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QUANTIFYING PAST TRANSMISSIONS USING THE SAN MARINO SCALE

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ABSTRACT

To date, at least five experiments which could be classified as Active SETI, or METI (Messaging to Extra-Terrestrial Intelligence) have been conducted from Planet Earth: the well-known Arecibo Message of 1974, two Cosmic Call transmissions from Evpatoria, the Teen-Age Message to the Stars also transmitted from Evpatoria, and the paradigm-altering Invitation to ETI, being quasi-transmitted continuously via the Internet. In addition, planetary defense radar transmissions from Earth, radiated for the purpose of detecting potentially hazardous asteroids, can be considered inadvertent METI signals, to the extent that they can be detected over interstellar distances. Planetary radar transmissions from both Goldstone and Arecibo are considered. Each of these various emissions is analyzed in terms of duration, directionality, information content, and transmitter power, and then each is assigned an integer ordinal value on the proposed San Marino scale for quantifying transmissions from Earth. A comparative analysis of these quantified transmissions underscores the difference in impact of various METI experiments, suggesting the utility of the San Marino Scale as a valuable analytical tool for making informed policy decisions.

INTRODUCTION

SETI, the well established science involved with Searching for Extra-Terrestrial Intelligence, has traditionally applied high-gain antennas and sensitive microwave receivers to the challenge of detecting artificial emissions from distant civilizations. The companion activity becoming known as METI (Messaging to Extra-Terrestrial Intelligence) involves the converse: transmitting from Earth signals which extraterrestrial SETI scientists could presumably detect. Recognizing that such transmissions are not wholly without risk, The San Marino Scale (Almár, 2007) has been introduced as an integer ordinal index for quantifying the potential impact of such transmissions from Earth. Here we apply the San Marino Scale to several historical transmissions, to better assess its utility.

SIGNAL INTENSITY REFERENCE

An important factor in determining the significance of a transmission from Earth is its intensity, which is in term related to effective isotropic radiated power (EIRP) and spectral dispersion. Such characteristics can be readily quantified for any transmission, historical or hypothetical, planned, past, or proposed, and then expressed by comparison to an established standard.

It has been shown (Shuch, 2006) that the Sun affords us with such a standard, when describing the intensity of transmissions from Earth. Solar radiation varies with frequency in a predictable way, which we can readily model. However, we must consider that the sun's spectral flux density tends to vary widely throughout an eleven year solar activity cycle (see Figure 1).

We describe transmission intensity as a multiple relative to the solar flux. It can be seen in Figure 1 that this value can vary by perhaps a factor of five between minimum and maximum values. Rather than addressing the daunting task of determining the actual solar flux density which prevailed at the instant of each transmission being analyzed, we propose to model the quiet sun. Establishing a minimum noise baseline seems especially appropriate in the case of long-duration METI experiments during which the solar flux can be expected to vary widely. At minima in the cycle of solar activity, the background radiation emitted by the sun is obviously at a minimum, hence has the least impact on the signal to noise ratio (SNR) of any terrestrial transmission being received by purported alien civilizations.

By quantifying our transmissions relative to minimum solar flux, we are perhaps overstating the SNR which a given terrestrial transmission might impart on extraterrestrial receivers. This approach ensures that our resulting Intensity term, which contributes to the overall San Marino Scale value, is a best-case number as far as signal detectability is concerned. Since it is the potential negative consequences of transmission which we seek to quantify, we believe this conservative approach, which may slightly overstate signal impact, is appropriate to the function the San Marino Scale was intended to serve.

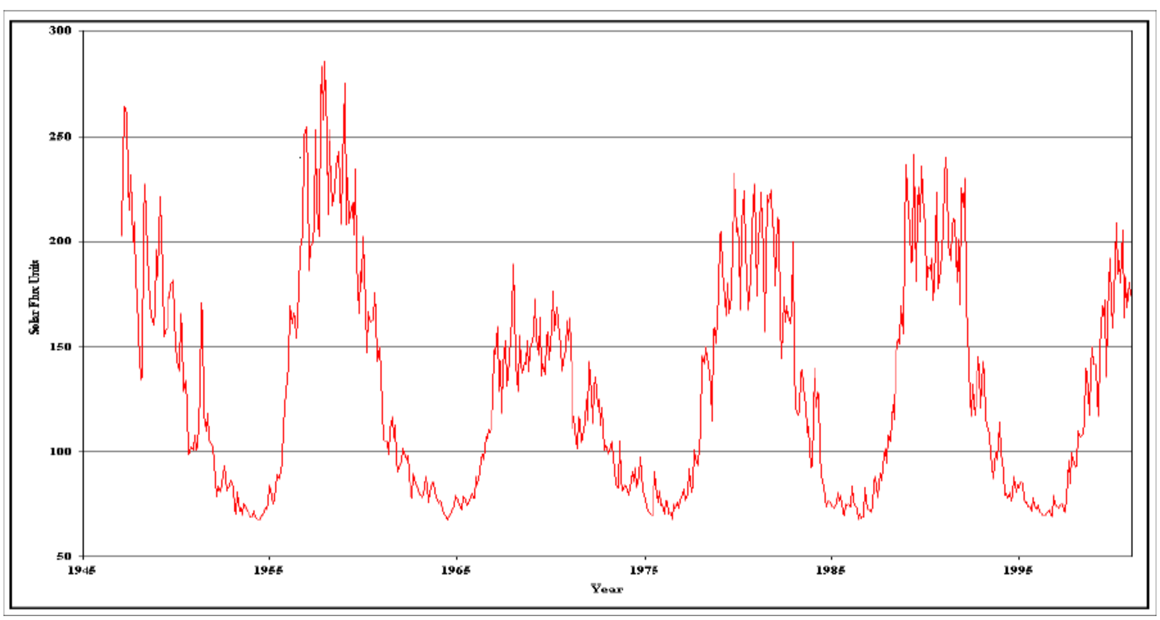

Figure 1
Solar intensity plotted over five full solar cycles (from Tapping, 2001)

QUANTIFYING THE QUIET SUN

Figure 1 above, which records daily average solar flux densities in Solar Flux Units (SFU) over more than half a century of observations at a wavelength of 10.7 cm (corresponding to a frequency of 2.8 GHz), derives from data taken first near Ottawa ON, Canada, and later at the Dominion Radio Astrophysical Observatory in Penticton BC, Canada. [1]

Solar flux density at the minimum of the solar cycle (with no sunspots or other geomagnetic activity in evidence) has been quantified (Tapping, 2001) over a wide range of frequencies in the microwave spectrum. The unit of measure, SFU, equates to Watts x 10^{-22} per Hz of bandwidth per square meter of area at the Earth's surface. Since one Jansky (Jy) equals 10^{-26} W m^{-2} Hz^{-1}, it follows that 1 SFU equals 10^4 Jy. Quiet sun values across the entire microwave spectrum are plotted in Figure 2.

Nonlinear regression analysis shows that Tapping's data fit closely a cubic equation, the respective coefficients for which are depicted in Figure 2. We use this cubic model to interpolate flux density values for the quiet Sun at any frequency for which we are analyzing the impact of a terrestrial transmission.

[1] Sunspots or geomagnetic storms can of course occur even during a solar cycle minimum, as suggested in Figure 1.

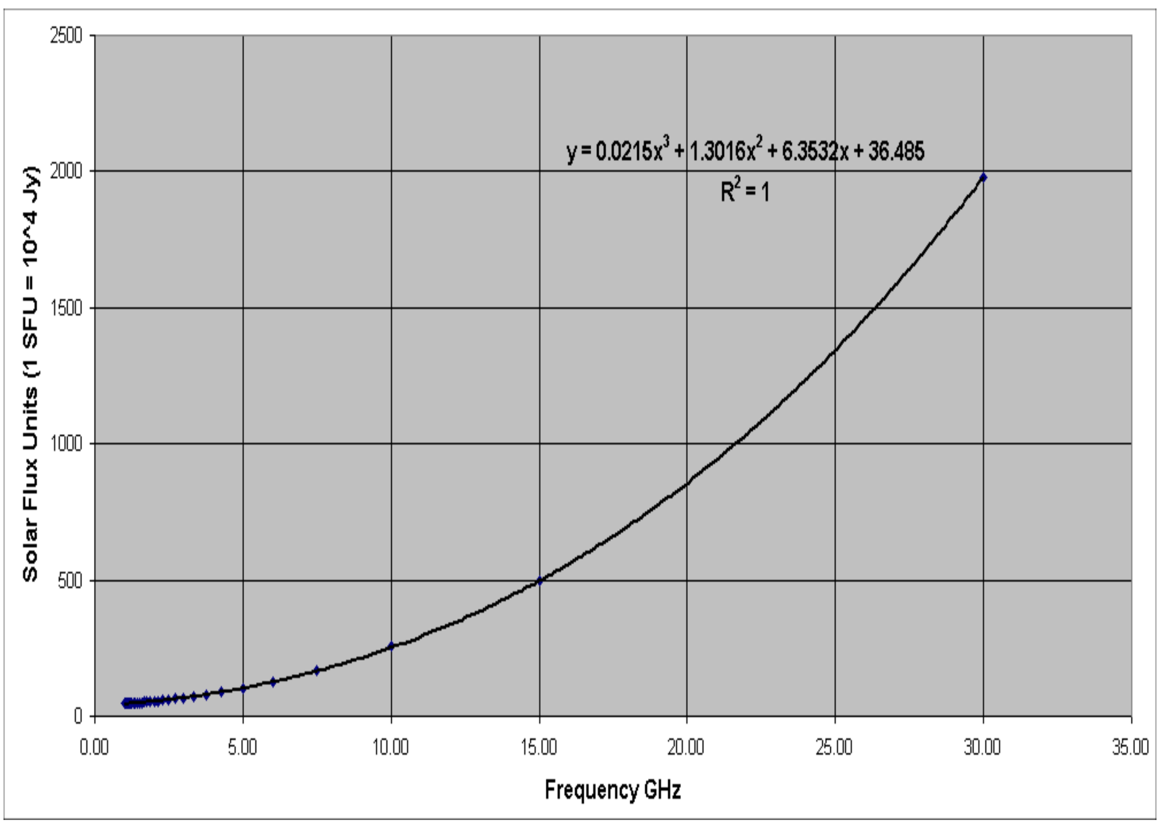

Figure 2
Flux density of the quiet Sun, as a function of microwave frequency (from data in Tapping, 2001)

OUTPUT OF THE SOLAR SPHERE

It is common practice, when analyzing terrestrial transmission intensity, to multiply transmitter power (typically in Watts) by antenna gain relative to an isotropic radiator. An isotropic source would radiate uniformly across all 4π steradians of space.[2]

The isotropic reference is a mathematical convenience, since physical, truly isotropic radiators do not exist (you cannot build one, buy one, or find one in nature). [3] Nevertheless, practical antennas are calibrated in decibels relative to isotropic (dBi).

Similarly, although we have quantified solar flux density relative to one square meter of area on the Earth's surface, the Sun radiates (almost) isotropically, [4] Thus, to determine the total Solar radiation output, we calculate the surface area of a sphere of radius 1 Astronomical Unit (AU), the mean distance between Earth and Sun. This radius is a distance of 1.5×10^{11} meters, hence the relevant surface area is 4π steradians multiplied by 1 AU, or 2.83×10^{23} m^2.

Remember that flux density refers to radiation intensity over one square meter at the Earth's surface. Multiplying the solar flux density (at any given frequency) by the area of the sphere defined by the Earth's orbit, we find the total Solar spectral density centered on the selected frequency, in Watts per Hz.

For example, at 15 GHz, Figure 2 suggests a quiet sun flux density of 500 SFU. Multiplying 500 SFU by 10^{-22} W m^{-2} Hz^{-1} (our definition of the SFU) by 2.83×10^{23} m^2 (the surface area of our sphere of 1 AU radius), we see that the quiet Sun delivers about 1.4×10^4 W/Hz isotropically at 15 GHz. By applying the cubic model for solar flux derived in Figure 2, we can arrive at similar values for solar spectral density, centered on any frequency in the microwave spectrum.

All that remains now is to similarly express the spectral strength of any transmission from Earth in Watts per Hz (isotropic). To do so, we need to know transmitter power, antenna gain, and modulation bandwidth. We then compare the resulting value to the corresponding solar spectral density, as calculated previously, to determine the 'I' (intensity) term of the San Marino Scale.

A Microsoft Excel® template for calculating the 'I' term for any terrestrial transmission is shown as Figure 3. This template is available for download from the website of the IAA SETI Permanent Study Group, at this URL:

<http://iaaseti.org/SMI_I.xls>

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2 In other words, an isotropic antenna works equally poorly in all directions!

3 The cosmic microwave background radiation is very nearly isotropic, but (as evidenced by WMAP satellite measurements) even that radiation demonstrates some irregularities.

4 We say "almost" because the Sun, like all rotating bodies, is slightly oblate, hence its radiation pattern cannot be truly isotropic. In addition, coronal holes and active regions further disturb its isotropy.

San Marino Scale Intensity Calculator

The Signal:			Quiet Sun:		
λ =	5.99	cm	λ =	5.99	cm
ν =	5.01	GHz	ν =	5.01	GHz
P xmtr =	1.50E+05	W	ψ =	103.7	SFU
G ant =	69.4	dBi	=	1.04E+06	Jy
EIRP =	1.21E+02	dBW	=	1.04E-20	W/Hz*m^2
=	1.31E+12	W	α =	1.50E+11	m
Δf =	2.40E+04	Hz	4πα^2 =	2.83E+23	m^2
Data Rate =	2000	Baud	P sun =	2.93E+03	W/Hz Isotropic
BW =	5.00E+04	Hz			
Duty Cycle =	100	%			
P sig =	2.61E+07	W/Hz Isotropic			

SNR max =	
P sig / P sun =	8.92E+03
San Marino 'I' =	4

Calculator rev. 19 Dec 2006 by H. Paul Shuch

Figure 3
San Marino Scale 'I' term calculator template
See http://iaaseti.org/SMI_I.xls

CONSIDERING THE 'C' TERM

In calculating San Marino Scale values (as currently defined), the intensity term 'I' takes on integer values between 0 and 5. Since the overall San Marino Scale yields an integer value between 1 and 10, it is clear that intensity tells only half the story. The character of the information content contained in the signal is also important, as far as the signal's overall impact is concerned.

The Characteristic term 'C' in the San Marino scale is a categorical, ordinal integer between 1 and 5, related to information content.

At the lower extreme, it is argued that either a radar pulse or a steady, unmodulated CW carrier imparts only limited useful information, hence its associated 'C' term is 1.[5]

At the opposite extreme, any transmission from Earth in response to a confirmed SETI detection would be information-rich, [6] suggesting its associated 'C' term would have to take on a maximum value of 5. Other degrees of information content will of course take on intermediate values for 'C'.

SAN MARINO SCALE

As described in Shuch (2006) and Almar (2007), the San Marino Scale combines a parametric term quantifying intensity with a categorical one indicating message content. The resulting sum of two integers, one on a scale of 0 to 5, the other varying between 1 and 5, takes on an intuitive (and appealing) range of values: 1 to 10.

Next, we shall determine 'I' and 'C' values for a variety of transmissions from Earth, and combine them into descriptive San Marino Scale indices unique to each example.

EXAMPLE: EVPATORIA

The Evpatoria Planetary Radar Telescope on the Crimea Peninsula in Ukraine boasts a 150 kW C-band transmitter, normally operated at 5.01 GHz, driving a 70 meter diameter fully steerable parabolic antenna providing an estimated gain of +69.4 dBi, for a maximum EIRP of 1.3 x 10^{12} Watts.

Evpatoria has been the uplink facility for three METI experiments to date, the Cosmic Call transmissions of 1999 and 2003, and the Teen Age Message to the Stars in 2001 (Zaitsev, 2006). Although all three of these transmissions included different information content, they shared similar modulation characteristics, encoding their messages with frequency shift keying at $\pm$24 kHz peak deviation, at a maximum data rate of 2 kBits per second. The corresponding modulation bandwidth is 50 kHz, for a spectral signal density of 2.6 x 10^7 Watts per Hz.

At the 5.99 cm wavelength corresponding to the frequency of Evpatoria's transmitter, the minimum isotropic solar flux equates to 2.9 x 10^3 Watts per Hz. Thus, the signal amplitude of the Evpatoria METI experiments exceeds that of the quiet sun by roughly four orders of magnitude. By design, the 'I' term of the San Marino scale is the integer common logarithm of this ratio, which in this case is a value of 4 out of a possible 5.

In terms of their message content, each of the three Evpatoria METI experiments was a "special signal targeting a specific star or stars, at a preselected time, in order to draw the attention of ETI astronomers." As described in Almár (2007), this corresponds to a 'C' term of 3, also out of a possible 5. Thus, the total San Marino Scale value for these particular messages is 7, a level to which we have assigned a significance descriptor of "high" (Shuch 2006).

[5] Some argue that such a signal contains no data, hence the corresponding 'C' integer should actually be zero. In fact, even an unmodulated carrier can be considered a one-bit digital message, clearly conveying information: "Here I am!" Additionally, an unmodulated carrier onto which Doppler shift has been imparted can convey a wealth of astronomical data.

[6] Implicit in a reply to a confirmed SETI detection, even absent any message of our own, is the information "We have heard you," which conveys to our communications partners our (admittedly limited) technological prowess.

EXAMPLE: ARECIBO MESSAGE

The world's largest radar telescope, the 305 meter diameter spherical dish at Arecibo, Puerto Rico, was home to the first METI experiment on record, in November 1974. A 950 kW transmitter driving the +72.4 dBi antenna produced an effective isotropic radiated power (EIRP) of 1.65×10^{13} Watts at a wavelength of 12.6 cm (LaLonde, 1974). Narrow frequency shift keying at a 10 bit per second data rate produced a modulation bandwidth on the order of 20 kHz. Consequently, the isotropic spectral density of the radiated signal was on the order of 8.2×10^{8} Watts per Hz.

At the 2380 MHz transmission frequency of the Arecibo Message, a quiet Sun would produce an isotropic flux of 1.68×10^{3} Watts per Hz. Thus, the Arecibo Message can be seen to have outshone the Sun by a factor of 10^{5}, for a San Marino Scale 'I' term of 5.

Directed as it was toward M13, a star cluster some 25,100 LY from Earth, the Arecibo Message (like the Evpatoria transmissions discussed in the foregoing section) was indeed a "special signal targeting a specific star or stars, at a preselected time, in order to draw the attention of ETI astronomers." This corresponds to a San Marino 'C' term of 3.

The overall San Marino score for the Arecibo message is thus 8, which characterizes its significance as "far-reaching."

EXAMPLE: NEO RADAR

Planetary protection radars at Arecibo and Goldstone are routinely used to manage the risk of impact from near earth objects (NEOs) such as asteroids, comets, and meteors. Although not intended as interstellar transmissions, their very nature makes them potentially detectable over interstellar distances. Thus, we consider such radar leakage to serve as a de-facto METI signal, and will analyze them accordingly.

Existing NEO radar transmitters employ high power klystrons and high gain antennas, operating at S-band (Arecibo) and X-band (Goldstone). Modulation is either continuous wave (CW) for detection or binary phase-coded CW for range resolution (Ostro, 2006).

In the case of the Arecibo transmissions, hardware is quite similar to that used for the 1974 Arecibo Message transmission, thus, the EIRP is similar to that in the prior example. However, significantly reduced modulation bandwidth is observed for either CW or binary phase-coded CW. Thus, the signal density exceeds that of the Sun by more than five orders of magnitude, yielding a San Marino Scale 'I' term of 5.

The X-band signals from Goldstone consist of a similarly modulated transmitter, this time at a wavelength of 3.5 cm (frequency of 8.56 GHz), driving a dish with +74.4 dBi gain. The resulting EIRP is 1.24×10^{13} W, similar to that at Arecibo, also producing a spectral density more than five orders of magnitude greater than the quiet Sun. Hence, the 'I' term from Goldstone also equals 5.

The signal characteristic for both of these NEO detection transmissions is best described as "A beacon without any message content (e.g., planetary radar)," for a corresponding 'C' value of 1. The resulting San Marino Scale index for NEO radars thus totals 6, for an overall significance descriptor of "noteworthy." Although planetary defense radar signals are among the most powerful artificial emissions emanating from planet Earth, earning the highest possible 'I' value, their information content is minimal, rating the lowest possible value of the 'C' term. Thus, it is not surprising that they score near the middle of the San Marino Scale.

EXAMPLE: IETI

Unlike other METI experiments, the Invitation to ETI initiative does not rely upon interstellar transmissions in order to establish contact with our cosmic companions. This experiment contemplates the existence of ETI civilizations so advanced that they possess the technology to monitor the terrestrial internet. Implicit in this assumption is the existence of ETI probes somewhere in the vicinity of our solar system (Tough, 2000).

As a rule, our terrestrial internet is just that – a network of *terrestrial* signal distribution links, employing coaxial cable, fiber optics, low-power wireless relay, and the occasional microwave communications satellite. Of these, only the communications satellite uplink is of interest for the purpose of the present analysis, because it is susceptible to intercept by any alien probes purported monitoring our planet's electromagnetic environment.

Analyzing the link budget of a wide variety of telecommunications satellite uplinks, for either geosynchronous (Clarke orbit) or low Earth orbit (LEO) satellite constellations, we find that even the most powerful uplink signal emitted is still *many* orders of magnitude weaker than the solar flux. Thus, even if pages from the Invitation to ETI website (http://ieti.org) happen to be accessed by an internet user via satellite link, the corresponding San Marino Scale 'I' term will be zero.

The Invitation to ETI itself, on the other hand, is extremely information-rich. The website's many pages provide a wealth of information about human technology, culture, and society, as the ultimate goal of the experiment is to encourage dialog. Thus, the content of the 'transmission' is best described as a "continuous, broadband transmission of a message to ETI," which corresponds to a San Marino Scale 'C' term of 4. The resulting overall San Marino Scale value is 4, which corresponds to a significance described as "moderate."

For the foregoing examples, the relevant San Marino Scale terms, score, and significance descriptor, are summarized in Table 1.

	San Marino Scale			
METI Experiment	**"I"**	**"C"**	**Overall**	**Significance**
Arecibo Message	5	3	8	Far-Reaching
Evpatoria	4	3	7	High
NEO Radar	5	1	6	Noteworthy
Invitation to ETI	0	4	4	Moderate

Table 1
Analysis of Example METI Transmissions on San Marino Scale

CONCLUSIONS

By applying the San Marino Scale to a variety of historical METI experiments, both willful and de-facto, we have demonstrated its utility in comparing the impact of disparate transmissions into space from planet Earth. It is clear from this analysis that blanket policy decisions, either restricting or sanctioning transmissions from Earth on an across-the-board basis, are inappropriate. Instead, we feel we have demonstrated the importance of quantifying each transmission on its individual merits, using an objective scale, and taking this quantification into consideration in the policy-making arena.

Following a process of review by and feedback from our colleagues, we recommend that the San Mario Scale proposed herein be considered, and possibly adopted, by the SETI Permanent Study Group of the International Academy of Astronautics.

We emphasize that the San Marino Scale remains a work in progress, having been neither endorsed nor adopted by the International Academy of Astronautics, or any other body. Nevertheless, we consider it a useful tool for assessing the potential impact of transmissions from Earth.

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