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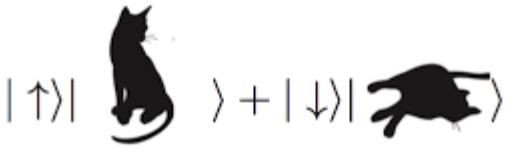
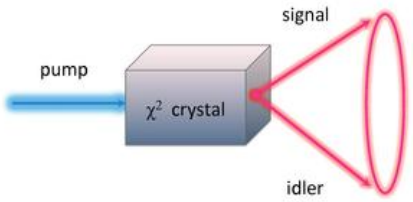
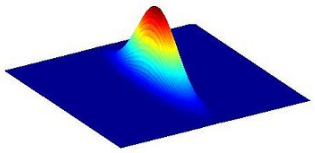
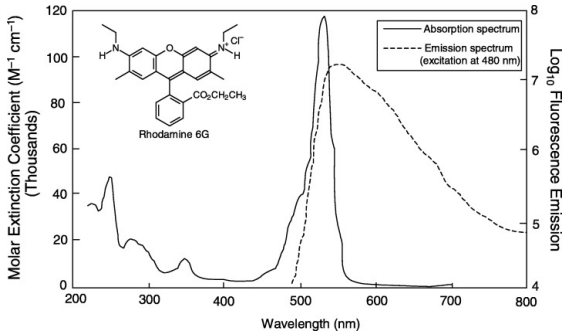


Enhanced Spectroscopy with Quantum States of Light

Dr. Jiří Svozilík







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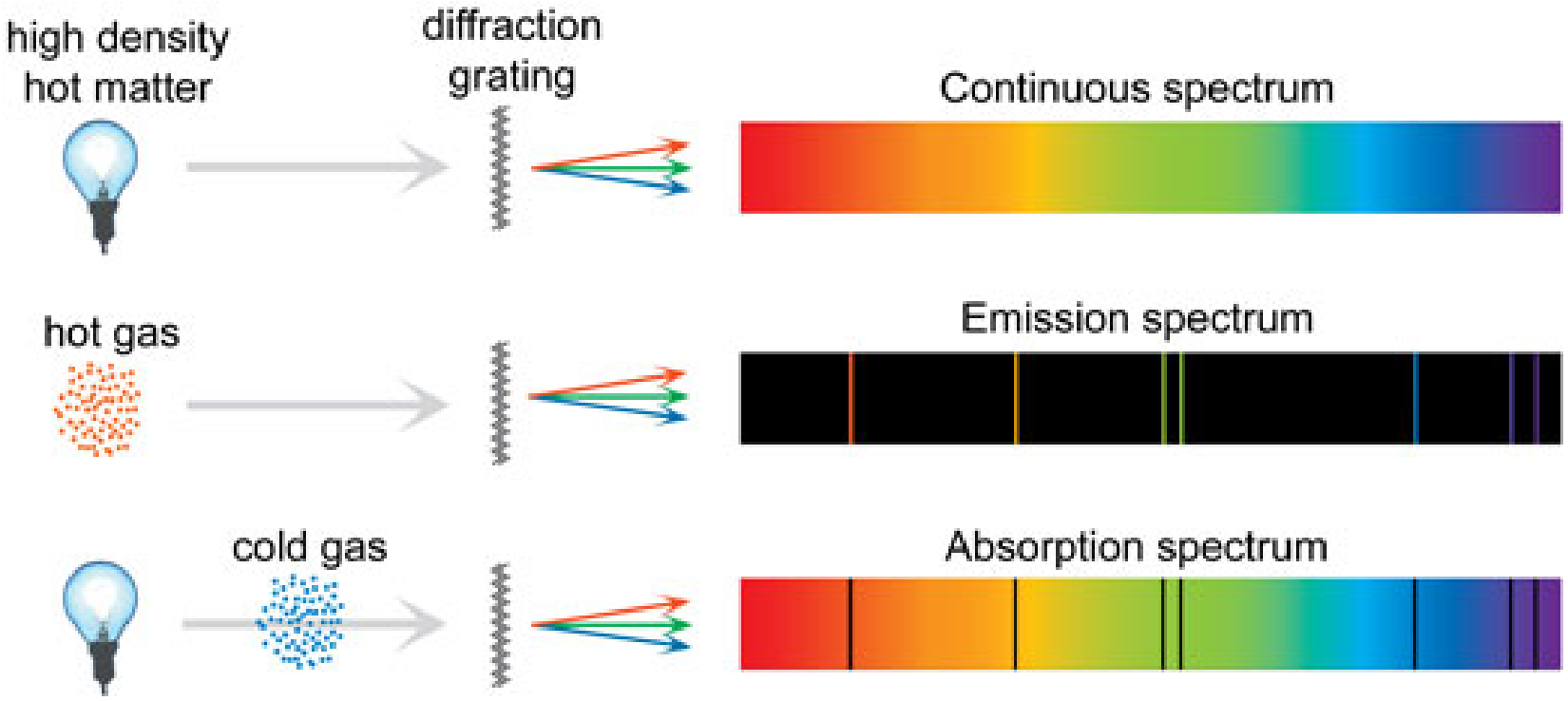
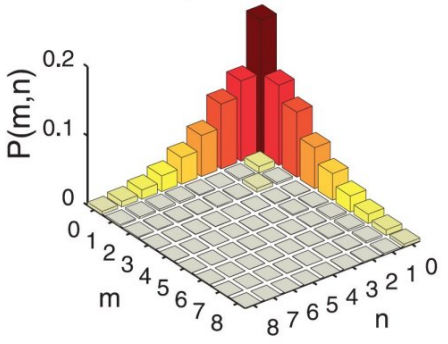
Spectroscopy ???



Tools in use

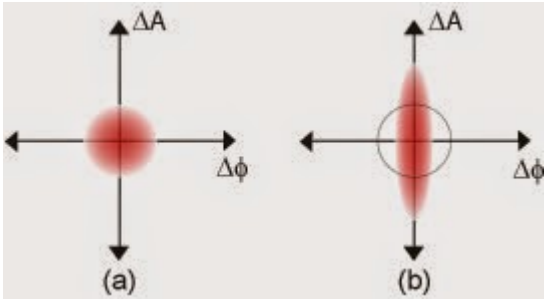
Quantum States Of Light

N00N State

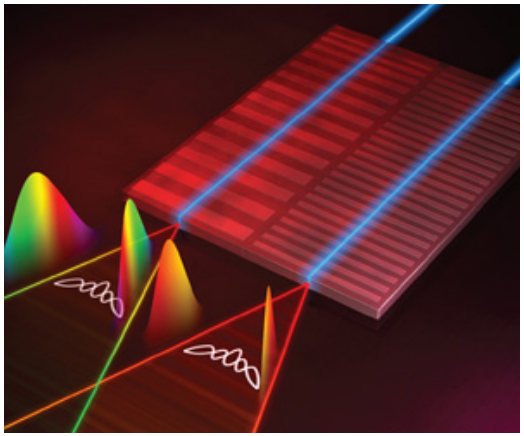


$$|\psi_{\mathrm{NOON}}\rangle = \frac{|N\rangle_a|0\rangle_b + e^{iN\theta}|0\rangle_a|N\rangle_b}{\sqrt{2}},$$

Squeezed State



SPDC State

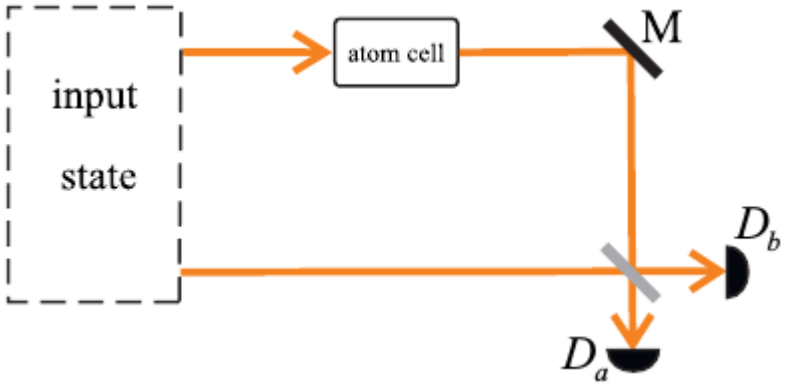


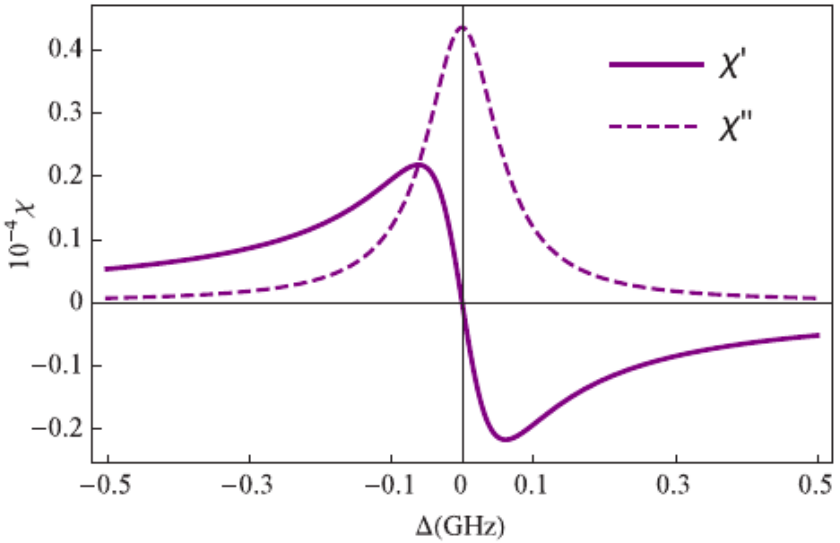
Content

Spectroscopic methods:

- Enhanced absorption spectroscopy
- Enhanced sensitivity in the FM spectroscopy
- Entangled Pump-probe Spectroscopy
- Virtual State Spectroscopy

Enhanced-Absorption





The phase uncertainty scaling:

- Individual photons 1/√N
- Entangled photons 1/N

$$\chi(\Delta) = \chi'(\Delta) + i\chi''(\Delta) = \frac{2\mathcal{N}\mu^2}{\hbar\varepsilon_0}\frac{\Delta + i\gamma_s}{\Delta^2 + \gamma_s^2}$$

$$|\psi_{\mathrm{NOON}}\rangle = \frac{|N\rangle_a|0\rangle_b + e^{iN\theta}|0\rangle_a|N\rangle_b}{\sqrt{2}},$$

The Fisher Information:

$$\mathrm{var}(\Delta) \geqslant 1/F(\Delta) \qquad F(\Delta) = \sum_{n_1,n_2}\frac{1}{P_{n_1,n_2}(\Delta)}\left(\frac{\partial P_{n_1,n_2}(\Delta)}{\partial\Delta}\right)^2$$

Optimized ent. state

$$|\psi\rangle = \sum_{k=0}^{N}\psi_k|N-k,k\rangle$$

Dinani et al, Phys. Rev. A 93, 063804 (2016)

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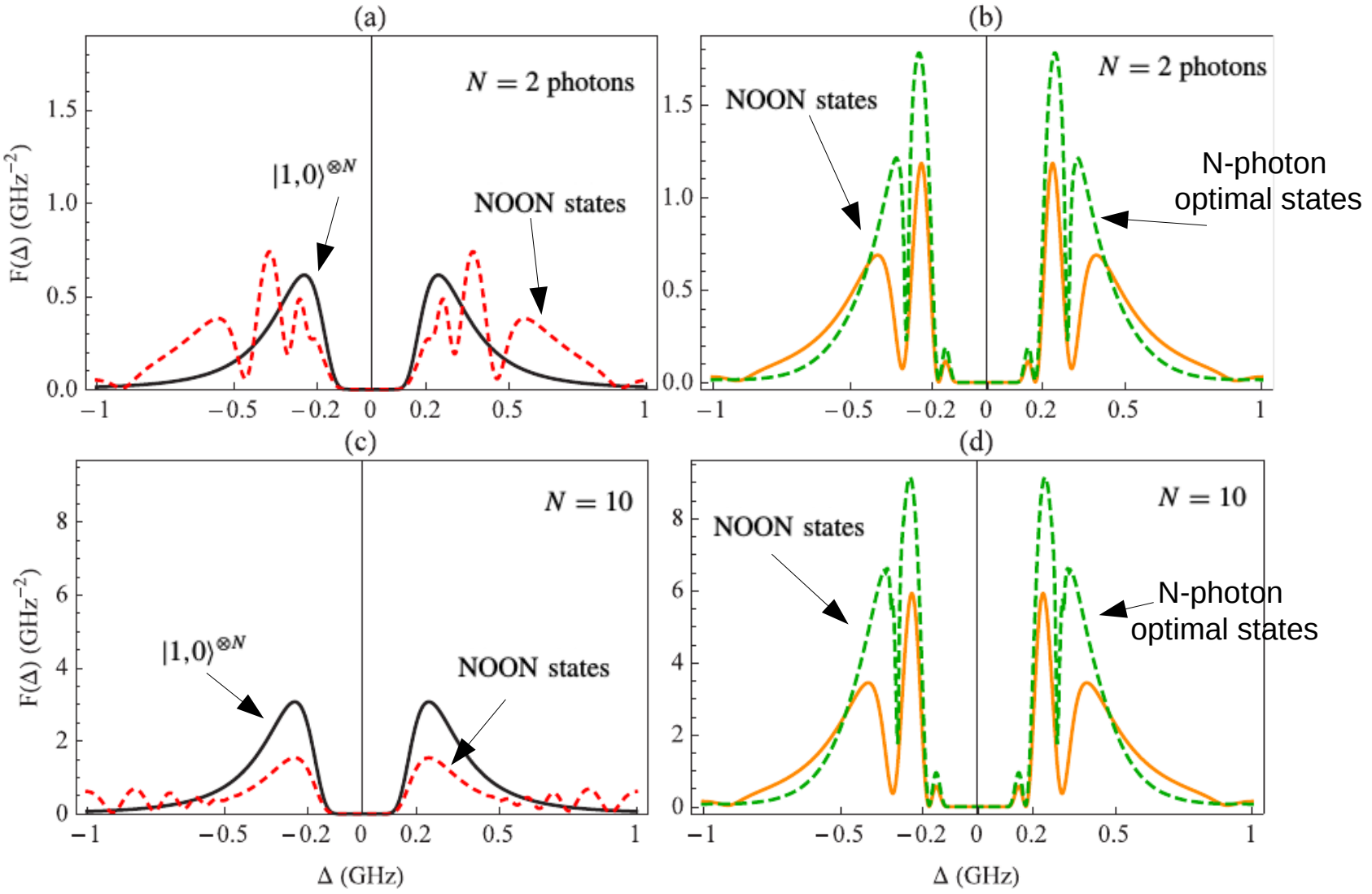
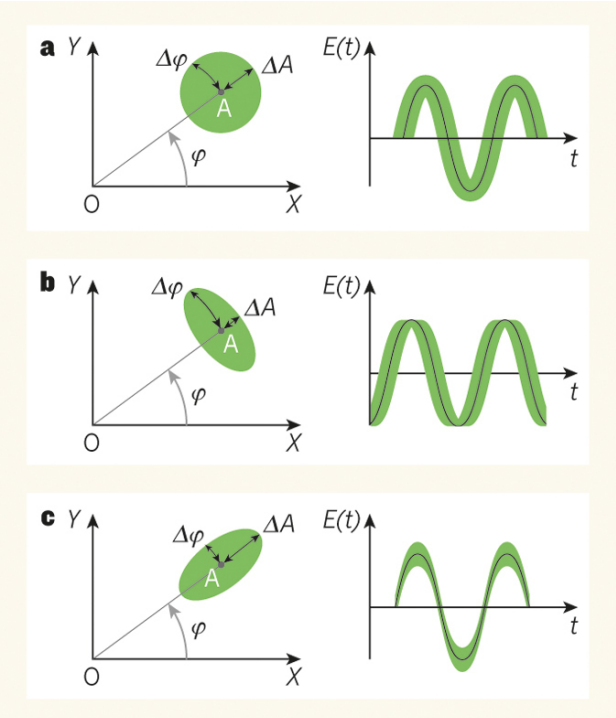
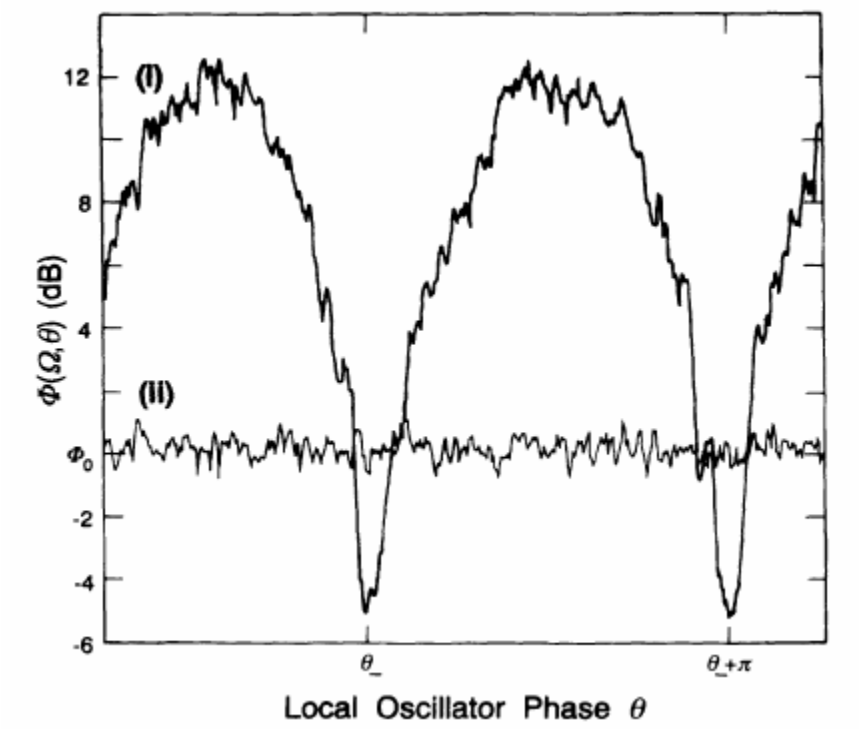
Enhanced-Absorption



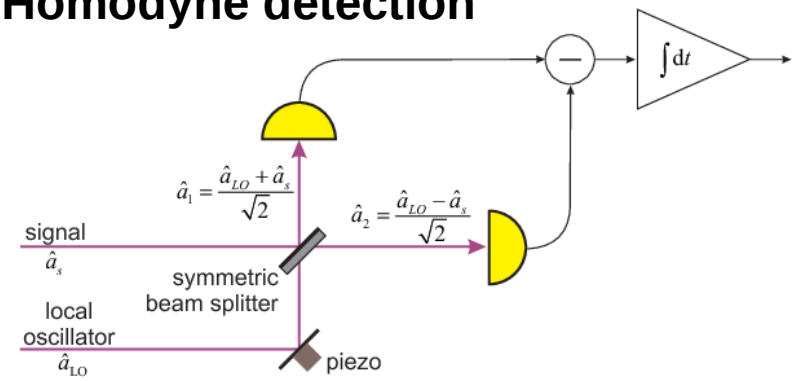
Danini et al, Phys. Rev. A 93, 063804 (2016)

Squeezed light



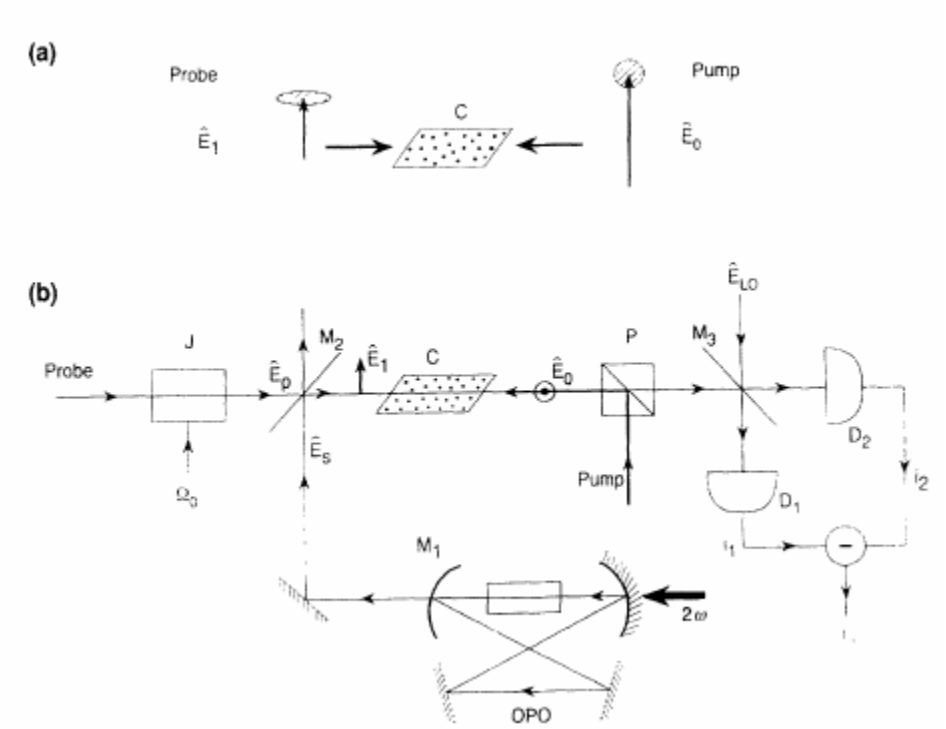


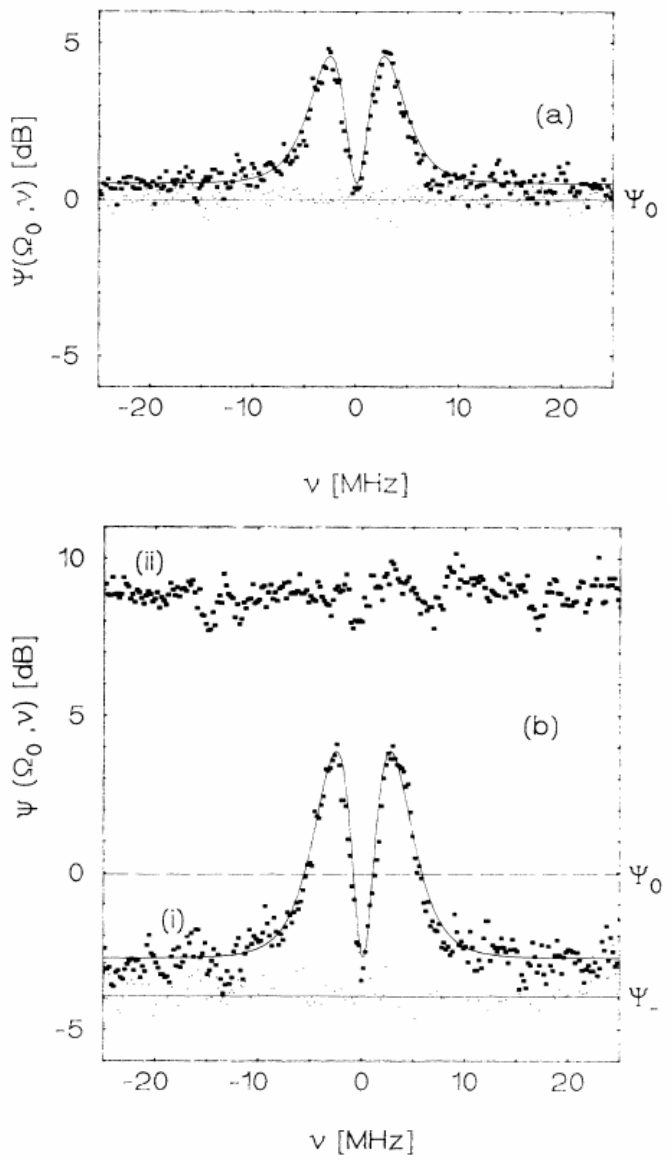
Homodyne detection



Polzik et al, Phys. Rev. Lett. 68, 3020 (1992).

Squeezed light





Polzik et al, Phys. Rev. Lett. 68, 3020 (1992).

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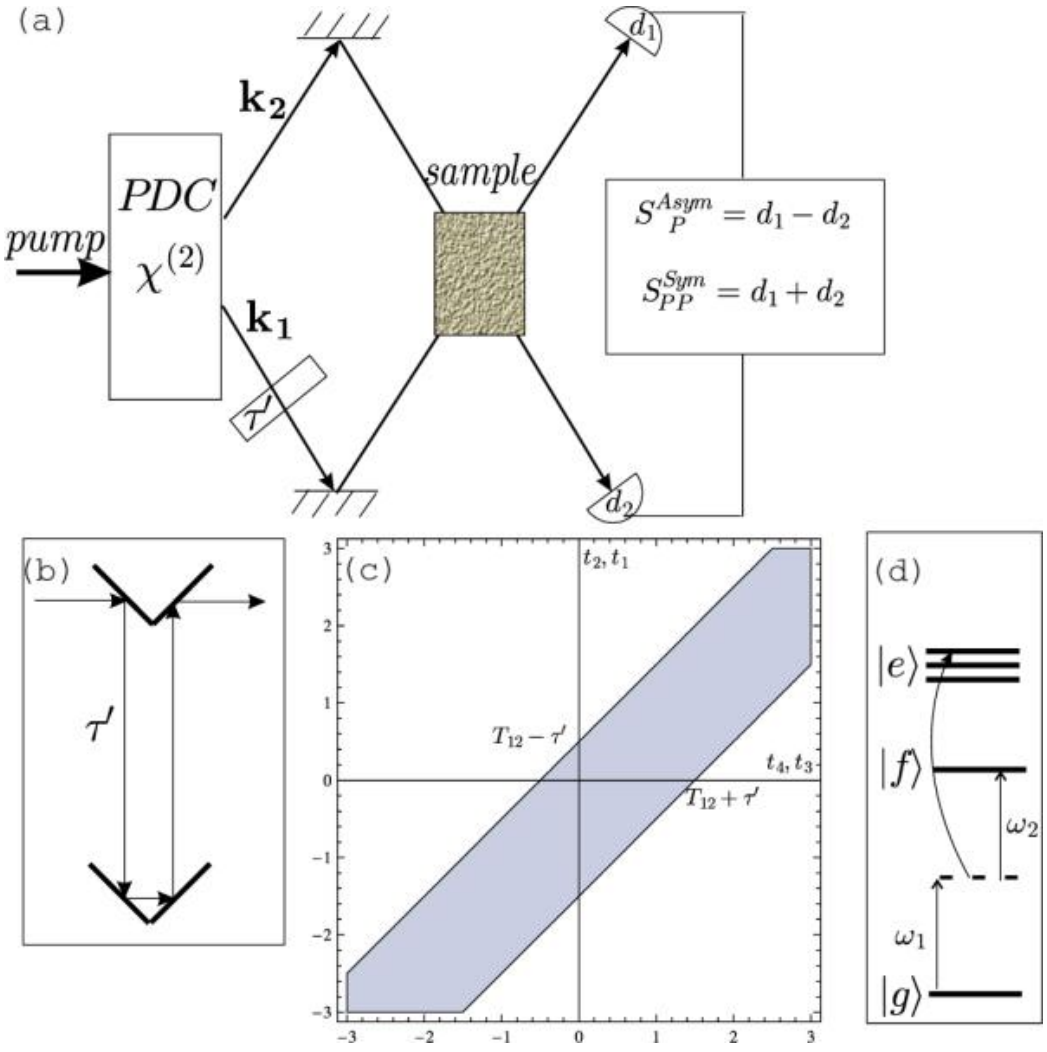
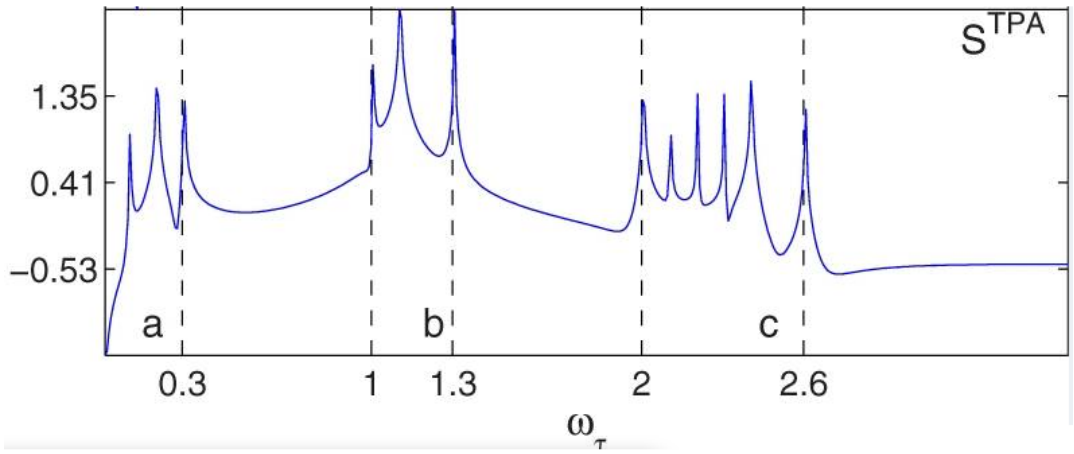
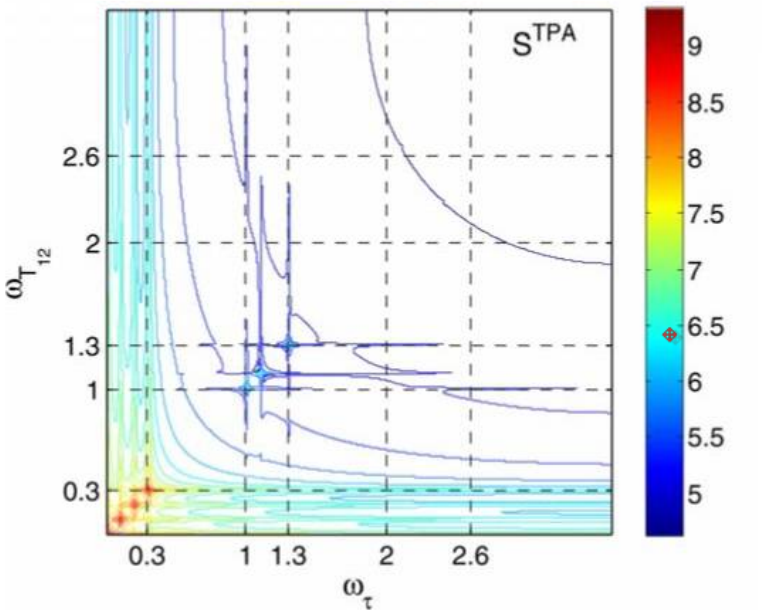
Pump-Prope Spectroscopy



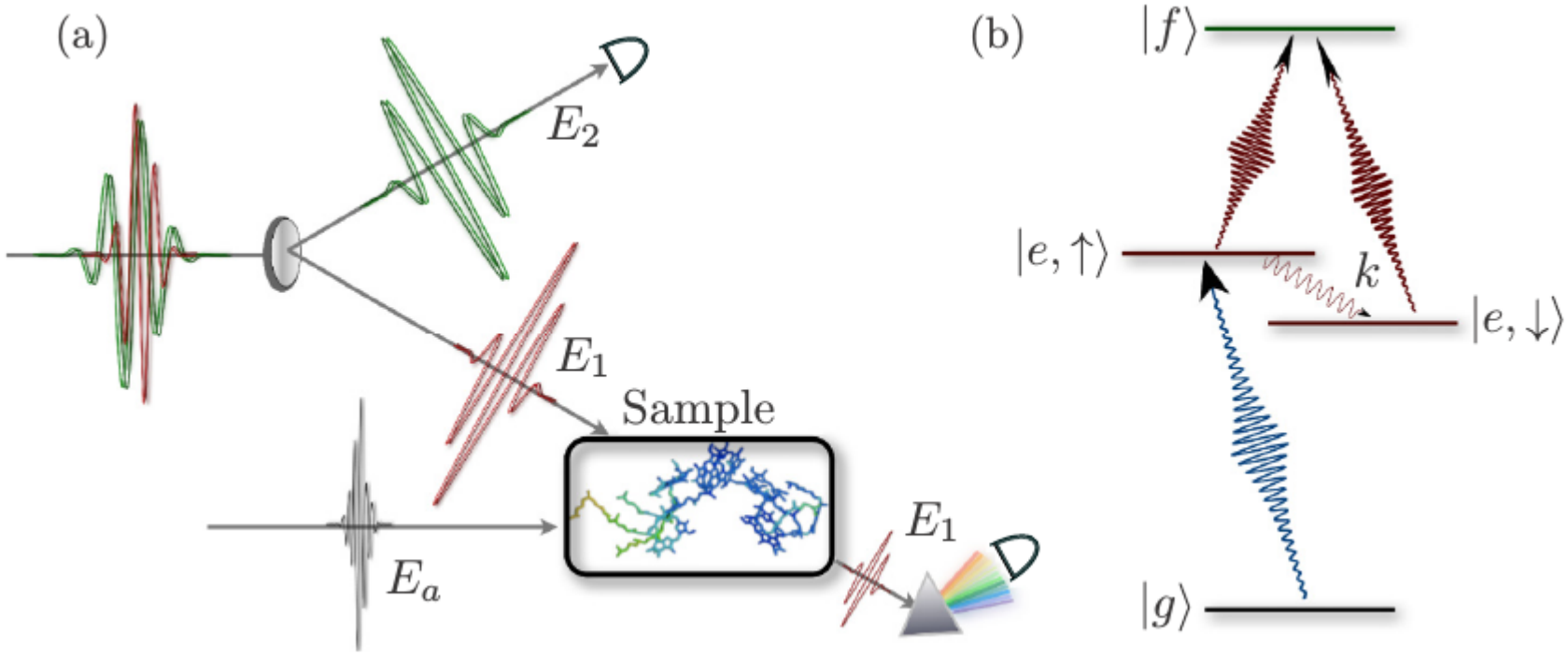
Roslyak et al, Phys. Rev. A 79, 063409 (2009)





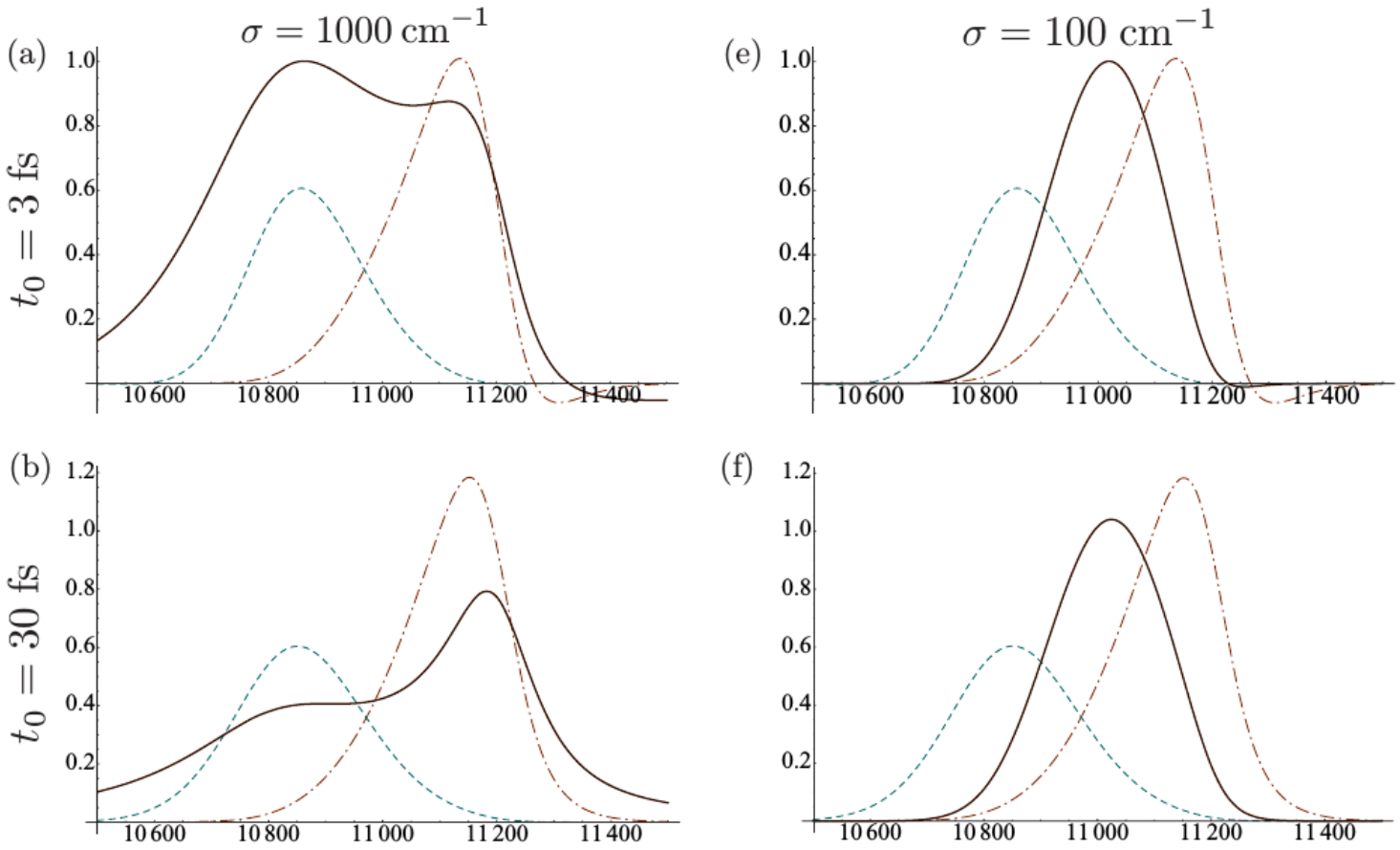
Roslyak et al, Phys. Rev. A 79, 063409 (2009)

Pump-Prope Spectroscopy 2



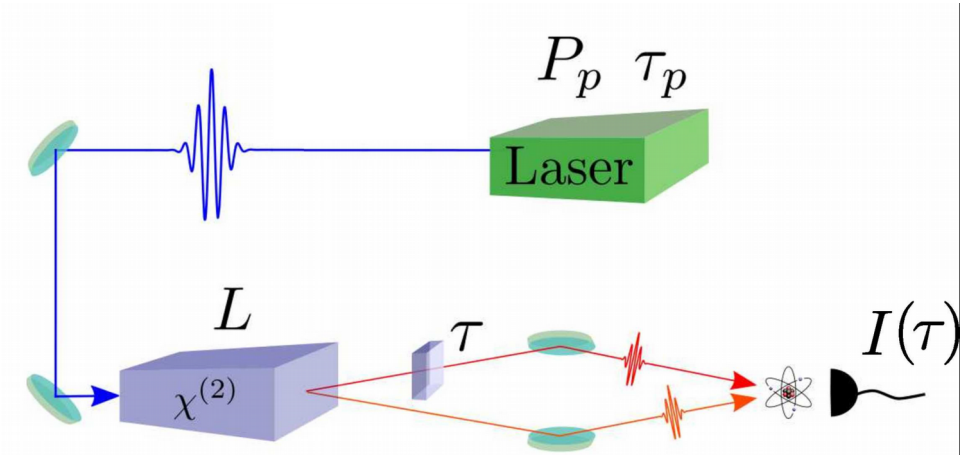
Schlawin et al, Phys. Rev. A 93, 023807 (2016)

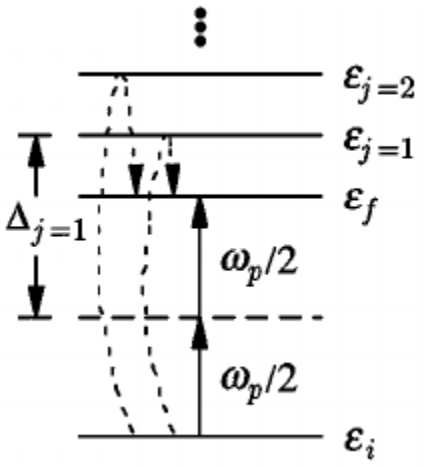
Pump-Prope Spectroscopy 2



Schlawin et al, Phys. Rev. A 93, 023807 (2016)

Virtual state spectroscopy





Probability of the two-photon absorption

$$P_{g\to f} = \int_{-\infty}^{\infty} dt_2 \int_{-\infty}^{t_2} dt_1 \int_{-\infty}^{\infty} dt_2' \int_{-\infty}^{t_2'} dt_1' M^*(t_2,t_1)\, G^{(2)}(t_2,t_1;t_2',t_1')\, M(t_2',t_1')$$

Atom-correlation function

$$M(t_2,t_1) = \sum_j \frac{\mu_{fj}\mu_{jg}}{\hbar^2} \exp\left[i(\varepsilon_f - \varepsilon_j)t_2 + i(\varepsilon_j - \varepsilon_g)t_1\right]$$

Field-correlation function

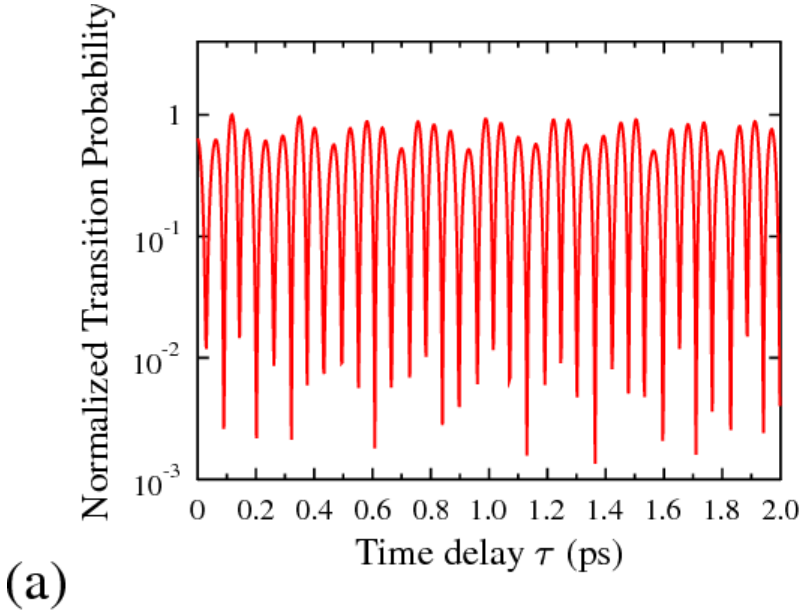
$$G^{(2)}(t_2,t_1;t_2',t_1') = \langle \hat{E}^{(-)}(t_2)\hat{E}^{(-)}(t_1)\hat{E}^{(+)}(t_2')\hat{E}^{(+)}(t_1')\rangle$$

Entangled intense photon fields

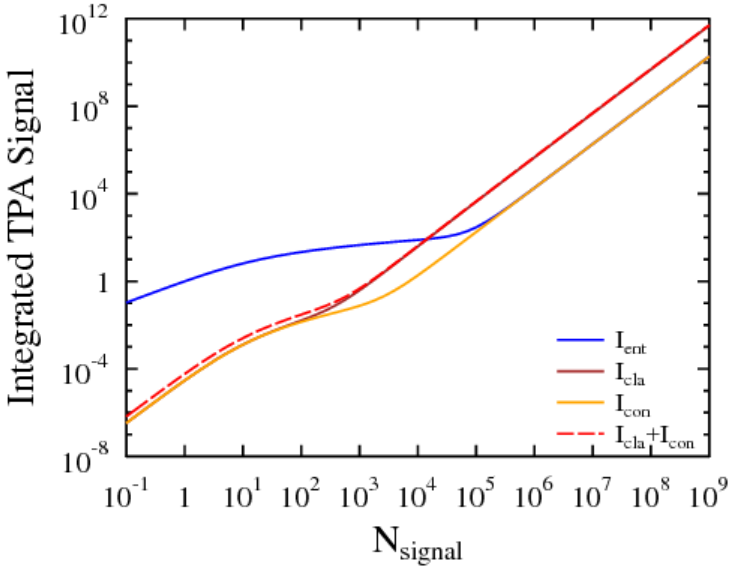
$$|\Phi\rangle = \mathcal{N}\sum_{g=1}^{\infty} \lambda_g \hat{a}_{s,g}^{\dagger}\hat{a}_{i,g}^{\dagger}|\mathrm{vac}\rangle$$

J. Svozilik et al, submitted to Sci.Rep.

Virtual state spectroscopy



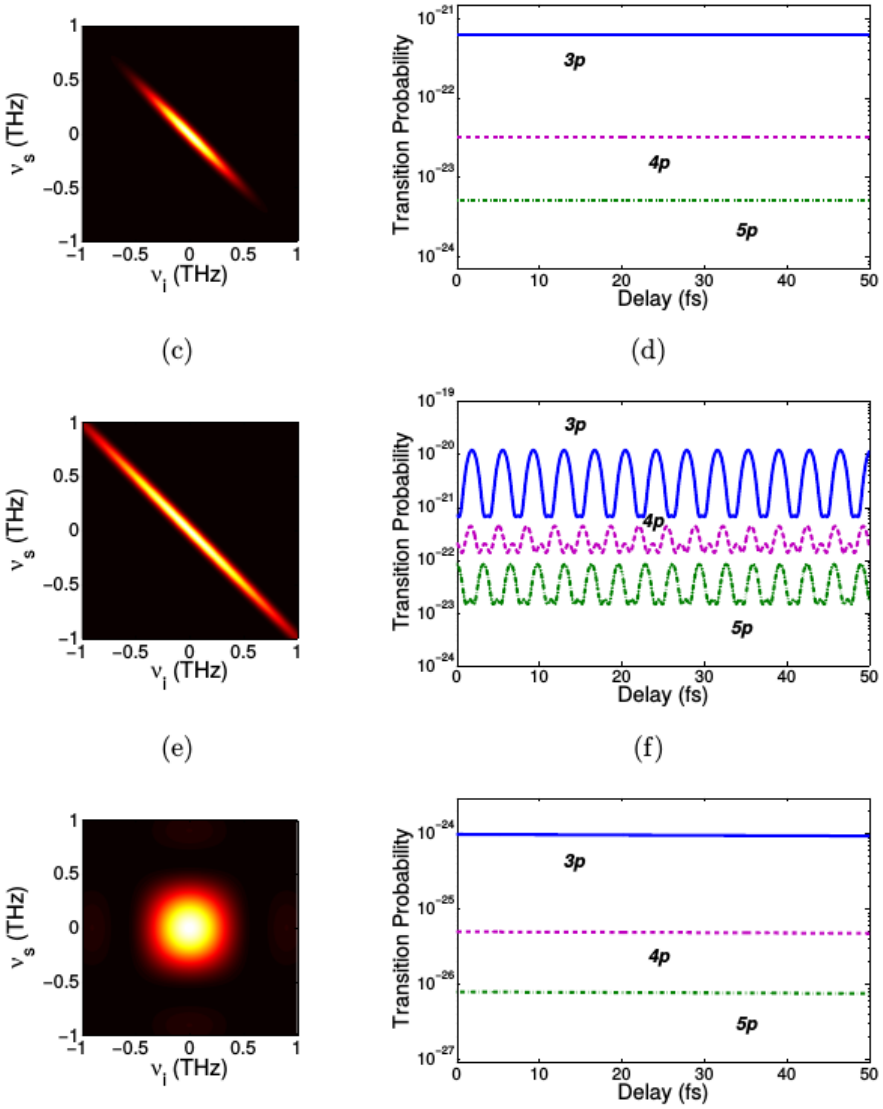
(a)



(b)

J. Svozilik et al, submitted to Sci.Rep.

Virtual state spectroscopy



R. de J. Leon-Montiel et al, New J. Phys. 15, 053023 (2013)

Summary

Applications of **quantum states of light:**

- Enhanced Absorption – **N00N States**
- Enhanced Sensitivity – **Squeezed states**
- Entangled Pump-probe Spectroscopy
- Virtual State Spectroscopy

} **SPDC States**

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Thank you for your attention!!!

May the (quantum) force be with you.