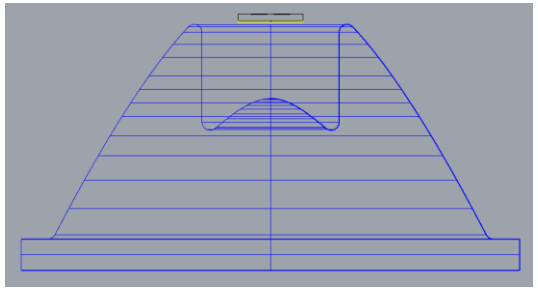
Predicting Color Separation & Designing Color Mixing Optic Solutions

Eric Frydendall
LTI Optics
eric@ltioptics.com

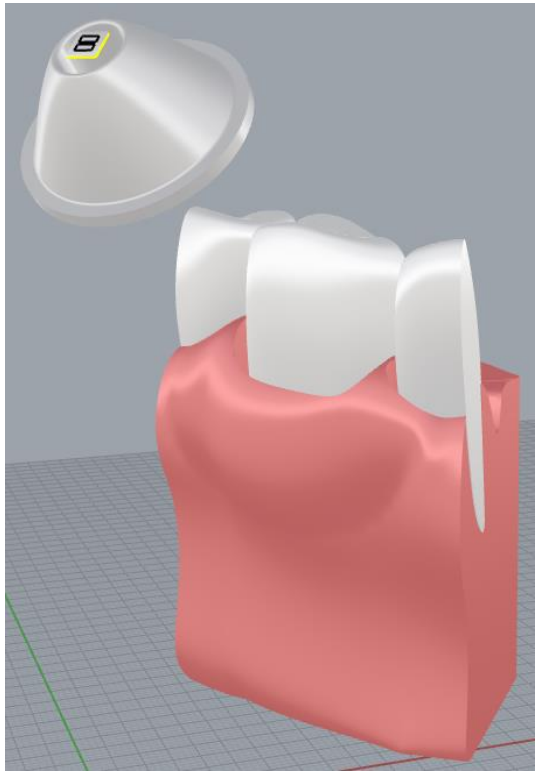
an example of the problem

Dental Headlamp

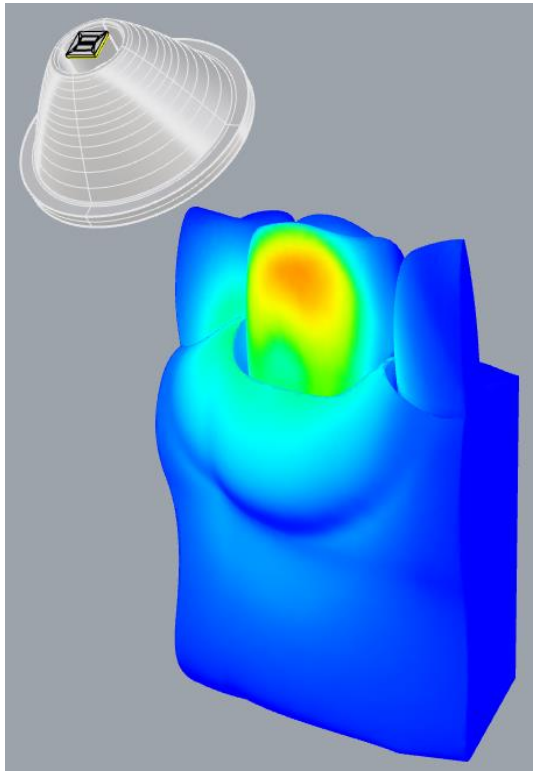
- Limitations
  - Optic size
  - Single source
- Goals
  - Narrow beam
  - High intensity
  - Good color uniformity



TIR collimator design



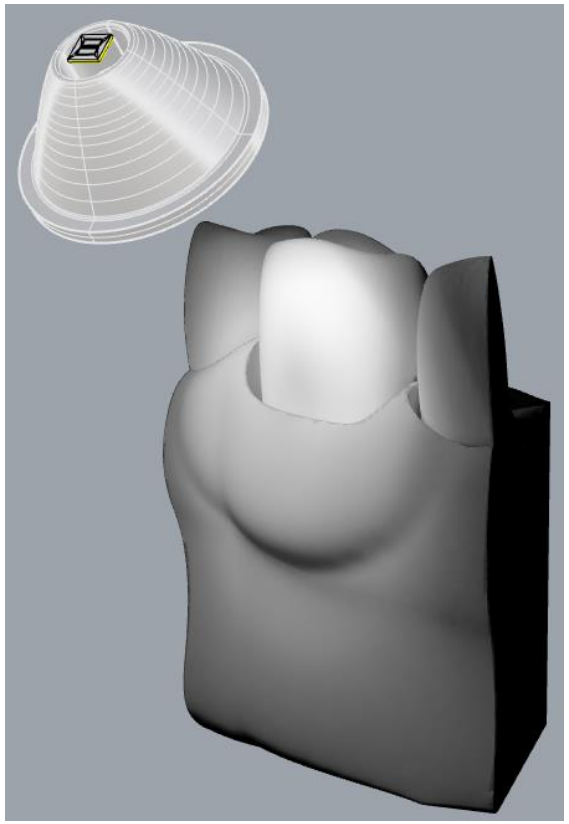
Tooth and gum model



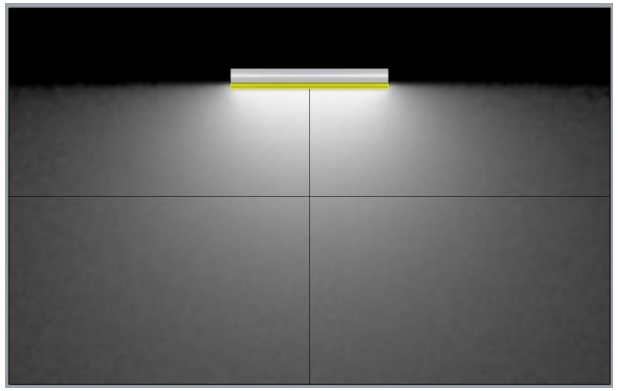
False color illuminance

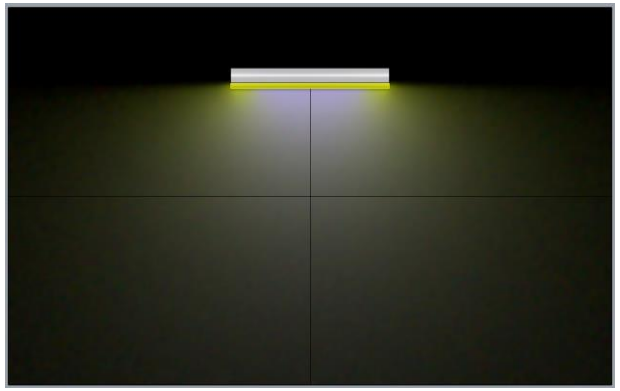
an example of the problem

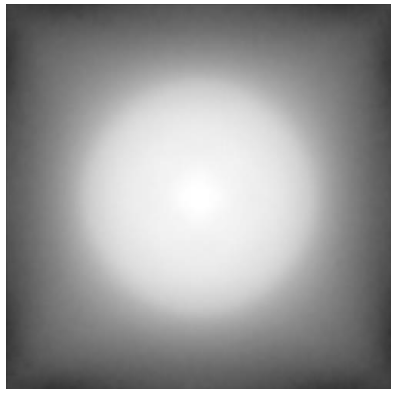
Grayscale illuminance

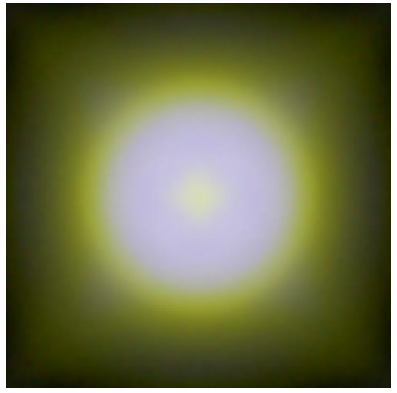


Cross section through LED



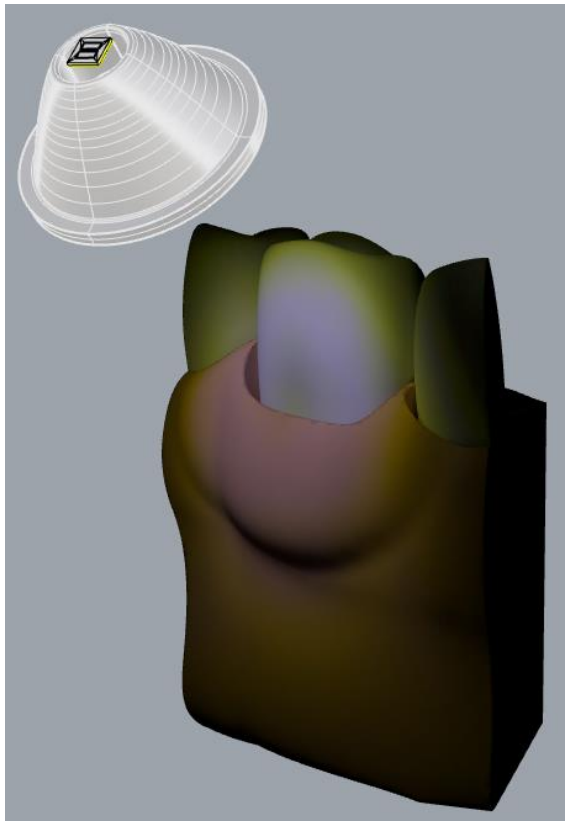






Beam produced by optic

True color illuminance



A full spectral source model adds detail to the simulation, predicting color uniformity (or lack thereof)

abstract

Full spectral source models & detailed color properties → **More accurate simulations & better designed optics**

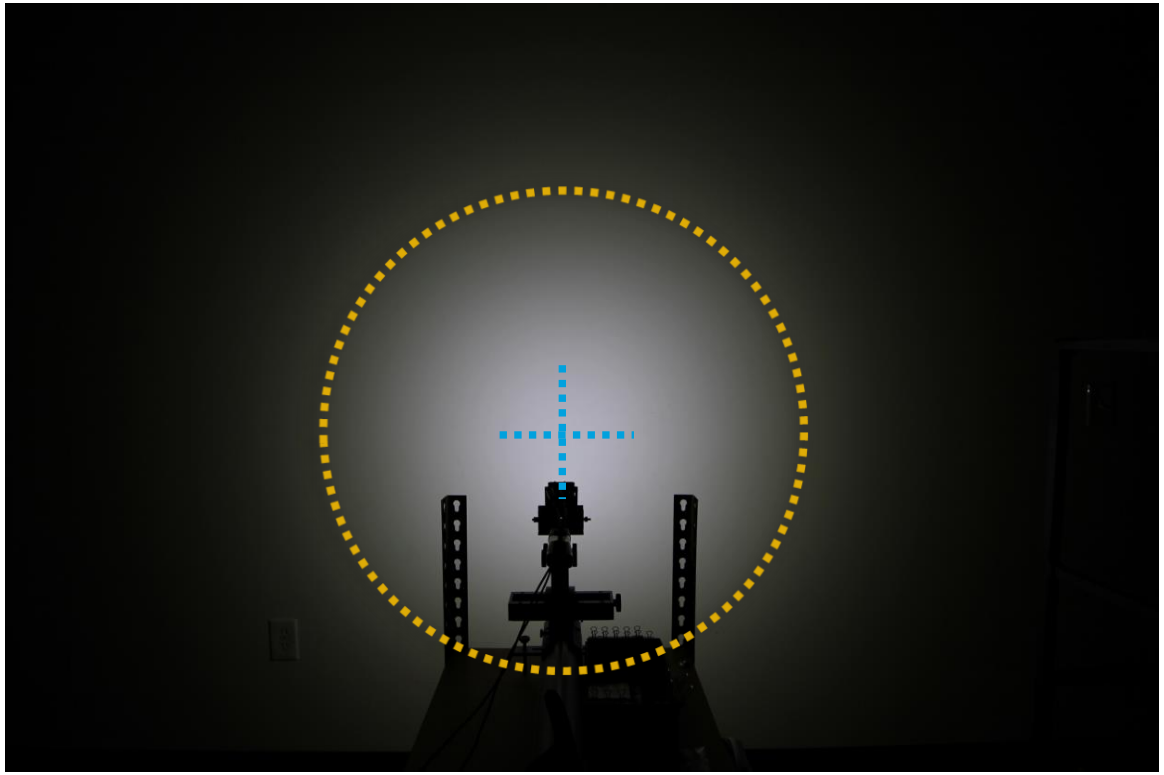


Photo of a beam from a LED/lens optic system that results in a blue & yellow color shift

lamp models

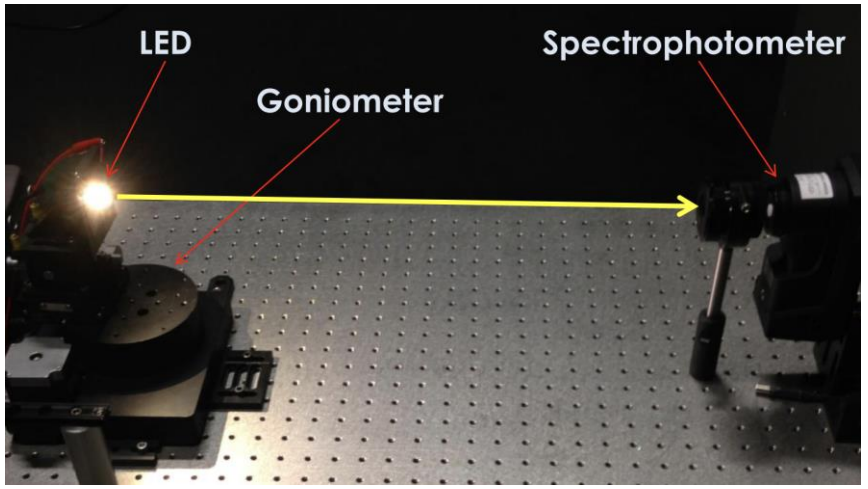
Traditional rayset lamp models

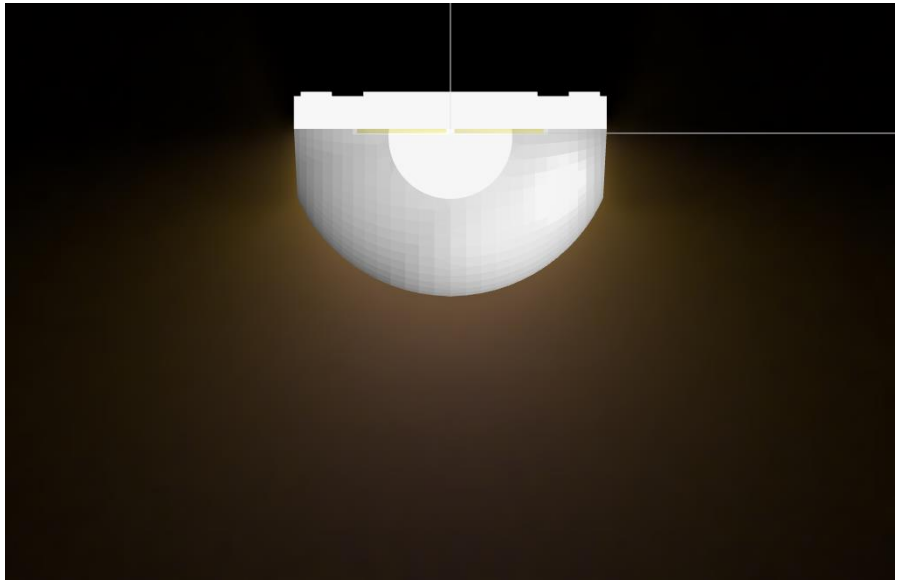
- Can have precise emission angle & location.
- No spectral data by default.
- Some manufacturers provide blue & yellow raysets.

Full spectrum lamp model

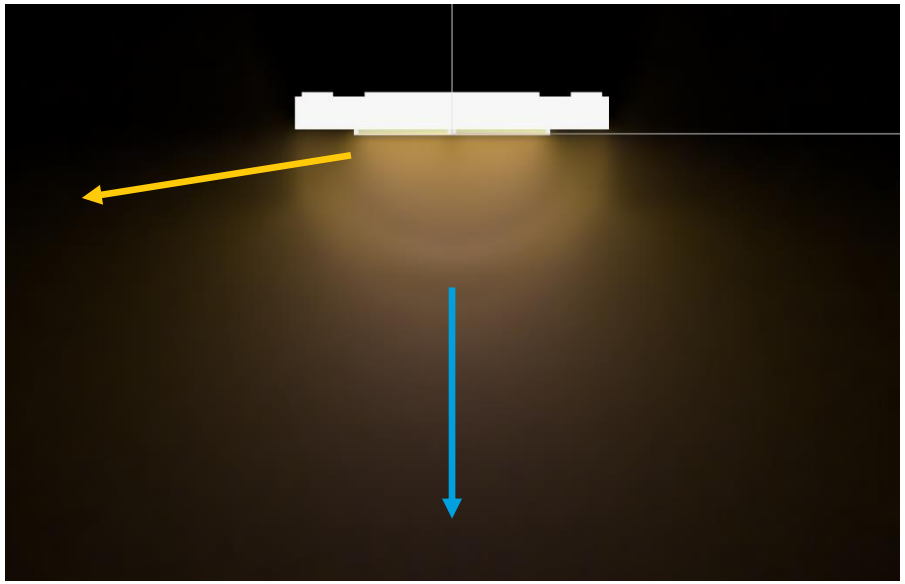
- Can be geometry driven.
- Measured color over angle.
- Measured color over area.
- Note - TM25 raysets can include full spectral data, but they are not yet widely adopted.

full spectral source model – color over angle





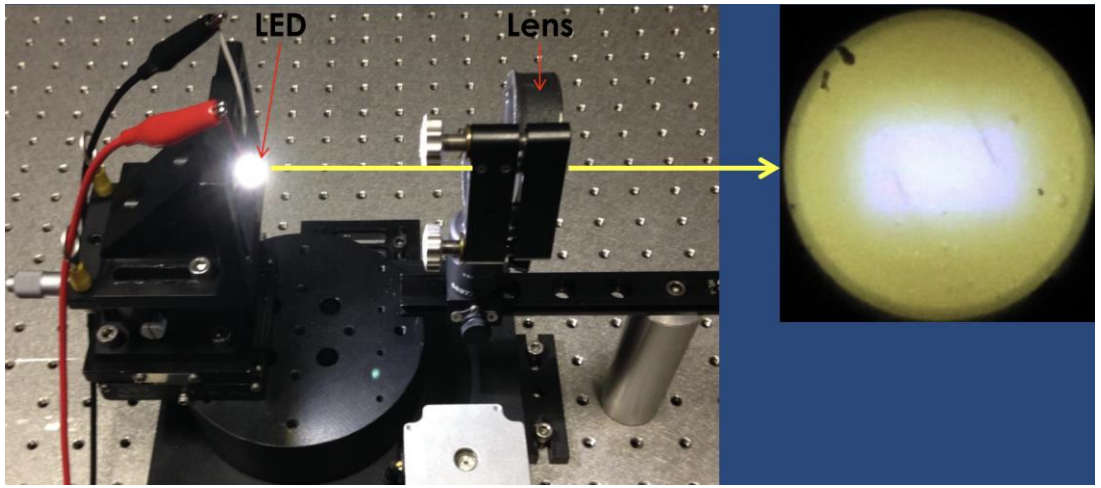
Lamp model includes all details including dome

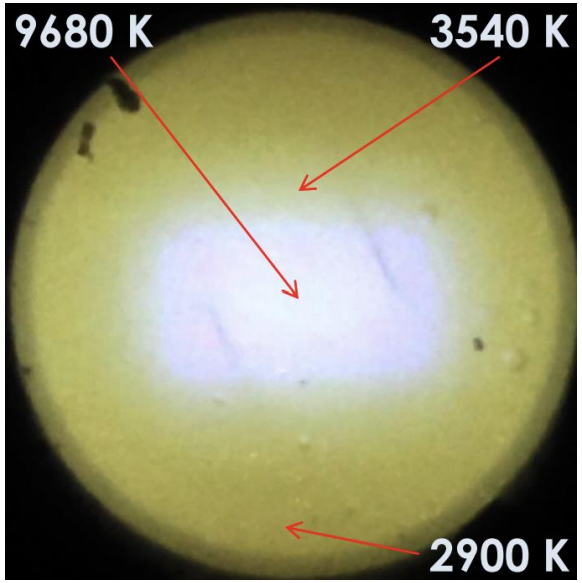


Dome hidden to show color shift over angle

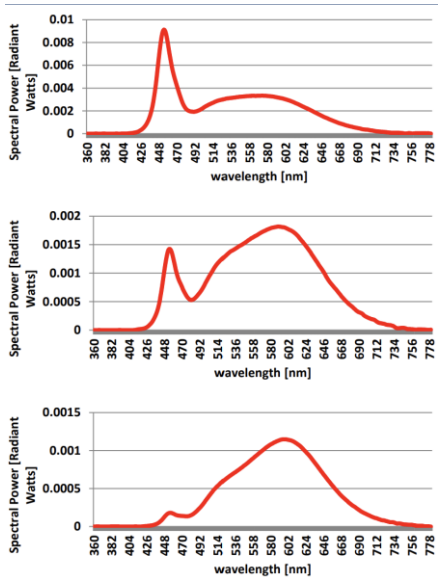
Key takeaway: measure color at each angle for entire source

full spectral source model – color over area

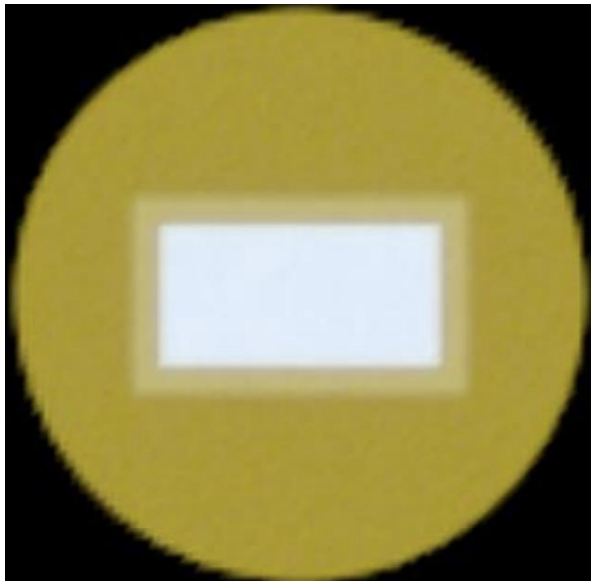




Imaged lamp model



SPD measurements from each area



Lamp model for simulation

Key takeaway: luminance and color varies across the emitting surface

full spectral lamp model – complete COB lamp

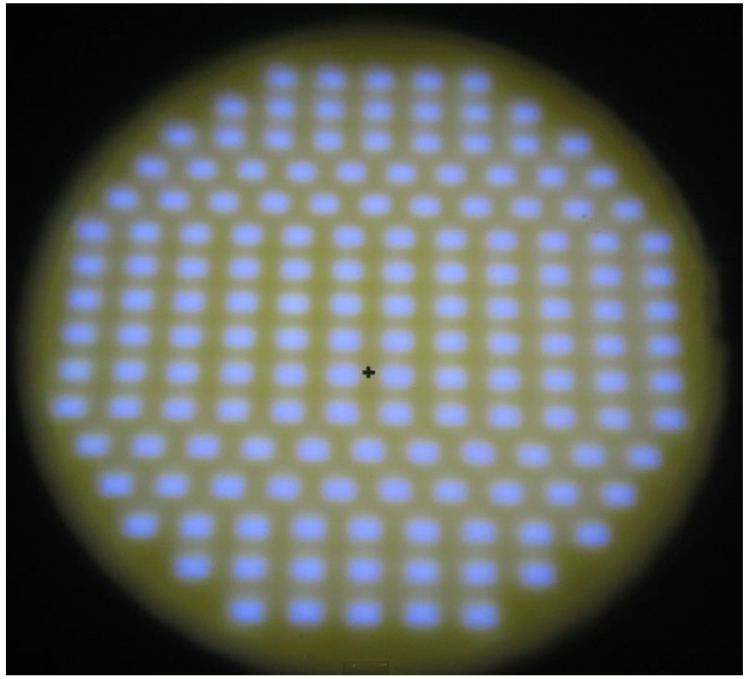
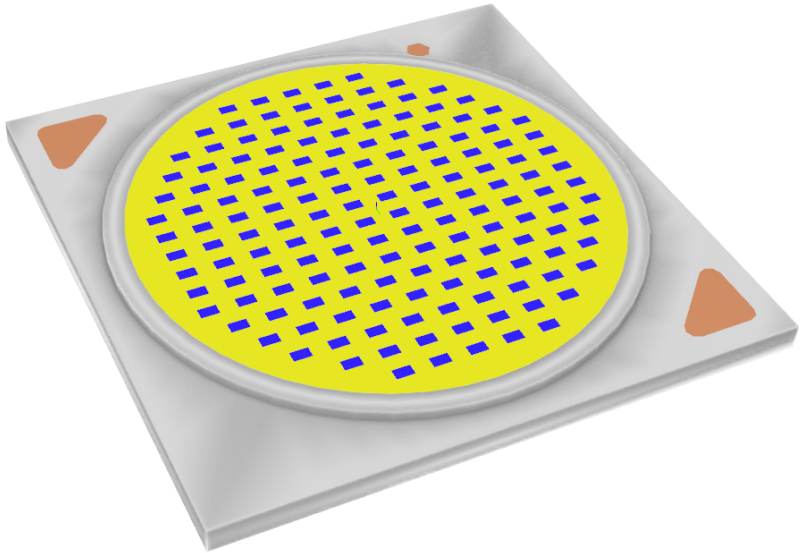
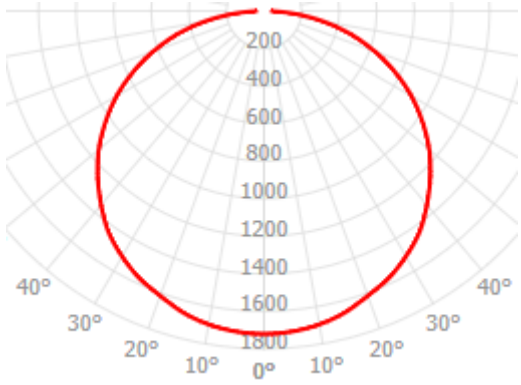
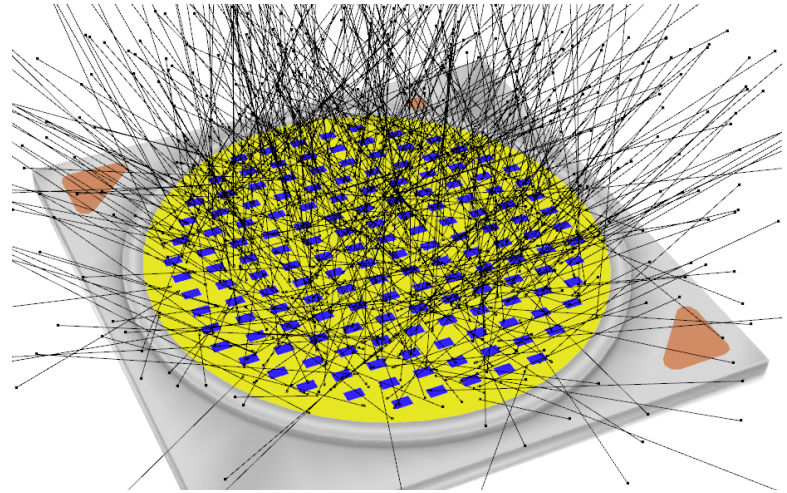


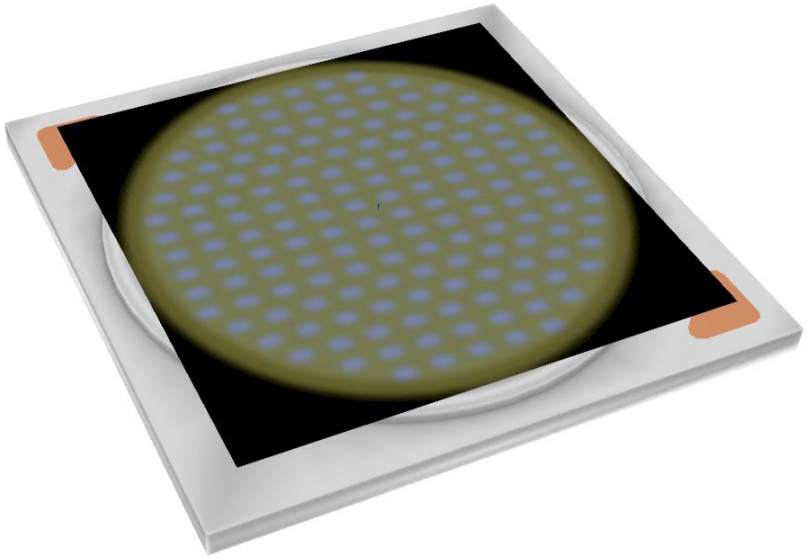
Photo of projected COB lamp





Lamp model details include 3D CAD, emitting area, and intensity pattern

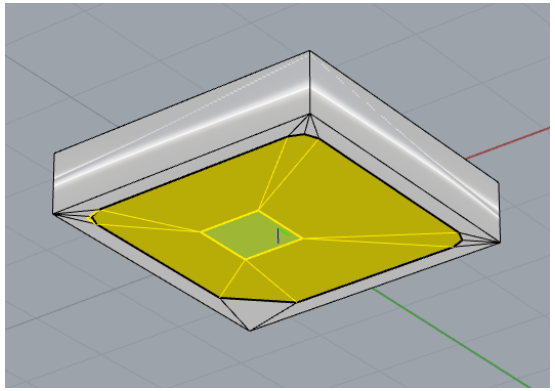


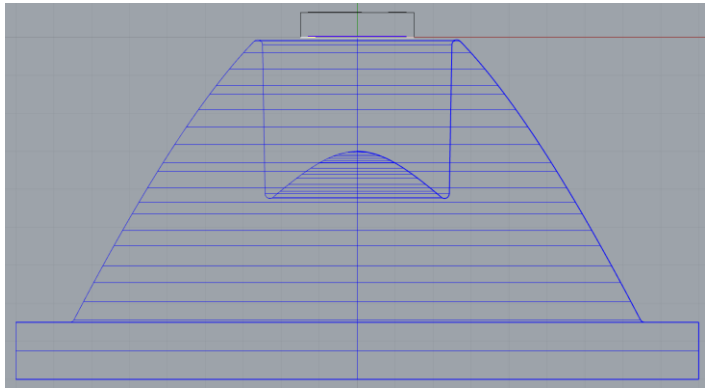


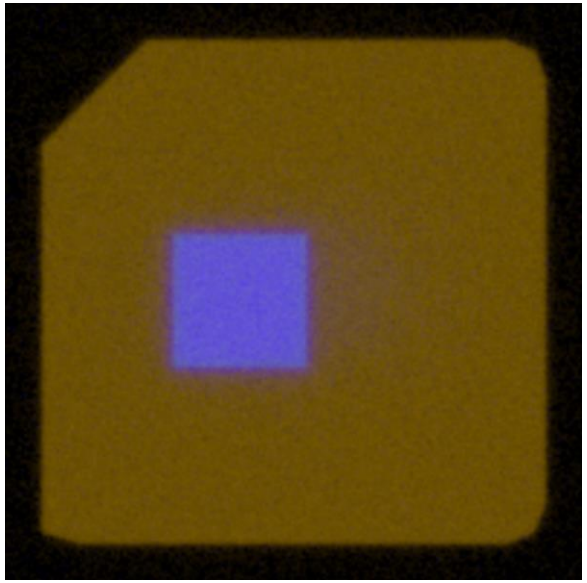
Simulation of lamp model

Color prediction & common optical designs

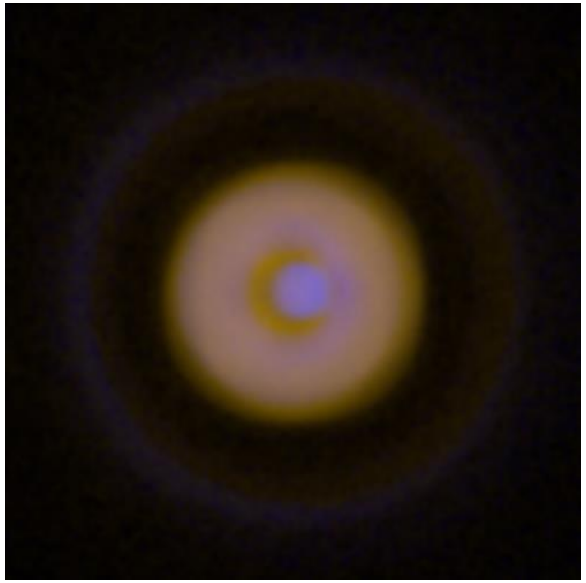
example 1 – mid-power LED, TIR collimator



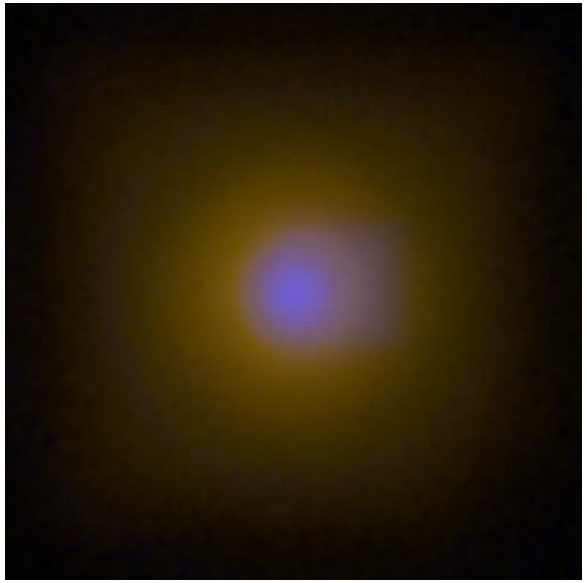




True color illuminance - LED



True color illuminance – 10mm in front of optic

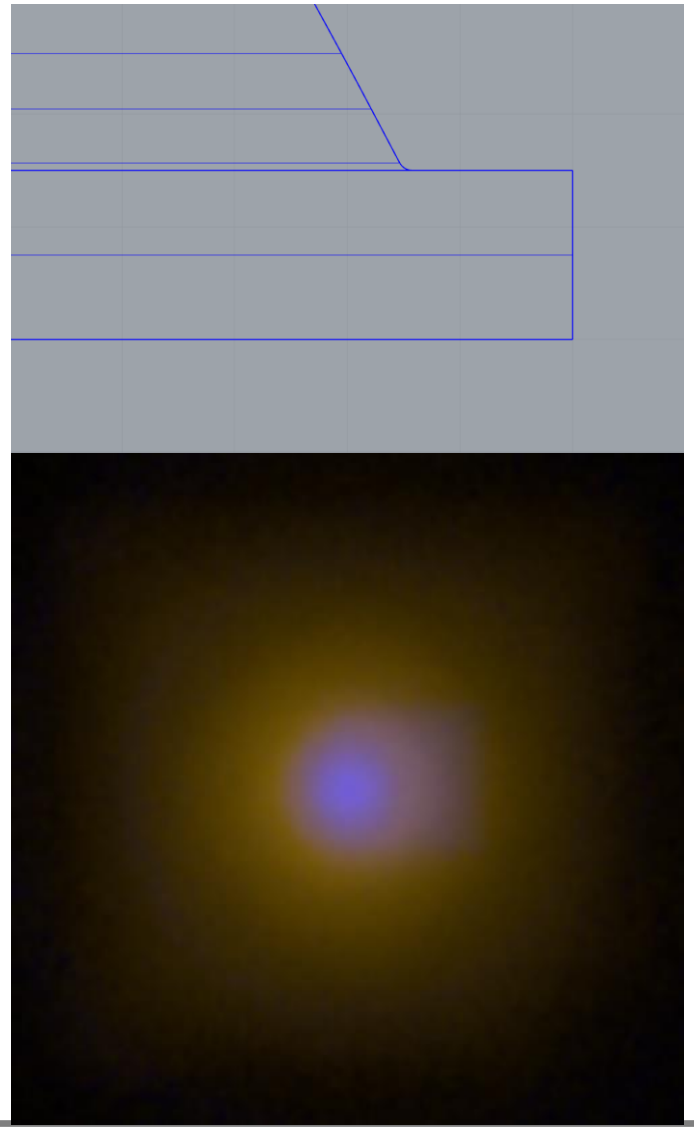


True color illuminance – 1m in front of optic

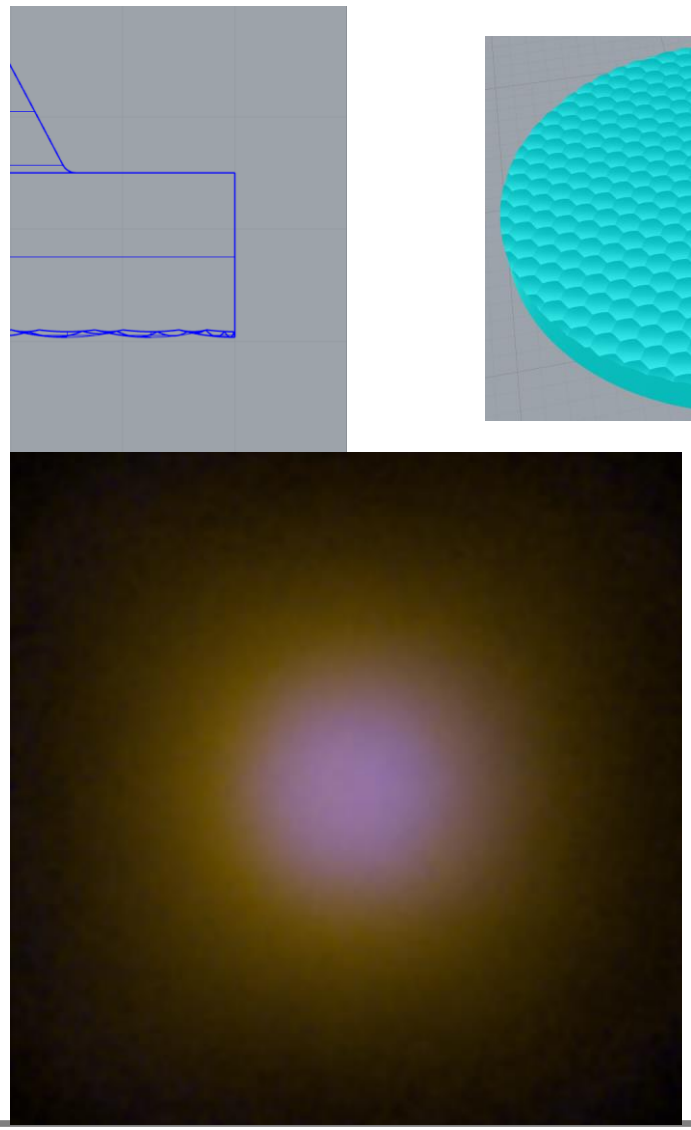
Key takeaway: non-uniform emitting area can echo across beam

example 1 – mid-power LED, TIR collimator with pillows

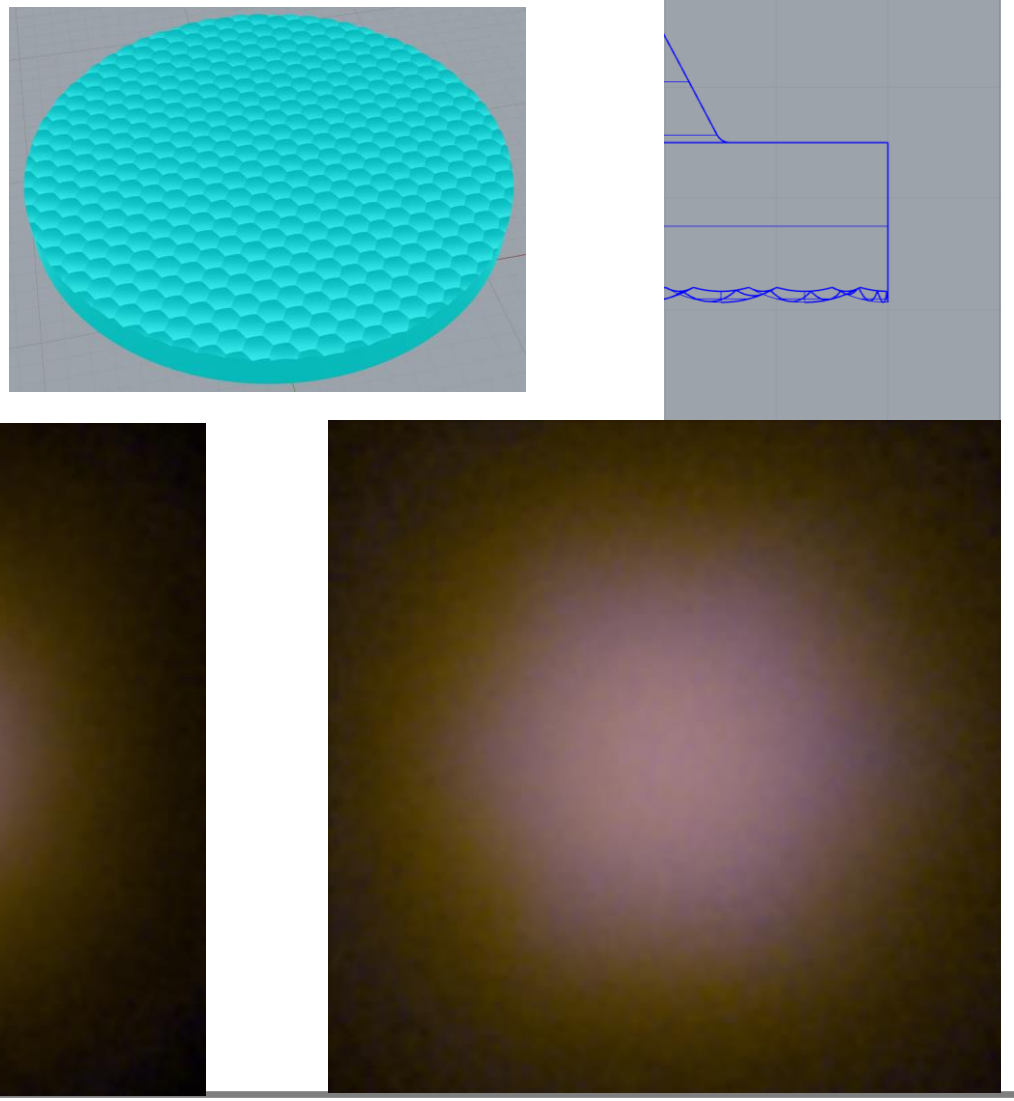
Flat exit surface



Shallow pillows

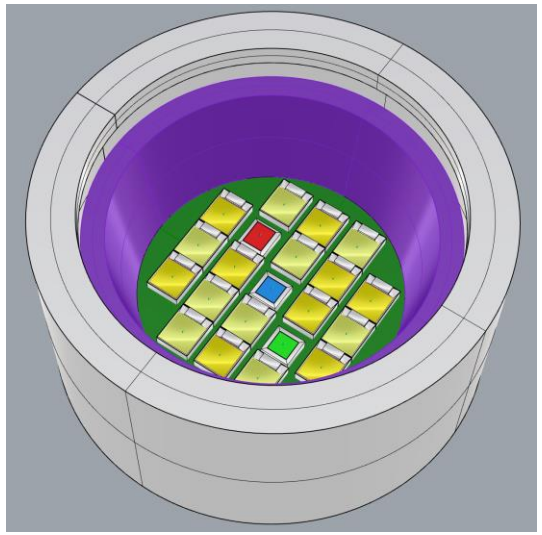


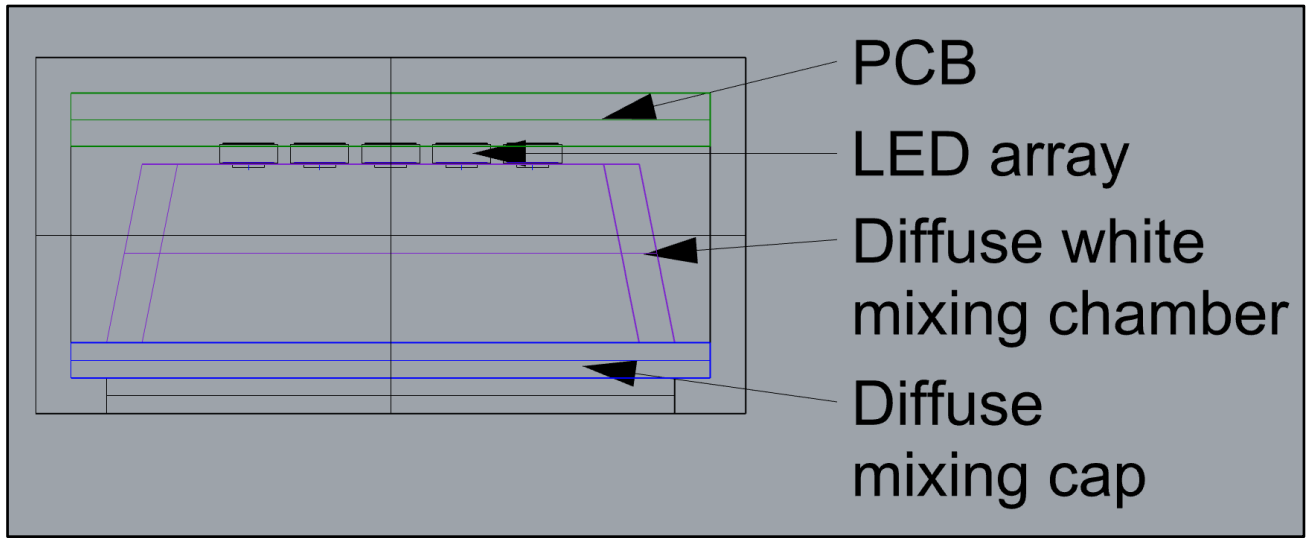
Deeper pillows

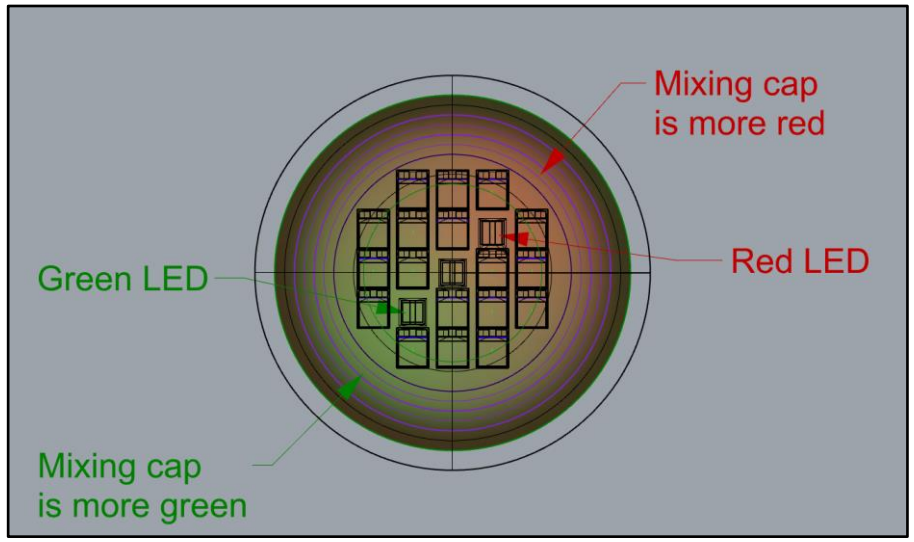


Key takeaway: color uniformity can be improved, there are always tradeoffs

example 2 – LED array, mixing chamber and cap



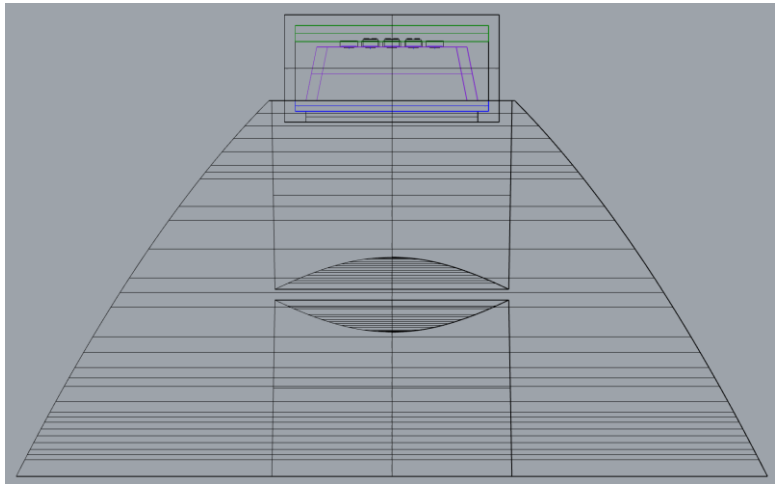




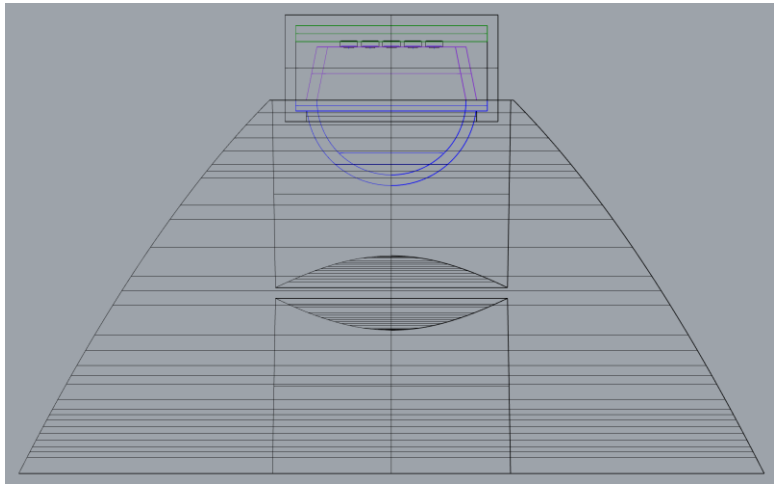
Key takeaway: far-field vs near-field quality

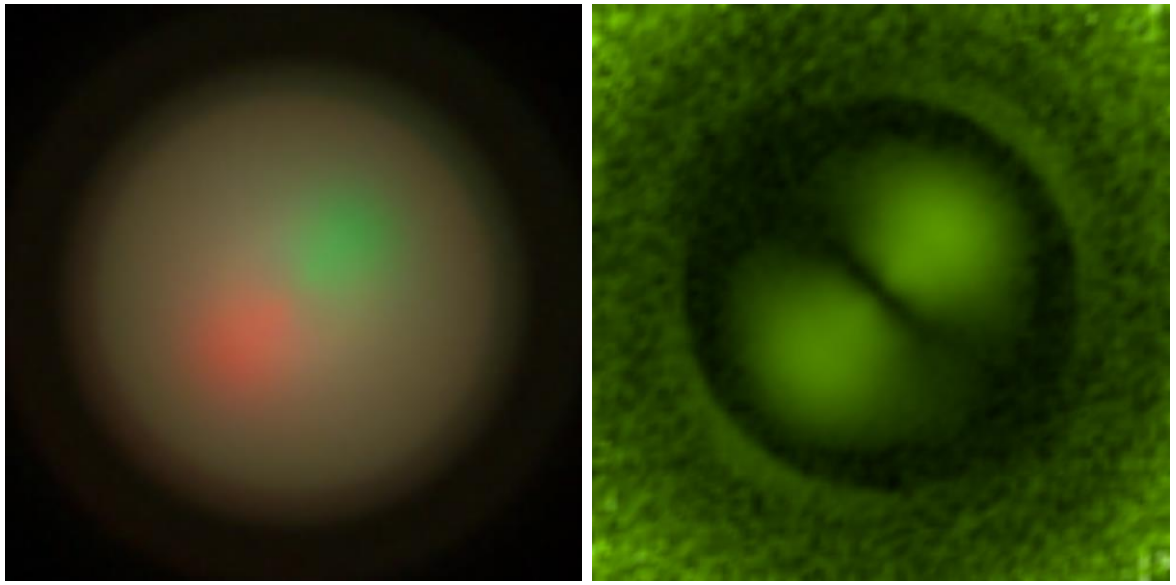
example 2 – LED array, mixing chamber and dome

Mixing cap

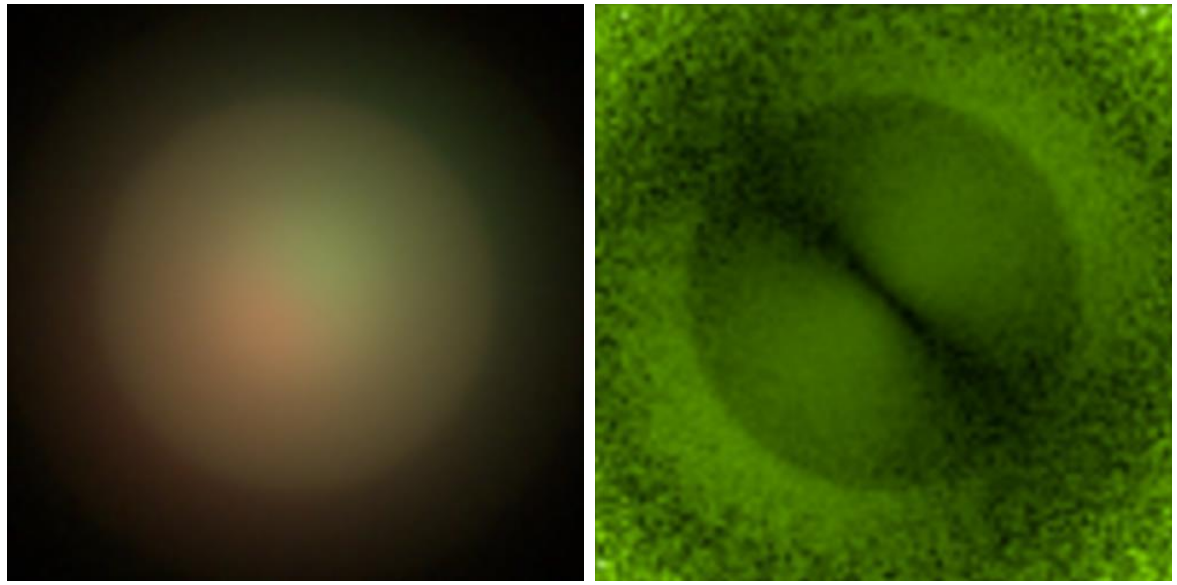


Mixing dome





Max delta u'v' – 0.449

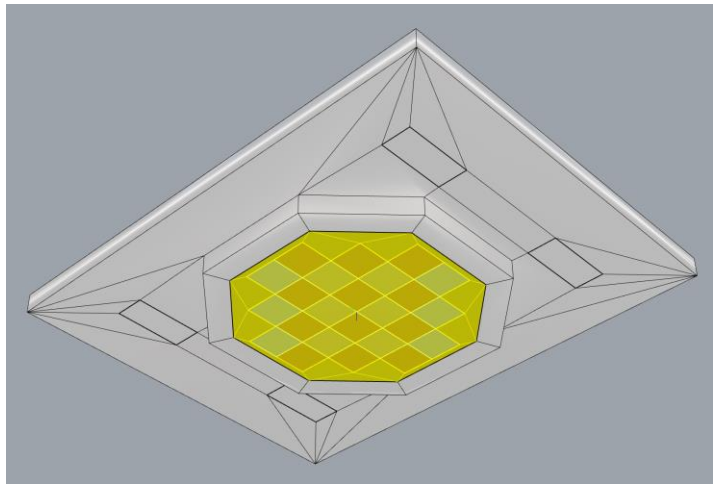


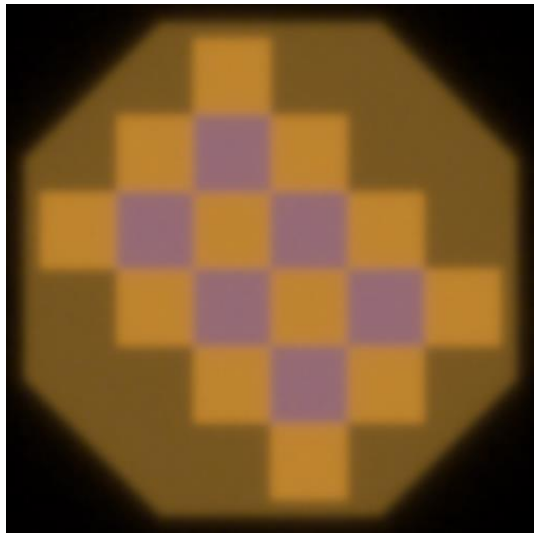
Max delta u'v' – 0.249

Key takeaway: visual and numerical tools for color evaluation

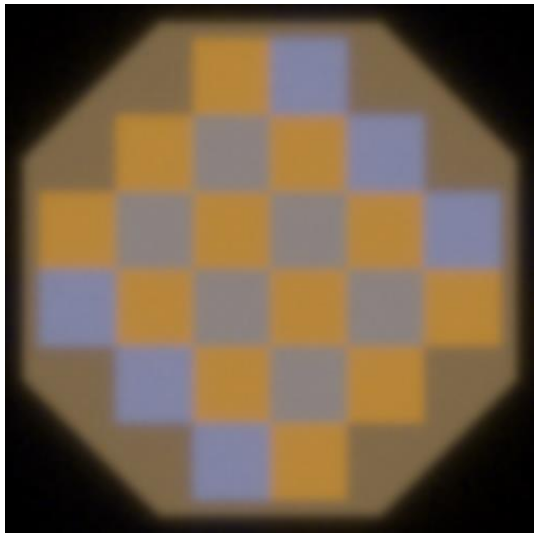
A design solution for a color issue – Faceted pillow pattern

example 3 – tunable white module

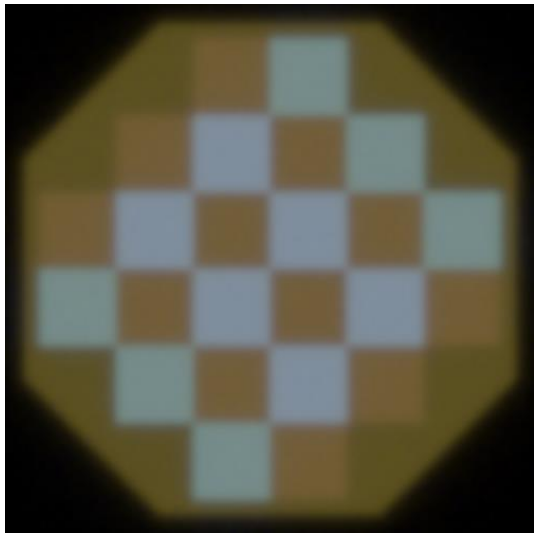




2700K



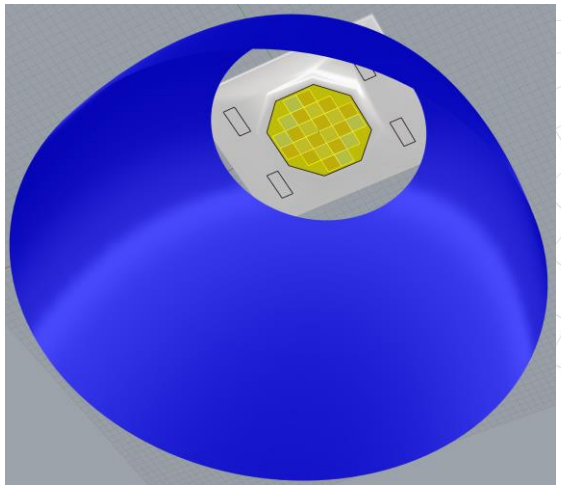
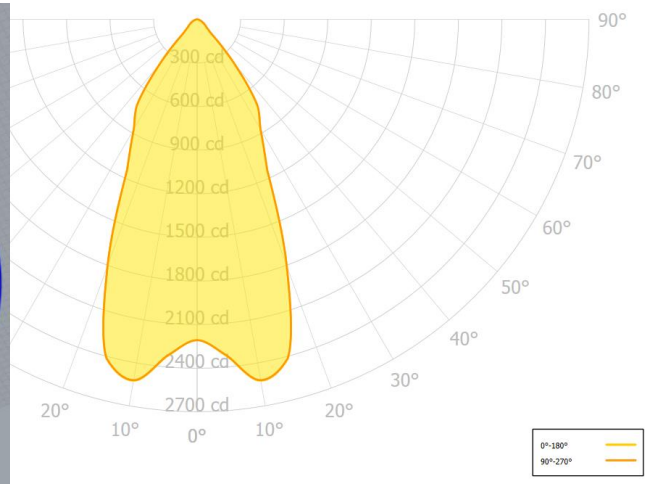
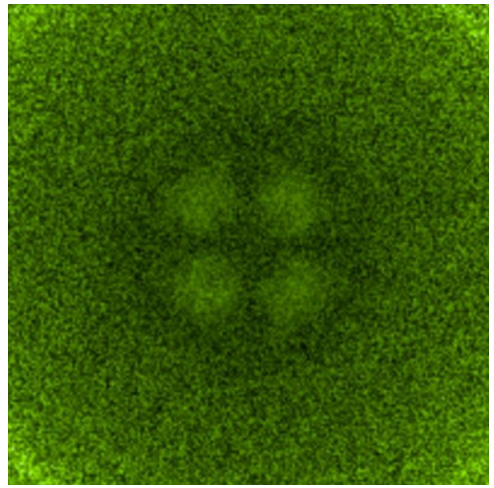
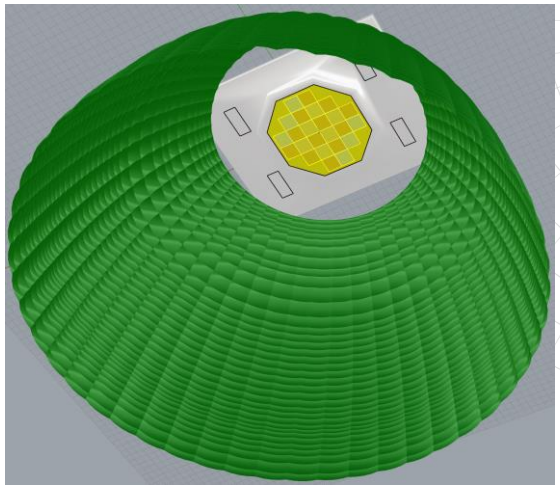
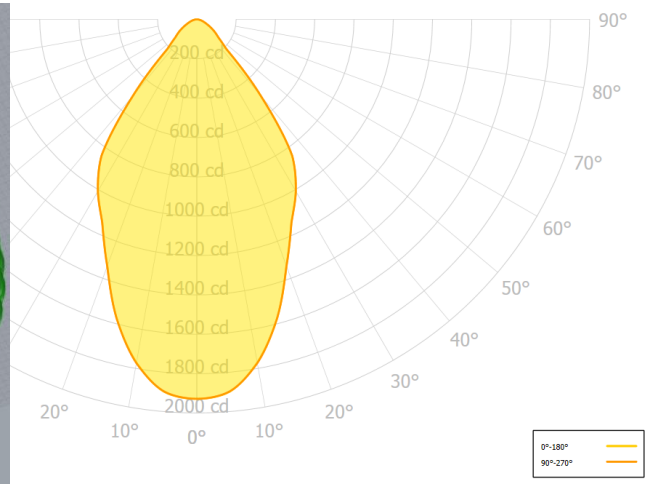
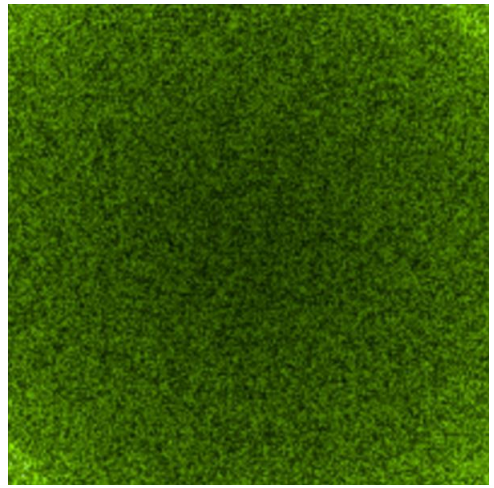
3500K

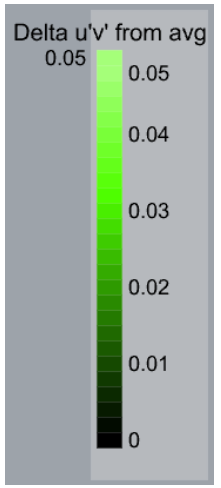


5000K

Key takeaway: ability to simulate a range of outputs for the same lamp

example 3 – tunable white, reflector with faceted pillows

	Reflector	Candela polar plot	True color illuminance	Delta u'v' from average
Before: smooth				
After: faceted pillow				

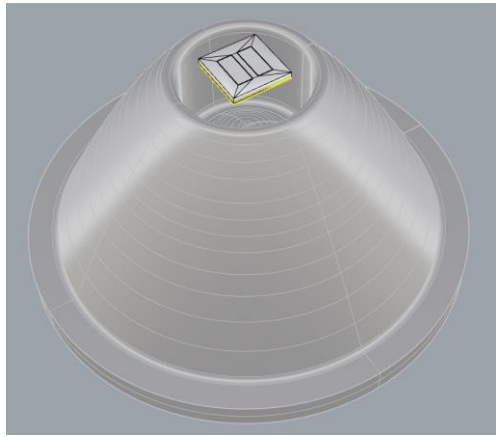


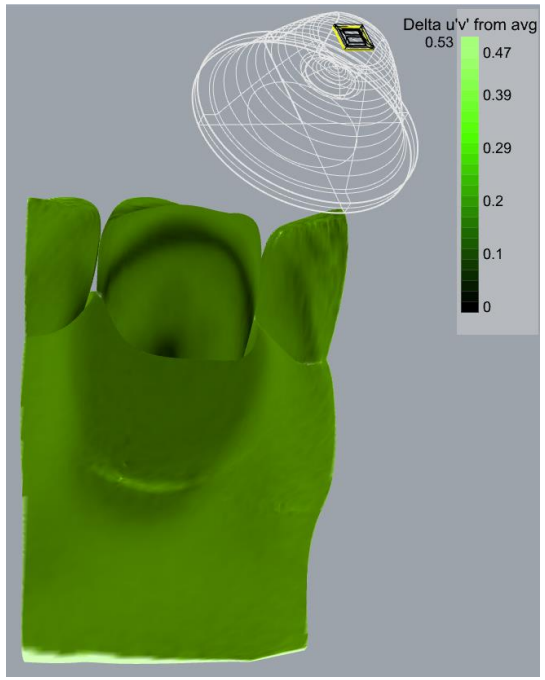
Key takeaway: color analysis leads to design improvements

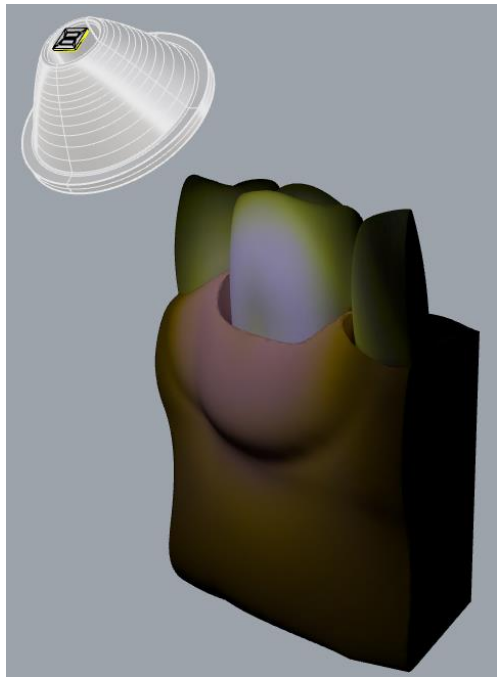
dental headlamp – design improvement

Before

- Smooth TIR surfaces
- Distinct blue/yellow color shift
- Tradeoff – Tightly controlled beam with high peak intensity

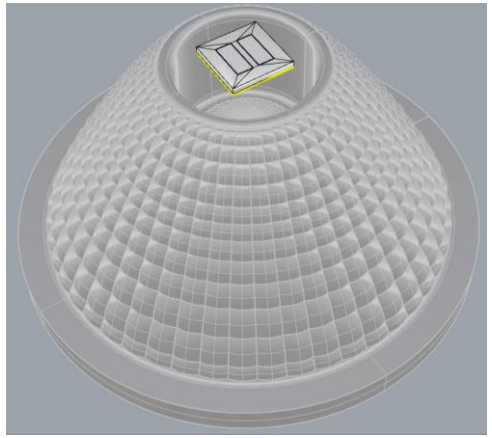


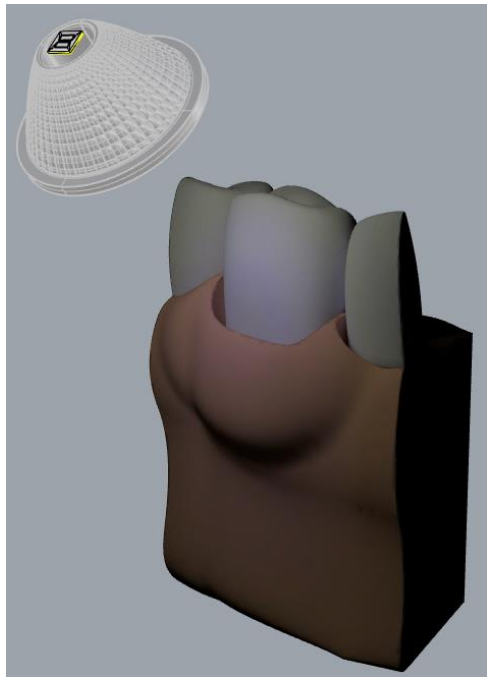


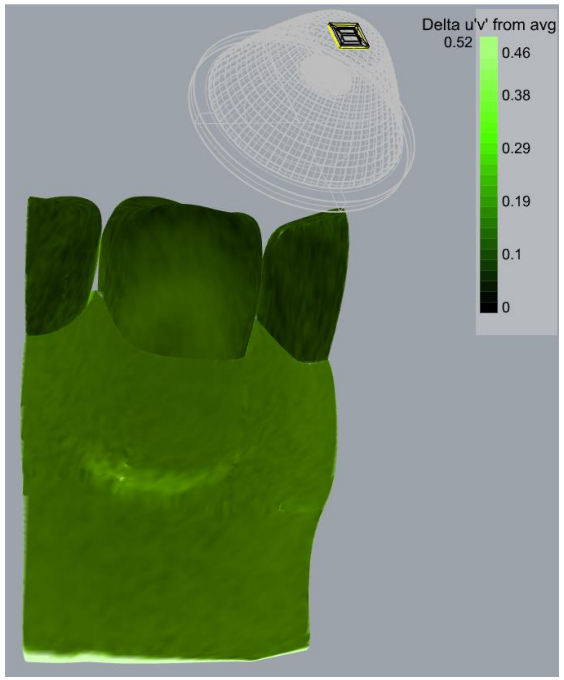


After

- Added facet pillows
- Improved color uniformity across teeth, also gums
- Tradeoff – wider beam, but that also has smoother cutoff



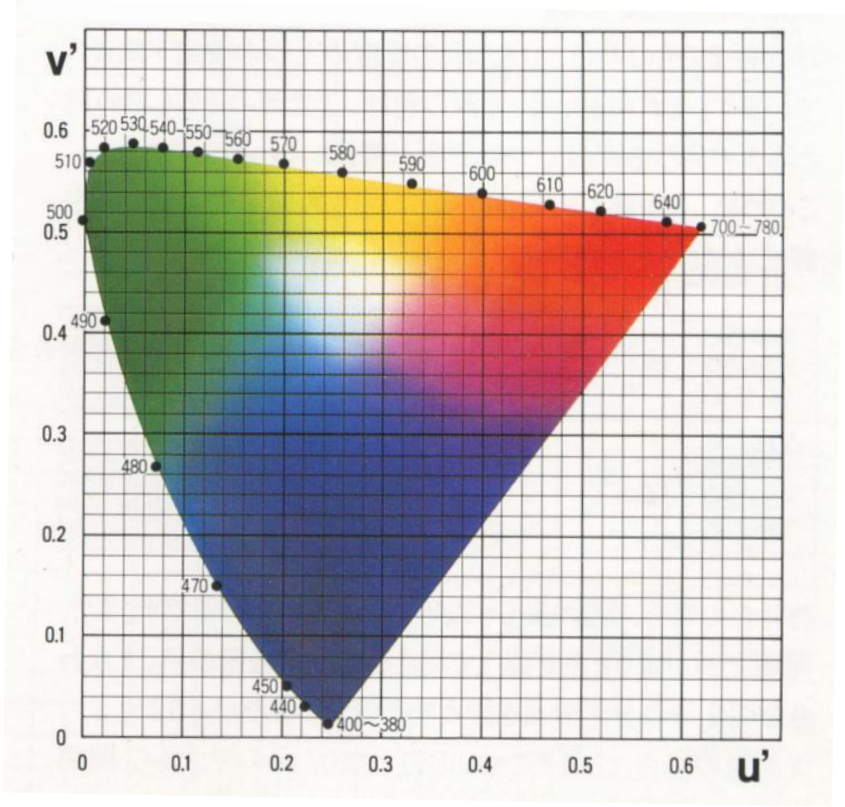




Questions?

Eric Frydendall
LTI Optics
eric@ltioptics.com

uniform color space (u'v')



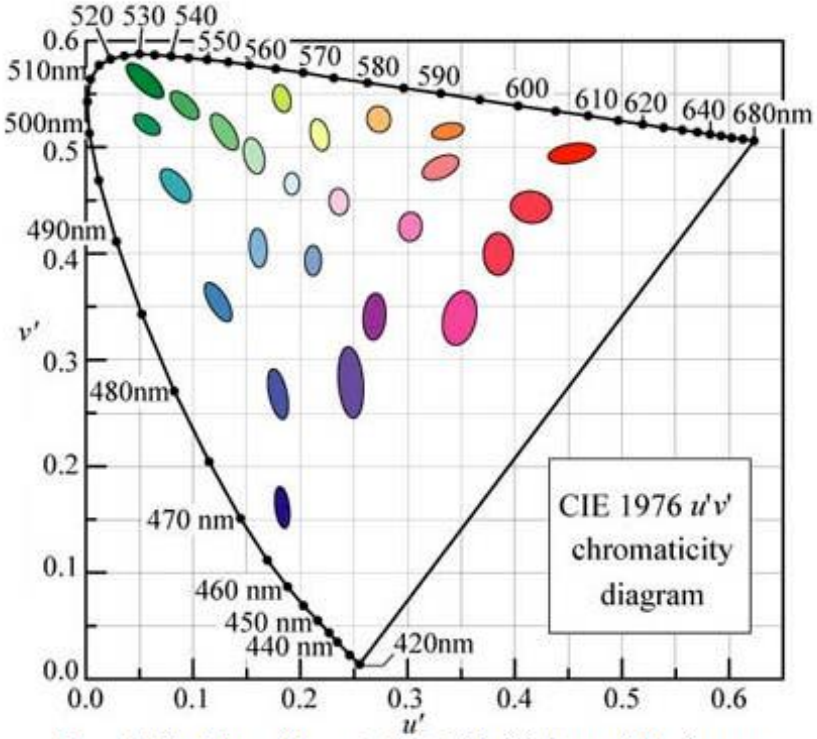


Figure 5: MacAdam ellipses in CIE 1976 u'v' chromaticity diagram