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Against the Use of Power Law Luminosity Functions for ET Beacons

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Abstract. Not infrequently it is suggested that the luminosity function (the distribution of the space densities of objects as a function of their luminosities) of extraterrestrial transmitters can plausibly be modeled as a power law, $L^{-\alpha}$, of the luminosity L (Drake 1973; Gulkis 1985; Lampton 2002). This assertion is usually motivated by analogy to the luminosity function for stars in the solar vicinity, which can be (very) roughly modeled as such a power law Fig. 1, data from Mihalas and Binney (1981). The argument then continues that if the power law is sufficiently flat ($\alpha < 1.5$), then a flux limited sample of transmitters will be dominated by the most luminous, since their relative scarcity is more than made up by the much larger volume in which they can be detected. This is an extreme example of the infamous *Malmquist bias* (Mihalas & Binney 1981). It is then concluded that if the distribution of ET transmitters were to have such a flat distribution, then the seemingly obvious SETI search strategy of starting with the nearest stars and working outward would be incorrect, and, since we do not know the value of α it makes sense to "hedge" our bets by performing all-sky SETI searches even if such searches are much less sensitive.

1. Why the Luminosity Function for Beacons Will Not be a Power Law

Looking at Fig. 1, one cannot but note that the luminosity function for stars is not, in fact, very well represented by a power law. But it is very broad, and that is, fundamentally, what really matters: we know comparatively little about the least luminous stars because there are very few of them in even the largest flux-limited samples. Why is this distribution so broad? The processes that form stars are believed to involve random aggregation and fragmentation processes. The resulting mass distribution spans about three orders of magnitude; the extremely steep dependence of luminosity with mass for stars then expands the range of stellar luminosity to about 11 orders of magnitude. In other astrophysical contexts random processes produce power law distributions that also span many orders of magnitude, even without the "stretch" provided by the stellar luminosity-mass relationship (interstellar grains, Frisch et al. 1999; impactor sizes, Werner et al. 2002; cosmic ray energies, Wolfendale 1983).

Current SETI systems are not sensitive enough to detect "leakage" radiation from ET technologies, even if they were (as seems unlikely) as dreadfully

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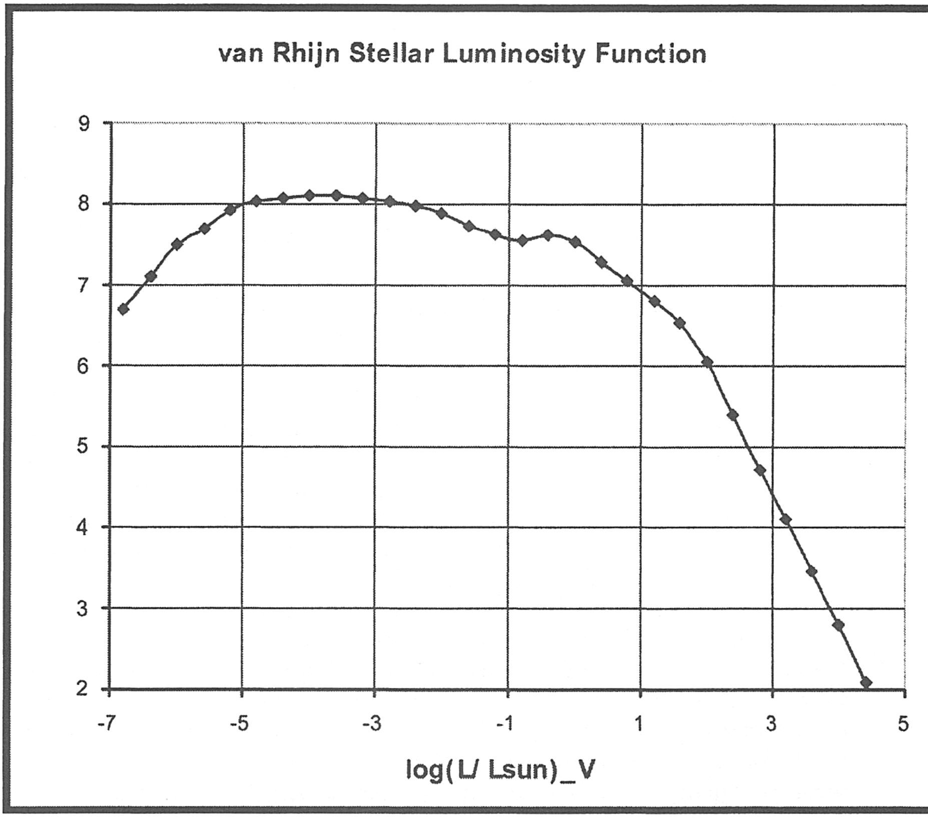

Figure 1. The van Rhijn Stellar Lunimosity Function.

inefficient as our own, so for the present SETI systems must be considered primarily as searches for transmitters *designed* to serve as interstellar beacons. What kind of distribution function should we expect for the effective isotropic radiated power (EIRP) of such beacons? Figure 2 (the "initial mass function" for passenger vehicles, U.S. Environmental Protection Agency 1991) and Fig. 3 (floor areas of single family housing, U.S Census Bureau 2001) are some examples of the distributions of 'sizes' for some designed objects here on Earth. These distributions are not power laws, nor are they broad when compared to the astrophysical distributions discussed above. The reason is obvious: these objects have been designed to serve a purpose. The same will be true for ET beacons. The designer of such a beacon will not have nearly as precise a design goal as the designer of a passenger vehicle possesses, yet it is not unreasonable to expect at least some constraints on the design. The first thing that would become obvious to such a hypothetical designer is the gross inefficiency of using an isotropic (or, to be more precise, an untargeted) beacon. We will address this below. But making the assumption that they do want to build an untargeted beacon, our own experience with the receiving end suggests a range of plausible transmitter powers. Clearly a fairly substantial beacon is needed to do any good. Even a fairly big search system such as Cyclops could not do a very good job of detecting transmitters with EIRP of $< 10^9$ W (Oliver 1972). On the other hand, even at our current, "new kid on the block" level, several of our searches can detect 10^{14} W at 1000 ly. So it is plausible that interstellar beacons, to do their job, will have EIRP somewhere in the range $10^{11\pm3}$ W. Given the number of factors that will enter into the ET engineers' design requirements, it is plausible that the resulting distribution will be centrally concentrated, that is to say roughly Gaussian. However, for the luminosity function of the beacons to be considered to be *broad*, it must span a range much greater than the range in the geometric dilution factor ($1/4\,\pi\,r^2$). For our own Galaxy, this factor has a range of about $(10^5/4)^2 \sim 10^9$; for those wishing to consider extragalactic beacons, the range is much much larger. Since the range of the dilution factor is much larger than the plausible range of beacon luminosities, the appropriate approximation to "astrophysical accuracy" will be a delta function rather than a power law even IF the actual distribution were a power law over a luminosity range of order 10^6.

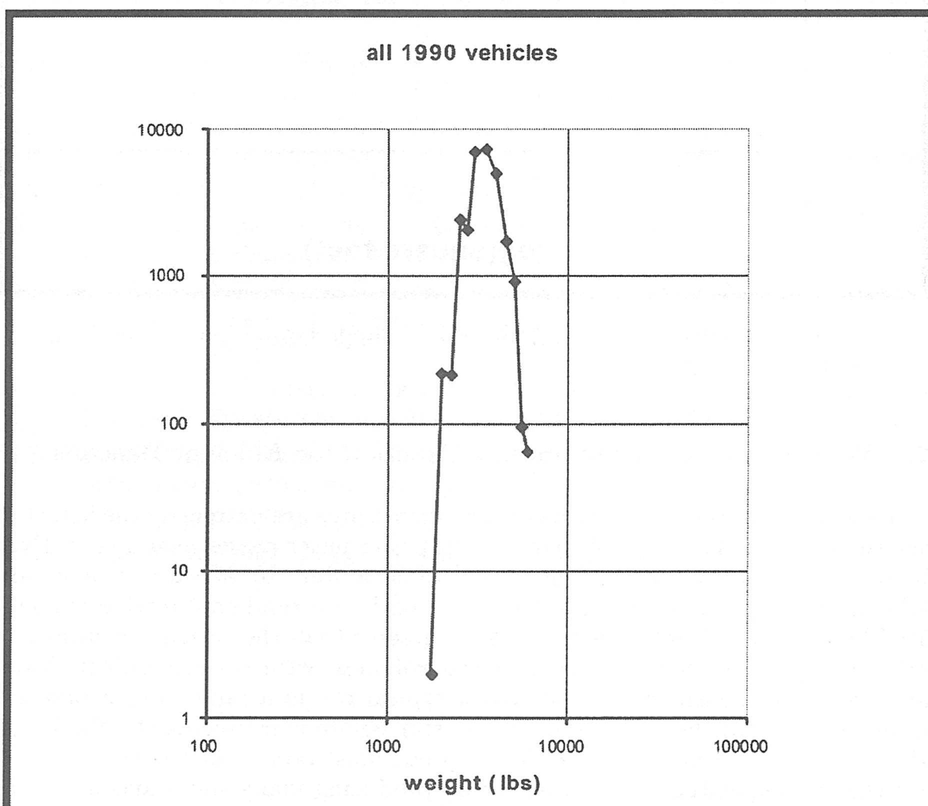

Figure 2. Weight Distribution of passenger vehicles sold in the U.S.A. during 1990.

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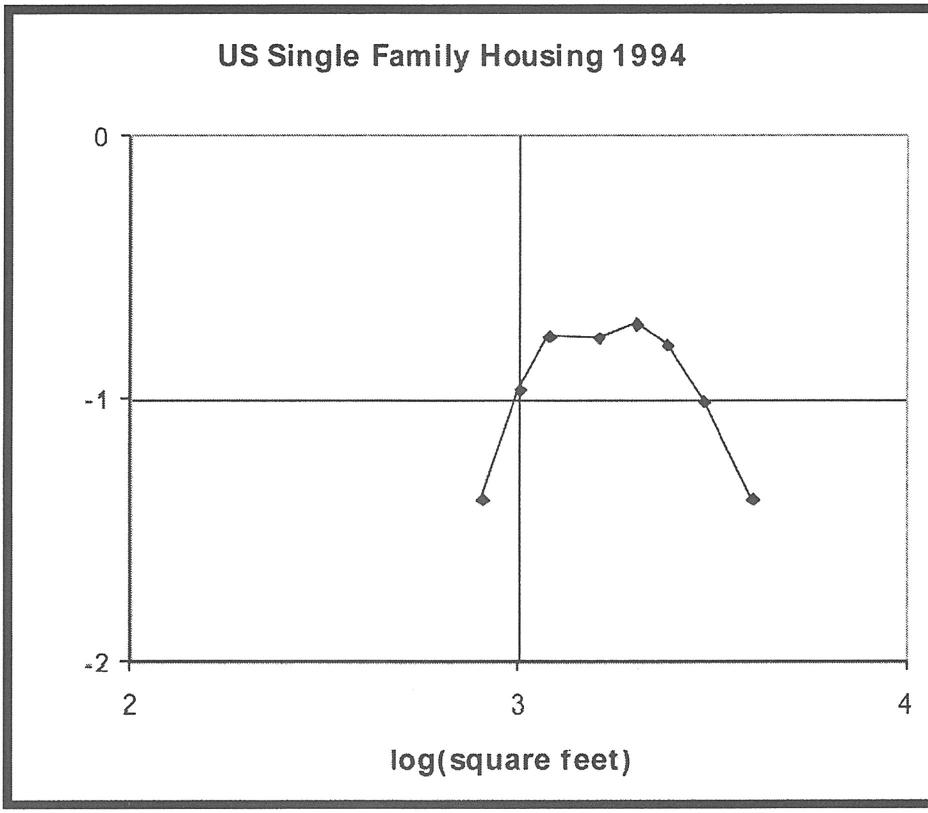

Figure 3. Distribution of floor area of single family housing built in the U.S.A. in 1994.

2. Why There Is No Luminosity Function for Efficient Beacons

The class of non-targeted beacons considered above are extremely inefficient in the sense that virtually all of their output power never passes near a star. Even if we adopt a fairly large target zone around a star, 10 AU across, and take all stars to be good targets, the mean free path in a random direction is about 10^{10} ly at the local stellar density, vastly greater than the actual dimensions of our Galaxy. If we consider cosmological volumes, with correspondingly lower average stellar densities, we find that a typical ray in a random direction will never pass within the target zone of any star before it intercepts the Big Bang. Hence for any reasonable power efficiency one must target one's beacon at stars – either by sequential illumination or by producing many simultaneous beams (from a phased array).

The use of a luminosity function makes an implicit assumption that the luminosity of an object (in this case a beacon) is a property of the object. This assumption is violated for a targeted beacon, because the luminosity depends both on the object (transmitter) and on the observer. For a given targeted beacon, if we are on the target list we see a large EIRP, but if we are not, then we see nothing. In a statistical sense, this effect might be overcome, were it not that it is very likely that the probability of a star being on the target list of a beacon will be related to its distance from the beacon. Personally, I would be very surprised indeed if our star were on the target list of a beacon located outside our own Galaxy. (Note that targeting our entire Galaxy at once does not improve the efficiency, since virtually all the power still misses the stars.)

Even worse, an maximally-efficient beacon will not even try to deliver a fixed EIRP to each target but rather a fixed flux (W/m^2) at the target. In this case there is no $(1/r^2)$ effect at all, and the concept of a single luminosity characterizing the beacon is useless.

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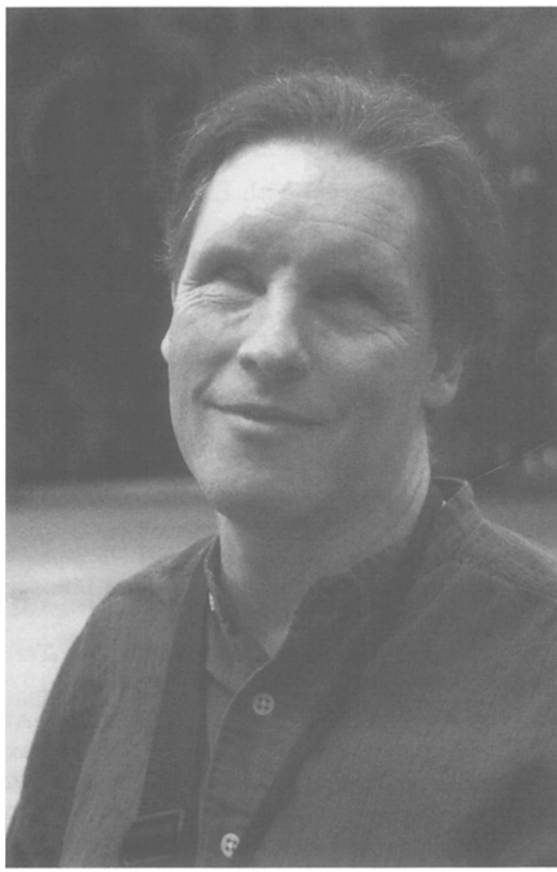

Kent Cullers (*photo: Seth Shostak*)