



A colour scheme for the display of astronomical intensity images

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Abstract. I describe a colour scheme that is appropriate for the screen display of intensity images. This – unlike many currently available schemes – is designed to be monotonically increasing in terms of its perceived brightness. Also, when printed on a black and white postscript printer, the scheme results in a greyscale with monotonically increasing brightness. This scheme has recently been incorporated into the radio astronomical analysis packages CASA and AIPS.

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1. The problem

Images in astronomy often, but not always, represent the intensity of some source. However, the colour schemes used to display images are not perceived as increasing monotonically in brightness, which does not aid the interpretation of the images. The perceived brightness of red, green and blue are not the same, with green being seen as the brightest, then red, then blue. For example a bright yellow (i.e. full intensity red and green) is perceived as being very much brighter than a bright blue. So if a colour scheme has yellow for intermediate intensities, but blue or red for higher intensities, then the blue or red is perceived at lower brightness. This can be also seen when such colour images are printed in black and white, when increasing intensity in the image does not correspond to a greyscale with monotonically increasing brightness. This problem was noted by Rappaport (2002) for the colour schemes then available in the MATLAB¹ computing package. Rappaport constructed – in an *ad hoc* manner – a colour scheme² that does result in a greyscale with monotonically increasing brightness when printed on a black and white device.

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¹see: <http://www.mathworks.com/products/matlab/>

²see: <http://www.mathworks.com/matlabcentral/fileexchange/2662-cmrmap-m>

Here I describe colour schemes for the display of images that take into account the different perceptions of the brightnesses of red, green and blue, in order to maintain a monotonically increasing perception of intensity.

2. Background

An example of where colour needs to be converted to black and white, to preserve perceived brightness, is the addition of colour to black and white television. In the US, the National Television System Committee (NTSC) specifications from 1953, red, green and blue (hereafter R , G , B) are mapped to a Y ‘luma’ value (i.e. the black and white brightness) signal using (see, for example, Lee 2005 or Hunt 2004)

$$Y = 0.30R + 0.59G + 0.11B \quad (1)$$

(In addition there were two other components, ‘ Q ’ and ‘ I ’ which encoded the colour.)

The coefficients in equation 1 are appropriate for the colour phosphors then in use, and reflect the perceived intensity of the different colours. Modern monitors differ somewhat, but the coefficients of the different perceived intensities are similar, e.g. the European PAL colour TV standard uses very similar coefficients, with $Y = 0.299R + 0.587G + 0.114B$, and more recently HDTV uses $Y = 0.2126R + 0.7152G + 0.0722B$ (ITU-R Recommendation 709, originally from 1993). In all cases the perceived brightness of green is largest, then red, then blue.

The NTSC coefficients are also used: (1) to map from the DeviceRGB to DeviceGray colourspace used within Postscript if the `colorimage` operator is used with a black and white device³, and (2) to convert from colour to greyscale for greyscale only devices, within the PGPLOT package⁴.

3. A solution

In the 1980s, a colour scheme was implemented for the Sigma ARGS graphics display on the Cambridge STARLINK VAX, by a colleague, John Fielden. This was from black to white, spiralling around the greyscale diagonal in an R , G , B colour cube. However, this treated R , G , B equivalently, i.e. not taking into account these colours are perceived differently in terms of their brightness. I adapted this colour scheme so that it *is* monotonically increasing in terms of perceived brightness, according to equation 1.

The colour scheme – a squashed helix around the diagonal of a colour cube, ‘cubehelix’ – is implemented as follows. For a unit colour cube (i.e. 3-D coordinates for R , G , B , each in the

³PostScript Language Reference, Third Edition, see: <http://www.adobe.com/devnet/postscript/>

⁴Section 5.1 of the PGPLOT manual, see: <http://www.astro.caltech.edu/~tjp/pgplot/contents.html>

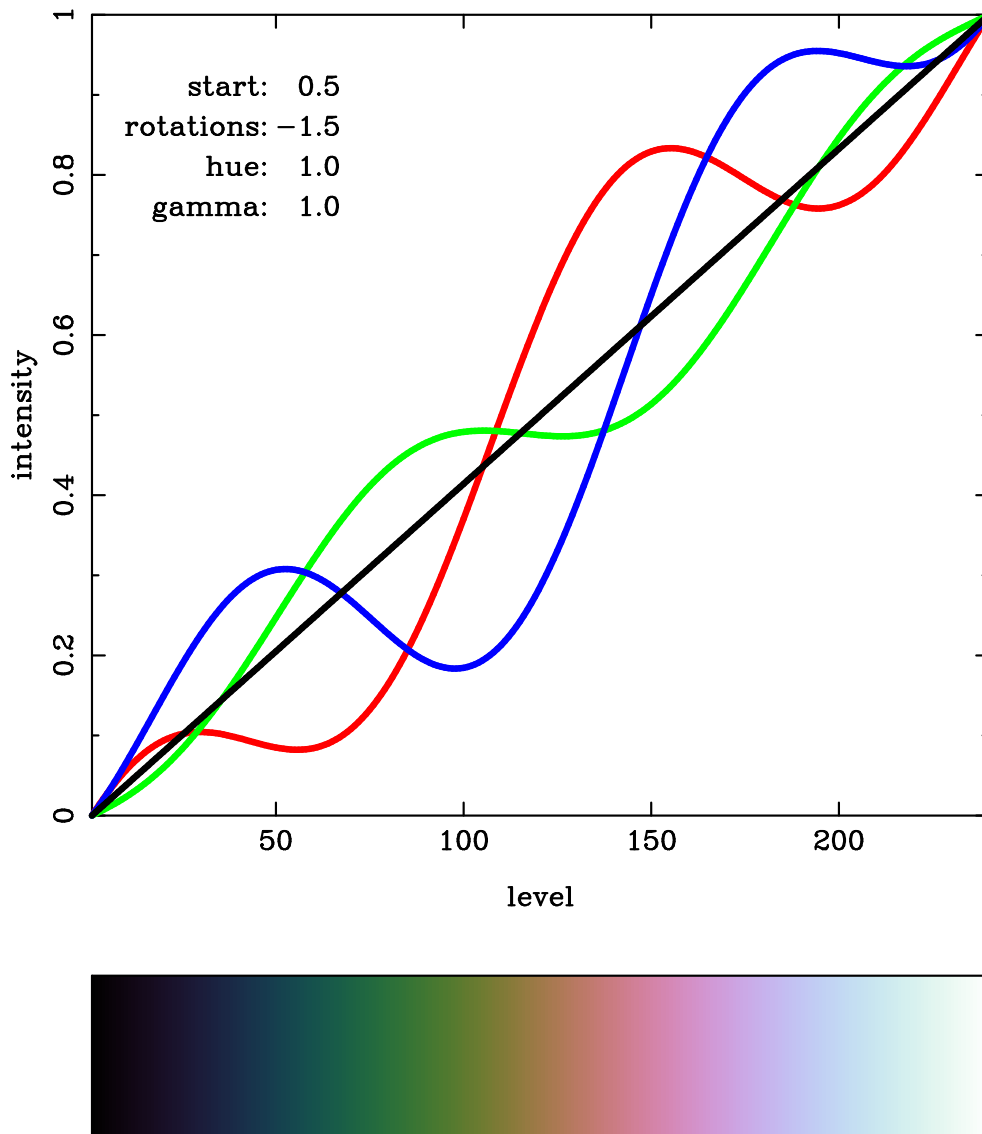


Figure 1. An example ‘cubehelix’ colour scheme with 256 colour levels, as recently added in CASA. Top: the variation in red, green and blue intensity, and the perceived intensity according to equation 1. Bottom: a colour wedge to illustrate the scheme. This has a start colour of 0.5, i.e. purple (which is between $R = 1$ and $B = 3 \equiv 0$ when using modulo 3 arithmetic, with $R = 1$, $G = 2$, $B = 3$), with -1.5 rotations, i.e. $\rightarrow B \rightarrow G \rightarrow R \rightarrow B$, a hue value of 1.2 (as with the chosen start colour and rotations this value does not lead to any clipping), and gamma of 1.0.

range 0 to 1), the colour scheme starts at $(R, G, B) = (0, 0, 0)$, i.e. black, and finishes at $(R, G, B) = (1, 1, 1)$, i.e. white. For some fraction λ between 0 and 1, the colour is the corresponding grey value at that fraction along the black to white diagonal, i.e. $(\lambda, \lambda, \lambda)$, plus a colour element. The colour element is calculated in a plane of constant perceived intensity, which can be defined in terms of two unit (R, G, B) colour vectors $(-0.074, -0.146, 0.986)$ and $(0.891, -0.453, 0.0)$, the first of which is predominantly blue. The additional colour element of the scheme is controlled by three parameters.

- The start colour (s). This is the direction of the predominant colour deviation from black at the start of the colour scheme.
- The number of R, G, B rotations (r) in colour that are made from the start (i.e. black) to the end (i.e. white) of the colour scheme.
- A hue parameter (h), which controls how saturated the colours are. The amplitude of the colour deviation from the grey diagonal is zero at each end and largest in the middle. If this parameter is zero then the colour scheme is purely a greyscale, increasing in brightness. If the parameter is too large, then R, G , or B may be out of the 0 to 1 range near start or end of colour scheme, so will have to be clipped (although if only a few colour levels are clipped, the resulting colour scheme, may still be satisfactory).

In addition, a ‘gamma factor’ can be used to provide mapping of λ to λ^γ , to emphasise either low intensity values ($\gamma < 1$), or high intensity values ($\gamma > 1$). For a fraction λ between 0 and 1, then the R, G, B values are given by

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} \lambda^\gamma \\ \lambda^\gamma \\ \lambda^\gamma \end{pmatrix} + a \begin{pmatrix} -0.14861 & +1.78277 \\ -0.29227 & -0.90649 \\ +1.97294 & 0 \end{pmatrix} \begin{pmatrix} \cos \phi \\ \sin \phi \end{pmatrix} \quad (2)$$

where $\phi = 2\pi(s/3 + r\lambda)$ and $a = h\lambda^\gamma(1 - \lambda^\gamma)/2$ (i.e. the angle and amplitude for the deviation from the black to white diagonal) in the plane of constant perceived intensity). Appendix A gives FORTRAN 77 code for this algorithm, and Fig. 1 shows one example of a colour scheme constructed using this algorithm.

Note that printed versions of this colour scheme may not be perceived as monotonically increasing in brightness. This is because the range of colours that can be represented by colour printers (their ‘gamut’) is usually poorer than the range that can be represented in computer displays (e.g. see Hunt 2004). However, this colour scheme should print as a greyscale with monotonically decreasing density on black and white postscript devices.

A version of this colour scheme, as shown in Fig. 1, has recently been incorporated into the VIEWER task in version 3.1.0 of the ‘Common Astronomy Software Application’, CASA⁵

⁵see: <http://casa.nrao.edu/>

(e.g. Jaeger 2008), called CubeHelix. This colour scheme has also been recently added to the 31DEC10 version of the 'Astronomical Image Processing System', AIPS⁶ (e.g. Greisen 2005) via the TVHELIX verb, which allows interactive control of start colour, number of rotations (and direction), the hue parameter and gamma factor using the AIPS TV buttons and cursor position.

4. Discussion and conclusion

It should be noted that the colour scheme described in Section 3 is only one example which is suitable for the display of intensity images. Clearly others could be constructed to take into account the difference in perception of colours discussed in Section 2. Colour is not only for the display of intensity images, but is also used in other situations, for example: (i) for polarisation images, where intensity or polarised intensity is represented by an underlying greyscale, with polarisation angle with added colour, or (ii) for spectral line observations, where intensity (or, for example, column density) is represented by an underlying greyscale, with colour represented radial velocity. In these cases, ideally the addition of different colours should not distort perception of intensity also intended. A further subtlety is that the perception of differences between similar colours is not the same for all colours (e.g. MacAdam 1943a,b), and hence an appropriate mapping between colour and polarisation angle/velocity is needed.

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References

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⁶see: <http://www.aips.nrao.edu/>

A. FORTRAN 77 code

This is FORTRAN 77 code that implements the colour scheme as described in Section 3.

```

C=====72
C Calculates a "cube helix" colour table. The colours are a tapered
C helix around the diagonal of the [R,G,B] colour cube, from black
C [0,0,0] to white [1,1,1] Deviations away from the diagonal vary
C quadratically, increasing from zero at black, to a maximum, then
C decreasing to zero at white, all the time rotating in colour.
C
C The input parameters controlling the colour helix are:
C
C   START colour (1=red, 2=green, 3=blue; e.g. 0.5=purple);
C   ROTS rotations in colour (typically -1.5 to 1.5, e.g. -1.0
C       is one blue->green->red cycle);
C   HUE for hue intensity scaling (in the range 0.0 (B+W) to 1.0
C       to be strictly correct, larger values may be OK with
C       particular start/end colours);
C   GAMMA set the gamma correction for intensity.
C
C The routine returns a colour table NLEV elements long in RED, GRN
C and BLU (each element in the range 0.0 to 1.0), and the numbers,
C NLO and NHI, of red, green or blue values that had to be clipped
C because they were too low or too high.
C-----72
C Dave Green --- MRAO --- 2011 June 13th
C-----72
C See:
C   Green, D. A., 2011, Bulletin of the Astronomical Society of India,
C   Vol.39, p.289
C-----72
      SUBROUTINE CUBHLX(START,ROTS,HUE,GAMMA,NLEV,RED,GRN,BLU,NLO,NHI)
C   =====
C
      INTEGER    NLEV,I,NLO,NHI
      REAL       START,ROTS,HUE,GAMMA
      REAL       RED(NLEV),GRN(NLEV),BLU(NLEV)
      REAL       PI,FRACT,ANGLE,AMP
C
      PI=4.0*ATAN(1.0)
      NLO=0
      NHI=0
C
      DO 1000 I=1,NLEV
          FRACT=FLOAT(I-1)/FLOAT(NLEV-1)
          ANGLE=2*PI*(START/3.0+1.0+ROTS*FRACT)

```

```
FRACT=FRACT**GAMMA
AMP=HUE*FRACT*(1-FRACT)/2.0
RED(I)=FRACT+AMP*(-0.14861*COS(ANGLE)+1.78277*SIN(ANGLE))
GRN(I)=FRACT+AMP*(-0.29227*COS(ANGLE)-0.90649*SIN(ANGLE))
BLU(I)=FRACT+AMP*(+1.97294*COS(ANGLE))
C
IF(RED(I).LT.0.0)THEN
  RED(I)=0.0
  NLO=NLO+1
ENDIF
IF(GRN(I).LT.0.0)THEN
  GRN(I)=0.0
  NLO=NLO+1
ENDIF
IF(BLU(I).LT.0.0)THEN
  BLU(I)=0.0
  NLO=NLO+1
ENDIF
C
IF(RED(I).GT.1.0)THEN
  RED(I)=1.0
  NHI=NHI+1
ENDIF
IF(GRN(I).GT.1.0)THEN
  GRN(I)=1.0
  NHI=NHI+1
ENDIF
IF(BLU(I).GT.1.0)THEN
  BLU(I)=1.0
  NHI=NHI+1
ENDIF
1000 CONTINUE
C
RETURN
END
```