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Some Thoughts on the Implications of Faster-Than-Light Interstellar Space Travel

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'Tis an overvaluing ourselves to reduce all to the narrow measure of our capacities; and to conclude all things impossible to be done, whose manner of doing exceeds our comprehension.

John Locke, *An Essay Concerning Human Understanding* (1690)

SUMMARY

There are reasons for believing that faster-than-light (FTL) interstellar space travel may be consistent with the laws of physics, and a brief review of various FTL travel concepts is presented. It is argued that FTL travel would revolutionize the scientific exploration of the Universe, but would only significantly shorten the Galactic colonization timescale from the 10^6 years estimated on the assumption of sub-light interstellar travel if the mass-production of FTL space vehicles proves to be practical. FTL travel would permit the development of interstellar social and political institutions which would probably be impossible otherwise, and may therefore strengthen the 'zoo hypothesis' as an explanation for the apparent absence of extraterrestrial beings in the Solar System.

1 INTRODUCTION

For many space exploration and colonization projects that we might wish to undertake in the future it would be a great help if space vehicles could travel faster than the speed of light. It is true that orthodox scientific opinion, based largely on a narrow interpretation of the special theory of relativity, holds faster-than-light (FTL) travel to be impossible, but is this necessarily so?

While it may come as a surprise to many, the truth is that contemporary physics is not able to answer this question with any degree of confidence. We simply do not know whether FTL travel is possible. However, we do know, contrary to some widely held opinions, that FTL travel does not necessarily conflict with the special theory of relativity (e.g. Bilaniuk, Deshpande & Sudarshan 1962, Feinberg 1967), and we have some grounds for believing that it may also be consistent with the general theory of relativity (e.g. Fuller & Wheeler 1962, Morris & Thorne 1988, Alcubierre 1994). Indeed, the FTL stretching of spacetime is now considered orthodox within the context of inflationary cosmologies (e.g. Linde 1990, 1994). We may perhaps also note that there are philosophical reasons, arising from consideration of the separability of quantum systems, for considering that the FTL propagation of information (or, at least, of quantum mechanical influences) may occur (d'Espagnat 1979).

Given that we are currently unable to rule out the possibility of FTL travel and communication, it may be worth considering some of the implications should these turn out to be achievable in practice. This is the purpose of the present paper. However, before proceeding to a discussion of these issues, it will be helpful to provide a review of some of the key FTL travel concepts which may be found in the literature.

2 A REVIEW OF FTL TRAVEL CONCEPTS

In this section we outline the main arguments in support of the possibility of FTL travel within the laws of physics as currently understood. The review itself is fairly brief, but it is hoped that readers wishing to explore the subject in greater detail will find here many of the references that they will require.

2.1 *Tachyons*

The name 'tachyon' (from ταχύς, meaning fast in Greek) has been coined for hypothetical particles which travel through space faster than the speed of light. A concise description has been given by Narlikar & Sudarshan (1976) in a paper dealing with the possible implications of such particles for cosmology:

> Tachyons are particles travelling faster than light. Contrary to the general belief their existence does not violate the theory of relativity, although their detection may require a modification of certain established notions of causality in physics.

Within the framework of special relativity the energy, E, and momentum, p, of a particle are given by

$$E = \frac{m_0 c^2}{\sqrt{[1-(v^2/c^2)]}} \qquad p = \frac{m_0 v}{\sqrt{[1-(v^2/c^2)]}}, \tag{1}$$

where m_0 is the particle rest mass, c is the speed of light and v is the particle velocity in the observer's frame of reference.

The difficulty with tachyons is that, according to Equation (1), both E and p would be imaginary for $v > c$, whereas if such particles are to have any claim to physical existence it would seem that these quantities must be real. This problem may be overcome by postulating tachyons to have an imaginary rest mass (Bilaniuk *et al.* 1962, Feinberg 1967). Following Feinberg, we may then write $m_0 = i\mu_0$ (where $i = \sqrt{-1}$), in which case the energy and momentum will be real quantities satisfying the equations

$$E = \frac{\mu_0 c^2}{\sqrt{[(v^2/c^2)-1]}} \qquad p = \frac{\mu_0 v}{\sqrt{[(v^2/c^2)-1]}}, \tag{2}$$

where now $v > c$.

Figure 1 shows the relativistic factors $\gamma = 1/\sqrt{(1-\beta^2)}$, and $\Gamma = 1/\sqrt{(\beta^2-1)}$, for sub-light particles and tachyons, respectively (where $\beta = v/c$). Thus, we see that while the energy and momenta of sub-light particles are monotonically increasing functions of v over the range $0 < v < c$, for tachyons they are decreasing functions over the range $c < v < \infty$.

From the foregoing it will be seen that, far from denying the possibility of FTL particles, there is a sense in which the special theory of relativity actually

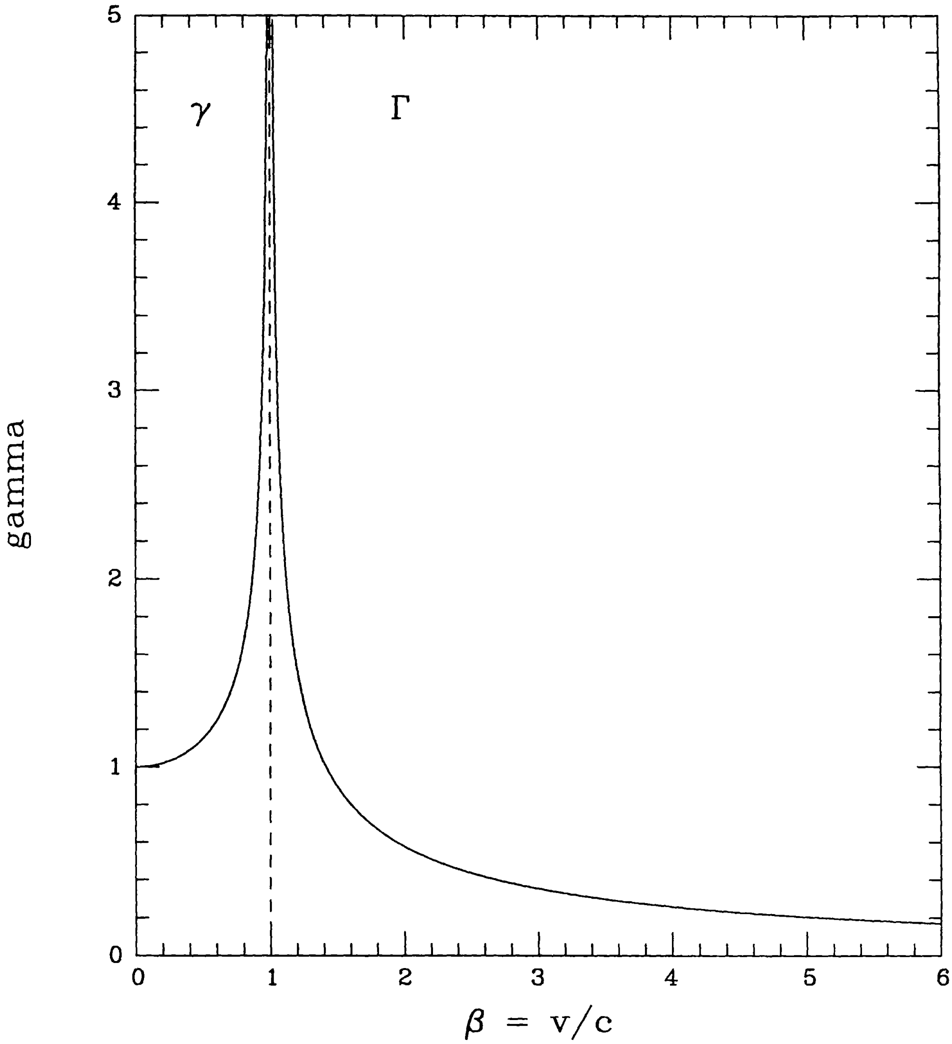

FIG. 1. The relativistic factors $\gamma = 1/\sqrt{(1-\beta^2)}$, and $\Gamma = 1/\sqrt{(\beta^2-1)}$, for sub-light particles and tachyons, respectively.

predicts their existence. The reason why special relativity is said to preclude FTL travel is because, under certain circumstances, it also predicts that such particles may travel backwards in time, in violation of the principle of causality. However, it must be clearly understood that there is a large parameter space within which FTL space travel may occur without impinging on the principle of causality.

The time travel problem arises when relative motion is introduced between observers exchanging tachyons (e.g. Feinberg 1967). For example, consider two observers, A and B, separated by a distance x_0 at time $t = 0$, with B moving away from A with a velocity $u(< c)$ in the direction of increasing x. Let A emit a tachyon having velocity $v(> c)$ towards B at $t = 0$. If, upon reception of this tachyon, B then emits a second tachyon back towards A (with velocity $-v$ in B's frame), the Lorentz transformation of velocities shows that this second tachyon will be received by A at a time

$$t_{\rm rec} = \frac{x_0}{(v-u)^2}[v-u+v(1-uv/c^2)]. \qquad (3)$$

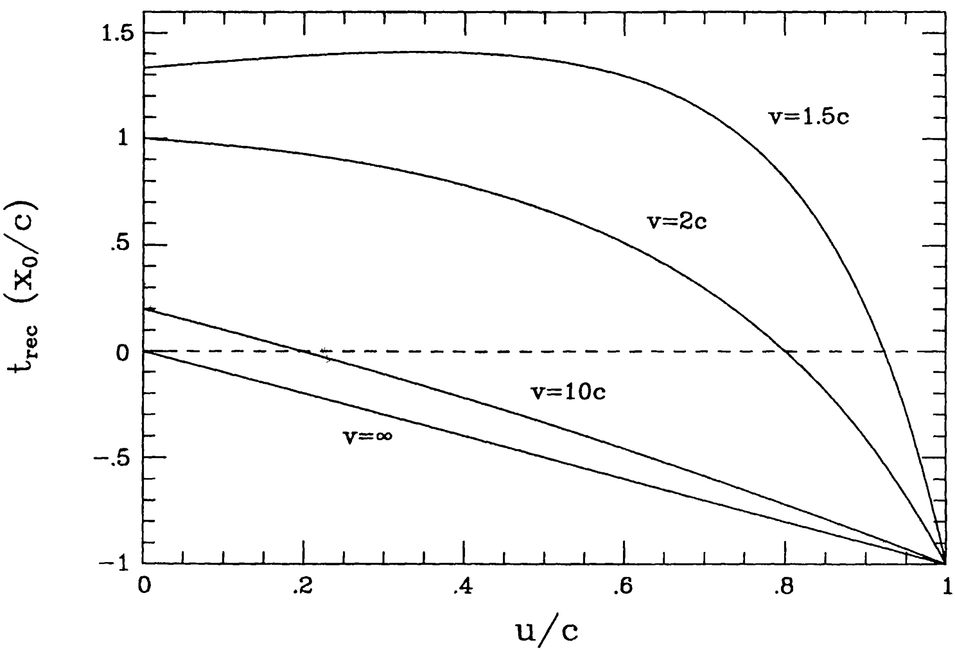

FIG. 2. The variation of t_{rec} as a function of u for different tachyon velocities, v; $t_{rec} < 0$ implies a violation of causality (see text).

It is instructive to plot t_{rec} as a function of u for different tachyon velocities, v, and this is done in Fig. 2. For $u = 0$, $t_{rec} = 2x_0/v$, which is exactly what we would have expected (i.e. the time taken is equal to the total distance travelled divided by the tachyon velocity), and no violation of causality will occur even though $v > c$. However, there is a critical value of u, above which tachyon velocities which previously did not give rise to causal anomalies will now do so (i.e. t_{rec} will become negative). As we might expect, this critical value of u is lower (i.e. causality violation is easier) for higher tachyon velocities. Note that as u tends to c, t_{rec} tends to $-x_0/c$ for all tachyon velocities, so a causal anomaly will always be possible for a sufficiently large relative velocity between the observers.

However, while we may (tentatively) accept the principle of causality, it is clear that arguments based upon it relate only to time travel, and not to FTL space travel *per se*. For example, we might follow Birch (1984) and Hawking (1992) and conjecture that physical mechanisms exist to prevent time travel, while permitting FTL space travel in those cases where causality violation is not an issue. As pointed out by Birch (1984), this suggestion is not as *ad hoc* as it may at first appear: the principle of causality absolutely requires the existence of some such mechanism, and whatever Nature's speed limits eventually turn out to be, if these are based on the principle of causality, they will be far from arbitrary.

Finally, we note that while the theory of tachyons gives us some grounds for believing that FTL travel is consistent with the special theory of relativity, it is very difficult to see how a sub-light material particle could overcome the apparently impenetrable energy barrier which exists at $v = c$ (see Fig. 1). Unless it can be shown that it is possible to 'tunnel' through this barrier, it would seem that tachyons can exist only if they are created as such. While this may still permit their use for interstellar communication, it would probably exclude them as a means of achieving the kind of FTL space travel discussed in Section 3.

2.2 *Wormholes*

It has been known for some time that general relativity predicts the possible existence of 'wormholes', topological tunnels which connect distant parts of the Universe (e.g. Fuller & Wheeler 1962; see also Morris & Thorne 1988, and references therein). In principle, such tunnels through spacetime might permit FTL travel, in the sense that a spaceship might use them as shortcuts to travel between two points faster than a beam of light could do if it ignored the wormhole. Fuller & Wheeler (1962) explain it thus:

> There are alternative routes for a disturbance to pass from a point *A* to a point *B*. A disturbance going by one of these routes as fast as it can – at the speed of light* – may arrive only to find itself outpaced by a disturbance which has gone through a handle or 'wormhole' and a much shorter path.

Morris & Thorne (1988) have given a very useful summary of the various types of wormhole permitted by general relativity, together with a discussion of the theoretical and practical objections to their use for interstellar travel. The main problem appears to be that most wormhole solutions are unstable against small perturbations, and therefore any attempt to pass something through (even a photon, never mind a space vehicle) would cause the wormhole to collapse before whatever entered had a chance to emerge from the other side. This objection was effectively eliminated by Morris & Thorne (1988), who identified solutions to Einstein's equations which describe traversible wormholes: that is to say, wormholes that may remain permanently open, which would impose only modest tidal forces and radiation fluxes on a spaceship passing through, and which would permit two-way travel with rapid transit times as seen by both the travellers themselves and external observers.

In order to keep a traversible wormhole open, Morris & Thorne (1988) have shown that it will be necessary to thread it with matter (or fields) having a non-zero (i.e. non-vacuum) stress-energy tensor (for a definition of this parameter see Chapter 5 of Misner, Thorne & Wheeler 1970). Moreover, this material must have the unusual property that its tension exceeds its total mass-energy density†, giving it the peculiarity of appearing to have a negative mass-energy density as observed from certain frames of reference. Such material is said to be 'exotic', and until relatively recently reliance on it would have been sufficient for most physicists to deny the possibility of traversible wormholes.

* Fuller & Wheeler have here implicitly discounted the possibility of tachyons; the discussion in Section 2.1 shows that this may not be reasonable, but this does not affect the essential point about wormholes.

† Both tension (force per unit area) and energy density (ρc^2) have dimensions of $\mathrm{ML^{-1}\,T^{-2}}$, so they may be compared in this way.

However, Morris & Thorne (their Section III F(2); see also Morris, Thorne & Yurtsever 1988) have pointed out that modern quantum field theory does permit the existence of local negative energy densities in the quantum vacuum (for a thorough review of the properties of which, see Aitchison 1985). Indeed, negative vacuum energies have long been predicted to have observable consequences, of which perhaps the most famous is the Casimir effect (the attractive force between two closely spaced conducting plates which results from the exclusion of vacuum fluctuations with wavelengths longer than the plate separation; Casimir 1948, see also Harris 1972, Aitchison 1985). The various experimental attempts to detect the Casimir effect have been reviewed briefly by Forward (1984; see also Sukenik *et al.* 1993) and, while it is true that these experiments have proved to be very difficult, they are in at least qualitative agreement with the theoretical predictions. Moreover, the analogous force between isolated atoms and a conducting plate (usually known as the Casimir–Polder force, after Casimir & Polder 1948) has now been directly measured, and found to be in excellent agreement with the theory (Sukenik *et al.* 1993). Thus, our present understanding of the quantum vacuum means, in the words of Morris & Thorne (1988), that we "should not blithely assume the impossibility of the exotic material that is required for the throat of a traversible wormhole".

As for the construction of a traversible wormhole, Morris & Thorne suggested that it may in principle be possible to exploit another property of the vacuum, namely its probable foam-like topology on scales of the order of the Planck length (10^{-33} cm) (Wheeler 1957, 1962; see also Misner *et al.* 1970, Section 44.3). Morris & Thorne put it thus:

> One could *imagine* an exceedingly advanced civilization pulling a wormhole out of this submicroscopic, quantum mechanical, spacetime foam and enlarging it and moving its openings around the Universe until it has assumed the size, shape, and location required for some specific interstellar travel project (their italics).

Once constructed, such a wormhole would probably be unstable, and Morris and Thorne suggested that continuous monitoring of its structure might be necessary, together with the application of feedback forces to prevent the growth of instabilities.

Finally, it is necessary to point out that, just as was the case for tachyons, it is possible to contrive situations in which travel through wormholes would appear to violate the principle of causality (Morris *et al.* 1988). This led Hawking (1992) to put forward what he calls the "chronology protection conjecture", namely that "the laws of physics prevent the appearance of closed time-like curves," thereby making time travel impossible. However, we again reiterate that these arguments concern time travel, and not FTL space travel *per se*; Hawking's conjecture might still permit travel through wormholes in those cases where causality violation would not occur.

2.3 *Warp Drive*

The debate concerning the feasibility of FTL travel within the context of general relativity has recently taken a new turn with the work of Alcubierre (1994). Alcubierre attempts to demonstrate the theoretical possibility of distorting spacetime ahead of and behind a space vehicle, in such a way as to permit it to travel at superluminal velocities as measured by observers outside the distorted region – quite literally a 'warp drive'! By distorting spacetime in this way, wormholes are not required in order to achieve FTL travel. As Alcubierre puts it:

> the fact that within the framework of general relativity and without the need to introduce non-trivial topologies (wormholes), one can actually make ... a round trip in an arbitrarily short time as measured by an observer that remained at rest will probably come as a surprise to many people.

While this may indeed come as a surprise to those brought up on special relativistic strictures against FTL travel (strictures which are themselves at least questionable, Section 2.1), Alcubierre points out that a not dissimilar state of affairs is actually orthodox in modern cosmology. During the inflationary period of the early Universe the relative speed of separation of co-moving observers (defined as the rate of change of proper spatial distance divided by proper time) was much larger than the speed of light, where "the enormous speed of separation comes from the expansion of spacetime itself". Alcubierre's 'warp drive' would rely on a different manifestation of the same phenomenon, albeit one somehow contrived artificially.

Just as is the case with wormholes, Alcubierre demonstrates that exotic matter (i.e. material possessing a negative energy density) is required for his warp drive solution. As we saw in Section 2.2, however, this may not be a fundamental objection. Alcubierre himself draws attention to the implications of the Casimir effect, and concludes that "the need for exotic matter therefore doesn't necessarily eliminate the possibility of using a space time distortion ... for hyper-fast interstellar travel".

At the end of his paper, Alcubierre notes that while the particular spacetime distortion he has described contains no closed causal curves (and therefore does not lead to time travel), it might be possible to construct a spacetime which does using the same basic ideas. This would again seem to raise the spectre of causality violation, and reinforces the probable need for something along the lines of Birch's (1984) "censor field" or Hawking's (1992) "chronology protection conjecture" if FTL travel is to be compatible with the principle of causality.

2.4 *The question of practicality*

It is of course true that no one currently has any idea how to exploit the ideas sketched above in order to achieve FTL travel in practice. No one has any idea how to build a warp drive, or construct a wormhole, or turn a spaceship and its crew into tachyons. However, the essential point is that achieving FTL travel may be theoretically possible even within the laws of physics as currently understood. Moreover, there is no reason to assume that our present understanding of the physical world is anything like complete – the whole history of scientific discovery leads us to expect that major new discoveries lie ahead, some of which (especially any relating to higher dimensions, the nature of spacetime, quantum gravity, and the various 'goings on' in the quantum vacuum) might have a significant bearing on the possibility and practicality of FTL travel.

In any case, if FTL travel should turn out to be theoretically possible, the question of practicality is essentially a technological one, which we are free to speculate might be solved by a sufficiently advanced civilization.

3 THE IMPLICATIONS OF FTL INTERSTELLAR SPACE TRAVEL

We now turn to a discussion of the implications of FTL interstellar space travel should it prove to be attainable. We can identify significant implications for the scientific exploration of the Universe, for the cultural development of humanity, for the colonization of the Galaxy, and for the search for extraterrestrial intelligence (SETI).

3.1 *Implications for scientific exploration*

It is easy to see that FTL interstellar space travel would have profound implications for the scientific exploration of the Galaxy. In an earlier paper (Crawford 1990) I have argued that, just as our knowledge of the Solar System has been vastly enriched by our ability to send space probes to other planets, so the rest of astronomy would benefit enormously if it were possible actually to visit more distant astronomical objects. Moreover, it is not only astronomy that would benefit, or even the physical sciences generally, but essentially every scientific discipline. In particular, we may expect that the science of biology would undergo explosive new developments resulting from the discovery and study of alien lifeforms.

It is true that FTL travel is not a prerequisite for interstellar space travel, and that a great deal of useful scientific exploration could be carried out using vehicles travelling at sub-light, semi-relativistic, velocities (for reviews of possible sub-light propulsion methods see Mallove & Matloff 1989 and Crawford 1990). However, while sub-light interstellar travel would permit scientific data to be returned from the nearer stars in a matter of decades, many of the most interesting astrophysical objects (O type stars, red giant stars, interacting binary stars, planetary nebulae, galactic nebulae, supernova remnants, star-forming regions, neutron stars, black hole candidates etc.) lie at such great distances (anywhere from a hundred parsecs up to several kiloparsecs) that direct investigation based on sub-light interstellar travel would take millennia.

On the other hand, the prospects for the direct investigation of distant astronomical objects would be immeasurably improved if significant FTL velocities could be attained. In this case, a small number of FTL interstellar probes (and automatic probes would be sufficient for most purposes) would be able to make *in situ* observations of representative examples of a wide range of astrophysical objects, perhaps in a matter of years. Moreover, if, as hinted at by Alcubierre (1994), round-trip travel times could be made arbitrarily short, there would be no reason to restrict destinations to within the Milky Way Galaxy, making it possible to visit representative examples of some of the most important extragalactic objects.

Needless to say, all this would revolutionize the way in which astronomy is conducted. Instead of applying for time on telescopes, astronomers would find themselves applying for time on FTL interstellar probes, in the certain knowledge that the information returned would be far more reliable (i.e. far less model-dependent) than anything that could be provided by a telescope. And if this seems far-fetched, readers might like to reflect that it is exactly analogous to the situation that planetary astronomers have been in since the dawn of the space age.

It is necessary to point out, however, that while the availability of FTL travel would vastly increase our astronomical knowledge, the huge number of interesting objects in the Galaxy (never mind the rest of the Universe) is such that even this technology is most unlikely to answer all our astrophysical questions overnight. FTL probes would provide a very powerful means of answering specific questions about specific astronomical objects, even if these happened to lie on the other side of the Galaxy. But with 10^{11} stars, it would be impossible to make a detailed survey of the whole Galaxy in a reasonable time, even if the travel time itself was arbitrarily short. For example, if it took each probe a week to make scientific measurements at a given location (and, depending on what was to be studied, many investigations would surely require a lot longer than this), it would still take a thousand probes a million years (or a million probes a thousand years) to explore each star in the Galaxy, even if travel between each star was instantaneous!

3.2 *Implications for future cultural developments*

It is not only science that would benefit from an interstellar spaceflight capability, but the whole cultural life of humanity. Indeed, I have argued elsewhere (Crawford 1993) that the flood of new discoveries, and new perspectives, resulting from an ambitious space programme, and especially from a programme of interstellar exploration, would help humanity avoid the cultural stagnation predicted for the world by Fukuyama (1992).

While it is true that many of these cultural benefits would follow from even a sub-light exploration of the nearer stars, we may expect that the cultural, like the scientific, consequences would be vastly richer if FTL interstellar travel proves possible. Whereas reliance on sub-light interstellar travel would mean that new sources of cultural inspiration would arrive from the nearest stars slowly over many decades, FTL travel would mean that new knowledge (including knowledge of alien lifeforms and, perhaps, alien cultures) would arrive from all over the Galaxy on a much shorter timescale. While the social and cultural responses to this situation are completely unpredictable, it is hard to see how it could fail to have a profoundly stimulating influence on the art, science and philosophy of the time.

3.3 *Implications for Galactic colonization*

The implications of FTL travel for the human colonization of the Galaxy depend very strongly on whether our own species turns out to be the first to discover and exploit the technology. Following the arguments of Hart (1975) and Tipler (1980), we shall here tentatively assume that humanity is alone in the Galaxy (although, as we shall see in Section 3.4, the possibility of practical FTL travel may make it necessary to re-examine the strength of this assumption).

It will be convenient to break this discussion into two parts, dealing first with the consequences for Galactic colonization timescales, and then with the implications for the development of interstellar-scale social structures.

3.3.1 *Galactic colonization timescales*. If the Galaxy is indeed lacking in other intelligent technological species, then it is very likely that human beings (or our evolutionary descendants) will eventually colonize a significant fraction of it. This conclusion does not depend on the feasibility of FTL travel, as sub-light interstellar spaceflight will be quite adequate for the task (Hart 1975). Thus, barring any major disasters which may prevent us from leaving our home world within the next century or so, humanity may expect eventually to inherit the Galaxy.

The extent to which the timescale of galactic colonization would be shortened by the availability of FTL travel depends on the colonization strategy adopted, and, in particular, on the ease with which FTL starships could be mass-produced. In models of colonization which rely on sub-light interstellar travel, it is generally assumed that a colonization wavefront advances through the Galaxy as a result of each new colony sending out colonists of its own. In this case it can be shown (e.g. Newman & Sagan 1985) that the speed of the colonization wavefront can be approximated by

$$v_{\rm col} = \frac{D}{(t_{\rm travel} + t_{\rm con})}, \qquad (4)$$

where D is the average spacing between colonies, $t_{\rm travel}$ is the travel time between colonies ($t_{\rm travel} = D/v_{\rm s}$, where $v_{\rm s}$ is the ship speed), and $t_{\rm con}$ is the consolidation time that each colony requires before it is able to establish colonies of its own.

It can be seen from Equation (4) that $v_{\rm col}$ will in general be much less than $v_{\rm s}$ because of the time required by each colony to establish itself. It is easy to see that for $t_{\rm con} \sim 50$ years (which must surely be optimistic) this term dominates if $v_{\rm s} \geqslant 0{\cdot}1c$. Putting $D = 4$ light-years, and $t_{\rm con} = 50$ years, we get $v_{\rm col} = 0{\cdot}04$ light years year^{-1} for $v_{\rm s} = 0{\cdot}1c$. This is increased by less than a factor of two (to 0·07 light years year^{-1}) for space vehicles travelling at the speed of light ($v_{\rm s} = c$), and is only a fraction higher (0·08 light years year^{-1}) for the ultimate ($v_{\rm s} = \infty$) FTL space ships. As the Galaxy is approximately 10^5 light years in diameter, this model would predict a colonization timescale of the order of 10^6 years, regardless of whether the space vehicles used to achieve it travel at a tenth of the speed of light, or infinitely fast!

On the other hand, if it were possible to mass-produce large numbers of FTL space vehicles in the Solar System, galactic colonization could proceed without having to wait for colony worlds to establish their own interstellar spaceflight capability. In this case the resulting colonization timescale might be very much shorter, as it would be possible to colonize other star systems just as quickly as we could build the starships. For example, if we were able to do this at the rate with which we currently produce motor cars (of the order of 10^7 year^{-1}) then the colonization timescale would be 10^4 years if each space vehicle was used only once (and $\leqslant 10^3$ years if each vehicle was reusable with a turn-around time of a few decades).

3.3.2 *Interstellar social structures*. Given only sub-light travel and communication, it would be quite impossible to maintain any significant degree of uniformity on the human expansion into the Galaxy. If the speed of interstellar travel were very much less than that of light, every colonized planetary system would, of necessity, be left to evolve on its own, both socially and biologically. Even if very relativistic spaceflight were employed, though it might then be possible for colonies up to a few tens of light years apart to remain loosely affiliated, on larger scales it would seem that the pattern must lose coherence.

On the other hand, if FTL interstellar travel were possible, and especially if travel times could indeed be made almost arbitrarily short, it would then be possible to maintain social (and perhaps also biological) coherence over large, perhaps arbitrarily large, interstellar distances. This would make possible social, cultural and political institutions on interstellar (perhaps even Galaxy-wide) scales, in a way which would be quite impossible otherwise. In particular, it would permit some degree of central political control over the entire colonization process: FTL travel would, at least in principle, make possible Galactic Empires (e.g. Asimov 1950) and/or Federations (e.g. Roddenberry 1966), although it must be admitted that at some point the sheer number of colonies would pose a major problem in political organization, and one suspects that a federal structure would cope much better than a highly centralized imperial one.

The possibility of interstellar political institutions will be seen to be particularly important if we consider the interaction of humanity with planets harbouring indigenous lifeforms (and here I have in mind worlds inhabited by micro-organisms, as was Earth for most of its history, as much as anything more complicated). We may all agree that interference with such worlds would be morally wrong, but it seems very unlikely that a sub-light (and therefore necessarily unstructured) human expansion into the Galaxy could long maintain a policy of non-interference towards any alien lifeforms which might be encountered. Only the interstellar institutions made possible by FTL travel would permit the widespread implementation of such a policy.

3.4 *Implications for SETI*

In Section 3.3 we were concerned with the future of humanity and, for simplicity, made the assumption that we are currently the only technologically advanced civilization in the Galaxy. Although we do not yet know whether this assumption is true, fairly persuasive arguments have been advanced in its favour (Hart 1975, Tipler 1980). However, we shall see that these arguments may need to be modified if FTL travel is allowed.

As pointed out by Hart (1975), the most significant observational fact concerning extraterrestrial intelligent beings (ETI) is their apparent absence from the Solar System. Hart identified a number of possible explanations for this, of which the most important are (a) 'physical explanations' (e.g. interstellar space travel is impossible); (b) 'sociological explanations' (e.g. ETI are not motivated to explore the Galaxy, or, if they are, they agree not to interfere with inhabited planets); and (c) ETI either do not exist or are extremely rare. After dismissing the various physical and sociological explanations, Hart concluded that we are in all probability alone in the

Galaxy. The same conclusion was reached by Tipler (1980), who showed that the first spacefaring species to appear would be able to colonize the Galaxy in a time that is short in comparison with that required for biological evolution, and that all subsequent civilizations would find the Galaxy fully occupied (if indeed the evolution of other intelligent species was not curtailed by the colonization activities of the first). As our own evolution appears not to have been interfered with, and as we see no evidence that the Galaxy has been colonized by others, Tipler argued that we must be the first (and therefore only) technological civilization in the Galaxy.

There is little doubt that Hart and Tipler are correct in arguing that interstellar space travel will be technically possible for an advanced civilization. Indeed, as discussed in Section 3.1, several semi-relativistic ($v \sim 0{\cdot}1c$) propulsion technologies can already be identified (e.g. Mallove & Matloff 1989, Crawford 1990). Thus, the conclusion that we are alone in the Galaxy rests on rejecting the sociological explanations identified by Hart (1975). The most important of these is the 'zoo hypothesis' advanced by Ball (1973; cf. also the *Codex Galactica* of Shklovskii & Sagan 1966), according to which ETI may already be here, observing events on Earth but neither interfering nor letting their presence be known to us.

As any civilization which has developed an interstellar spaceflight capability must be supposed to have the technological competence to remain hidden should they wish to do so, there are no physical grounds for rejecting the zoo hypothesis. On the other hand, as Hart points out, there are clear 'sociological' objections to this idea because it implicitly assumes that an ETI civilization would be able to maintain a non-interference policy indefinitely at a location very distant from its political centre. Furthermore, it assumes that every spacefaring civilization in the Galaxy must agree on essentially the same non-interference policy.

It is in this context that consideration of FTL interstellar travel has its greatest implications for the SETI debate. As we saw in Section 3.3.2, FTL travel would make possible social and political institutions on an interstellar scale, something that is almost certainly impossible given only sub-light travel and communication. In particular, FTL travel would make it possible for a Galactic civilization to maintain a policy of non-interference (a 'Prime Directive' in *Star Trek* parlance) which would be quite unattainable otherwise. Thus, I suggest that the zoo hypothesis can only be a valid explanation for the apparent absence of extraterrestrials if FTL travel is allowed.

It follows that Hart's (1975) conclusion must be modified: the apparent absence of ETI in the vicinity of the Earth means either that ETI are extremely rare in the Galaxy (as he argues), or that ETI are common, but that, having discovered how to travel and communicate faster than the speed of light, they have formed a Galactic civilization able to maintain a common, and long-lived, policy of non-interference towards non-member worlds. Clearly, if the latter scenario turns out to be the case, there will be no future human colonization of the Galaxy of the kind discussed in Section 3.3; the best that we could hope for would be to be admitted to an already existing interstellar civilization, presumably when and if we meet some criteria for membership.

4 CONCLUSIONS

There are some reasons for believing that FTL interstellar travel may be permitted by the laws of physics as currently understood. However, there is a major philosophical difficulty owing to the apparent possibility of causality violation, and it is almost certainly necessary to postulate some (as yet undiscovered) physical principle which would prevent time travel while permitting FTL space travel in those circumstances where causality is not at stake.

If FTL space travel could be achieved, it would be possible to make *in situ* observations of a wide range of astronomical objects, most of which would take many thousands of years to reach at sub-light speeds. This would lead to a vast increase in scientific knowledge, and might also be expected to have significant, though unpredictable, cultural consequences. However, while FTL travel may make the size of the Galaxy almost irrelevant, the sheer number of objects it contains would ensure that its exploration and colonization would probably still take between thousands and millions of years, depending on the rate at which FTL space vehicles could be constructed.

Faster-than-light travel would permit the creation of social and political institutions on an interstellar scale, which would probably be impossible otherwise. This would make possible the implementation of a non-interference policy towards alien lifeforms, and is important not only for consideration of possible future human interactions with extraterrestrial life, but also for the SETI debate. Clearly, if other technological civilizations have discovered FTL travel, thereby enabling them to adopt a policy of non-interference towards us, one of the key objections to the 'zoo hypothesis' would be removed. In this case, the otherwise persuasive arguments of Hart and Tipler that we are alone in the Galaxy would lose some of their force.

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