AMOP Lectures 6.0
Tue 2.18 2014

Introduction to Relativistic Classical and Quantum Mechanics I.

(Ch. 2-5 of Unit 8)

Review of group velocity vs. phase velocity and tangent contacts
- *"Sin-Tan" geometry in "Relawavity" (www.uark.edu/ua/modphys/testing/markup/RelaWavityWeb.html)*
- *"Sinh-Tanh" geometry*
- *"Per-Space-Time" geometry*
- *The rare case where group velocity is both Δω/Δk and dω/dk*

How optical CW group and phase properties give relativistic mechanics
- *What's the Matter with Mass?*
  - *Brief look at Higgs*
- *Three kinds of mass (Einstein rest mass, Galilean momentum mass, Newtonian inertial mass)*
  - *What's the matter with light?*

Bohr-Schrodinger (BS) approximation throws out Mc^2

Relativistic Classical and Quantum Mechanics

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"Sin-Tan" geometry in "Relawavity" *(www.uark.edu/ua/modphys/testing/markup/RelaWavityWeb.html)*

"Sinh-Tanh" geometry

"Per-Space-Time" geometry

The rare case where group velocity is both $\Delta\omega/\Delta k$ and $d\omega/dk$

"Sin-Tan Rosetta"

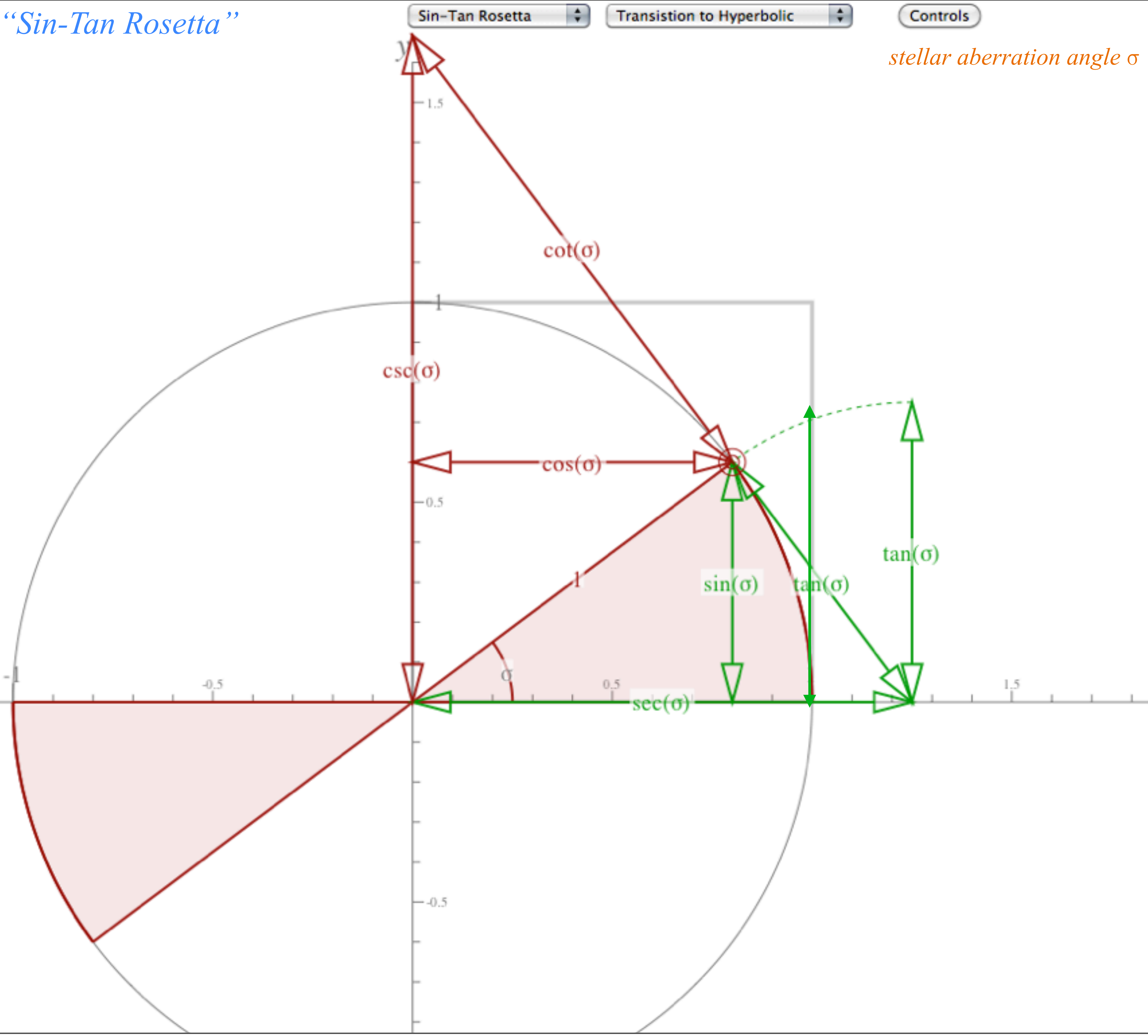
stellar aberration angle σ

Circular Functions

$m\angle(\sigma) = 0.6435$
Length(σ) = 0.6435
Area(σ) = 0.6435

sin(σ) = 0.6000
tan(σ) = 0.7500
sec(σ) = 1.2500

cos(σ) = 0.8000
cot(σ) = 1.3333
csc(σ) = 1.6667



"Sin-Tan Rosetta"

Sin-Tan Rosetta | Transistion to Hyperbolic | Controls

Circular Functions

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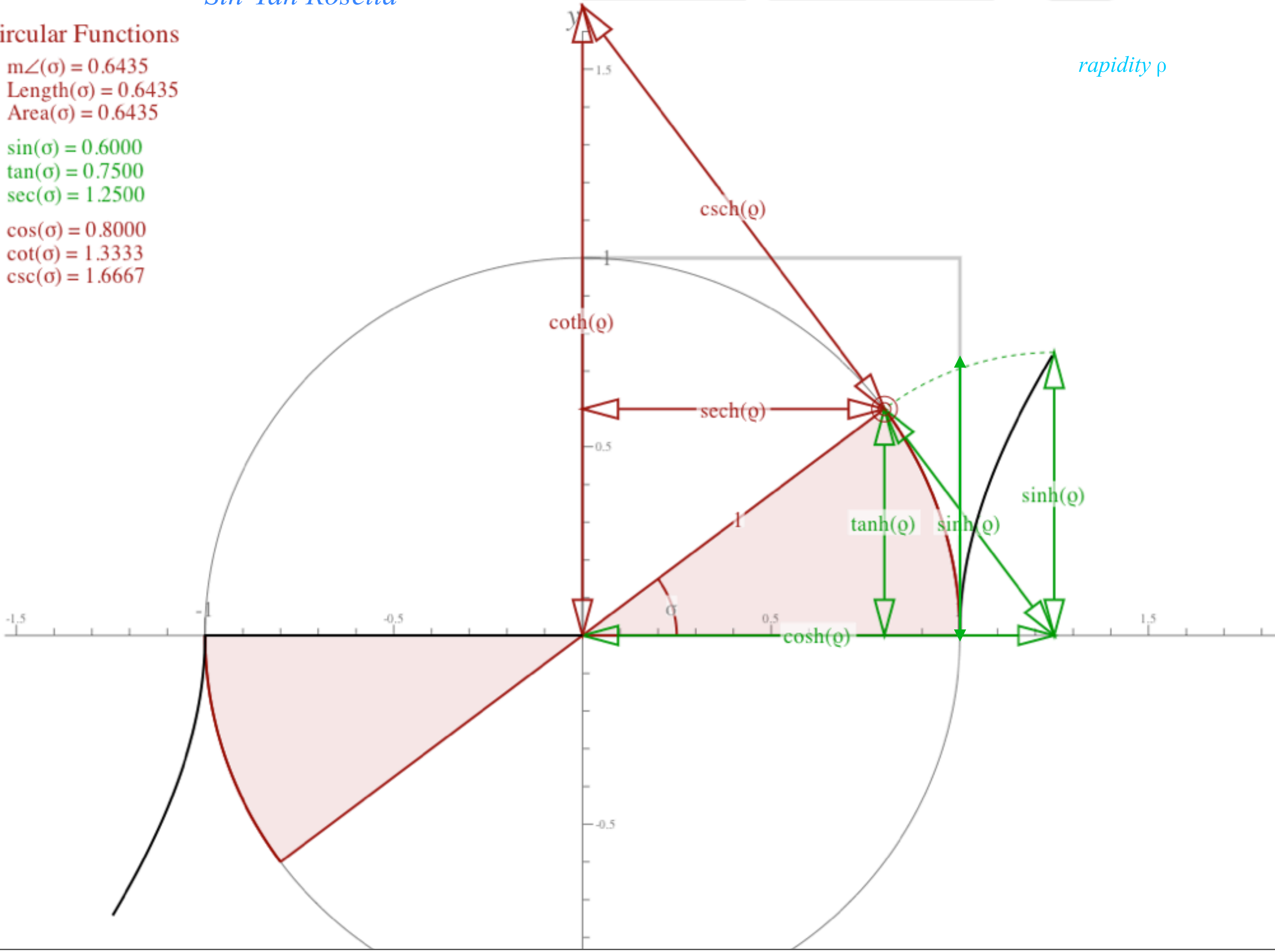
rapidity ρ



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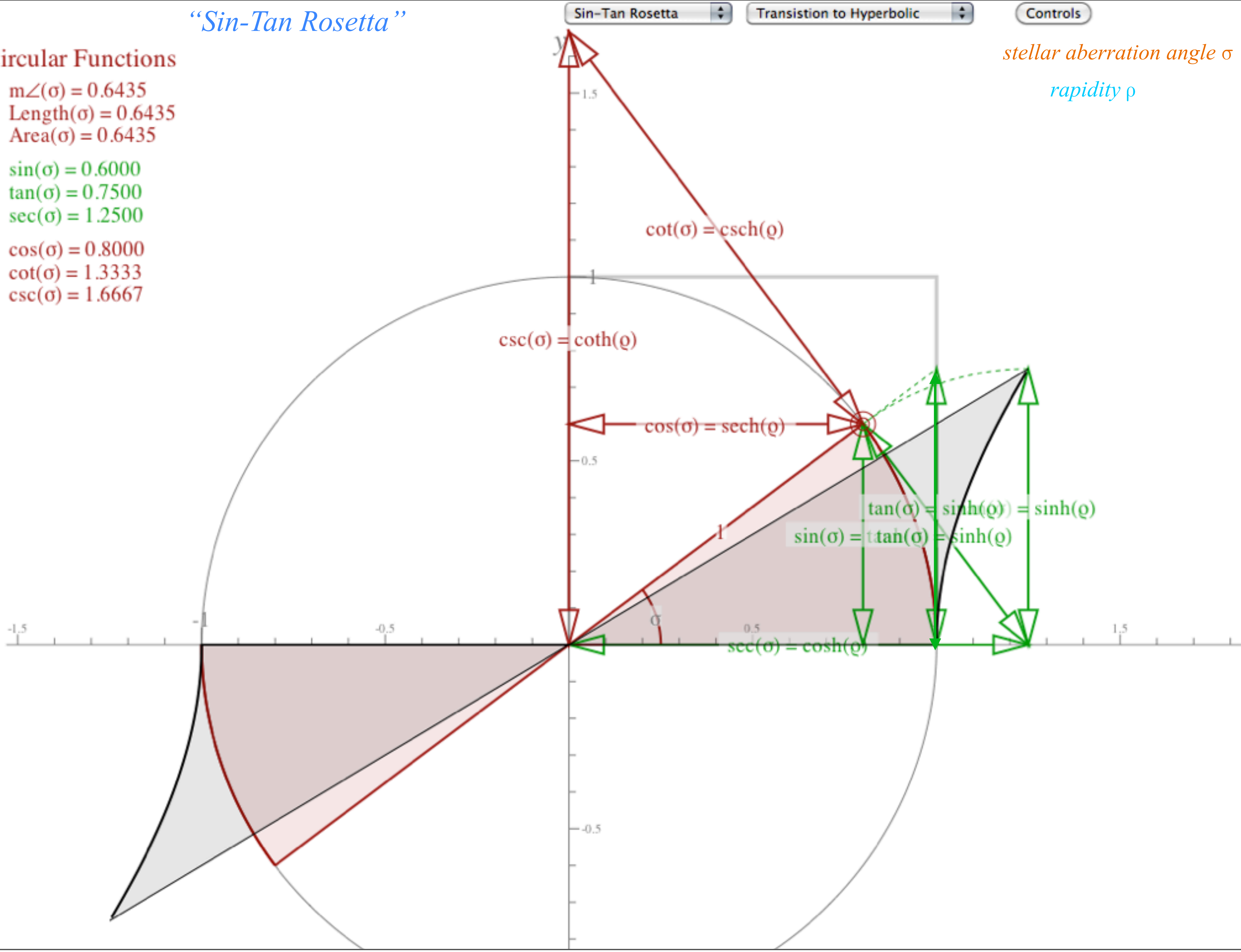

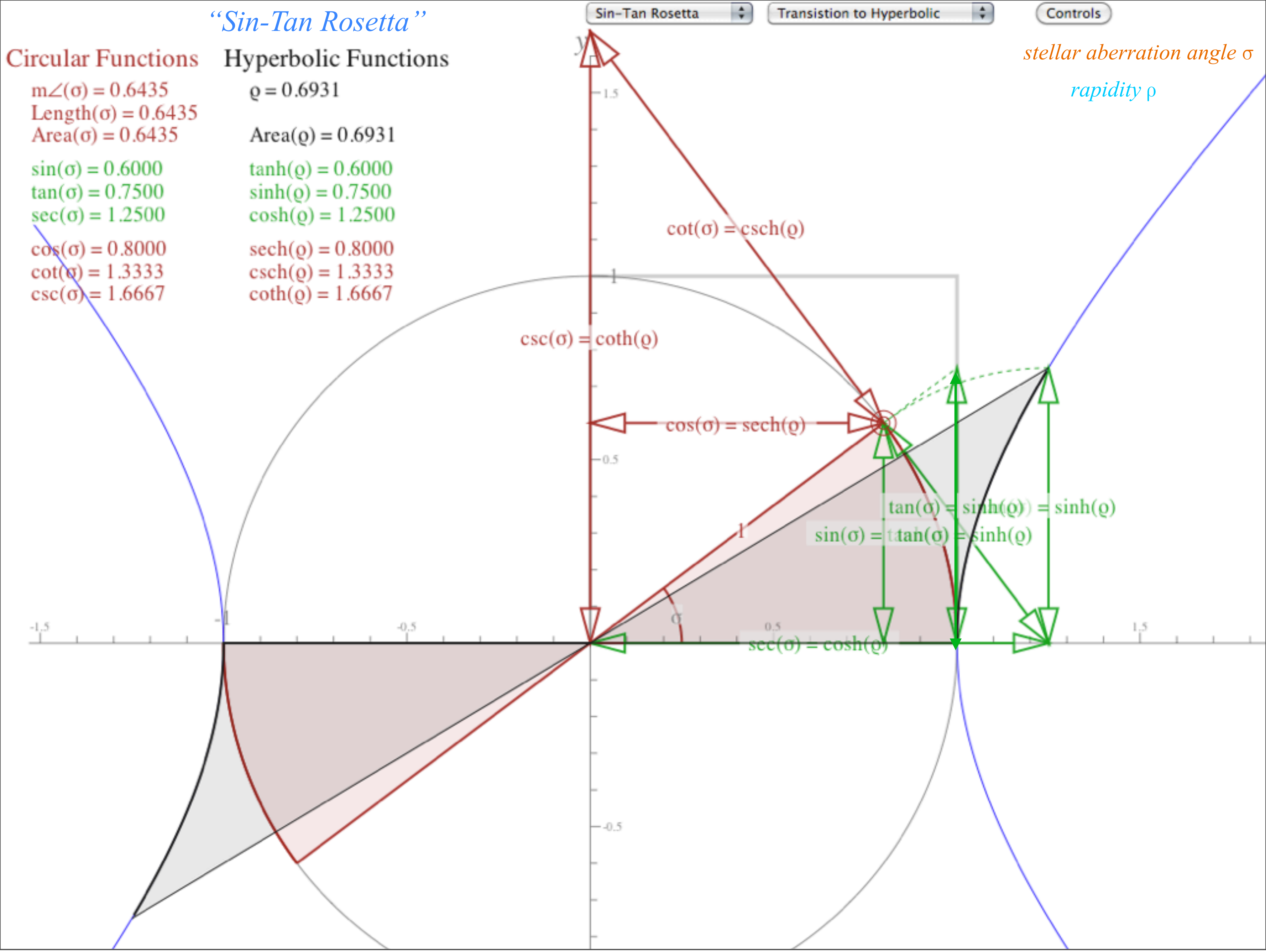

"Sin-Tan Rosetta"
Sin-Tan Rosetta
Transistion to Hyperbolic
Controls
Circular Functions
Hyperbolic Functions
m∠(σ) = 0.6435
Length(σ) = 0.6435
Area(σ) = 0.6435
ϱ = 0.6931
Area(ϱ) = 0.6931
sin(σ) = 0.6000
tan(σ) = 0.7500
sec(σ) = 1.2500
tanh(ϱ) = 0.6000
sinh(ϱ) = 0.7500
cosh(ϱ) = 1.2500
cos(σ) = 0.8000
cot(σ) = 1.3333
csc(σ) = 1.6667
sech(ϱ) = 0.8000
csch(ϱ) = 1.3333
coth(ϱ) = 1.6667
stellar aberration angle σ
rapidity ρ
cot(σ) = csch(ϱ)
csc(σ) = coth(ϱ)
cos(σ) = sech(ϱ)
tan(σ) = sinh(ϱ)
sin(σ) = tanh(ϱ)
sec(σ) = cosh(ϱ)

Relativistic Classical and Quantum Mechanics

Review of group velocity vs. phase velocity and tangent contacts

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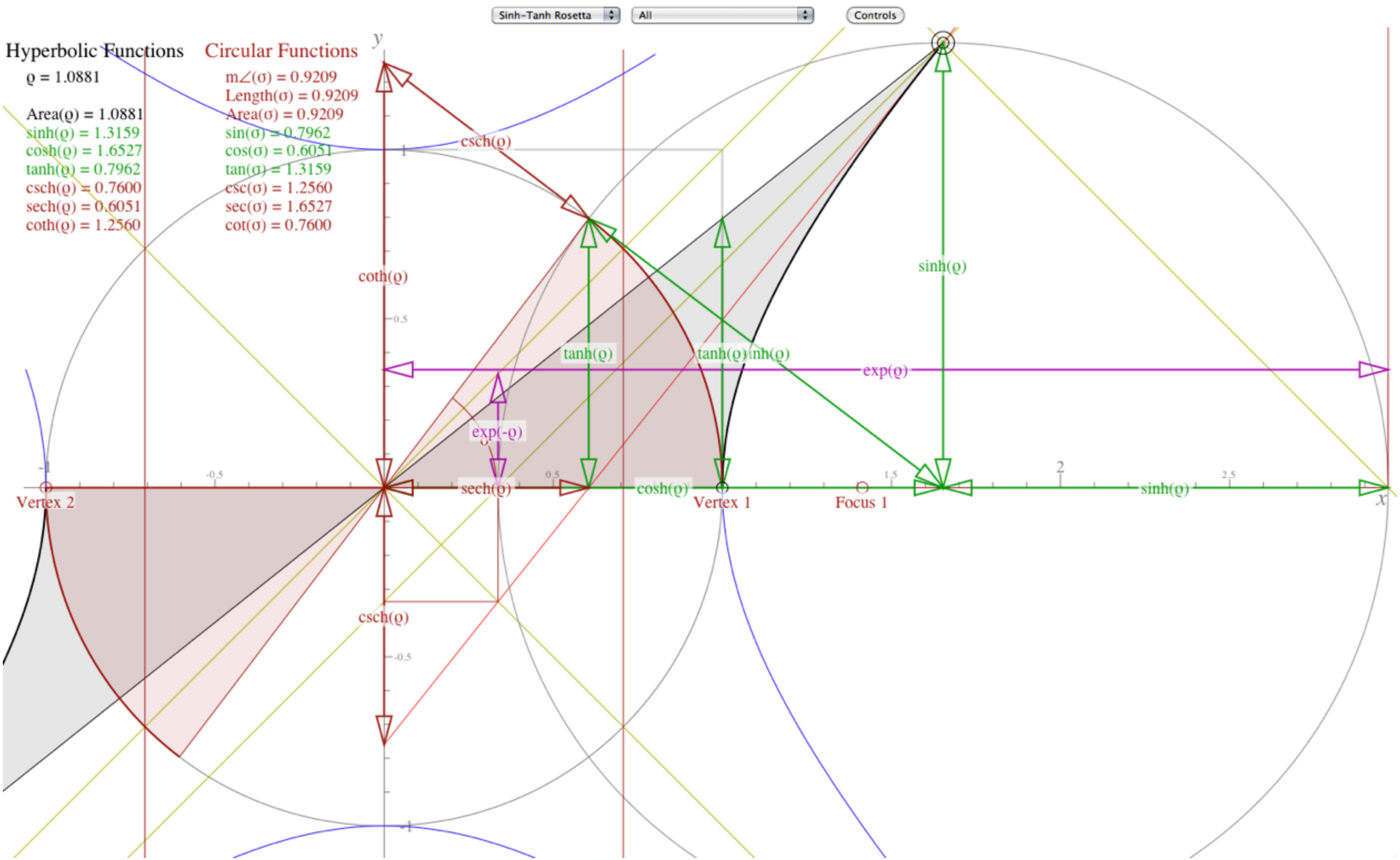
"Sinh-Tanh" geometry

"Per-Space-Time" geometry

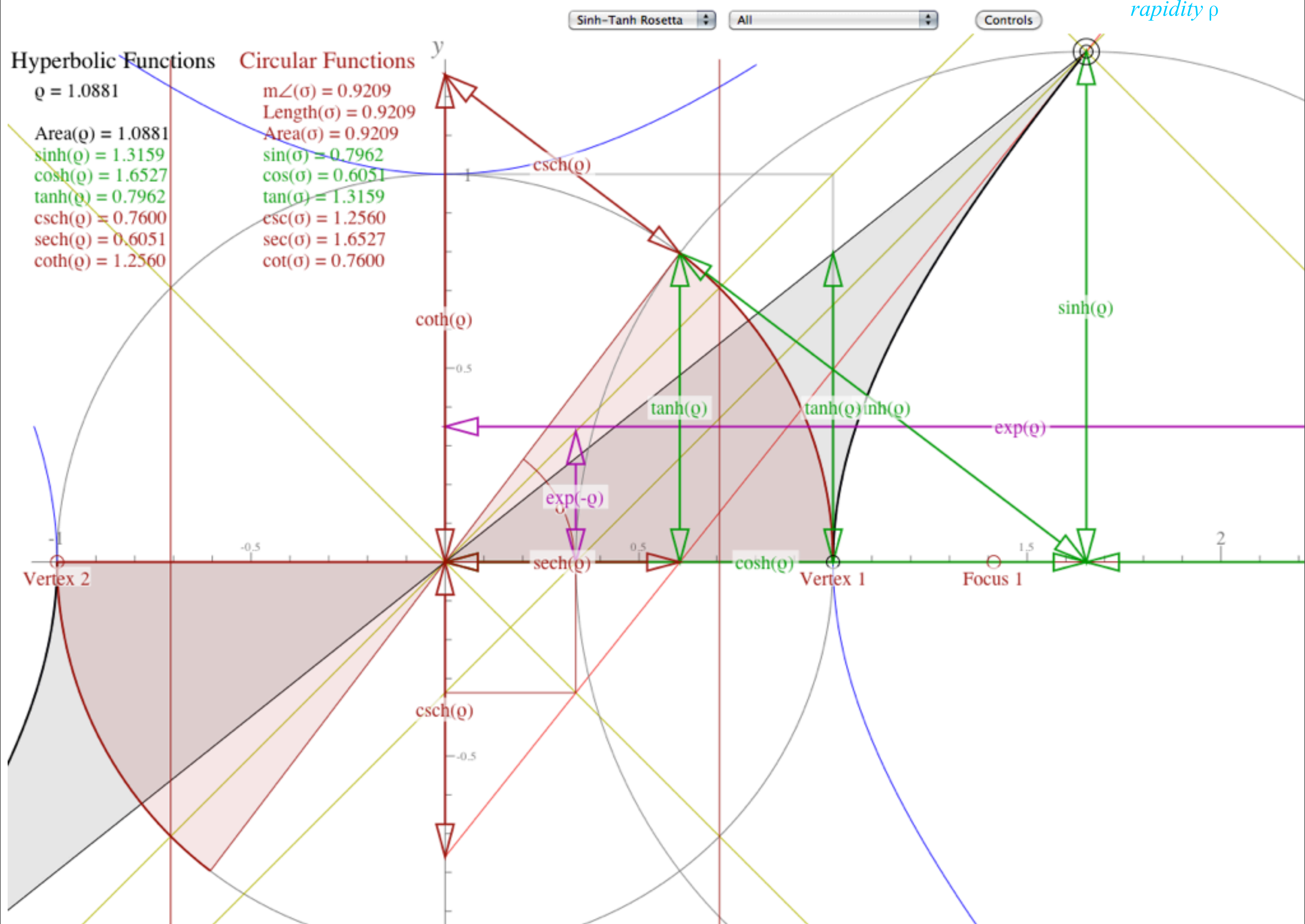
The rare case where group velocity is both $\Delta\omega/\Delta k$ and $d\omega/dk$

The "Sinh-Tanh Rosetta"

rapidity ρ



The "Sinh-Tanh Rosetta"



Relativistic Classical and Quantum Mechanics

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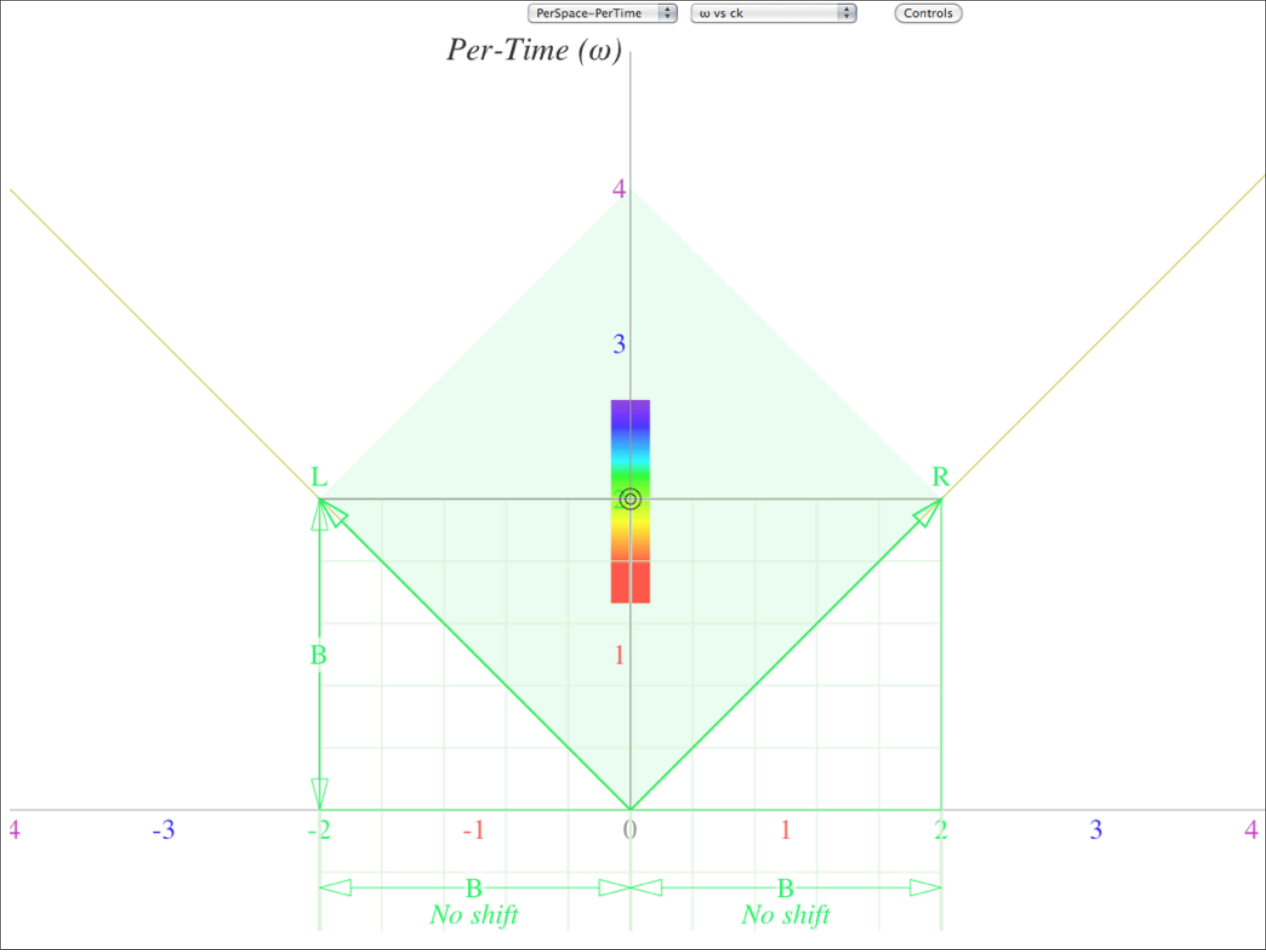
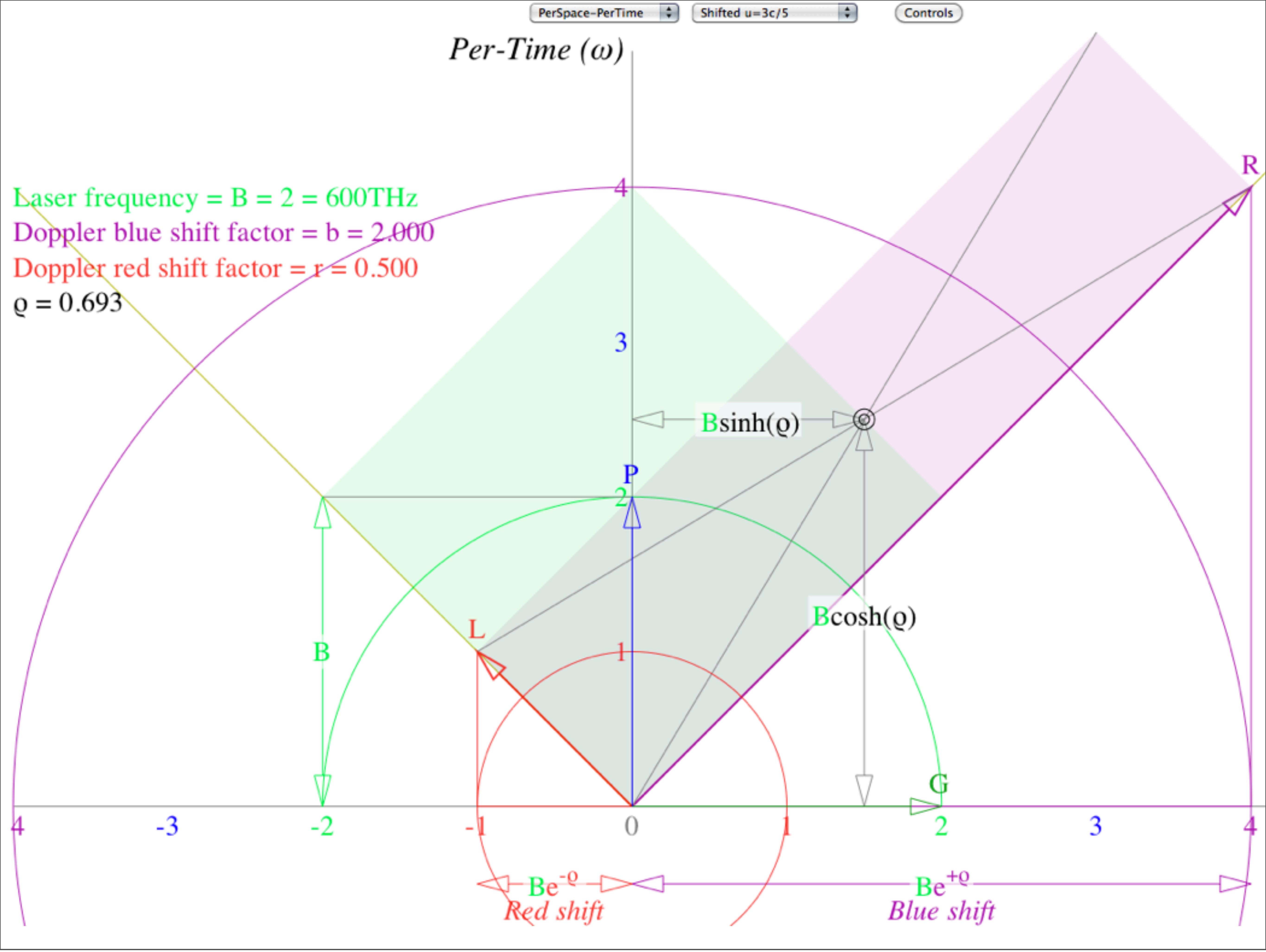
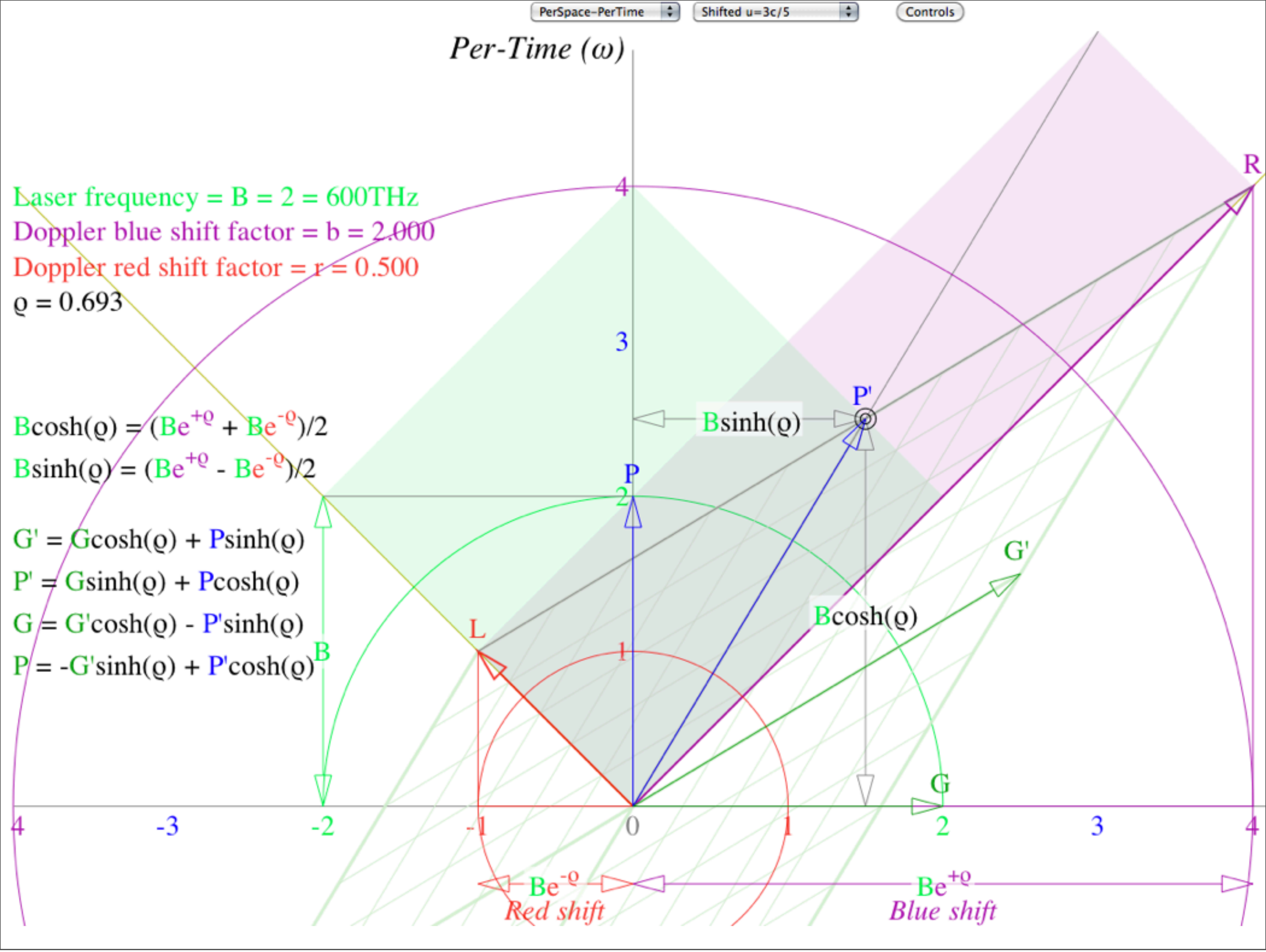
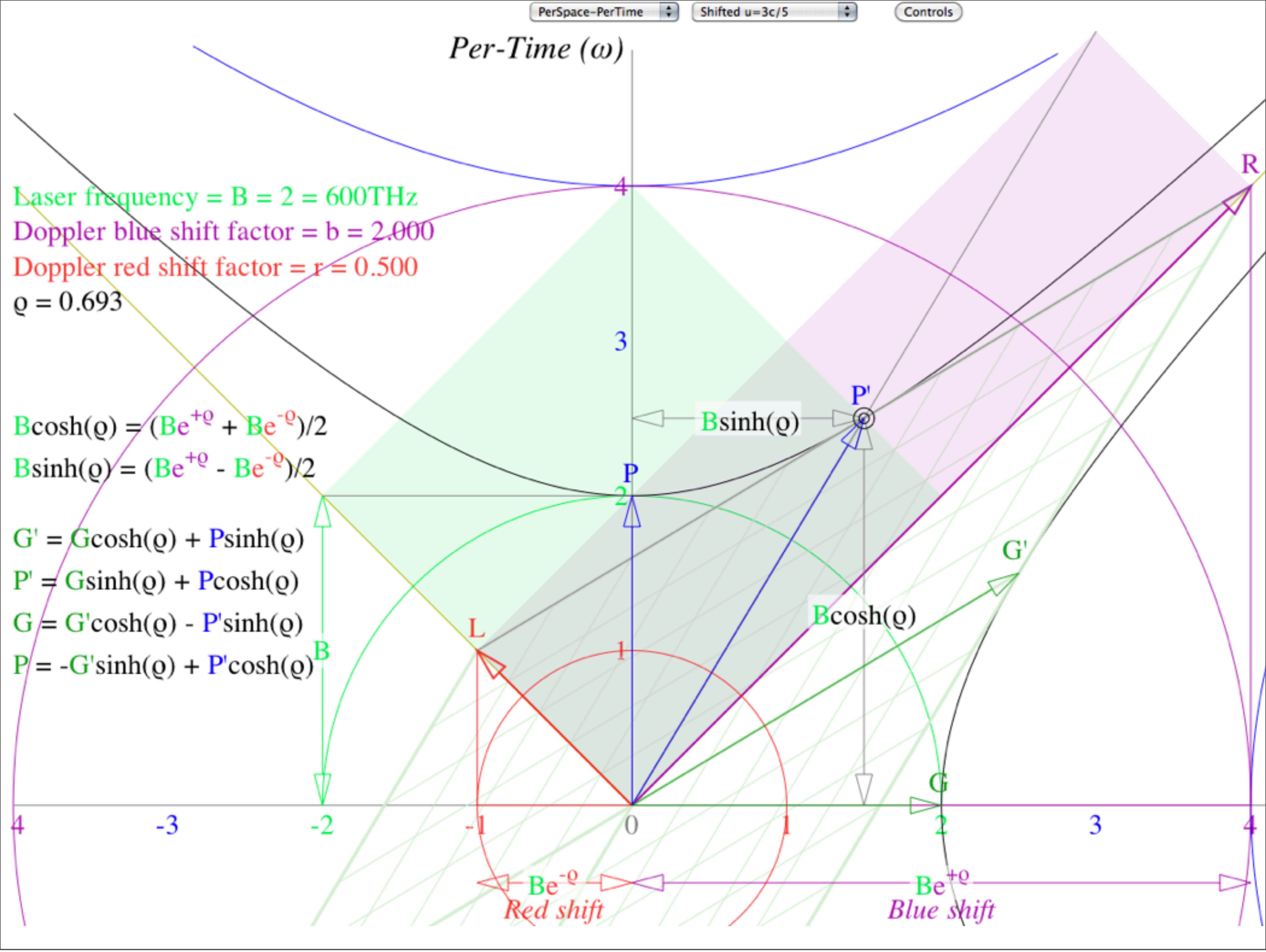


PerSpace-PerTime
ω vs ck
Controls
Per-Time (ω)
4
3
L
R
B
1
-4
-3
-2
-1
0
1
2
3
4
B
No shift
B
No shift

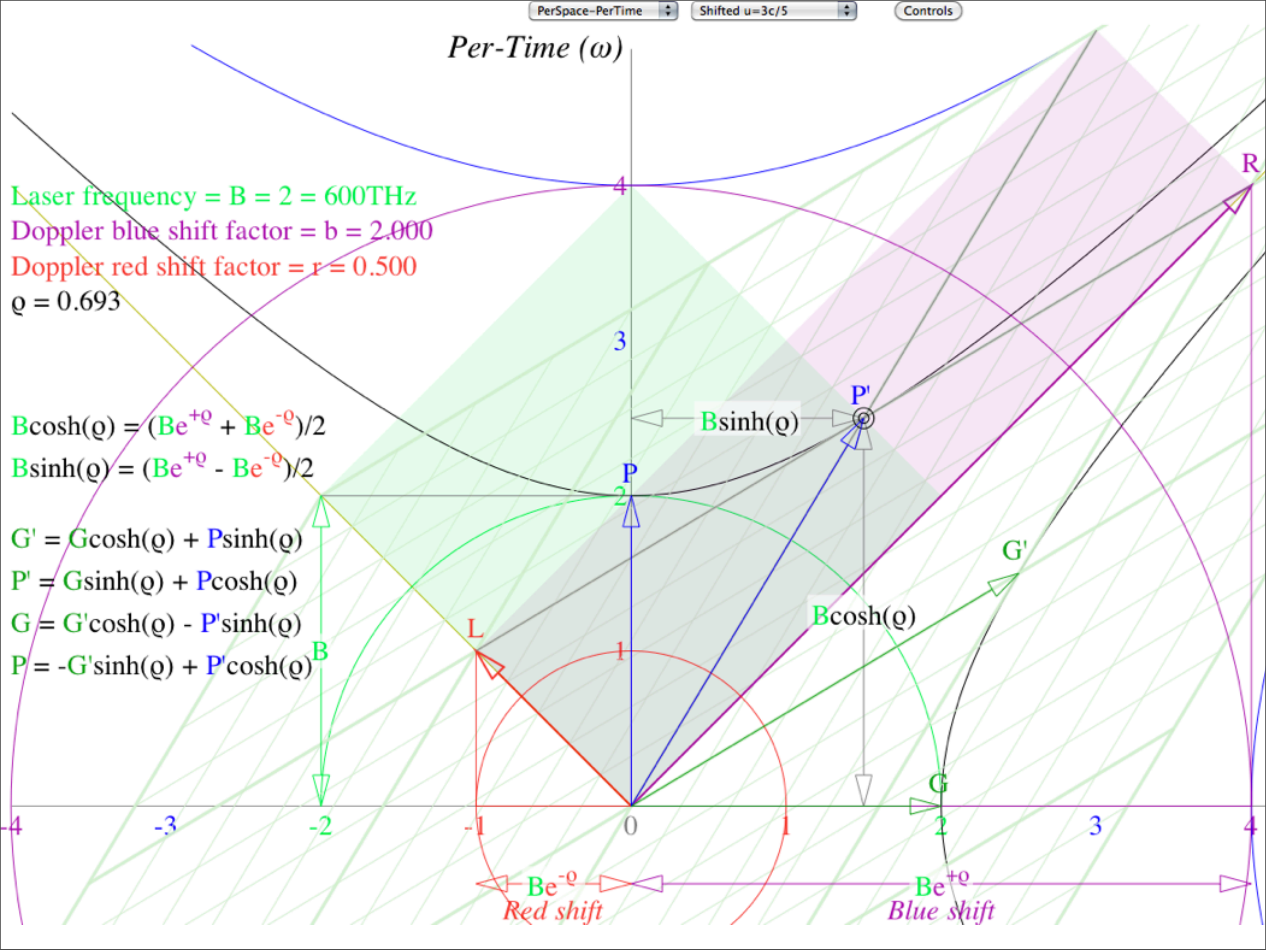

PerSpace-PerTime
Shifted u=3c/5
Controls
Per-Time (ω)
Laser frequency = B = 2 = 600THz
Doppler blue shift factor = b = 2.000
Doppler red shift factor = r = 0.500
ϱ = 0.693
Bsinh(ϱ)
Bcosh(ϱ)
R
P
L
B
G
Be-ϱ
Red shift
Be+ϱ
Blue shift



PerSpace-PerTime
Shifted u=3c/5
Controls
Per-Time (ω)
Laser frequency = B = 2 = 600THz
Doppler blue shift factor = b = 2.000
Doppler red shift factor = r = 0.500
ϱ = 0.693
Bcosh(ϱ) = (Be^{+ϱ} + Be^{-ϱ})/2
Bsinh(ϱ) = (Be^{+ϱ} - Be^{-ϱ})/2
G' = Gcosh(ϱ) + Psinh(ϱ)
P' = Gsinh(ϱ) + Pcosh(ϱ)
G = G'cosh(ϱ) - P'sinh(ϱ)
P = -G'sinh(ϱ) + P'cosh(ϱ)
R
P'
Bsinh(ϱ)
P
G'
Bcosh(ϱ)
L
B
G
4
3
2
1
-4
-3
-2
-1
0
1
2
3
4
Be^{-ϱ}
Red shift
Be^{+ϱ}
Blue shift



PerSpace-PerTime
Shifted u=3c/5
Controls
Per-Time (ω)
Laser frequency = B = 2 = 600THz
Doppler blue shift factor = b = 2.000
Doppler red shift factor = r = 0.500
ρ = 0.693
Bcosh(ρ) = (Be^+ρ + Be^-ρ)/2
Bsinh(ρ) = (Be^+ρ - Be^-ρ)/2
G' = Gcosh(ρ) + Psinh(ρ)
P' = Gsinh(ρ) + Pcosh(ρ)
G = G'cosh(ρ) - P'sinh(ρ)
P = -G'sinh(ρ) + P'cosh(ρ)
Bsinh(ρ)
Bcosh(ρ)
P'
P
G'
G
L
R
B
Be^-ρ
Red shift
Be^+ρ
Blue shift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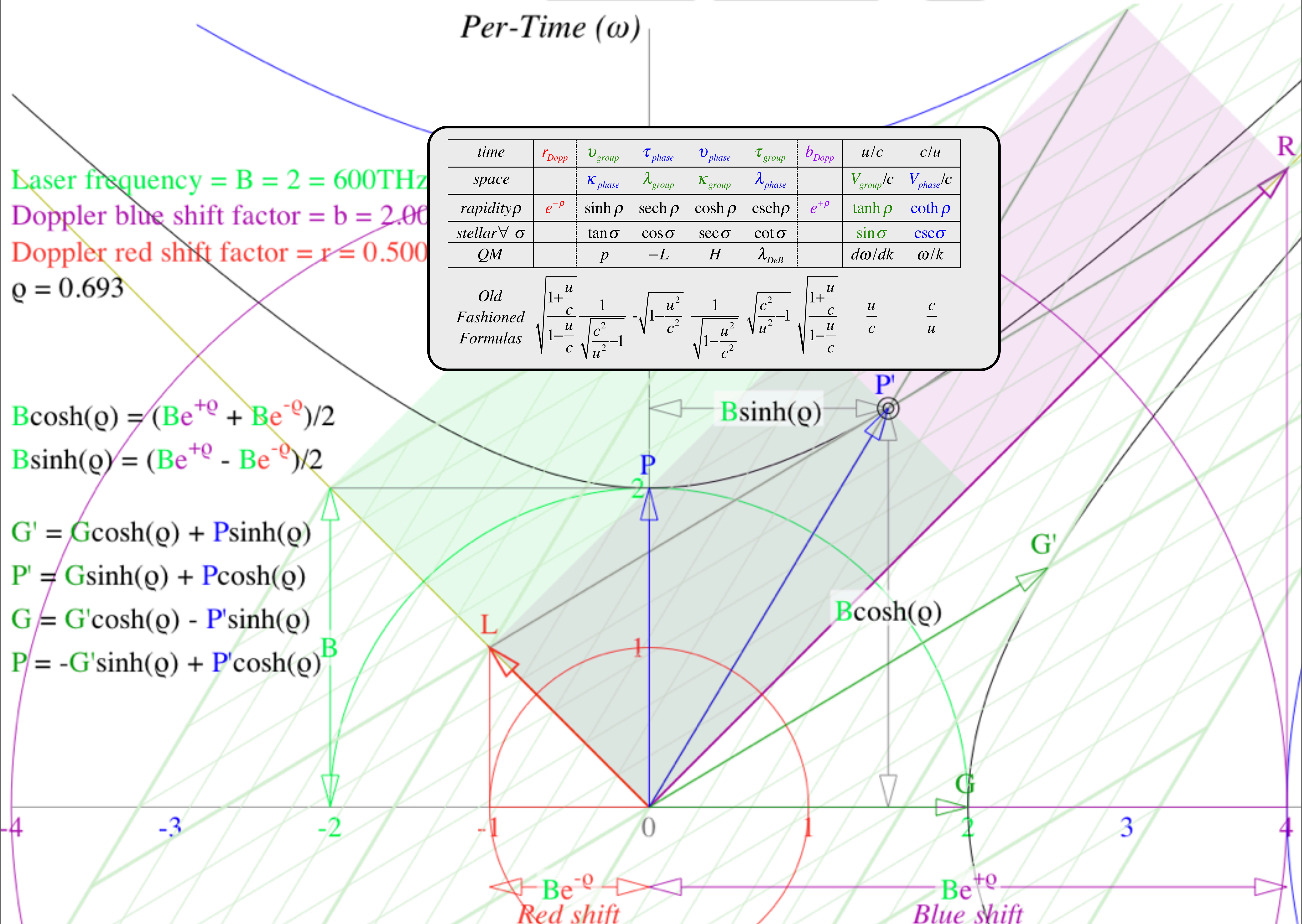
G = G'cosh(ϱ) - P'sinh(ϱ)
P = -G'sinh(ϱ) + P'cosh(ϱ)
Bsinh(ϱ)
Bcosh(ϱ)
P'
P
G'
G
L
B
R
Be^-ϱ
Red shift
Be^+ϱ
Blue shift
-4
-3
-2
-1
0
1
2
3
4



time	r_{Dopp}	υ_{group}	τ_{phase}	υ_{phase}	τ_{group}	b_{Dopp}	u/c	c/u
space		κ_{phase}	λ_{group}	κ_{group}	λ_{phase}		V_{group}/c	V_{phase}/c
rapidity ρ	$e^{-\rho}$	$\sinh\rho$	$\operatorname{sech}\rho$	$\cosh\rho$	$\operatorname{csch}\rho$	$e^{+\rho}$	$\tanh\rho$	$\coth\rho$
stellar∀ σ		$\tan\sigma$	$\cos\sigma$	$\sec\sigma$	$\cot\sigma$		$\sin\sigma$	$\csc\sigma$
QM		p	$-L$	H	λ_{DeB}		$d\omega/dk$	ω/k
Old Fashioned Formulas	$\sqrt{\frac{1+\frac{u}{c}}{1-\frac{u}{c}}}$	$\frac{1}{\sqrt{\frac{c^2}{u^2}-1}}$	$-\sqrt{1-\frac{u^2}{c^2}}$	$\frac{1}{\sqrt{1-\frac{u^2}{c^2}}}$	$\sqrt{\frac{c^2}{u^2}-1}$	$\sqrt{\frac{1+\frac{u}{c}}{1-\frac{u}{c}}}$	$\frac{u}{c}$	$\frac{c}{u}$

Per-space-time has Minkowski coordinates, too!

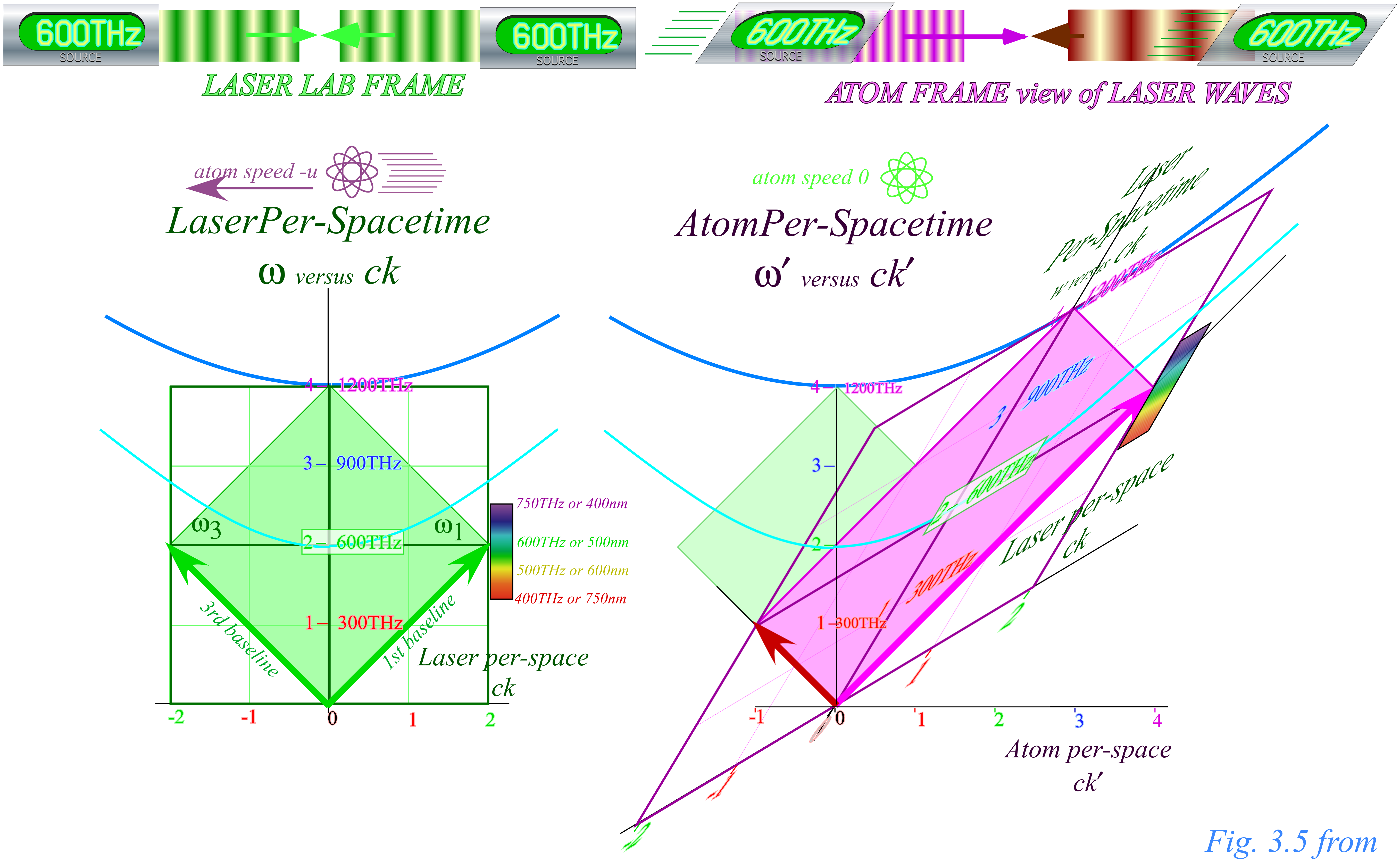


Fig. 8.3.5 Dispersion hyperbolas for 2-CW interference (a) Laser lab view. (b)Atom frame view.

Fig. 3.5 from CMwBang! Ch. 3 of Unit 8.

Relativistic Classical and Quantum Mechanics

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Group velocity u and phase velocity c^2/u are hyperbolic tangent slopes

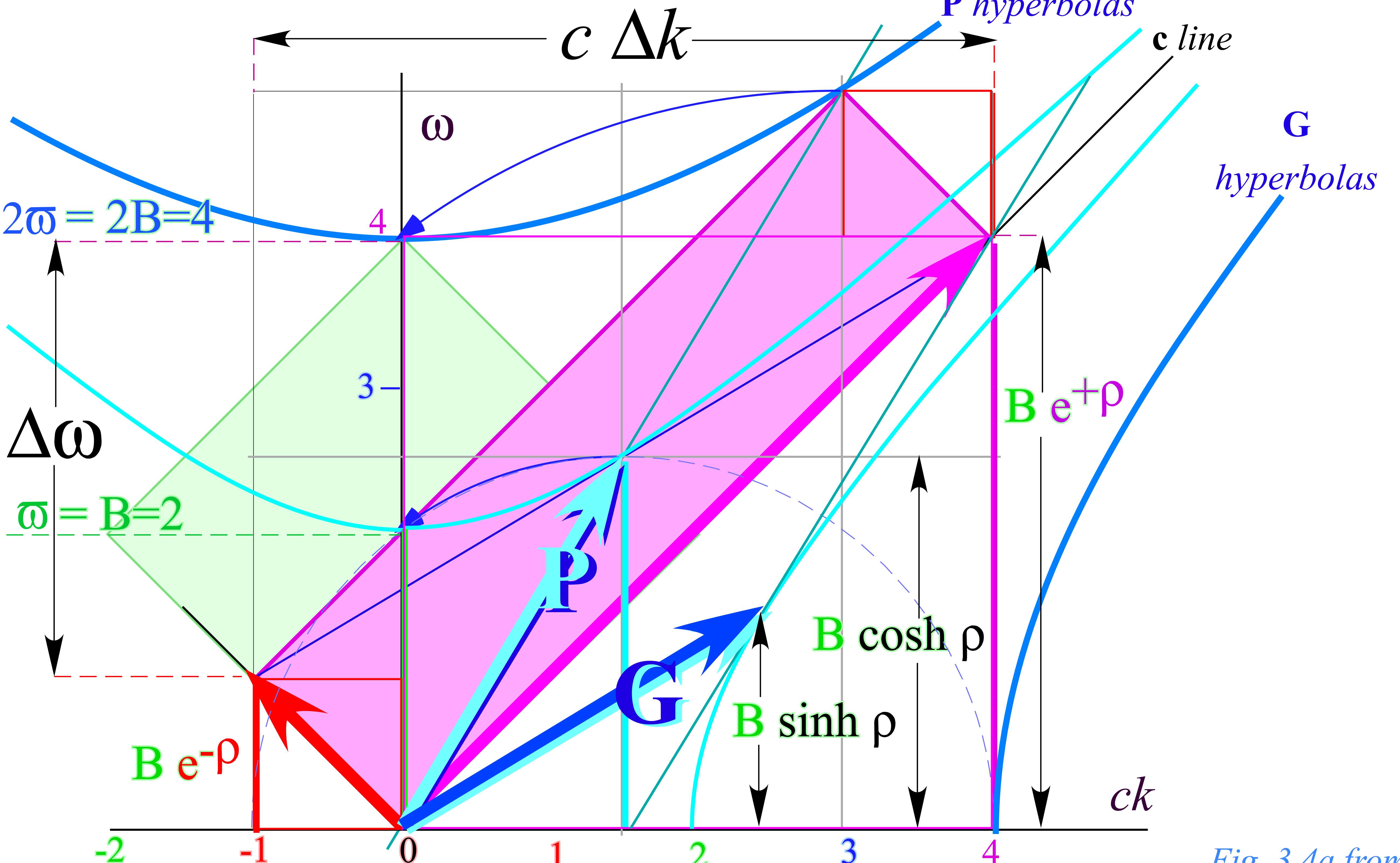


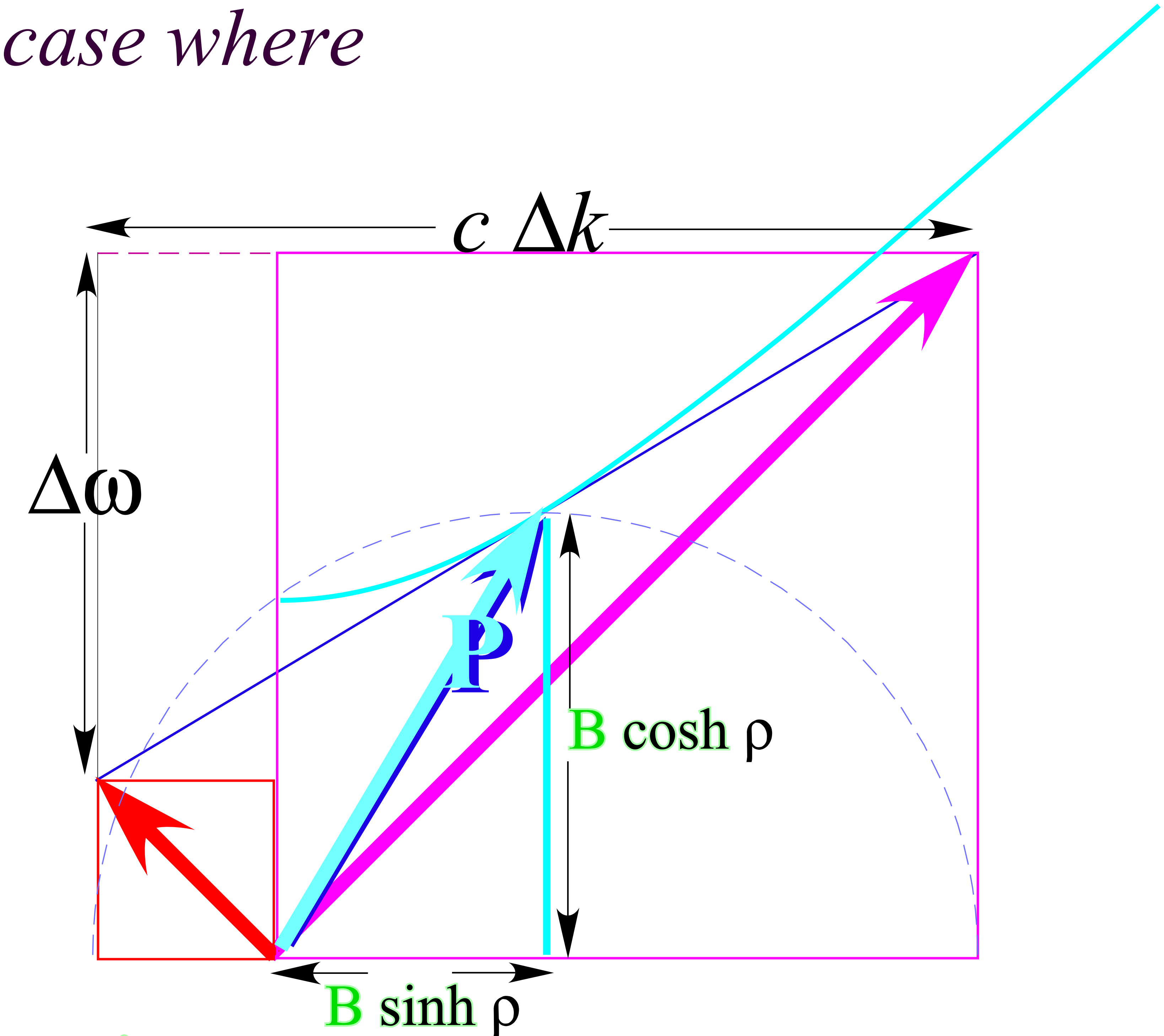
Fig. 3.4a from CMwBang! Ch. 3 of Unit 8.

Group velocity u *and phase velocity* c^2/u *are hyperbolic tangent slopes*

Rare but important case where

$$\frac{d\omega}{dk} = \frac{\Delta\omega}{\Delta k}$$

with LARGE Δk *(not infinitesimal)*



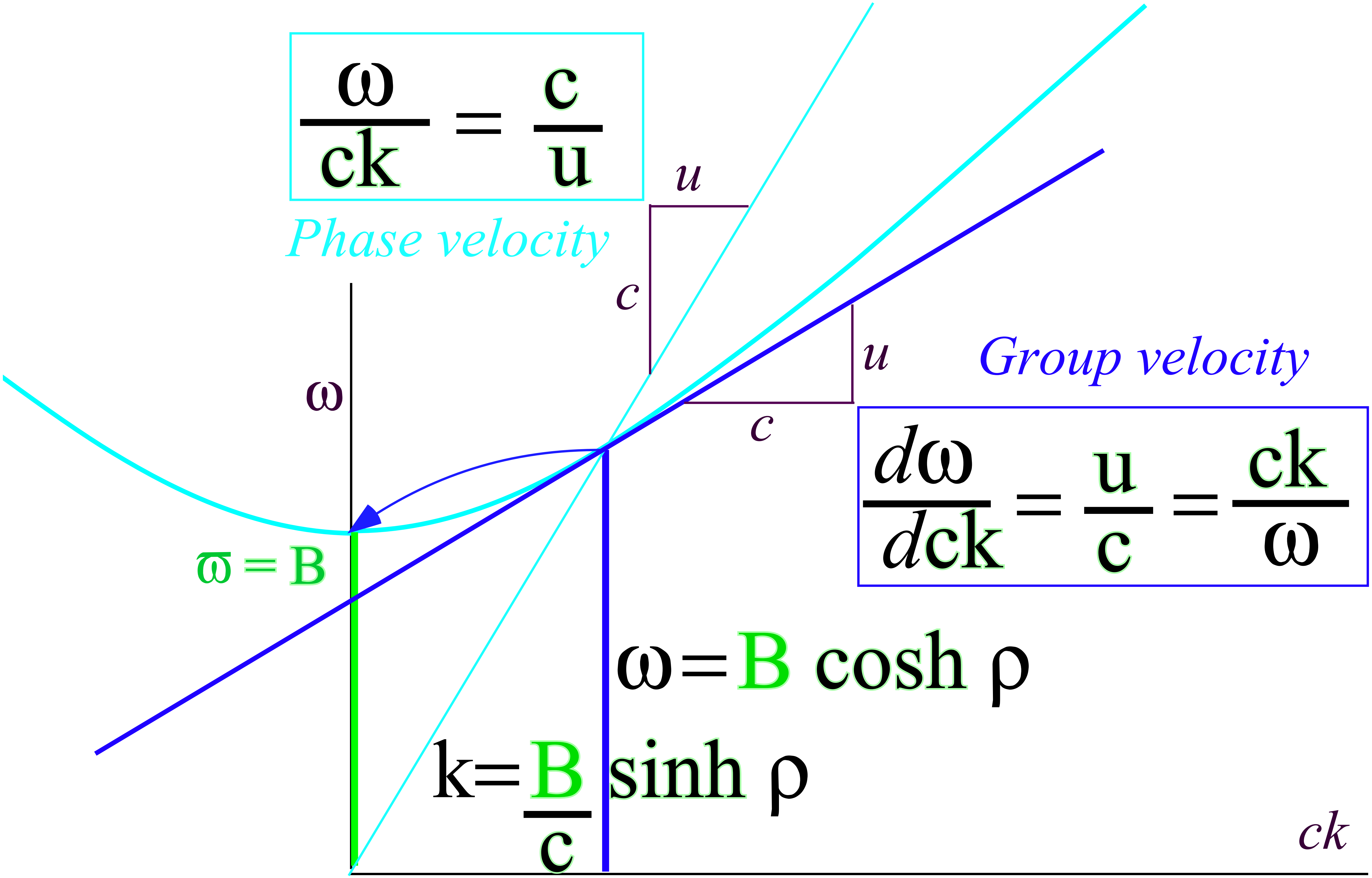
Relativistic group wave speed $u=c \tanh \rho$

Low speed approximation

Newtonian speed $u \sim c\rho$

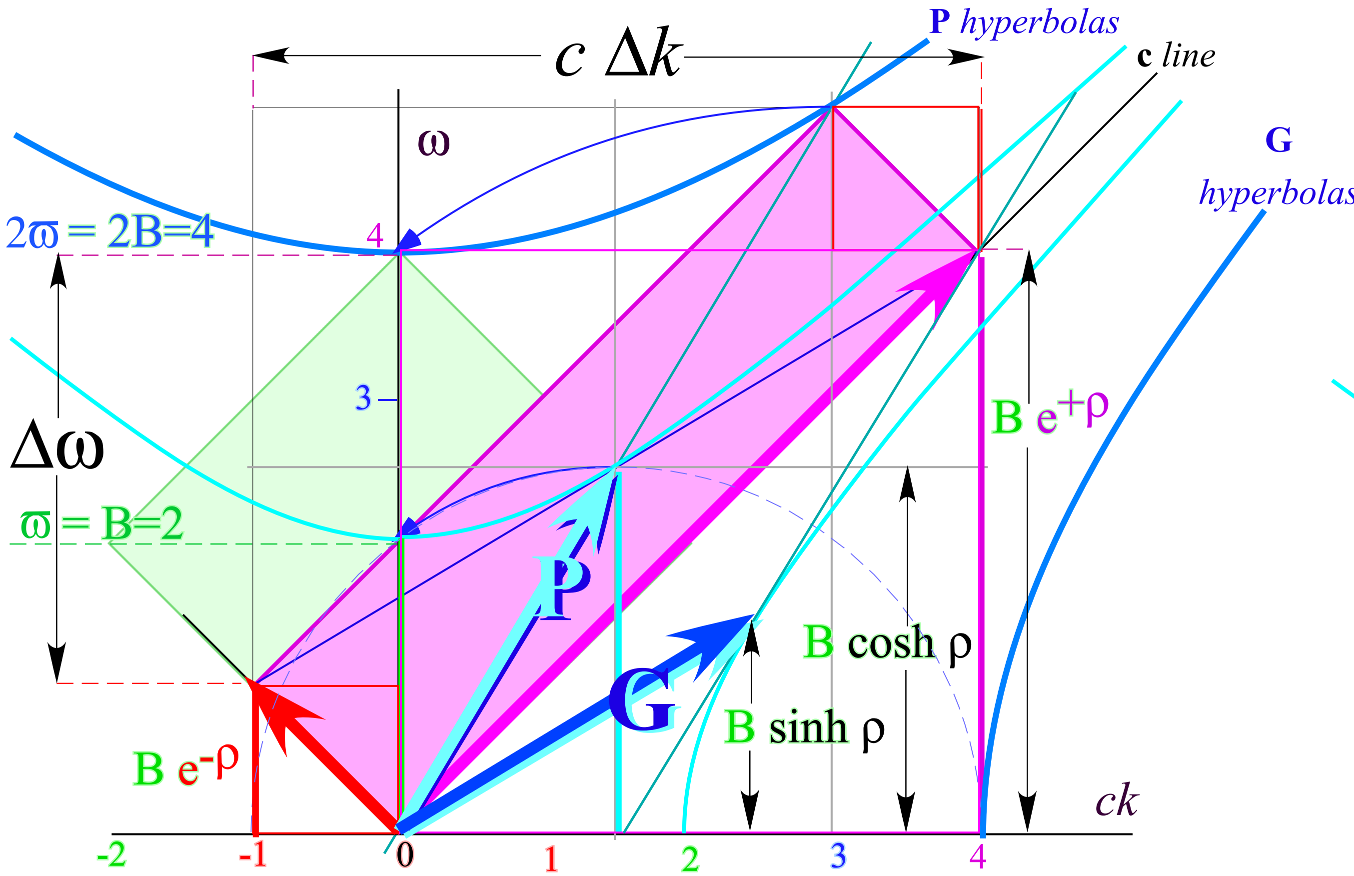
Rapidity ρ *approaches* u/c

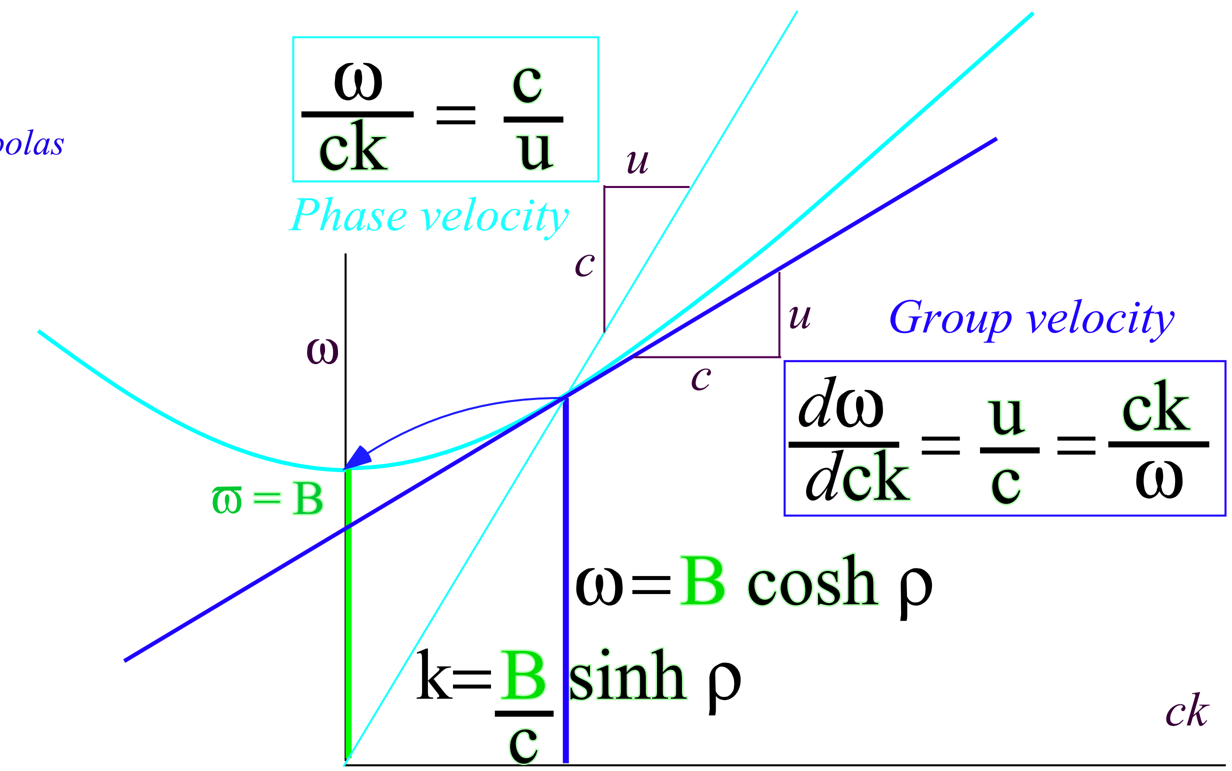
Group velocity u *and phase velocity* c^2/u *are hyperbolic tangent slopes*



Group velocity u *and phase velocity* c^2/u *are hyperbolic tangent slopes*

Fig. 3.4 from CMwBang! Ch. 3 of Unit 8.





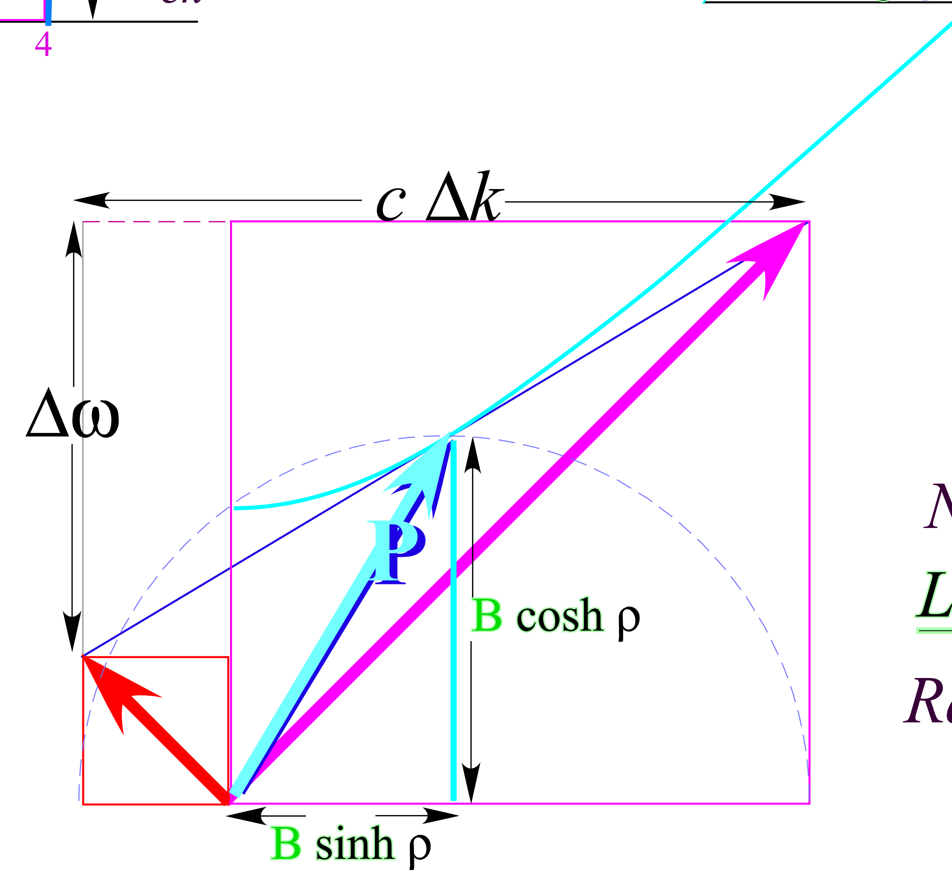
Rare but important case where

$$\frac{d\omega}{dk} = \frac{\Delta\omega}{\Delta k}$$

with LARGE Δk

(not infinitesimal)

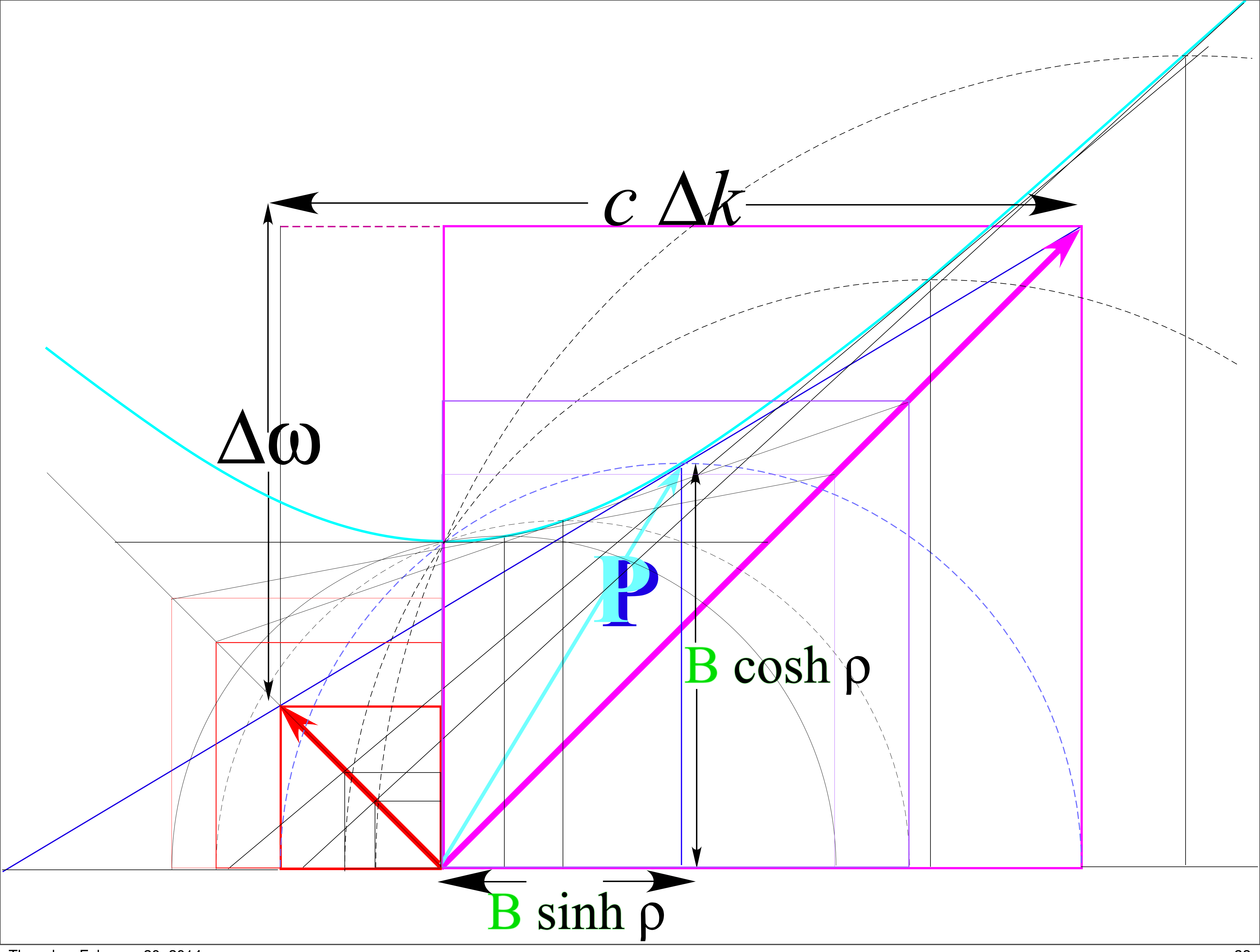
Relativistic group wave speed $u=c \tanh \rho$



Newtonian speed $u \sim c\rho$

Low speed approximation

Rapidity ρ *approaches* u/c



c Δk
Δω
P
B cosh ρ
B sinh ρ

Relativistic Classical and Quantum Mechanics

- *How optical CW group and phase properties give relativistic mechanics*
  - *What's the Matter with Mass?*
    - *Brief look at Higgs*
  - *Three kinds of mass (Einstein rest mass, Galilean momentum mass, Newtonian inertial mass)*
    - *What's the matter with light?*
- *Bohr-Schrodinger (BS) approximation throws out Mc^2*

Start with low speed approximations : $\omega = B\cosh\rho = B(1+\frac{1}{2}\rho^2+...)$ where: $\rho \simeq \frac{u}{c}$

CW Axioms (“All colors go c.” and “r=1/b) imply hyperbolic dispersion then mechanics of matter

$$\omega = B\cosh\rho \cong B + \frac{1}{2}\frac{B}{c^2}u^2$$

These follow from CW axioms

$$k = \frac{B}{c}\sinh\rho \cong \frac{B}{c^2}u$$

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$$\omega = B\cosh\rho \cong B + \frac{1}{2}\frac{B}{c^2}u^2 \qquad k = \frac{B}{c}\sinh\rho \cong \frac{B}{c^2}u$$

$$E = \text{constant} + \frac{1}{2}Mu^2 \qquad p = Mu$$

(Newton's energy) *(Galileo's momentum)*

So *2-CW*-light *frequency* ω is like *energy* *E* while *k-number* is like *momentum p*, *Start with low speed approximations:* $\omega = B\cosh\rho = B(1+\frac{1}{2}\rho^2+\ldots)$ where: $\rho \simeq \frac{u}{c}$

CW Axioms ("All colors go c." and "r=1/b") imply hyperbolic dispersion then mechanics of matter

These follow from CW axioms

$\omega = B\cosh\rho \cong B + \frac{1}{2}\frac{B}{c^2}u^2$

$k = \frac{B}{c}\sinh\rho \cong \frac{B}{c^2}u$

$E = \text{constant} + \frac{1}{2}Mu^2$ (Newton's energy)

$p = Mu$ (Galileo's momentum)

So 2-CW-light *frequency* ω is like *energy* E while *k-number* is like *momentum p*, implies *Planck's E=s·ω* scaling with factors: *s=ħ=s equal* to *DeBroglie's p=s·k*.

$E = s\omega = sB\cosh\rho \cong sB + \frac{1}{2}\frac{sB}{c^2}u^2$

$p = sk = \frac{sB}{c}\sinh\rho \cong \frac{sB}{c^2}u$

Start with low speed approximations : $\omega = B\cosh\rho = B(1+\frac{1}{2}\rho^2+...)$ where: $\rho \simeq \frac{u}{c}$

CW Axioms ("All colors go c." and "r=1/b") imply hyperbolic dispersion then mechanics of matter

These follow from CW axioms

$$\omega = B\cosh\rho \cong B + \frac{1}{2}\frac{B}{c^2}u^2$$

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$$E = s\omega = sB\cosh\rho \cong sB + \frac{1}{2}\frac{sB}{c^2}u^2$$

$$p = sk = \frac{sB}{c}\sinh\rho \cong \frac{sB}{c^2}u$$

Both relations imply: $M = \frac{sB}{c^2}$ giving a (famous) *rest energy constant.* : $sB = Mc^2$

This then gives the famous *Einstein* *energy* *E* and also the *Einstein* *momentum p*

CW Axioms ("All colors go c." and "r=1/b) imply hyperbolic dispersion then mechanics of matter

These follow from CW axioms

$$\omega = B\cosh\rho \cong B + \frac{1}{2}\frac{B}{c^2}u^2 \qquad k = \frac{B}{c}\sinh\rho \cong \frac{B}{c^2}u$$

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Both relations imply: $M = \frac{sB}{c^2}$ giving a (famous) *rest energy constant.* : $sB = Mc^2$

This then gives the famous *Einstein energy E* and also the *Einstein momentum p*

$$E = s\omega = Mc^2\cosh\rho \cong Mc^2 + \frac{1}{2}Mu^2 \qquad p = sk = Mc\sinh\rho \cong Mu$$

$$= \frac{Mc^2}{\sqrt{1-u^2/c^2}} \qquad = \frac{Mu}{\sqrt{1-u^2/c^2}}$$

Rest energy(u=0): $\hbar B = Mc^2$

Scale factors determined by experiment

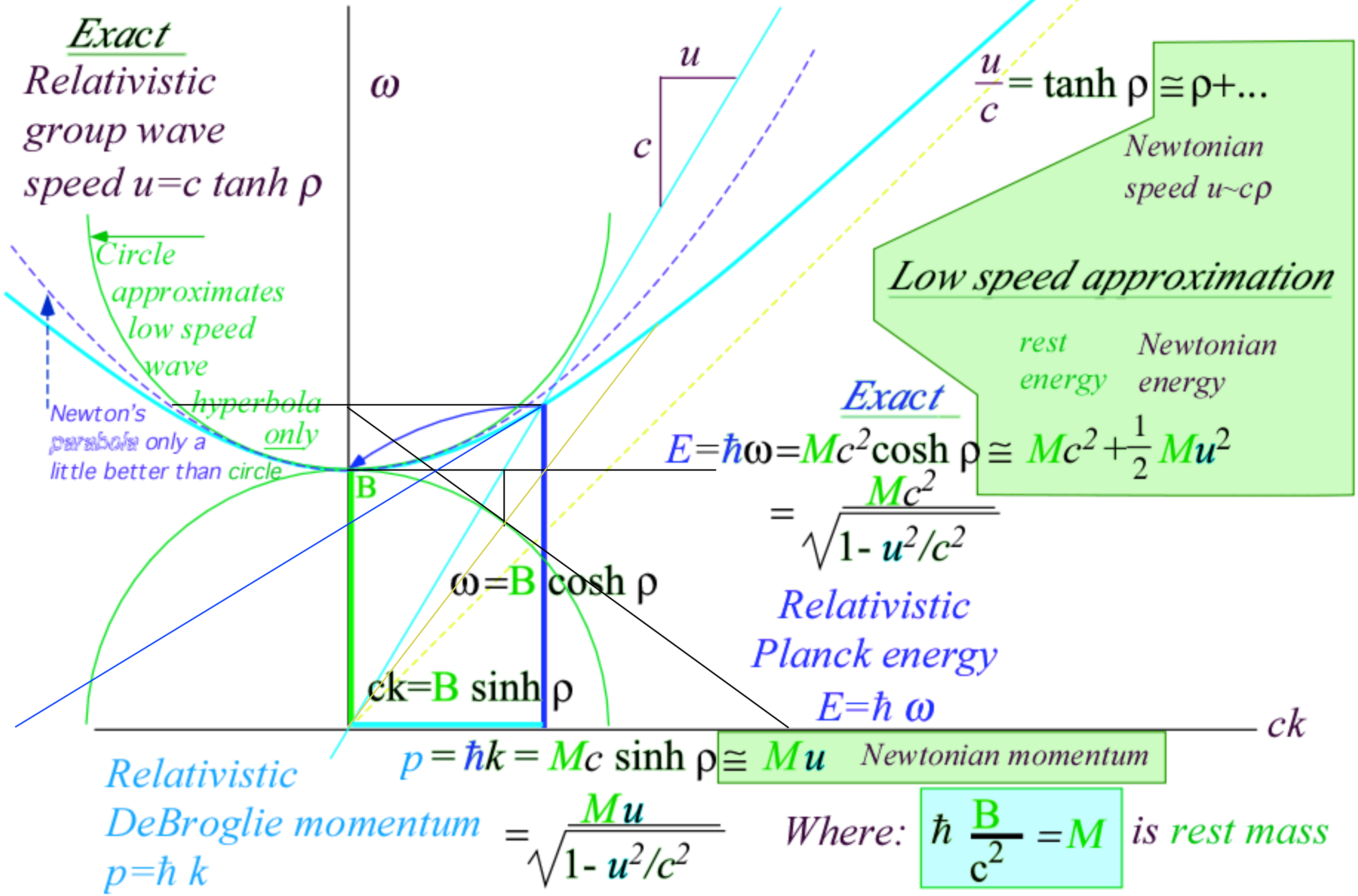
Planck's constant

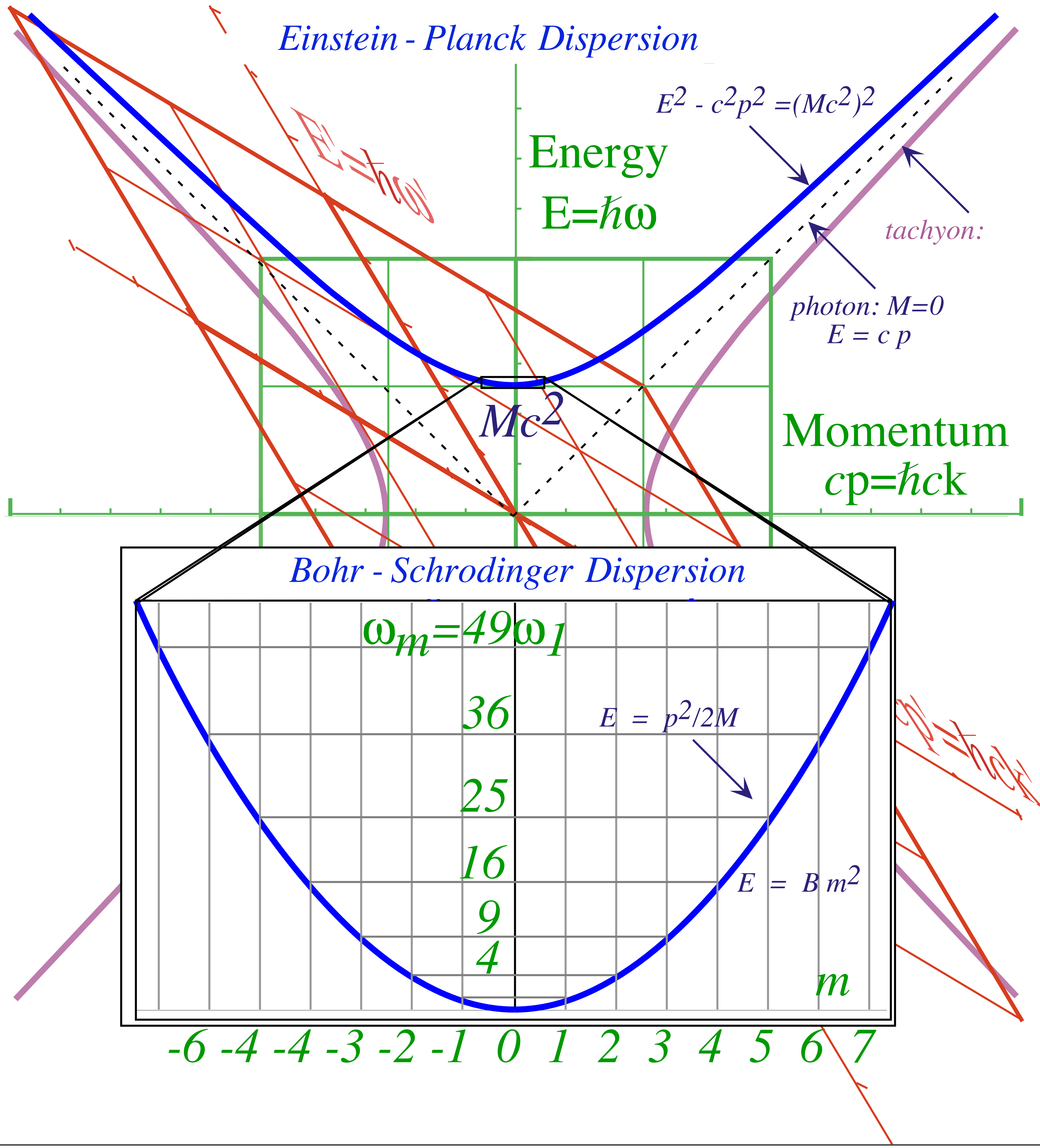
$s = \hbar = 1.054572 \cdot 10^{-34}$ *Joule·s*

$h = 6.626069 \cdot 10^{-34}$ *J·s* $= 2\pi\hbar$

Rest momentum(u=0): p=0

Summary of geometry ω-*vs*-*ck* or *E*-*vs*-*cp* relations with velocity *u* or rapidity ρ





Einstein - Planck Dispersion
$E^2 - c^2p^2 = (Mc^2)^2$
Energy
$E=\hbar\omega$
tachyon:
photon: M=0
$E = c p$
Mc^2
Momentum
$cp=\hbar ck$
Bohr - Schrodinger Dispersion
$\omega_m=49\omega_1$
36
25
16
9
4
$E = p^2/2M$
$E = B m^2$
m
-6 -4 -4 -3 -2 -1 0 1 2 3 4 5 6 7

Relativistic Classical and Quantum Mechanics

How optical CW group and phase properties give relativistic mechanics

What's the Matter with Mass?

Brief look at Higgs

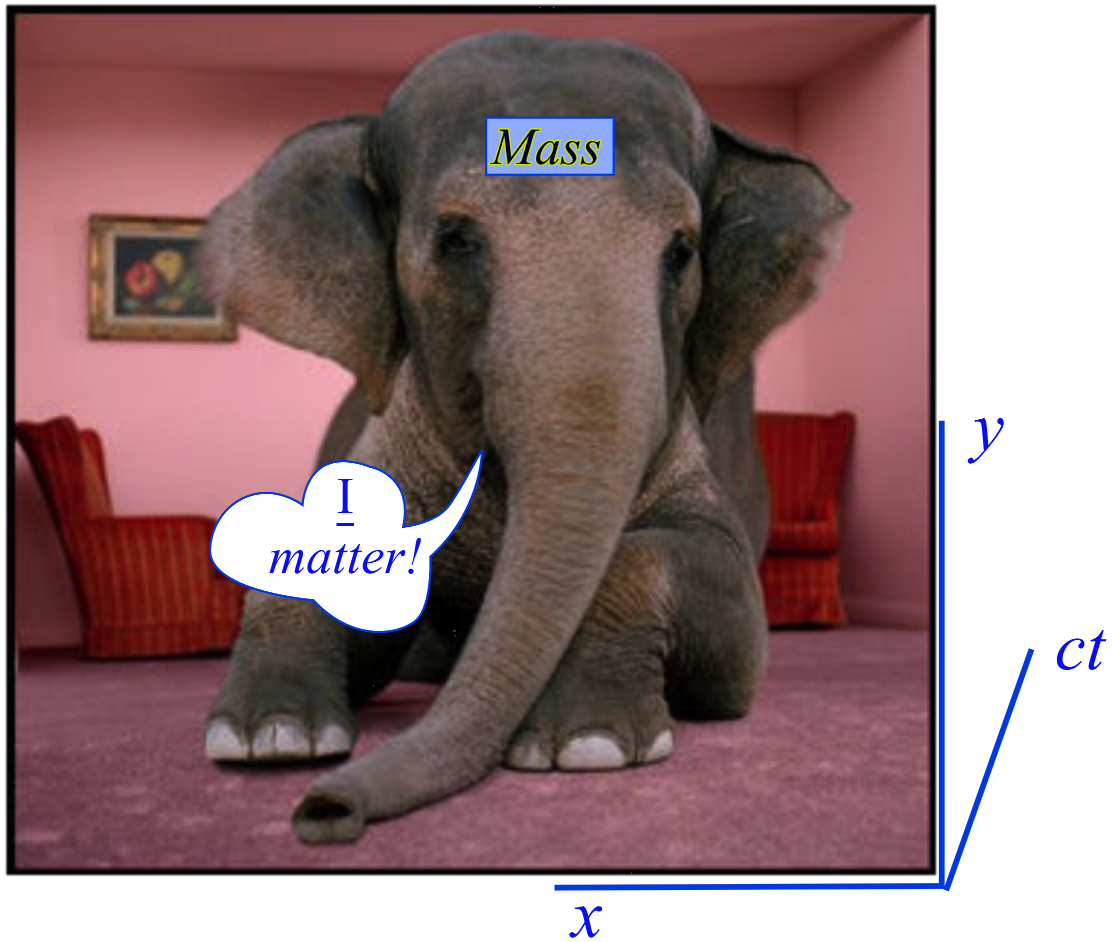
Three kinds of mass (Einstein rest mass, Galilean momentum mass, Newtonian inertial mass)

What's the matter with light?

Bohr-Schrodinger (BS) approximation throws out Mc^2

What's the matter with Mass?

Dealing with one of the elephants in the spacetime room:



A brief History of defining Mass M :

1590 Galileo's "impago"

$$M_{Galileo} = \frac{\text{Momentum}}{\text{Velocity}} = \frac{M \cdot v}{v}$$

1687 Newton's "inertia"

$$M_{Newton} = \frac{\text{Change in Momentum}}{\text{Change in Velocity}} = \frac{M \cdot a}{a}$$

1905 Einstein's "rest mass"

$$M_{Einstein} = \frac{\text{Energy}}{(\text{lightspeed})^2} = \frac{M \cdot c^2}{c^2}$$

What's the matter with Mass?

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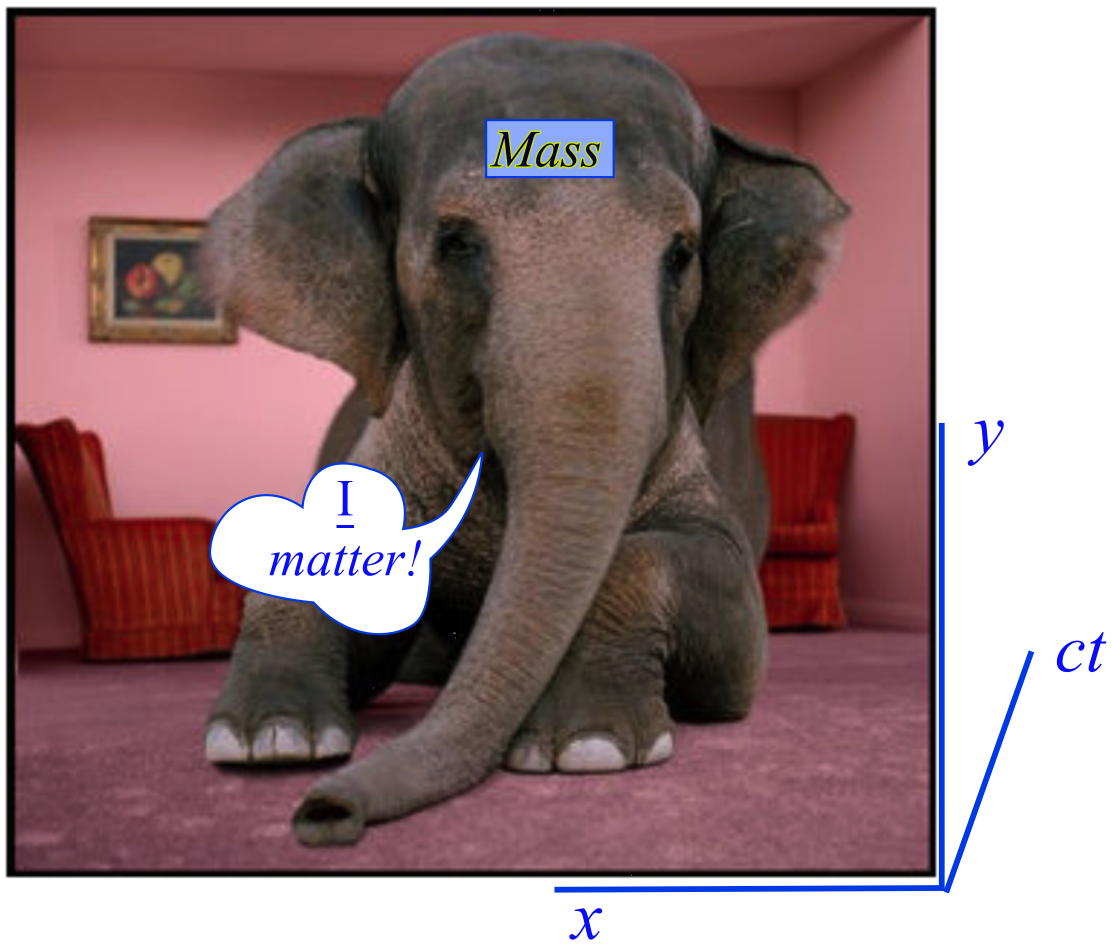

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$$M_{Newton} = \frac{Change\ in\ Momentum}{Change\ in\ Velocity} = \frac{M \cdot a}{a}$$

1905 Einstein's "rest mass"

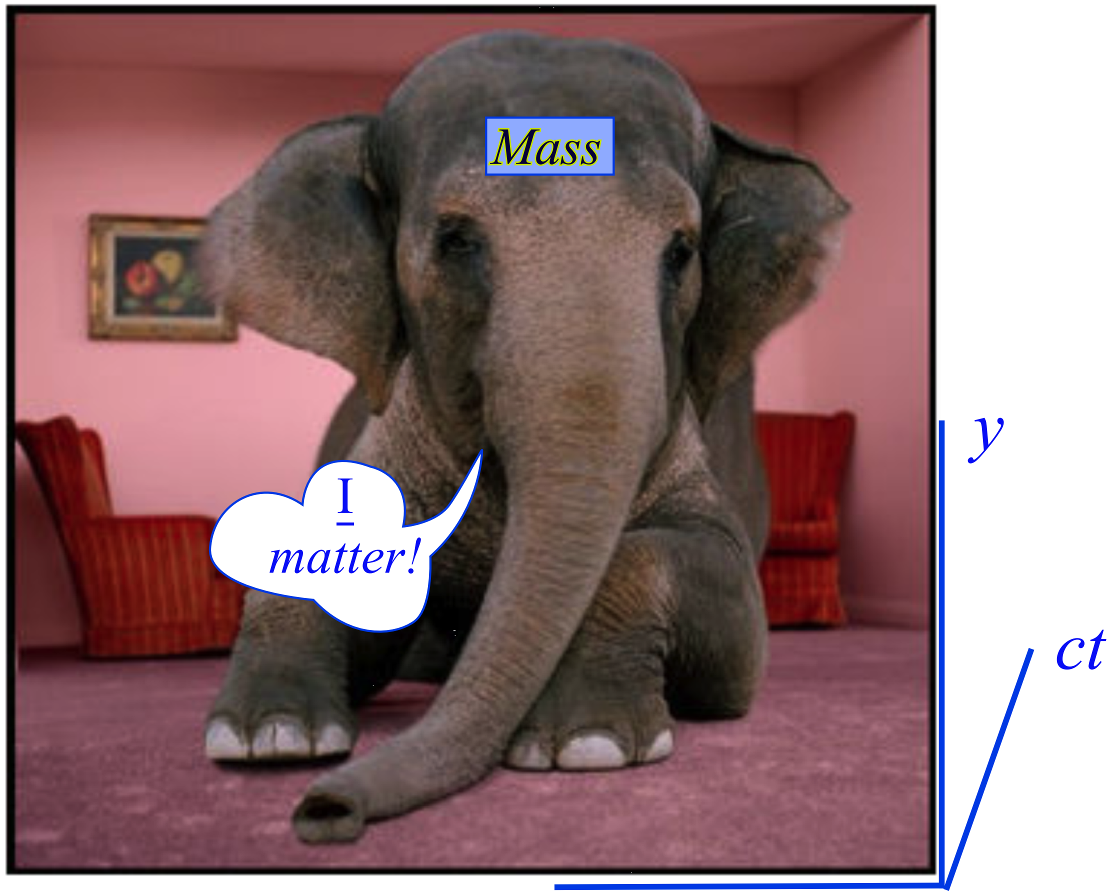
$$M_{Einstein} = \frac{Energy}{(lightspeed)^2} = \frac{M \cdot c^2}{c^2}$$

2013 Higgs "Boson"

$M_{Higgs} = ?$ *(No simple formula)*

What's the matter with Mass?

Dealing with one of the elephants in the spacetime room:



News for **higgs boson**

Working on the '**God particle**' saved my life, says Peter Higgs

The Independent - by Kunal Dutta - 1 day ago

The Nobel prize-winning physicist Peter Higgs has described the fame he has endured since the discovery of his "**God particle**" as "a bit of a ...

A brief History of defining Mass M :

1590 Galileo's "impago"

$$M_{Galileo} = \frac{Momentum}{Velocity} = \frac{M\cdot v}{v}$$

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2013 Higgs "Boson"

$M_{Higgs}=?$ *(No simple formula)*

What's the matter with *Mass*?

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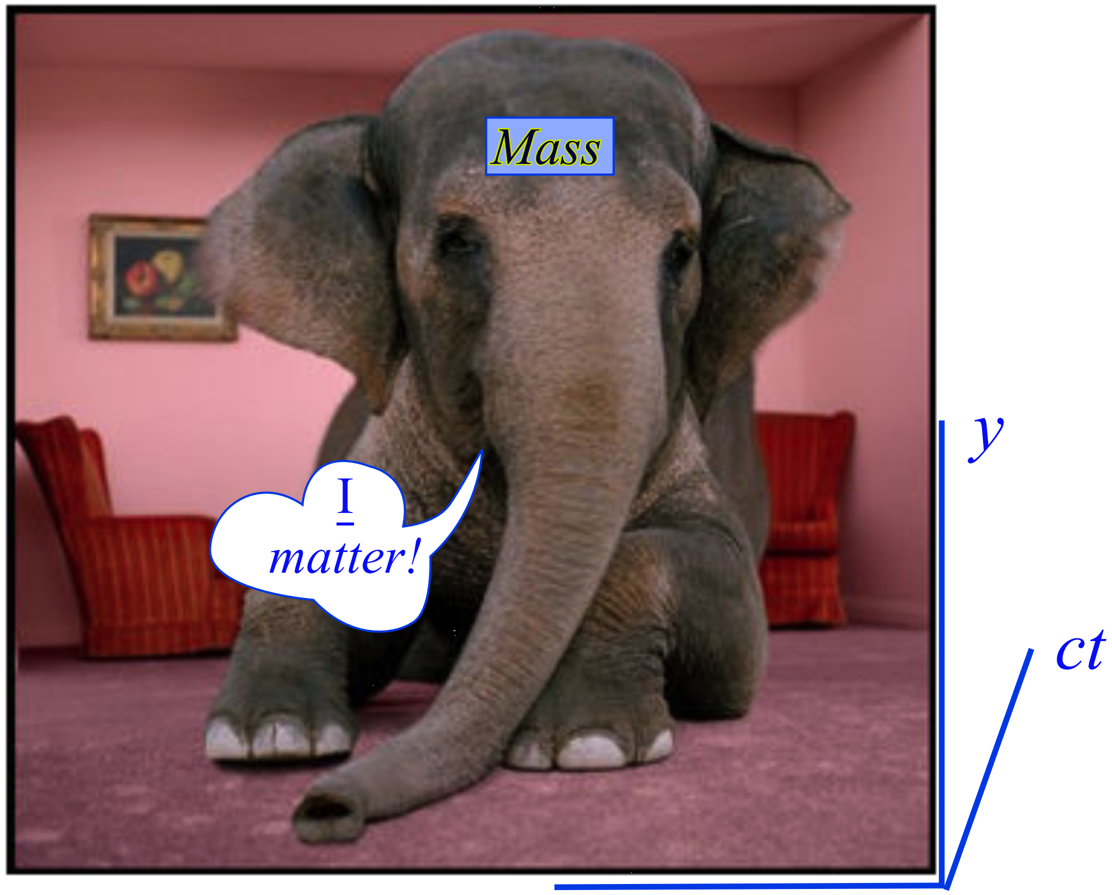

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Father of 'the **God particle**' Peter Higgs says fame is a bit of a nuisance
The Guardian - 1 day ago

Professor **Higgs** Says Fame Is 'A Bit Of A Nuisance' Since **Boson's** Discovery
Huffington Post UK - 1 day ago

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http://www.ph.ed.ac.uk/higgs/

The University of Edinburgh

School of Physics & Astronomy

- Peter Higgs and the Higgs Boson
- In the News
- Companion of Honour
- Letters of Congratulation
- Higgs Boson Discovery
- Higgs Centre for Theoretical Physics
- Searching for the Higgs Boson
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- Brief History of the Higgs Mechanism
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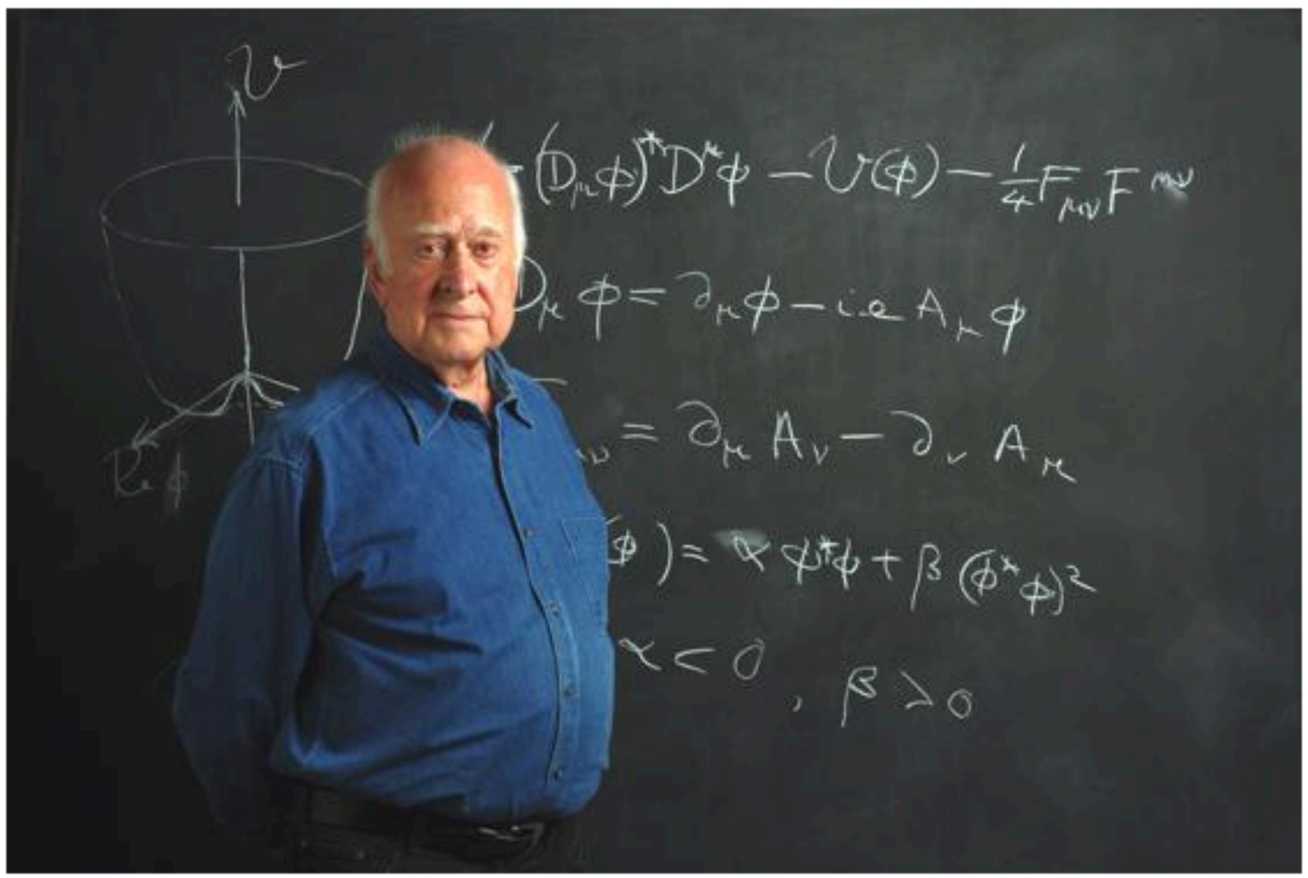
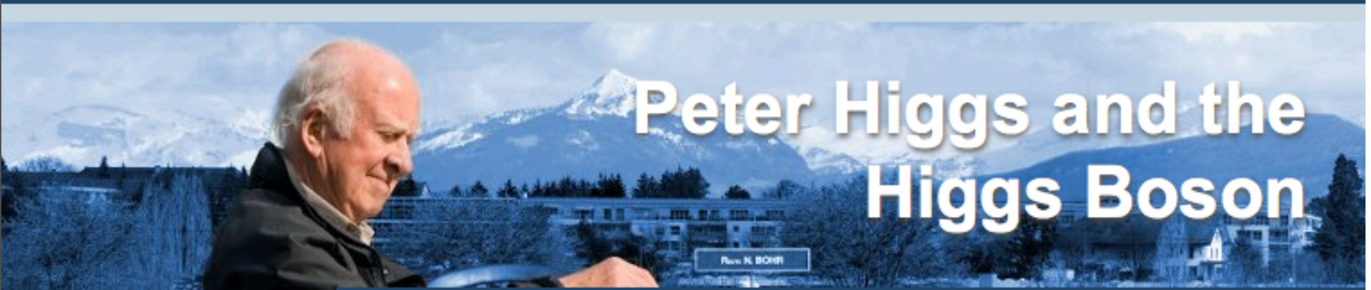
Peter Higgs and the Higgs Boson



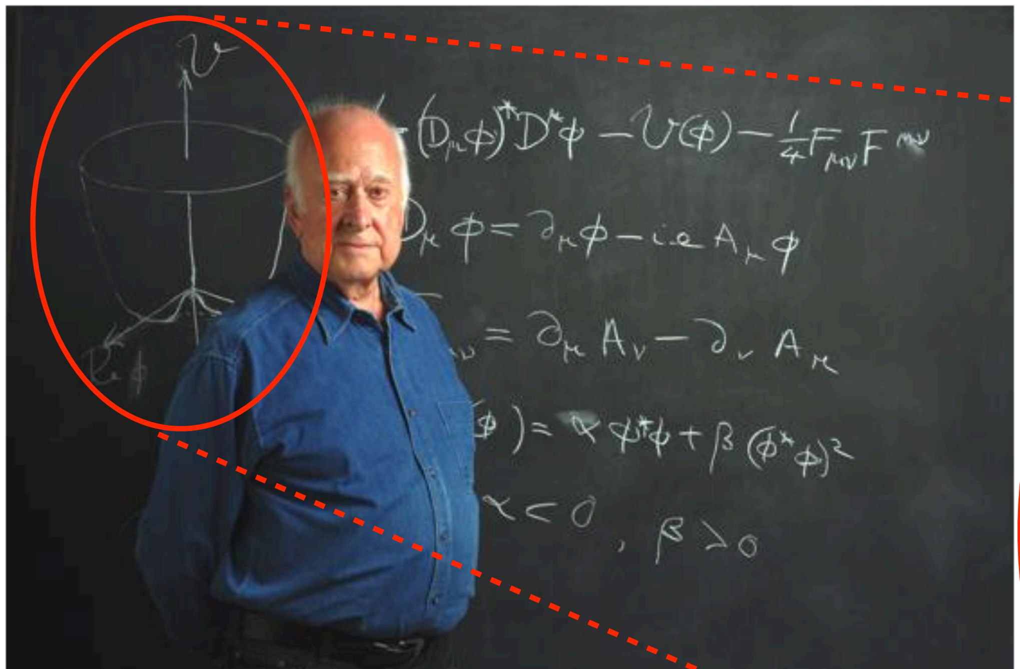
Welcome to the Higgs site at the University of Edinburgh

8th October 2013: The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"* **Nobel Prize**

The University of Edinburgh
School of Physics & Astronomy



Peter Higgs and the Higgs Boson



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Higgs Model based on Molecular Symmetry Stability *(Jahn, Teller, Renner, ...)*

The electronic eigenstates can be expressed very nicely in terms of the normal coordinate polar angle for the case $r = 0$

$$|\varepsilon_+\rangle = \cos(\phi/2)\left|\begin{matrix}E\\1\end{matrix}\right\rangle - \sin(\phi/2)\left|\begin{matrix}E\\2\end{matrix}\right\rangle,$$

$$|\varepsilon_-\rangle = \sin(\phi/2)\left|\begin{matrix}E\\1\end{matrix}\right\rangle + \cos(\phi/2)\left|\begin{matrix}E\\2\end{matrix}\right\rangle. \qquad (6.7.9)$$

$E_{1,2}$-Coordinate Plots

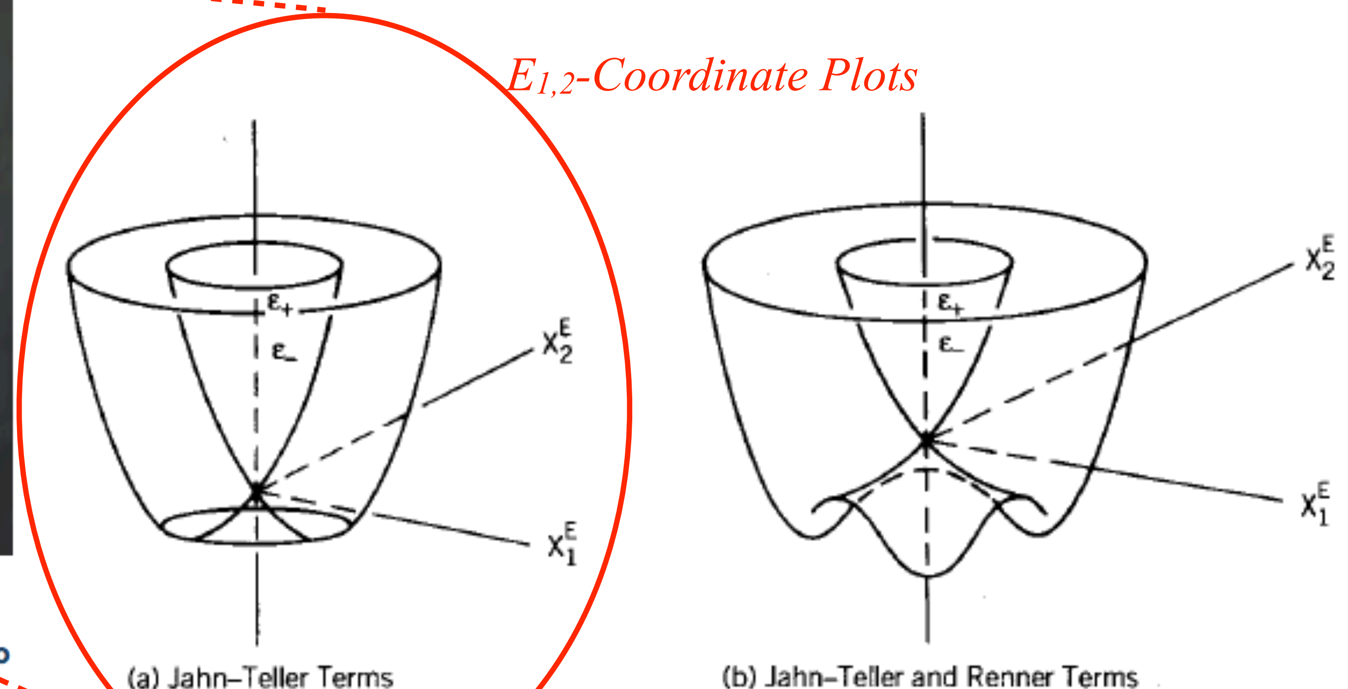


Figure 6.7.1 Potential energy functions of the E-type coordinates. (a) Jahn-Teller terms ($r = 0$). (b) Jahn-Teller and Renner terms ($r > 0$).

Fig. 6.7.1-2 from Principles of Symmetry, Dynamics and Spectroscopy

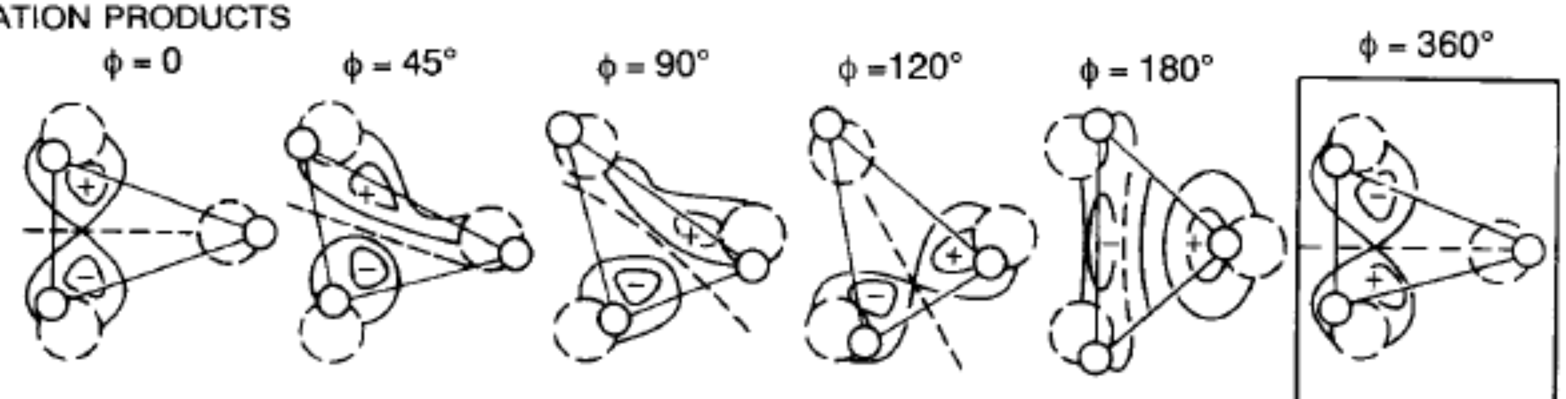


Figure 6.7.2 Electronic state $|\varepsilon_-\rangle$ for various nuclear positions allowed by varying E coordinates.

Relativistic Classical and Quantum Mechanics

How optical CW group and phase properties give relativistic mechanics

What's the Matter with Mass?

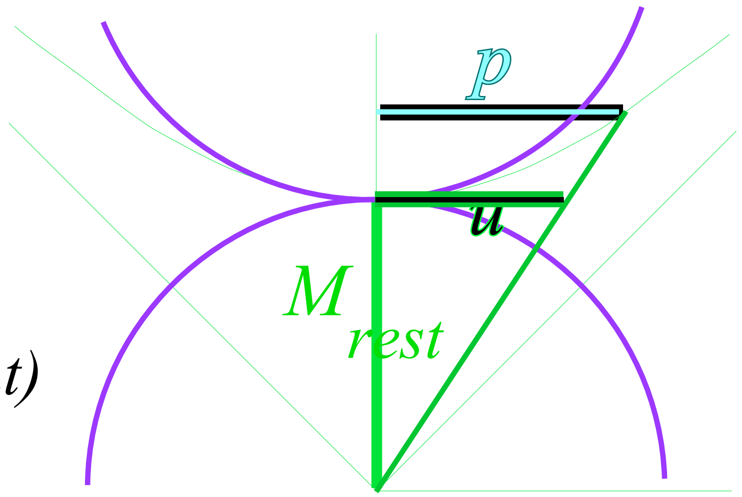
Brief look at Higgs

Three kinds of mass (Einstein rest mass, Galilean momentum mass, Newtonian inertial mass)

What's the matter with light?

Bohr-Schrodinger (BS) approximation throws out Mc^2

What's the Matter With Light? *Three definitions of "optical mass"*

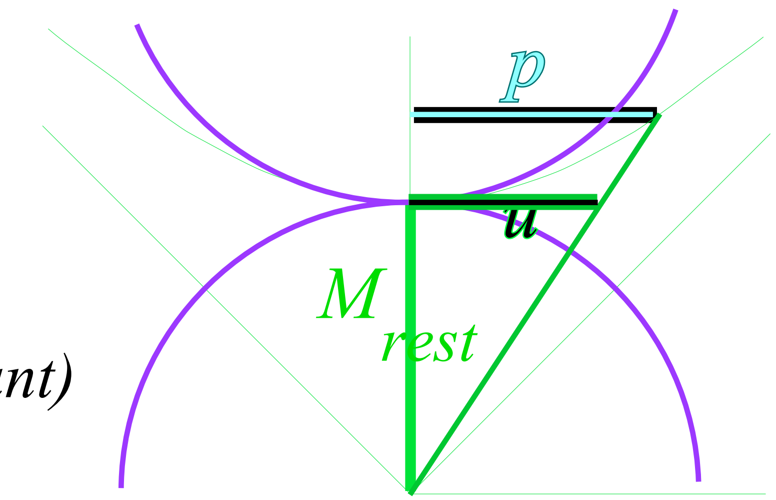


1. *Rest mass* $M_N = h\upsilon_N / c^2$ based on Planck's law $E = h\upsilon_N = Nh\upsilon_1$

Rest mass: $M_{rest} = E/c^2 = h\upsilon_N / c^2$

(Is ρ *-invariant)*

What's the Matter With Light? *Three definitions of "optical mass"*



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Rest mass: $M_{rest} = E/c^2 = h\upsilon_N/c^2$

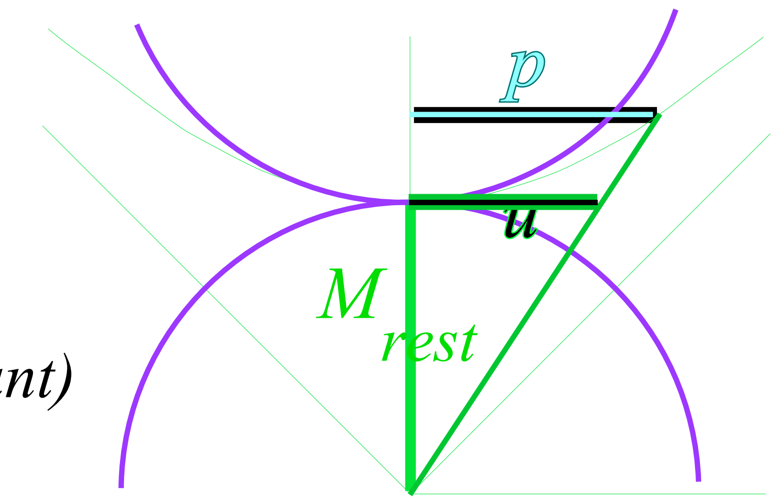
(Is ρ-invariant)

2. *Momentum mass* is defined by Galileo's old formula $p=Mu$ with newer forms for momentum $p = M_{rest} u \cdot \cosh \rho = M_{rest} u \cdot /(1-u^2/c^2)^{1/2}$ and group velocity $u = d\omega/dk$.
It is the ratio p/u of *momentum* to *velocity.*

Momentum mass: $M_{momentum} = p/u = M_{rest} \cosh \rho$ $= M_{rest}/(1-u^2/c^2)^{1/2}$

(Not ρ-invariant)

What's the Matter With Light? *Three definitions of "optical mass"*



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$$\text{Momentum mass: } M_{momentum} = p/u = M_{rest} \cosh\rho = M_{rest}/(1-u^2/c^2)^{1/2}$$

(Not ρ-invariant)

3. *Effective mass* is defined by Newton's old formula $F = Ma$ with newer forms for $F = dp/dt = \hbar dk/dt$ *and* $a = du/dt =$ to give $F/a = (\hbar dk/dt)(dt/du) = \hbar dk/du = \hbar/(du/dk)$.
It is the ratio F/a of *change of momentum* to the *change of velocity*,

$$\text{Effective mass: } M_{effective} = \hbar/(du/dk) = \hbar/(d^2\omega/dk^2) = M_{rest} \cosh^3\rho = M_{rest}/(1-u^2/c^2)^{3/2}$$

(Not ρ-invariant)

Relativistic Classical and Quantum Mechanics

How optical CW group and phase properties give relativistic mechanics

- *What's the Matter with Mass?*
  - *Brief look at Higgs*
- *Three kinds of mass (Einstein rest mass, Galilean momentum mass, Newtonian inertial mass)*
  - *What's the matter with light? (Not too much.)*

Bohr-Schrodinger (BS) approximation throws out Mc^2

What's the matter with light?

Three kinds of mass for photon γ *in CW relativistic theory*

(1)Einstein rest mass

$$M_{rest} = \frac{\hbar\omega_{proper}}{c^2}$$

(2) Galilean momentum mass

$$M_{mom} = p/u = \frac{\hbar k}{\frac{d\omega}{dk}}$$

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$$M_{rest}(\gamma) = 0$$

$$M_{mom}(\gamma) = p/c = \hbar k/c = \hbar\omega/c^2$$

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Equations (4.11) in Unit 8

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Equations (4.11) in Unit 8

A 2-CW *600THz* cavity has zero total momentum *p*, but each photon adds a tiny mass M_γ to it.

$$M_\gamma=\hbar\omega/c^2=\omega\ (1.2\cdot 10^{-51})kg\cdot s= 4.5\cdot 10^{-36}kg \qquad (for:\ \omega=2\pi\cdot 600\text{THz})$$

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A 1-CW state has no rest mass, but 1-photon momentum is a non-zero value $p_\gamma = M_\gamma c$. *(Galilean revenge II.)*

$$p_\gamma = \hbar k = \hbar\omega/c = \omega\,(4.5\cdot 10^{-43})\,kg\cdot m = 1.7\cdot 10^{-27}\,kg\cdot m\cdot s^{-1} \qquad (for:\ \omega = 2\pi\cdot 600\text{THz})$$

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How optical CW group and phase properties give relativistic mechanics

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$$E = \left[\left(Mc^2\right)^2 + \left(cp\right)^2\right]^{1/2} \approx Mc^2 + \frac{1}{2M}p^2 \xrightarrow[BS-approx]{} \frac{1}{2M}p^2$$

ft.

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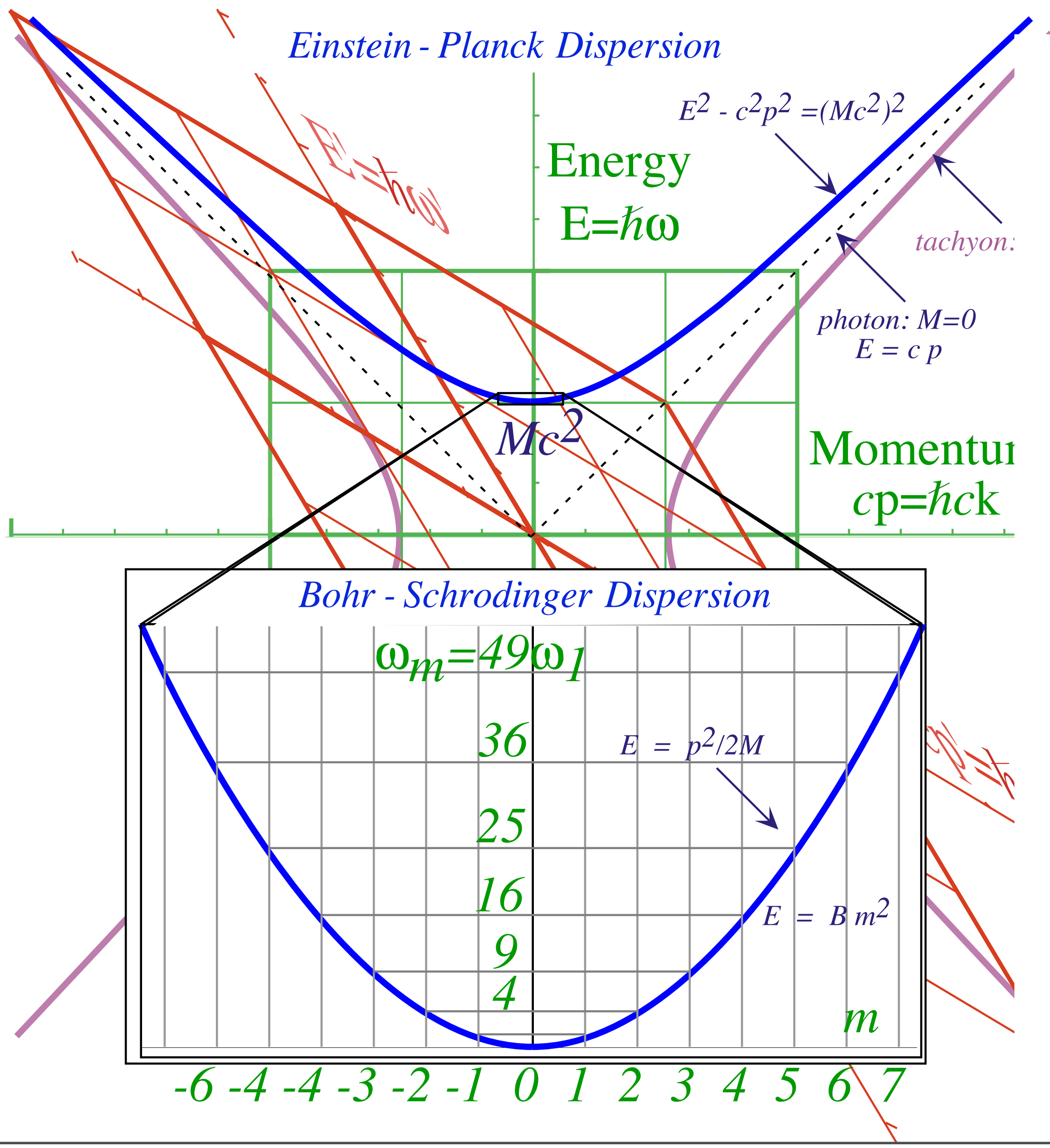
The BS claim: may shift energy origin *(E=Mc², cp=0)* to *(E=0, cp=0)*. (*Frequency is relative!*)



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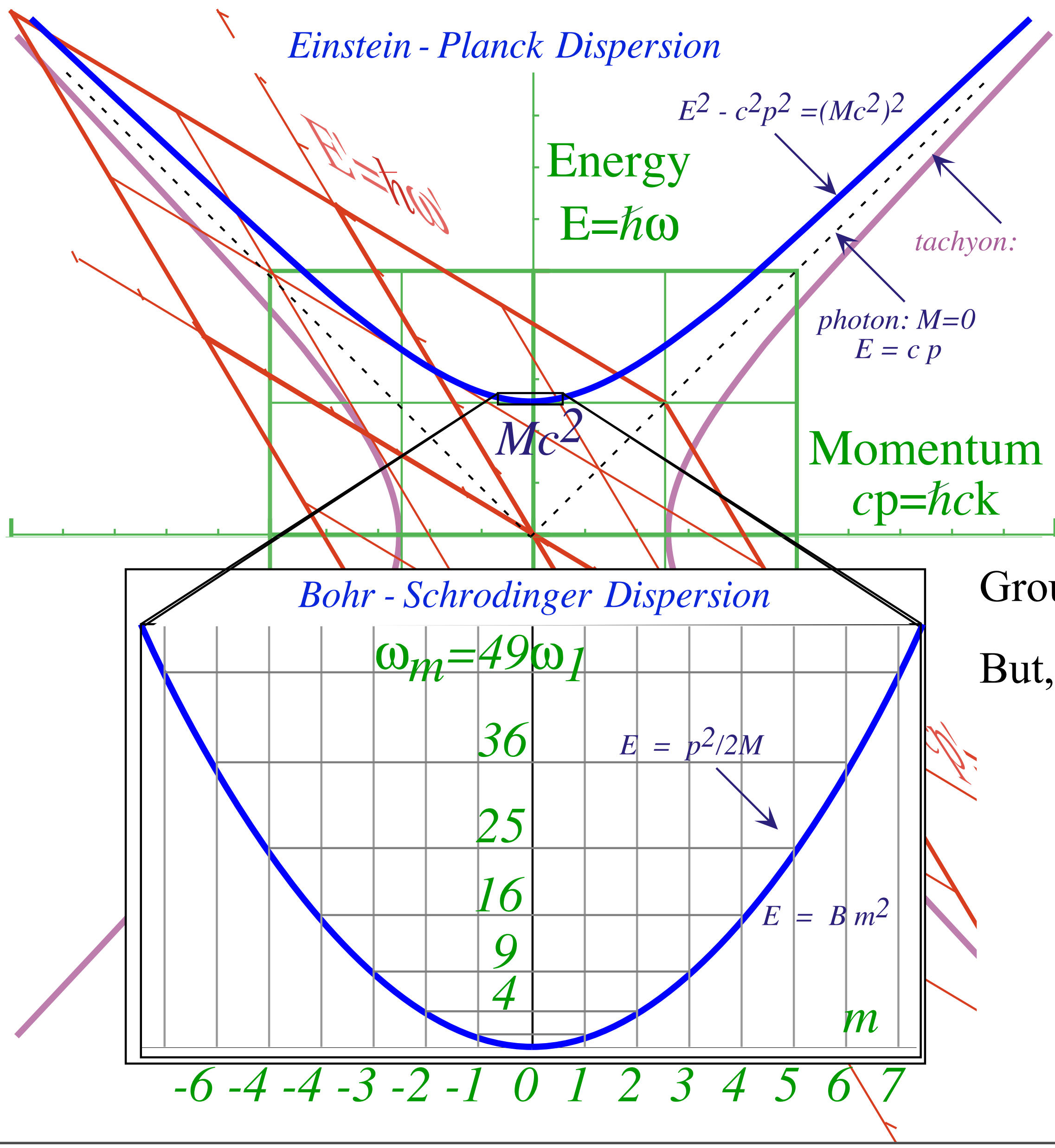

Group velocity $u=V_{group}=\frac{d\omega}{dk}$ is a differential quantity unaffected by origin shift.

But, Phase velocity $\frac{\omega}{k}=V_{phase}$ is greatly reduced by deleting Mc^2 from $E=\hbar\omega$.

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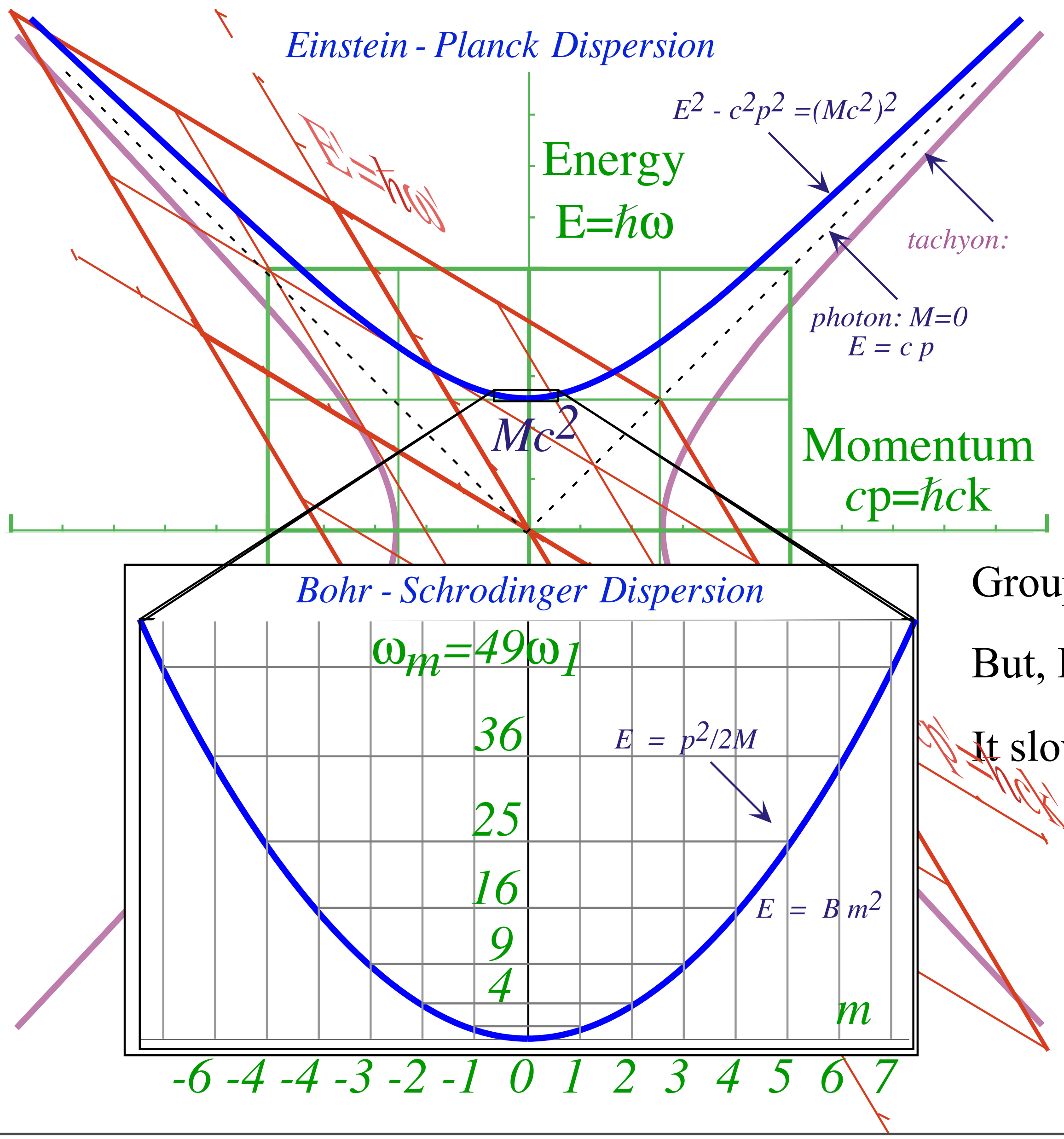

Group velocity $u=V_{group}=\frac{d\omega}{dk}$ is a differential quantity unaffected by origin shift.

But, Phase velocity $\frac{\omega}{k}=V_{phase}$ is greatly reduced by deleting Mc^2 from $E=\hbar\omega$.

It slows from $V_{phase}=c^2/u$ to a sedate sub-luminal speed of $V_{group}/2$.

$$\omega_{BS}(k) = \frac{k^2}{2M} \quad \text{gives:} \quad V_{phase} = \frac{\omega_{BS}}{k} = \frac{k}{2M}$$

$$\text{and:} \quad V_{group} = \frac{d\omega_{BS}}{dk} = \frac{k}{M}$$

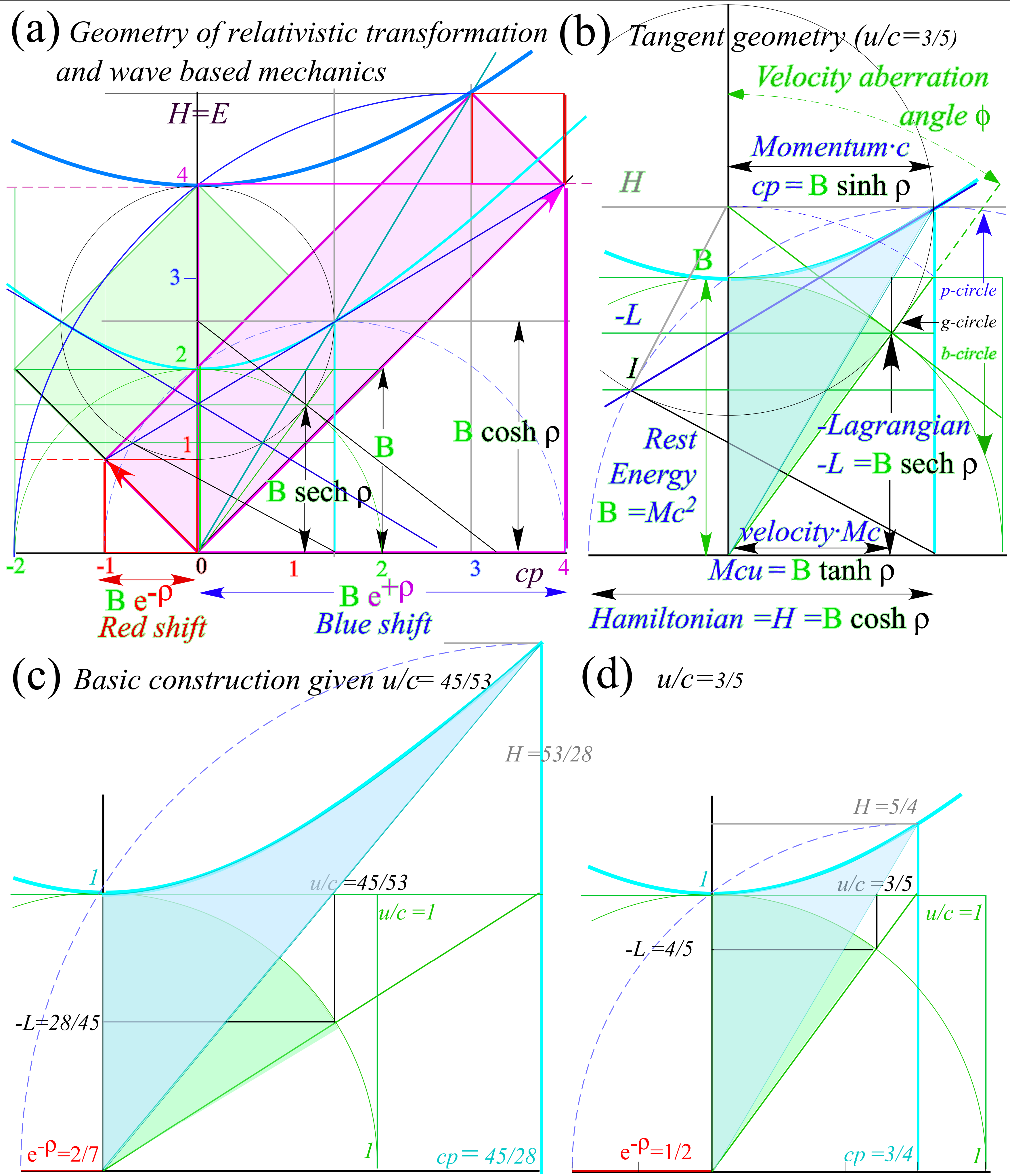

Fig. 5.5
Relativistic wave mechanics geometry.
(a) Overview.

(b-d) Details of contacting tangents.