

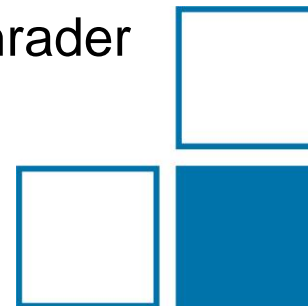
Measurement of lighting with temporal light modulation and EcoDesign

Deep dive into the MetTLM project

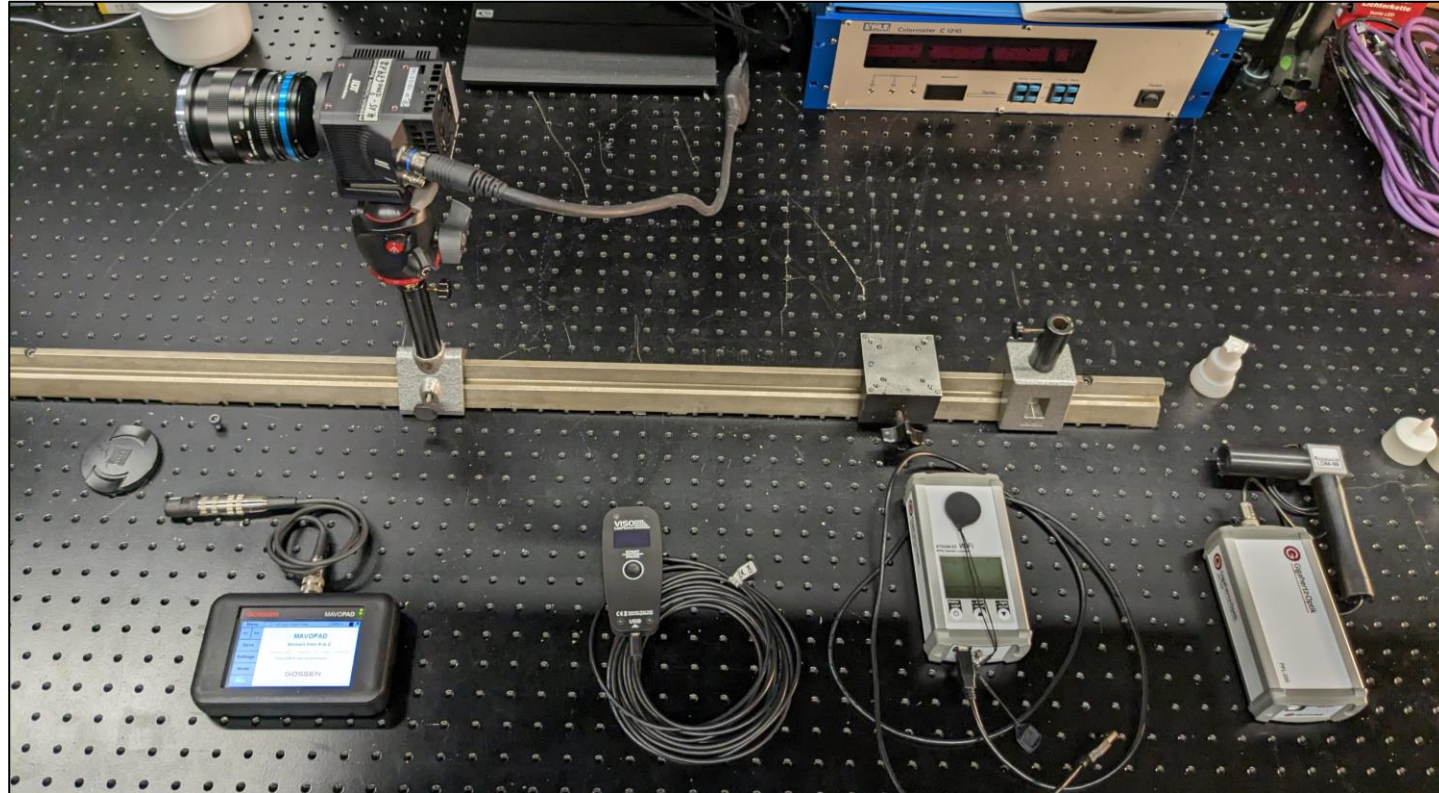
**Colour and spatial TLA - temporal lighting artefacts**

Johannes Ledig, Philipp Wiswesser, Annika Stein, Christian Schrader  
Konstantinos Pountoukidis (ICCS/NTUA)

12<sup>th</sup> April 2024



# Handheld TLM measurement devices



Exemplary collection of flicker meters for illuminance and luminance measurements

# ***Novel methods for TLM measurement***



**Objective 3:** To develop novel methods for measuring TLM of the illuminated environment in extended scenes (e.g. offices, roads or tunnels) and for multispectral TLM measurement of light sources.

## *Need:*

Real scenes and life environments are often illuminated with a mix of **multiple light sources** and daylight presenting an effective luminance pattern of **high contrast** and an inhomogeneous distribution of TLM parameters. Mapping the TLM of such environment would require multiple measurements with a single spot TLM measurement device.

**Task 2.1: Temporal luminance modulation measurement of **extended luminaires and scenes****

**Task 2.2: **Multispectral TLM measurement of light sources****

- Color-TLA (i.e. spectral dependent metrics, as chromaticity affects visibility threshold)
- Temporal Color Modulation (TCM  $\neq$  Color-TLM)  
multispectral TLM, i.e. PWM or an RGBW-LED combination that leads to color breakup in TLA



# Spatial and multispectral TLM measurement

I

RGB-camera  
Imaging Solutions – IDT OS 7 – S3



CMOS Sensortechnology  
4200 fps @ 1920 x 1280  
Max: 130000 fps  
Global Shutter  
Costs > 40.000 €

II

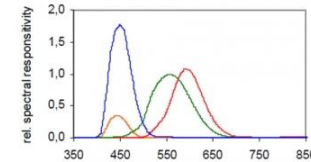
RGB-camera  
Sony – DSC-RX100 M5A



CMOS Sensortechnology  
1000 fps @ 1920 x 1080  
Rolling shutter  
Internal ND-filter  
Costs < 800 €

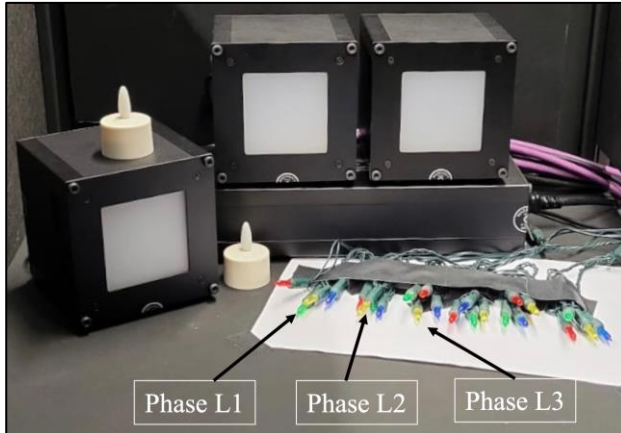
III

Tristimulus Flickermeter  
Gigahertz-Optik CT-4501 & PFL-200-V01



Photometric illuminance measurement  
High-speed transimpedance amplifiers  
with anti-aliasing low-pass filter  
Synchronized parallel signal acquisition

# TLM measurement – Scene 1



# TLM measurement – Scene 1



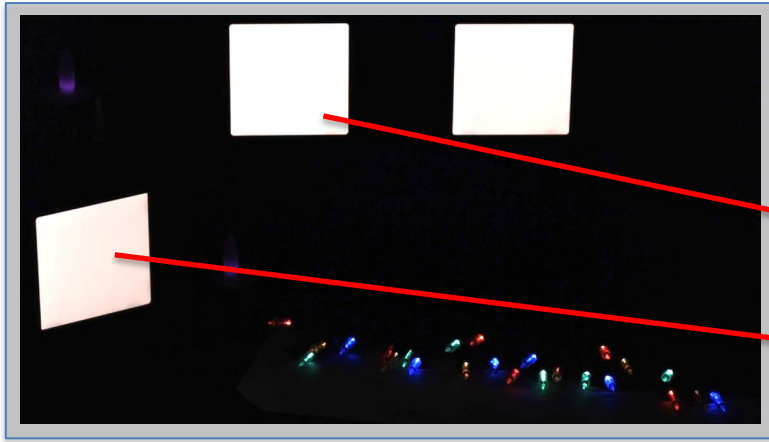
**Resolution:**  
1696 x 936;  
5790 fps;  
 $t_{\text{int}} = 169 \mu\text{s}$ ;

video slowed down  
290x

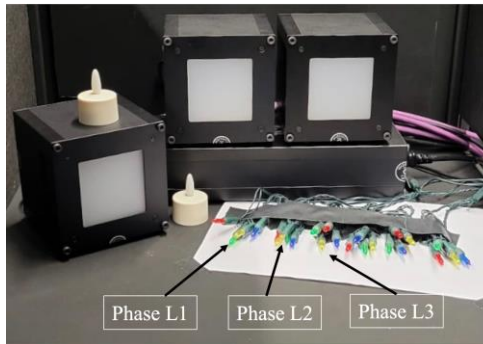
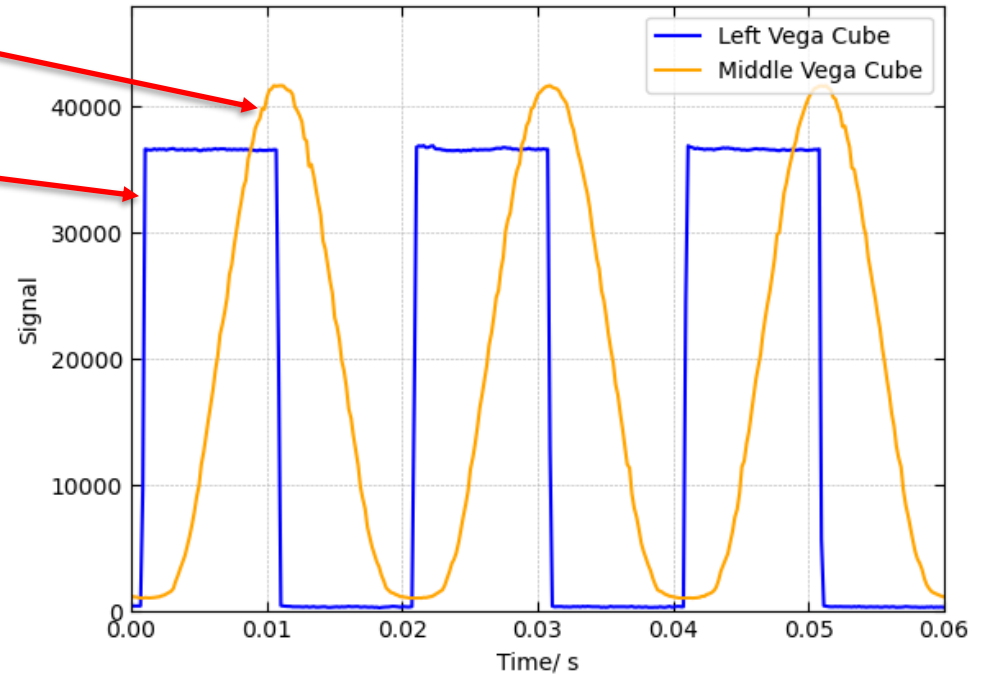
Highspeed RGB-camera:



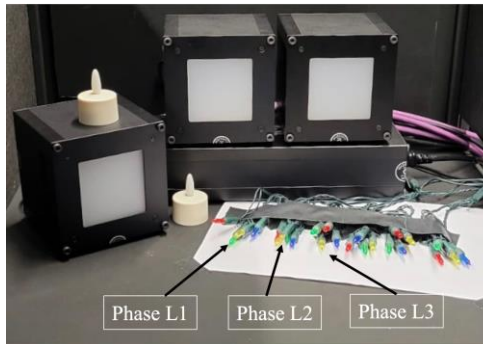
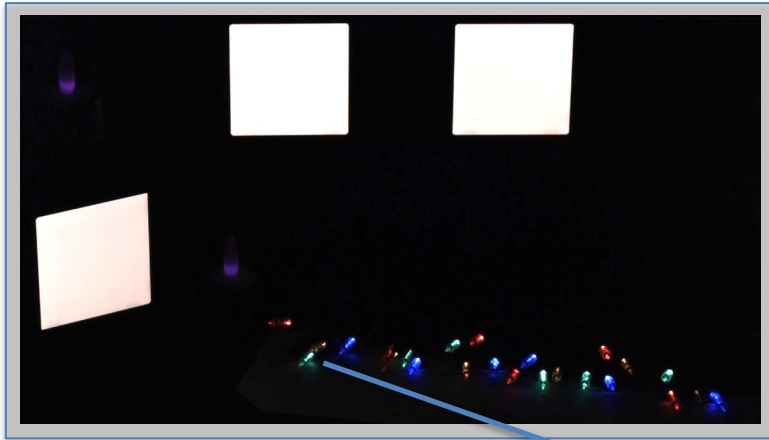
# TLM measurement – Scene 1



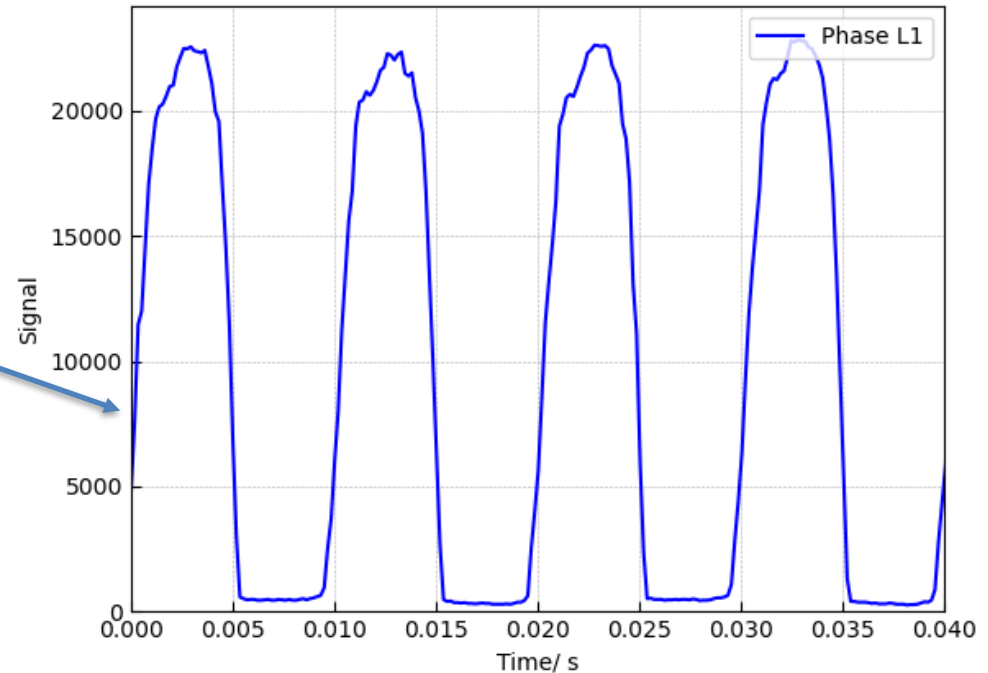
## Waveform of the TLM-Luminance standard



# TLM measurement – Scene 1

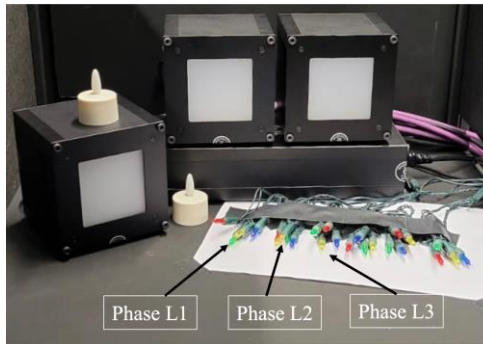
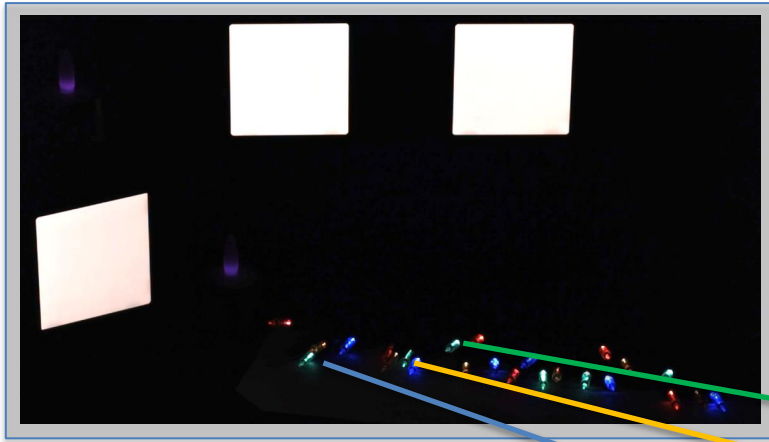


## Waveform of the fairy lights

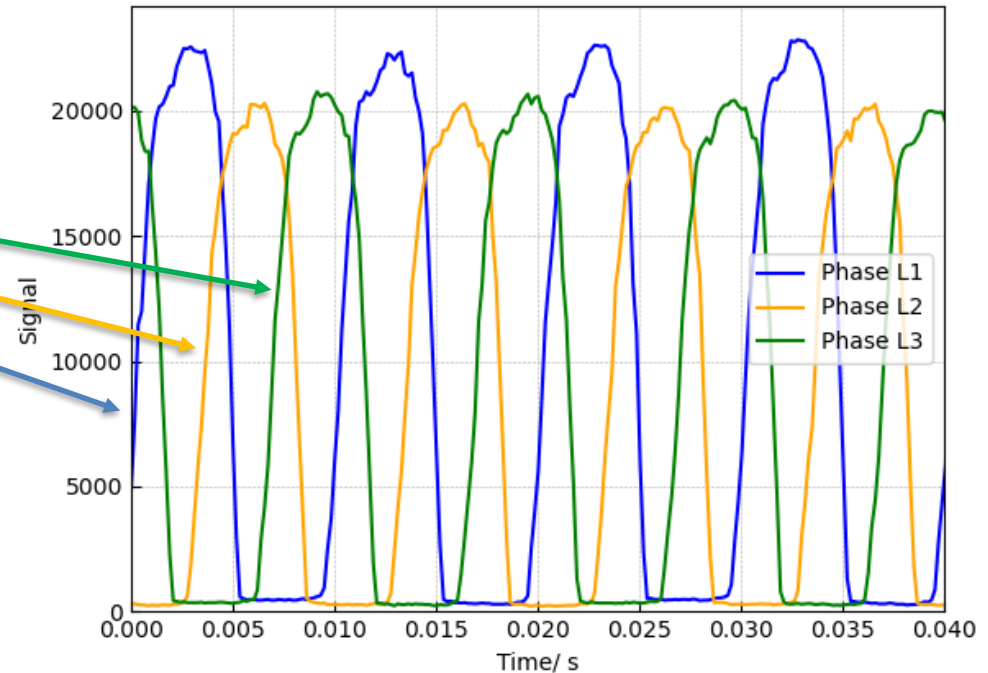




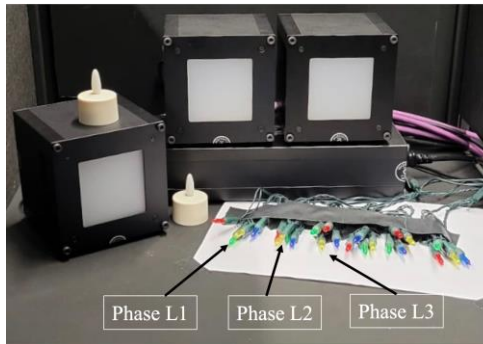
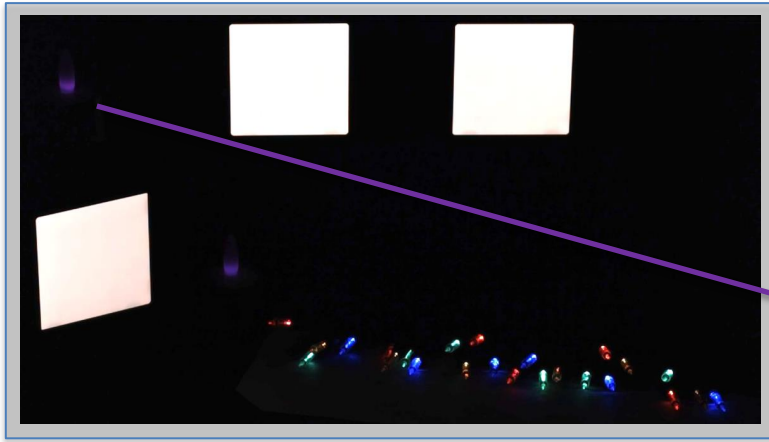
# TLM measurement – Scene 1



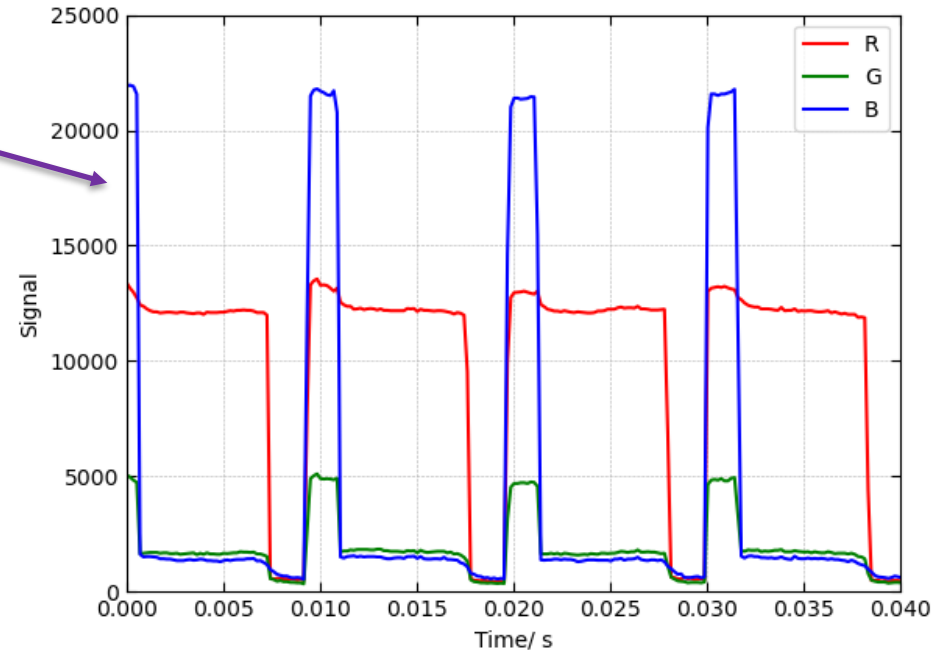
## Waveform of the three fairy light chains



# TLM measurement – Scene 1



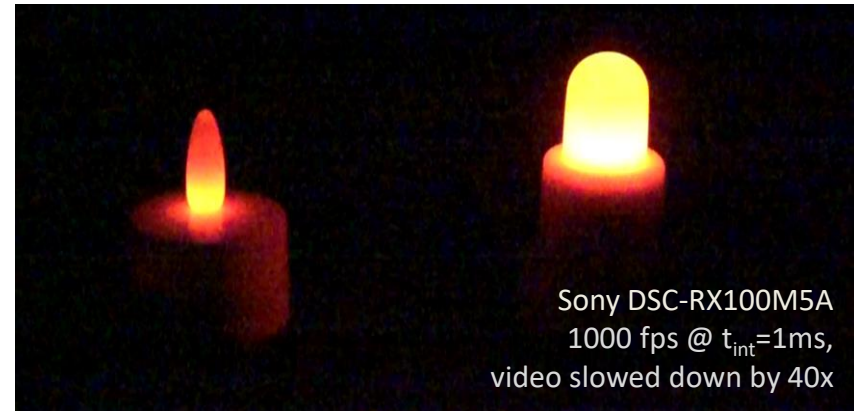
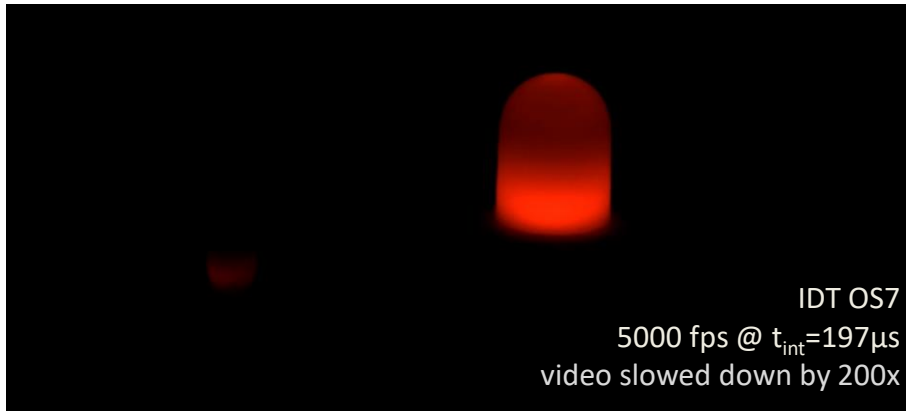
## Multispectral waveform of the colour tunable LED candle



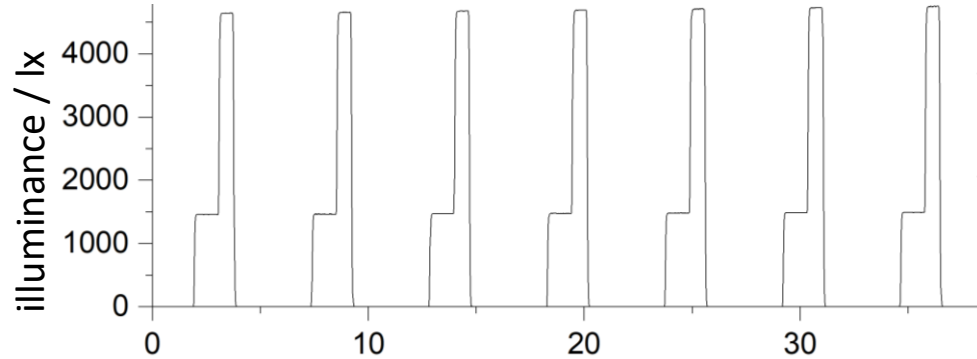
# Temporal colour modulation of RGB LEDs



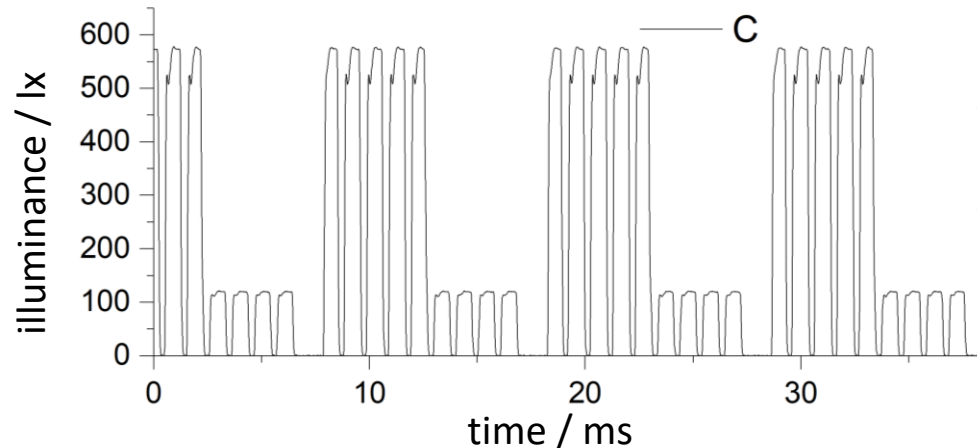
- Dimming by pulse-width modulation (PWM)
- Variable lamp colour by PWM of RGB LEDs
- RGB channels are simultaneously lit
- TLM of each RGB channel in various driving/multiplexing schemes to another



# Temporal Light Modulation of RGB LEDs

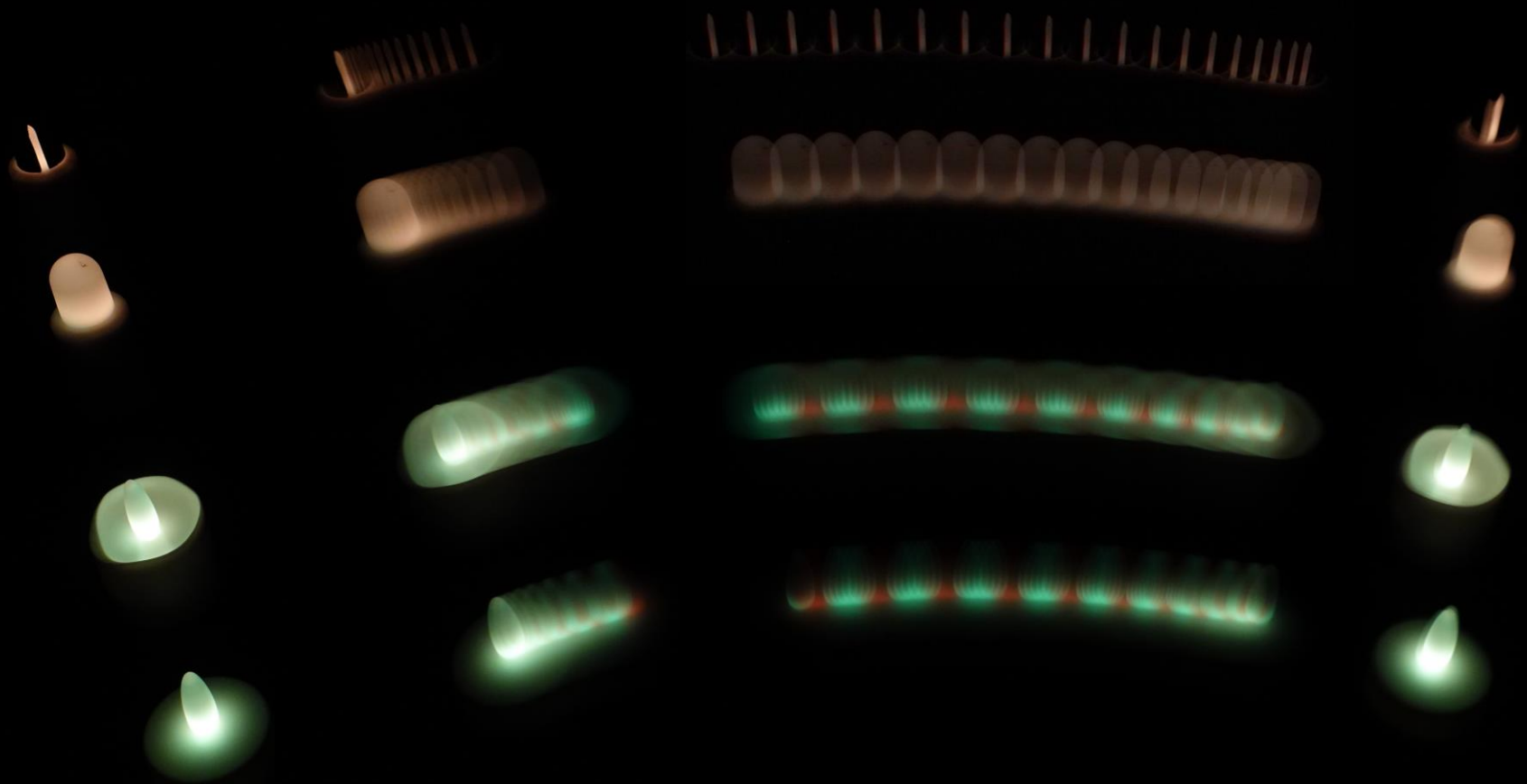


- RGB channels start simultaneously, one PWM
- Dimming by duty cycle of colour tuning PWM

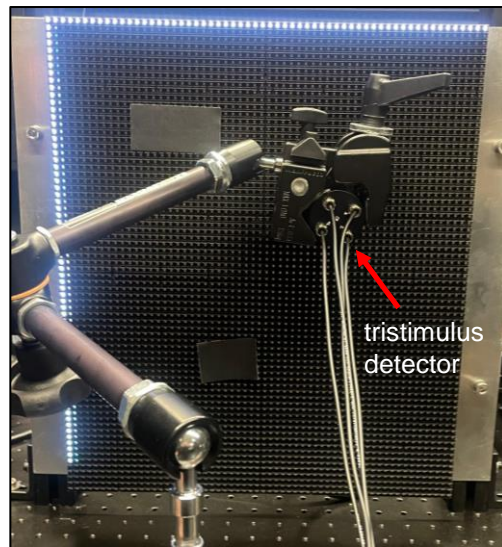
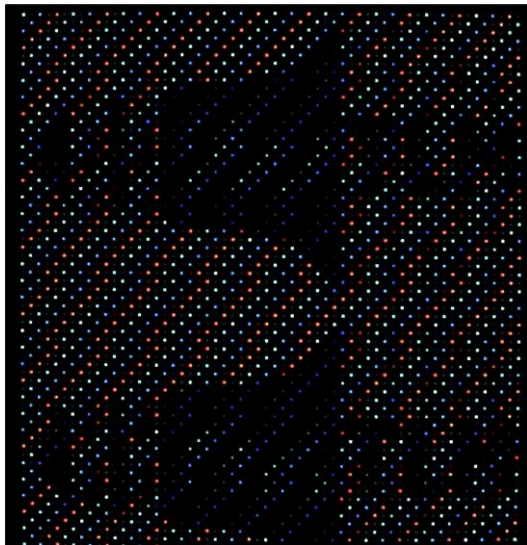


- Dimming by fast PWM multiplexed to all RGB LEDs
- Colour tuning by slow PWM





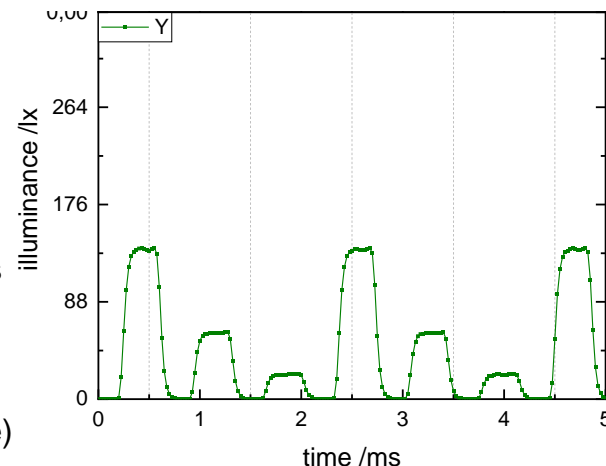
# LED Display for outdoor advertisement



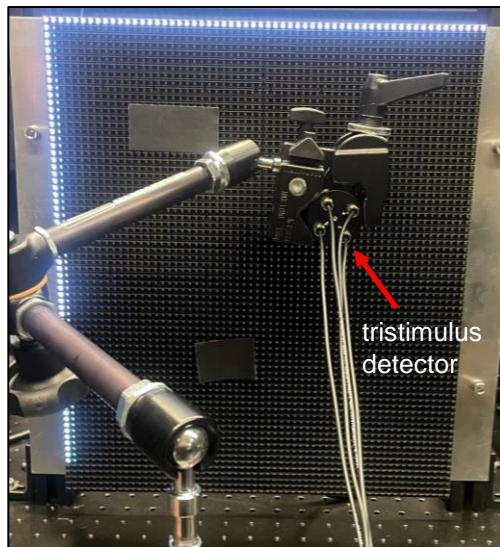
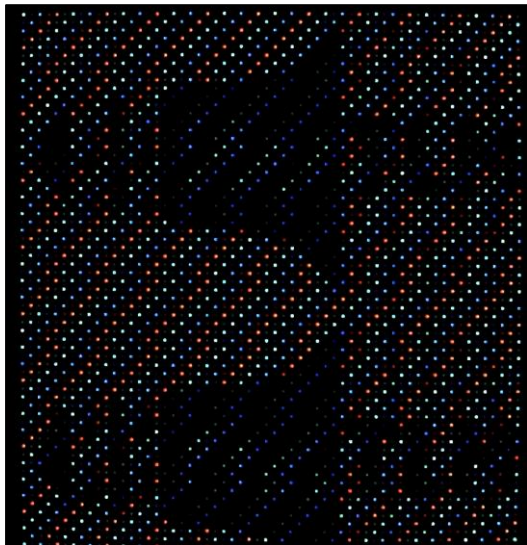
(outdated display generation)

- current dimming, driver multiplexed to LEDs of several pixels
- Phase shifted duty cycle of the RGB LEDs per pixel

- Test image with single white pixel colour
- Photocurrent waveform of four channels is transformed to tristimulus waveforms
- Waveform of chromaticity coordinates is calculated for all tristimulus values (for the graph a threshold is used to exclude noise)



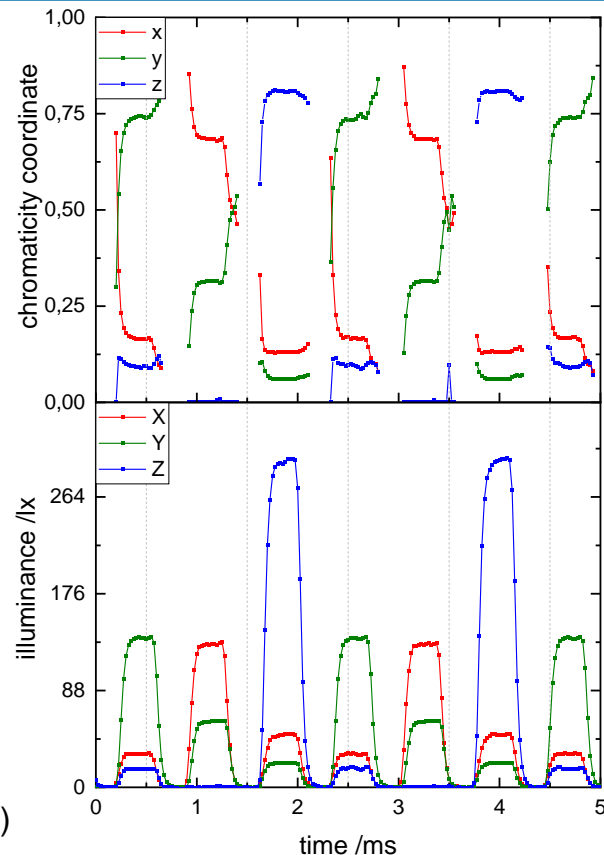
# LED Display for outdoor advertisement



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- Test image with single white pixel colour
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- Waveform of chromaticity coordinates is calculated for all tristimulus values (for the graph a threshold is used to exclude noise)



# Multispectral Imaging of Tunable White



9000 fps,  
 $t_{\text{int}}=197\mu\text{s}$ ,  
ROI=928x488 pixels



Philipps Hue White Ambiance Filament E27

Philipps Hue White Ambient E27



# Field Measurement – Scene 2: Renault Zoe E-tech

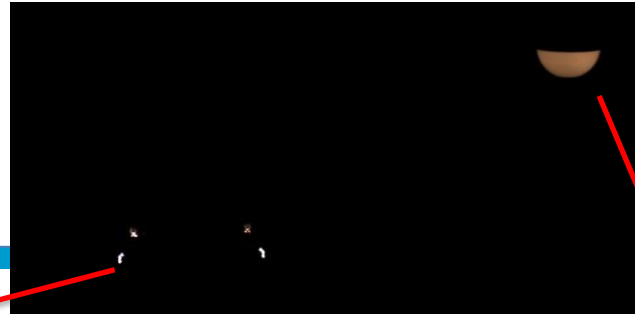


# Field Measurement – Scene 2: Renault Zoe E-tech



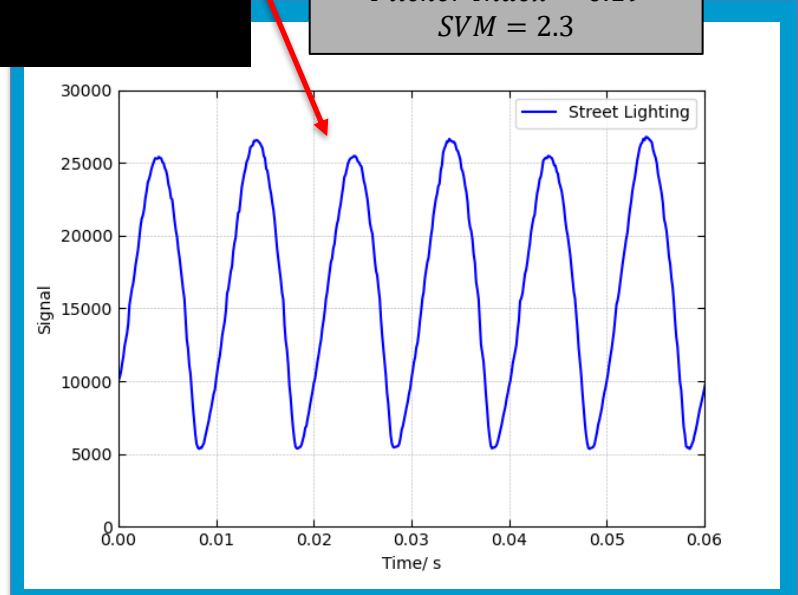
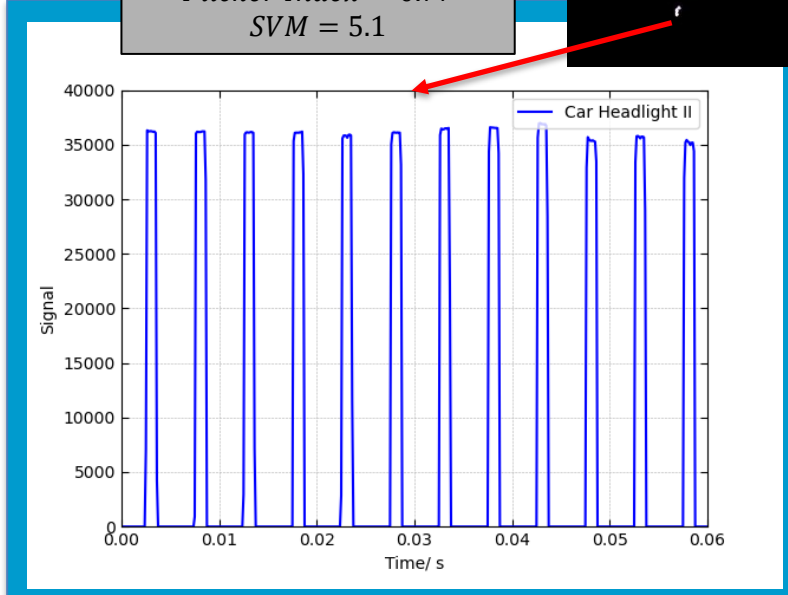
**Resolution:**  
1184 x 584;  
8000 fps;  
 $t_{int} = 122 \mu\text{s}$ ;  
video slowed  
down 400x

# Field Measurement – Scene 2: Renault Zoe E-tech

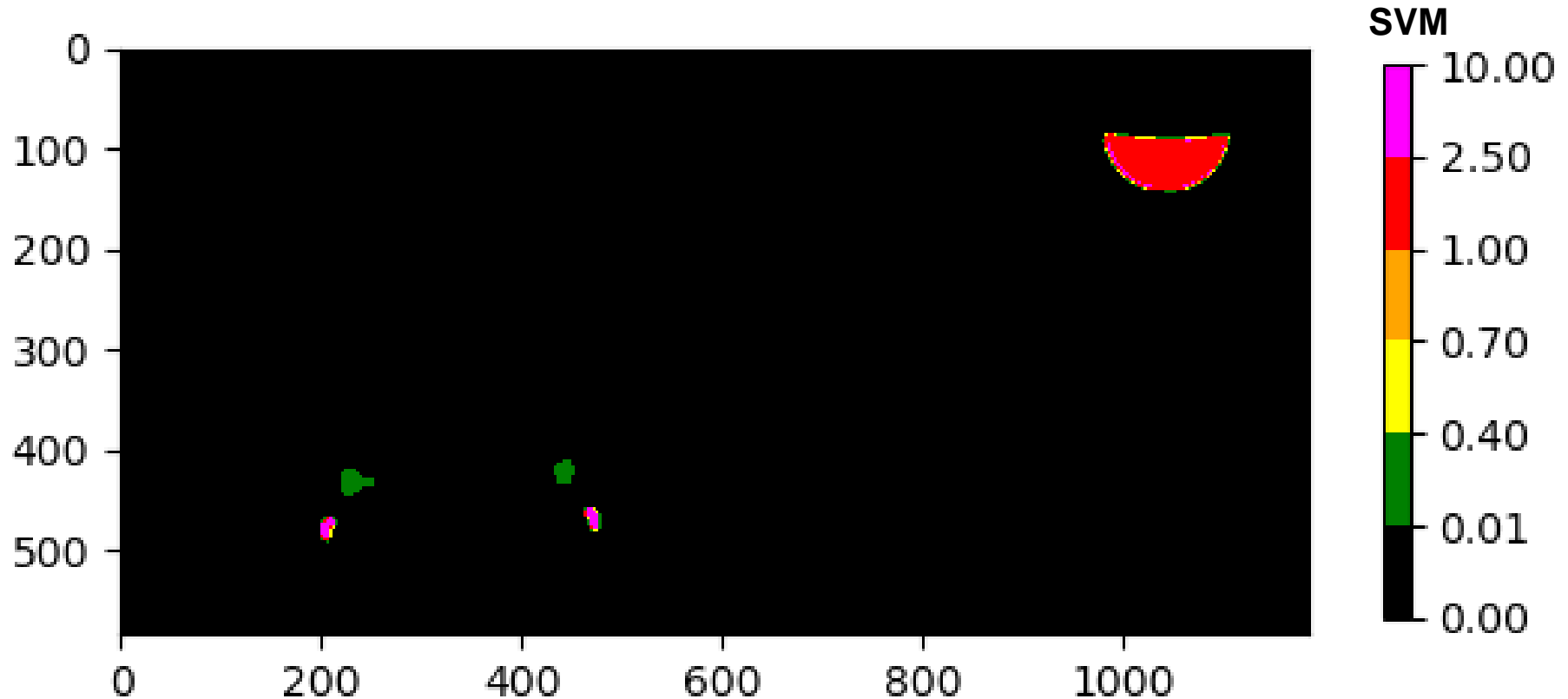


$f_{flicker} = 200 \text{ Hz}$   
 $Flicker \text{ Percent} = 100 \%$   
 $Flicker \text{ Index} = 0.77$   
 $SVM = 5.1$

$f_{flicker} = 50 \text{ Hz}$   
 $Flicker \text{ Percent} = 67 \%$   
 $Flicker \text{ Index} = 0.19$   
 $SVM = 2.3$



# Field Measurement – Scene 2: Renault Zoe E-tech



# X-mas tree with different fairy lights

Highspeed RGB-camera:

IDT OS7-S3 color

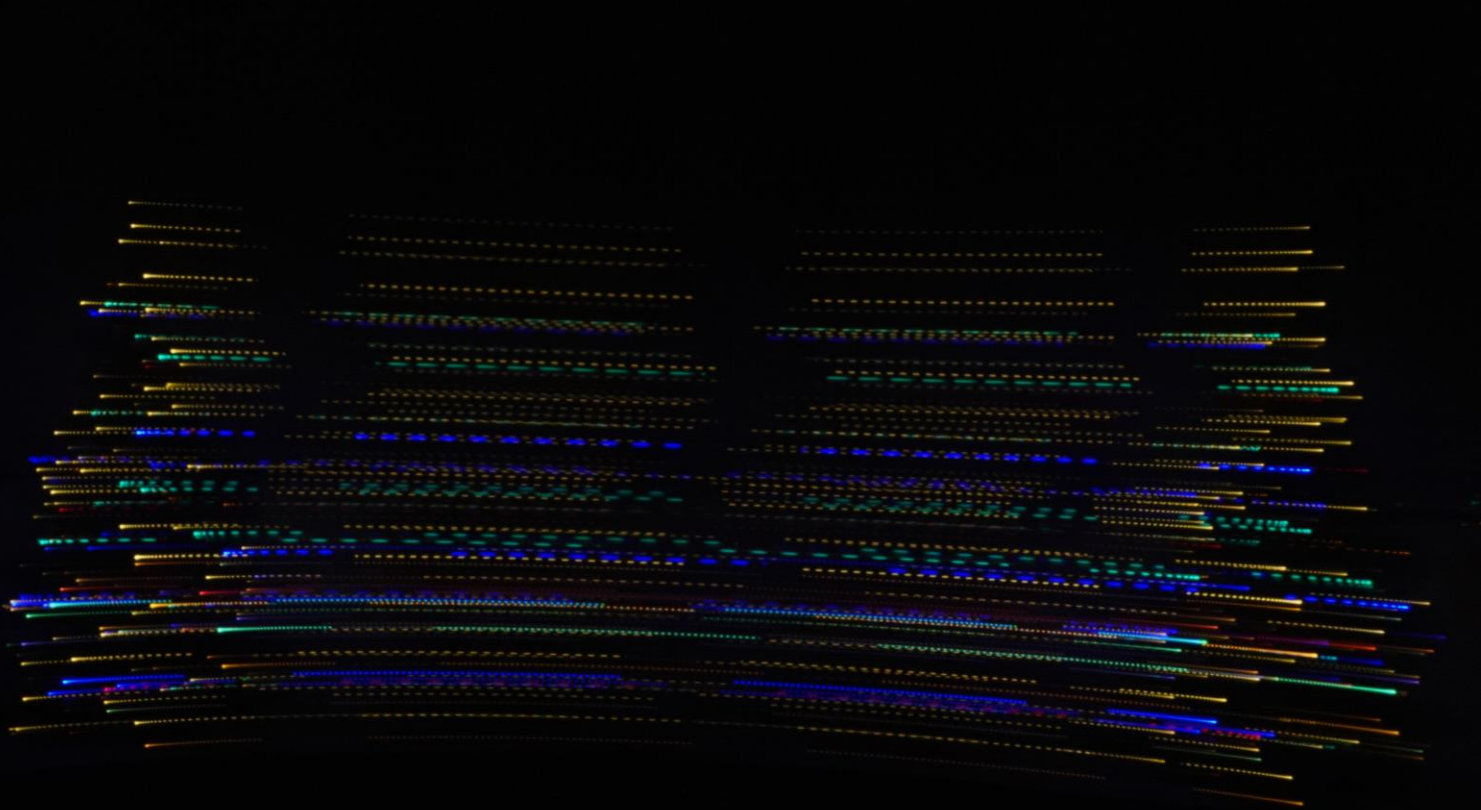


Fading LEDs (PWM) and color LEDs (100Hz by rectified mains, two strains with 120° phase shift)

IDT OS7-S3

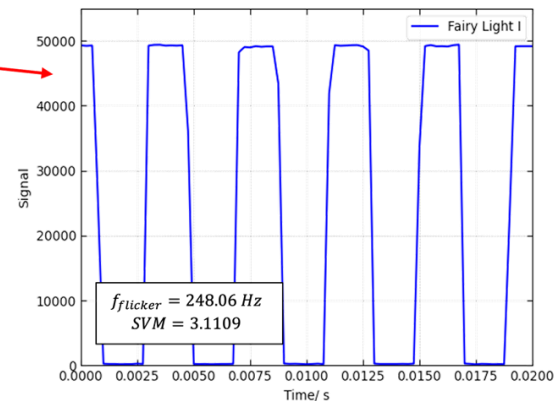
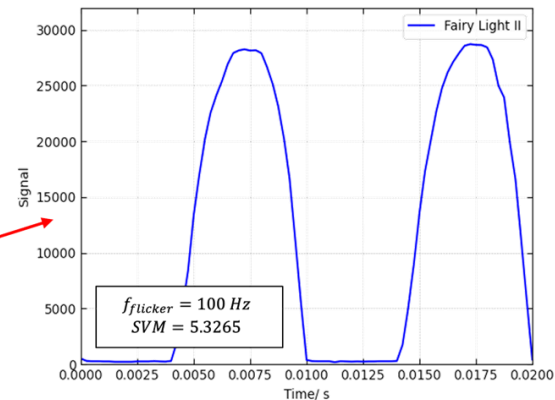
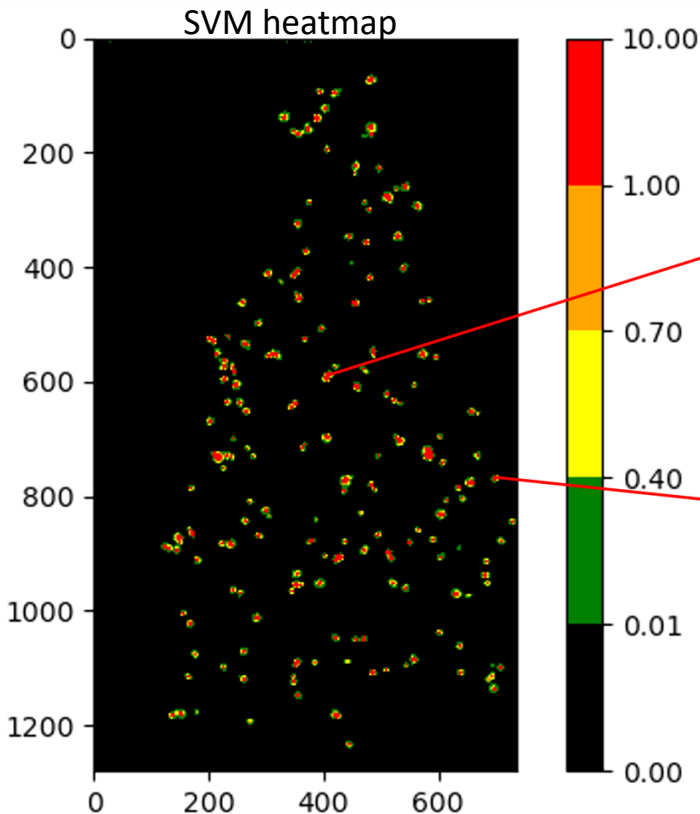


4000 fps @  $t_{\text{int}}=247\mu\text{s}$ ,  
video slowed down by 266x



camera pan during sequence of  
four images at  $t_{int}=100\text{ms}$

# X-mas Tree with different fairy lights



Fading LEDs (PWM) and color LEDs (100Hz by rectified mains, two strains with 120° phase shift)

# Summary & Outlook

- ✓ Camera is able to measure TLM of a light source  
→ **TLM visualization**
- ✓ Analysis of relevant TLM and TLA quantities is possible  
Limitations: amount of data, sampling rate, noise / contrast
- ✓ Possibility of measuring light scenes and in the field
  
- ✓ Multispectral measurements of TLM using RGB cameras
- ✓ Tristimulus flickermeter: waveform of chromaticity coordinates
  
- Contribute to a potential metric for the Phantom Array Effect
- Initiate a metric for TLA from temporal colour modulation
- Determine the measurement uncertainty of the metrics

