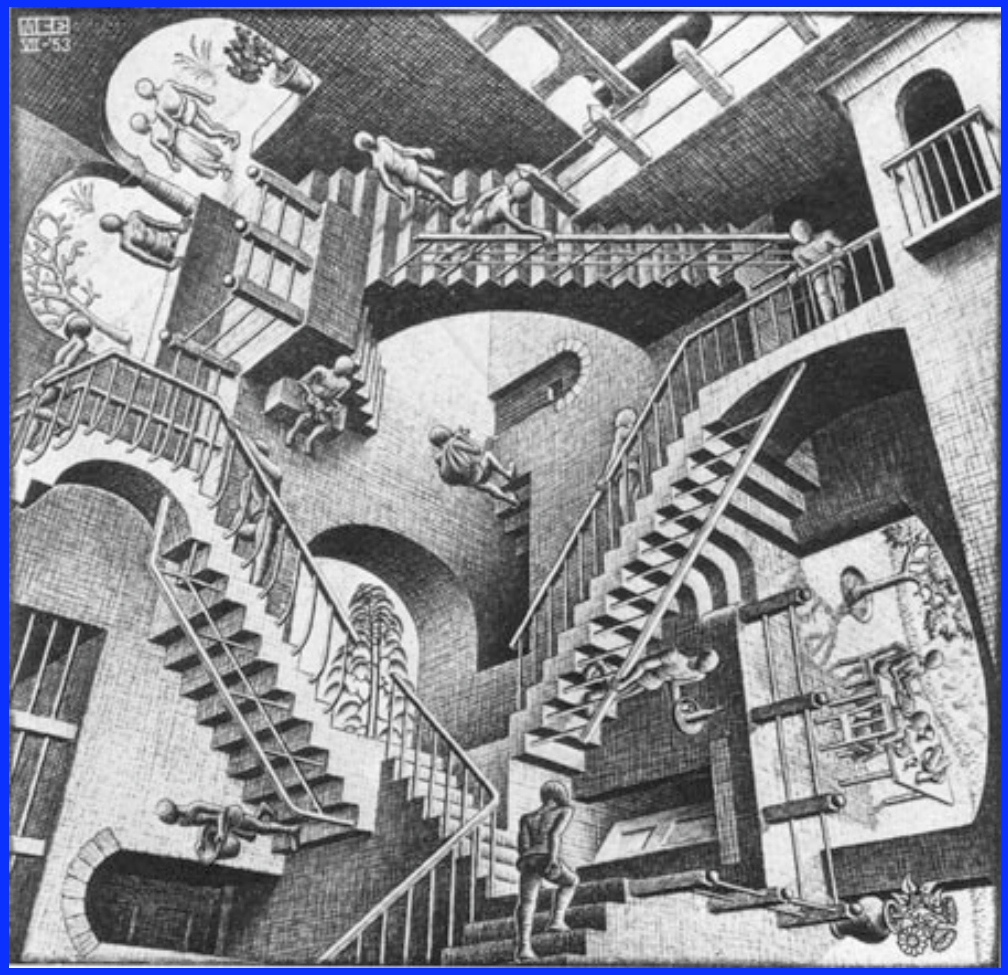
# ASTR 380
# Relativity and Time Travel



M. C. Escher

# Outline

- Special relativity
- The twin paradox
- General relativity
- Time travel and the grandfather paradox
- Faster than the speed of light?
- Wormholes and warp drive

Idea: what could an arbitrarily advanced alien species do?

# The Equivalence Principle

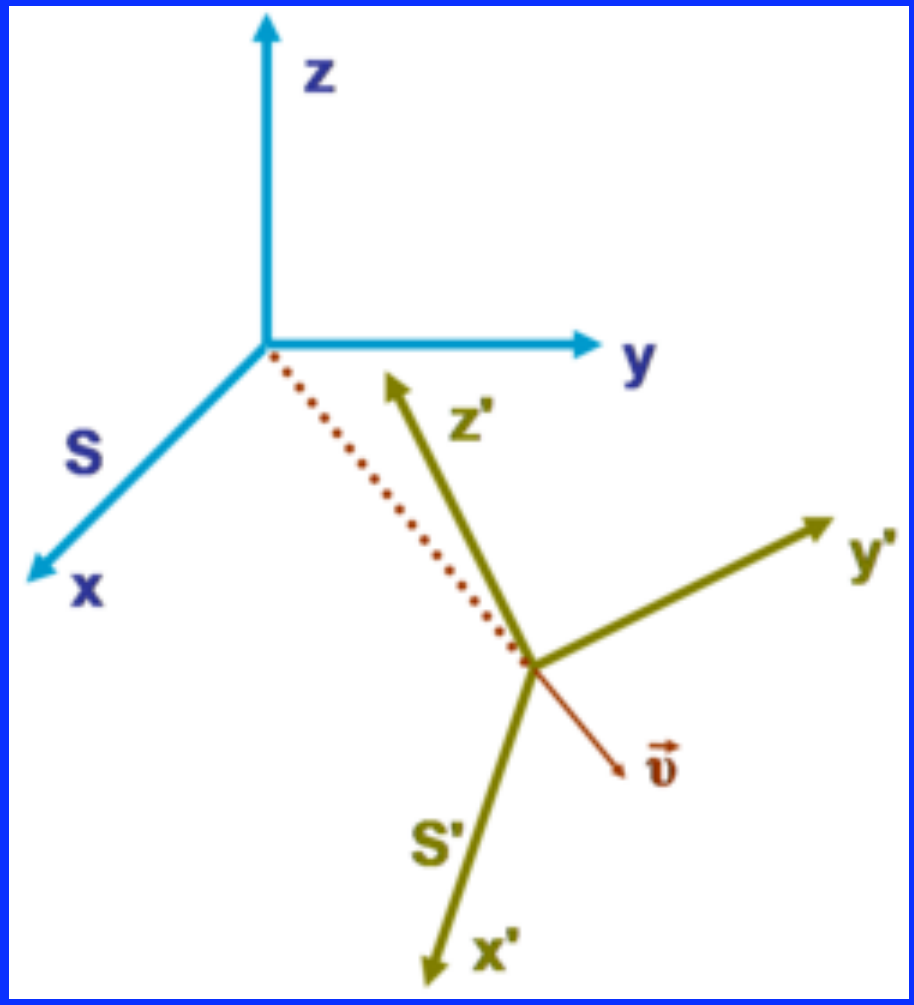
Throughout this lecture, please keep in mind:

No matter how something moves or how strong a gravitational field it is in, all local effects/times/whatever appear to operate normally to it.

Therefore, I can't increase my lifetime as I see it, although others may see me living longer than normal in some situations.

# What Do We Mean By Relativity?

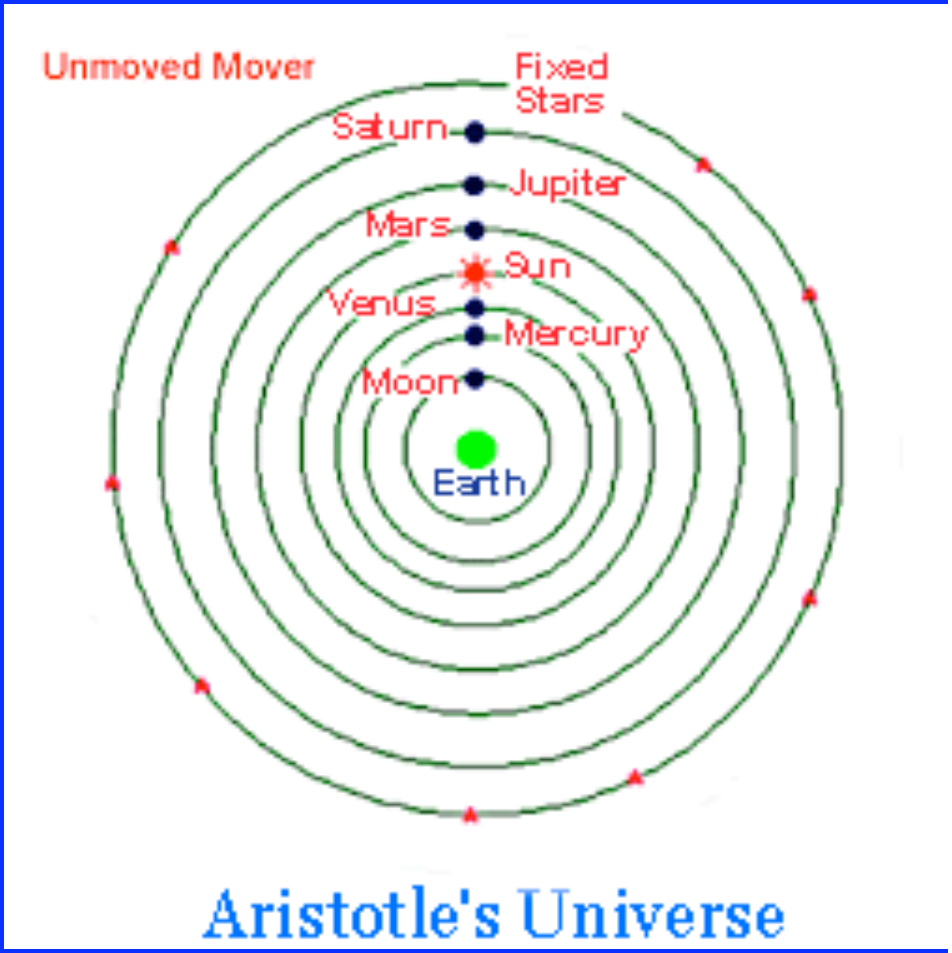
- Suppose you make measurements of some event or process
- Suppose I am in a different *reference frame* (e.g., moving differently)
- What do I measure?




wikipedia/commons/thumb/6/6a/Inertial_frames.PNG

# Ancients: Absolute Motion

- Argument against moving Earth
- We'd feel it, right?
- Motion in air clearly different from non-motion, so Earth can't rotate or move




http://www.abu.nb.ca/Courses/GrPhil/aristotle_universe.gif

# Galilean Relativity

- Galileo: only relative motion matters
- In uniformly moving ship, all experiments come out same way as at rest on ground
- Earth *can* move!

http://www.mariner.org/exploration/mm_images/ND2068C67_12ChineseJunk-2_large.jpg

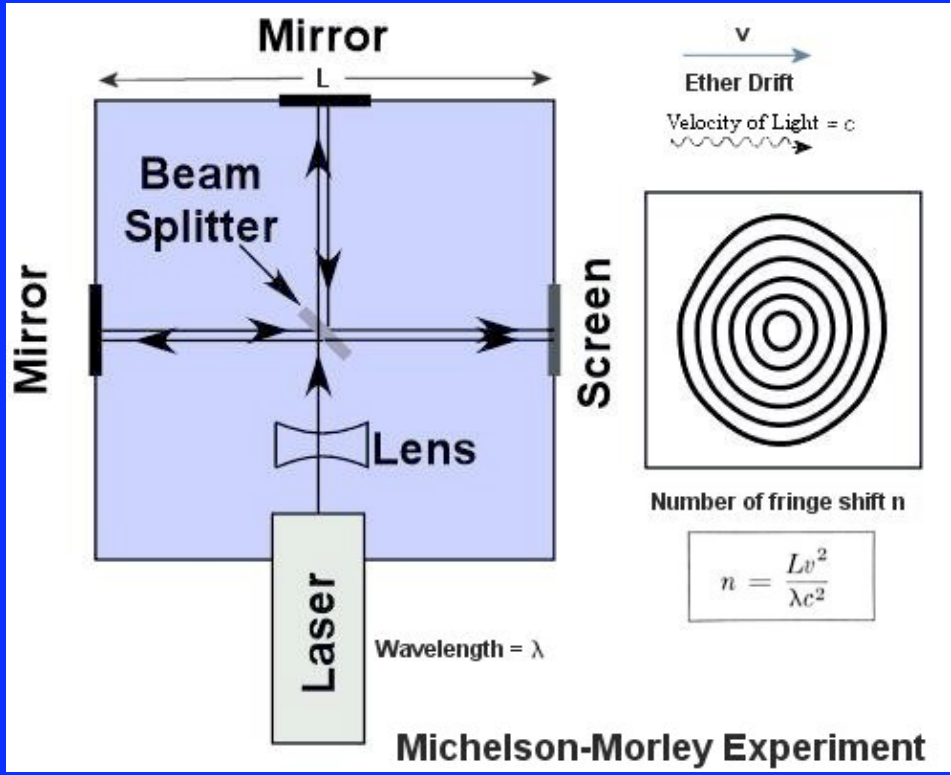
# Velocity Addition

- Common sense
- Moving on train at speed $v_1$
- Throw ball in same direction at speed $v_2$
- On ground, would see $v_1+v_2$
- Obvious, right?

http://www.camp5museum.org/media/photos1/train1.jpg

# Michelson-Morley Experiment

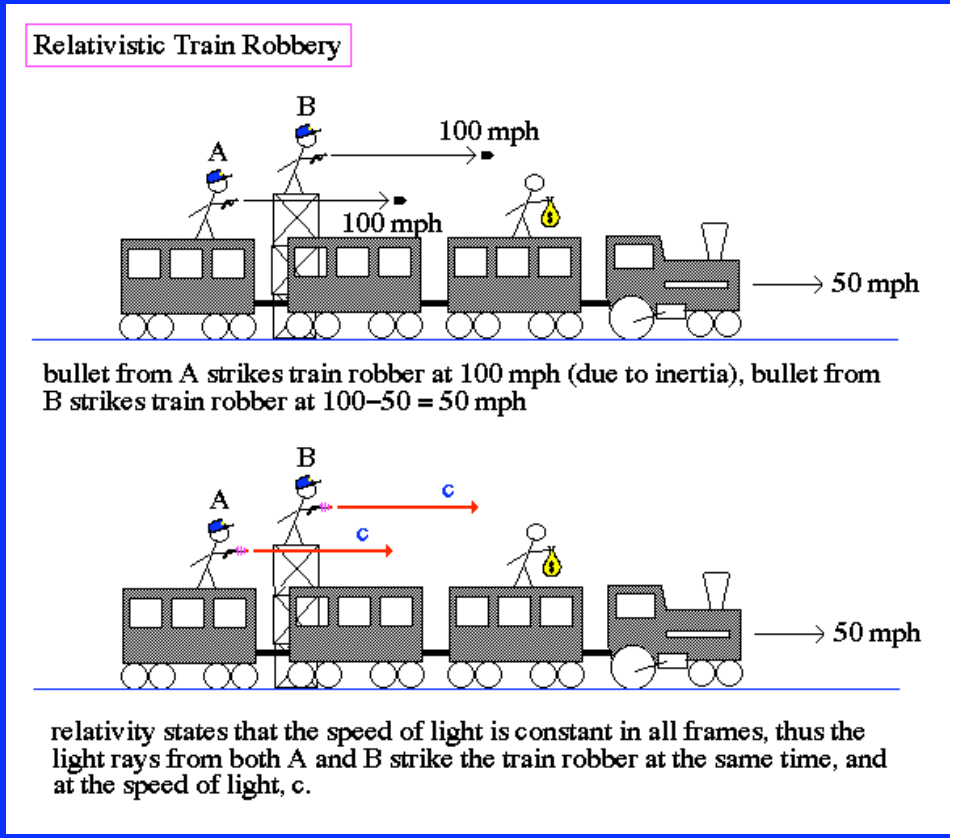
- Should be that speed of light also seems different to different observers
- But experiment shows *everyone* measures same speed!
- What gives?




http://universe-review.ca/I15-57-ether.jpg

# Constancy of Speed of Light

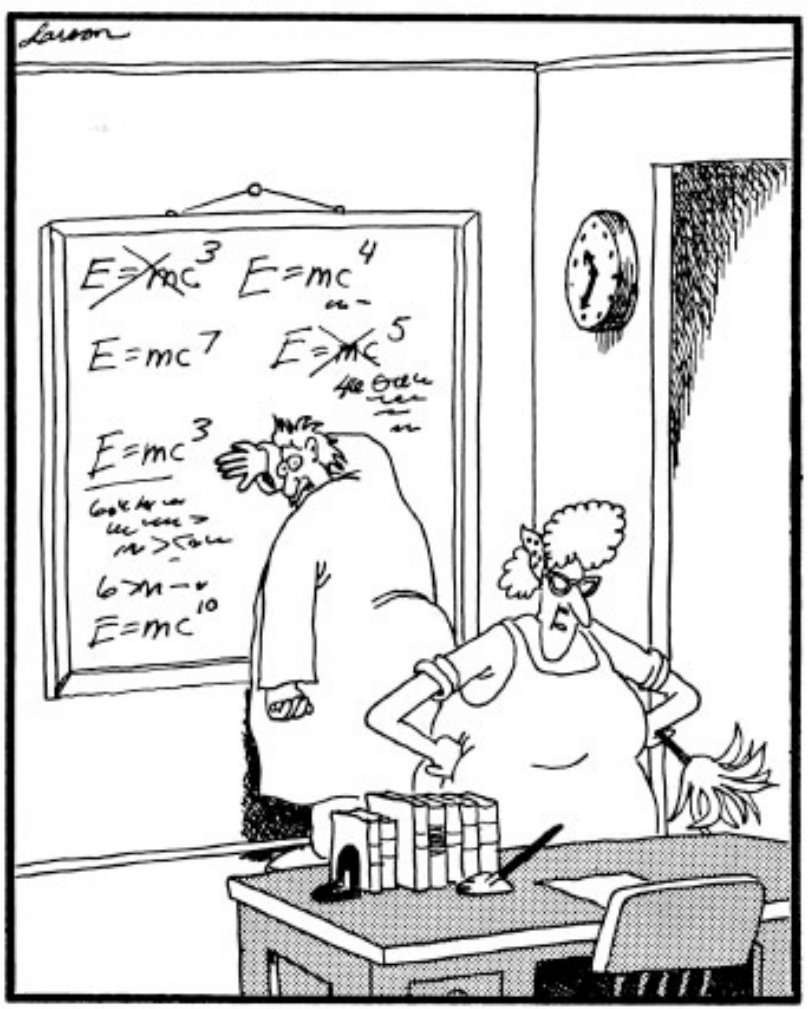
- Einstein elevated this to a fundamental principle
- Previously unnoticed because we move slowly compared to light
- c~300,000 km/s




http://abyss.uoregon.edu/~js/images/train_robbery.gif

# Special Relativity

- Leads to special relativity
- Effects: moving objects seem more massive and compressed in direction of motion
- Factor: $\gamma = 1/(1-v^2/c^2)^{1/2}$
- Since motion is relative, both see the other this way!
- Verified by experiments

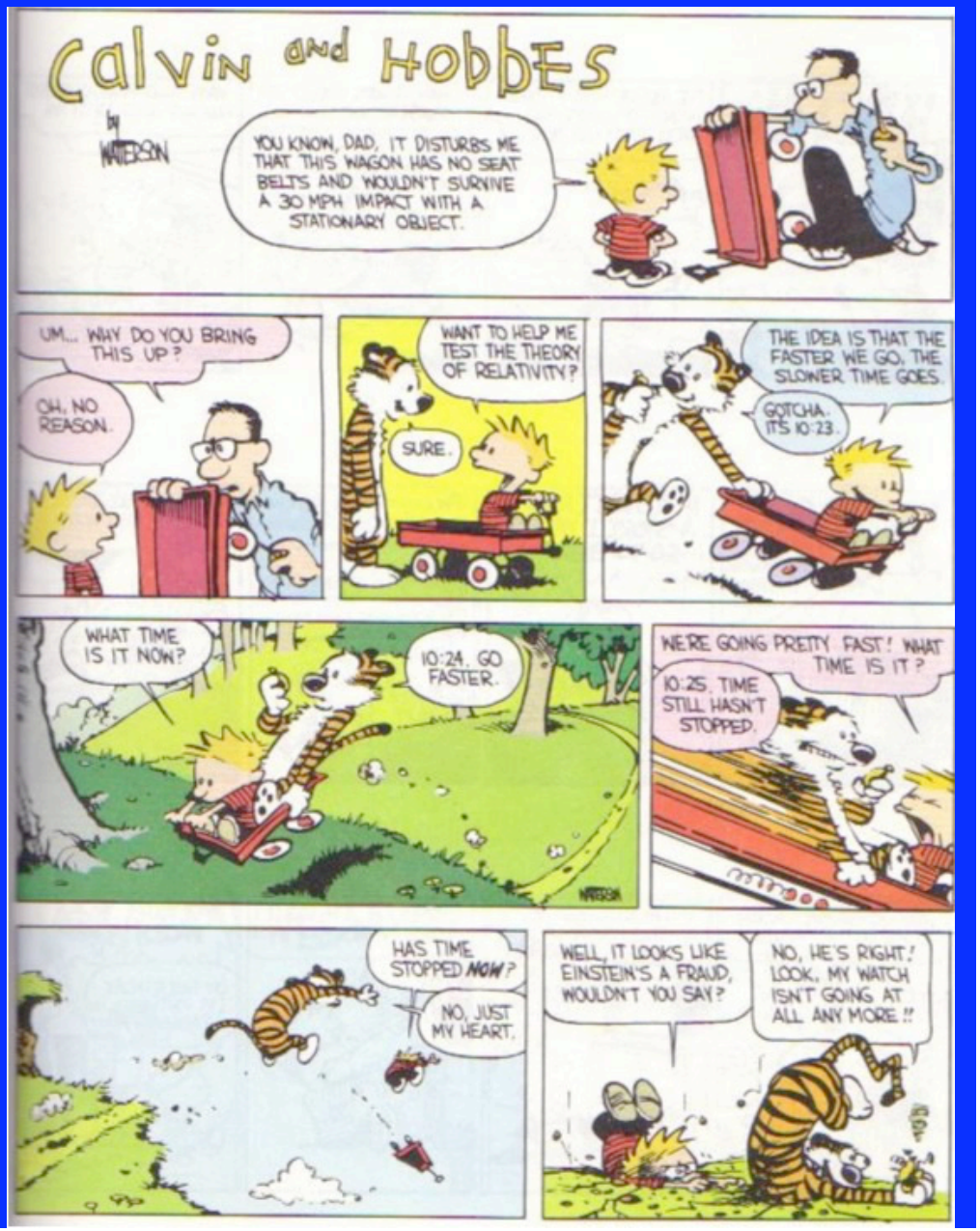



"*Now* that desk looks better. Everything's squared away, yessir, squaaaaaared away."

From 'Valley of the Far Side' by Gary Larson
(Andrews and McMeel, Kansas City and New York)
ISBN 0-8362-2067-6

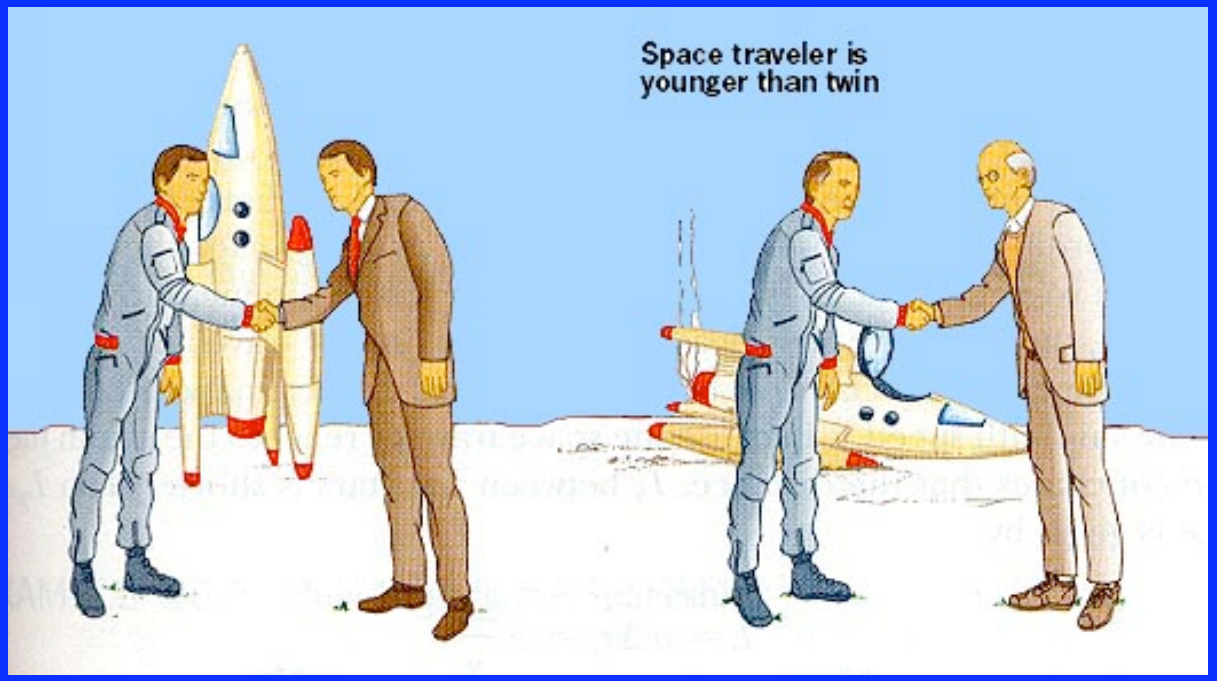
# Time Dilation

- Moving clocks also seem slow, by same factor $\gamma$
- Therefore, if you travel close to the speed of light, I see you aging more slowly



# The Twin Paradox

- Identical twins
- One goes on v~c journey, appears to age less
- When they meet, traveler is younger
- Can explore galaxy in human lifetime!



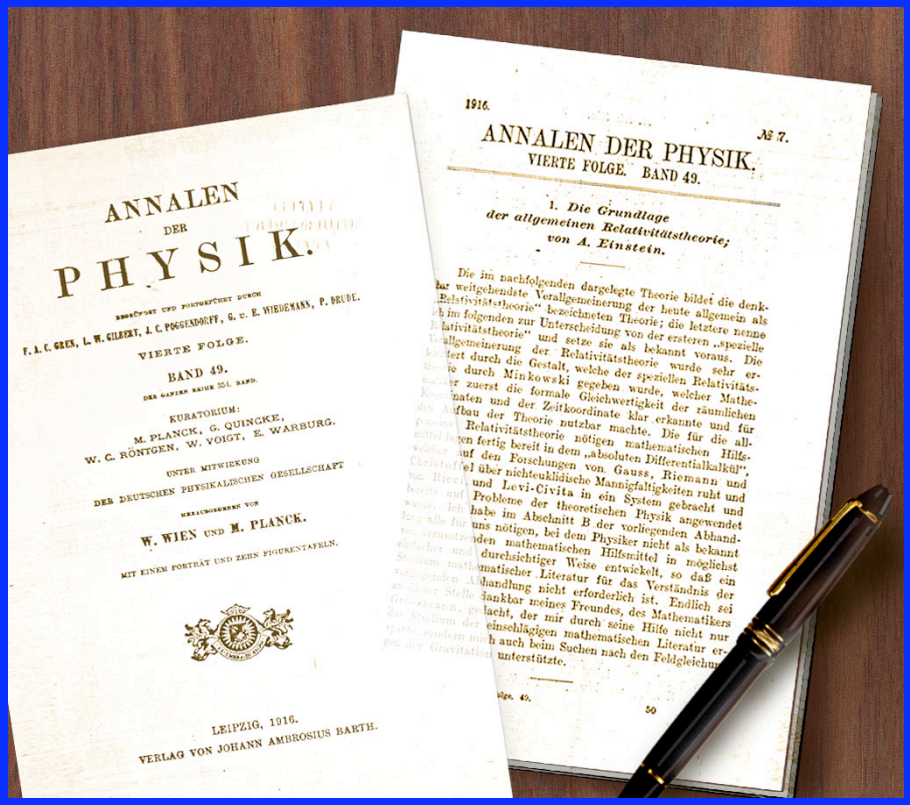

http://sol.sci.uop.edu/~jfalward/relativity/twinparadox.jpg

# Interstellar Travel, Revisited

- Therefore, consider a super-advanced species
- Since $\gamma=1/(1-v^2/c^2)^{1/2}$ can become as large as desired for v close enough to c, time dilation factor can be as big as wanted
- Want to go a billion years into future? Ramp up $\gamma$, wait 10 years of your time!

# General Relativity

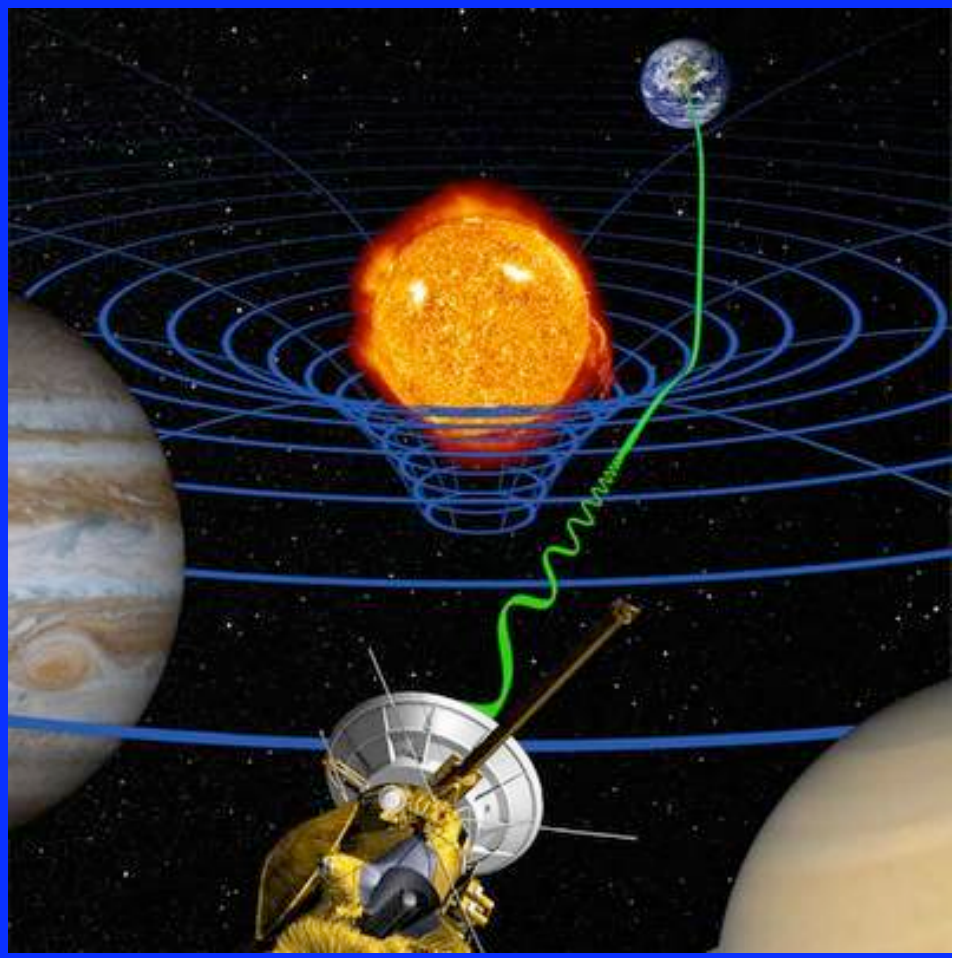
- Einstein wasn't done
- Special theory only deals with uniform motion
- What about accelerations?
- General theory is our best theory of gravity




http://io.uwinnipeg.ca/~vincent/4500.6-001/Cosmology/Gen-relativity_einstein_article1916.jpg

# Warping Spacetime

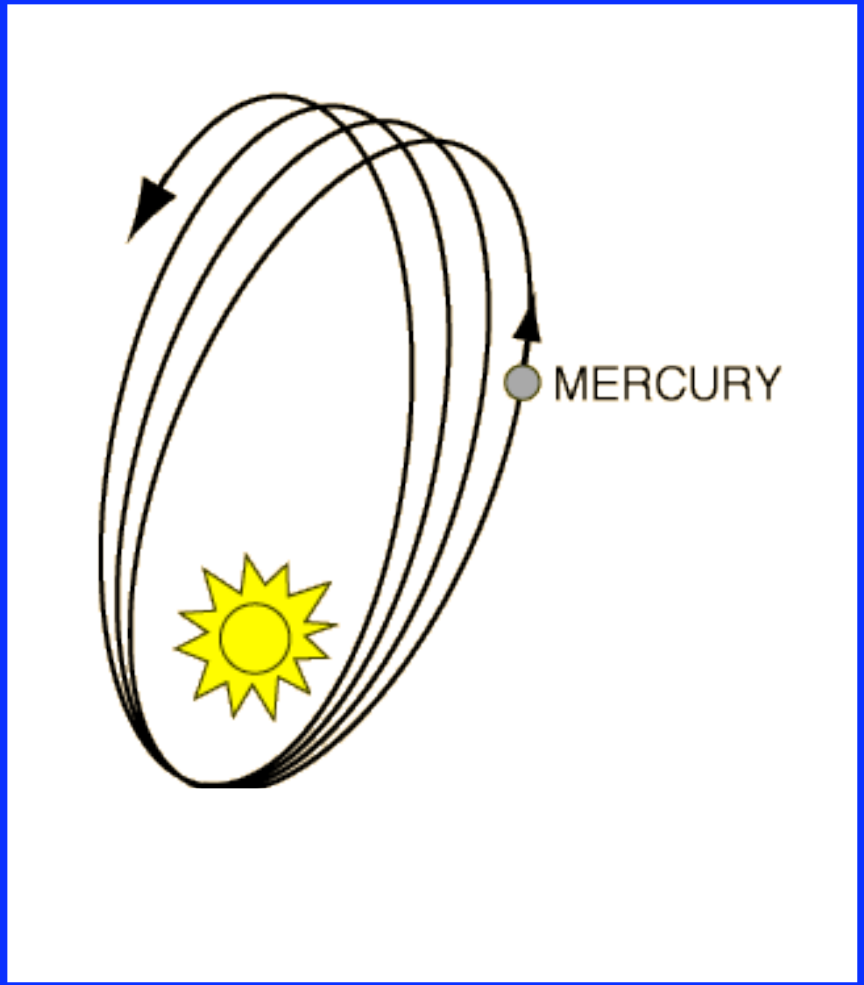
- Basic idea: gravity warps spacetime
- Changes distances but also times measured from different places



Cassini mission to Saturn

# Effect: Orbital Precession

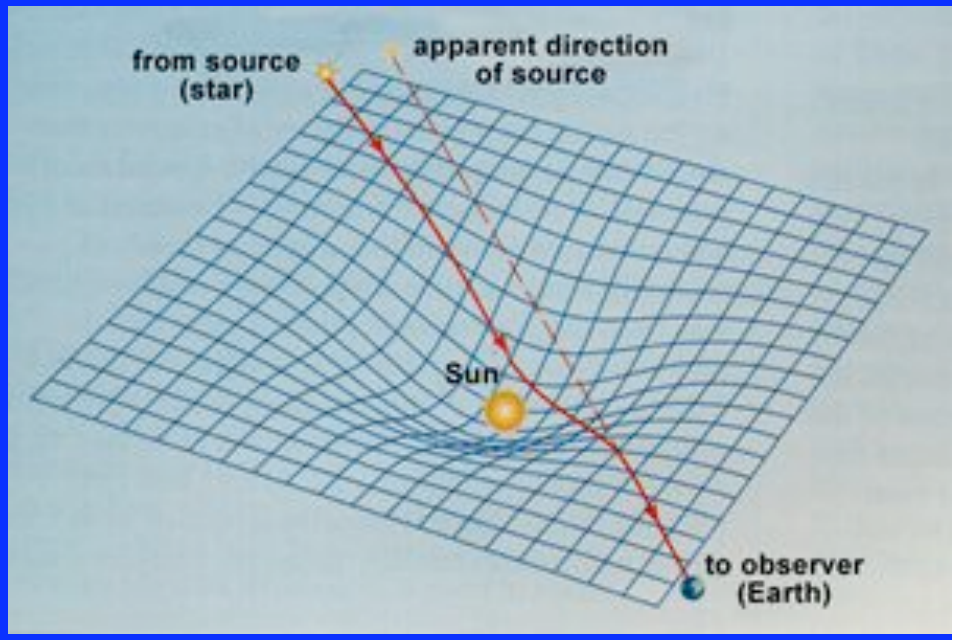
- Orbits don't quite close
- Tiny amount of precession, but observed in Mercury
- Explained well by Einstein's theory




http://hyperphysics.phy-astr.gsu.edu/hbase/Relativ/imgrel/merc.gif

# Effect: Light Deflection

- Warping of spacetime changes path of light
- Only 1/2000 of degree near limb of Sun
- Near black hole, can circle many times around



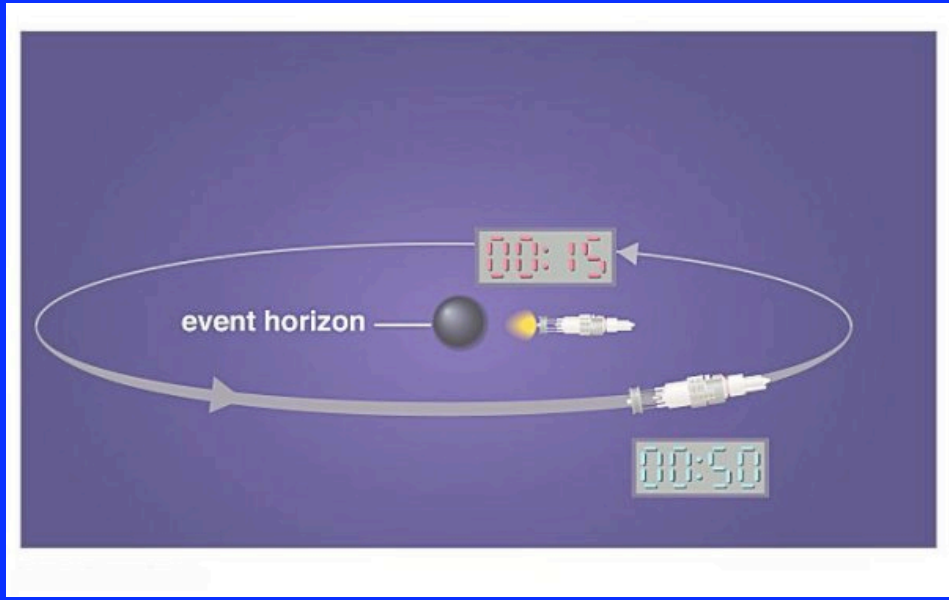

http://www.open2.net/science/finalfrontier/space_time/images/map.jpg

# Einstein the Superstar

- Light deflection made Einstein into a global celebrity
- In 1919, after World War I, Sir Arthur Stanley Eddington confirmed prediction
- English astronomer confirms German physicist's overthrow of Newton, an English physicist

# Time Dilation

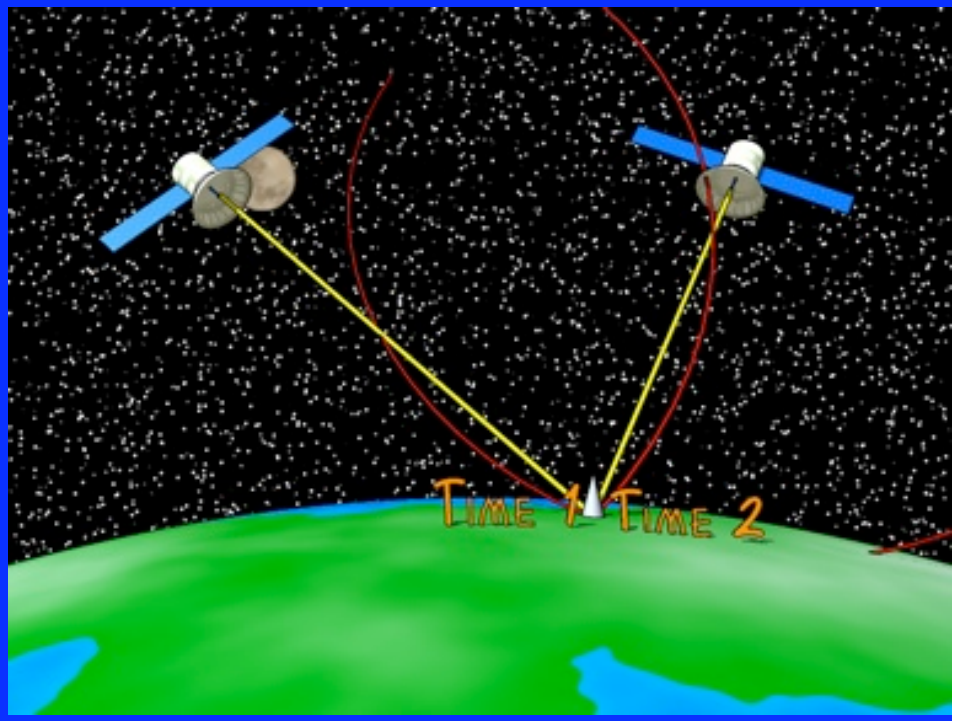
- Most important effect for our purposes!
- Clock deep in gravitational well seems to run slowly
- It would see ours running fast
- Effects subtle except close to a black hole




http://universe-review.ca/I15-61-dilation.jpg

# Practical Effects of GR?

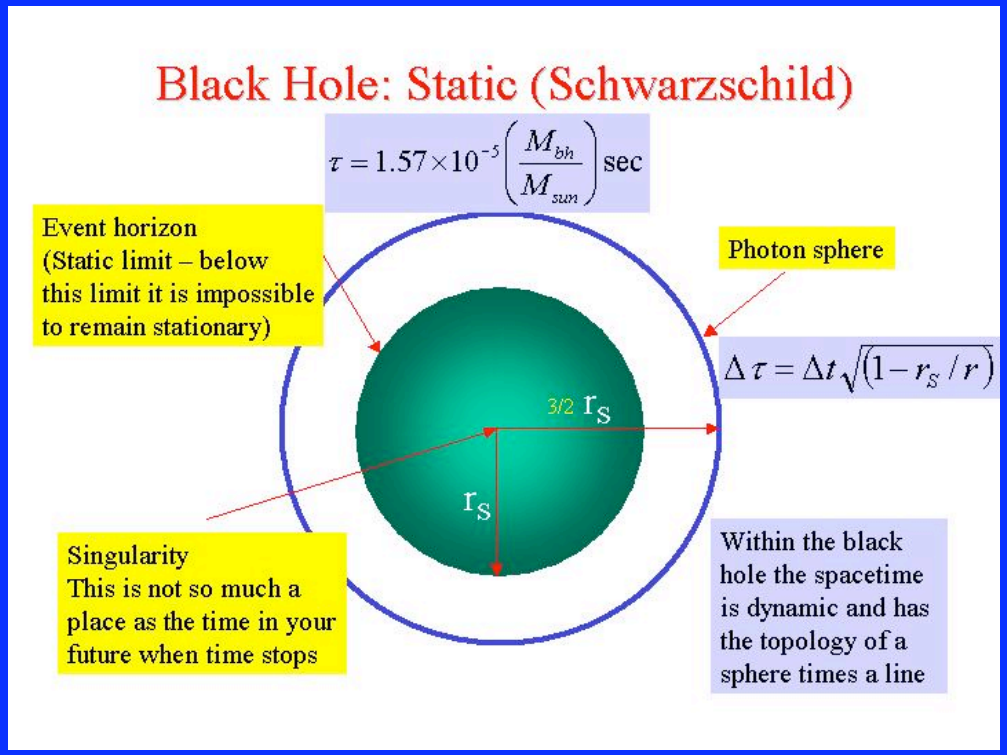
- Global positioning system
- Must account for GR time dilation effect
- Otherwise, would drift rapidly out of alignment
- You never know the benefits of research!



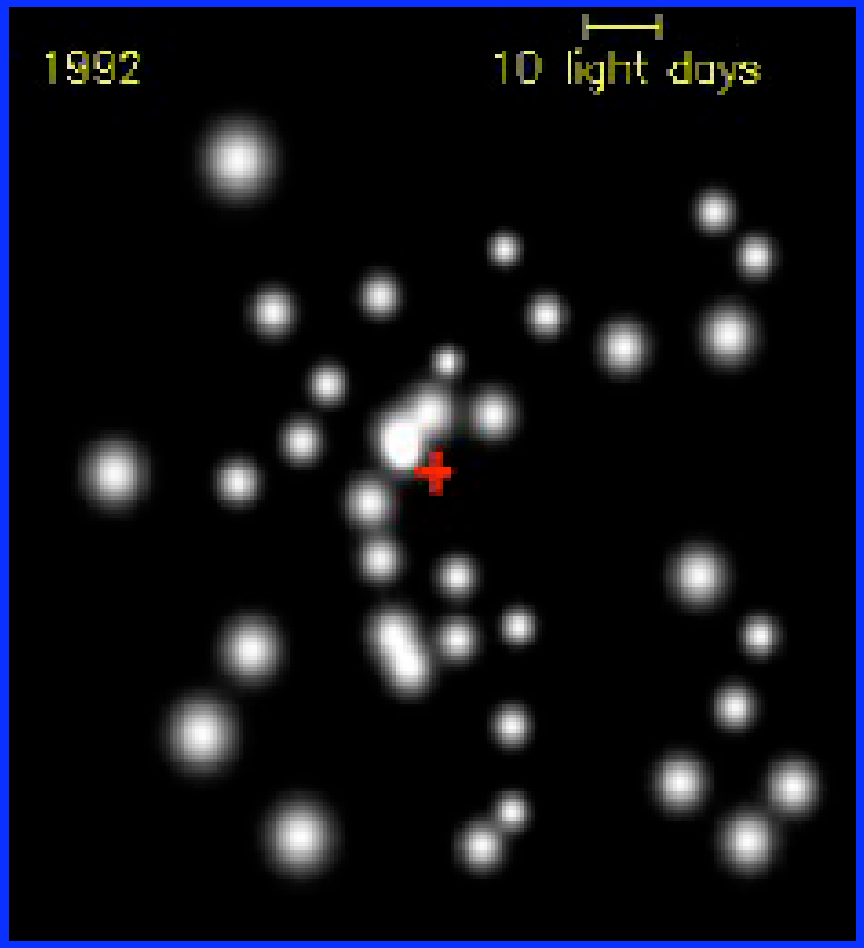

http://www.whylearnthat.co.uk/GPSPic.jpg

# Black Holes

- John Michell, 1783: would most massive things be dark?
- Modern view based on general relativity
- Event horizon: point of no return
- Near BH, strong distortions of spacetime



# Do BH exist? Yes!
# Stars at the Galactic Center




Reinhard Genzel et al.

# Black Holes as Powerhouses

- Matter spiraling into black hole is hot
- Emits lots of energy
- Powers brightest things in universe (quasars)
- Could be used by aliens as power source!

Image credit: NASA

# Implications for Aliens

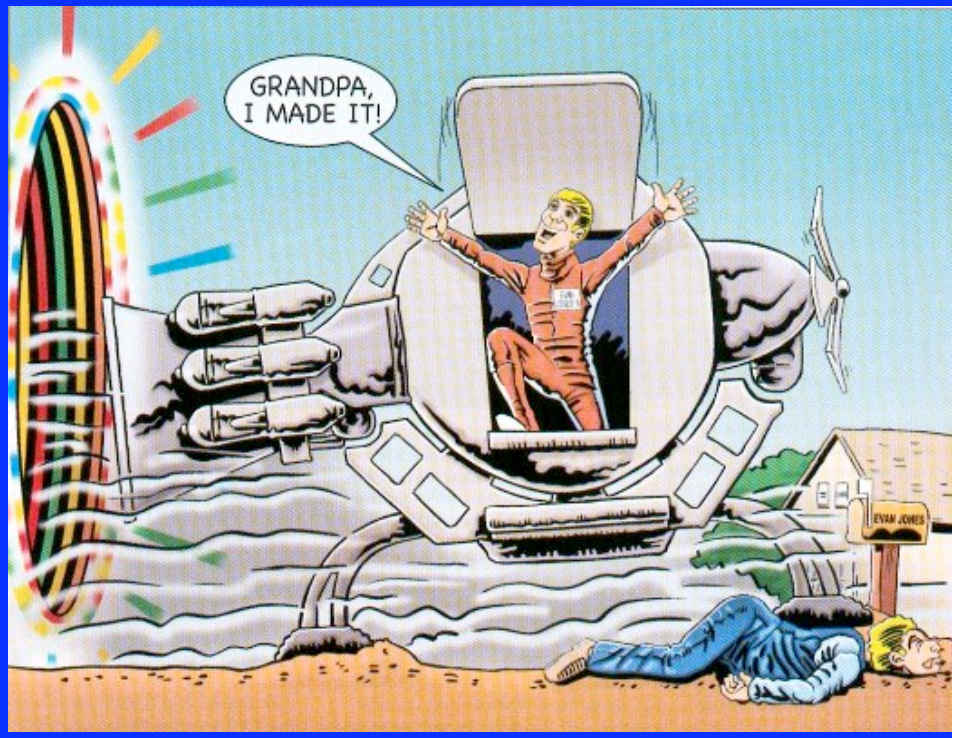
- Suppose an alien wanted to see the future but not travel
- If they could withstand gravity, and had unlimited rockets, could hover just outside a black hole
- In short time for them, long time would pass for universe

# What About the Past?

- We have seen two ways (in principle!) to advance rapidly in time
- But could we go backwards?
- What are the implications of time travel?

# The Grandfather Paradox

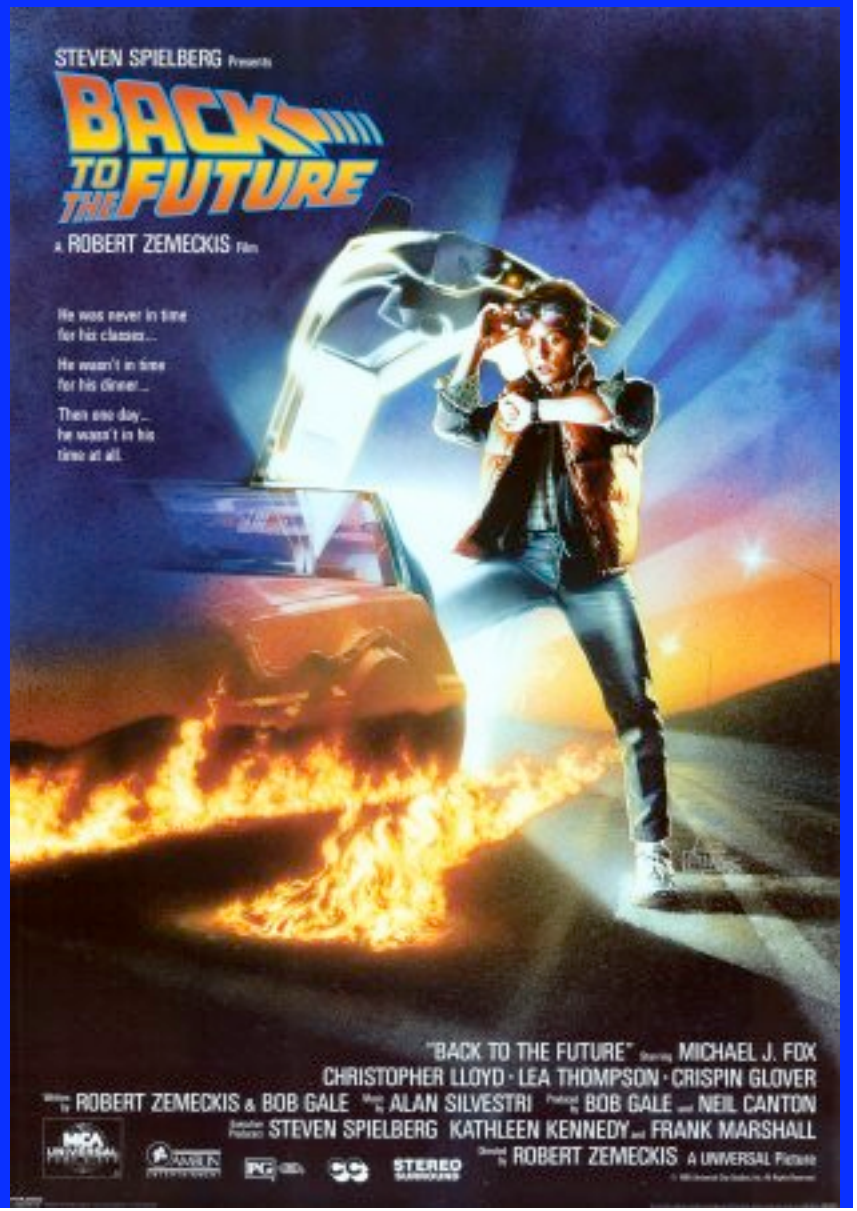
- Suppose I go back in time and kill my grandfather
- Thus, no father and no me
- But then I couldn't go back, so grandpa lives
- But then I *could* go back, so he dies
- ...and so on




http://universe-review.ca/I15-50-grandpa2.jpg

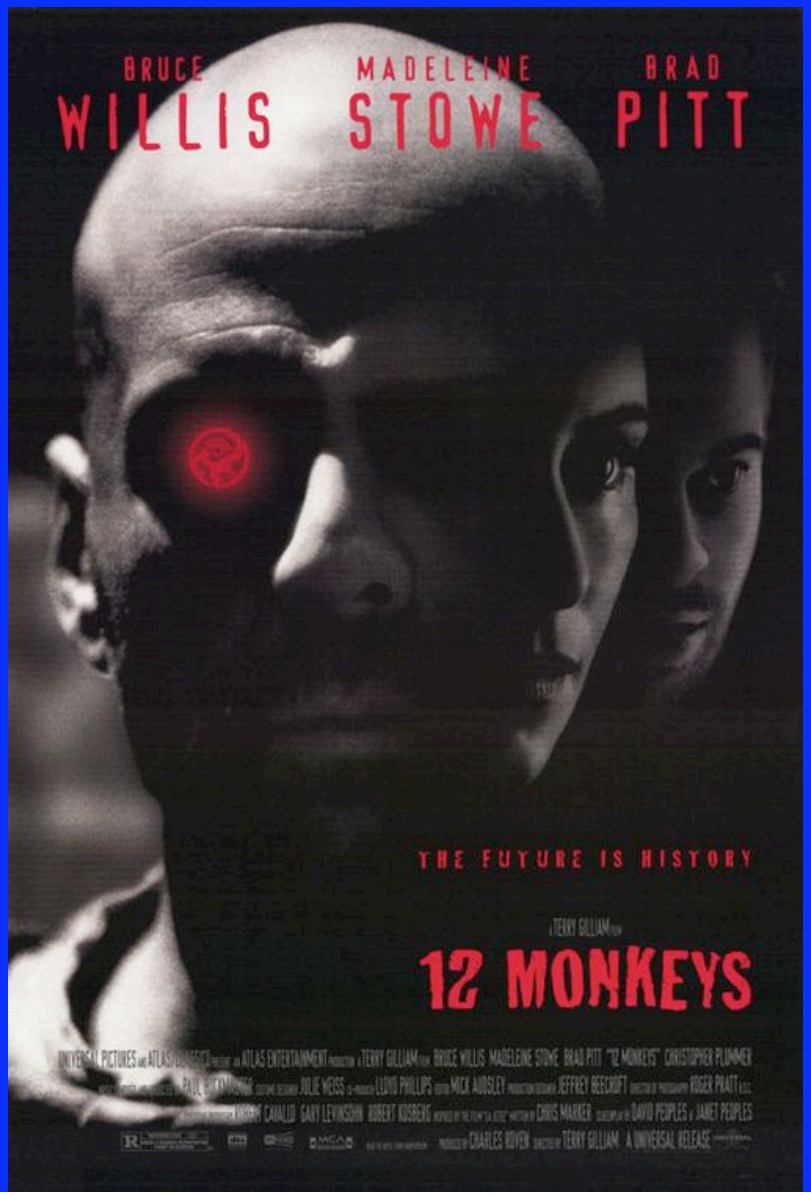
# Resolution 1: Change, But Okay

- In some stories, timeline is changed, but traveler lives
- Can be better or worse
- However, is this really consistent?



# Resolution 2: Self-Consistency

- Really, have to demand self-consistency
- For example, going back in time could cause the effect that made the traveler go back originally!
- Can phrase in ways that don't need decisions

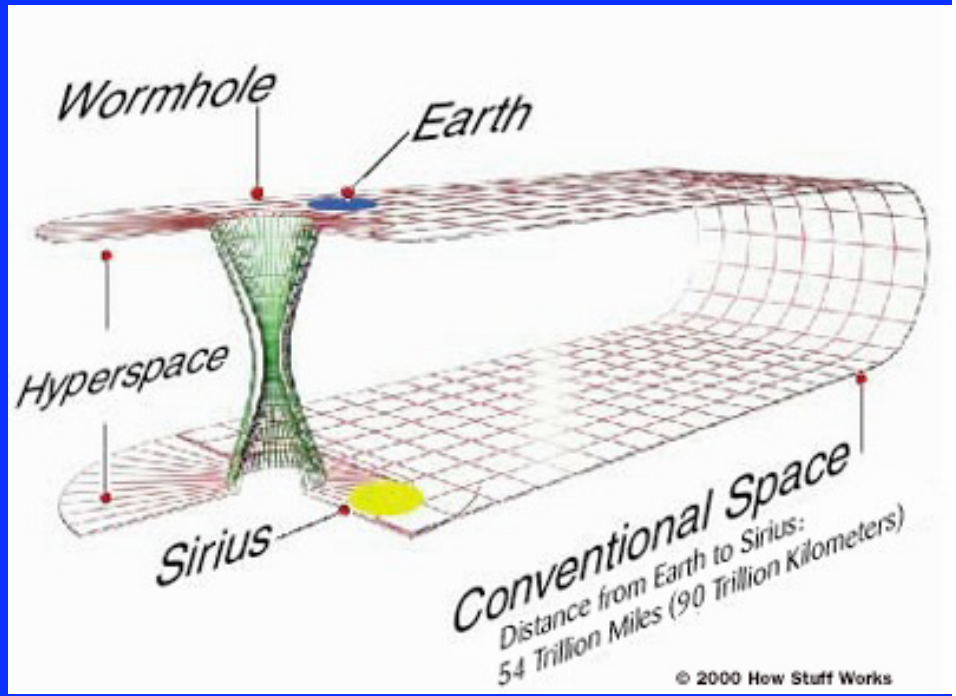


# Faster Than Light?

- If we accept that self-consistent time travel is possible in principle, how do we do it?
- From special relativity, might think that we can manage this by going faster than light
- But remember: approaching c means mass goes up indefinitely, so can't reach c
- Must find another way

# Wormholes

- What about shortcuts through space?
- Travel is less than speed of light, but through smaller distance
- Gets there faster than light would through normal space

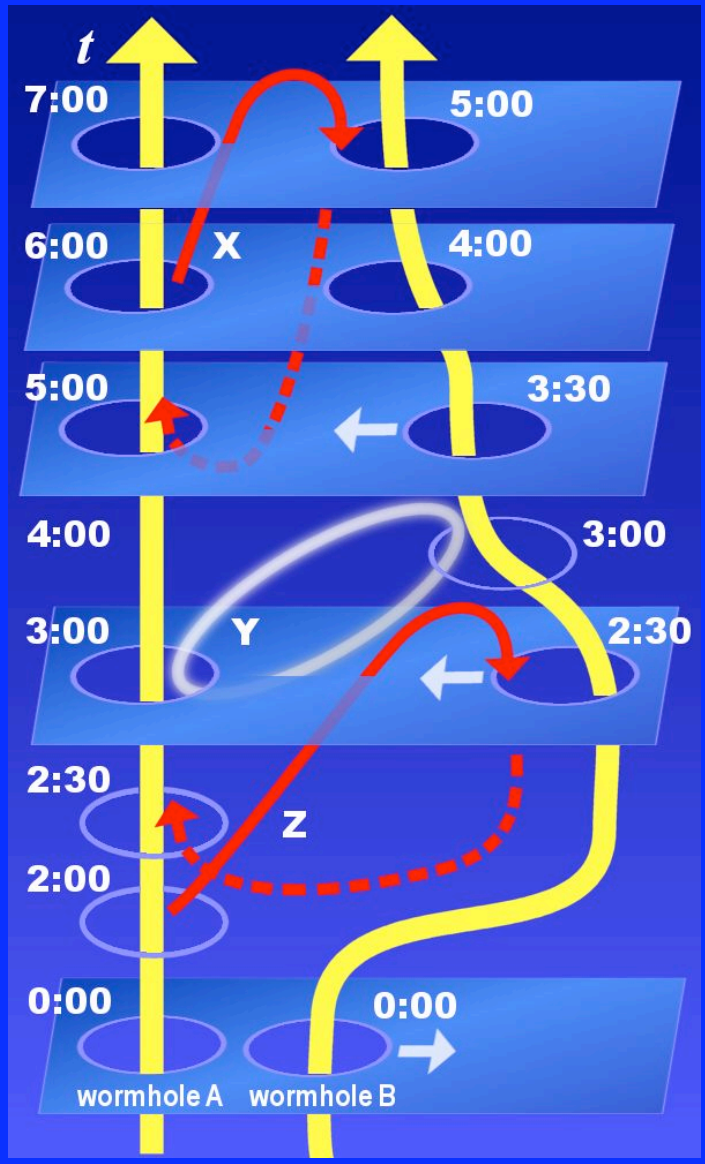


# Requirement: Exotic Matter

- One problematic detail!
- Trying to make wormhole of normal stuff means it collapses at speed of light when anything goes through!
- To be traversable, must be made of matter with negative energy density!
- Weird, but exists in theory and similar stuff is needed to make universal expansion accelerate(!)

# Wormholes and Time Travel

- Going faster than light in normal space still means you can go back in time
- Is this a viable mechanism?



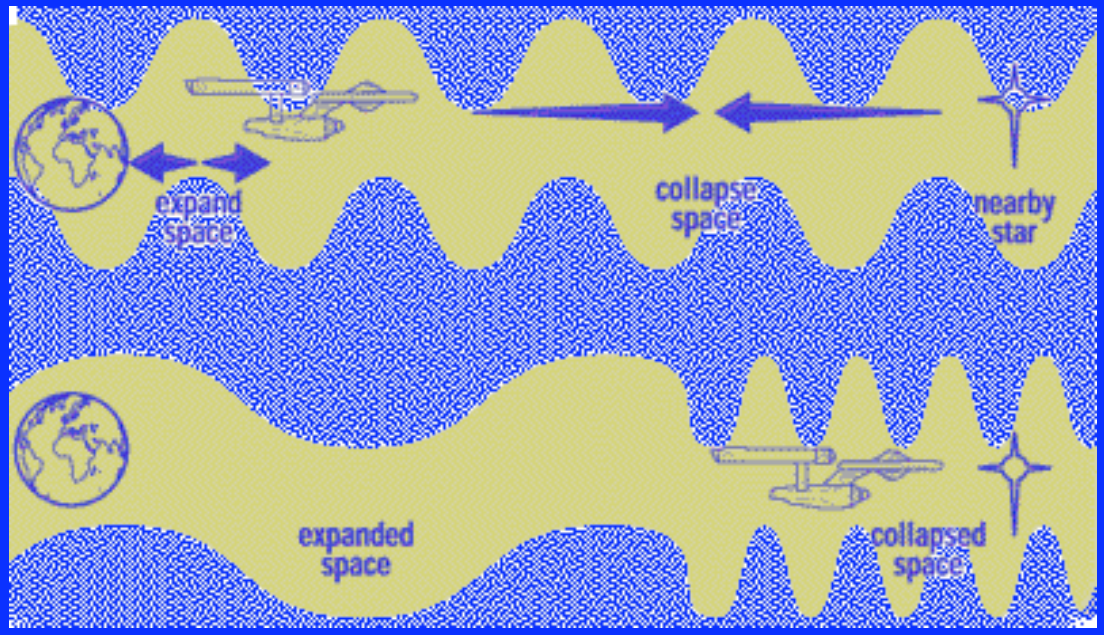

http://www.nasa.gov/centers/glenn/images/content/84540main_warp24.gif

# Self-Destructive Wormholes?

- Time travel aspect could be problematic
- Suppose a wormhole is opened
- Then matter goes in, comes out, goes back in again...
- All has positive energy density, so wormhole is shut down immediately
- Not certain if this is fatal

# Warp Drive

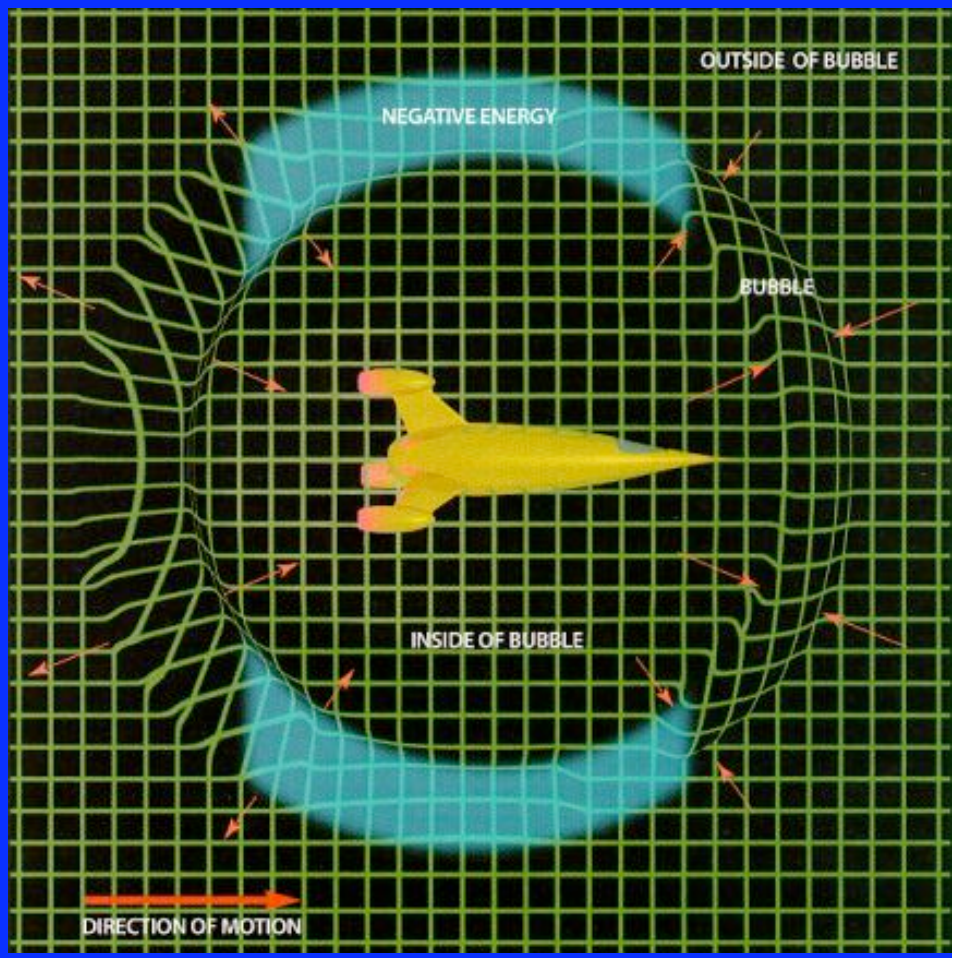
- Can we think of another way?
- What if we collapse space in front of a ship and stretch it behind to compensate?
- Still travel at <c in vicinity of the ship




http://www.daviddarling.info/images/warp_drive.gif

# Alcubierre Drive

- Suggestion of this type made by Miguel Alcubierre
- Maybe, but:
  Needs negative energy
  Have to lay out first
- Also might need to set up faster than light!
- Not looking probable




http://www.orbitalvector.com/FTL/Warp%20Drives/Alcubierre%20wd.jpg

# Summary

- Can never change subjective time!
- There are ways to go forward in time rapidly relative to rest of universe
- Could use this to explore galaxy
- But backwards looks difficult
  Can't yet absolutely rule out