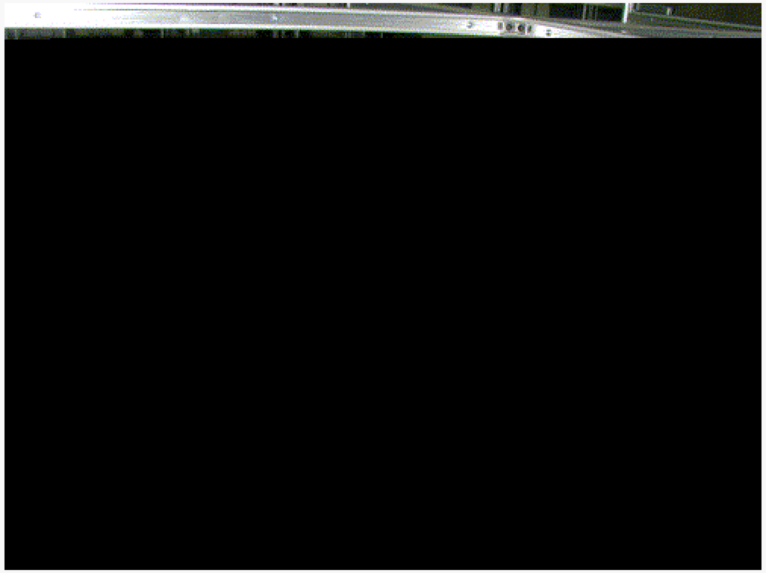
National Laboratory of Solid State Microstructures

Nanjing University



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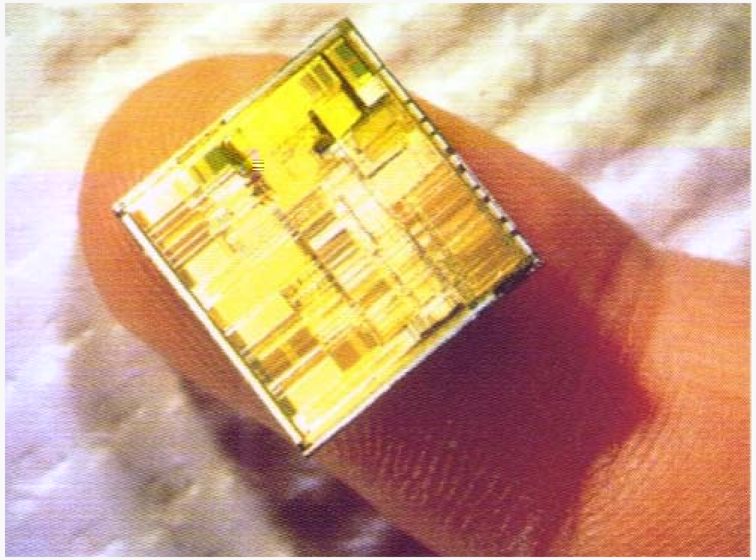

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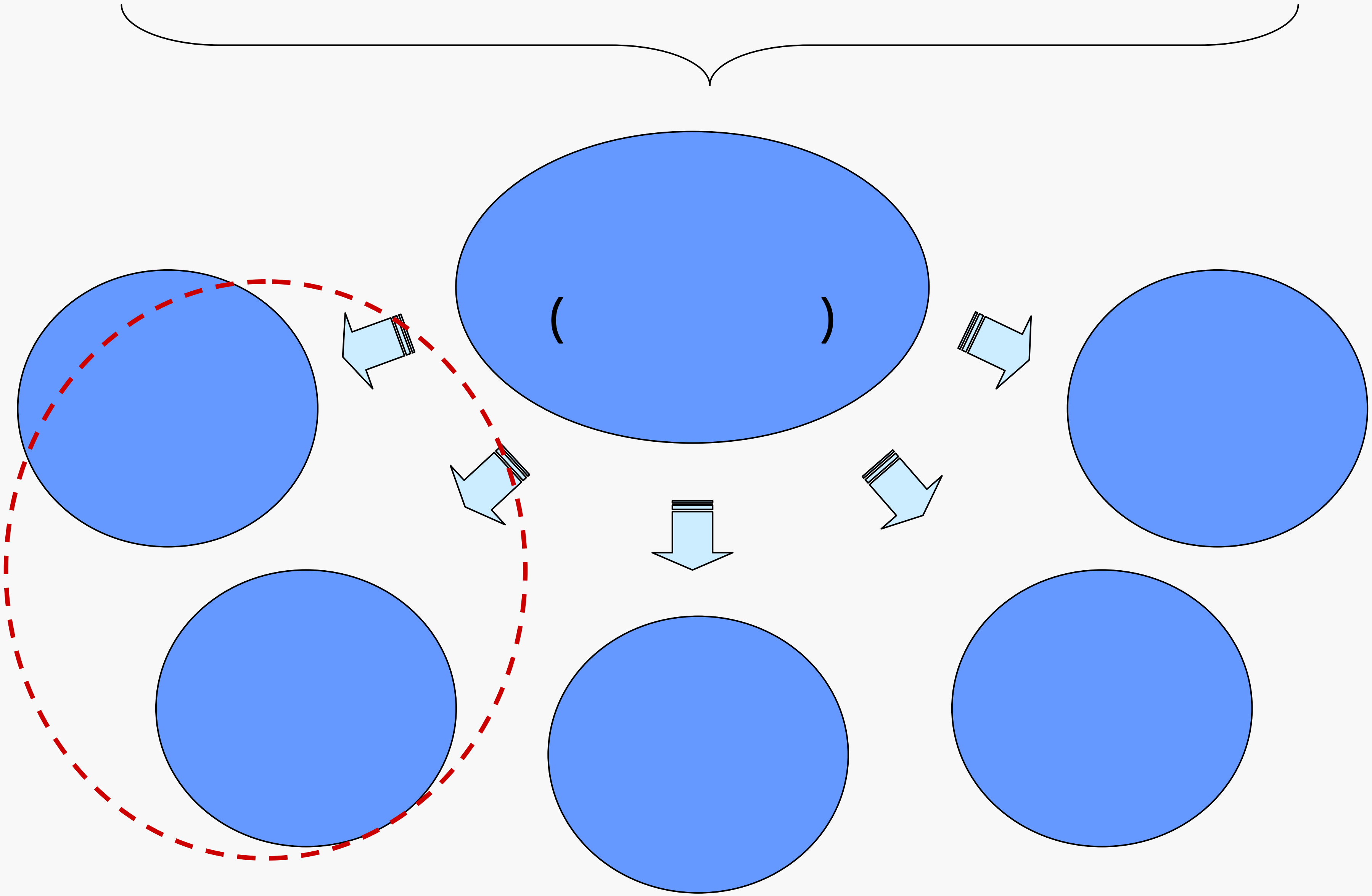
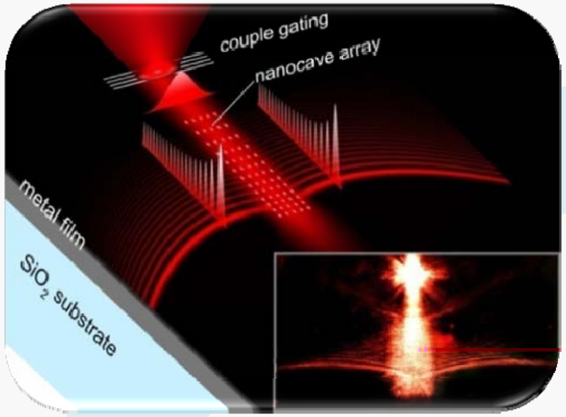
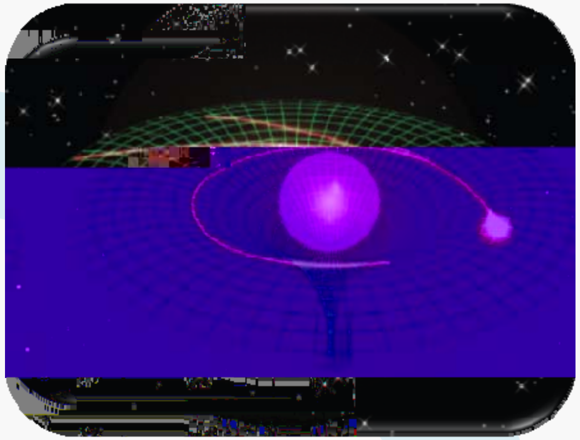
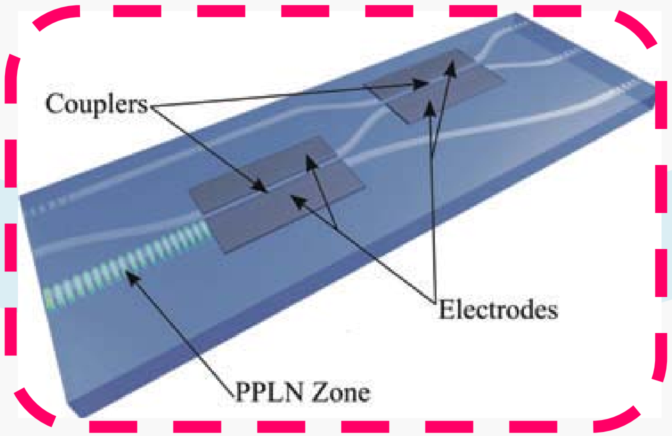


SPP



couple gating
nanocave array
metal film
SiO_2 substrate





Couplers
Electrodes
PPLN Zone

LN

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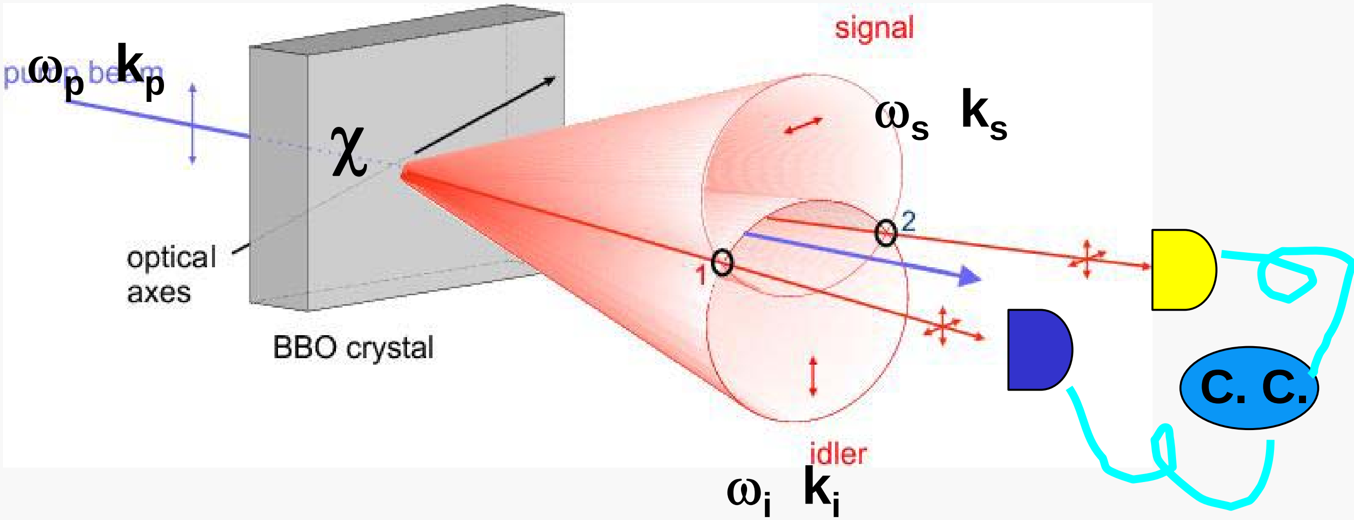
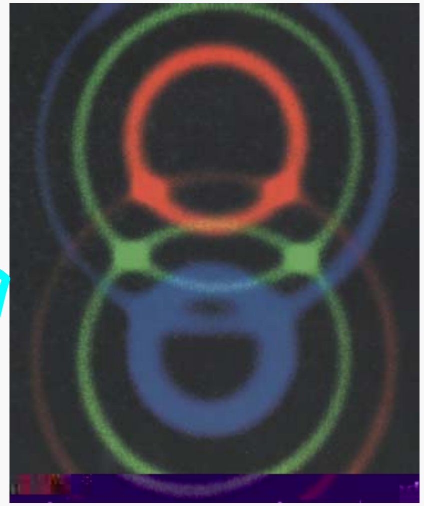
Spontaneous parametric down-conversion (SPDC)





$$\omega_p = \omega_s + \omega_i$$

$$\vec{k}_p = \vec{k}_s + \vec{k}_i$$

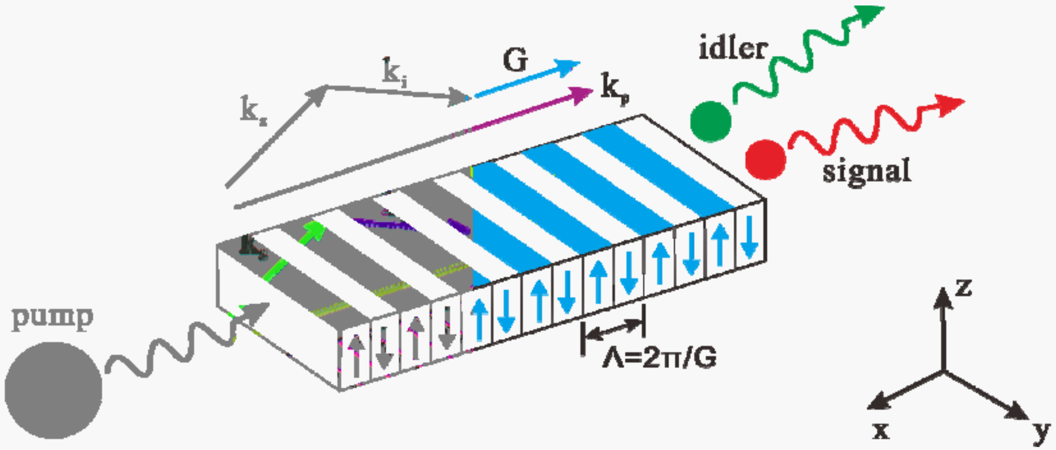
$$|\Psi\rangle = \frac{}{\sqrt{}}\, |V\rangle\, |H\rangle + |H\rangle\, |V\rangle$$

$$|\Psi\rangle = \psi \sum_{\vec{k}_i\,\vec{k}_s} \delta\, \omega_i + \omega_s - \omega_p\ \delta\, \vec{k}_i + \vec{k}_s - \vec{k}_p\ a^{\dagger}_{\vec{k}_i} a^{\dagger}_{\vec{k}_s} |\ \rangle$$

1935 EPR

( )

Spontaneous parametric down-conversion (SPDC)



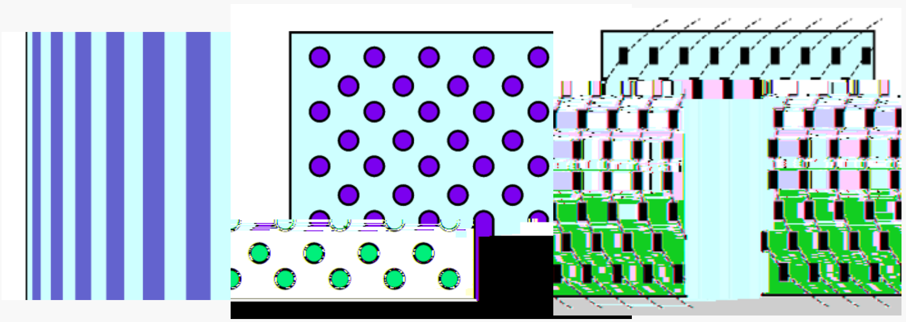
$$\omega_p = \omega_s + \omega_i$$
$$\vec{k}_p = \vec{k}_s + \vec{k}_i$$

$$\omega_p = \omega_s + \omega_i$$
$$\vec{k}_p = \vec{k}_s + \vec{k}_i + \vec{G}$$

$$|\Psi\rangle = \psi \sum_{k_s\, k_i} \delta\ k_s + k_i + G - k_p\ a_s^+ a_i^+ |\ \rangle$$

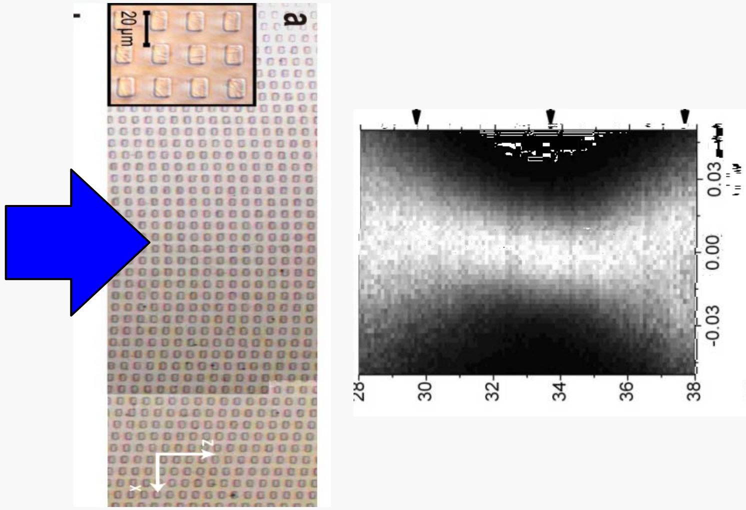
$$G_m = \frac{m\pi}{\Lambda}$$

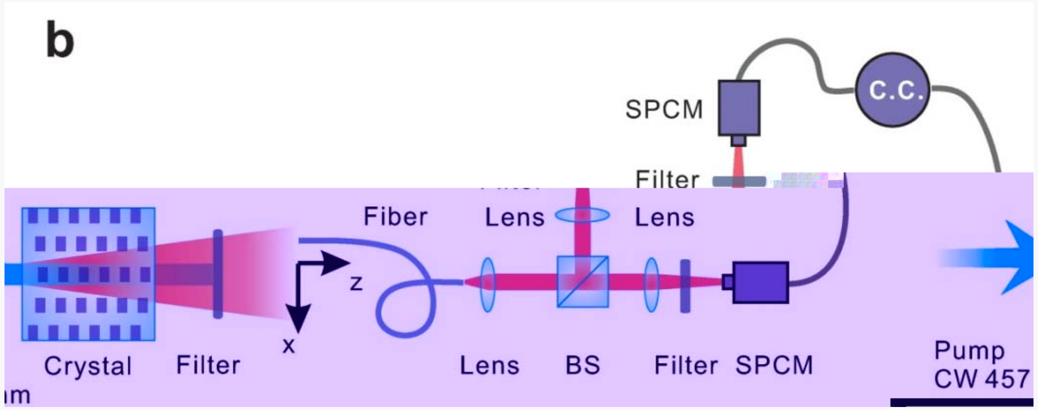
Different structures

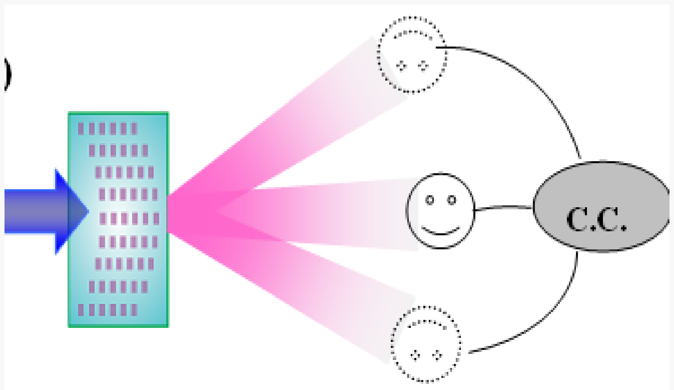


Key features

- ◆**High efficiency, 1-2 order higher (bulk), 4-5 orders higher than BPM crystals**
- ◆**Designable wavelength**
- ◆**Engineerable state**







$$\frac{}{d}+\frac{}{d}=\frac{}{f_{eff}}$$

$$f_{eff}=\frac{\pi}{g_3\alpha\lambda_p}$$

et al.,

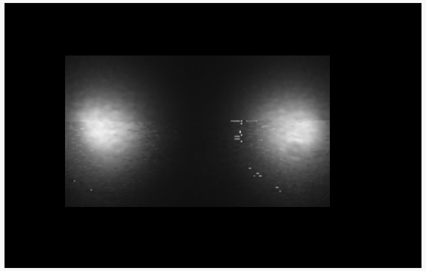
et al,

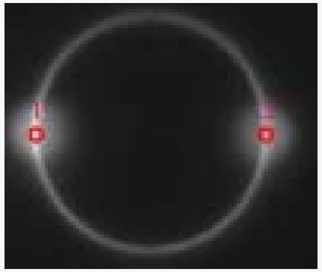
AIP ADVANCES 2, 041401 (2012)

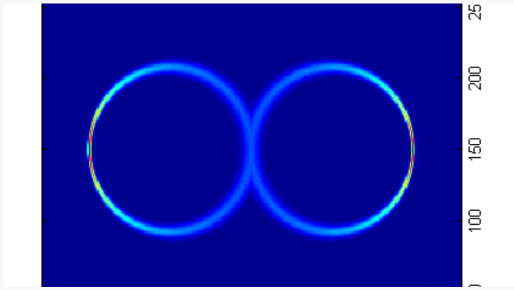
Review Article: Quasi-phase-matching engineering of entangled photons

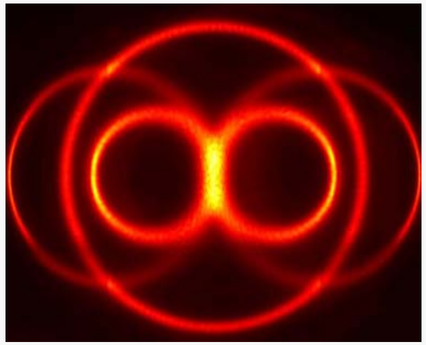
P. Xu[a] and S. N. Zhu[b]
National Laboratory of Solid State Microstructures and School of Physics, Nanjing University, Nanjing 210093, China

(Received 15 August 2012; accepted 17 October 2012; published online 28 December 2012)









NOON

Phys. Rev. Lett. 111, 023603 (2013) **Phys. Rev. A 86, 023835 (2012)**

Research Highlights

Subject Category: Physics

PRL 101, 233601 (2008)

Published online: 17 December 2008 | doi:110.1038/nchina.2008.298

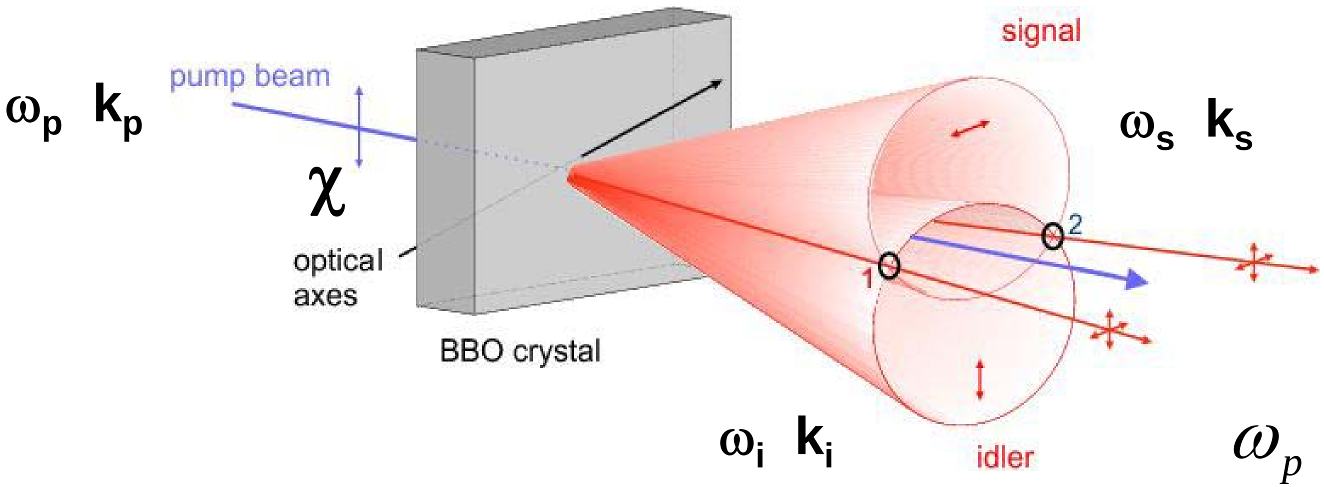
Quantum entanglement: Crystal control

Tim Reid

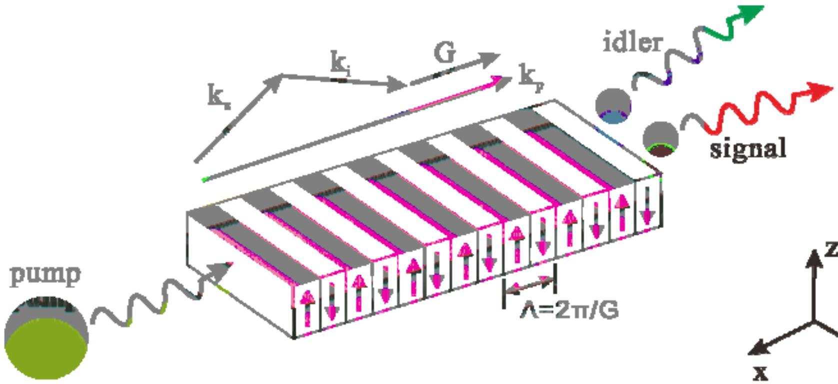
Researchers in China have shown how to control the properties of entangled photon states using engineered crystal patterns

Original article citation
Yu, X. Q. *et al*. Transforming spatial entanglement using a domain-engineering technique. *Phys. Rev. Lett.* **101**, 233601 (2008).

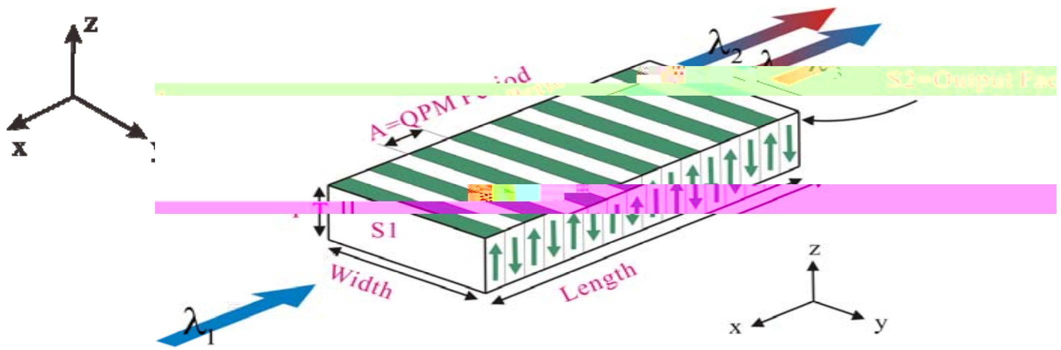
The phenomenon of quantum entanglement, by which two objects are intrinsically linked even when separated by some distance, could have powerful implications for future methods of communication. Shining Zhu at Nanjing University and co-workers[1] have illustrated a way to control the quantum entanglement of two photons by carefully engineering a nonlinear crystal.

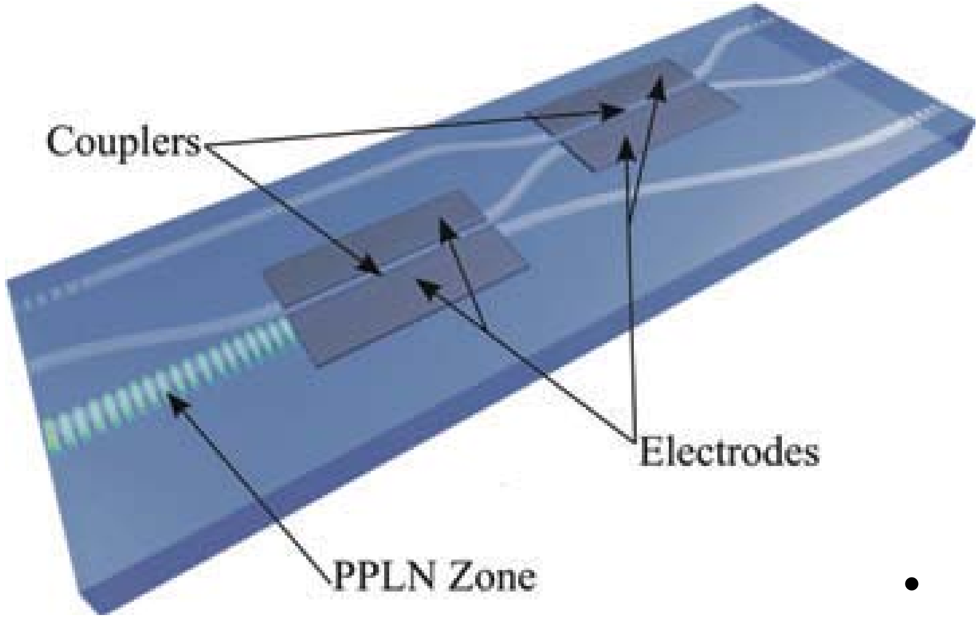


$$\omega_p = \omega_s + \omega_i$$
$$\vec{k}_p = \vec{k}_s + \vec{k}_i$$



$$\omega_p = \omega_s + \omega_i$$
$$\vec{k}_p = \vec{k}_s + \vec{k}_i + \vec{G}$$





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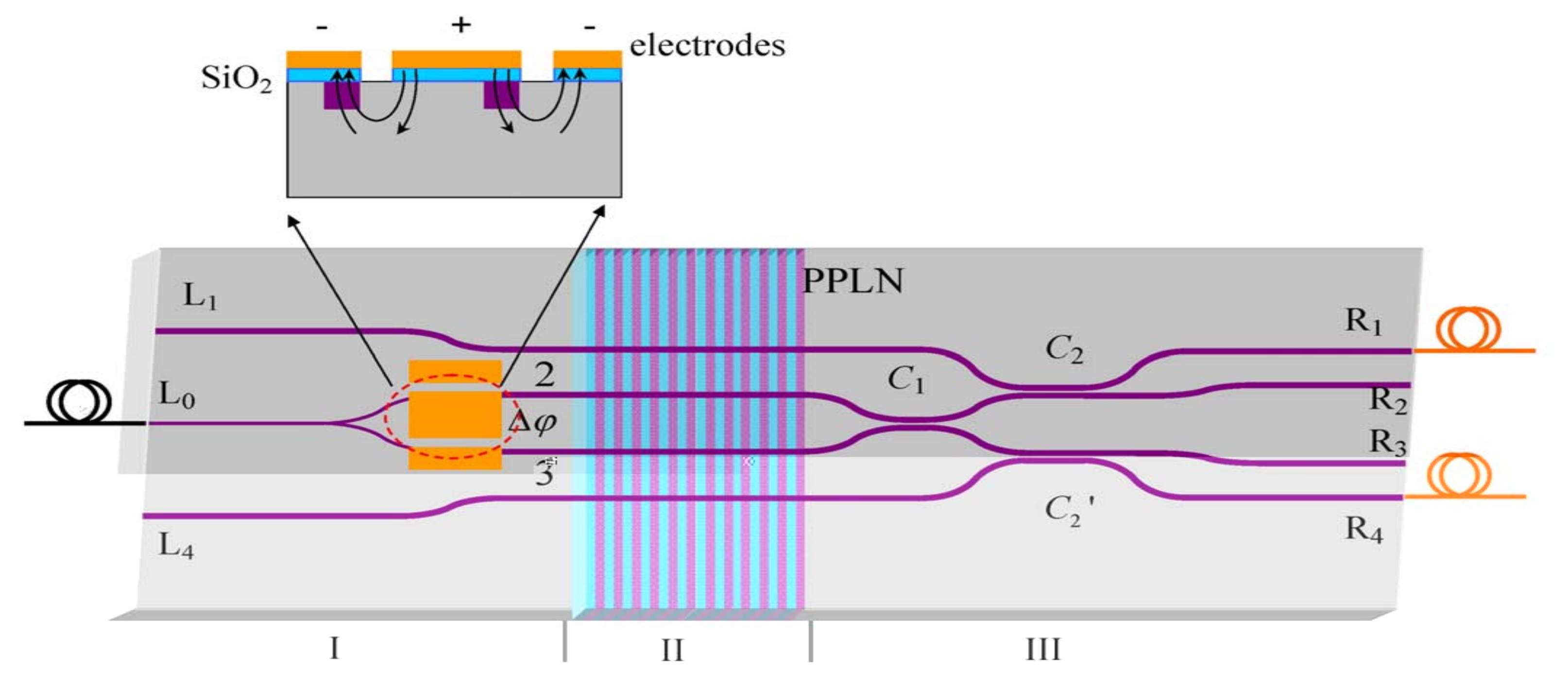

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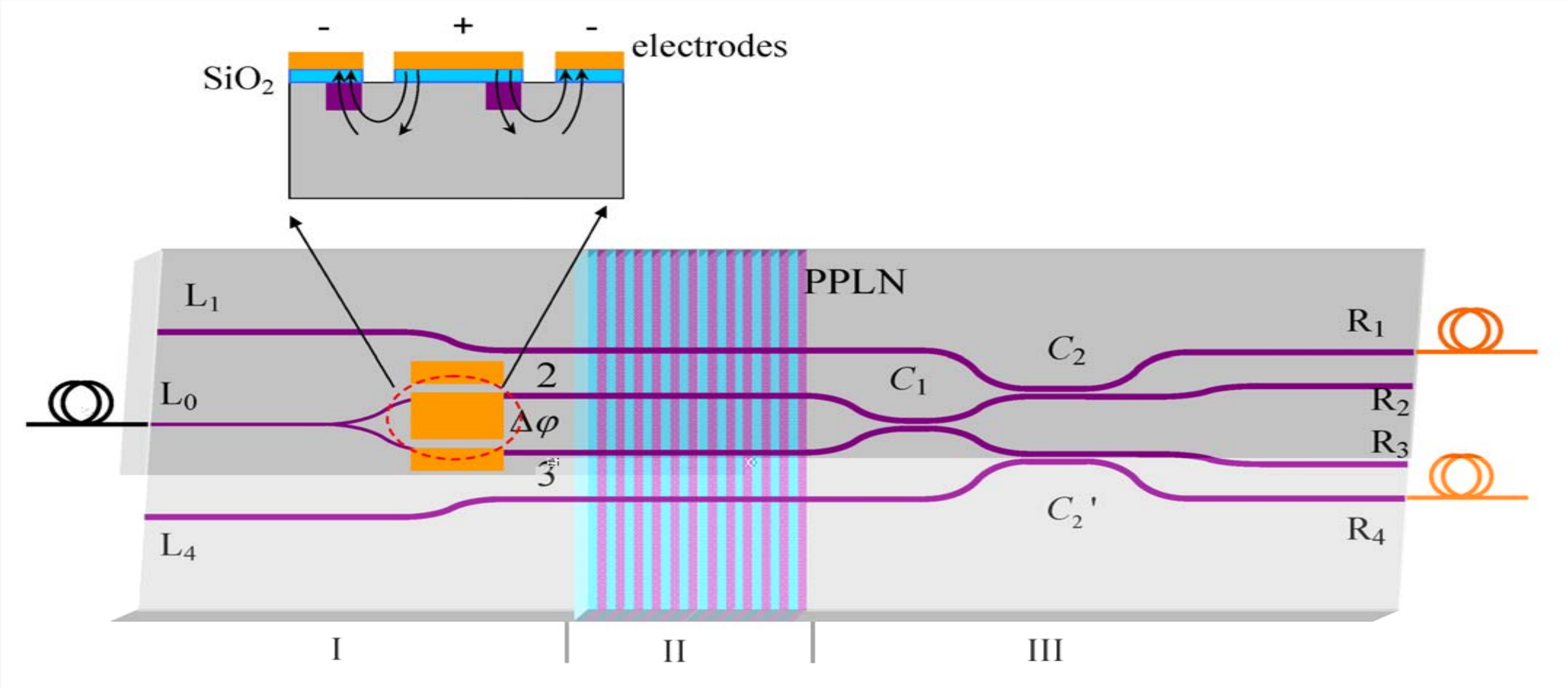
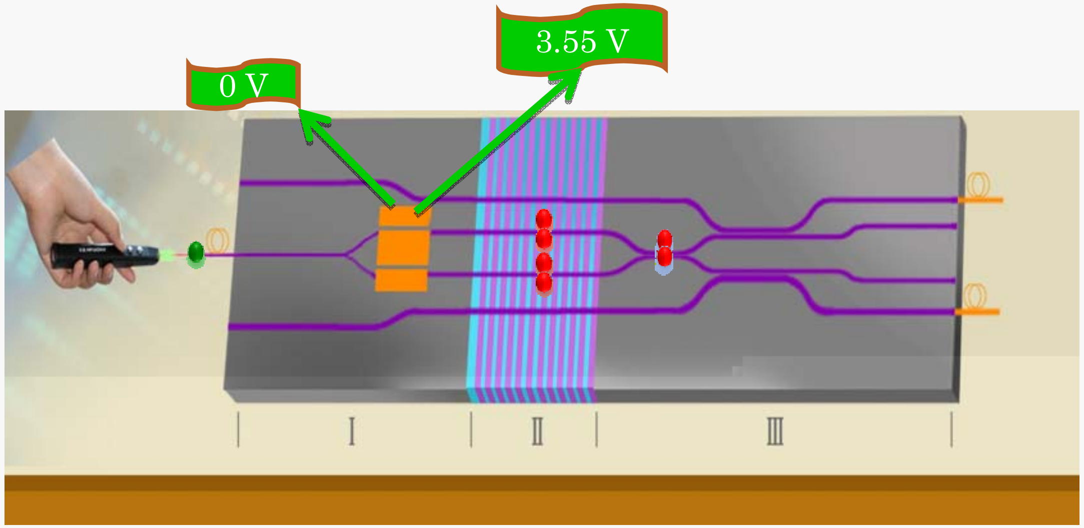


$$\frac{}{\sqrt{}}\left(\left| \quad \right\rangle + e^{i\Delta\varphi}\left| \quad \right\rangle\right) \xrightarrow{EOPS} \frac{}{\sqrt{}}\left(\left| \quad \right\rangle - \left| \quad \right\rangle\right) \quad \Delta\varphi \quad + \left| \quad \right\rangle \quad \Delta\varphi$$

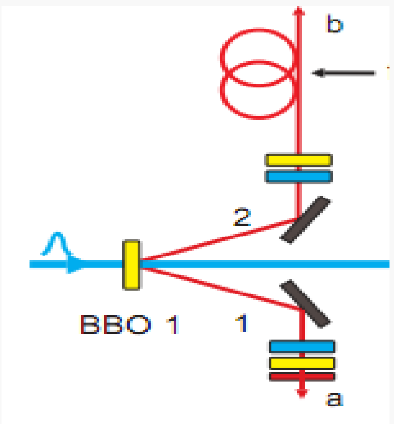
$$\left|\Psi\right\rangle_{bunch} = \frac{}{\sqrt{}}\left(\left| \quad \right\rangle - \left| \quad \right\rangle\right) \quad \Delta\varphi = \pi \qquad \left|\Psi\right\rangle_{sep} = \left| \quad \right\rangle \quad \Delta\varphi =$$

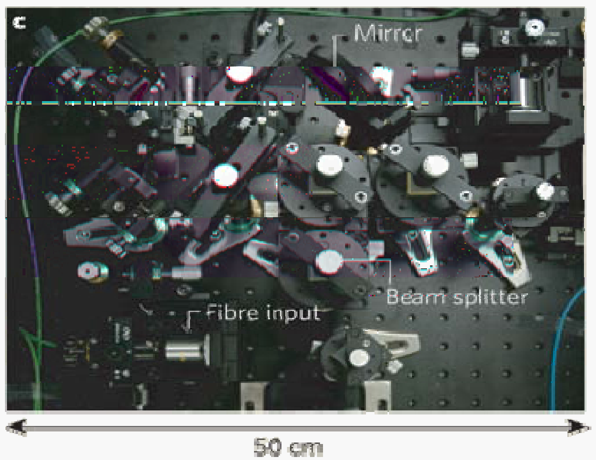


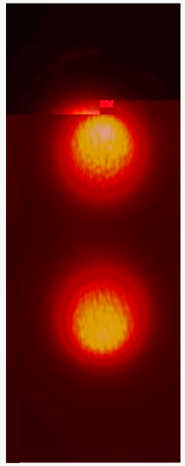
I
Pump region

II
PPLN
(classical → Quantum)

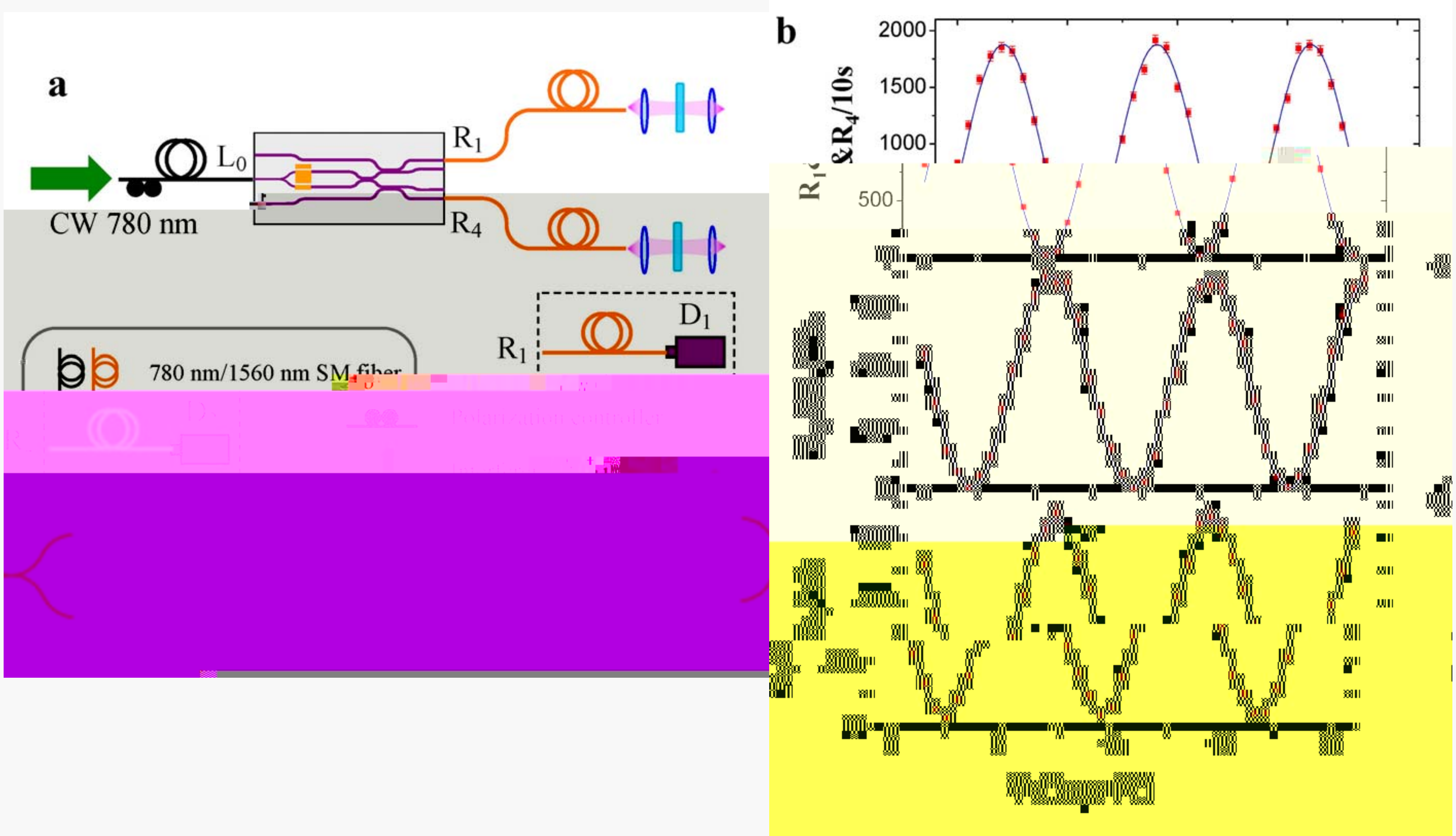
III
Quantum interference



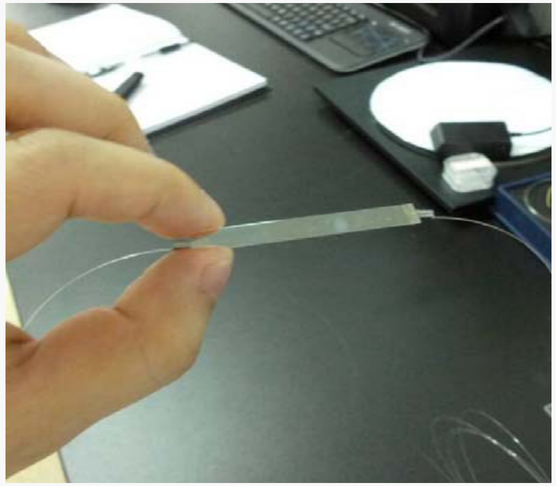




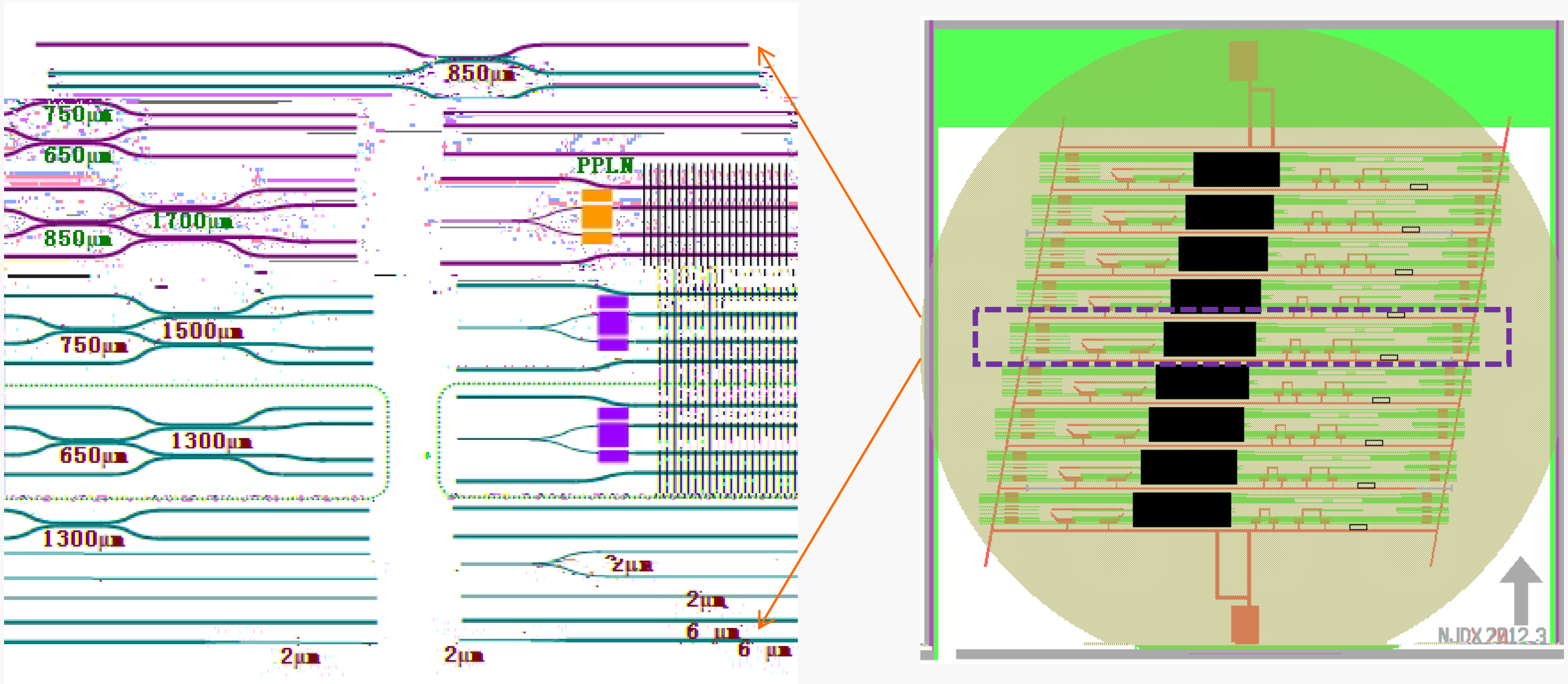
$$|\Psi\rangle = \frac{}{\sqrt{}}\left(| \quad \rangle - | \quad \rangle\right) \quad \Delta\varphi/ \quad + | \quad \rangle \quad \Delta\varphi/$$


a
CW 780 nm
L0
R1
R4
R1
D1
780 nm/1560 nm SM fiber
b
2000
1500
1000
500

Input: classical pump laser



Output: Quantum light



nature photonics

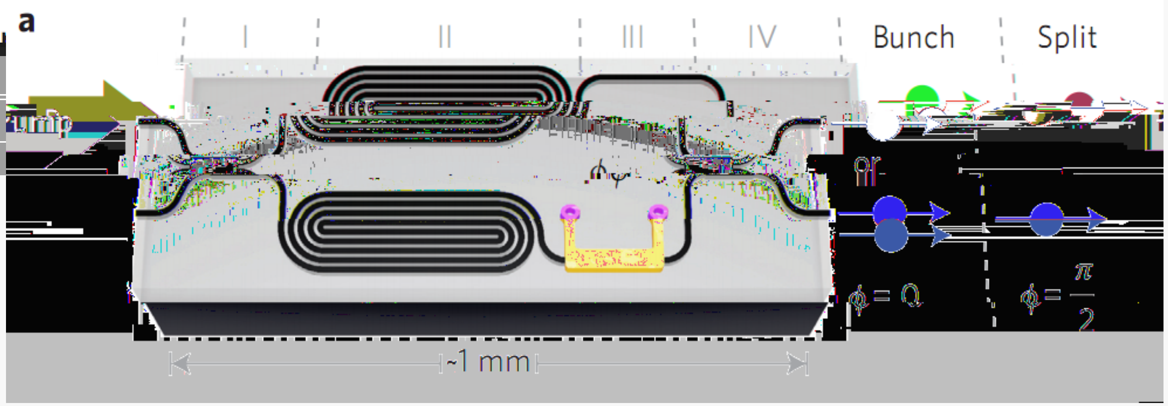
LETTERS

PUBLISHED ONLINE: 15 DECEMBER 2013 | DOI: 10.1038/NPHOTON.2013.339

On-chip quantum interference between silicon photon-pair sources

Ezaki[2], J. W. Silver

G. D. Marshall[1], J. G. Rarity[1],



LN V.S. SOI chip

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1.
2. ;
3. ;
4. :

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Physics

spotlighting exceptional research

Ho

Synopsis: Quantum Photonics on a Chip

On a single chip, sources of entangled photons are combined with optical elements that can perform complex manipulations of quantum signals.

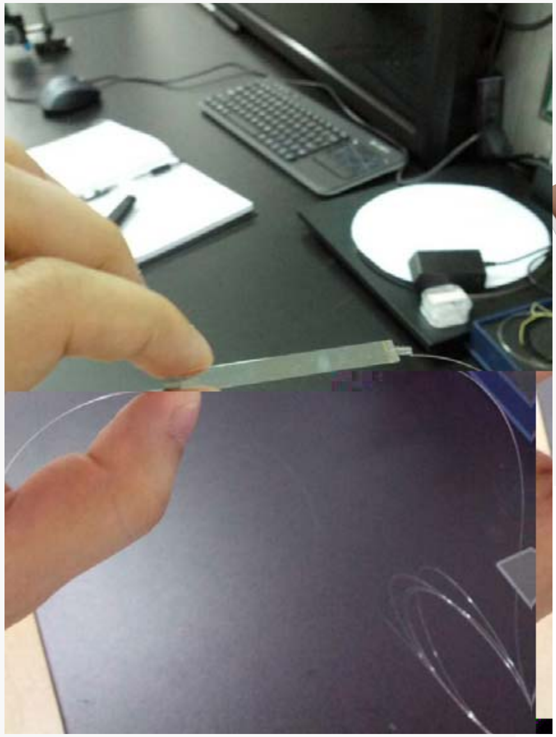
Featured in Physics | Editors' Suggestion

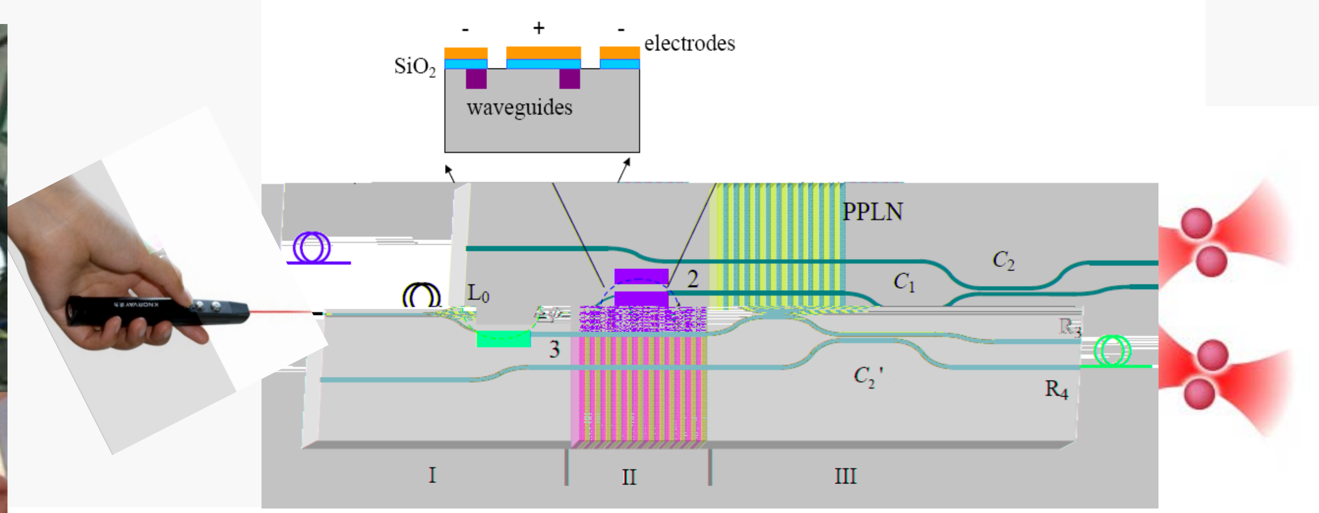
On-Chip Generation and Manipulation of Entangled Photons Based on Reconfigurable Lithium-Niobate Waveguide Circuits

H. Jin, F. M. Liu, P. Xu, J. L. Xia, M. L. Zhong, Y. Yuan, J. W. Zhou, Y. X. Gong, W. Wang, and S. N. Zhu

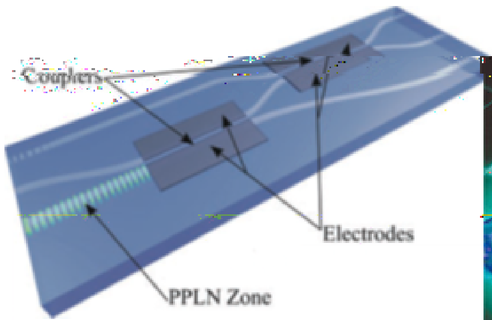
Phys. Rev. Lett. 113, 103601 (2014) – Published 4 September 2014

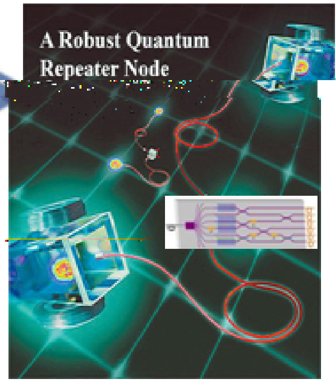
Quantum sources in the hands

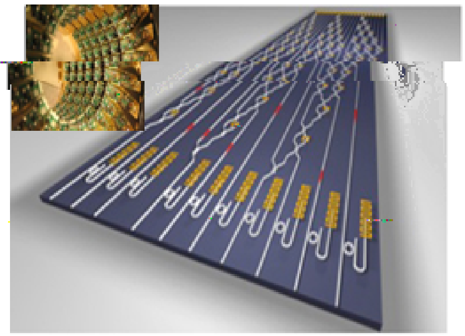


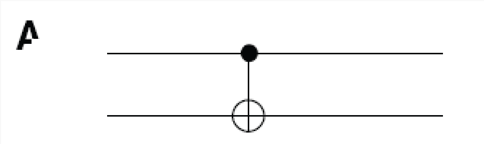


应用

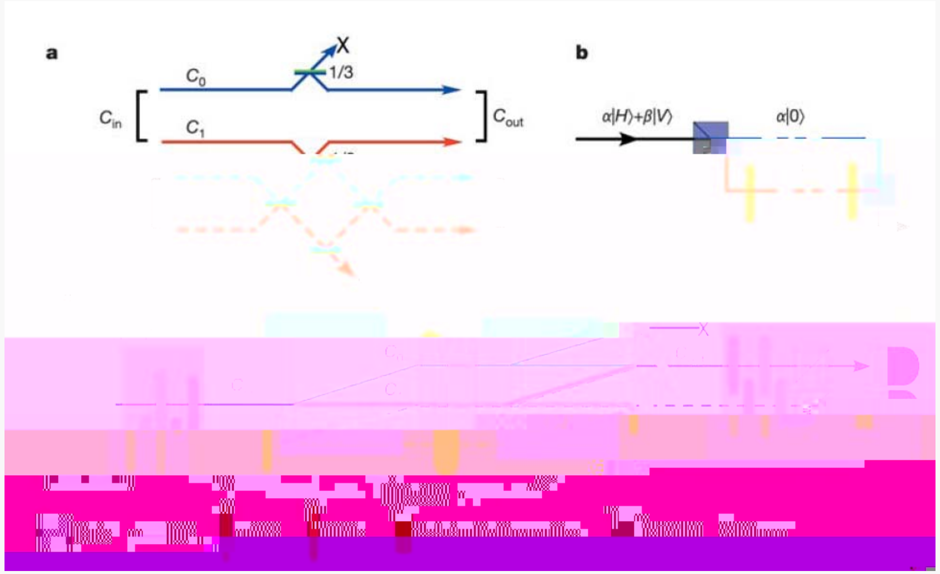




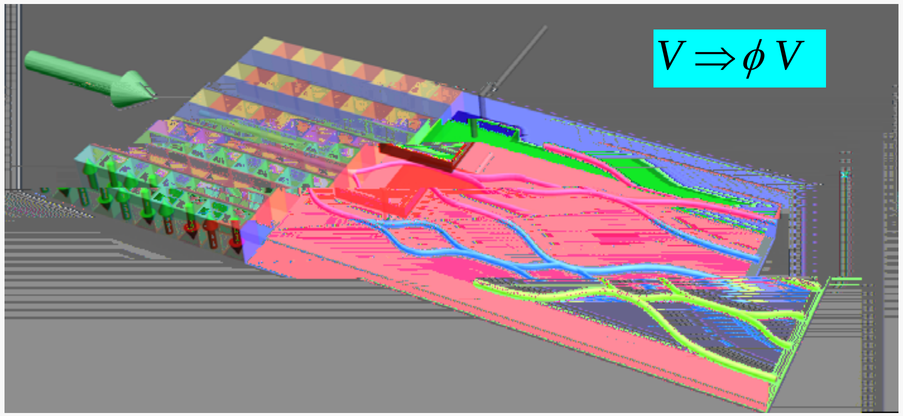


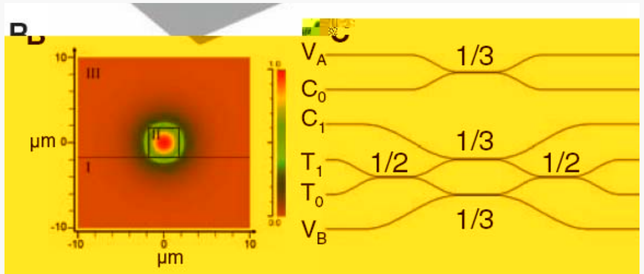


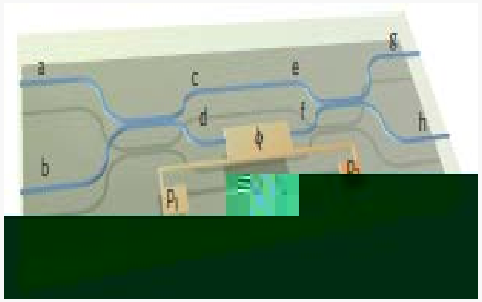
$$\mathcal{U}_{CNOT} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}.$$



et al



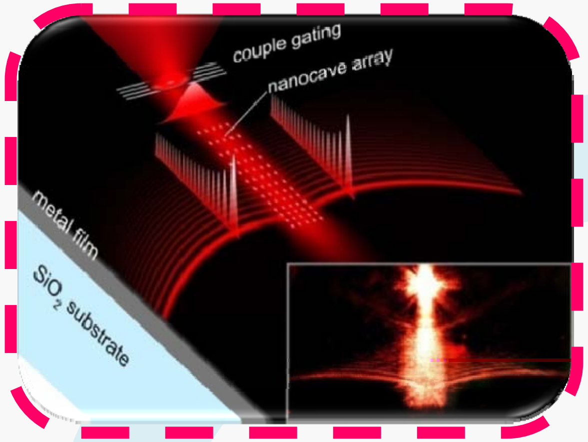


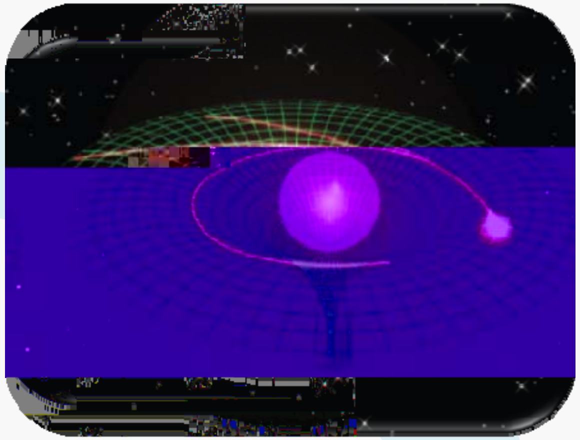


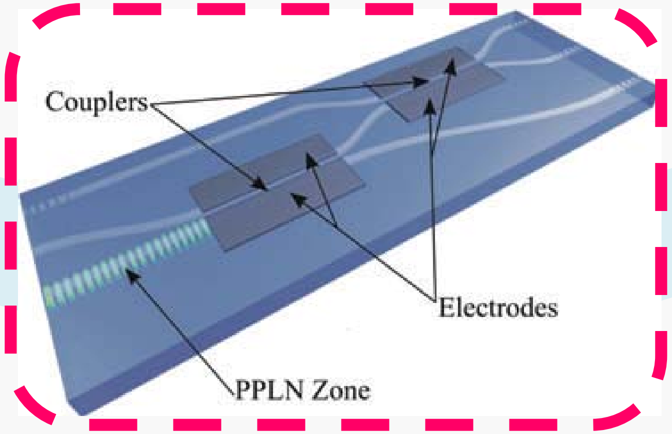
:LN ; 2.Si PPLN

et al

SPP

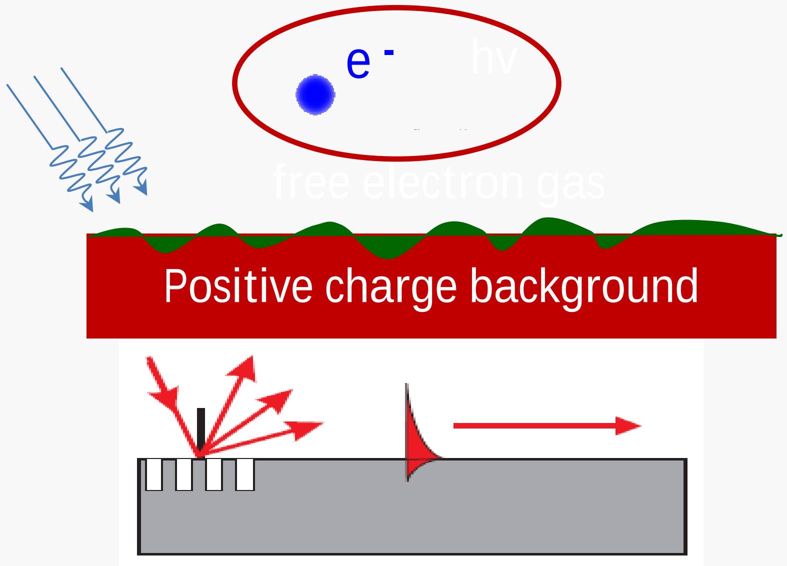

couple gating
nanocave array
metal film
SiO2 substrate

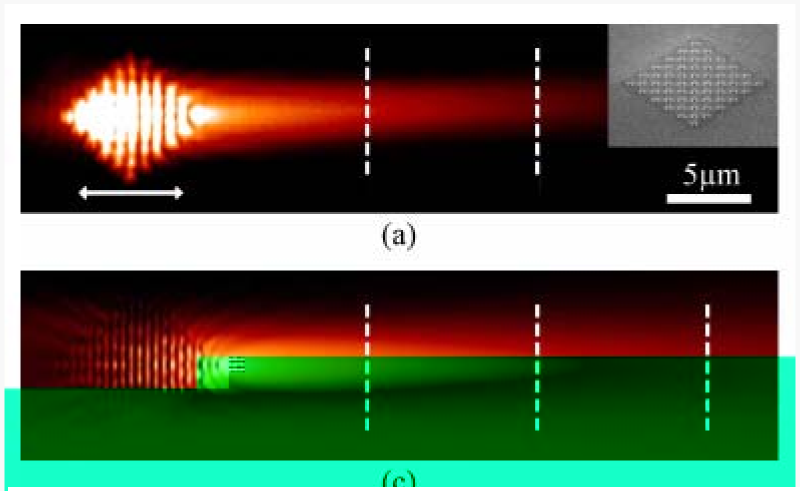


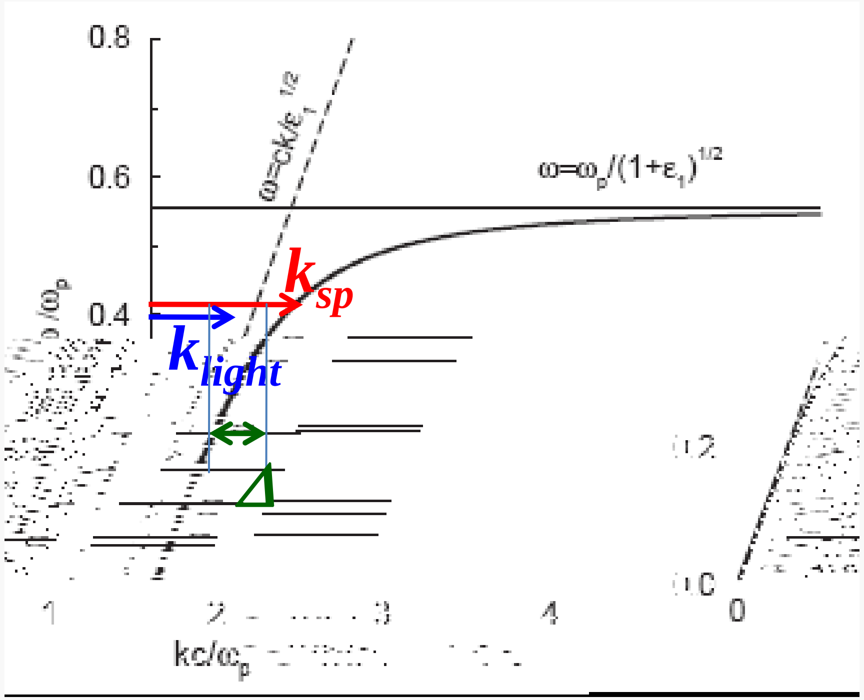

Couplers
Electrodes
PPLN Zone

LN

: I.



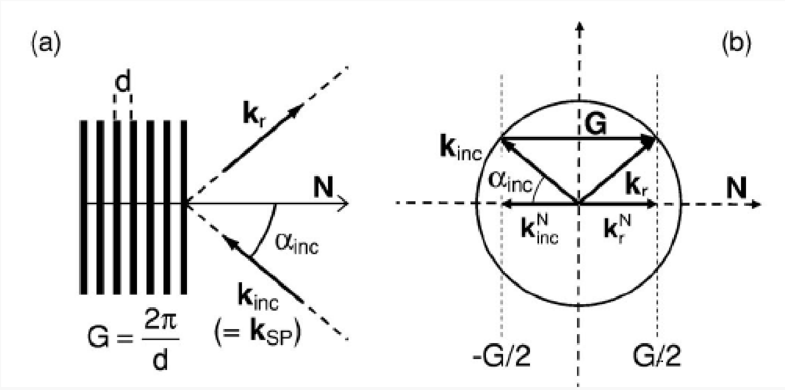




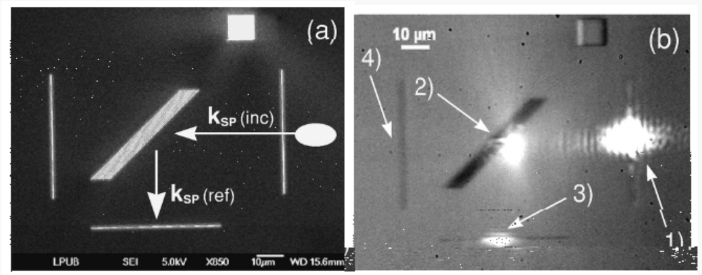
$$\Delta\varpi =$$

$$\Delta k =$$

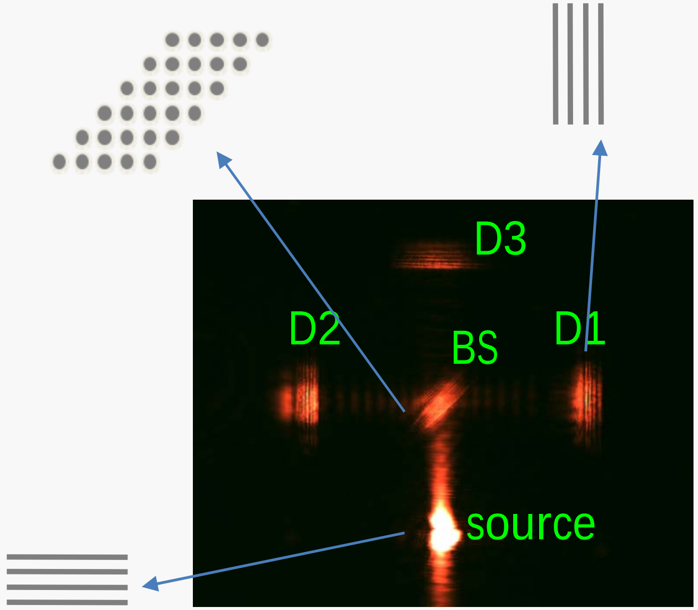
: II.



(a)
d
k_r
N
α_{inc}
k_{inc}
$(= k_{SP})$
$G = \frac{2\pi}{d}$
(b)
G
k_{inc}
α_{inc}
k_r
N
k_{inc}^N
k_r^N
-G/2
G/2



(a)
k_{SP} (inc)
k_{SP} (ref)
(b)
10 μm
4)
2)
3)
1)



D3
D2
BS
D1
source

letters to nature

NATURE | VOL 418 | 18 JULY 2002 |

-assisted transmission of ed photons

M. P. van Exter & J. P. Woerdman

; Huygens Laboratory, PO Box 9504, 2300 RA Leiden,

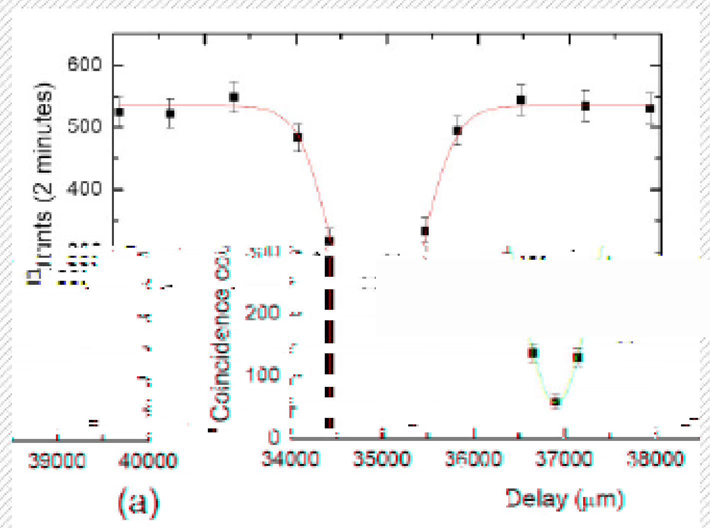
Plasmon entangl

E. Altewischer,

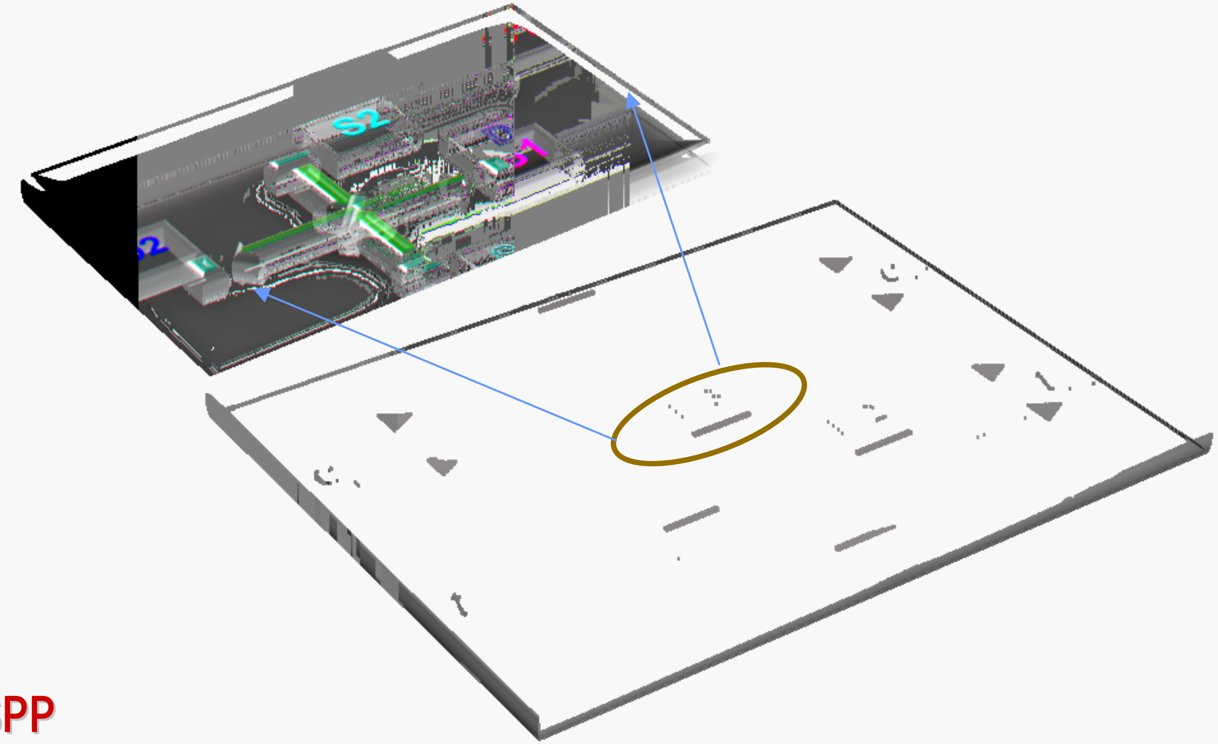
Leiden University
The Netherlands

Hong-Ou-Mandel interference mediated by the magnetic plasmon waves in a three-dimensional optical metamaterial

X. Zhang[2]

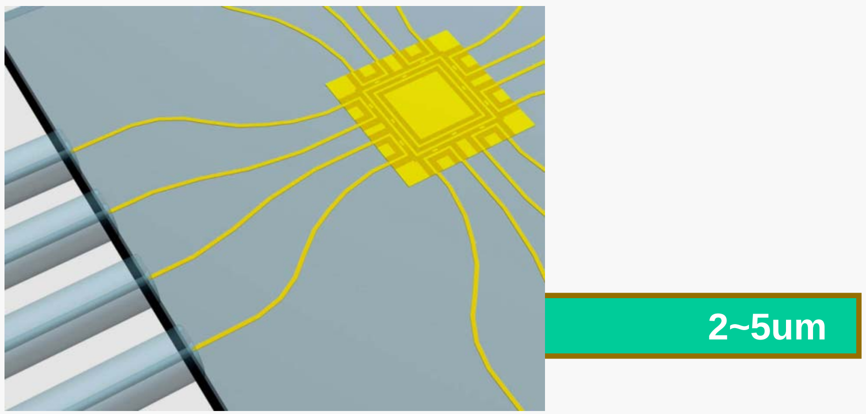


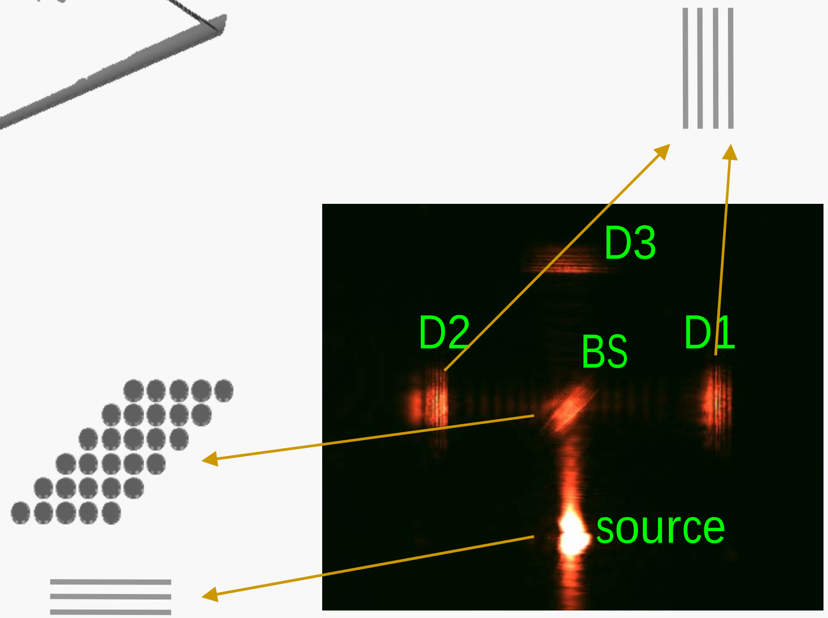
SPP MPP( )



CNOT

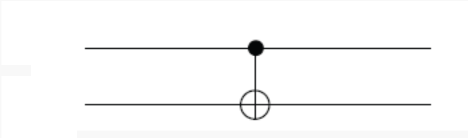
SPP

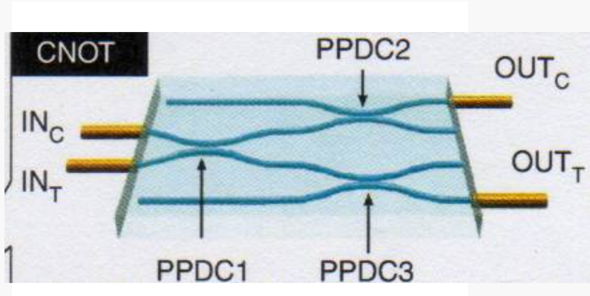


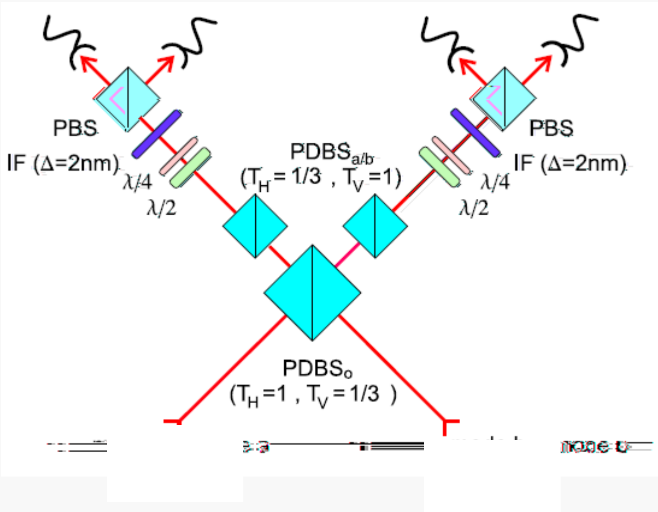


SPP

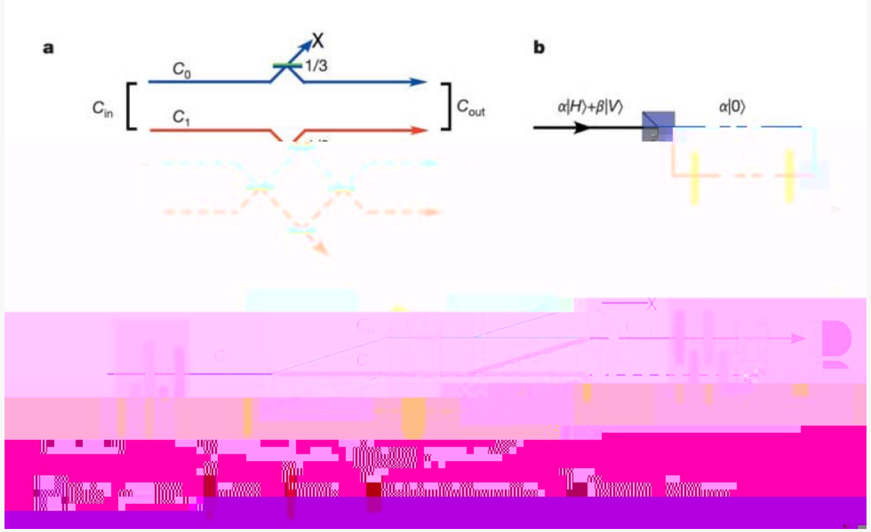
： III. Q-CNOT gate



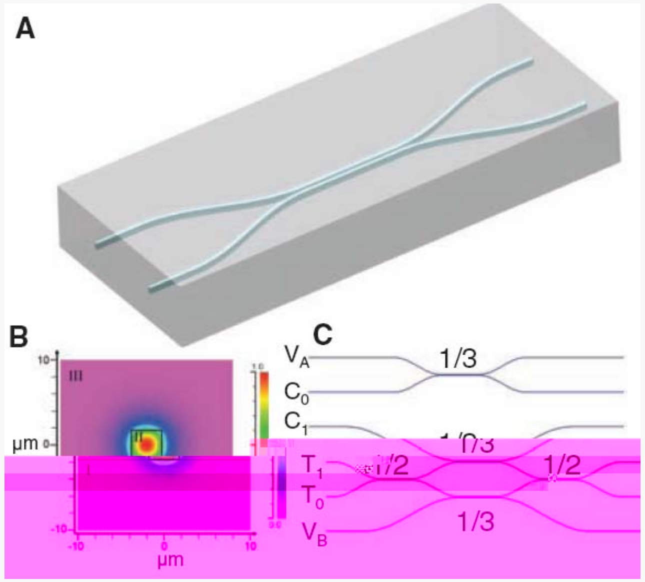




et al



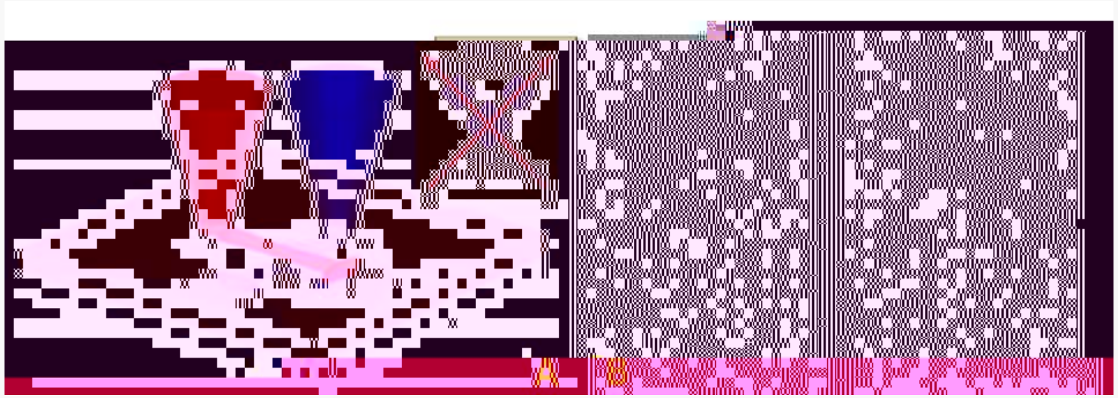
et al

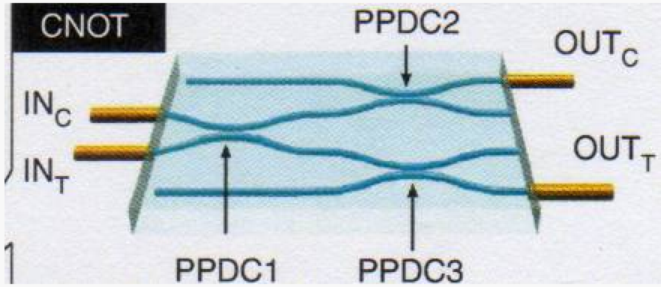


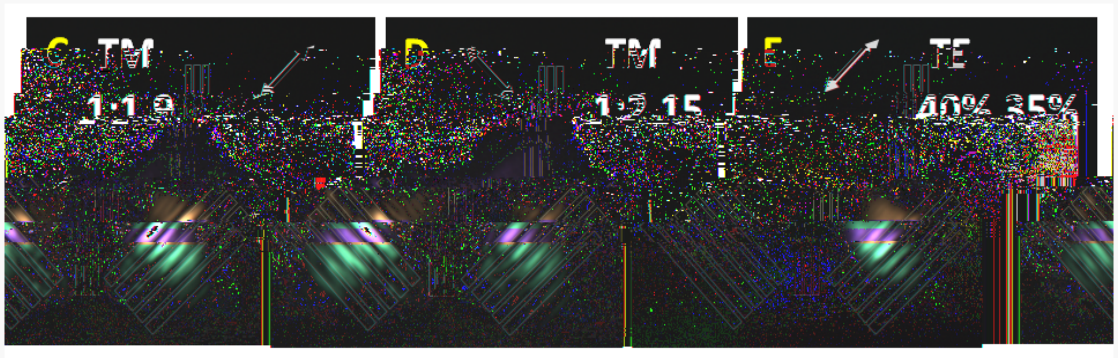
et al

: III. Q-CNOT gate

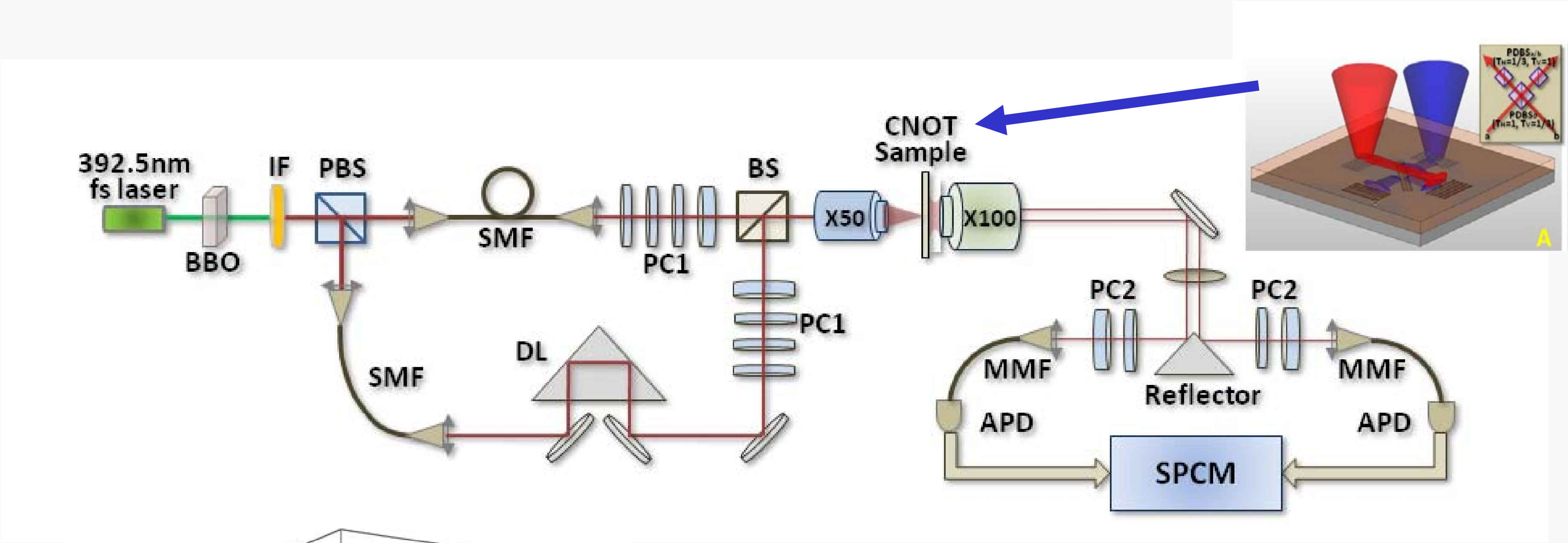
SPP TM TE → **CNOT**

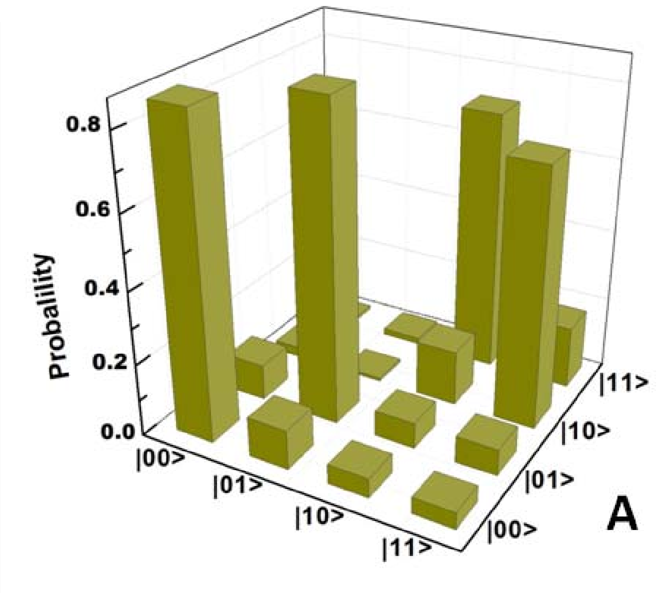






: III. Q-CNOT gate





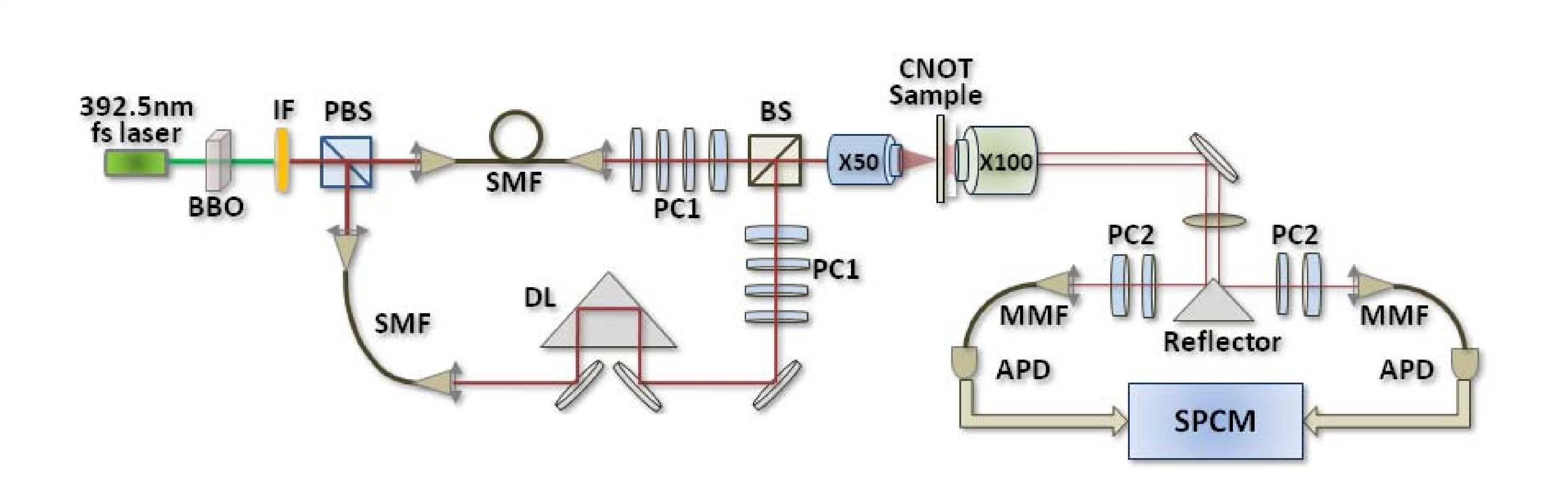
$$\rangle_c \equiv TE\rangle_c$$

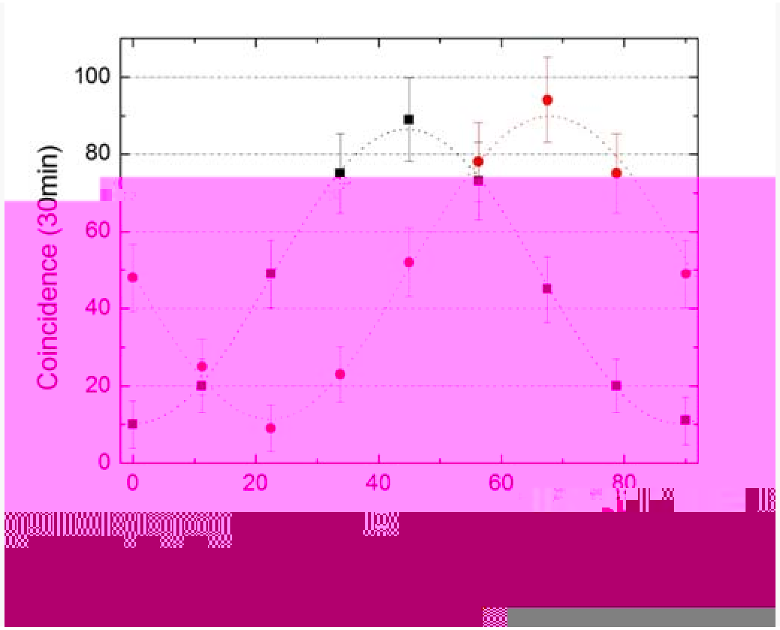
$$\rangle_c \equiv TM\rangle_c$$

$$|\ \rangle_t \equiv |D\rangle_t = \left(|TE\rangle_t + |TM\rangle_t\right)/\sqrt{\ }$$

$$|\ \rangle_t \equiv |A\rangle_t = \left(|TE\rangle_t - |TM\rangle_t\right)/\sqrt{\ }$$

: III. Q-CNOT gate



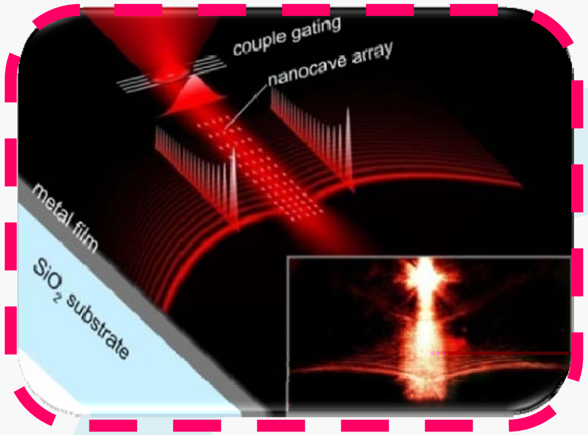


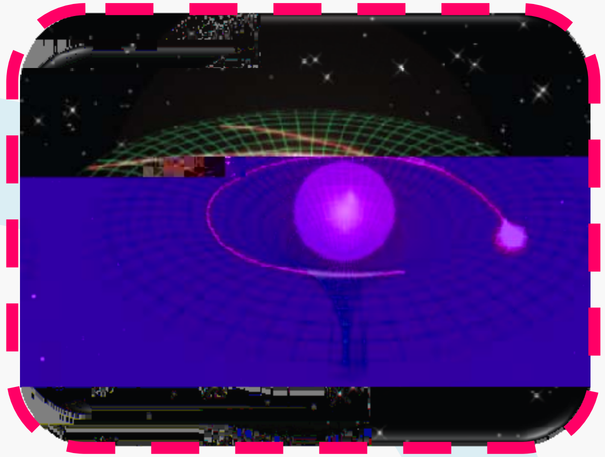
$$(\quad \rangle_c - \quad \rangle_c) \quad \rangle_t / \sqrt{\quad}$$

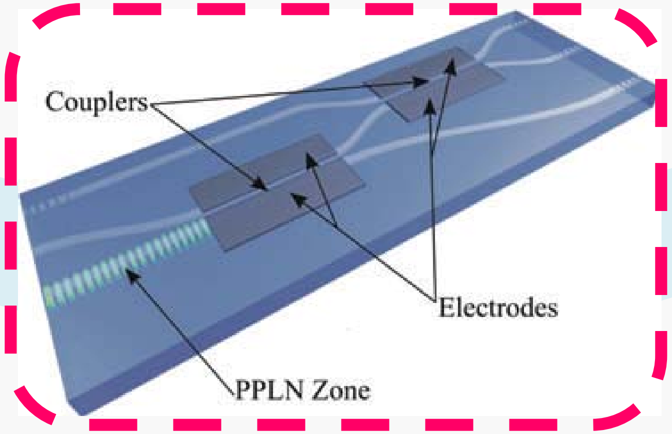
$$\rangle_c \quad (\quad \rangle_c + \quad \rangle_c) / \sqrt{\quad}$$

$$\psi^- \rangle = (\quad \rangle - \quad \rangle) / \sqrt{\quad}$$

SPP


couple gating
nanocave array
metal film
SiO2 substrate



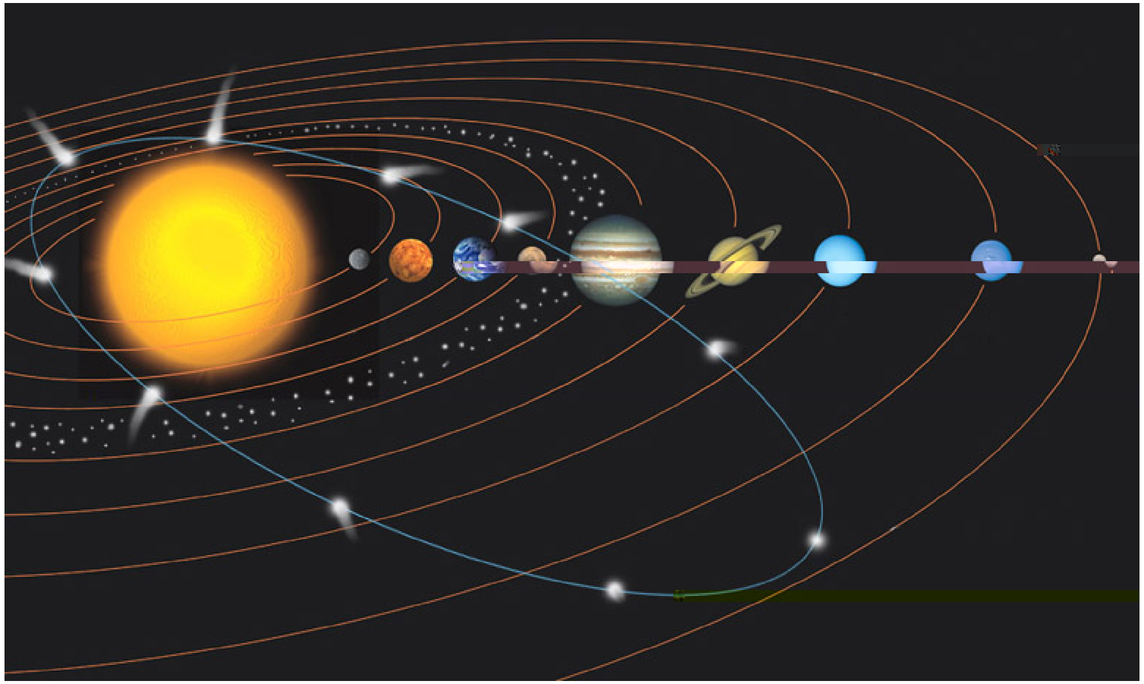

Couplers
Electrodes
PPLN Zone

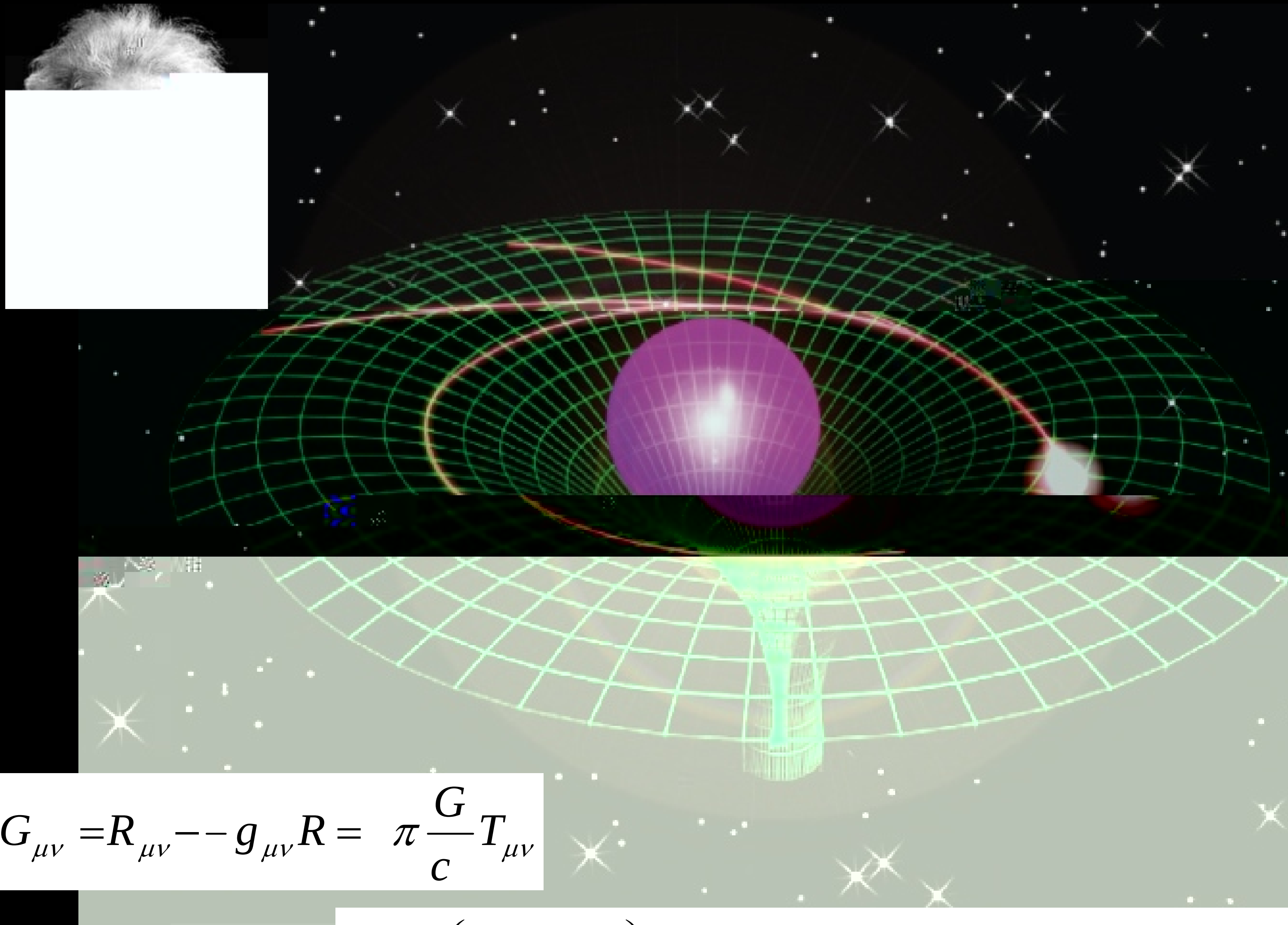
LN

( )

$$F = G\frac{mM}{r}$$

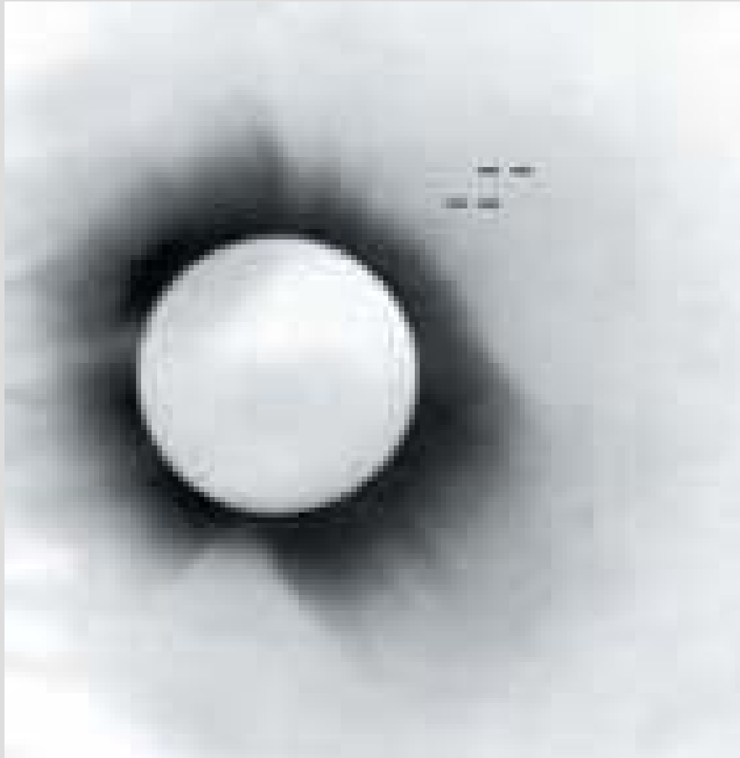
$$r = x + y + z$$



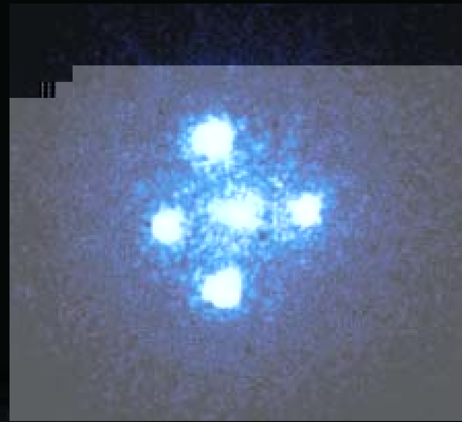


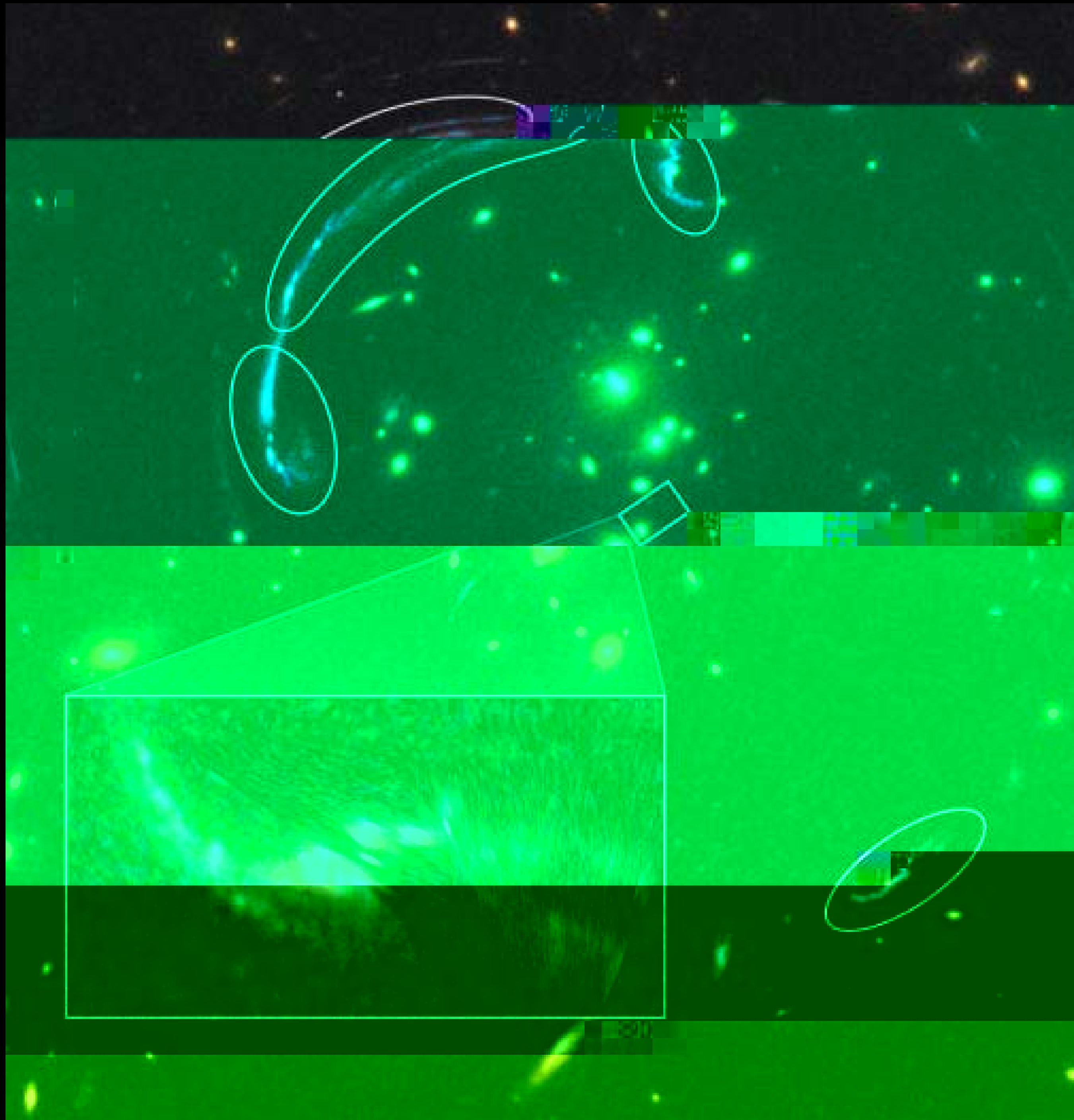
$$G_{\mu\nu} = R_{\mu\nu} - - g_{\mu\nu} R = \pi \frac{G}{c} T_{\mu\nu}$$

$$ds = \left(- \frac{GM}{r} \right) dt - \frac{dr}{- \frac{GM}{r}} - r \; d\theta - r \qquad ^{\vartheta} d\theta$$



1919





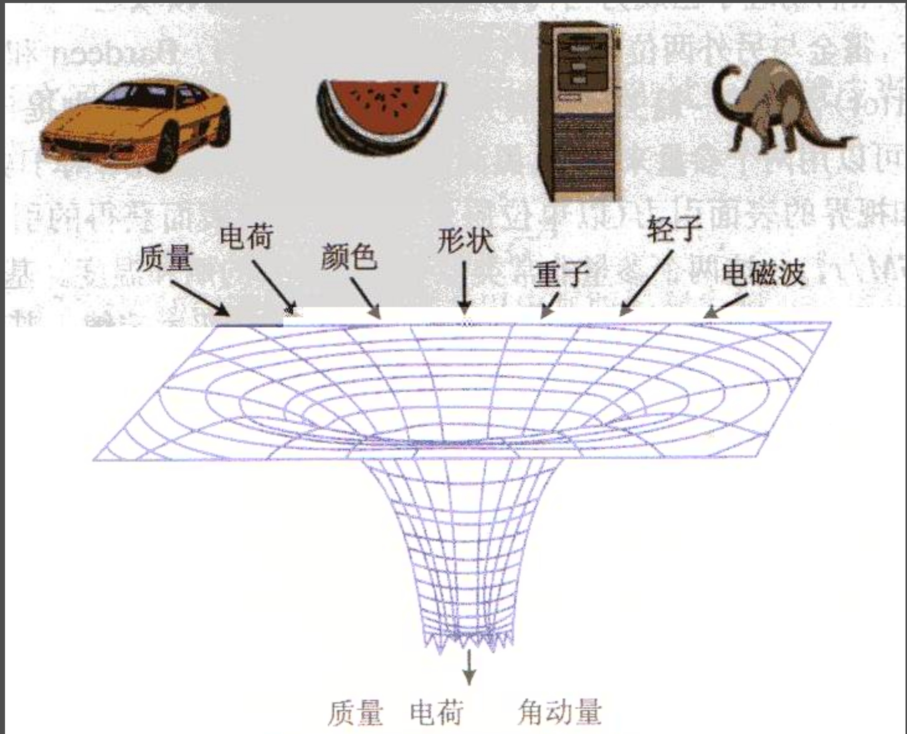


图 4.10 黑洞的"三毛定理"

表 4.1 典型天体的密度与表面引力场强度

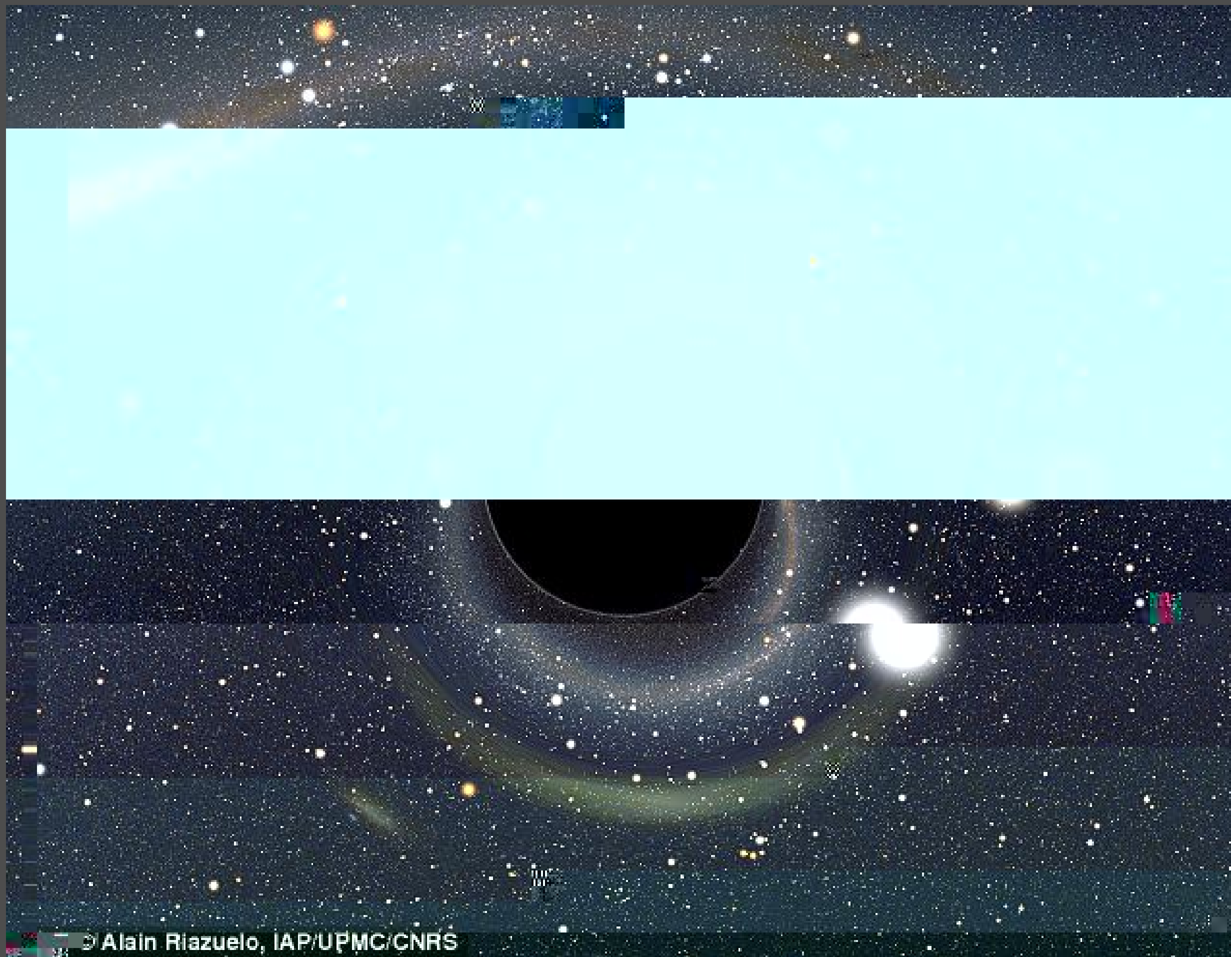
天体名称	平均密度(g/cm^3)	引力强度参数($2GM/Rc^2$)
地球	5	10^{-9}
太阳	1	10^{-6}
白矮星	$\sim 10^6$	$\sim 10^{-4}$
中子星	$\sim 10^{14}$	$\sim 10^{-1}$
黑洞		1

$< 1.4\ M_\odot$

$> 3.2\ M_\odot$

$$\upsilon = \frac{GM}{R}$$

$$r_s \equiv \frac{GM}{c}$$


© Alain Riazuelo, IAP/UPMC/CNRS

:

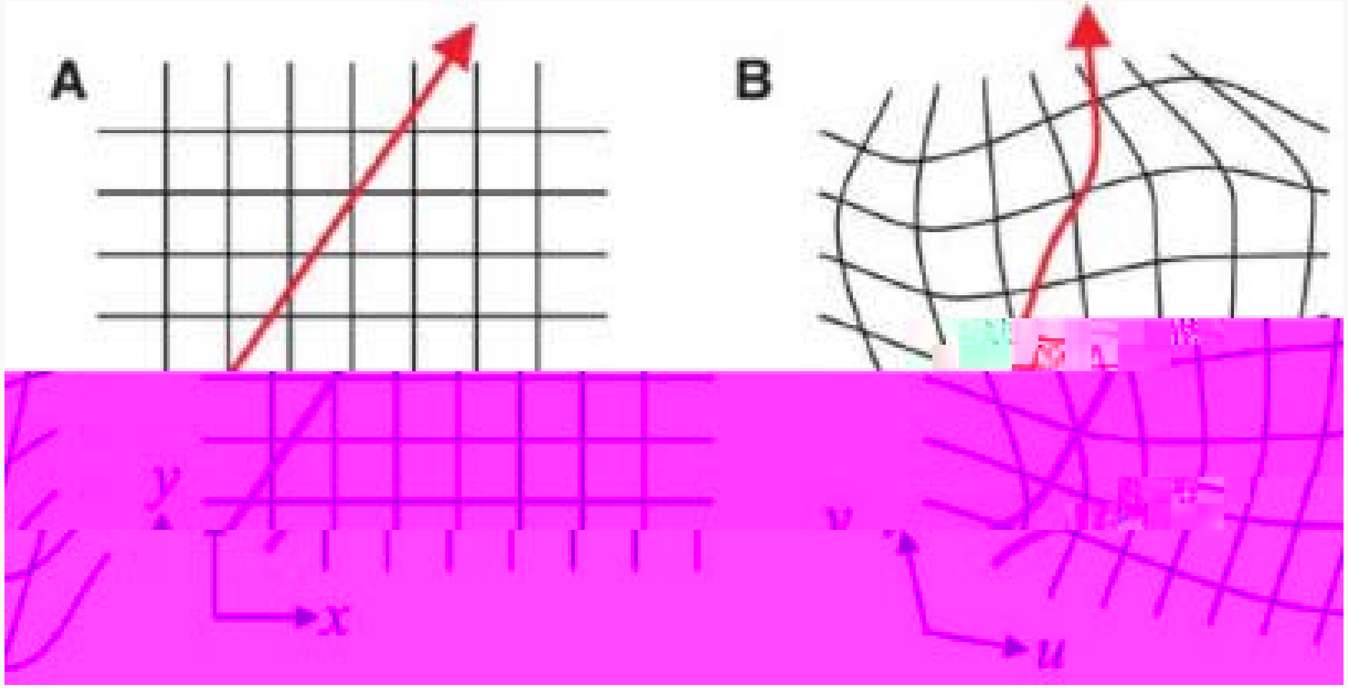
$$G_{\mu\nu} = -T_{\mu\nu} = -\rho u_{\mu} u_{\nu} - p \; u_{\mu} u_{\nu} - g_{\mu\nu}$$

$$ds \;\; = e^{\;\nu} c \;\; dt \;\; - e^{\;\lambda} \;\; dr \;\; + r \;\; d\Omega$$

:

$$\begin{cases} \nabla \times \qquad \mu(\quad) \cdot \dfrac{\partial}{\partial} \\ \nabla \times \qquad \varepsilon(\quad) \cdot \dfrac{\partial}{\partial} \end{cases}$$

$$\Rightarrow \nabla \quad - \frac{(\quad)}{\quad} \cdot \frac{\partial}{\partial} =$$



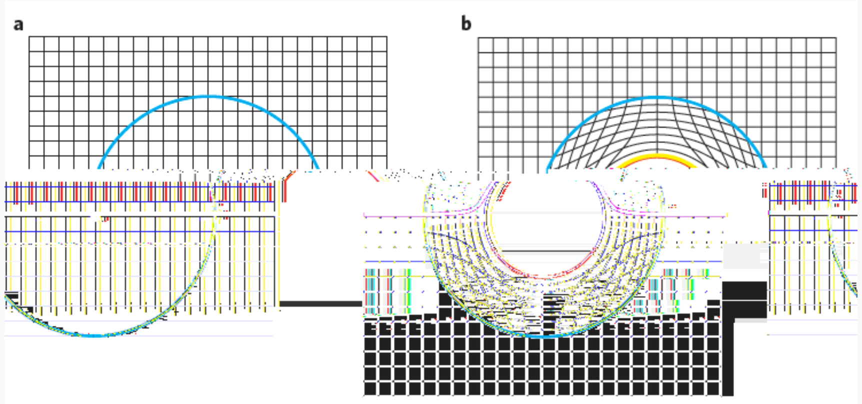
$$\varepsilon_u' = \varepsilon_u \frac{Q_u Q_v Q_w}{Q_u^{\ 2}}$$

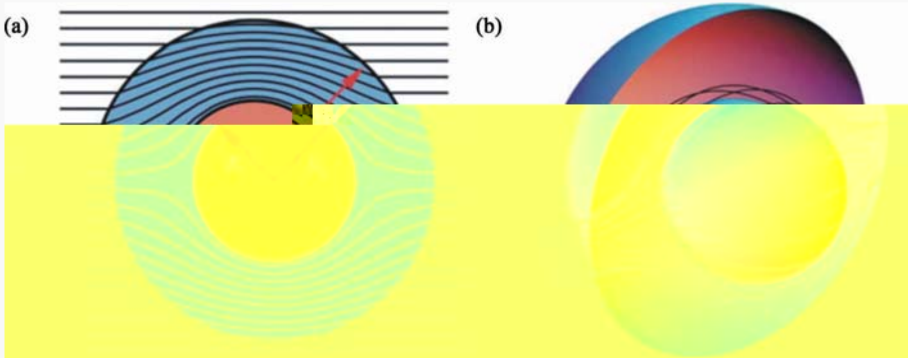
$$\mu_u' = \mu_u \frac{Q_u Q_v Q_w}{Q_u^{\ 2}}$$

$$Q_u^2 = \left(\frac{\partial x}{\partial u}\right)^2 + \left(\frac{\partial y}{\partial u}\right)^2 + \left(\frac{\partial z}{\partial u}\right)^2$$

$$Q_v^2 = \left(\frac{\partial x}{\partial v}\right)^2 + \left(\frac{\partial y}{\partial v}\right)^2 + \left(\frac{\partial z}{\partial v}\right)^2$$

$$Q_w^2 = \left(\frac{\partial x}{\partial w}\right)^2 + \left(\frac{\partial y}{\partial w}\right)^2 + \left(\frac{\partial z}{\partial w}\right)^2$$

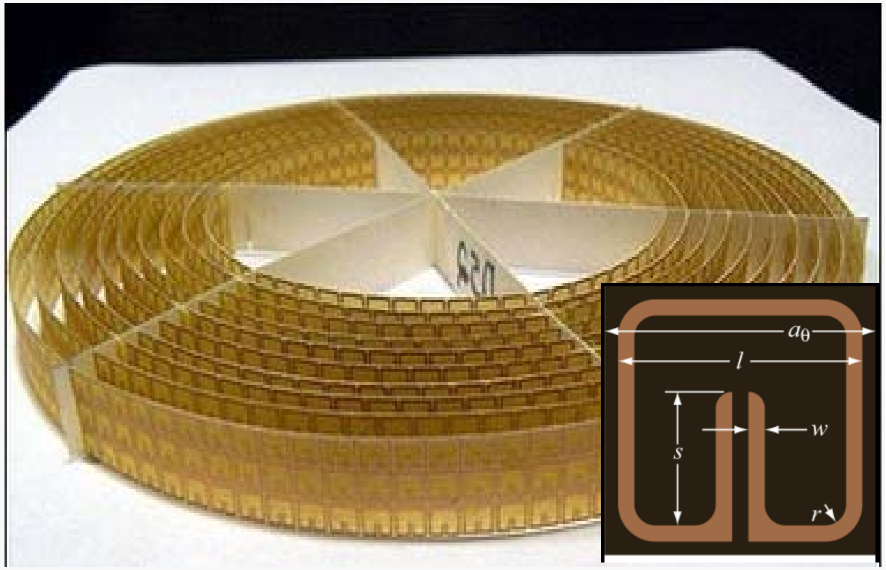




$$\varepsilon'_{r'} = \mu'_{r'} = \frac{R_2}{R_2 - R_1}\frac{(r' - R_1)^2}{r'},$$

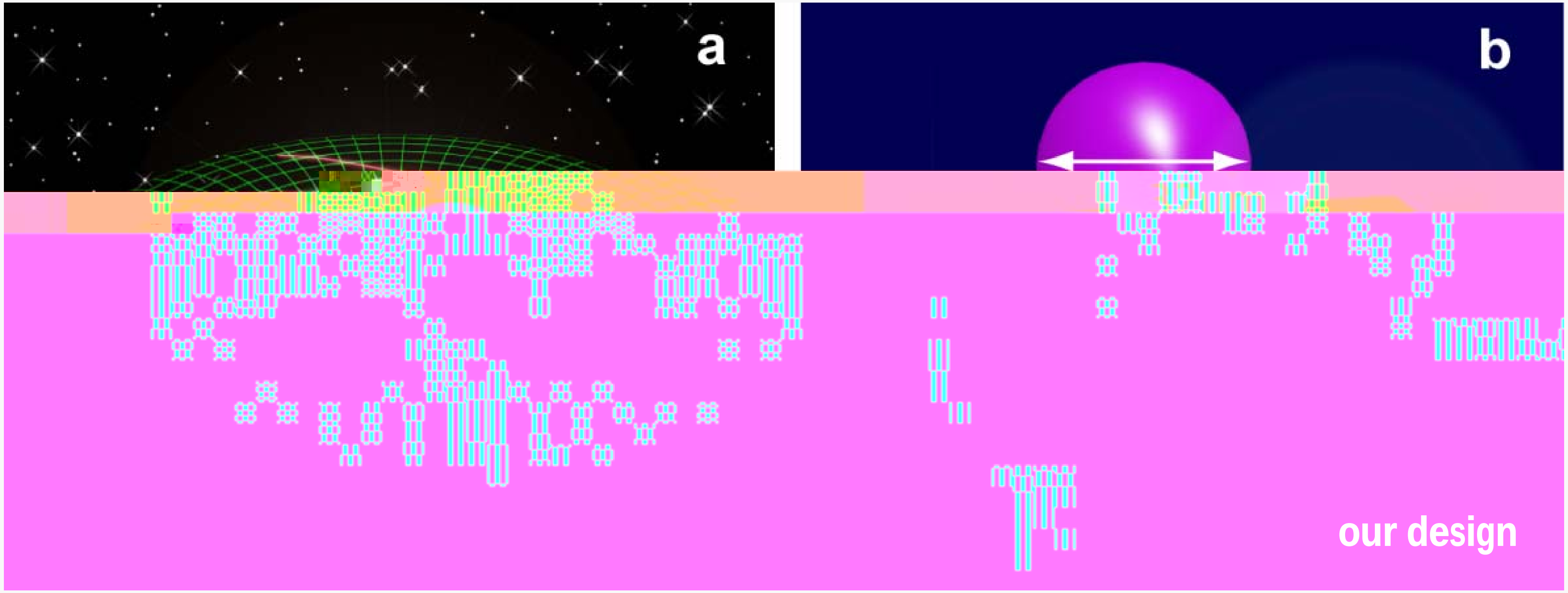
$$\varepsilon'_{\theta'} = \mu'_{\theta'} = \frac{R_2}{R_2 - R_1},$$

$$\varepsilon'_{\phi'} = \mu'_{\phi'} = \frac{R_2}{R_2 - R_1}$$



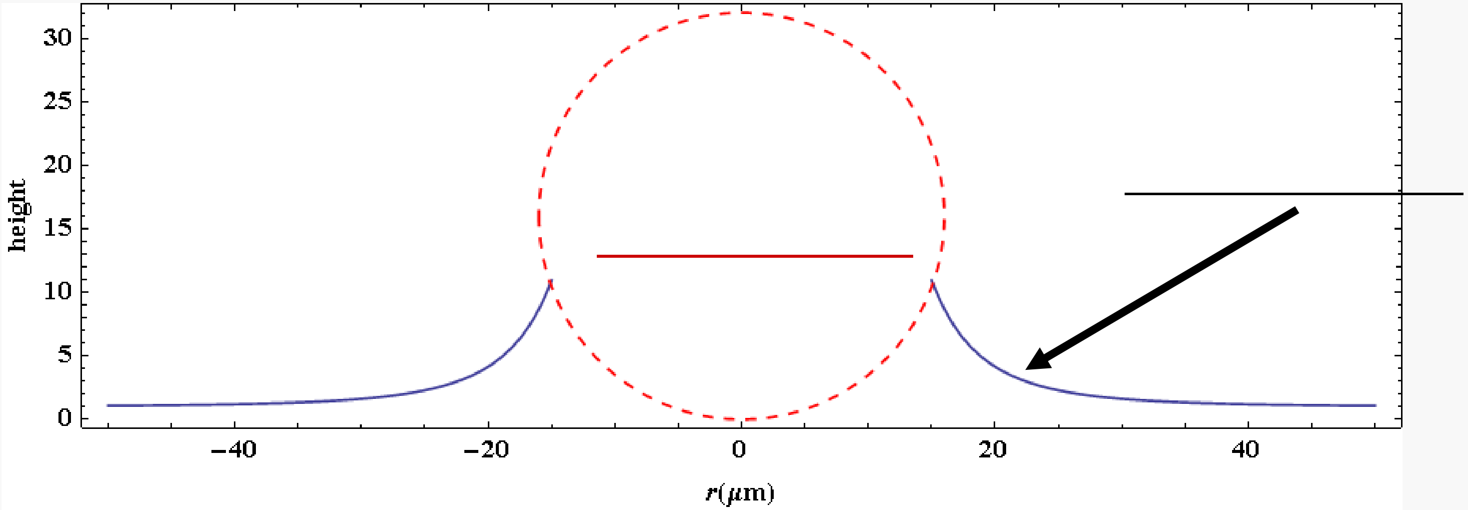
J. B. Pendry et al.,Science

U. Leonhardt, Science


a
b
our design

= ; =

PMMA

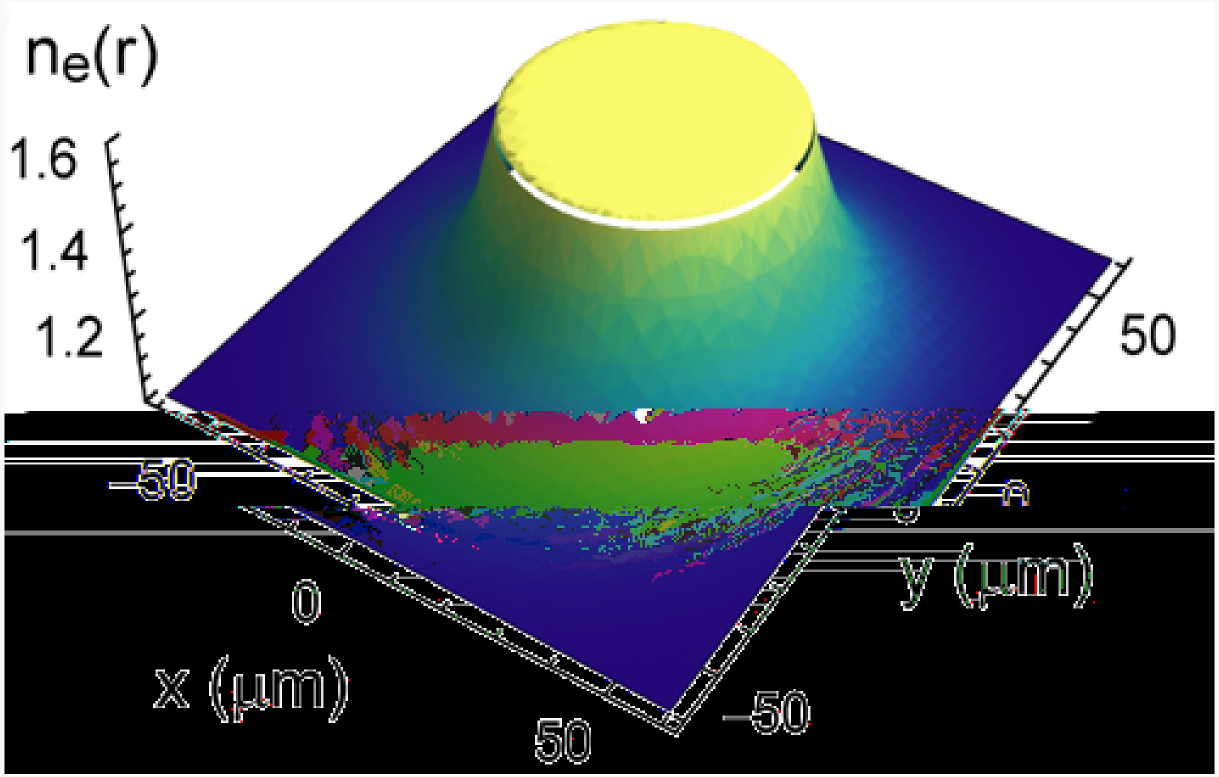


PMMA , 20

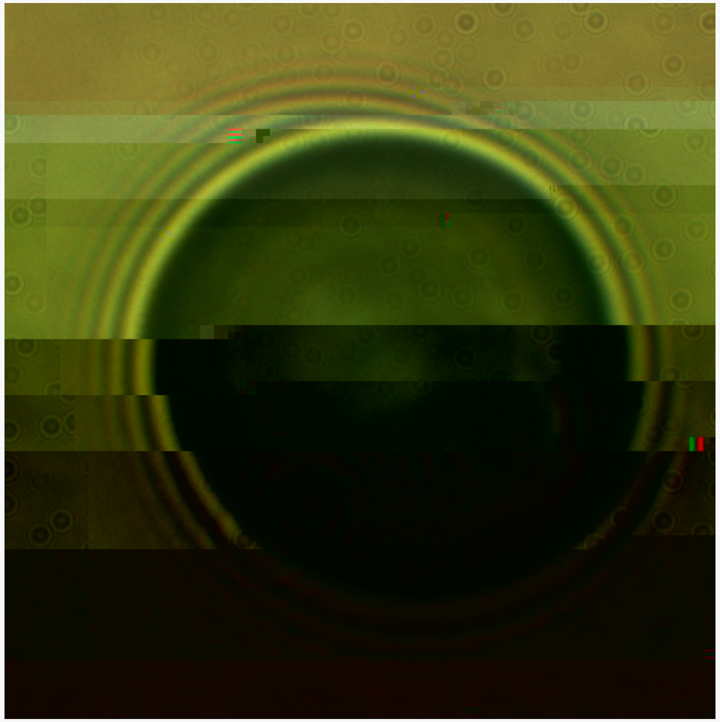
PMMA PMMA

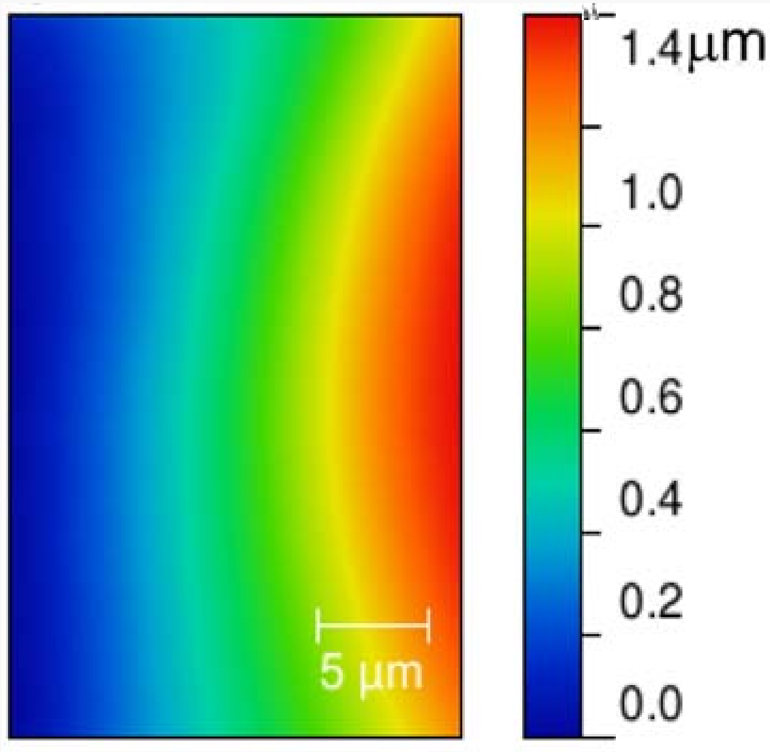
$$h(r) = \quad + \frac{R}{r}$$

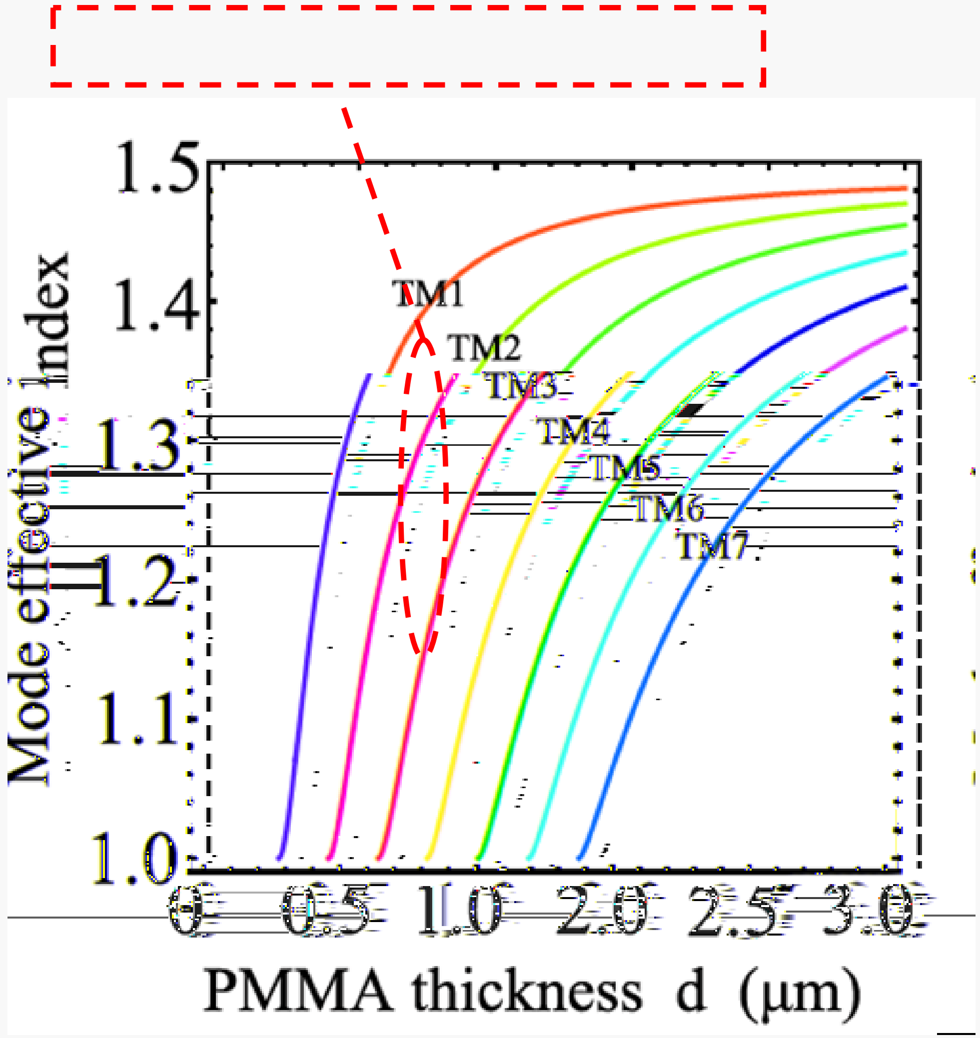
$R \approx \quad \mu m$



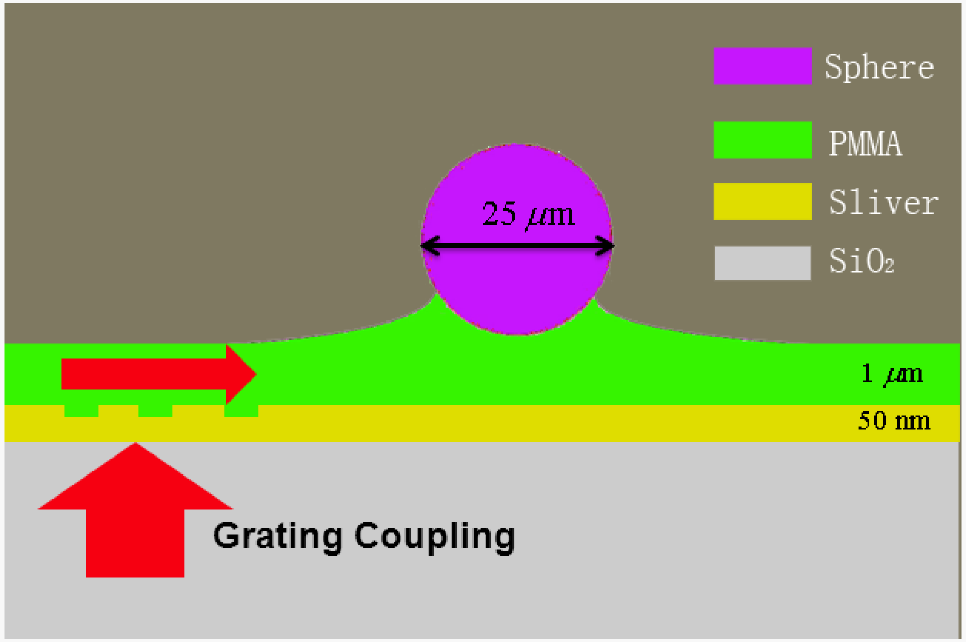
n_e(r)
1.6
1.4
1.2
50
−50
0
y (µm)
0
x (µm)
50
−50

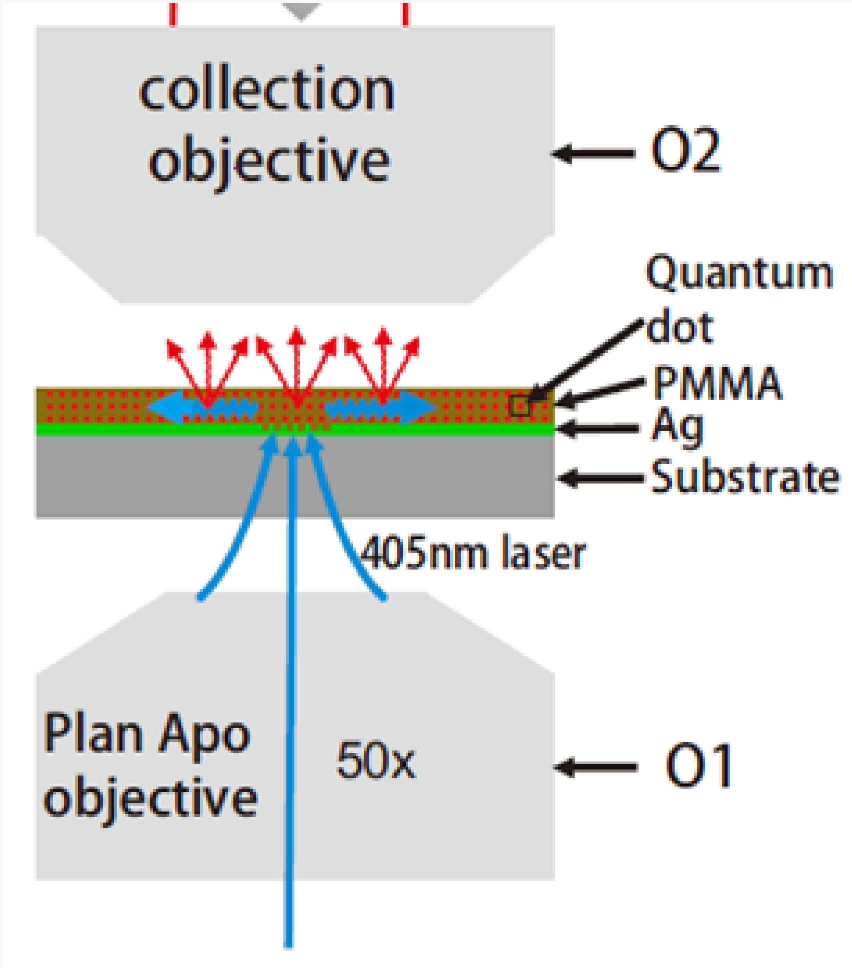



1.4μm
1.0
0.8
0.6
0.4
0.2
0.0
5 μm

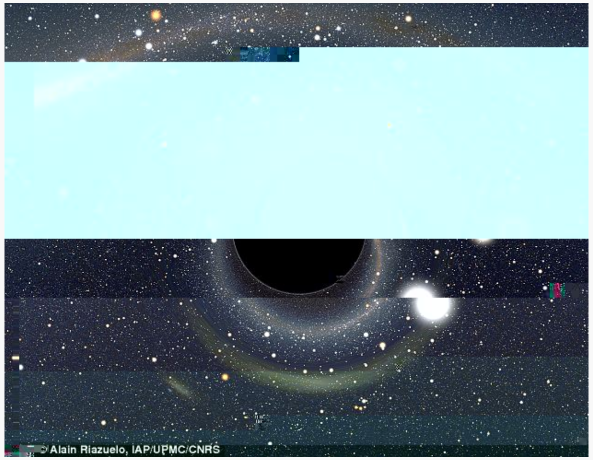


Mode effective index
1.5
1.4
1.3
1.2
1.1
1.0
TM1
TM2
TM3
TM4
TM5
TM6
TM7
0
0.5
1.0
2.0
2.5
3.0
PMMA thickness d (μm)





Nature Photonics, in press (2013)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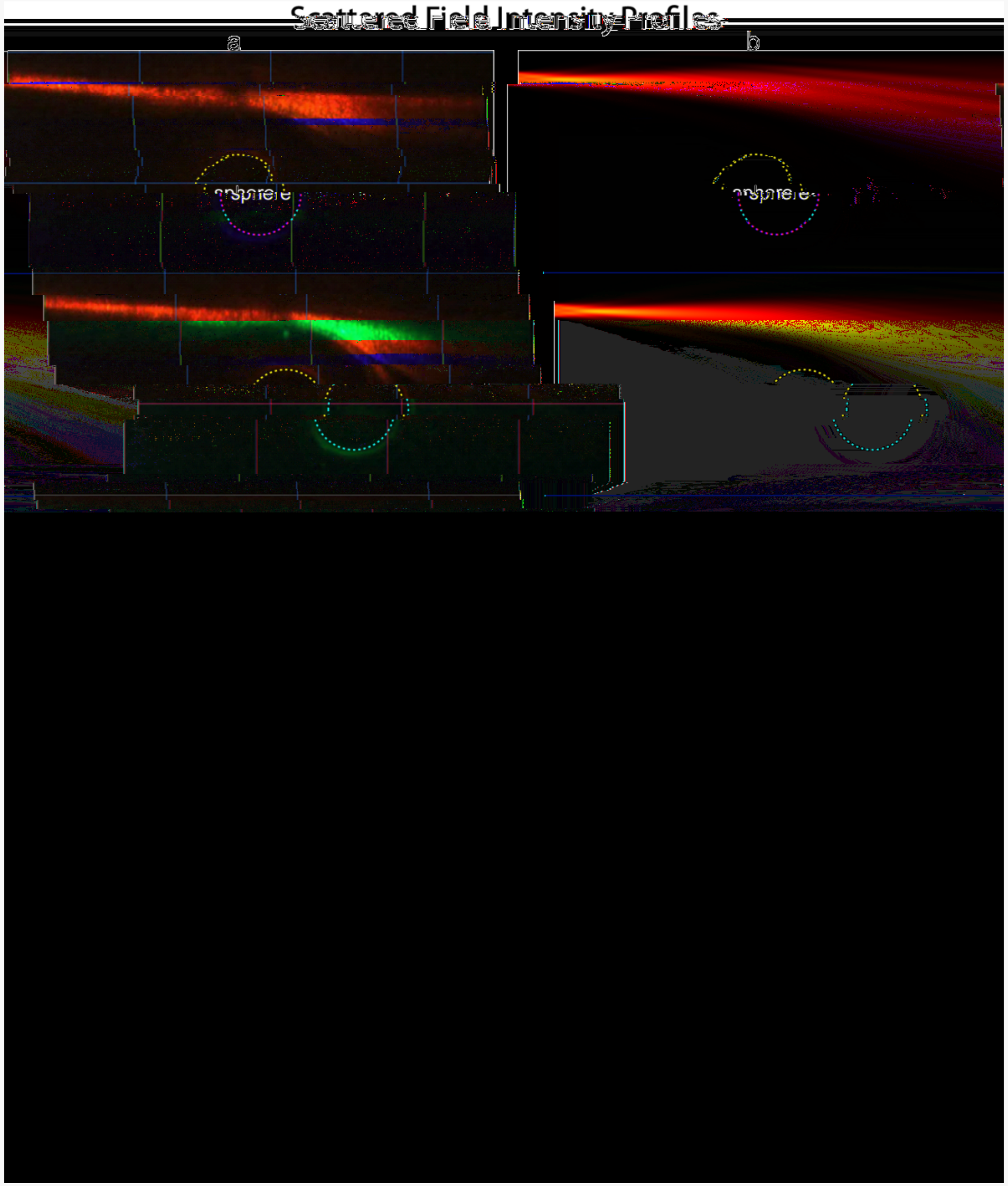

Scattered Field Intensity Profiles
a
b

[redacted]

$$\varepsilon(r) = n^2(r) \approx n_\infty^2\left[1+\left(\frac{a}{r}\right)^4\right]$$

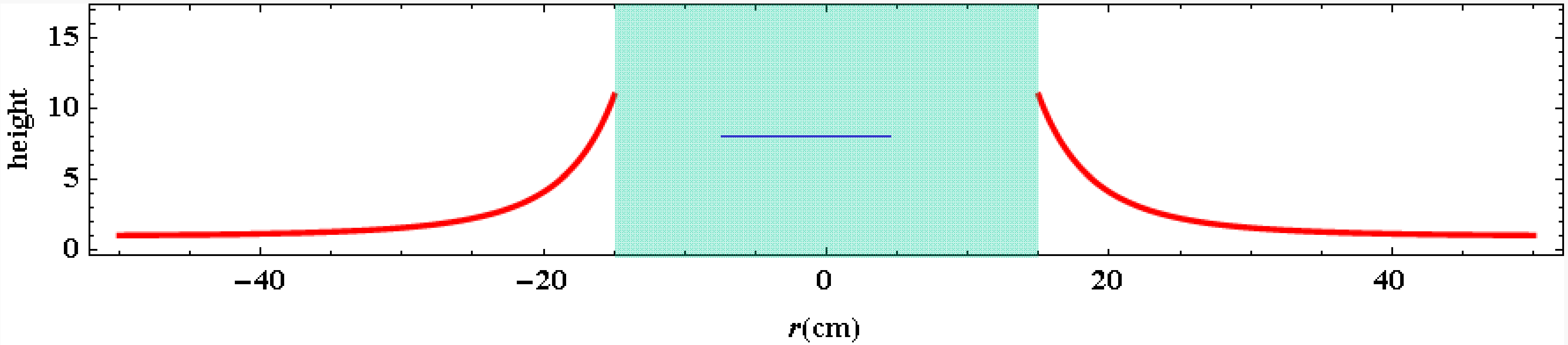
$$\left(\frac{dr}{d\varphi}\right)^2 = \frac{n^2(r)r^4}{b^2} - r^2$$

$$\theta = 2K[u_t^4]\sqrt{1+u_t^4} - \pi$$

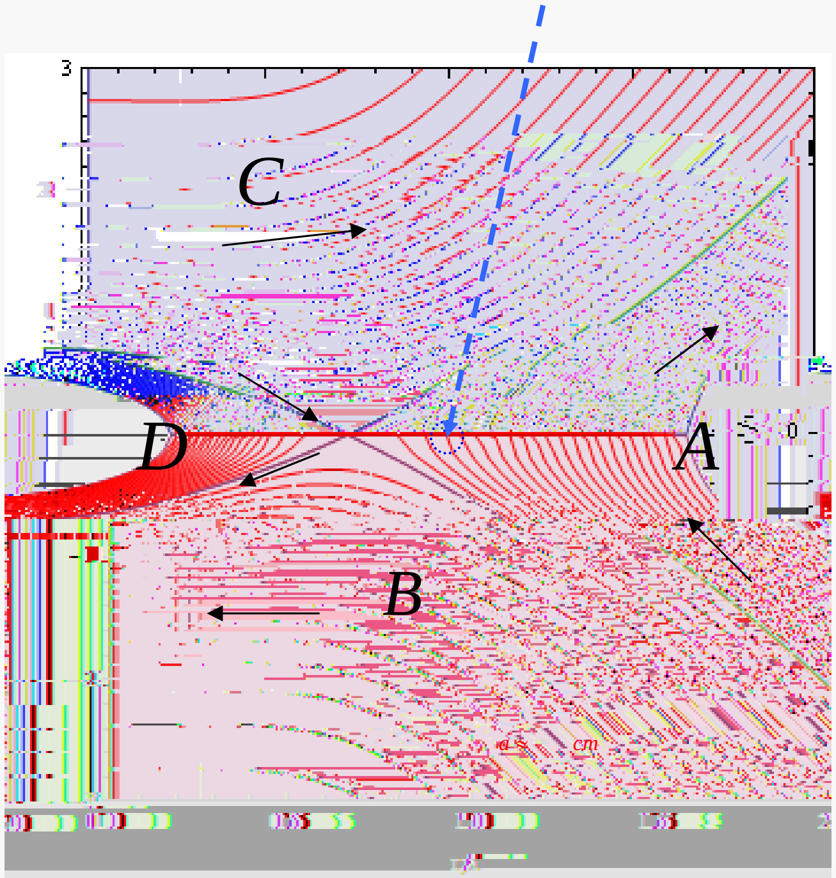
32cm PMMA

$$h(r) = h_\infty + \frac{R}{r} s$$

$$h\ r = + \frac{cm}{r} \quad \mu$$



$$h_\infty = \quad \mu m$$



$$r_{ph} = a$$

$$\frac{dr}{d\varphi} = \qquad \frac{d\ \ r}{d\ \ \varphi} =$$

$$: \quad n\left(r\right) \approx \quad + \left(\frac{a}{r}\right)$$

:

$$a = \qquad cm$$

Phase space

A,

B

C

D trapping

: $n(r) \approx \sqrt{\;\; + \left(\frac{a}{r} \right) \;}$

$$r_{ph} = a$$

$$\left| \frac{dn}{dr} \right| = \frac{a}{r \;\; \sqrt{a \;\; + r \;}}$$

$r_{ph} = a$

$$\left. \left| \frac{dn}{dr} \right| \right|_{r = r_{ph}} = \frac{a}{r \;\; \sqrt{a \;\; + r \;}} = \frac{\sqrt{\;\;}}{a}$$

$$\frac{\sqrt{\;\;}}{a}$$

表 4.1　典型天体的密度与表面引力场强度

天体名称	平均密度(g/cm^3)	引力强度参数($2GM/Rc^2$)
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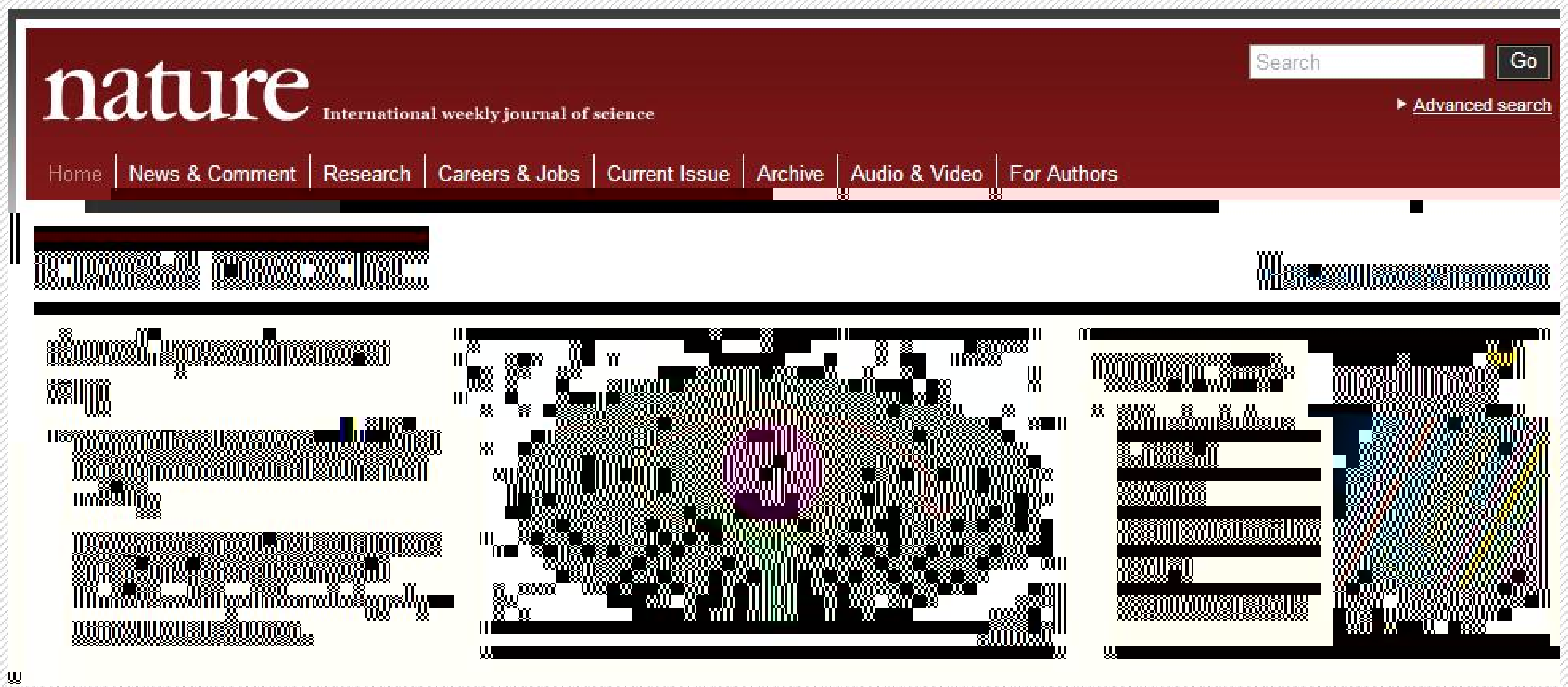
太阳	1	10^{-6}
白矮星	$\sim 10^{6}$	$\sim 10^{-4}$
中子星	$\sim 10^{14}$	$\sim 10^{-1}$
黑洞		1

$$= \quad GM \quad Rc \quad = a / R =$$

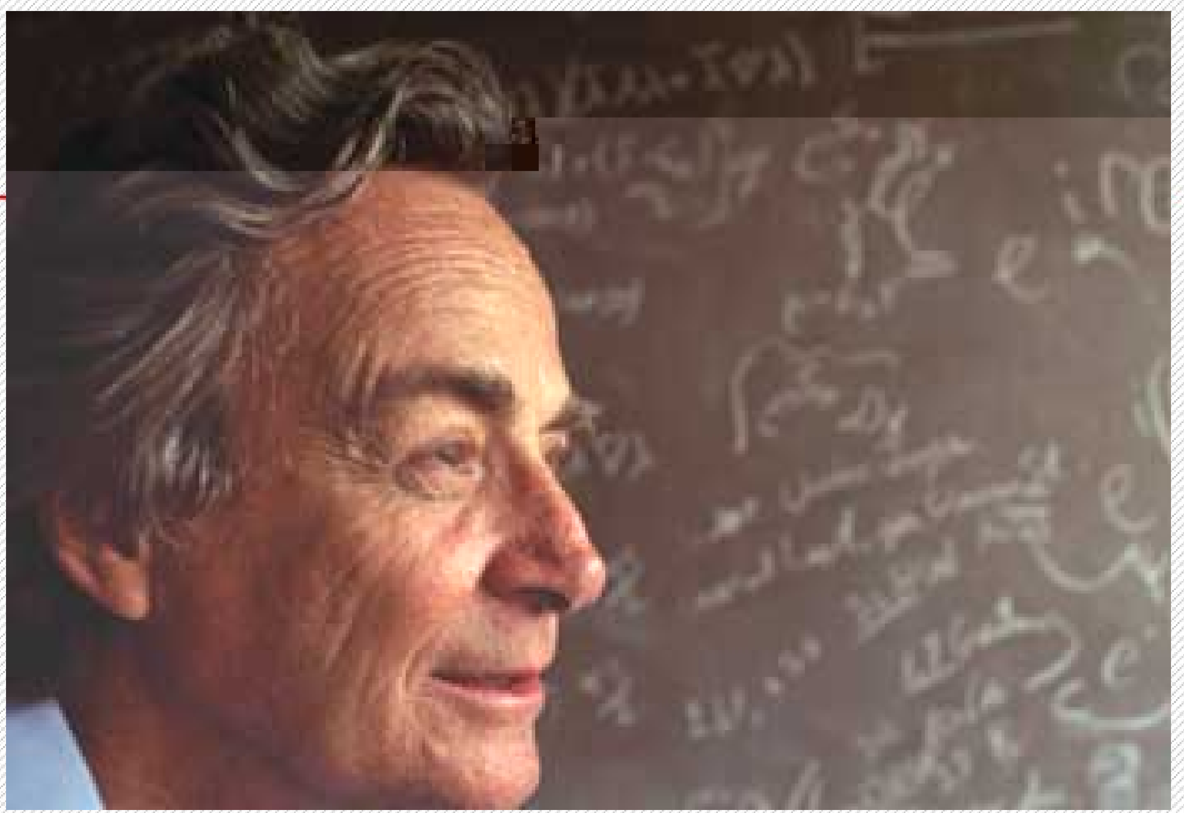
$$a \equiv \quad GM \quad c$$

$$\rho \propto M \quad a \quad \propto \quad M$$

1. $M = 10^{15}$ g, $r = 1.5 * 10^{-13}$ cm => 10^{53} g / cm^3;
2. $M = 3 * 10^{55}$ g, $r = 4 * 10^{27}$ cm (10^{10}) => 10^{-29} g / cm^3.



“This is indeed the first time an exact solution of Einstein's equations was mimicked” using an optical model, says Leonhardt. The simplicity of the experiment — microspheres on plastics — “beautifully illustrates some of the ideas of general relativity”, he adds.

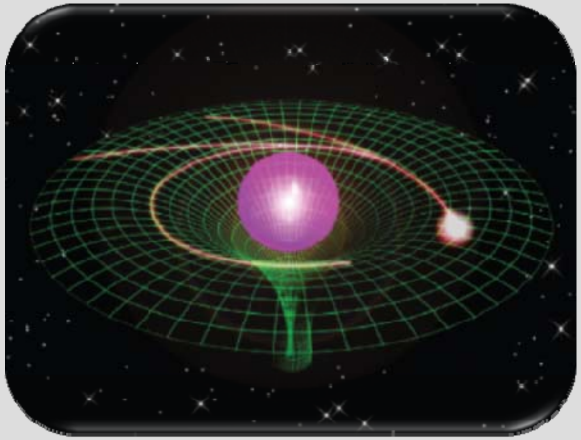


Richard Feynman

Still, says study coauthor Dentcho Genov of Louisana Tech University in Ruston, the team's microchip model "may hold the key to the elucidation of phenomena based on general relativity that are extremely difficult to study through direct astronomical observations". This includes cases of radio waves with wavelengths comparable to the size of the celestial object, he notes.

:


uple gating
nanocave array
metal film



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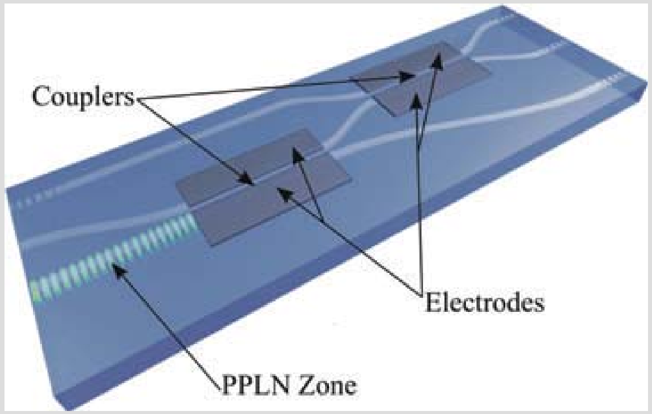
Couplers
Electrodes
PPLN Zone

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Supported by :

the State Key Program for Basic Research in China and the National Natural Science Foundations of China

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http://dsl.nju.edu.cn