Wavelengths and Colors

Ankit Mohan

MAS.131/531 Fall 2009

Epsilon over time (Multiple photos)

Prokudin-Gorskii, Sergei Mikhailovich, 1863-1944, photographer. ``The Bukhara Emir'', Prints and Photographs Division, Library of Congress.

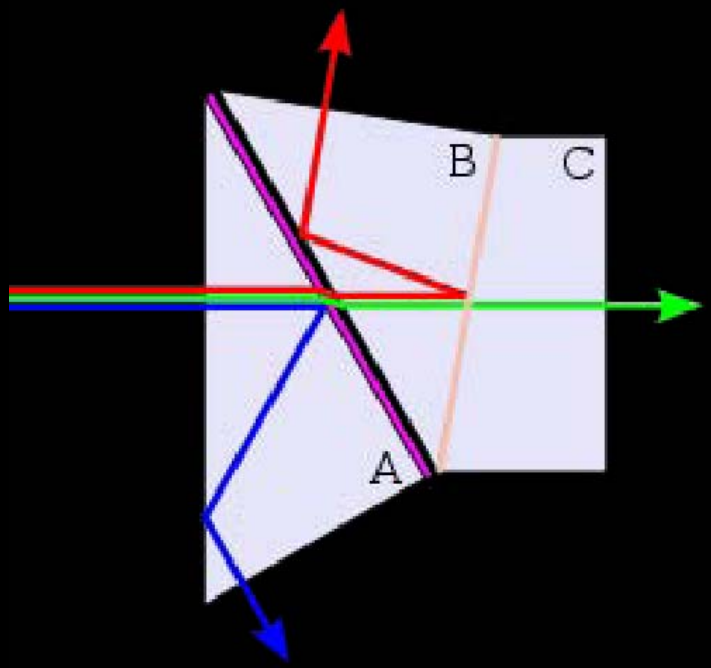
Epsilon over **time** (*Bracketing)*

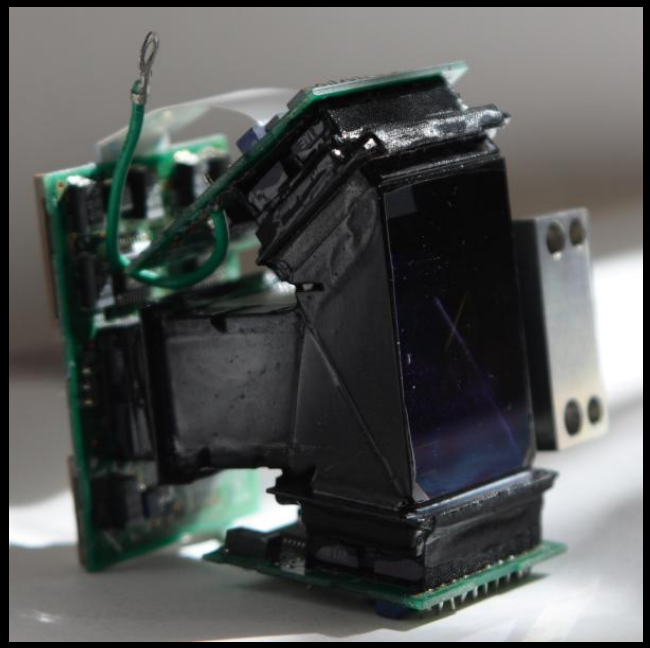
Image courtesy of shannonpatrick17 on Flickr.

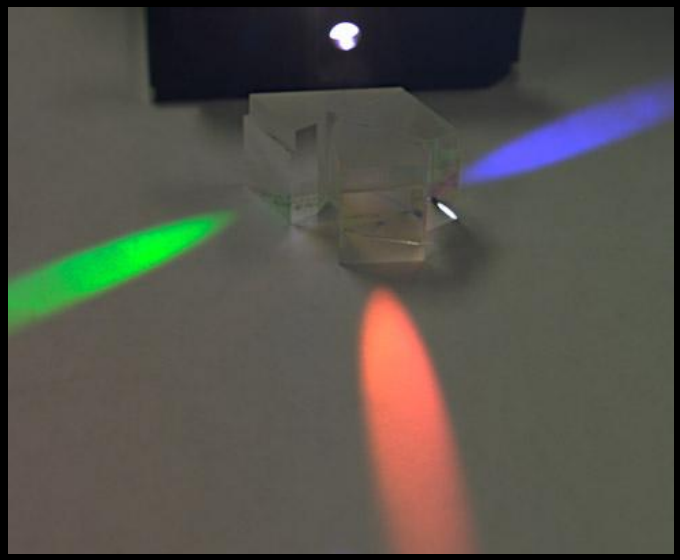
Color wheel used in DLP projectors

Epsilon over **sensors**

3CCD imaging system for color capture

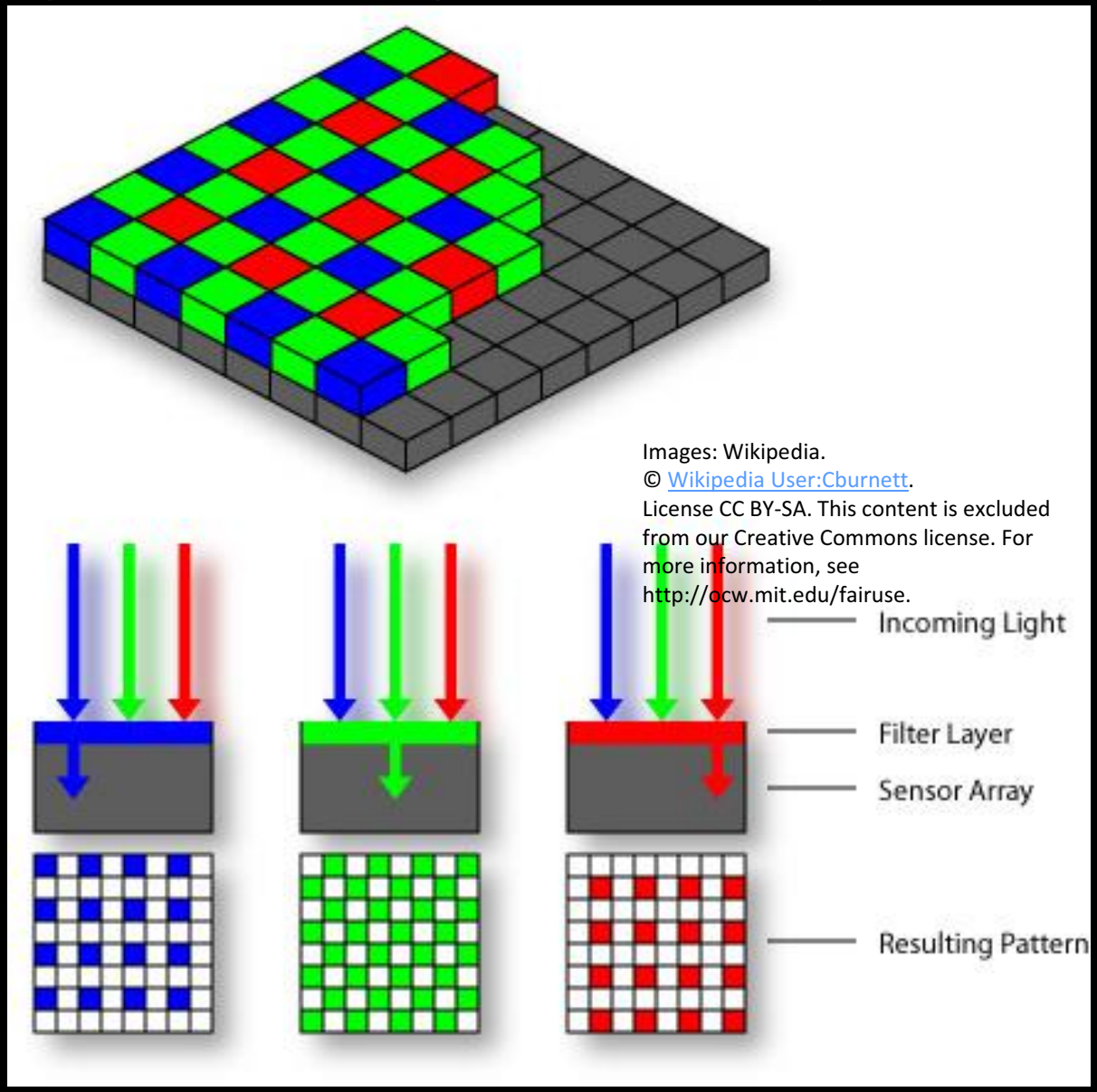






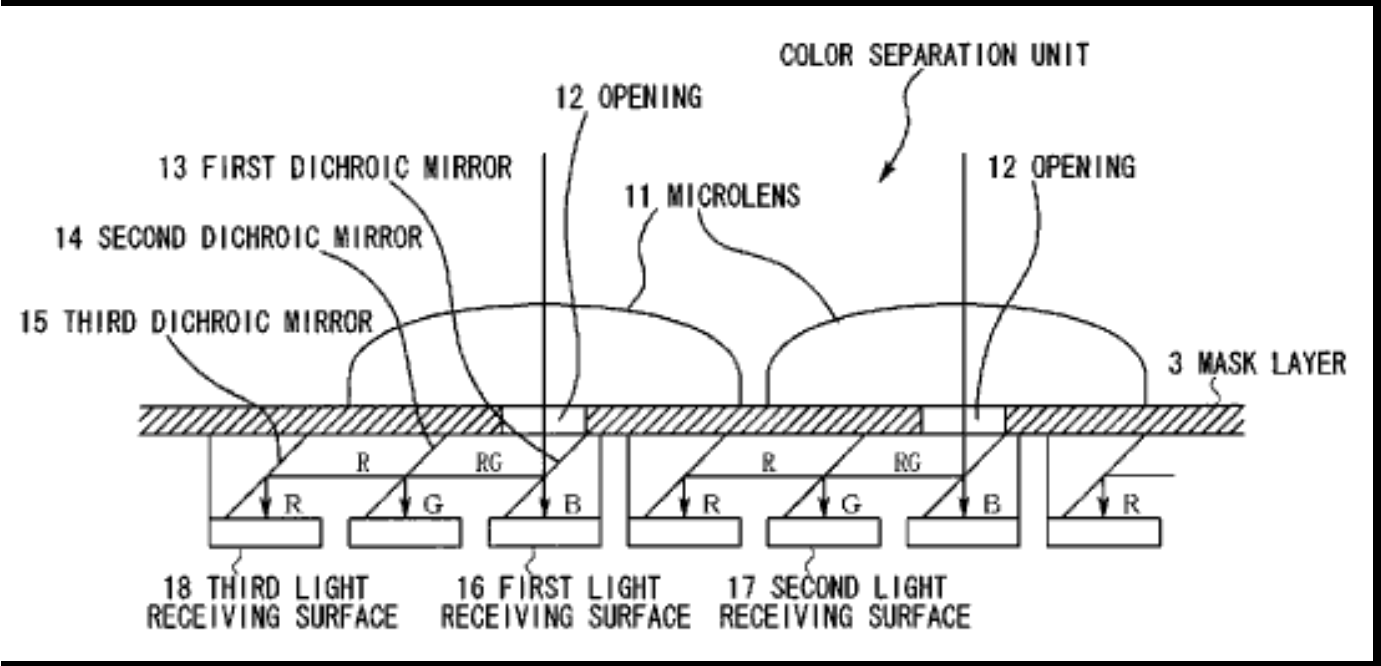
Epsilon over **pixels**

Bayer Mosaicing for color capture



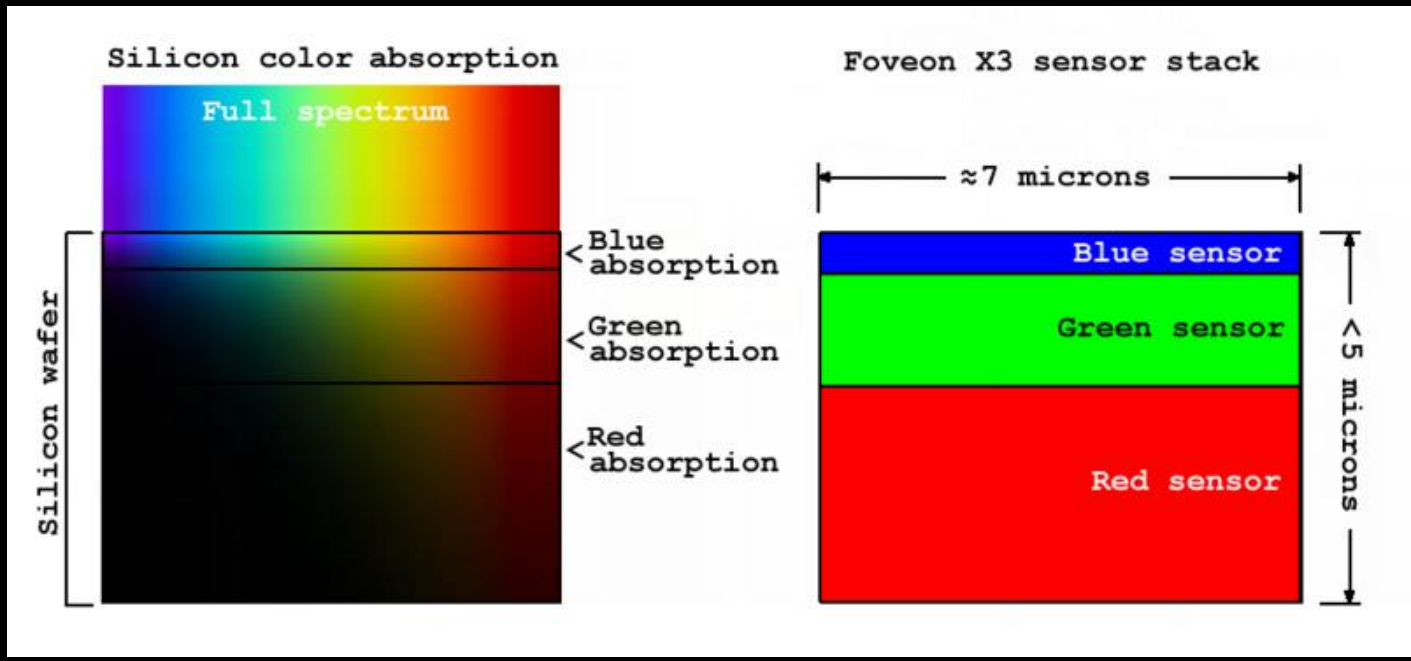
Demosaicing to interpolate a full color, high resolution image

Color sensing in Digital Cameras

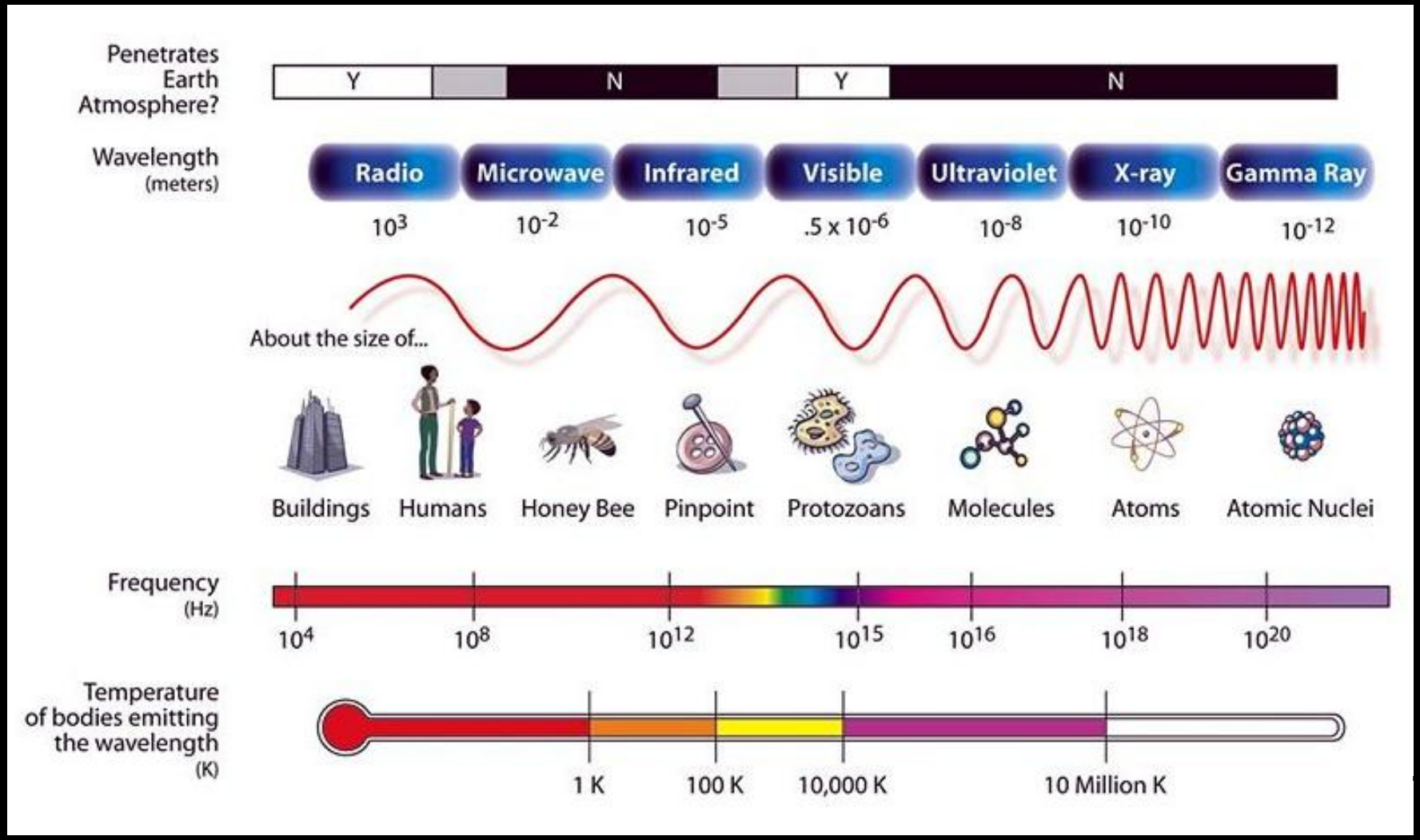


Nikon dichroic mirrors

Foveon X3 sensor



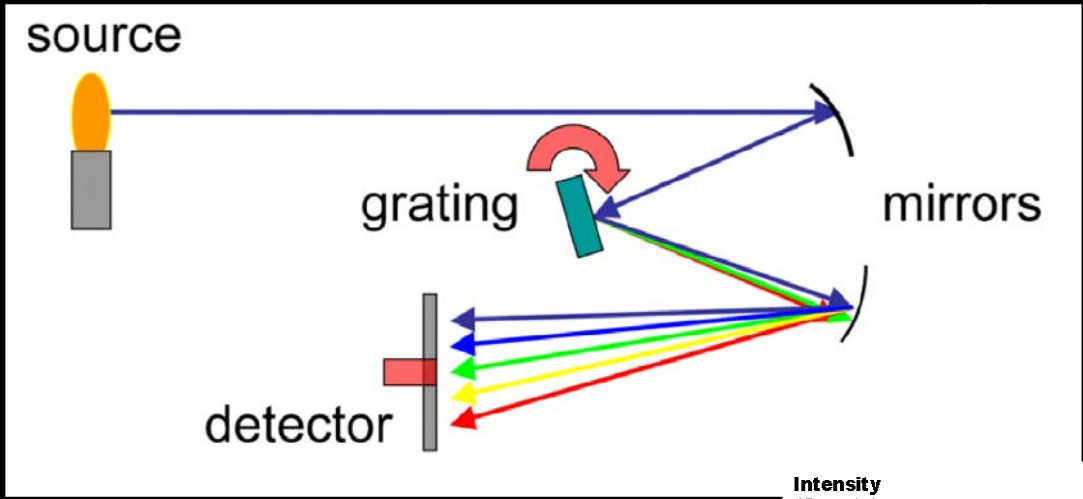
Electromagnetic spectrum

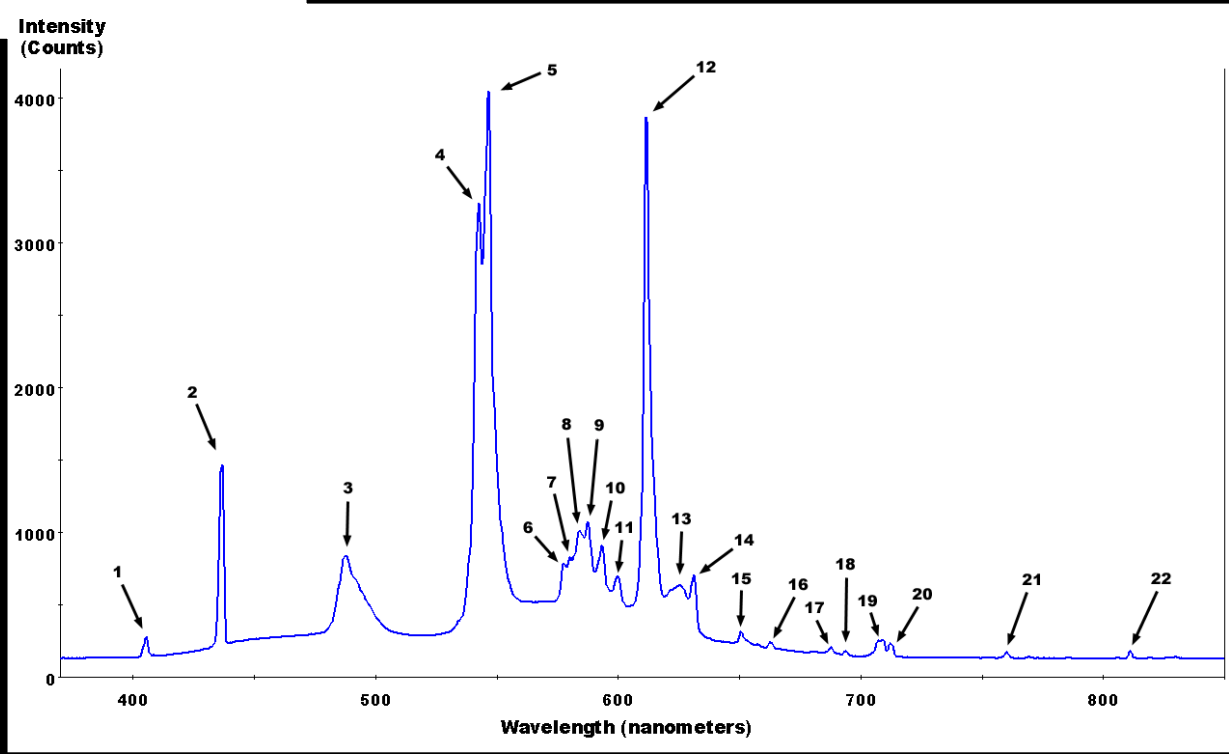


Visible Light: ~400-700 nm wavelength

Spectroscope

[http://en.wikipedia.org/wiki/Spectroscopy]





Multispectral Imaging

Image removed due to copyright restrictions.
See Fig. 2.2, (p. 22) "Remote sensing systems…" (Jensen 2007).
In Klemas, V. V. "Sensors and Techniques for Observing Coastal Ecosystems." In Remote Sensing and Geospatial Technologies for Coastal Ecosystem Assessment. Edited by Xiaojun Yang. Springer, 2009.
Preview in Google Books.

Multispectral Scanning (data cube)

Diagram removed due to copyright restrictions.

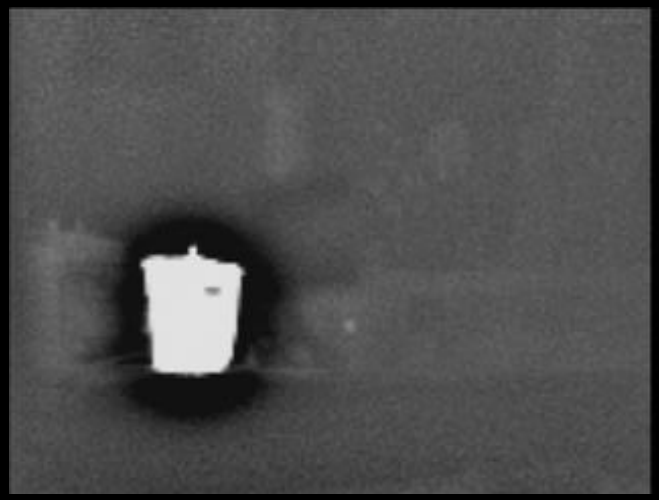
Thermal Imaging

[http://www.cas.sc.edu/geog/rslab/551]

Glass is opaque;
use **Germanium** lenses

Set of Thermal Imaging photos removed due to copyright restrictions.

Thermal Imaging



[http://www.falstad.com/thermal]

[Pavlidis et al., Nature 2002]

Near Infrared Photography

Four photos removed due to copyright restrictions.

Remote Sensing

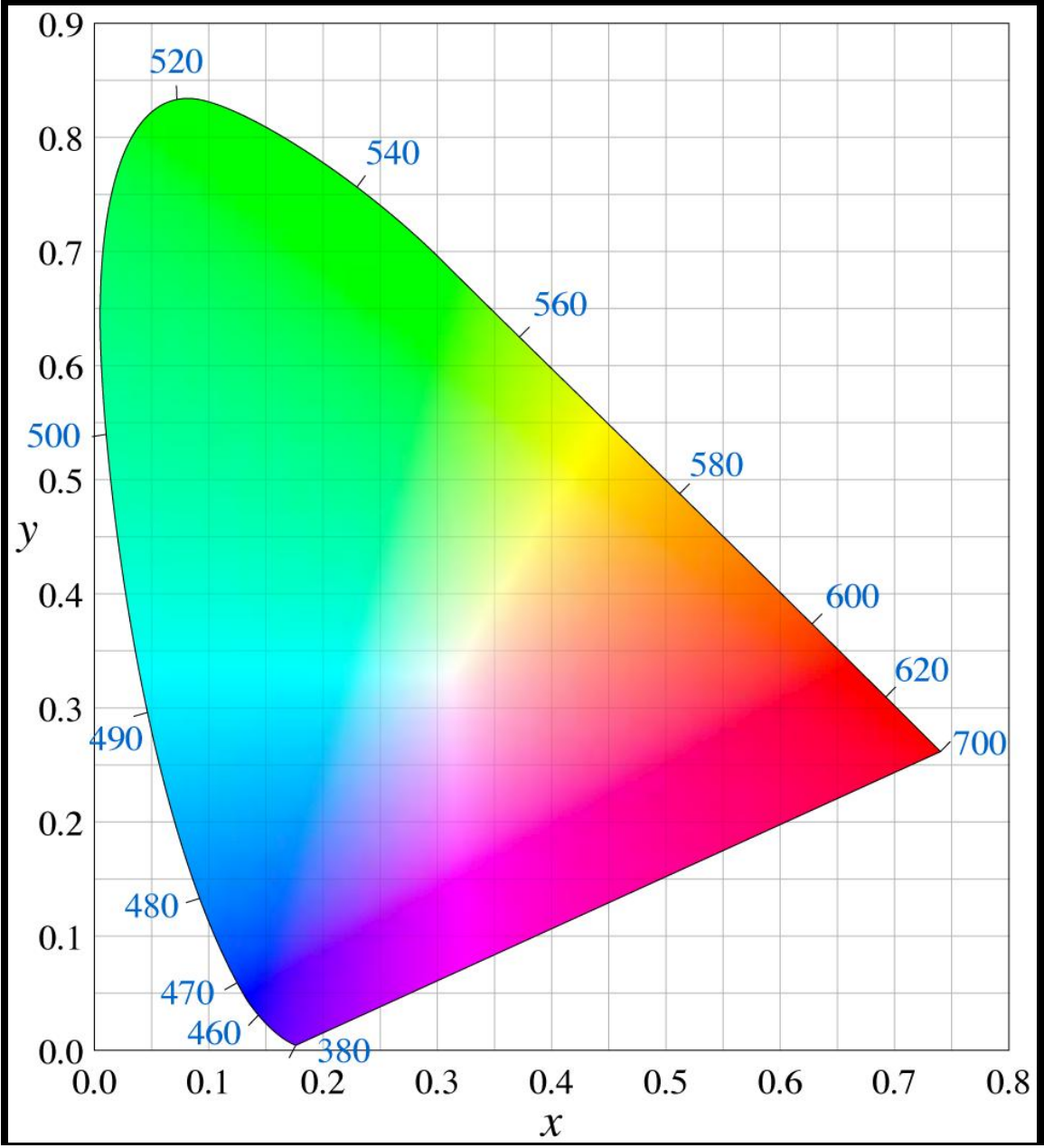
Images removed due to copyright restrictions.

UV photography [http://www.naturfotograf.com]

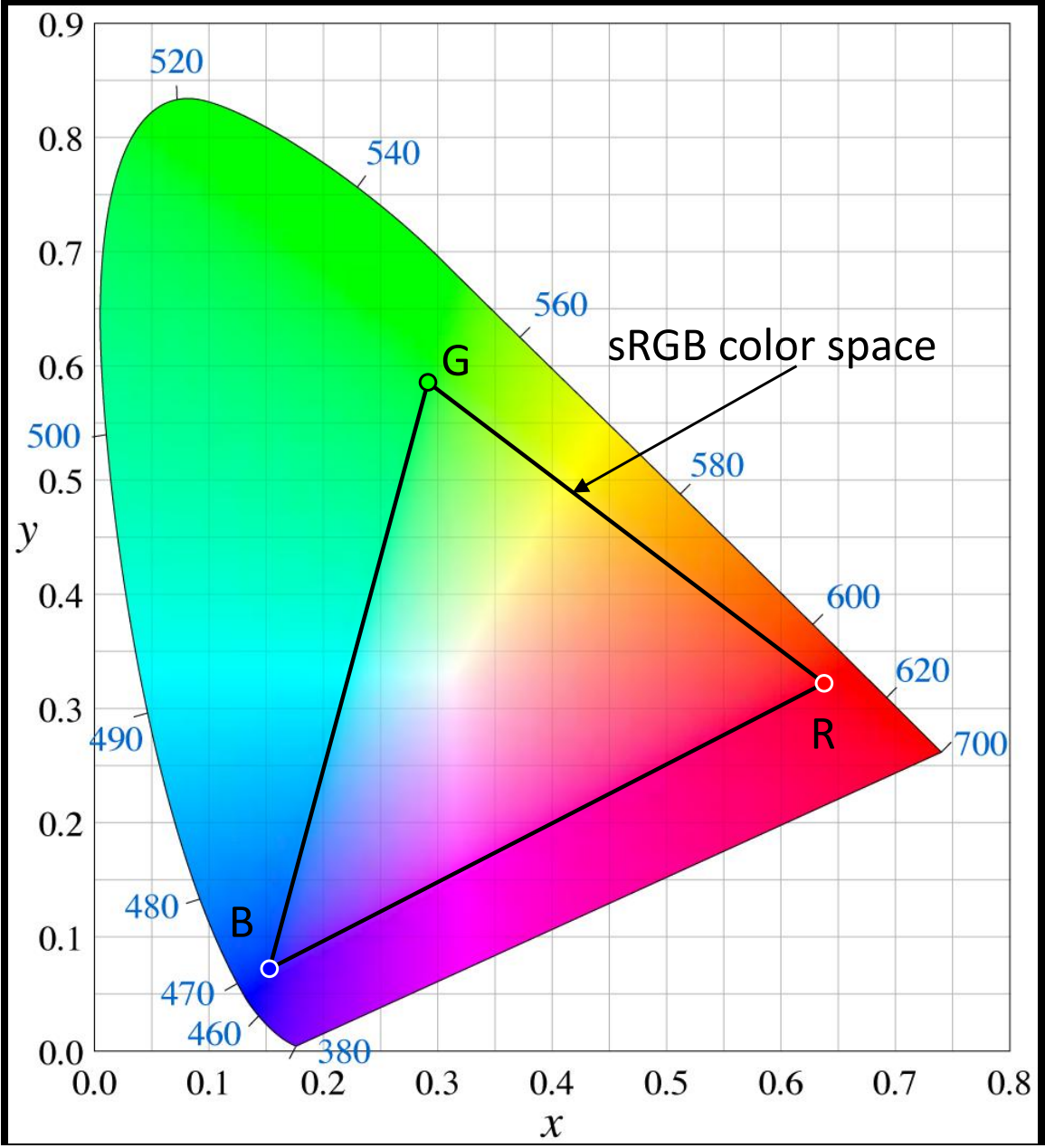
Quartz lenses

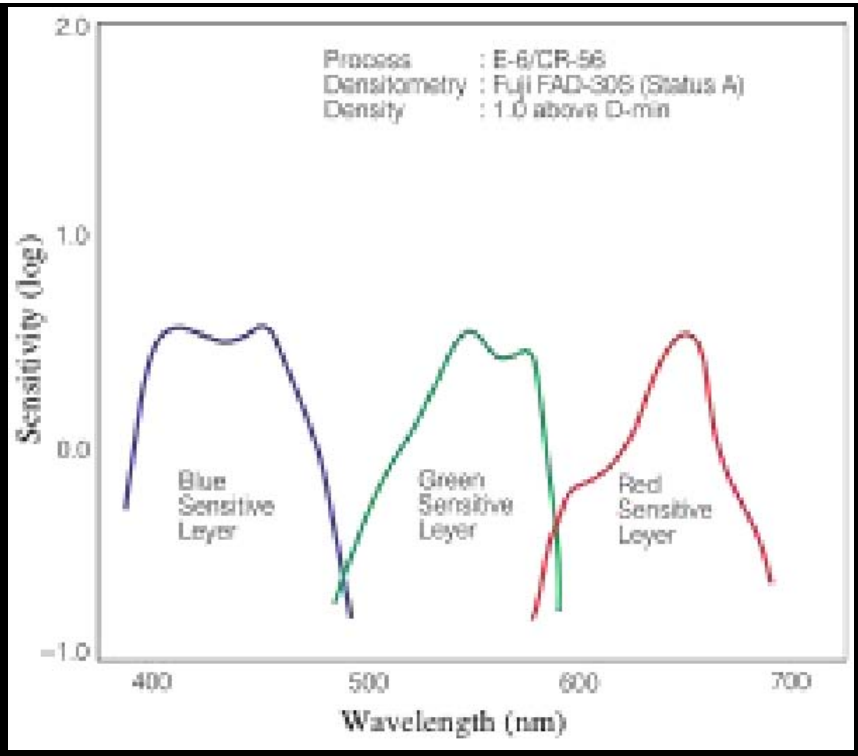
Six flower photos removed due to copyright restrictions.

CIE 1931 Chromaticity Diagram



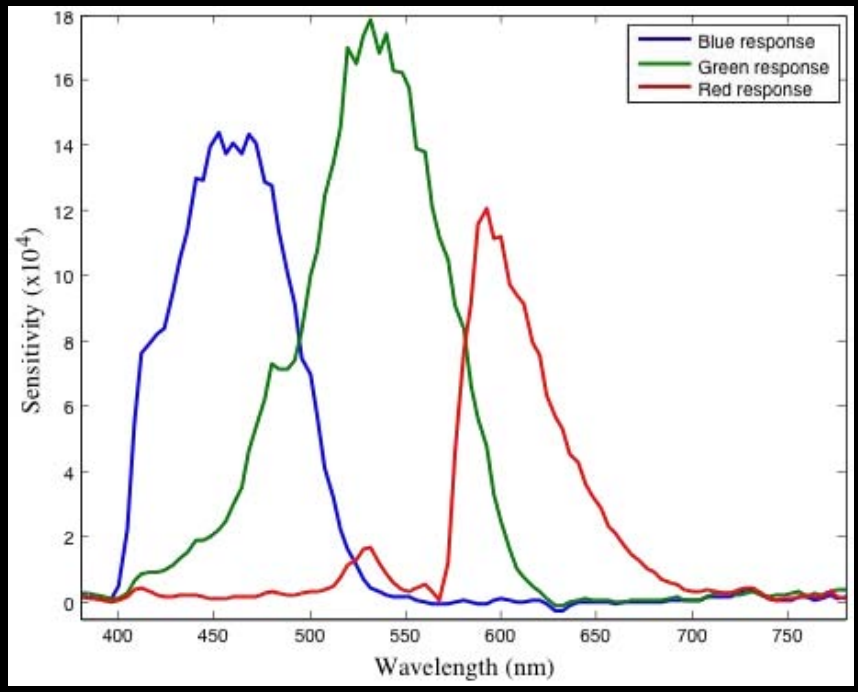
Fixed color primaries



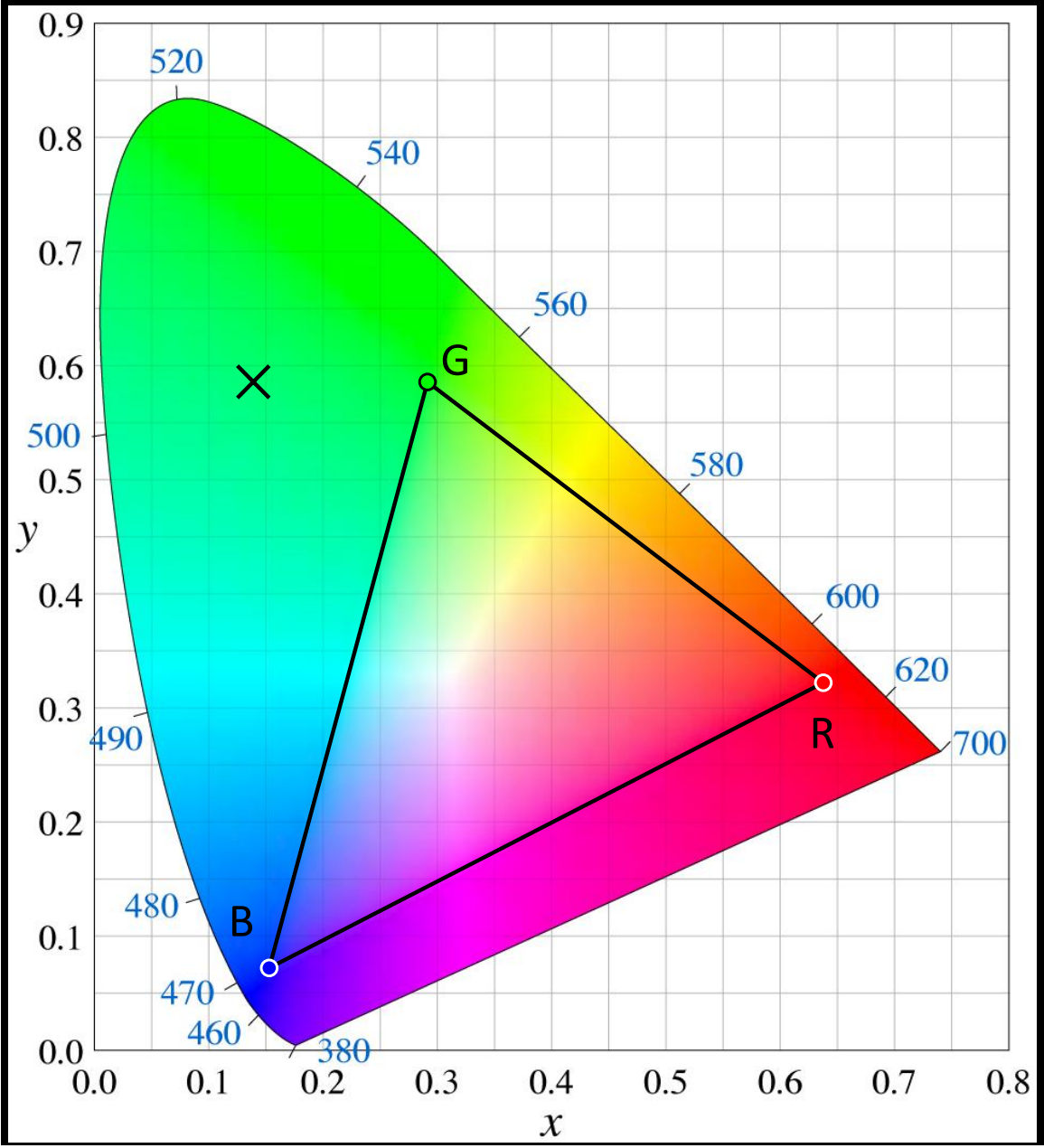


Fuji Velvia 50 film

Nikon D70 camera



Outside the Color Gamut

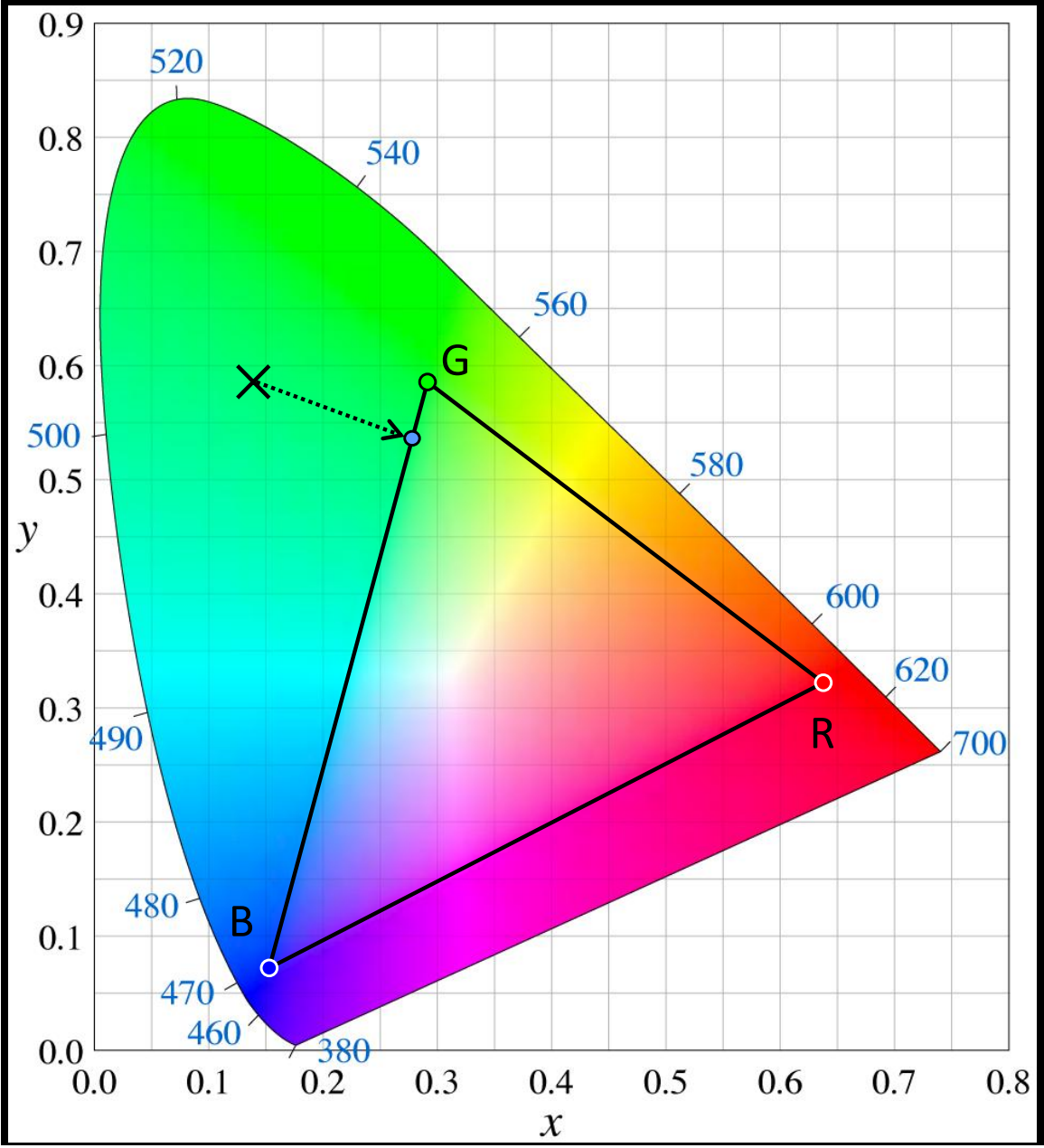


R = ?

G = ?

B = ?

Colorimetric or Photometric mapping

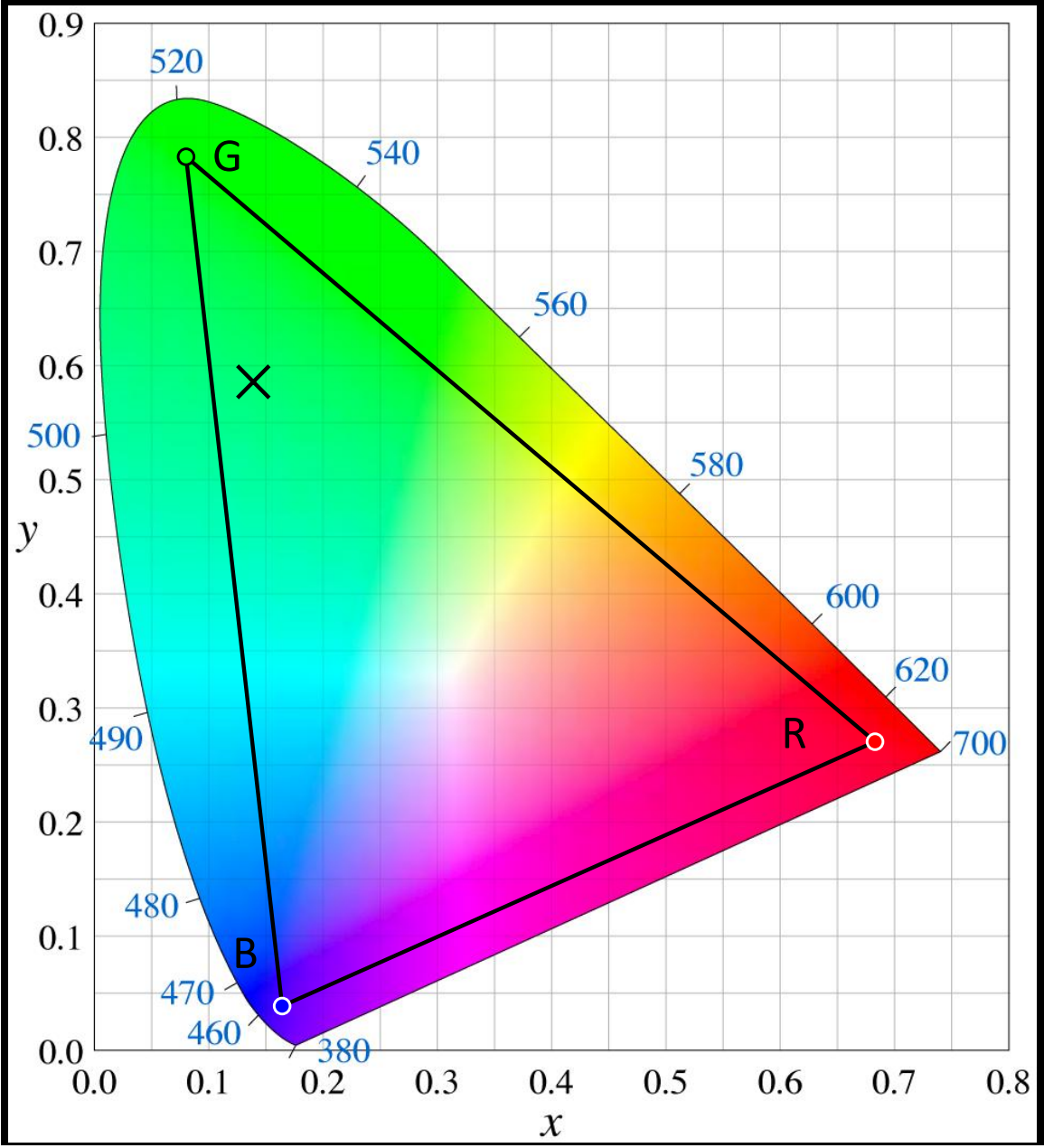


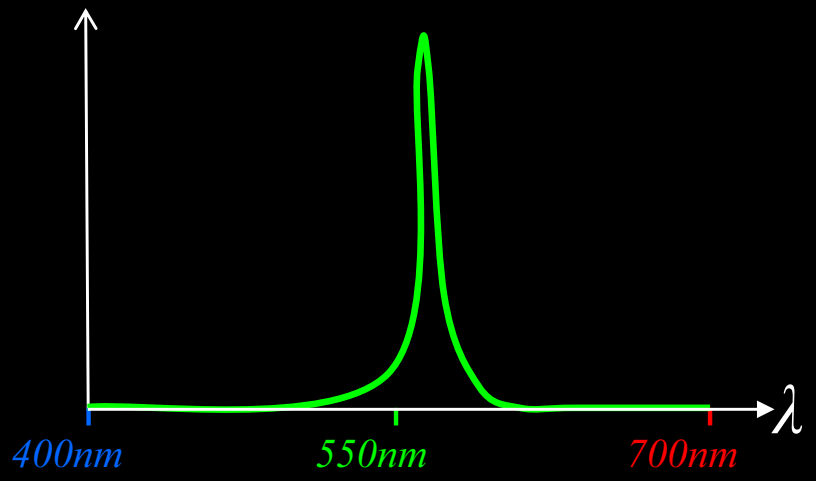
R ≈ 0.0

G ≈ 0.2

B ≈ 0.8

Wide Color Gamut

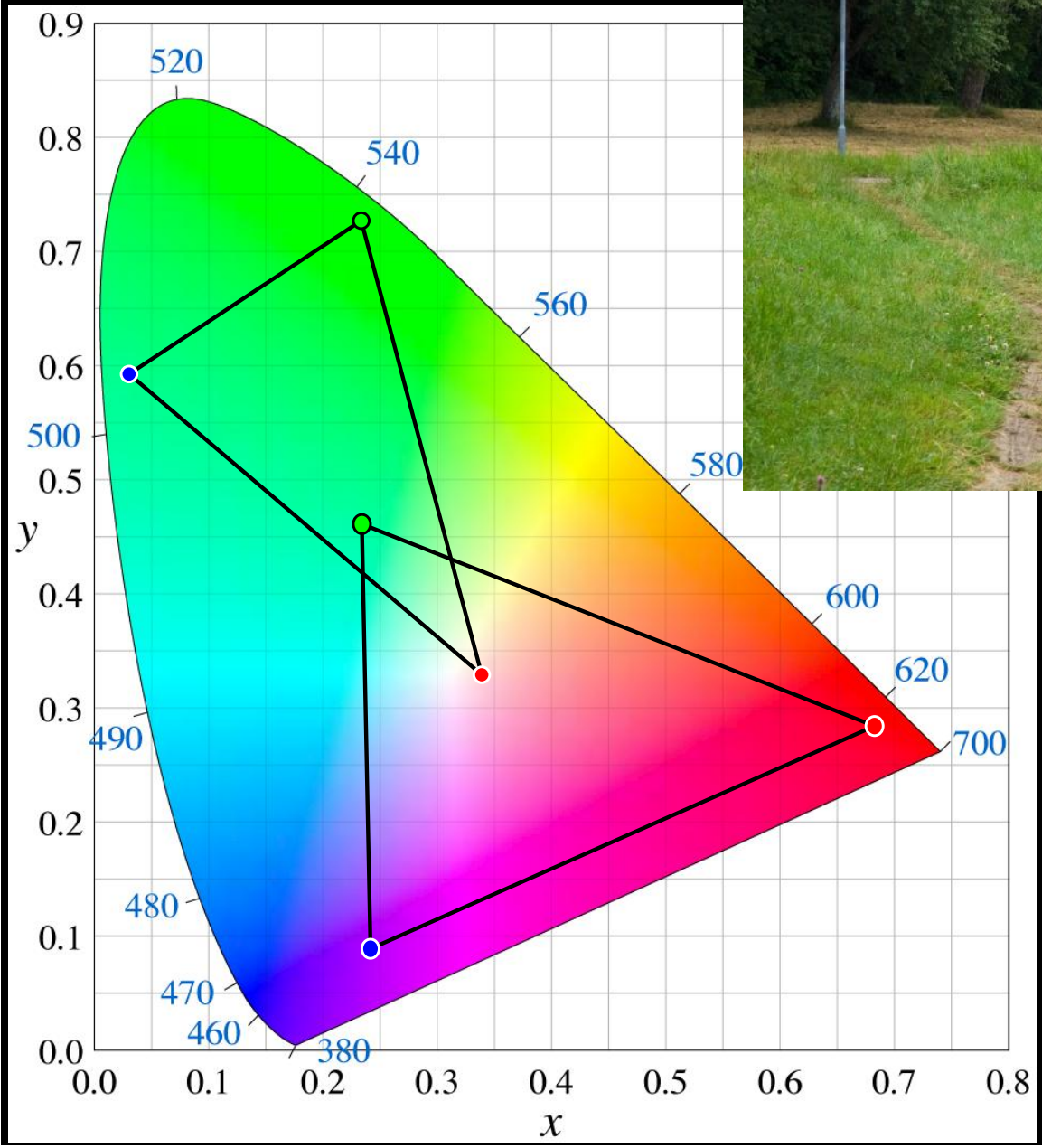




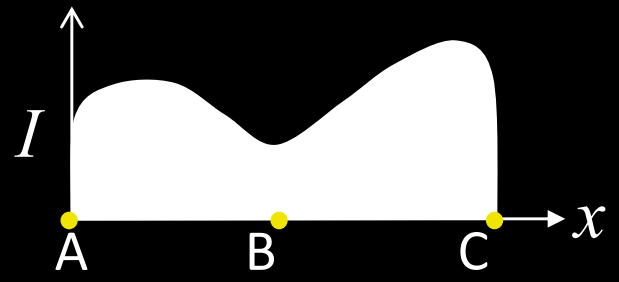
"Best" primaries compromise:

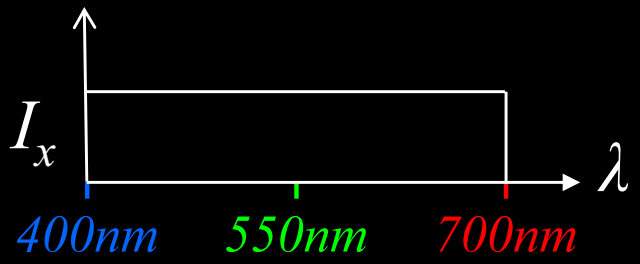
Wide Gamut vs. High Power

Adaptive Color Primaries

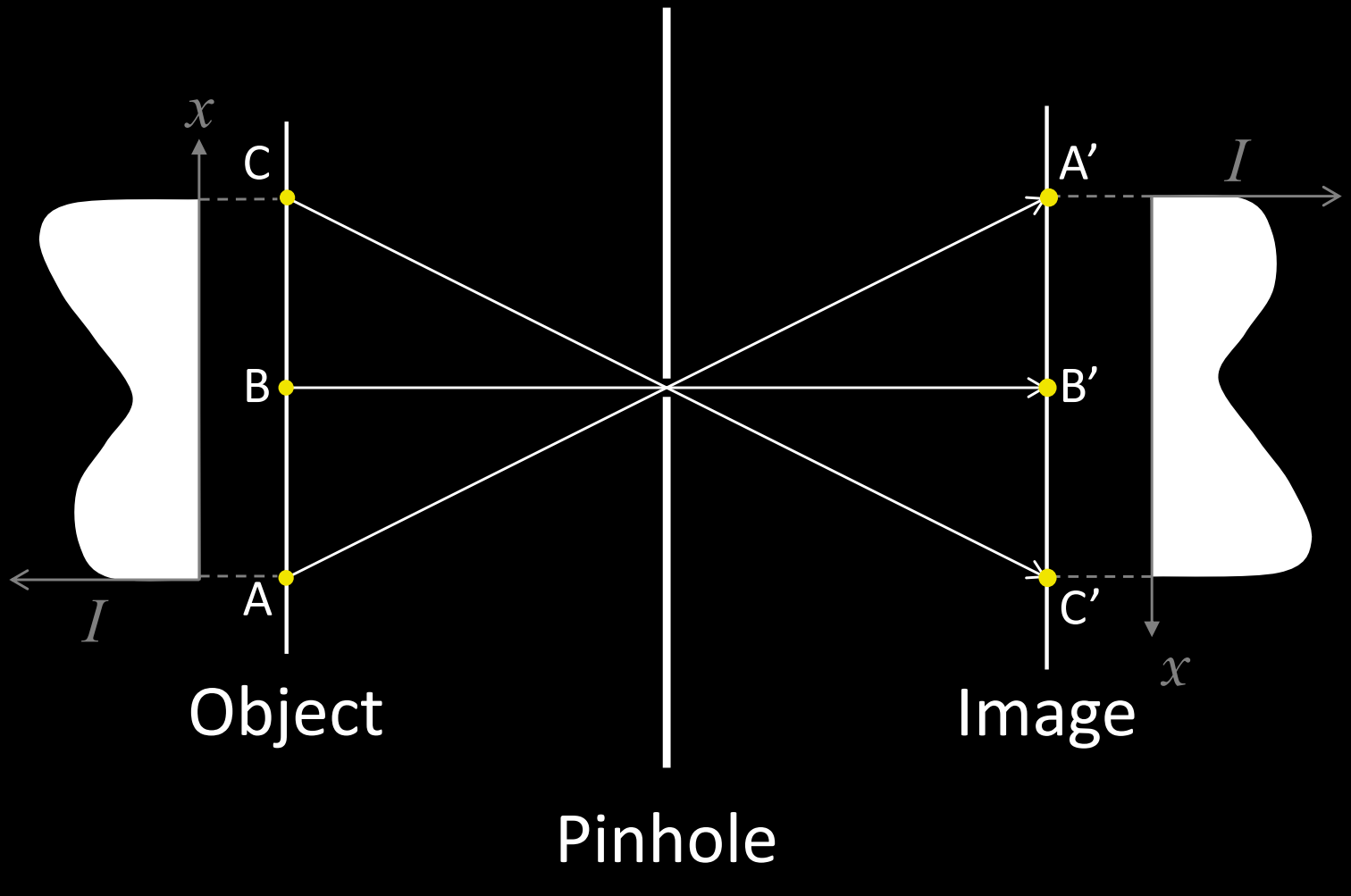


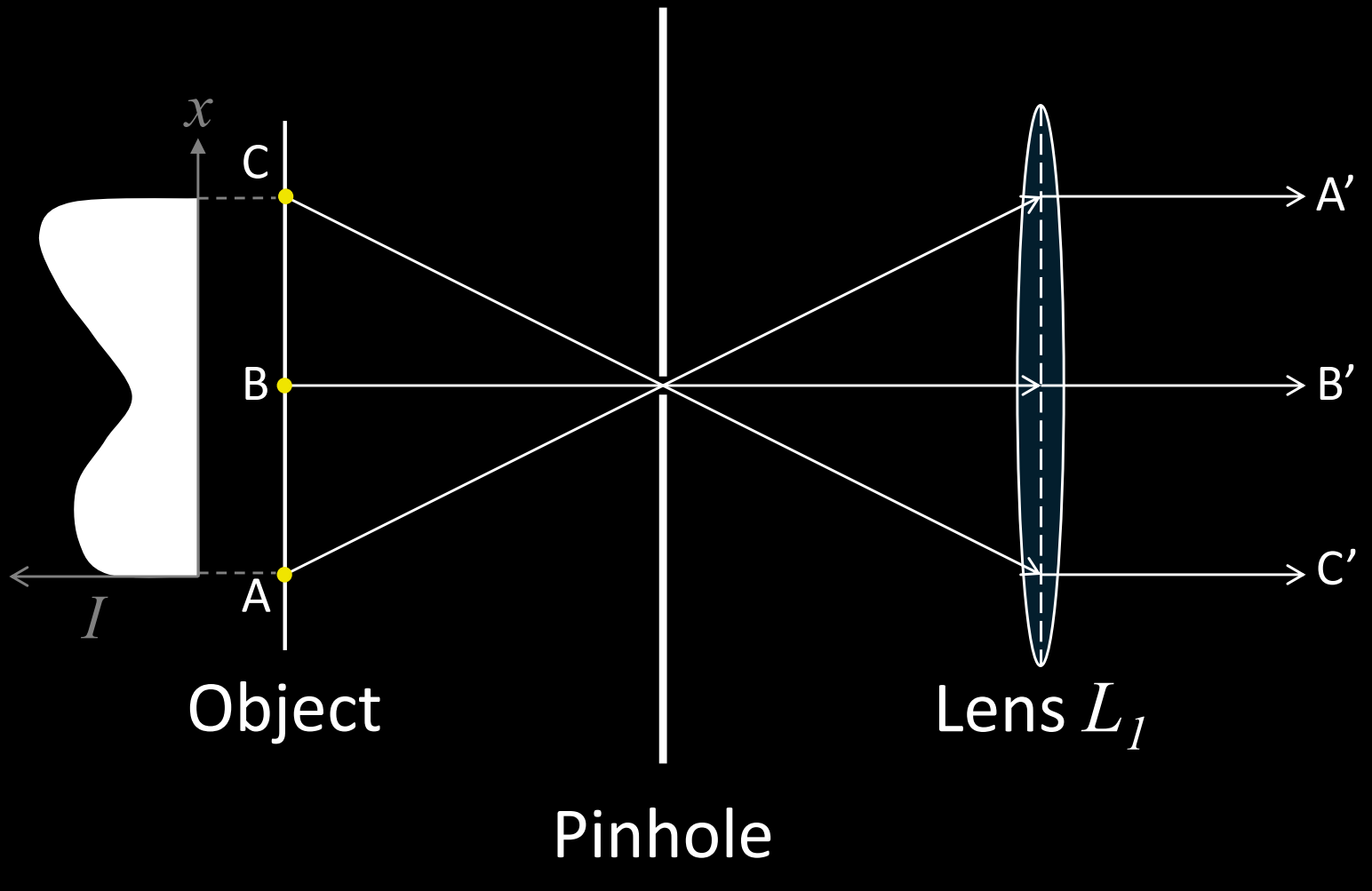
Arbitrary *white* 1D signal

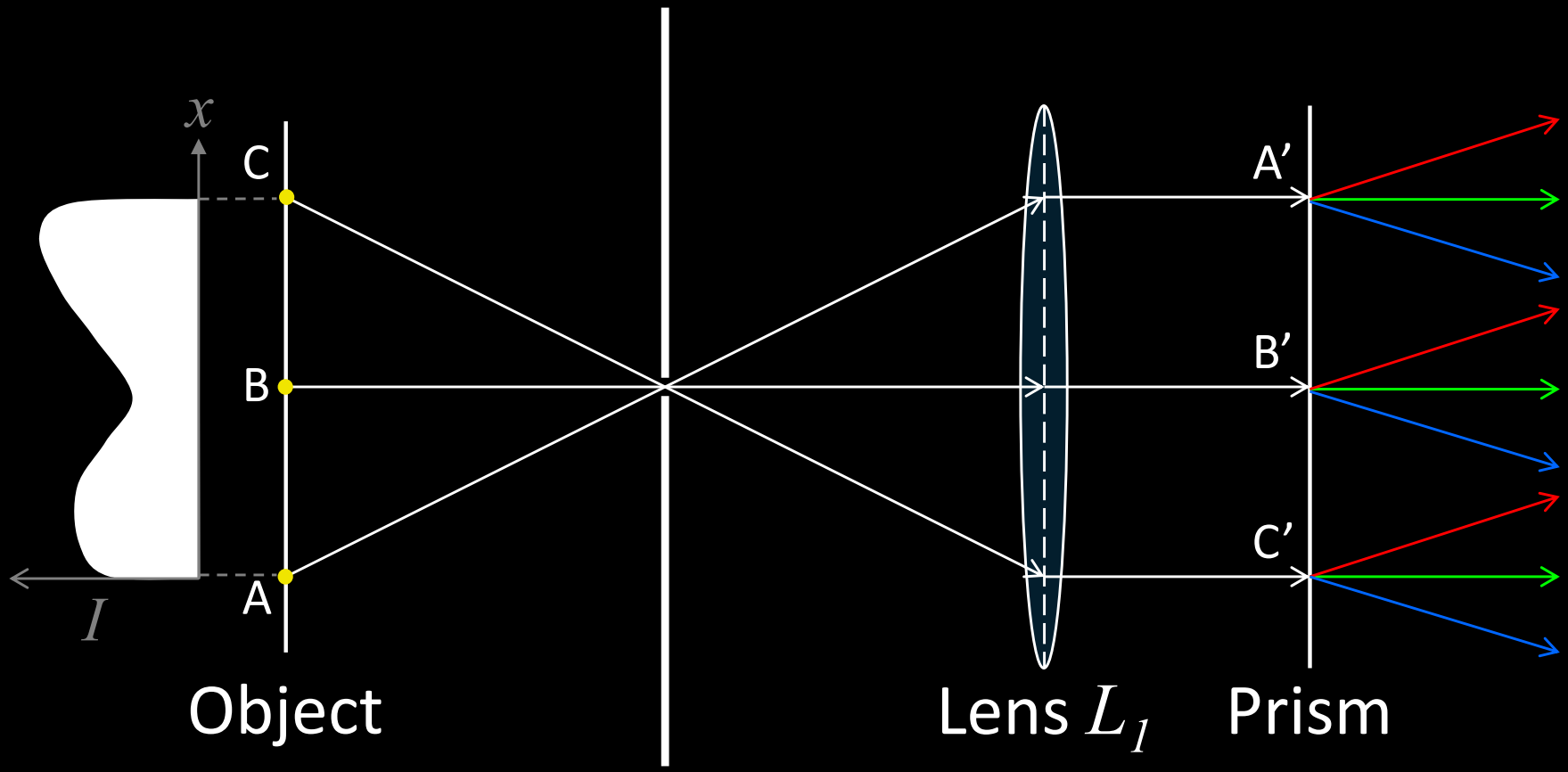


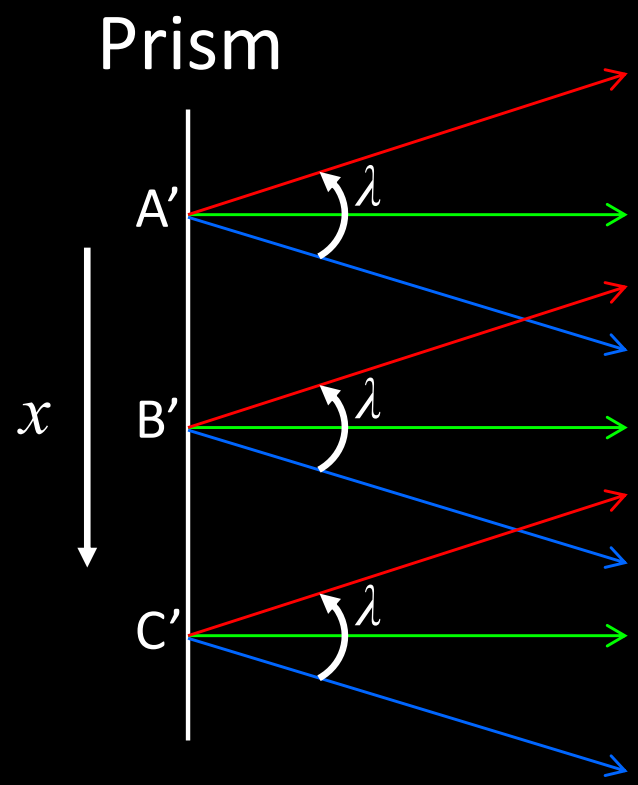


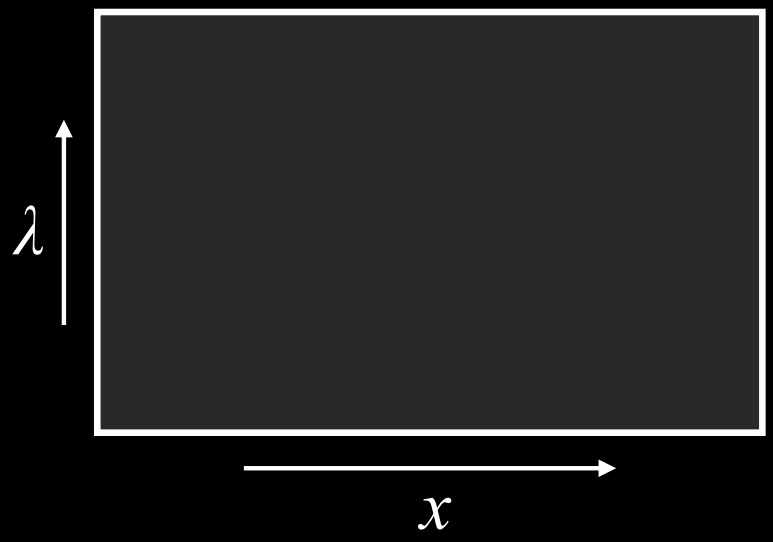
Pinhole Camera




x
C
B
A
I
A'
B'
C'
Object
Pinhole
Lens L_1


x
C
B
A
I
A'
B'
C'
Object
Pinhole
Lens L_1
Prism

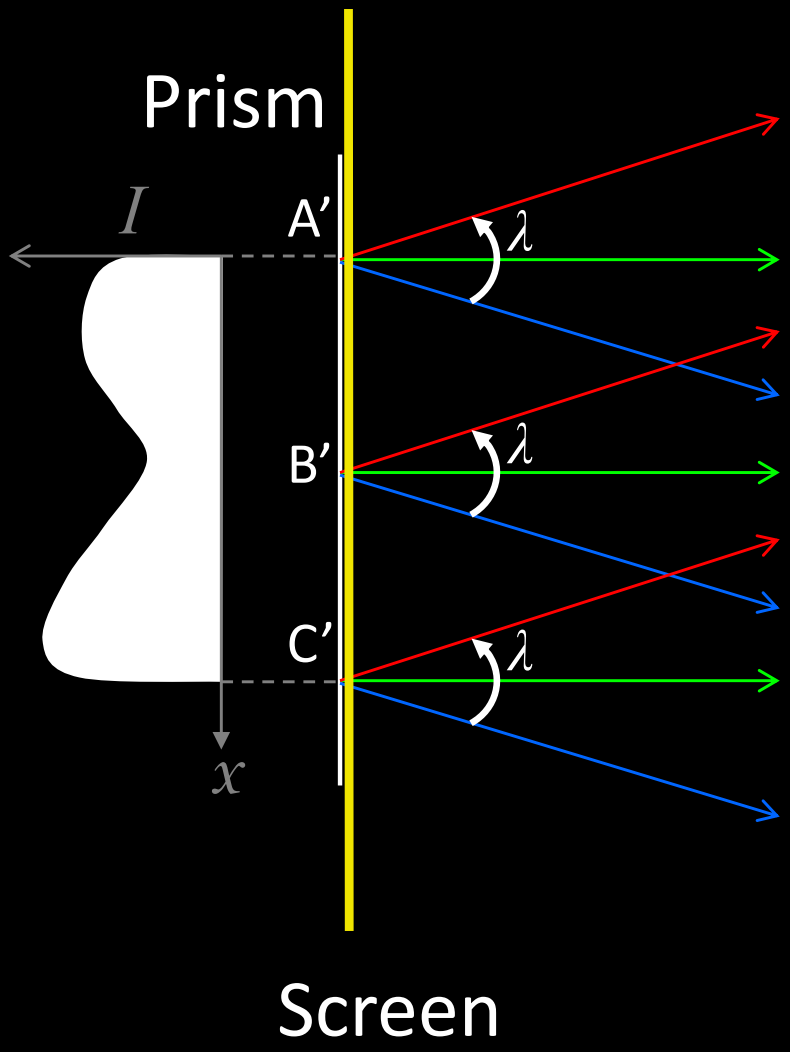


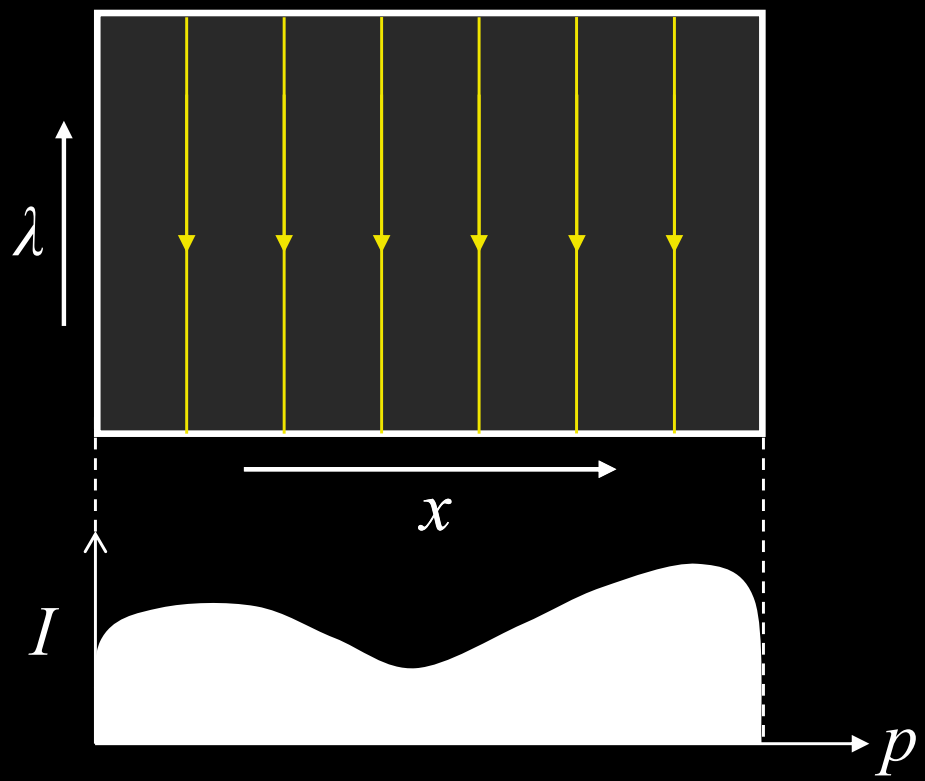


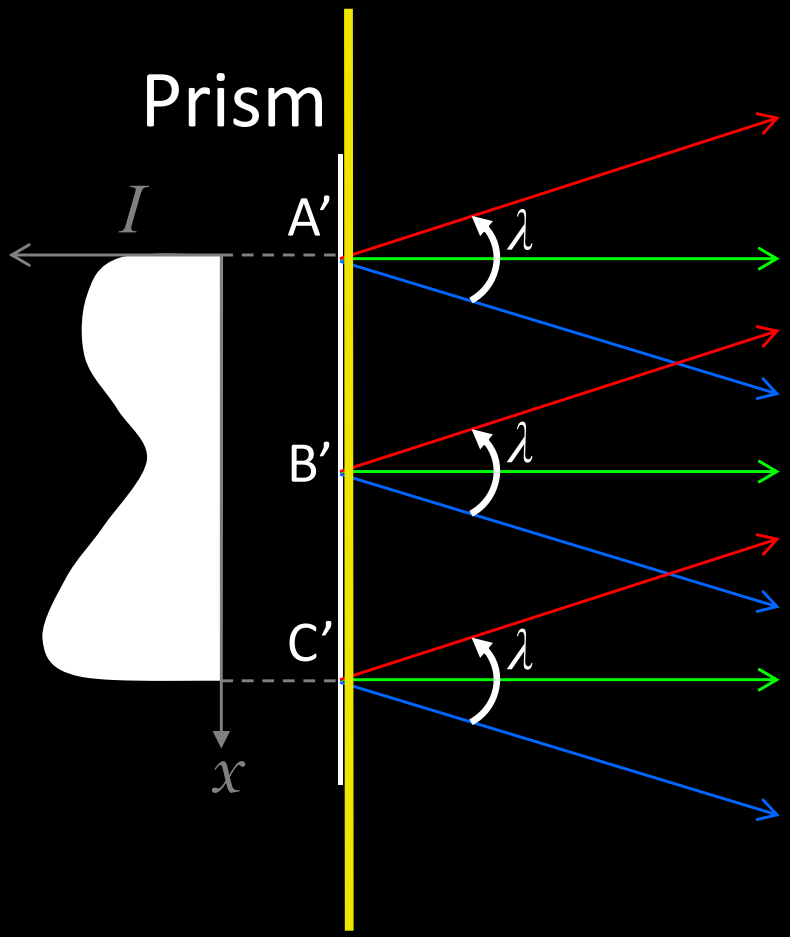
Spectral Light Field

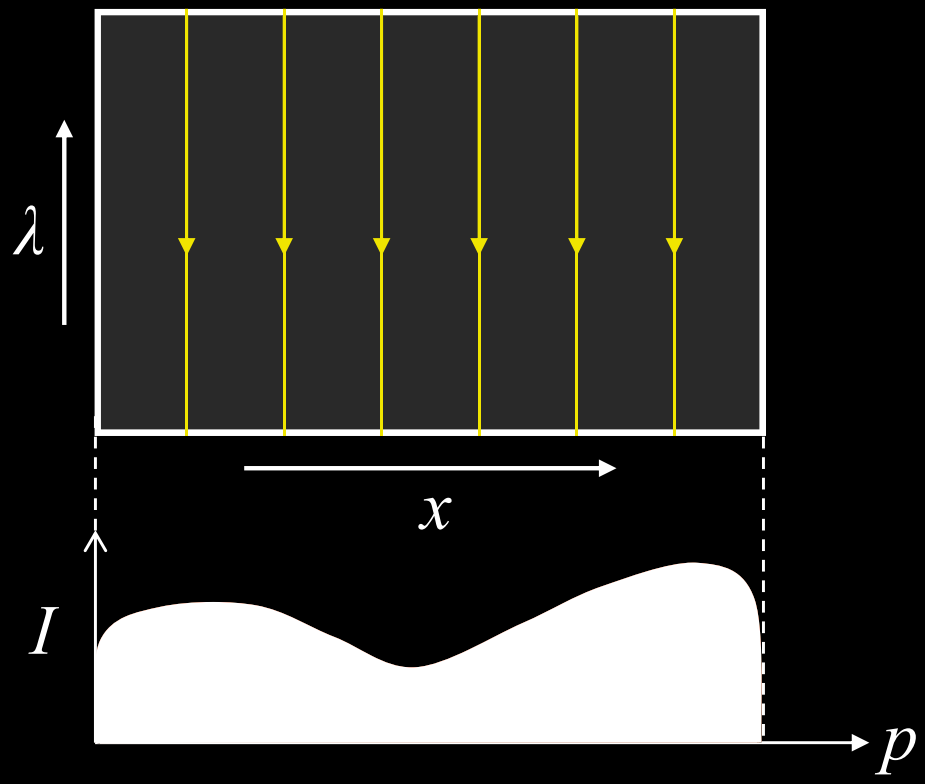
Light-Field

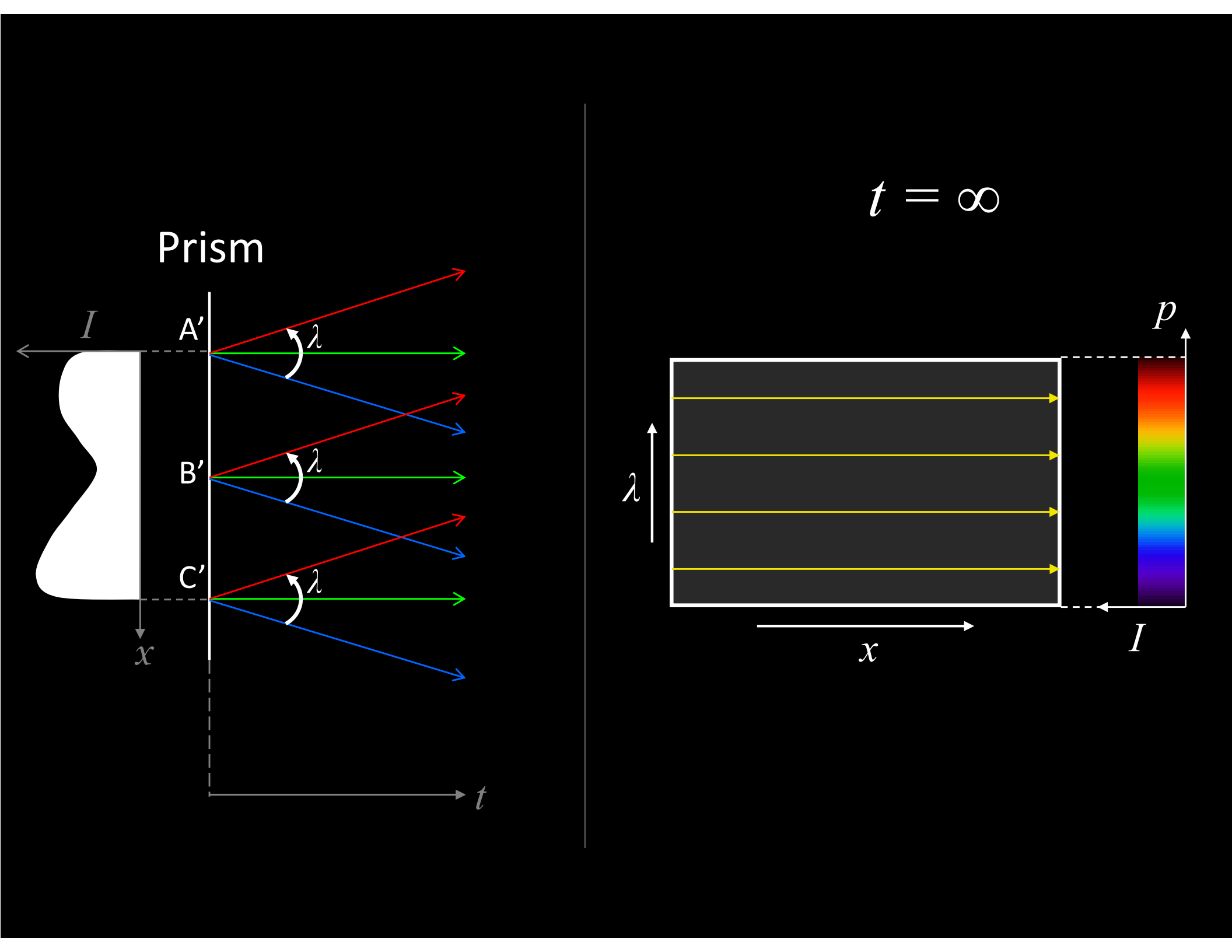
Placing a 1D screen in a 2D light-field gives a 1D **projection** in a direction perpendicular to the screen.

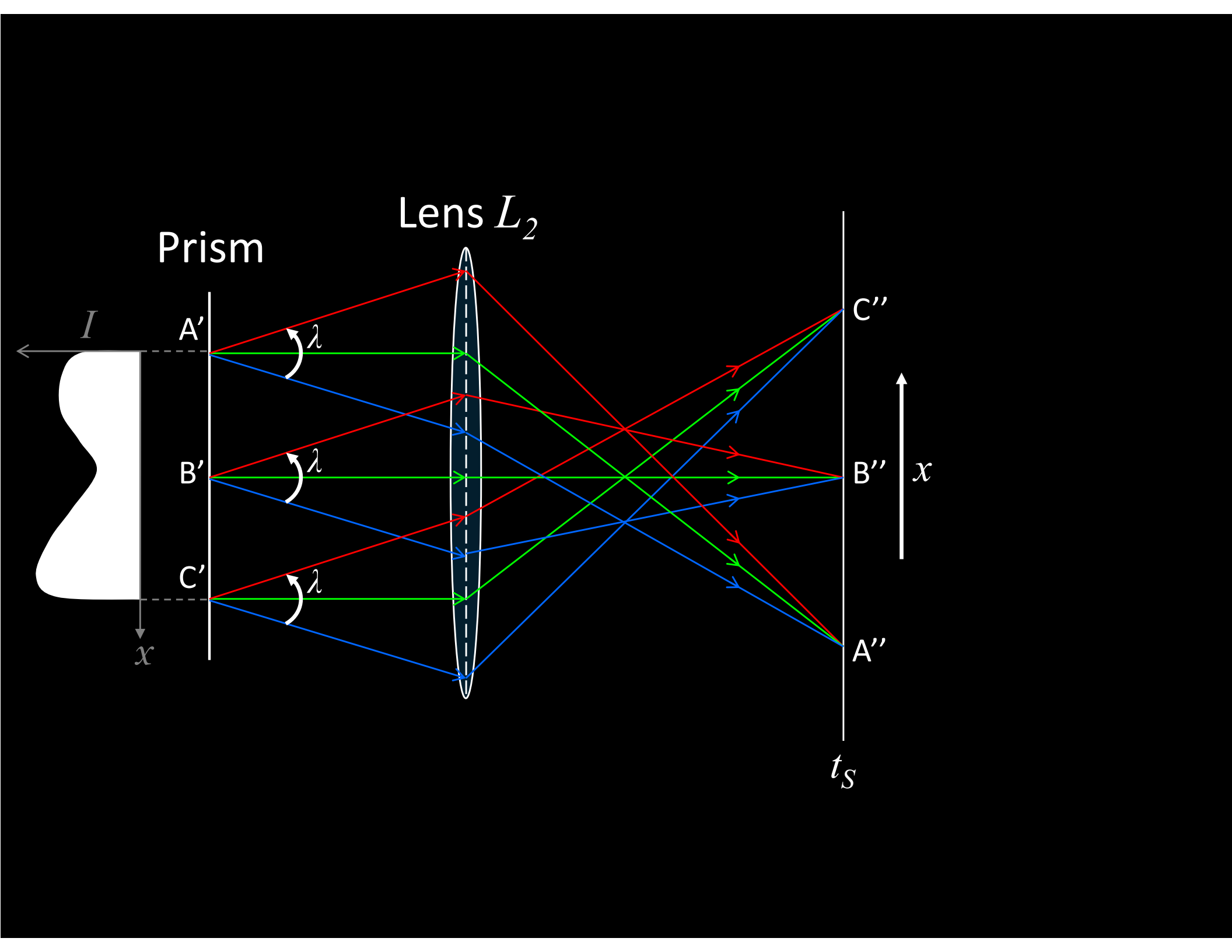

Prism
I
A’
B’
C’
λ
λ
λ
x
Screen

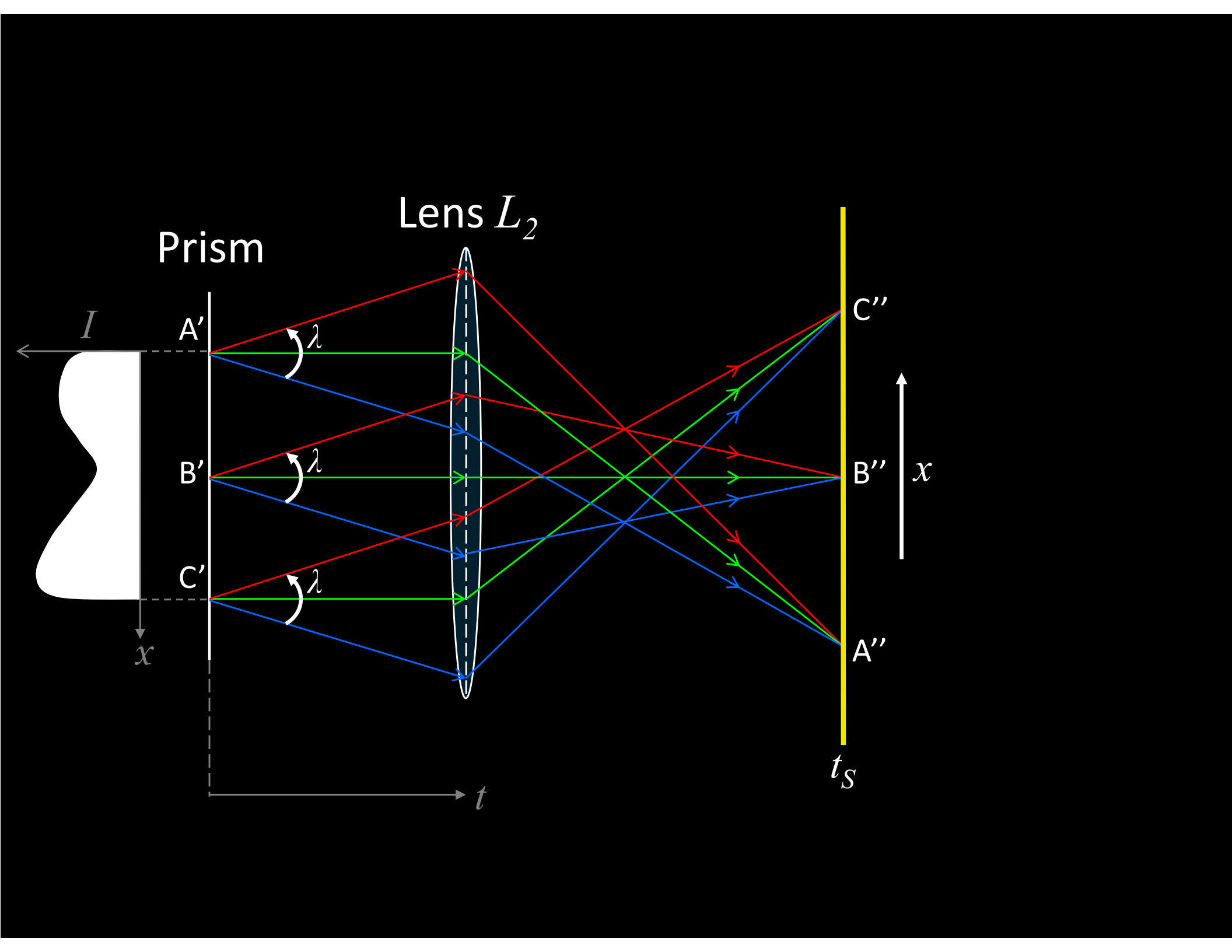

λ
x
I
p

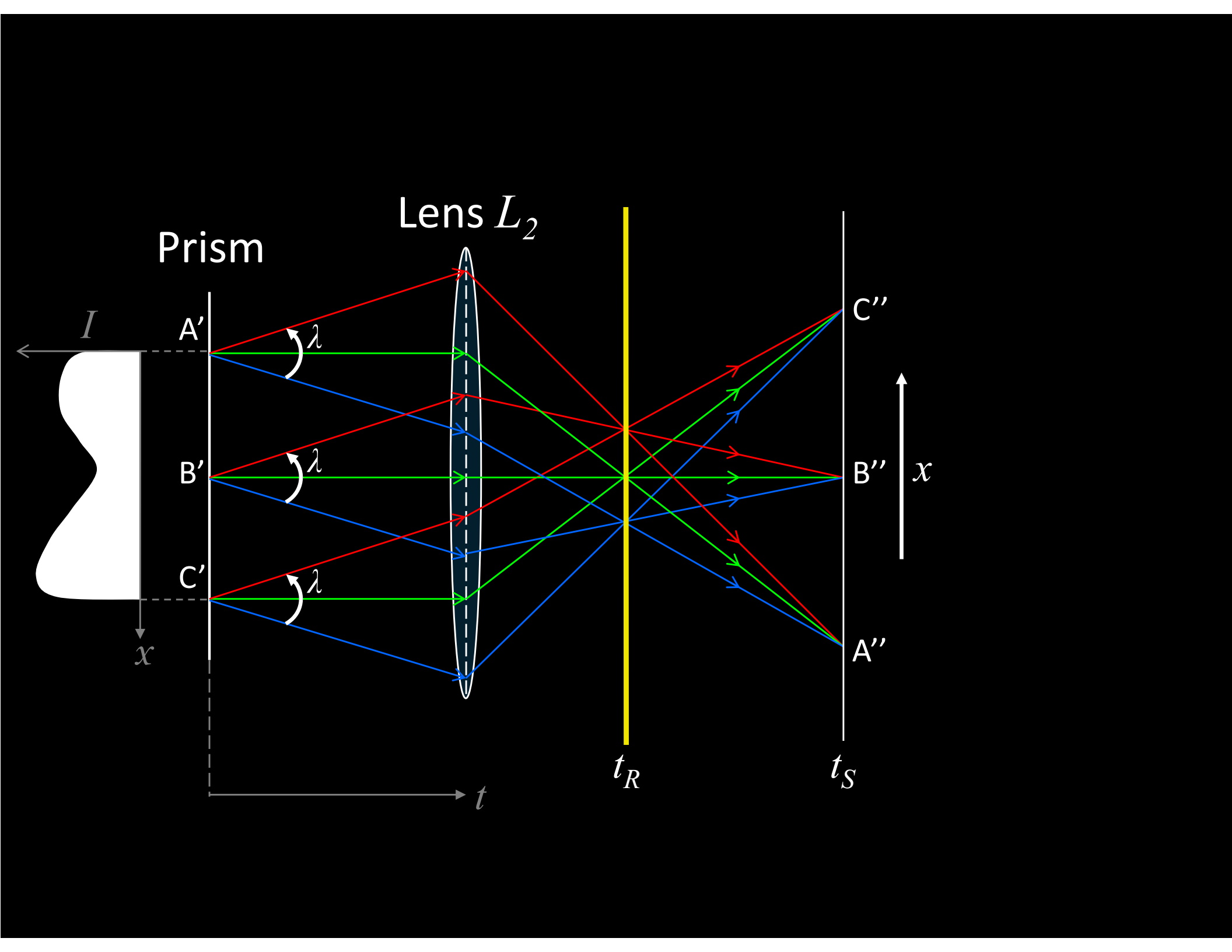

Prism
I
A’
B’
C’
λ
λ
λ
x

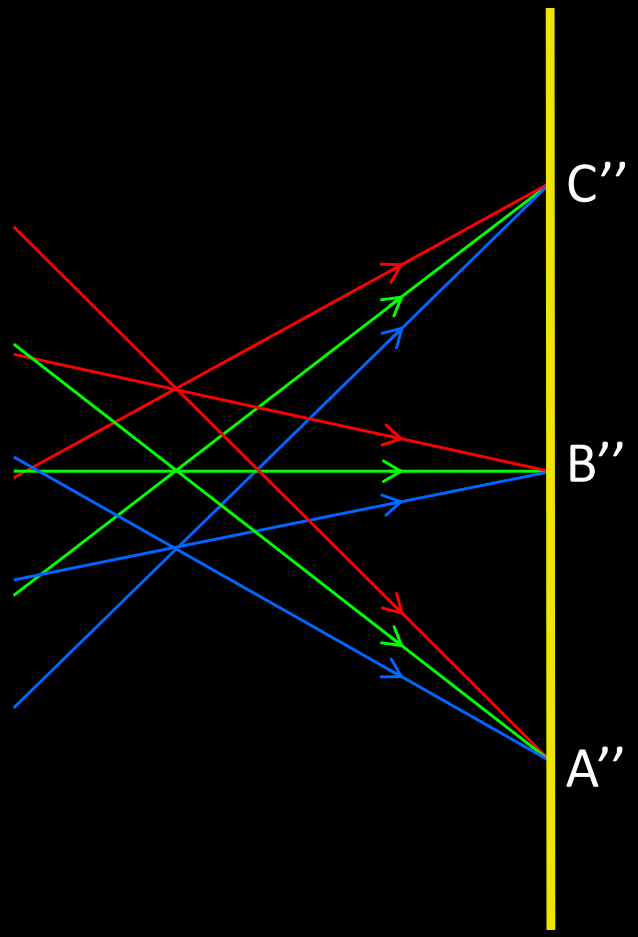

λ
x
I
p


Prism
I
A’
B’
C’
λ
λ
λ
x
t
$t = \infty$
p
λ
x
I

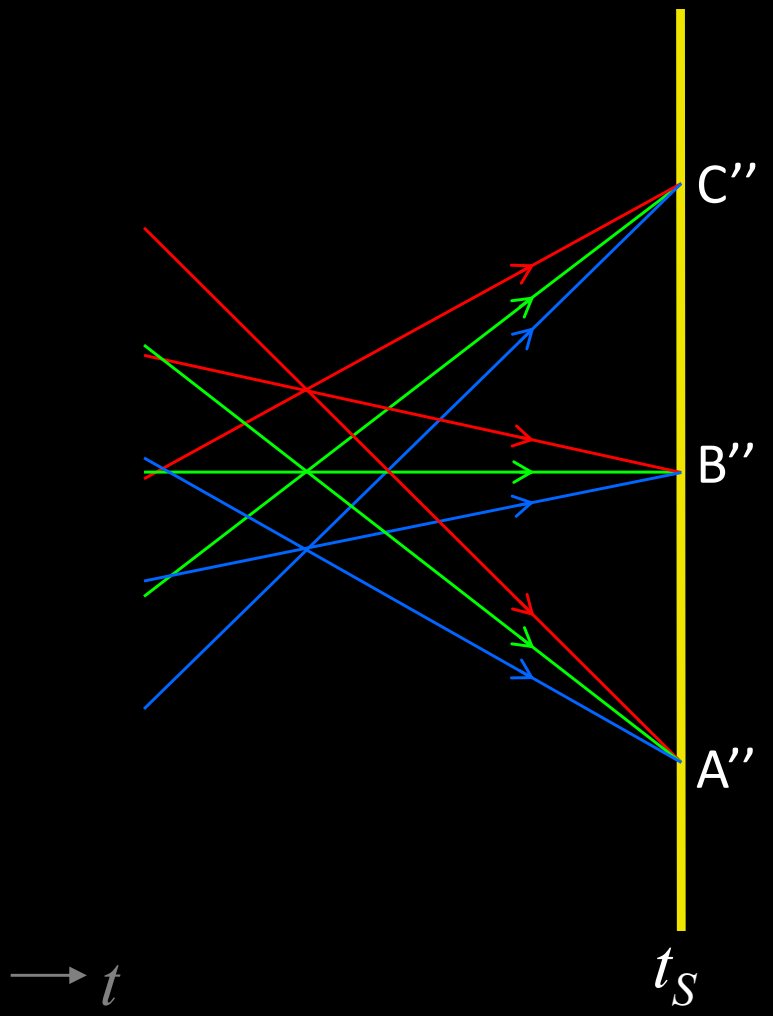

Prism
Lens L_2
I
A’
B’
C’
λ
λ
λ
x
C’’
B’’
A’’
x
t_S

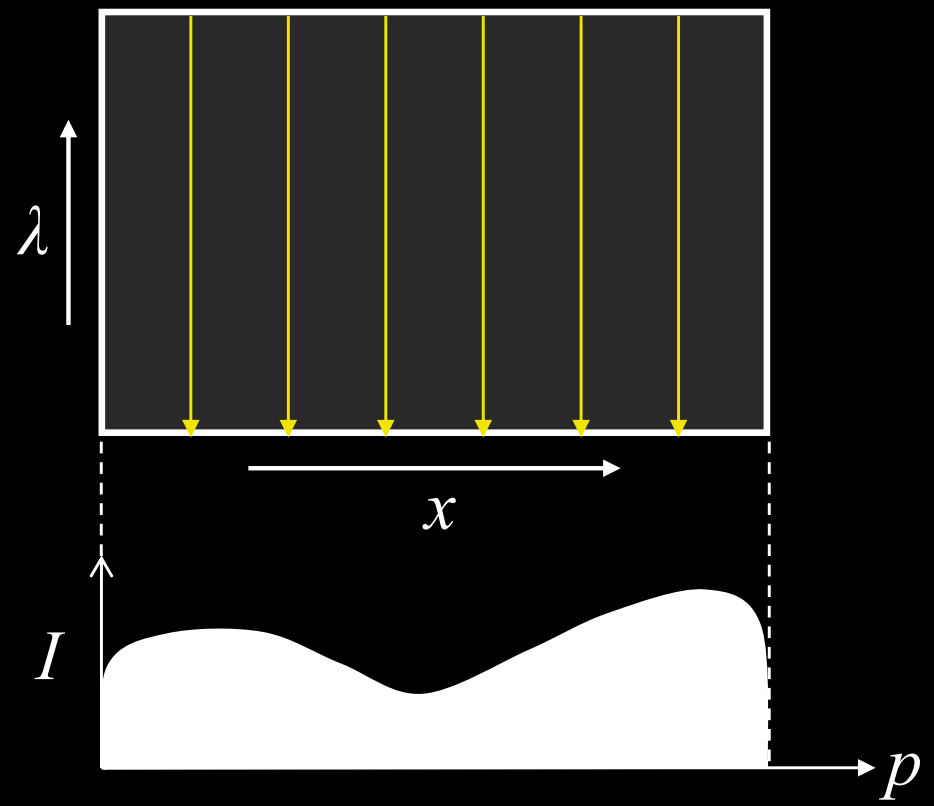

Prism
Lens L_2
I
A’
B’
C’
λ
λ
λ
x
t
C’’
B’’
A’’
x
t_S


Prism
Lens L_2
I
A’
B’
C’
λ
λ
λ
x
t
C’’
B’’
A’’
x
t_R
t_S

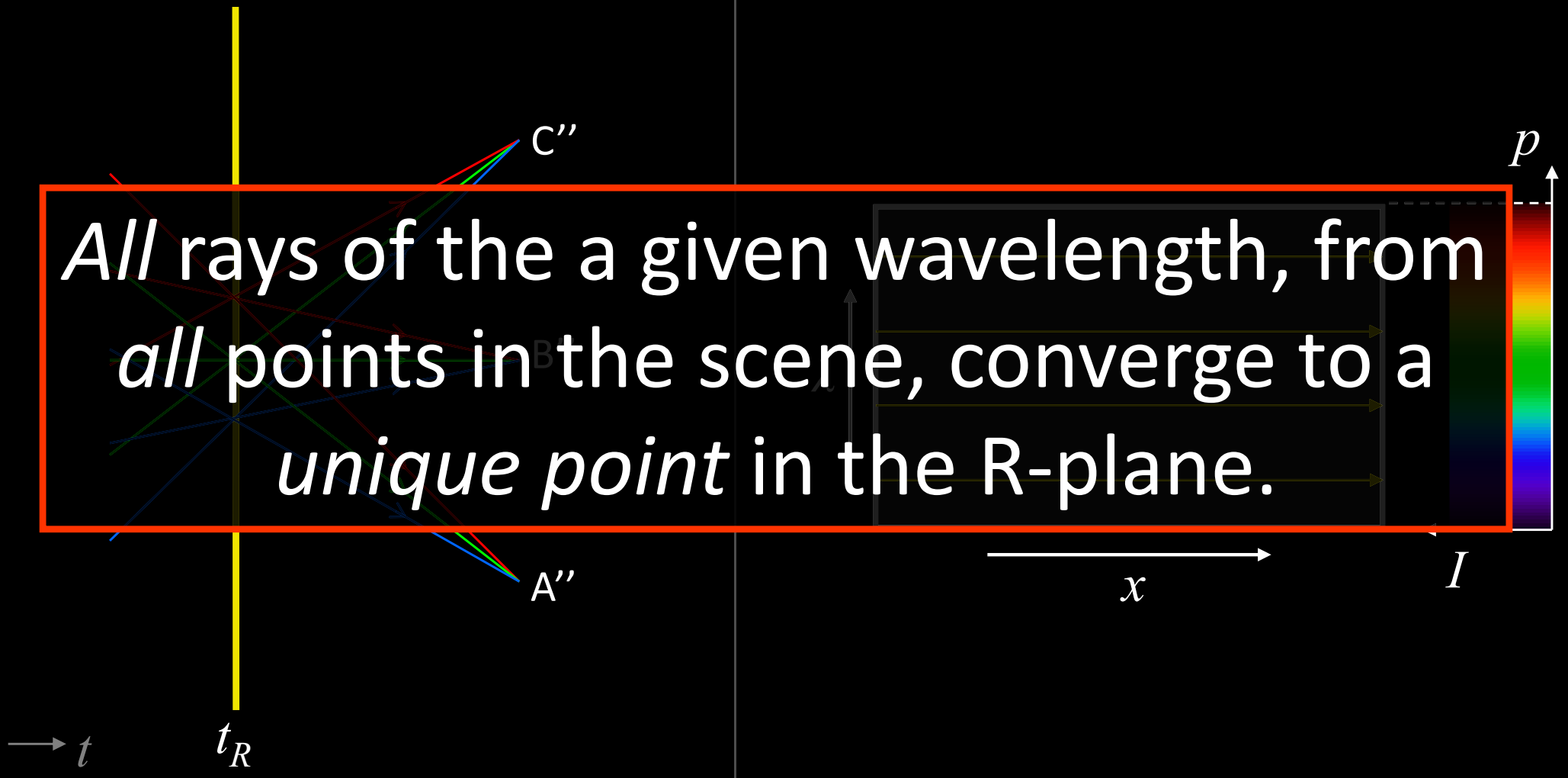

C''
B''
A''

Sensor plane ($t=t_s$)



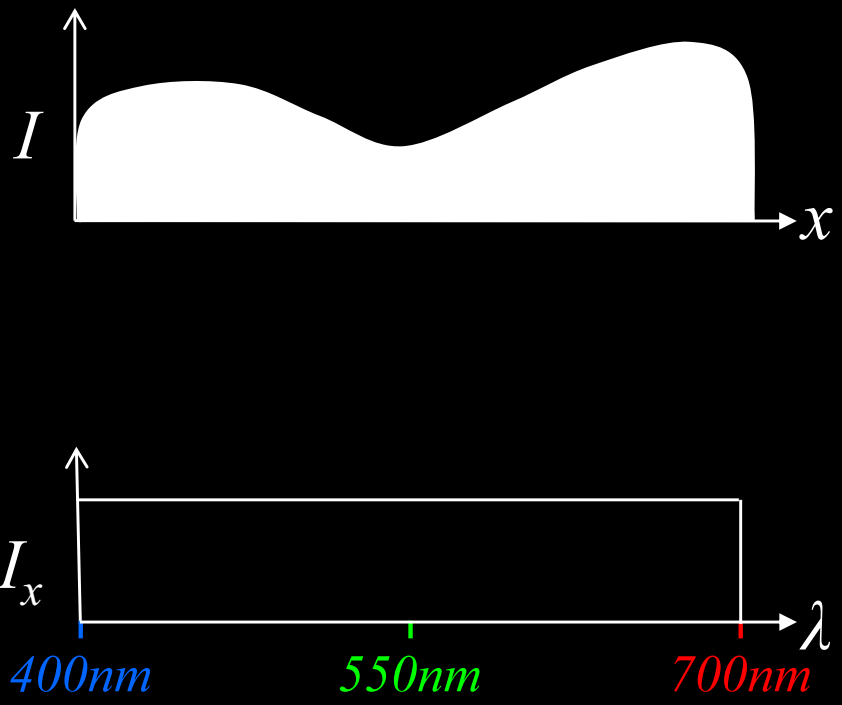


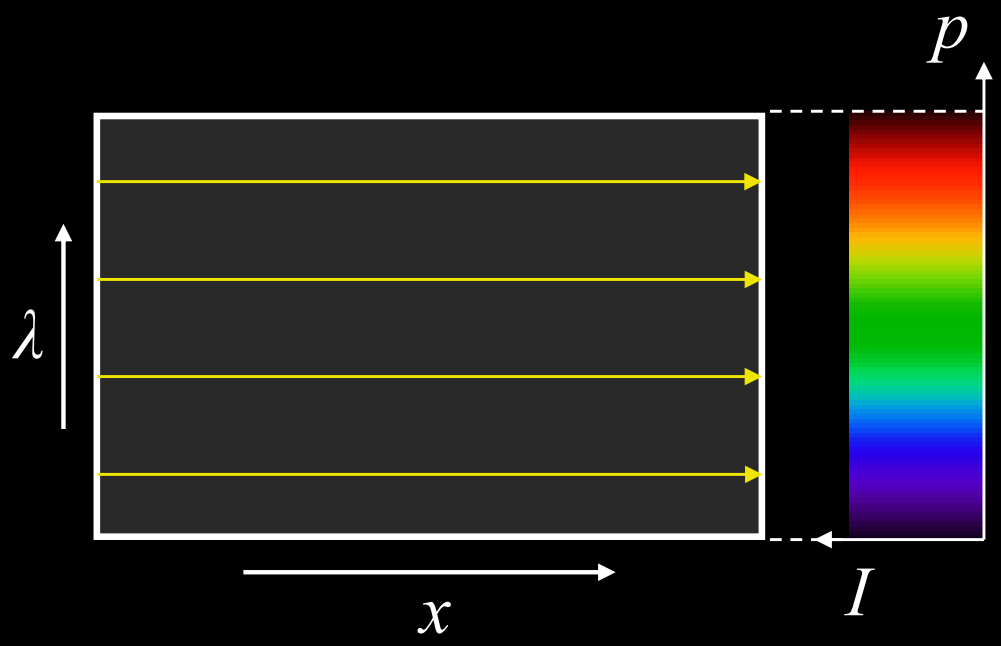
Rainbow plane ($t=t_R$)



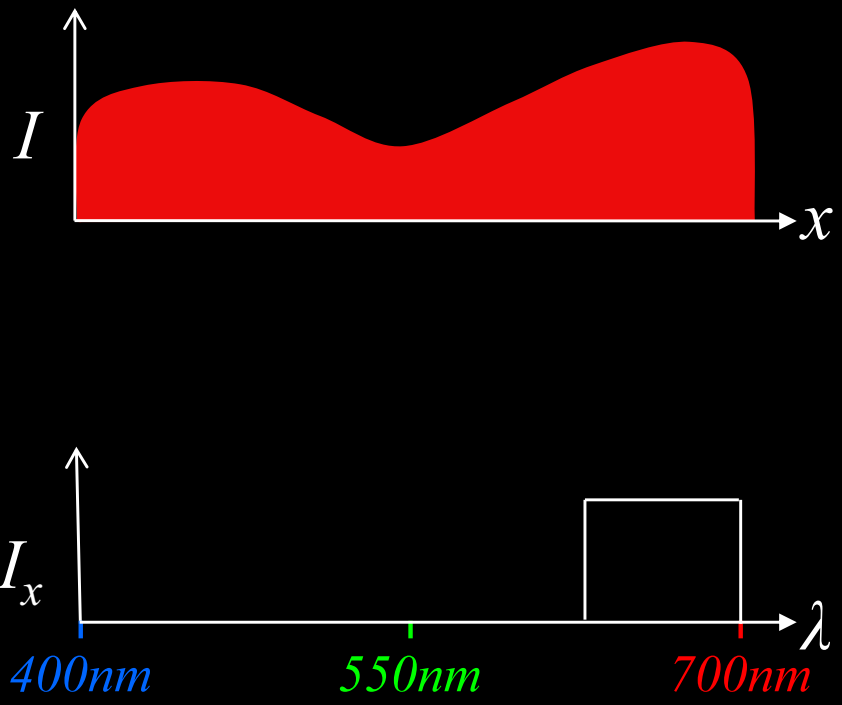
All rays of the a given wavelength, from *all* points in the scene, converge to a *unique point* in the R-plane.

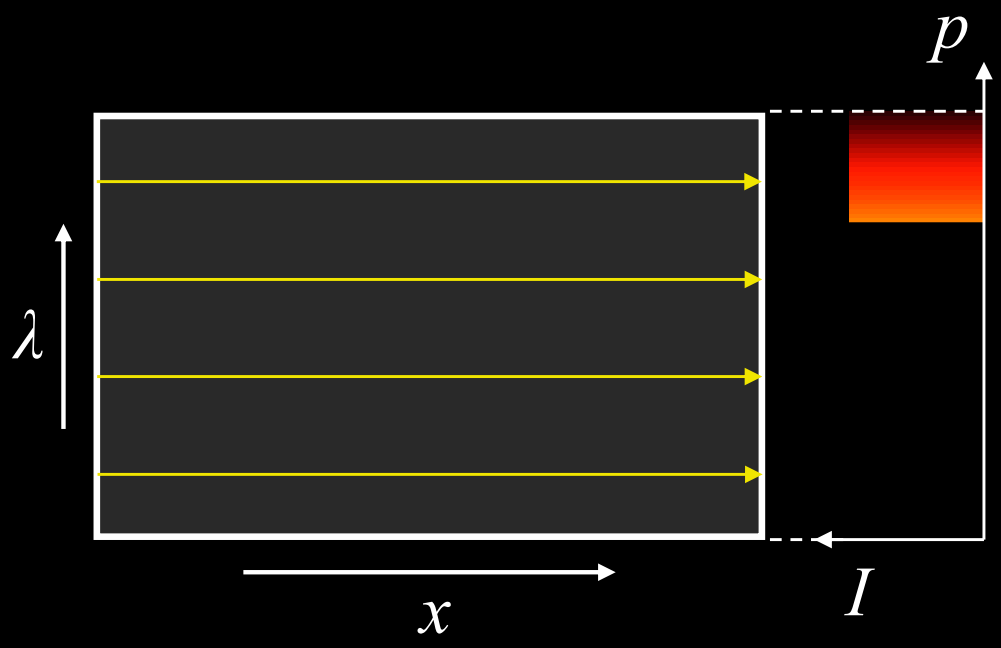
Rainbow plane ($t=t_R$)



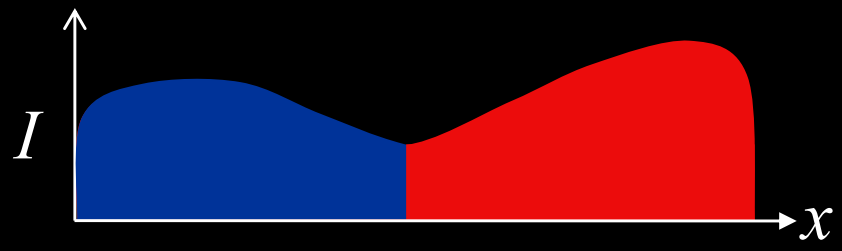


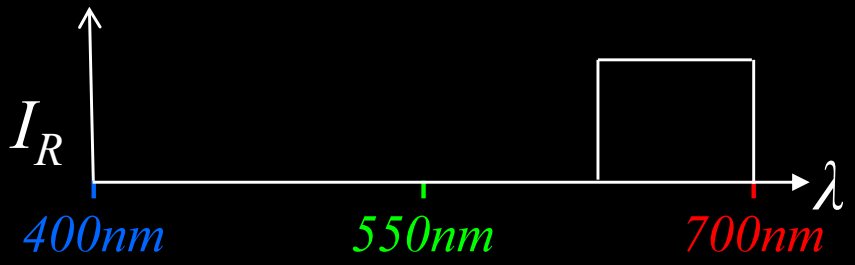
Rainbow plane ($t=t_R$)

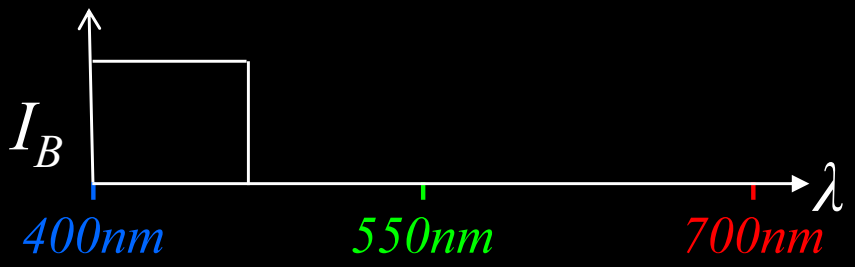


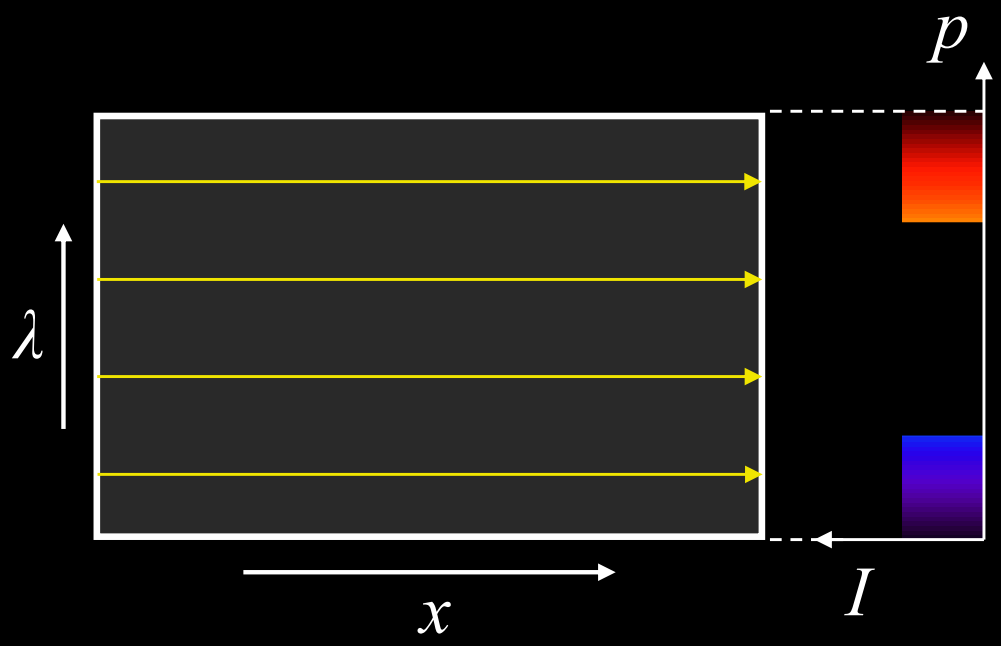


Rainbow plane ($t=t_R$)

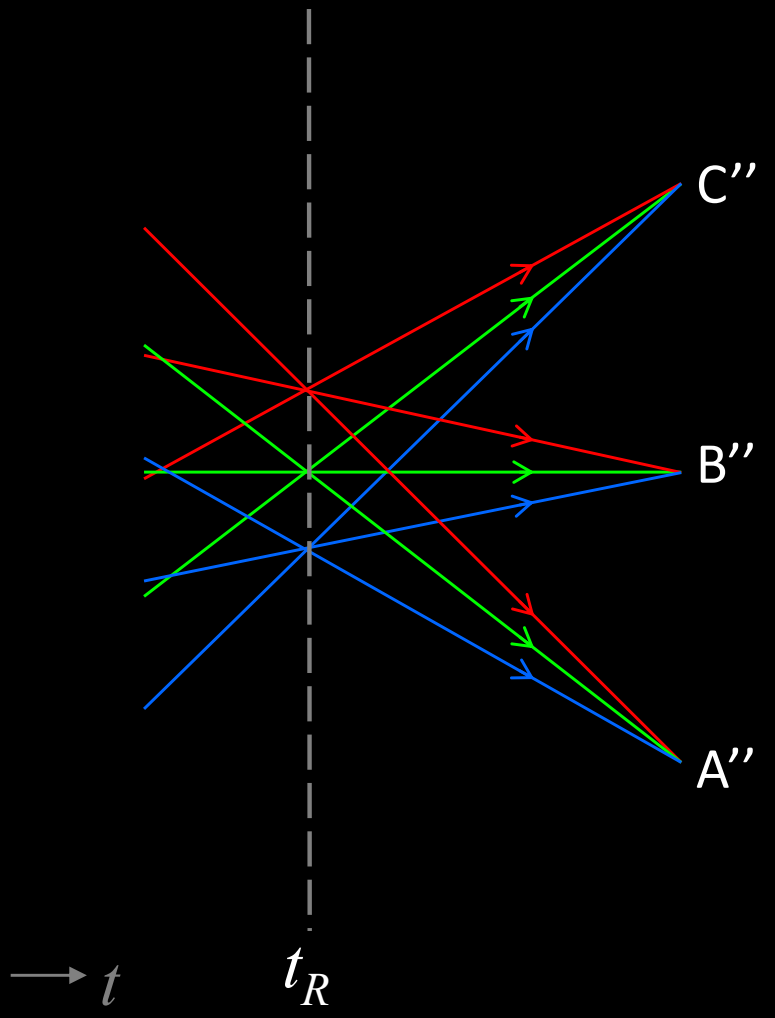






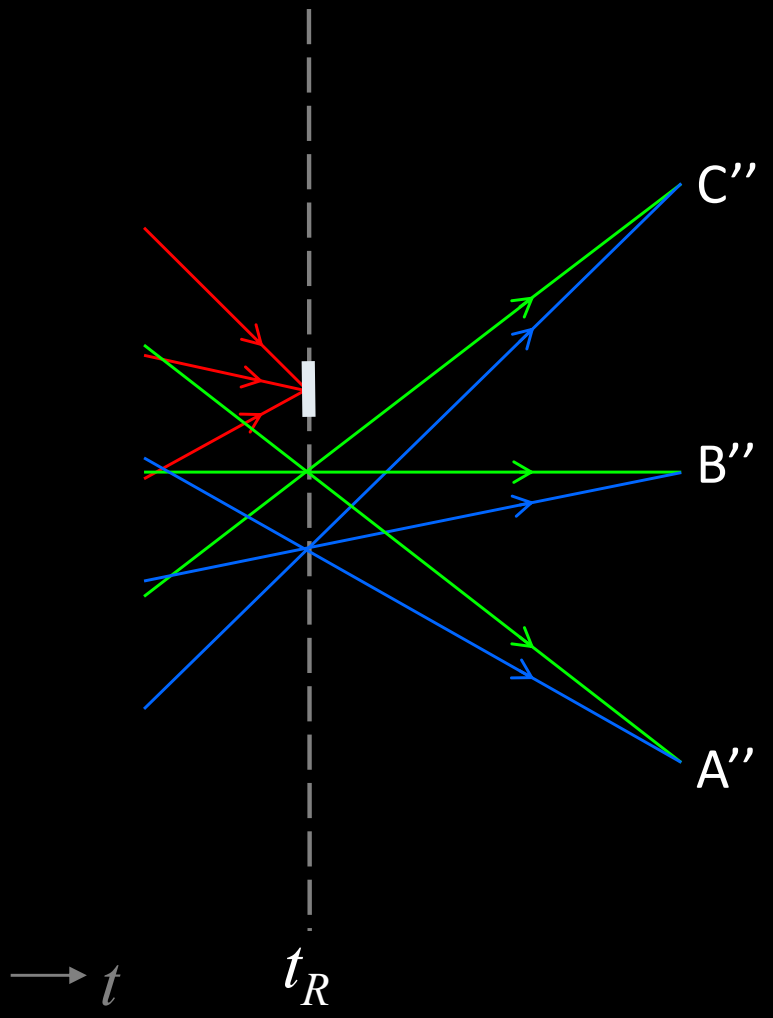


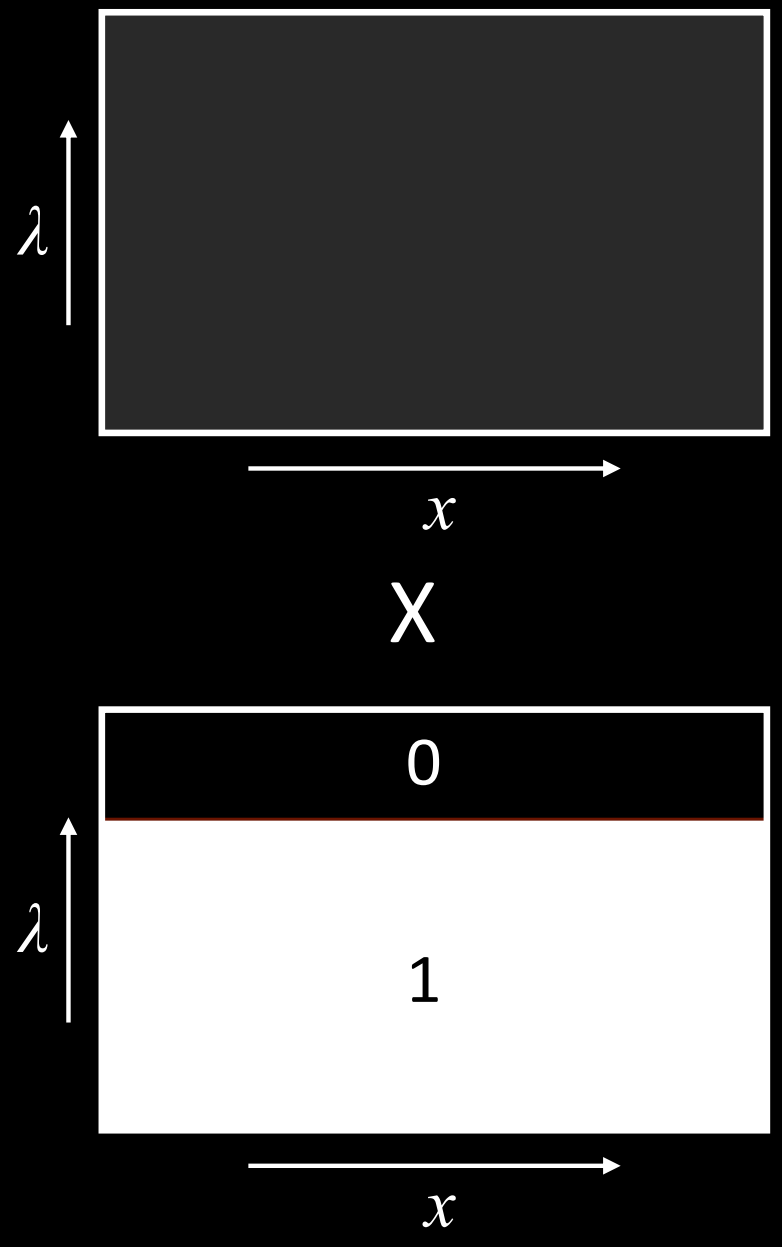
Rainbow plane ($t=t_R$)



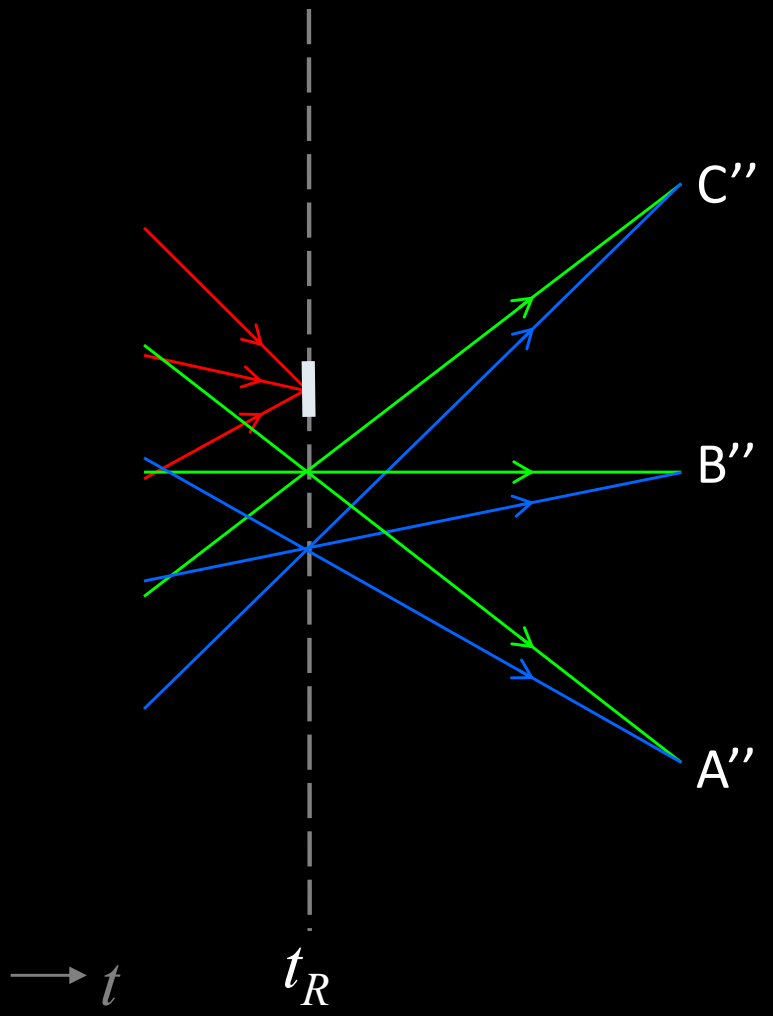
$\lambda \leftrightarrow$ position

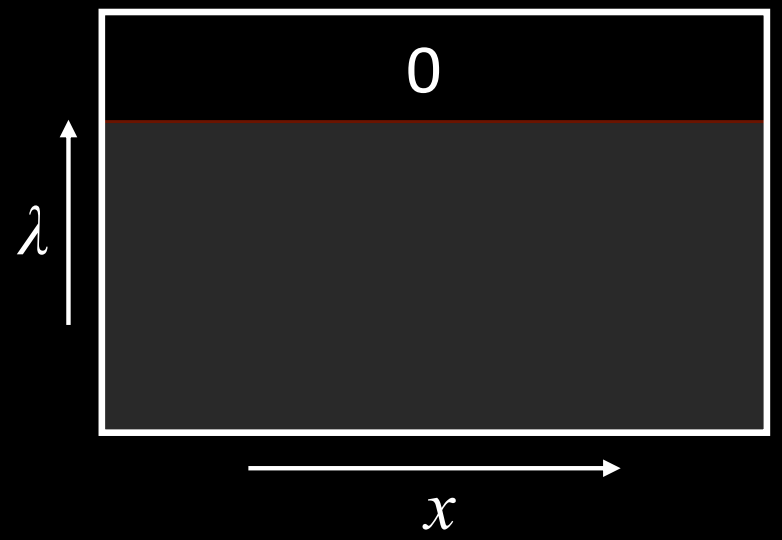
Mask in the Rainbow plane



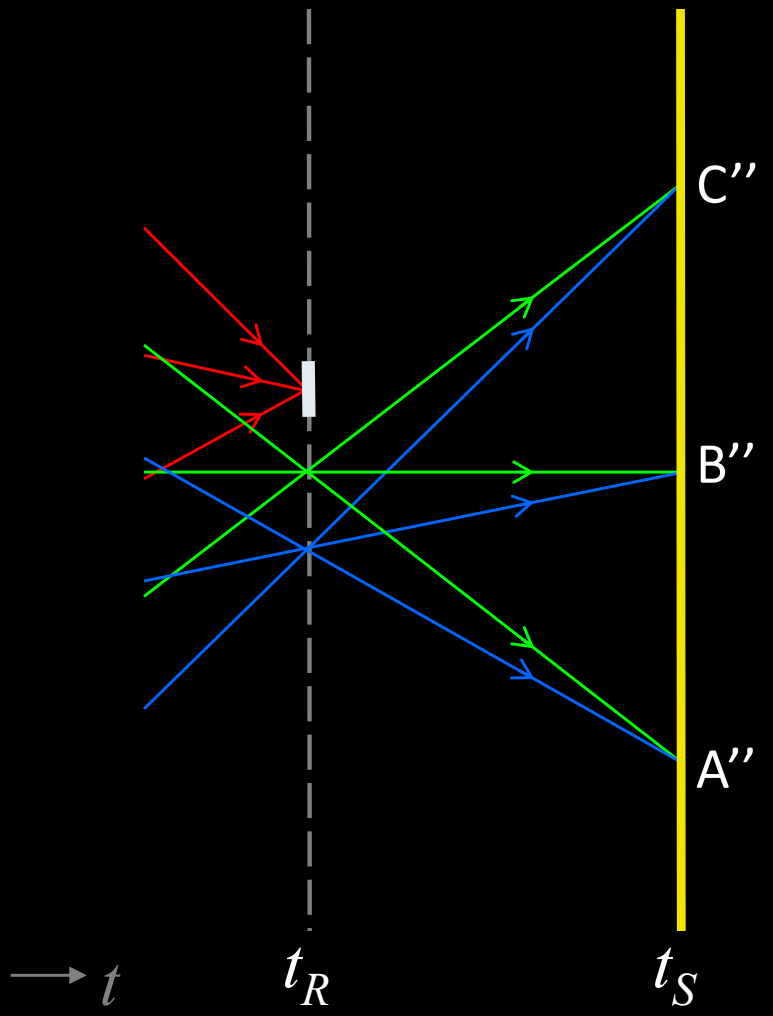


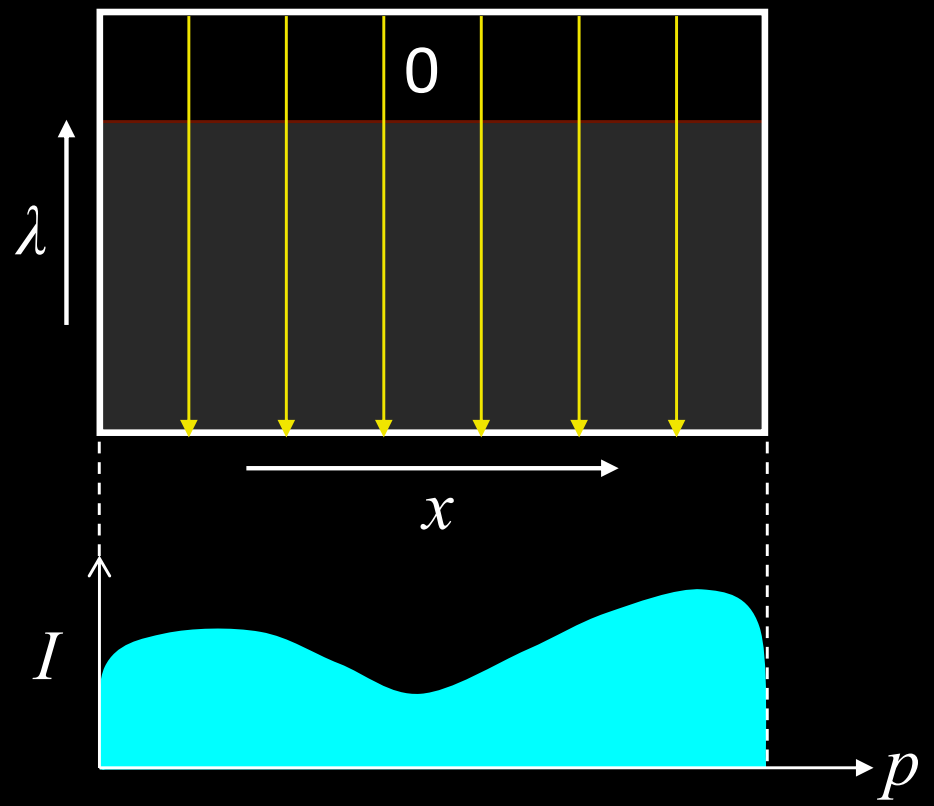
Mask in the Rainbow plane



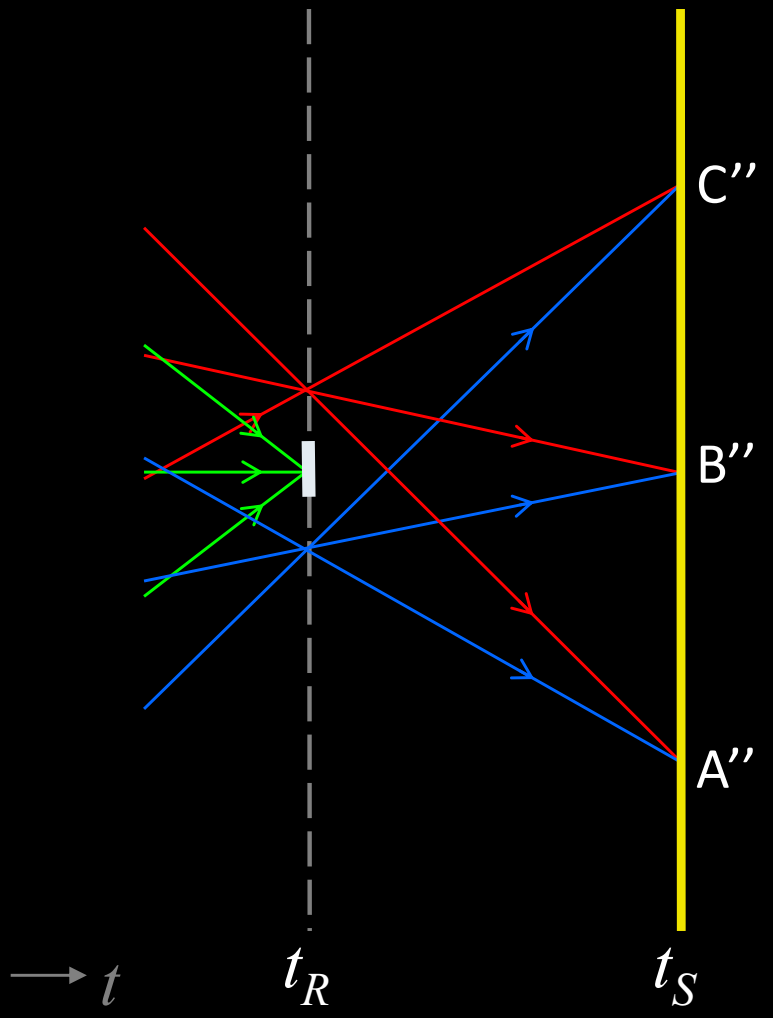


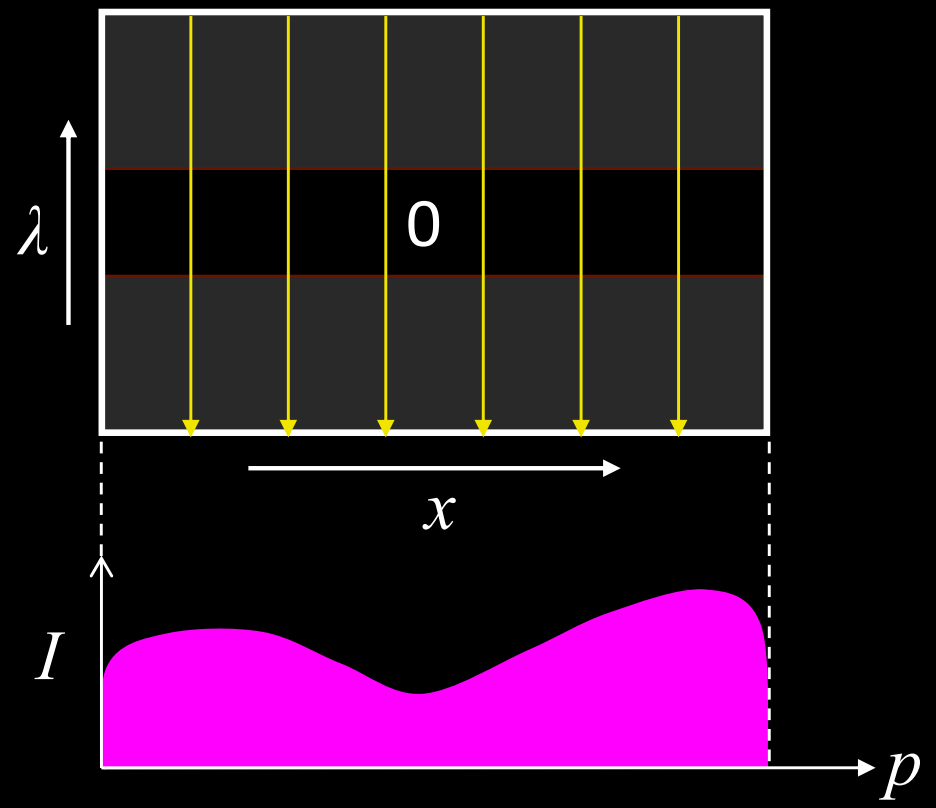
Mask in the Rainbow plane



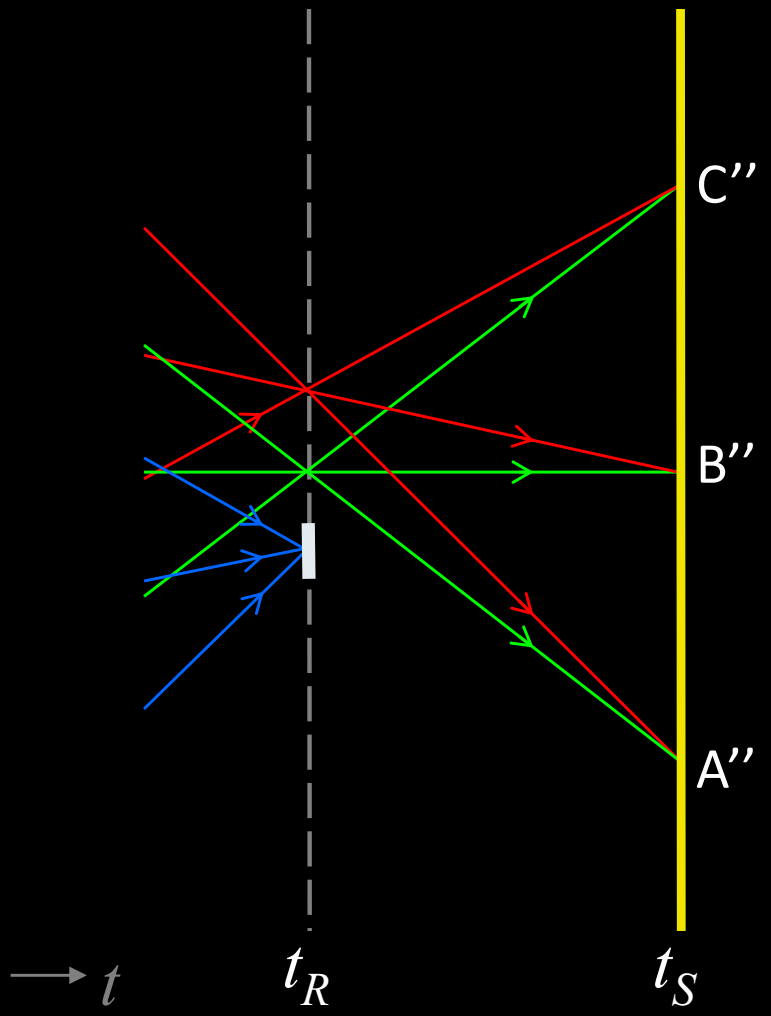


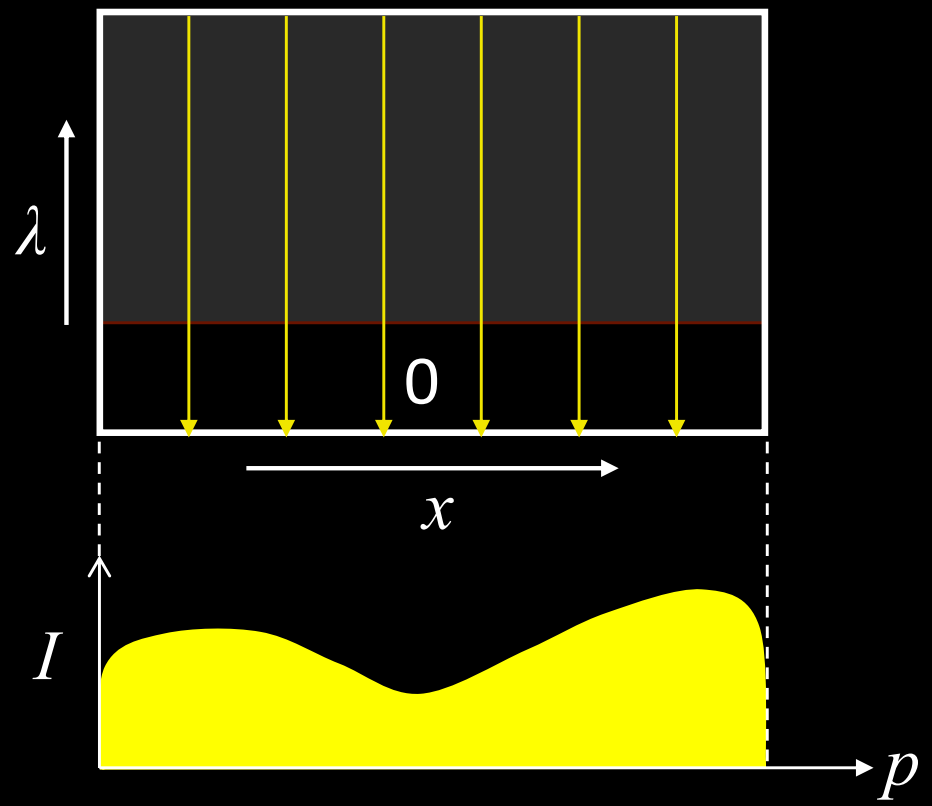
Mask in the Rainbow plane



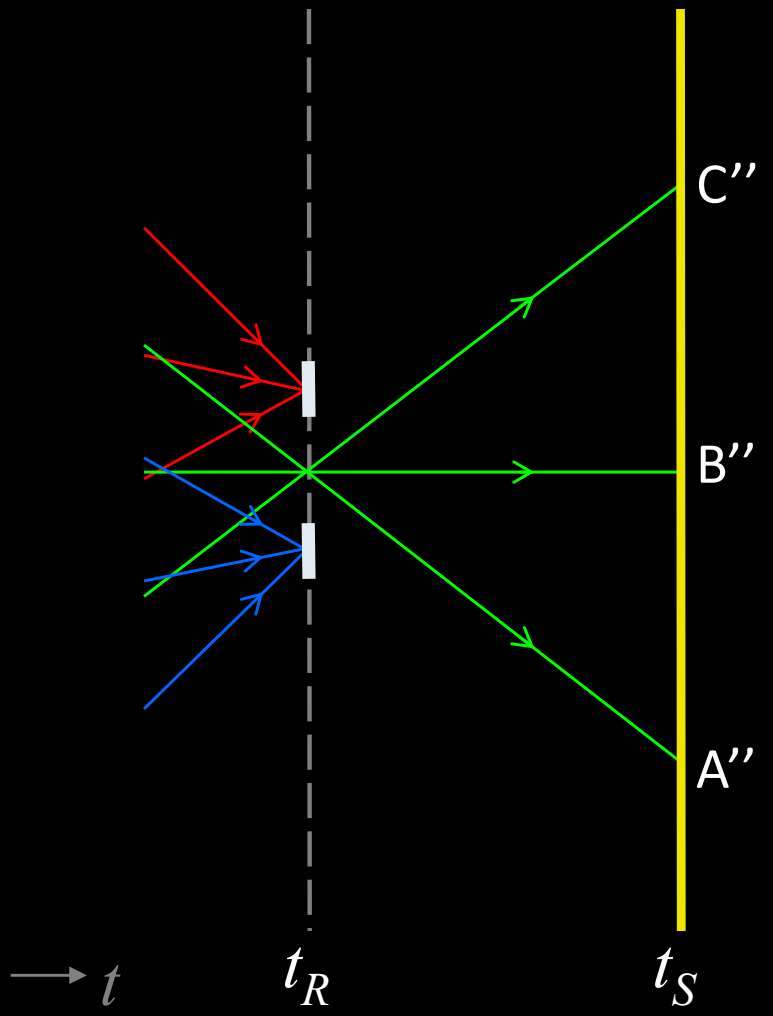


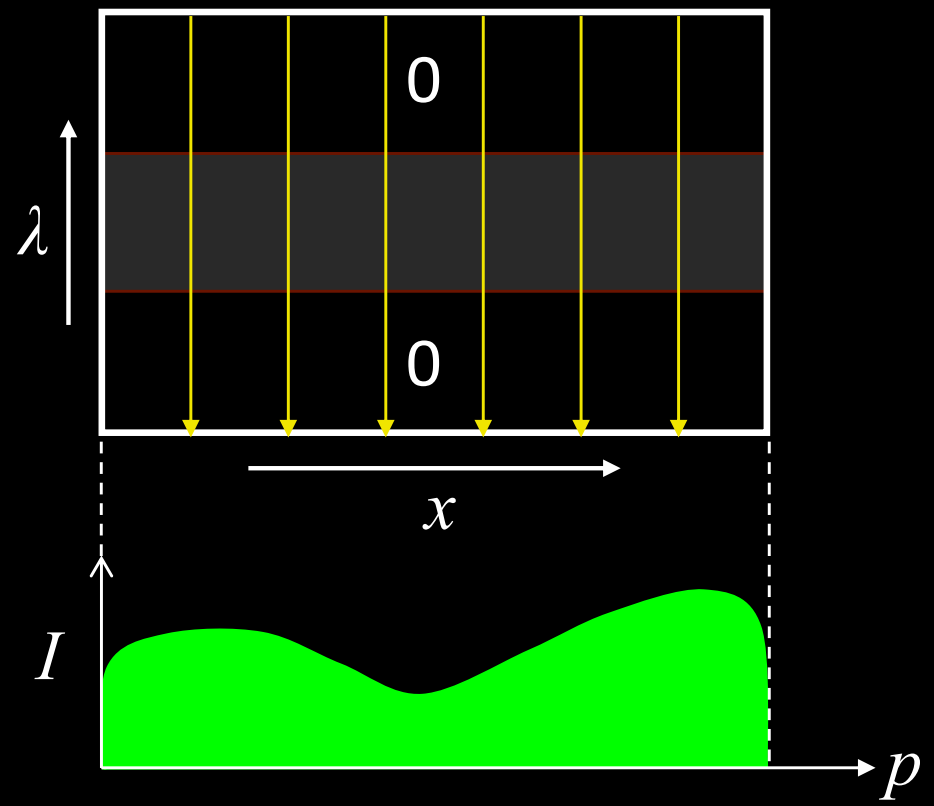
Mask in the Rainbow plane



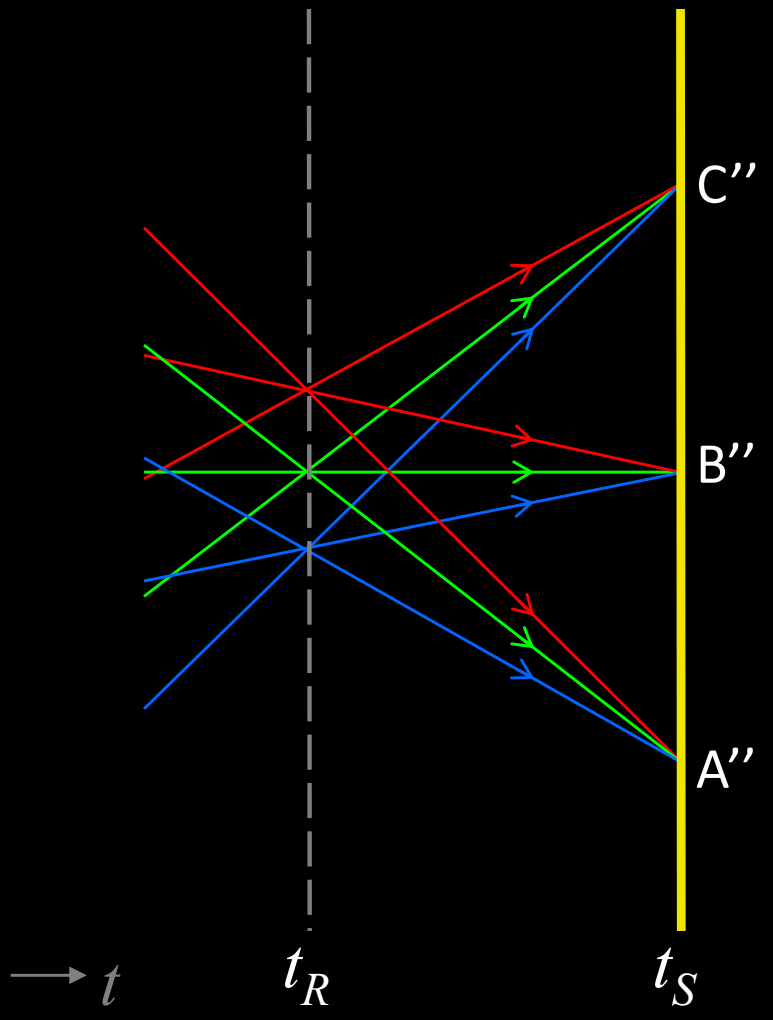


Mask in the Rainbow plane

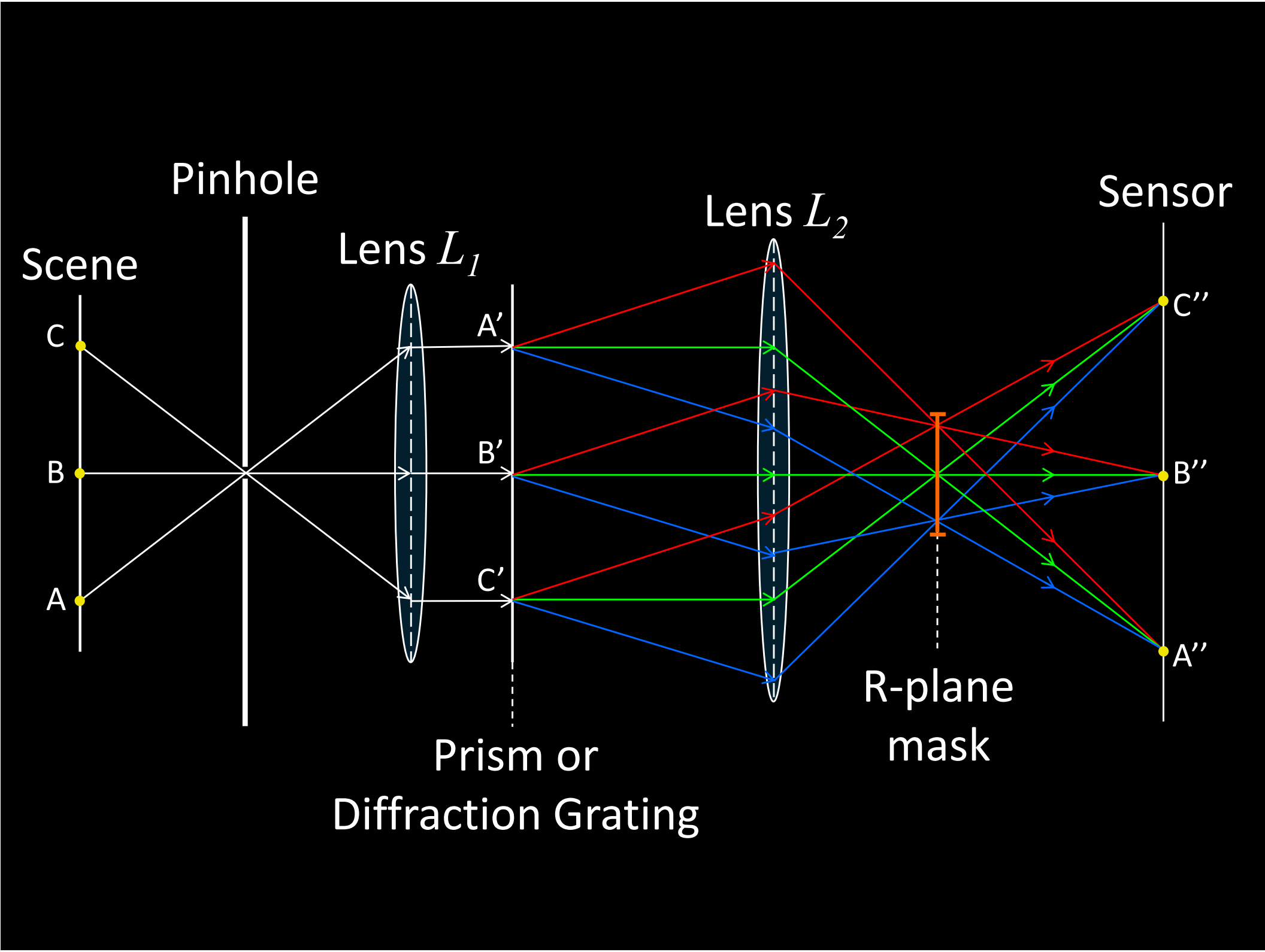


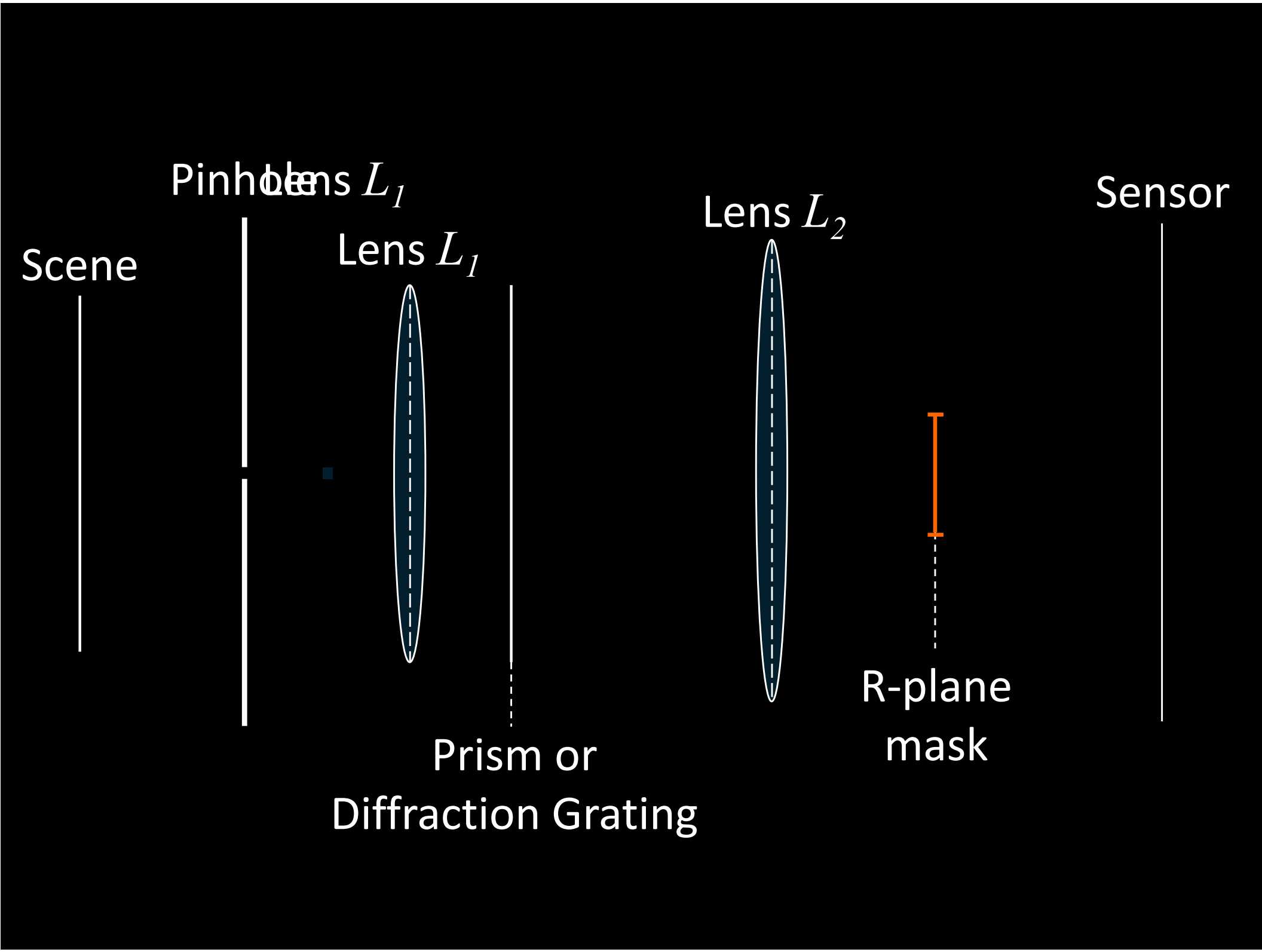


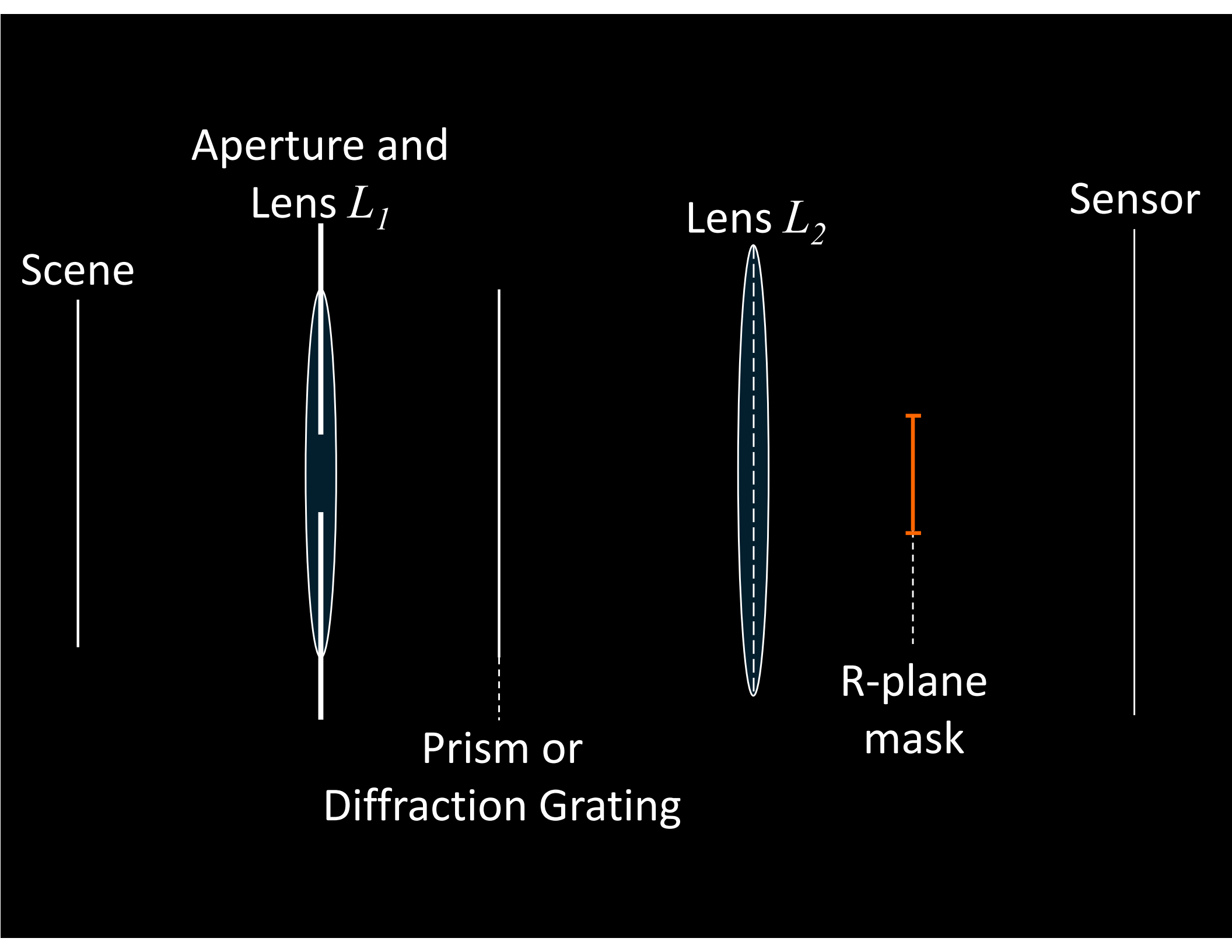
Rainbow plane ($t=t_R$)

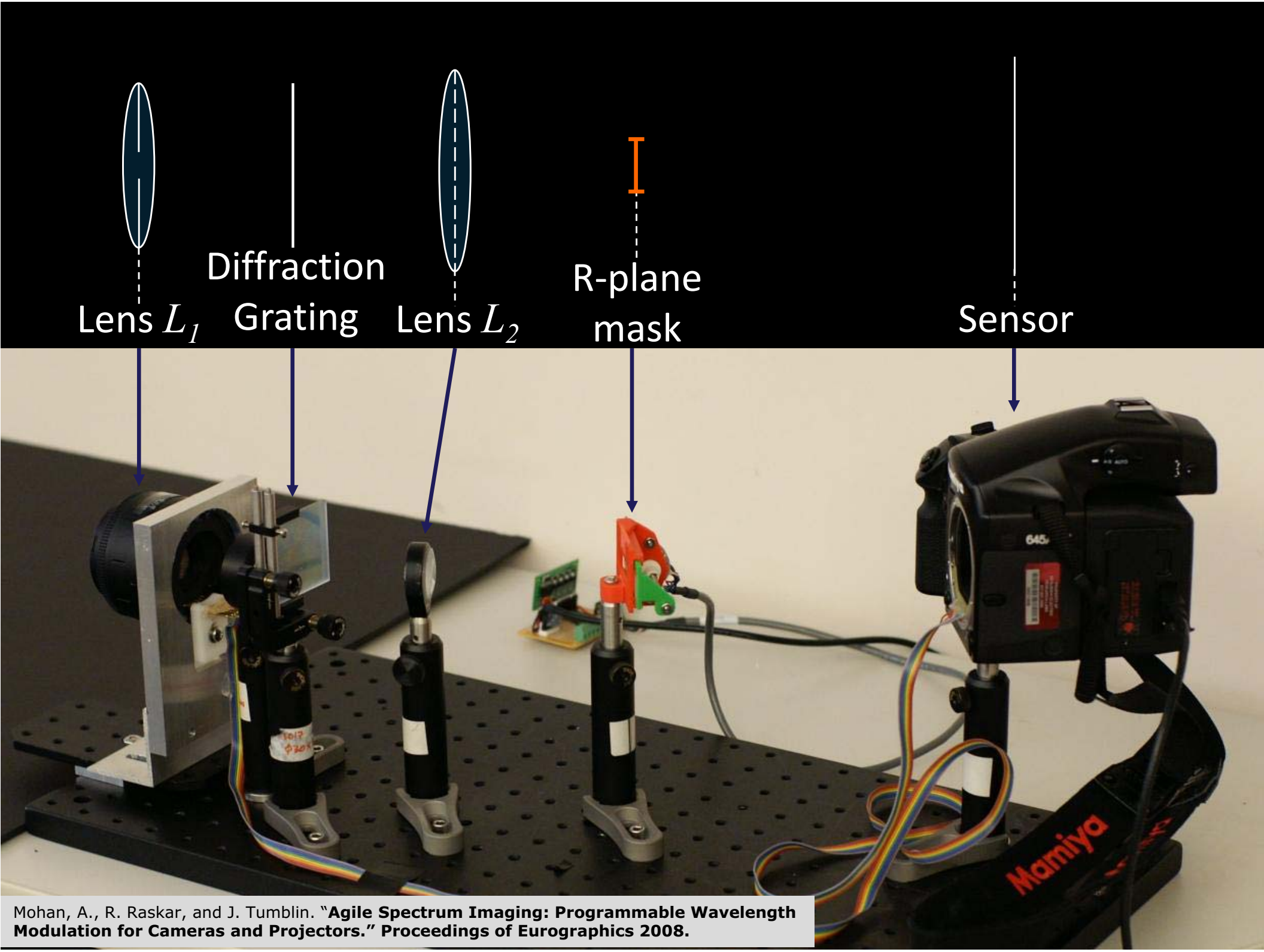


Control the *spectral sensitivity* of the sensor by placing an appropriate *grayscale masks* in the R-plane.


Pinhole
Scene
Lens L_1
Lens L_2
Sensor
C
B
A
A’
B’
C’
C’’
B’’
A’’
Prism or
Diffraction Grating
R-plane
mask

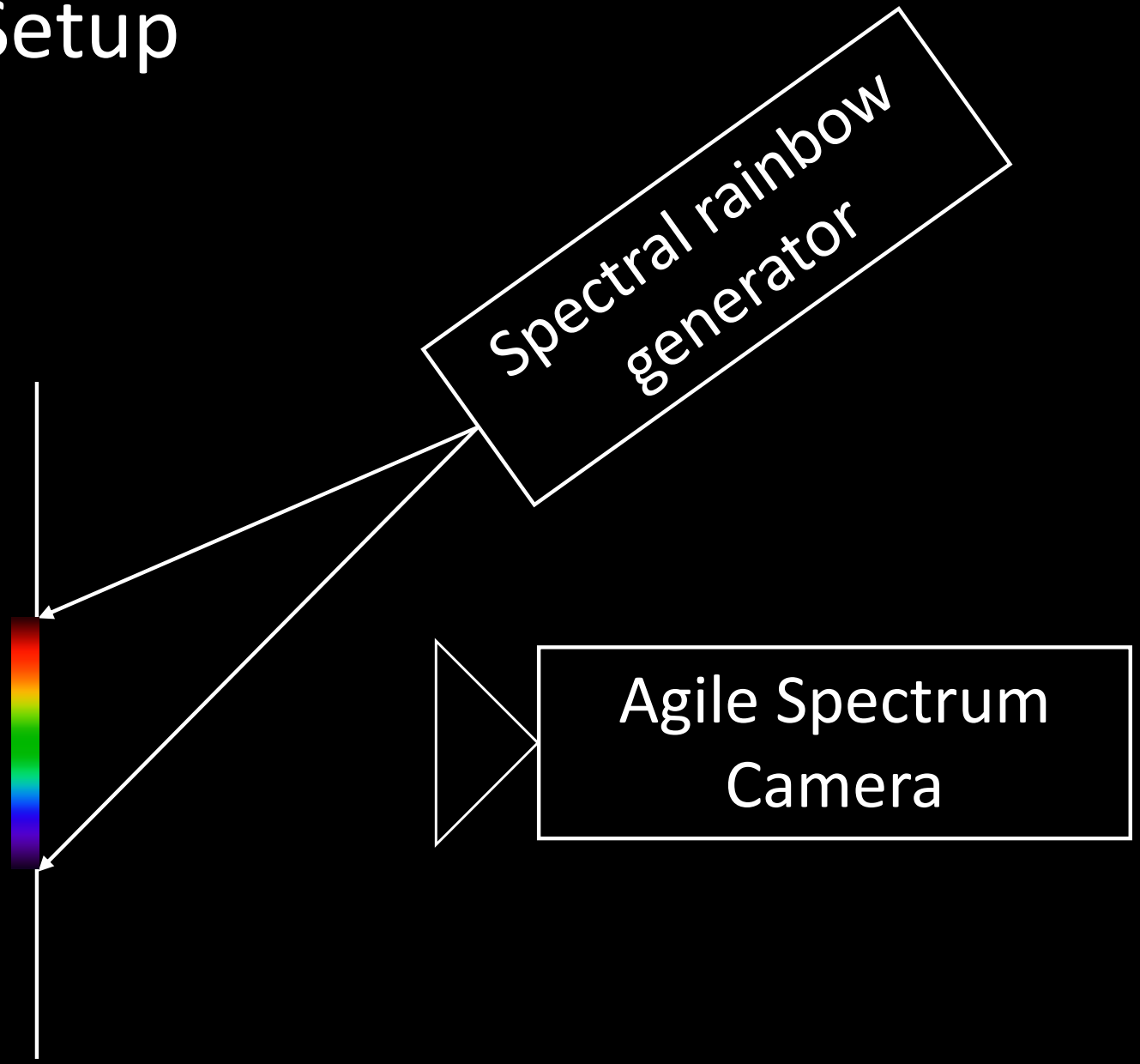

Scene
Pinhole
Lens L_1
Lens L_1
Prism or
Diffraction Grating
Lens L_2
R-plane
mask
Sensor

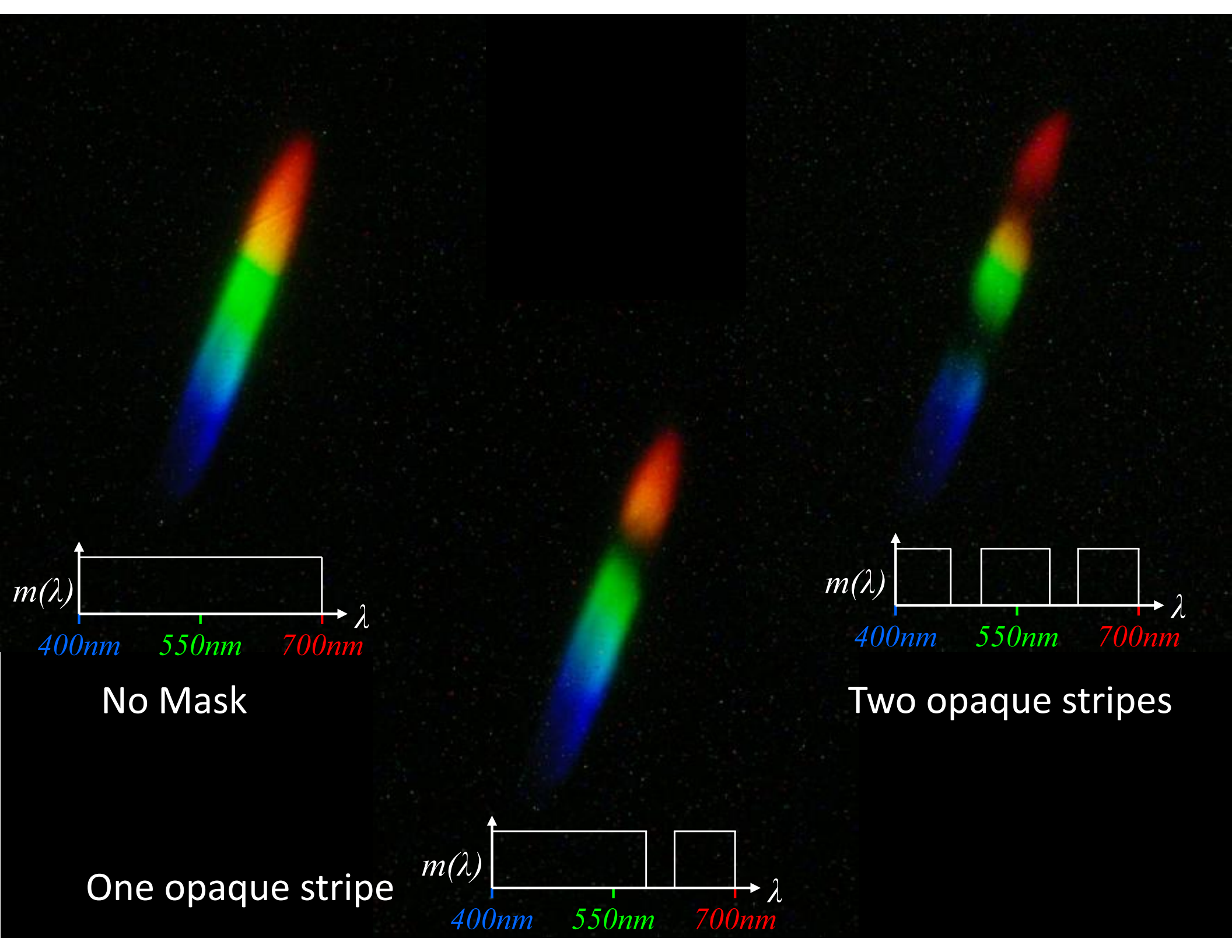

Aperture and
Lens L_1
Lens L_2
Sensor
Scene
Prism or
Diffraction Grating
R-plane
mask

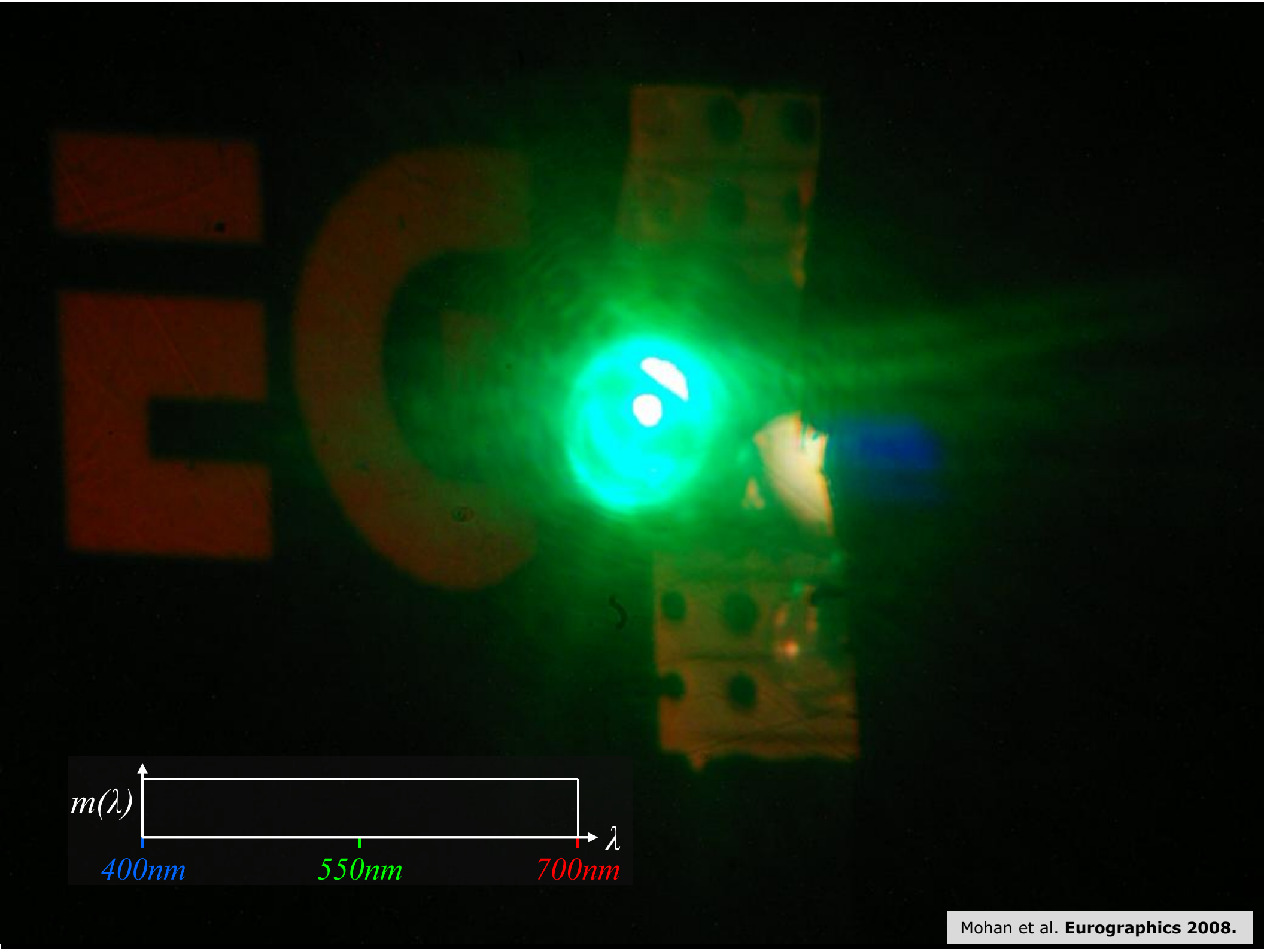


Mohan, A., R. Raskar, and J. Tumblin. "**Agile Spectrum Imaging: Programmable Wavelength Modulation for Cameras and Projectors.**" **Proceedings of Eurographics 2008.**

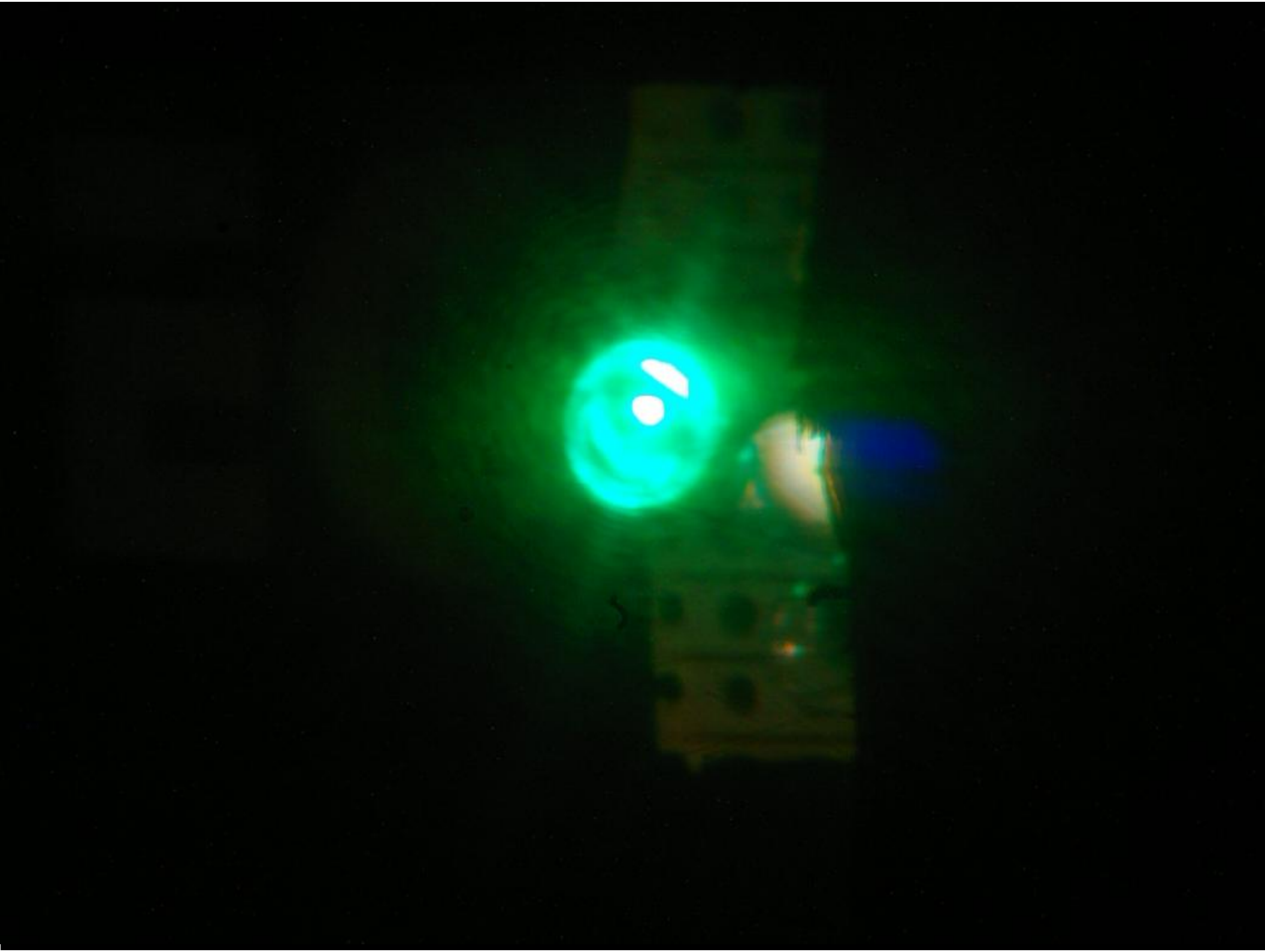
Test Setup

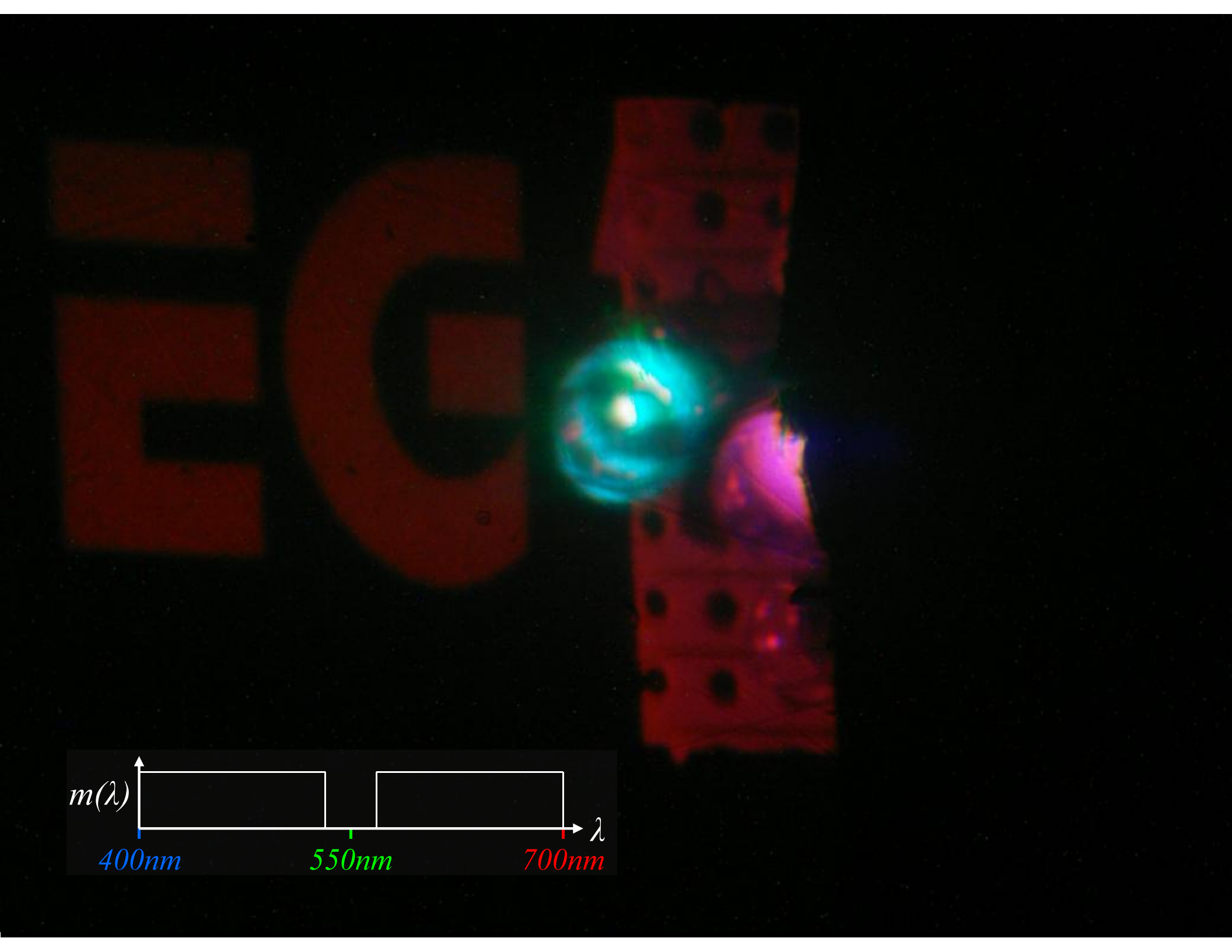


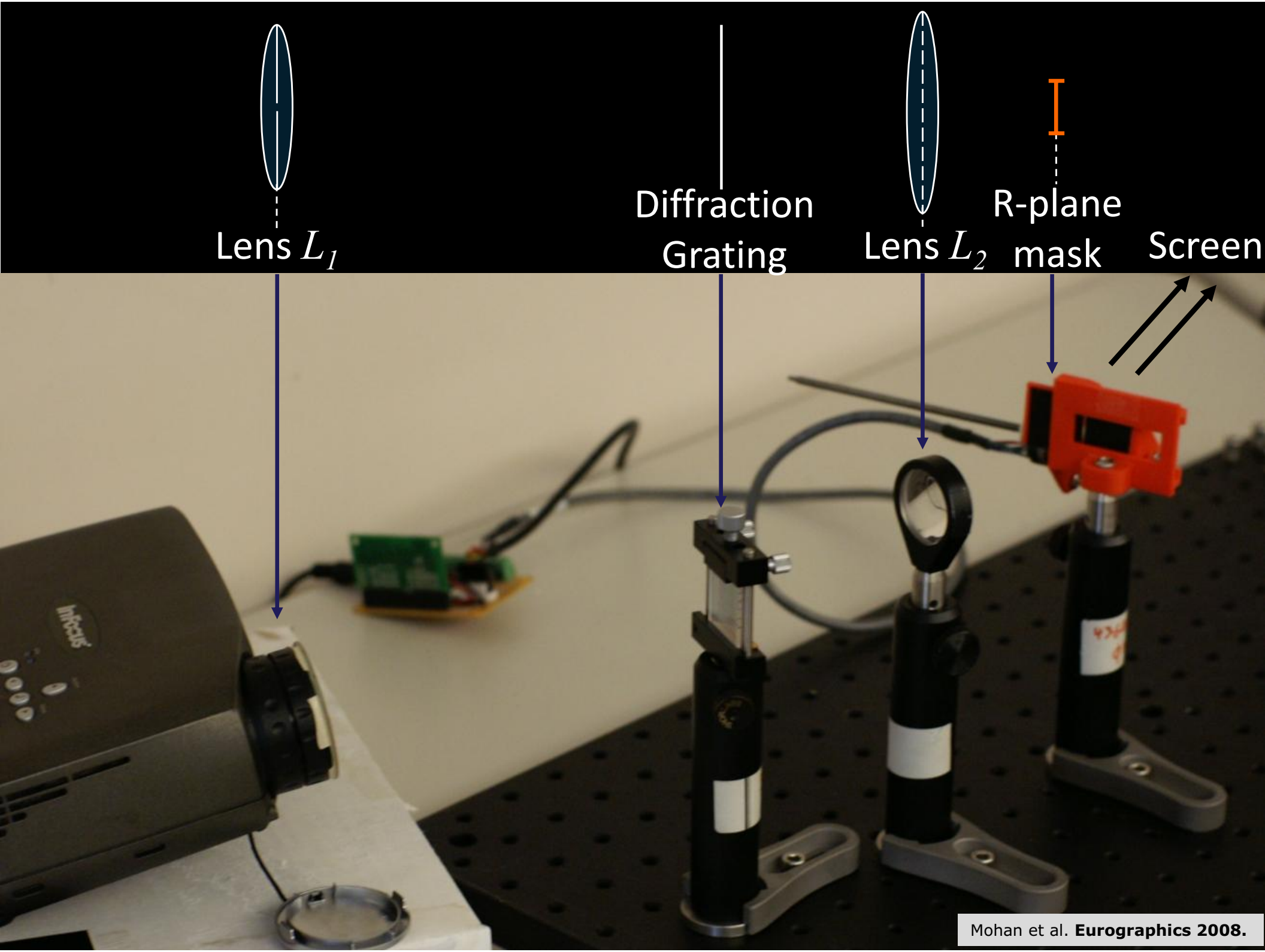

m(λ)
λ
400nm
550nm
700nm
No Mask
m(λ)
λ
400nm
550nm
700nm
Two opaque stripes
m(λ)
λ
400nm
550nm
700nm
One opaque stripe



Mohan et al. **Eurographics 2008.**



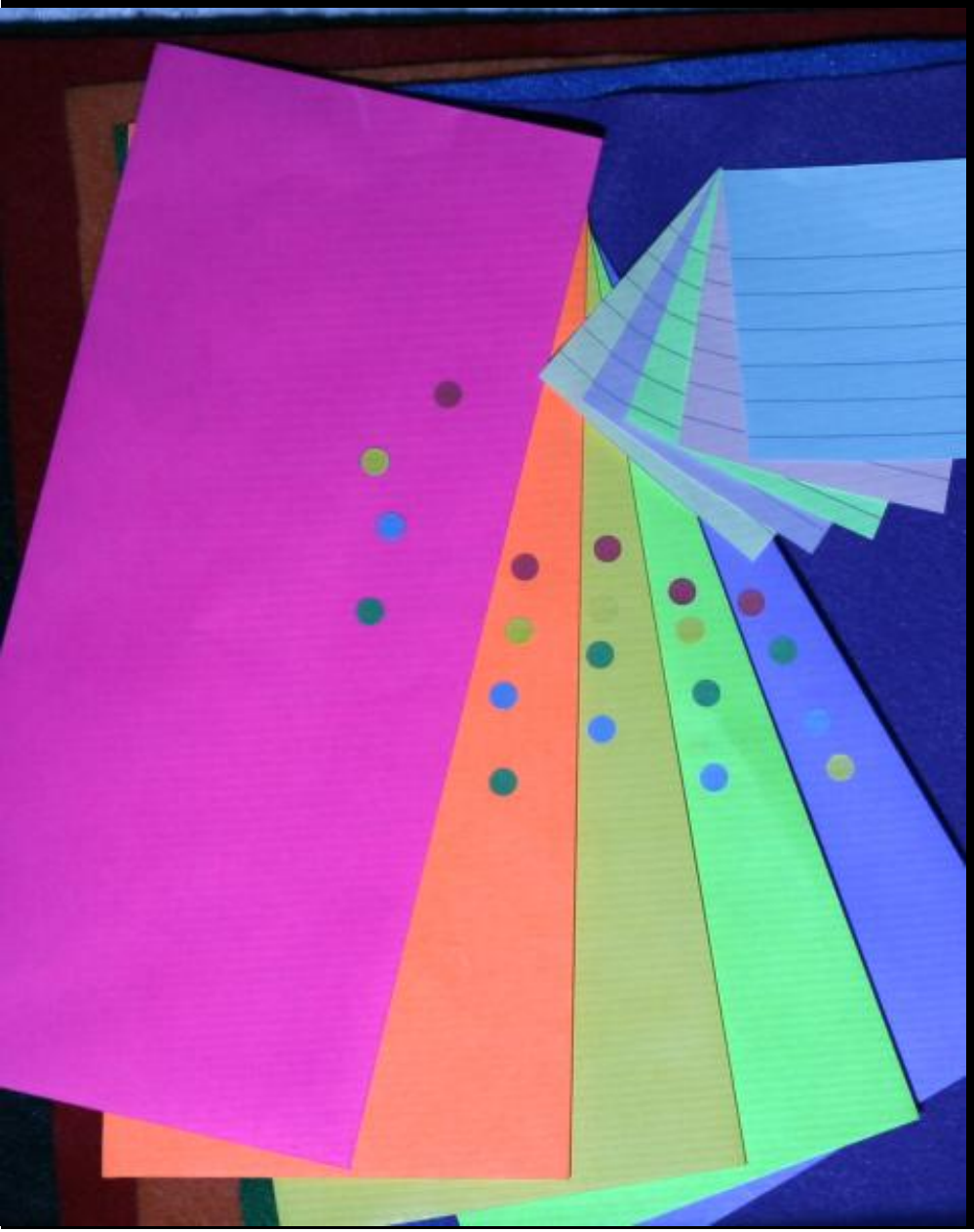

m(λ)
λ
400nm
550nm
700nm



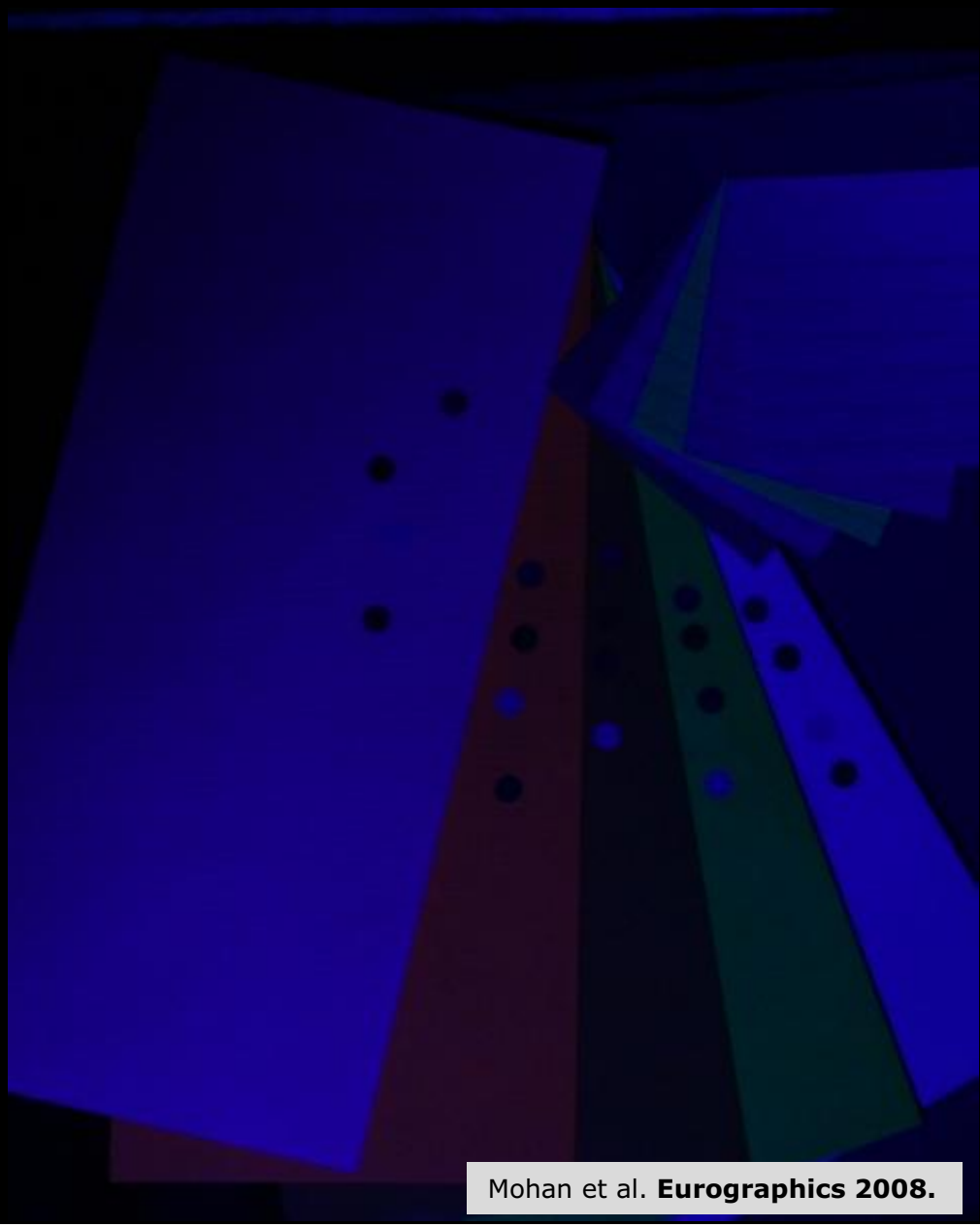
Mohan et al. **Eurographics 2008.**

Metamers

White Illumination

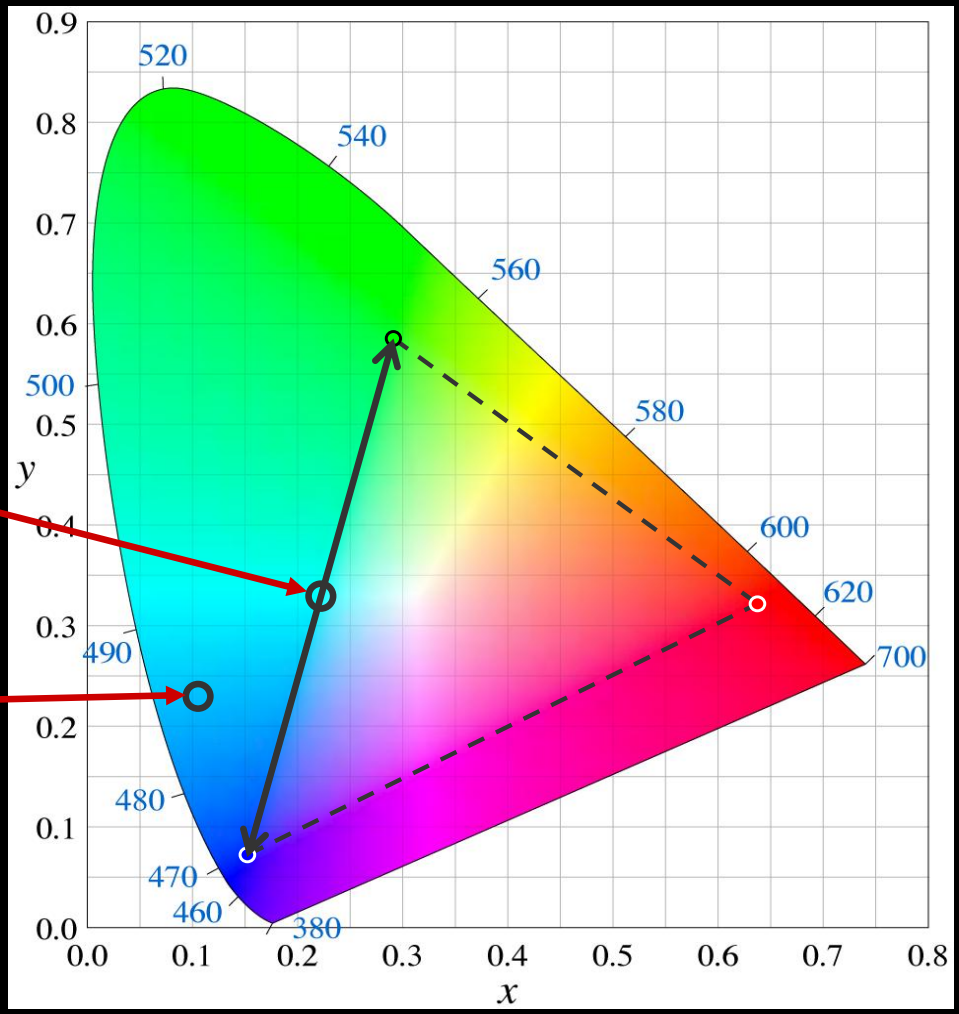


Monochromatic Illumination



Mohan et al. **Eurographics 2008.**

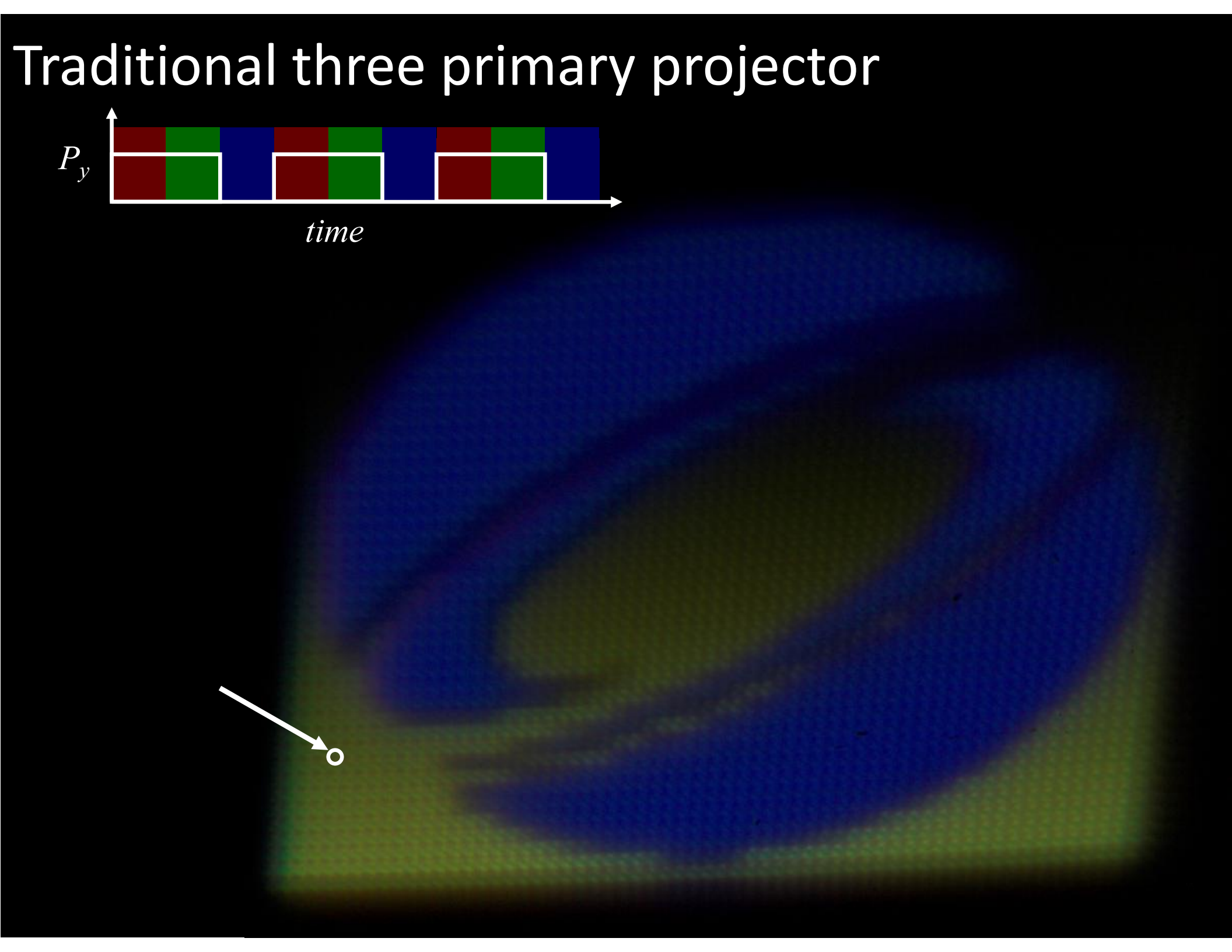
Traditional three primary projector



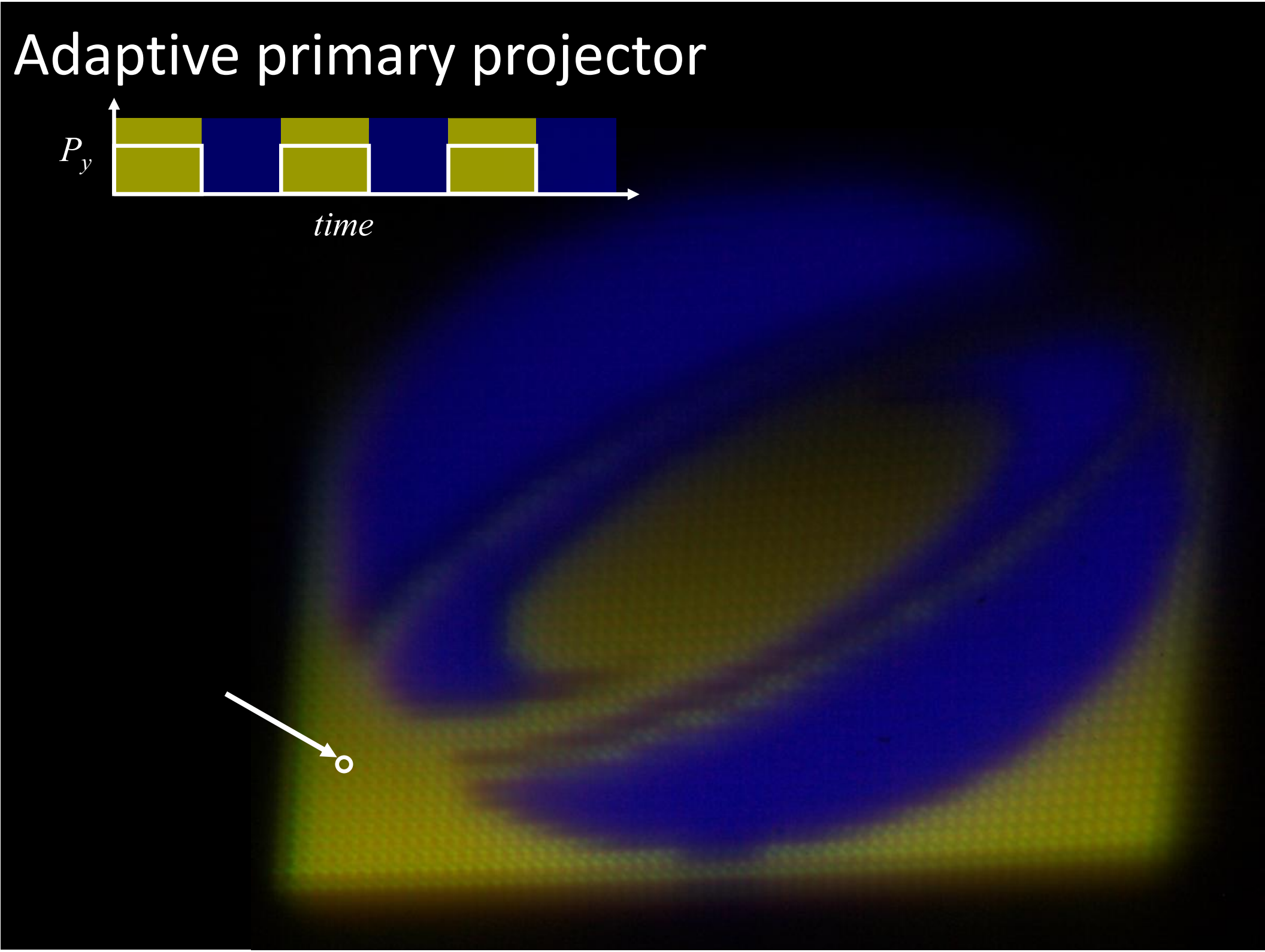
Agile-spectrum projector

Mohan et al. **Eurographics 2008.**

Traditional three primary projector



Adaptive primary projector



Deuteranope – red/green color blindness

White light

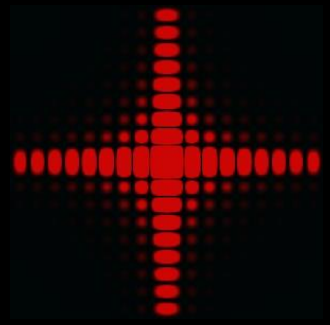
Magenta light

Deuteranope simulation

Mohan et al. **Eurographics 2008.**

Limitations

- Relatively coarse control due to crude setup with off-the-shelf components.
- Diffraction artifacts.

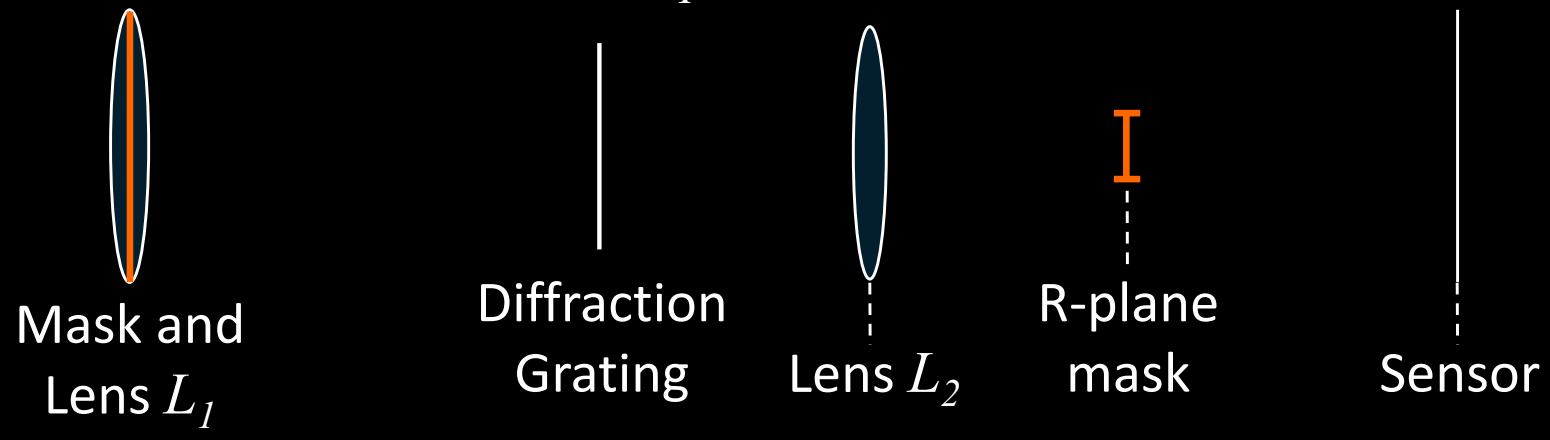


- Small F-number of the objective lens (we used ~f/16).

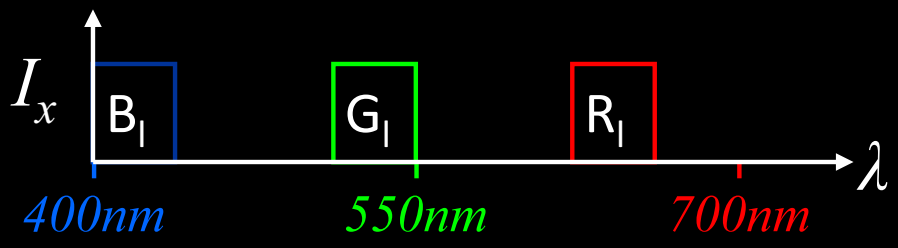
- Chromatic artifacts in out-of-focus regions for the projector.

Future work

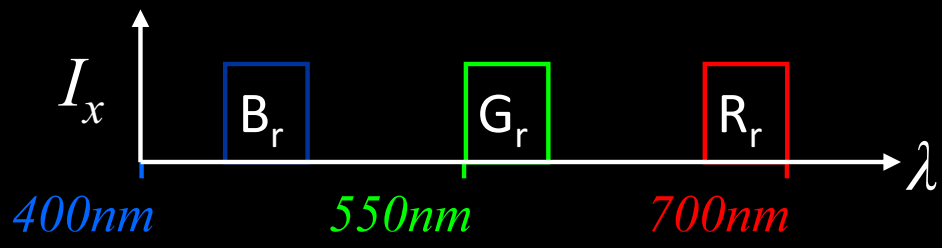
- Improved design
  - Mask instead of pinhole at L_1



  - Better optics (LCD/DMD) and calibration
- Applications
  - Adaptive color primaries
  - Stereo projector

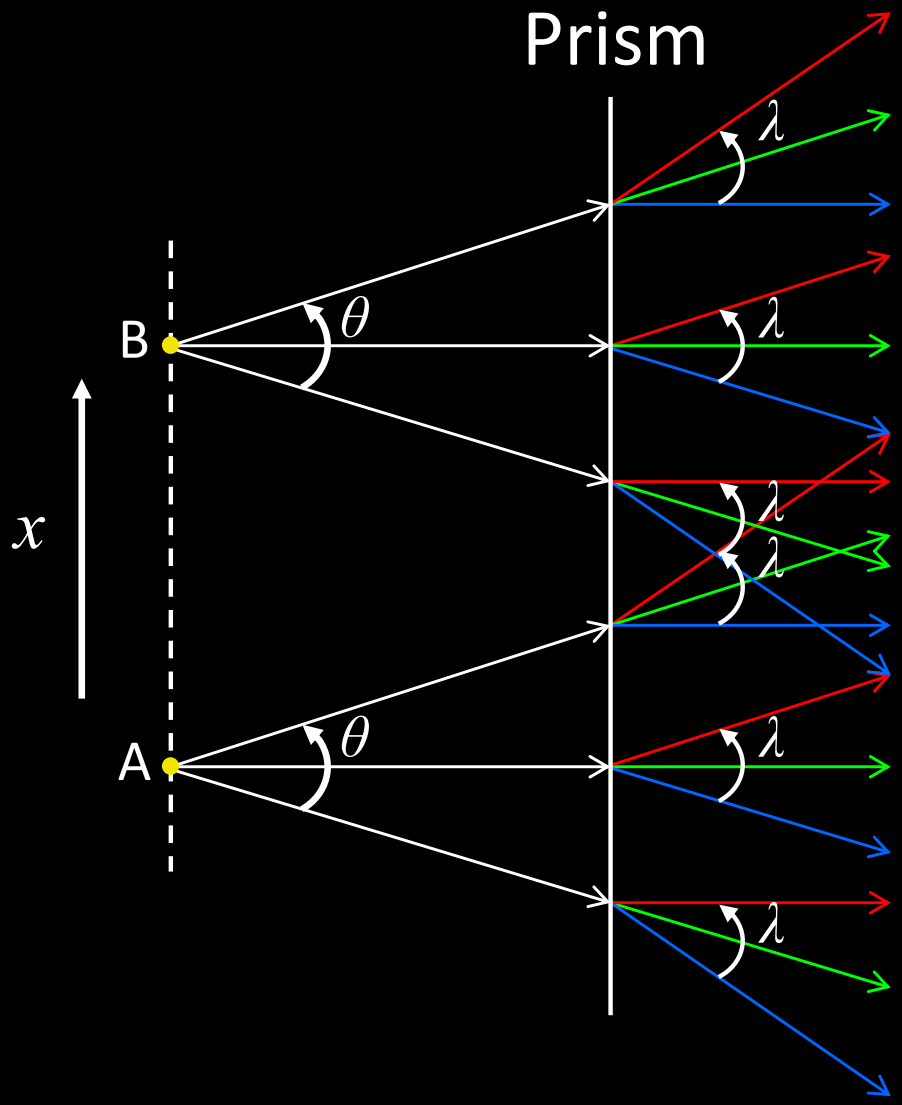


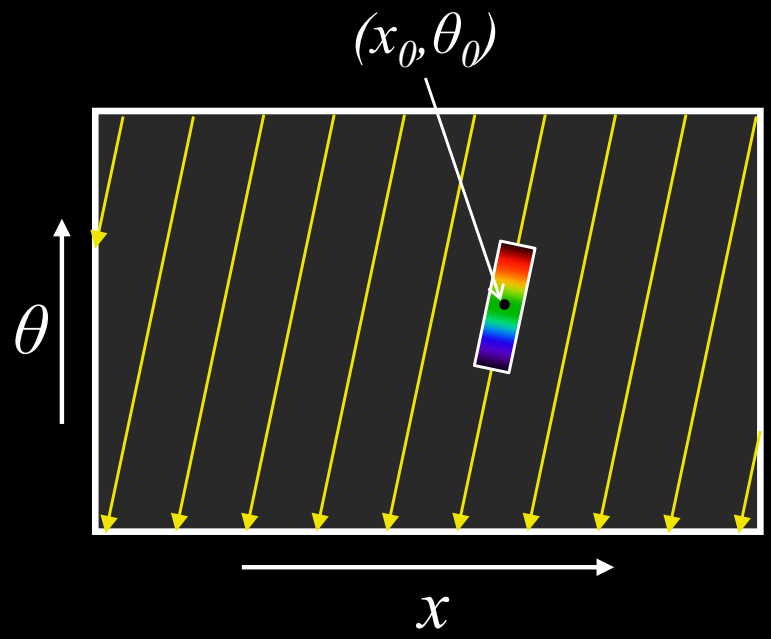
Left eye



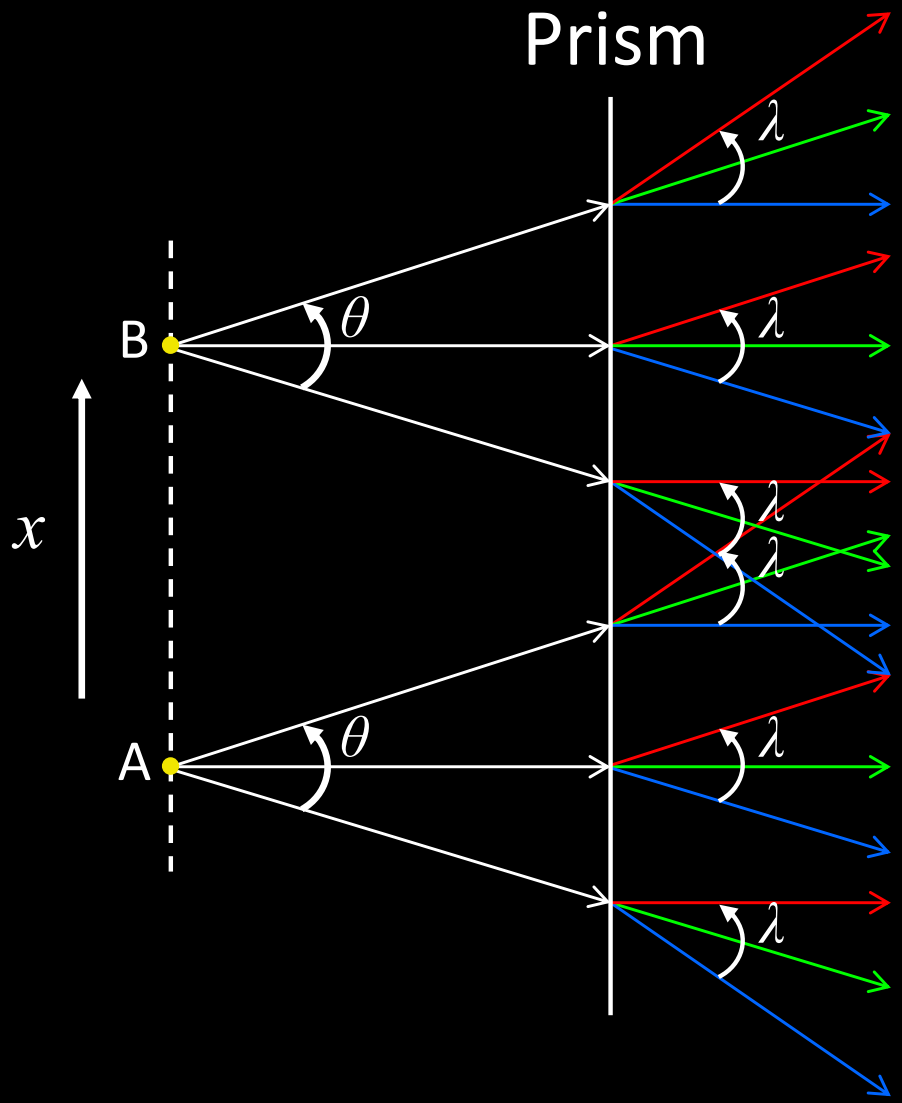
Right eye

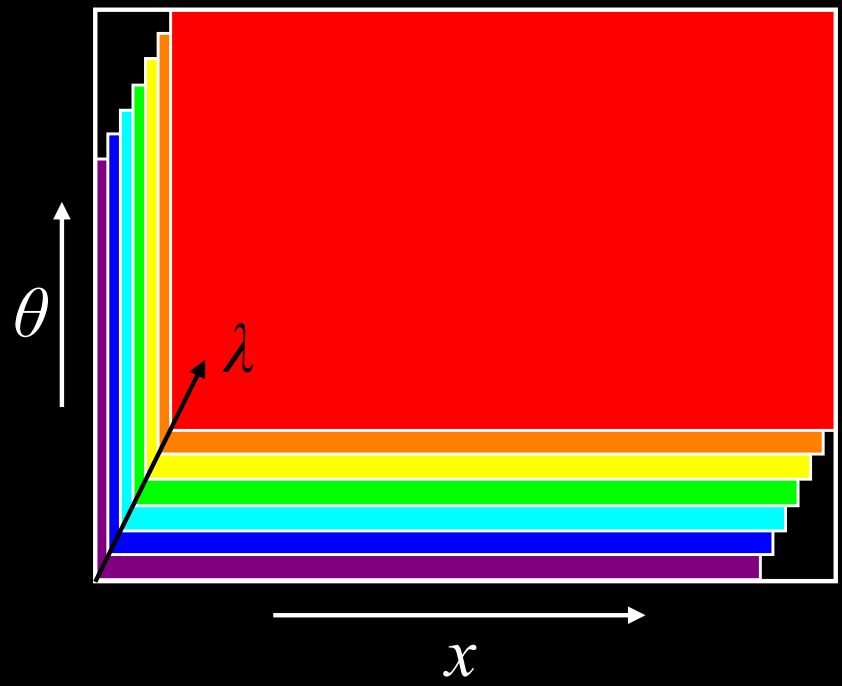
Overlapping Light Fields



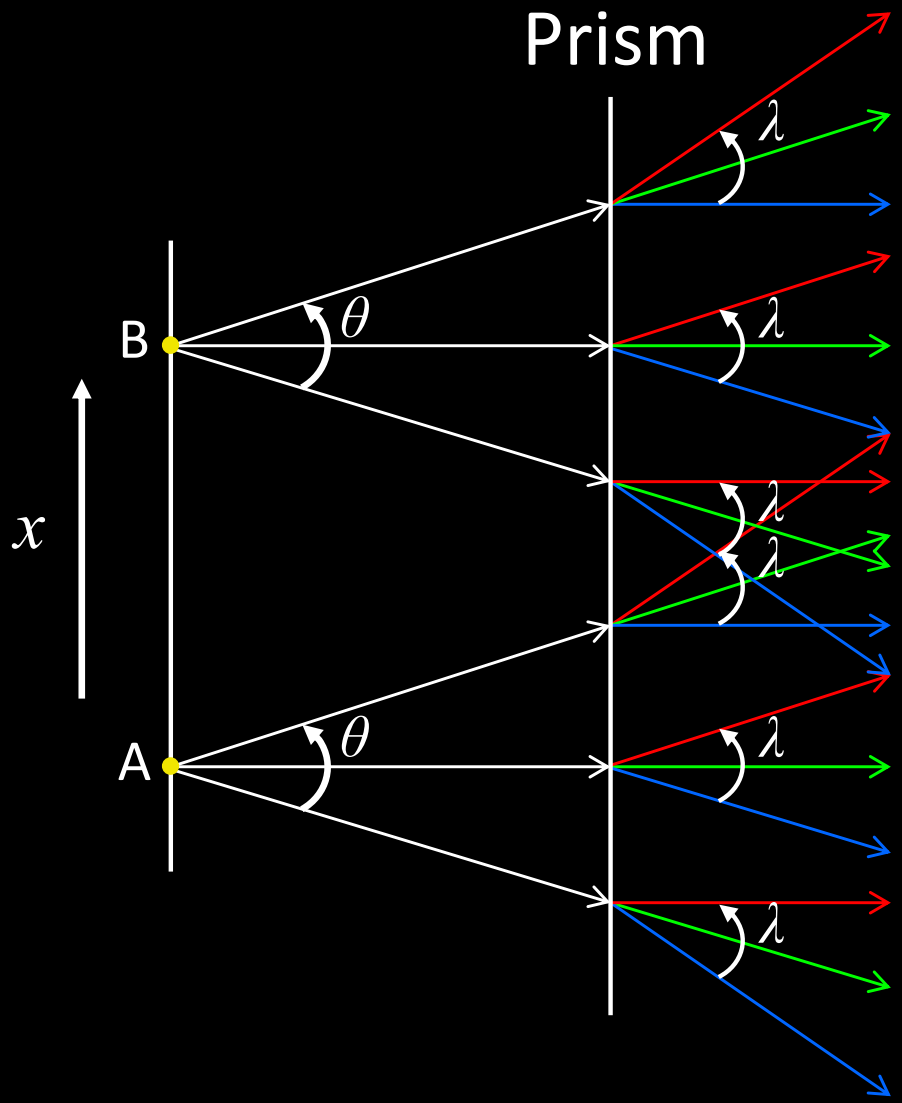


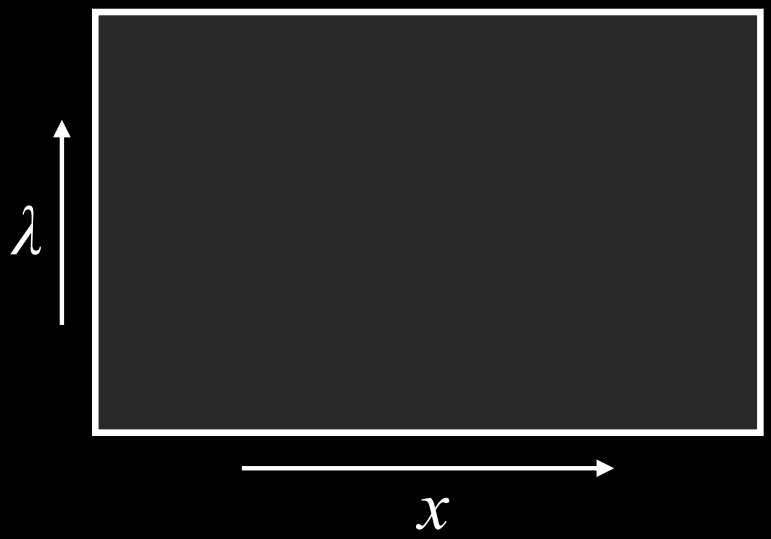
Overlapping Light Fields



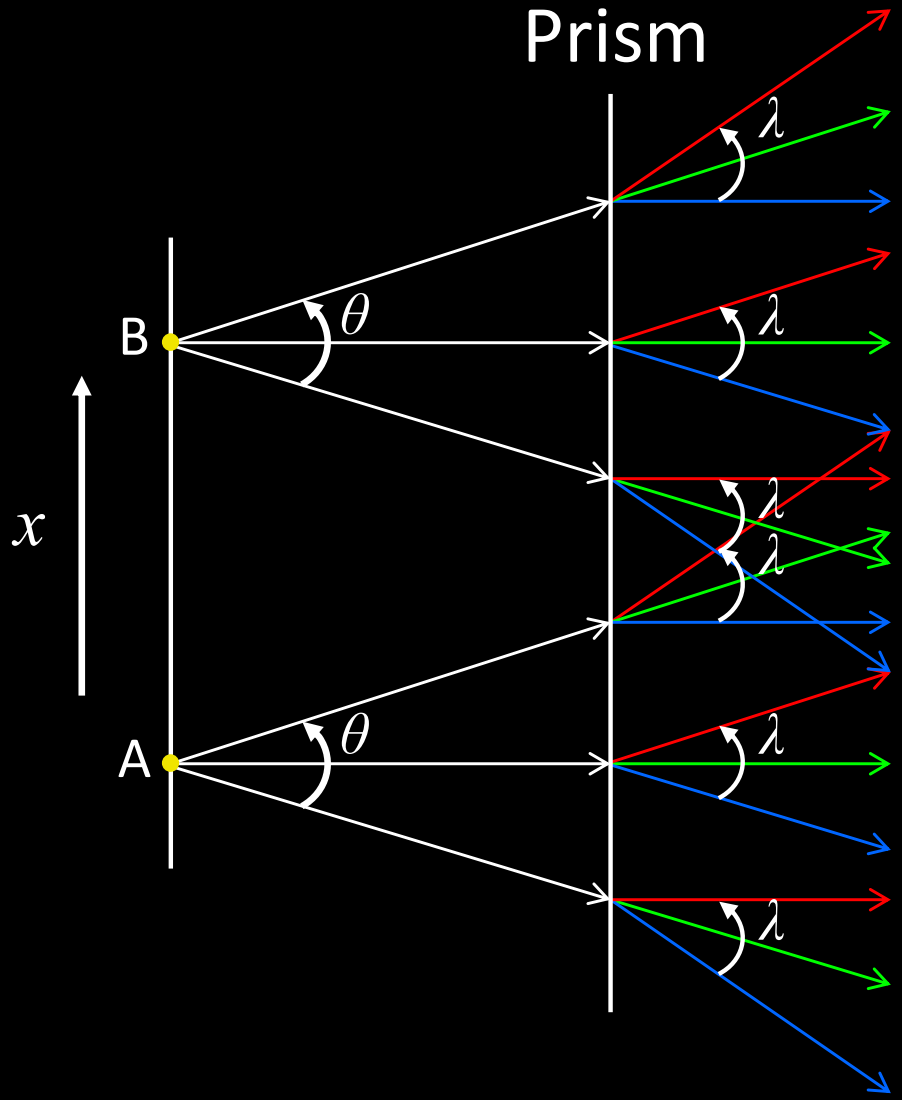


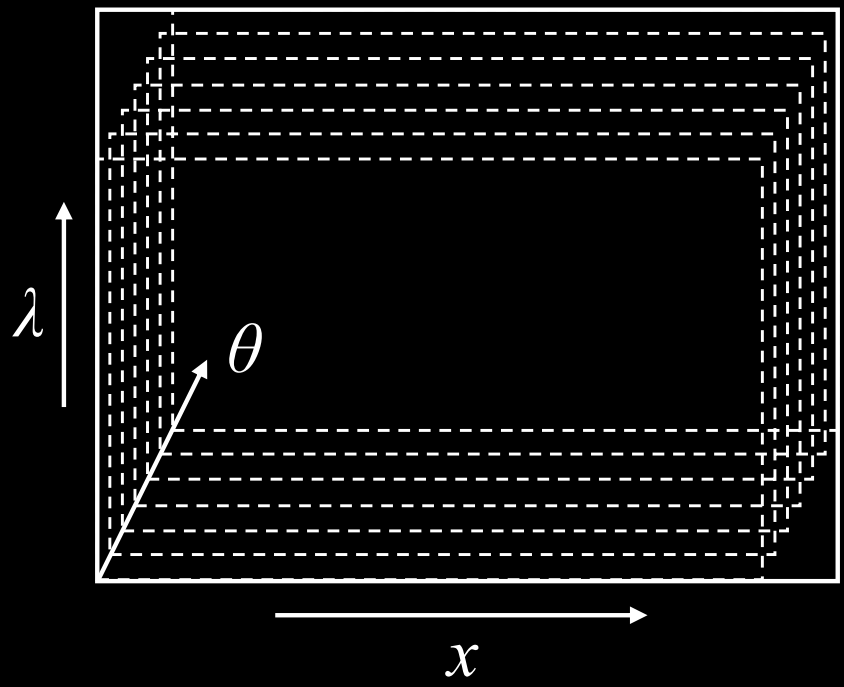
Diffuse, fronto-parallel case





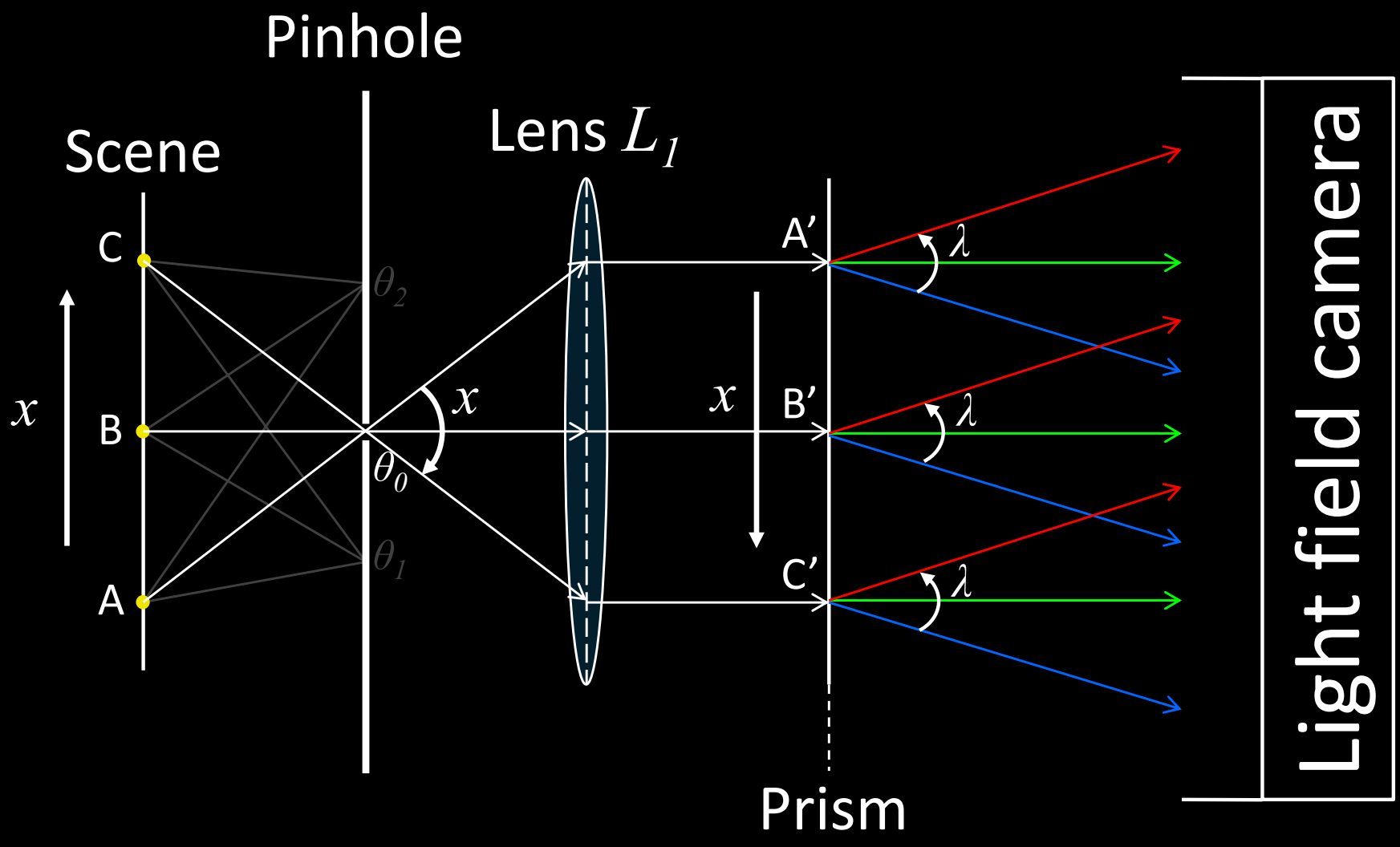
Blurred Light Fields

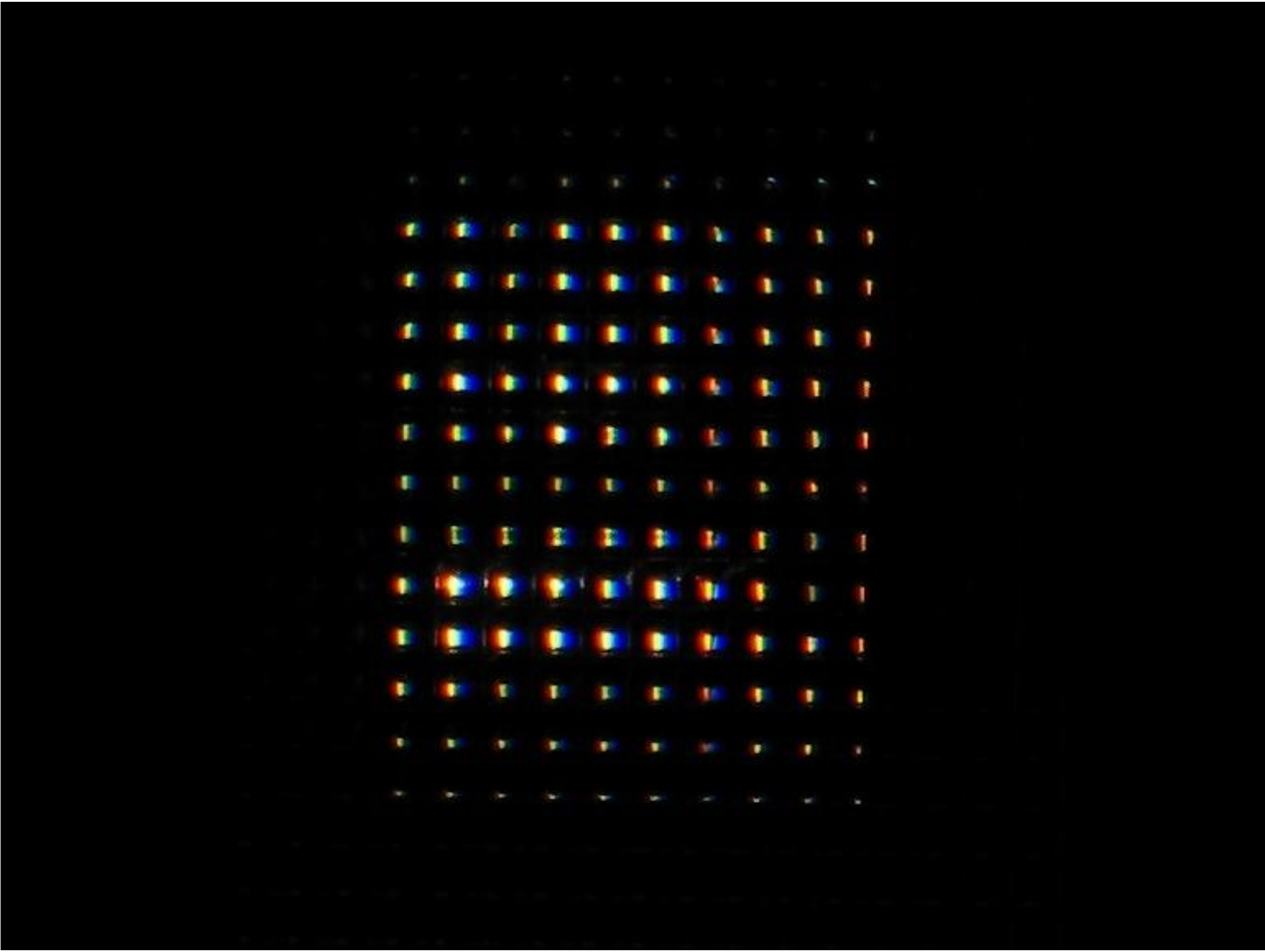




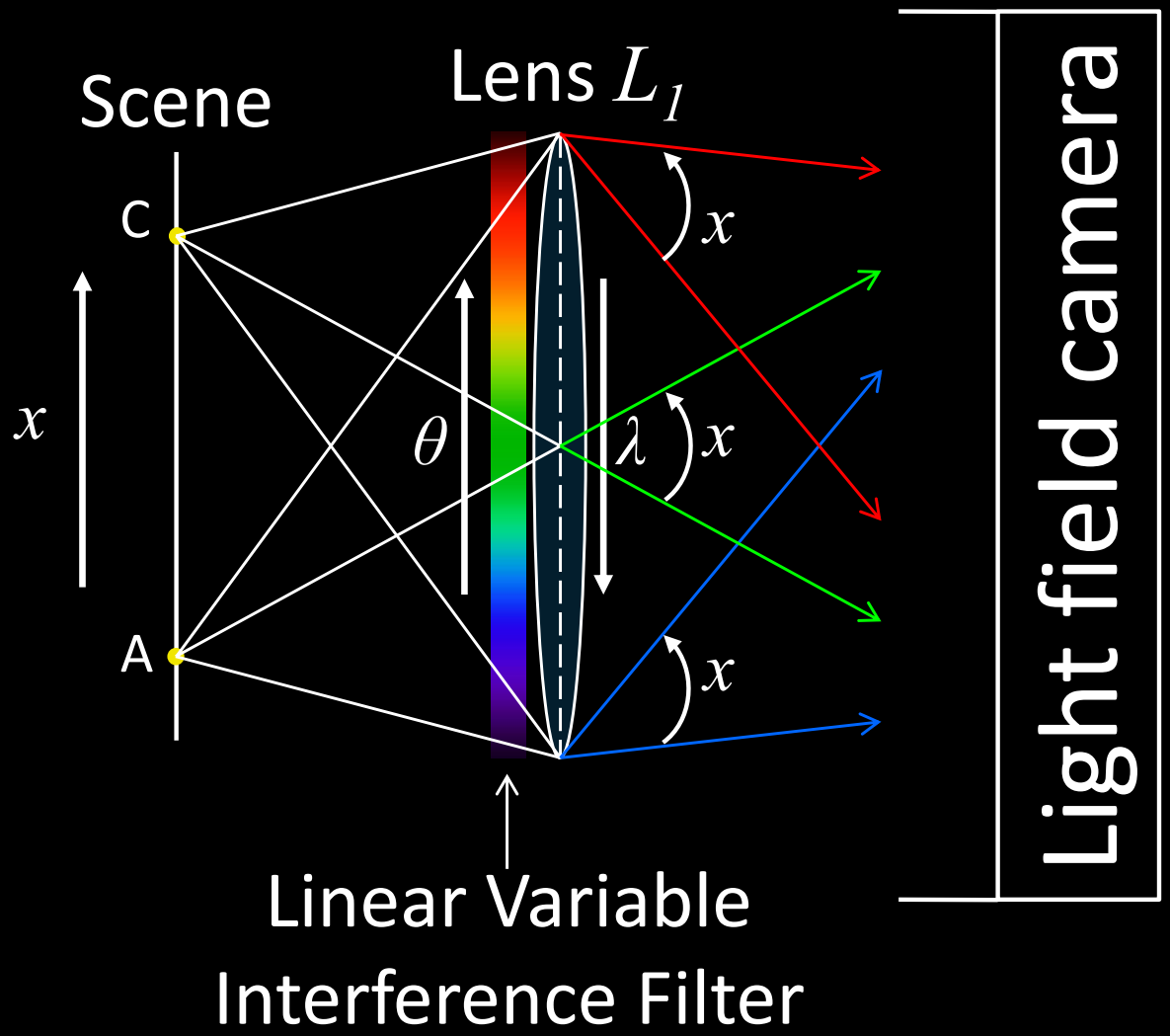
Convolution of spectral light field with a box filter

Pinhole multi-spectral camera

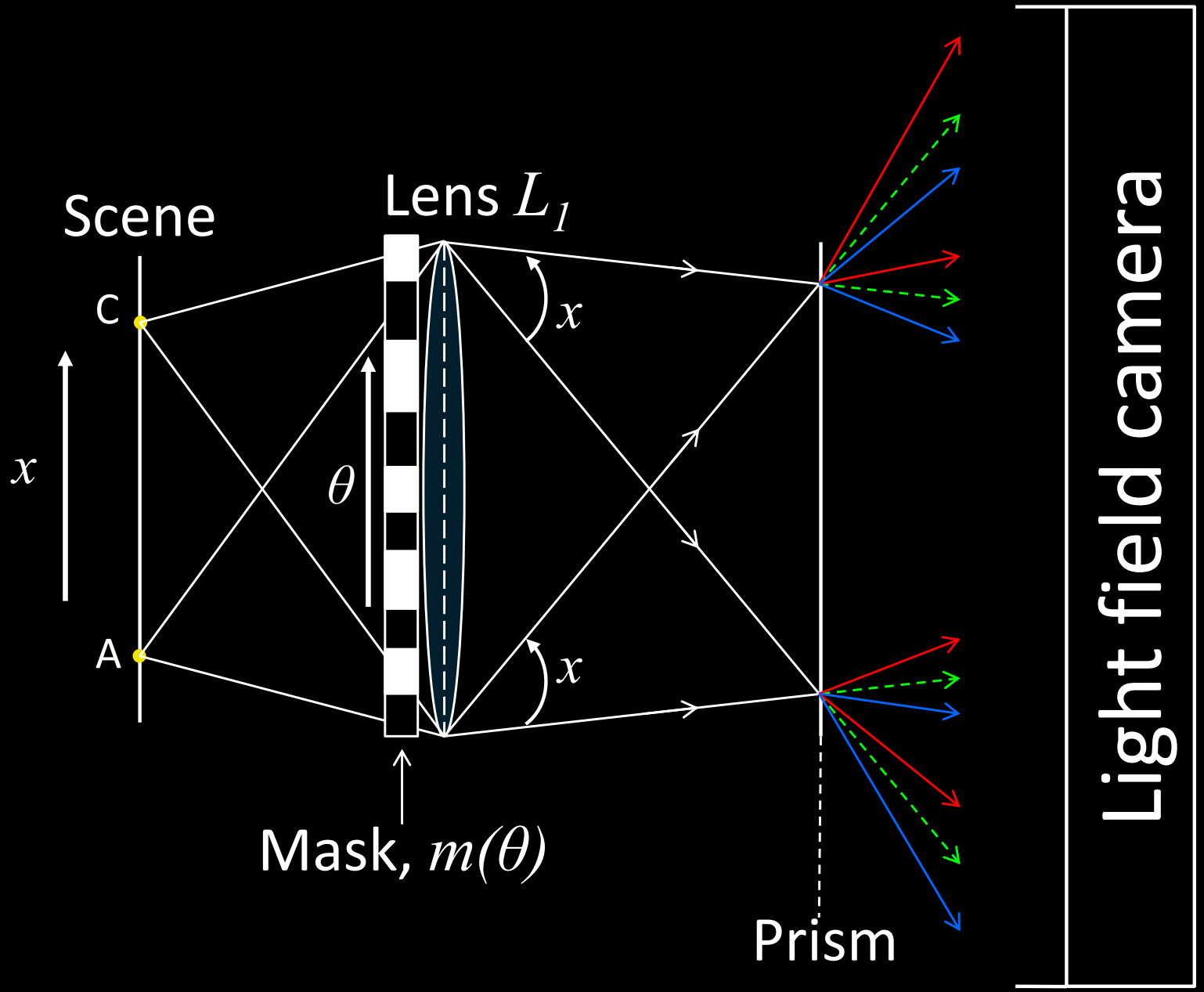




Rainbow multi-spectral camera



Mask based multi-spectral camera



MAS.531 Computational Camera and Photography

Fall 2009