Advanced Propulsion 3: Bending space and time

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https://cdn.mos.cms.futurecdn.net/xo34RuJAA6qm4yw7Qn8Job-970-80.jpg
• **Postulate 1: Principle of relativity**
  • Laws of physics are invariant in all inertial frames of reference (i.e. non-accelerating FoR)

• **Postulate 2: Principle of invariant light speed**
  • Vacuum light speed is the same for all observers, regardless of motion of source or observer

Most accurate model to-date for all motions
→ neglects gravity
→ only works for flat space-time
**Relativity:** there is no well-defined state of rest
Simultaneity is not absolute

Whether or not two events at different locations are simultaneous depends on the state of motion of the observer. So the time interval between two events may be different in different frames of reference.
*Space-Time*

- When and where does an event take place?

---

**O-frame of reference**

**ct**

**O'-world line**

**O'-x line**

**A**

**B**
• When and where does an event take place?
• Euclidean geometry does not give consistent answer!
• Space-time interval does (Minkowski space): 
  \[ ds^2 = dx^2 + dy^2 + dz^2 - (cdt)^2 \]
Space-Time

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- Euclidean geometry does not give consistent answer!
- Space-time interval does (Minkowski space):
  \[ ds^2 = dx^2 + dy^2 + dz^2 - (c dt)^2 \]
- What happens below the 45° line?
Space-Time

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• Space-time interval does (Minkowski space):
\[ ds^2 = dx^2 + dy^2 + dz^2 - (cdt)^2 \]

• What happens below the 45° line?

• What about an accelerating object?

By Cyp - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=283995
Dilation Effects

Dilation: \( \gamma = \frac{1}{\sqrt{1 - \frac{u^2}{c^2}}} \rightarrow \) Lorentz transformation

Time: \( t' = \gamma t \)

Length: \( L' = L / \gamma \)

Mass: kinetic energy of a moving body:
\[
E_k = m_0 c^2 (\gamma - 1)
\]

\( \rightarrow \) expand in binomial series
\[
E = mc^2 \approx m_0 c^2 + m_0 \frac{u^2}{2} + \frac{3}{8} m_0 \frac{u^4}{c^2} + \cdots
\]

\( \rightarrow \) First term is intrinsic energy of the body \( E \) at rest
\( \rightarrow \) Implies \( \Delta mc^2 = E_{kin} \) or other forms of energy

<table>
<thead>
<tr>
<th>Gasoline</th>
<th>Uranium</th>
<th>Deuterium</th>
<th>Antimatter</th>
</tr>
</thead>
<tbody>
<tr>
<td>46 MJ/lit</td>
<td>80,620,000 MJ/kg</td>
<td>579,000,000 MJ/kg</td>
<td>89,875,517,874 MJ/kg</td>
</tr>
</tbody>
</table>
GRAVITY IS NOT REAL
General relativity is a theory of gravitation.

→ Initial conflict with Newton’s picture of the universe

Newton: ‘gravity is the force of attraction between two bodies at rest or in motion’.

Einstein: 'gravity is a manifestation of spacetime curvature’. or John Wheeler: ‘space tells matter how to move, and matter tells space how to curve’

→ Is the earth accelerating towards us? Gravity is a fictitious force

→ Einstein predicts reality better and proven again and again
General Relativity replaces Newton’s gravity

• Einstein field equation specifies how the presence of matter curves spacetime.

• General relativity is a continuous field theory in contrast to the particle theory of matter.

\[ R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = -\frac{8\pi G}{c^4} T_{\mu\nu} \]

- Ricci tensor
- Scalar curvature
- Energy-momentum tensor
- Geometry of spacetime
- The metric
- Mass-energy
Mach (Woodward) Effect Thruster

How can we measure inertia, if all motion is relative?

**Mach’s principle:**

→ Einstein “...inertia originates in a kind of interaction between bodies...”

→ Inertia arises as a property of the mass distribution throughout the entire universe. Motion of matter in one place affects which frames are inertial in another place.

→ Gravitational absorber theory and advanced waves

Assuming Mach’s principle holds true:

\[
\nabla^2 \phi = -\nabla \vec{g} = 4\pi G \rho_0 + \left[ -\frac{1}{\rho_0} \frac{\partial E_0}{\partial t} \right]^2 + \frac{1}{\rho_0 c^2} \frac{\partial^2 E}{\partial t^2}
\]

⇒ \( \Delta m_0 = -\frac{1}{4\pi G c^2 \rho_0} \frac{\partial P}{\partial t} \)

→ Effect is orders of magnitude larger than what \( E = mc^2 \) would suggest
Mach Effect Thruster

- NOT conclusively proven
- Governing physics are not settled

## Propellantless space flight

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Takeoff Mass</th>
<th>Payload fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ariane 5 (vehicle + payload)</td>
<td>746,000 kg (^{[1]}) (~1,645,000 lb)</td>
<td>2.506%</td>
</tr>
<tr>
<td>SpaceX Starship (vehicle + payload)</td>
<td>4,400,000 kg (9,700,000 lb) (^{[2]})</td>
<td>5.341%</td>
</tr>
<tr>
<td>SpaceX Starship (payload only)</td>
<td>4,400,000 kg (9,700,000 lb) (^{[2]})</td>
<td>3.409%</td>
</tr>
<tr>
<td>Soyuz-2.1b</td>
<td>312,000 kg</td>
<td>2.63%</td>
</tr>
<tr>
<td>Soyuz-2.1a</td>
<td>312,000 kg</td>
<td>2.25%</td>
</tr>
<tr>
<td>Saturn V</td>
<td>3,038,500 kg(^{[5]}) (~6,700,000 lb)</td>
<td>4.33%</td>
</tr>
<tr>
<td>Space Shuttle (vehicle + payload)</td>
<td>2,040,000 kg (~4,500,000 lb)</td>
<td>6.49%</td>
</tr>
<tr>
<td>Space Shuttle (payload only)</td>
<td>2,040,000 kg (~4,500,000 lb)</td>
<td>1.41%</td>
</tr>
</tbody>
</table>

https://en.wikipedia.org/wiki/Payload_fraction
Faster than light (FTL) travel

- Slow down light
- Light spots and shadows
- Quantum mechanics?
- **Alcubierre warp drive**

- Hyperspace
- Superfluid theories
- Tachyons

NOOOOO!!! YOU CANT JUST GO FASTER THAN THE SPEED OF LIGHT

haha  warp drive go brrrrrrr
The Alcubierre Warp Drive

Remember the metric $g$:
$$ds^2 = -dt^2 + (dx - v_s f(r_s)dt)^2 + dy^2 + dz^2$$

- Shape of bubble
- Size of bubble
- Wall thickness of bubble

→ Required matter distribution!

$$T^{00} = -\frac{1}{8\pi} \frac{v_s^2 \rho^2}{4r_s^2} \left(\frac{df}{dr_s}\right)^2$$

Energy density component of the stress tensor

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Energy density component of the stress tensor

→ Requires negative energy density or Exotic Matter

→ Initially more matter than the entire universe: can play with that

Updated concept based on Dr. White’s theoretical findings, rendered by Mark Rademaker with artwork and inputs from Mike Okuda.
What happens at FTL?

$v = 1.5c$

Alcubierre drive

Problems with FTL

- Causal and energy condition violations
- Navigation
  - Causal disconnection between interior and exterior of bubble
- Gamma, X-ray, Hawking radiation
  - Cannot see anything in front of the ship due to Doppler shift, see only Microwave background
  - Release of energy upon deceleration
- Time dilation

https://what-if.xkcd.com/1/
Negative Energy/Mass

- Virtual particles
  - Hawking radiation
- Casimir effect
  - Restrict quantum wavelengths and corresponding type of virtual particles
- Squeezed light/vacuum
  - Quantum uncertainty of squeezed state lower than of coherent state
- Exotic bare mass of electrons

YouTube: Seraaron, [https://www.youtube.com/watch?v=TV5oiBtu8AQ](https://www.youtube.com/watch?v=TV5oiBtu8AQ)
My Online Profile Pic vs Real Life

#BlackHole

12:41 PM - 10 Apr 2019 from Milan, Lombardy
What is a Black Hole?

Collapse of **massive** stellar objects

→ Gravitational acceleration can overcome building pressure

→ Schwarzschild radius \( r_g = \frac{2Gm}{c^2} \) also event horizon radius

→ Nothing beyond an event horizon has bearing on an observer outside of it, time seems to freeze

→ Most efficient compression of mass into a region

**Static (Schwarzschild) and rotating (Kerr) black holes**
1935 Albert Einstein and Nathan Rosen:

- Extending Schwarzschild metric to infinity $\rightarrow$ singularity disappears, connect different regions of space(s)
  - Schwarzschild wormhole
  - White holes and parallel universes

Morris and Thorne, "Wormholes in spacetime and their use for interstellar travel: A tool for teaching general relativity". Theoretical Astrophysics (1987)
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Wheeler & Fuller 1950’s & Morris and Thorne 1980’s:

→ Metric to describe a spherically symmetric and static intra-universe wormhole
→ Need to avoid singularity
→ Need to avoid event horizon
→ Need to avoid excessive tidal forces
→ Need time to traverse the wormhole

BUT: requires exotic matter with negative energy density again, to keep wormhole throat stable!

Traversing a Wormhole

Fig. 13. Still frames of a voyage through a short wormhole ($a/r = 0.5$) with weak lensing ($\gamma^2/r = 0.05$), as computed with our DNKR code.

Extracting work from a Black Hole?

- Black hole bomb
  - Penrose process $\rightarrow$ extract angular momentum/energy by particle scattering
  - Requires spinning (Kerr) black hole
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- **Hawking radiation**
  - Collect energy as we would with other kinds of radiation
  - Use it as basis for propulsion device

YouTube: Kurzgesagt “The Black Hole Bomb and Black Hole Civilizations”, [https://www.youtube.com/watch?v=ulCdoCfw-bY&t=488s](https://www.youtube.com/watch?v=ulCdoCfw-bY&t=488s)
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$m_{BH} = 606,000 \text{ t}$

$r_g = 0.9 \text{ attometer}$

$(1/1000 \text{ of proton})$

$\Delta t = 3.5 \text{ years}$

$P = 160 \text{ petaWatt}$

YouTube: Kurzgesagt “The Black Hole Bomb and Black Hole Civilizations”,
https://www.youtube.com/watch?v=ulCdoCfw-bY&t=488s
- Need very small/light black holes for this to work
- Black hole from particle collider
- Energy required $1 \text{ TeV}/c^2 - 1.2 \times 10^{22} \text{ TeV}/c^2$
- LHC at CERN: 13 TeV
- Evaporation time $10^{-25} \text{ s}$
• Potential for breakthroughs, BUT
  • Some answers require unification of GR and quantum mechanics
  • Concepts often based on borderline concepts of current physical understanding

• Very useful to stretch one’s imagination and to work hard problems → progress in our fundamental understanding of reality
Further learning and sources

- PBS Space time: Curved spacetime in general relativity
  https://www.youtube.com/playlist?list=PLsPUh22kYmNAmjsHke4pd8S9z6m_hVRur

- Wikipedia:
  - Special relativity
  - Lorentz transformation
  - Spacetime diagrams
  - General relativity
  - Black Holes
  - Wormholes

- Sean M. Carrol: Lecture Notes on General Relativity UCSB

- Leonard Susskind’s Stanford lectures on general relativity:
  https://www.youtube.com/watch?v=SwhOfh0kEE&list=PLpGHT1n4mAvcXwzO1z3dHnGZaQP1LEib

- Stanford notes on dilation:
Further learning and sources

**Mach-Effect Thruster:**

**Black holes and Wormholes:**

**Warp drives:**
- Subject Zero, Alcubierre warp field and anti matter: [https://www.youtube.com/watch?v=gHAaoTMrc3A](https://www.youtube.com/watch?v=gHAaoTMrc3A) (I do not agree 100% with the explanation but it is a nice summary)