A Prism-based System for Multispectral Video Acquisition

Hao Du[*#] Xin Tong[§] Xun Cao[♩] Stephen Lin[§]

[*] Fudan University
[#] University of Washington
[§] Microsoft Research Asia
[♩] Tsinghua University

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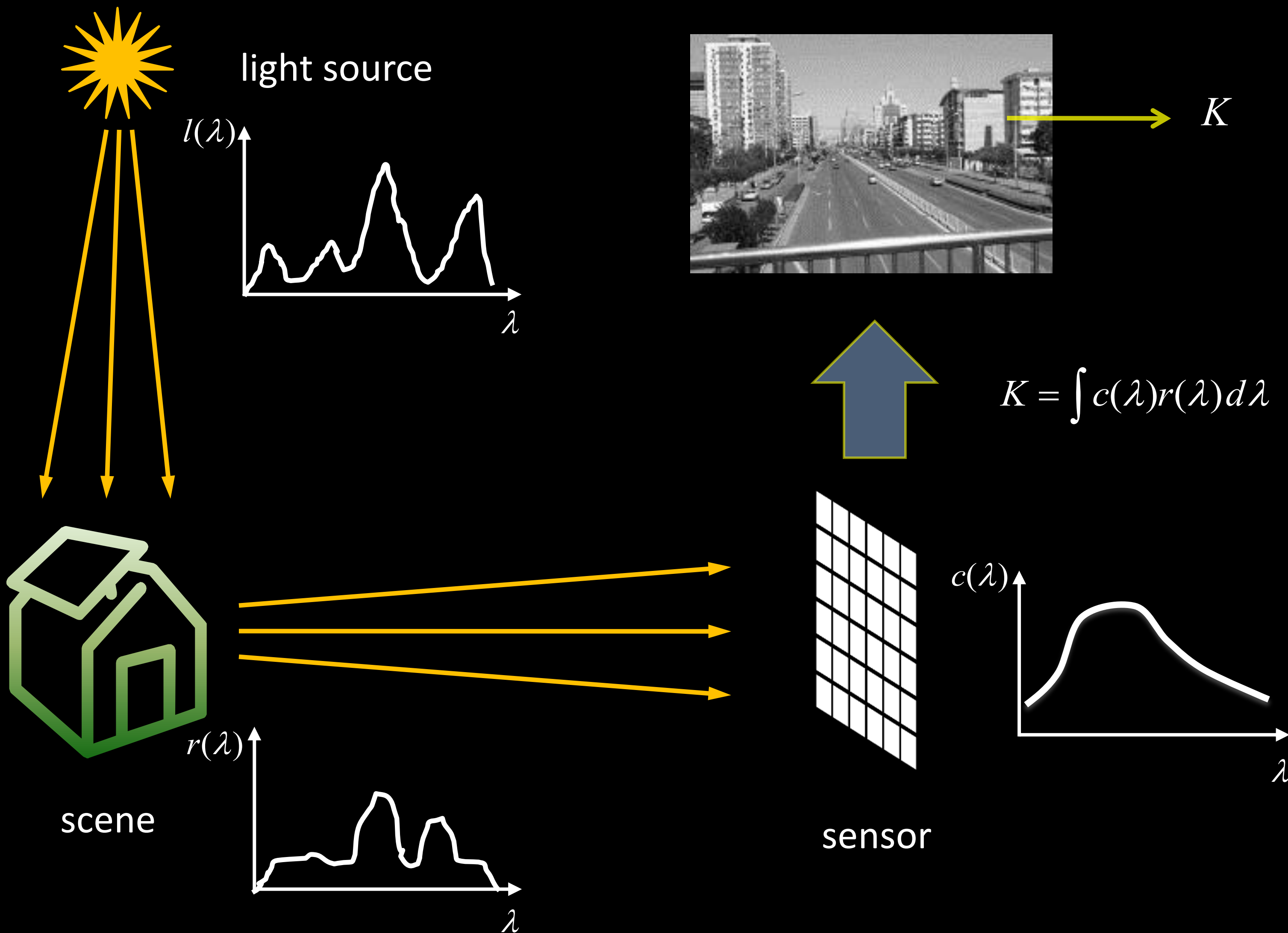
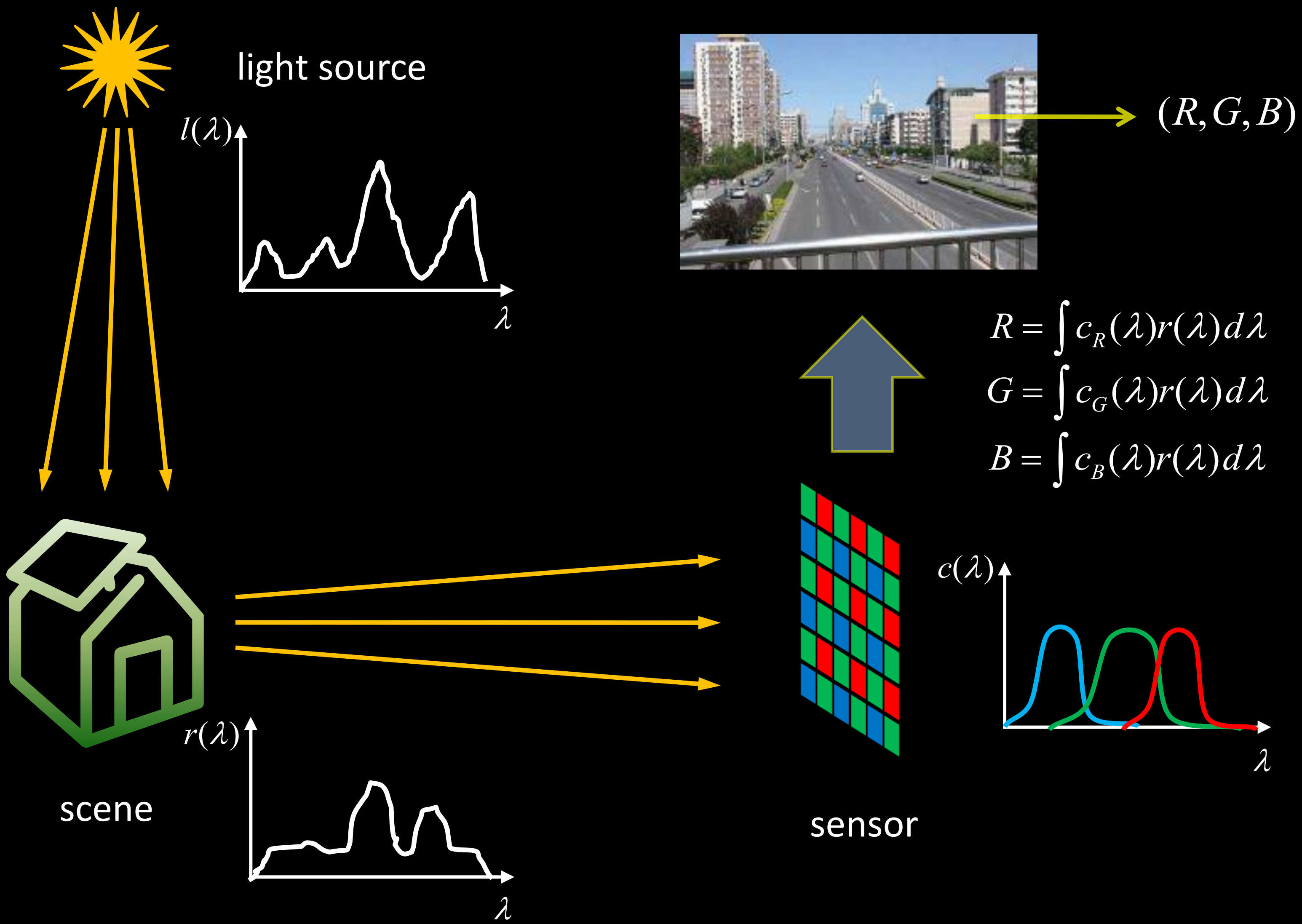
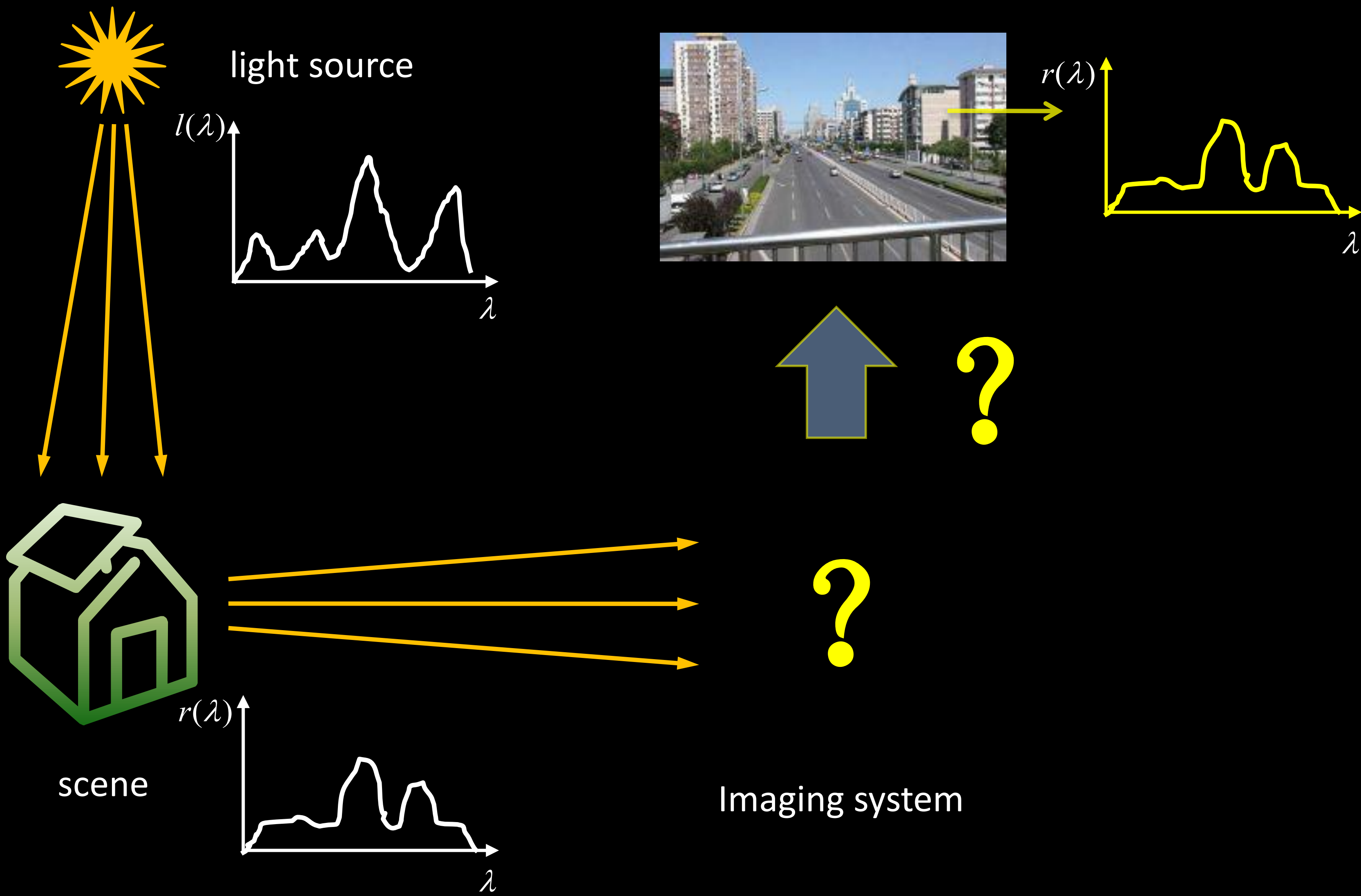
Grayscale Imaging



Color Imaging

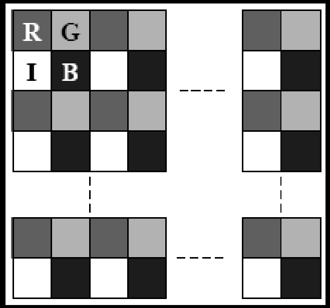


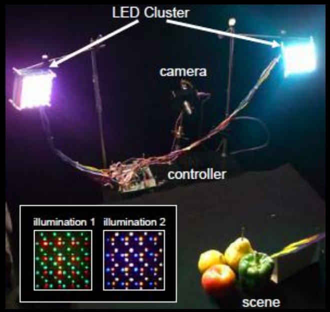
Multispectral Imaging

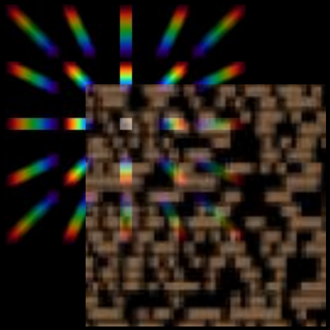


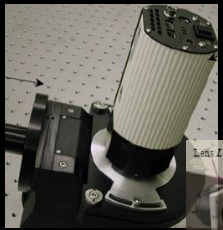
Related Works

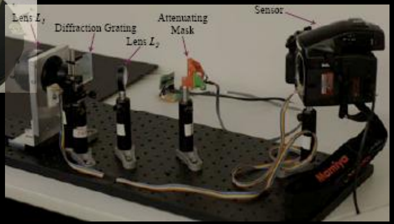
- Sensor filter-mask
  - [Kidono07]
  - Four channels -- R,G,B and IR
- Filter switching
  - [Gat00][Yamaguchi06][Schechner02]
  - Too slow for video acquisition
- Active illumination
  - [Park07]
  - Requires controlled light source
- Computation Based
  - [Descour95][Vandervlugt07][Wagadarikar08]
  - Difficult to calibrate; High computation cost
- Other optical systems
  - [Harvey05] Requires special optical devices
  - [Mohan08] No high spectrum resolution demonstrated









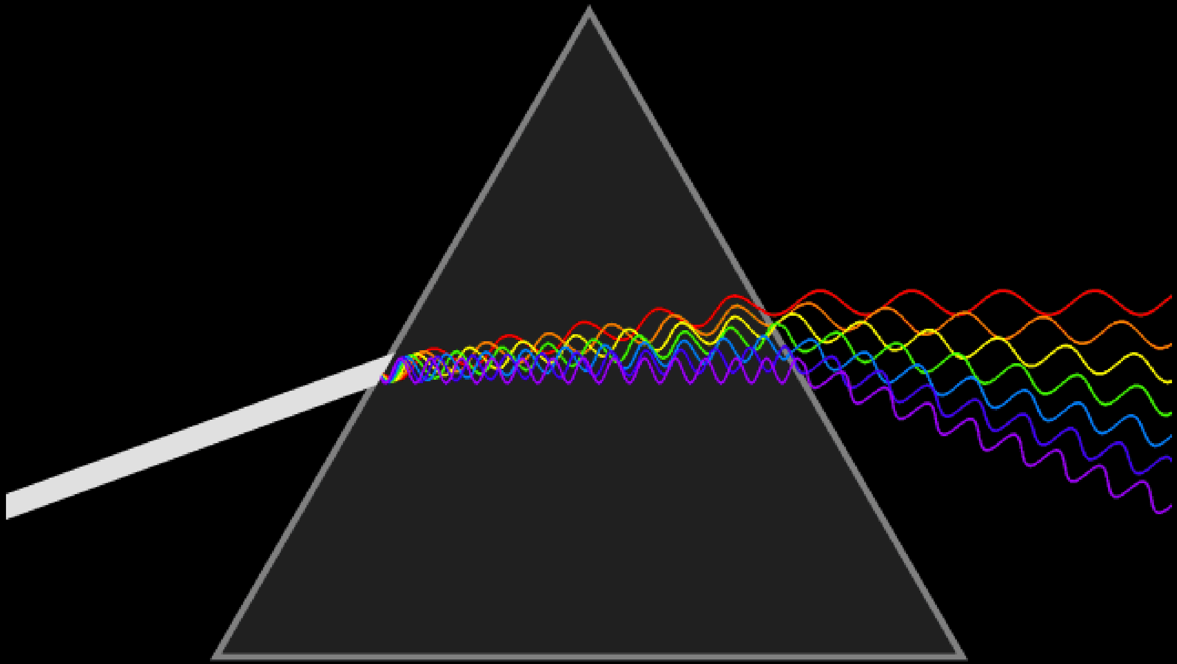


Our Work

A Prism-based Imaging System

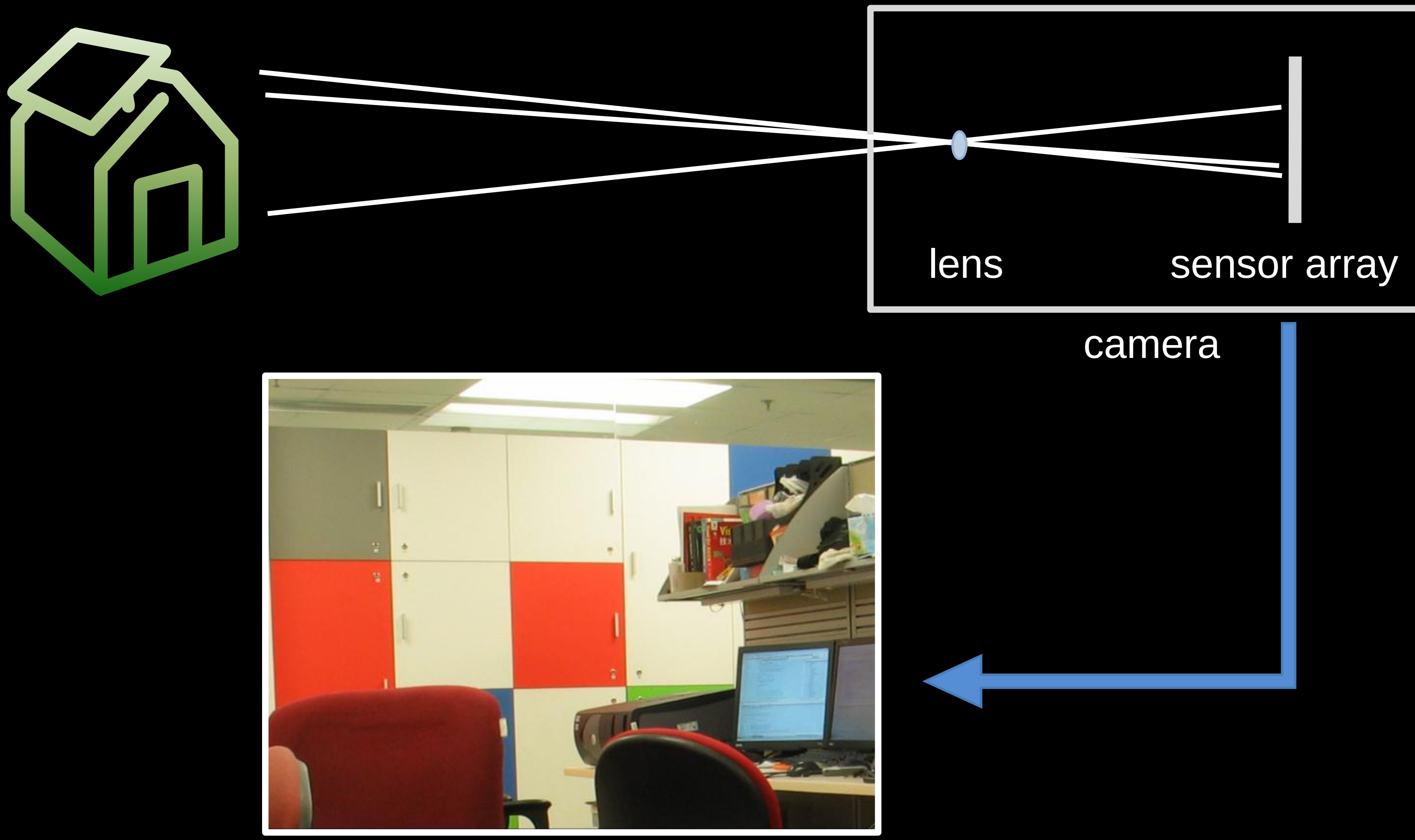
- Passively capturing multispectral video
- High spectra-resolution
- Low cost
- Easy setup and calibration

A Prism

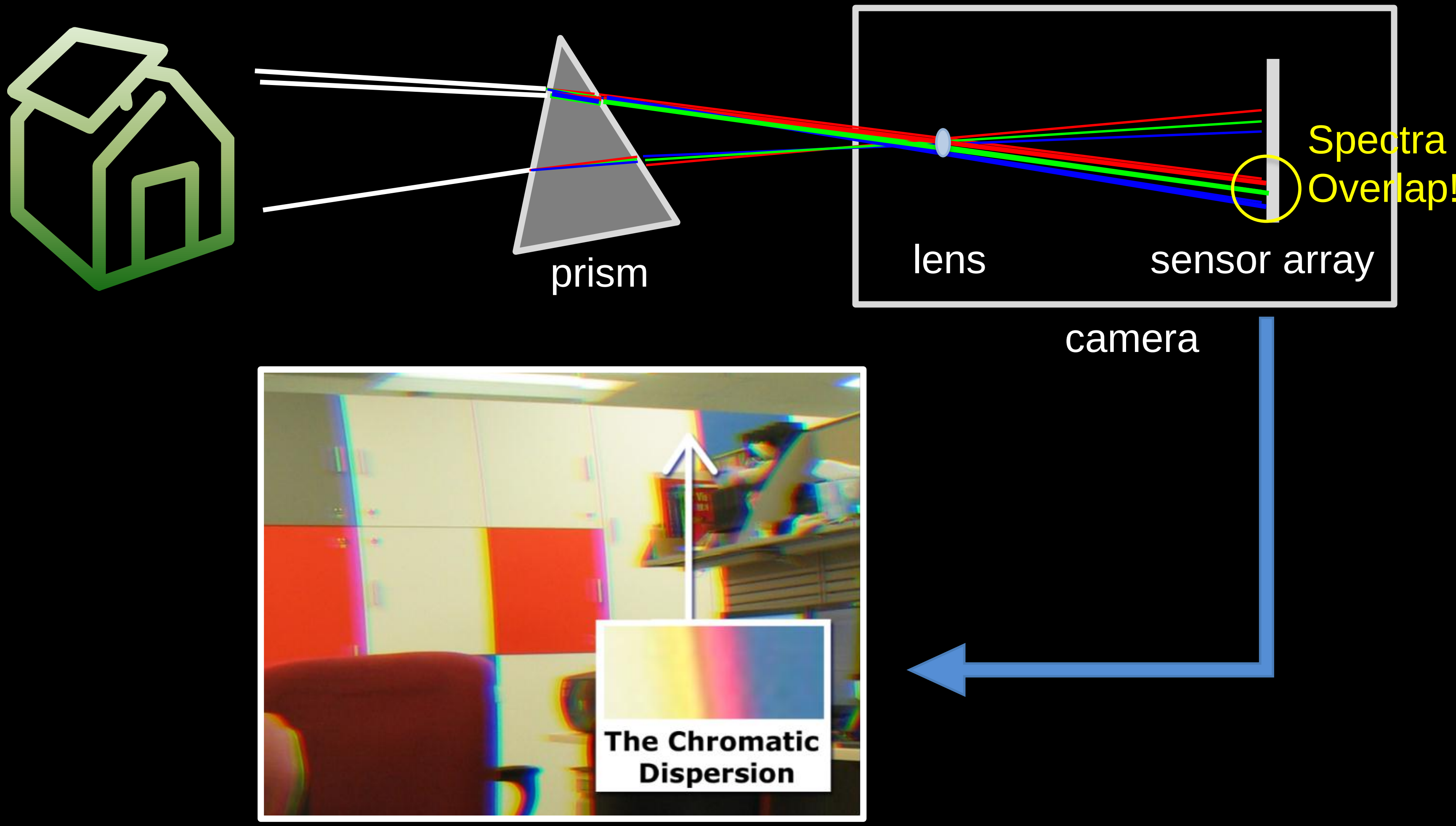


[This GIF animation is referenced from Wikipedia]

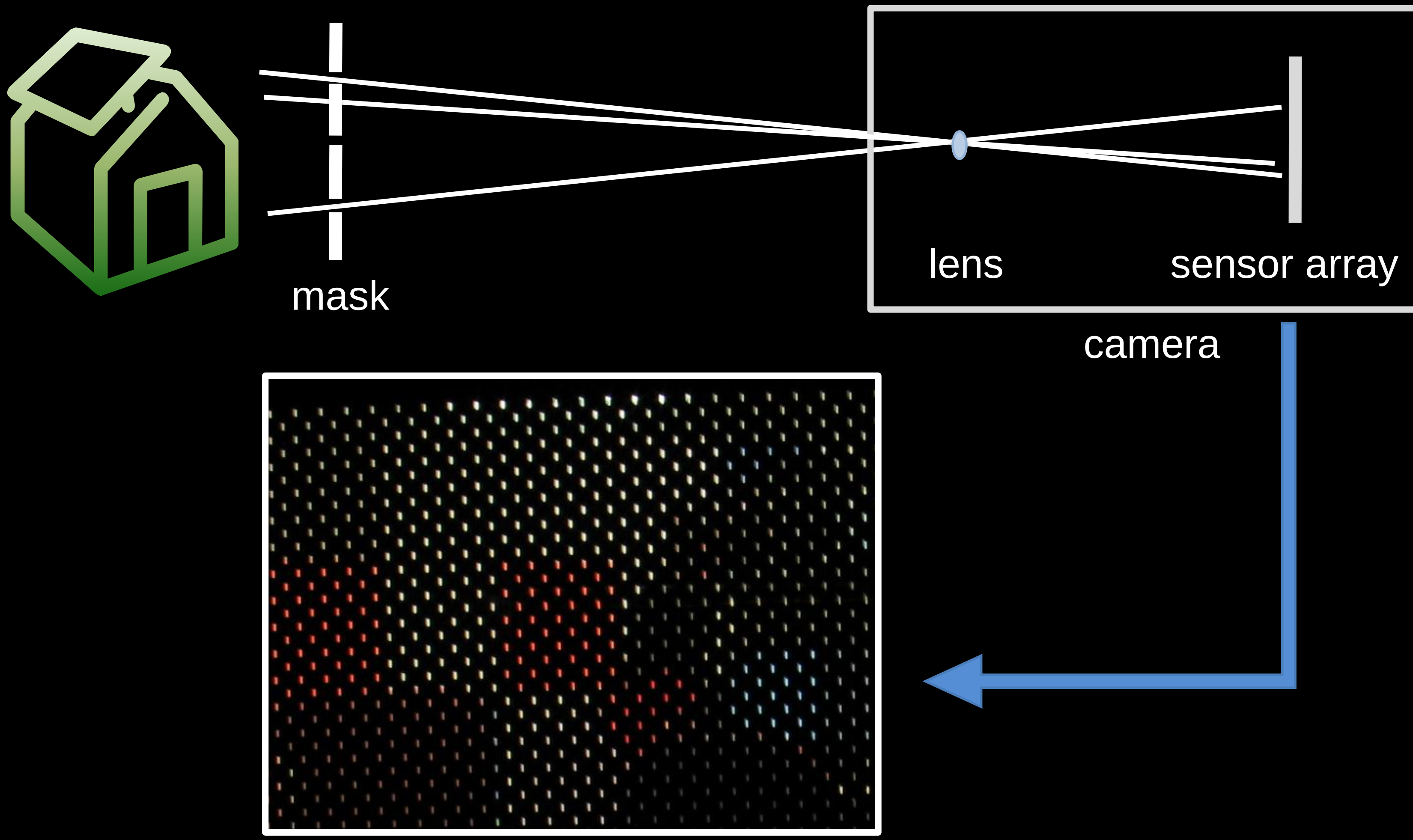
A Typical Camera



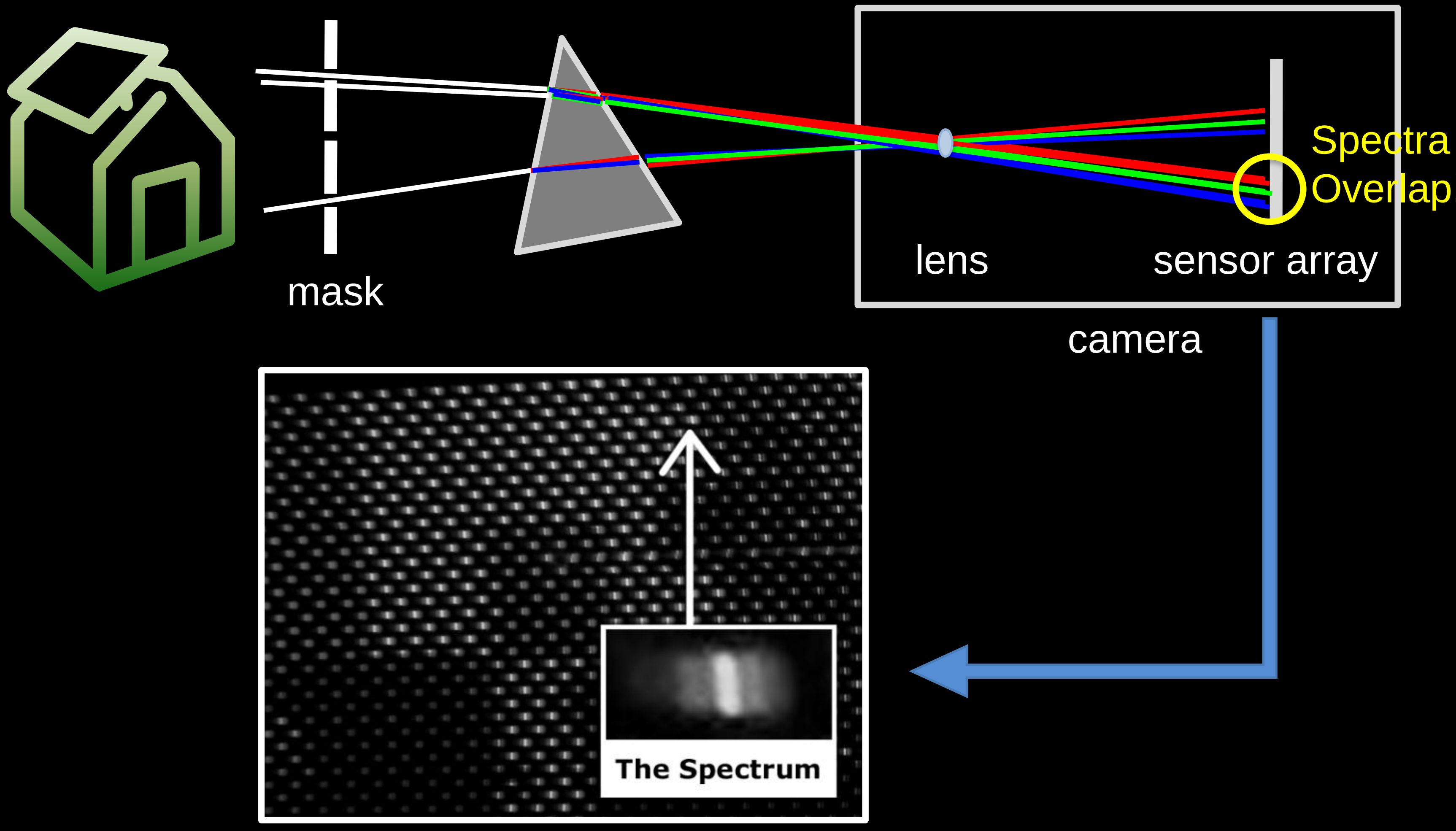
Camera & Prism



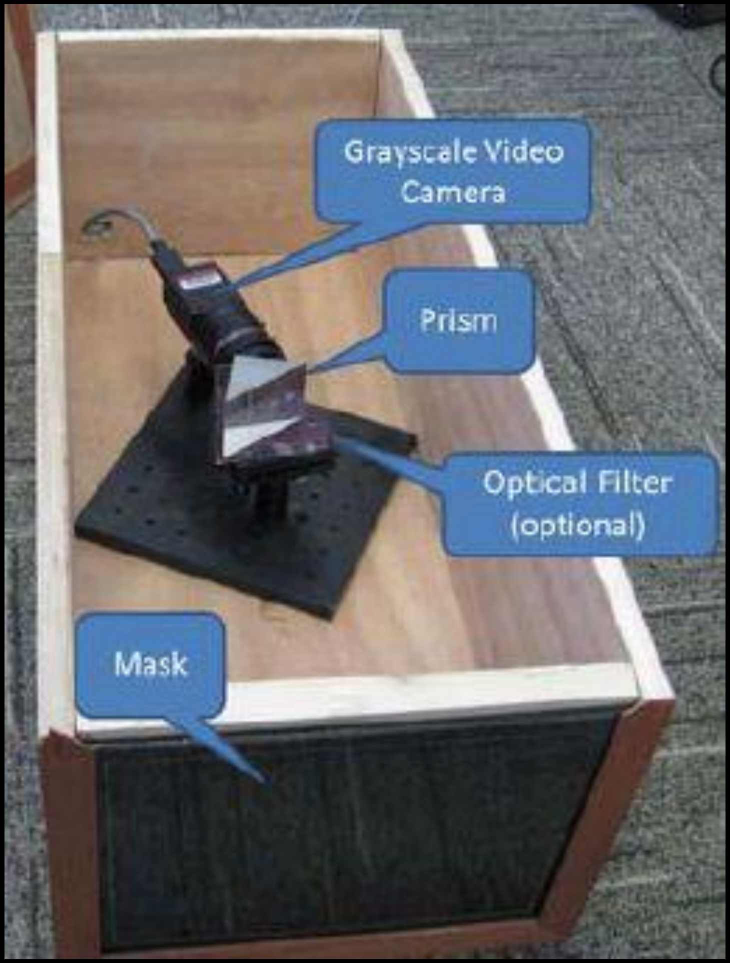
Camera & Mask



Camera & Mask & Prism

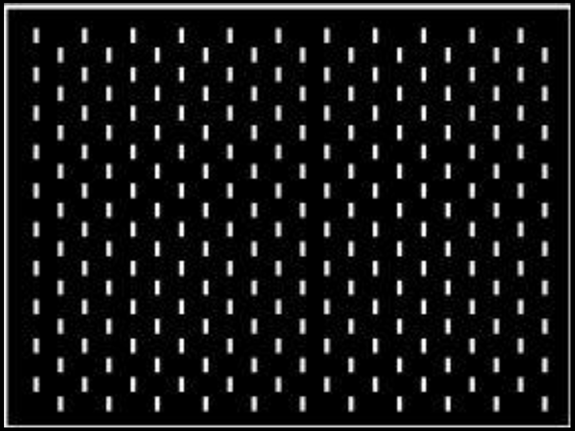


Prototype System



capturing system

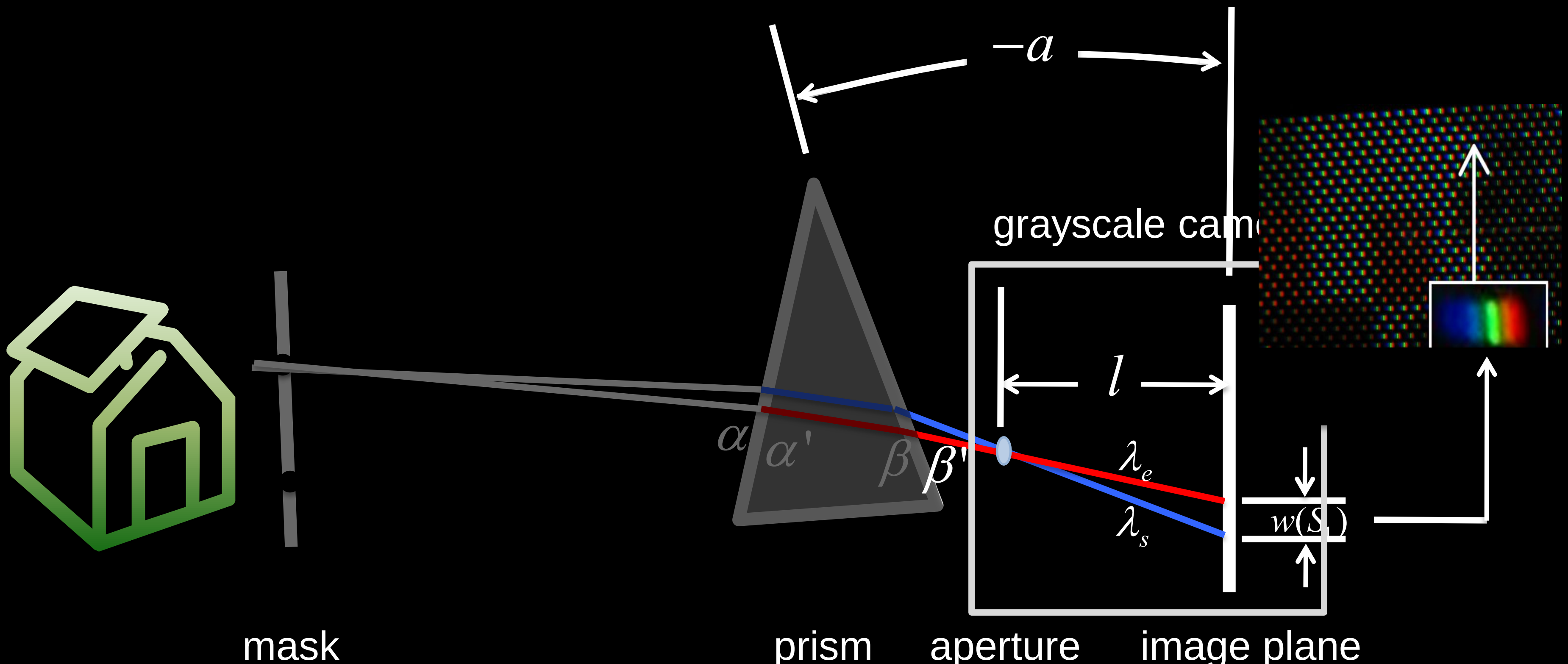
Pointgrey grayscale camera
2248x2048 @15fps



mask

Device Setup

Spectrum Width

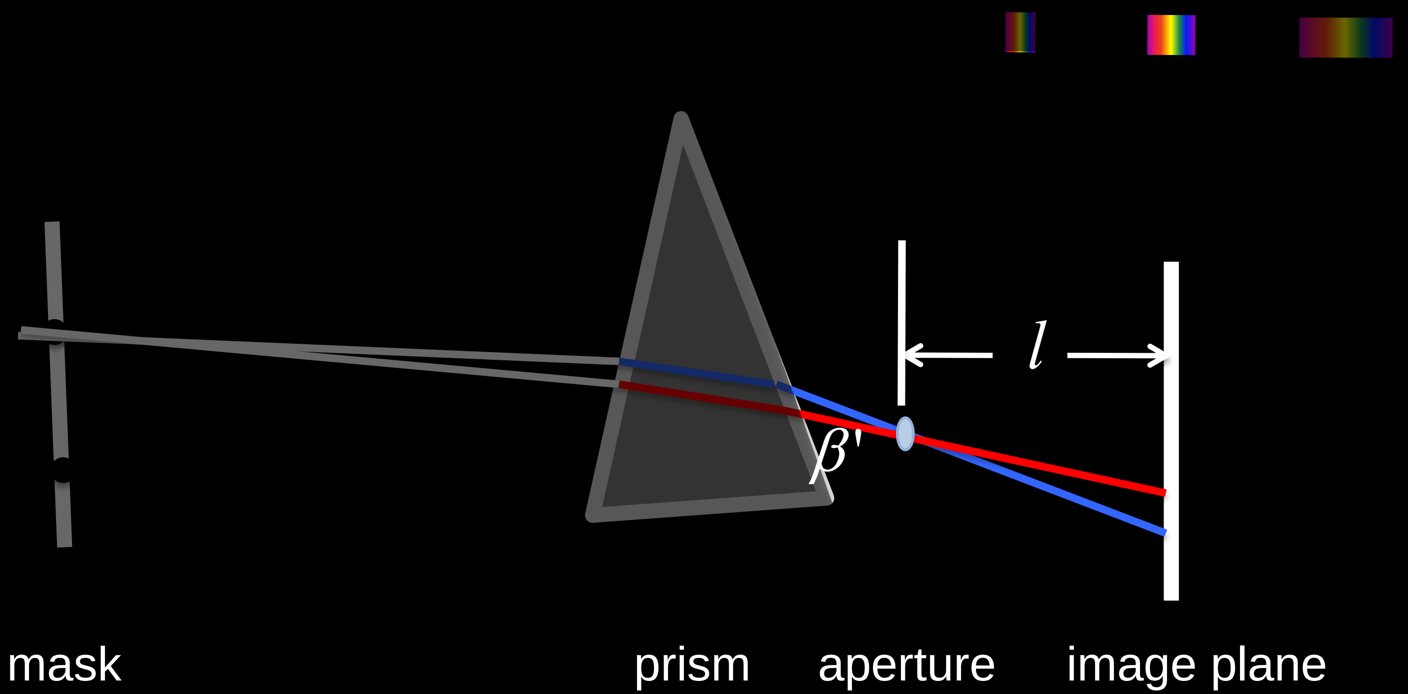


$$n_\lambda = \frac{\sin(\alpha)}{\sin(\alpha'(\lambda))} = \frac{\sin(\beta'(\lambda))}{\sin(\beta(\lambda))}$$

$$w(S_1) = l \cdot \left(\tan(a + \beta'(\lambda_e)) - \tan(a + \beta'(\lambda_s))\right)$$

Spectrum Width

- Tradeoff Spatial/Spectral Resolution



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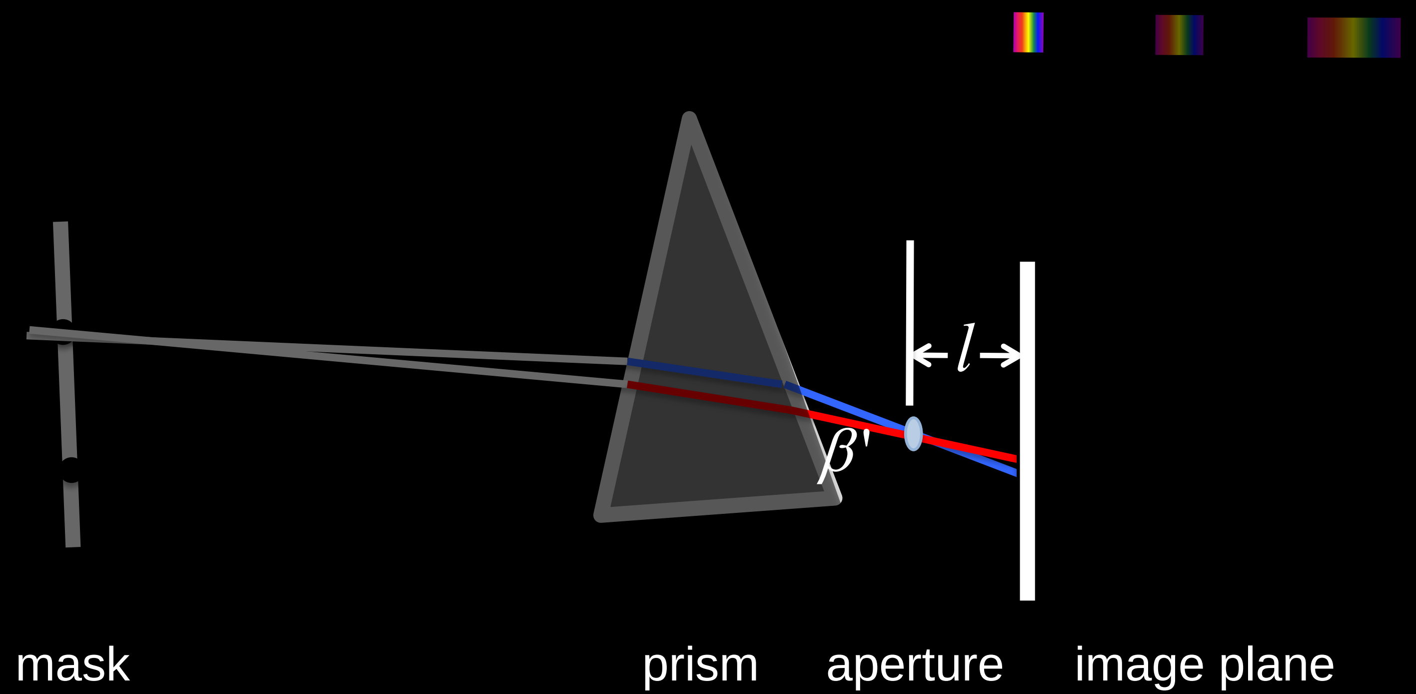

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Spectrum Width

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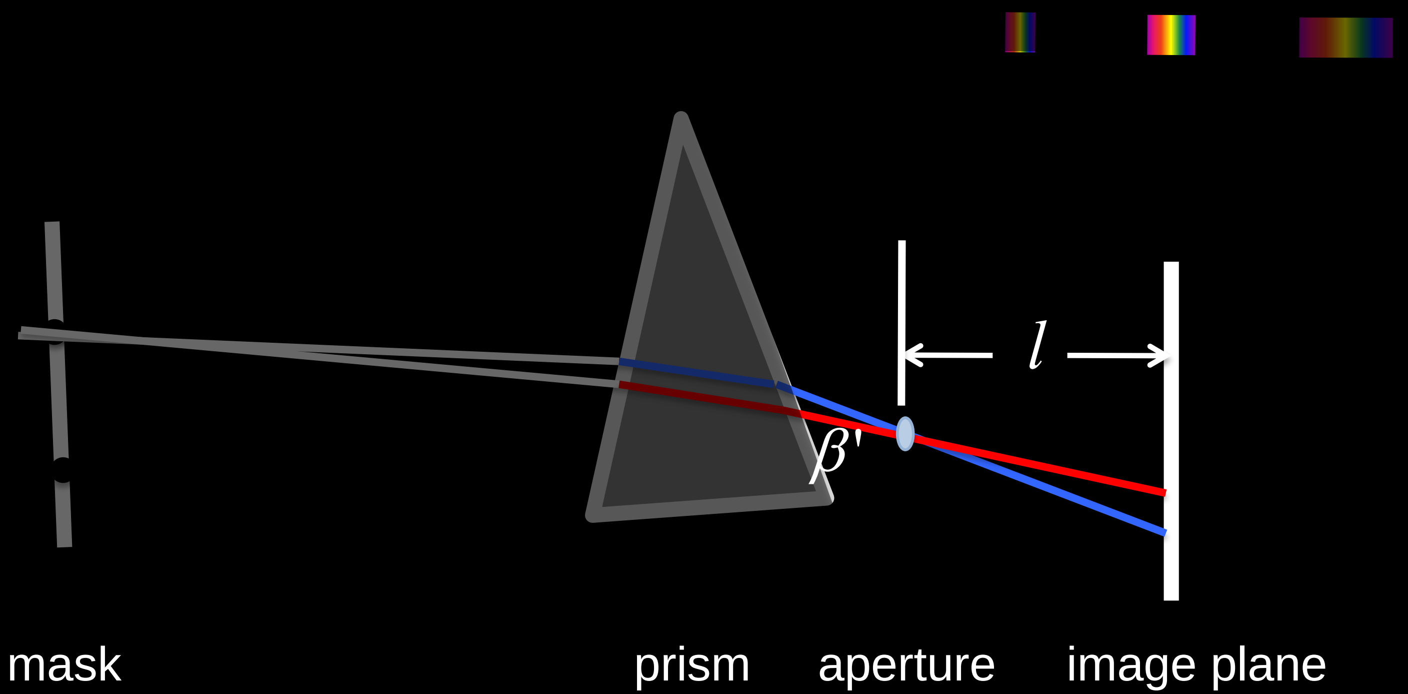

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Spectrum Width

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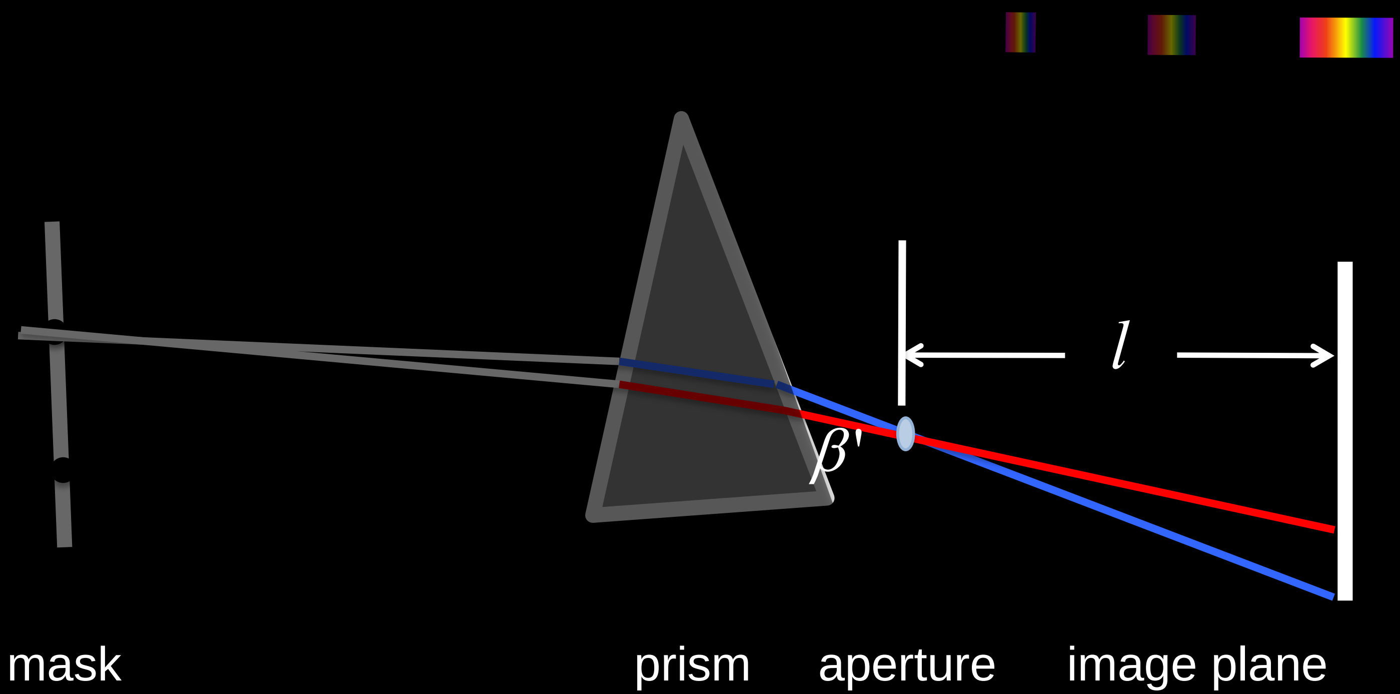
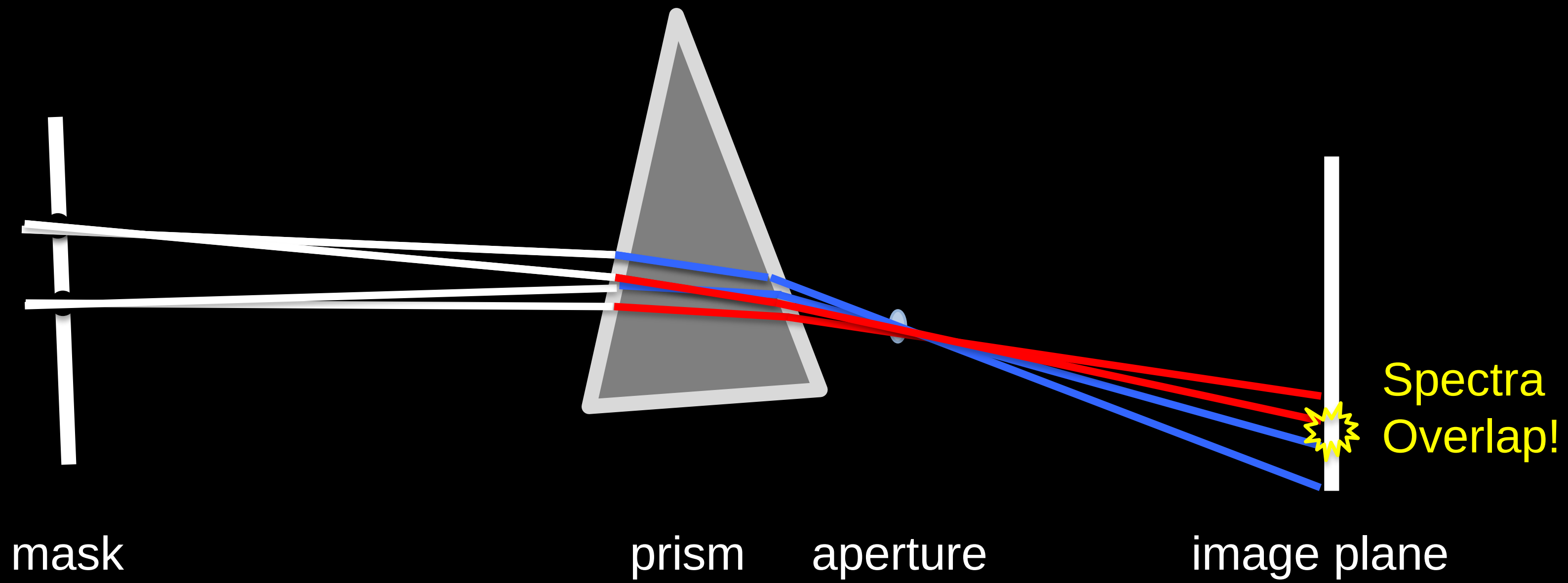
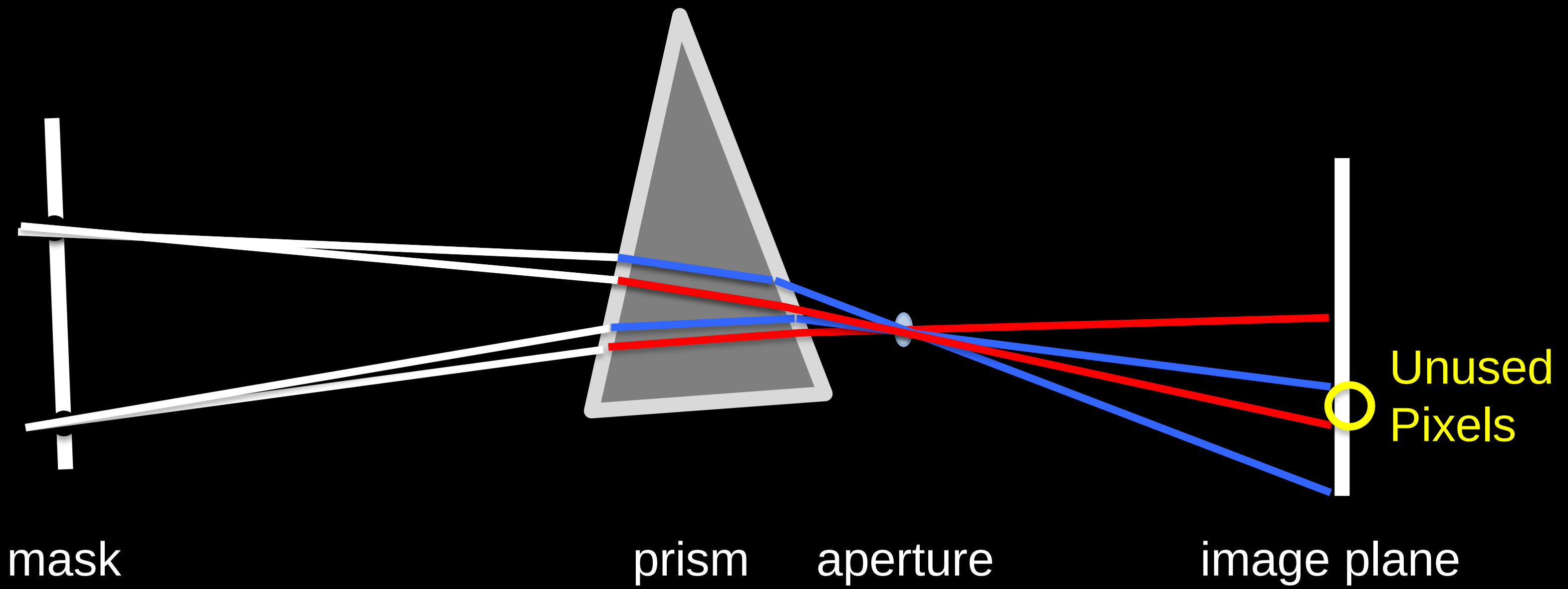


$$w(S_1) = l \cdot \left(\tan(a + \beta'(\lambda_e)) - \tan(a + \beta'(\lambda_s))\right)$$

Mask-Hole Distance

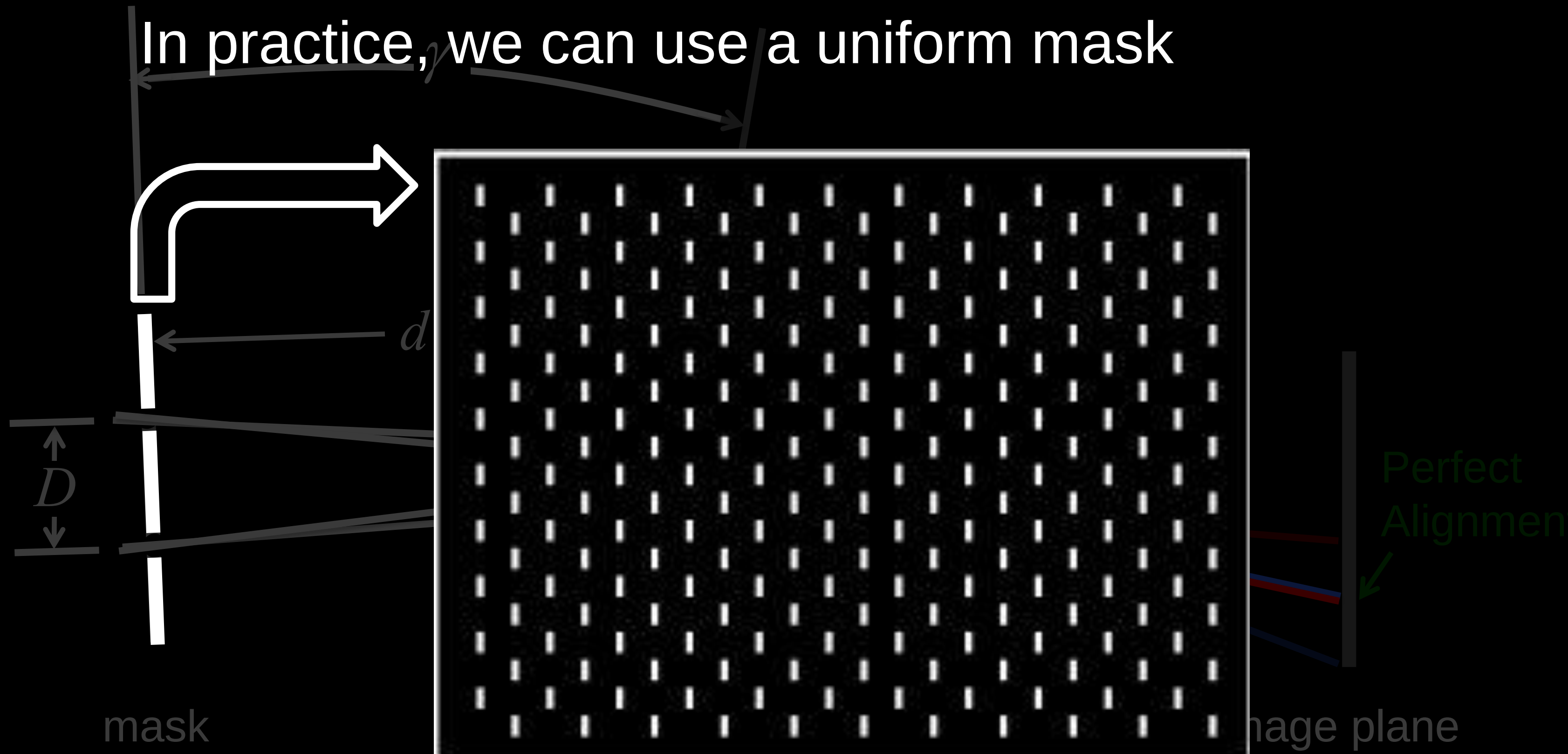


Mask-Hole Distance



Mask-Hole Distance

In practice, we can use a uniform mask



$$D = d \cdot \left(\tan(\gamma + \alpha(\lambda_e)) - \tan(\gamma + \alpha(\lambda_s)) \right)$$

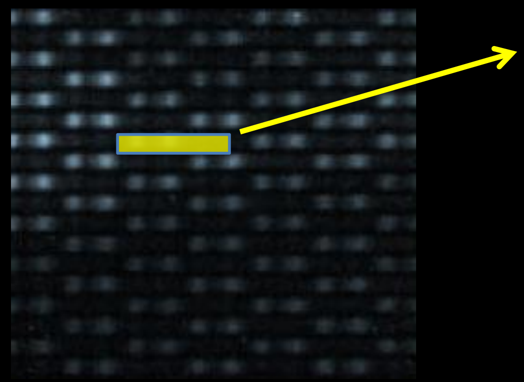
Device Calibration

Calibration Overview

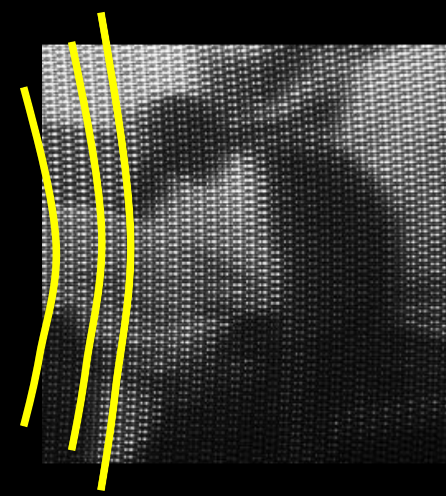
Spectrum Calibration

Geometry Calibration

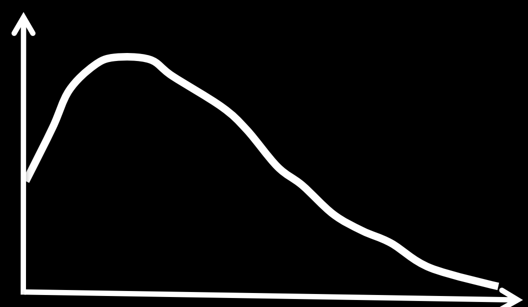
Radiance Calibration



Mapping Position to Wavelength



Geometry Distortion caused by the prism



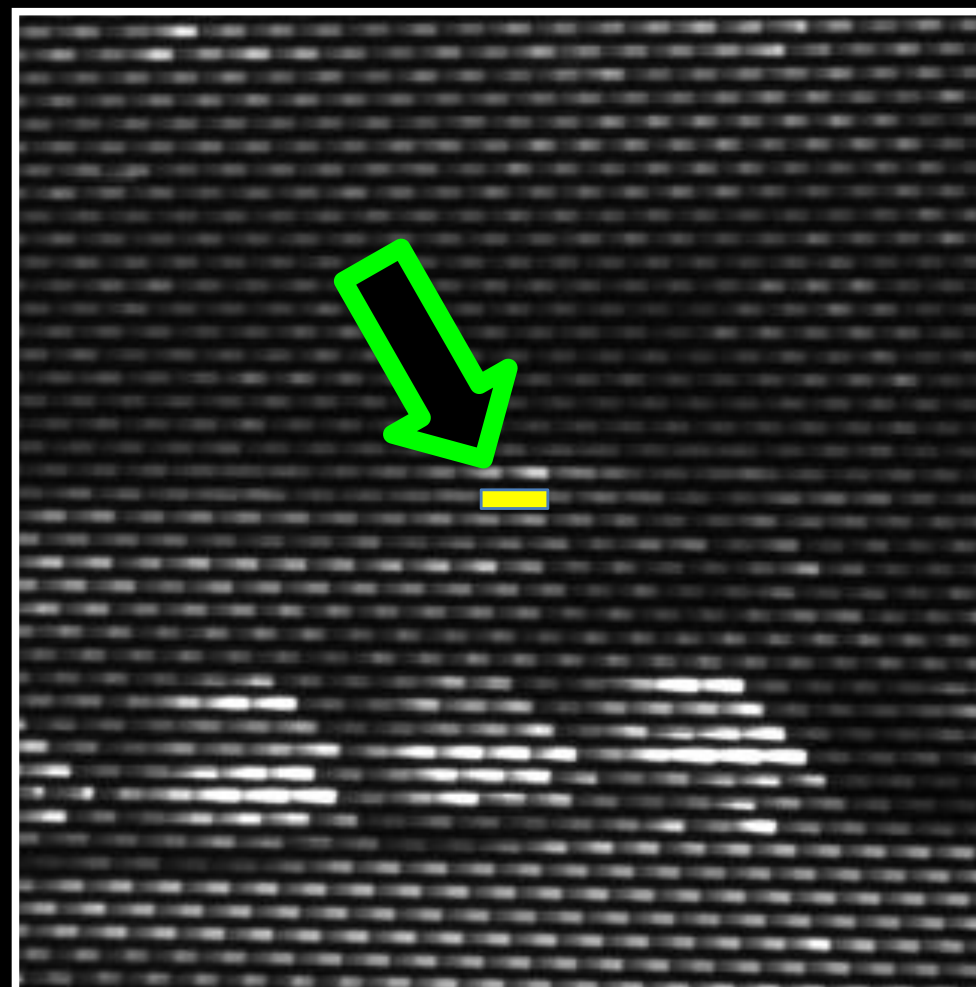
Non-constant CCD Sensitivity

Spectrum Calibration

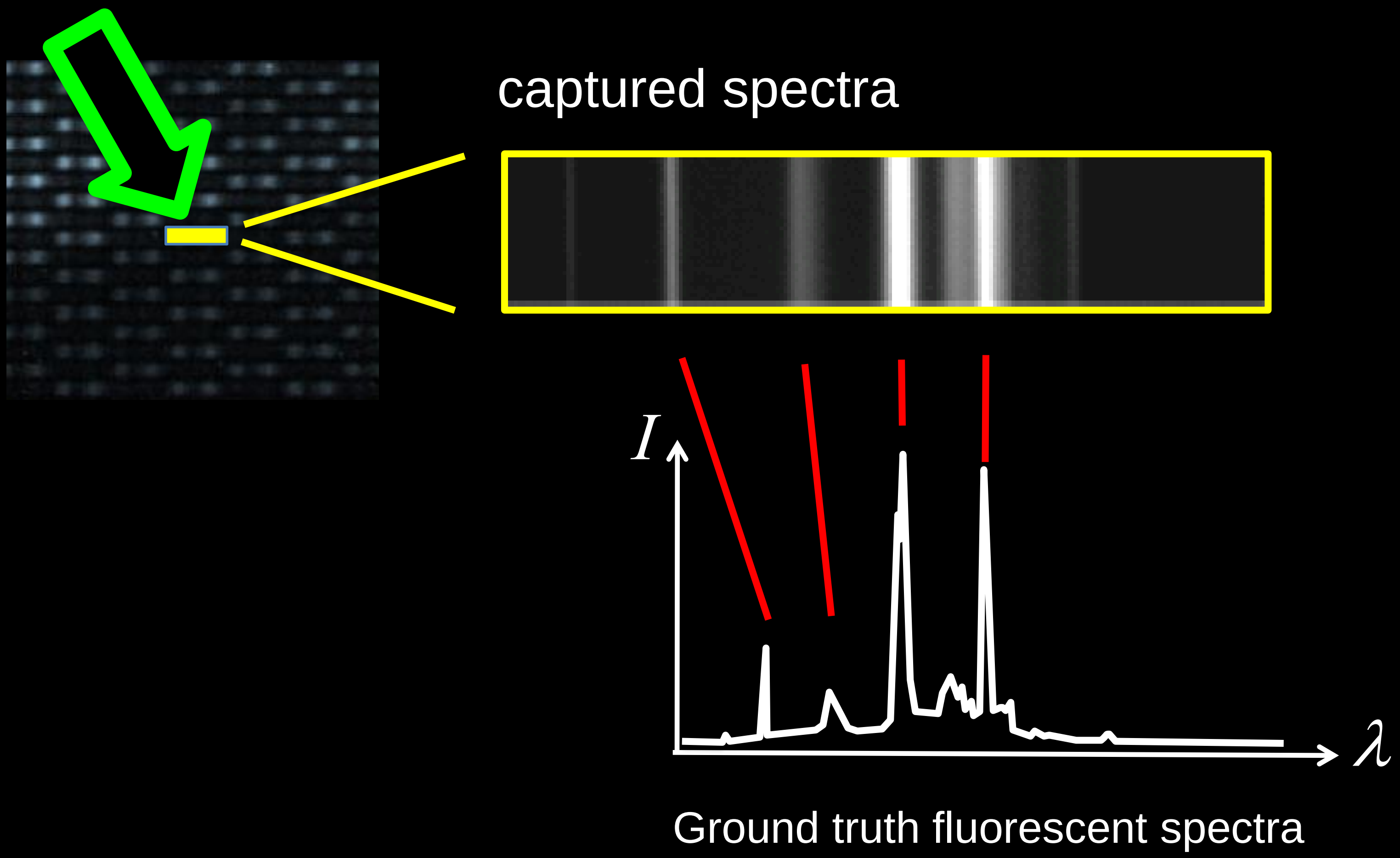
Spectrum Calibration

Geometry Calibration

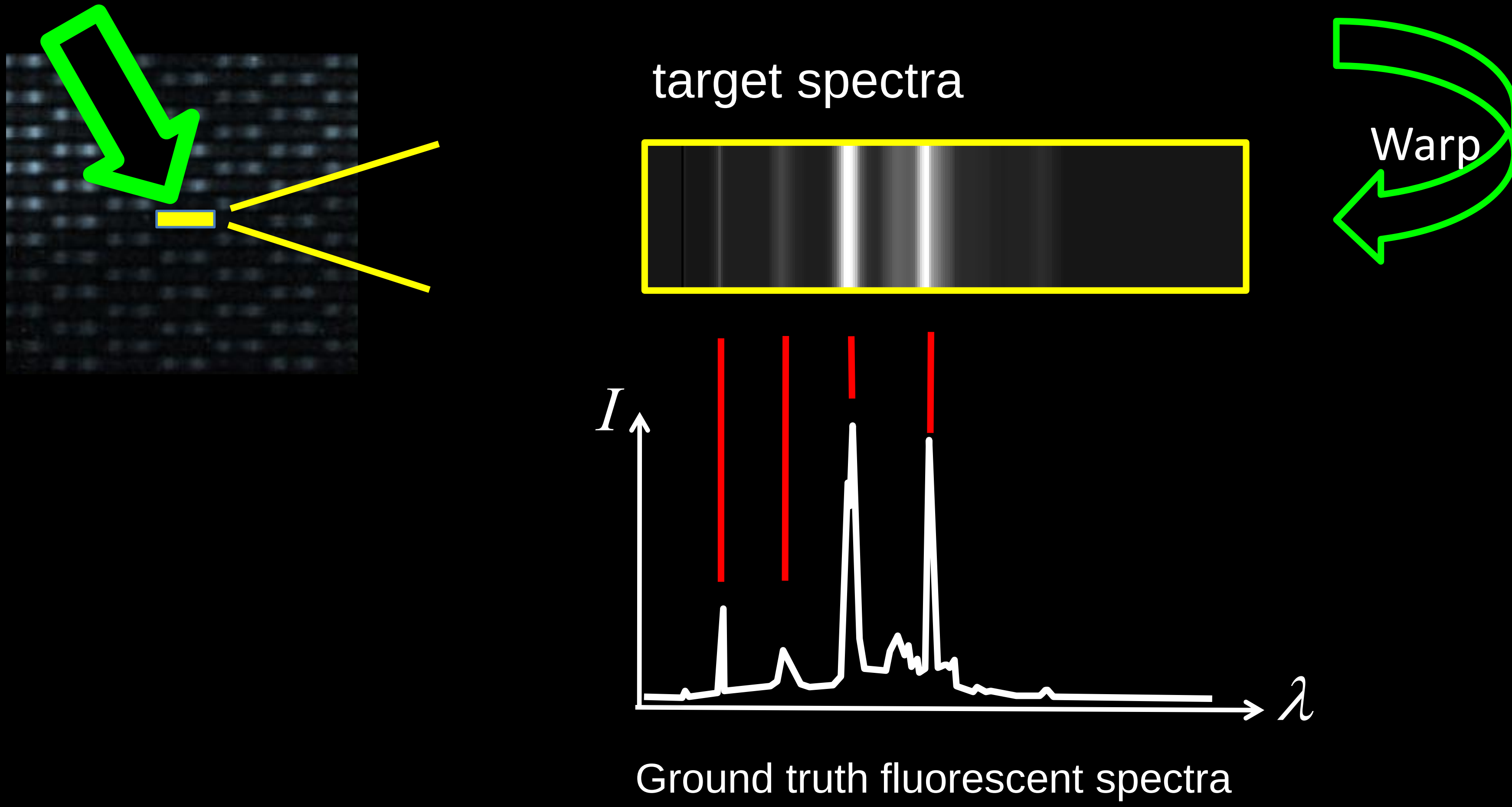
Radiance Calibration



Spectrum Calibration

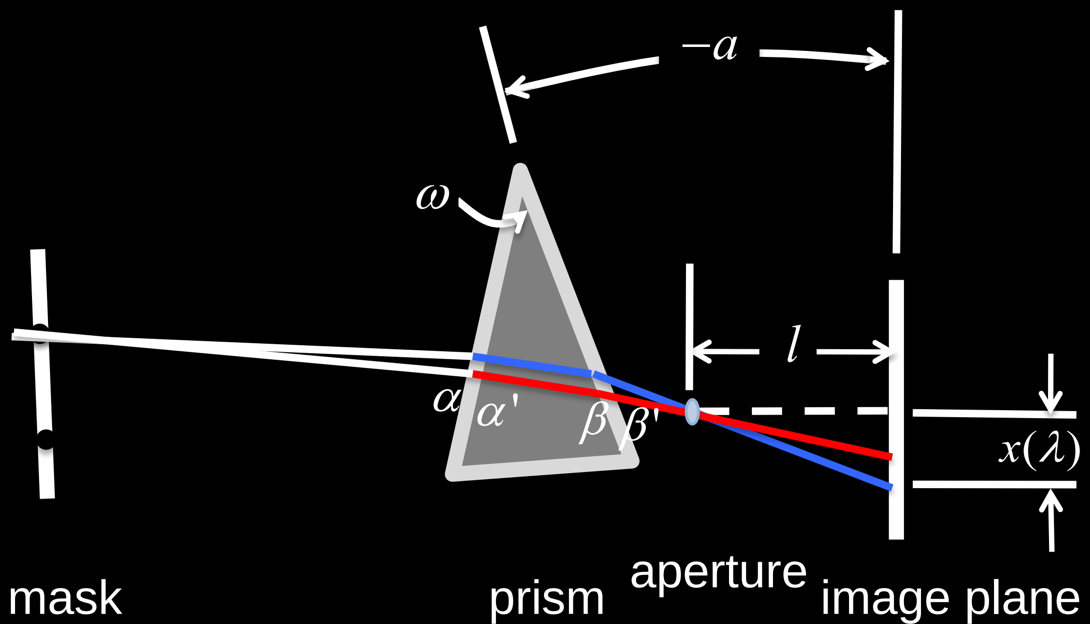


Spectrum Calibration



Spectrum Calibration

- Mapping Function : Wavelength <-> Position



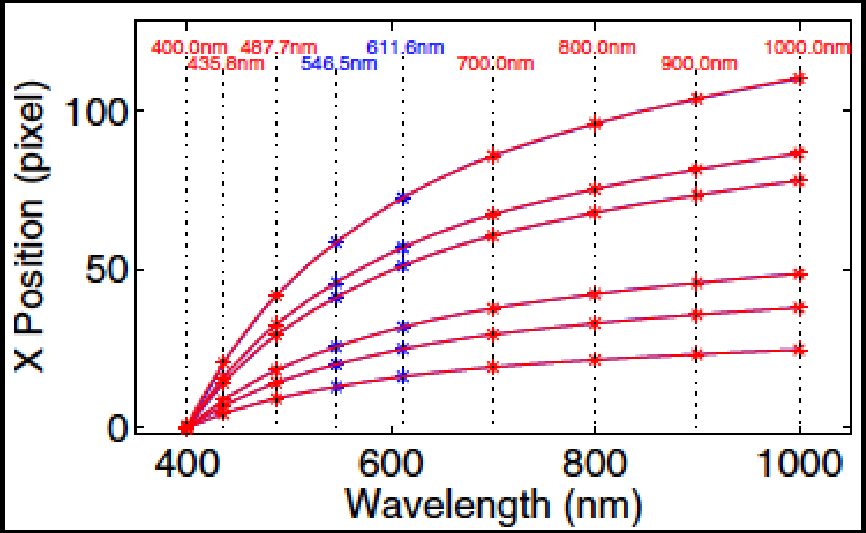
$$x(\lambda) = l \cdot \tan\left(a + \arcsin(n_\lambda \cdot \sin(\omega - \arcsin(\frac{\sin\alpha}{n_\lambda}))\right)$$

Non linear , but smooth curve !

Mapping Function

- Simulation

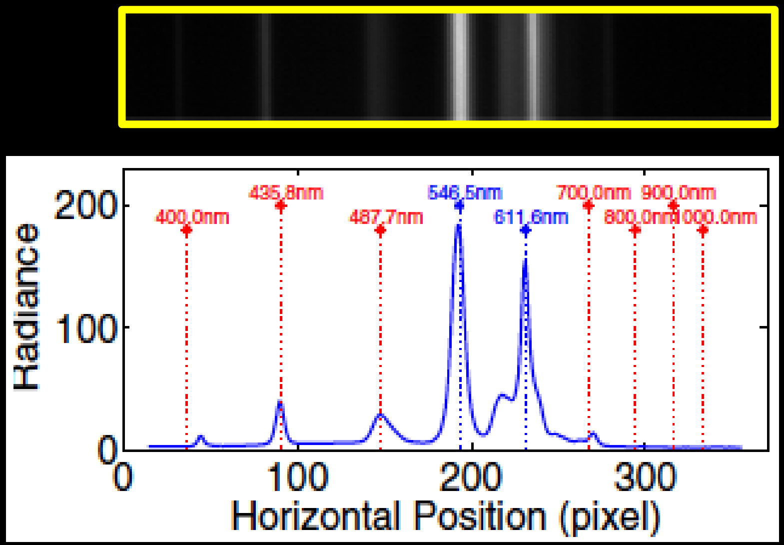
$$x(\lambda) = l \cdot \tan\left(a + \arcsin(n_\lambda \cdot \sin(\omega - \arcsin(\frac{\sin\alpha}{n_\lambda}))\right)$$



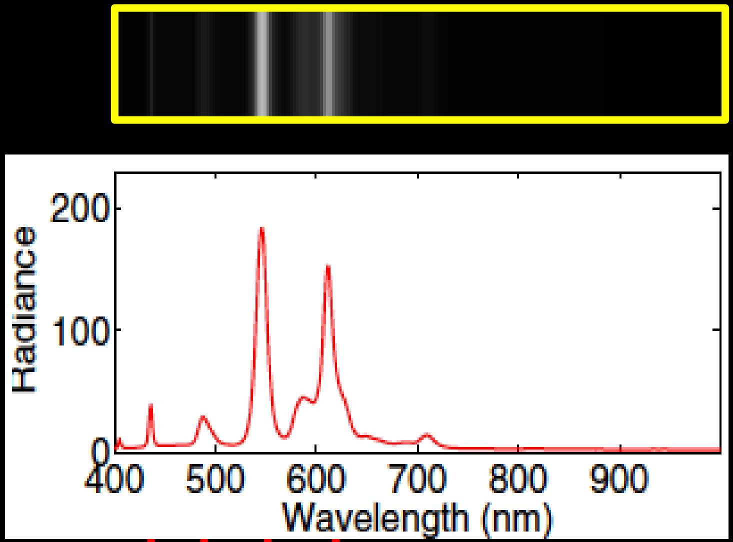
- The Method
  - B-Spline << 2 seeds + 7 control points
  - Low reconstruction error : < 0.7%

The Process

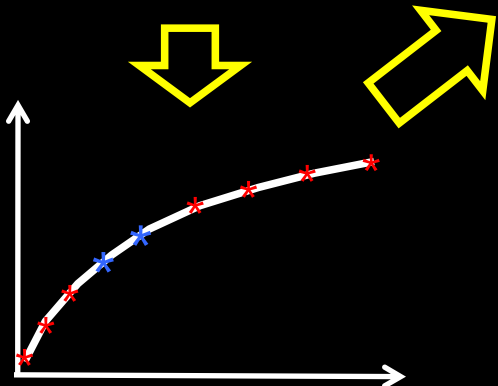
captured spectra

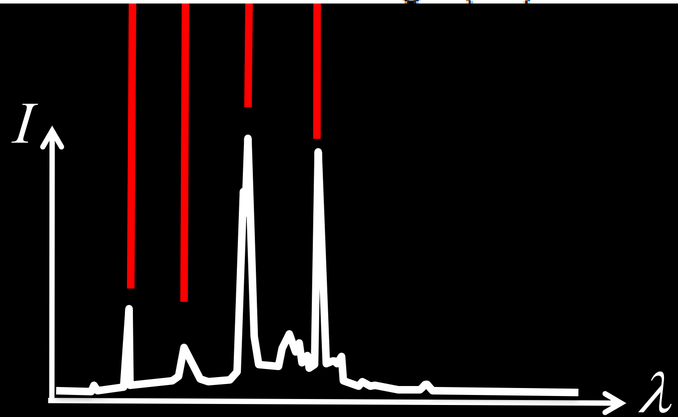


target spectra



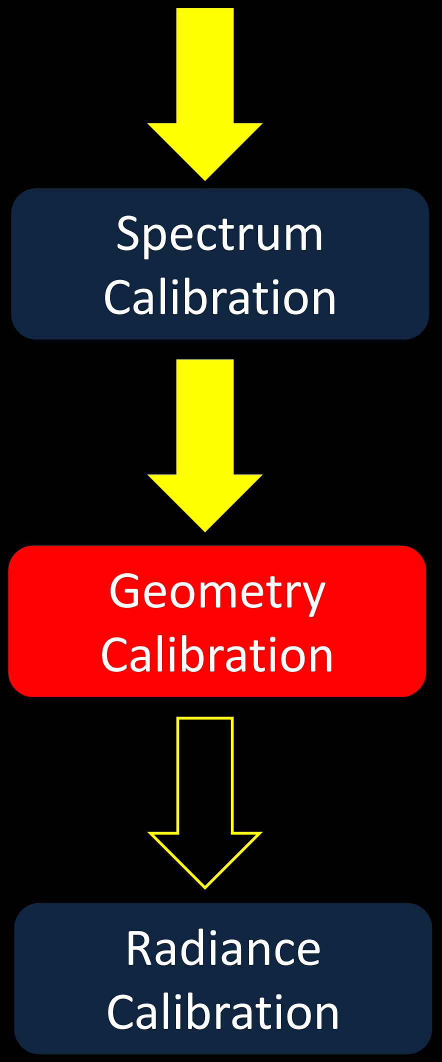
Warp Function





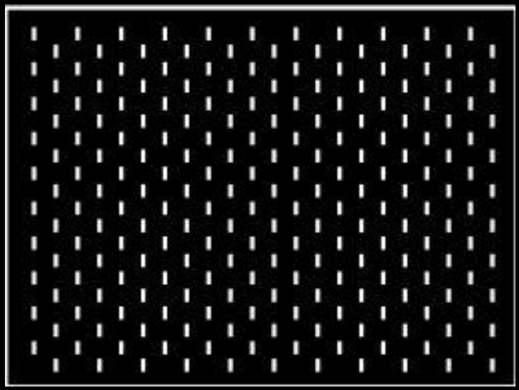
Ground truth fluorescent spectra

Geometry Calibration

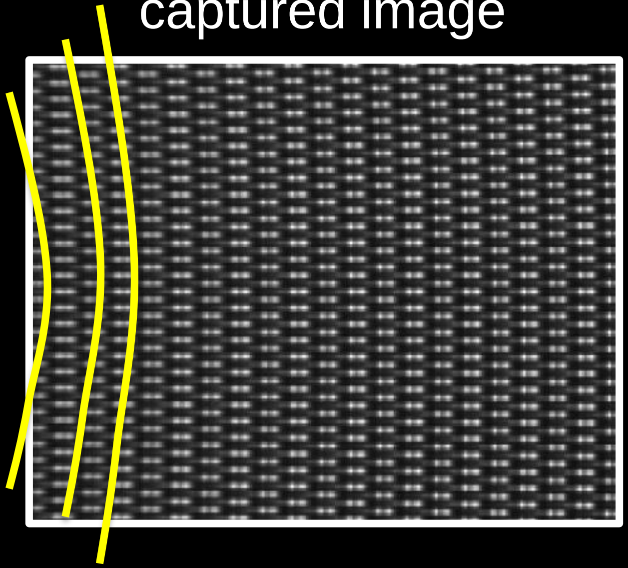


Geometry Calibration

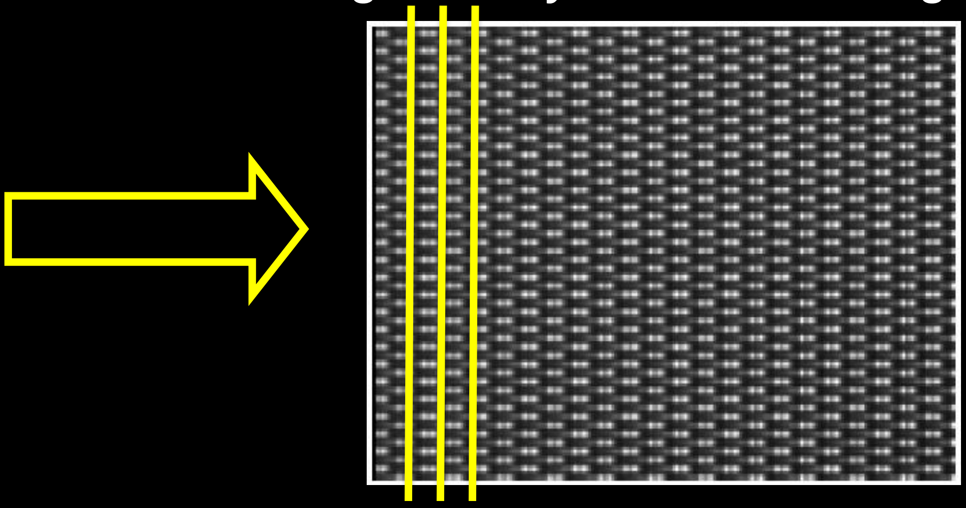
Predefined mask pattern



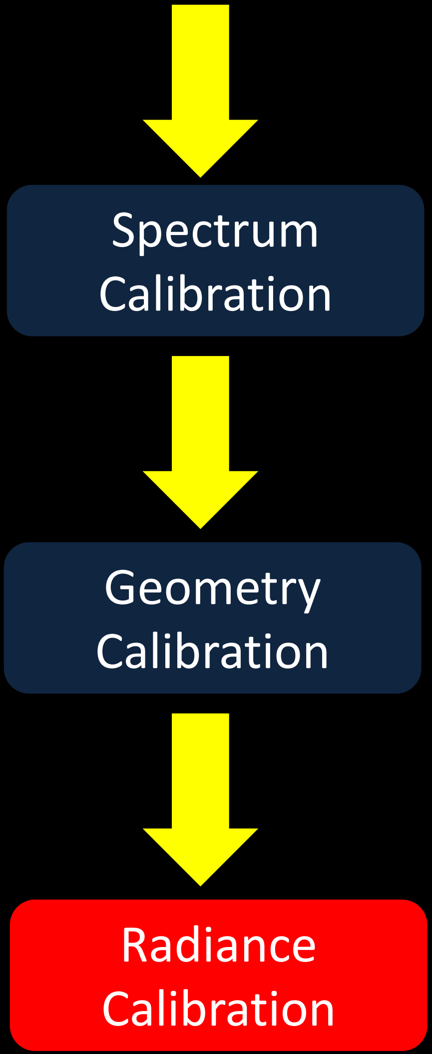
captured image

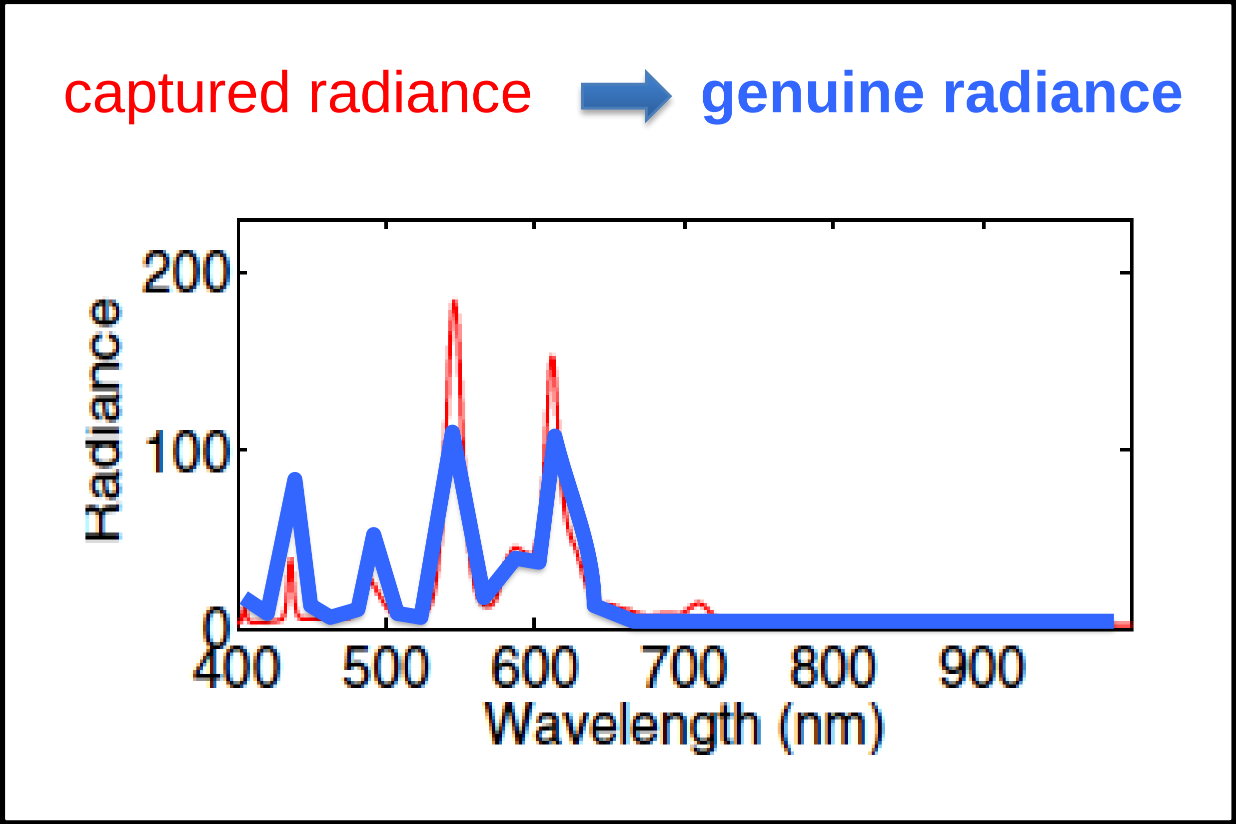


geometry calibrated image



Radiance Calibration





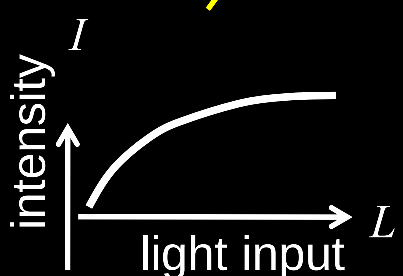
Radiance Calibration

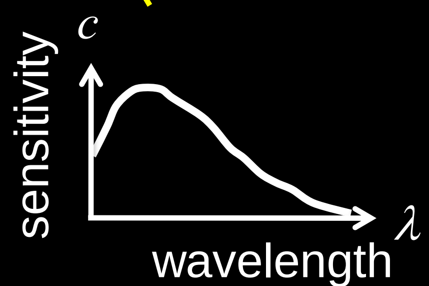
captured radiance

genuine radiance

$$I(x) = f\left(\int_{x(\lambda_a)}^{x(\lambda_b)} c(\lambda)\, l(\lambda)\, d\lambda\right)$$

assuming $c(\lambda)$, $l(\lambda)$ locally constant



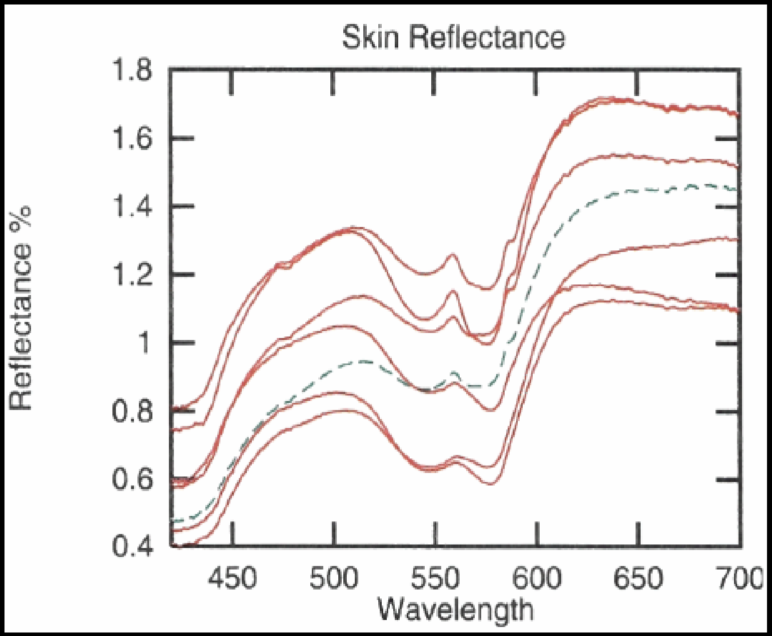


$$l(\lambda_s) \approx \frac{f^{-1}(I(x))}{c(\lambda)(\lambda_b - \lambda_a)}$$

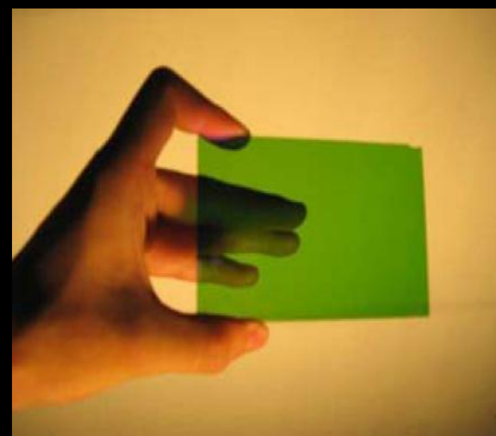
Applications

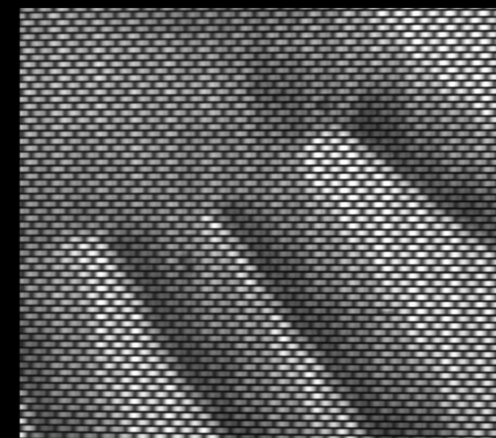
Human Skin Detection

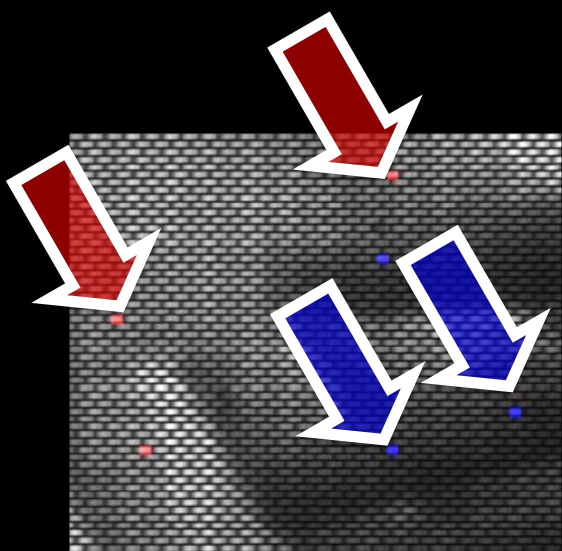
- The ‘W’ pattern in human skin reflectance
    - [Angelopoulou01]

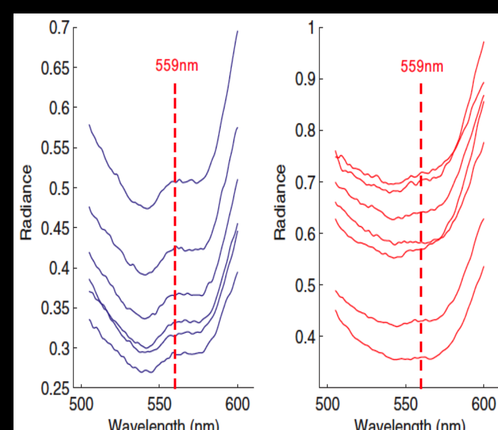


Human Skin Detection



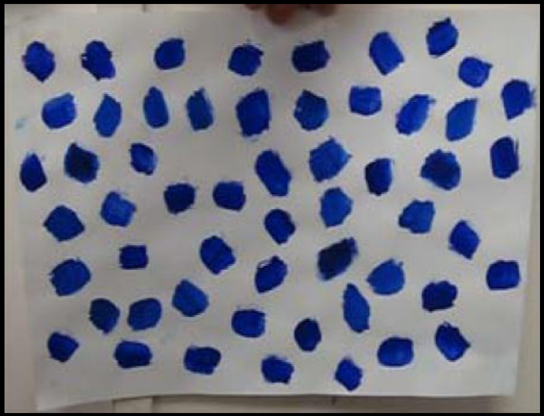




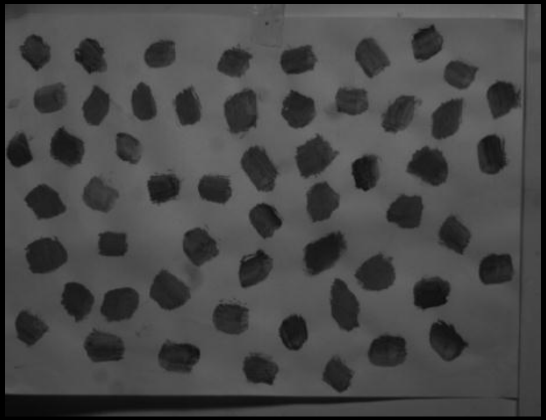


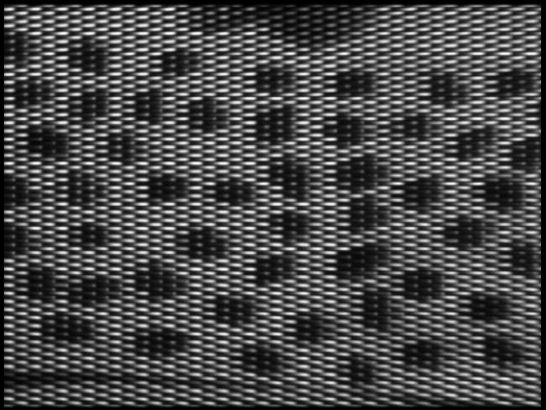
Material Discrimination

RGB Image

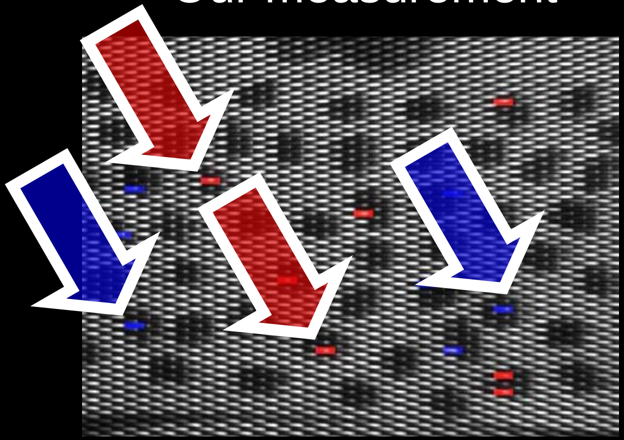


IR Image

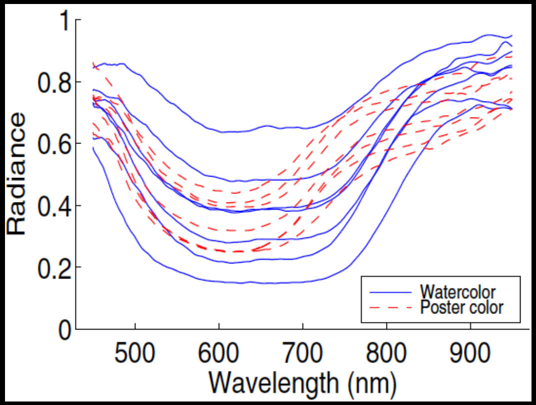




Our measurement

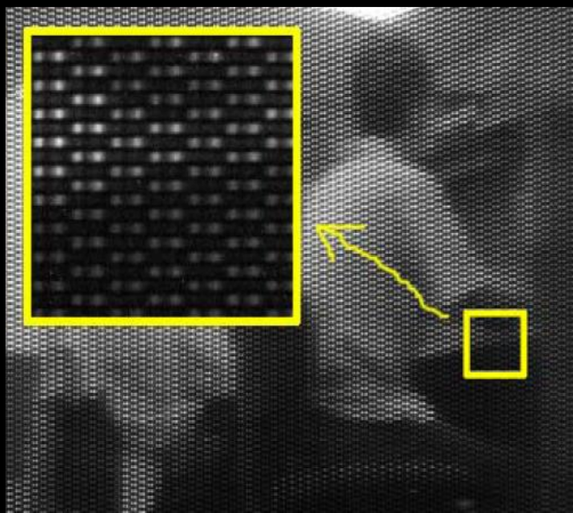


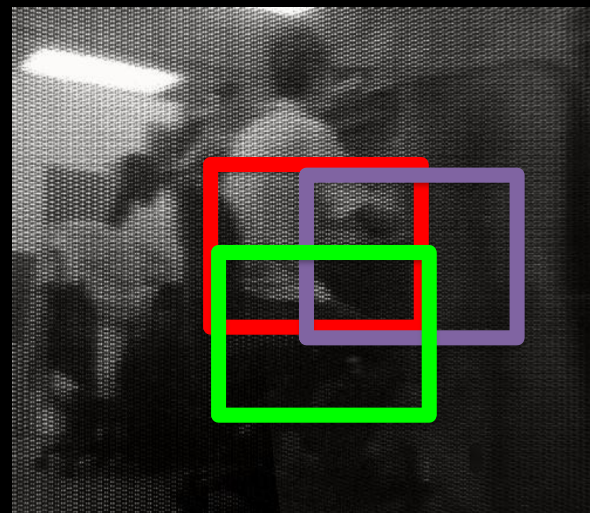
The differences in IR

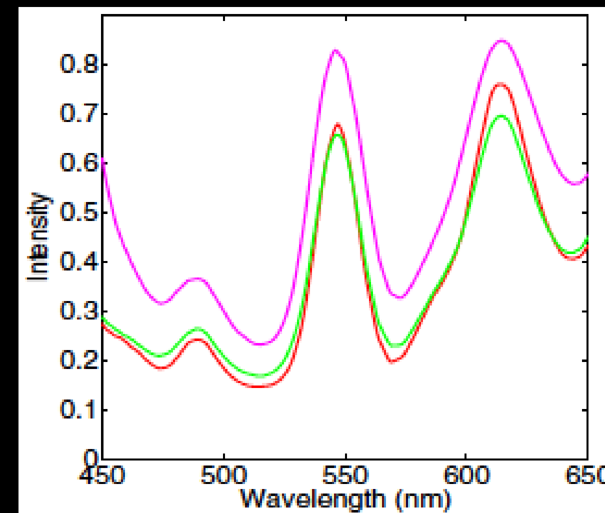


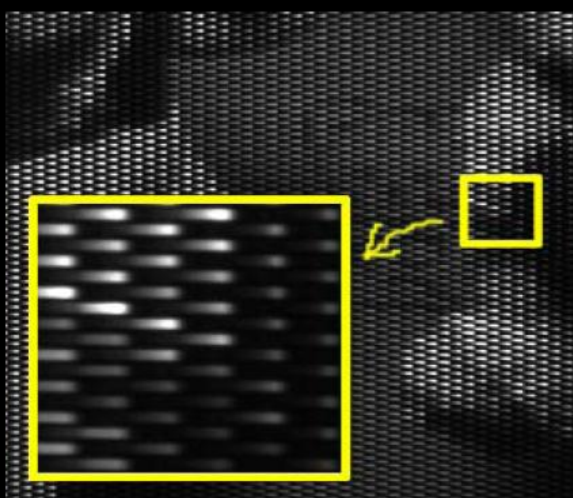
RGB Video Generation and Illumination Detection

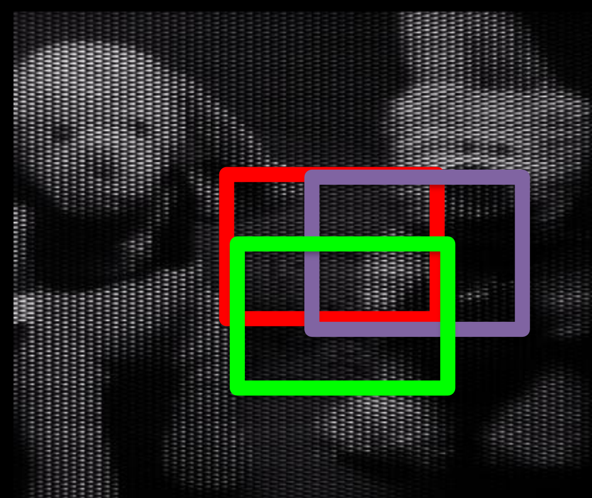
Illumination Detection

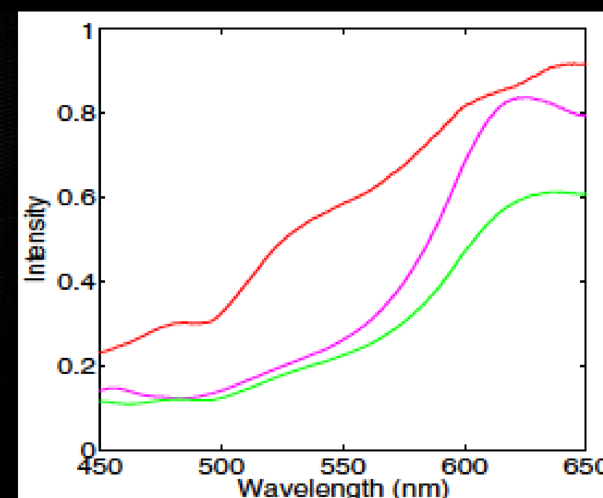






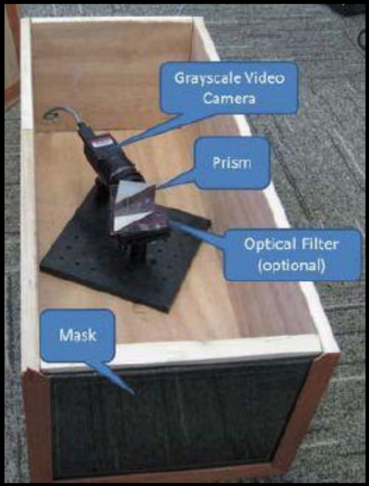




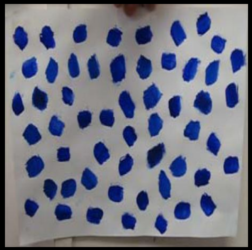
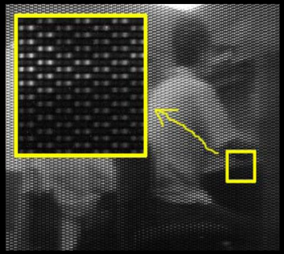


Conclusion

- A prism based Imaging System
  - Passive Multispectral Video
  - High spectrum resolution
  - Tradeoff spectral and spatial resolution
  - Easy setup and calibration

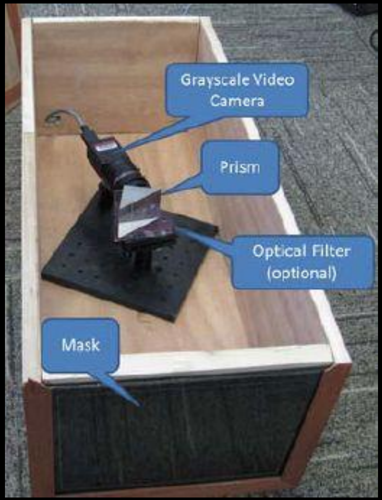


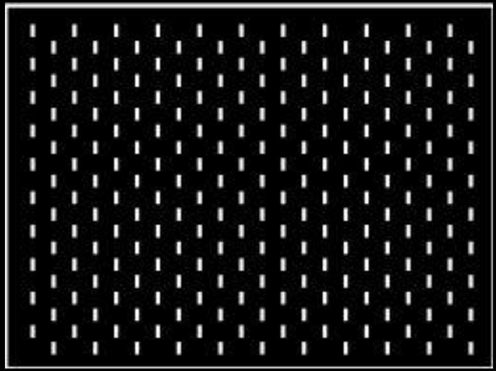
- Applications
  - Skin detection
  - Material Recognition
  - Illumination Identification

Limitations

- Light flow is limited by
  - occlusion mask
  - relatively small aperture





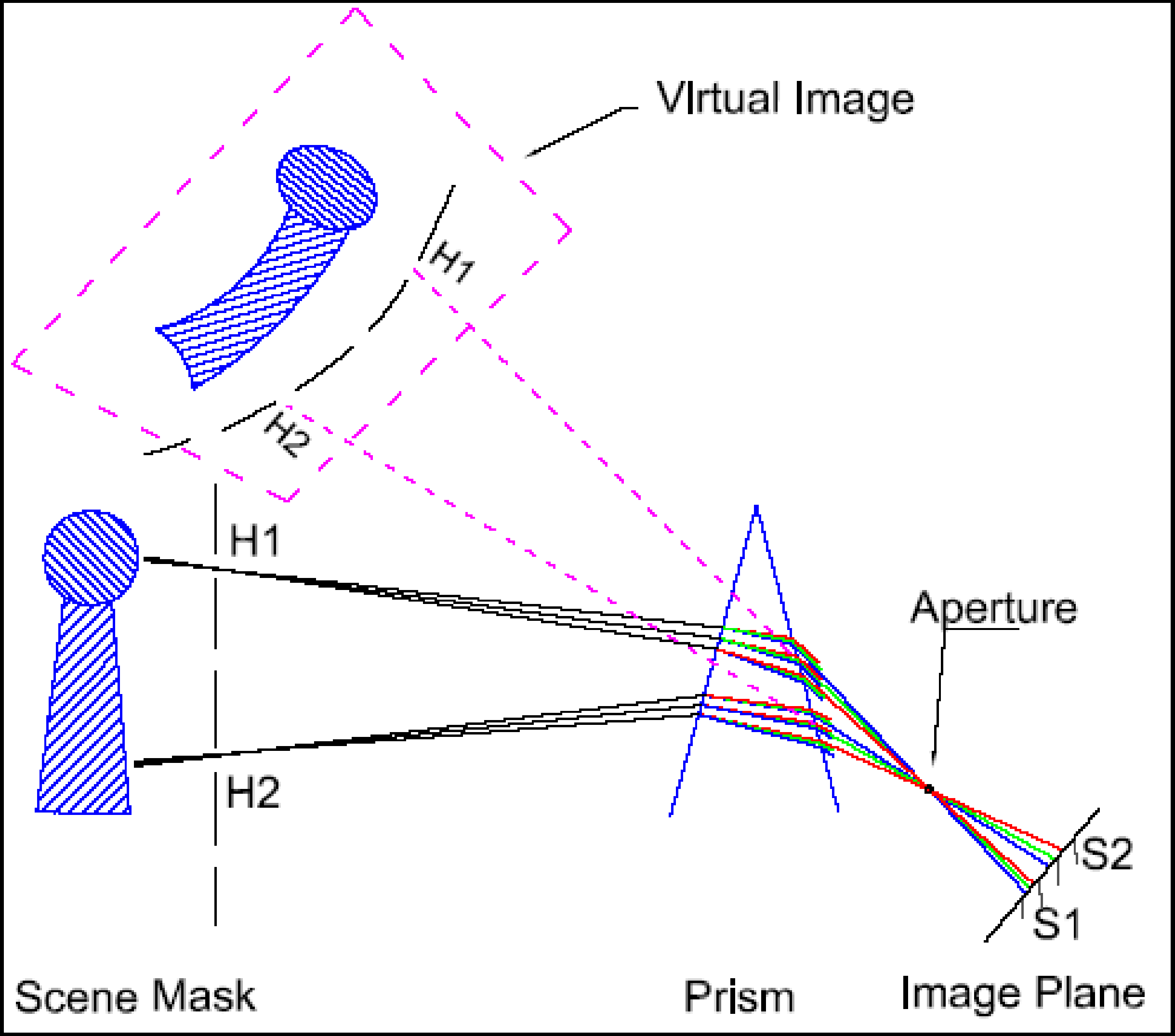
- Cannot achieve both high spatial and spectral resolution
  - Limited CCD resolution

Acknowledgements

- Yue Xu
  - Assistance in experimentation
- Moshe Ben-Ezra
  - Helpful discussions on implementation issues
- Reviewers
  - Constructive comments

THANK YOU

The Optical Path

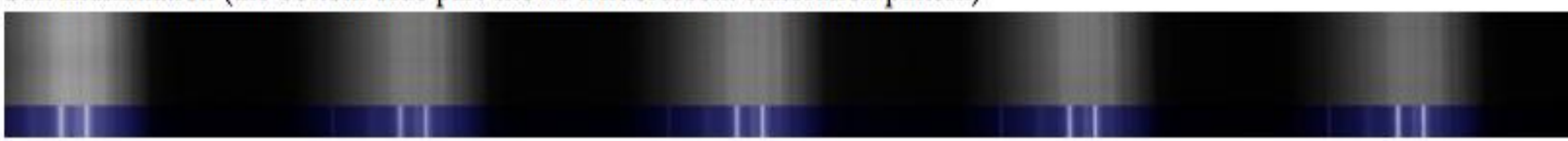


Spectra of Illuminations

- Fluorescent Illumination

- Tungsten Illumination (the bottom blue part shows a fluorescent calibration pattern)

- Sun Illumination (the bottom blue part shows a fluorescent calibration pattern)



- Fluorescent Illumination with a 650nm red laser beam