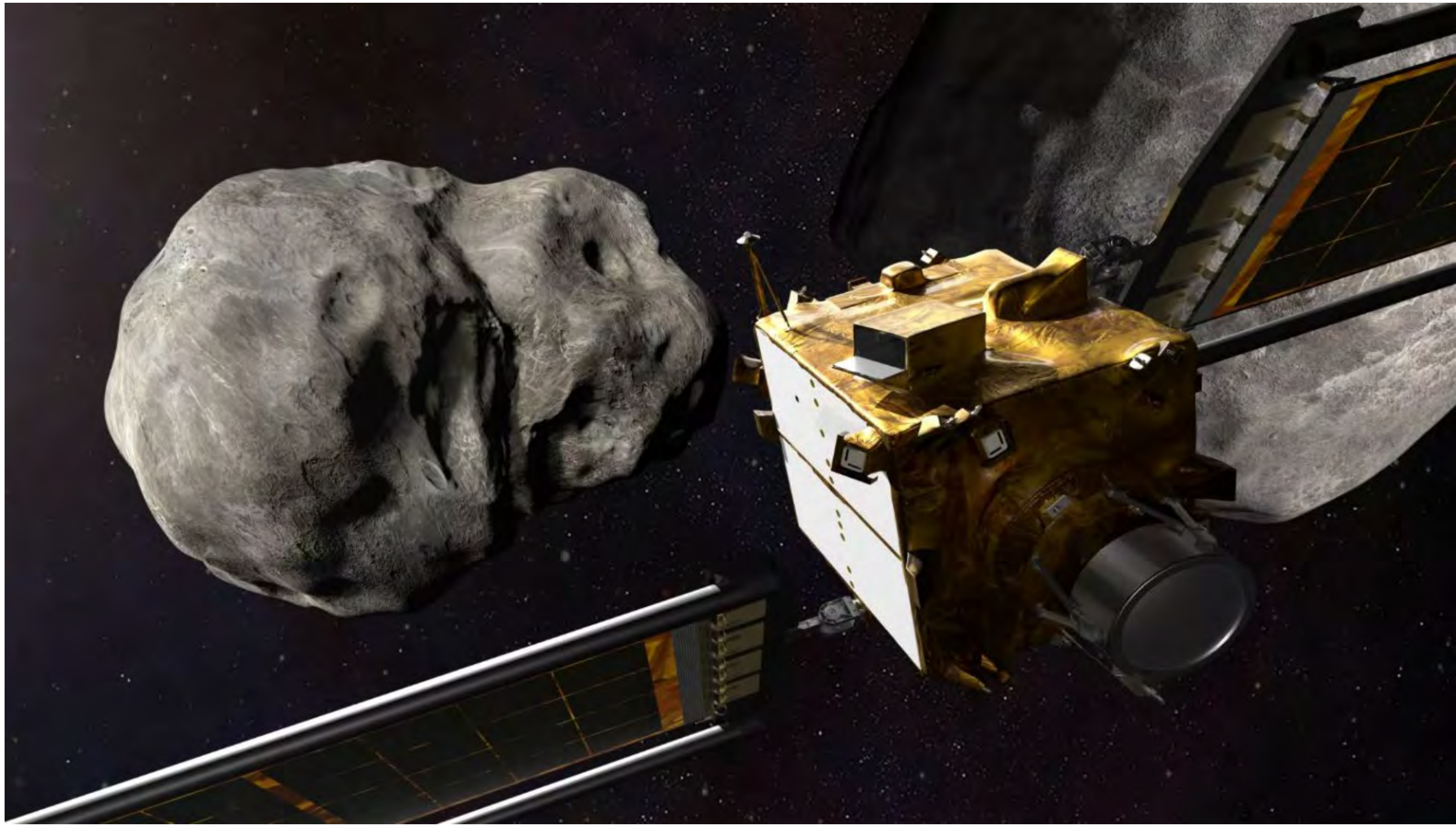
The NEO Surveyor will be able to detect objects in the Sun's glare that we cannot currently see

WHAT IS BEING DONE?

On the 26th September 2022 NASA conducted the **Double Asteroid Redirection Test (DART)**, slamming a probe into an asteroid called Dimorphos.

The orbit of the smaller asteroid was shortened by 33 minutes.

This was the first **successful asteroid deflection**.



The target asteroid (Dimorphos) orbits a bigger asteroid (Didymos) every 12 hours. The aim is to change its orbit by 10 minutes.

IMPACT HAZARD IS UNIQUE

As a natural hazard, an impact is potentially the most devastating.

But impacts are also the only natural disaster that can be entirely avoided.

The most important factor is **time**.

MITIGATION STRATEGIES

1. **Fragmentation**

- Blow the asteroid up
- Requires landing on an asteroid (we have done this now)
- Requires drilling into the asteroid
- Creates the risk of multiple impacts
- Takes a long time to prepare

MITIGATION STRATEGIES

2. **Rapid Orbit Adjustment**

- Nuclear warhead or smash a projectile into the asteroid
- Requires a warning period

MITIGATION STRATEGIES

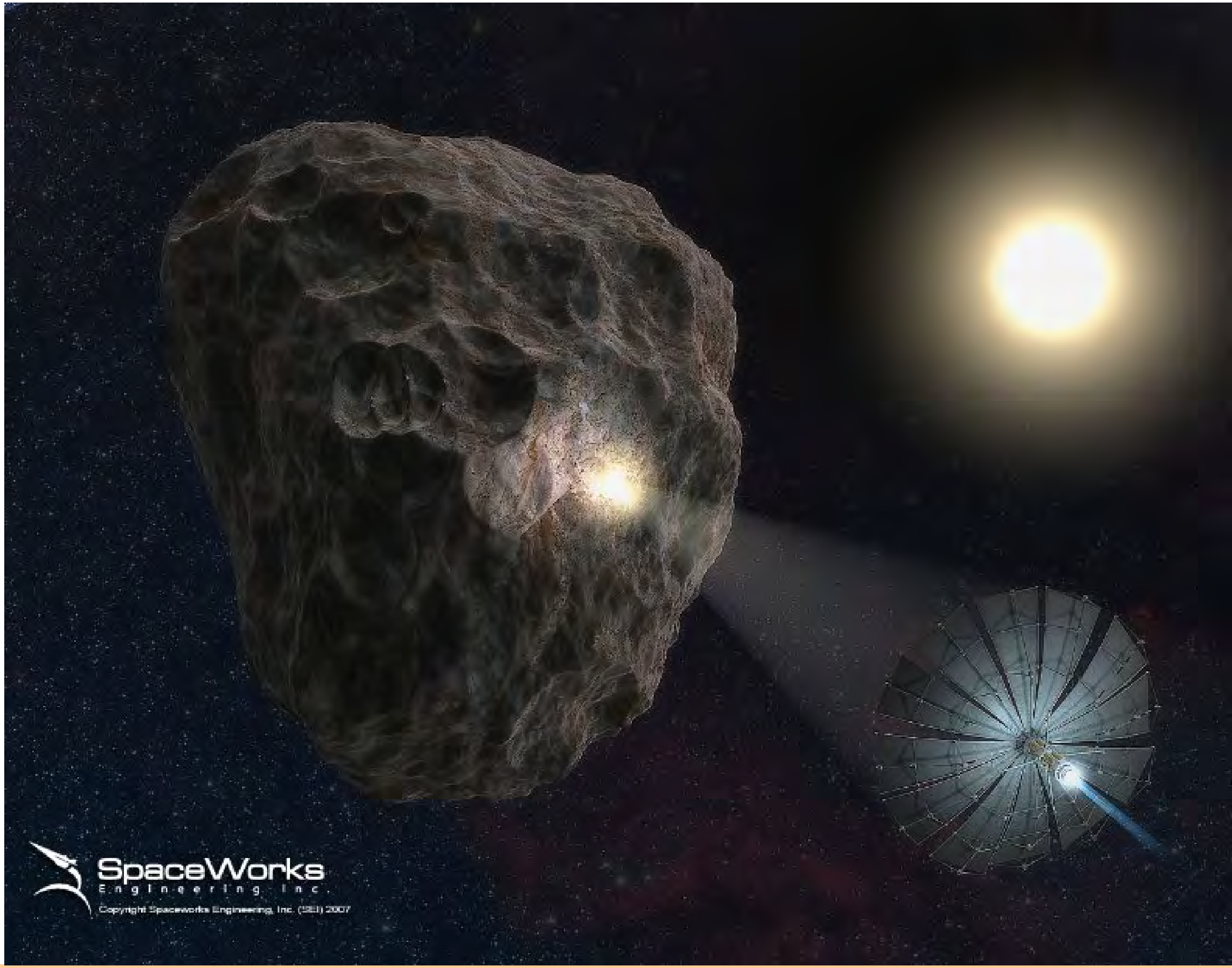
3. **Gradual Orbit Adjustment**

- Could use chemical, electric, or nuclear propulsion
- Mass drivers might work (excavate and accelerate material off the asteroid)
- Requires a warning period but this method is predictable

MITIGATION STRATEGIES

4. **Ablation**

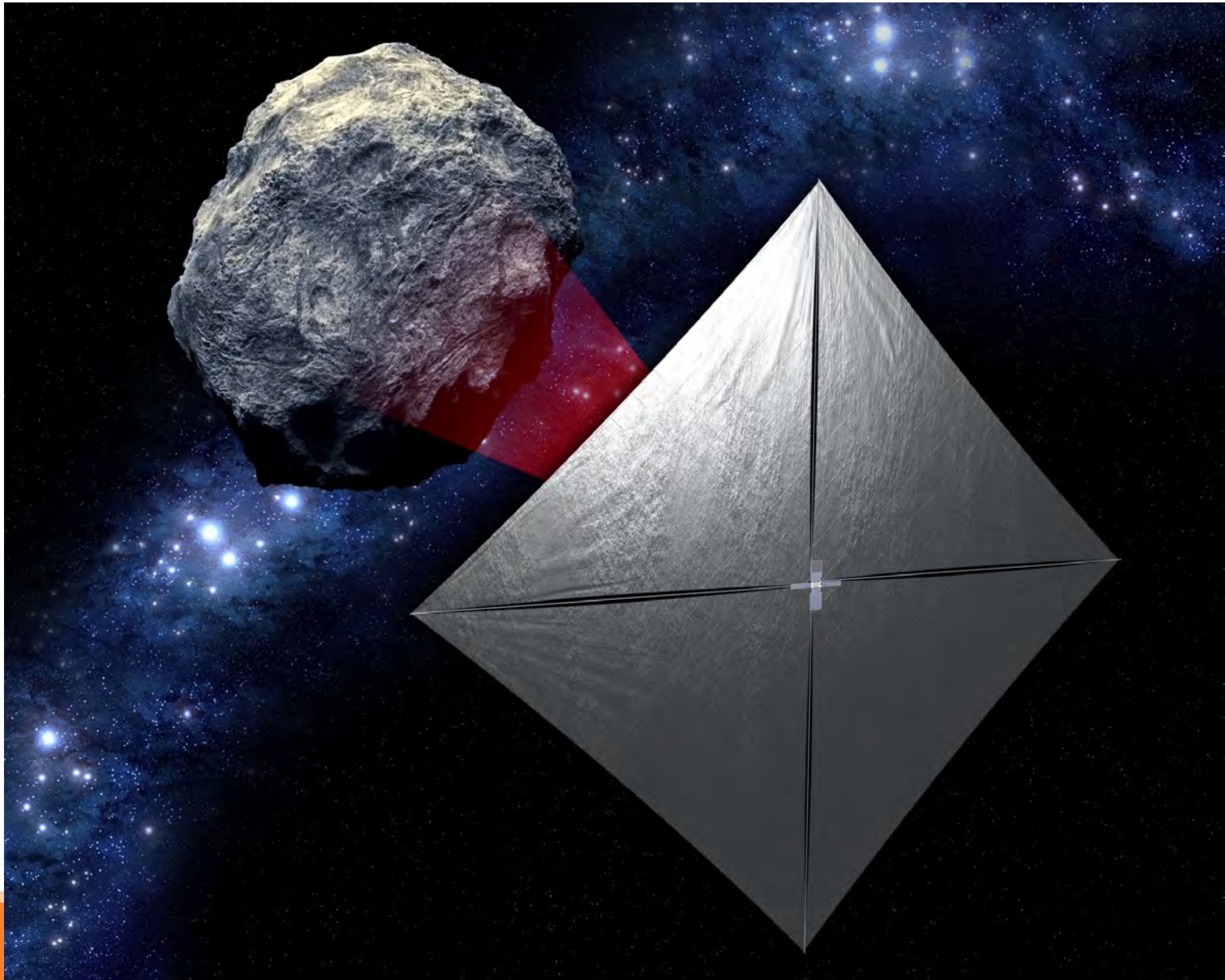
- Focus sunlight onto the surface of the asteroid, or use lasers
- The goal would be to flash-vaporize or ablate away the asteroid mass, or deflect the object's path
- Would need to place a satellite in orbit around the asteroid (we have done this)



MITIGATION STRATEGIES

5. **Ride the Solar Winds**

- Install solar sails (mirrors) on the asteroid. ‘Radiative pressure’ from sunlight would deflect it.
- Requires a very long warning time
- NASA’s **Near-Earth Asteroid Scout** mission will test a solar-sail flyby of asteroid 2020GE in 2023.



THE REALITY

These mitigation strategies are real proposals and some are being tested in space now.

After the Shoemaker Levy 9 impact, scientists and governments began taking impacts very seriously.

However, all methods require:

- Research
- Lots of warning time
- Lots of money

We face a lot of other challenges, too: climate change, cancer, HIV, pandemics, earthquakes, poverty… should we divert resources to impacts?

Impacts are very low frequency, but could have a catastrophic impact on civilisation.

IMPACTS 4

Impacts and Humans: Frequency and Mitigation

Dr Mitch D’Arcy

SUMMARY

1. Asteroids, meteors, and comets are common in different parts of the Solar System and present an impact risk for the Earth.
2. There is a logarithmic relationship between object size and the average recurrence interval: We expect a ~10 km object to impact the Earth every ~100 Myr on average.
3. Shoemaker’s Hypothesis is that impacts affect the Earth regularly over geological timescales, and have indeed happened.
4. Raup and Sepkoski’s Hypothesis is that impacts—and extinctions caused by them—occur with a ~25 Myr cyclicity that might reflect gravitational disruption of the Oort cloud.
5. Humanity is actively tracking potential threats and testing mitigation technologies, but recent near misses and impacts show that we are not well-prepared yet.

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