AMOP Lecture 1
Tue. 1.13.2014

2-Wave Interference: Phase and Group Dynamics

(Ch. 0-1 of Unit 8 CMwBang! and p.1-20 Relativity&QuantumTheory by Rule&Compass)

1. Review of basic formulas for waves in space-time (x,t) or per-space-time (ω,k)
    - 1-Plane-wave phase velocity
    - 2-Plane-wave phase velocity and group velocity (1/2-sum &1/2-diff.)
    - 2-Plane-wave real zero grid in (x,t) or (ω,k)
    - Geometric analysis of Bohr-Schrodinger "matter-wave"
    - Algebraic analysis of Bohr-Schrodinger "matter-wave"
2. Geometric construction of wave-zero grids
    - Continuous Wave (CW) grid based on $\mathbf{K}_{phase}=(\mathbf{K}_a+\mathbf{K}_b)/2$ and $\mathbf{K}_{group}=(\mathbf{K}_a-\mathbf{K}_b)/2$ vectors
    - Pulse Wave (PW) grid based on primitive $\mathbf{K}_a=\mathbf{K}_{phase}+\mathbf{K}_{group}$ and $\mathbf{K}_b=\mathbf{K}_{phase}-\mathbf{K}_{group}$ vectors
    - When this doesn't work (When you don't need it!)
3. Beginning wave relativity
    - Dueling lasers make lab frame space-time grid
    - Einstein PW Axioms versus Evenson CW Axioms (Occam at Work)
        - Only CW light clearly shows Doppler shift
    - Dueling lasers make lab frame space-time grid

Anatomy of single 1D right-moving plane Continuous Wave (CW)

$$\psi(x,t)=Ae^{i(kx-\omega t)}=A\left(\cos(kx-\omega t)+i\,\sin(kx-\omega t)\right)$$

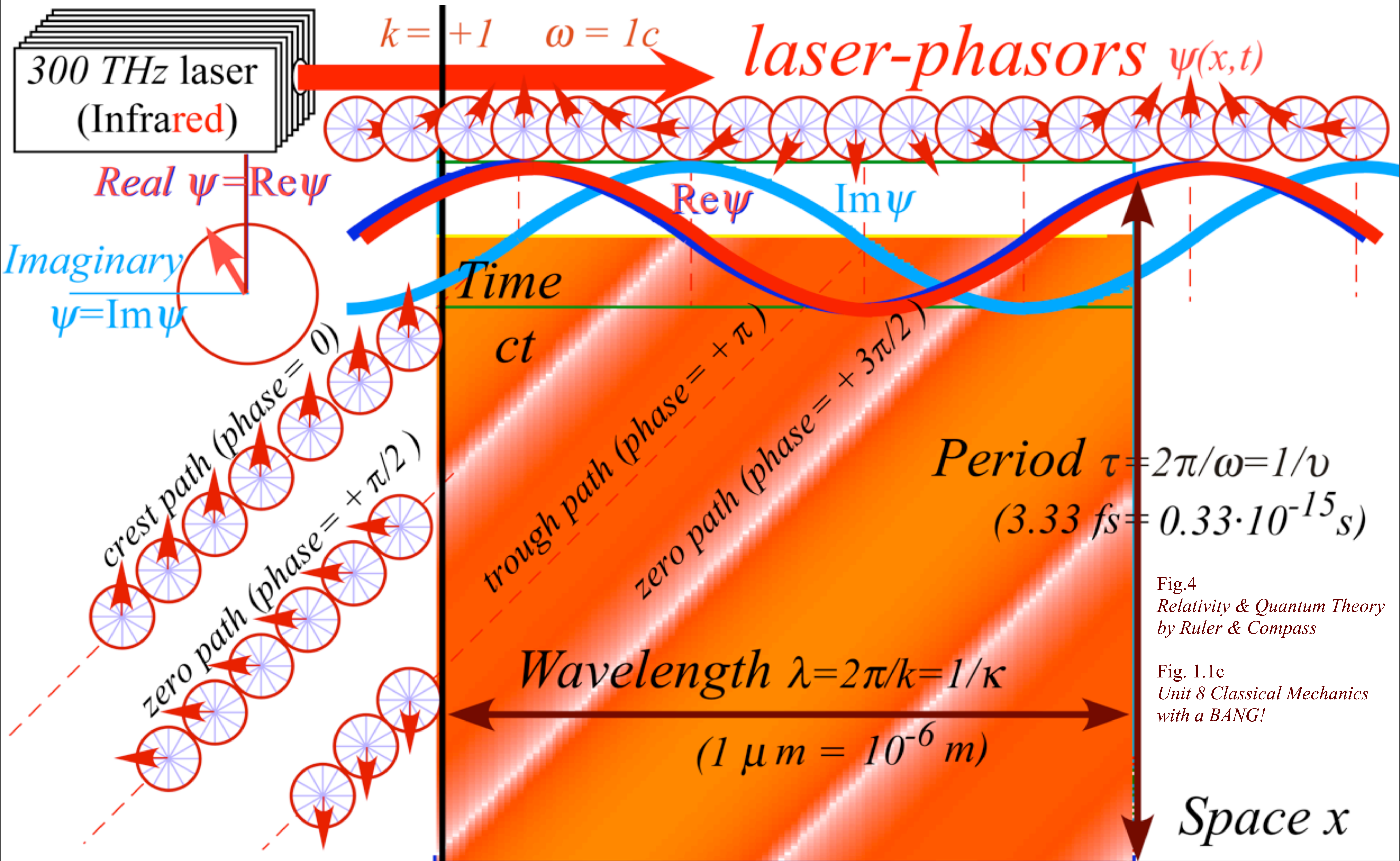


Fig.4
Relativity & Quantum Theory by Ruler & Compass

Fig. 1.1c
Unit 8 Classical Mechanics with a BANG!

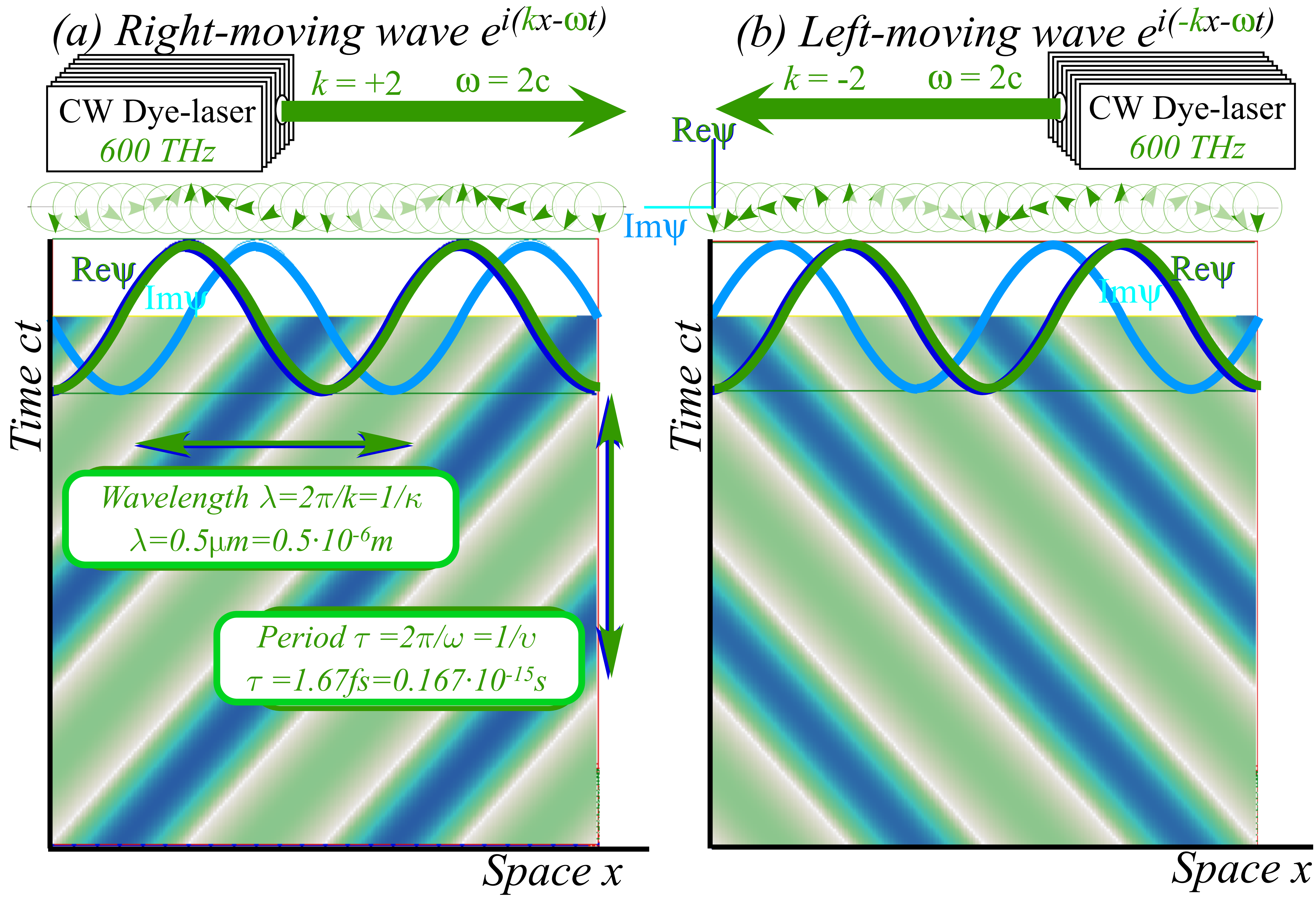


Fig.5(a-b) *Relativity & Quantum Th. by Ruler & Compass*

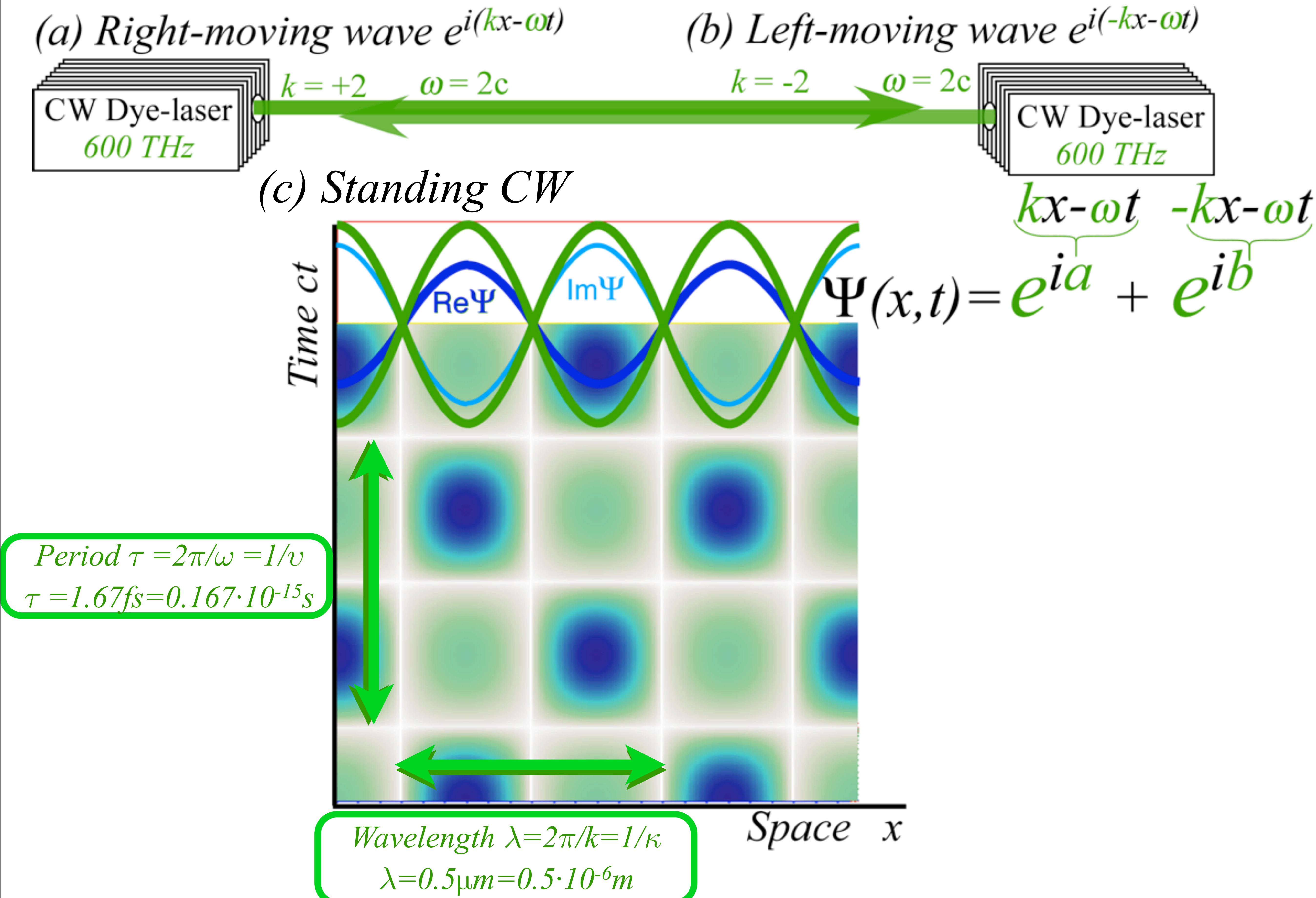


Fig.5(a-c) *Relativity & Quantum Th. by Ruler & Compass*

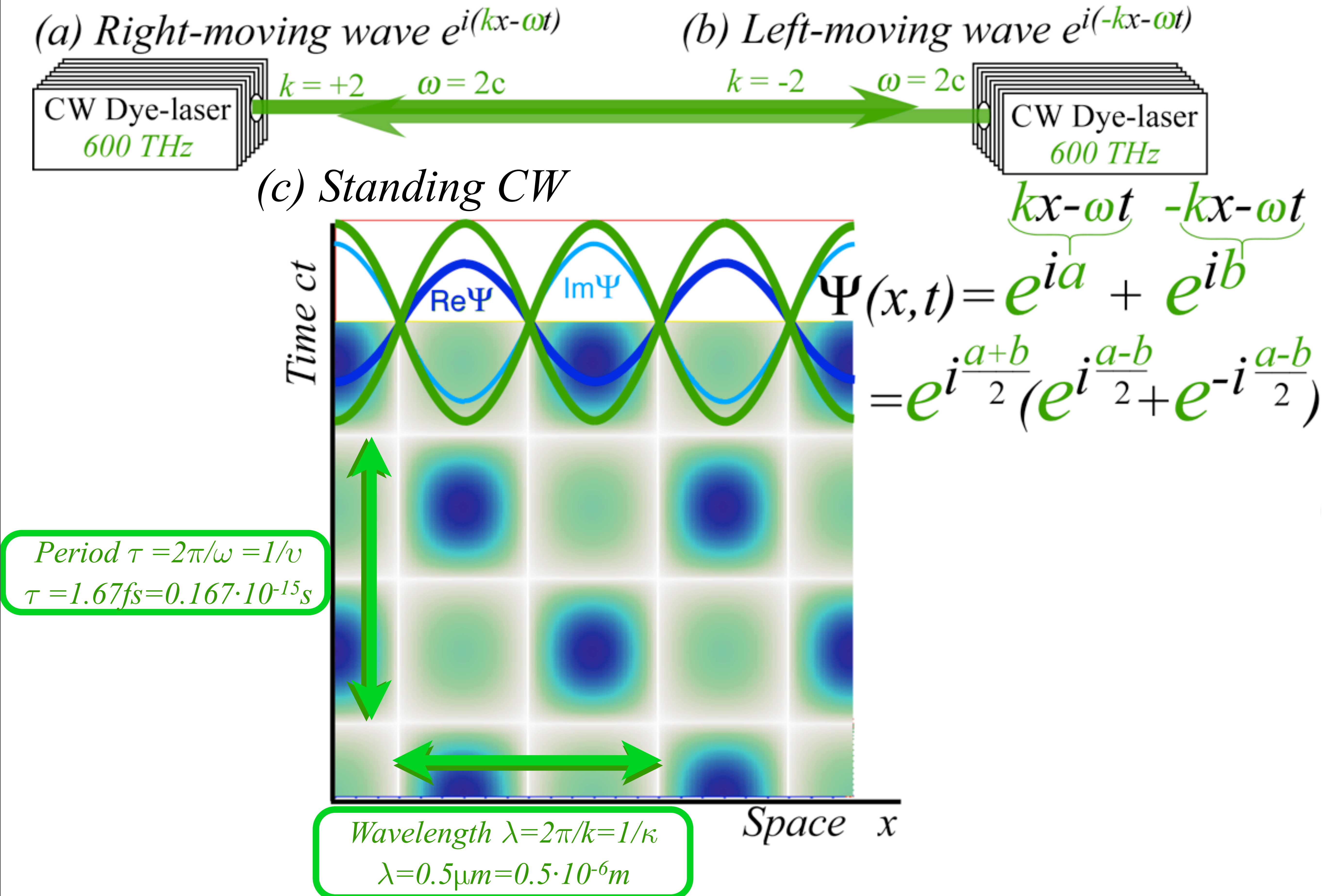


Fig.5(a-c) *Relativity & Quantum Th. by Ruler & Compass*

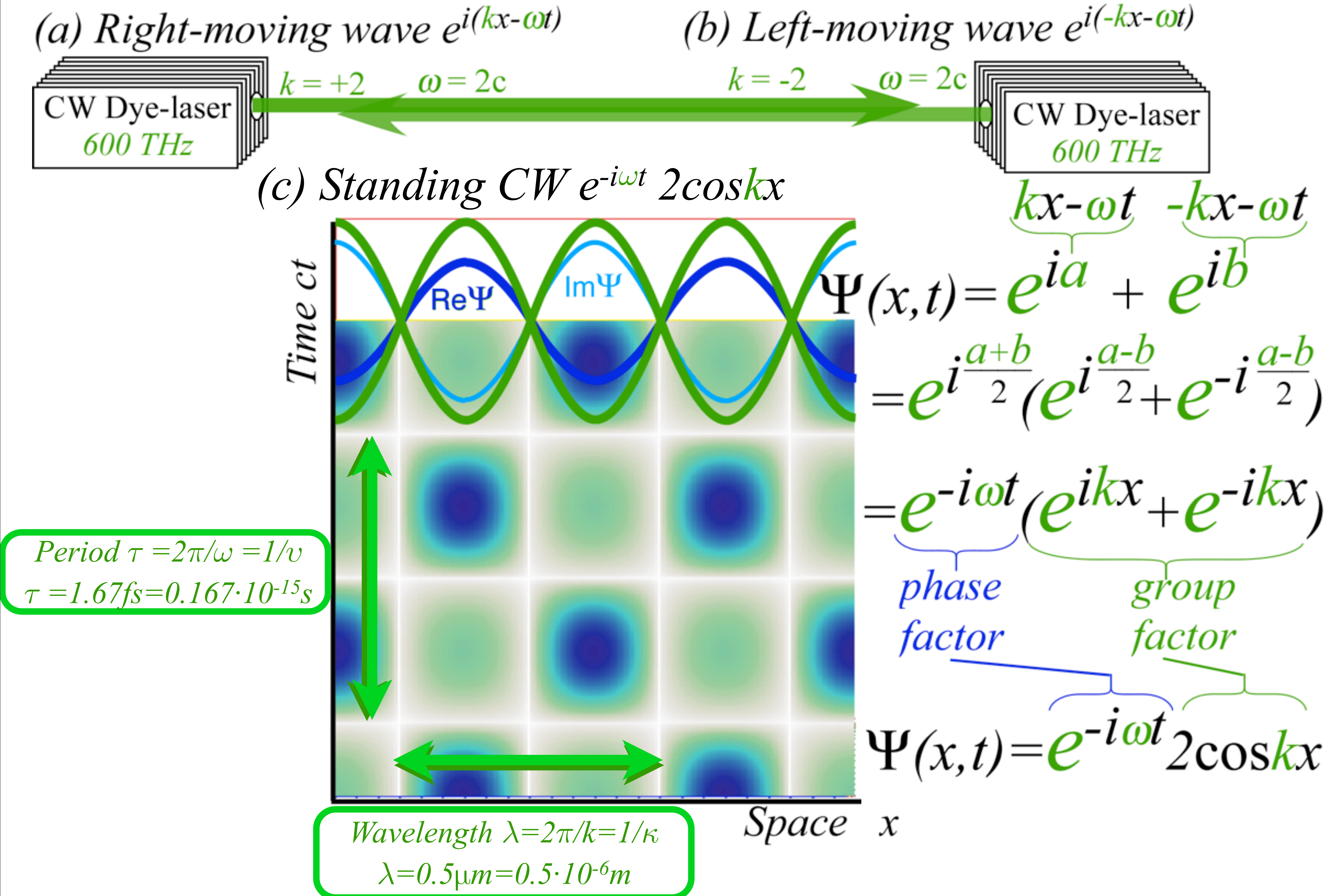


Fig.5(a-c) *Relativity & Quantum Th. by Ruler & Compass*

→ *Geometric analysis of Bohr-Schrodinger "matter-wave"*

Algebraic analysis of Bohr-Schrodinger "matter-wave"

Geometric Analysis of Bohr-Schrodinger "matter-wave" - Fig.6(top) *Rel&Quant.Th. by R&*

$$\Psi_{(x,t)} = e^{ia} + e^{ib} = \text{Re}\Psi + i\,\text{Im}\Psi$$

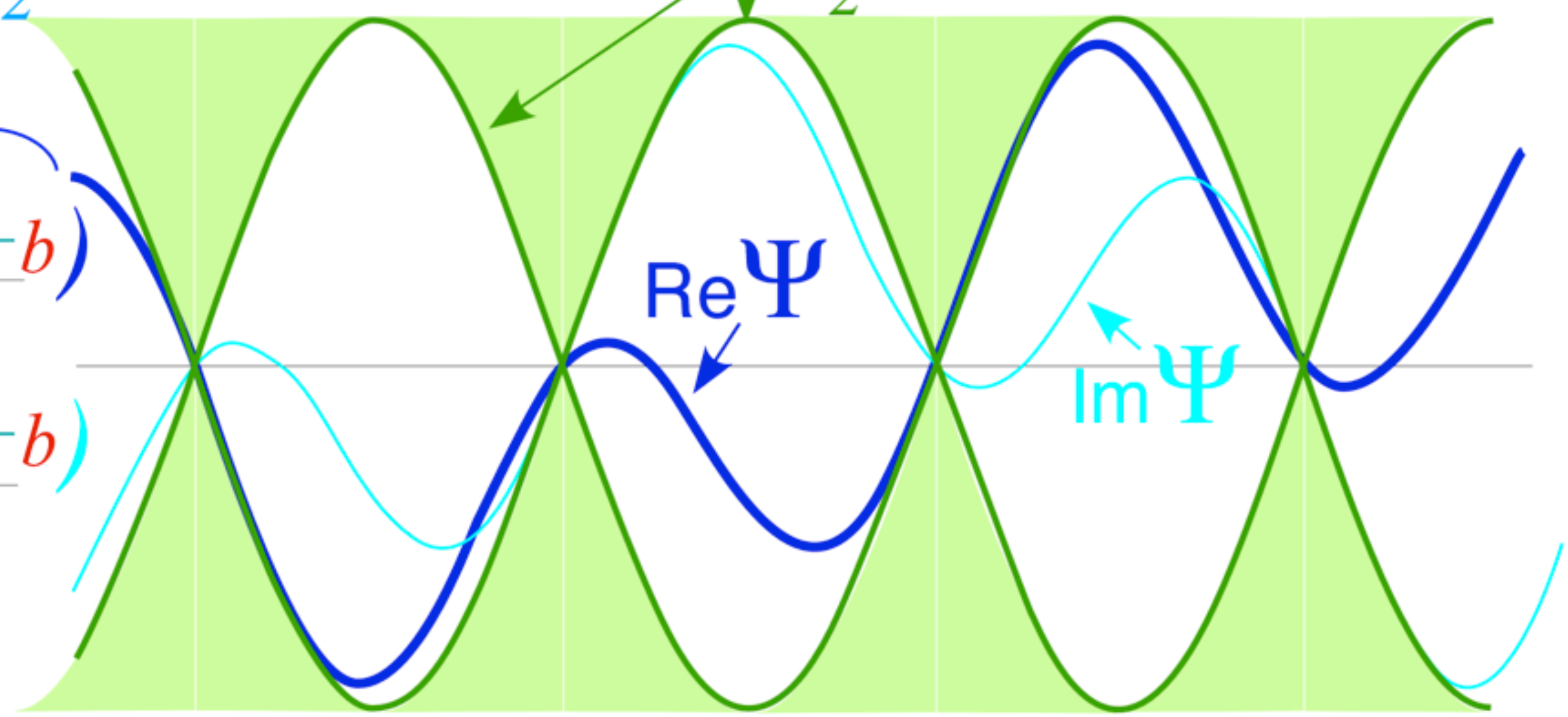
where $a = (k_1 x - \omega_1 t)$ and $b = (k_2 x - \omega_2 t)$

$$= e^{i(a+b)/2}\left(e^{i(a-b)/2} + e^{-i(a-b)/2}\right)$$

Phase factor: $e^{i(a+b)/2}$

Group factor: $2\cos\left(\frac{a-b}{2}\right)$

$$e^{i(a+b)/2} = \cos\left(\frac{a+b}{2}\right) + i\sin\left(\frac{a+b}{2}\right)$$



Geometric Analysis of Bohr-Schrodinger "matter-wave" - Fig.6(top) *Rel&Quant.Th. by R&C*

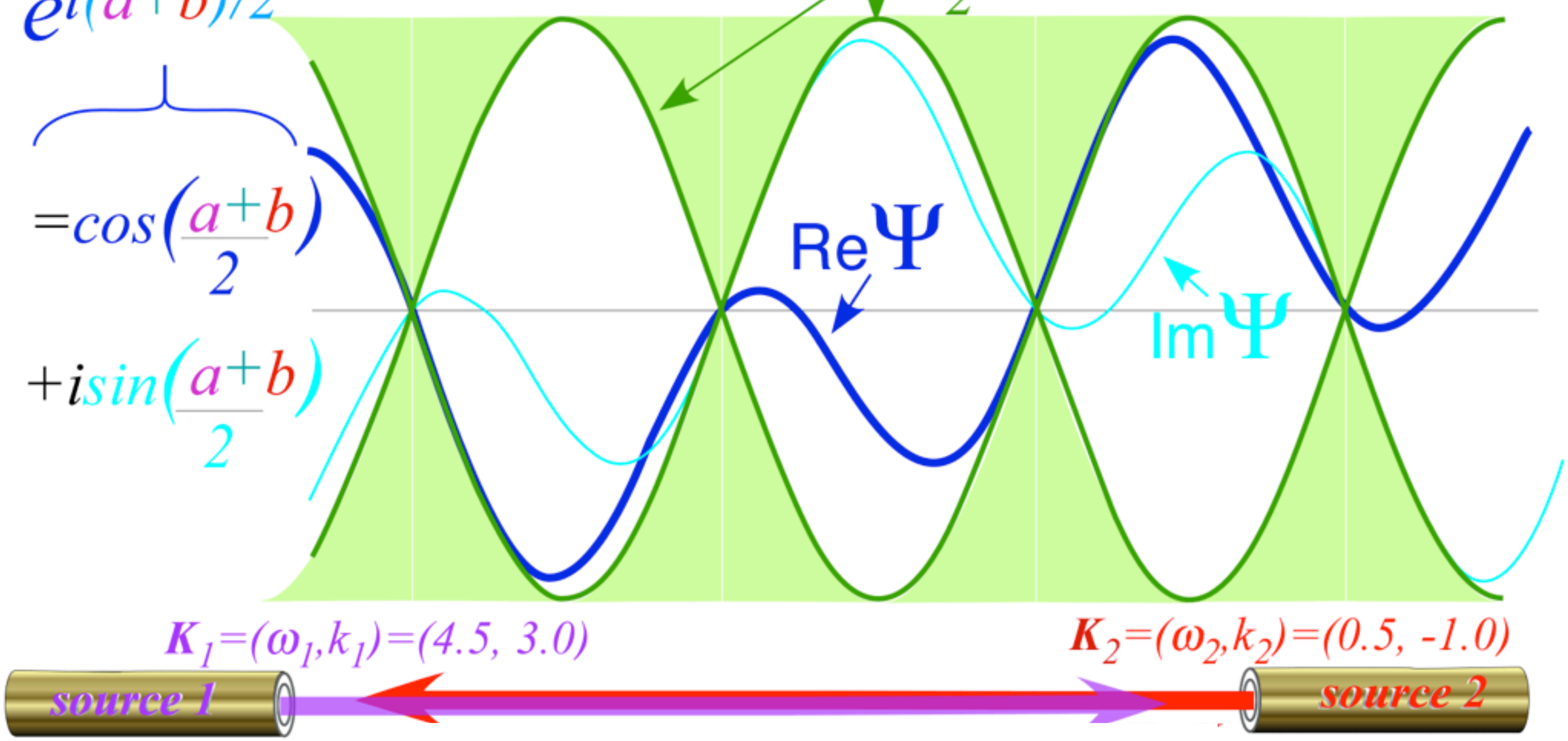
$$\Psi(x,t) = e^{ia} + e^{ib} = \mathrm{Re}\Psi + i\,\mathrm{Im}\Psi, \quad a = (k_1 x - \omega_1 t), \quad b = (k_2 x - \omega_2 t)$$

$$= e^{i(a+b)/2}\left(e^{i(a-b)/2} + e^{-i(a-b)/2}\right)$$

Phase factor: $e^{i(a+b)/2}$

Group factor: $2\cos\left(\frac{a-b}{2}\right)$

$$e^{i(a+b)/2} = \cos\left(\frac{a+b}{2}\right) + i\sin\left(\frac{a+b}{2}\right)$$



B-S m-w parameters:

$(\omega_1, k_1) = (4.5, 3.0)$

$(\omega_2, k_2) = (0.5, -1.0)$

Geometric Analysis of Bohr-Schrodinger "matter-wave" - Fig.6(top) *Rel&Quant.Th. by R&C*

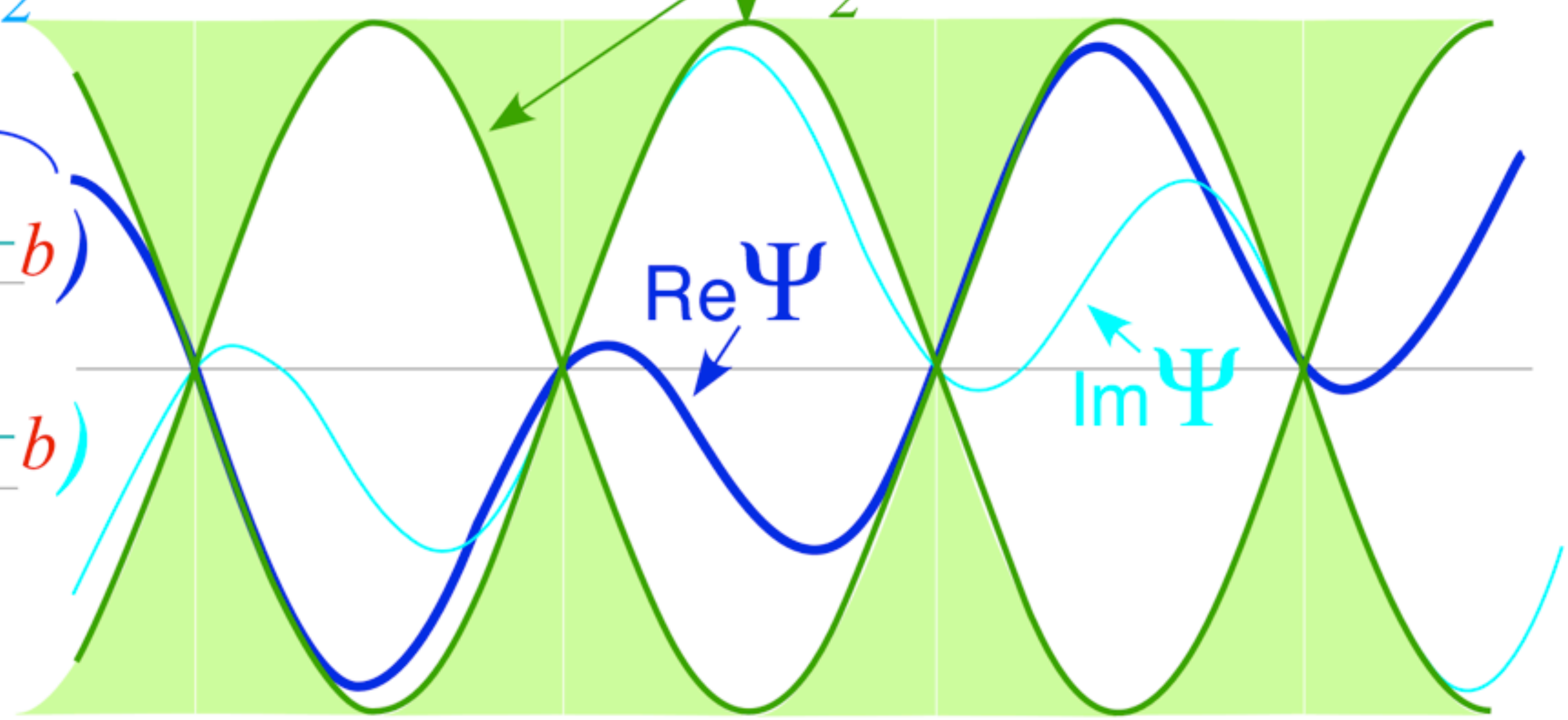
$$\Psi(x,t) = e^{ia} + e^{ib} = \text{Re}\Psi + i\,\text{Im}\Psi, \quad a = (k_1 x - \omega_1 t),\; b = (k_2 x - \omega_2 t)$$

$$= e^{i(a+b)/2}\left(e^{i(a-b)/2} + e^{-i(a-b)/2}\right)$$

Phase factor: $e^{i(a+b)/2}$

Group factor: $2\cos\left(\frac{a-b}{2}\right)$

$$e^{i(a+b)/2} = \cos\left(\frac{a+b}{2}\right) + i\sin\left(\frac{a+b}{2}\right)$$



$K_1 = (\omega_1, k_1) = (4.5, 3.0)$

$K_2 = (\omega_2, k_2) = (0.5, -1.0)$

$$K_{phase} = \frac{K_1 + K_2}{2} = (2.5, 1.0) = (\omega_{phase}, k_{phase})$$

$$K_{group} = \frac{K_1 - K_2}{2} = (2.0, 2.0) = (\omega_{group}, k_{group})$$

B-S m-w parameters:

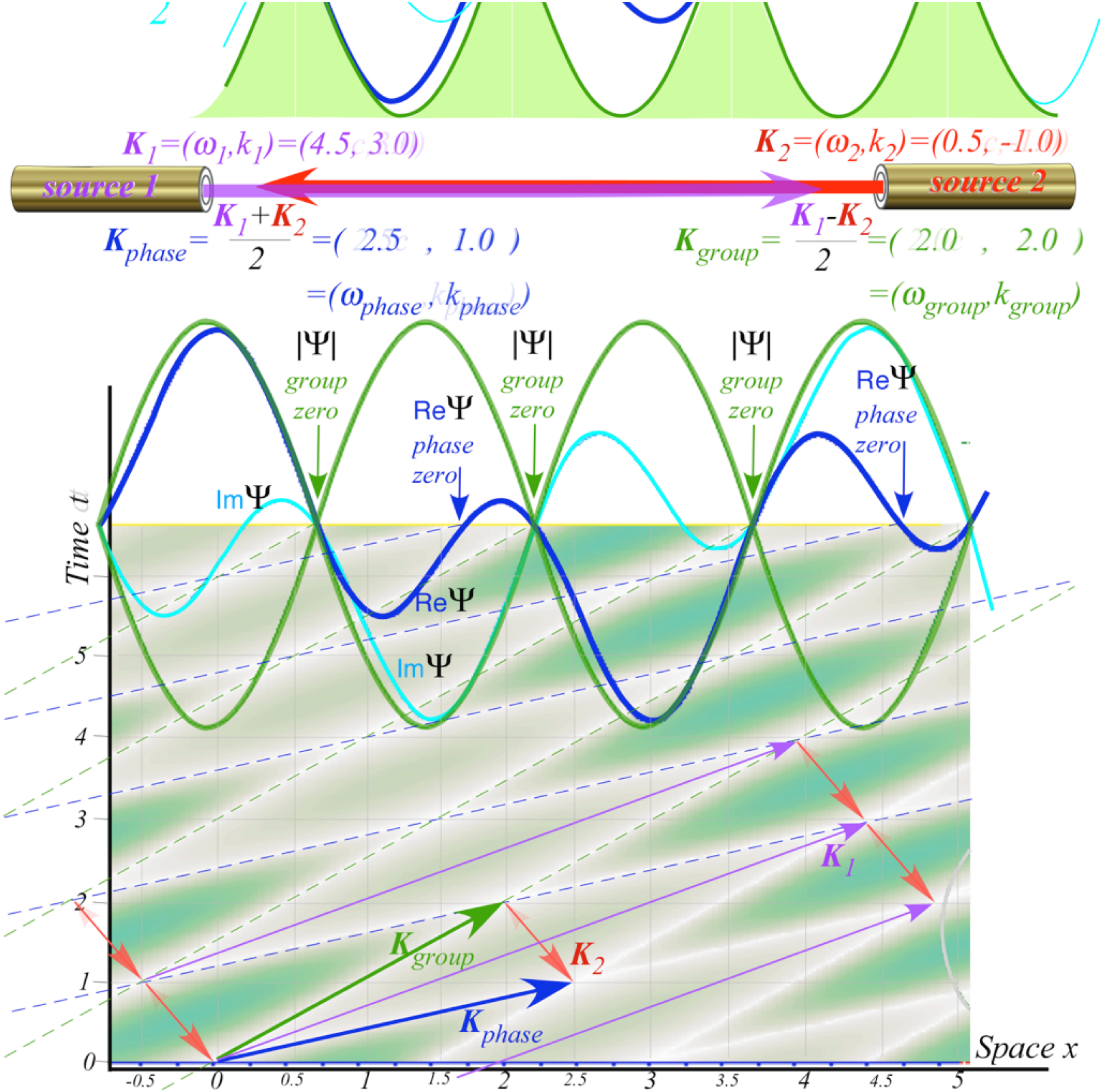
$(\omega_1, k_1) = (4.5, 3.0)$

$(\omega_2, k_2) = (0.5, -1.0)$

$(\omega_{phase}, k_{phase}) = (2.5, 1.0)$

$(\omega_{group}, k_{group}) = (2.0, 2.0)$

Geometric Analysis of Bohr-Schrodinger "matter-wave" - Fig.6(top) *Rel&Quant.Th. by R&C*



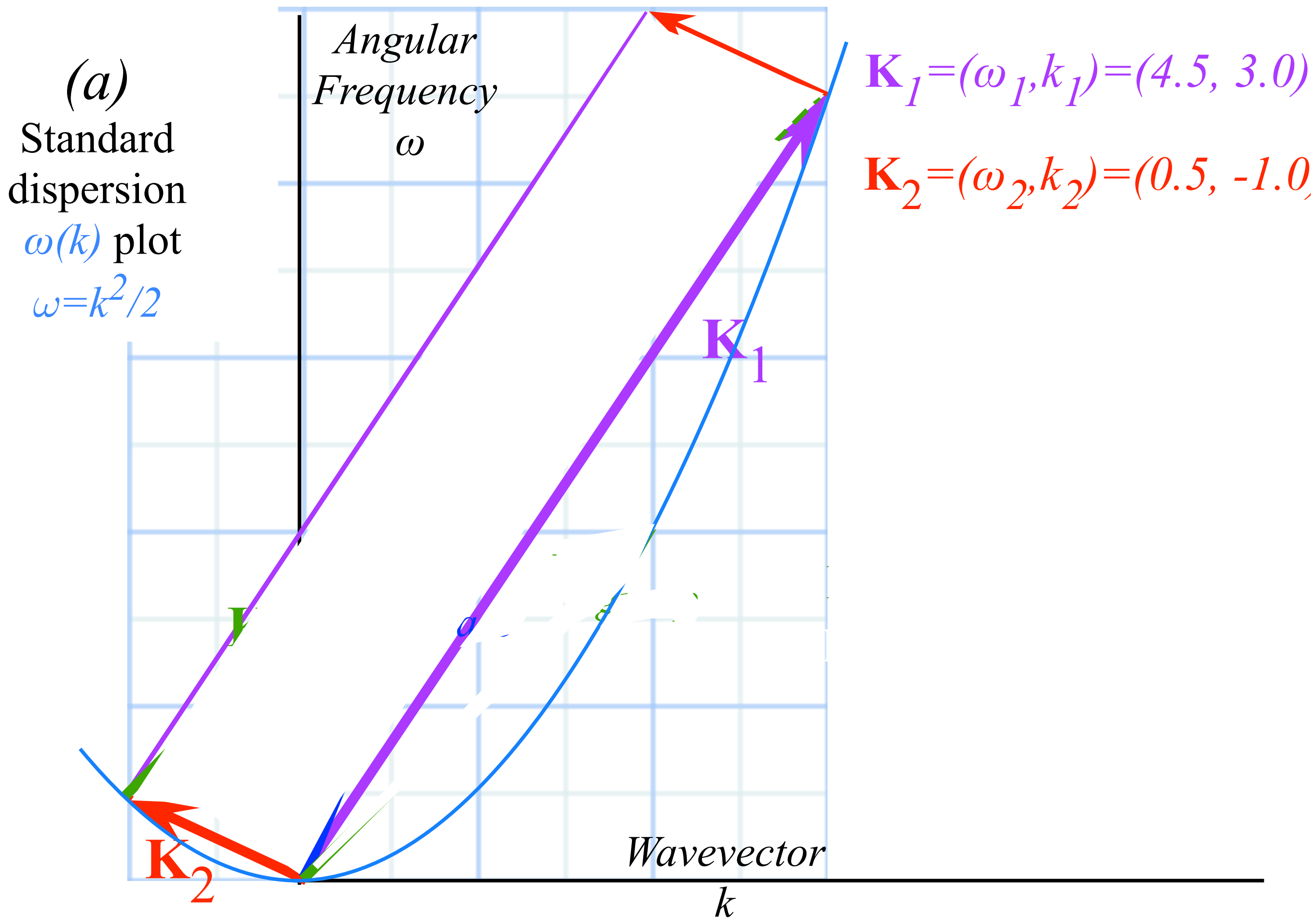
B-S m-w parameters:

$(\omega_1, k_1) =$
$(4.5, 3.0)$

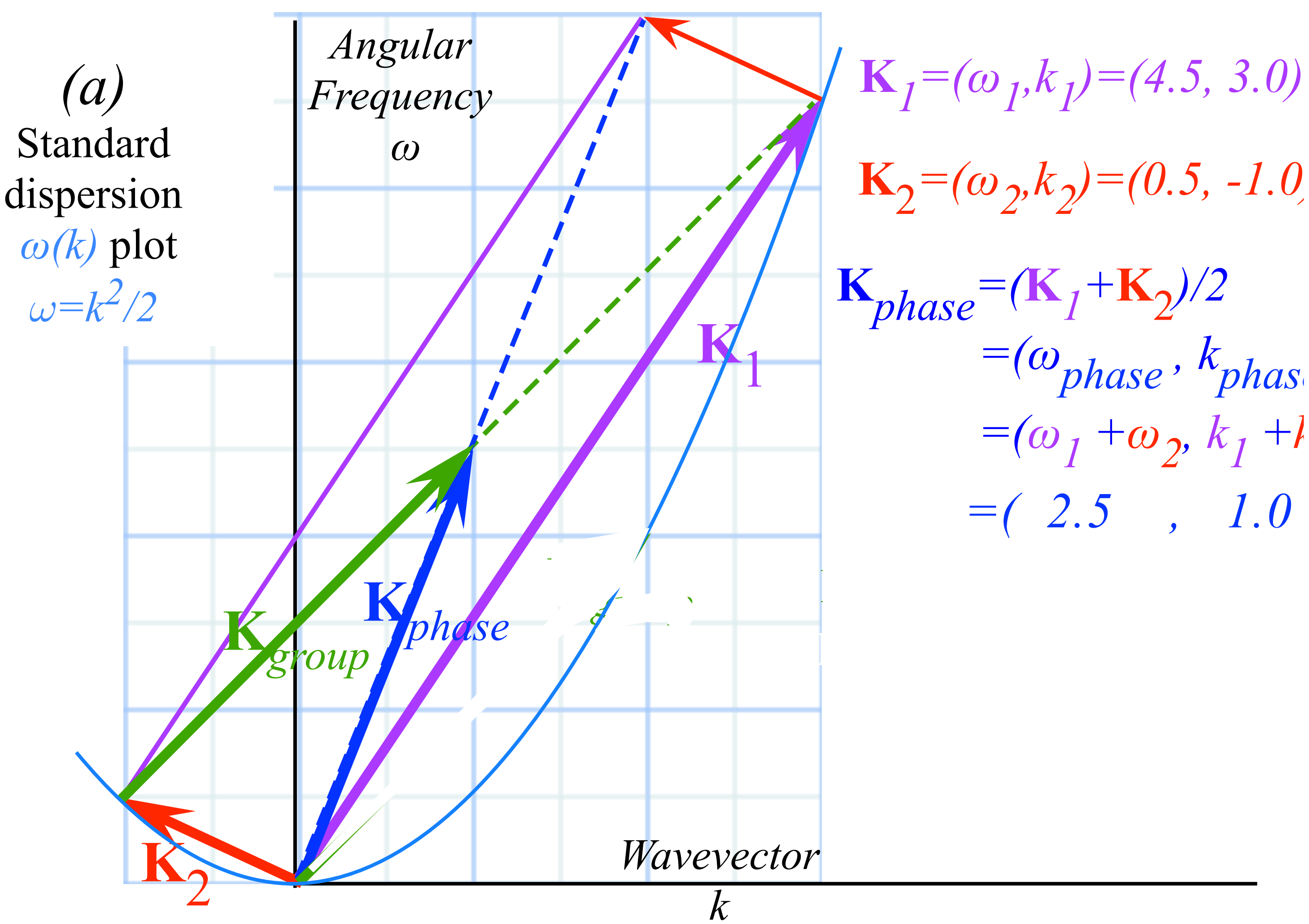
$(\omega_2, k_2) =$
$(0.5, -1.0)$

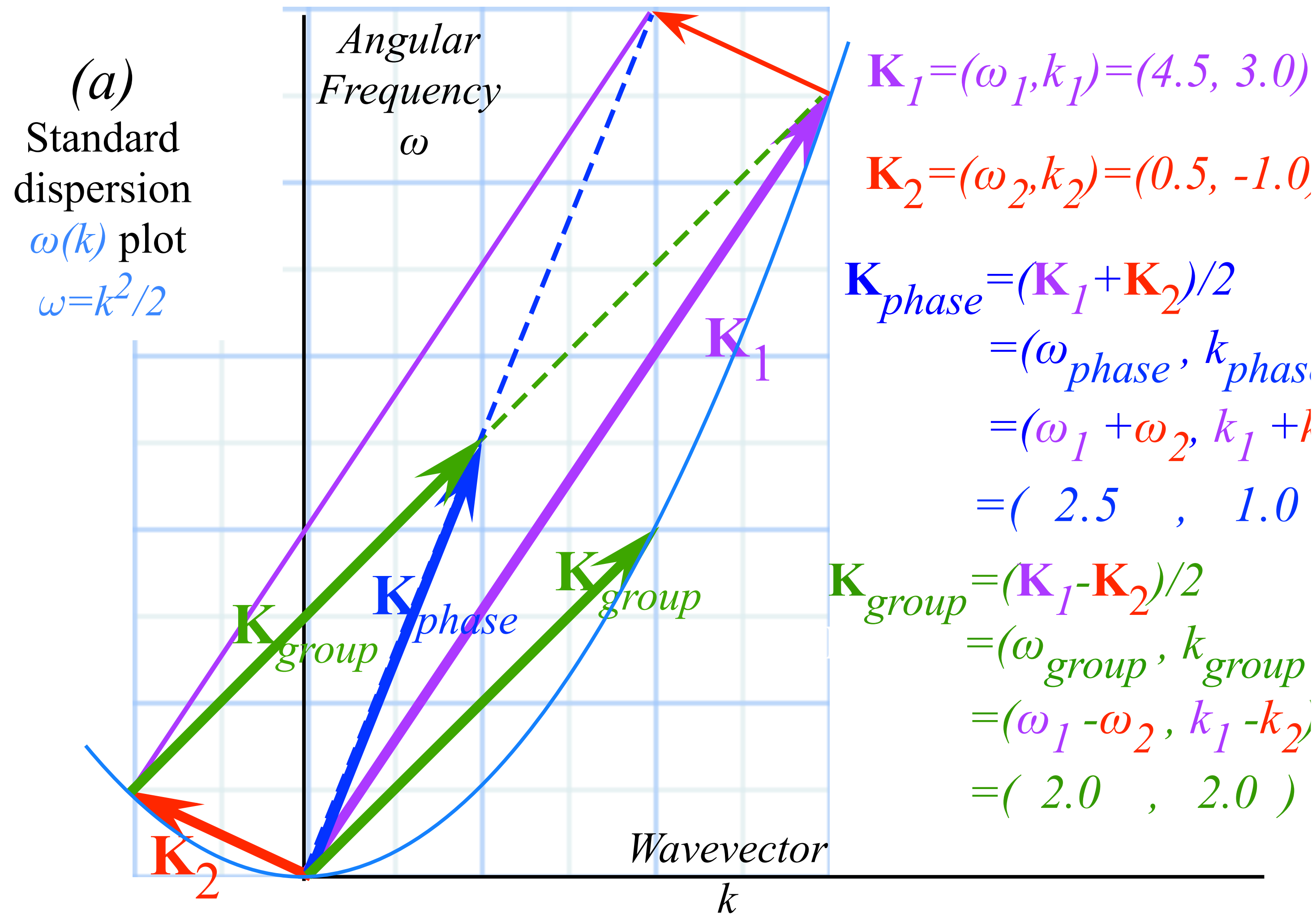
$(\omega_{phase}, k_{phase}) =$
$(2.5, 1.0)$

$(\omega_{group}, k_{group}) =$
$(2.0, 2.0)$

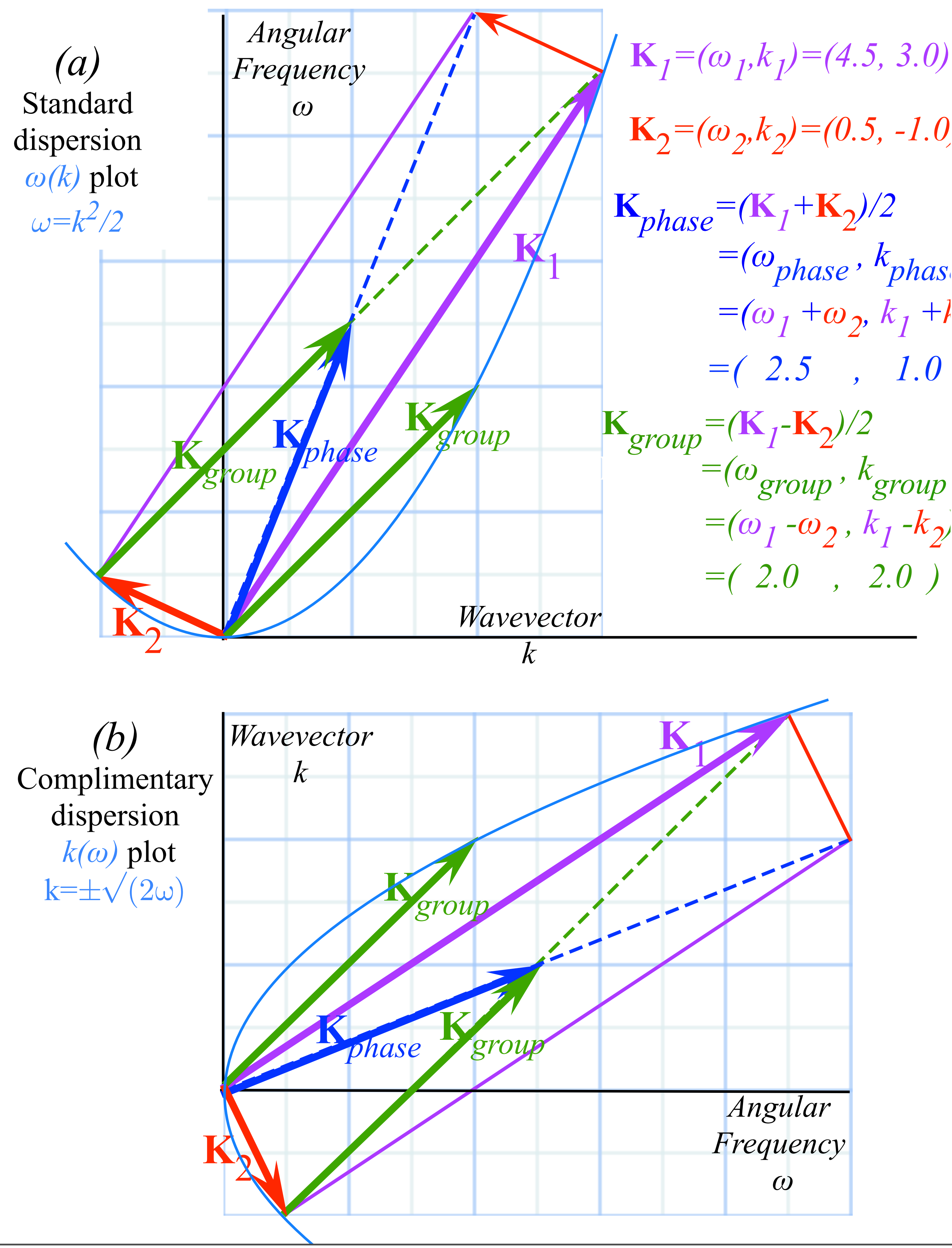


(a)
Standard dispersion
ω(k) plot
ω=k²/2
Angular Frequency
ω
K1=(ω1,k1)=(4.5, 3.0)
K2=(ω2,k2)=(0.5, -1.0
K1
K2
Wavevector
k

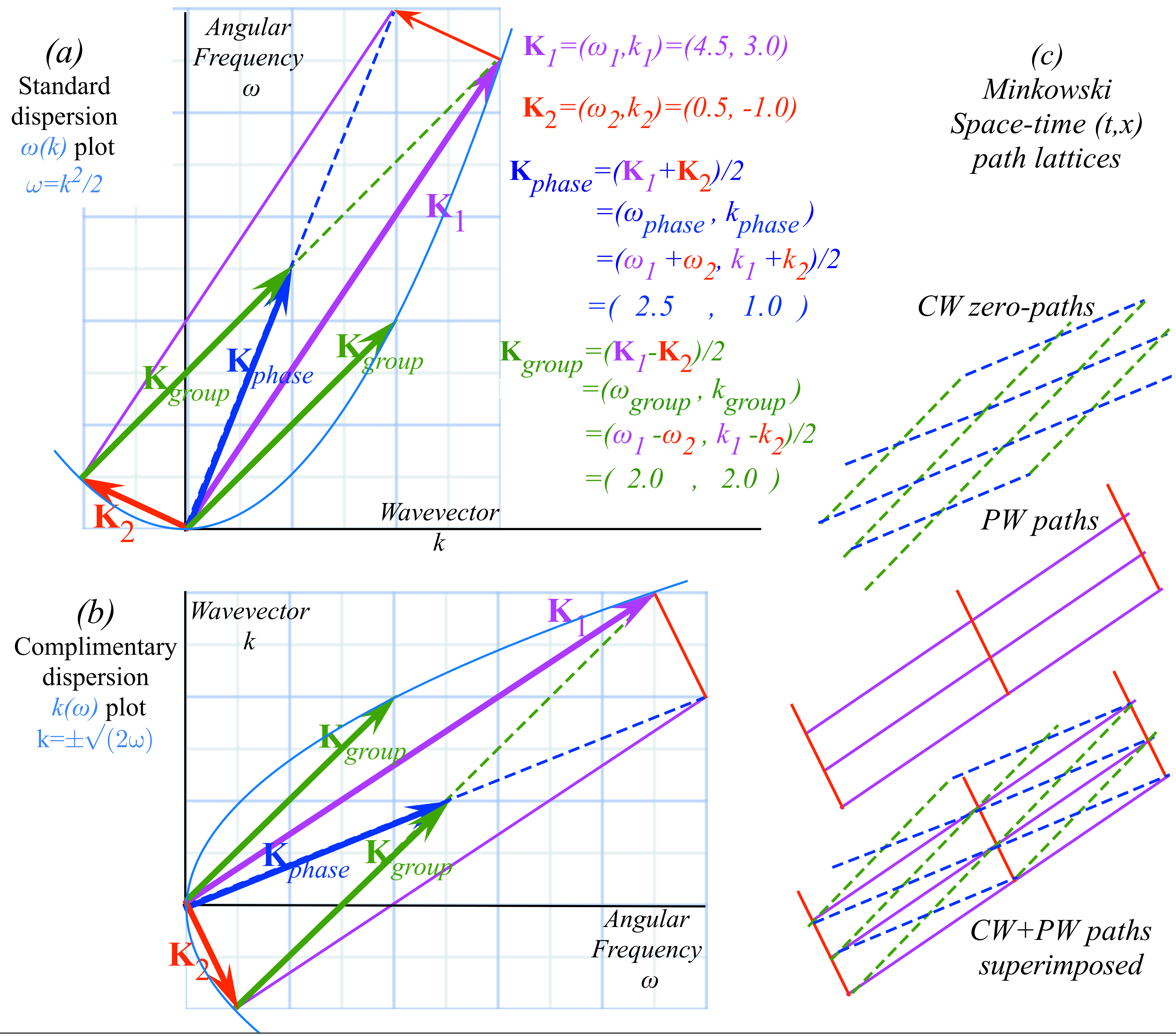

(a)
Standard dispersion
ω(k) plot
ω=k²/2
Angular Frequency ω
Wavevector k
K₁
K₂
K_group
K_phase
K₁=(ω₁,k₁)=(4.5, 3.0)
K₂=(ω₂,k₂)=(0.5, -1.0
K_phase=(K₁+K₂)/2
=(ω_phase , k_phas
=(ω₁ +ω₂, k₁ +
=(2.5 , 1.0


(a)
Standard
dispersion
ω(k) plot
ω=k²/2
Angular
Frequency
ω
Wavevector
k
K1
K2
Kphase
Kgroup
Kgroup
K1=(ω1,k1)=(4.5, 3.0)
K2=(ω2,k2)=(0.5, -1.0
Kphase=(K1+K2)/2
=(ωphase , kphas
=(ω1 +ω2, k1 +
=(2.5 , 1.0
Kgroup=(K1-K2)/2
=(ωgroup , kgroup
=(ω1 -ω2 , k1 -k2
=(2.0 , 2.0)

Geometric Analysis of Bohr-Schrodinger "matter-wave" - Fig.7(a) *Rel&Quant.Th. by R&C*



Geometric Analysis of Bohr-Schrodinger "matter-wave" - Fig.7(a) *Rel&Quant.Th. by R&C*



Fundamental wave dynamics based on Euler Expo-cosine Identity

$$(e^{ia} + e^{ib})/2 = \quad e^{i(a+b)/2}(e^{i(a-b)/2}+e^{-i(a-b)/2})/2 = e^{i(a+b)/2} \bullet \cos(a-b)/2$$

Balanced (50-50) plane wave combination:

$\omega_p=(\omega_1+\omega_2)/2$ $\omega_g=(\omega_1-\omega_2)/2$

$k_p=(k_1+k_2)/2$ $k_g=(k_1-k_2)/2$

Overall or Mean phase   Relative or Group phase

$$\Psi_{50_1\text{-}50_2}(x,t) = (1/2)\psi_{k_1}(x,t) + (1/2)\psi_{k_2}(x,t)$$

$$(1/2)e^{i(k_1x-\omega_1t)} + (1/2)e^{i(k_2x-\omega_2t)} = e^{i(k_px-\omega_pt)} \bullet \cos(k_gx-\omega_gt)$$

Velocity: $\frac{\text{meters}}{\text{second}}$ or $\frac{\text{per-seconds}}{\text{per-meter}}$

1st plane phase velocity	2nd plane phase velocity	Phase or Carrier velocity	Group or Envelope velocity
$V_1 = \frac{\omega_1}{k_1}$	$V_2 = \frac{\omega_2}{k_2}$	$V_p = \frac{\omega_p}{k_p} = \frac{\omega_1+\omega_2}{k_1+k_2}$	$V_g = \frac{\omega_g}{k_g} = \frac{\omega_1-\omega_2}{k_1-k_2}$

Define **K**-vectors in per-spacetime

$\mathbf{K}_1=(\omega_1, k_1) = \mathbf{K}_p+\mathbf{K}_g$

$\mathbf{K}_2=(\omega_2, k_2) = \mathbf{K}_p-\mathbf{K}_g$

$\mathbf{K}_p=(\omega_p, k_p) = (\mathbf{K}_1+\mathbf{K}_2)/2$

$\mathbf{K}_g=(\omega_g, k_g) = (\mathbf{K}_1-\mathbf{K}_2)/2$

Geometric analysis of Bohr-Schrodinger "matter-wave"

➡ *Algebraic analysis of Bohr-Schrodinger "matter-wave"*

However, CW-paths require wave interference to make group and phase *zeros*. Space-time lattice points are real-zeros for *both* phase-factor *and* group-factor in Fig.5 (top half).

Algebraic Analysis of CW pair

Rel&Quant. Th. by R&C p.20

$$\text{Re}\ \textit{phase factor} = \cos\left(\frac{k_1+k_2}{2}x - \frac{\omega_1+\omega_2}{2}t\right) = 0 \Rightarrow k_{phase}x - \omega_{phase}t = n_{phase}^{(odd)}\frac{\pi}{2} \tag{6}$$

$$\text{Re}\ \textit{group factor} = \cos\left(\frac{k_1-k_2}{2}x - \frac{\omega_1-\omega_2}{2}t\right) = 0 \Rightarrow k_{group}x - \omega_{group}t = n_{group}^{(odd)}\frac{\pi}{2} \tag{7}$$

However, CW-paths require wave interference to make group and phase *zeros*. Space-time lattice points are real-zeros for *both* phase-factor *and* group-factor in Fig.5 (top half).

Algebraic Analysis of CW pair

Rel&Quant. Th. by R&C p.20

$$\text{Re}\, phase\ factor = \cos\left(\frac{k_1+k_2}{2}x - \frac{\omega_1+\omega_2}{2}t\right) = 0 \Rightarrow k_{phase}x - \omega_{phase}t = n_{phase}^{(odd)}\frac{\pi}{2} \quad (6)$$

$$\text{Re}\, group\ factor = \cos\left(\frac{k_1-k_2}{2}x - \frac{\omega_1-\omega_2}{2}t\right) = 0 \Rightarrow k_{group}x - \omega_{group}t = n_{group}^{(odd)}\frac{\pi}{2} \quad (7)$$

This is a matrix equation equating each phase $(kx - \omega t)$ to odd integers times $\pi/2$.

$$\begin{pmatrix} k_{phase} & -\omega_{phase} \\ k_{group} & -\omega_{group} \end{pmatrix} \begin{pmatrix} x \\ t \end{pmatrix} = \begin{pmatrix} n_{phase}^{(odd)} \\ n_{group}^{(odd)} \end{pmatrix} \frac{\pi}{2} \quad (8)$$

However, CW-paths require wave interference to make group and phase *zeros*. Space-time lattice points are real-zeros for *both* phase-factor *and* group-factor in Fig.5 (top half).

Algebraic Analysis of CW pair

Rel&Quant. Th. by R&C p.20

$$\text{Re}\ phase\ factor = \cos\left(\frac{k_1+k_2}{2}x - \frac{\omega_1+\omega_2}{2}t\right) = 0 \Rightarrow k_{phase}x - \omega_{phase}t = n_{phase}^{(odd)}\frac{\pi}{2} \quad (6)$$

$$\text{Re}\ group\ factor = \cos\left(\frac{k_1-k_2}{2}x - \frac{\omega_1-\omega_2}{2}t\right) = 0 \Rightarrow k_{group}x - \omega_{group}t = n_{group}^{(odd)}\frac{\pi}{2} \quad (7)$$

This is a matrix equation equating each phase $(kx - \omega t)$ to odd integers times $\pi/2$.

$$\begin{pmatrix} k_{phase} & -\omega_{phase} \\ k_{group} & -\omega_{group} \end{pmatrix}\begin{pmatrix} x \\ t \end{pmatrix} = \begin{pmatrix} n_{phase}^{(odd)} \\ n_{group}^{(odd)} \end{pmatrix}\frac{\pi}{2} \quad (8)$$

Matrix inverse gives (x, t) loci of the group-phase CW zero-path intersection lattice.

$$\begin{pmatrix} x \\ t \end{pmatrix} = \begin{pmatrix} -\omega_{group} & \omega_{phase} \\ -k_{group} & k_{phase} \end{pmatrix}\begin{pmatrix} n_{phase}^{(odd)} \\ n_{group}^{(odd)} \end{pmatrix}\frac{\pi}{2D} \quad (9)$$

Algebraic Analysis of CW pair

Rel&Quant. Th. by R&C p.20

However, CW-paths require wave interference to make group and phase *zeros*. Space-time lattice points are real-zeros for *both* phase-factor *and* group-factor in Fig.5 (top half).

$$\mathrm{Re}\; phase\; factor = \cos\left(\frac{k_1+k_2}{2}x - \frac{\omega_1+\omega_2}{2}t\right) = 0 \Rightarrow k_{phase}x - \omega_{phase}t = n_{phase}^{(odd)}\frac{\pi}{2} \quad (6)$$

$$\mathrm{Re}\; group\; factor = \cos\left(\frac{k_1-k_2}{2}x - \frac{\omega_1-\omega_2}{2}t\right) = 0 \Rightarrow k_{group}x - \omega_{group}t = n_{group}^{(odd)}\frac{\pi}{2} \quad (7)$$

This is a matrix equation equating each phase $(kx - \omega t)$ to odd integers times $\pi/2$.

$$\begin{pmatrix} k_{phase} & -\omega_{phase} \\ k_{group} & -\omega_{group} \end{pmatrix}\begin{pmatrix} x \\ t \end{pmatrix} = \begin{pmatrix} n_{phase}^{(odd)} \\ n_{group}^{(odd)} \end{pmatrix}\frac{\pi}{2} \quad (8)$$

Matrix inverse gives (x, t) loci of the group-phase CW zero-path intersection lattice.

$$\begin{pmatrix} x \\ t \end{pmatrix} = \begin{pmatrix} -\omega_{group} & \omega_{phase} \\ -k_{group} & k_{phase} \end{pmatrix}\begin{pmatrix} n_{phase}^{(odd)} \\ n_{group}^{(odd)} \end{pmatrix}\frac{\pi}{2D} \quad (9)$$

So group-phase lattice vectors are odd-integer multiples of $\mathbf{K}_{phase}$ or $\mathbf{K}_{group}$ and π/D .

$$\begin{pmatrix} x \\ t \end{pmatrix} = \frac{n_{group}^{(odd)}\pi}{D}\begin{pmatrix} \omega_{phase} \\ k_{phase} \end{pmatrix} - \frac{n_{phase}^{(odd)}\pi}{D}\begin{pmatrix} \omega_{group} \\ k_{group} \end{pmatrix} = \frac{\pi}{D}\left(n_{group}^{(odd)}\mathbf{K}_{phase} - n_{phase}^{(odd)}\mathbf{K}_{group}\right) \quad (10)$$

Matrix determinate D equals area spanned by CW lattice vectors $\mathbf{K}_{phase}$ and $\mathbf{K}_{group}$.

$$D = \left|\mathbf{K}_{phase} \times \mathbf{K}_{group}\right| = k_{group}\omega_{phase} - k_{phase}\omega_{group} = (\omega_1 k_2 - \omega_2 k_1)/2 \quad (11)$$

2. Geometric construction of wave-zero grids

→ *Continuous Wave (CW) grid based on* $\mathbf{K}_{phase}=(\mathbf{K}_a+\mathbf{K}_b)/2$ *and* $\mathbf{K}_{group}=(\mathbf{K}_a-\mathbf{K}_b)/2$ *vectors*

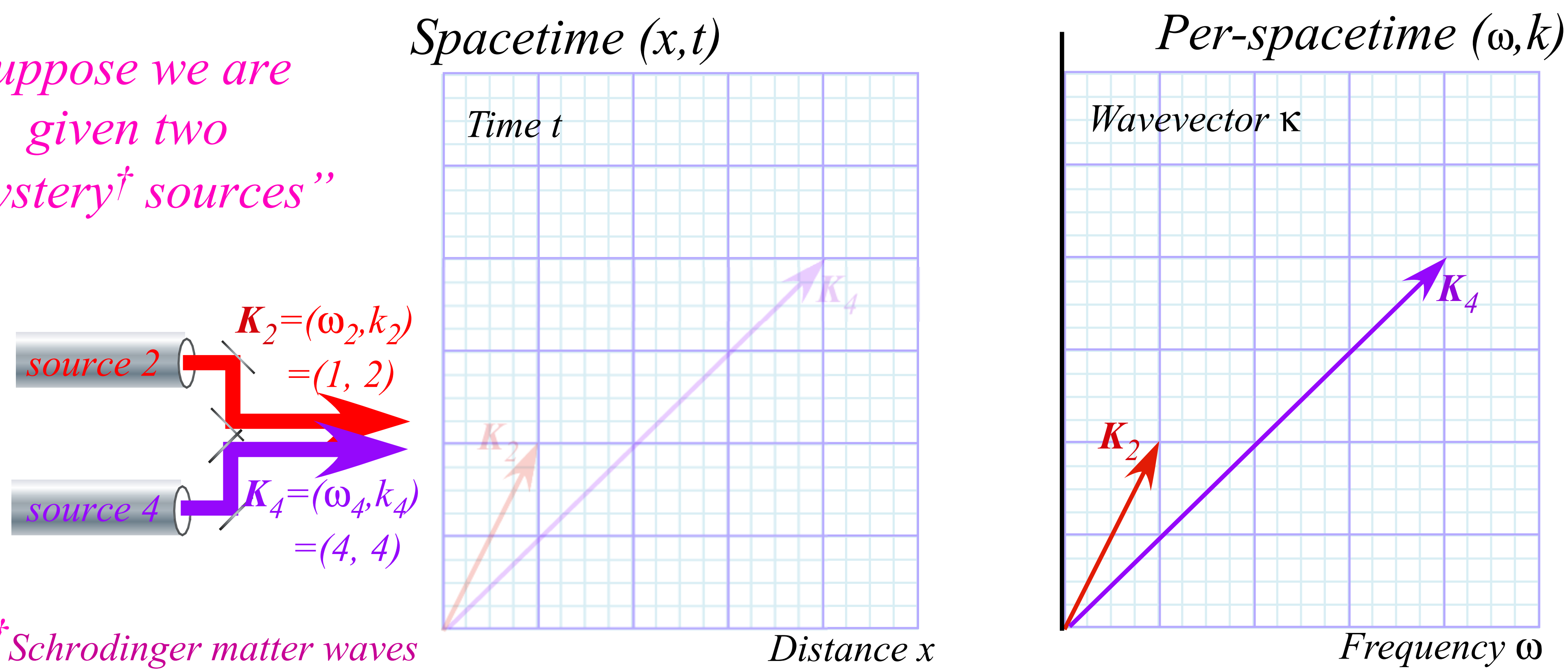
Pulse Wave (PW) grid based on primitive $\mathbf{K}_a=\mathbf{K}_{phase}+\mathbf{K}_{group}$ *and* $\mathbf{K}_b=\mathbf{K}_{phase}-\mathbf{K}_{group}$ *vectors*

When this doesn't work (When you don't need it!)

2-Wave Source: Unifying Trajectory-Space-time (x,t) and Fourier-Per-space-time (ω,k)

$$\psi_+ = e^{ia} + e^{ib} = e^{i\frac{a+b}{2}}\left(e^{i\frac{a-b}{2}} + e^{-i\frac{a-b}{2}}\right) = 2e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = 2(\cos\frac{a+b}{2} + i\sin\frac{a+b}{2})\cos\frac{a-b}{2}$$

Suppose we are given two "mystery† sources"



†Schrodinger matter waves

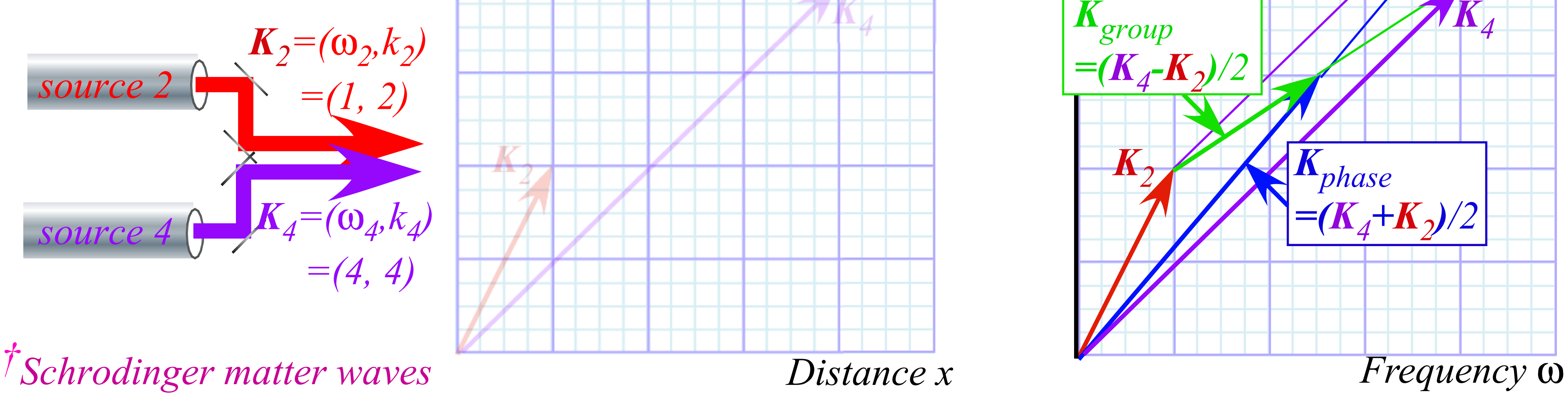
$$0 = \mathrm{Re}\,\psi_+ = \mathrm{Re}\,e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = \cos\frac{a+b}{2}\cos\frac{a-b}{2} = \cos\left(\frac{k_a+k_b}{2}x - \frac{\omega_a+\omega_b}{2}t\right)\cos\left(\frac{k_a-k_b}{2}x - \frac{\omega_a-\omega_b}{2}t\right)$$

$$= \cos\left(k_{phase}x - \omega_{phase}t\right)\cos\left(k_{group}x - \omega_{group}t\right)$$

2-Wave Source: Unifying Trajectory-Space-time (x,t) and Fourier-Per-space-time (ω,k)

$$\psi_+ = e^{ia} + e^{ib} = e^{i\frac{a+b}{2}}\left(e^{i\frac{a-b}{2}} + e^{-i\frac{a-b}{2}}\right) = 2e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = 2(\cos\frac{a+b}{2} + i\sin\frac{a+b}{2})\cos\frac{a-b}{2}$$

Suppose we are given two "mystery† sources"



†Schrodinger matter waves

$$0 = \mathrm{Re}\,\psi_+ = \mathrm{Re}\,e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = \cos\frac{a+b}{2}\cos\frac{a-b}{2} = \cos\left(\frac{k_a+k_b}{2}x - \frac{\omega_a+\omega_b}{2}t\right)\cos\left(\frac{k_a-k_b}{2}x - \frac{\omega_a-\omega_b}{2}t\right)$$

$$= \cos\left(k_{phase}x - \omega_{phase}t\right)\cos\left(k_{group}x - \omega_{group}t\right)$$

Space-time Reψ−zeros determined by:

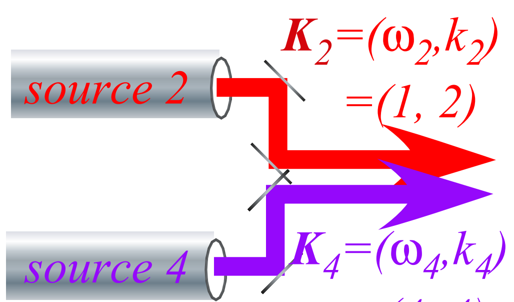
$k_{phase}x - \omega_{phase}t = m(\pi/2) \qquad m = \pm1, \pm3, \ldots$

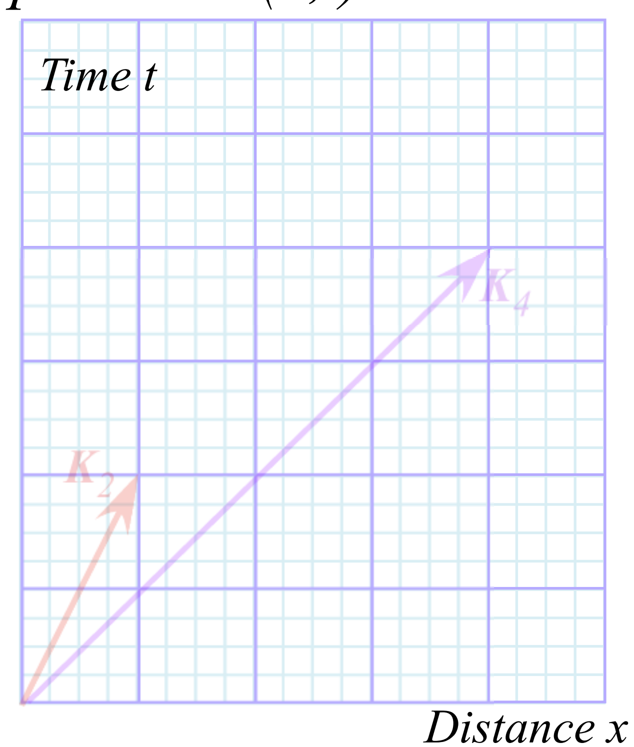
$k_{group}x - \omega_{group}t = n(\pi/2) \qquad n = \pm1, \pm3, \ldots$

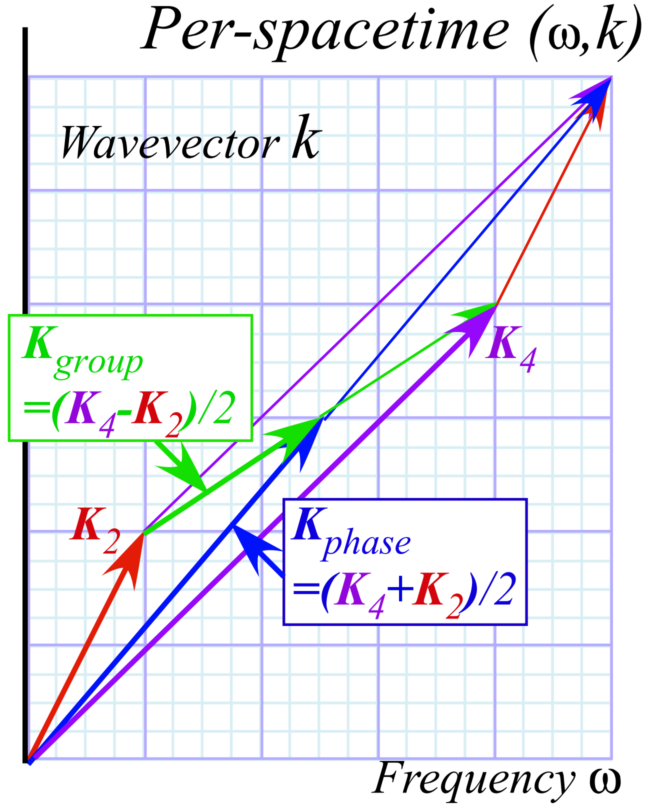
2-Wave Source: Unifying Trajectory-Space-time (x,t) and Fourier-Per-space-time (ω,k)

$$\psi_+ = e^{ia} + e^{ib} = e^{i\frac{a+b}{2}}\left(e^{i\frac{a-b}{2}} + e^{-i\frac{a-b}{2}}\right) = 2e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = 2(\cos\frac{a+b}{2} + i\sin\frac{a+b}{2})\cos\frac{a-b}{2}$$

Suppose we are given two "mystery† sources"







†Schrodinger matter waves

$$0 = \mathrm{Re}\,\psi_+ = \mathrm{Re}\,e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = \cos\frac{a+b}{2}\cos\frac{a-b}{2} = \cos\left(\frac{k_a+k_b}{2}x - \frac{\omega_a+\omega_b}{2}t\right)\cos\left(\frac{k_a-k_b}{2}x - \frac{\omega_a-\omega_b}{2}t\right)$$

$$= \cos\left(k_{phase}x - \omega_{phase}t\right)\cos\left(k_{group}x - \omega_{group}t\right)$$

Space-time Reψ−zeros determined by:

$$k_{phase}x - \omega_{phase}t = m(\pi/2) \qquad m = \pm1, \pm3, \ldots$$

$$k_{group}x - \omega_{group}t = n(\pi/2) \qquad n = \pm1, \pm3, \ldots$$

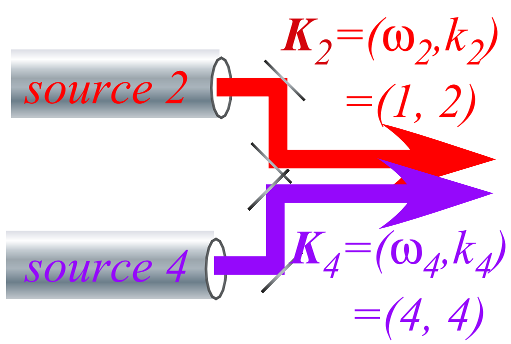
Matrix equation:

$$\begin{pmatrix} k_{phase} & -\omega_{phase} \\ k_{group} & -\omega_{group} \end{pmatrix}\begin{pmatrix} x \\ t \end{pmatrix} = \begin{pmatrix} m \\ n \end{pmatrix}\frac{\pi}{2}$$

2-Wave Source: Unifying Trajectory-Space-time (x,t) and Fourier-Per-space-time (ω,k)

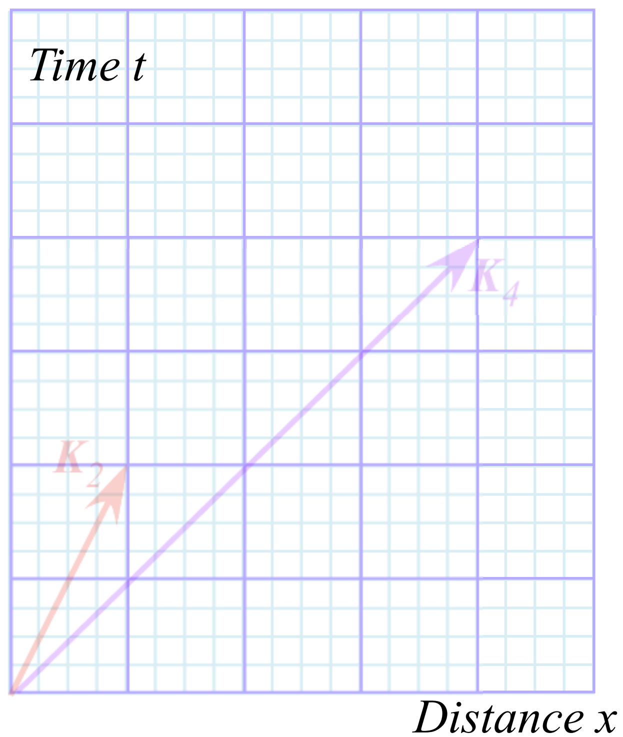
$$\psi_+ = e^{ia} + e^{ib} = e^{i\frac{a+b}{2}}\left(e^{i\frac{a-b}{2}} + e^{-i\frac{a-b}{2}}\right) = 2e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = 2\left(\cos\frac{a+b}{2} + i\sin\frac{a+b}{2}\right)\cos\frac{a-b}{2}$$

Suppose we are given two "mystery† sources"

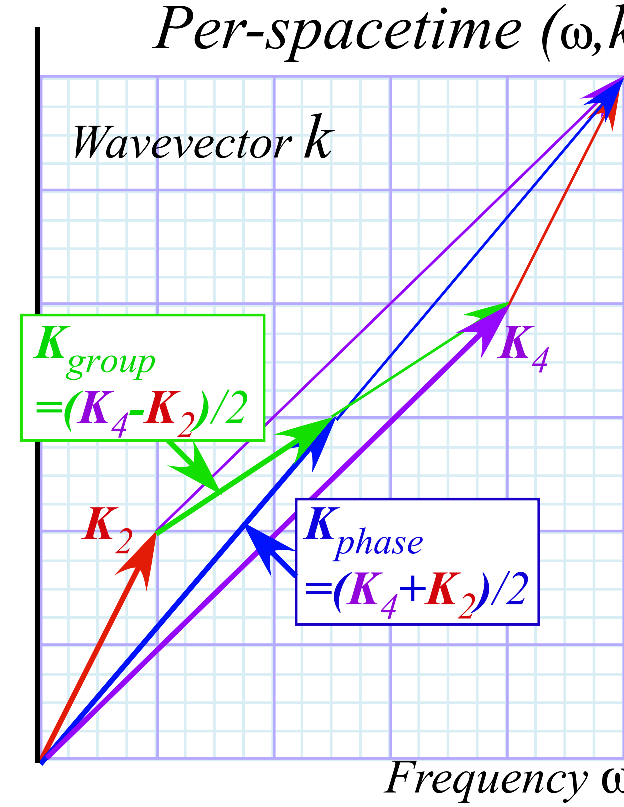


†*Schrodinger matter waves*

Spacetime (x,t)



Per-spacetime (ω,k)



$$0 = \mathrm{Re}\,\psi_+ = \mathrm{Re}\,e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = \cos\frac{a+b}{2}\cos\frac{a-b}{2} = \cos\left(\frac{k_a+k_b}{2}x - \frac{\omega_a+\omega_b}{2}t\right)\cos\left(\frac{k_a-k_b}{2}x - \frac{\omega_a-\omega_b}{2}t\right)$$

$$= \cos\left(k_{phase}x - \omega_{phase}t\right)\cos\left(k_{group}x - \omega_{group}t\right)$$

Space-time Reψ−zeros $\mathbf{X}_{m,n}$ *determined by:*

$$k_{phase}x - \omega_{phase}t = m(\pi/2) \qquad m = \pm1, \pm3, \ldots$$

$$k_{group}x - \omega_{group}t = n(\pi/2) \qquad n = \pm1, \pm3, \ldots$$

Matrix equation:

$$\begin{pmatrix} k_{phase} & -\omega_{phase} \\ k_{group} & -\omega_{group} \end{pmatrix}\begin{pmatrix} x \\ t \end{pmatrix} = \begin{pmatrix} m \\ n \end{pmatrix}\frac{\pi}{2}$$

Inverse matrix equation:

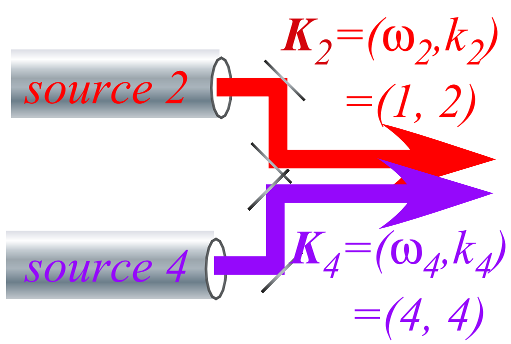
$$\begin{pmatrix} x_{m,n} \\ t_{m,n} \end{pmatrix} = \frac{\begin{pmatrix} \omega_{group} & -\omega_{phase} \\ k_{group} & -k_{phase} \end{pmatrix}}{\left|\omega_{group}k_{phase} - \omega_{phase}k_{group}\right|}\begin{pmatrix} m \\ n \end{pmatrix}\frac{\pi}{2}$$

$$\begin{pmatrix} x_{m,n} \\ t_{m,n} \end{pmatrix} = \mathbf{X}_{m,n} = \left[m\mathbf{K}_{group} - n\mathbf{K}_{phase}\right]s_{gp}$$

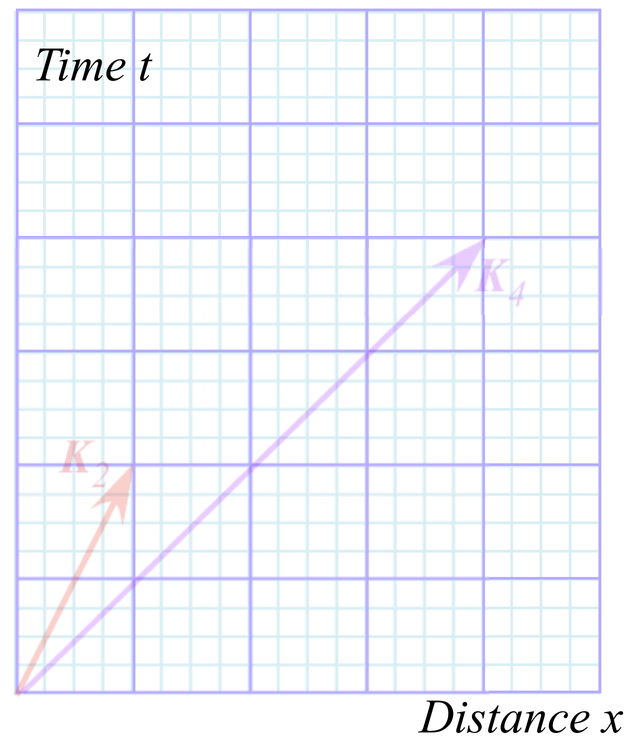
2-Wave Source: Unifying Trajectory-Space-time (x,t) and Fourier-Per-space-time (ω,k)

$$\psi_+ = e^{ia} + e^{ib} = e^{i\frac{a+b}{2}}\left(e^{i\frac{a-b}{2}} + e^{-i\frac{a-b}{2}}\right) = 2e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = 2\left(\cos\frac{a+b}{2} + i\sin\frac{a+b}{2}\right)\cos\frac{a-b}{2}$$

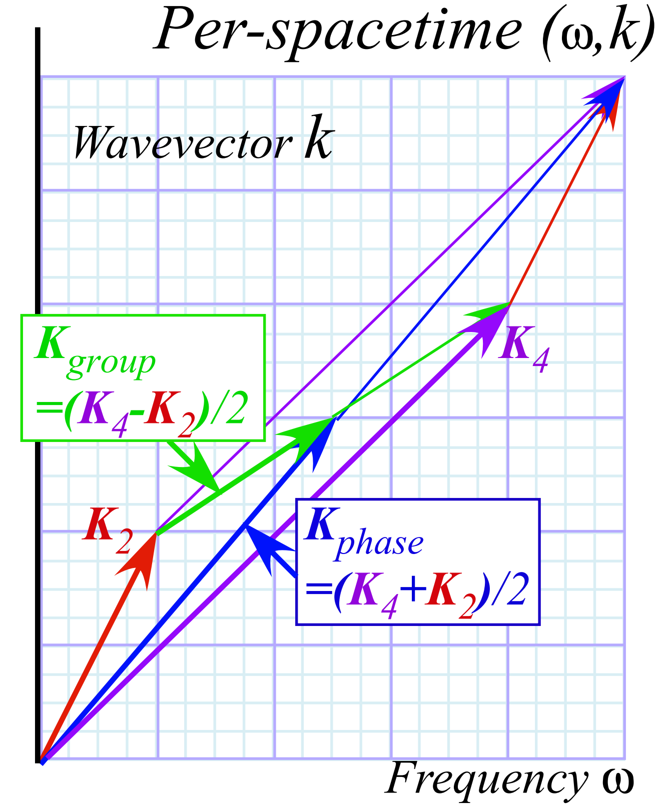
Suppose we are given two "mystery† sources"



Spacetime (x,t)



Per-spacetime (ω,k)



† Schrodinger matter waves

$$0 = \mathrm{Re}\,\psi_+ = \mathrm{Re}\,e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = \cos\frac{a+b}{2}\cos\frac{a-b}{2} = \cos\left(\frac{k_a+k_b}{2}x - \frac{\omega_a+\omega_b}{2}t\right)\cos\left(\frac{k_a-k_b}{2}x - \frac{\omega_a-\omega_b}{2}t\right)$$

$$= \cos\left(k_{phase}x - \omega_{phase}t\right)\cos\left(k_{group}x - \omega_{group}t\right)$$

Space-time Reψ−zeros $\mathbf{X}_{m,n}$ determined by:

$$k_{phase}x - \omega_{phase}t = m(\pi/2) \qquad m = \pm1,\pm3,\ldots$$

$$k_{group}x - \omega_{group}t = n(\pi/2) \qquad n = \pm1,\pm3,\ldots$$

Matrix equation:

$$\begin{pmatrix} k_{phase} & -\omega_{phase} \\ k_{group} & -\omega_{group} \end{pmatrix}\begin{pmatrix} x \\ t \end{pmatrix} = \begin{pmatrix} m \\ n \end{pmatrix}\frac{\pi}{2}$$

Inverse matrix equation:

$$\begin{pmatrix} x_{m,n} \\ t_{m,n} \end{pmatrix} = \frac{\begin{pmatrix} \omega_{group} & -\omega_{phase} \\ k_{group} & -k_{phase} \end{pmatrix}}{\left|\omega_{group}k_{phase} - \omega_{phase}k_{group}\right|}\begin{pmatrix} m \\ n \end{pmatrix}\frac{\pi}{2}$$

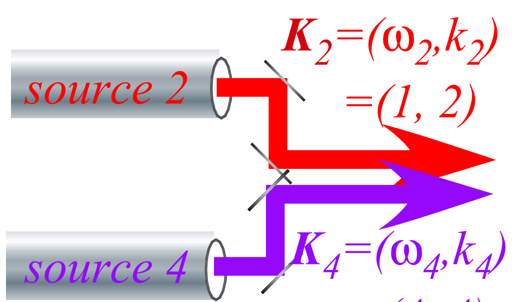
...and space-time scale factor: $s_{gp} = \dfrac{\pi}{2\left|\mathbf{K}_{group} \times \mathbf{K}_{phase}\right|}$

$$\begin{pmatrix} x_{m,n} \\ t_{m,n} \end{pmatrix} = \mathbf{X}_{m,n} = \left[m\mathbf{K}_{group} - n\mathbf{K}_{phase}\right]s_{gp}$$

2-Wave Source: Unifying Trajectory-Space-time (x,t) and Fourier-Per-space-time (ω,k)

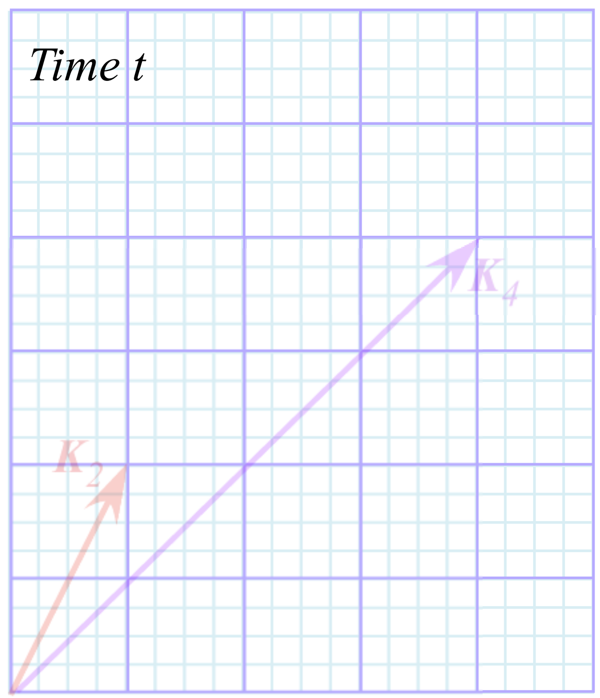
$$\psi_+ = e^{ia} + e^{ib} = e^{i\frac{a+b}{2}}\left(e^{i\frac{a-b}{2}} + e^{-i\frac{a-b}{2}}\right) = 2e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = 2\left(\cos\frac{a+b}{2} + i\sin\frac{a+b}{2}\right)\cos\frac{a-b}{2}$$

Suppose we are given two "mystery† sources"

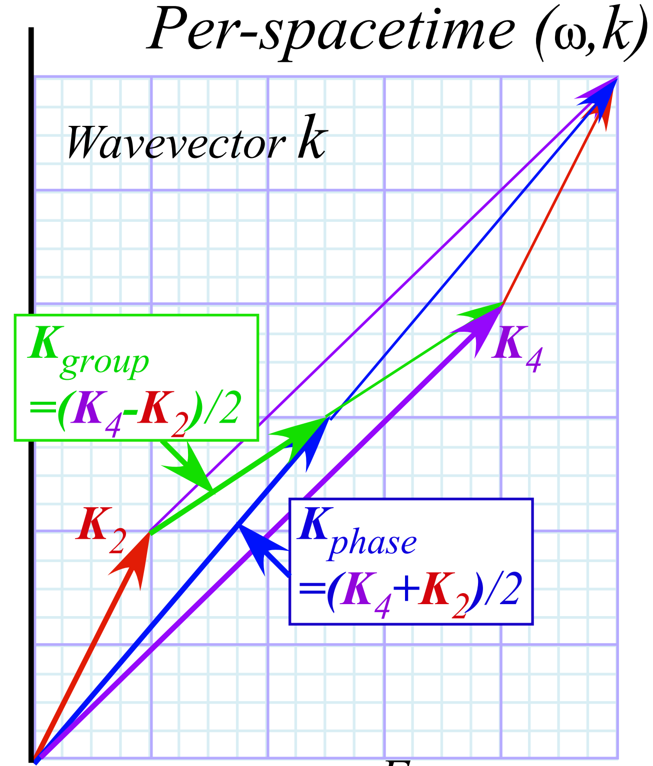


† Schrodinger matter waves

Spacetime (x,t)



Per-spacetime (ω,k)



$$0 = \mathrm{Re}\,\psi_+ = \mathrm{Re}\,e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = \cos\frac{a+b}{2}\cos\frac{a-b}{2} = \cos\left(\frac{k_a+k_b}{2}x - \frac{\omega_a+\omega_b}{2}t\right)\cos\left(\frac{k_a-k_b}{2}x - \frac{\omega_a-\omega_b}{2}t\right)$$

$$= \cos\left(k_{phase}x - \omega_{phase}t\right)\cos\left(k_{group}x - \omega_{group}t\right)$$

Space-time Reψ−zeros $\mathbf{X}_{m,n}$ determined by:

$$k_{phase}x - \omega_{phase}t = m(\pi/2) \qquad m = \pm1, \pm3, \ldots$$

$$k_{group}x - \omega_{group}t = n(\pi/2) \qquad n = \pm1, \pm3, \ldots$$

Matrix equation:

$$\begin{pmatrix} k_{phase} & -\omega_{phase} \\ k_{group} & -\omega_{group} \end{pmatrix}\begin{pmatrix} x \\ t \end{pmatrix} = \begin{pmatrix} m \\ n \end{pmatrix}\frac{\pi}{2}$$

Inverse matrix equation:

$$\begin{pmatrix} x_{m,n} \\ t_{m,n} \end{pmatrix} = \frac{\begin{pmatrix} \omega_{group} & -\omega_{phase} \\ k_{group} & -k_{phase} \end{pmatrix}}{\left|\omega_{group}k_{phase} - \omega_{phase}k_{group}\right|}\begin{pmatrix} m \\ n \end{pmatrix}\frac{\pi}{2}$$

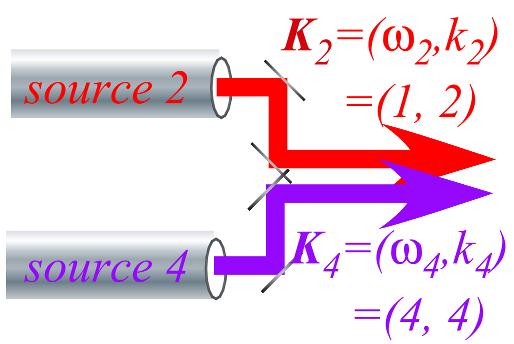
...and space-time scale factor: $s_{gp} = \dfrac{\pi}{2\left|\mathbf{K}_{group} \times \mathbf{K}_{phase}\right|} = \dfrac{\pi}{2\left|1.5\cdot3.0 - 2.5\cdot1.0\right|} = \dfrac{\pi}{4}$

$$\begin{pmatrix} x_{m,n} \\ t_{m,n} \end{pmatrix} = \mathbf{X}_{m,n} = \left[m\mathbf{K}_{group} - n\mathbf{K}_{phase}\right]s_{gp} \qquad m = \pm1, \pm3, \ldots \quad n = \pm1, \pm3, \ldots$$

2-Wave Source: Unifying Trajectory-Space-time (x,t) and Fourier-Per-space-time (ω,k)

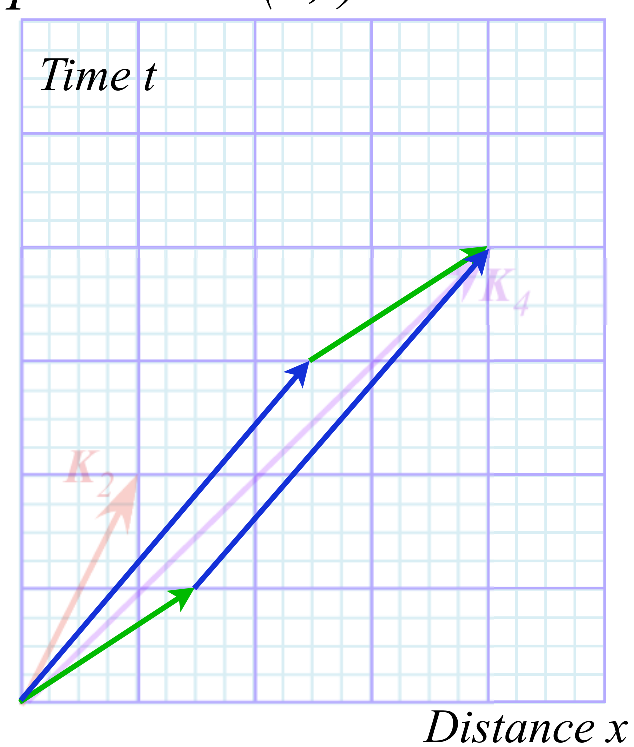
$$\psi_+ = e^{ia} + e^{ib} = e^{i\frac{a+b}{2}}\left(e^{i\frac{a-b}{2}} + e^{-i\frac{a-b}{2}}\right) = 2e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = 2(\cos\frac{a+b}{2} + i\sin\frac{a+b}{2})\cos\frac{a-b}{2}$$

Suppose we are given two "mystery† sources"

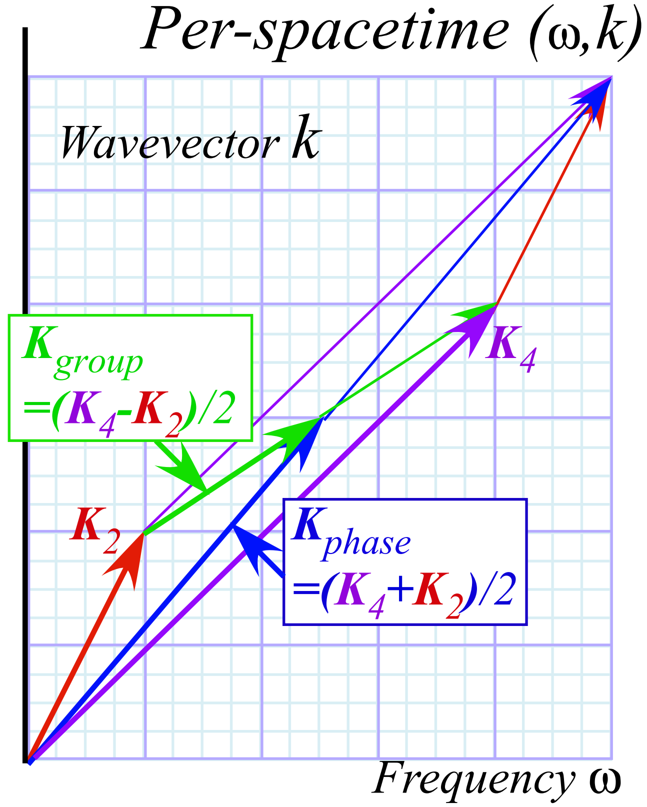


† Schrodinger matter waves

Spacetime (x,t)



Per-spacetime (ω,k)



$$0 = \mathrm{Re}\,\psi_+ = \mathrm{Re}\,e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = \cos\frac{a+b}{2}\cos\frac{a-b}{2} = \cos\left(\frac{k_a+k_b}{2}x - \frac{\omega_a+\omega_b}{2}t\right)\cos\left(\frac{k_a-k_b}{2}x - \frac{\omega_a-\omega_b}{2}t\right)$$

$$= \cos\left(k_{phase}x - \omega_{phase}t\right)\cos\left(k_{group}x - \omega_{group}t\right)$$

Space-time Reψ−zeros $\mathbf{X}_{m,n}$ determined by:

$$k_{phase}x - \omega_{phase}t = m(\pi/2) \qquad m = \pm1, \pm3, \ldots$$

$$k_{group}x - \omega_{group}t = n(\pi/2) \qquad n = \pm1, \pm3, \ldots$$

Matrix equation:

$$\begin{pmatrix} k_{phase} & -\omega_{phase} \\ k_{group} & -\omega_{group} \end{pmatrix}\begin{pmatrix} x \\ t \end{pmatrix} = \begin{pmatrix} m \\ n \end{pmatrix}\frac{\pi}{2}$$

Inverse matrix equation:

$$\begin{pmatrix} x_{m,n} \\ t_{m,n} \end{pmatrix} = \frac{\begin{pmatrix} \omega_{group} & -\omega_{phase} \\ k_{group} & -k_{phase} \end{pmatrix}}{\left|\omega_{group}k_{phase} - \omega_{phase}k_{group}\right|}\begin{pmatrix} m \\ n \end{pmatrix}\frac{\pi}{2}$$

...and space-time scale factor:

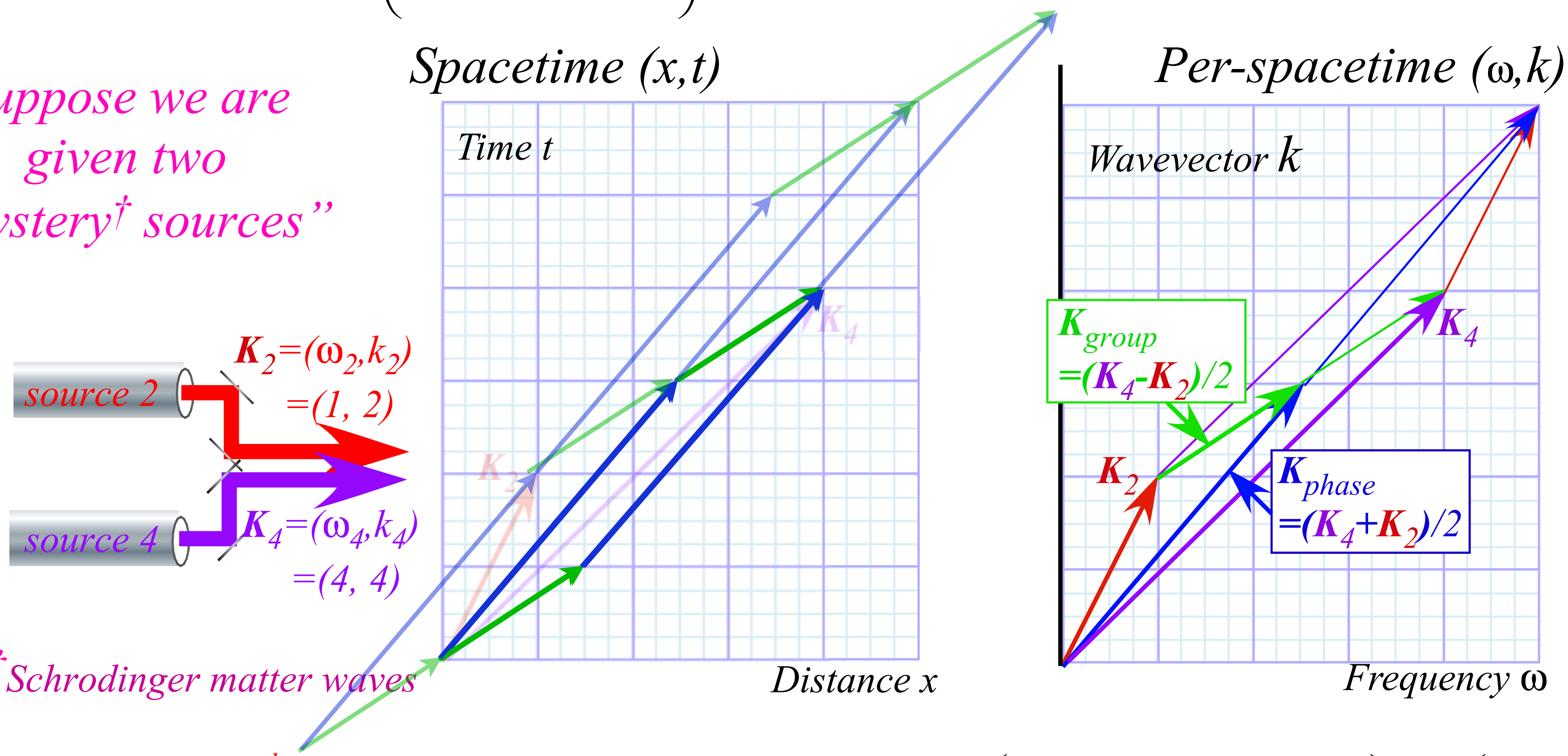
$$s_{gp} = \frac{\pi}{2\left|\mathbf{K}_{group} \times \mathbf{K}_{phase}\right|} = \frac{\pi}{2\left|1.5\cdot3.0 - 2.5\cdot1.0\right|} = \frac{\pi}{4}$$

$$\begin{pmatrix} x_{m,n} \\ t_{m,n} \end{pmatrix} = \mathbf{X}_{m,n} = \left[m\mathbf{K}_{group} - n\mathbf{K}_{phase}\right]s_{gp} \qquad \begin{matrix} m = \pm1, \pm3, \ldots \\ n = \pm1, \pm3, \ldots \end{matrix}$$

2-Wave Source: Unifying Trajectory-Space-time (x,t) and Fourier-Per-space-time (ω,k)

$$\psi_+ = e^{ia} + e^{ib} = e^{i\frac{a+b}{2}}\left(e^{i\frac{a-b}{2}} + e^{-i\frac{a-b}{2}}\right) = 2e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = 2(\cos\frac{a+b}{2} + i\sin\frac{a+b}{2})\cos\frac{a-b}{2}$$

Suppose we are given two "mystery† sources"



† Schrodinger matter waves

$$0 = \mathrm{Re}\,\psi_+ = \mathrm{Re}\,e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = \cos\frac{a+b}{2}\cos\frac{a-b}{2} = \cos\left(\frac{k_a+k_b}{2}x - \frac{\omega_a+\omega_b}{2}t\right)\cos\left(\frac{k_a-k_b}{2}x - \frac{\omega_a-\omega_b}{2}t\right)$$

$$= \cos\left(k_{phase}x - \omega_{phase}t\right)\cos\left(k_{group}x - \omega_{group}t\right)$$

Space-time Reψ−zeros $\mathbf{X}_{m,n}$ determined by:

$$k_{phase}x - \omega_{phase}t = m(\pi/2) \quad m = \pm1, \pm3, \ldots$$

$$k_{group}x - \omega_{group}t = n(\pi/2) \quad n = \pm1, \pm3, \ldots$$

Matrix equation:

$$\begin{pmatrix} k_{phase} & -\omega_{phase} \\ k_{group} & -\omega_{group} \end{pmatrix}\begin{pmatrix} x \\ t \end{pmatrix} = \begin{pmatrix} m \\ n \end{pmatrix}\frac{\pi}{2}$$

Inverse matrix equation:

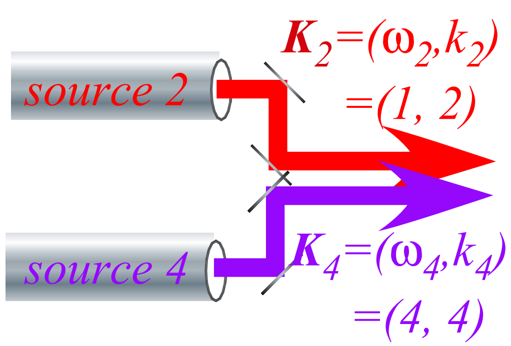
$$\begin{pmatrix} x_{m,n} \\ t_{m,n} \end{pmatrix} = \frac{\begin{pmatrix} \omega_{group} & -\omega_{phase} \\ k_{group} & -k_{phase} \end{pmatrix}}{\left|\omega_{group}k_{phase} - \omega_{phase}k_{group}\right|}\begin{pmatrix} m \\ n \end{pmatrix}\frac{\pi}{2}$$

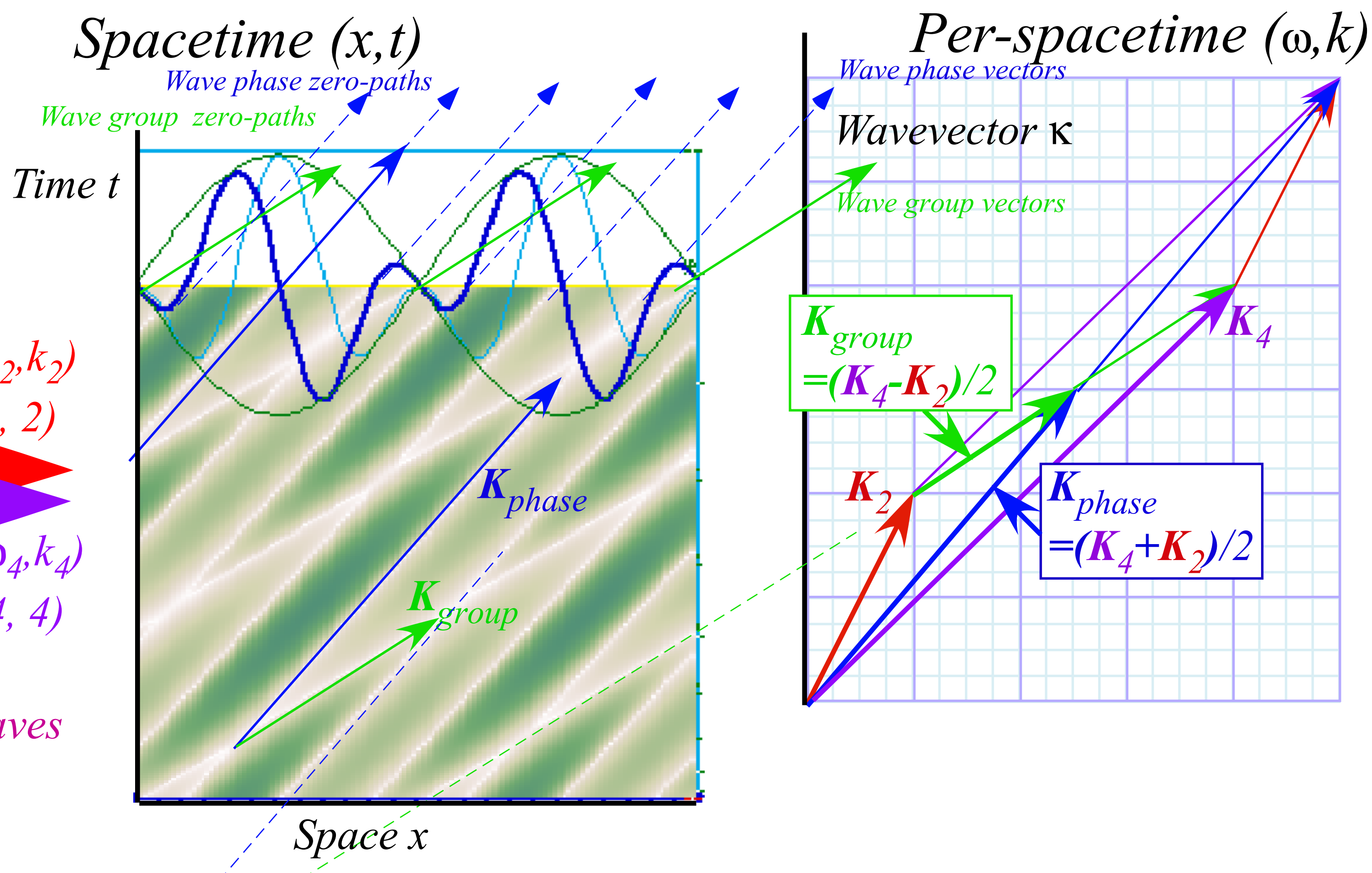
...and space-time scale factor: $s_{gp} = \dfrac{\pi}{2\left|\mathbf{K}_{group} \times \mathbf{K}_{phase}\right|} = \dfrac{\pi}{2\left|1.5\cdot3.0 - 2.5\cdot1.0\right|} = \dfrac{\pi}{4}$

$$\begin{pmatrix} x_{m,n} \\ t_{m,n} \end{pmatrix} = \mathbf{X}_{m,n} = \left[m\mathbf{K}_{group} - n\mathbf{K}_{phase}\right]s_{gp} \qquad m = \pm1, \pm3, \ldots \quad n = \pm1, \pm3, \ldots$$

2-Source Case: Unifying Trajectory-Spacetime (x,t) and Fourier-Per-spacetime (ω,k)

Suppose we are given two "mystery† sources"





†Shrodinger matter waves

Wave("coherent")Lattice(Bases: K_{group} and K_{phase})

The wave-interference-zero paths given by K-vectors (ω_g,k_g) and (ω_p,k_p) .

2. Geometric construction of wave-zero grids

Continuous Wave (CW) grid based on $\mathbf{K}_{phase}=(\mathbf{K}_a+\mathbf{K}_b)/2$ *and* $\mathbf{K}_{group}=(\mathbf{K}_a-\mathbf{K}_b)/2$ *vectors*

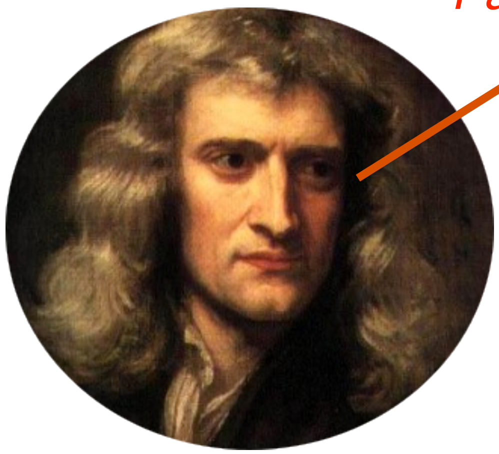
→ *Pulse Wave (PW) grid based on primitive* $\mathbf{K}_a=\mathbf{K}_{phase}+\mathbf{K}_{group}$ *and* $\mathbf{K}_b=\mathbf{K}_{phase}-\mathbf{K}_{group}$ *vectors*

When this doesn't work (When you don't need it!)

"Waves are illusory!"

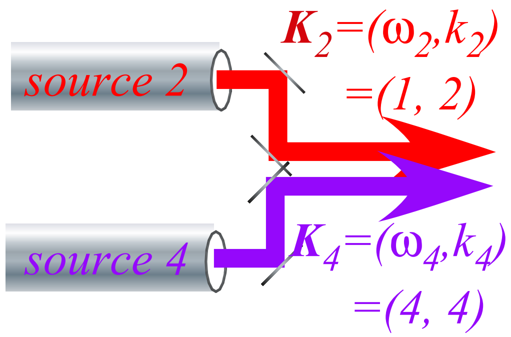
Corpuscles rule!

Pa-tooey!

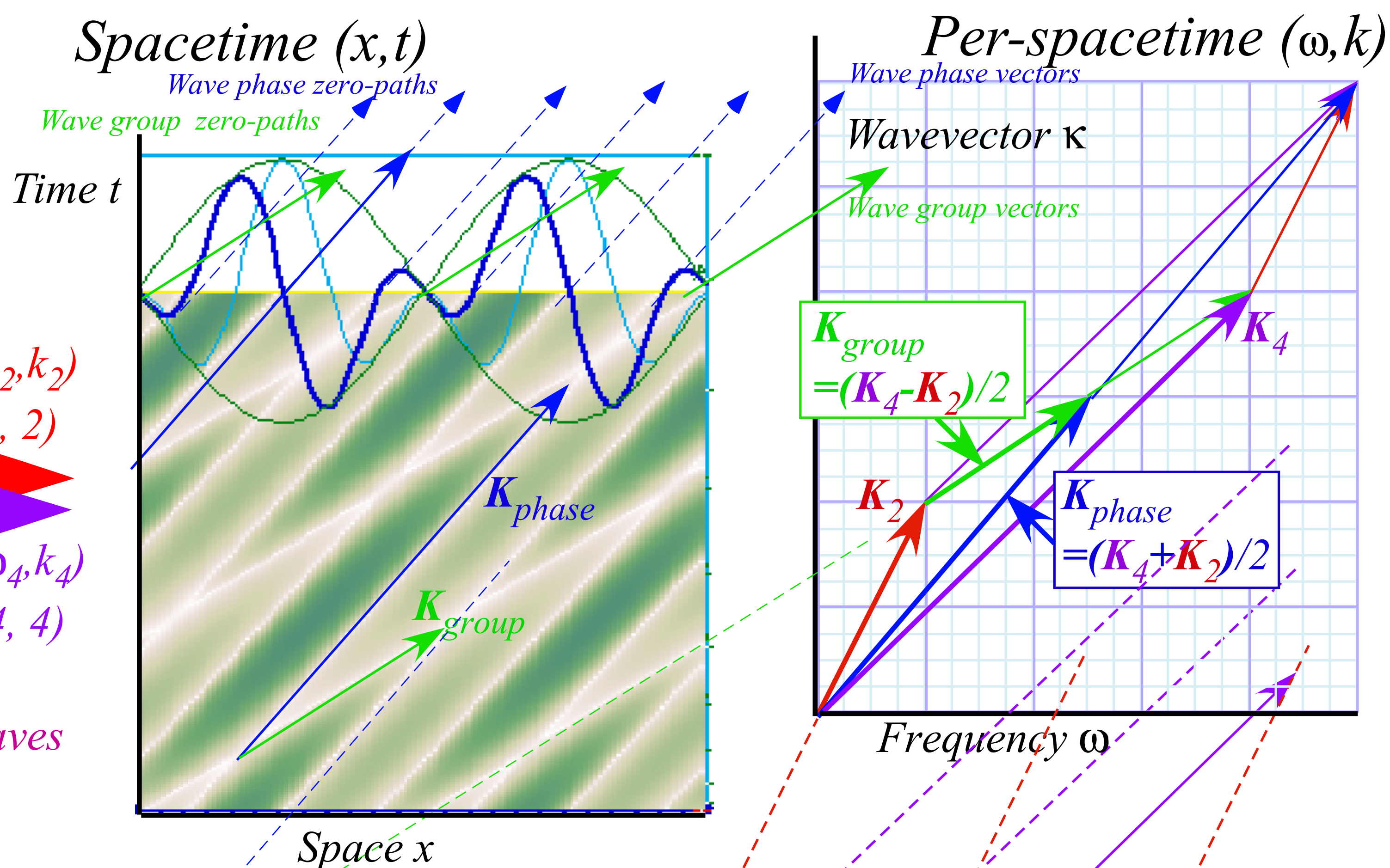


2-Source Case: Unifying Trajectory-Spacetime (x,t) and Fourier-Per-spacetime (ω,k)

Suppose we are given two "mystery† sources"

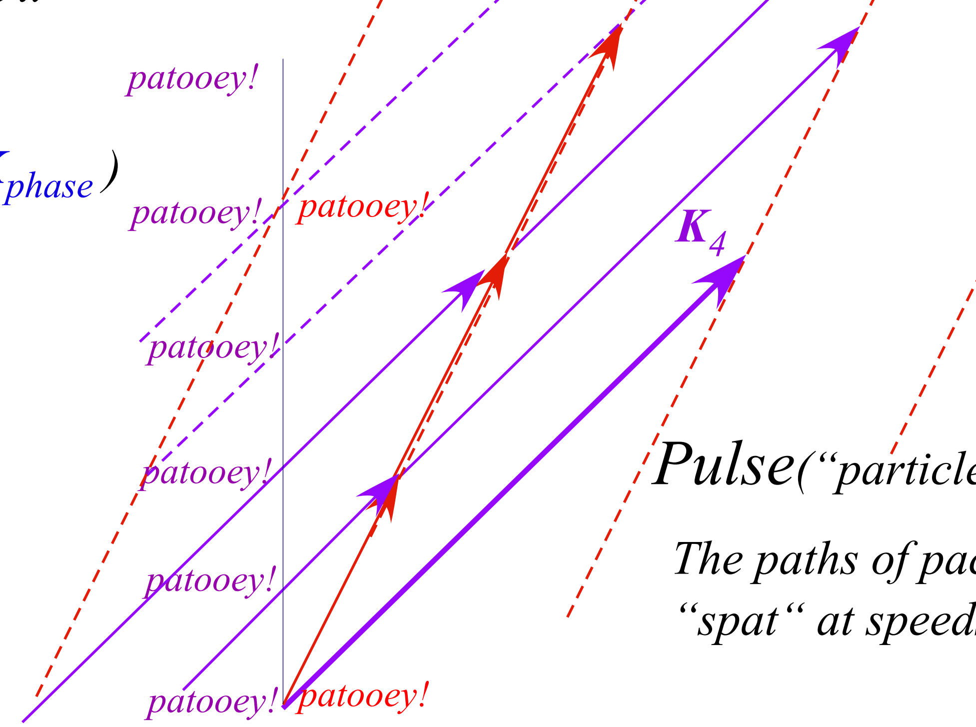


† Shrodinger matter waves

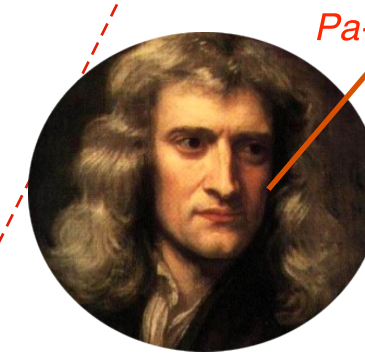


Wave("coherent")Lattice(Bases: K_{group} and K_{phase})

The wave-interference-zero paths given by K-vectors (ω_g,k_g) and (ω_p,k_p) .



"Waves are illusory!"
Corpuscles rule!
Pa-tooey!



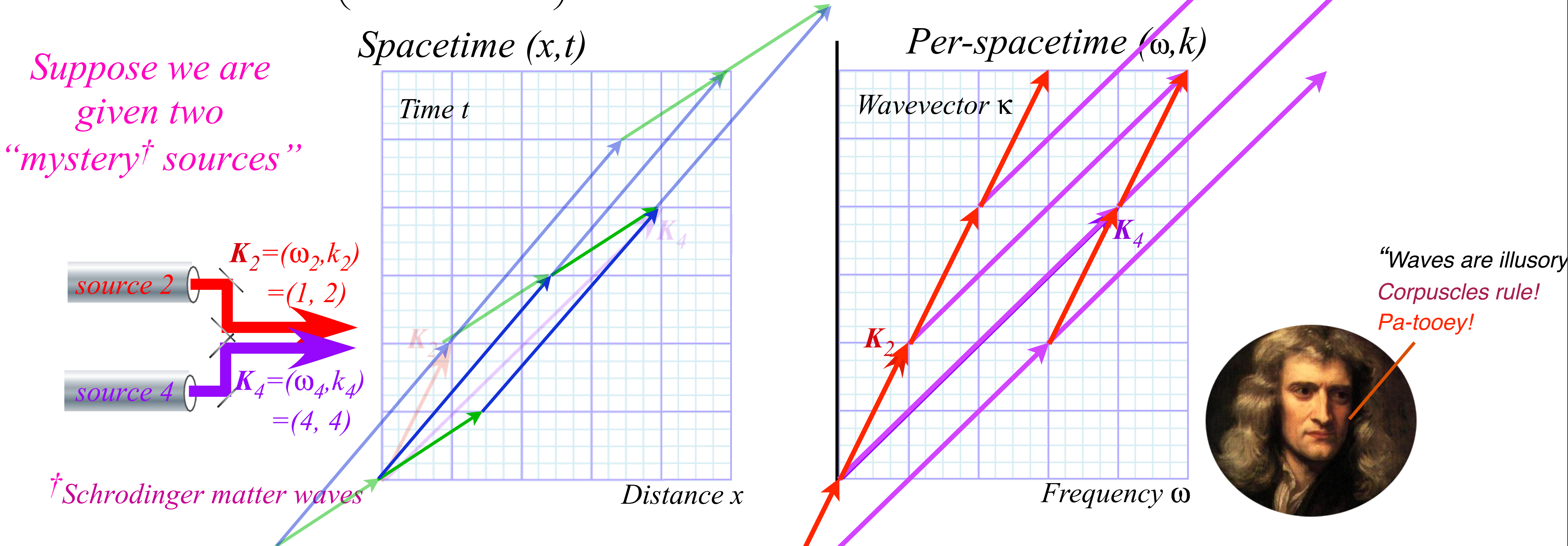
Pulse("particle")Lattice(Bases: K_2 and K_4)

The paths of packets or Newtonian "corpuscles" "spat" at speeds V_2 and V_4 and rates ω_2 and ω_2

patooey! patooey! patooey! patooey!
patooey! patooey! patooey!

2-Wave Source: Unifying Trajectory-Space-time (x,t) and Fourier-Per-space-time (ω,k)

$$\psi_+ = e^{ia} + e^{ib} = e^{i\frac{a+b}{2}}\left(e^{i\frac{a-b}{2}} + e^{-i\frac{a-b}{2}}\right) = 2e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = 2\left(\cos\frac{a+b}{2} + i\sin\frac{a+b}{2}\right)\cos\frac{a-b}{2}$$



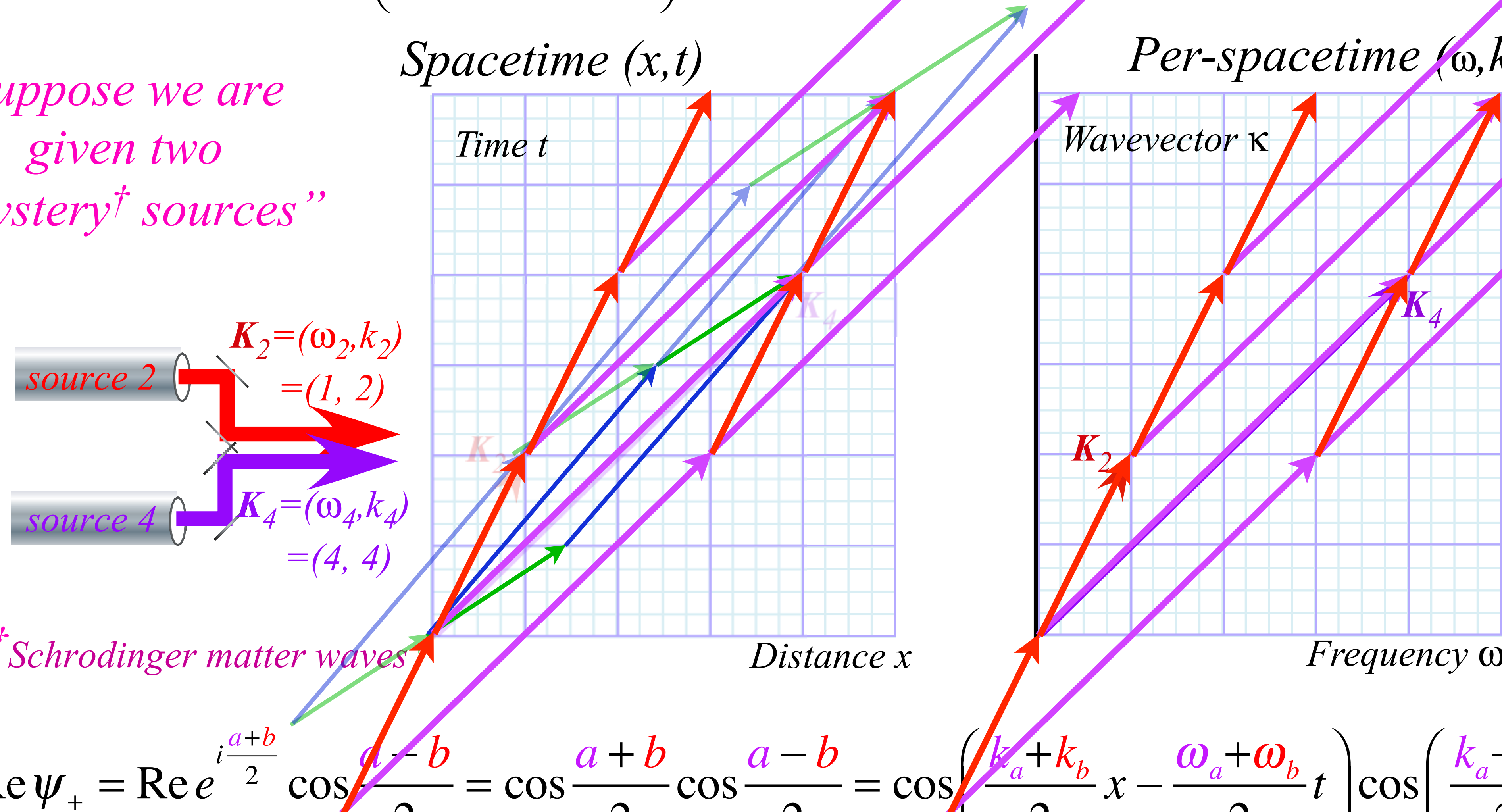
$$0 = \mathrm{Re}\,\psi_+ = \mathrm{Re}\,e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = \cos\frac{a+b}{2}\cos\frac{a-b}{2} = \cos\left(\frac{k_a+k_b}{2}x - \frac{\omega_a+\omega_b}{2}t\right)\cos\left(\frac{k_a-k_b}{2}x - \frac{\omega_a-\omega_b}{2}t\right)$$

$$= \cos\left(k_{phase}x - \omega_{phase}t\right)\cos\left(k_{group}x - \omega_{group}t\right)$$

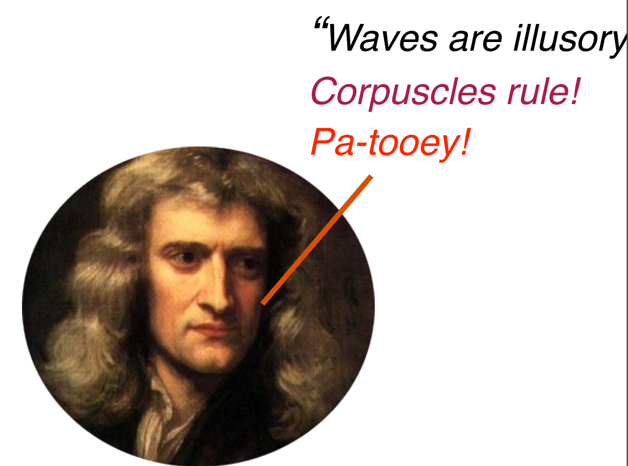
2-Wave Source: Unifying Trajectory-Space-time (x,t) and Fourier-Per-space-time (ω,k)

$$\psi_+ = e^{ia} + e^{ib} = e^{i\frac{a+b}{2}}\left(e^{i\frac{a-b}{2}} + e^{-i\frac{a-b}{2}}\right) = 2e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = 2(\cos\frac{a+b}{2} + i\sin\frac{a+b}{2})\cos\frac{a-b}{2}$$

Suppose we are given two "mystery† sources"

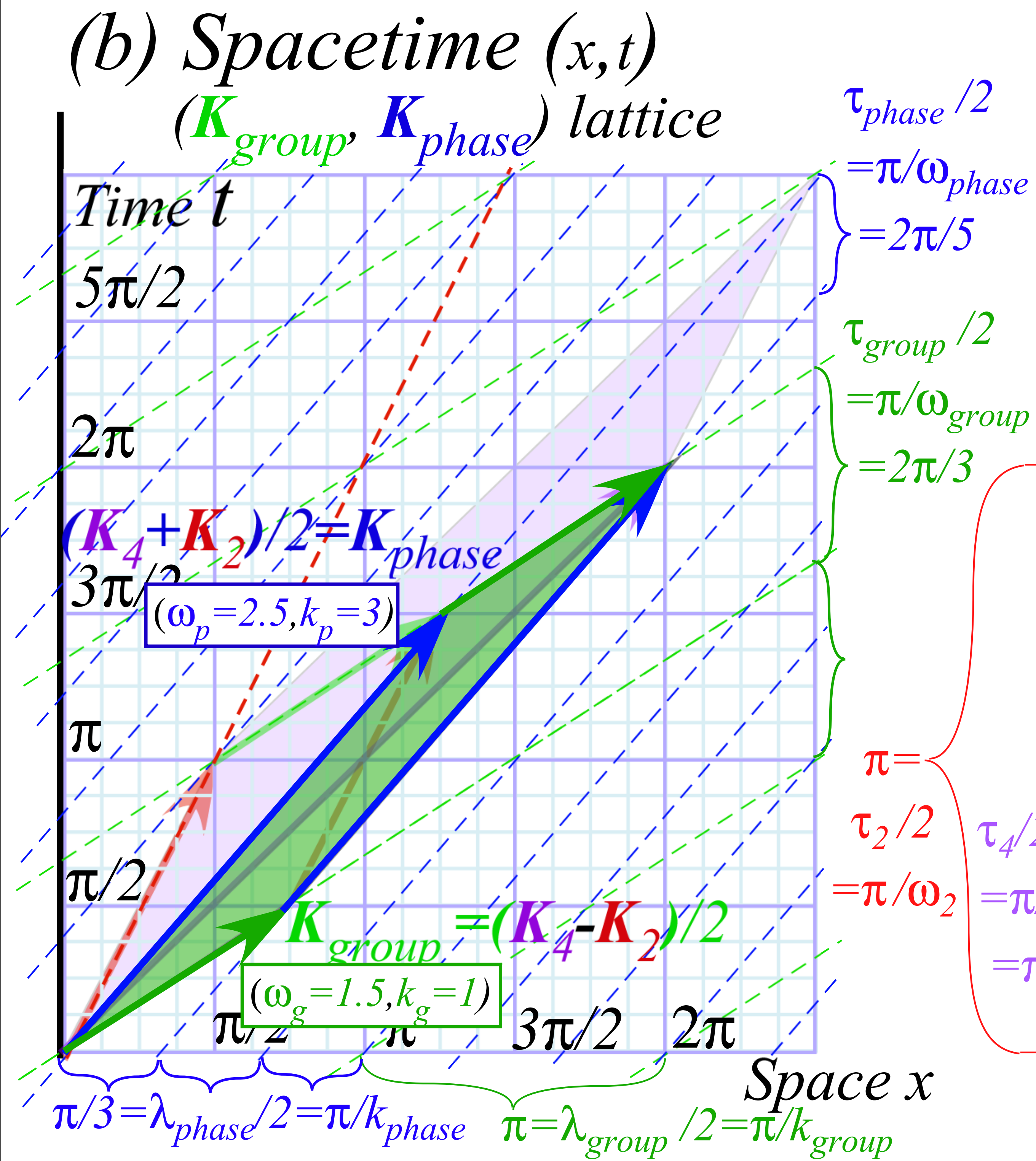


†Schrodinger matter waves

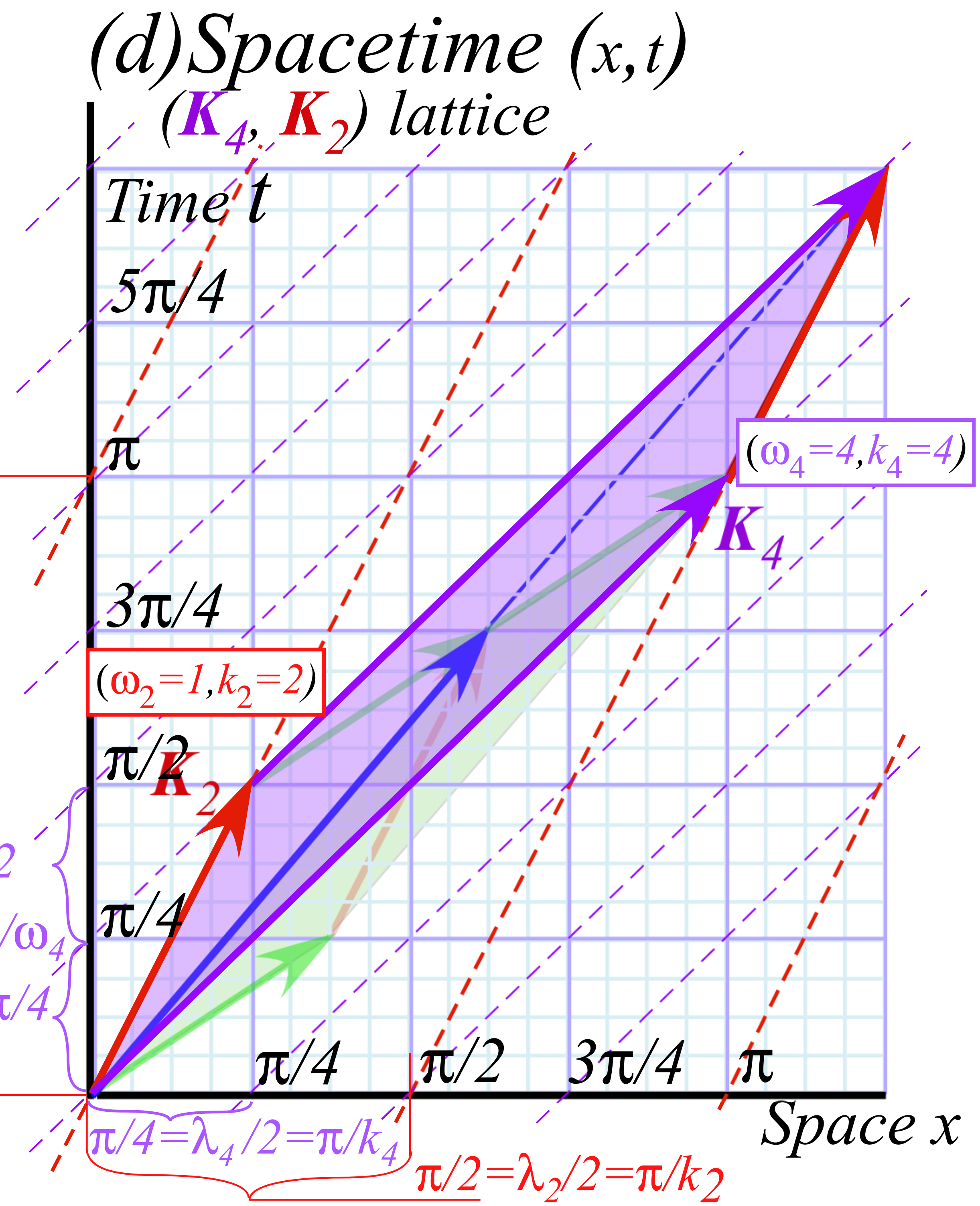


$$0 = \mathrm{Re}\,\psi_+ = \mathrm{Re}\,e^{i\frac{a+b}{2}}\cos\frac{a-b}{2} = \cos\frac{a+b}{2}\cos\frac{a-b}{2} = \cos\left(\frac{k_a+k_b}{2}x - \frac{\omega_a+\omega_b}{2}t\right)\cos\left(\frac{k_a-k_b}{2}x - \frac{\omega_a-\omega_b}{2}t\right)$$

$$= \cos\left(k_{phase}x - \omega_{phase}t\right)\cos\left(k_{group}x - \omega_{group}t\right)$$



(b) Spacetime (x,t)
(K_{group}, K_{phase}) lattice
Time t
5π/2
2π
3π/2
π
π/2
π/2
π
3π/2
2π
Space x
$\tau_{phase}/2$
$=\pi/\omega_{phase}$
$=2\pi/5$
$\tau_{group}/2$
$=\pi/\omega_{group}$
$=2\pi/3$
$(K_4+K_2)/2=K_{phase}$
$(\omega_p=2.5,k_p=3)$
$K_{group}=(K_4-K_2)/2$
$(\omega_g=1.5,k_g=1)$
$\pi/3=\lambda_{phase}/2=\pi/k_{phase}$
$\pi=\lambda_{group}/2=\pi/k_{group}$



(d)Spacetime (x,t)
(K_4, K_2) lattice
Time t
5π/4
π
3π/4
π/2
π/4
π/4
π/2
3π/4
π
Space x
$(\omega_4=4,k_4=4)$
K_4
$(\omega_2=1,k_2=2)$
K_2
$\pi=$
$\tau_2/2$
$=\pi/\omega_2$
$\tau_4/2$
$=\pi/\omega_4$
$=\pi/4$
$\pi/4=\lambda_4/2=\pi/k_4$
$\pi/2=\lambda_2/2=\pi/k_2$

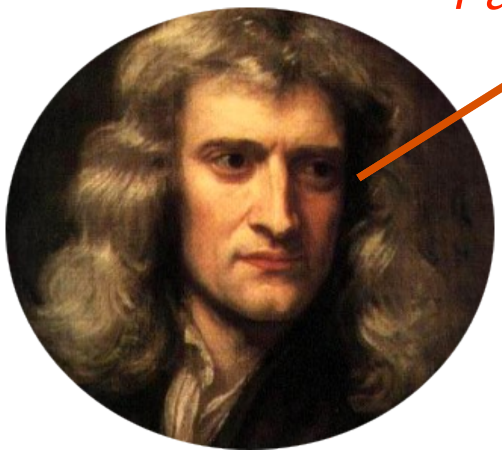
2. Geometric construction of wave-zero grids

Continuous Wave (CW) grid based on $\mathbf{K}_{phase}=(\mathbf{K}_a+\mathbf{K}_b)/2$ *and* $\mathbf{K}_{group}=(\mathbf{K}_a-\mathbf{K}_b)/2$ *vectors*

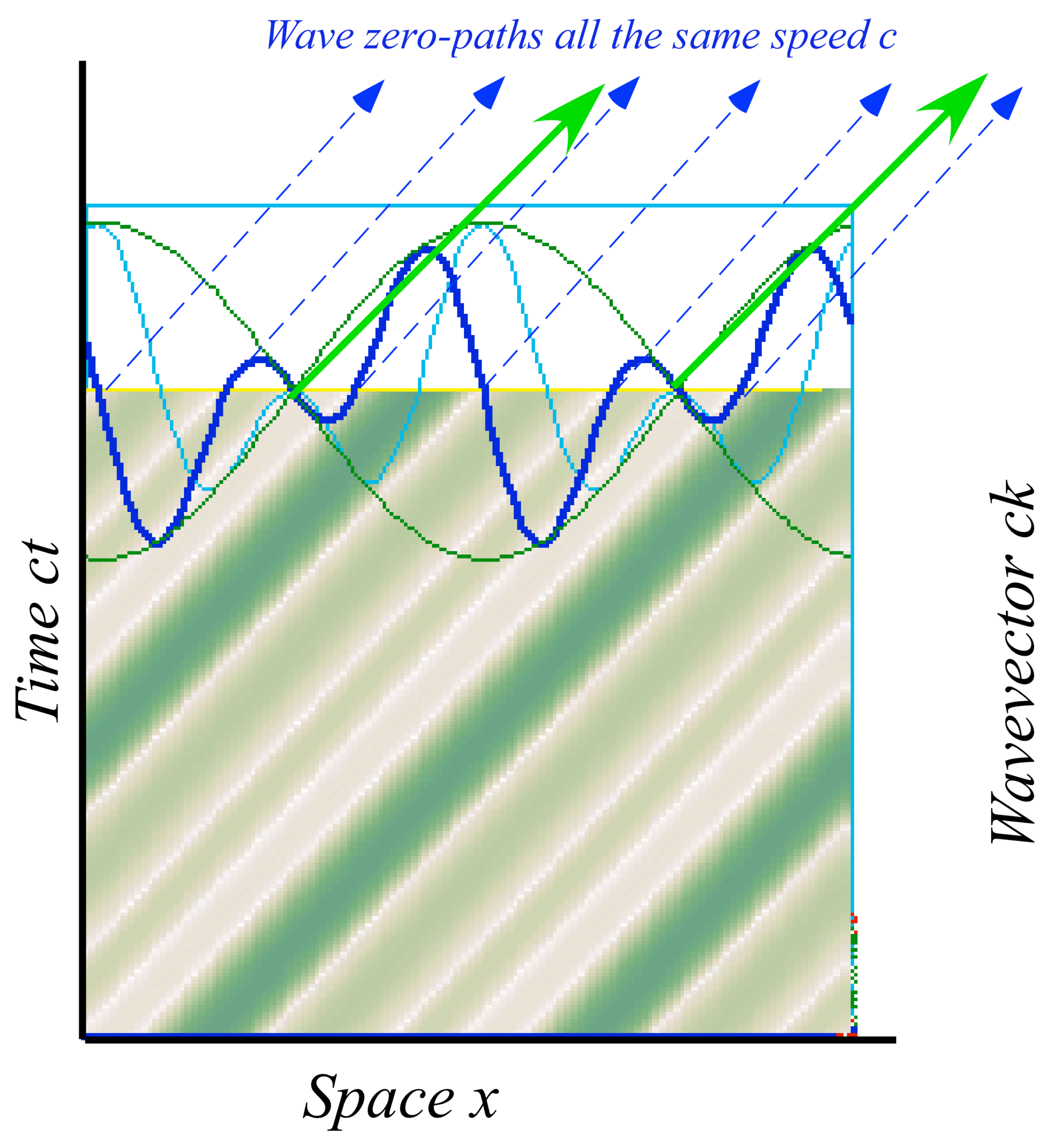
Pulse Wave (PW) grid based on primitive $\mathbf{K}_a=\mathbf{K}_{phase}+\mathbf{K}_{group}$ *and* $\mathbf{K}_b=\mathbf{K}_{phase}-\mathbf{K}_{group}$ *vectors*

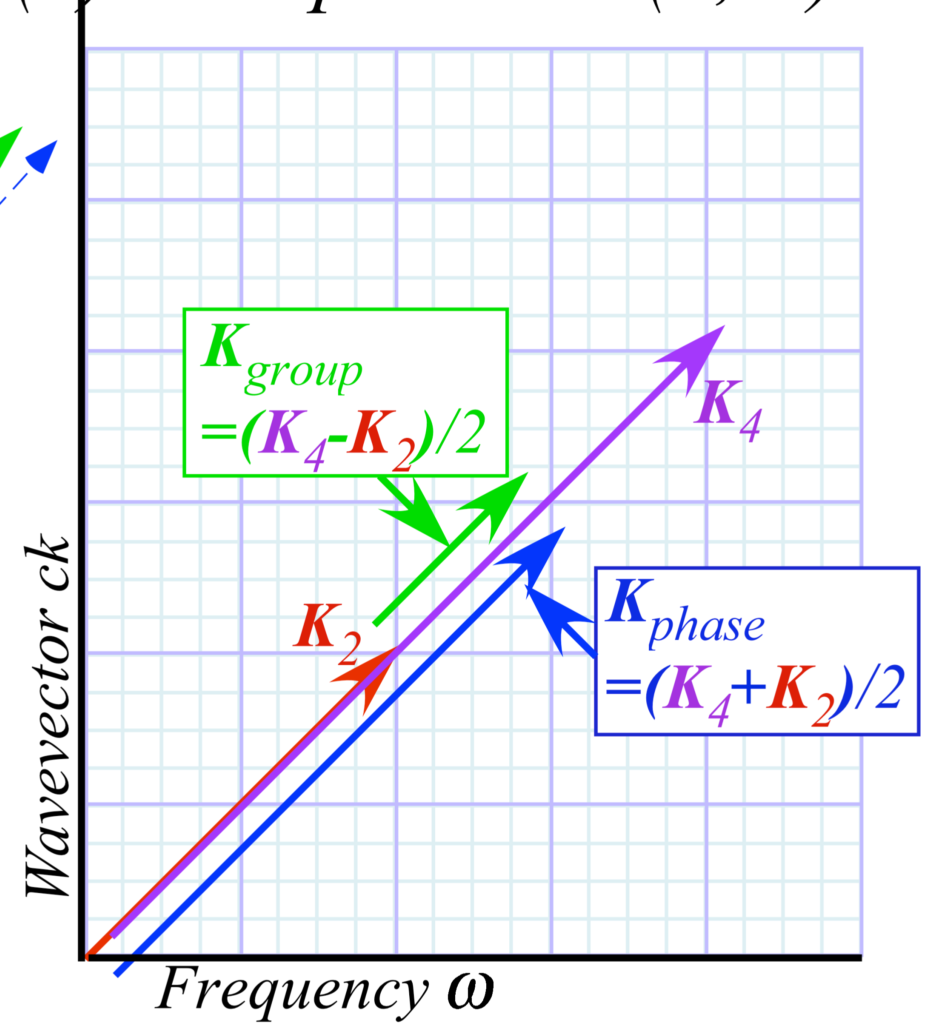
→ *When this doesn't work* *(When you don't need it!)*

"Waves are illusory!"
Corpuscles rule!
Pa-tooey!



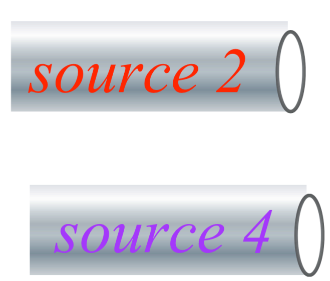
(a) Spacetime (x,ct)   (b) Per-spacetime (ω,ck)



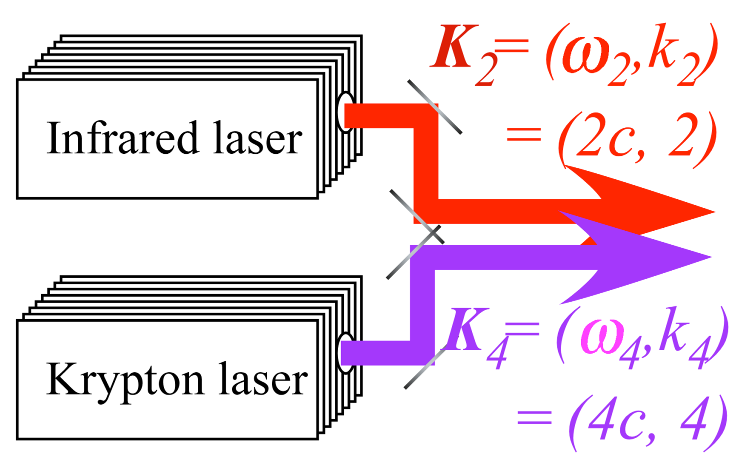


What happens when the grid area $\mathbf{K}_{group} \times \mathbf{K}_{phase}$ is ZERO:

$$s_{gp} = \frac{\pi}{2\left|\mathbf{K}_{group} \times \mathbf{K}_{phase}\right|} = \infty$$



Replaced by:



...But, if you collide the beams Head-On...

3. Beginning wave relativity

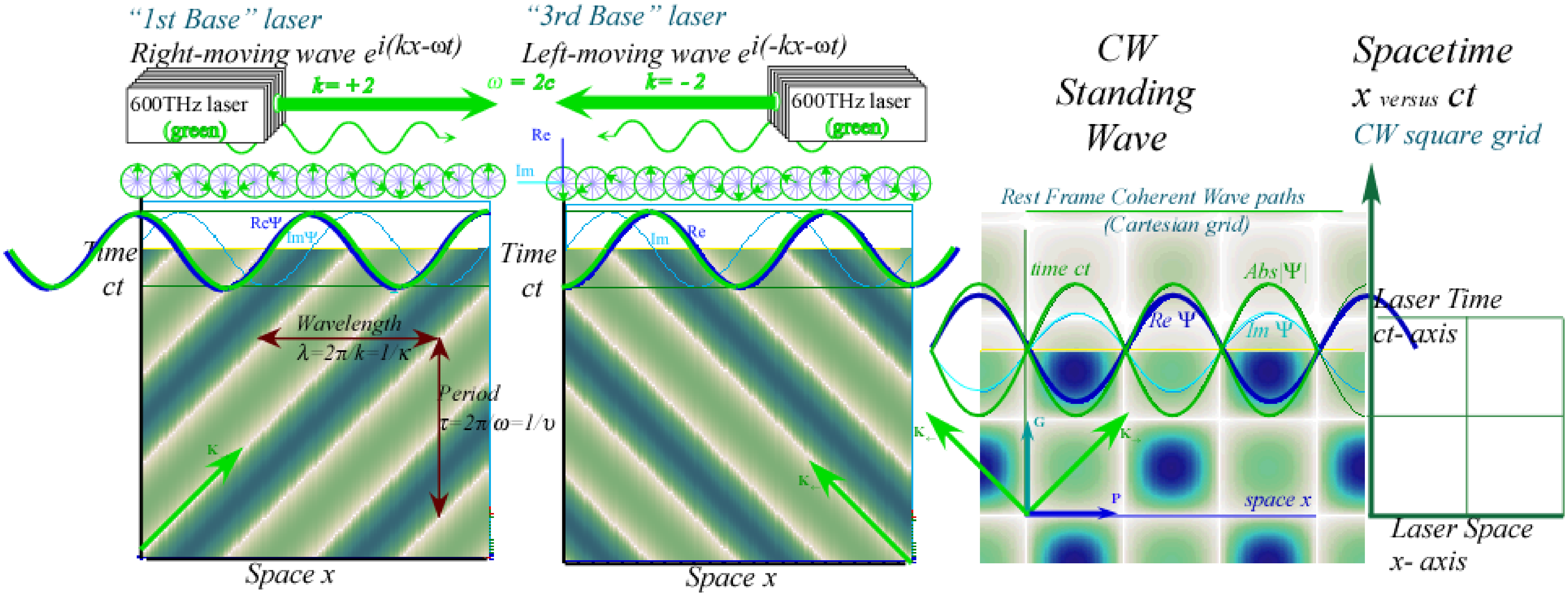
Dueling lasers make lab frame space-time grid (CW or PW)

Einstein PW Axioms versus Evenson CW Axioms (Occam at Work)

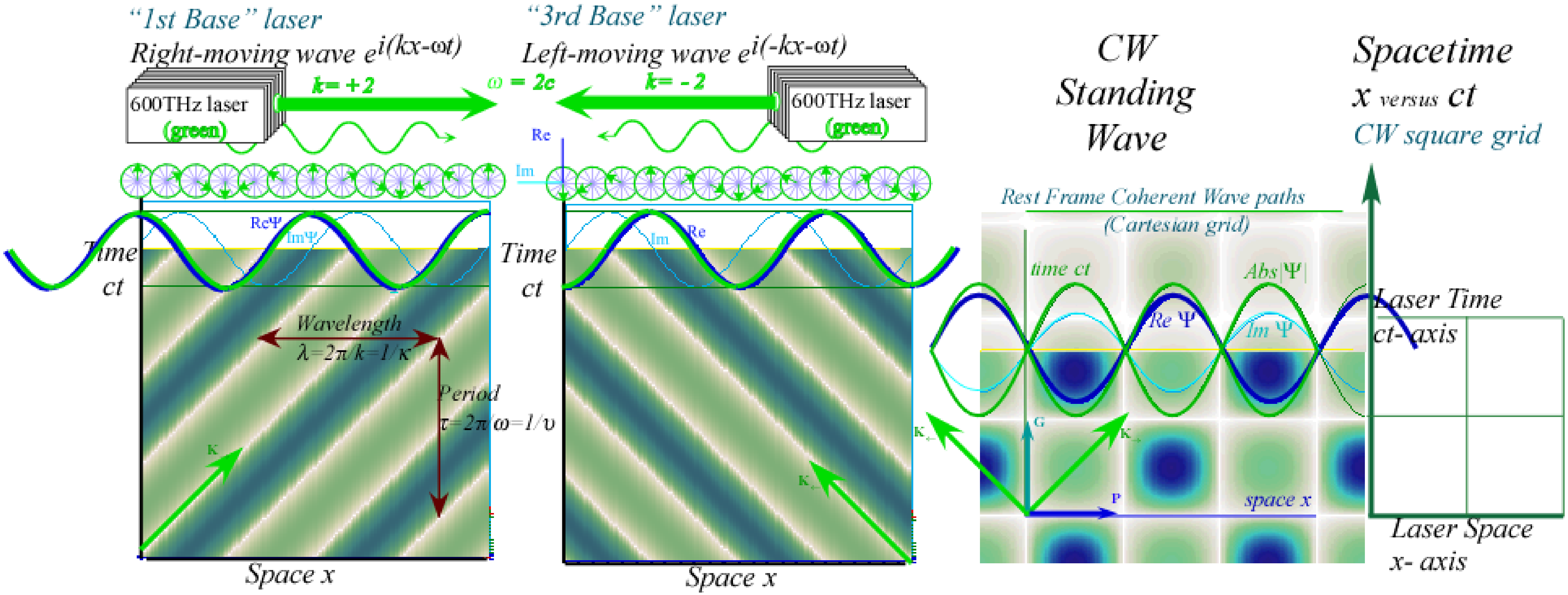
Only CW light clearly shows Doppler shift

Dueling lasers make lab frame space-time grid

Zeros of head-on CW sum gives (x,ct)-grid



Zeros of head-on CW sum gives (x,ct)-grid



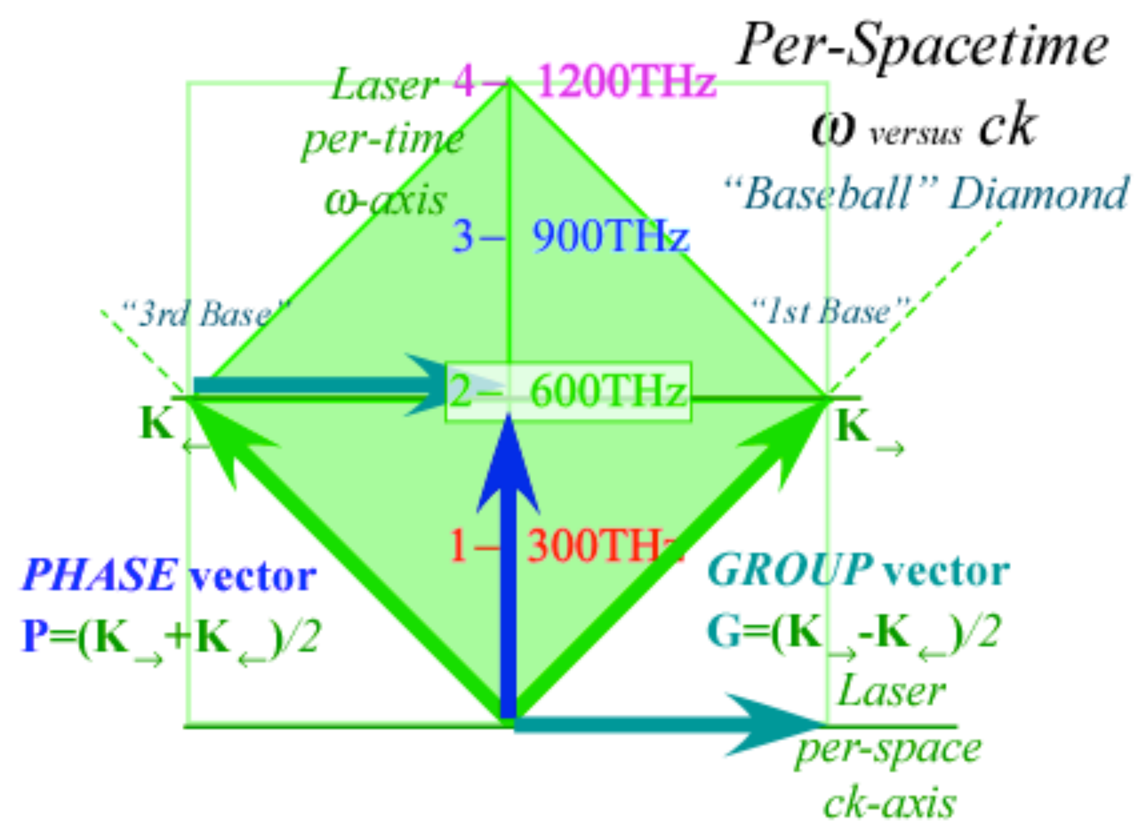
Find zeros by factoring sum:

$$\Psi = \overbrace{e^{ia}}^{(kx-\omega t)} + \overbrace{e^{ib}}^{(-kx-\omega t)}$$

$$= \underbrace{e^{i(a+b)/2}}_{\text{Phase factor:}} \underbrace{\left(e^{i(a-b)/2} + e^{-i(a-b)/2}\right)}_{\text{Group factor:}}$$

Phase factor: $\exp i\left(\frac{a+b}{2}\right) = e^{-i\omega t}$

Group factor: $2\cos\left(\frac{a-b}{2}\right) = 2\cos(kx)$

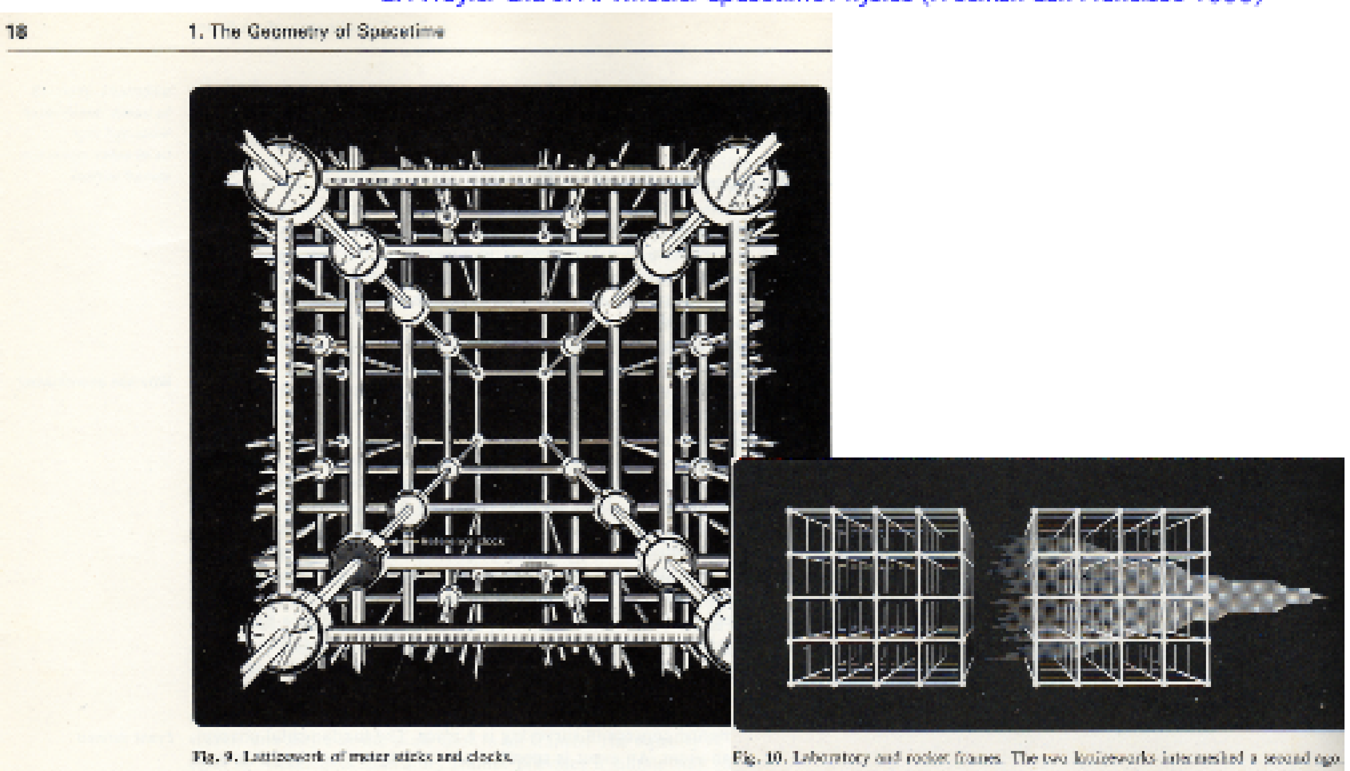


• Optical wave coordinate manifolds and frames

Shining some light on light using complex phasor analysis

Old-fashioned meter-stick-clock frames

E. F.Taylor and J. A. Wheeler Spacetime Physics (Freeman San Francisco 1966)



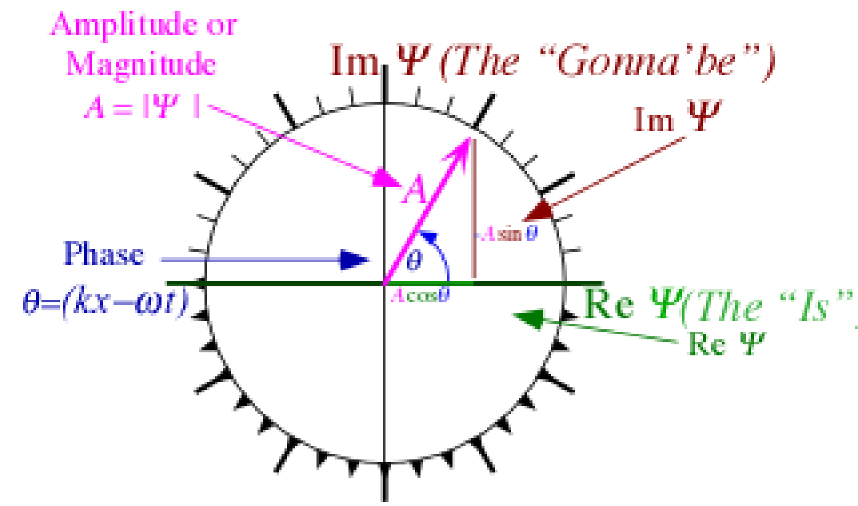
New-fashioned laser clocks & meter sticks

Complex Phasor Clocks : Tesla's AC "phasor"

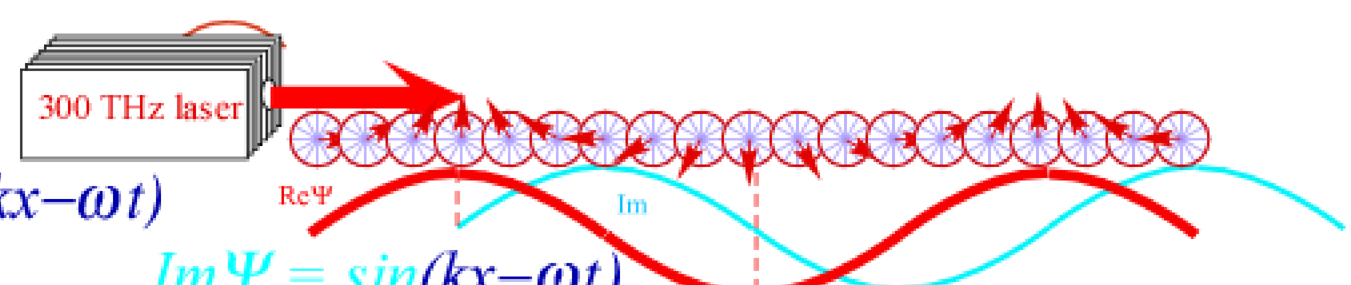
Quantum Phasor Clock

$$\Psi = Ae^{i(kx-\omega t)} = A\cos(kx-\omega t) + i\,A\sin(kx-\omega t)$$

Phasor clocks turn clockwise in time for positive ω



300THz Laser plane wave $\langle x,t\,|\,k,\omega\rangle = Ae^{i(kx - wt)}$



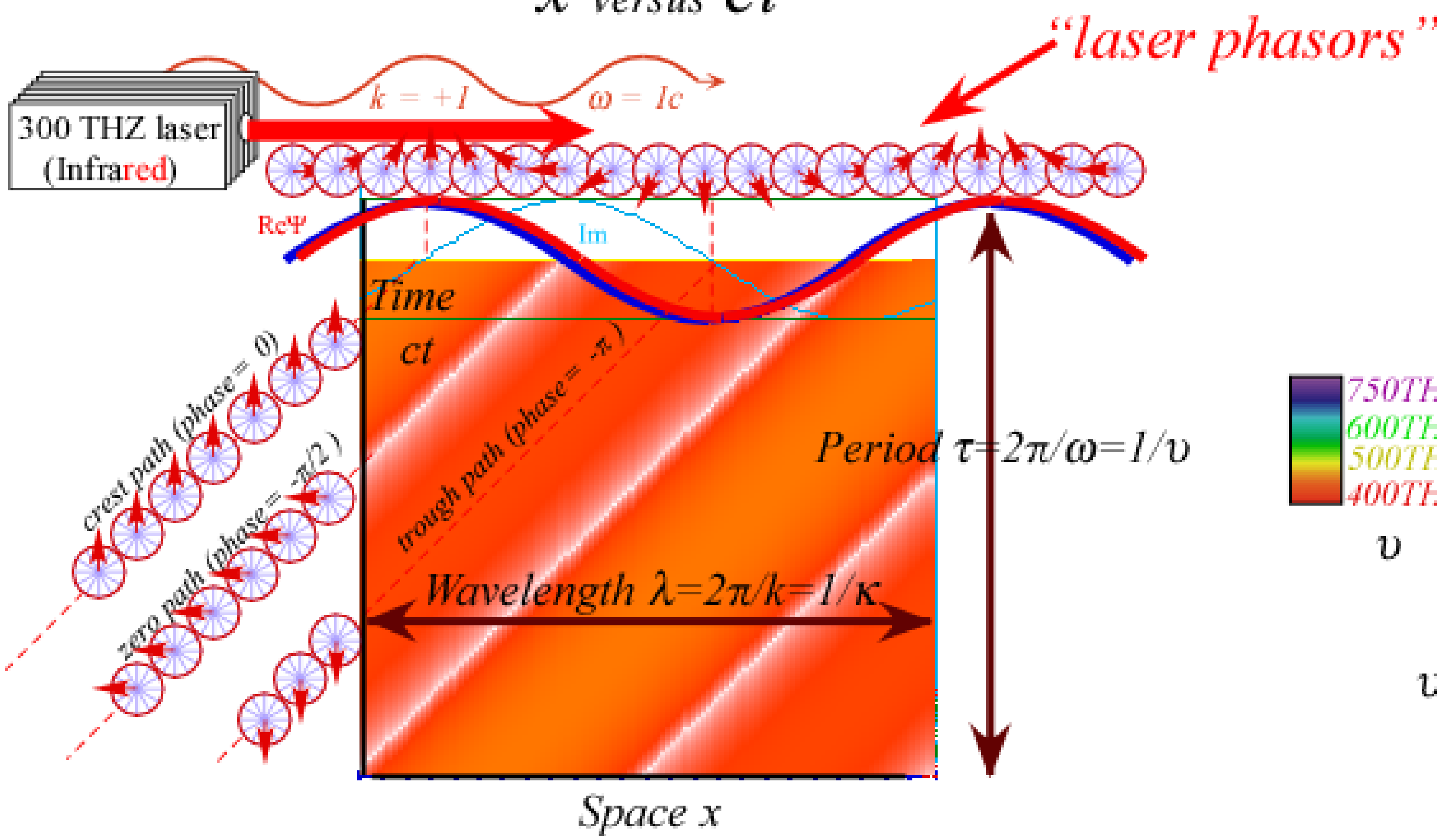
$Re\,\Psi = \cos(kx-\omega t)$

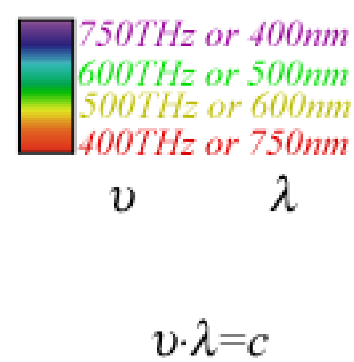
$Im\,\Psi = \sin(kx-\omega t)$

New-fashioned laser clocks & meter sticks (contd.)
Dual views:

(1.) Spacetime

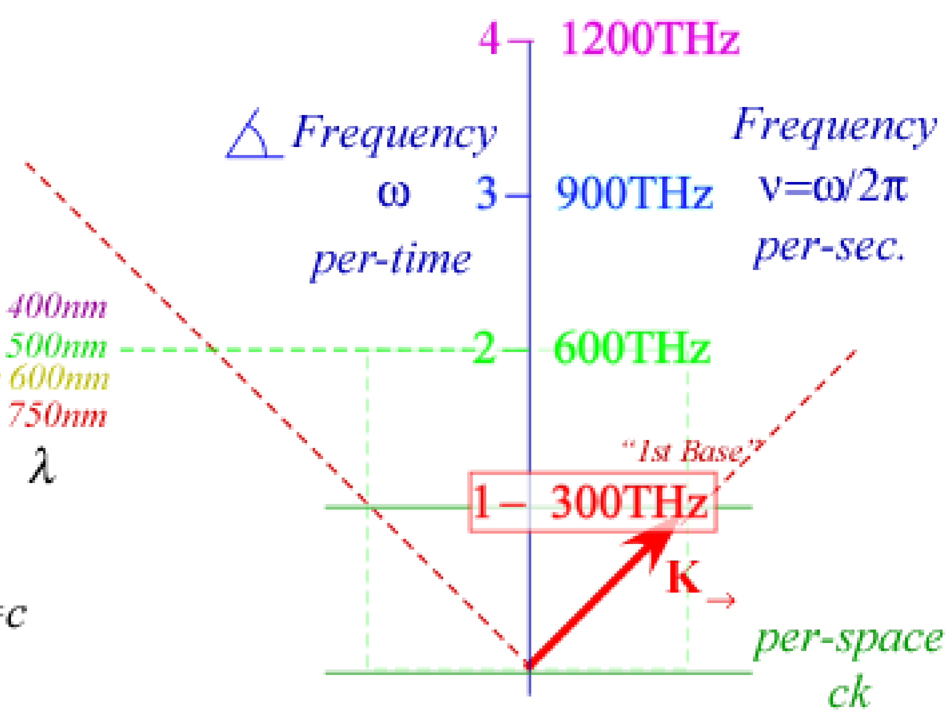
x versus ct





(2.) Per-Spacetime

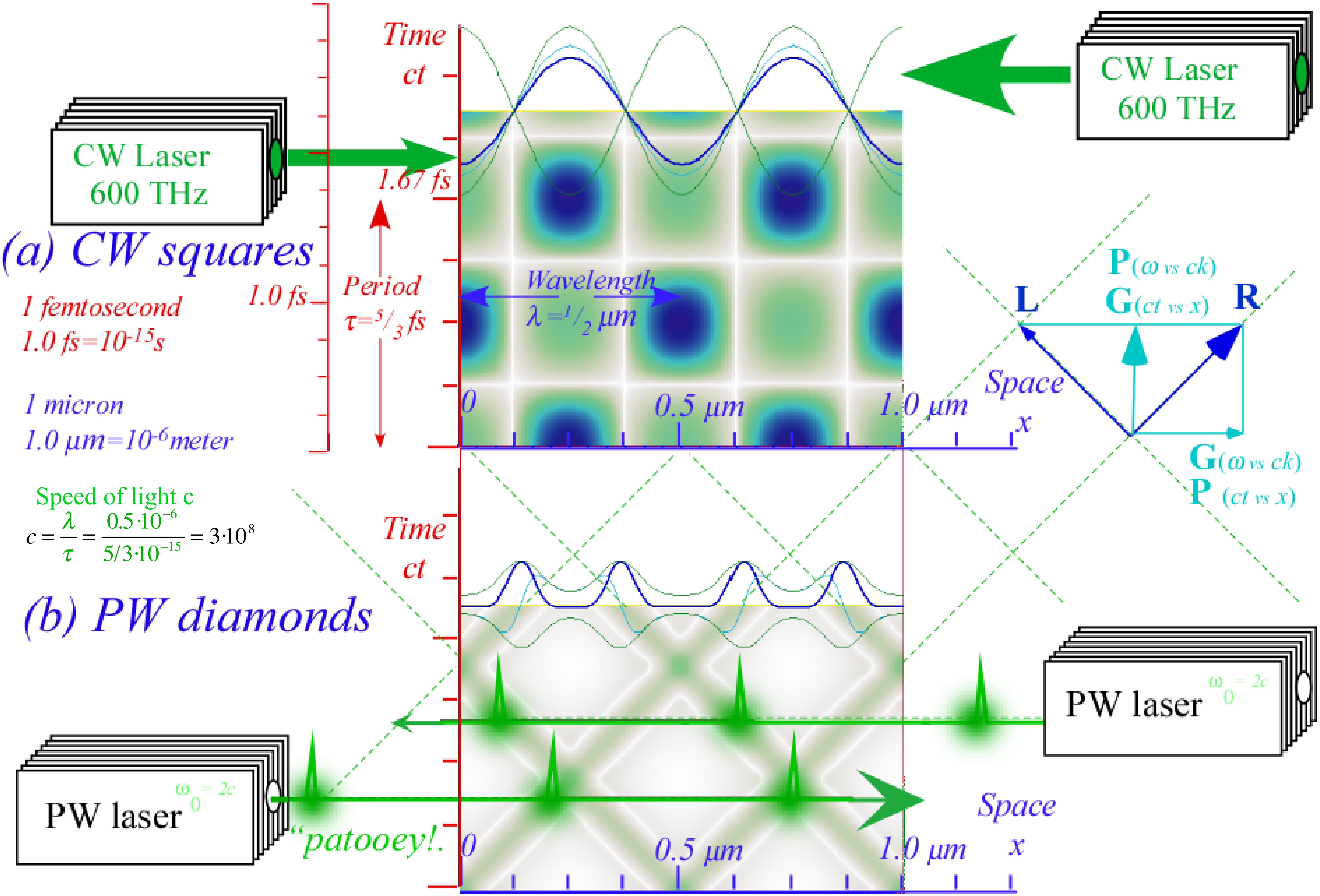
ω versus ck



Single plane-wave meter-stick-clocks are too fast (can't catch'em)

(...But at least this view is constant)

Interfering wave pairs needed to make rest frame coordinates...

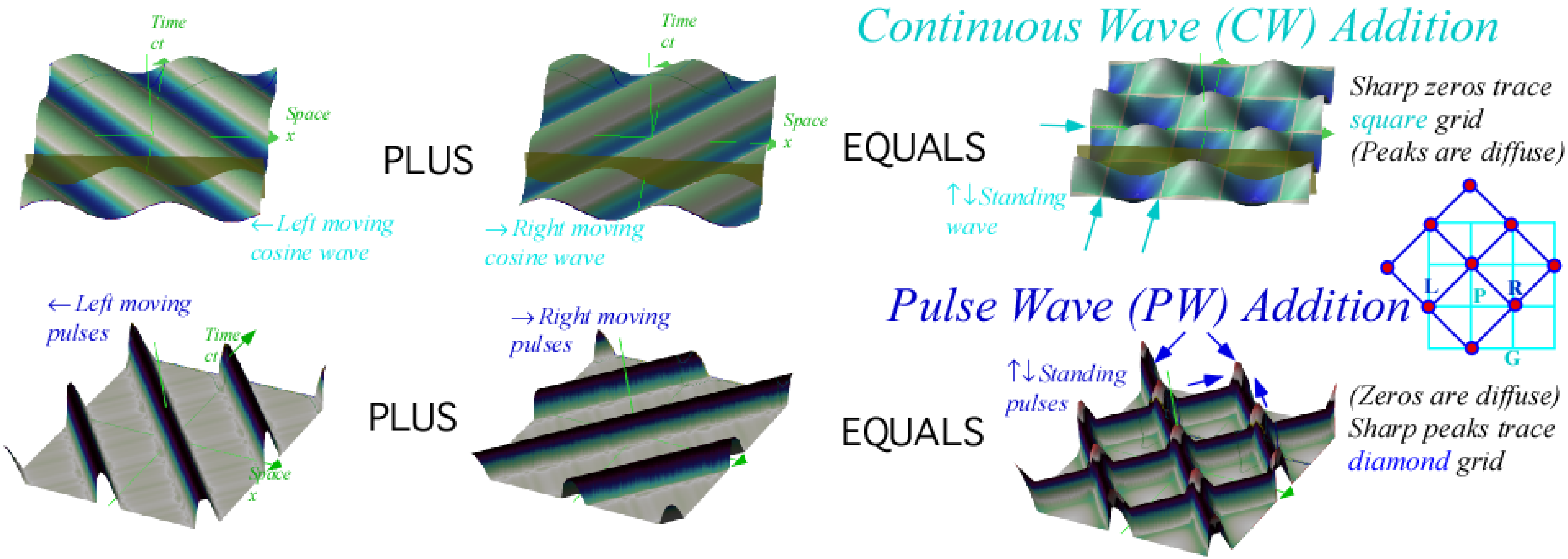


CW Laser
600 THz
CW Laser
600 THz
(a) CW squares
1 femtosecond
1.0 fs=10-15s
1 micron
1.0 μm=10-6meter
Time
ct
1.67 fs
1.0 fs
Period
τ=5/3 fs
Wavelength
λ=1/2 μm
0
0.5 μm
1.0 μm
Space
x
P(ω vs ck)
G(ct vs x)
L
R
G(ω vs ck)
P (ct vs x)
Speed of light c
c = λ/τ = 0.5·10−6 / 5/3·10−15 = 3·108
(b) PW diamonds
Time
ct
PW laser
PW laser
"patooey!"
Space
x

Newton's "Fits" in Optical Interference

Newton complained that light waves have *"fits"* (what we now know as wave *interference* or *resonance*.)

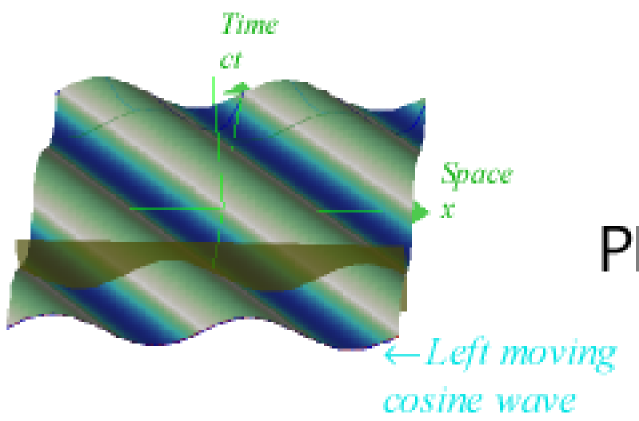
Examples of interference are head-on collision of two *Continuous Waves (2-CW)* or two *Pulse Waves (PW)*



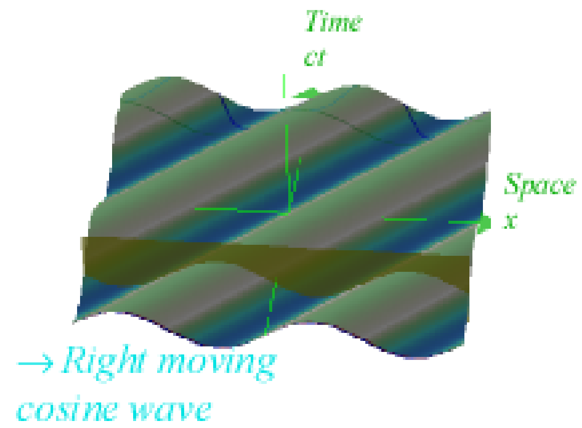
Newton's "Fits" in Optical Interference

Newton complained that light waves have *"fits"* (what we now know as wave *interference* or *resonance*.)
Examples of interference are head-on collision of two *Continuous Waves (2-CW)* or two *Pulse Waves (PW)*

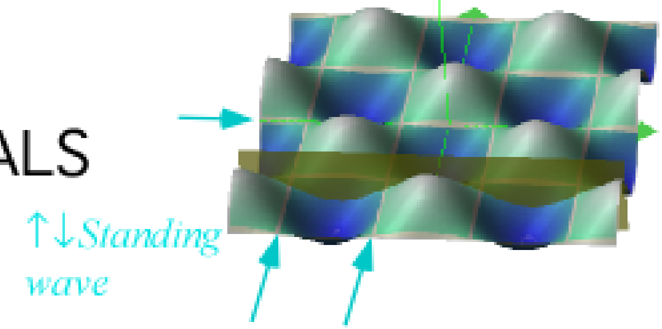
Continuous Wave (CW) Addition



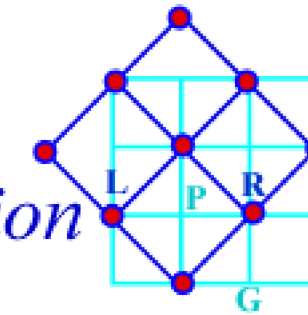
PLUS



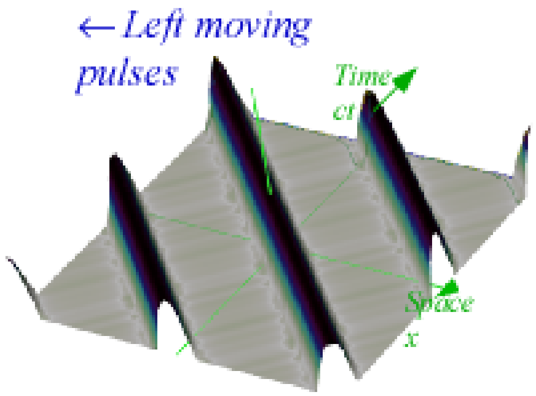
EQUALS



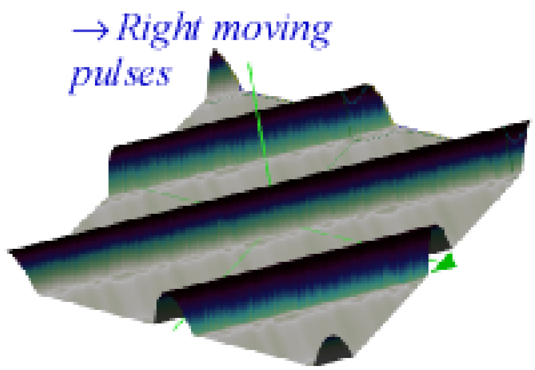
Sharp zeros trace square grid (Peaks are diffuse)



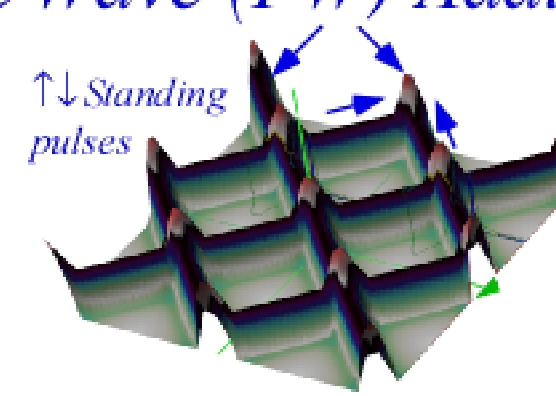
Pulse Wave (PW) Addition



PLUS



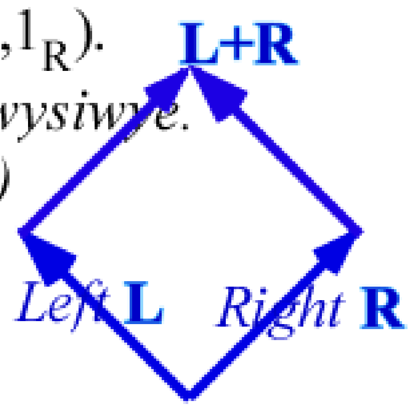
EQUALS



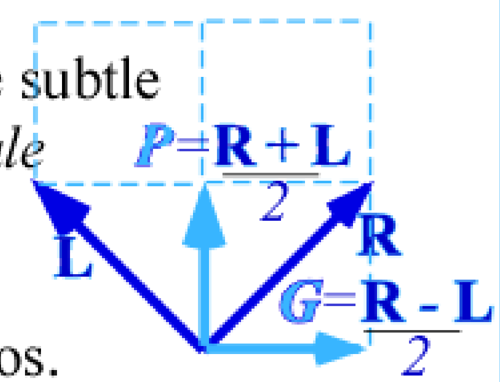
(Zeros are diffuse) Sharp peaks trace diamond grid

Pulse Wave (PW) sum compared with *Continuous Wave (CW)* sum

- *PW* waves are OFF (0) or ON (1)
- *PW* sum is Boolean $(0_L,0_R),(0_L,1_R),(1_L,0_R),(1_L,1_R)$.
- *PW* time *peak-diamond* paths are *wysiwye*. *(What you see is what you expect!)*



- *CW* waves range continously from -1 to +1
- *CW* sum is more subtle and nuanced *interference*.
- *CW* time *zero-square* paths are subtle results of the *half-sum* ***P****-rule* and the *half-difference* ***G****-rule* of *phase* ***P*** and *group* ***G*** zeros.



3. Beginning wave relativity

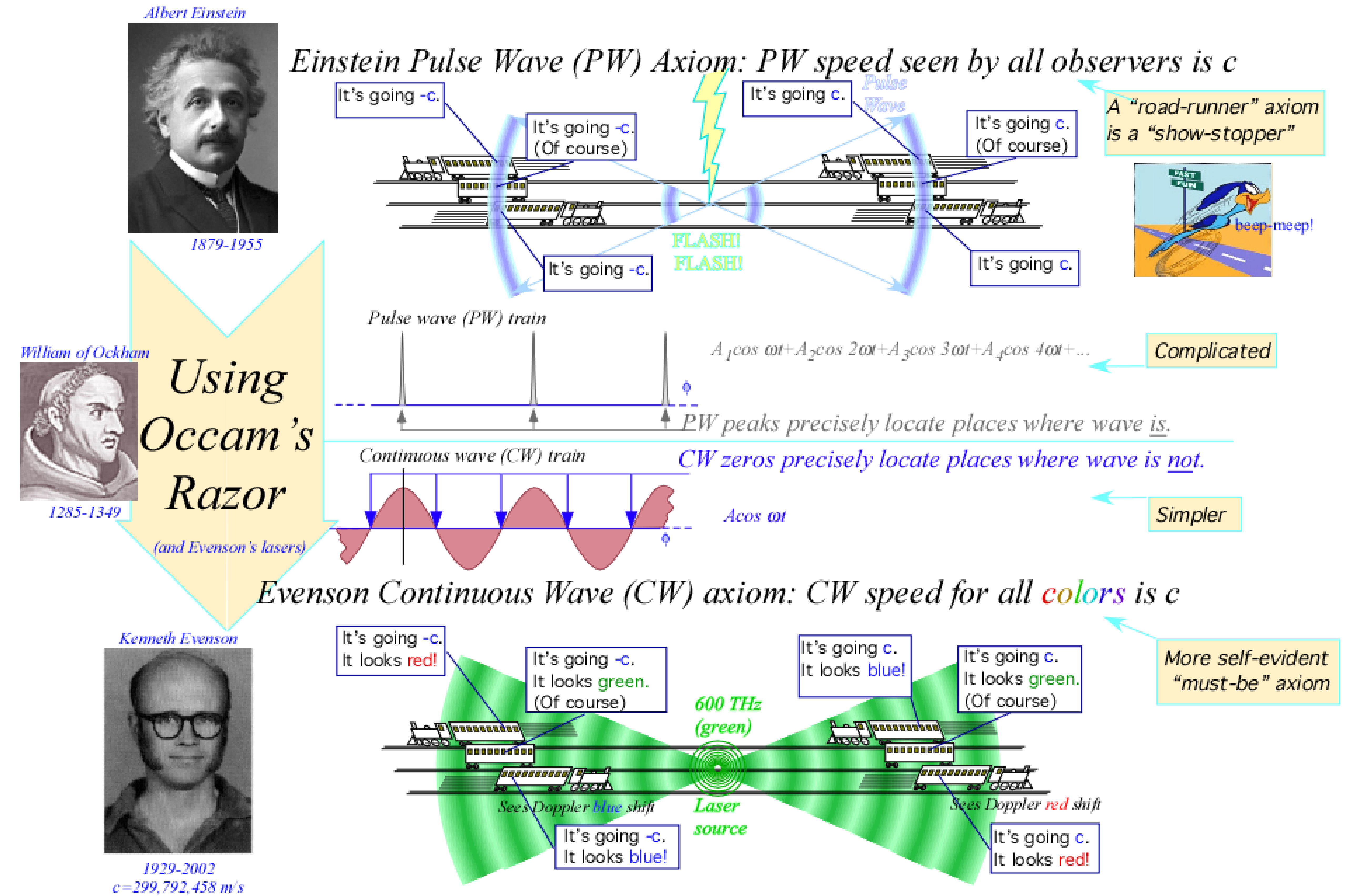
Dueling lasers make lab frame space-time grid (CW or PW)

➡ *Einstein PW Axioms versus Evenson CW Axioms (Occam at Work)*

Only CW light clearly shows Doppler shift

Dueling lasers make lab frame space-time grid

Einstein PW Axioms versus Evenson CW Axioms (Occam at Work)



List 1-17 of Roadrunner Episodes
Chuck Jones-Wikipedia-2012

#	Release date	Title	Duration	Credits		Pseudo-Latin names given		Acme Corporation devices used	Books Studied
				Story/writing	Direction	For the Road Runner	For the Coyote		
1	1949·9·17	*Fast and Furry-ous*	6:55	Michael Maltese	Chuck Jones	Acceleratii incredibus	Carnivorous vulgaris	ACME Super Outfit	
2	1952·5·24	*Beep, Beep*	6:45	Michael Maltese	Chuck Jones	Accelerati incredibilus	Carnivorous vulgaris	Asprin, Matches, Rocket-Powered Roller Skates	None
3	1952·8·23	*Going! Going! Gosh!*	6:25	Michael Maltese	Chuck Jones	Acceleratti incredibilis	Carnivorous vulgaris	an anvil, a weather balloon, a street cleaner's bin, and a fan	
4	1953·9·19	*Zipping Along*	6:55	Michael Maltese	Chuck Jones	Velocitus tremenjus	Road-Runnerus digestus	Giant Kite Kit, Bomb, Detonator, Nitroglycerin	
5	1954·8·14	*Stop! Look! And Hasten!*	7:00	Michael Maltese	Chuck Jones	Hot-roddicus supersonicus	Eatibus anythingus	Bird Seed, Triple Strength Fortified Leg Muscle Vitamins	"How to Build a Burmese Tiger Trap
6	1955·4·30	*Ready, Set, Zoom!*	6:55	Michael Maltese	Chuck Jones	Speedipus Rex	Famishus-Famishus	Glue	
7	1955·12·10	*Guided Muscle*	6:40	Michael Maltese	Chuck Jones	Velocitus delectiblus	Eatibus almost anythingus	ACME Grease	
8	1956·5·5	*Gee Whiz-z-z-z-z-z-z*	6:35	Michael Maltese	Chuck Jones	Delicius-delicius	Eatius birdius	ACME Triple Strength Battleship Steel Armor Plate, Rubber Band, Jet Bike	
9	1956·11·10	*There They Go-Go-Go!*	6:35	Michael Maltese	Chuck Jones	Dig-outius tid-bittius	Famishius fantasticus		
10	1957·1·26	*Scrambled Aches*	6:50	Michael Maltese	Chuck Jones	Tastyus supersonicus	Eternalii famishiis	ACME Dehydrated Boulders, Outboard Steam Roller	
11	1957·9·14	*Zoom and Bored*	6:15	Michael Maltese	Chuck Jones	Birdibus zippibus	Famishus vulgarus	ACME Bumblebees	
12	1958·4·12	*Whoa, Be-Gone!*	6:10	Michael Maltese	Chuck Jones	Birdius high-ballius	Famishius vulgaris ingeniusi	Tornado Seeds	
13	1958·10·11	*Hook, Line and Stinker*	5:55	Michael Maltese	Chuck Jones	Burnius-roadibus	Famishius-famishius		
14	1958·12·6	*Hip Hip-Hurry!*	6:13	Michael Maltese	Chuck Jones	digoutius-unbelieveablii	eatius-slobbius		
15	1959·5·9	*Hot-Rod and Reel!*	6:25	Michael Maltese	Chuck Jones	Super-sonicus-tastius	Famishius-famishius	Jet-Propelled Pogo Stick, Jet-Propelled Unicycle	None.
16	1959·10·10	*Wild About Hurry*	6:45	Michael Maltese	Chuck Jones	Batoutahelius	Hardheadipus oedipus	Giant Elastic Rubber Band, 5 Miles of Railroad Track, Rocket Sled, Bird Seed, Iron Pellets, Indestructo Steel Ball	None
17	1960·1·9	*Fastest with the Mostest*	7:20	None	Chuck Jones	Velocitus incalcublii	Carnivorous slobbius		

List 17-34 of Roadrunner Episodes
Chuck Jones-Wikipedia-2012

18	1960·10·8	*Hopalong Casualty*	6:05	Chuck Jones	Chuck Jones	speedipus-rex	Hard-headipus ravenus	Christmas Packaging Machine, Earthquake Pills
19	1961·1·21	*Zip 'N Snort*	5:50	Chuck Jones	Chuck Jones	digoutius-hot-rodis	evereadii eatibus	
20	1961·6·3	*Lickety-Splat*	6:20	Chuck Jones	Chuck Jones, Abe Levitow	Fastius tasty-us	Appetitius giganticus	Roller skis, dart bombs
21	1961·11·11	*Beep Prepared*	6:00	John Dunn, Chuck Jones	Chuck Jones, Maurice Noble	Tid-bittius velocitus	Hungrii flea-bagius	ACME Iron Bird Seed
Film	1962·6·2	*Adventures of the Road Runner*	26:00	John Dunn, Chuck Jones, Michael Maltese	Chuck Jones	Super-Sonnicus Idioticus	Desertous-operativus Idioticus	
22	1962·6·30	*Zoom at the Top*	6:30	Chuck Jones	Chuck Jones, Maurice Noble	disappearialis quickius	overconfidentii vulgaris	Bird seed, instant icicle-maker, boomerang
23	1963·12·28	*To Beep or Not to Beep*[1]	6:35	John Dunn, Chuck Jones	Chuck Jones, Maurice Noble	None	None	
24	1964·6·6	*War and Pieces*	6:40	John Dunn	Chuck Jones, Maurice Noble	Burn-em upus asphaltus	Caninus nervous rex	Invisible Paint
25	1965·1·1	*Zip Zip Hooray!*[2]	6:15	John Dunn	Chuck Jones	Super-Sonnicus Idioticus	None	
26	1965·2·1	*Road Runner a Go-Go*[2]	6:05	John Dunn	Chuck Jones	None	None	None
27	1965·2·27	*The Wild Chase*	6:30	None	Friz Freleng, Hawley Pratt	None	None	
28	1965·7·31	*Rushing Roulette*	6:20	David Detiege	Robert McKimson	None	None	
29	1965·8·21	*Run, Run, Sweet Road Runner*	6:00	Rudy Larriva	Rudy Larriva	None	None	
30	1965·9·18	*Tired and Feathered*	6:20	Rudy Larriva	Rudy Larriva	None	None	
31	1965·10·9	*Boulder Wham!*	6:30	Len Janson	Rudy Larriva	None	None	Deluxe Hi-bounce Trampoline Kit
32	1965·10·30	*Just Plane Beep*	6:45	Don Jurwich	Rudy Larriva	None	None	War Surplus Biplane
33	1965·11·13	*Hairied and Hurried*	6:45	Nick Bennion	Rudy Larriva	None	None	Snow Machine, Magnetic Gun, Practice Bombs, Super Bomb, Kit
34	1965·12·11	*Highway Runnery*	6:45	Al Bertino	Rudy Larriva	None	None	

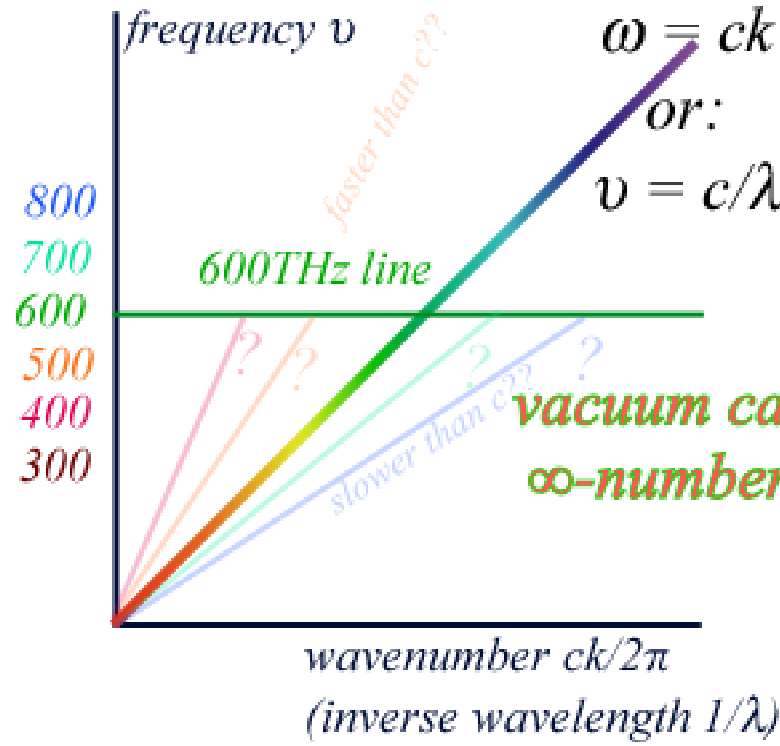
35	1965·12·25	*Chaser on the Rocks*	6:45	Tom Dagenais	Rudy Larriva	None	None		
36	1966·1·8	*Shot and Bothered*	6:30	Nick Bennion	Rudy Larriva	None	None	Suction Cups	N
37	1966·1·29	*Out and Out Rout*	6:00	Dale Hale	Rudy Larriva	None	None	No ACME labeled devices used.	" H "
38	1966·2·19	*The Solid Tin Coyote*	6:15	Don Jurwich	Rudy Larriva	None	None		
39	1966·3·12	*Clippety Clobbered*	6:15	Tom Dagenais	Rudy Larriva	None	None		
40	1966·11·5	*Sugar and Spies*	6:20	Tom Dagenais	Robert McKimson	None	None	Do-it-Yourself Kit Remote Control Missile-Bombs	N
41	1979·11·27	*Freeze Frame*	6:05	John W. Dunn Chuck Jones	Chuck Jones	Semper food-ellus	Grotesques appetitus		
42	1980·5·21	*Soup or Sonic*	9:10	Chuck Jones	Chuck Jones, Phil Monroe	Ultra-sonicus ad infinitum	Nemesis ridiculii		
43	1994·12·21	*Chariots of Fur*[3]	7:00	Chuck Jones	Chuck Jones	Boulevardius-burnupius	Dogius ignoramii		
44	2000·12·30	*Little Go Beep*	7:55	Kathleen Helppie-Shipley, Earl Kress	Spike Brandt	Morselus babyfatius tastius	Poor schnookius		
45	2003·11·1	*The Whizzard of Ow*	7:00	Chris Kelly	Bret Haaland	*Geococcyx californianus*[4]	*Canis latrans*[4]	Book of Magic, Flying Broom, Bomb, Clear Paint	" N
Film	2003·11·14	*Looney Tunes: Back in Action*	91:00	Larry Doyle	Joe Dante	None	Desertus operatus idioticus		
46	2010·7·30	*Coyote Falls*[3]	2:59	Tom Sheppard[10]	Matthew O'Callaghan	None	None	Bird Seed, Bungee Cord	N
47	2010·9·24	*Fur of Flying*[3]	3:03[11]	Tom Sheppard	Matthew O'Callaghan[11]	None	None	Bonnie Bike, Mega-Motor, Football Helmet, Ceiling Fan	N
48	2010·12·17	*Rabid Rider*[3]	3:07	Tom Sheppard	Matthew O'Callaghan	None	None	Hyper-Sonic Transport	N
49	TBA	*Untitled Wile E. Coyote and Road Runner Short Film*	5:38	Tom Sheppard	Matthew O'Callaghan	None	None		

Evenson CW Axiom ("All colors go c.") is only reasonable conclusion:

Linear dispersion: $\omega = ck$

Linear dispersion means NO dispersion

Einstein PW is corollary of Evenson CW



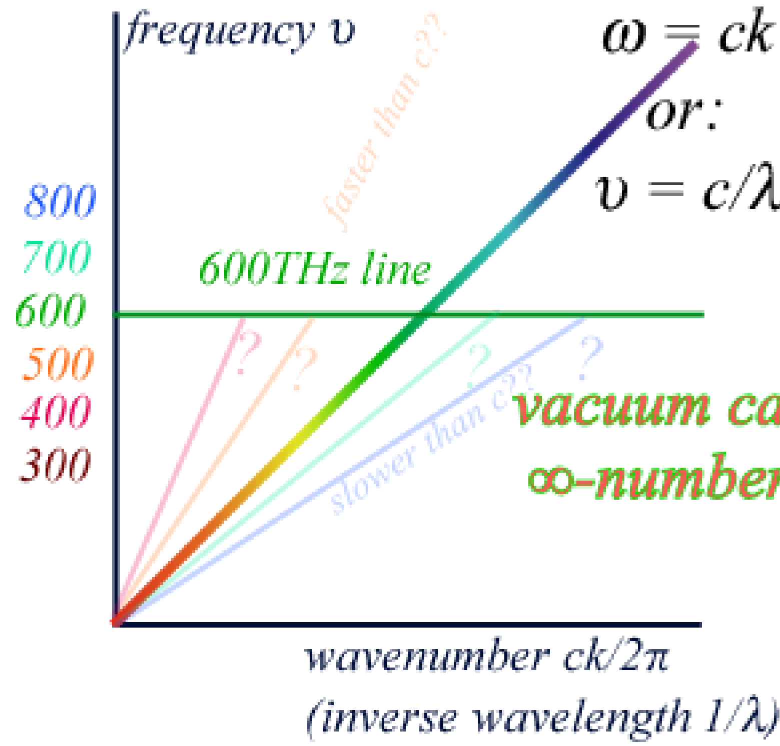
vacuum can't support an ∞-number of "other speeds"

Evenson CW Axiom ("All colors go c.") is only reasonable conclusion:

Linear dispersion: $\omega = ck$

Linear dispersion means NO dispersion

Einstein PW is corollary of Evenson CW



vacuum can't support an ∞-number of "other speeds"

What if blue were to travel 0.001% slower than red from a galaxy 9 billion light years away? (..and show up 10^5 years late)

That would mean Good-Bye Hubble Astronomy!

3. Beginning wave relativity

Dueling lasers make lab frame space-time grid (CW or PW)

Einstein PW Axioms versus Evenson CW Axioms (Occam at Work)

→ *Only CW light clearly shows Doppler shift*

Dueling lasers make lab frame space-time grid

Doppler Shifts in Spacetime

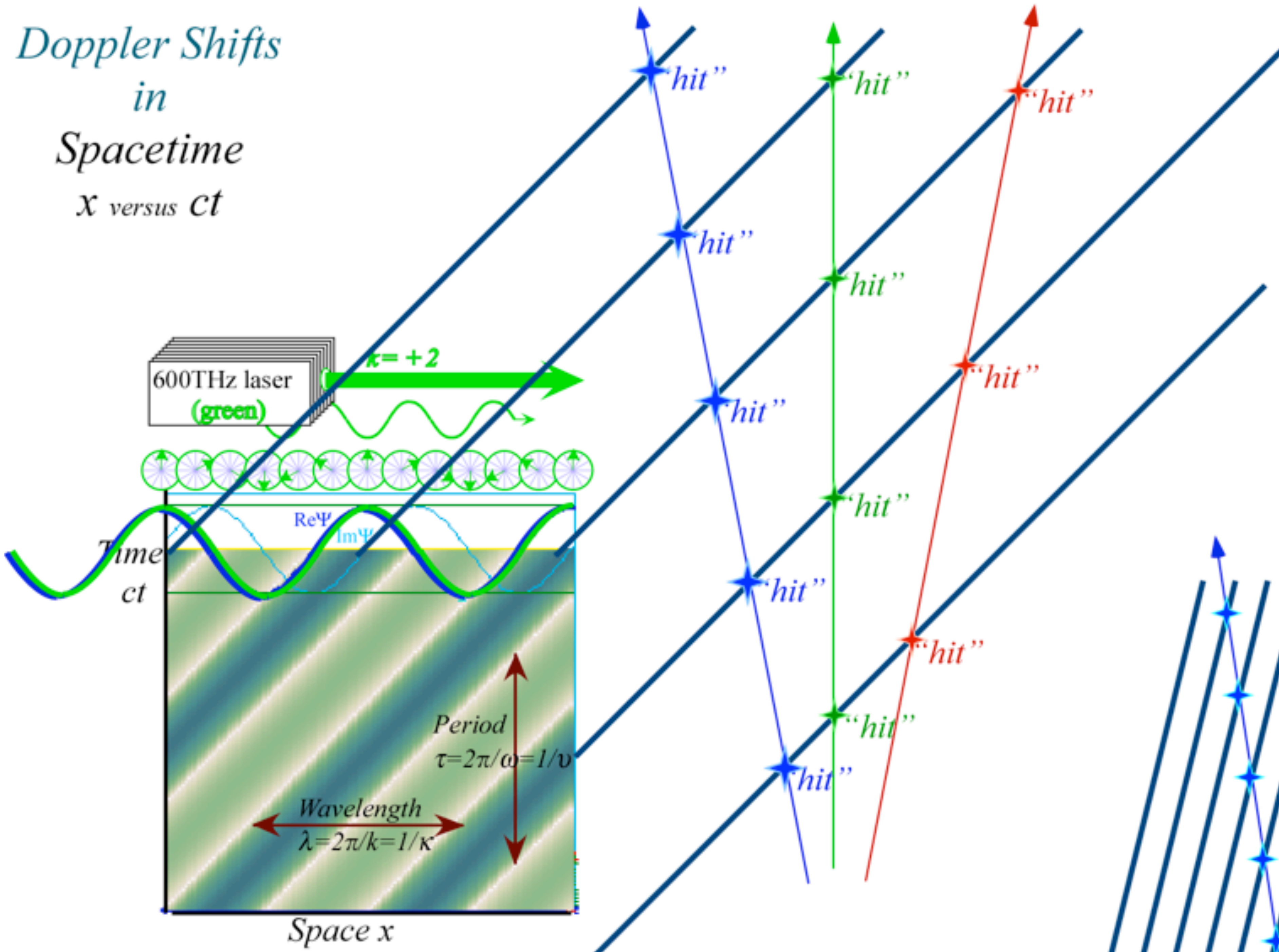
x versus ct

Doppler Blueshift

More "hits" per sec. if moving toward laser source

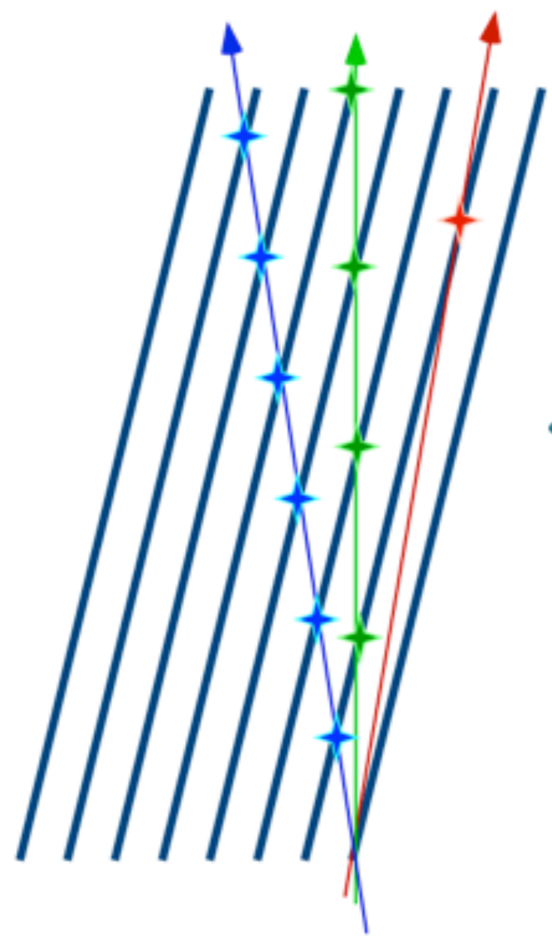
Doppler Redshift

Fewer "hits" per sec. if moving away from laser source



Doppler's picture needs revision for light whose period and wavelength both shift.

Why?



...So that all colors go the same speed!

$$\upsilon \cdot \lambda = \frac{\lambda}{\tau} = \frac{\omega}{k} = c$$

$$\upsilon \cdot \lambda = \frac{\lambda}{\tau} = \frac{\omega}{k} = c \qquad \text{etc.}$$

$$\upsilon \cdot \lambda = \frac{\lambda}{\tau} = \frac{\omega}{k} = c$$

3. Beginning wave relativity

Dueling lasers make lab frame space-time grid (CW or PW)

Einstein PW Axioms versus Evenson CW Axioms (Occam at Work)

Only CW light clearly shows Doppler shift

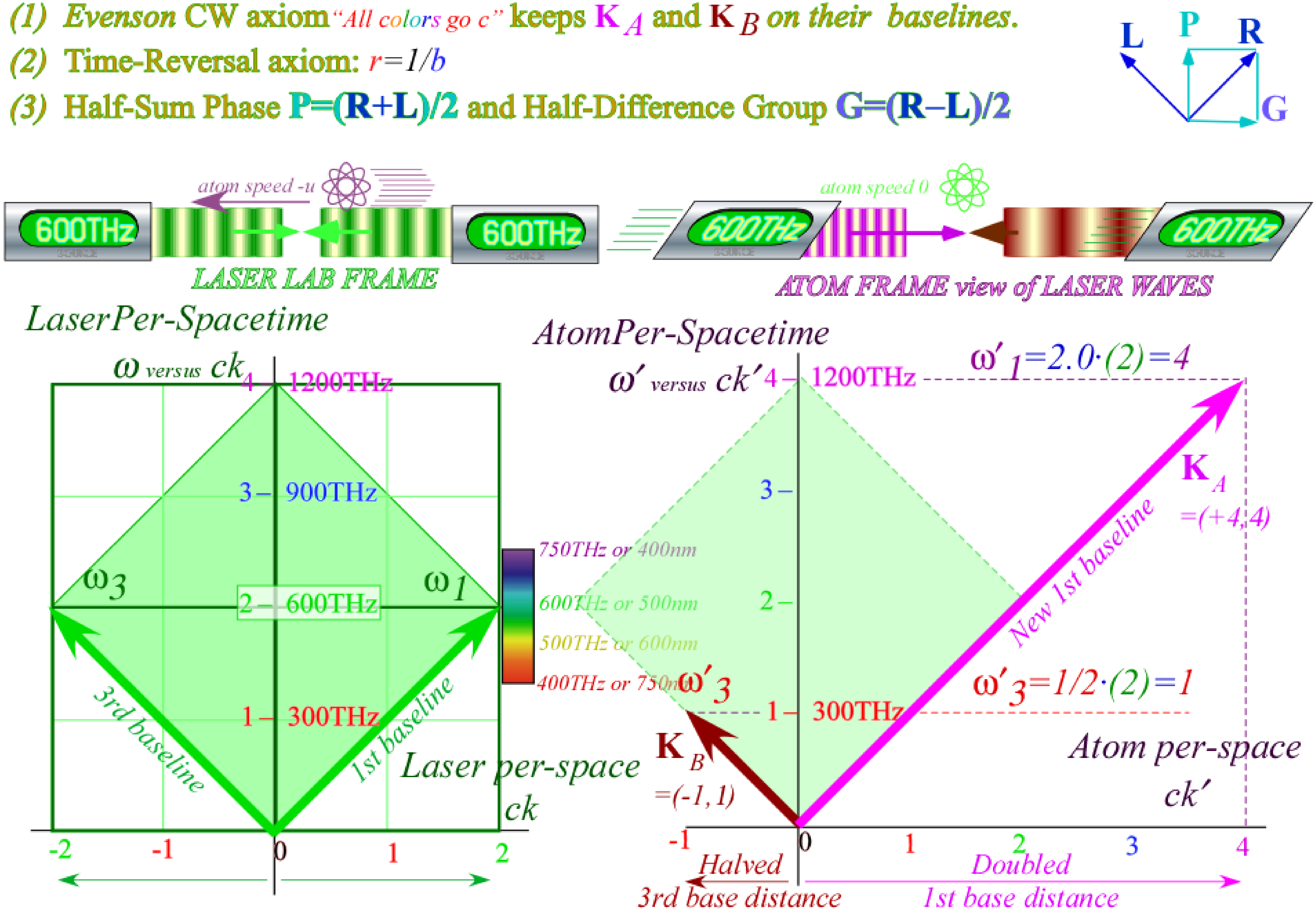
→ *Dueling lasers make lab frame space-time grid*

Deriving Spacetime and per-spacetime coordinate geometry by:

(1) Evenson CW axiom "All colors go c" keeps K_A and K_B on their baselines.

(2) Time-Reversal axiom: $r=1/b$

(3) Half-Sum Phase P=(R+L)/2 and Half-Difference Group G=(R−L)/2

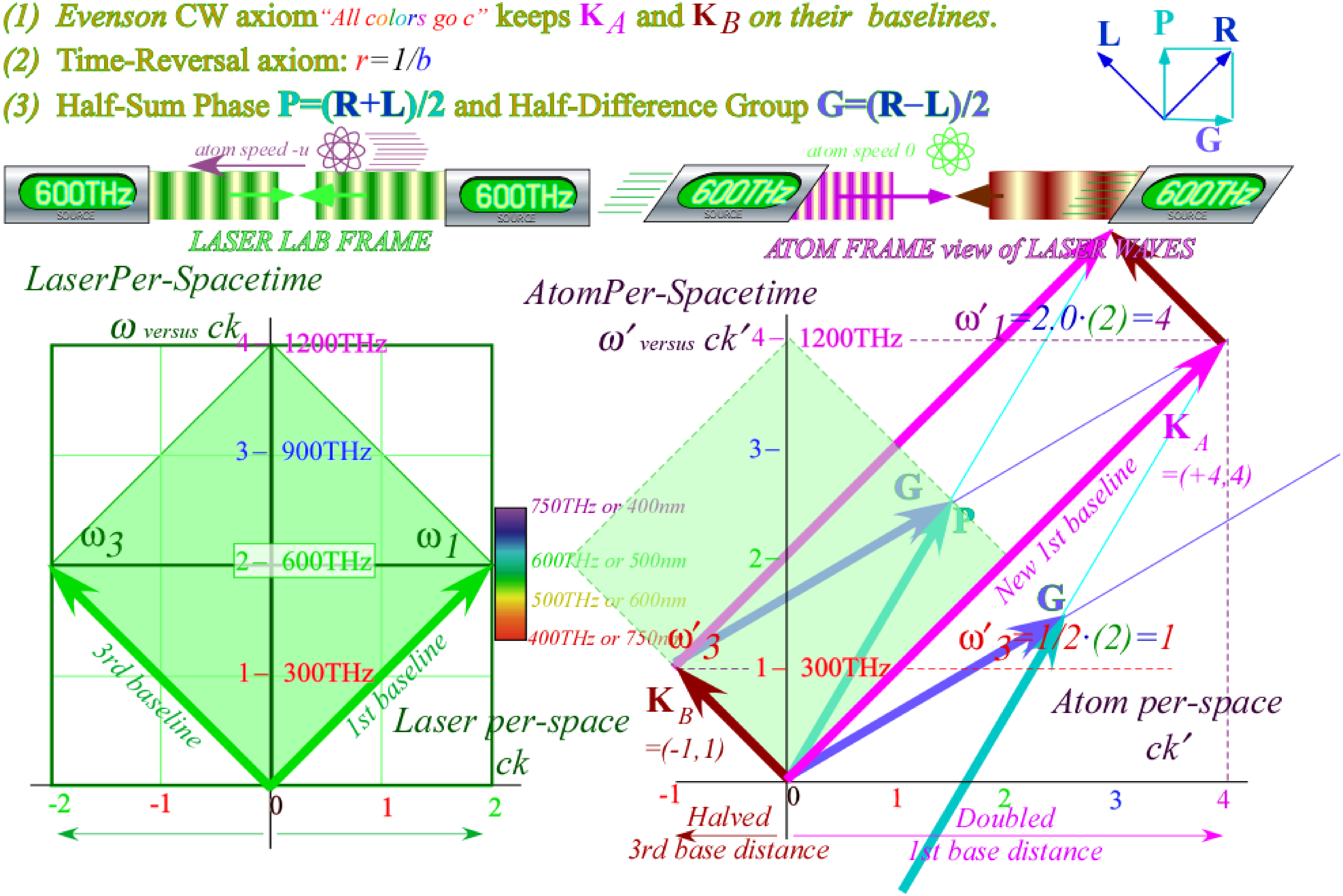


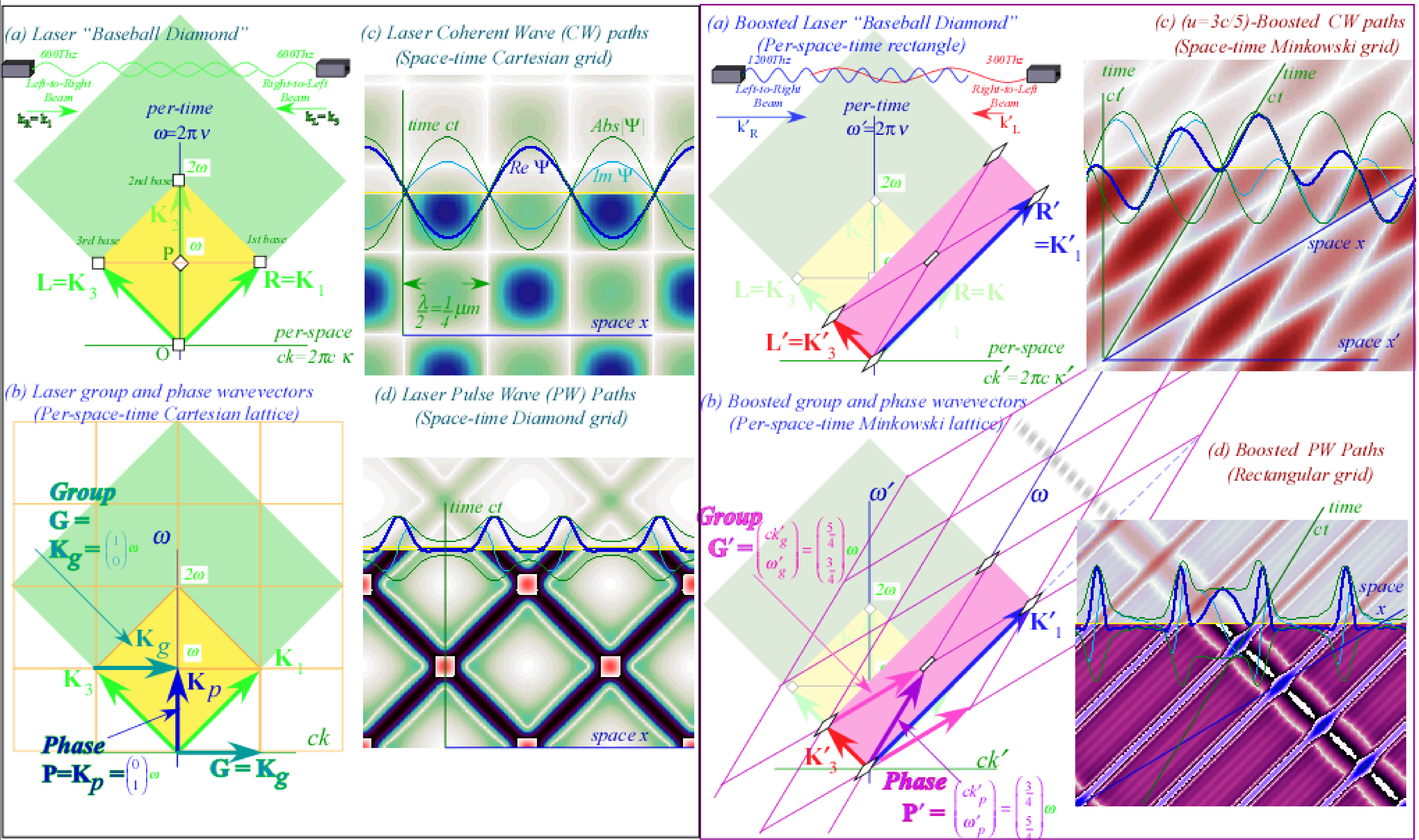
Deriving Spacetime and per-spacetime coordinate geometry by:

(1) Evenson CW axiom *"All colors go c"* keeps $\mathbf{K}_A$ and $\mathbf{K}_B$ *on their baselines.*

(2) Time-Reversal axiom: $r=1/b$

(3) Half-Sum Phase **P=(R+L)/2** and Half-Difference Group **G=(R−L)/2**

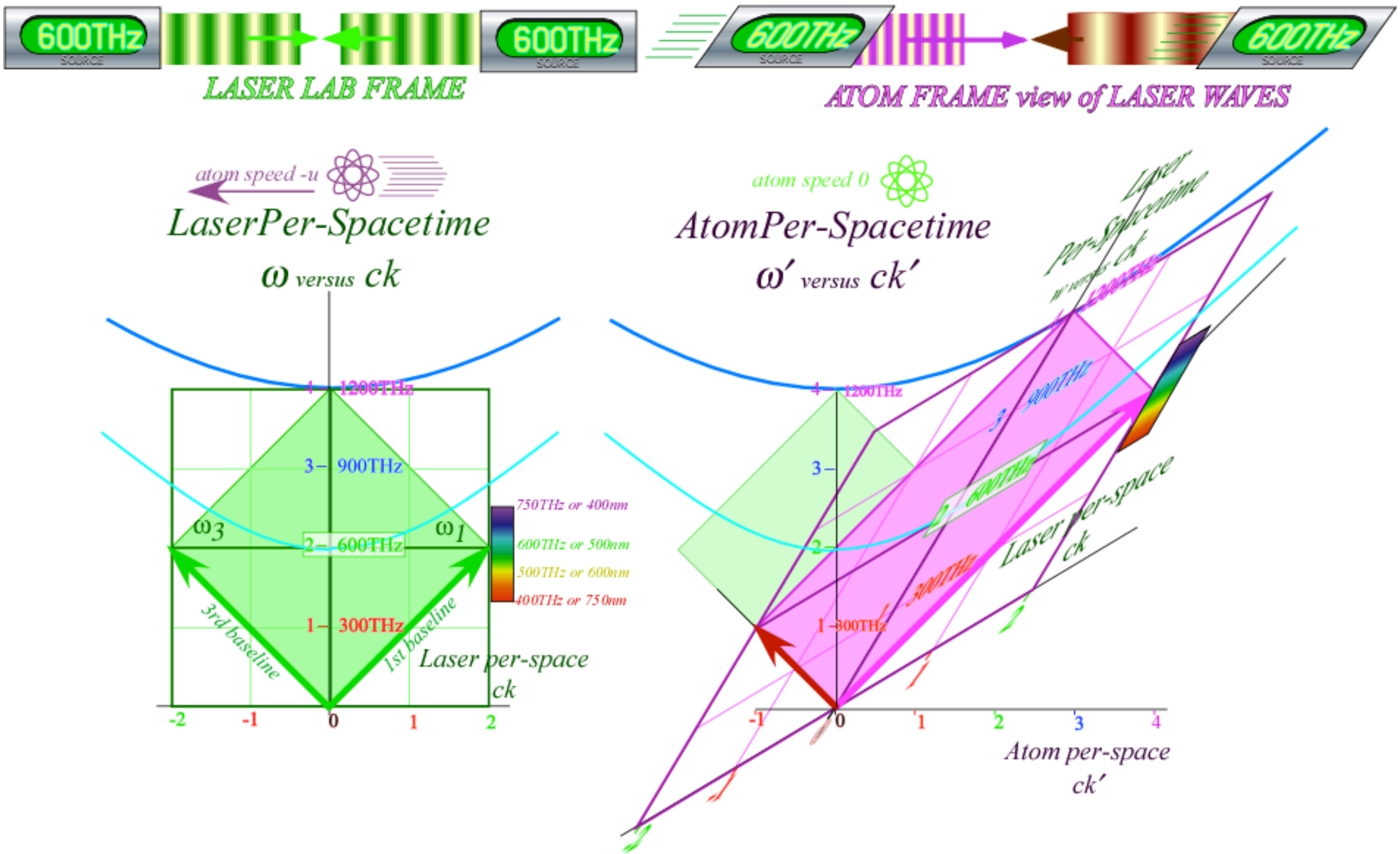




atom speed $-u=-\frac{3}{5}c$

Laser lab views

Atom views (sees lab going $+u=\frac{3}{5}c$)



600THz
SOURCE
LASER LAB FRAME
ATOM FRAME view of LASER WAVES
atom speed -u
LaserPer-Spacetime
ω versus ck
atom speed 0
AtomPer-Spacetime
ω′ versus ck′
1200THz
900THz
600THz
300THz
ω3
ω1
3rd baseline
1st baseline
Laser per-space
ck
750THz or 400nm
600THz or 500nm
500THz or 600nm
400THz or 750nm
Laser Per-Spacetime ω versus ck
Laser per-space ck
Atom per-space ck′

Euclidian Geometry for Per-spacetime Relativity

relative speed~slope

$u/c = \sinh\rho / \cosh\rho = \tanh\rho$

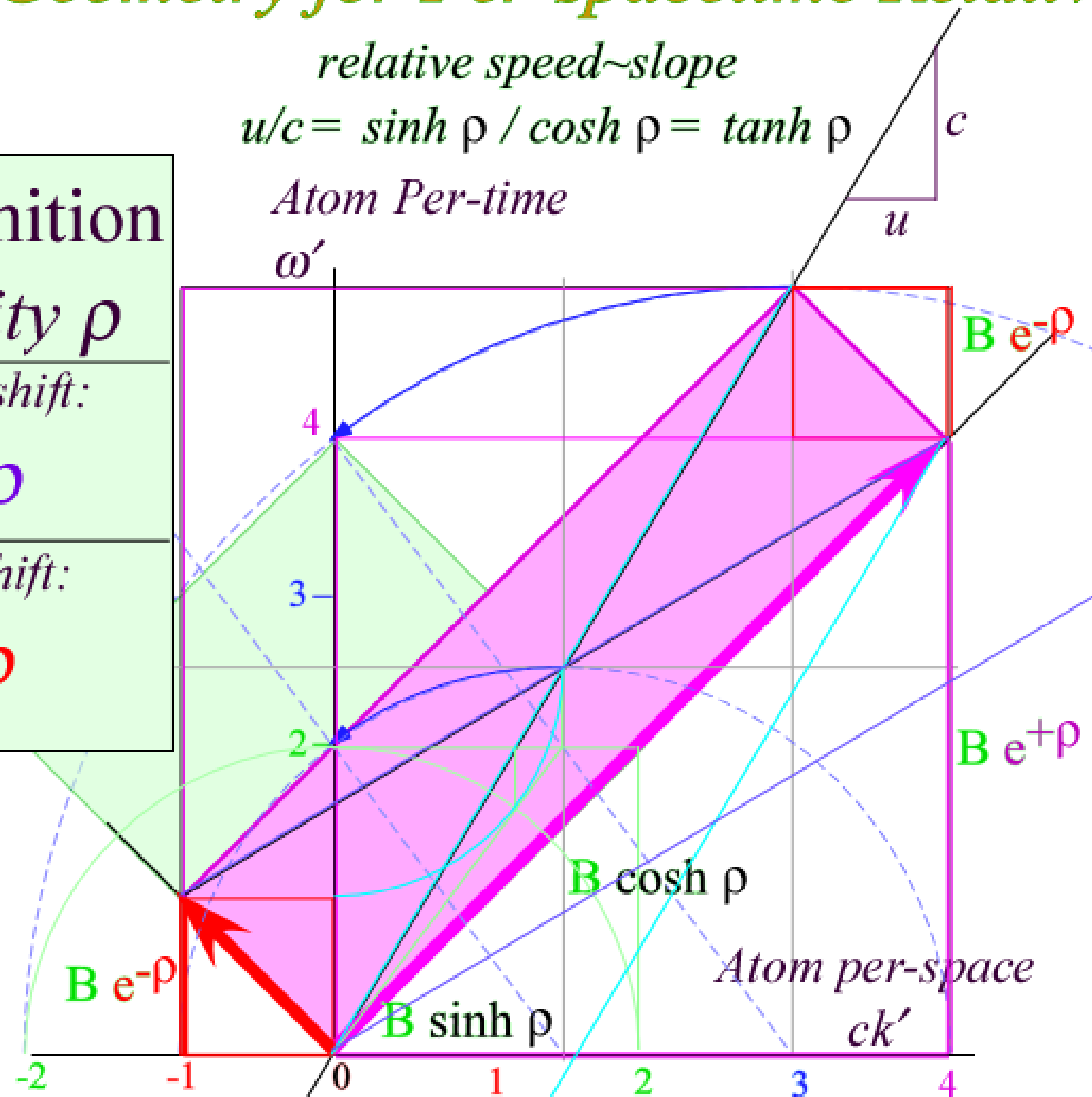
Key Definition of Rapidity ρ

Doppler blue shift:

$Bb = Be^{+\rho}$

Doppler red shift:

$Br = Be^{-\rho}$



Key Results:

ω *vs.* ck

"winks" vs. "kinks"

$\omega = B\cosh\rho$

$ck = B\sinh\rho$

group velocity:

$$\frac{\omega}{ck} = \frac{u}{c} = \tanh\rho$$

phase velocity:

$$\frac{ck}{\omega} = \frac{c}{u} = \coth\rho$$

$B\sinh\rho = (Be^{+\rho} - Be^{-\rho})/2$

$B\cosh\rho = (Be^{+\rho} + Be^{-\rho})/2$

$\sinh\rho = \frac{\frac{u}{c}}{\sqrt{1-\frac{u^2}{c^2}}}$	**Key Quantities** *Lorentz-Einstein factors*	$\cosh\rho = \frac{1}{\sqrt{1-\frac{u^2}{c^2}}}$