False Color Photographs in Scientific Communication

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Photographic images are used in scientific communication to convince an expert audience of the authority of the text being presented, but has the secondary effect of democratizing scientific communication for non-technical audiences (Mogull & Stanfield, 2015, pp. 1-2). The photographs in scientific communication often go beyond the normal reach of human vision, such as in the use of micrographs to show microscopic images at a size that can be seen by normal vision. Another form of augmented photograph that exists in scientific communication is the false color photograph. False color uses alternative colors to highlight a difference or to present forms of energy that are outside of the human perceived light range. False color photographs do not appear as their subject would appear to the human eye, but rather are presented in a symbolically interpreted way. In some cases, this means that visual information is pre-interpreted for the viewer and in other cases non-visible information is presented in a simple form that is visually understandable by a human with average color perception.

On Human Visual Capacity

The electromagnetic spectrum contains all forms of energy from gamma rays (1 picometer) to low-frequency radio (100 megameters). The forms of energy that are classified as light range from near ultraviolet (10 nm) through far infrared (1 mm or 1,000,000 nm). Human visual perception is limited to the range between 390 nm (violet) through 700 nm (red) (Sliney, 2016, pp. 223-224). Humans can only see a small subset of observable energy, which limits the range of what can be represented visually using *real* color as it would be normally interpreted by human eyes. Human sensitivity to the presence of light energy is somewhat better than the sensitivity to color due to the two separate types of photoreceptors found in the human eye. Rods perceive the presence of light and aid in night vision, whereas cones perceive ranges of color (Buser & Imbert, 1992, p. 83). Further, there is a limitation to amount of light that the human eye can perceive due to sampling at roughly 30 times per second (Rector, Arcand, & Watzke, 2015, p. 6).

The physiological sensory receptors are only half of the experience of color vision. Cognition is the other component. Color perception in the way that humans experience it is based upon the cognitive translation of physiological signals into meaningful information. This in itself is not a limitation of the human capacity to perceive color, but it does introduce a variance which can make subtle details in images difficult to discern based on human attention limitations and liminal thresholds (Firestone & Scholl, 2016, p. 2).

On Technological Visual Capacity

A factor that is essential in understanding how false color and scientific imaging in general works is the relationship between the human eye and the instruments that produce images. Human eyes, cameras and various “sensors” are all essentially based on the concept of a sensitized medium which can convert light to a meaningful signal. Human visual anatomy is most closely analogous to a camera, having a sensitized medium behind a focal system with a variable aperture. Photographic film is coated with layers of photosensitive chemicals, in grainlike structures similar to digital pixels. Each layer is sensitive to a different color, similar to the distinction between the S, M and L cones in the eye. For black and white film, there is only one layer, which detects the presence of light, similar to the rods. This translates the same into digital imagery wherein clusters of color-sensitive pixels recognize the presence of a specific range of color. More generally, sensors of various types are designed to be sensitive to specific types or ranges of energy, whether it is infrared, ultraviolet, X-ray or something else.

As mentioned previously, the human eye samples light at the rate of about 30 times per second, which translates into a 1/30" exposure time. Cameras and sensors also have a sampling interval, whether it is a continuous set rate like the human eye, or a variable rate that can be adjusted as needed for various applications. Fast times, like 1/4000", can create the appearance of stopped motion, whereas slower times, such as 1/10" or longer, permit motion to be observed. Ironically, the longer exposure times that permit motion to be seen also permit objects to disappear from the image completely by virtue of moving too quickly to make an impression on the medium relative to the surrounding exposure.

One concept that does not translate easily between technical vision and organic vision is the concept of focal length or field of view. The average field of view for a human is around 47° diagonal, or a focal length of 52mm on a full-frame camera. Smaller fields of view are usually referred to as a *telephoto* perspective and larger fields of view are referred to as *wide* (Ray, 2002). Humans have a fixed field of view, but are not hindered by it due to the ability for the human eye to pan in multiple directions, whereas scientific instruments may have a variable field of view but typically are stationary while in operation (Rector, Arcand, & Watzke, 2015, p. 21).

Why do these differences and similarities between organic and technical sensors matter to a discussion of false color? Perspective. The hardware is of a similar design whether it is electronic or organic, but each type of "sensor system" *sees* things differently.

What is False Color?

False color is a technique for assigning color values to a range of energy. There are several forms that this takes: energy representation, filtration, high-dynamic range tonal mapping, and long-exposure (Akyuz & Kaya, 2016, pp. 2-3). The most common form of false color is energy representation. The forms of false color are not exclusive of each other and multiple modes are often used in one photographic composition.

Energy representation is the process of interpreting the subject as only the value of the energy emitted. The value is then encoded in a way that can be translated to a visual image (Rector & Arcand, 2017, p. 47). This method of false color does not necessarily have to include color in the final output and may be represented as a monochromatic (black and white) image. Monochromatic photography is commonly combined with filtration to isolate or highlight a particular part of the light spectrum, such as infrared or near infrared. In figure 1 a red rose was photographed on infrared film through an infrared pass filter, which blocks all light that is below 720 nm, permitting only near infrared and infrared to reach the film (Kularski, 2017). The representative

Figure 1 (Kularski, 2017)

image of the rose is lacking in background details because those surfaces did not reflect the wavelengths of light that could be rendered on the destination medium. As a result, the fine details of the rose petals, which reflect infrared light well, are very distinctly visible. Elements that could detract from the technical accuracy of the image, such as variations in the density of red pigmentation in the petals, are eliminated.

Color photographs can be composed in the same way as their monochrome counterparts, utilizing a technique known as stacking. Stacking involves taking the same image multiple times, sometimes several hundred or several thousand times, with different wavelengths being measured in each slice of the image. Often these images are not in color when initially captured, but do have ranges of gray. For technical reasons the grays are coded across 256 shades (values), ranging from 0, as black and lacking in energy, to 255, as white at the maximum range of energy when processed digitally. In astrophotography various filters, cameras and other instruments may be used to obtain the various slices which are then composited into a single image. The sum of all of the slices without coloration would produce a confusing and busy-looking grayscale image that would provide no additional information to the viewer. Instead, color assignment and color value scaling are used to interpret the content of each slice in a way that makes visual sense in the final image. If an image is to be composed of slices from an infrared camera, a near-infrared camera and an X-ray observatory, then the infrared may be assigned to values of red, near infrared to oranges or yellows and X-rays in blue and violet. The result is a colorful image that contains each set of data confined to its own range, but presenting an overall image that is representative of the subject or phenomena being studied (Rector & Arcand, 2017, pp. 47-48).

High dynamic range tone mapping can be applied similar to the representative stacking method, but typically involves scaling color in images that were captured in the visible light spectrum (Eiersten, Mntiuk, & Unger, 2015). “Dynamic range is defined as the ratio of the brightest object in an image to the faintest” (Rector & Arcand, 2017, p. 48) . Imaging systems on telescopes typically have a larger range than human vision, even when remaining inside the visible spectra. This is also true of some modern professional camera sensors. The capability to perceive a greater range of luminance values than human standard vision is referred to as *high dynamic range* (Akyuz & Kaya, 2016, p. 2). High dynamic range does not have to be native to the device, it can be accomplished with stacking as long as the device can record information at various luminance values, such as by varying exposure times. To include this expanded luminance in an image that can be viewed under normal conditions requires compressing the range back to normal, in the roughly 256 tonal values that can be perceived by human eyes. A common way to accomplish this is a color tone map. The principles are similar to the color mapping used for representative coloring, except that the colors remain in the same spectral range, but with an adapted color value. Figure 2 is a tone mapped high-dynamic range photograph that was composed using three separate frames taken in sequence with different exposure times varied by

Figure 2 (Crews, 2015)

a set number of standard exposure values (Crews, 2015). The image depicts a body of water, foliage, structures and sky near sunset. In normal photography there would be extreme shadows or extreme bright areas of the image due to the variance of the light in the situation. Utilizing tone mapping the three exposures are overlaid and can be balanced for optimal luminance across the scene, enabling all elements to be seen in a single frame at a comfortable luminance level.

Long exposure is the most natural of the false color techniques. The color is true in the sense that no work is done to transform energy into light or to modify existing colors, but is false from the perspective of the captured scene does not match what would be seen with naked eye viewing. Long exposure is used to overcome the 1/30" sample rate of the human visual system. Figure 4 is a long exposure photograph of the Pleiades Star Cluster taken by the Hubble Space Telescope. The blue color is the color of the cluster as observed visually, but the long exposure reveals more of the structures involved in the stellar cluster (Space Telescope Science Institute, 2018, p. 1562). Figure 3 is a terrestrial photograph made under presumably typical conditions. Figure 3 shows the same general region of the sky and the same stellar arrangement, but without the aid of long exposure to highlight the presence of interstellar gasses

Figure 4 (Space Telescope Science Institute, 2018:1562)

Figure 3 (King, 2014)

(King, 2014). Many long exposures reveal even more hidden color than the difference between these two example images.

False color techniques all have one common objective, to show more information in a single image. The different techniques have different reasons for being used. Filtration shows more information by permitting less energy to enter the image. Color energy representation makes otherwise invisible energy visible to human eyes. High dynamic range and long exposure aim to represent more energy in a single image than could otherwise be seen in such a way. Filtration and stacking are used in multiple different techniques to achieve a specific effect.

Uses of False Color in Scientific Communication

Many scientific fields utilize false color imaging. Some fields use it as a way of providing evidence for a phenomenon, whereas others use it as an investigative tool directly in their research methods. Astronomy is perhaps the most easily recognizable field where false color is used in research, but archeology, medicine, engineering and other fields also benefit from false color techniques (Akyuz & Kaya, 2016, p. 4). For the purpose of this paper, astrophotography will be used as the field of reference due to its reliance on false color and other indirect observational techniques and the inability for most audiences to ever directly observe the depicted phenomena.

The core principle that separates scientific photographs from casual photography or other non-scientific illustrative methods is that scientific photographs are intended to be a source of knowledge rather than aesthetically impactful images (Ventura, 2013). Images in scientific communication add an additional descriptive layer to the communication beyond what is expressed in the often limited amount of text space in academic or scientific journals (Mogull

& Stanfield, 2015). In the case of astrophotography, the images tend to stand alone or are accompanied by relatively little text. Text that does accompany astrophotography can be very technical and of little use to helping a non-expert viewer understand the image (Arcarnd, et al., 2013). Missing context, other than a few notes about the object depicted, leaves a non-expert viewer on their own to interpret the image, often based on the assumption that photographic images are depictions of an objective perceivable reality. Some view the images with distrust or disbelief in the authenticity of the images, usually because they do not match what they see when they look into the night sky or when they look through a terrestrial telescope (Smith, et al., 2011, p. 204).

Astrophotography is the most common type of scientific imagery containing false color that non-scientists encounter on a regular basis (Rosenberger 65). These images are perhaps more prominent in the public sphere than other scientific images because of the nature of scientific communication. Arcand, et. al. describe that astronomy is largely funded by public money and as such requires some form of meaningful result be result be released to the public. Other fields produce results that have a more direct benefit and therefore do not have to prepare their results for public consumption in the same way. Due to the public funding and the necessity of public interest to the progress of astronomy, there is incentive for the "results" to be aesthetically appealing and accessible to the public audience (Arcarnd, et al., 2013).

The Issue with False Color in Scientific Communication

In the course of assembling images that are aesthetically appealing and accessible to a non-expert audience, I believe that astronomers are failing to reach the "accessible" component of their goal. Images from the Hubble Space Telescope have been of public interest since they were first made available, but generally there has been no noticeable increase in public knowledge of space (Rector, Arcand, & Watzke, 2015). Data is received from telescopes from a wide range of wavelengths of energy. When the data is transmitted it is raw observational information that has no native representation in the visual space. The data must be "translated" by astronomers into visual images that can be consumed by a non-expert audience. The translation process involves many different choices that must be made about how the data is presented, such as which wavelengths to represent, which to leave out, what the relative luminosity of each range will be and what colors will be used to represent each wavelength. Making decisions about how information is portrayed visually extends beyond the scope of science. Scientists select techniques for observation but in most fields do not have the same latitude to select how to information is displayed because there are field standards for how information is displayed (Arcarnd, et al., 2013). Making decisions about what each color will represent and what elements to include in the image gives astronomers a foot into the realm of artistry. While this aesthetic and discretionary freedom is a benefit for breaking the boundaries of science, it also places astronomers in a dubious epistemological position. Society grants scientists of all classes the role of creators and arbiters of truth, empowered by the deified scientific method and the canon of scientific history. That unique position carries a moral responsibility to represent findings truthfully and convey a true knowledge. The existence of an objective truth is a topic of ontological debate, but the expected role of science is enshrined in a collective societal understanding.

I do not question the techniques that are used by astronomers to achieve their desired result in the final images or their liberty to use methods of their choosing to create an image that is both scientifically meaningful and culturally perceived as beautiful by non-experts. My concern is in the absence of detailed documentation of the creation of an image that would ordinarily be found alongside any other work of scientific research. Further, I believe it to be problematic that content released for general public consumption is not accompanied by more descriptive text that is written for a non-technical audience. I also have a concern about the lack of knowledge that the general public has around the dimensions of light and other energy that they do not have direct observational access to, but that concern is better reserved for a discussion of perception awareness in primary education systems.

Current State of Literature

There are a variety of themes in the current literature on the topic of false color. Akyuz and Kaya (2016) state that false color is presently used in a problematic way because of a lack of consistency and transparency. Akyuz and Kaya describe methods for evaluating false color maps generally in science and propose a few key objectives that they believe would be beneficial in making mapped and representative images more intuitive. The color scale should be in a perceivable order that is consistent with the data being modeled, colors should be uniformly applied and differences should be consistent with the magnitude of difference in the values, finally the color scale should have continuity, not creating any artificial boundaries that are not present in the data (Akyuz & Kaya, 2016).

Rector, Arcarnd, et. al. (2015) describe the challenges in communicating astronomical data visually and detail some of the standard scientific practices. One challenge discussed is that of the approach that novices take to interpreting astronomical images. Most self-identified novices in a study admitted to approaching the images primarily aesthetically first, before attempting to read the images for information. It was proposed that one possible way to improve the increase in knowledge from being exposed to false color images is to invert the communication process, using the image as a way of beginning the communication process, then augmenting it with easily comprehended descriptive text. Some of the individuals surveyed about their perceptions of astronomical images stated that they wished to see images of space in a more raw way, rather than what they perceived as "stylized" images. Most concerning were reactions of feeling deceived upon learning that the images were not representations of what the human eye would see (Smith, et al., 2011).

Ventura (2013) describes the expectation of photographic images as representations of "truth", but argues that due to the invisible nature of many of the objects photographed with false color techniques, there really is no other alternative or more accurate way of representing the data without the aid of astronomer creativity and decision making to compose an image. One aspect that Ventura highlights is the need for professionalism among astronomers with regard to their discretion in utilizing technological methods to create images. A specific example given in the article is addition of shadows around stars in a nebula image to make the stars more visible, when the modification was not consistent with the particular phenomena that particular image was intending to depict (Ventura, 2013).

The Role of the Technical Communicator

In the quest for better communication between scientists and non-scientists, it seems logical that technical communicators could perhaps function as arbiters of true representations. Skilled technical communicators who understanding the background of the false color images may be capable of being the advocate for those who will see the images and to advise for ways to introduce more intuitive visual frameworks into the images or clever ways to incorporate meaningful text alongside the image.

Conclusion

There is no clear solution to all of the potential problems I have highlighted or those that are highlighted by the relevant literature. Much of what is depicted in false color images is invisible and therefore there can be no "true" representation, for whatever value or truth might be contained in such a representation, therefore the choice is to see the subject in a representative way or to have only textual descriptions of what cannot be seen in the visible spectrum. Astronomers who produce the images do not directly make claims of truth in the images, it is only the experience of society and the expectations of human cognition that assign those claims. I do not believe that there are general harms caused by the misunderstanding or lack of transparency in the presentation of false color images, but there is much room for improvement in the ways in which astronomers communicate what they are conveying visually.

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