

# Colors and your research

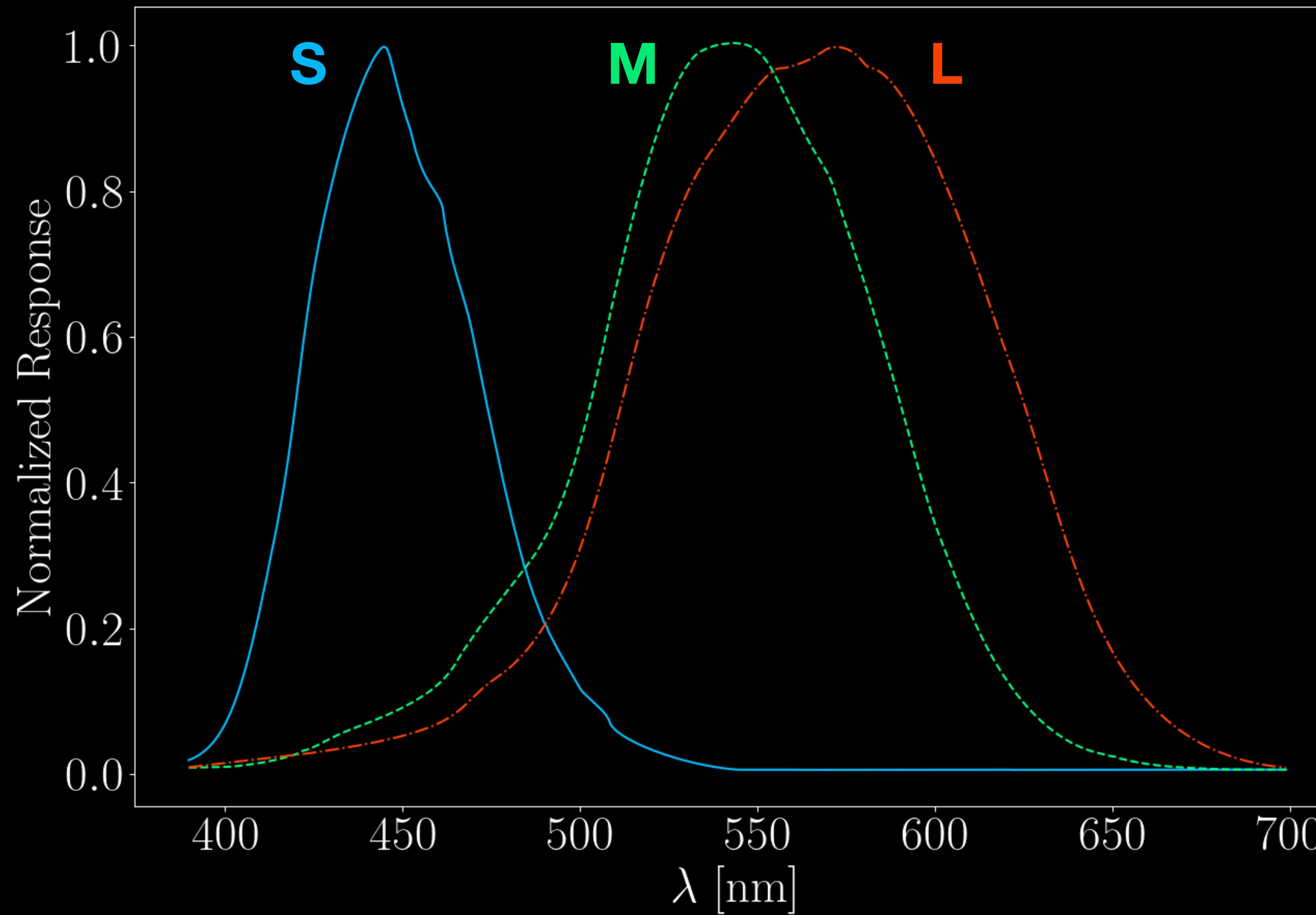
Wolf Cukier, February 5 2025

\*Inspired by a talk by Chris White at Princeton

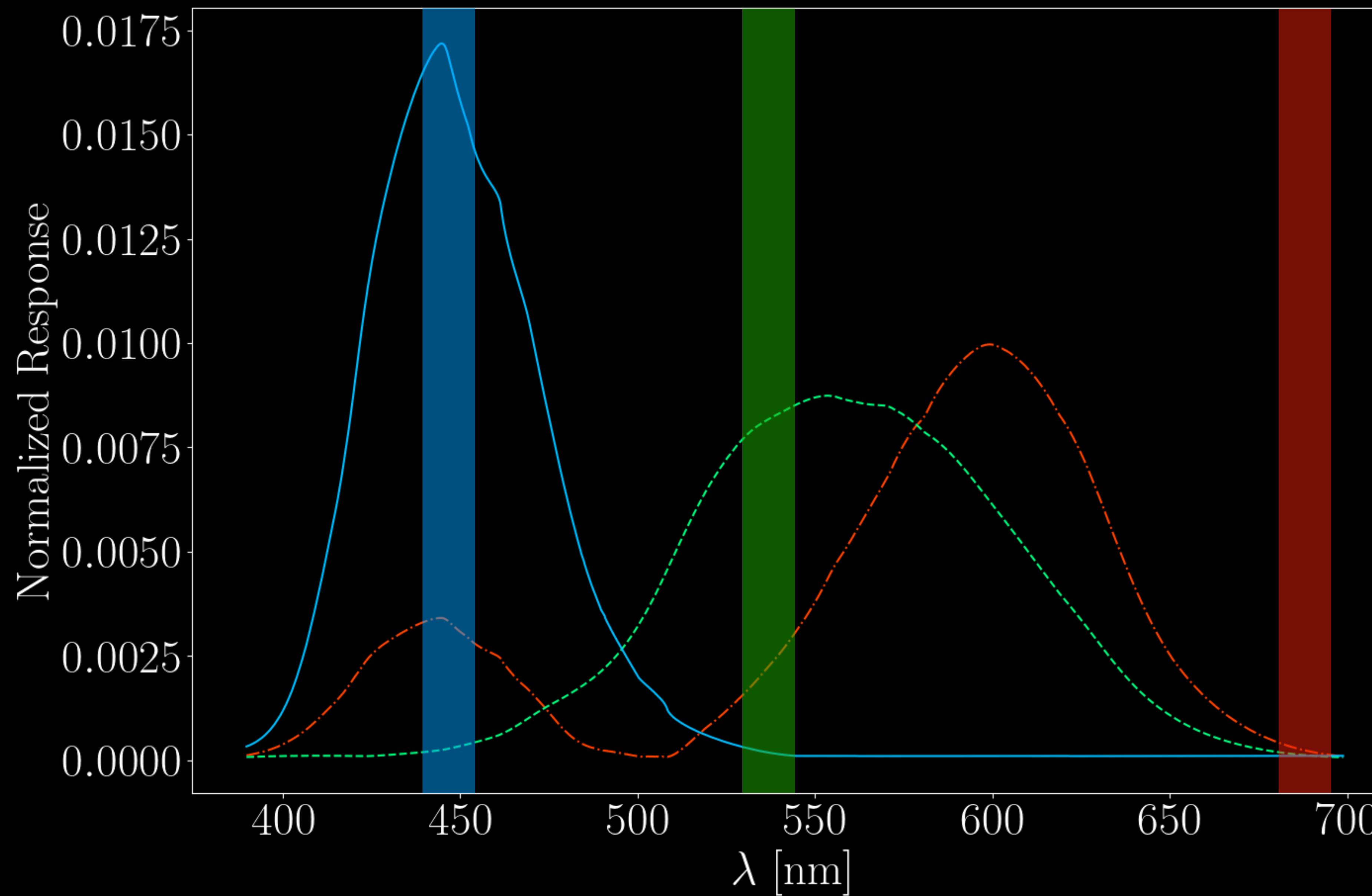
# Outline

- Color Vision and Color Spaces
- Colormaps
- Color and Line Plots
- Color Vision Deficiency

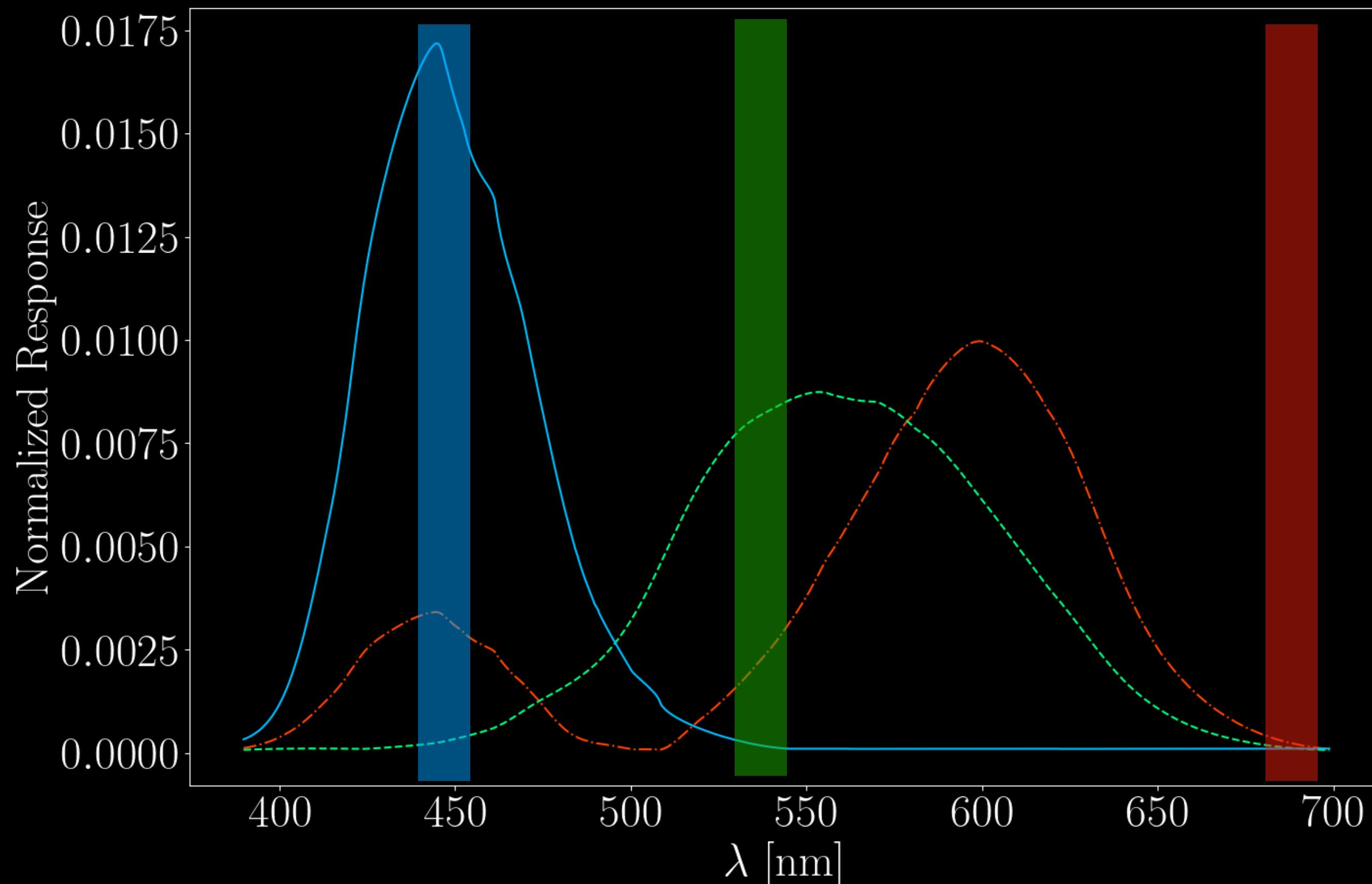
# LMS Color Space



# LMS Color Space

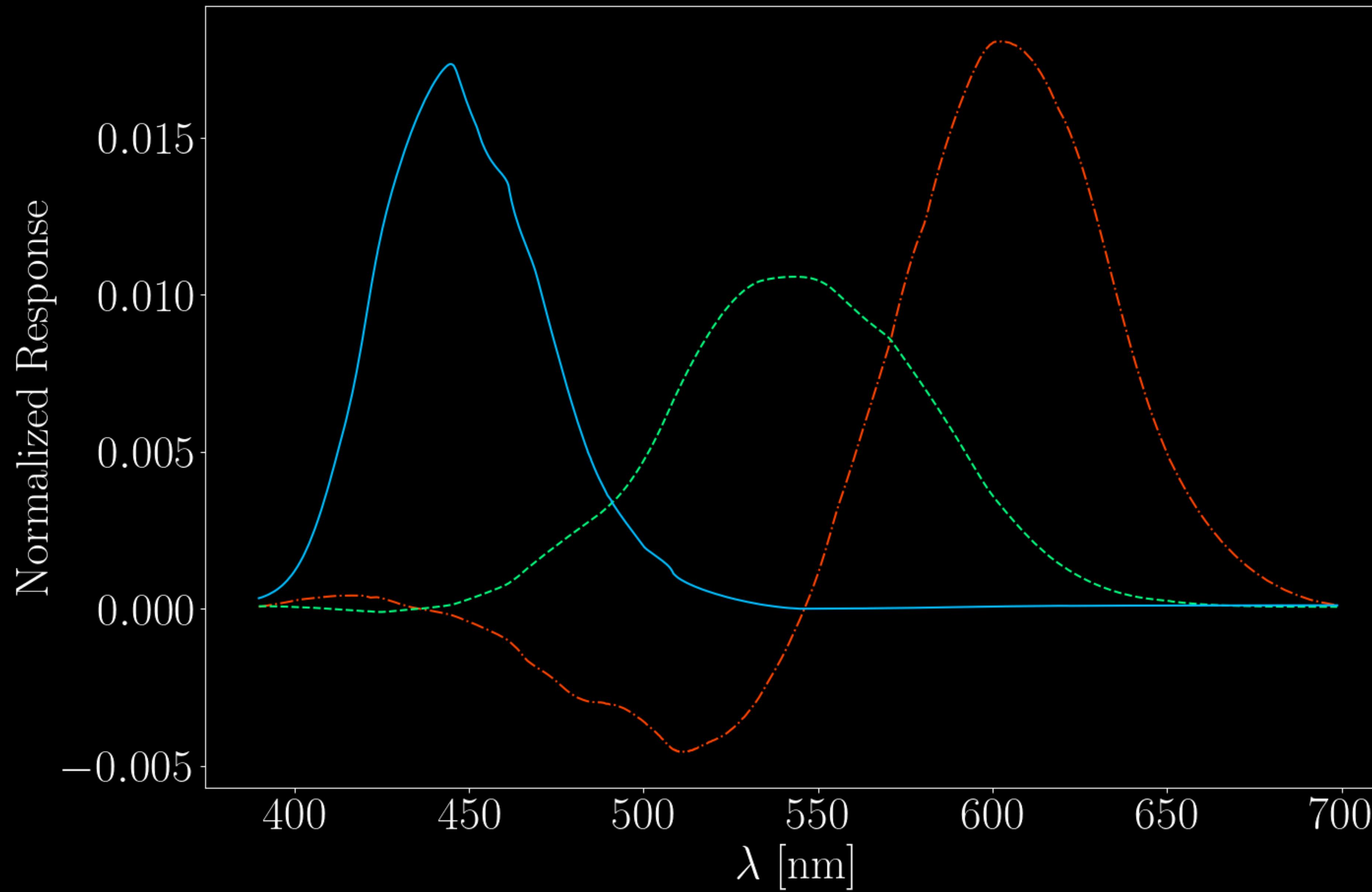


# LMS Color Space

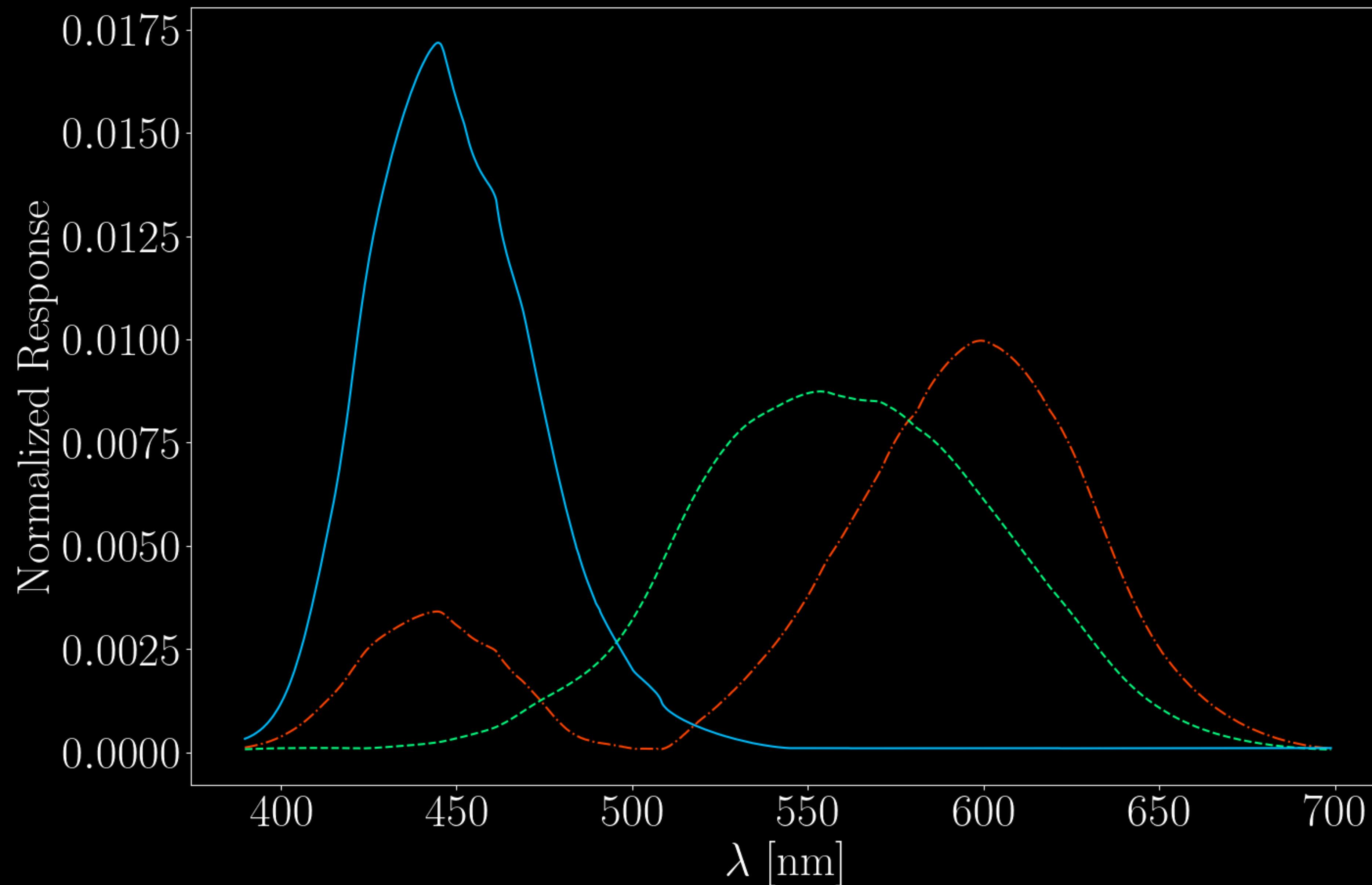


$$\begin{pmatrix} f_L(R) & f_L(G) & f_L(B) \\ f_M(R) & f_M(G) & f_M(B) \\ f_S(R) & f_S(G) & f_S(B) \end{pmatrix} \begin{pmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{pmatrix} = \begin{pmatrix} f_L(\lambda) \\ f_M(\lambda) \\ f_S(\lambda) \end{pmatrix}$$

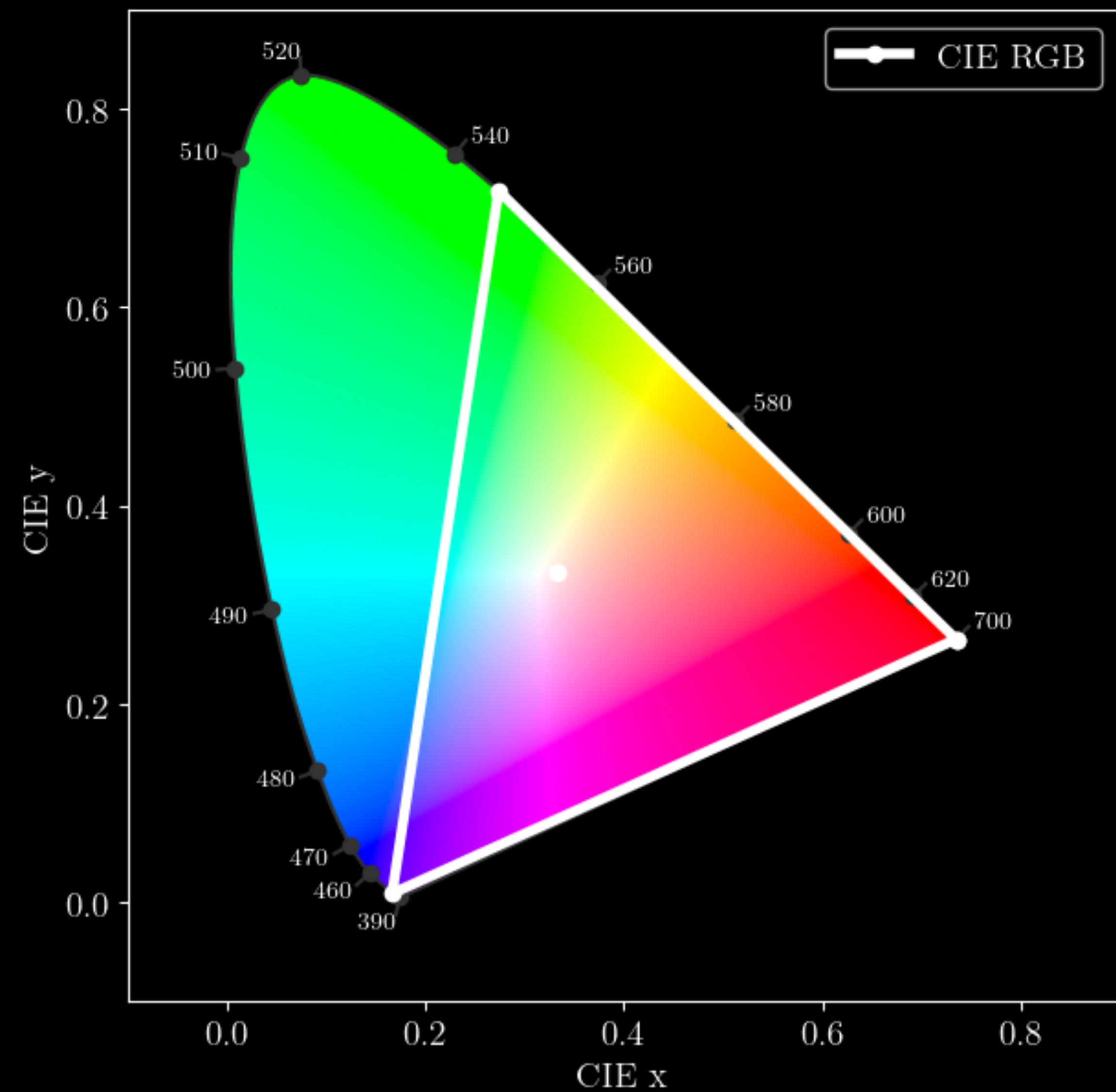
# CIE 1931 RGB



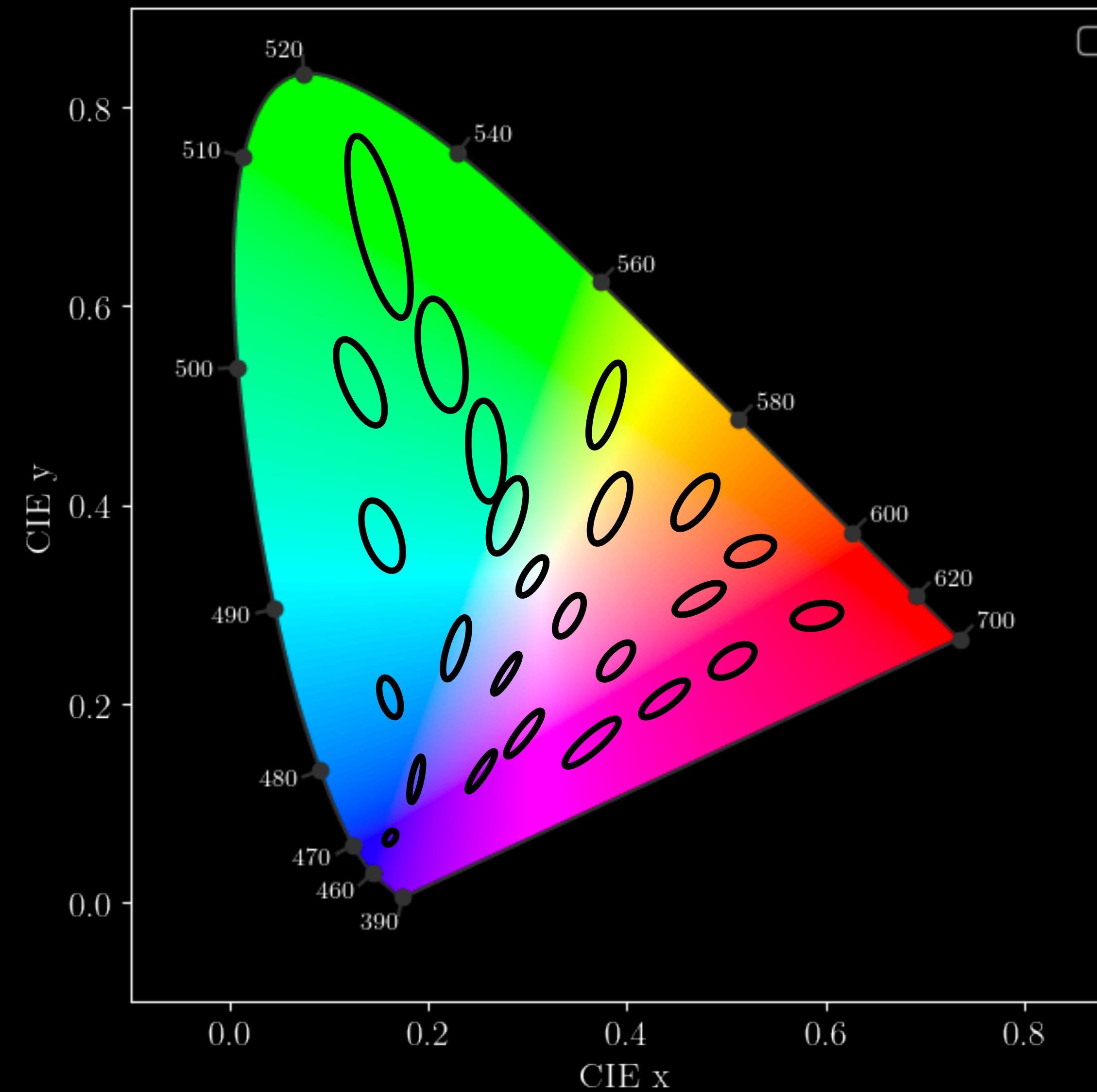
# CIE 1931 XYZ

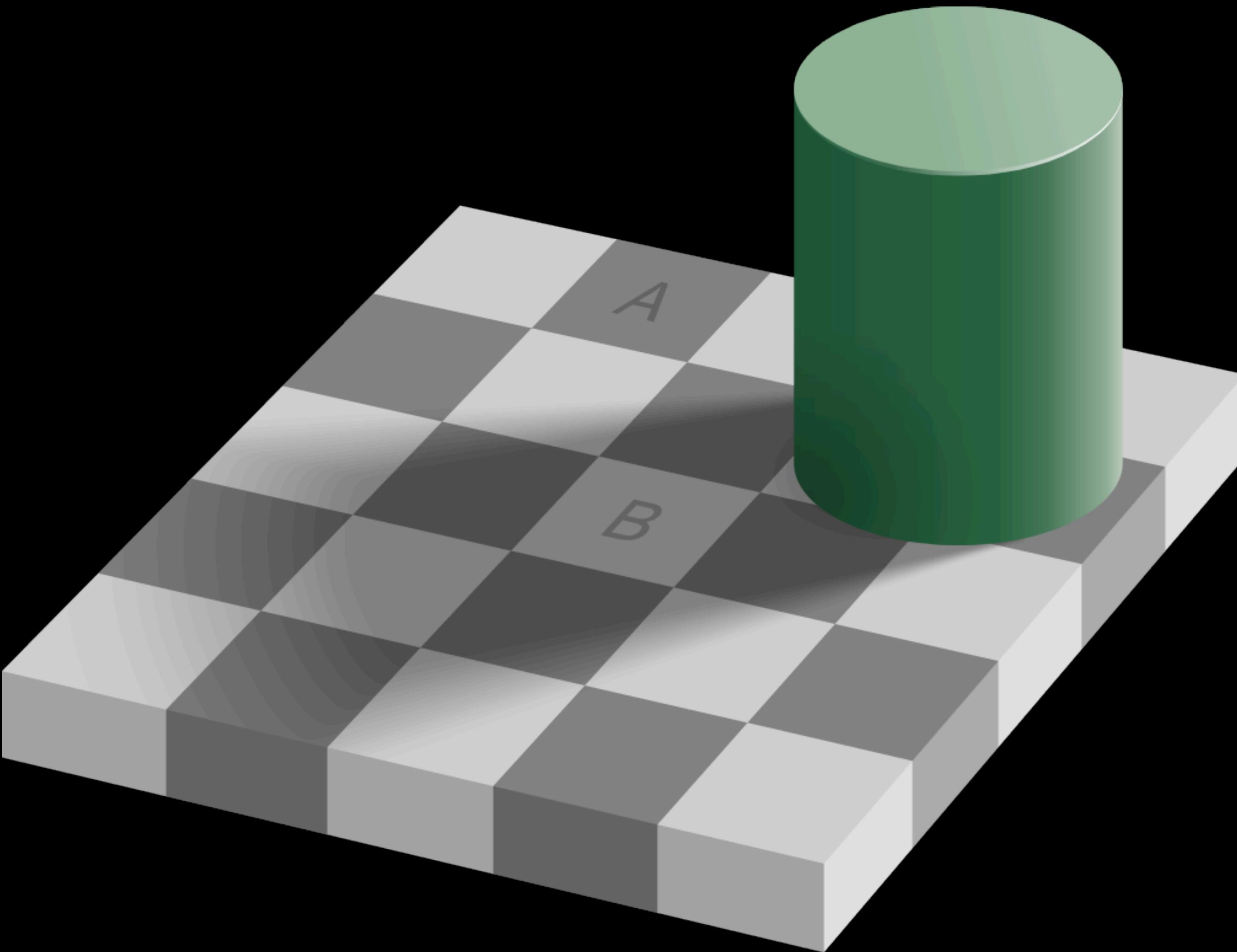


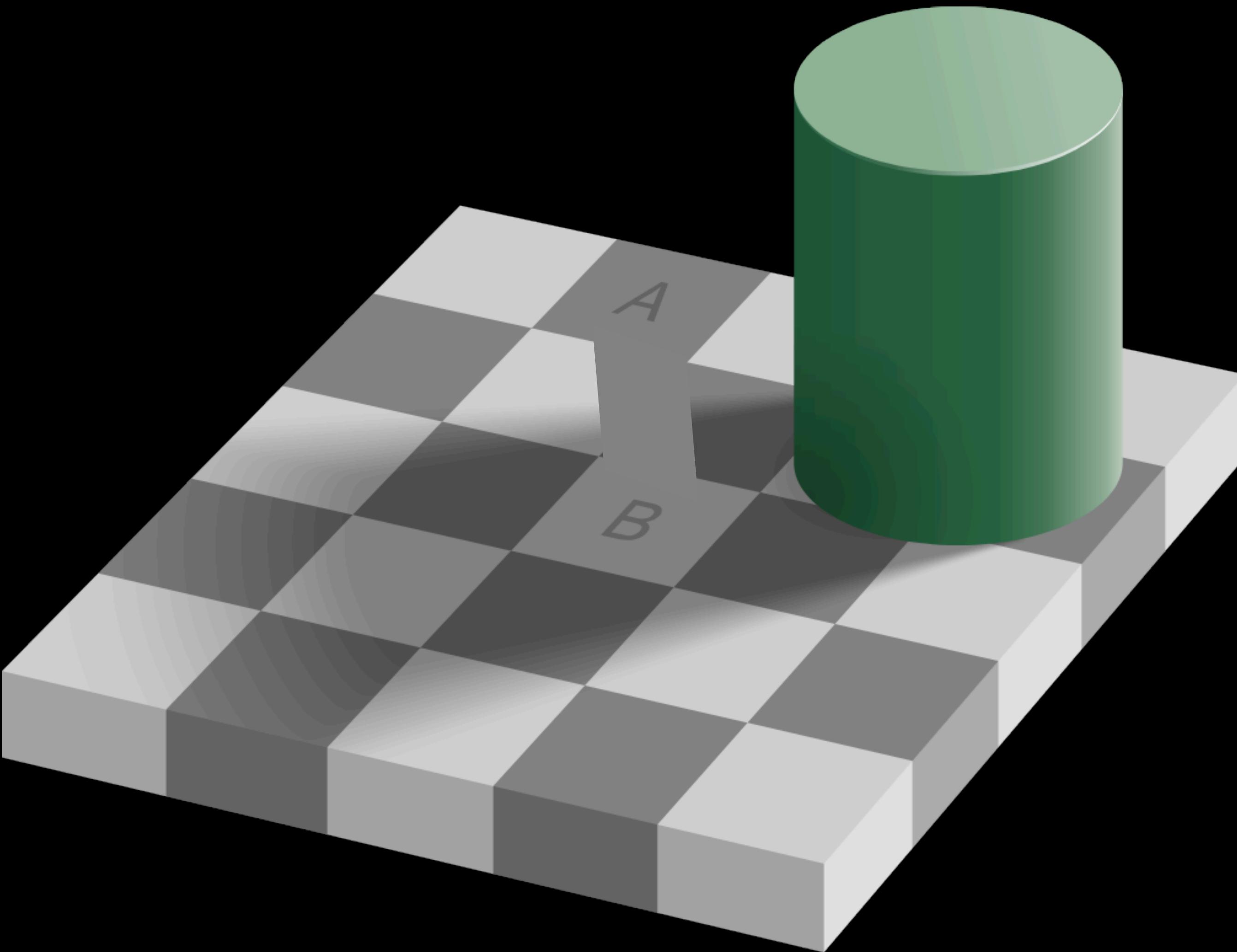
# Color Gamut



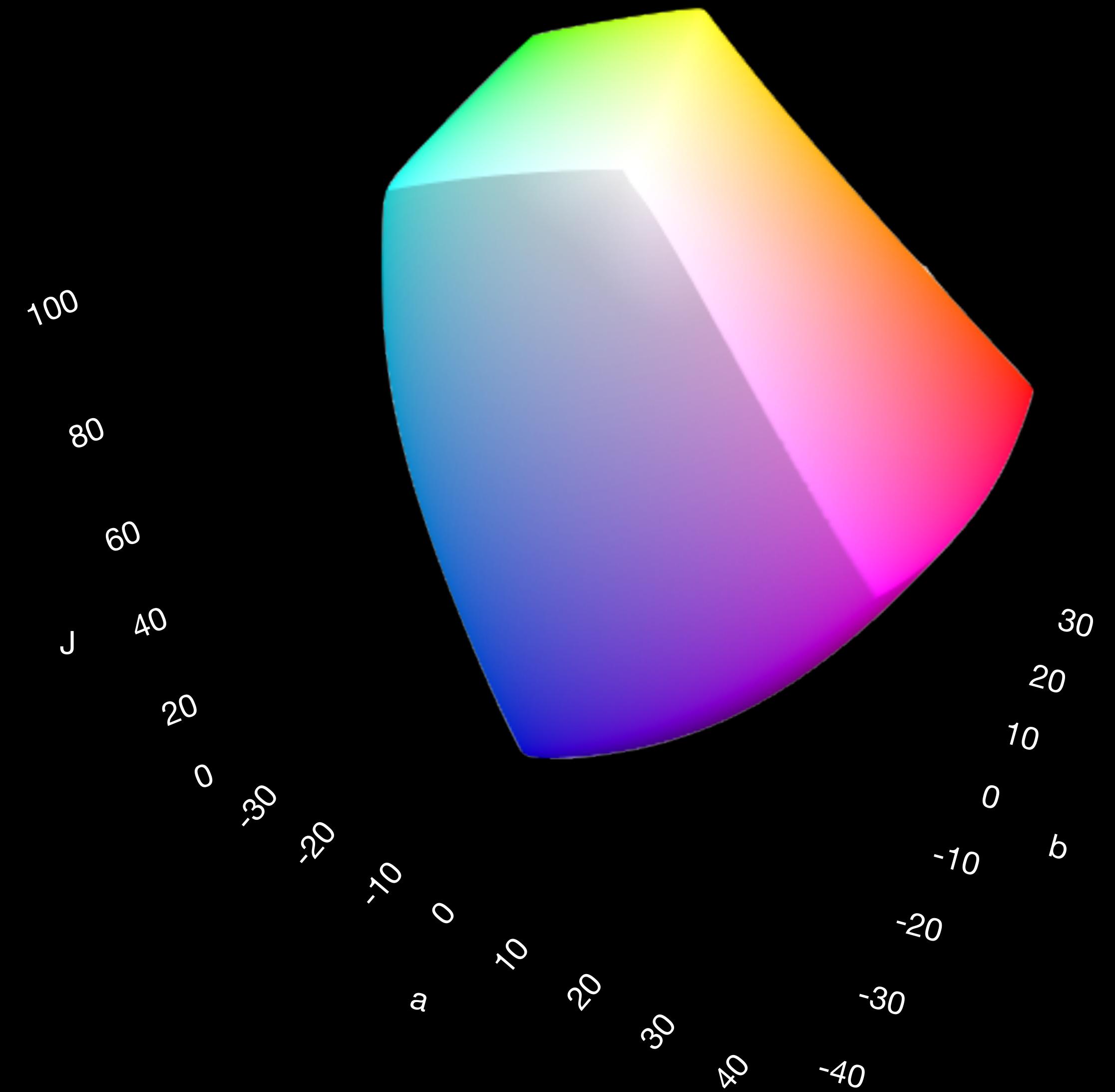
# Perceptual Uniformity



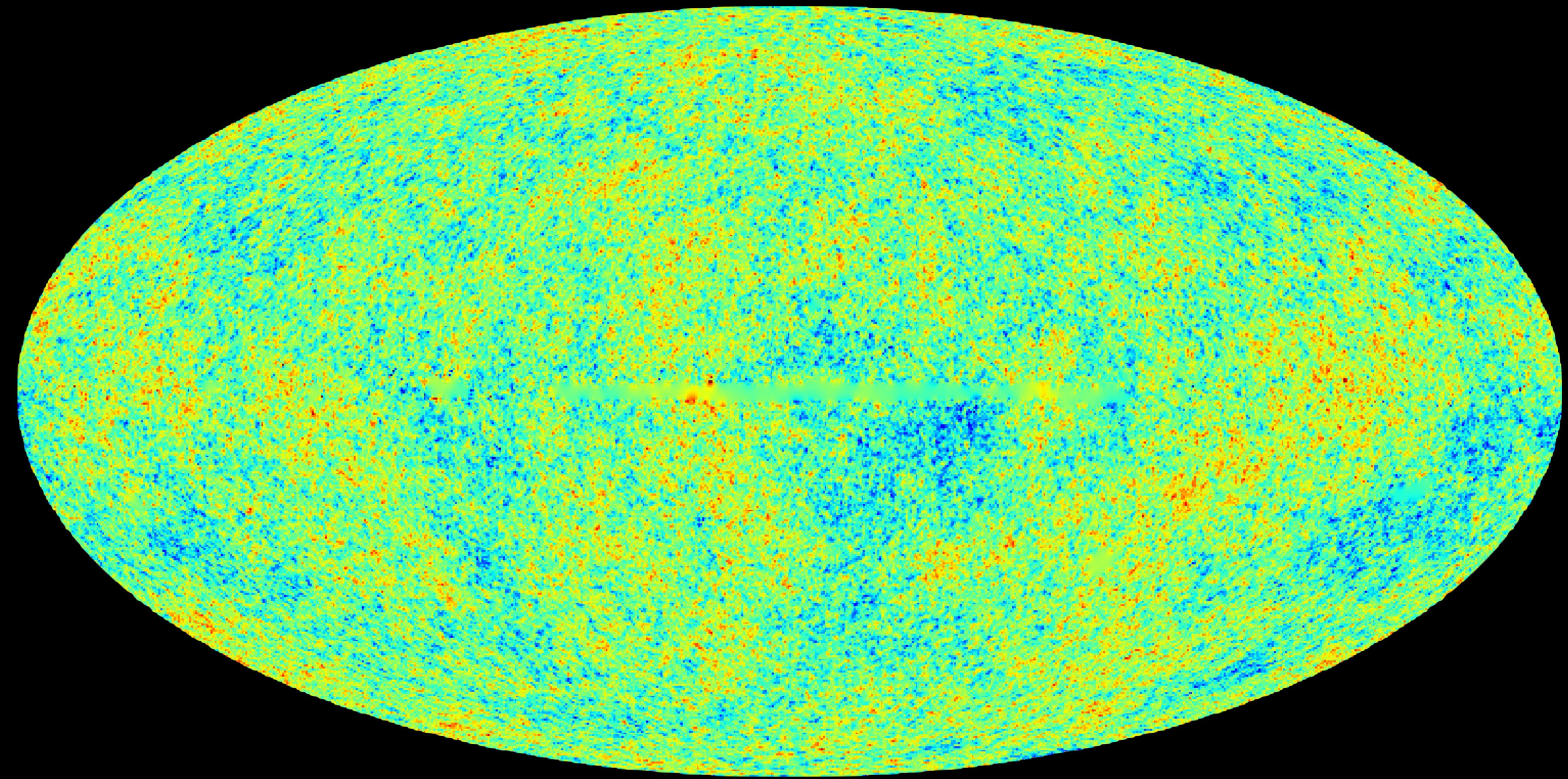


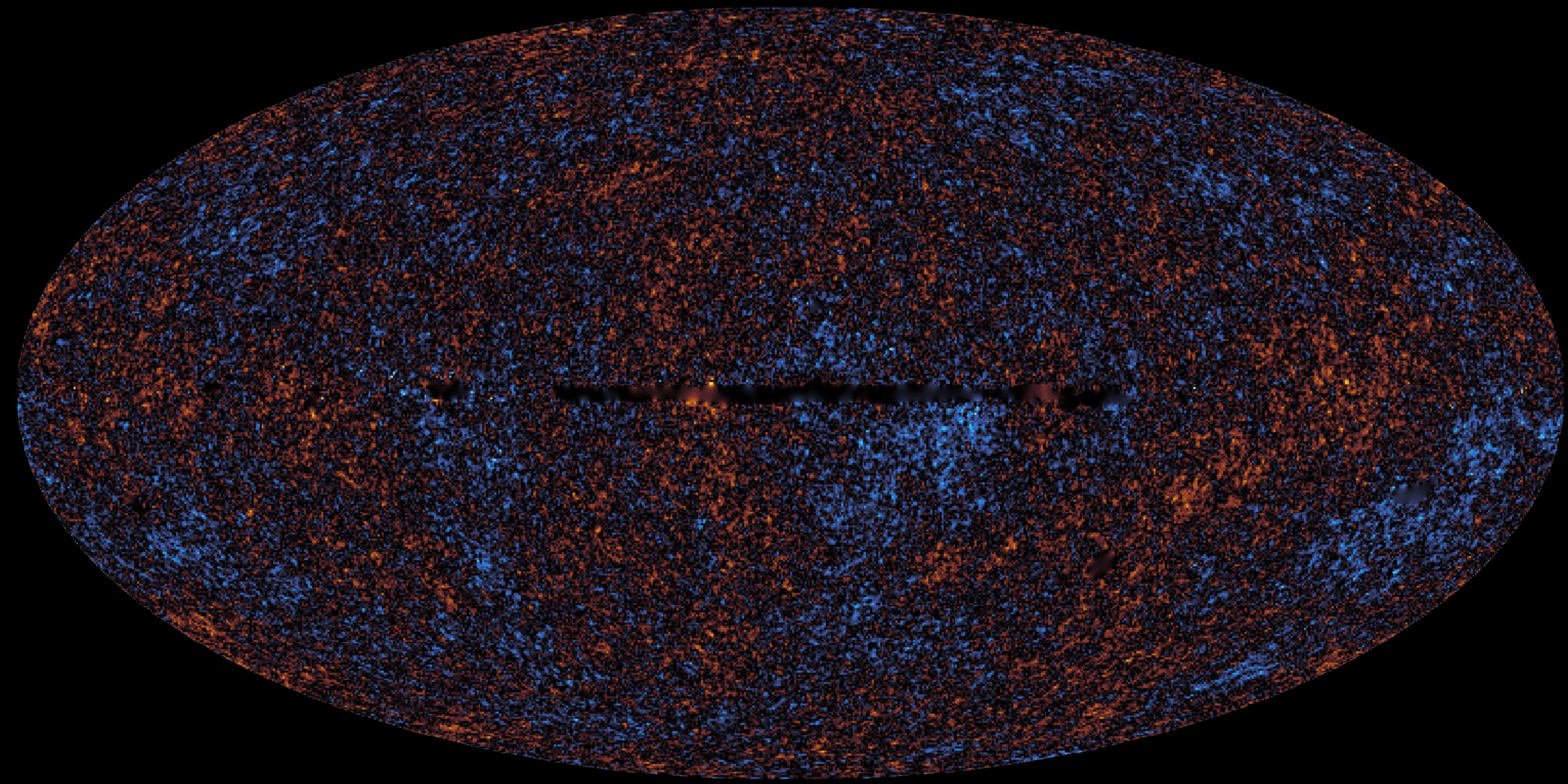


# CAM16-UCS



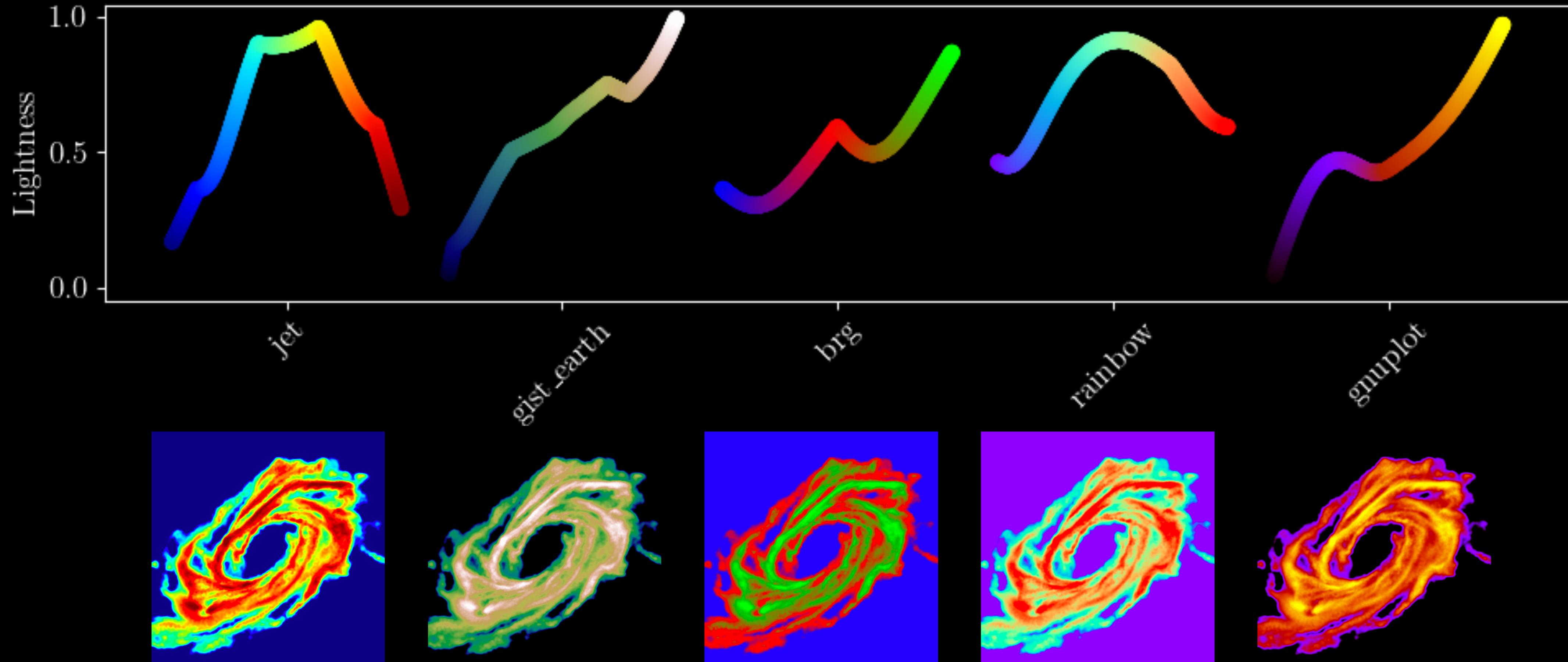
# Colormaps





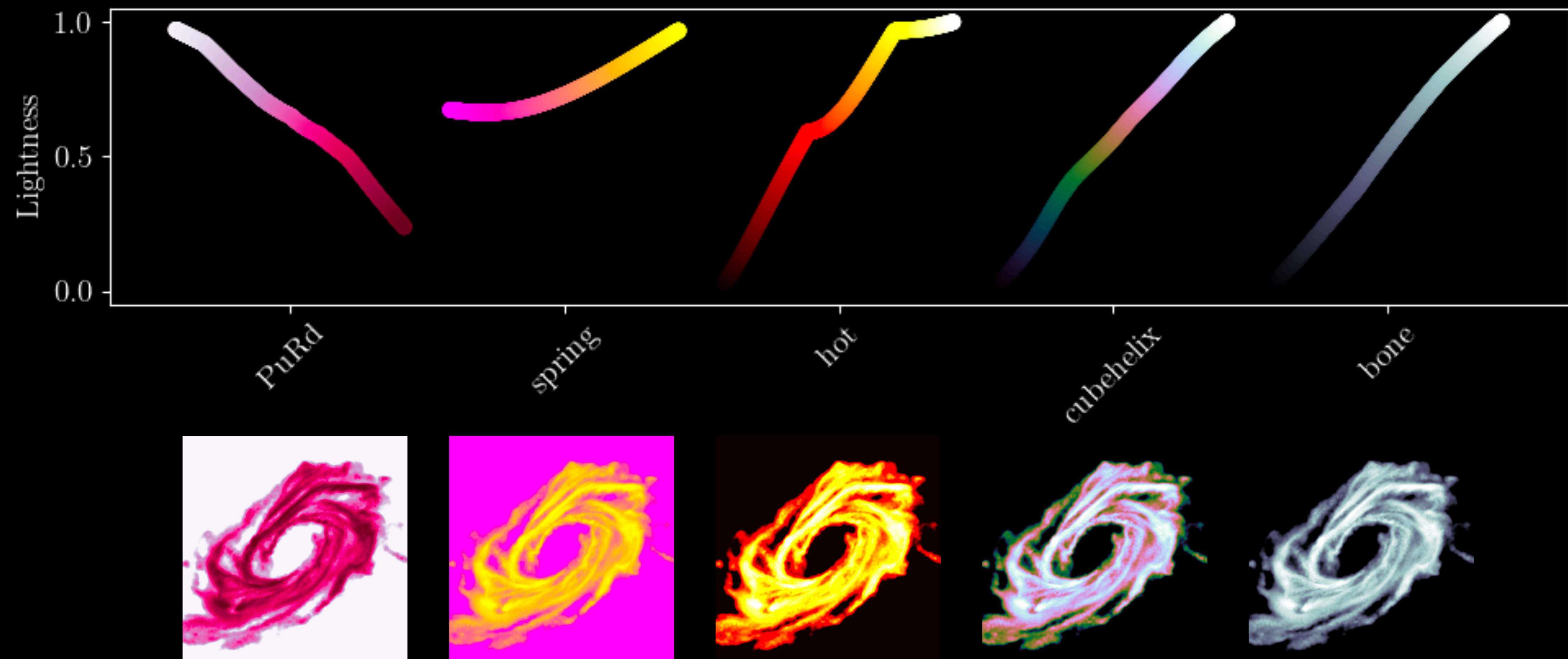
# What makes a good colormap?

J



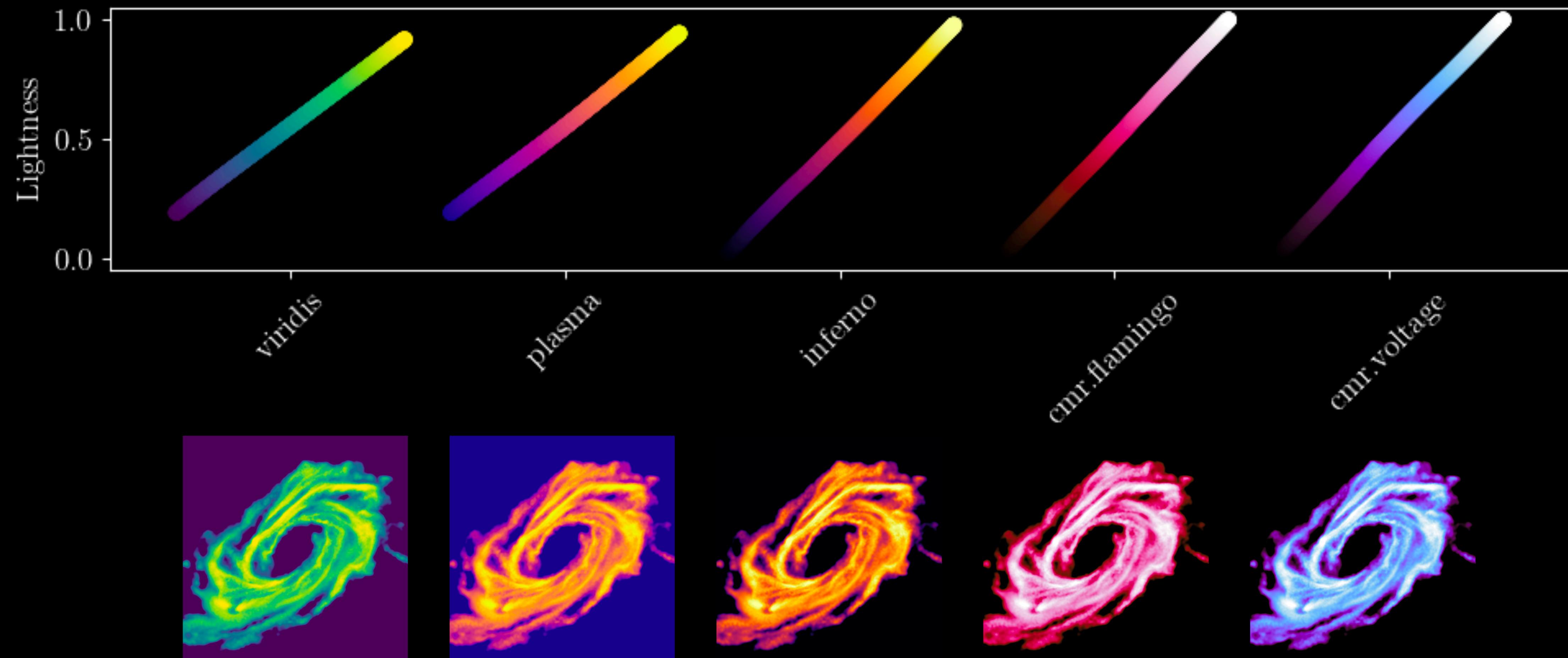
# What makes a good colormap?

J—Monotonic



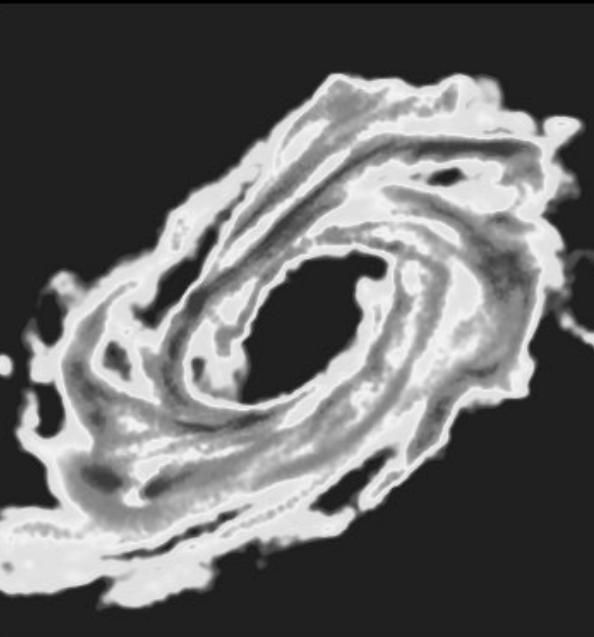
# What makes a good colormap?

J – Monotonic + Uniform

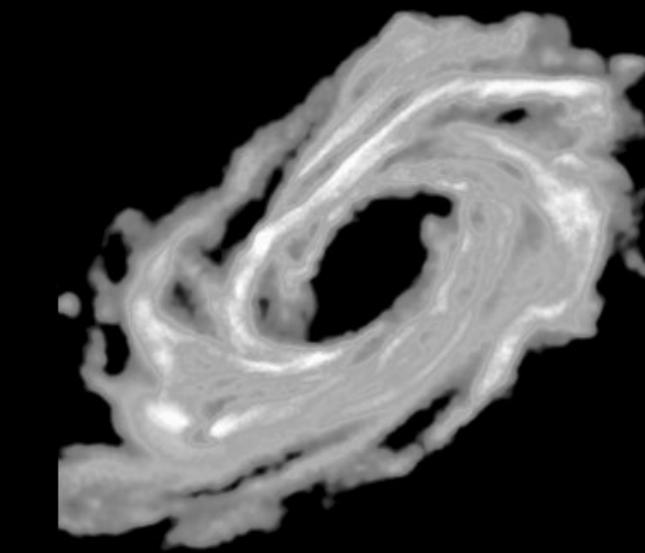


# What makes a good colormap?

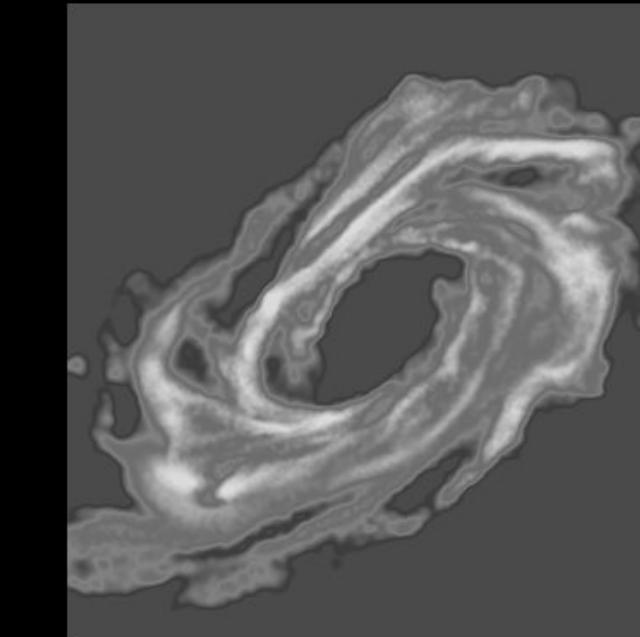
## Test 1: Black and White



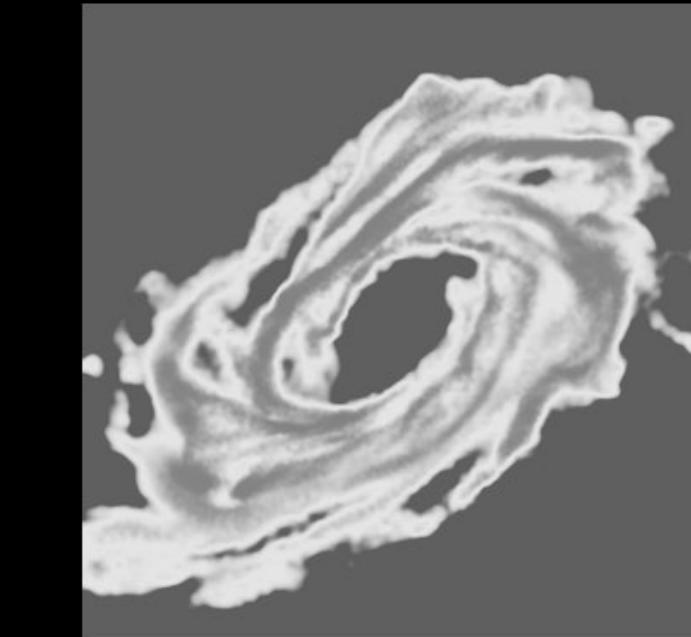
jet



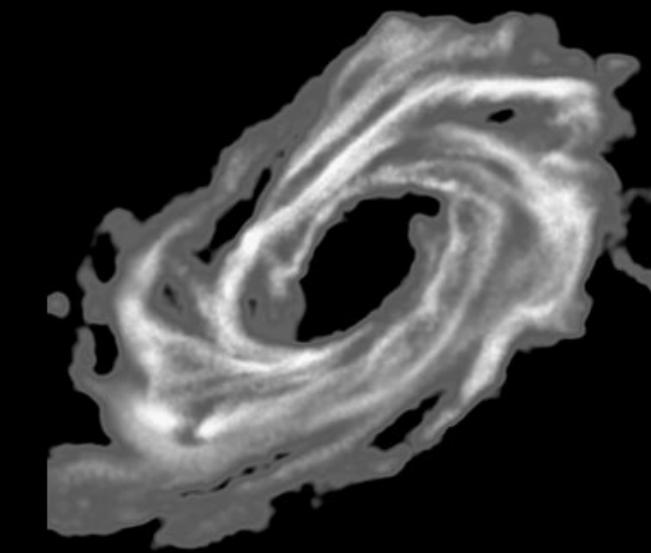
gist\_earth



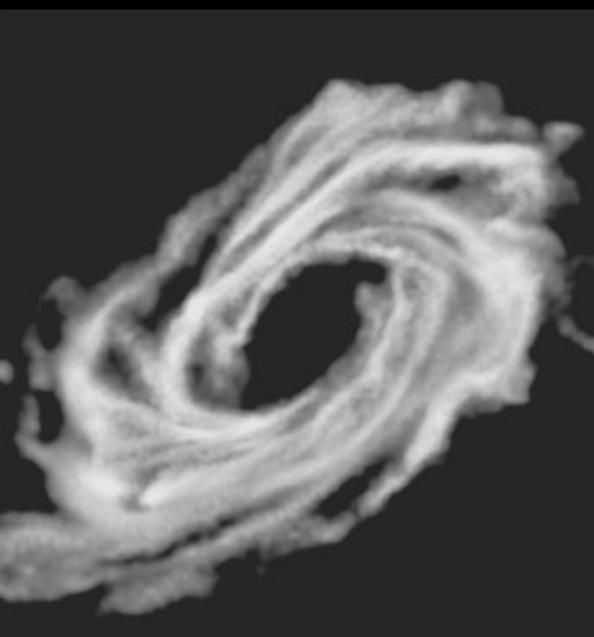
brg



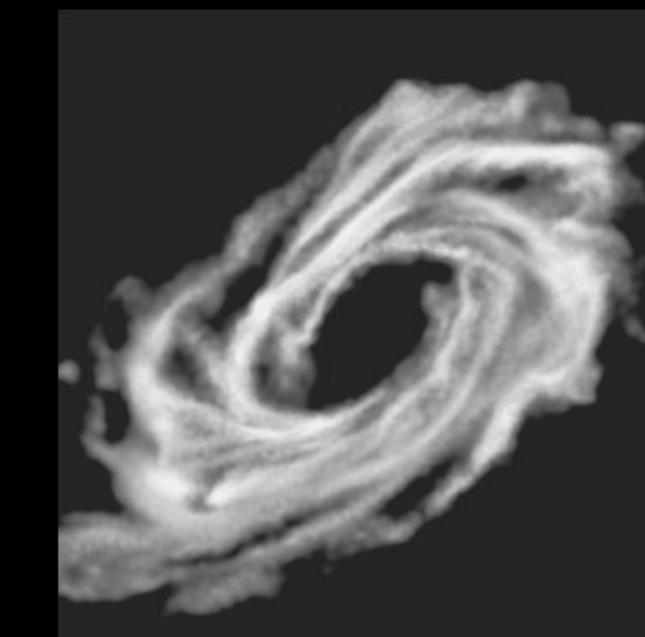
rainbow



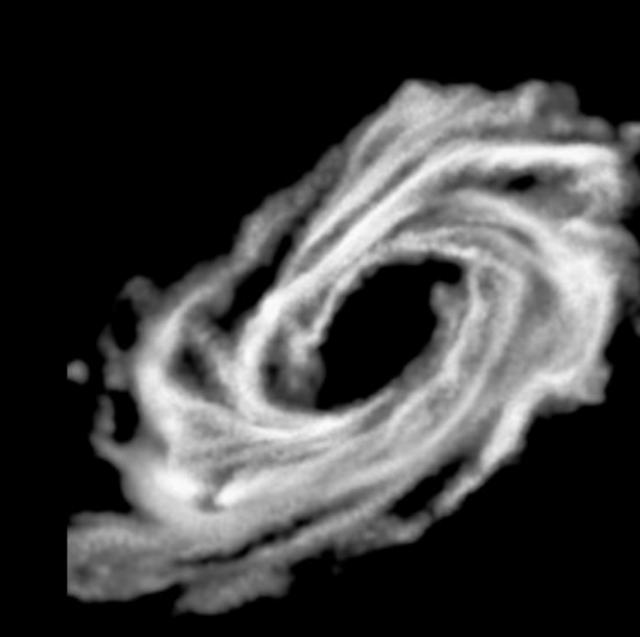
gnuplot



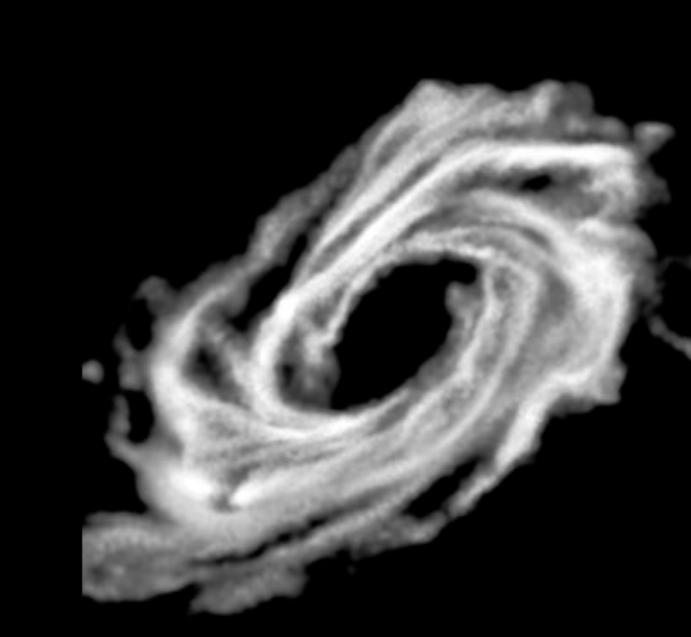
viridis



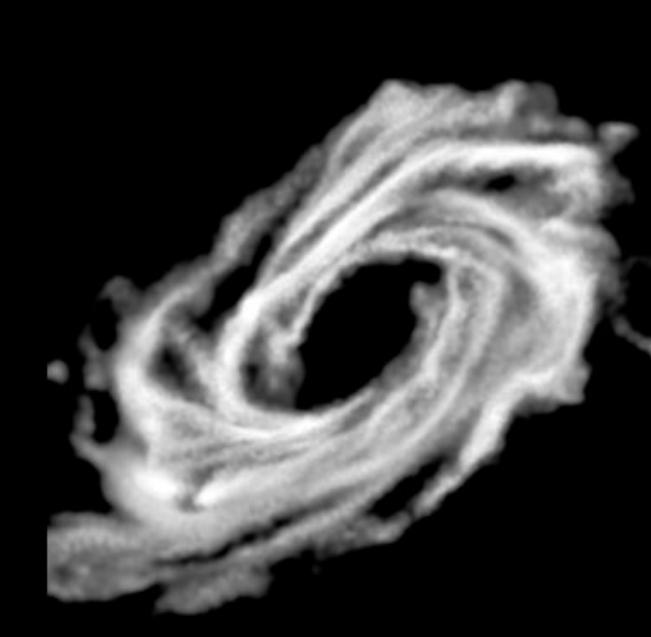
plasma



inferno



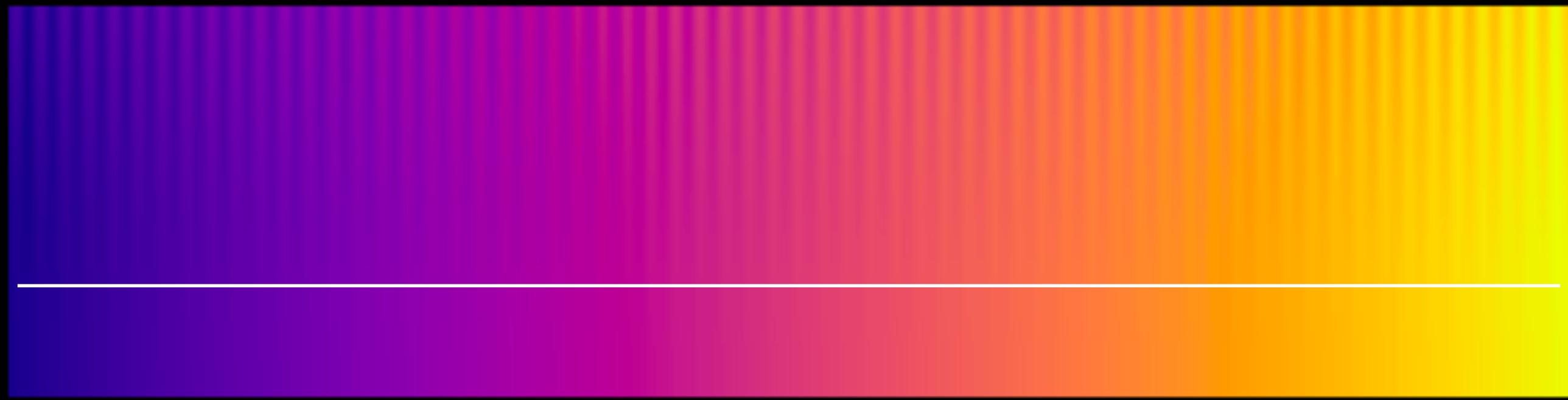
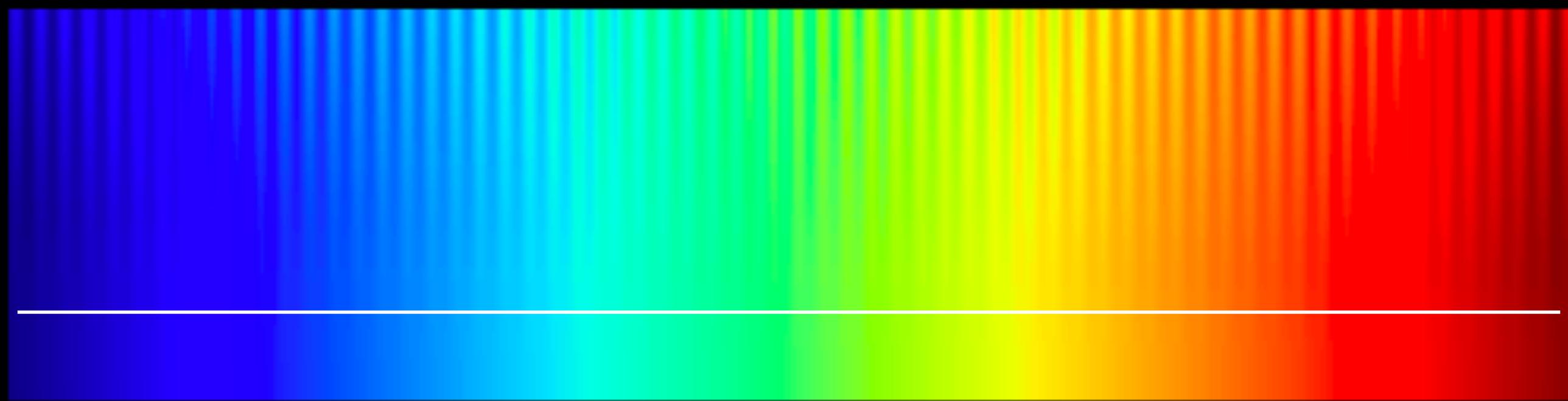
cmr.flamingo



cmr.voltage

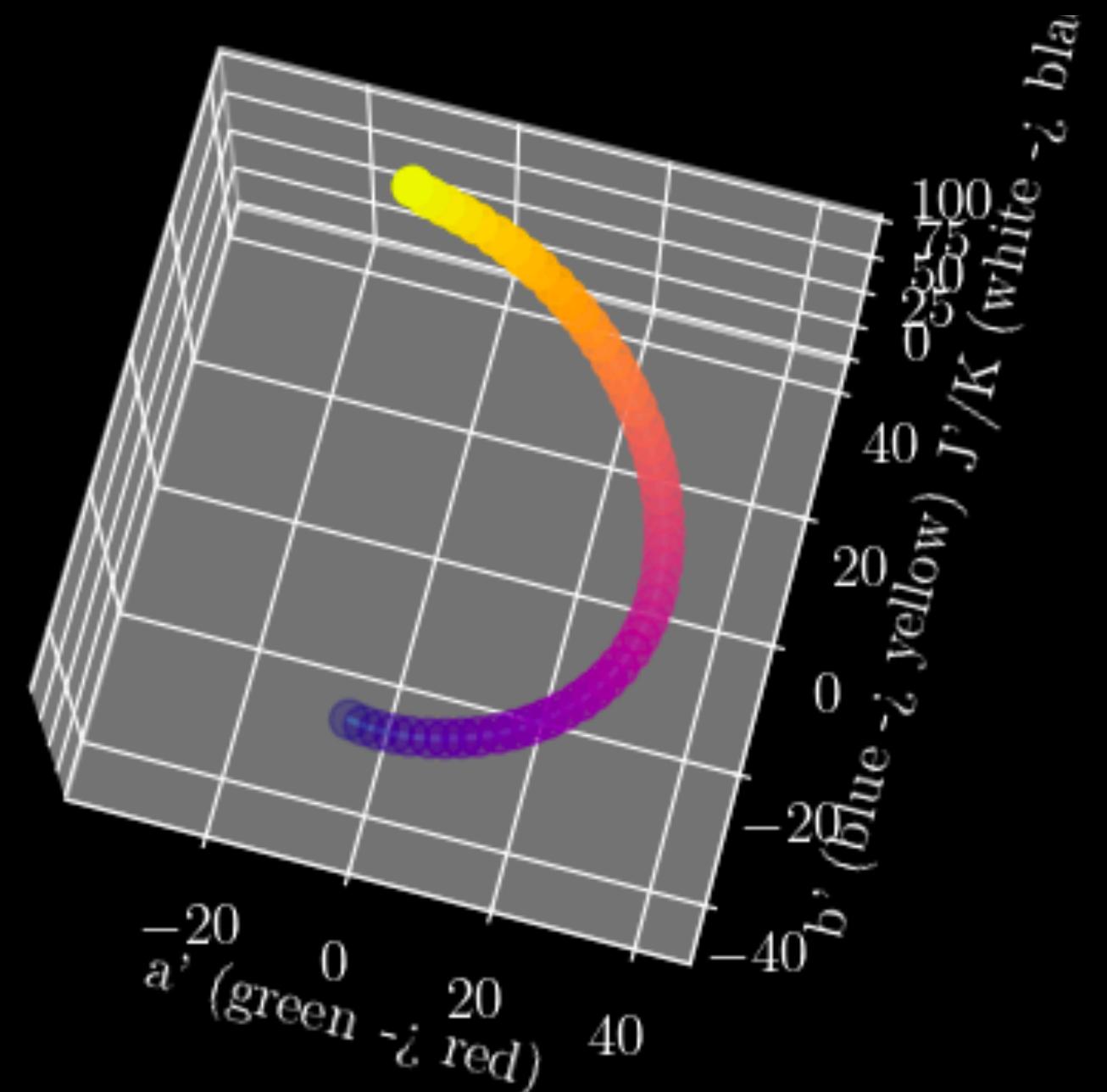
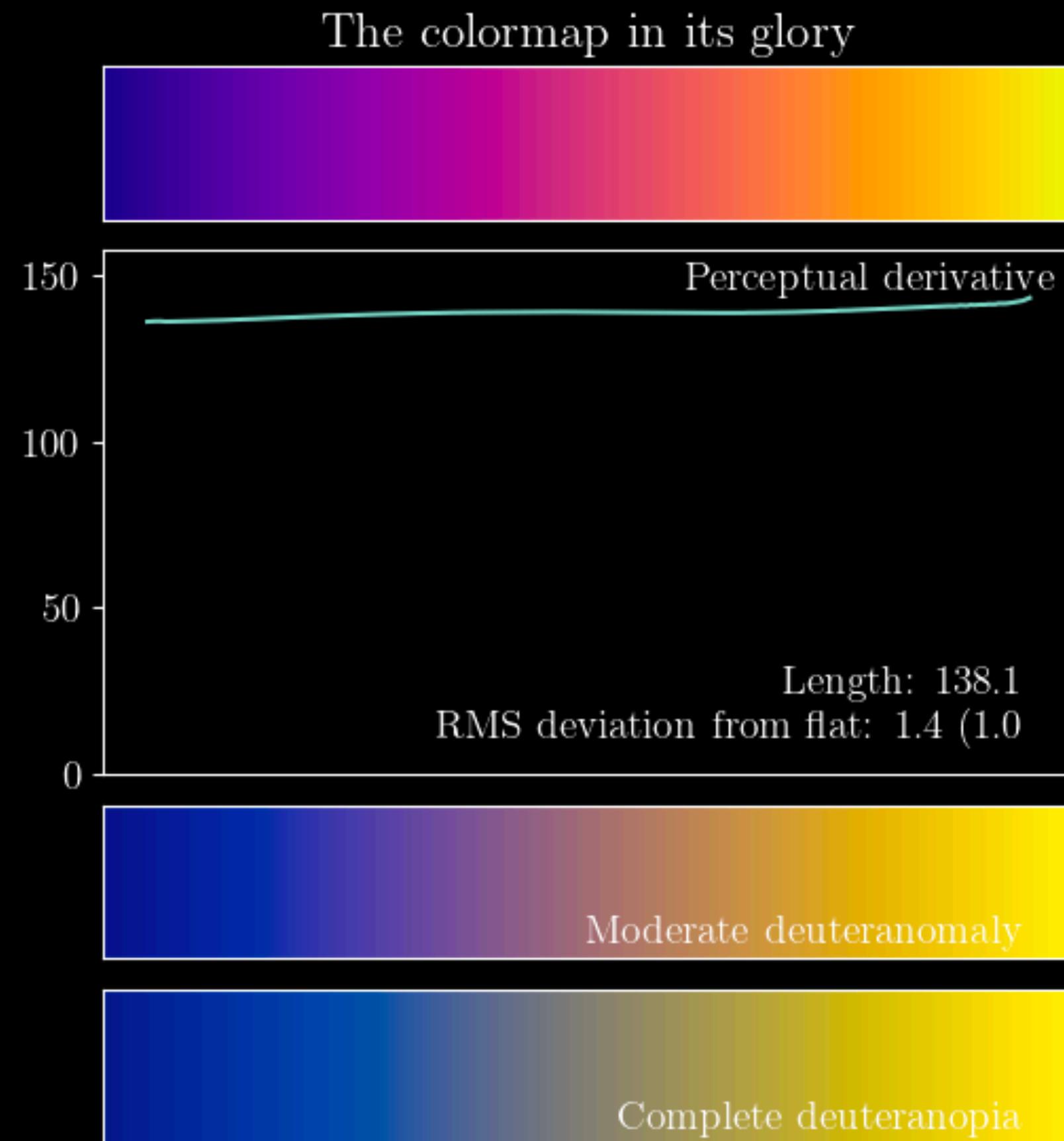
# What makes a good colormap?

Test 2: Test Bar



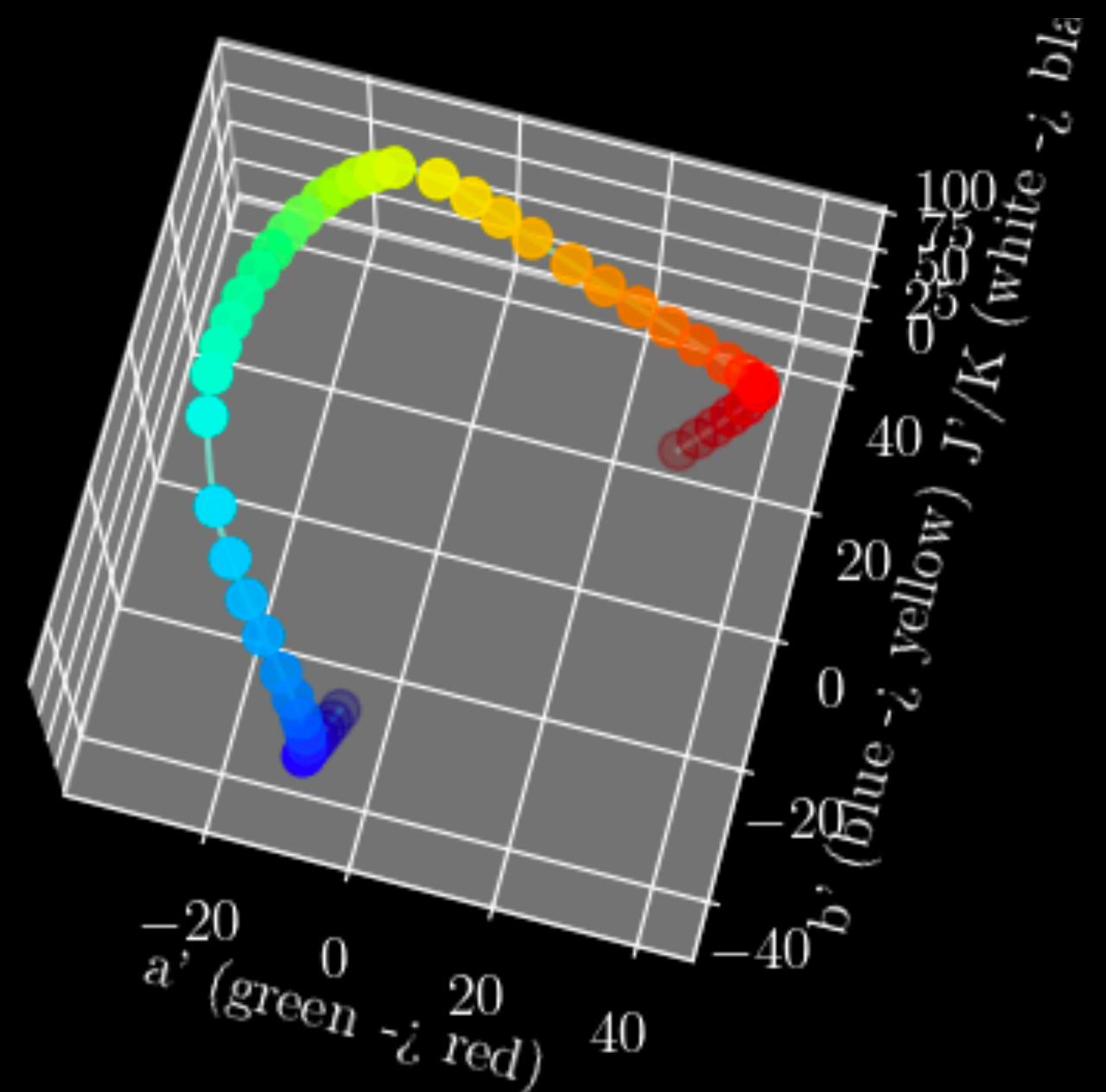
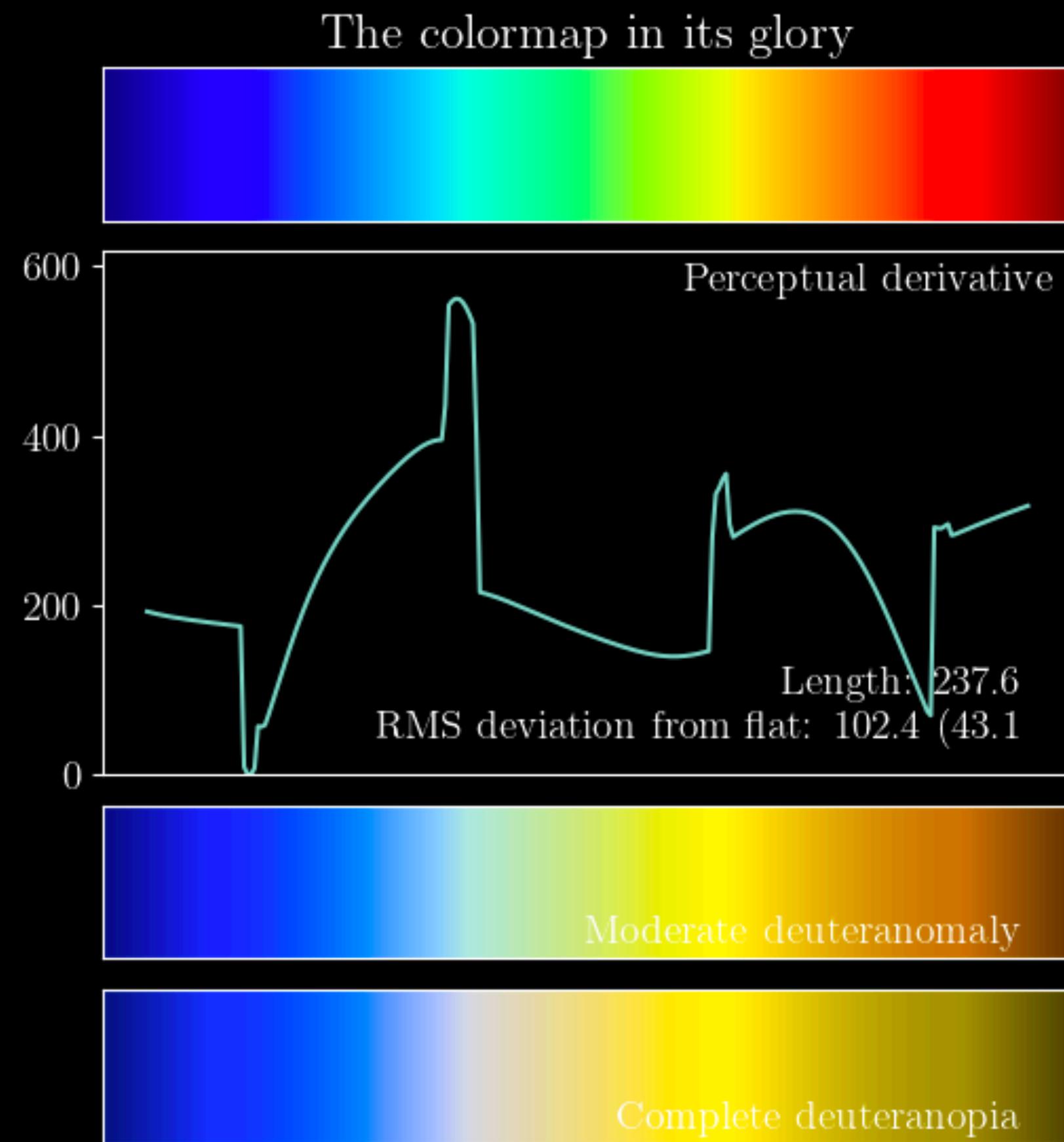
# What makes a good colormap?

## Test 3: viscm

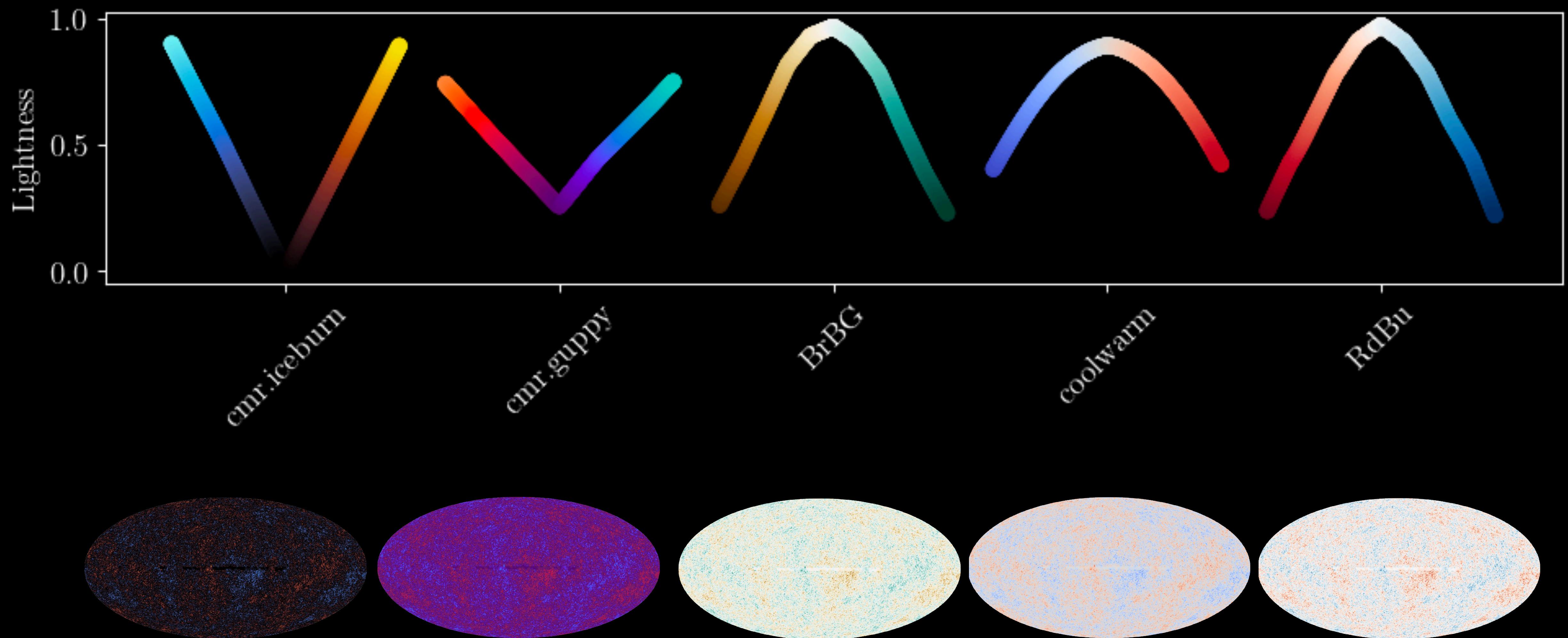


# What makes a good colormap?

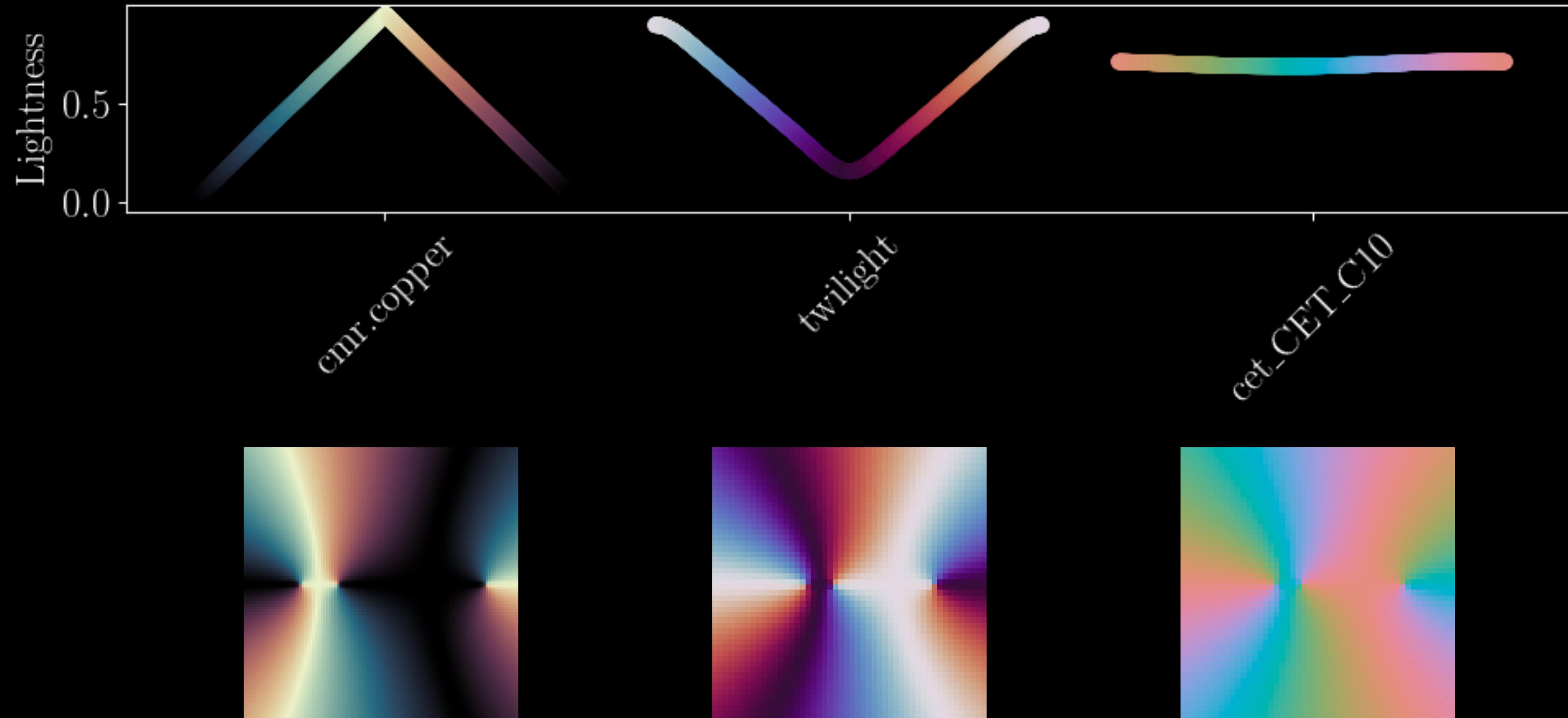
## Test 3: viscm



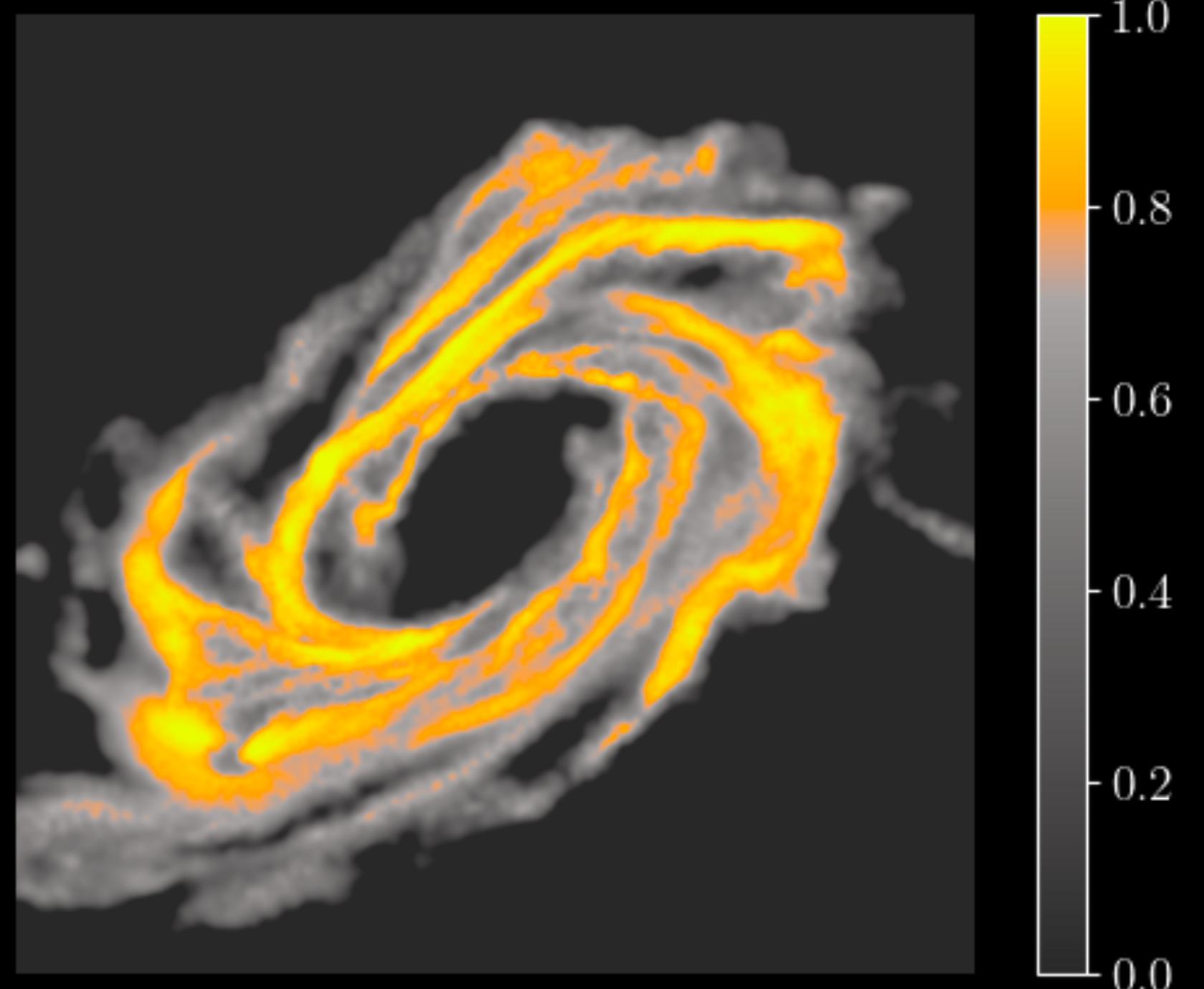
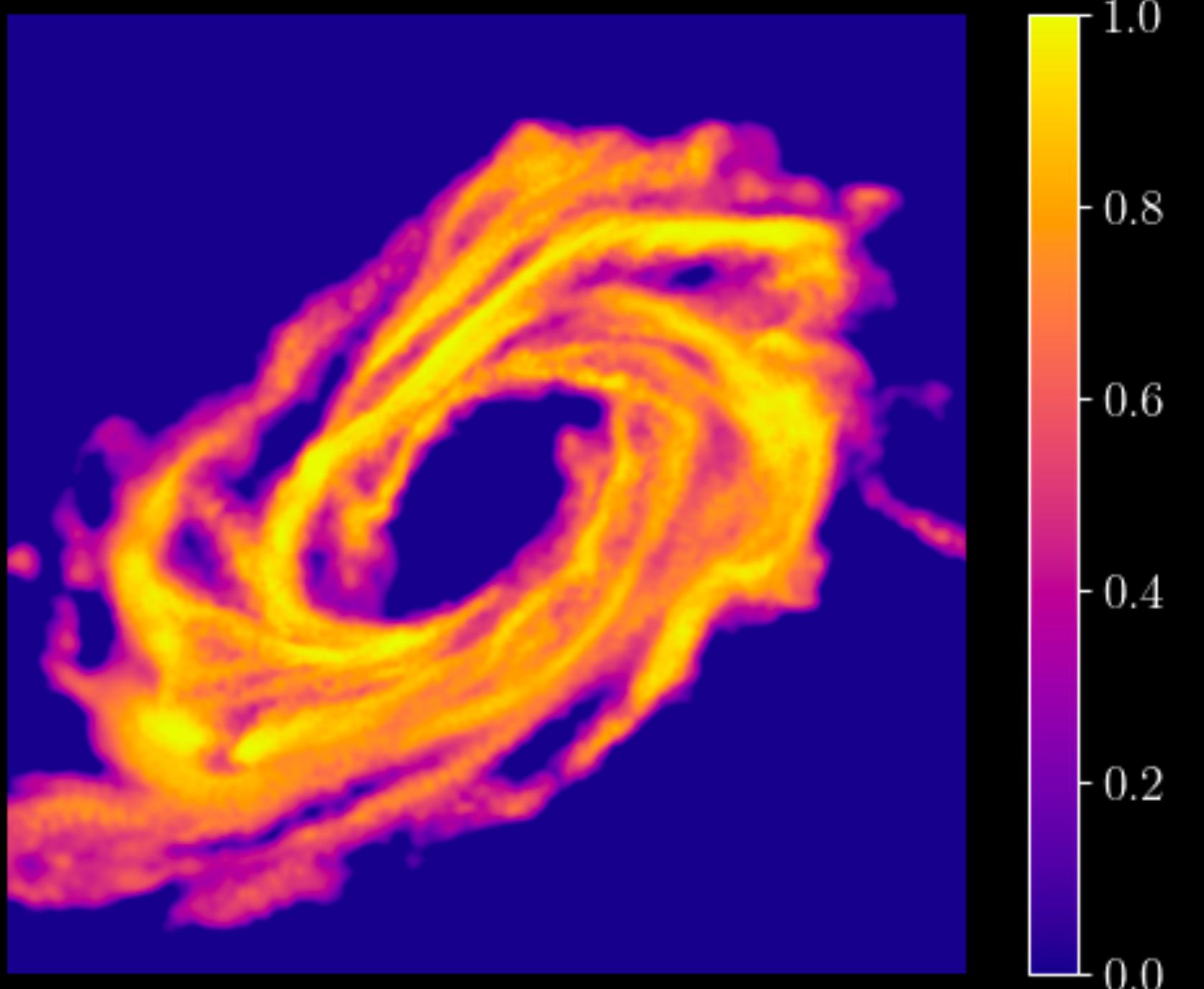
# Diverging Colormaps



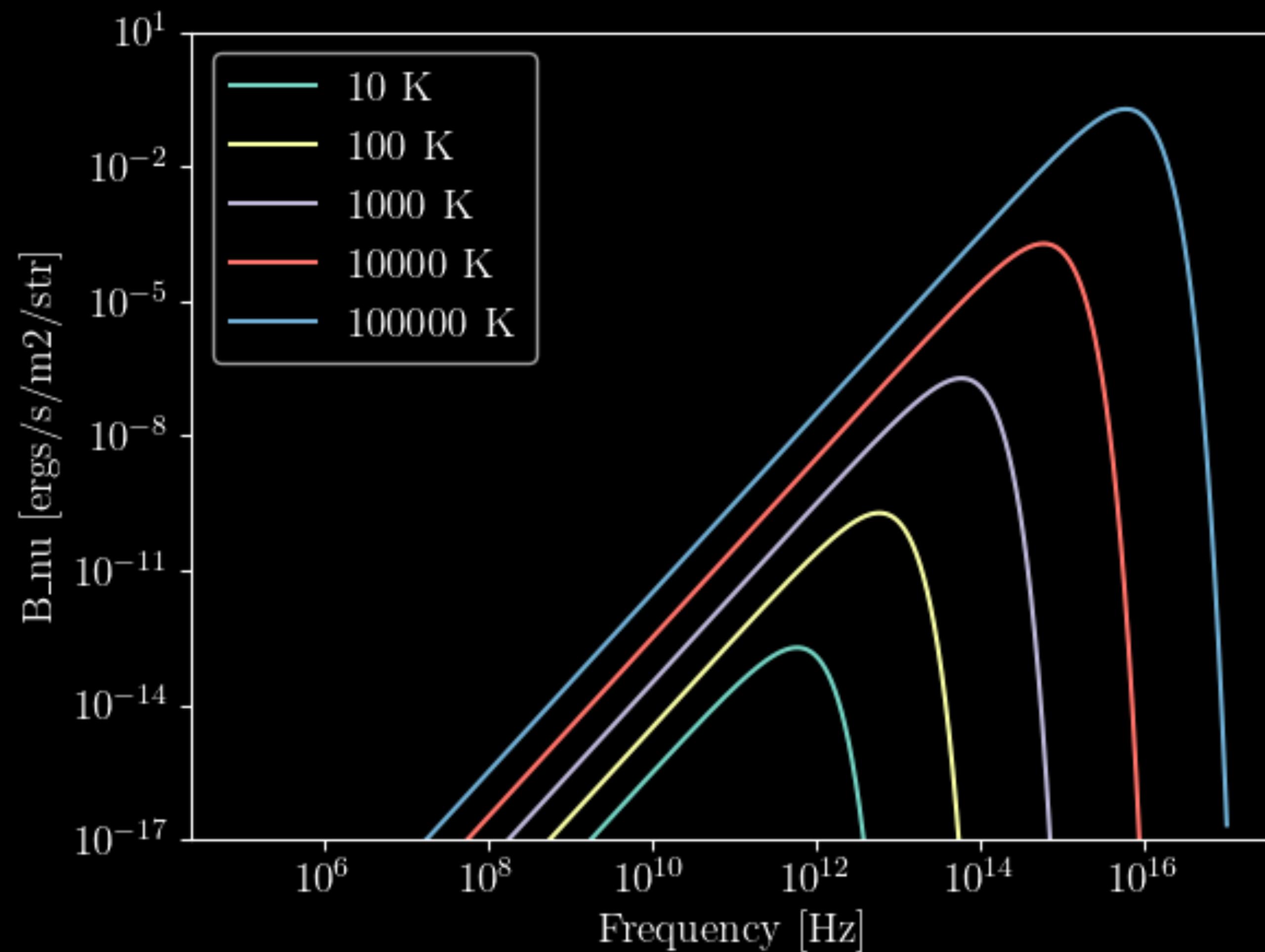
# Cyclic Colormaps



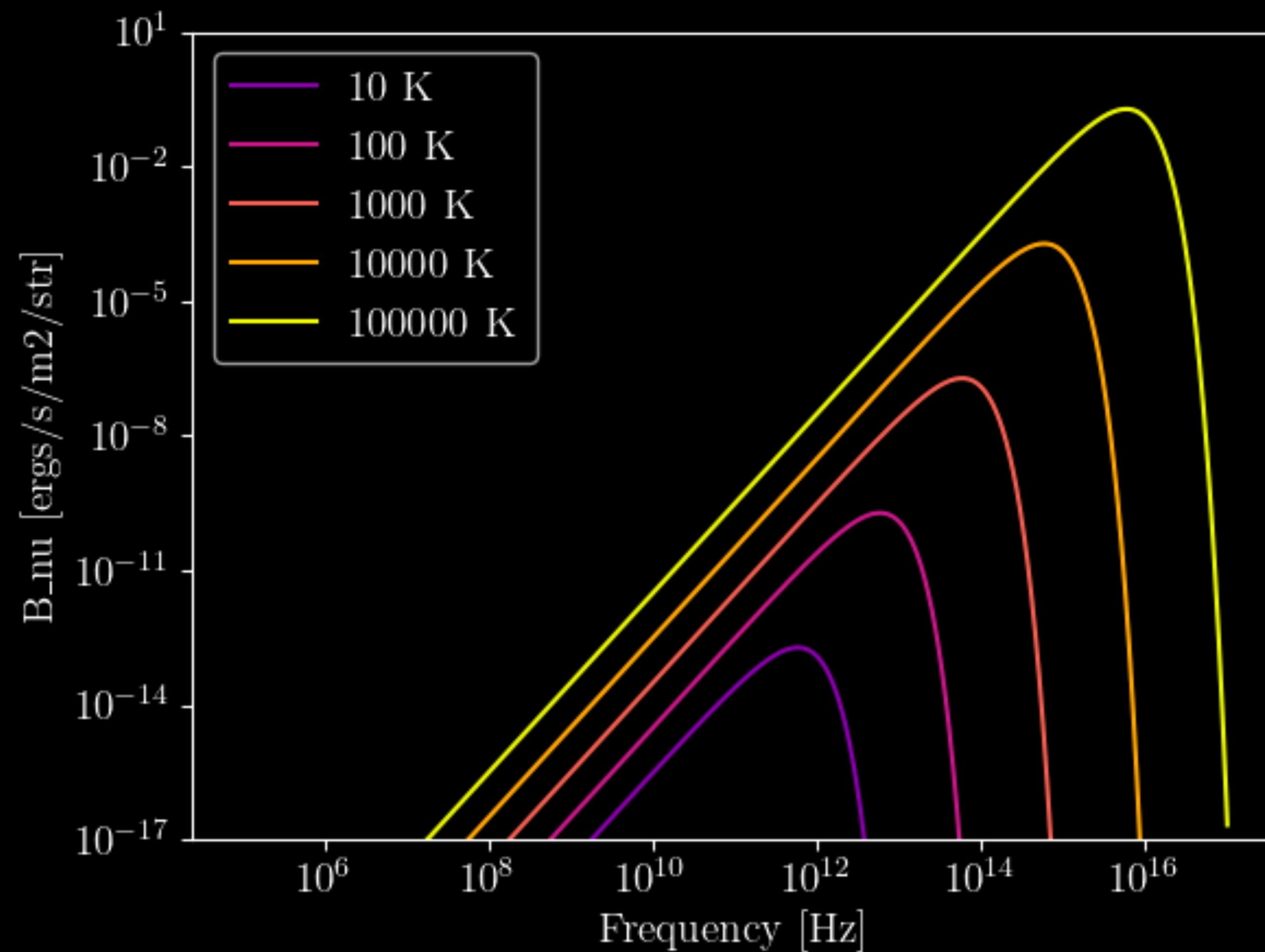
# Mixing Colormaps



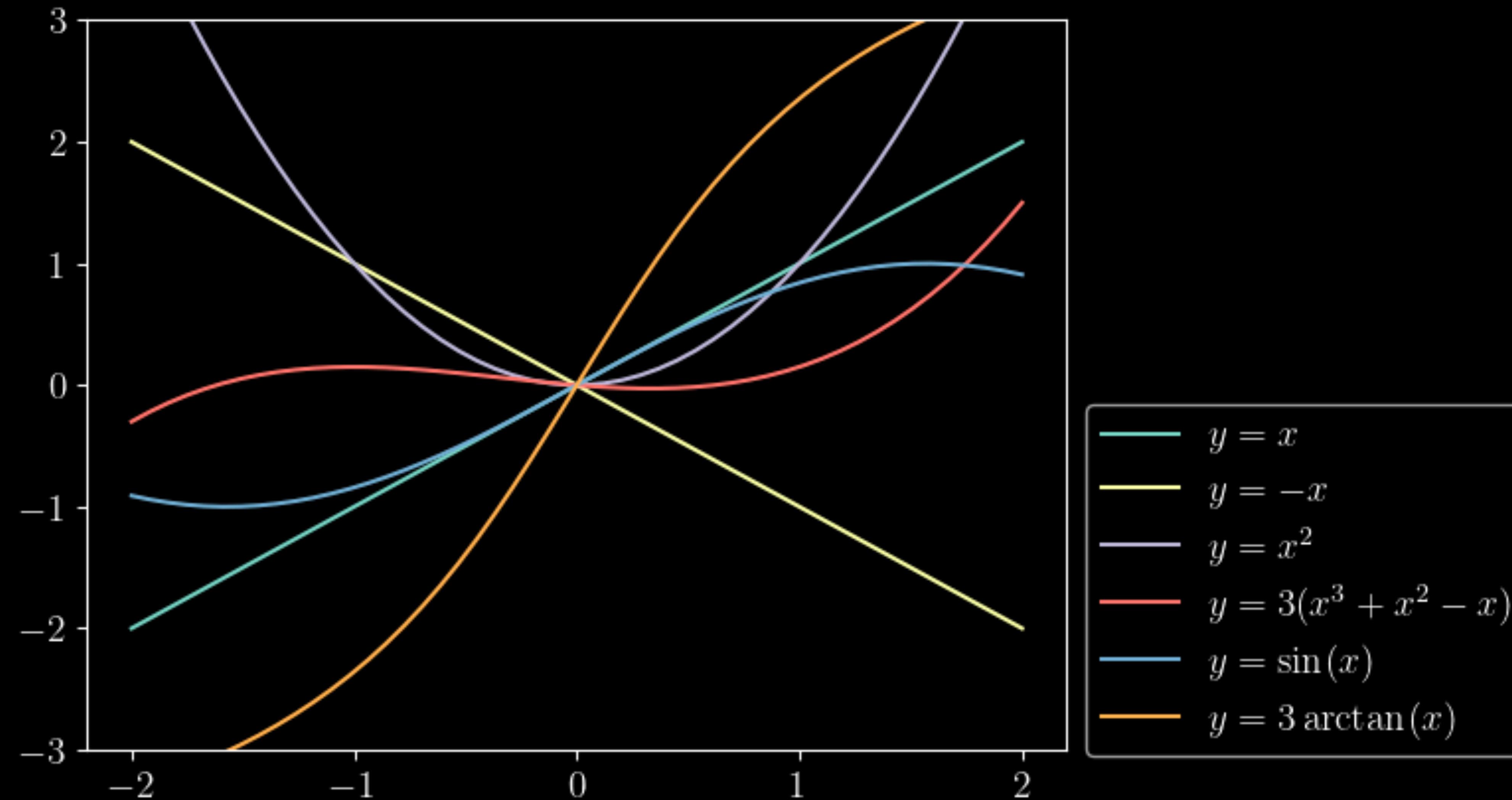
# Line Plots and Colors



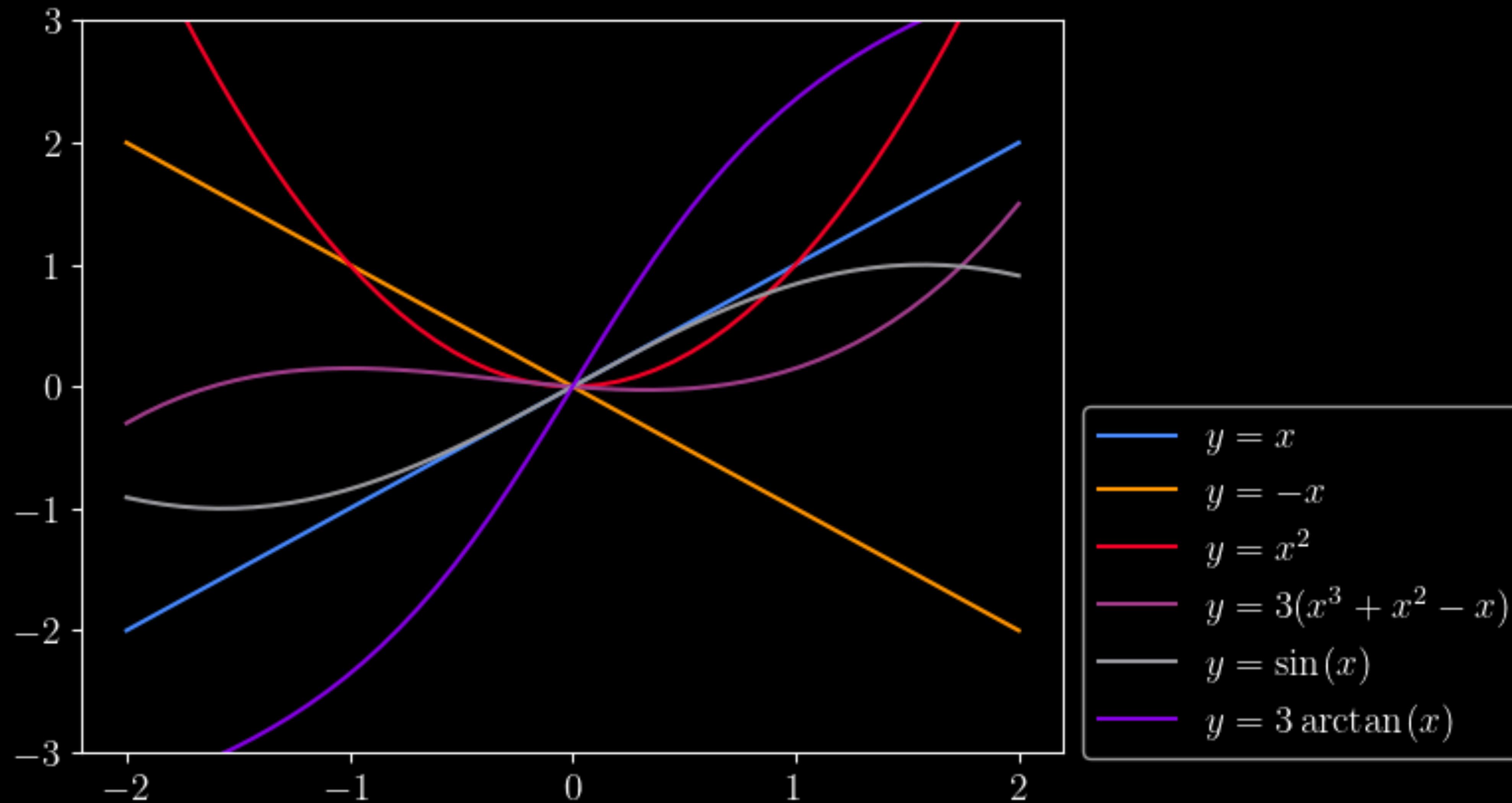
# Line Plots and Colors



# Line Plots and Colors

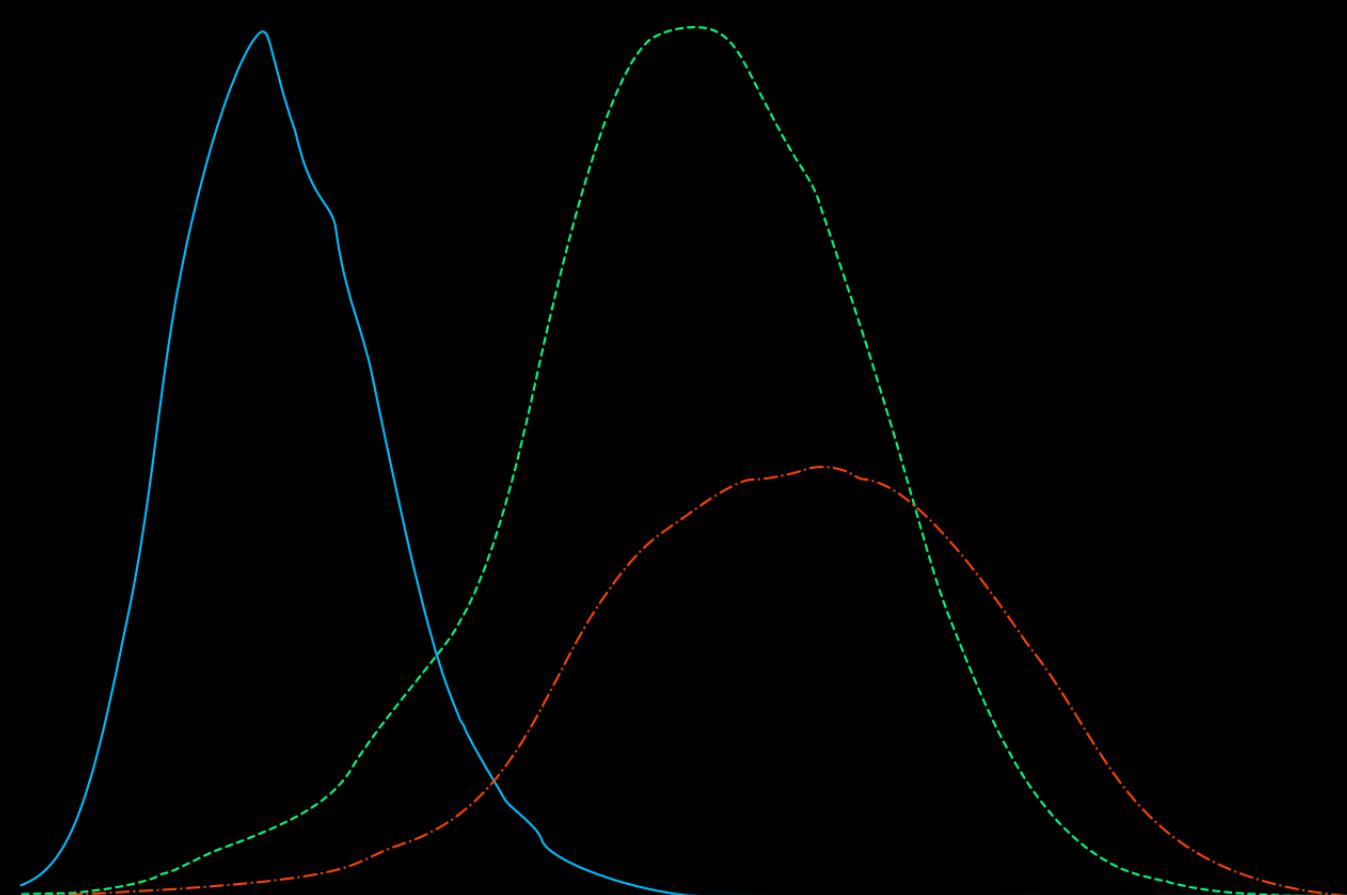


# Line Plots and Colors



# Color Vision Deficiency

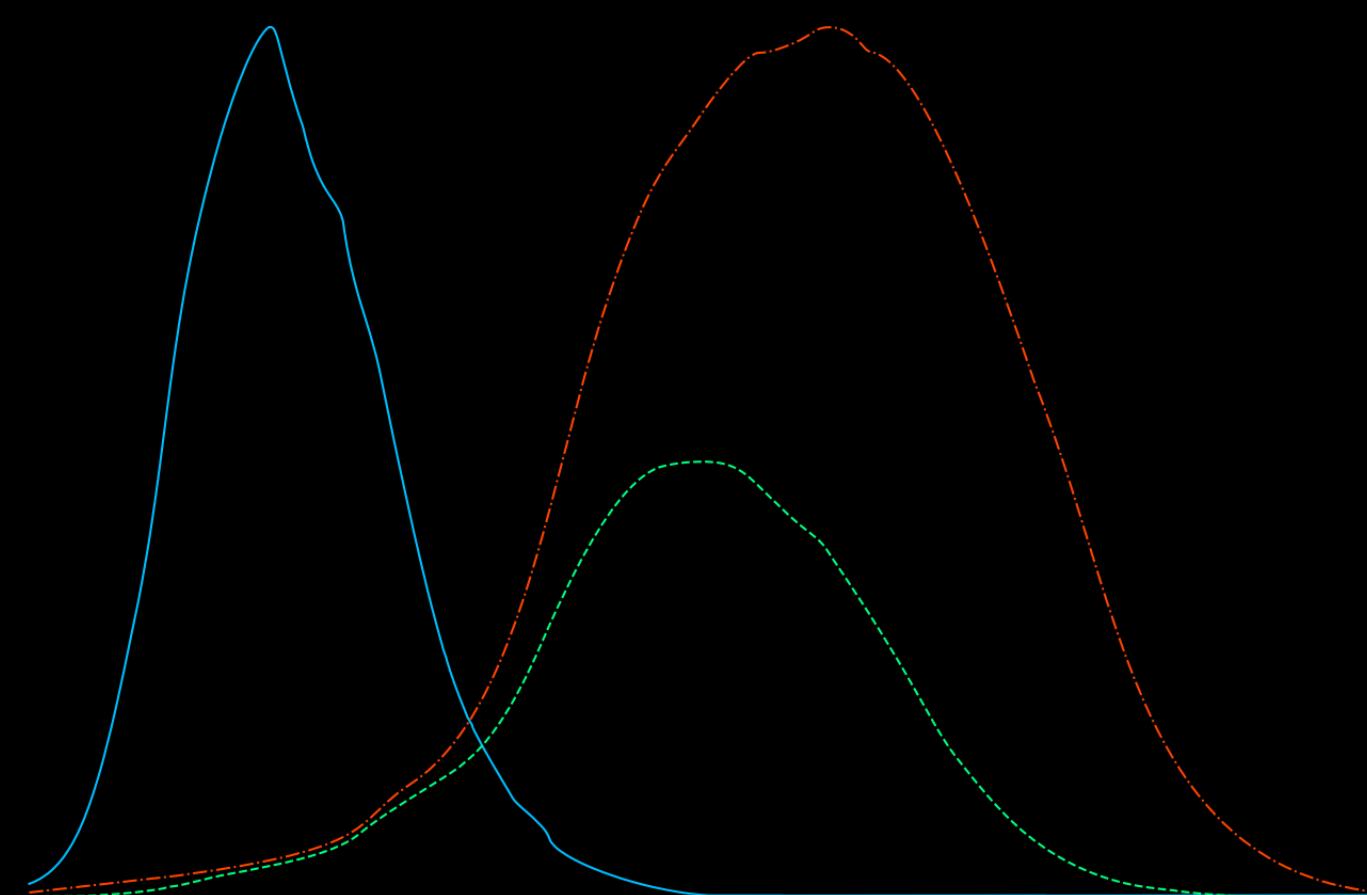
Protanomaly



~1%



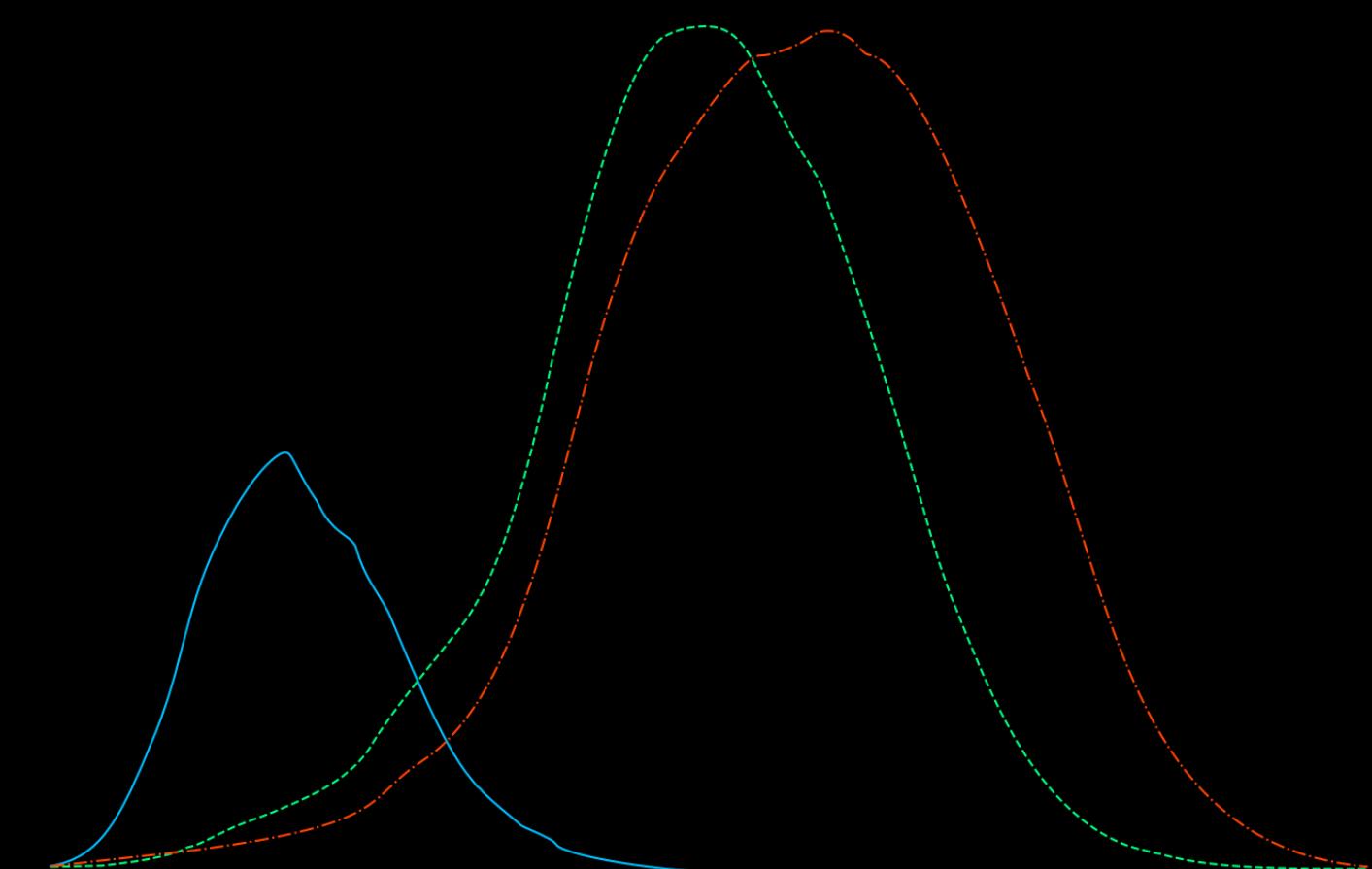
Deuteranomaly



~3%



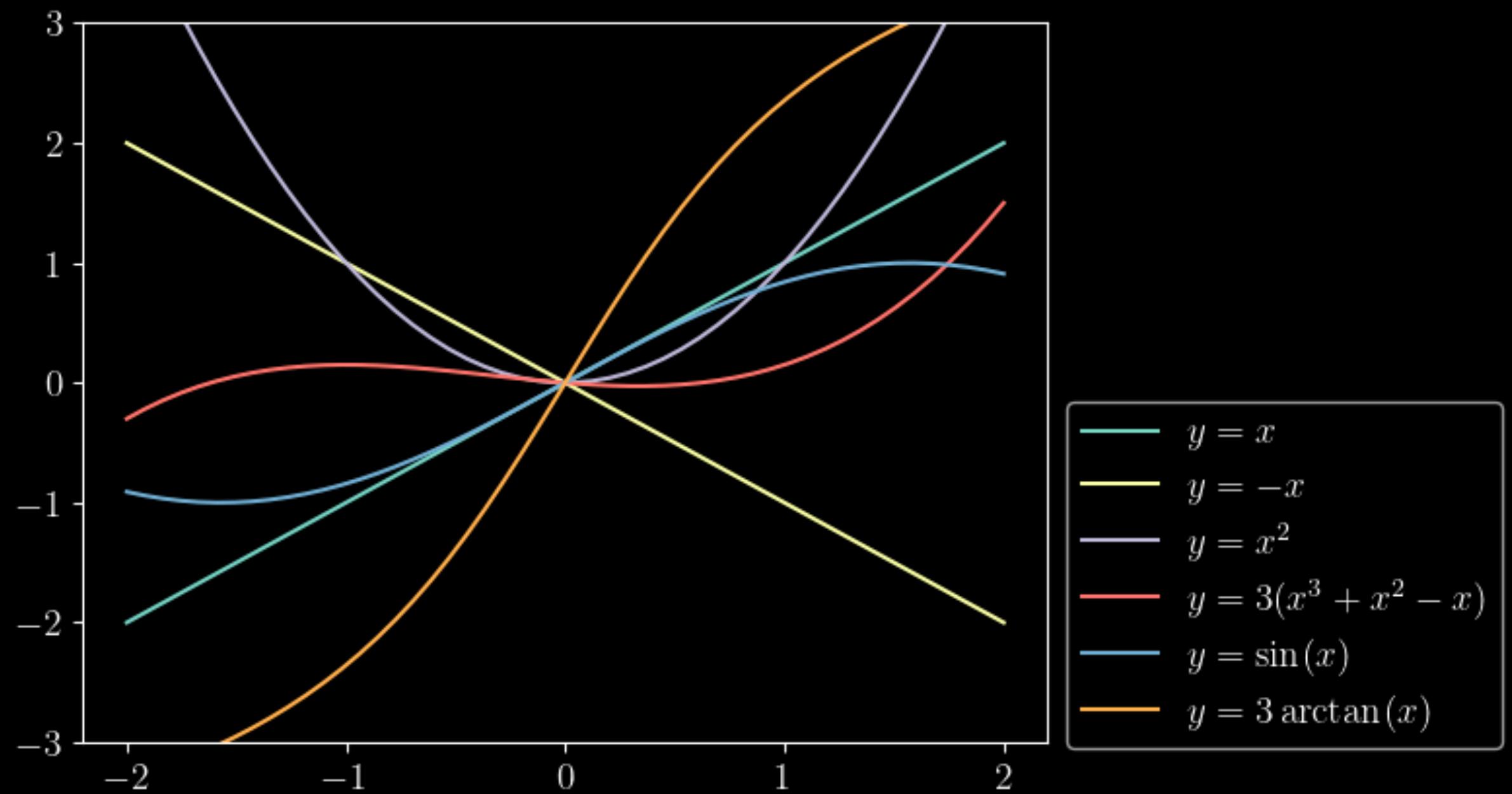
Tritanomaly



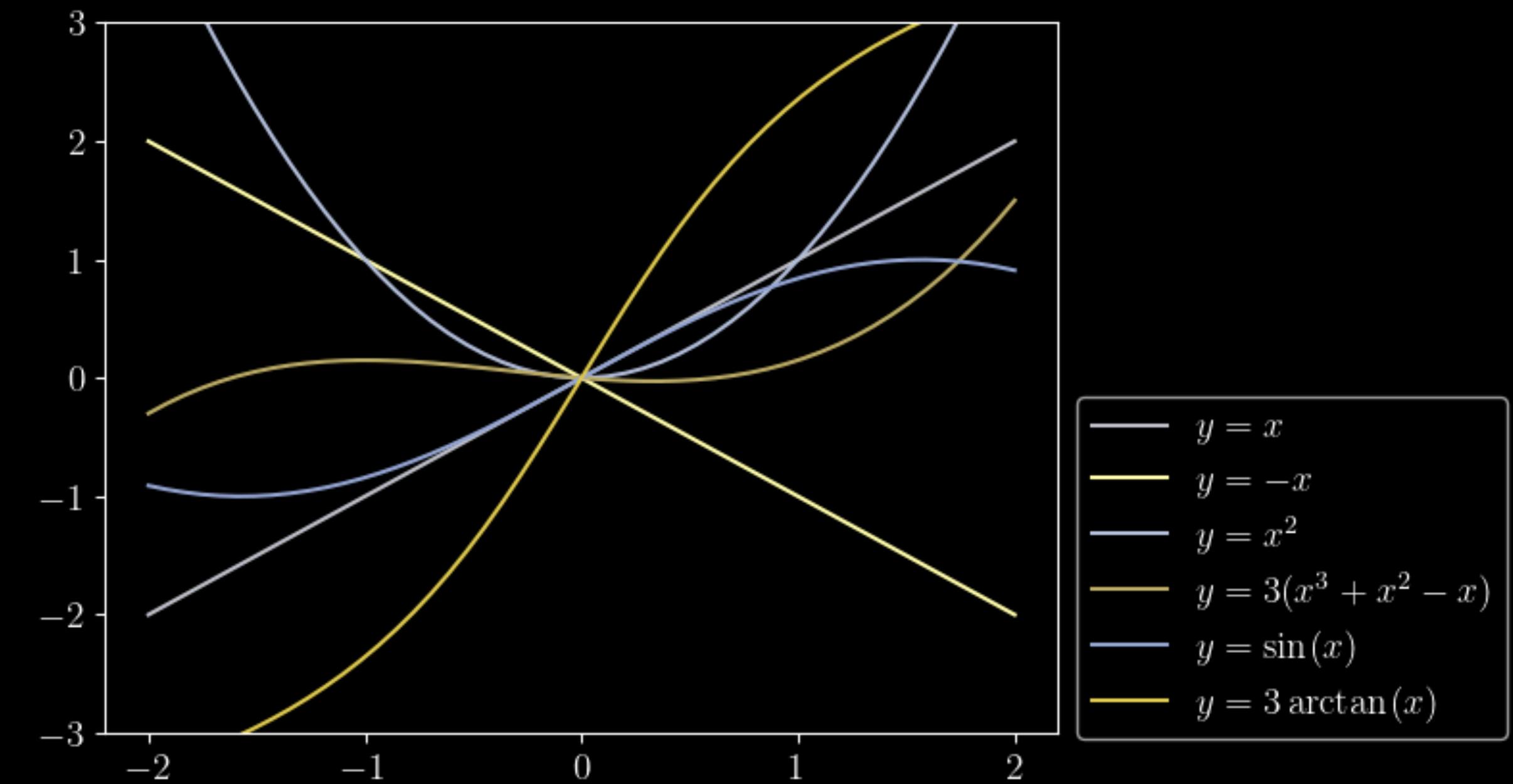
< 0.01%



# Color Vision Deficiency

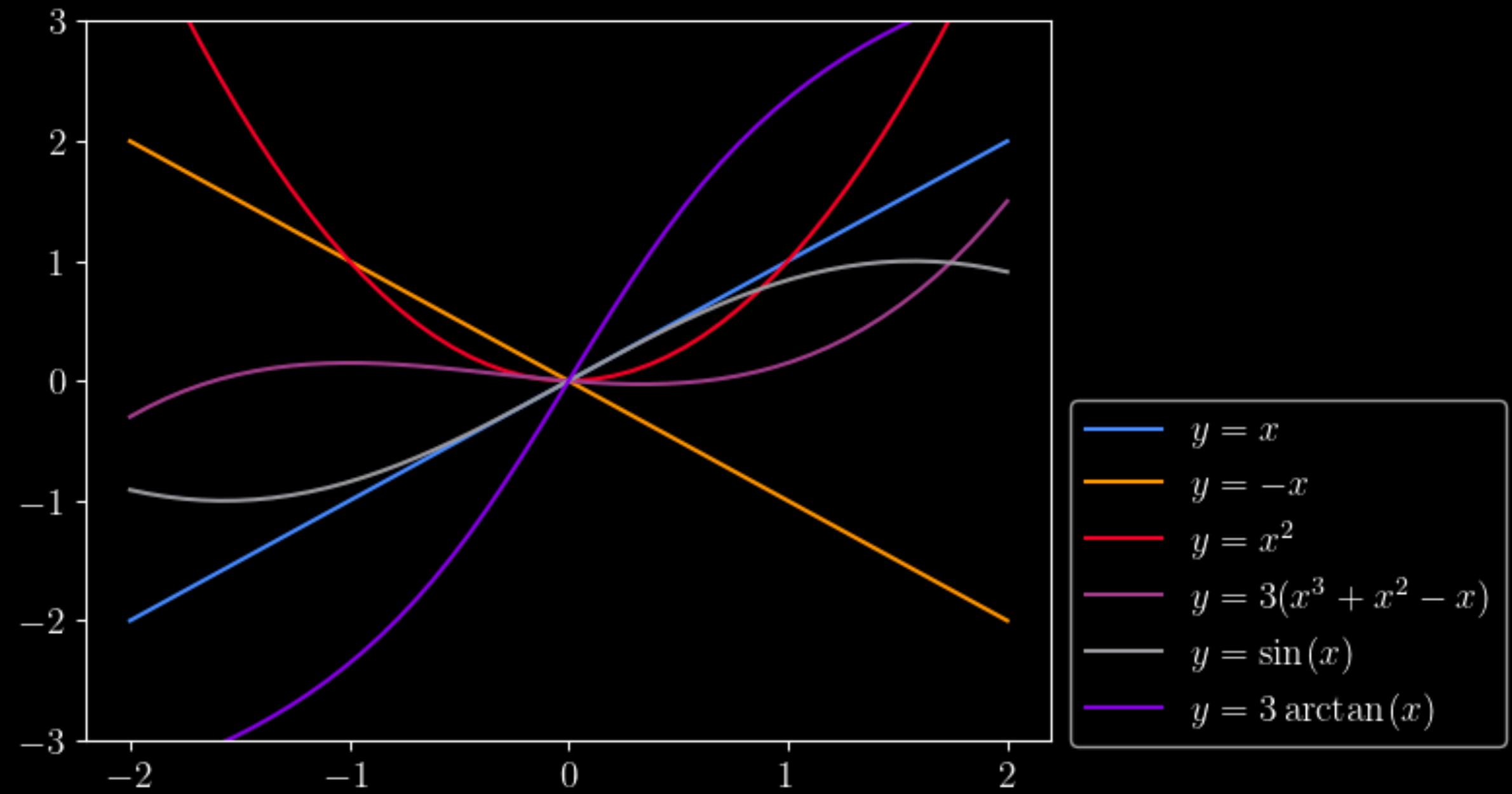


Original

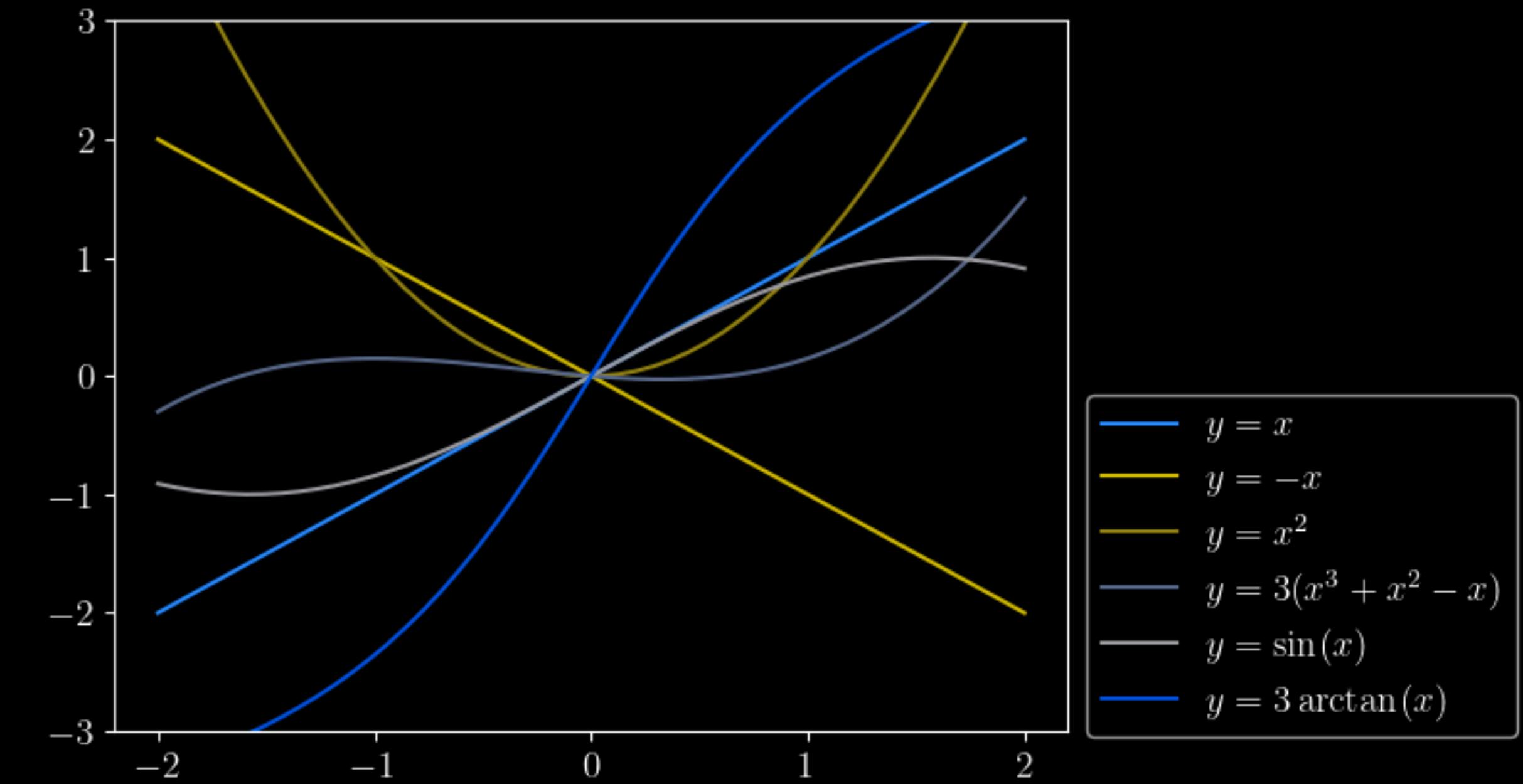


Deuternomaly (100%)

# Color Vision Deficiency

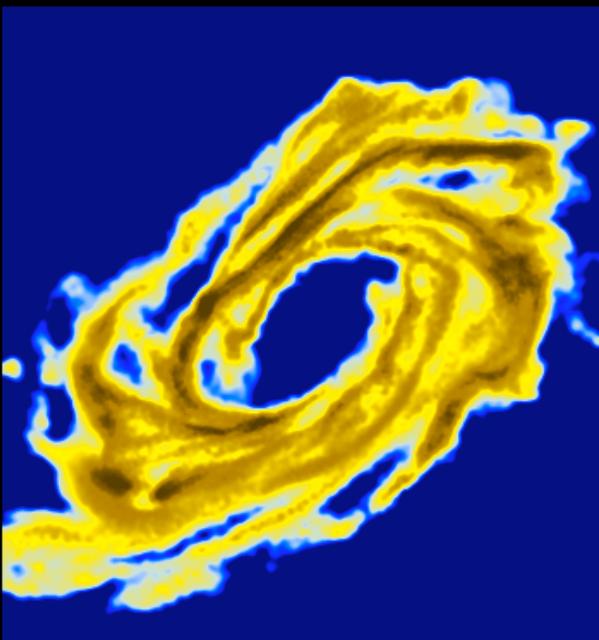


Original

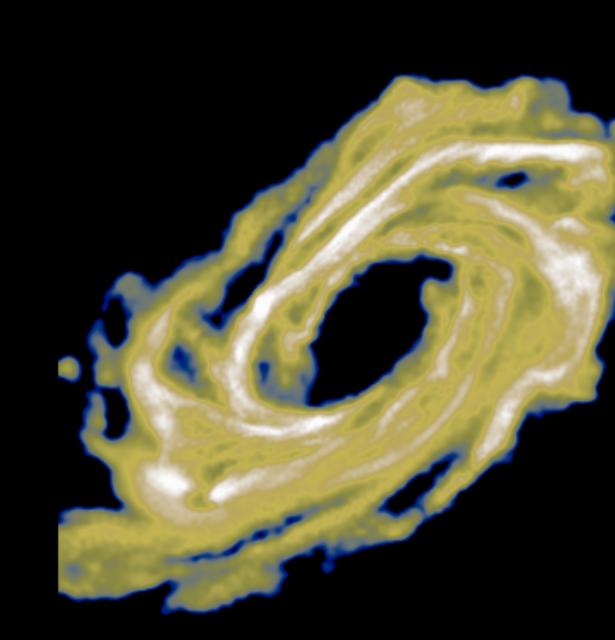


Deuternomaly (100%)

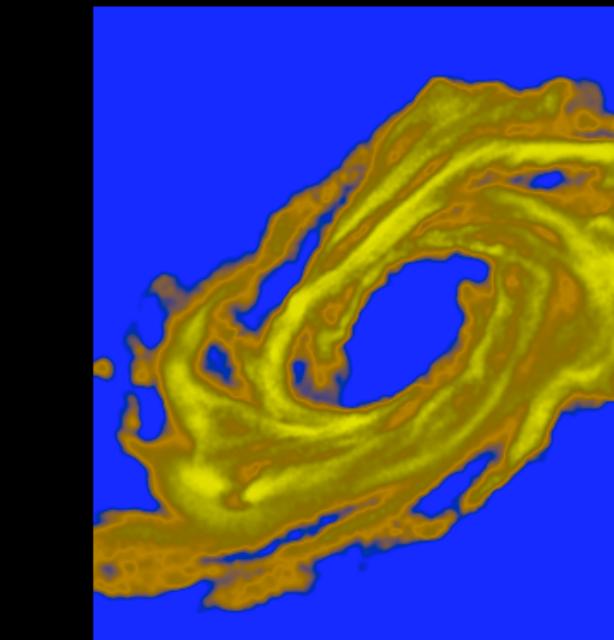
# Color Vision Deficiency



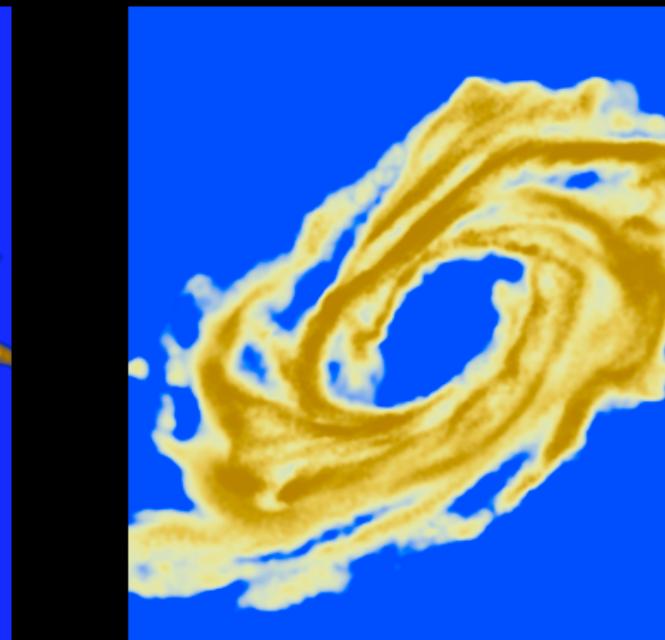
jet



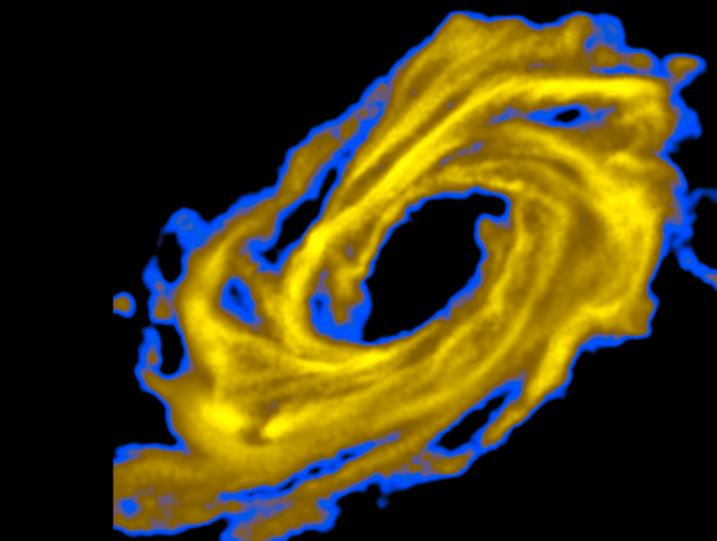
gist\_earth



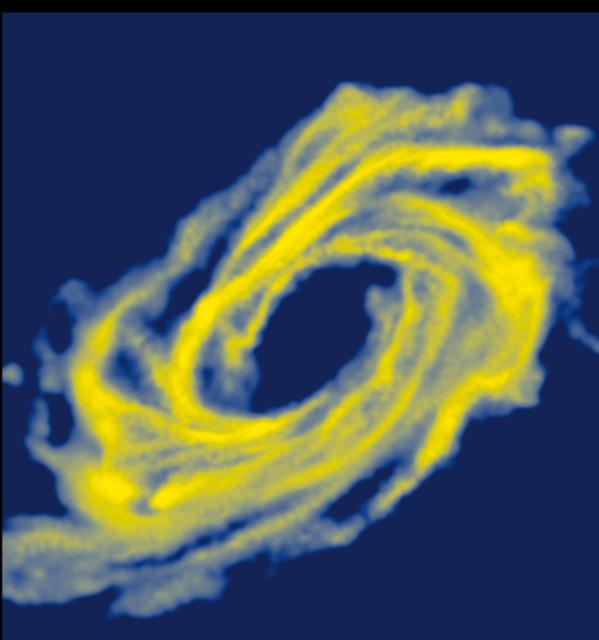
brg



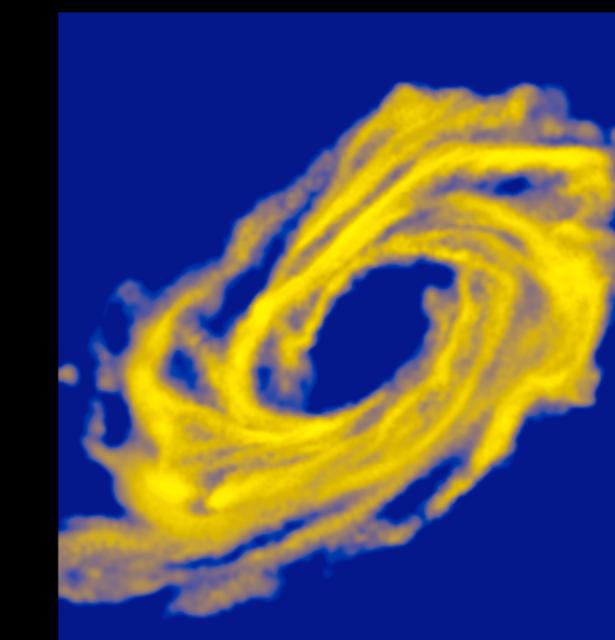
rainbow



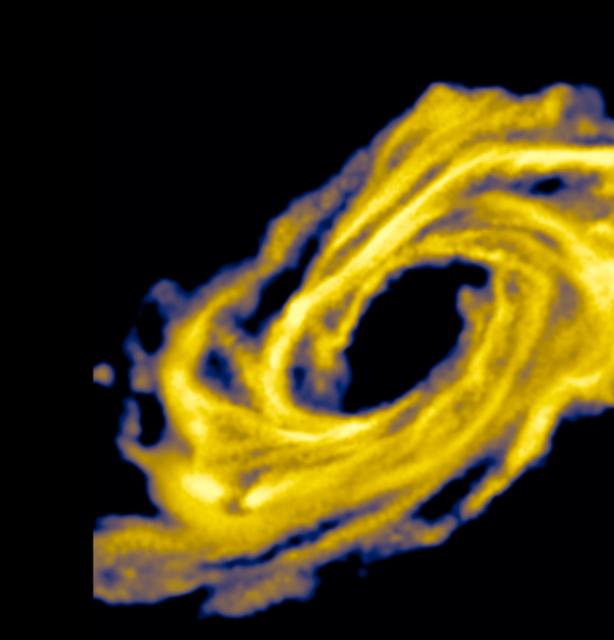
gnuplot



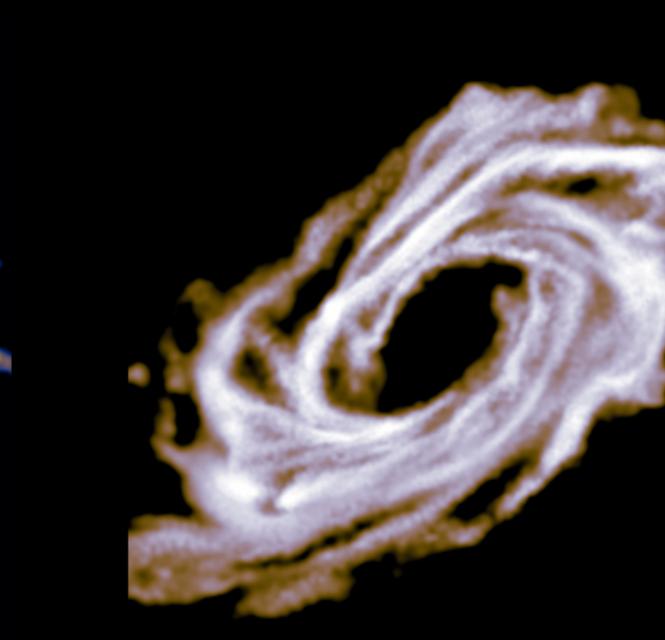
viridis



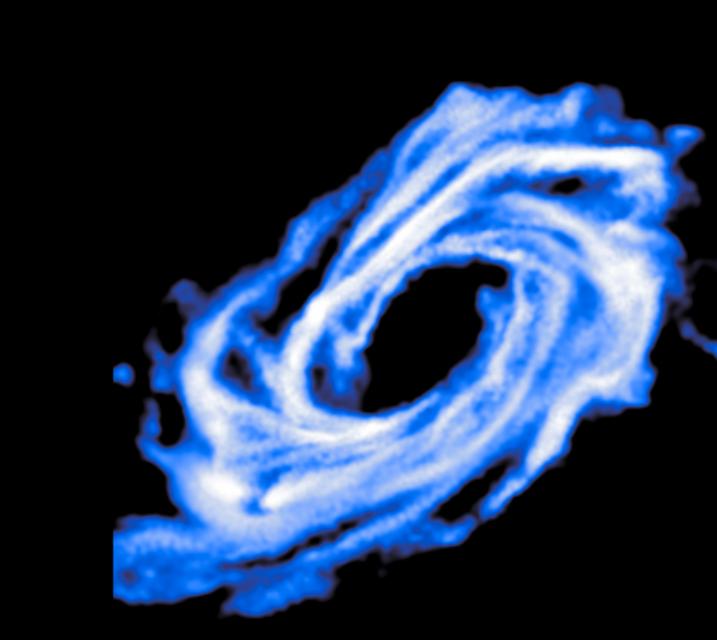
plasma



inferno



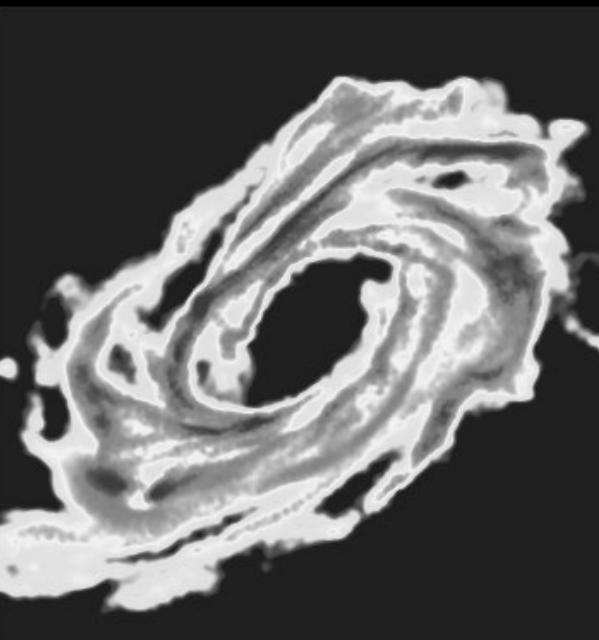
cmr.flamingo



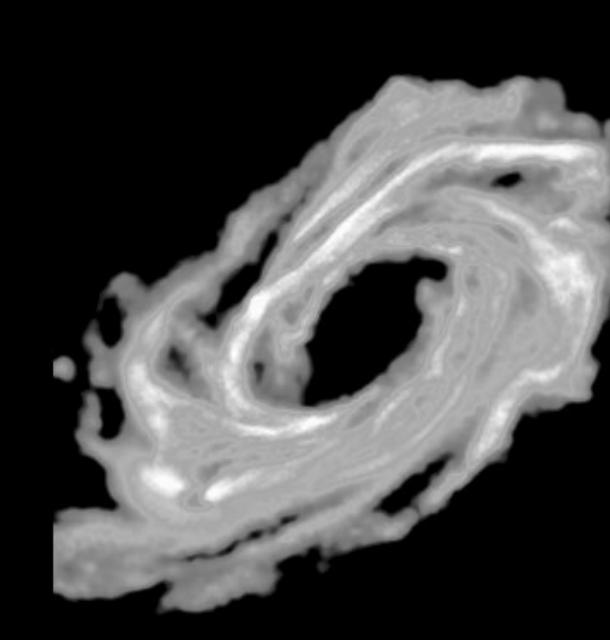
cmr.voltage

# Color Vision Deficiency

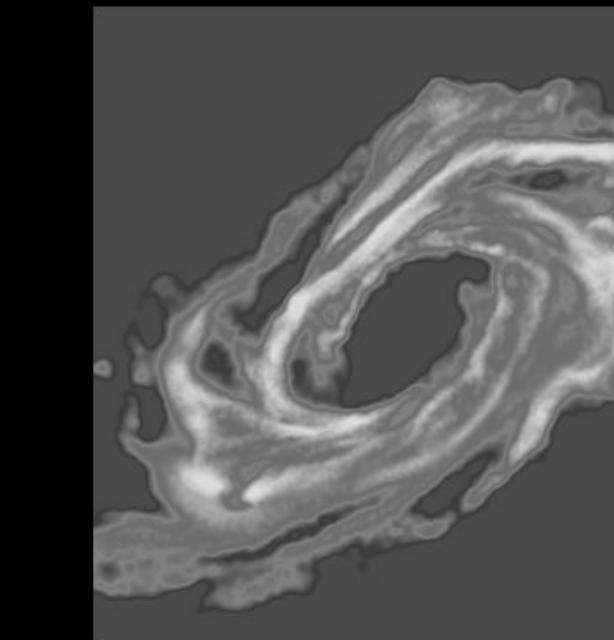
## Test: Black and White



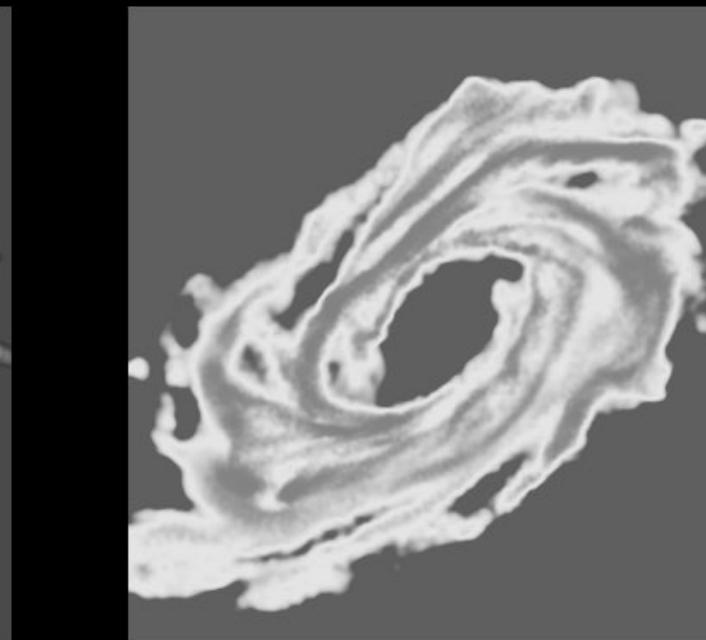
jet



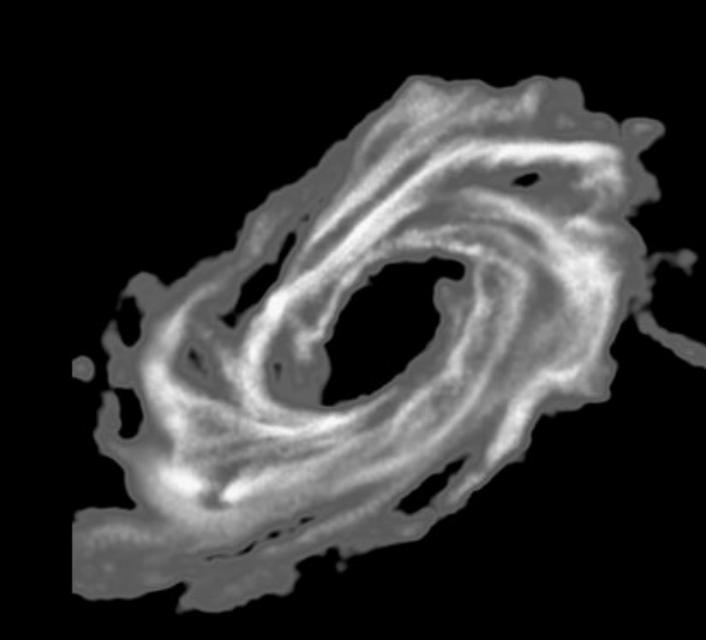
gist\_earth



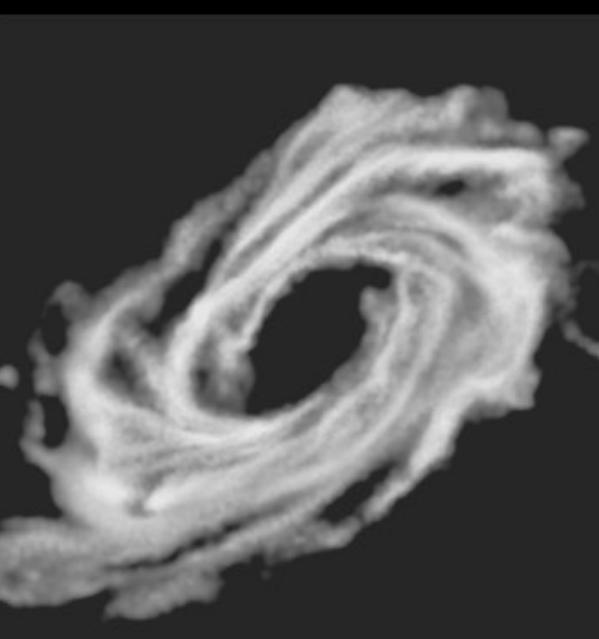
brg



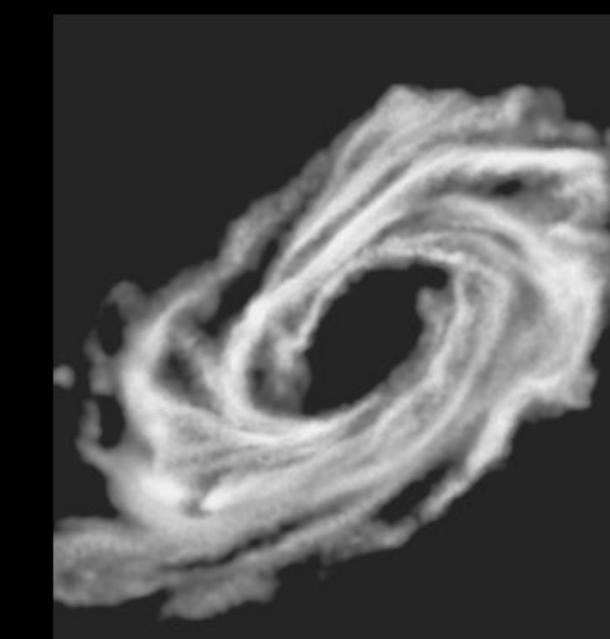
rainbow



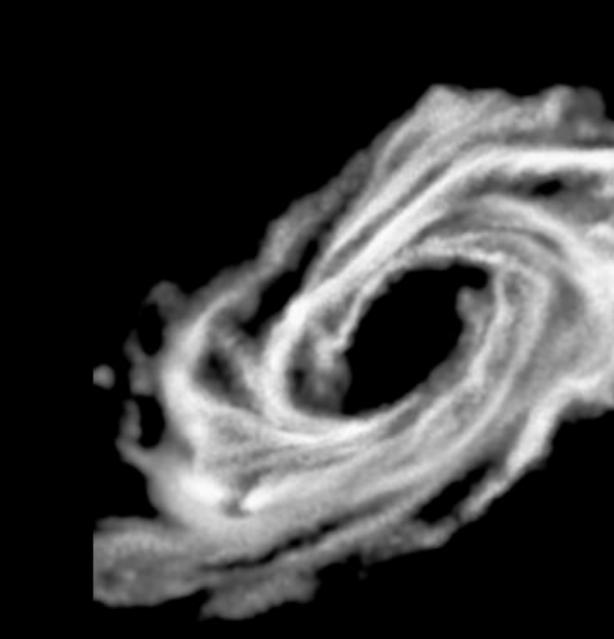
gnuplot



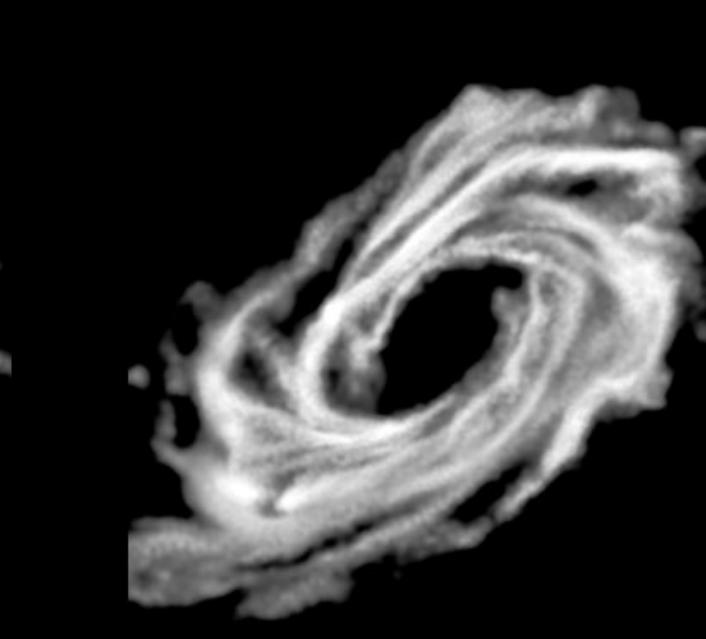
viridis



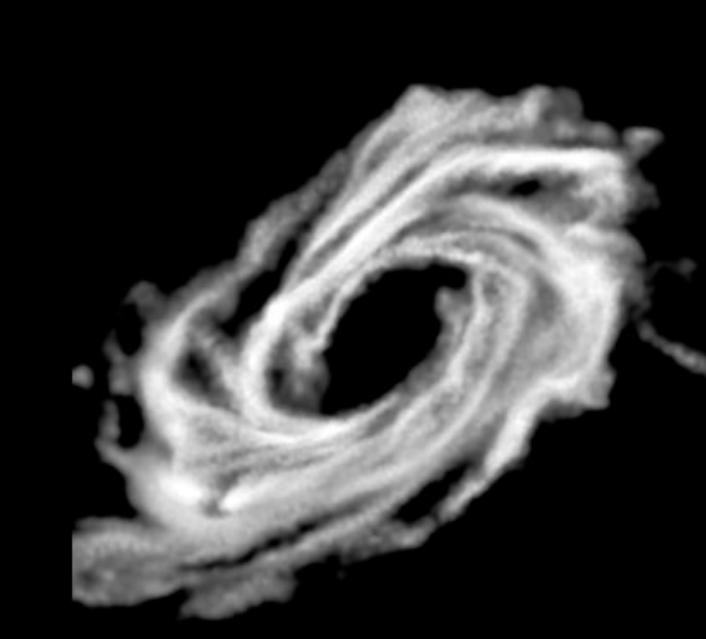
plasma



inferno

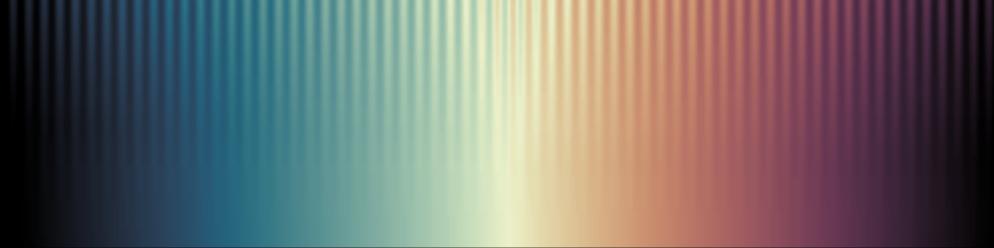
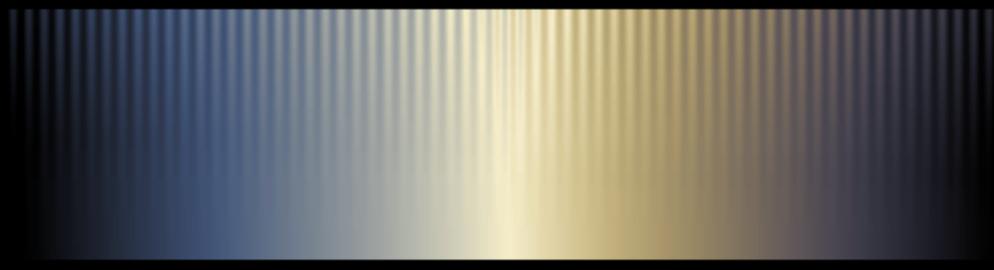
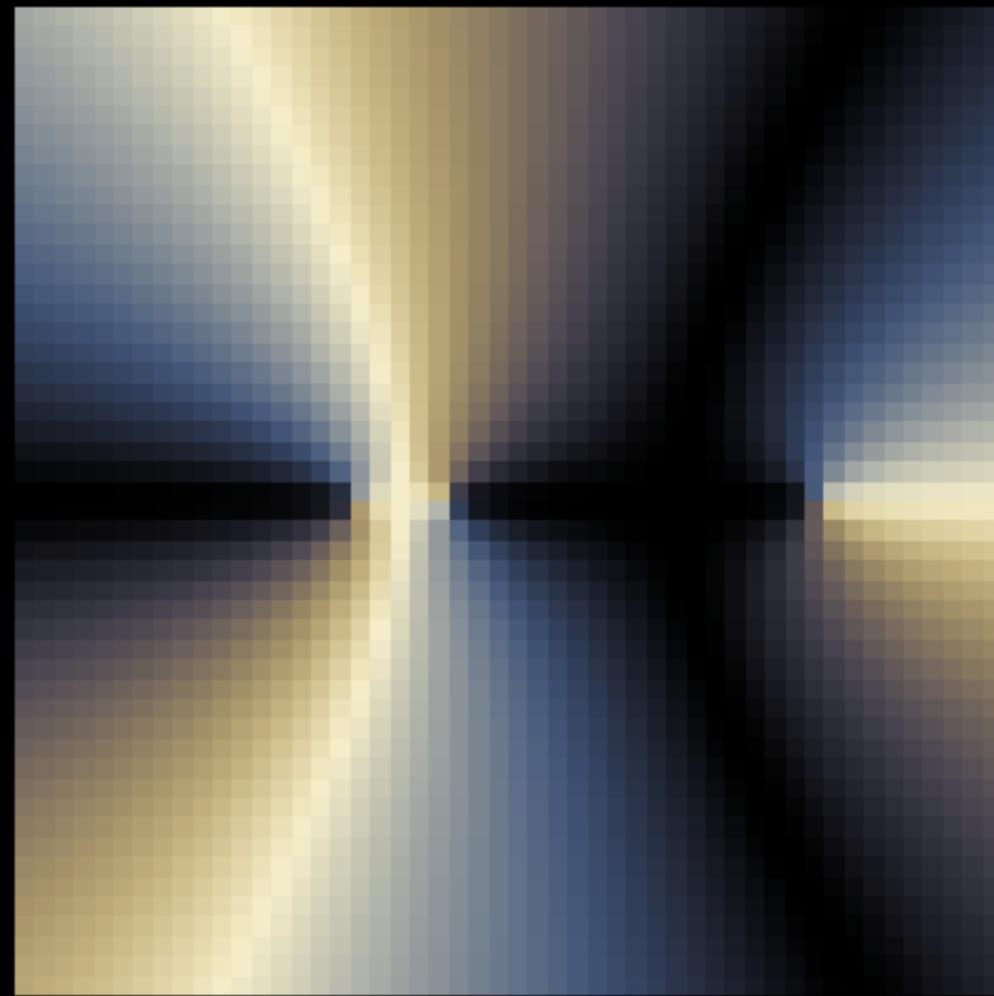


cmr.flamingo

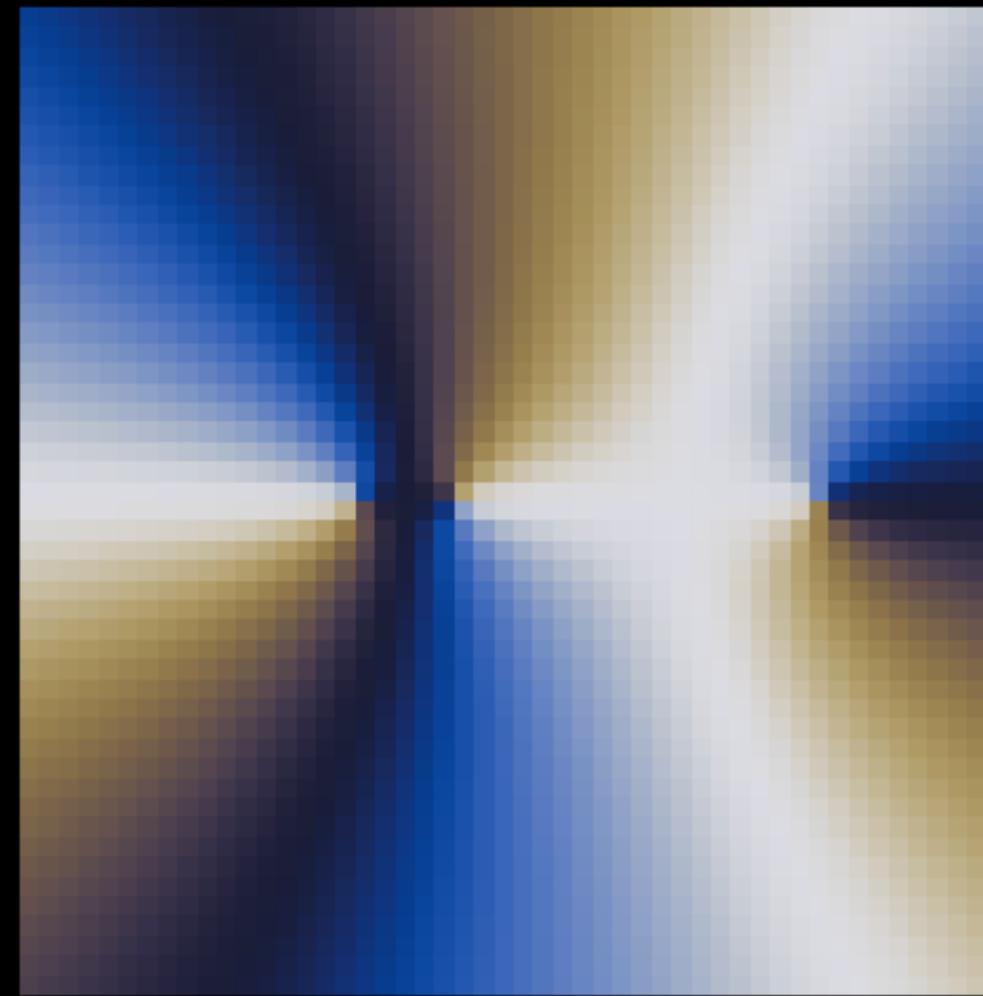


cmr.voltage

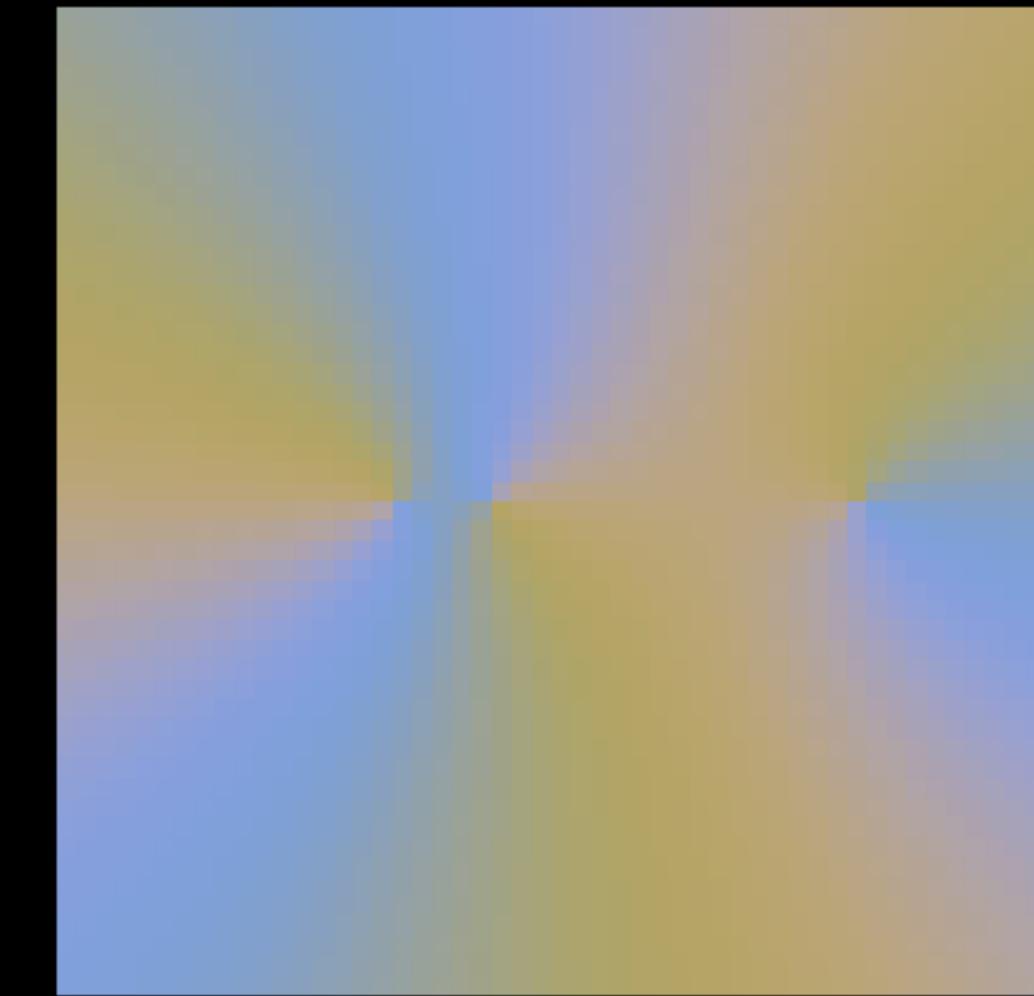
# Color Vision Deficiency



Copper



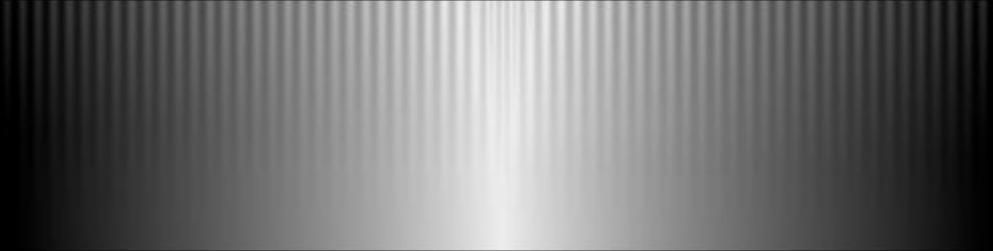
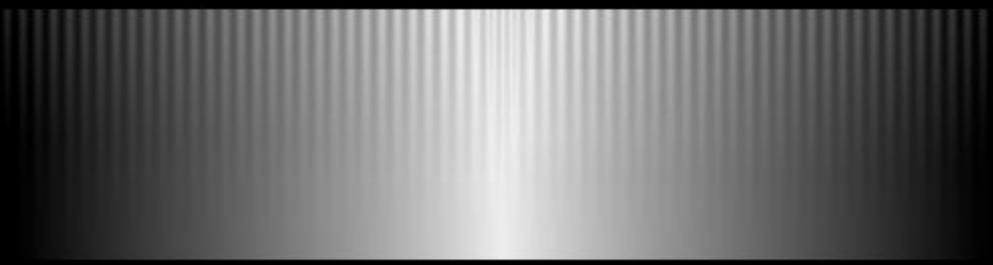
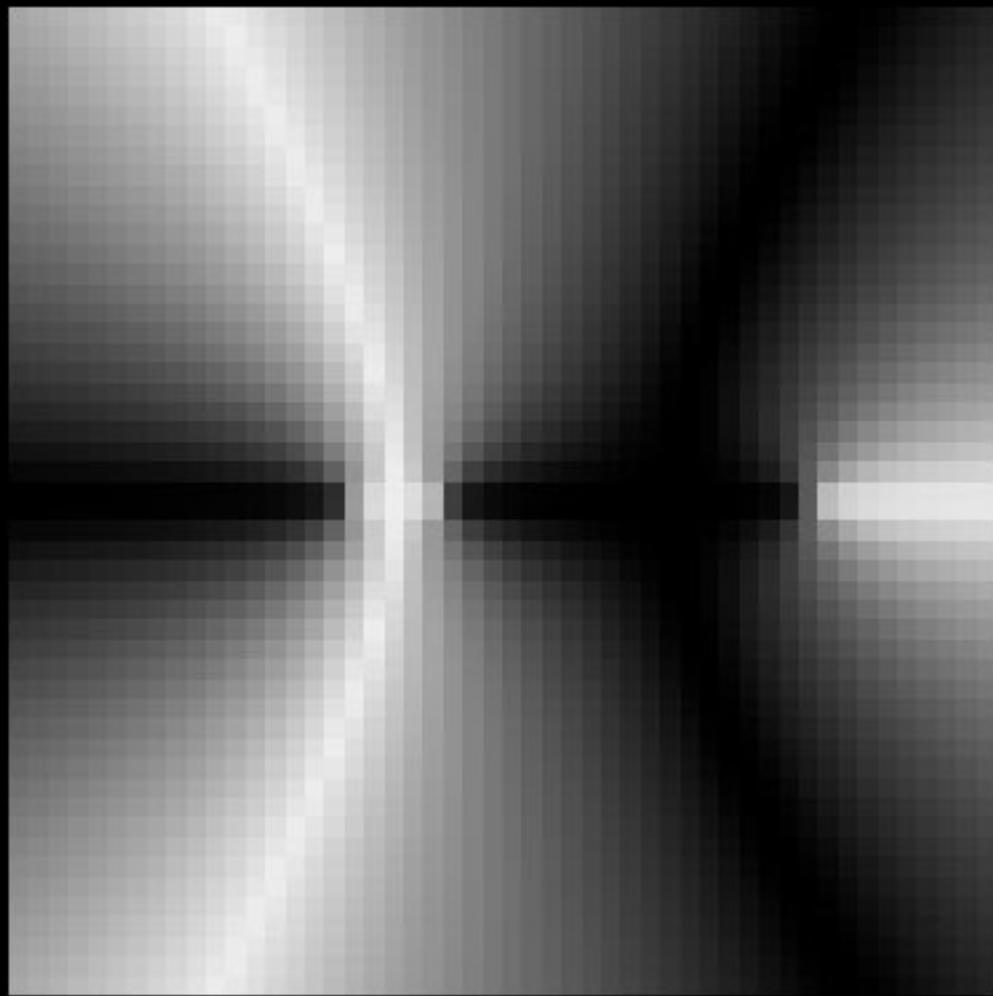
Twilight



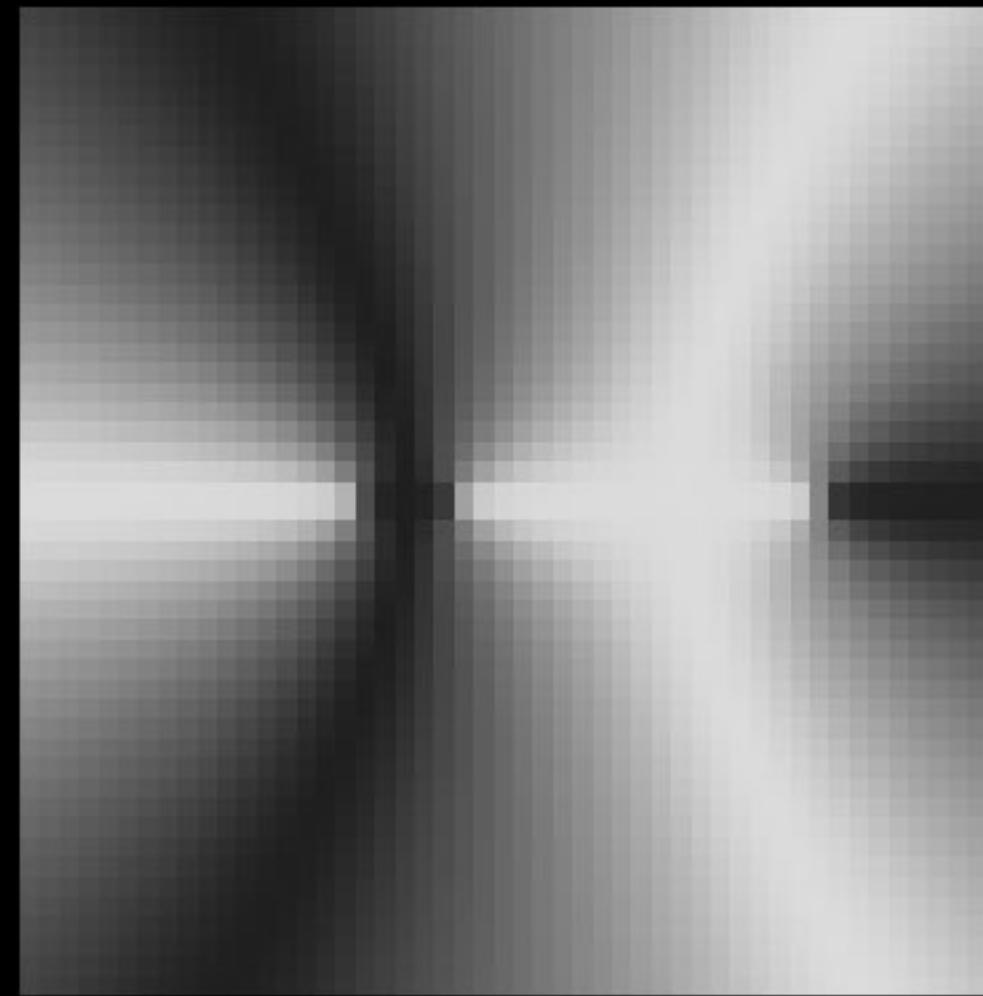
CET\_C10

# Color Vision Deficiency

Test: Black and White



Copper



Twilight



CET\_C10

# Resources

## Colormaps

matplotlib: <https://matplotlib.org/stable/users/explain/colors/colormaps.html>

cmocean: <https://matplotlib.org/cmocean/>

cmasher: <https://cmasher.readthedocs.io/>

## Categorical Color Sequences

Petroff (2024): <https://arxiv.org/abs/2107.02270>

(Or just `plt.style.use('petroff10')`)

## Useful Color Packages

Colour: <https://colour.readthedocs.io/en/v0.3.11/>

Colorspacious: <https://colorspacious.readthedocs.io/en/latest/>

# Petroff (2024) Color Palettes

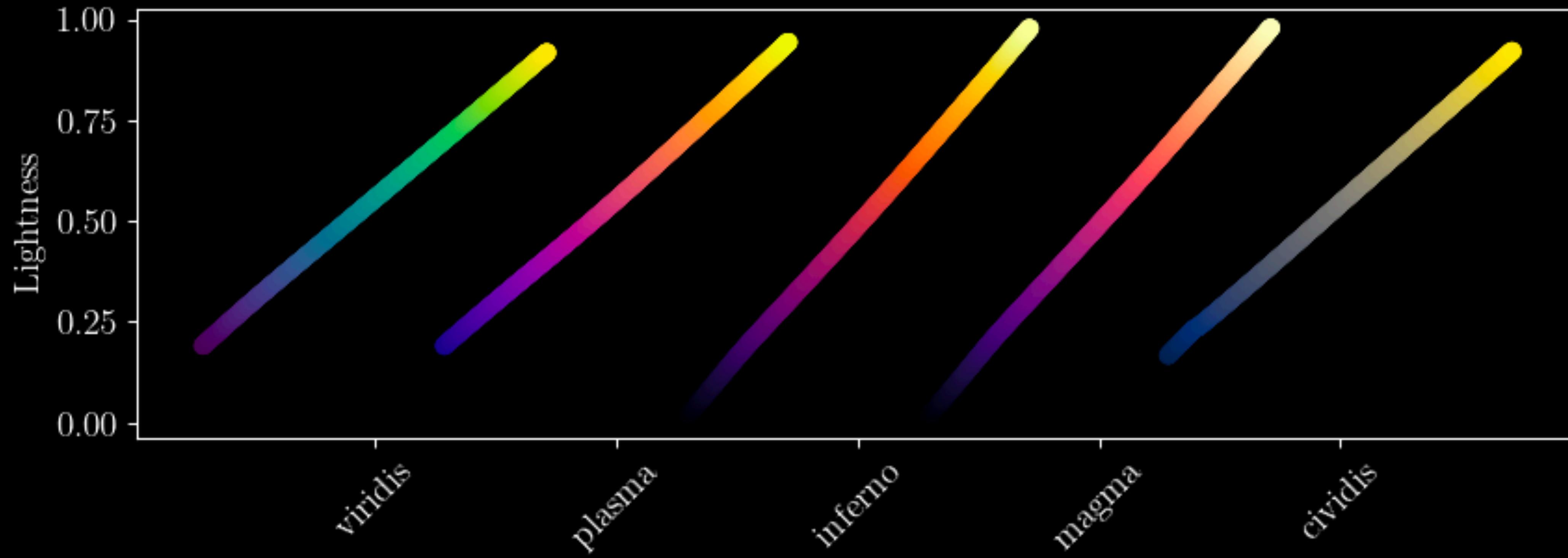
Six Colors					Eight Colors				
	R	G	B	min $\Delta E_{\text{cvd}}$		R	G	B	min $\Delta E_{\text{cvd}}$
blue ■	87	144	252	100.0	blue ■	24	69	251	100.0
orange ■	248	156	32	57.1	orange ■	255	94	2	66.9
red ■	228	37	54	21.3	red ■	201	31	22	18.2
purple ■	150	74	139	21.3	purple ■	200	73	169	18.1
gray ■	156	156	161	21.3	gray ■	173	173	125	18.1
purple ■	122	33	221	20.5	light blue ■	134	200	221	18.1
					blue ■	87	141	255	18.1
					gray ■	101	99	100	18.1

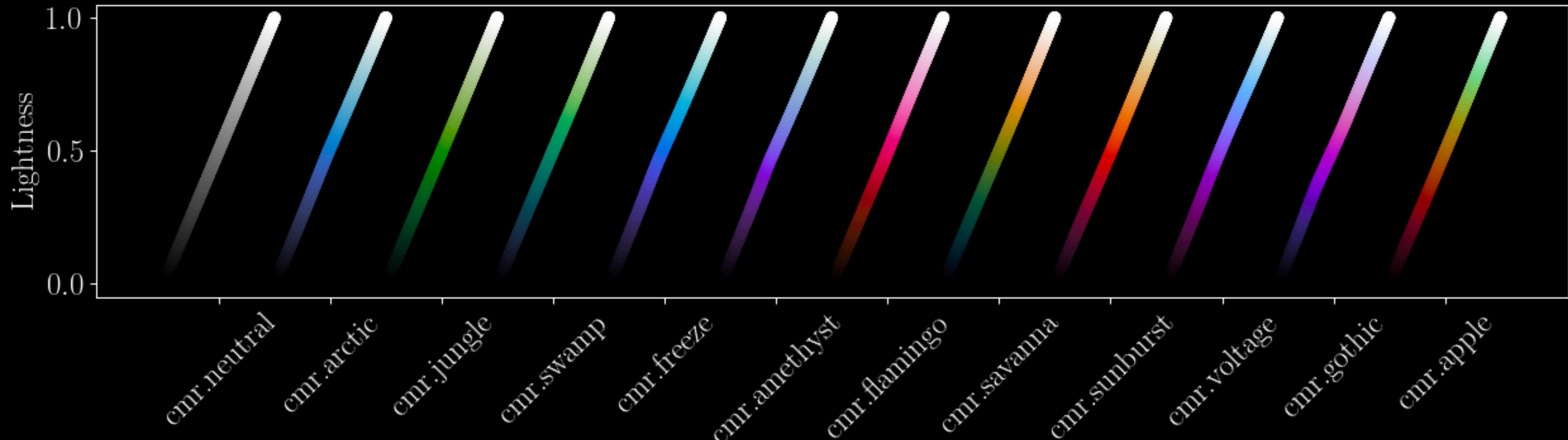
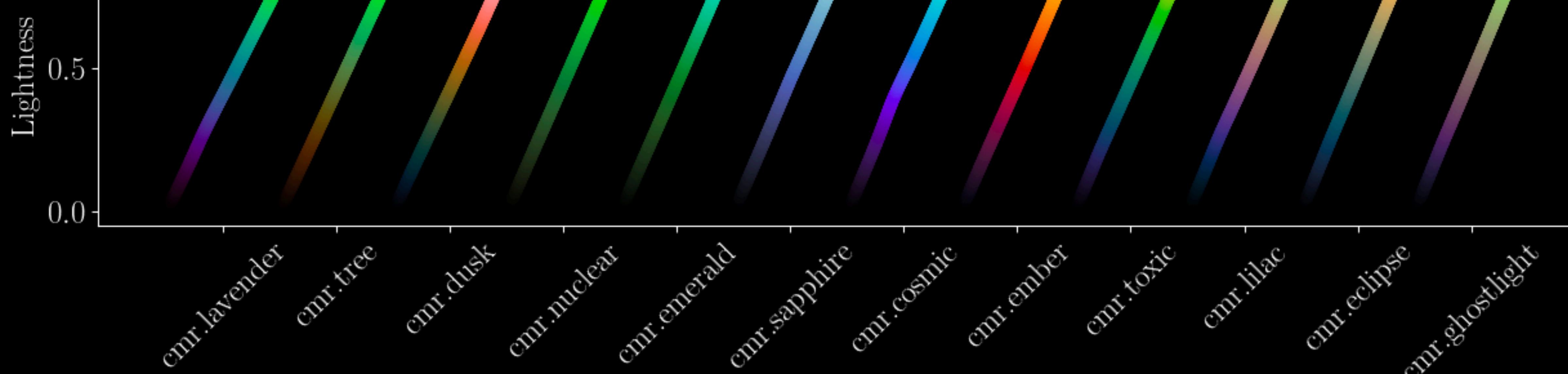
Ten Colors				
	R	G	B	min $\Delta E_{\text{cvd}}$
blue ■	63	144	218	100.0
orange ■	255	169	14	56.8
red ■	189	31	1	33.4
gray ■	148	164	162	22.3
purple ■	131	45	182	18.3
brown ■	169	107	89	16.4
orange ■	231	99	0	16.3
tan ■	185	172	112	16.1
gray ■	113	117	129	16.1
light blue ■	146	218	221	16.1

# Wolf Approved™ Perceptually Uniform Colormaps

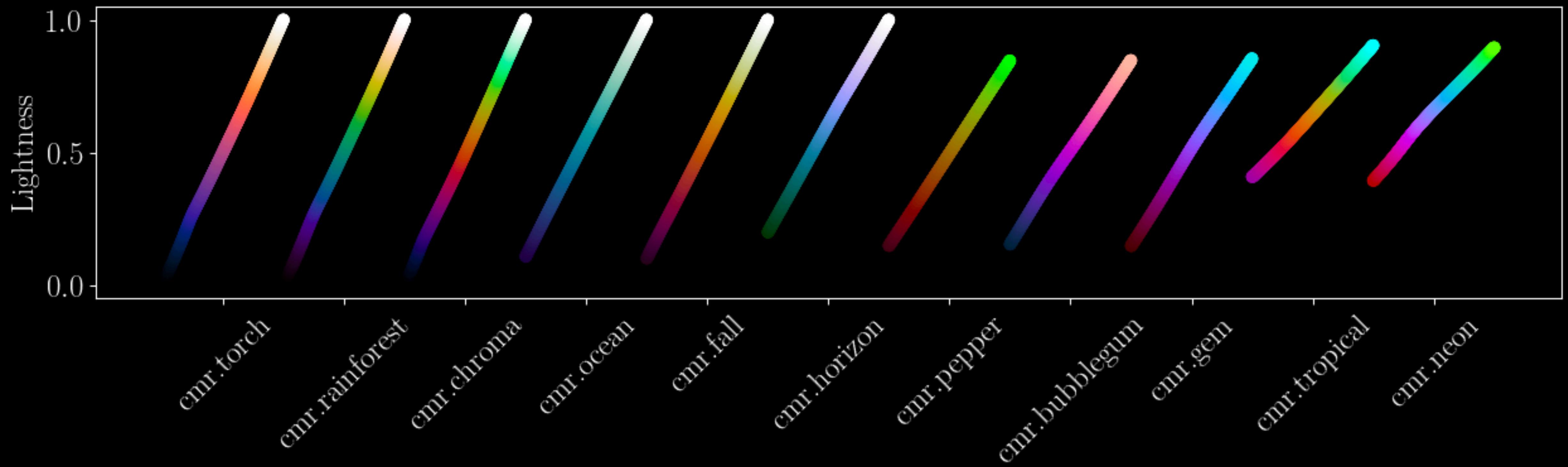
# matplotlib



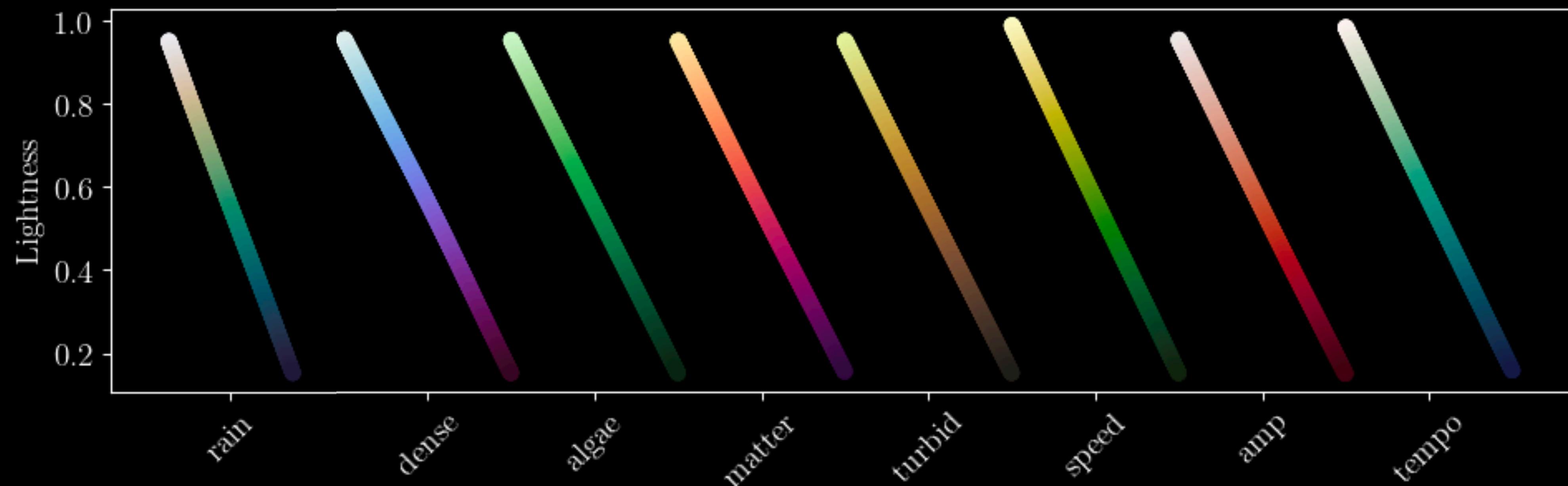
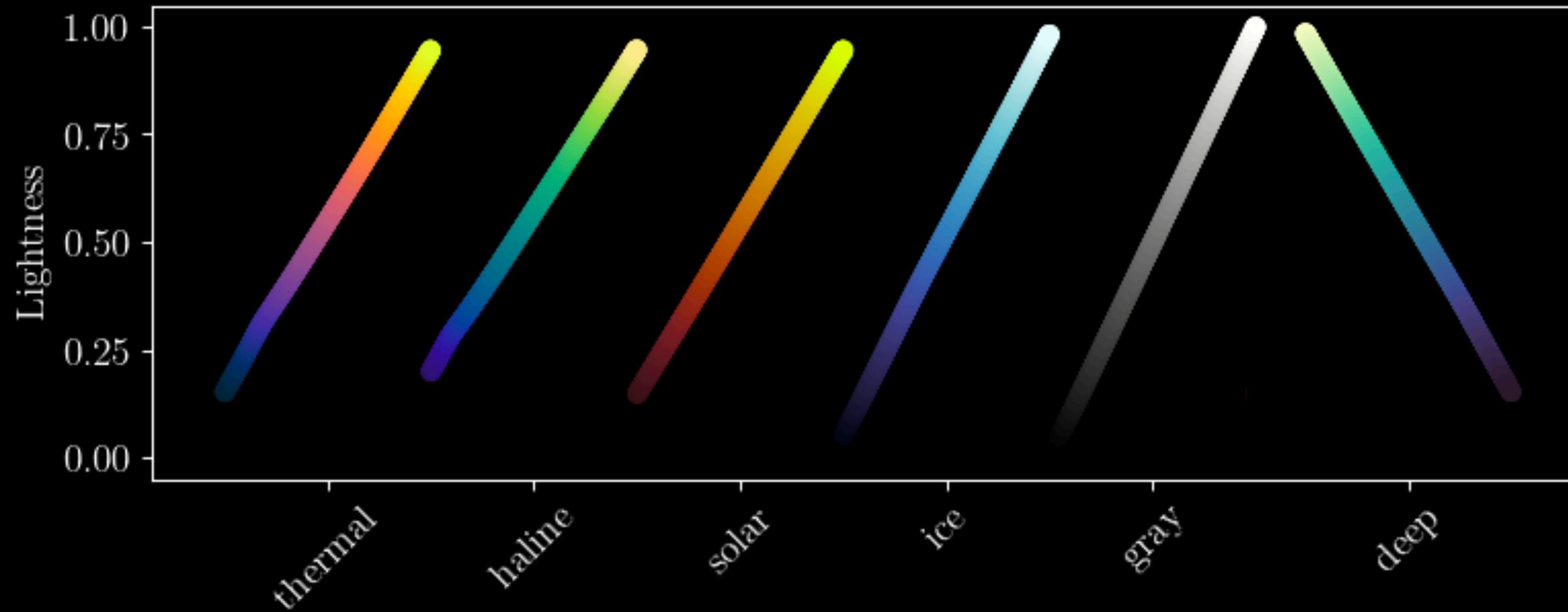
# cmasher



# cmasher

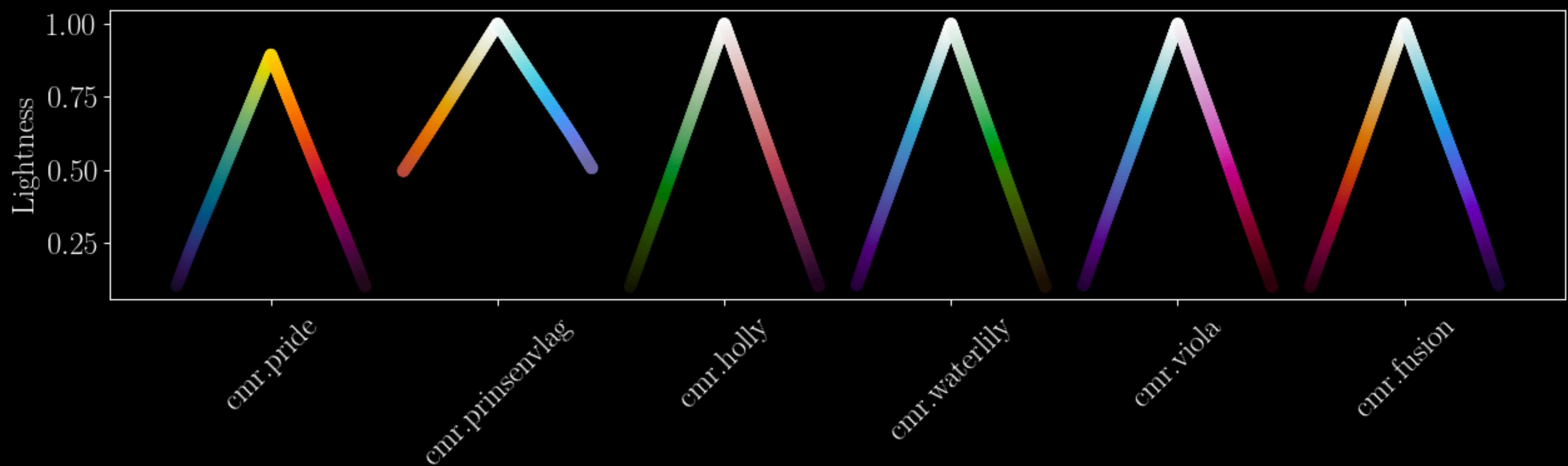
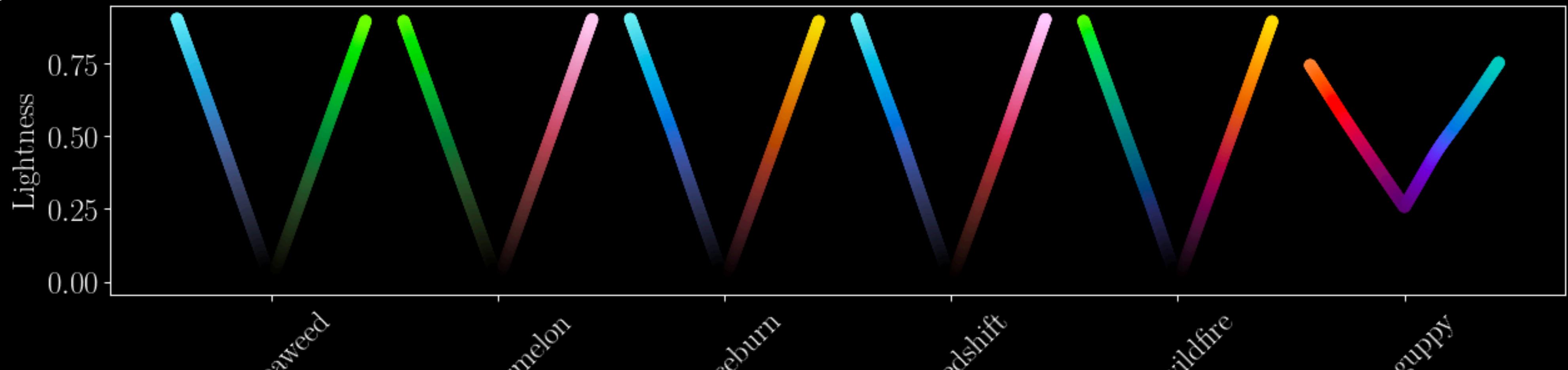


# cmocean

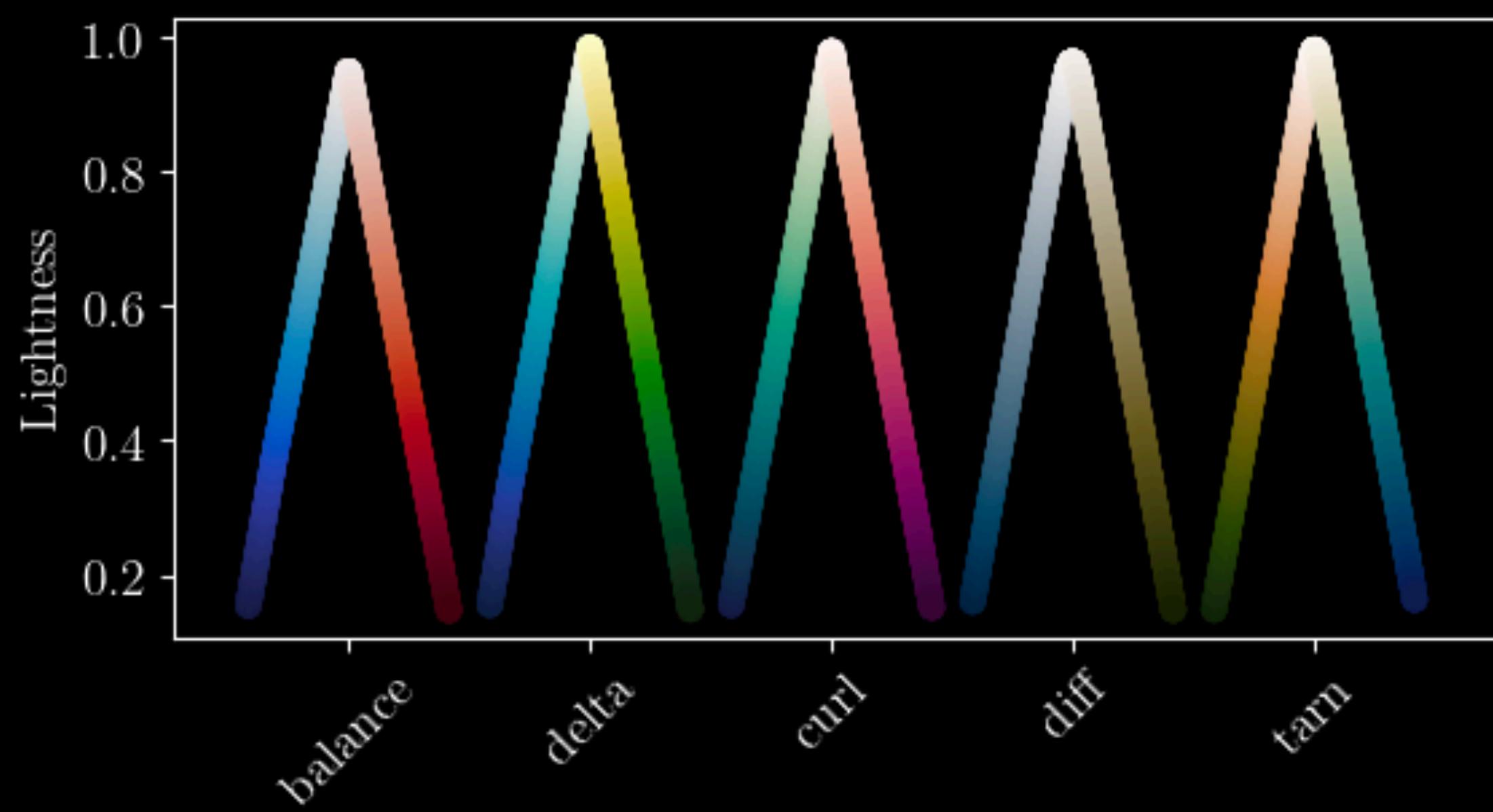


# Wolf Approved™ Diverging Colormaps

# cmasher

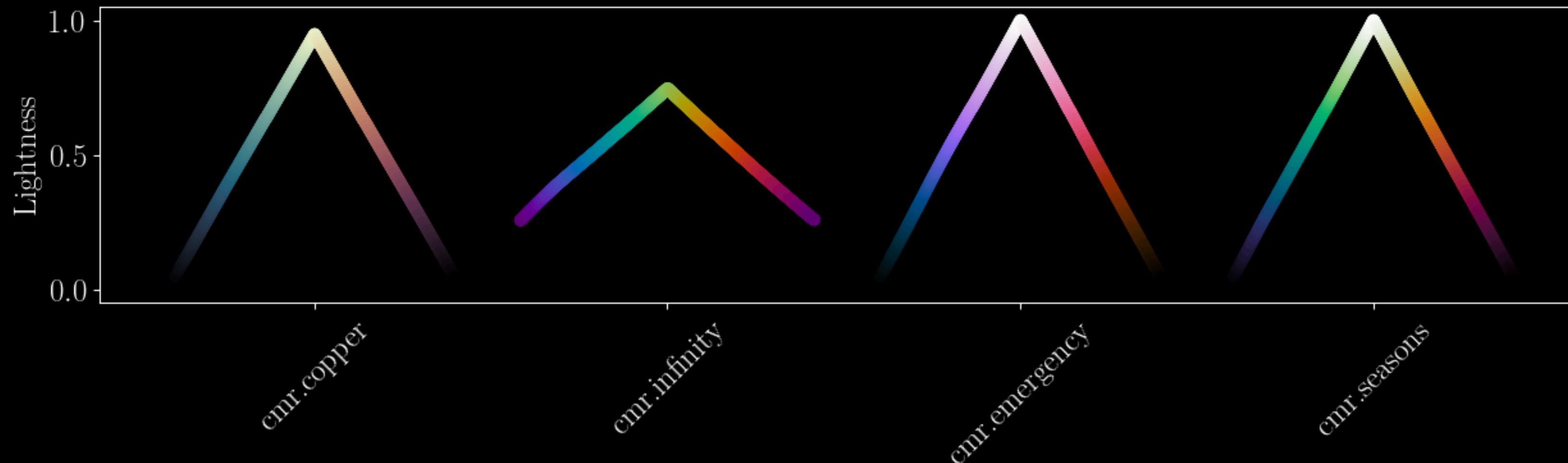


# cmocean



# Wolf Approved™ Cyclic Colormaps

# cmasher



# matplotlib

