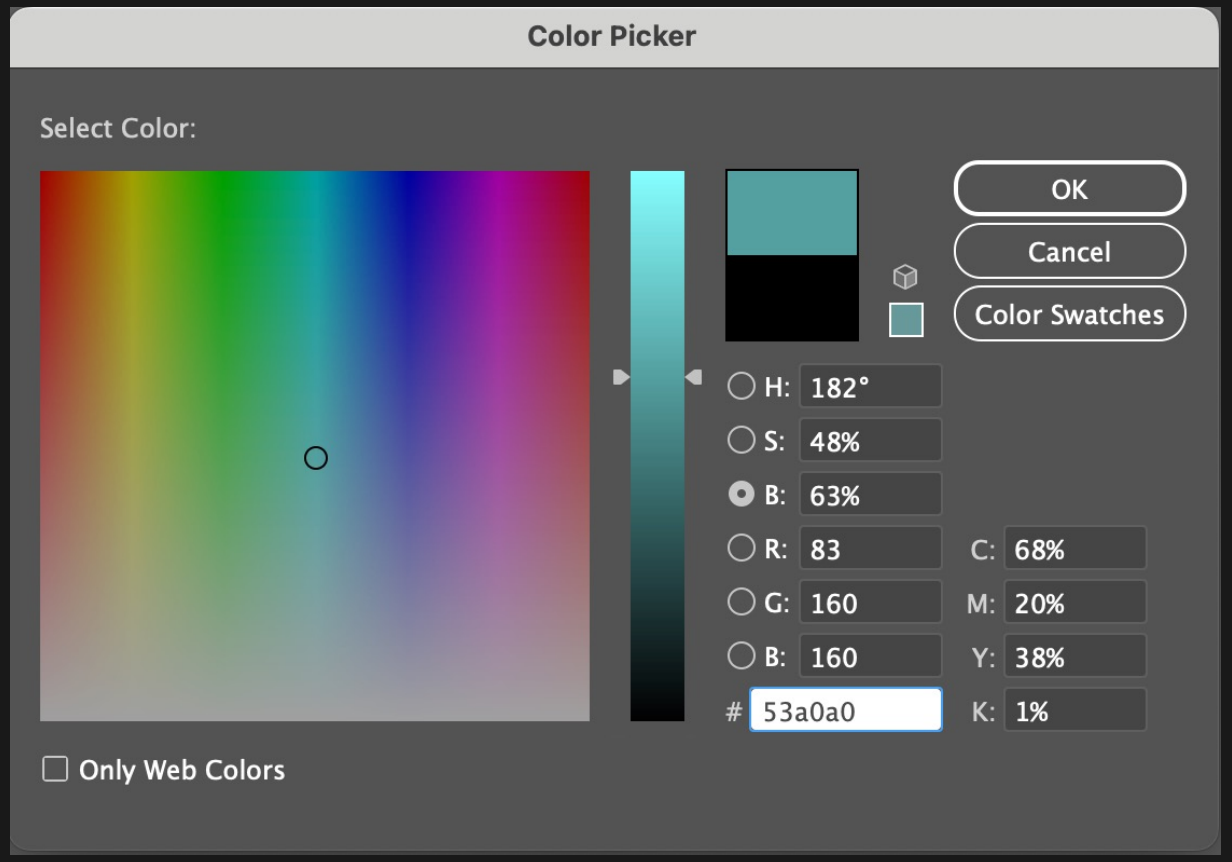
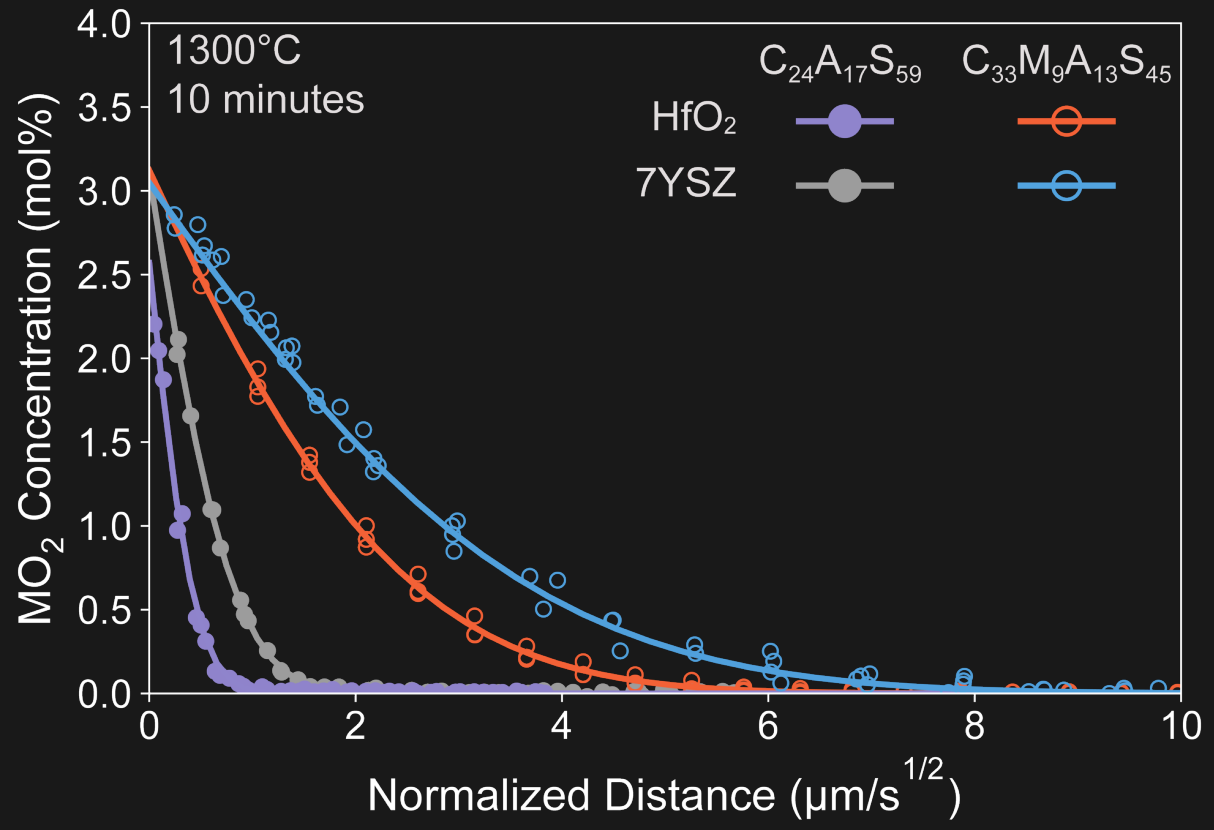
Colors!

CS Holgate

How can I choose good colors for plots and artwork?





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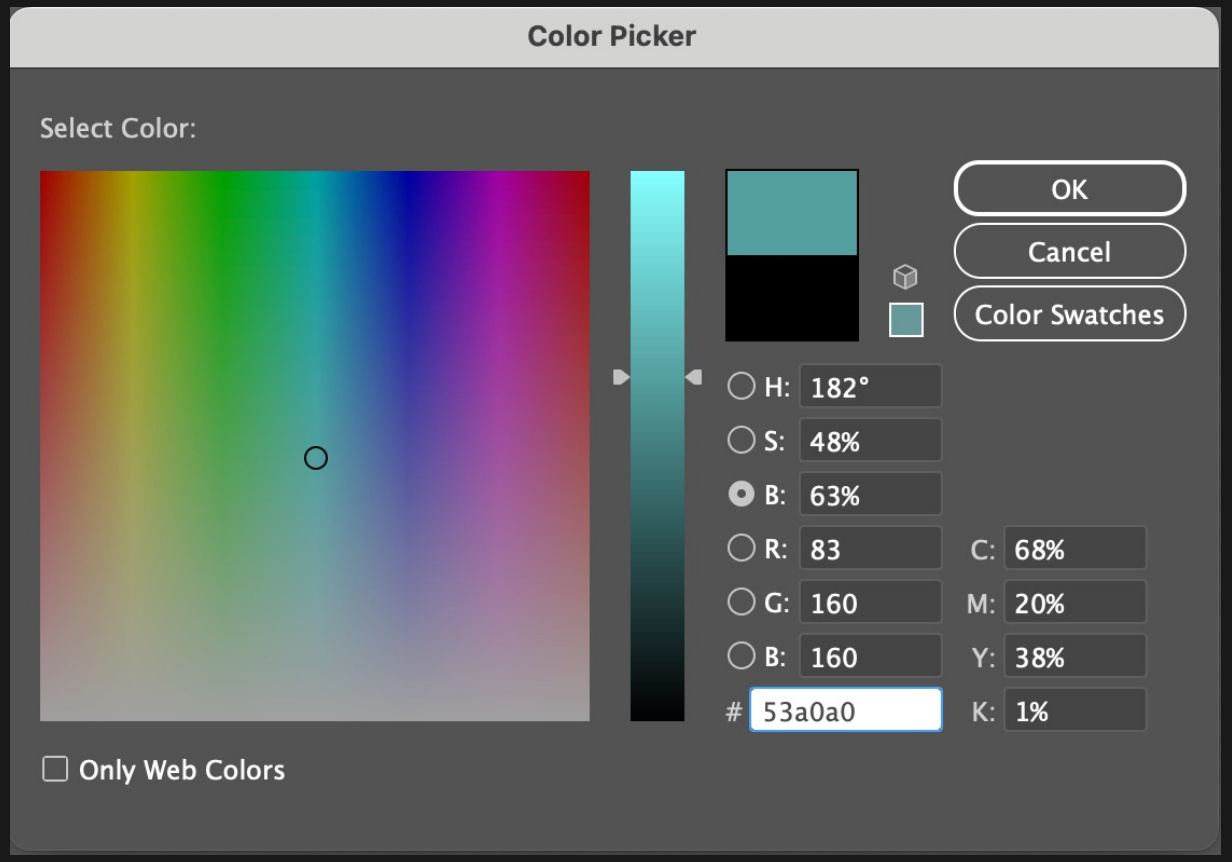
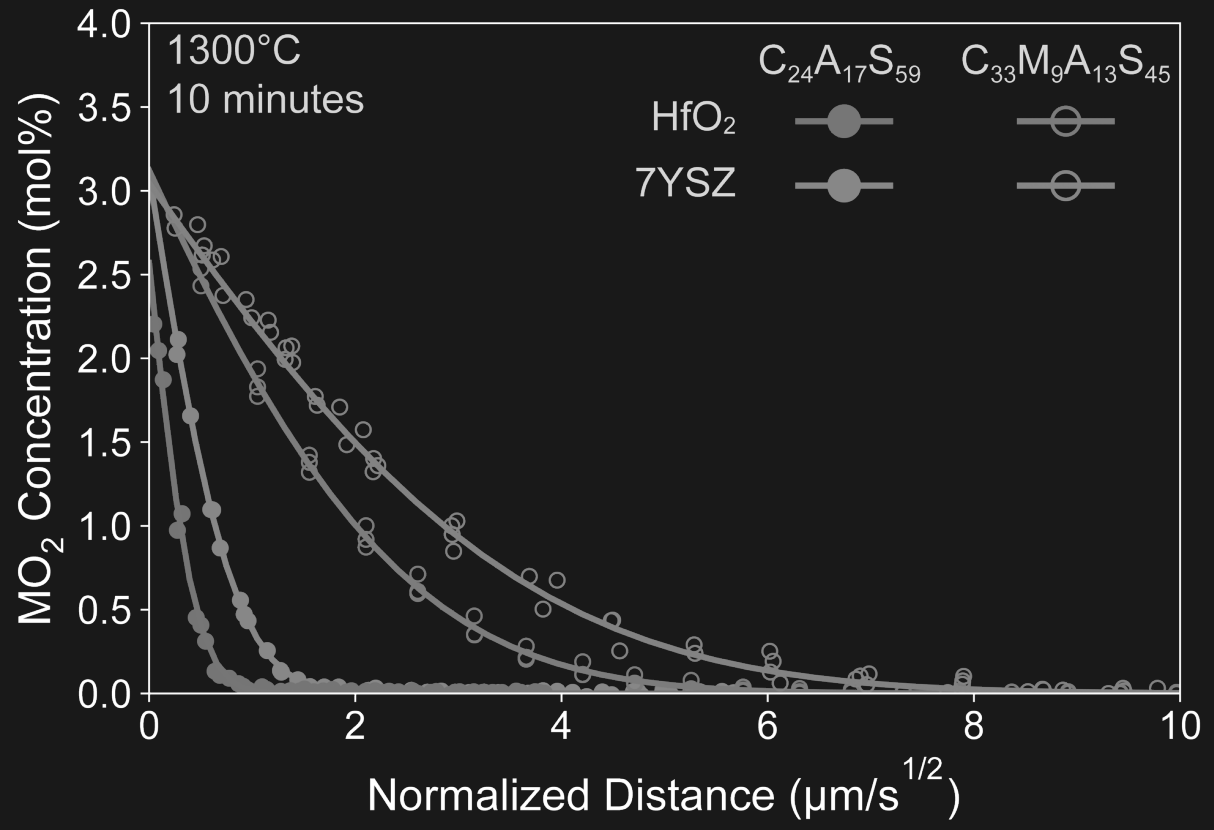
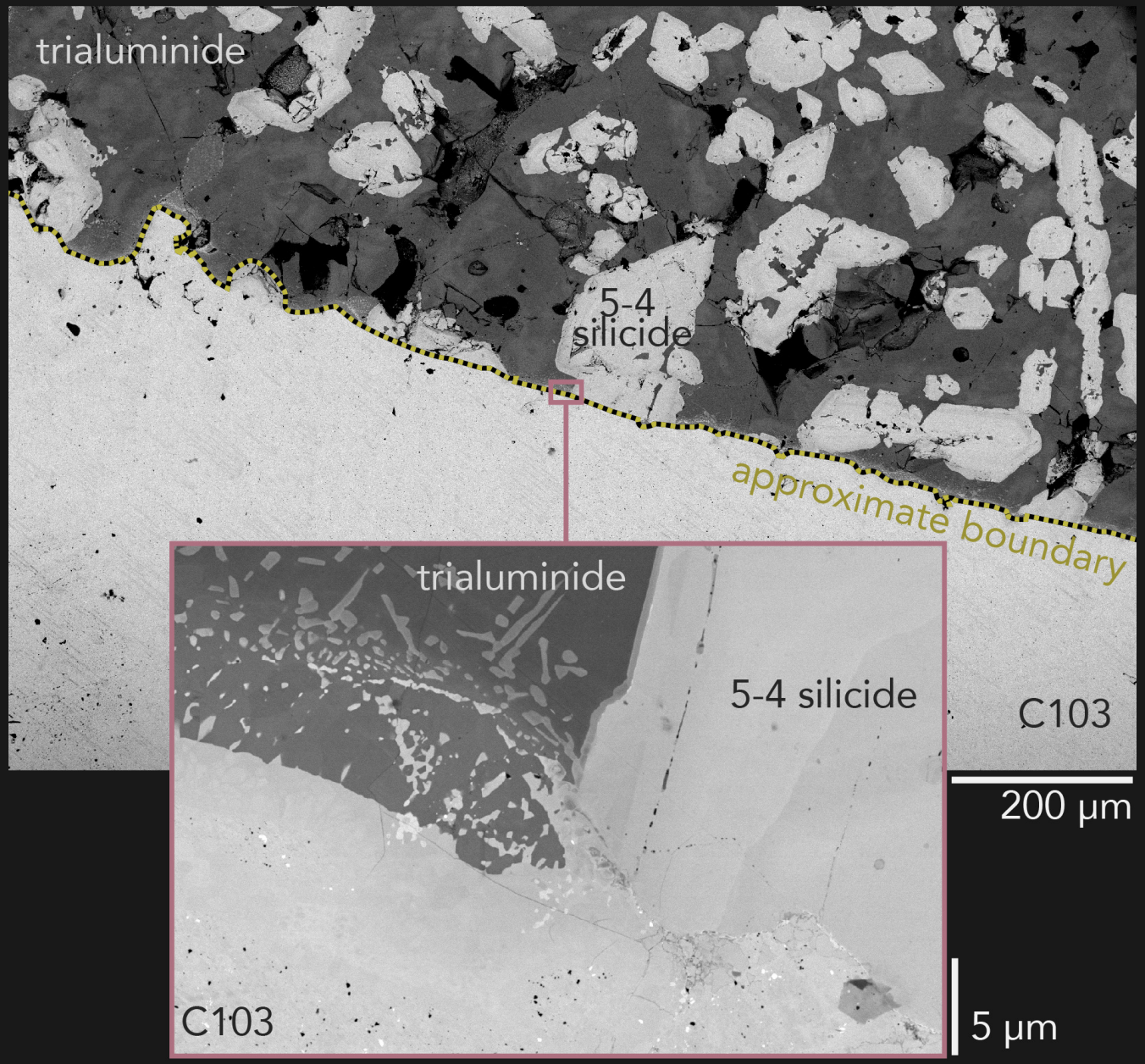




Conversion to greyscale *sucks*. Like *really sucks*.
Often you get unpredictable results, which results in a lack of contrast.

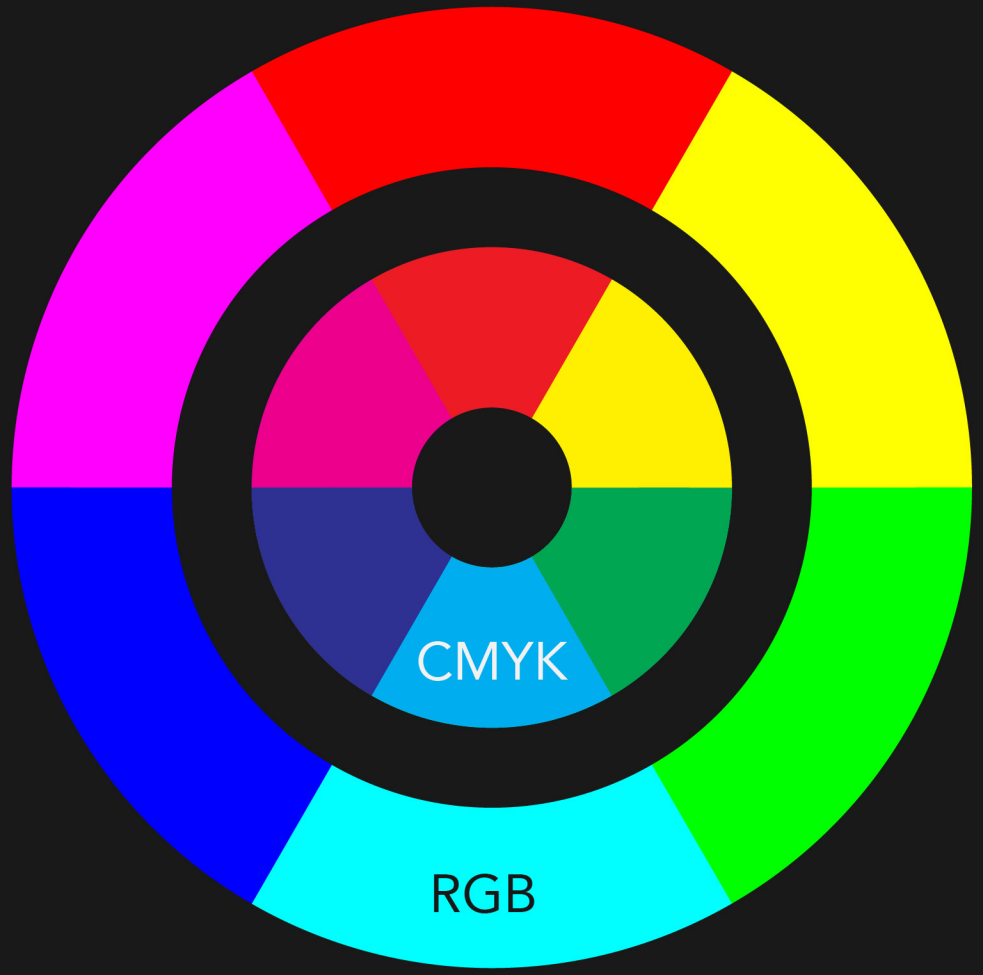
How can I have text or lines stand out on an SEM image?

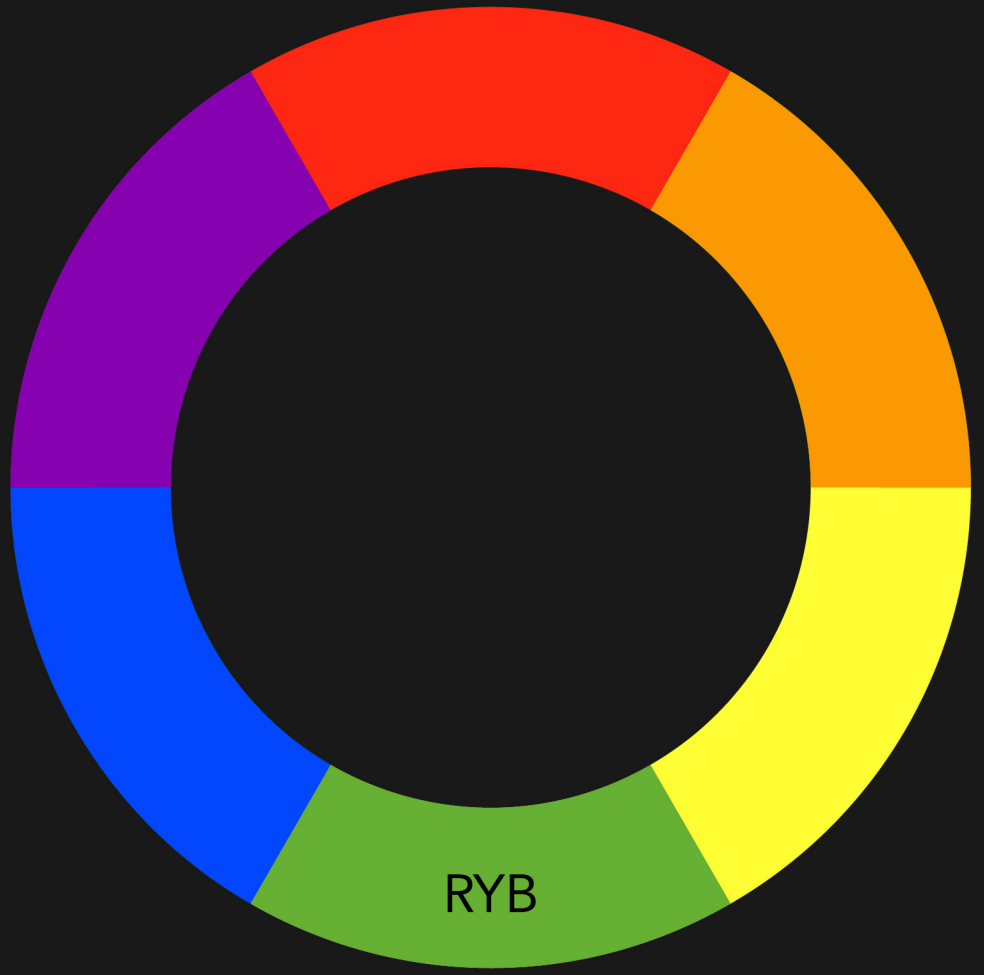


The contrast between the line art and SEM image behind depends on relative lightness differences, but we can also exploit how saturation differences.

What is a color?

What is a primary color?

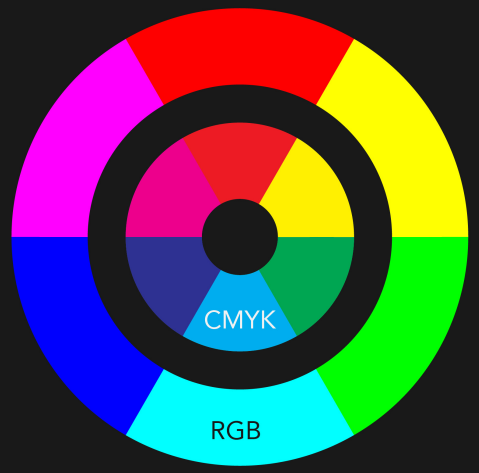




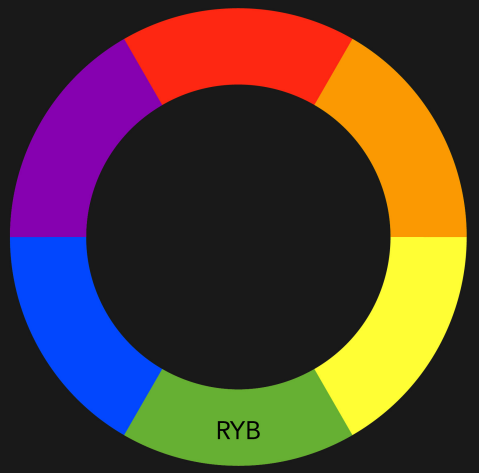
What is red's "opposite"?

Colors can be mathematically defined through color spaces

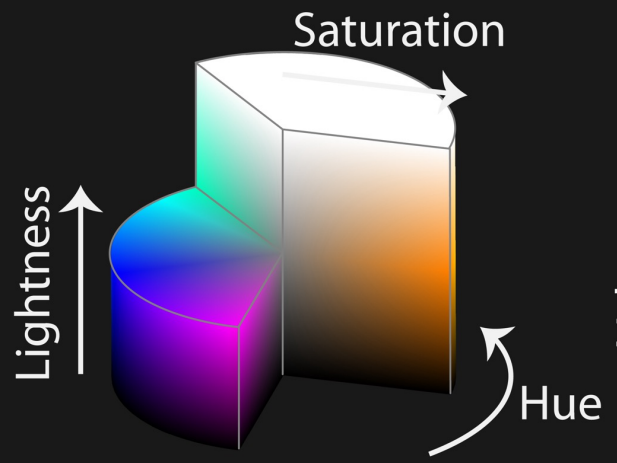
RGB/CMYK



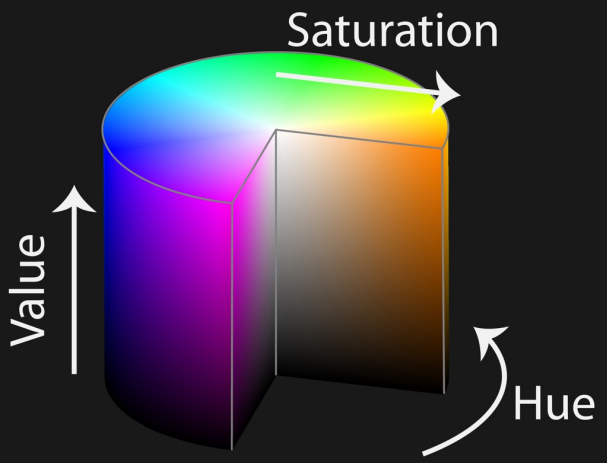
RYB



HSL



HSV/B

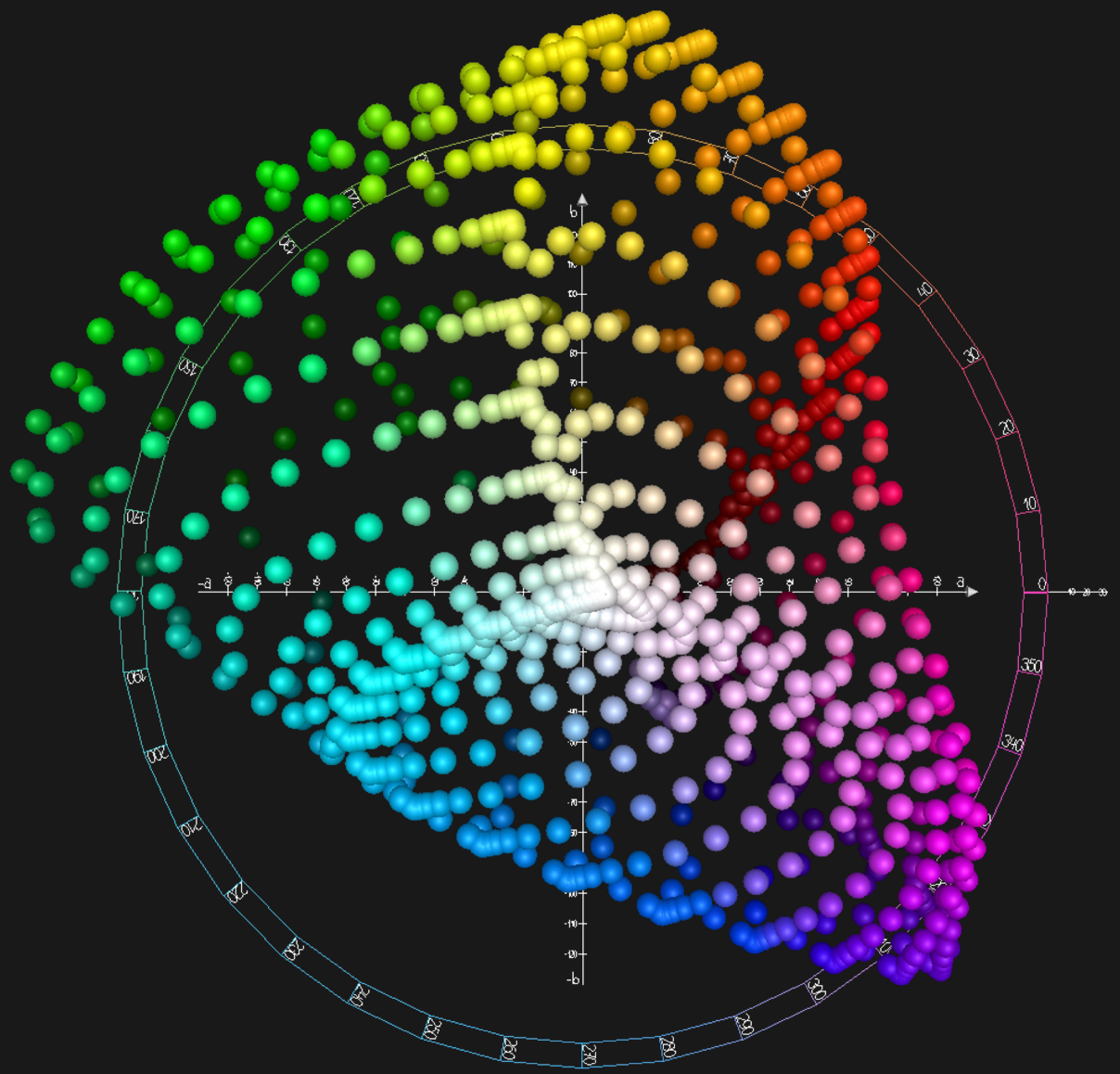


Adapted from Wikipedia article on HSL and HSV

Illustrator uses RGB, CMYK, and HSB color spaces, which are all related through relatively simple transformations.

Each model benefits from putting all of color space into a nice “shape”, either cubic or cylindrical. But nature doesn’t fit in this shape, which creates issues.

More realistic color spaces exist, but they can be hard to work with



The (arguably) most realistic color spaces are those defined by CIE (*International Commission on Illumination*, translated from French).

Their most commonly used color space is CIELAB or L*a*b*. This defines colors with three axes:

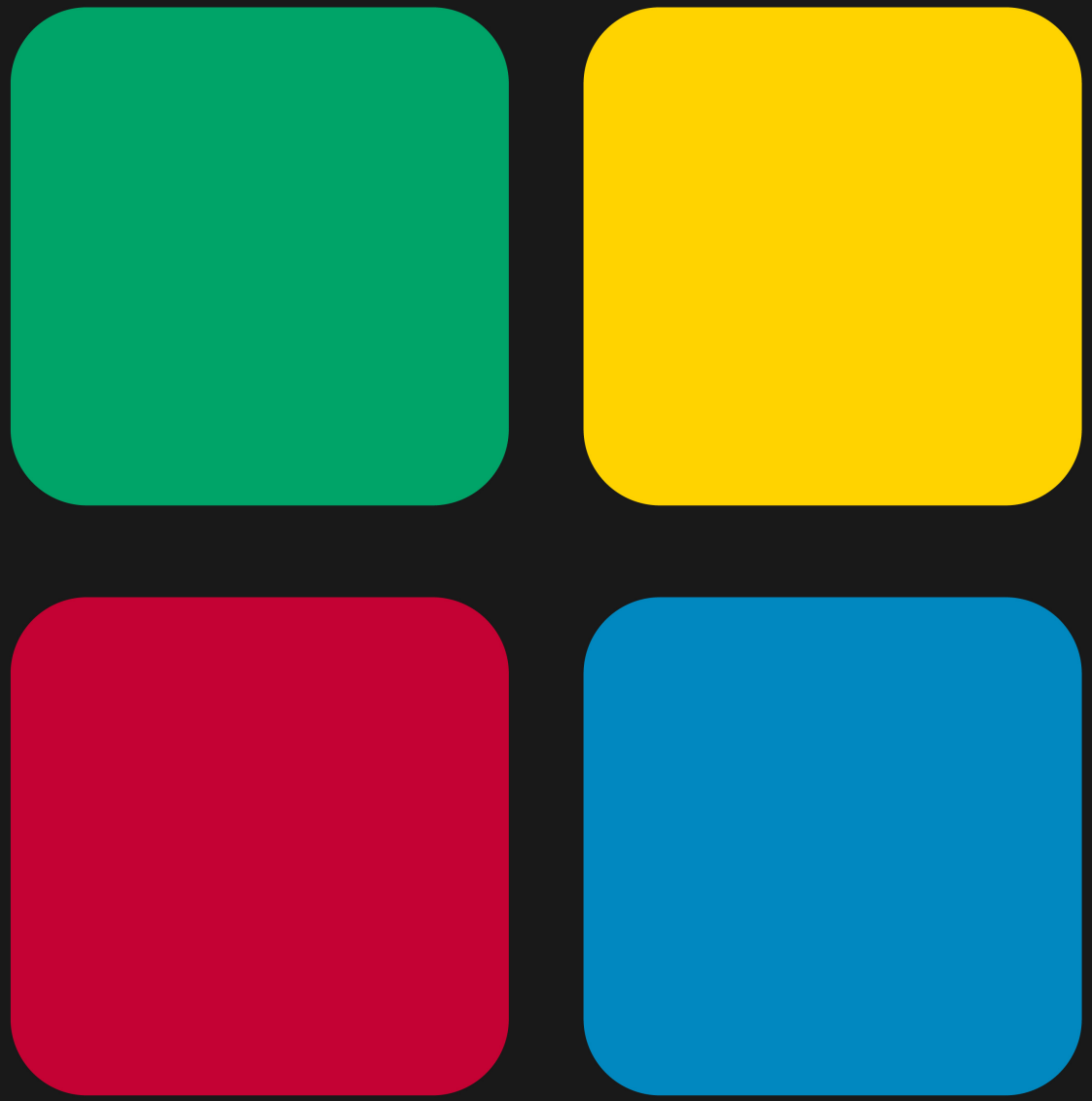
- L: perceptual lightness
- a: green-red
- b: blue-yellow

The a-axis and b-axis covers negative and positive values, and is unbounded. The color space volume has a complex shape, sort of like a sheared teardrop. This makes moving about the space not very intuitive.

Interestingly, this space is in Photoshop, but not Illustrator.

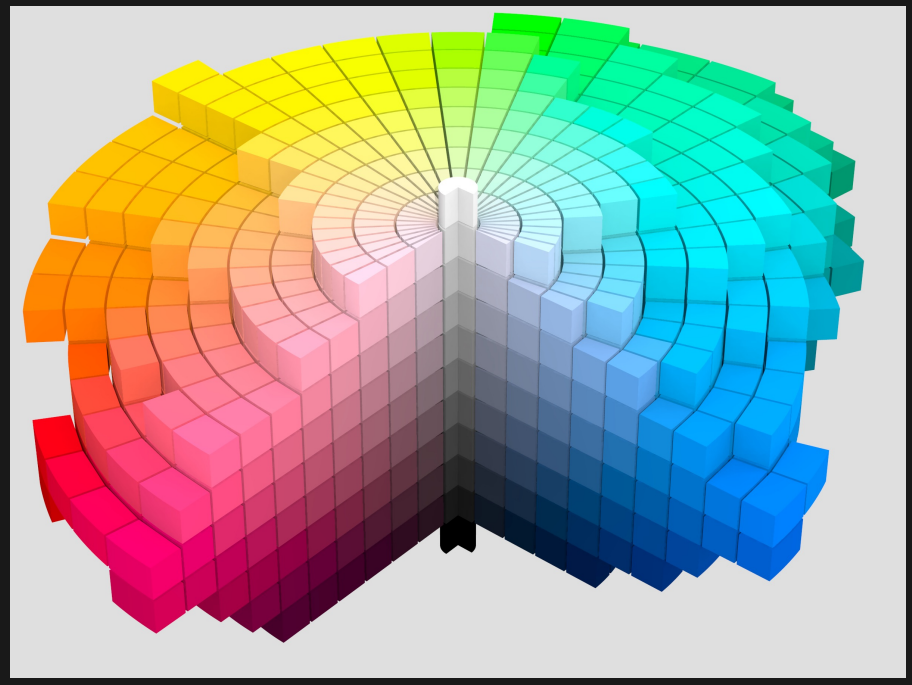
Taken from Wikipedia article on CIELAB

And there are more!



Opponent process theory (left) suggests the primary colors are red, yellow, cobalt blue, and cobalt green. This has yielded the "Natural Color System".

The Munsell color system (below) is closely related to Natural Color System and the CIELAB system, with slightly different "primary" colors.



Adapted from Wikipedia article on Opponent Process

Taken from Wikipedia article on Munsell Color System

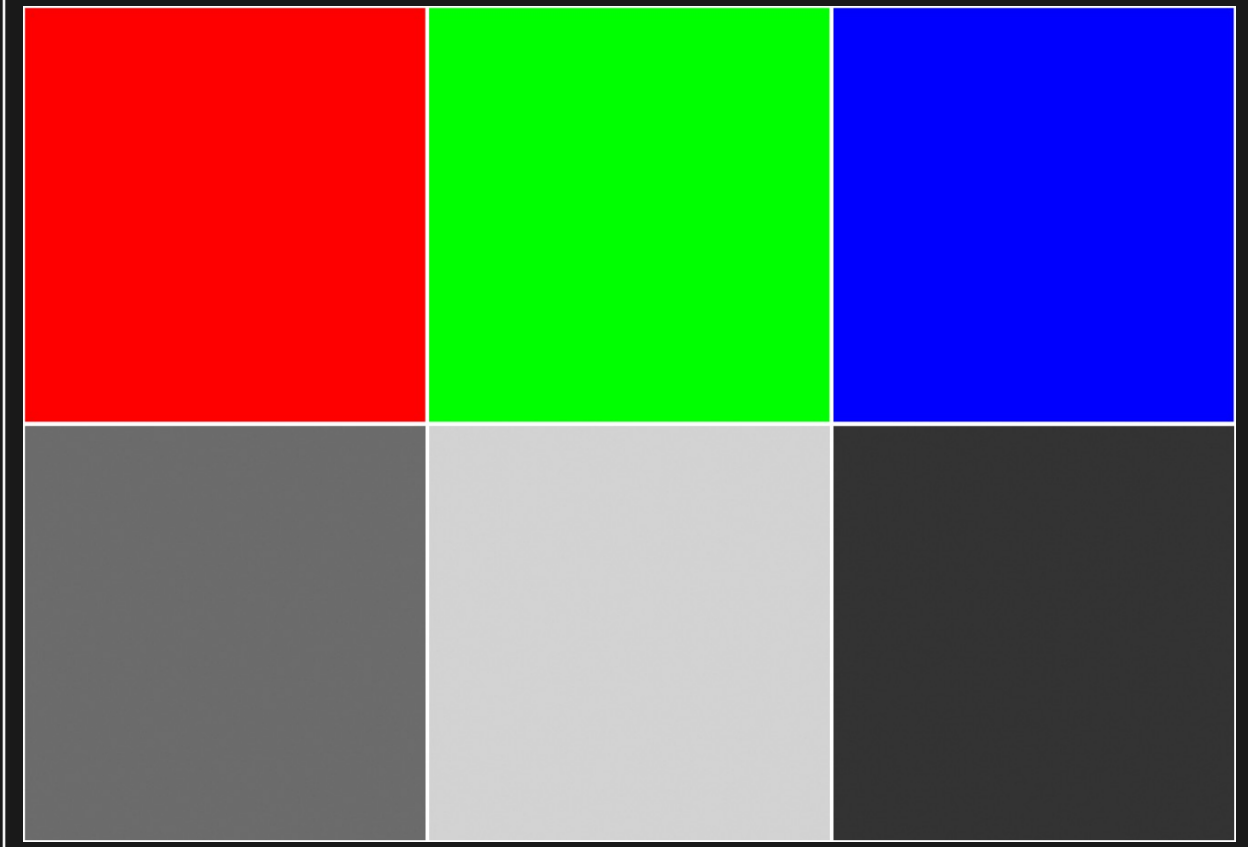
Realistic color spaces do an excellent job at preserving the distances between two colors linearly. Really, there are three things we care about here:

1. What is the hue?
2. How colorful is the color (its "saturation", "chroma", or "chromaticity")?
3. How light or dark is the color?

Using realistic color spaces effectively guarantees that two colors are actually contrasting, and it is trivial to see how that will be converted to greyscale.

They also help avoid common pitfalls with defining colors in RGB/HSB space.

Pitfall 1



In RGB space, different pure colors have drastically different lightness.

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Pitfall 2

In HSB space, the brightness is also not well conserved. Most detail in the flames is lost.

Adapted from Wikipedia article on HSL and HSV

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Pitfall 2

Comparatively, the L* axis of CIELAB retains this detail.

Adapted from Wikipedia article on HSL and HSV

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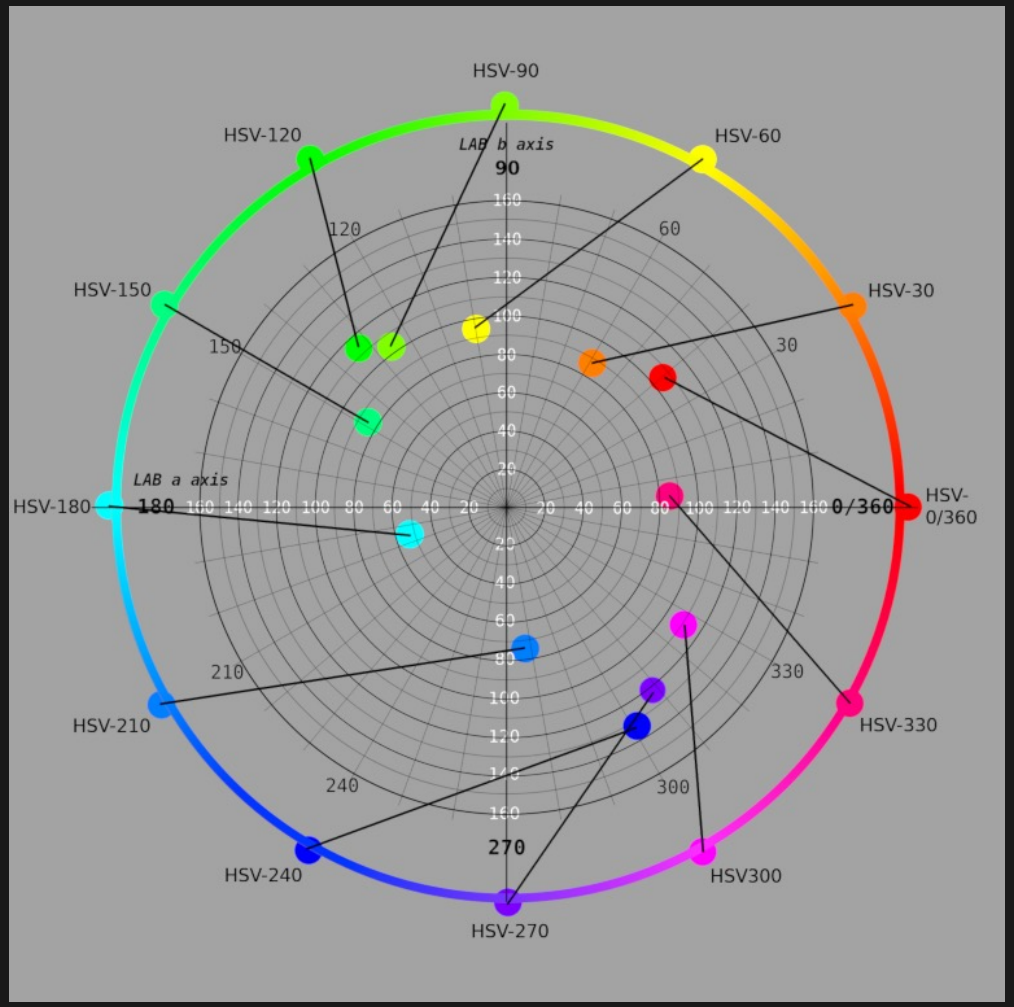
Pitfall 3



Any changes in RGB/CMYK/HSB space yields non-linear changes to **all** other axes.

Adapted from Wikipedia article on HSL and HSV

What can we do?

RGB/CYMK/HSB just lies to us.

CIELAB just doesn’t want to be worked with.

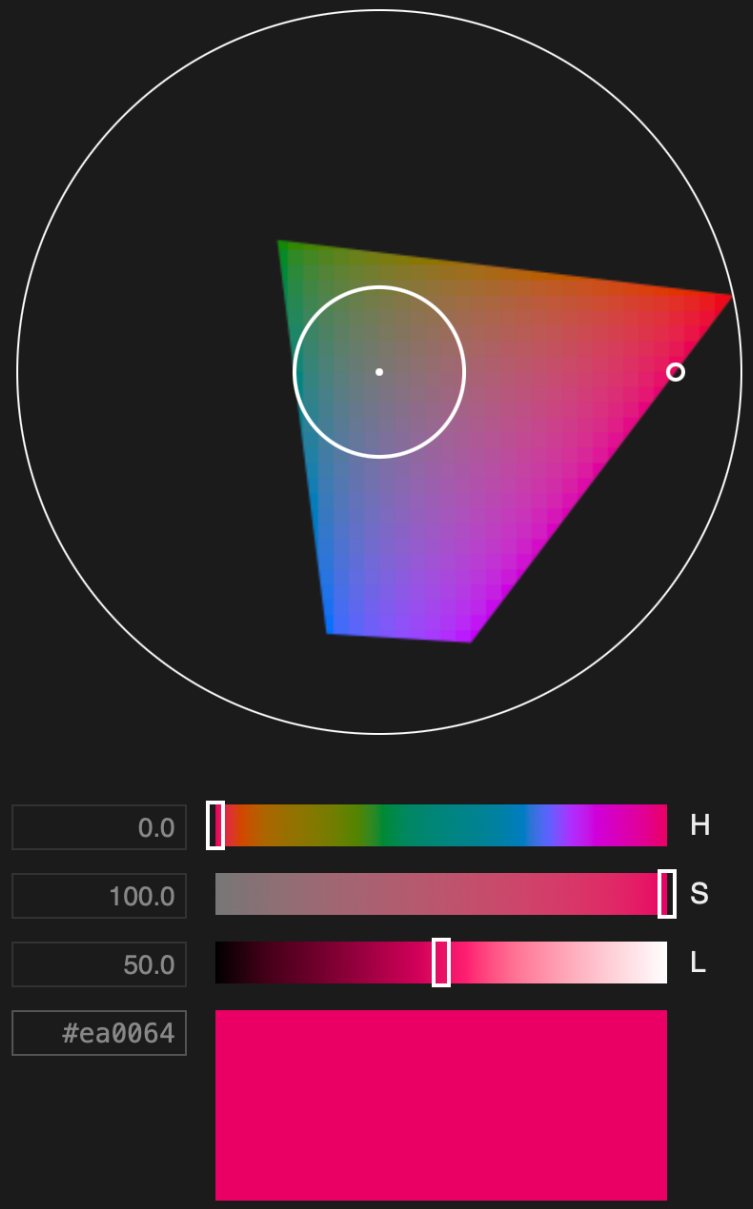
Online tools exist to help navigate perceptually uniform color spaces

My favorite is hsluv.org.

This tool effectively keeps the L* axis of CIE tools, but converts the color axes into cylindrical coordinates with a hue (°) and chroma (%). The key distortion here is that the chroma axis is normalized to always go between 0 and 100%. This assumption eliminates "out of bounds" values, at the cost of saturation contrast between two hues. Helpfully, it outputs a color hex-code that can be copied and pasted into Illustrator.

The tool gives an excellent color picker (top) that removes this chroma normalization. It allows you to see the absolute chroma of a given hue and lightness combination.

The most important implication:
The colorfulness of a hue depends on its lightness!

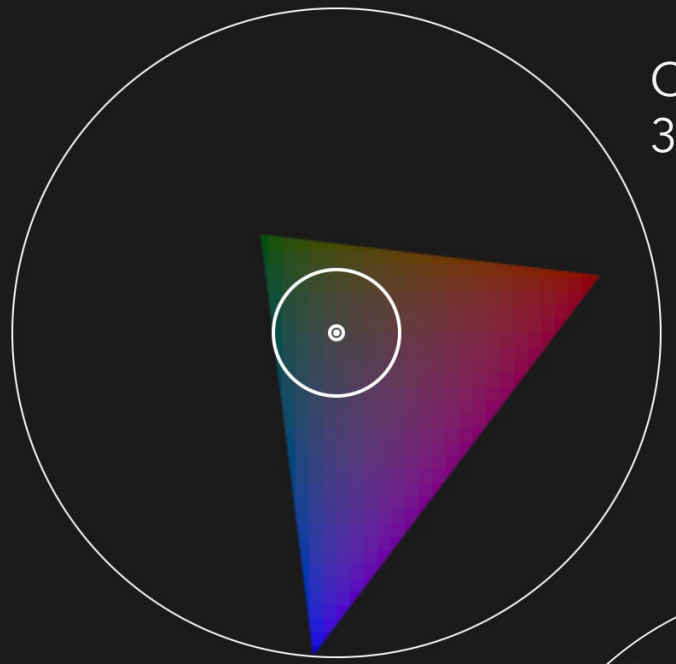


Key takeaway: the colorfulness of a hue depends on its lightness

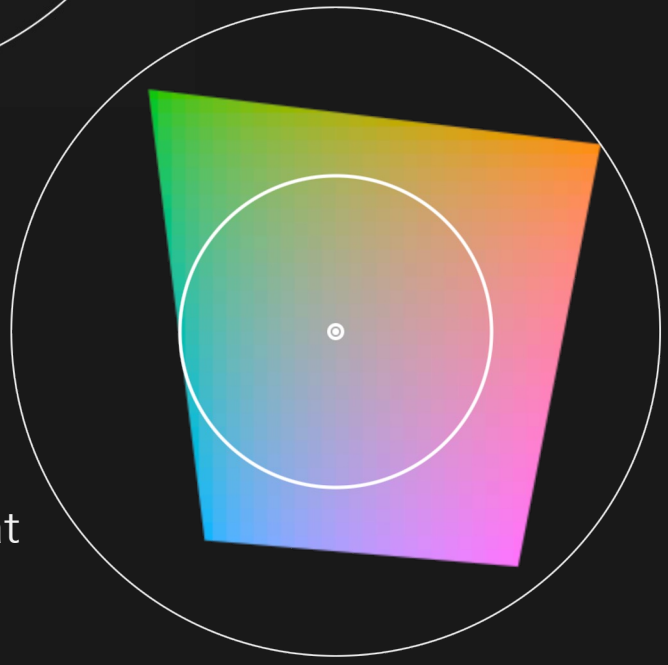
What values of lightness do different hues become most colorful at?

- Reds: 40–55% lightness
- Oranges: 55–70% lightness
- Yellows: 97% lightness
- Greens: 71–90% lightness
- Blues: 0–40% lightness
- Purples: 40% lightness

In a practical sense, more hues exhibit more colorfulness when they are brighter than darker.



Colors available at 30% lightness



Colors available at 70% lightness

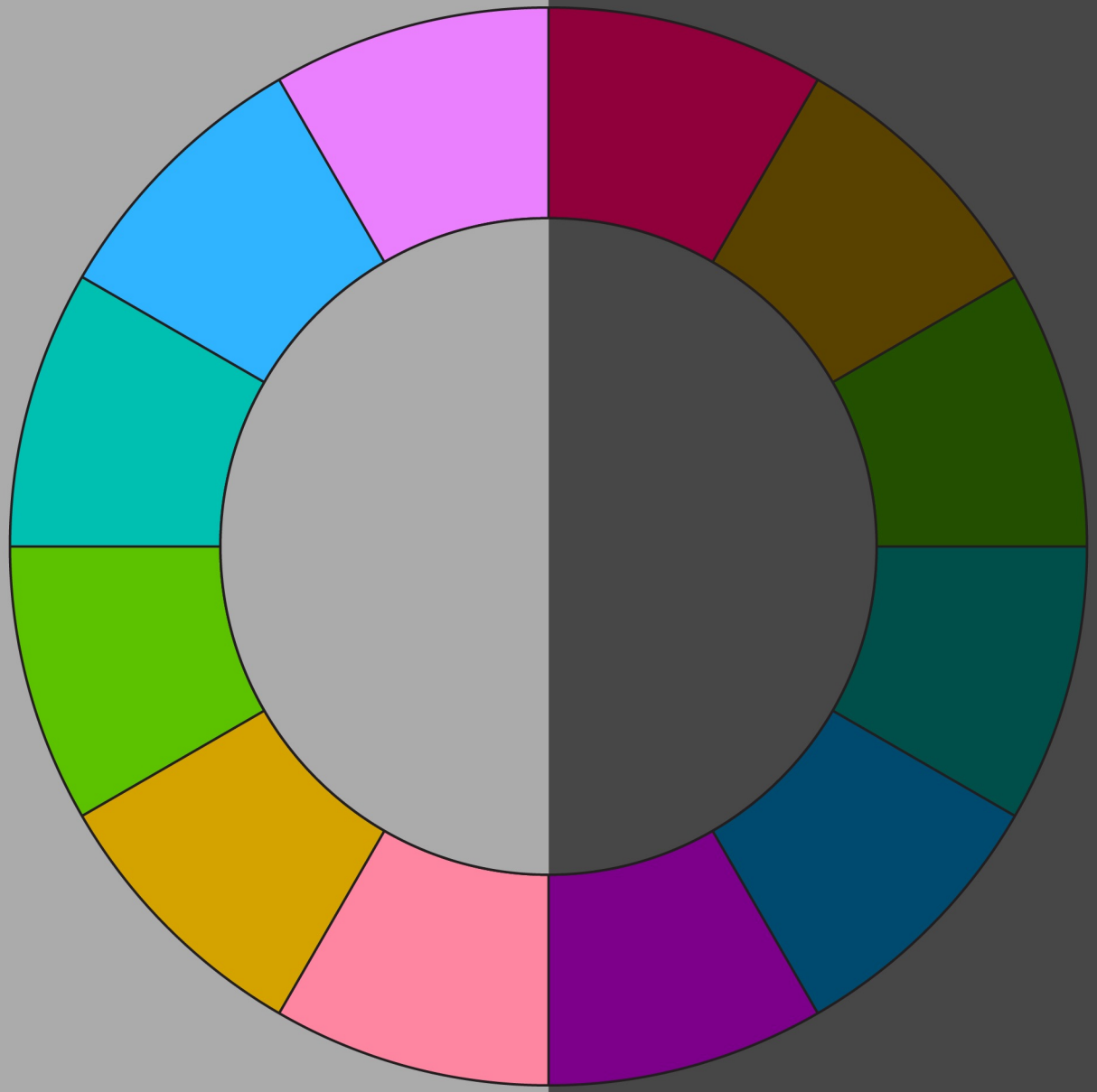
An example:

Here is a background of 8.8% brightness, with colors all set to 70% brightness.

Compare this to a background at 91.2% brightness with colors all set to 30% brightness.

Colors on the left provide much better contrast with the background and each other.

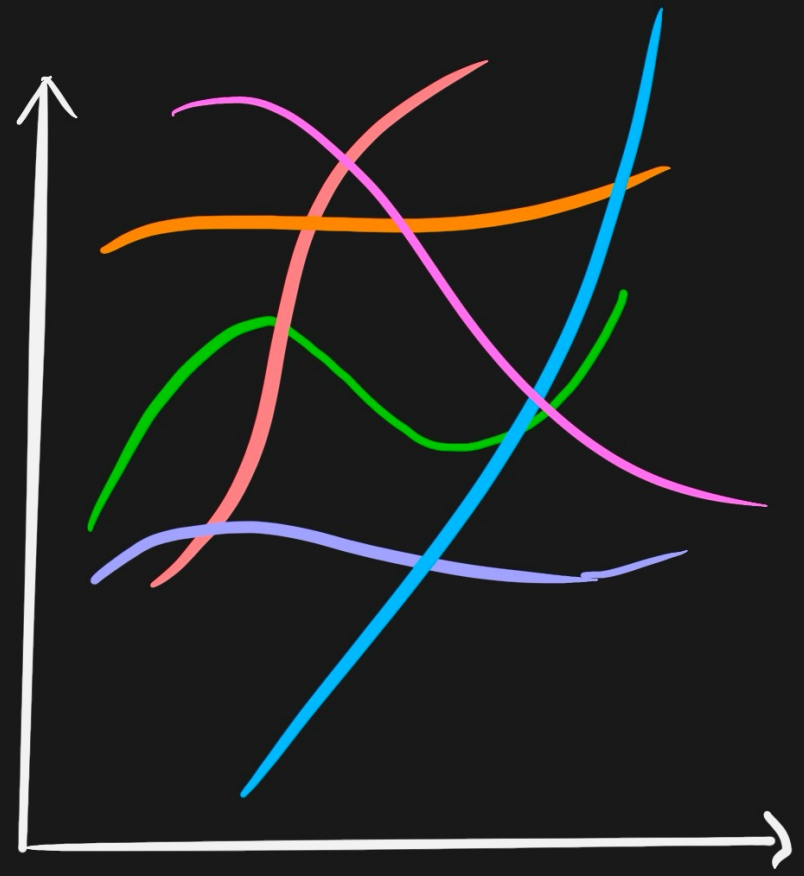
Here are the same colors (70% brightness) now on a background of 70% bright grey.

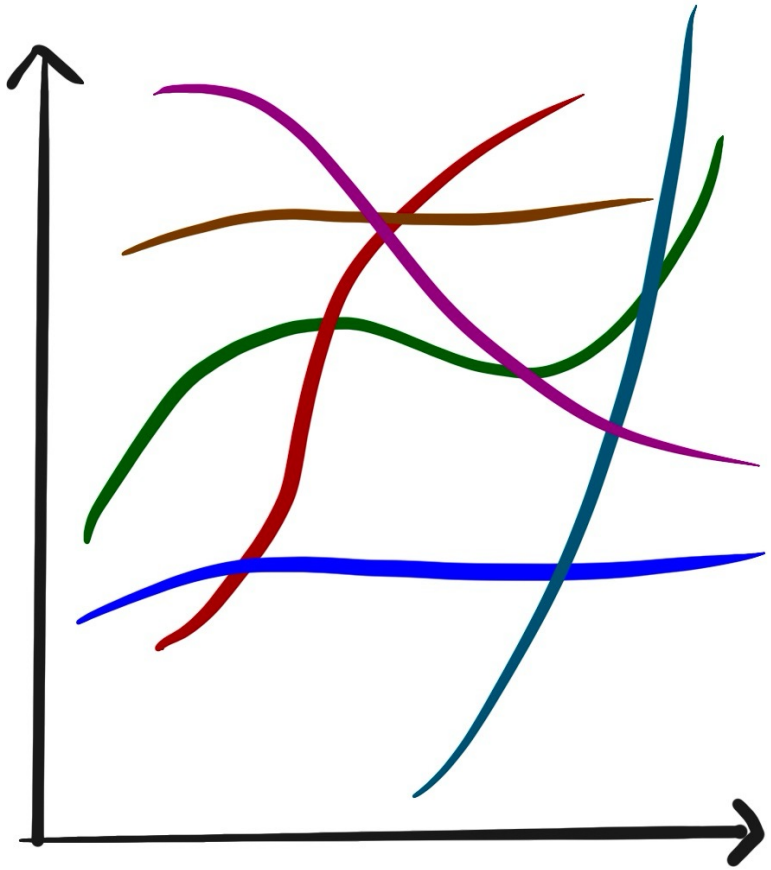


Here are the same colors (30% brightness) now on a background of 30% bright grey.

The colorfulness contrast is much more important when brightness contrast is removed.

Brighter colors contrast better





Wrap up and useful tools

Use a color picker with absolute lightness. This makes conversion to greyscale trivial. Also it helps ensure that line art will actually stand out from an SEM image behind it.

Think about contrast—both in terms of lightness and colorfulness. Remember that different hues reach peak colorfulness at different absolute lightness.

(As an aside: This is why I think dark-themed slides are so great! They give you access to the 70% bright colors with a lot of color contrast and lightness contrast to the background.)

hsluv.org: Excellent color picker that preserves perceived brightness, so great for converting to greyscale

WebAIM.org: Includes a contrast checker to ensure two colors are sufficiently visually distinct.