

A STUDY OF OBSERVER METAMERISM FOR REFLECTANCE-INDUCED STIMULI

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of Technology

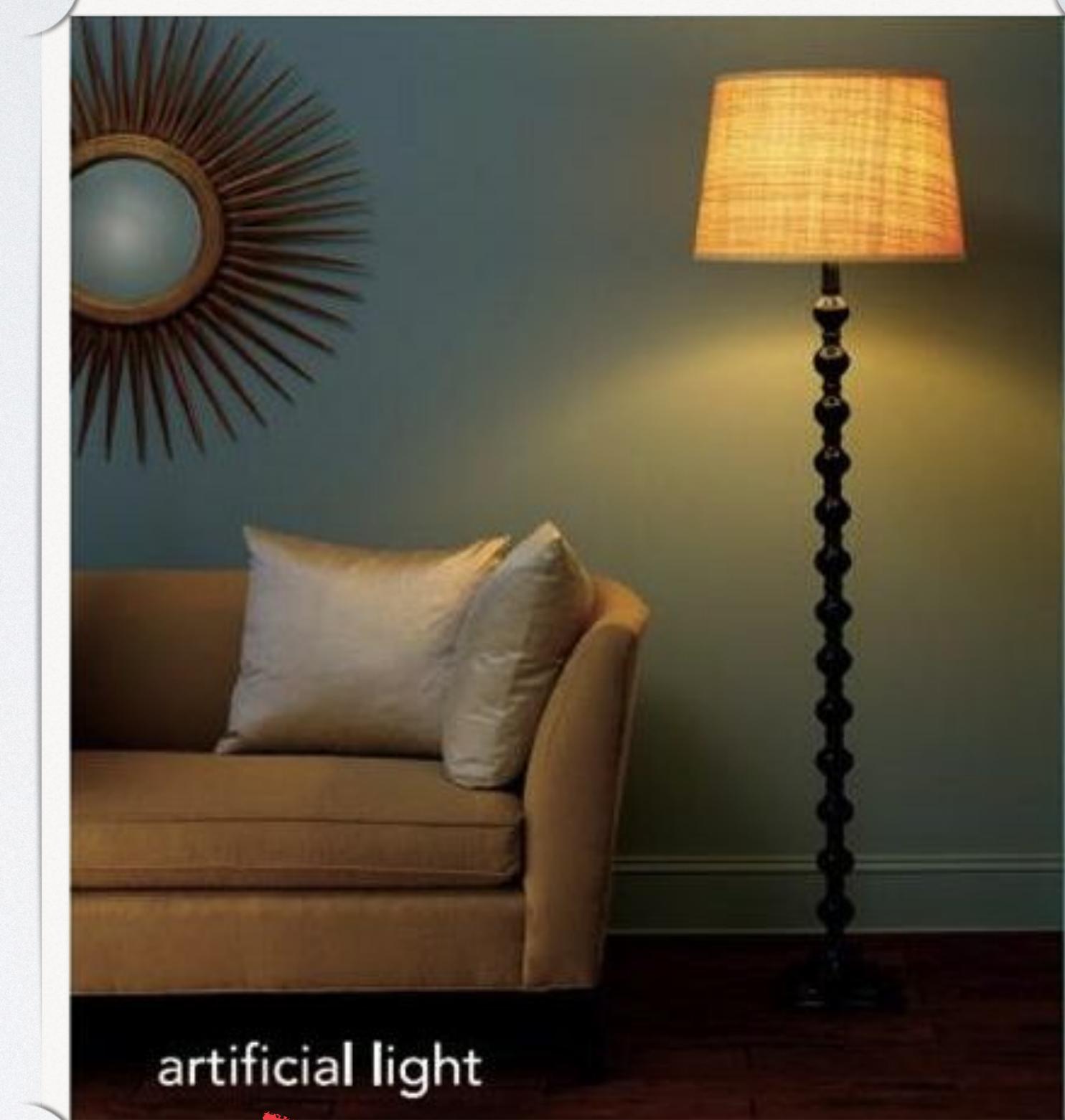
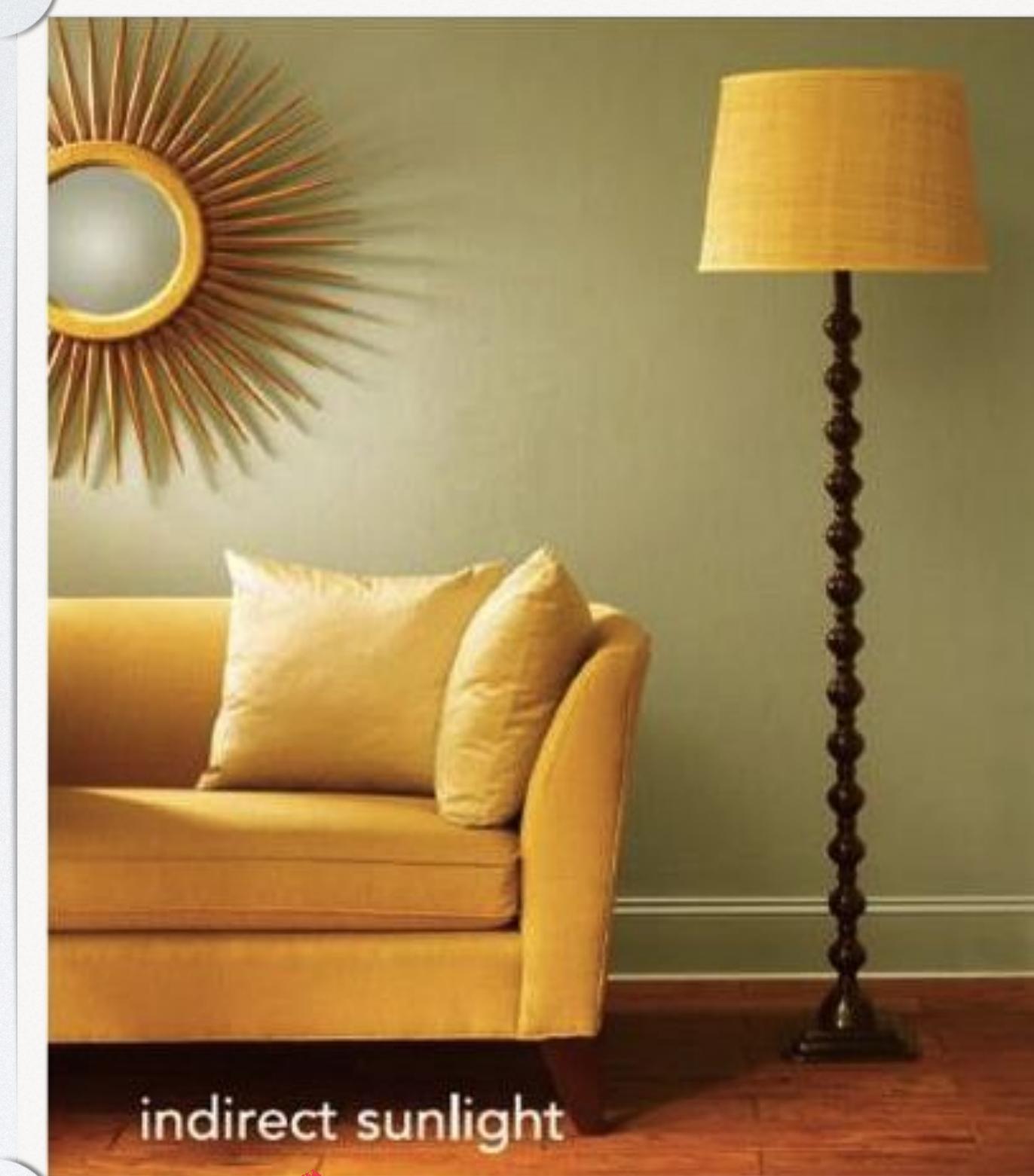


OBSERVER MEASUREMENT

$$a_i = \int_{\Lambda} \bar{r}_i(\lambda) \rho(\lambda) L(\lambda) d\lambda$$

Observer's spectral response, channel i
Reflectance
Illuminant
Observer measurement, channel i

METAMERIC "FAILURE"

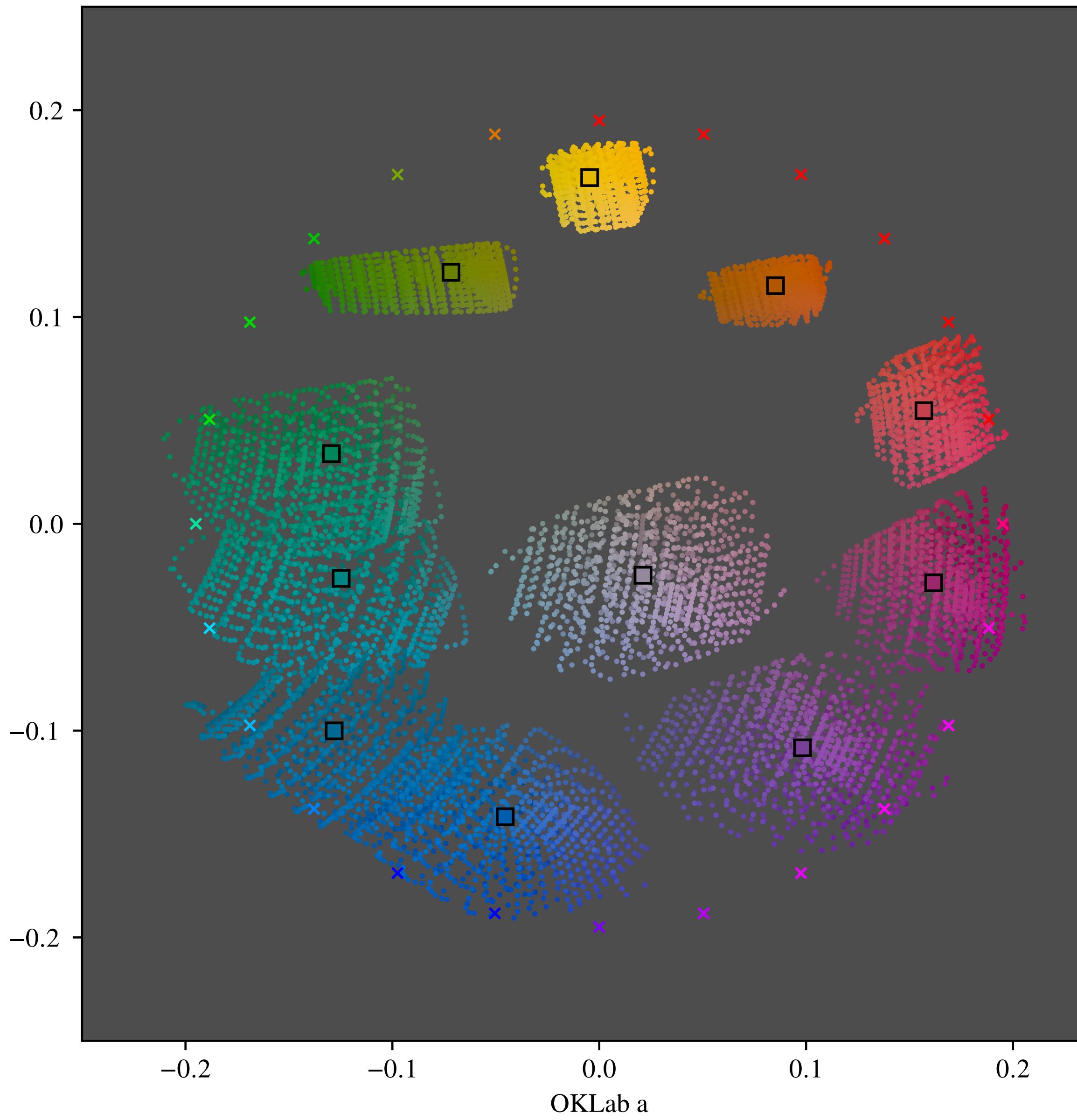


(in truth this is illuminant-induced)





Canon-5D MarkII metamers (DUT) as seen by XYZ-1931 (ref)



MAXIMAL CMV

"Color Mismatch Volume"

"Device Under Test"

DUT: Canon 5D MkII

Ref: XYZ 1931

OKLab color space (a/b plane)

OKLAB COLOR SPACE

$$\begin{bmatrix} L_{\text{ok}} \\ a_{\text{ok}} \\ b_{\text{ok}} \end{bmatrix} = M_2 \begin{bmatrix} \sqrt[3]{l_{\text{ok}}} \\ \sqrt[3]{m_{\text{ok}}} \\ \sqrt[3]{s_{\text{ok}}} \end{bmatrix}$$
$$\begin{bmatrix} l_{\text{ok}} \\ m_{\text{ok}} \\ s_{\text{ok}} \end{bmatrix} = M_1 \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

1. Go to "LMS" space
(not a true LMS space)

2. Take cubic root

3. Arrive to OKLab space

```
graph LR; A["Lok, aok, bok"] --> B["l, m, s"]; B --> C["X, Y, Z"]; C --> D["l(ok), m(ok), s(ok)"]; D --> E["sqrt[3]l(ok), sqrt[3]m(ok), sqrt[3]s(ok)"]; E --> F["Lok, aok, bok"];
```

M_1/M_2 optimized to place Munsell patches as close as possible to their expected locations in Lab space

CAMERA OKLAB TRANSFORM

$$\begin{bmatrix} L_{\text{ok}} \\ a_{\text{ok}} \\ b_{\text{ok}} \end{bmatrix} = M_2^{\text{cam}} \begin{bmatrix} \sqrt[3]{l_{\text{ok}}} \\ \sqrt[3]{m_{\text{ok}}} \\ \sqrt[3]{s_{\text{ok}}} \end{bmatrix}$$
$$\begin{bmatrix} l_{\text{ok}} \\ m_{\text{ok}} \\ s_{\text{ok}} \end{bmatrix} = M_1^{\text{cam}} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

1. Go to "LMS" space
(even less of a true LMS space)

2. Take cubic root

3. Arrive to OKLab space

Camera M_1/M_2 re-optimized to place Munsell patches as close as possible to their canonical OKLab locations

Bootstrap optimizer with $M_1^{\text{cam}} = M_1 \cdot M_{\text{XYZ}}^{\text{RGB}}$

CAMERA OKLAB TRANSFORM

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = M_1^{-1} \begin{bmatrix} (l_{\text{ok}})^3 \\ (m_{\text{ok}})^3 \\ (s_{\text{ok}})^3 \end{bmatrix}$$

$$\begin{bmatrix} l_{\text{ok}} \\ m_{\text{ok}} \\ s_{\text{ok}} \end{bmatrix} = M_2^{-1} \cdot M_2^{\text{cam}}$$

$$\begin{bmatrix} \sqrt[3]{l_{\text{ok}}^{\text{cam}}} \\ \sqrt[3]{m_{\text{ok}}^{\text{cam}}} \\ \sqrt[3]{s_{\text{ok}}^{\text{cam}}} \end{bmatrix}$$

$$\begin{bmatrix} l_{\text{ok}}^{\text{cam}} \\ m_{\text{ok}}^{\text{cam}} \\ s_{\text{ok}}^{\text{cam}} \end{bmatrix} = M_1^{\text{cam}} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Canonical OKLab inverse

Camera OKLab direct

Camera OKLab provides an opportunity for tonemapping camera RGB data: apply the optimized transform and then a canonical inverse OKLab transform, obtaining a CameraRGB to XYZ1931 mapping



Image courtesy of Johannes Hanika

Adobe DNG 3-by-3

OKLab⁻¹(CamOKLab)

Spectral Luma/Chroma LUT

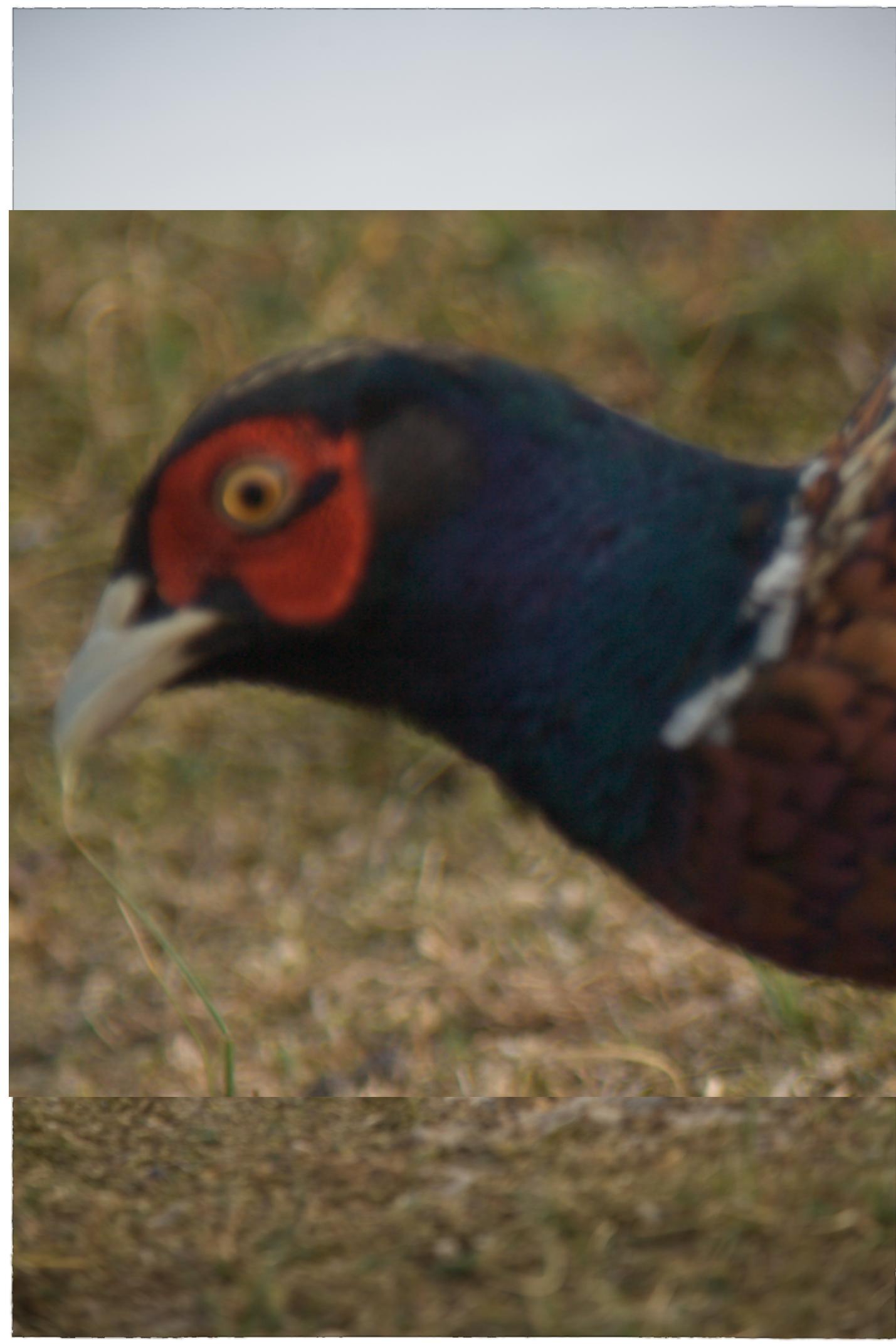
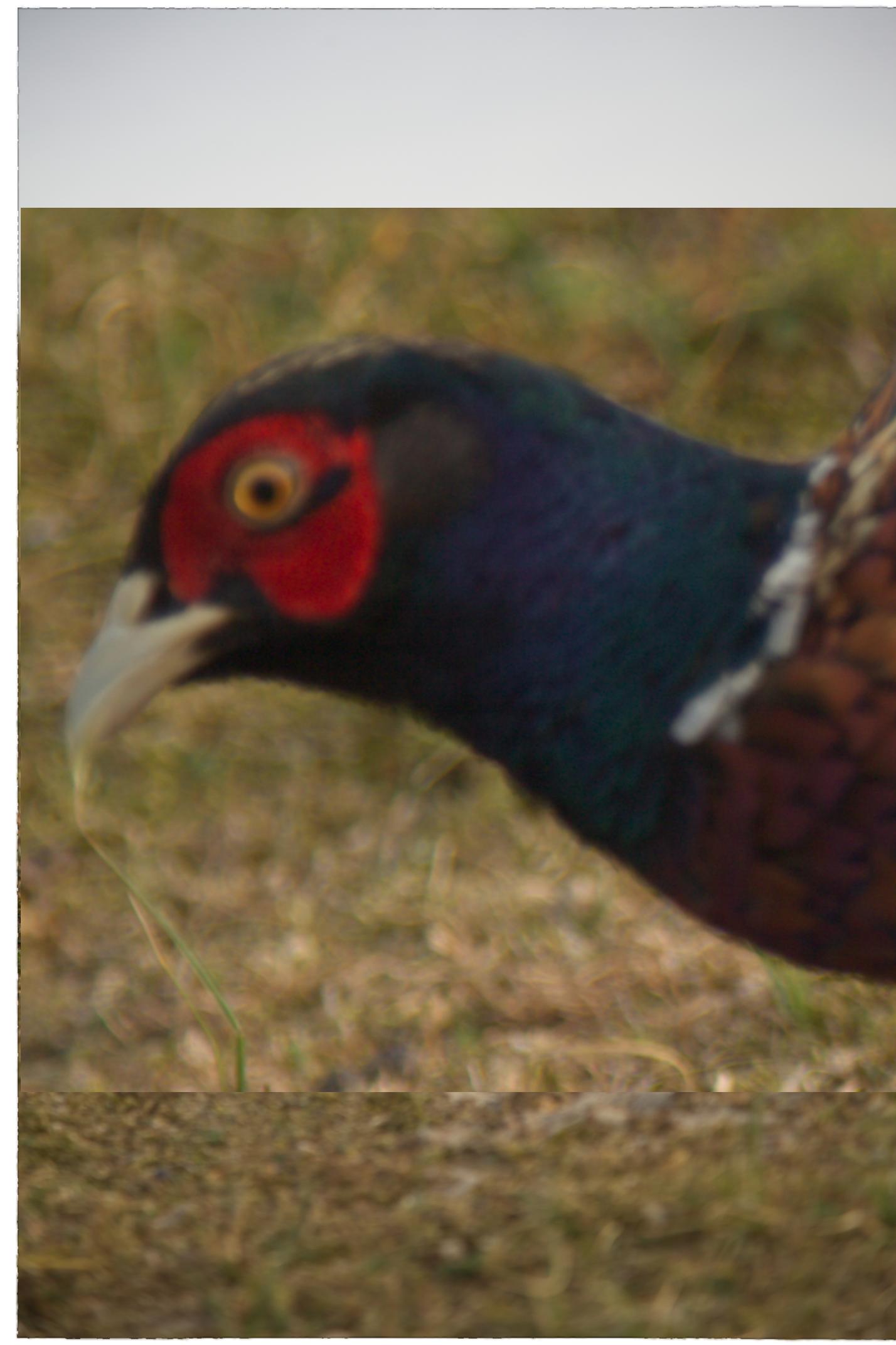
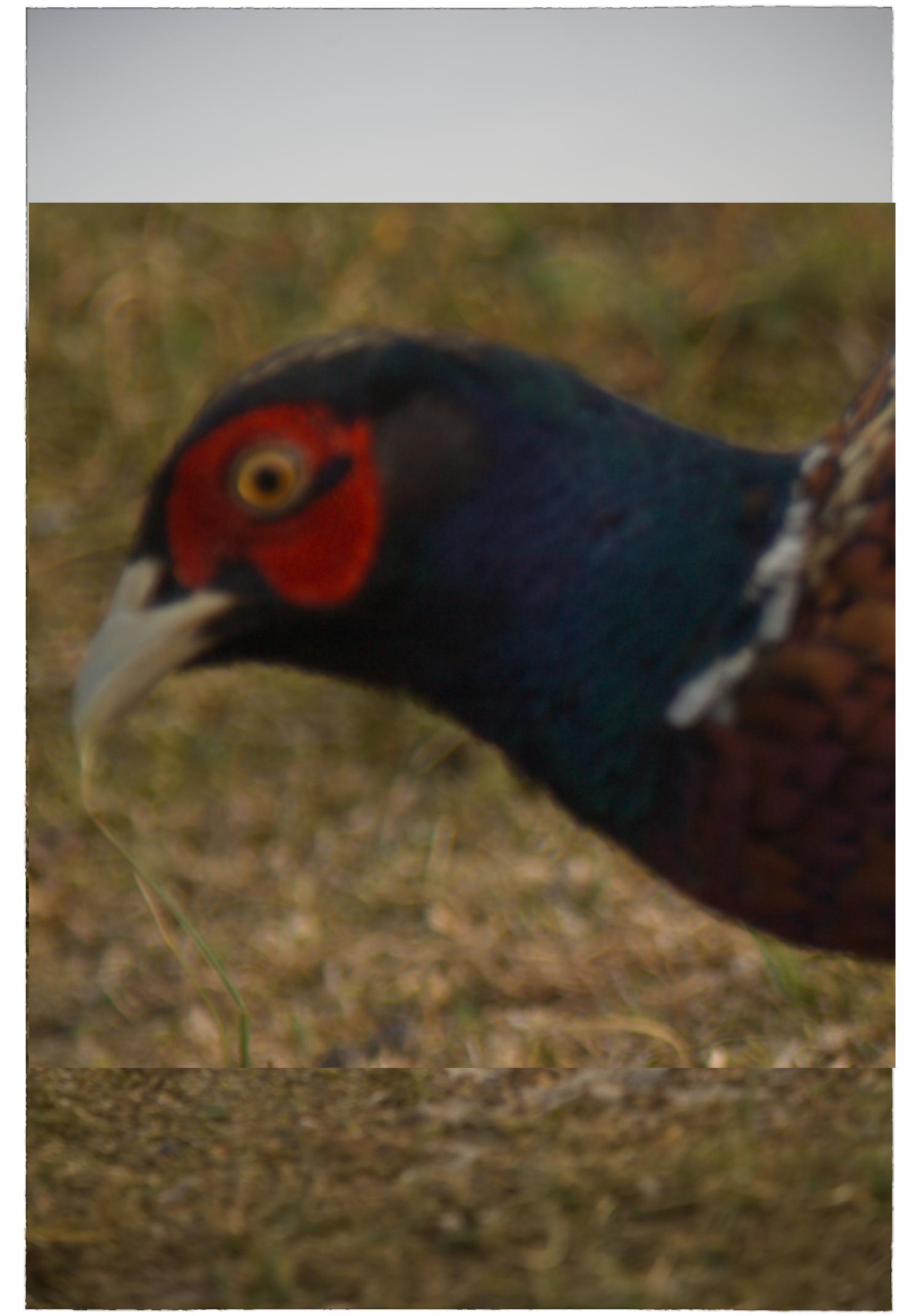


Image courtesy of Johannes Hanika

Adobe DNG 3-by-3

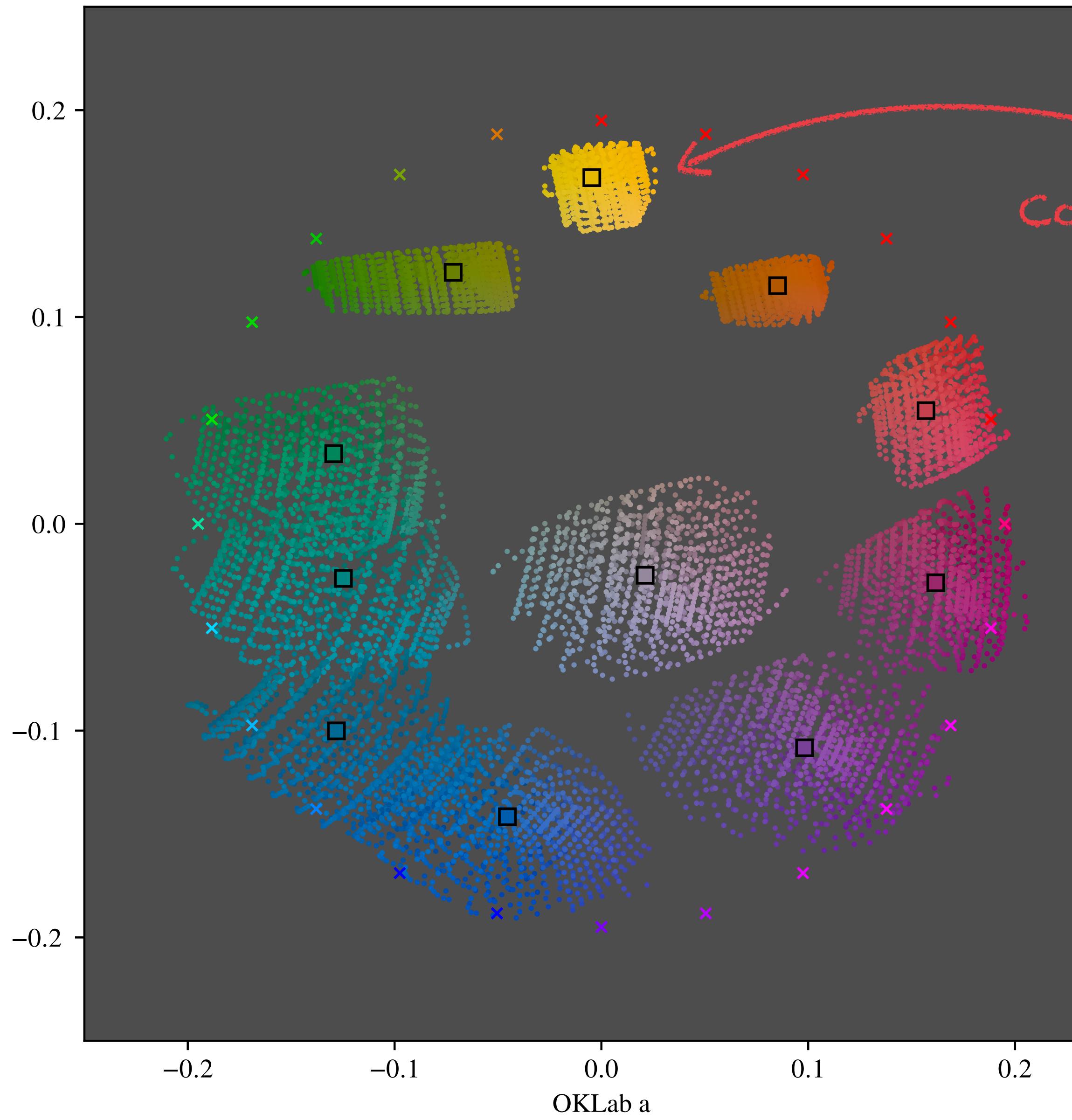


OKLab⁻¹(CamOKLab)



Spectral Luma/Chroma LUT

Canon-5D MarkII metamers (DUT) as seen by XYZ-1931 (ref)



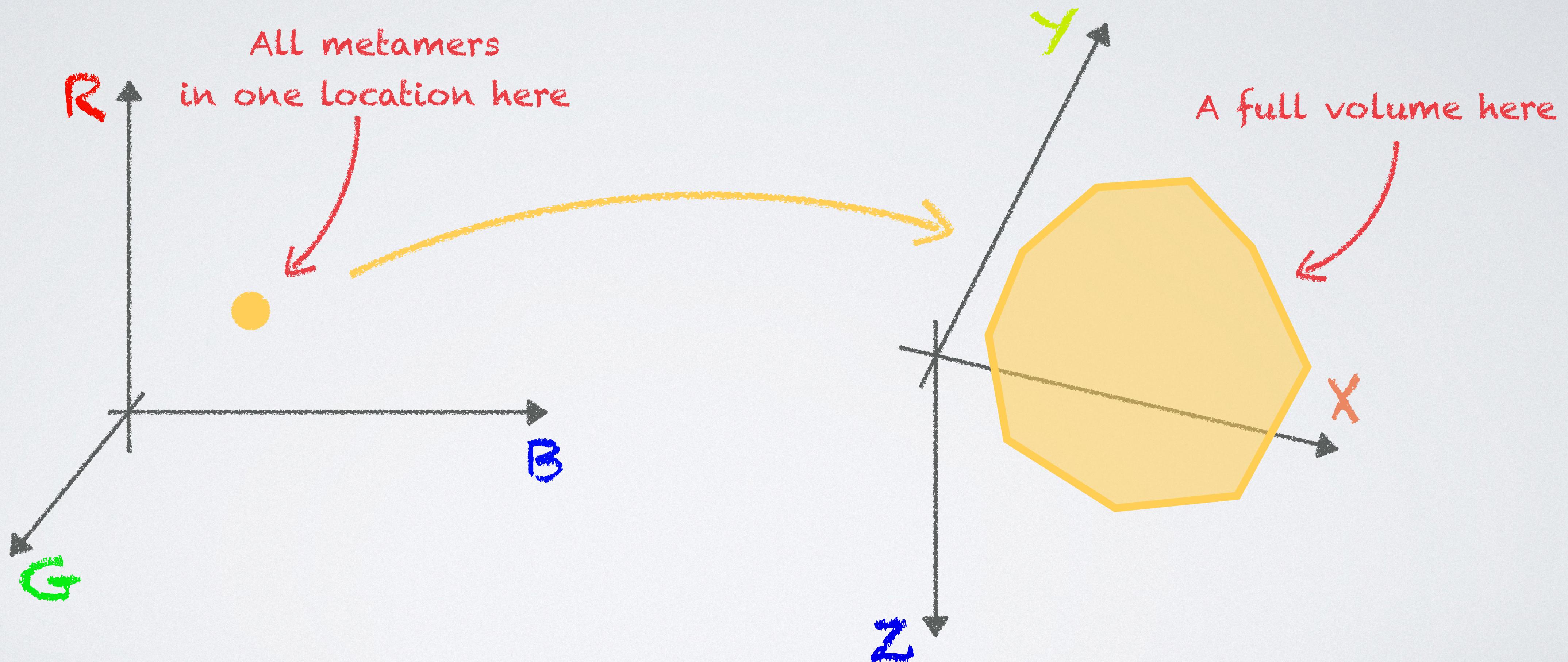
MAXIMAL CMV

DUT: Canon 5D MkII

Ref: XYZ 1931

OKLab color space (a/b plane)

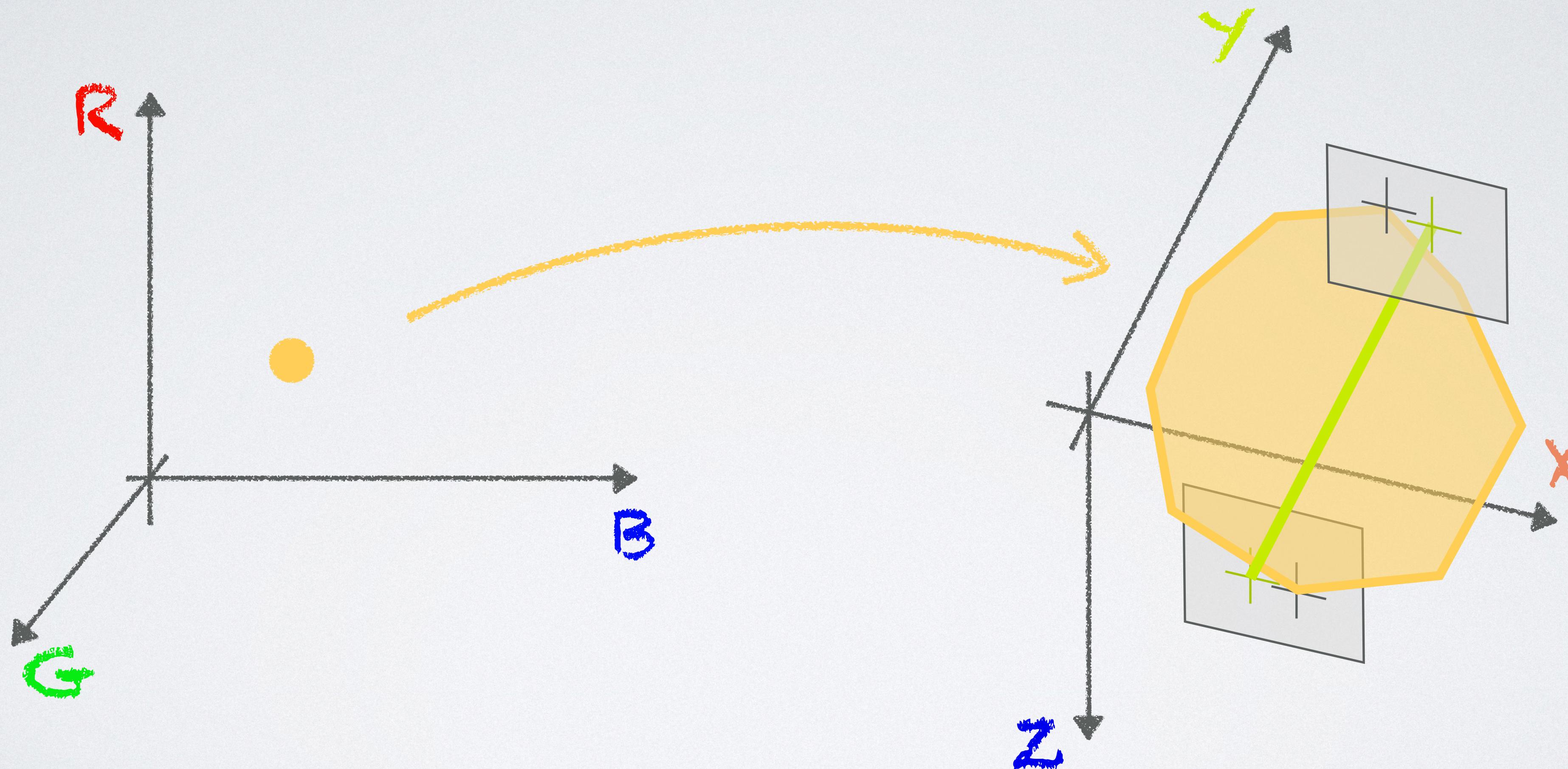
MAXIMAL CMV



DUT: Canon 5D MkII

Ref: XYZ 1931

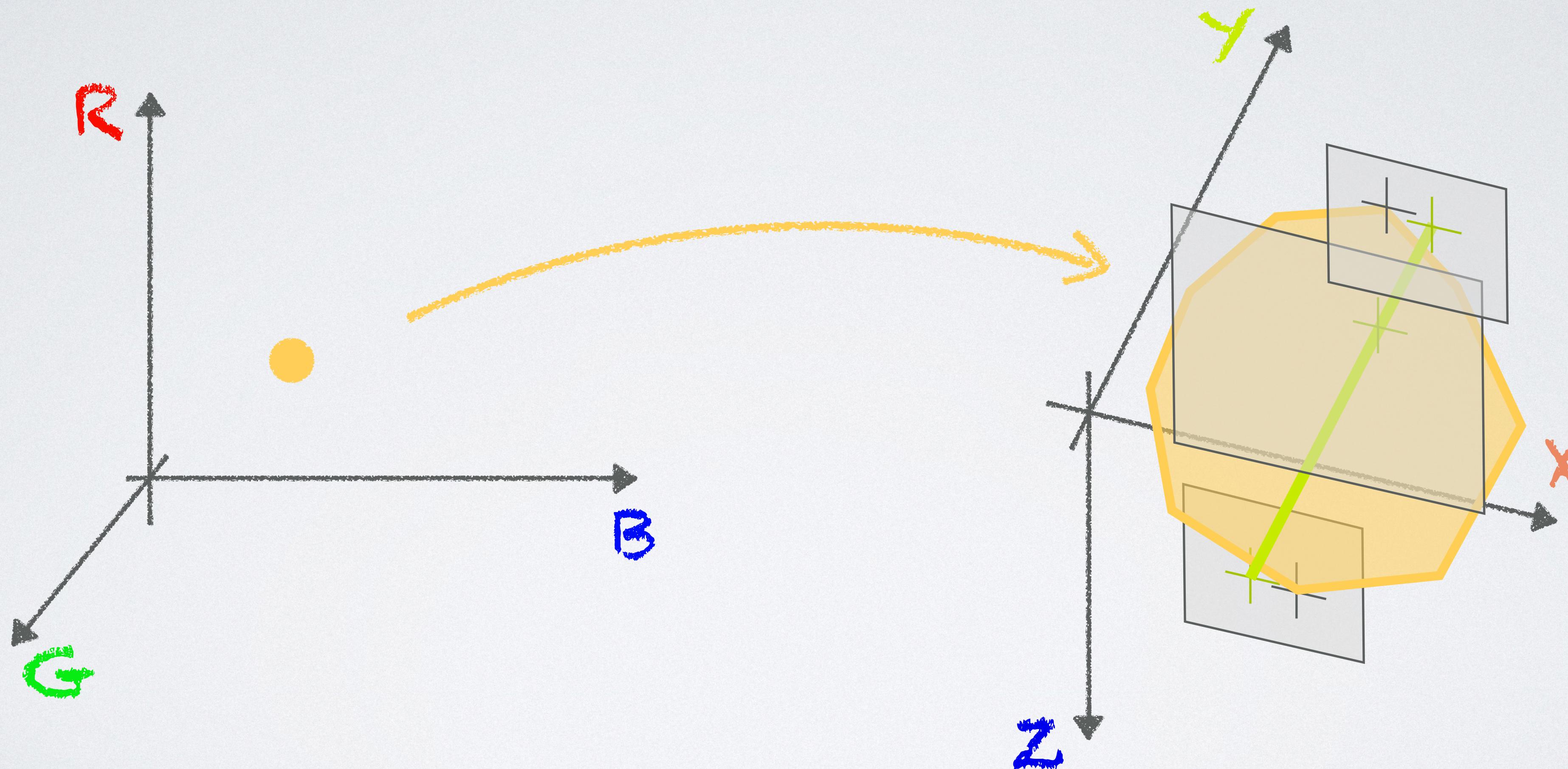
MAXIMAL CMV



DUT: Canon 5D MkII

Ref: XYZ 1931

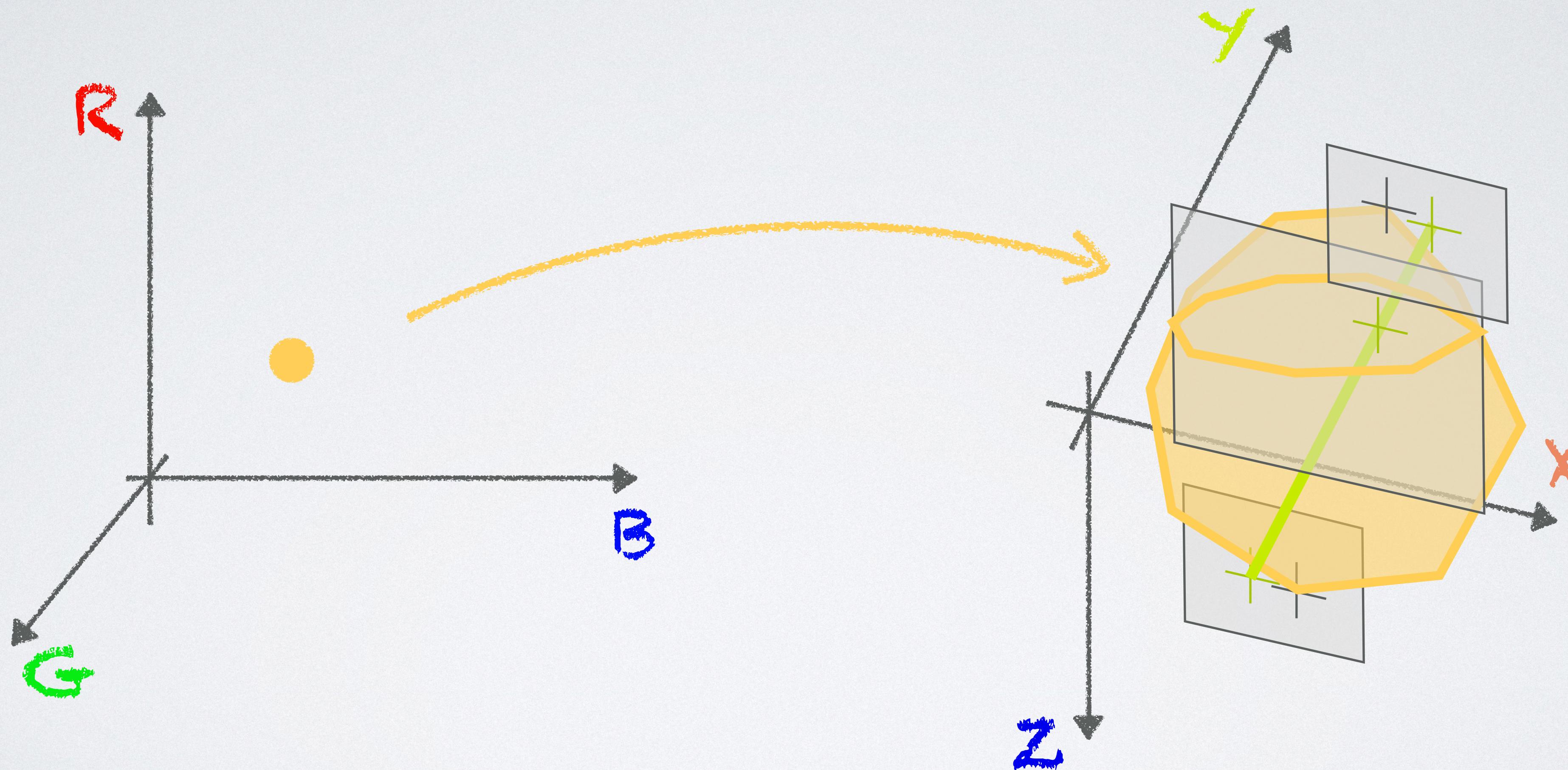
MAXIMAL CMV



DUT: Canon 5D MkII

Ref: XYZ 1931

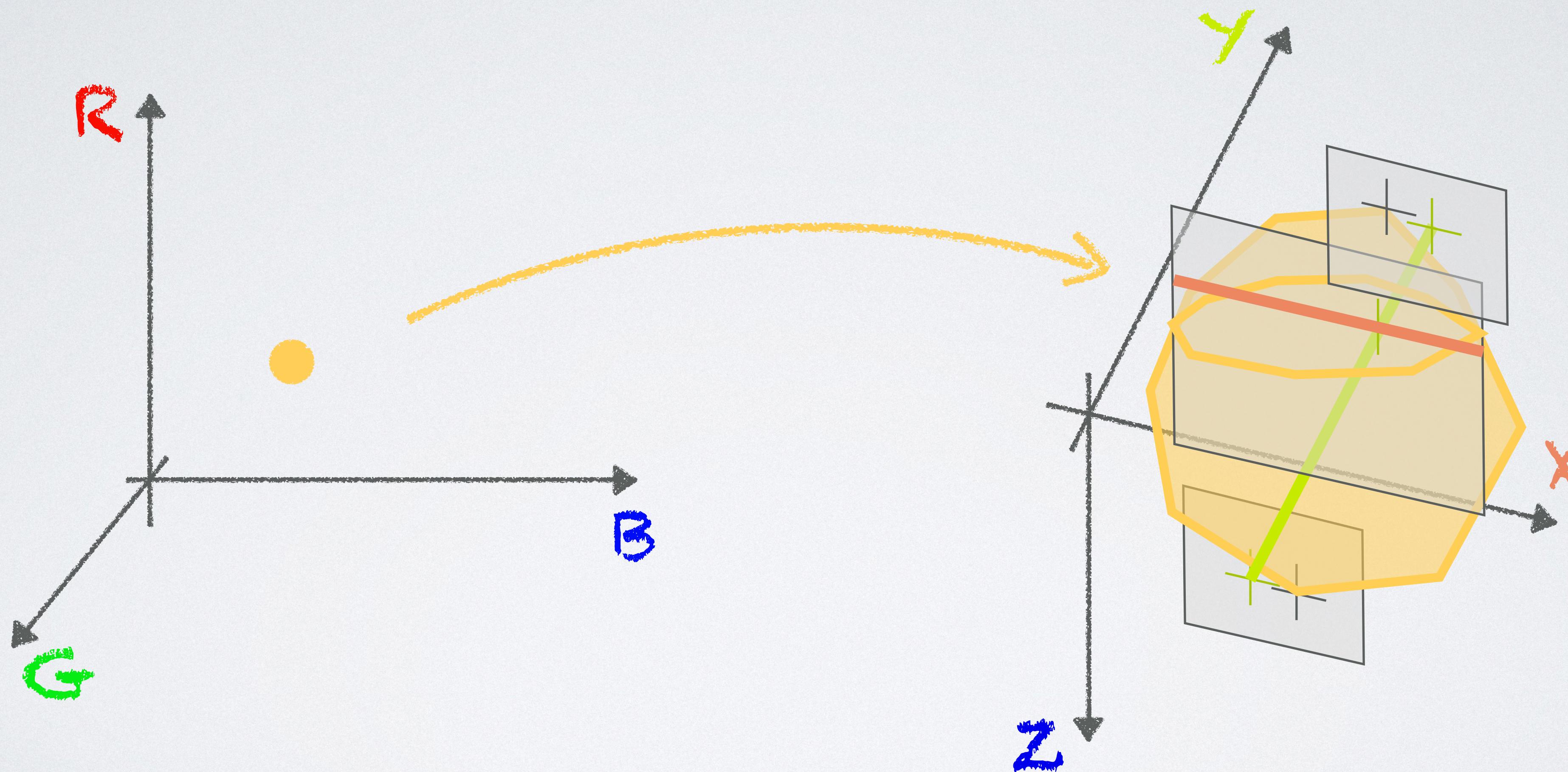
MAXIMAL CMV



DUT: Canon 5D MkII

Ref: XYZ 1931

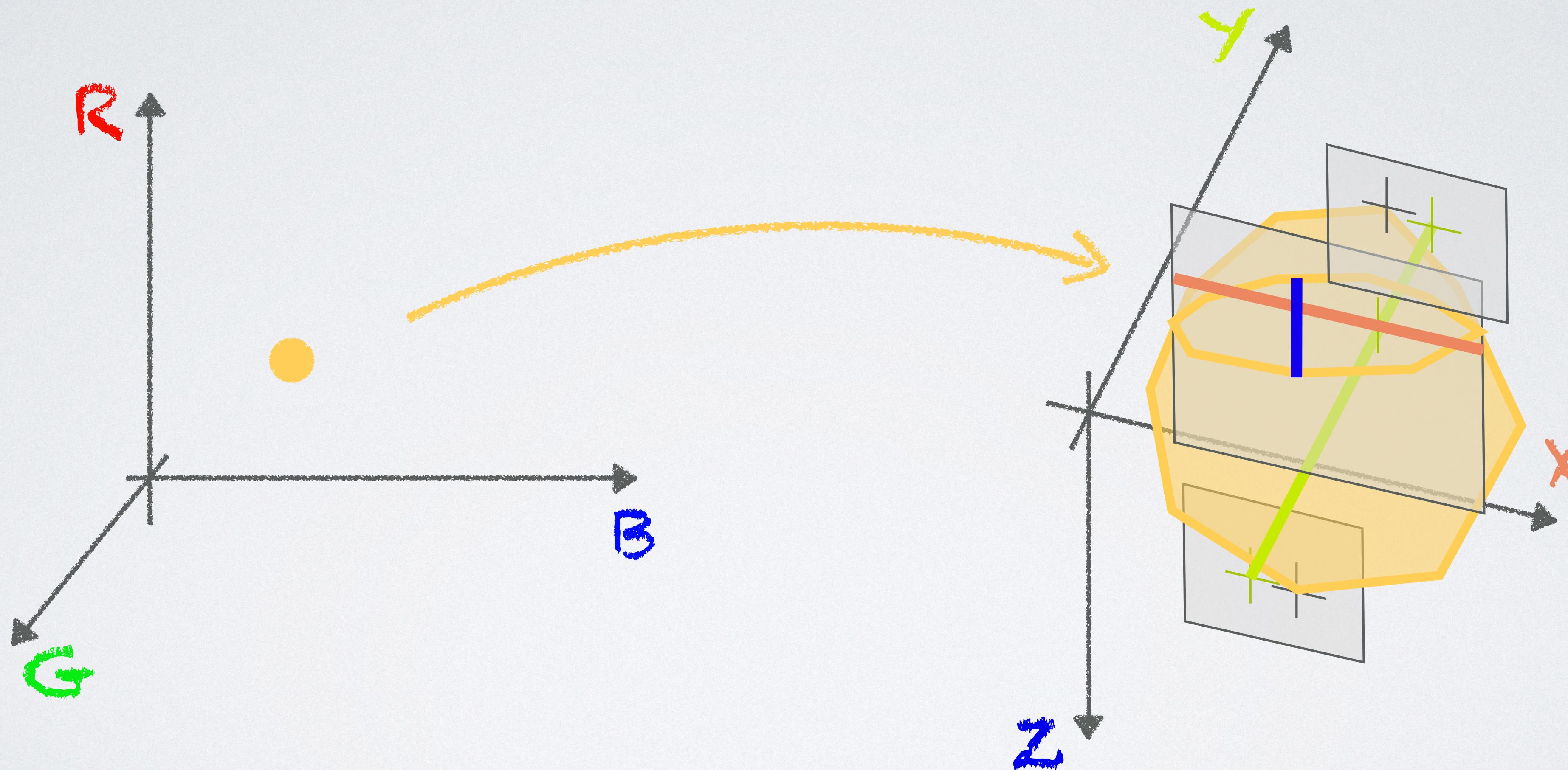
MAXIMAL CMV



DUT: Canon 5D MkII

Ref: XYZ 1931

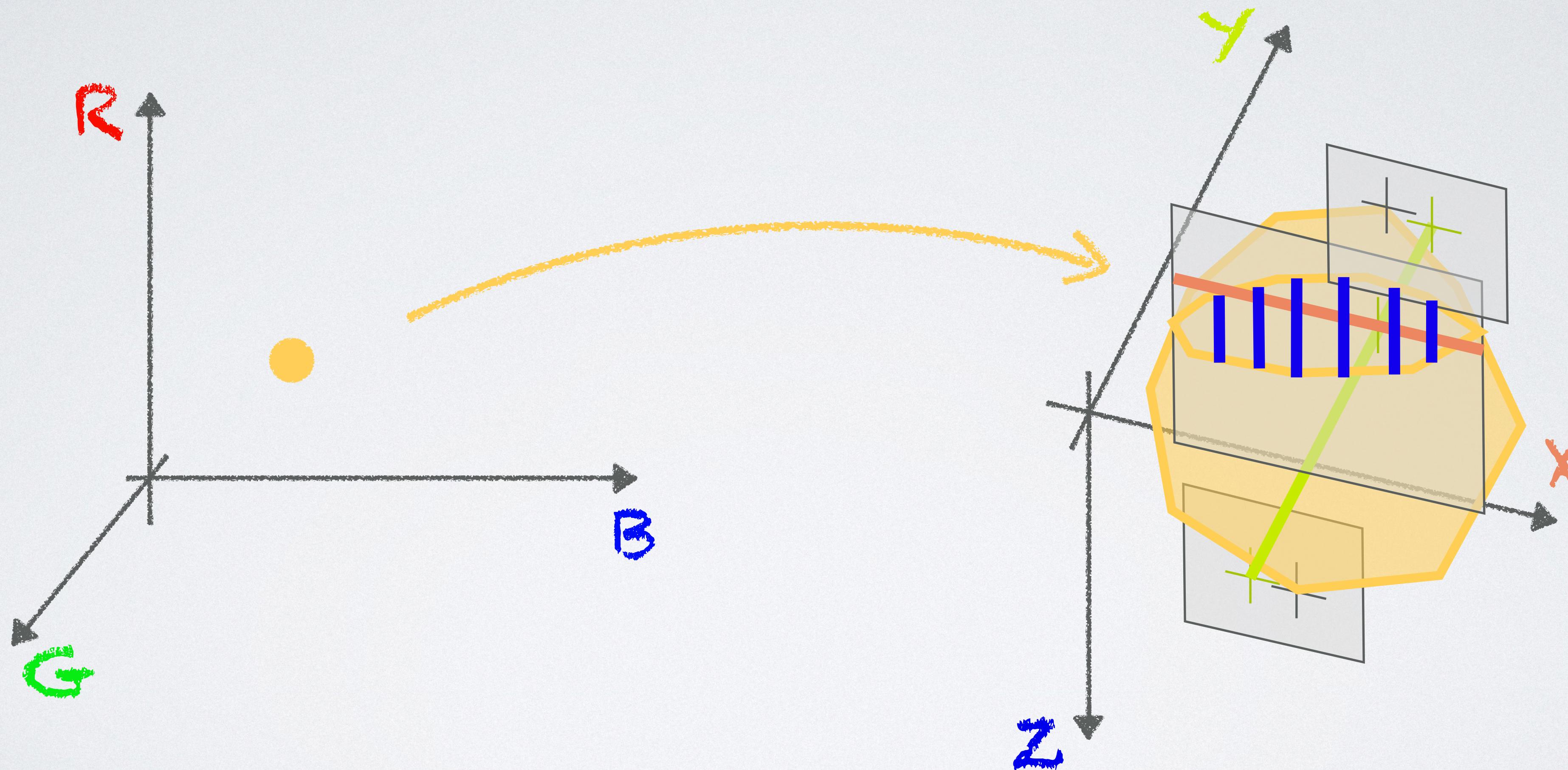
MAXIMAL CMV



DUT: Canon 5D MkII

Ref: XYZ 1931

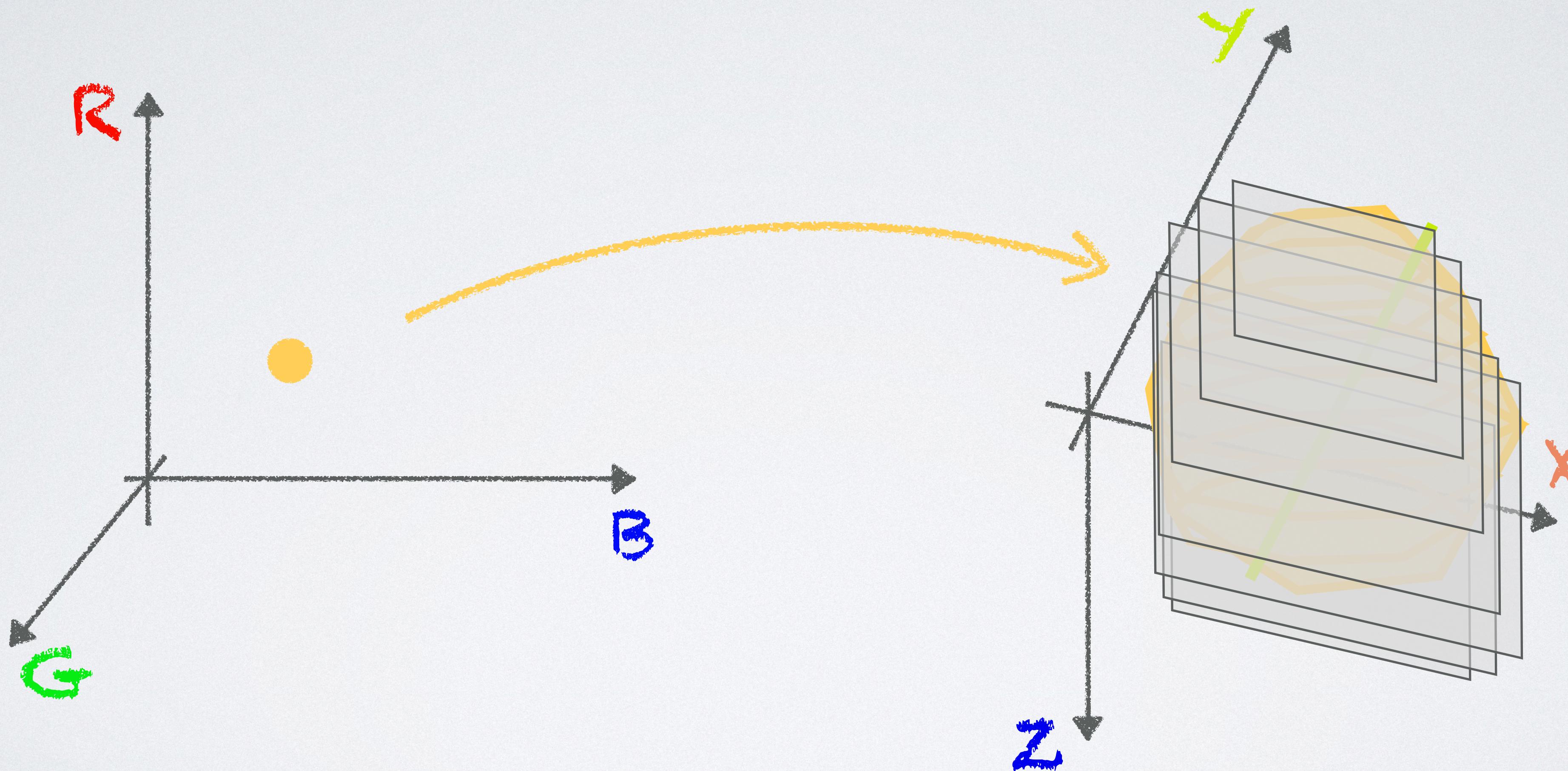
MAXIMAL CMV



DUT: Canon 5D MkII

Ref: XYZ 1931

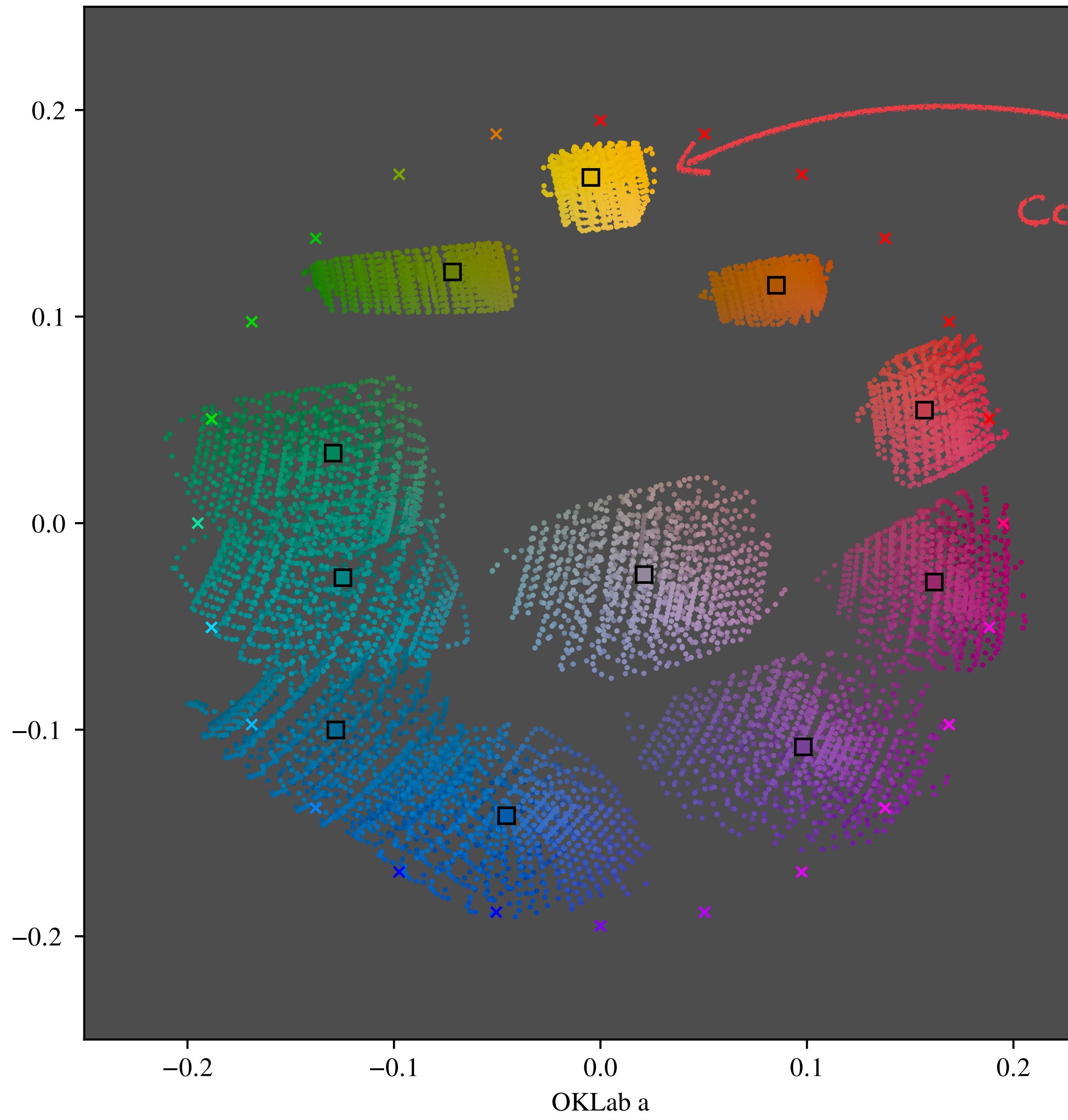
MAXIMAL CMV



DUT: Canon 5D MkII

Ref: XYZ 1931

Canon-5D MarkII metamers (DUT) as seen by XYZ-1931 (ref)



MAXIMAL CMV

DUT: Canon 5D MkII

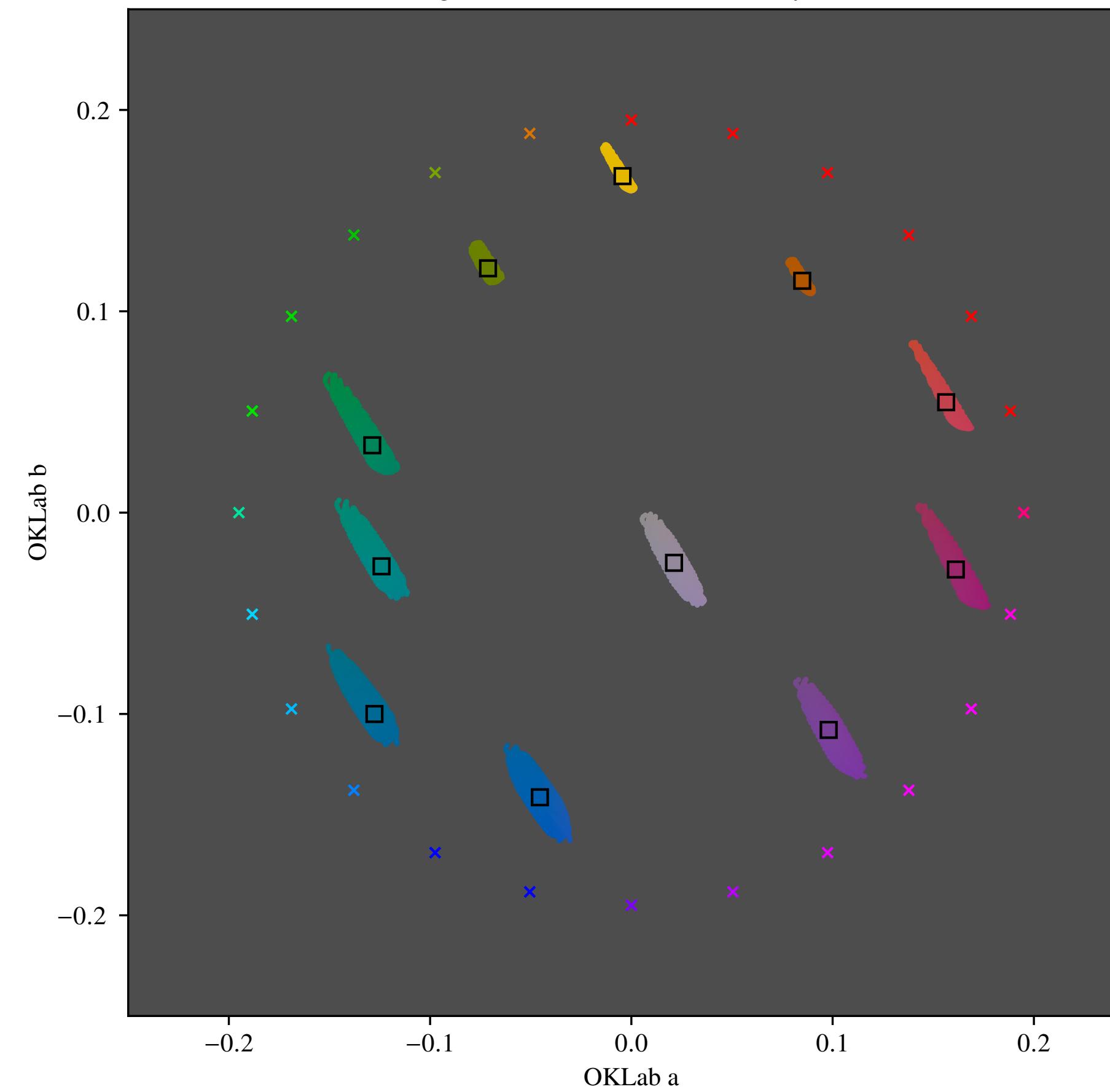
Ref: XYZ 1931

OKLab color space (a/b plane)

MAXIMAL CMV

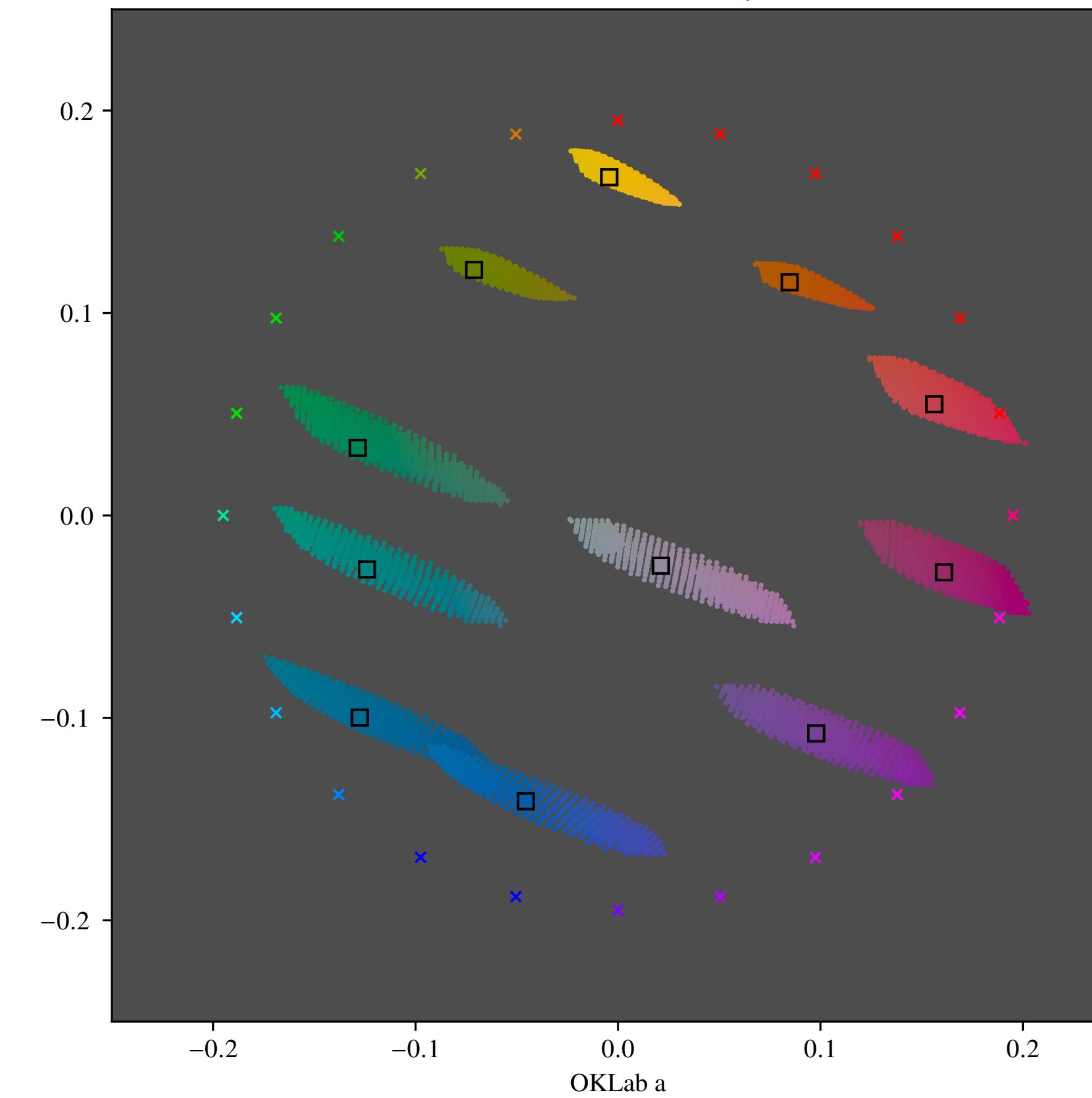
DUT: LMS2006

LMS-2006-2deg metamers (DUT) as seen by XYZ-1931 (ref)



DUT: XYZ1964 (10°)

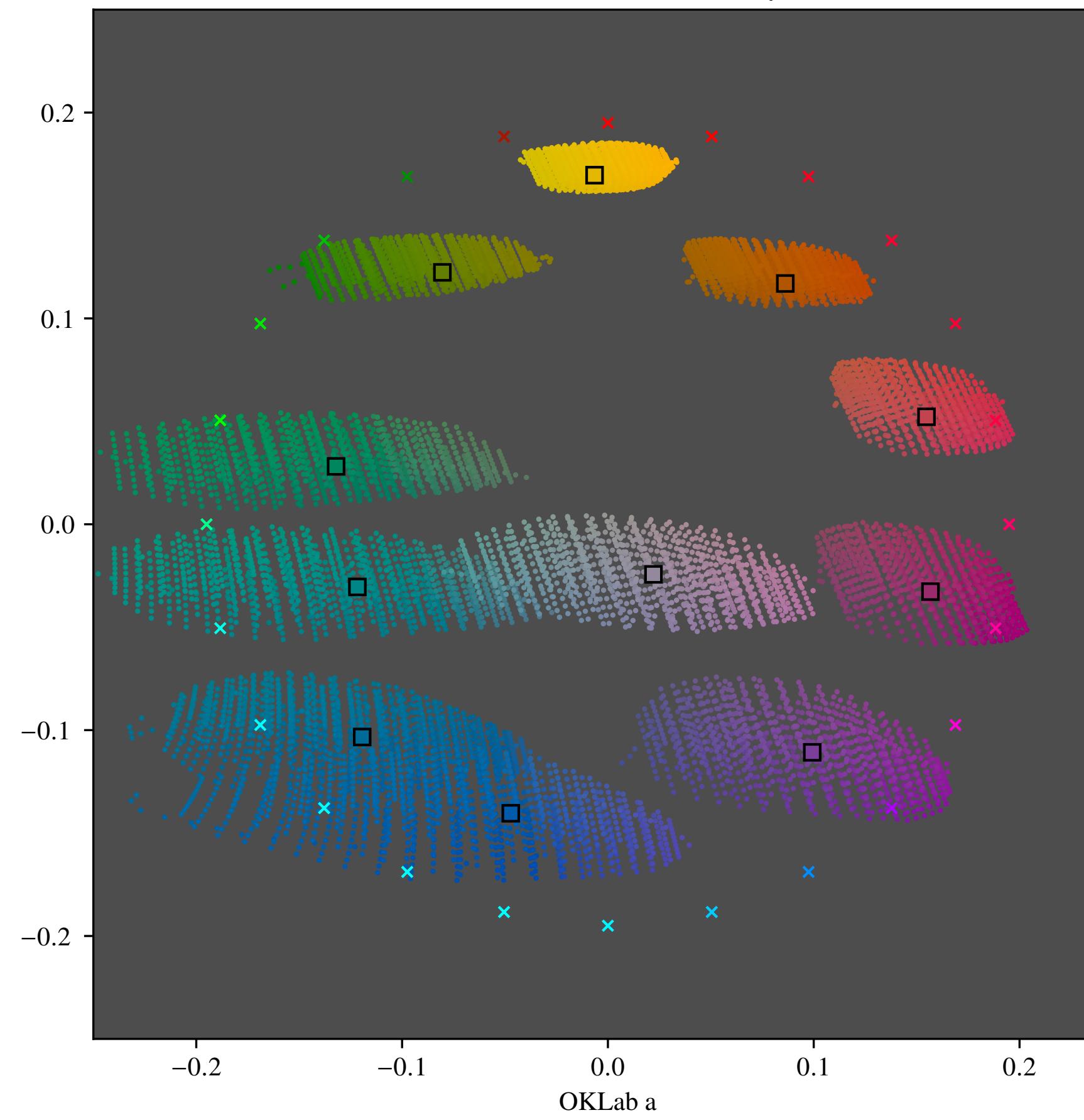
XYZ-1964 metamers (DUT) as seen by XYZ-1931 (ref)



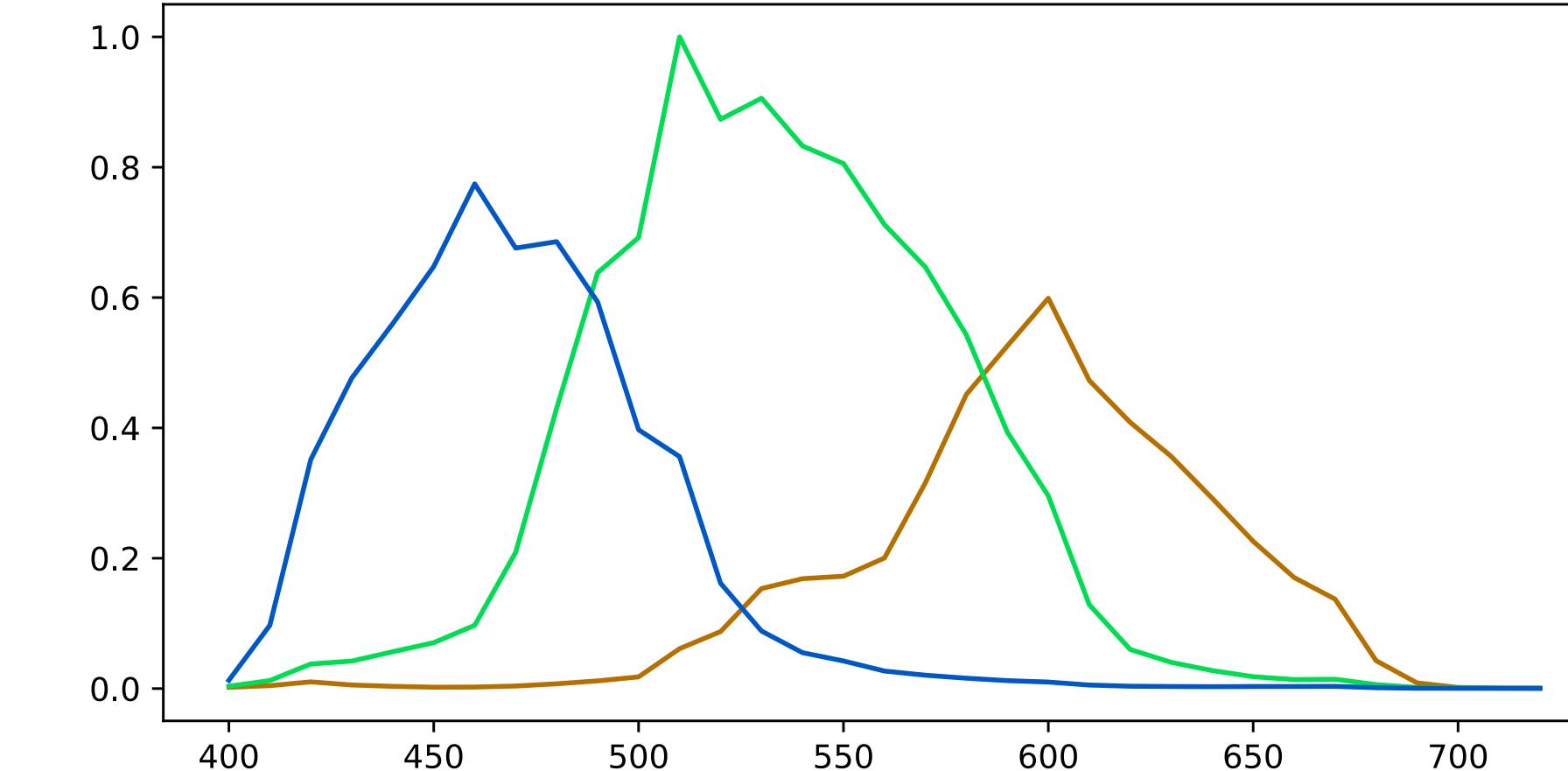
MAXIMAL CMV

DUT: Canon 5DMkII - Ref: Nikon D700

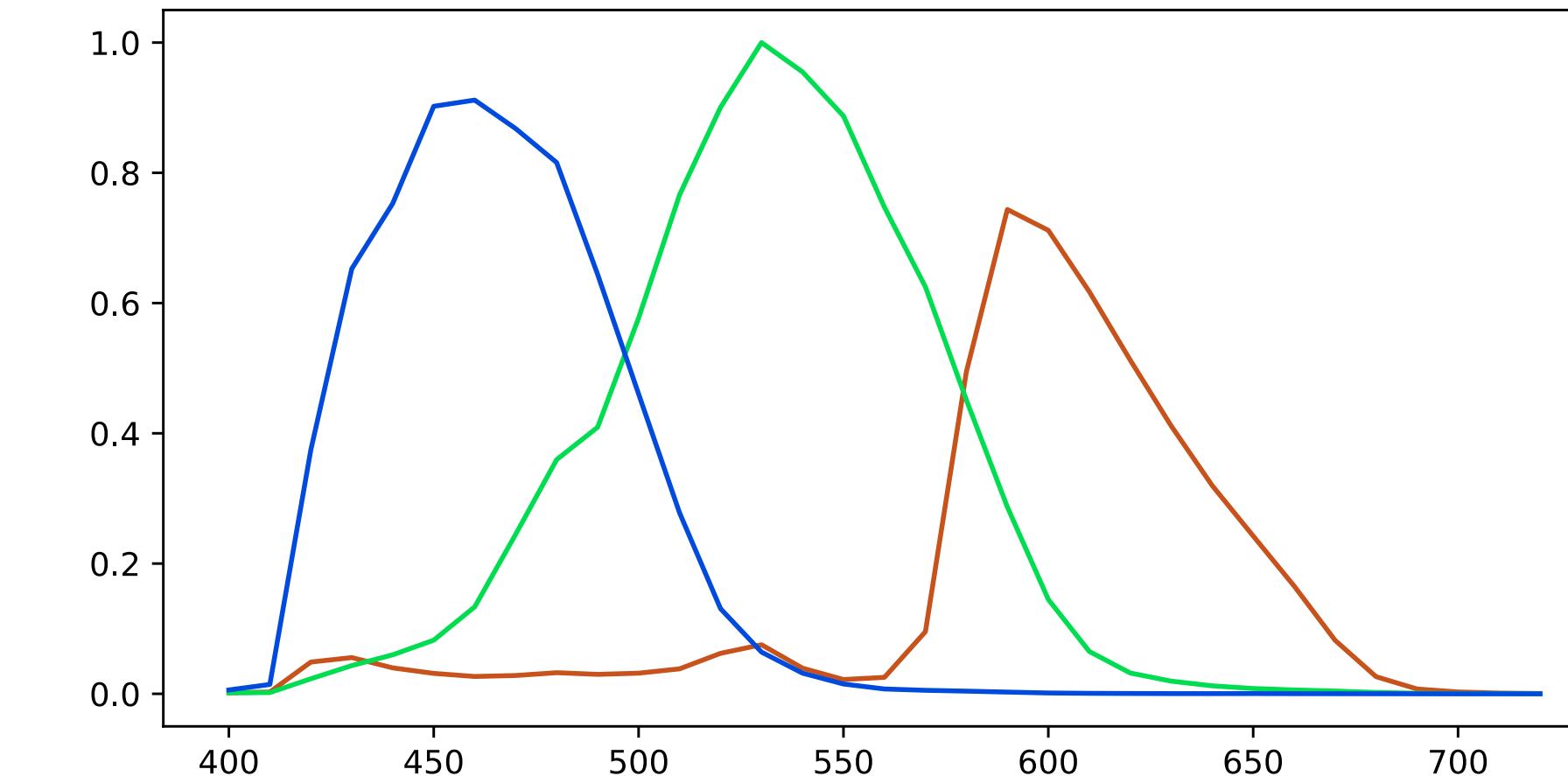
Canon-5DmarkII metamers (DUT) as seen by Nikon-D700 (ref)



Spectral response of Canon_5DMarkII



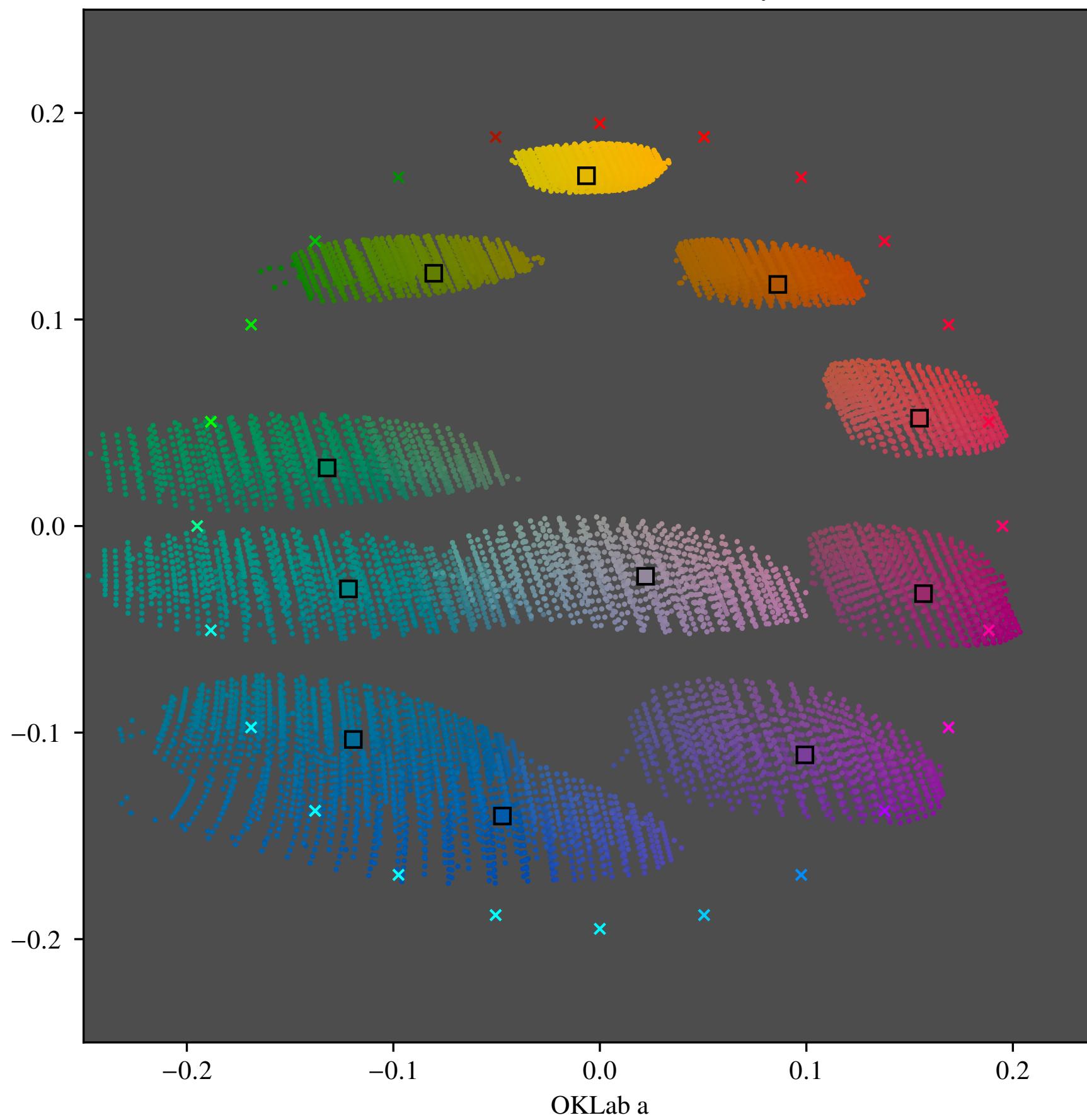
Spectral response of Nikon_D700



MAXIMAL CMV

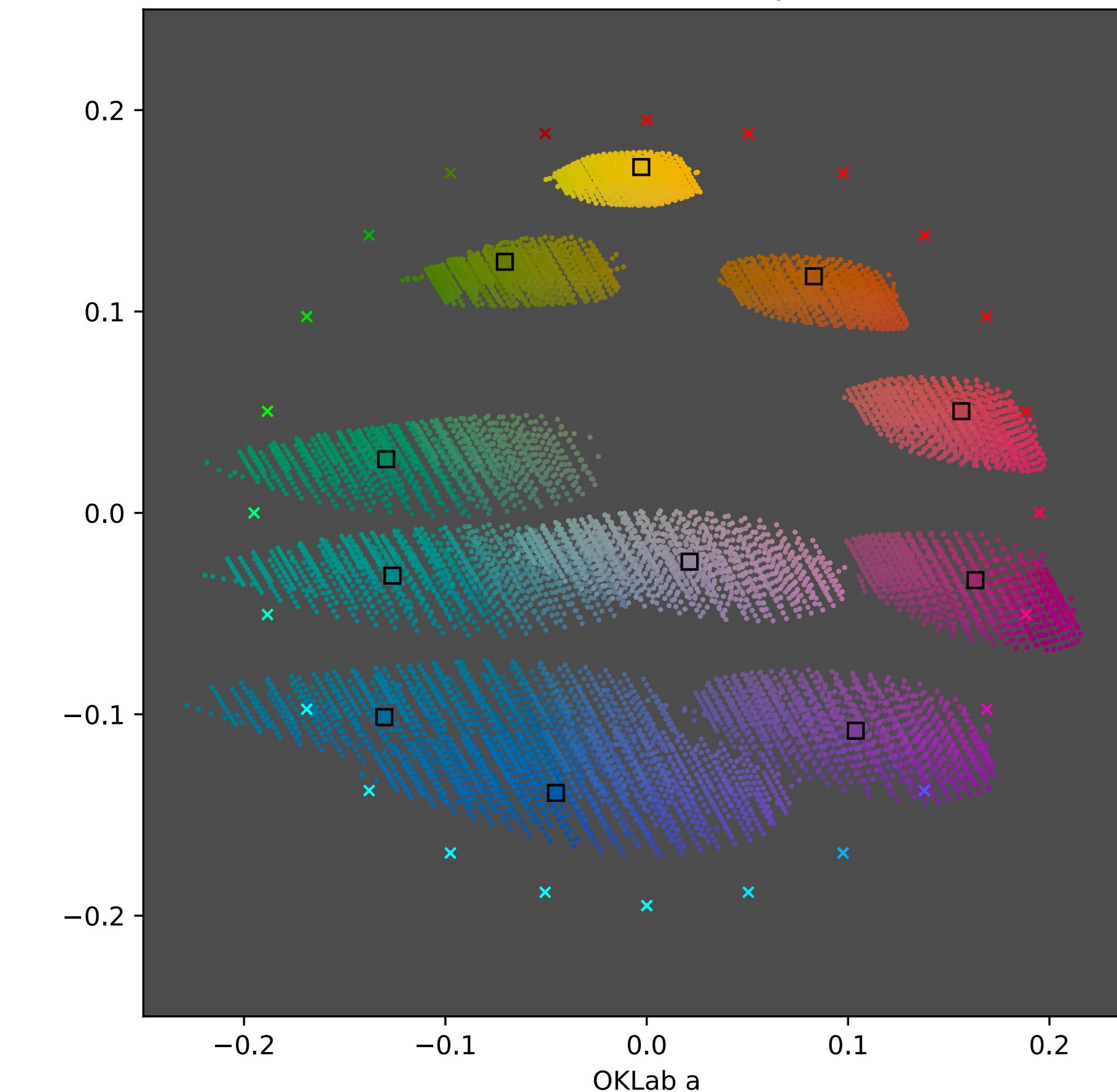
DUT: Canon 5DMkII - Ref: Nikon D700

Canon-5DMarkII metamers (DUT) as seen by Nikon-D700 (ref)

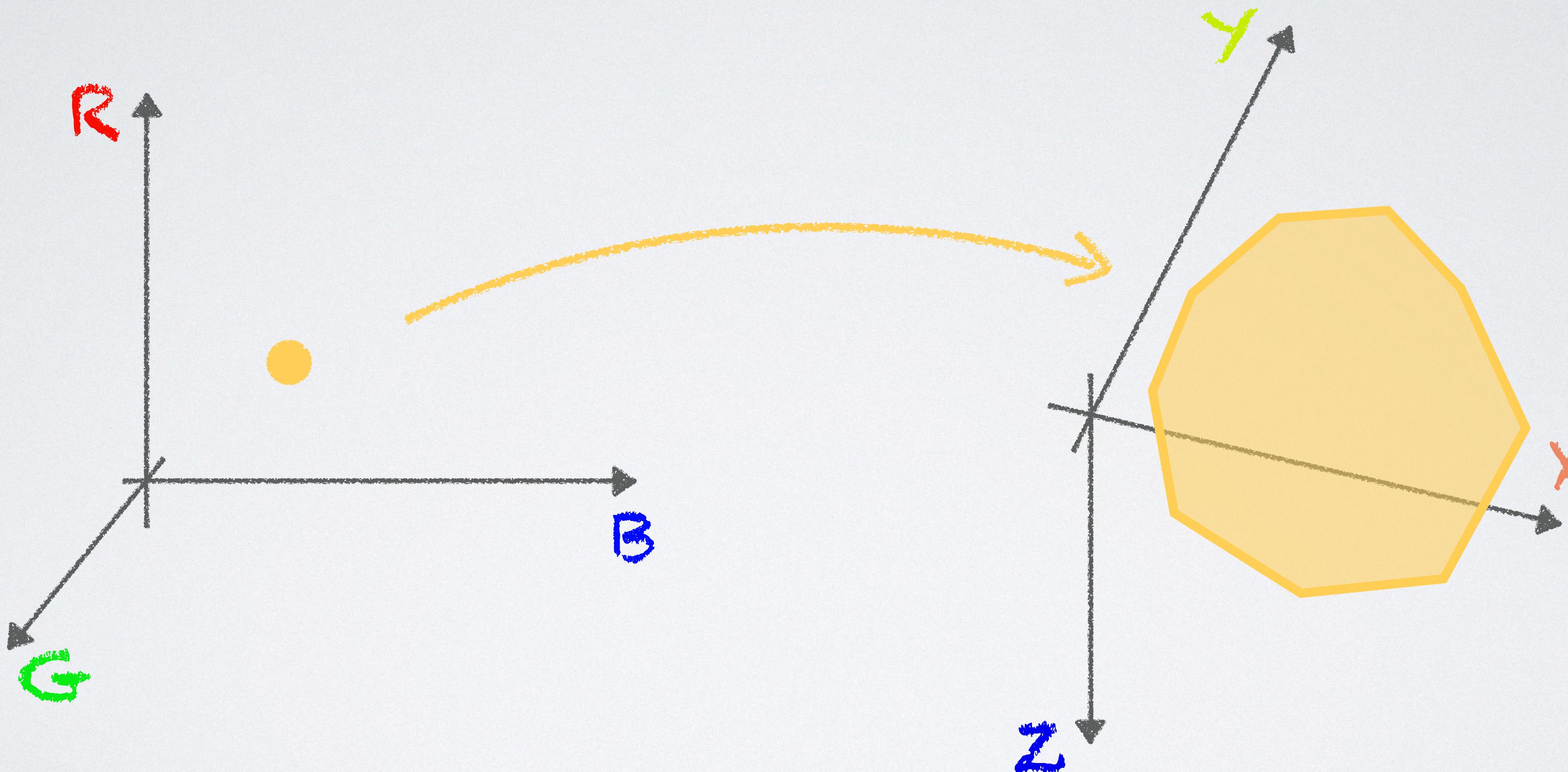


DUT: Nikon D700 - Ref: Canon 5DMkII

Nikon-D700 metamers (DUT) as seen by Canon-5DMarkII (ref)



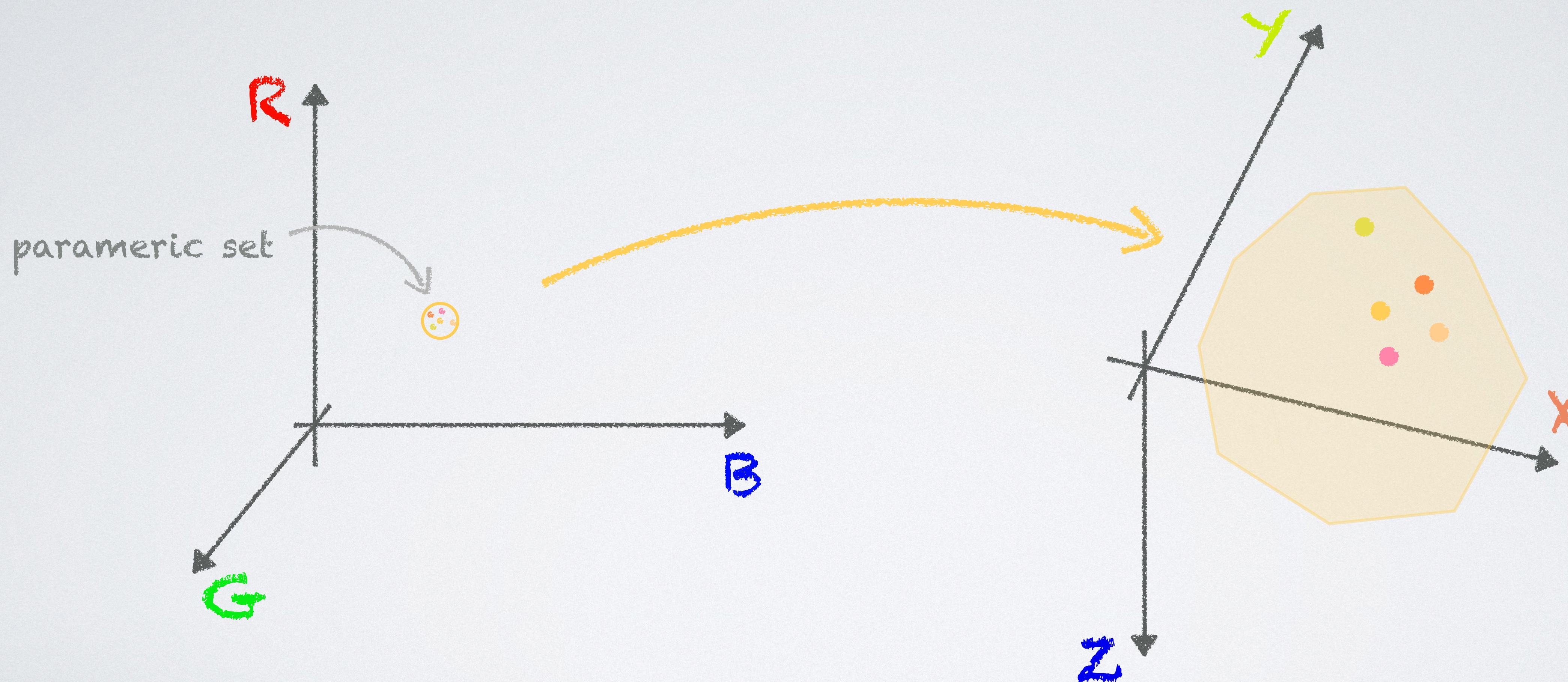
EMPIRICAL MISMATCH VOLUMES



DUT: Canon 5D MkII

Ref: XYZ 1931

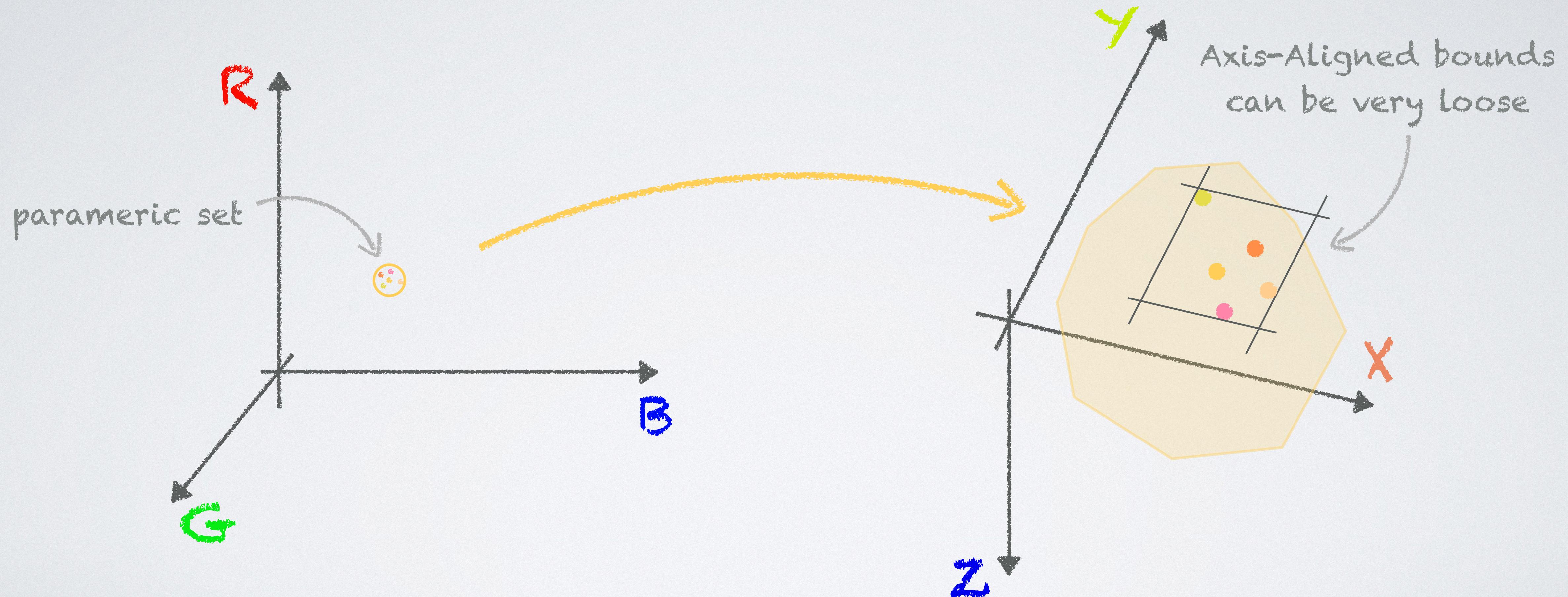
EMPIRICAL MISMATCH VOLUMES



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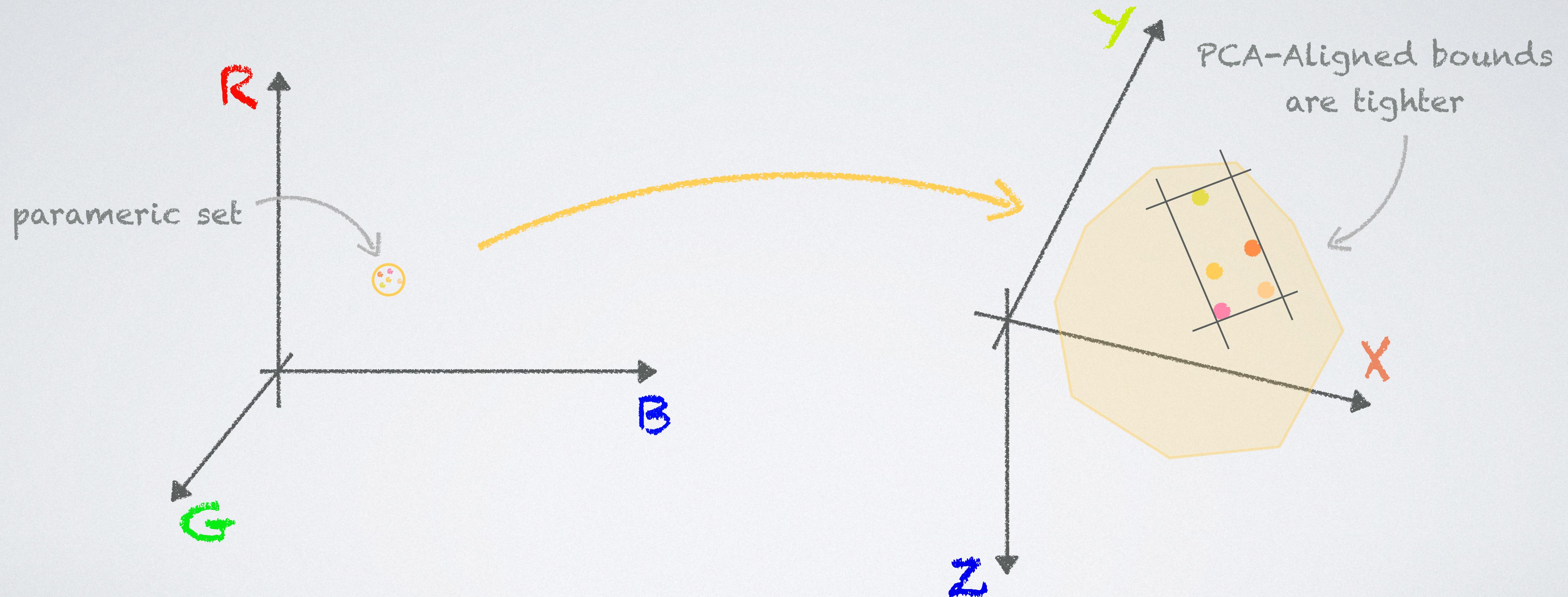
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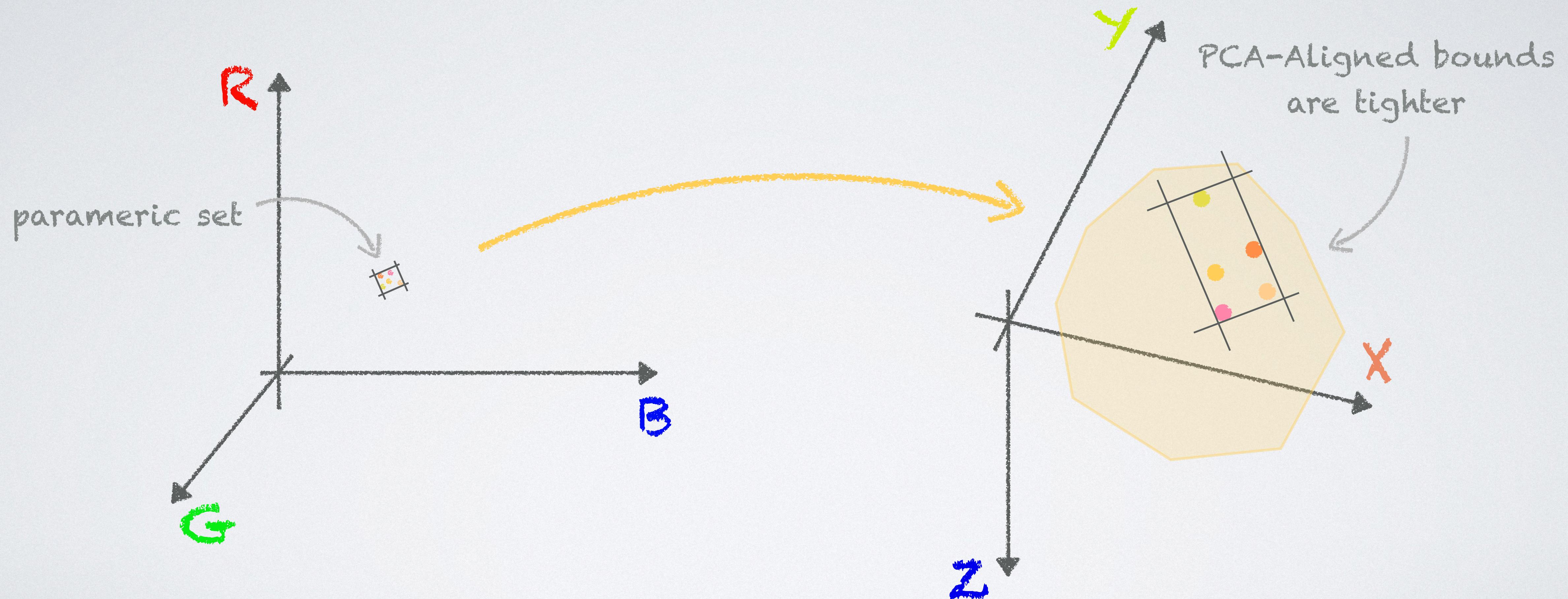
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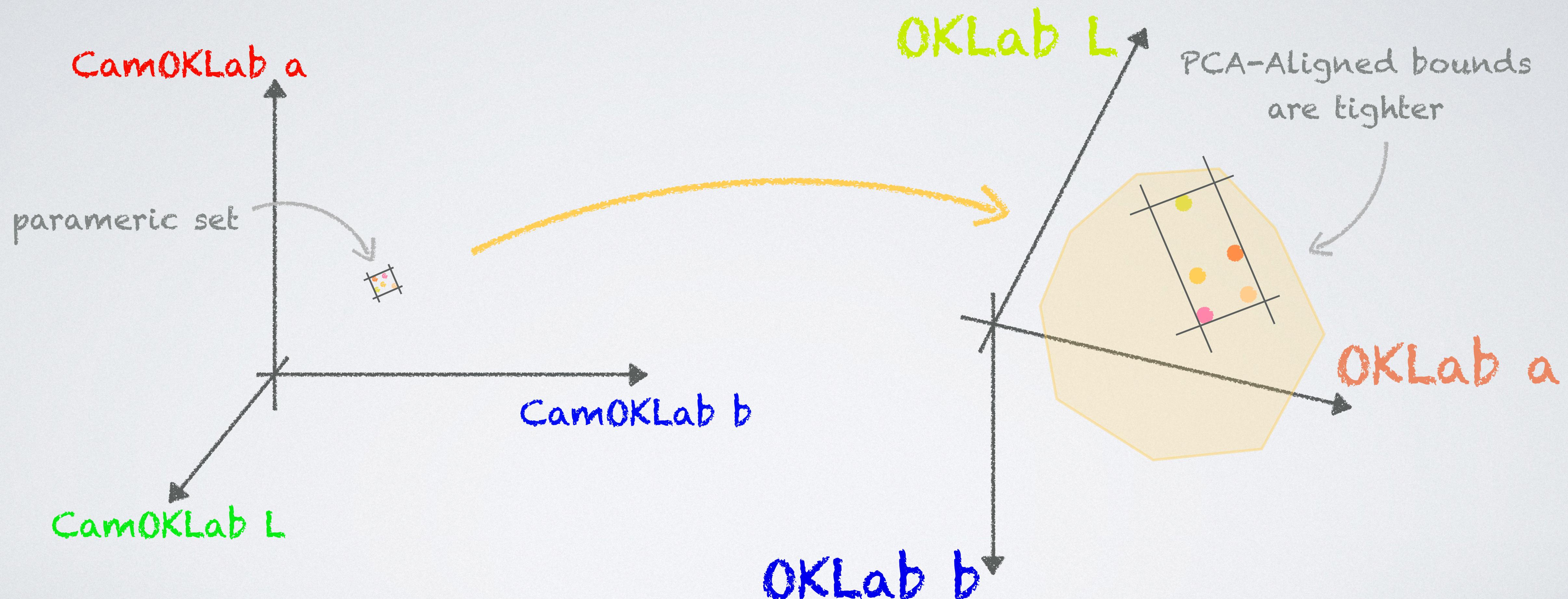
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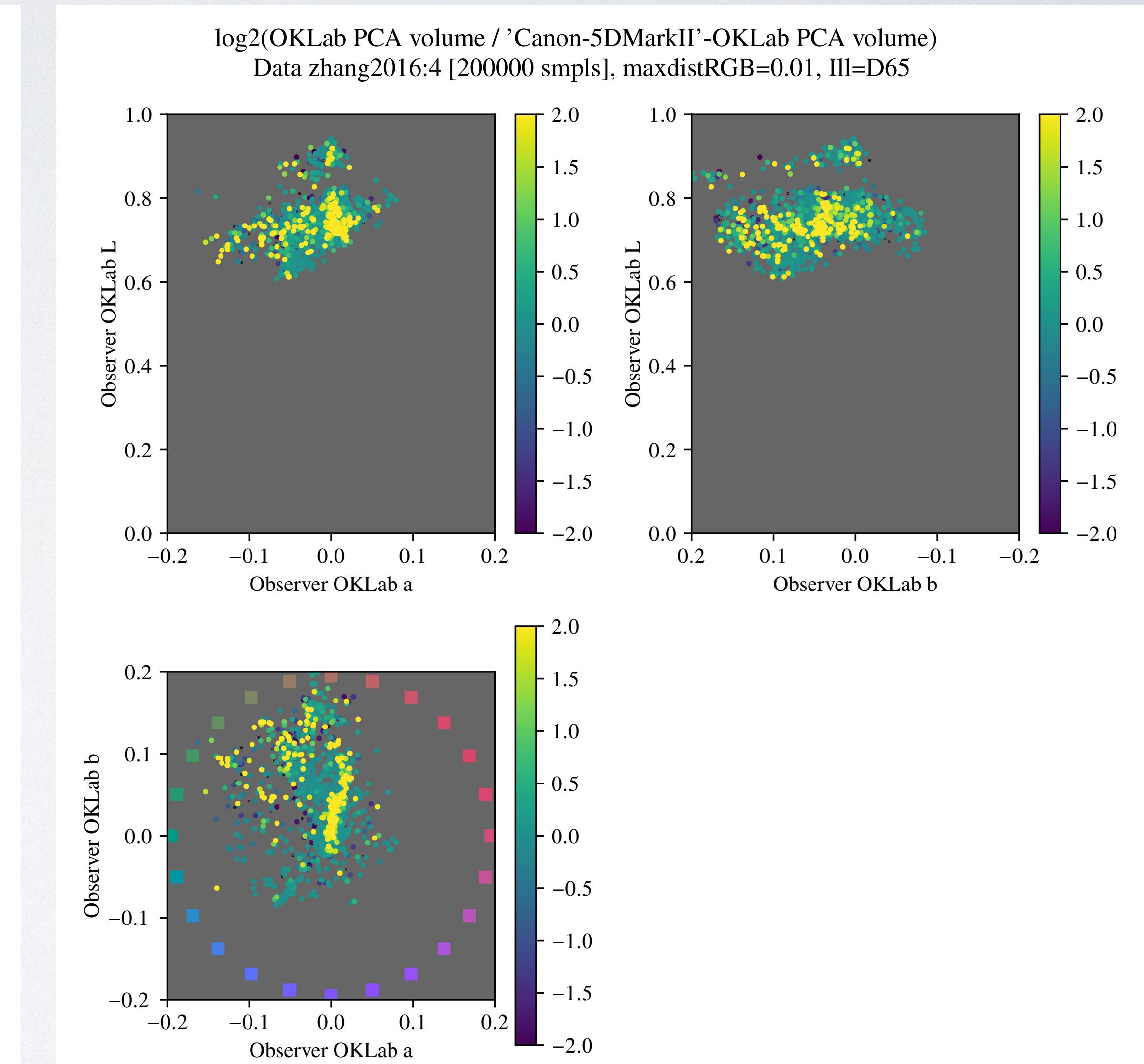
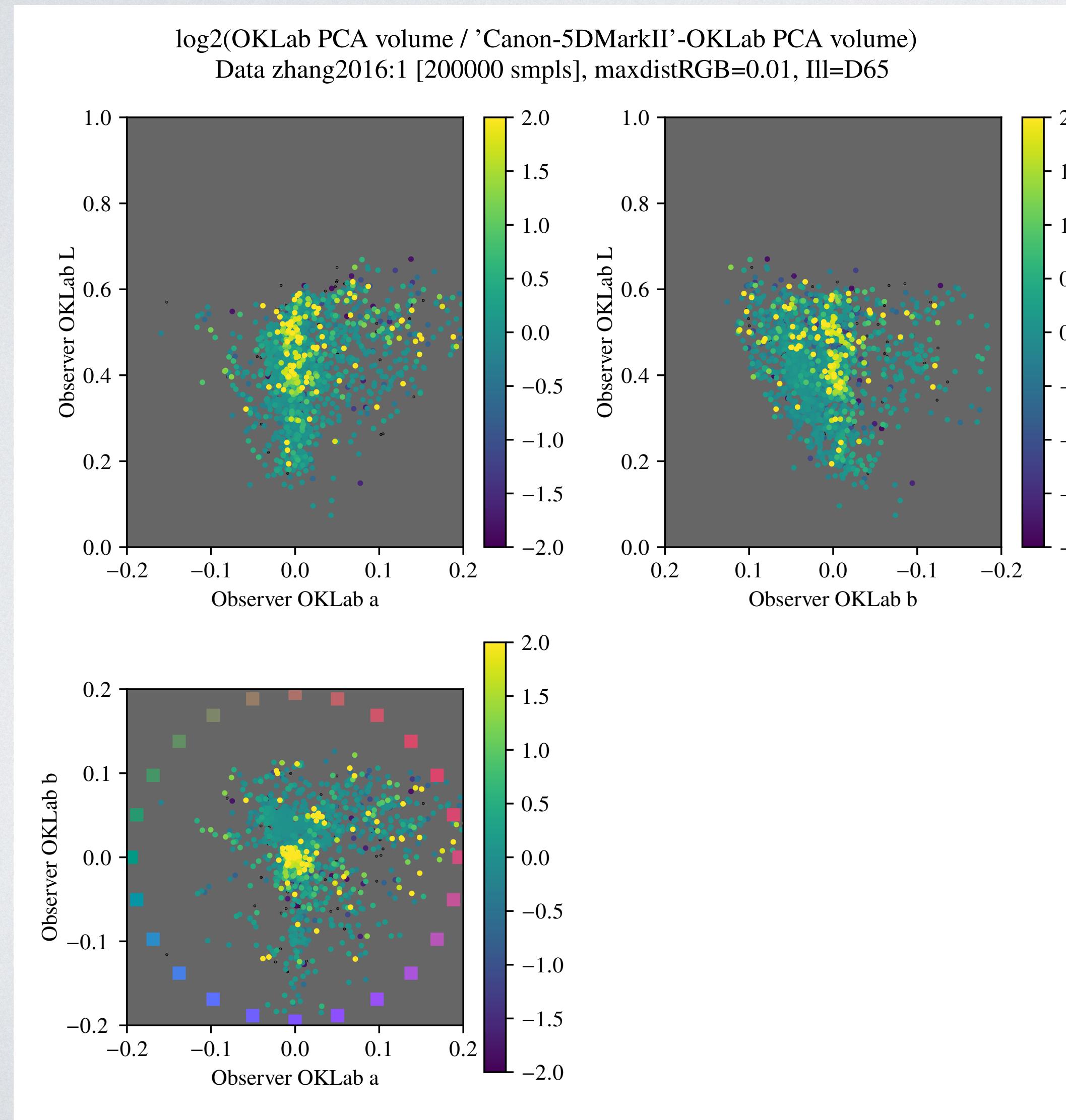
EMPIRICAL MISMATCH VOLUMES



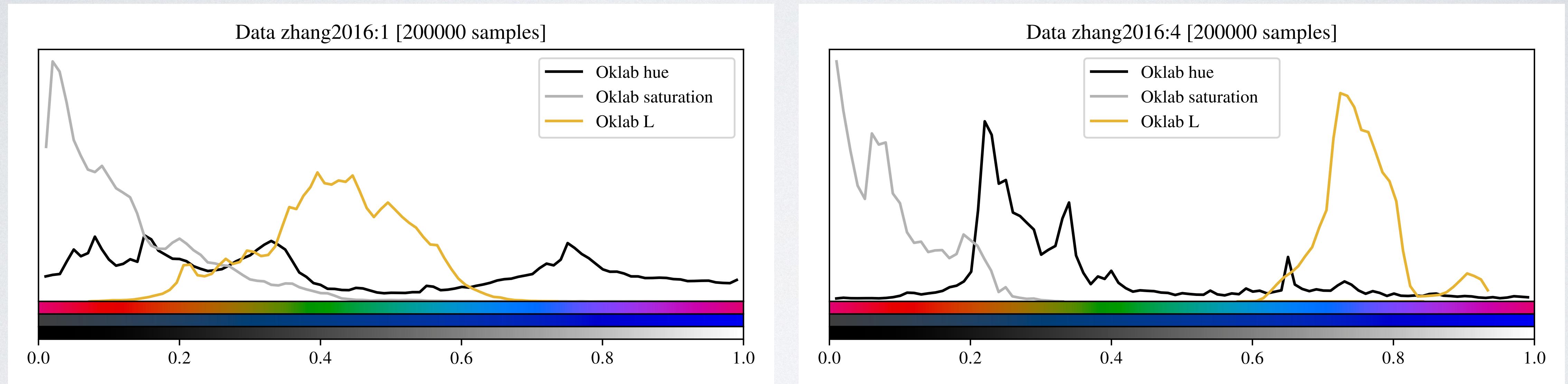
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EMPIRICAL MISMATCH VOLUMES

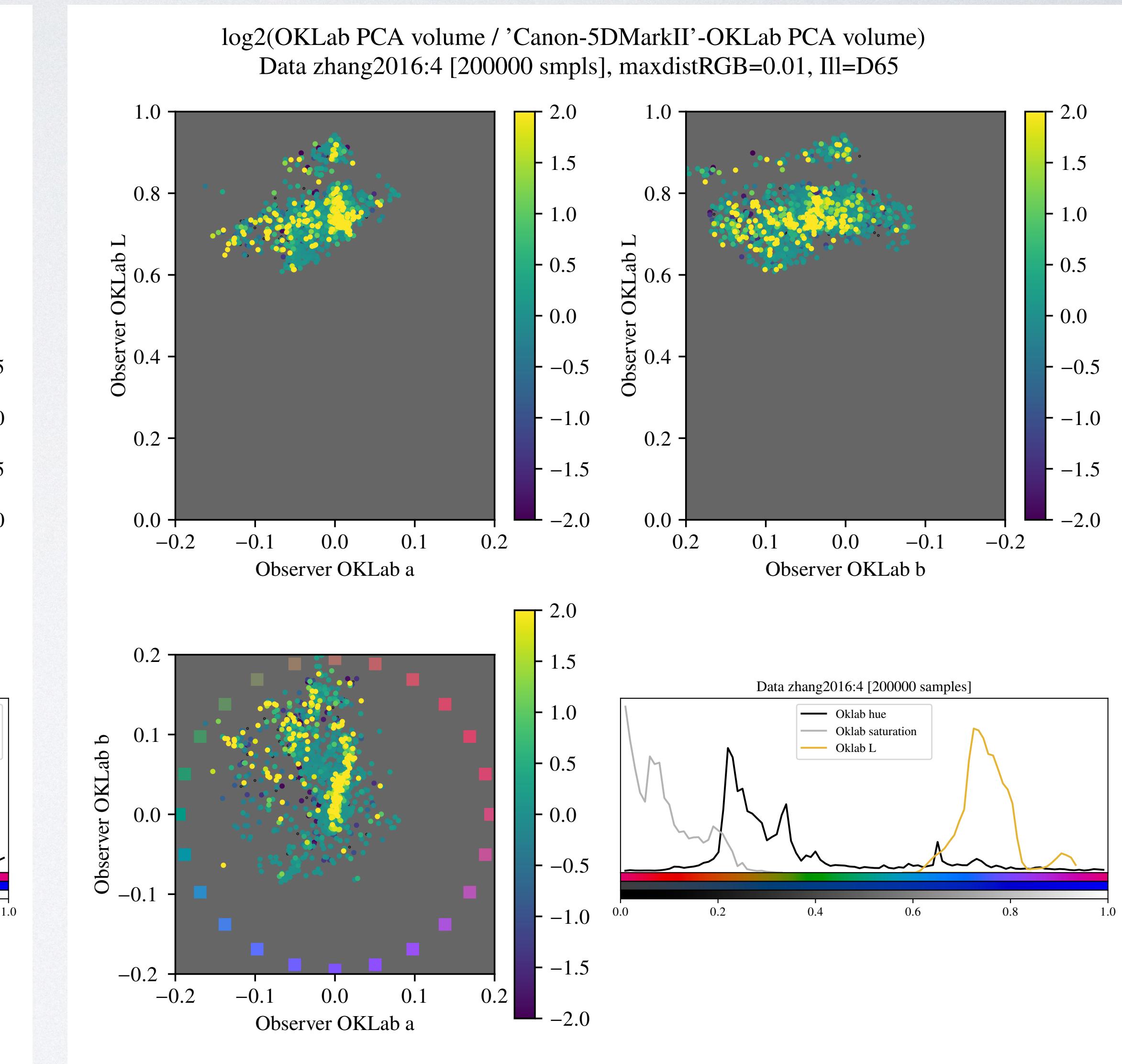
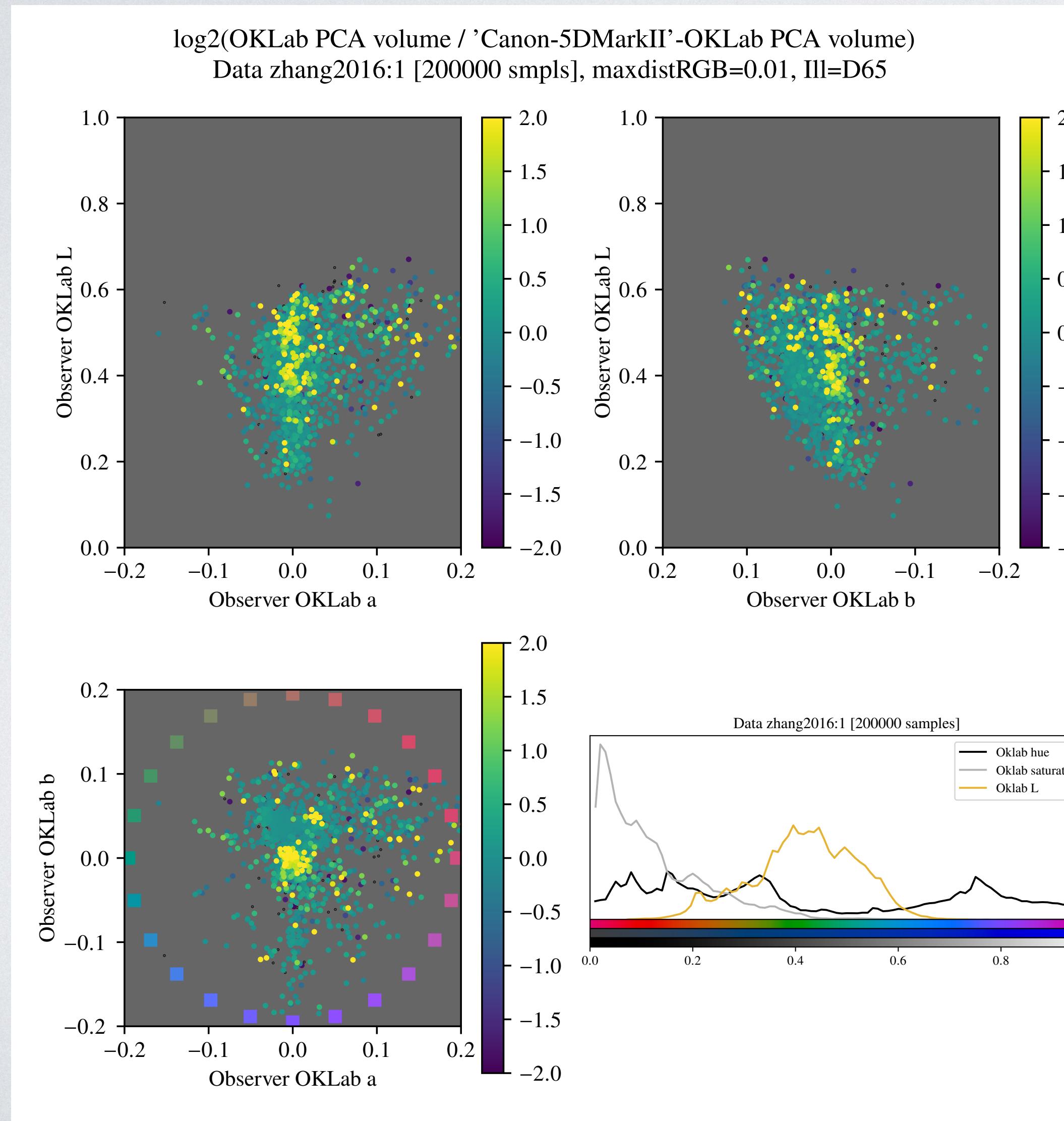


LARGE DATASETS

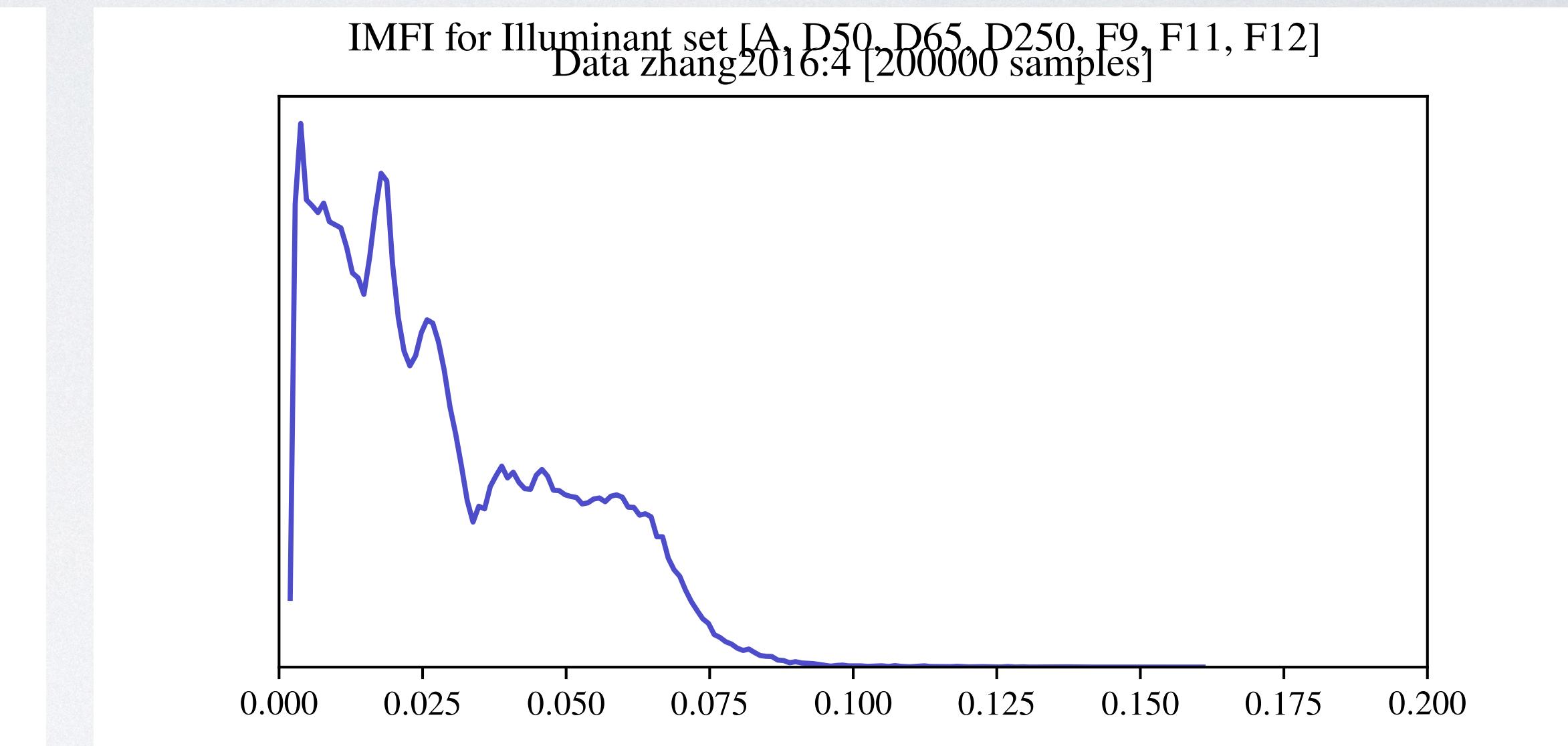
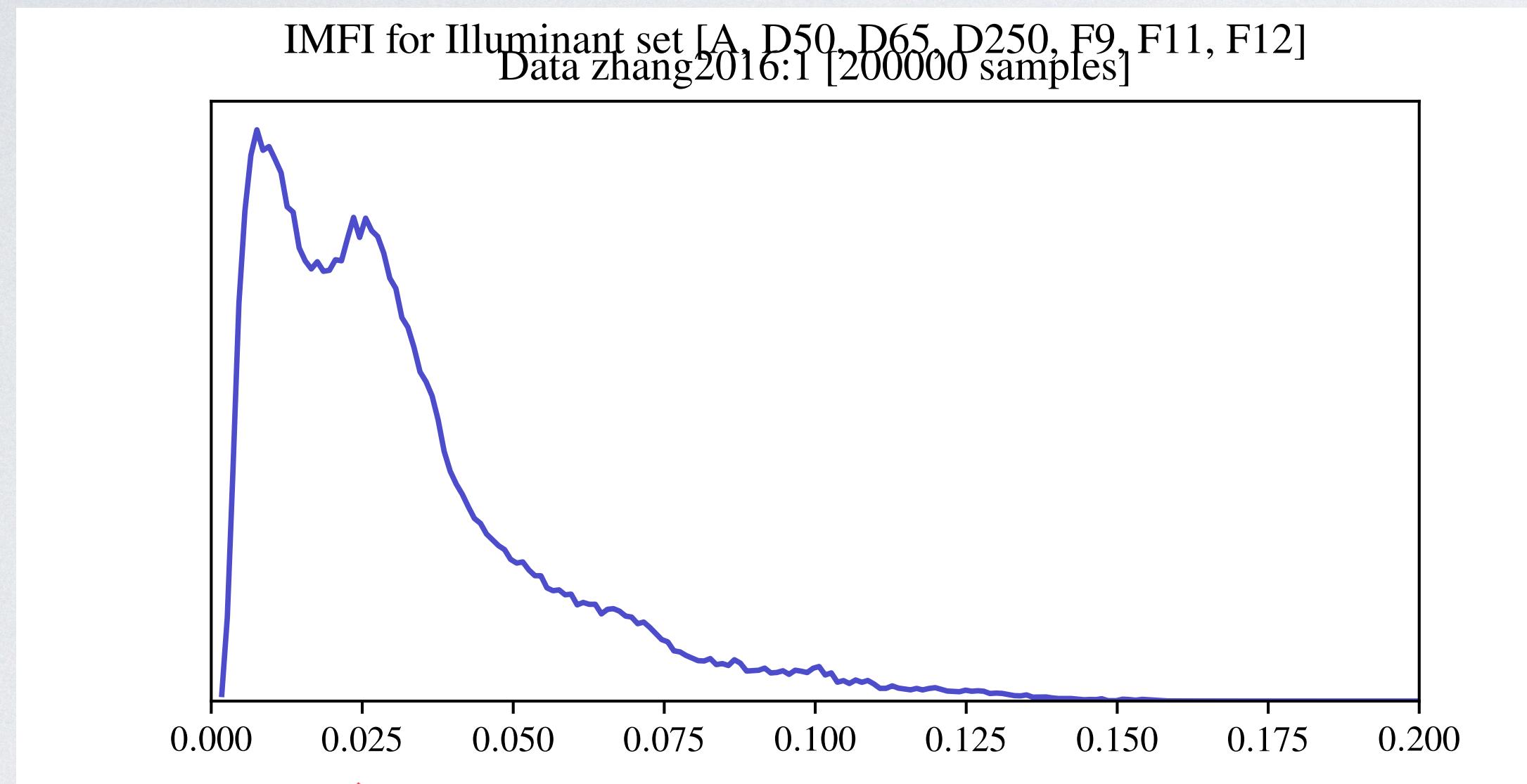


Probability distribution of a sample having the given value under the reference illuminant (D65 in this case)

EMPIRICAL MISMATCH VOLUMES



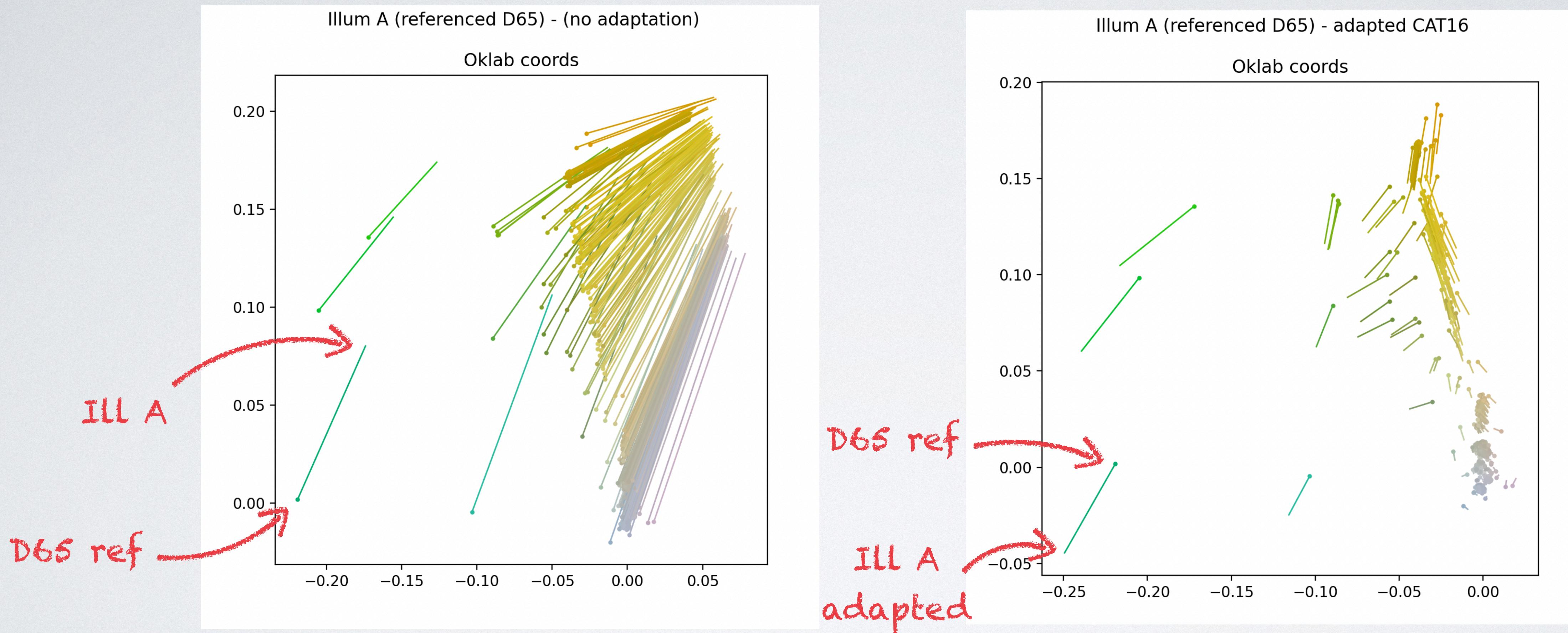
ILLUMINANT SENSITIVITY: IMFI



OKLab DeltaE
JND ≈ 0.023
1 JND/div

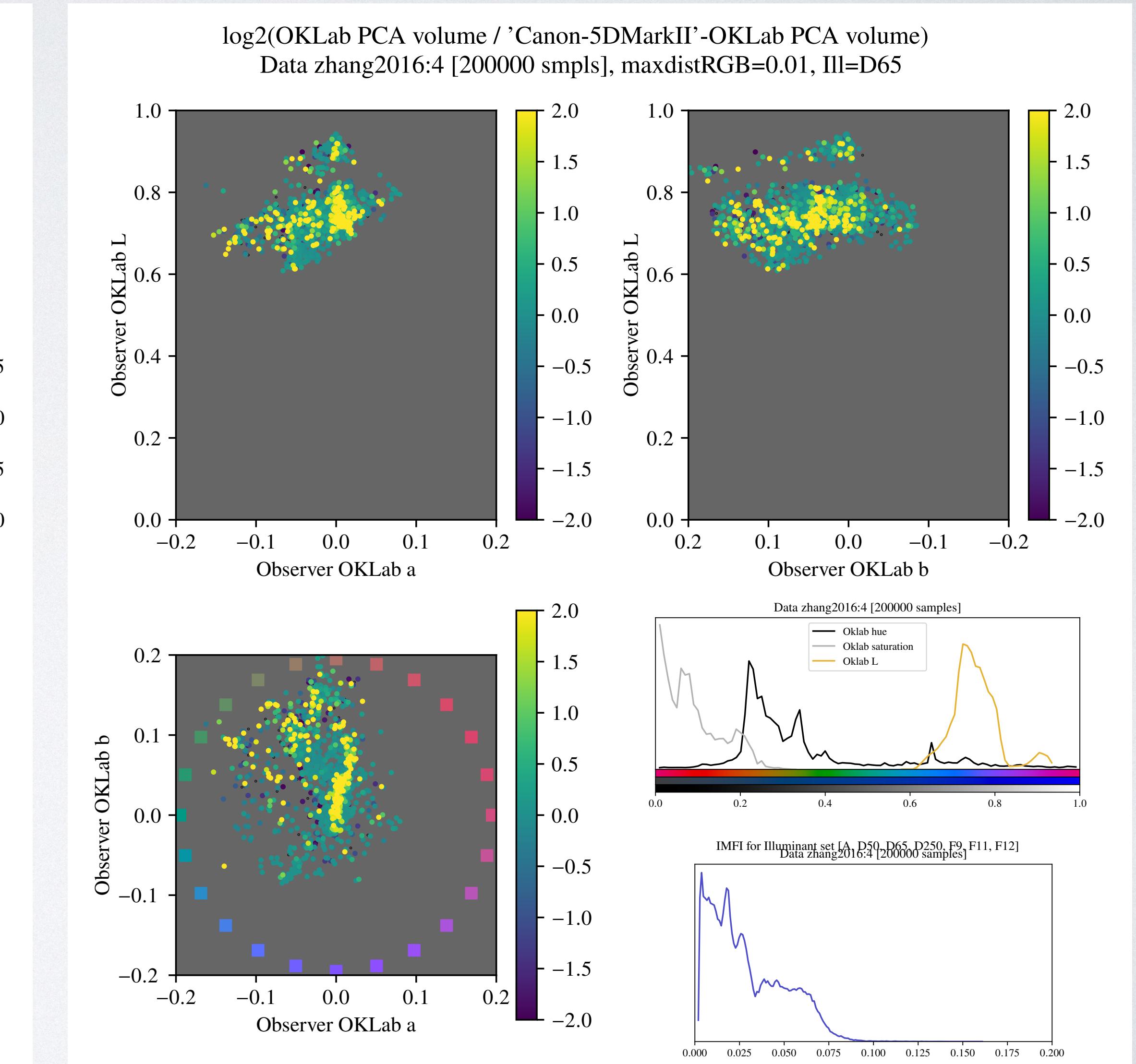
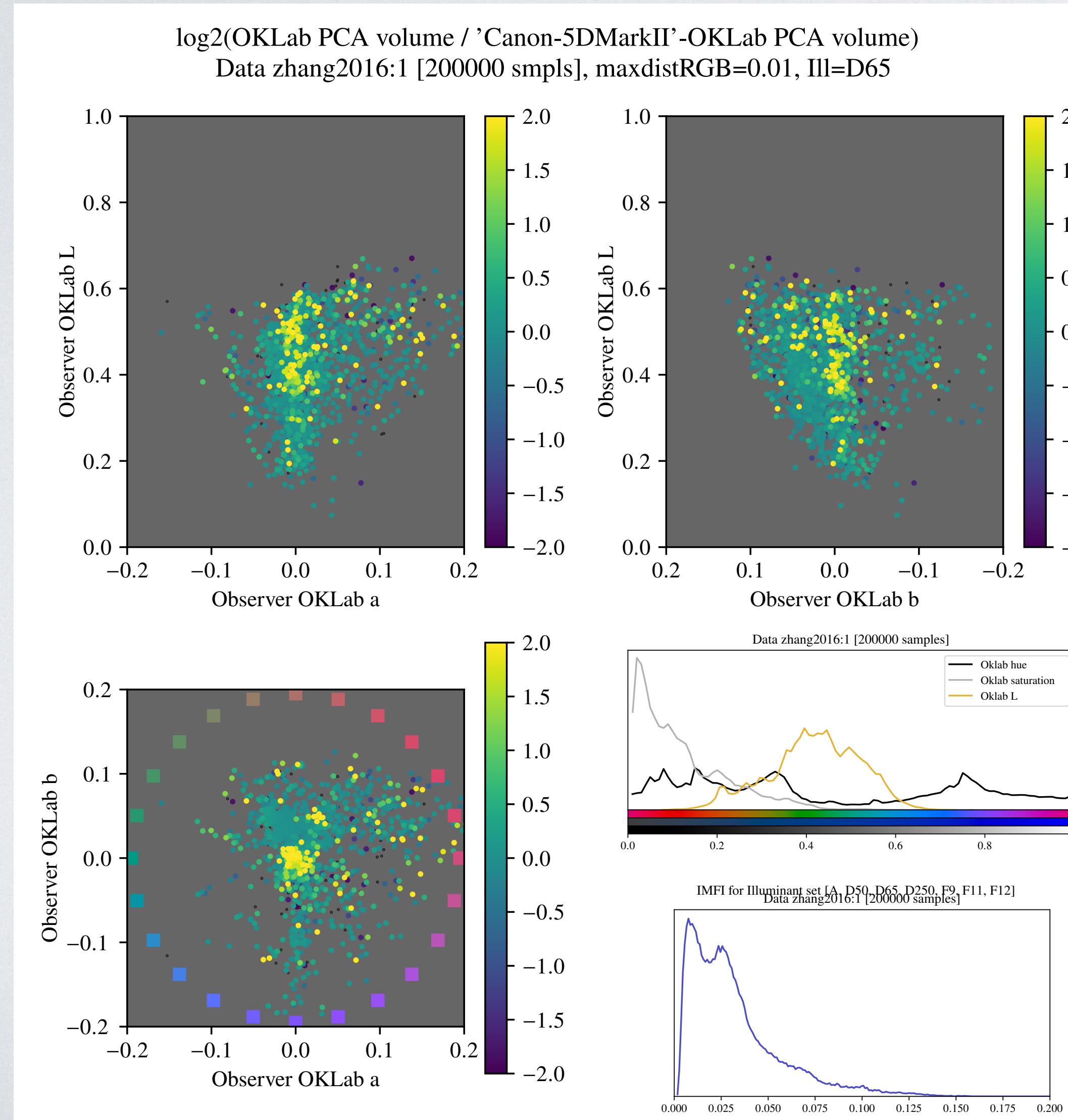
RMS average of how much can CAT16
compensate the appearance shift
induced by a change of illuminant

ILLUMINANT SENSITIVITY: IMFI



Adaptation is important to "tame" the overall color shift

EMPIRICAL MISMATCH VOLUMES



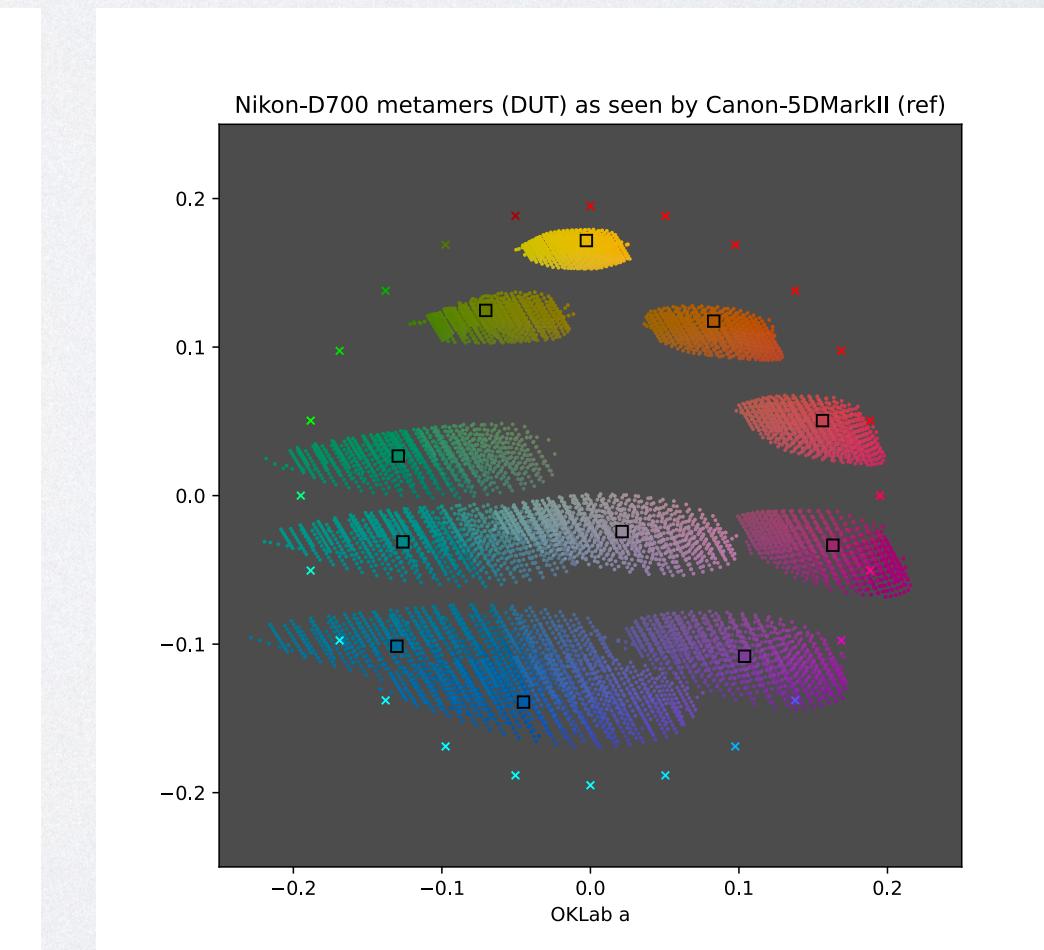
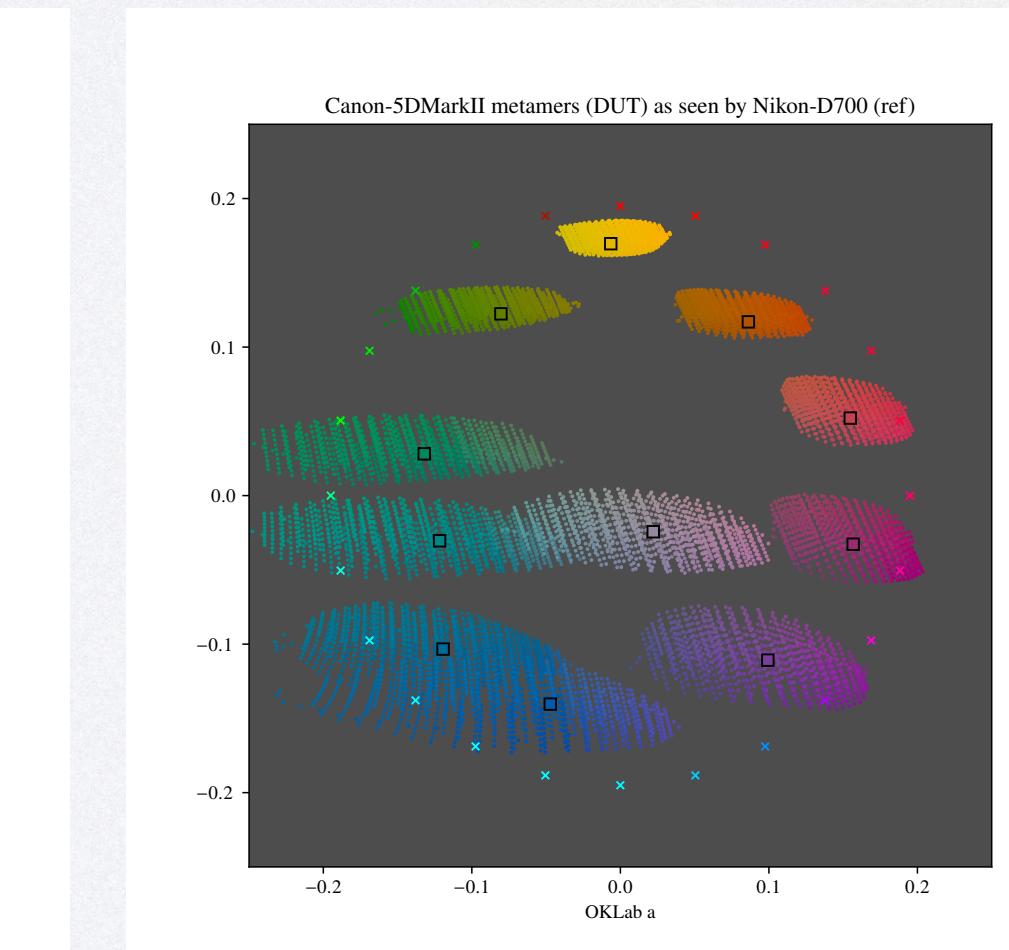
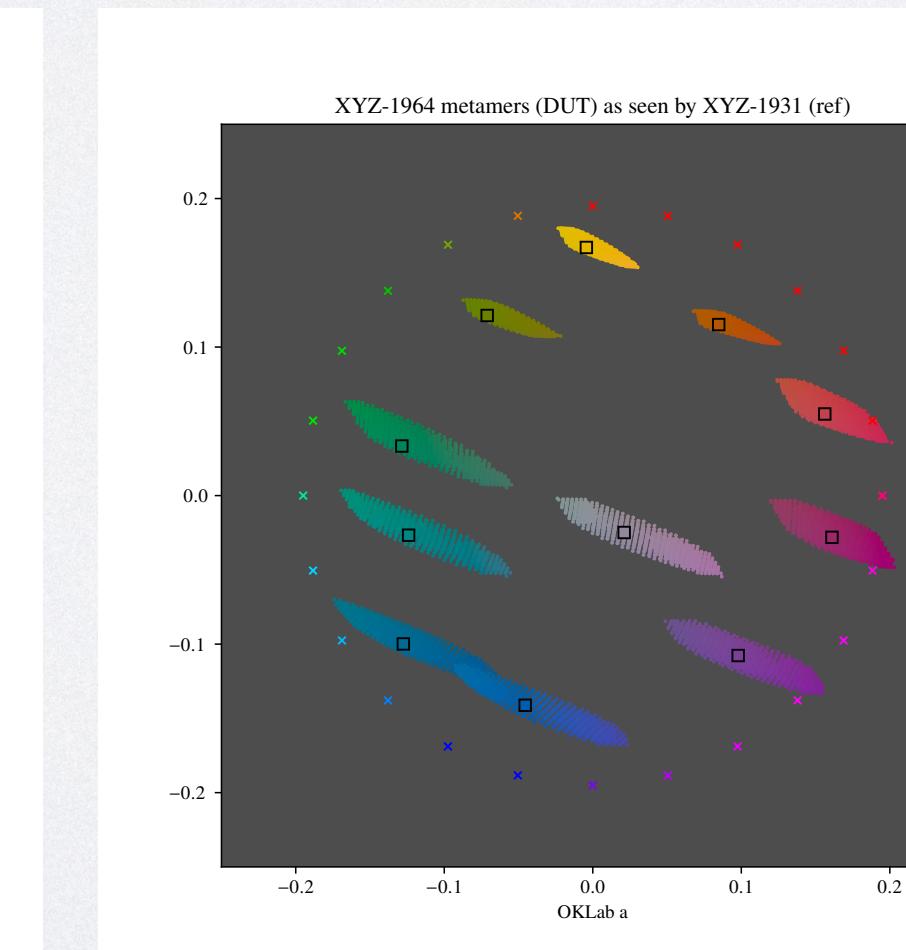
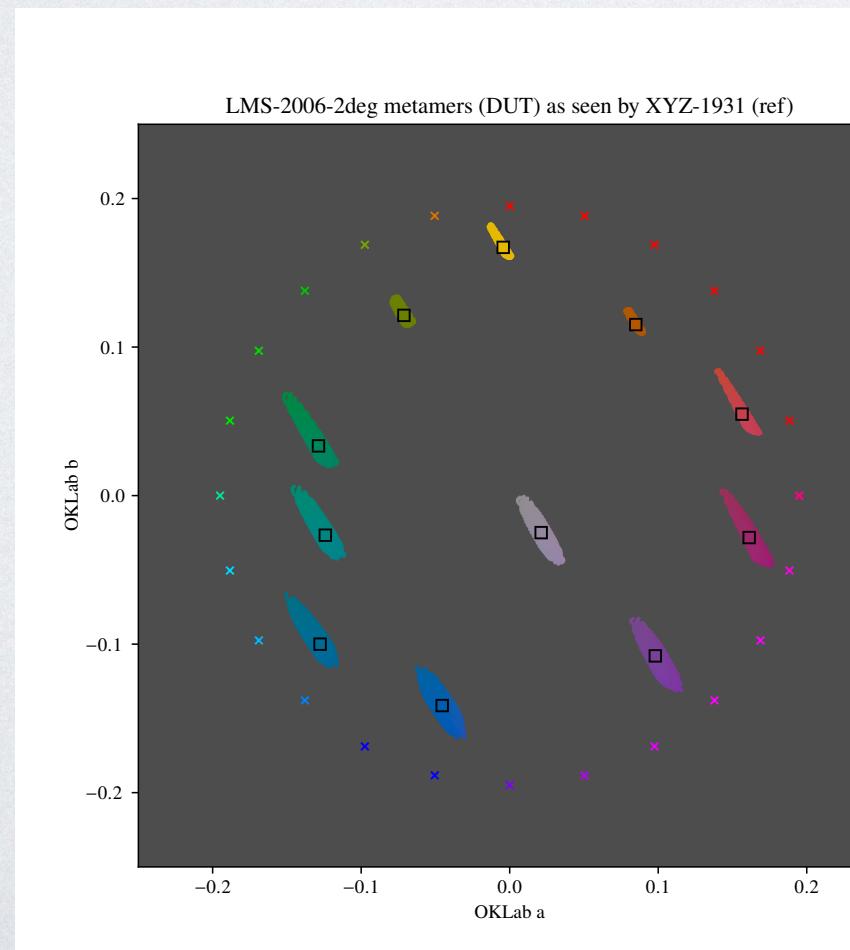
SUMMING UP

- "klangfarbe" is a key tool for musicians.
 - is "farbklang" a problem or a missed opportunity?



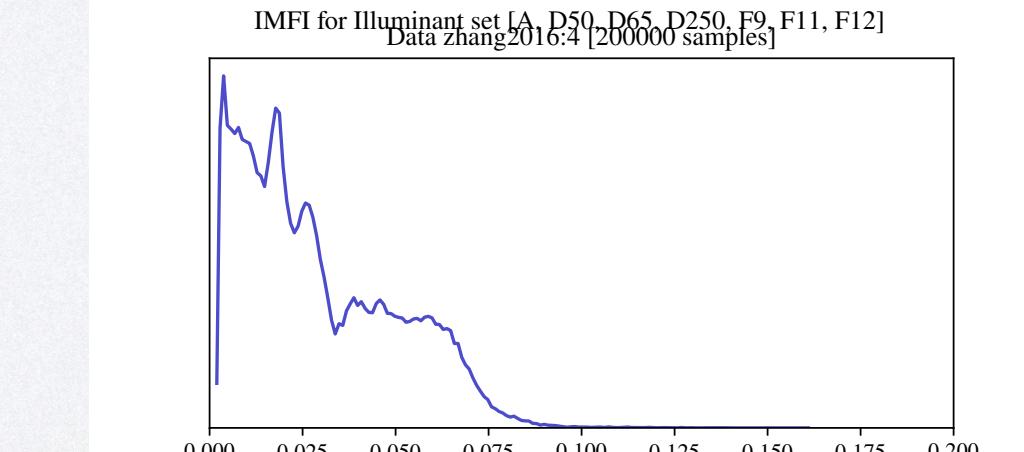
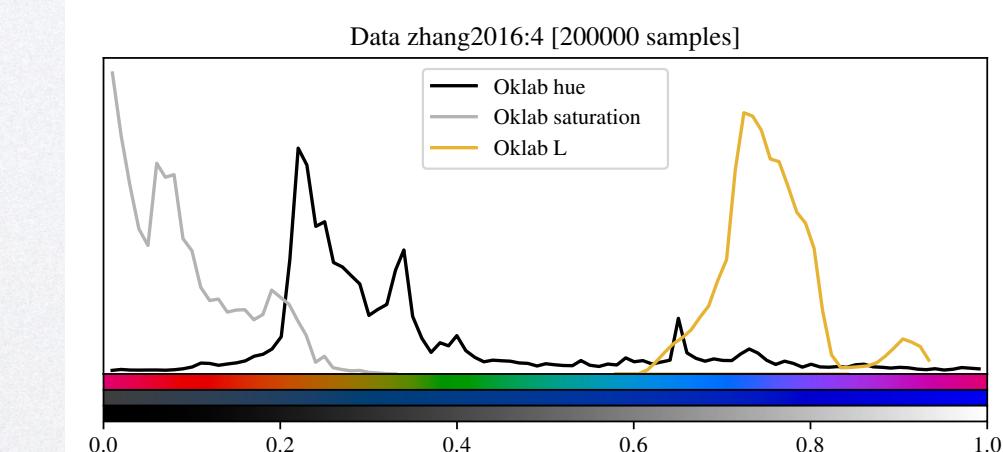
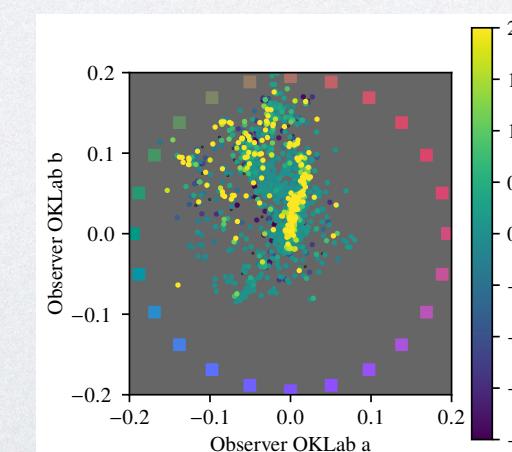
SUMMING UP

- "klangfarbe" is a key tool for musicians.
 - is "farbklang" a problem or a missed opportunity?
- maximal CMV's look quite large. But what exactly are they saying?
 - are we sure that a big CMV signifies enhanced chromatic acuity?
 - are maximal reflectance spectra relevant in real life?



SUMMING UP

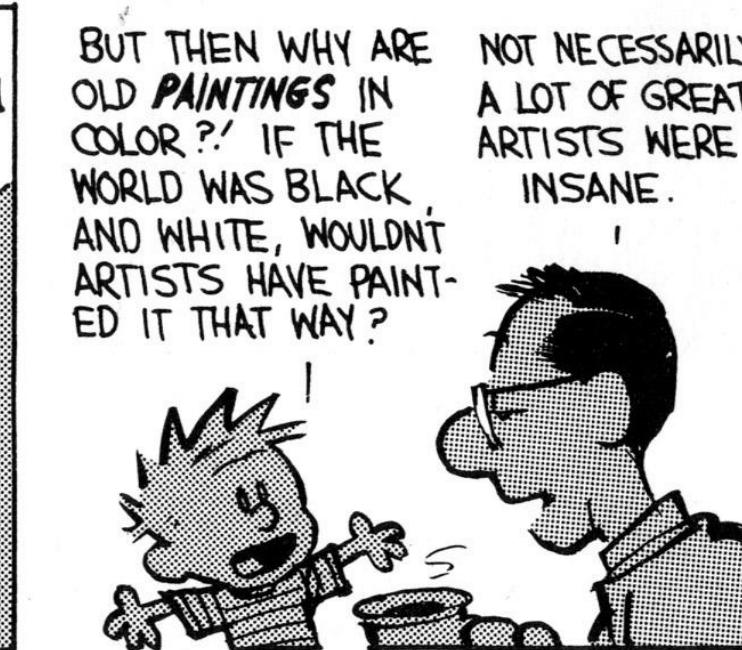
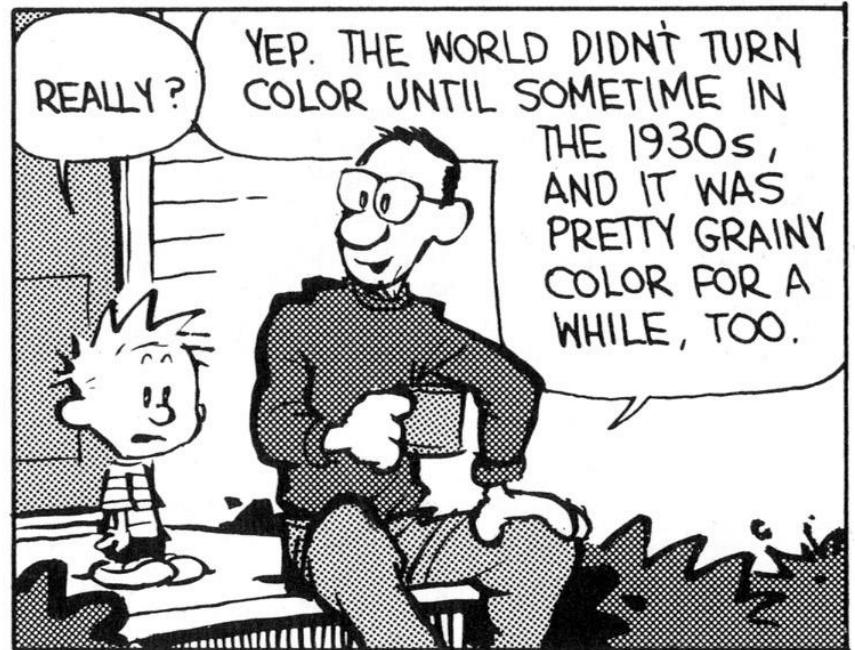
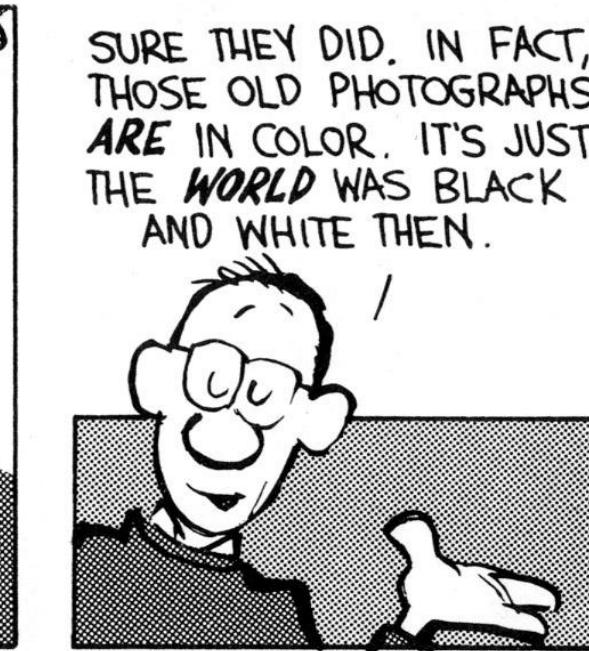
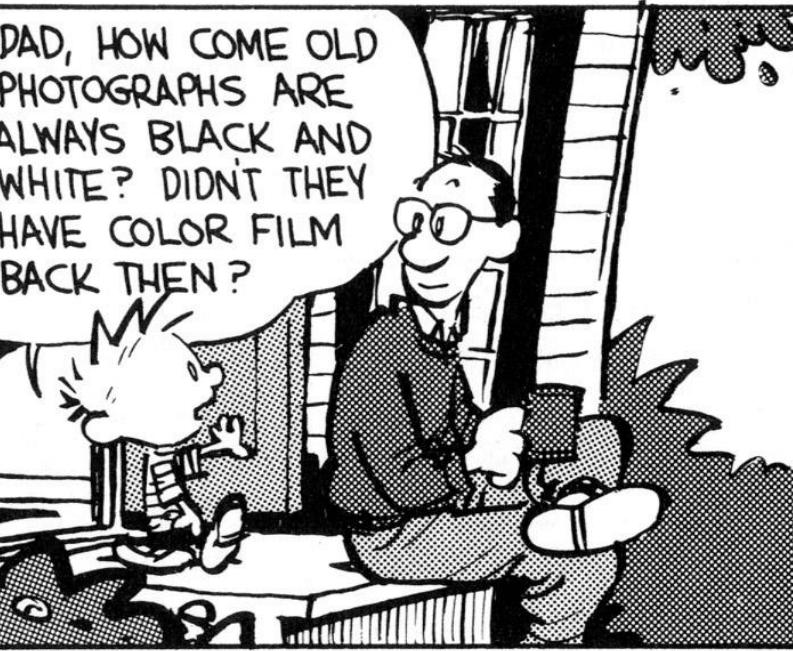
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 - is "farbklang" a problem or a missed opportunity?
- maximal CMV's look quite large. But what exactly are they saying?
 - are we sure that a big CMV signifies enhanced chromatic acuity?
 - are maximal reflectance spectra relevant in real life?
- empirical mismatch volumes show strong dependency on specific dataset
 - what should we measure to check if a dataset is relevant?



Calvin and Hobbes

by WATTERSON

WOW, HONEY, YOU'RE
MISSING A BEAUTIFUL
SUNSET OUT HERE!



THANK YOU

A study of observer metamerism
for reflectance-induced stimuli

Luca Fascione and Johannes Hanika

NVIDIA



Karlsruhe Institute
of Technology

