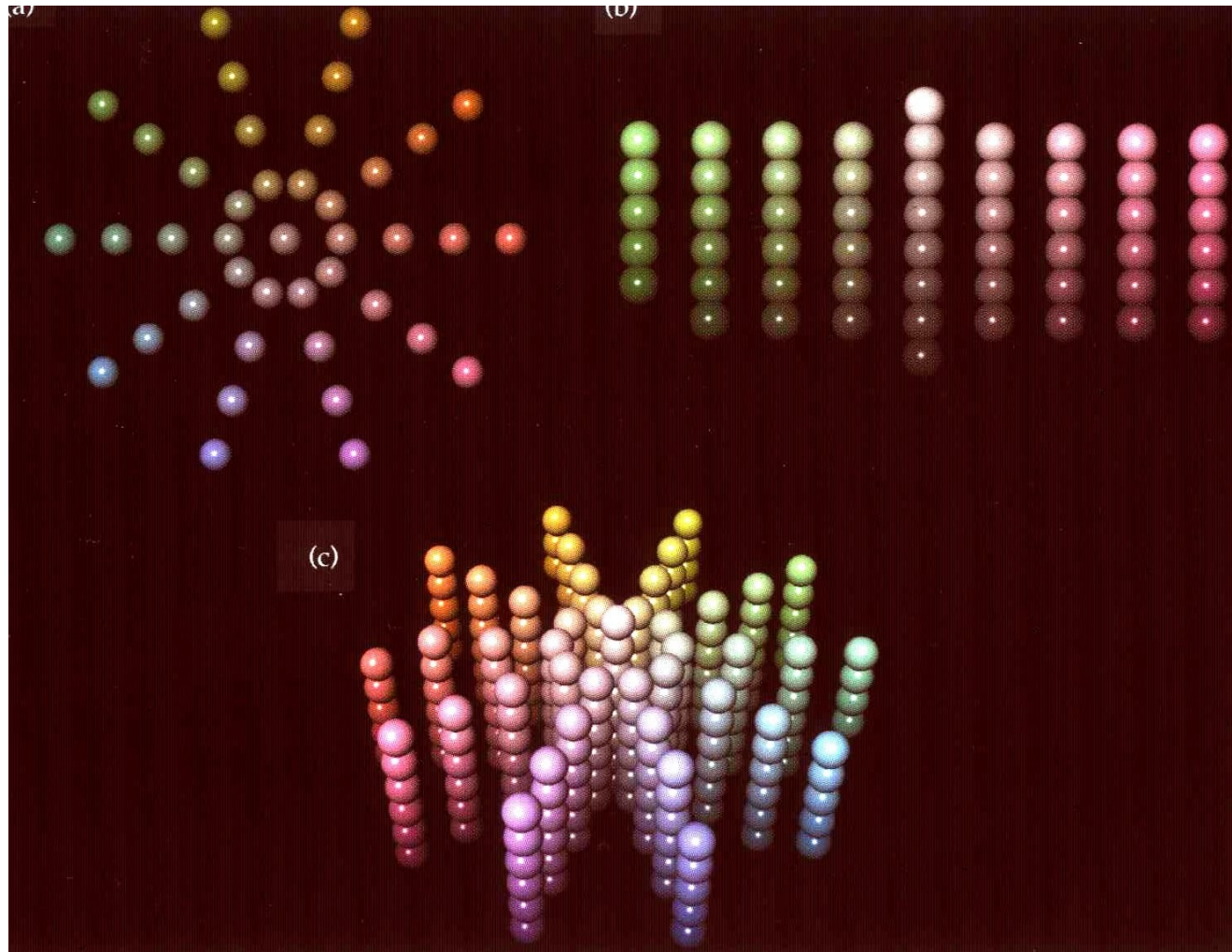


# Definition and application of perceptually uniform colormaps

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IAG/USP



# Outline

## The problem

- Why perceptually uniform maps need to be developed

## Human color vision

- Human color space
- CIE Lab color space

## Limitations of standard colormaps

- Why rainbows are bad
- Limitations of other common maps

## Development of uniform colormaps

- Standard color maps in different color spaces

## Defintion of maps from CIE Lab space

- Fully uniform maps
- Smooth maps

## Examples

## Dynamic maps

- High Dynamic Range (HDR) rendering

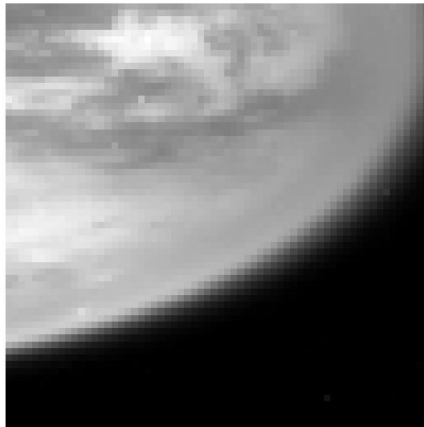
## Summary

# The problem

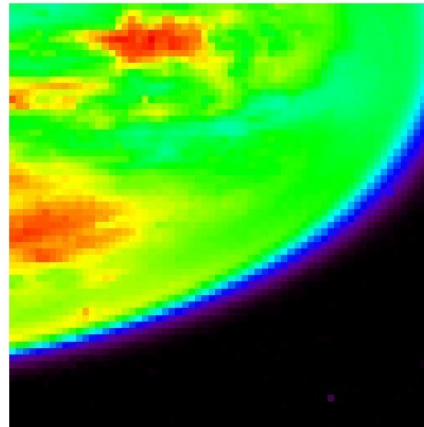
Displaying a 2D array as 1-channel image is one of the most common visualization tasks.

Requires choosing a colormap, that goes from the 1D range of data values, to some trajectory in the 3D display colorspace (the RGB cube, with  $256^3$  uniformly distributed points).

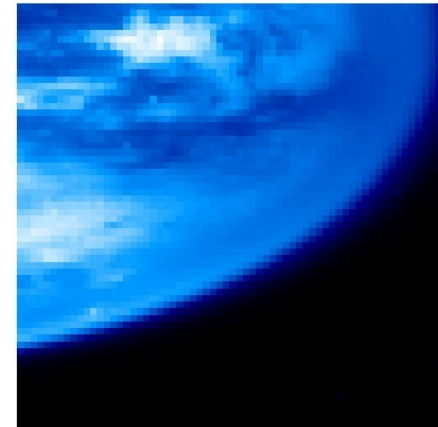
B-W linear



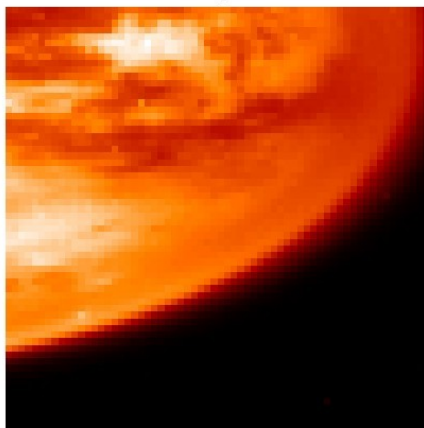
Rainbow



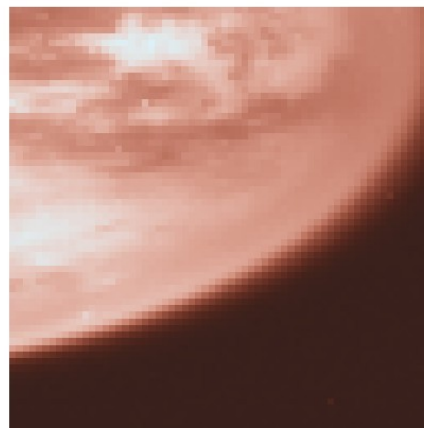
Blue/white



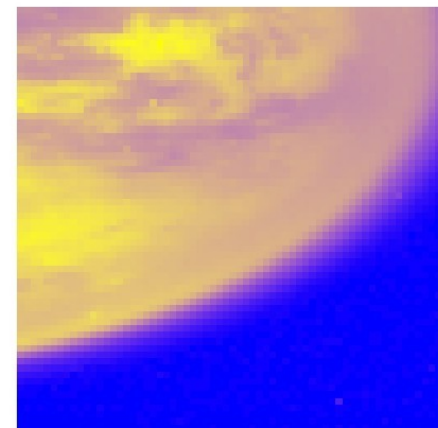
Red temperature



B-W nonuniform



B-Y uniform



(Cassini VIMS data retrieved from PDS through pp\_titanbrowse)

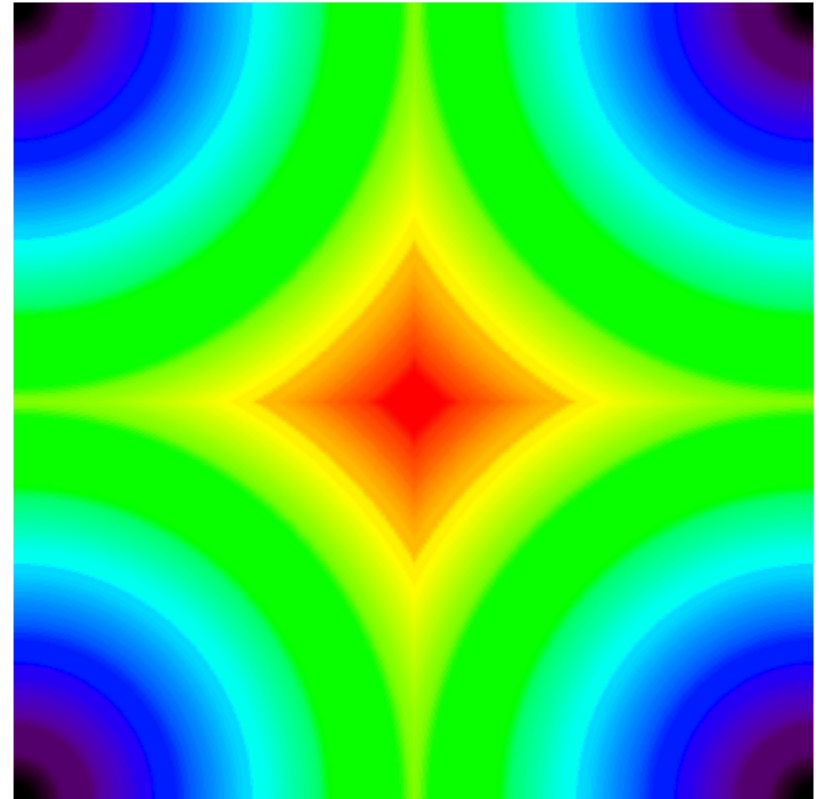
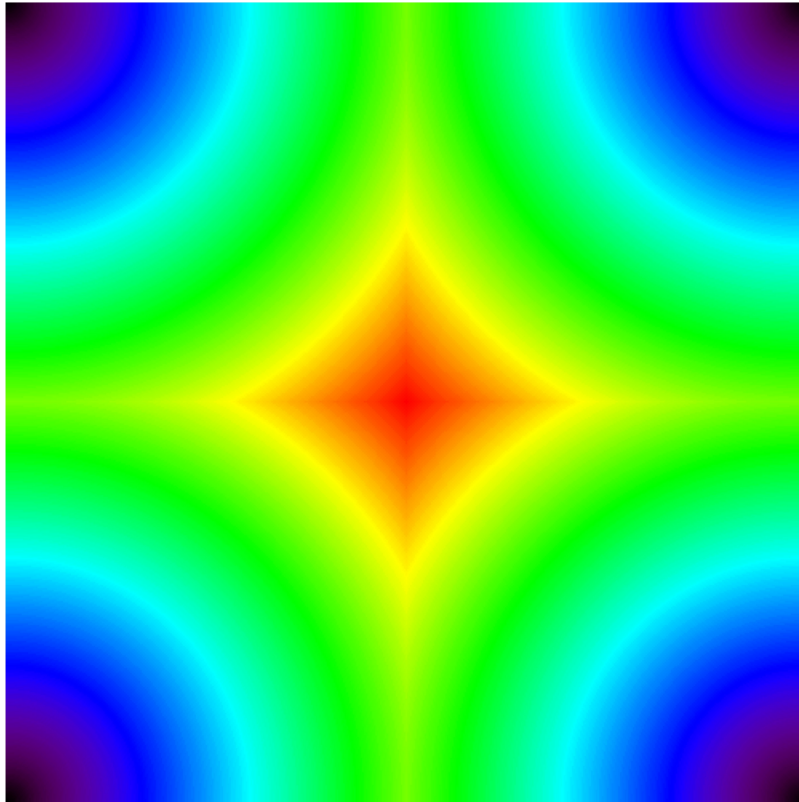
# Problems with standard colormaps

Their definition did not consider how colors are perceived by humans

- Create artifacts, suppressing some data structures, and creating false ones

They are usually limited to 256 values

- Remnant from the days of 8-bit colormapped displays.
- Low dynamic range saturates the ends of the range, or suppresses small variations.





# Limitations of standard colormaps

Rainbow colormaps are as evil as goto:

“Rainbow Color Map (Still) Considered Harmful” - Borland and Taylor, 2007  
IEEE Computer Graphics and Applications, vol. 27, no. 2:

*The goal is to make the rainbow color map as rare in visualization as the goto statement is in programming (...)*

“Go To Statement Considered Harmful” - Dijkstra, 1968  
Communications of the ACM, vol. 11, no. 3

Still very commonly used:

**Table 1. Statistics from the 2001 through 2005 IEEE Visualization Conference proceedings papers implementing pseudocoloring to display data and that use the rainbow color map.**

<b>Year</b>	<b>Relevant Papers Including Medical Images (%)</b>	<b>Relevant Papers Excluding Medical Images (%)</b>	<b>Number of Pages</b>
2001	47	62	8
2002	40	45	18
2003	52	71	32
2004	59	68	62
2005	52	59	61
Total	51	61	181

# Limitations of standard colormaps

Same 5 images, in a 3D surface, and 2 colormaps.

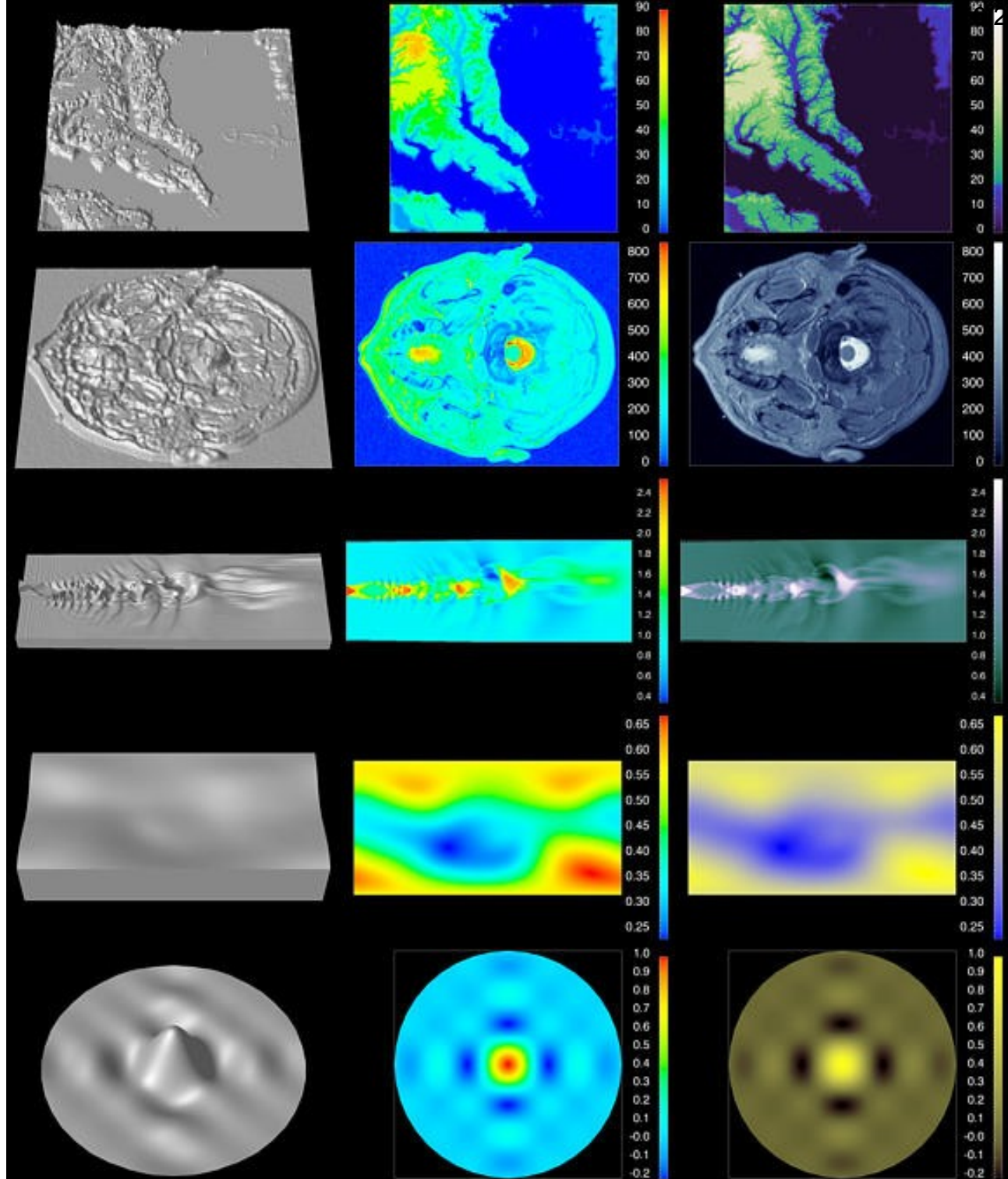
Rainbow creates false steps

Rainbow hides the high frequency structure.

From

Rogowitz and Treinish,

*Why Should Engineers and Scientists Be Worried About Color?*

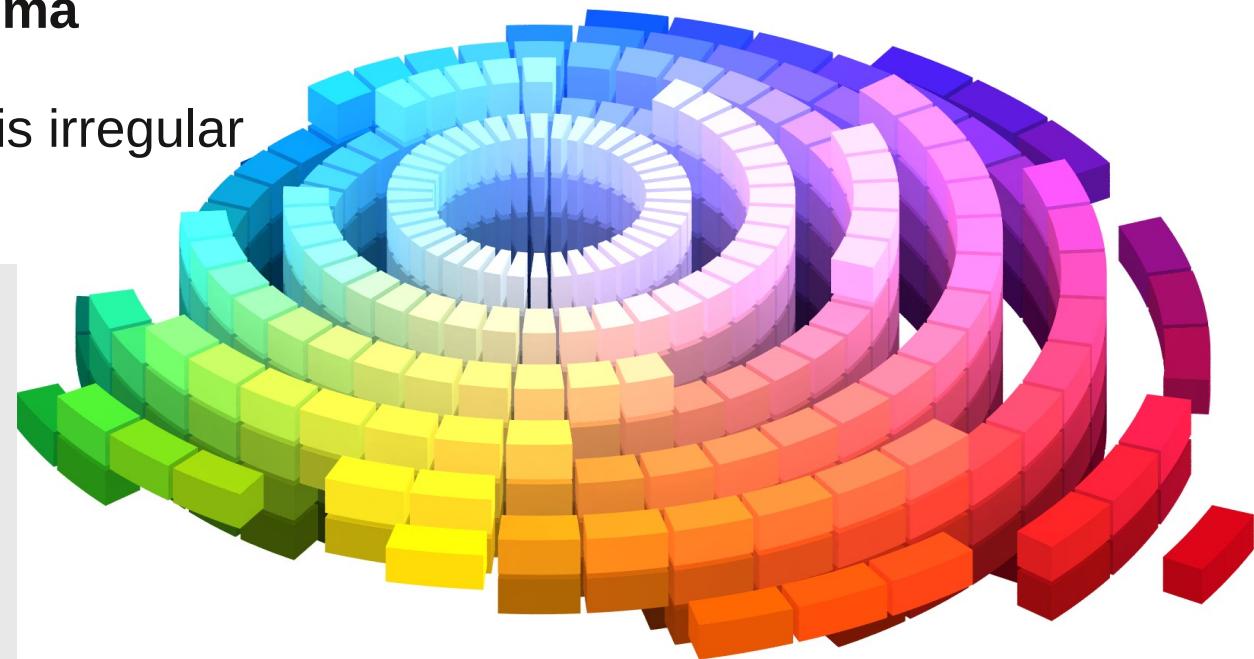
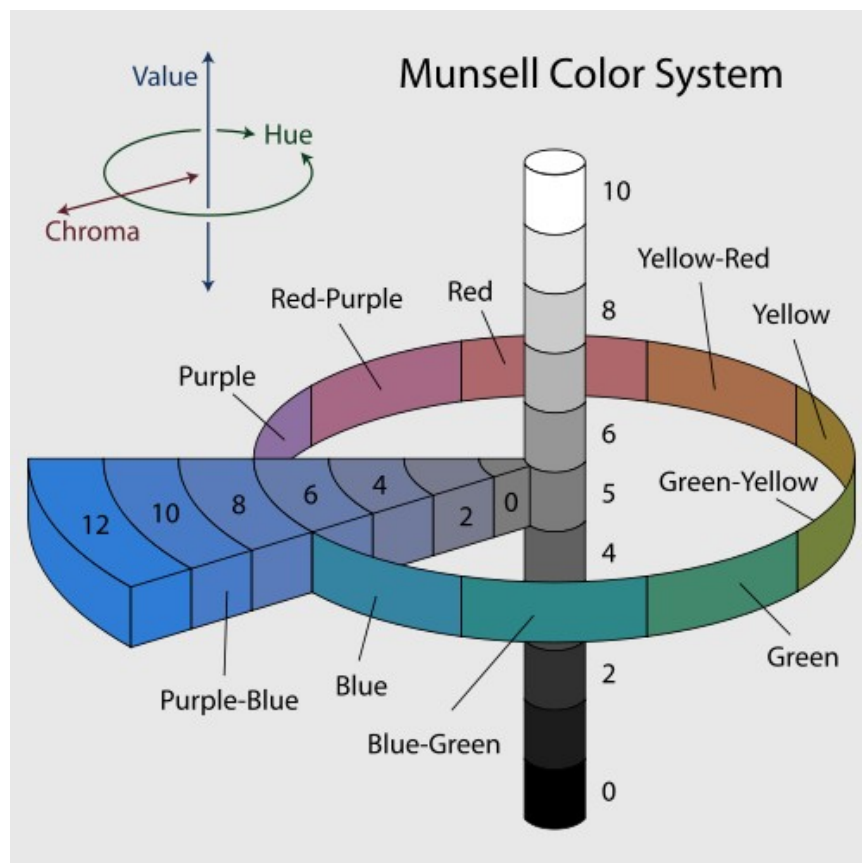


# Human color vision - Human color space

The brain does **not** get a 3-filter image from the eyes.

Munsell (~1900) : first perceptually uniform color catalog

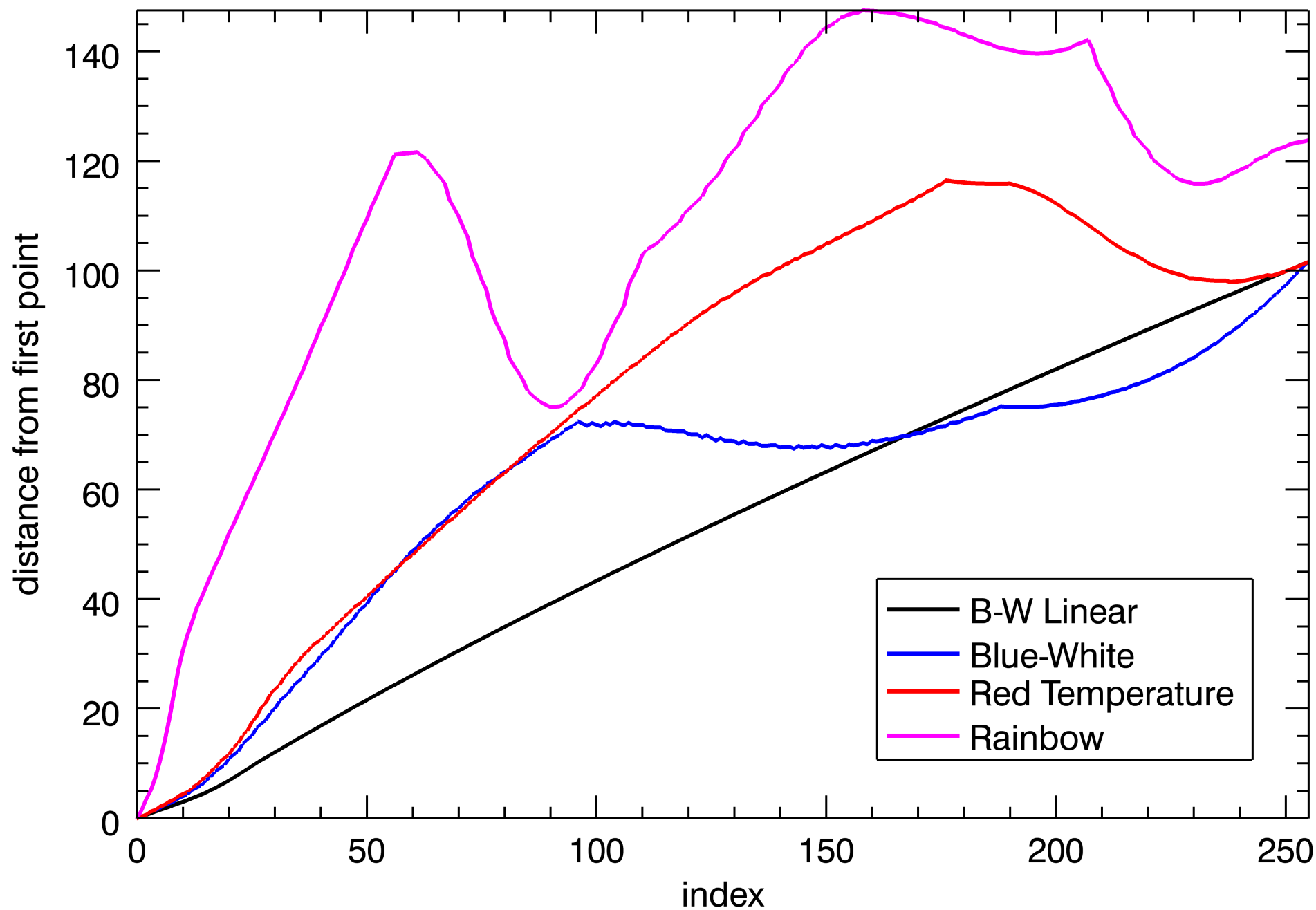
- Discrete color chips mapped into regular distances in its 3 independent dimensions: perceived **hue**, **value** and **chroma**
- Showed that the human gamut is irregular



CIE Lab and Luv (1976):

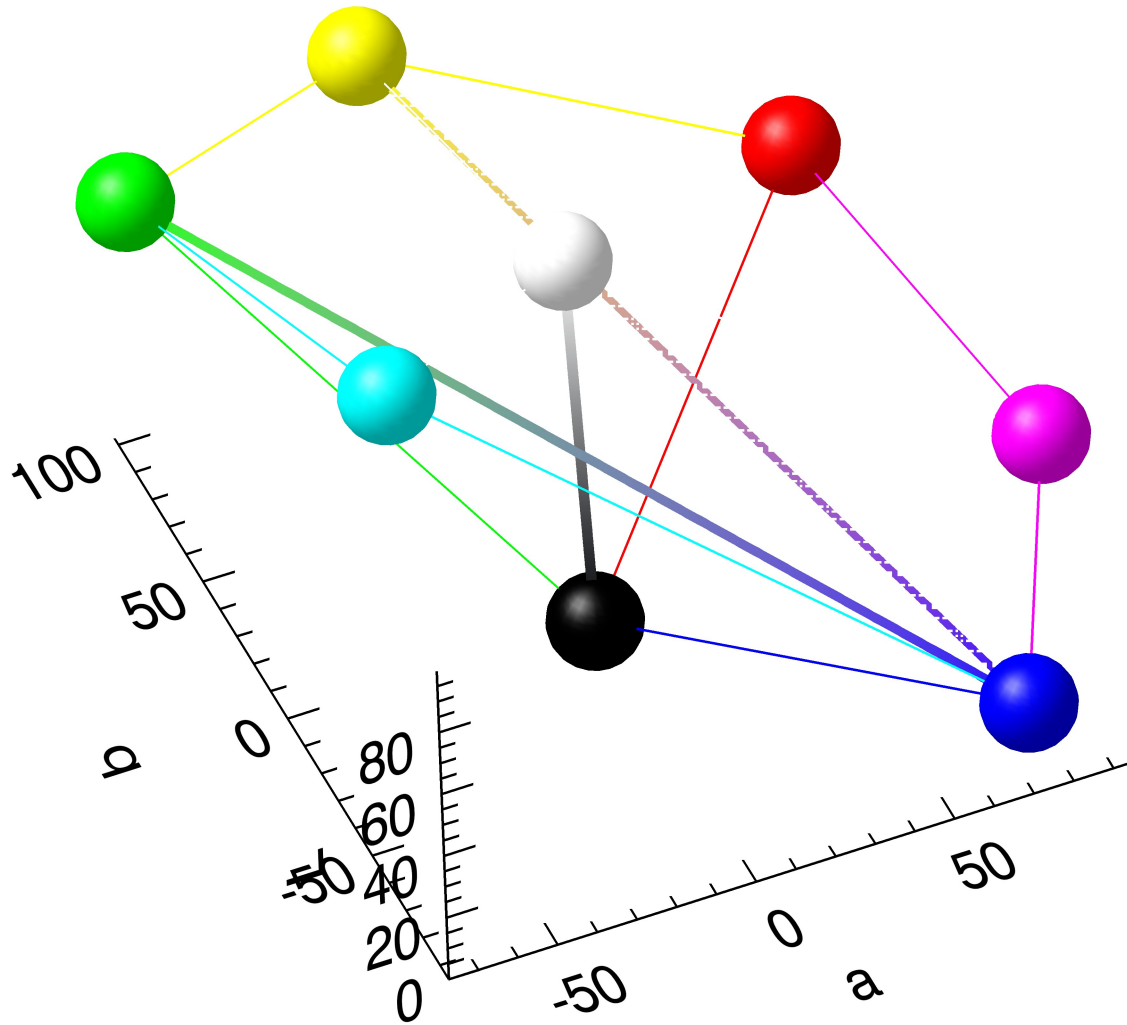
- Continuous mapping functions based on psychophysical measurements
- Cartesian distances in Lab/Luv correspond to perceptual distances

# Development of uniform colormaps - Distances from the map origin

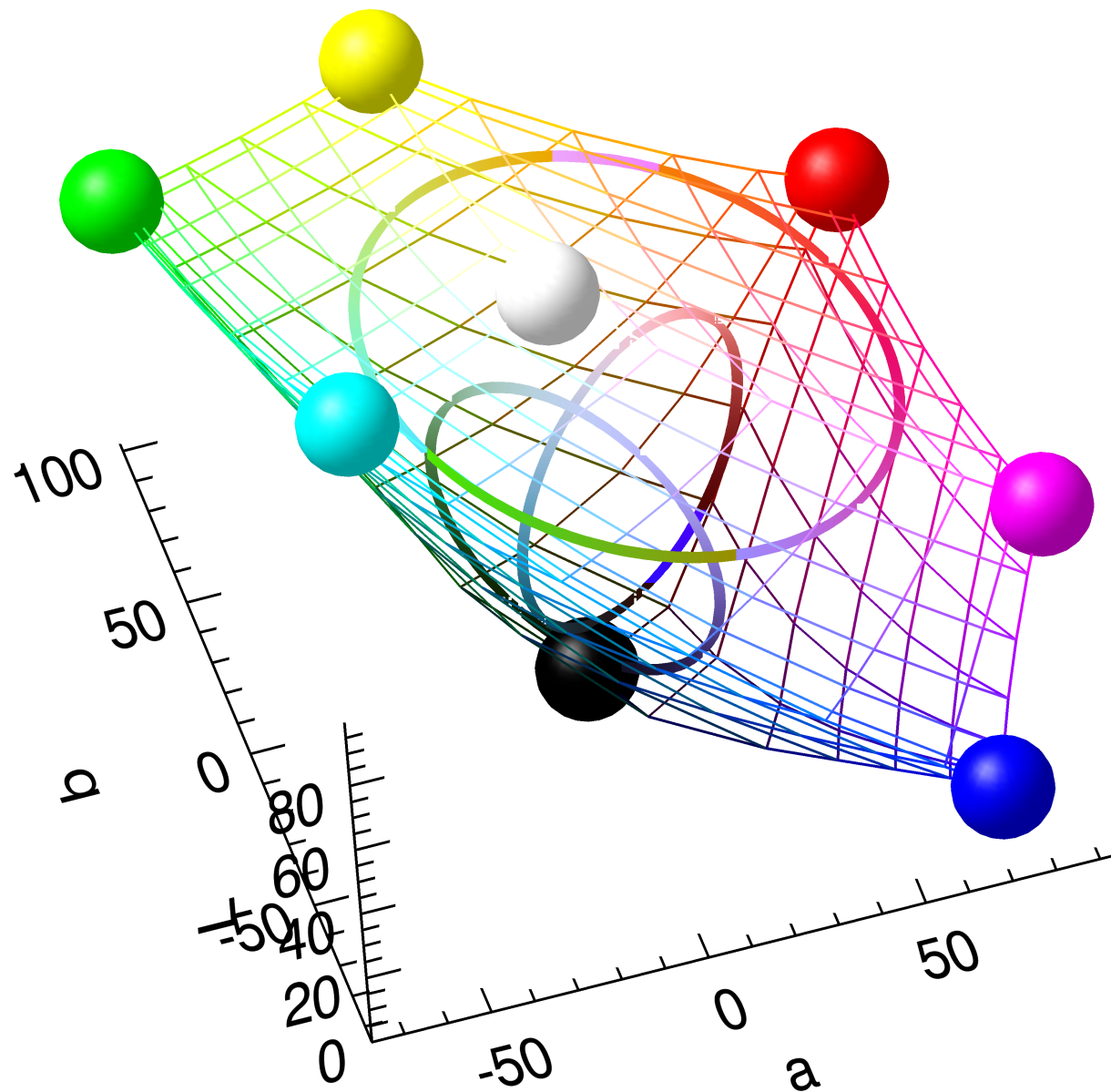




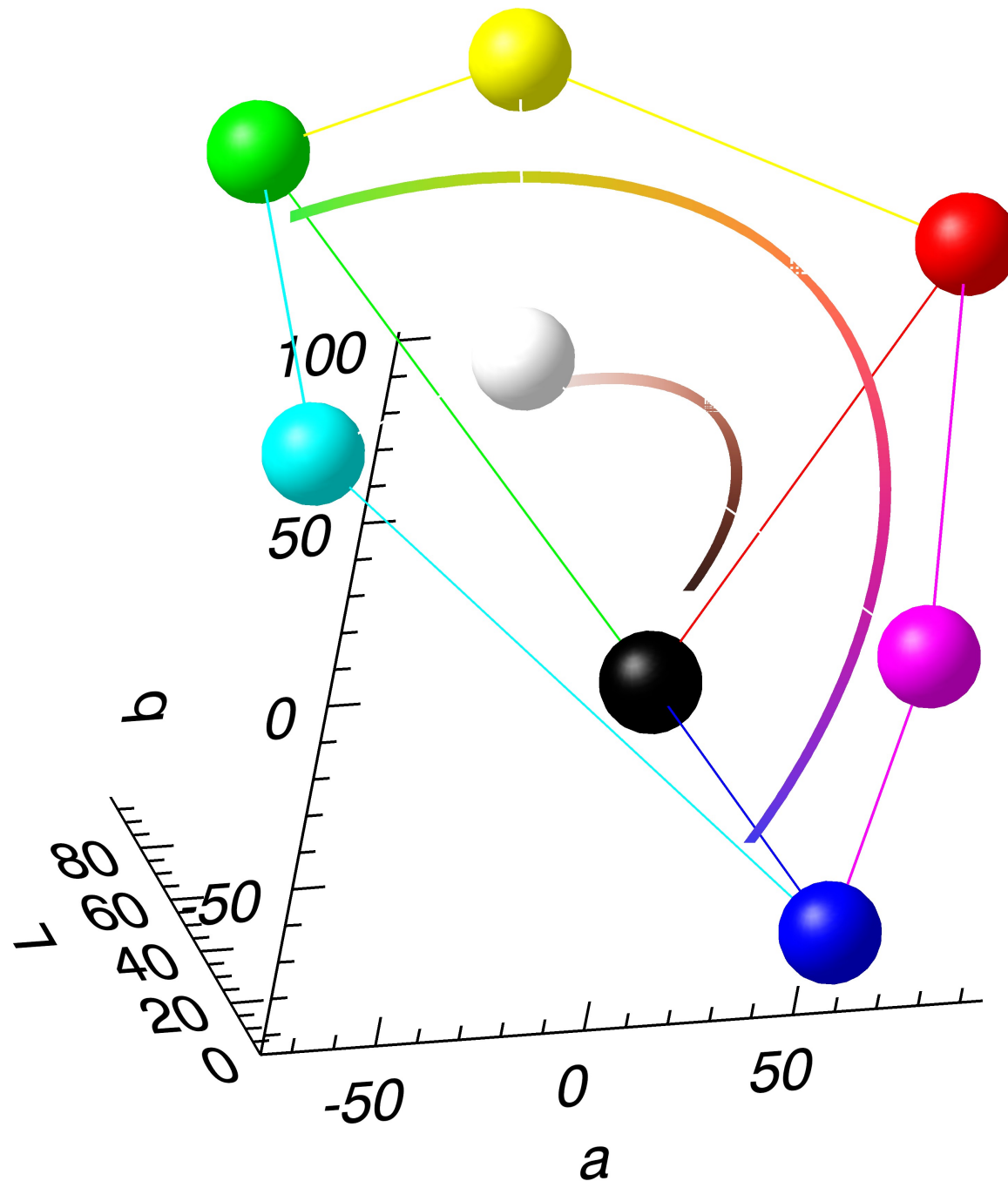
# Definition of maps from CIE Lab space - Fully uniform acyclic maps



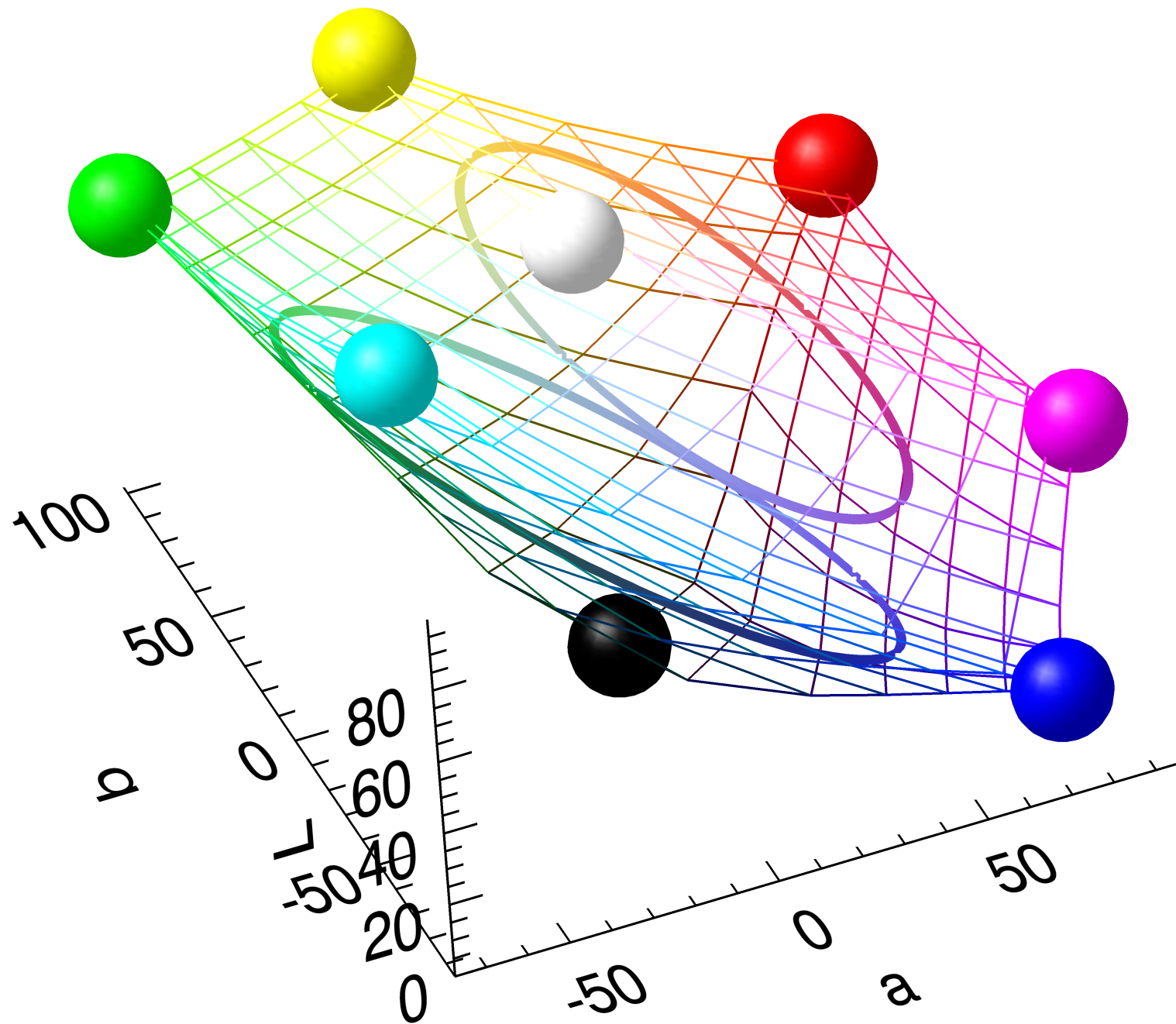
# Definition of maps from CIE Lab space - Fully uniform cyclic maps



# Definition of maps from CIE Lab space - Smooth acyclic maps



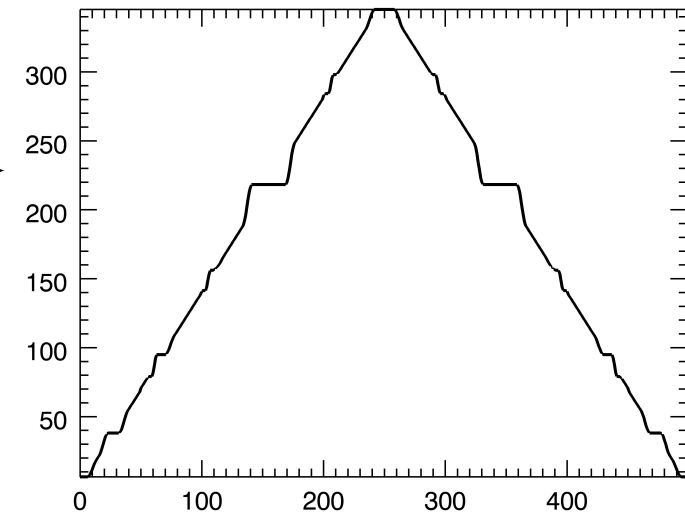
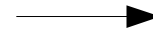
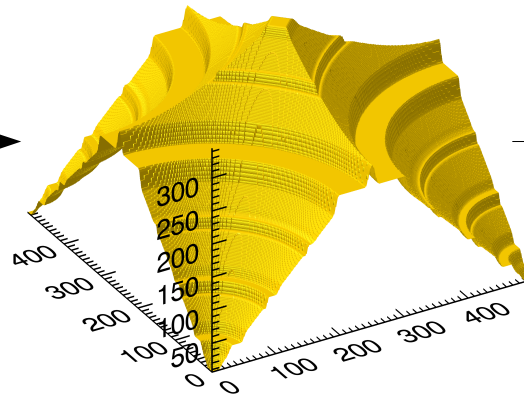
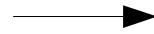
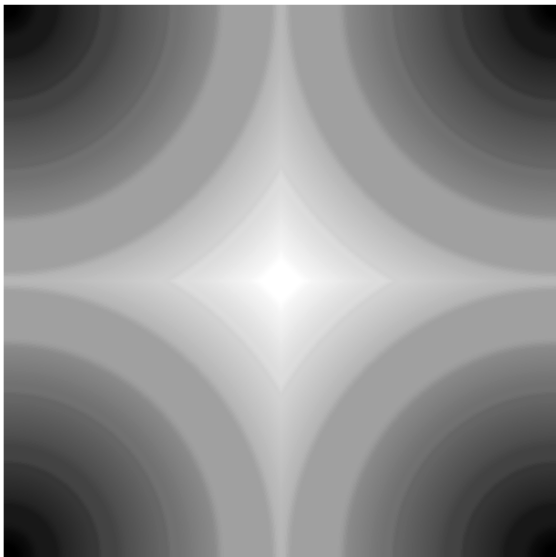
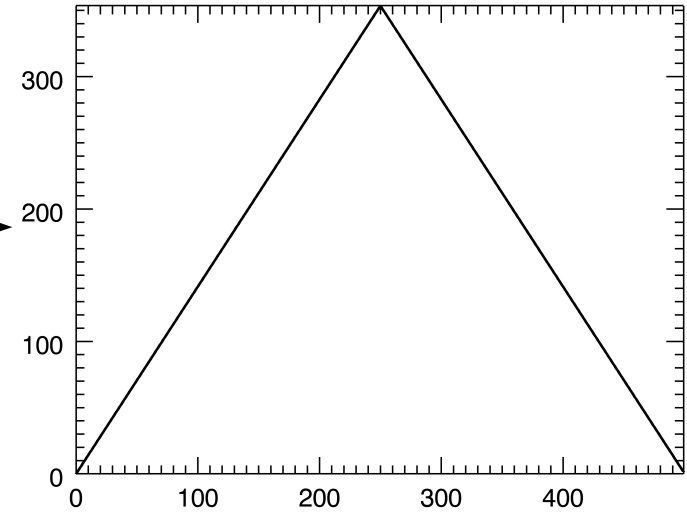
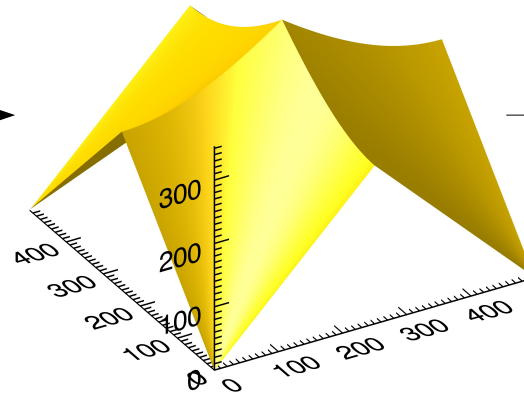
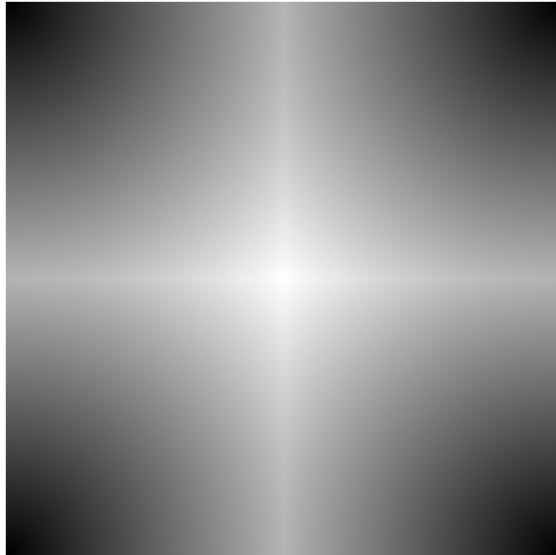
# Definition of maps from CIE Lab space - Smooth cyclic maps





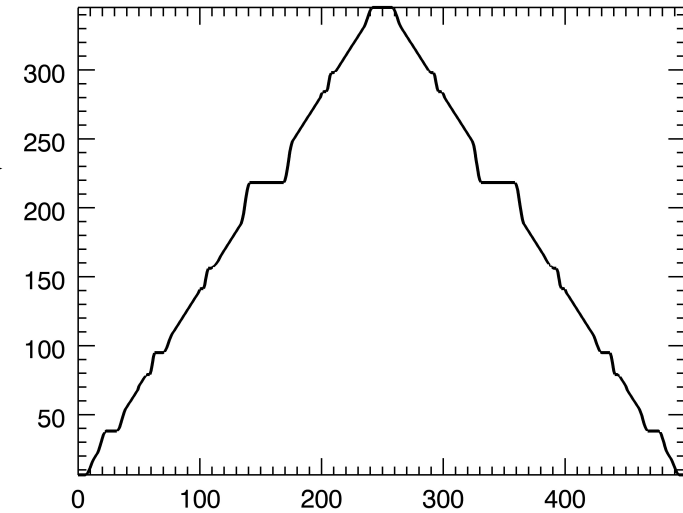
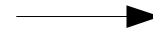
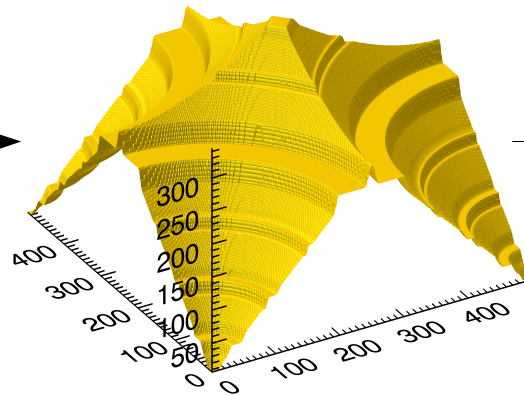
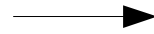
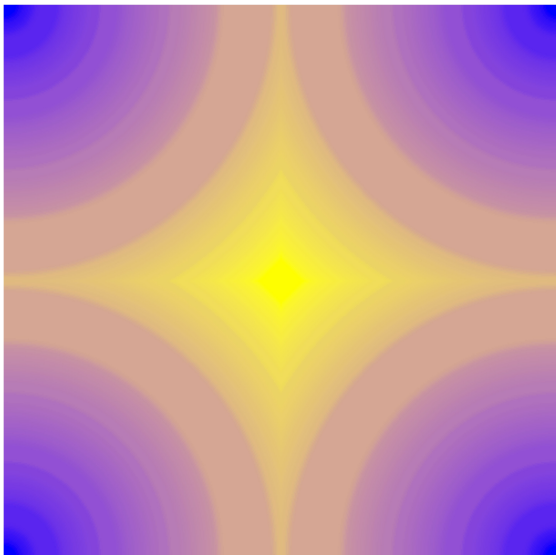
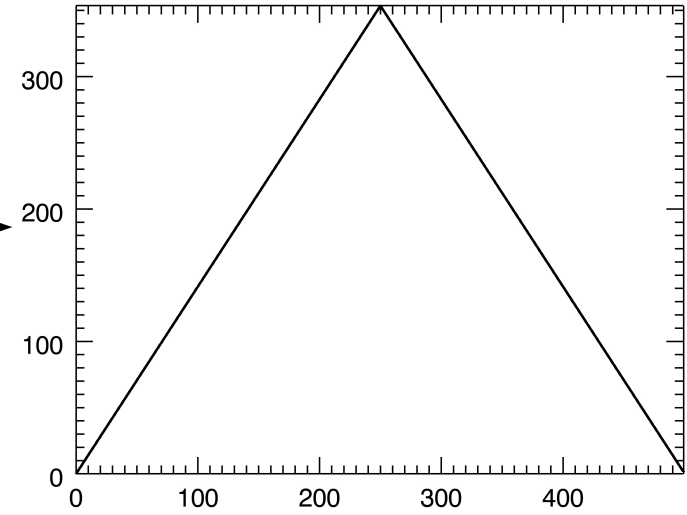
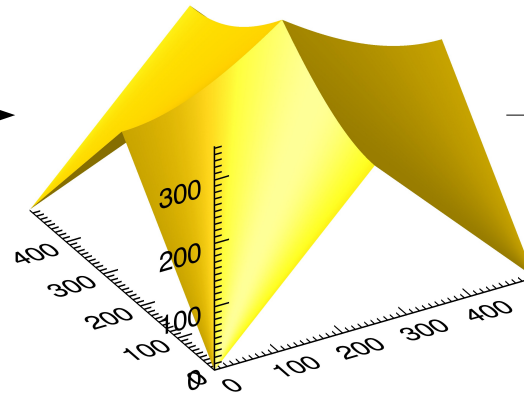
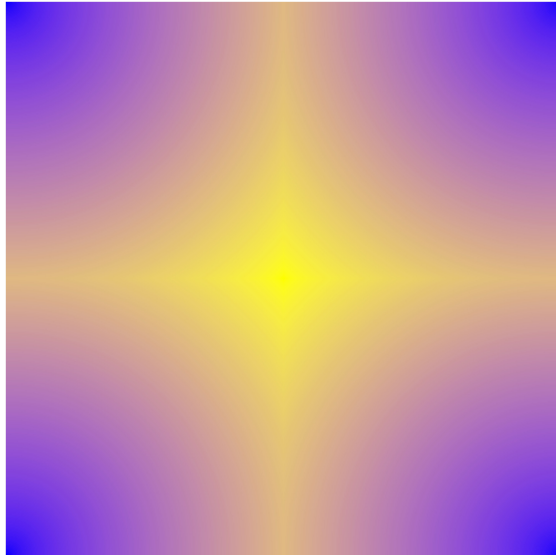
# Examples

## B-W Linear



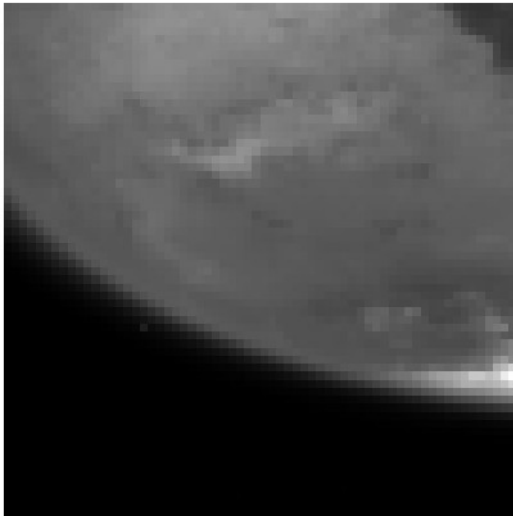
# Examples

## Blue-yellow uniform

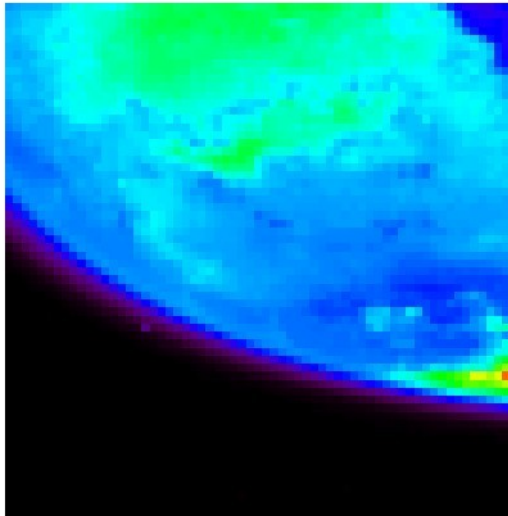


# Examples – Titan on several maps

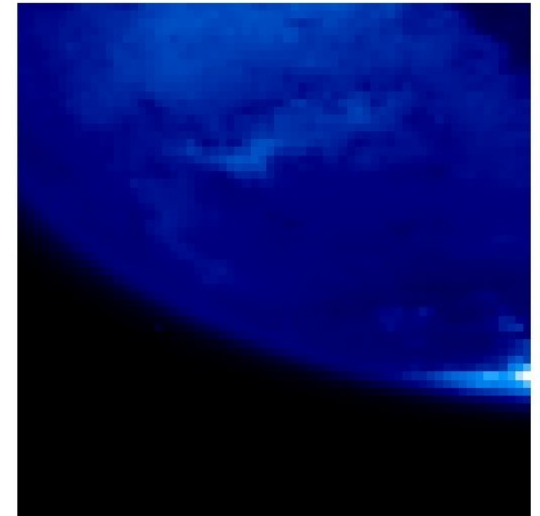
B-W linear



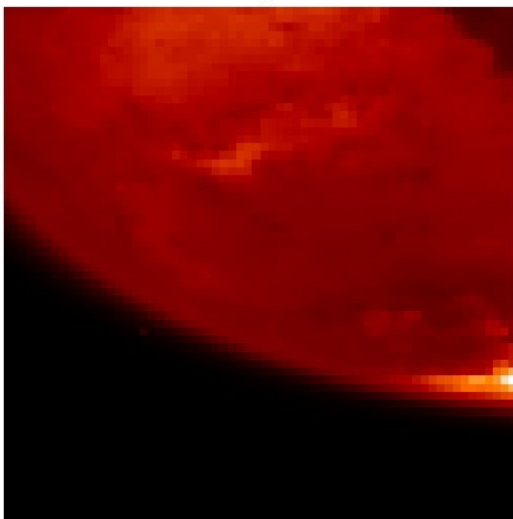
Rainbow



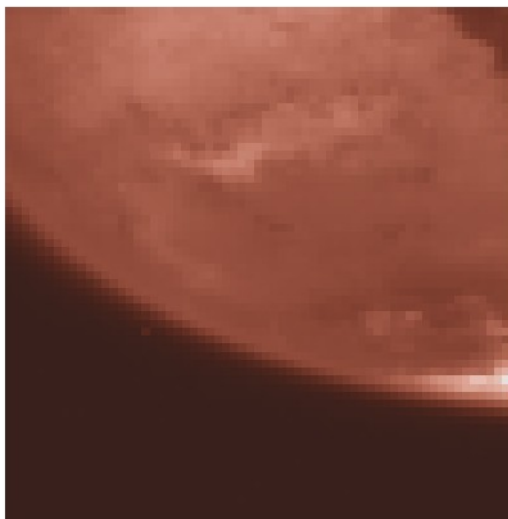
Blue/white



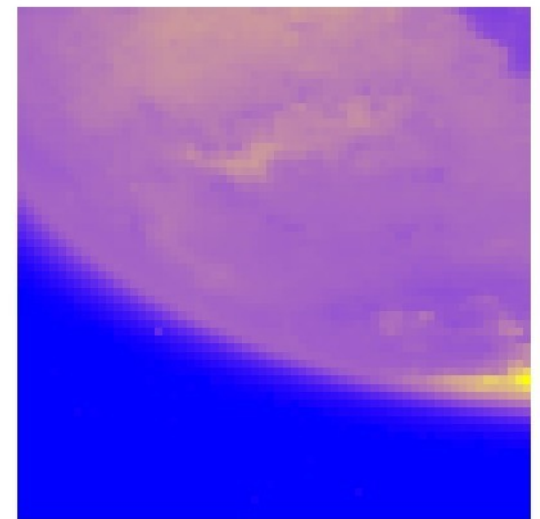
Red temperature



B-W nonuniform



B-Y uniform



(Cassini VIMS data retrieved from PDS through pp\_titanbrowse)

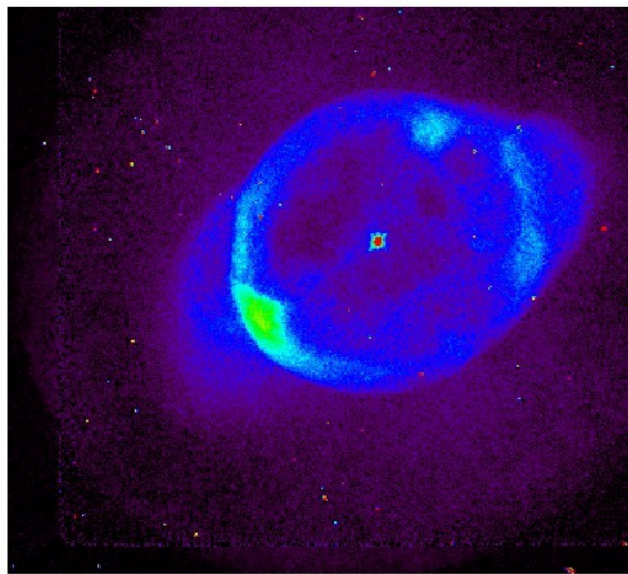


# Examples – NGC3242 (HST) on several maps

## B-W linear



## Rainbow



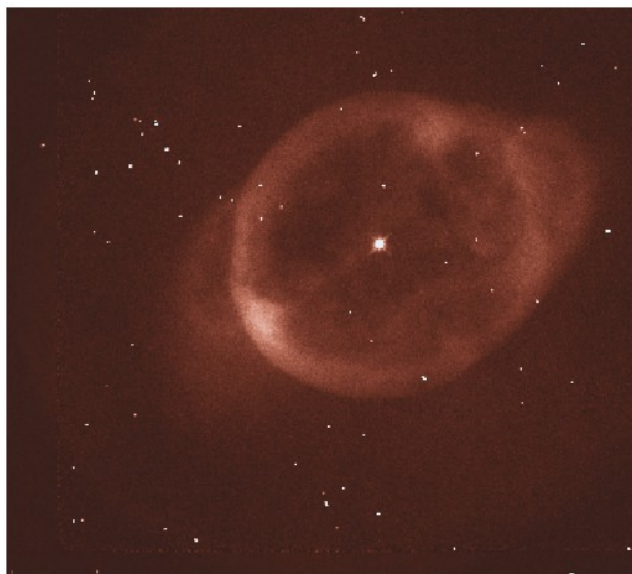
## Blue/White



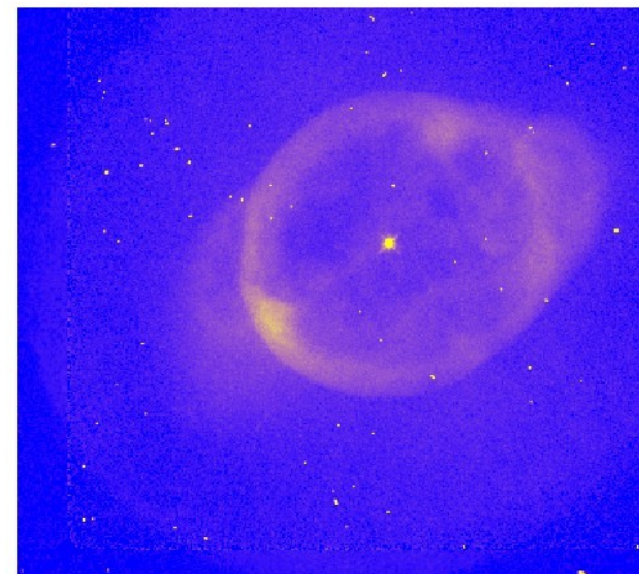
## Red temperature



## B-W nonuniform



## B-Y uniform



(HST data retrieved from MAST)

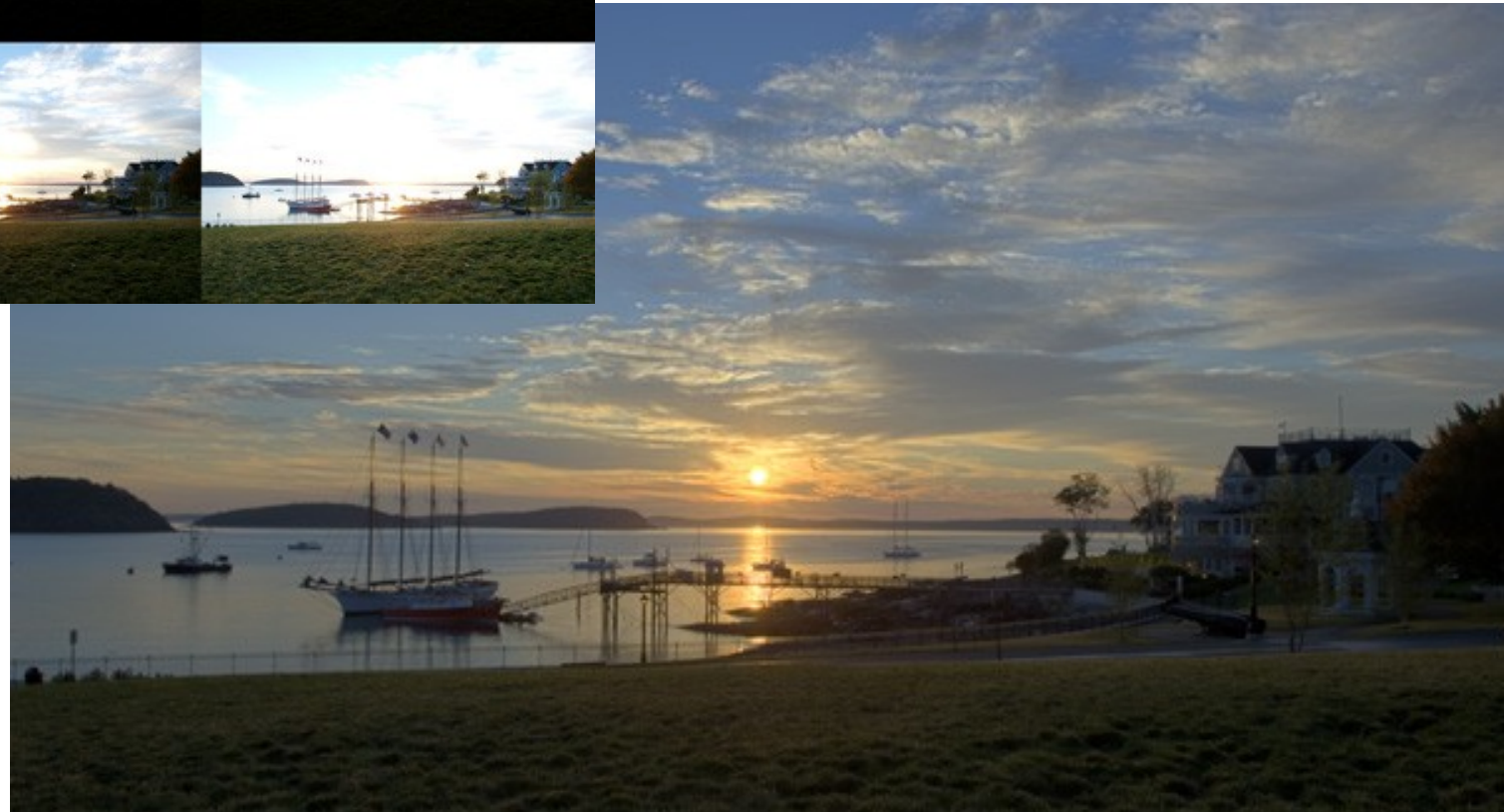
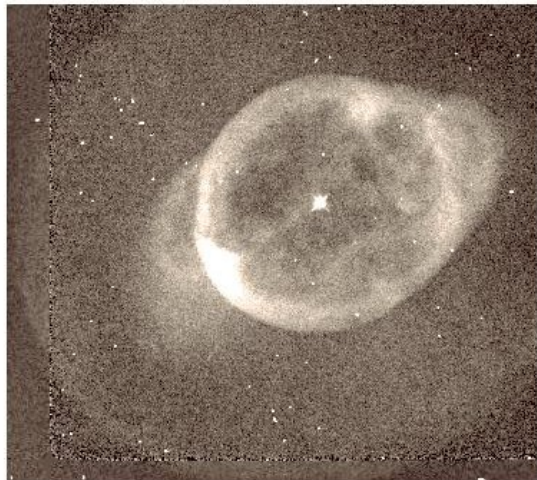


# Dynamic maps

Image Color Appearance Models (iCAMs) predict the perceived image appearance.  
Example: High Dynamic Range (HDR) rendering



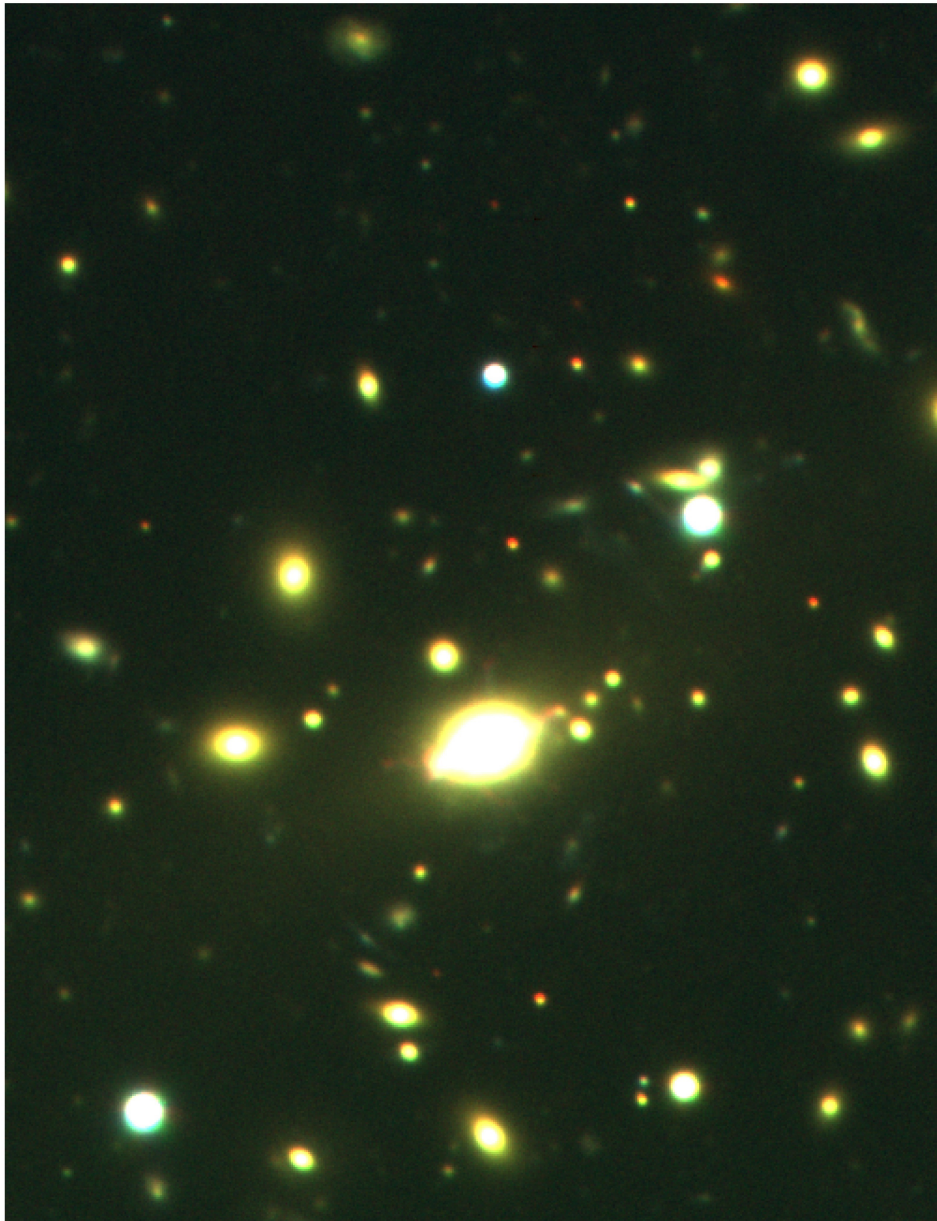
Mark Fairchild,  
The HDR Photographic Survey  
<http://www.cis.rit.edu/fairchild/HDR.html>



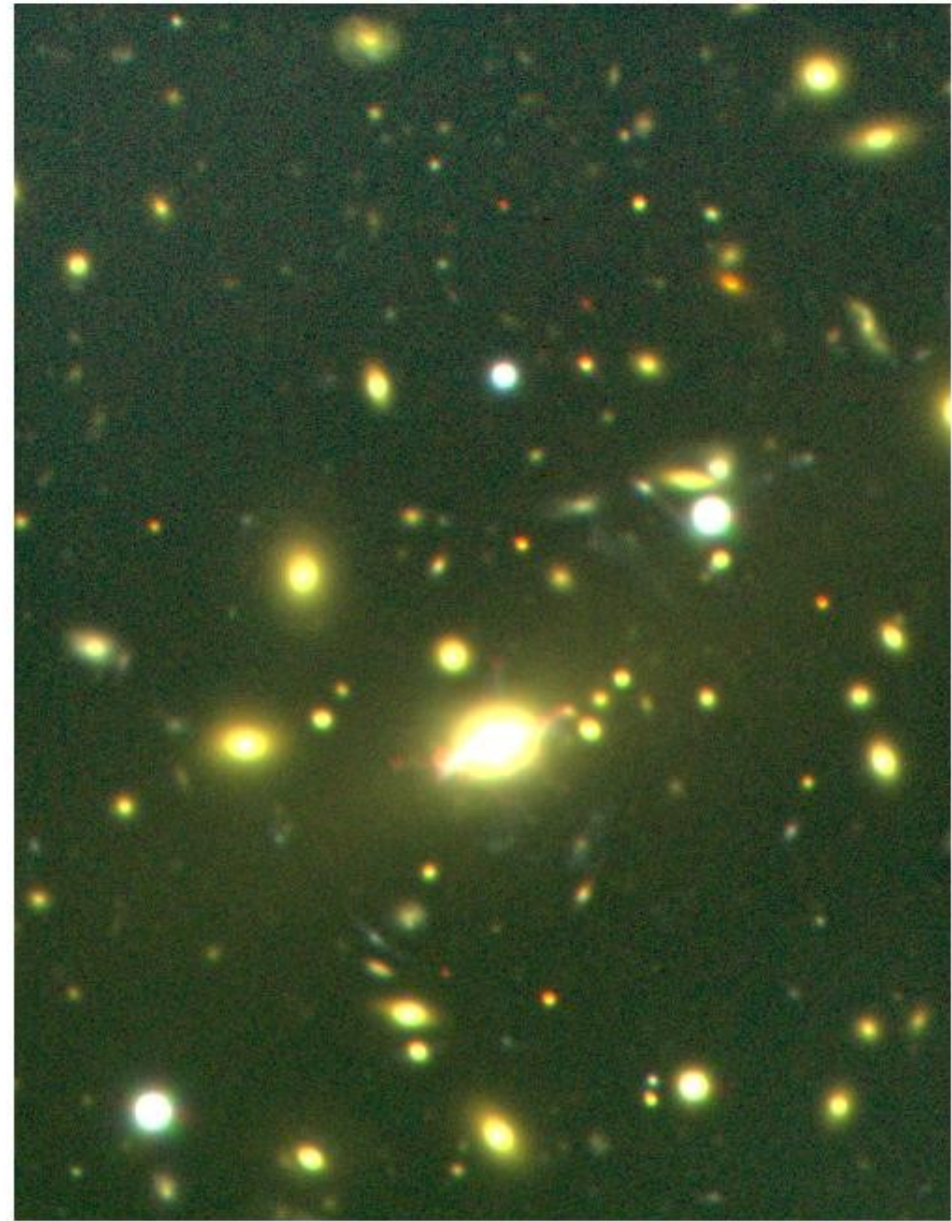


# Example: RXC J1504.1-0248 (Gemini) at G,R,I filters

Linear stretch (saturated)



HDR



(data provided by A.C. Soja)

# Summary

Standard colormaps found in common software tend to be too simple.

Rainbow maps are particularly inadequate.

CIE Lab space provides a framework to measure color differences and define maps.

This work defines maps in CIE Lab for:

- Low or high spatial frequencies.
- Cyclic or acyclic variables.
- Standard (8-bit) or wider dynamic range.
- Completely uniform, or (wider) smooth color variations.

Map definitions are still being experimented with:

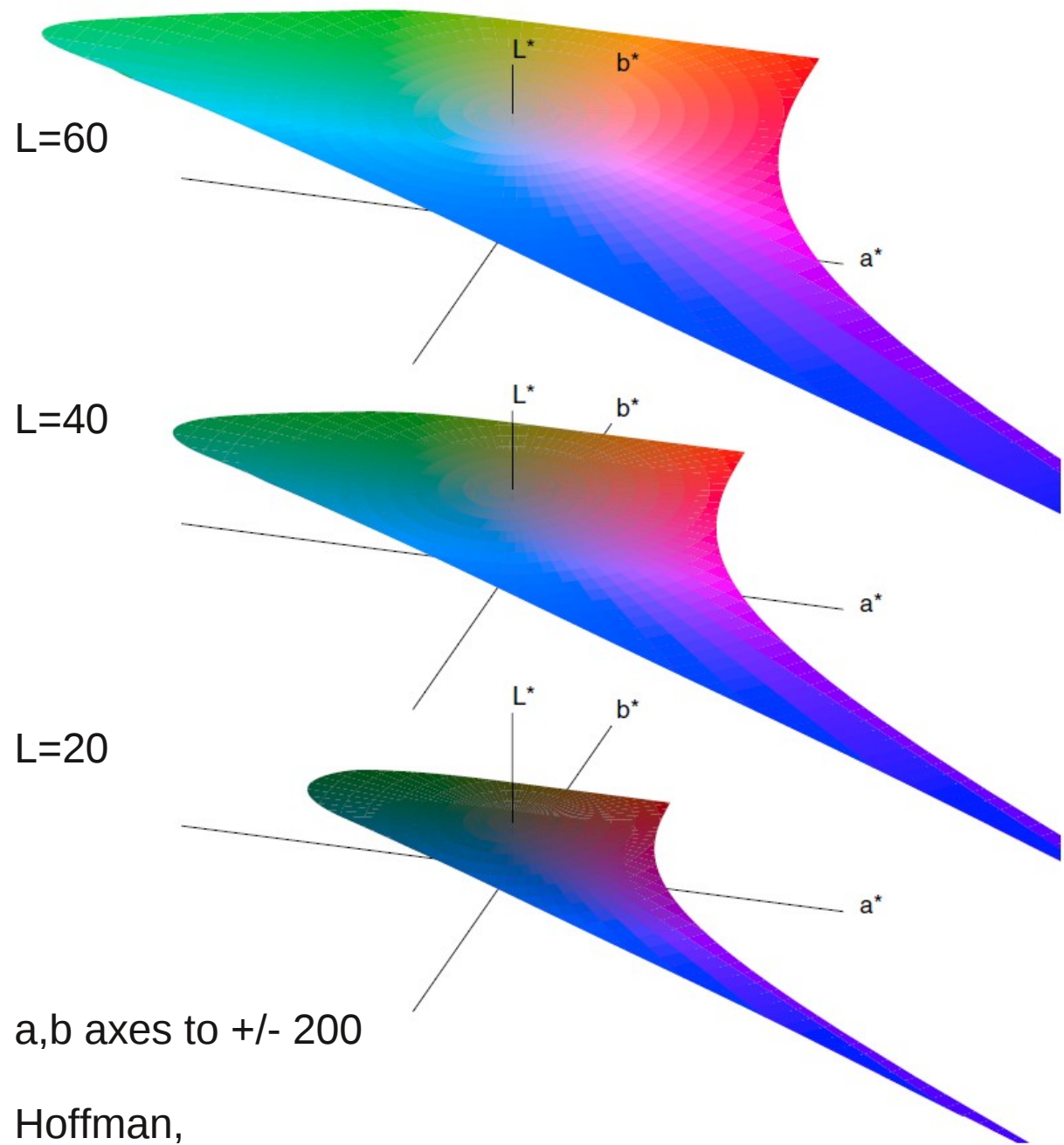
- other trajectories need to be tested (simultaneous hue/lightness variation)
- more work on their optimization (through CAMs) is needed.

[http://www.ppenteado.net/ast/pfp\\_sab2011.pdf](http://www.ppenteado.net/ast/pfp_sab2011.pdf)  
[pp.penteado@gmail.com](mailto:pp.penteado@gmail.com)

Work supported by Fapesp (postdoc grant)



# Human gamut in CIE Lab



a,b axes to +/- 200

Hoffman,  
<http://www.fho-emden.de/~hoffmann/cielab03022003.pdf>

# sRGB gamut in CIE Lab

