General Physics: Mechanics

PHYS-101(en)

Lecture 1a: Motion in one, two and three dimensions

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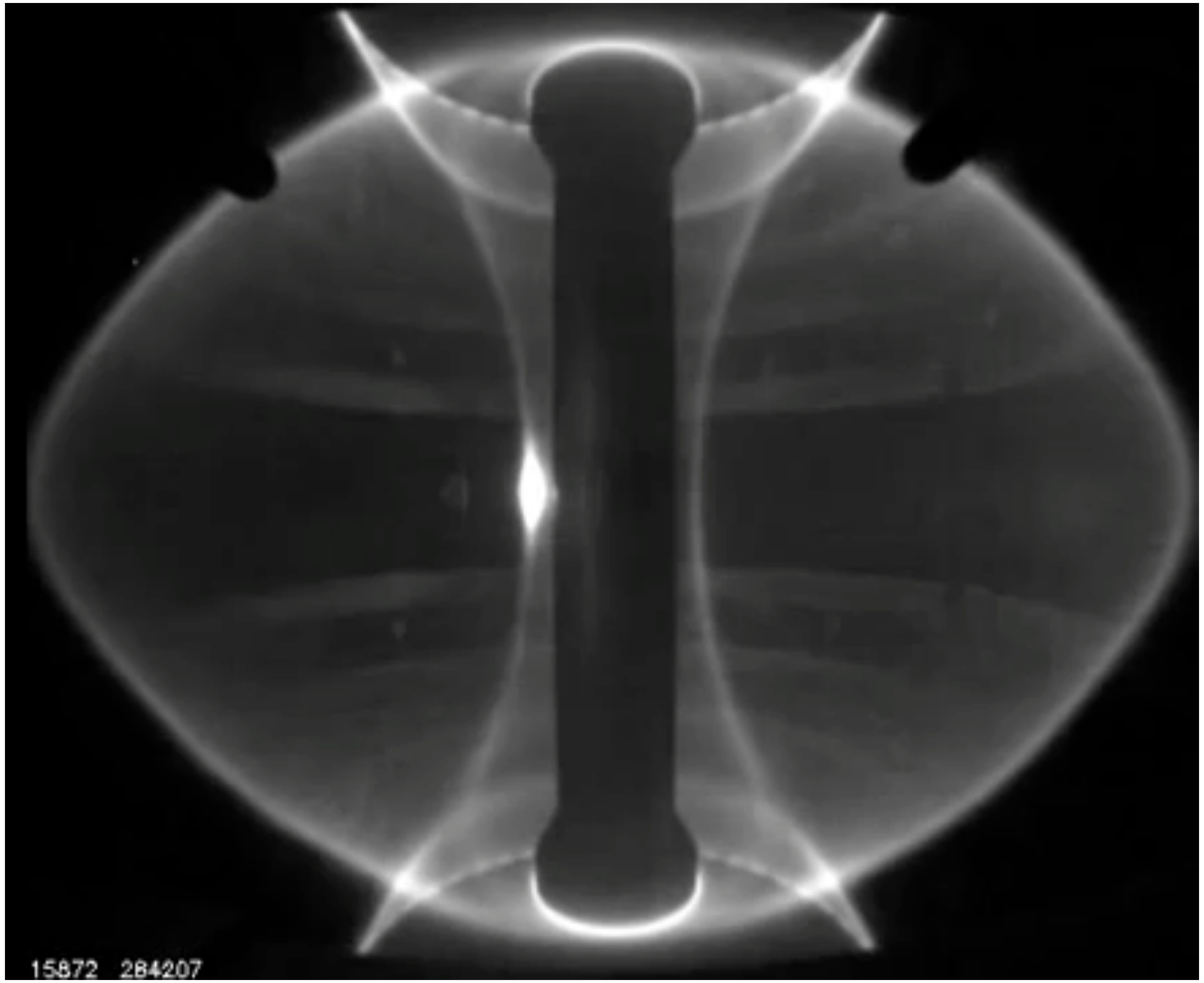
EPFL
Swiss Plasma Center



Welcome!

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Welcome!

Me Dr. Marcelo Baquero

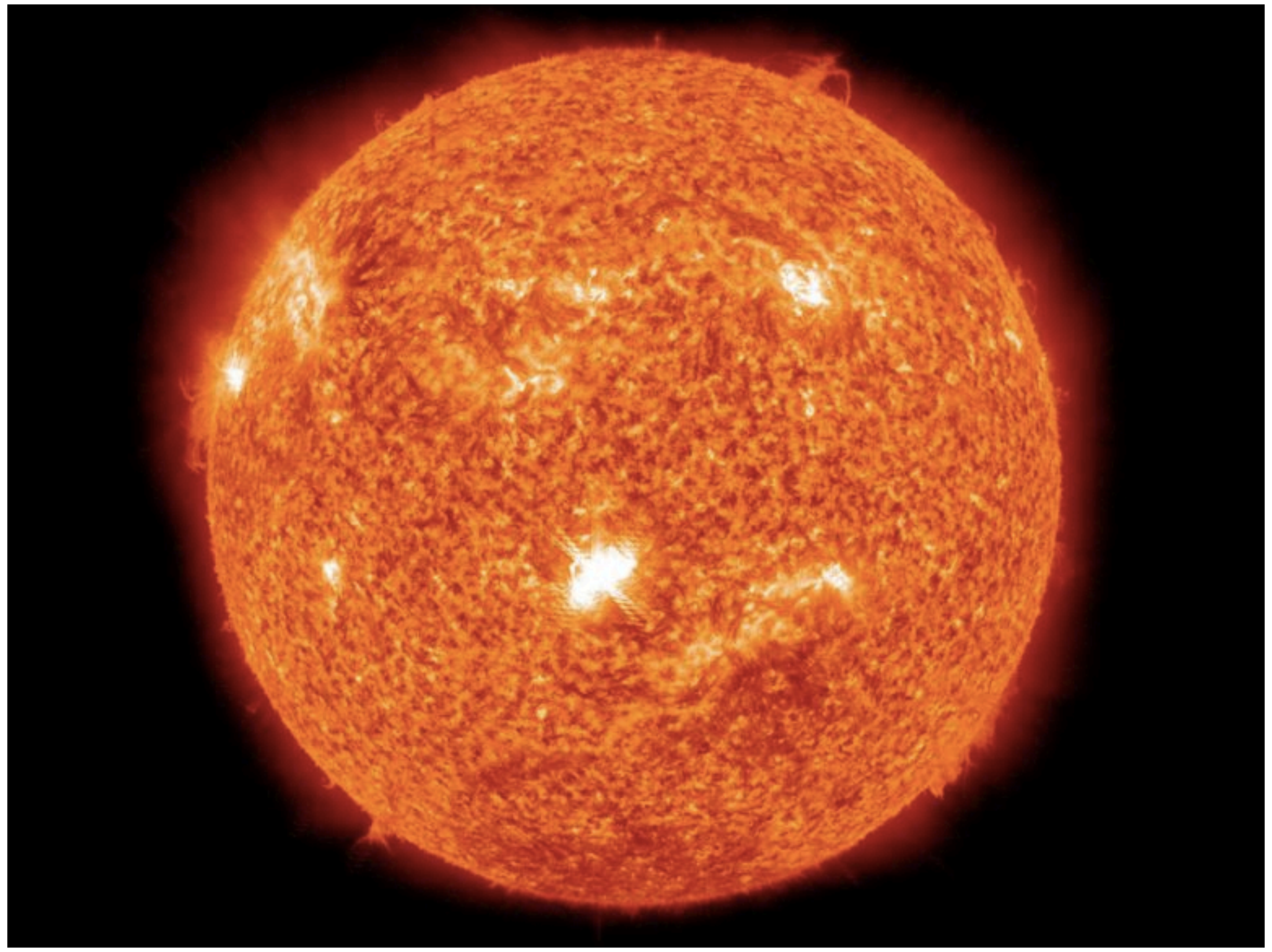
"El Pibe" Valderrama

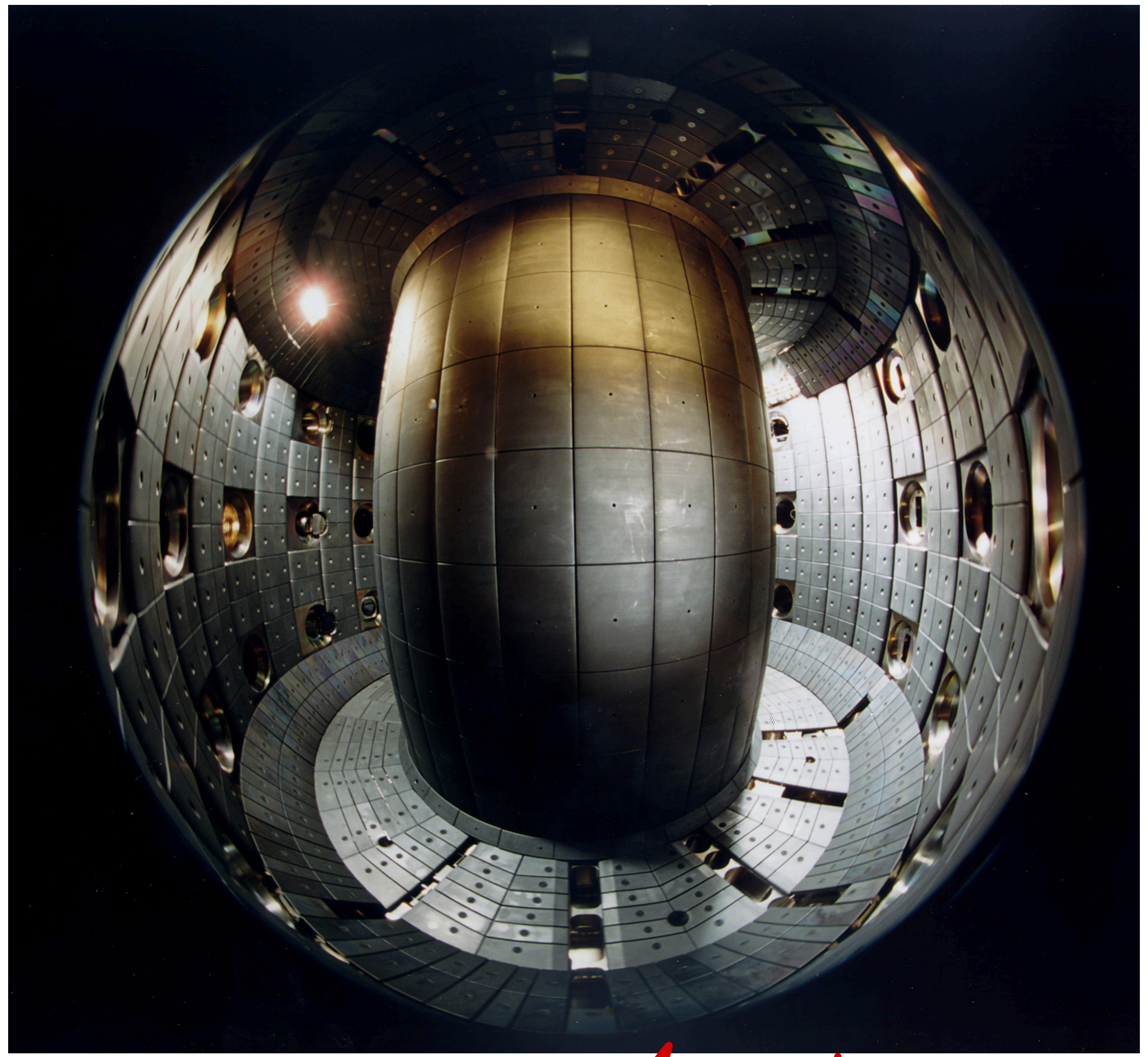
Juan Valdez

Café de Colombia

My research — fusion energy

- Help create a star on Earth and use it to generate limitless, safe, carbon-free electricity.
- Basic experiments and modeling to better understand turbulent transport and plasma-gas interactions in fusion devices.





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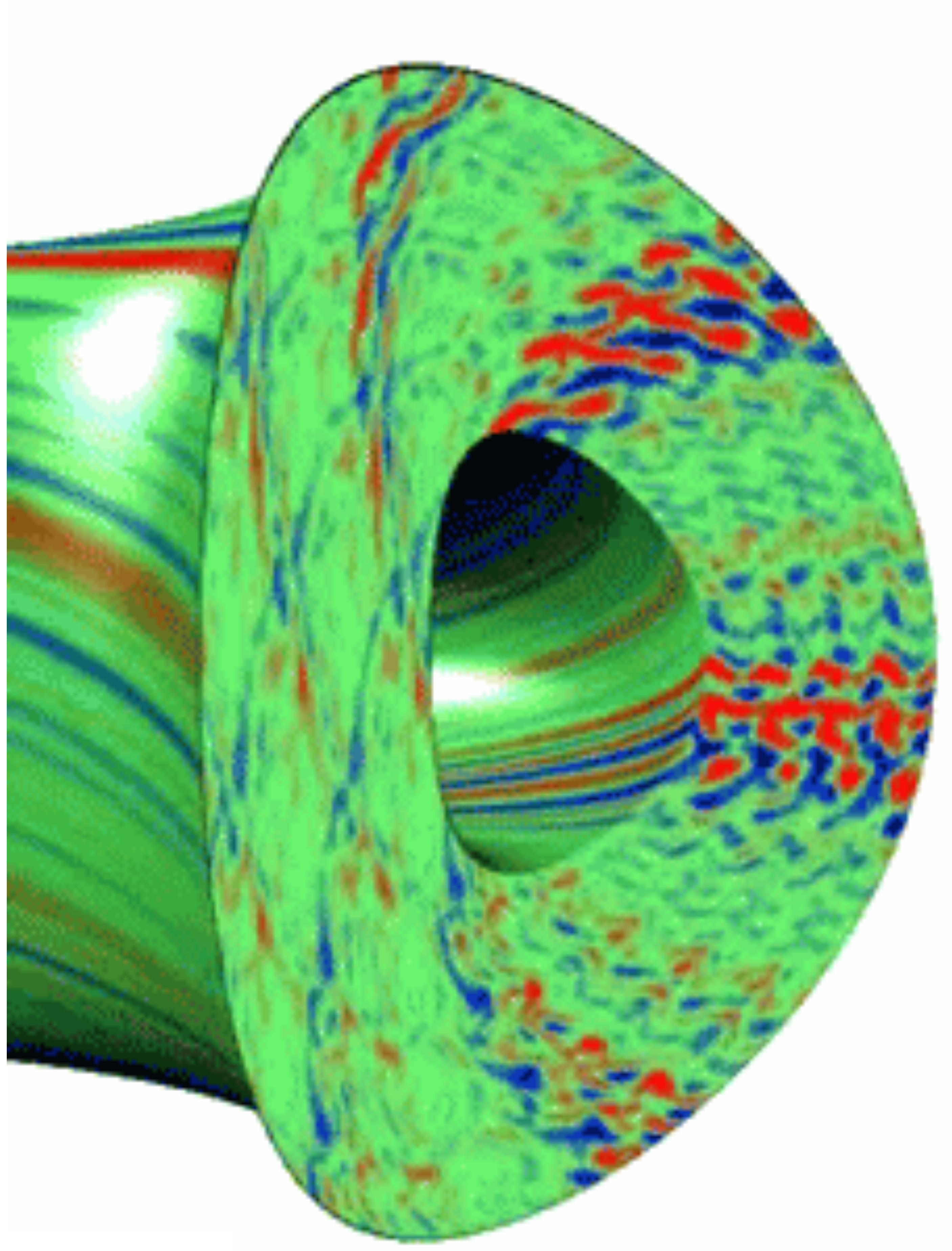

Today's agenda

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1. Course overview
   - Content
   - Resources
   - Exam
   - Logistics

2. Topics for you to review

Today's agenda (continued)

3. Motion in one dimension (Serway 2 and/or MIT 4)
    - Position
    - Velocity
    - Acceleration

4. Motion in two and three dimensions in Cartesian coordinates (Serway 3,4, MIT 3)
    - Acceleration due to gravity
    - Using vectors in equations

Course content

- Introduction to the motion of objects:
  - Motion of a point mass in one, two, and three dimensions (e.g. ballistics)
  - Newton's laws
  - Gravity, friction, drag, and collisions
  - Work and conservation of momentum and energy
  - Solid body dynamics (e.g. center of mass, rotation)
  - Oscillators

Weekly schedule

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- Monday lectures **[INTRODUCE]**
  - Mondays from 16:15-19:00 in **CE6**
  - Presentation of concepts, cool demonstrations, and conceptual questions

- Tuesday lectures **[WATCH]**
  - Tuesdays from 10:15-11:00 in SG1
  - Guided exercises and conceptual questions

Weekly schedule (continued)

- Wednesday exercise sessions **[DO]**
  - Wednesdays from 17:15-19
  - One teaching assistant per ~10 students
  - You can already sign up for a tutoring group on Moodle
  - Depending on which group you join, you will be in the CO or CE building
  - Exercises will be found on the Moodle (bring your own paper copy or way to access them digitally)

Resources

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- Moodle
  - **https://go.epfl.ch/PHYS-101_en**
  - Problem sets and solutions, lecture notes, additional material

- Textbooks
  - MIT Open Courseware (see Moodle for link)
  - “Physics for Scientists and Engineers” by Serway
  - “Mécanique” by Ansermet (parts 1, 2, 3) [in French]

- Extra problems found in Serway textbook or in the Exoset database

Resources (continued)

- Supplementary Q&A sessions
  - Discuss problem sets further for those who **want** to
  - Tuesdays 17:30-19:00 and Thursdays 18:00-19:30 in room CO 121
    - Starting from first week of October until the end of the semester

- Office hours
  - Ask me general questions
  - Tuesdays at 11:15 (right after class) in room ELG 116
    - Starting from second week (Sept. 17)

Interactive learning

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"Self-education is, I firmly believe, the only kind of education there is. The only function of a school is to make self-education easier."

- Isaac Asimov

- Answer multiple choice conceptual questions in lecture
- More information can be found at https://www.epfl.ch/education/teaching/teaching-support/resources-for-students/student/using-your-smartphone/
- Smartphone/computer: navigate to responseware.eu, connect to session ID "epflphys101en"
- No login or personal information required

Conceptual question

responseware.eu
Session ID: epflphys101en

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What do you think about *El Pibe* Valderrama?

A. *El Pibe* Valderrama is **the best**
B. *El Pibe* is **the worst**
C. Prior to today I did not know *El Pibe*
D. Who/what is *El Pibe*?

- Note: Normally the question is a bit more technical, so I'll leave time for you to think, draw diagrams, make calculations, talk with neighbors, etc.

- Another note: you can change your answer

The exam

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- All students registered for this course will take a written exam at the end of the semester
- It entirely determines your grade, which is on a scale between 1 and 6 (4 or above is passing)
- 3.5 hours long, in English, no calculator, one formula sheet (A4, front and back, handwritten by you)
- The exam is coordinated between all sections of PHYS-101 to ensure consistency/fairness
- You will <u>not</u> have seen the questions during the exercise sessions

Preparing for the exam

- Work consistently throughout the semester
- Follow the lectures and study further the material you don't understand
- Attend the exercise sessions and try the problems on your own before asking for help
- Practice lots of problems and do your own mock exams
  - The exam is a set of timed PHYS-101 problems
  - **The best way to improve at something is usually to do it, repeatedly**
- Working in groups with classmates can be helpful during the final preparations

For review

- Units and dimensions (MIT 2.2, Serway 1.1, 1.5)
- Dimensional analysis (MIT 2.3, Serway 1.4)
- Orders of magnitude (MIT 2.4, Serway 1.6)
- Trigonometry (see resources on Moodle)
- Vectors (MIT 3 and see resources on Moodle)
- Derivatives and integrals (see resources on Moodle)
- Differential equations (comprehensive list on Moodle)

For review: Units and dimensions

Fundamental units		
Quantity		**SI unit**
length L	L	m (meter)
mass M	M	kg (kilogram)
time T	T	s (second)
Derived units		
velocity	L/T	m/s
acceleration	L/T^2	m/s^2
force	$M\ L/T^2$	$kg\ m/s^2$ (Newton)
density	M/L^3	kg/m^3

For review: Dimensional analysis

- Use units to check for accidental math errors
- Example:
  - A stone is dropped from a height h and you have calculated the time it takes to hit the ground to be $t = \sqrt{2h/g}$, where g is the acceleration
  - Show that this solution is plausible, as it is dimensionally correct
  - While this is very useful a check to do, it doesn't guarantee the solution is completely correct (e.g. the factor of 2 could be wrong)

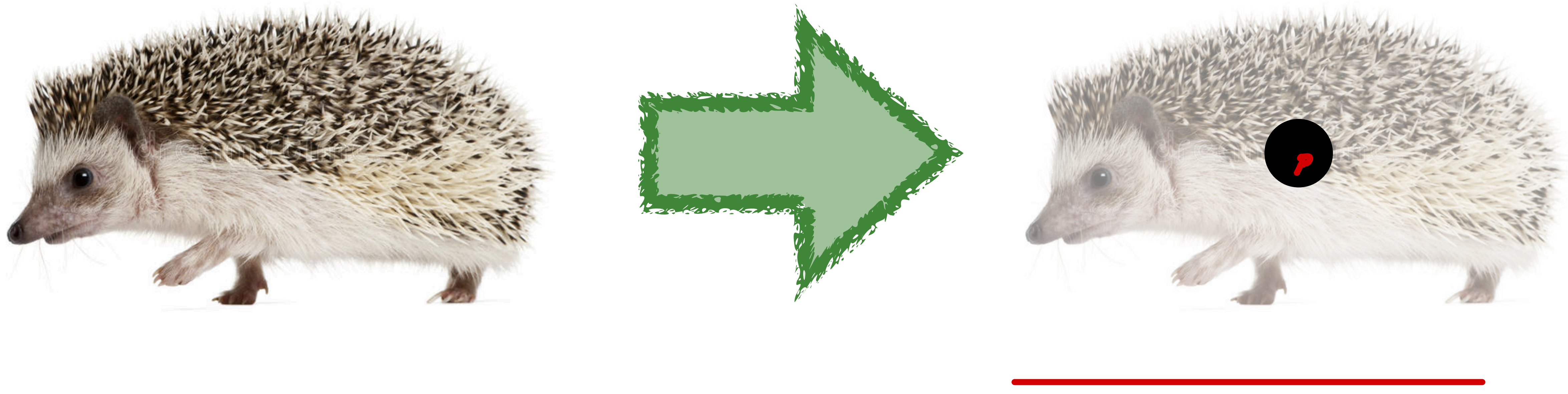
$$[h] = L, \quad [g] = \frac{L}{T^2} \quad \Rightarrow \quad \left[\frac{h}{g}\right] = \frac{L}{L/T^2} = T^2 \cdot \frac{L}{L} = T^2$$

$$\left[\sqrt{\frac{h}{g}}\right] = \sqrt{T^2} = T$$

$$\left[\sqrt{\frac{2h}{g}}\right] = \left[\sqrt{\frac{h}{g}}\right] = T$$

Point mass

- Approximating an object as a "point mass" can be a very useful simplification
- Ignore the fact that an object is distributed in space



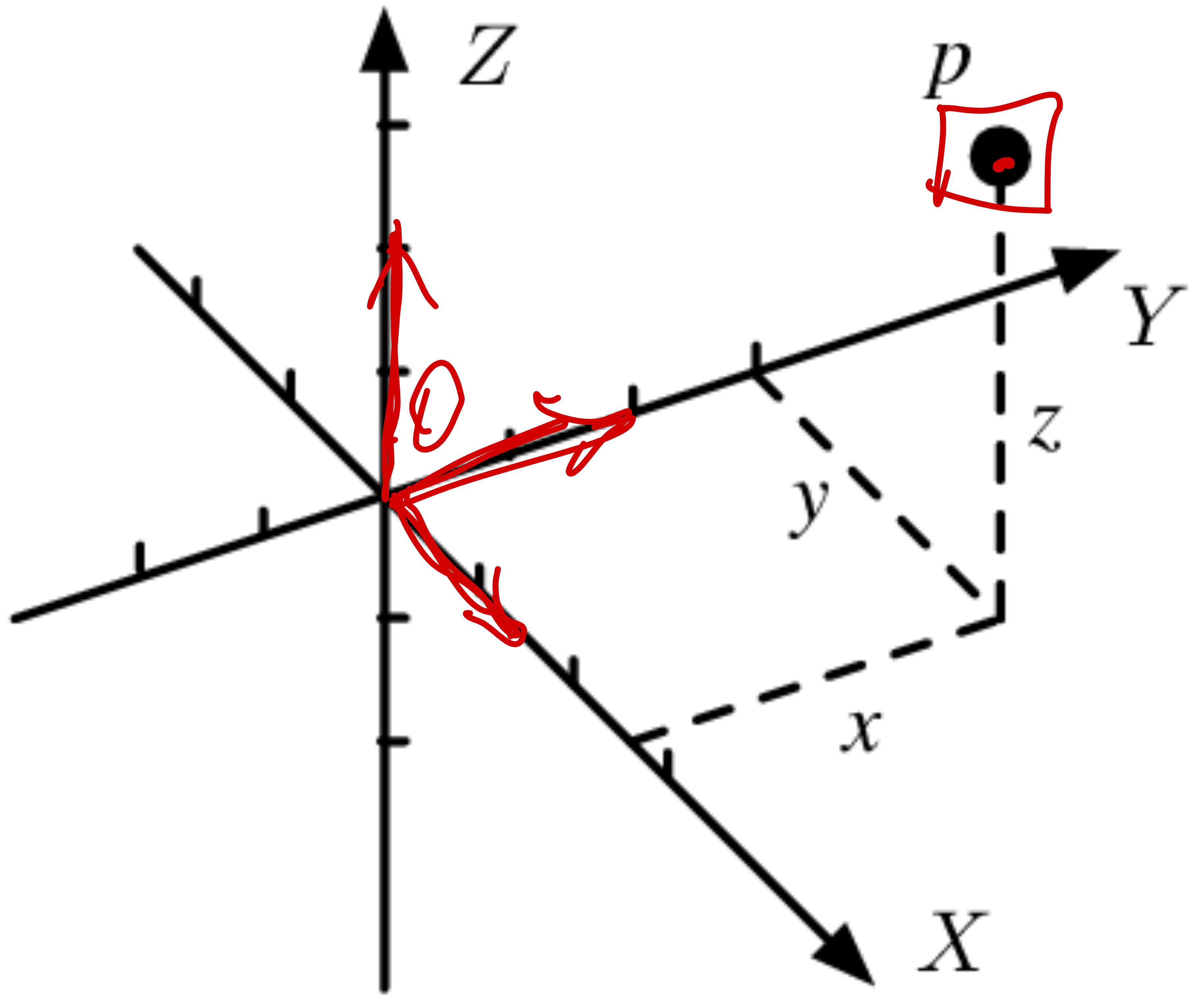
- Attribute all the mass of the system to a single, infinitesimally small point
- This approach can be accurate even for large objects (e.g. the Earth)
- As we will see later in the course, it has limitations (e.g. objects that stretch and bend, rotation)

Quantifying motion

- Position is the location of an object with respect to a *frame of reference*

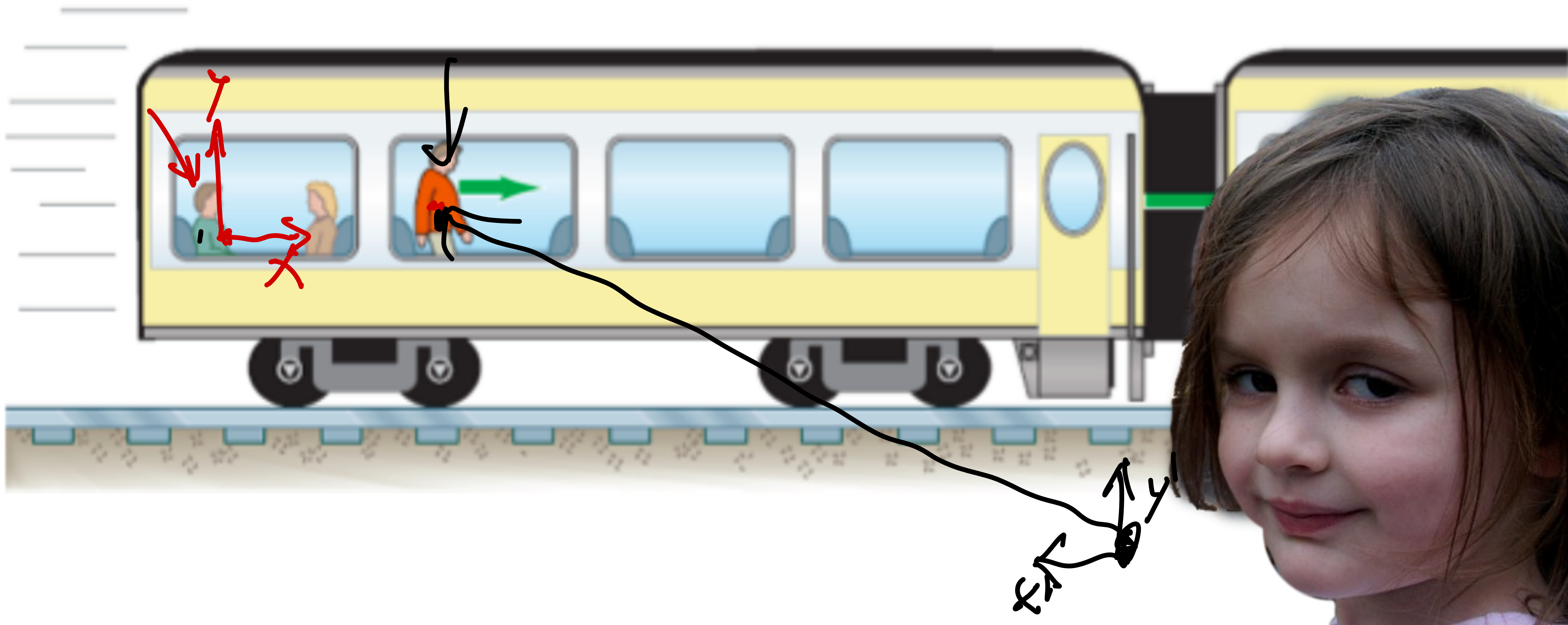
Reference frames

- Any measurement concerning motion must be made with respect to a reference frame
- **A reference frame is a coordinate system**
- To see the motion in a reference frame, imagine the perspective of an observer staying at the origin of the coordinate system
- Observers in different reference frames will report different measurements
- That’s okay, as they should be consistent



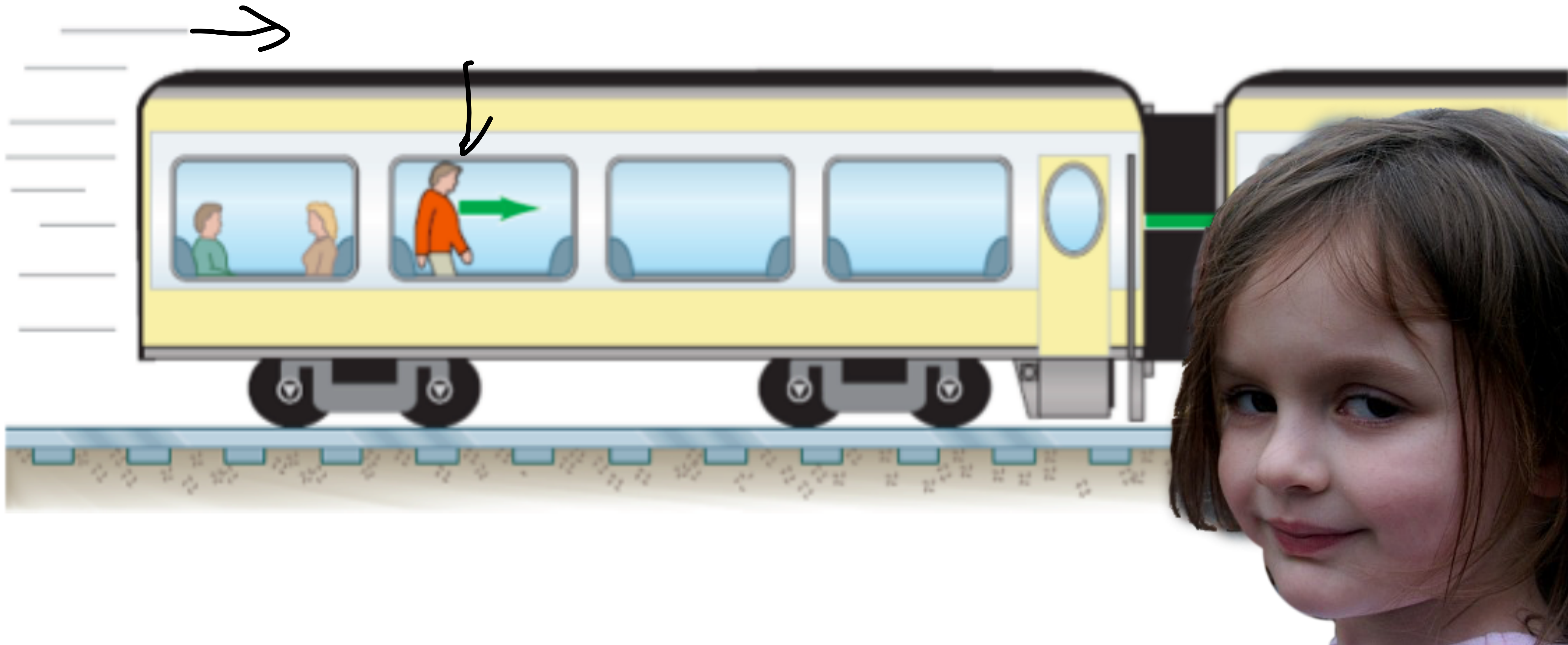
Reference frames

- **Example**:
  - You're sitting on a train and someone walks down the aisle. The person's speed with respect to your reference frame is at most a few kilometers per hour.



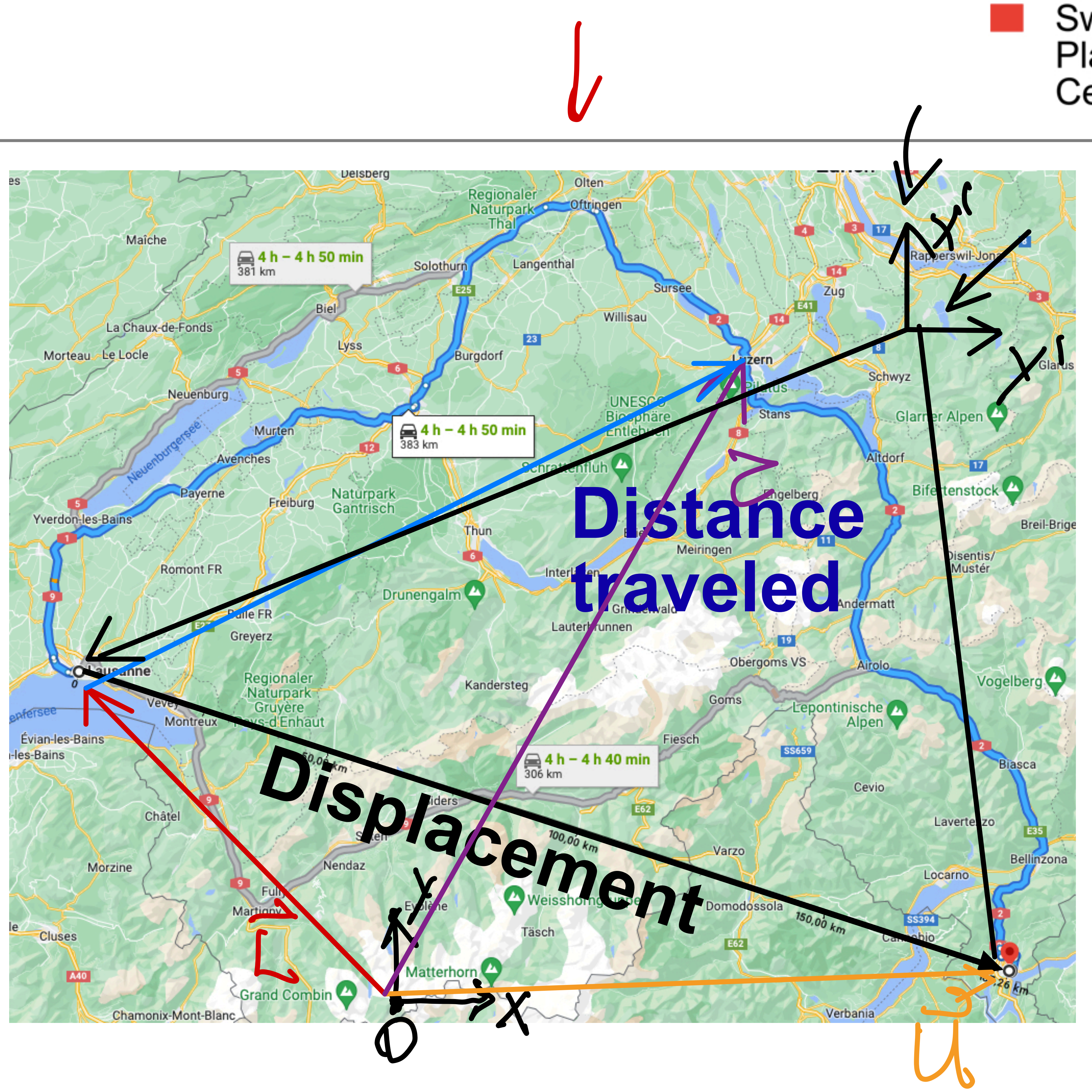
Reference frames

- Moving reference frames are perfectly acceptable
- A reference frame that moves at a constant velocity (or is stationary) is called an "inertial reference frame"
- Reference frames with a changing velocity are called "non-inertial" and are more complicated (as we will see later in the course)



Quantifying motion

- Position is the location of an object with respect to a *frame of reference* (i.e. the origin of a coordinate system)
- Distance traveled is the length of the path taken by an object
- Displacement is the change in position "as the crow flies"
- Position and displacement are vectors (a number with a direction), while distance traveled is a positive scalar (just a number)



- **For one-dimensional motion we can ignore vectors** because direction is indicated by the sign of a number (positive or negative)

Distance versus displacement

- **Example:** You're driving a car on a straight road due north. You start at home, drive to a destination 5.0 km away, but miss the turn into the parking lot. You have to drive 500 m more, turn around and return to the parking lot.

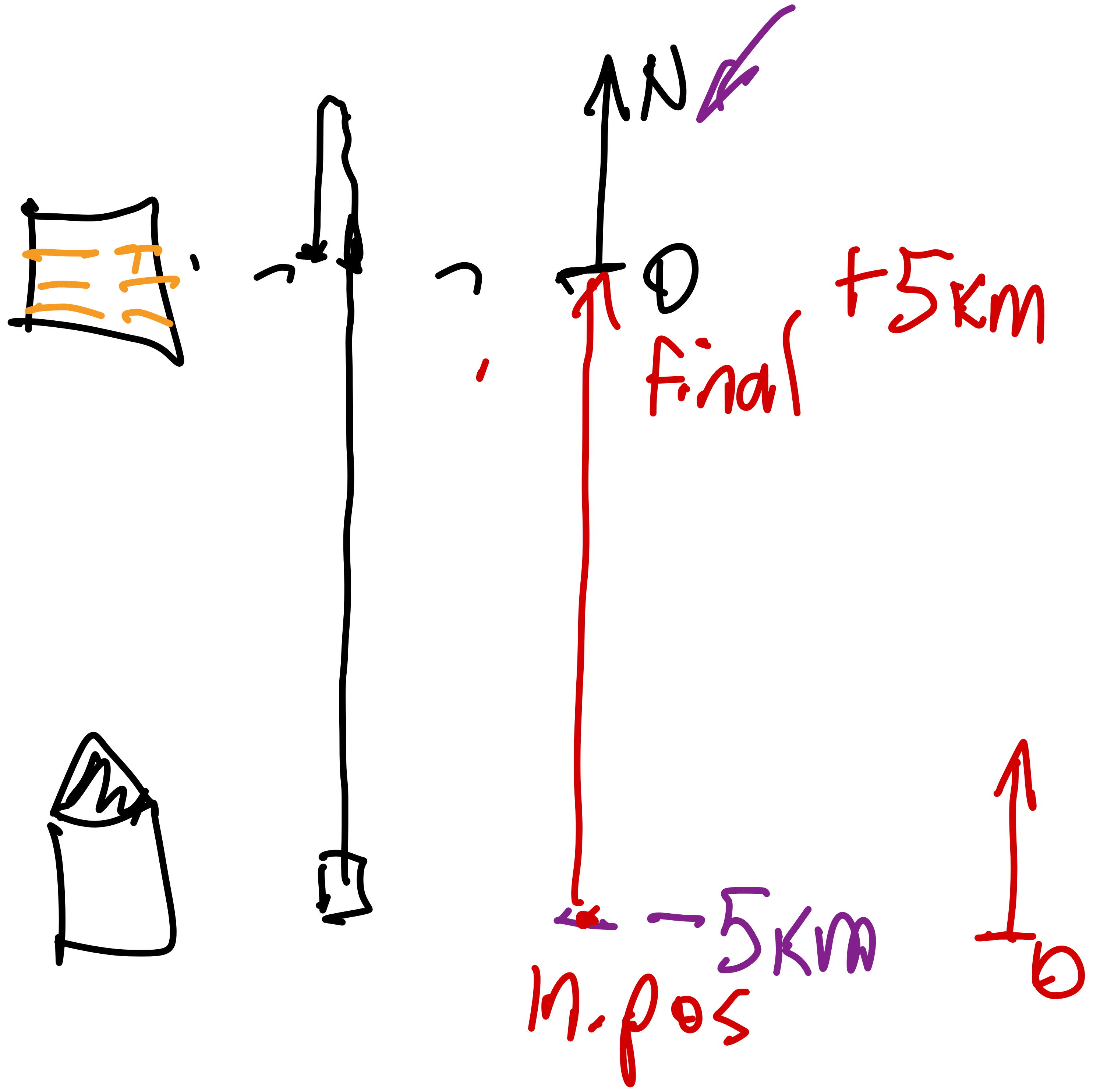
- What's the car's position at the end of the trip?

  0 or +5km depending on ref. frame

- What distance did you travel? 6 km

- What is your displacement?

  5km north

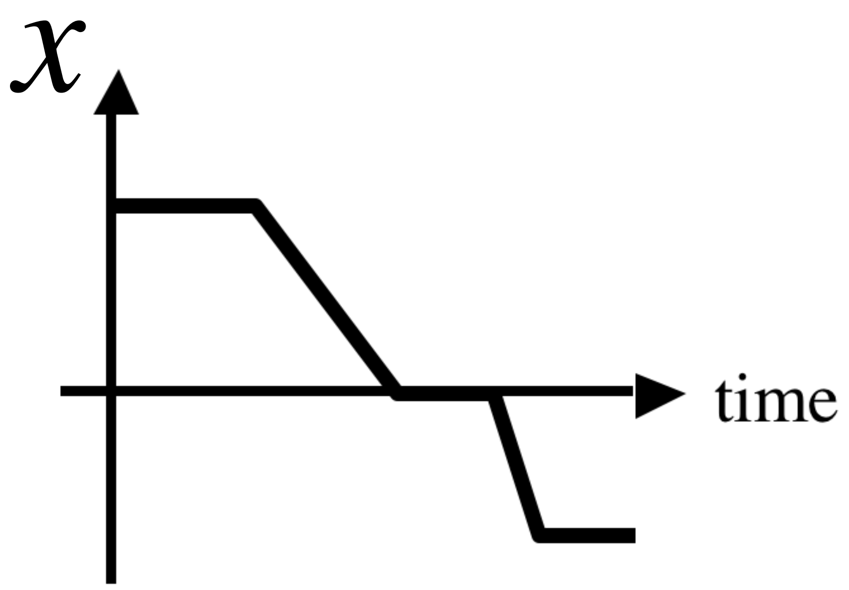


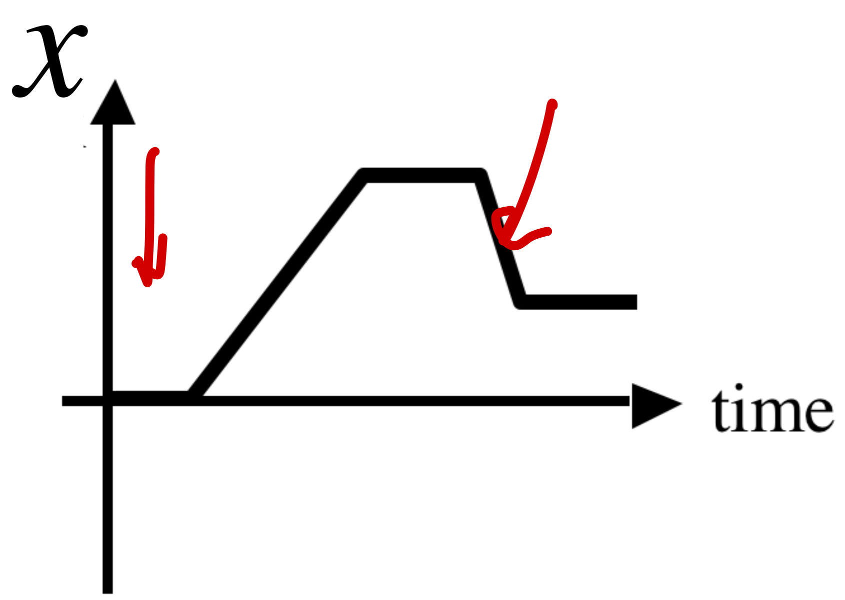
Conceptual question

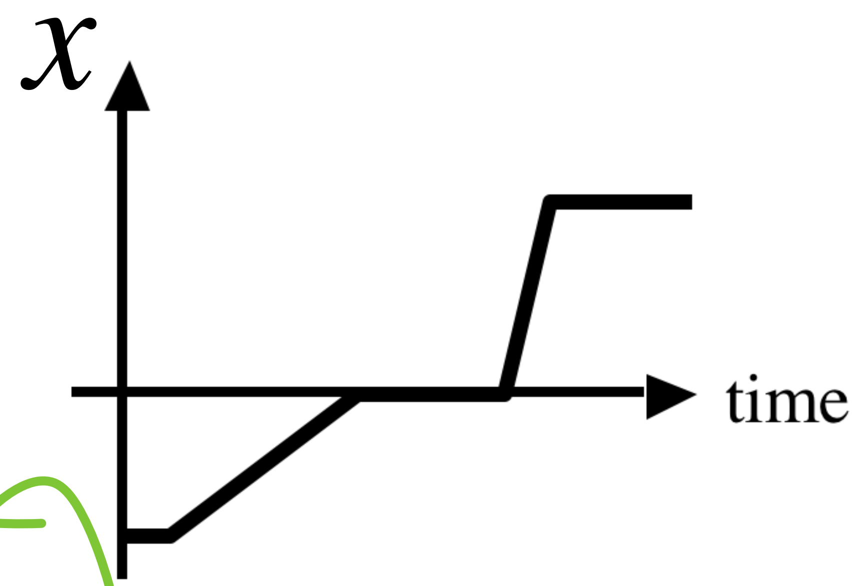
responseware.eu
Session ID: epflphys101en

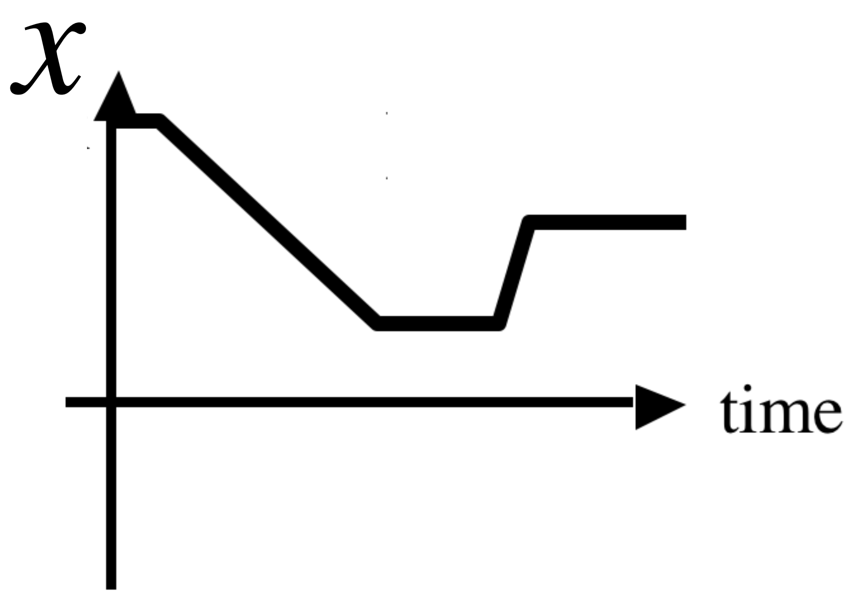
A person (me) stands around for a while at point “c”, then walks straight forward to point “a”, waits there a bit, then runs straight to point “b”, and finally stops.

Which of the following represents this motion, given the reference frame below?

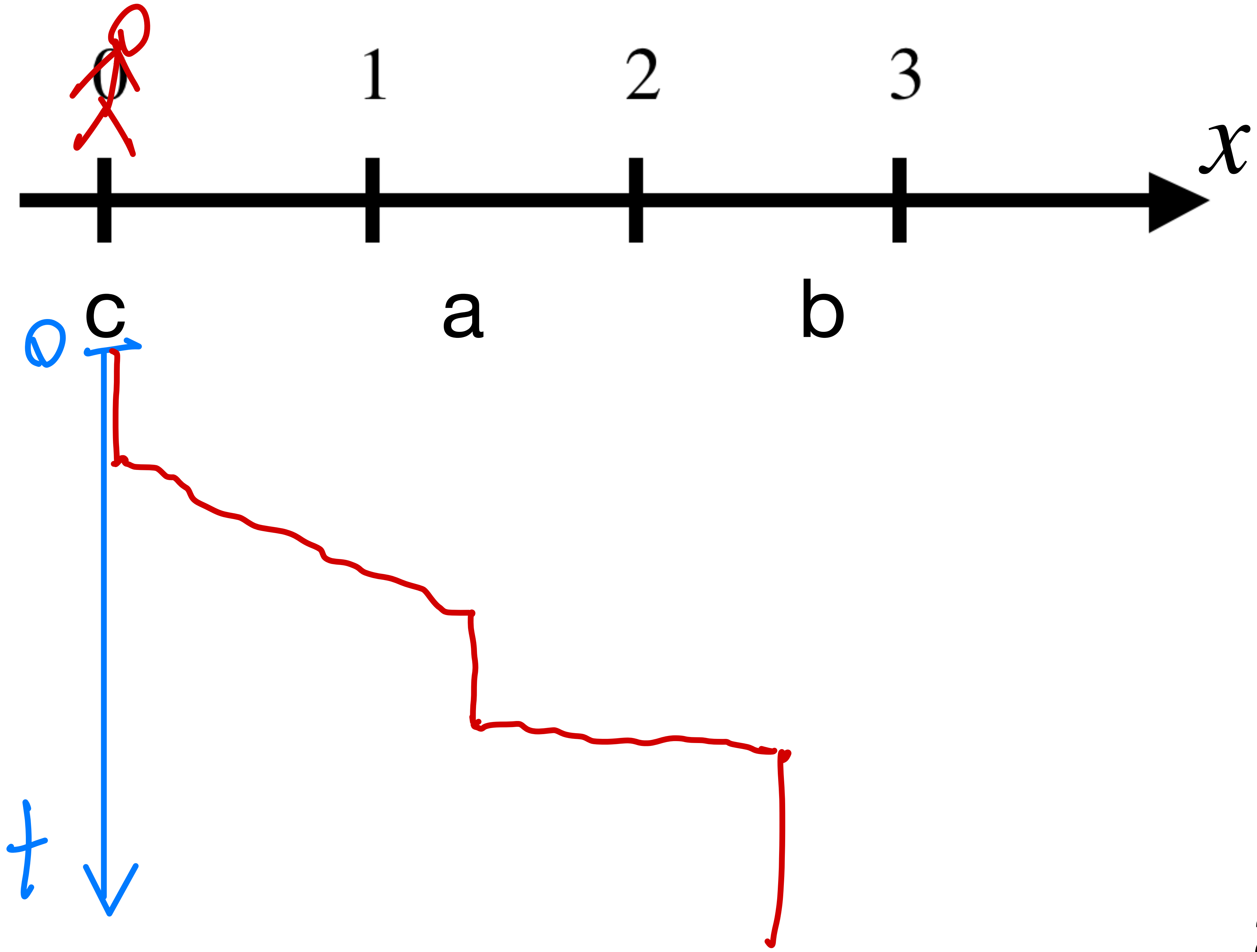
A.


B.


C.


D.


E. None of these



Speed versus velocity

- Both quantify a change in position with time
- Speed is how fast an object travels
  - E.g. 50 kilometers per hour, 50 km/hr
- Velocity is speed together with the direction of motion
  - E.g. 50 kilometers per hour south, $v = -50$ km/hr

$$\text{average speed} = \frac{\text{distance traveled}}{\text{time elapsed}}$$

$$\text{average velocity} = \frac{\text{displacement}}{\text{time elapsed}}$$

Speed versus velocity

- What does the speedometer in a car measure?
  - The average speed, but over a very short elapsed time Δt
  - It approximates the "instantaneous" speed — the average speed in the limit of an infinitesimally short time interval:

$$\text{instantaneous speed} = \lim_{\Delta t \to 0} \frac{\text{distance traveled}}{\Delta t}$$

- Instantaneous velocity is analogous:

$$\text{instantaneous velocity} = \lim_{\Delta t \to 0} \frac{\text{displacement}}{\Delta t}$$

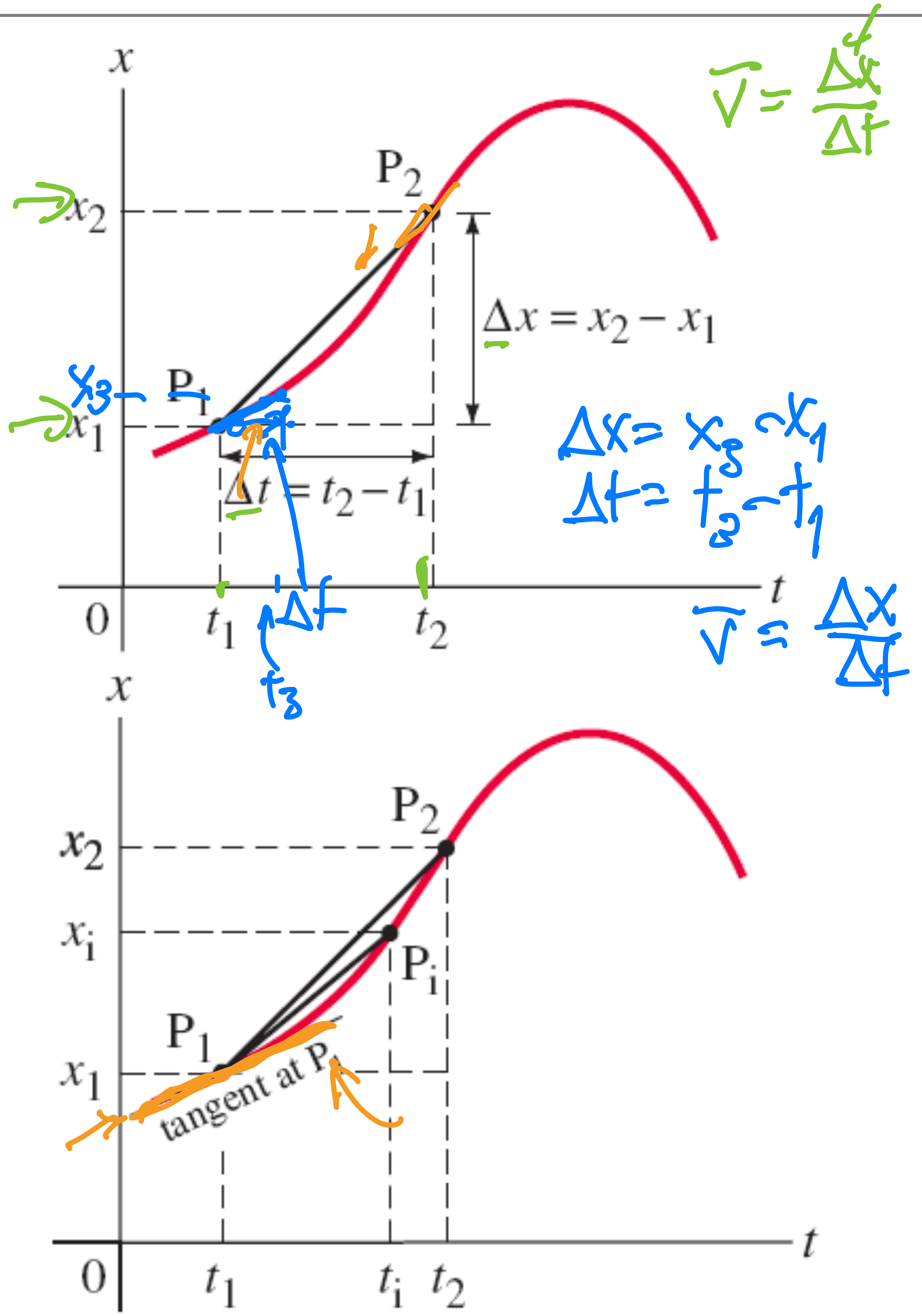
- Instantaneous speed and instantaneous velocity have equal *magnitudes* (i.e. ignoring the directional info) because: distance traveled $=$ |displacement| $= \Delta x$

Instantaneous velocity in one dimension

- The average velocity between t_1 and t_2 is the slope of the line between the two points on a position vs. time plot
- The instantaneous velocity at t_1 is the tangent to the curve at that location

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

- Instantaneous velocity is the derivative of the position in time



Conceptual question

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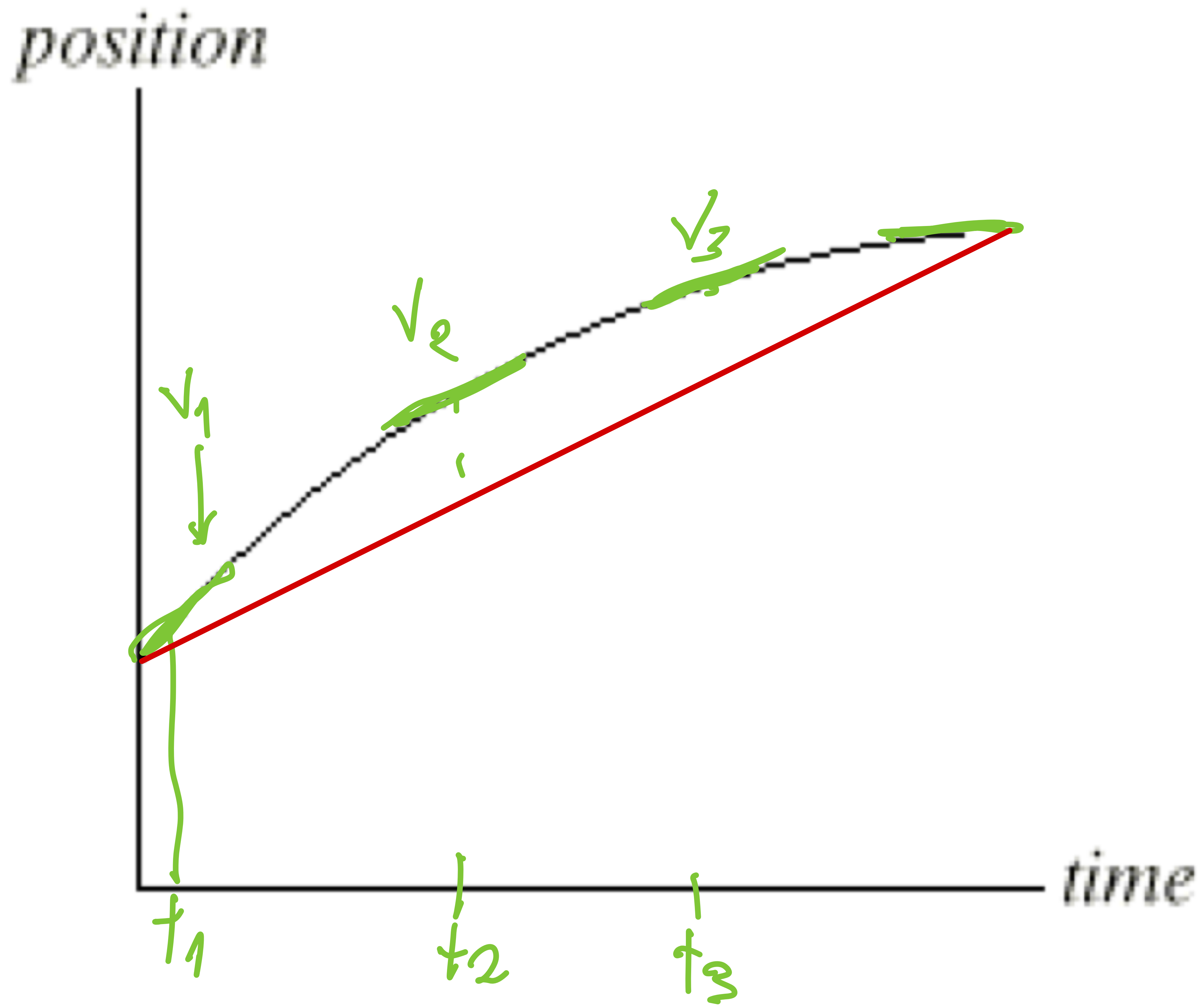
A train car moves along a long straight track. The graph shows the position as a function of time for this train.

The graph shows that the train…

A. speeds up all the time.
B. slows down all the time.
C. speeds up part of the time and slows down part of the time.
D. moves at a constant velocity.



Acceleration in one dimension

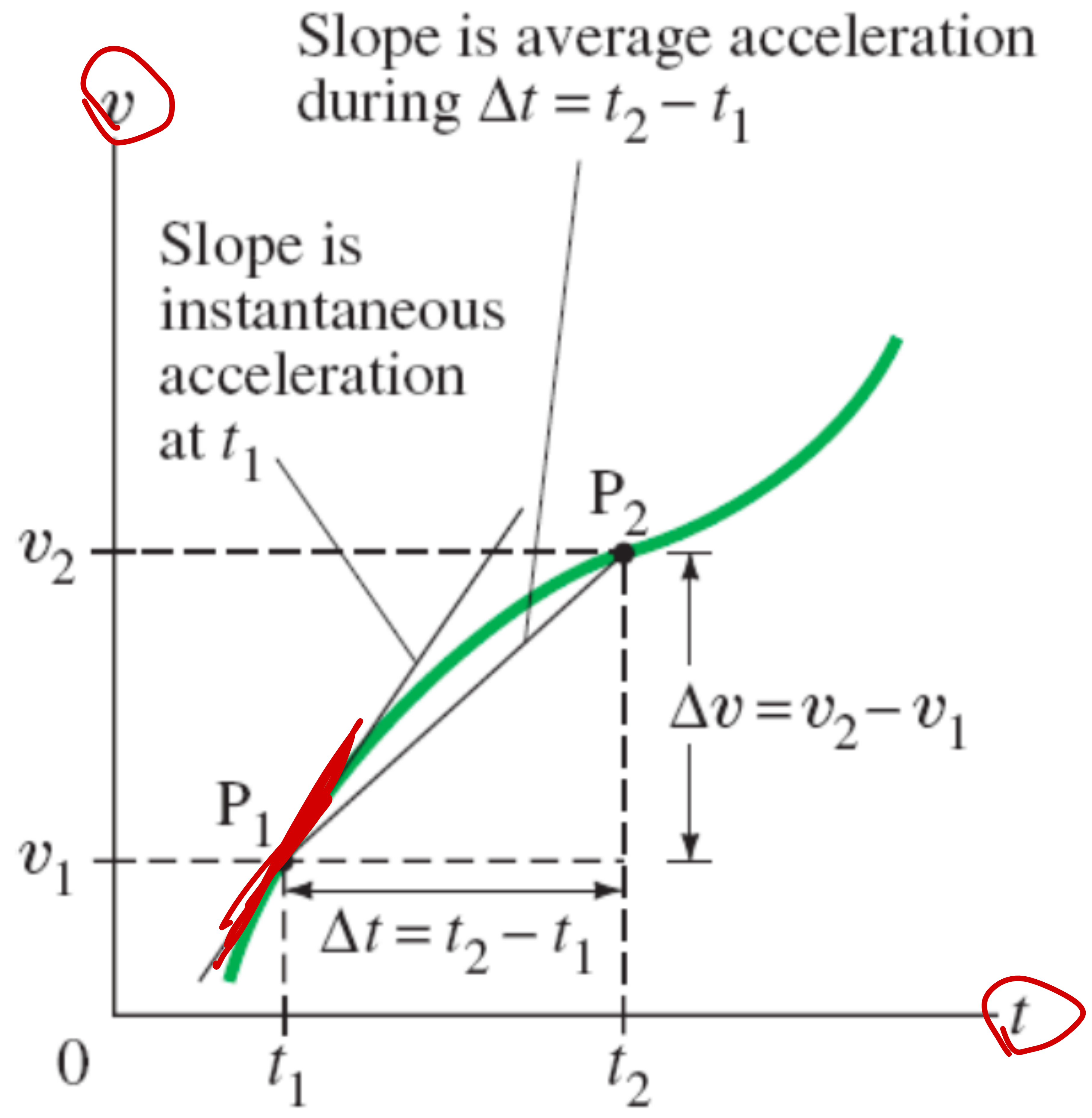
- Acceleration is the rate of change of velocity

$$\text{average acceleration} = \frac{\text{change of velocity}}{\text{time elapsed}}$$

- Instantaneous acceleration is the average acceleration in the limit of an infinitesimally short time interval:

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} = \dot{v}$$

- Instantaneous acceleration is the derivative of the velocity in time



Summary of motion in one dimension

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- Position of an object as a function of time denoted by $x(t)$
- Average velocity: $\bar{v} = \dfrac{\text{change of position}}{\text{time elapsed}} = \dfrac{\Delta x}{\Delta t}$
- Instantaneous velocity: $v(t) = \lim\limits_{\Delta t \to 0} \dfrac{\Delta x}{\Delta t} = \dfrac{dx}{dt} = x'(t) = \dot{x}$
- Average acceleration: $\bar{a} = \dfrac{\text{change of velocity}}{\text{time elapsed}} = \dfrac{\Delta v}{\Delta t}$
- Instantaneous acceleration:

$$a(t) = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} \Rightarrow a(t) = \frac{d^2x}{dt^2}$$

Integrals!

- The displacement of an object is the area under the velocity-time curve

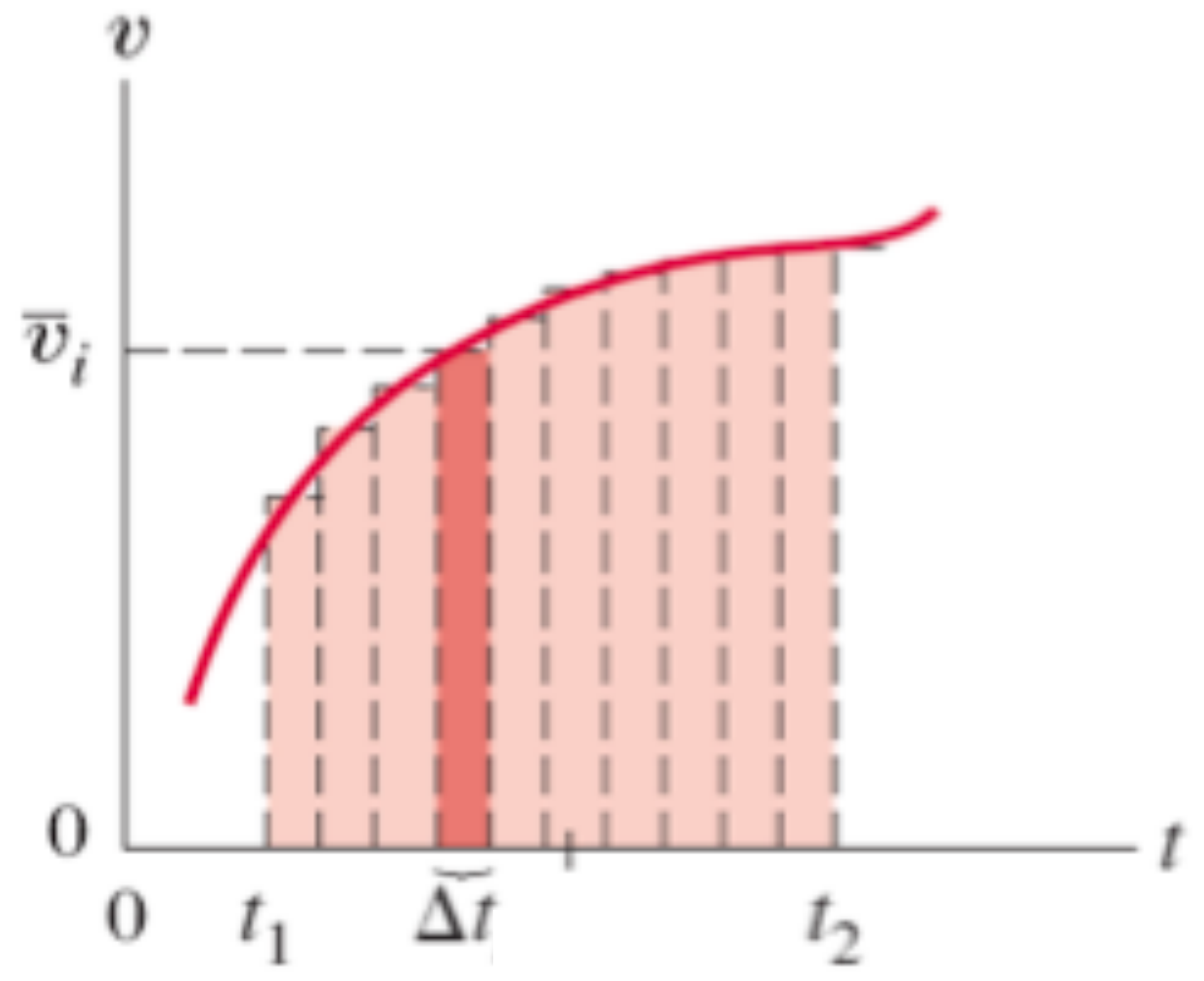
$$\bar{v} = \frac{\Delta x}{\Delta t} \quad \Rightarrow \quad \Delta x = \bar{v}\Delta t$$

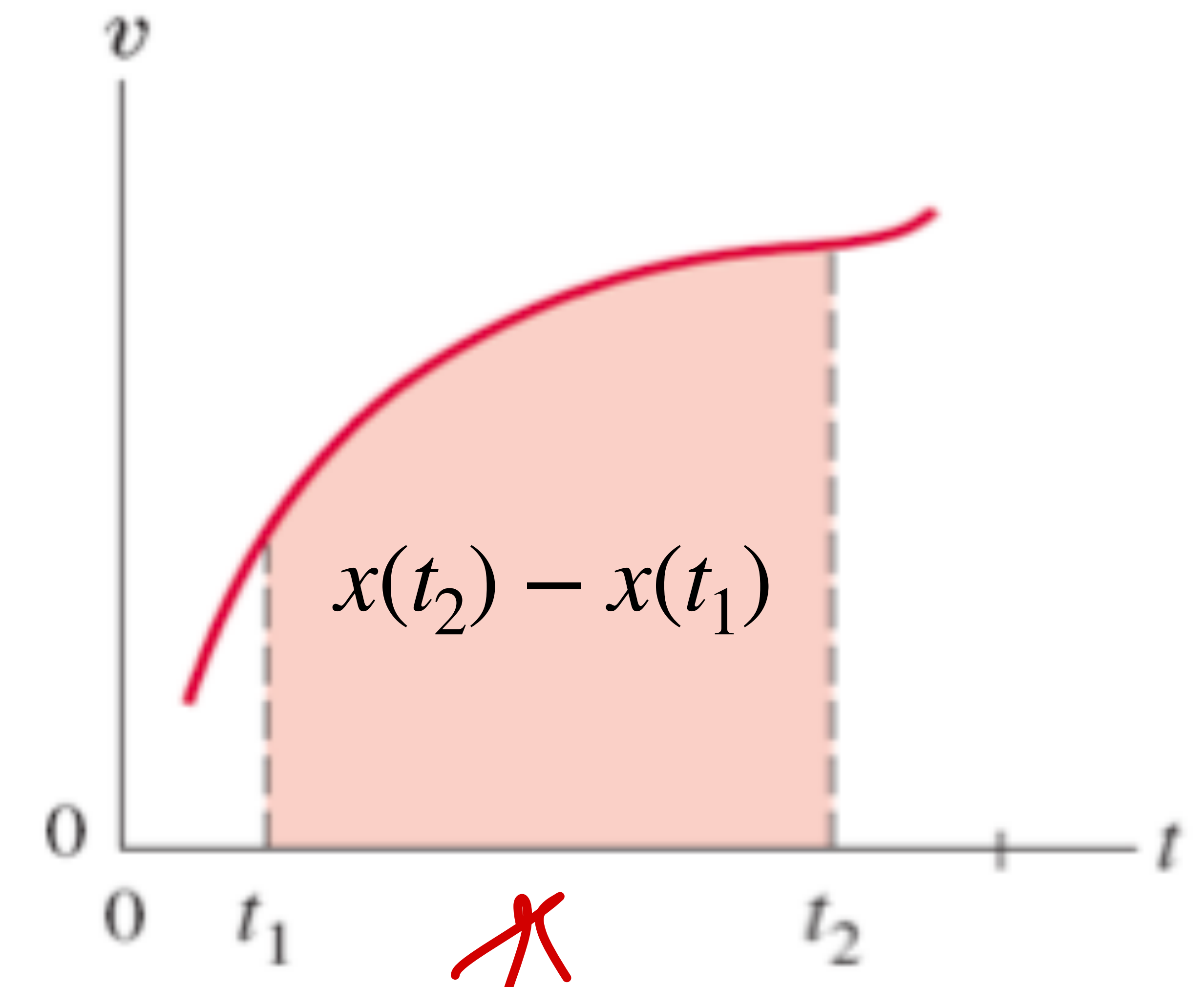
- Now imagine adding up lots of infinitesimally small time intervals:

$$x(t_2) - x(t_1) = \lim_{\Delta t \to 0} \sum_i \bar{v}_i \Delta t$$

$$= \int_{t_1}^{t_2} v(t)dt$$

- The change in position is the <u>integral</u> of the velocity





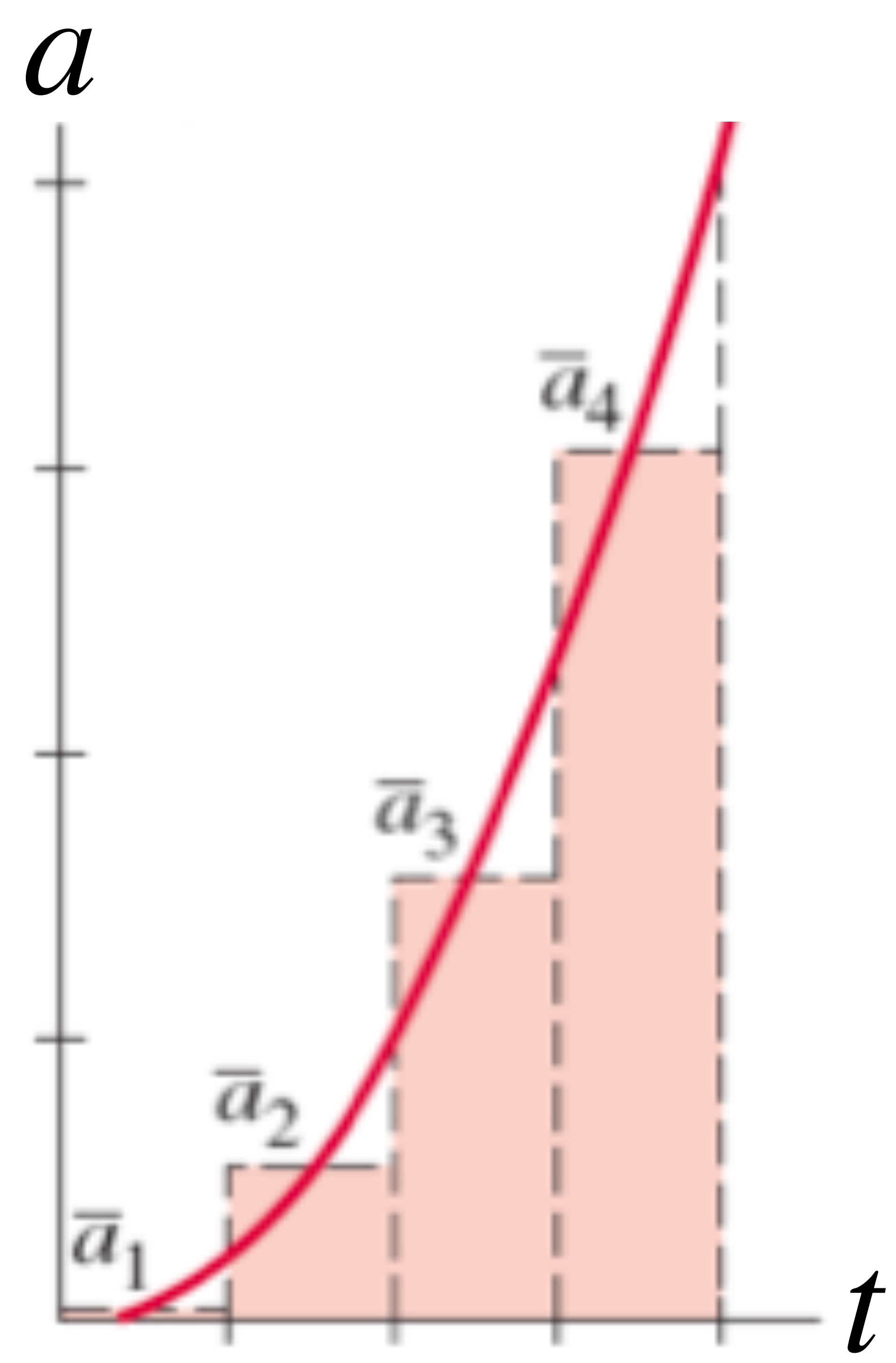
Finding velocity from acceleration

$$\bar{a} = \frac{\Delta v}{\Delta t} \Rightarrow \Delta v = \bar{a}\Delta t$$

- Analogously, the change in velocity is the area under the acceleration-time curve

$$v(t_2) - v(t_1) = \lim_{\Delta t \to 0} \sum_i \bar{a}_i \Delta t$$

$$= \int_{t_1}^{t_2} a(t)dt$$



- The change in velocity is the integral of the acceleration

DEMO (9)

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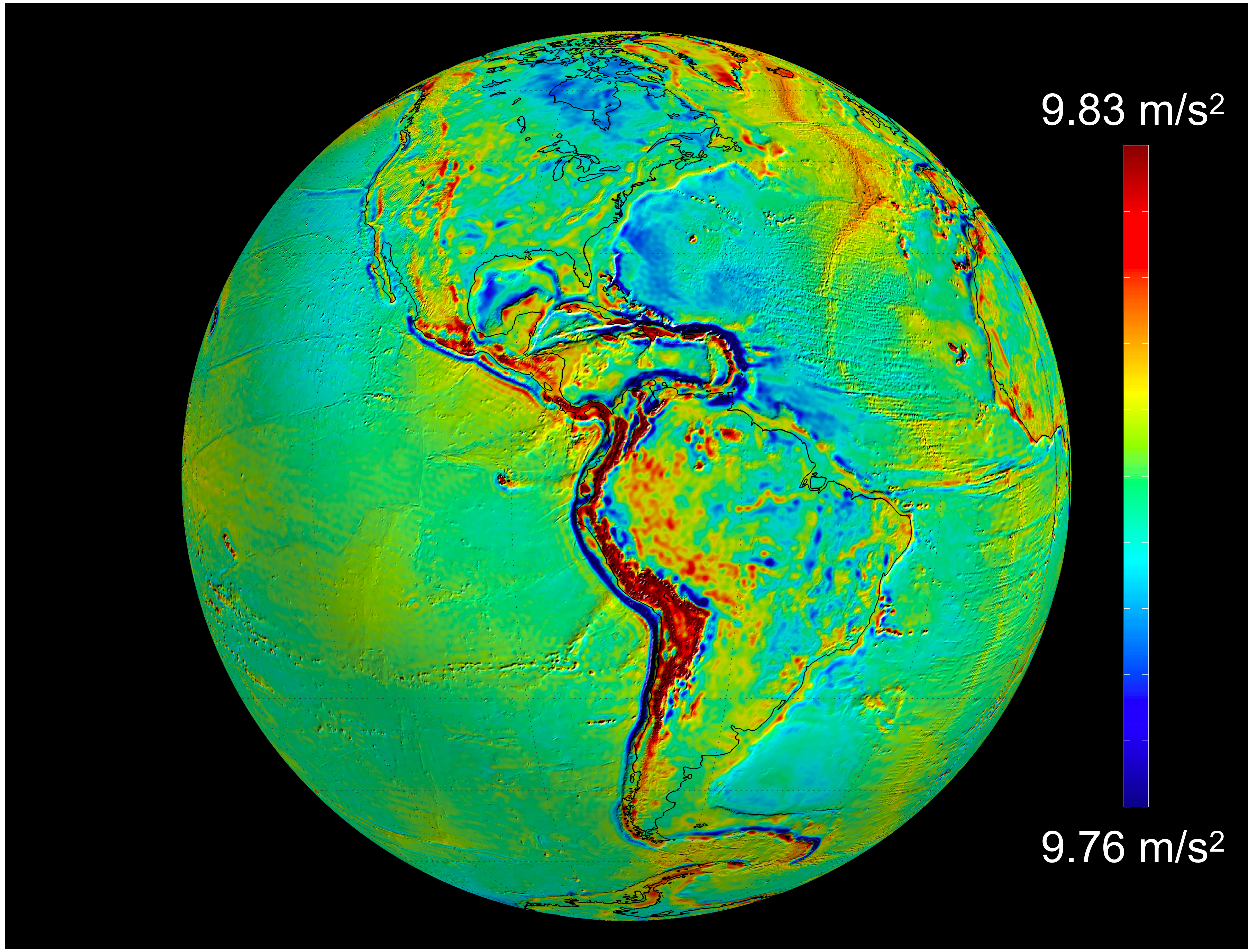
The feather and the coin

Motion under constant acceleration

- **Example:** Objects in free fall
  - Near the surface of Earth, all objects experience *almost* the same acceleration due to gravity
    - In the absence of air resistance, all objects fall downwards with an acceleration of $g = 9.81$m/s^2
  - This makes for lots of great problems that 1st year undergrads can solve :)

Uniformity of gravity $g = 9.81$m/s²

- This is a good, but not perfect approximation (no approximations are…)



DEMO (92)

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Measuring “g”

h	t (metal)	t (plastic)
1.6m	0.572 s	0.572 s
0.4m	0.288 s	0,285 s

See you at lecture tomorrow!

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Tuesday from 10:15 to 11:00 in SG1