Astronomy 150: Killer Skies
Lecture 9, February 6

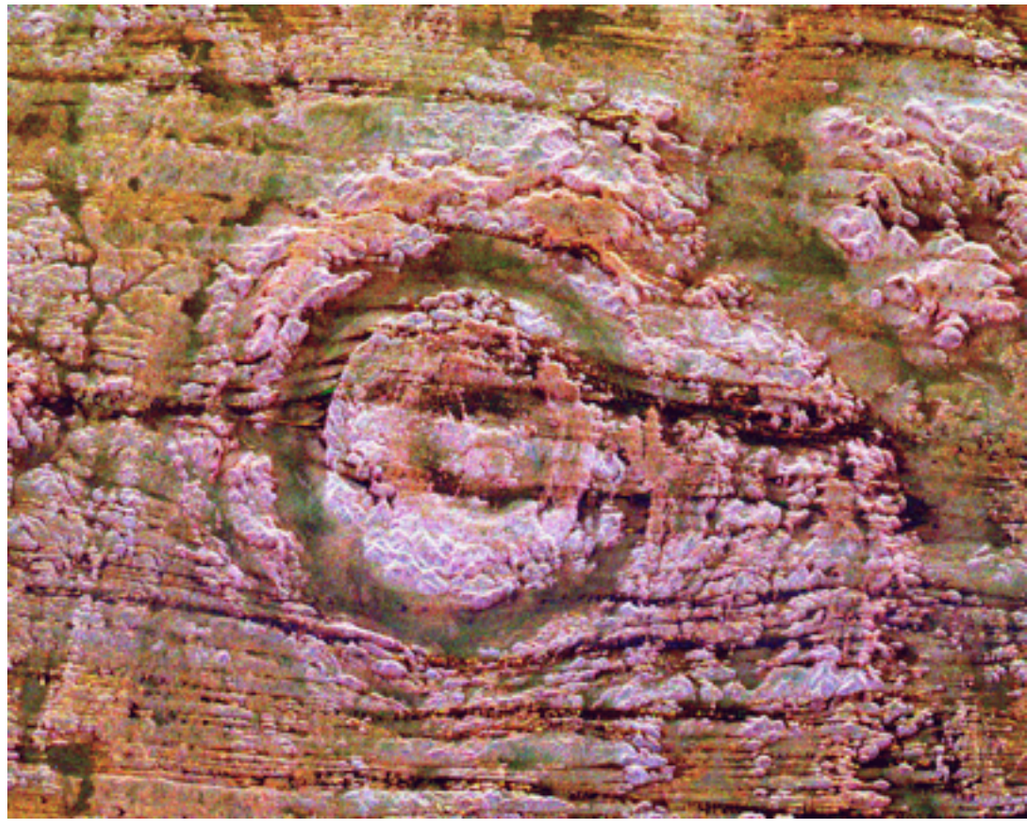
Last time: Origin of the Solar System II

Today: Meteors and the Earth

Assignments:

- **HW 3 due next Friday at start of class**
- **Planetarium shows this week and next; info and reservations on class website**

http://apod.nasa.gov/apod/ap091015.html



http://epod.usra.edu/blog/2002/02/aorounga-impact-crater.html

Recap:
The Violent Birth and Infancy of the Planets

Heavy Bombardment

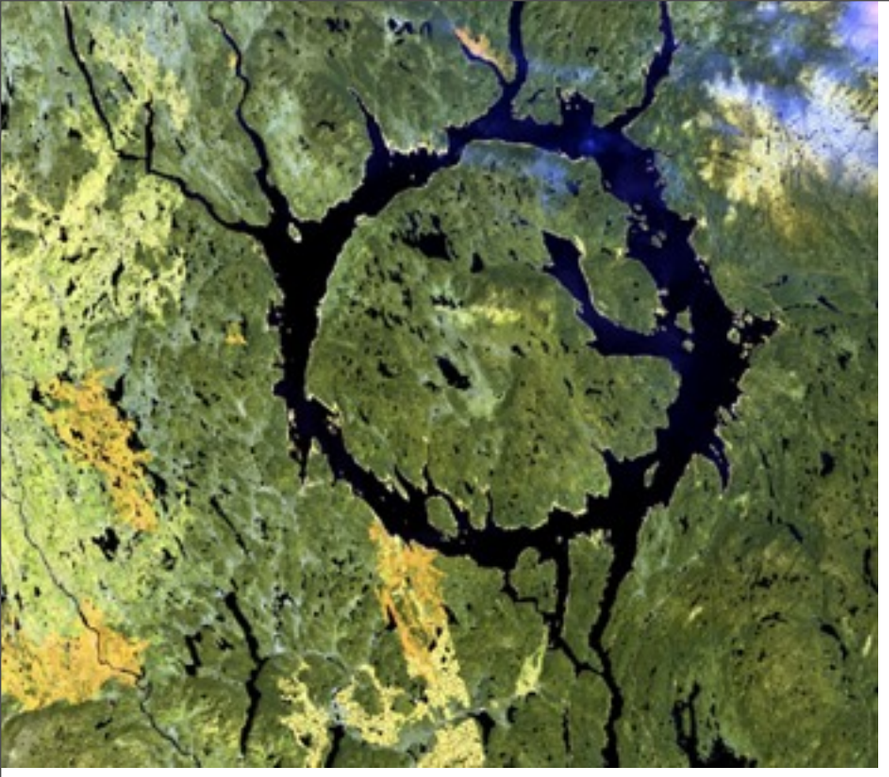
- planetesimals collide with young planets
- lasted 800 million years

Formation of the Moon: Smack!

- Mars-sized object collided with young earth
- orbiting debris clumped to form Moon
- collision gave Earth its 23.5 degree spin tilt

Early Earth

- constant bombardments
- no water until brought by comet impacts



Meteors and Earth

How can falling objects cause so much damage?
Impacts occur at enormous speed!

- Space debris moving at high speeds
- Earth's orbital speed: 30 km/s (67,000 mph)
- Impactor speeds entering the atmosphere
  - Range: 11-72 km/s
  - average asteroid speed: 17 km/s
  - average comet speed: 51 km/s

Does Large Space Junk Ever Impact Objects in the Solar System?

Proof in the Pudding:

http://antwrp.gsfc.nasa.gov/apod/ap090206.html

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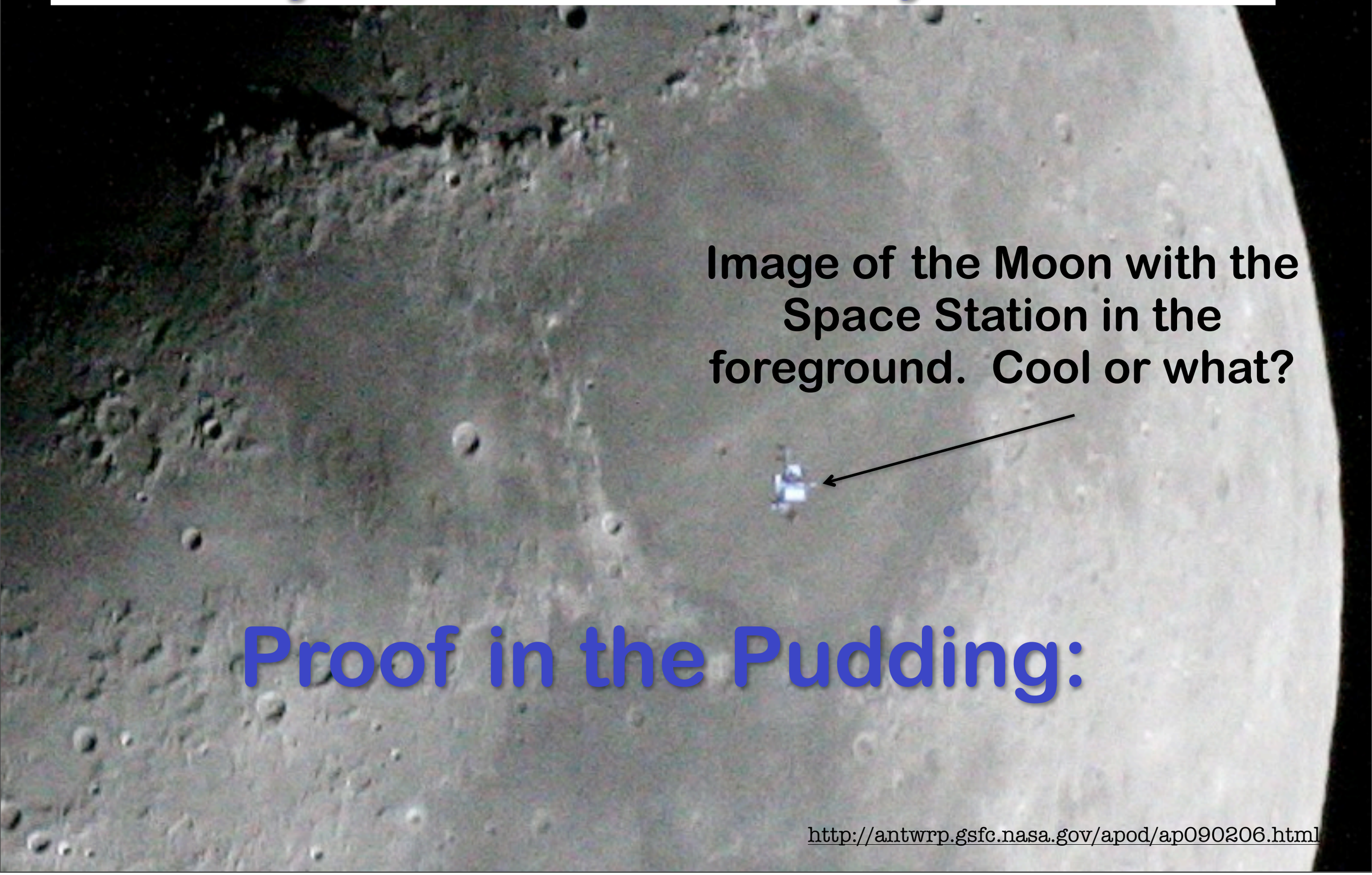
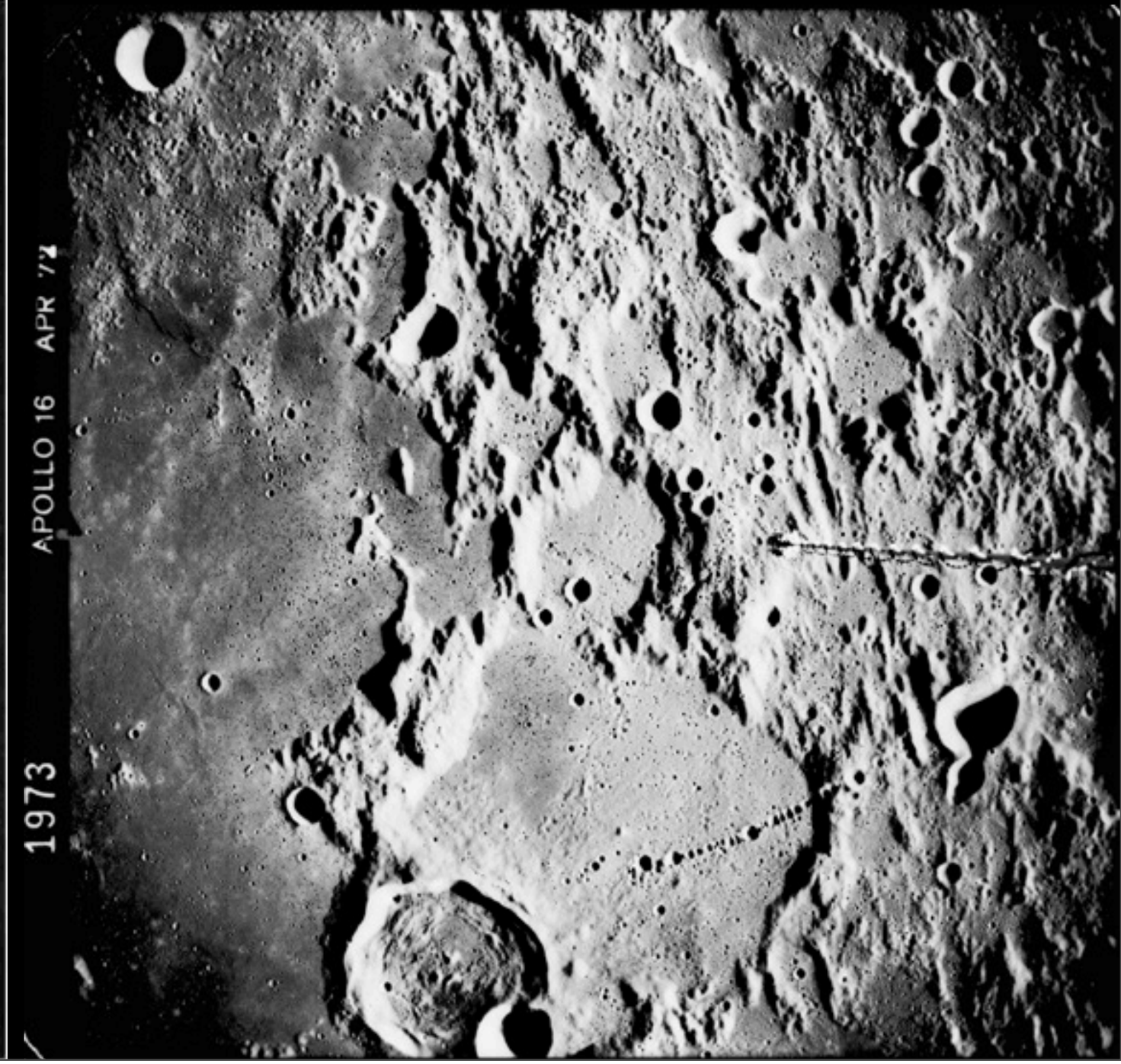


Proof in the Pudding: Moon Pie

With even a small telescope, you can see **>30,000 craters** on the Moon.

http://antwrp.gsfc.nasa.gov/apod/ap071120.html

- Full Moon (telescope view) with lighter highlands and darker basalt plains, filling multi-ringed basins
- Apollo 16 view of Descartes Highlands, with impact craters on all scales



Group Discussion

The Moon clearly has had some LARGE impacts over its lifespan of ~4.5 billion years.

Why didn't the Earth?

- I didn't fall into a crater on the way over here today.

More than one reason!

a) When your group has a good answer click A on your iClicker.

Earth-Moon Cratering Differences

Most impactors burn up in Earth's atmosphere

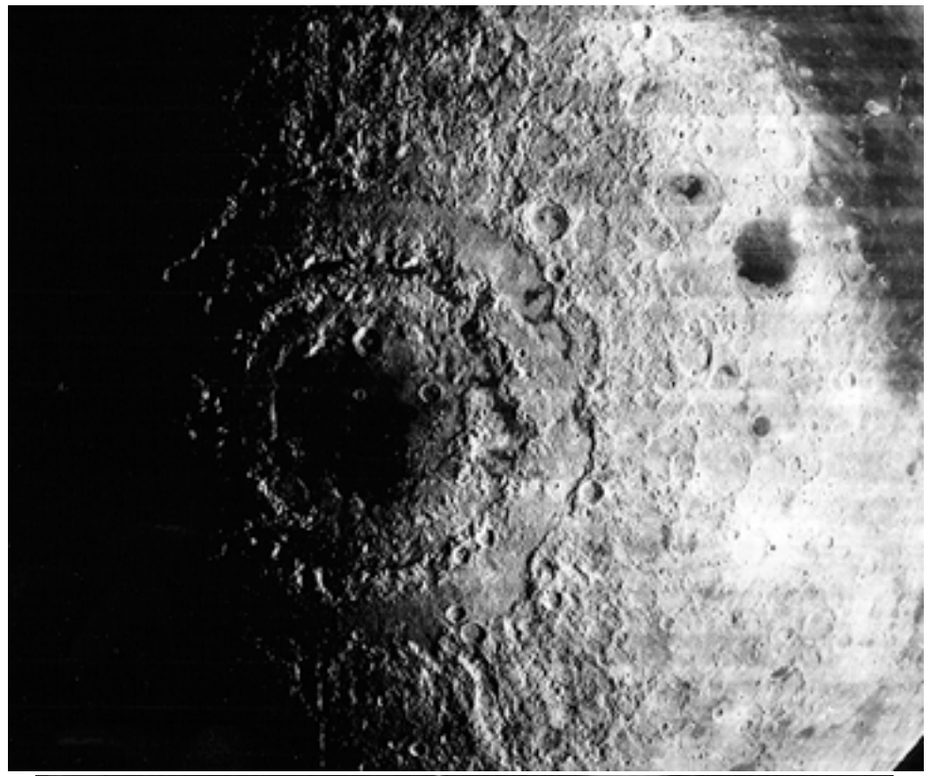
- the Moon has no atmosphere to protect it

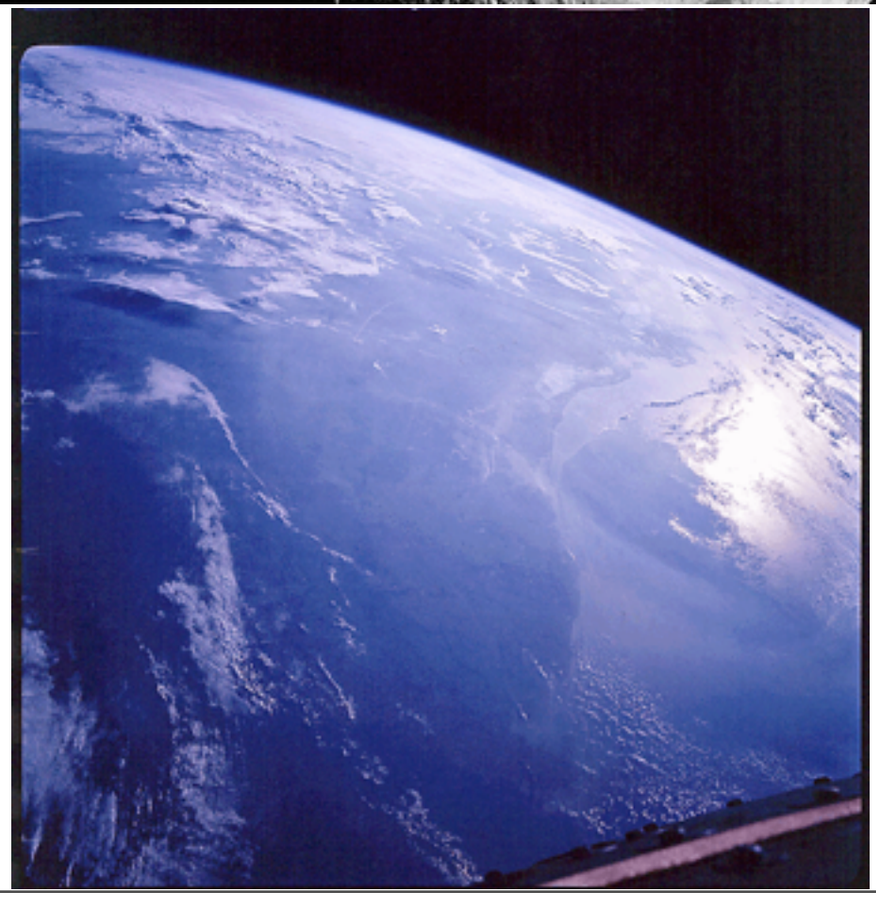
Earth's surface is about 75% water

- most meteorites go to bottom of ocean

Erosion due to wind and water slowly covers up craters on land

But still, the Earth does have some craters...





Meteorites and the Earth

- Many bodies in the solar system show massive amounts of cratering
- Earth is relatively crater free
- But we do know of many impact sites (~200)

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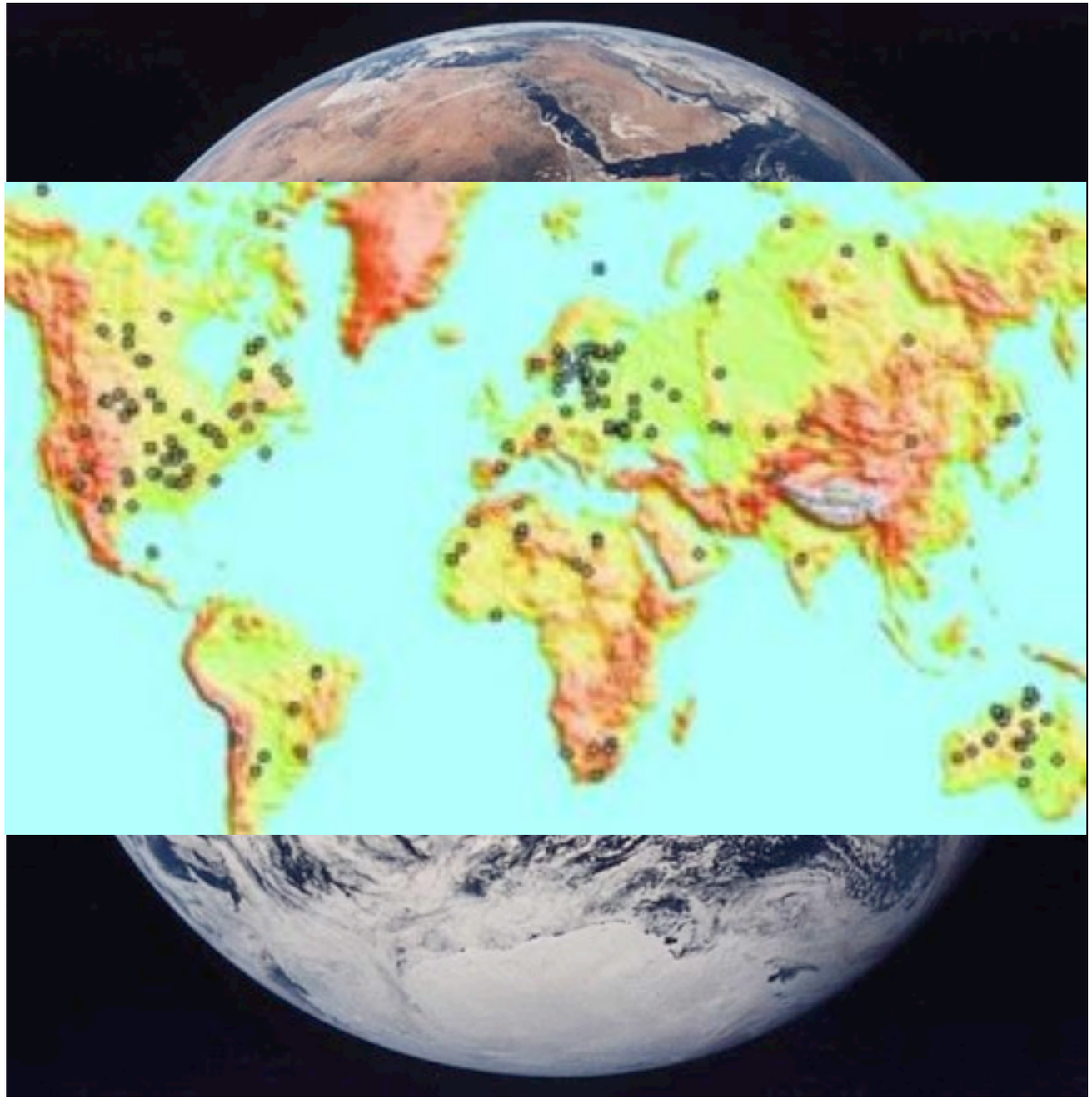


Where are the big craters?

There are good reasons why there are not small craters on Earth...but why so few big ones?

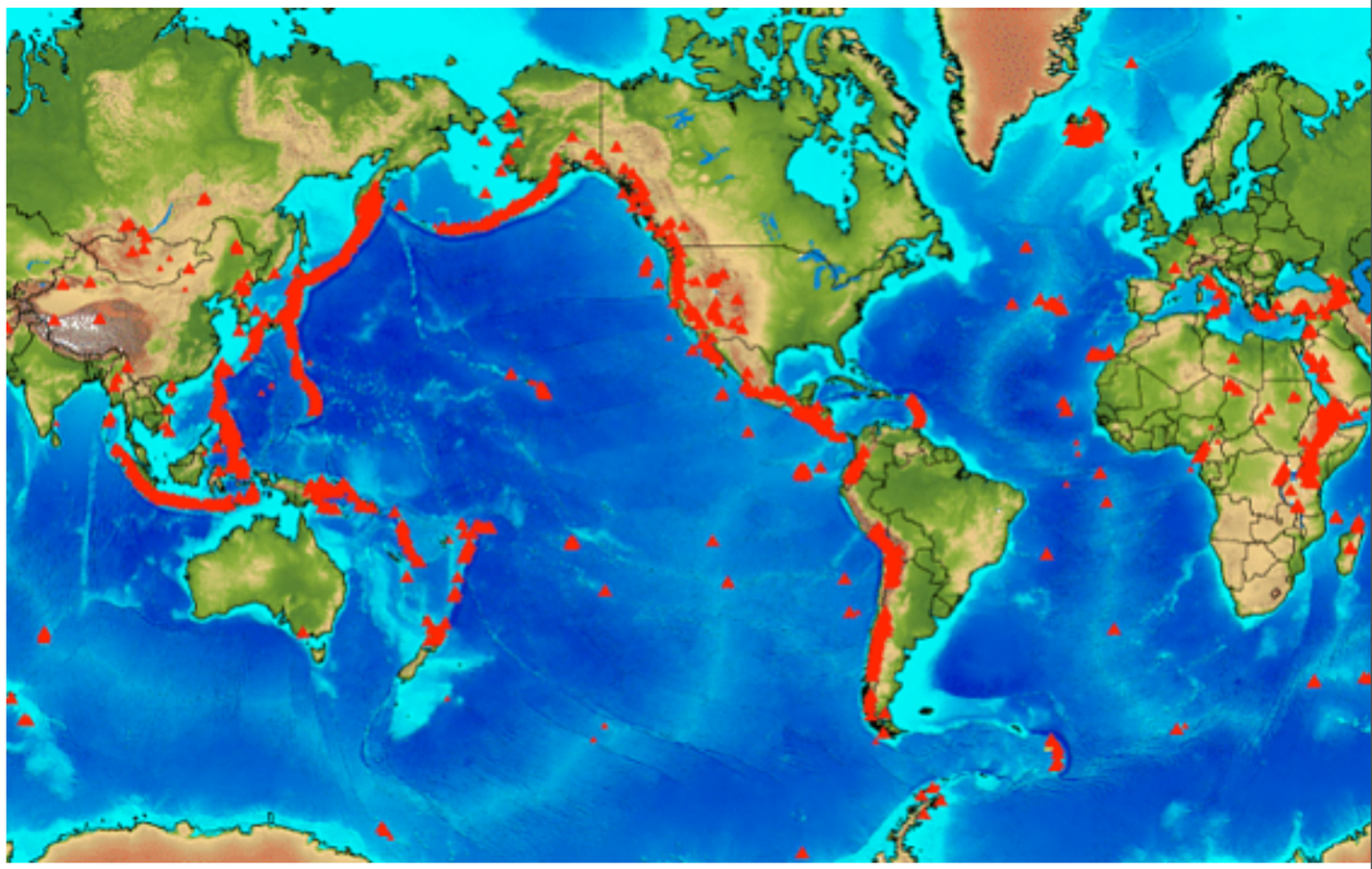
As we will see--the Earth's atmosphere does not protect from the largest impactors

Yet the Earth has much fewer large craters than the Moon does

What does this tell us?

The Active Earth

Volcanos



Radioactive dating:

- rocks on Earth have a variety of ages since formation,

  some millions of years "young"

  some billions of years old

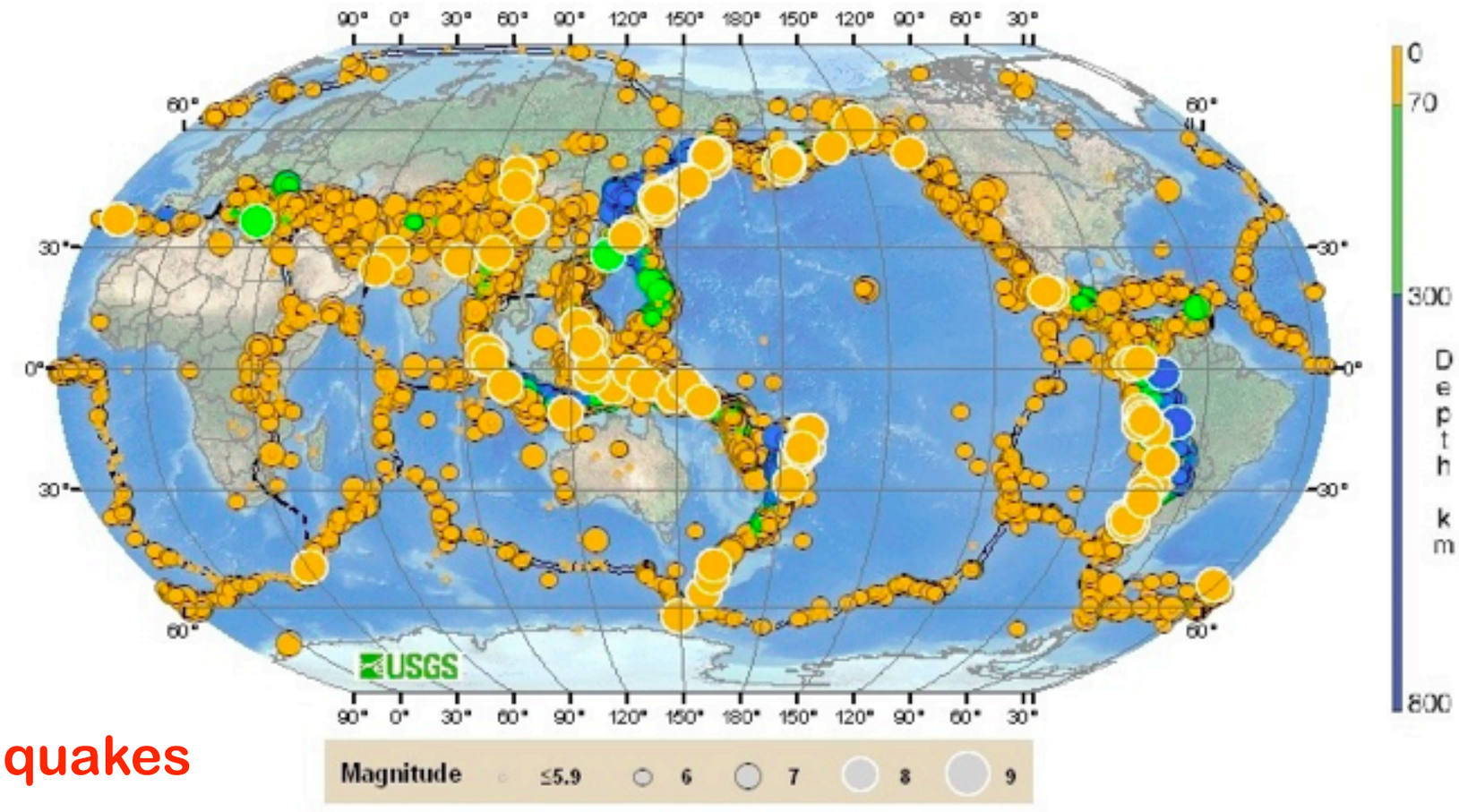
Global earthquake and volcano locations:

- form patterns! outline continents!

GPS measurements:

- continents slowly moving!
- North America moving away from Europe at about 1cm/ year!

What does it all mean?



Earthquakes

Plate Tectonics

The interior of the earth is hot!

Continents are solid "rafts" = "plates" floating on a sea of slowly oozing molten rock

Plates interact

- **collide: form mountains, volcanos**
- **slide against each other: earthquakes**
- **spread apart: form ocean trenches**

The Earth's surface is constantly "repaved" by motion of plates

- **Earth's surface is younger than Moon's**
- **ancient craters have been erased!**
- **Earth is geologically active, Moon interior cold, geologically "dead"**

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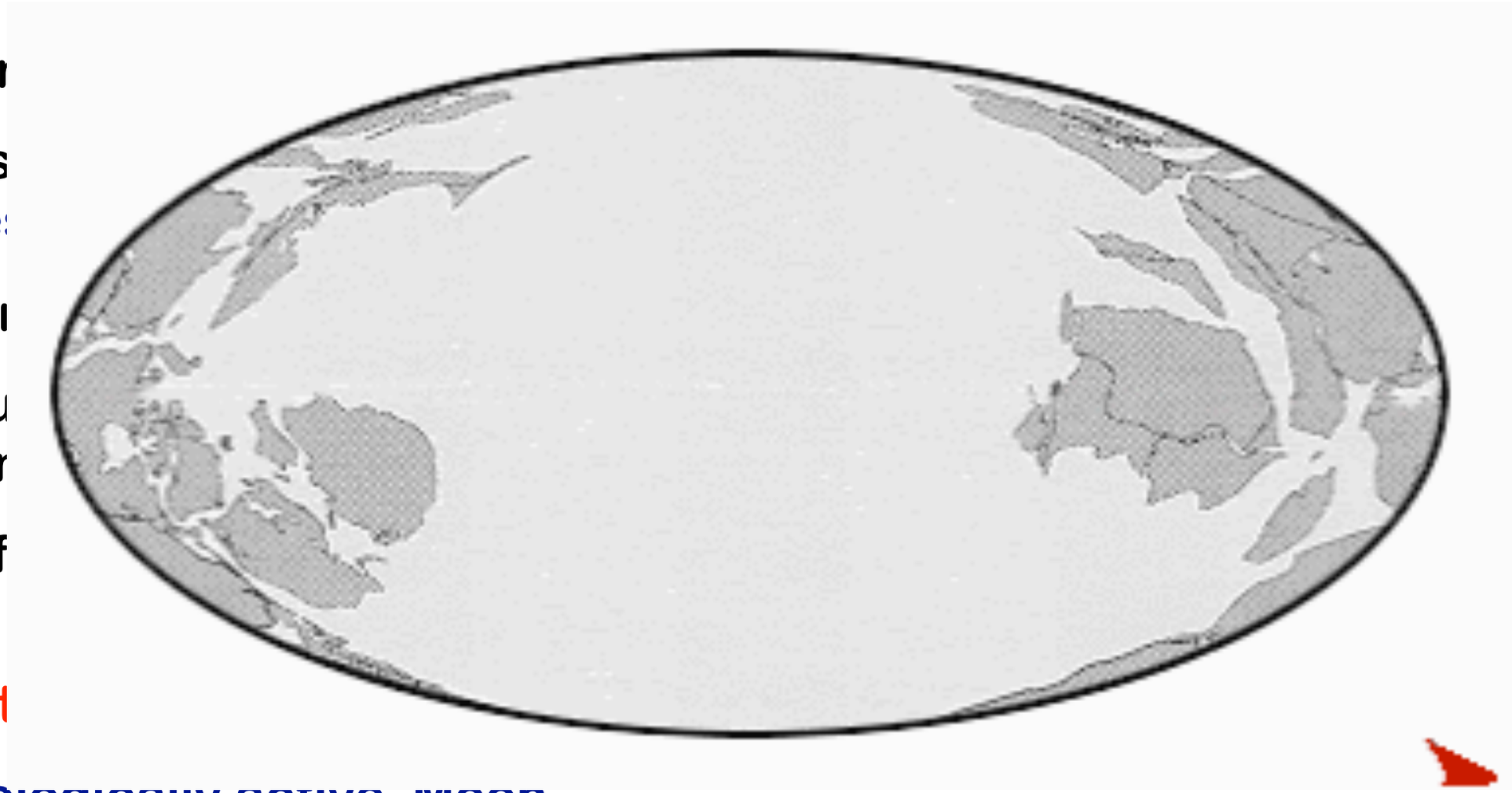

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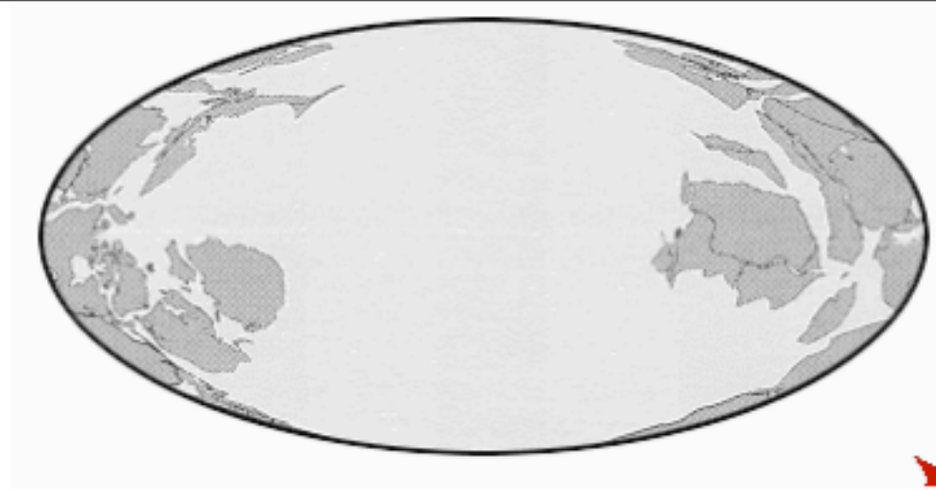

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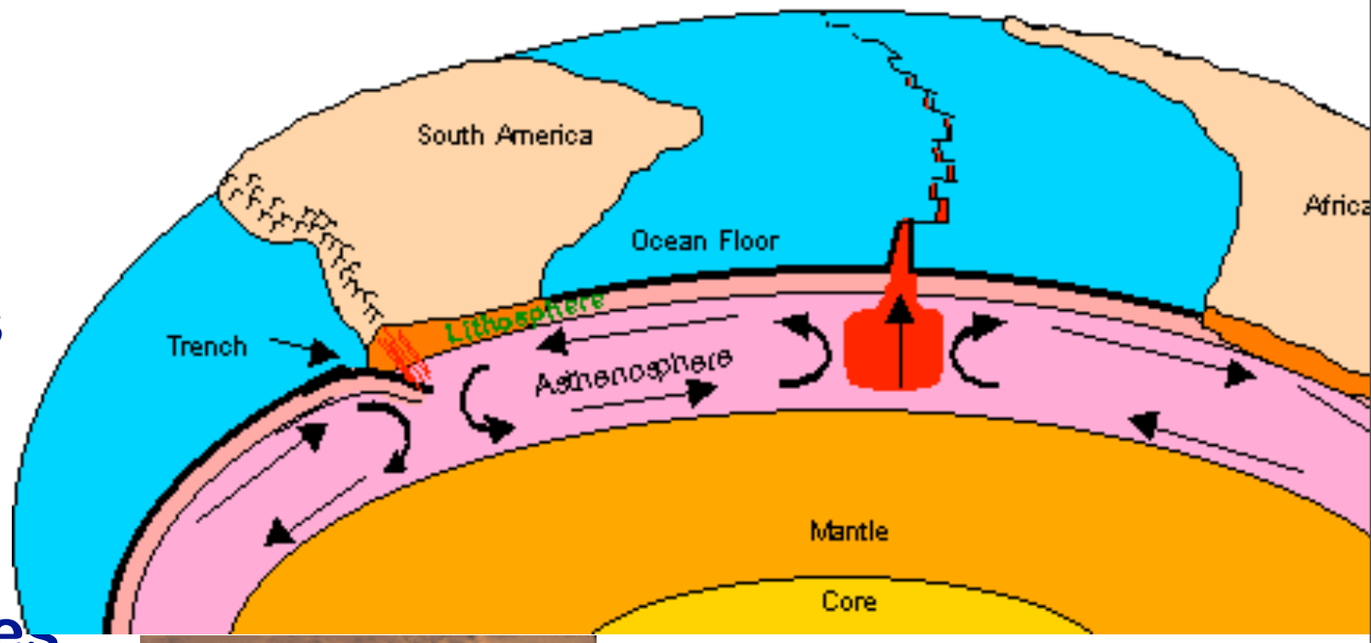

San Andreas fault, CA: sliding plates

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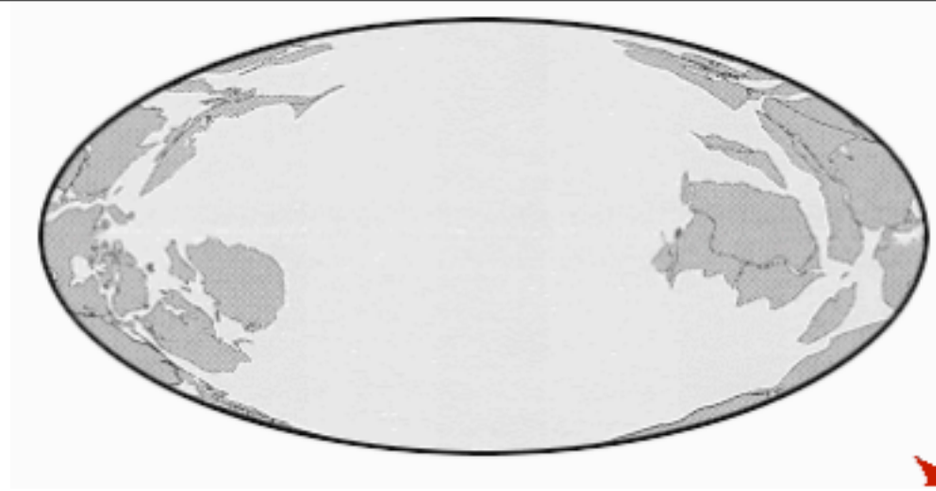

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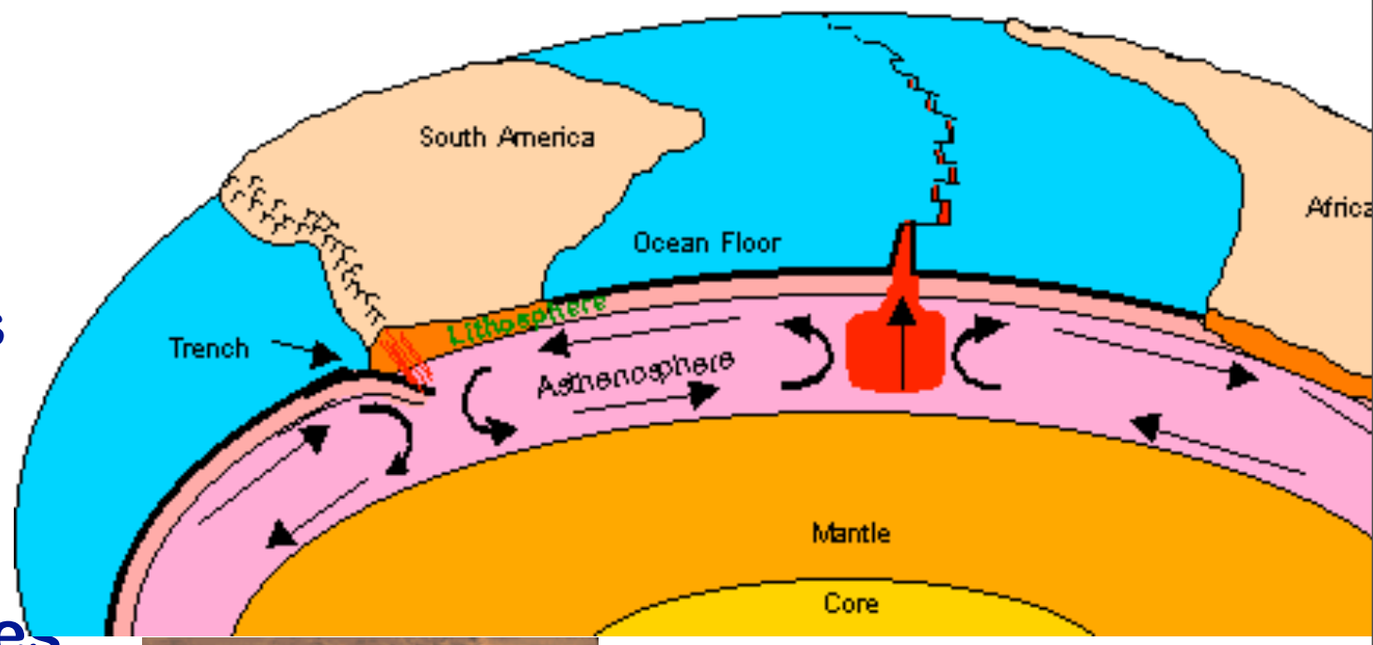

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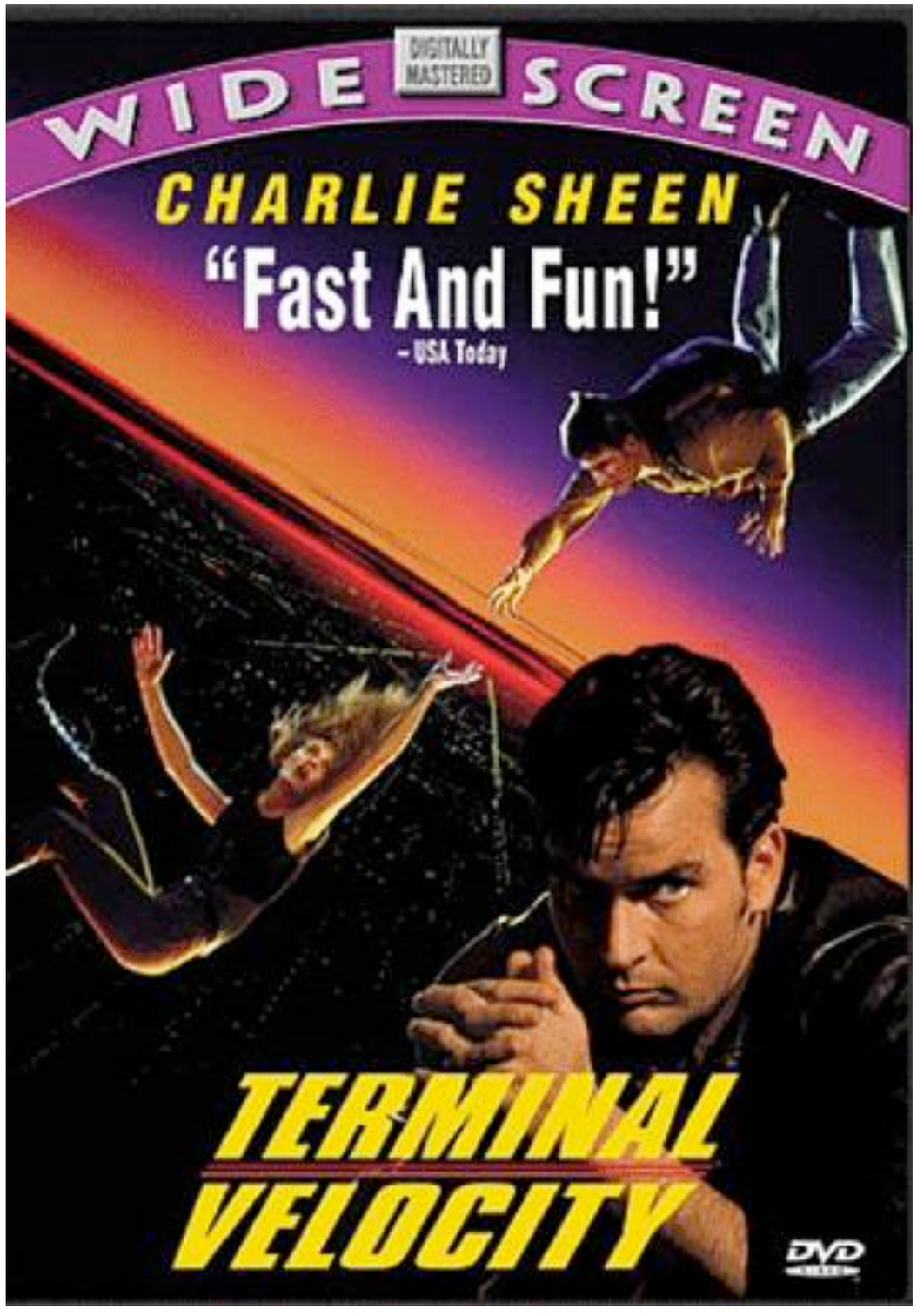
Air Brakes:
Falling Through the Atmosphere

Air causes resistance

An object falling in the atmosphere will have gravity pulling downward, and air resistance pushing upward

When the two cancel, the object reaches its maximum velocity, or its terminal velocity



Terminal Velocity

Consider a skydiver:

1. At the start of the jump, no air resistance, so diver accelerates downwards, speed increasing.
2. As the speed increases, air resistance increases. Diver still accelerates, but less than before, speed still increasing.
3. Air resistance increases until it equals the pull of gravity, and the diver no longer accelerates. The speed is at the terminal velocity.

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Still considering a skydiver:

4. When opening the parachute, shape changes, more air resistance, so diver decelerates, speed decreases
5. Because object is slowing down the air resistance decreases until it balances gravity. Diver has now reached a new, lower terminal velocity, allowing him to land safely.

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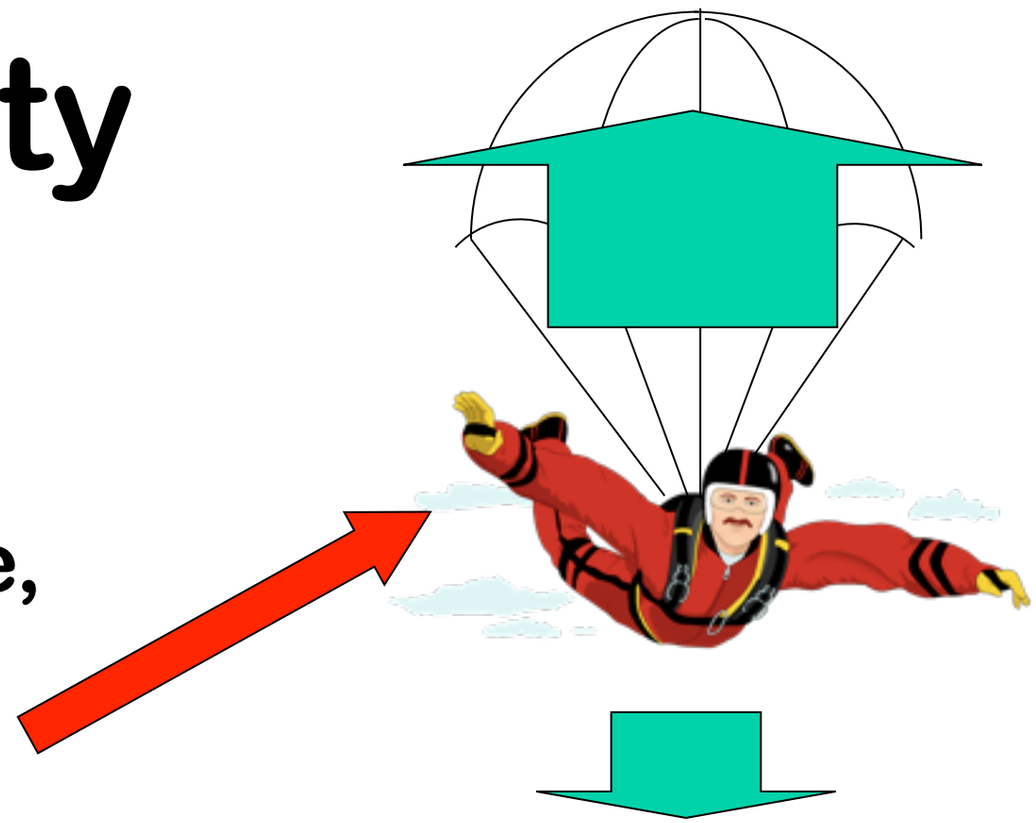

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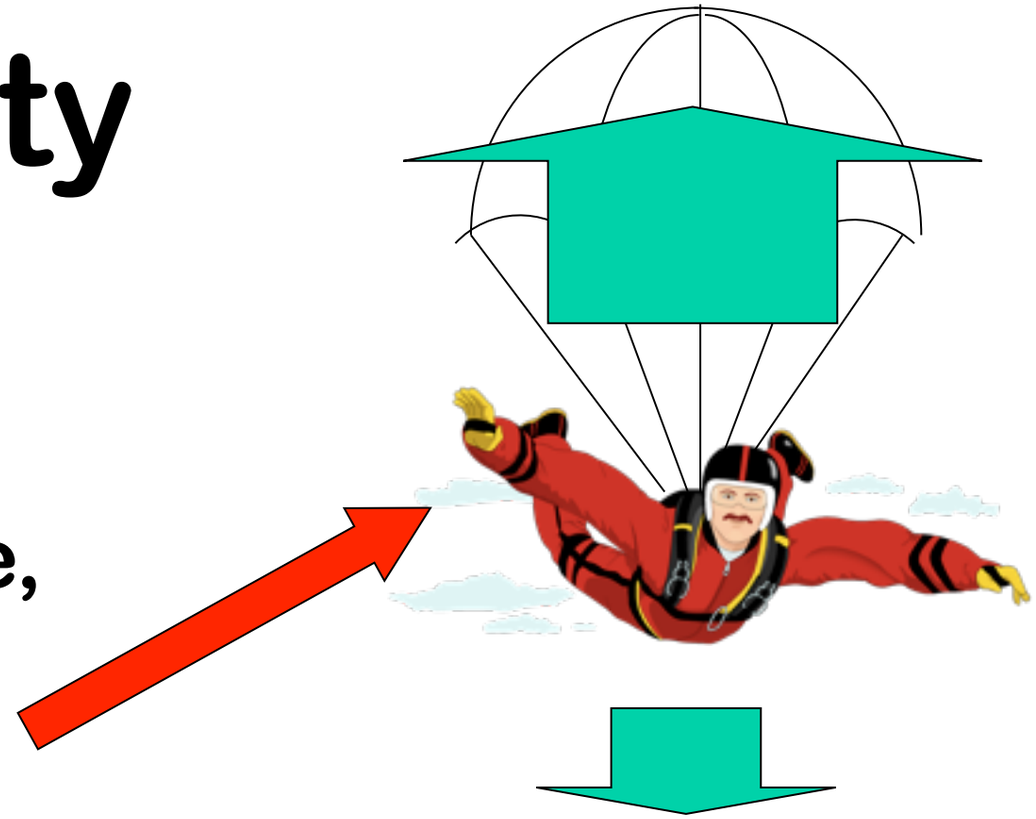

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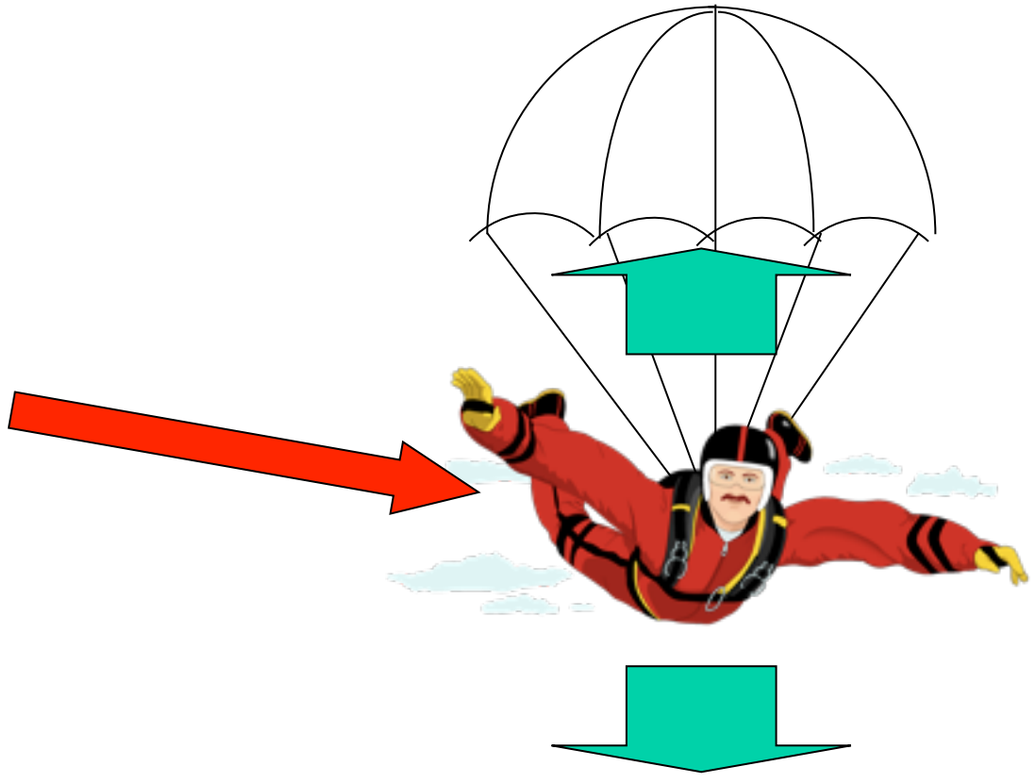
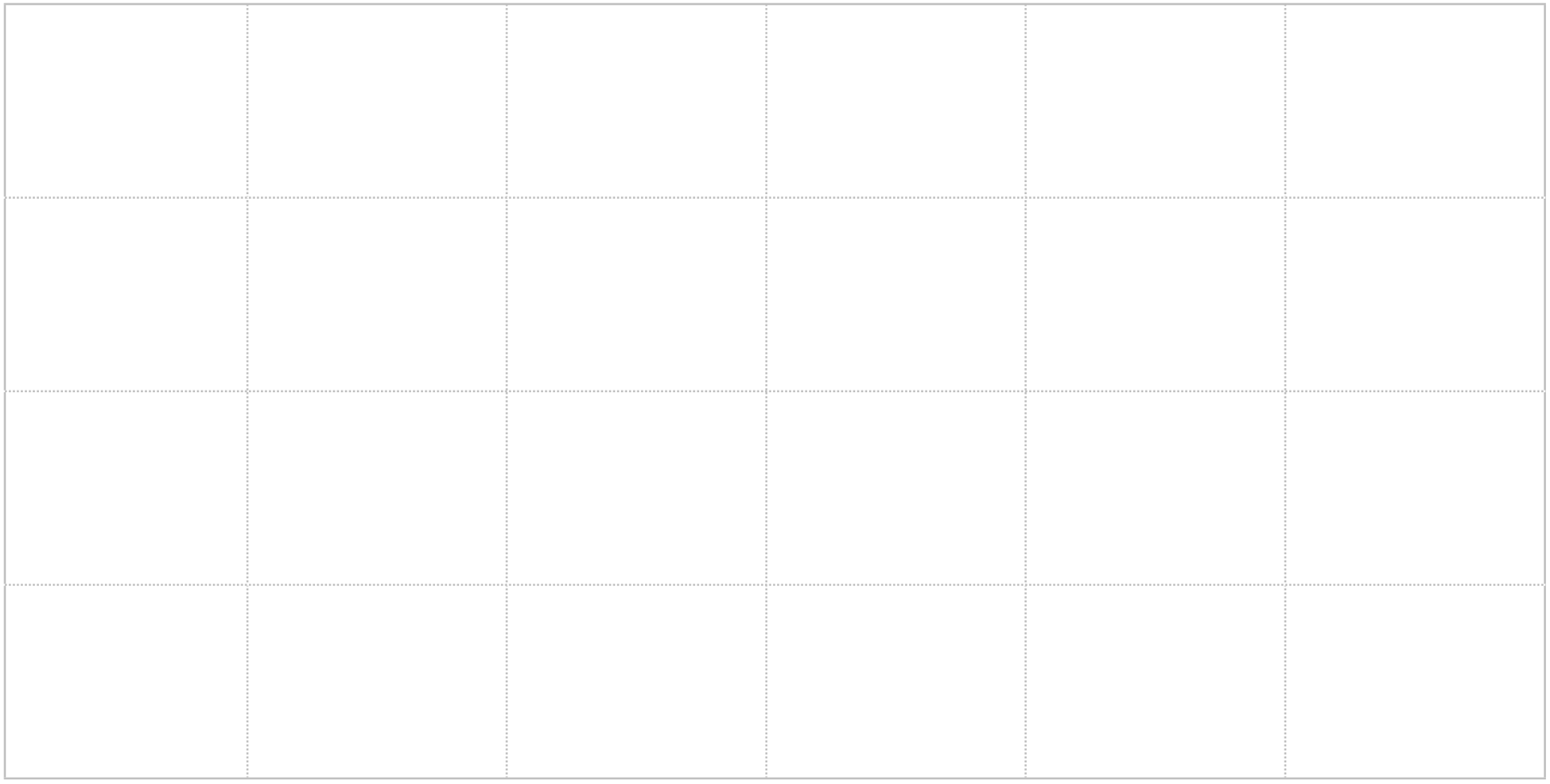


Velocity-time graph for skydiver terminal

Velocity



Time

Velocity-time graph for skydiver terminal

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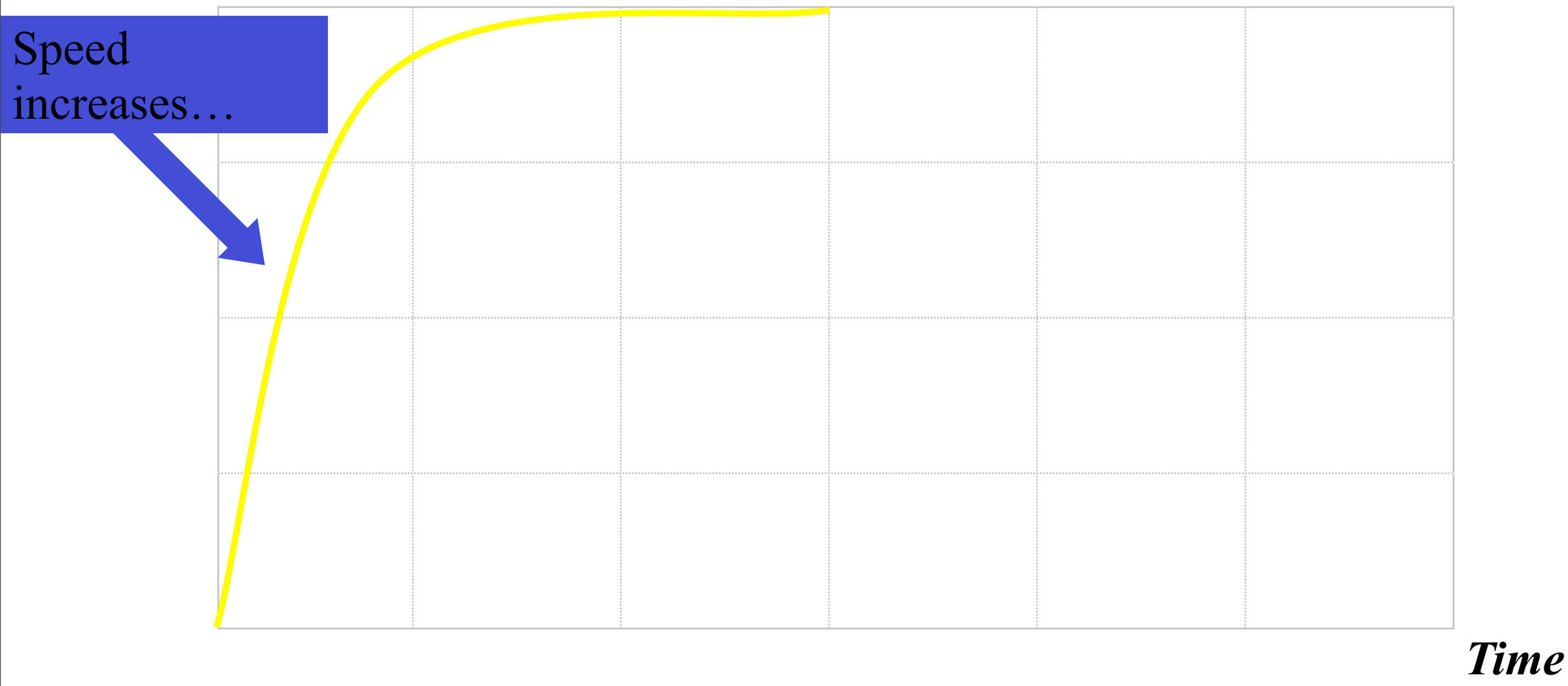

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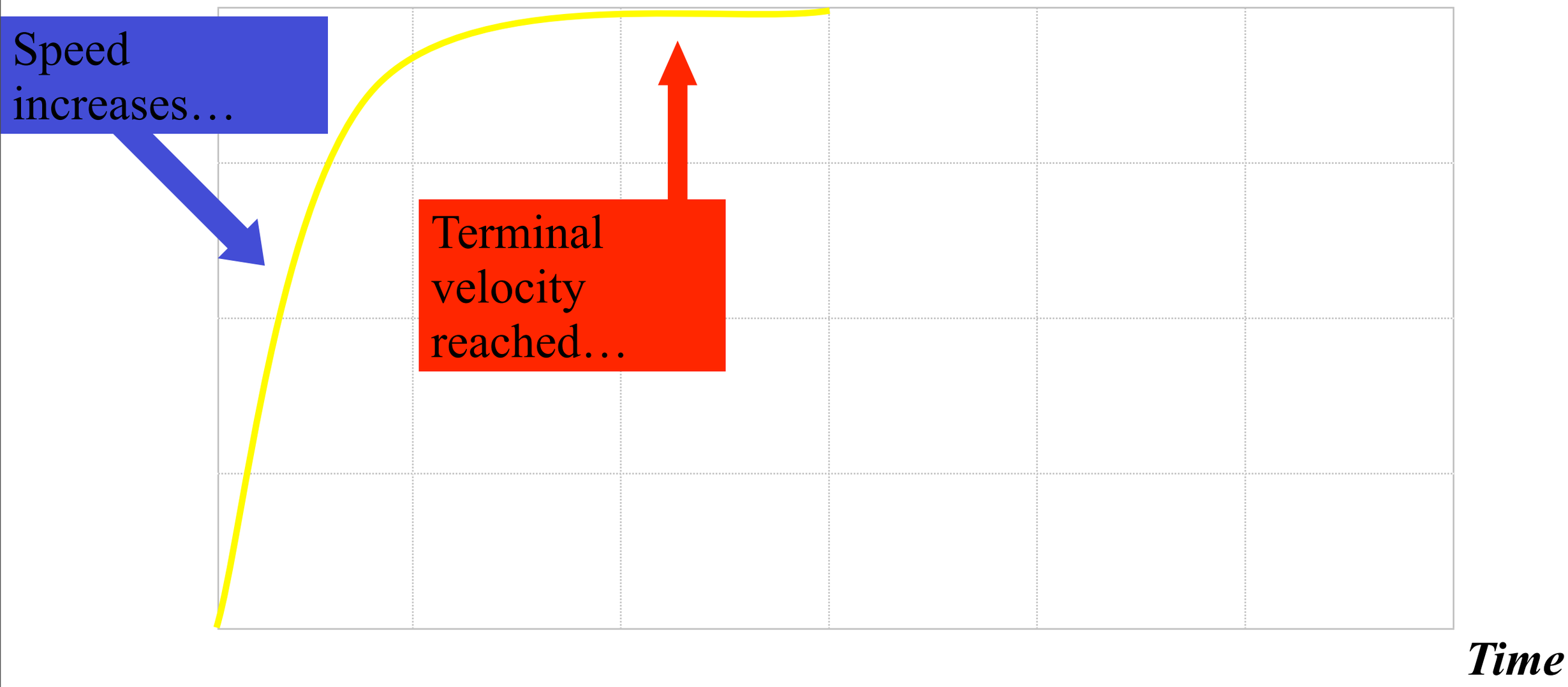

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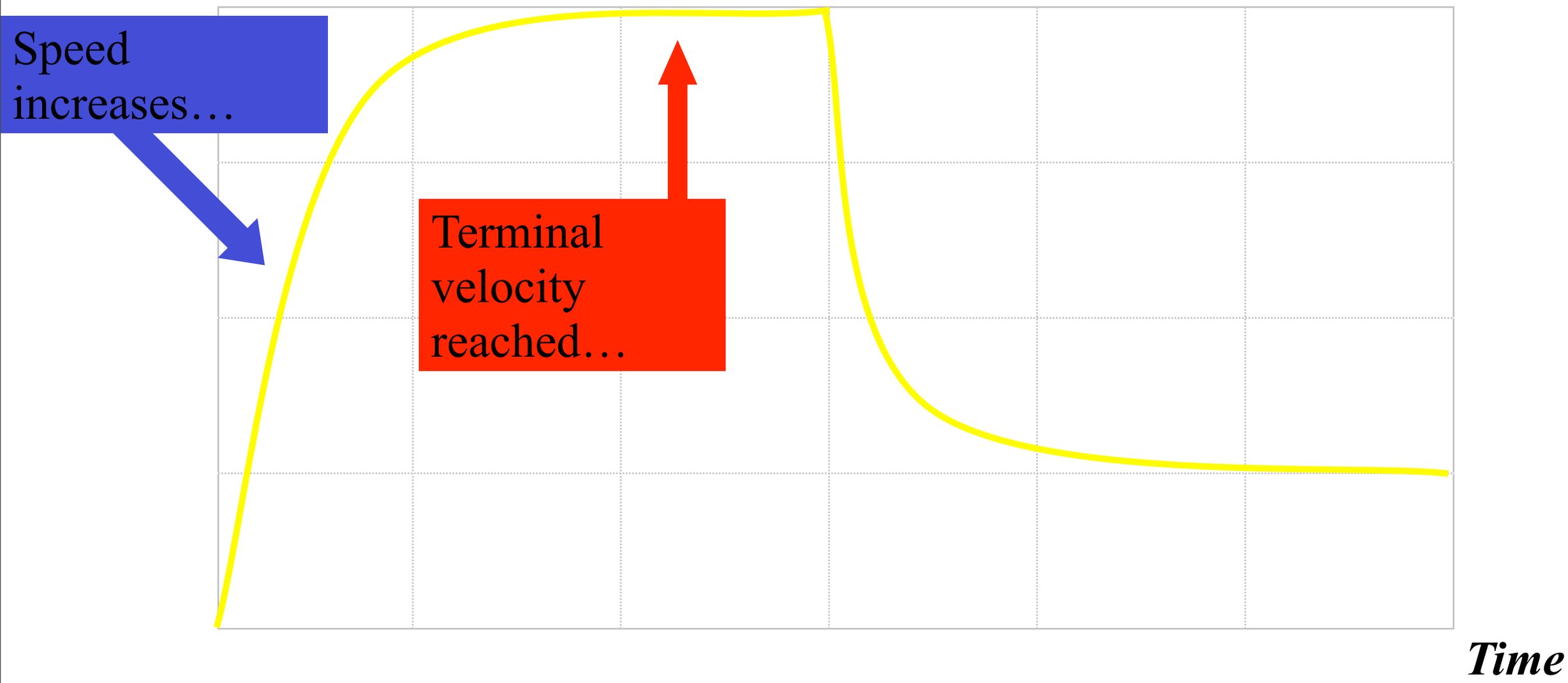

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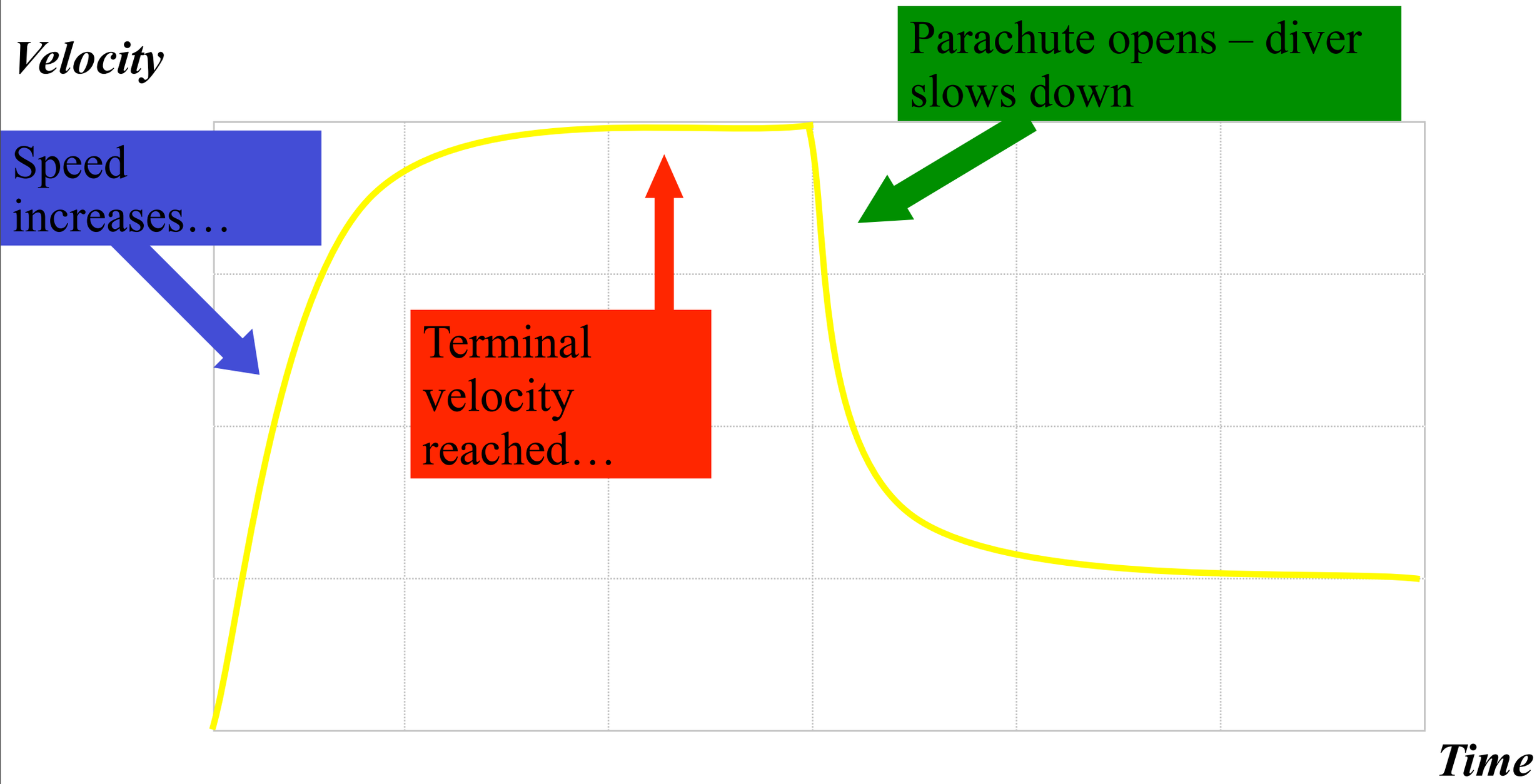

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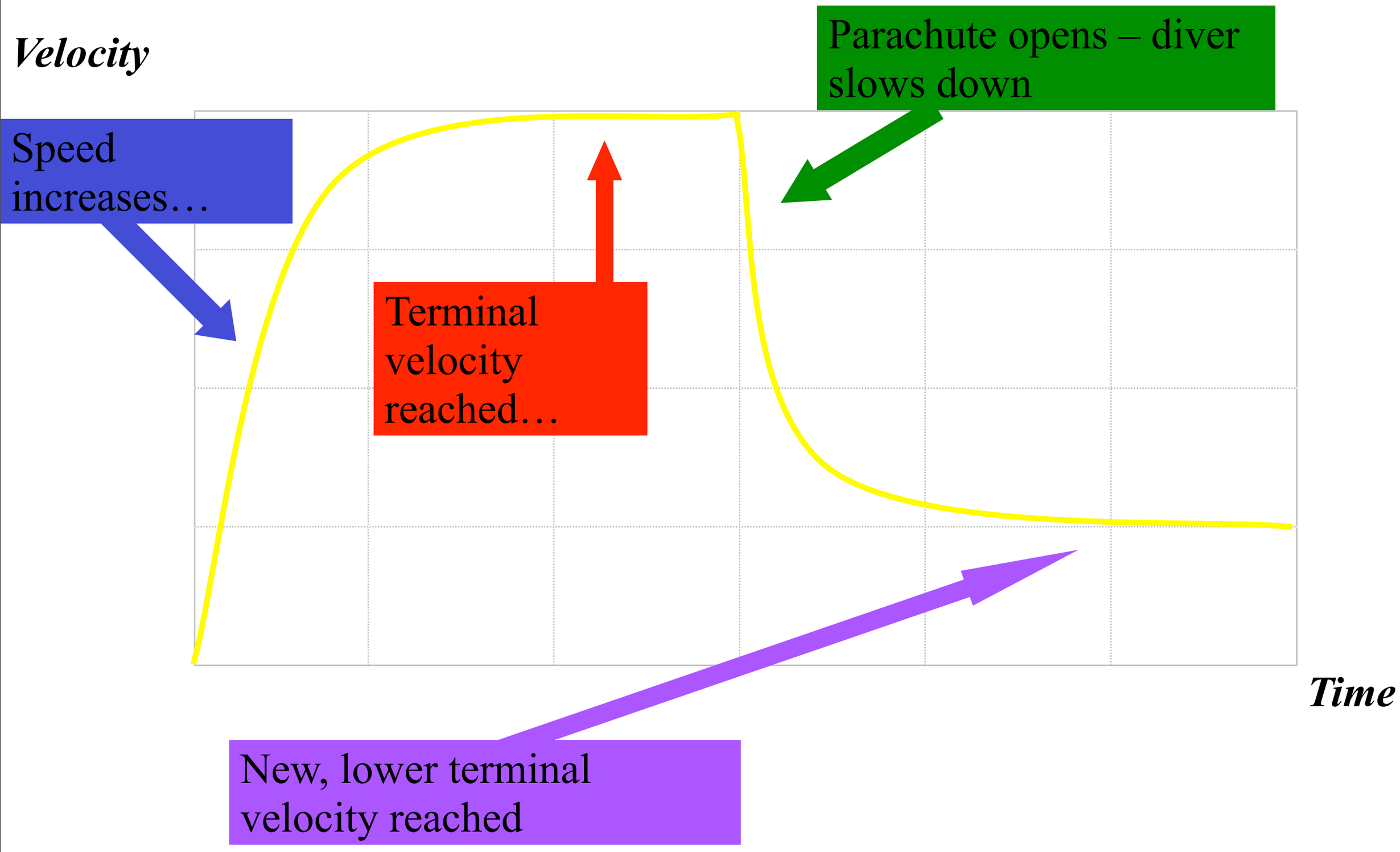

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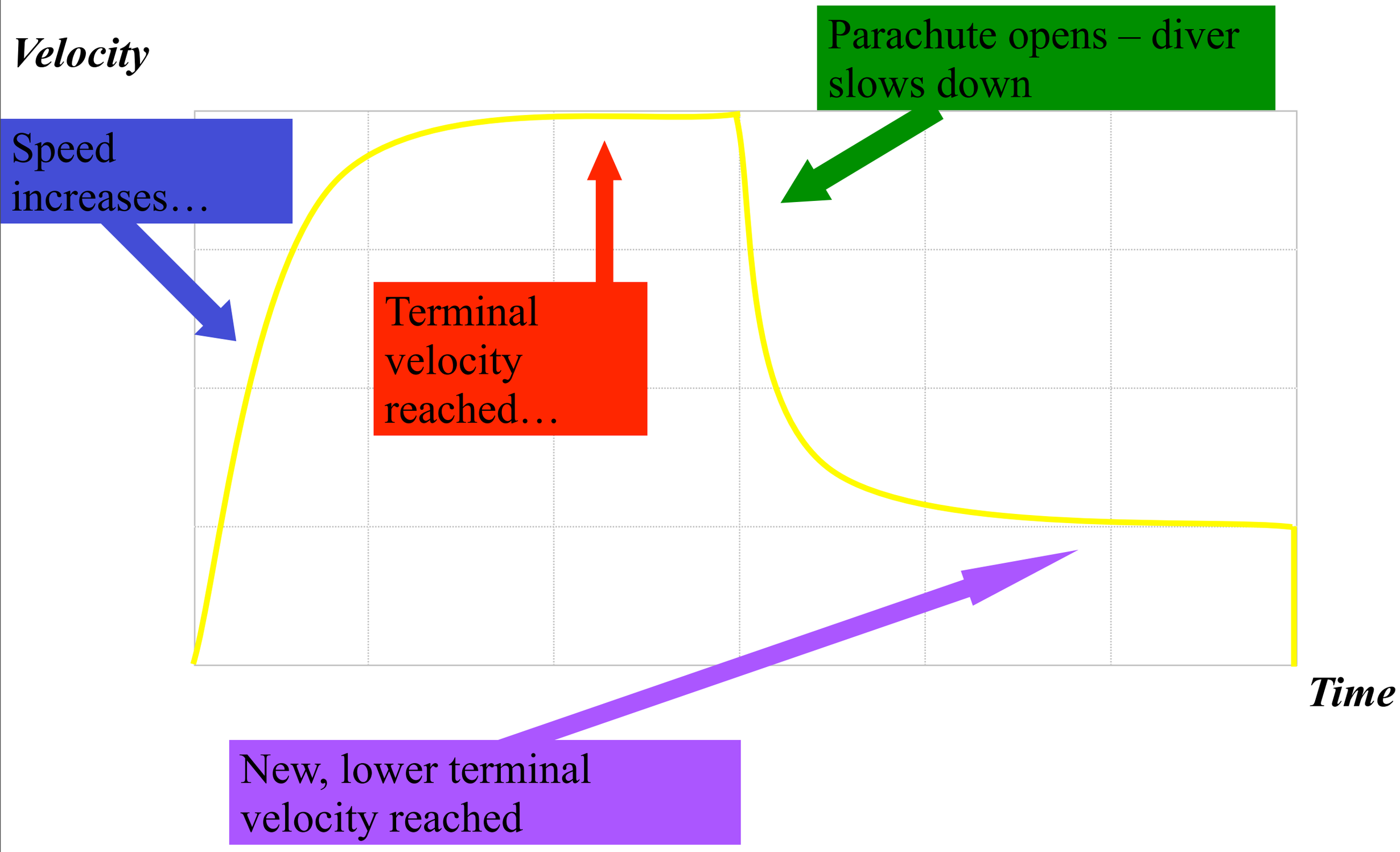

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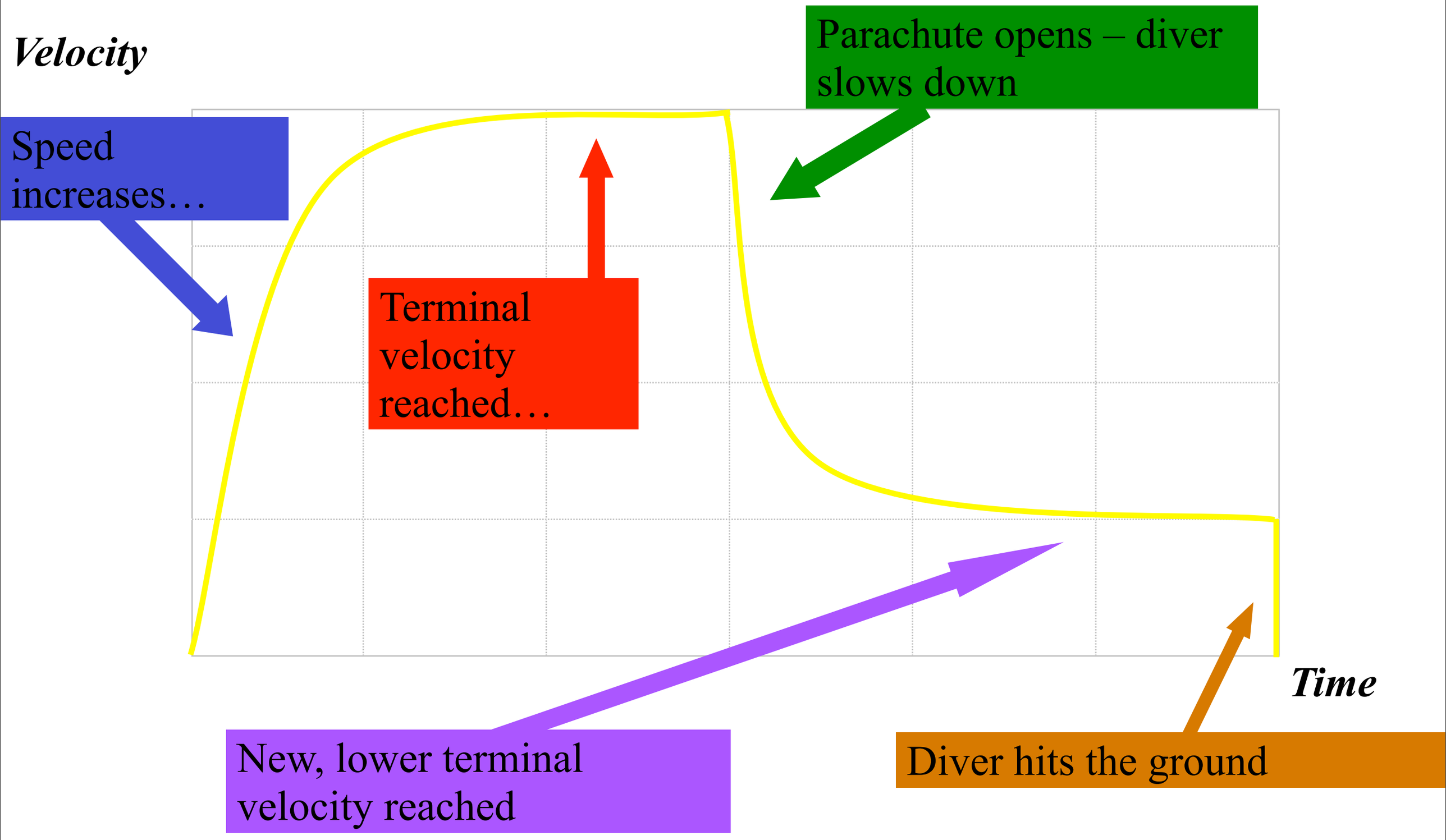

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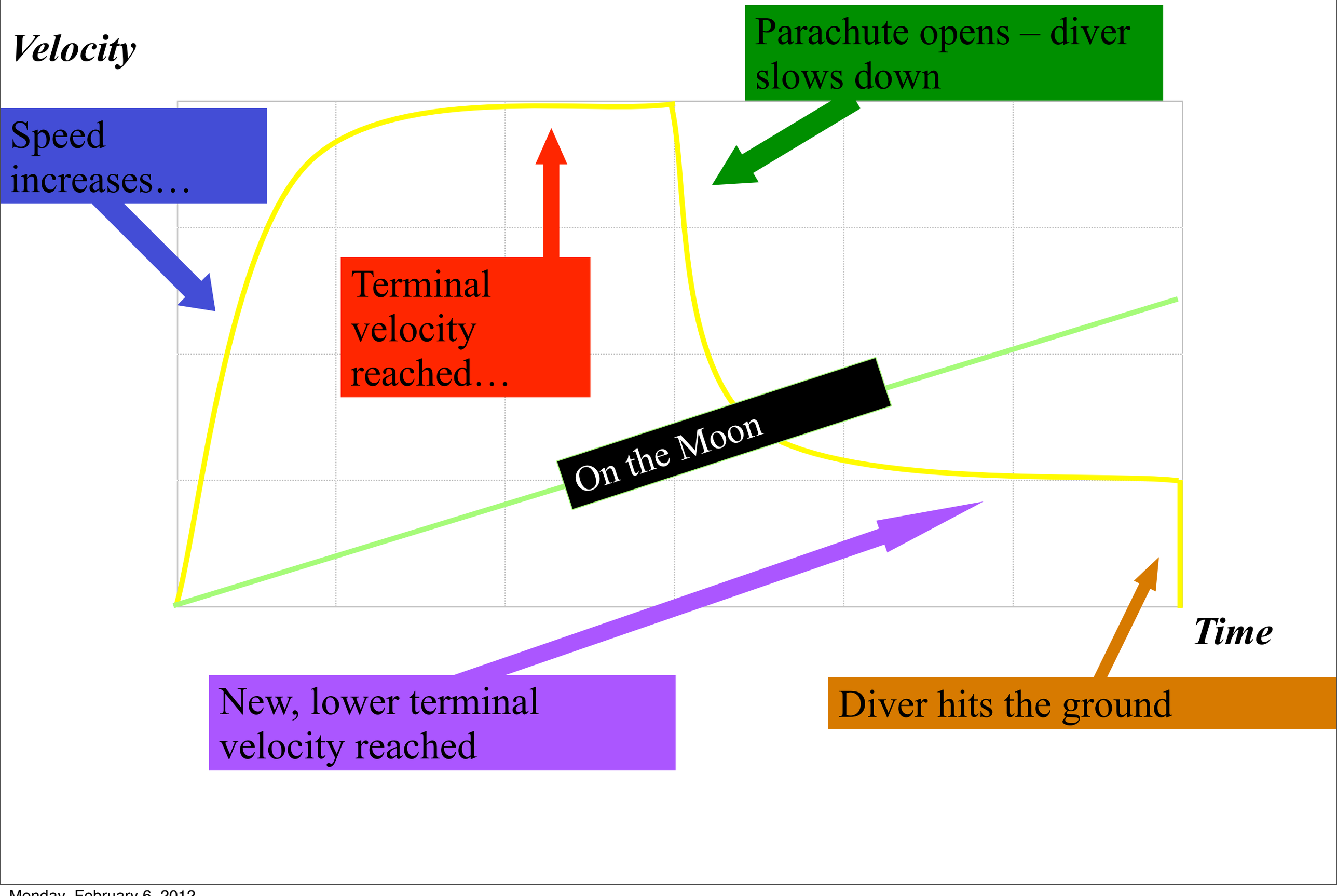
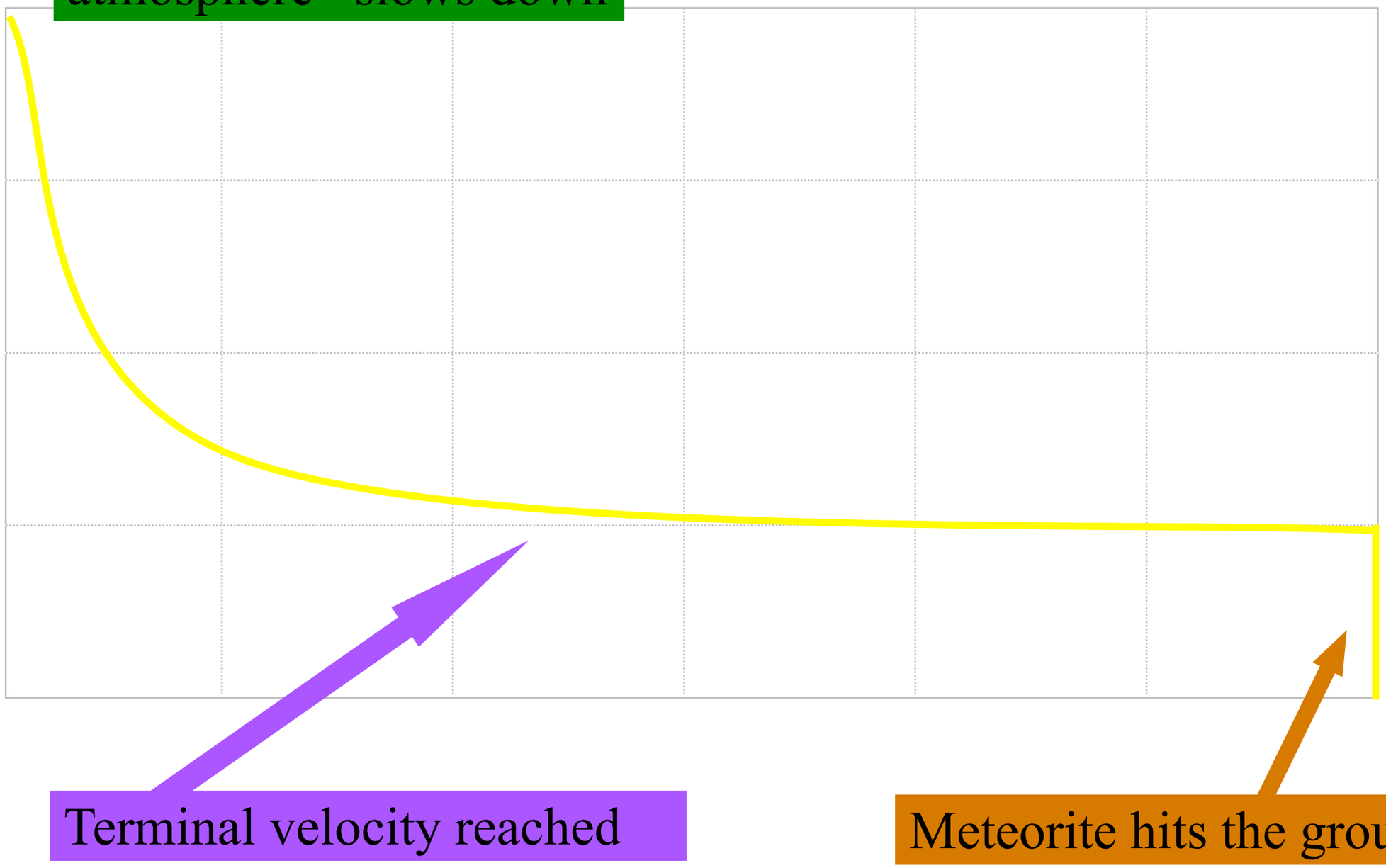


i>clicker question

Why would a skydiver not have a terminal velocity on the Moon?

A. No air.
B. No gravity.
C. No parachutes.
D. No time.
E. No sky.

Meteoroid terminal velocity graph



Up on Speed

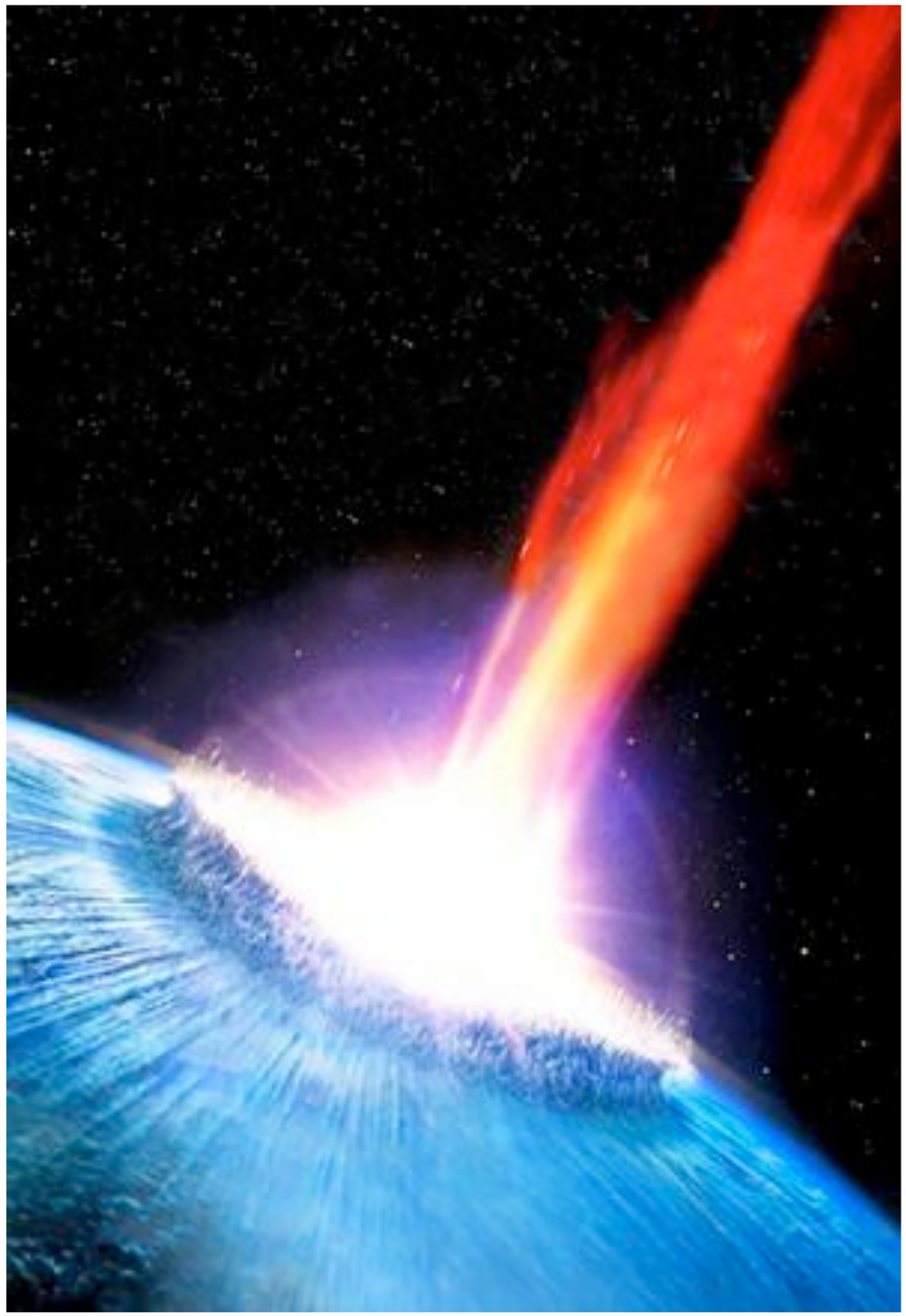
- Terminal velocity depends on
  - Shape of the object
  - Mass of the object
  - Size of the object
- Rougher shape = lower terminal velocity
- More mass = higher terminal velocity
- Bigger size = lower terminal velocity

Ramming Speed!

- Objects less than a few kilograms will burn up completely in the atmosphere
- Objects a few kg to 7000 kg will slow down due to the atmospheric drag
- These reach their terminal velocity – about 90-180 m/s (200-400 mph)

The Big One

- Objects ~9,000 kg will keep some of their initial velocity – impact at ~2-4 km/s
  - (1.5 miles per second!)
- Really big objects (~10^6 kg) won't be noticably slowed,
  - impact at near their initial velocities (>11 km/s!)



Why does a meteor shine?

Meteroid compresses the air in front of it, called ram pressure

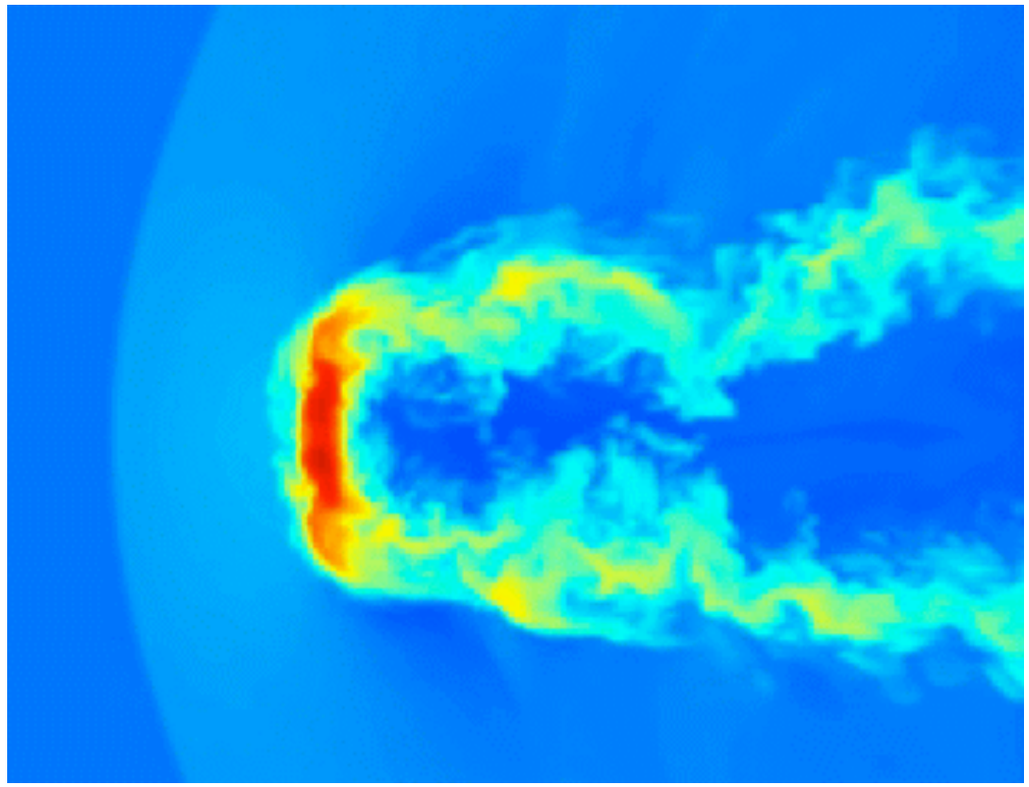
Rapid compression heats up the air, like quickly pumping up a bicycle tire

Hot air heats up the meteoroid

Why does a meteor shine?

Due to ram pressure, the outer layers of the object can melt or boil away, called ablation.

The meteor light you see is a combination of ablation and ionizing of the air by the extreme heat



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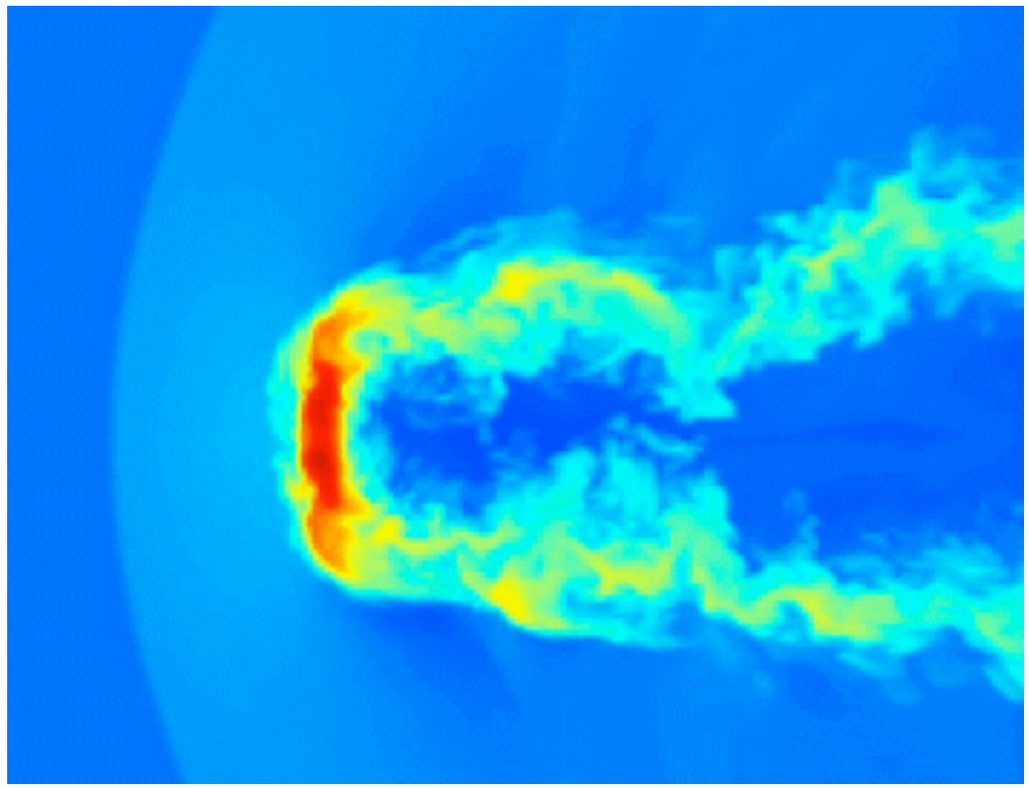


It's a Drag

Atmospheric flight stresses an object

- Newton III: meteor pushes on and compresses air
- but compressed air pushes back on meteor

Large objects may break apart into many pieces at 11-27 km (7-17 miles) up

Causes an series of smaller meteorites on the ground.

Cool Touch

After the meteor reaches terminal velocity, the ram pressure is gone, and the lights go out.

Meteor cools off fast

Meteoroid has been in space for 4.5 billion years, so it is cold and the upper atmosphere is cold

- **Small meteorites never hot**
- **Some meteorites found with frost on them!**

Small meteorites do not start fires!

What do meteorites look like?

Metetorite outside cooked during fall

New stony meteorites have a fusion (melted) crust – dark color.

Iron meteorites, a welded metal look

Older meteorites can be weathered, look like Earth rocks

Why Does it Hurt So?

- It's really about the energy released
- Kinetic energy from motion:

$$KE = \frac{1}{2}Mv^2$$

- 250m asteroid impact at 20 km/s releases 1,000 MT of energy - 10x the largest nuclear weapon!

Meteoroids move at high speeds; small objects can cause significant damage

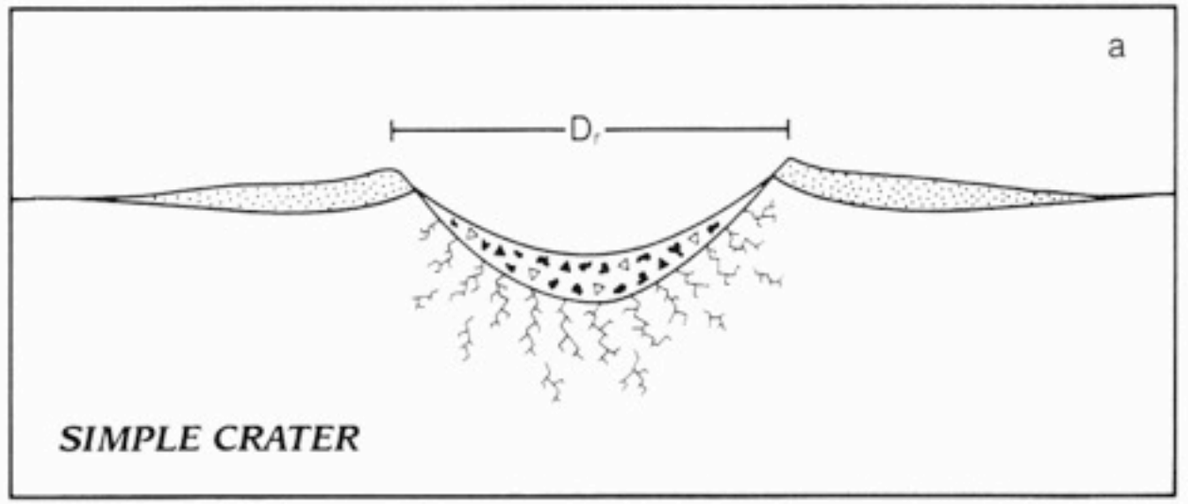
i>clicker Question

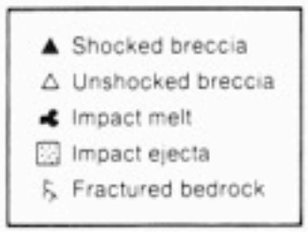
Which meteorite imparts the most energy?

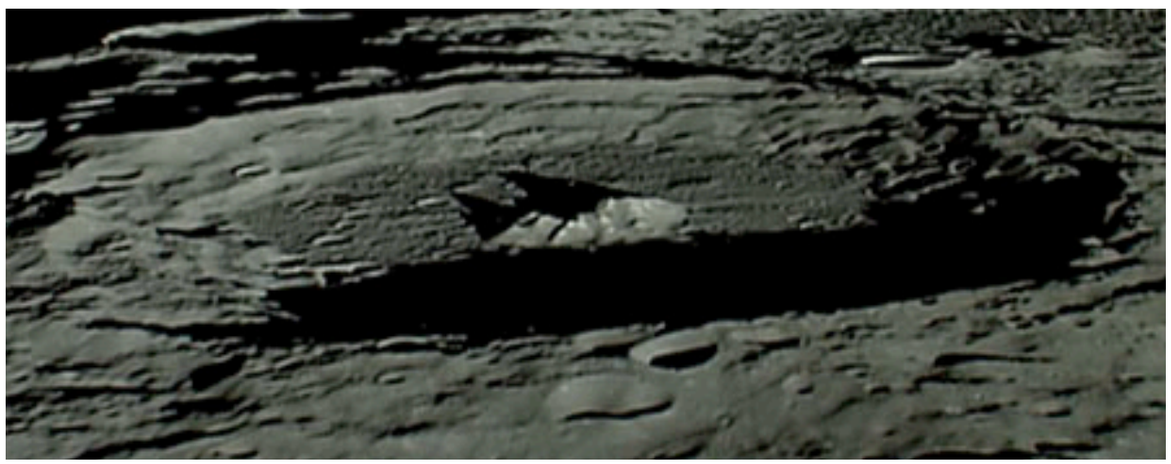
A. 1 kg moving at 100 km/hr
B. 1 kg moving at 200 km/hr
C. 2 kg moving at 100 km/hr
D. 100 kg moving at 10 km/hr
E. 100 kg moving at 1 km/hr

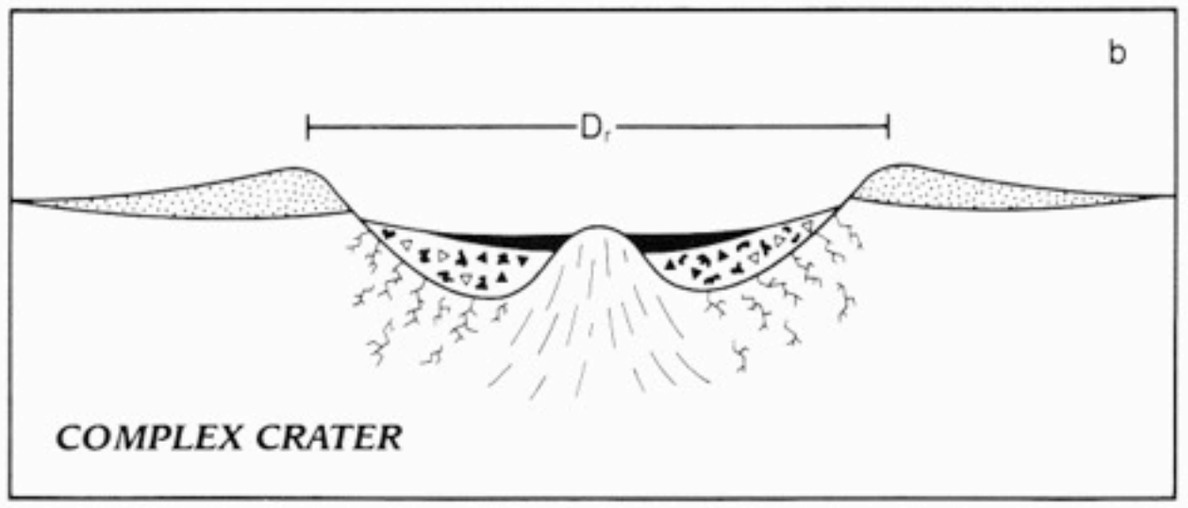
Hints: $1^2 = 1$, $2^2 = 4$, $10^2 = 100$,
$100^2 = 10{,}000$, $200^2 = 40{,}000$

Simple vs. Complex Craters

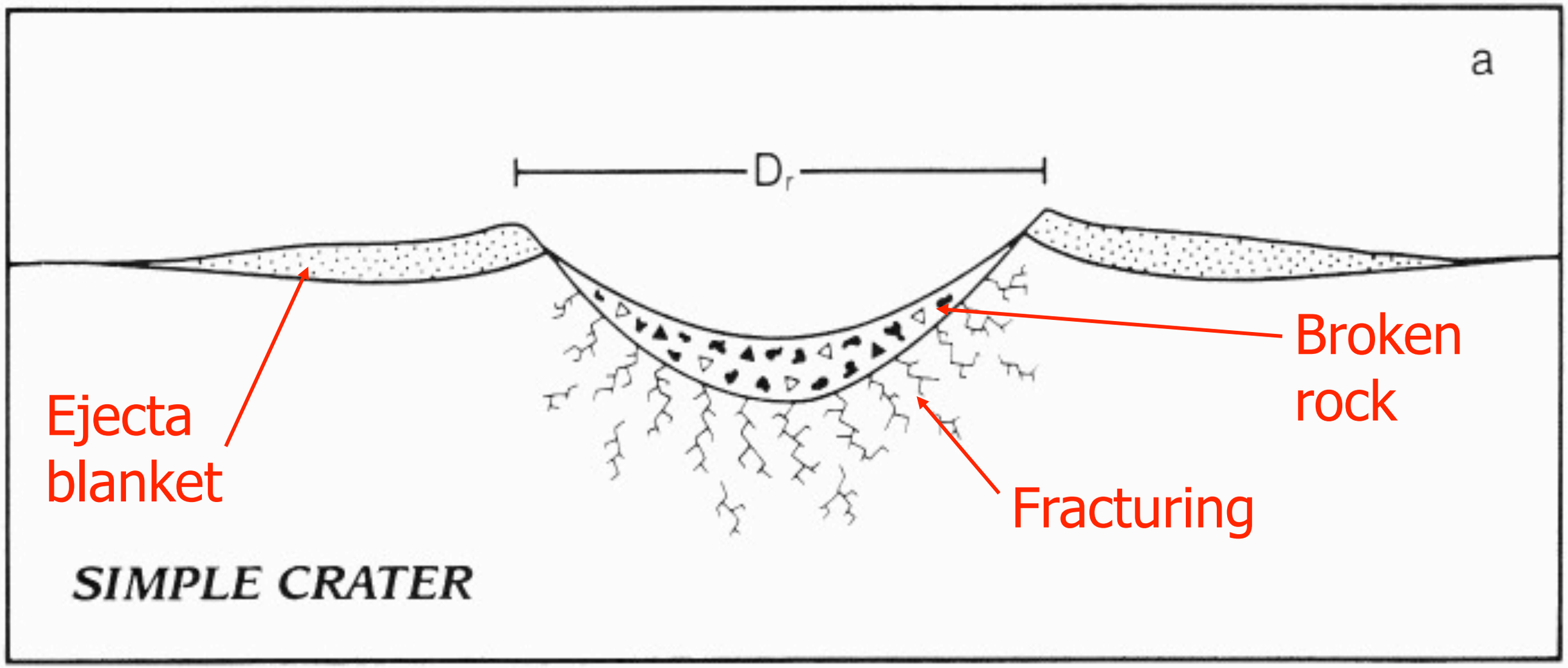






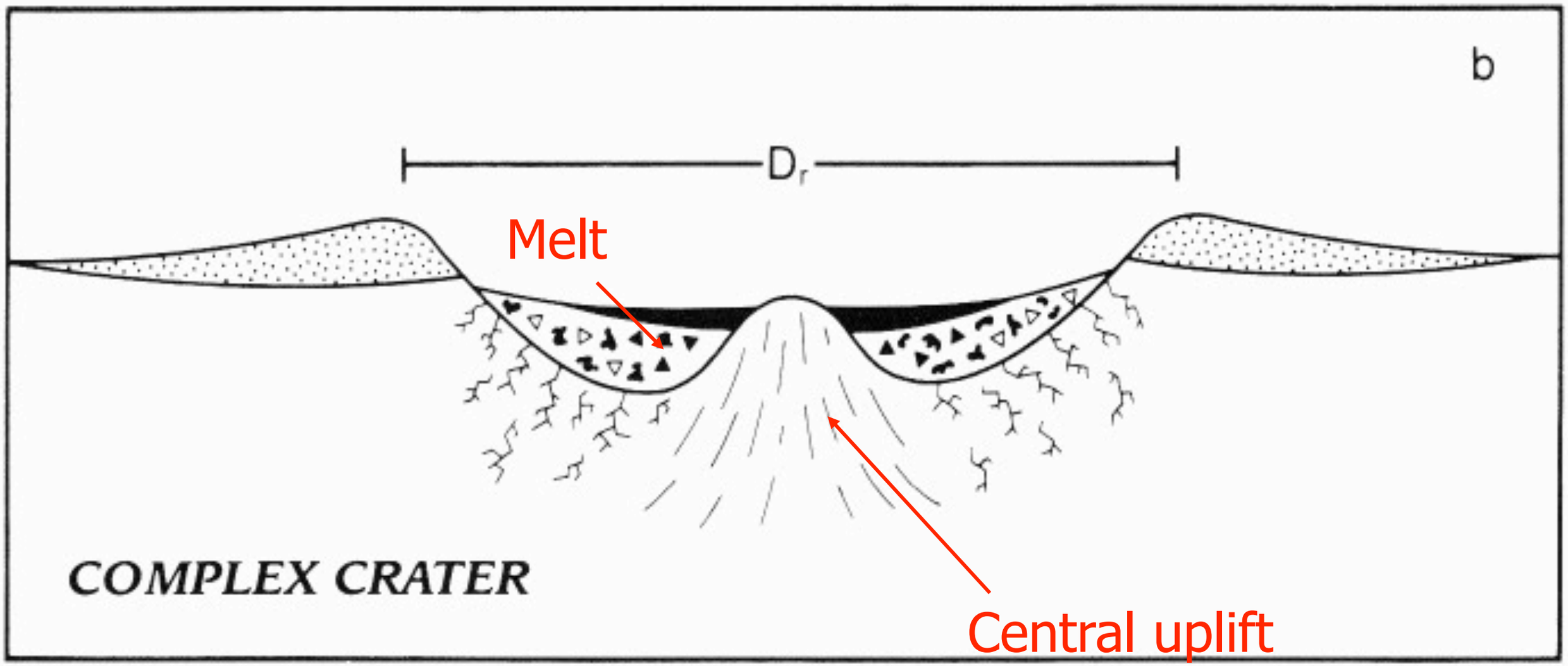


Simple craters

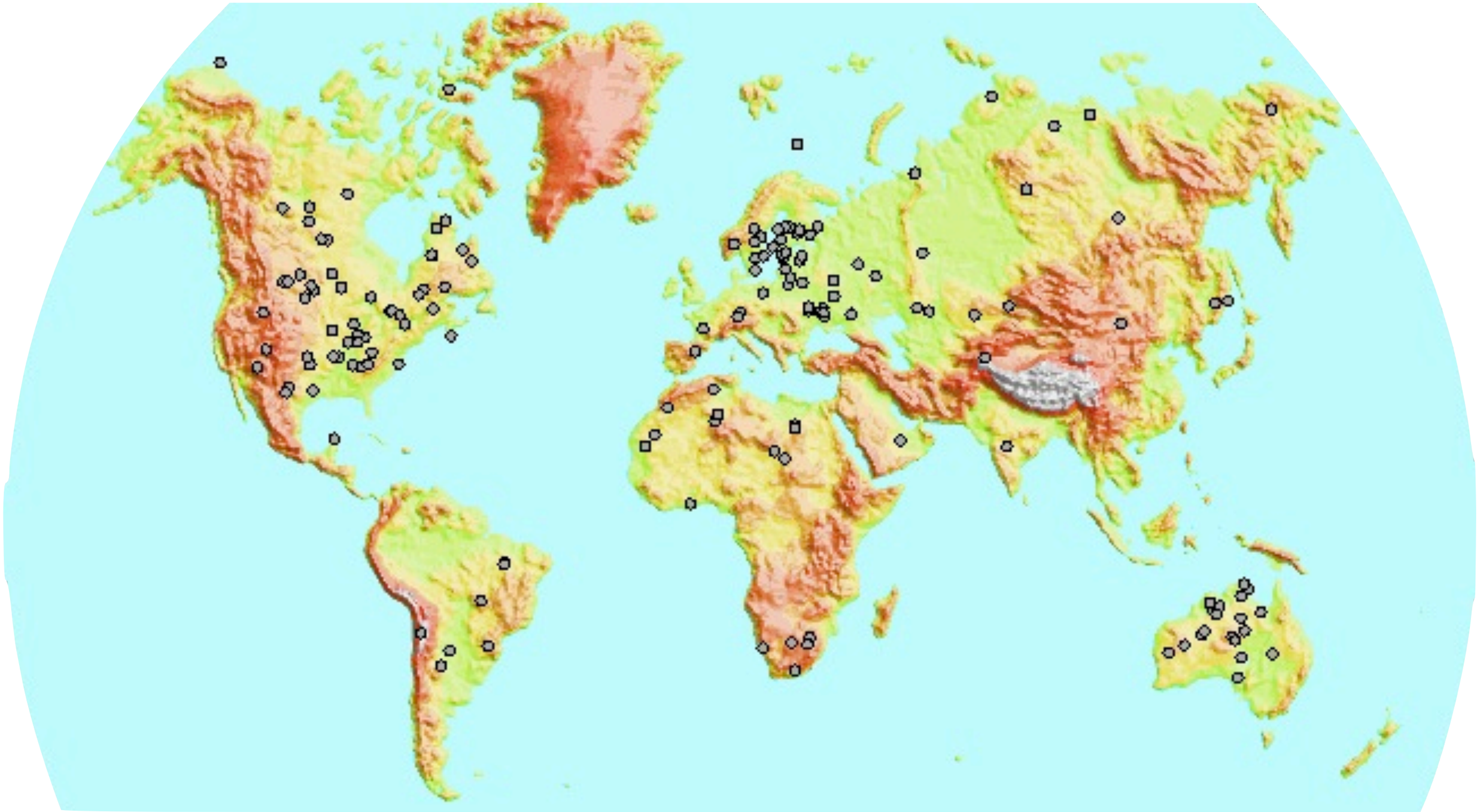


- Bowl structure
- 15-20 times diameter of impacting object
- All less than 1-2 miles across on Earth

Complex craters



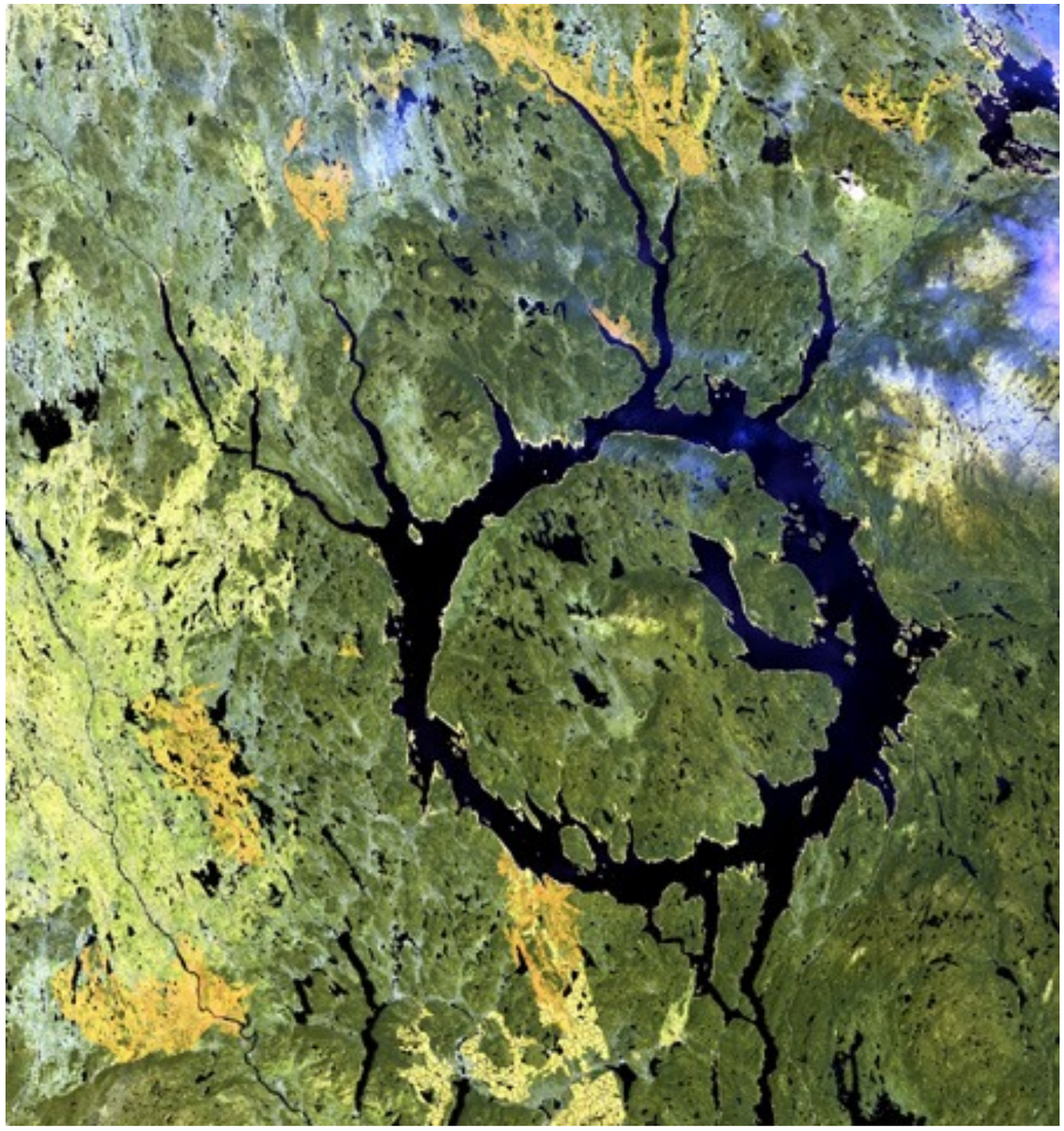
- Central peak, peak ring, or multiple rings
- Melt sheet generated
- About 10x impactor diameter
- Why the central peak? loss of overlying material -- less downward force (weight) -- central region “rebounds”



There are about 200 large, well-preserved impact craters worldwide…BUT…>>200 impact events during Earth's history

Earth's Craters

Manicouagan Crater in Quebec, Canada 100 km wide

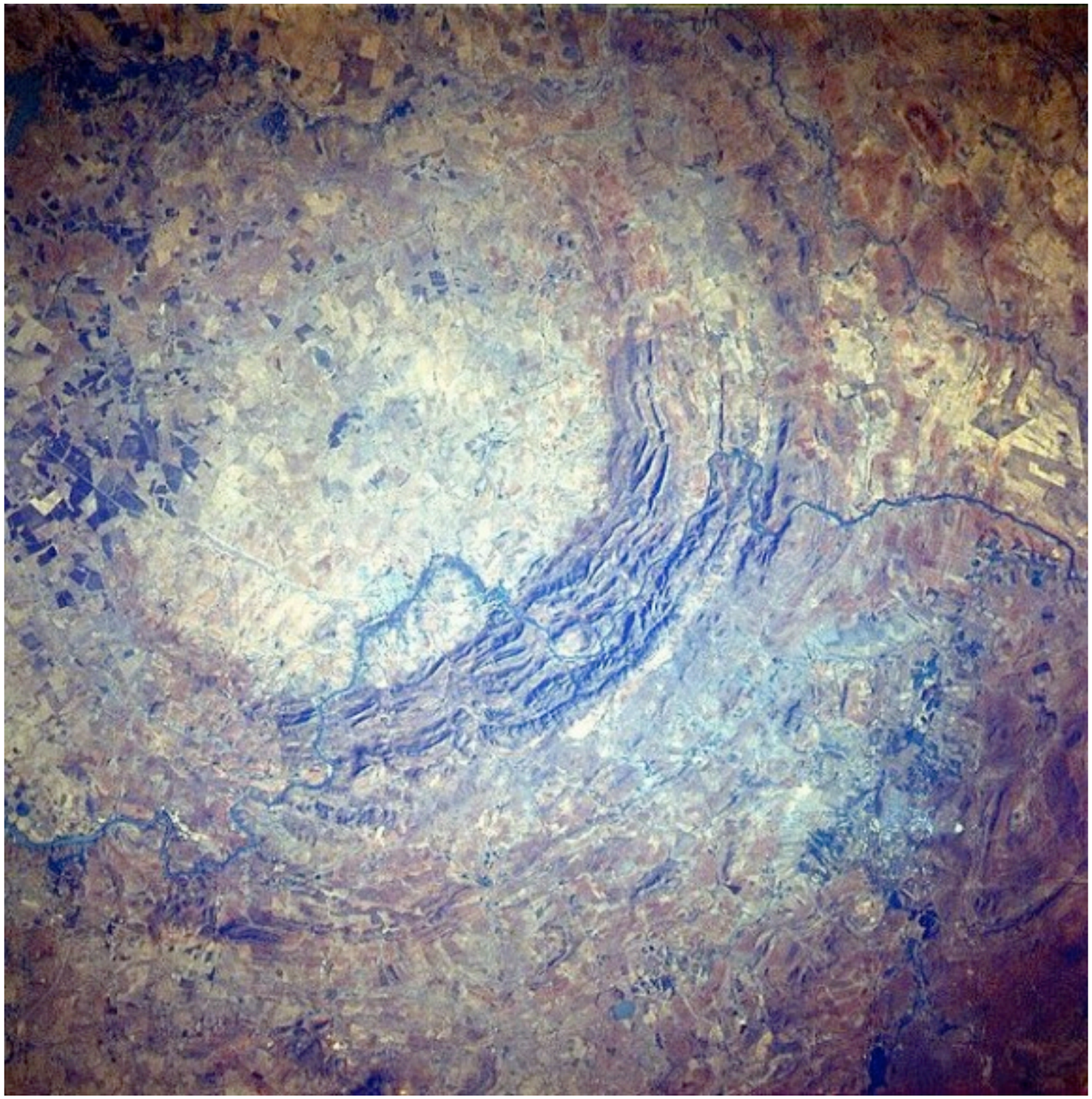


http://www.unb.ca/passc/ImpactDatabase/images/manicouagan.htm

Earth's Craters

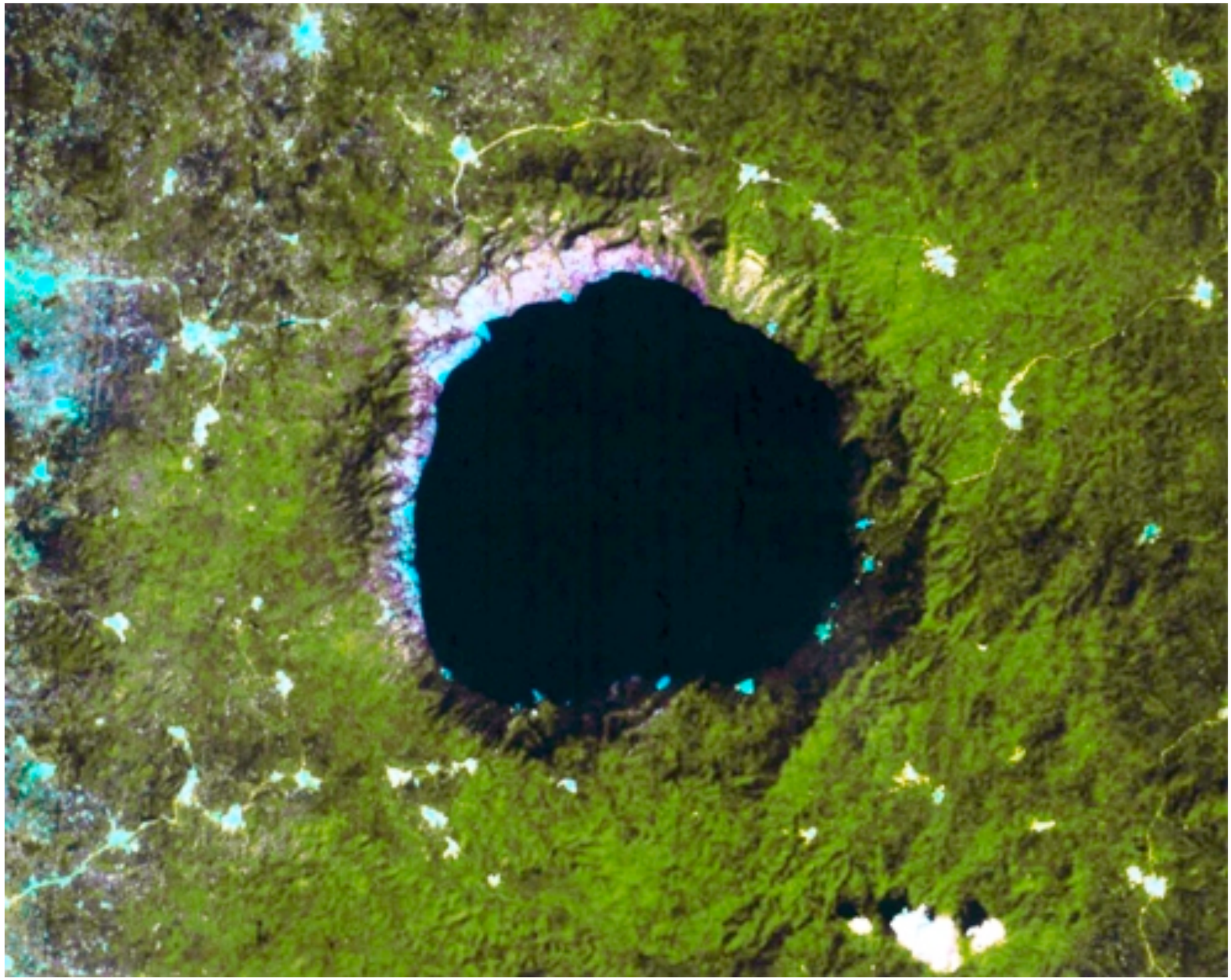
- Clearwater Lakes in Quebec, Canada – 26 km wide (290 million years ago) from a double impact!
- Submerged central peak in smaller lake.

Vredefort Crater

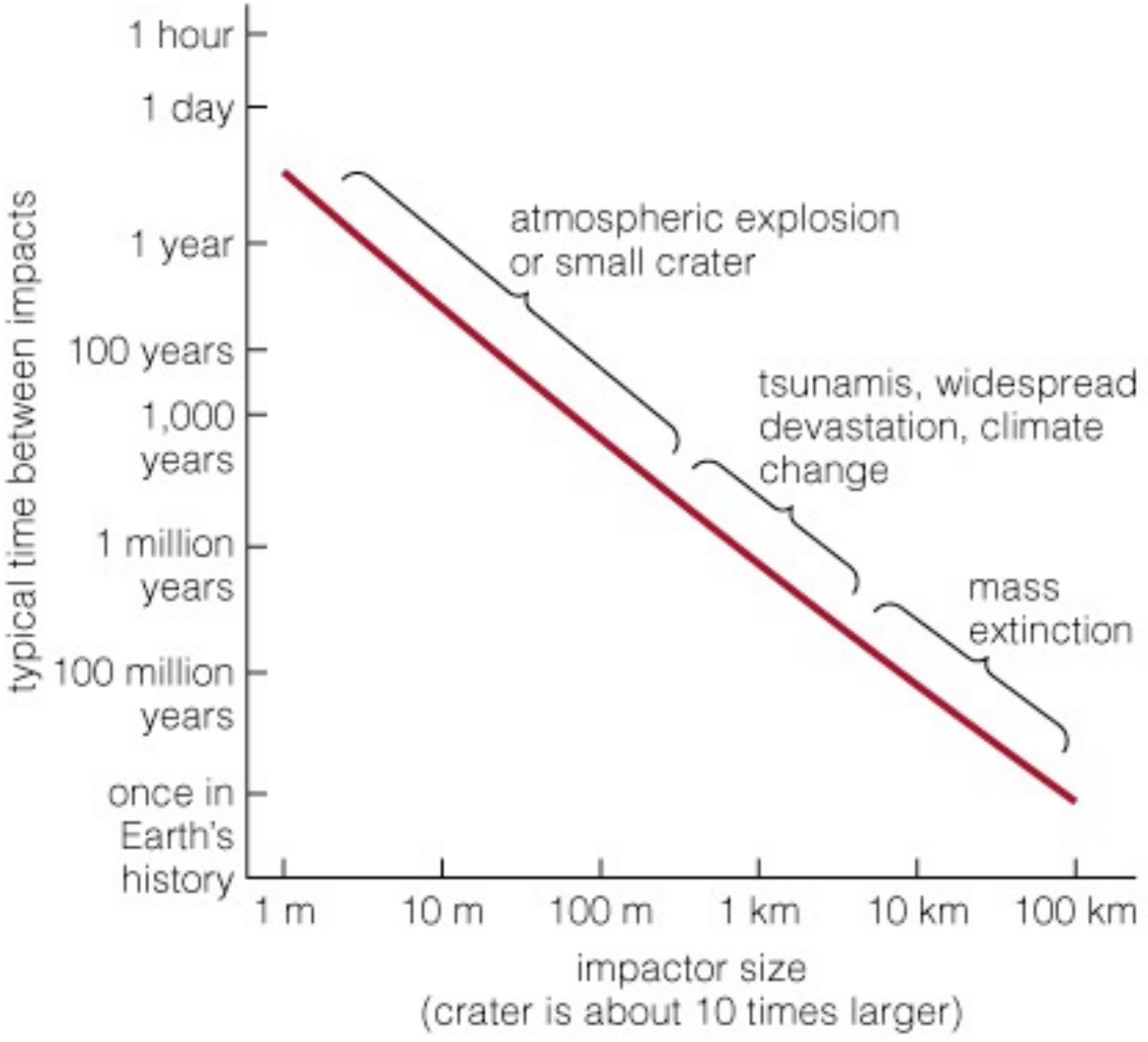


Wolfe Creek crater (Kandimalal), Australia

Bosumtwi Crater, Ghana



Frequency vs. impactor size



Small impacts happen almost daily

Impacts large enough to cause mass extinctions are many millions of years apart