VILNIAUS UNIVERSITETAS
FIZIKOS FAKULTETAS
KVANTINĖS ELEKTRONIKOS KATEDRA

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Topologinio krūvio tvermė optinėje parametrinėje generacijoje kaupinant aukštesnės eilės Beselio-Gauso pluoštais

LTC Seminaras

Optiniai sūkuriai

Helmholco (*Helmholtz*) lygtis:

$$\Delta A + k^2 A = 0$$

k- banginis skaičius.

1974m. J. F. Nye, M. V. Berry, Dislocations in wave trains, Proc. R. Soc. London A:

$$A(r, \varphi, z, t) \sim r^{|m|} \exp(im\varphi + ikz - i\omega t)$$

m - topologinis krūvis

Singuliarumas:

$r = 0$ → A=0

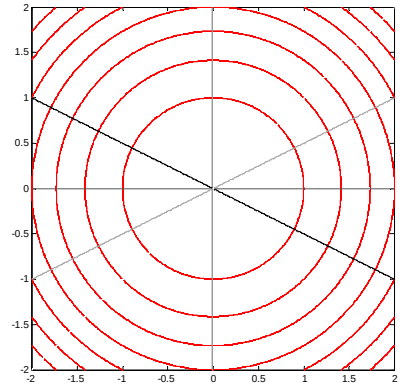
fazė neapibrėžta

Optiniai sūkuriai

$r=const$

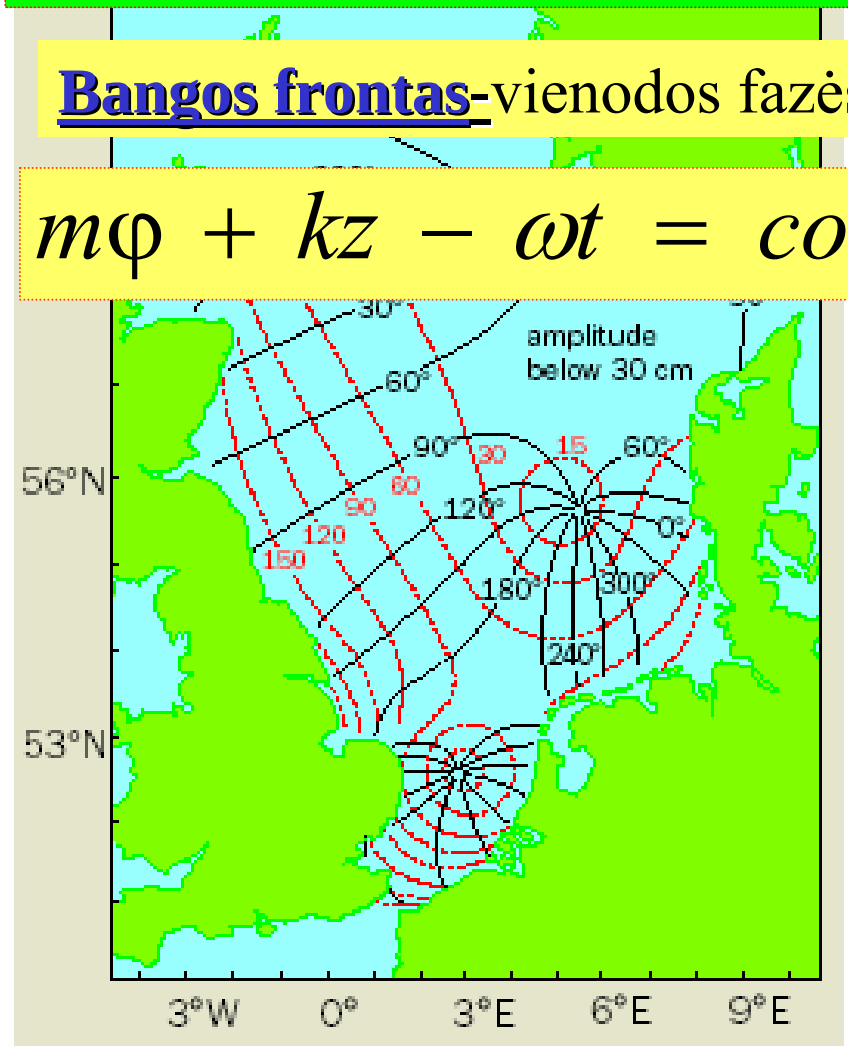
$\varphi=const$

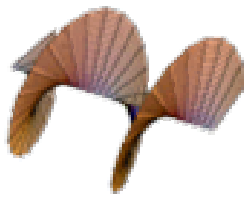
$$A(r,\varphi,z,t)\sim r^{|m|}\exp(im\varphi+ikz-i\omega t)$$



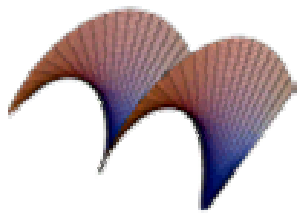
Bangos frontas-vienodos fazės paviršius

$$m\varphi + kz - \omega t = const + 2\pi n$$

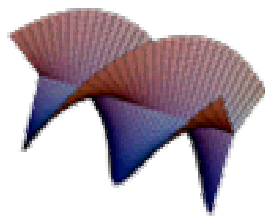




$m=1$



$m=2$



$m=3$

http://www.physics.gla.ac.uk/Optics/projects/AM/VisserPhysicsWorld.pdf

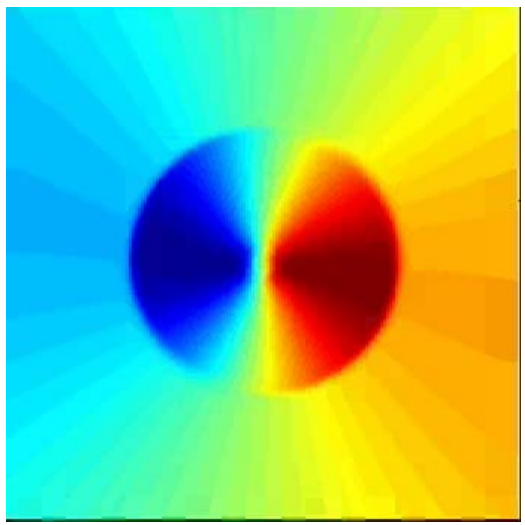
http://www.physics.gla.ac.uk/Optics/projects/AM/

Optiniai sūkuriai lazeryje

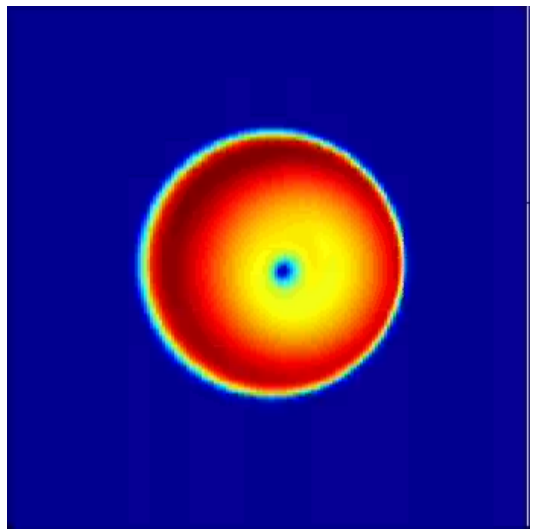
1989m. - P. Coullet, L. Gil, F. Rocca, Optical vortices, Opt. Commun.

L. Gil, K. Emilsson, G.-L. Oppo, Phys. Rev. A (1992)

Re(E)



$|E|^2$

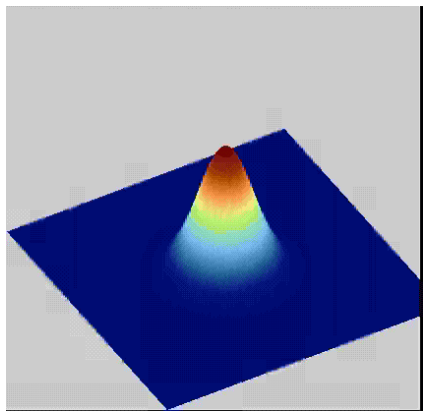


Lagero-Gauso modos

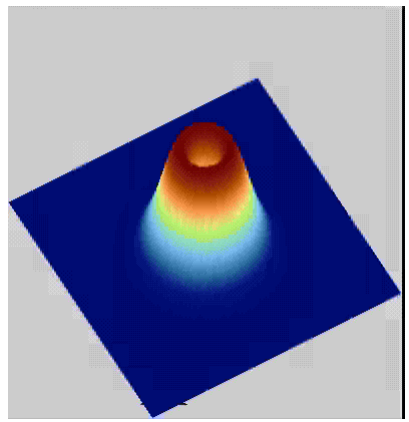
Lagero-Gauso moda $A=\mathrm{LG}^{p}_{m}$:

Intensyvumas: $|A|^2$

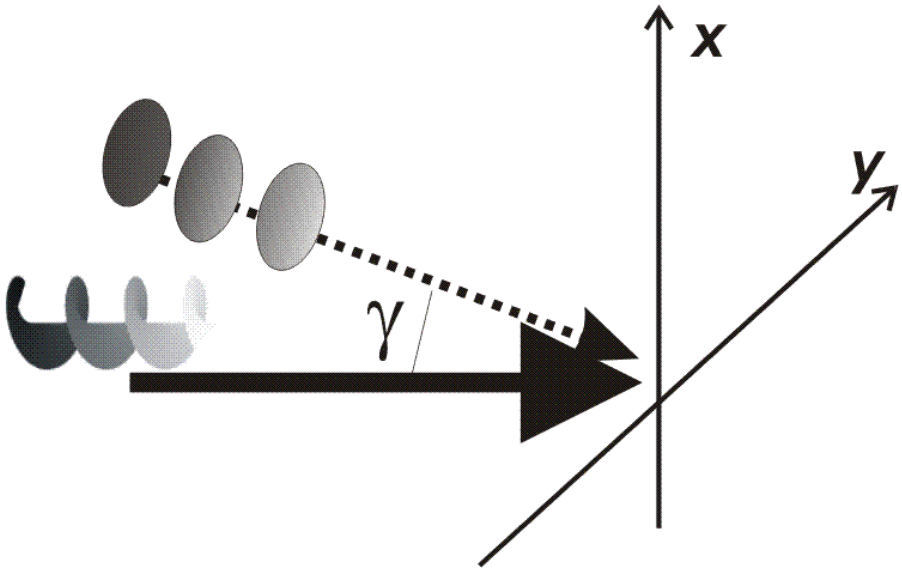
m=0

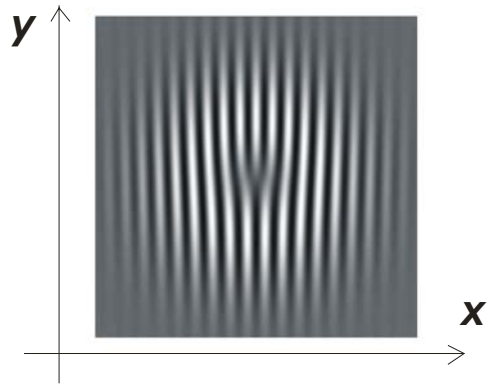


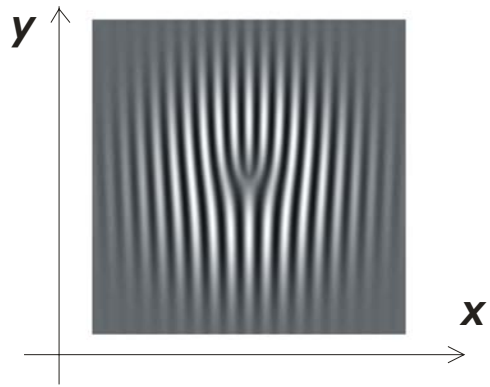
m=1



Hologramos



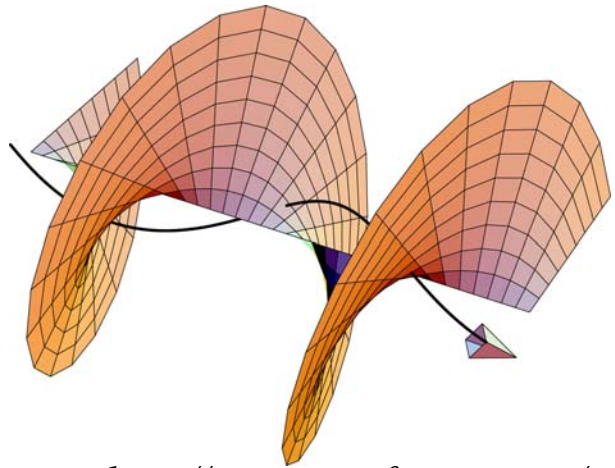




Judesio kiekio momentas

L. Allen et al., Orbital angular momentum of light and transformation of Laguerre-Gaussian modes, Phys. Rev. A, (1992).

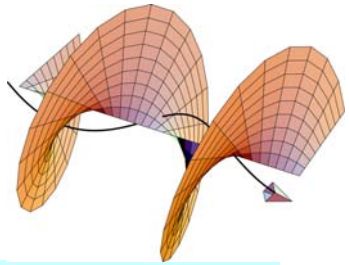
Įrašė tiesiškai poliarizuotos šviesos vektorinį potencialą
$\boldsymbol{A}=\boldsymbol{x}u(x,y,z)\exp(-ikz)$,
kur u- $LG^0_m=a(r)\exp(im\varphi)$



http://antwrp.gsfc.nasa.gov/apod/ap031119.html

Judesio kiekio momento srautas/energijos srautas:
$L/cP=m/\omega$
Apskritimiškai poliarizuotai šviesai:
$J/cP=(m+\sigma)/\omega$, $\sigma=0, \pm1$

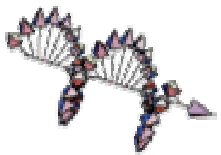
J=L+S
Orbitinis ir sukininis judesio kiekio momentai

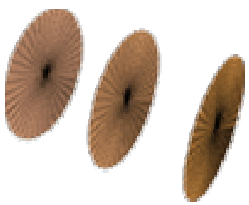


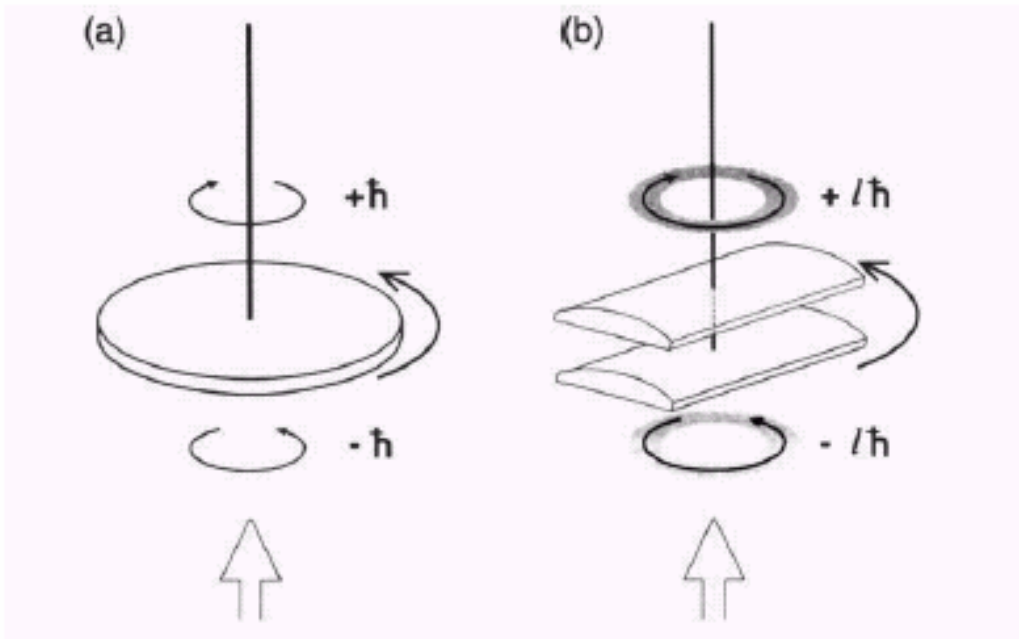
$J/cP = (m+\sigma)/\omega,\ \sigma = 0, \pm 1$

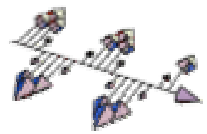
R. A. Beth (1936) - apskrimiškai poliarizuota šviesa

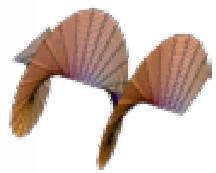
L. Allen et al. (1992) - pasiūlė eksperimentą:





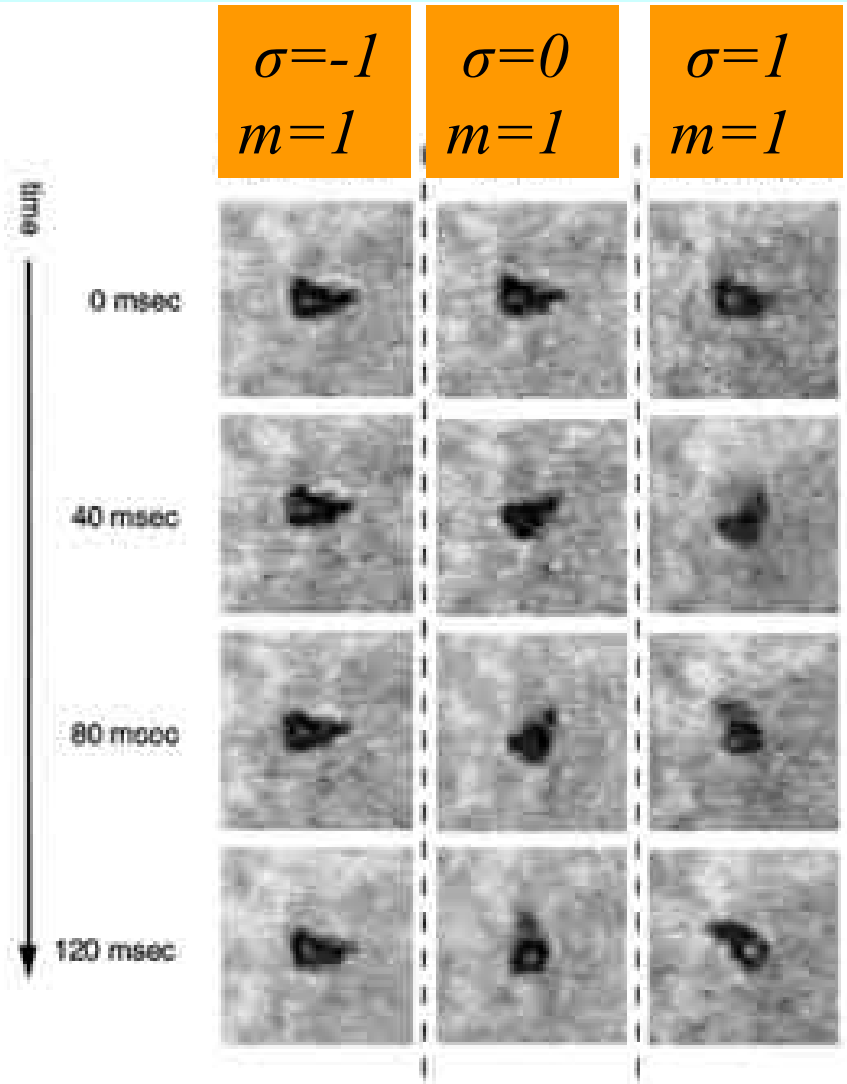


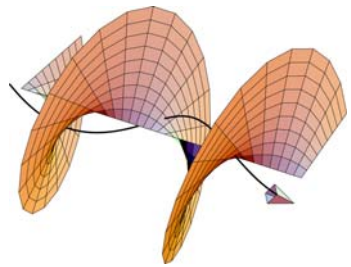




$J/cP = (m+\sigma)/\omega,\ \sigma = 0, \pm 1$

N. B. Simpson, K. Dholakia, L. Allen and M. J. Padgett, Opt. Lett. (1997).

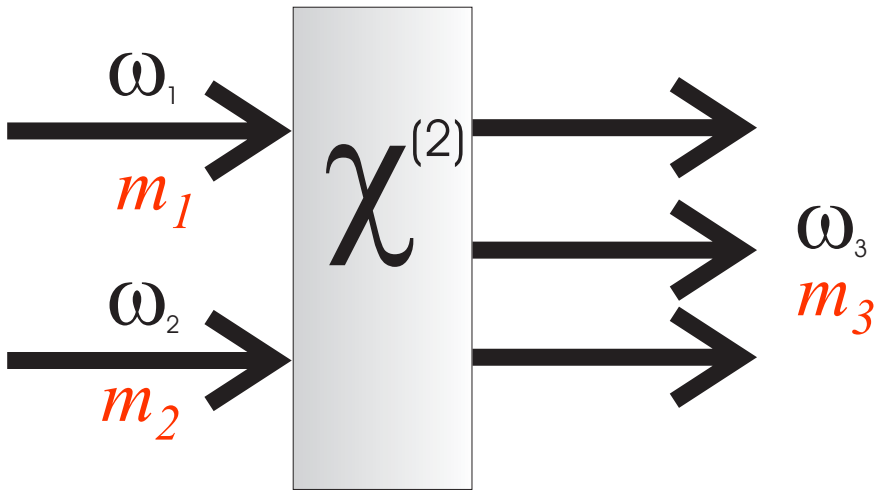




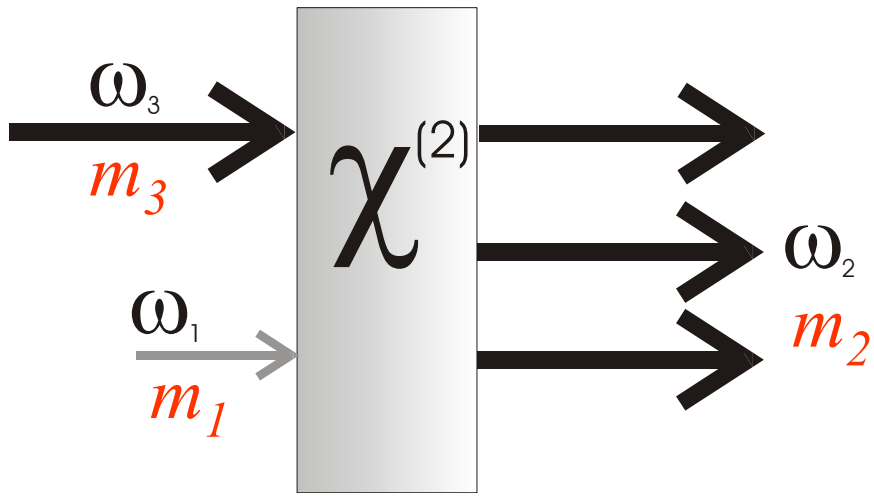
Tribangė sąveika

A. Beržanskis et al.,Conversion of topological charge of optical vortices in a parametric frequency converter, Opt. Commun., (1997).

Suminio dažnio generacija



Parametrinis stiprinimas

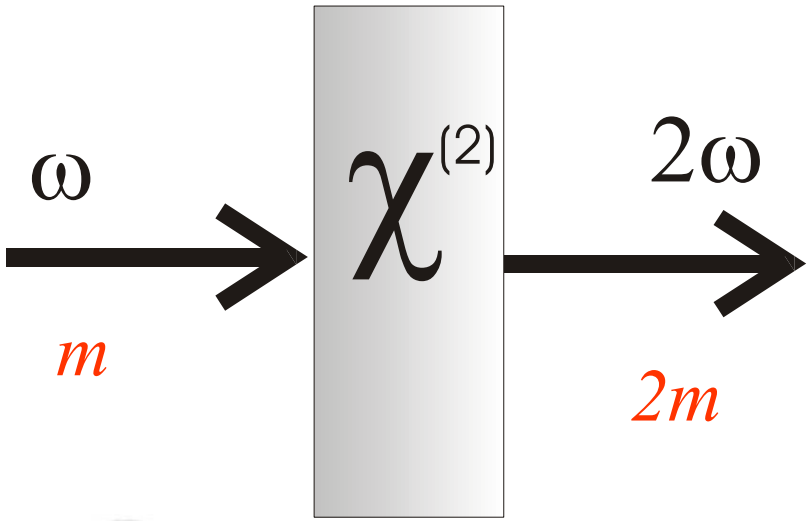


$$\omega_3 = \omega_1 + \omega_2$$

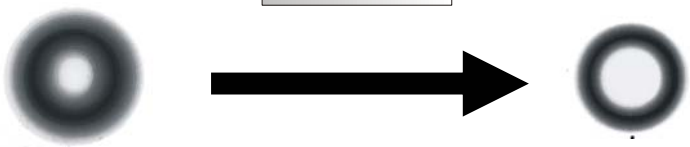
$$m_3 = m_1 + m_2$$

K. Dholakia, N. B. Simpson, M. J. Padgett et al.,Conversion of topological charge of optical vortices in a parametric frequency converter, Opt. Commun., (1997).

Antros harmonikos generacija



Eksperimentas:

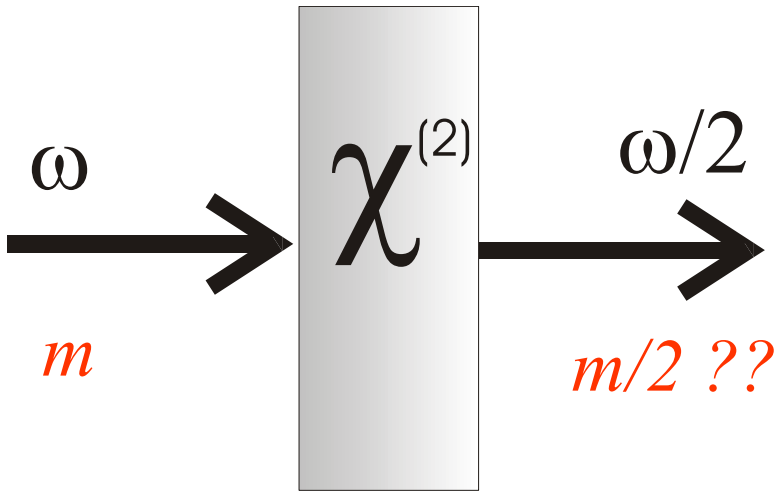


λ=1064nm LG^0_1 *m=1*

λ=532nm LG^0_2 *2m=2*

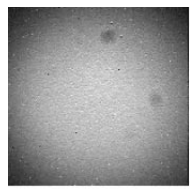
J. Arlt, K. Dholakia, L. Allen, and M. J. Padgett, Parametric down-conversion for light beams possessing orbital angular momentum, Phys. Rev. A (1999).

Parametrinė šviesos generacija

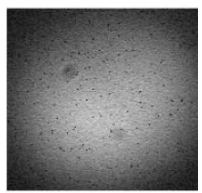


Eksperimentas: λ=532nm λ=1064nm

LG^0_1 m=1

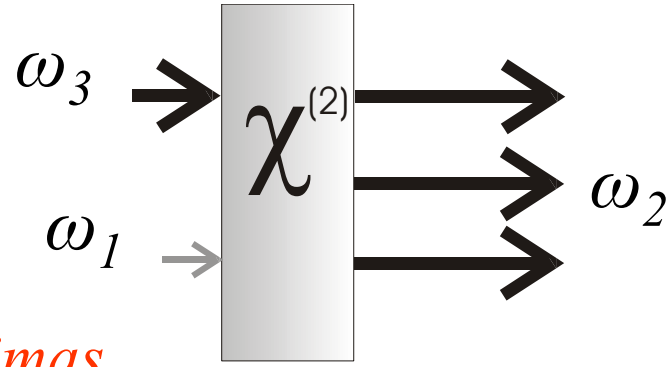


LG^0_2 m=2

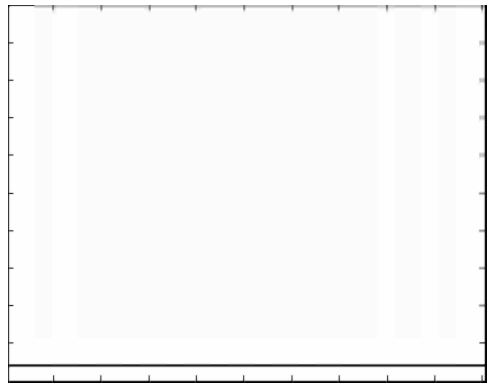


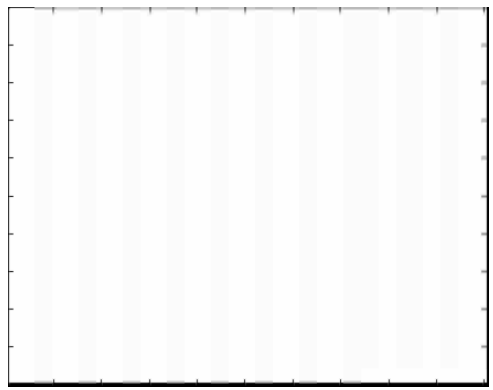
Judesio kiekio momentas PŠG neišsilaiko kaip stebimas dydis!?

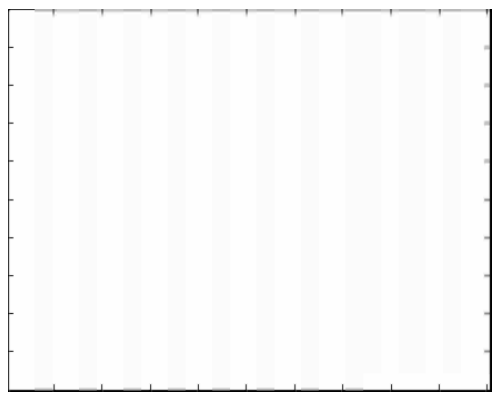
$$\omega_3 = \omega_1 + \omega_2$$



Plokščios bangos







Parametrinis stiprinimas

$$\frac{\partial A_1}{\partial z} = -i\kappa A_2^* A_3$$

$$\frac{\partial A_2}{\partial z} = -i\kappa A_1^* A_3$$

$$\frac{\partial A_3}{\partial z} = -i\kappa A_1 A_2$$

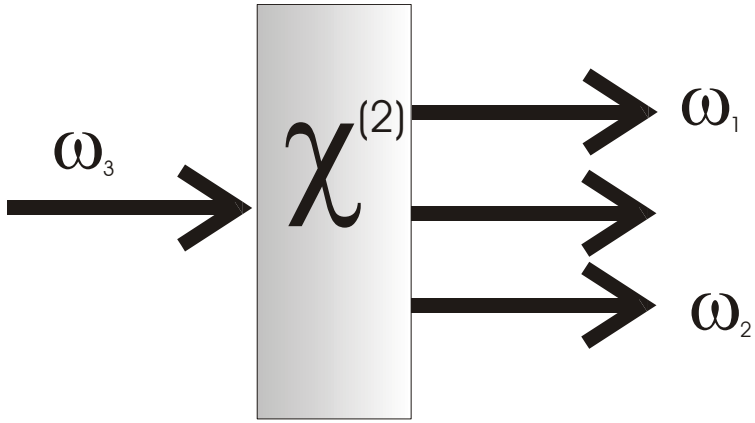
$$A_1 \propto \exp(im_1\varphi)$$

$$A_2 \propto \exp(im_2\varphi)$$

$$A_3 \propto \exp(im_3\varphi)$$

$$m_3 = m_1 + m_2$$

Parametrinė generacija



$$\omega_3 = \omega_1 + \omega_2$$

$$\frac{\partial A_1}{\partial z} = -i\kappa A_2^* A_3$$

$$A_1|_{z=0} = 0$$

$$\left.\frac{\partial A_1}{\partial z}\right|_{z=0} = 0$$

$$\frac{\partial A_2}{\partial z} = -i\kappa A_1^* A_3$$

$$A_2|_{z=0} = 0$$

$$\left.\frac{\partial A_2}{\partial z}\right|_{z=0} = 0$$

$$\frac{\partial A_3}{\partial z} = -i\kappa A_1 A_2$$

$$A_3|_{z=0} = A_{30}$$

klasikinis aprašymas bejėgis!

Parametrinė generacija: kvantmechaninis aprašymas

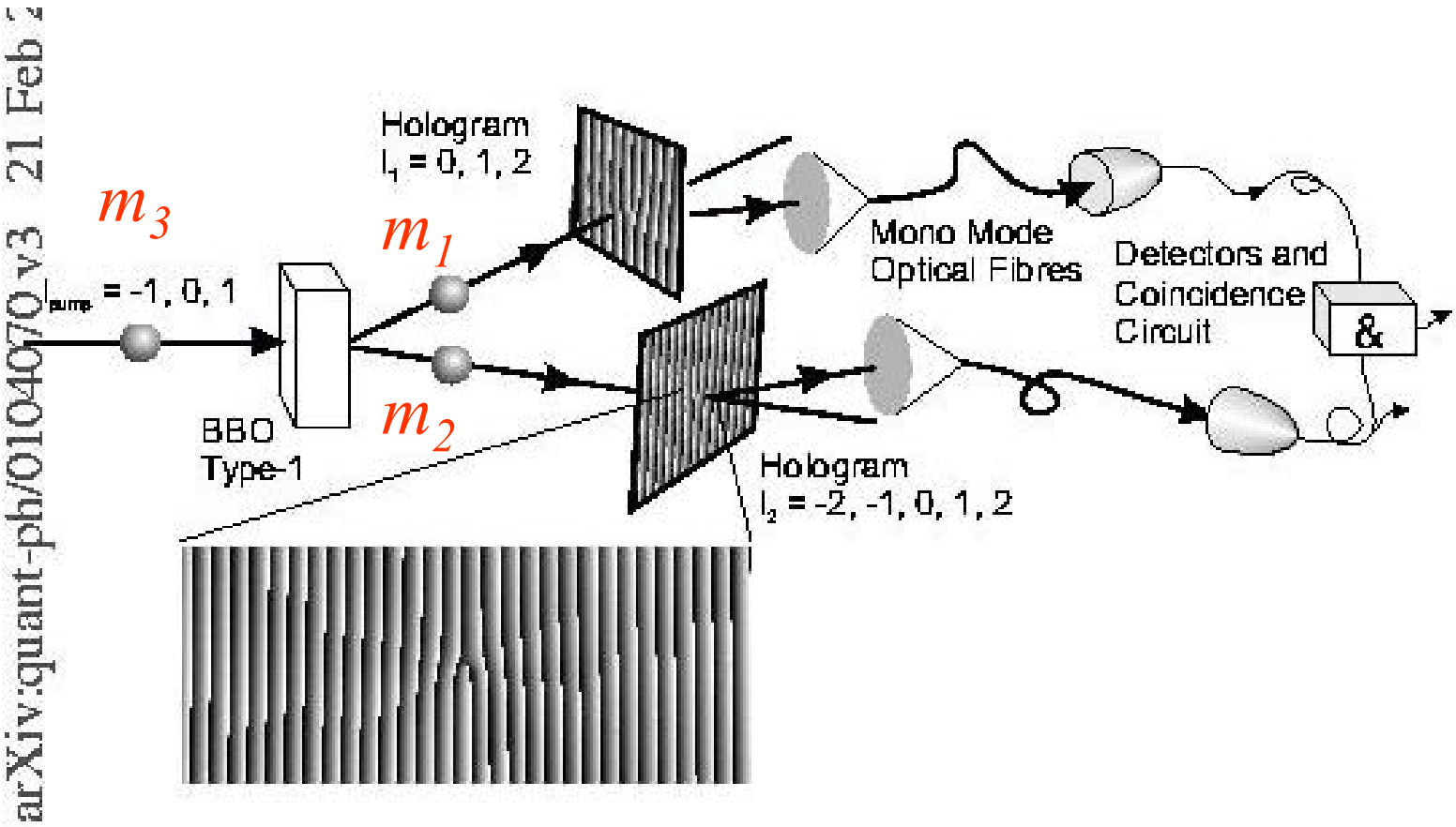
Skaičiaus operatorius: $\mathbf{n}=\mathbf{a}^{+}\mathbf{a}$

$\langle n_{1,2}(t)\rangle \neq 0$, *net kai* $\langle n_{1,2}(0)\rangle = 0$

Fotonai atsiranda iš kvantinių triūkšmų!

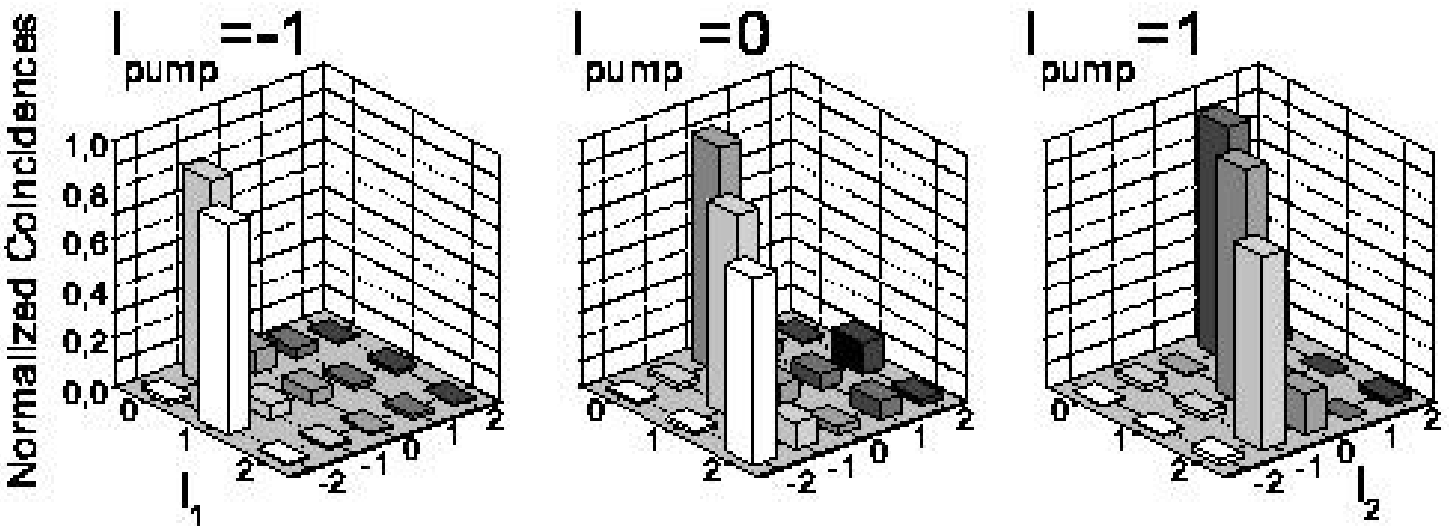
A. Mair, A. Vaziri, G. Wiehs, A. Zeilinger, Entanglement of the orbital angular momentum states of photons, Nature (London) (2001).

Parametrinė generacija: pavienių fotonų LG^0_m *modų*



A. Mair, A. Vaziri, G. Wiehs, A. Zeilinger, Entanglement of the orbital angular momentum states of photons, Nature (London) (2001).

Parametrinė generacija: pavienių fotonų LG^0_m *modų*



$l_{pump} = l_1 + l_2$, *pvz.:* $1 = 2 + (-1)$

$1 = 1 + 0$

$1 = 0 + 1$

Judesio kiekio momentas PŠG išsilaiko!

Klaiskiniu atveju stebima LG modų superpozicija.

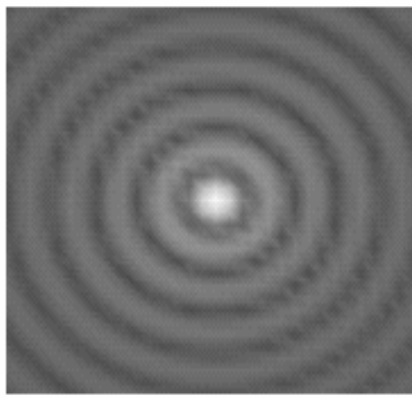
Beselio-Gauso modos

J. Durnin, Exact solutions for nondifracting beams. The scalar theory. JOSA A. , (1987):

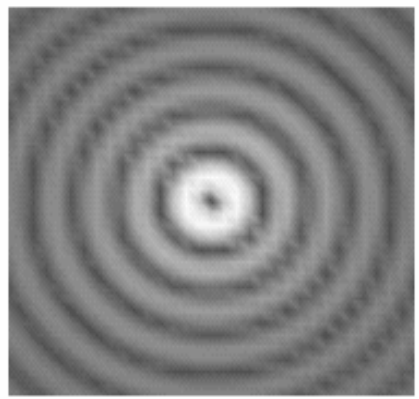
$$A(r,\varphi)=J_m(\beta r)\exp(im\,\varphi)exp(-r^2/d^2)$$

Intensyvumo skirstinys:

$m=0$



$m=1$

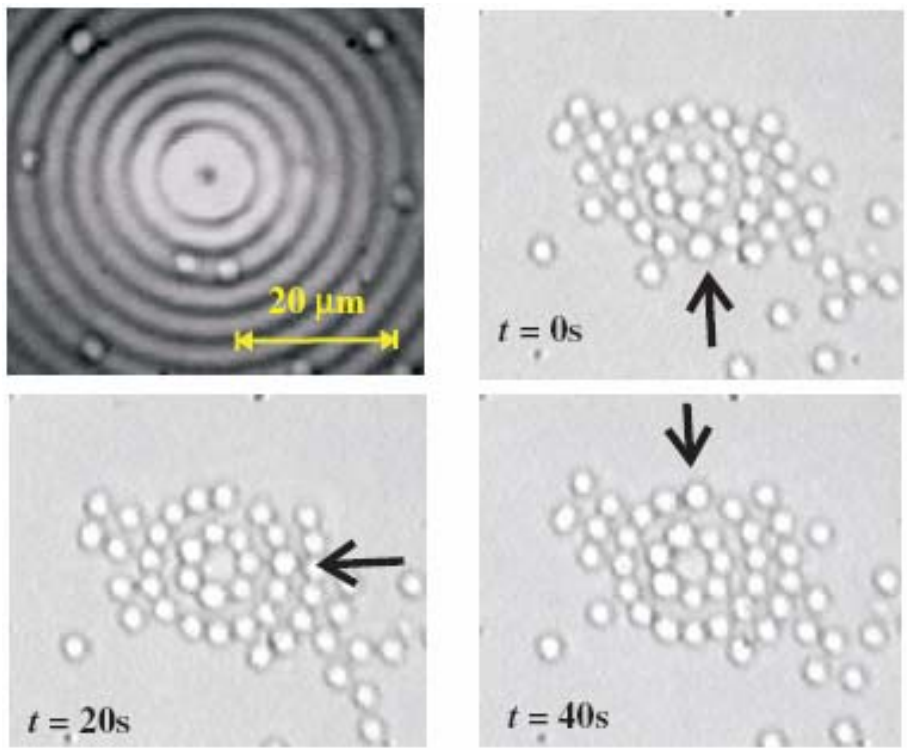


Beselio-Gauso modos

Judesio kiekio momento srautas/energijos srautas:

$L/cP = m/\omega$

K. Volke-Sepulveda et al., Orbital angular momentum of a high-order Bessel light beam, Journal of Optics B, (2002):



Parametrinė šviesos generacija kaupinant Beselio-Gauso moda

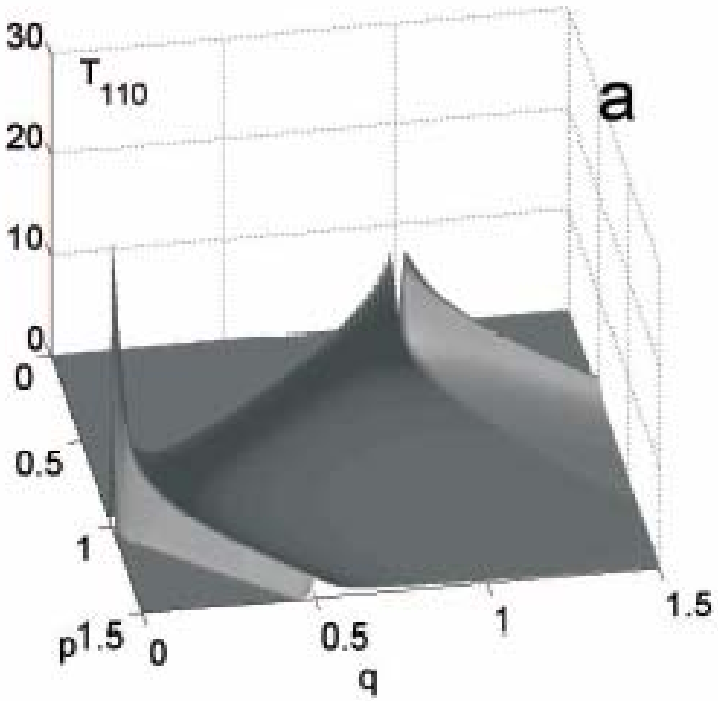
Parametrinis šviesos stiprinimas: *skersinio fazinio sinchronizmo integralas:*

$$T_{m_3 m_1 m_2} = \left| \int_0^\infty x \exp(-x^2 / g^2) J_{m_1}(px) J_{m_2}(qx) J_{m_1+m_2}(x) dx \right|$$

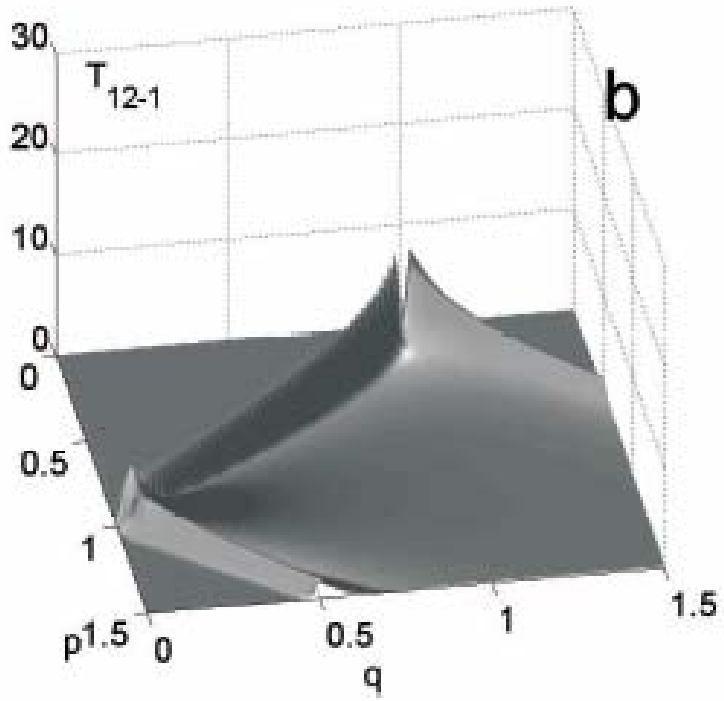
Topologinio krūvio tvermės dėsnis: $m_3 = m_1 + m_2$

Jei kaupinimo bangos $m_3 = 1$, *tai kuri pora* m_1 , m_2 *bus efektyviausiai stiprinama???*

Kaupinimas: $m_3 = 1$



$m_1=1,\ m_2=0$



$m_1=2,\ m_2=-1$

Stiprinimas efektyviausias, kai $m_1=m_3$, $m_2=0$ *arba* $m_1=0$, $m_2=m_3$*!*

Patvirtinta eksperimentu. Klaiskinių laukų atveju galima patikrinti judesio kiekio momento tvermės dėsnį.

Šalutinės bangos stiprinimas, kai kaupinama $m_3=1$ eilės
Beselio-Gauso moda: spektrai

$m_1=0,\ m_2=1$

$m_1=1,\ m_2=0$

$m_1=2,\ m_2=-1$


Ačiū už dėmesį!