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Astronomy with the color blind

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The standard method to create dramatic color images in astrophotography is to record multiple black and white images, each with a different color filter in the optical path, and then tint each frame with a color appropriate to the corresponding filter. When combined, the resulting image conveys information about the sources of emission in the field, although one should be cautious in assuming that such an image shows what the subject would "really look like" if a person could see it without the aid of a telescope. The details of how the eye processes light have a significant impact on how such images should be understood, and the step from perception to interpretation is even more problematic when the viewer is color blind. We report here on an approach to manipulating stacked tricolor images that, while abandoning attempts to portray the color distribution "realistically," do result in enabling those suffering from deuteranomaly (the most common form of color blindness) to perceive color distinctions they would otherwise not be able to see.

The human eye contains two types of light sensitive cells: rods and cones. The rods are not color-sensitive and mostly reside around the outer ring of the retina. Within that ring lie the cones.[1] The cones are less sensitive to the intensity of incident light than the rods, but they have the ability to distinguish color. There are three types of cones, each of which has a peak sensitivity at different wavelengths.[2] L-cones (or long-wave cones) have a peak sensitivity at 564 nm and therefore grant us the ability to perceive red. M-cones (or medium-wave cones) react to green at 533 nm. Finally, the S-cones (or short-wave cones) give us the blues around 437 nm.[3] By combining the output from these three receptors, our brains can construct a perception of color, much as computer screens use pixels or astronomers use filters.

There are three major forms of color blindness, each having to do with ways that these three types of cones can be faulty. The most common form of color blindness is anomalous trichromacy, in which a mutation limits but does not eliminate the function of one type of cone. A sufferer from this form of color blindness can perceive all normal types of color, but cannot distinguish between shades of particular kinds of color due to the reduced function of one type of cone. In this paper, we restrict our discussion to the case of deuteranomaly (the mutation of M-cones), the most common form, which affects 4.63% of men and 0.36% of women.[4]

Someone who is color blind with deuteranomaly has difficulty distinguishing between red and green.[5] Since yellow is a combination of red and green, shades of yellow are also difficult to distinguish. Figure 1 shows a standard RGB three-color combined image of the Orion Nebula (M42), taken with the 16-in PROMPT-3 telescope at CTIO in Chile. A normal-sighted person will distinguish the red ridges on the edges of the golden clouds, but someone with deuteranomaly will only perceive subtle shades of gold.

Because S-Cones are unaffected by this mutation, it has been found that adding a blue tint into the red color layer of an image, turning the red into magenta, will enable the deuteranomalous observer to be able to perceive color differences between red, yellow, and green that were invisible in a standard image.[6] To our knowledge, this technique has not

Fig. 1. RGB combined image of M42 using RCOS 16-in PROMPT-3 telescope[10] from CTIO (courtesy of James Missell and Skynet). Image is constructed from three 20-s exposures.

Fig. 2. Color-adjusted version of M42 image from Fig. 1, in which the red layer has been changed to magenta using AstroImageJ. The red ridges in Fig. 1 look green here, and the gold has turned blue. The green ridges against the blue cloud will now stand out to a deuteranomalous observer.

Fig. 3. NASA WISE false-color image of the Barnard 3 (the Wreath Nebula). The green tint represents emission at 12 μ, while the red represents 22-μ light. Blue and cyan represent 3.4- and 4.6-μ sources, respectively. A deuteranomalous observer will be able to distinguish the red core from the green wreath, but he will not notice that there are wisps and knots of yellow within the wreath.

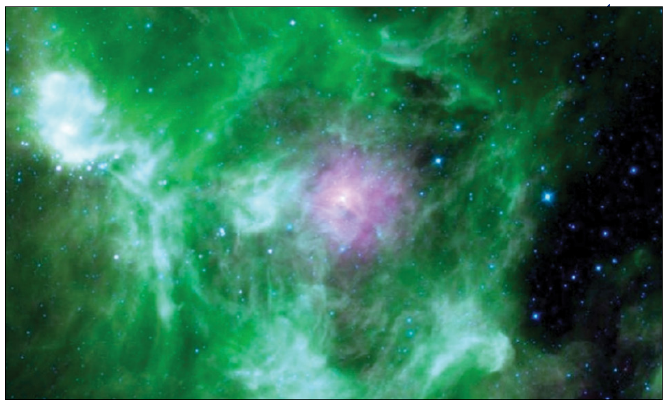

Fig. 4. Color-adjusted image of the Wreath Nebula. The knots in the lower-right half of the wreath will stand out to a deuteranomalous observer, particularly when compared with Fig. 3.

yet been applied in astronomical contexts. We used the freeware program AstroImageJ[7] to split multicolor astronomical images into RGB frames, alter the color of the "red" frame to "magenta," using the pull-down menu,[8] and combine the altered frames into multicolor images. In the color-altered image of M42, shown in Fig. 2, the fact that the ridges are a different color from the bulk of the nebula now stands out to the deuteranomalous observer.

This technique can be particularly useful in false color images, when the colors are meant to convey information about the invisible wavelengths of light recorded by telescopes. NASA's Wide-field Infrared Survey Explorer (WISE) produced a spectacular image of Barnard 3, or the Wreath Nebula,[9] shown in Fig. 3. The green tint represents emission at 12 μ, while the red represents 22-μ light. A deuteranomalous observer can perceive that there is a red disc in the middle of a green circle, but the fact that the lower half of the "wreath" has wispy structures of yellow (and therefore both forms of infrared radiation) will be lost. Shifting the red to magenta produces Fig. 4, and in this image the knots and structures will stand out.

It is important that the color blind individual sees both the original and the altered image side by side. Understanding the limitations of his own vision, and knowing what change has been made to the image, lets the observer properly interpret the presence or absence of colors he cannot normally perceive. Furthermore, changing red to magenta introduces blue into the image where there was none before, and this may lead to misinterpretations of the information encoded in blue. Since the deuteranomalous observer can perceive blue without difficulty, the differences between the two images can help the observer distinguish between blue that has been added and blue that was in the original image. It is also helpful to discuss the perceived changes with a normal-sighted person.

The method described here is effective at enabling a color blind observer (deuteranomaly only) to perceive the difference between regions of green, yellow, and red that would otherwise look the same. This can be useful in instruction, to ensure that a color blind student is not be left behind when the teacher points out imperceptible features in an image. If the color blind student is actively included in creating the images, this will increase engagement and investment in the topic. The process of construction of the image also reinforces the understanding of the artificial nature of color in images. When the limits of the technique are kept in mind, we have found this to be an effective way to include deuteranomalous students in the appreciation of astronomical images.

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