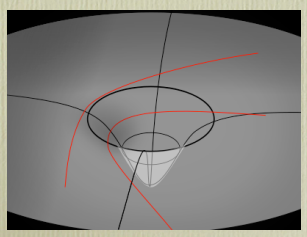
## Going Straight in a Bent Space: How Matter bends Time

Peter Watson



Cronholm144,


- Einstein's next question was
- Why do all masses fall at same rate?

All normal forces (e.g. electrical, friction, elastic...) don't produce same acceleration in all bodies.

$$F = m_I a$$

The inertial mass $m_I$) measures how hard things are to accelerate (2nd. law)

But the gravitational mass ($m_G$) measures gravitational force or weight

$$F = m_G g$$

but we know everything falls at the same rate (well, in a vacuum) so a = g only if the "inertial mass" ≅ "gravitational mass".

so

$$m_I \equiv m_G$$

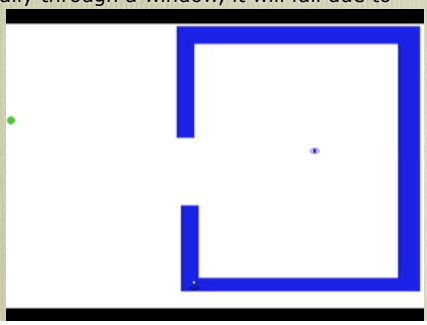
Are we really sure the m's are the same? This concerned Newton.

Can demonstrate this is true to 1 part in a trillion ($10^{12}$) (Eötvos experiment)

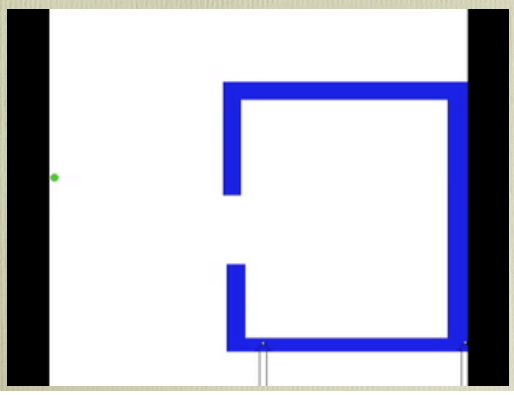
Special relativity said you cannot do an experiment to decide if you are moving.

General says that you cannot do an experiment to distinguish between a gravitational field and an acceleration (!!!!!!!!!!)

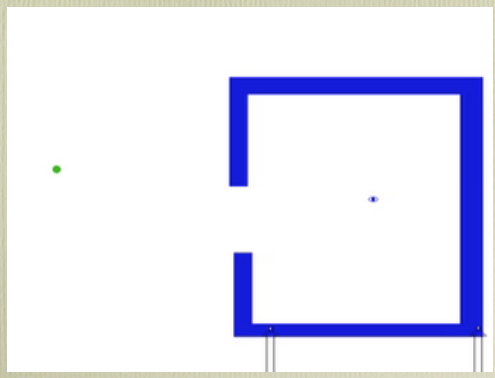
Suppose you are in a stationary elevator, and a bullet is shot horizontally through a window, it will fall due to gravity..



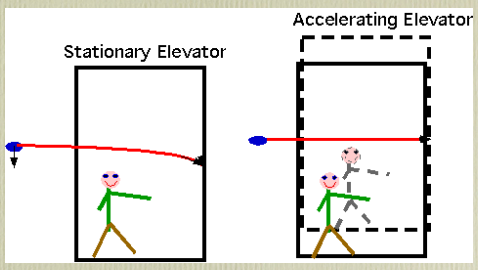
- Suppose you are in an accelerating elevator, and a bullet is shot horizontally, it will travel in a straight line (but the elevator will move up)



- so it will appear to fall inside the elevator.



## You cannot distinguish them

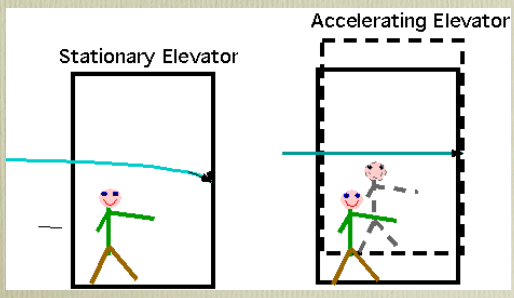



- This is known as the equivalence principle

Suppose you are in an accelerating elevator, and a beam of light is shot horizontally, it will appear to fall..

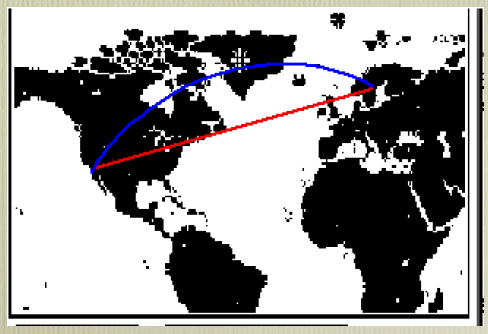
Suppose you are in a stationary elevator in a gravitational field, and a beam of light is shot horizontally, it will fall..

You cannot distinguish the two. Light gets affected by gravity?




**General relativity:**

- What is a straight line?
- A Socratic dialog.....



Which is the straight line?

- **A Body continues at rest or in a state of uniform motion unless acted on by a force.**

Uniform motion means in a straight line.

.....But we are in a curved space .....

Need a new word: **Geodesic**

A geodesic in Euclidean space ≡ straight line ≡ shortest path

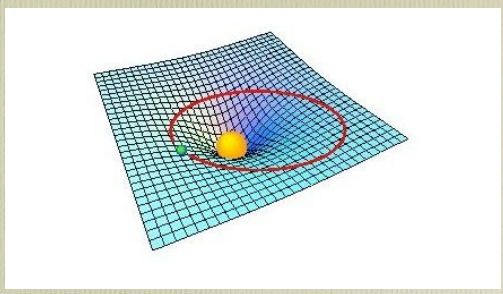
**Can either say:**

1. There is a force called gravity which acts on all energies (and hence attracts light)

2. There is no such thing as gravity, it's just that masses distort space-time in their neighbourhood

Either way, don't jump off tall buildings: you can be just as dead in a curved space!

Massive bodies follow timelike geodesics so planets are actually moving in "straight" lines in a curved space...



- "Lenses extend unwish through curving wherewhon till unwish returns on its unself" e.e.cummings

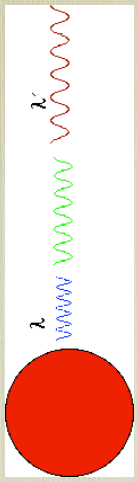
## Rhea Marshall-Denton

1. Why is time slower in space?
2. Why is this a good question?: Ever since I was little, I have been curious about astronauts and outer space. Space travel and the technological exploits involved amaze me. However, despite my interest, I know little about the topic. I thus think this is a good question because it's one I've always been curious about and because I would love to be able to explain it and impress others!
3. #3. I'm sure that a simple explanation can be formulated for the basic comprehension of lay people like me!

# Time and Gravity

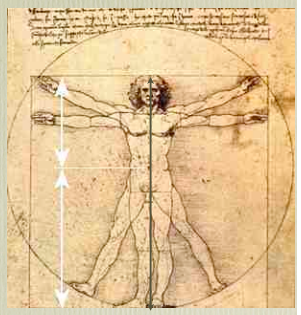
A ball thrown up near the earth's surface will lose energy.

- How about light?
- It must lose energy as well, (E=hf) frequency decreases
- so the light gets stretched out
- But light is a clock ....
- Implies that clocks run slow in gravitational fields



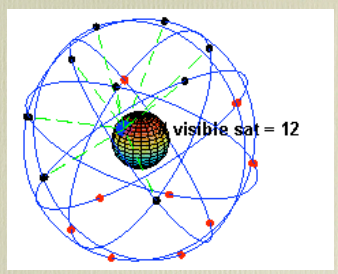

# Gravitational Red-shift

- This is another consequence of the equivalence principle:
- confirmed in numerous experiments over the last 40 years, starting with Pound-Rebka
- Means clocks at Earth's surface run slow by ~ .7 ns per second
- difference in time over height h is
- $\delta t/t = gh/c^2$
- so $10^{-16}$ secs/m
- Can just get this with next generation of atomic clocks!

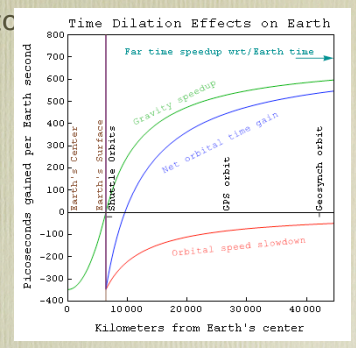


# GPS

- needs to be corrected for relativity
- 3 separate effects:
- Sagnac effect: earth rotates, so is not an inertial frame, so events are not simultaneous: can eliminate by using satellites to E and W




- Special relativity: satellite clock is moving relative to earth, so slows down ~ $10^{-10}$ or 7 μs/day
- GR: satellite clock is in free fall, so speeds up ~ $5x10^{-10}$ or 46 μs/day
- Would give an 11.7 km error after one day!

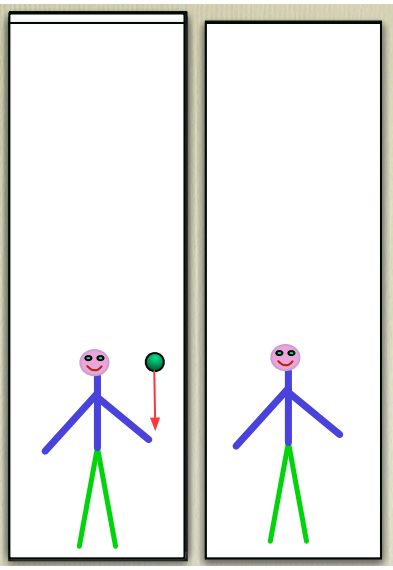



- But suppose gravity was **REALLY** strong.....

1. Cong Tran

1. How does is light affected by gravity?
2. Light seems to travel in straight paths from its source, but can light bend with enough gravity being exerted? Can light be trapped or slowed down due to high gravity?
3. - 3) The textbook tells of how light cannot escape a black hole because of its warping of spacetime, so I guess we could touch upon it in this class.

- A particle will escape from the earth if it has positive energy
- At the earth's surface, "escape velocity" is 11 km/s



- A particle will escape from the earth if it has positive energy

At the earth's surface, v~ 11 km/s

However we can interpret this differently: what radius would the earth have for a given escape velocity?

If the escape velocity is the speed of light c, nothing can escape

$$R = \frac{2GM}{c^2}$$

# Black Holes

$$R = \frac{2GM}{c^2}$$

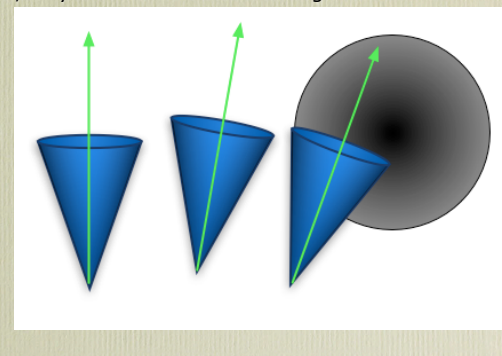
- This is the Schwarzchild radius (loosely the black-hole radius) for any mass.
- What is this for the earth?
- ~ 9 mm
- Statutory Warning:This is a fudge: you cannot treat light as a massive particle, nor can you handle a very strong gravitational field as if it were a weak one.....
  (there are actually two factors of 2 error which cancel out.....weren't we lucky!)

- If the earth was 9 mm in radius, it would be a Black hole
- This is the Schw hole radius

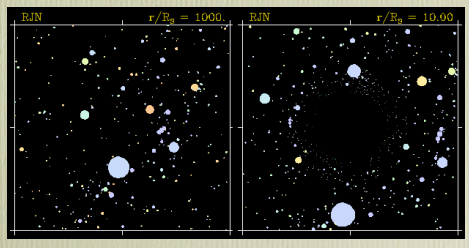
## What happens to time near a black hole

- Gravity modifies the light cone
- close to a black hole, all your futures include falling into it!

A consequence: time stops at the edge of a black-hole for an external observer.

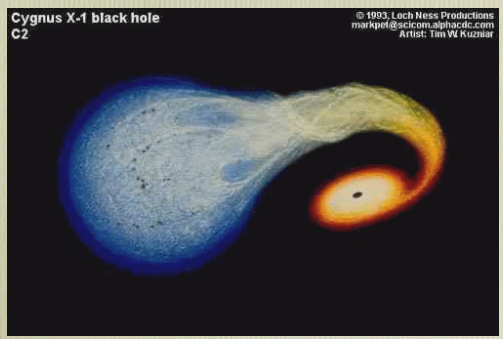


- One way to see a black hole: it's black!
- If we are really lucky....(or unlucky) as a gap in the sky




Too Close to a Black Hole
Credit & Copyright: Robert Nemiroff (MTU)<

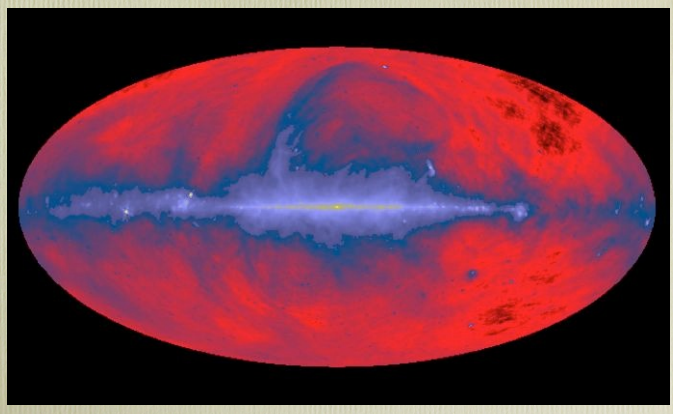
- Stuff falling in will become very hot and produce X-rays
- Cygnus X-1: visible star ~20 mass of sun
- Invisible object M~9$M_o$
- Power output in X-rays is 10,000 x total power output by sun!



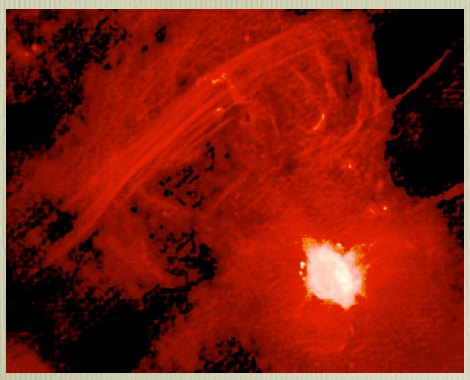
# The centre of the Milky Way

- This is the Milky way, showing the whole sky

- If we look at it with radio waves, see very intense source at centre



- which gets brighter as we zoom in



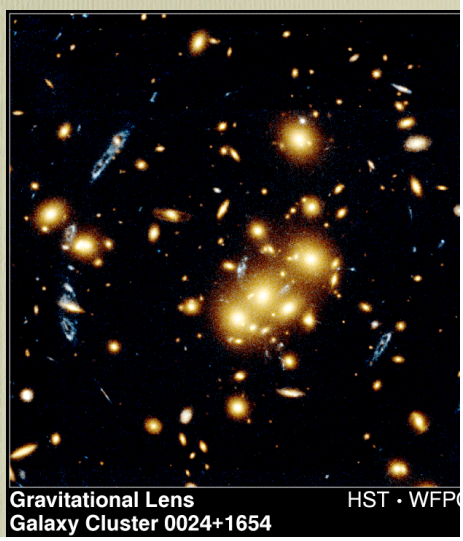
- The stars there are swirling round something 10 million times as heavy as the sun

And light does get bent by a massive object

This is a very large cluster of galaxies.

Acts as a very large (and rather bad!) lens.

It produces several images of a much more distant galaxy

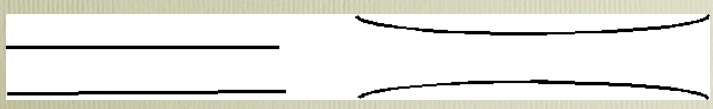



## Geometry of Curved spaces

Note we have carefully avoided saying what we mean by a curved space

- Bending of light by gravity allows two (or more) geodesics: i.e. many time-lines connecting same points
- 2-D curved surface of the Earth is embedded in a 3-D space. Hence If a massive body curves space, it almost implies extra dimensions.

Can carry out tests to decide if we live in a "normal" 3-D space (Euclidean) e.g. parallel lines may be impossible (they get further apart or closer together!)

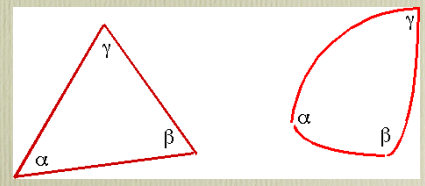


## Geometry of Curved spaces

- angles of a triangle add up to $180^0$

$\alpha + \beta + \gamma = 180$

These are experiments that we can almost do. (Gauss tried the 2nd!).




## Nandan Sharma

1. The Question: Is time travel possible (for human beings)?
2. Why it's a good question: This question has peaked my curiosity for many years. If we do develop some sort of H.G. Wells' time machine...do we create another timeline? Isn't it really the 'present' for us even though we're going 'back into the past'? Therefore, are we really 'time traveling' since we are still in the present? Furthermore, to answer this question, I think that we would need to explore the basic concepts stated in Einstein's theory of relativity (time, length relativity, etc.) The time travel question can also lead us to explore the idea of worm holes.

Text

## Michelle Haney

1. Is it possible for a molecule or a person to go back in time? Is It possible for a molecule or person to go to the future?
2. This question is a very interesting question and a fun thing to think about. It would be cool to know if and how something like this could happen in real life after seeing it in movies and hearing about ideas of time travel from scientists like Stephen Hawking.
3. This question is probably a 3 because the question can be answered to some extent at least in this class

FW

## Time travel is

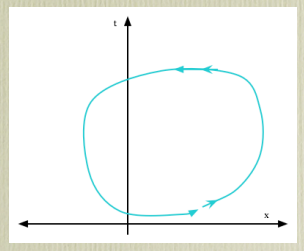
1. impossible: forbidden by Einstein's relativity
2. impossible: forbidden by increase of entropy
3. impossible: forbidden by requirement that universe must have positive energy everywhere.
4. impossible: time must flow and we have no control over it
5. impossible: forbidden by logical paradoxes
6. impossible: forbidden by cosmic censorship (Steven Hawking)

## Time travel is

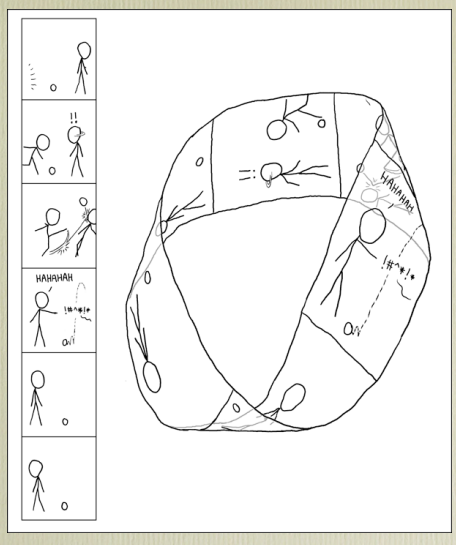
1. possible in theory, but in practice impossible (e.g. costs too much energy)
2. possible: paradoxes avoided by many-worlds model
3. possible: past can be seen as movie, but not altered
4. possible: free-will is an illusion, so it is irrelevant!
5. irrelevant: time is an illusion

## So can we build a time-machine?

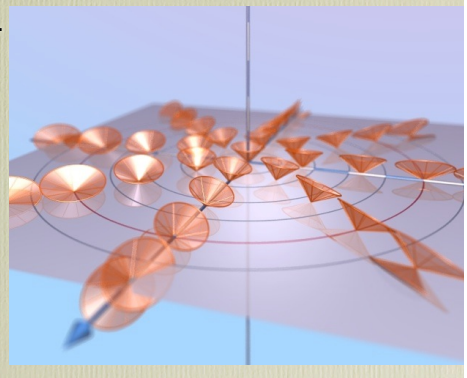
- Now we know the question to ask;
- Can we arrange for world-lines to be closed?



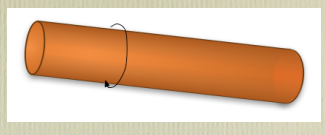
- xkcd.com



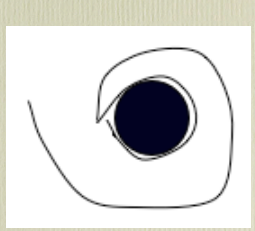

- Godel invented a model universe consistent with GR with closed time-lines. Not like ours:
- it has a centre (ours has no centre )
- it is not homogenous (ours is)
- It rotates (ours doesn't).



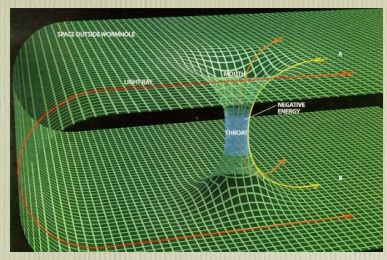
- Tipler showed that can construct time machine from infinite rotating massive cylinder



Light cone gets bent round cylinder, so starting point lies inside light cone



- However once we allow space to be bent, we can construct wormholes!

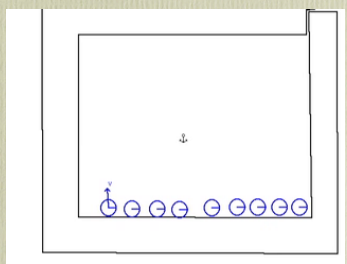



- Allow instantaneous communication across space
- (And innumerable stupid TV shows)
- But they requires negative energy: now known (see Ford and Roman Sci Am. article) that negative energy allows time-travel, so probably can't construct in practice.

- IF we could time-travel, we run into the paradoxes
- The "Grandfather Paradox"; if I invent a time machine, I can time-travel to the past, murder my grandfather before my father is conceived, so I am not born so I cannot invent the time machine so I cannot .....
- The "Where are they" paradox; if time travel is possible, why aren't we over-run by time tourists?

# Entropy

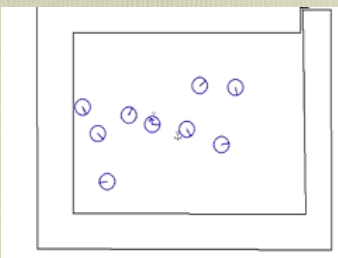
- Essentially the relative probability of finding a particular arrangement by chance. If arrangement is improbable, we can always get work out of it.



## Time and Entropy..

- how is tomorrow different from yesterday

Or better, how do you know if a movie film is being run backwards?



The "arrow of time" is defined via an increase in entropy.

e.g "Time's Arrow" Martin Amis

## Increase of Entropy?

- Unsatisfactory for forbidding time travel since it doesn't forbid travel into the future
- (let's skip tomorrow and move on to Saturday!)
- Also (refrigerator example) we can decrease entropy localy as long as it increases overall

## Maybe time simply "flows"

- You could not step twice into the same river; for other waters are ever flowing on to you. Heraclitus

River analogy is not uncommon: e.g

Time is a sort of river of passing events, and strong is its current; no sooner is a thing brought to sight than it is swept by and another takes its place, and this too will be swept away. Marcus Aurelius

e. g. Books:

"Randall and the River of Time" (C. S. Forester)

"Riverworld" (Philip Jose Farmer)

But in reality the analogy of time flowing is not very useful:

flow of something is "rate of change"

e.g. flow of a river is amount of water that passes you in a given time.

If time is to flow, it is the amount of time that passes you in a given time .... at the rate of 1 second per second?

Seems to require "meta-time"

Does "meta-time" flow?

## Unknown physical principle?

- Not an argument

## Let's try to summarize the mess we are in

- We have lost the idea of universal time and with it
  - The concept of simultaneity
  - The concept of a universal "now"
  - The idea that Euclid was right!

## Let's try to summarise the mess we are in

- We have gained
  - The linking of time and space into space-time
  - Black holes
  - Curved Spaces
  - Multiple time-lines connecting events
  - Time-travel ??????????????????????
  - The concept of space without time

## Why is the speed of light so special?

- It isn't: it's just the maximum speed that anything can move at.
- Anything massless always moves at c (photons, neutrinos almost)
- Anything massive (protons, electrons, spaceships) can approach c but not get there
- It is really a number that relates distance to time

## Finally

- A somewhat subtle point
- Originally we had "universal time"
- Not crazy to think that time can change, but then it should be tied to measurement (e.g. clock, photon, biology .....)
- It is now connected to a "frame of reference", disconnected from any measurement

## So can we time-travel?

- Probably not, but we don't know