Solar image color tables and their perception

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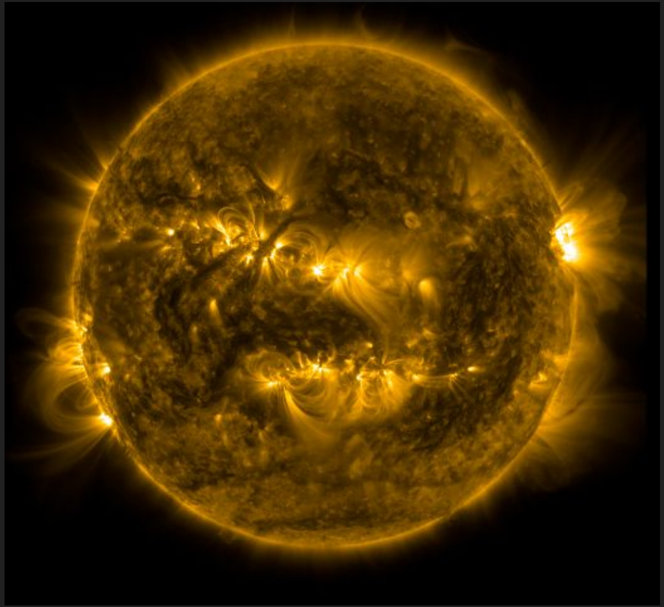
borrowing heavily from the matplotlib colormap pages

Scaling an image so it looks “good”: SSWIDL

Typically a version of the original data is plotted.

1. Clip data to some range: $c = C(x)$
2. Rescale: $y = R(c)$
3. Display using y and color table (colormap).



Scaling an image so it looks “good”: Matplotlib / Astropy / Sunpy

Original data does not have to be changed.

Colors in displayed images of data are defined by a ***mapping*** from the original data to colormap indices.

1. Normalize to range [0,1] (can involve clipping): $y = N(x)$
2. Rescale in range [0,1]: $z = f(y)$
3. Mapping $x \rightarrow f(N(x))$ relates data values to a colormap index.
4. Display x using mapping $x \rightarrow f(N(x))$ and colormap.

Types of color maps

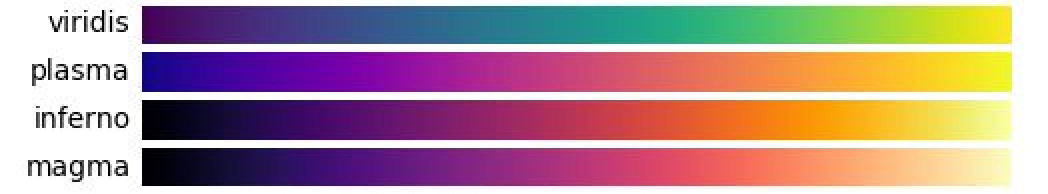
1. **Sequential**
    - change in lightness and often saturation of color incrementally, often using a single hue; should be used for representing information that has ordering, e.g. intensity

2. **Diverging**
    - change in lightness and possibly saturation of two different colors that meet in the middle at an unsaturated color; should be used when the information being plotted has a critical middle value, such as topography or when the data deviates around zero, e.g. magnetogram, Doppler velocity.

3. **Qualitative**
    - often are miscellaneous colors; should be used to represent information which does not have ordering or relationships, e.g. maps of different solar features.

Perceptually uniform color maps

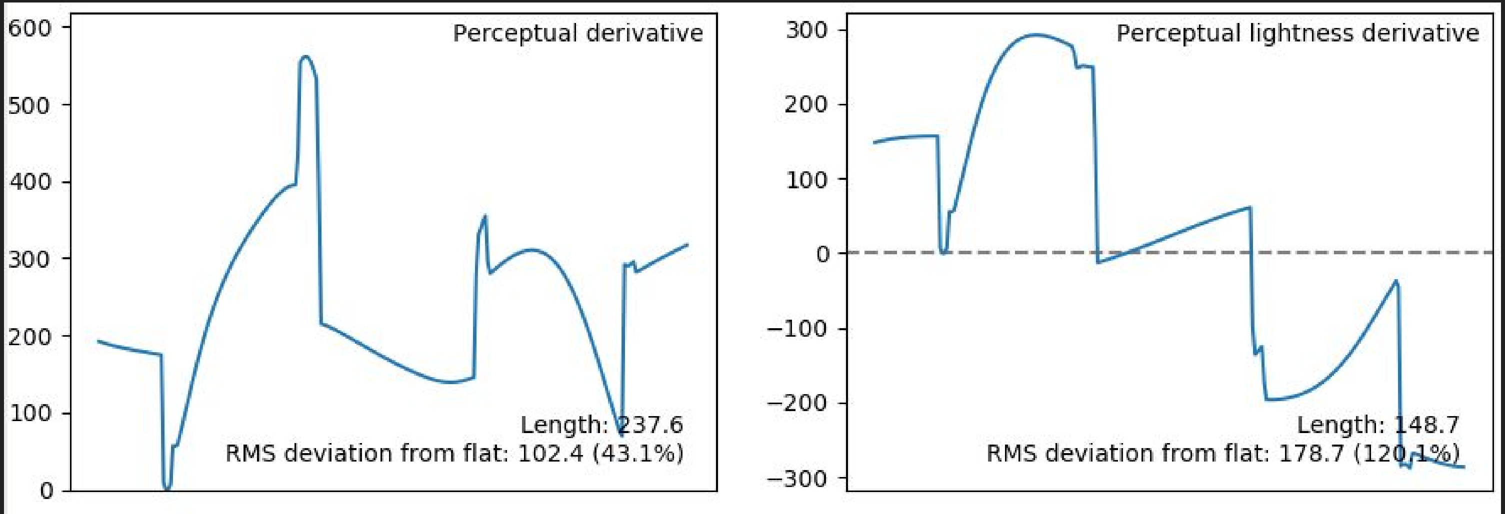
A perceptually uniform colormap has the property that if your data goes from 0.1 to 0.2, this should create about the same *perceptual change* as if your data goes from 0.8 to 0.9.



Matplotlib uses the CAM02-UCS model of perceptual distance.

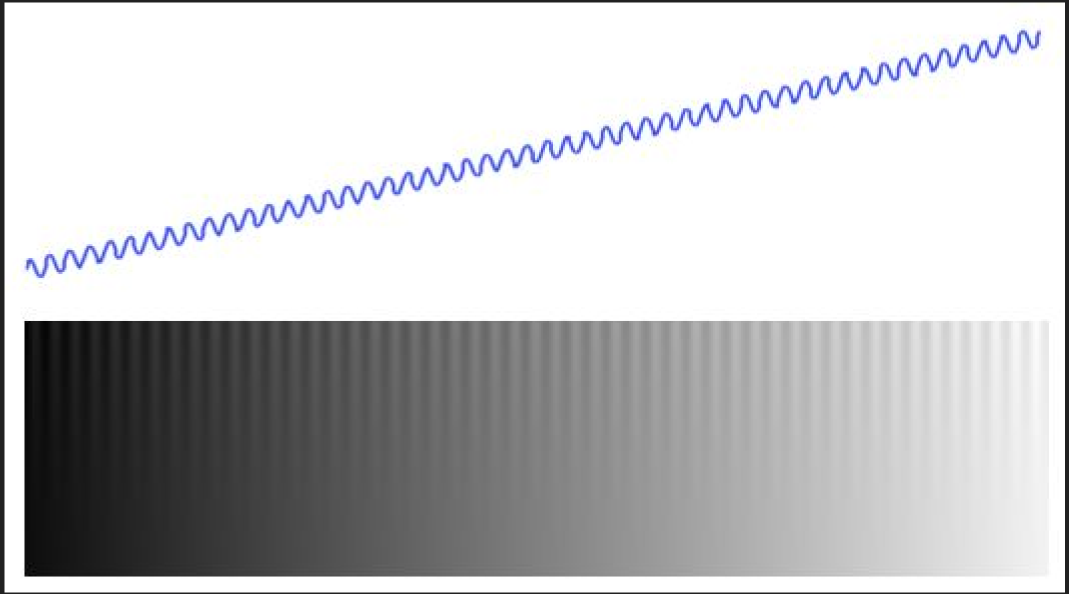
Perceptual deltas

A "perceptually uniform" colormap is one for which the "perceptual deltas" plot makes a simple horizontal line. This is essentially the derivative of the colormap in perceptual space with respect to the data.



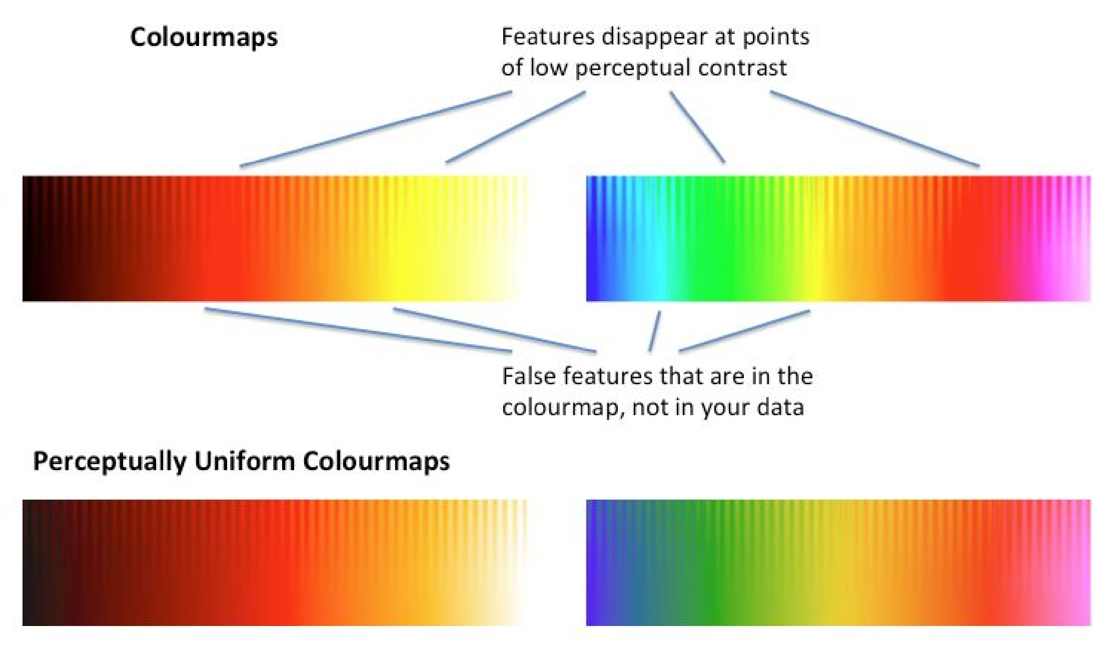
Test image: sine wave plus ramp

The test image consists of a sine wave superimposed on a ramp function. The sine wave amplitude is set so that the range from peak to trough represents a series of features that are 10% of the total data range. The amplitude of the sine wave is modulated from its full value at the top of the image to 0 at the bottom. Here the image is displayed using a linear grey colour map.



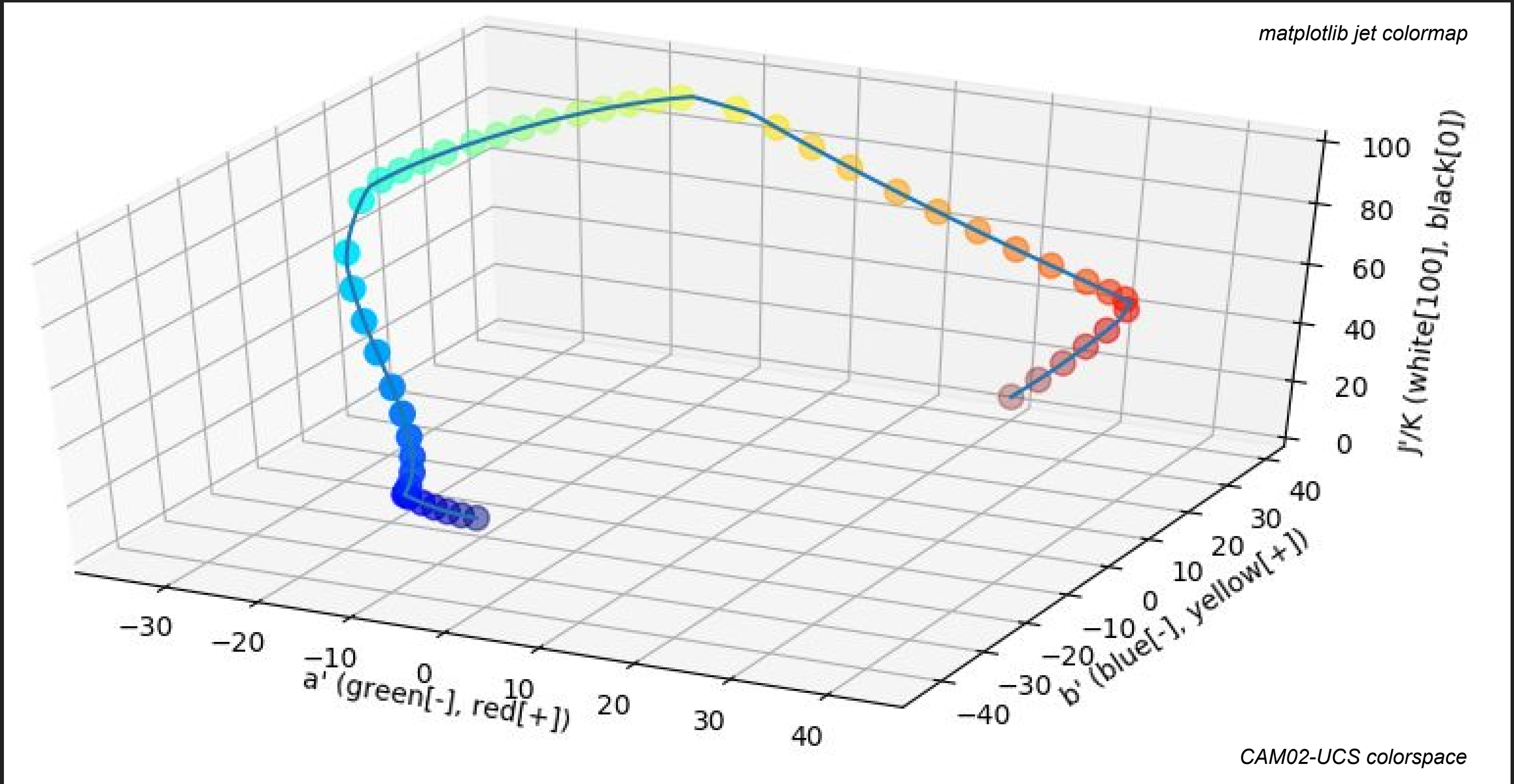
http://peterkovesi.com/projects/colourmaps/
http://peterkovesi.com/projects/colourmaps/colourmaptestimage.html

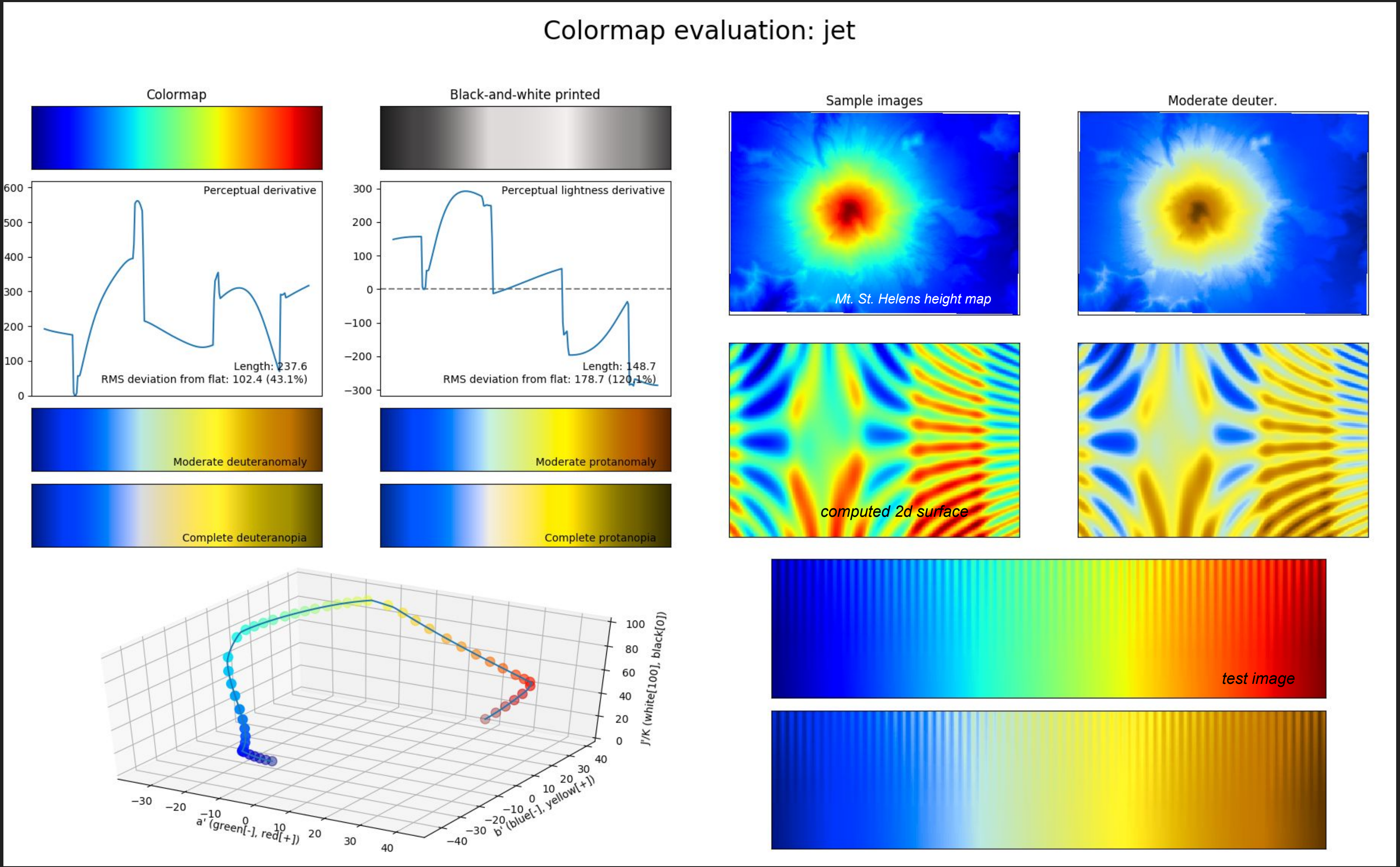
Test image with colormaps



http://peterkovesi.com/projects/colourmaps/
http://peterkovesi.com/projects/colourmaps/colourmaptestimage.html

Colormap in the color space

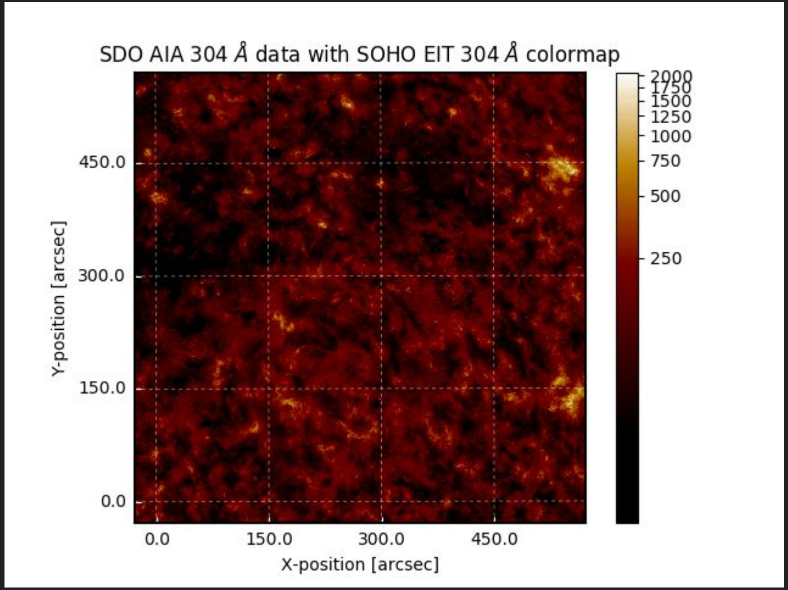




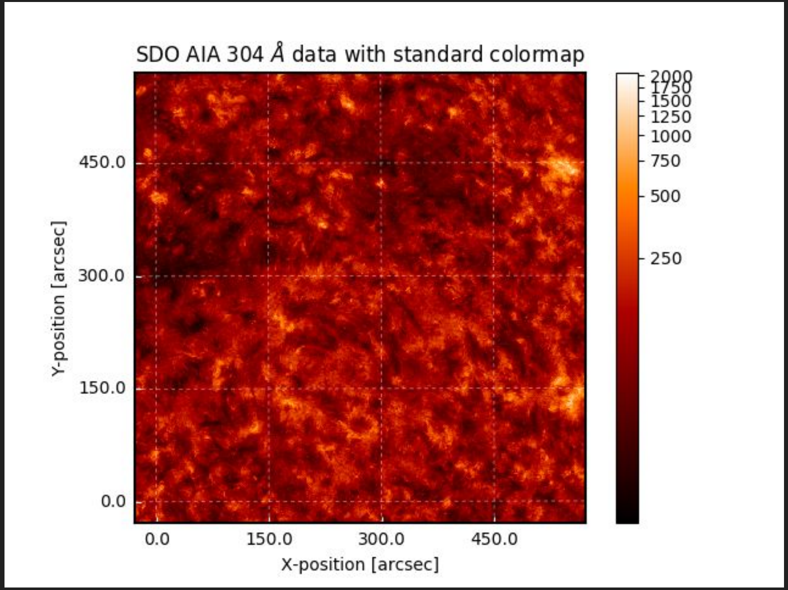
Colormap evaluation: jet
Colormap
Black-and-white printed
Sample images
Moderate deuter.
Perceptual derivative
Length: 237.6
RMS deviation from flat: 102.4 (43.1%)
Perceptual lightness derivative
Length: 148.7
RMS deviation from flat: 178.7 (120.1%)
Mt. St. Helens height map
computed 2d surface
Moderate deuteranomaly
Moderate protanomaly
Complete deuteranopia
Complete protanopia
test image
a' (green[-], red[+])
b' (blue[-], yellow[+])
J'/K (white[100], black[0])

Same data, image scaling, different color table

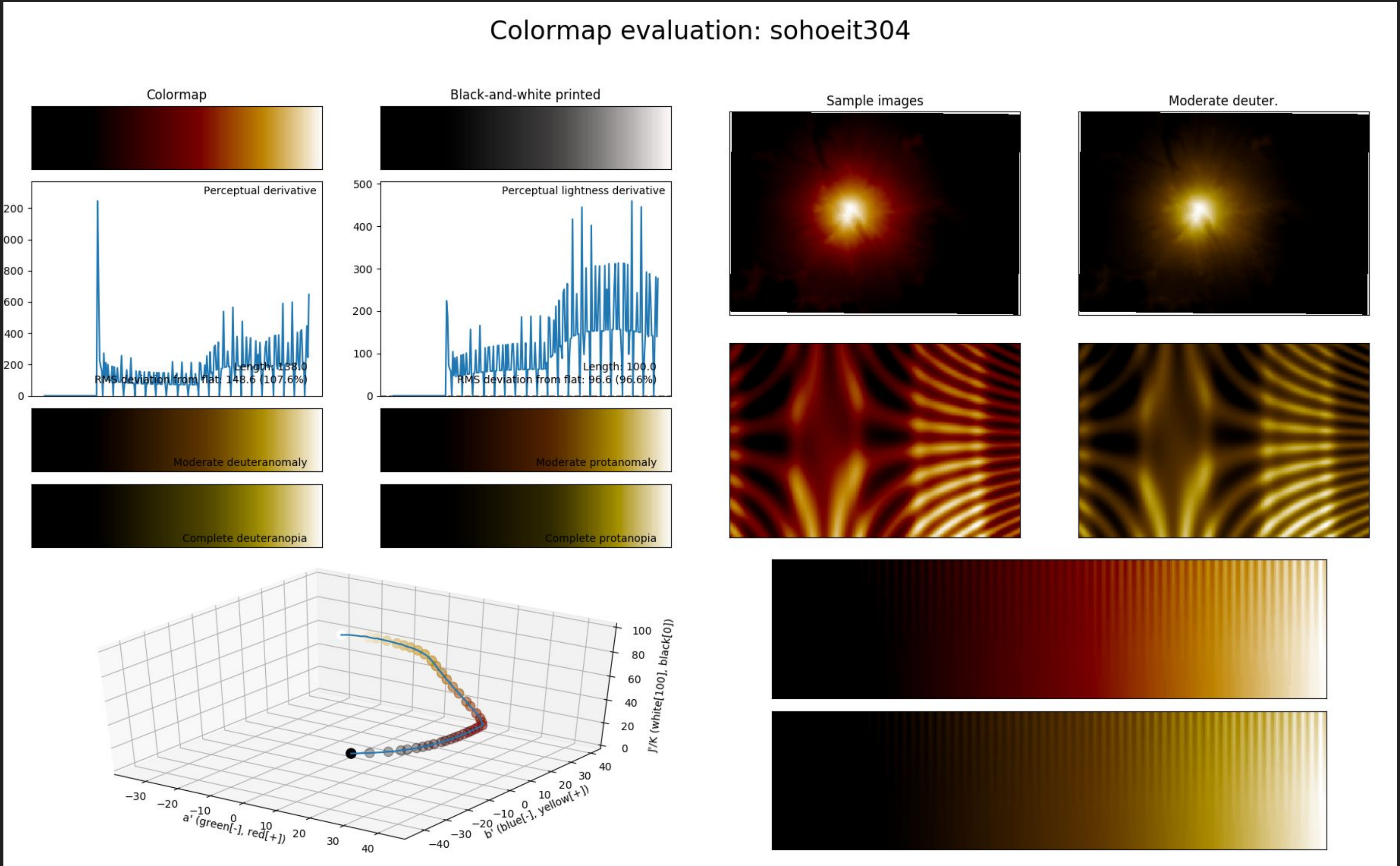
Stark demarcation between light and dark features



Smooth gradation between features is accentuated

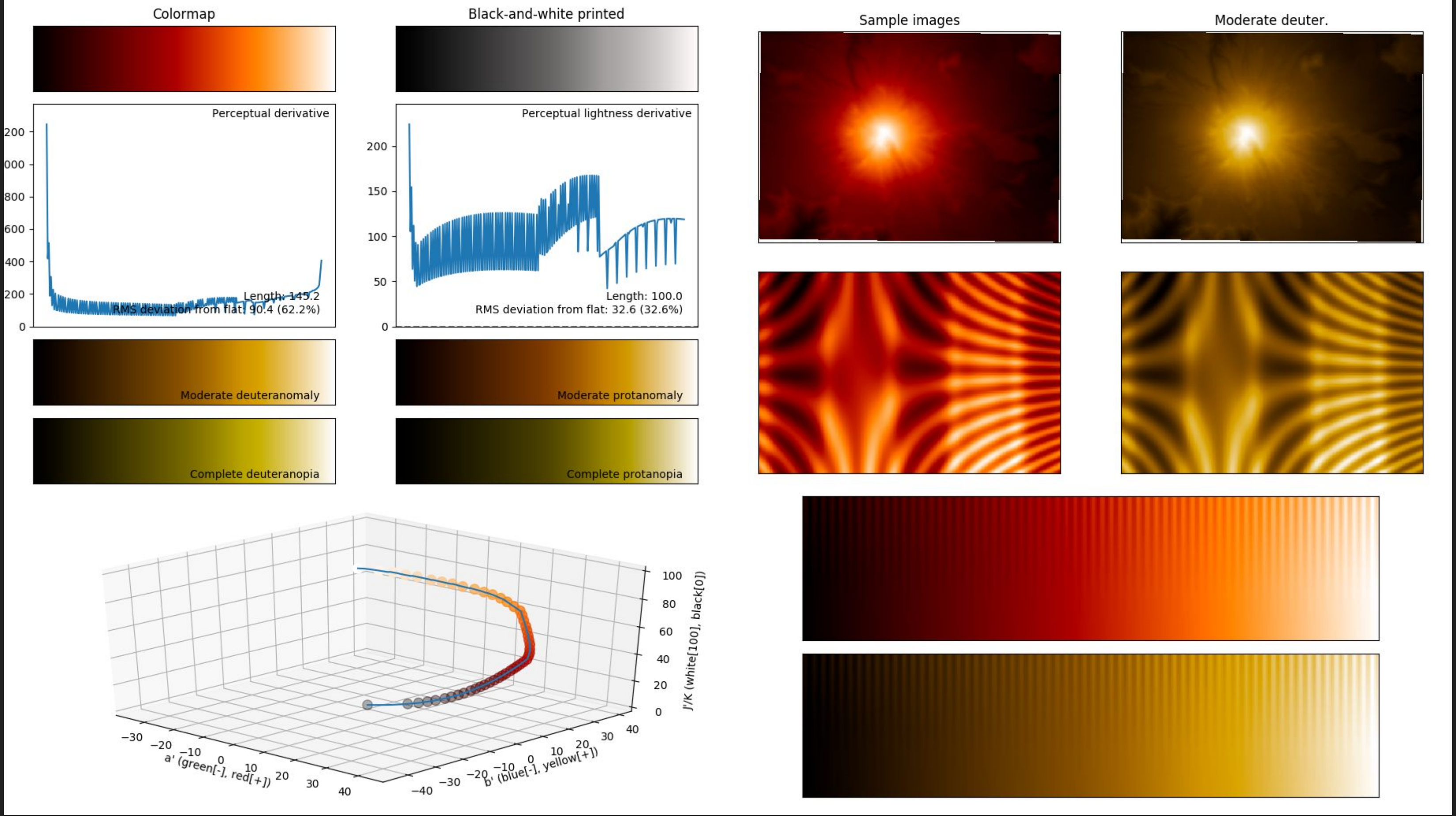


Identical AIA 304 image from July 26, 2010

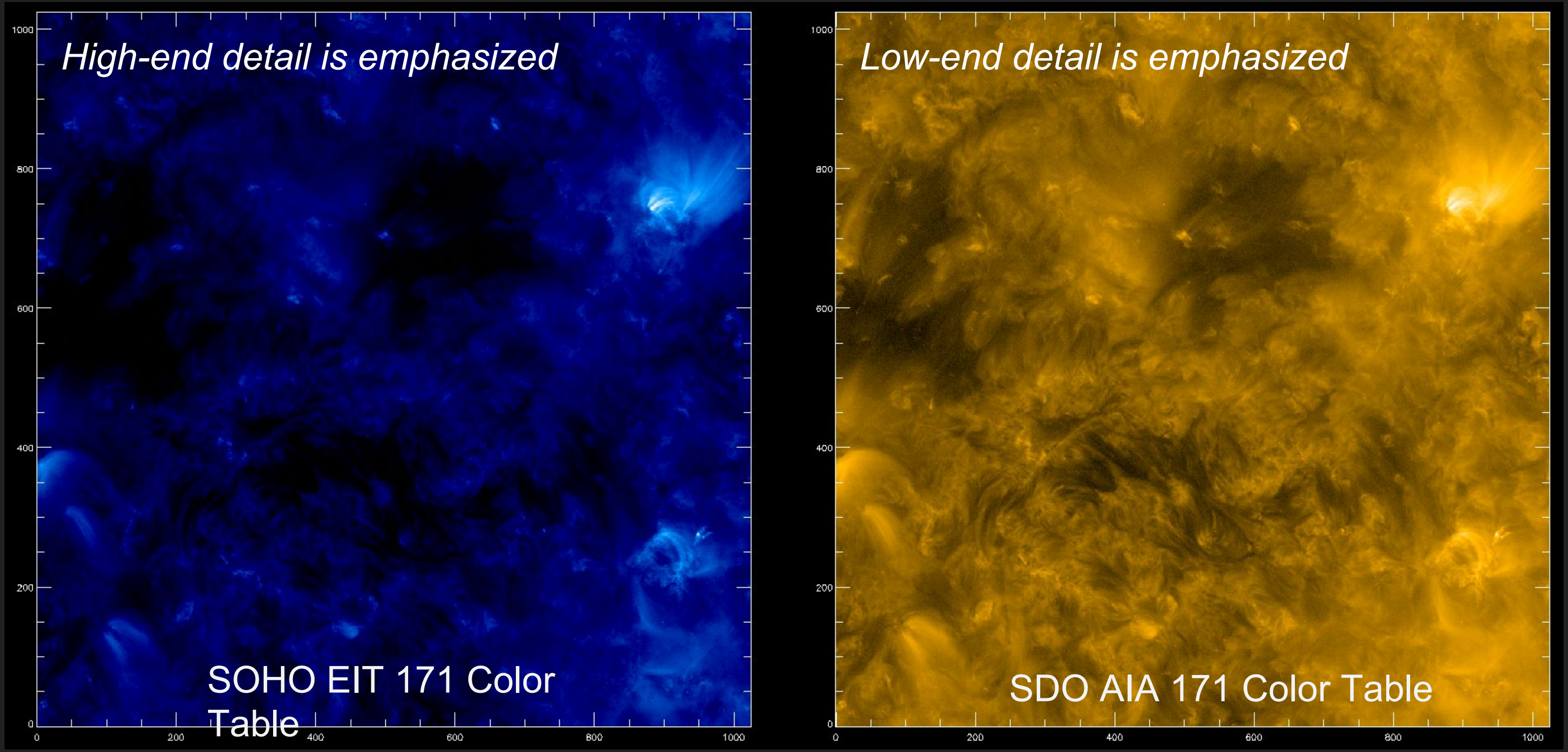


Colormap evaluation: sohoeit304
Colormap
Black-and-white printed
Sample images
Moderate deuter.
Perceptual derivative
Length: 138.0
RMS deviation from flat: 148.6 (107.6%)
Perceptual lightness derivative
Length: 100.0
RMS deviation from flat: 96.6 (96.6%)
Moderate deuteranomaly
Moderate protanomaly
Complete deuteranopia
Complete protanopia
a' (green[-], red[+])
b' (blue[-], yellow[+])
J'/K (white[100], black[0])

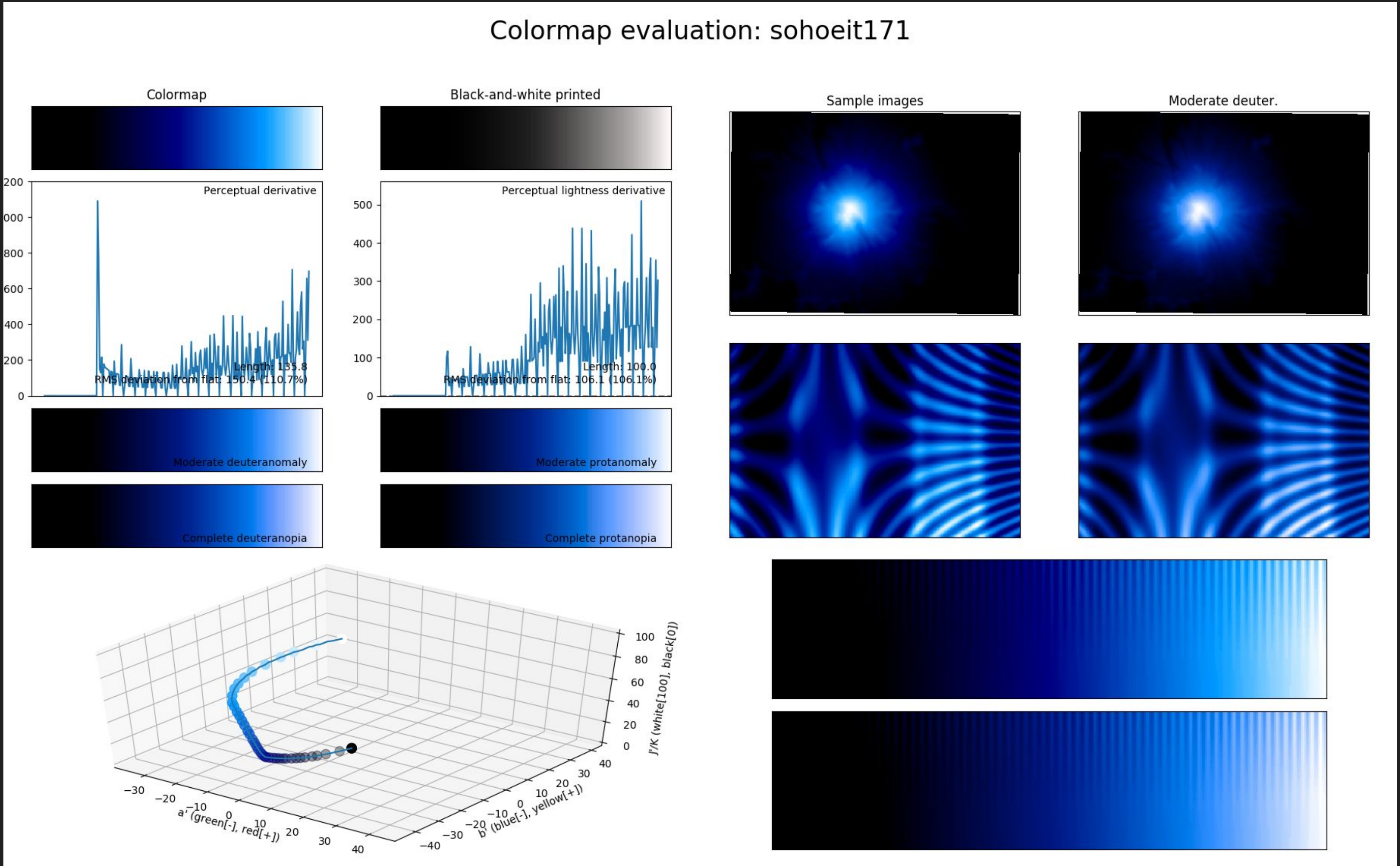
Colormap evaluation: sdoaia304



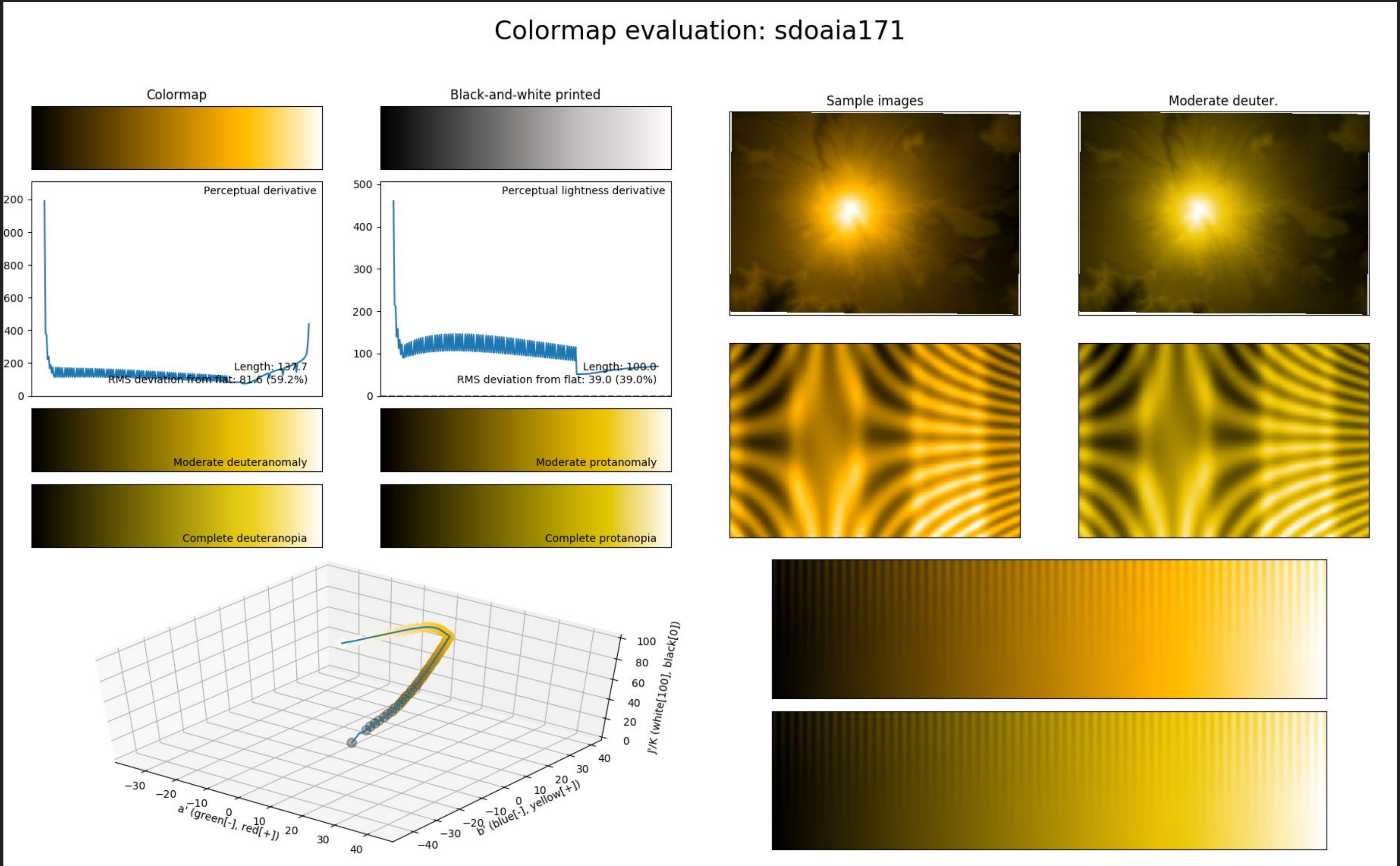
Same data, image scaling, different color table (2)



Identical AIA 171 Image from July 26, 2010

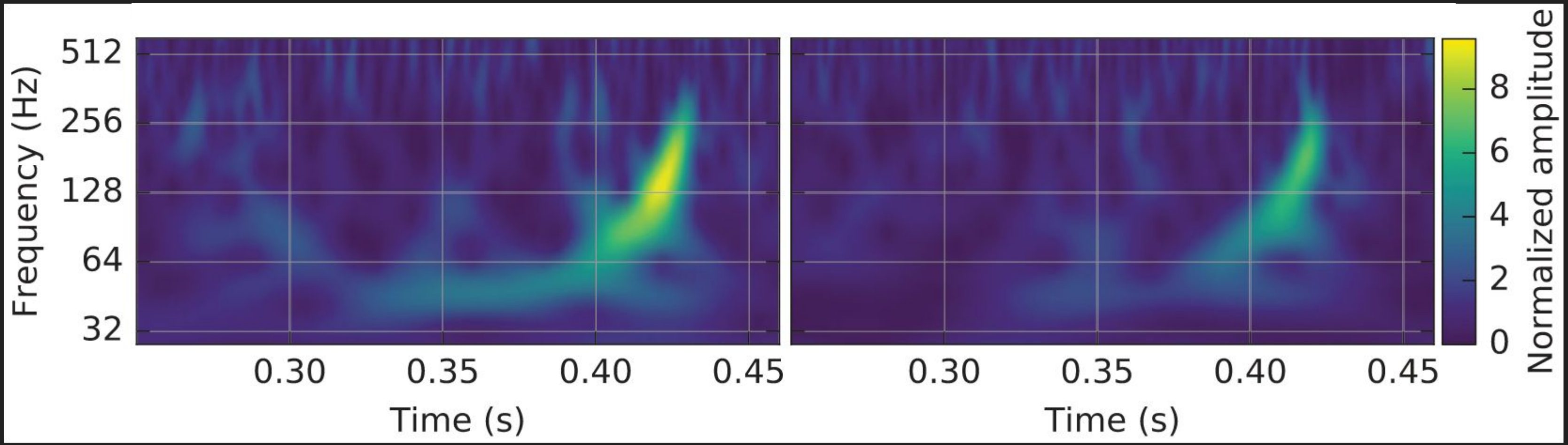


Colormap evaluation: sohoeit171
Colormap
Black-and-white printed
Sample images
Moderate deuter.
Perceptual derivative
Length: 135.8
RMS deviation from flat: 150.4 (110.7%)
Perceptual lightness derivative
Length: 100.0
RMS deviation from flat: 106.1 (106.1%)
Moderate deuteranomaly
Moderate protanomaly
Complete deuteranopia
Complete protanopia
a' (green[-], red[+])
b' (blue[-], yellow[+])
J'/K (white[100], black[0])

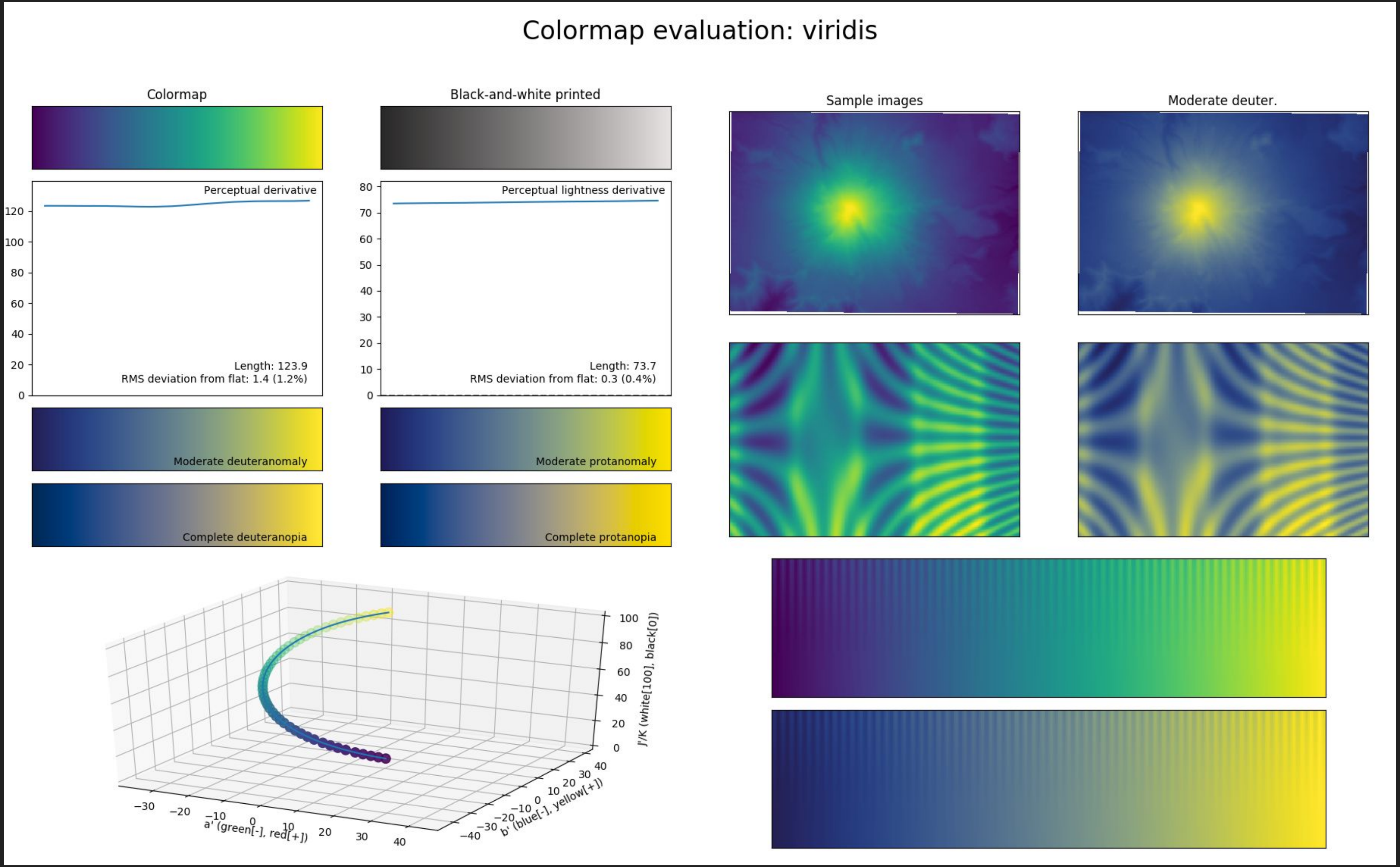


Colormap evaluation: sdoaia171
Colormap
Black-and-white printed
Sample images
Moderate deuter.
Perceptual derivative
Length: 137.7
RMS deviation from flat: 81.6 (59.2%)
Perceptual lightness derivative
Length: 100.0
RMS deviation from flat: 39.0 (39.0%)
Moderate deuteranomaly
Moderate protanomaly
Complete deuteranopia
Complete protanopia
a' (green[-], red[+])
b' (blue[-], yellow[+])
J'/K (white[100], black[0])

Other data...



matplotlib viridis colormap


Colormap evaluation: viridis
Colormap
Black-and-white printed
Sample images
Moderate deuter.
Perceptual derivative
Length: 123.9
RMS deviation from flat: 1.4 (1.2%)
Perceptual lightness derivative
Length: 73.7
RMS deviation from flat: 0.3 (0.4%)
Moderate deuteranomaly
Moderate protanomaly
Complete deuteranopia
Complete protanopia
J'/K (white[100], black[0])
a' (green[-], red[+])
b' (blue[-], yellow[+])

Try it for yourself

1. Follow the SunPy installation instructions on sunpy.org
2. *git clone https://github.com/wafels/viscm*
3. Change directory to where you cloned the git repository above
4. *git checkout -b sunpy*
5. *python setup.py install*
6. *python -m viscm view sdoaia171*

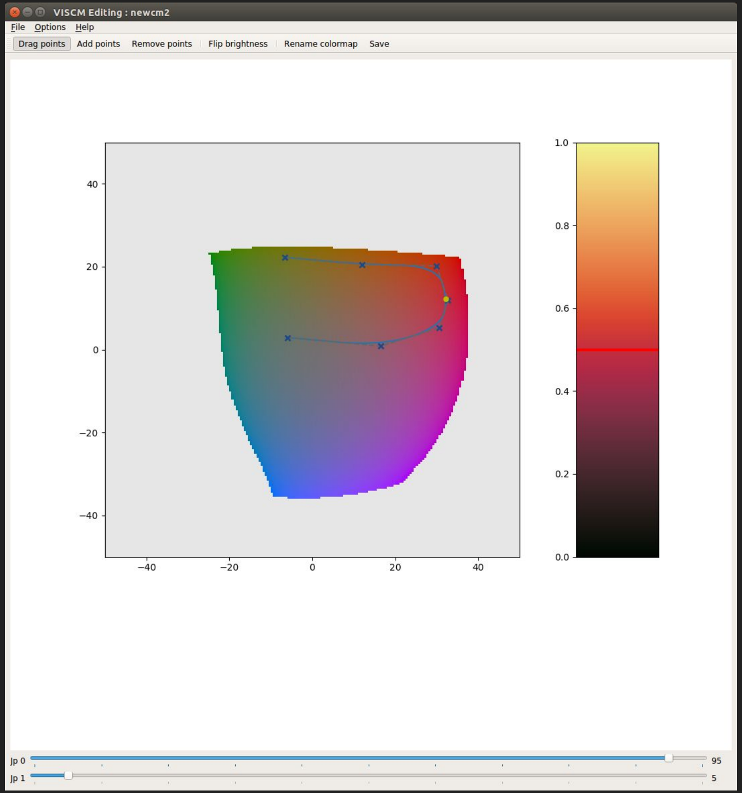
The main repository *https://github.com/matplotlib/viscm* contains much more information about the perception of colormaps and how to **make your own perceptually uniform colormaps.**

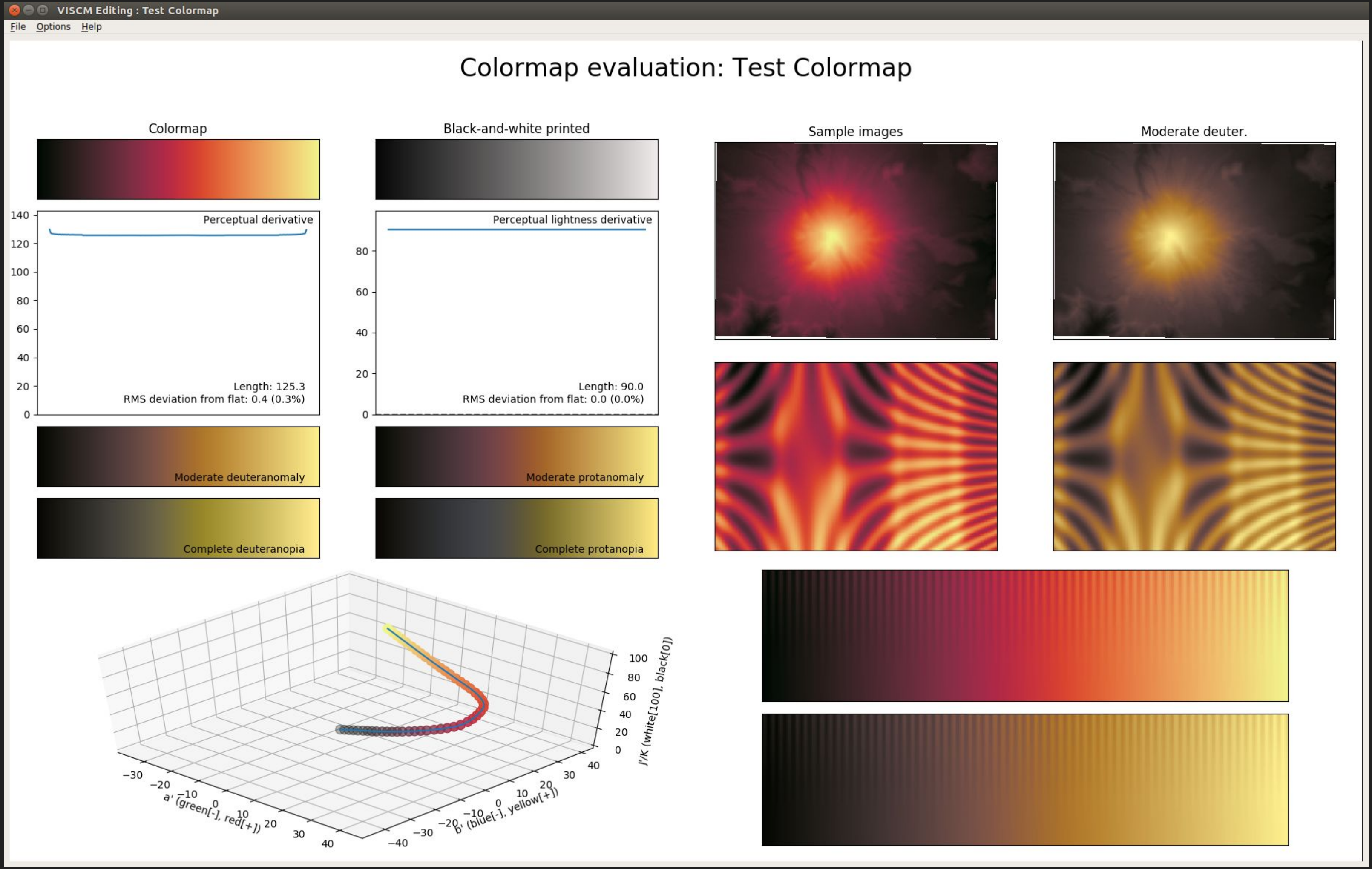
Design your own AIA 304Å scaling function and colormap

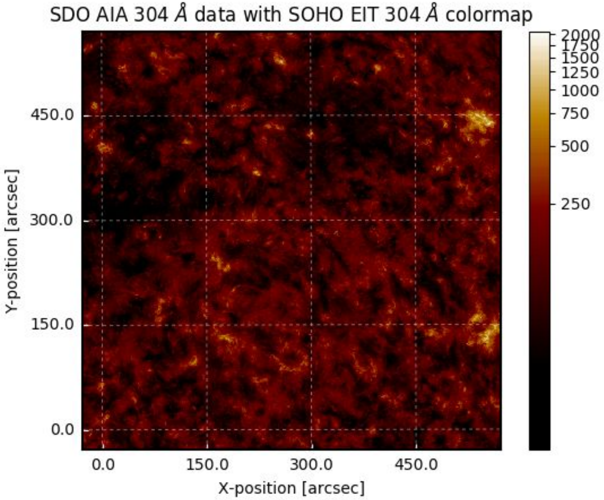
Requirements

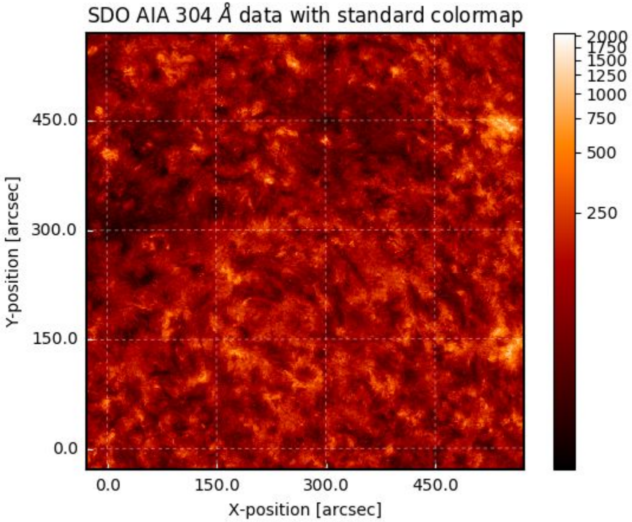
1. Reddish-orangey colors (because that's what the community expects now).
2. As perceptually uniform as we can make it.

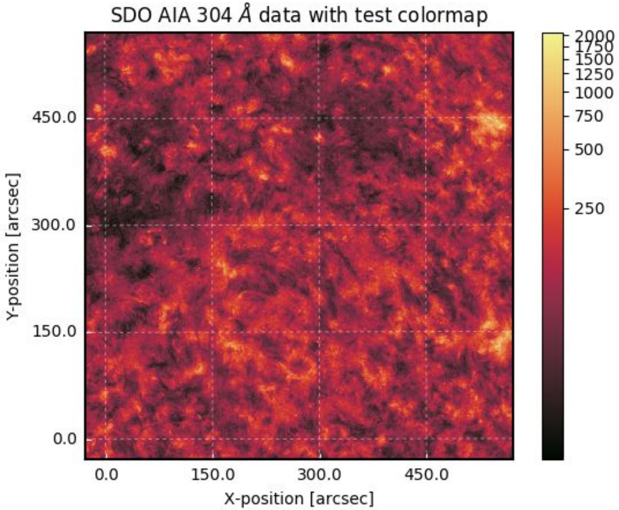
python -m viscm edit




VISCM Editing : Test Colormap
File Options Help
Colormap evaluation: Test Colormap
Colormap
Black-and-white printed
Sample images
Moderate deuter.
Perceptual derivative
Length: 125.3
RMS deviation from flat: 0.4 (0.3%)
Perceptual lightness derivative
Length: 90.0
RMS deviation from flat: 0.0 (0.0%)
Moderate deuteranomaly
Moderate protanomaly
Complete deuteranopia
Complete protanopia
a' (green[-], red[+])
b' (blue[-], yellow[+])
J'/K (white[100], black[0])


SDO AIA 304 Å data with SOHO EIT 304 Å colormap
Y-position [arcsec]
0.0
150.0
300.0
450.0
X-position [arcsec]
0.0
150.0
300.0
450.0
2000
1750
1500
1250
1000
750
500
250


SDO AIA 304 Å data with standard colormap
Y-position [arcsec]
0.0
150.0
300.0
450.0
X-position [arcsec]
0.0
150.0
300.0
450.0
2000
1750
1500
1250
1000
750
500
250


SDO AIA 304 Å data with test colormap
Y-position [arcsec]
0.0
150.0
300.0
450.0
X-position [arcsec]
0.0
150.0
300.0
450.0
2000
1750
1500
1250
1000
750
500
250

Conclusions

- Many colormaps used in solar physics have large variation in their perception.
- Advice is available on the selection of colormaps to best display your data, taking into account common types of colorblindness.
- Tools are available to test and design colormaps using their *perception* as a criterion.
- We can understand how the colormap is biasing our perception.

More information

- http://matplotlib.org/users/colormaps.html
- https://bokeh.github.io/colorcet/
- http://www.kennethmoreland.com/color-advice/
- https://gist.github.com/endolith/2719900#id7
- https://mycarta.wordpress.com/2012/10/14/the-rainbow-is-deadlong-live-the-rainbow-part-4-cie-lab-heated-body/
- http://ccom.unh.edu/sites/default/files/publications/Ware_1988_CGA_Color_sequences_univariate_maps.pdf
- http://www.research.ibm.com/people/l/lloydt/color/color.HTM
- https://en.wikipedia.org/wiki/CIE_1931_color_space
- https://en.wikipedia.org/wiki/Lab_color_space
- https://en.wikipedia.org/wiki/CIECAM02
- http://dba.med.sc.edu/price/irf/Adobe_tg/models/cielab.html
- https://www.youtube.com/watch?v=xAoljeRJ3IU
- https://www.youtube.com/watch?v=TojFwkglCKs
- https://bids.github.io/colormap/
- http://peterkovesi.com/projects/colourmaps/
- http://colour-science.org/
- http://python-colormath.readthedocs.io/en/latest/
- https://pypi.python.org/pypi/ciecam02/
- http://markkness.net/colorpy/ColorPy.html

Updates to this presentation

Any updates to this presentation will be made here:

https://docs.google.com/presentation/d/1nFfxHEDElUu3tQtQgxjnWw6FvWTGCN1UUGAlenAQelk/edit?usp=sharing

End