ASTR 380
Relativity and Time Travel

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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?
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?

![Inertial_frames.png](https://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!
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
- $c \approx 300,000 \text{ km/s}$

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
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 $v \sim c$ 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
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
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