



南京理工大学

NANJING UNIVERSITY OF SCIENCE & TECHNOLOGY

# 计算光学成像与 光信息处理技术前沿

(第10讲)

左超

南京理工大学电光学院光电技术系

Jiangsu Key Laboratory of Spectral Imaging & Intelligent Sense (SIIS)

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Nanjing, Jiangsu Province 210094, China



电子工程与光电技术学院

School of Electronic and Optical Engineering



江苏省光谱成像与智能感知重点实验室

Jiangsu Key Laboratory of Spectral Imaging & Intelligent Sense



南京理工大学

NANJING UNIVERSITY OF SCIENCE & TECHNOLOGY



Smart Computational Imaging

# 光场成像

## Light-field imaging

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Jiangsu Key Laboratory of Spectral Imaging & Intelligent Sense

**What ?**



<http://blog.novelsee.com/archives/29622>



<https://www.duitang.com/blog/?id=26388510>

复眼

懂啦



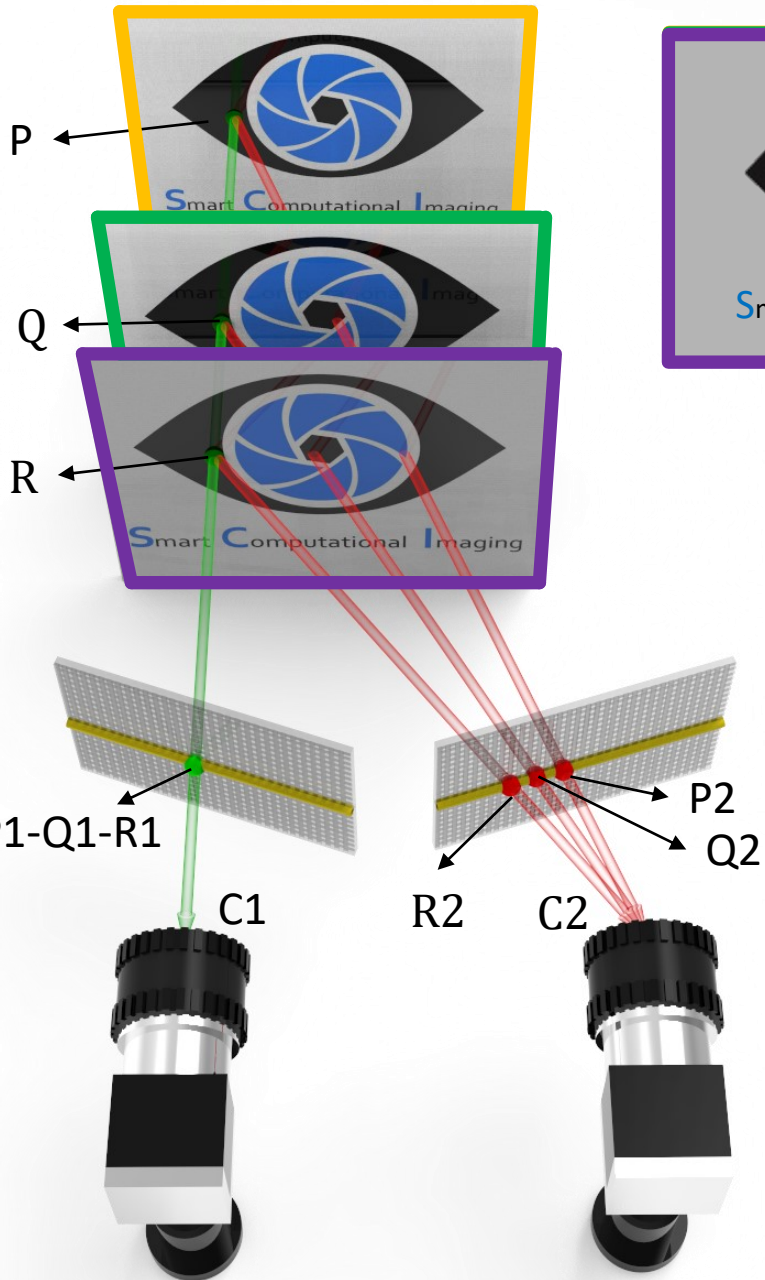
# 复眼



# 双目立体视觉

Left camera

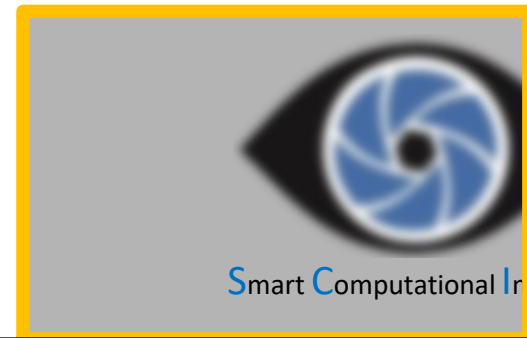
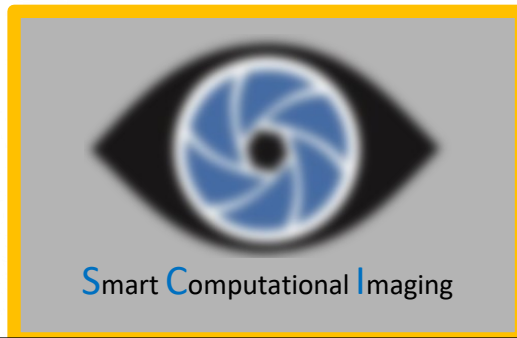
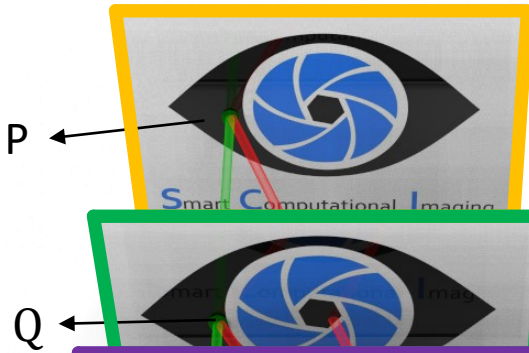
Right camera



# 双目立体视觉

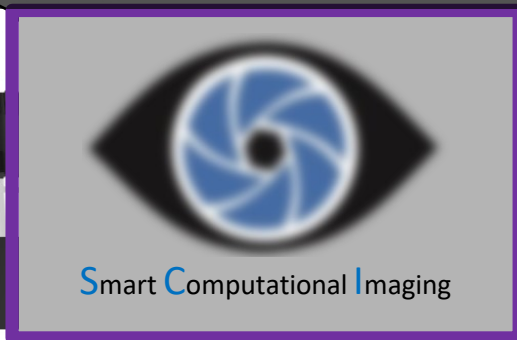
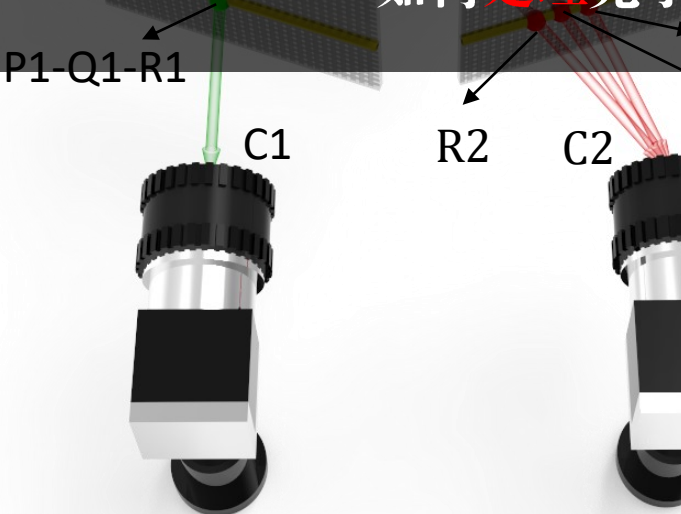
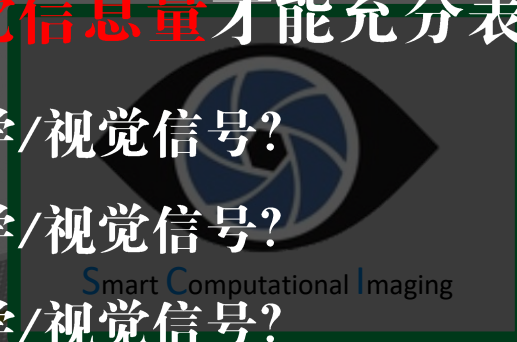
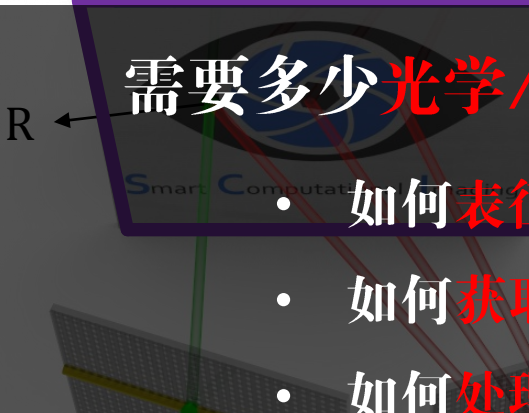
Left camera

Right camera



需要多少**光学/视觉信息量**才能充分表达/感知观测场景?

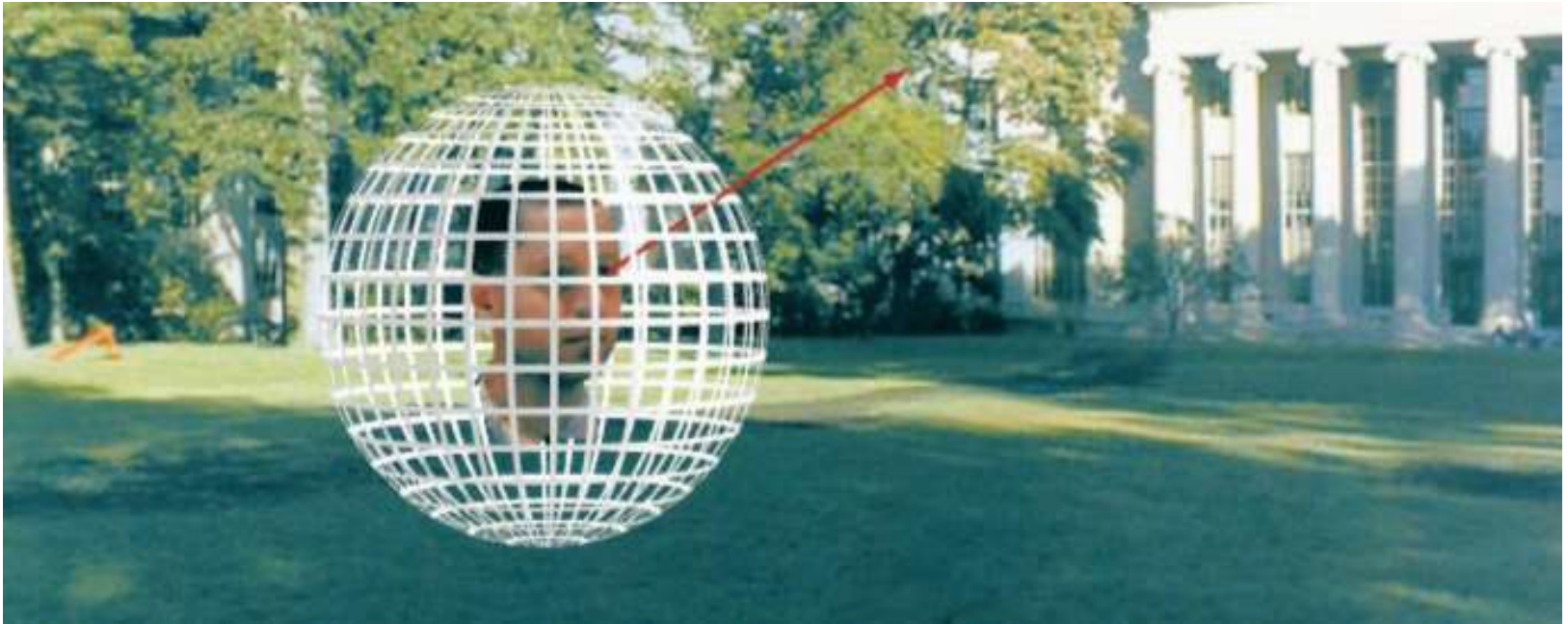
- 如何**表征**光学/视觉信号?
- 如何**获取**光学/视觉信号?
- 如何**处理**光学/视觉信号?





# 全光函数

固定视点



$$P(\theta, \varphi, \lambda, t)$$

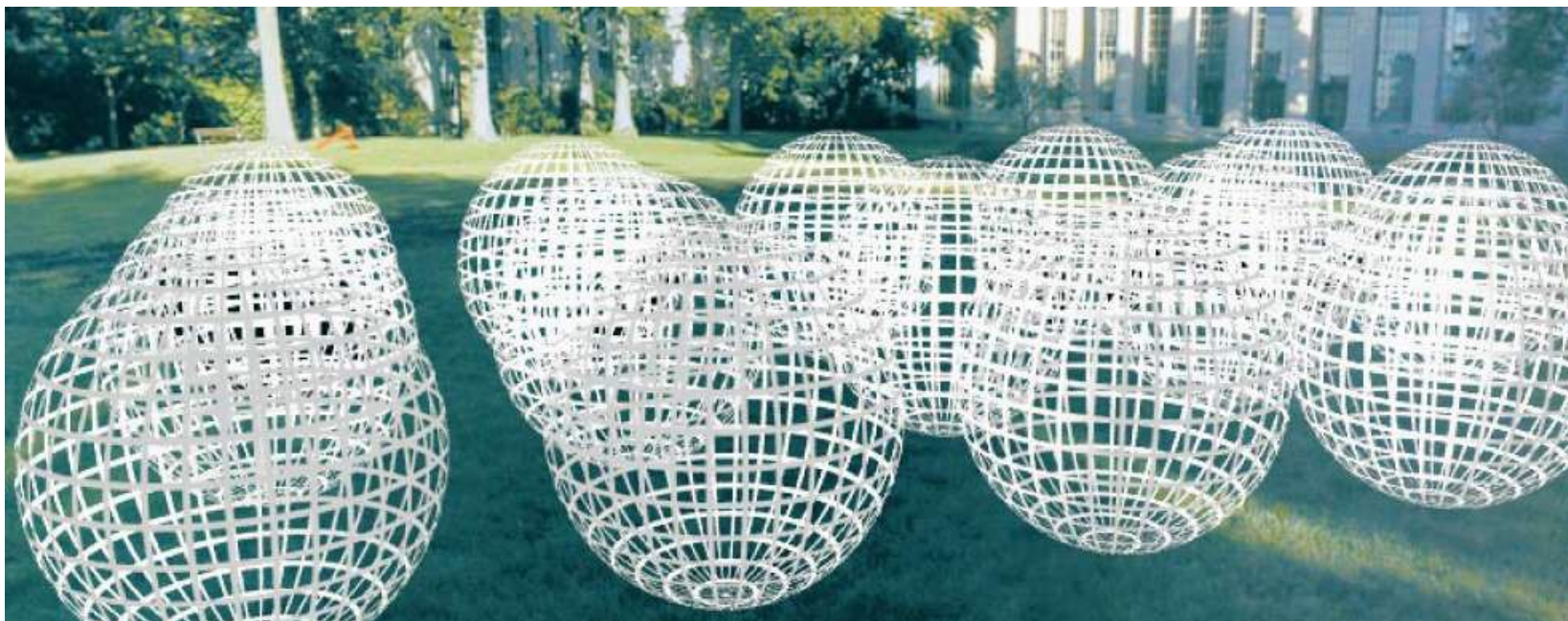
光线角度:  $(\theta, \varphi)$

波长:  $\lambda$

时间:  $t$

# 全光函数

## 全空间



$$P(x, y, z, \theta, \varphi, \lambda, t)$$

视点位置:  $(x, y, z)$

光线角度:  $(\theta, \varphi)$

波长:  $\lambda$

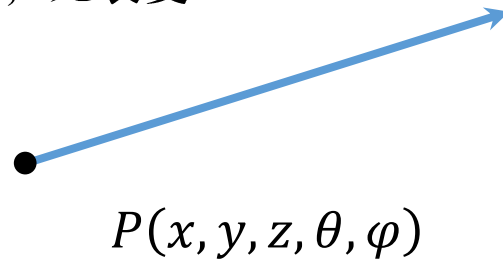
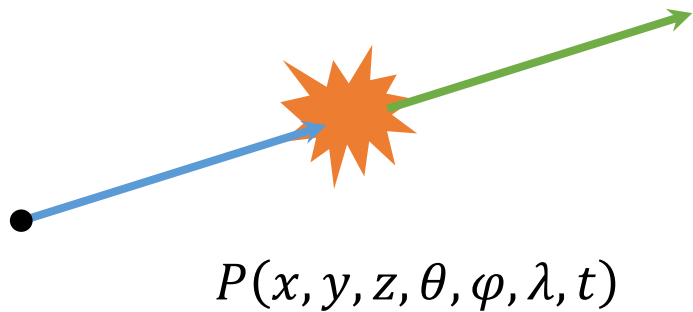
时间:  $t$

### 7D全光函数:

- 任意位置、任意方向的光线传播
- 光线的空间分布特性
- 光线集合

# 全光函数

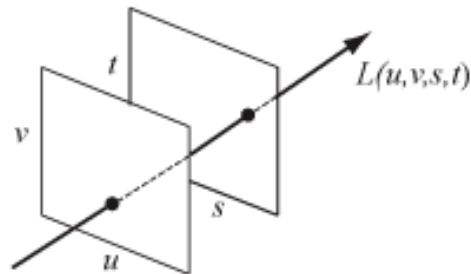
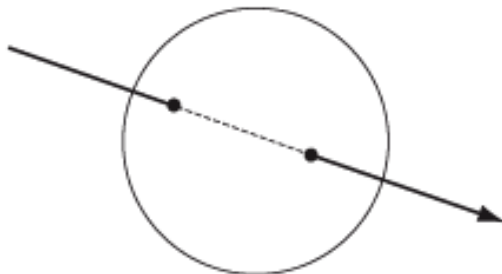
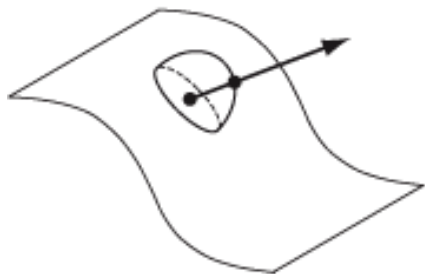
自由空间传播：无遮挡；无衰变



空间冗余

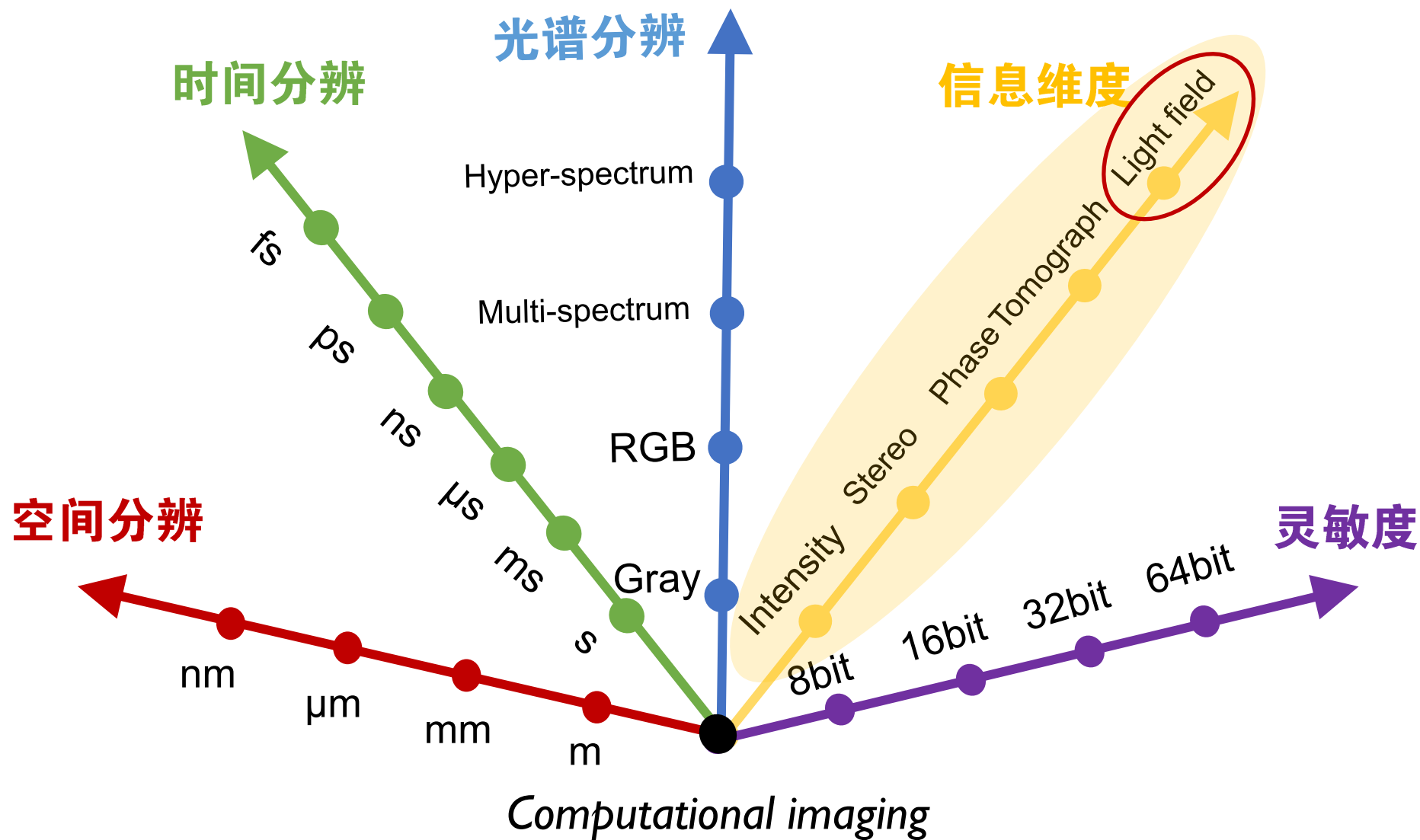


4D全光函数/光场： $L(x, y, u, v)$



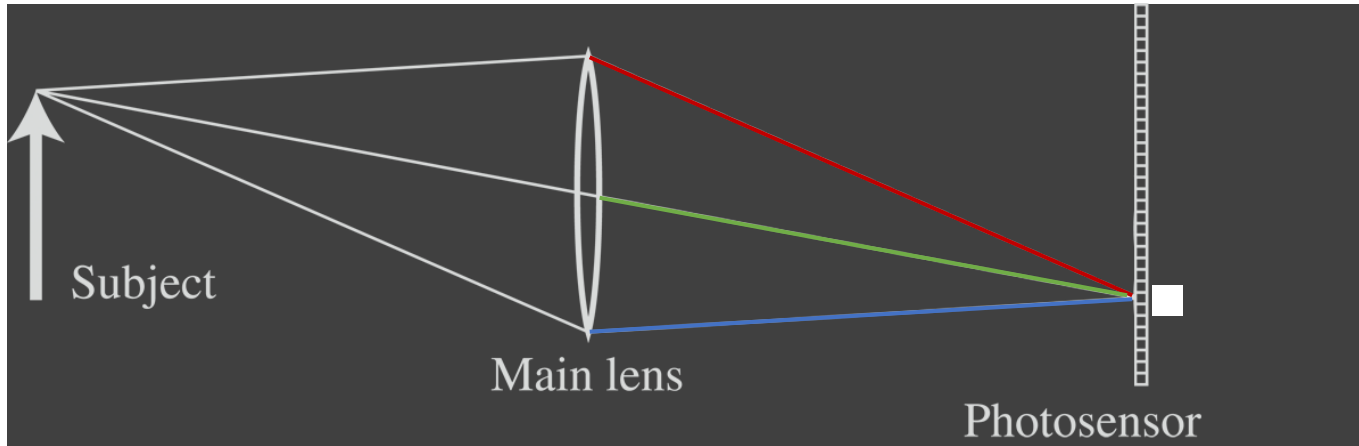
[Levoy and Hanrahan 1996; Gortler et al. 1996]

# 计算光学成像：光场成像



# 光场成像 v.s. 传统成像

传统成像

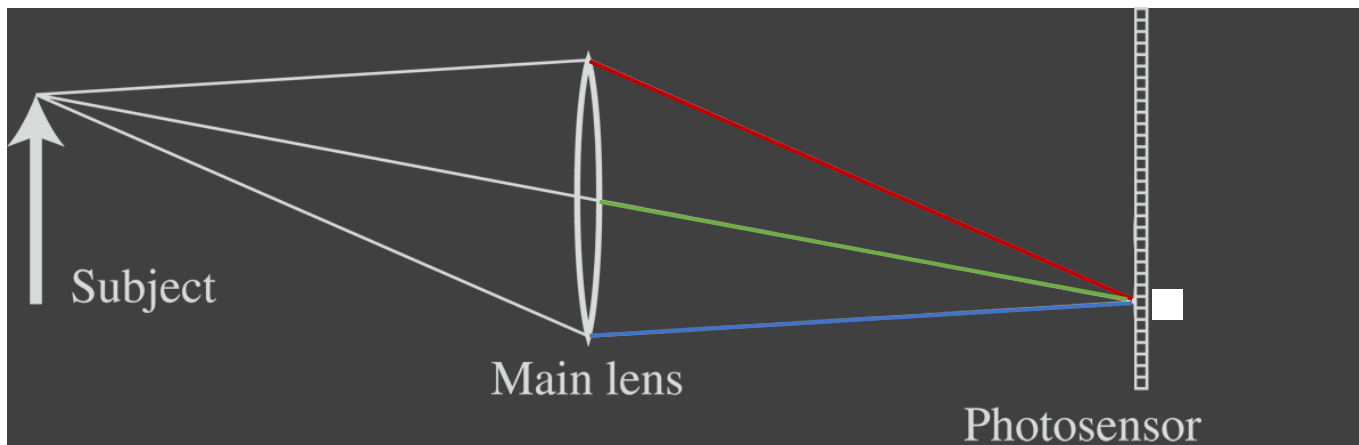


$$L(x, y, u, v) \rightarrow I(x, y)$$

积分投影，**丢失角度信息**

# 光场成像 v.s. 传统成像

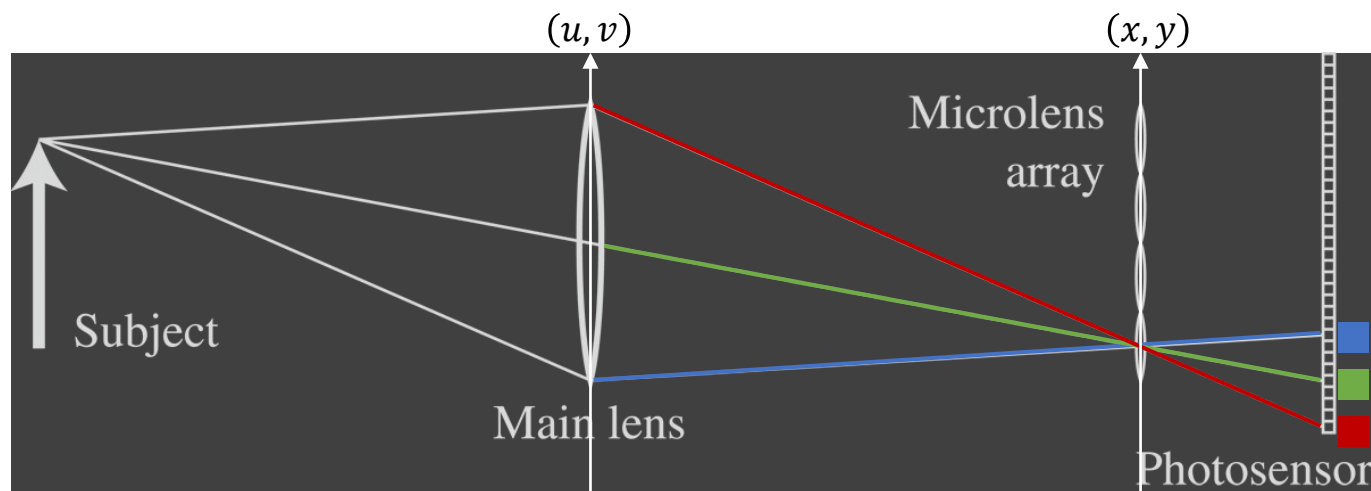
传统成像



$$L(x, y, u, v) \rightarrow I(x, y)$$

积分投影，丢失角度信息

光场成像



$$L(x, y, u, v)$$

同时记录光线空间和角度信息

# 光场成像：发展历程

No. 725,567.

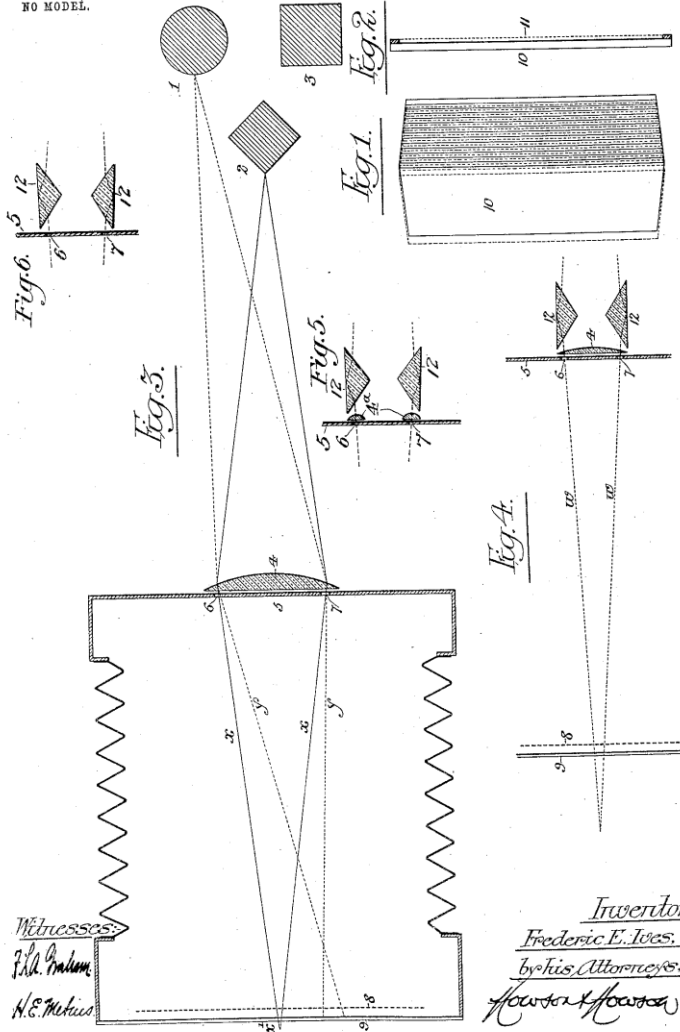
PATENTED APR. 14, 1903.

F. E. IVES.

PARALLAX STEREOGRAM AND PROCESS OF MAKING SAME.

APPLICATION FILED SEPT. 25, 1902.

NO MODEL.



[Ives: Parallax stereogram 1903]

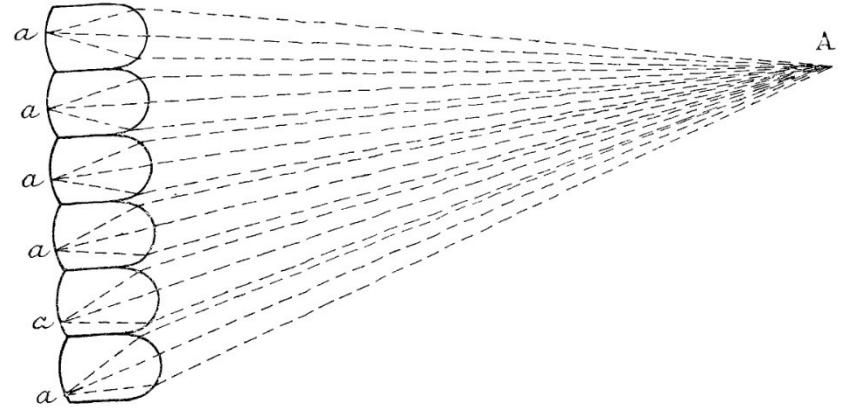


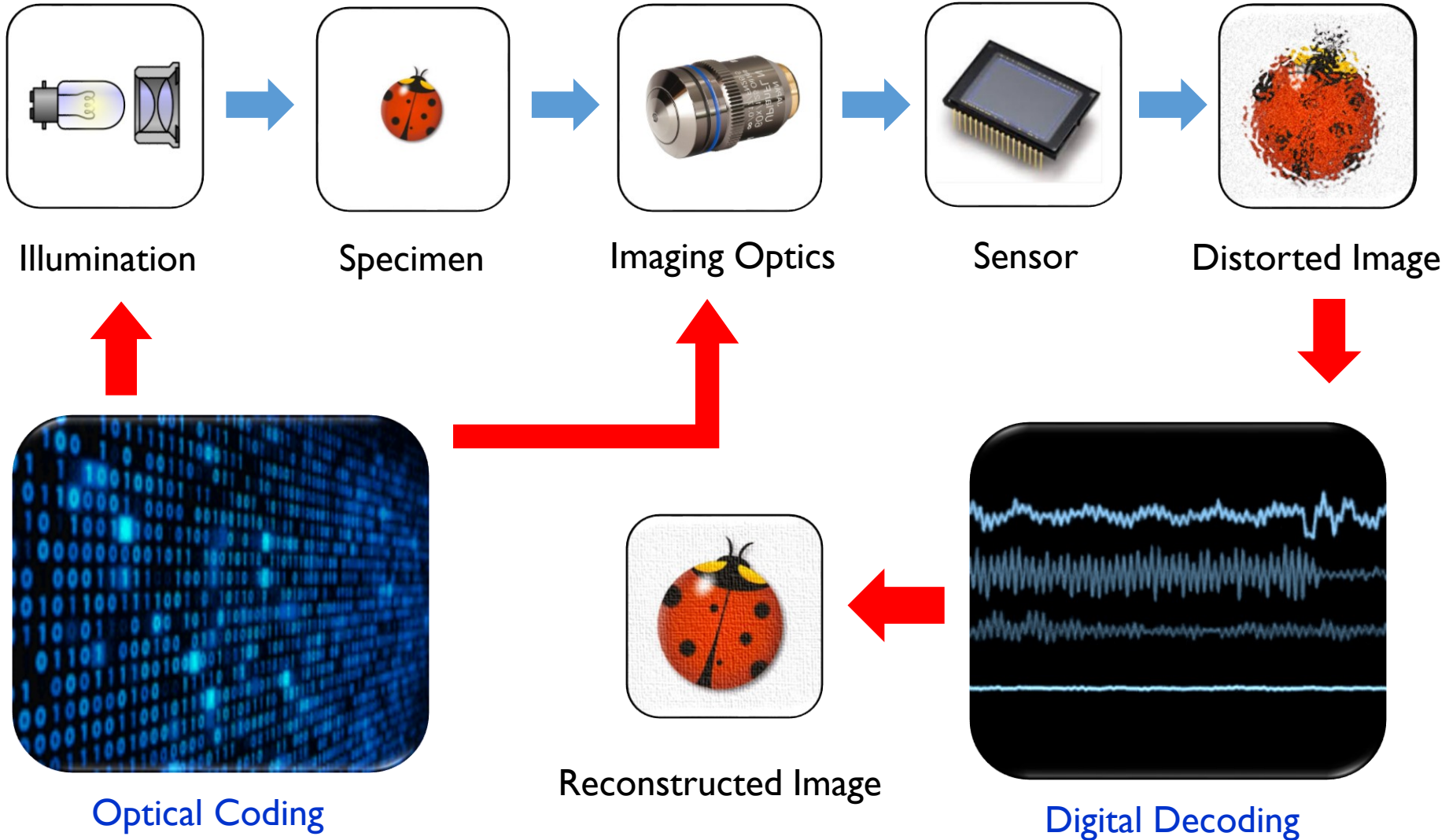
FIG. 1.



[Lippmann: Integral photography 1908]



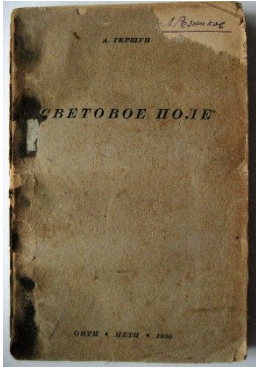
# Computational Imaging





# 光场成像：发展历程

## 光场：光线的空间辐射特性



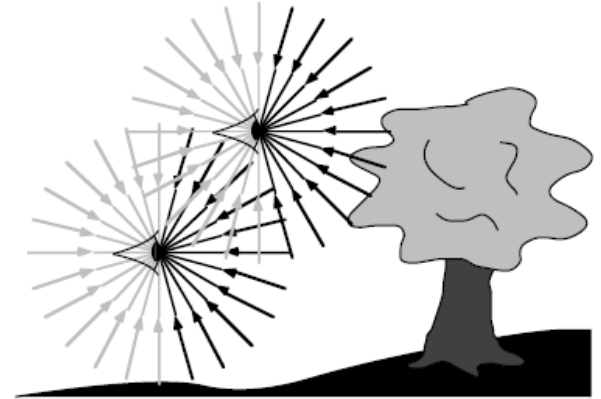
THE LIGHT FIELD  
By A. GERSHUN  
Translated by PARRY MOON and GREGORY TIMOSHENKO

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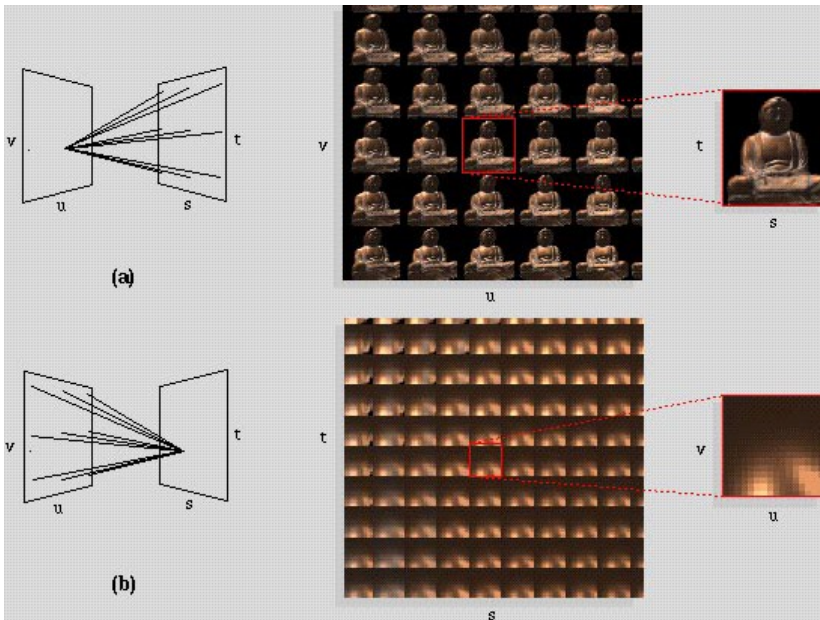
[Gershun: The light field 1939]

## 七维全光函数



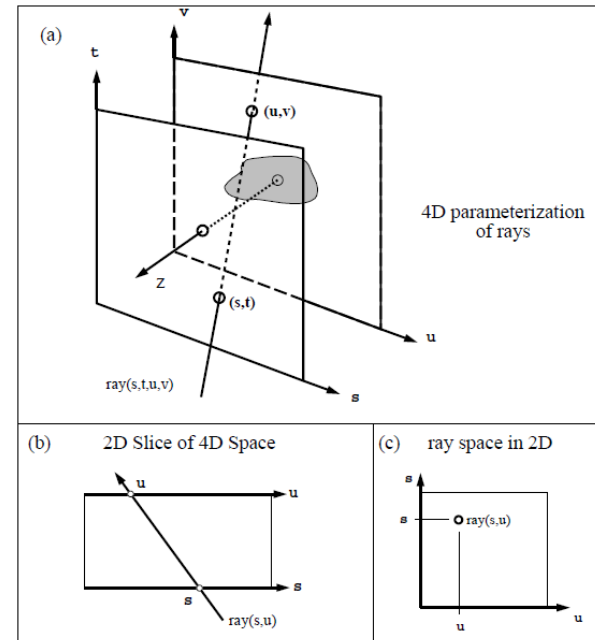
[Adelson: Plenoptic function 1991]

## 四维光场渲染



[Levoy and Hanrahan: Light field rendering 1996]

## 四维流明图



[Gortler et al.: The lumigraph 1996]

# 光场成像：光场相机

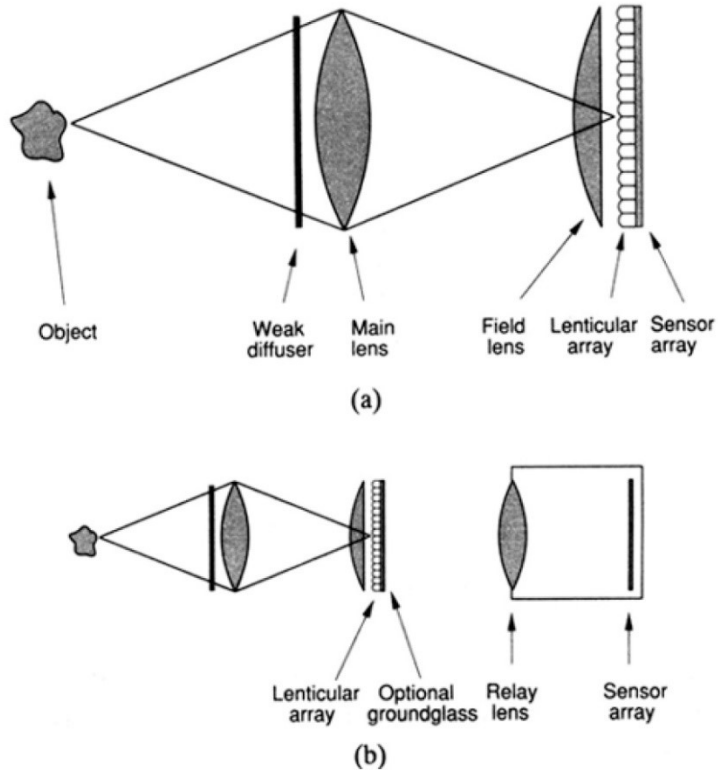


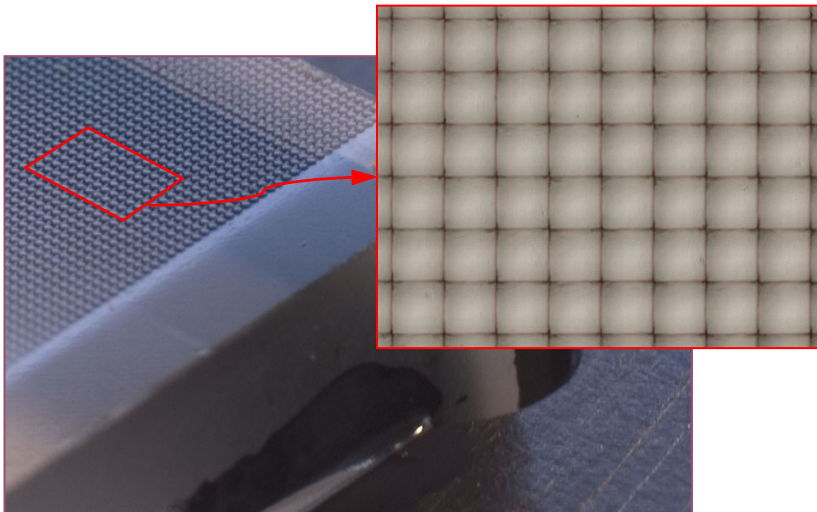
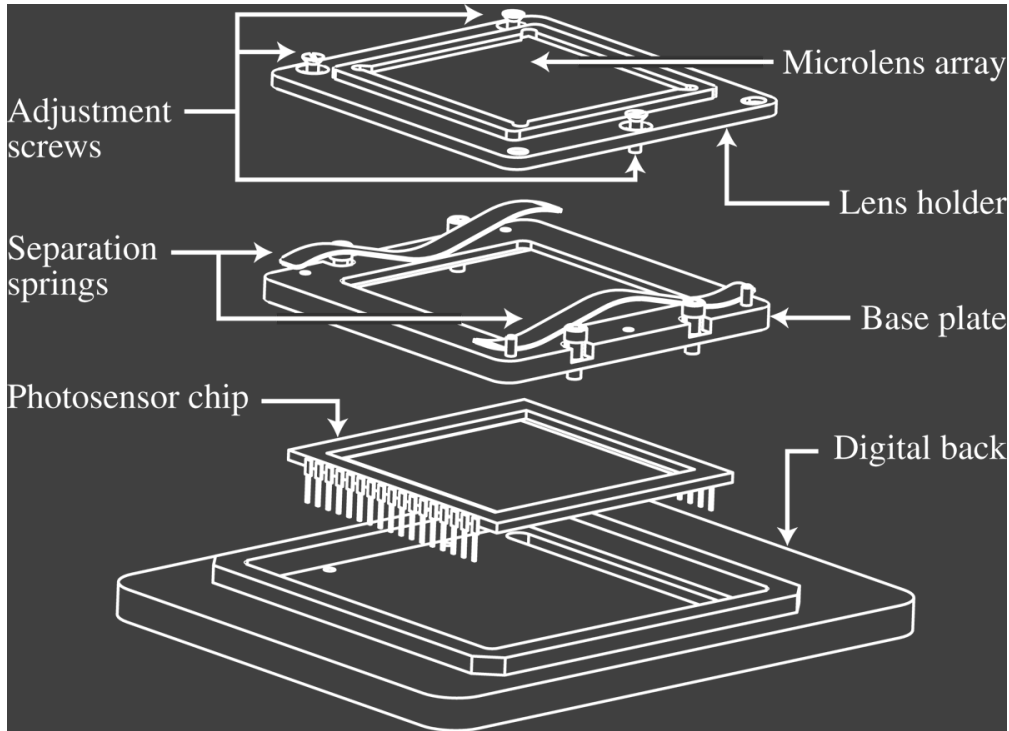
Fig. 6. (a) Optical system of a plenoptic camera; (b) plenoptic camera utilizing relay optics.

[Adelson and Wang 1992]

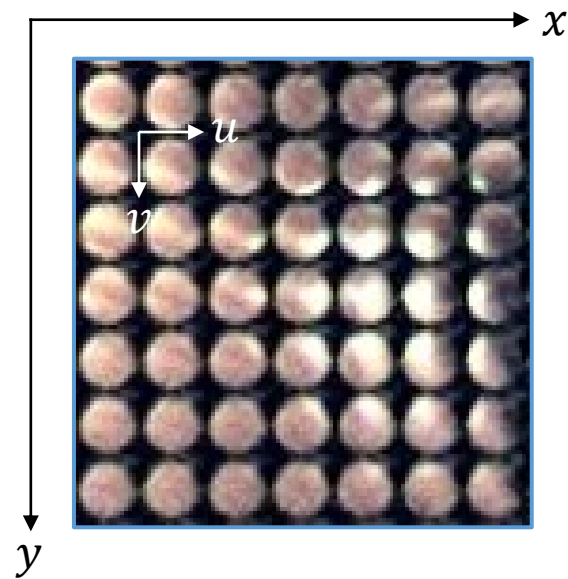
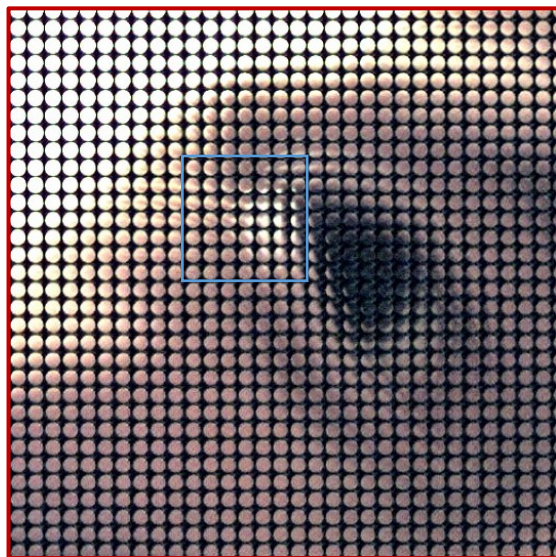
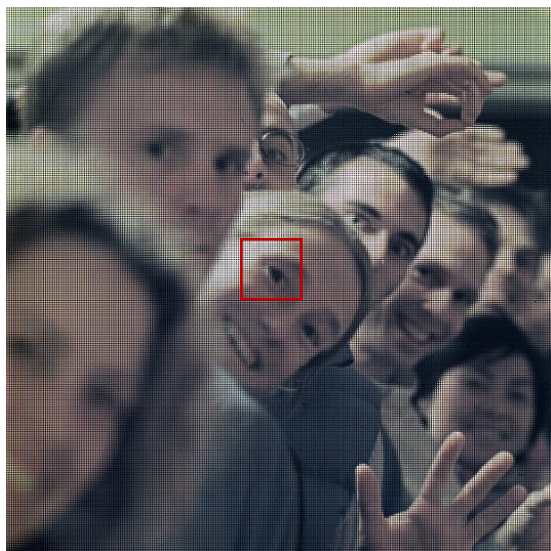


[Ng 2005]

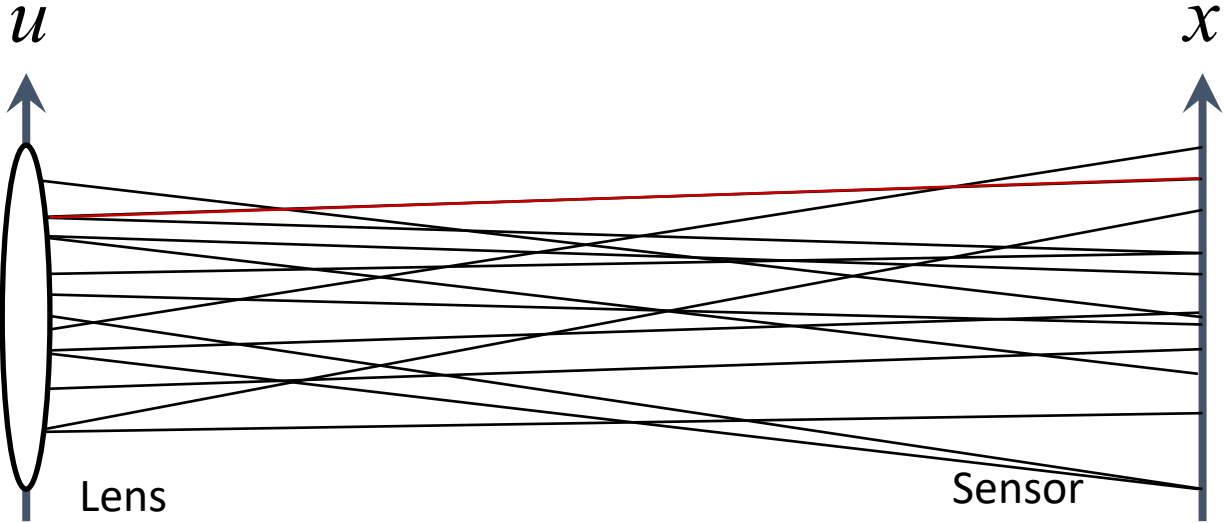
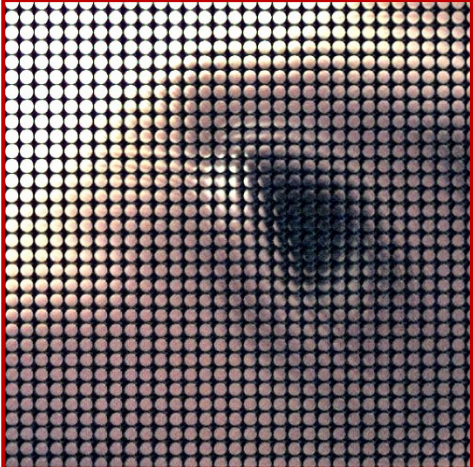
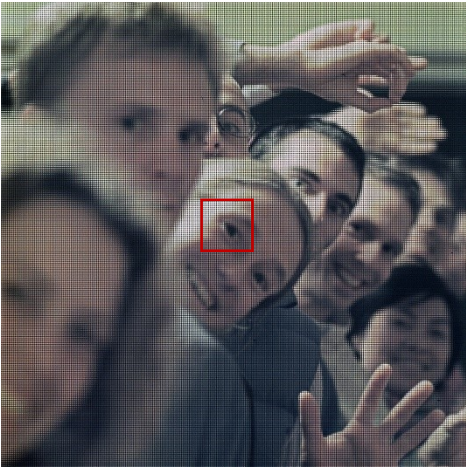
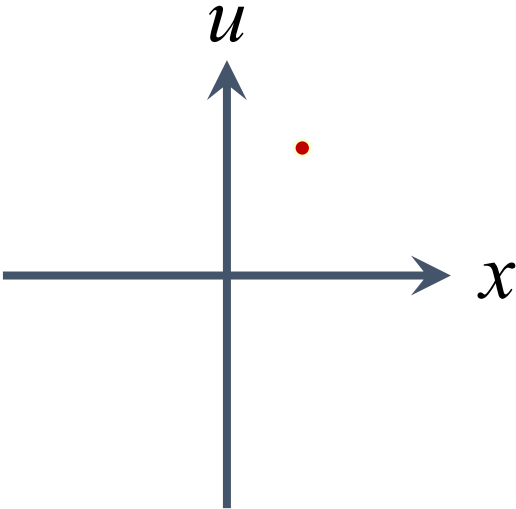
# 光场成像：光场相机



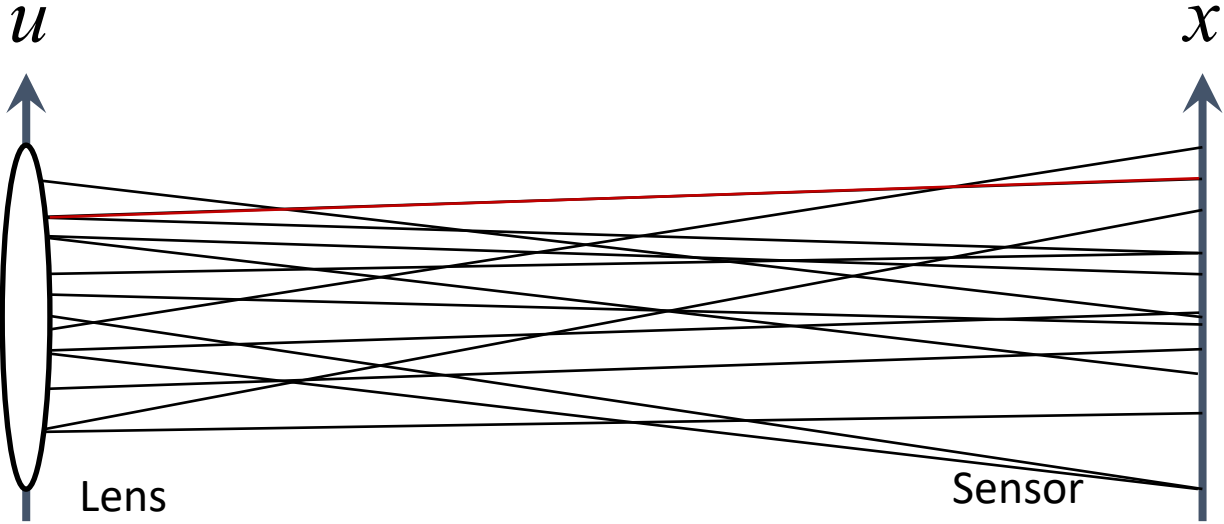
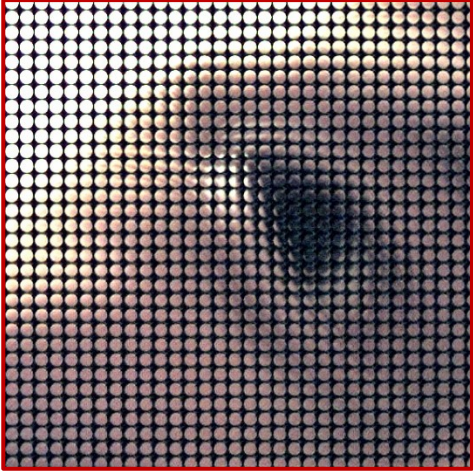
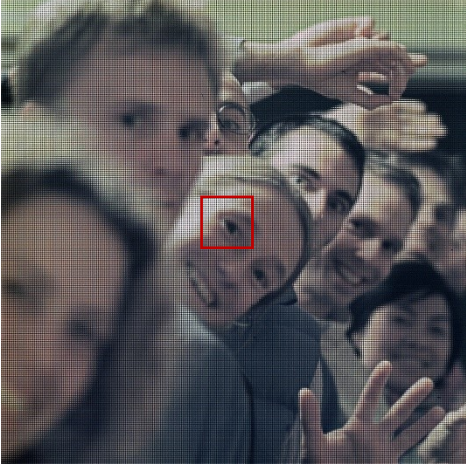
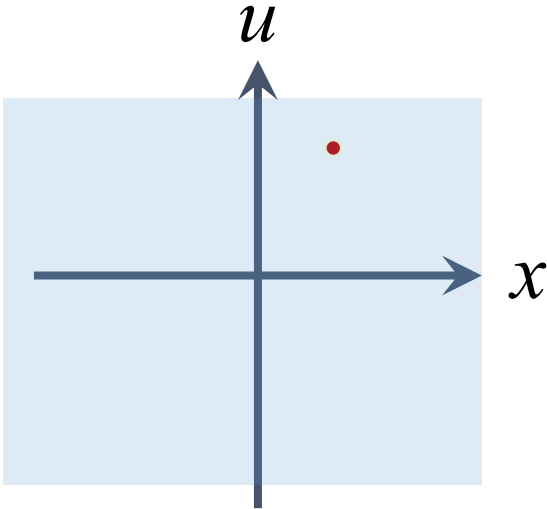
# 光场成像：光场相机



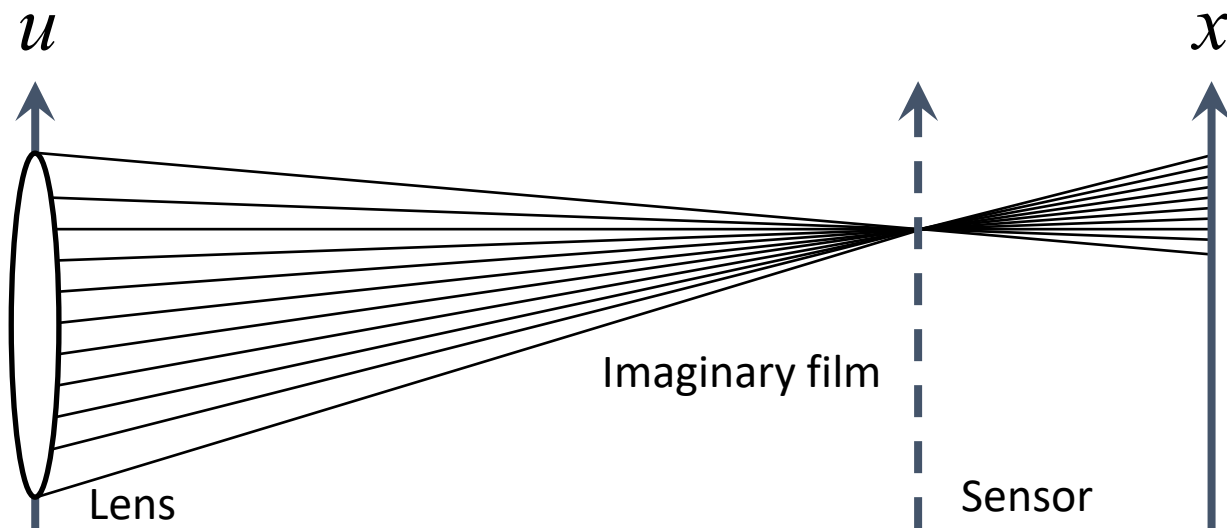
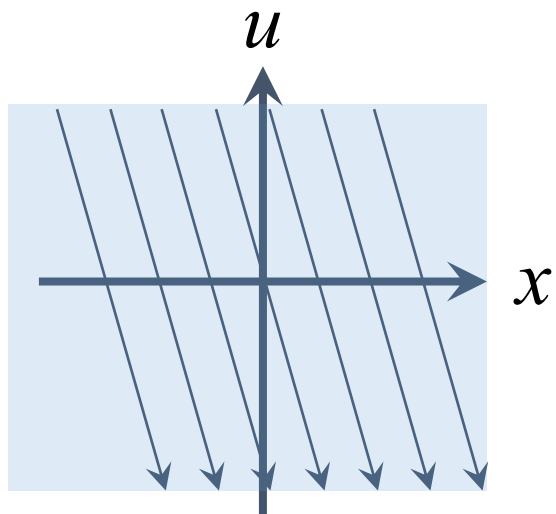
# 光场成像：光场相机 数字重聚焦



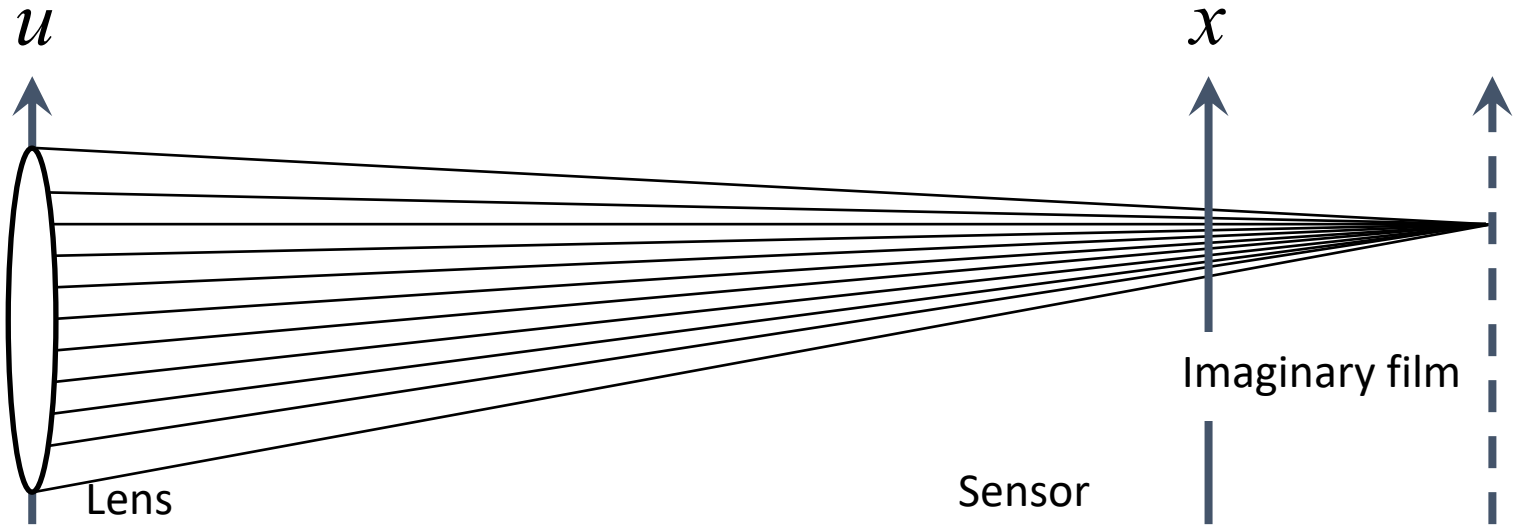
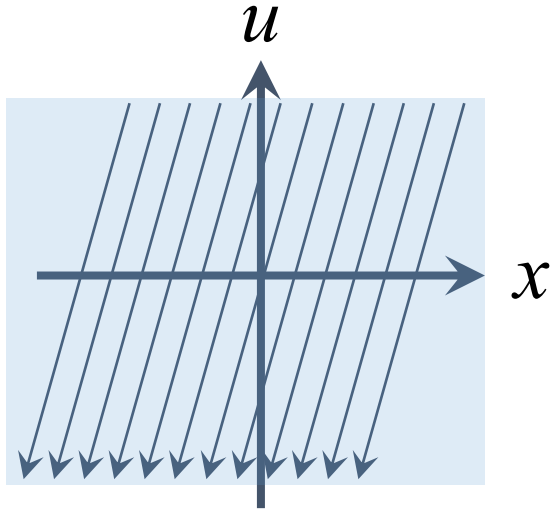
# 光场成像：光场相机 数字重聚焦



# 光场成像：光场相机 数字重聚焦

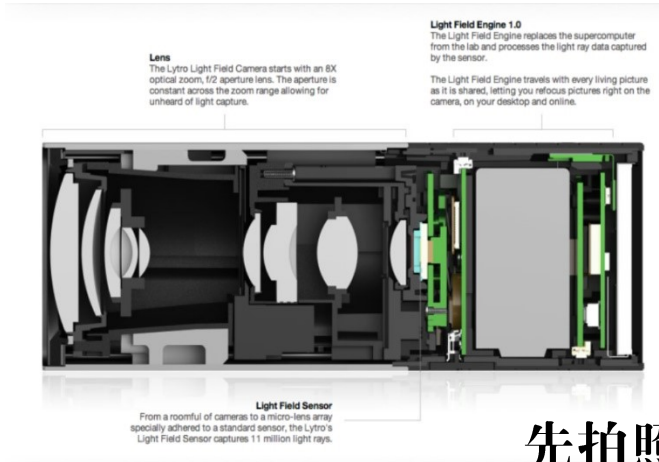


# 光场成像：光场相机 数字重聚焦





# 光场成像：光场相机-Lytro



先拍照，后聚焦

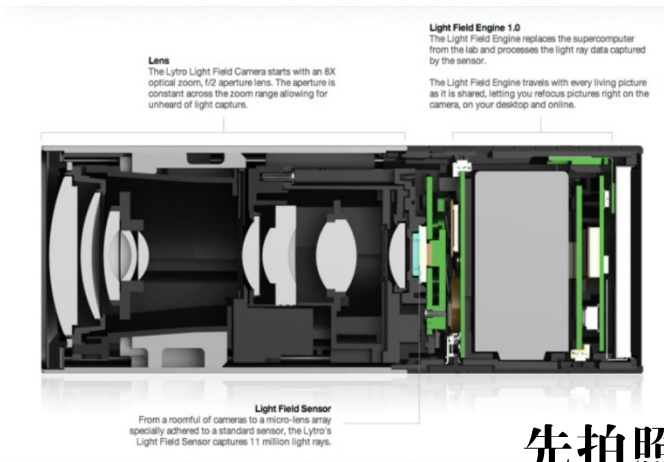
# 光场成像：光场相机-Lytro

优酷

LYTRO  
ILLUM



# 光场成像：光场相机-Lytro



先拍照，后聚焦

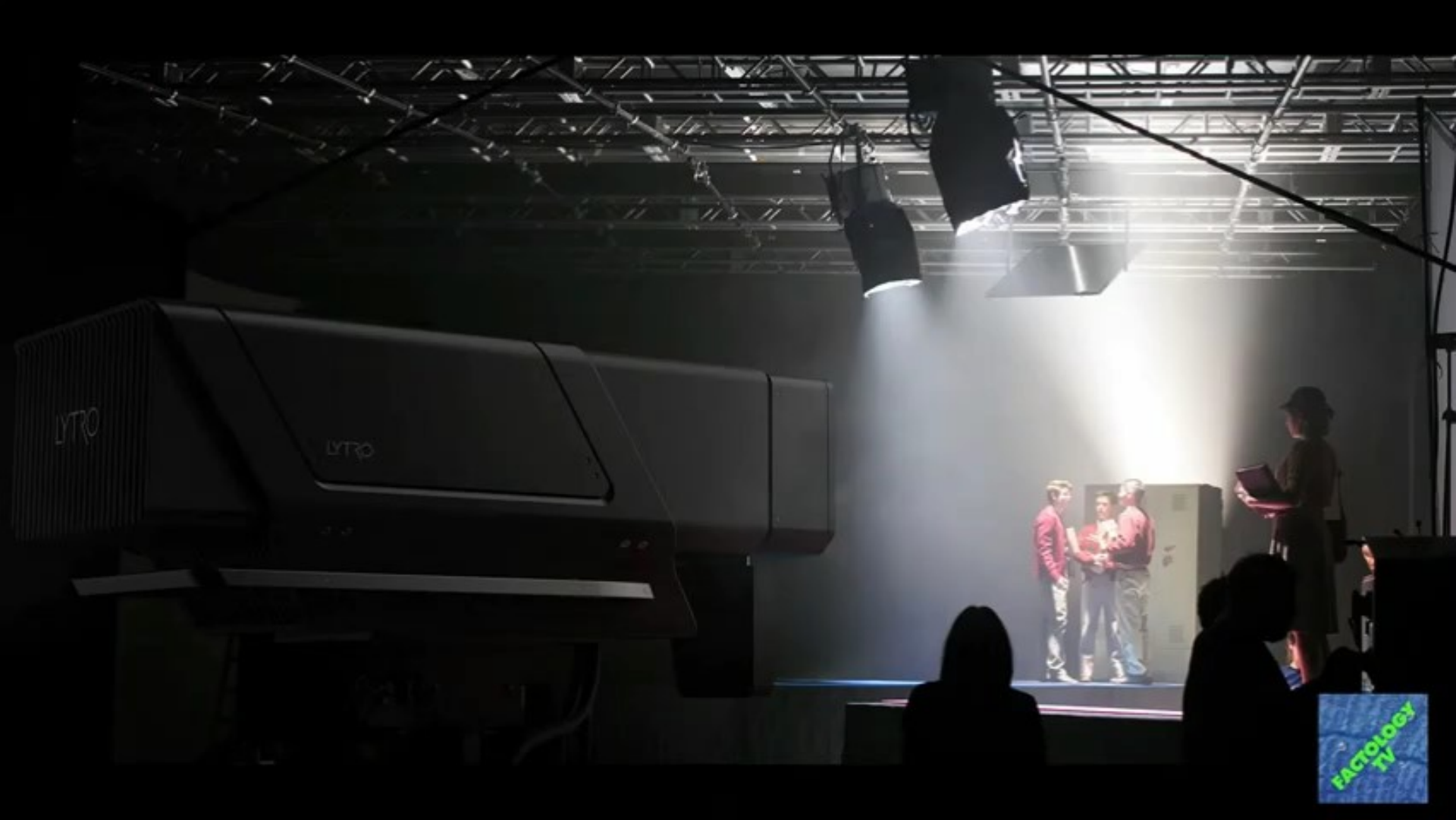


电影光场摄像系统

# 光场成像：光场相机-Lytro



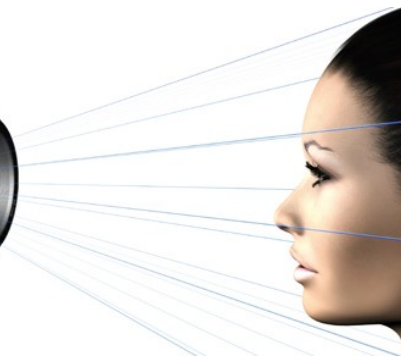
# 光场成像：光场相机-Lytro



# 光场成像：光场相机-Raytrix

## 3D light field cameras

- single lens
- calibration-free
- high resolution 3D depth
- extended depth-of-field
- one shot software refocus

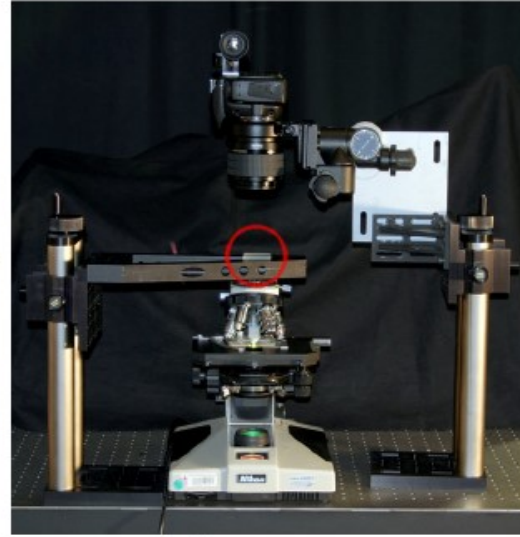
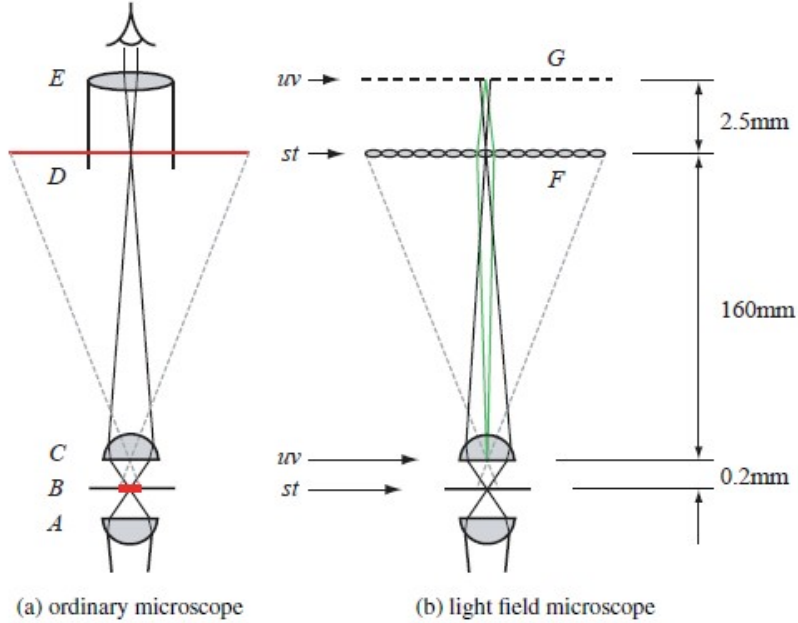


 **raytrix**  
3D light field cameras

[www.raytrix.de](http://www.raytrix.de)



# 光场成像：光场显微

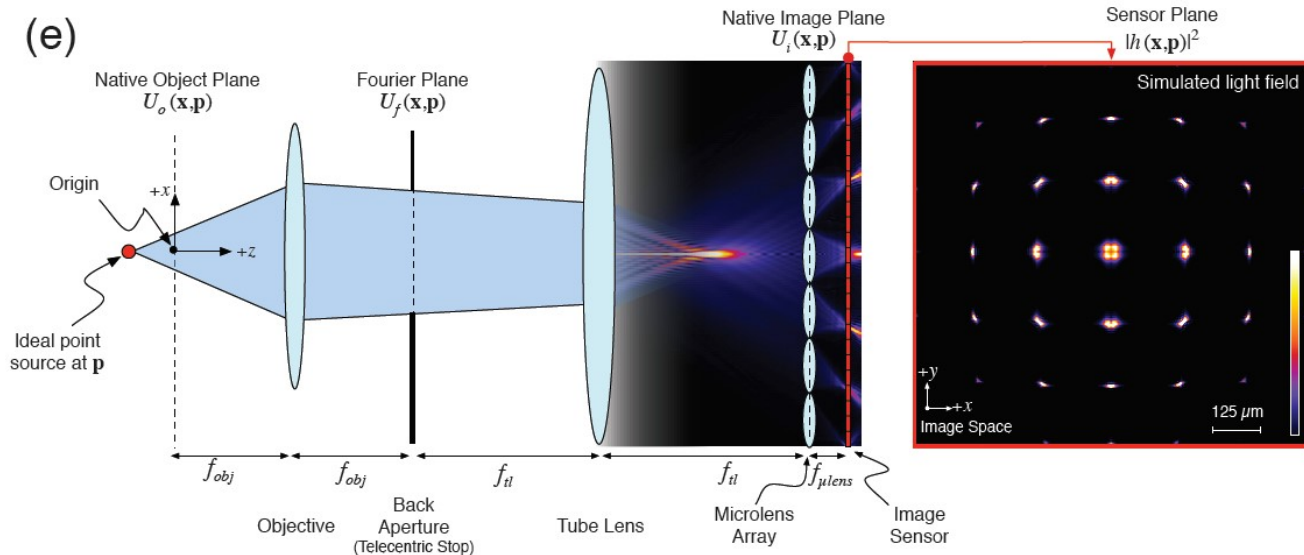


## 几何光学模型

[Levoy et al. 2006]

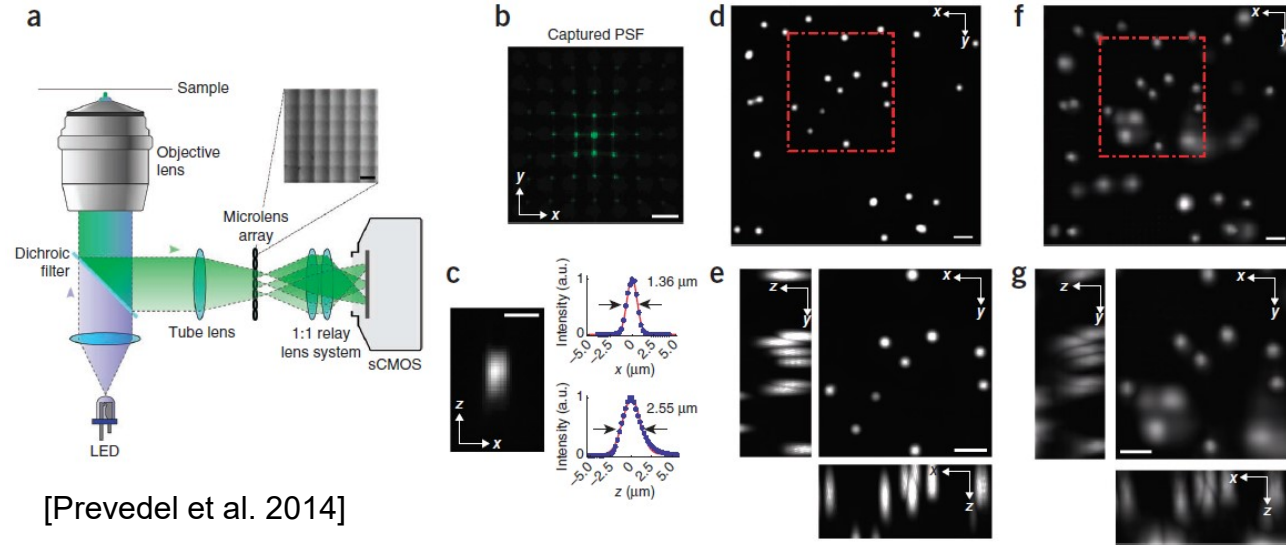
## 波动光学模型

[Broxton et al. 2013]

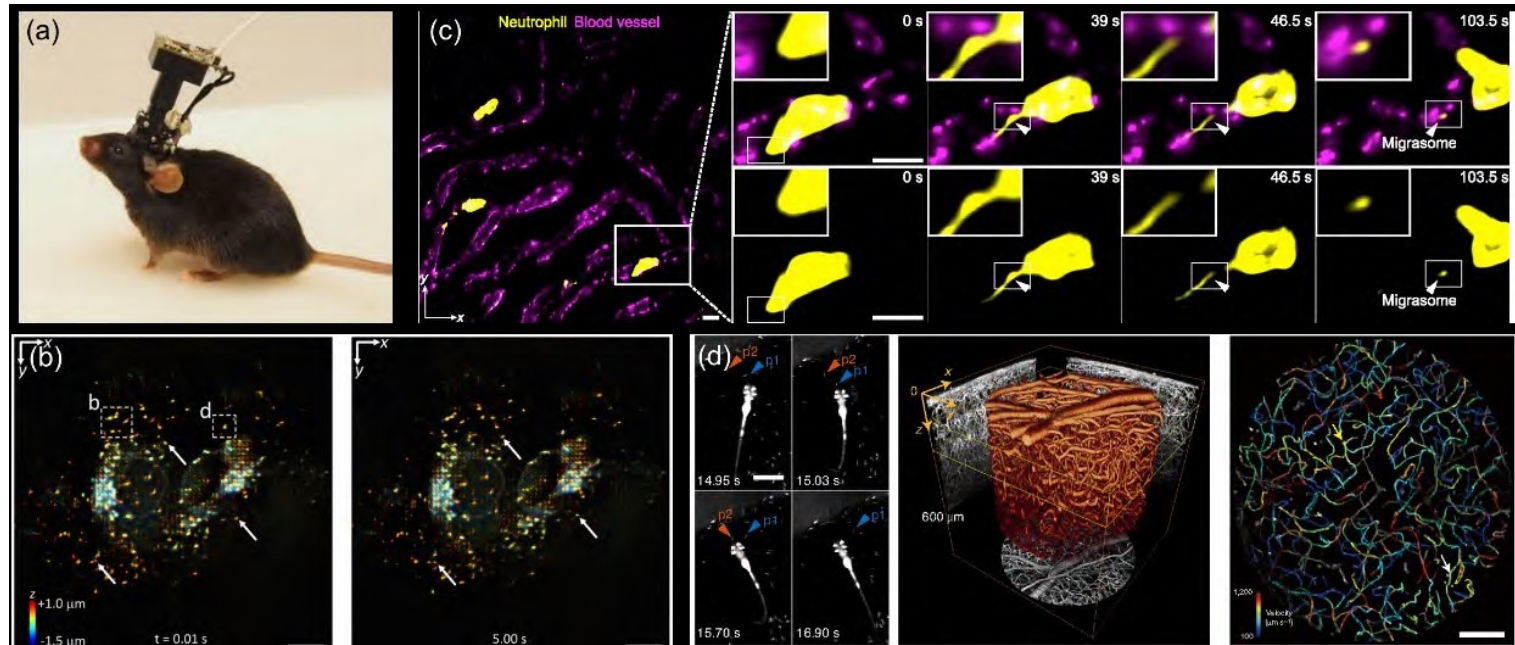




# 光场成像：光场显微

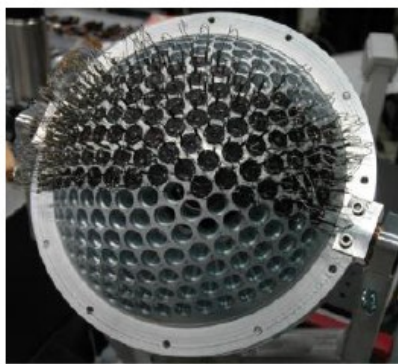
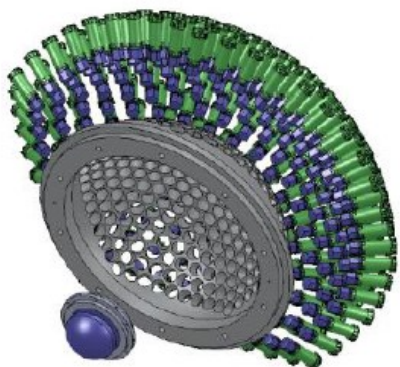
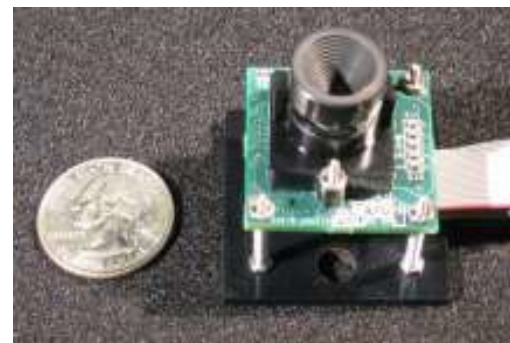
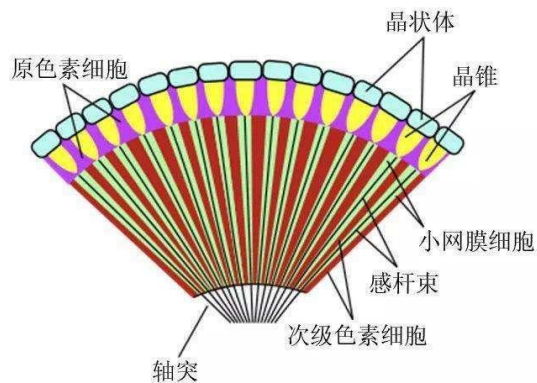
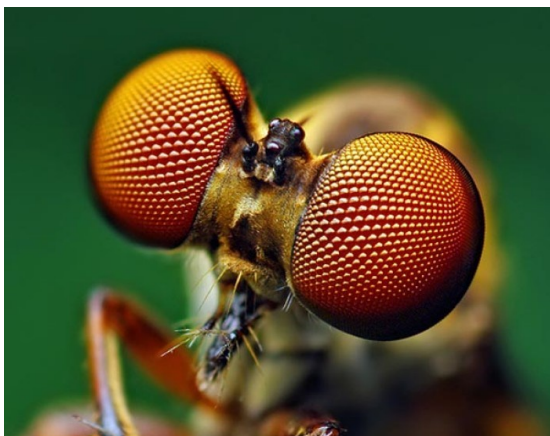


[Prevedel et al. 2014]



[Skocek et al. 2018; Li et al. 2019; Wu et al. 2021; Zhang et al. 2021]

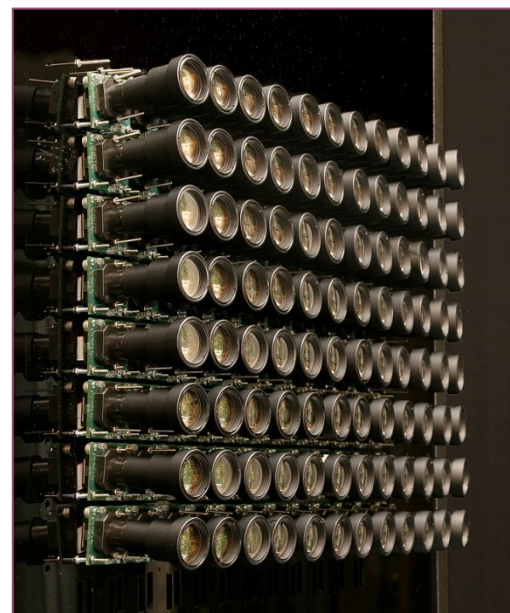
# 光场成像：相机阵列



[Brady et al. 2012]

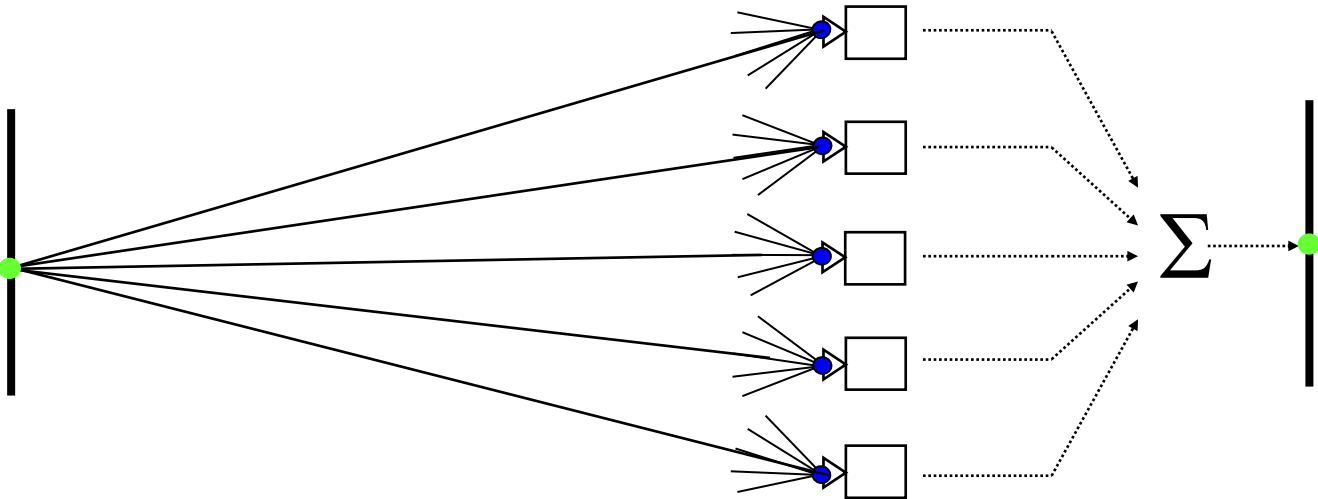
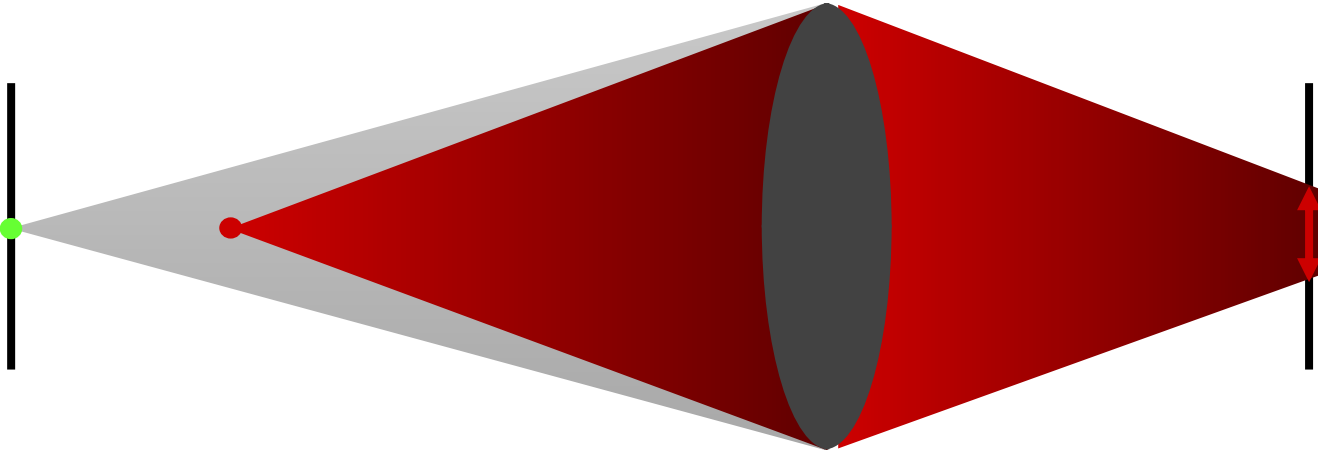


[Song et al. 2013]



[Wilburn et al. 2005]

# 光场成像：相机阵列 合成孔径



# 光场成像：相机阵列 合成孔径

去遮挡



# 光场成像：相机阵列 全景成像

几何和颜色校正前



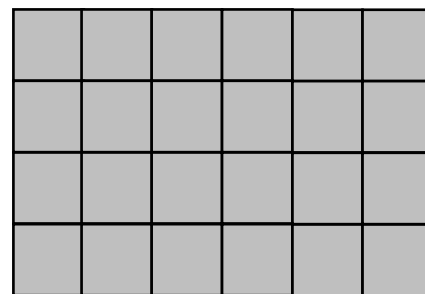
# 光场成像：相机阵列 全景成像

几何和颜色校正后

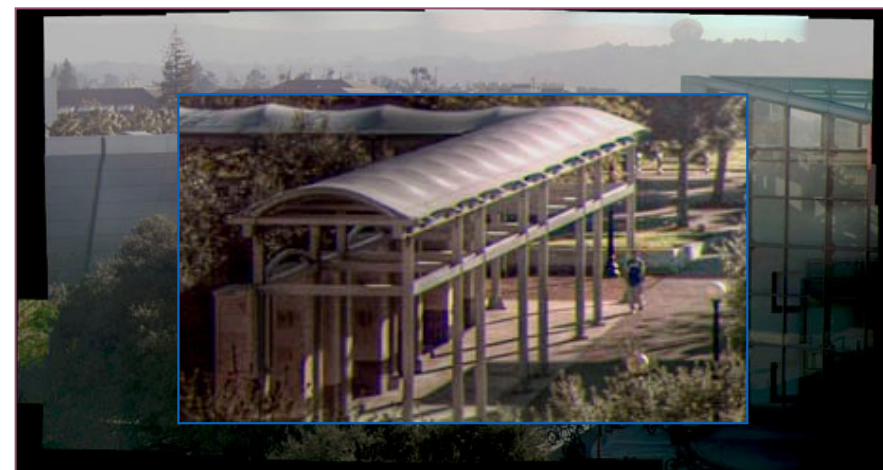
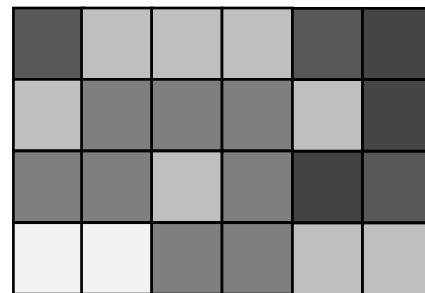




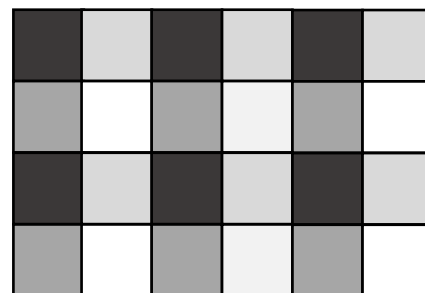
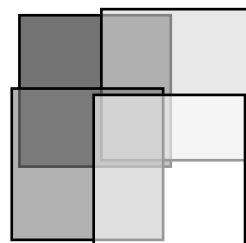
相同曝光时间



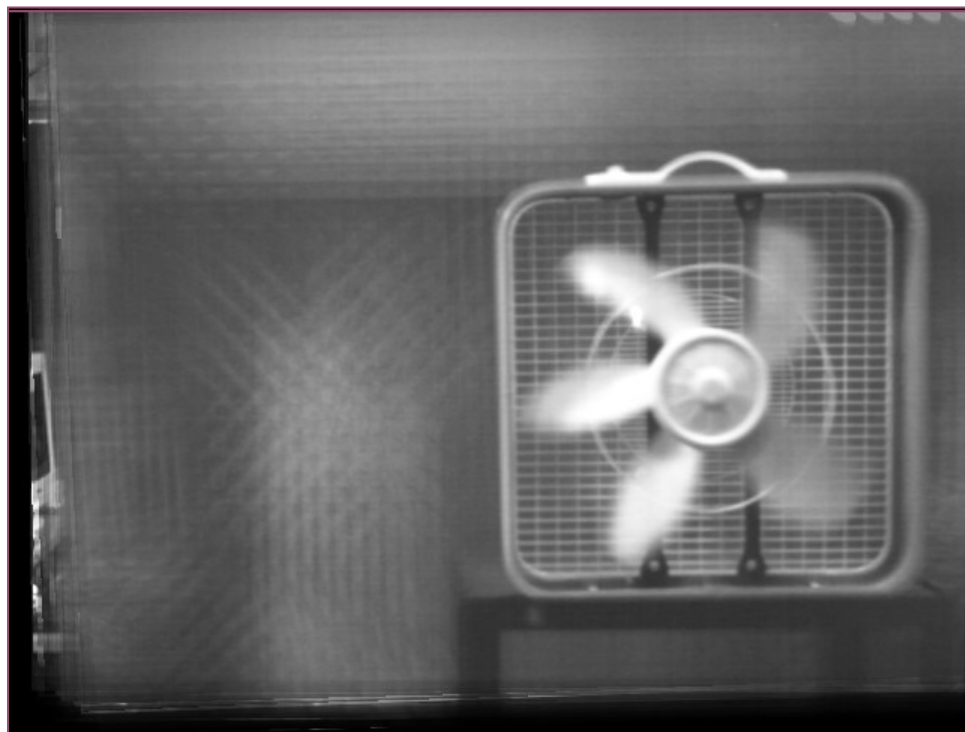
不同曝光时间



交错曝光



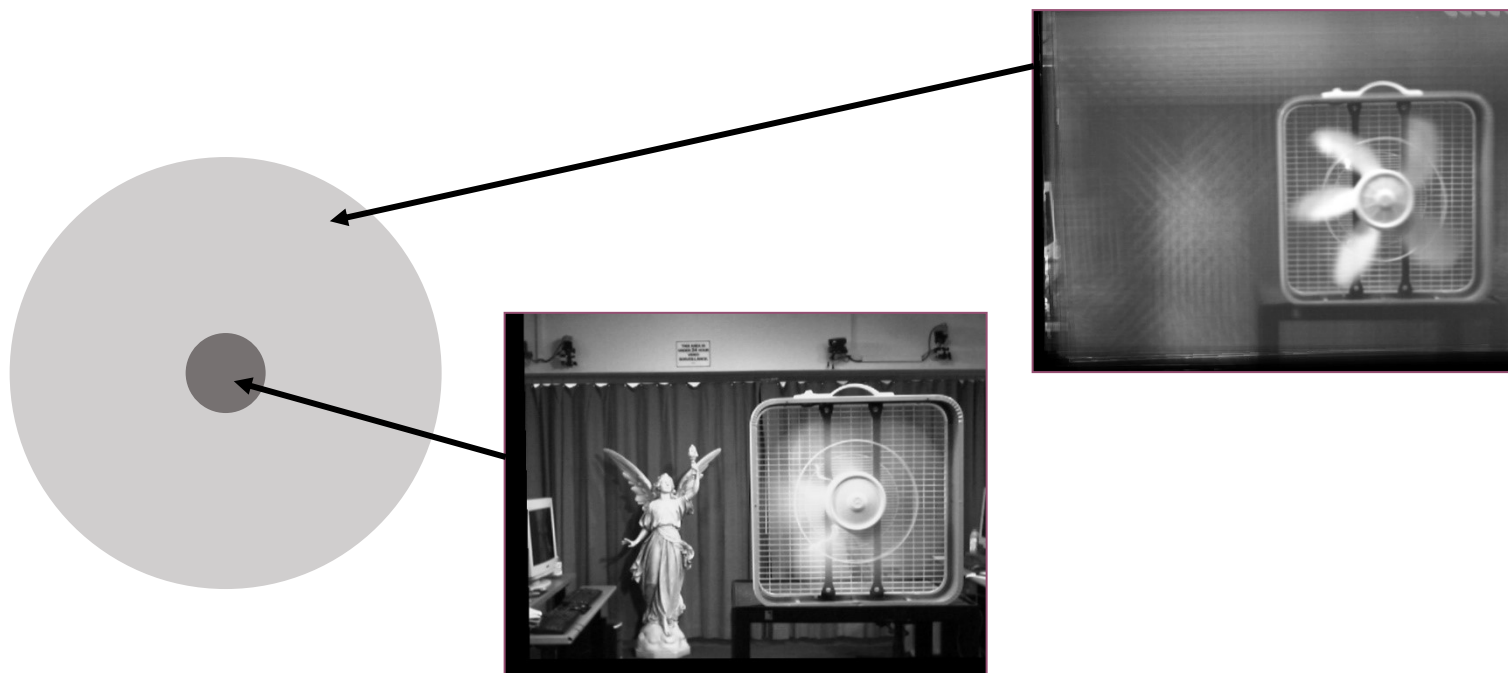
# 光场成像：相机阵列 计算孔径成像



- 减少曝光时间捕捉动态场景 → 太暗
- 增加对比度/增益 → 噪声
- 增大（合成）孔径获得更高光通量 → 景深缩短



# 光场成像：相机阵列 计算孔径成像

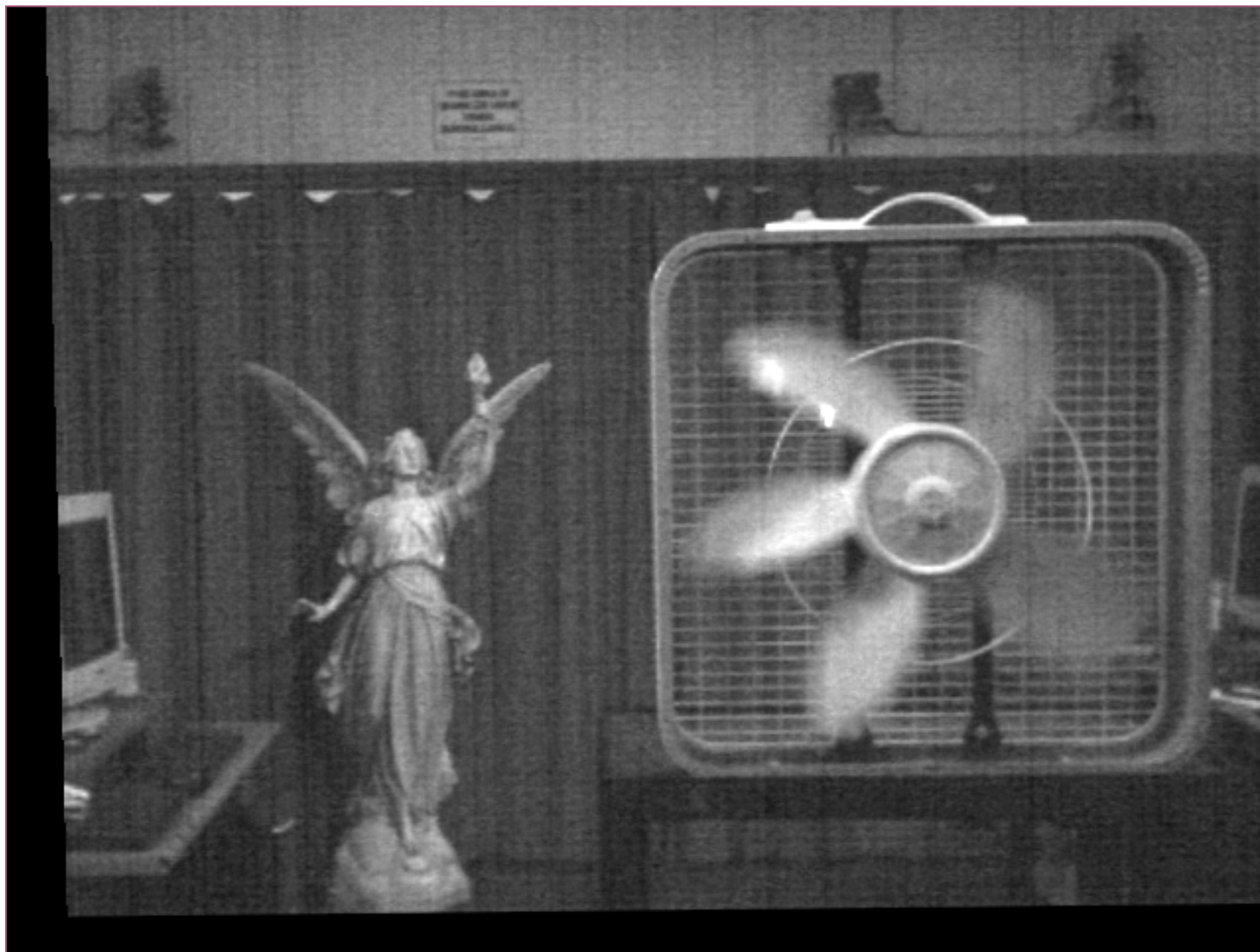


- 中间孔径：少数相机，长曝光 → 景深大，噪声低，但运动模糊
- 边缘孔径：多数相机，短曝光 → 捕捉动态，噪声低，但景深小

# 光场成像：相机阵列 计算孔径成像



# 光场成像：相机阵列 计算孔径成像



# **High Performance Imaging Using Large Arrays of Cameras**

**Online ID: papers\_0440**

# 光场渲染



西瓜视频

影视CHARM  
精彩新奇



*Thank you*