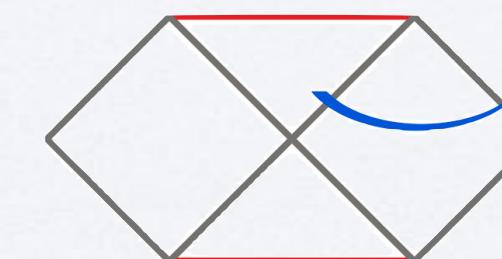


THE CENTER OF GRAVITY

RELATIVITY AND CURVED SPACETIME

Rodrigo Panosso Macedo



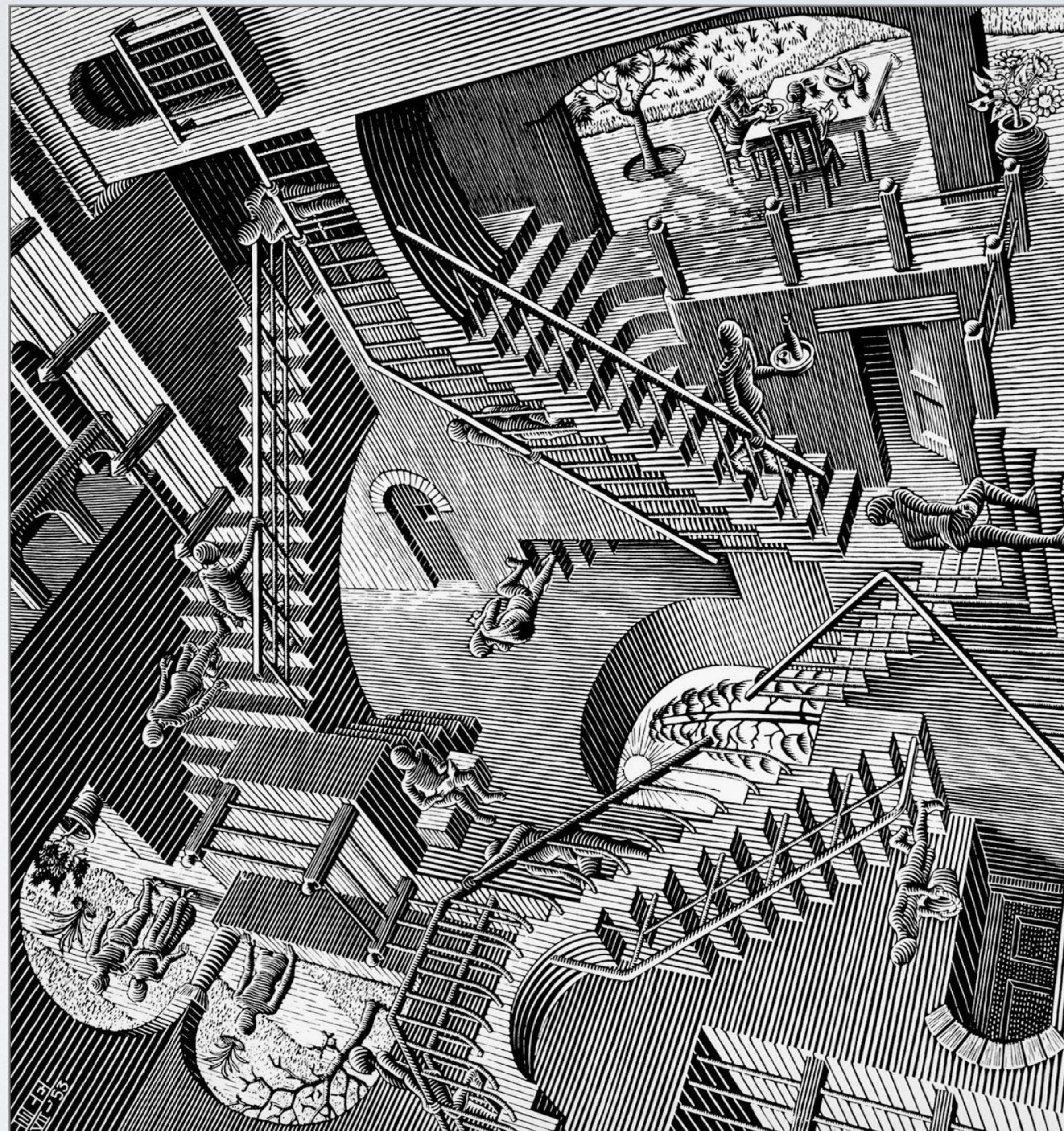
<https://hyperboloid.al>

EVERYTHING IS RELATIVE !



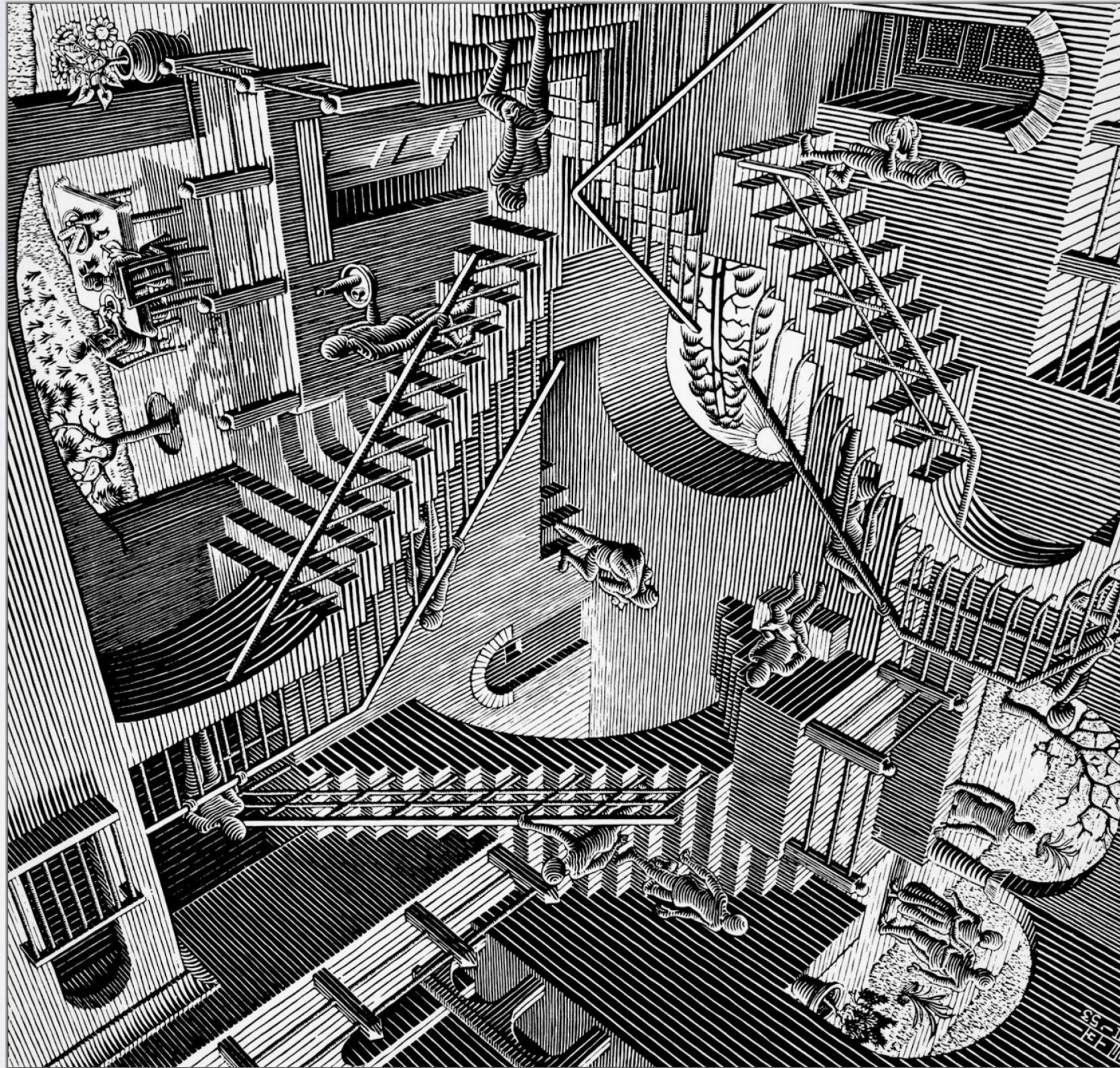
Relativity, by M. C. Escher

EVERYTHING IS RELATIVE !



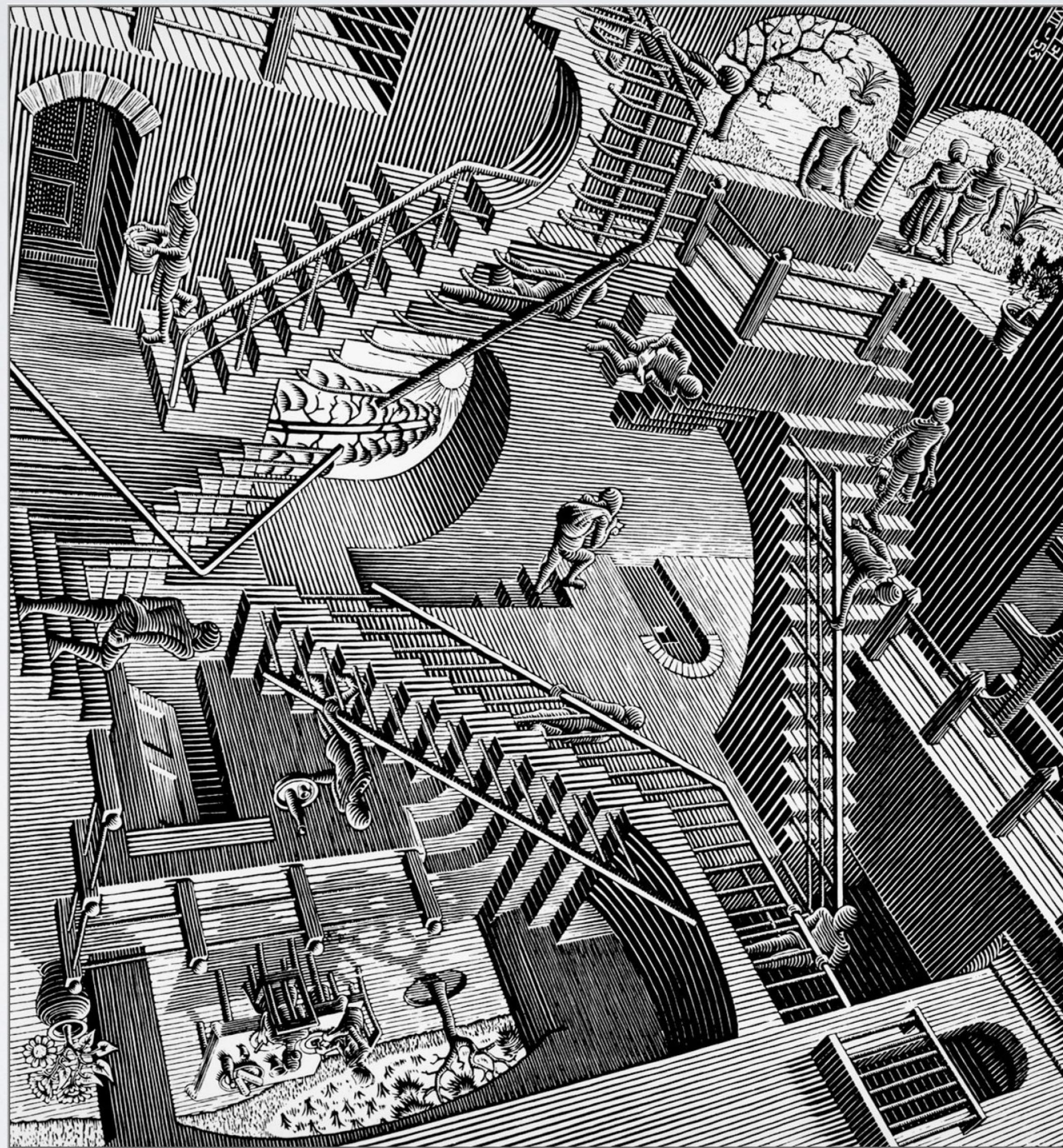
Relativity, by M. C. Escher

EVERYTHING IS RELATIVE !



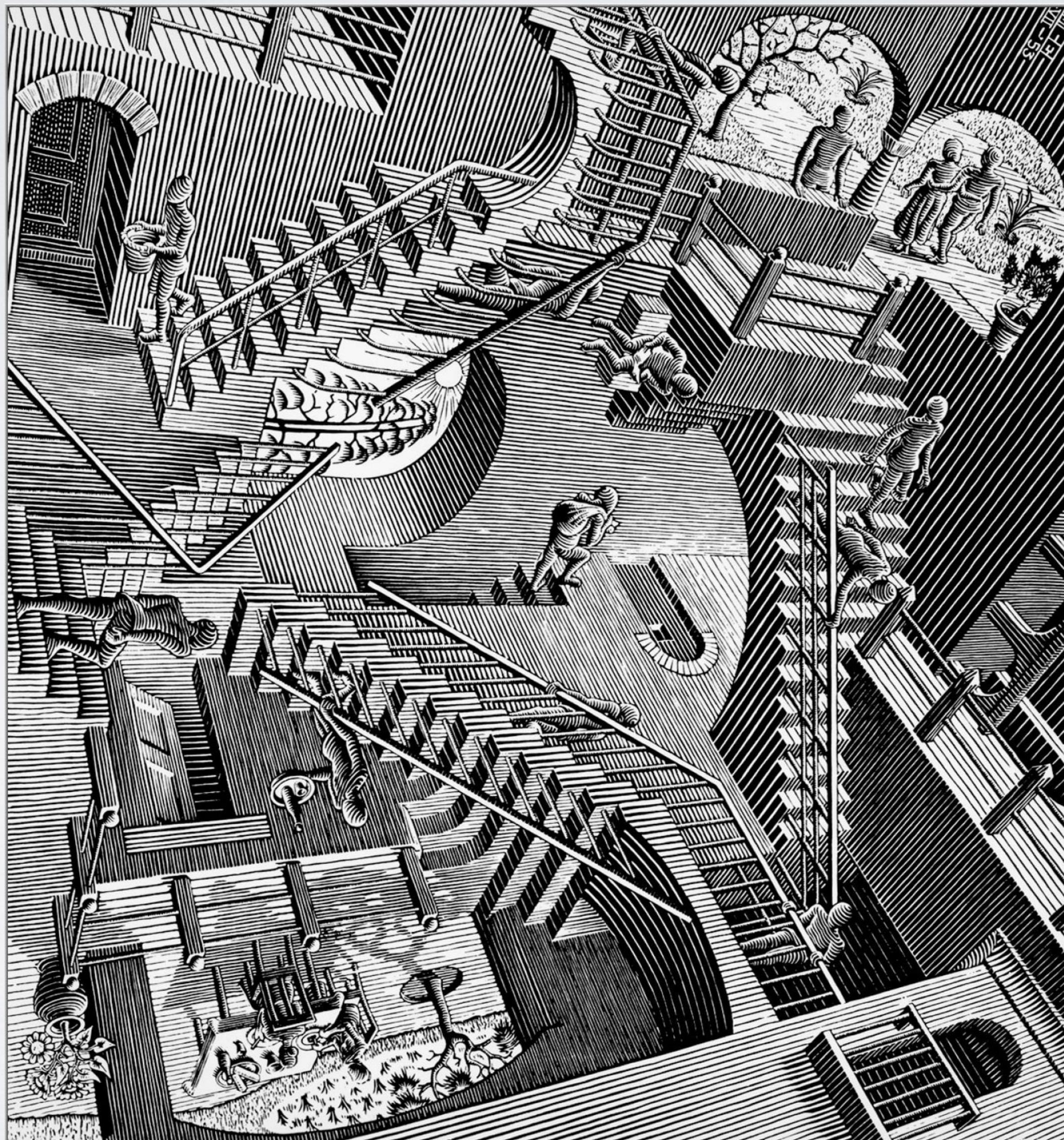
Relativity, by M. C. Escher

EVERYTHING IS RELATIVE !



Relativity, by M. C. Escher

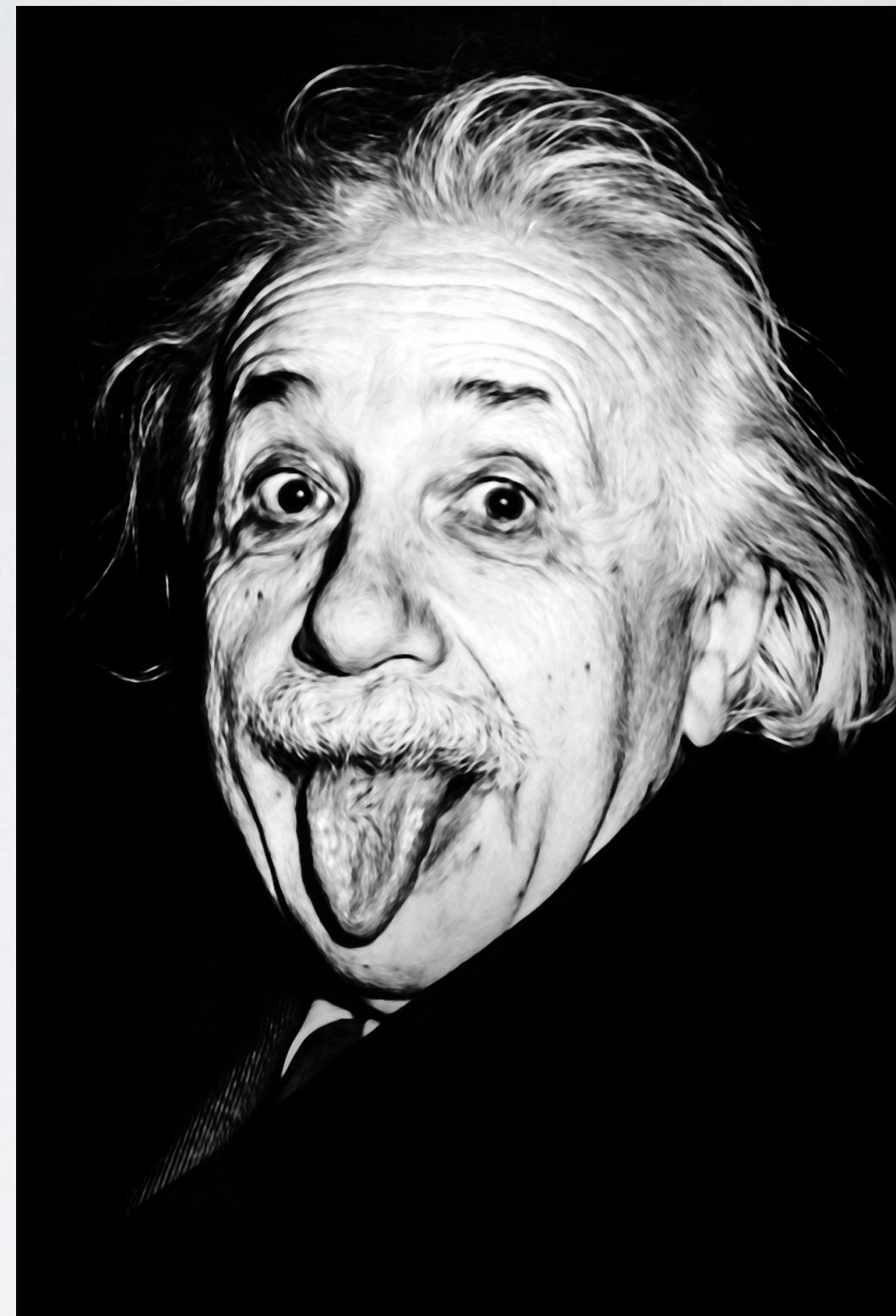
IS EVERYTHING RELATIVE ?



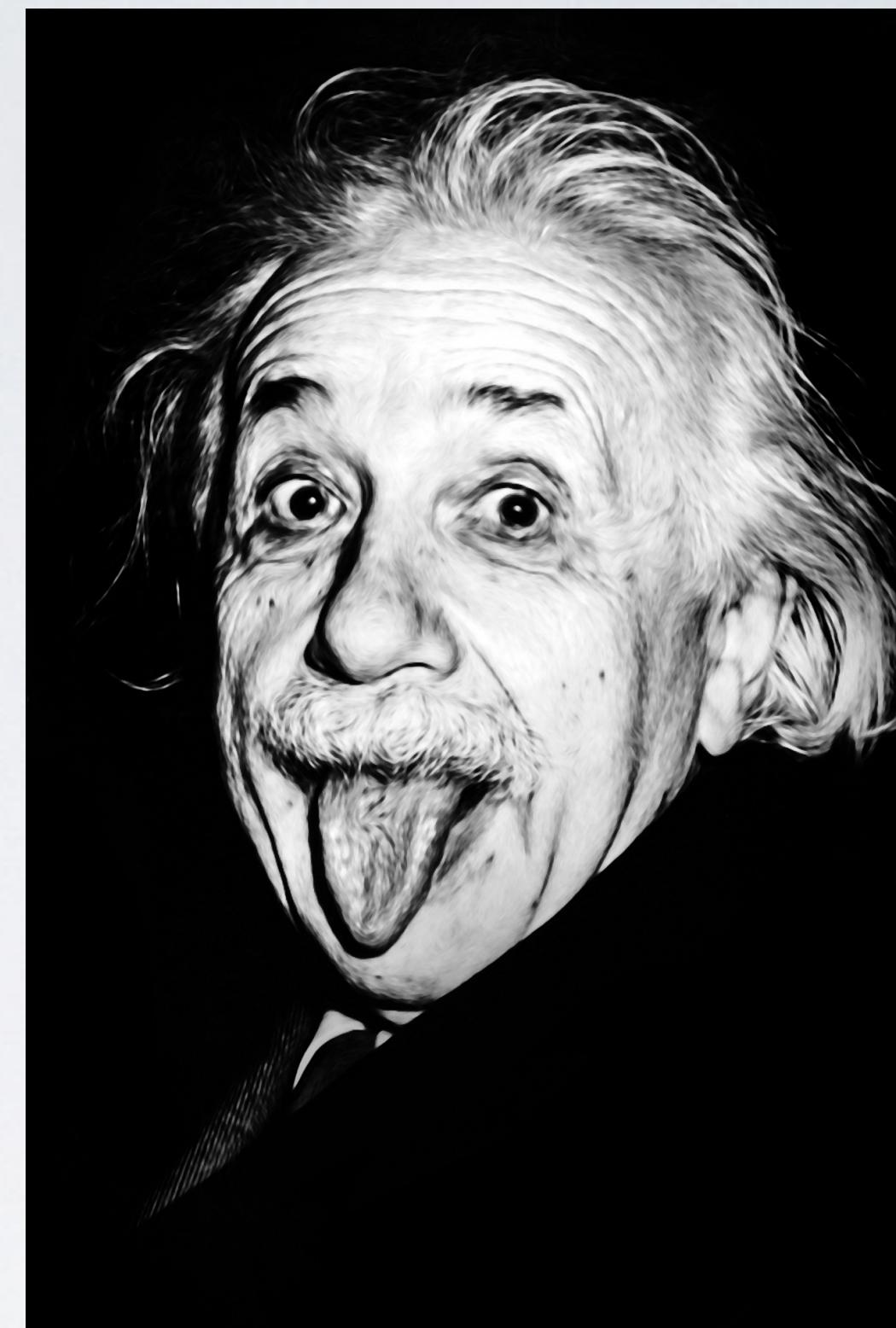
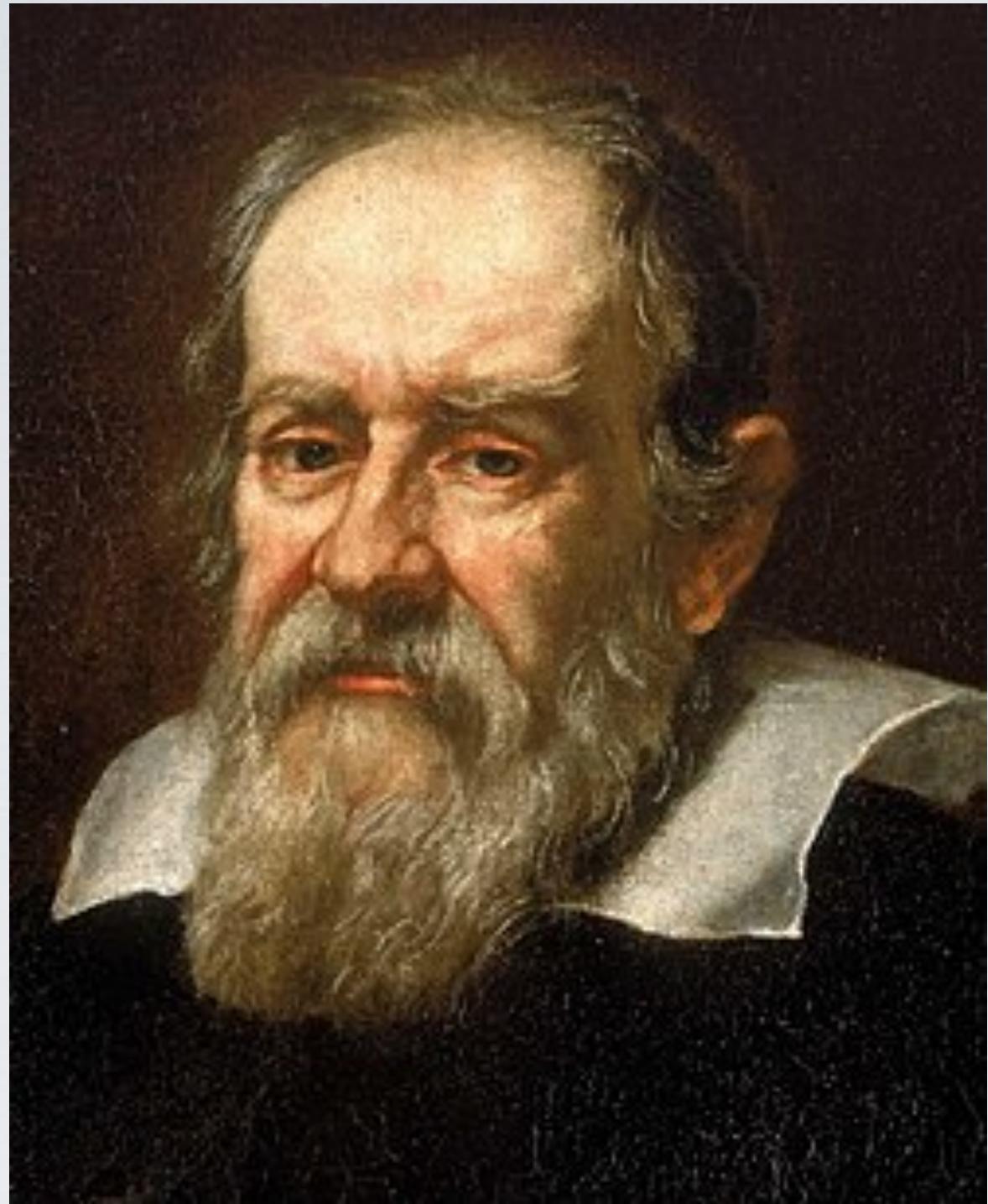
Relativity, by M. C. Escher

WHAT IS RELATIVITY ?

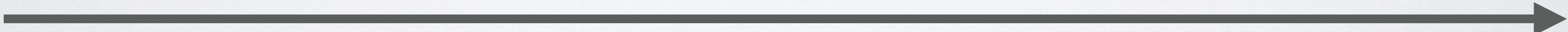
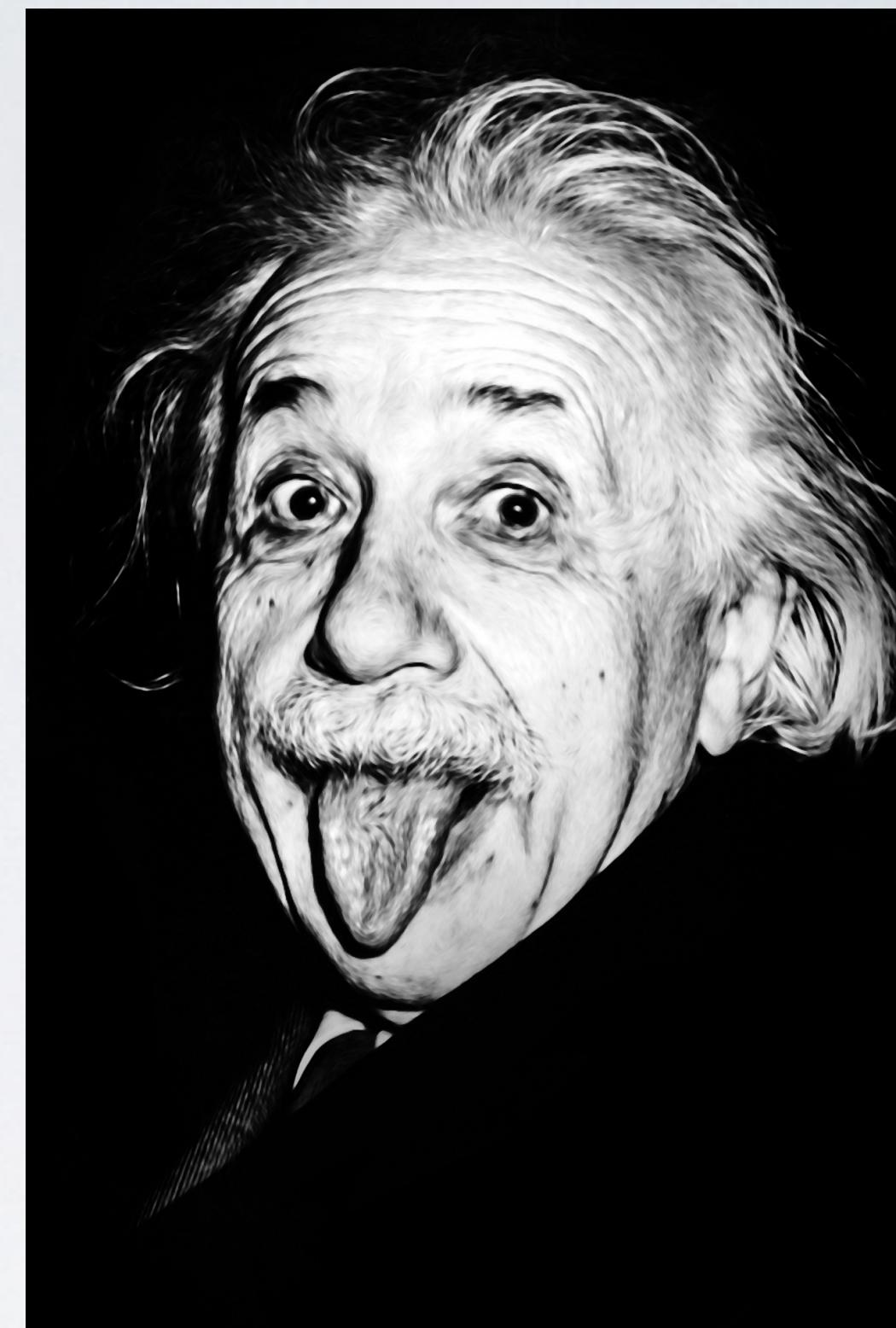
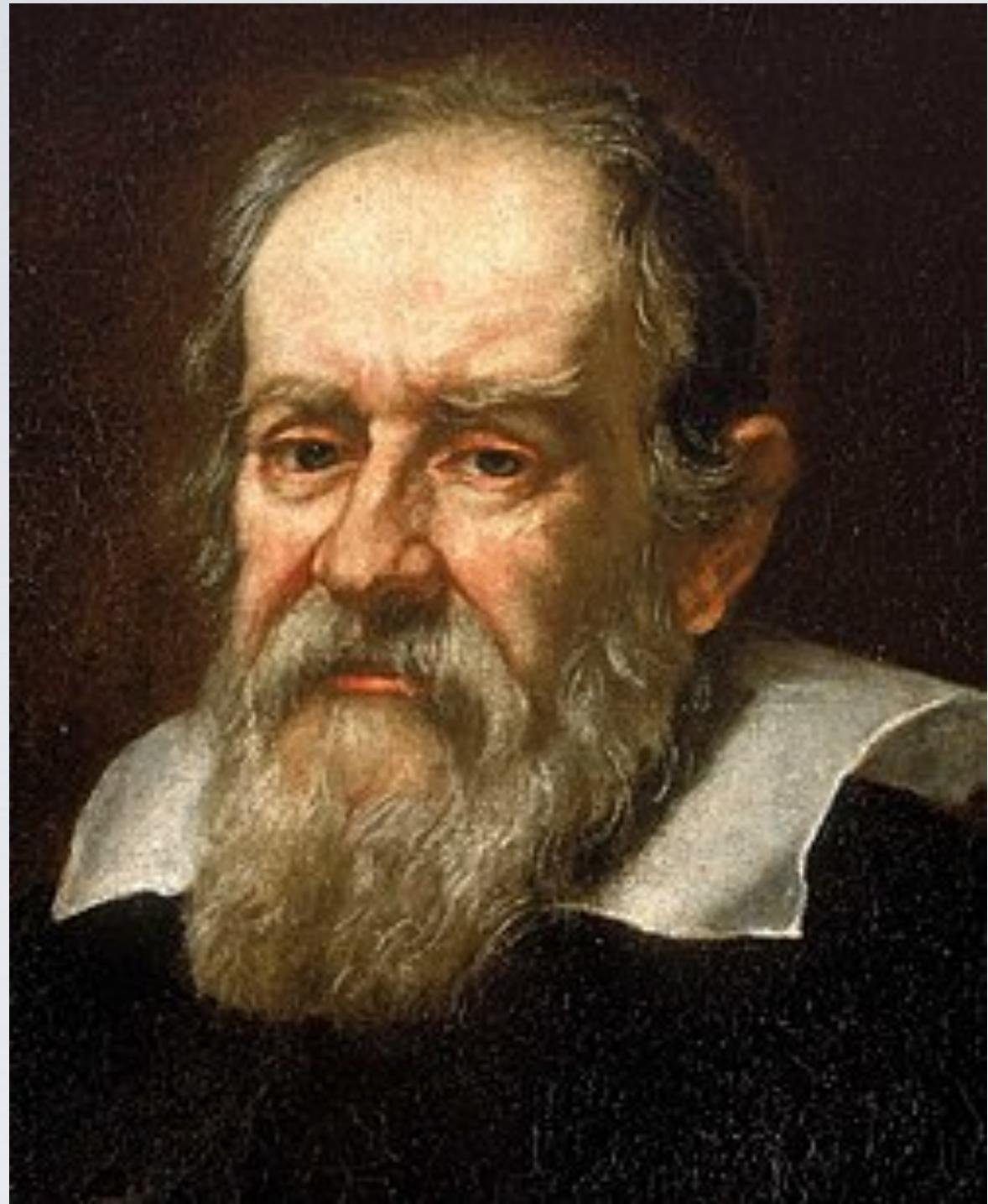
WHAT IS RELATIVITY ?



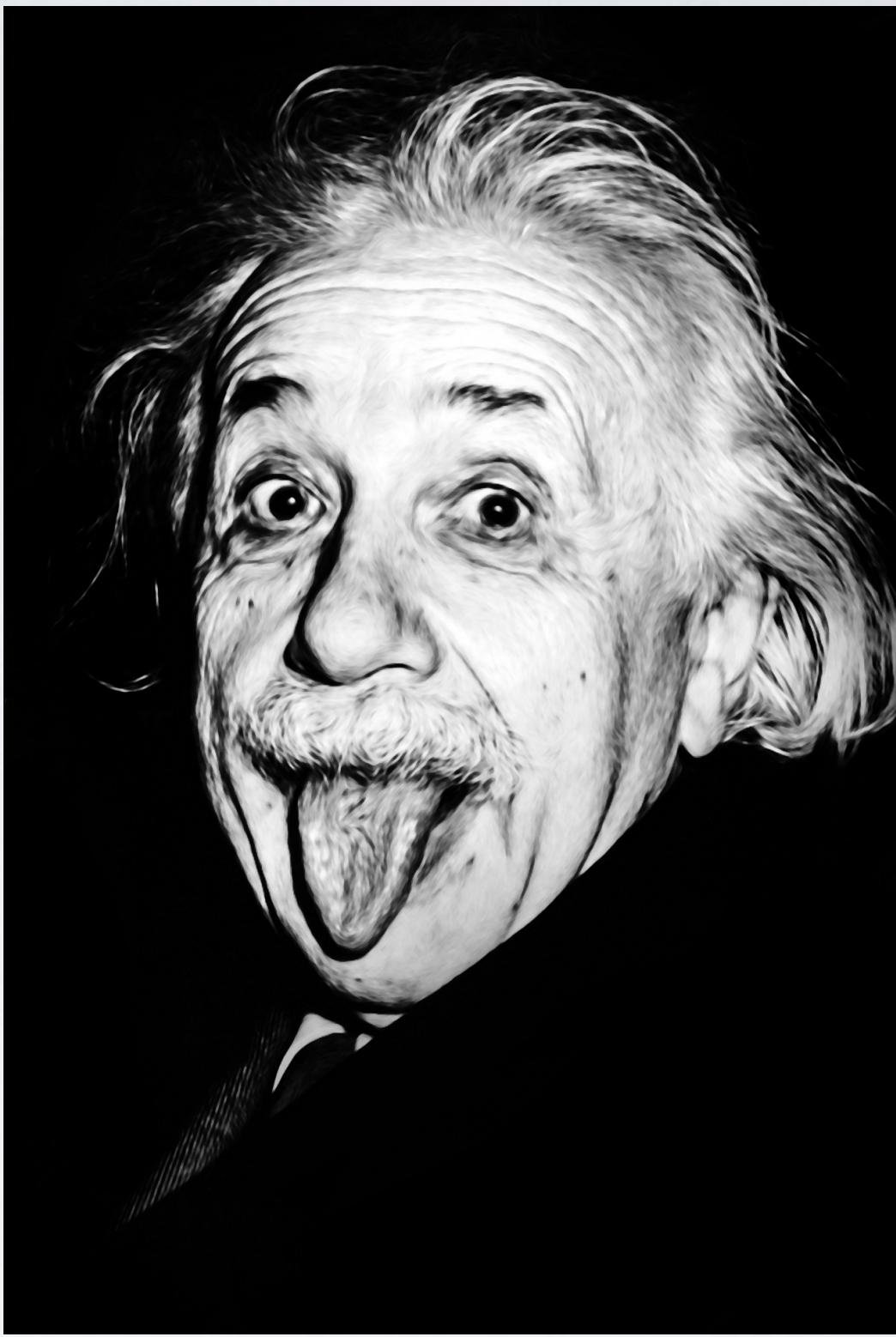
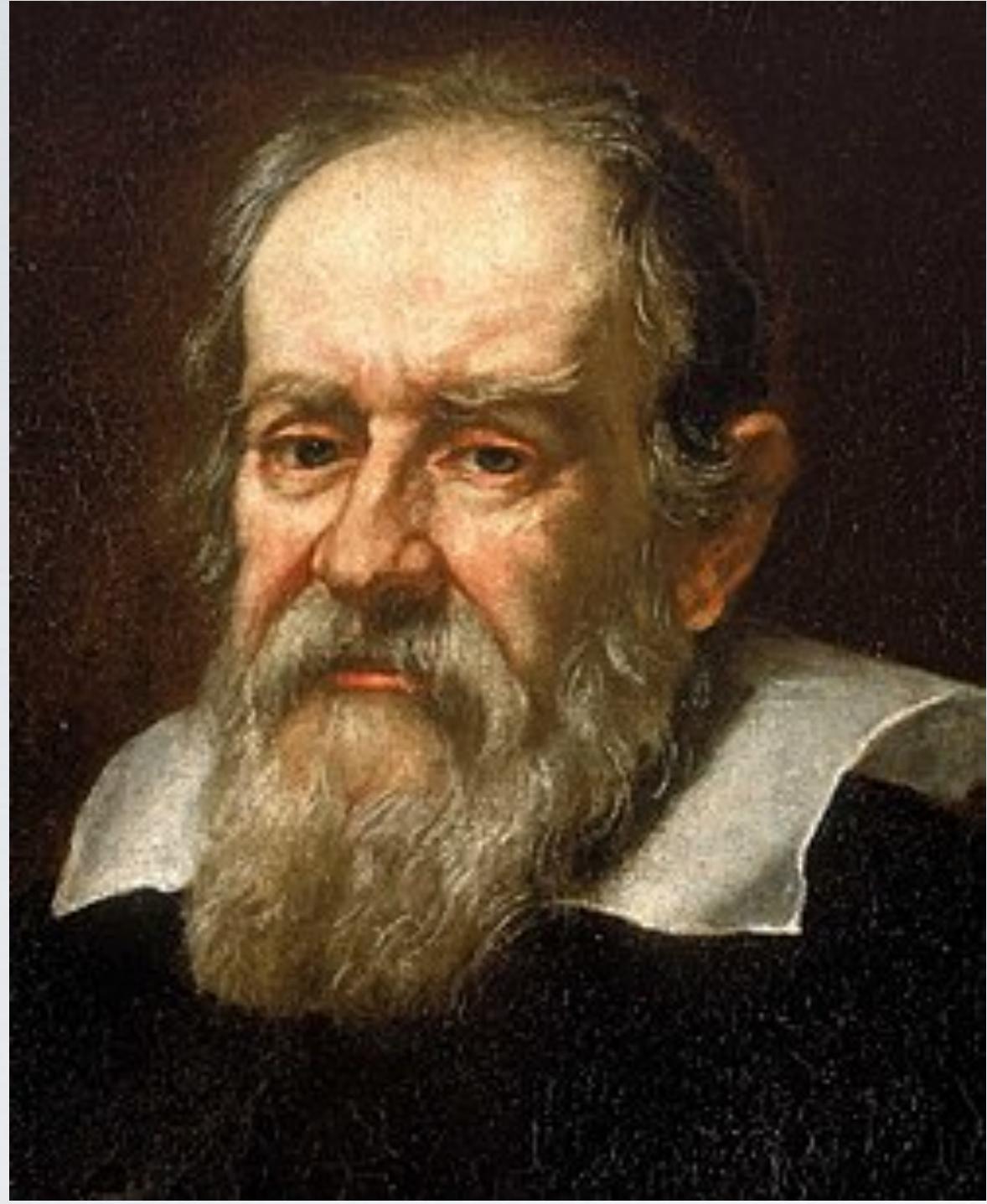
WHAT IS RELATIVITY ?



WHAT IS RELATIVITY ?



WHAT IS RELATIVITY ?

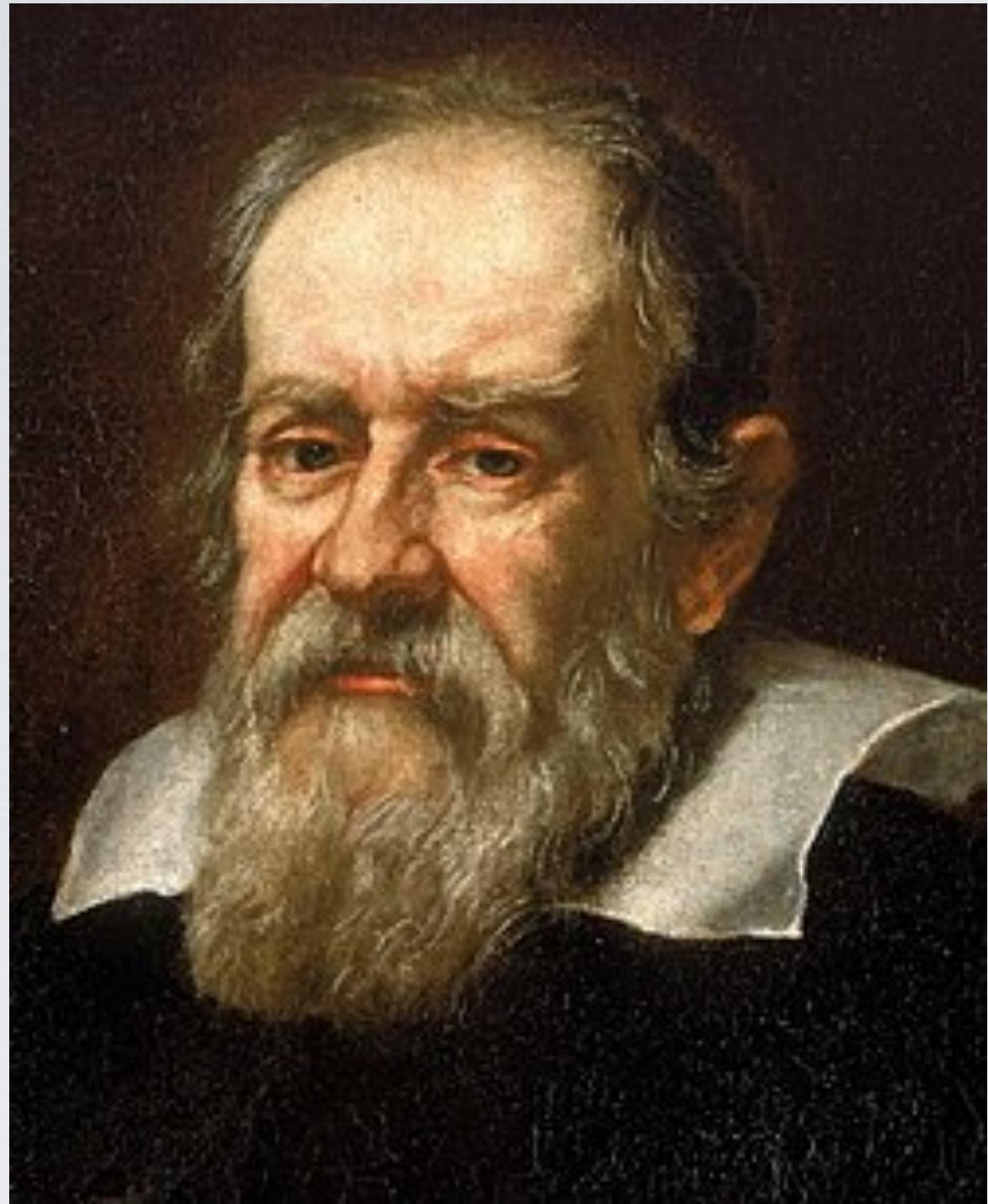


1632



Principle of Relativity
(velocities)

WHAT IS RELATIVITY ?

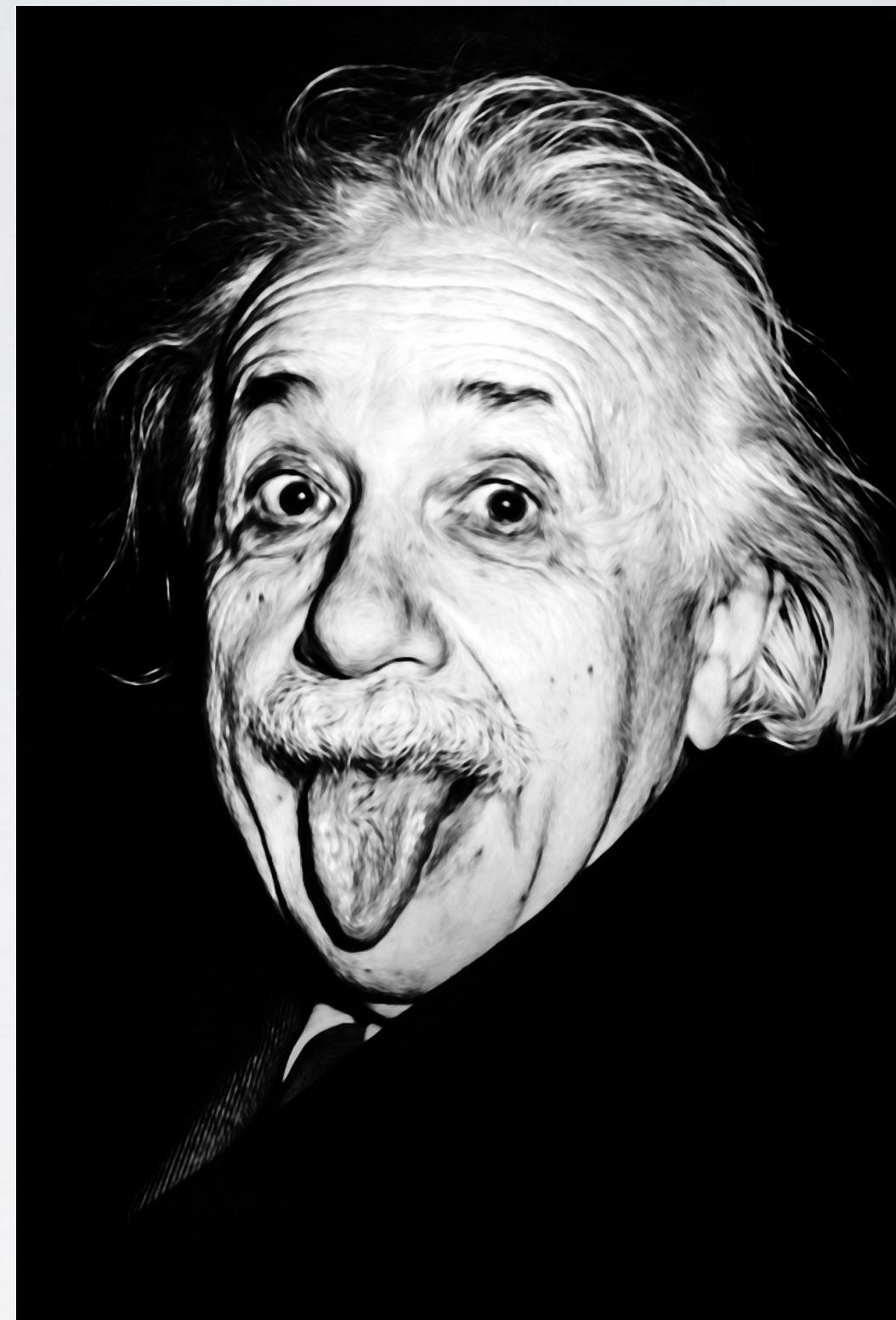


1632

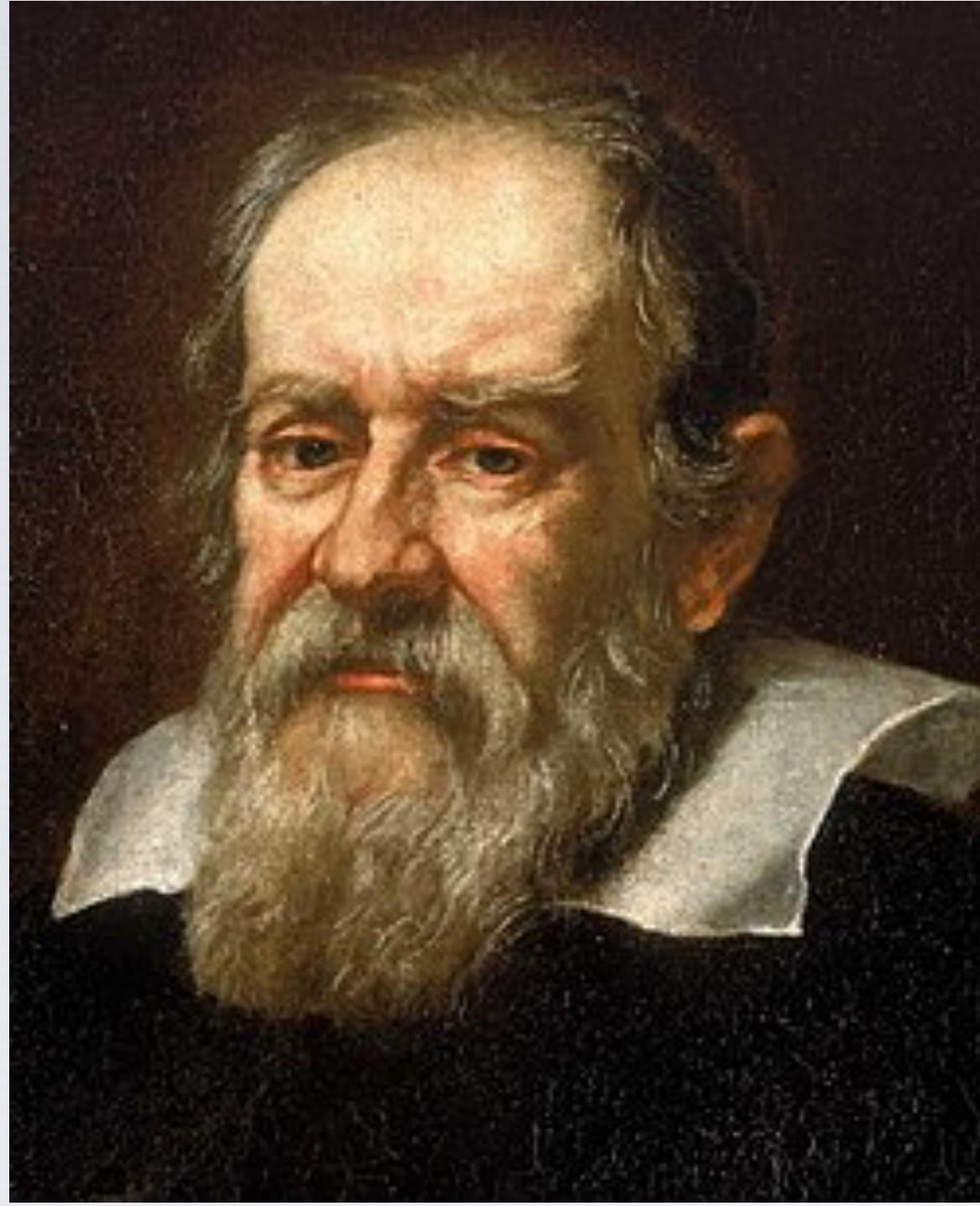


Principle of Relativity
(velocities)

Special Relativity
(Galileo+light)



WHAT IS RELATIVITY ?



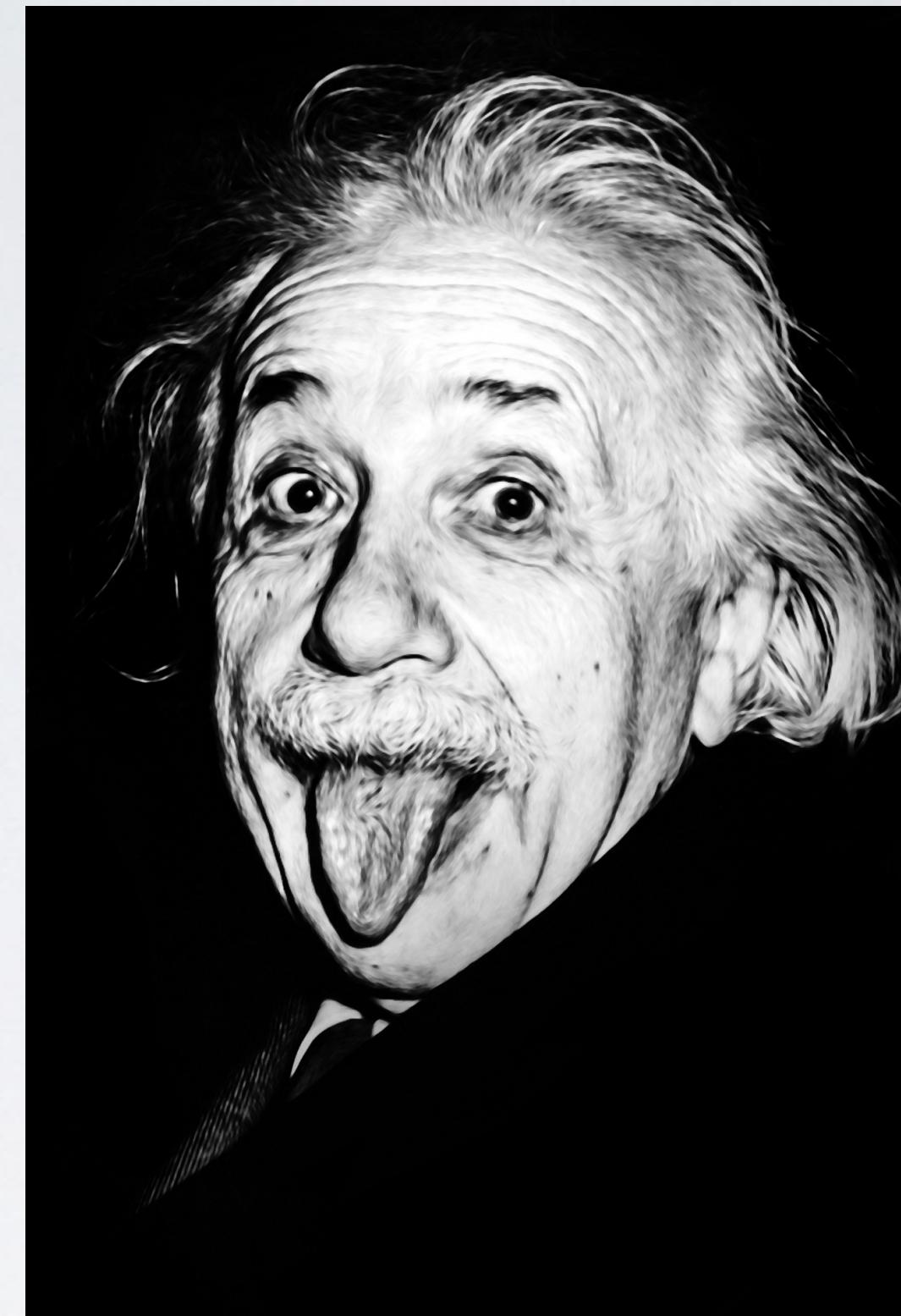
1632



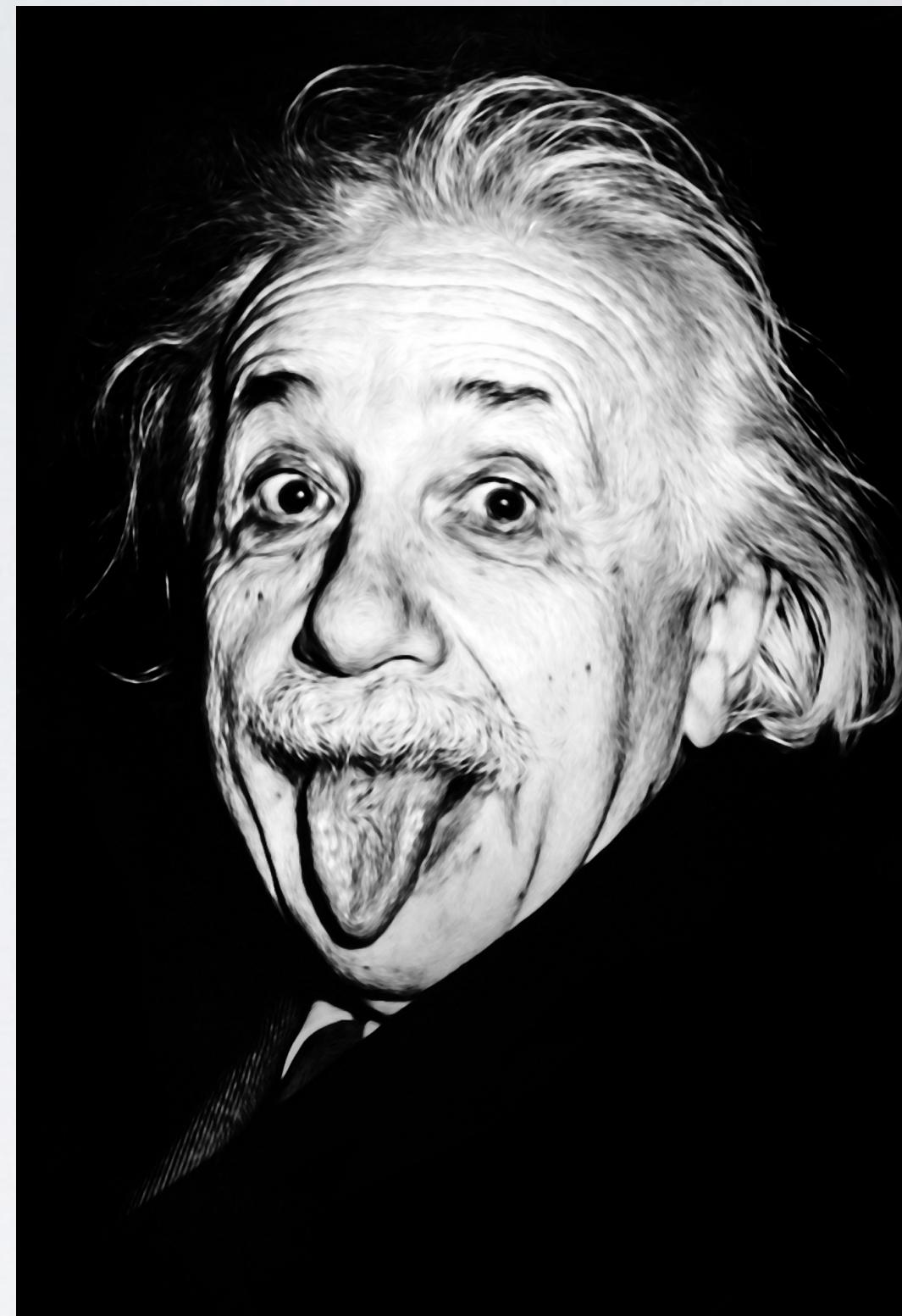
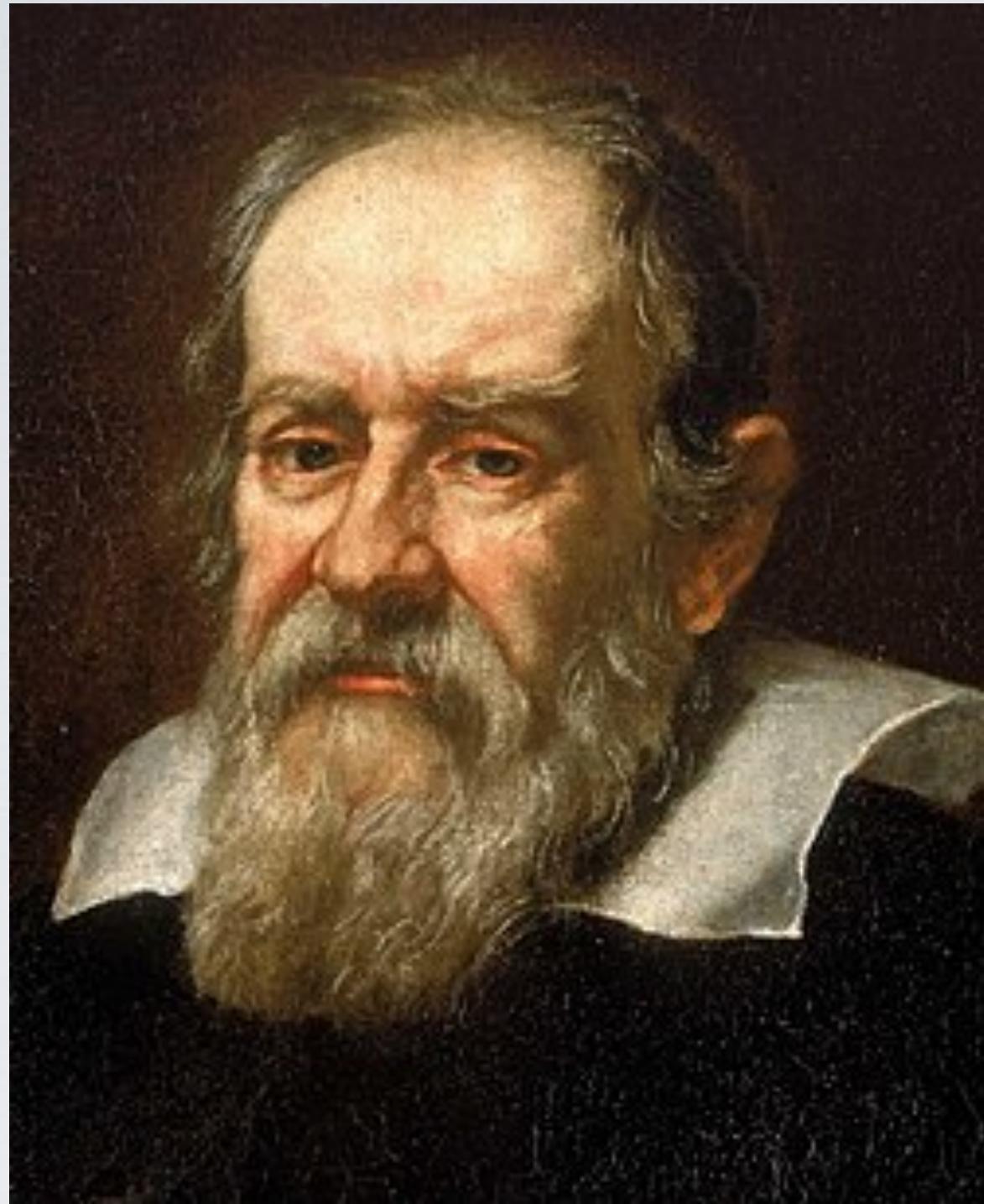
Principle of Relativity
(velocities)

Special Relativity
(Galileo+light)

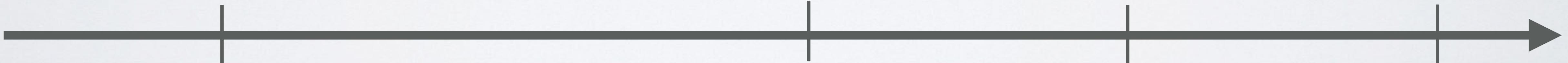
Equivalence Principle
(acceleration=gravity)



WHAT IS RELATIVITY ?



1632



Principle of Relativity
(velocities)

1905

Special Relativity
(Galileo+light)

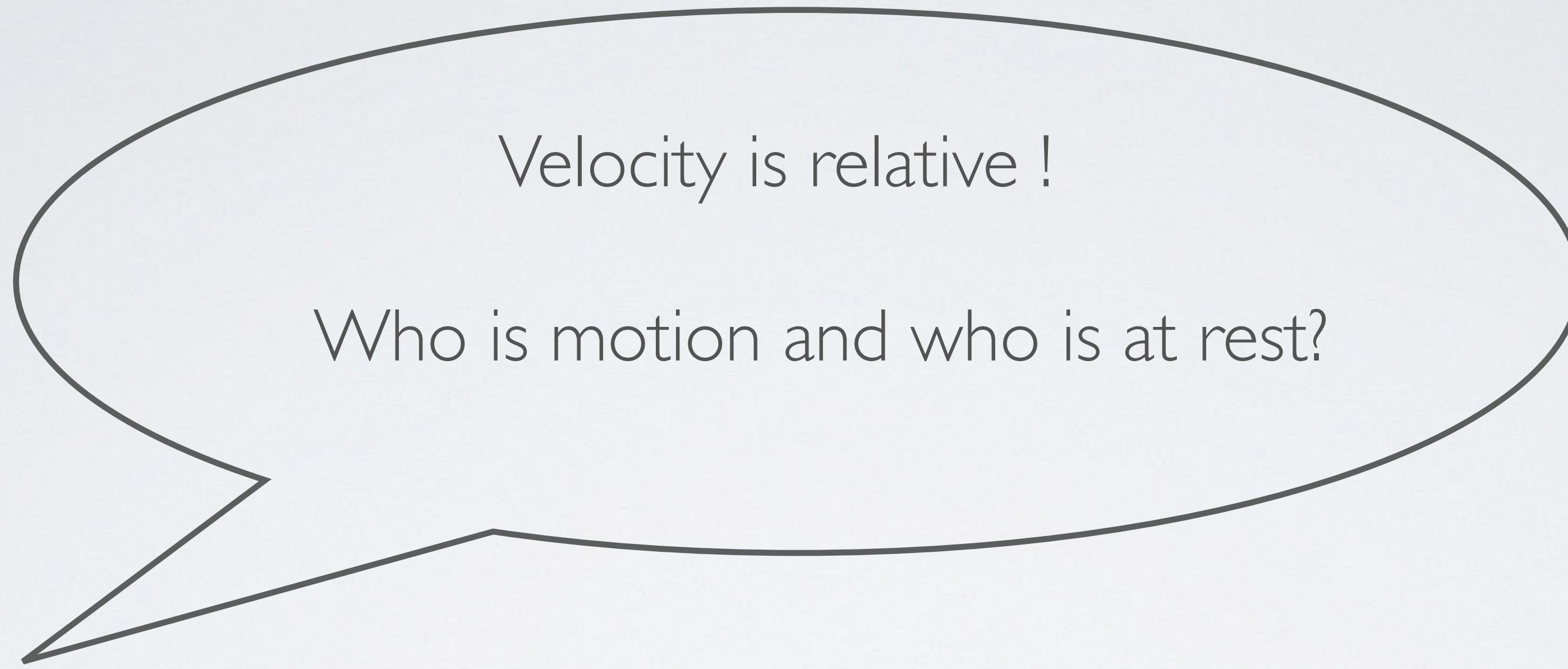
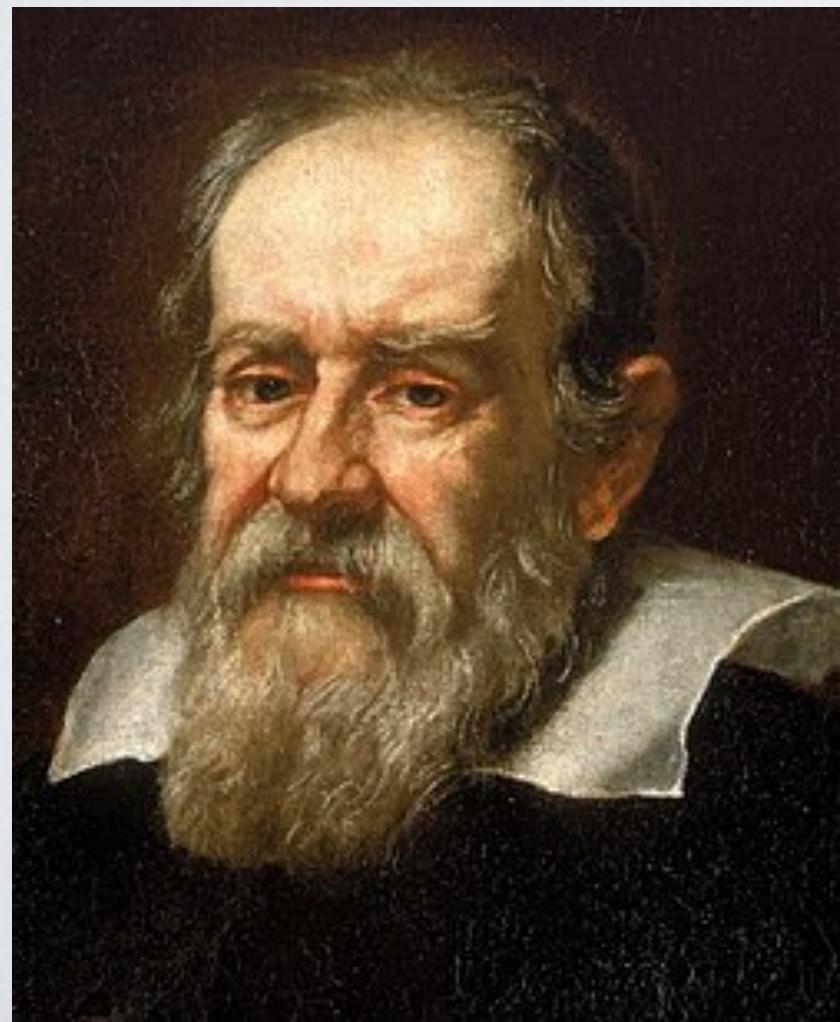
1907

Equivalence Principle
(acceleration=gravity)

1915

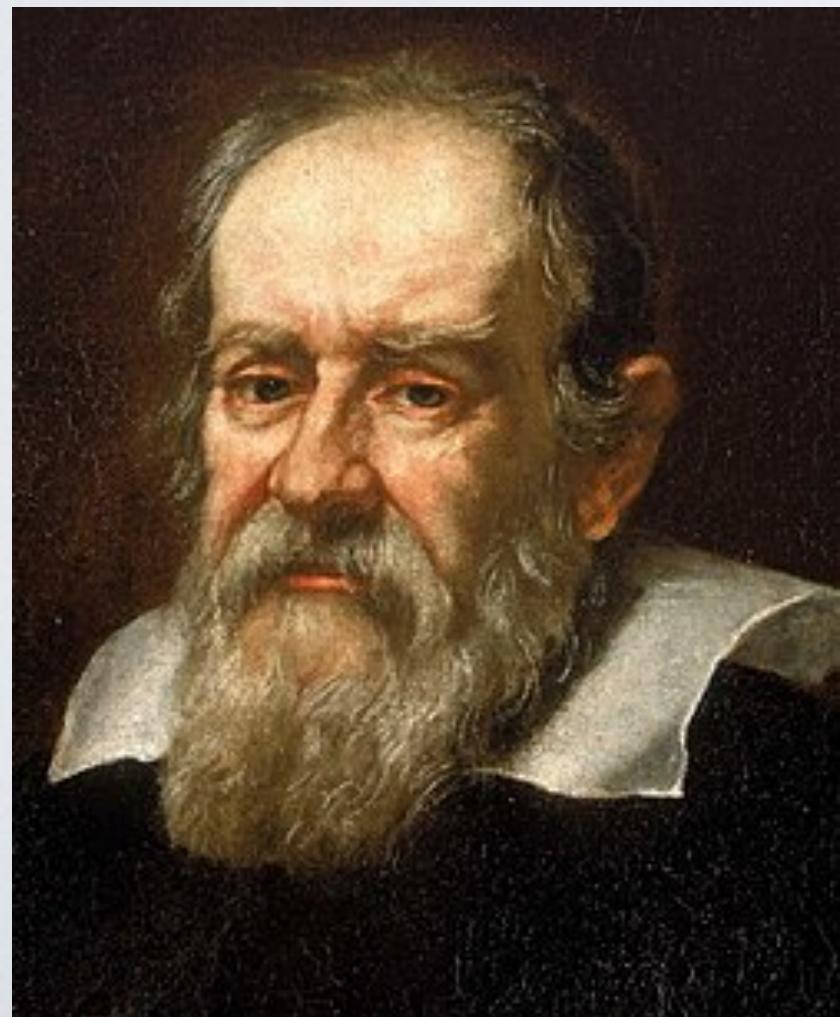
General Relativity Theory
(Special Relativity
+gravity)

GALILEO'S PRINCIPLE OF RELATIVITY



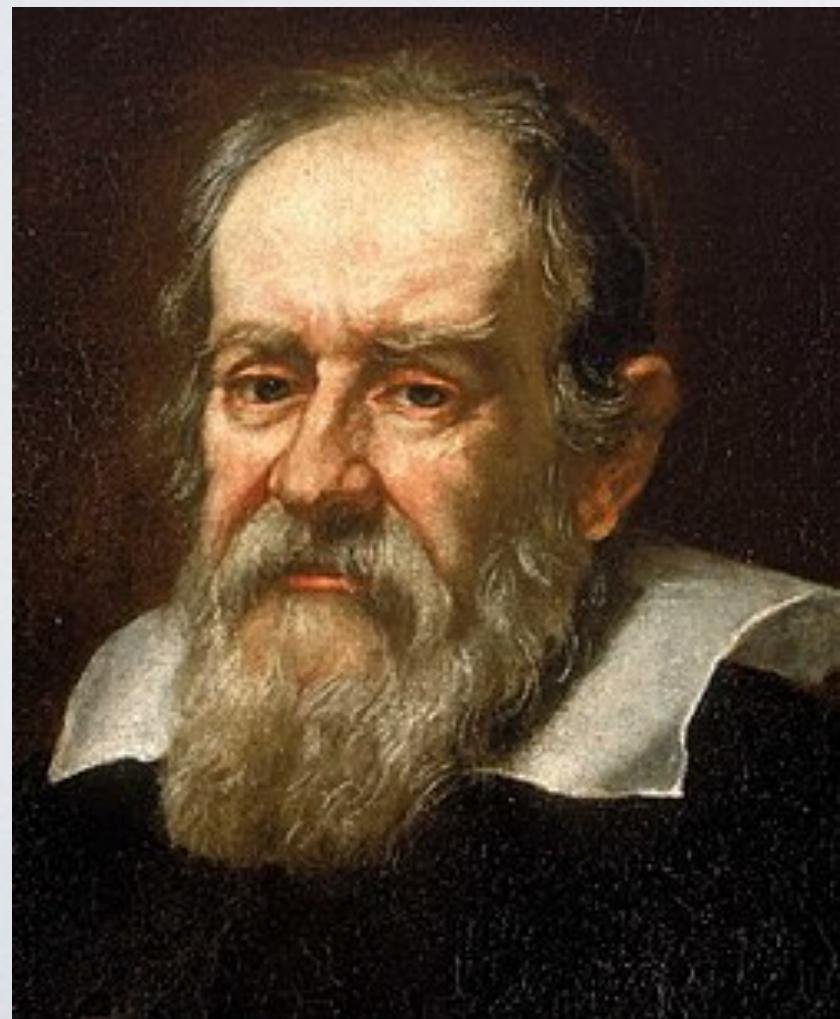
GALILEO'S PRINCIPLE OF RELATIVITY

The laws of physics are the
same for all inertial
observers !

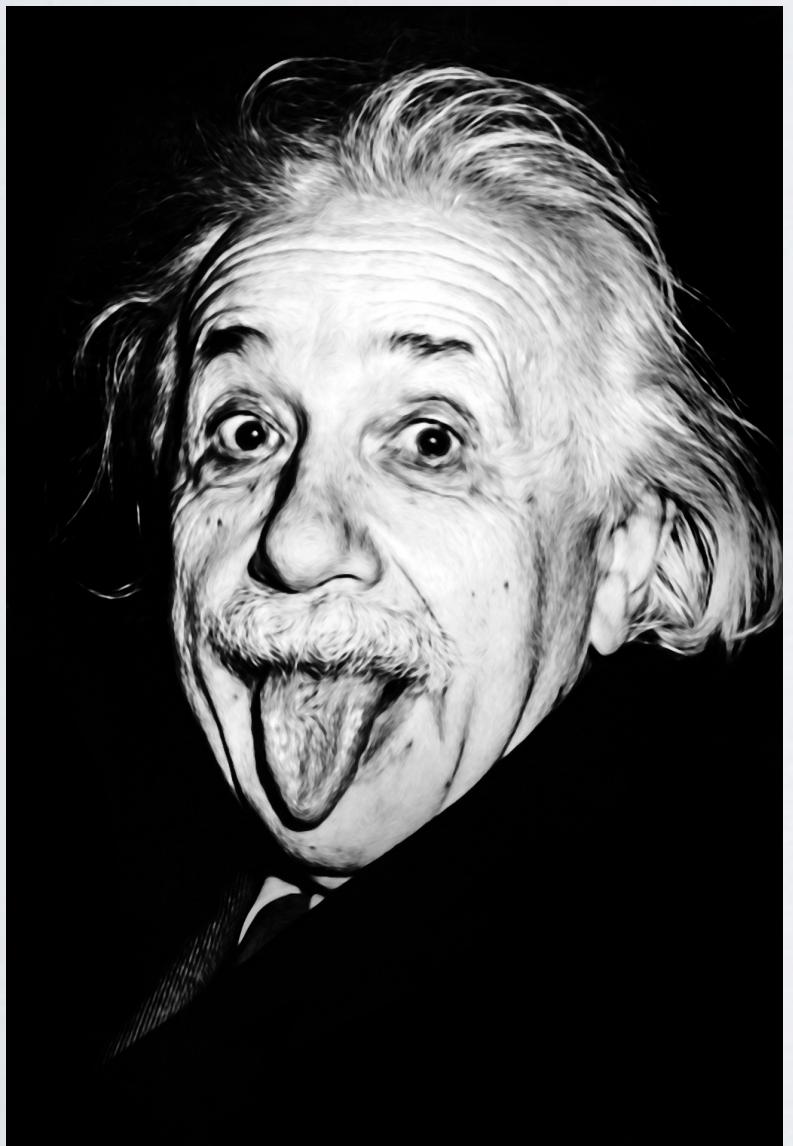


GALILEO'S PRINCIPLE OF RELATIVITY

Nothing (*absolute nothing*)
can tell if we are at rest, or
with a constant velocity



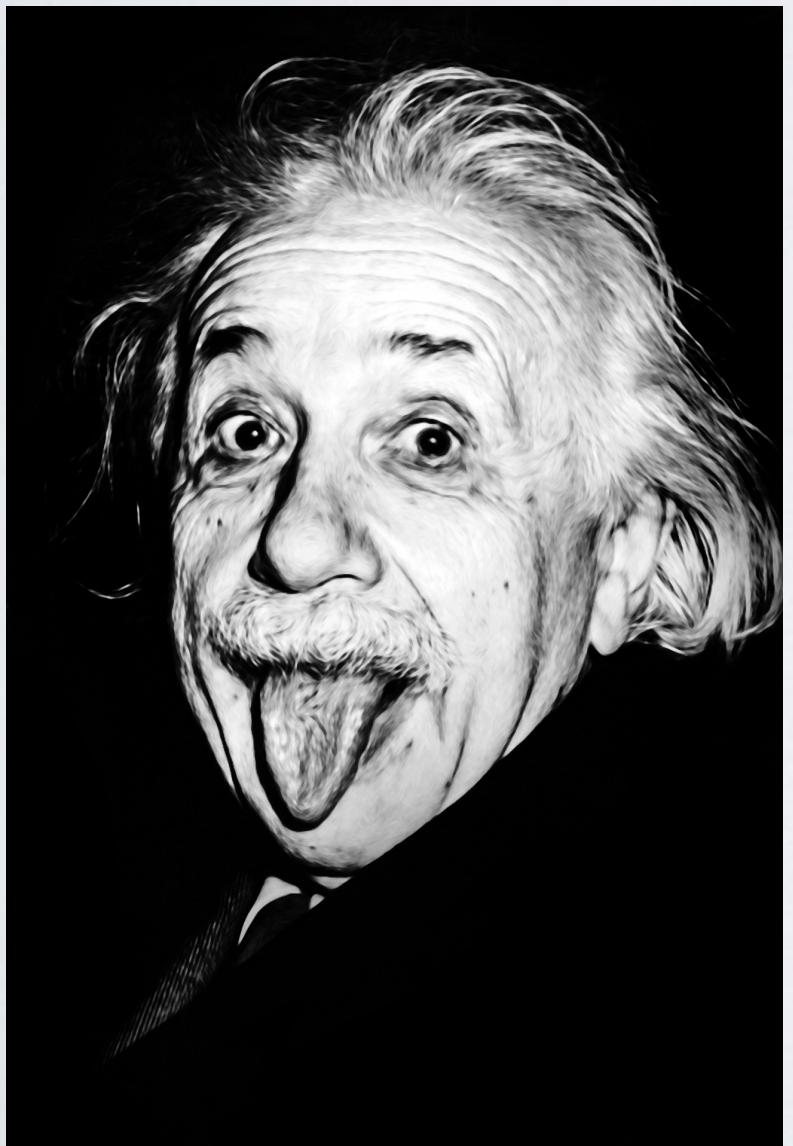
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)



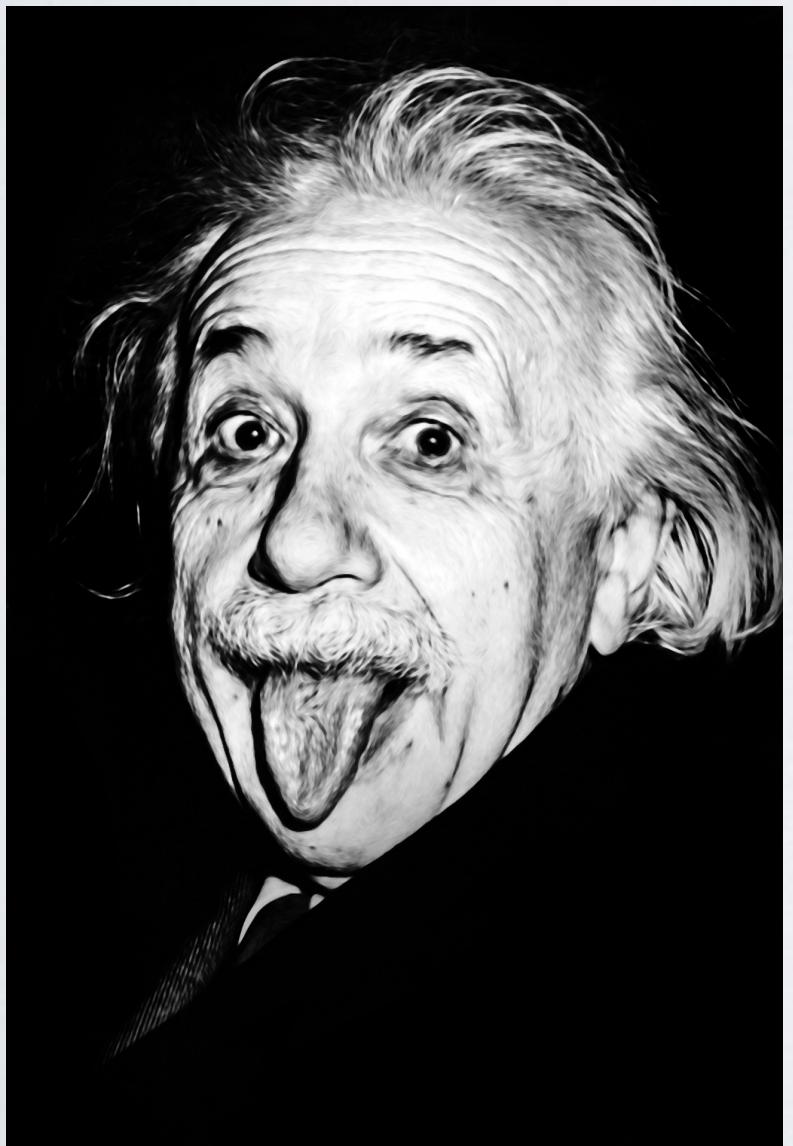
The effects of gravity are
indistinguishable from an
accelerated observer

EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

The effects of gravity are
indistinguishable from an
accelerated observer



EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)



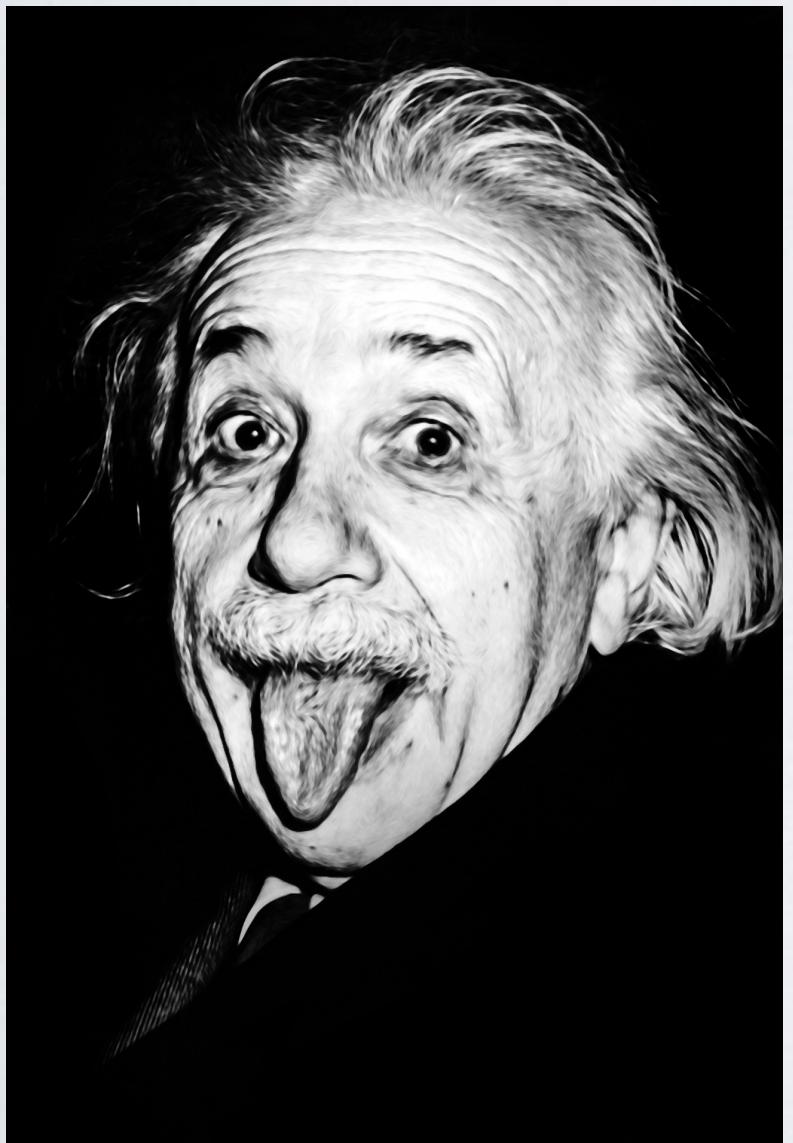
The effects of gravity are indistinguishable from an accelerated observer

$$\vec{g} \downarrow$$



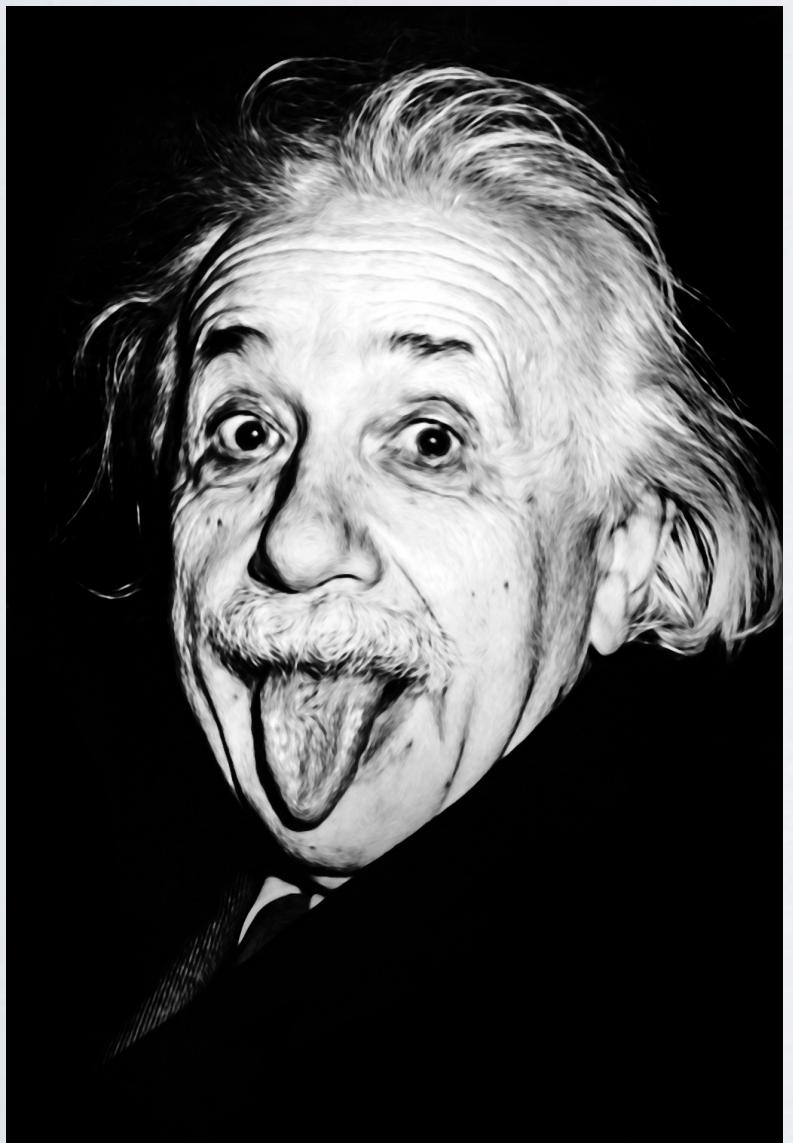
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

The effects of gravity are
indistinguishable from an
accelerated observer



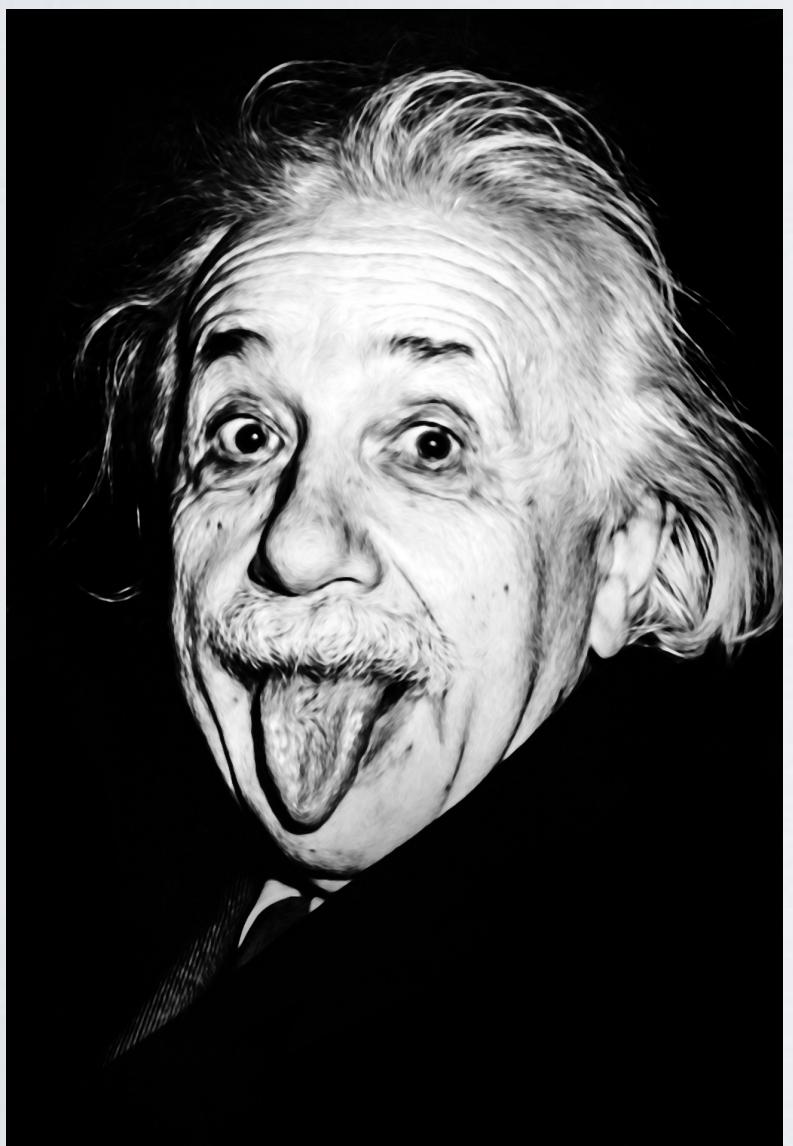
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

The effects of gravity are
indistinguishable from an
accelerated observer



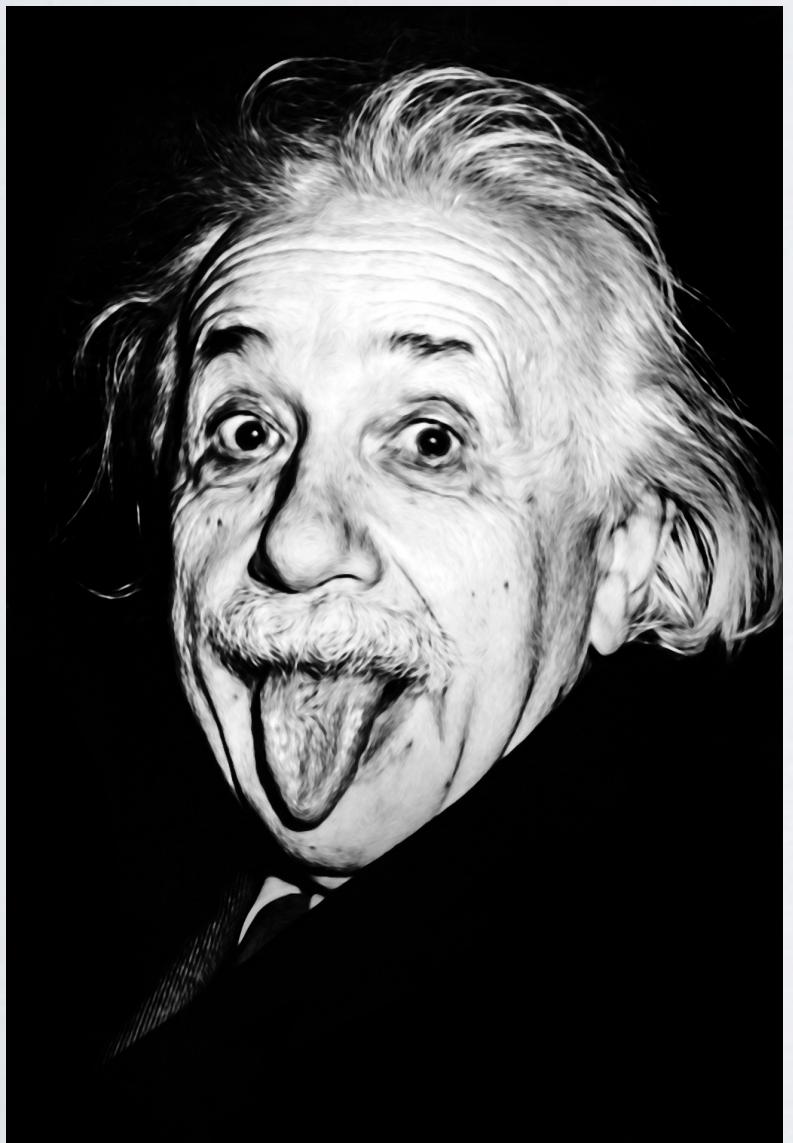
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

The effects of gravity are
indistinguishable from an
accelerated observer



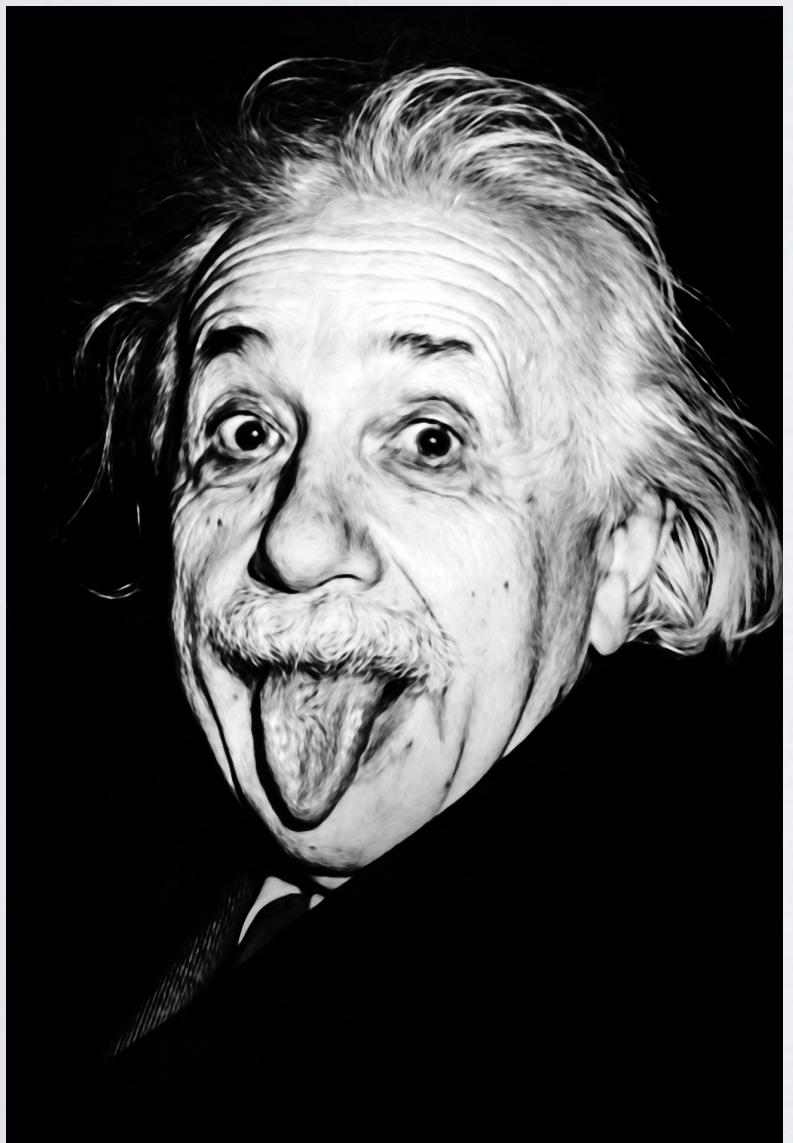
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

The effects of gravity are
indistinguishable from an
accelerated observer



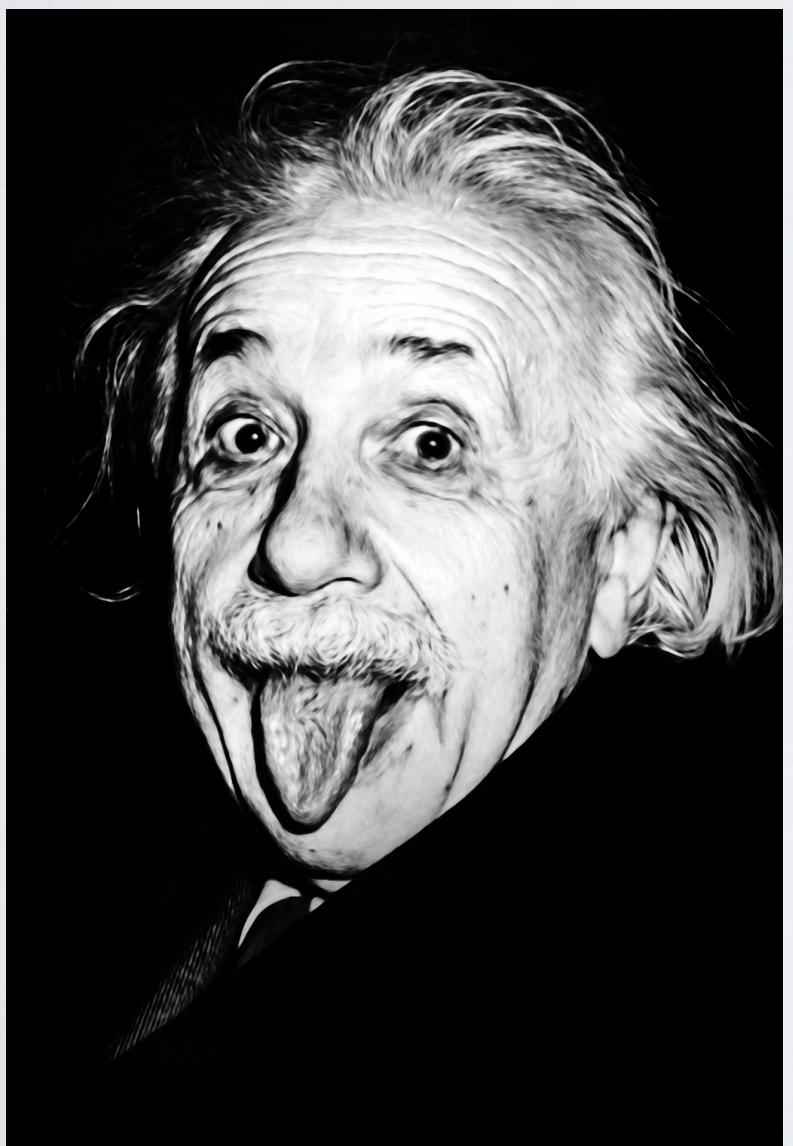
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

The effects of gravity are
indistinguishable from an
accelerated observer



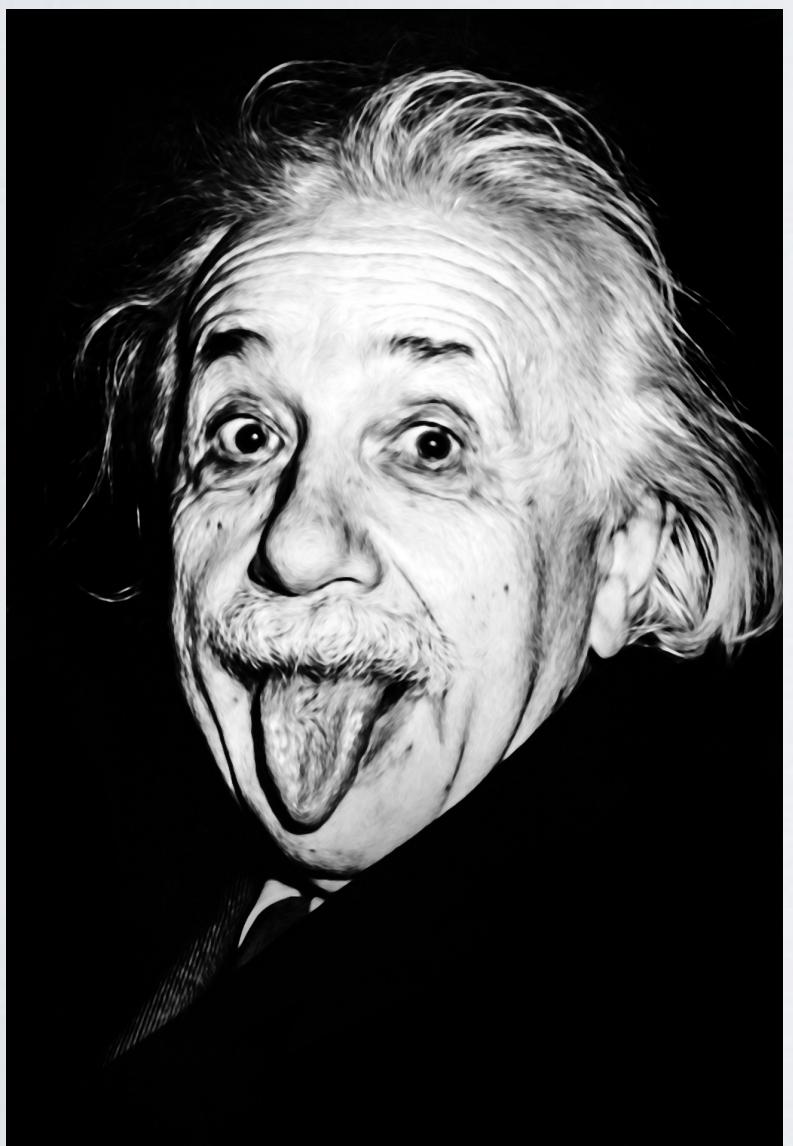
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

The effects of gravity are
indistinguishable from an
accelerated observer



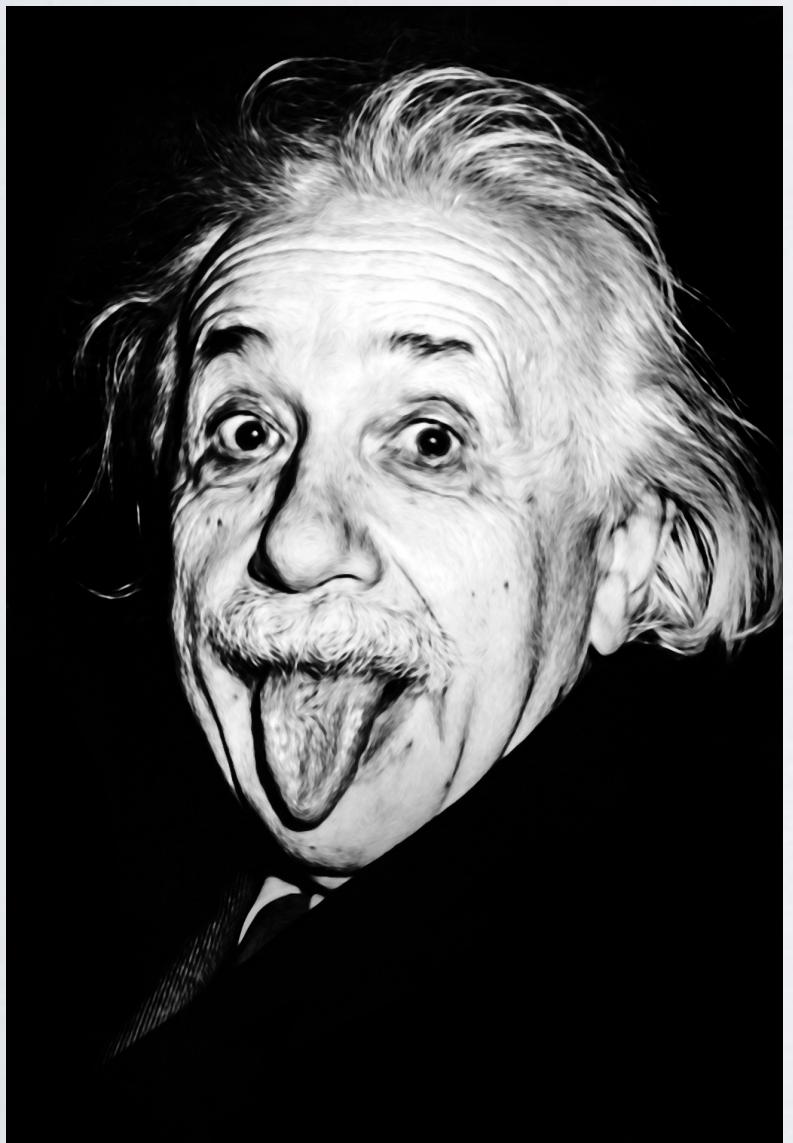
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

The effects of gravity are
indistinguishable from an
accelerated observer



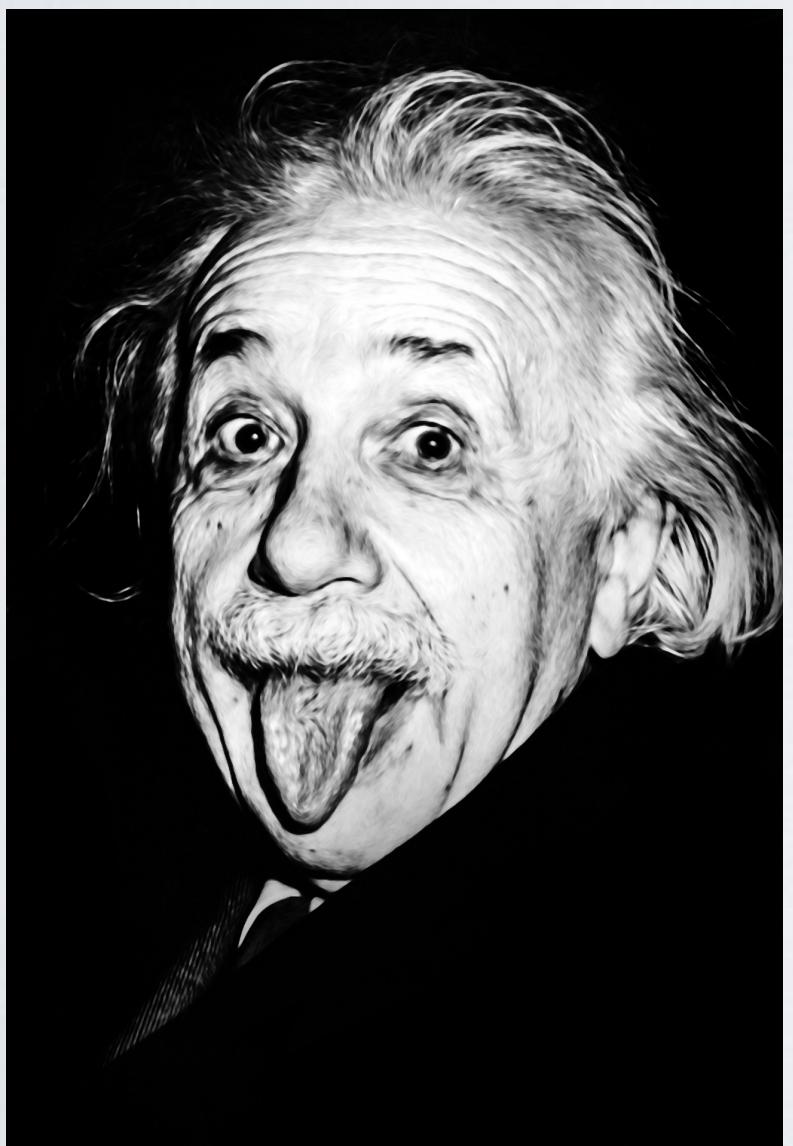
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

The effects of gravity are
indistinguishable from an
accelerated observer



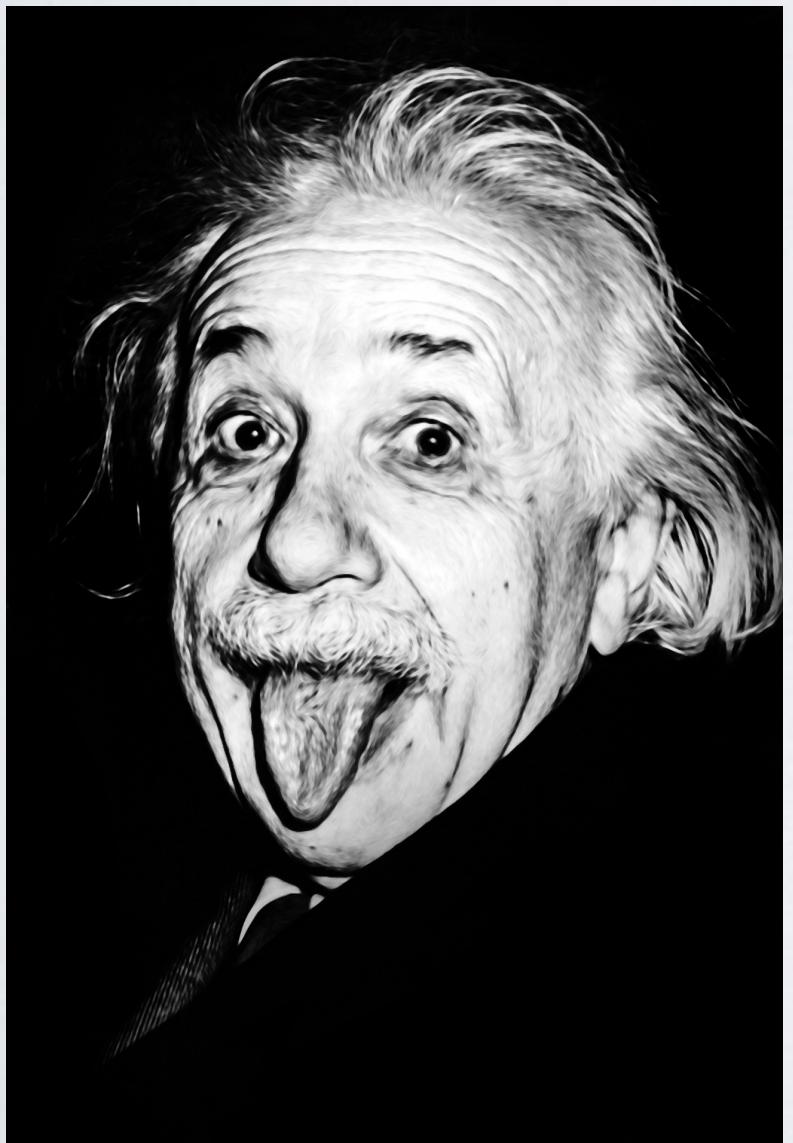
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

The effects of gravity are
indistinguishable from an
accelerated observer

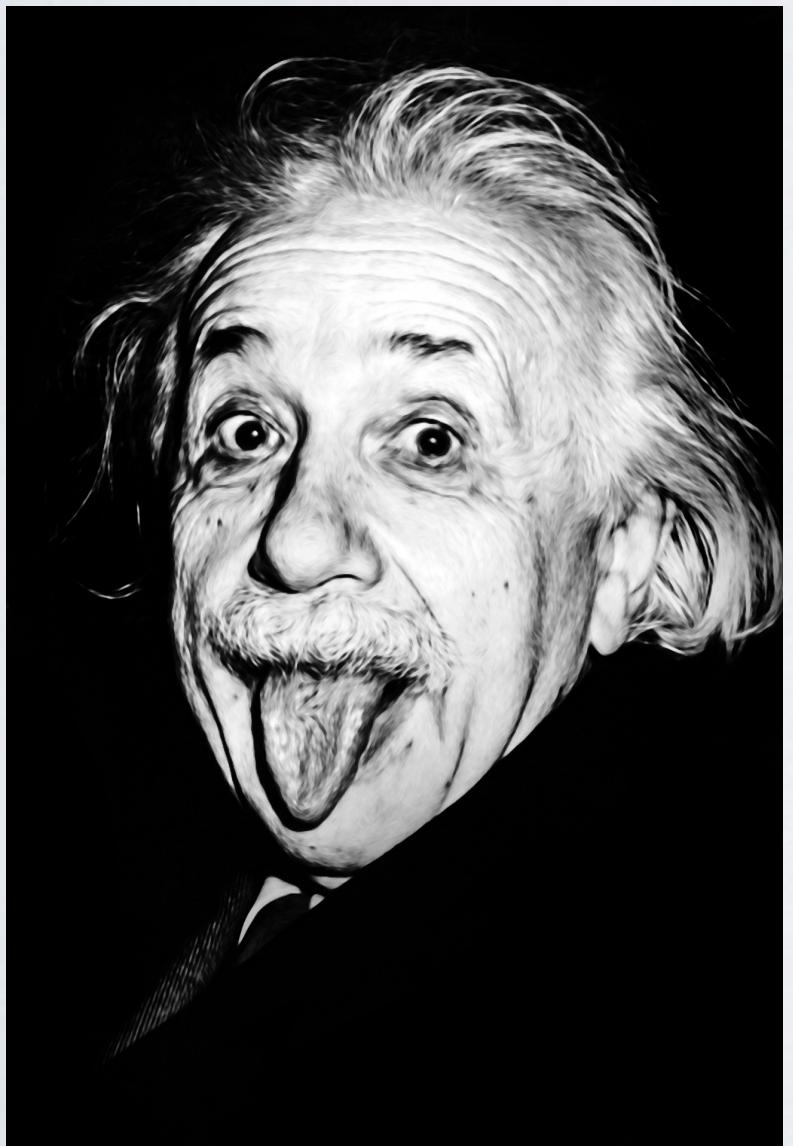


EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

The effects of gravity are
indistinguishable from an
accelerated observer

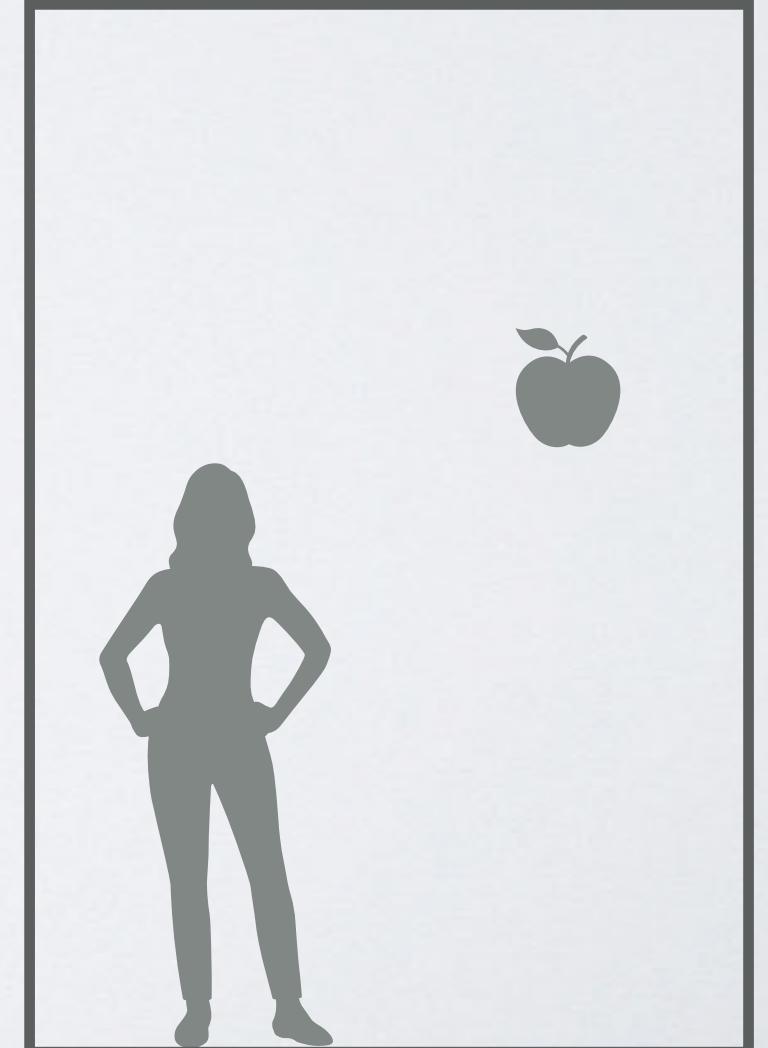


EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

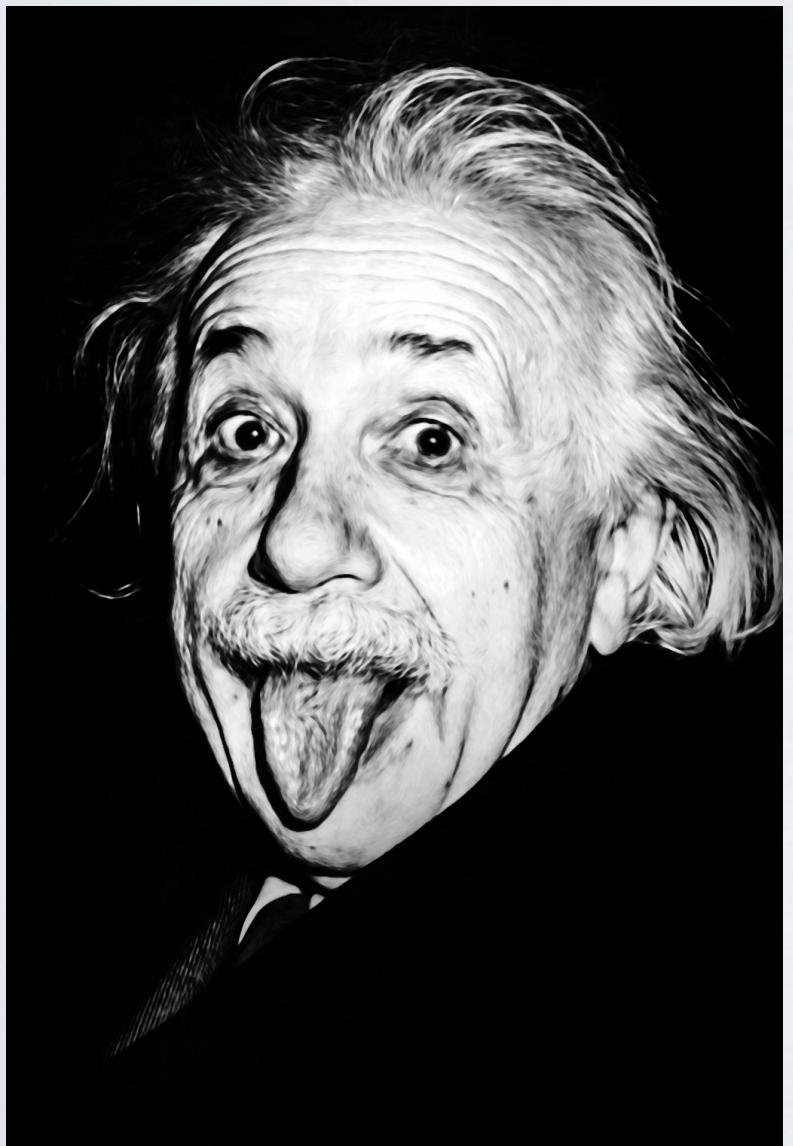


The effects of gravity are indistinguishable from an accelerated observer

$$\vec{g} \uparrow$$

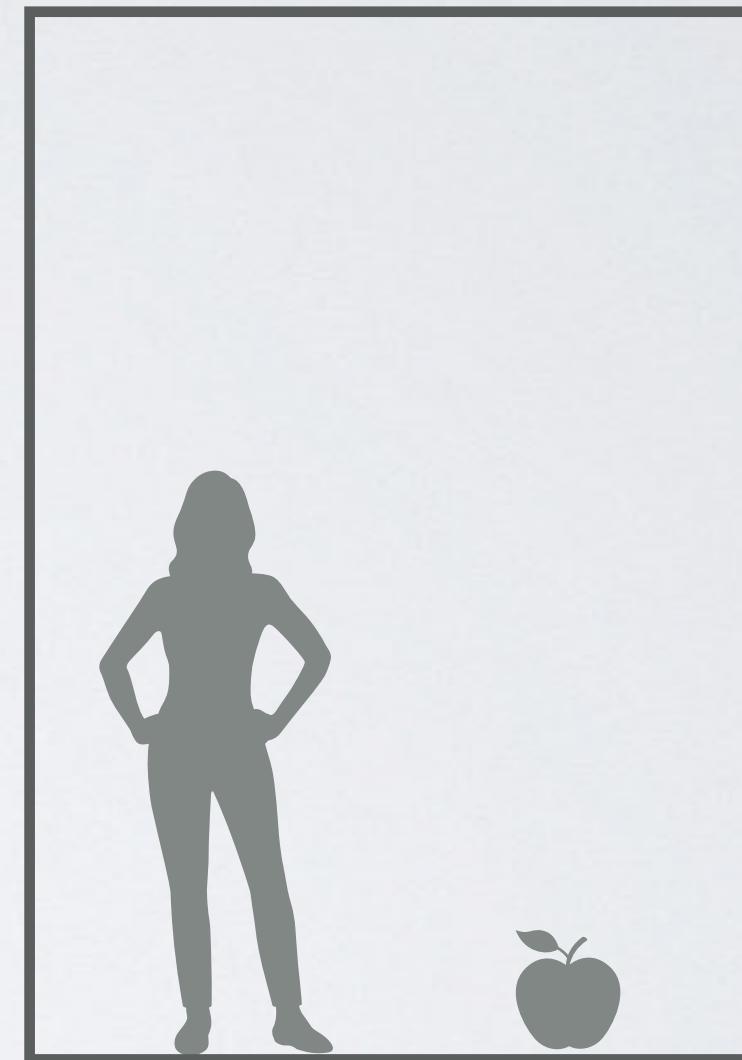


EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

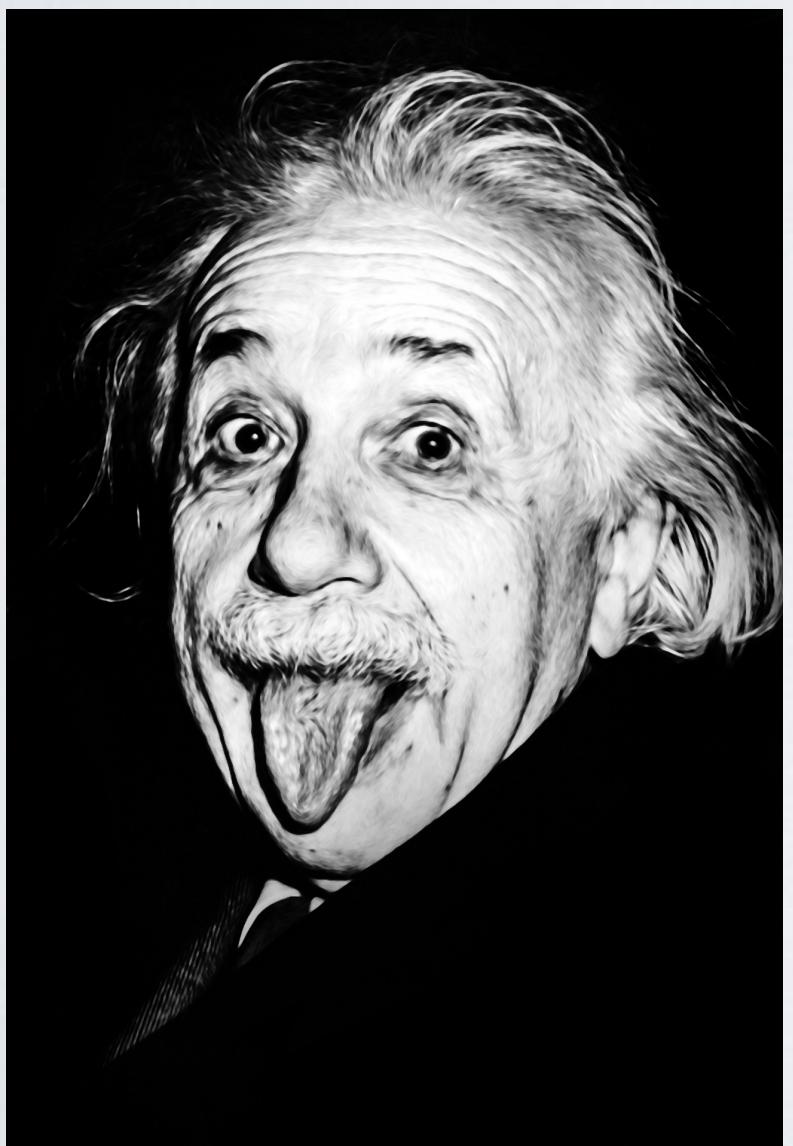


The effects of gravity are indistinguishable from an accelerated observer

$$\vec{g} \uparrow$$

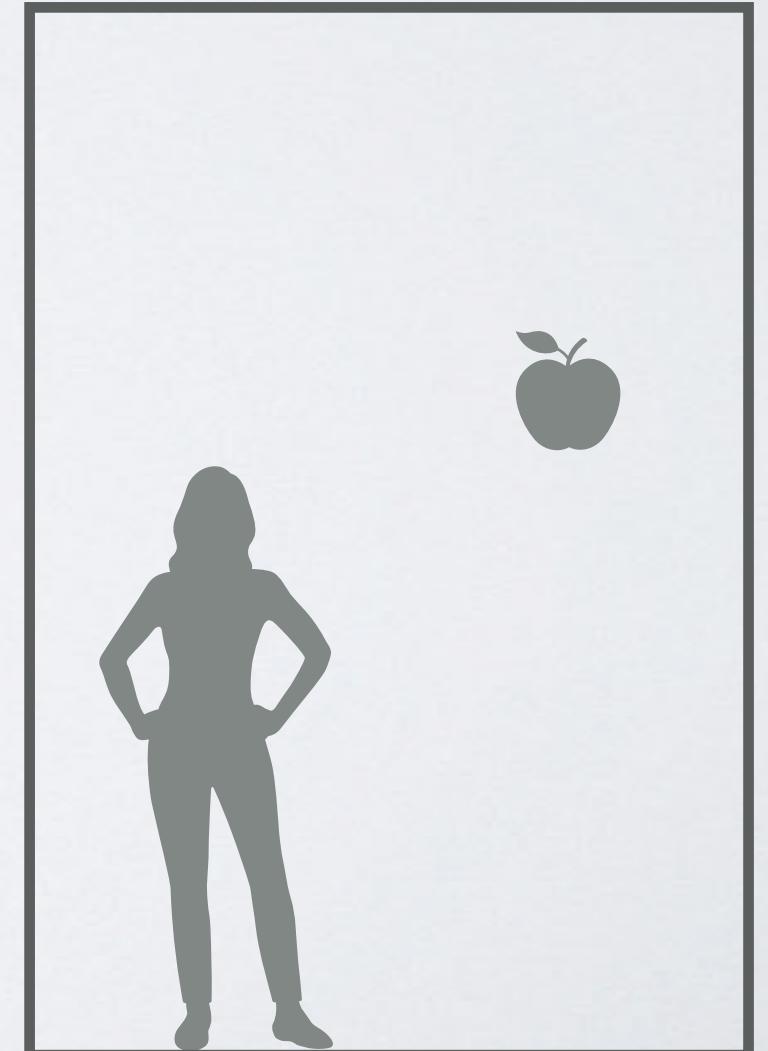


EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

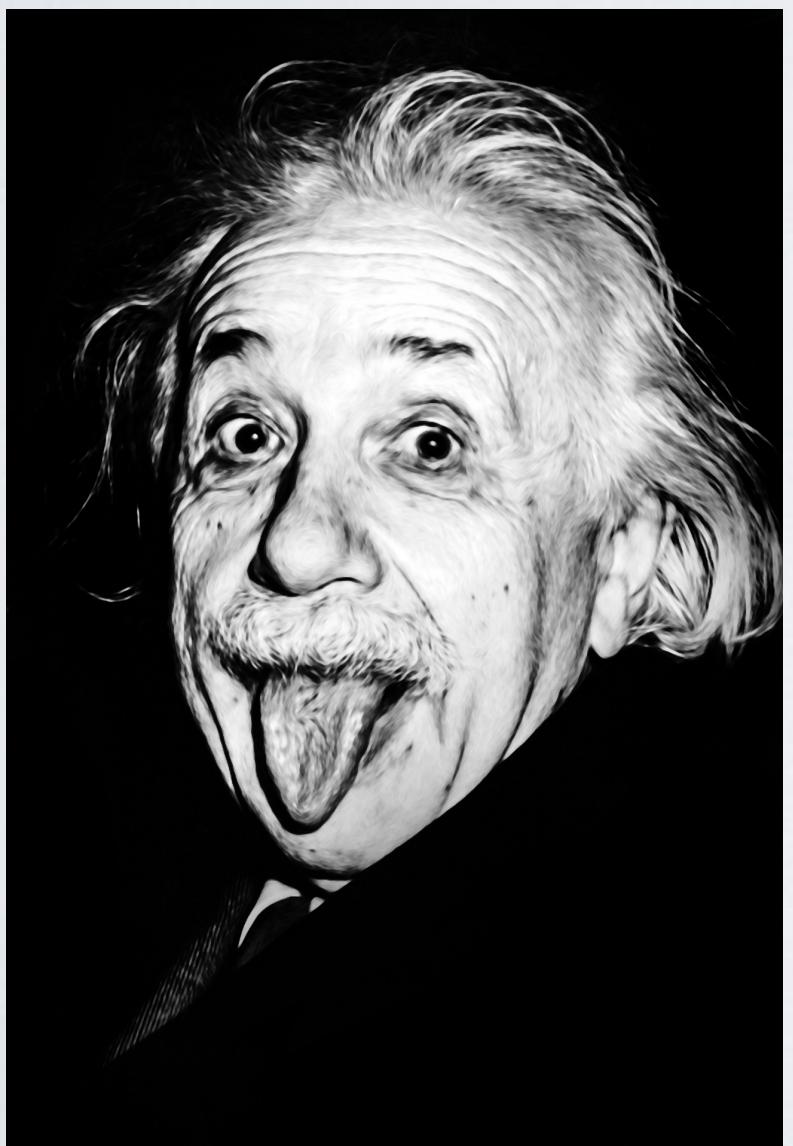


The effects of gravity are indistinguishable from an accelerated observer

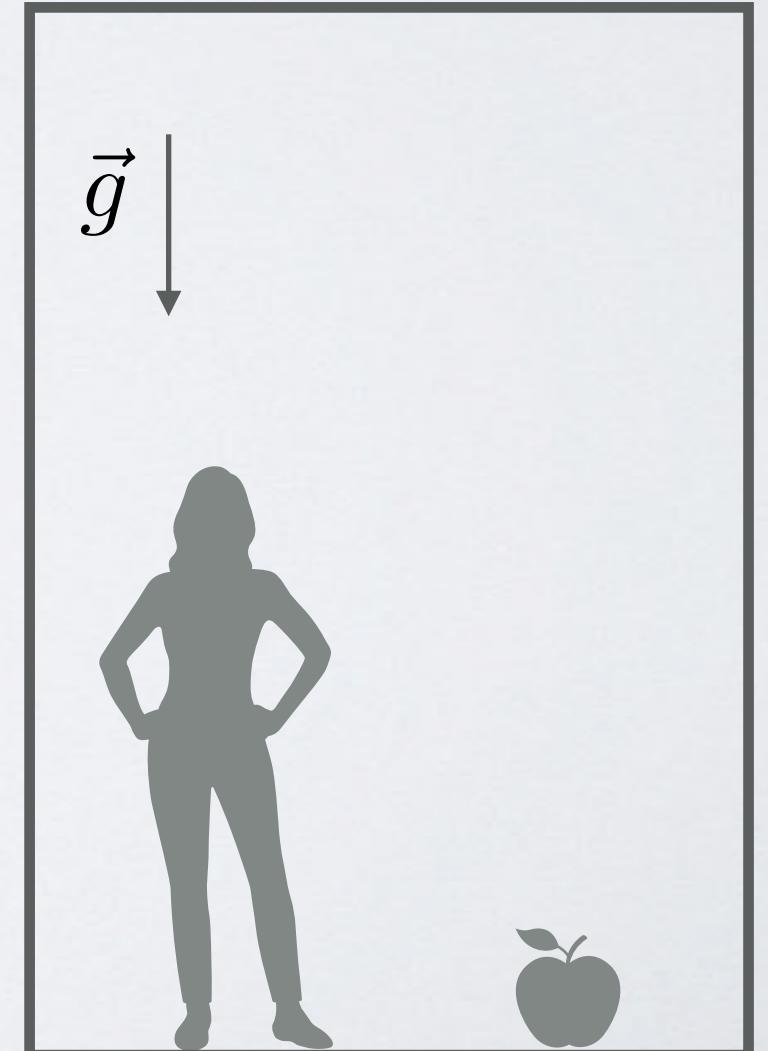
$$\vec{g} \uparrow$$



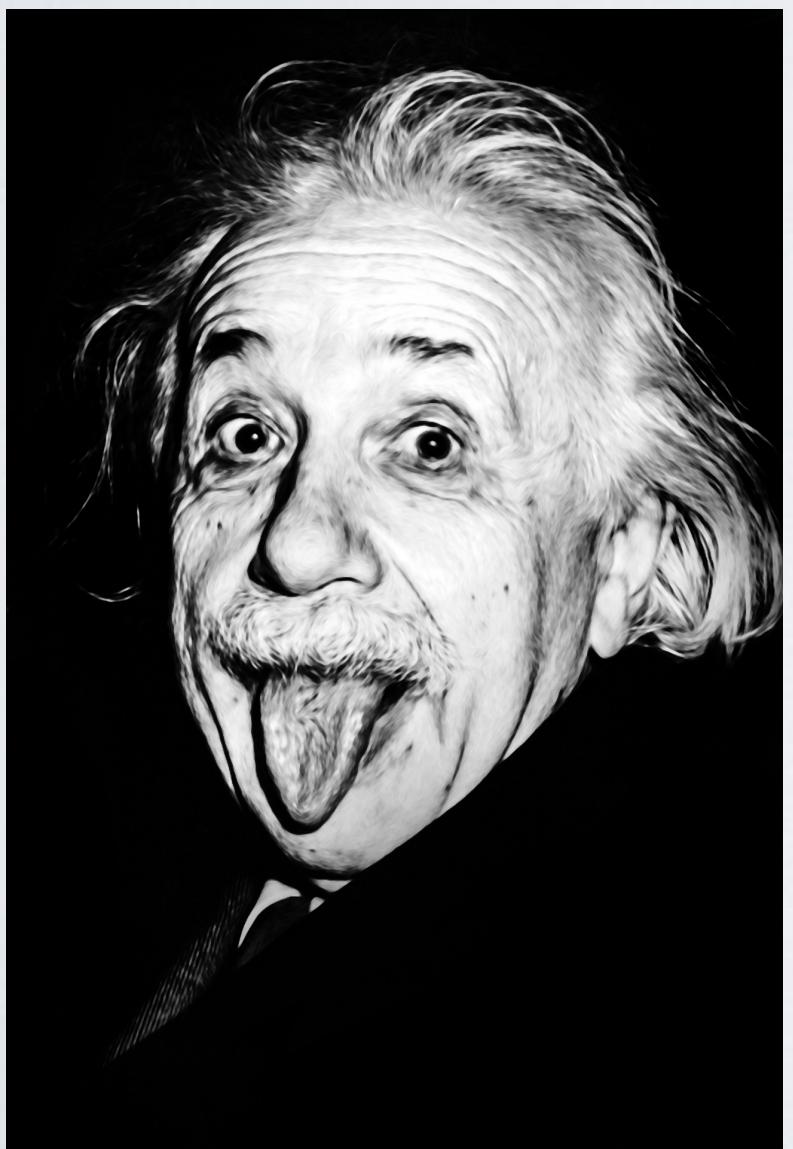
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)



The effects of gravity are indistinguishable from an accelerated observer



EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

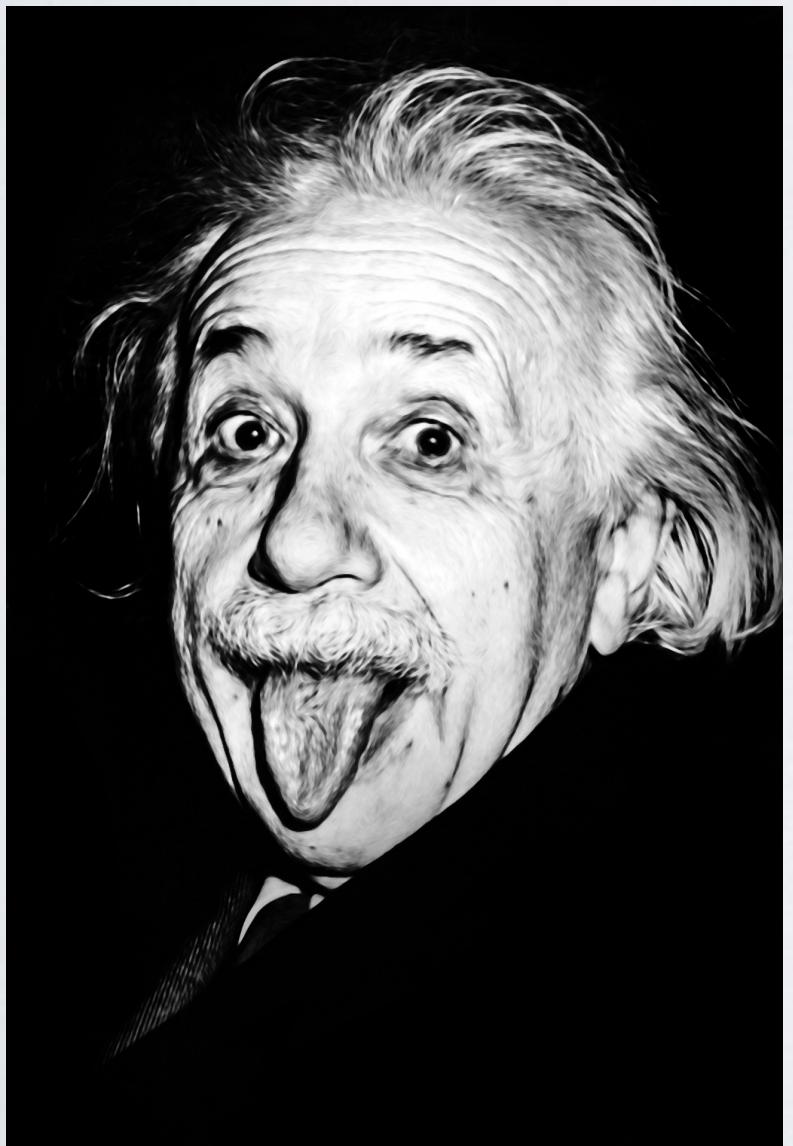


Nothing (*absolute nothing*)
can tell if we are in a
gravitational field, or in an
accelerated “elevator”

Gravity affects all
bodies in the
exact same way

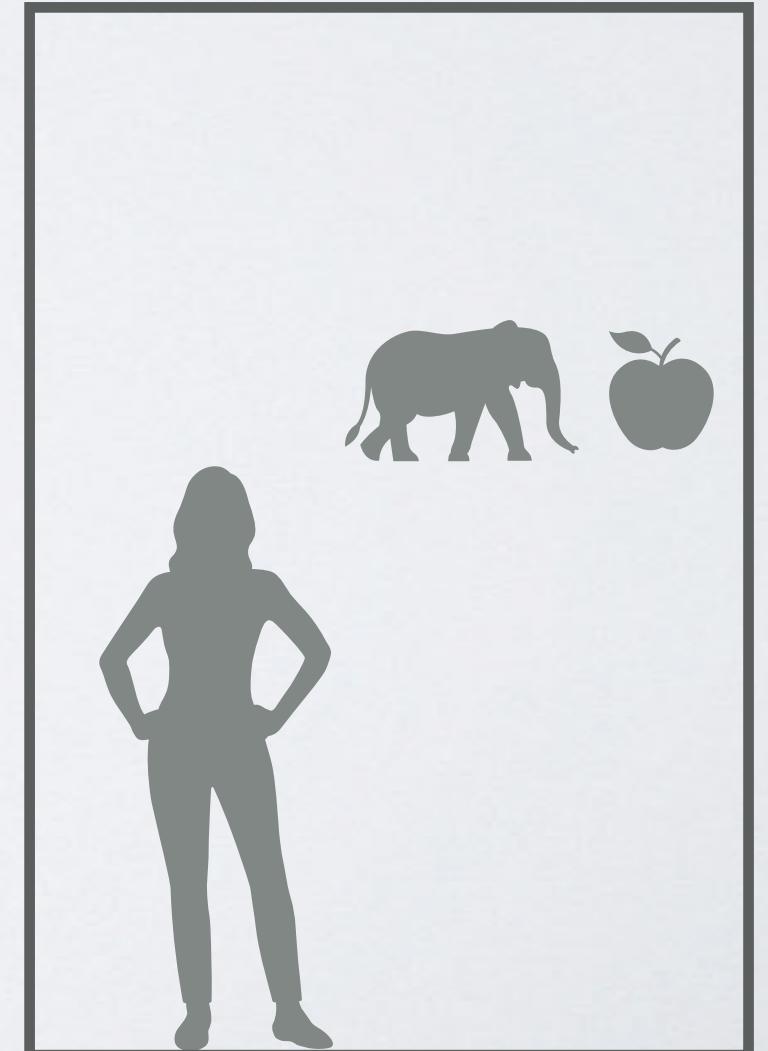
BECAUSE IT IS A RELATIVE EFFECT

EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

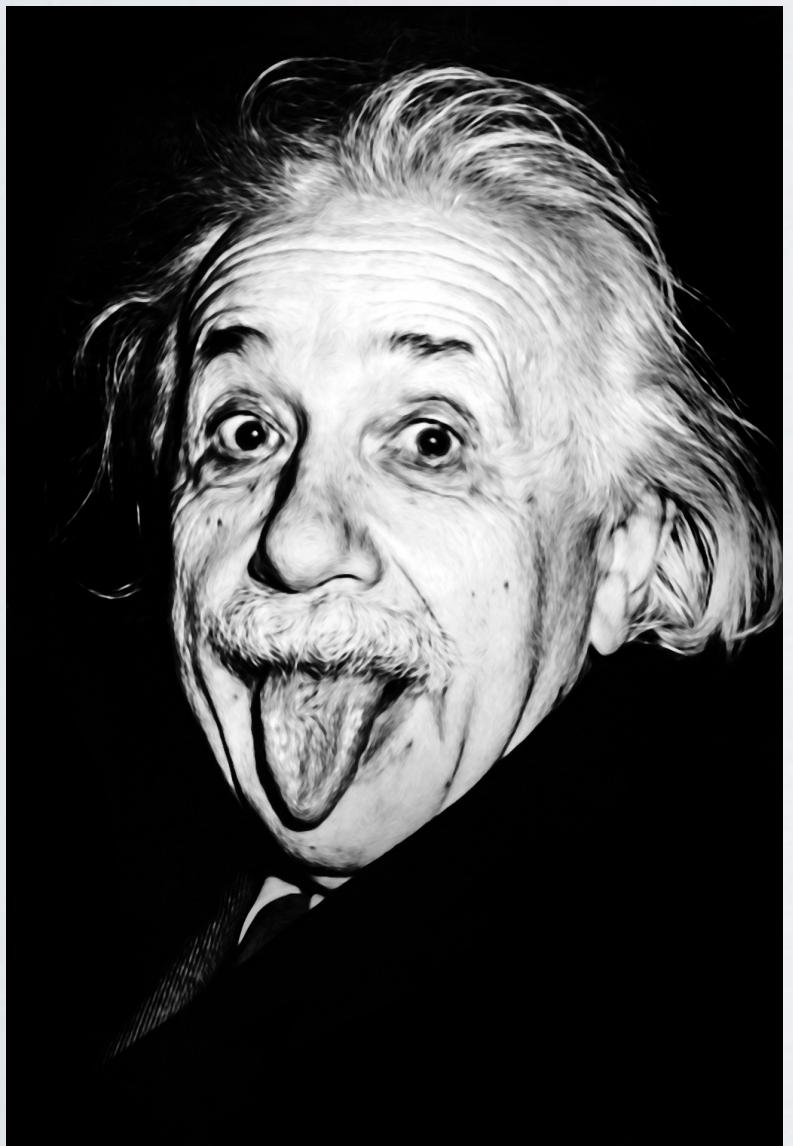


The effects of gravity are indistinguishable from an accelerated observer

$$\vec{g} \uparrow$$

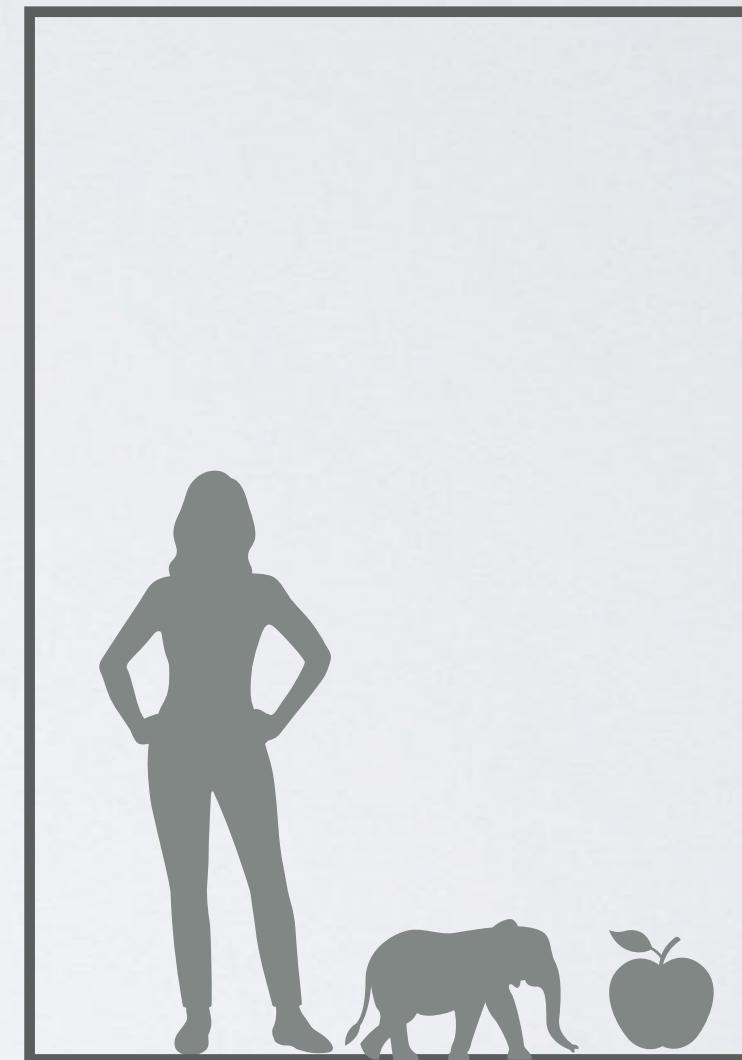


EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

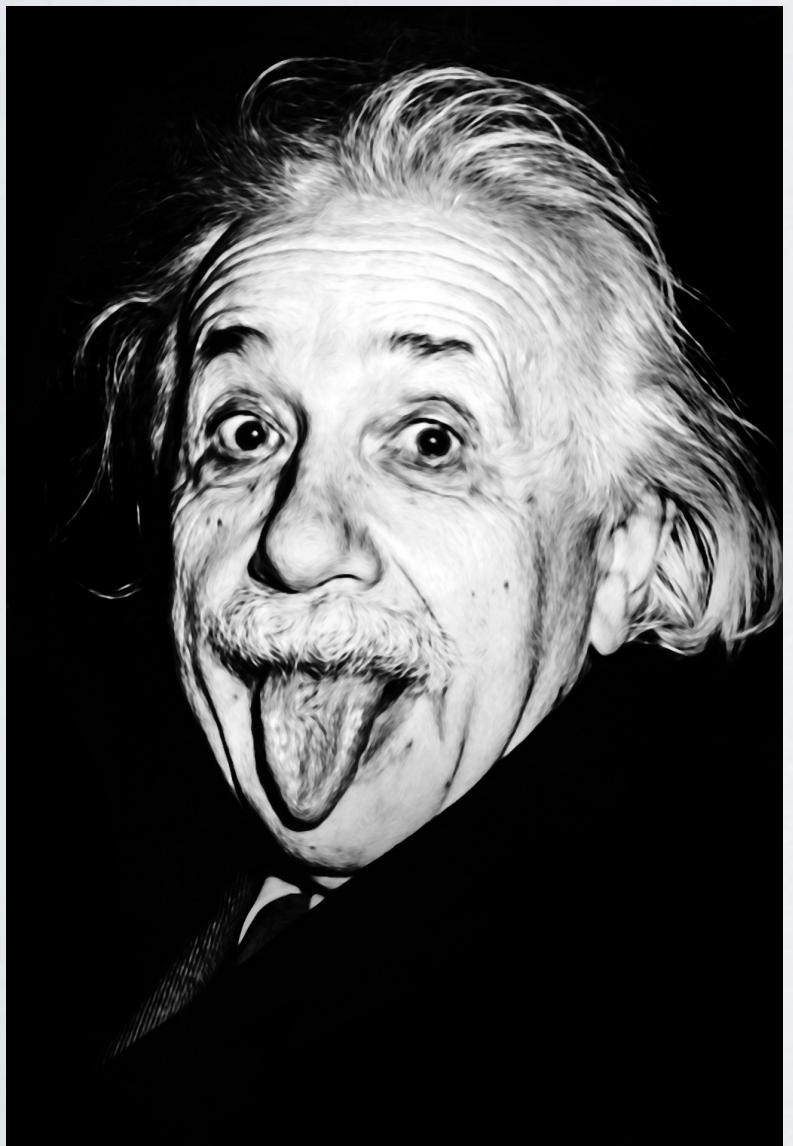


The effects of gravity are indistinguishable from an accelerated observer

$$\vec{g} \uparrow$$

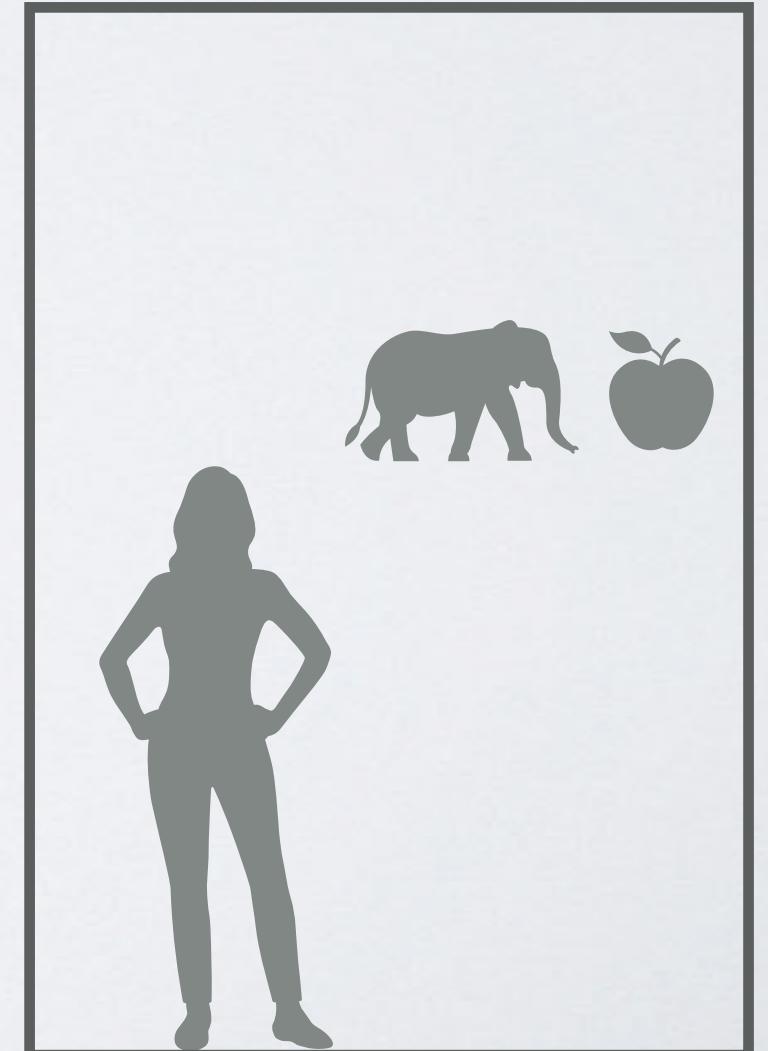


EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

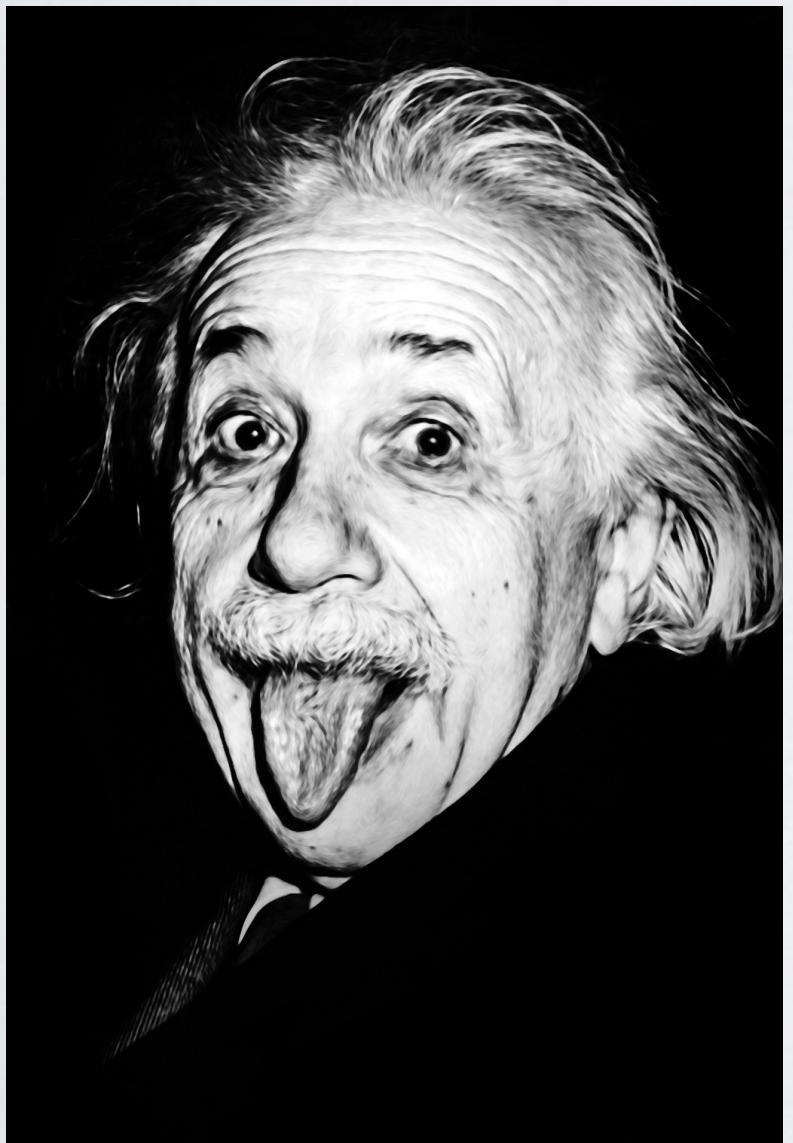


The effects of gravity are indistinguishable from an accelerated observer

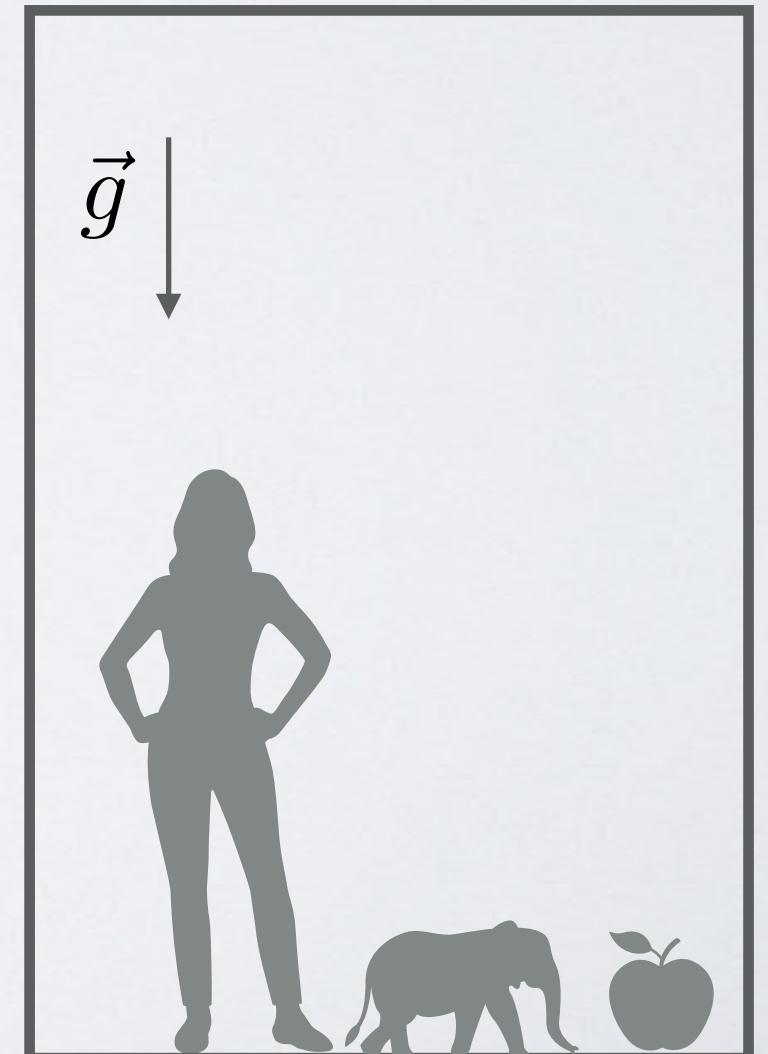
$$\vec{g} \uparrow$$



EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)



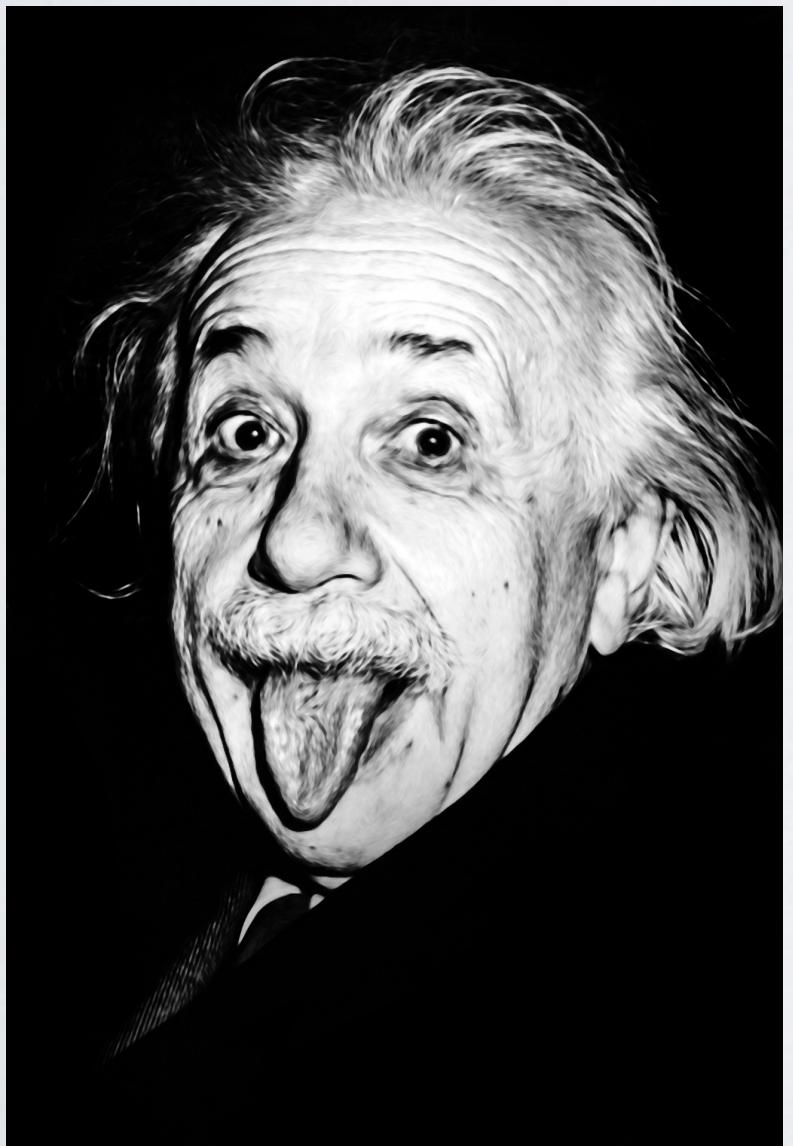
The effects of gravity are indistinguishable from an accelerated observer



Gravity affects all
bodies in the
exact same way

HOW ABOUT LIGHT?

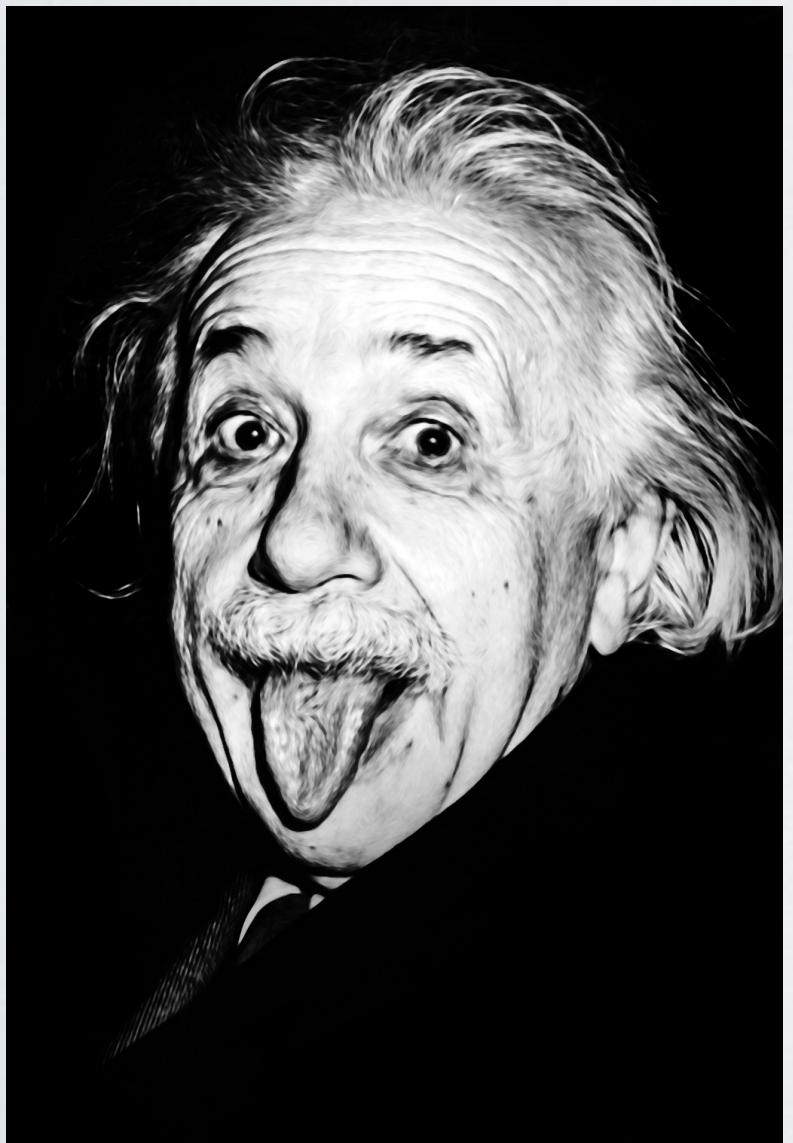
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)



The effects of gravity are indistinguishable from an accelerated observer



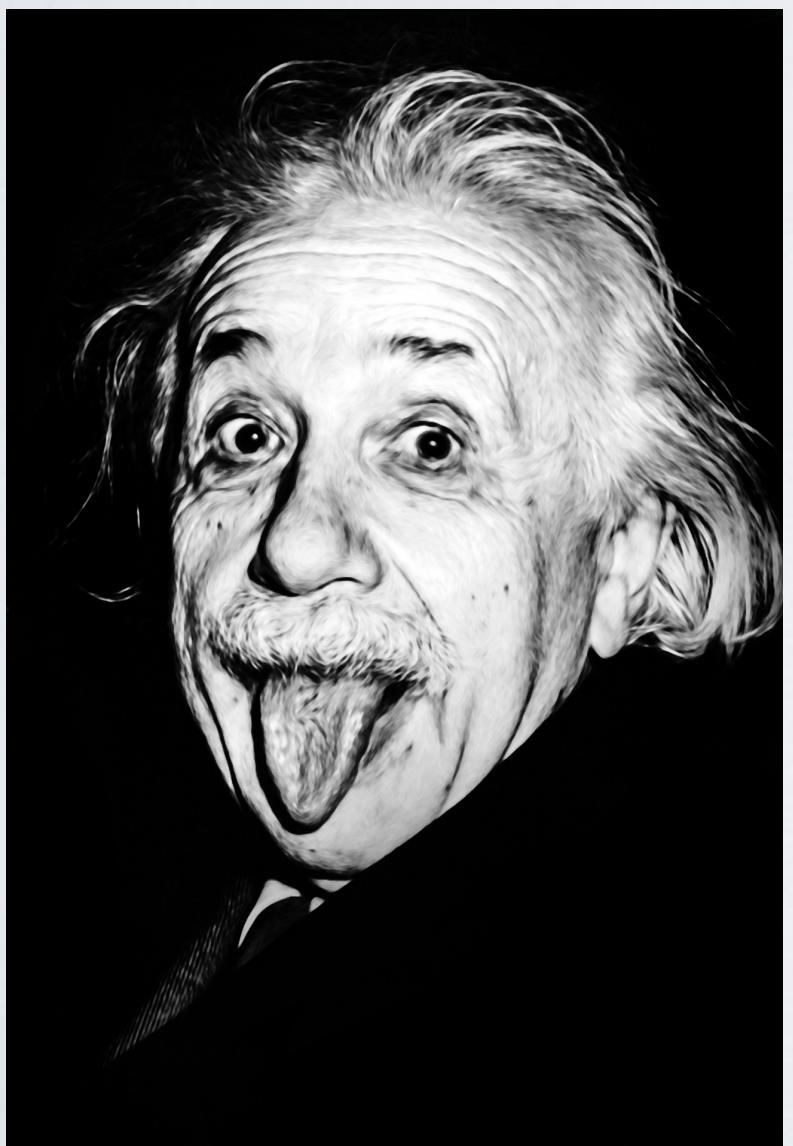
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)



The effects of gravity are indistinguishable from an accelerated observer

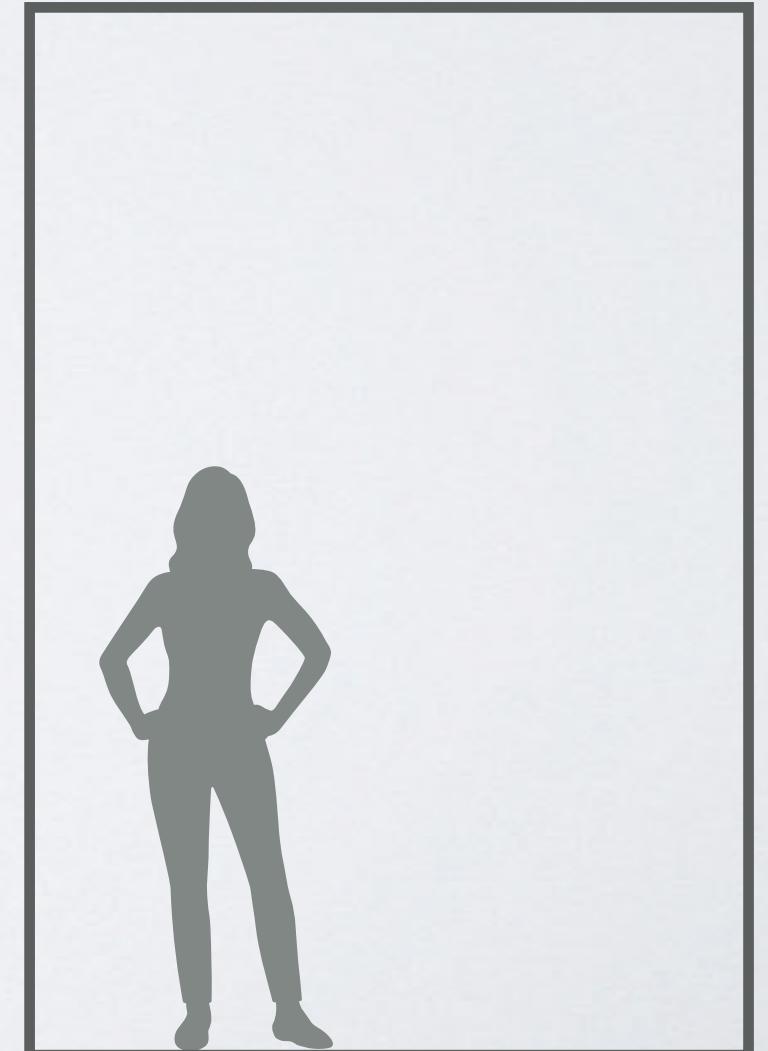


EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

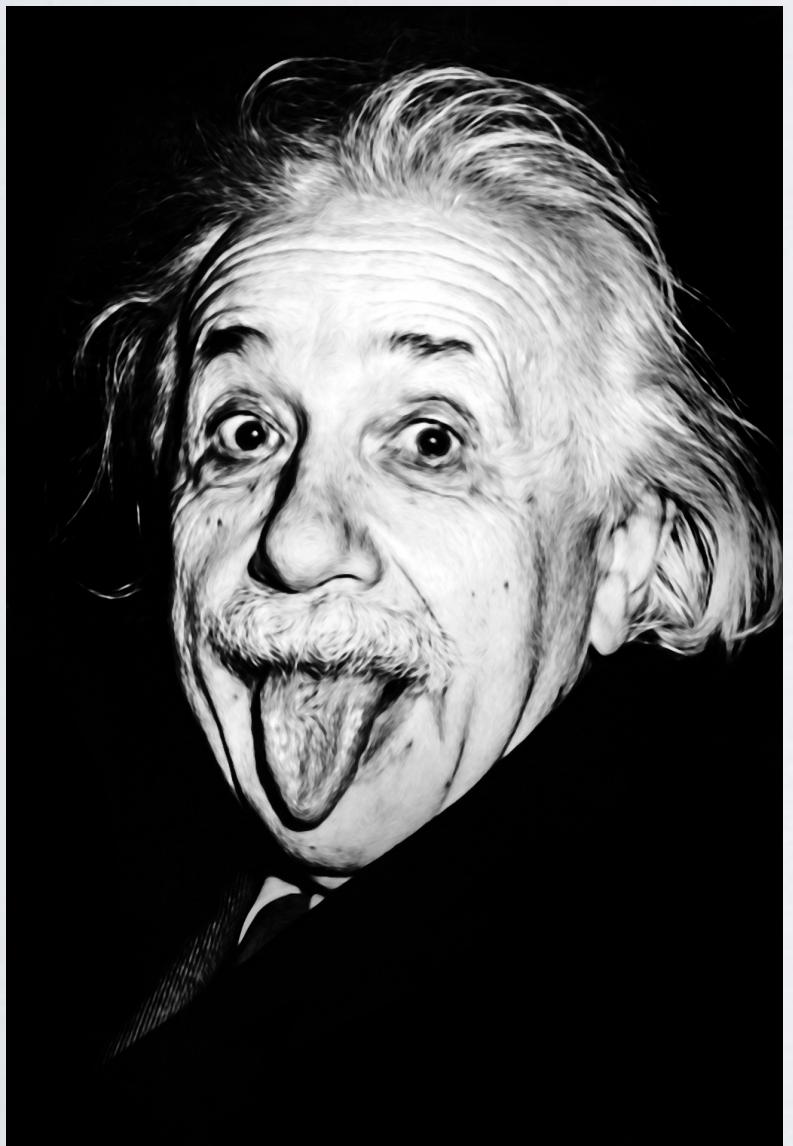


The effects of gravity are indistinguishable from an accelerated observer

$$\vec{g} \uparrow$$

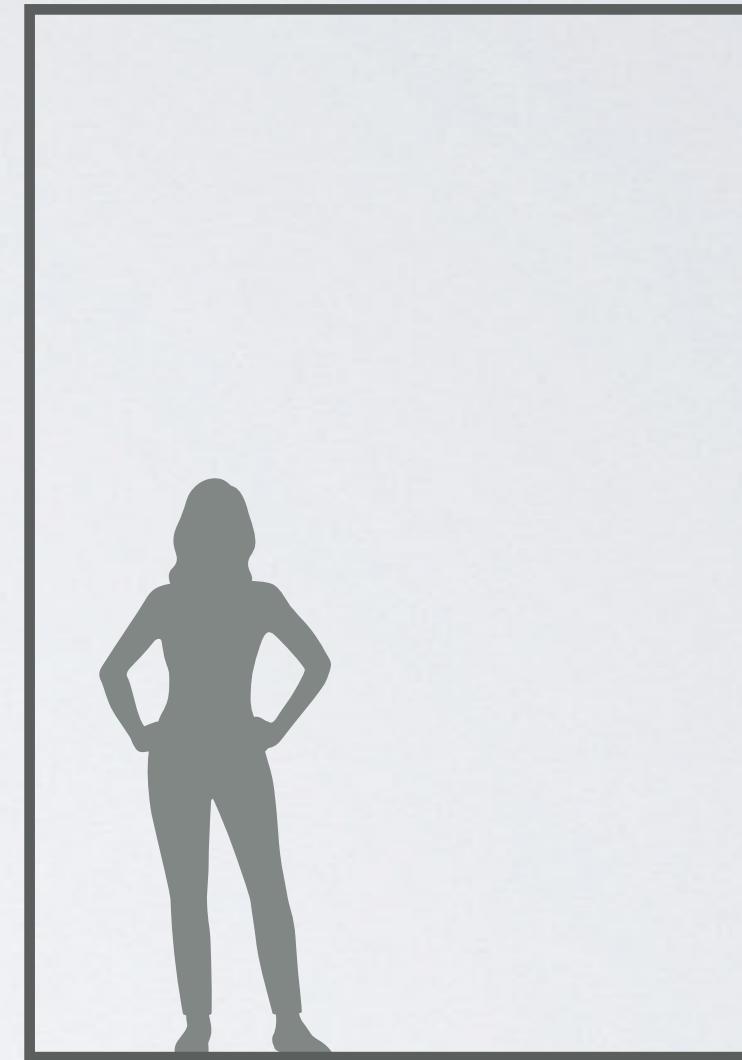


EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

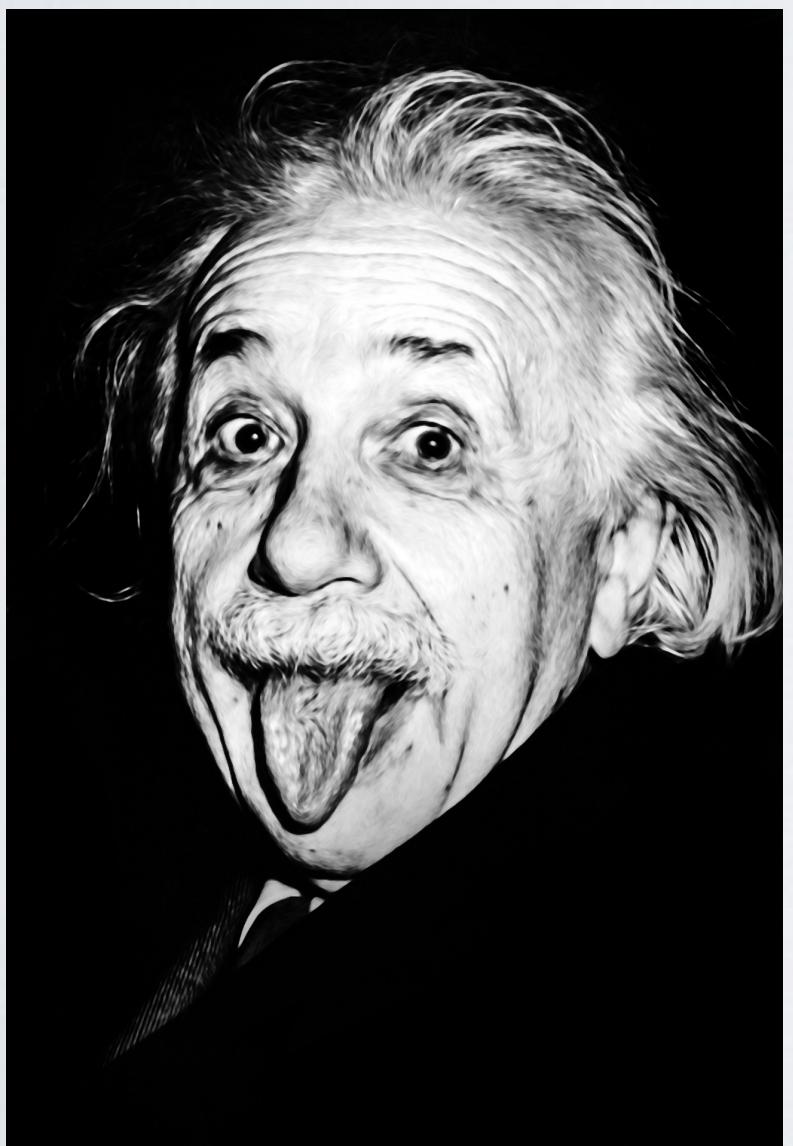


The effects of gravity are indistinguishable from an accelerated observer

$$\vec{g} \uparrow$$

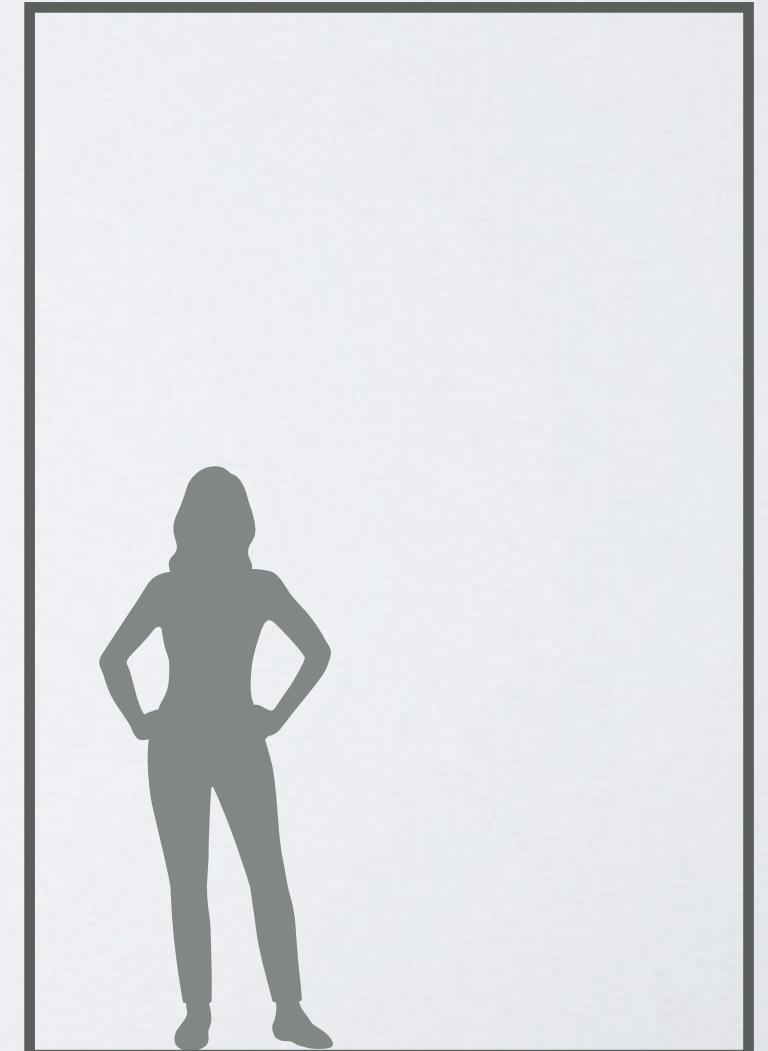


EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)

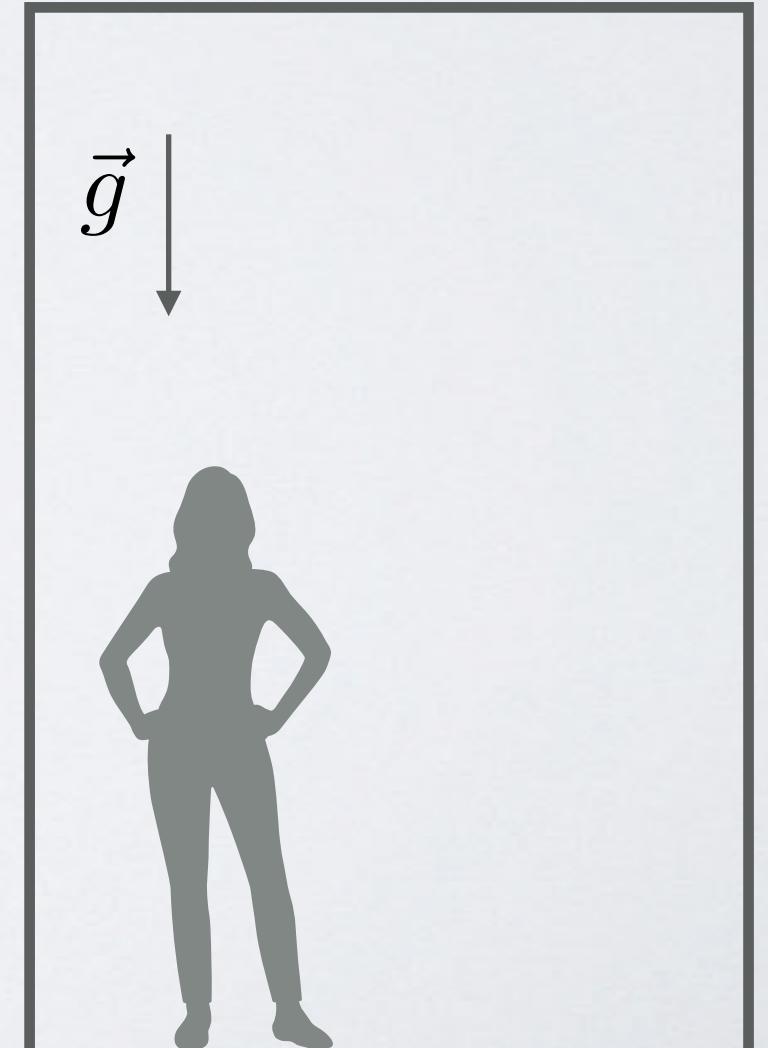
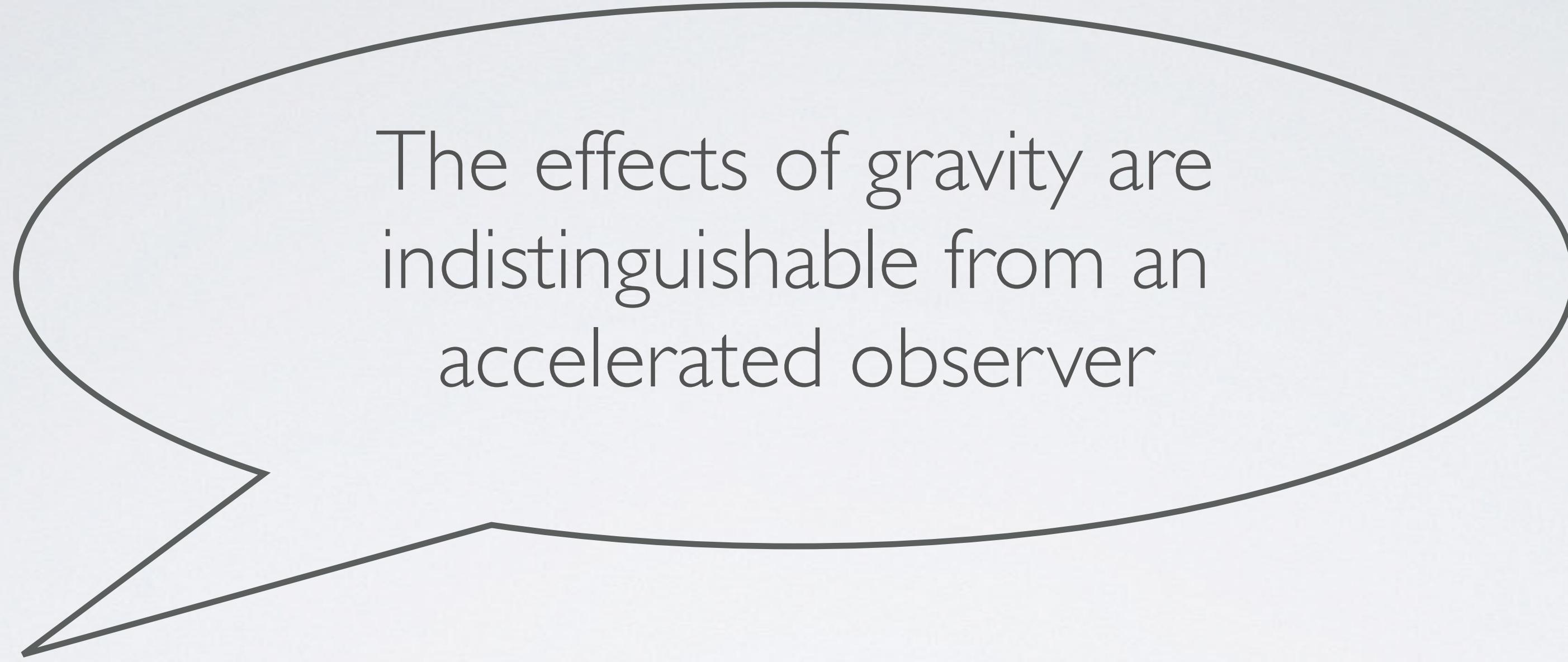
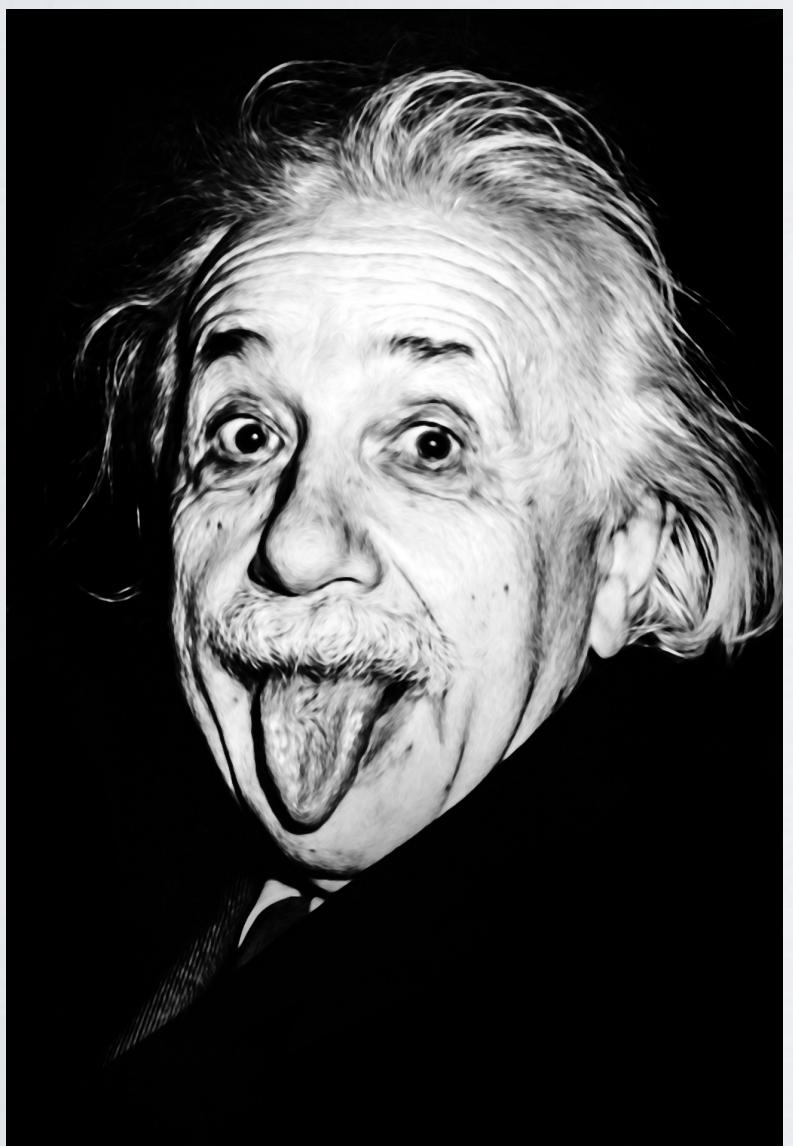


The effects of gravity are indistinguishable from an accelerated observer

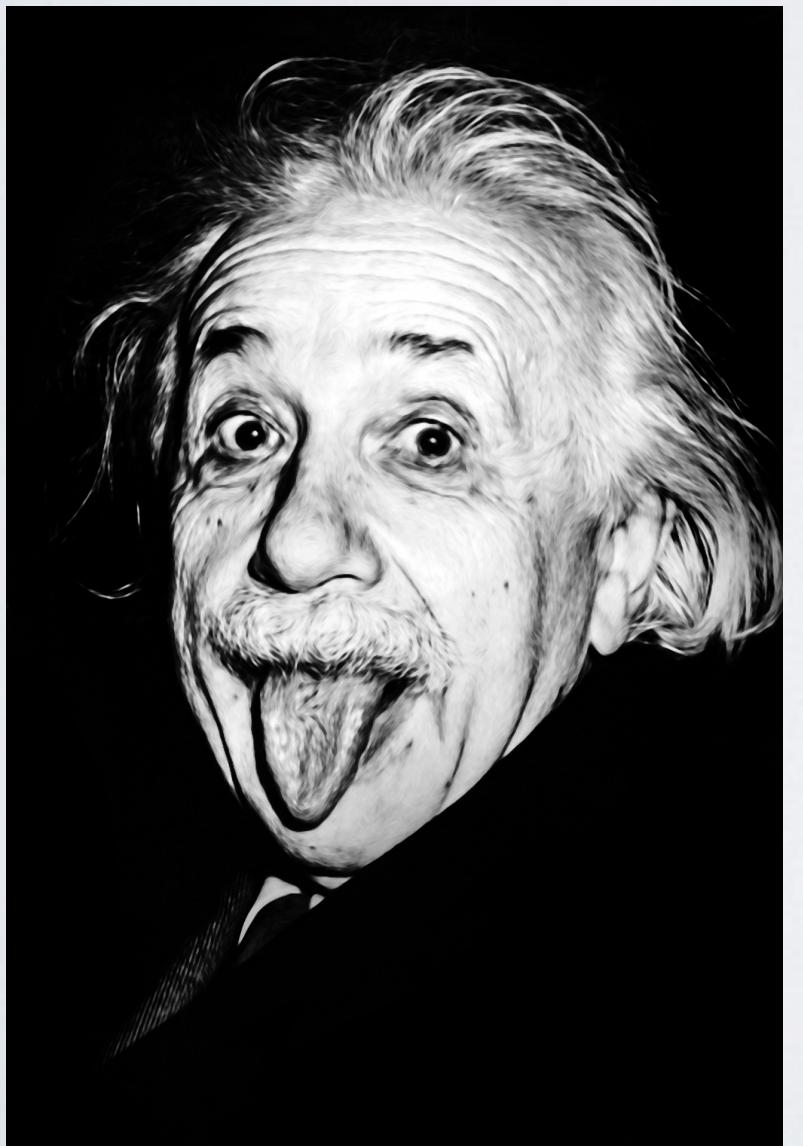
$$\vec{g} \uparrow$$



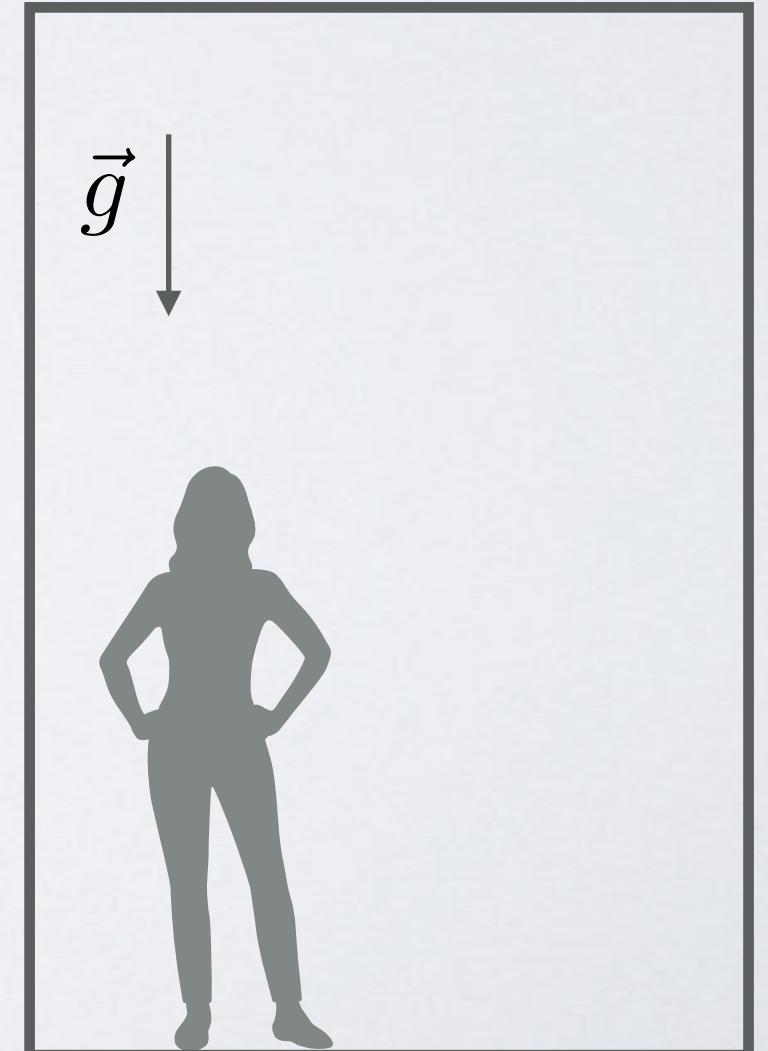
EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)



EINSTEIN'S PRINCIPLE OF RELATIVITY (EQUIVALENCE PRINCIPLE)



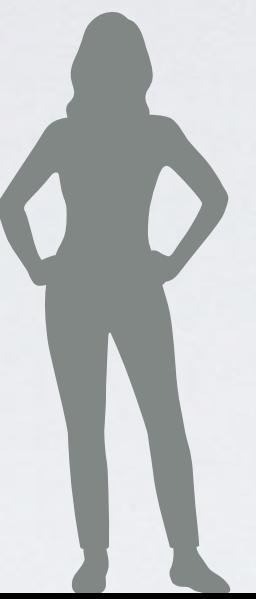
The effects of gravity are indistinguishable from an accelerated observer

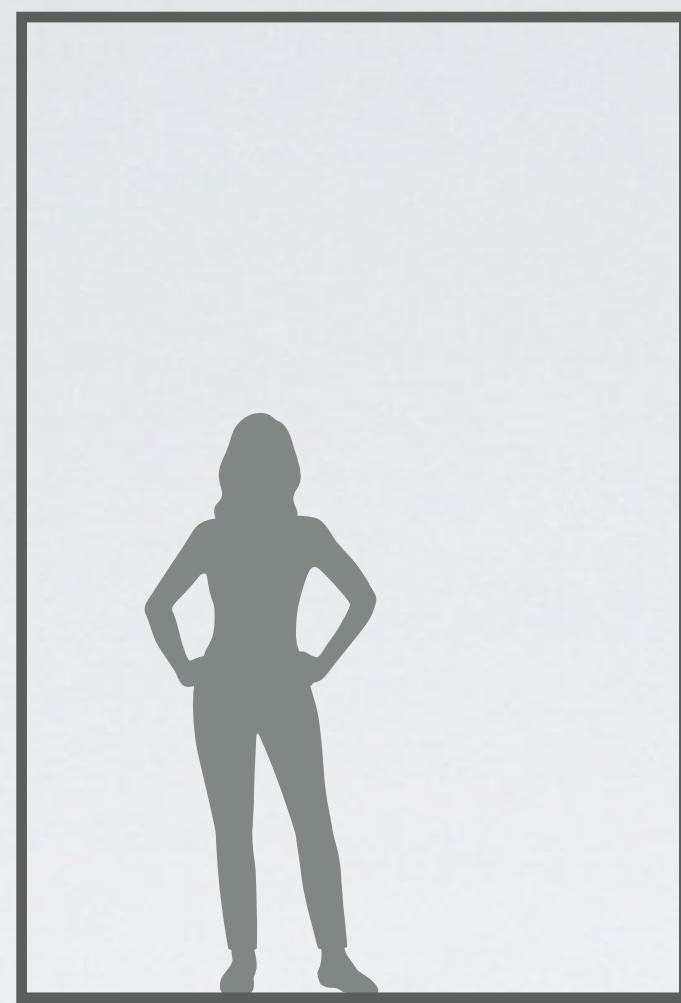


Gravity affects all
bodies in the
exact same way

THUS, GRAVITY BENDS LIGHT!

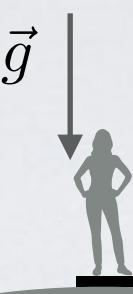
$$\vec{g} \downarrow$$

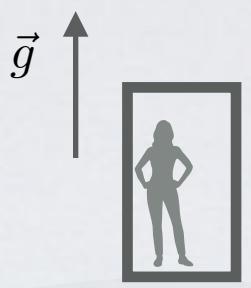


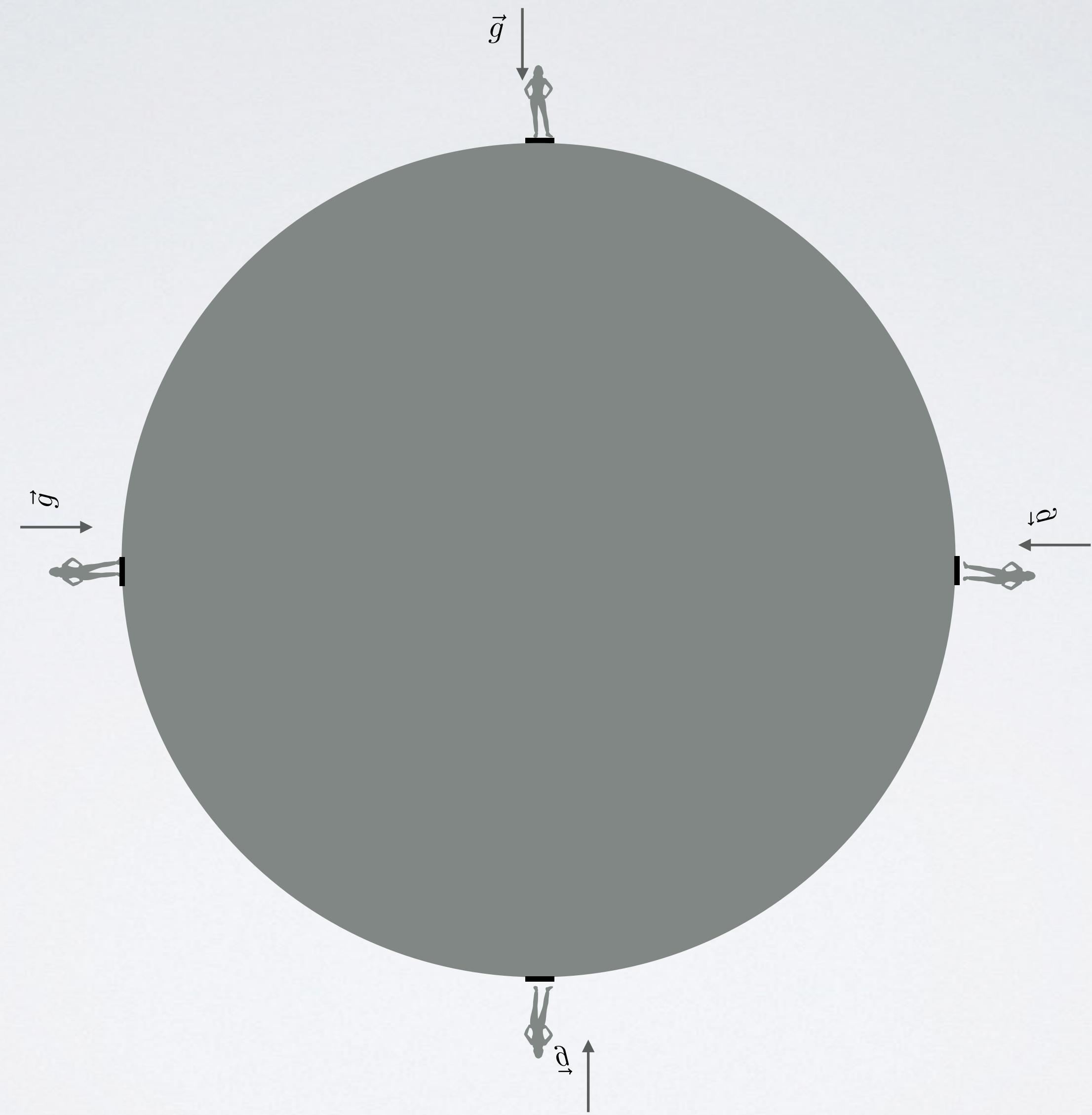


\vec{g} ↑





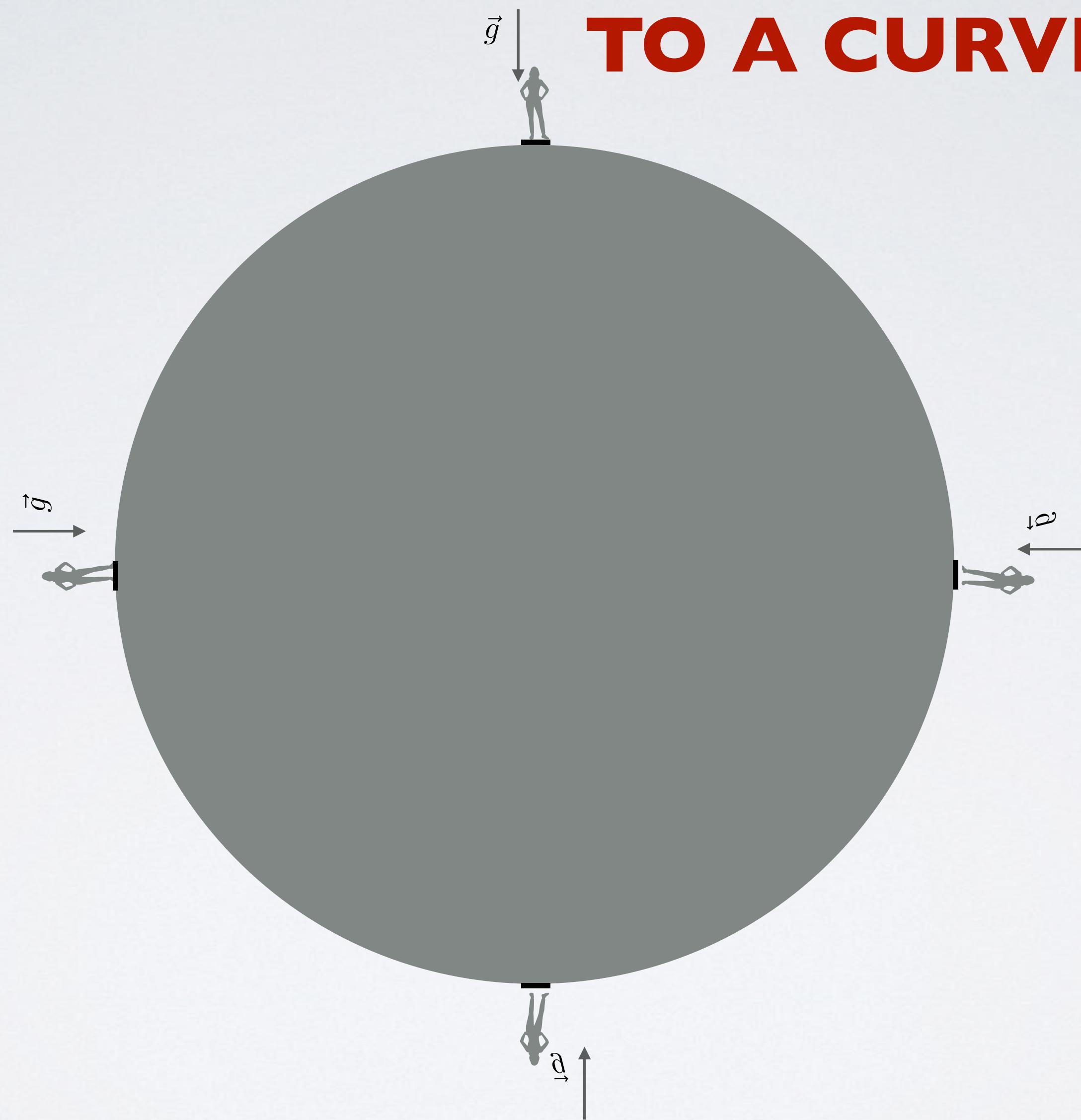






FROM A FLAT “ELEVATOR”

TO A CURVED “ELEVATOR”



FROM A FLAT SPACE

TO A CURVED SPACE

FROM A FLAT SPACE-TIME

TO A CURVED SPACE-TIME