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PHYSICS

A numerical computation with Topological Dipole Field Theory

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ABSTRACT

Topological Dipole Field Theory was proposed as an extension of the Standard model of particle physics. The transition amplitude per time for a propagation of a gauge boson can be computed from this theory. This research paper shows a numerical implementation of Topological Dipole Field Theory for a simple photon propagation. For simplicity the numerical simulation is applied to a monochromatic gamma ray such that it can be executed in one space and one time direction. Effects of Topological Dipole Field Theory like the high probability for fluctuations of energy and momentum are taken into account.

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INTRODUCTION

Gamma rays are used in various branches of science and technology and are occurring during some cosmic phenomena. There are a couple of experiments with gamma rays described in literature (Bloser 2006). An open question is whether effects predicted by TDFT can be observed. TDFT is a quantum field theory where bosons are coupled to an additional 2-form field B which is governed by a topological quantum field theory (Linker 2015). The Lagrangian density of this theory contains also another 2-form field W, a Lagrange multiplier λ and a coupling constant b. It has the form:

$$L = tr(bB' \wedge W + \lambda W \wedge W). \qquad (1)$$

A calculation of a process, where a single boson is coming in with momentum k_{μ_1}, energy E and polarization $\chi^a_{\nu_1}$ and a single boson is coming out with momentum k'_{μ_2}, energy E' and polarization $\chi^{*b}_{\nu_2}$ can be performed analytically. The transition rate per volume $V = l_1 l_2 l_3$ with the length scales l_i and time l_0 is given by the expression:

$$\frac{w\left(k_{\mu_1}, k'_{\mu_2}; \chi^a_{\nu_1}, \chi^{*b}_{\nu_2}\right)}{} = \frac{|\Omega|^2}{4EE' l_0 V (2\pi)^6},$$

$$\Omega = \frac{i}{16} k_{\mu_1} \chi^a_{\nu_1} k'_{\mu_2} \chi^{*b}_{\nu_2} \Lambda^{\mu_1\nu_1\mu_2\nu_2\alpha_1\beta_1}_{ab\,\alpha_1\beta_1} \prod_{K=0}^{3} l_K sinc\left((k_K - k'_K) g_{KK} l_K\right). \qquad (2)$$

Equation (2) is difficult to implement in numerical simulations especially due to the topological

constants $\Lambda_{ab\ \alpha_1\beta_1}^{\mu_1\nu_1\mu_2\nu_2\alpha_1\beta_1}$. However, if the degrees of freedom are reduced in a suitable way, the transition rate (2) can be simplified. This research paper shows an application of Topological Dipole Field Theory to a high-energetic gamma ray. In this research paper a gamma ray that propagates through a vacuum (such that interactions with matter can be neglected) in one single space direction x is considered. The following assumptions hold for this simulation:

- 2-dimensional formulation (one space direction and one time direction)

- There is only one direction of propagation (along the x-axis) denoted by k and therefore the energies can always be expressed as $E = k, E' = k'$.

- Only quantum electrodynamics with TDFT extension is considered (there is only one Lie algebra generator necessary)

- It is averaged over all photon polarizations (polarization dependence can be neglected in this case).

Applying these assumptions to (2) one obtains for the transition rate:

$$w(k,k') = \frac{\eta|k||k'|\sin^2((k-k')l_0)\sin^2((k-k')l_1)}{l_0 l_1 (k-k')^4}. \qquad (3)$$

The constant η is determined only by the coupling constant b by the relation $\eta = \zeta b^{-8}$ where ζ is a constant. From the transition rate (3) the Master equation is used in this research paper to compute the time evolution of the photon density function $f(t,x,k)$ that measures the probability to find a photon at spacetime position (t,x) with momentum k. After this, the master equation is discretized to obtain an algorithm on which a numerical solution of the Master equation can be computed. Finally, the results of this numerical computation are discussed.

THEORY AND RESULTS

From now one the ordinary SI-unit system is used instead of the unit system $c = \hbar = 1$ and the constant η is called “coupling constant”. It is assumed that a photon propagates with constant speed of light c (due to Einstein’s theory of special relativity), i.e. for an initial position x_0 the kinematic equation for the photon has the form $x = x_0 + ct$. With this equation the x-dependence of the function $f(t,x,k)$ can be omitted. This leads to the following Master equation (The transition probability is time reversal symmetric, i.e. $w(k,k') = w(k',k)$):

$$\frac{\partial f(t,k')}{\partial t} = \int_{-\infty}^{\infty} w(k,k')l_1(f(k) - f(k'))dk. \qquad (4)$$

In (4) it is used the transition probability per time $w(k,k')l_1$ and not the transition probability per time and volume $w(k,k')$. Denoting $\bar{k}$ the characteristic wave number scale of the system (it is used for practical purposes). For the numerical solution of equation (4) the following discretizations are performed (these discretizations resolve all scattering processes):

- $\frac{\partial f(t,k')}{\partial t} = \frac{1}{l_0}\left(f(t+l_0,k') - f(t,k')\right) \qquad (5a)$

- $\int_{-\infty}^{\infty} w(k,k')l_1(f(k)-f(k'))dk = p\sum_{j=-N}^{N} w(\bar{k}+jp,k')l_1(f(\bar{k}+jp)-f(k'))$. (5b)

The time increment per iteration step is l_0 and the wave number increment per iteration step is p (with cutoff number N for wave number integration), where the maximum wave number respected in the simulation is given by $k_m = \bar{k} + Np$. Equating (5a) and (5b) and substituting (3), the resulting recursion for the solution of the Master equation has the form:

$$f(t+l_0,k') = f(t,k') + \eta p \sum_{j=-N}^{N} \frac{|jp+\bar{k}||k'|\sin^2\left((jp+\bar{k}-k')cl_0\right)\sin^2\left((jp+\bar{k}-k')l_1\right)}{(jp+\bar{k}-k')^4}\left(f(\bar{k}+jp)-f(k')\right). \quad (6)$$

The initial condition used in this simulation is as follows: At $t = 0$ (the time where the gamma ray starts) the gamma ray is monochromatic with the wave number $k_\gamma = \bar{k} = 10^{13}m^{-1}$ (it is obvious to identify this wave number with the characteristic wave number scale) such that it holds $f(0,k) = \frac{1}{p}$ for $k = k_\gamma$ and $f(0,k) = 0$ elsewhere. The following program code written in FORTRAN uses the following parameter:

- $p = 10^{11}m^{-1}$
- $l_0 = 10^{-22}s$
- $l_1 = 10^{-13}m$.
- $N = 10$
- Number of time iteration steps: 90.

The code which solves equation (6) is given here:

! Numerical solution of the Master equation for a gamma ray with TDFT interaction (Process: photon -> photon).

```
! Subroutine for computing the gain in photon density function

subroutine gain(F,ww,Fgain)

integer N, Ntime ! Increments
parameter (N = 10, Ntime = 90)
double precision F(0:Ntime,-1*N:N) ! input density function
double precision Fgain(0:Ntime,-1*N:N) ! output density function
double precision ww(-1*N:N,-1*N:N) ! transition probability input
```

```
integer i,j,k ! Loop variables


do i = 0,Ntime
  do j = -1*N,N
    Fgain(i,j) = 0 ! Initialization
    do k = -1*N,N
    Fgain(i,j) = Fgain(i,j) + ww(k,j)*F(i,k) - ww(k,j)*F(i,j)
    end do
  end do
end do


end subroutine


program Gamma_Ray_TDFT


! Variable declarations
double precision kgamma ! Gamma ray wave number (is set equal to characteristic wave number scale)
double precision k ! wave number variable
double precision t ! time variable
integer ii,jj ! Loop variables


integer N ! Wave number cutoff number
integer Ntime ! Number of time steps


double precision l0 ! Time increment
double precision l1 ! Space resolution
double precision p ! Wave number increment


double precision eta ! Coupling constant
double precision c ! Velocity of light
```

```
      ! Assignment of parameters


      parameter (kgamma = 10 ! 10^12 meter^(-1)
     &  , l0 = 1E-2 ! 10^(-20) second
     &  , l1 = 1E-1 ! 10^(-12) meter
     &  , p = 1E-1 ! 10^(12) meter^(-1)
     &  , N = 10, Ntime = 90
     &  , c = 3) ! 10^(8) meter/second


C      kgamma = 10E12
C
C      l0 = 1E-22
C      l1 = 1E-13
C      p = 10E11
C
C      N = 100
C      Ntime = 100


      ! Introducing photon density function (unit = 10^(-12) meter) , transfer rate, updated photon density
function and assigning initial values


      double precision f(0:Ntime,-1*N:N), w(-1*N:N,-1*N:N),
     & fup(0:Ntime,-1*N:N)  ! Photon density function f(t,k) and transfer rate w(k,k')


      do ii = -1*N,N
        f(0,ii) = 0
        if (ii.ne.0) goto 100 ! corresponds to k = kgamma
        f(0,ii) = 1/p
  100   continue
      end do


      ! Assignment of the coupling constant
```

```
      print *, 'Enter a coupling constant (in 10^(-12) meter)'
      read *, eta ! has dimensions 10^(-12) meter

      ! Assignment of transition probability density

      do ii = -1*N,N
        do jj = -1*N,N
          if (ii.ne.jj) goto 200 ! Avoiding division by zero
          w(ii,jj) = eta*p*abs(ii*p+kgamma)*abs(jj)*
     &     (sin((ii*p-jj*p)*c*l0)*(sin((ii*p-jj*p)
     &     *l1)))**2/(ii*p-jj*p)**4
200       continue
          w(ii,jj) = eta*p*abs(ii*p+kgamma)*abs(jj)*
     &     (c*l0*l1)**2
        end do
      end do

      ! COMPUTING SOLUTION

      do ii = 0,Ntime-1
        do jj = -1*N,N
        call gain(f,w,fup) ! Computing transition integral
        f(ii + 1,jj) = f(ii,jj) + fup(ii,jj) ! Updating
        end do
      end do

      ! Output

      do ii = 0,Ntime/30
        print *, 'Time: ', 30*ii, '*10^(-22) seconds: '
        do jj = -1*N,N
```

```
            print *, 'Photon density at wavenumber',
     &       kgamma + jj*p, '*10^(12) meter^(-1): '
            print *, f(30*ii,jj), '*10^(-12) meter'
          end do
          print *, '...'
        end do

C       open (UNIT = 100, FILE = 'Gamma_Ray_TDFT_Output.txt')
C       rewind (UNIT = 100)
C       do ii = 0,Ntime
C         do jj = -N,N
C           write (UNIT = 100, FMT = *) f(ii,jj)
C         end do
C         write (UNIT = 100, FMT = *) '----------'
C       end do
C       close (UNIT = 100)

        end program
```

The results are plotted for different values of η (Dimensions for η: lengths in meter). Output for the choice of $\eta = 10^{-17}m$ is listed here (the probability density function is captured every $3 * 10^{-21}$ seconds):

```
Enter a coupling constant (in 10^(-12) meter)
1e-5
 Time:           0 *10^(-22) seconds:
 Photon density at wavenumber   8.9999999850988388      *10^(12) meter^(-1):
  0.0000000000000000      *10^(-12) meter
 Photon density at wavenumber   9.0999999865889549      *10^(12) meter^(-1):
  0.0000000000000000      *10^(-12) meter
 Photon density at wavenumber   9.1999999880790710      *10^(12) meter^(-1):
  0.0000000000000000      *10^(-12) meter
```

Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):
9.9999998509883898 *10^(-12) meter

Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
...
Time: 30 *10^(-22) seconds:
Photon density at wavenumber 8.9999999850988388 *10^(12) meter^(-1):
2.6999996074169182E-007 *10^(-12) meter
Photon density at wavenumber 9.0999999865889549 *10^(12) meter^(-1):
2.4299997132693597E-007 *10^(-12) meter
Photon density at wavenumber 9.1999999880790710 *10^(12) meter^(-1):
2.1599998043231064E-007 *10^(-12) meter
Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):
1.8899998805781584E-007 *10^(-12) meter
Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):
1.6199999420345152E-007 *10^(-12) meter
Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):
1.3499999886921743E-007 *10^(-12) meter
Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):
1.0800000205511373E-007 *10^(-12) meter
Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):
8.1000003761140188E-008 *10^(-12) meter
Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):
5.4000003987296777E-008 *10^(-12) meter
Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):
2.7000002733583407E-008 *10^(-12) meter
Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):
9.9999998509883898 *10^(-12) meter
Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):
2.7000002733583407E-008 *10^(-12) meter
Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):
5.4000003987296777E-008 *10^(-12) meter

Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):
8.1000003761140188E-008 *10^(-12) meter

Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):
1.0800000205511373E-007 *10^(-12) meter

Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):
1.3499999886921743E-007 *10^(-12) meter

Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):
1.6199999420345152E-007 *10^(-12) meter

Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):
1.8899998805781584E-007 *10^(-12) meter

Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):
2.1599998043231064E-007 *10^(-12) meter

Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):
2.4299997132693597E-007 *10^(-12) meter

Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):
2.6999996074169182E-007 *10^(-12) meter

...

Time: 60 *10^(-22) seconds:

Photon density at wavenumber 8.9999999850988388 *10^(12) meter^(-1):
5.3999984858341691E-007 *10^(-12) meter

Photon density at wavenumber 9.0999999865889549 *10^(12) meter^(-1):
4.8599989082199138E-007 *10^(-12) meter

Photon density at wavenumber 9.1999999880790710 *10^(12) meter^(-1):
4.3199992703903049E-007 *10^(-12) meter

Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):
3.7799995723453371E-007 *10^(-12) meter

Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):
3.2399998140850072E-007 *10^(-12) meter

Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):
2.6999999956093058E-007 *10^(-12) meter

Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):
2.1600001169182257E-007 *10^(-12) meter

Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):
1.6200001780117623E-007 *10^(-12) meter

Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):
1.0800001788899073E-007 *10^(-12) meter

Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):
5.4000011955265574E-008 *10^(-12) meter

Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):
9.9999998509883898 *10^(-12) meter

Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):
5.4000011955265574E-008 *10^(-12) meter

Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):
1.0800001788899073E-007 *10^(-12) meter

Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):
1.6200001780117623E-007 *10^(-12) meter

Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):
2.1600001169182257E-007 *10^(-12) meter

Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):
2.6999999956093058E-007 *10^(-12) meter

Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):
3.2399998140850072E-007 *10^(-12) meter

Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):
3.7799995723453371E-007 *10^(-12) meter

Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):
4.3199992703903049E-007 *10^(-12) meter

Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):
4.8599989082199138E-007 *10^(-12) meter

Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):
5.3999984858341691E-007 *10^(-12) meter

...

Time: 90 *10^(-22) seconds:

Photon density at wavenumber 8.9999999850988388 *10^(12) meter^(-1):
8.0999966352520873E-007 *10^(-12) meter

Photon density at wavenumber 9.0999999865889549 *10^(12) meter^(-1):
7.2899975848518545E-007 *10^(-12) meter

Photon density at wavenumber 9.1999999880790710 *10^(12) meter^(-1):
6.4799983982016848E-007 *10^(-12) meter

Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):
5.6699990753015508E-007 *10^(-12) meter

Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):
4.8599996161514545E-007 *10^(-12) meter

Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):
4.0500000207513473E-007 *10^(-12) meter

Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):
3.2400002891012164E-007 *10^(-12) meter

Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):
2.4300004212010396E-007 *10^(-12) meter

Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):
1.6200004170507921E-007 *10^(-12) meter

Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):
8.1000027665045354E-008 *10^(-12) meter

Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):
9.9999998509883898 *10^(-12) meter

Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):
8.1000027665045354E-008 *10^(-12) meter

Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):
1.6200004170507921E-007 *10^(-12) meter

Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):
2.4300004212010396E-007 *10^(-12) meter

Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):
3.2400002891012164E-007 *10^(-12) meter

Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):
4.0500000207513473E-007 *10^(-12) meter

Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):
4.8599996161514545E-007 *10^(-12) meter

Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):
5.6699990753015508E-007 *10^(-12) meter
Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):
6.4799983982016848E-007 *10^(-12) meter
Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):
7.2899975848518545E-007 *10^(-12) meter
Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):
8.0999966352520873E-007 *10^(-12) meter
...

Also for $\eta = 10^{-15}m$ one can compute the following results:

Enter a coupling constant (in 10^(-12) meter)
1e-3
Time: 0 *10^(-22) seconds:
Photon density at wavenumber 8.9999999850988388 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 9.0999999865889549 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 9.1999999880790710 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):

9.9999998509883898 *10^(-12) meter

Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

...

Time: 30 *10^(-22) seconds:

Photon density at wavenumber 8.9999999850988388 *10^(12) meter^(-1):

2.6999647252684660E-005 *10^(-12) meter

Photon density at wavenumber 9.0999999865889549 *10^(12) meter^(-1):

2.4299749119948591E-005 *10^(-12) meter

Photon density at wavenumber 9.1999999880790710 *10^(12) meter^(-1):

2.1599836189080815E-005 *10^(-12) meter

Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):

1.8899908460003031E-005 *10^(-12) meter

Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):

1.6199965932636931E-005 *10^(-12) meter

Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):

1.3500008606904190E-005 *10^(-12) meter

Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):

1.0800036482726504E-005 *10^(-12) meter

Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):

8.1000495600255564E-006 *10^(-12) meter

Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):

5.4000478387230308E-006 *10^(-12) meter

Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):

2.7000313187406180E-006 *10^(-12) meter

Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):

9.9999998509883898 *10^(-12) meter

Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):

2.7000313187406180E-006 *10^(-12) meter

Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):

5.4000478387230308E-006 *10^(-12) meter

Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):

8.1000495600255564E-006 *10^(-12) meter

Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):

1.0800036482726504E-005 *10^(-12) meter

Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):

1.3500008606904190E-005 *10^(-12) meter

Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):

1.6199965932636931E-005 *10^(-12) meter

Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):

1.8899908460003031E-005 *10^(-12) meter

Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):

2.1599836189080815E-005 *10^(-12) meter

Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):

2.4299749119948591E-005 *10^(-12) meter

Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):

2.6999647252684660E-005 *10^(-12) meter

...

Time: 60 *10^(-22) seconds:

Photon density at wavenumber 8.9999999850988388 *10^(12) meter^(-1):

5.3998565537591834E-005 *10^(-12) meter

Photon density at wavenumber 9.0999999865889549 *10^(12) meter^(-1):

4.8598979939503103E-005 *10^(-12) meter

Photon density at wavenumber 9.1999999880790710 *10^(12) meter^(-1):

4.3199334130803244E-005 *10^(-12) meter

Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):

3.7799628110832282E-005 *10^(-12) meter

Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):

3.2399861878930156E-005 *10^(-12) meter

Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):

2.7000035434436813E-005 *10^(-12) meter

Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):

2.1600148776692226E-005 *10^(-12) meter

Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):

1.6200201905036311E-005 *10^(-12) meter

Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):

1.0800194818809021E-005 *10^(-12) meter

Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):

5.4001275173502786E-006 *10^(-12) meter

Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):

9.9999998509883898 *10^(-12) meter

Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):

5.4001275173502786E-006 *10^(-12) meter

Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):

1.0800194818809021E-005 *10^(-12) meter

Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):

1.6200201905036311E-005 *10^(-12) meter

Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):

2.1600148776692226E-005 *10^(-12) meter

Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):

2.7000035434436813E-005 *10^(-12) meter

Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):

3.2399861878930156E-005 *10^(-12) meter

Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):

3.7799628110832282E-005 *10^(-12) meter

Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):

4.3199334130803244E-005 *10^(-12) meter

Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):

4.8598979939503103E-005 *10^(-12) meter

Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):

5.3998565537591834E-005 *10^(-12) meter

...

Time: 90 *10^(-22) seconds:

Photon density at wavenumber 8.9999999850988388 *10^(12) meter^(-1):

8.0996754888042465E-005 *10^(-12) meter

Photon density at wavenumber 9.0999999865889549 *10^(12) meter^(-1):

7.2897692477902362E-005 *10^(-12) meter

Photon density at wavenumber 9.1999999880790710 *10^(12) meter^(-1):

6.4798493834101472E-005 *10^(-12) meter

Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):

5.6699158954374105E-005 *10^(-12) meter

Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):

4.8599687836454250E-005 *10^(-12) meter

Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):

4.0500080478076055E-005 *10^(-12) meter

Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):

3.2400336876973543E-005 *10^(-12) meter

Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):

2.4300457030880739E-005 *10^(-12) meter

Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):

1.6200440937531588E-005 *10^(-12) meter

Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):

8.1002885946600514E-006 *10^(-12) meter

Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):

9.9999998509883898 *10^(-12) meter

Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):

8.1002885946600514E-006 *10^(-12) meter

Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):

1.6200440937531588E-005 *10^(-12) meter

Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):

2.4300457030880739E-005 *10^(-12) meter

Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):

3.2400336876973543E-005 *10^(-12) meter

Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):

4.0500080478076055E-005 *10^(-12) meter

Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):

4.8599687836454250E-005 *10^(-12) meter

Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):

5.6699158954374105E-005 *10^(-12) meter

Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):

6.4798493834101472E-005 *10^(-12) meter

Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):

7.2897692477902362E-005 *10^(-12) meter

Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):

8.0996754888042465E-005 *10^(-12) meter

...

Finally, for $\eta = 10^{-13}m$ one has the results:

Enter a coupling constant (in 10^(-12) meter)

1e-1

Time: 0 *10^(-22) seconds:

Photon density at wavenumber 8.9999999850988388 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.0999999865889549 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.1999999880790710 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):

9.9999998509883898 *10^(-12) meter

Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):

0.0000000000000000 *10^(-12) meter

Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):
0.0000000000000000 *10^(-12) meter
...
Time: 30 *10^(-22) seconds:
Photon density at wavenumber 8.9999999850988388 *10^(12) meter^(-1):
2.6964814650656211E-003 *10^(-12) meter
Photon density at wavenumber 9.0999999865889549 *10^(12) meter^(-1):
2.4274976458384485E-003 *10^(-12) meter
Photon density at wavenumber 9.1999999880790710 *10^(12) meter^(-1):
2.1583664065873017E-003 *10^(-12) meter
Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):
1.8890876692842968E-003 *10^(-12) meter
Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):
1.6196613558617187E-003 *10^(-12) meter
Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):
1.3500873882120058E-003 *10^(-12) meter
Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):
1.0803656881877306E-003 *10^(-12) meter
Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):
8.1049617760157761E-004 *10^(-12) meter

Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):
5.4047877822632675E-004 *10^(-12) meter

Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):
2.7031341179483136E-004 *10^(-12) meter

Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):
9.9999998509883898 *10^(-12) meter

Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):
2.7031341179483136E-004 *10^(-12) meter

Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):
5.4047877822632675E-004 *10^(-12) meter

Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):
8.1049617760157761E-004 *10^(-12) meter

Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):
1.0803656881877306E-003 *10^(-12) meter

Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):
1.3500873882120058E-003 *10^(-12) meter

Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):
1.6196613558617187E-003 *10^(-12) meter

Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):
1.8890876692842968E-003 *10^(-12) meter

Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):
2.1583664065873017E-003 *10^(-12) meter

Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):
2.4274976458384485E-003 *10^(-12) meter

Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):
2.6964814650656211E-003 *10^(-12) meter

...

Time: 60 *10^(-22) seconds:

Photon density at wavenumber 8.9999999850988388 *10^(12) meter^(-1):
5.3857050545415754E-003 *10^(-12) meter

Photon density at wavenumber 9.0999999865889549 *10^(12) meter^(-1):
4.8498306592493733E-003 *10^(-12) meter

Photon density at wavenumber 9.1999999880790710 *10^(12) meter^(-1):
4.3133588782991754E-003 *10^(-12) meter

Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):
3.7762890567027800E-003 *10^(-12) meter

Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):
3.2386205387660997E-003 *10^(-12) meter

Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):
2.7003526680884037E-003 *10^(-12) meter

Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):
2.1614847875615737E-003 *10^(-12) meter

Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):
1.6220162393693520E-003 *10^(-12) meter

Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):
1.0819463649866014E-003 *10^(-12) meter

Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):
5.4127450517853985E-004 *10^(-12) meter

Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):
9.9999998509883898 *10^(-12) meter

Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):
5.4127450517853985E-004 *10^(-12) meter

Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):
1.0819463649866014E-003 *10^(-12) meter

Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):
1.6220162393693520E-003 *10^(-12) meter

Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):
2.1614847875615737E-003 *10^(-12) meter

Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):
2.7003526680884037E-003 *10^(-12) meter

Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):
3.2386205387660997E-003 *10^(-12) meter

Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):
3.7762890567027800E-003 *10^(-12) meter

Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):
4.3133588782991754E-003 *10^(-12) meter

Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):
4.8498306592493733E-003 *10^(-12) meter

Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):
5.3857050545415754E-003 *10^(-12) meter

...

Time: 90 *10^(-22) seconds:

Photon density at wavenumber 8.9999999850988388 *10^(12) meter^(-1):
8.0677038527882921E-003 *10^(-12) meter

Photon density at wavenumber 9.0999999865889549 *10^(12) meter^(-1):
7.2670181687958177E-003 *10^(-12) meter

Photon density at wavenumber 9.1999999880790710 *10^(12) meter^(-1):
6.4649863181379203E-003 *10^(-12) meter

Photon density at wavenumber 9.2999999895691872 *10^(12) meter^(-1):
5.6616060613337285E-003 *10^(-12) meter

Photon density at wavenumber 9.3999999910593033 *10^(12) meter^(-1):
4.8568751552180737E-003 *10^(-12) meter

Photon density at wavenumber 9.4999999925494194 *10^(12) meter^(-1):
4.0507913529355000E-003 *10^(-12) meter

Photon density at wavenumber 9.5999999940395355 *10^(12) meter^(-1):
3.2433524039342460E-003 *10^(-12) meter

Photon density at wavenumber 9.6999999955296516 *10^(12) meter^(-1):
2.4345560539602447E-003 *10^(-12) meter

Photon density at wavenumber 9.7999999970197678 *10^(12) meter^(-1):
1.6244000450511054E-003 *10^(-12) meter

Photon density at wavenumber 9.8999999985098839 *10^(12) meter^(-1):
8.1288211553007521E-004 *10^(-12) meter

Photon density at wavenumber 10.000000000000000 *10^(12) meter^(-1):
9.9999998509883898 *10^(-12) meter

Photon density at wavenumber 10.100000001490116 *10^(12) meter^(-1):
8.1288211553007521E-004 *10^(-12) meter

Photon density at wavenumber 10.200000002980232 *10^(12) meter^(-1):
1.6244000450511054E-003 *10^(-12) meter
Photon density at wavenumber 10.300000004470348 *10^(12) meter^(-1):
2.4345560539602447E-003 *10^(-12) meter
Photon density at wavenumber 10.400000005960464 *10^(12) meter^(-1):
3.2433524039342460E-003 *10^(-12) meter
Photon density at wavenumber 10.500000007450581 *10^(12) meter^(-1):
4.0507913529355000E-003 *10^(-12) meter
Photon density at wavenumber 10.600000008940697 *10^(12) meter^(-1):
4.8568751552180737E-003 *10^(-12) meter
Photon density at wavenumber 10.700000010430813 *10^(12) meter^(-1):
5.6616060613337285E-003 *10^(-12) meter
Photon density at wavenumber 10.800000011920929 *10^(12) meter^(-1):
6.4649863181379203E-003 *10^(-12) meter
Photon density at wavenumber 10.900000013411045 *10^(12) meter^(-1):
7.2670181687958177E-003 *10^(-12) meter
Photon density at wavenumber 11.000000014901161 *10^(12) meter^(-1):
8.0677038527882921E-003 *10^(-12) meter
...

From these results it can be seen that all photon density functions look very similar to photon density functions on $t = 0$. As expected, only a small deviation in the wavenumber distribution due to TDFT scattering processes can be observed. Interactions predicted by TDFT become significant after approximate

3 zeptoseconds. These TDFT correction clearly increases if the TDFT coupling constant increases. In the neighborhood of the characteristic wave number that has the value $10^{13} m^{-1}$ one can observe values in the wavenumber density which are much smaller than the wavenumber density at the characteristic wave number; these values are oscillating, but remain on the same magnitude scale over the remaining observation time. There is a cloud of other photons with lower intensity around the dominating photon (which has the characteristic wave number).

CONCLUSIONS

From the simplified version of the transition rate there can be obtained statements about a system that is governed by interactions predicted by TDFT. When plotting the results diagrammatically one cannot see the deviations in wavenumber distribution, because these are very small. The numerical results have shown that a monochromatic photon governed by TDFT interactions generates some other

photon rays with distinct frequency with much smaller intensity. For the experimental validation of TDFT one has to check whether these photon rays with distinct frequencies exist even if a monochromatic photon is emitted to the vacuum.

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