

# Black Hole evaporation

(and mini-black holes)

1

- mini-BH as a power source
  - $4 \times 10^{14} c^2 = 3.6 \times 10^{35} \text{ erg} = 1 L_{\text{sun}}$  for 2 minutes!
  - $L = 4.1 \times 10^{15} \text{ erg/s}$   
 $= 4.1 \times 10^8 \text{ W} = 410 \text{ megaW!}$  – a modest power plant!
  - but where do you put it?!
- “primordial” mini black holes
  - $M < 4 \times 10^{14} \text{ g}$  → would have “popped” by now
  - $M < 1.9 \times 10^{14} \text{ g}$  → “ “ “  $10^9 \text{ yr}$  after BB
- Low mass BH are HOT!
  - $M \sim 6.0 \times 10^{14} \text{ g}$  →  $t_{\text{evap}} = 30 \text{ Gyr}$ ,  $T_{\text{HR}} = 3 \times 10^{11} \text{ K}$
  - if common could produce a gamma-ray background
  - none seen, so  $M_{\text{LMBH}} < 10^{-8} M_{\text{univ}}$
- The Krennrich search for evaporating primordial BH

# Time and Time Travel

2

- time requires at least a 2-object universe
- physics on the **micro** scale
  - + ⇔ – distance okay
  - + ⇔ – time okay too
- BUT we sense directionality (if not speed) absolutely
  - water spills (mechanical)
  - wood burns (chemical)
  - milk spoils (chemical)
  - you just know

# 3 kinds of time

3

1. **psychological** (looks, feels “right”)
  2. **cosmological** (Hubble Law, expanding univ.)
  3. **thermodynamic** (2nd law of thermodynamics)
    - things get more disordered when left alone
    - takes energy (“purpose”) to assemble things
    - energy generates heat that produces disorder elsewhere
- Hawking:
    - 1 and 3 are related
    - cognition is an ordered biochemical state
    - ordered at the expense of brain heat
    - “food for thought”
    - disorder increases with time because that is the direction by which we perceive
    - we remember the past defines “past”

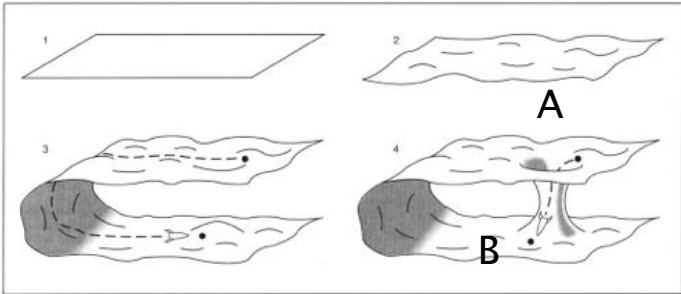
# can we travel in time?

4

- **Forwards?**
  - no problem, especially at 1 s/s
  - fast forward via special relativity
    - the twin paradox
    - Planet of the Apes
- **Backwards?**
  - instant logical inconsistencies: the “kill your grandfather” paradox
  - must solve paradox(es) to justify pursuit of time travel
  - ways “out” – infinite, parallel universes, restricted free will, ...

## a “wormhole” time machine

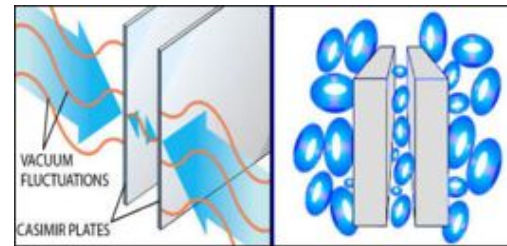
- wormhole: a theoretical connection between distinct locations in (otherwise flat) space-time
- allows apparent faster-than-light travel
- can exist briefly (i.e. as a black hole forms), but is rapidly closed off



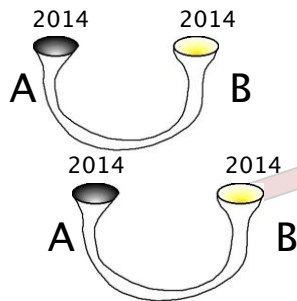
How to sidestep the speed of light. Empty, four-dimensional space-time is shown here as a flat, two-dimensional sheet (1). Matter distorts or curves space (2), and very dense concentrations can bend it drastically (3). A wormhole connecting two regions that lie far apart in space might let a spaceship take a shortcut (4) and apparently travel faster than light.

## stabilizing wormholes: the Casimir effect

- exploit the energy density of the vacuum
- curved space  $\Leftrightarrow$  acceleration  $\Leftrightarrow$  gravity
- need “antigravity” = pressure
- parallel plates, close together, smaller vacuum energy because  $\Delta x$  gets small
- use negative refractive materials – reverse the sign of the force, making it repulsive

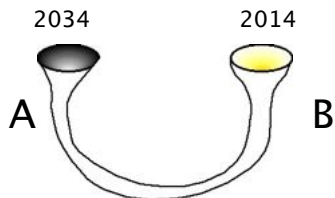


## wormhole time machine



- start: A, B in 2014
- Take B, move at near  $c$  for 20 years, then return
- Now B is a gateway back to 2014 in 2034

- in 2034:
  - walk from A to B and look “in”
  - see A as it was in 2014
  - Hop into B, emerge from A in 2014, shake hands with the young “old” you!



## what about the paradoxes?

- the two of you both jump in – now there are 4 of you!
- Grandfather paradox:
  - Igor Novikov’s Billiard Balls
    - “Principle of least action”
    - of all the paths available, the path taken is always one that minimizes the quantity called “action”
    - A simplified version of the grandfather paradox:
      - compute **action** for such a path
      - **NOT** a path of least action!
      - **NOT** allowed!
- why not? Why the 2nd law? Why gravity?
- Free will isn’t entirely free – we can’t violate physical laws despite our will to do so. Why should grandpa paradox be any different?

