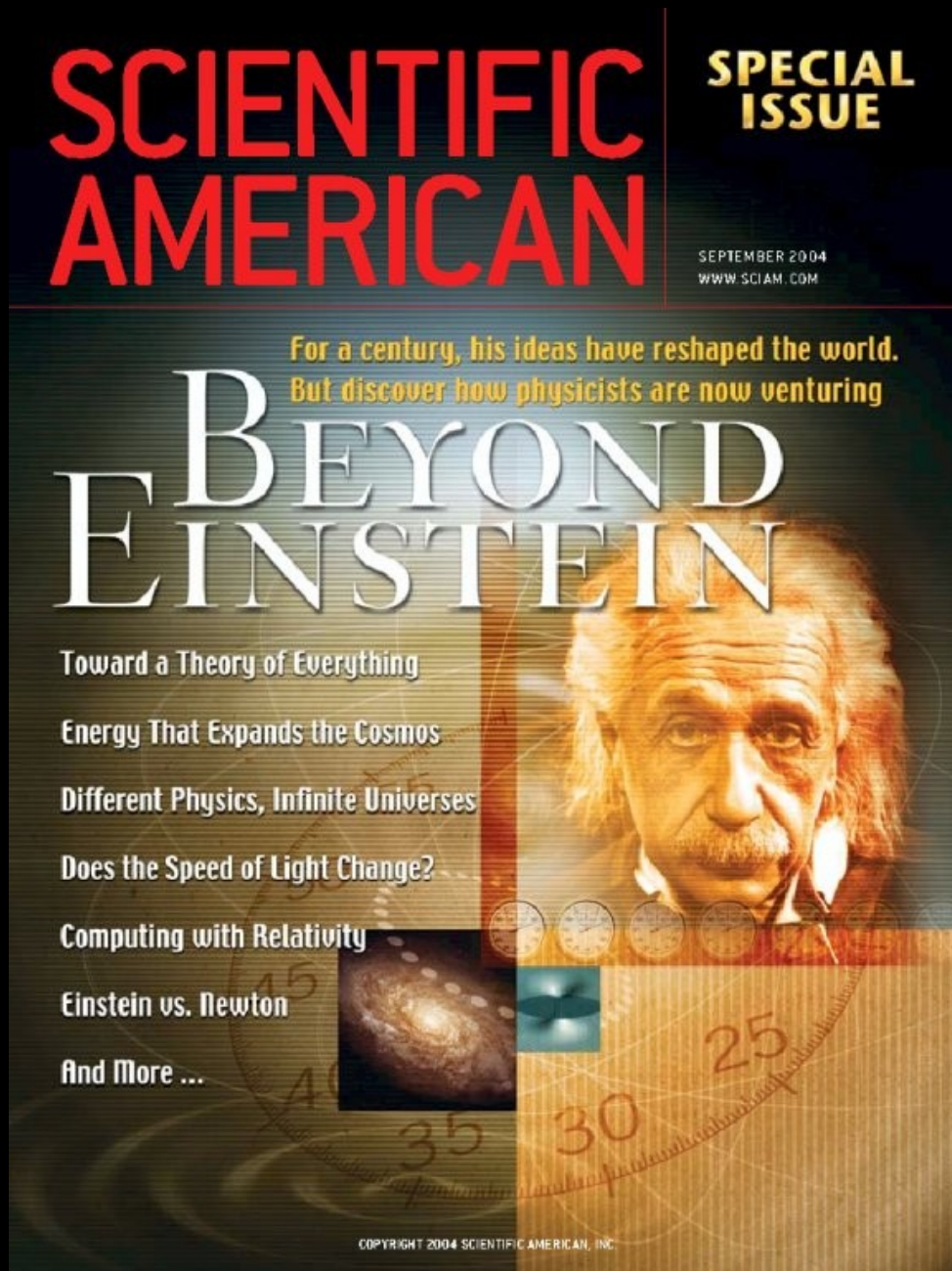


*Why “Was Einstein Wrong?”  
is the Wrong Question*

Dr. Robert Knop

AAPT NC Meeting  
2007/10/20

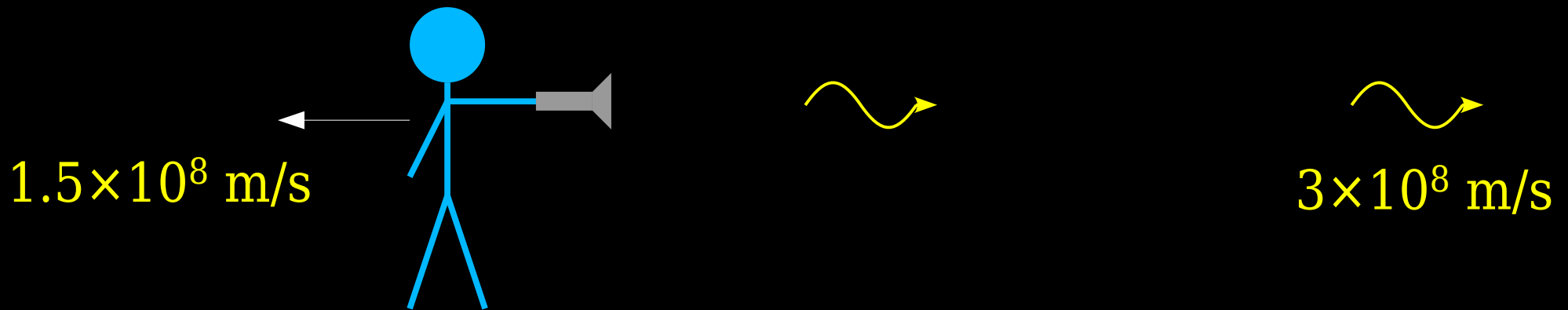
# Challenges to Relativity



- Special and General Relativity are pillars of modern physics
- Many predictions are extremely well-tested
- They aren't going anywhere, but...
- ...General Relativity *can't* be completely right!

# Special Relativity

Introduced to reconcile Maxwell's E&M with mechanics

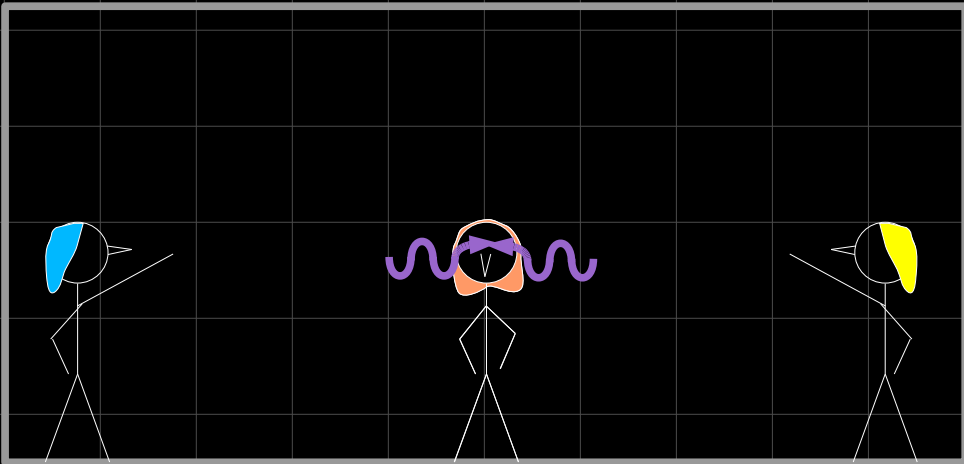
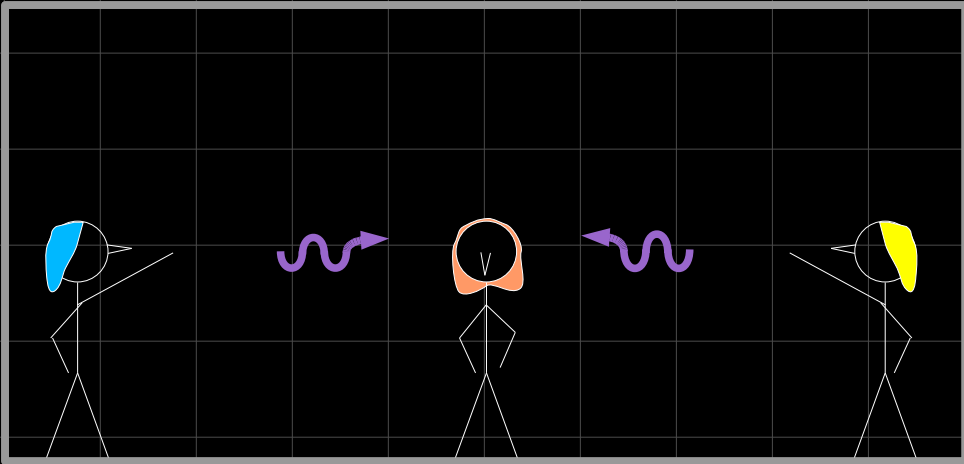
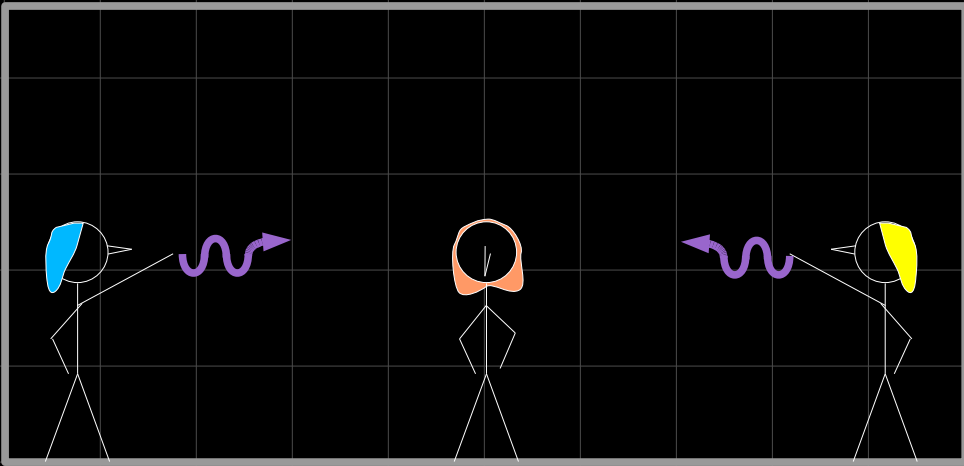


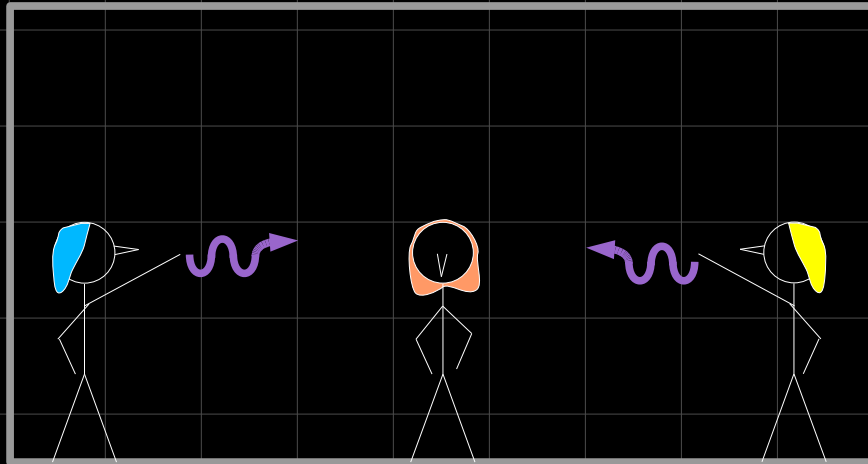
What speed does the flashlight-holder measure for the light pulses?

$3 \times 10^8$  m/s ... *not*  $4.5 \times 10^8$  m/s

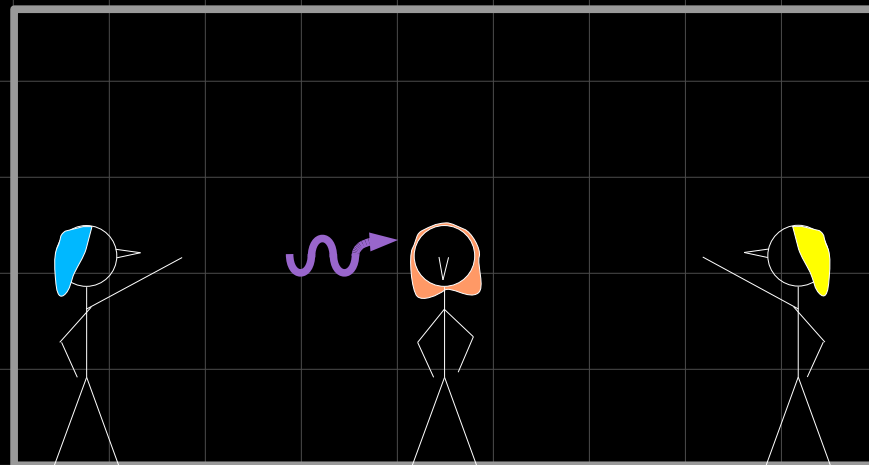
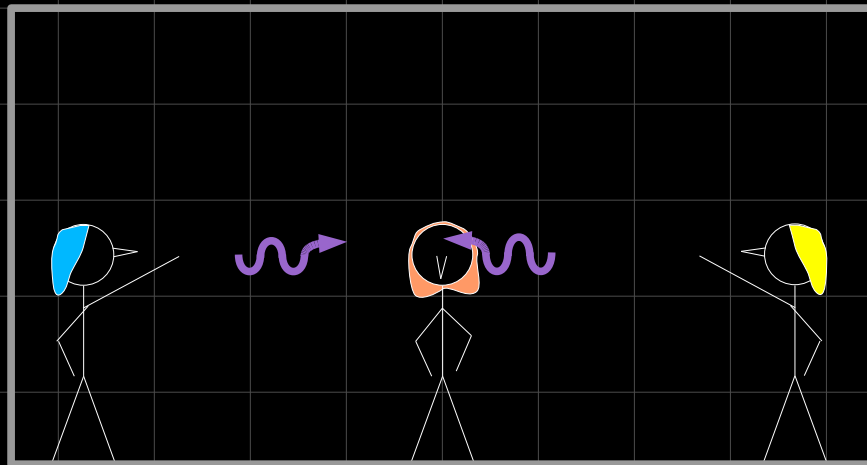
# Postulates of Special Relativity

1. The speed of light in a vacuum is a constant
2. The laws of physics (including #1 above) are the same for every observer moving at constant velocity

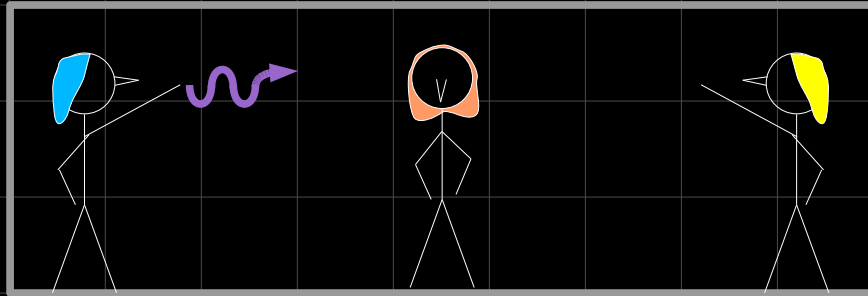




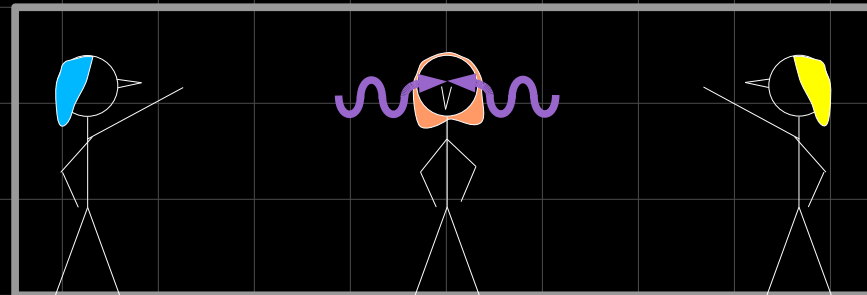
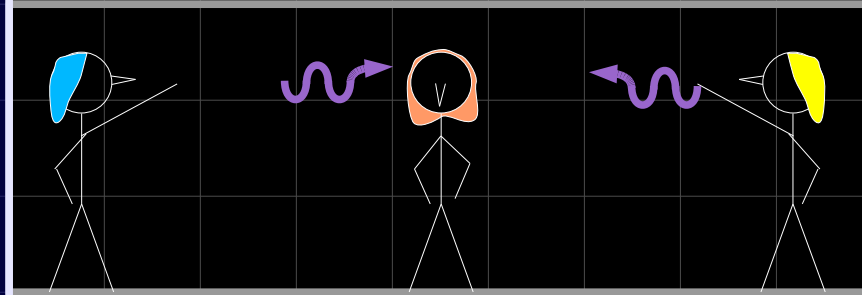
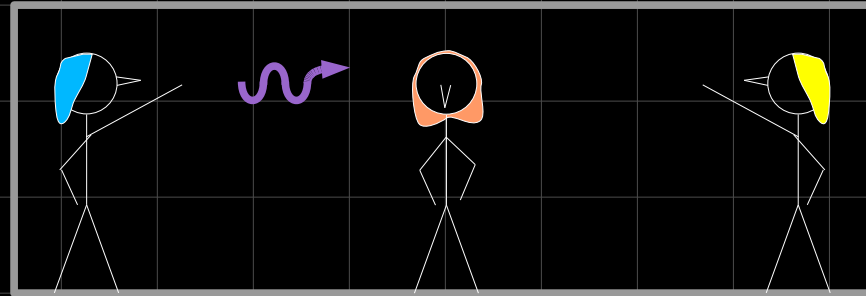
$1.5 \times 10^8 \text{ m/s}$



**Not the same  
experiment as  
on the last  
slide!**

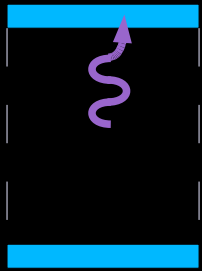
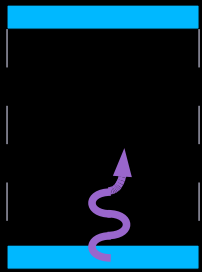
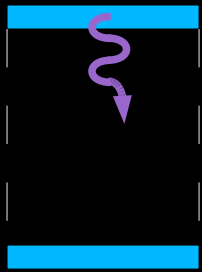


$1.5 \times 10^8 \text{ m/s}$



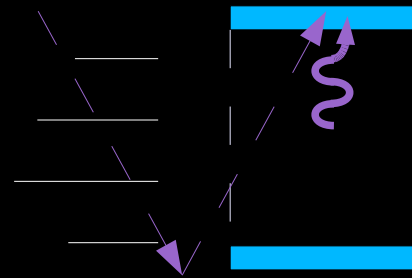
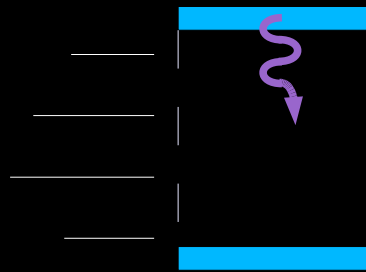
So who released the photon first? That depends on the frame of reference!

Simultaneity is absolute only for events which happen at the same point in space!



Case A:

1 Second Elapsed

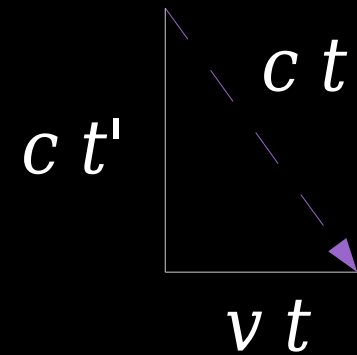


Case B

Moving clocks run slow!

$t' = \frac{1}{2}$  second  
(time for clock B)

$t =$  time for clock B  
to tick  $\frac{1}{2}$  second  
(time for us)



$$(ct')^2 + (vt)^2 = (ct)^2$$

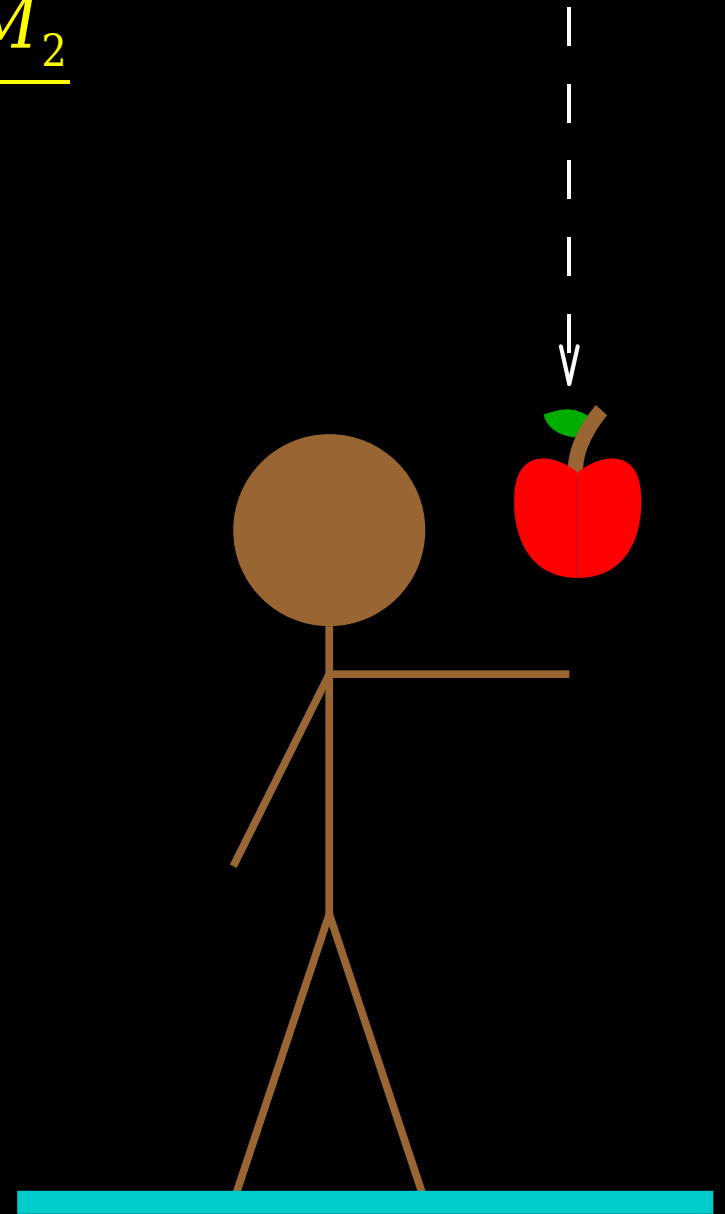
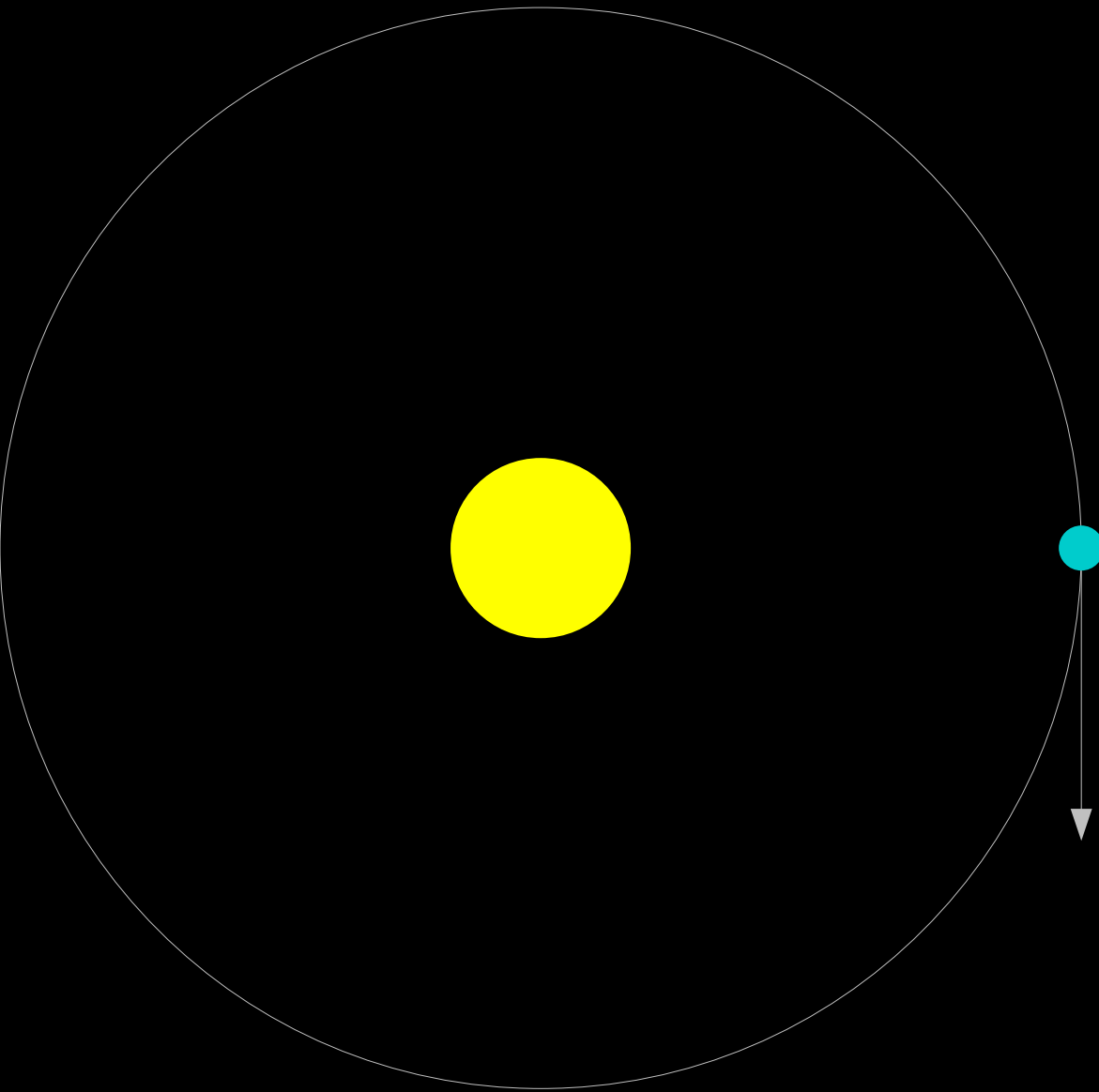
$$(t')^2 = t^2 - \left(\frac{v}{c}t\right)^2$$

$$t' = t \sqrt{1 - \left(\frac{v}{c}\right)^2} < t$$



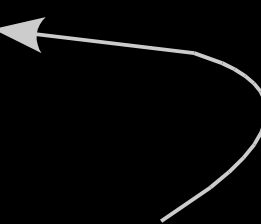
# Newton's Law of Universal Gravitation

$$F = \frac{GM_1M_2}{d^2}$$



# Was Newton Wrong??

$$F = \frac{GM_1M_2}{d^2}$$



Newton's gravity  
implies instant  
communication over  
distance  $d$ ...!

*Solution: General Relativity*

# The Principle of Equivalence

$$F = \frac{G M_1 m_g}{d^2} \quad \text{True for gravity}$$

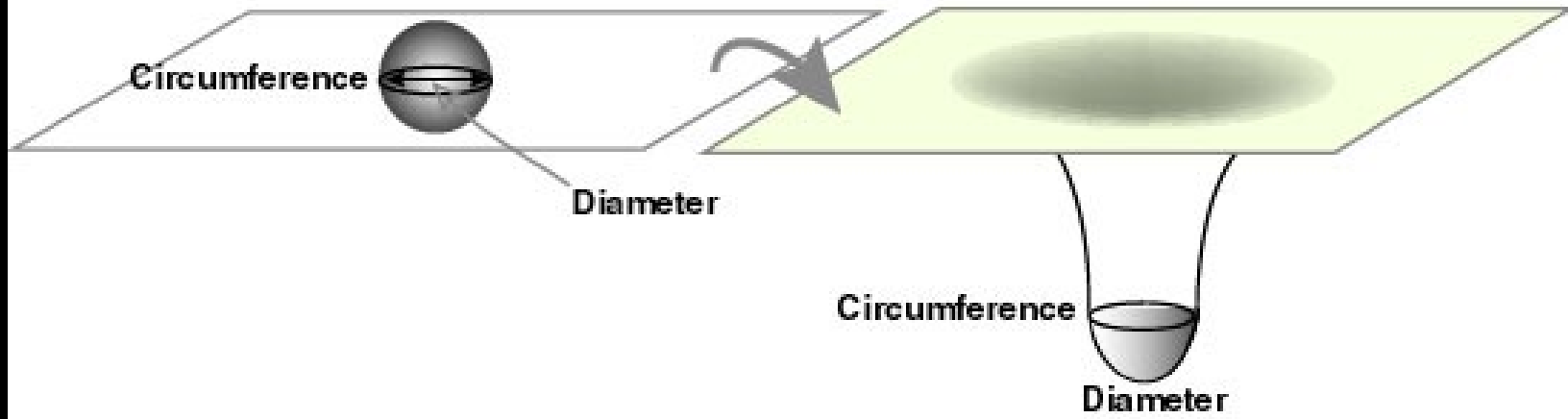
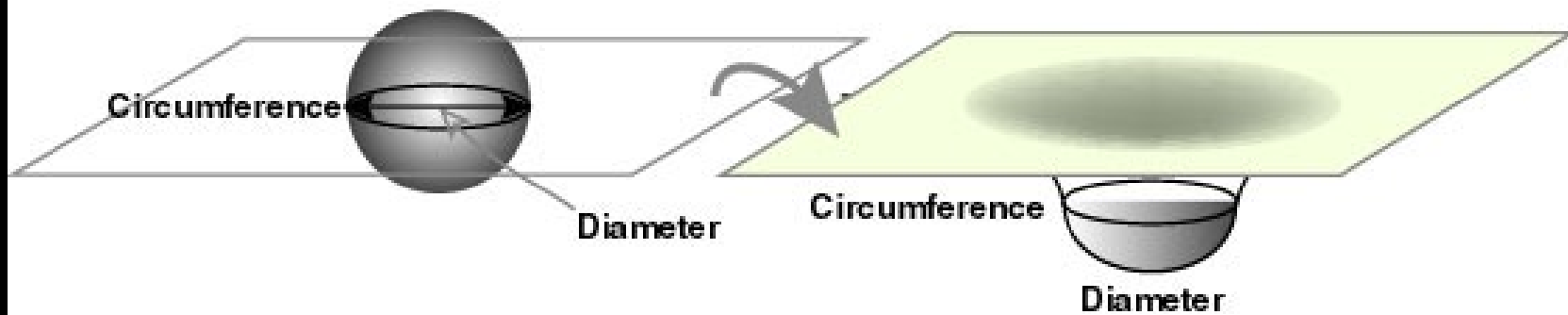
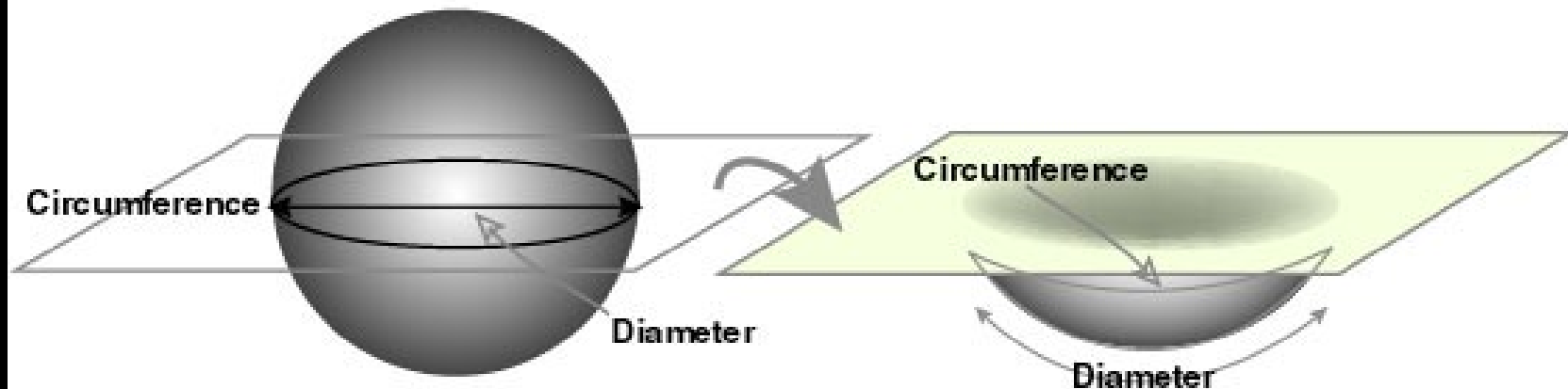
$$F = m_i a \quad \text{True for *any* force}$$

Inertial Mass ( $m_i$ ) = Gravitational Mass ( $m_g$ )

Central concept of General Relativity:

Gravity is not a force, it is the *curvature of spacetime*

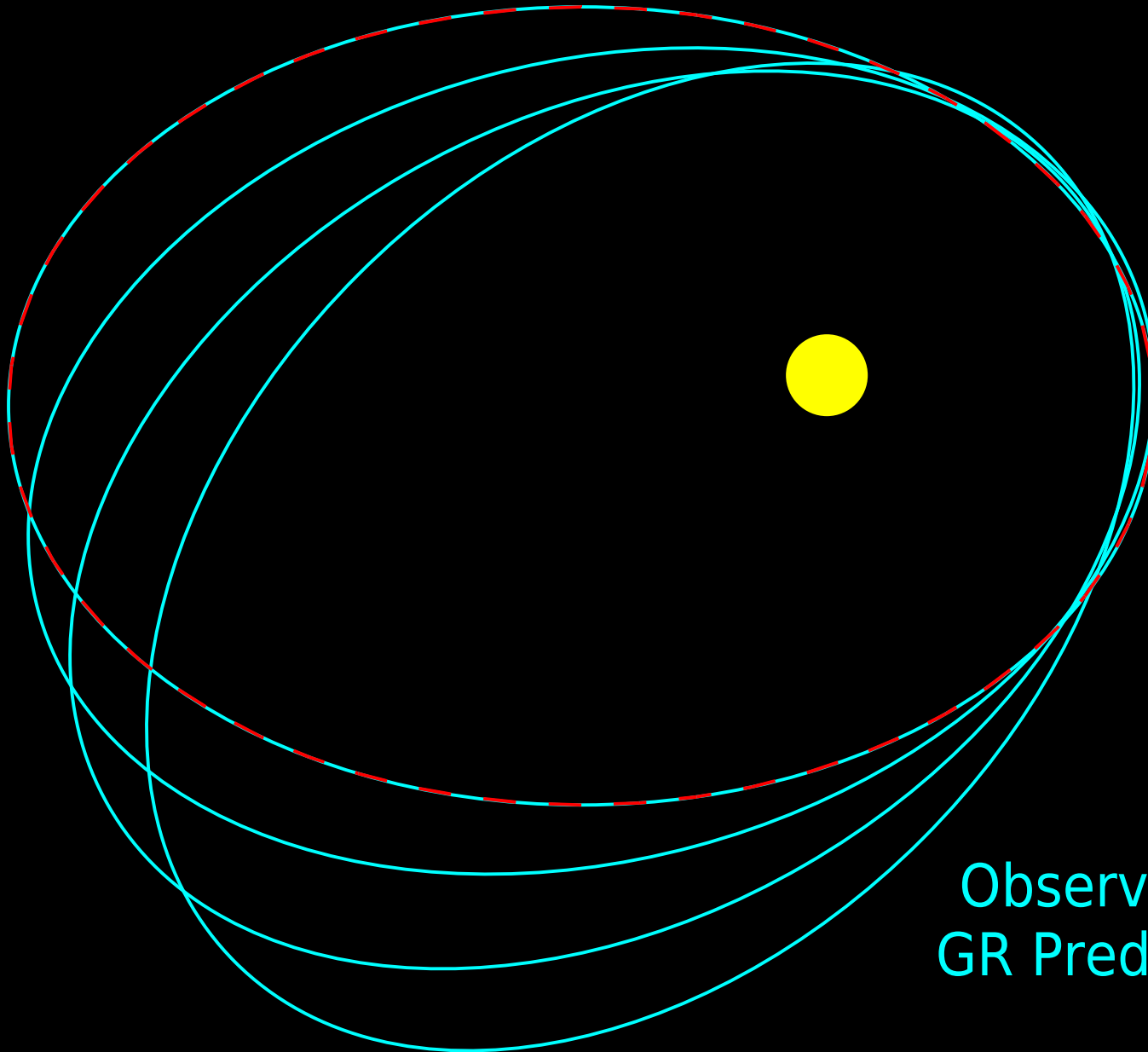
# STARS WITH THE SAME MASS, BUT DIFFERENT SIZES: HOW CURVED?



Newton's Gravity  
Prediction

Mercury's Orbit  
Around the Sun

(Ellipticity, precession  
exaggerated.)



Observed &  
GR Prediction

# Gravitational Lensing



**Galaxy Cluster Abell 2218**

**HST • WFPC2**

NASA, A. Fruchter and the ERO Team (STScI) • STScI-PRC00-08

# GPS (Global Positioning System)

Routinely must include general relativity corrections for gravitational redshift and gravitational time dilation.



# Was Newton Wrong???

Yes

General Relativity gives us a deeper understanding of gravity consistent with other laws of Physics, borne out by experiment.

No

Newton's Gravity is exactly what General Relativity gives you if things aren't moving too close to the speed of light and there isn't too much mass in too small a volume. We still use Newton's Law of Universal Gravitation all the time!!!

*Newton Was Incomplete*



# Einstein Was Wrong

Quantum Mechanics : the physics of the very small, of atoms, molecules, electrons, quarks, etc.

Quantum Mechanics and Special Relativity are fully compatible.

Quantum Mechanics and General Relativity are not compatible...! ☹️

A working theory of Quantum Gravity is a (the?) holy grail of modern theoretical physics.

*The Elegant Universe* by Brian Greene (book & Nova Special)

# Einstein Was Right

GR is very well tested; any deeper theory will incorporate it, just as GR incorporates Newtonian gravity.

## Challenges to Relativity

- Quantum Gravity
- Variable Speed of Light (early universe *or* only tiny variations over billions of years)
- Push experiments further to test General Relativity's predictions, look for cracks
- ...and more nutty things ☺

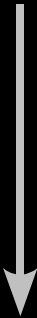
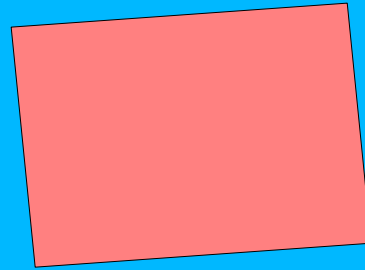
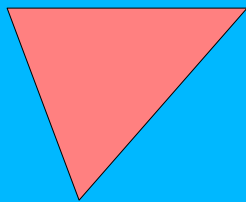
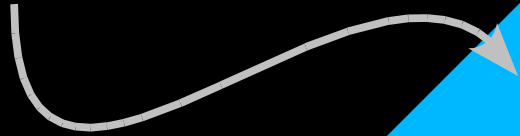
*Why “was Einstein wrong?” is the wrong question :*

- Current physics must be incomplete
- Current results *will still stand*
- Relativity, like Newtonian gravity, is so useful and well-tested that it *will be a limit* of anything that supercedes it
- If you see somebody peddling a theory claiming that all of current modern science is on the wrong track – they are probably selling snake oil!

*Extra Slides...*

*Flatland*

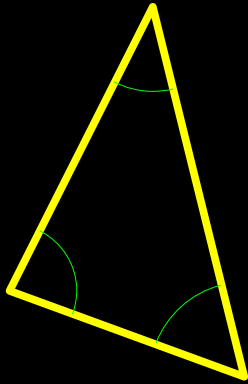
This is the Universe



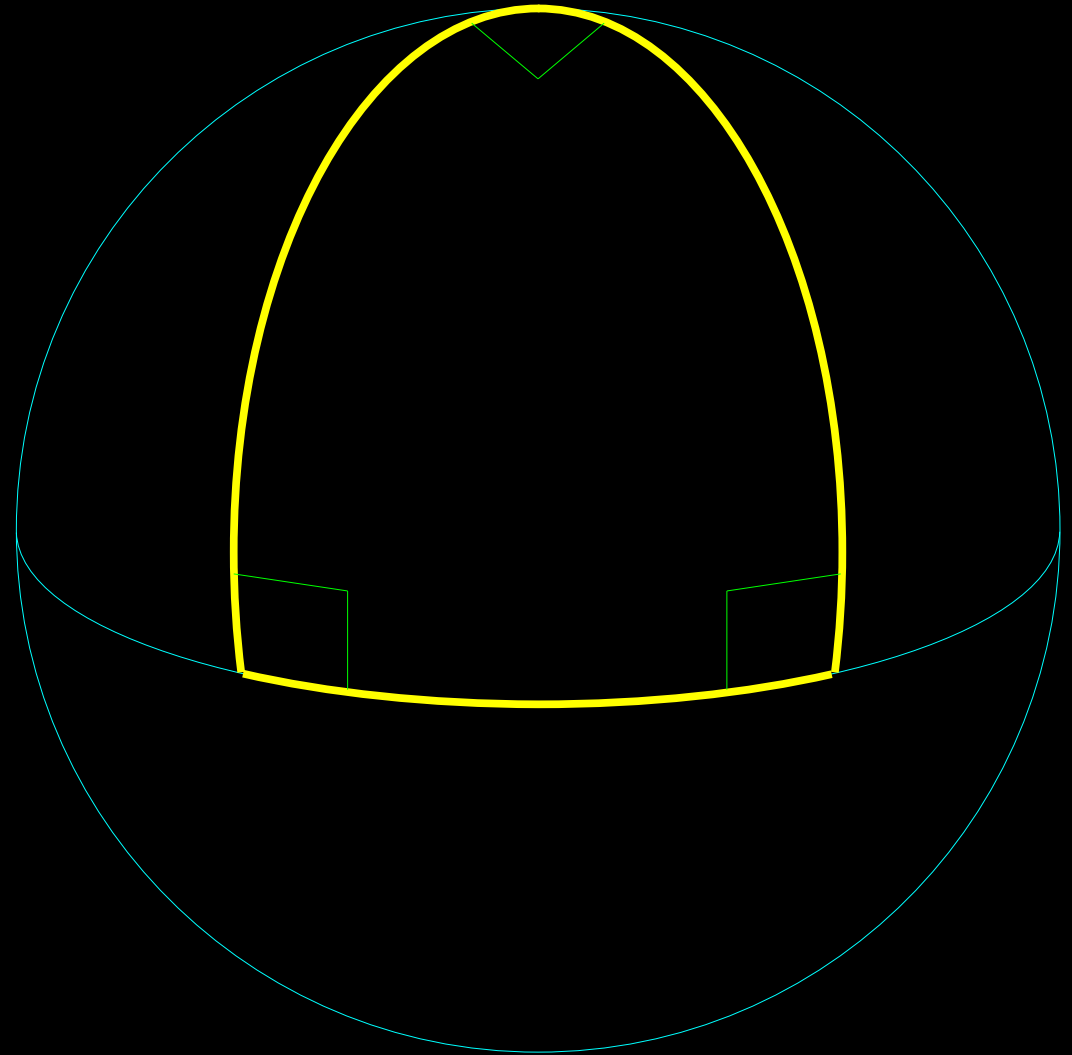
This dimension doesn't exist  
(or is something we can't measure, and thus is meaningless)

## Flat (Euclidean) Space:

Any triangle, three interior angles add to  $180^\circ$



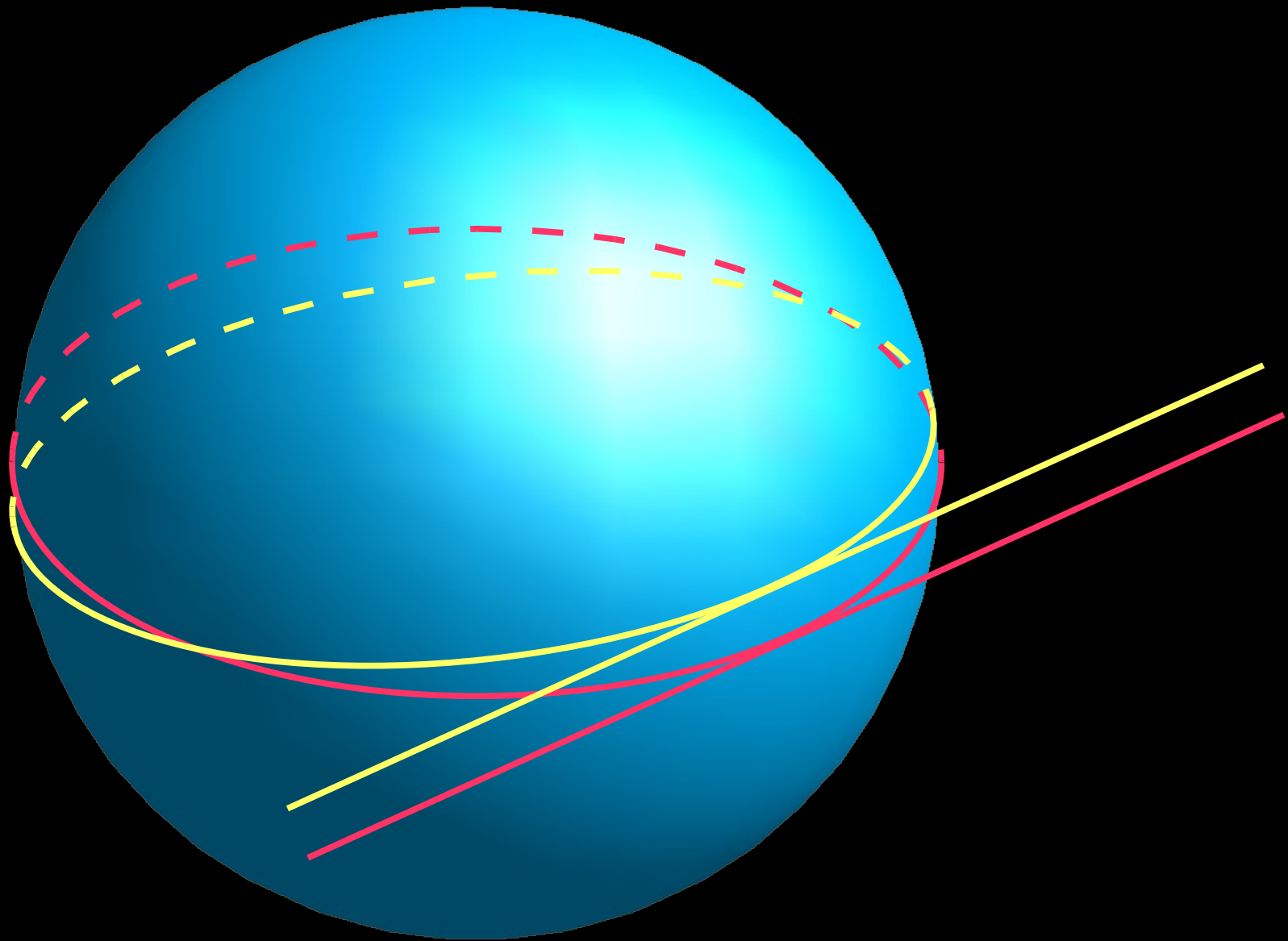
Flatland (2-dimensional) creatures could measure this curvature without reference to the third dimension we use to describe this here!

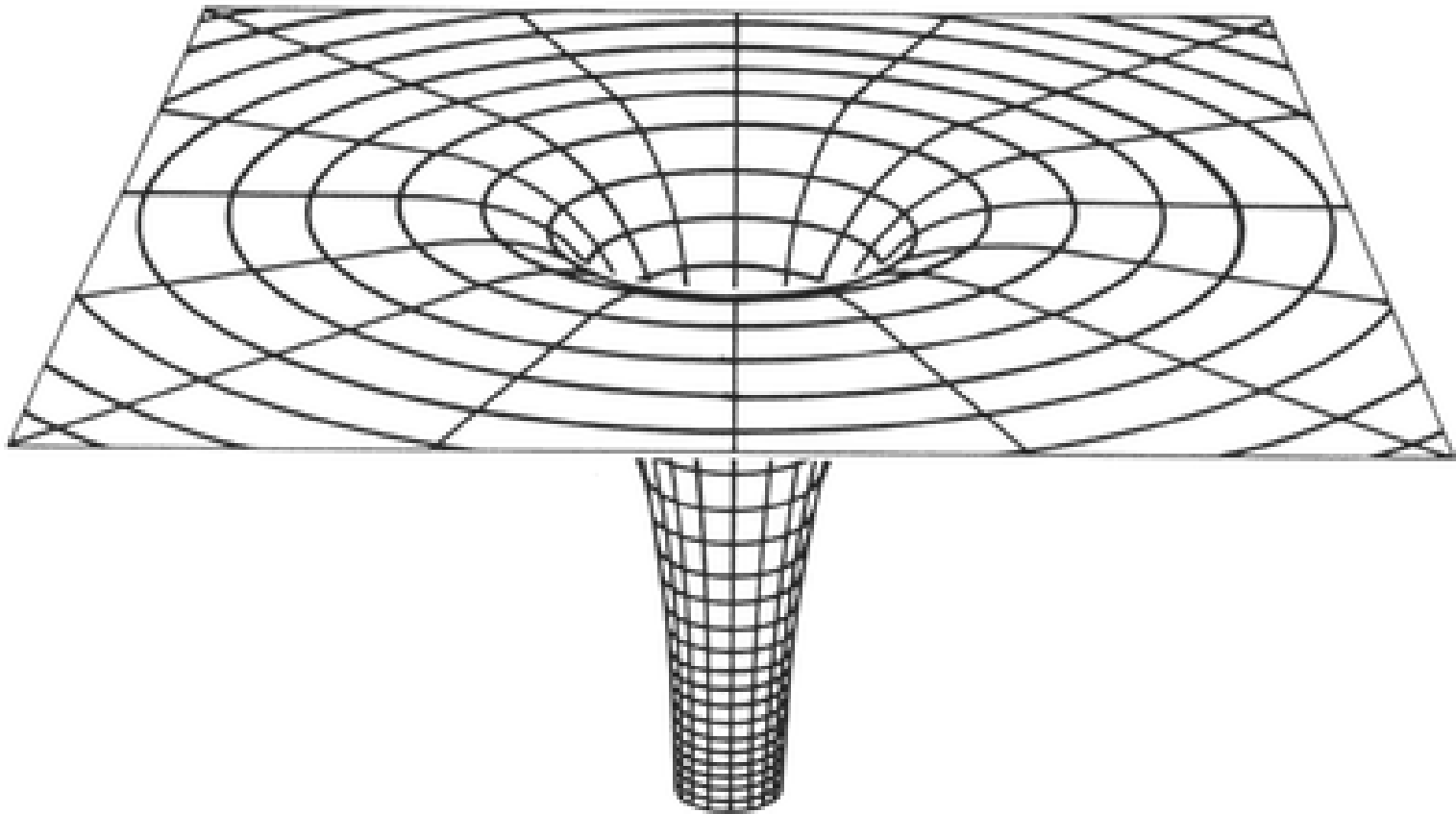


Curved Space: *This* triangle, three interior angles add to  $270^\circ$

(In general:  $>180^\circ$  : positive curvature  
 $<180^\circ$  : negative curvature)

In curved space, parallel lines may cross (!!!)







## More kinds of redshift:

**Doppler effect** : light from a receding source is redshifted

**Gravitational redshift** : light from a source in a gravitational well is redshifted

**Cosmological redshift** : light redshifts as the Universe expands (special case of Gravitational redshift)

# Is the Universe really expanding?

Yes! Redshift can't be "tired light"

