Gravitational redshift / time dilation

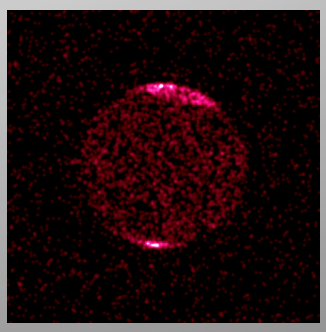
- light escaping from a gravitating body is redshifted
- clocks deep in a gravitational potential run slow

Descriptions of light

Particles (photons) or packets of energy

Travel at speed c, have energy E

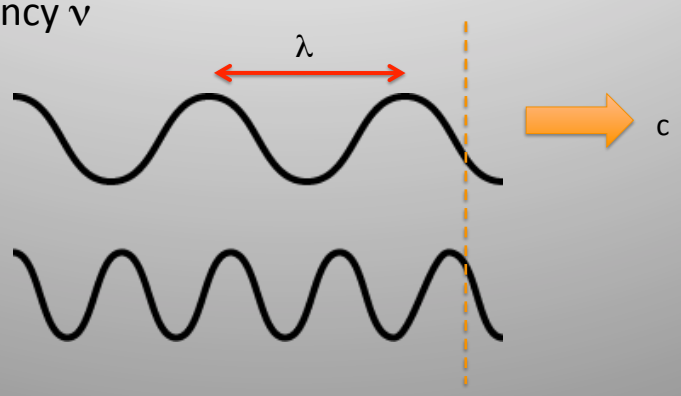
e.g. detect X-rays from Jupiter on a CCD – each photon deposits energy in one spot



Descriptions of light

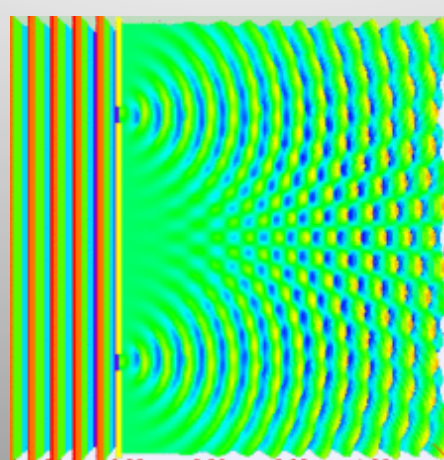
Electromagnetic waves travelling through vacuum

Travel at speed c, have wavelength λ and frequency ν



crests pass at frequency ν

Descriptions of light



Quantum mechanics

Light behaves as *both* a wave and as a particle

$$\lambda = \frac{c}{\nu}$$

wave – higher frequencies mean shorter wavelength

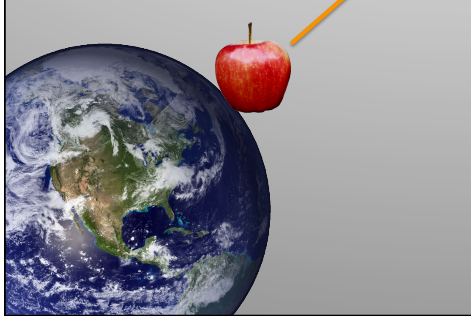
$$E = h\nu$$

particle – energy is proportional to frequency

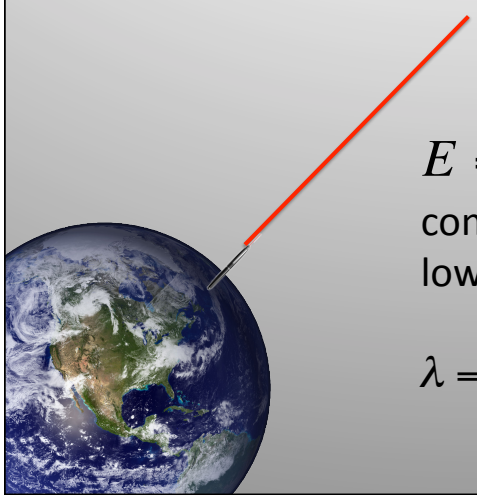
h is Planck's constant: measures how small quanta of energy are…

Gravitational red shift

gravity extracts energy from escaping mass (conservation of energy)



Gravitational red shift



gravity extracts energy from escaping *light*

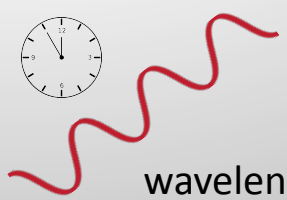
$$E = h\nu$$

consider as photons, means lower frequency

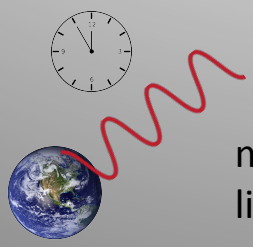
$$\lambda = \frac{c}{\nu}$$

as waves, longer wavelength, "redshift"

Gravitational time dilation

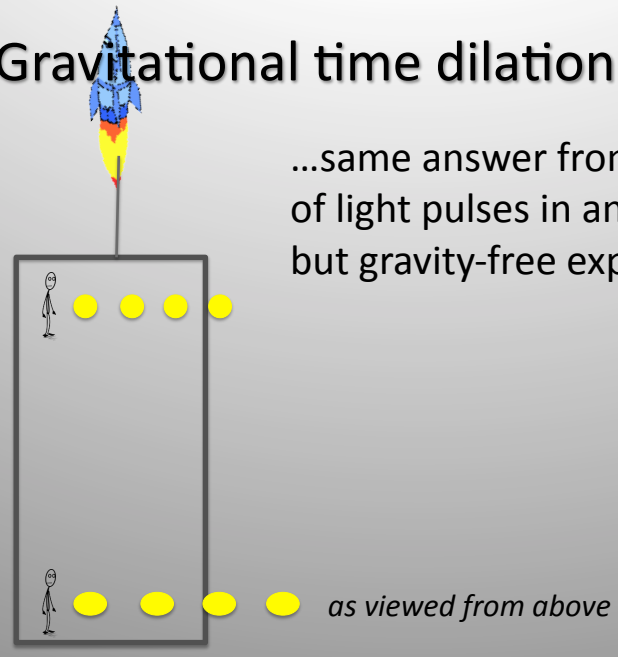


wavelength is longer but speed the same, c, so time ticks slower



measure time as light crests pass

Gravitational time dilation

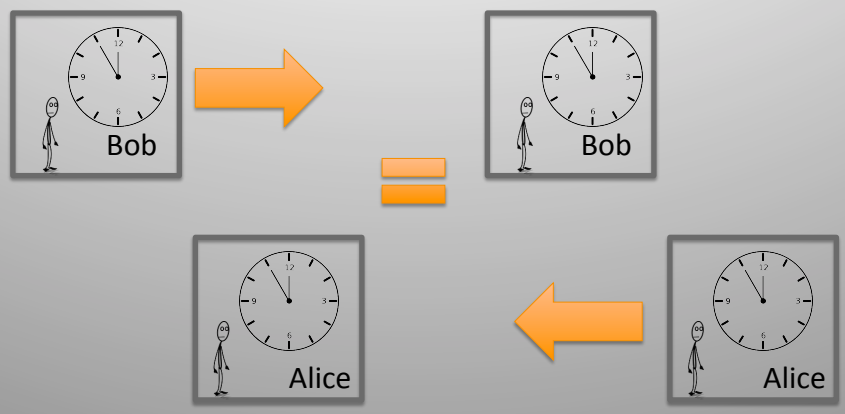


…same answer from thinking of light pulses in an accelerating but gravity-free experiment

as viewed from above

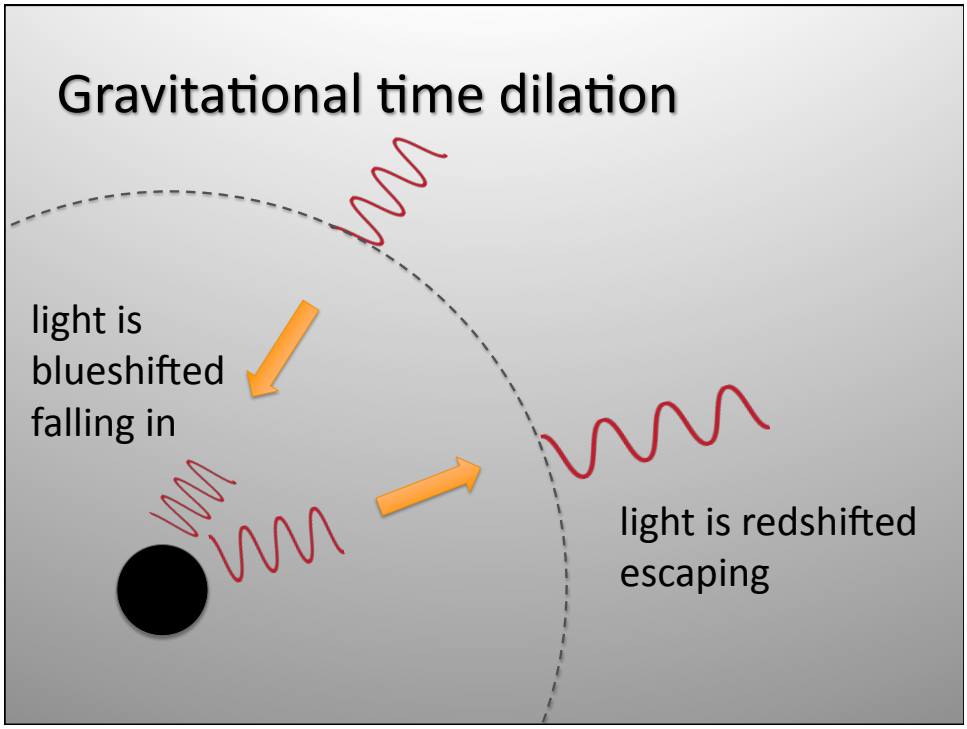
Special vs general relativistic time dilation

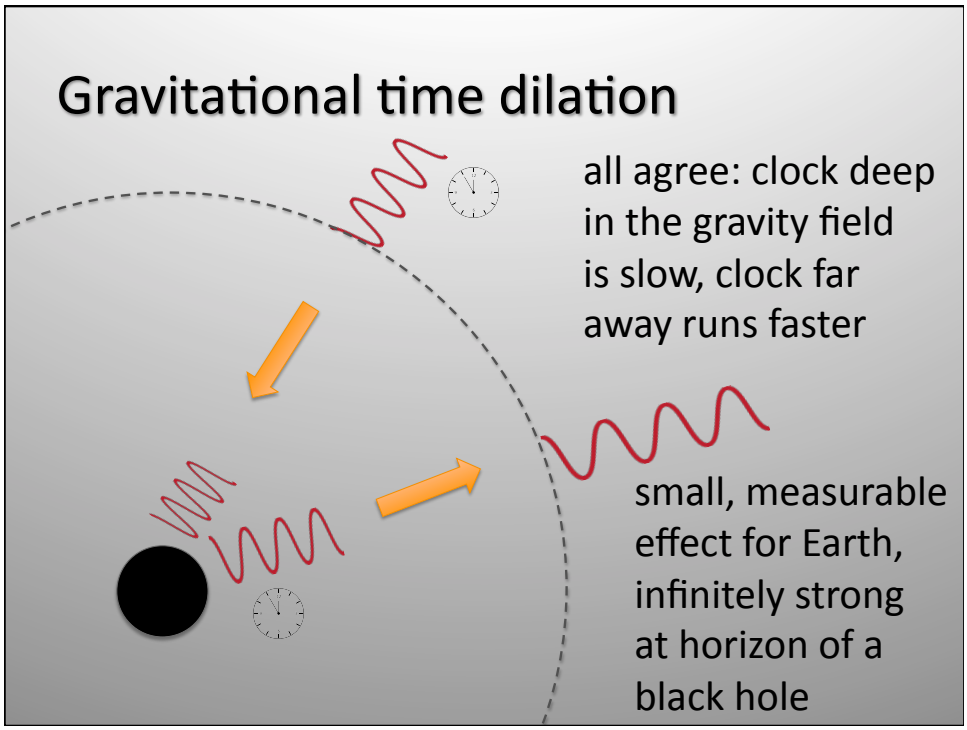
Bob: "Alice's clock is slow"



Alice: "Bob's clock is slow"

symmetric...


Gravitational time dilation
light is
blueshifted
falling in
light is redshifted
escaping


Gravitational time dilation
all agree: clock deep
in the gravity field
is slow, clock far
away runs faster
small, measurable
effect for Earth,
infinitely strong
at horizon of a
black hole