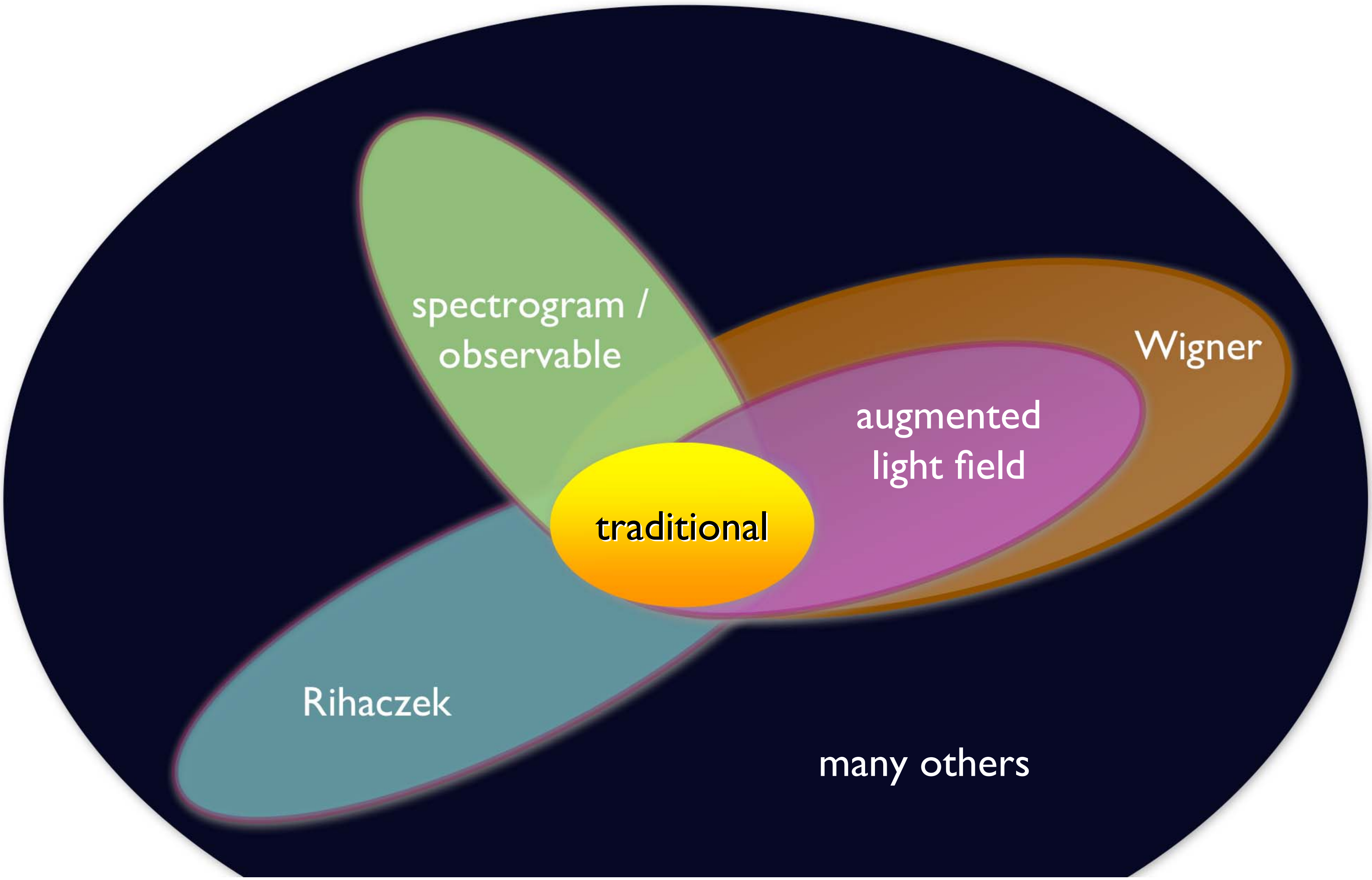
Light Fields in Ray and Wave Optics

Introduction to Light Fields	Ramesh Raskar
Wigner Distribution Function to explain Light Fields	Zhengyun Zhang
Augmenting LF to explain Wigner Distribution Function	Se Baek Oh
Q&A	
Break	
Light Fields with Coherent Light	**Anthony Accardi**
New Opportunities and Applications	Raskar and Oh
Q&A	All

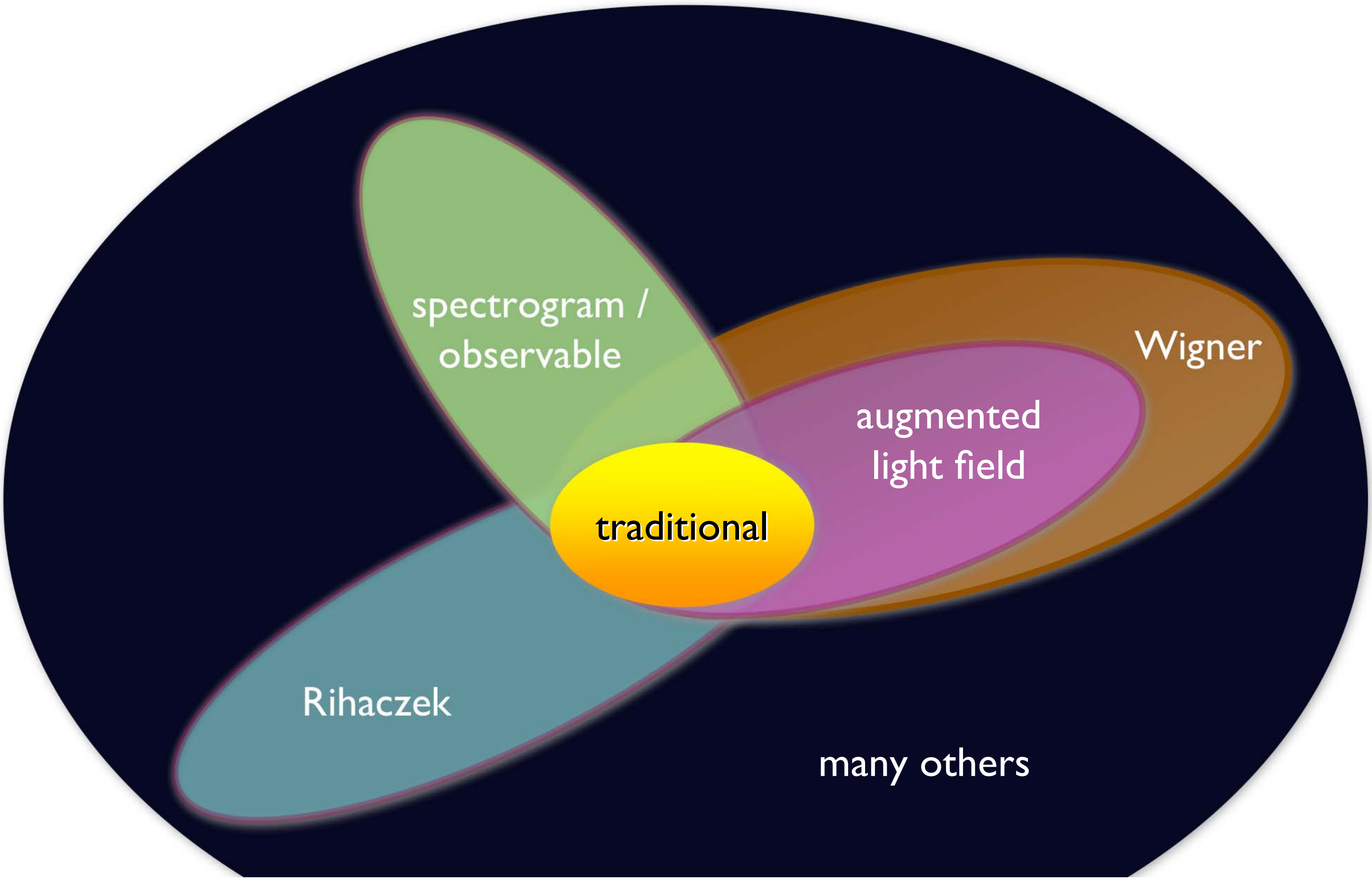
Generalized radiance functions

Phase-space distributions / quasi-probability distributions

Quadratic class of time-frequency distributions / Cohen's class



Quasi light fields

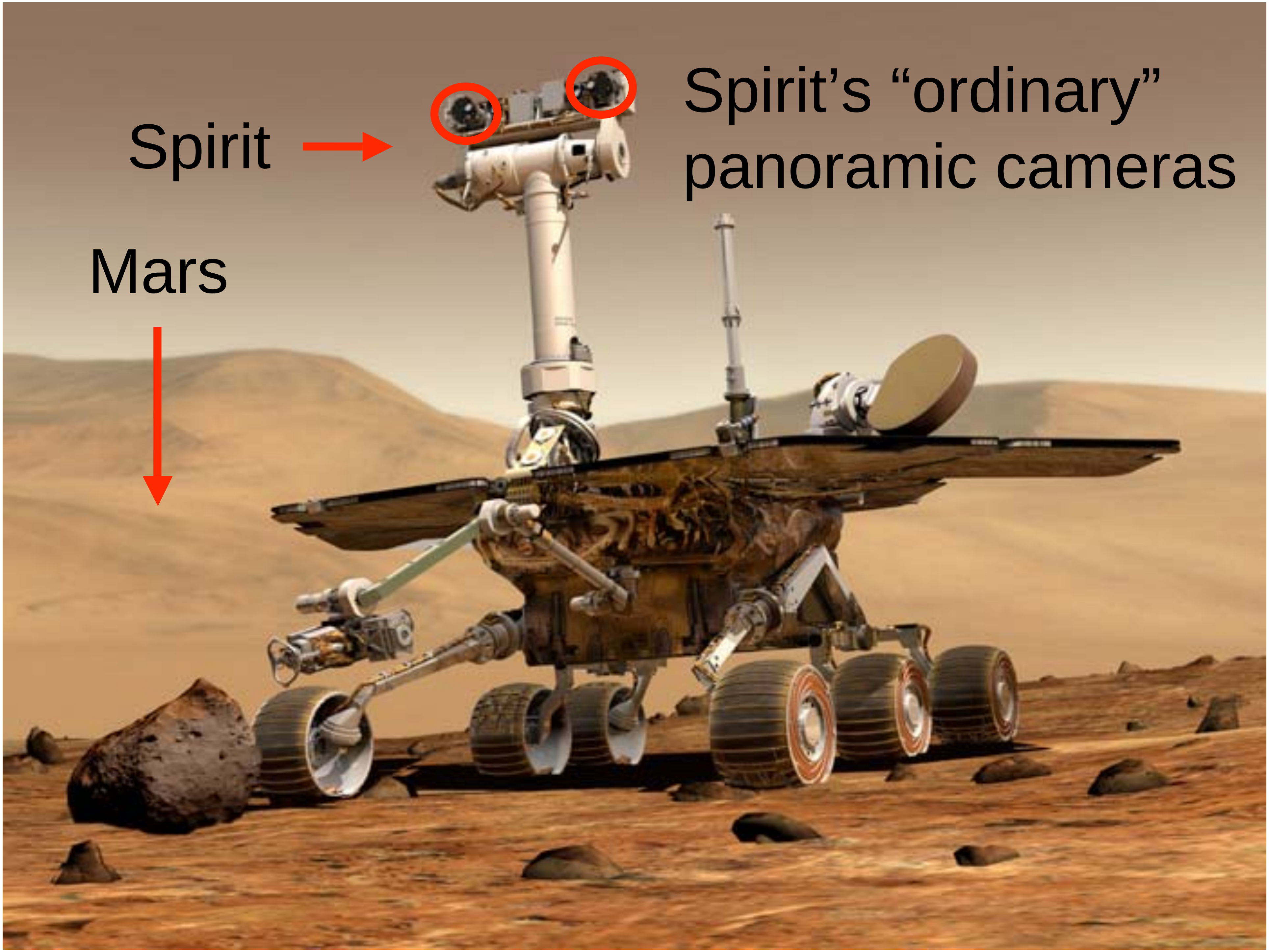


Quasi light fields

extending the light field to coherent radiation

Anthony Accardi
Gregory Wornell

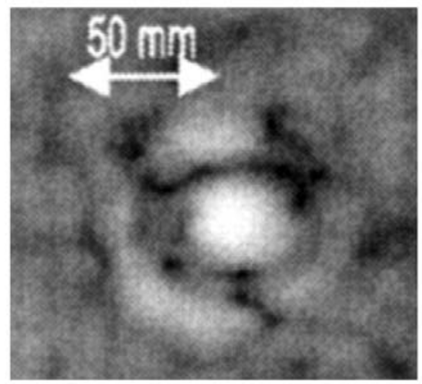
June 20, 2009


Spirit
Spirit's "ordinary" panoramic cameras
Mars

Millimeter-wave radar is the right size for new applications

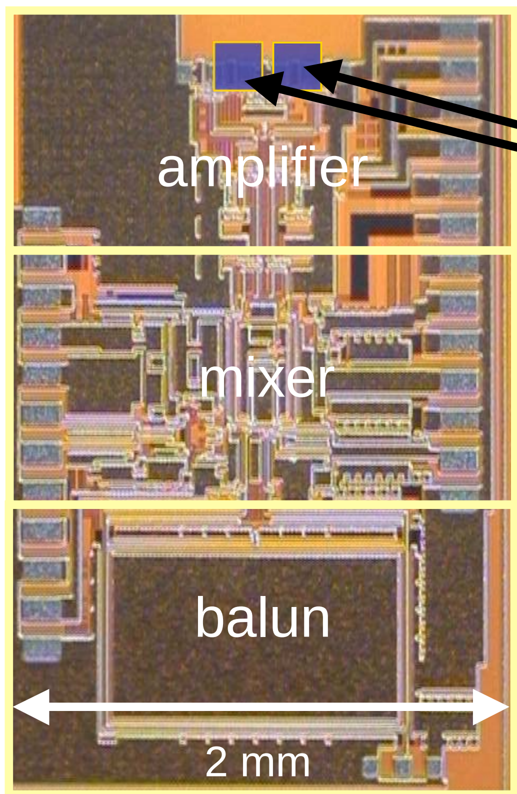
avoid car accidents

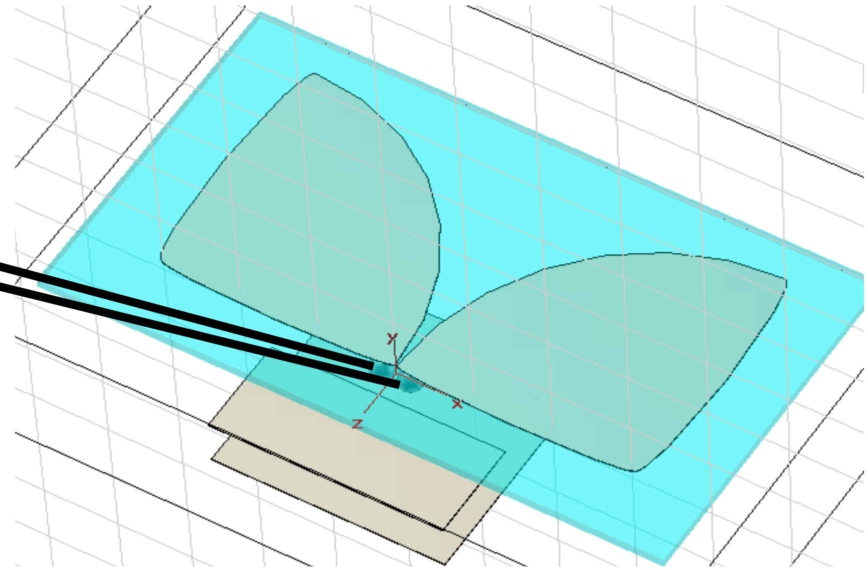
discover landmines

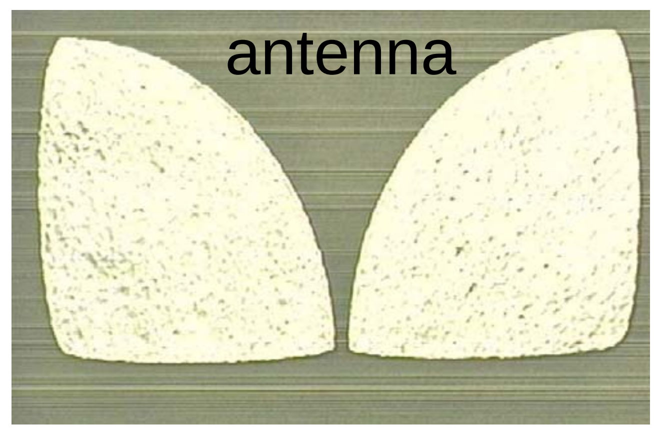


find concealed weapons

Millimeter-wave circuitry is small and cheap





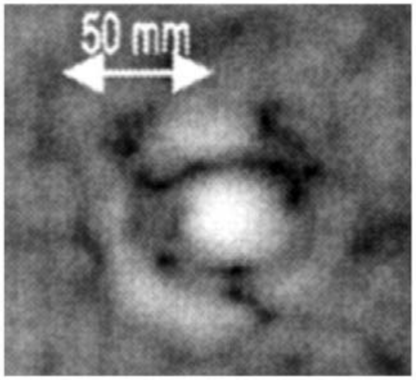


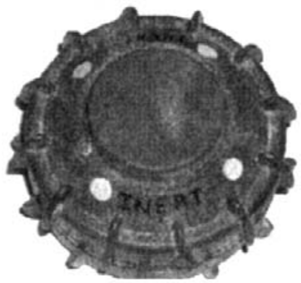
supporting circuitry
(100 GHz in silicon!)

But how do we solve these problems?

estimate car position and velocity?

match landmine pattern?





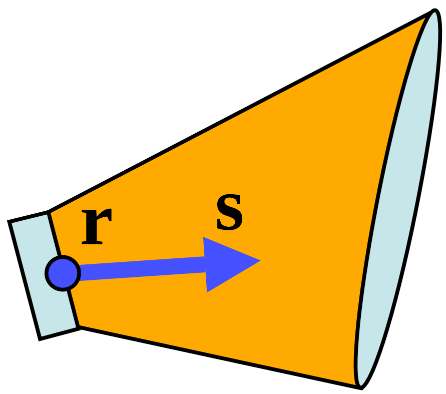
identify what is out of the ordinary?

Opportunity to use light field for many more imaging applications

3D television

holography

incoherent



?

coherent

plenoptic camera

ultrasound

Quasi light fields

the utility of light fields, the versatility of Maxwell

We form coherent images by

formulating,

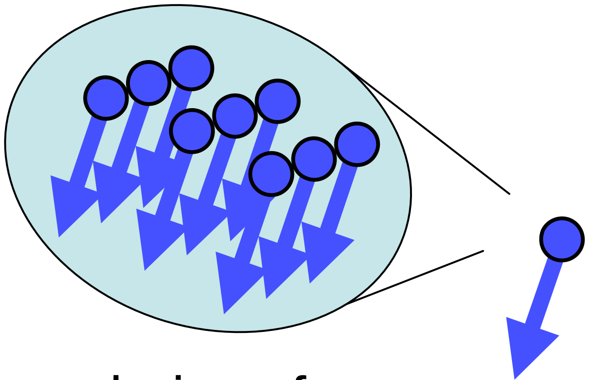
capturing,

and integrating

quasi light fields.

Quasi light fields

the utility of light fields, the versatility of Maxwell



choice of
light field

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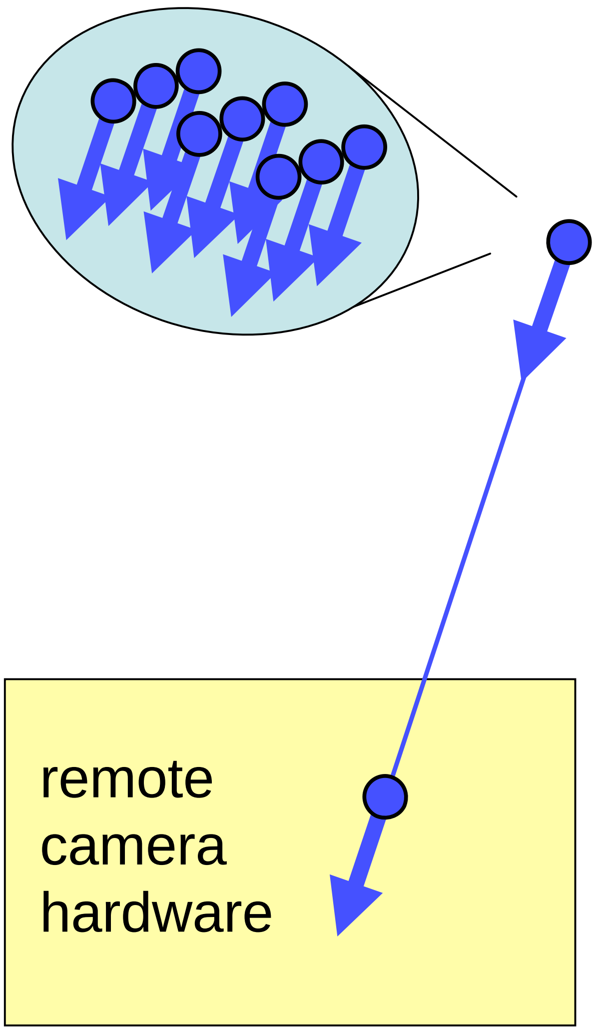
Quasi light fields

the utility of light fields, the versatility of Maxwell



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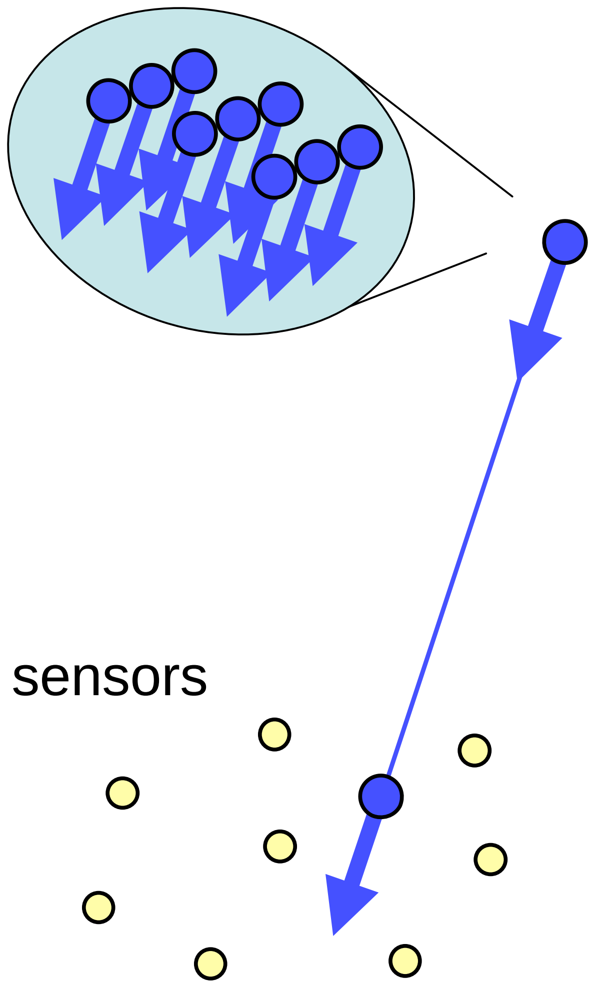

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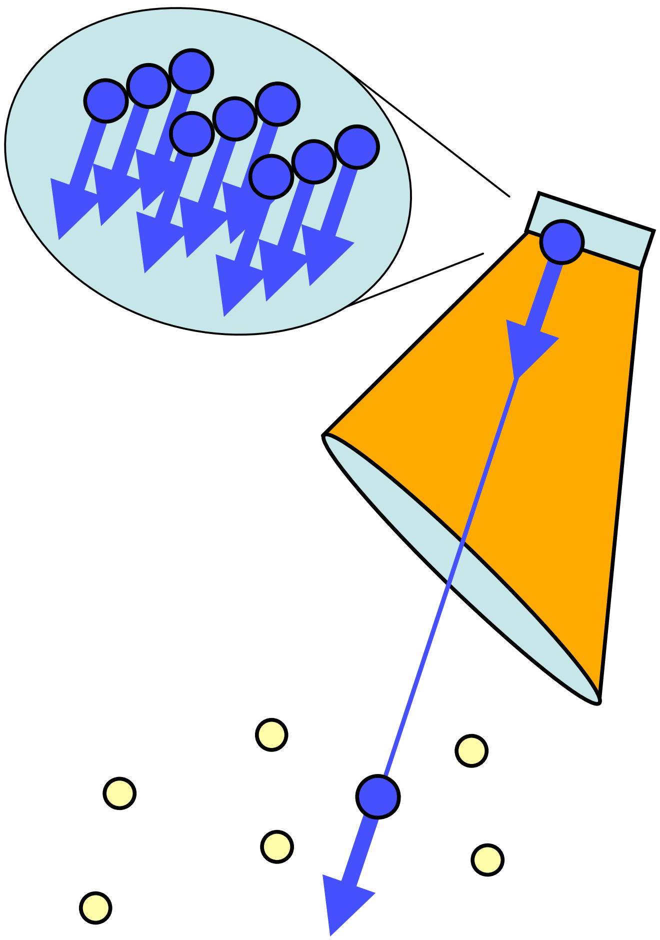

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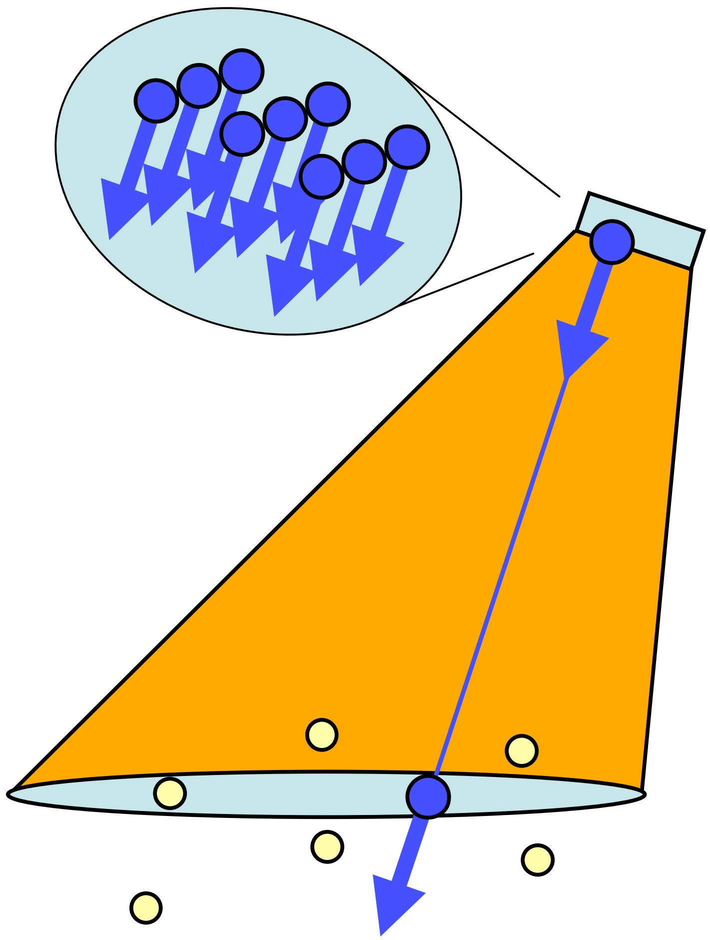

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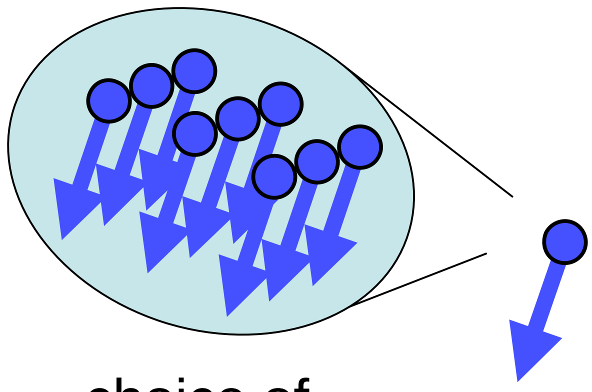


choice of
light field

We form coherent images by

formulating,

Distribute energy
over **r** and **s**

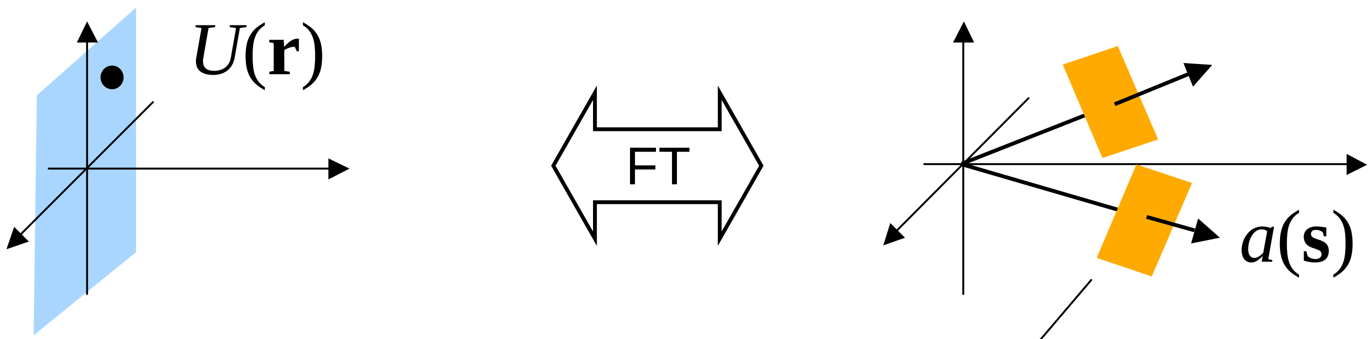
Match energy with
scalar field U

capturing,

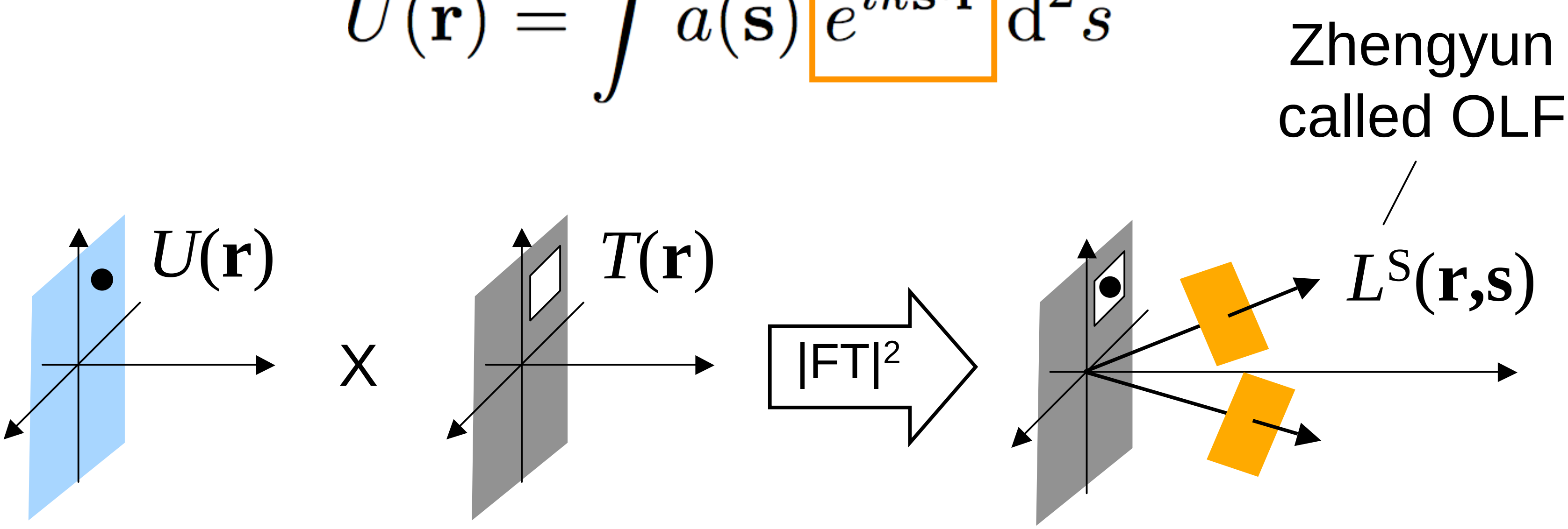
and integrating

quasi light fields.

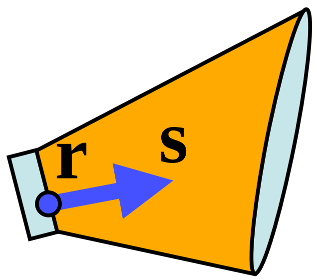
Fourier maps **r** to **s**, revealing spectrogram light field



$$U(\mathbf{r}) = \int a(\mathbf{s}) \boxed{e^{ik\mathbf{s}\cdot\mathbf{r}}} \mathrm{d}^2 s$$



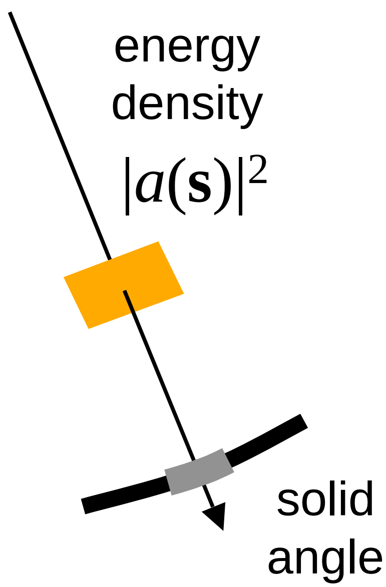
Matching energy reveals Wigner light field



$$\text{radiance (light field)} = \frac{\text{flux}}{\text{solid angle x projected area}}$$

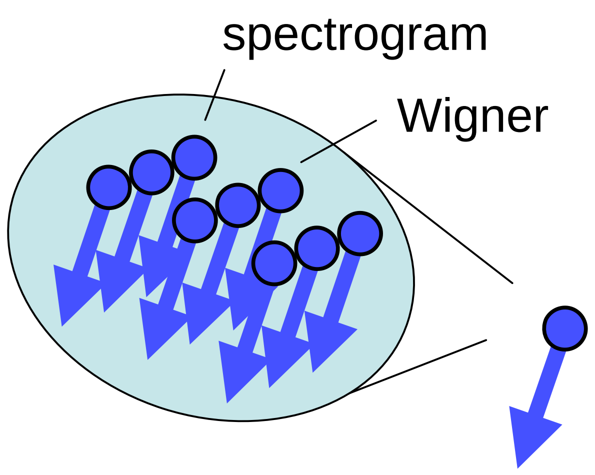
$$= \int \boxed{\int U\left(\mathbf{r}+\frac{1}{2}\mathbf{r}'\right) U^*\left(\mathbf{r}-\frac{1}{2}\mathbf{r}'\right) e^{-ik\mathbf{s}\cdot\mathbf{r}'}\,\mathrm{d}^2 r'}\,\mathrm{d}^2 r$$

$L^{\mathrm{W}}(\mathbf{r},\mathbf{s})$



$$\frac{\text{flux}}{\text{solid angle}} = |a(\mathbf{s})|^2$$

Quasi light fields



We form coherent images by

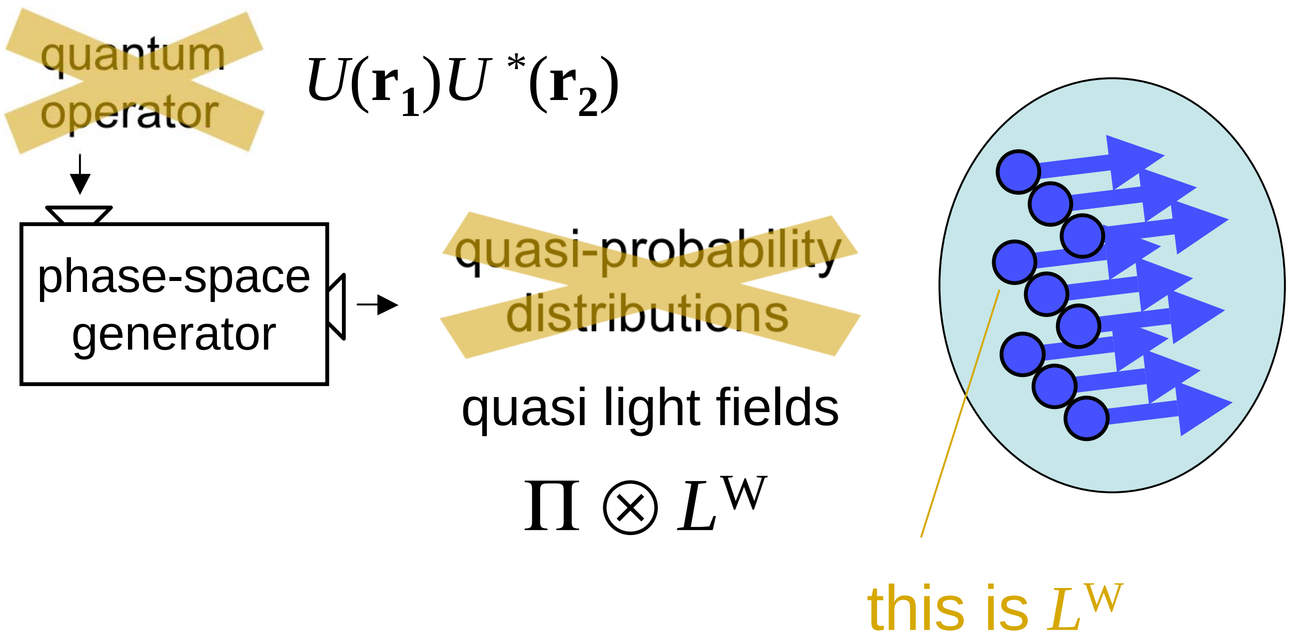
formulating, — Find the rest!

capturing,

and integrating

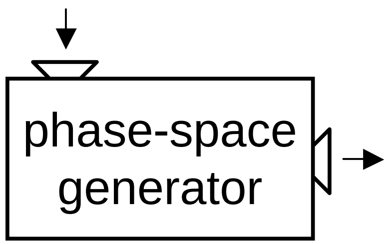
quasi light fields.

Exploit phase-space theory to generate all light fields



Exploit phase-space theory to generate all light fields

$U(\mathbf{r}_1)U^*(\mathbf{r}_2)$



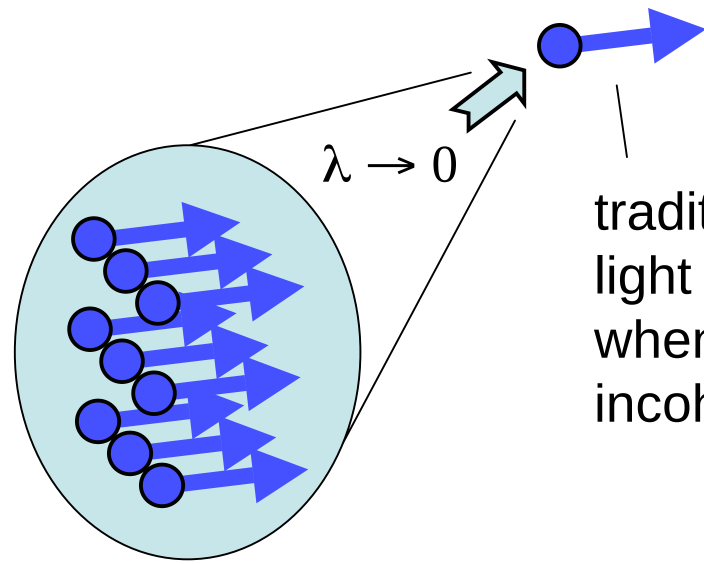
quasi light fields

$$\Pi \otimes L^{\mathrm{W}}$$

1:1

quadratic class of time-frequency distributions

(well-studied!)



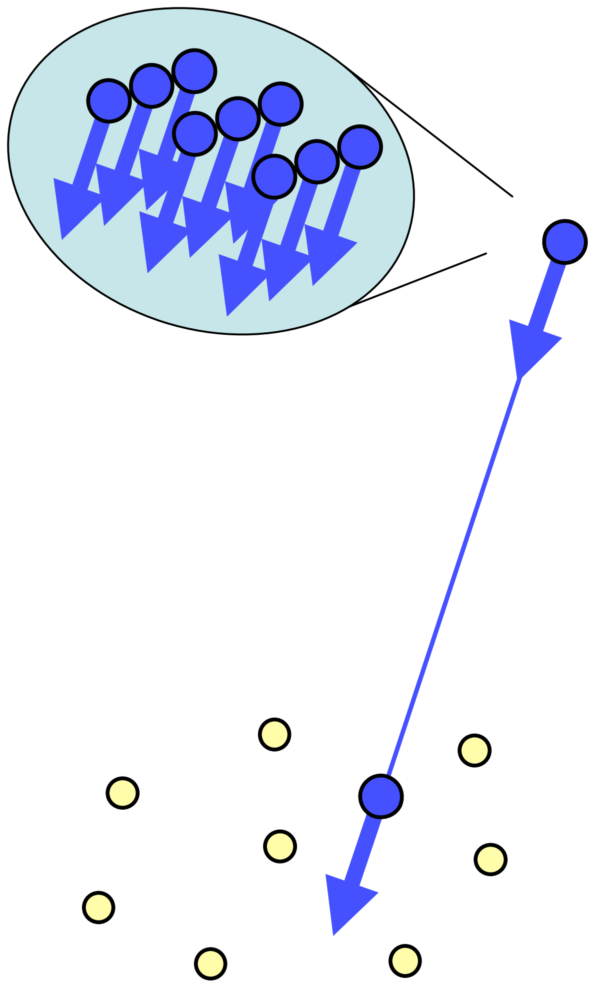
traditional light field when incoherent

position + direction shift invariant

$$U(\mathbf{r}) \rightarrow U(\mathbf{r}-\mathbf{r}_0)e^{ik\mathbf{s}_0\cdot\mathbf{r}}$$

$$L(\mathbf{r},\mathbf{s}) \rightarrow L(\mathbf{r}-\mathbf{r}_0,\mathbf{s}-\mathbf{s}_0)$$

Quasi light fields



We form coherent images by

formulating,

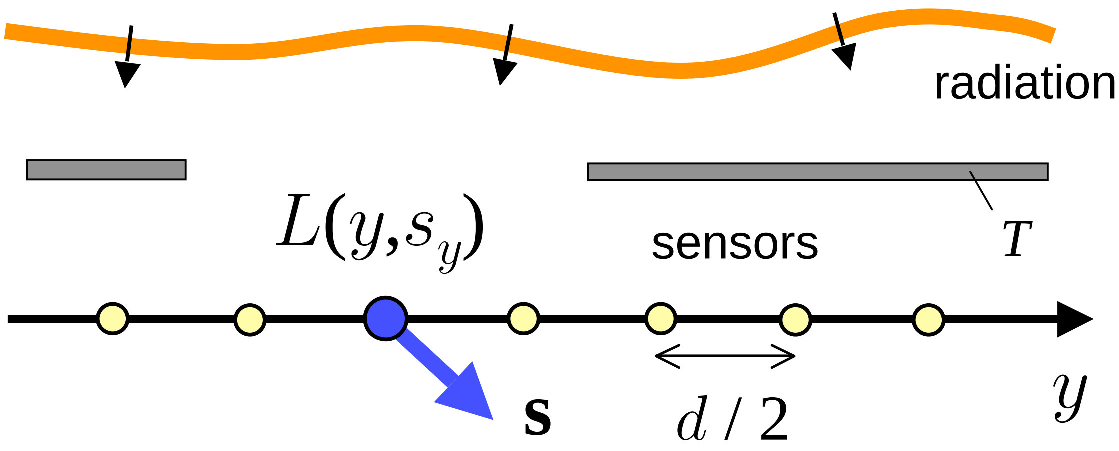
capturing,

- Sample scalar field and compute
- Compare three different light fields

and integrating

quasi light fields.

Compute any quasi light field from scalar field samples



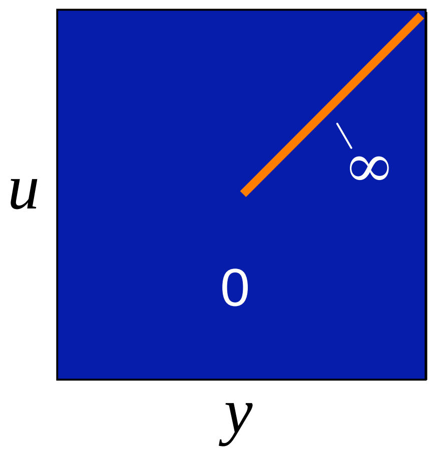
spectrogram $$L^{\mathrm{S}}(y, s_y) = \left| \sum_n T(nd) U(y + nd) e^{-iknds_y} \right|^2$$

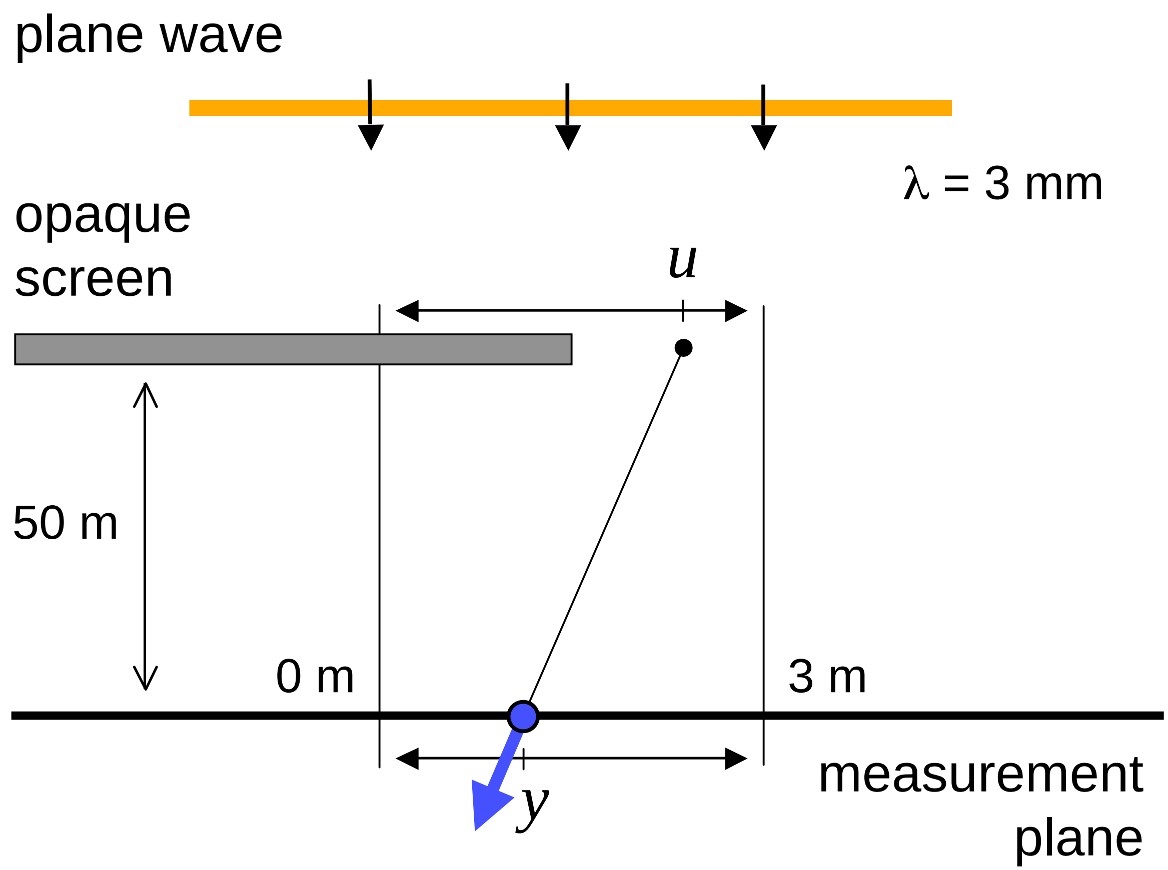
Wigner $$L^{\mathrm{W}}(y, s_y) = \sum_n U\left(y + \frac{1}{2}nd\right) U^*\left(y - \frac{1}{2}nd\right) e^{-iknds_y}$$

Rihaczek $$L^{\mathrm{R}}(y, s_y) = U^*(y) e^{ikys_y} \sum_n U(nd) e^{-iknds_y}$$

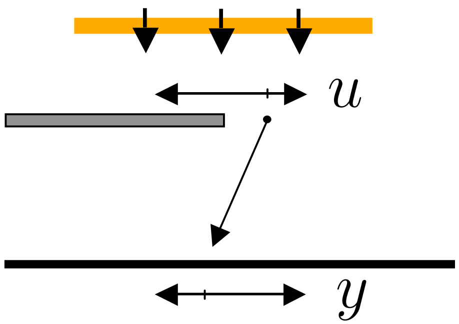
Estimate position of screen edge and direction of plane wave

ideal
light field

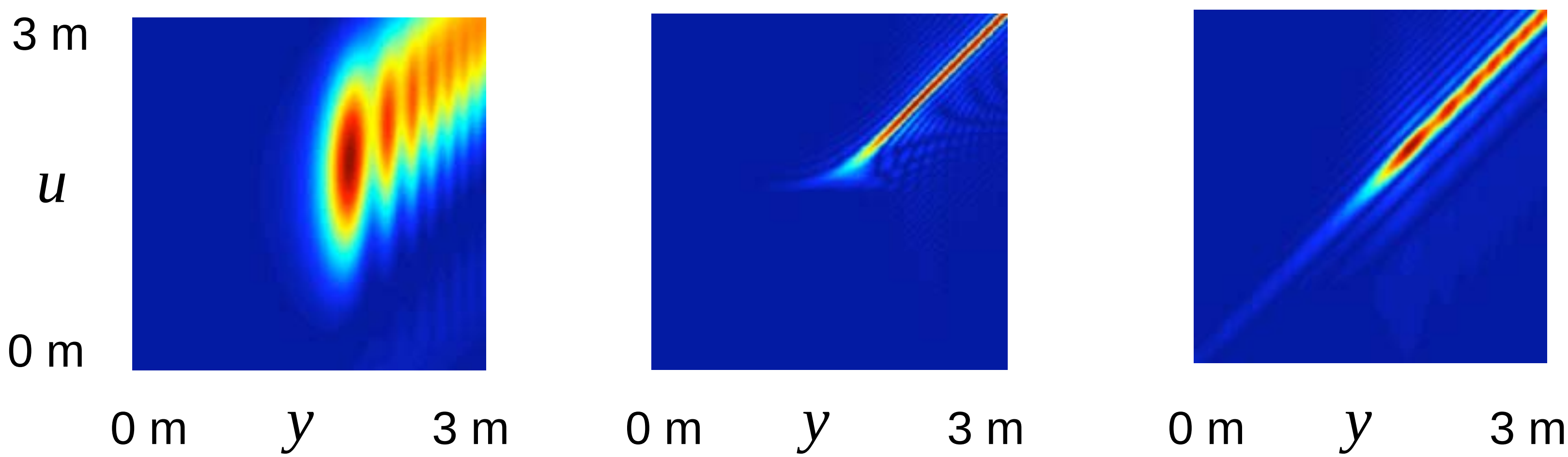




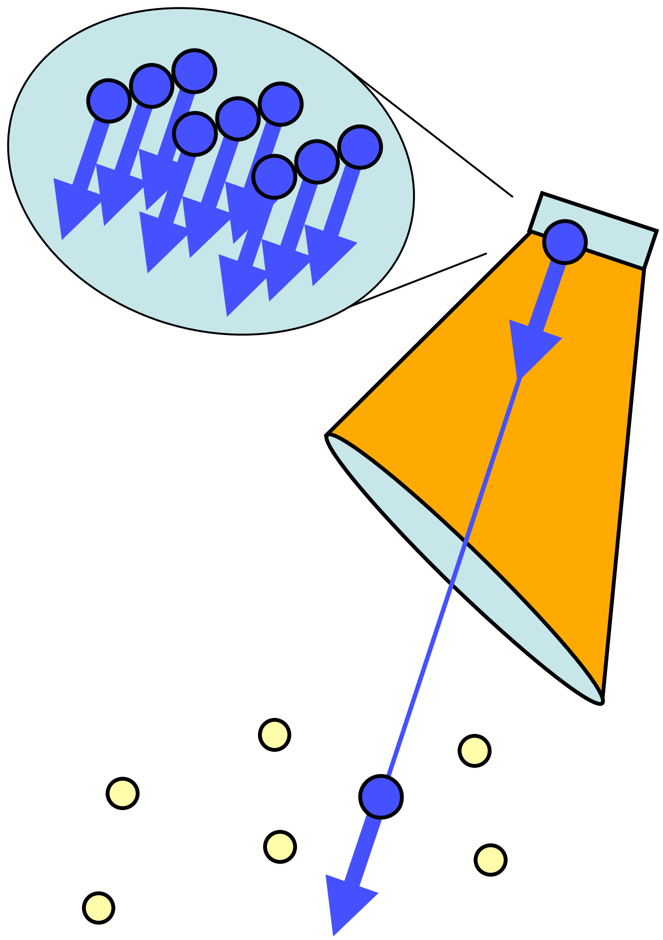
Each light field appropriate for different task



spectrogram	Wigner	Rihaczek
non-negative	localization	localization
localization	cross terms	complex



Quasi light fields



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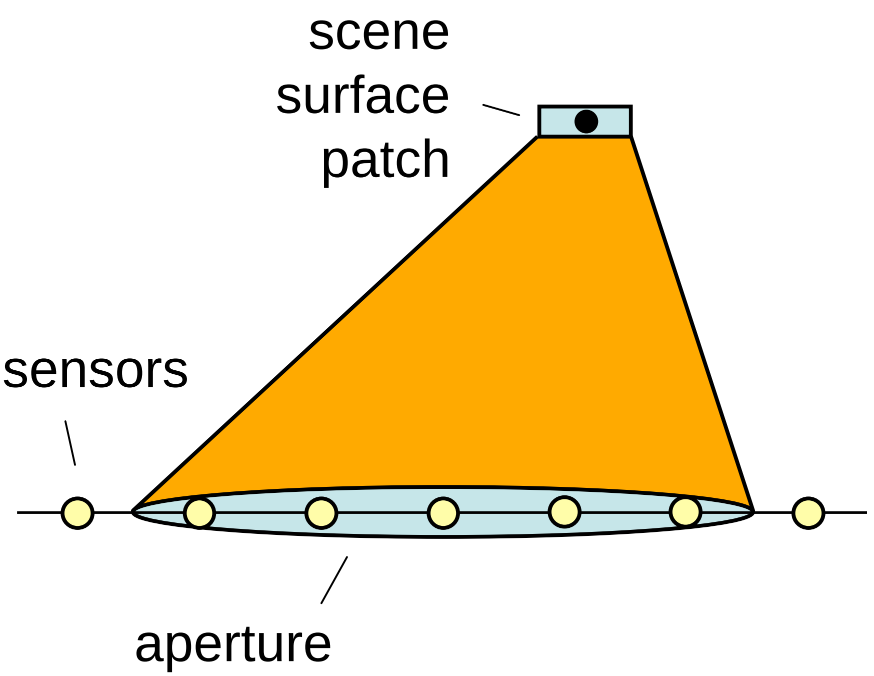
Implicit far zone assumption

Not all constant along rays

Construct camera by integrating light field

$$L^{\mathrm{R}}(\mathbf{r},\mathbf{s}) =$$

$$U^*(\mathbf{r})a(\mathbf{s})e^{ik\mathbf{s}\cdot\mathbf{r}}$$



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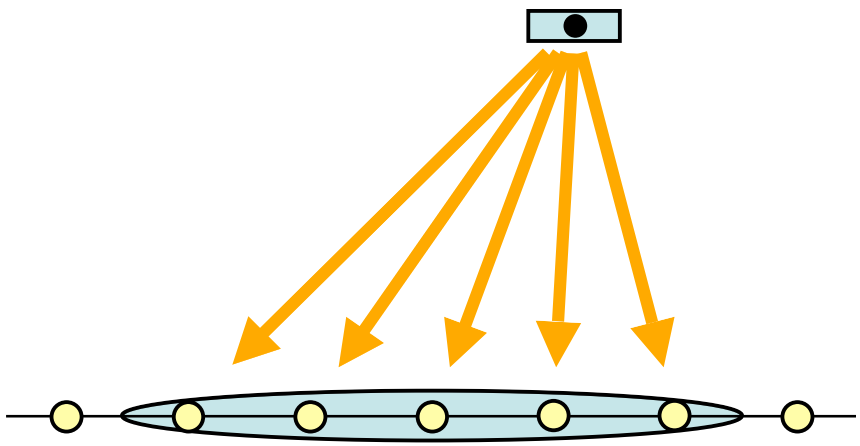

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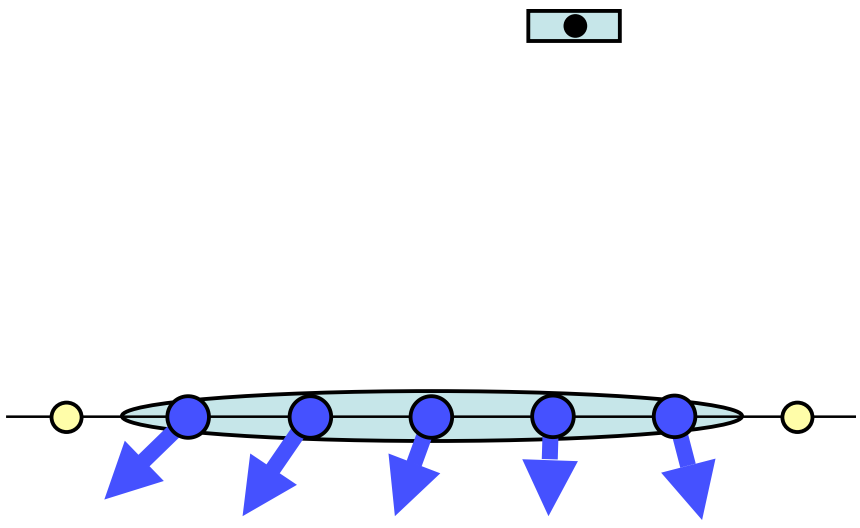

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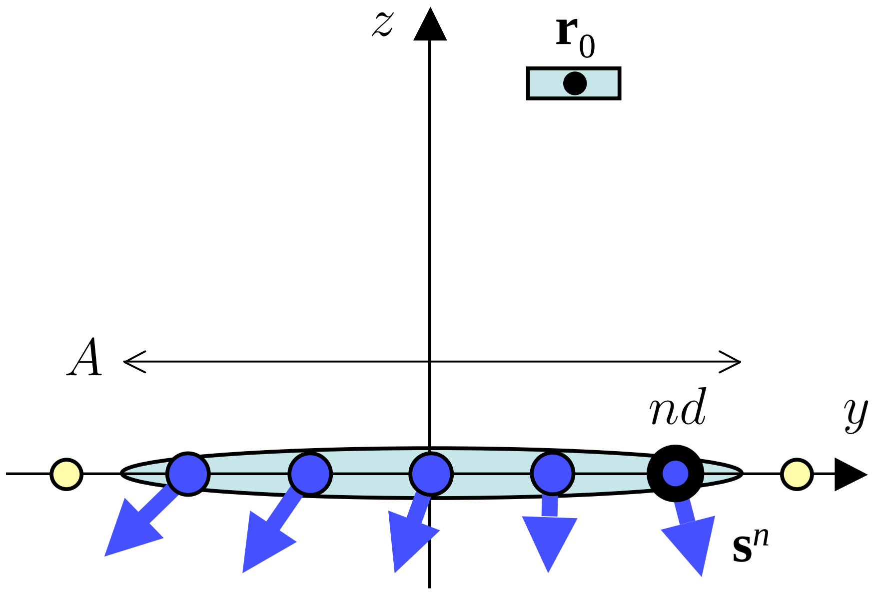
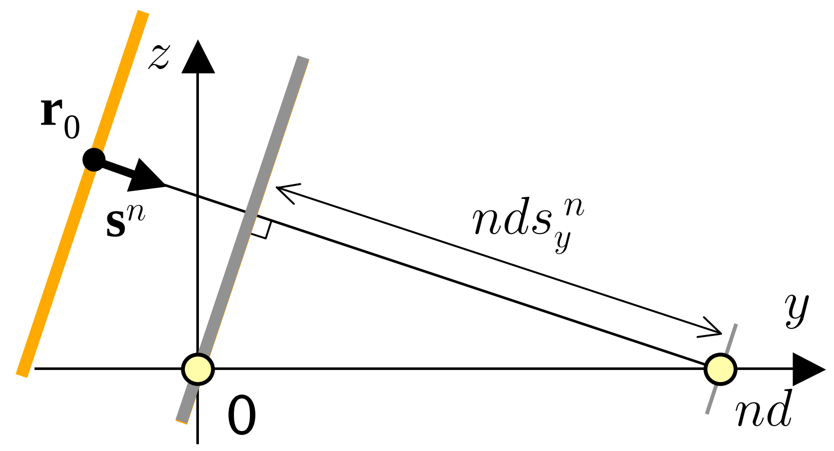


$$P^{\mathrm{R}} = \sum_{|nd|<A/2} U^*(nd)a(\mathbf{s}^n)\boxed{e^{iknds_y^n}}$$

$$a(\mathbf{s}^n) = \sum_m U(md)\boxed{e^{-ikmds_y^n}}$$

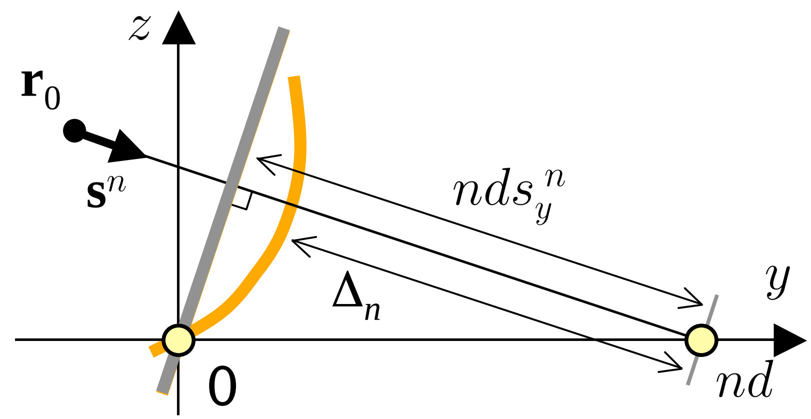
Camera makes Fraunhofer diffraction approximation



Camera makes Fraunhofer diffraction approximation

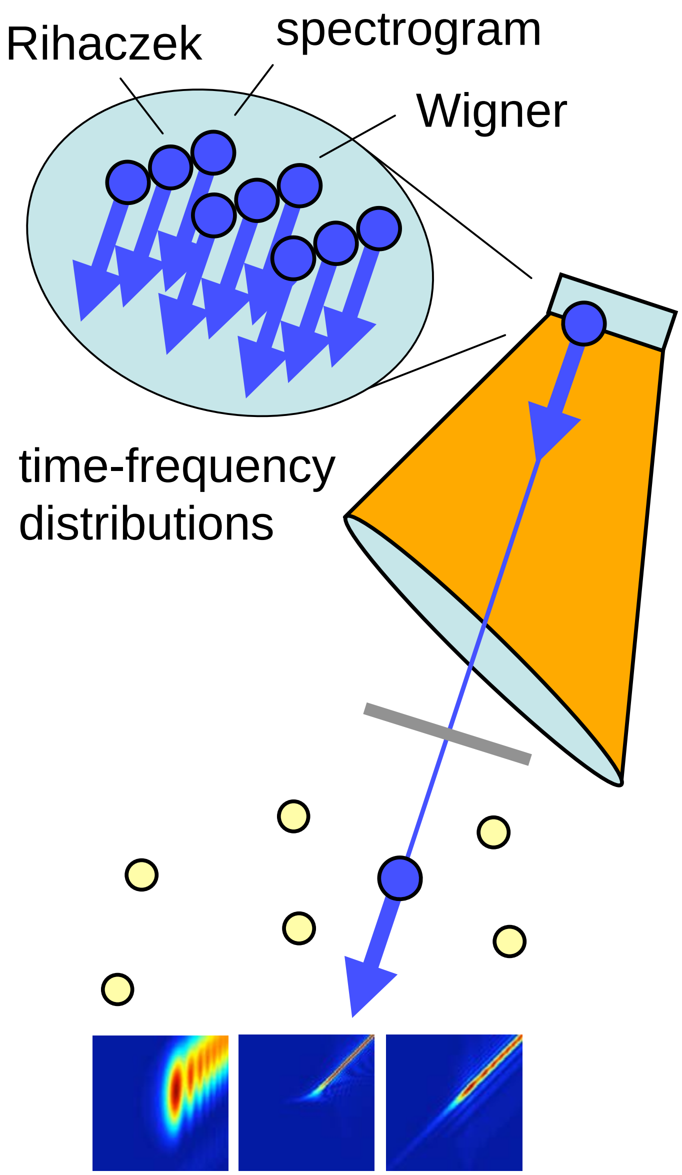
$$P^{\mathrm{R}} = \sum_{|nd|<A/2} U^*(nd)a(\mathbf{s}^n)\, e^{iknds_y^n}$$

$$a(\mathbf{s}^n) = \sum_m U(md)\, e^{-ikmds_y^n}$$



$$\tilde{P}^{\mathrm{R}} = \left(\sum_{|nd|<A/2} U(nd)e^{-ik\Delta_n} \right)^* \left(\sum_m U(md)e^{-ik\Delta_m} \right)$$

Quasi light fields



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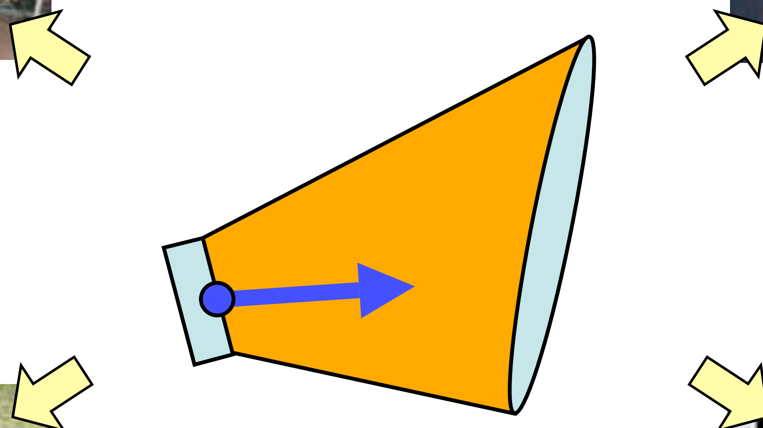
The utility of light fields, and the versatility of scalar field theory

3D television

holography

incoherent



coherent

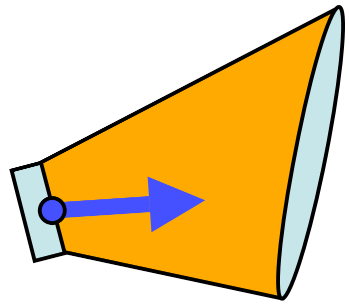
plenoptic camera

ultrasound

Some parting thoughts…

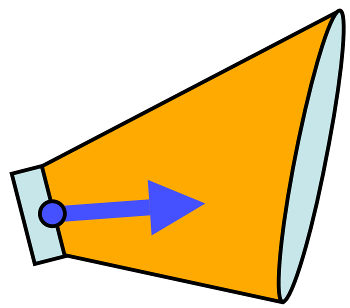
incoherent,
small λ
image

$\triangleq$



coherent,
finite λ
image

$\triangleq$

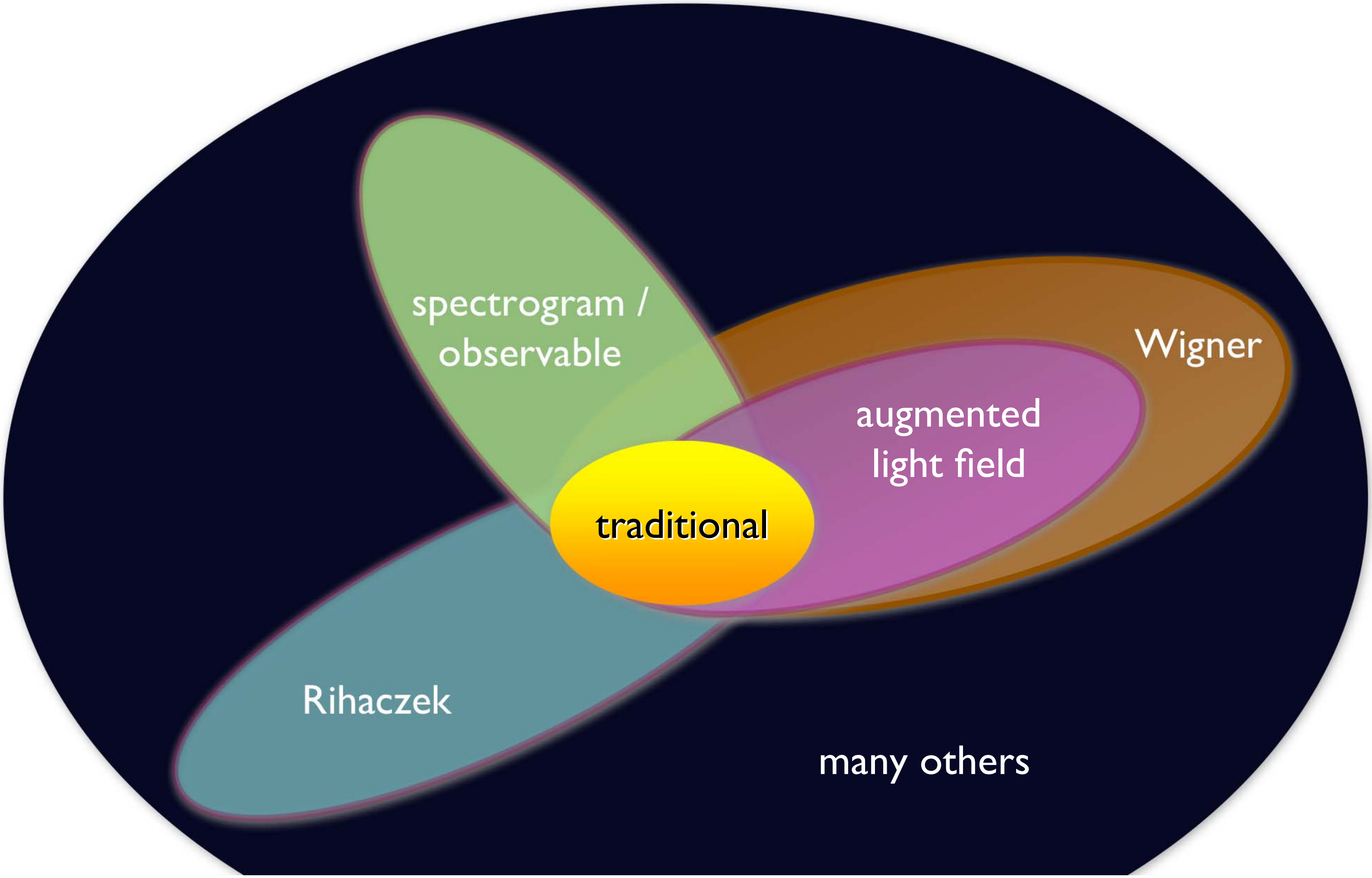


$+$

quasi
light field

1. Do we have the right definition?
2. Do we have the right physics?
3. Do the answers depend on the application?

Quasi light fields



Properties of light fields

	Constant along rays	Non-negativity	Coherence	Wavelength	Interference Cross terms
traditional	yes	yes	only incoherent	zero	no
spectrogram (observable)	no	yes	any	any	no
augmented light field	no (only paraxial)	no (real-valued)	any	any	yes
Wigner	no (only paraxial)	no (real-valued)	any	any	yes
Rihaczek	no (linear drift)	no (complex-valued)	any	any	yes (reduced)

Benefits and limitations of light fields

	Ability to propagate	Modeling wave optics	Simplicity of computation	Adaptability to current pipe line	Near Field	Far Field
traditional	x-shear	no	very simple	high	yes	yes
spectrogram (observable)	not x-shear	yes	modest	low	no	yes
augmented light field	x-shear	yes	modest	high	no	yes
Wigner	x-shear	yes	modest	low	no	yes
Rihaczek	x-shear	yes	simple	low	no	yes

Light Fields in Ray and Wave Optics

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Wigner Distribution Function to explain Light Fields	Zhengyun Zhang
Augmenting LF to explain Wigner Distribution Function	Se Baek Oh
Q&A	
Break	
Light Fields with Coherent Light	Anthony Accardi
New Opportunities and Applications	**Raskar and Oh**
Q&A	All