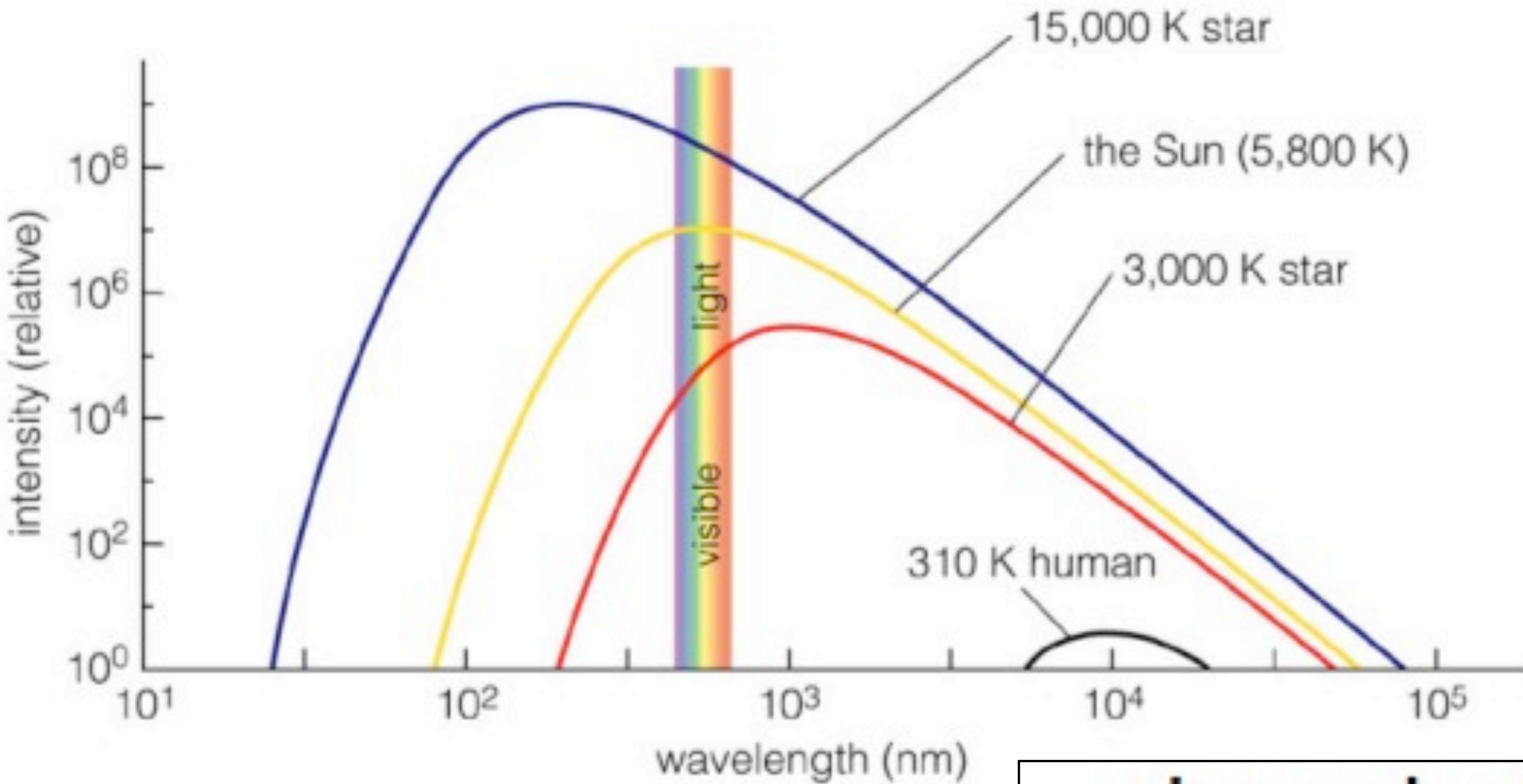
Blackbody Spectrum



hotter bodies: emit at shorter wavelengths (bluer), and also more luminous

Temperature alone determines
1) ‘colour’
2) ‘intensity’

- the peak of the radiation moves to higher freq. for higher T: Wien’s Law:

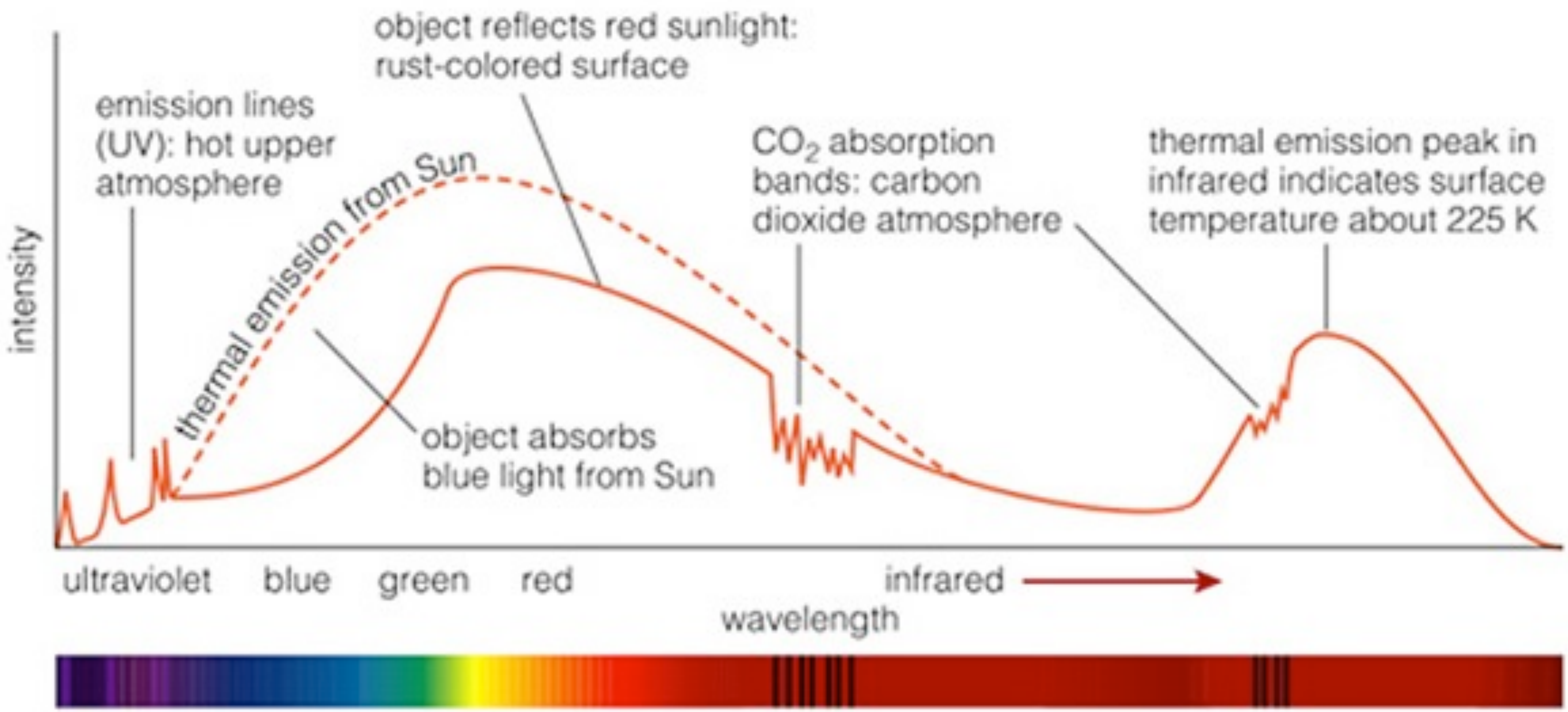
$$\boxed{\lambda max=0.0029/T\ m}$$

- the total energy/unit time/ unit area: Stefan-Boltzmann Law:

$$\boxed{E= \sigma T^4\ j/m^2 s}$$

where $\sigma = 5.67\times10^{-8}$ watt/m^2K^4

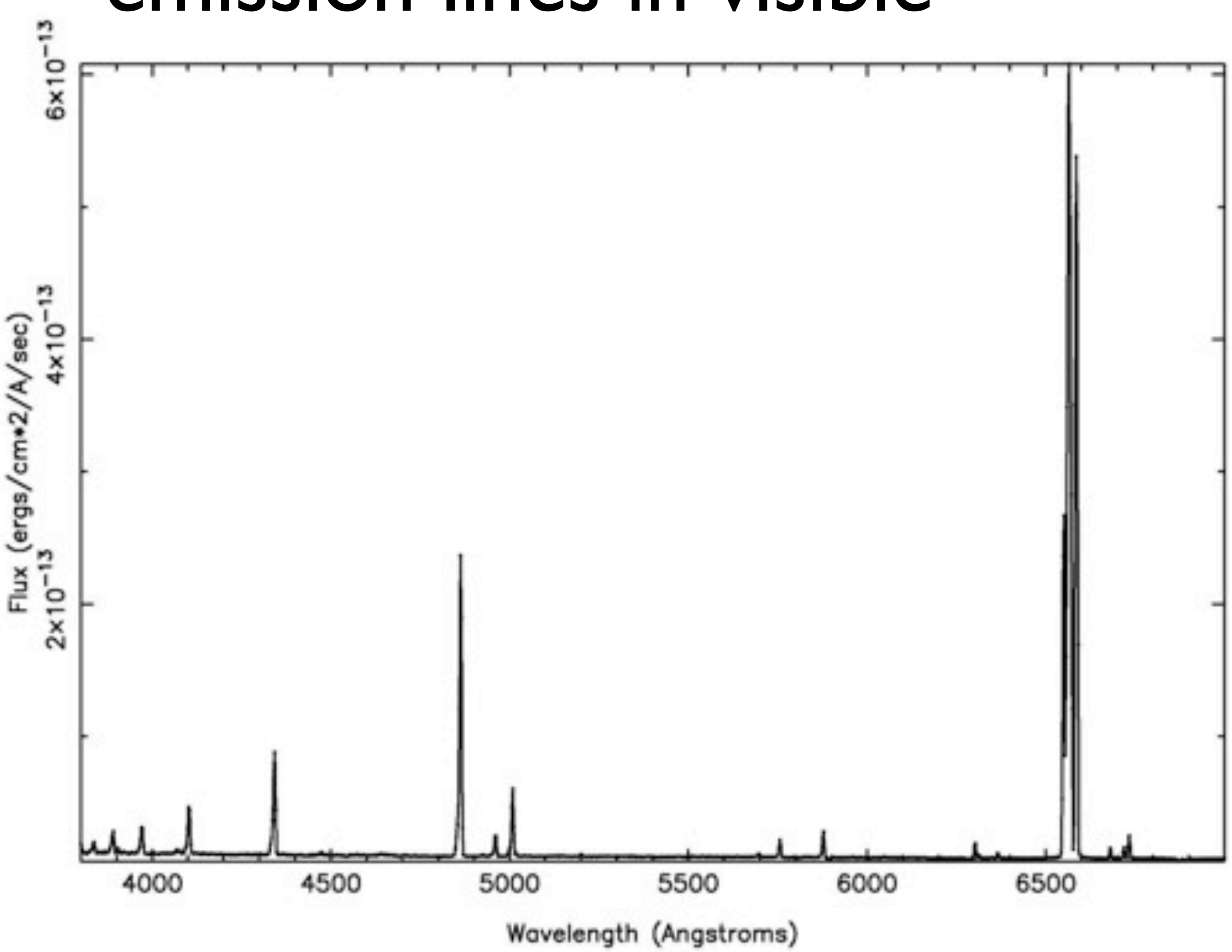
Spectrum of Mars



Blackbody radiation of a cold body: long wavelengths.

Sometimes, we can see short wavelength radiation from very cold bodies. "Emission Lines"

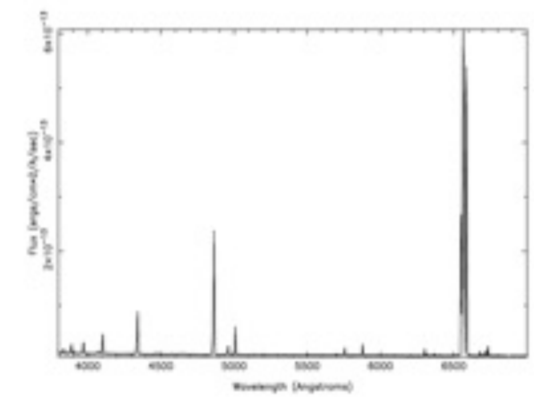
emission lines in visible

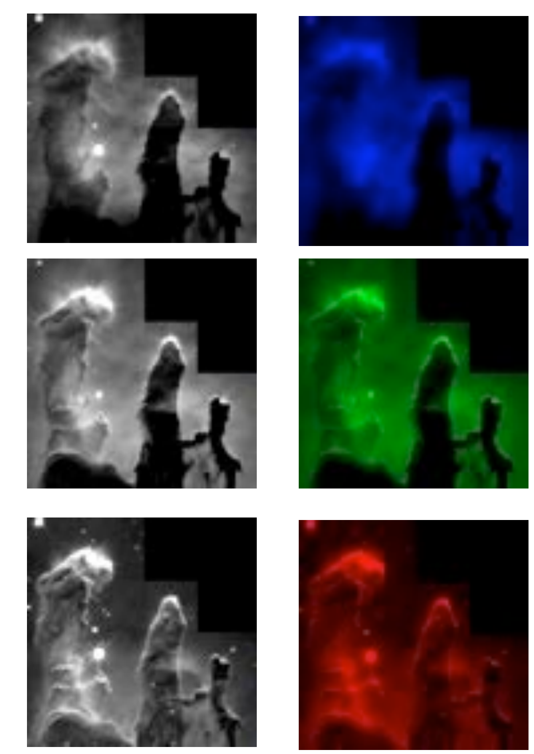


gaseous nebula T ~ 20 K

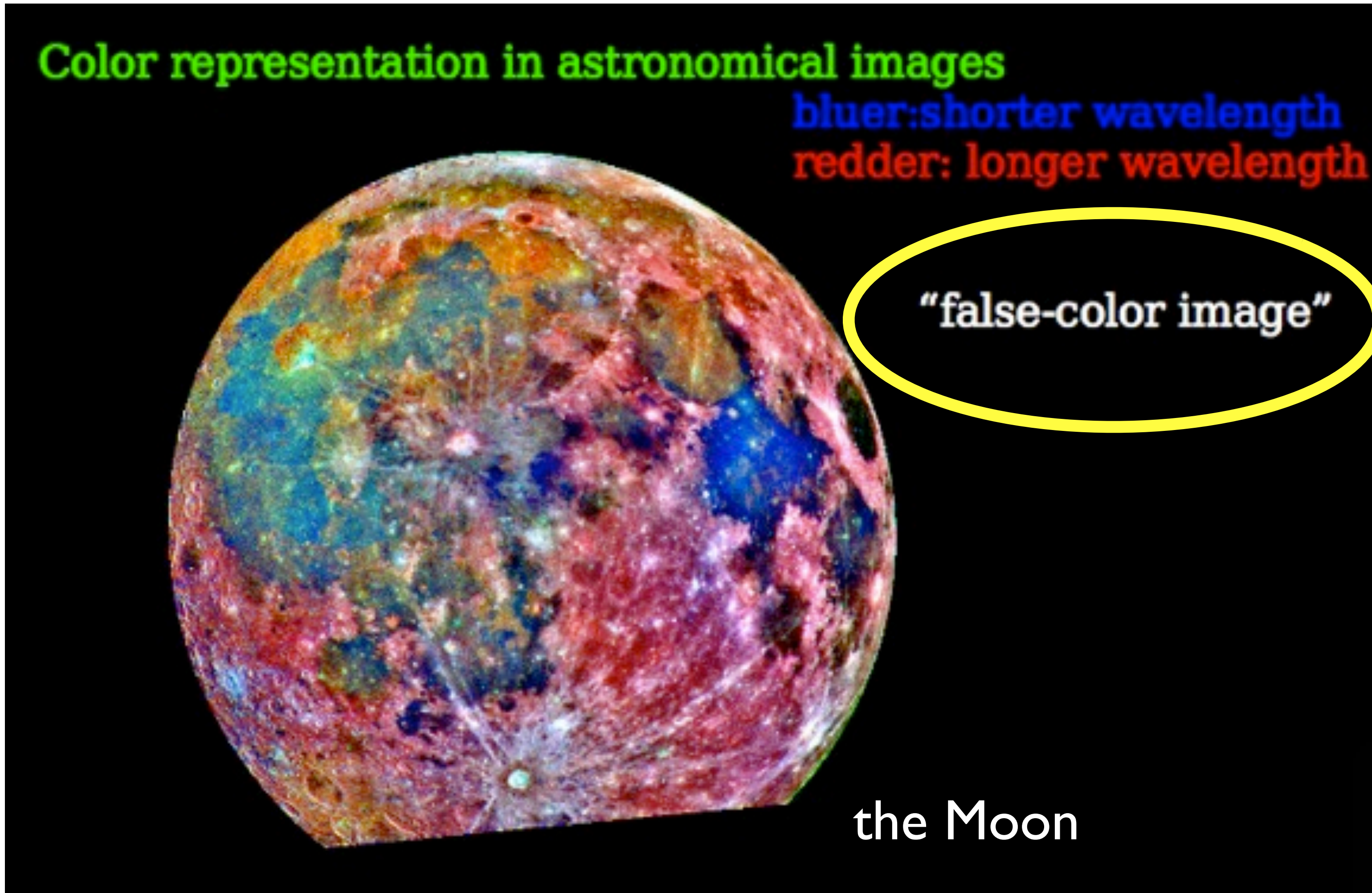
blackbody peak ~ 0.15mm (radio)

Suppose you are to fly out to the Eagle Nebula, is this really what your eyes see?



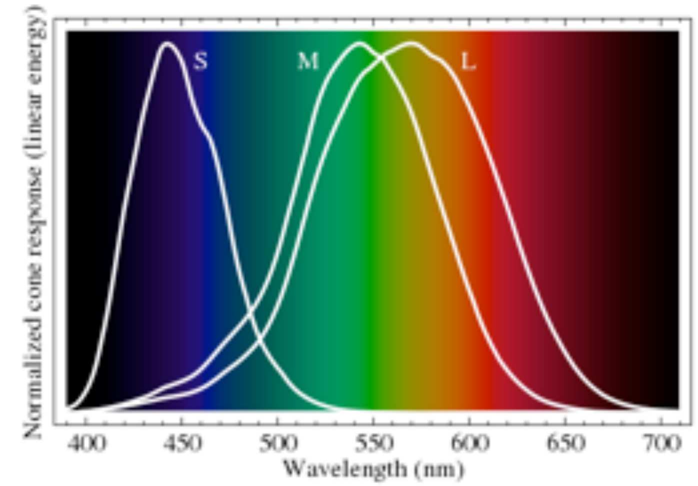


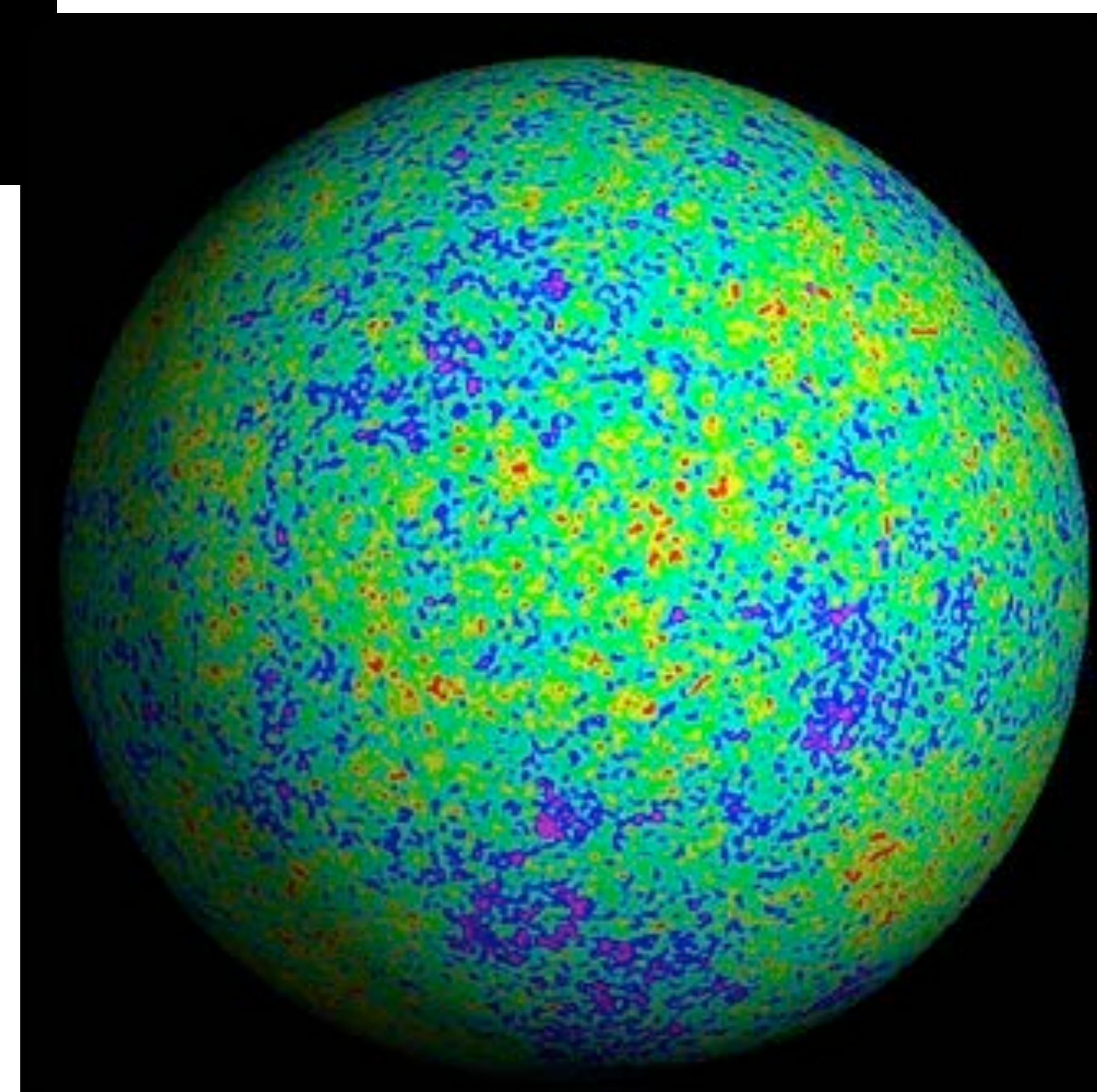
digital images at different λ
each assigned a color
single images combine



the Moon

human's tri-chromatic colour vision

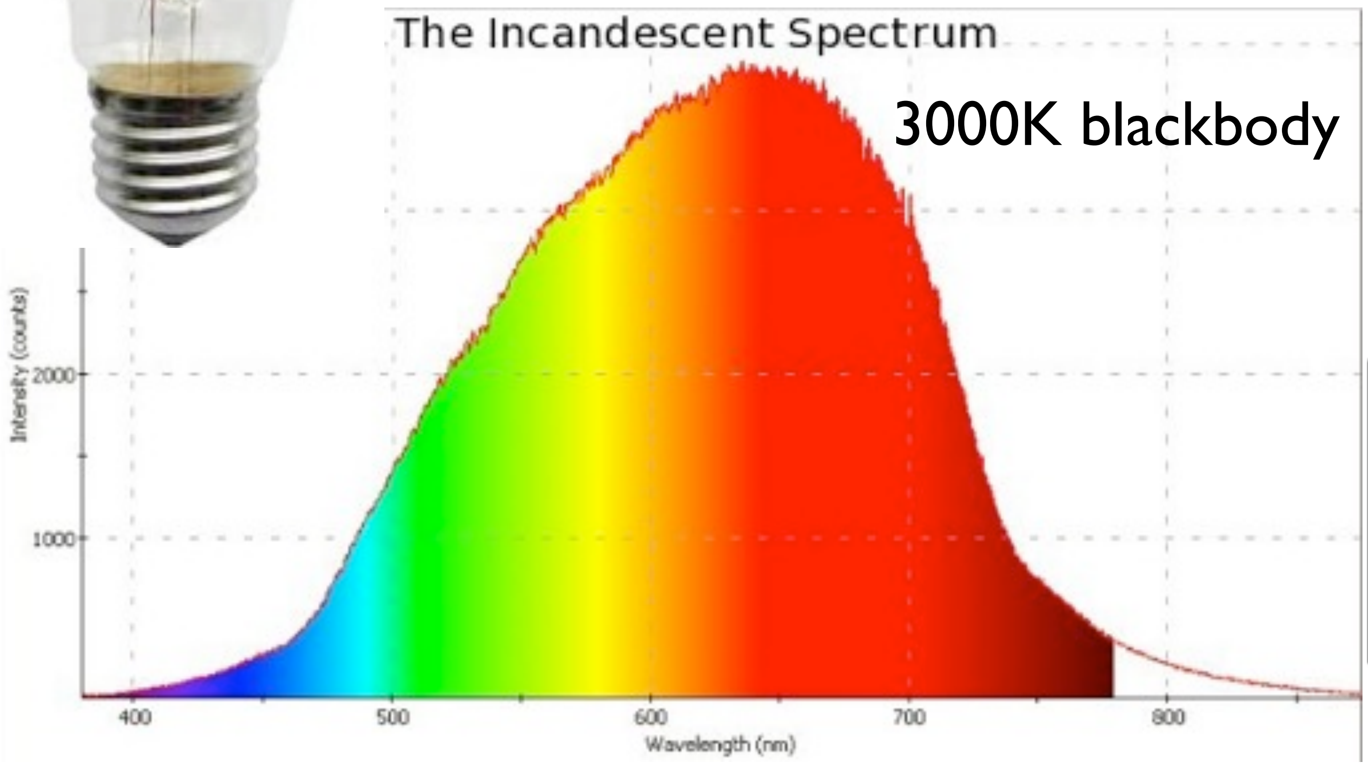


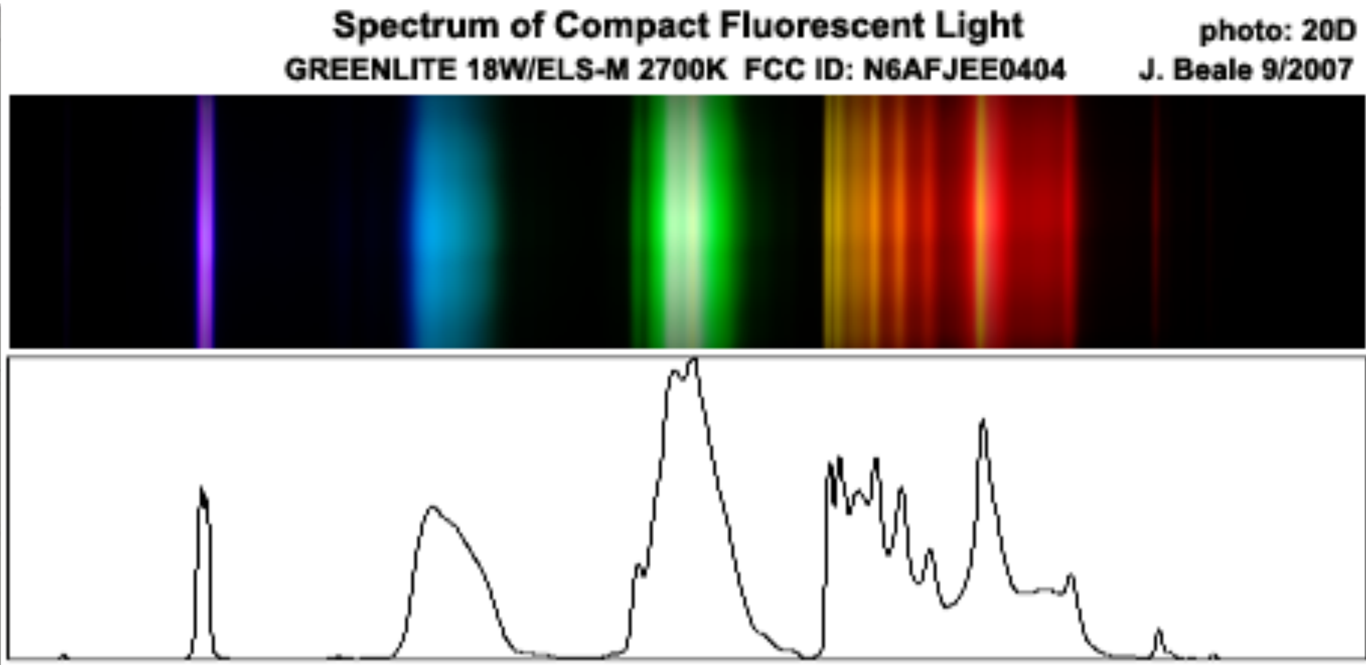


the cosmic microwave background

Real World Applications:

why do compact fluorescent bulbs cut your monthly energy bills?

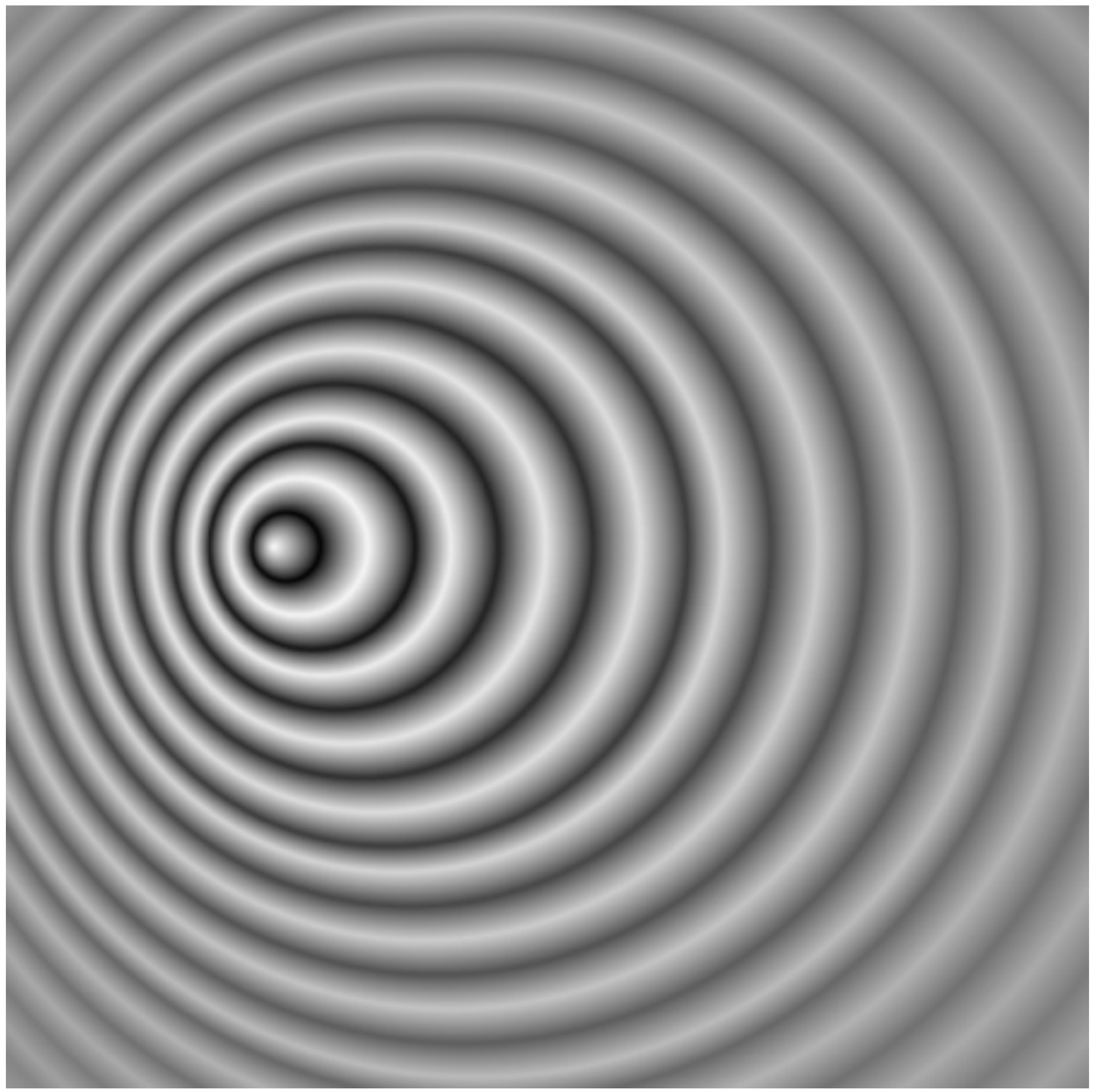




Energy efficient lights work by emitting in only a narrow range of wavelength (emission lines), and fool our brains into thinking the light is a broad spectrum.
They are more efficient because the bulbs don't have to be heated up to high temperature, unlike conventional bulbs (and wasting energy in infrared lights)

The (Classical) Doppler effect

Light is a wave, just like sound wave, or water wave.



light source moving toward you

$\lambda = \lambda_0 * (1 - v/c)$

light blue-shifted

moving away from you

$\lambda = \lambda_0 * (1 + v/c)$

light red-shifted

perpendicular direction

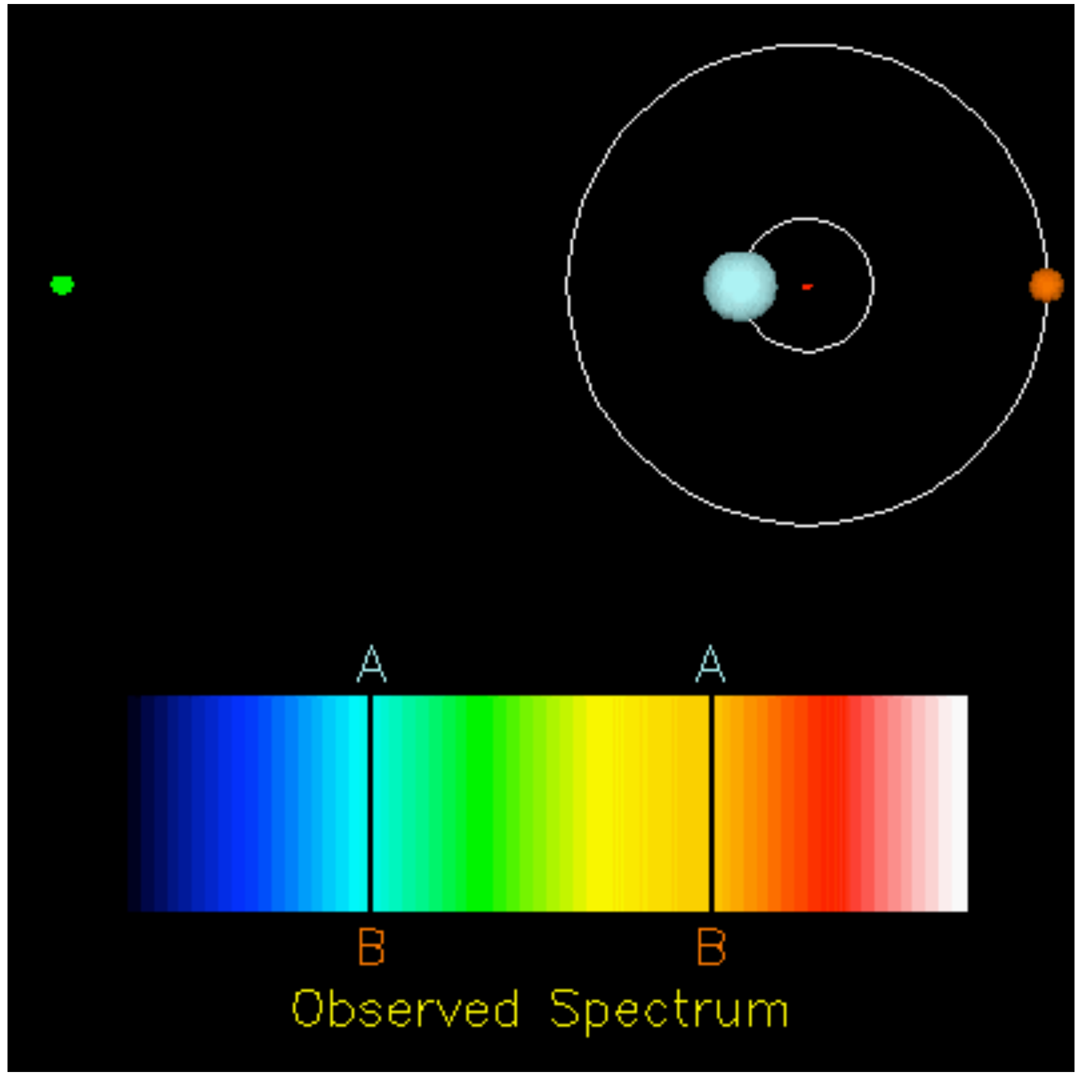
$\lambda = \lambda_0$ (rest wavelength)

light unchanged

if photons are water waves

Doppler effect revealing motion in a binary star system

observer



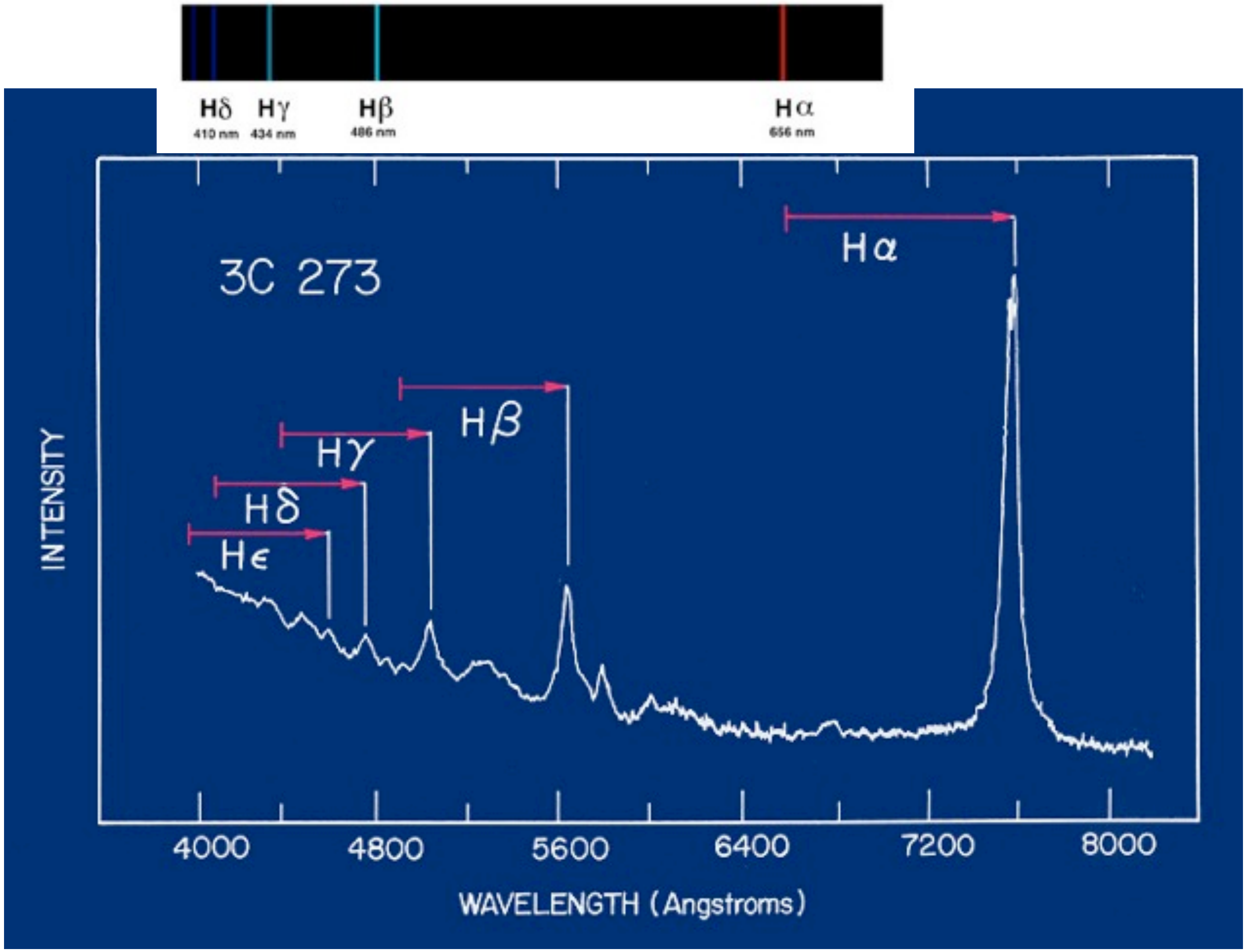
only line-of-sight velocity matters

moving away from you

$\lambda = \lambda_0 * (1 + v/c)$
light red-shifted

useful for detecting extra-solar planets!

Spectrum of Quasar 3C 273



quasar discovered by Maarten Schmidt (1963) in 3C 273: all hydrogen lines red-shifted by 15%:

$z = 0.15$

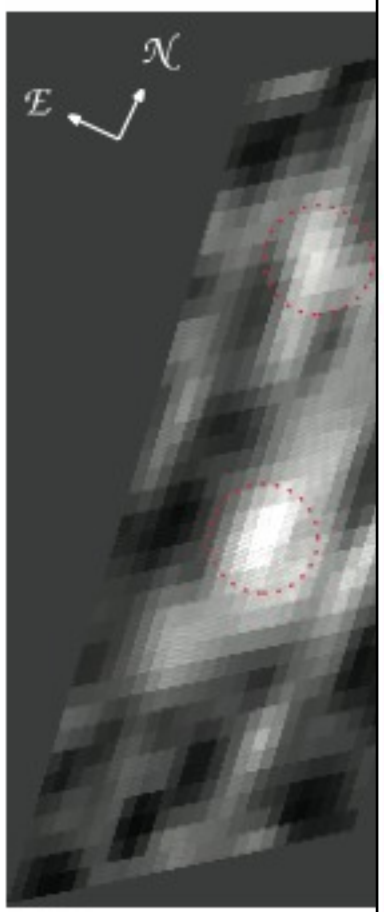
define redshift:

$z = \lambda/\lambda_0 - 1 \sim v/c$

galaxy holding the redshift record:

DISCOVERY OF A VERY BRIGHT STRONGLY LENSED GALAXY CANDIDATE AT $z \approx 7.6$[1]

L. D. BRAD
M.

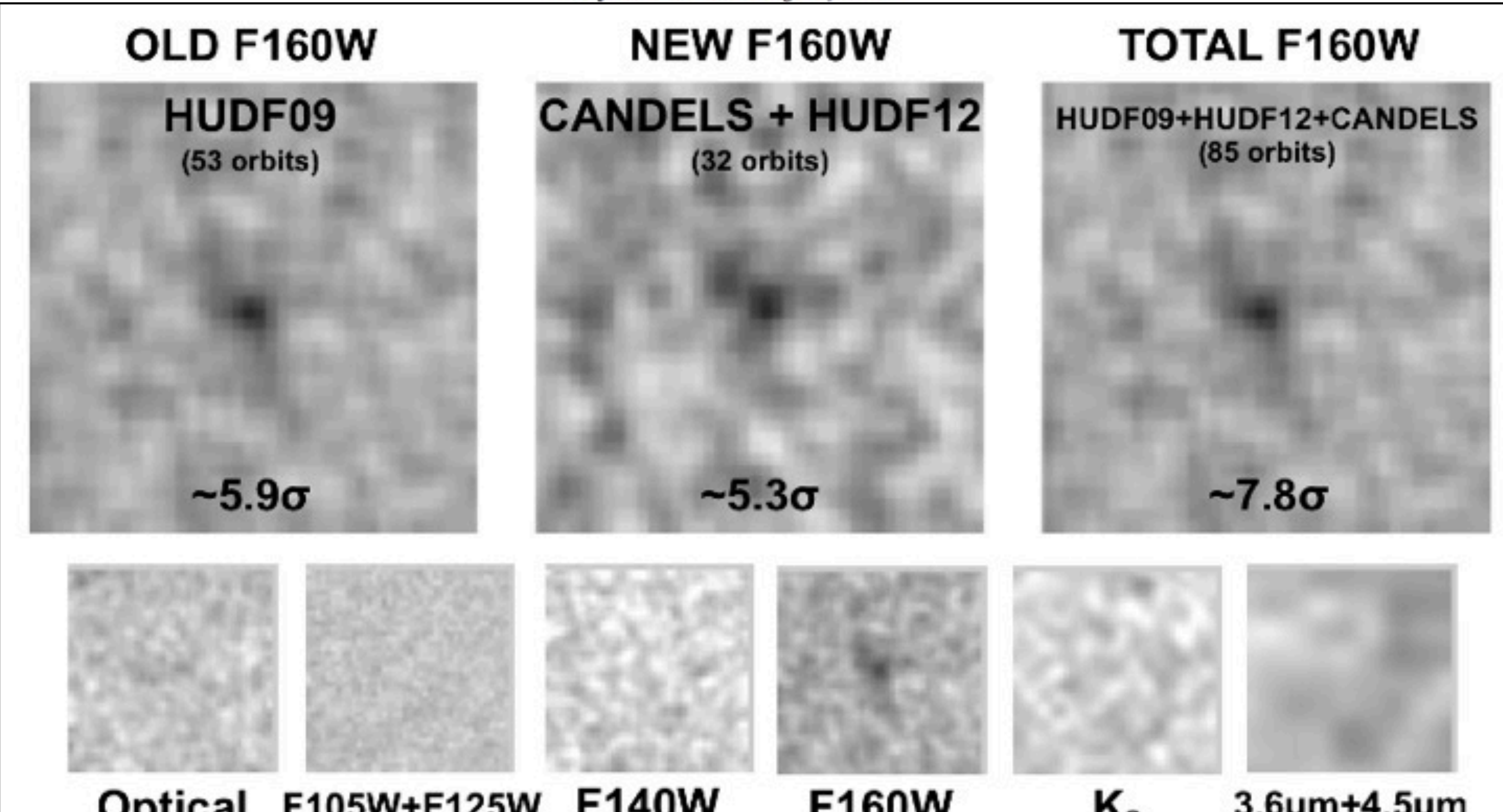


DRAFT VERSION JANUARY 25, 2013
Preprint typeset using LaTeX style emulateapj v. 5/2/11

PHOTOMETRIC CONSTRAINTS ON THE REDSHIFT OF $Z \sim 10$ CANDIDATE UDFJ-39546284 FROM DEEPER WFC3/IR+ACS+IRAC OBSERVATIONS OVER THE HUDF[1]

R. J. BOUWENS[2,3], P. A. OESCH[3,†], G. D. ILLINGWORTH[3], I. LABBÉ[2], P. G. VAN DOKKUM[4], G. BRAMMER[5], D. MAGEE[3], L. SPITLER[7,8], M. FRANX[2], R. SMIT[2], M. TRENTI[6], V. GONZALEZ[3,9], C. M. CAROLLO[10]

Draft version January 25, 2013



the Cosmic Microwave Background is at z~1100

cosmological redshift $\quad z = \lambda/\lambda_0 - 1 \sim v/c$

. how fast are these objects receding from us? can it be faster than speed of light?

Classical Doppler Effect

$$\lambda = \lambda_0 \, (1 + v/c)$$

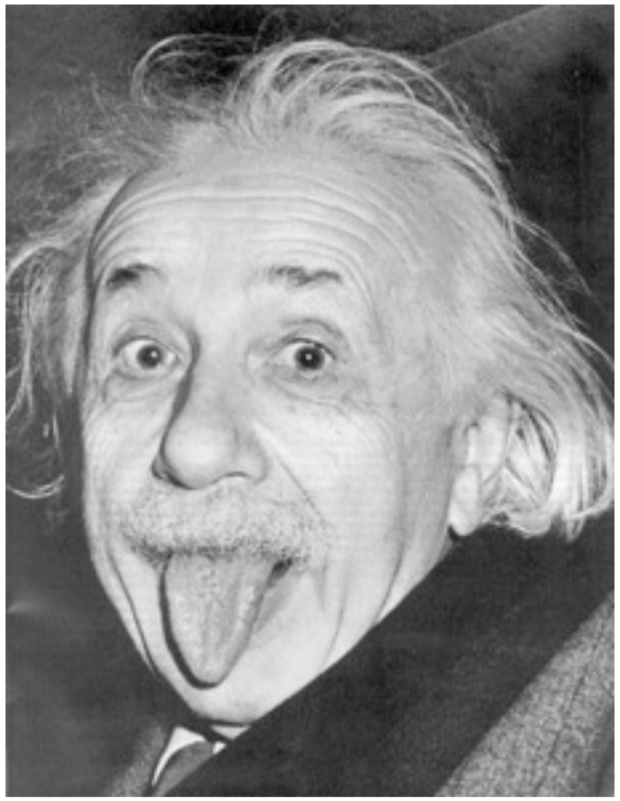
observed wavelength

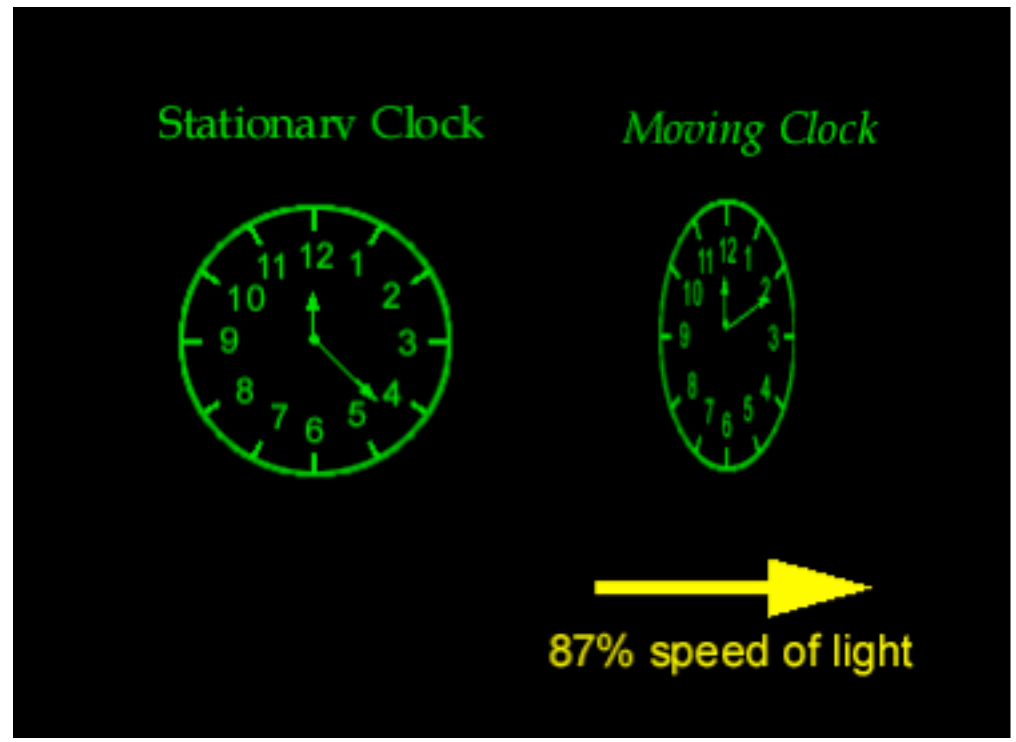
rest-wavelength

. why are we left in the middle?

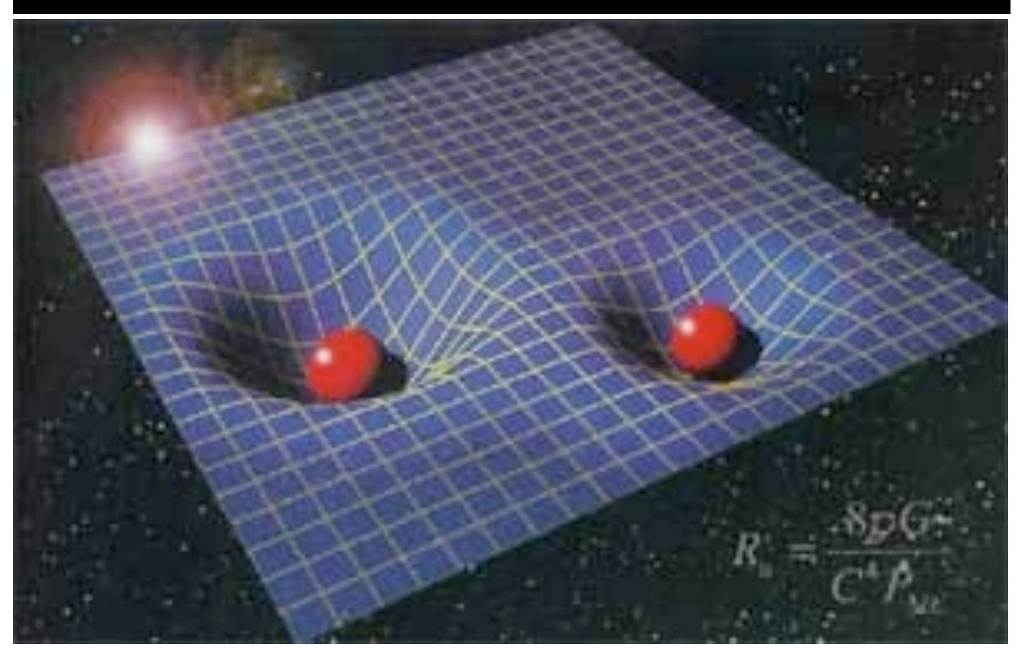
we will discuss these in later lectures

Lecture 3: Nature of Space & Time





special relativity
1905



general relativity
1912

We can travel faster than sound.

Can we, one day, travel faster than light?

Concord supersonic jet (1976-2003)

Speed of light is same for everybody, always.

starts from a paradox in one of Einstein's thought experiment

`If I [Einstein at the age of 16] pursue a beam of light with the velocity c, I should observe such a beam of light as a spatially oscillatory electromagnetic field at rest. However, there seems to be no such thing... From the very beginning it appeared to me intuitively clear that,.... everything would have to happen according to the same laws as for an observer who, relative to the earth, was at rest.

For how, otherwise, should the first observer know, i.e., be able to determine, that he is in a state of fast uniform motion? ...

and is experimentally verified time and again

Huh? Common sense says this is crazy.

Drive in car at speed U.
Throw ball out at speed V.
Speed of ball now? V'

V' = U + V

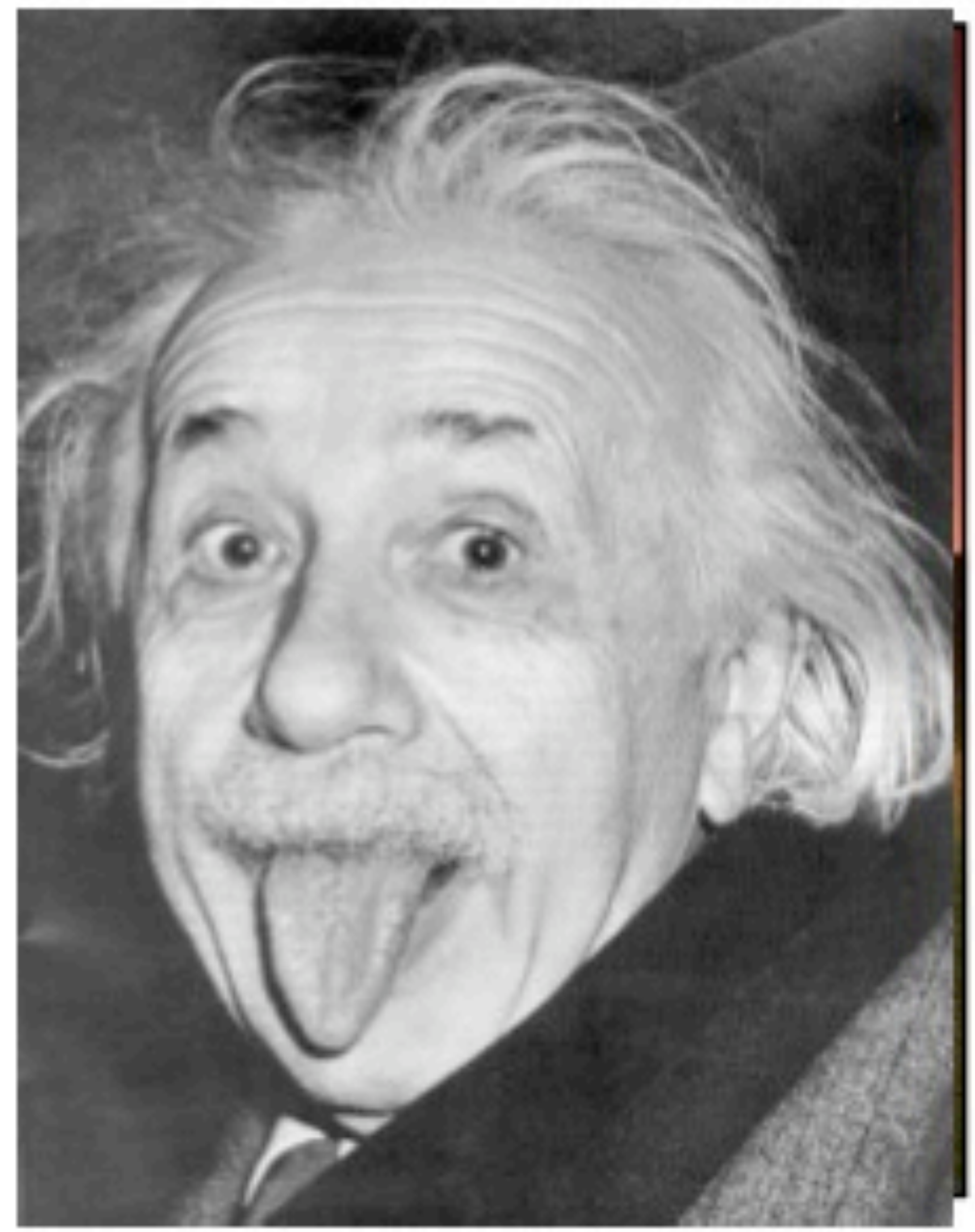
So if U=50 km/h and V=100 km/h, V'=150 km/h

But what if U=0.5 speed of light, and V= speed of light.
Then V' = 1.5 x the speed of light!

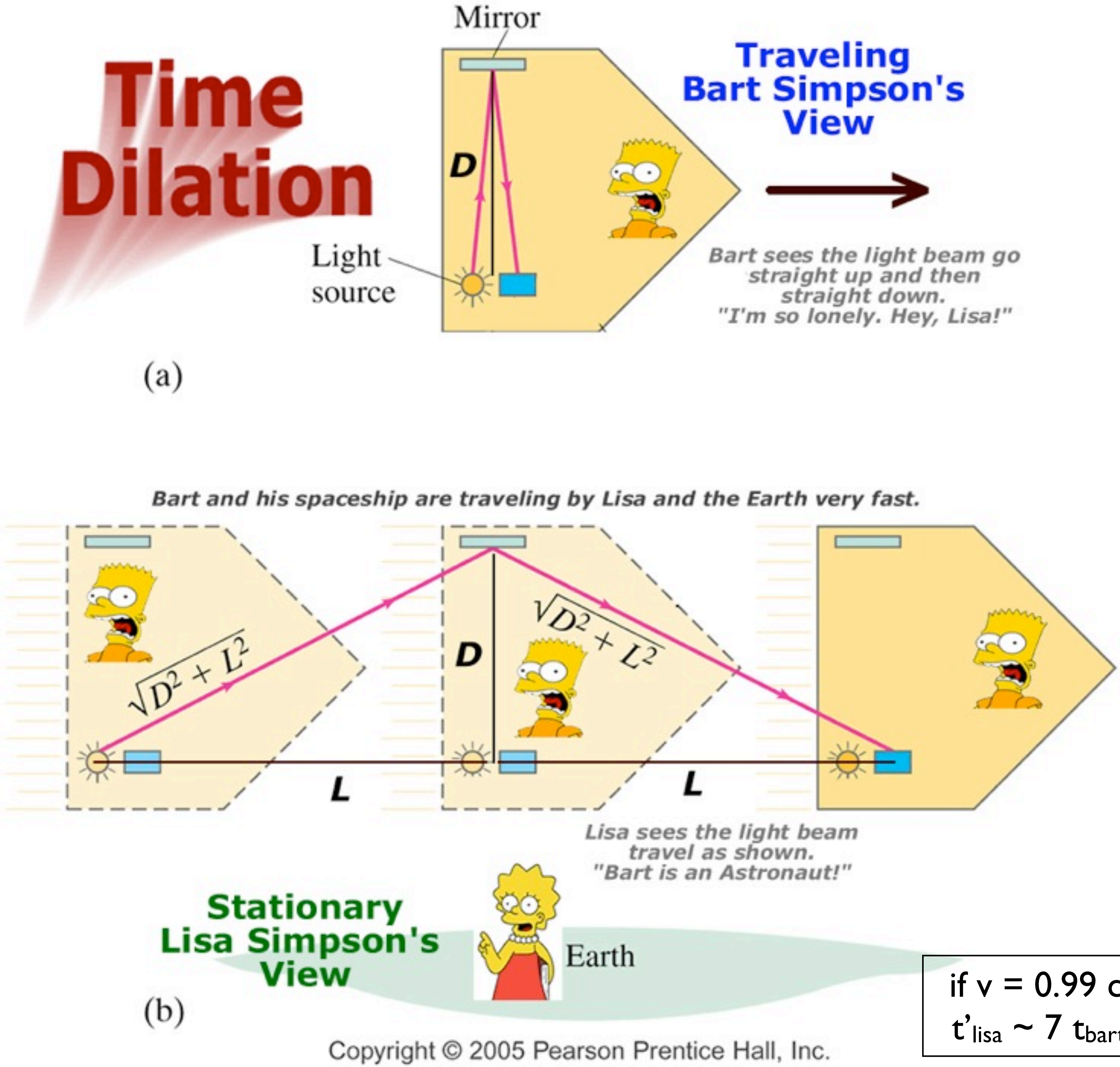
This would violate the rule that the speed of light is a constant...
and it isn't seen to happen.

Einstein Says…

- "Common Sense is the collection of prejudices acquired by age eighteen."
- Time is simply that thing that you measure with clocks.
- Huh?



What do clocks have to do with it?



assume c is constant

Only solution: time is relative.

$$t'_{lisa} = \frac{t_{bart}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

clock on spaceship appears (to earth observer) to run slower

if v = 0.99 c, $t'_{lisa} \sim 7\, t_{bart}$

Implications for Space travel

- 90% speed of light slows time by factor of about 2.

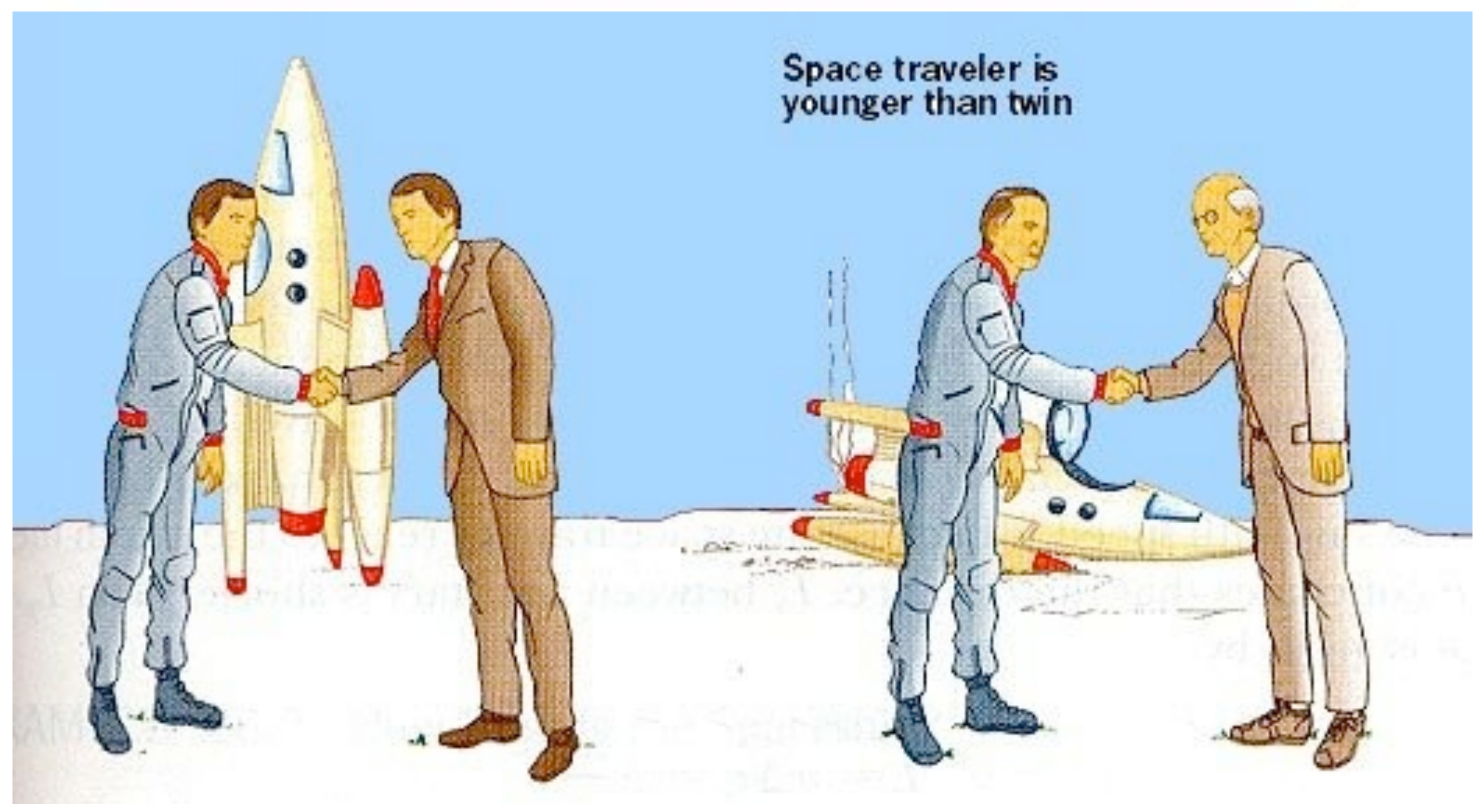
99%	"	7.
99.9%	"	22.
99.99%	"	71.
99.999%	"	224.

- E.g. at 99% of the speed of light the trip to the nearest star would seem to take you about 2 months while people on earth would age about 8 years.

PONDER:

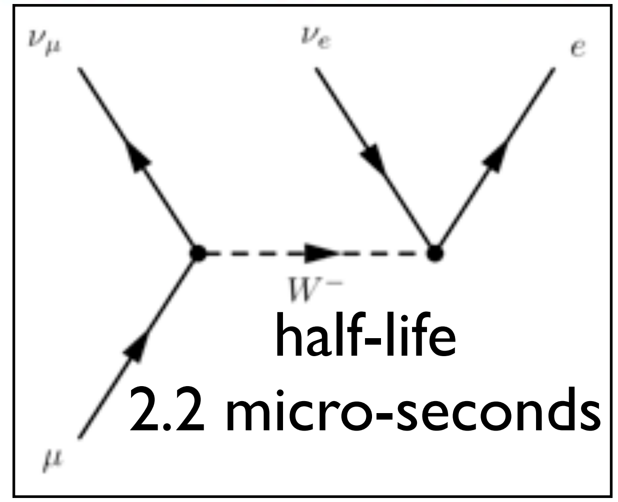
1. An extreme case: you could get the center of the galaxy and back in a few years of your time… but tens of thousands of years will have elapsed back home.

2. The twin paradox



but, really, who is travelling?

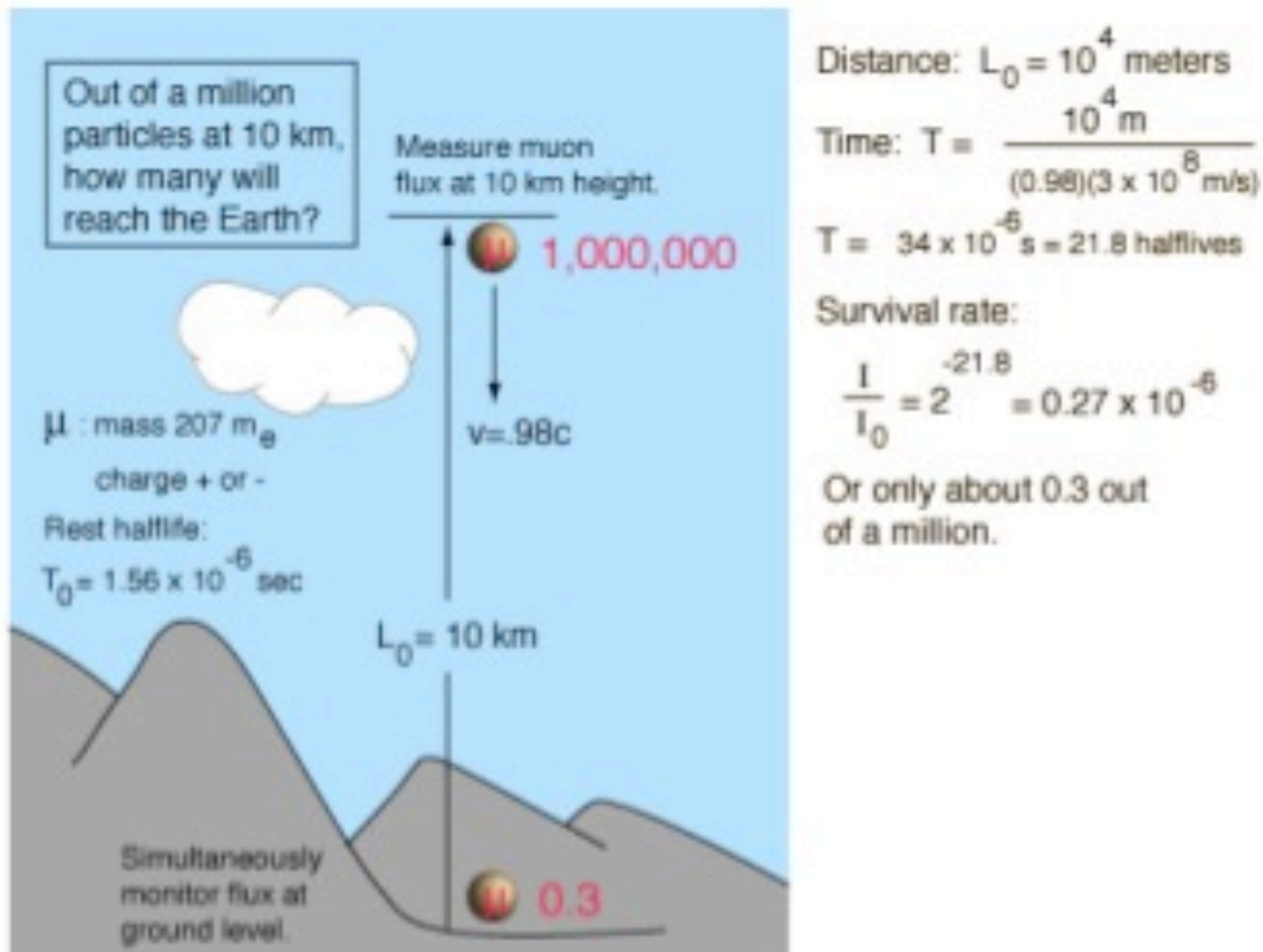
Experimental tests of special relativity I: Muon Decay



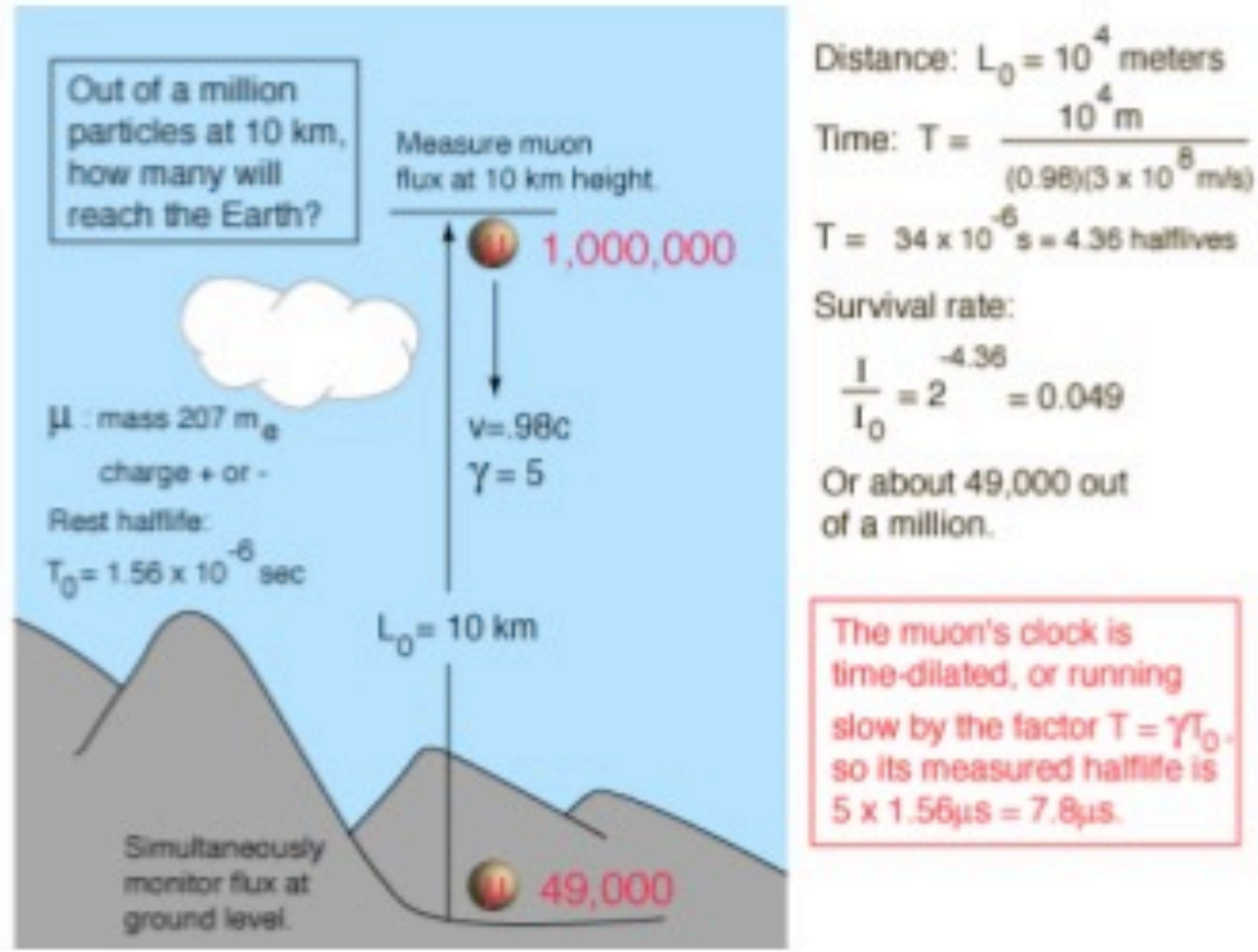
weak interaction

= 0.66 km

If Einstein was wrong less than 1 out of a million muons make it to the ground.



But Einstein was right! Because of time dilation loads of muons make it to the ground.



Time is relative. So is Space.

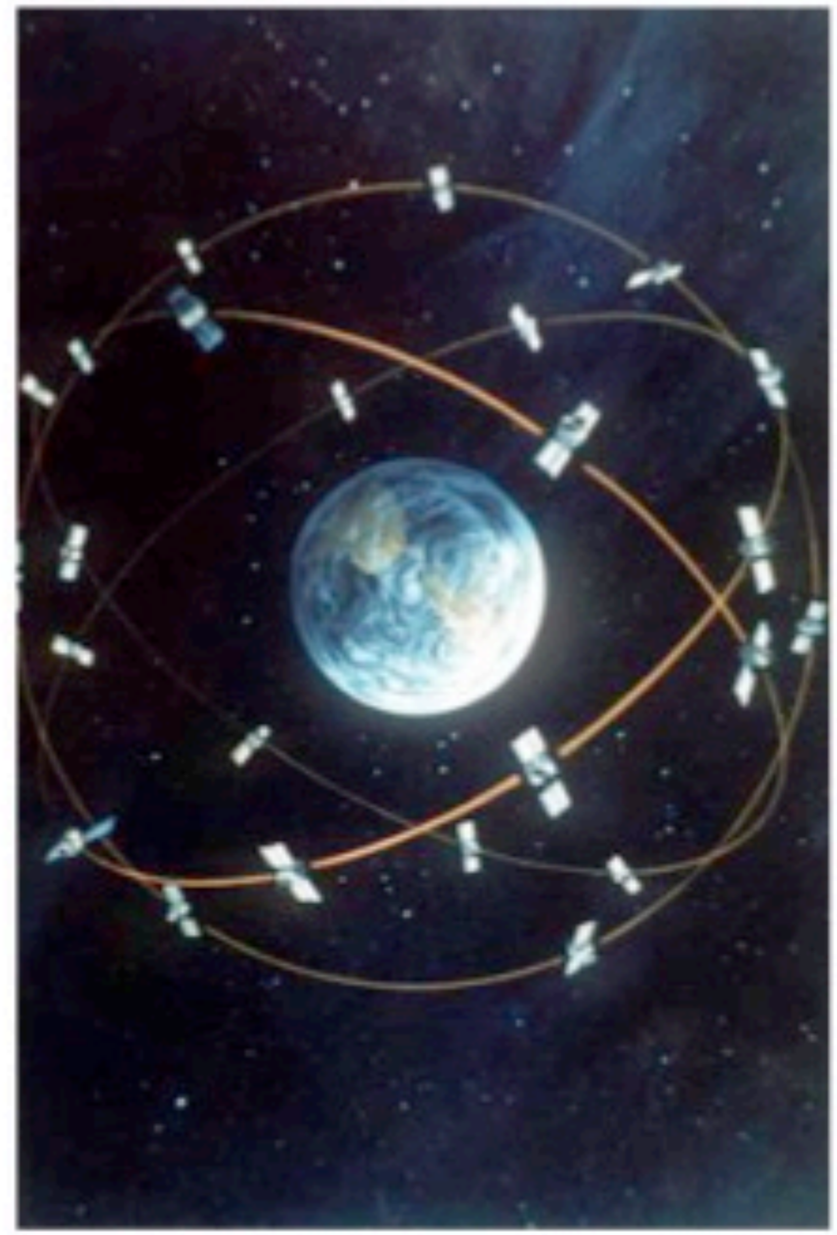
$$L' = \frac{L}{\gamma(v)} = L\sqrt{1 - v^2/c^2}$$

As observers on earth, we see that muon's internal clock is slowed by its motion. But for little muons, it sees the length it has to travel being contracted. So it has no trouble reaching the earth.

These are equivalent explanations, but from different perspectives.

Experimental Test of Special Relativity II
The Global Positioning System (GPS)

- Network of 24 satellites. One can see at least 4 from any position on earth at any time.
- Each is moving at 14000 km/h.
- Each carries an atomic clock that ticks every nanosecond.
- They give you your absolute position to within 5-10m. To be this accurate they have to keep accurate time to within 20-30ns.
- The effects of relativity on the satellites are about 40,000ns per day.
- Without correcting for the effects of relativity, accuracy would only be 10km after only one day, and grow worse by similar amounts each day. GPS would be useless!



Aspects of Special Relativity: Definitions of Momentum and Energy

$$\boxed{p = \gamma\, m v}$$

Rest mass

$$\boxed{\begin{aligned} E &= \gamma\, mc^2 \\ &= KE + mc^2 \end{aligned}}$$

Relativistic energy

Intrinsic energy

where $\gamma^2 = 1/(1-\beta^2)$; $\beta = v/c$;

(Note: m=rest mass)

as v approaches c,
E --> infinity,
unless m=0

Aspects of Special Relativity: The relationship between energy and momentum

$$\boxed{E^2 = p^2c^2 + m^2c^4}$$

- If a particle has no mass then it has no intrinsic energy. The photon is an example of such a particle.

- However, being massless does not prevent it from having energy: $E=pc$

- Similarly, being massless does not prevent it from having momentum: $p=E/c$ so photons have momentum, and exert radiation pressure.

only massless particles can move at exactly c

Our modern understanding of space & time:

- space & time are specific to the observer (SR)
- space-time is curved by energy (GR)
- by coincidence(?), we live in 3+1 space-time
- space-time can have a beginning and an end