PHYS-101 WEEK 4

EPFL

Physique générale : mécanique (classe inversée en anglais)

Prof. Emma Tolley, 29 September 2025

EVENING SESSIONS

- From **week 4** up to and **including week 13**, optional support sessions will be offered by the Centre Propédeutique. Teaching assistants will be on hand to answer your questions and provide guidance with the exercises.
- **Tuesday** in CE 1 101, from 5.30 to 7
- **Thursday** in MA A1 10, from 6.15 to 7.45

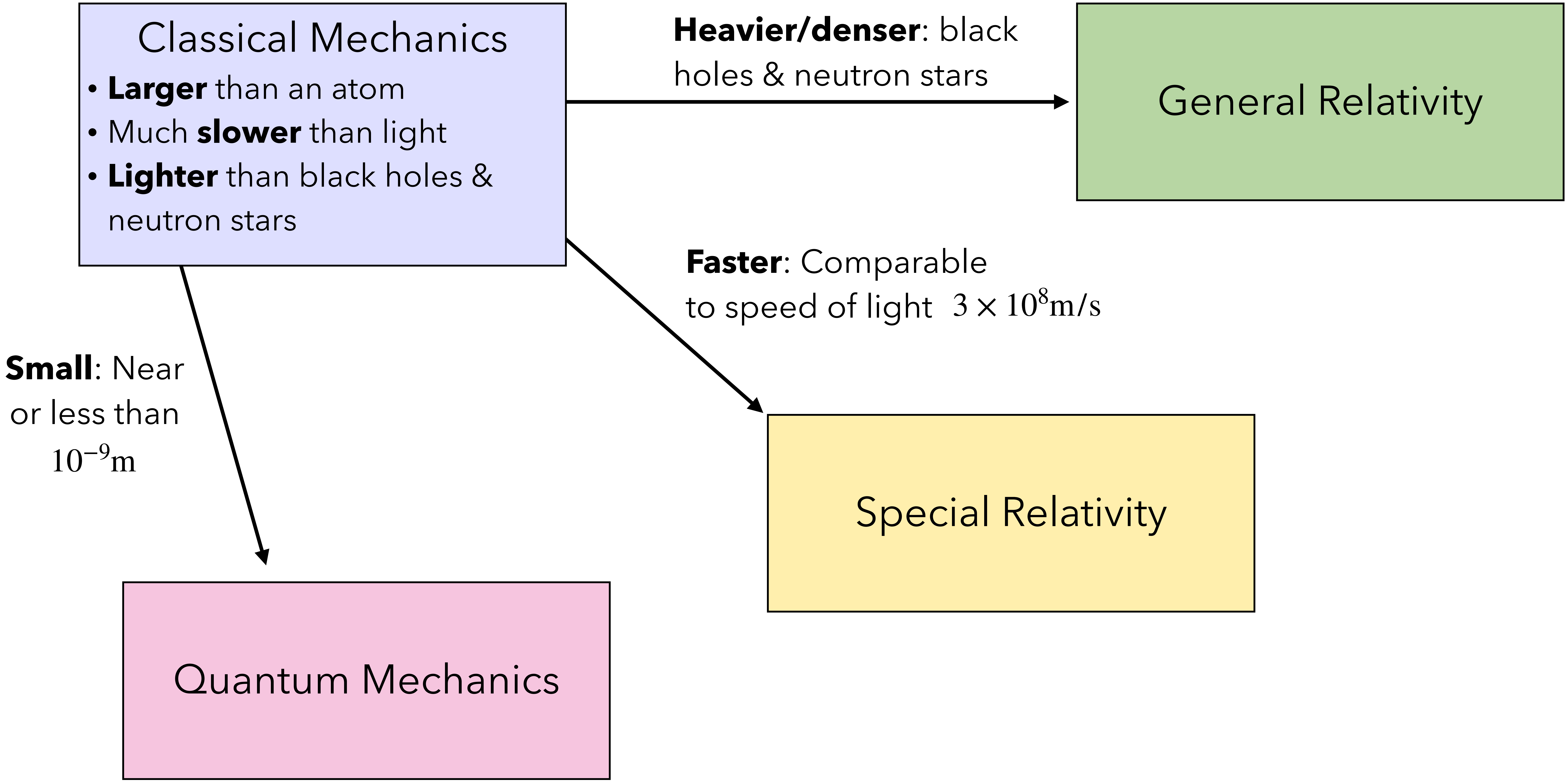
NEWTON'S LAWS

State of motion: $\vec{p} = m\vec{v}$

1st Law: if $\sum \vec{F} = 0, \ \dfrac{d\vec{p}}{dt} = 0$

2nd Law: $\sum \vec{F} = \dfrac{d\vec{p}}{dt}$ If mass is constant: $\sum \vec{F} = m\vec{a}$

3rd Law: $\vec{F}1 = -\vec{F}2, \ \sum \vec{F}_{\text{internal}} = \vec{0}$

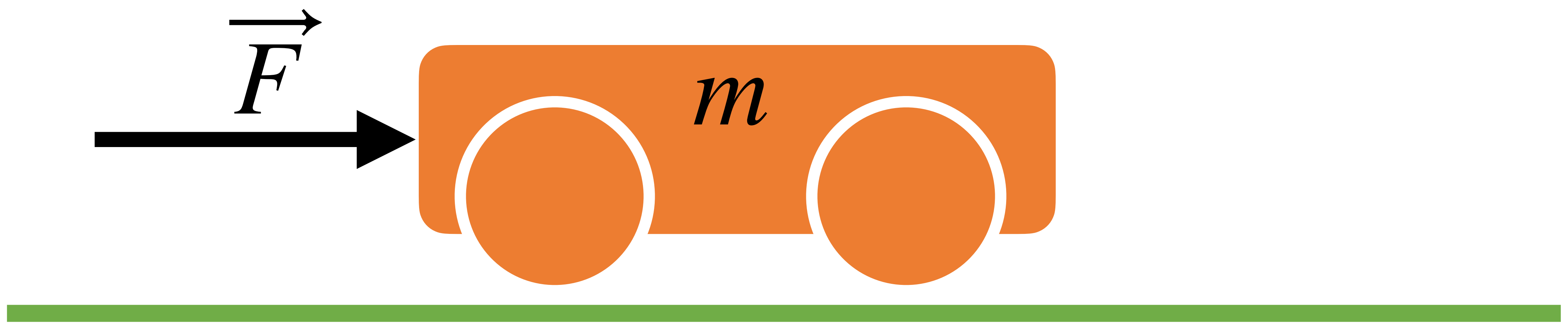

Classical Mechanics
• **Larger** than an atom
• Much **slower** than light
• **Lighter** than black holes & neutron stars
Heavier/denser: black holes & neutron stars
General Relativity
Faster: Comparable to speed of light $3 \times 10^8 \mathrm{m/s}$
Special Relativity
Small: Near or less than $10^{-9}\mathrm{m}$
Quantum Mechanics

AROUND THE BEND

A car takes a bend at a speed of 80 km/h, which it maintains throughout the bend. Is a nonzero total force applied to the car while it drives through the bend? (total force is sum of all external forces $\vec{F}_{\text{tot}} = \sum \vec{F}_{\text{ext}}$

- Yes, it turns — 0%
- No, its speed is constant — 0%
- It depends on whether the bend is tight — 0%

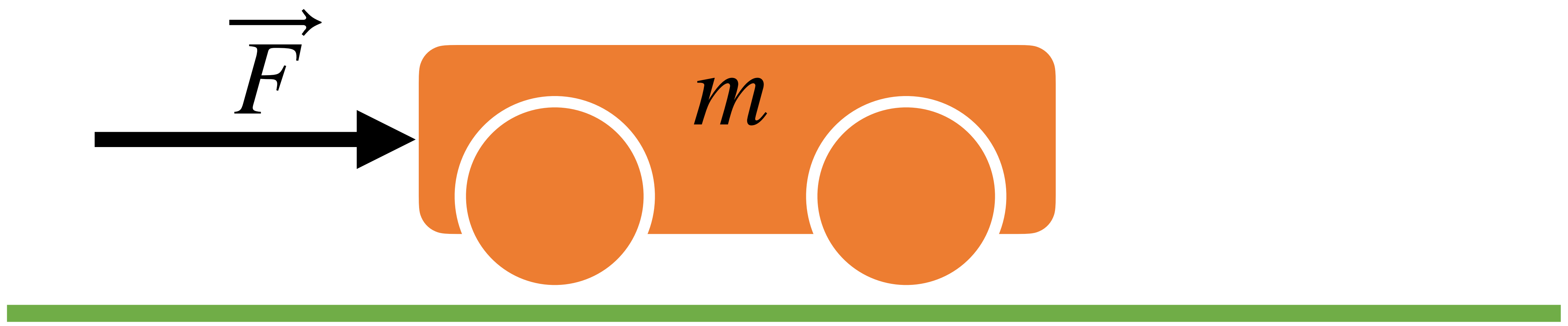
TROLLEY PROBLEM #1



A constant force is exerted on a trolley with mass m, initially at rest, which moves without friction on a track. The force acting during Δt gives the trolley a final velocity $\vec{v}$. To reach the same final velocity with a force half as strong, it would take a time:

- 4 times longer: $4\Delta t$ — 0%
- 2 times longer: $2\Delta t$ — 0%
- identical: Δt — 0%
- 2 times shorter: $\Delta t/2$ — 0%
- 4 times shorter: $\Delta t/4$ — 0%

TROLLEY PROBLEM #2



A constant force is exerted on a trolley with mass m, initially at rest, which moves without friction on a track. The force acting during Δt gives the trolley a final velocity $\vec{v}$. Using the same force for the same time on a chariot with mass $2m$ would give a final velocity:

- 4 times larger: $4\vec{v}$ 0%
- 2 times larger: $2\vec{v}$ 0%
- identical: $\vec{v}$ 0%
- 2 times smaller: $0.5\vec{v}$ 0%
- 4 times smaller: $0.25\vec{v}$ 0%

LOCOMOTIVE

A locomotive pulls a series of cars and accelerates from rest. What is the correct analysis of the situation?

- A: The train accelerates because the locomotive pulls harder on the cars than the cars pull the locomotive.
- B: Because of the principle of action and reaction, the locomotive cannot pull the cars. The force exerted on the cars by the locomotive has the same magnitude as the force exerted by the locomotive on the cars. Nothing moves.
- C: The locomotive sets the cars in motion by exerting a momentary jerk, during which the force of the locomotive on the cars is greater than the force of the cars on the locomotive.
- D: The force of the locomotive on the cars has the same magnitude as the force of the cars on the locomotive, but the external force is greater and moves the whole system forward
- E: The locomotive can only pull the cars if it is heavier than them.

FICTITIOUS FORCES

$$\overrightarrow{\omega} = \text{constant}$$

$$m\vec{a}_{\mathscr{R}'}(P) = \sum \overrightarrow{F}_{ext} - m[\vec{a}_{\mathscr{R}}(A) + \overrightarrow{\omega} \wedge (\overrightarrow{\omega} \wedge \overrightarrow{AP}) + 2\overrightarrow{\omega} \wedge \vec{v}_{\mathscr{R}'}(P)]$$

FICTITIOUS FORCES

$$\vec{\omega} = \text{constant}$$

$$m\vec{a}_{\mathscr{R}'}(P) = \sum \vec{F}_{ext} - m[\vec{a}_{\mathscr{R}}(A) + \vec{\omega} \wedge (\vec{\omega} \wedge \overrightarrow{AP}) + 2\vec{\omega} \wedge \vec{v}_{\mathscr{R}'}(P)]$$

Transport force: $\vec{a}_{\mathscr{R}}(A) + \vec{\omega} \wedge (\vec{\omega} \wedge \overrightarrow{AP})$

Centrifugal force: $\vec{\omega} \wedge (\vec{\omega} \wedge \overrightarrow{AP})$

Coriolis force: $2\vec{\omega} \wedge \vec{v}_{\mathscr{R}'}(P)$

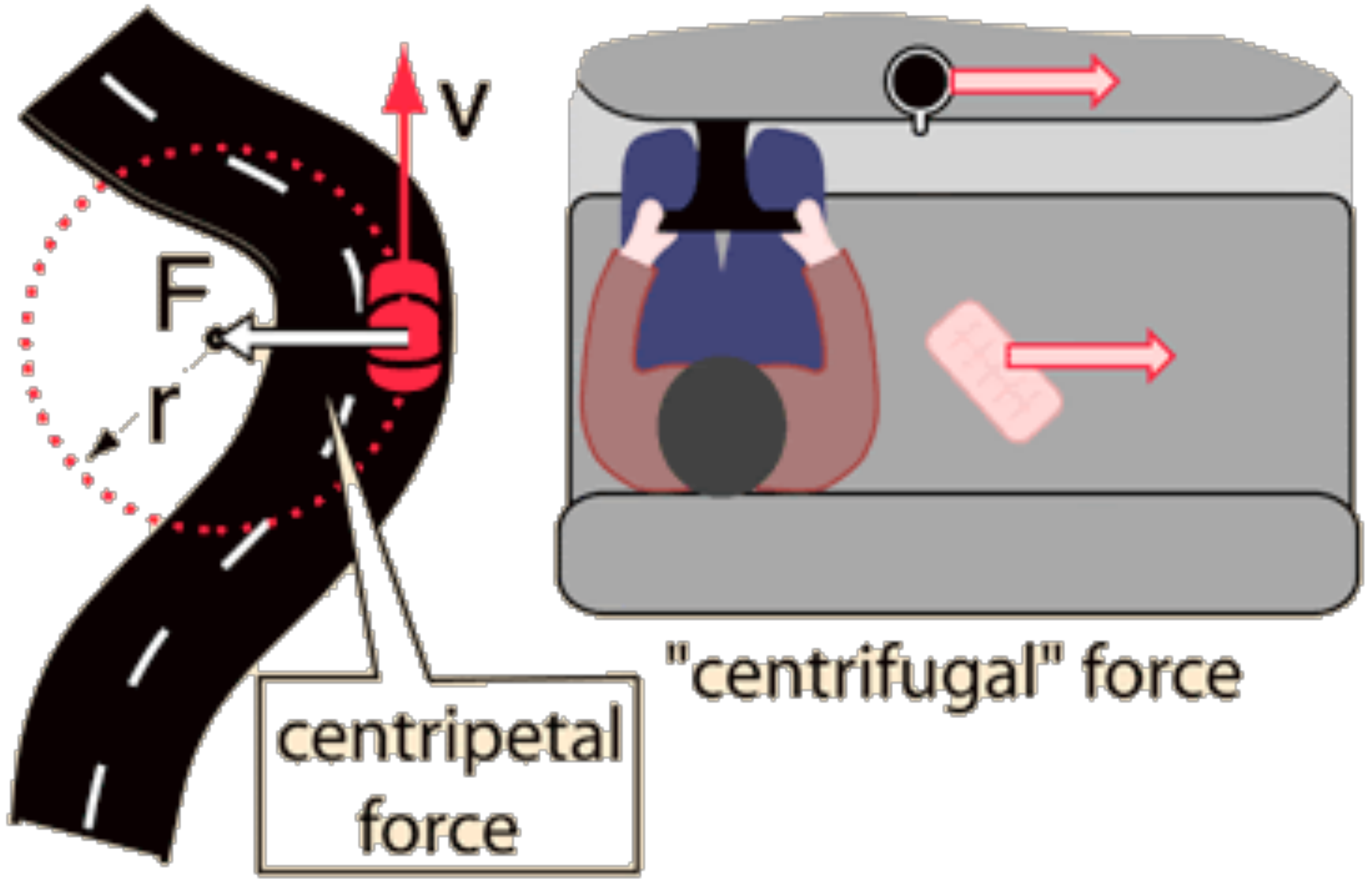
FICTITIOUS FORCES

$$\vec{\omega} = \text{constant}$$

$$m\vec{a}_{\mathscr{R}'}(P) = \sum \vec{F}_{ext} - m[\vec{a}_{\mathscr{R}}(A) + \vec{\omega} \wedge (\vec{\omega} \wedge \overrightarrow{AP}) + 2\vec{\omega} \wedge \vec{v}_{\mathscr{R}'}(P)]$$

Transport forces — Centrifugal force — Coriolis force

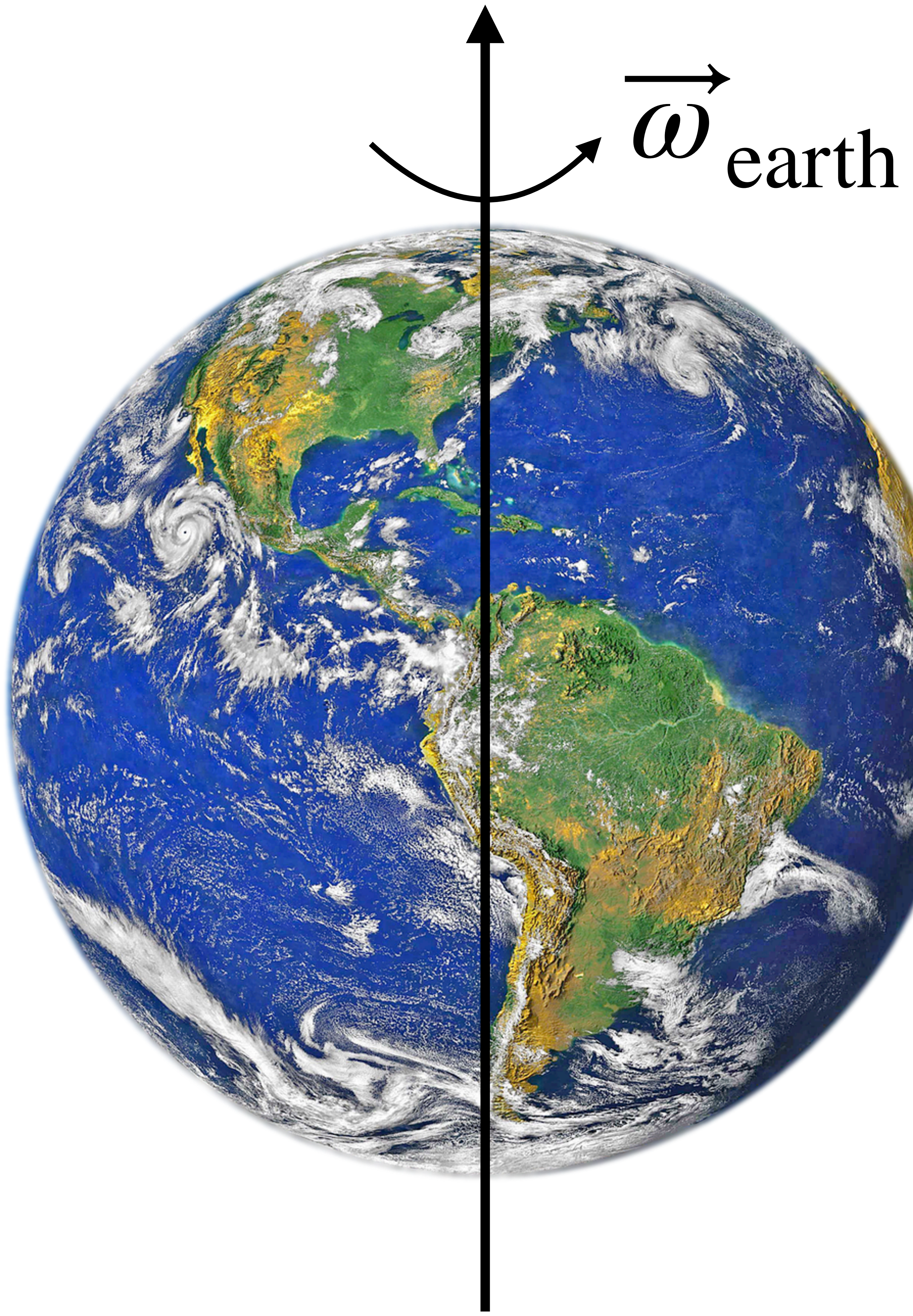
Not to be confused with the **centripetal force**, which is not fictitious!



FICTITIOUS FORCES

$$\vec{\omega} = \text{constant}$$

$$m\vec{a}_{\mathscr{R}'}(P) = \sum \vec{F}_{ext} - m[\vec{a}_{\mathscr{R}}(A) + \vec{\omega} \wedge (\vec{\omega} \wedge \overrightarrow{AP}) + 2\vec{\omega} \wedge \vec{v}_{\mathscr{R}'}(P)]$$

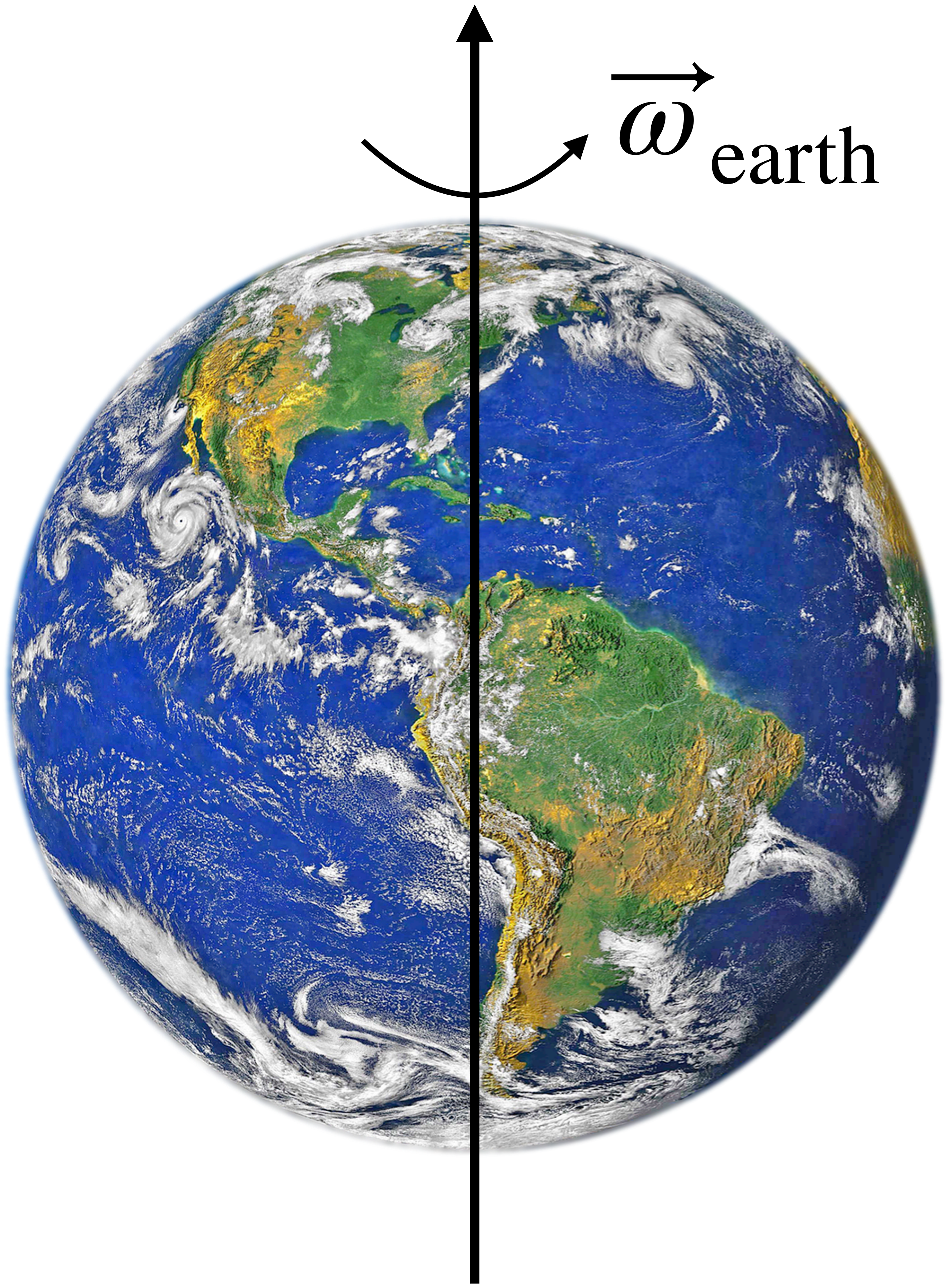


$$|\vec{\omega}_{\text{earth}}| = \frac{2\pi}{24 \text{ hours}} = \approx 7 \times 10^{-5}\text{s}^{-1}$$

FICTITIOUS FORCES

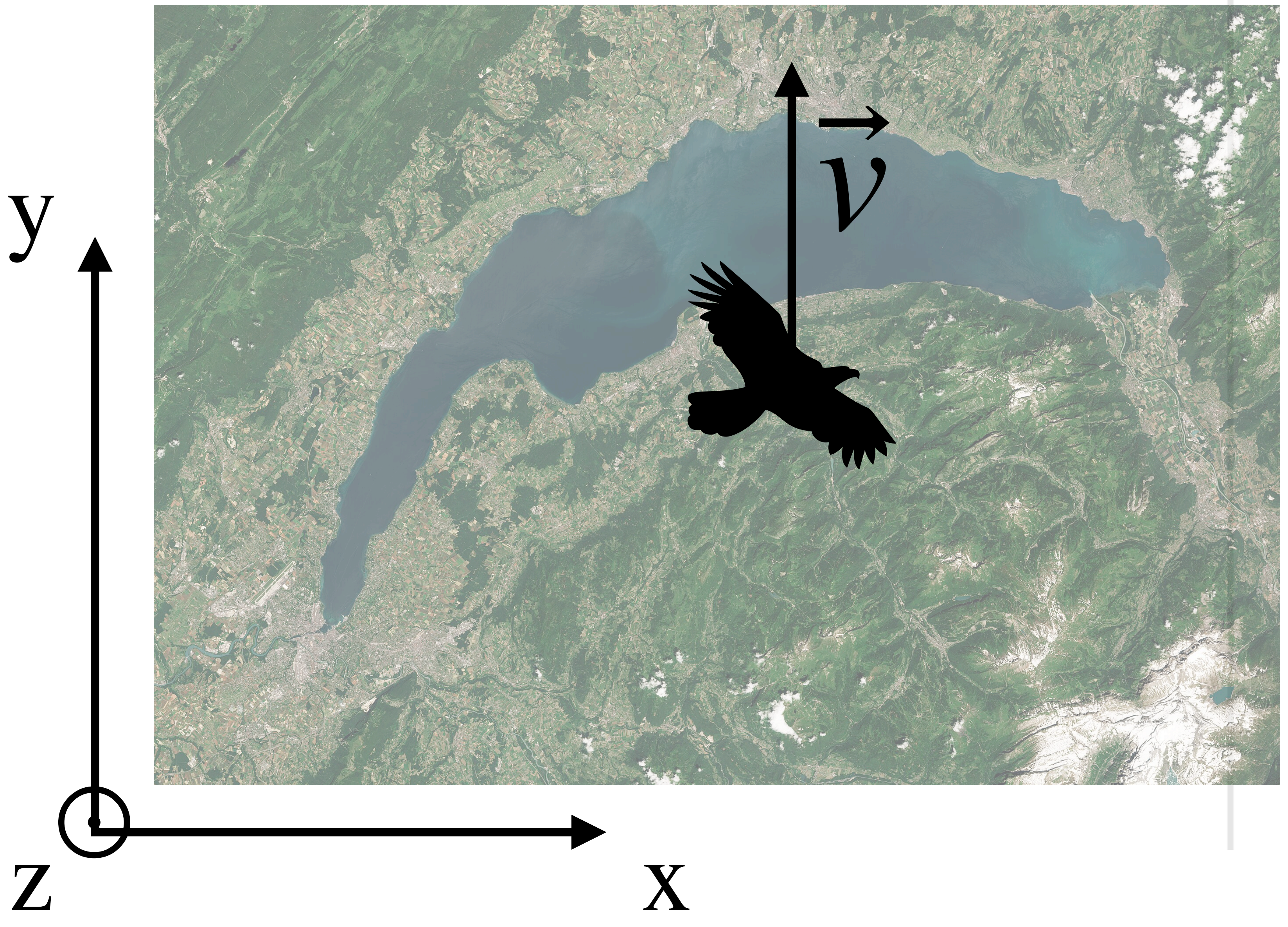
$$\overrightarrow{\omega} = \text{constant}$$

$$m\vec{a}_{\mathscr{R}'}(P) \approx \sum \overrightarrow{F}_{ext} - 2m\overrightarrow{\omega} \wedge \vec{v}_{\mathscr{R}'}(P)$$



$$|\overrightarrow{\omega}_{\text{earth}}| = \frac{2\pi}{24 \text{ hours}} = \approx 7 \times 10^{-5}\text{s}^{-1}$$

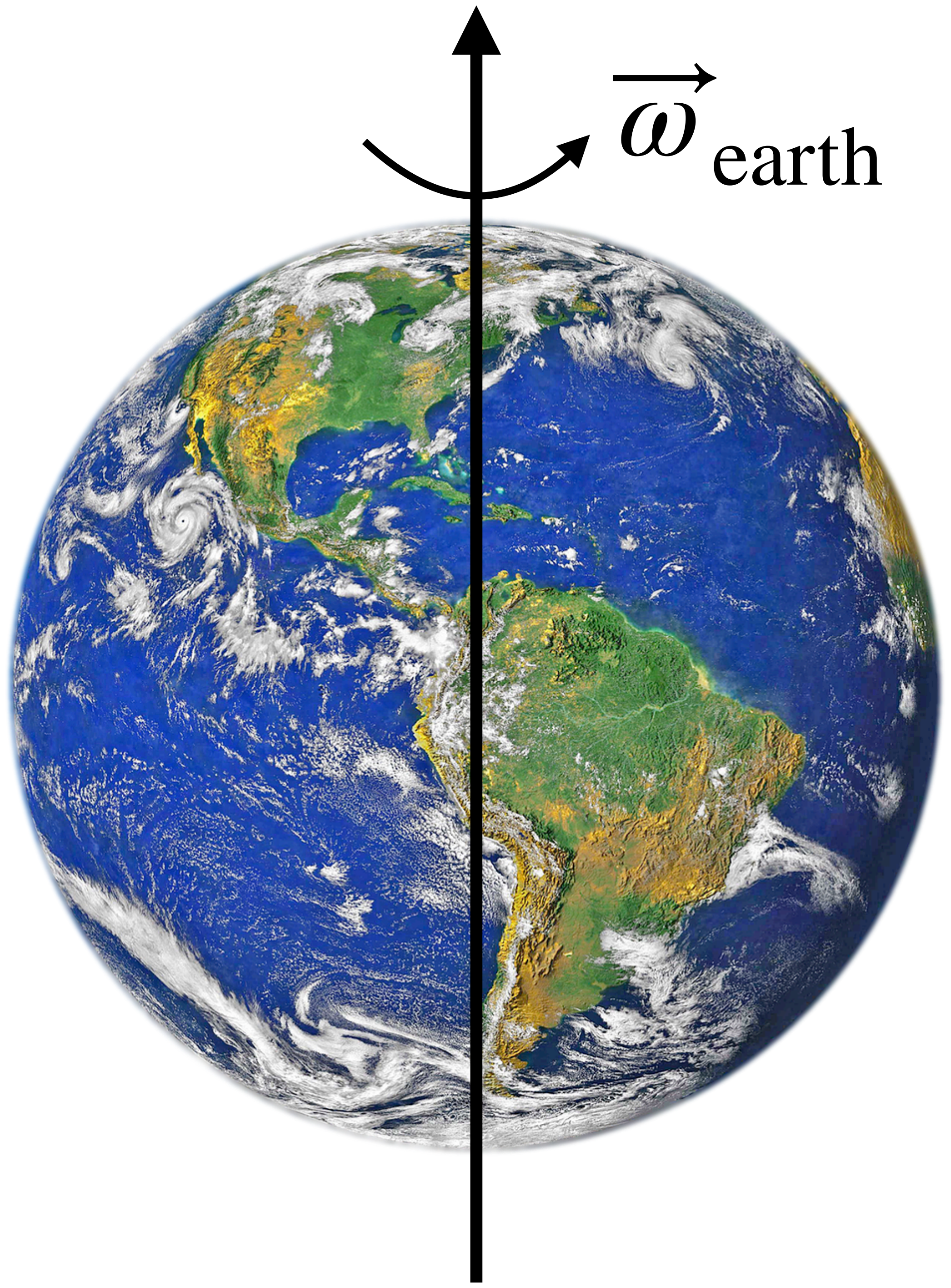
CORIOLIS FORCE



A bird is flying north across Lac Leman, keeping a constant altitude above the lake. In a reference frame using west-east as the x, north-south as the y-axis, and the vertical as the z-axis, which expression is correct for the direction of the Coriolis Force due to the rotation of the Earth, $\vec{F}_{\text{cor}}$? We define $F = |\vec{F}_{\text{cor}}|$ The bird's velocity is $\vec{v} = v\vec{e}_y$

- A: $\vec{F}_{\text{cor}} = F\vec{e}_x$
- B: $\vec{F}_{\text{cor}} = -F\vec{e}_x$
- C: $\vec{F}_{\text{cor}} = \vec{0}$
- D: $\vec{F}_{\text{cor}} = F\vec{e}_z$
- E: $\vec{F}_{\text{cor}} = -F\vec{e}_z$

CORIOLIS FORCE



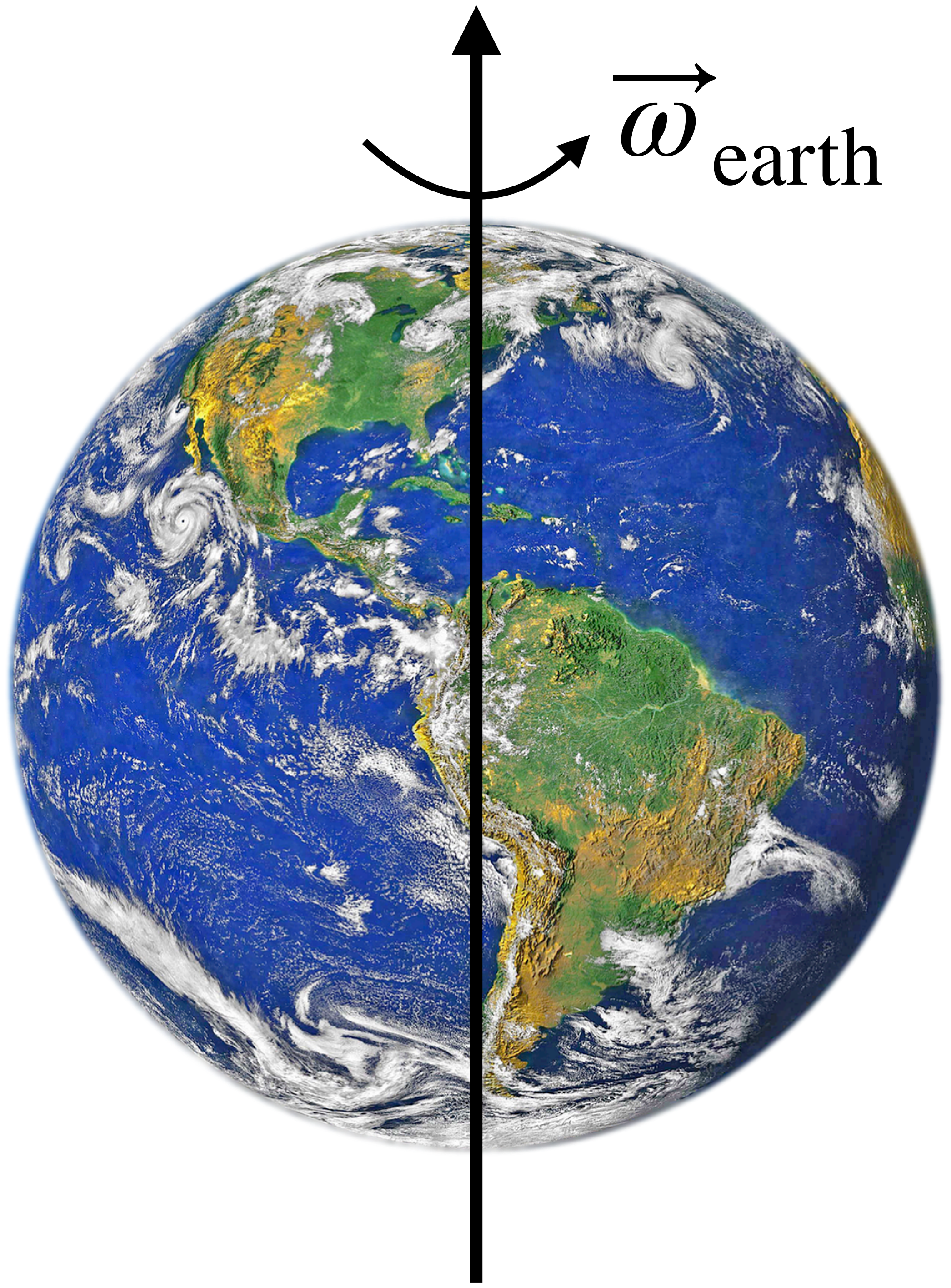
$$\omega_{\text{earth}} = 7 \times 10^{-5}\text{s}^{-1}$$

$$\vec{F}_{\text{cor}} = -2m\vec{\omega} \wedge \vec{v}_{\mathscr{R}'}(P)$$

$$\vec{F}_g = m\vec{g}, \quad g \approx 10 \text{ m/s}^2$$

Under what conditions will the magnitudes of these forces be be similar?

CORIOLIS FORCE



$$\omega_{\text{earth}} = 7 \times 10^{-5} \text{s}^{-1}$$

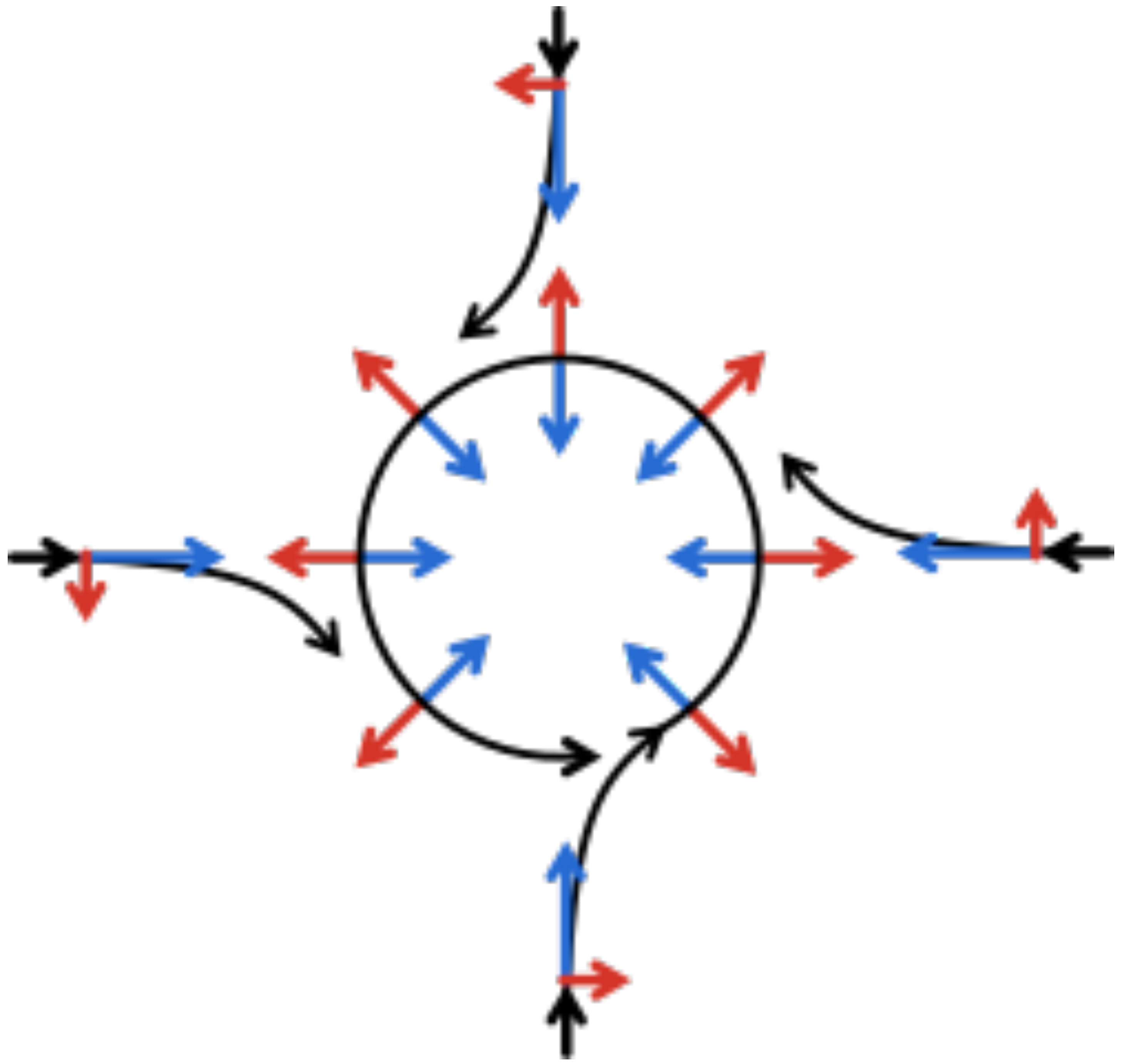
$$\vec{F}_{\text{cor}} = -\,2m\vec{\omega} \wedge \vec{v}_{\mathscr{R}'}(P) \qquad \vec{F}_g = m\vec{g}, \quad g \approx 10 \text{ m/s}^2$$

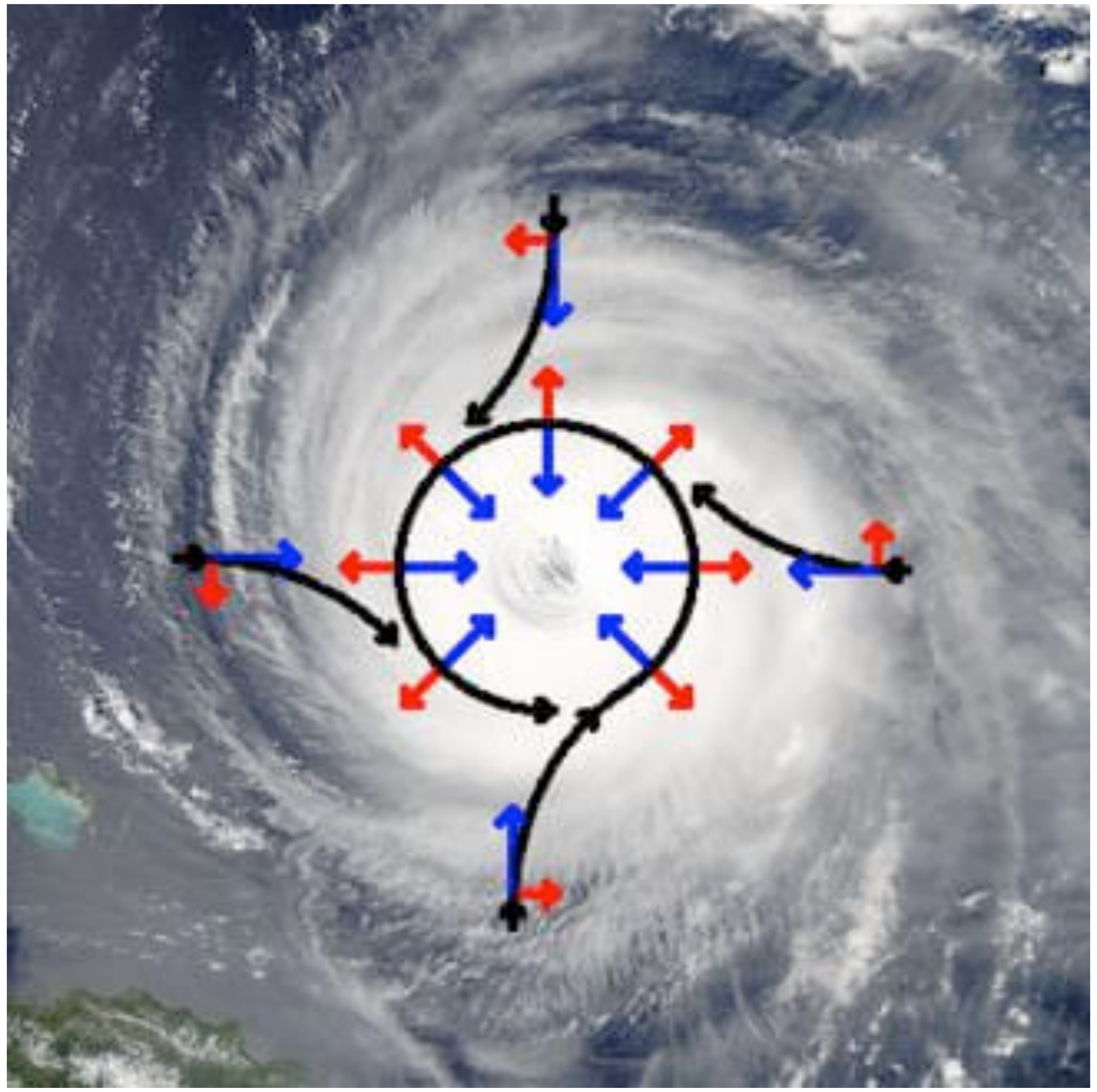
$$a_{\text{cor}} = |\,\vec{F}_{\text{cor}}|/m = 2\ \omega\ v_{\mathscr{R}'}(P)\ \sin\theta$$

$$\text{for}\ \sin\theta = 1, \quad v_{\mathscr{R}'}(P) = 70{,}000 \text{ m/s}$$

$$a_{\text{cor}} \approx g \approx 10 \text{ m/s}^2$$

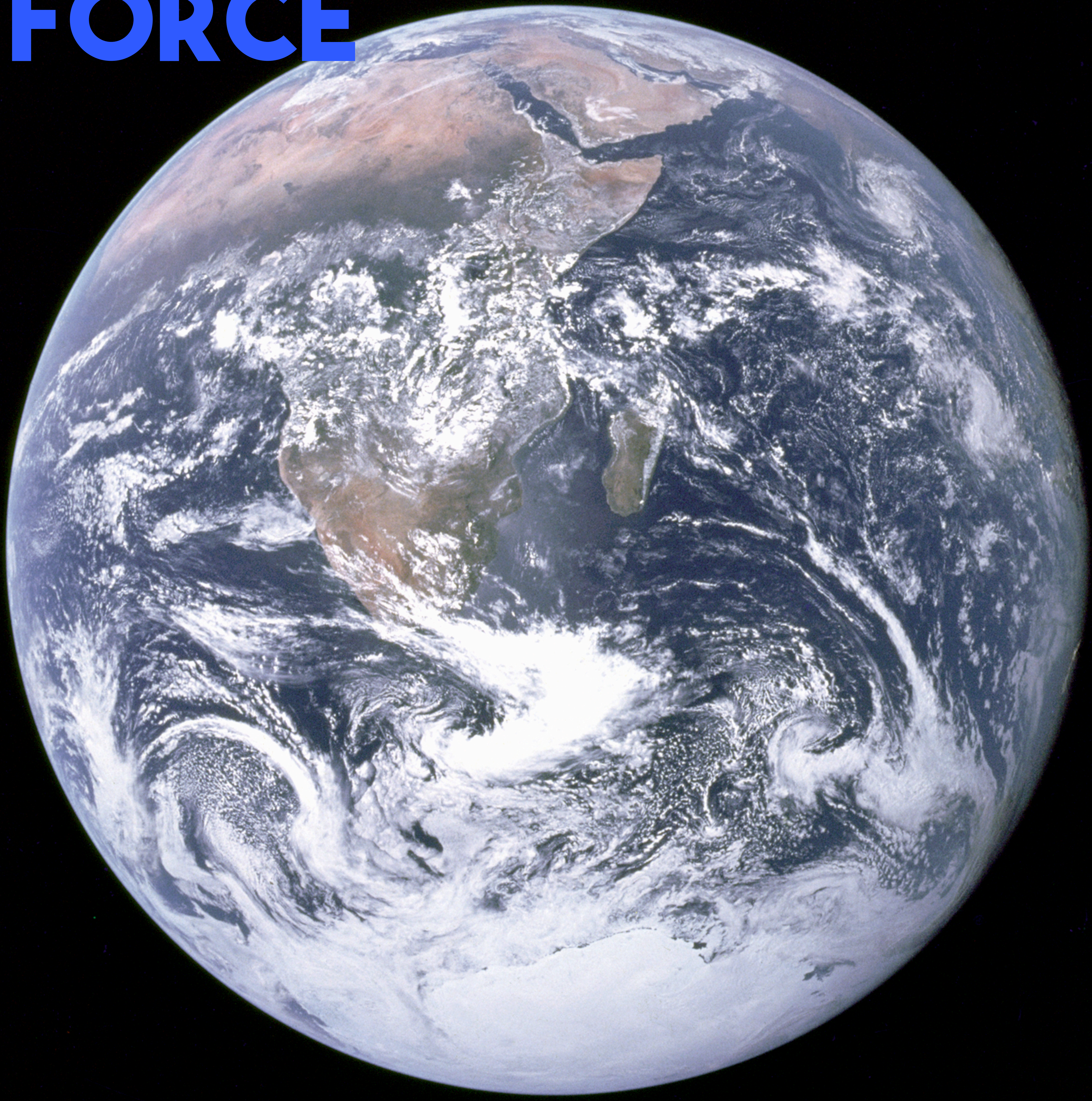
CORIOLIS FORCE





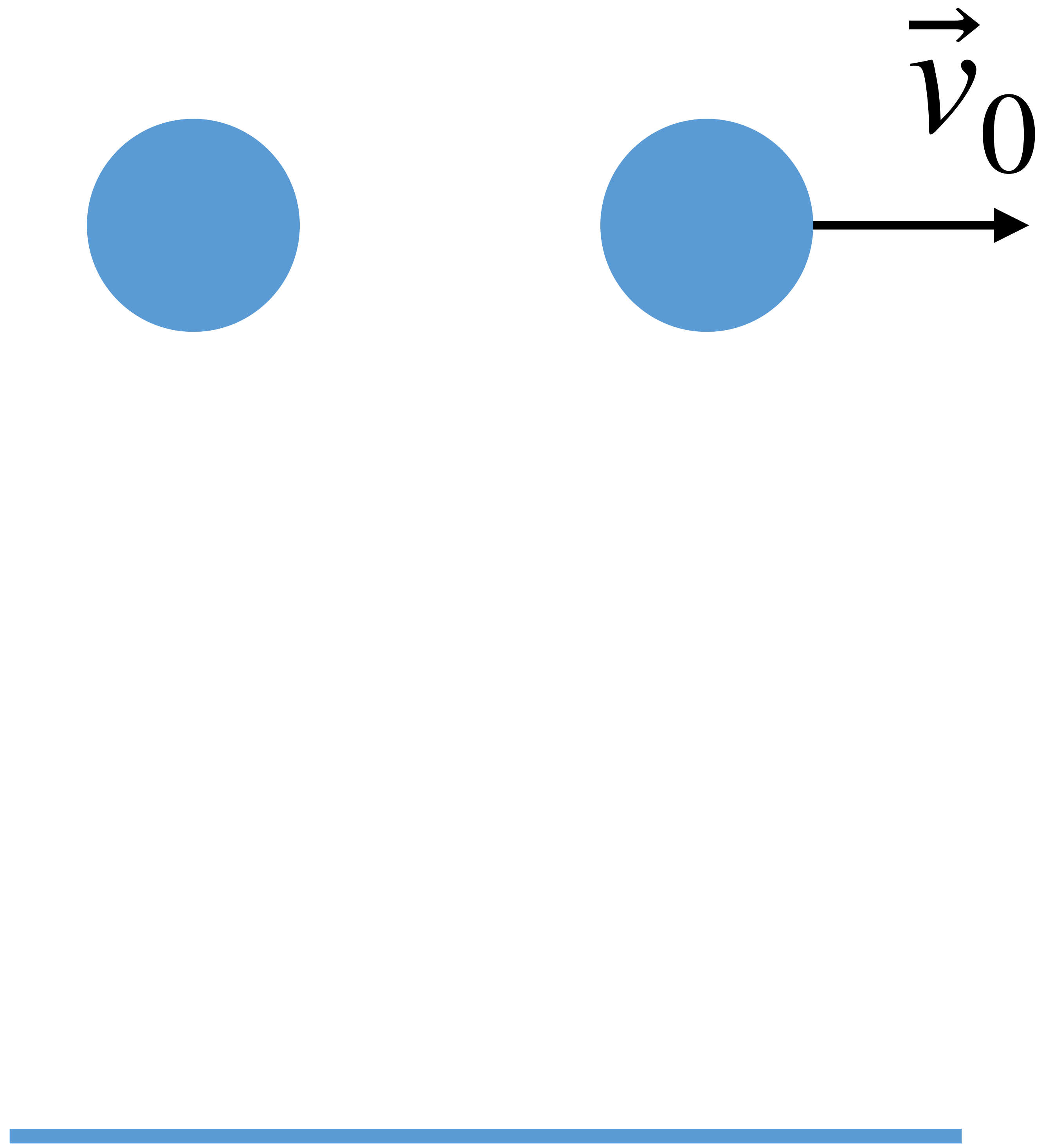
CORIOLIS FORCE

CORIOLIS FORCE



BALLISTICS

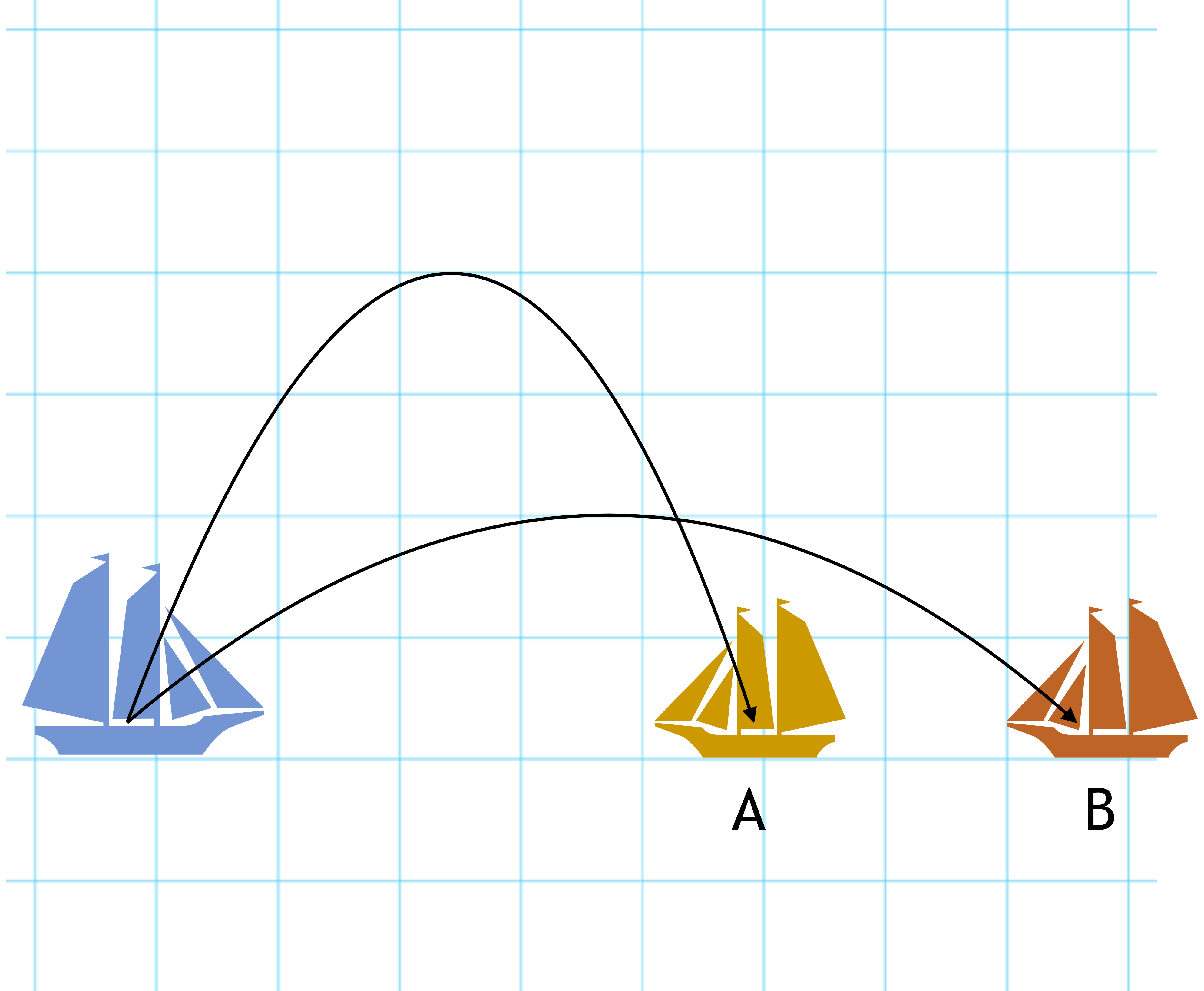
FALL TIME



Which marble will hit the ground first?

- The one that is thrown horizontally — 0%
- The one that is released without initial velocity — 0%
- They will land at the same time — 0%

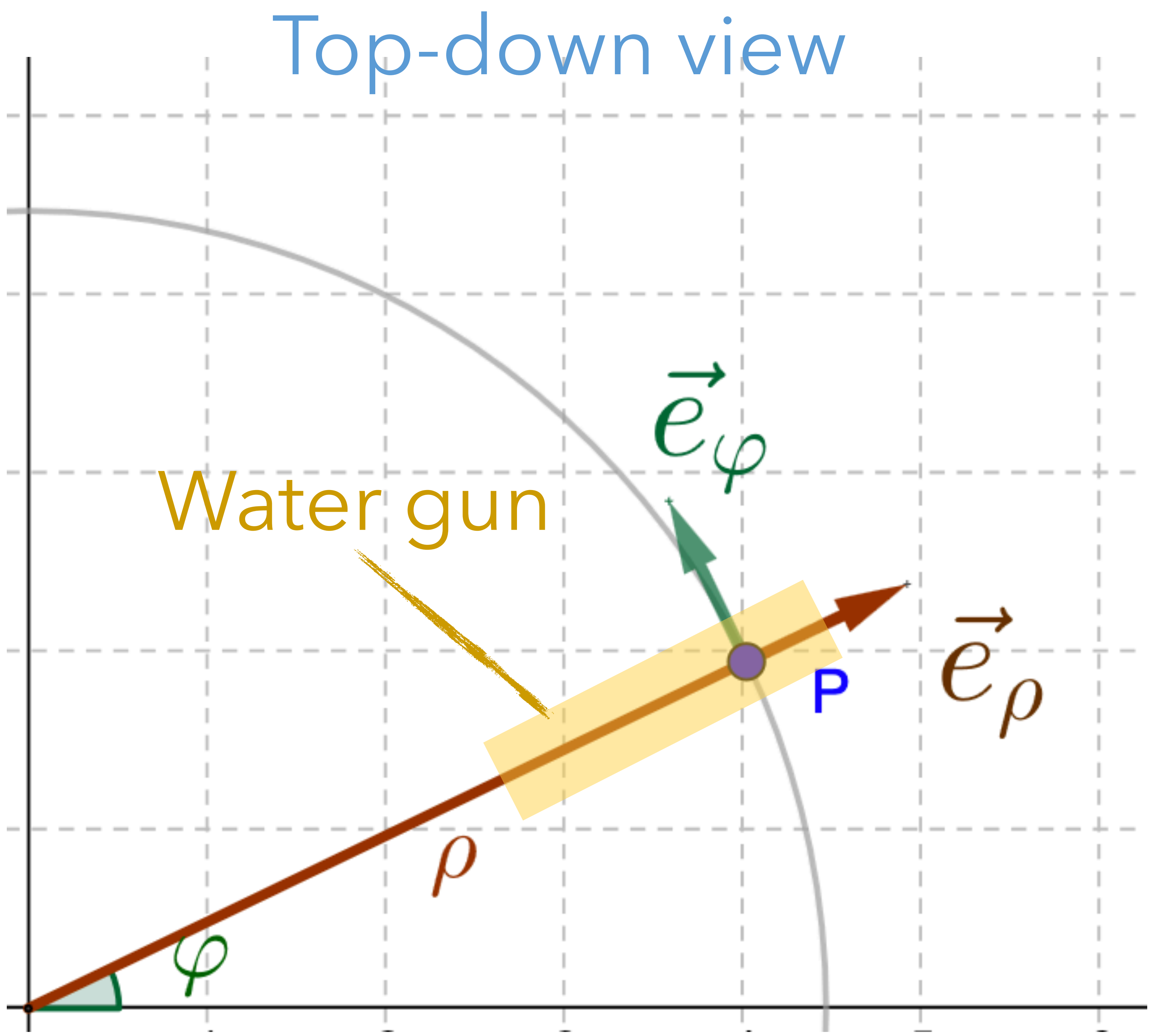
BATTLESHIPS



A warship fires two cannonballs at the same time from two different cannons, at two boats A and B. Which boat is hit first?

- Boat A 0%
- Boat B 0%
- Both at the same time 0%

WATER GUNS



Two students are having a summer water pistol fight. Anne holds her pistol horizontally, which shoots water out at a certain speed v_0. At the same time, she makes horizontal back-and-forth movements between $\phi = 0$ and $\phi = \phi_m$. What is the correct representation of the trajectory of the water drop that comes out of the gun *exactly* when it is at angle ϕ_m ...?

- A parabola in the direction of $\vec{e}_\rho$ 0%
- The drop falls straight down 0%
- A parabola in the direction of $\vec{e}_\phi$ 0%
- A parabola in between $\vec{e}_\phi$ and $\vec{e}_\rho$ 0%

EXERCISE

James Bond escapes from a hovering helicopter. He falls vertically in freefall, without friction. His friend must save him with her motorcycle. She starts from a ramp pointing towards James Bond, who is hanging from the helicopter. She leaves the ramp at a speed of v_0, and at the same time, James lets go of the helicopter. Will she be able to save him?