Announcements

- Problem 1 is due 01/24 @ 11:59pm
  - 5 pts for on-time submission
  - 20 pts for correct solution

Today:

- Today continues “The Nature of Space and Time”
  - Newton II, Newton III, Law of Gravitation
  - Beginning of special relativity

Newton's Laws of Motion (in an inertial reference frame)

I: Inertia - an object in motion stays in motion under no external forces

II: Force - the force on an object is equal to its change in its momentum with time

III: Action & Reaction - A force exerted by an object on another object is met with an opposite reaction force

I: Inertia -

"Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it."

- Isaac Newton;

Principia Mathematica (1687)

An object will continue in its state of uniform motion or rest, unless acted upon by an external force.

- *uniform* motion
- *external* force

II: Force - The application of an external force changes the momentum of the body it acts on

$$F = \frac{\Delta p}{\Delta t} = m\frac{\Delta v}{\Delta t} = ma$$

$$p = mv$$

momentum is the mass multiplied by speed assuming a constant mass

II: Force - The application of an external force changes the momentum of the body it acts on

$$F = \frac{\Delta p}{\Delta t} = m\frac{\Delta v}{\Delta t} = ma$$

$$p = mv$$

If an object experiences a change in velocity over some period of time, an external force must have been applied to that object

II: Force - The application of an external force changes the momentum of the body it acts on

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$\boxed{\text{Larger velocities \& shorter times imply stronger forces}}$

If an object experiences a change in velocity over some period of time, an external force must have been applied to that object

Star Trek V: The Final Frontier

Directed:
William Shatner

Paramount (1989)

Kirk free climbs El Capitan: ~900m up!

$$F = \frac{\Delta p}{\Delta t} = m\frac{\Delta v}{\Delta t} = ma$$

What can be deduced about Spock's jet boots while he is talking with Kirk?

The jet boots must be exerting a force equal but opposite to gravity — why?

Kirk falls from El Capitan: ~900m up!

Does Kirk accelerate the entire time?

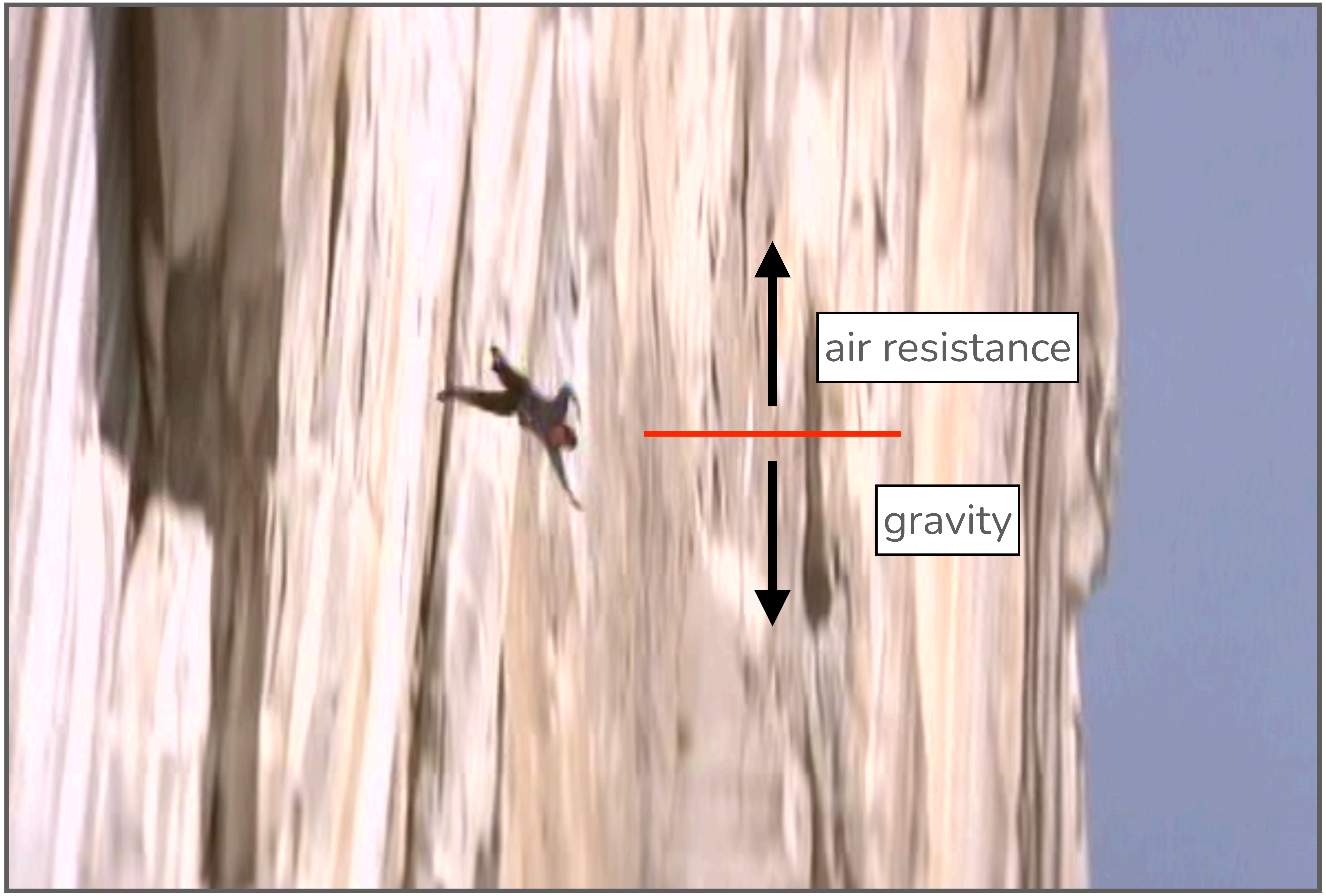
Terminal velocity is reached once air resistance is fully balanced by gravity

Kirk falls from El Capitan: ~900m up!

Terminal velocity
is reached once air resistance is fully balanced by gravity

$$F_{\text{gravity}} - F_{\text{air resistance}} = 0\,N$$

Kirk falls from El Capitan: ~900m up!



Terminal velocity

is reached once air resistance is fully balanced by gravity

$$F_{\text{gravity}} - F_{\text{air resistance}} = 0\,N$$

Is Kirk still accelerating?

$$a = 0, v_{\text{terminal}} = 56\,\text{m/s}$$

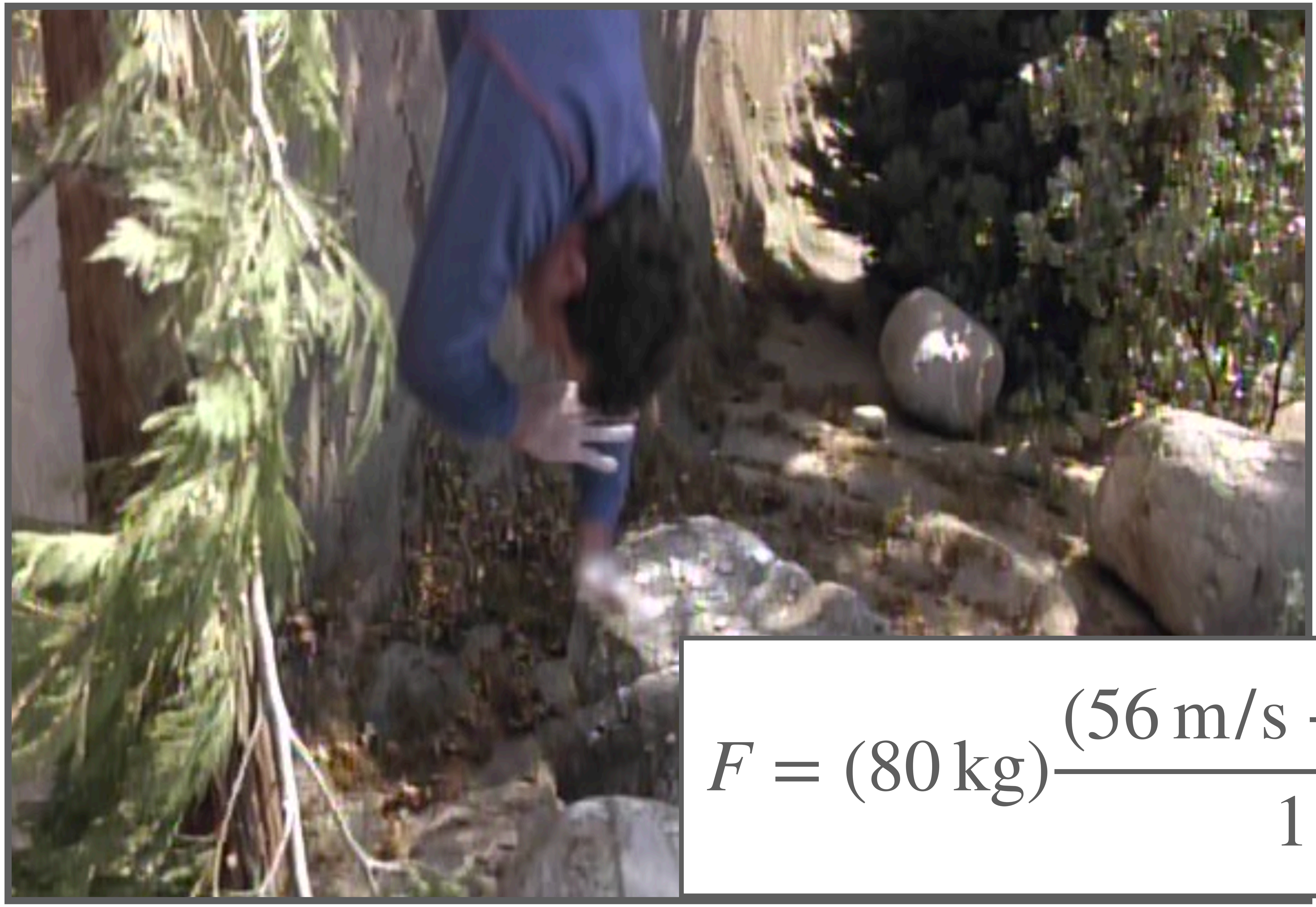
Will Kirk survive the fall?

What force does Kirk feel?

Using **reasonable assumptions,** and Newton's 2nd law what variables do we need to consider?

Mass: 80 kg
Initial velocity: 56 m/s
Final velocity: 0 m/s
Change in time: 1 s

What force does Kirk feel?



Mass: 80 kg

Initial velocity: 56 m/s

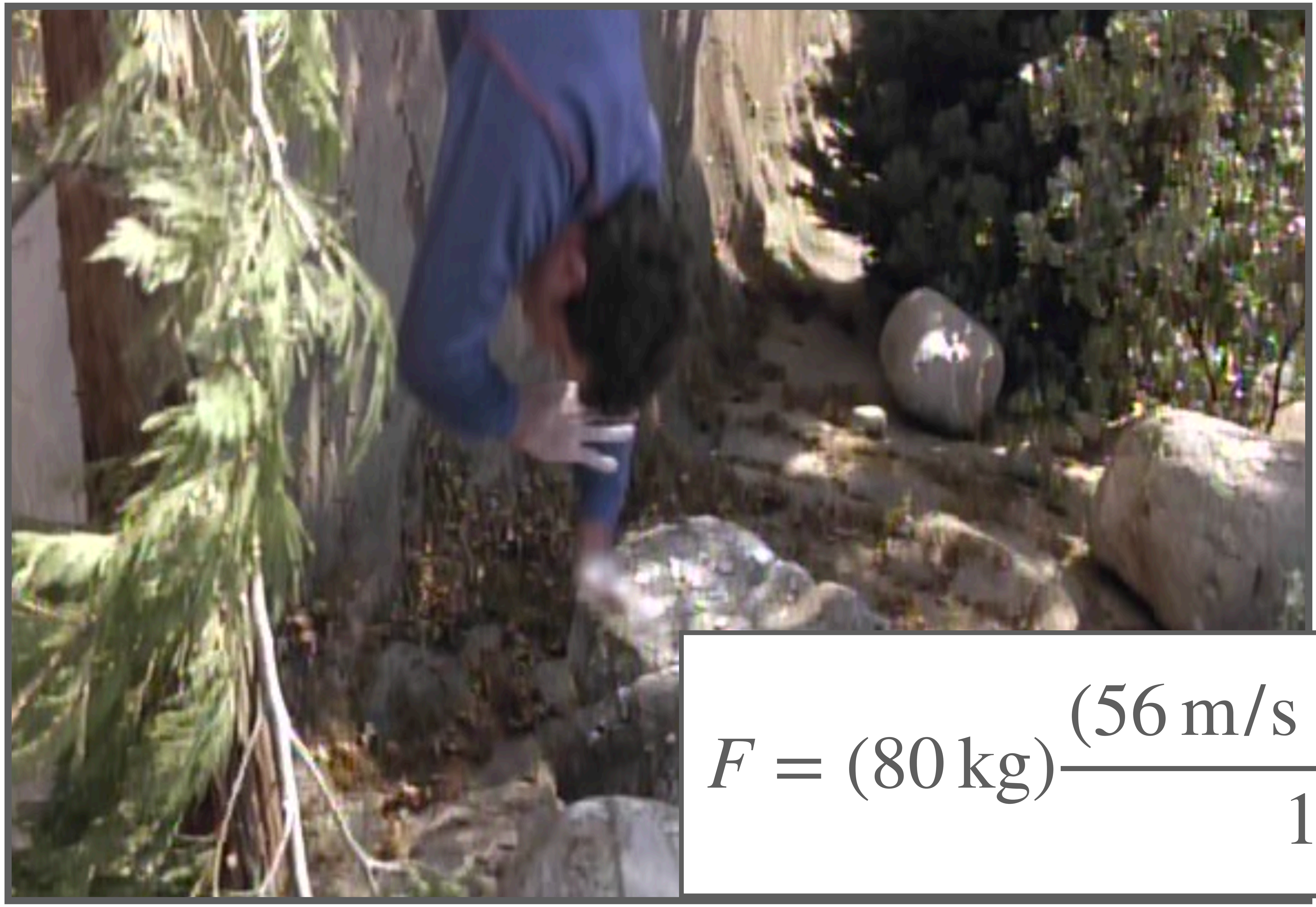
Final velocity: 0 m/s

Change in time: 1 s

$$F = \frac{\Delta p}{\Delta t} = m\frac{\Delta v}{\Delta t} = ma$$

$$F = (80\,\mathrm{kg})\frac{(56\,\mathrm{m/s} - 0\,\mathrm{m/s})}{1\,\mathrm{s}} = 4480\,\mathrm{kg\,m/s^2}$$

What force does Kirk feel?



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$$F = \frac{\Delta p}{\Delta t} = m\frac{\Delta v}{\Delta t} = ma$$

$$F = (80\,\mathrm{kg})\frac{(56\,\mathrm{m/s} - 0\,\mathrm{m/s})}{1\,\mathrm{s}} = 4480\ \text{Newtons}$$

What force does Kirk feel?

4880 N converted to pounds is:
1097 pounds

** Nearly half a ton! **

What **acceleration** does Kirk feel?

If F=4880 N, m=80kg, what is the acceleration?

$$a = \frac{F}{m} = \frac{4880\,\mathrm{N}}{80\,\mathrm{kg}}$$

$$a = 56\,\mathrm{m/s^2} \sim 5.7\mathrm{g}$$

He'll "survive"
(but he won't be happy)

What about Spock??

What ways could our estimations for Force and accelerations change for Spock?

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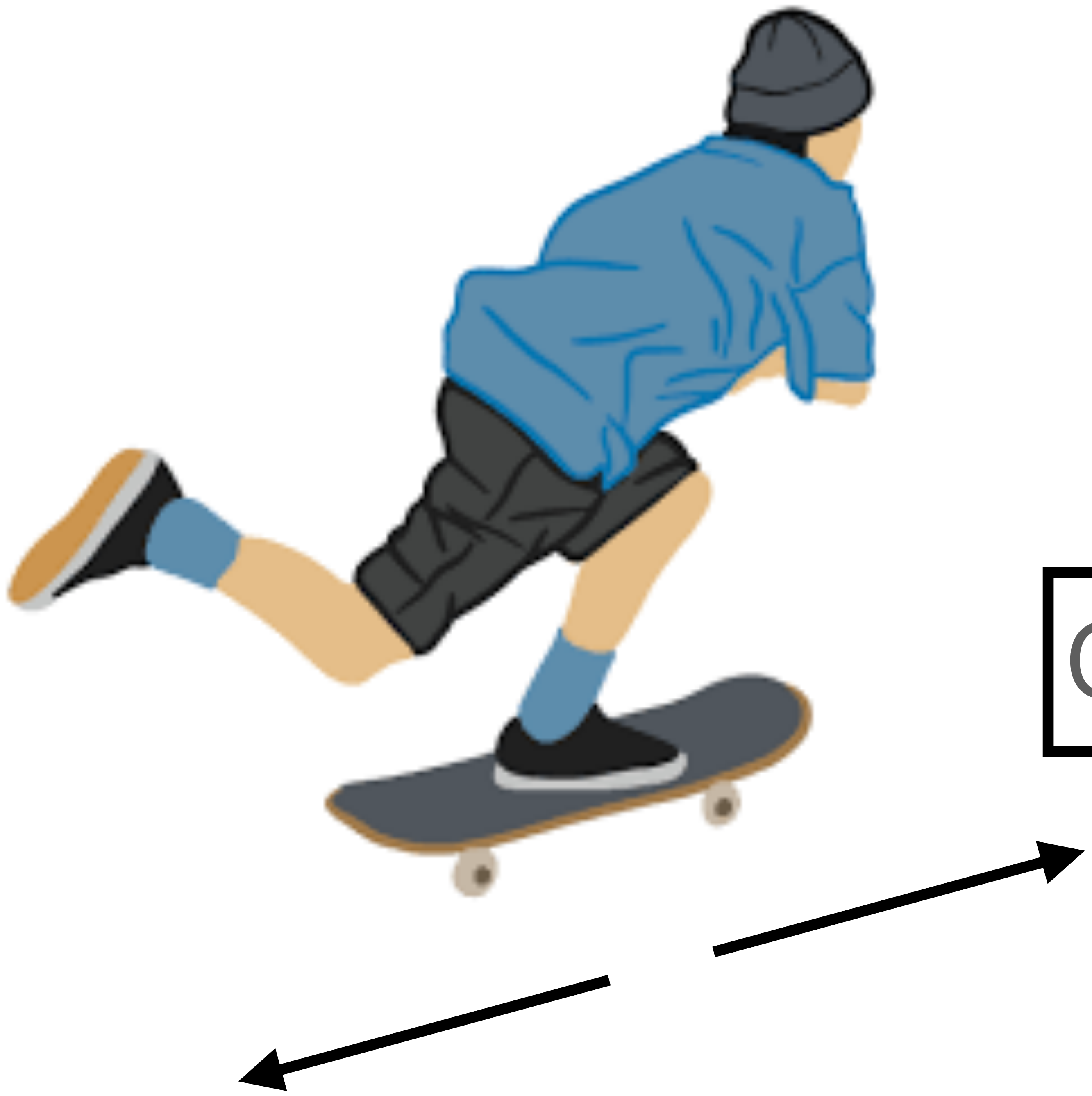


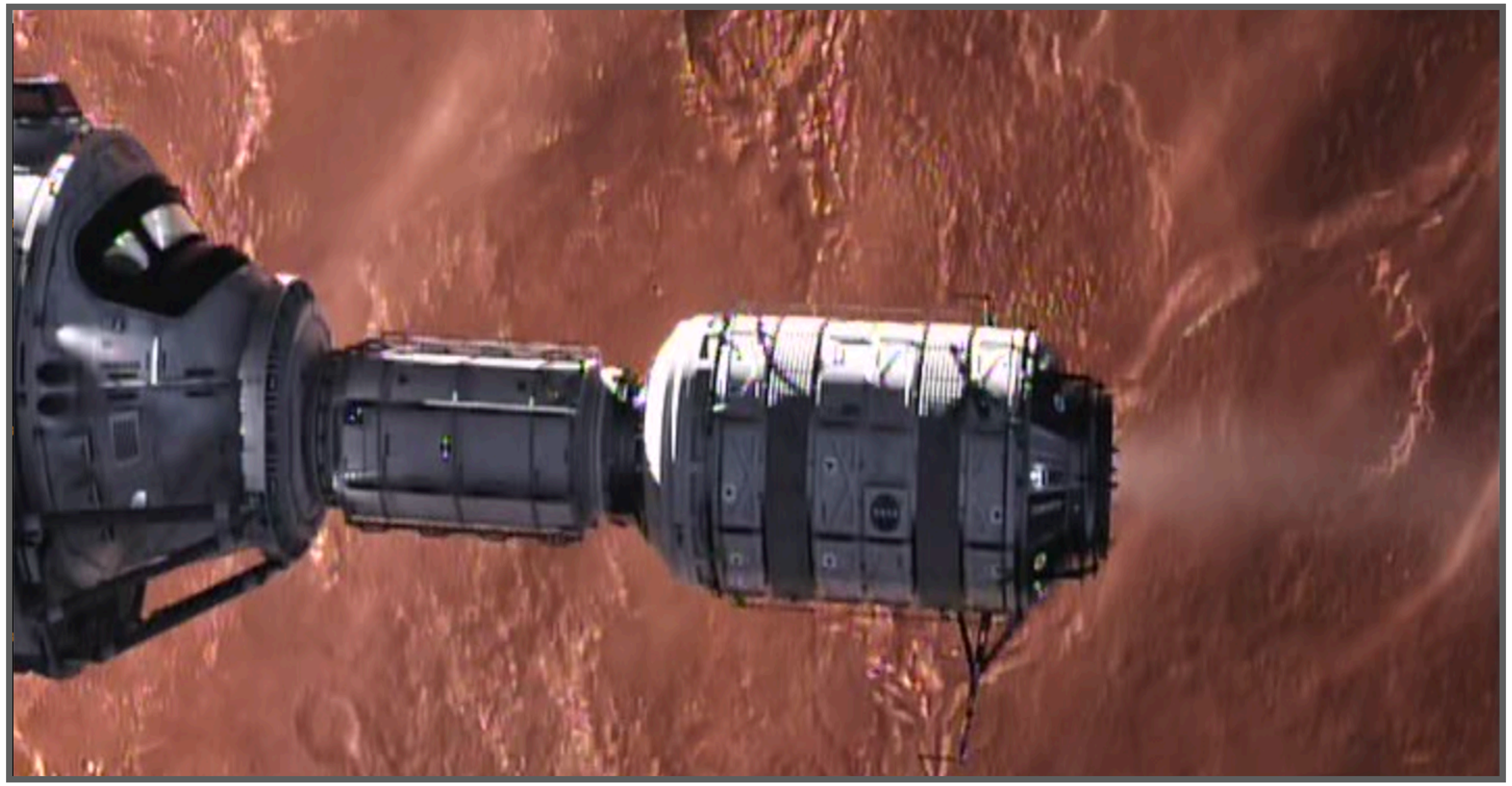
The Martian

Directed:
Ridley Scott

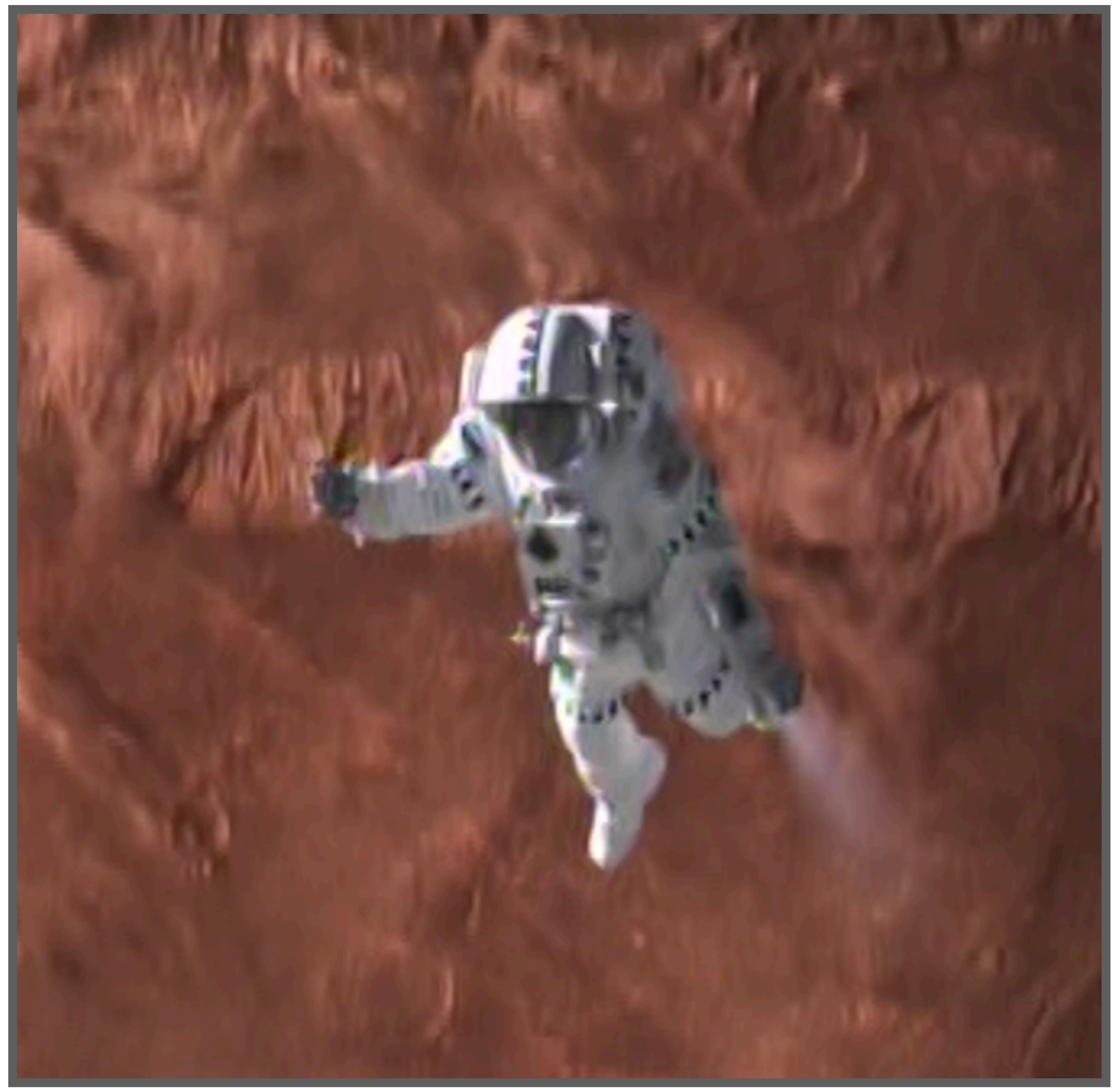
20th Century Fox
(2015)

The Martian: Some complicated motion early on in the film!

What slows down the *Hermes*?



How does Watney fly?



Newton's Law of (Universal) Gravitation

$$F = G\frac{\boxed{m_1 m_2}}{\boxed{r^2}}$$

every object with mass in the Universe is gravitationally attracted to every other object with mass in the Universe

The force due to gravity decreases significantly with distance

The force due to gravity increases with mass of the objects

Newton's Law of (Universal) Gravitation

$$F = G\frac{m_1 m_2}{r^2}$$

every object with mass in the Universe is gravitationally attracted to every other object with mass in the Universe

$$F = G\frac{m_{\text{Human}} m_{\text{Earth}}}{r_{\text{Earth}}^2}$$

$$F = G\frac{m_{\text{Human}} m_{\text{Moon}}}{r_{\text{Moon}}^2}$$

Which force do you expect to be stronger?

Newton's Law of (Universal) Gravitation

$$F = G\frac{m_1 m_2}{r^2}$$

every object with mass in the Universe is gravitationally attracted to every other object with mass in the Universe

$$F = G\frac{m_{\text{Human}} m_{\text{Moon}}}{r^2_{\text{Moon}}}$$

$$F = G\frac{m_{\text{Human}} m_{\textbf{Earth}}}{D^2_{\text{Moon}}}$$

What about the gravitational force of the Earth on a person on the Moon?

Newton's Law of (Universal) Gravitation

$$F = G\frac{m_1 m_2}{r^2}$$

every object with mass in the Universe is gravitationally attracted to every other object with mass in the Universe

There is no **time dependence** in this equation

→ This is the *instantaneous* force due to gravity

Newton’s concept of time

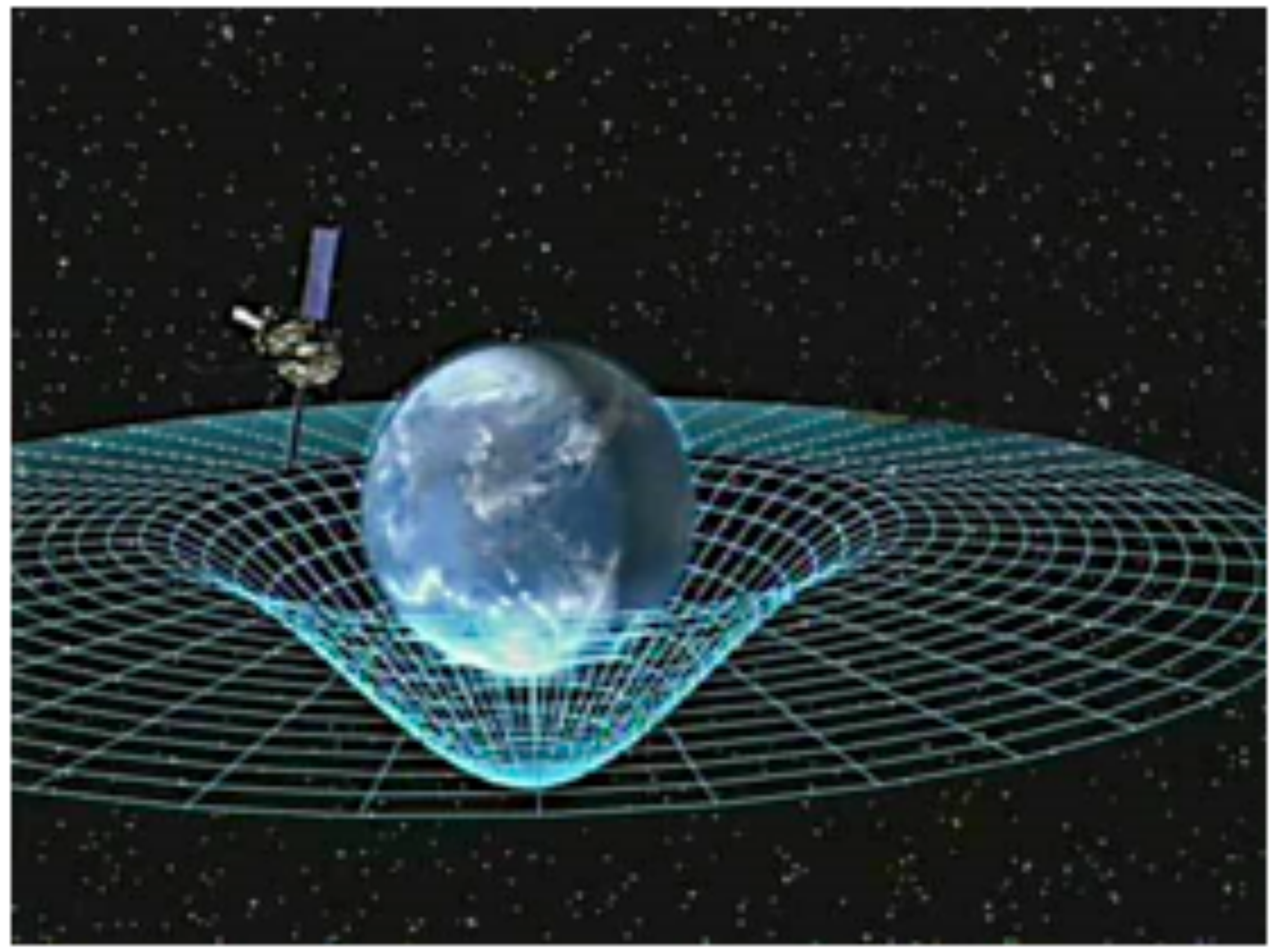
Time moves forward *continuously from past to future*

Time is completely *independent* from 3d space

Everyone experiences time the same way

Next time:

- Continue relativity!
  - Why is c the max speed of the Universe?
  - Time dilation calculations
  - Dive into general relativity



What is the nature of space and time?

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