Canonical Form of Alcubierre Metric

Canonical Form of Alcubierre metric:

\[ ds^2 = \left[ v_s^2 f(r_s)^2 - 1 \right] \left( dt - \frac{v_s f(r_s)}{v_s^2 f(r_s)^2 - 1} \, dx \right)^2 - dx^2 + dy^2 + dz^2 \]

\[ ds^2 = -dt^2 + (dx - v_s f(r_s) dt)^2 + dy^2 + dz^2 \]

Since the equation is now in canonical form, the boost can be derived:

\[ -e^{\frac{2\Phi}{c^2}} = \left[ v_s^2 f(r_s)^2 - 1 \right] \]

Or taking \( c = 1 \)...

\[ \Phi = \frac{1}{2} \ln \left[ 1 - v_s^2 f(r_s)^2 \right] \]

Trivially, the Lorentz Transform or boost field is: \( \gamma_\Phi = \cosh(\Phi) \)
Boost Field

Surface plots of boost, $\langle v \rangle = 10c$, 10 meter diameter volume

Note pseudo-horizon surface at $V^2f(r_s)^2 = 1$

Pseudo-horizon surface not visible with larger integration step

Note pseudo-horizon at $v^2f(r_s)^2 = 1$ where photons transition from null-like to space-like and back to null like upon exiting. This is not seen unless the field mesh is set fine enough. The coarse mesh on the right did not detect the horizon.
Modified Concept of Operations

- A modified concept of operations is proposed that may resolve symmetry/symmetry paradox.
- Spacecraft departs earth and establishes an initial sub-luminal velocity $v_i$ then initiates field.
- When active, field’s boost acts on initial velocity as a scalar multiplier resulting in a much higher apparent speed, $v_{\text{eff}} = \gamma v_i$ as measured by either an earthbound observer or an observer in the bubble.
- Within shell thickness of the warp bubble region, the spacecraft never locally breaks the speed of light and the net effect as seen by earth/ship observers is analogous to watching a film in fast forward.
- Consider the following to help illustrate the point –
  - Assume the spacecraft heads out towards Alpha Centauri and has a conventional propulsion system capable of reaching 0.1c.
  - The spacecraft initiates a boost field with a value of 100 which acts on the initial velocity resulting in an apparent speed of 10c.
  - The spacecraft will make it to Alpha Centauri in 0.43 years as measured by an earth observer.

Gedanken experimental NASA golf ball ship.
Brane Cosmology: Chung-Freese metric

- In 2000, Chung and Freese published a paper\(^1\) that mapped a Friedmann-Robertson-Walker (FRW) metric into a higher dimensional manifold to address the cosmological horizon problem (e.g. COBE sphere smoothness).
  
  - In this model, our 3 + 1 universe exists as a brane imbedded in a higher dimensional bulk.

  - By considering the null solutions for the metric (e.g. light rays), thermodynamic information can be communicated over vast distances without violating causality by means of transiting through the bulk.

  - Model can be generalized to represent an n-dimensional space, and compactification can be included if desired.

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Chung Freese metric:

\[ ds^2 = -c^2 dt^2 + \frac{a^2(t)}{e^{2kU}} dX^2 + dU^2 \]

- The \( dX^2 \) term represents the 3+1 space (on the brane).
- The \( dU^2 \) term represents the bulk with the brane being located at \( U=0 \).
- The \( a(t) \) term is the scale factor, and \( k \) is a compactification factor for the extra space dimensions.
- A conventional analogy to help visualize the brane-bulk relationship, consider a 2D sheet that exists in a 3D space:
  - The 2D inhabitants of the “flat-land” subspace have a manifold that is mapped out with the simple metric, \( dx^2 + dy^2 \), where this can be viewed as being analogous to the \( dX^2 \) term.
  - The remainder of the 3D bulk space is mapped by the z-axis, and anything not on the sheet would have a non-zero z-coordinate.
  - This additional \( dz^2 \) term is, from the perspective of the 2D inhabitants, the \( dU^2 \) term.
  - Anything not on the 2D sheet would be labeled as being in the bulk with this simplified analogy.
Comparison of null geodesics (e.g. light rays)

\[ \frac{dX}{dt} = \frac{ce^{kU}}{a(t)} \sqrt{1 - \frac{dU^2}{c^2 dt^2}} \]

\[ \gamma \approx e^{U} \]

- \( \frac{dX}{dt} \) is the speed of a photon in coordinate space.
- For \( U = 0 \), \( \frac{dX}{dt} = 1 \) as expected.
- If \( dU/dt \) is set to 1, then test photon that has a velocity vector orthogonal to the brane would have a zero speed as measured on the brane, \( \frac{dX}{dt} = 0 \).
- If a test photon has \( dU/dt = 0 \), but arbitrarily large \( U \) coordinate, \( \frac{dX}{dt} \) will be large, possibly \( \gg 1 \). Remember that \( c \) was set to 1, so \( \frac{dX}{dt} > 1 \) is analogous to the hyper-fast travel character of the Alcubierre metric.
- The behavior of the null-like geodesics in the Chung-Freese metric becomes space-like as \( U \) gets large.
- The null-like geodesics in the Alcubierre metric become space-like within the warp bubble, or where the boost gets large.
- This suggest that hyperspace coordinate serves same role as boost, and the two can be informally related by simple relationship above.

A large boost corresponds to an object being further off the brane and into the bulk.
Cis-lunar Mission Planning

- To this point, discussion has been centered on interstellar capability, but a more "domestic" application within the earth's gravitational well will be considered.
- Energy density for metric is negative, so process of turning on a theoretical system with ability to generate negative energy density, or a negative pressure as shown in [1], will add an effective negative mass to the spacecraft’s overall mass budget.
- In reference mission development using low-thrust electric propulsion systems for in-space propulsion, planners will cast part of trade space into domain that compares specific mass a to transit time. (see LEO to L1 inset)
- Specific mass of an architecture element can be determined by dividing spacecraft's beginning of life wet mass by the power level.
- Transit time for a mission trajectory can be calculated and plotted on graph that compares specific mass to transit time.
- If negative mass is added to spacecraft's mass budget, then the effective specific mass and transit time are reduced without necessarily reducing payload.
- A question to pose is what effect does this have mathematically? If energy is to be conserved, then \( \frac{1}{2} m v^2 \) would need to yield a higher effective velocity to compensate for apparent reduction in mass.

**EXAMPLE:**
- Assuming a point design solution of 5000 kg BOL mass coupled to a 100 kW Hall thruster system (lower curve), expected transist time is \(~70\) days for a specific mass of 50 kg/kW without the aid of a warp drive.
- If a very modest warp drive system is installed that can generate a negative energy density that integrates to \(~2000\) kg of negative mass when active, the specific mass is dropped from 50 to 30 which yields a reduced transit time of \(~40\) days.
- As the amount of negative mass approaches 5000 kg, the specific mass of the spacecraft approaches zero, and the transit time becomes exceedingly small, approaching zero in the limit.
- In this simplified context, the idea of a warp drive may have some fruitful domestic applications "subliminally," allowing it to be matured before it is engaged as a true interstellar drive system.


Dr. Harold "Sonny" White
05/02/2011
Humanity should explore and colonize the Solar System in the next fifty years, while making human-crewed and robotic interstellar flights a real possibility by the end of the 21st Century. To that end, many dedicated teams and individuals are actively working to research and develop both the science and technology (propulsion & power) required to accomplish these goals. Propulsion and Power are the keys to exploration and utilization of the Solar System and beyond. Godspeed!

Derivation of Gravitational Constant
Quantum Vacuum Fluctuations and Big-Bang Cosmology

1000kN Thruster (4x Force density of leading EP tech, \(1_p = 1 \times 10^{11}\) s)

2.45GHz Quantum Vacuum Plasma thruster

How It Works

Test Results

2.45GHz Test Article

Ultra-low Thrust Torsion Pendulum Test-Bed for Model Investigation
Potential Warp Field Experiment

- Since we know how to make a large spacetime expansion boost value, a test configuration could be invoked conceptually as shown.

- The figure depicts a modified Michelson-Morley Interferometer setup that makes use of a 1 cm diameter toroidal ring of positive energy density on one leg of the interferometer.

- A He-Ne laser beam ($\lambda = 633$ nm) is split allowing one part of the beam to pass through the center of the ring and hence the spherical warp field region.

- This warp field region will induce a relative phase shift between the split beams that could be detectable provided the magnitude of the phase shift is sufficient.

- If the desired phase shift goal were set to be roughly 1/4th wavelength (reasonable expectation), then the necessary boost field is on the order of 1.0000001 to 1.0000002.

From a purely Special Relativistic perspective, this equates to a velocity of $\sim 0.0004c$ which could be achieved potentially with a toroidal ring of plasma. Additionally, we could take the route of acting on the boost by means of the potential or gauge, $\gamma = \cosh(\phi)$. In this scenario, we would employ a ring of capacitors driven at high voltage and possibly moderately high frequencies to act on the potential ($\phi$) of the ions within the dielectric.

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White-Juday Warp Field Interferometer

- White-Juday Warp Field Interferometer uses He-Ne laser to generate interference signal at a detector with test device placed in proximity to one leg of beam path to evaluate York-Time effects (expansion/contraction of space).
- He-Ne laser beam ($\lambda = 633$ nm) is split allowing one part of beam to pass near /through device being tested.
- Presence of warp field region will induce relative phase shift between split beams that should be detectable provided magnitude of phase shift is sufficient.
- Using 2D Analytic Signal processing of the, the Magnitude and phase of the field can be extracted for study and comparison to theoretical models.

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“2nd star to the right, straight on till morning…”

Godspeed!

Condensation by artist Les Bossinas found at http://www.grc.nasa.gov/WWW/bpp/APP_Art.htm