Draft Technical Note:

On the Absence of Causality Paradoxes in Alcubierre Drive FTL Signaling Due to Worldline Intersection Constraints

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Abstract:
We analyze the theoretical implications of faster-than-light (FTL) signaling using an Alcubierre warp drive framework. Unlike conventional signals propagating continuously through spacetime, FTL communication via warp bubbles represents discrete spacetime events that must intersect the receiver's worldline precisely in both space and proper time. We show that this intrinsic targeting constraint prevents the formation of closed timelike curves (CTCs) that lead to causality paradoxes. Specifically, failure to account for relativistic proper time and frame differences results in the FTL message "missing" the recipient, thus preventing paradoxical signaling loops. Additionally, we discuss the practical impossibility of docking or interacting with relativistic or superluminal ships, further limiting causality-violating scenarios. This note clarifies misunderstandings about causality violations in Alcubierre-based FTL scenarios and emphasizes operational limits on messaging in warped spacetime.

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1. Introduction

FTL travel and communication pose foundational challenges to causality and relativity. The Alcubierre drive metric proposes a warp bubble transporting an object by contracting and expanding spacetime itself, theoretically enabling superluminal effective speeds without local violation of special relativity. Prior literature raises concerns about closed timelike curves (CTCs) and associated paradoxes resulting from FTL signaling between moving frames [1,2].

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2. Nature of Alcubierre FTL signaling

Unlike electromagnetic waves, which propagate continuously through intermediate spacetime points, Alcubierre FTL signals are realized as discrete spacetime "jumps" or warp bubble transitions. This implies that signals do not gradually fill the path between sender and receiver but instead appear at a spacetime event where the receiver's worldline intersects the bubble's terminus.

3. Worldline intersection and operational constraints

Successful reception requires precise knowledge of the recipient's spacetime coordinates, including relativistic proper time effects. When the sender calculates the target position solely in their own inertial frame (e.g., Earth frame), ignoring Lorentz transformations or proper time elapsed on the recipient craft, the FTL message will not coincide with the recipient's worldline — effectively "missing" the craft.

Example: Craft at 0.8c and FTL message at 10c

Consider a craft departing Earth at speed v=0.8cv = 0.8cv=0.8c. After te=4t_e = 4te=4 years in Earth frame, a message is sent from Earth at FTL speed vm=10cv_m = 10cvm=10c towards the craft's calculated position.

- The craft's distance at Earth time of sending is:

$$d = v \times t_e = 0.8c \times 4\,\mathrm{yr} = 3.2\,\mathrm{ly}$$

- The message travel time from Earth to this position is:

$$t_m = \frac{d}{v_m} = \frac{3.2\,\mathrm{ly}}{10c} = 0.32\,\mathrm{yr} \approx 3.8\,\mathrm{months}$$

- Therefore, message arrival at Earth frame time is:

$$t_a = t_e + t_m = 4 + 0.32 = 4.32\,\mathrm{yr}$$

- Meanwhile, the craft's proper time elapsed at message arrival is calculated using time dilation factor γ:

$$\gamma = \frac{1}{\sqrt{1-(v/c)^2}} = \frac{1}{\sqrt{1-0.64}} = \frac{1}{0.6} \approx 1.667$$

  The craft's proper time at Earth time t_a is:

$$\tau = \frac{t_a}{\gamma} = \frac{4.32}{1.667} \approx 2.59\,\mathrm{years}$$

However, the message was targeted based on Earth time position at 4 years. Because the craft's own clock reads less time, the message does not intersect the craft's **actual** spacetime worldline unless the sender accounts for this relativistic difference.

Thus, the message can "miss" the craft, preventing unintended paradoxical signaling.

4. Practical constraints on docking or interaction at relativistic and superluminal speeds

Even assuming the possibility of Alcubierre-style superluminal travel, practical challenges severely limit any real-time interaction between ships traveling at relativistic or superluminal speeds:

- **Relative velocity differences:** Two warp bubble craft traveling at or near light speed relative to each other experience extreme relativistic effects. Matching velocity vectors for docking or close approach would require precise coordination with negligible margin for error.
- **Transitioning in and out of warp bubbles:** Entering or exiting a warp bubble involves complex spacetime distortions. Synchronizing such transitions between two independent craft moving at different relativistic velocities is expected to be prohibitively difficult.
- **Spacetime causal structure:** The effective ‘distance’ between superluminal craft in spacetime is non-trivial. Even if two craft aim to rendezvous, the necessary causal and geometric conditions to meet may not be realizable without violating other constraints.

These factors imply that *even if* FTL travel is possible, the likelihood of “closing the loop” by returning or interacting with a ship moving at relativistic or superluminal speeds is extremely low, further reducing chances of paradoxical time loops.

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5. Implications for causality paradoxes

The operational constraints on signal targeting and practical interaction severely limit the formation of closed timelike curves via FTL signaling or travel. Since paradoxes require messages or travelers to arrive before their emission events in some frames, the inability to consistently intersect the recipient’s worldline or physically rendezvous effectively blocks causality-violating scenarios.

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6. Conclusion

The requirement that Alcubierre FTL signals intersect the recipient’s worldline in spacetime imposes a fundamental limit on their operational use. Coupled with severe practical challenges in interacting or docking at relativistic and superluminal speeds, these constraints eliminate the possibility of closed timelike curves formed solely by FTL signaling or travel. This resolves a major paradox concern in warp drive theories and guides future work towards formalizing these operational and geometric limits within the full general relativistic framework.

7. Notes

The author thanks ChatGPT for assistance in drafting and calculations.

References

[1] M. Alcubierre, "The Warp Drive: Hyper-fast Travel Within General Relativity," *Classical and Quantum Gravity*, vol. 11, no. 5, pp. L73-L77, 1994.

[2] M. Everett, "Observations on the 'Warp Drive' spacetime," *Class. Quantum Grav.*, vol. 28, no. 21, 215021, 2011.