THE USE OF COLOR IN INTERSTELLAR MESSAGE DESIGN

by Kimberly A. Jameson & Jon Lomberg

Communicating with others...

Considerable effort has been devoted to understanding the consciousness of others, the ways human consciousness resembles that of other terrestrial species, and what assumptions about others' consciousness are sensible. Aspects of consciousness, mental experience, and self-awareness have been deliberated for a range of Earth's creatures: from the highest forms of mammals-humans, non-human primates, cetacean[1]–to the lowly nematode.[2] Some believe that consciousness proper occurs in few species, whereas others believe it is widespread. Animal behaviorist Donald R. Griffin has suggested that the

> *...belief that mental experiences are a unique attribute of a single species is not only unparsimonious; it is conceited. It seems more likely than not that mental experiences, like many other characters, are widespread, at least among multicellular animals, but differ greatly in nature and complexity.*[3]

At a minimum, we can assume many non-human primate species experience consciousness, and humans will aim to communicate with these *others*, and seek out appropriate languages–fundamental units, signs or symbols–for communicating our thoughts and ideas with these different species. Nevertheless, despite consciousness in other terrestrial animals, the challenges impeding shared communication are substantial. This is because although humans share environments with other species, our perceptions of environmental sounds, sights, smells and tastes do not always systematically relate, or even greatly overlap, with those of other species. Thus, although our specific sensory experiences define *our* reality, there are good reasons for communication gaps with our non-human terrestrial neighbors.

Is anybody out there conscious like us?

Like seeking to communicate with non-human earthlings, there is also a strong desire to communicate with conscious beings that might reside beyond our planet. Since 1961, astronomers have been conducting a Search for Extraterrestrial Intelligence (SETI), scanning the skies for radio messages from intelligences possibly sharing our Milky Way galaxy. The belief is that if–and it is a big *if*–intelligent extraterrestrial beings (ETI) are out there, they may be transmitting radio beacons to find other civilizations. Intriguing questions concern what features an ETI radio beacon would have, and how we might devise our own messages to be correctly decoded by ETI recipients across vast interstellar distances. In general, because it seems plausible that, if they exist, ETIs might inhabit planets revolving around other star systems, then the universal laws of physics and its mathematics could be something other intelligent beings might share. These universal laws might therefore be an appropriate basis for designing messages between the stars, and information about a star's electromagnetic spectrum may be a basis for communicating with ETI beings (a point elaborated below).

Similar to pursuits of intraterrestrial communications, efforts to communicate with inhabitants of other planets proceed by assuming that (i) an extraterrestrial consciousness exists, (ii) some sets of *translation rules* can be found to relate human and ETI experiences, and (iii) that the laws of stellar and planetary physics and its mathematics are a solid basis for communication.

Based on these assumptions, several kinds of *fundamental units* and ways of messaging have already been developed for human-ETI communication. Here we consider one specific approach, and its particular use of features of solar light that humans experience as “color”, that created the most elaborate message artifact yet sent out from Earth, namely the Voyager Interstellar Record (VIR).

Communicating across the cosmos?

Probably because human communication modalities rely heavily on visual and auditory components, SETI researchers have focused on developing ways to send pictures using radio signals that encode visual data in ways that allow ETI to reconstruct any images (e.g., of our planet, terrestrial species or scientific diagrams) we might choose to send.

Financial and other practical considerations have constrained most interstellar messages to the domain of radio waves, but ETI message artifacts have been attached to some NASA spacecraft leaving the solar system. The most ambitious of these was the VIR which was constructed using a science-based approach to identify features of human “seeing” and “listening” that might be successfully communicated to ETI. The VIR is a copper disk containing music, sounds, speech, and images from Earth.[4] Each of the two *Voyager* spacecraft carries identical copies of this record, whose projected lifetime is a billion years. Both were launched in 1977 and are now far beyond Pluto on an endless cruise between the stars.

The pictorial portion of the VIR contains 120 images from Earth, and reviewing those images now–32 years after the satellite launch–still poses interesting questions. For example, are pictorial and photographic images even useful and appropriate for designing interstellar communications? As the VIR team suggests, this is a very complicated question and is beyond the scope of the present paper.[4] Still, it is probably unreasonable to assume that ETIs possess sense modalities that parallel those of humans–especially considering the diversity of sense-modes found across terrestrial species. Thus, it is unclear whether VIR pictures can be processed and understood by non-human intelligences. Anthropologists know that isolated groups unfamiliar with 2-D representations of 3-D scenes have difficulty understanding them without training and experience.

But if we assume that ETIs *could* understand a picture, would color information add to that understanding? The color of environmental objects seems like something every being–animal, human or ETI–could equally appreciate. Specifically, (1) can any aspect of color serve as the *fundamental basis* for communication, and what assumptions would this require? And, (2) what aspects of color experience are not appropriate for the task of developing messages intended for ETI? These questions are considered here, largely because the VIR team not only employed pictures in their message, but they also considered it important to transmit color information as humans perceive it.

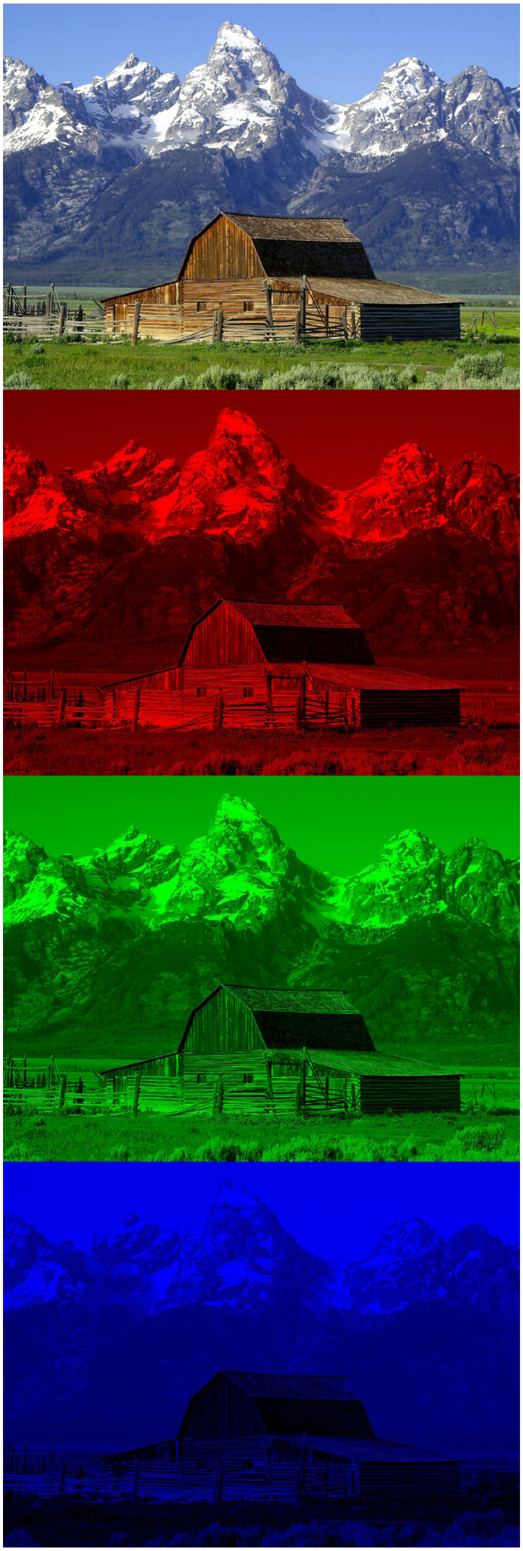
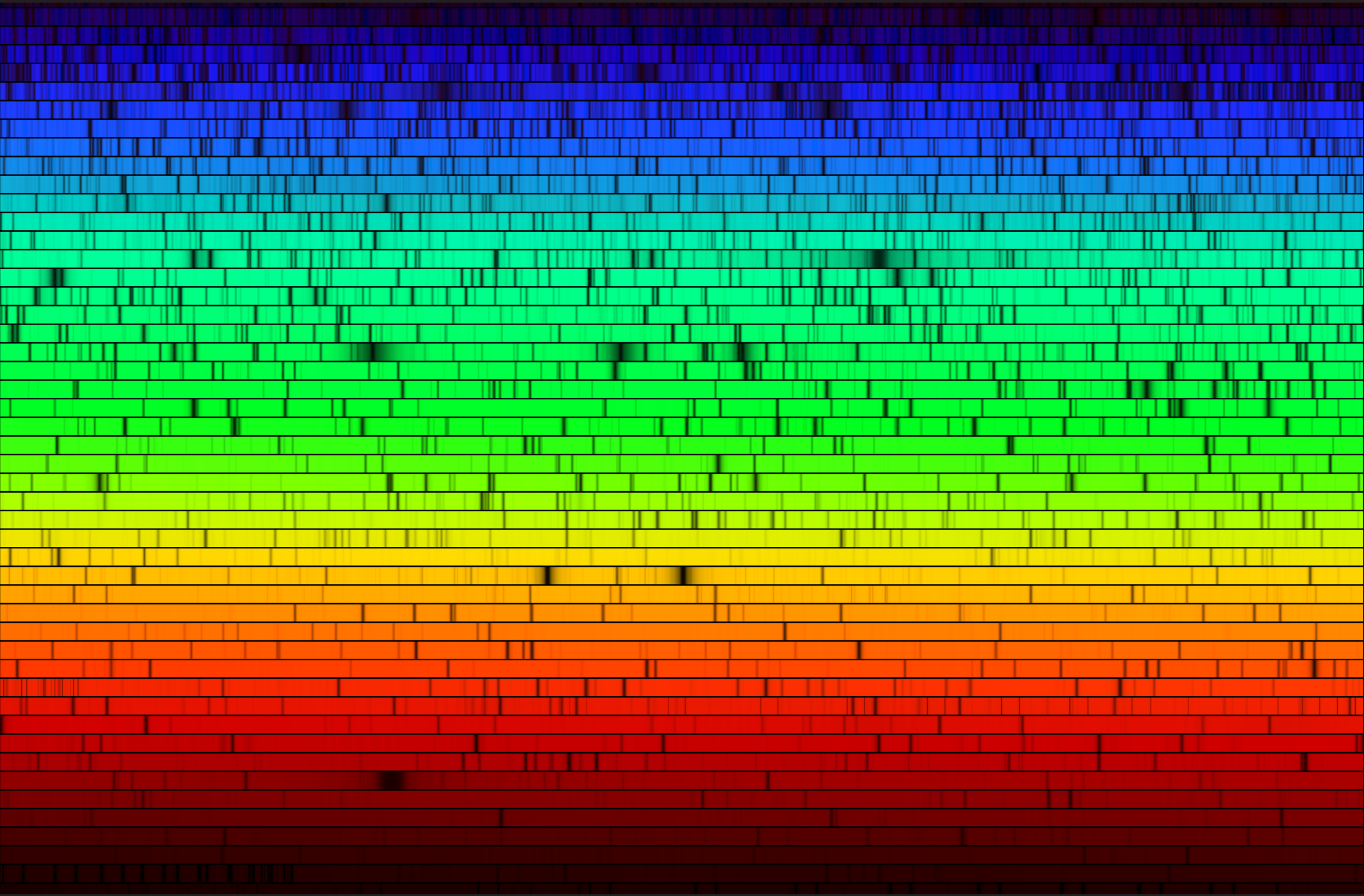


Figure 1. *A color film image of the Grand Tetons (top) with the R, G, B primary separations of the image shown below as three panels. The VIR used the same approach with twenty color images included in the message, with the exception that the three R, G, B, components of each image were sent as* grayscale versions *of the R, G, B components. Image courtesy of Wikipedia member: Mike1024.*



Lucid in the sky with color?

A survey of all the color images of the VIR would be a lengthy task, and is detailed elsewhere.[5] Briefly, two design objectives guided the use of color during the construction of the VIR message. The aim was to use physical information from the Sun's spectrum to (1) point out the Sun's star class, and (2) to define a color code for message construction to be used to exemplify salient attributes of human color experience, and the ways humans perceive (e.g., in sunsets and flowers) and use color (e.g., anatomy diagrams and textile designs).

The use of color in VIR images was limited to 20 of the 120 images sent. These twenty appeared in the VIR as sequenced triples depicting grayscale portions of each image's content, separated into component contributions of red, blue and green photographic primaries used by the human visual system to reproduce the original composite image (Figure 1).

The key for a naïve ETI recipient to decode our human experience of these multicolored composite images is to recognize our Sun's *atomic fingerprint* based on a transmitted segment of elemental gaps in the Sun's emission spectrum (e.g., Figure 2). This distinctive pattern of chemical *absorption lines* from our Sun was considered useful for simultaneously identifying the type of star we orbit and an important portion of it's spectrum: the range of humanly visible light. Thus, VIR did not include the Sun's entire absorption spectrum data; rather, to convey information about Earth's humans, only the absorption line data from our *visible spectrum* was included. Absorption lines within this range are known as Fraunhofer lines (Figure 3).

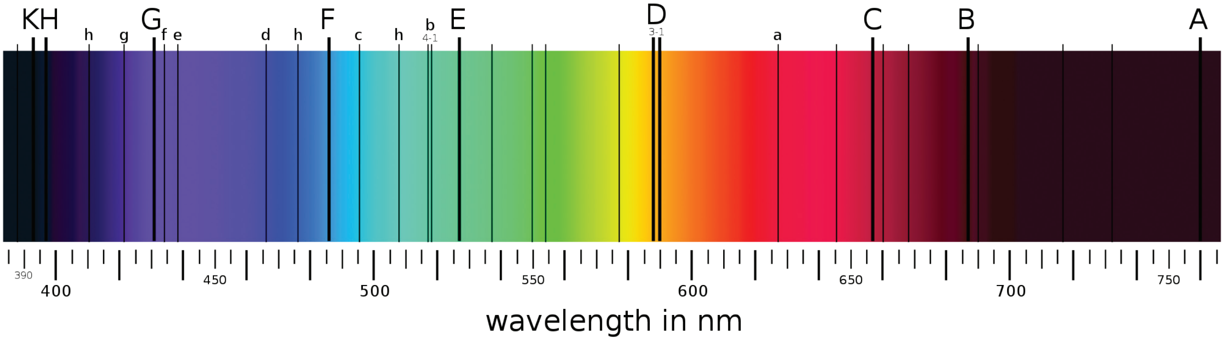
Figure 4 shows the VIR version of Fraunhofer lines, in color with absorption lines marked, and the grayscale R, G, B components of the color image. This spectrum was obtained using refraction–that is, using a glass prism similar to that shown in Figure 5. In addition to this spectrum, other triple-imaged photos included the Earth from space, landscapes, plants and animals, humans with varied skin pigmentation, electric lights of cities, and fire. The VIR designers hoped that the color information contained in Figure 4 would communicate information about the substances in the pictures (e.g. the blues of sky and ocean).

Below we consider some ways to improve the creative color-coding ideas that VIR used. The exercise is also instructive for recognizing just how much our human dependency on color–typically considered an

Figure 2 (opposite page). *NASAs modern hi-res representation of spectral lines as dark gaps in the solar spectrum. The image shows 50 vertical slices of wavelength continua, each covering 60 angstroms (in 1 nanometer steps from top to bottom), with shorter wavelengths shown at left in blue, and longer wavelengths at right in red, giving a complete spectrum across the visual range from 4,000 to 7,000 Angstroms. Beyond the left side of the figure the solar spectrum continues into the ultraviolet, x-rays and gamma rays (at 1/10,000 Angstrom), whereas off the right side the solar spectrum continues as infrared, microwaves, and radiowaves (through 100 kilometers). Dark horizontal dashes or gaps show spectral absorption lines. Both the color spectral emissions and the dark spectral absorption lines shown are constant and specific for each element. Approximately 92 naturally-occurring earthly elements and 72 solar elements exist. Fusion generates both heat and light in the sun's core, and all 72 solar elements each emit unique spectral signatures.. Image adapted from, and courtesy of, N.A.Sharp, NOAO/NSO/Kitt Peak FTS/AURA/NSF.*

Figure 3 (bottom). *A more classic representation of absorption lines in the solar spectrum characteristic of the Sun's G2 star-type between 400 nm and 700 nm (i.e., 4000 to 7000 angstroms). These are known as "Fraunhofer lines" after the German physicist Joseph von Fraunhofer (1787-1826) who made a very careful systematic study of the lines. Fraunhofer determined that the dark lines are absorbed, missing regions of the spectrum Image courtesy of Wikipedia member: Gebruiker:MaureenV.*

Unnumbered (below). *1987 Deutsche Bundespost postage stamp, depicting Fraunhofer lines in the visible spectrum, honoring the 200th anniversary of the birth of Bavarian physicist and optician Joseph von Fraunhofer. Image courtesy of Maiken Naylor, Sci-Philately, University at Buffalo Libraries, http://ublib.buffalo.edu/libraries/asl/exhibits/stamps/.*



immutable physical attribute—is tied lockstep with our specific human physiology, and to a far greater degree than it is with the very physical attributes of solar radiation that make human color experience possible.

The trouble with color

Colorless light bathes us curiously. Starlight or sunlight, electromagnetic waves carry no intrinsic color; and this fact alone, apart from any uncertainty about the visual processing features of message senders or receivers, makes color a tricky code for use in cross-species communication on Earth, as well as for human-ETI communications.

Sir Isaac Newton put it aptly: “For the Rays to speak properly are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a sensation of this or that colour”[6] (Figure 6).

Newton intimates what vision scientists now completely understand: color perception is highly species dependent. Which is to say that any measurable light source (the Sun, Aldebaran, or a compact florescent light-bulb) has a quantifiable amount of power and a specific characterizable spectral profile, that produce color perceptions that are entirely dependent on the types of sensors used for detecting the rays of light. In other words, observed color is entirely viewer-dependent. Color does not occur in the wavelengths themselves; it is a product of the organism viewing the wavelength and strictly rooted in its physiology.

In fact, all of Earth’s “seeing” species have their own specialized sets of “detectors” that allow them to process environmental electromagnetic radiation (light) in a manner specific to their individual environmental needs and purposes—see endnotes 7 and 8 for examples of non-human color experiences that differ from those of humans. Some creatures register ultraviolet features of light, some infrared, others (e.g., humans) detect ~400 nm to ~700 nm wavelengths. And “seeing” is done in different ways even when largely similar ranges of the electromagnetic spectrum are detected.

Moreover, neither cephalopods (e.g., octopodes, cuttlefish, etc.) from our oceans that discriminate polarized light (which humans do not), nor cichlid fish from the Great Lakes in Africa that are sensitive to a range of ultraviolet light (that we do not register), would experience the same color phenomena that humans experience when viewing colors associated with temperatures from, for example, a black-body radiator scale used in astronomical spectroscopy (Figure 7, following page).

Thus, while the physics and mathematics of the black-body radiator only depends on physical temperature, the visible colors on Planck’s locus as it varies along the Kelvin temperature scale will be

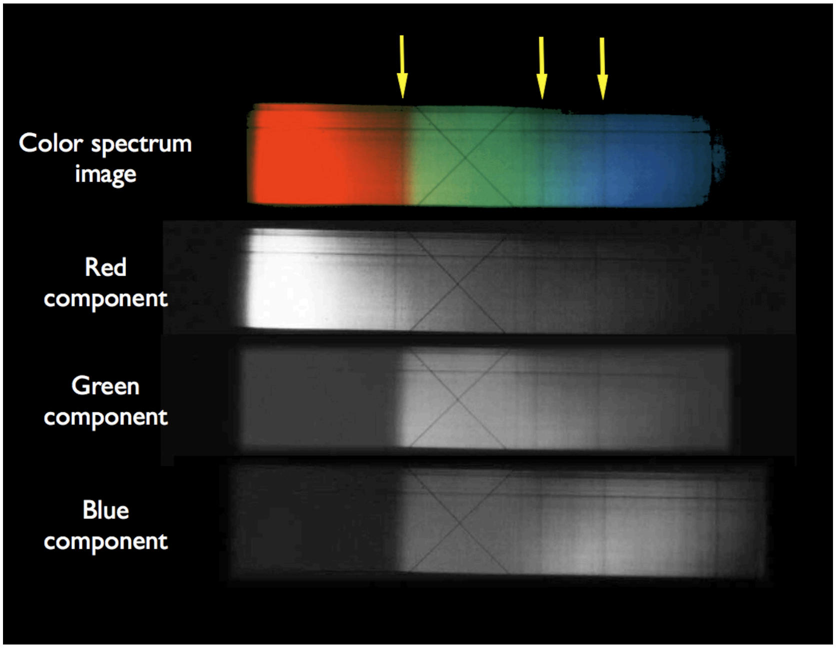


Figure 4 (left). *The Voyager Interstellar Record (VIR) used the concept of Fraunhofer lines (Figure 3) to convey both (a) the range of solar electromagnetic radiation visible to the human eye, and (b) the signature absorption lines of our G2-class star within that narrow visible range. The top panel shows the VIR color image version of Fraunhofer lines with absorption lines marked by arrows. Below it the grayscale images of the separate R, G, B components of the color image are shown. The continuous color spectrum showing the three absorption lines was produced by refraction, and because, in part, the image was photographed and processed in the 1970’s (when color resolution was not of high definition), the subtle color gradient is not easily apparent. The three separate grayscale images representing the red, green and blue components were included to suggest the primaries one would need to reconstruct the color image as human observers would perceive it. The VIR solar spectra depicted are courtesy of the National Astronomy and Ionosphere Center (NAIC) at Cornell University, New York*

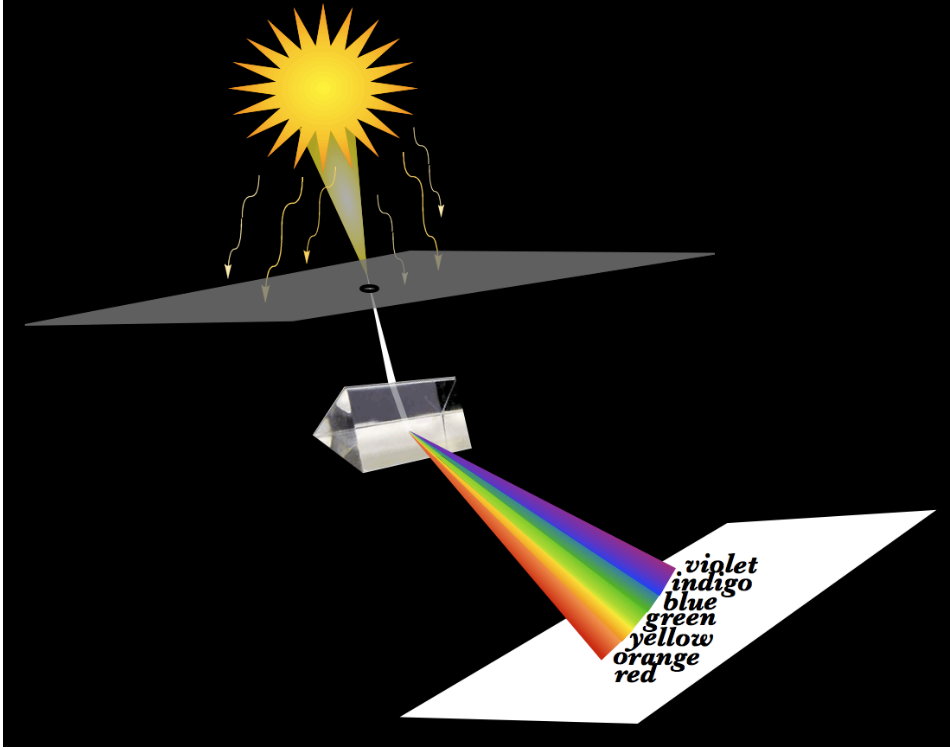
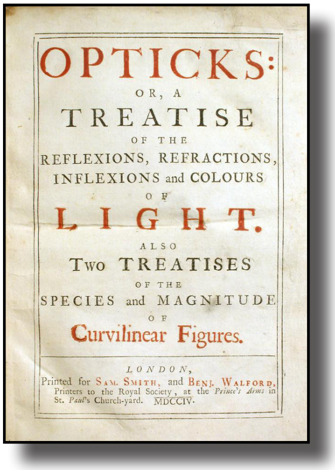


Figure 5 (right). *Sir Isaac Newton in 1666 used a small aperture and a glass prism to collect a narrow beam of sunlight, and separated the beam using refraction into its component parts.[6] Refracted spectra, like the one depicted, produce color scales that are non-linear with respect to wavelength. Image courtesy of Kimberly A. Jameson.*

Figure 6 (below). *Newton's* Opticks[6] *first published in 1704, although the results existed in 1672, and some experiments were done in 1666.*



OPTICKS:
OR, A
TREATISE
OF THE
REFLEXIONS, REFRACTIONS,
INFLEXIONS and COLOURS
OF
LIGHT.
ALSO
Two TREATISES
OF THE
SPECIES and MAGNITUDE
OF
Curvilinear Figures.

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Printed for SAM. SMITH, and BENJ. WALFORD,
Printers to the Royal Society, at the *Prince's Arms* in
St. *Paul's* Church-yard. MDCCIV.

varying if different (or more, or fewer) visual detectors are used to view colors correlated with temperature. To use "color" as a basis for communication, it is important to appreciate that terrestrial animals *would not* have our human color experiences—or experience the color gradient seen in Figure 7 (following page). Their perceptions of this physically based temperature scale would simply be different.

More generally then, if ETIs visually process electromagnetic radiation like many birds, reptiles or insects, they *would not* be expected to have a correlated color temperature scale analogous to what humans experience. Indeed, a worst-case scenario could be that no range of electromagnetic radiation sensitivities that any terrestrial species (including humans) experiences coincides with the range(s) of spectra that are "visible" to an ETI recipient.

Does this invalidate the use of the Sun's spectrum as a basis for ETI communication? In some ways, yes, it definitely does. In other ways, however, maybe not, if one proceeds carefully (as elaborated below).

Sending our Sun's spectrum... which one? Aside from the abovementioned difficulties inherent in communicating "color" as a physically-based experience, there is the question of *which* solar spectrum to use. This difficulty has two components: (i) where and when the solar spectrum is sampled, and (ii) the production method used to produce the continuous spectrum.

Where and when to sample. Two particular things affect spectral measurements: First, if solar data is measured in a standardized identical way from (a) the surface of Earth, (b) outside the Earth's Atmosphere, or (c) outside the Earth's magnetosphere, then three *very different* measures are obtained. The reasons for this include that these all filter the Sun's spectrum to varying degrees. The VIR electromagnetic spectrum was measured at the Earth's surface, filtered by Earth's

Figure 7 (left). *The classic color gradient of a heated black-body radiator on the Kelvin temperature scale. Color temperature is based on the principle that an object at some fixed temperature, like an oven, is observed to glow. At 1000 Kelvin, an oven looks red; at 6000 Kelvin, it looks white. This temperature gradient forms a line in color space know as* Planck's locus. *Planck's theory suggests that colors of a black-body radiator only depend on such temperatures, implying that light at different temperatures has a different distribution of energy among the different wavelengths. In general, most human observers will experience the color gradient shown here. However, some human observers with color vision anomalies that give rise to color confusions among yellowish and bluish colors (i.e., tritanopic confusions) will perceive a different gradient of appearances between about 3000K and 10000K. Others with deficiencies involving reddish-yellowish-greenish confusions (i.e., protanopic and deuteranopic confusions) may perceive a slightly different color gradient between 1000K to 5000K. And, in general, any observer with highly yellowed optical lenses (due to, for example, a long history of exposure to tobacco smoke) may experience a slightly different color gradient than the one shown in the 7000K to 10000K portion of the scale. Moreover, organisms possessing different visual processing systems would each have their own, different, color appearance scales correlated with color temperature; and while to be sure they would be based on Planck's law of black-body radiation, their own gradients of color appearance within the scale would differ from the one shown here. Image courtesy of Wikipedia member: Eyrian*

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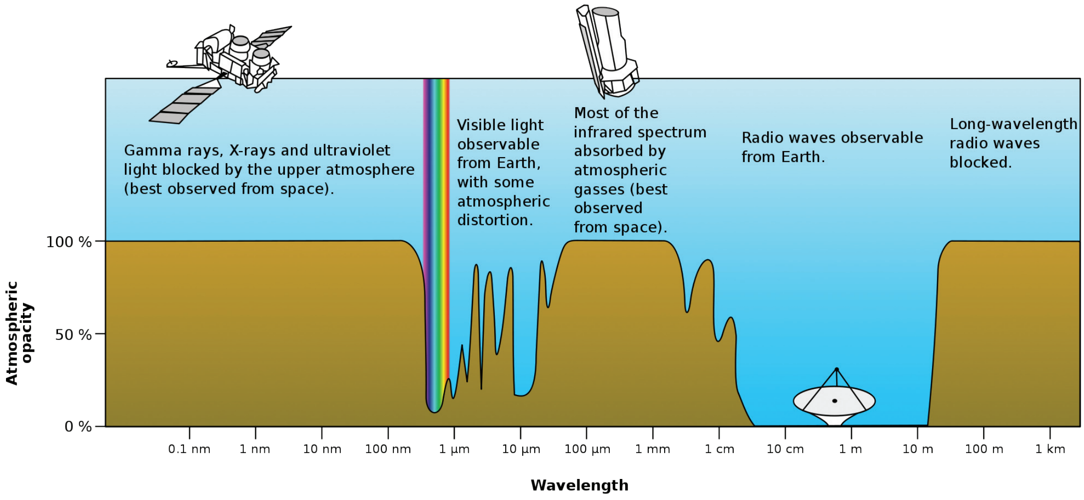
atmosphere. This has the advantage of conveying a geocentric perspective of the solar spectrum, but it is very unrepresentative of what one would detect if measuring from across distant space (Figure 8).

Second, filtering features of Earth's atmosphere are in flux, and have changed significantly since life arose on the planet. The Sun's spectrum at Earth's surface today differs considerably from what an ETI astronomer might have observed during the Cretaceous period—say 145 million years ago. The point is, solar spectra samples are also time-dependent. This might be a good feature (i.e., it could help specify when a transmission was sent) or it might be a bad feature (i.e., it makes recognizing our Sun's star class difficult when information is incomplete regarding conditions under which the measurements were taken). In either case it is inherent in any solar spectrum measures, and therefore consideration should be given to whether additional information is needed to accurately communicate the data's origins, whether filtered or not. Note that the VIR included a diagram showing the composition of the Earth's atmosphere (Figure 9, facing page).

Refracted versus diffracted spectra. Typically, astronomical spectroscopy uses high-dispersion diffraction gratings to observe spectra at very high spectral resolutions on a scale that is linear with respect to wavelength. Producing a continuous solar spectrum with *diffraction* differs from that produced using *refraction* via a glass prism (Figure 5). Refraction produces spectra that are not linear with respect to wavelength. VIR used a spectrum formed using refraction; but what should we assume ETI would use? This is a non-trivial question because if the scale is compressed in some regions of the spectrum sent, then accurate recognition of our Sun's spectral lines might not be achieved by the message recipients. There are an uncountable number of stars in space—estimated at 10^{11} stars multiplied by 10^{11} galaxies—and Figure 10 (following page) gives but a hint of their class diversity and physical properties. The

Figure 8 (below). *Schematic depiction of the electromagnetic radiation filtering achieved by the Earth's atmosphere. Note that the portions of the Sun's spectrum that are filtered (i.e., the tan areas shown in the bottom panel) are a substantial part of our Sun's atomic fingerprint, but are absent from any spectral measurements made at the Earth's surface. The solar spectrum measured in deep space, unfiltered by the Earth's atmosphere and magnetosphere and other filters would appear very different. This is important because the radiation emitted by the Sun involves a wide range covering the entire electromagnetic spectrum, from radio wavelengths to micro wavelengths. Image courtesy of NASA.*



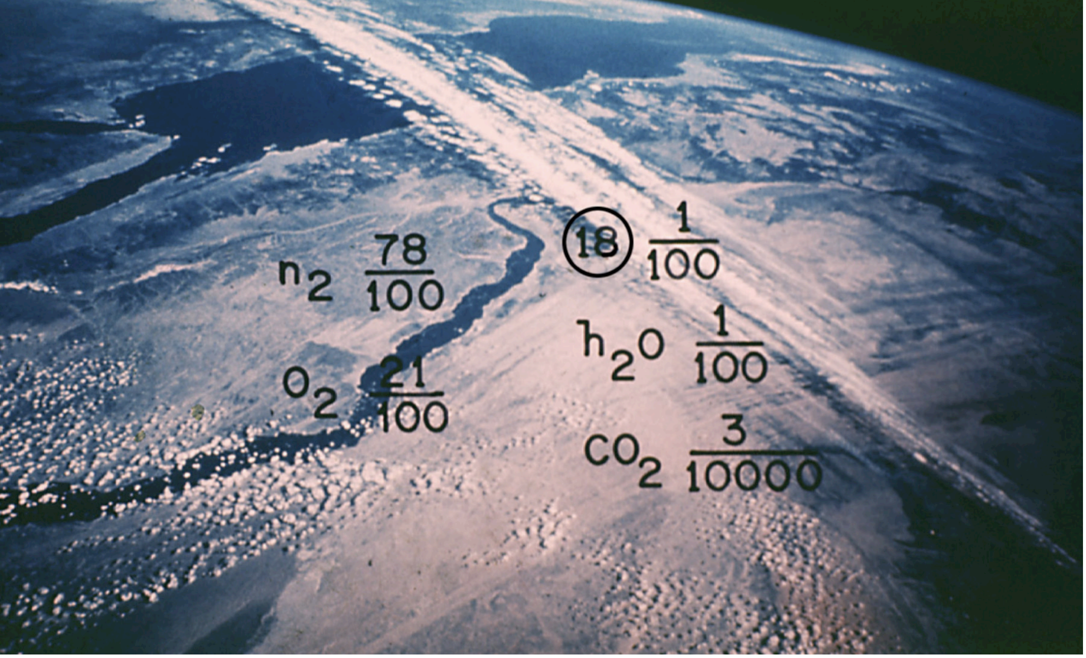


Figure 9. *Voyager Record #13 of 120, depicting an orbital view of Earth. This was one of the twenty images sent in color, in hopes that the colors of land, cloud, and water would facilitate understanding about the chemical composition of each. The symbols identify gases and their relative proportions in Earth's atmosphere. (These symbols were defined by a diagrammatic dictionary earlier in the VIR sequence.) Diagram by Jon Lomberg.*

possibility exists that an under-sampled rendering of non-linear absorption lines may more closely resemble a segment of spectral lines found in some sampled section of another star-class. Thus, a section of transmitted spectra might be interpreted as originating from somewhere very different than from a G2 class star such as our Sun.

Designing a better ETI communiqué

The question is whether in three decades since the *Voyager* launch, we can imagine ways to improve upon the Voyager Interstellar Record, and find color processing universals that can be used as a basis for human-ETI communication. Above we merely noted some assumptions inherent in sending pictures, and avoided elaborating further. But all VIR pictorial images require an ETI ability to interpret 2-D representations of 3-D scenes, and graphic or numeric representations. We feel it's best to avoid such assumptions, because these capacities may not be universal.

One suggestion is to transmit the full data of the Sun's spectrum. Although such content may be less interesting to us, the senders, it requires fewer assumptions about the recipients. Furthermore, if sent from an ETI perspective—the unfiltered solar spectrum data as measured from deep space-the chances of ETI correctly decoding our Sun's unique signature would be optimized. The repetitive, linear-sequenced configuration of a broadcast beacon rather than a message artifact might be the way to accomplished this. Sending the full solar spectrum is also consistent with NASA's advice on Earthly astronomical spectroscopy:

> *It is essential to study the entire spectrum rather than just limited regions of it. Relying on the radiation that reaches Earth's surface is like listening to a piano recital with only a few of the piano's keys working.*[9]

And if we don't send the entire spectrum, then we should provide more information about the portion we do send—how it was filtered, why this portion is important, and so on (a task made easier by assuming that ETIs actually reside on planets with atmospheres and stars).

Here we suggest certain features to consider when constructing interstellar messages:

(1) Communicate the sun's unfiltered spectrum as measured from deep space.

(2) Communicate the sun's spectrum as it is diversely and dynamically filtered by the Earth's atmosphere.

(3) Communicate the most stable (over time and atmospheric flux) gaps in the spectrum, or those that uniquely distinguish our sun from other stars.

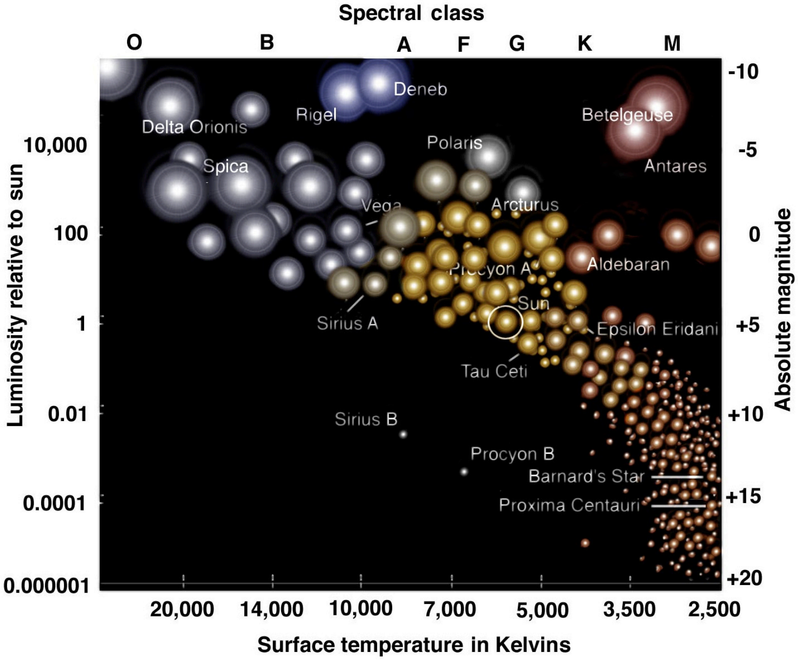


Figure 10. *This Hertzsprung-Russell diagram plots luminosity (absolute magnitude) against the color of the stars ranging from the high-temperature blue-white stars on the left side of the diagram to the low temperature red stars on the right side. Stars are classified into spectral types based on the temperature of a star's atmosphere. These are typically listed from hottest to coldest by classes O, B, A, F, G, K and M. The spectral classes O through M are subdivided by Arabic numerals (0 – 9). For example, "A0" denotes the hottest stars in the "A" class and "A9" denotes the coolest ones. The Sun is classified as "G2". The central band of stars that runs from the upper left corner to the lower right of the plot is called the* main sequence. *This figure shows about 60 random stars illustrating that there are many stars in each group, with 20 well-known stars also shown in their proper place. It illustrates the correct ratio of large stars to small, blue stars to red. The Sun is circled and central to the yellow grouping of G2 type stars. Only an infinitesimally small fraction of existing stars is depicted. Diagram by Jon Lomberg.*

(4) Do not attempt to communicate idiosyncratic color appearance information (unless other subjective perceptions or data are also intended) or use color appearance as a basis for a code.

And finally,

(5) Strive for redundancy in the content. If sending the solar spectrum, send a spectrum as measured from space to convey *star-level* information; send spectra filtered by atmosphere to convey *planet-level* information; and send portions of spectra used by humans to convey *species-level* information. These levels of transmitted spectra should be logically organized as three levels of information, while still recognizable as addressing our star's emission spectrum.

Summary

Color is an unreliable carrier of information for ETI messaging, and color experience—a chief delight of human sensory processing—is as idiosyncratic as gustatory preferences. Other biological intelligences have different sensory worlds. Which aspects of these sensory worlds overlap is one of the great mysteries of SETI. These caveats notwithstanding, careful use of universal features of our Sun's spectrum may serve to signal distant ETI astronomers that some lonely carbon-based life forms reside near a certain kind of star and imagine they are not entirely alone in space.

Endnotes

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