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The benefits and harm of transmitting into space

Jacob Haqq-Misra [a,*], Michael W. Busch [a,b], Sanjoy M. Som [a,1], Seth D. Baum [a,c]

[a] *Blue Marble Space Institute of Science, PO Box 85561, Seattle, WA 98145, USA*
[b] *Department of Earth and Space Sciences, University of California Los Angeles, 595 Charles Young Dr. E, Los Angeles, CA 90095, USA*
[c] *Department of Geography, Pennsylvania State University, 302 Walker Building, University Park, PA 16802, USA*

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ABSTRACT

Deliberate and unintentional radio transmissions from Earth propagate into space. These transmissions could be detected by extraterrestrial watchers over interstellar distances. This article analyzes the harm and benefits of deliberate and unintentional transmissions relevant to Earth and humanity. Comparing the magnitude of deliberate radio broadcasts intended for messaging to extraterrestrial intelligence (METI) with the background radio spectrum of Earth, we find that METI attempts to date have much lower detectability than emissions from current radio communication technologies on Earth. METI broadcasts are usually transient and several orders of magnitude less powerful than other terrestrial sources, such as astronomical and military radars, which provide the strongest detectable signals. The benefits of radio communication on Earth most probably outweigh the potential harm of detection by extraterrestrial watchers; however, the uncertainty regarding the outcome of contact with extraterrestrial beings creates difficulty in assessing whether or not to engage in long-term and large-scale METI.

1. Introduction

Does transmitting radio messages into space pose a risk to human civilization? Efforts to send messages to potential extraterrestrial watchers[2] have raised concerns that such actions may provoke unwanted attention. Similar transmissions into space, though unintentional, occur as a result of radio communication on Earth, and pose similar risks. This paper analyzes deliberate and unintentional transmissions into space and the degree to which these activities could entail benefits or harm to Earth and humanity.

Electromagnetic waves have been used to communicate for over 100 years. Television broadcasts, mobile phone conversations, satellite transmissions, and military, civil and astronomical radars all use some part of the electromagnetic spectrum—particularly radio and microwave wavelengths—to transmit encoded information from a sender to a watcher. These technologies have transformed communication across the globe and have enabled human spaceflight and robotic exploration of the solar system. Nearly all terrestrial electromagnetic transmissions used for communication also radiate into space. Although such signals decrease in intensity as they move away from Earth, this *leakage radiation* can be detected over interstellar distances with a sufficiently sensitive telescope [1,2].

Cocconi and Morrison [3] first suggested that a search for interstellar radio transmissions could uncover evidence of intelligent extraterrestrial life elsewhere in the galaxy. Over 50 years later, the search for extraterrestrial intelligence (SETI) has found no evidence of artificial signals in space, although efforts to broaden the search continue [4]. Another way to search for intelligence elsewhere in the universe involves transmitting messages toward target star systems. This is known as "messaging to extraterrestrial intelligence" (METI) [5]. The ultimate goal of METI is to transmit a signal that is eventually received by an extraterrestrial civilization, although the vast distances between stars render any conversation a multi-generational project [6]. Nevertheless, a handful of attempts at METI have been made over the past half century with messages increasing in size and complexity [7]. These efforts can be considered as symbolic or demonstrations of human technology rather than serious efforts to converse with extraterrestrial civilizations.

Both deliberate METI signals and unintentional leakage radiation contribute to the overall radio emission from Earth.[3] There has been concern that this signature of our technological civilization could

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* Corresponding author. Tel.: +1 814 441 4792.
E-mail address: jacob@bmsis.org (J. Haqq-Misra).

[1] Present address: Exobiology Branch, NASA Ames Research Center, Moffett Field, CA 94035, USA.

[2] Throughout this paper we use the term *watcher* to designate the recipient of an electromagnetic signal, although the term *observer* can be used interchangeably.

[3] Hereafter, we will use the term *radio* to describe electromagnetic radiation at frequencies greater than 10–30 MHz (which is the cutoff frequency for radiation to penetrate the ionosphere) and less than ~100 GHz (where atmospheric absorption becomes prohibitively high). This range of frequencies includes *microwaves* as well as lower radio frequencies.

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constitute a risk because it reveals our location in the galaxy to any potentially hostile extraterrestrial civilizations [8–18]. There have even been calls for a moratorium on deliberate METI transmissions until international agreements on how to proceed have been reached [19]. Others have argued that METI broadcasts do not pose a significant risk [7,20–23] because any extraterrestrial watchers would be able to establish the presence of life on Earth by the spectrum of reflected ultraviolet, optical, and near-infrared sunlight into space from the surface and the atmosphere. An extraterrestrial watcher could also potentially learn of our existence by detecting artificial night-time lighting of large urban areas [24].

Optimists suggest that contact with extraterrestrials could bring about great benefits for humanity [25], while others note that contact with technological civilizations has often resulted in the collapse of stone-age societies on Earth [14]. Given the potential consequences [26], if the risk from transmission into space is not zero, should transmissions into space be permitted, regulated or banned? If human activities can be detected across astronomical distances, then should humanity cease or attempt to disguise such actions? Does METI significantly increase risks to Earth and human civilization? These questions have been raised repeatedly in the research literature as well as in media and political coverage of SETI and METI research. This paper addresses these questions by reviewing existing knowledge of the Earth's radio signature, which includes the relative strength of signals potentially detectable over interstellar distances. We then develop an analytical framework for evaluating the consequences of transmission and discuss this in the context of existing policies and protocols.

2. Detectability of radio transmissions from Earth

Before about 100 years ago, Earth was "radio quiet" with no significant emission of radio waves compared to other objects in the Solar System (particularly the Sun and the gas giant planets). The development of radio transmitters initiated a new era where the technological activity of humans altered the electromagnetic spectrum of Earth. Other changes in Earth's spectrum driven by its biosphere include the rise in atmospheric oxygen about 2.4 billion years ago [27] and the proliferation of photosynthesis [28]. However, these changes to the spectrum primarily occurred in the near-infrared to ultraviolet regions of the electromagnetic spectrum, where the planet is brightest. By contrast, in the radio and microwave regions of the electromagnetic spectrum, Earth was previously very faint.

Earth's radio leakage comes from many different sources, which ranges from active cell phones to television and radio broadcasts to high-power radars used for astronomy and by the military.[4] All these signals travel through space at the speed of light, so television broadcasts that occurred 20 years ago are now 20 light years away from Earth (for comparison, Proxima Centauri, the closest star to the Sun, is 4.2 light years away). Leakage radiation from television transmitters occurs roughly in a sphere surrounding Earth, so that the distance at which Earth's radio signature can be detected has sometimes been termed the *radiosphere*. However, radar beams are the strongest source of radio leakage and spread into space from Earth like pins on a pincushion, with most of the beams (pins) concentrated in the northern hemisphere. The intensity of signals from Earth decays with distance according to an inverse square law, but prior analyses have shown that these faint signals could still be detected at astronomical distances by a sensitive receiver and a sufficiently large antenna [1,2].

To determine if a given transmission can be detected at a given distance, some assumptions must be made about the receiving radio telescopes. To quantify the relative detectability of different types of leakage, we assume a watcher equipped with a radio telescope or radio telescope array with high angular and frequency resolution. This is because, with low resolution in either angle or frequency, background galactic radio emission dominates the leakage radiation. This is quantified by comparing the spectral flux density (power per unit area per unit frequency) of the galactic background at a watcher's antenna with the flux of the leakage from Earth [29]. On the other hand, with high resolution only a very small fraction of the radio background overlies the leakage radiation and only the properties of the leakage radiation itself matter. In this case, a watcher will be able to detect and potentially interpret signals from Earth as long as the number of photons per unit area of antenna per bit of data is significantly greater than the unavoidable thermal noise in their receivers. Here we can express a single bit of data in terms of the bandwidth B of the signal as a time equal to $1/B$. The thermal noise in the receiver's detectors in this time and bandwidth will be proportional to B, meaning that broadband signals—such as television transmissions, cellphone networks and wireless Internet—are more difficult to detect.[5]

The relevant quantities for a transmitting antenna are the gain (effectively the fraction of the sky over which the antenna transmits), the transmitter power, and the choice of broadcast frequency. For a transmitting antenna with gain G and power P that operates at frequency ν, the ratio of the signal to the receiver noise per unit area of the watcher's *receiving* antenna is proportional to $PG/B\nu r^2$, where r is the distance from the transmitter to the receiver. There is therefore a limiting distance r_l for detectability of

$$r_l \propto P^{1/2} G^{1/2} B^{-1/2} \nu^{-1/2}. \tag{1}$$

Note that Eq. (1) is a proportionality, rather than an equality; the true value of the distance r_l depends on the collecting area and signal to noise threshold of the receiving antenna. A signal transmitted from Earth traverses a cone, with the vertex at Earth. The volume of the cone, and the volume over which the signal will be detectable is $V \propto r_l^3/G$, or

$$V \propto P^{3/2} G^{1/2} B^{-3/2} \nu^{-3/2}. \tag{2}$$

For example, the Arecibo Planetary Radar typically transmits at a power of 0.8 MW and a frequency of 2380 MHz, with a gain of $\sim 10^8$ (see Table 1). This means that low bandwidth transmissions from Arecibo, with $B \sim 0.1$ Hz, would be detectable by a watcher with a 1 km^2 receiving antenna at distances up to 200,000 light years, while high bandwidth signals, with $B \sim 10^7$ Hz, would be detectable out to about five light years by the same watcher. By comparison, television carrier waves have similar power but gain ~ 10, $B \sim 1$ Hz, and frequencies in the range of 100–2700 MHz; such signals could be detected with a square kilometer array out to a distance of about 50 light years.

Most sources of leakage radiation are transient. The volume over which they are detectable, and often the time for which they are detectable at any one point in space, is directly proportional to how much time they transmit for. We can account for this by including an additional factor T:

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[4] Civilian air traffic radars used for local navigation are much less powerful and have much lower gains than radars used for astronomy or to track spacecraft and intercontinental ballistic missiles. The ranges required for, e.g. air traffic control civilian radar are hundreds of times smaller and require much less power, while the requirement to scan all the local airspace requires much lower gain. We will therefore neglect consideration of civilian navigation radar in our analysis of leakage radiation.

[5] We here refer to the *detectability* of a signal, rather than to the ability of a watcher to interpret it. An encrypted or compressed signal may be detectable but not intelligible. See Sections 3 and 5 for further discussion.