Using the ISO 15339 characterized reference print conditions to test an hypothesis about common color appearance

John Seymour[1], Sept 23, 2016

Abstract

If I view an ad for my favorite cola in a newspaper and then later view that same ad in a glossy magazine, I will likely perceive those two images as looking the same. It is very unlikely that an observer who has not been involved in critical color evaluation would even notice the color difference unless the two images were seen adjacent to each other. This, despite the fact that the actual colors of the red of the can may be 40 ΔE_{ab} apart. There is legitimate debate about what this illusive quality should be named, but at least for the time being, it has been called "common color appearance" in CIE Reportership R8-13.

Even more *elusive* is the exact mathematical relationship between the colors in two images that gives the images common color appearance. While the images of the cola can differ greatly in chroma, if one of the images had even a relatively small difference in hue, the effect would be startling, and likely would be noticed by even the most any naïve observer.

In this paper, I propose a sufficient (but perhaps not necessary) condition that assures that two images will be perceived as having a common color appearance. This hypothesis is tested through the use of the characterized reference print conditions in ISO 15339.

For CIE RP8-13, this proposed condition gives rise to a metric for gauging the degree to which two images have a common color appearance. For ISO TC 130, the findings suggest a way to improve upon the current approach in ISO 15339.

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The hypothesis

The image below is a simple example of the effect of simultaneous contrast. The small gray square on the right appears darker than the one on the left, although the actual RGB values are the same. This effect is even more surprising when one considers that, like any optical system, the eye has scattered light. The image that is projected on the retina of the gray square on the right is actually *lighter* in color than the one on the left due to proximal scattering of the white surround.

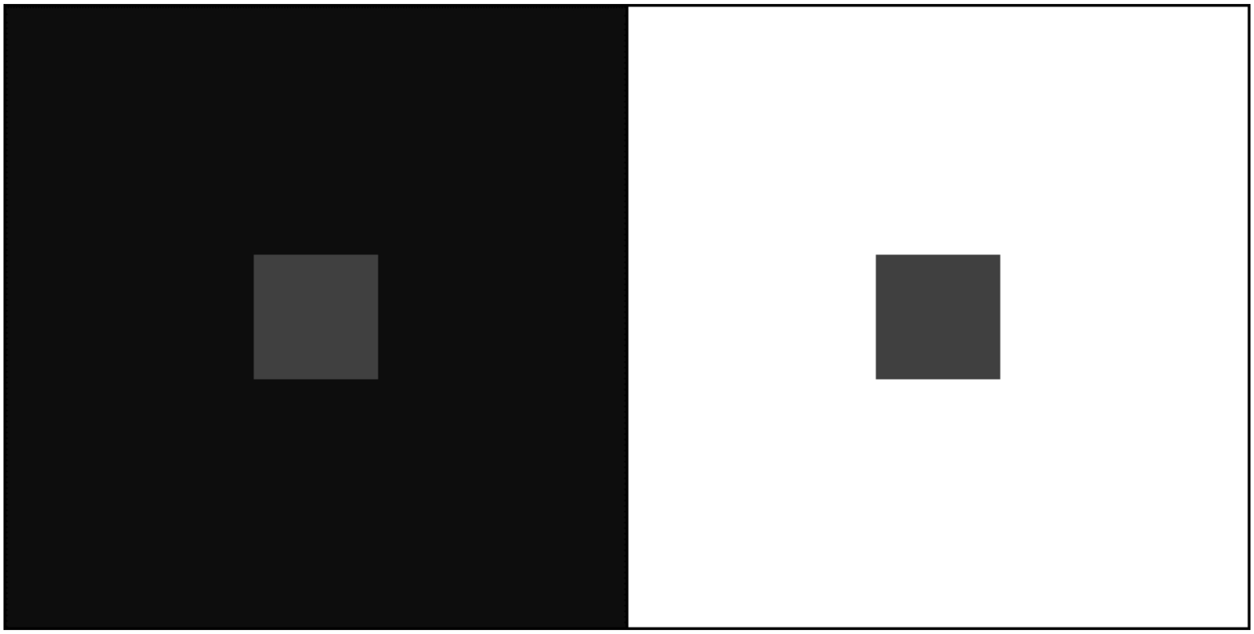


Figure 1 – An example of simultaneous contrast

The explanation for this effect is that the eye/brain does not interpret color absolutely, but rather relative to neighboring colors.

This leads to the following hypothesis:

> *Hypothesis 1: Two images will be perceived as having common color appearance if the relationships between adjacent parts of the image are similar between the two images.*

This, of course, is not a well-defined hypothesis, since "the relationships" has not been defined. Here is an attempt at a more precisely stated version of the same concept:

> *Hypothesis 2: Two images will be perceived as having common color appearance if the magnitudes and directions of color differences between adjacent parts of the image are similar between the two images.*

This condition can be met by two images if the color values of one image, as compared with the other are close to being 1) scaled and shifted in lightness, and 2) scaled in chroma. In other words,

> *Hypothesis 3: Two images will be perceived as having common color appearance if the color values of one image can be transformed into a close approximation of the color values in the other image by applying some combination of the three transformations:*

1. *Scaling in lightness.*
2. *Shifting up or down in lightness.*
3. *Scaling in chroma.*

The larger the difference, the more likely that the common color appearance will be spoiled. Therefore, the scaling and shifting must not be "too severe".

Hypothesis 3 is sufficient to meet the conditions laid out in Hypothesis 2, but are they necessary? Are there other transformations that could lead to "common color appearance"?

Would a common color appearance be possible if the scaling is anamorphic, that is, if the hue and chroma are scaled differently for different hue values? Based on anecdotal concerns, this seems unlikely. An image where yellows are made more vivid while the reds are muted does not *seem* to be acceptable.

Perhaps a rotation is color space would be acceptable? Anecdotally again, this seems unlikely, since as stated before, the brain is not particularly accepting of a soda can with a slight hue shift. How about a wholesale shift in the gray axis? Or a tilt, or… To some extent, these may mimic a change in whitepoint or color temperature of illumination, so there may be some acceptable transformations available.

Some of these alternative transforms may lead to common color appearance, but they will not be investigated in this paper.

Note that I have carefully avoided use of the terms L*, a*, and b* in this description. While it is expected that CIELAB may be an appropriate color space to use, it is likely that a color space which is more perceptually linear might be a better choice. While DIN 99 could improve the results, it will not be considered in this paper.

The CRPCs

The ISO committee on Graphic Technology, ISO TC 130, has published a set of seven transformations, which go from CMYK to L*a*b* for different gamut sizes. These are called "Characterized Reference Print Conditions" (CRPCs). The intent is to provide a standardized sets of definitions of the color of print in order to enable color management of print. The different CRPCs are intended for printing conditions with different gamut sizes.

The overall intent of these CRPCs is that if the same image is rendered according to each of the seven CRPCs, then the resulting images will all have common color appearance.

The development of the CRPCs was based, first off, on what real printing presses are capable of printing. Thus, one of the sets of the gamut boundaries are realistic target values for most all printing modalities available today. It is usually possible to adjust the values for the solid C, M, Y, and K values on a press, but it is not generally possible to adjust the values of the overprints of these (e.g. C over M).

The second criterion was that the gamut boundaries for solid C, M, Y, and K were set to approximately the same hue angles for all the seven CRPCs.

A third criterion was that the printing should be calibrated according to the "G7 methodology". Among other things, this stipulates which combinations of C, M, and Y should be gray, and provides a means for determining the target CIELAB values for these.

While the G7 methodology defines the color values of the near neutral CMY and K values, it has no requirements for the color values of any of the CMYK patches with higher chroma, except for the four solids. Thus, much of the CMYK color space is undefined. The non-neutrals in the CRPCs were selected as a reasonable approximation of what a real printing press might print.

Thus, it is seen that the CRPCs are a compromise between a set of rules which are thought to produce common color appearance and the actual output of a printing press.

The G7 methodology has been tested in practice for 10 years, and has gained a fair amount of market acceptance – so we know that it must at least partially deliver on its claims. The CRPCs based on 15339 have had less extensive use, but have been reviewed and approved of by ISO experts in print technology.

But to the best of my knowledge, there have been no systematic studies of the efficacy of either G7 or 15539. As such, the strength of the conclusions from this paper is dependent on a premise which has been commercially accepted, but has not been scientifically tested.

With that caveat noted, I will use the seven CRPCs in ISO 15339 as a means to test Hypothesis 3.

The test

Correlations

The Pearson correlation coefficient was computed between the L*, a*, and b* values of corresponding CMYK values between pairs of CRPCs. Here is a plot of the L* values from CRPC 5 (*x* axis of the plot) and those from CRPC 6 (*y* axis of the plot). The correlation coefficient for this pair is 0.9993. Clearly this is an excellent correlation. A simple linear equation, L*(6) = -1.98 + 1.054 L*(5), does an excellent job of transforming one set of L* values into the other.

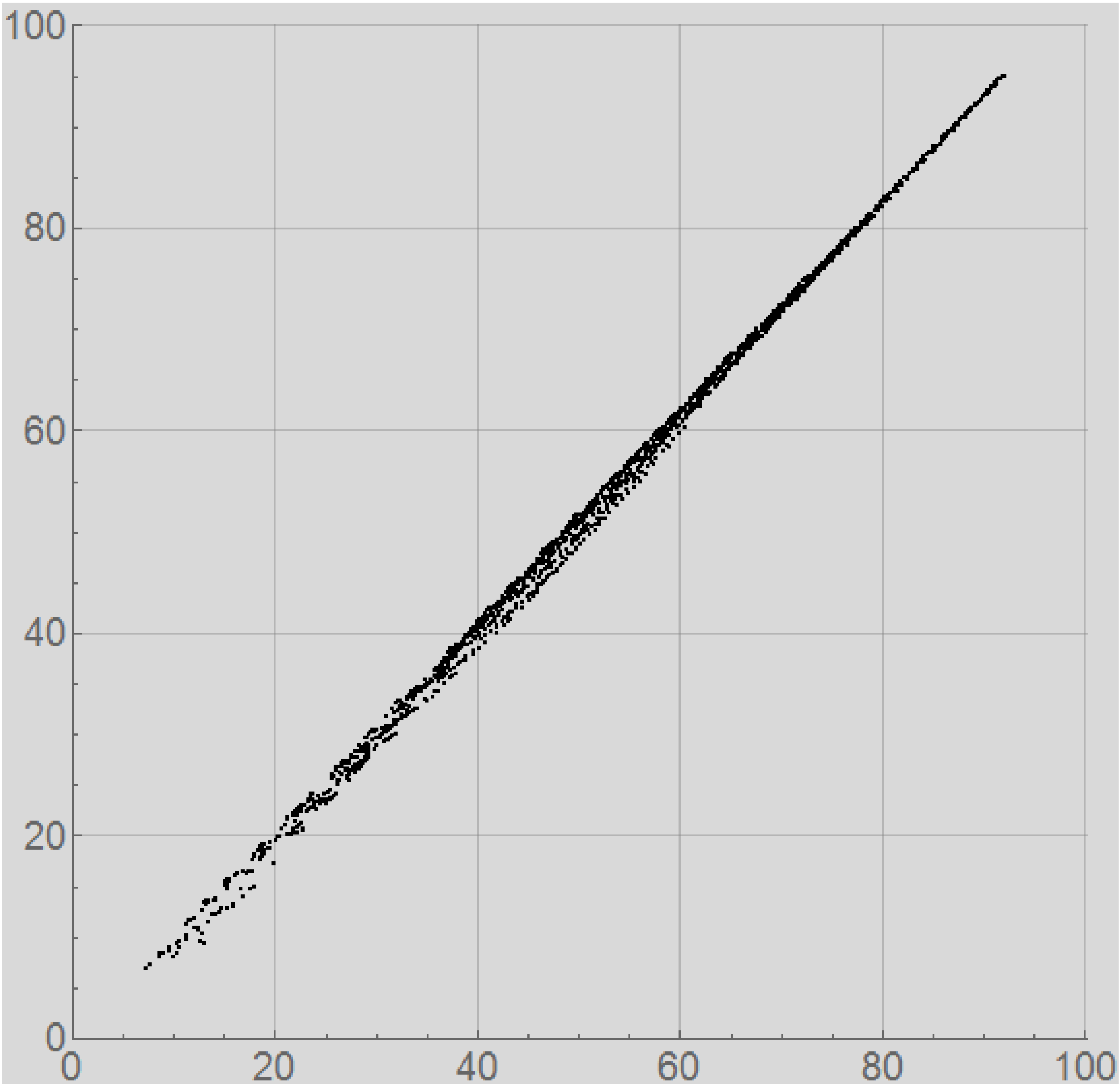


Figure 2 – Plot of the L values of CRPC 6 as a function of the L* values of CRPC 5*

The a* and b* transforms are also quite good, with correlation coefficients of 0.9996 and 0.9987, respectively. These results are not all that unexpected, since the two gamuts of the these two CRPCs are quite close in size.

At the extremes, comparing CRPC 1 and CRPC 7, we see a wider departure from linearity. The correlation coefficient here is still quite good: 0.9688.

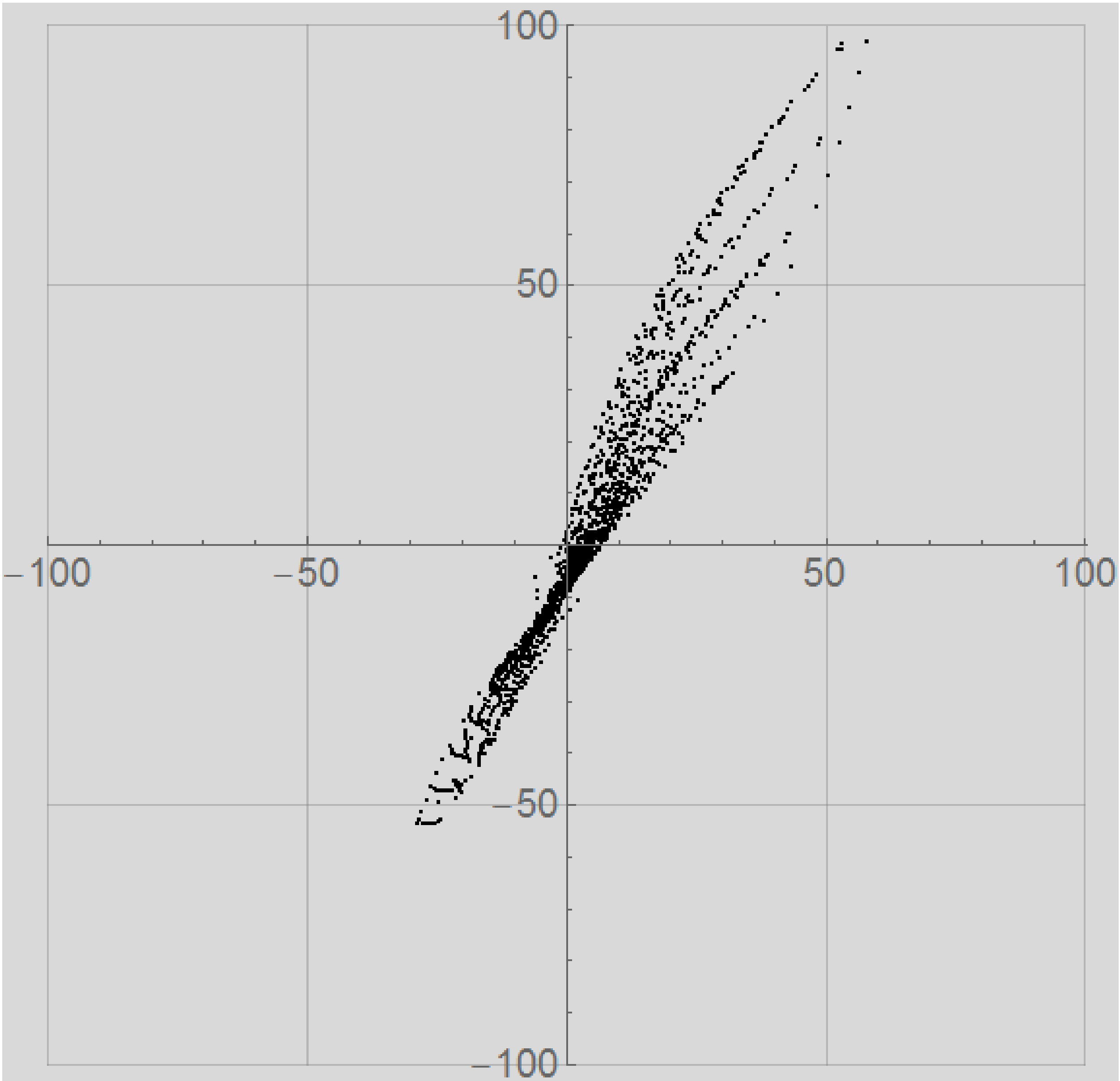


Figure 3 – Plot of the b values of CRPC 7 as a function of the b* values of CRPC 1*

The somewhat poorer correlation coefficient for this comparison is not surprising, since there is nearly a factor of two difference in magnitude between the two sets of b* values.

This quick test bolsters Hypothesis 3.

Defining a transform

The suggested common color appearance transform is shown below:

$$\hat{L}^* = k_1 L^* + k_2$$

$$\hat{a}^* = k_3 a^*$$

$$\hat{b}^* = k_3 b^*$$

where

$L^* a^* b^*$ is a color in one gamut,

$\hat{L}^* \hat{a}^* \hat{b}^*$ is that color, transformed into another gamut.

Linear regression can be used to determine the optimal values for k_1, k_2, and k_3 to transform one set of colors into another.

It would be possible to create separate linear transforms to go from any CRPC to any other. However, the results would be hard to interpret, since there would be 42 different transforms to evaluate. Hence, I chose a different approach. I defined one quintessential CRPC, and investigated the transforms from the quintessential CRPC to each of the seven existing CRPCs. I used the average of all the CRPCs for this quintessential CRPC (QCRPC).

Linear regression was used to determine the coefficients for the transforms, as shown in Table 1. The regression coefficients were used to generate approximations to the seven CRPCs from the QCRPC. The median and 90th percentile errors were computed, also shown in Table 1.

CRPC	k_1	k_2	k_3	Median ΔE_{00}	90th %tile ΔE_{00}
1	0.674	17.74	0.684	2.62	7.61
2	0.882	4.58	0.878	1.14	2.79
3	0.938	7.67	0.889	1.91	7.19
4	1.001	-1.98	1.001	0.91	3.16
5	1.096	-6.19	1.120	1.10	3.10
6	1.157	-8.57	1.168	1.34	3.28
7	1.247	-13.25	1.259	2.14	4.76

Table 1 – Results of regression to QCRPC

The results are good, but not fabulous. At least in part, the color errors can be attributed to idiosyncrasies in the CRPC data. This is one topic for further investigation. I don't have a feel for how smooth the data within the CRPC is. I would also like to look for systematic errors in the estimates for the CRPCs to better understand the source of the errors.

As expected, the CRPC estimates with the largest median color differences were CRPC 1 and CRPC 7, the two CPRCs that are furthest from the QCPRC. CRPC 3 is something of an anomaly, since the error is of comparable magnitude to CRPC 1 and CRPC 7. This bears further examination.

It is interesting to note that the scaling factors for L* and the scaling factors for a*b* are very close in all cases. I see two possible explanations for this:

1. This is another requirement for common color appearance – that the scaling factors for a*, b*, and L* must all be the same.
2. This is a natural result of the printing process – that the differences in gamut size are due mainly to the strength of the inks, and a change in ink strength will affect all three components L*, a*, and b* in a similar manner.

A metric

The transform immediately suggests a metric – apply the transform and see how well it works.

To flesh that out a little bit, the first step is to determine, through linear regression, the values of k_1, k_2, and k_3 which best transforms the L*a*b* values in one image to those of another. Next, the common color appearance transform is applied to the L*a*b* values in the first image. The color difference between corresponding color values (the transformed and those from the second image) is determined for each color.

The proposed common color appearance metric is the median of all these color differences.

One difficulty I see with the metric is that it is not commutative. In other words, comparing image a to image b will not give you the same answer as comparing image b to image a. One solution to this problem is to define the metric to be the average of the comparison of a to b and the comparison of b to a.

Alternately, one could accept the (perhaps dubious) premise that, when deciding whether two images have a common color appearance, we inherently choose one image as the reference, and ask the question as to whether the other image is a good representation of the one we chose as a reference.

Conclusions

For CIE R8-13

To the extent that the CRPCs in ISO 15339 can be through of as generating images with common color appearance, the experiment in this paper supports a rather simple hypothesis about common color appearance: That when the color values of one image can be “scaled” to closely match the color values of another image, then the two images can be said to have common color appearance.

This experiment is not able to test the reverse, that is, it remains unknown whether there exist pairs of images with common color appearance that do not meet this scaling criteria. If the reverse hypothesis is not true, then this test is not a reliable measure of the common color appearance.

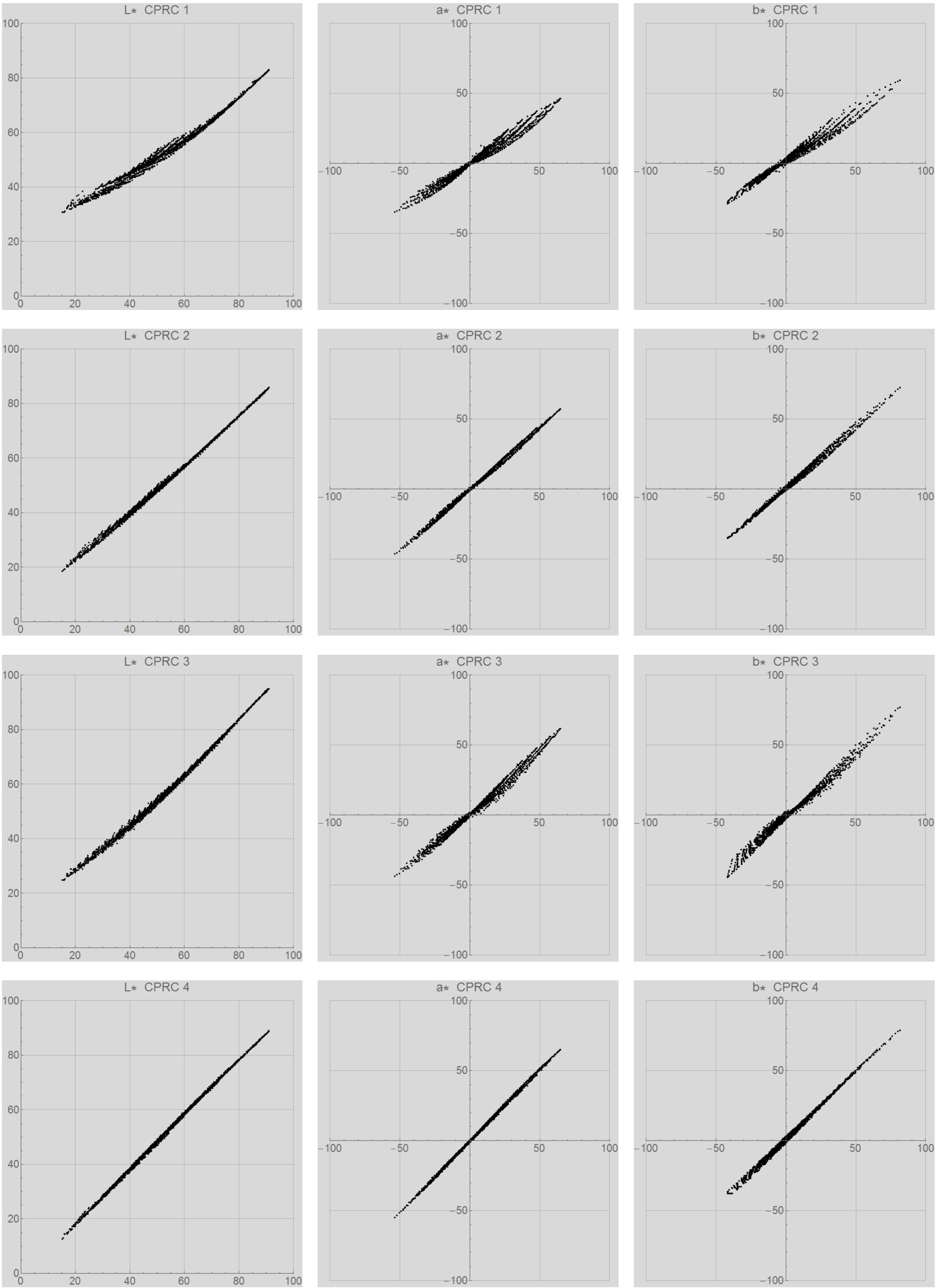
For ISO TC 130

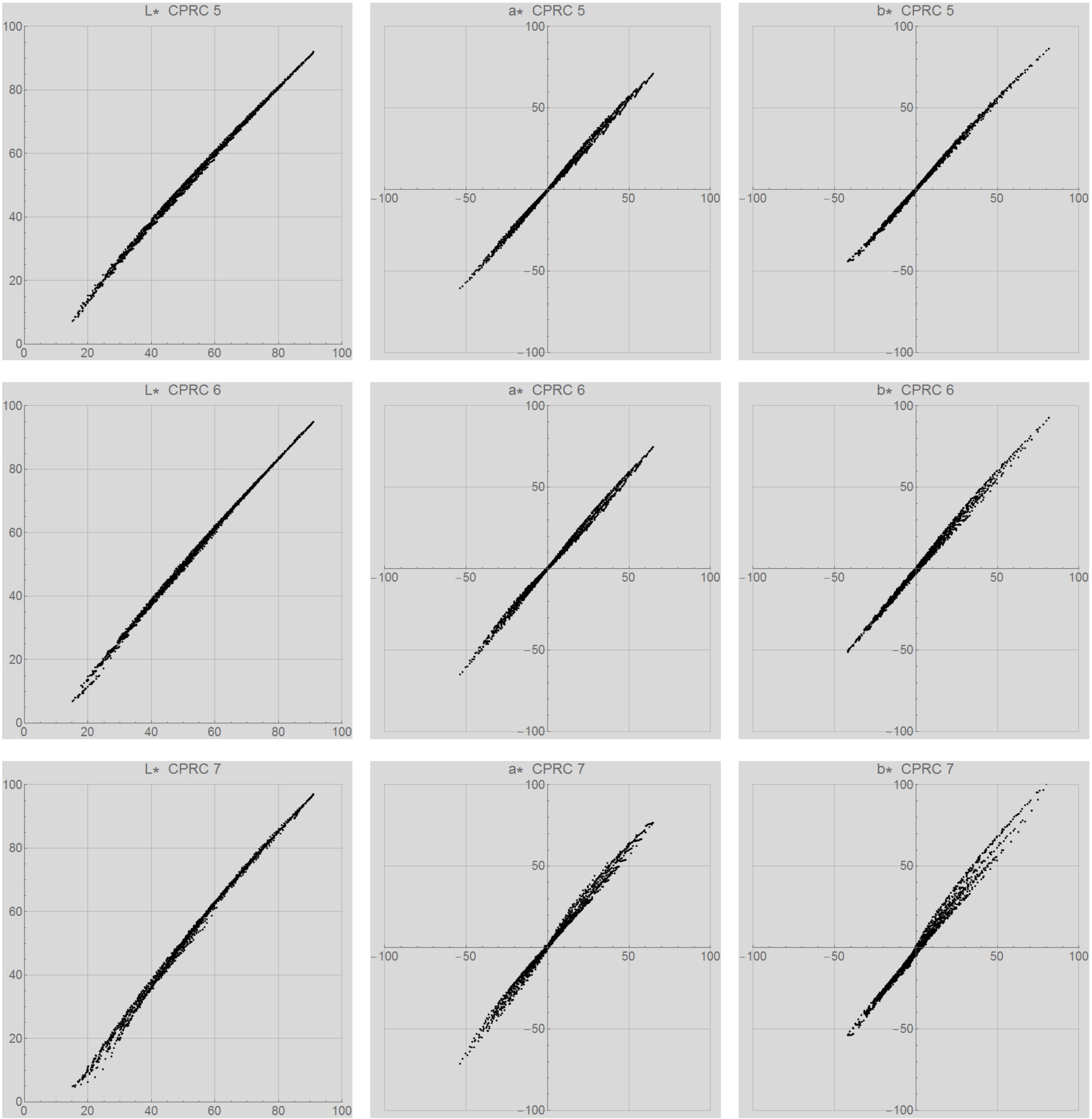
This paper has shown that the seven CRPCs of 15339 can be reasonably well approximated by simple scalings of a single, “quintessential” CRPC. One relatively insignificant implication of this is that the 7 X 1,617 color data points can be reduced to 1,617 data points plus 2 scaling factors. Since the seven CRPCs were developed (somewhat) independently, this is provides a way to determine the CRPCs in a way that is potentially more “accurate”.

More importantly, this paves the way for an approach to CRPCs which is continuous, rather than discrete. In other words, users could specify a computed CRPC that is a scaling of any rational value in the range of (perhaps) 0.6 to 1.3.

Further work needs to be done (I think) investigate systematic departures from the quintessential CPRC, and to make refine this CPRC.

Appendix – CRPCs plotted against QCRPC




L⋆ CPRC 5
a⋆ CPRC 5
b⋆ CPRC 5
L⋆ CPRC 6
a⋆ CPRC 6
b⋆ CPRC 6
L⋆ CPRC 7
a⋆ CPRC 7
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