Measurements of Flexible Displays

- Challenges and Solutions -

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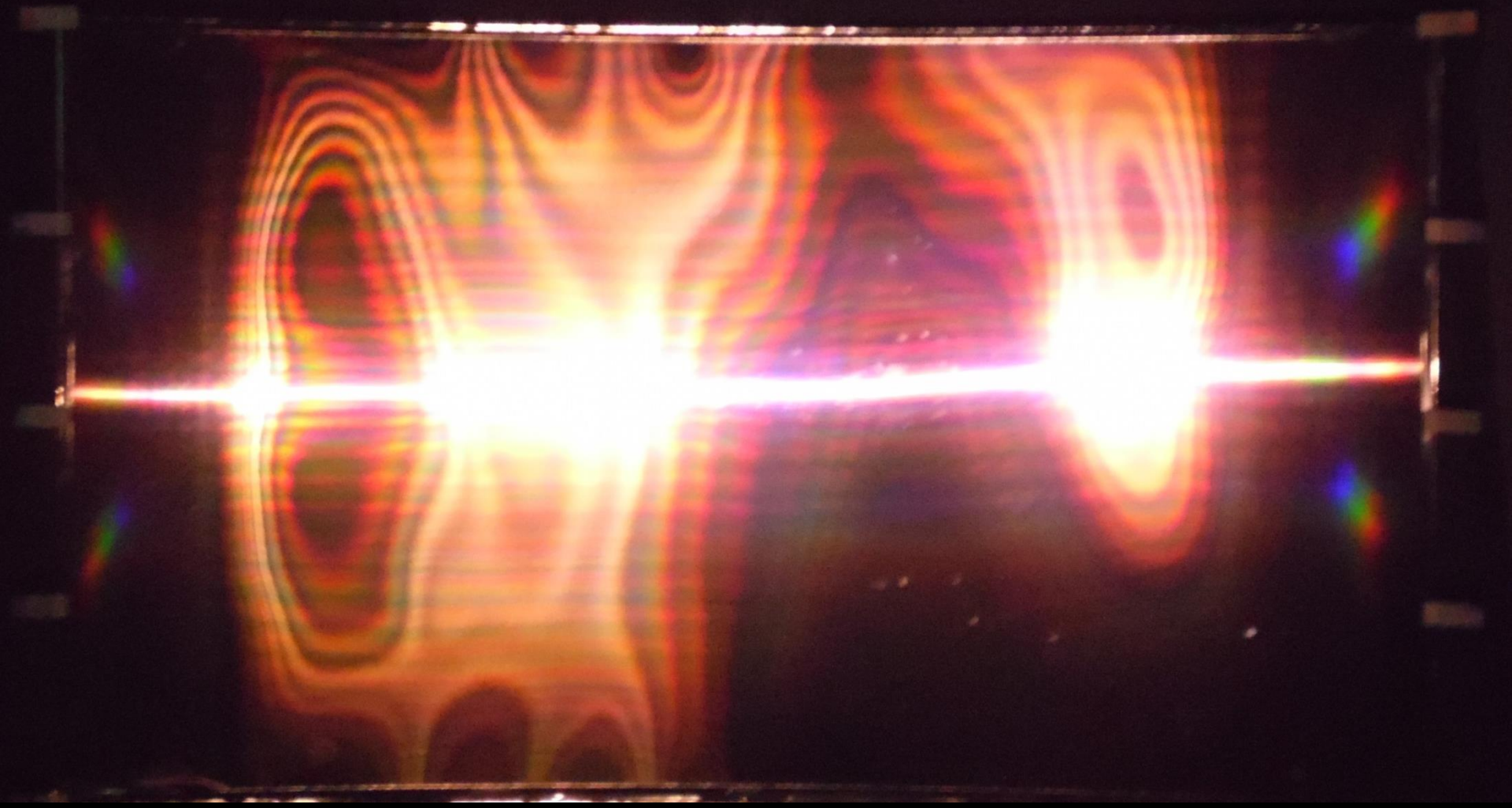
What is that?



Reflections of a small 1 W LED on concave curved TV screen

Display: 55", focal length = 2.25 m (measured), radius = 4.5 m (R = 2f; manufacturer: 4.2 m)
LED: 1 Watt, 30°, 3,200 K, Geometry: small light source distance ~ 4.5 m, observer distance ~ 3 m

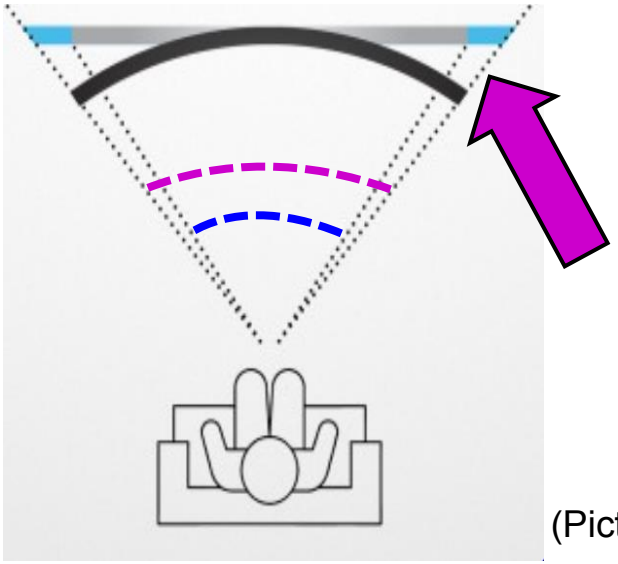
Overview

- Why curved?
- Measurement Set-Ups

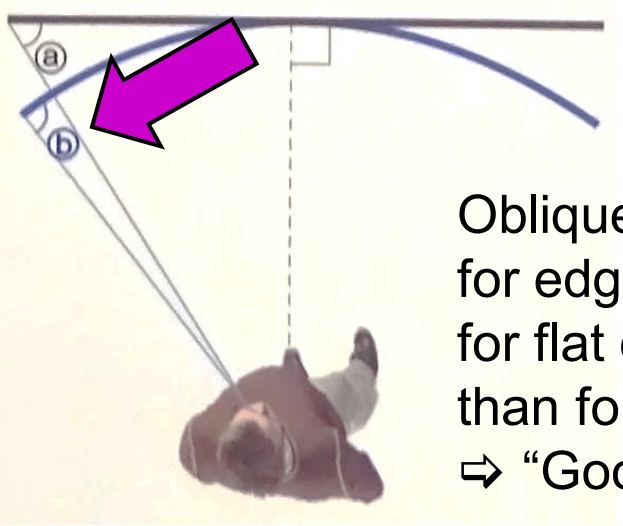
(References etc. see proceedings)

Arguments for Curved TV

- **Larger FOV as flat display of same size**



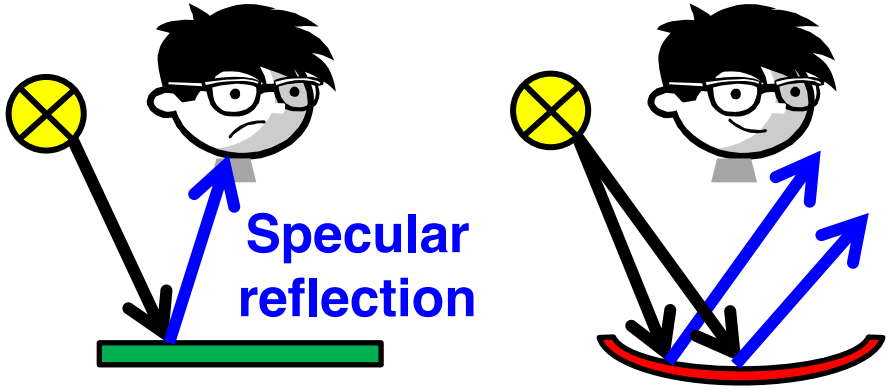
- **Less viewing angle degradations**



Oblique angle for edges is larger for flat display (a) than for curved (b).
⇨ "Good for LCDs"

(Pictures: SAMSUNG)

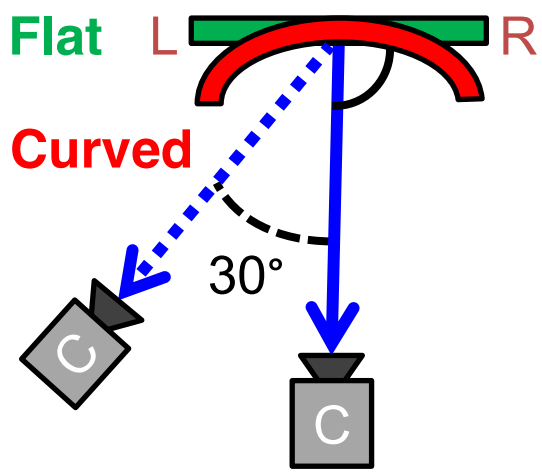
- **Reflection geometry:**
  - Flat displays "enable" specular reflections
  - Specular reflections are less likely for concave displays

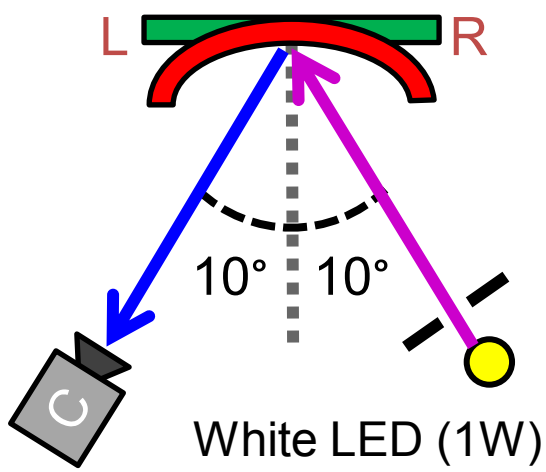


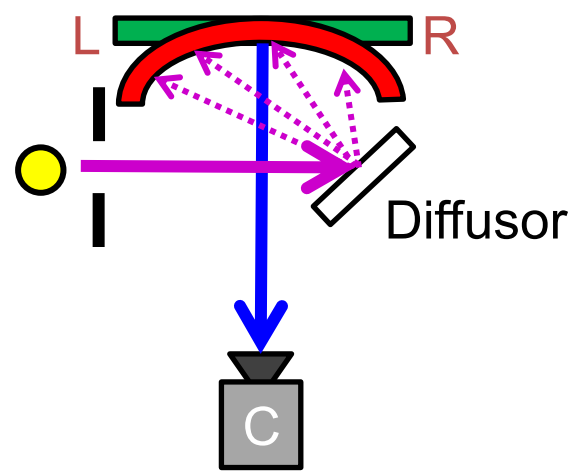
Measurement Set - Ups

*: similar to Kelley

Darkroom	Small light source*	Diffusor*
"Pure" display characteristics	Reflection from e.g. LED in living room	Reflection from e.g. white wall in living room





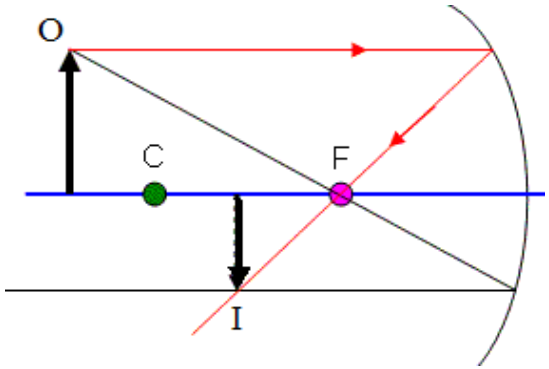


Imaging colorimeters are more suitable than spotmeters for these kind of measurements as the whole screen is captured at once.

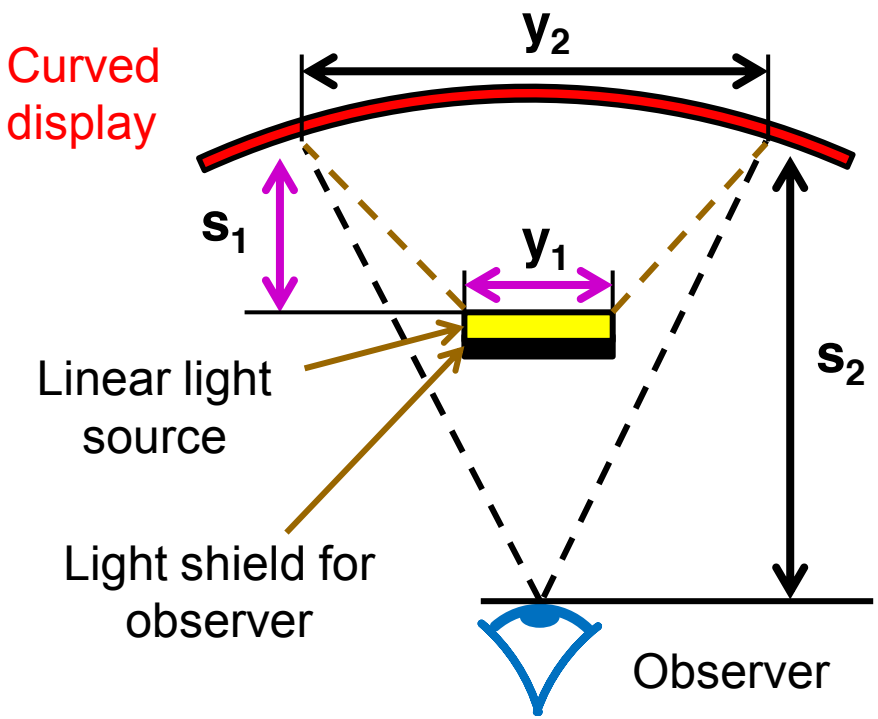
C: Imaging Colorimeter (INSTRUMENT SYSTEMS LUMICAM 1300), R and L refer to the view of the imager

Overview

- Geometrical optics
- Magnification vs. observer distance



"Concave Mirror" Optics



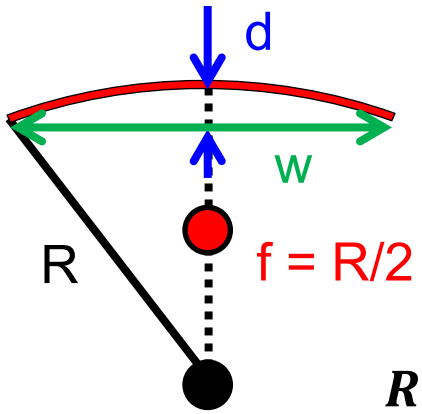
s_1: Distance light source - display

s_2: Distance observer - display

y_1: Object width

y_2: Image width

Geometrical optics



$$R = \frac{d}{2} + \frac{w^2}{8d}$$

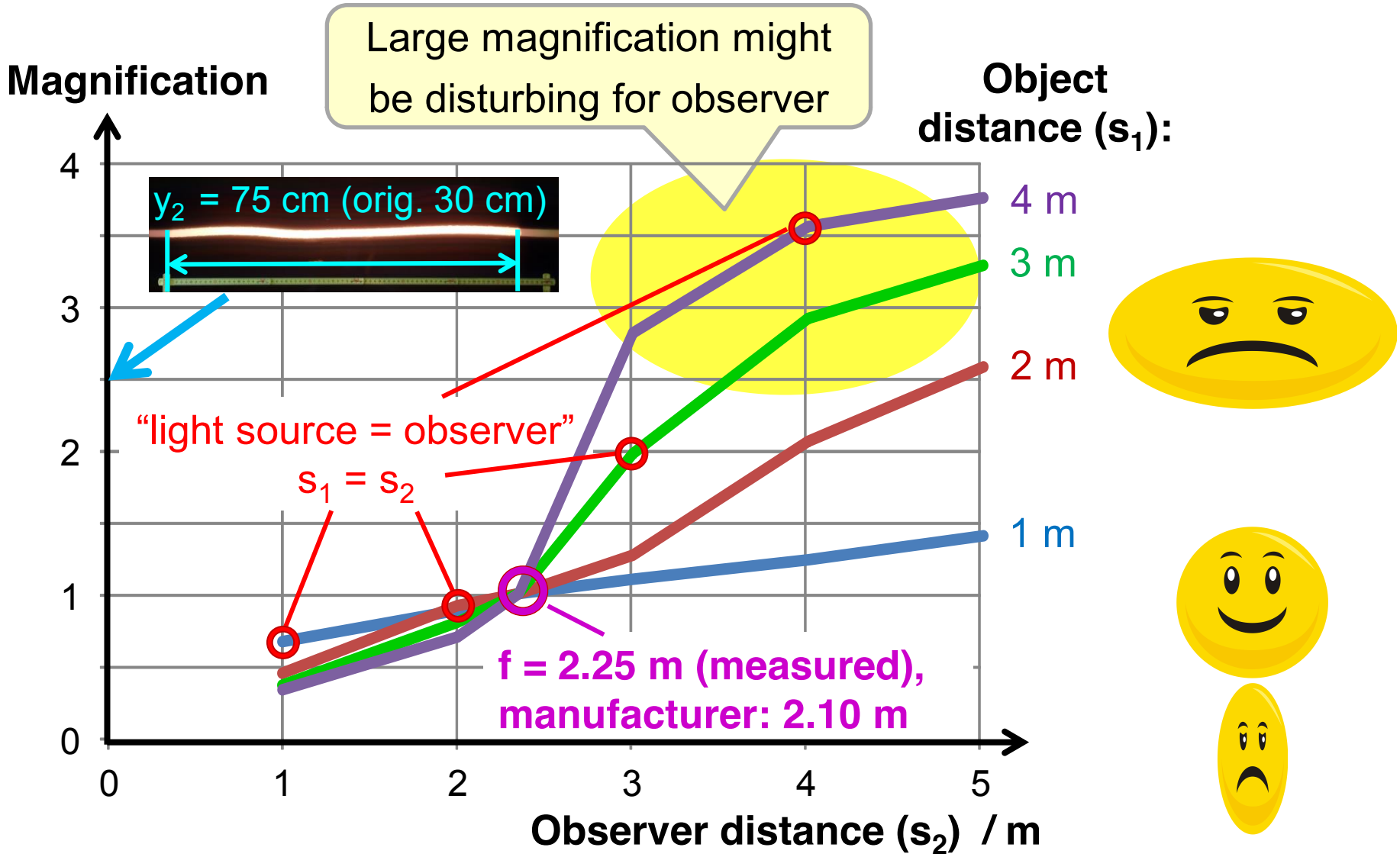
Here: w = 120 cm, $d_{measured}$ = 4 cm

⇨ R = 4.5 m (manufacturer 4.2 m).

But 1 mm error for $d_{measured}$ results in 10 cm for radius.

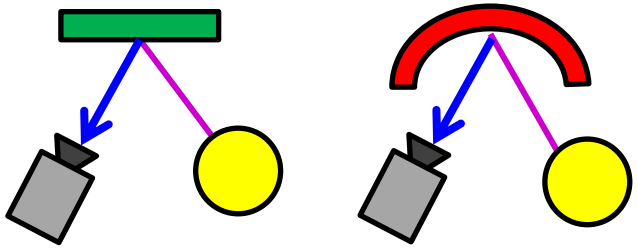
⇨ **Magnification = $\frac{y_2}{y_1}$; focal length f for $y_1 = y_2$ and $s_1 = s_2$** } **"best = both"**

Magnification - Playing with Distances



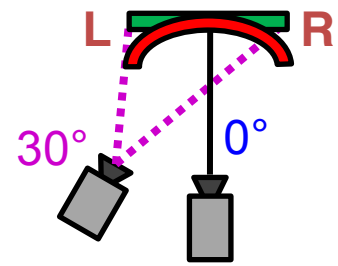
Overview

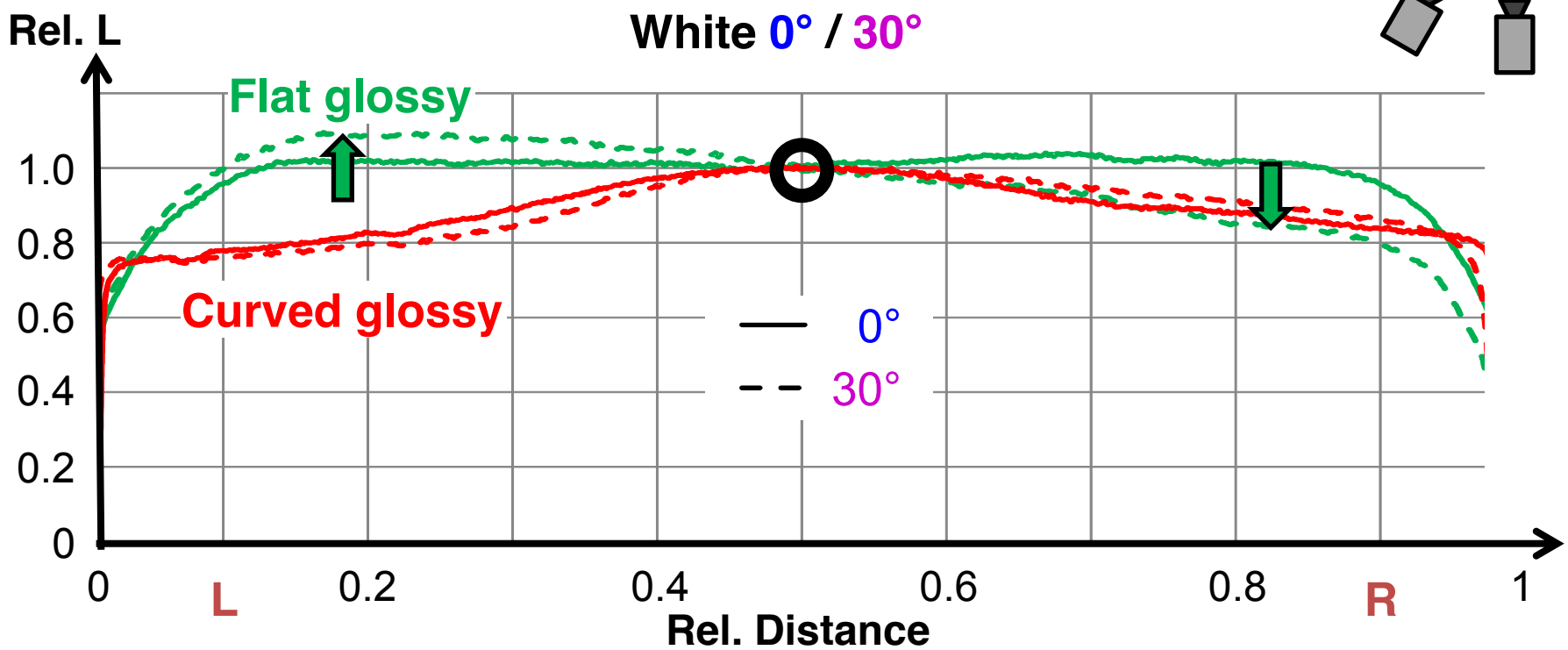
- Dark room (2 observer)
- Small light source



White Luminance for 0° and 30° @ 0 lx

Measured at 0° (perpendicular) and 30° (distance = 4.5 m)

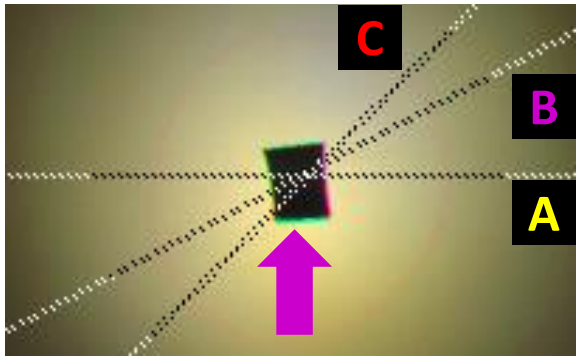
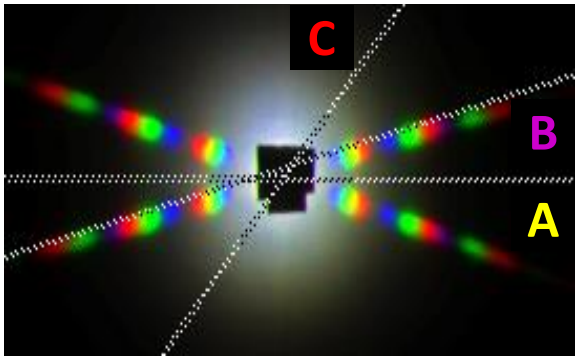
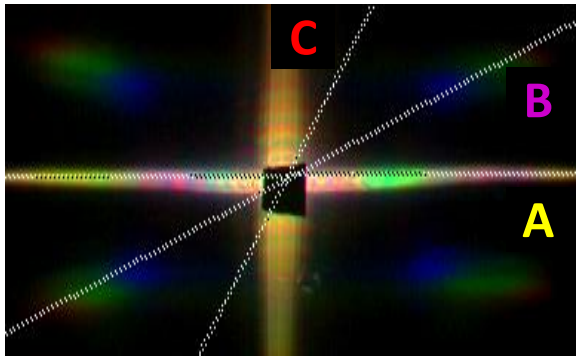




- **0°**: "Flat for flat" LCD, "curved for curved" (backlight non-uniformity)
- **30°**: Flat LCD: Luminance at "L" is higher and lower for "R" (viewing angle degradation, see #17). "Curved nearly unchanged".

Pictures of Small Light Source

Reflection of small light source in 1.5 m distance on (display off):

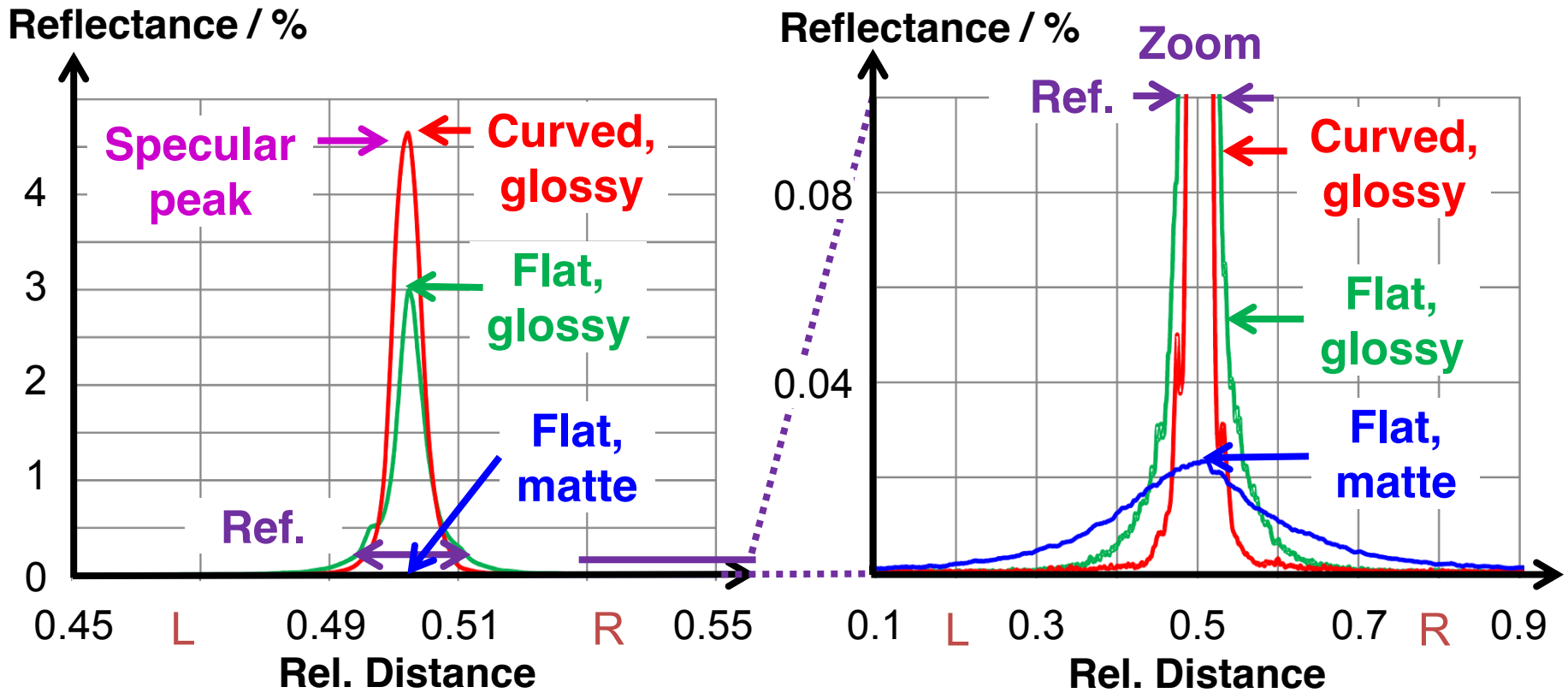
Flat, matte	Flat, glossy	Curved, glossy
		
Specular peak taped		Similar to Kelley

- Luminance profiles: horizontal (A), “color break-up” (B) and “outside” (C)
- Flat, matte: “typical” diffuse, A = B = C
- Flat, glossy: “sharp” reflection + “color break-up” cross (±20°)
- Curved, glossy: “sharp” reflection + bright “cross” + “color break-up” (±45°)

* Samsung LCD and OLED show similar horizontal characteristics

Measurement of Small Light Source

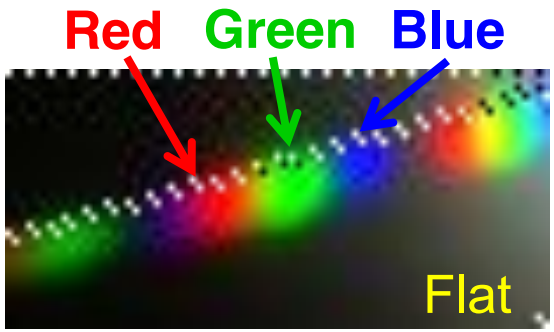
Specular reflection of small light source (1 watt) in 1.5 m, display off:

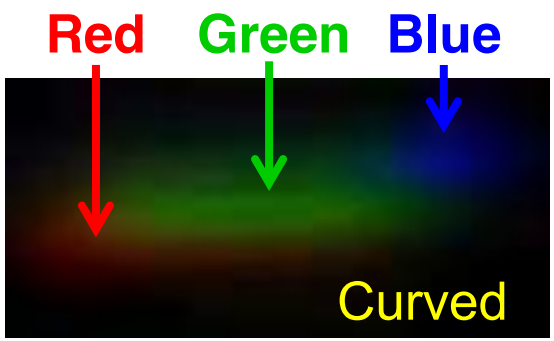


- All displays show typical behavior
- Matte display shows less luminance in specular region

"Color Break - Up" by Reflections

Plot of dark room primaries and reflections (LED 1 W)





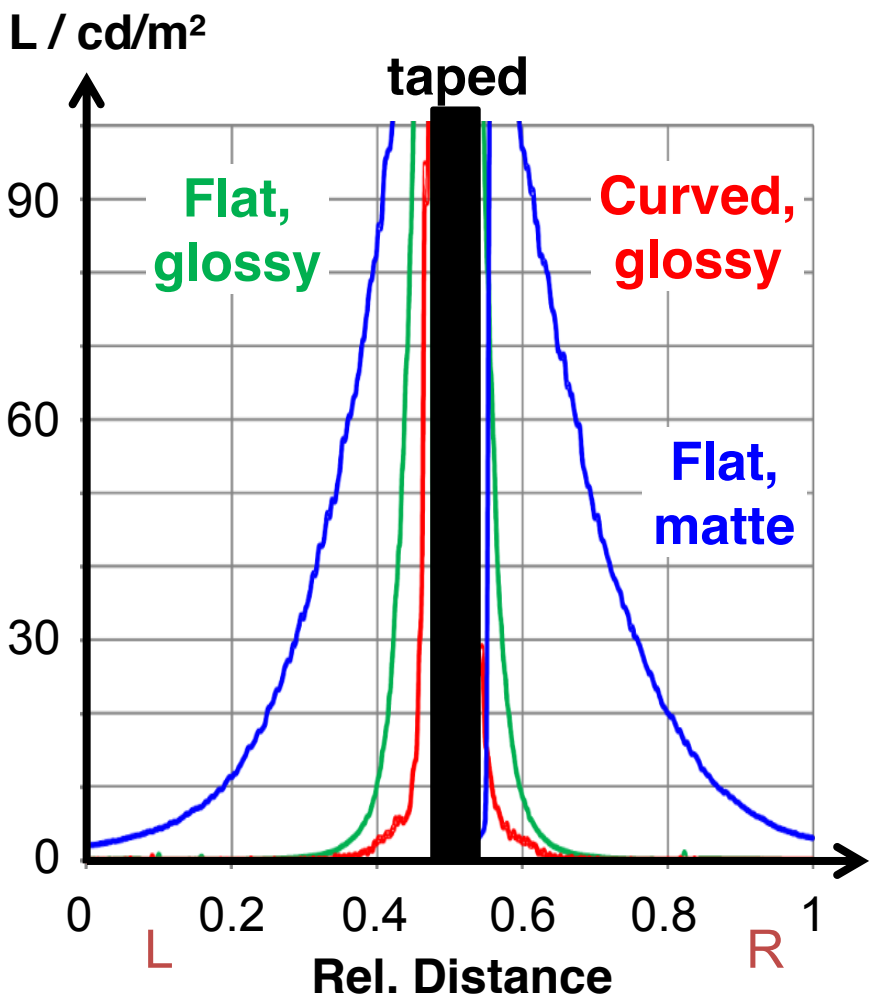
*: White BT.709

L / cd/m²	Flat		Curved	
	Break -up	Dark room*	Break -up	Dark room*
Red	40	60	4	69
Green	116	202	22	234
Blue	23	20	5	23

- The "color bursts" of flat glossy LCD show luminance comparable to white RGB portions (dark room measurements).
- The curved glossy "color bursts" are of lower effect, but it's vertical and horizontal line reflections are significantly higher.

Measurement of Small Light Source

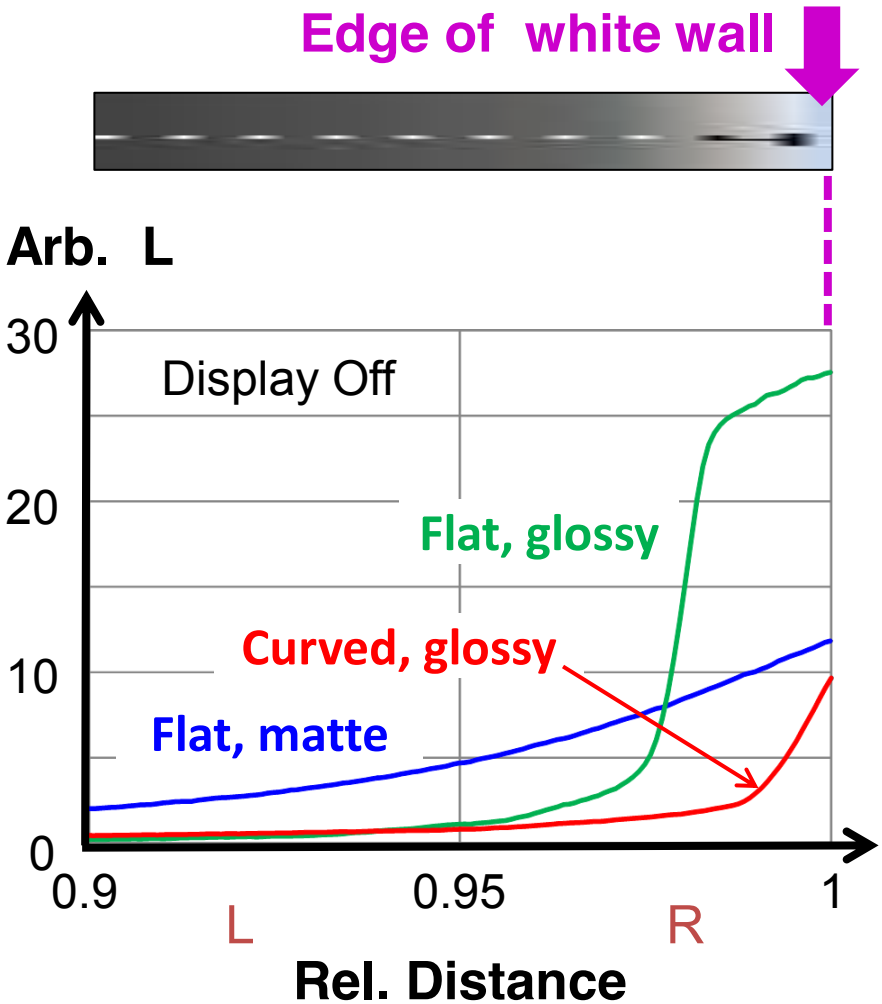
Line profile (C) "outside" A and B



- Outside specular area (of LED area, black tape) both glossy displays show the typical glossy behavior.
- The curved, glossy display shows smaller haze than the flat glossy display.
- The flat, matte display shows the typical diffuse characteristic.

Measurement with Diffusor

… similar to Kelley using large, non-specular light sources.



Set-up similar ISO 15008 daylight simulation or large non-specular light source

All displays show typical behavior, differences are due to different reflec-tance and “spreading” of reflections.

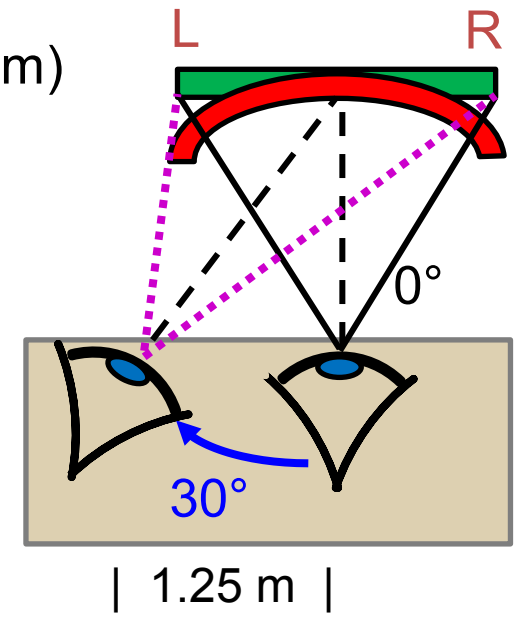
Overview

Solutions for Concave Displays (I)

1. Observer angles differ from flat displays

- Measure L (and CR, GL, color) for perpendicular and oblique angle(s)
- Different observer viewing angles for perpendicular and oblique (example 30°, 55”, viewing distance 2.2 m)

Angle	Flat		Curved	
Side	L	R	L	R
0°	-15°	+15°	-8°	+8°
0° Sum R / L	|30°|		|16°|	
-30°	-17°	-40°	-25°	-33°
-30° Sum R / L	|23°|		|8°|	

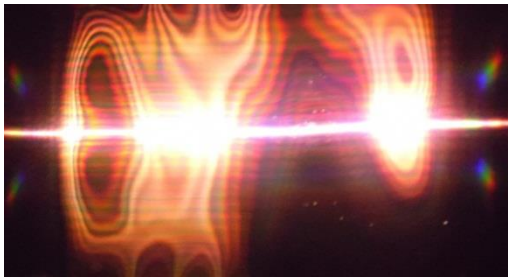


Concave has smaller differences of viewing angle for observers.

Solutions for Concave Displays (II)

2. Reflection characteristics differ from flat displays

- Measurements
  - Small light source specular (“LED in living room”)
  - Diffusor or diffuse screen (“wall in living room”) {ISO 15008 daylight}
  - Focal length (radius) of curved display
- Integrating spheres with typical size does not capture curved properties.
- Reflection reduction is essential for all displays but for concave curved displays, magnification effects should be avoided.



Observer should sit in focal point to avoid annoying reflections and magnification of objects.

Summary

Our experiences and results for flat and curved display measurements are:

Measurements become more complex for curved displays.

Measurement specifications for curved displays must be established.

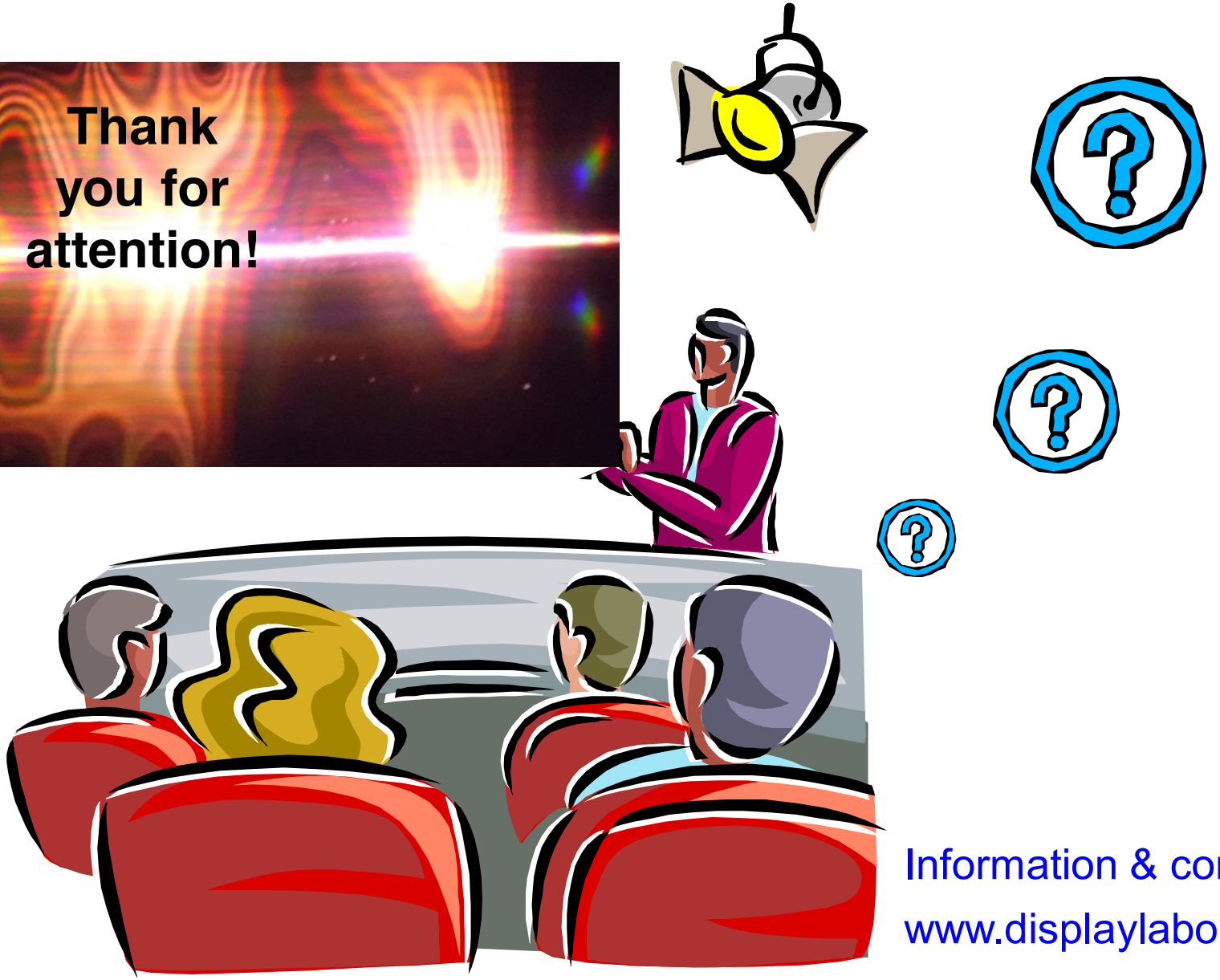
Modern LCD TVs show “extended” specular reflections.

1 W LEDs (less than LED lamps) can generate annoying reflections.

Observers should by located in focal length f distance from the screen.

Viewing angle advantages for curved displays, also for oblique viewer.

Radius (R = 2f) for hi res TV sets should be ~ 4 m due to viewing cone.



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