PUTTING THINGS IN PERSPECTIVE...
The challenge of Interstellar Flight

- Consider some of the statistic from the Voyager 1 mission: the 0.722 mt spacecraft launched in 1977 to study outer solar system and boundary with interstellar space.
- After 33 years, Voyager 1 is currently at 116 Astronomical Units (AU) from the sun travelling at 3.6 AU per year, and no spacecraft launched to date will overtake Voyager 1.
- If Voyager 1 were on a trajectory headed to one of the Sun’s nearest neighboring star systems, Alpha Centauri at 4.3 light years (or 271,931 AU), it would take ~75,000 years to traverse this distance at 3.6 AU/year.
- Recent informal studies of emerging technological capabilities being brought to bear on robotic interstellar precursor missions using high power plasma engines coupled to nuclear reactors suggest it may be possible to achieve the JPL Thousand-AU (TAU) mission [5](interstellar precursor to 1000 AU in 50 years) in as little as 15 years, meaning this Nuclear Electric Propulsion (NEP) architecture might overtake Voyager 1 in as little as two years after launch.
- While this is a handy improvement over the Voyager 1 performance, this theoretical craft would still take thousands of years to reach the nearest stars.
Interstellar Flight (Past Studies)

• The difficulty of interstellar flight is also illustrated in more detail in both the Project Daedelus study and the Project Longshot study.

  – Project Daedelus was sponsored by British Interplanetary Society in 1970’s to develop robotic interstellar probe capable of reaching Barnard’s star, at ~6 light years away, in 50 years.
    • The resulting spacecraft was very massive at 54,000mT, 92% of which was fuel for the fusion propulsion system.
    • This mass is well over 100 times the mass of the International Space Station (ISS) currently in orbit.

  – Project Longshot was joint NASA/Navy effort in late 1980’s to develop robotic interstellar spacecraft capable of reaching Alpha Centauri, at 4.3 light years away, in 100 years.
    • Solution for this study faired better than the Daedelus effort resulting in a spacecraft with a mass of ~400mt, with 67% being fuel to feed the nuclear pulse propulsion system.
    • This mass is a bit more feasible by today’s standards being almost equivalent to one ISS.
Inflation: Alcubierre Metric

• In 1994, Alcubierre published a paper\(^1\) exploring the consequences of inflation within the context of General Relativity.
  – Paper derived inflation-based metric allowing for rapid transit times between points without locally violating the speed of light.
  – Working mechanism was proposed to be the York Time (inflation).
  – Alcubierre metric requires a halo of negative energy density which violates several energy conditions and is considered to be classically non-physical.

• Concept of Operation
  – Spacecraft departs earth using conventional propulsion system and travels distance \(d\), where spacecraft is brought to stop relative to earth.
  – Field is turned on and craft zips off to interstellar destination, never locally breaking the speed of light, but covering the distance \(D\) in an arbitrarily short period of time.
  – Field is turned off at standoff distance \(d\) from the destination, and craft finishes journey conventionally.
  – This approach would allow journey to Alpha Centauri in weeks or months, rather than decades or centuries as measured by an earth bound observer (and spacecraft clocks).

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Dr. Harold “Sonny” White
05/02/2011
Inflation: Alcubierre Metric

Warp Drive Metric:

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

Apparent speed

Shaping Function:

Shell thickness parameter \[
\begin{align*}
\text{Shell size parameter} \\
\frac{\tanh(\sigma(r_s + R)) - \tanh(\sigma(r_s - R))}{2 \tanh(\sigma R)}
\end{align*}
\]

York Time:

\[ \theta = v_s \frac{x_s}{r_s} \frac{df(r_s)}{dr_s} \]

York Time is measure of expansion/contraction of space

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York Time Behavior

- Allowing the thickness of the warp bubble to get thicker greatly reduces the required York Time magnitude, while still achieving desired \( v_s \).
- The flat space-time region inside the bubble is slightly reduced, but manageable considering benefits.

Surface plots of York Time, \( <v>=10c \), 10 meter diameter volume, variable warp “bubble” thickness
Energy Density Behavior

Surface plots of $T^{00}$, $<v>\approx 10c$, 10 meter diameter volume, variable warp “bubble” thickness

- As the warp bubble gets thicker, the peak energy density is greatly reduced.
- Similarly, the total energy (integration of field) is also reduced, but to a point. Early indications suggest there is an optimal thickness that minimizes total energy for craft size and target velocity.

**Takeaway:** sloppy bubbles appear to be “easier” than precise ones.
Symmetry/Asymmetry Paradox

**Energy Density:**

\[
\frac{1}{8\pi} G^{00} = -\frac{1}{8\pi} \frac{v_s^2 (v^2 + z^2)}{4r_s^2} \left( \frac{df(r_s)}{dr_s} \right)^2
\]

Symmetry Surface

Gedanken experimental NASA golf ball ship. Illustrative Purposes Only

Energy density toroid profile – revolve around \( x \)-axis

If craft has zero initial velocity and initiates symmetrical energy density field, how does York Time know which way to go?

Dr. Harold “Sonny” White
05/02/2011
Canonical Form of Alcubierre Metric

- In 2003, this author published a paper\(^1\) that derived the canonical form of the Alcubierre metric allowing for a better understanding of the physical nature, and how it might be manifested (at least mathematically).

  - Canonical form mitigated energy density symmetry paradox and showed that working mechanism might be the boost sphere (resulting from halo) acting on initial velocity (e.g. boost = 2, initial \(v = 27,500\text{mph}\), apparent \(v = 55,000\text{mph}\)).
  - Boost is something that can be readily engineered, while the notion of inflation is less tangible.
  - This model by itself was still a mathematical toy, unless the need for negative energy density issue could be addressed.

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