Tuesday, 29 January

brought to you by the letters G R A V I T A T I O N

Stones

(pitchers and catchers report in 15 days)

and

help yourself to the hot chocolate

housekeeping

You're continuing to do great!

housekeeping

You're continuing to do great!

MasteringPhysics

okay?

housekeeping

You're continuing to do great!

MasteringPhysics

okay?

Stay up to date!

I sure hope you're keeping up

It's all here: http://www.chipbrock.org/lectures/

Thursday, January 31

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I don’t want you to walk here in subzero temperatures

No class on Thursday, January 31

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BUT: there are readings! Keep up!

Lessons 10 and 11 for Thursday, Jan 31

They are almost all history

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We’ll meet again next Tuesday

Lesson 12 for next Tuesday, Feb 5

in-class project will be worth 30 points

quiz worth 10 points

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in-class project will be worth 30 points

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It will be okay…Lessons 10, 11, and 12 all hang together

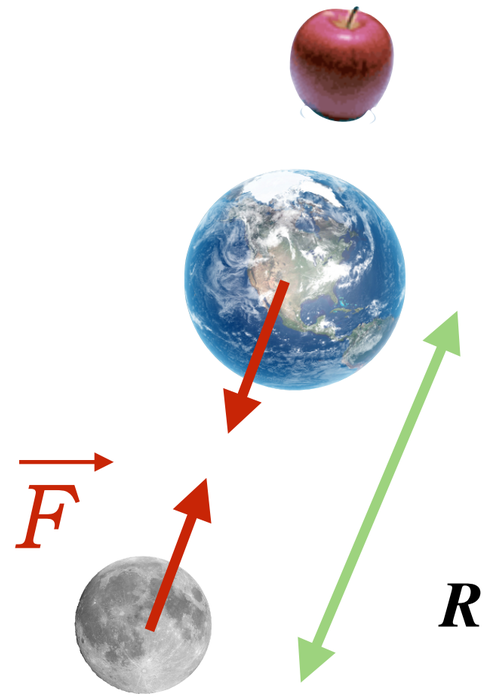
this week:

9. gravitation

10. electric charge and magnetism

this changed everything

One thing: Newton’s Universal law of Gravitation



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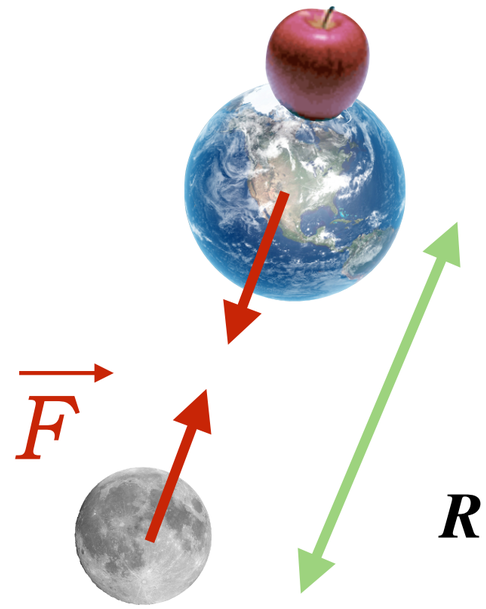

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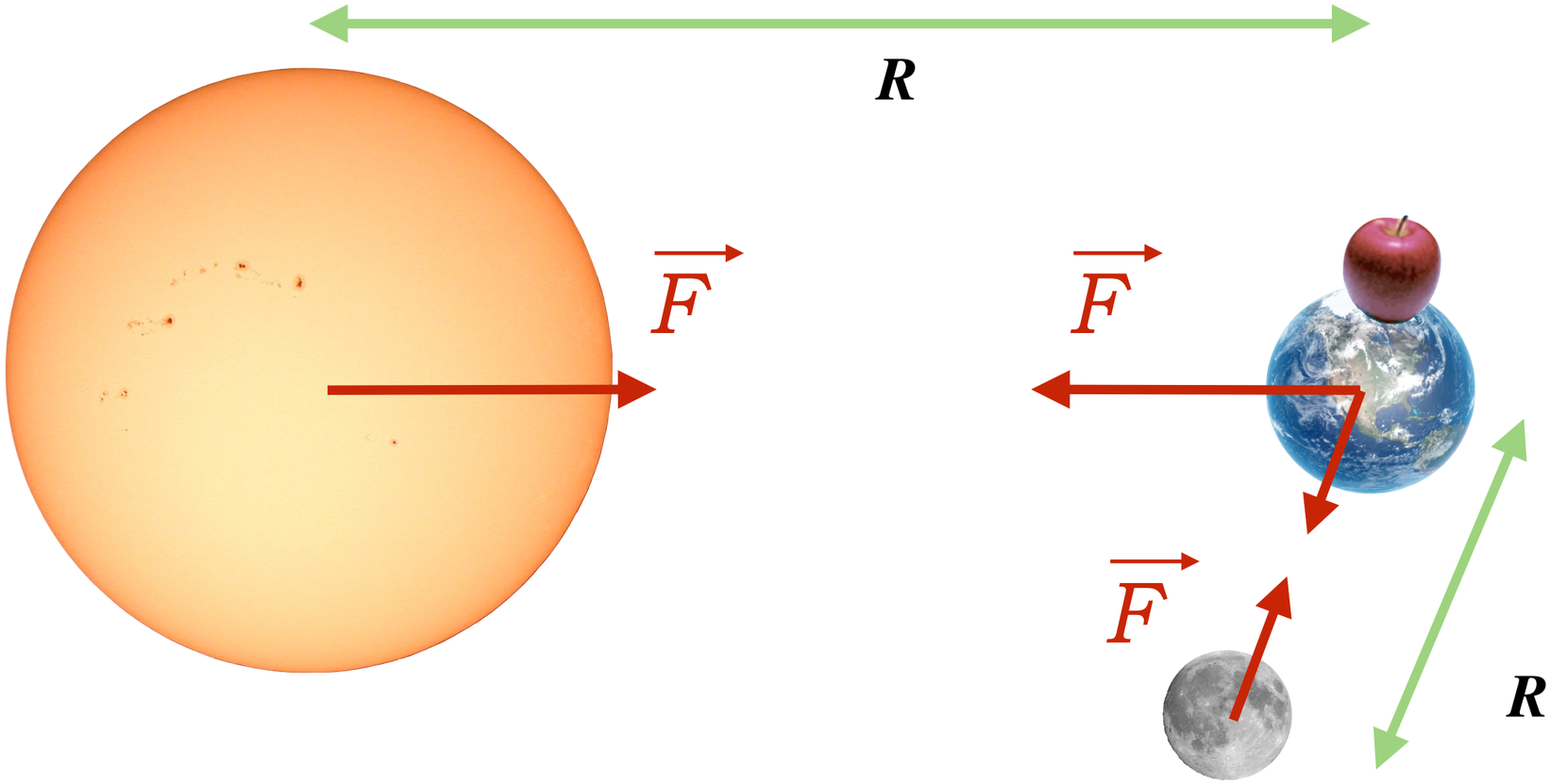

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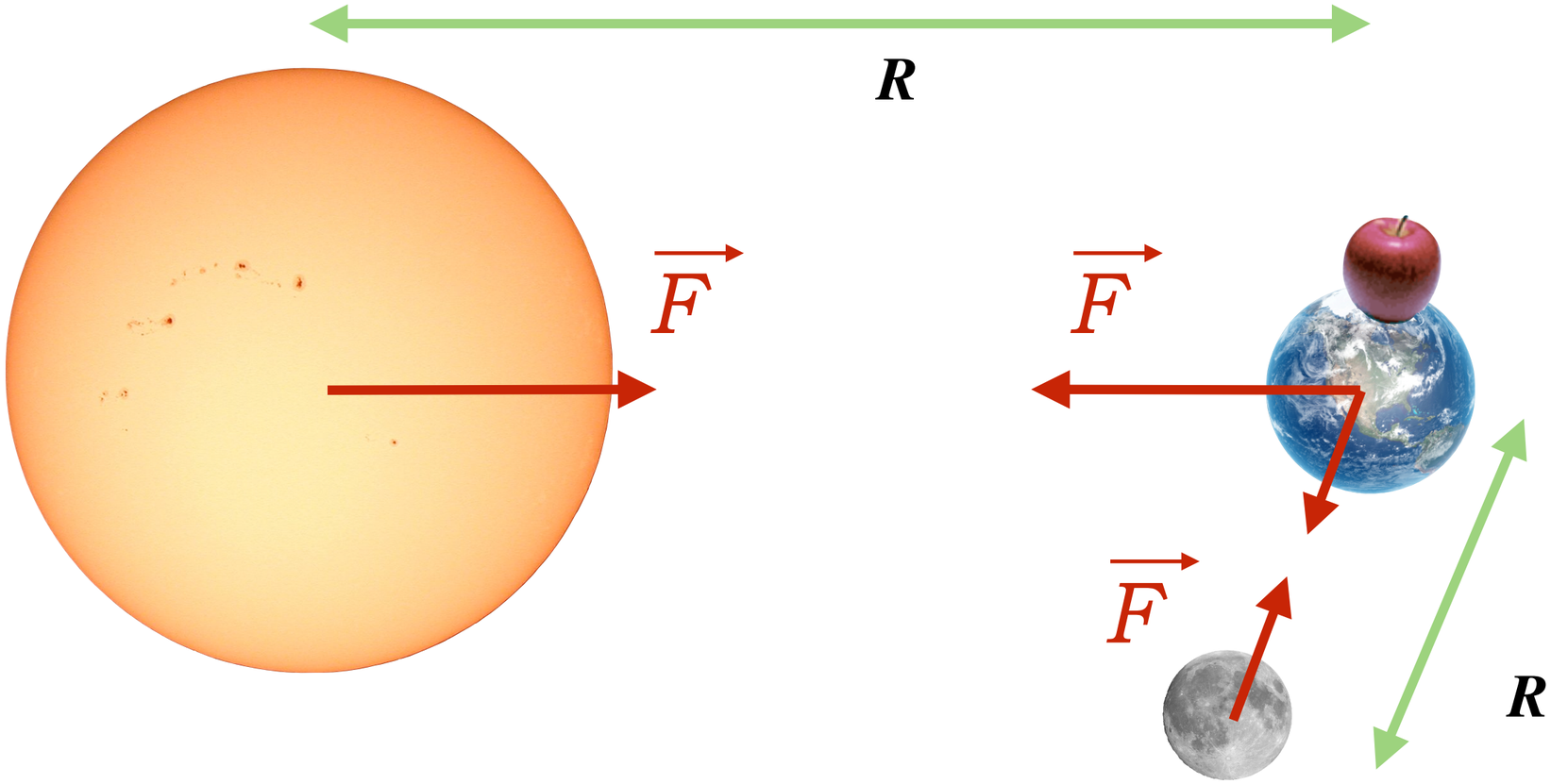

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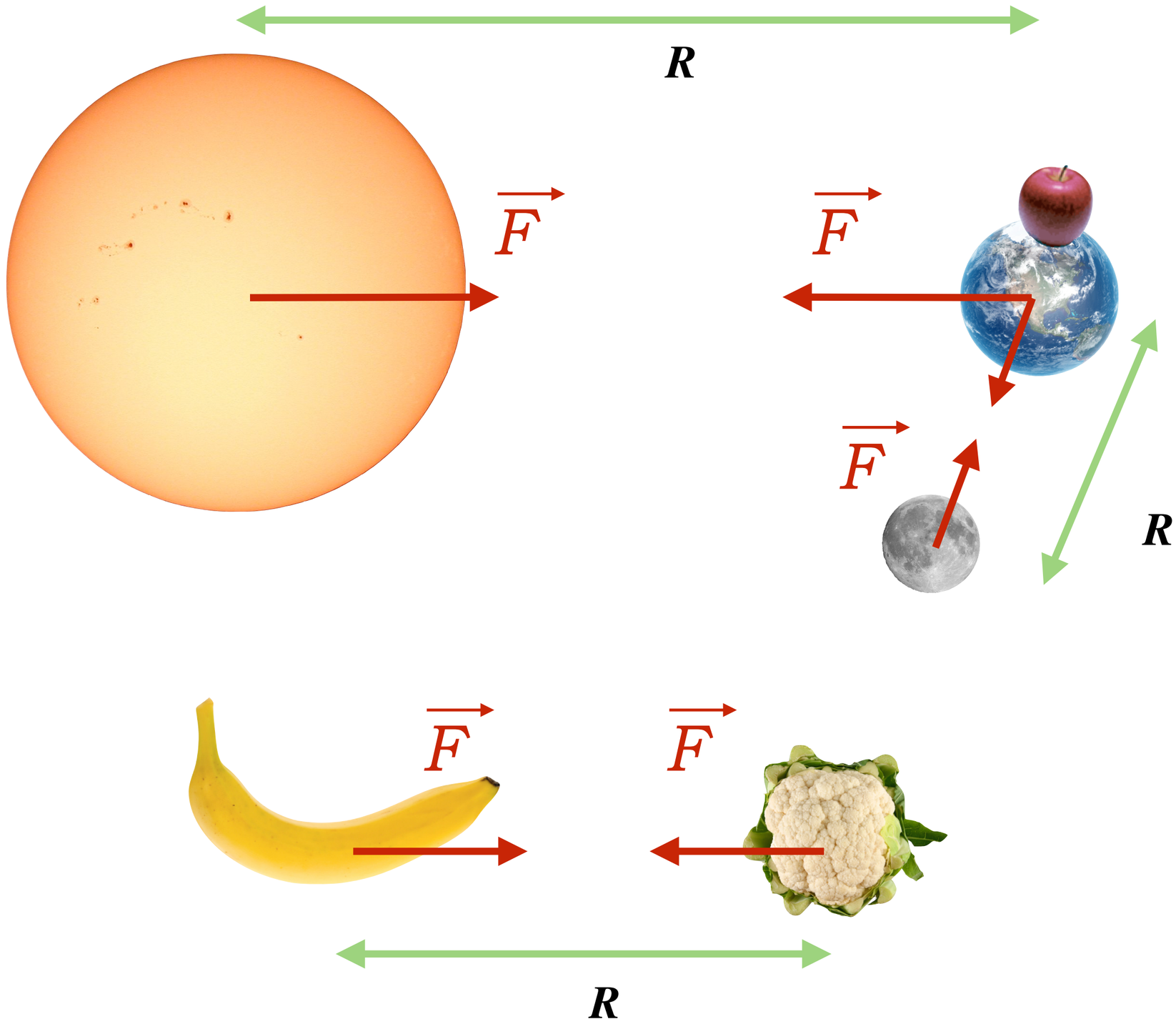

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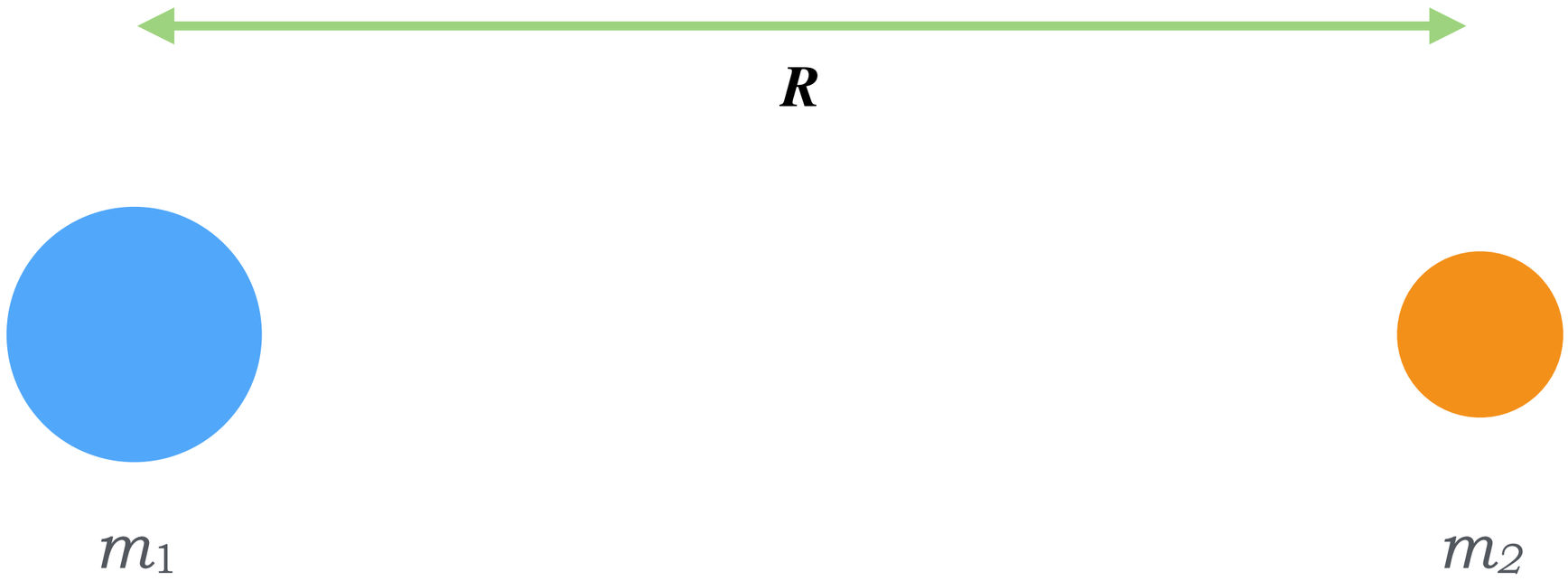

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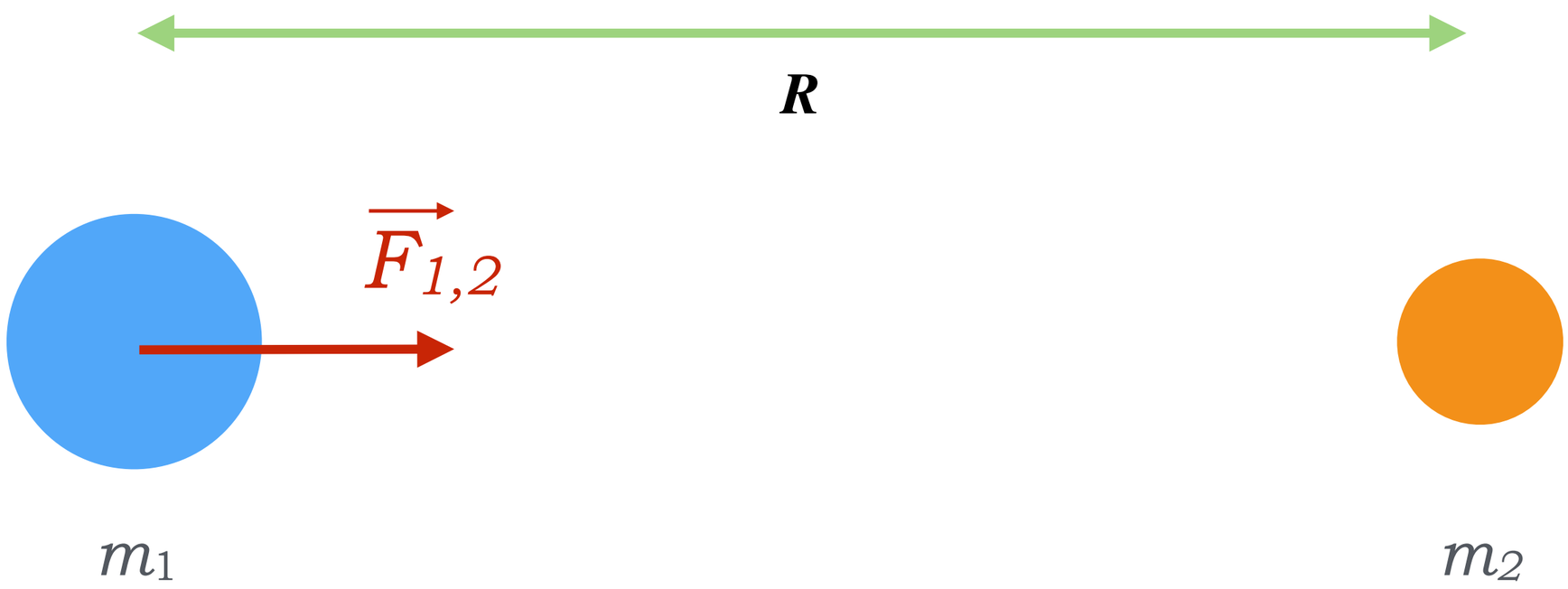

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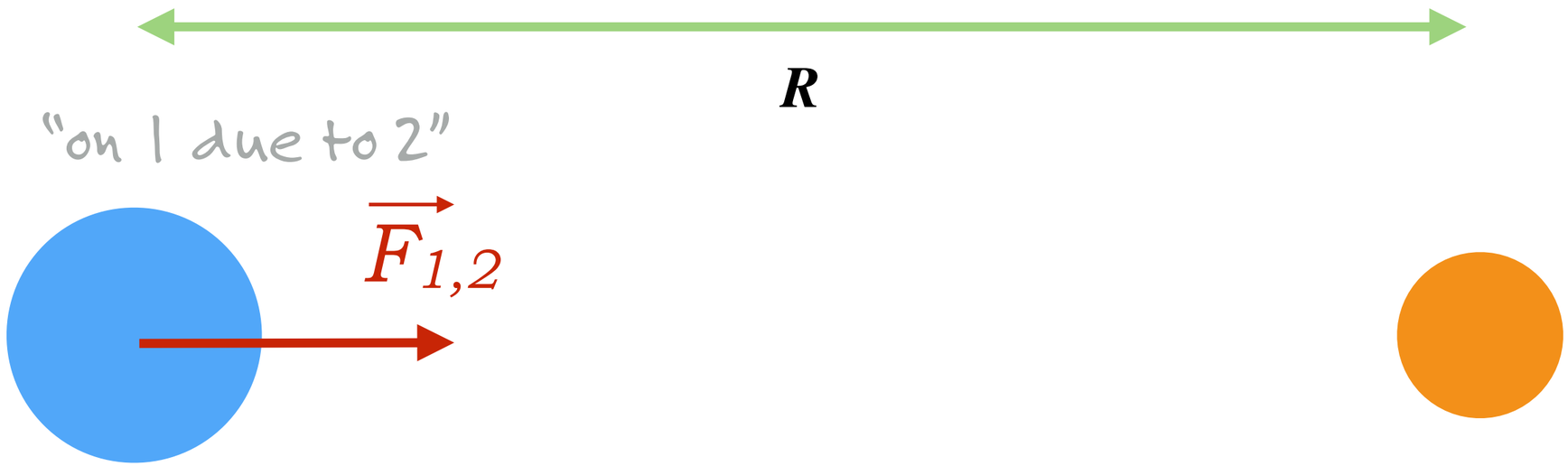

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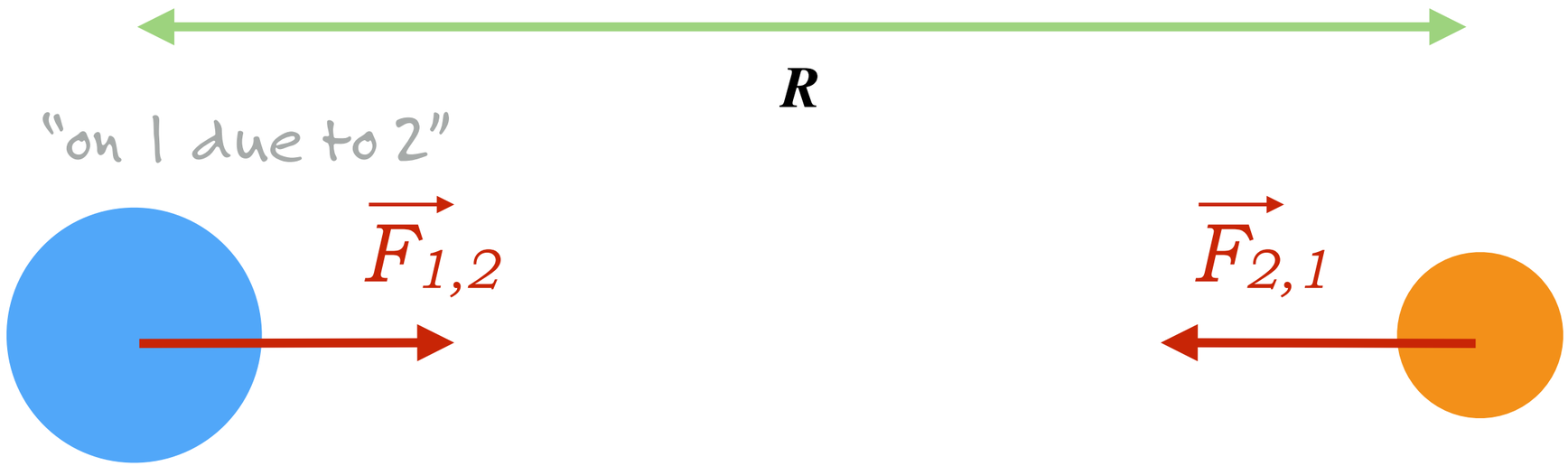

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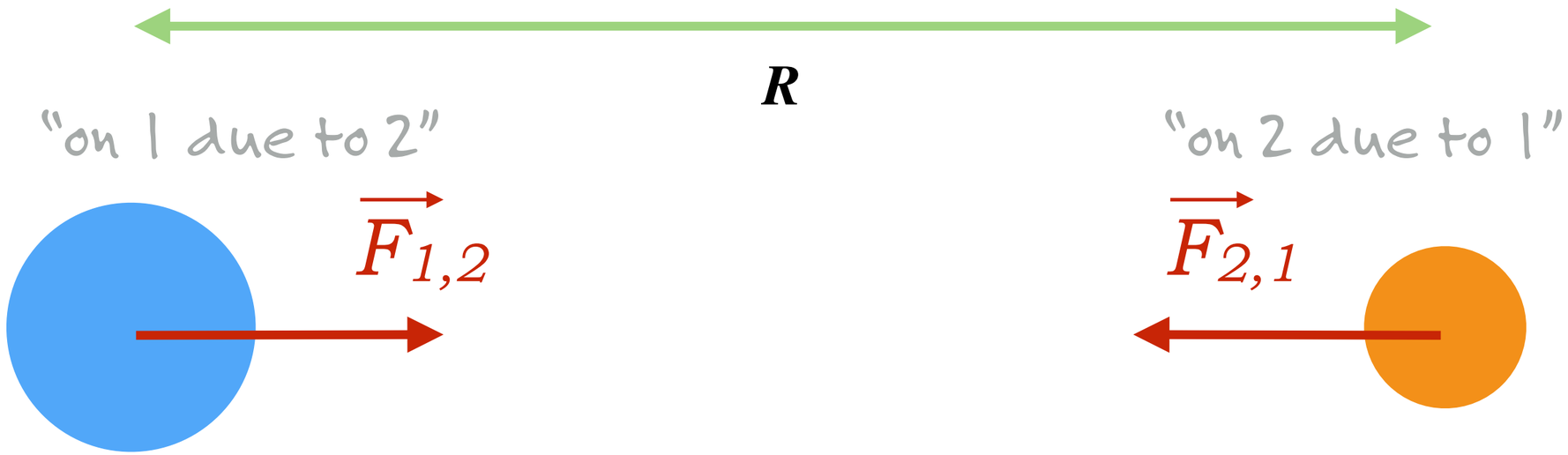

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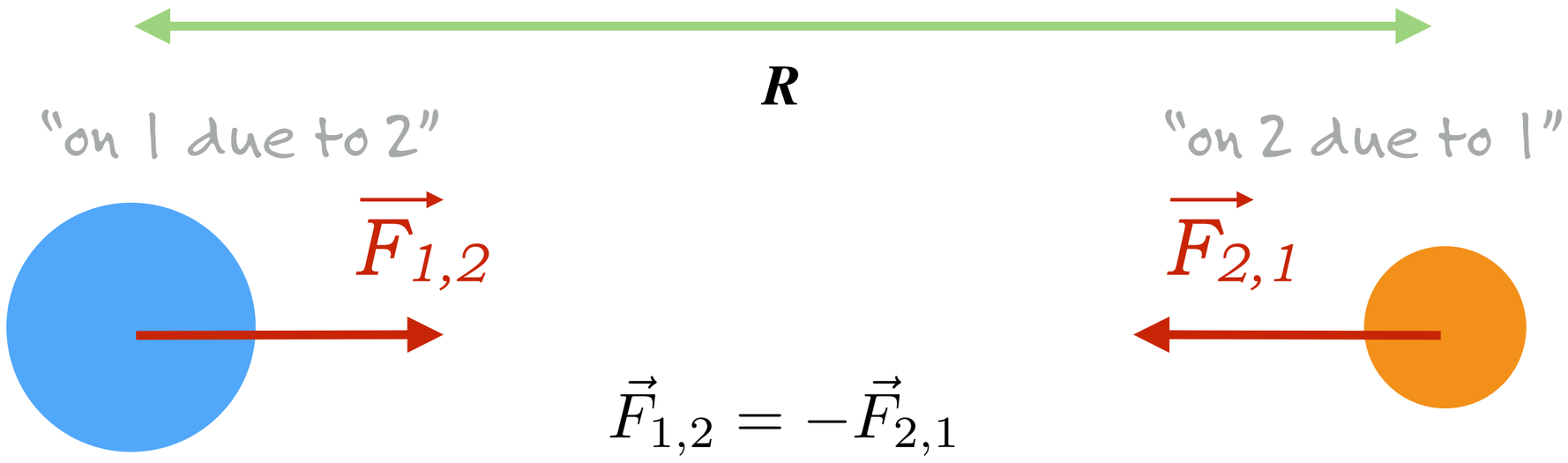

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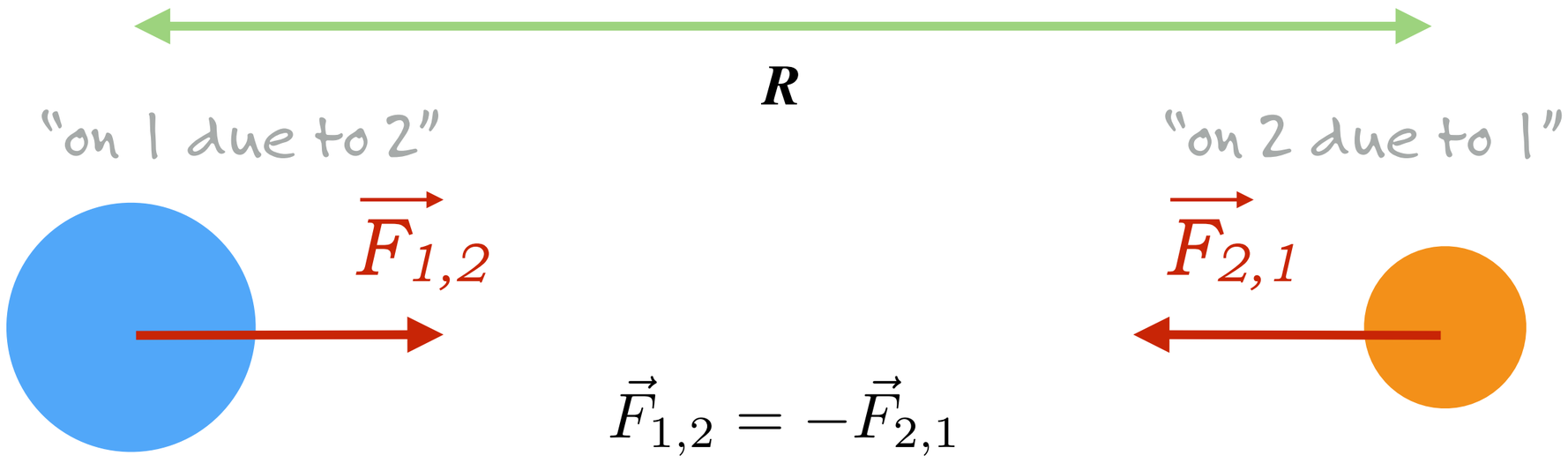

$$\vec{F}_{1,2} = -\vec{F}_{2,1}$$

m_1 m_2

$$|\vec{F}_{1,2}| = |\vec{F}_{2,1}| = F$$

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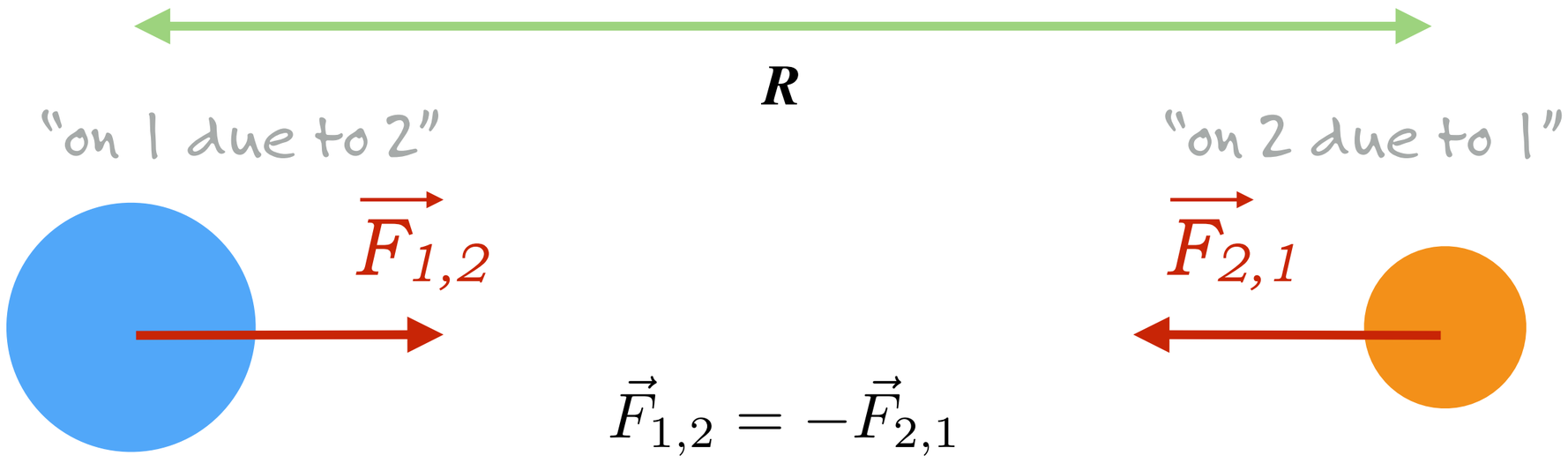

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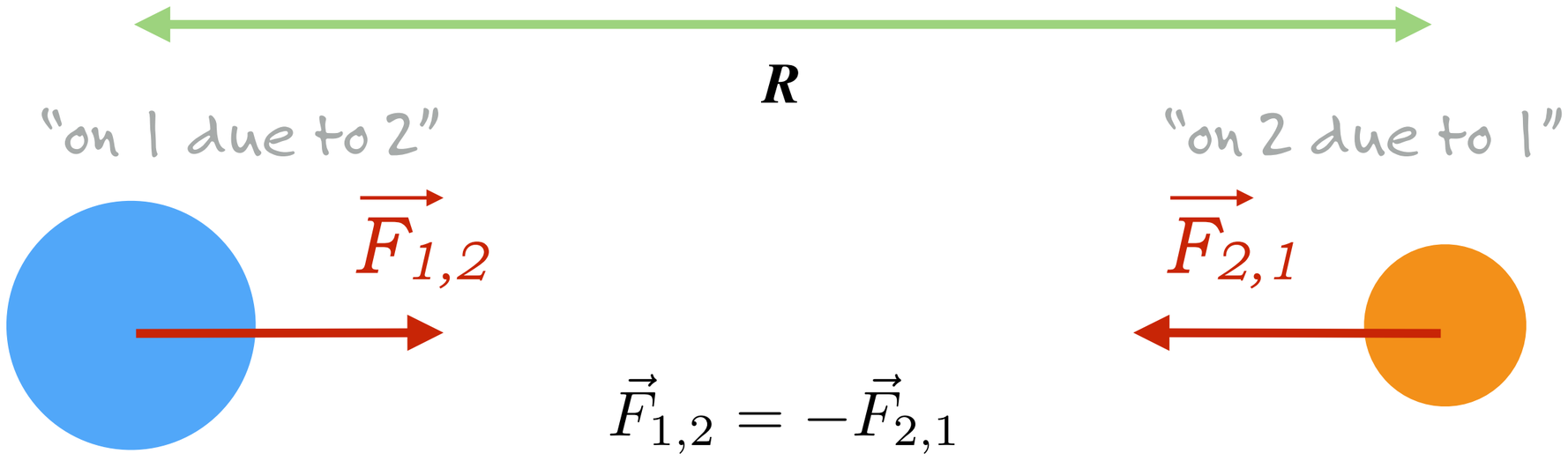

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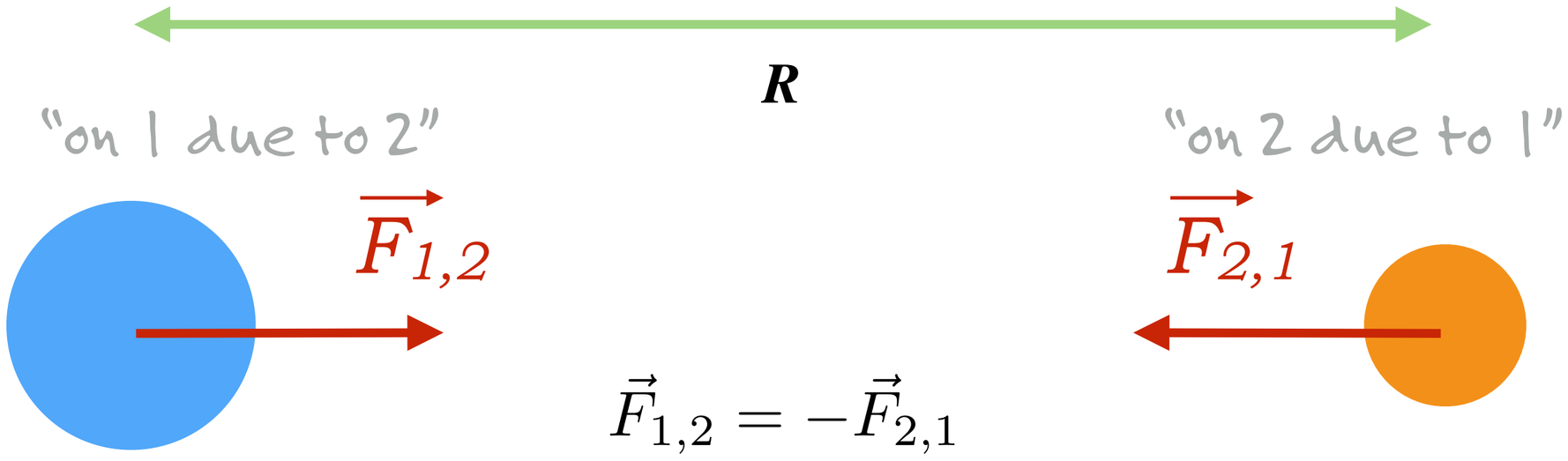

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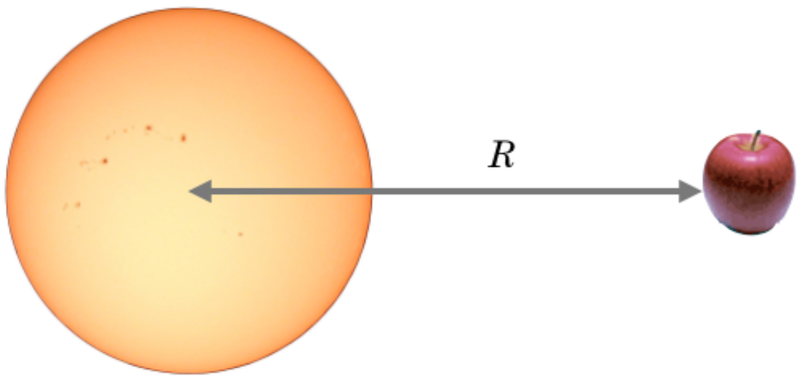
"Gravitational Constant"

answer, defend



$$F_{A,S} = G\frac{M_A M_S}{R^2}$$

The force on the apple at $R = \infty$ is:

A infinite

B between infinite and 0

C can't know that

D zero

energy conservation still good

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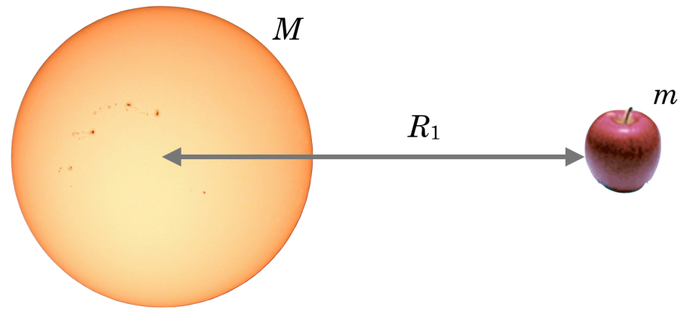

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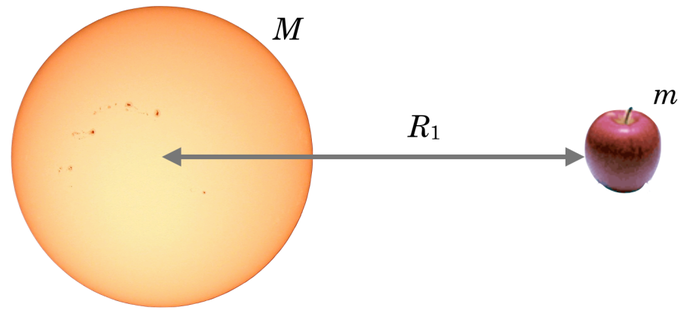

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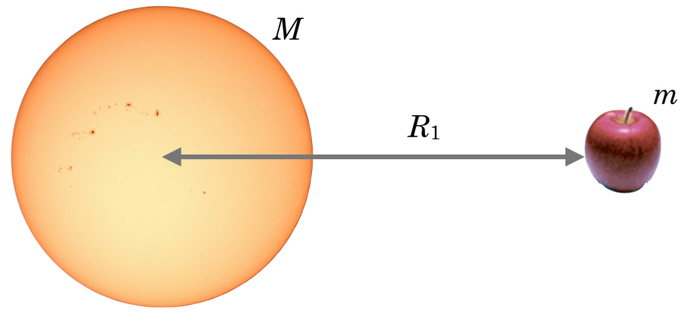

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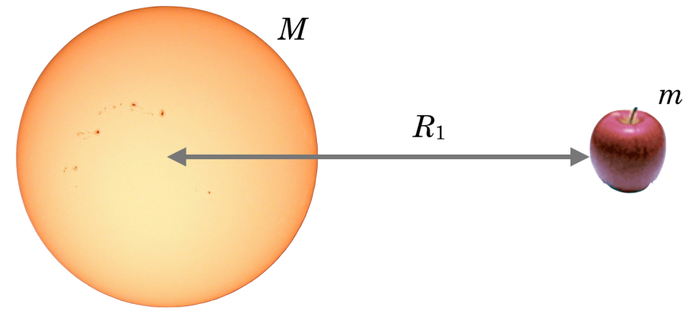

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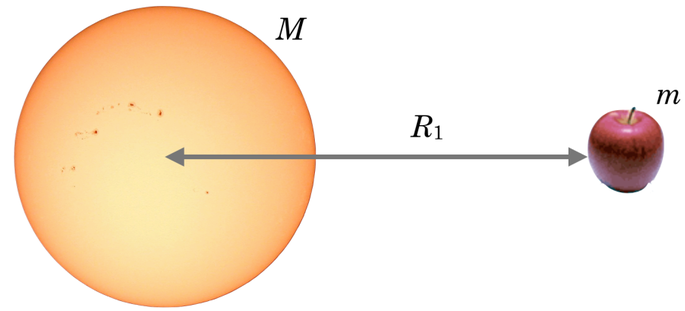

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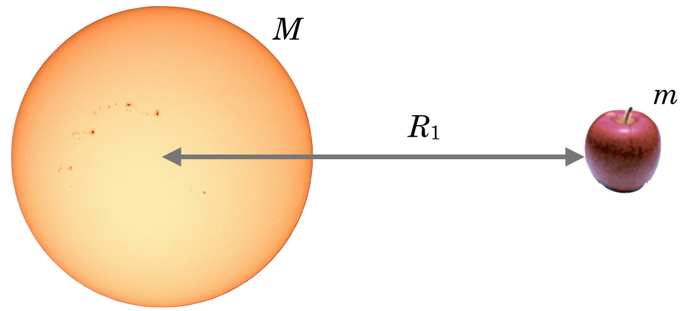

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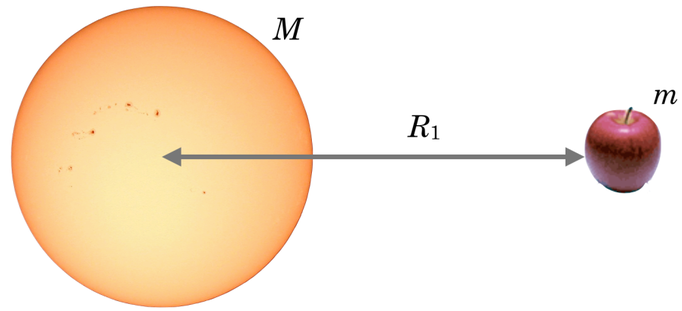

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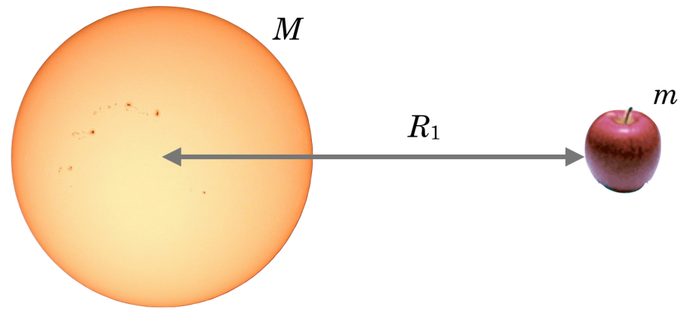

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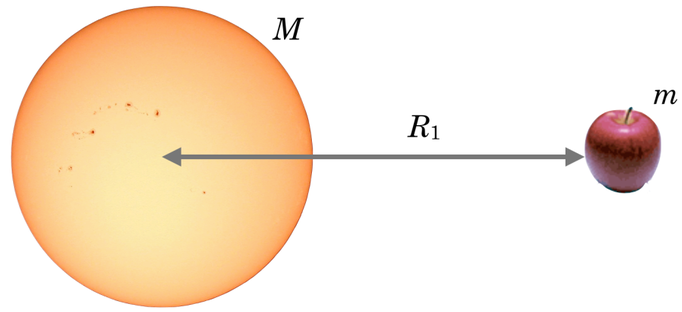

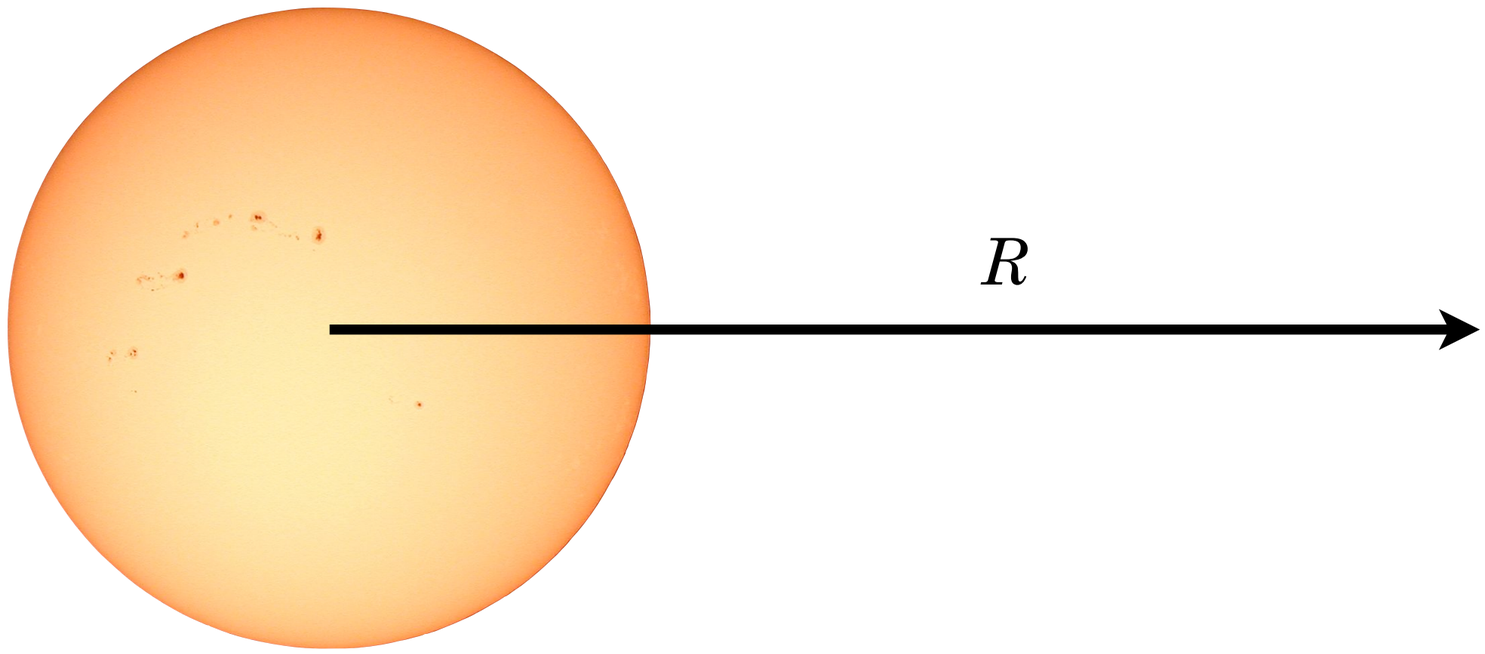

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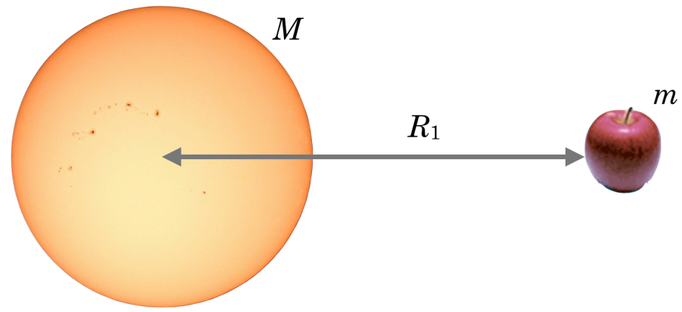

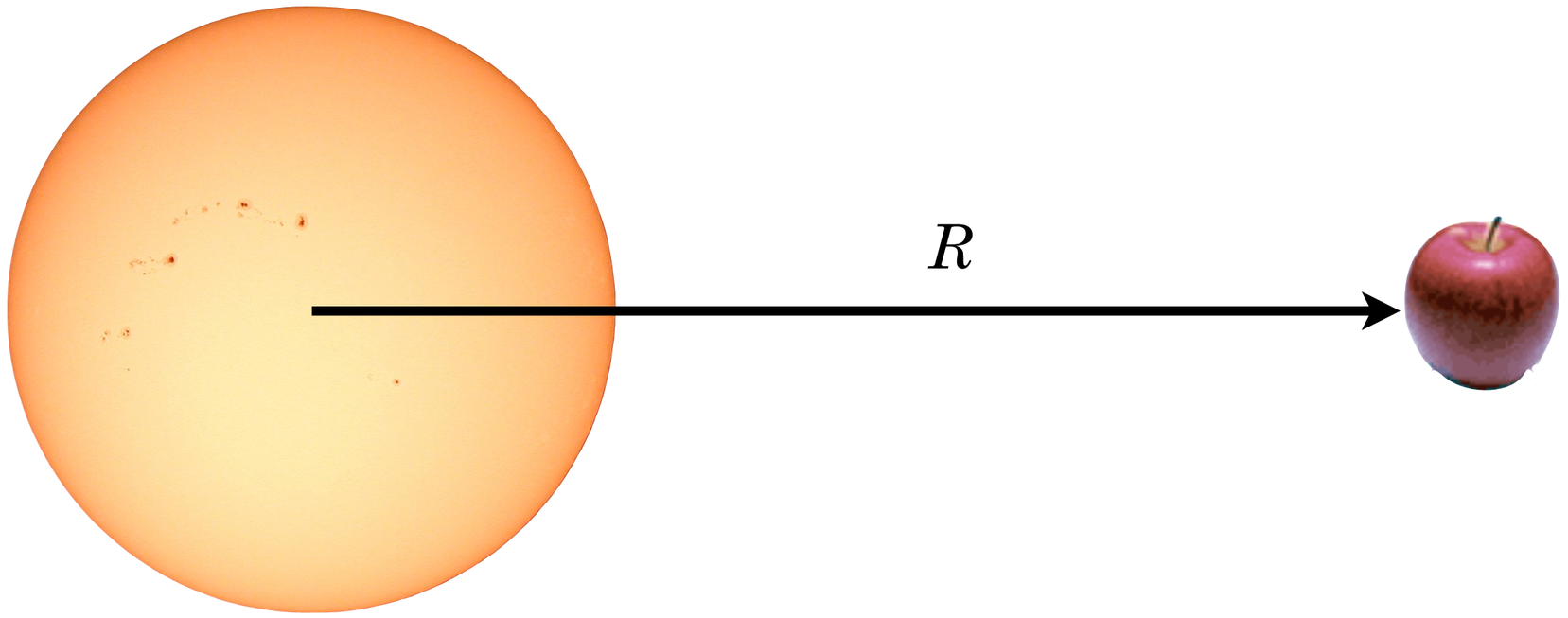

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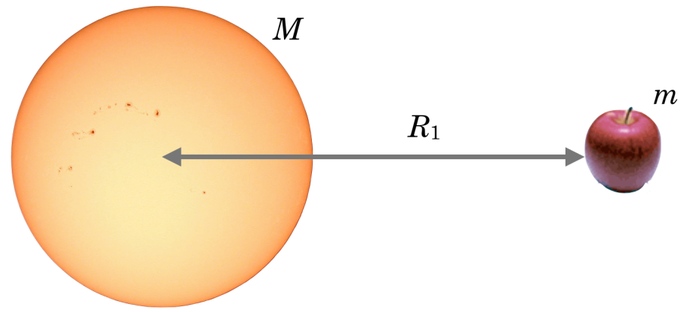

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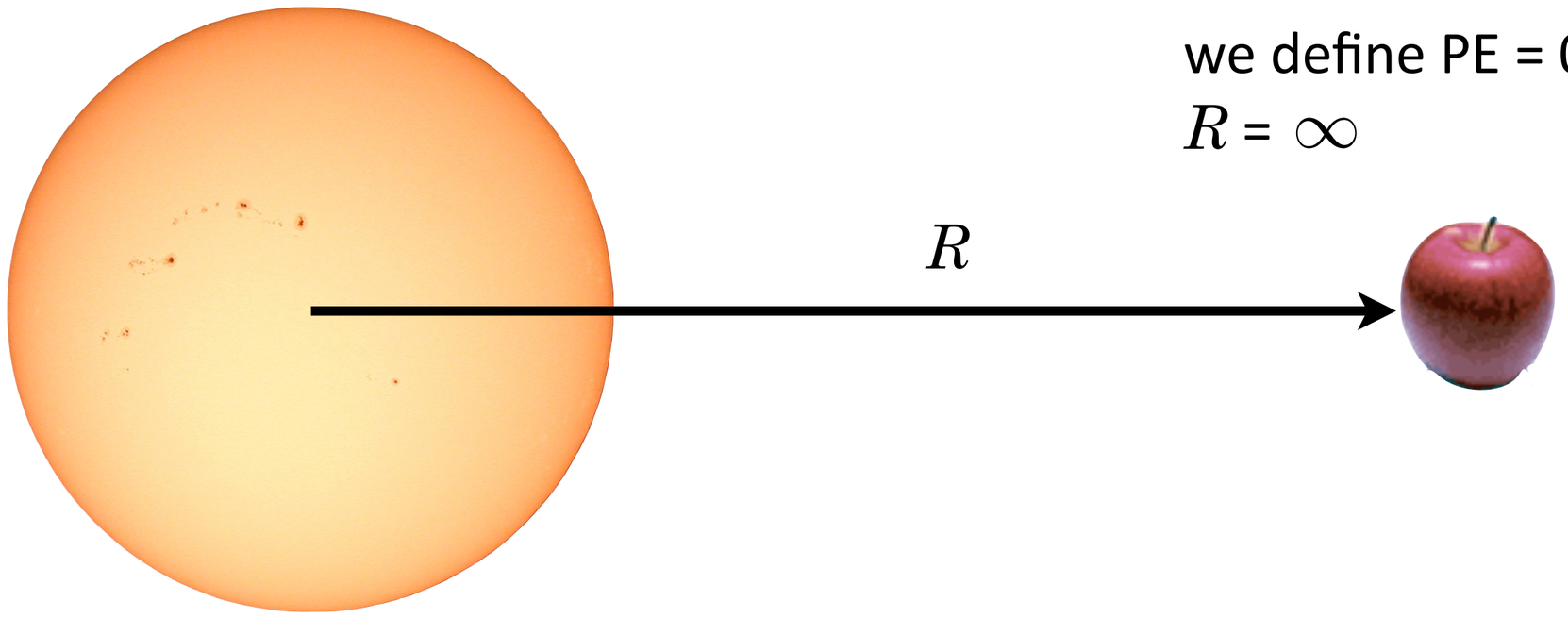

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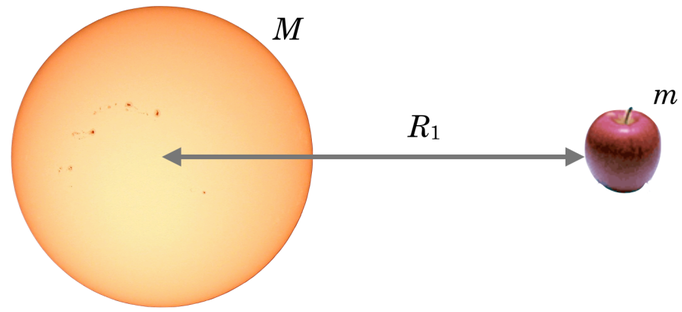

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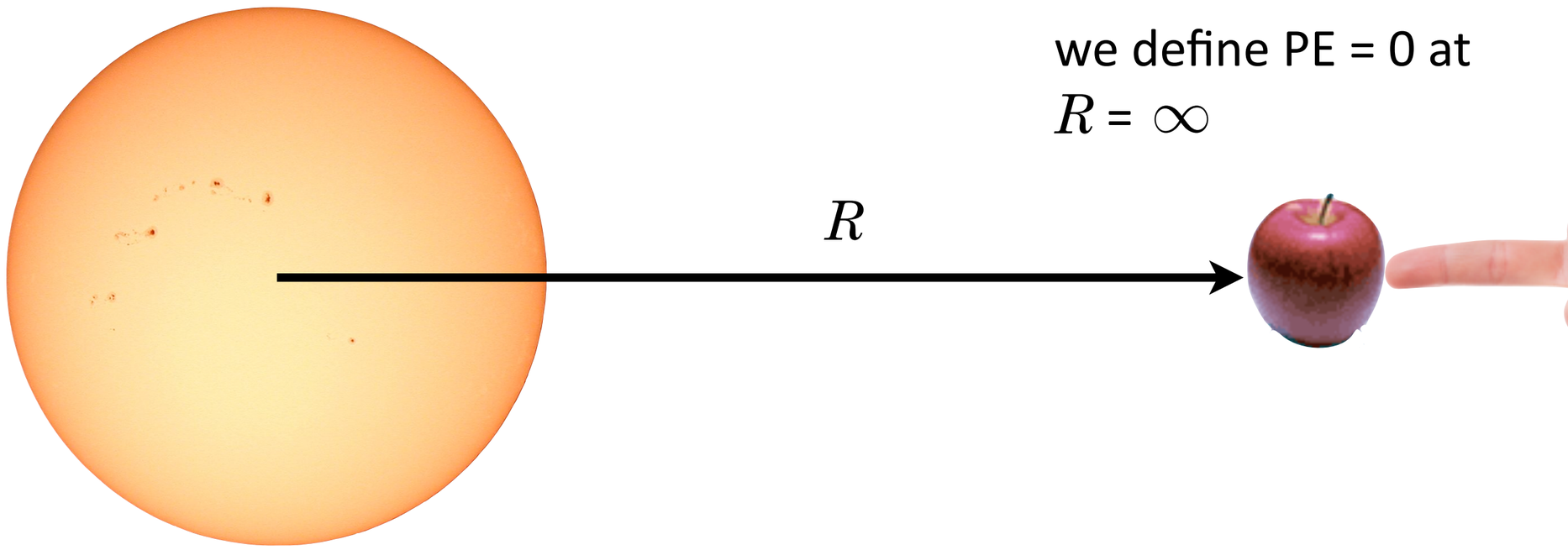

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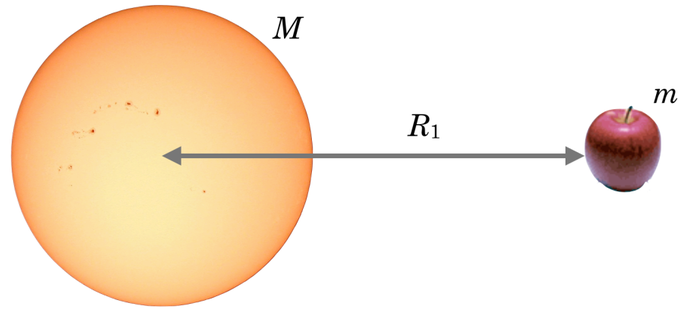
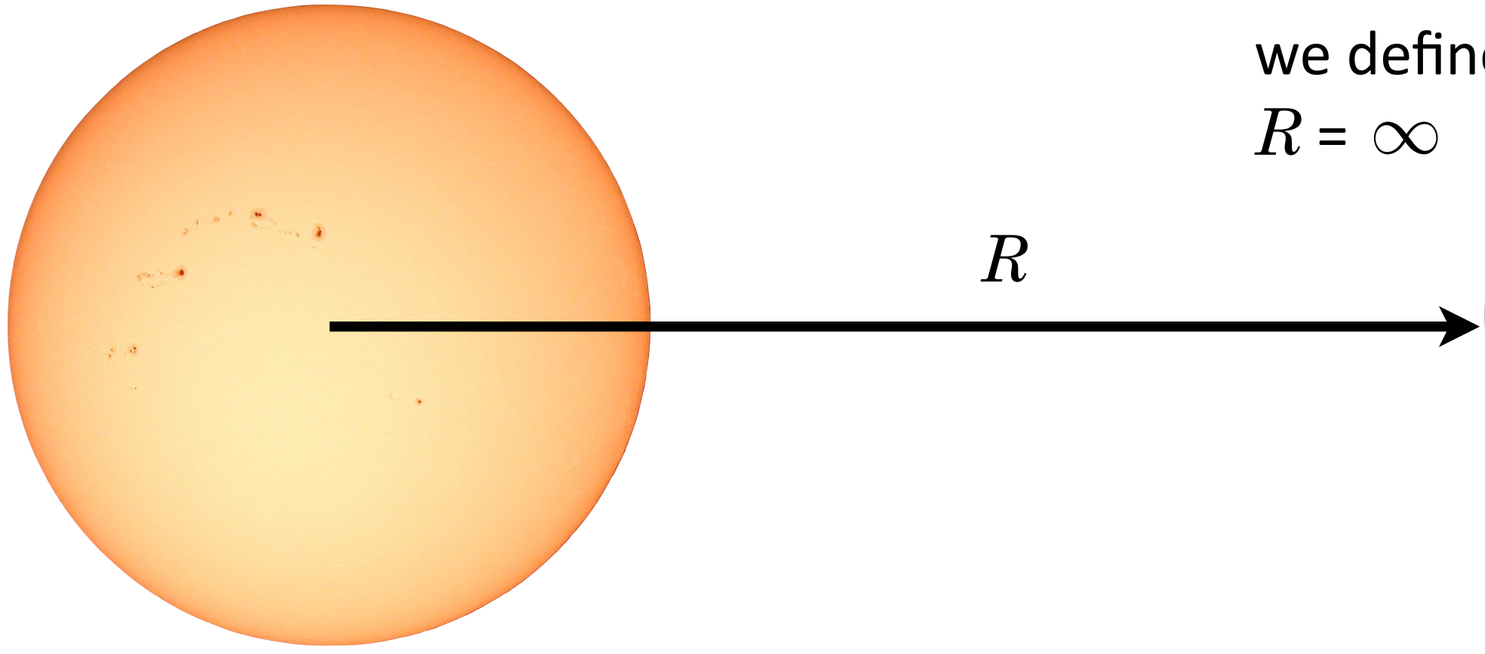


So, E_T = 0 when KE=0



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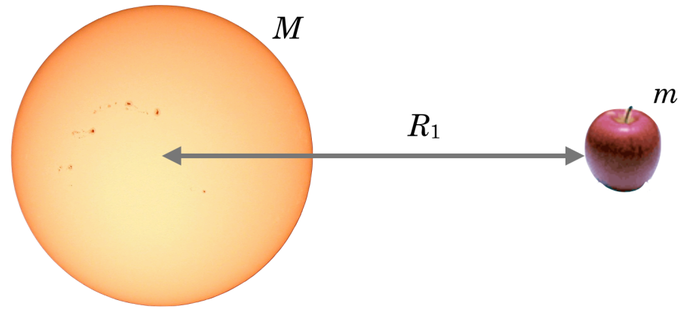

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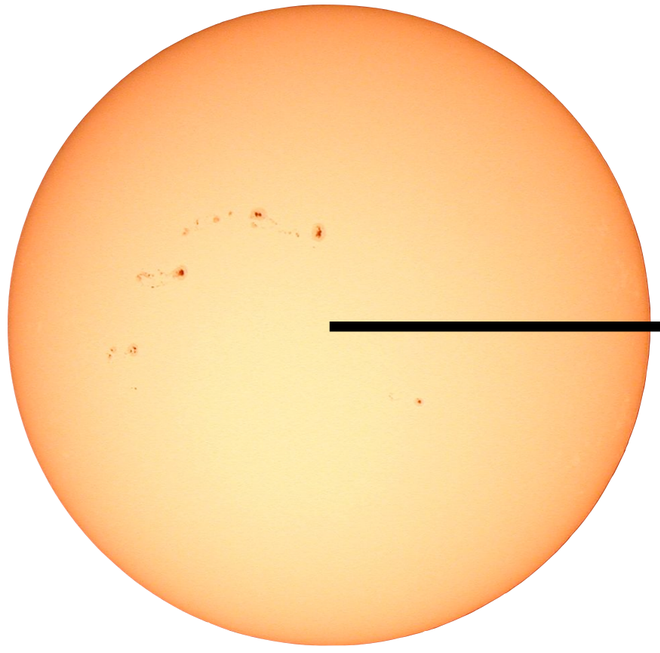

we define PE = 0 at $R = \infty$

nudge it a smidgen toward the Sun...

it starts to accelerate

energy conservation still good

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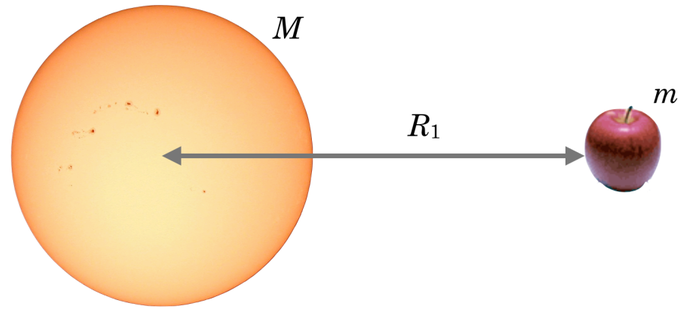

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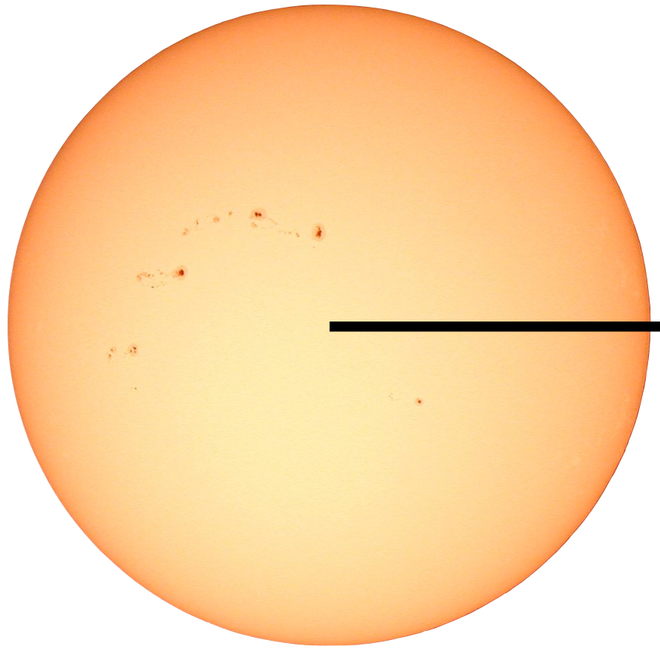

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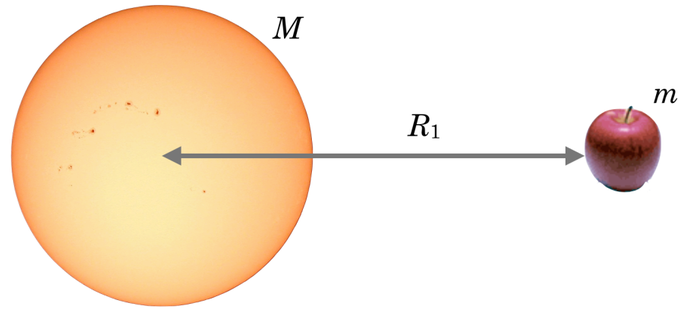

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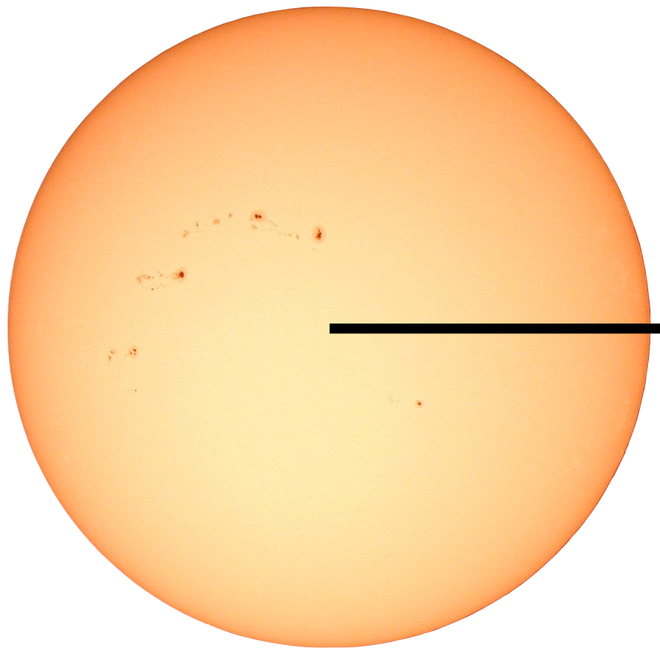

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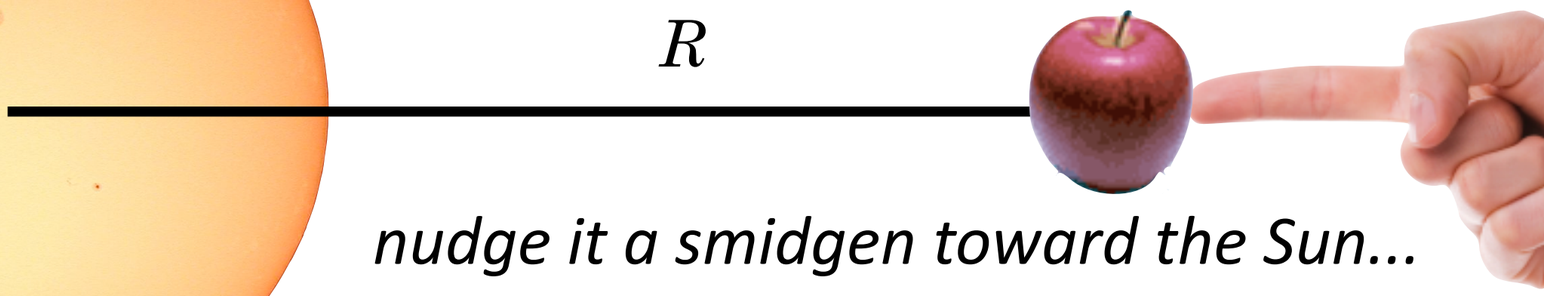


nudge it a smidgen toward the Sun...

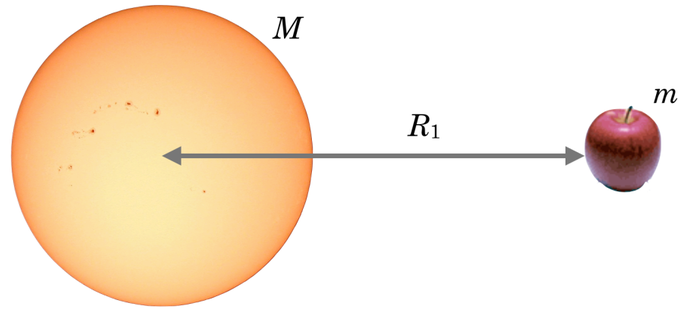
it starts to accelerate

$$KE + PE = \text{ constant}$$

this increases as apple approaches

energy conservation still good

Where is PE = 0? not so obvious



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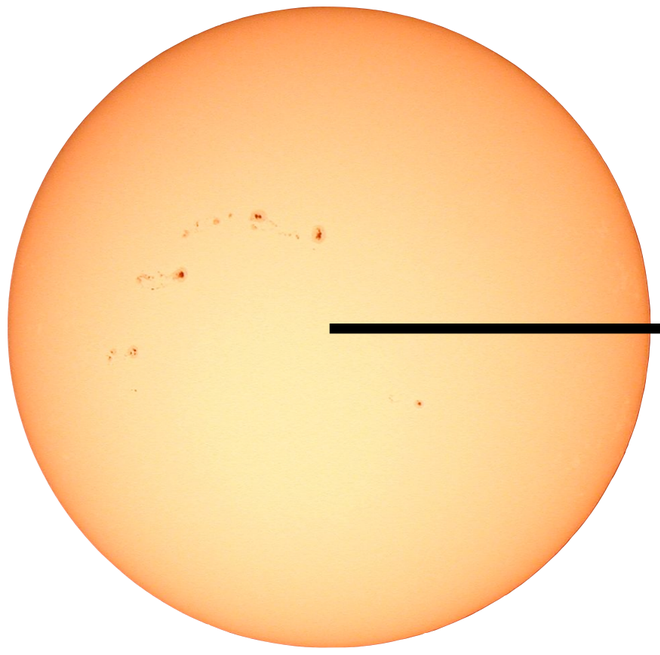
Where is KE = 0? when v = 0

So, E_T = 0 when KE=0



we define PE = 0 at $R = \infty$

nudge it a smidgen toward the Sun...

it starts to accelerate

$$KE + PE = \text{ constant}$$

so this *decreases* as apple approaches

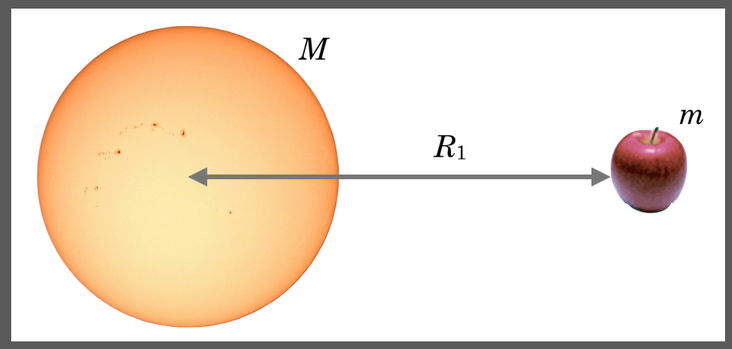
this increases as apple approaches

energy conservation still good

$$F_{A,S} = G\frac{M_A M_S}{R^2}$$

So, $E_T = 0$ when KE=0

Where is PE = 0? not so obvious



E

$KE + PE =$ constant

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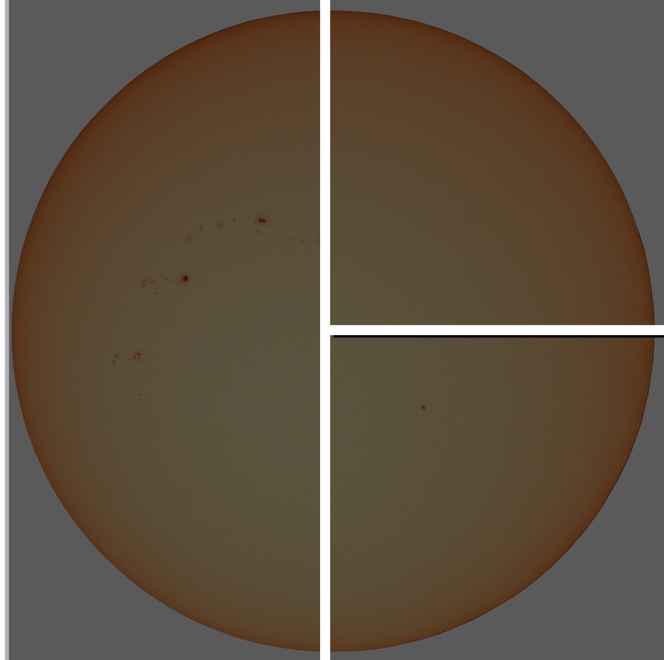

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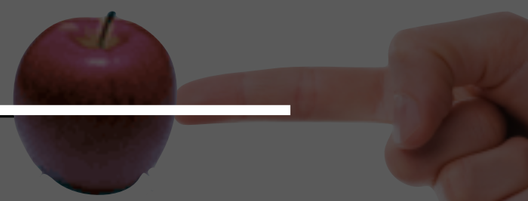


nudge it a smidgen toward the Sun...

R

it starts to accelerate

$KE + PE =$ constant

so this *decreases* as apple approaches

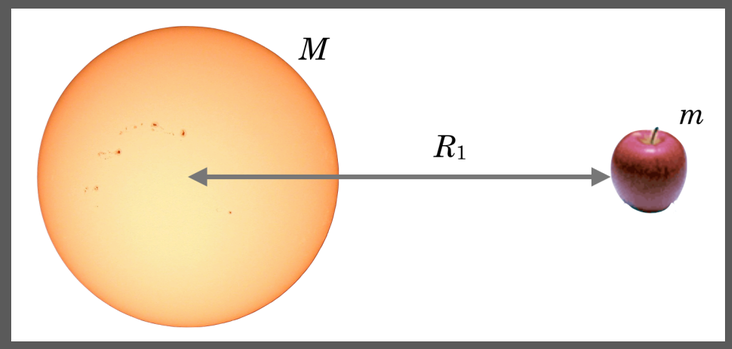
this increases as apple approaches

energy conservation still good

$$F_{A,S} = G\frac{M_A M_S}{R^2}$$

So, $E_T = 0$ when KE=0

Where is PE = 0? not so obvious

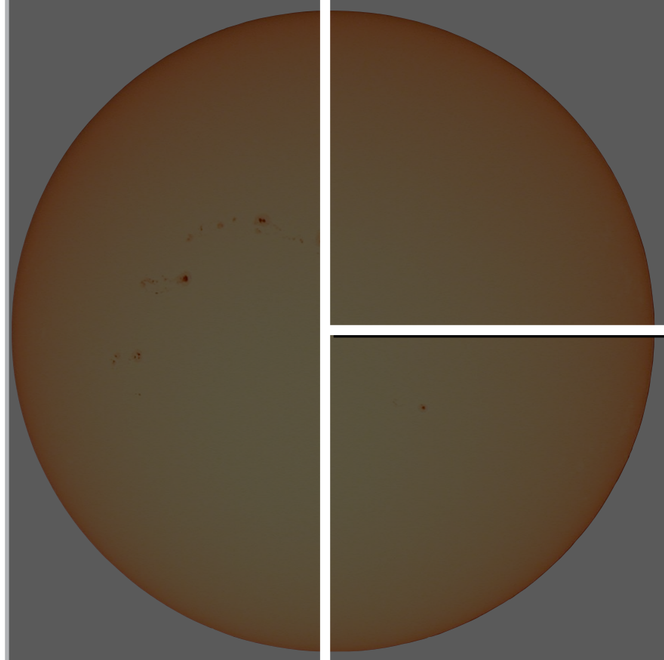


E

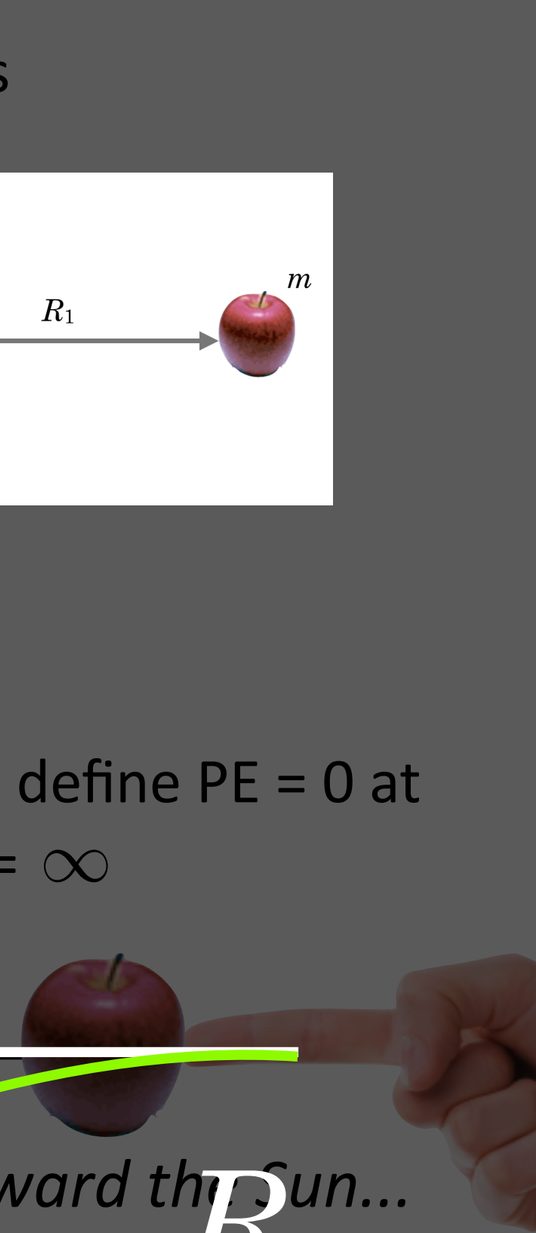
$KE + PE =$ constant

Where is KE = 0? when v = 0

we define PE = 0 at $R = \infty$



R



nudge it a smidgen toward the Sun...

R

$U(R)$

it starts to accelerate

$KE + PE =$ constant

so this *decreases* as apple approaches

this increases as apple approaches

energy conservation still good

$$F_{A,S} = G\frac{M_A M_S}{R^2}$$

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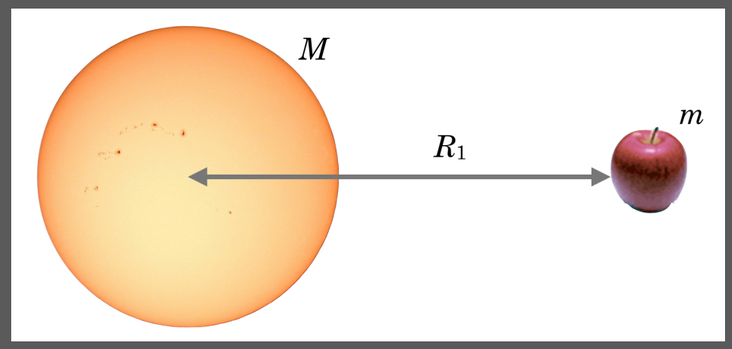

E

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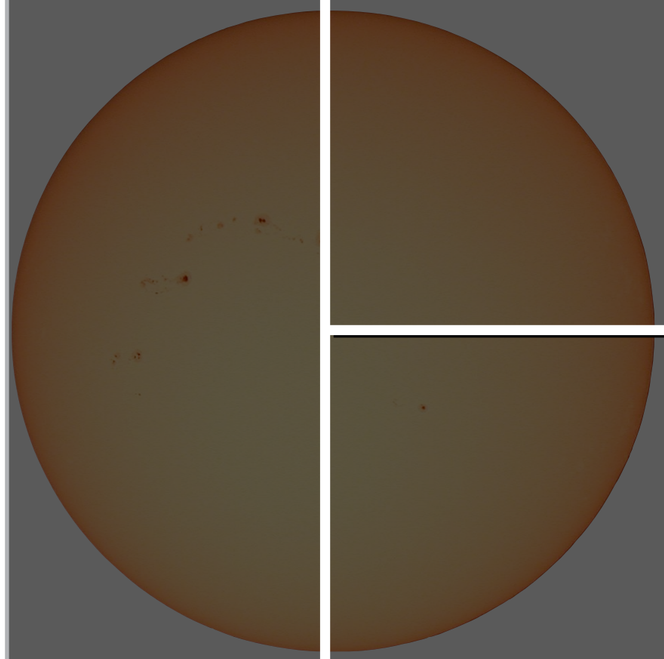
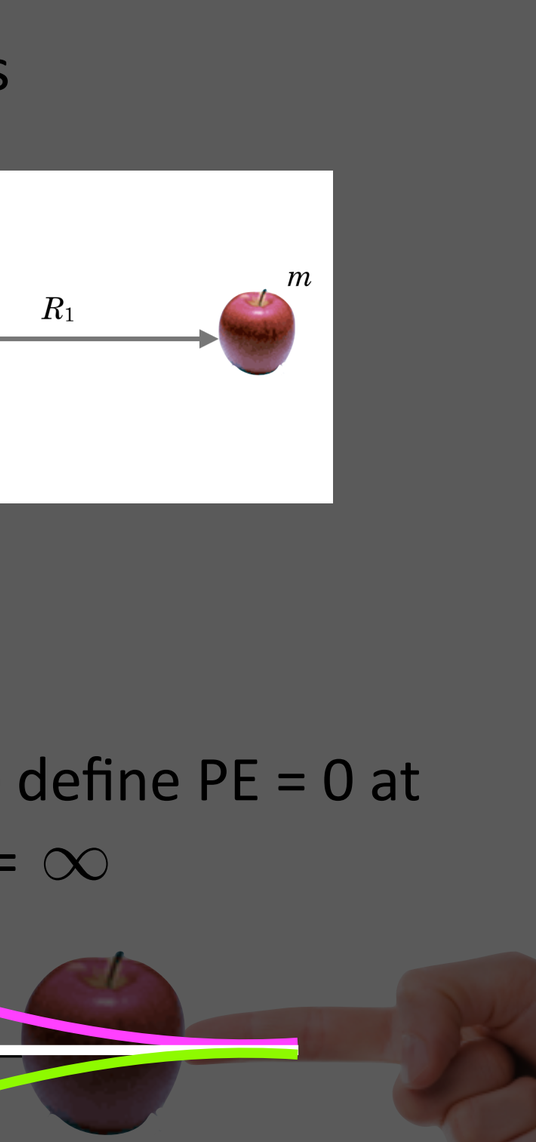


$K(R)$

we define PE = 0 at $R = \infty$

R



nudge it a smidgen toward the Sun...

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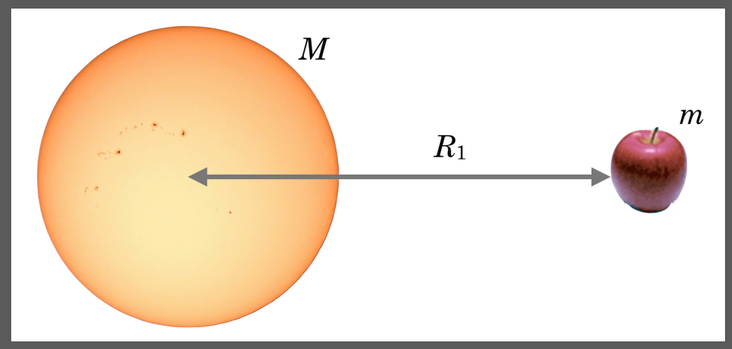
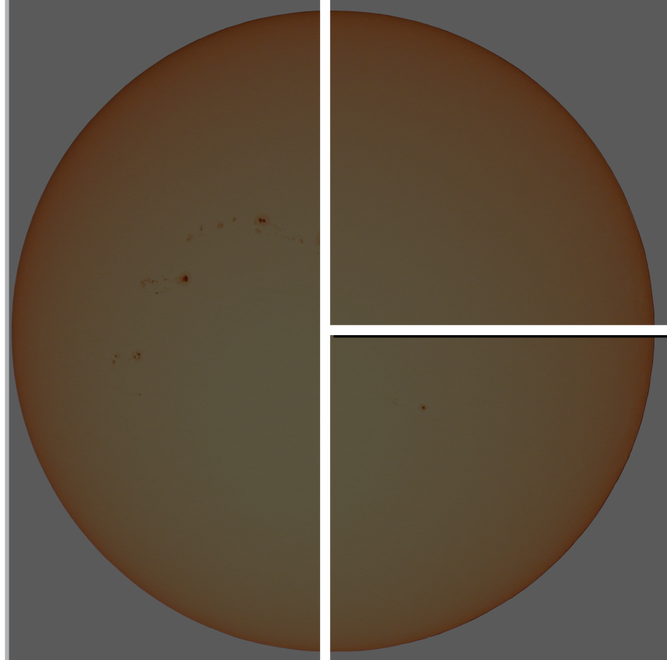


E

$KE + PE =$ constant

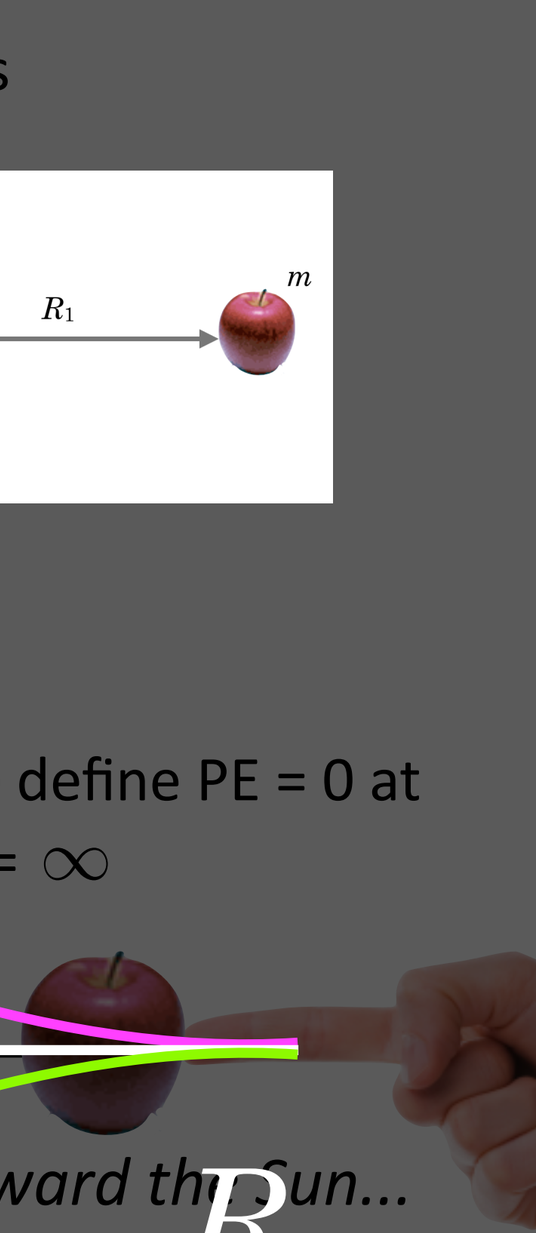
Where is KE = 0? when v = 0



$K(R)$

we define PE = 0 at $R = \infty$

R



nudge it a smidgen toward the Sun...

R

$U(R)$

it starts to accelerate

$$K(R) + U(R) = KE + PE = \text{ constant}$$

so this *decreases* as apple approaches

this increases as apple approaches

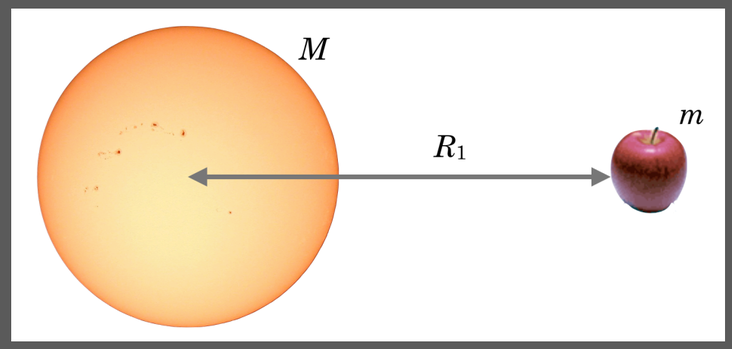
energy conservation still good

$$F_{A,S} = G\frac{M_A M_S}{R^2}$$

$$U(R) = -G\frac{Mm}{R}$$

So, $E_T = 0$ when KE=0

Where is PE = 0? not so obvious



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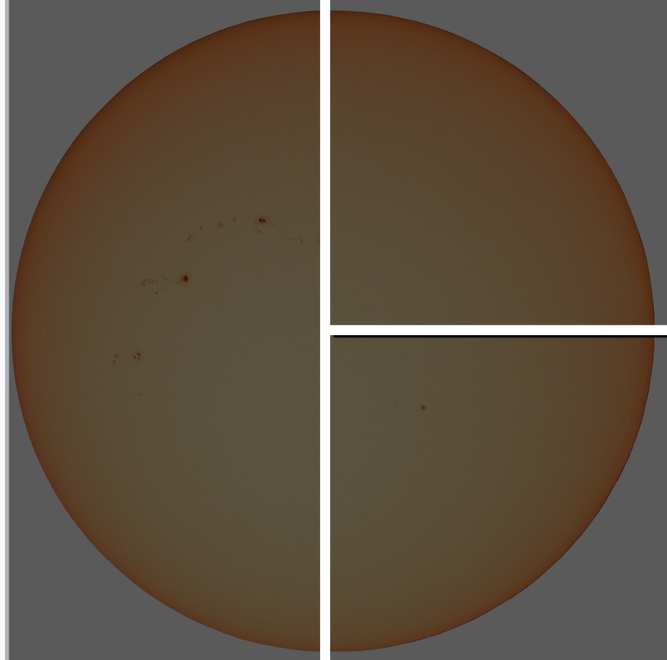

$K(R)$

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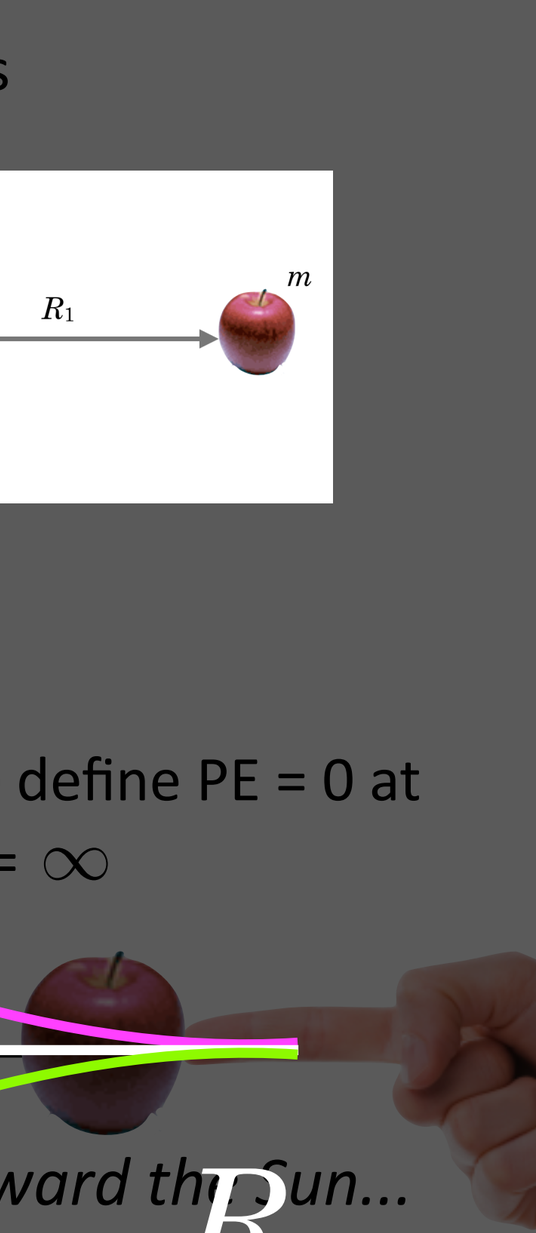
R



nudge it a smidgen toward the Sun...

R

$U(R)$

it starts to accelerate

$$K(R) + U(R) = KE + PE = \text{ constant}$$

so this *decreases* as apple approaches

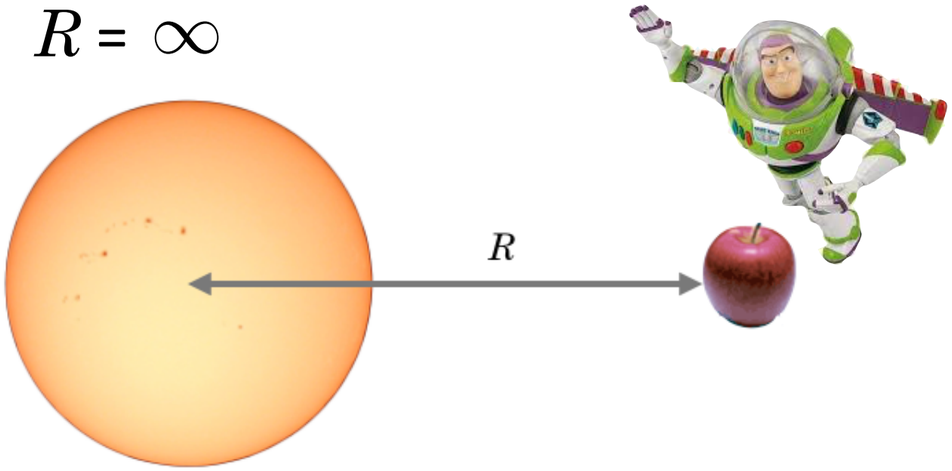
this increases as apple approaches

answer, defend

Energy is conserved

$$KE + PE = \text{ constant}$$

we define PE = 0 at $R = \infty$



start an apple at an infinite distance from the Sun at rest:

The total energy is

A infinite

B between infinite and 0

C can't know that

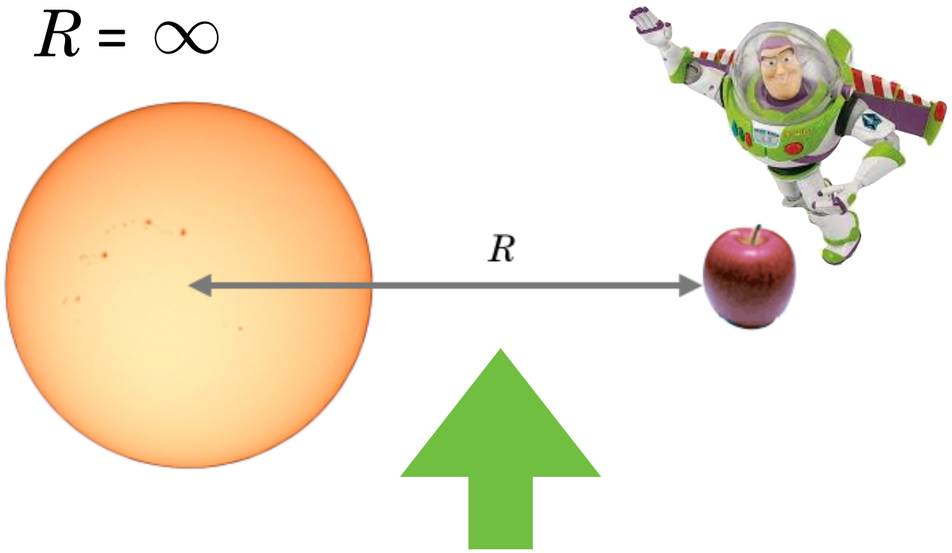
D zero

answer, defend

Energy is conserved

$$KE + PE = \text{ constant}$$

we define PE = 0 at
$R = \infty$



The kinetic energy of the apple at a midpoint from infinity to the sun is 10. At that point:

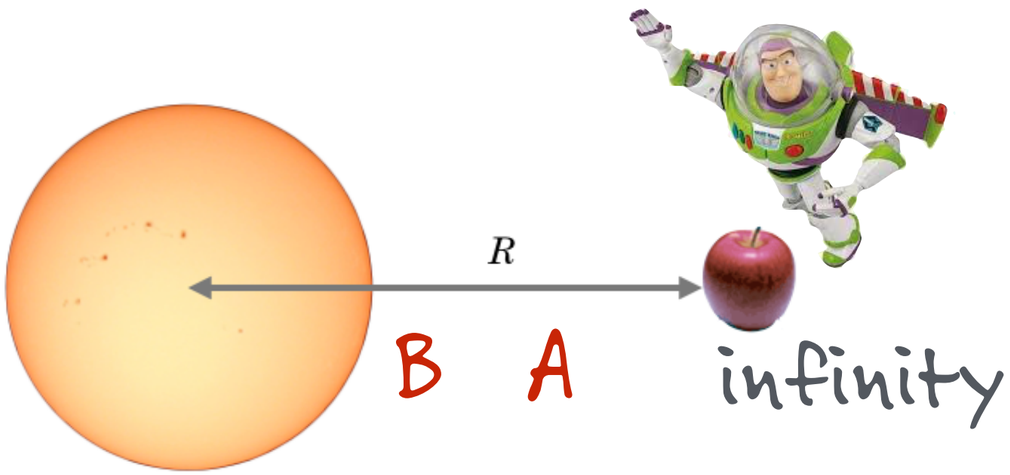
A its total energy is 10

B its potential energy is -10

C its potential energy is +10

D can't know that

answer, defend



Apple starts at rest at infinity and let go.

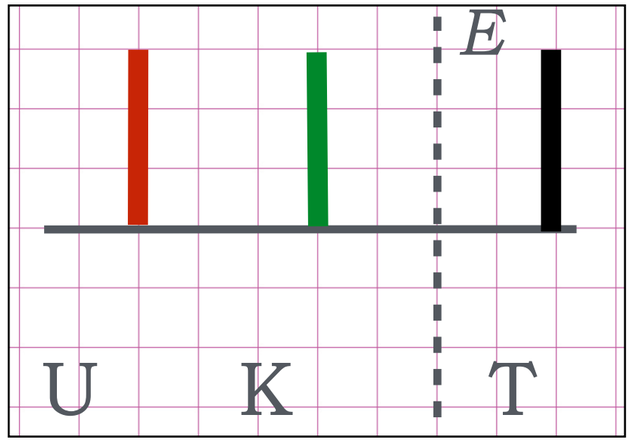
The energetics at $R = \infty$ were best represented as:

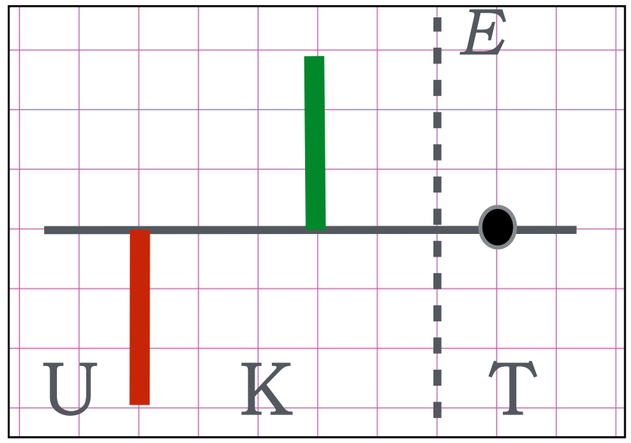
A

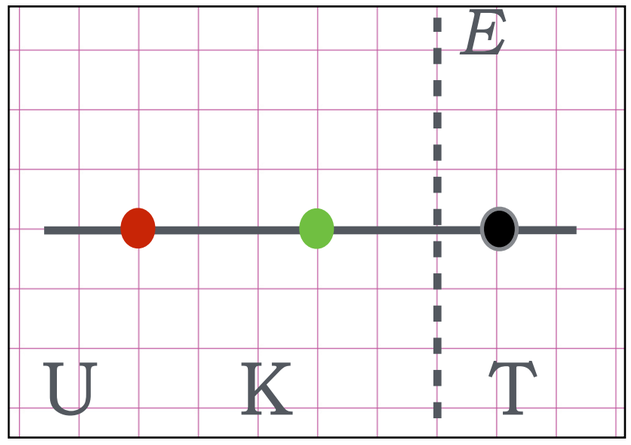
B

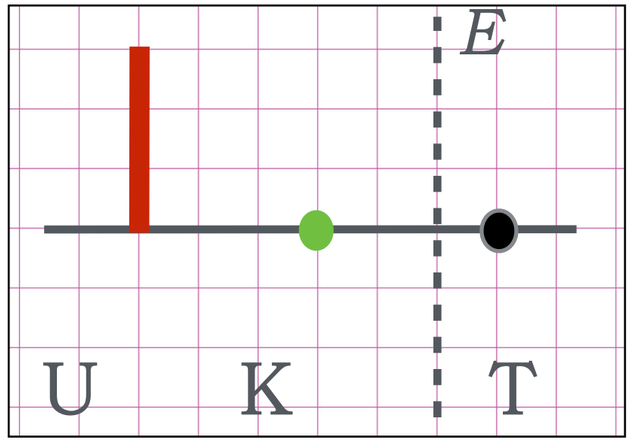
C

D

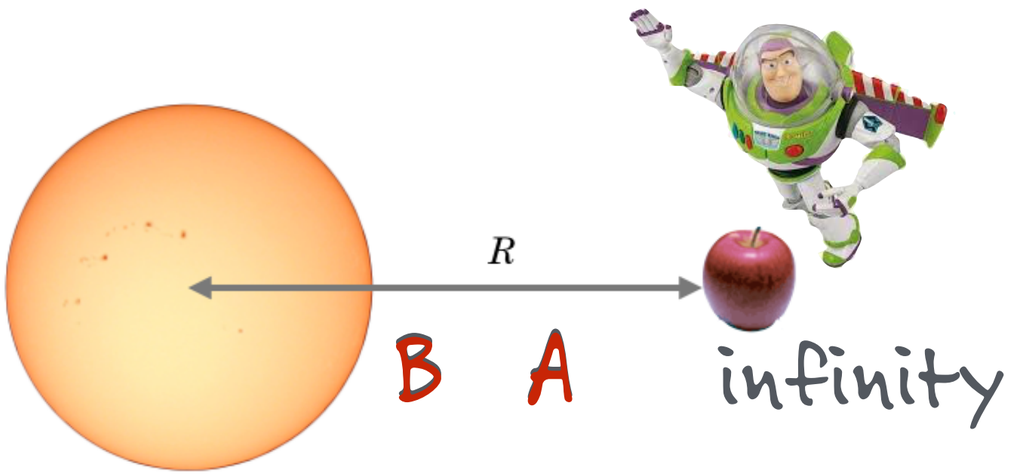








answer, defend

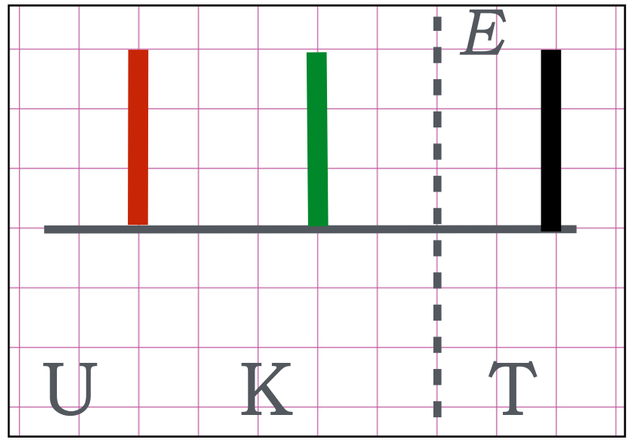


Apple starts at rest at infinity.

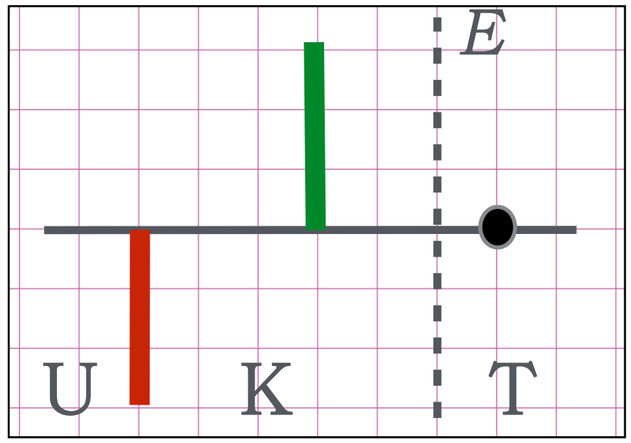
K at point A = 3

The energetics at A are best represented as:

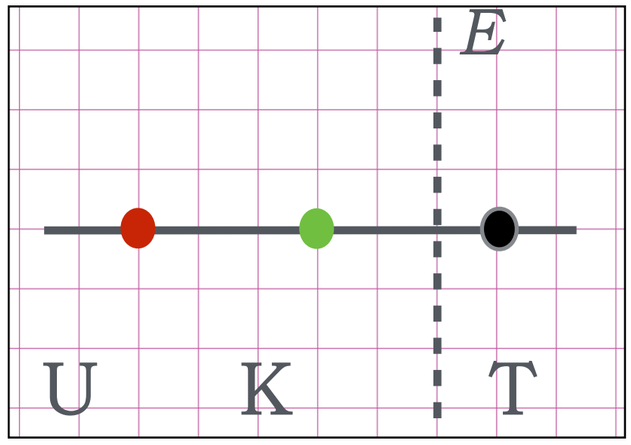
A



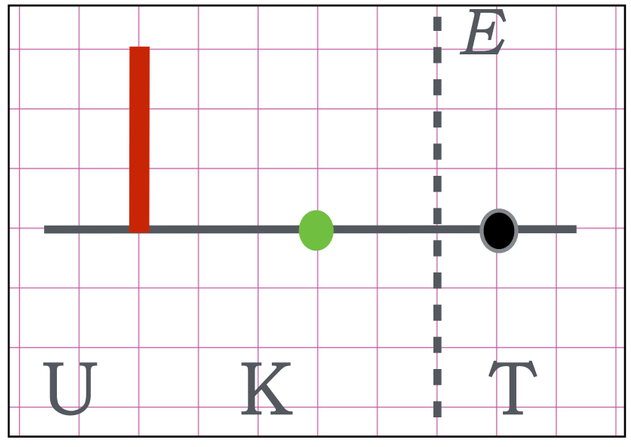
B



C

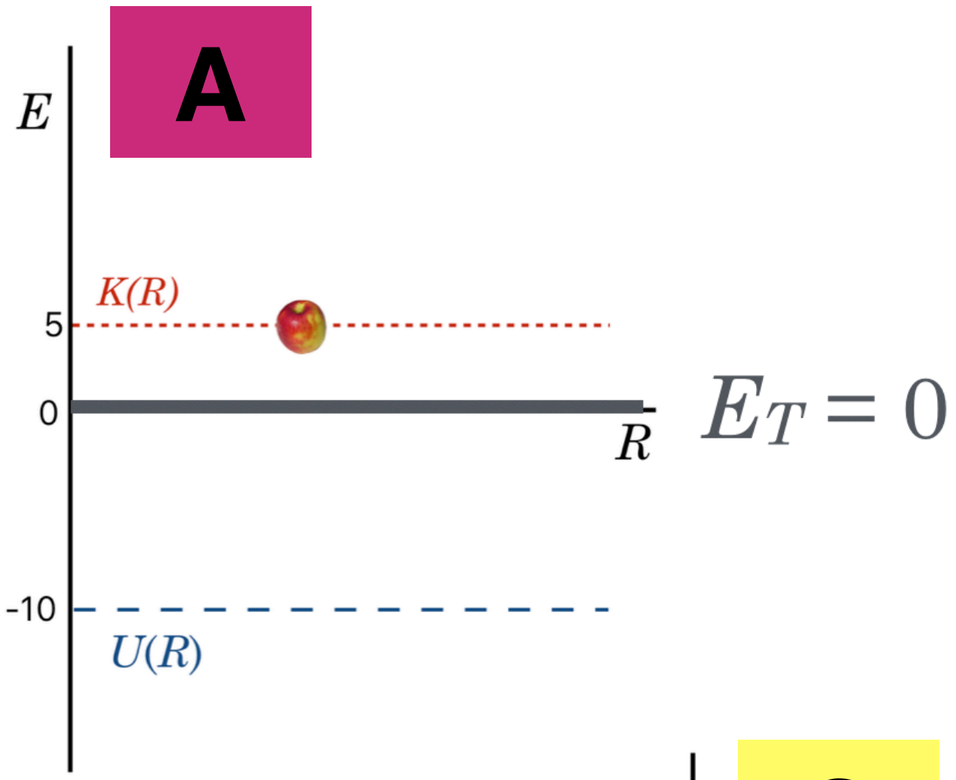


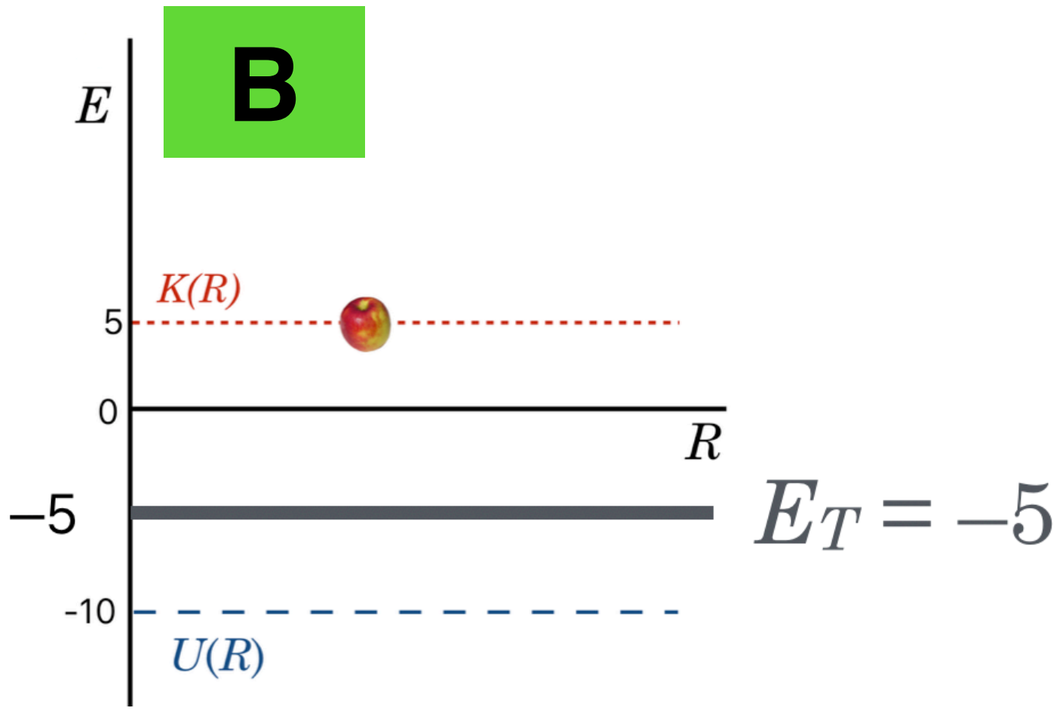
D

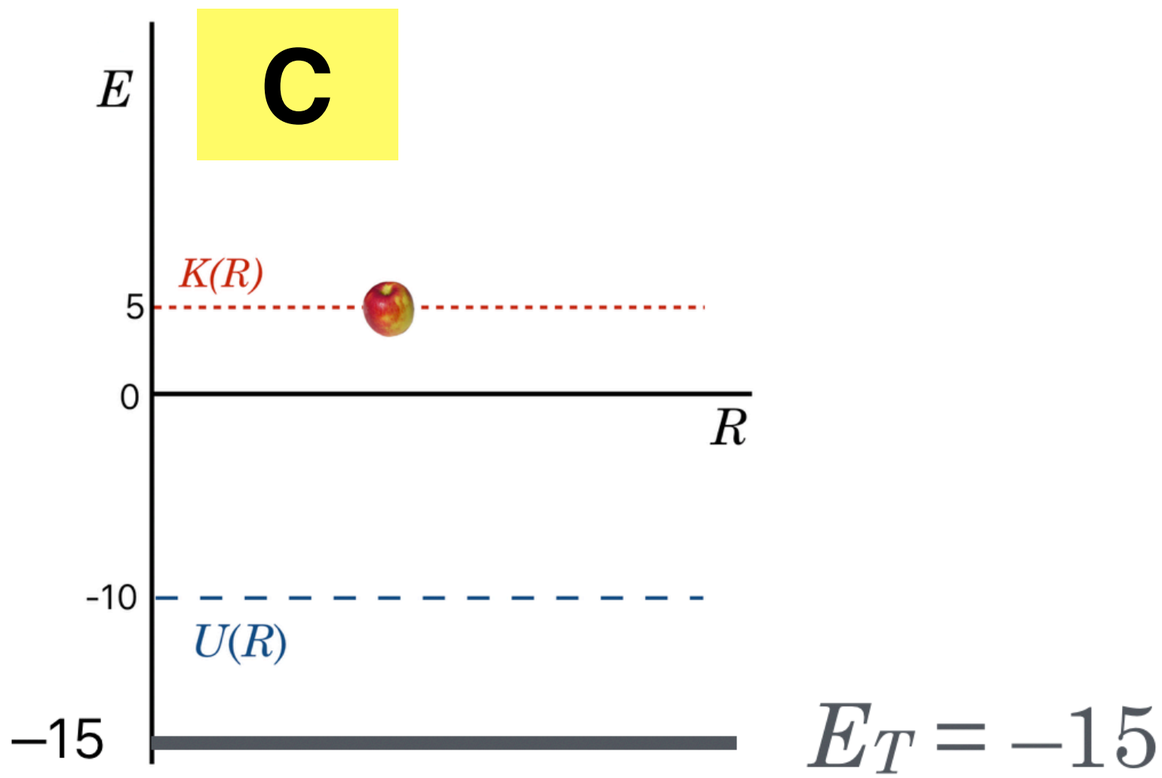


answer, defend

Given a K and a U, what best represents the total energy, E_T?

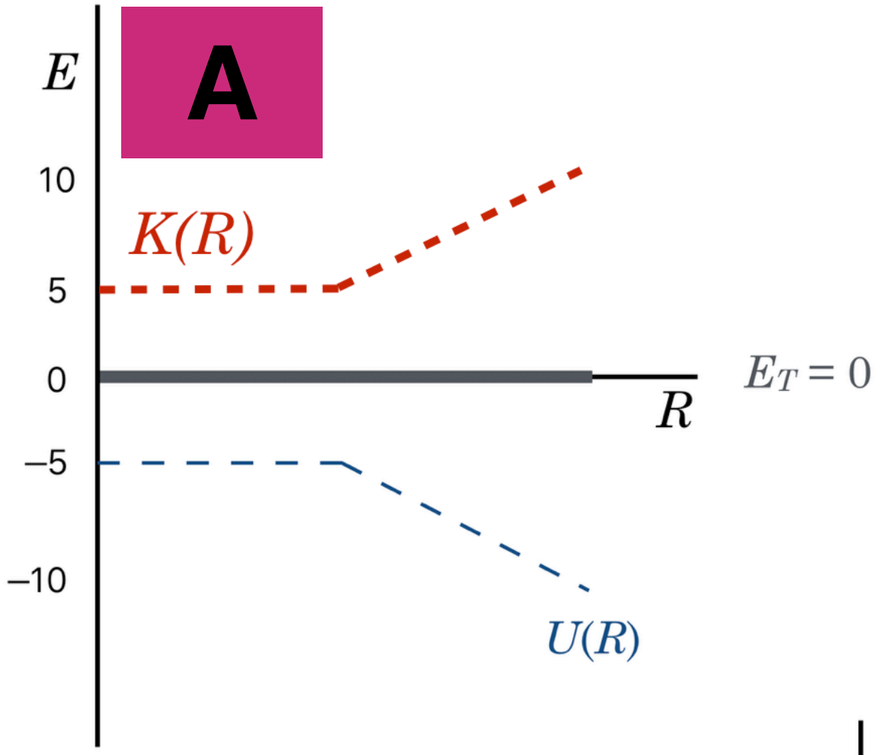


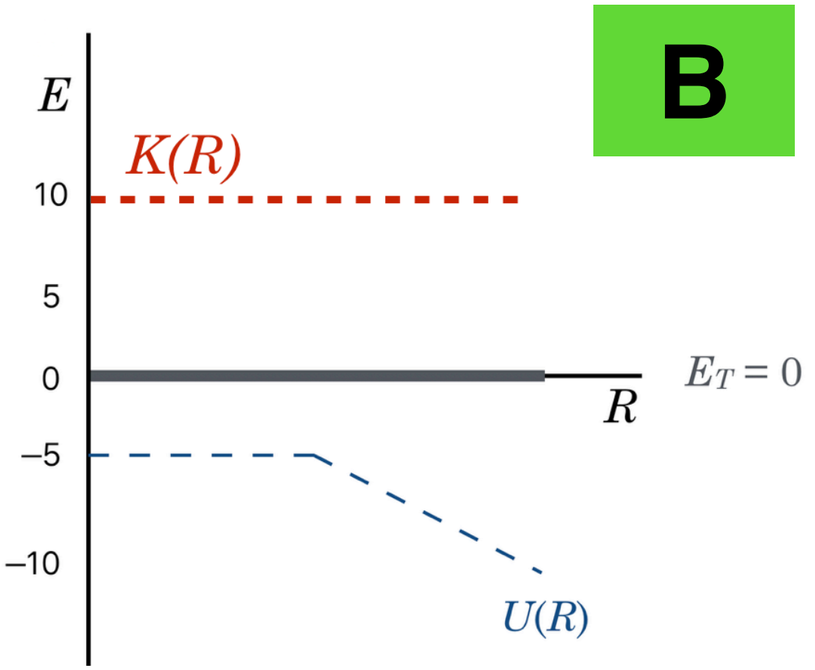


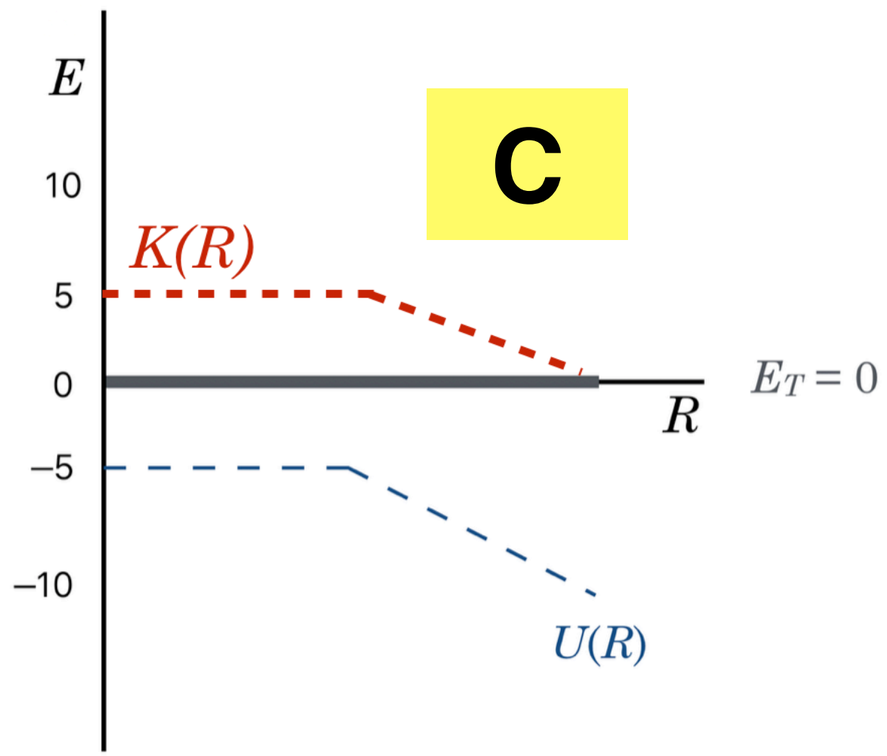


answer, defend

If the total energy = 0 and the PE is as shown, what KE is appropriate?

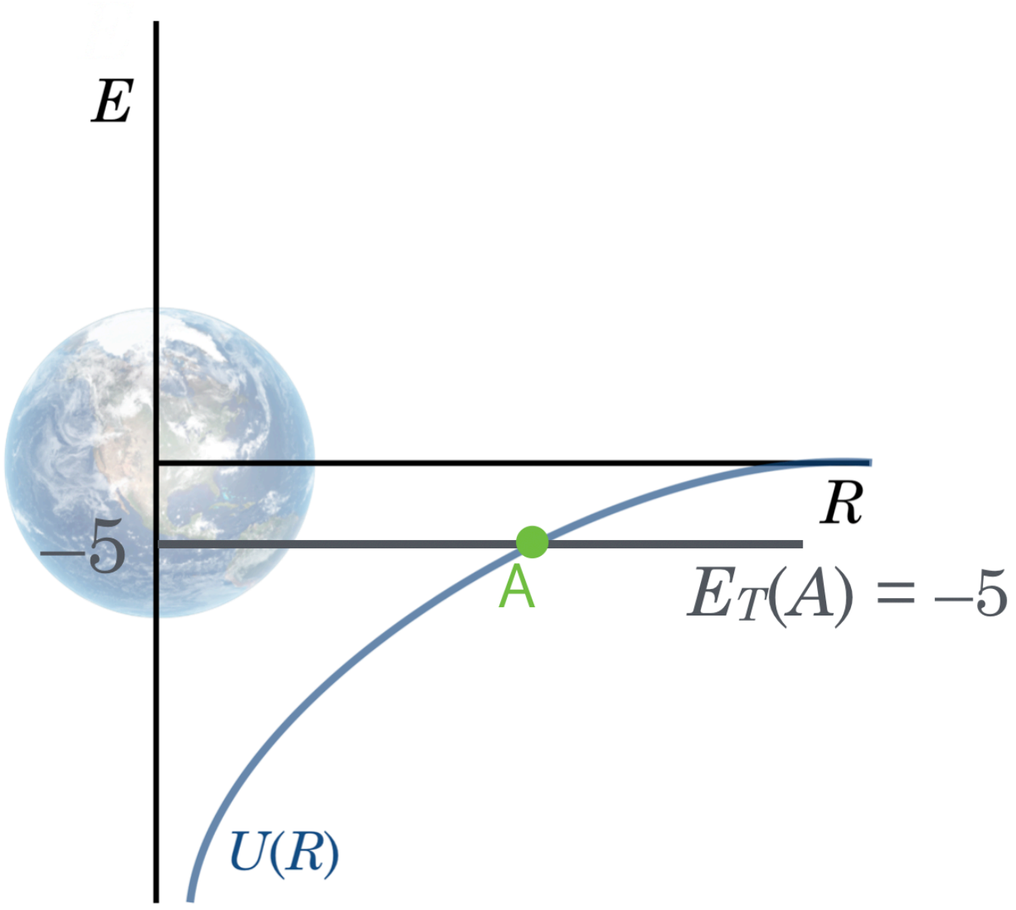




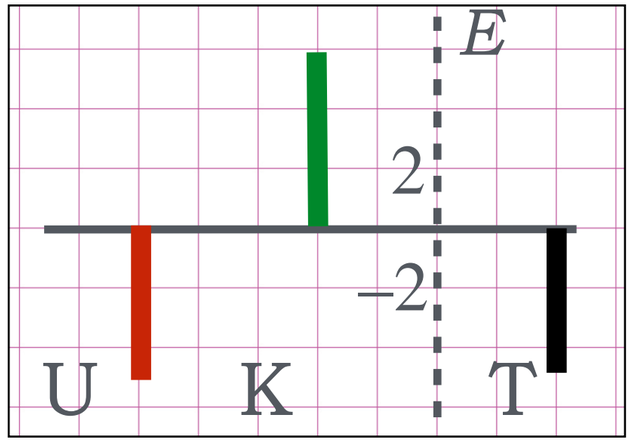


answer, defend

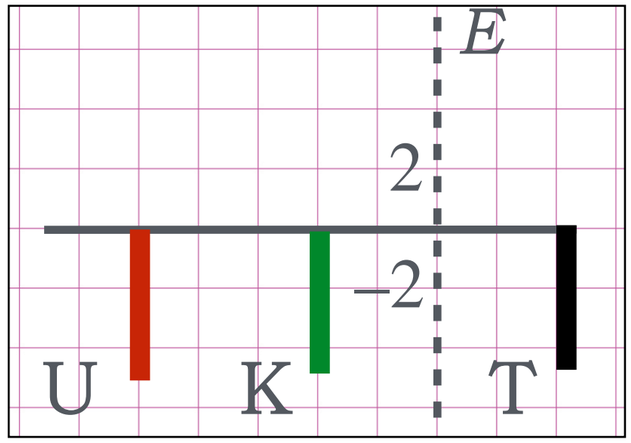
What is K at point A?



A



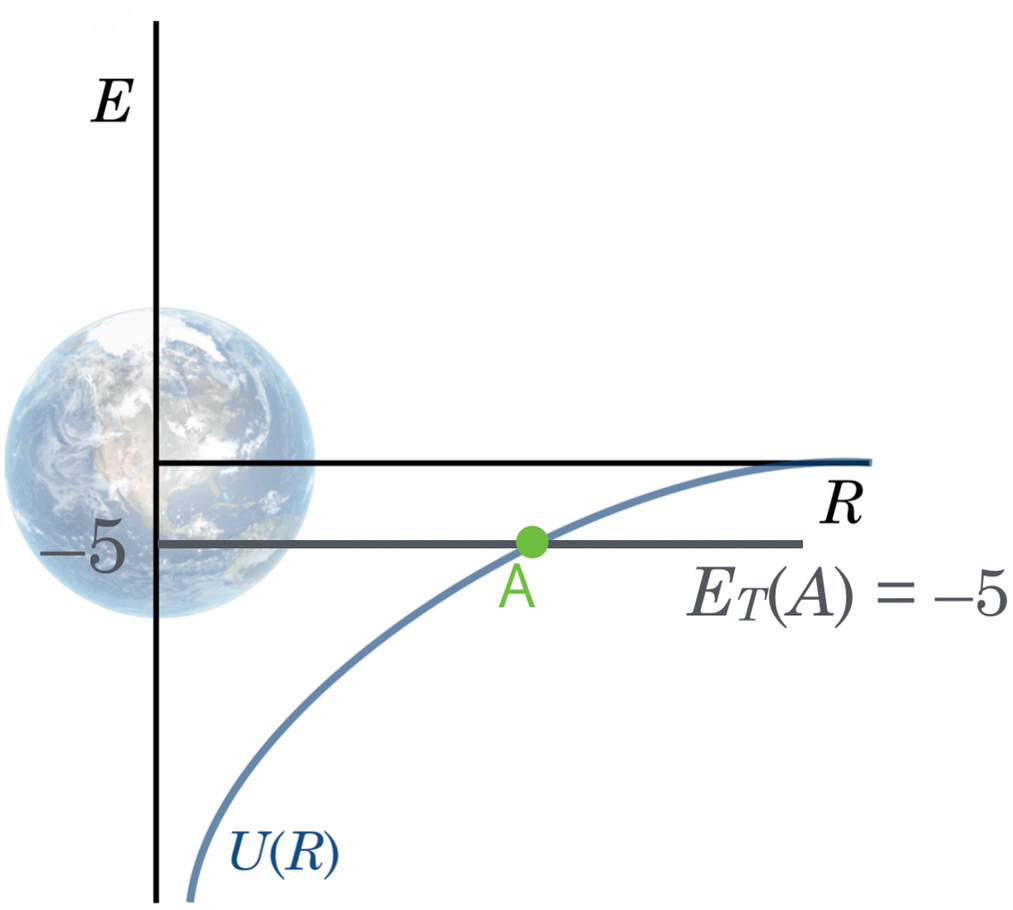
B



C

answer, defend

What is K at point A?



A -5

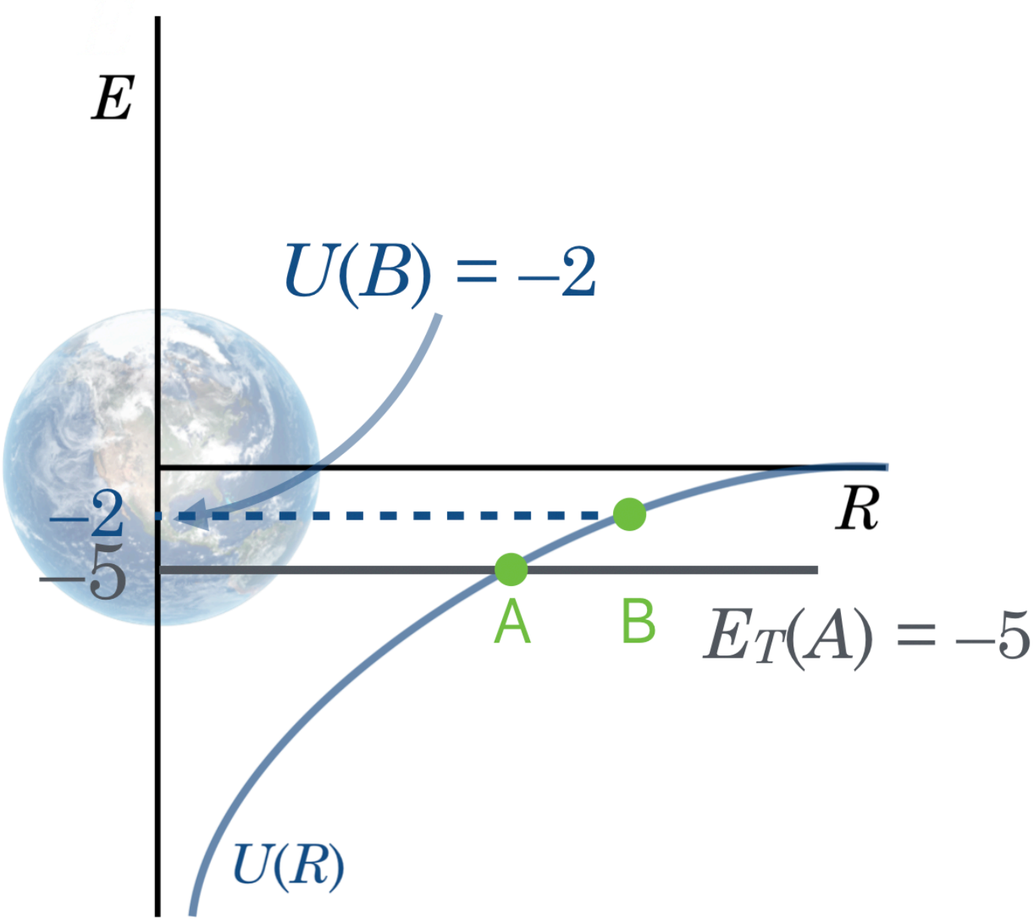
B 5

C 0

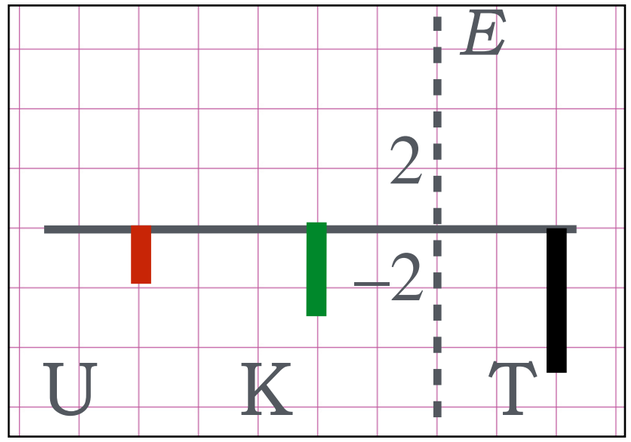
D can't know that

answer, defend

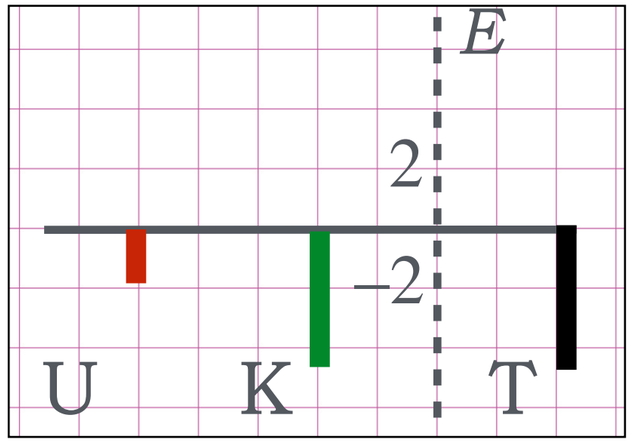
What is K at point B?



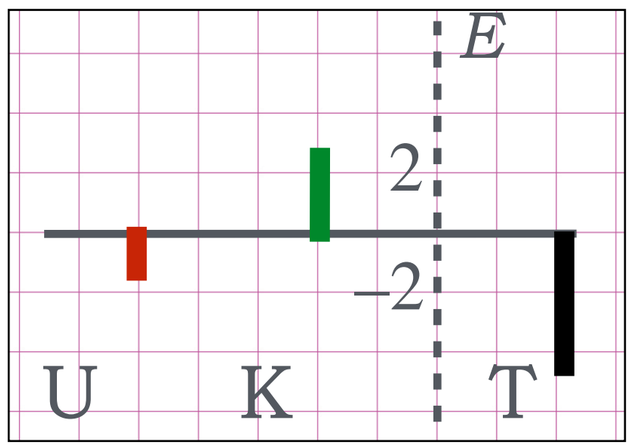
A



B



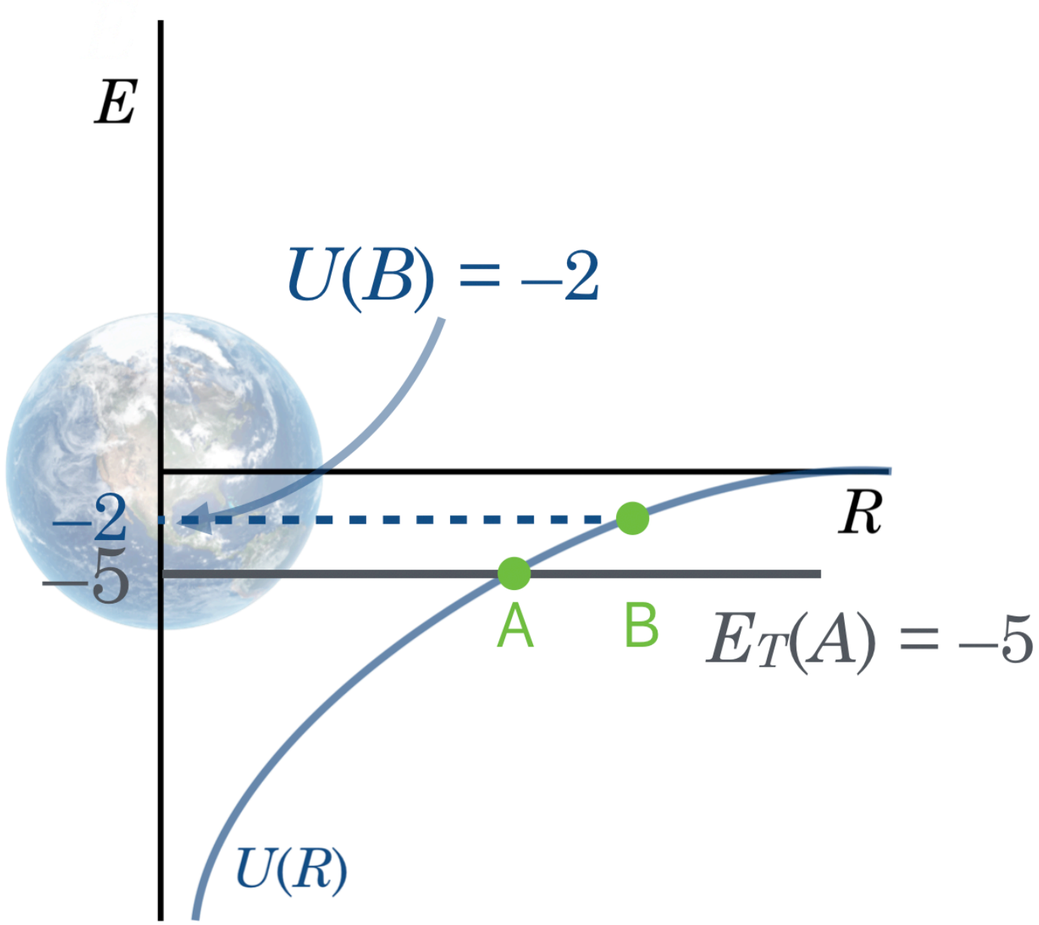
C



E

answer, defend

What is K at point B?



A +3

B 0

C -3

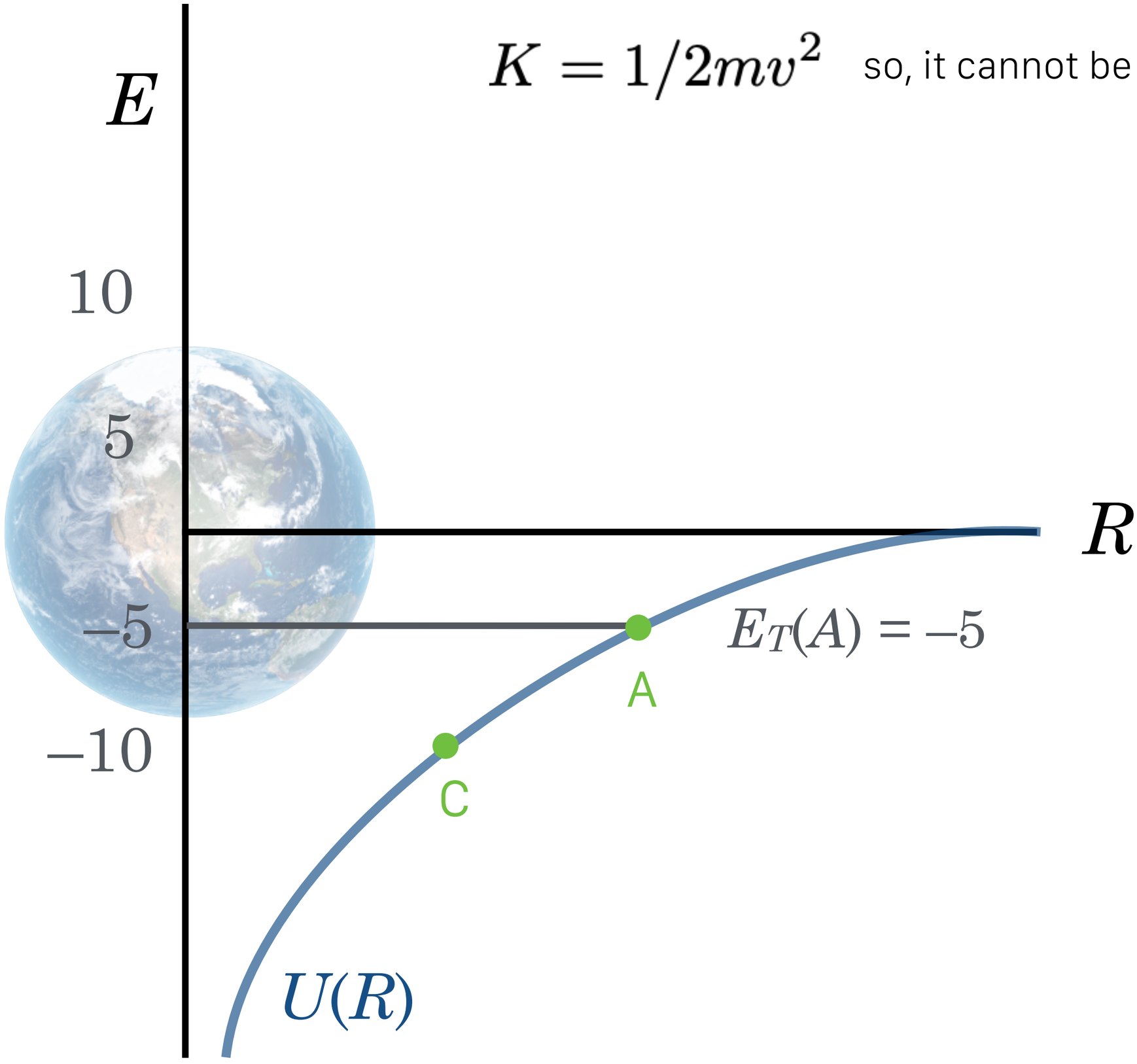
D 5

$$K = 1/2mv^2$$

so, it cannot be negative

wait.

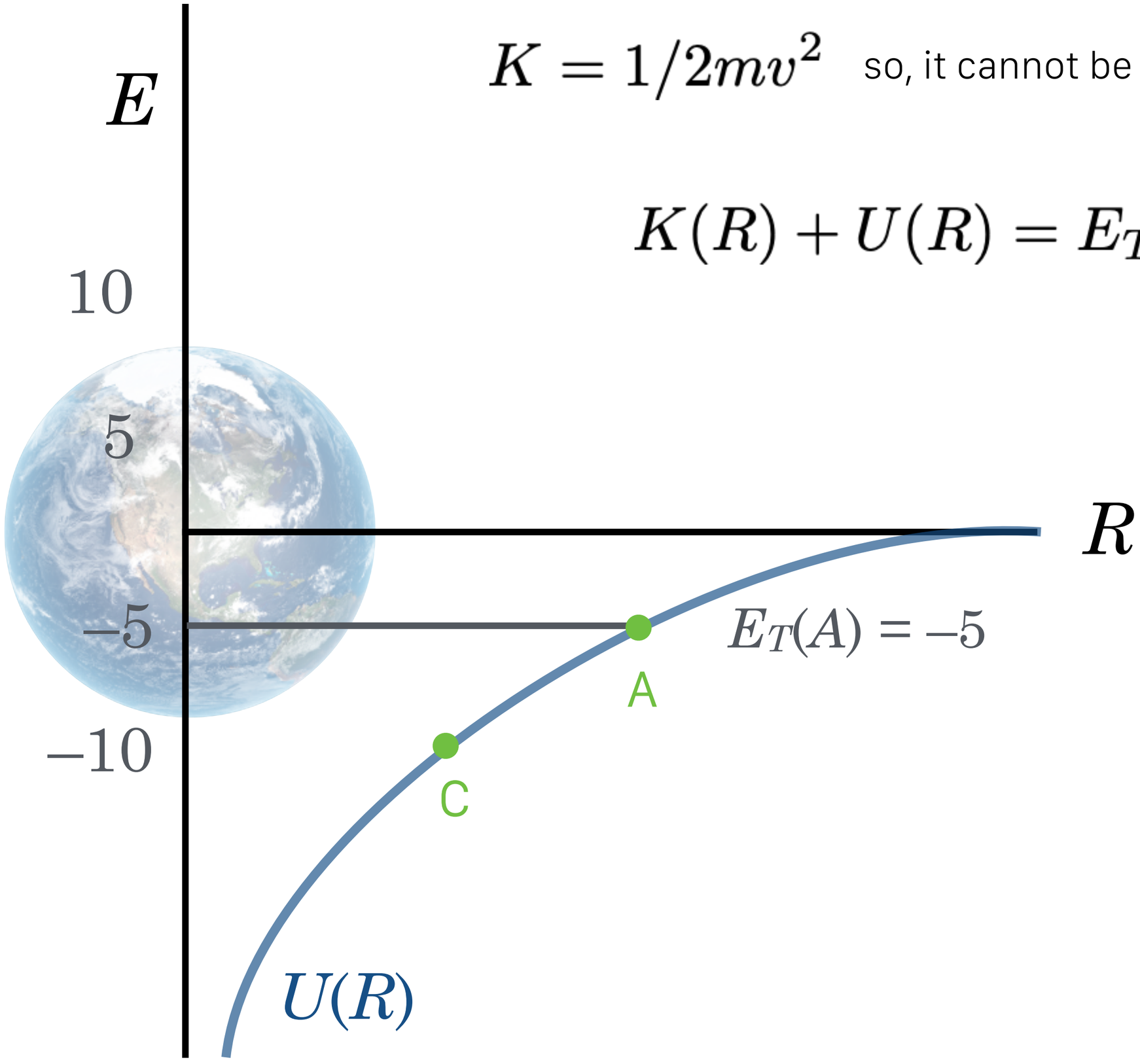
$K = 1/2mv^2$ so, it cannot be negative



wait.

$$K = 1/2mv^2$$ so, it cannot be negative

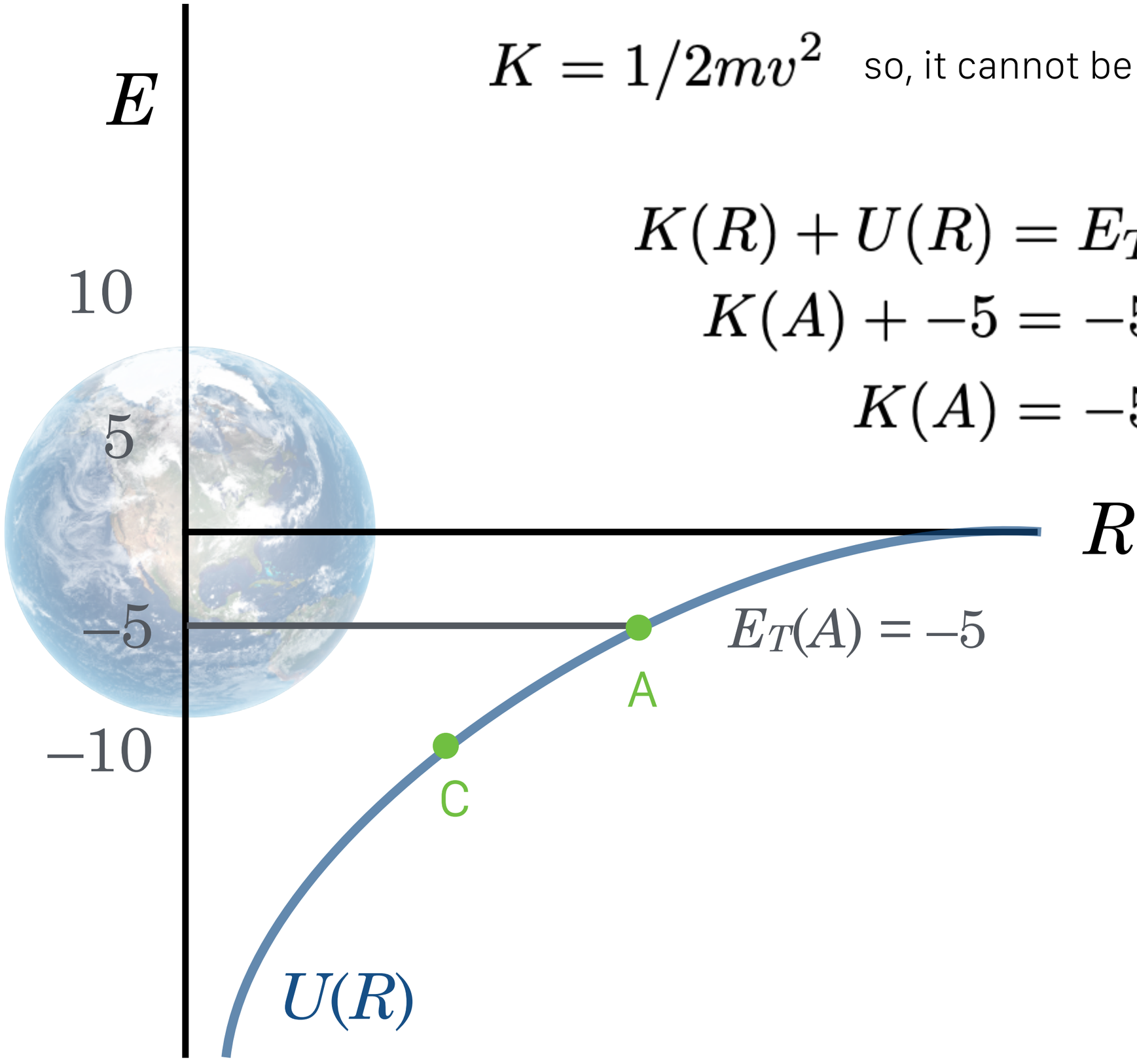
$$K(R) + U(R) = E_T$$



wait.

$K = 1/2mv^2$ so, it cannot be negative

$$K(R) + U(R) = E_T$$
$$K(A) + -5 = -5$$
$$K(A) = -5 + 5 = 0$$



wait.

$K = 1/2mv^2$ so, it cannot be negative

$$K(R) + U(R) = E_T$$
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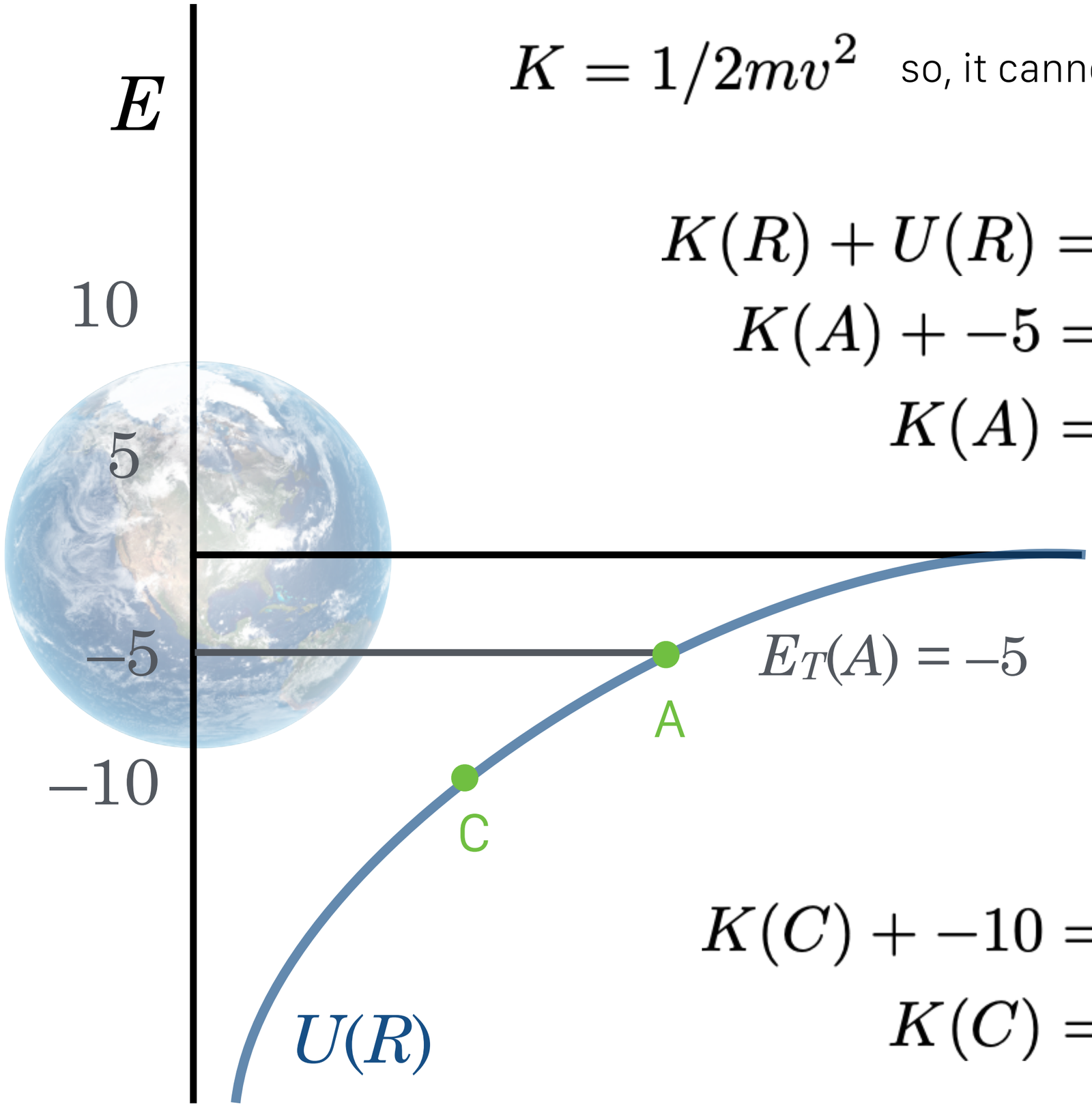
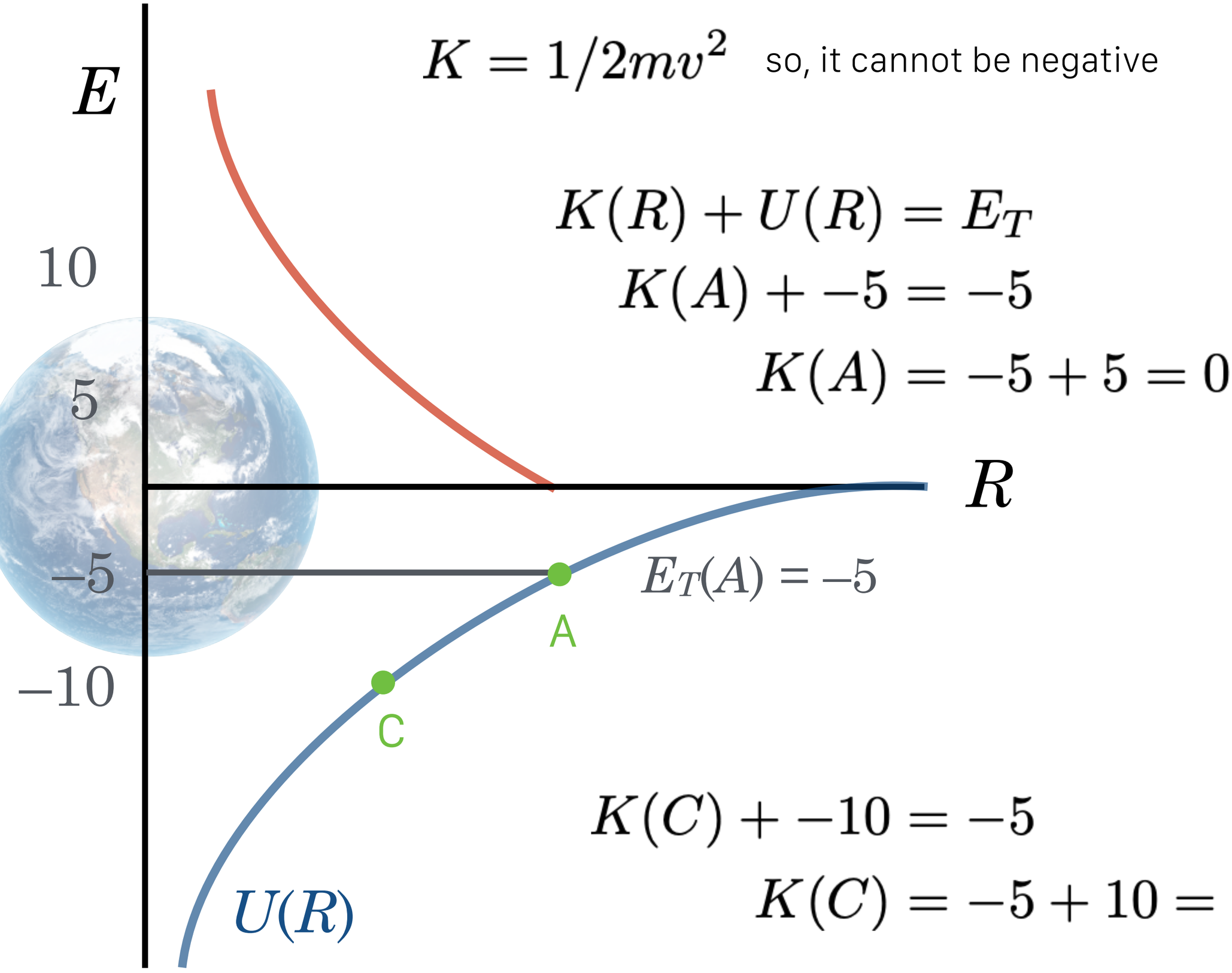


$$K(C) + -10 = -5$$
$$K(C) = -5 + 10 = 5$$

wait.

$K = 1/2mv^2$ so, it cannot be negative

$$K(R) + U(R) = E_T$$
$$K(A) + -5 = -5$$
$$K(A) = -5 + 5 = 0$$



$$K(C) + -10 = -5$$
$$K(C) = -5 + 10 = 5$$

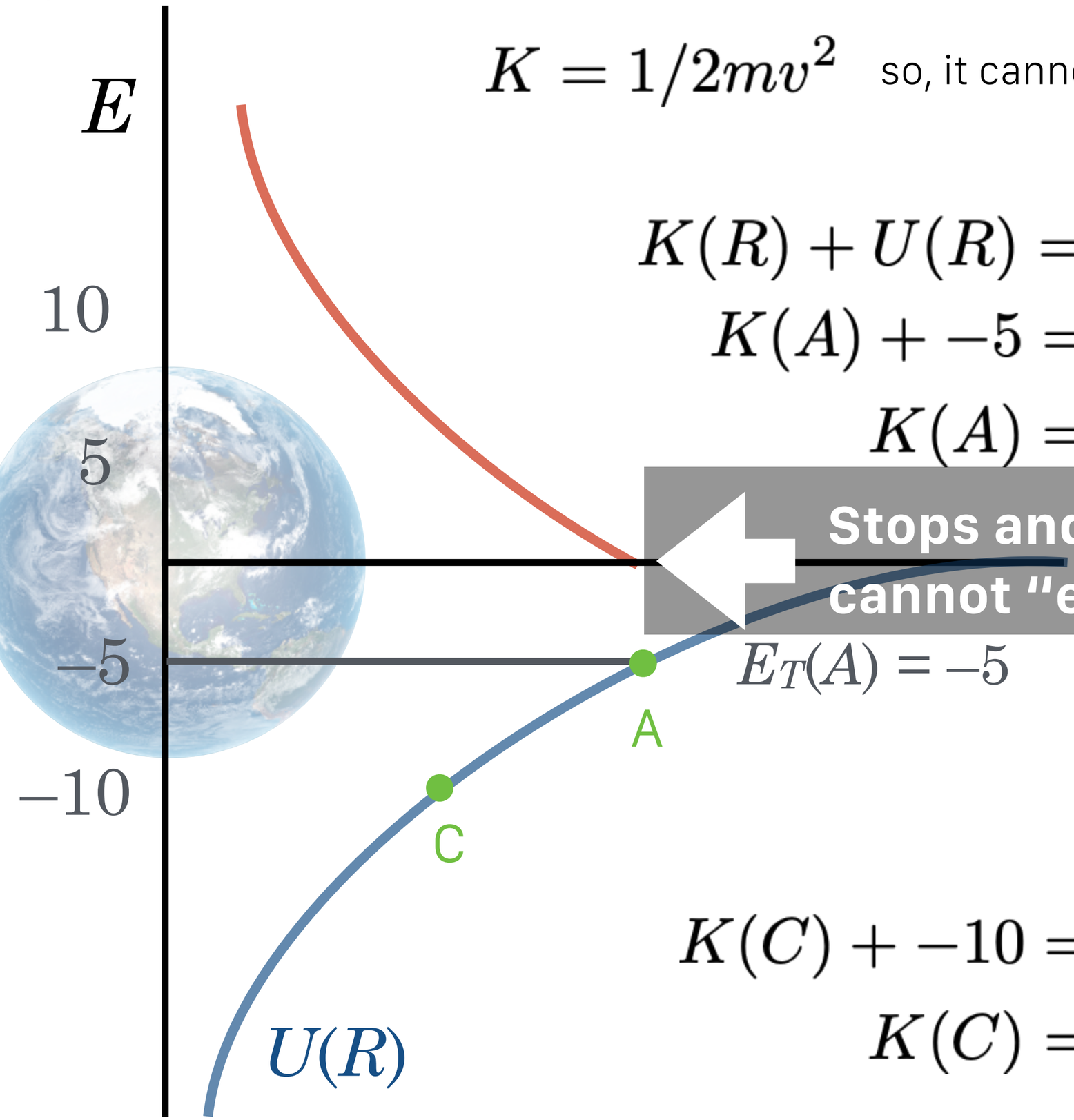
wait.

$$K = 1/2mv^2$$ so, it cannot be negative

$$K(R) + U(R) = E_T$$

$$K(A) + -5 = -5$$

$$K(A) = -5 + 5 = 0$$



Stops and turns around…
cannot "escape" Earth

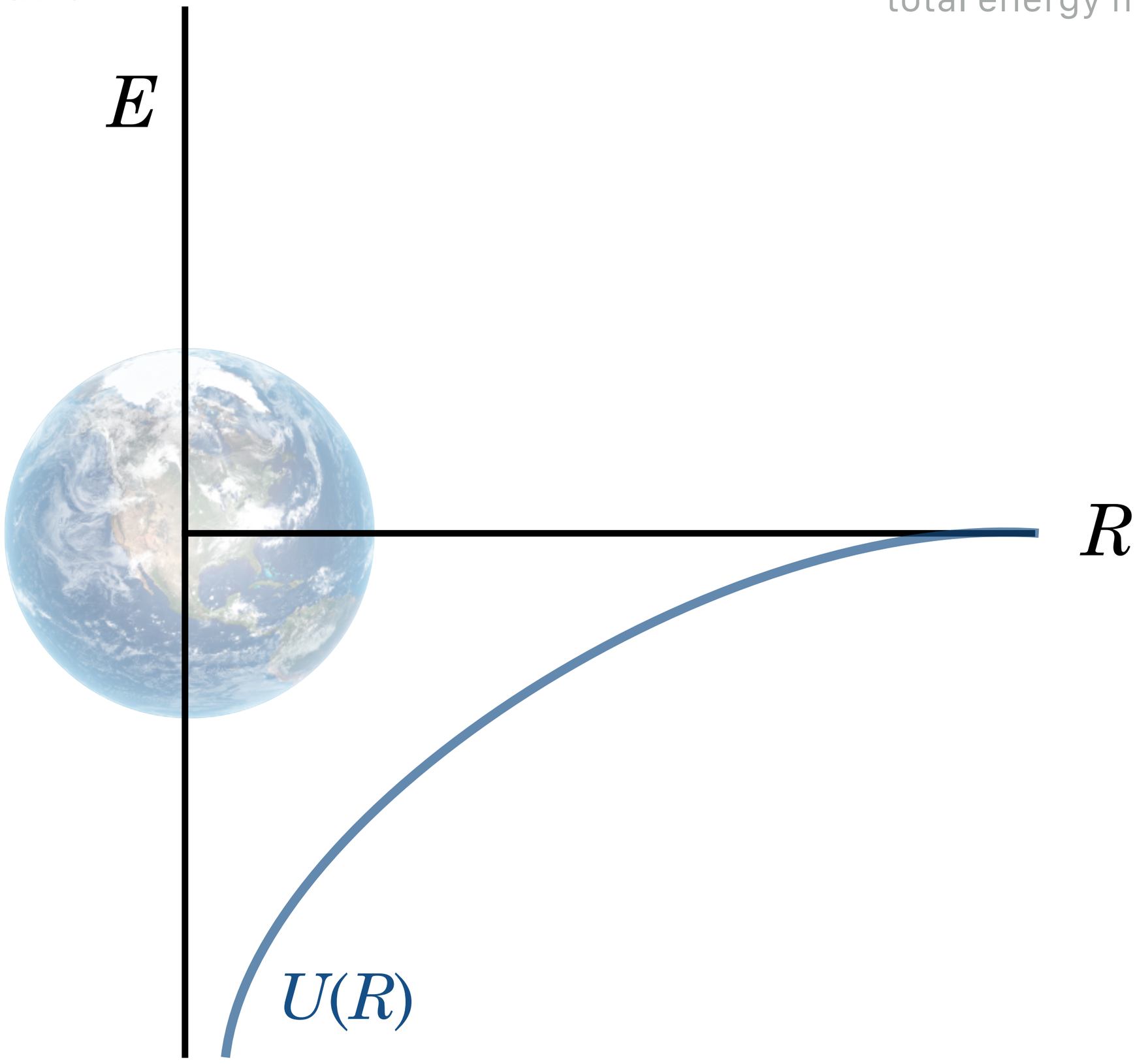
$$K(C) + -10 = -5$$

$$K(C) = -5 + 10 = 5$$

wait.

In order to escape Earth's pull

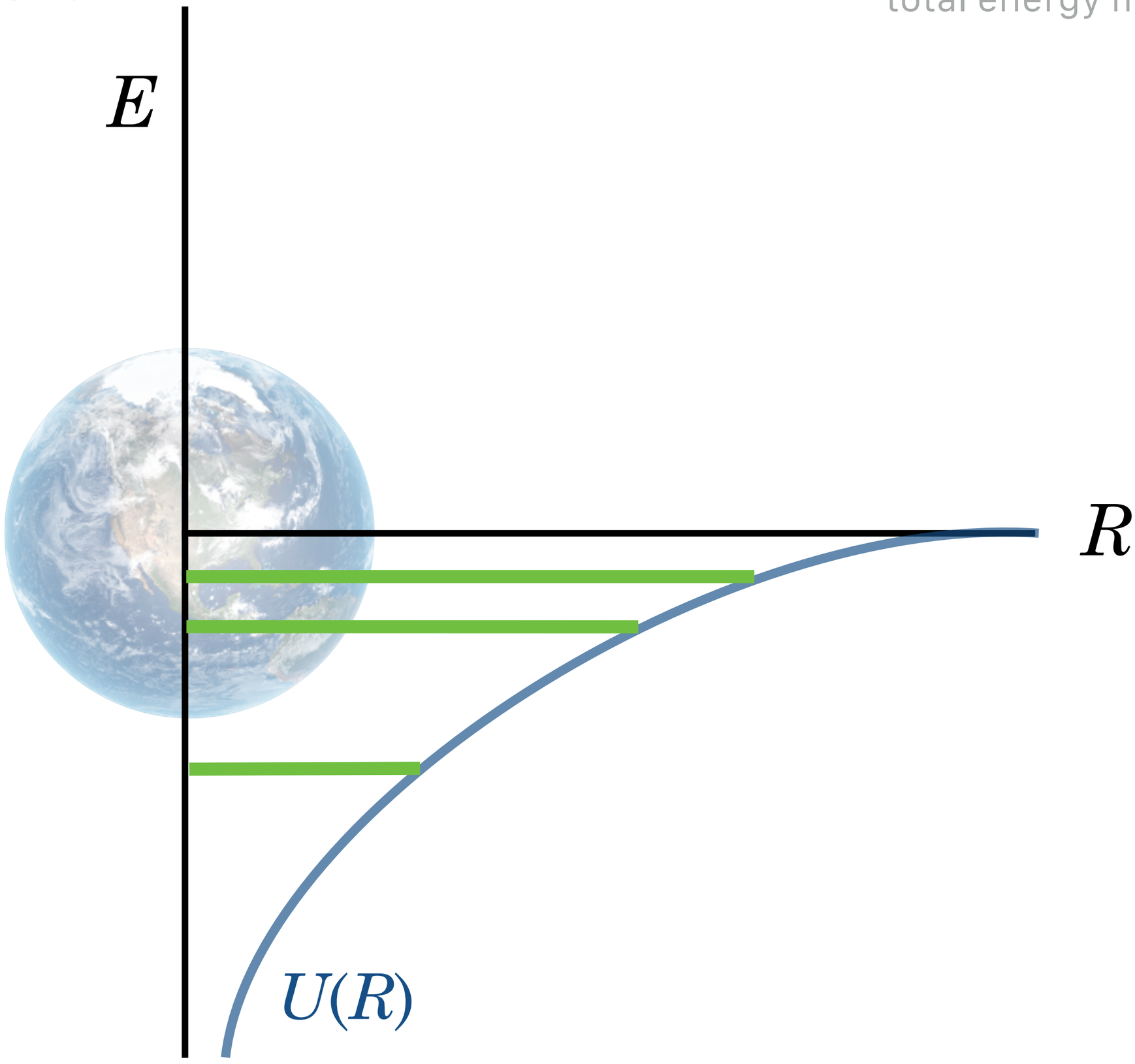
total energy must be >0 for all R



wait.

In order to escape Earth's pull

total energy must be >0 for all R



wait.

In order to escape Earth's pull

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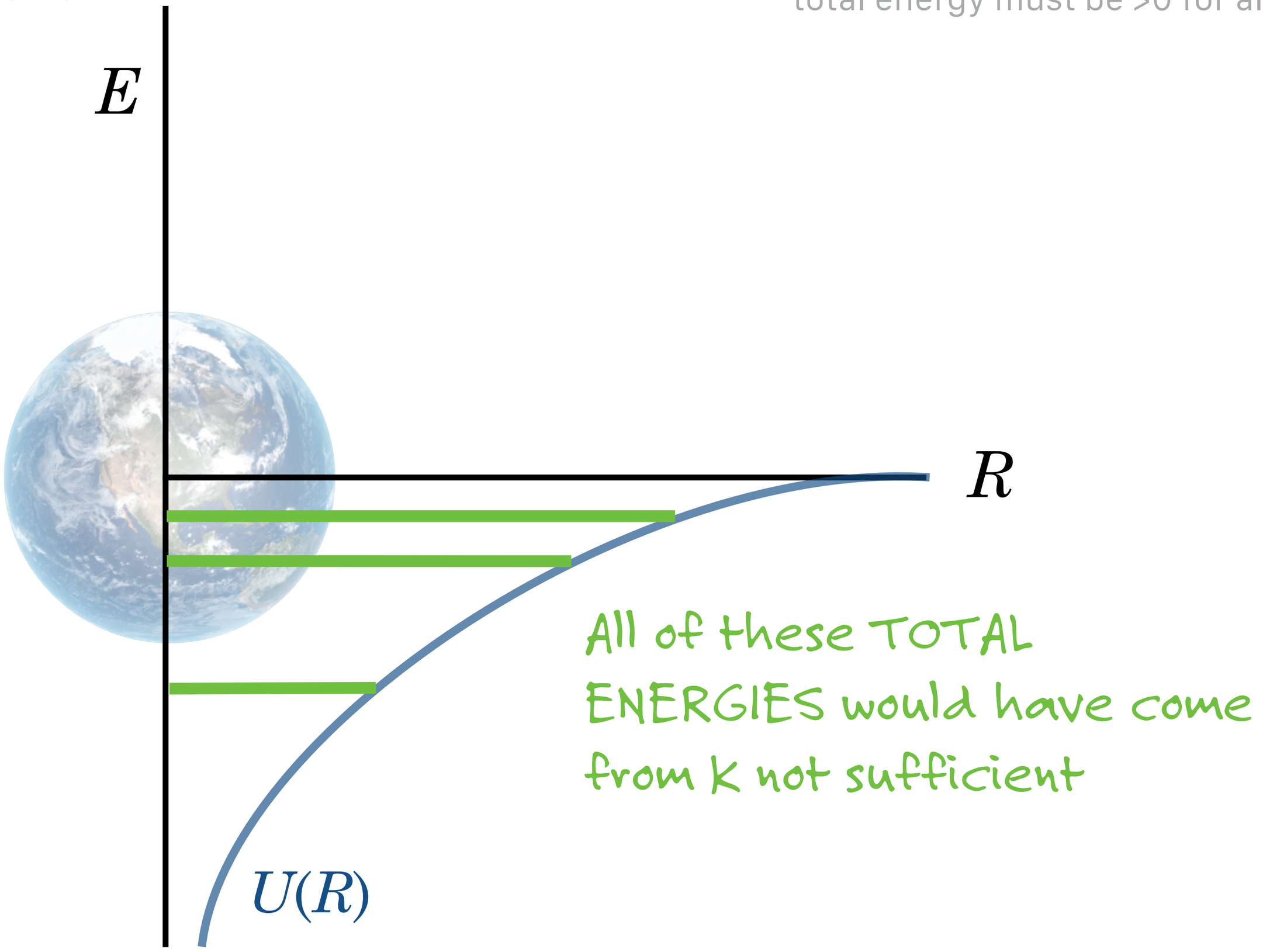
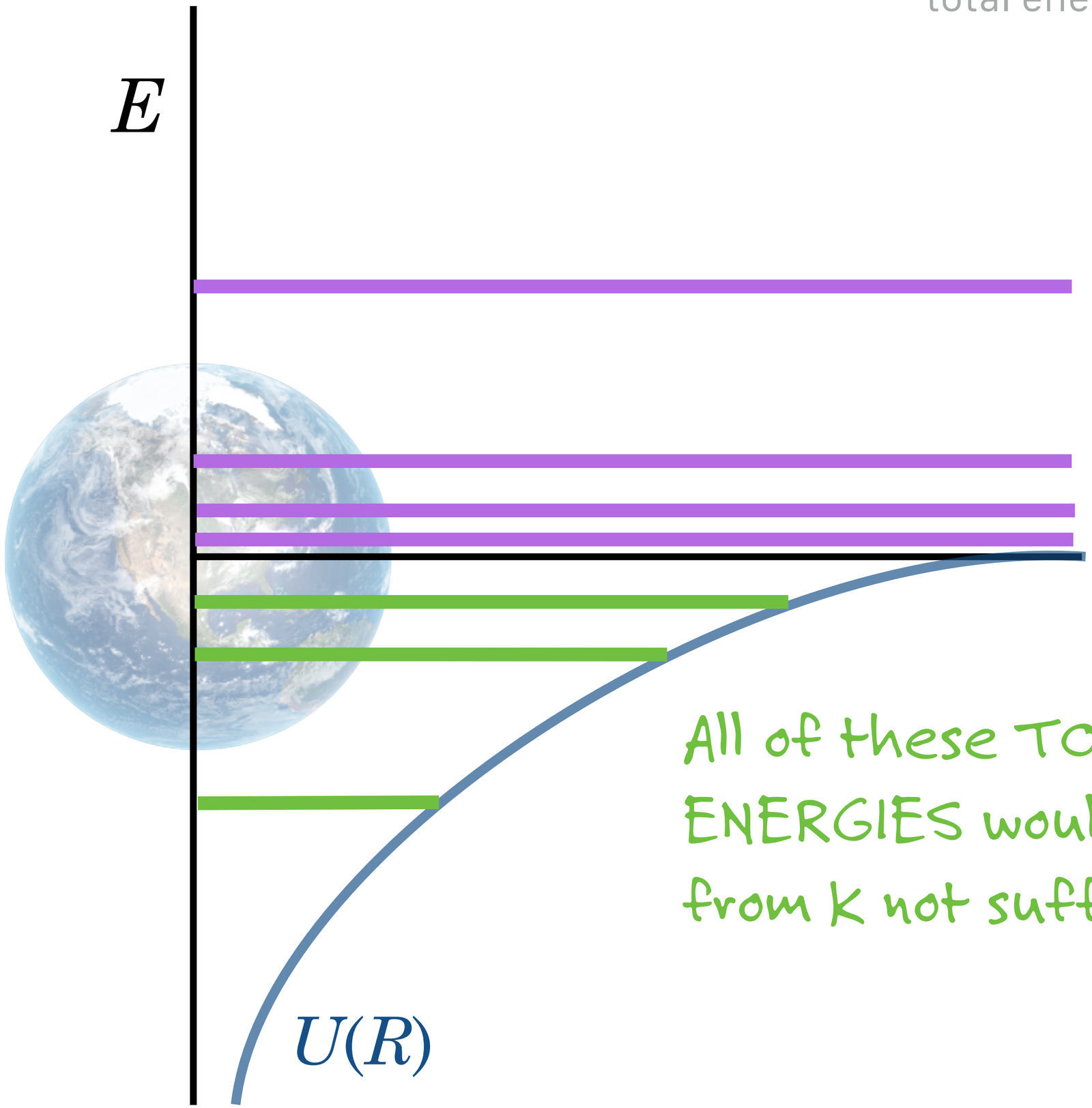


All of these TOTAL ENERGIES would have come from K not sufficient

wait.

In order to escape Earth's pull

total energy must be >0 for all R

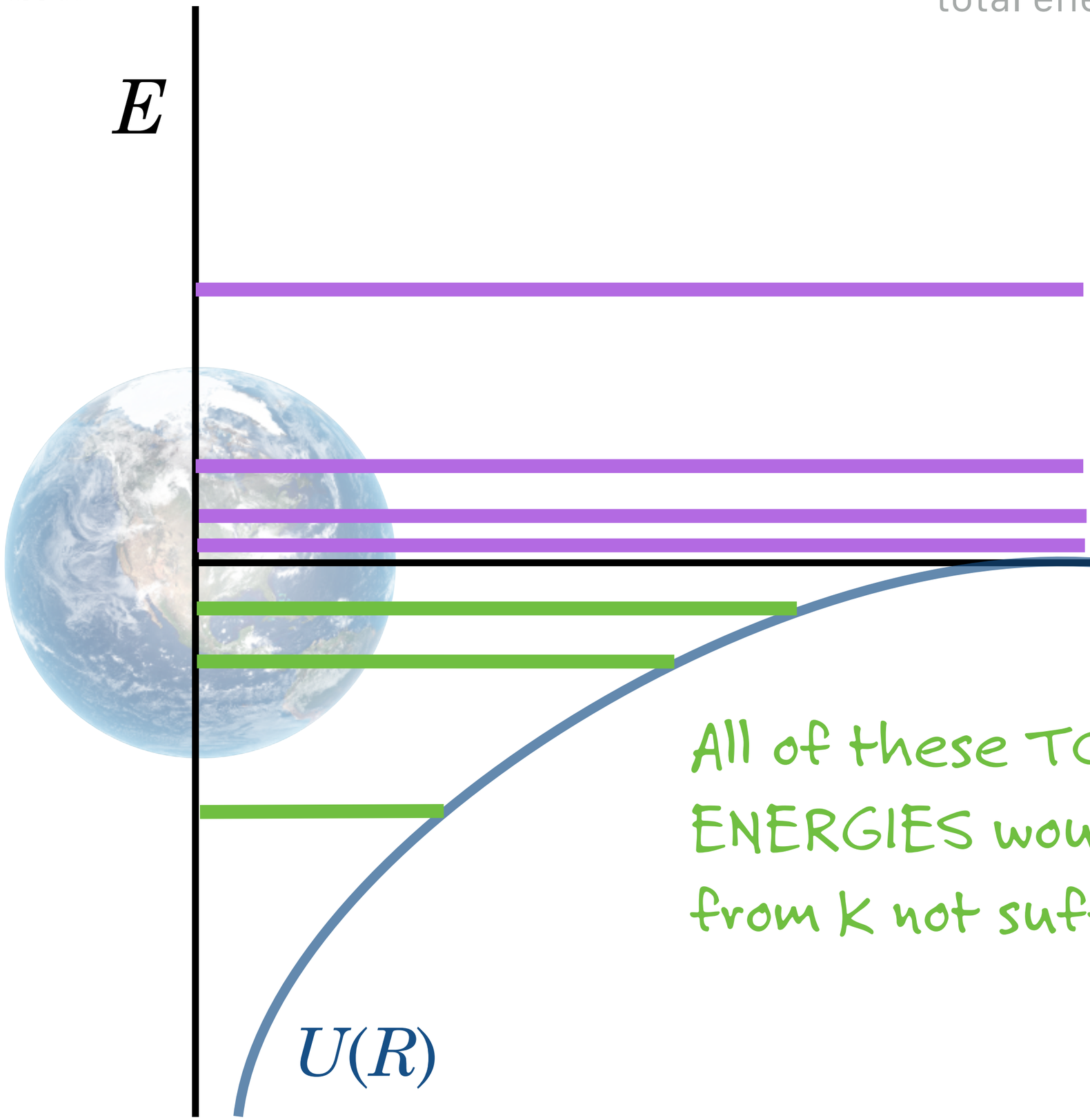


All of these TOTAL ENERGIES would have come from K not sufficient

wait.

In order to escape Earth's pull

total energy must be >0 for all R



K is large enough for these E_T to represent escape from Earth's gravity

All of these TOTAL ENERGIES would have come from K not sufficient

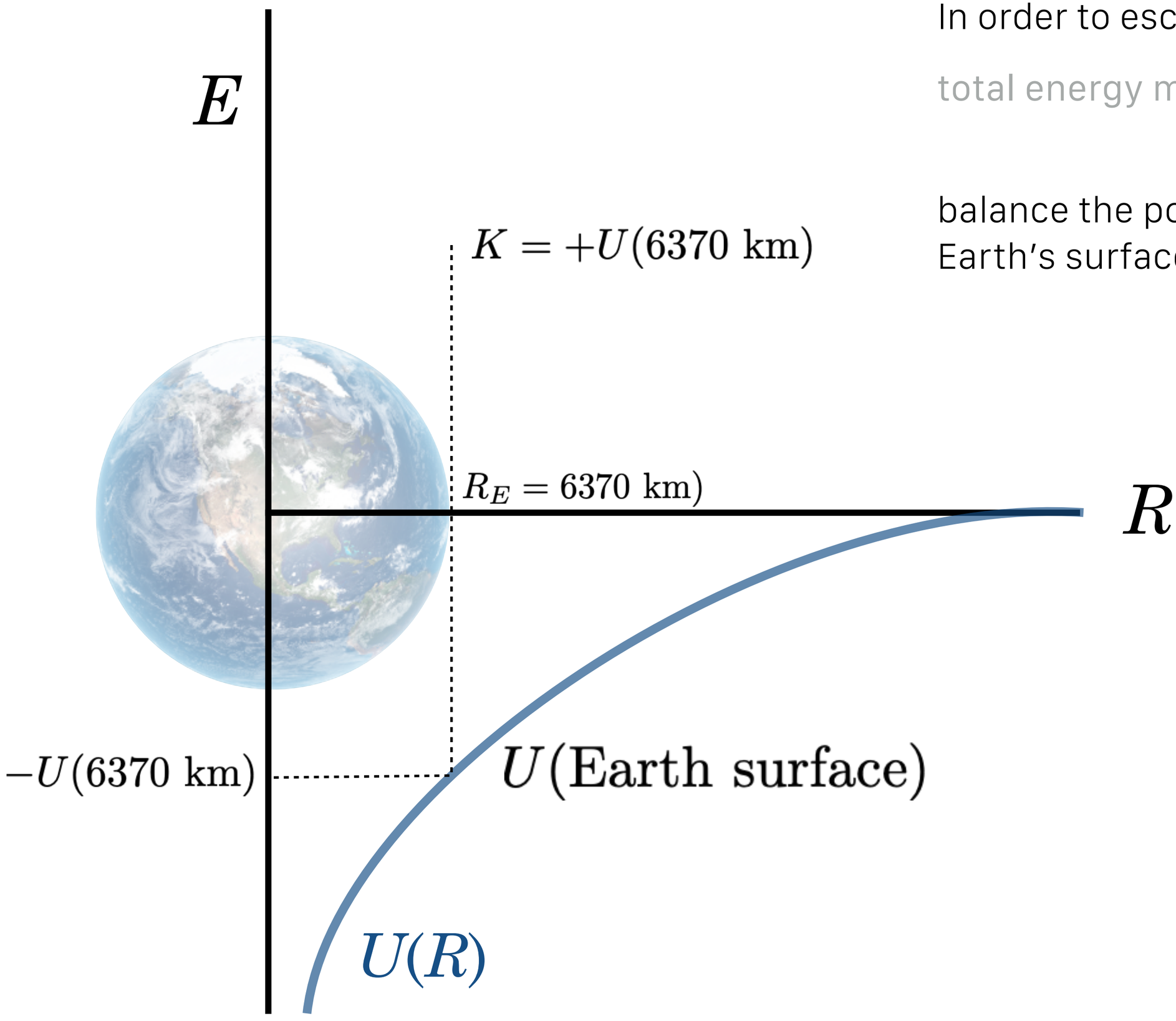
In order to escape the Earth’s gravity

The kinetic energy of a rocket must be enough so that E_T is always positive

that minimum speed is called the Escape Velocity

different for every massive “host”

Escape Velocity.



In order to escape Earth's pull

total energy must be >0 for all R

balance the potential energy at the Earth's surface

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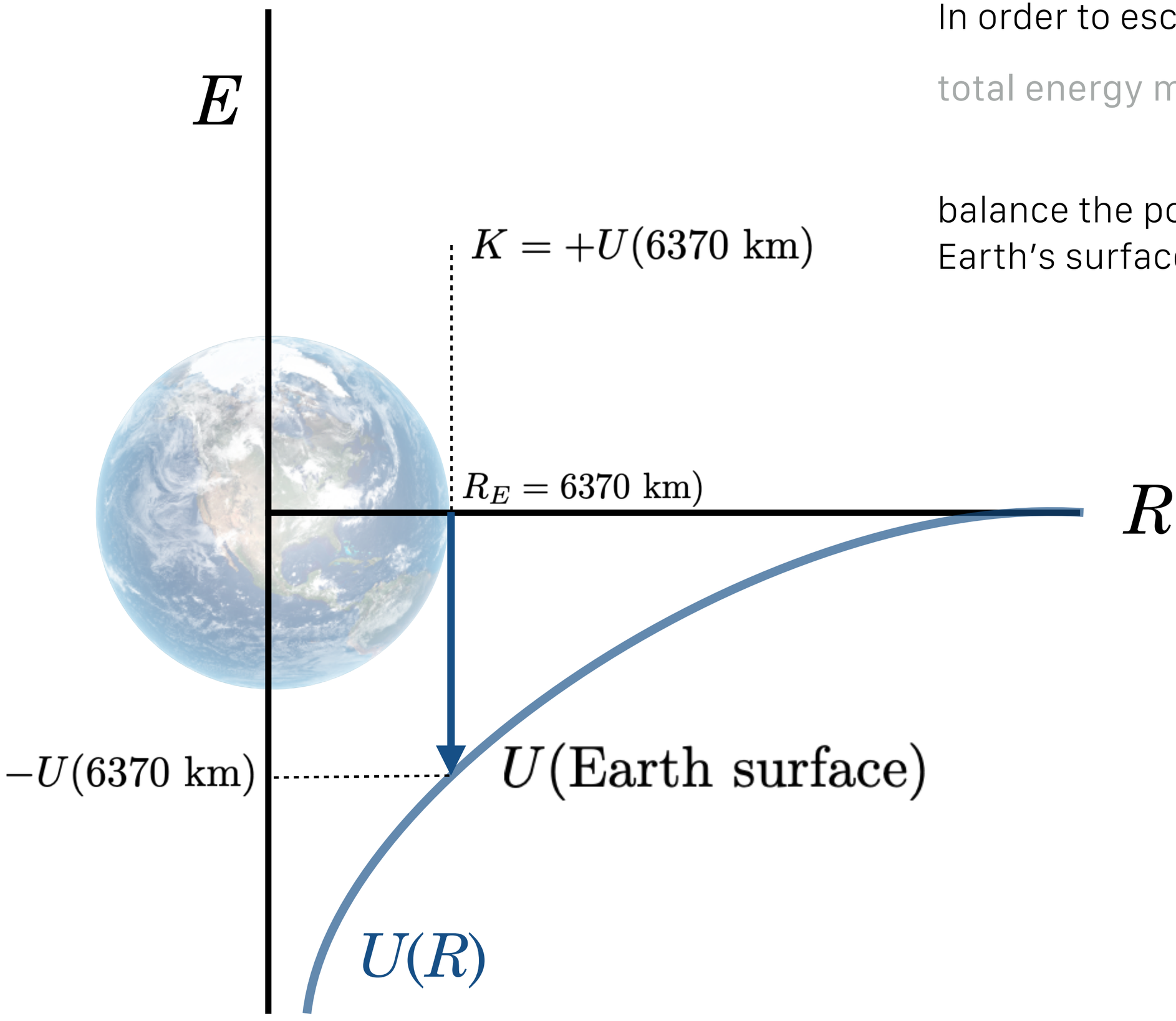

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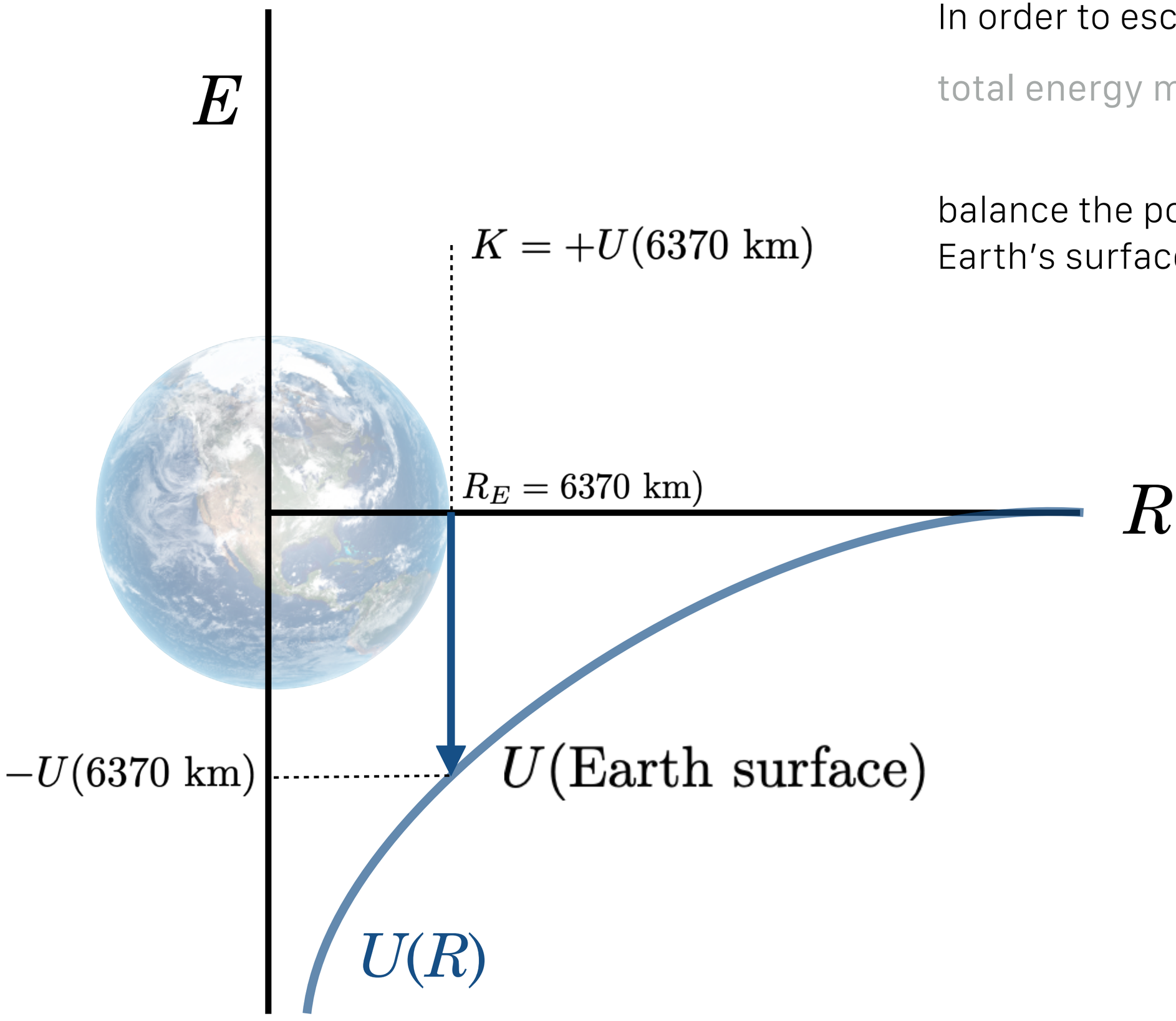

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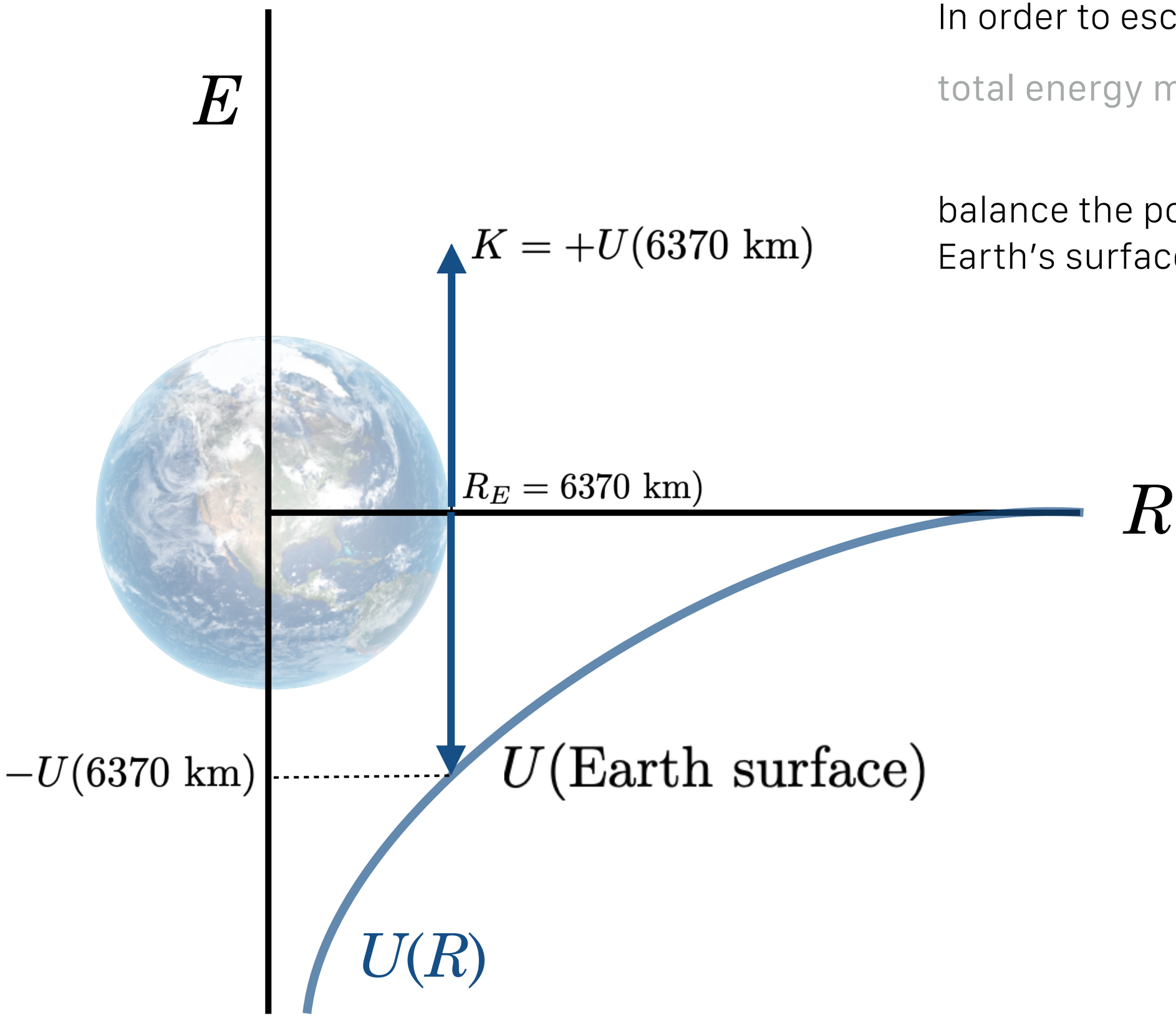

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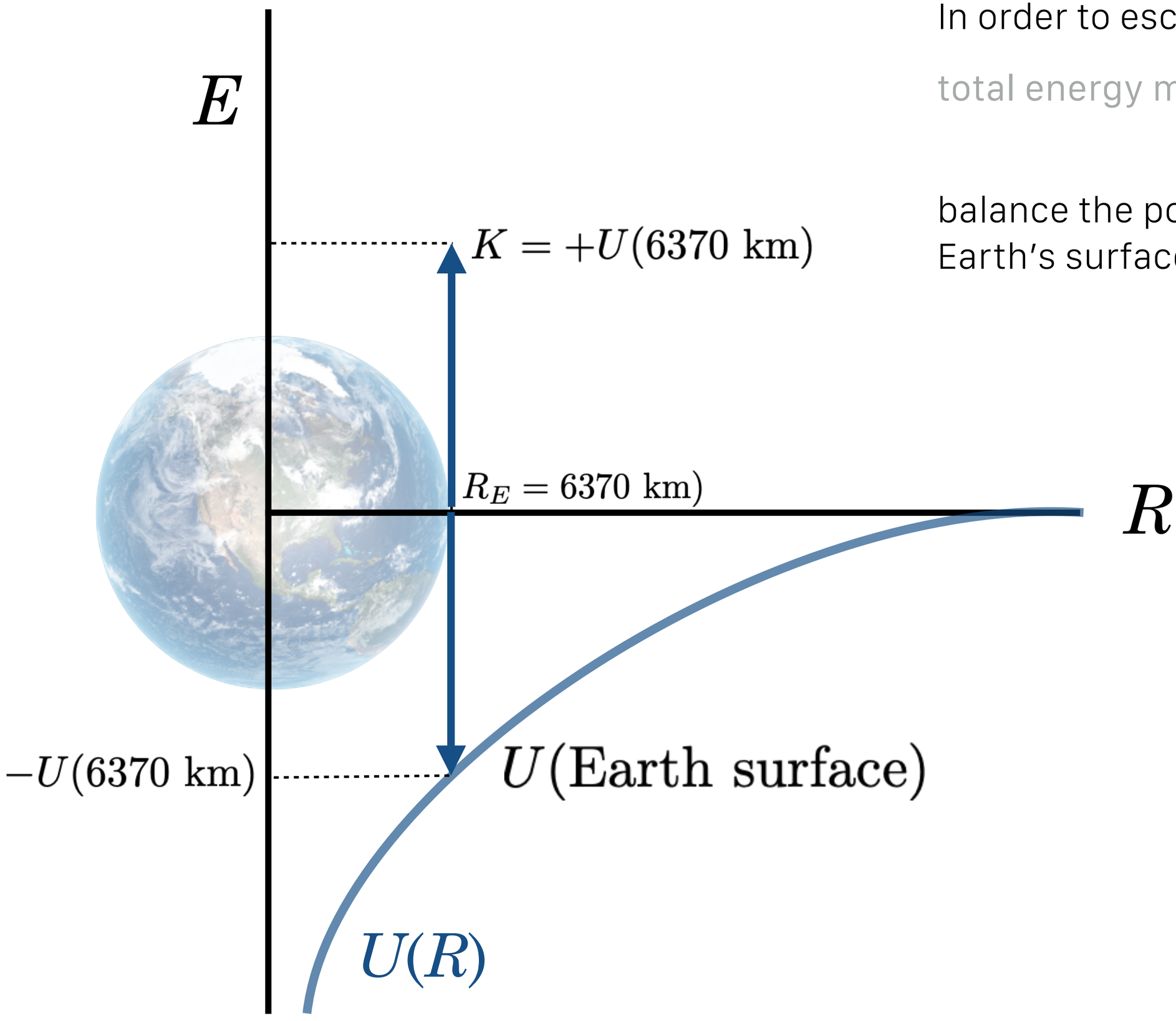

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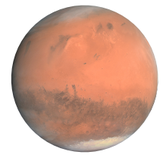
🖋 our first “pencils out” experience.

Newton had 3 issues:

1. "Action at a distance"
2. Stability of the Universe
3. Absolute Space and Time

1. Action at a Distance



1. Action at a Distance

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Step 1: what mechanism is gravity?

Step 2: derive the rule

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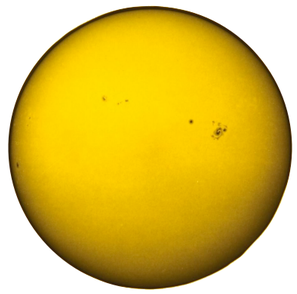

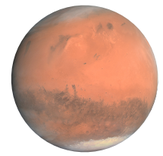

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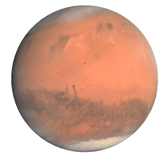

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BUT:

IT WORKS

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“I feign no hypotheses.”

hypotheses non fingo

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At this moment, physics becomes possible.

IT WORKS

“I feign no hypotheses.”

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At this moment, physics becomes possible.

“How" more important than “Why."

2. Stability of the Universe

He had a cosmology

of sorts

backed into a corner by his own mathematics

Major conclusion:

The universe must be infinite and static.

because the $\frac{1}{R^2}$ force is infinite in extent

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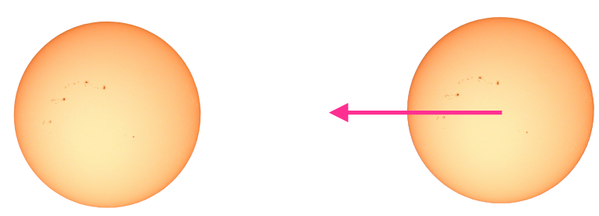

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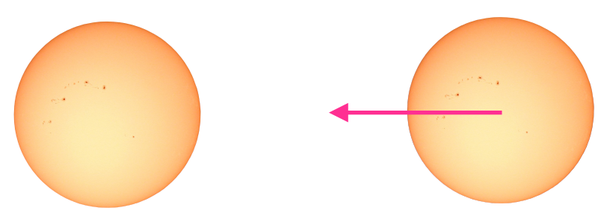

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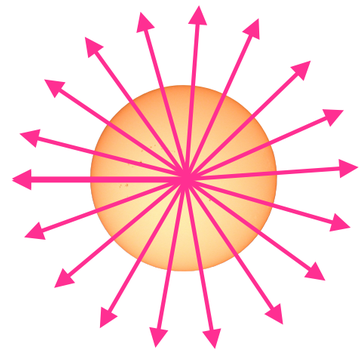

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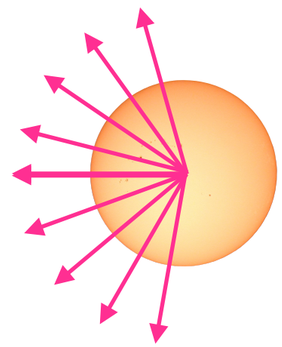

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it all seems very unstable

even the slightest jiggle…and the whole mess would unleash!

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Newton basically concludes:

that’s God’s job. Hold everything together

3. Absolute Space

what is Space?

Old question.

Greeks and contemporaries:

space is an accounting scheme—what separates things

without objects...no space: Greeks, Leibniz

conundrums 1687

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velocity seems …"relative"

you detect steady velocity only by comparison with other objects

and no particular velocity is special

conundrums 1687

velocity seems …"relative"

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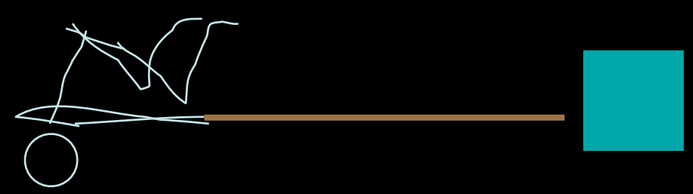
acceleration?

notsomuch.

you detect changes in velocity…sort of innately

as if there's a special reference for comparison



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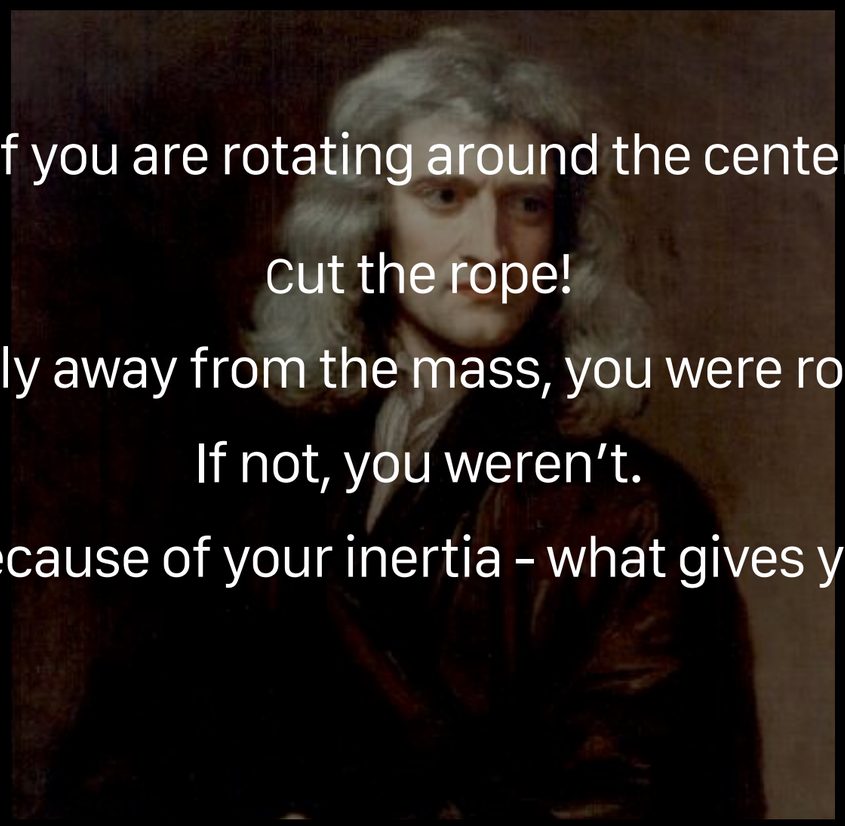

How can you tell if you are rotating around the center, ie *accelerating*?

Cut the rope!

If you fly away from the mass, you were rotating.

If not, you weren’t.

Why? Because of your inertia - what gives you that?

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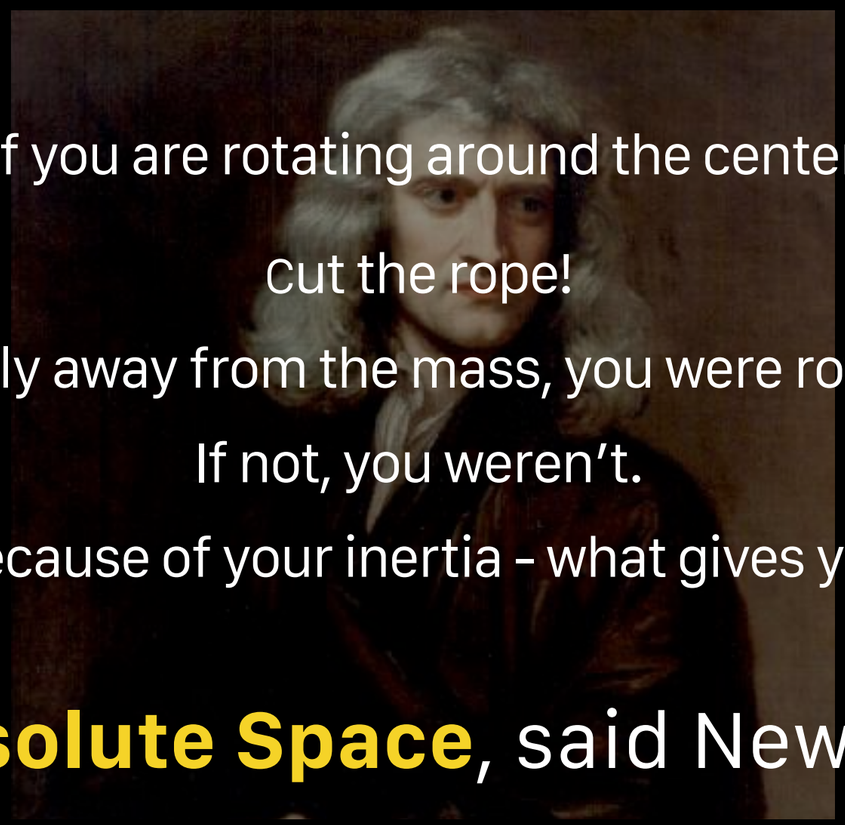

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Absolute Space, said Newton

for Newton

for Newton

Space is a Thing.

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Space is a Thing.

An infinitely big thing.

the accelerated reference frame is

accelerating with respect to Absolute Space

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Space is a Thing.

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All motion?

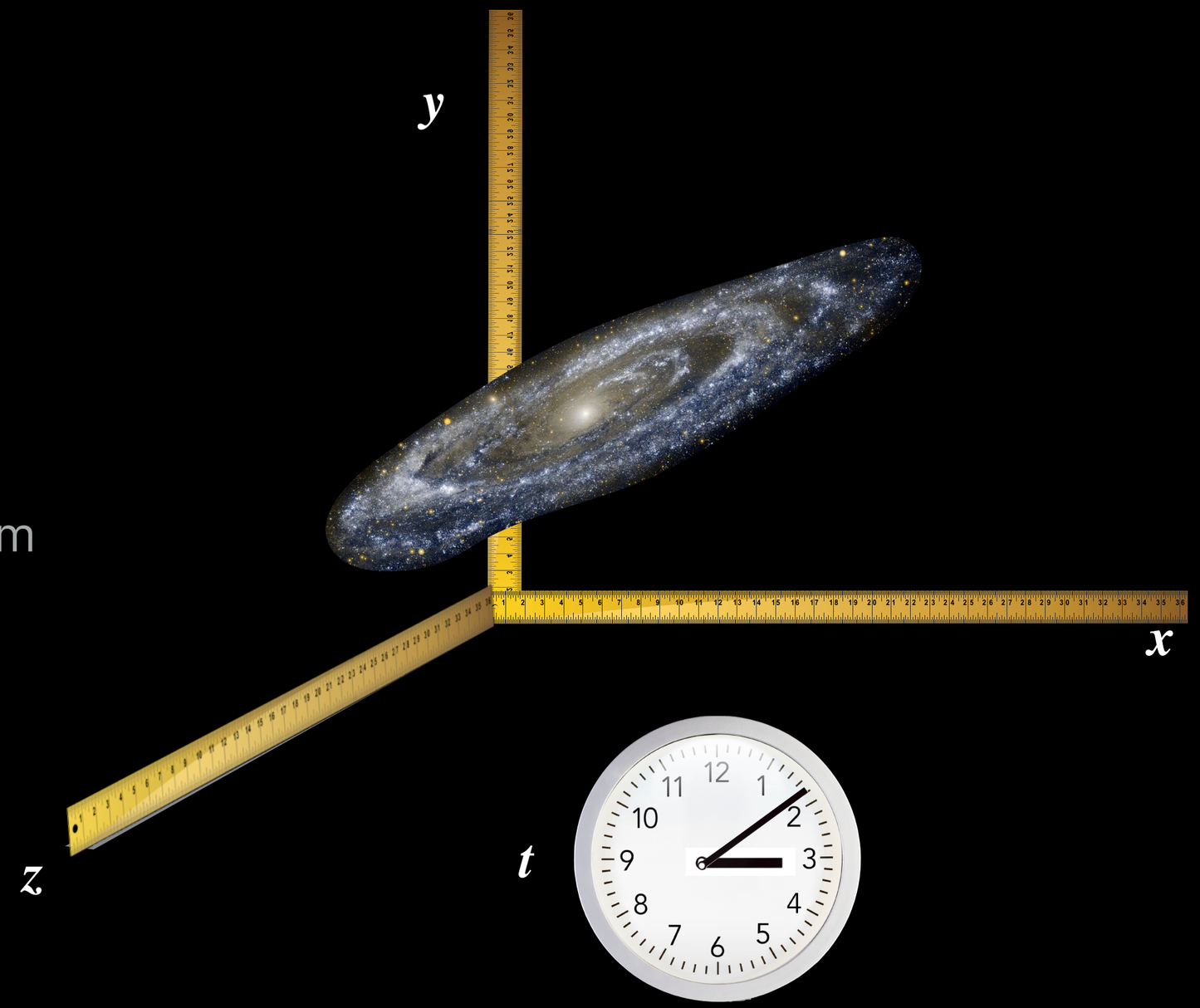
relative to that Big Coordinate System

3. Absolute Space and Time

are absolute

a universal coordinate system

a universal clock



follow-on to Newton

impact changed western civilization

no lie.

Newton’s telescope design

many solar-system discoveries

original 6 objects: Mercury, Venus, Earth, Moon, Mars, Jupiter, Saturn

17th century: 4 Jupiter moons, 5 Saturn moons

18th century: Uranus, 2 Uranus moons, 2 more Saturn moons

19th century: Neptune, 1 Neptune moon, 2 more Saturn moons, 2 Mars moons, 1 Jupiter moon

20th century: 12 more Jupiter moons, 7 Neptune moons, Pluto, 12 more Saturn moons, 16 Uranus moons

21st century: 35 more Saturn moons, 35 more Jupiter moons, 7 more Neptune moons, 4 Pluto moons, 7 more Uranus moons, plus a brand new planet (last week)?

+ >2000 exoplanets

predictions and confirmations galore

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Resistive media

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tides (moon and earth)

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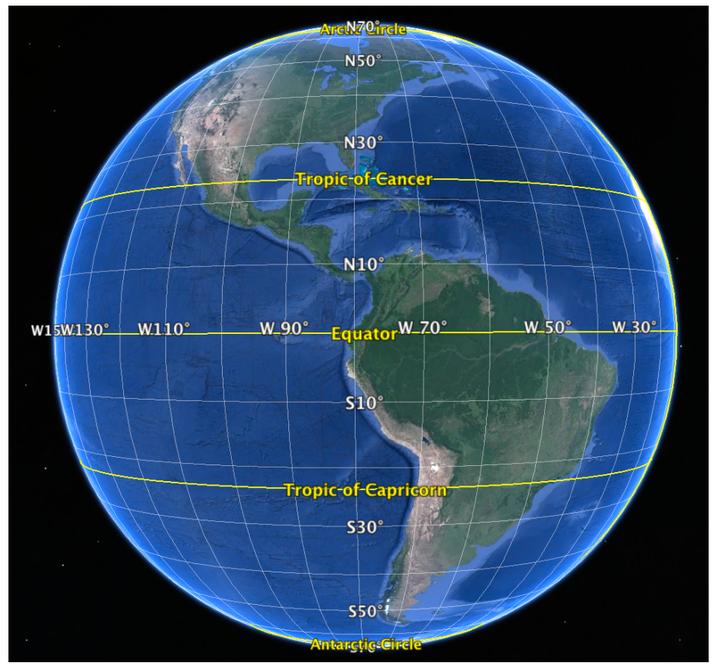

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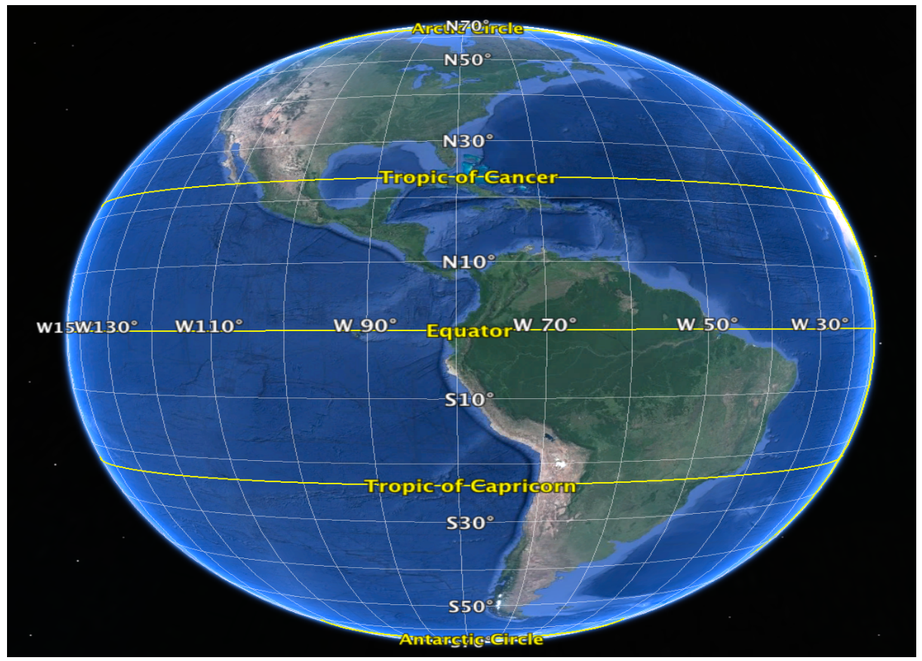

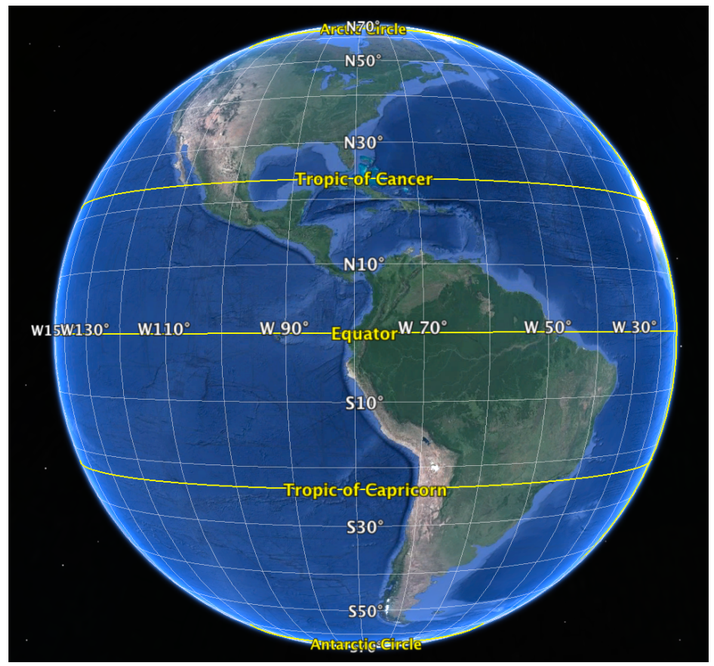

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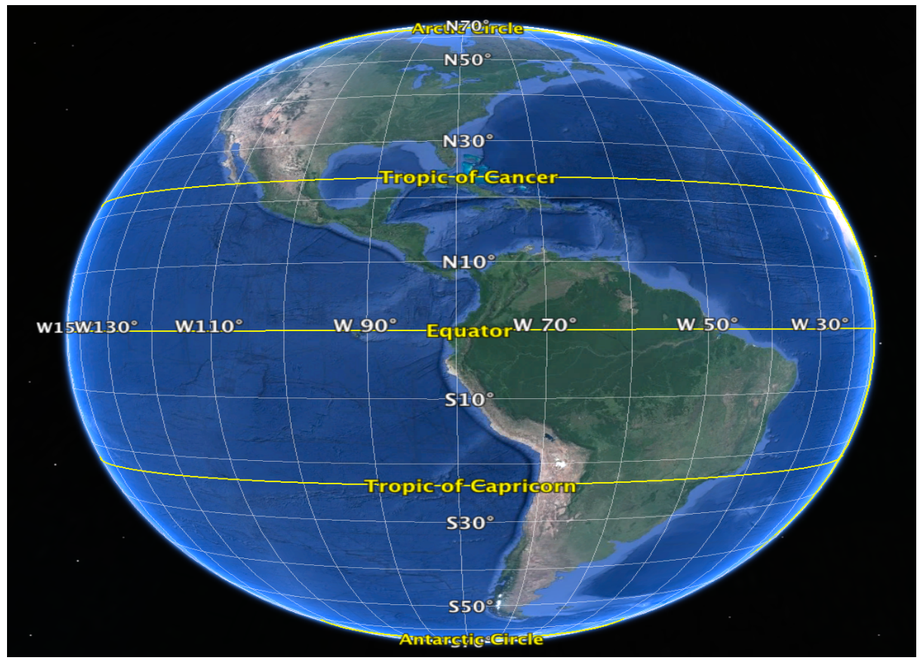

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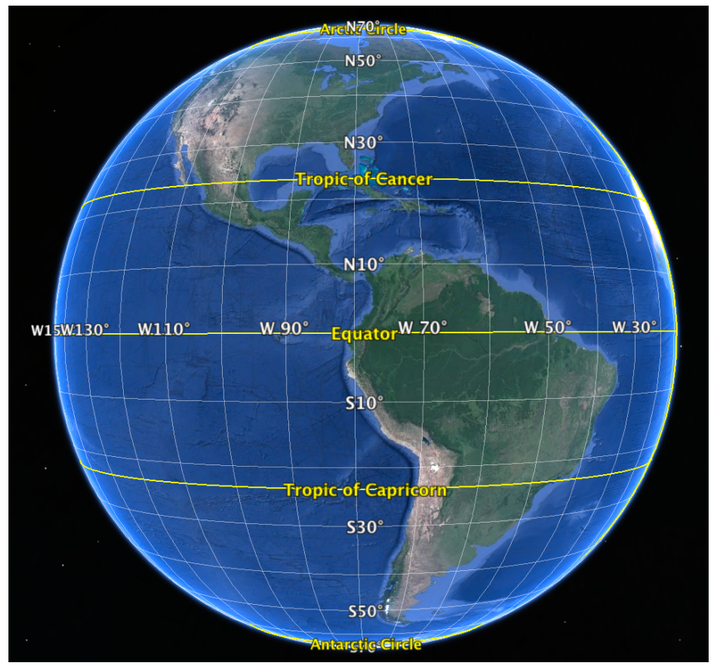

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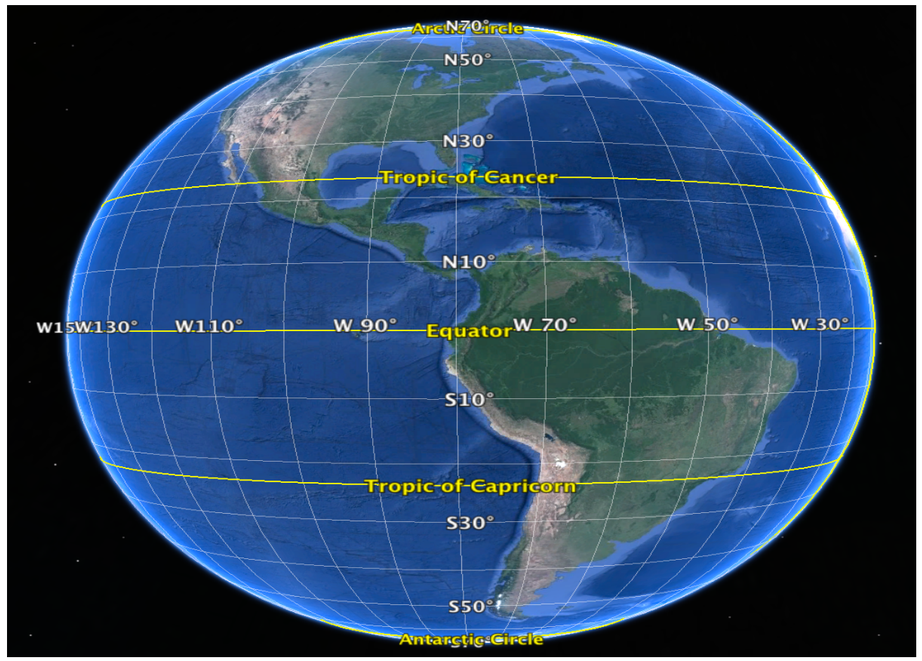

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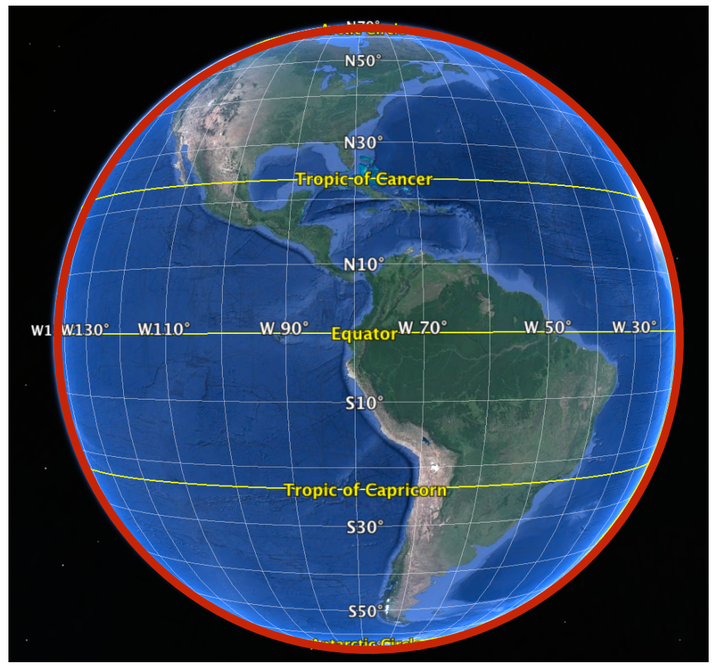

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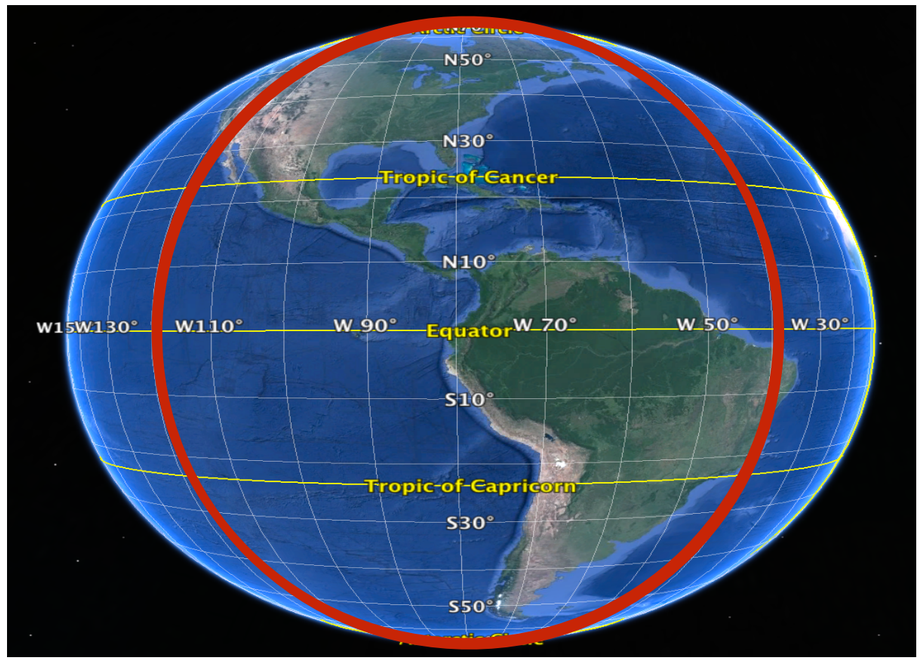

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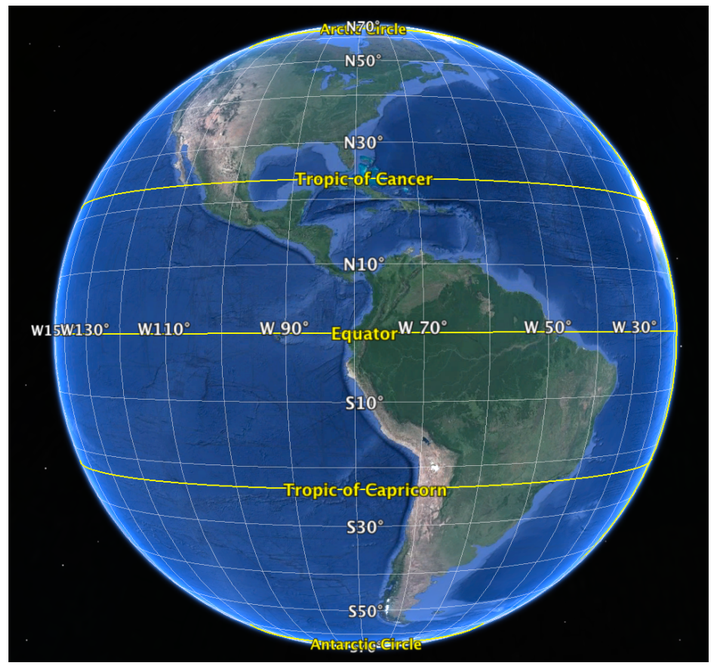

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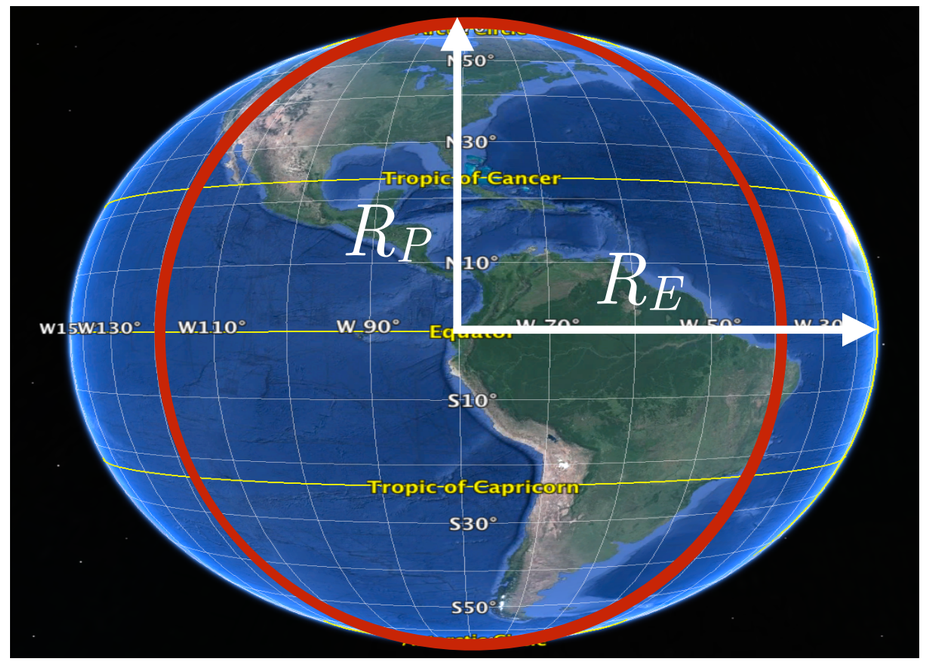

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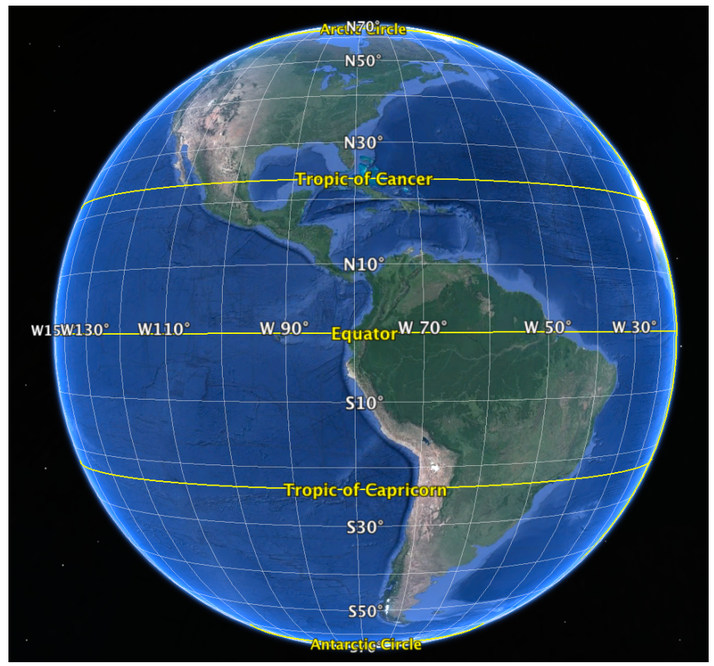

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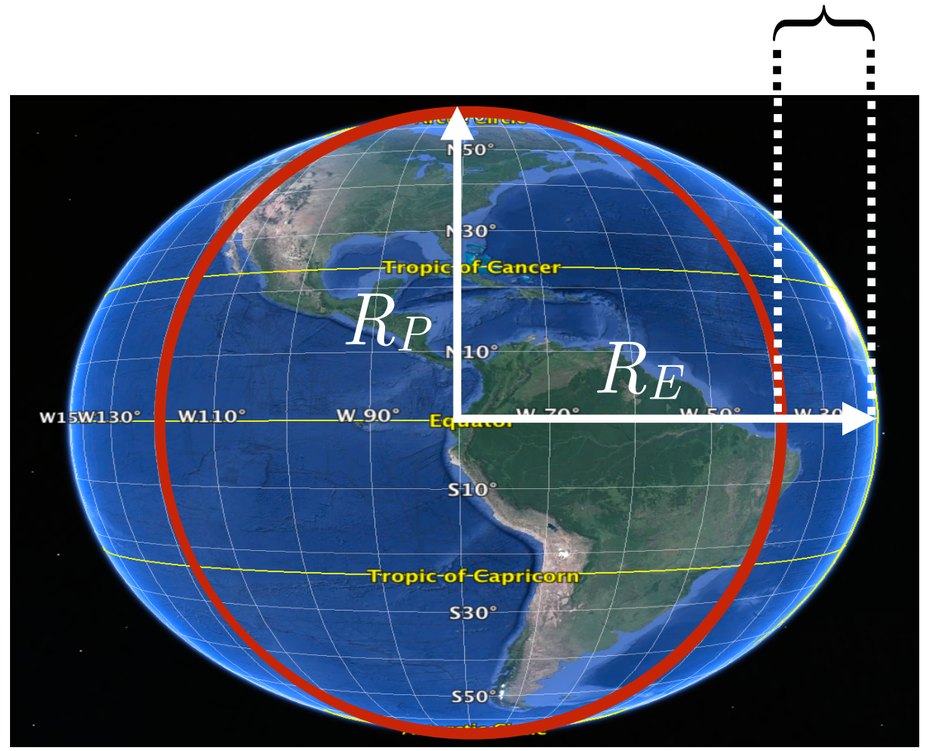

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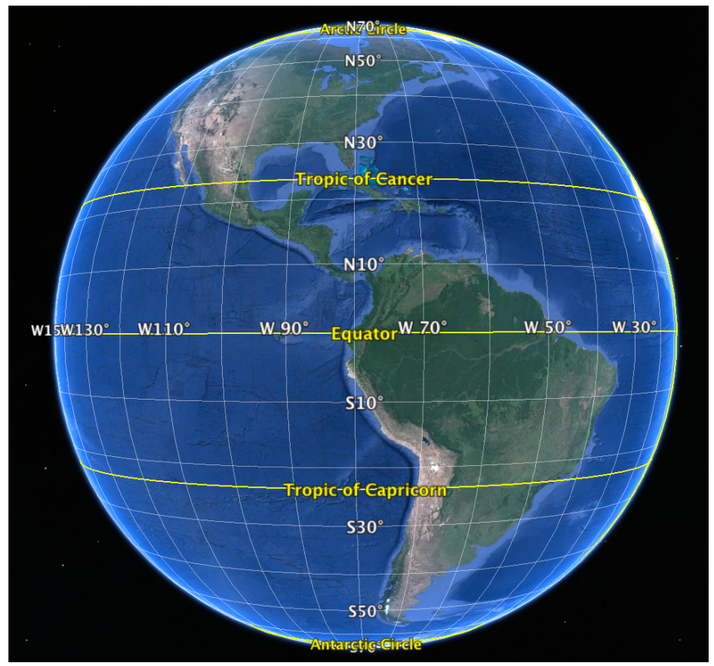

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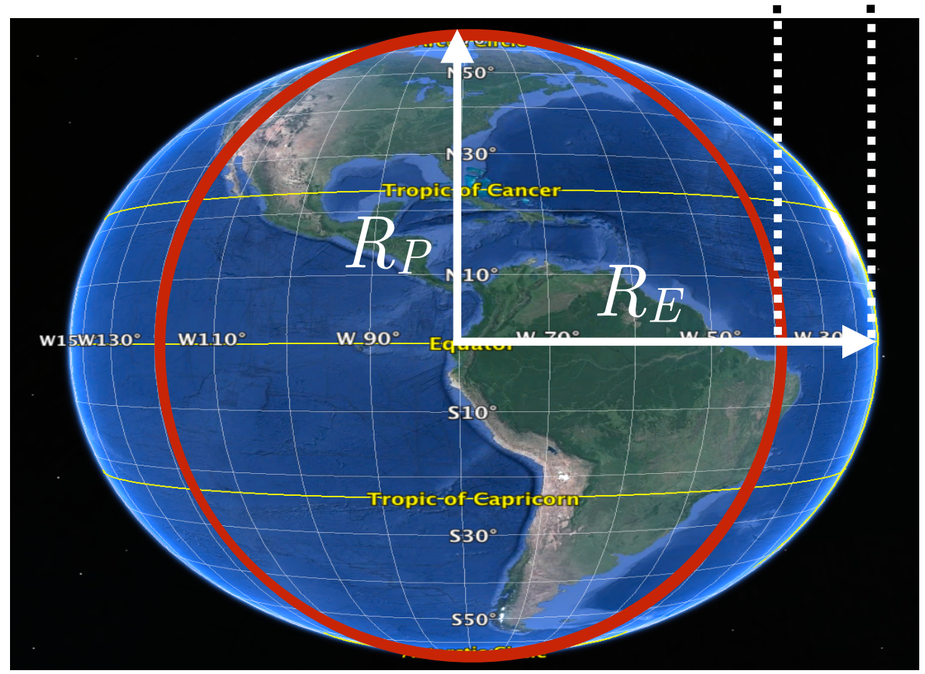

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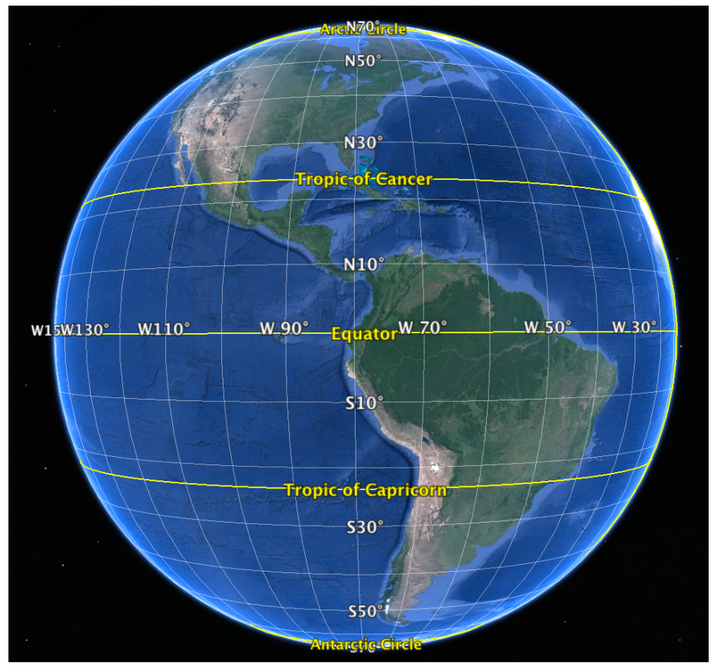

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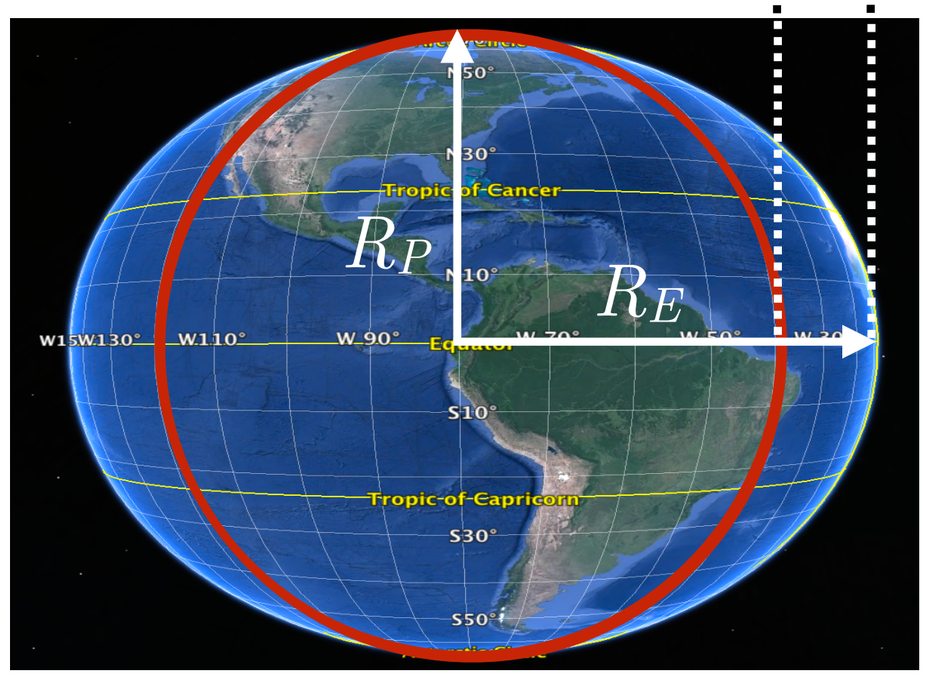

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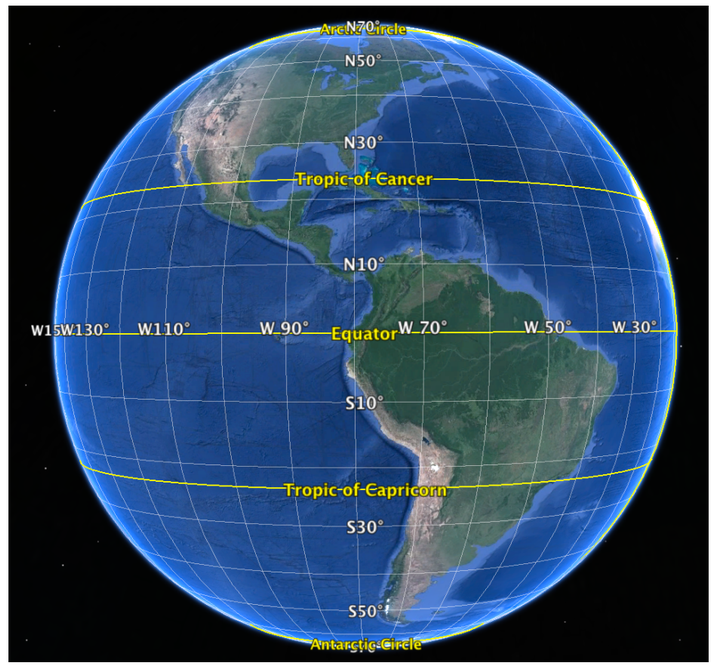

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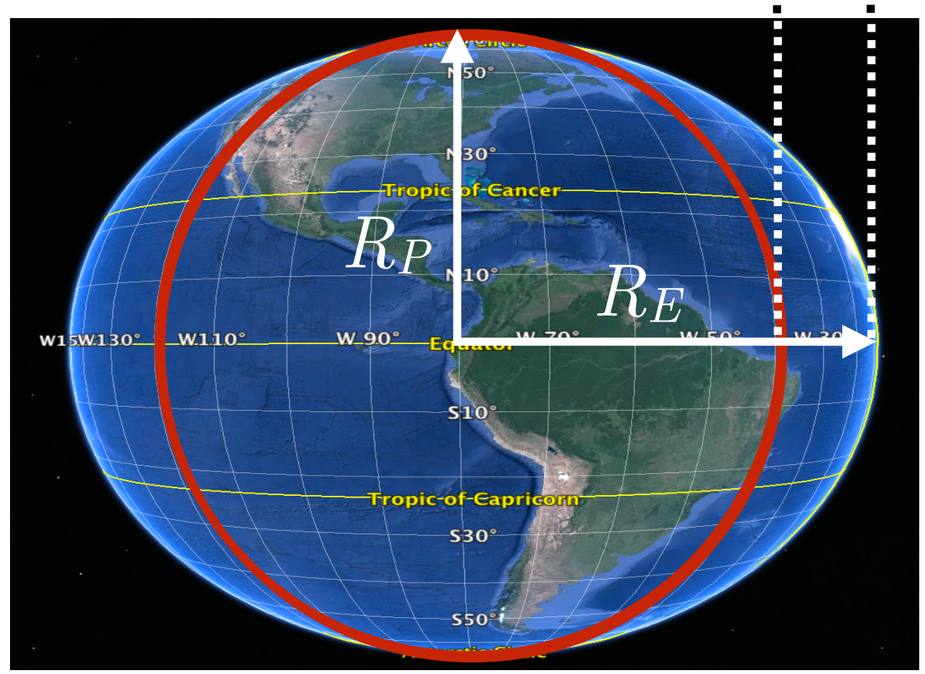

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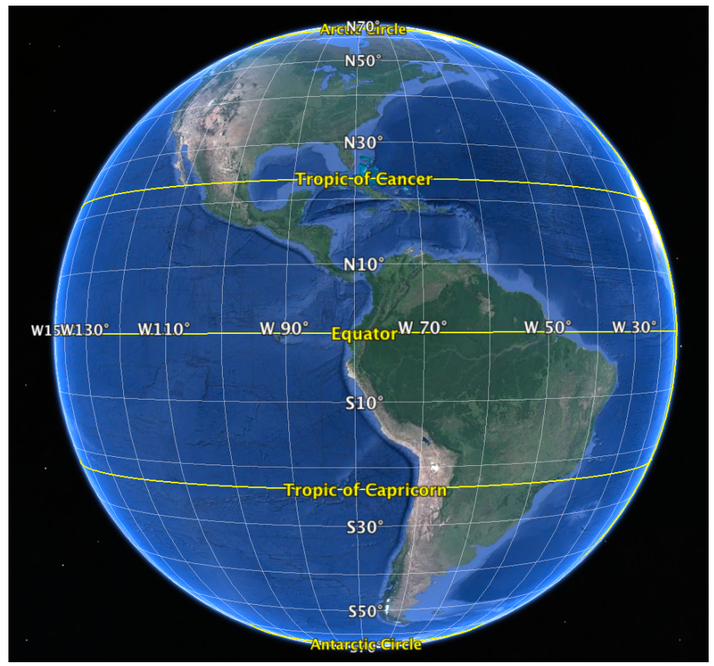

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method to determine the path of a comet with 3 measurements

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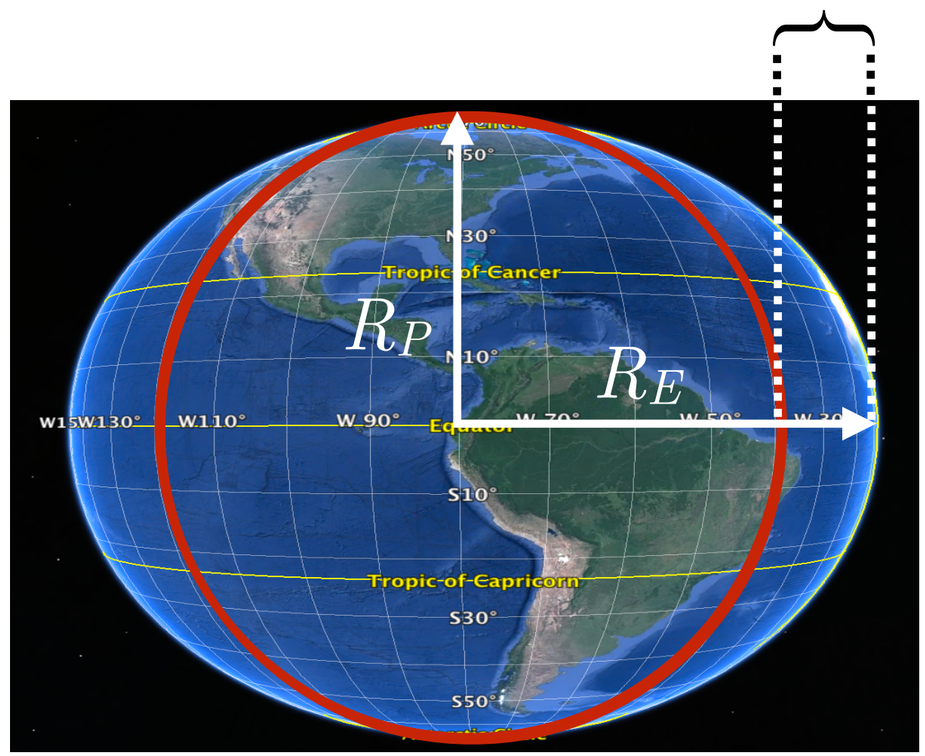

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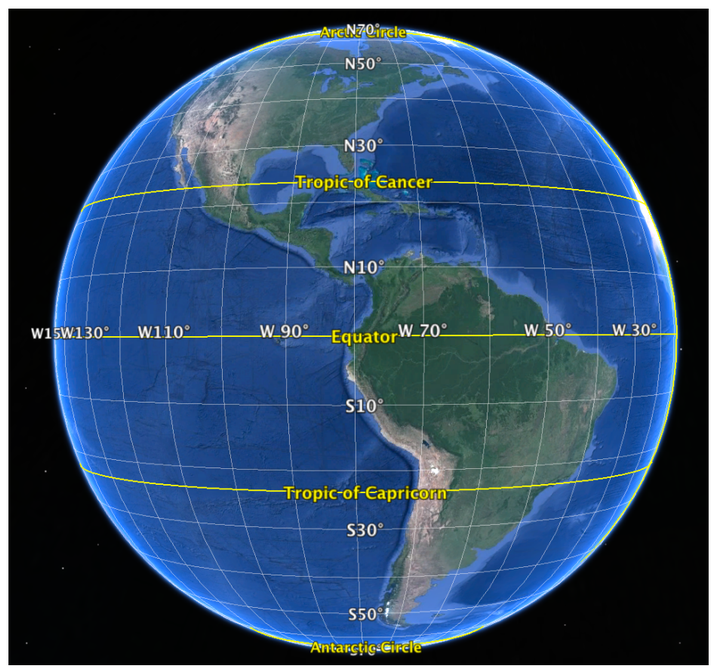
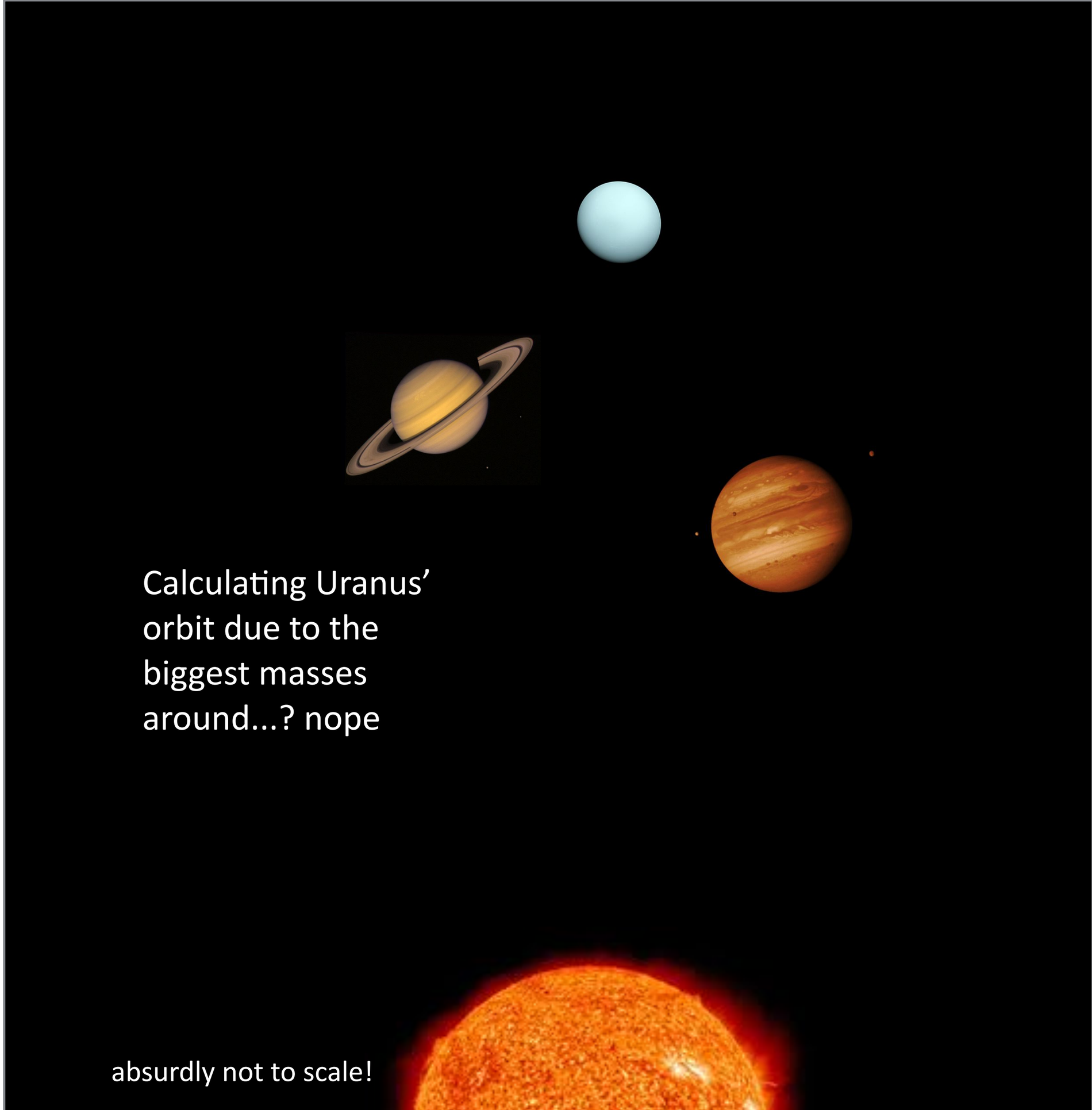


from a theory to a rule

by 1840, it was clear that something was wrong with the orbit of Uranus



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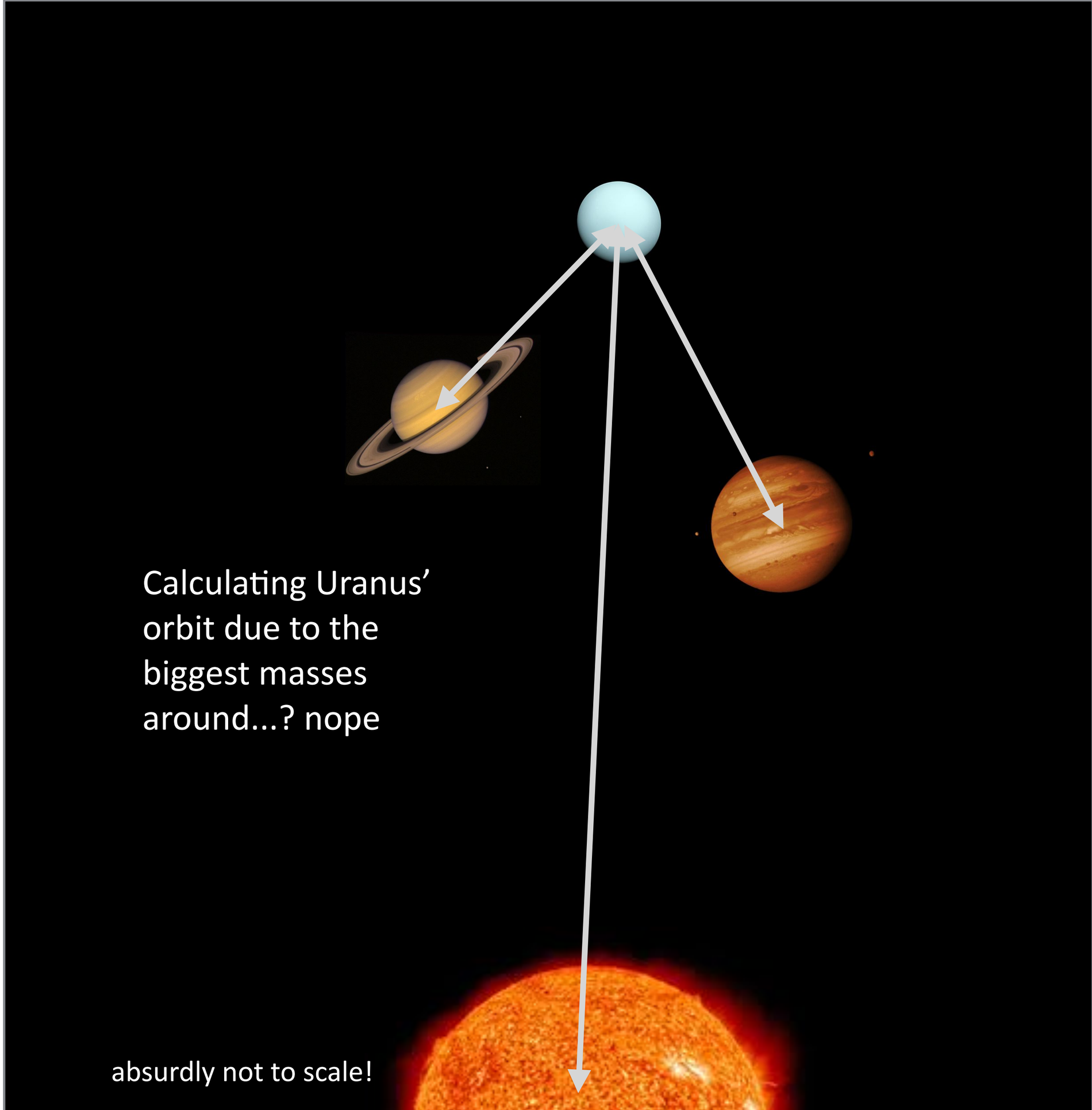

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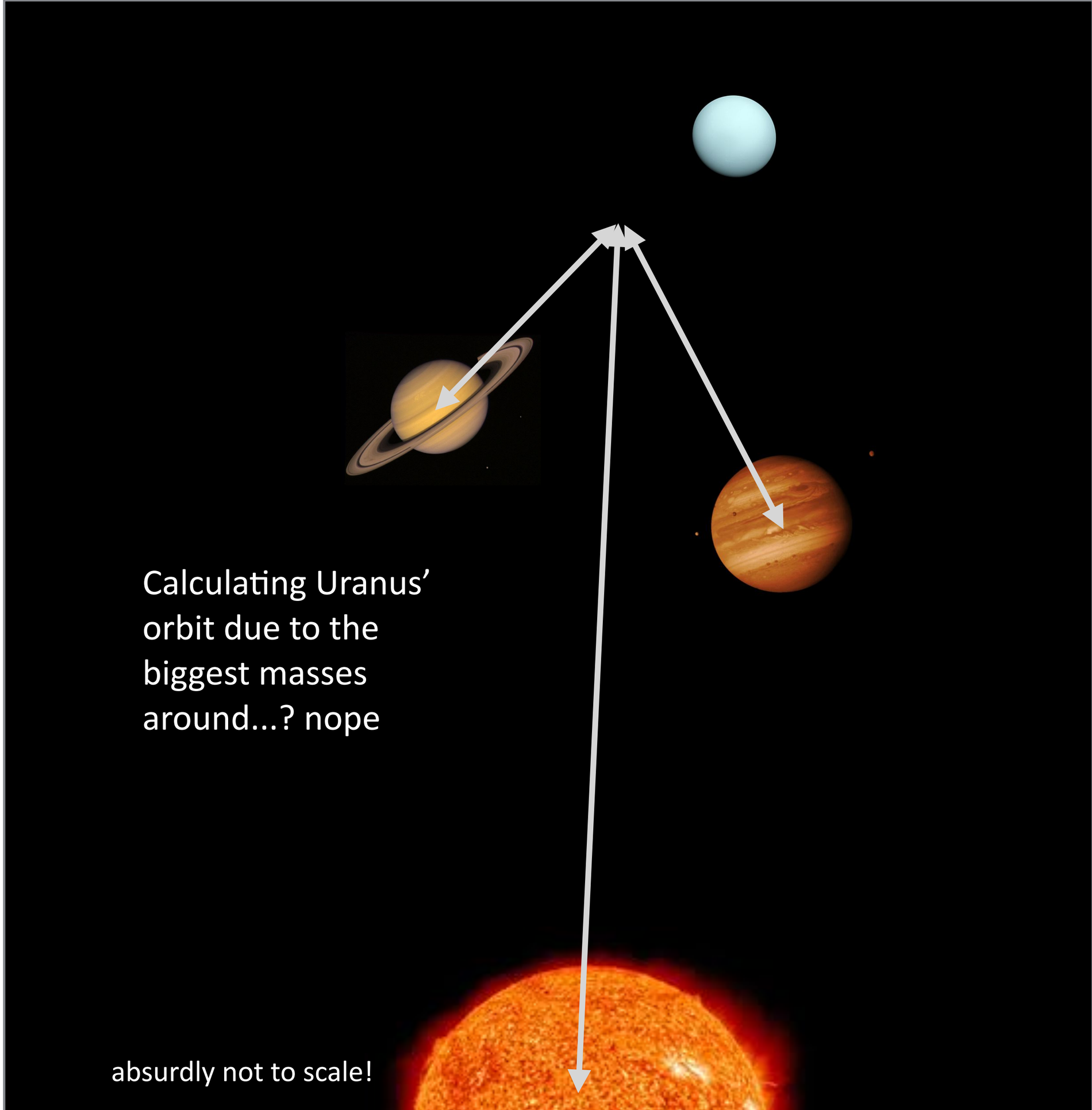

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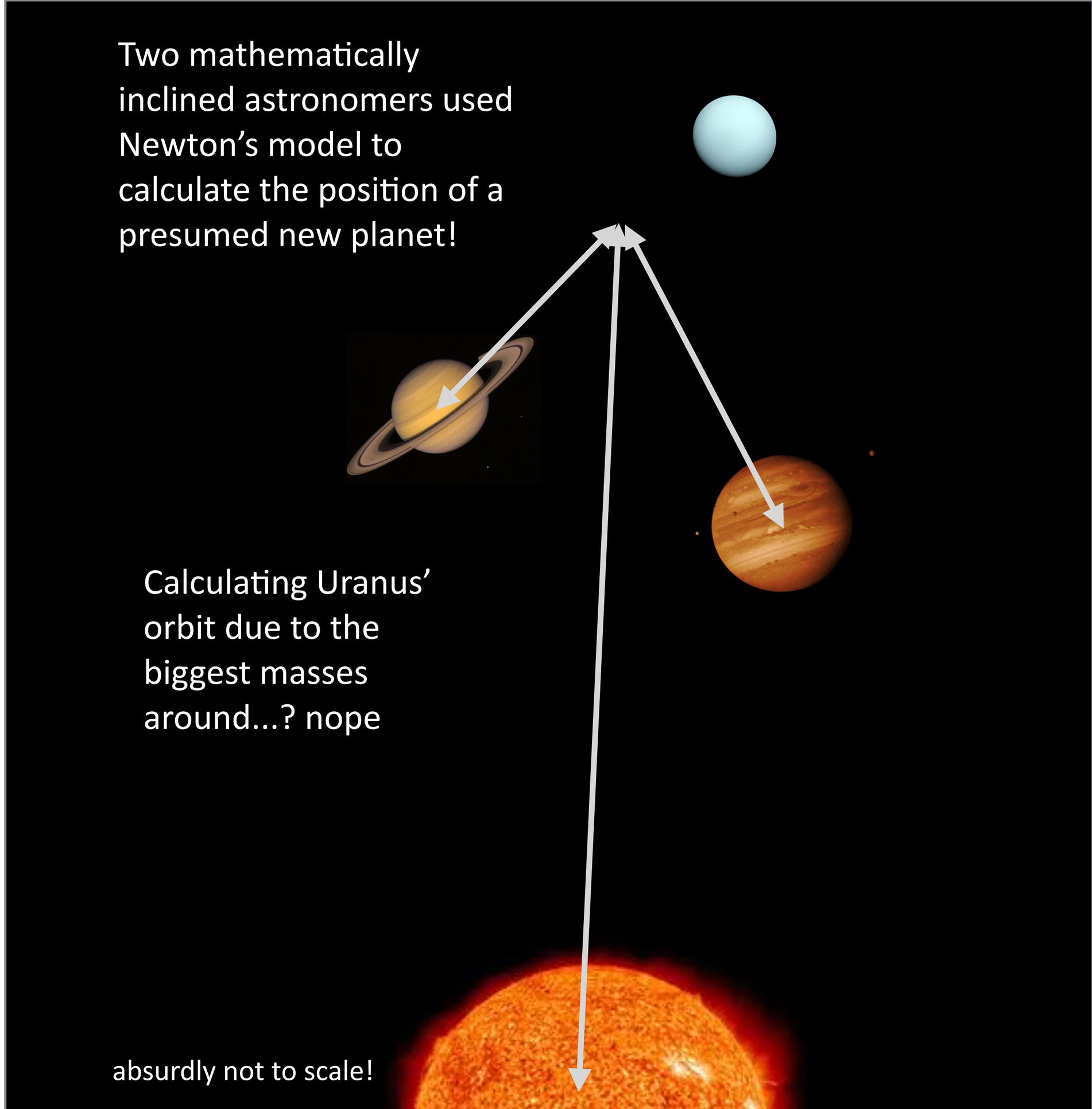

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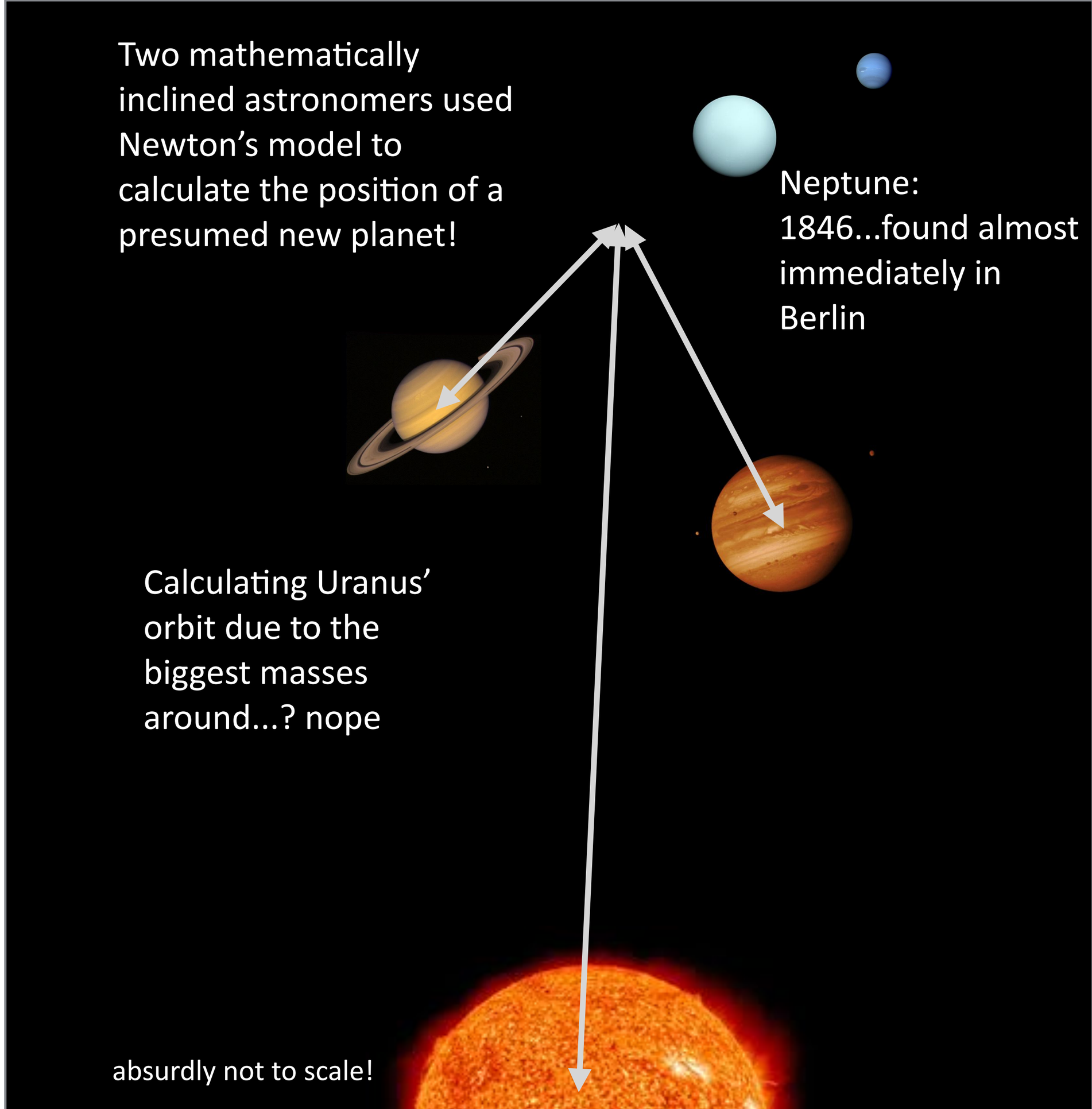

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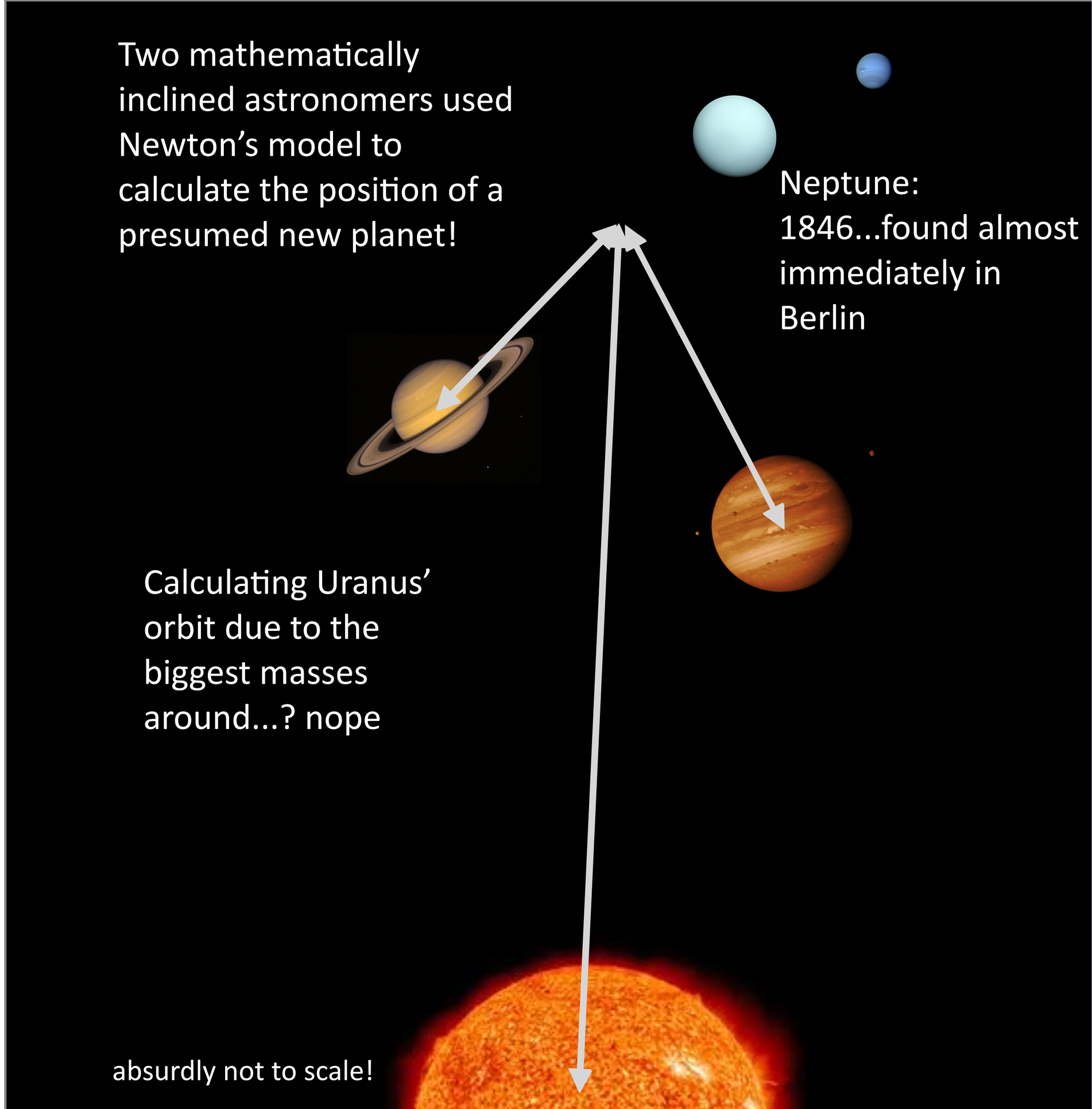
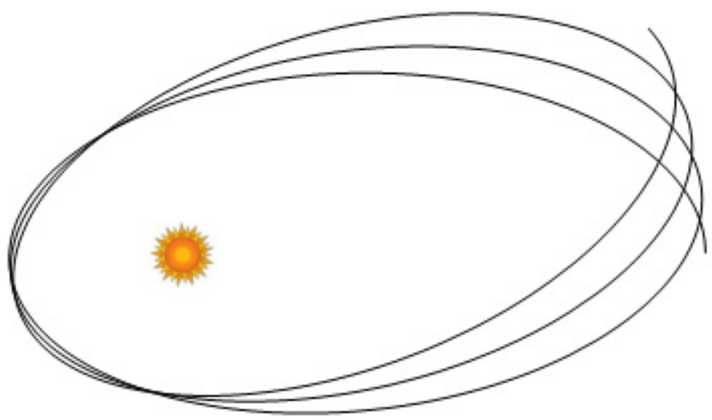


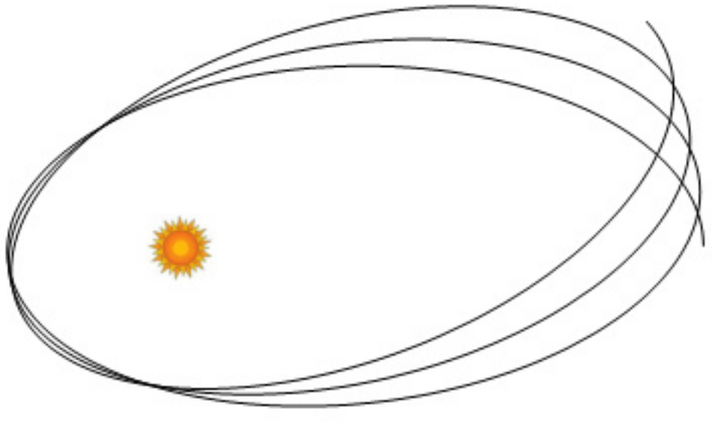
Mercury’s orbit is weird



Mercury’s orbit is weird

Vulcan?

nope



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There’s only been one other person in the history of physics as revolutionary as Isaac Newton

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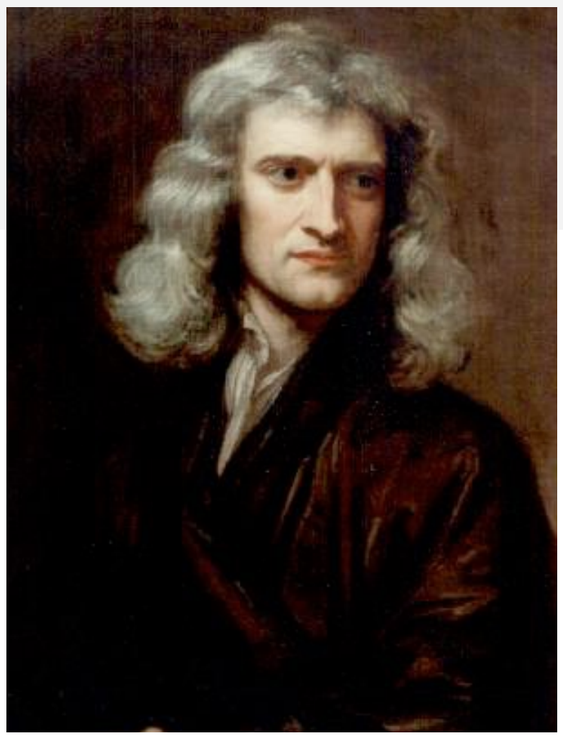

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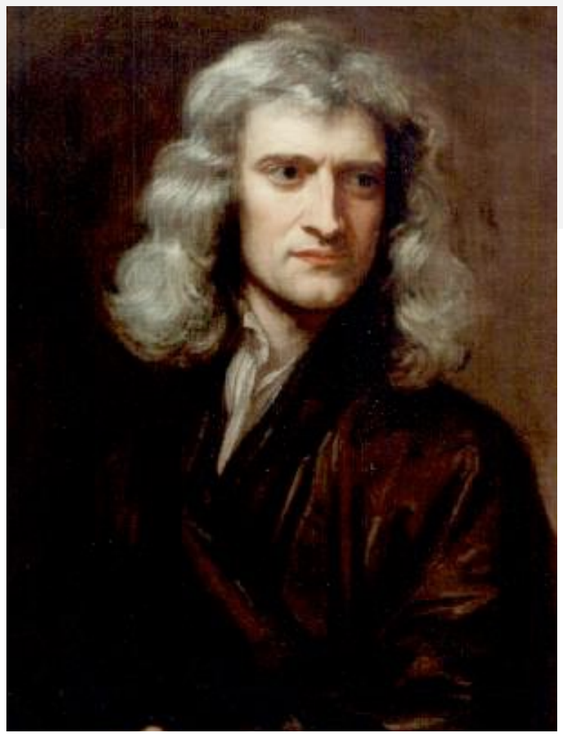

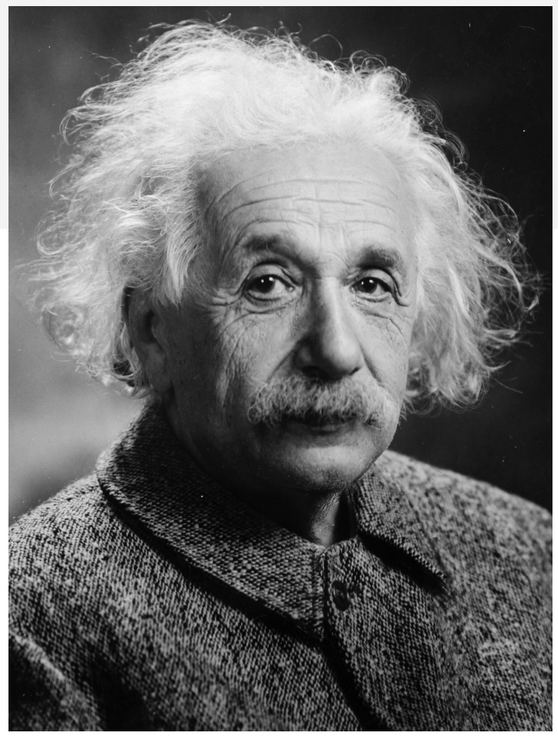

one manipulation using Gravitation…and our project

T-shirt equation:

$$F_{1,2} = m_1 a$$

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T-shirt equation:

$$F_{1,2} = m_1 a$$

$$\downarrow \frac{v^2}{R}$$

for a circular path:

one manipulation using Gravitation…and our project

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$$\frac{v^2}{R}$$

Gravitation:

$$G\frac{m_1 m_2}{R^2}$$

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put them together:

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T-shirt equation: $F_{1,2}$ a

for a circular path:

Gravitation:

put them together: $$G\frac{m_1 m_2}{R^2} = m_1\frac{v^2}{R}$$

any gravitationally-bound object

say a satellite (S) orbiting the earth (E)

$$F_{S,E} = G\frac{M_E M_S}{R^2}$$

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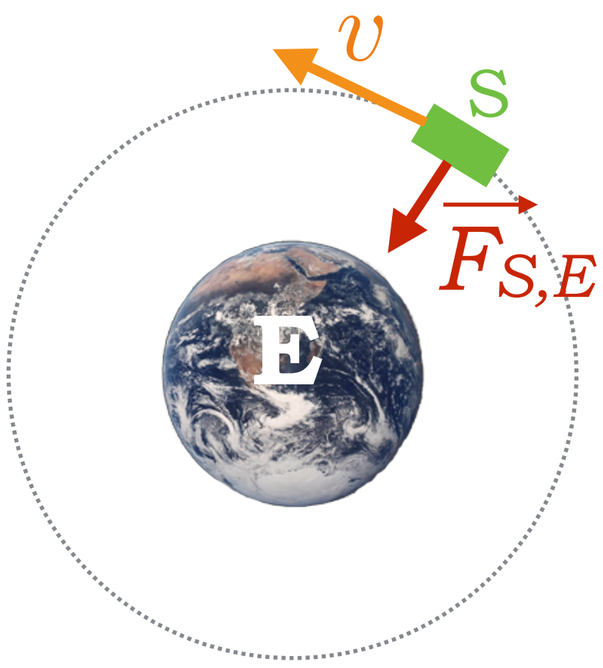

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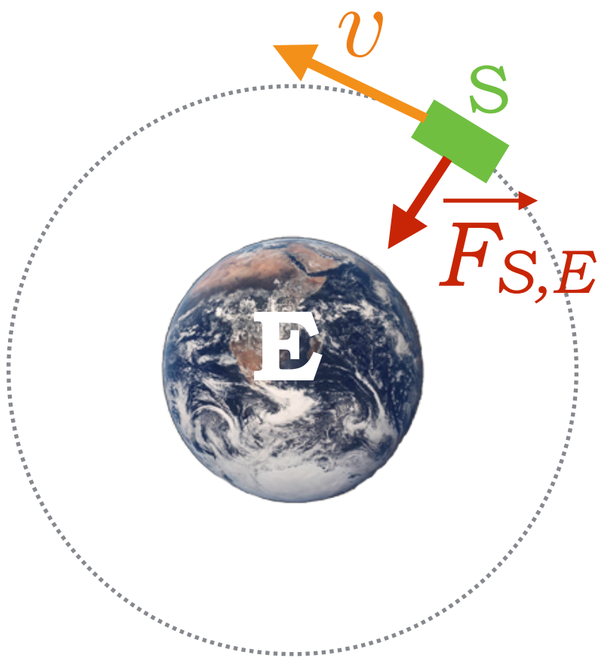

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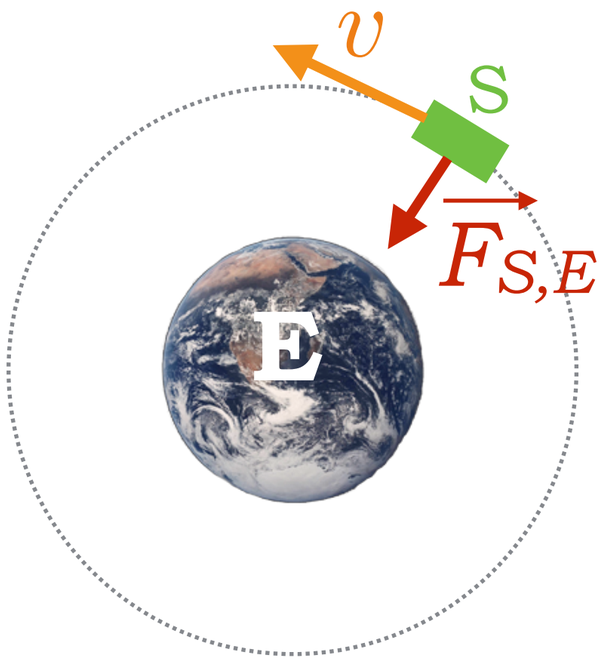

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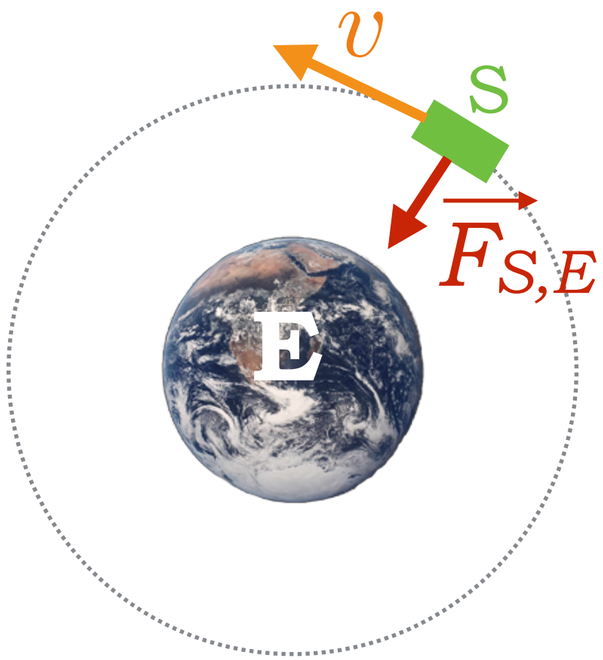

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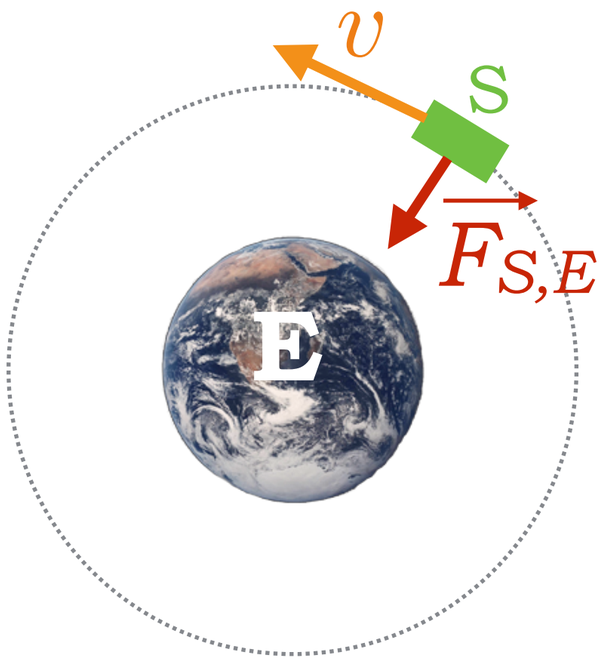

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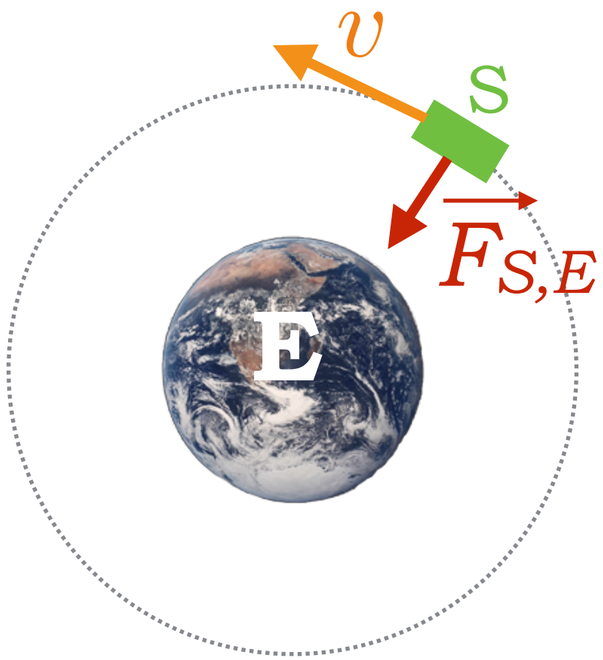

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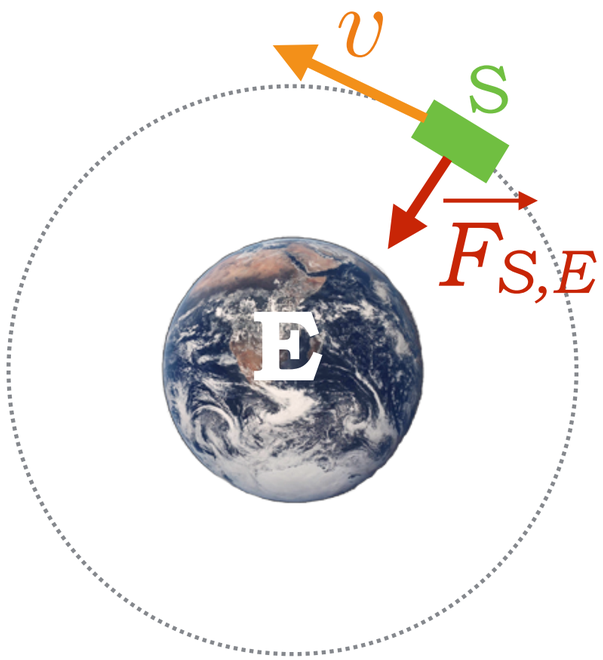

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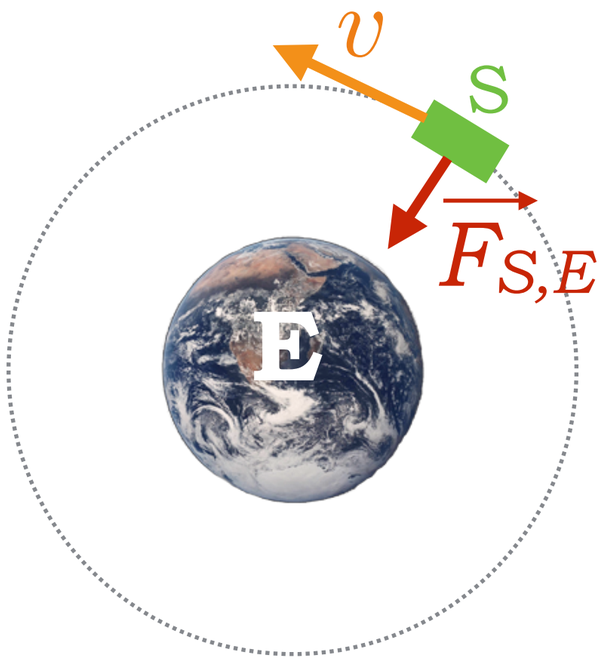

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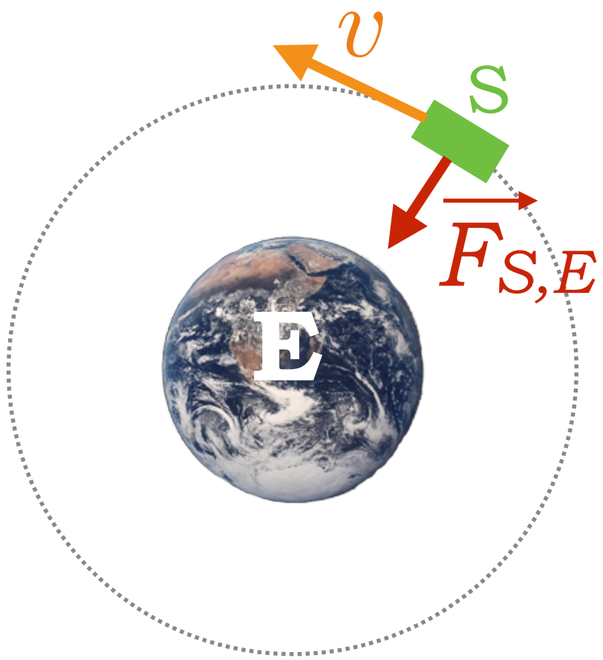

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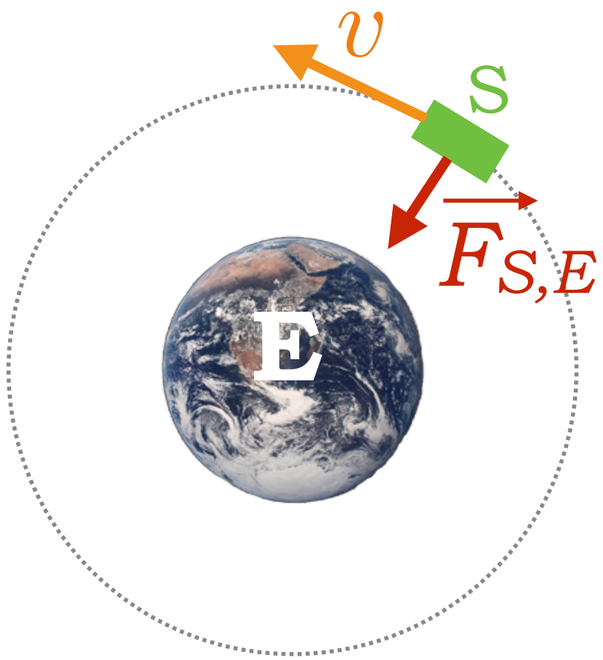

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$$v^2 = G\frac{M_E}{R}$$

$$v = \sqrt{G\frac{M_E}{R}}$$

answer, defend

Force on satellite due to earth:

$$F_{S,E} = G\frac{M_E M_S}{R^2}$$

$$v^2 = G\frac{M_E}{R}$$

A increases

B stays the same

C decreases

as the distance goes up,
the speed:

answer, defend

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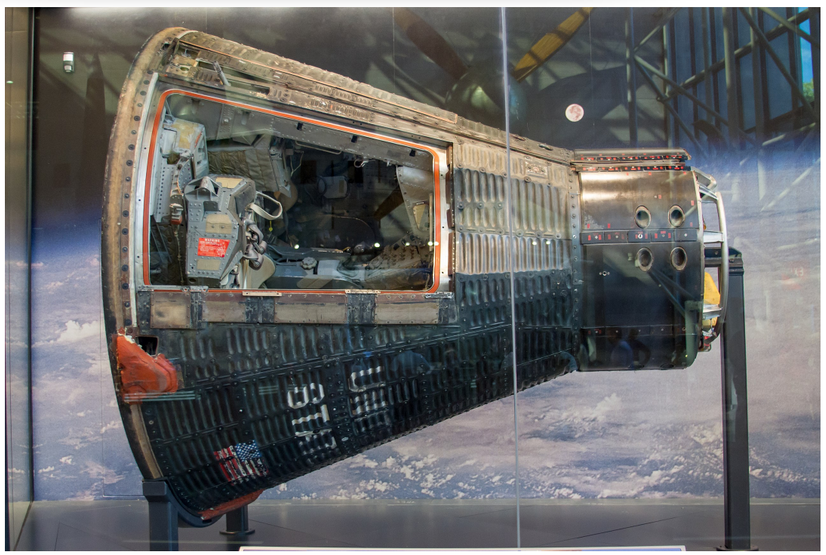
now go back to yesteryear of NASA

DOCKING!!

$$v^2 = G\frac{M_E}{R}$$



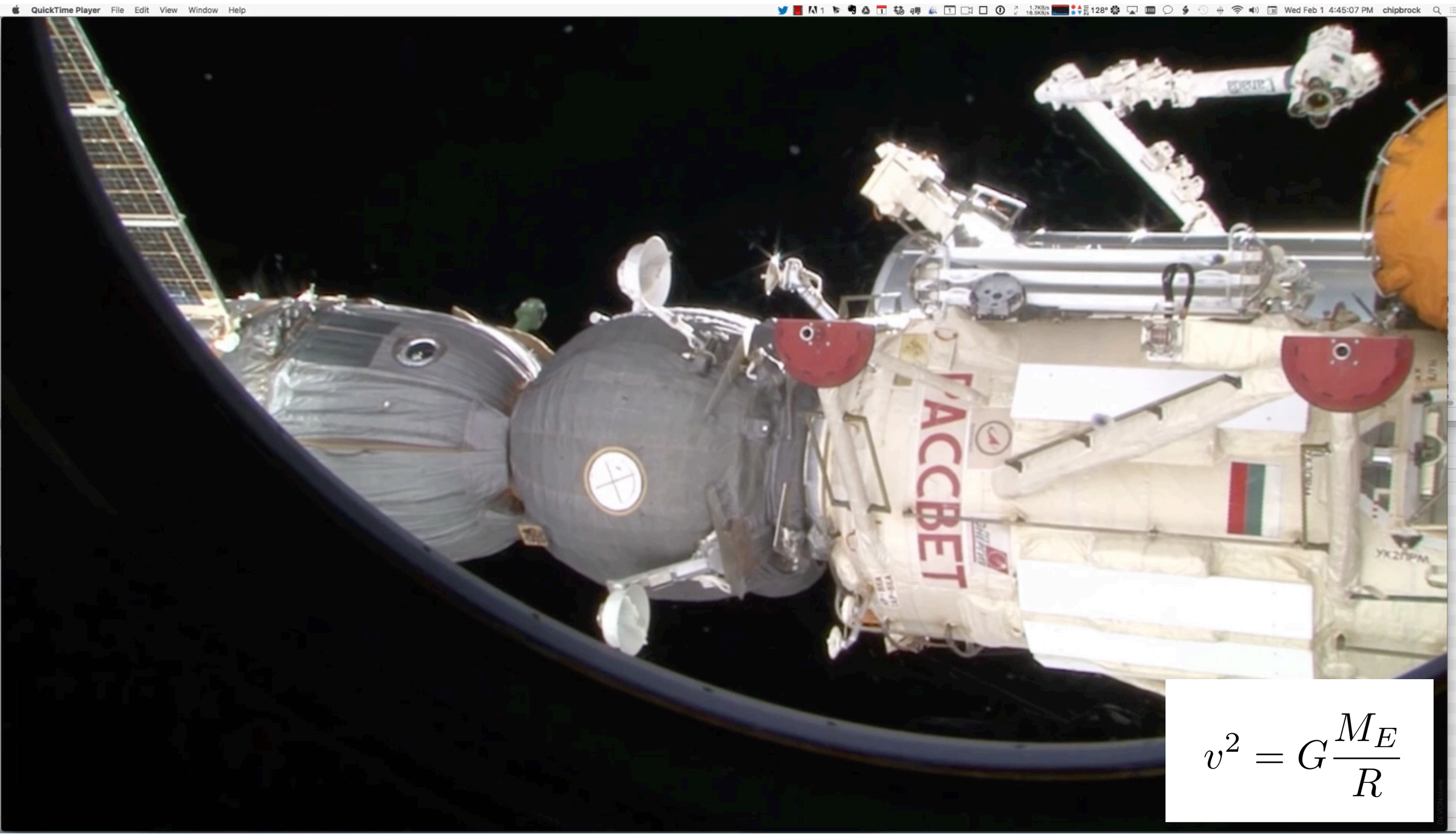
Gemini V

June 1965

James McDivitt and Ed White

quiz

docking…strange: “Hohmann Transfer”: 2 days



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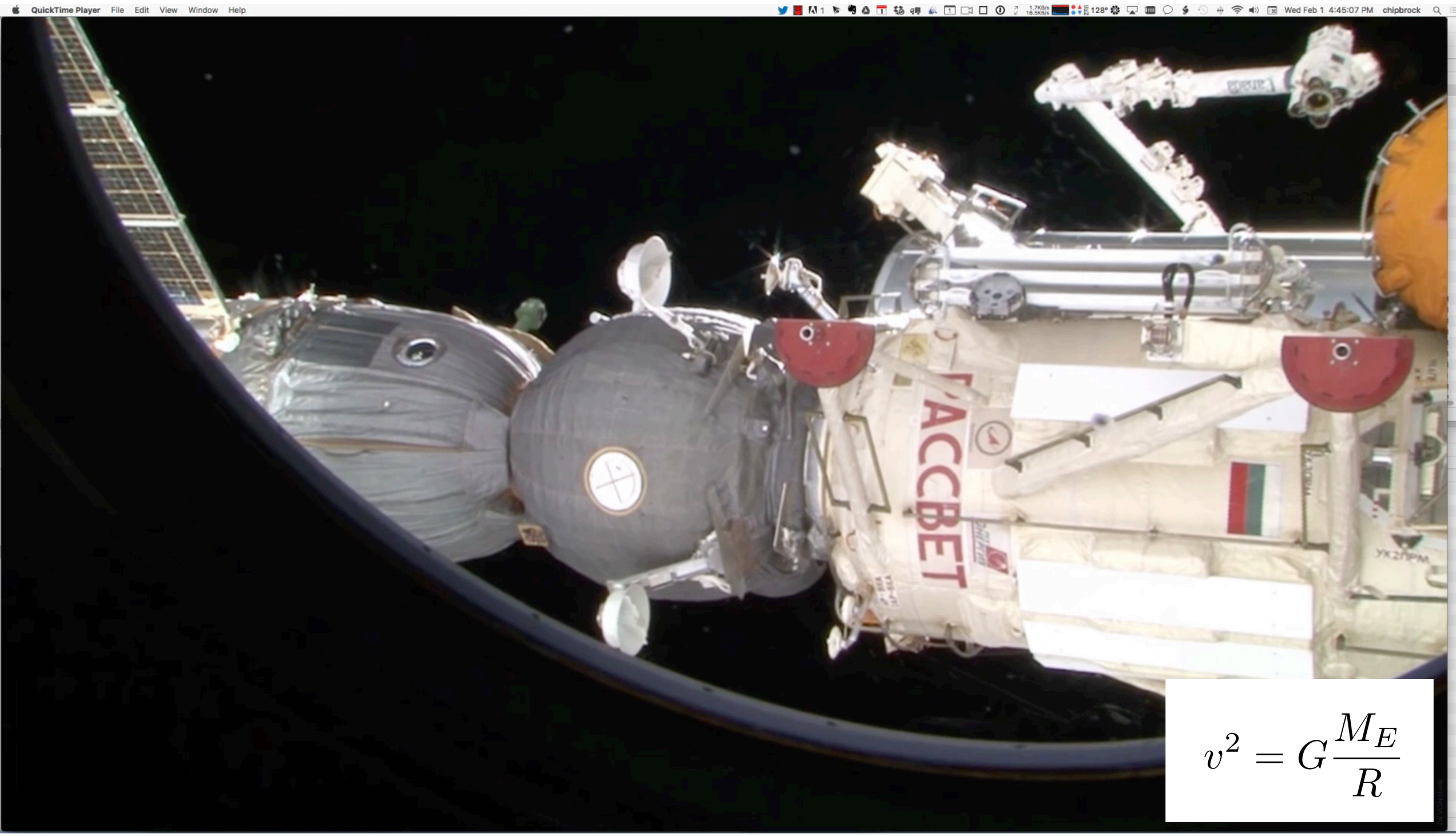

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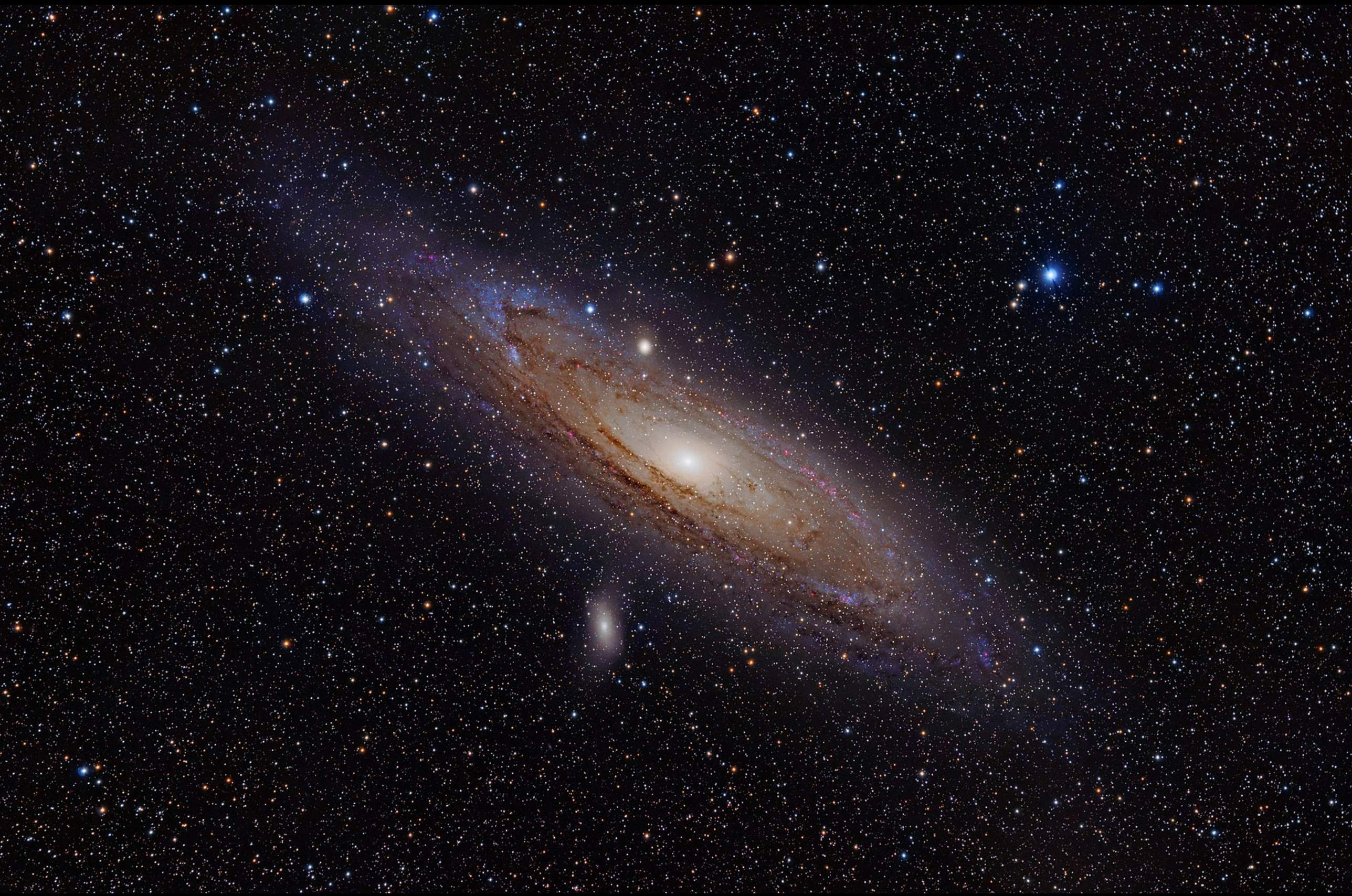
now one of the 2 biggest problems in all of physics and astronomy

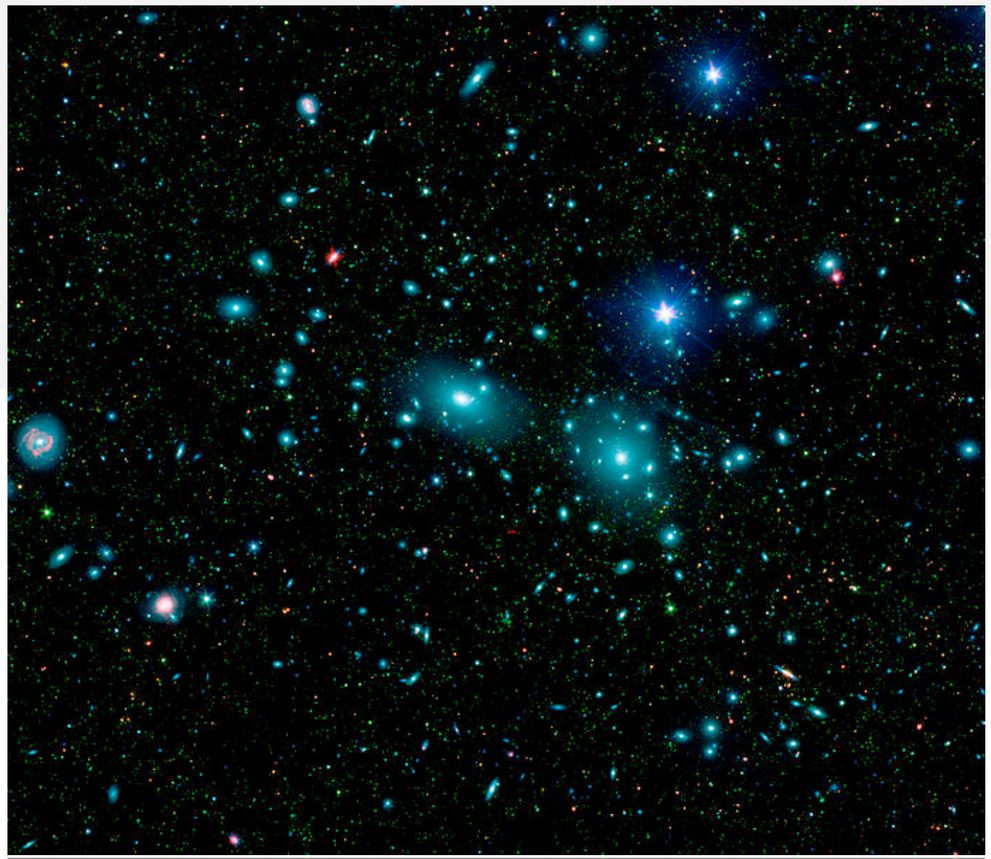


Andromeda Galaxy, aka M31

something is terribly wrong

with stellar and galactic motions

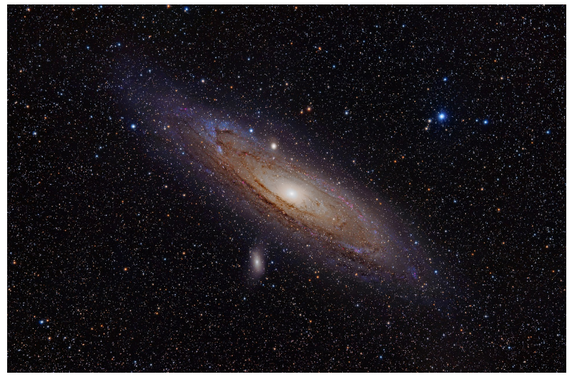
Coma cluster of galaxies
Fritz Zwicky, 1933

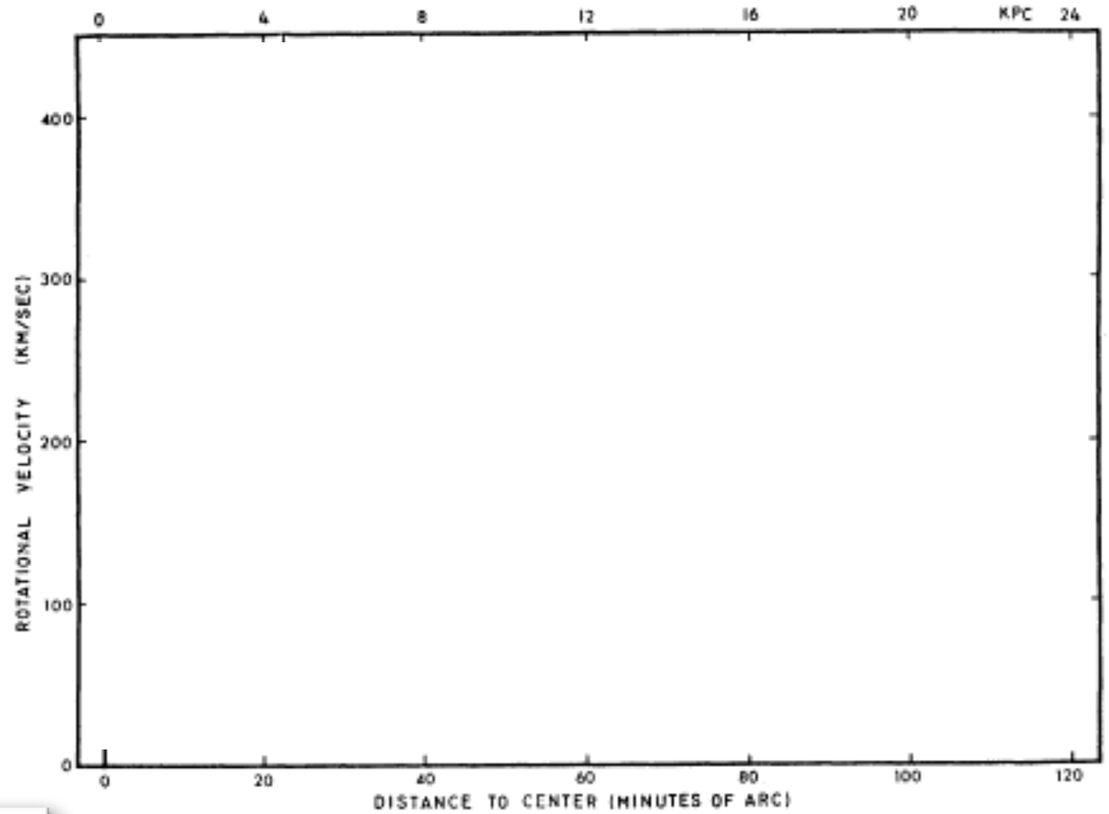


something's there

$$v = \sqrt{G\frac{M_{\text{galaxy center}}}{R}}$$

Vera Rubin, w/ Kent Ford, 1970: Andromeda





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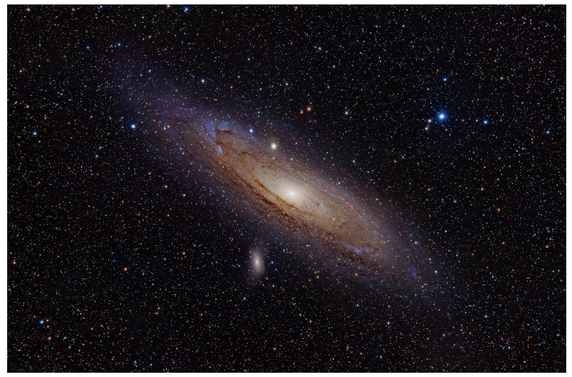

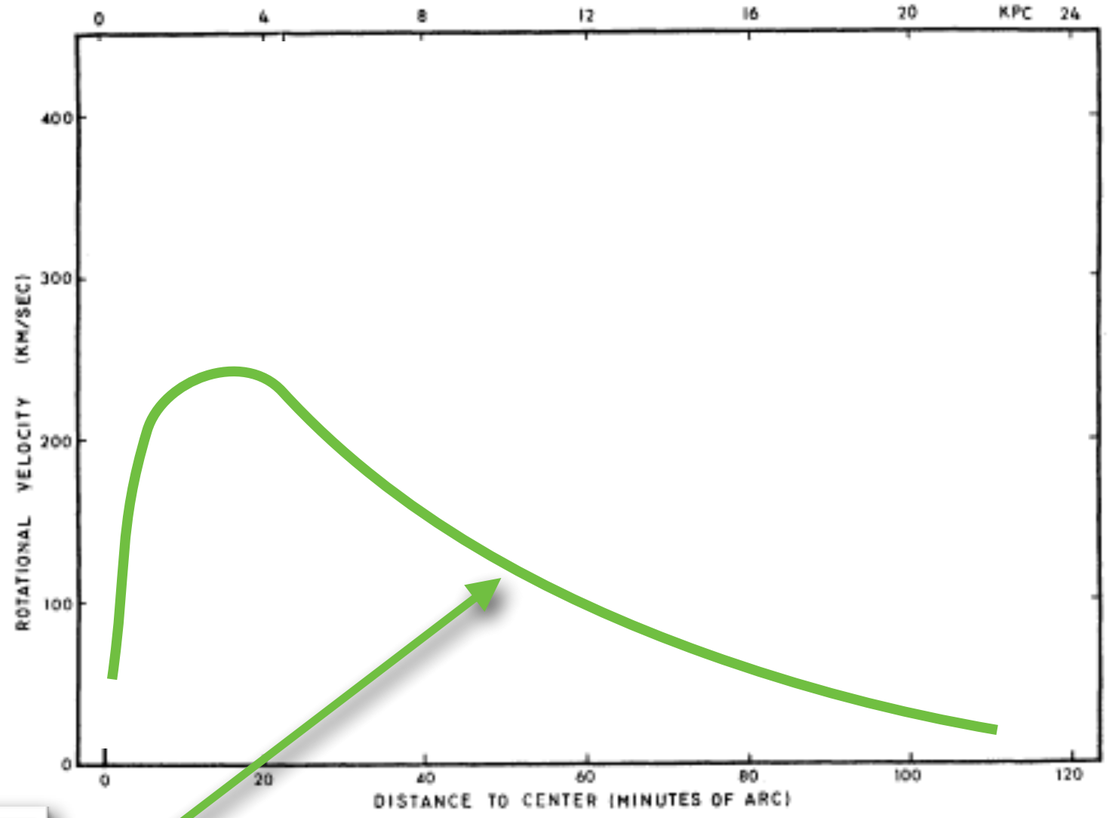

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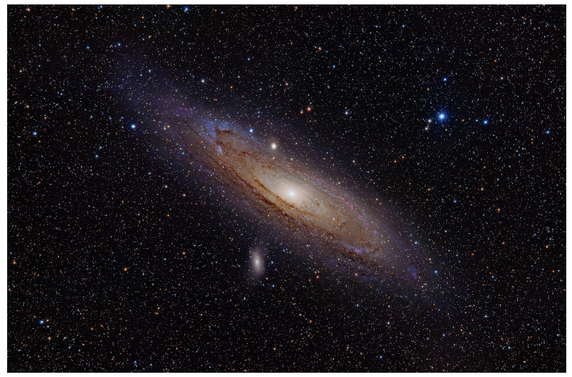

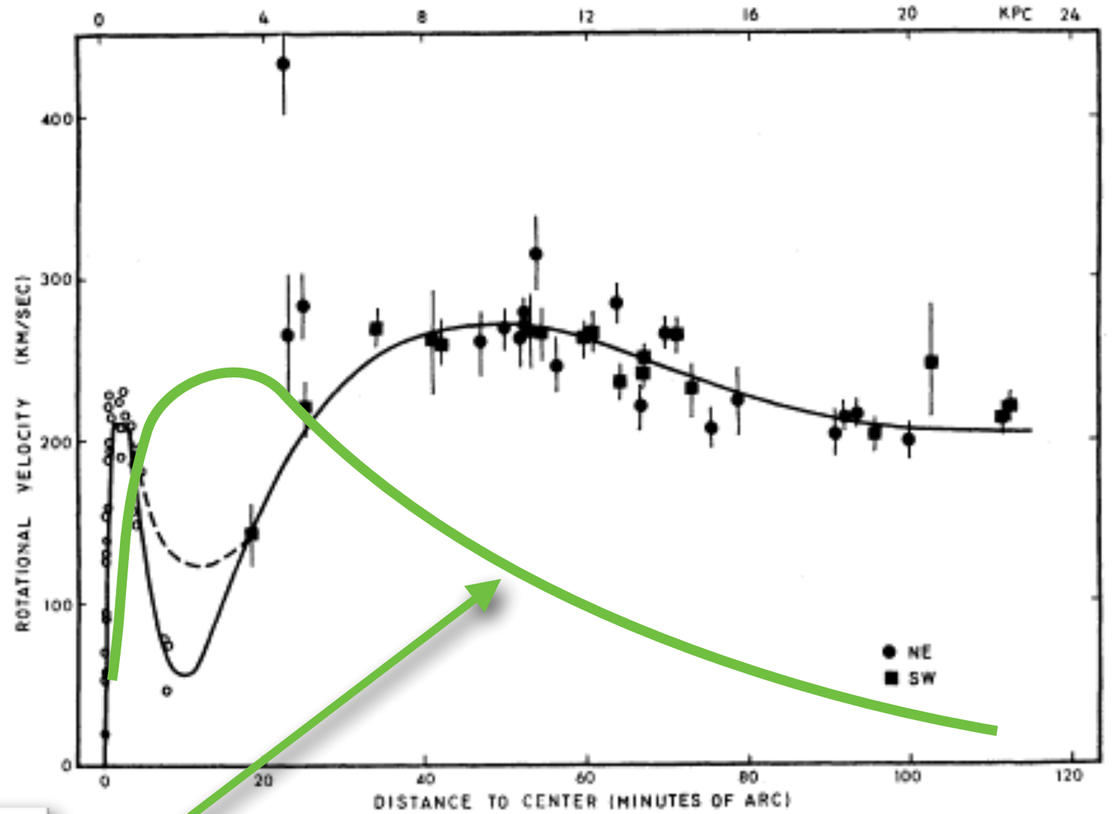

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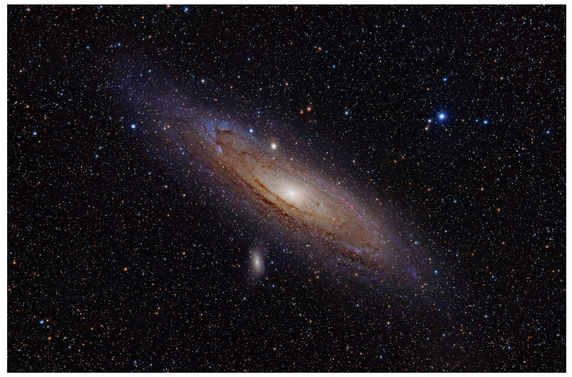

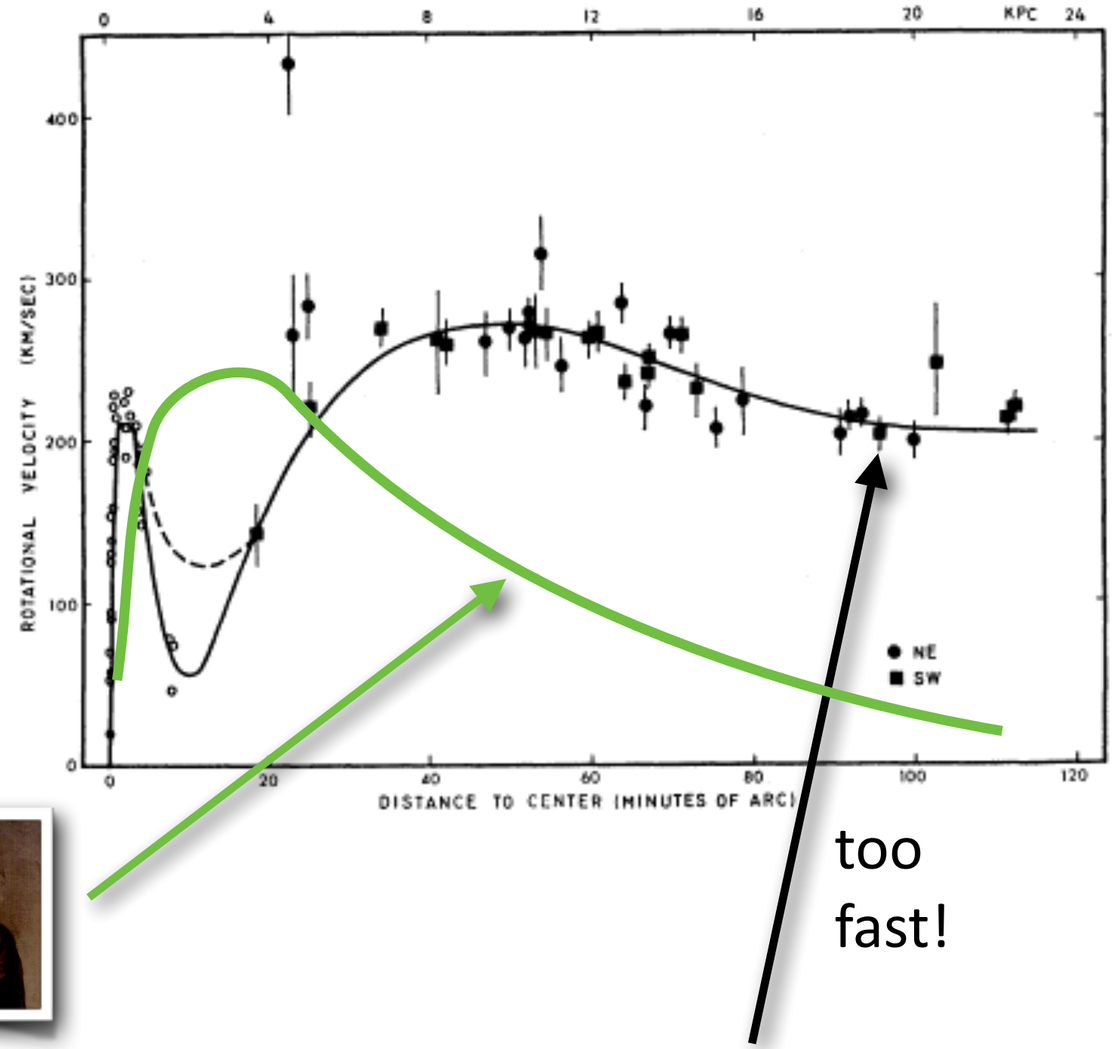

too fast!

something's there

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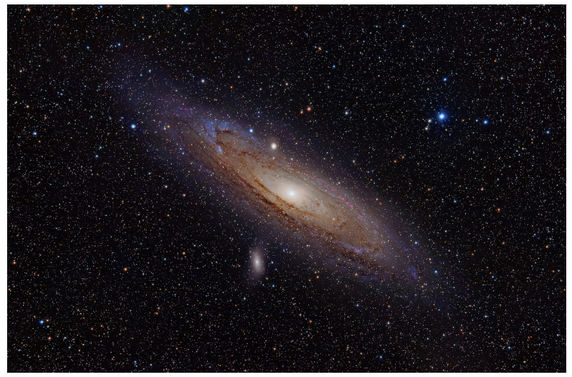

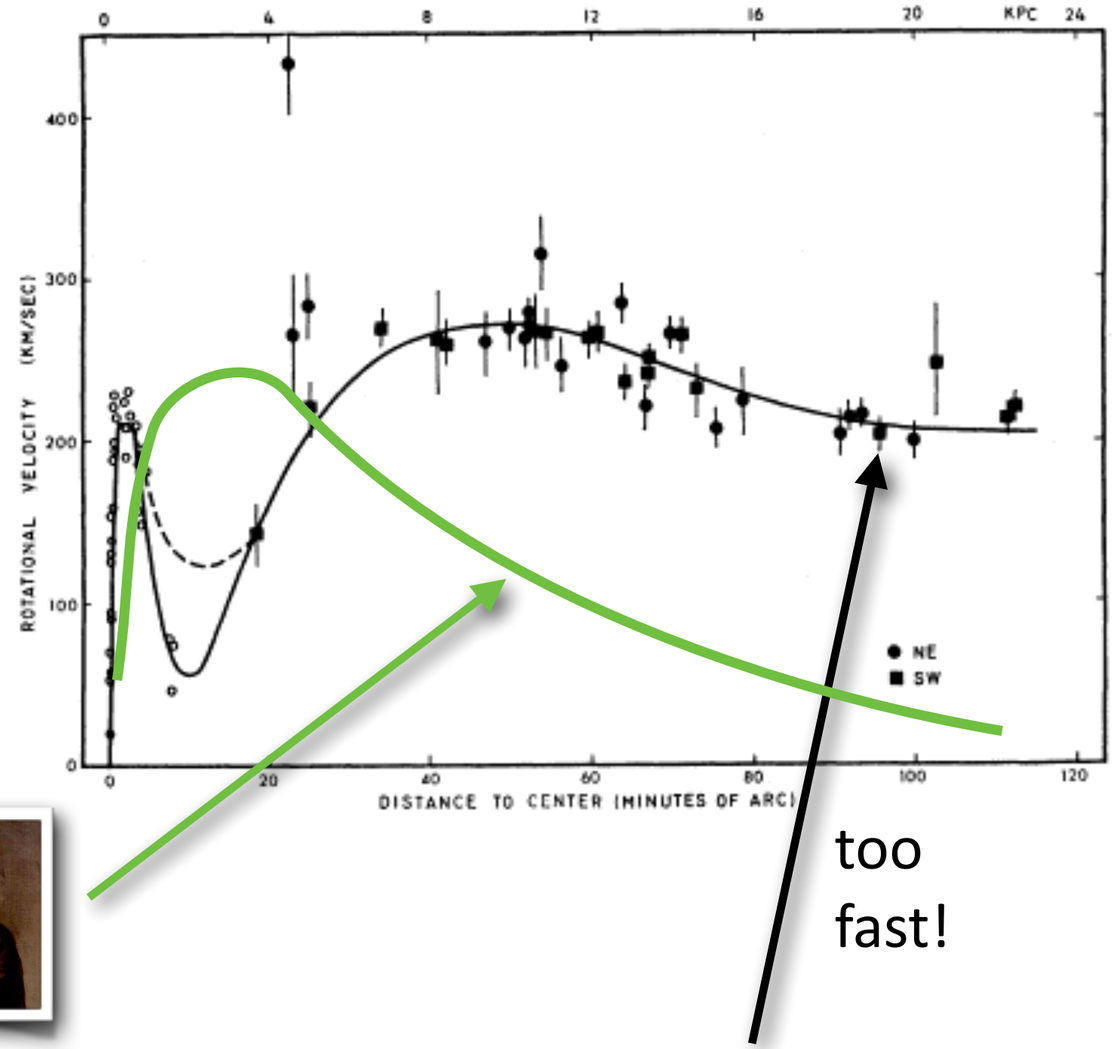

Something's wrong! The amount of mass required in order to match the motion is about 1/6 of what is observable.

something's there

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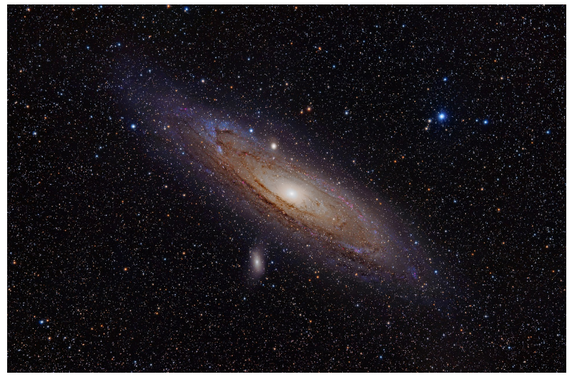

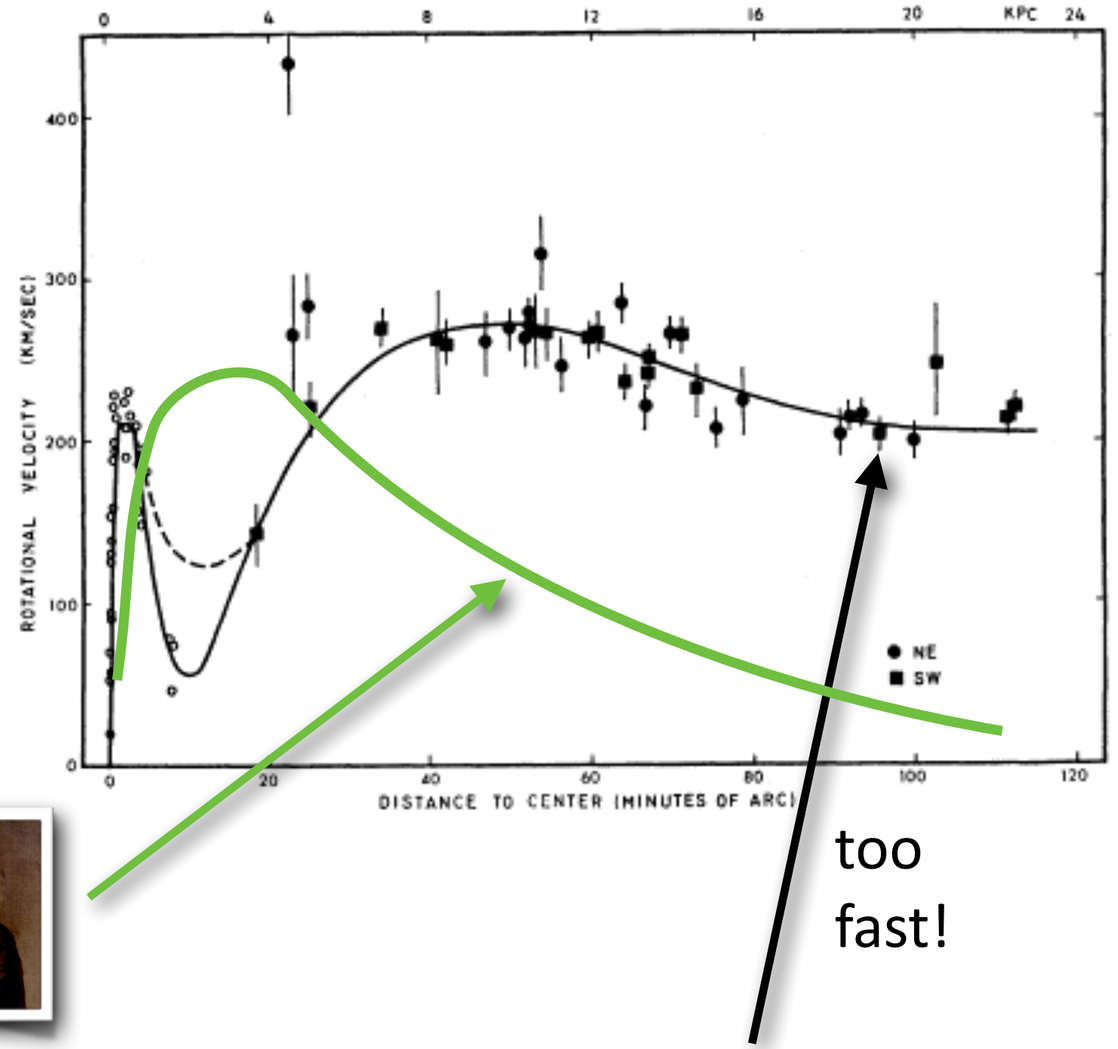

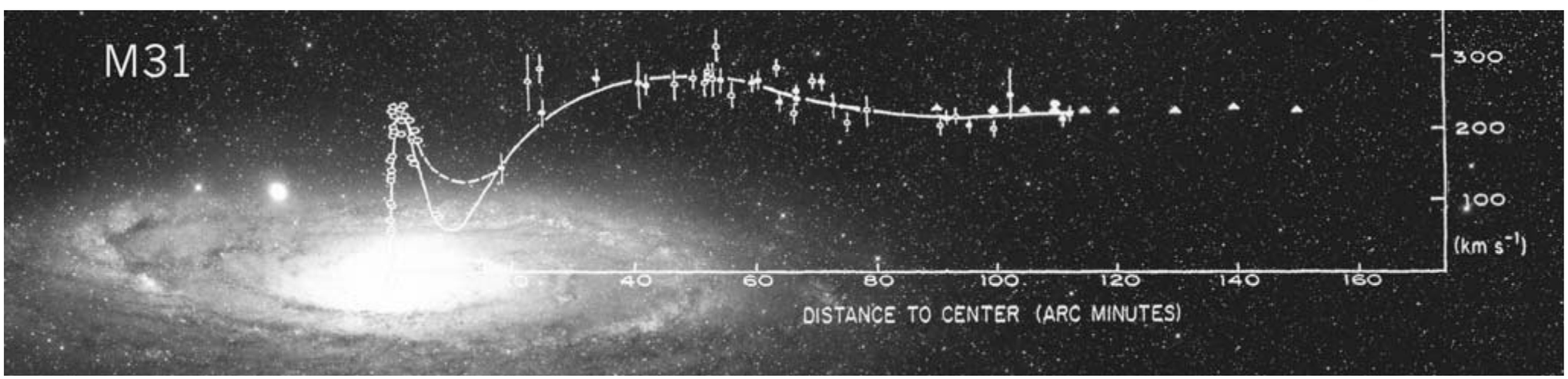

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TWO DISC 20TH ANNIVERSARY EDITION
LLOYD KAUFMAN AND MICHAEL HERZ PRESENT A TROMA TEAM RELEASE
TROMA
THERE'S NOTHING OUT THERE!
A ROLFE KANEFSKY FLICK
"NOTHING has a lot going for it!"
Los Angeles Times

it’s darker than you think

something is out there

something is out there

it doesn’t shine

something is out there

it doesn’t shine

visible light, X-rays, Infrared, UV…nothing.

something is out there

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so it’s not regular atoms

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visible light, X-rays, Infrared, UV…nothing.

so it’s not regular atoms

But. It gravitates.

silver bullet(s)

silver bullet(s)

Abel 1689 composite image from Hubble Space Telescope and the Chandra X-ray Observatory

silver bullet(s)

Abel 1689 composite image from Hubble Space Telescope and the Chandra X-ray Observatory

simulation-inspired artistic view of milky way…blue is the amount of dark matter required

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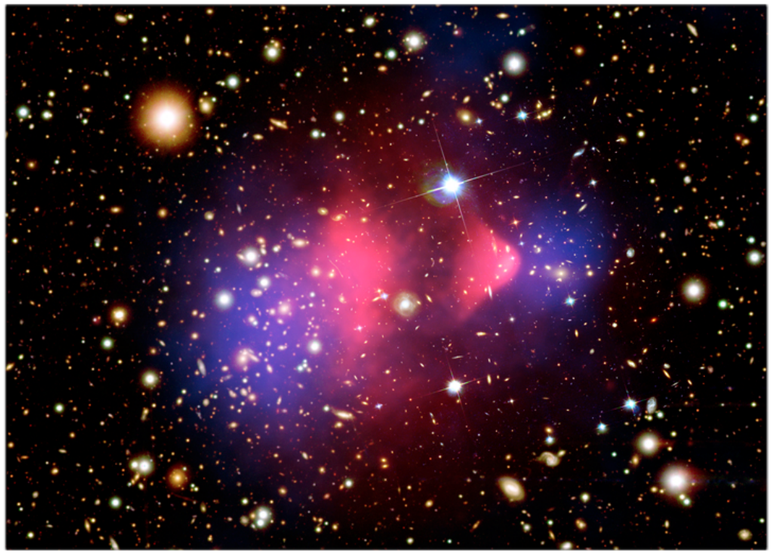

Bullet Cluster

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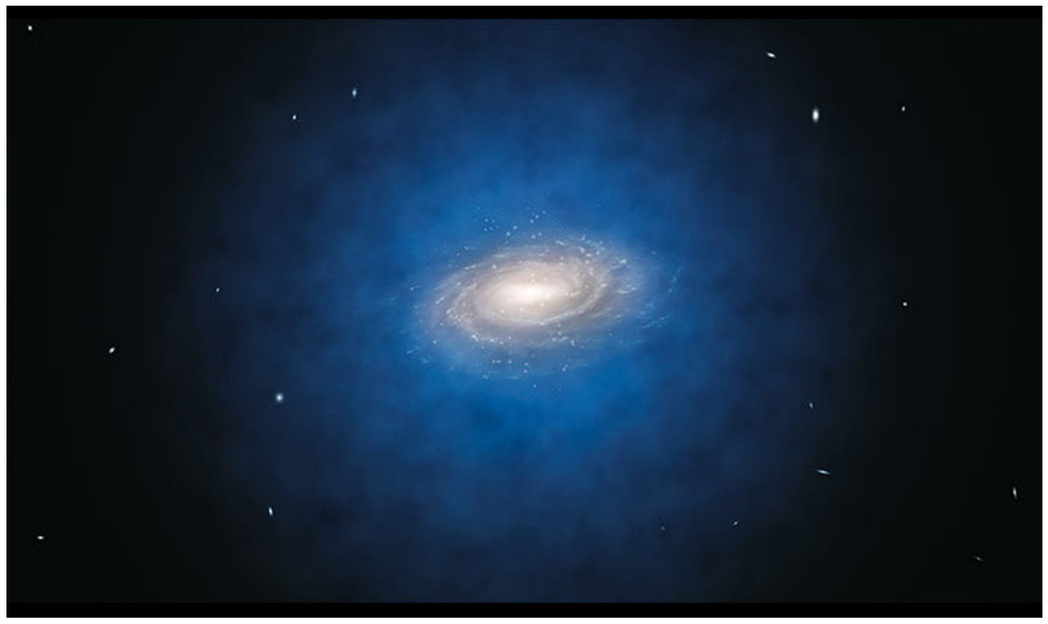

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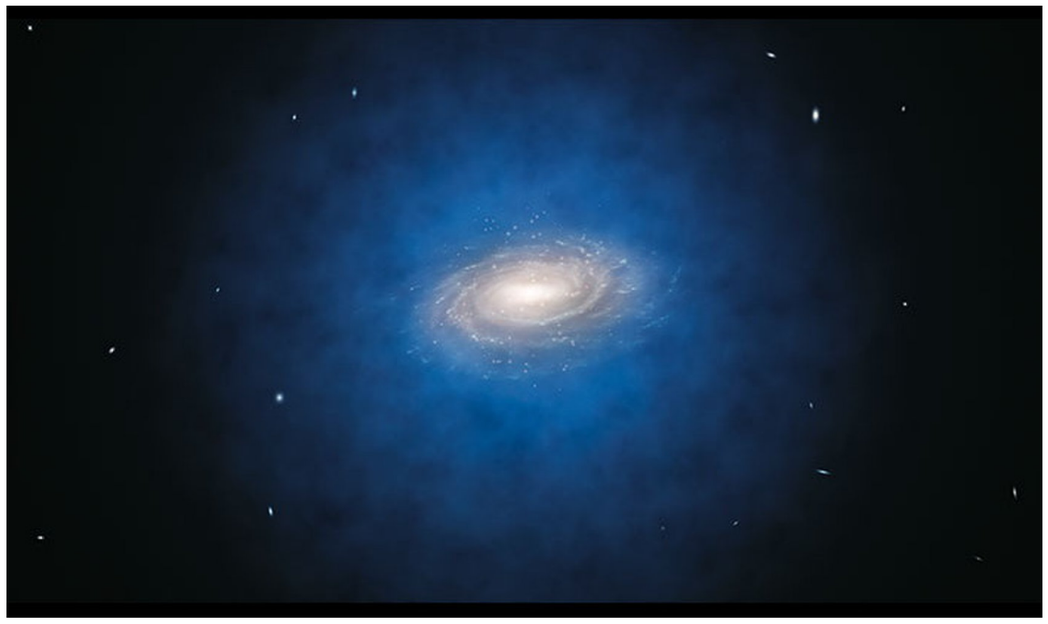
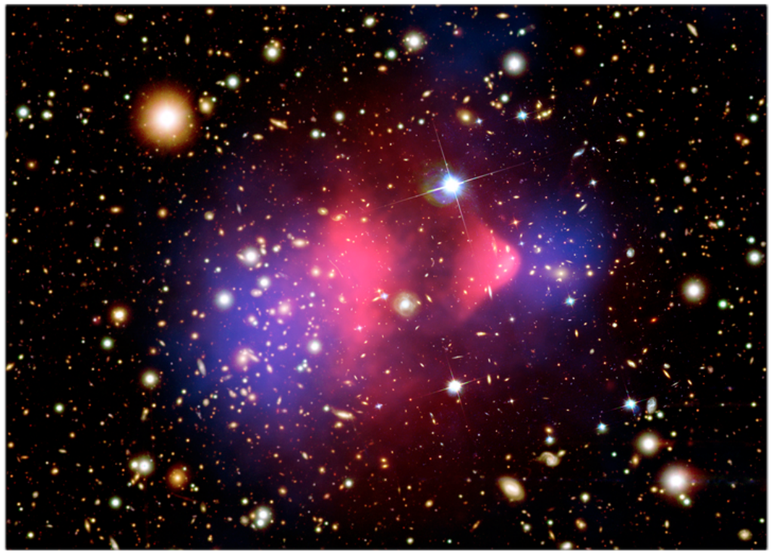
Simulation...

https://www.youtube.com/watch?v=rLx_TXhTXbs

simulation-inspired artistic view of milky way...blue is the amount of dark matter required



silver bullet(s)



Bullet Cluster

Abel 1689 composite image from Hubble Space Telescope and the Chandra X-ray Observatory

Simulation…

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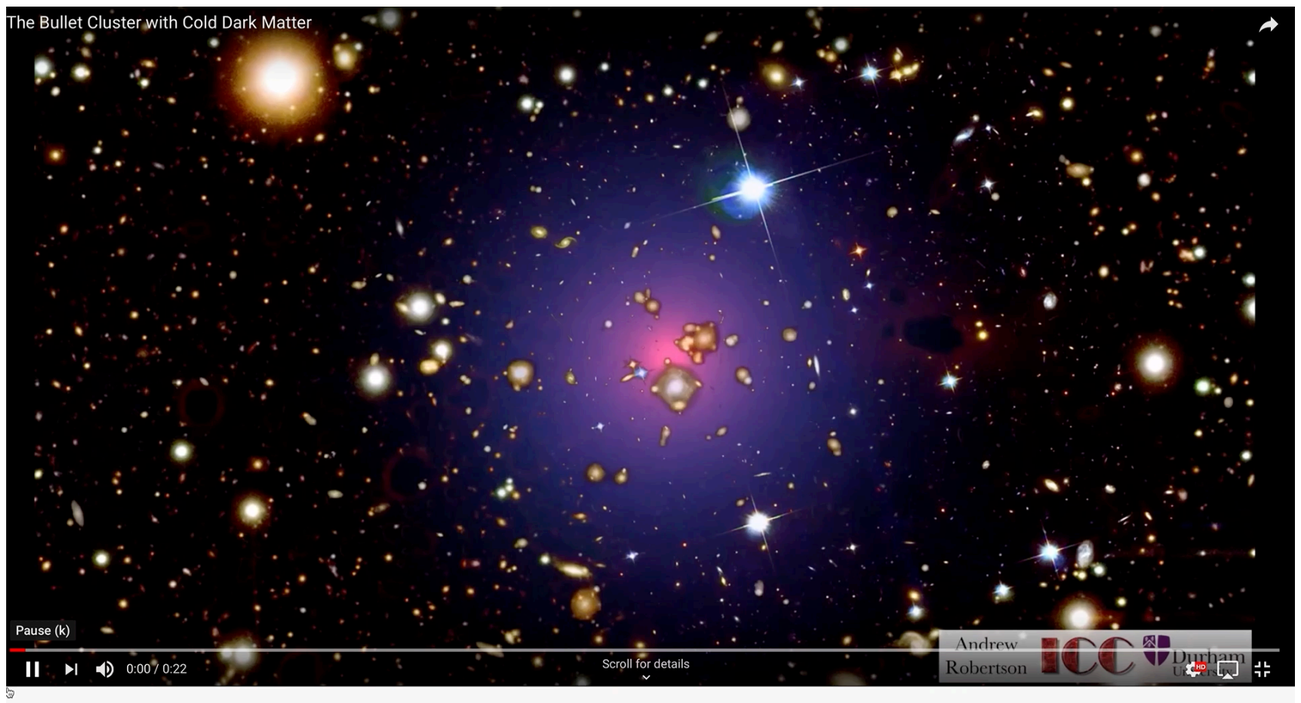
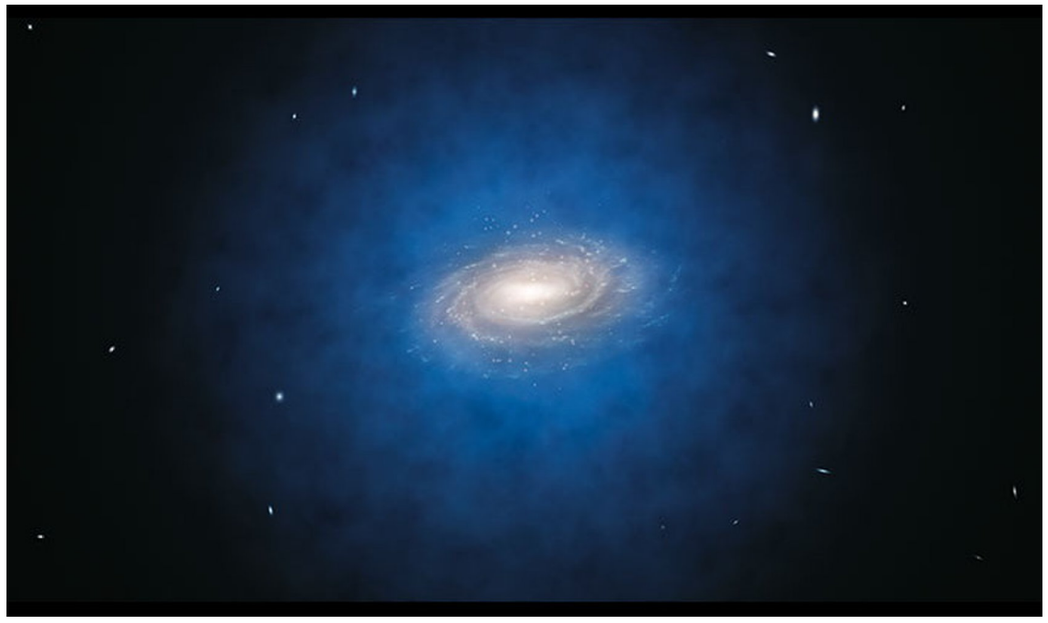


simulation-inspired artistic view of milky way…blue is the amount of dark matter required



if it’s not a particle

then, we’re completely lost

which would be…you know…kind of cool

DARK MATTER

a mantra

a mantra

which you’ll learn to repeat:

a mantra

which you'll learn to repeat:

"if there's a field, there's a particle"

a mantra

which you'll learn to repeat:

"if there's a field, there's a particle"

"if there's a particle, then there's a field"

a mantra

which you'll learn to repeat:

"if there's a field, there's a particle"

"if there's a particle, then there's a field"

and really, "everything is fields."

a mantra

which you'll learn to repeat:

"if there's a field, there's a particle"

"if there's a particle, then there's a field"

and really, "everything is fields."

or we don't know anything about quantum mechanics!

a mantra

which you'll learn to repeat:

"if there's a field, there's a particle"

"if there's a particle, then there's a field"

and really, "everything is fields."

or we don't know anything about quantum mechanics!

So there must be little Dark Matter particles: 

everywhere

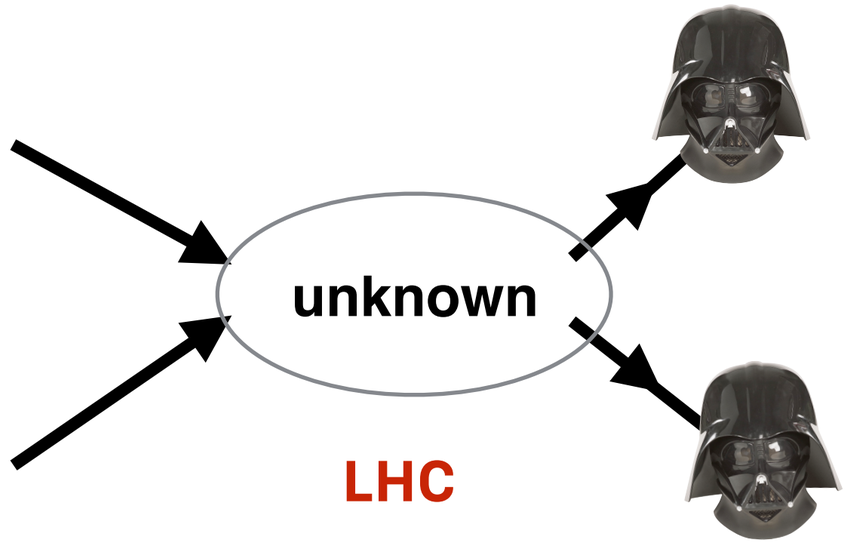
So there must be little Dark Matter particles:

experiments

on the Earth, in orbit, and deep under the Earth’s surface

experiments

production

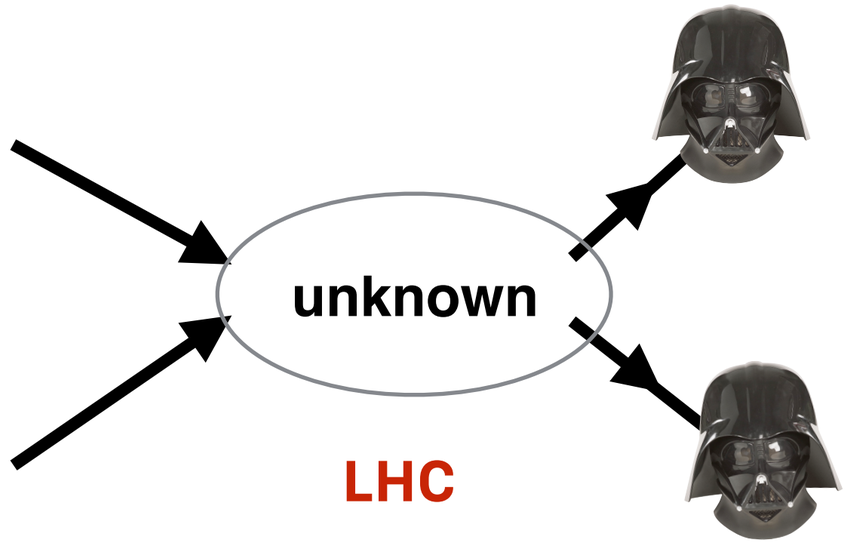


on the Earth, in orbit, and deep under the Earth's surface

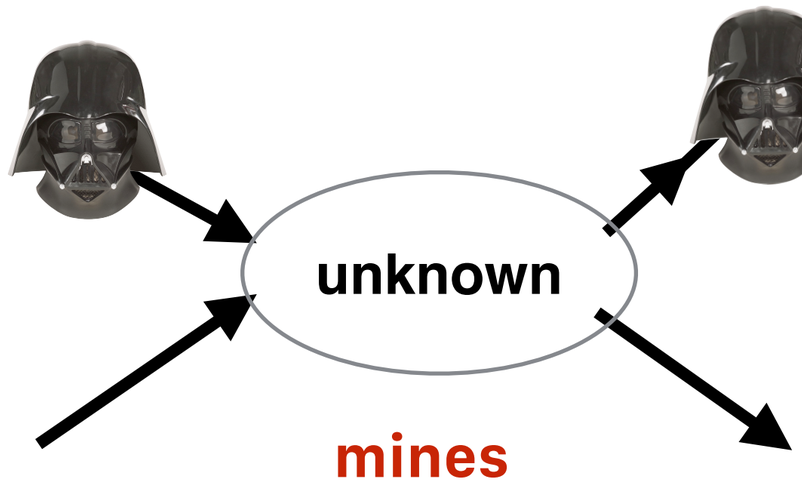
experiments

on the Earth, in orbit, and deep under the Earth's surface

production



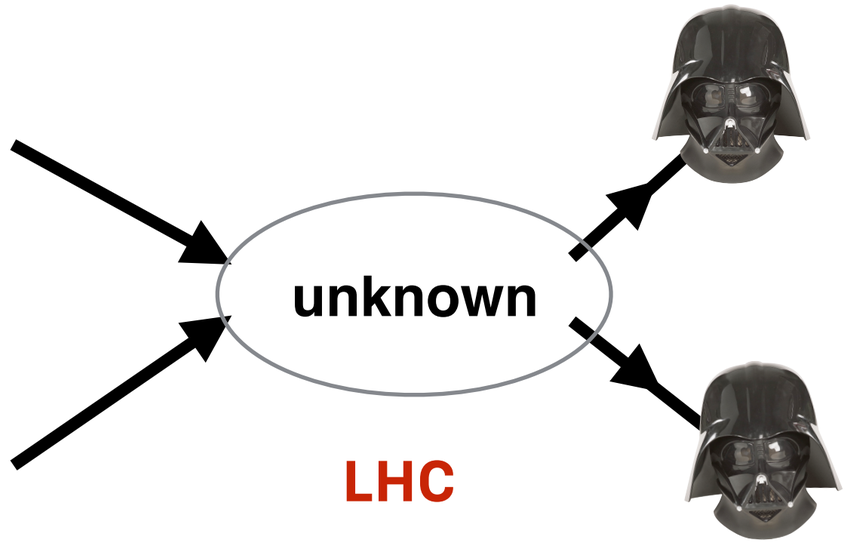
direct detection



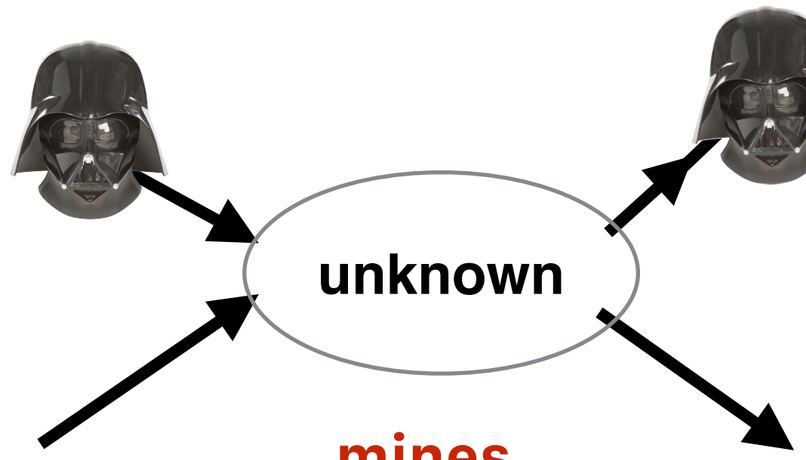
experiments

on the Earth, in orbit, and deep under the Earth's surface

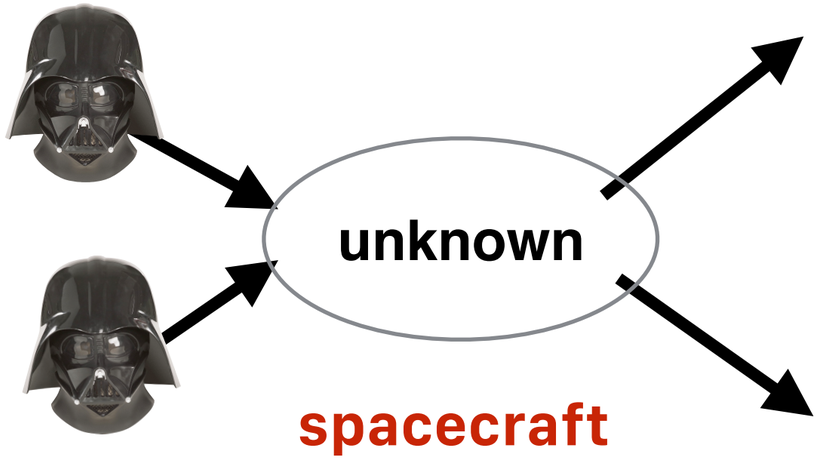
production



direct detection



indirect detection



hypothetical

Dark Matter

=:-o

? - but perhaps 30% of the universe

?

something entirely new

project

$$v = \sqrt{G \frac{M_{\text{center}}}{R}}$$