Improving STEM Teaching and Learning

William G. Harter and Tyle Reimer
Sponsored by Al Calabrese

Finding spectacular and interesting examples
…and simpler models to explain how they work

Deriving the simplest collision theory (By ruler&compass geometry)
 Galileo's relativity (an approximation)
 Project Ball and problems with selling superball missiles to Whammo Co.

Having fun with examples by stretching theory to its limits
 The *Astroblaster* (Superball towers and connection to Supernovae and toothpaste)
 The *Monster Mash* (Crushing a bouncing particle)
 The *Tiny-Big-Bang* (Watching Bohr wave-packet blow up …and down)
 …and how not to add fractions on the ***Titanic***
 …(Farey's sum & Ford's circles)

Showing cultural and historical connection to examples
 The *Trebuchet* (and how we owe almost everything to its mechanics)

Unifying Relativity with Quantum Theory (Why a ***Men In Black*** candidate shot little Suzy)
 If 2-ball-collisions give *Classical Mechanics,* what do 2-laser-beam collisions give?
 Lasers make relativistic (Minkowski) space-time (x,ct)-coordinates and (ω,ck), too

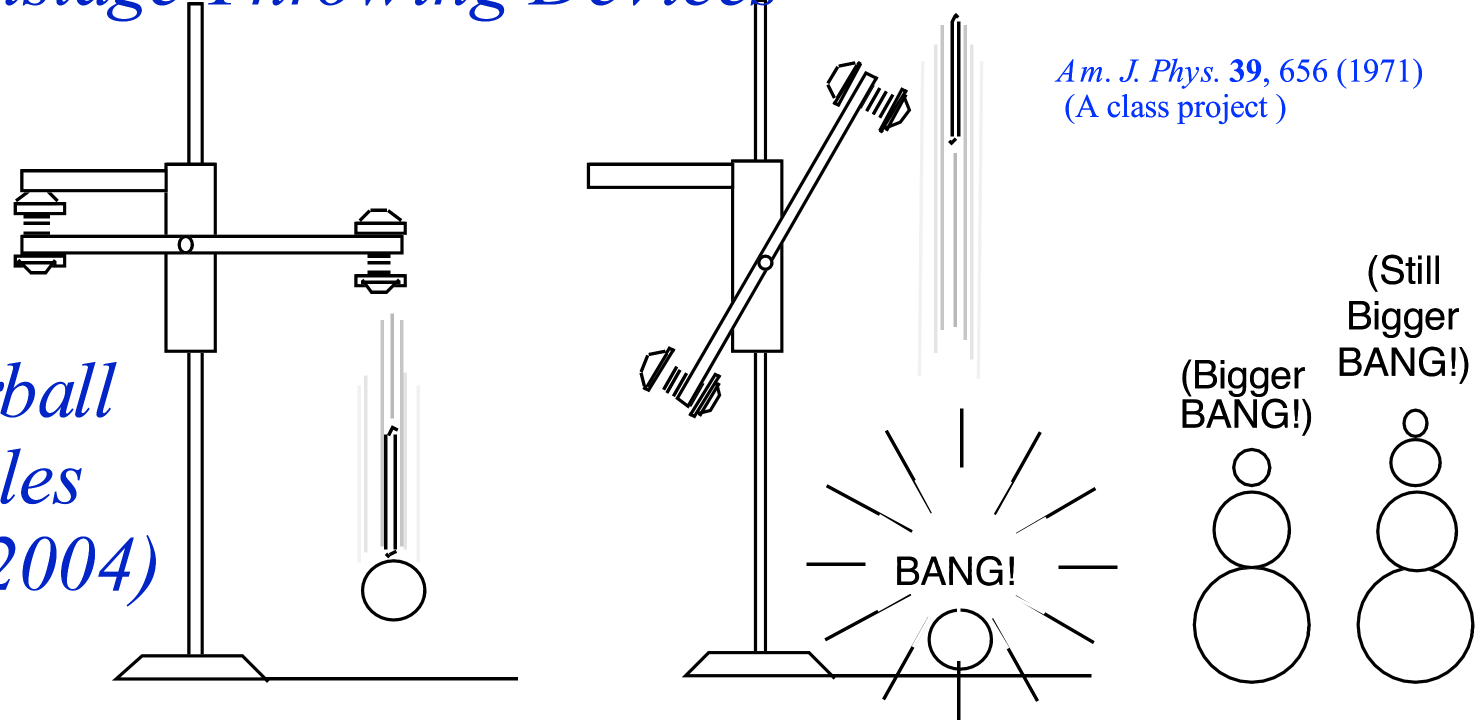
Find spectacular and interesting examples

Multistage Throwing Devices

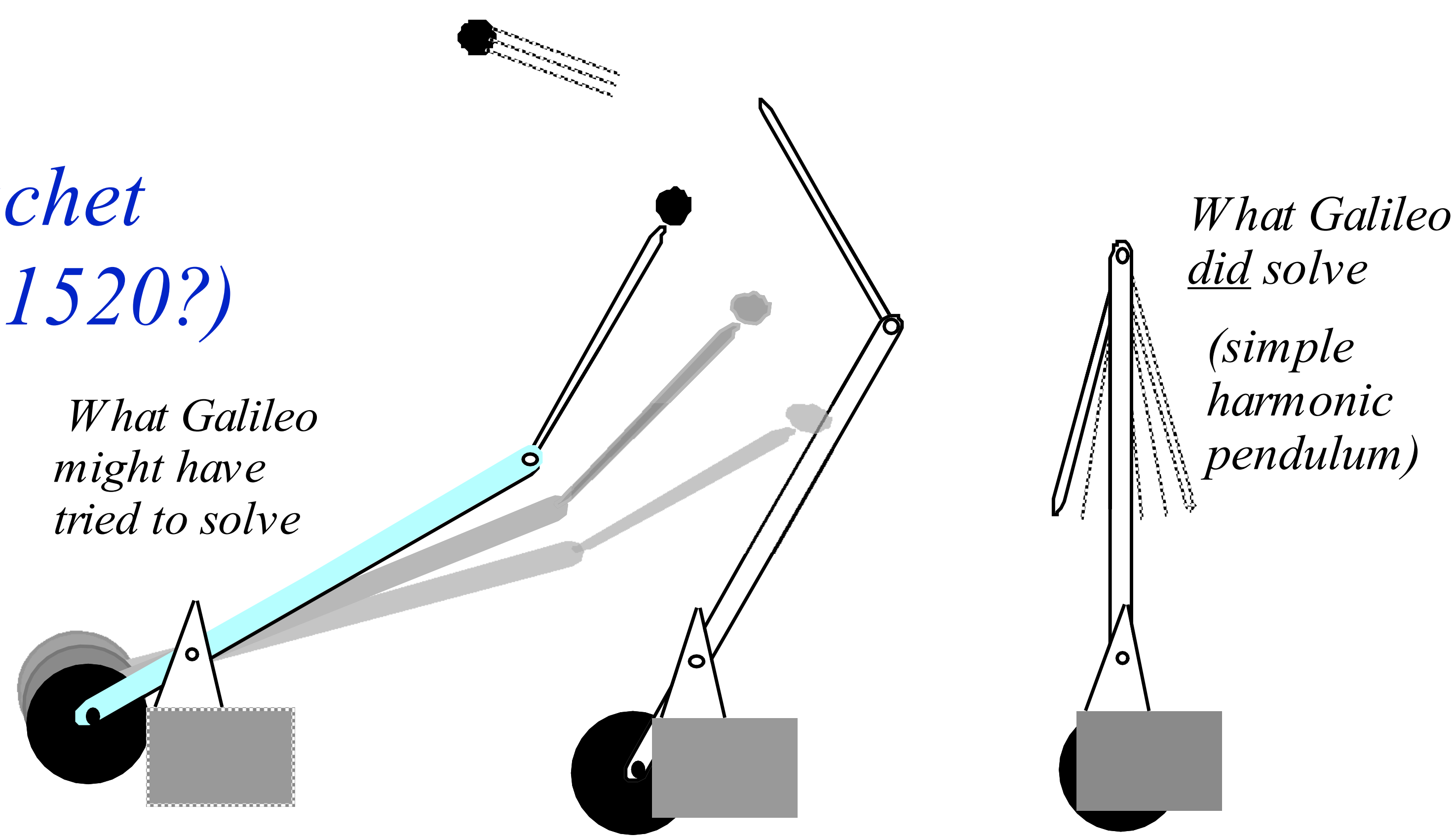
Am. J. Phys. **39**, 656 (1971)
(A class project)

X2 from Adv. Mechanics 2016

Superball Missles (1965-2004)



The Trebuchet ($\sim 10^3$ BC-1520?)



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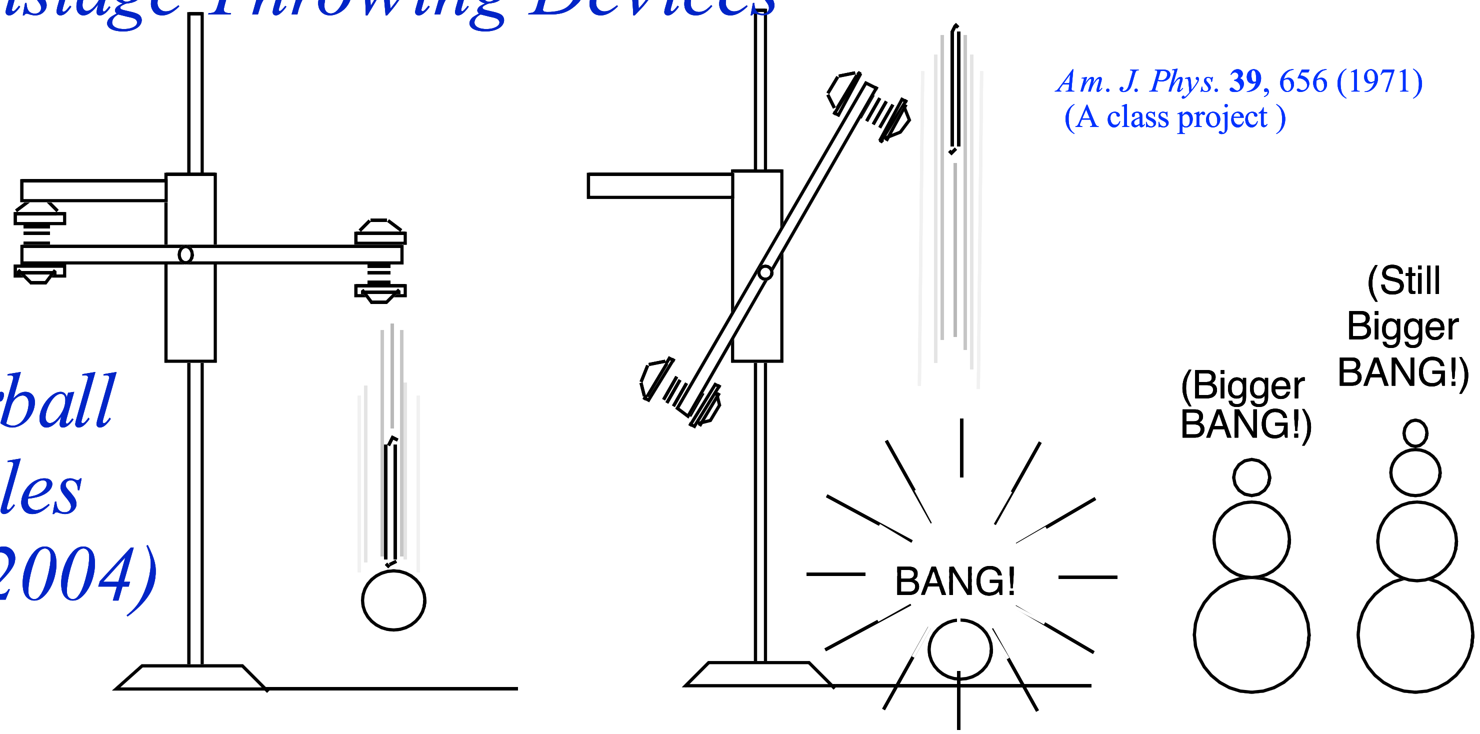

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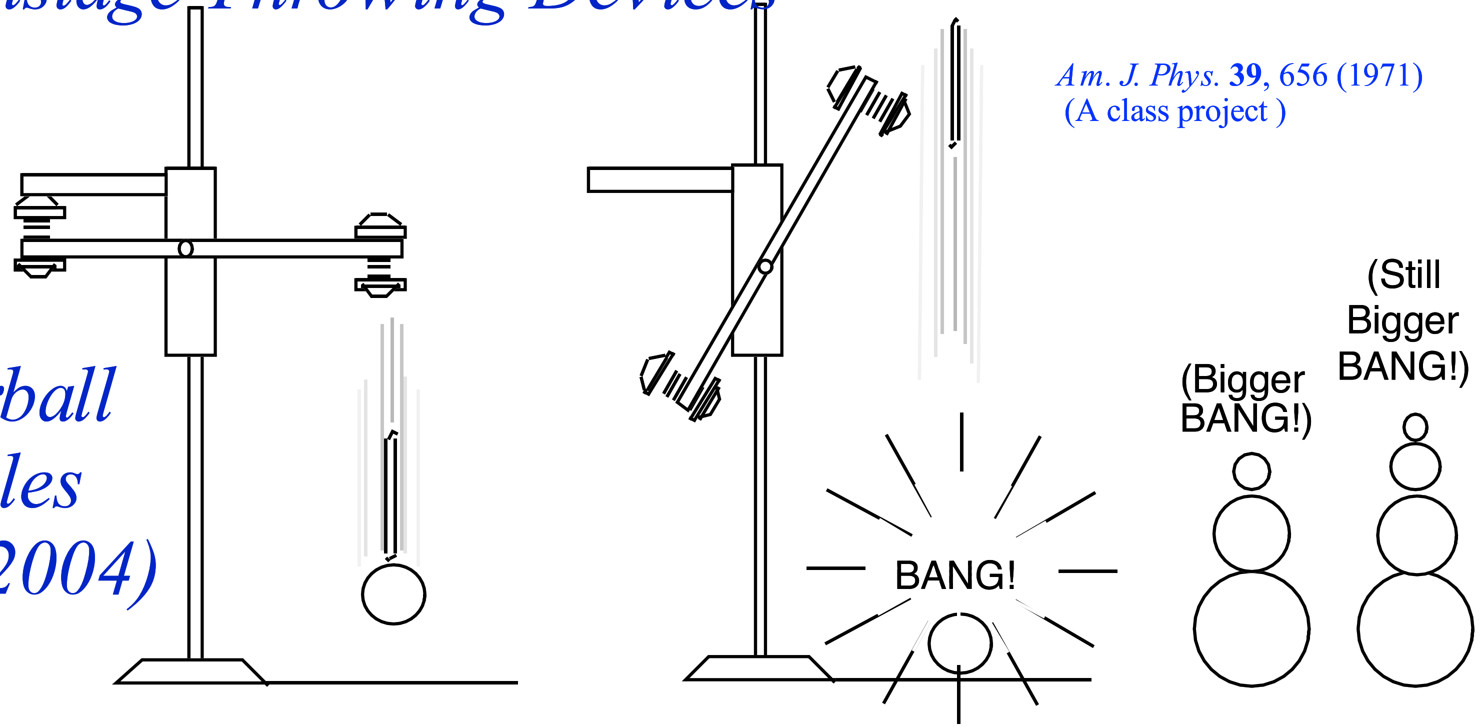

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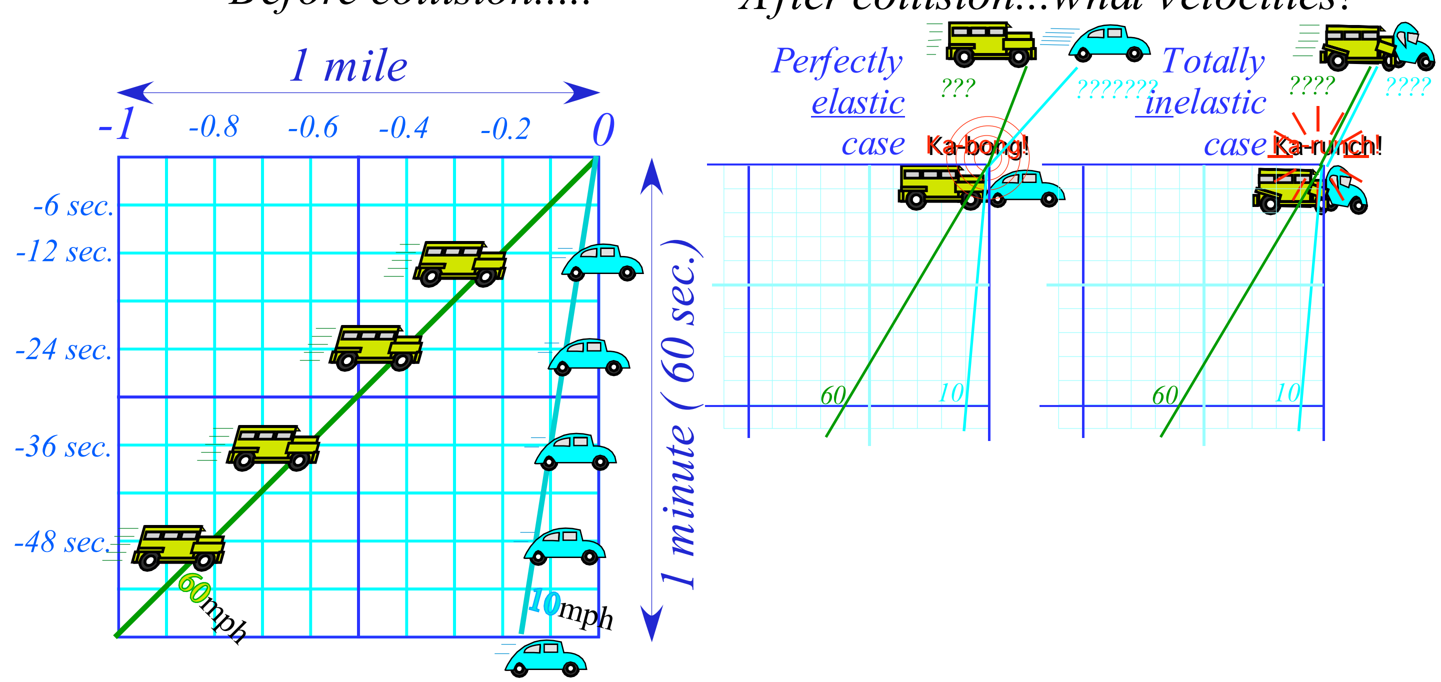
A problem in ***space-time*** : (60mph cell-faxing 4ton SUV rear-ends 10mph 1ton VW)

Before collision.....

After collision...what velocities?



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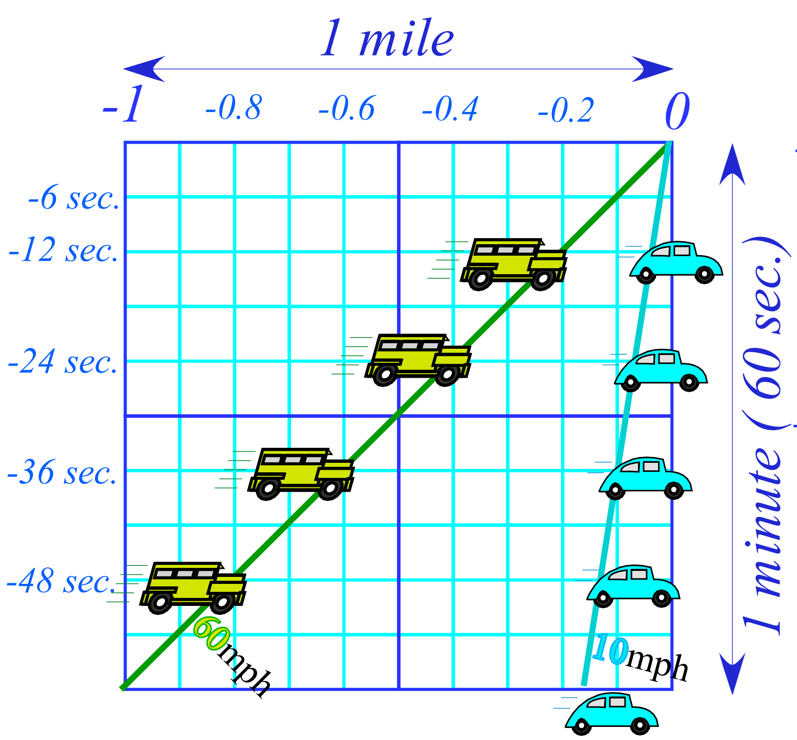

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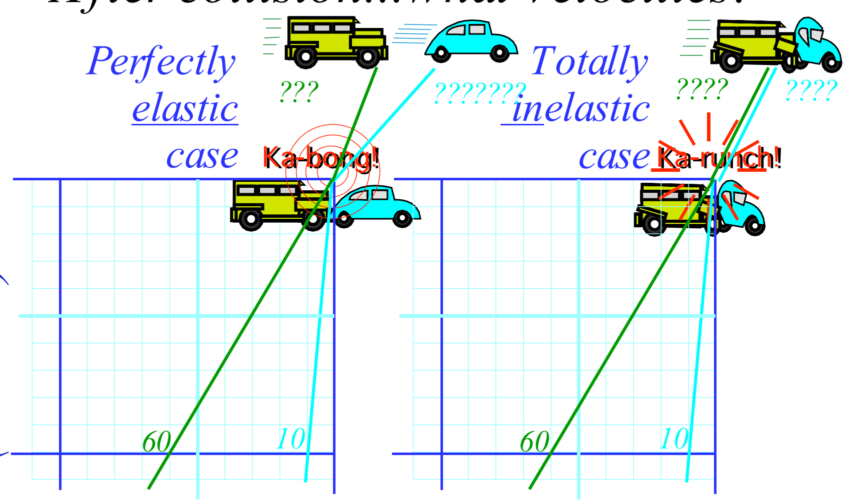

Simulator
[Elastic Collision](#)
[Dual Panel Space vs](#)
[Space and Time vs.](#)
[Space(Minkowski)](#)

Simulator
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**Launch Car Collision Web Simulator* *http://www.uark.edu/ua/modphys/markup/CMMotionWeb.html*

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Conventional solution:
Look up the usual *momentum* *and* *energy* *formulas/axioms and solve…:*

$\Sigma_i m V_i(initial) = \Sigma_i m V_i(final)$

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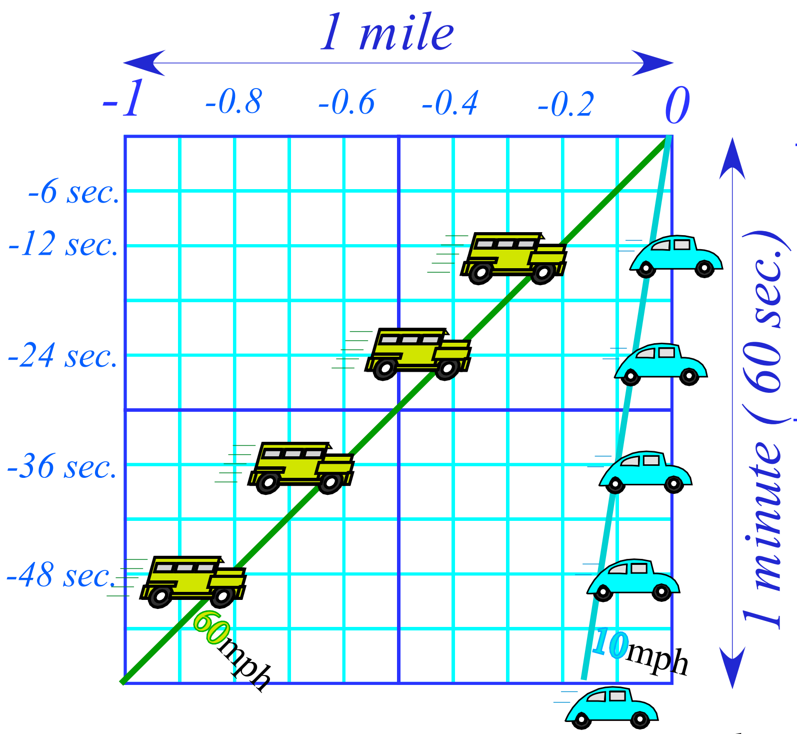
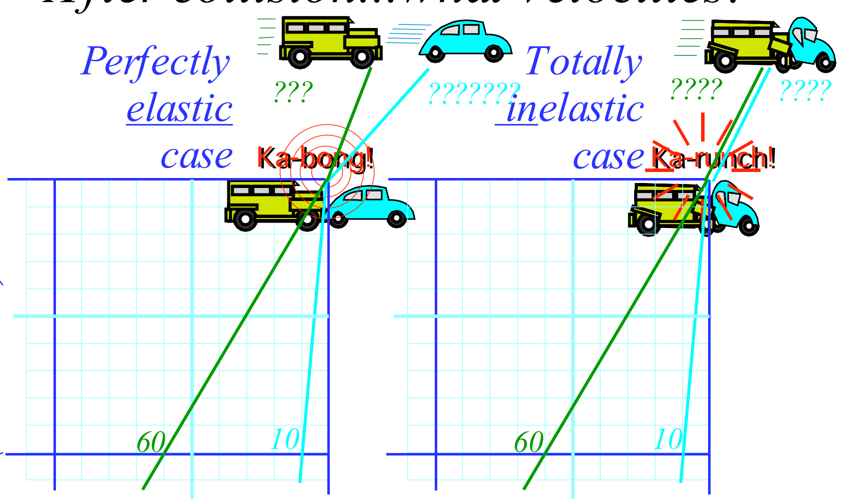
Before collision….. *After collision…what velocities?*





…But an UNconventional way is quicker and more revealing…..
….. (Just have to draw 2 lines!)

Inventor of
"Occam's Razor"

Let's see if we can solve this *easily* with just ***one*** (*or one-and-a-half*) axiom(s)

Axiom-1: All mass or masses keep their total momentum until it is changed by some outsider.

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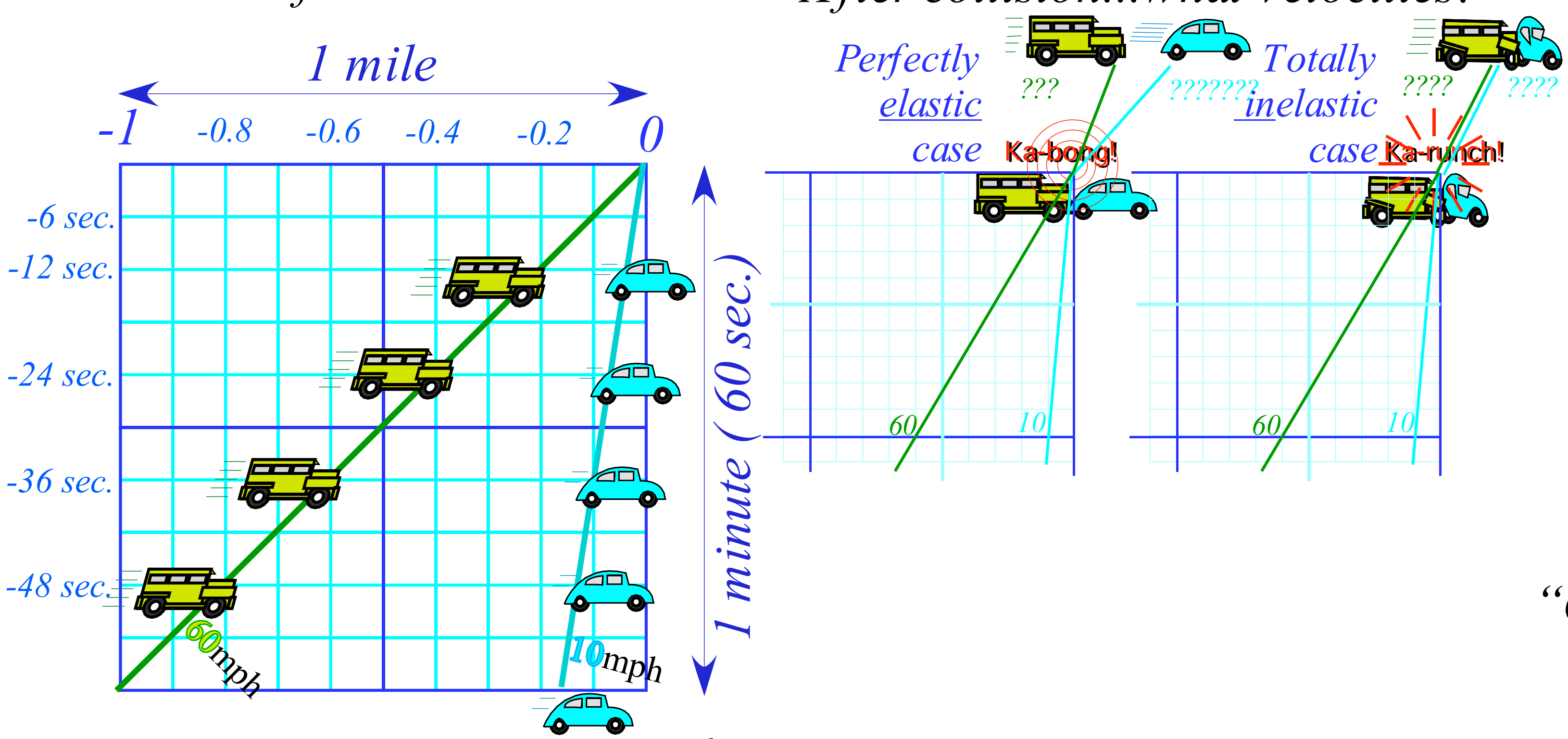

Conventional solution:
Look up the usual momentum and energy formulas/axioms and solve...:

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V_{SUV} and V_{VW} change violently
but ***total momentum*** is constant

$P_{Total} = M_{SUV} V_{SUV} + M_{VW} V_{VW}$

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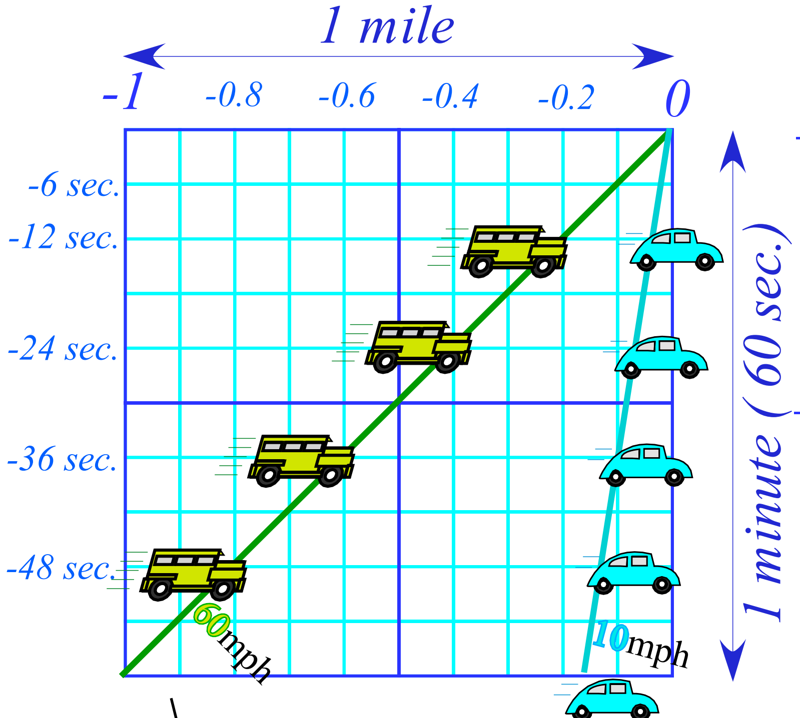

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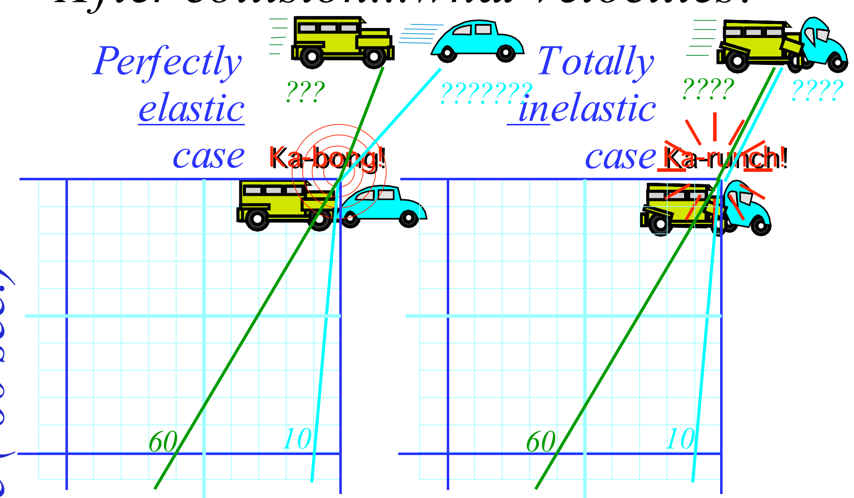

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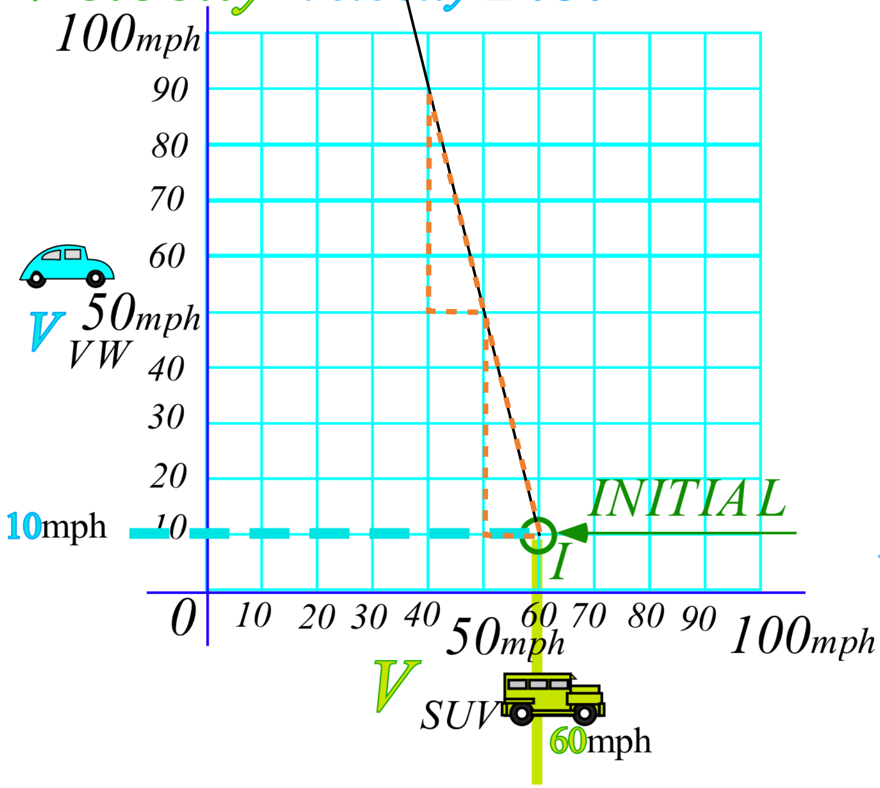
Velocity-velocity Plot



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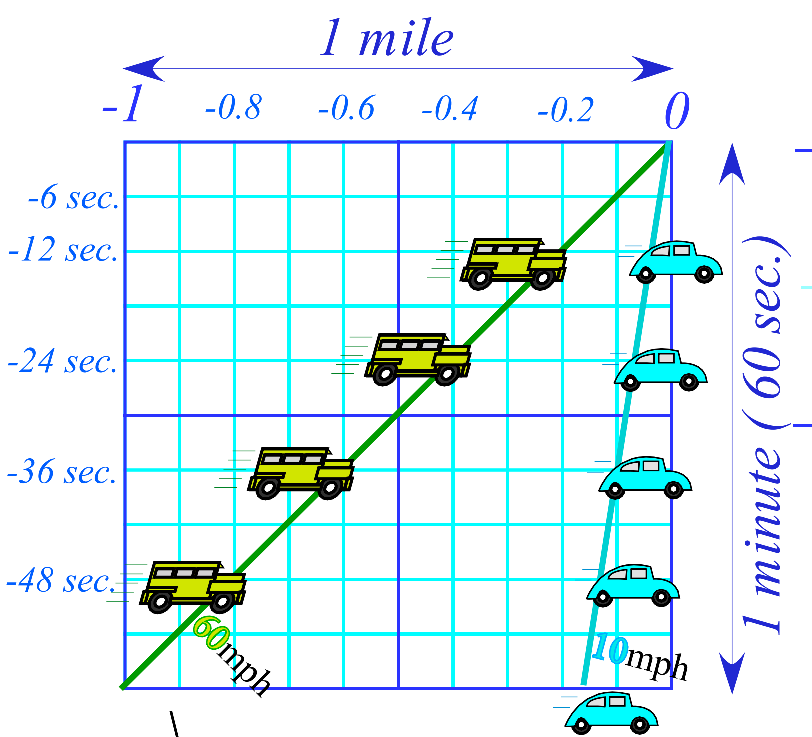

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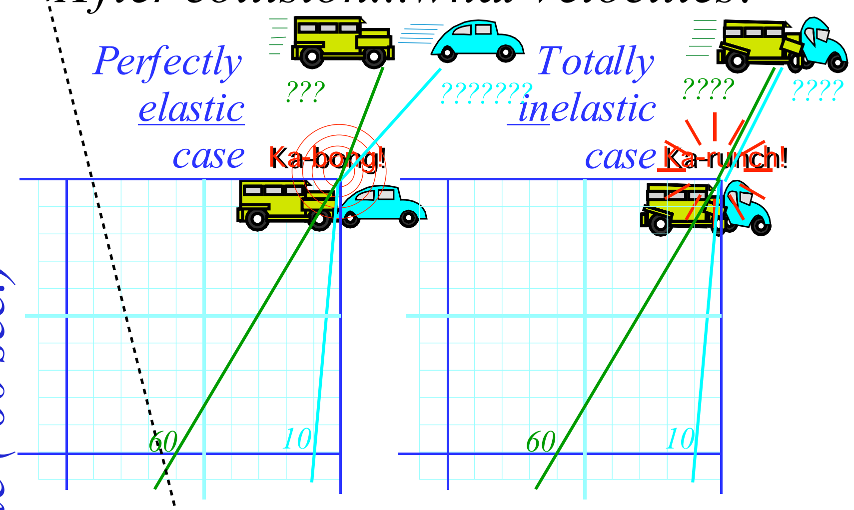

But, where-oh-where does it end?

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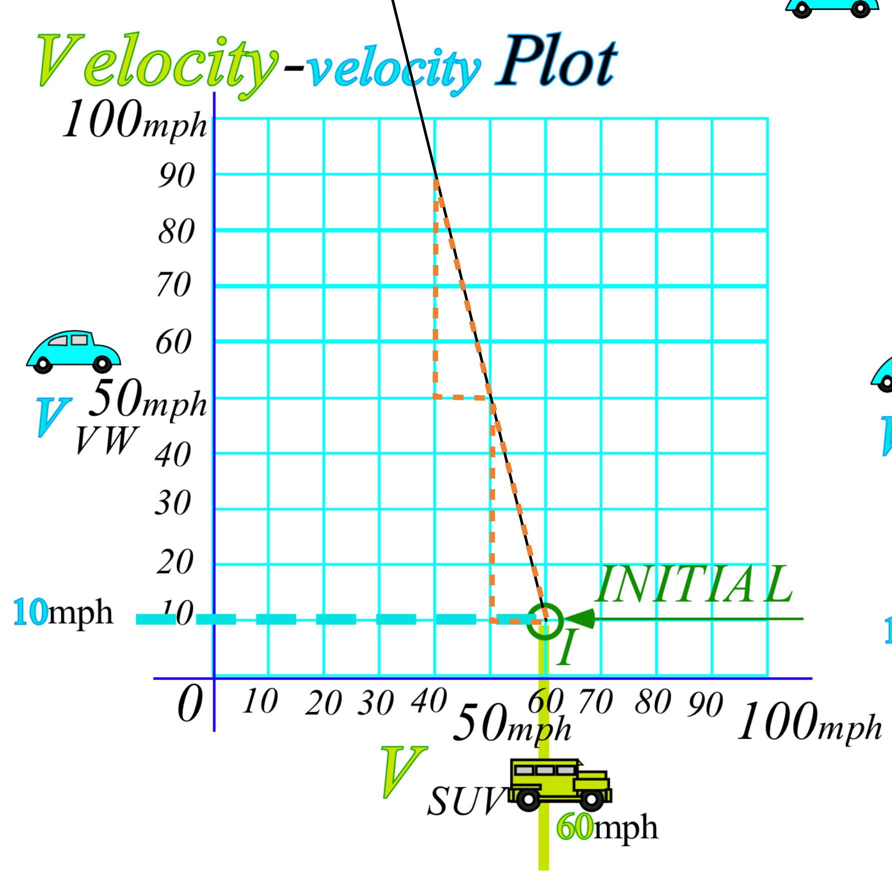

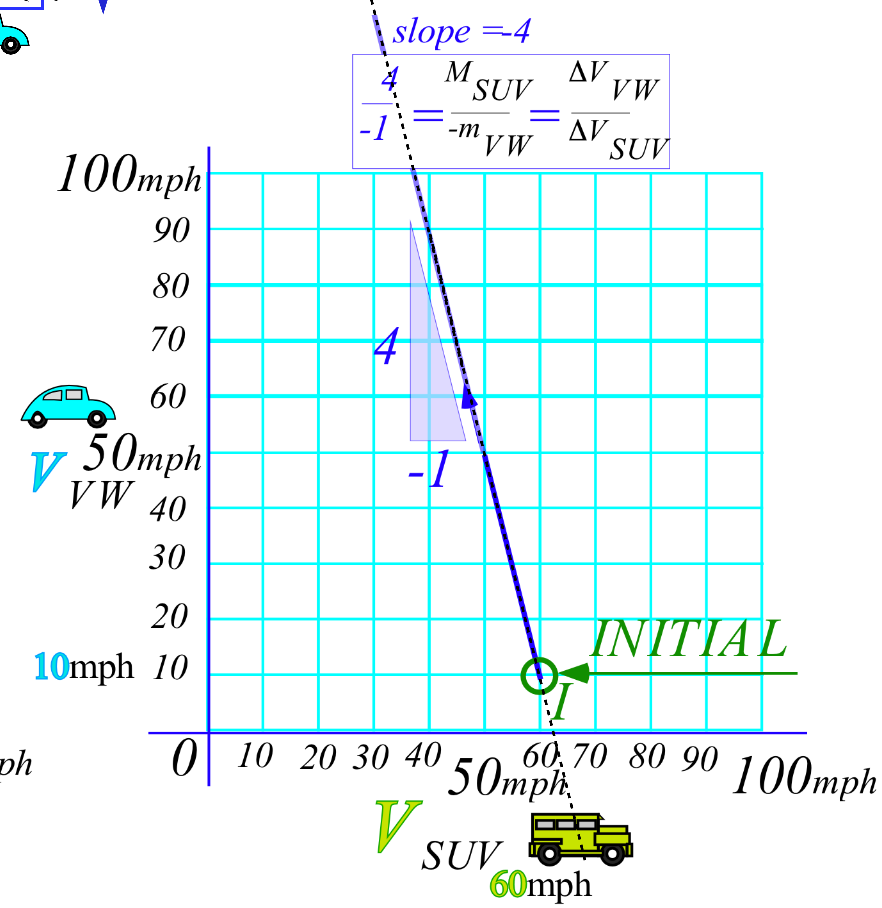

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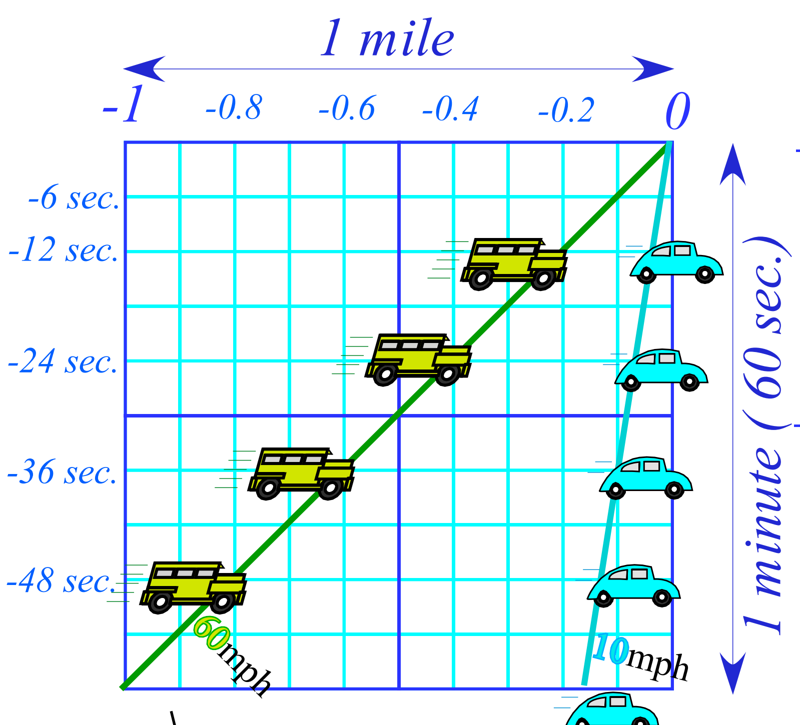

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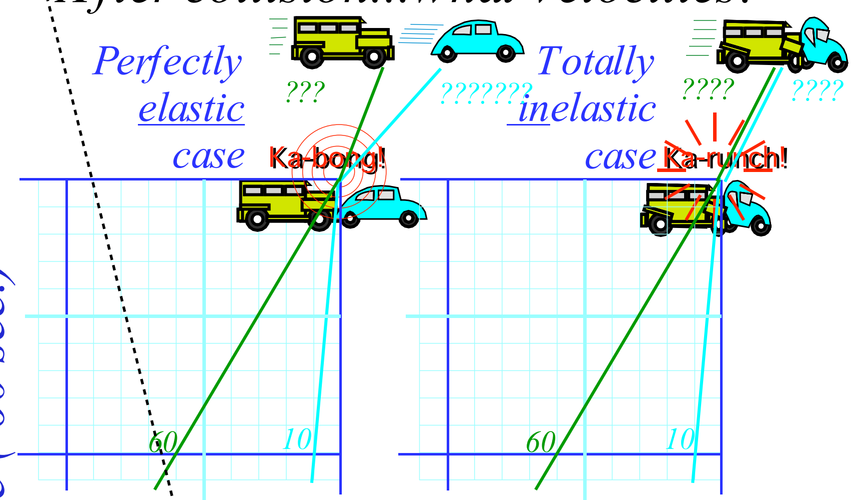

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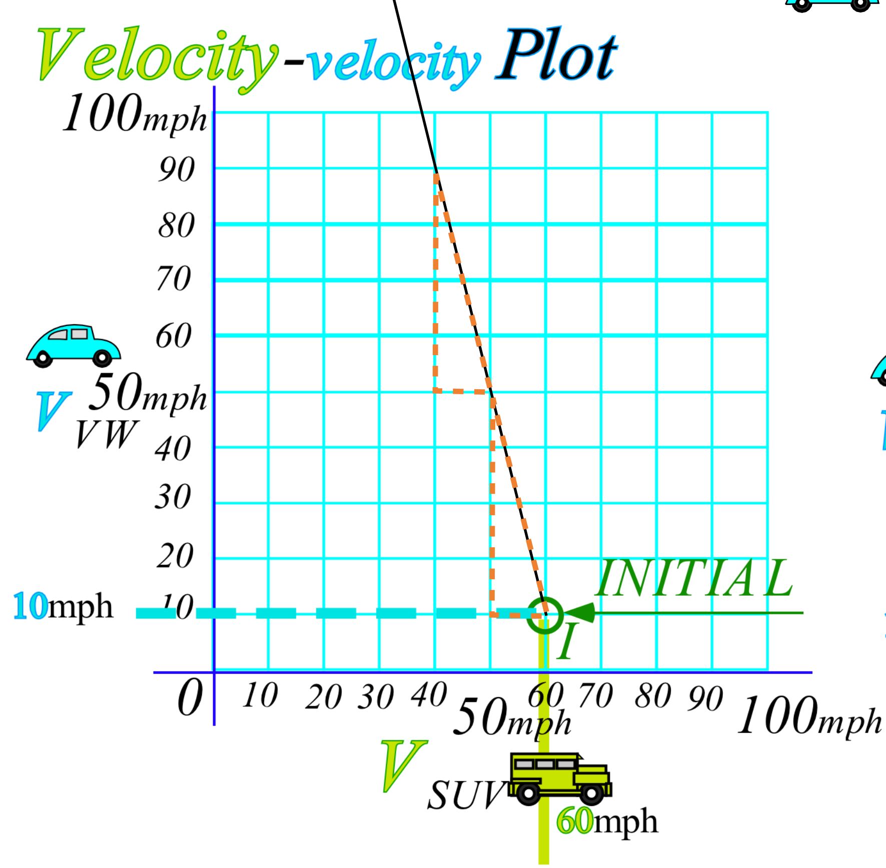

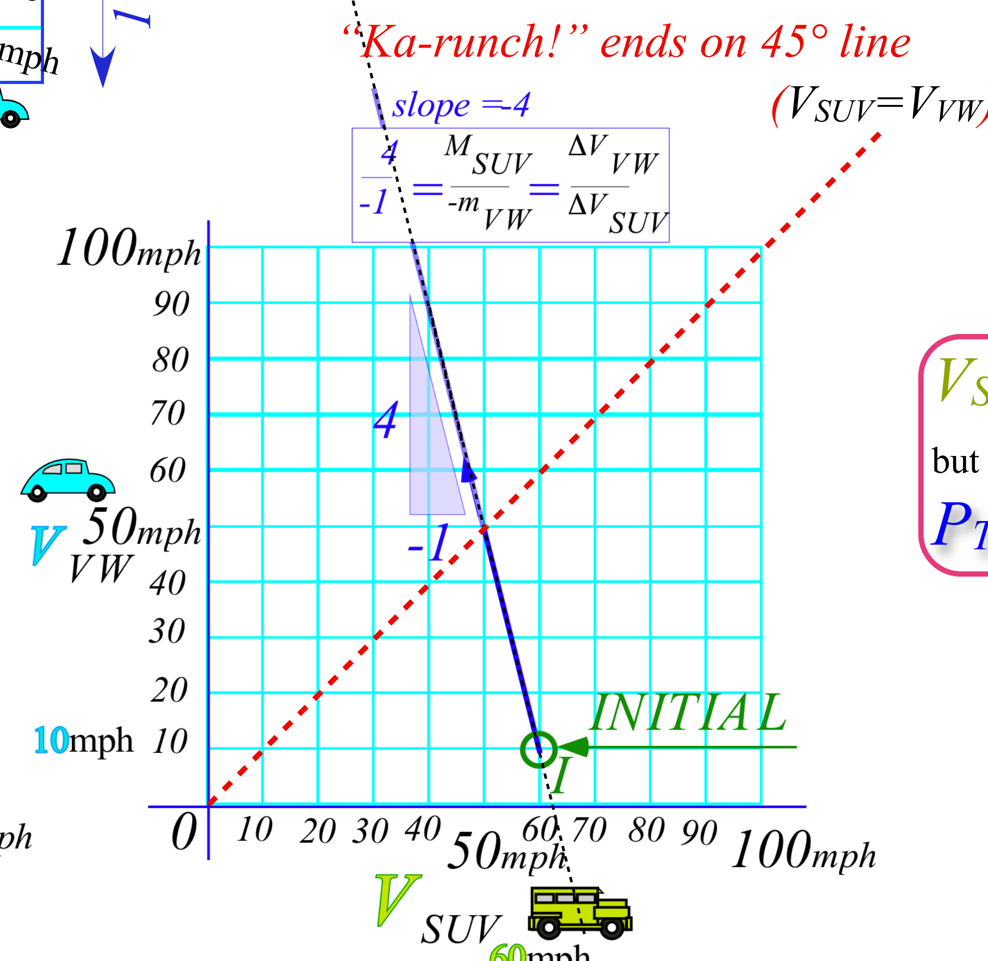

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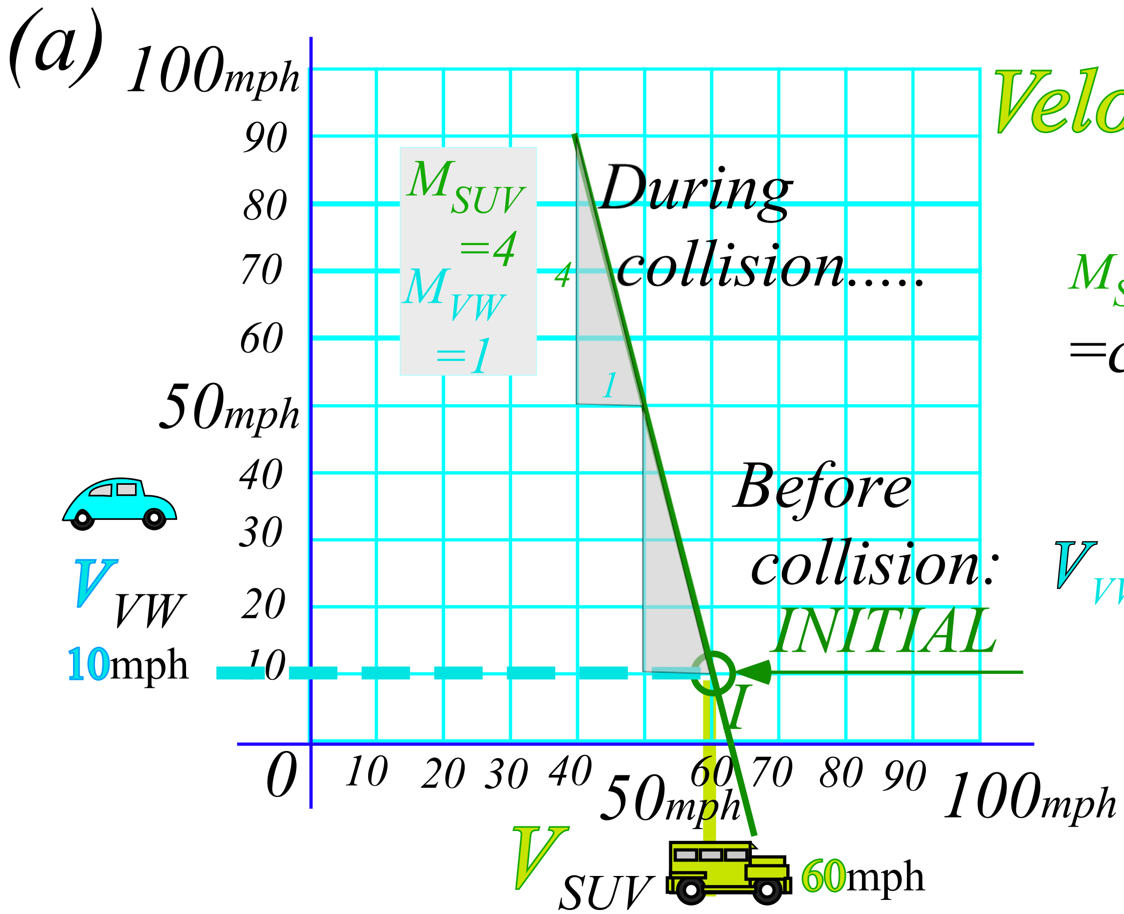


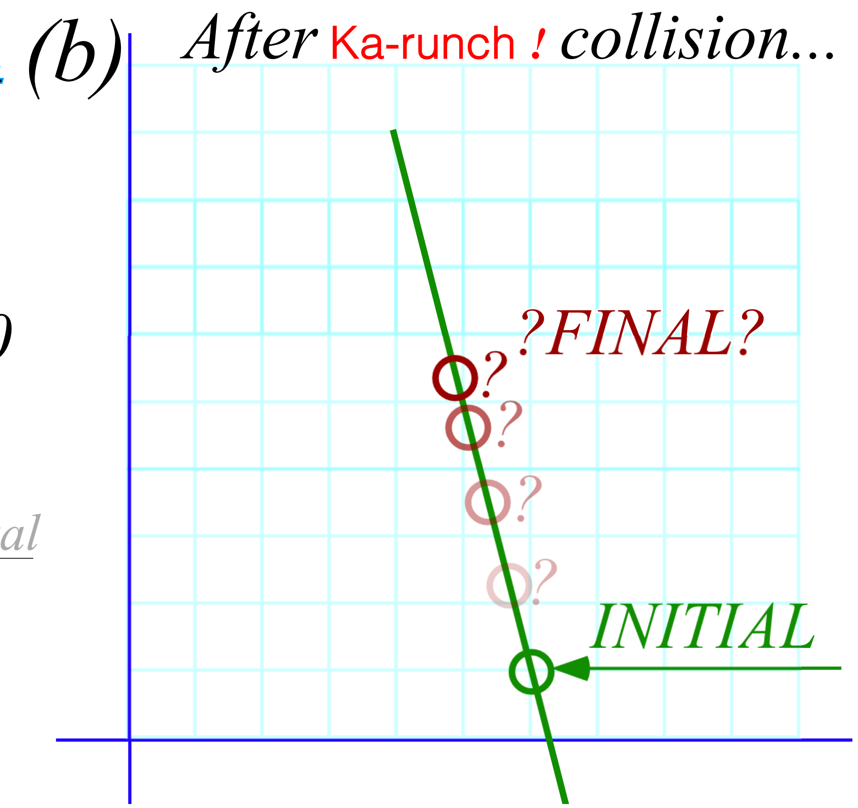
Velocity-velocity plot of Axiom-1:

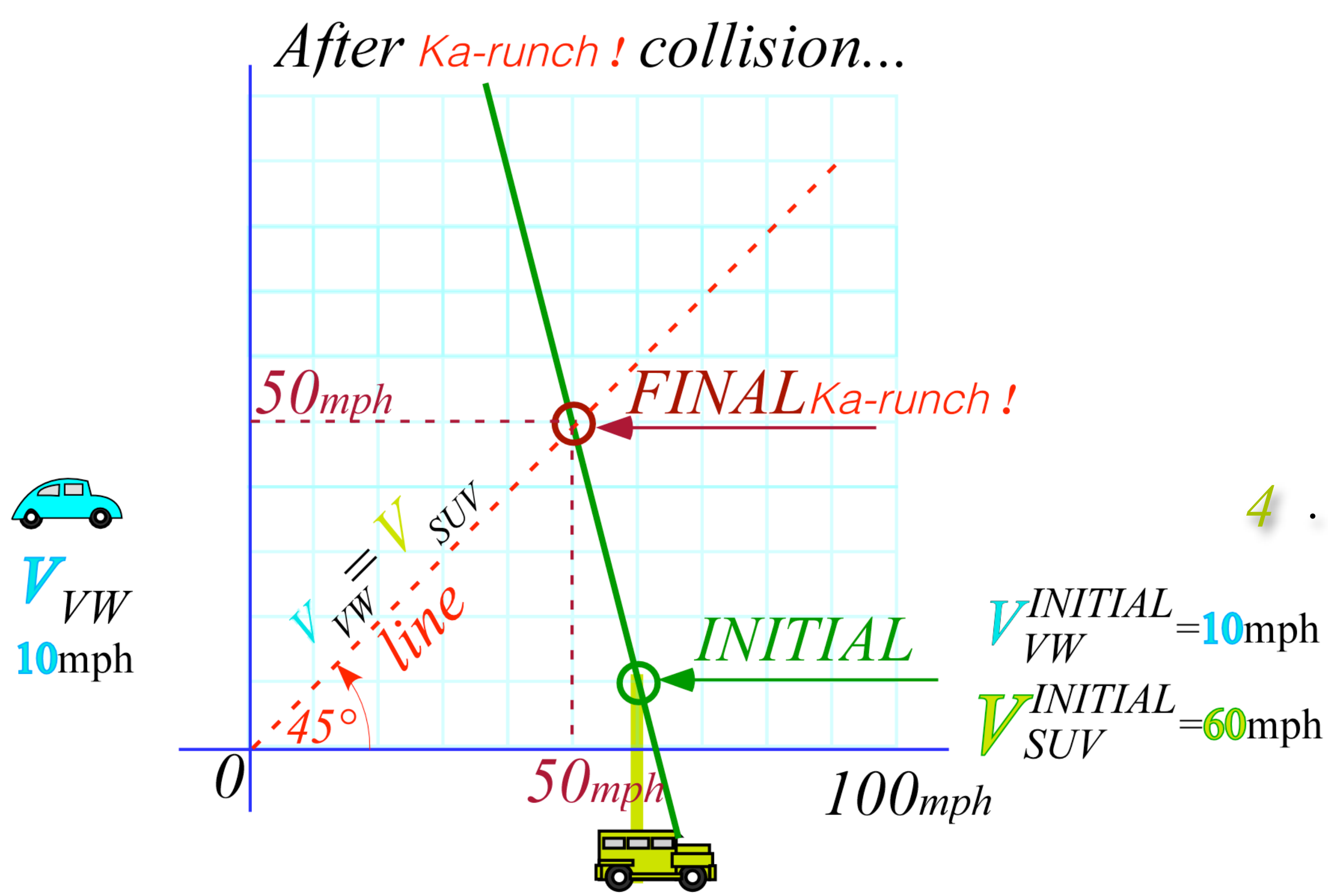
$$M_{SUV}V_{SUV} + M_{VW}V_{VW}$$

$$= constant = P_{Total} = 250$$

$$V_{VW} = -\frac{M_{SUV}}{M_{VW}}V_{SUV} + \frac{P_{Total}}{M_{VW}}$$

$$= -\ 4\ V_{SUV} + 250$$





It's a simple *Cartesian* equation...

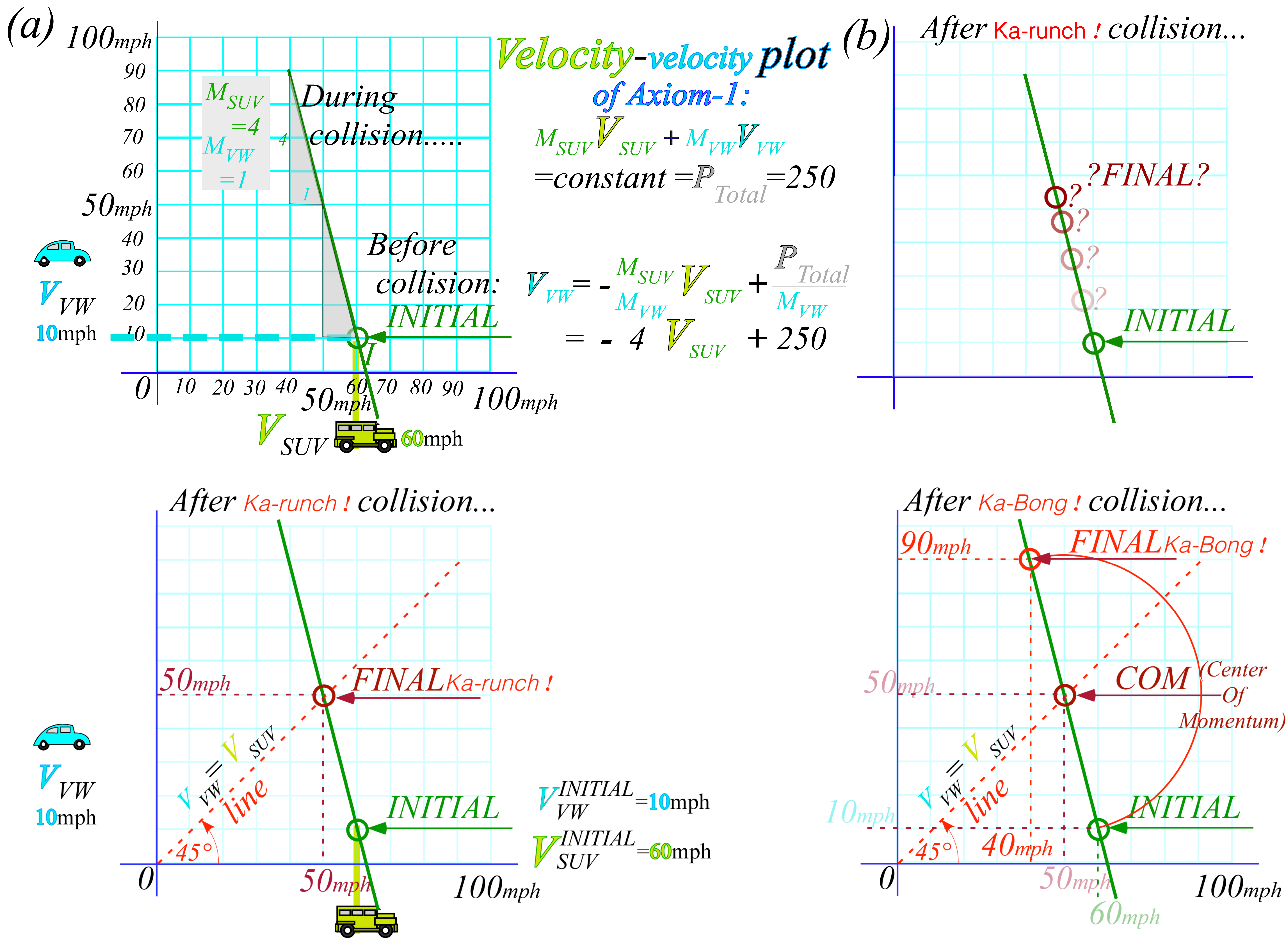
$$4\cdot x + 1\cdot y = 250$$

$$y = 250 - 4\cdot x$$

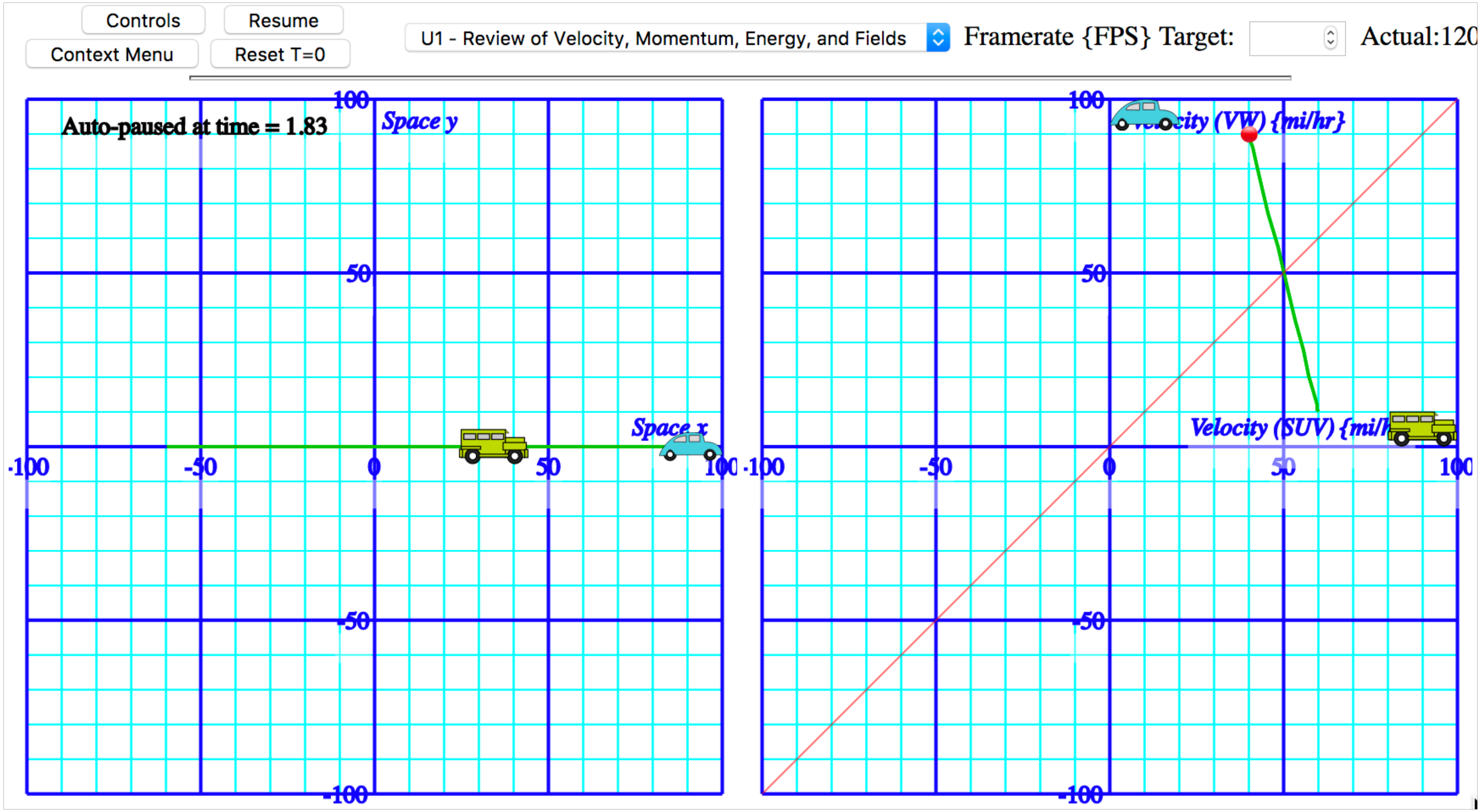
$5\cdot x = 250$ ...with $y = x = 50$

...with a simple *Cartesian* line-plot.

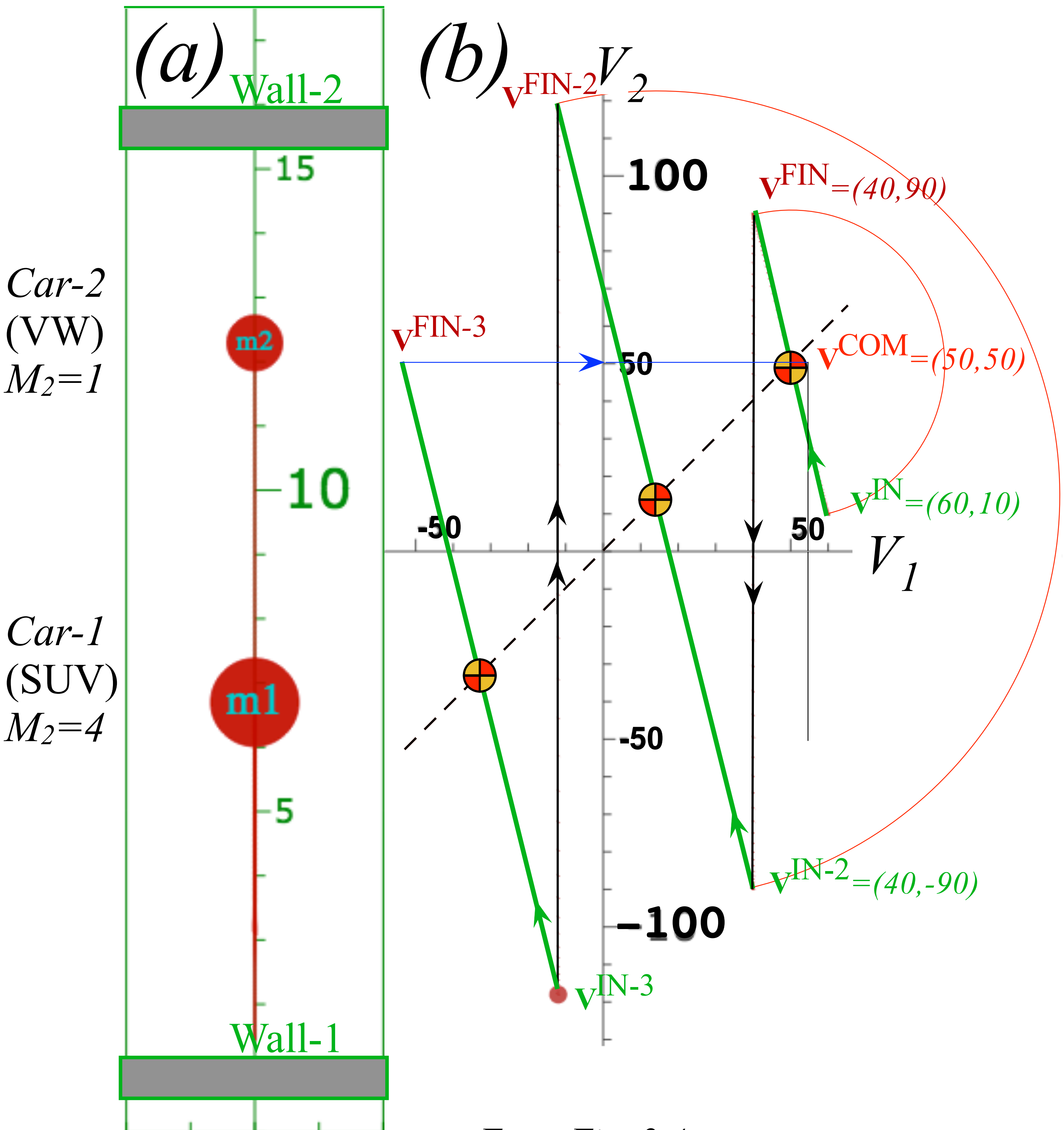
Rene Descartes
1596-1650



(a)
Velocity-velocity plot
of Axiom-1:
M SUV V SUV + M VW V VW
=constant =P Total =250
During
collision.....
Before
collision:
INITIAL
V VW = - M SUV / M VW V SUV + P Total / M VW
= - 4 V SUV + 250
M SUV =4
M VW =1
100mph
90
80
70
60
50mph
40
30
20
10
0
10 20 30 40 50mph 60 70 80 90 100mph
V VW
10mph
V SUV
60mph
(b)
After Ka-runch ! collision...
?FINAL?
INITIAL
After Ka-runch ! collision...
50mph
FINAL Ka-runch !
INITIAL
V VW = V SUV line
45°
0
50mph
100mph
V VW
10mph
V VW INITIAL =10mph
V SUV INITIAL =60mph
After Ka-Bong ! collision...
90mph
FINAL Ka-Bong !
50mph
COM
(Center Of Momentum)
V VW = V SUV line
10mph
45°
40mph
INITIAL
0
50mph
60mph
100mph


Controls
Resume
Context Menu
Reset T=0
U1 - Review of Velocity, Momentum, Energy, and Fields
Framerate {FPS} Target:
Actual:120
Auto-paused at time = 1.83
Space y
Space x
Velocity (VW) {mi/hr}
Velocity (SUV) {mi/h
100
50
0
-50
-100

BounceIt Simulation: frictionless 1D-track with elastic bumper cars bouncing between walls



From Fig. 2.4

BounceIt
Superball Web Simulator
Repeated elastic Collisions
Dual Panel Space vs Space
and V(VW) vs. V(SUV)

Collision *Web Simulator*
Basic *elastic Collision*
Dual Panel
Space vs Space
and
V(VW) vs. V(SUV)

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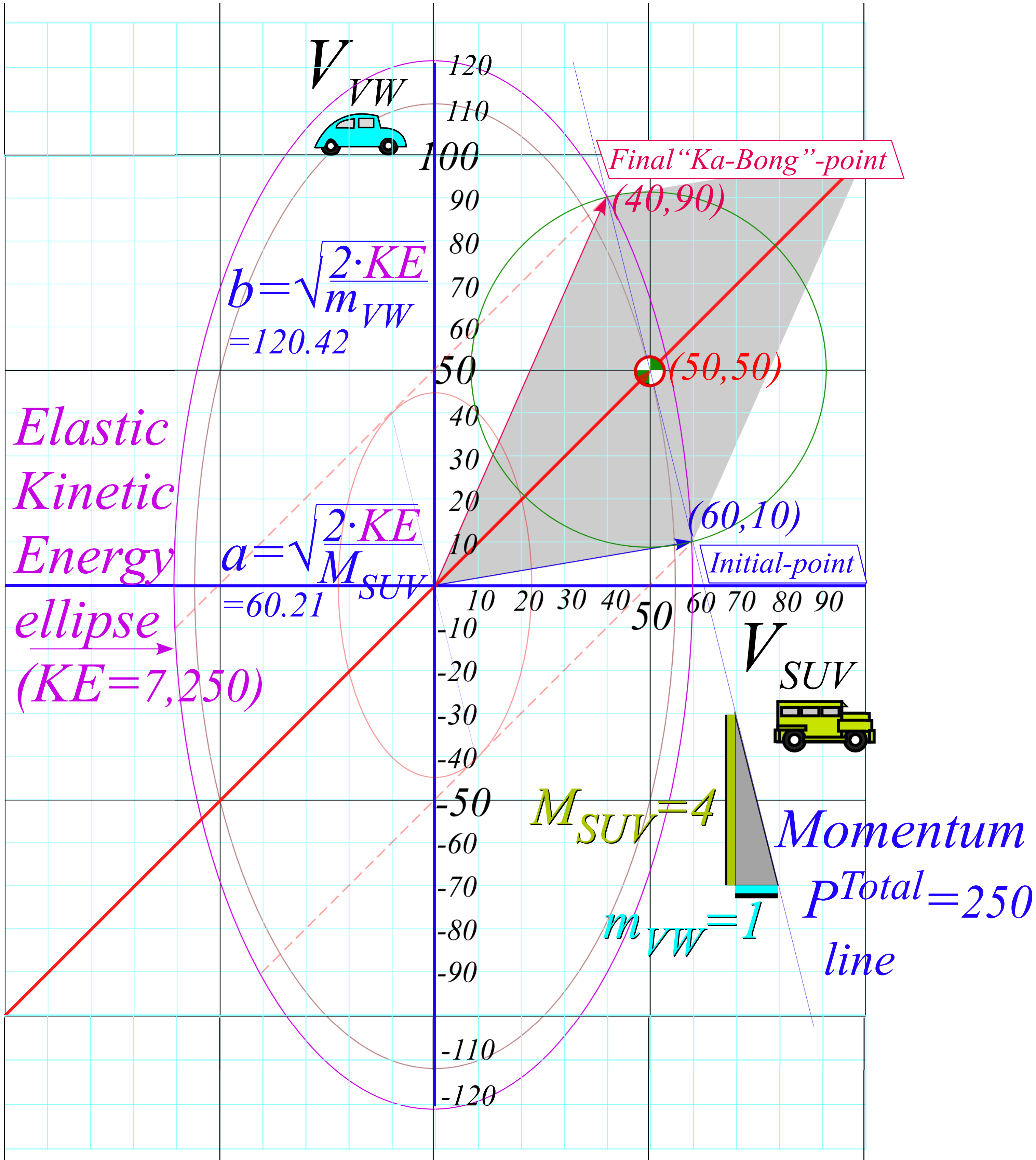

Fig. 3.1 a
in Unit 1

Developing

Conservation-of-Momentum

The key axiom of mechanics

leading to

Conservation-of-Energy Theorem

If and only if…

there is ***T-Symmetry***

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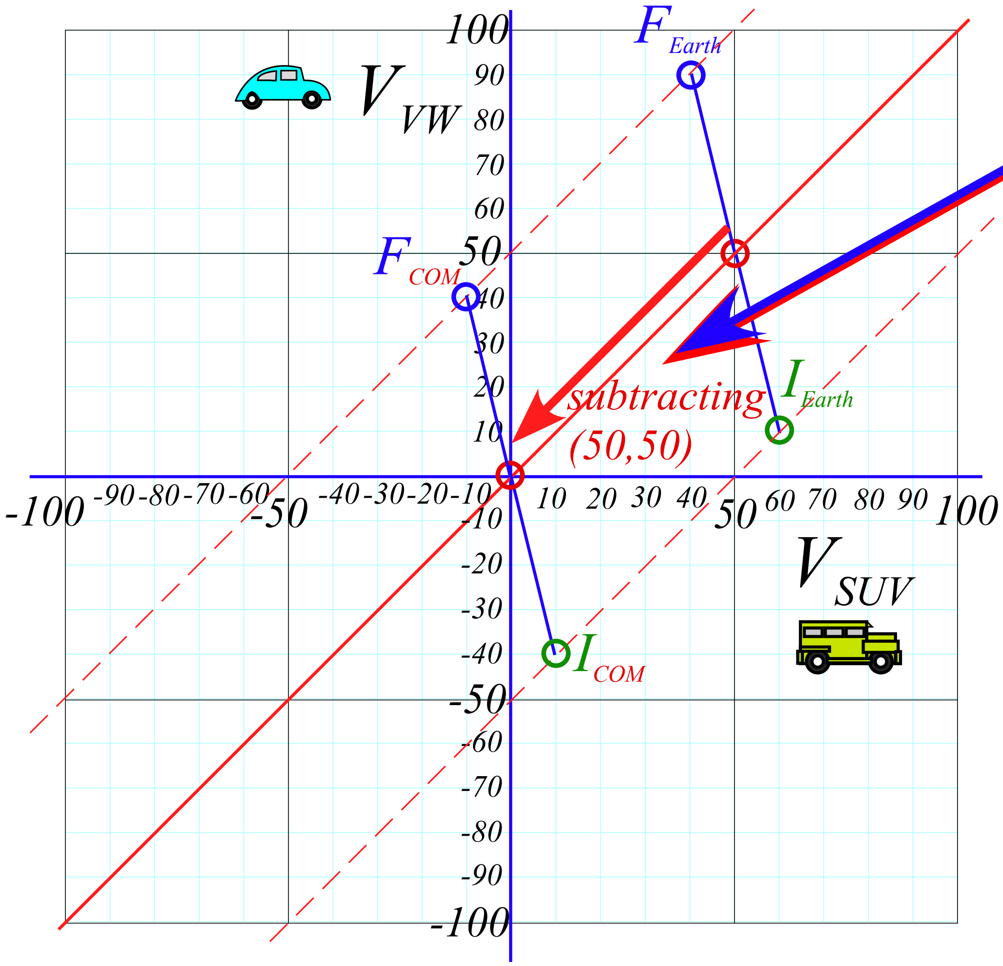
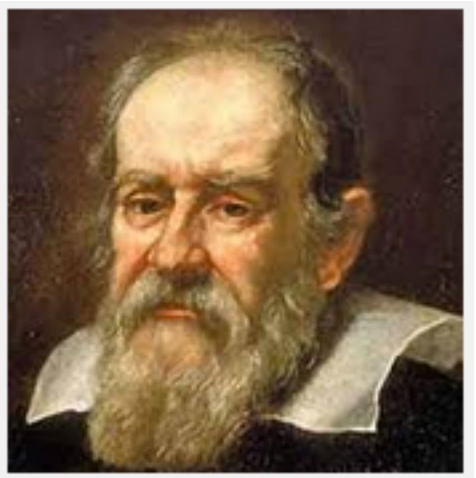
Geometry of Galilean translation (A symmetry transformation)

If you increase your velocity by 50 mph,... *(In some direction x,y, or z…)*

*...the rest of the world appears to be 50 mph **slower*** *(In that direction…)*

(a) Galileo transforms to COM frame





Galileo Galilei
1564-1642

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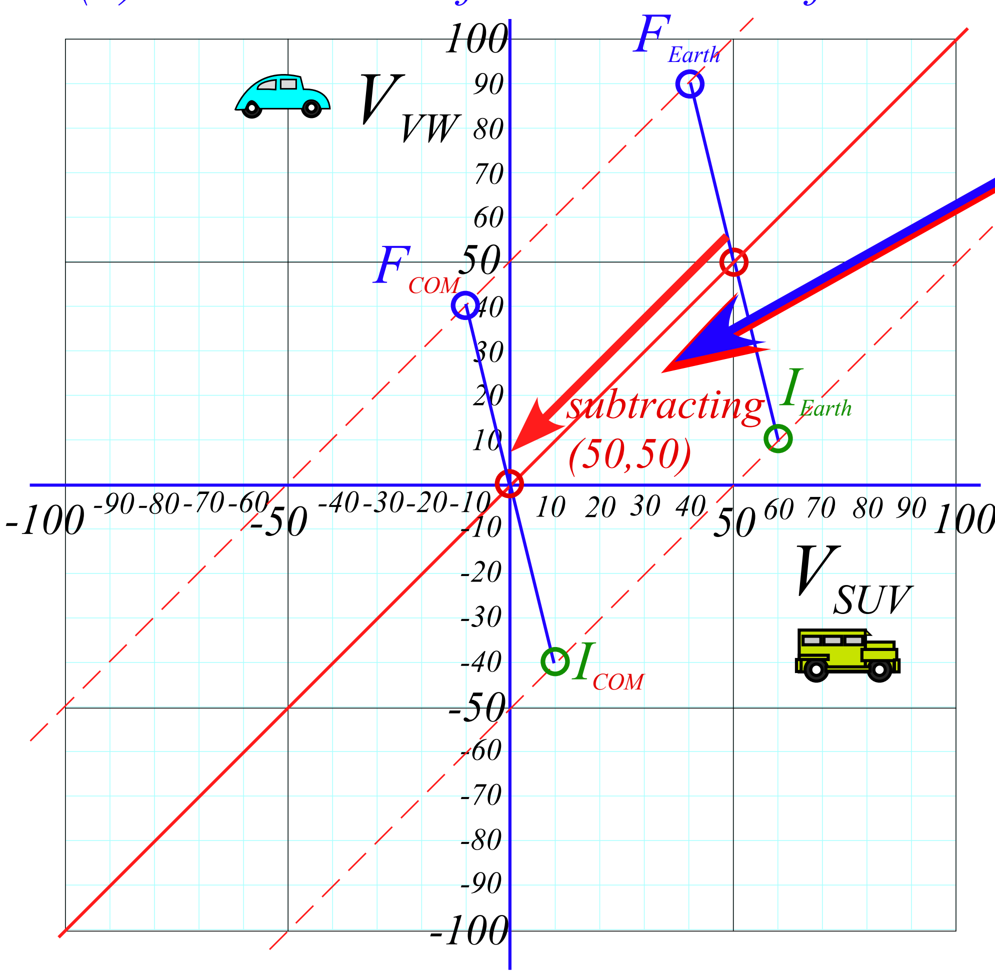


Fig. 2.5a
in Unit 1

(b) ... and to five or six other reference frames

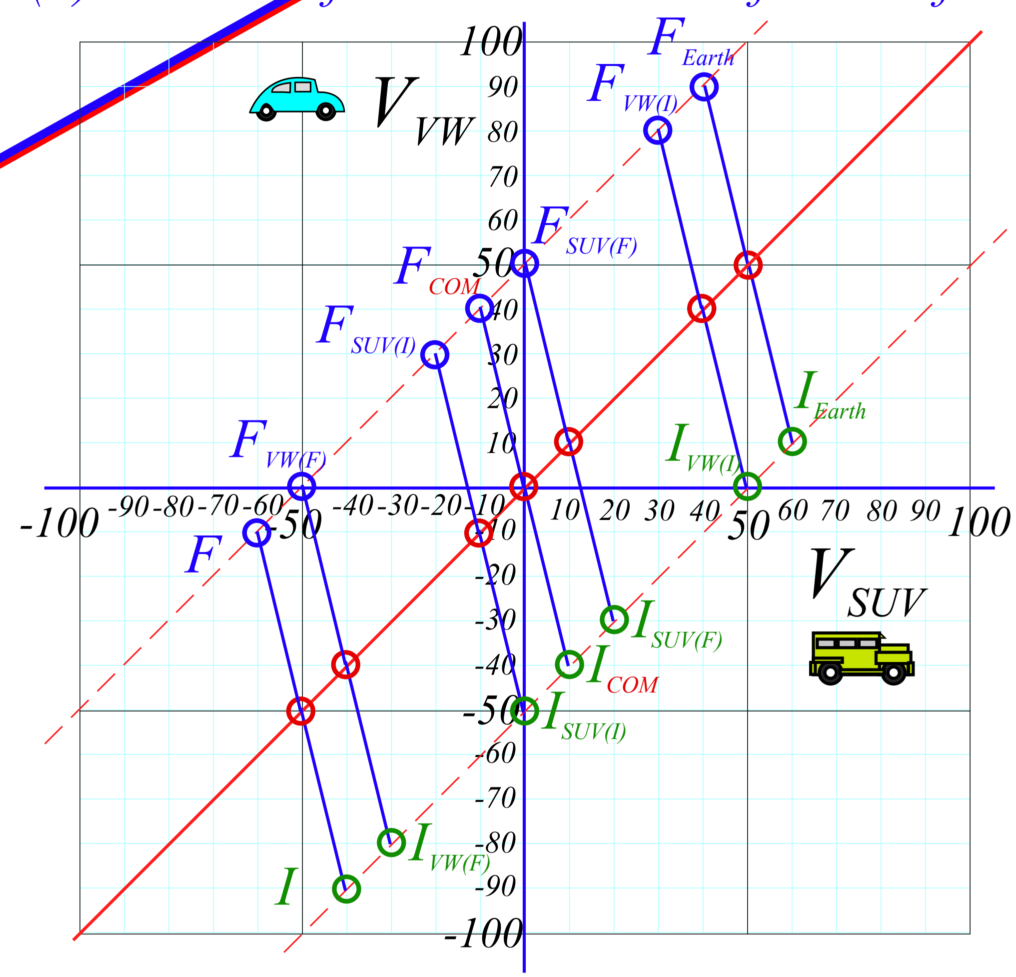
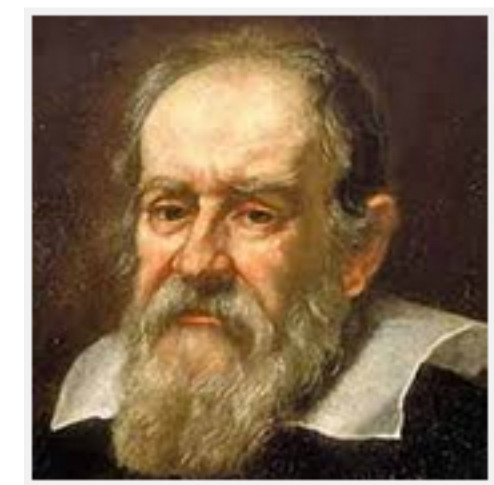


Fig. 2.5b
in Unit 1



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http://www.uark.edu/ua/modphys/markup/BounceItWeb.html?scenario=6300

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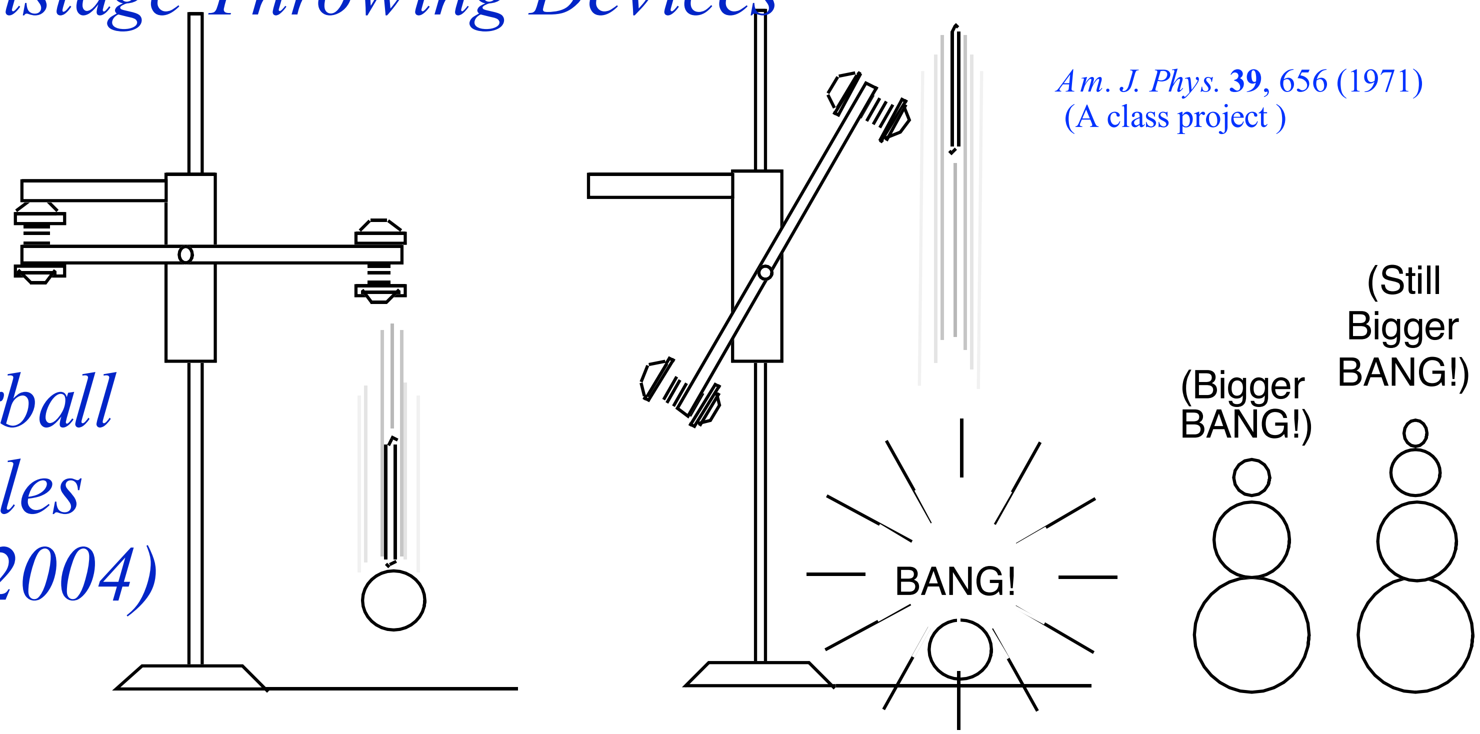

The X-2 Pen launcher and Superball Collision Simulator*

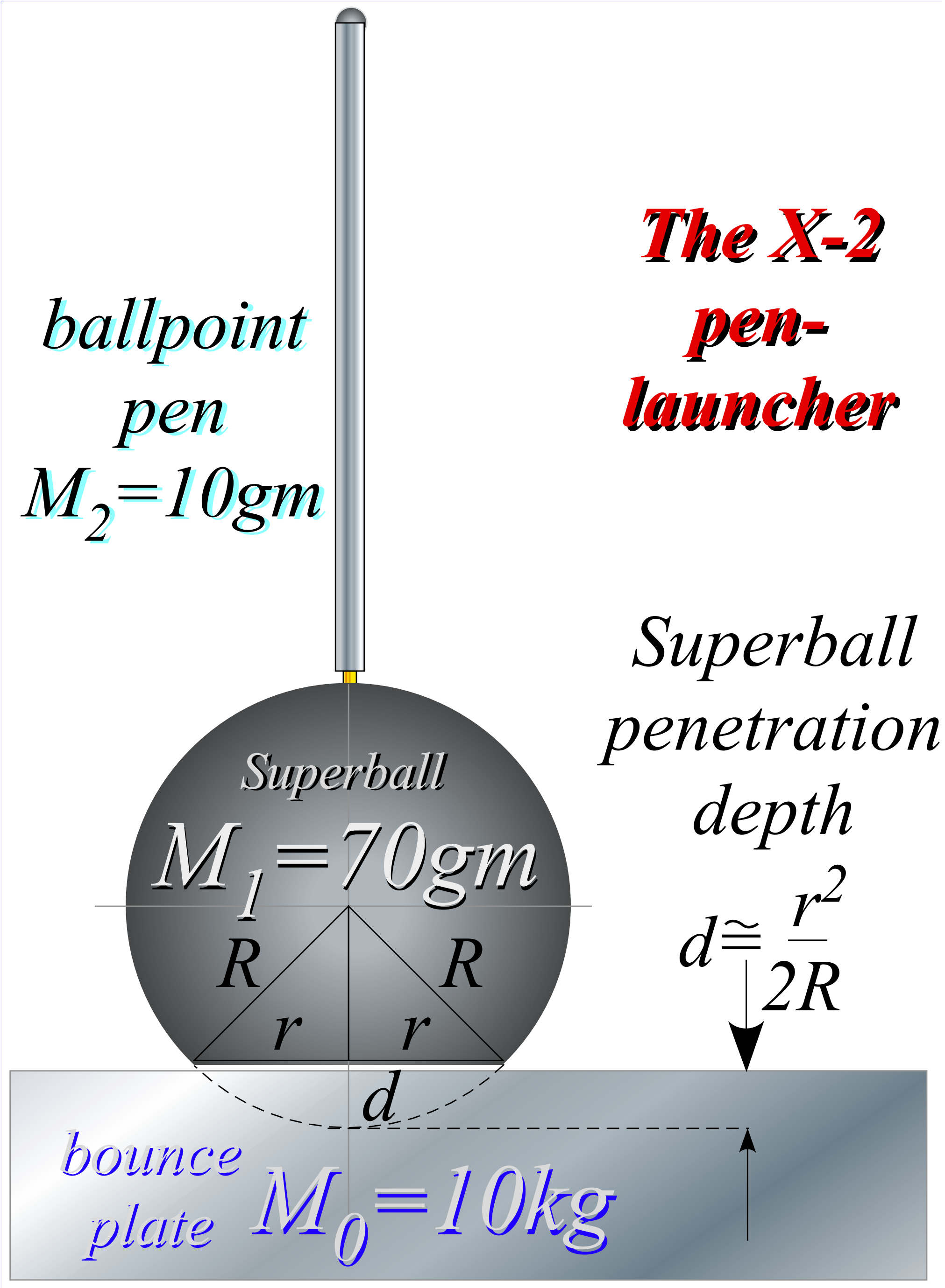

Fig. 3.1
(Unit 1)

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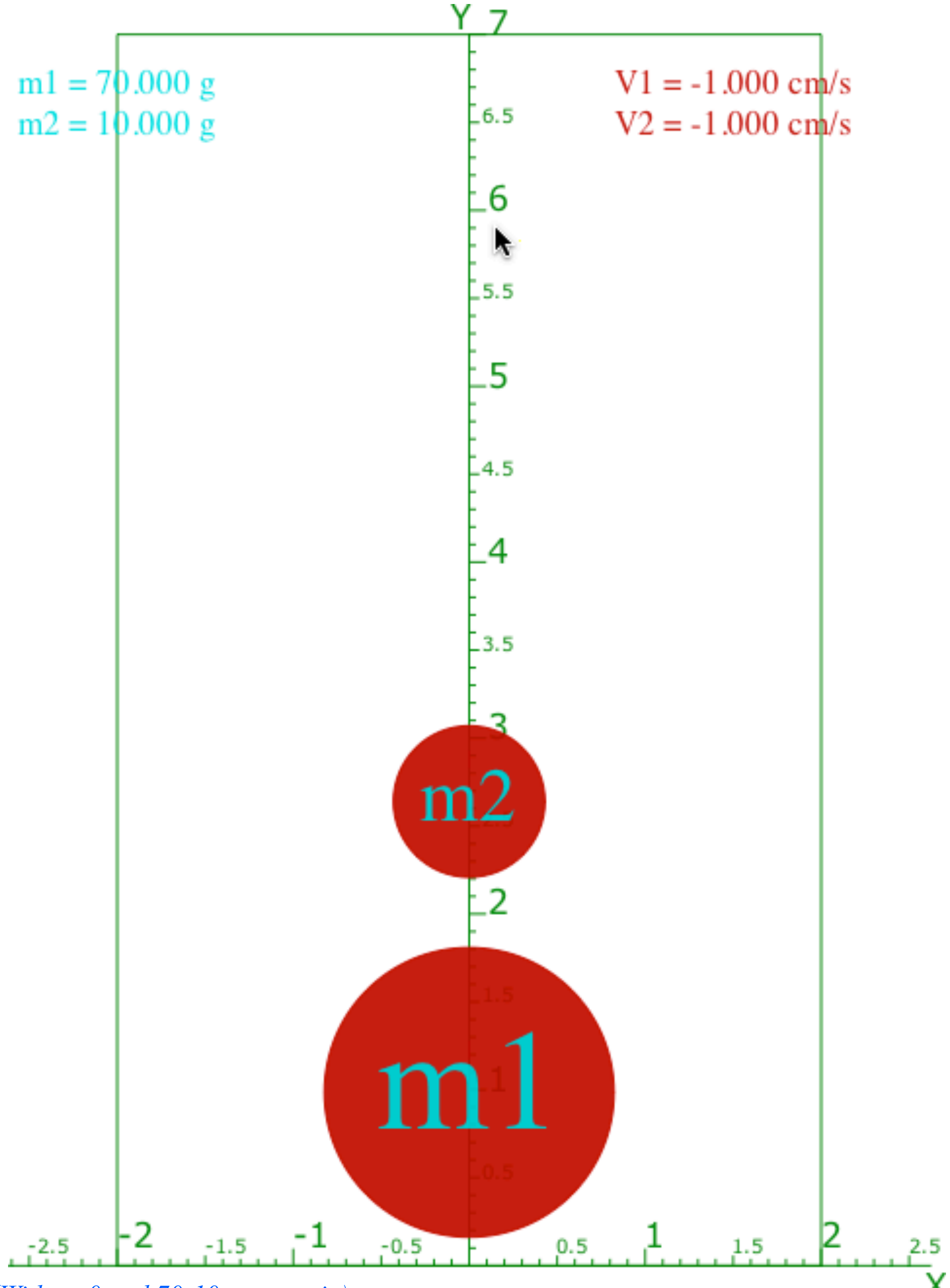
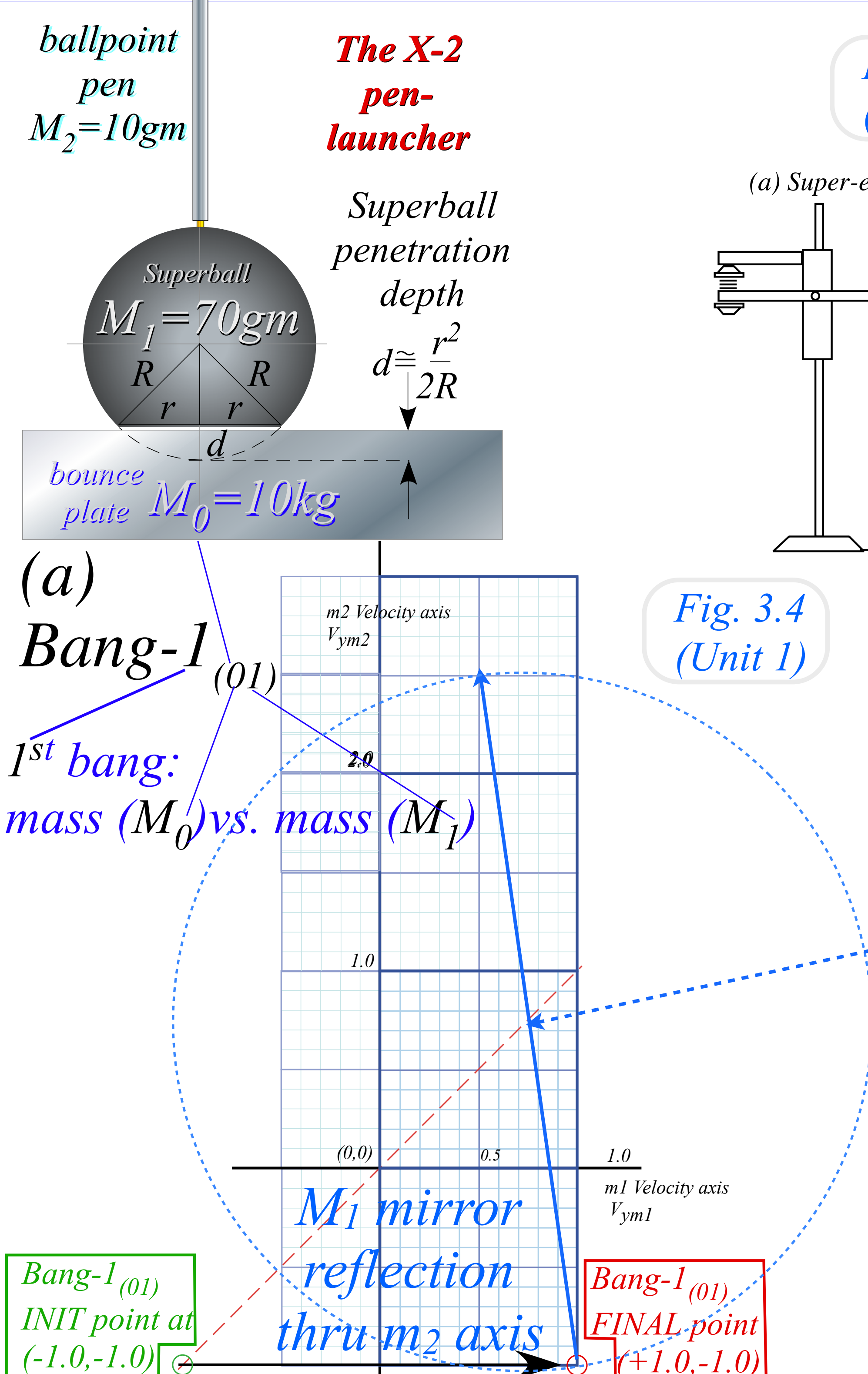
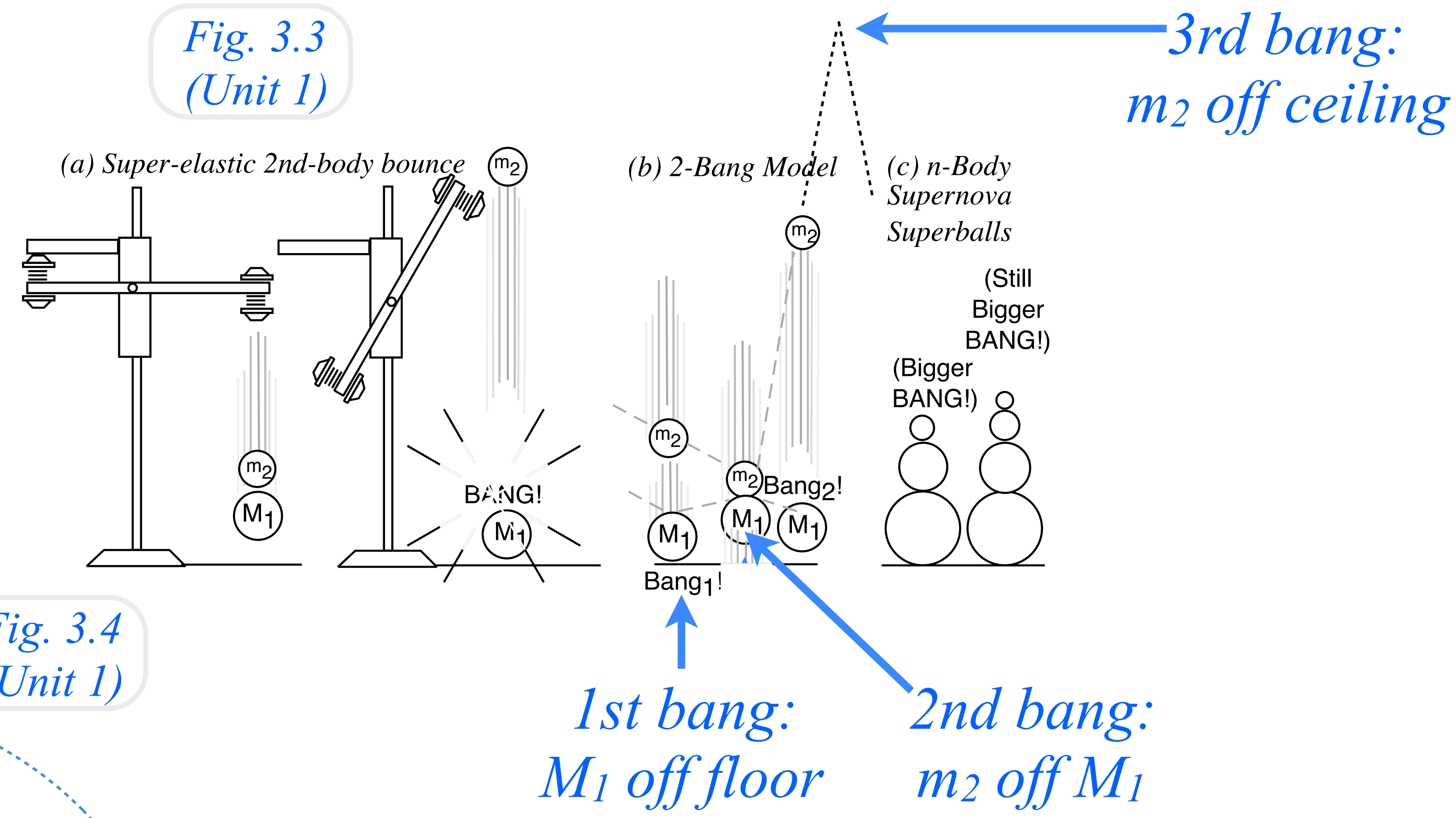


(With g=0 and 70:10 mass ratio)

*Launch Generic Superball Collision Web Simulator http://www.uark.edu/ua/modphys/markup/BounceItWeb.html?scenario=1007





This 1st bang is a floor-bounce of M_1 off very massive plate/Earth M_0

(With g=0 and 70:10 mass ratio)
http://www.uark.edu/ua/modphys/markup/BounceItWeb.html?scenario=1007

(With g and 70:35 mass ratio)
http://www.uark.edu/ua/modphys/testing/markup/BounceItWeb.html

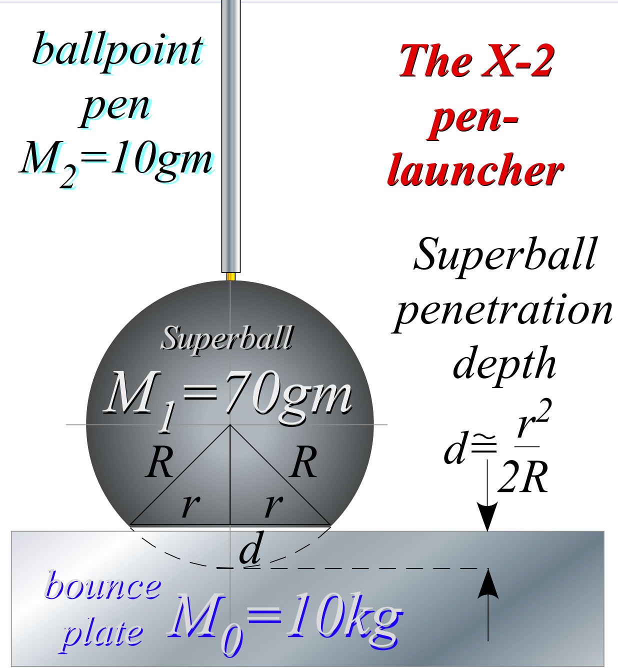
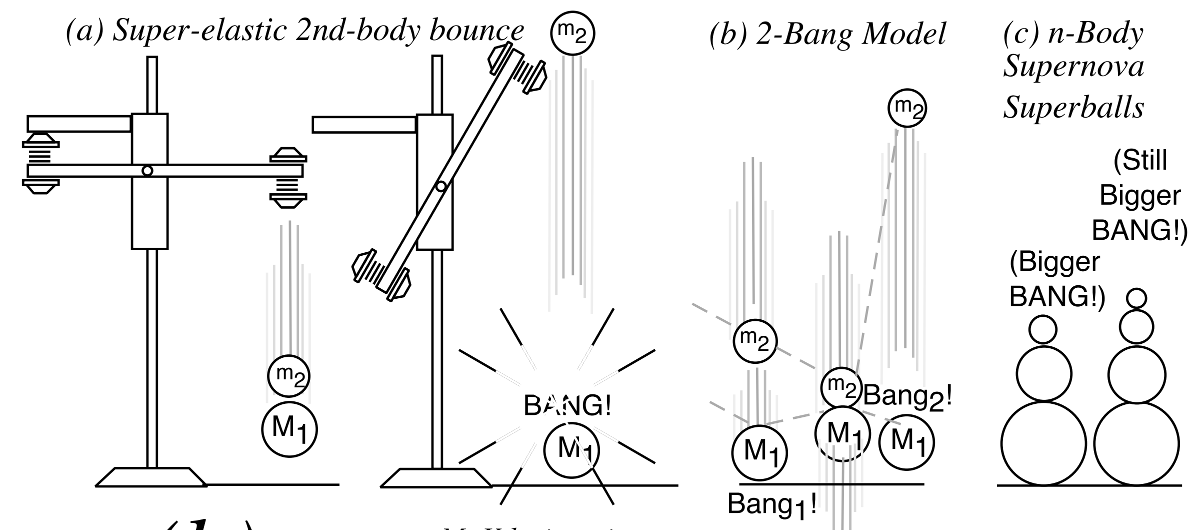


Fig. 3.3 (Unit 1)



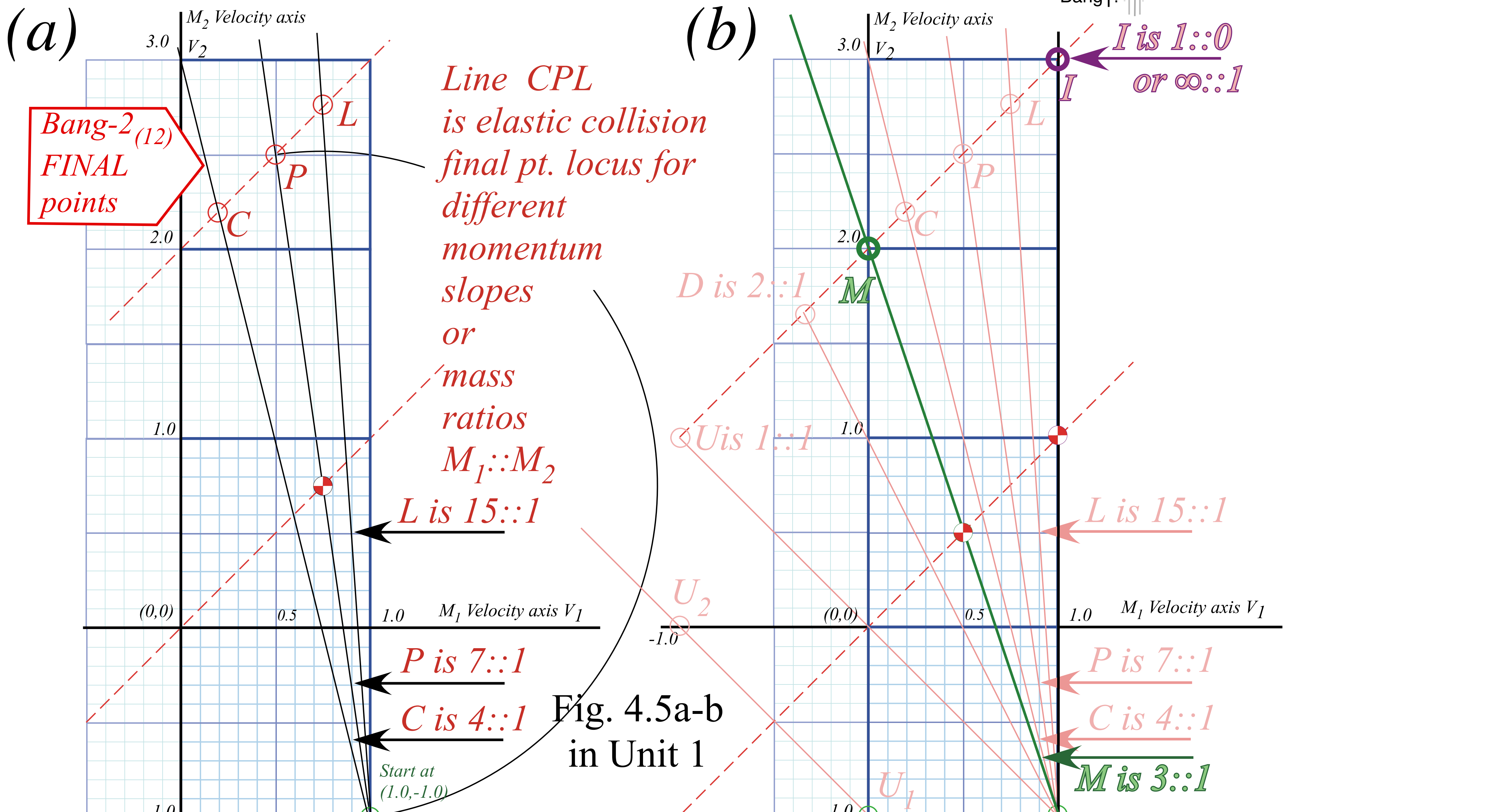


Fig. 4.5a-b in Unit 1

(With g=0 and 70:10 mass ratio)

http://www.uark.edu/ua/modphys/markup/BounceItWeb.html?scenario=1007

(With g and 70:35 mass ratio)

http://www.uark.edu/ua/modphys/testing/markup/BounceItWeb.html

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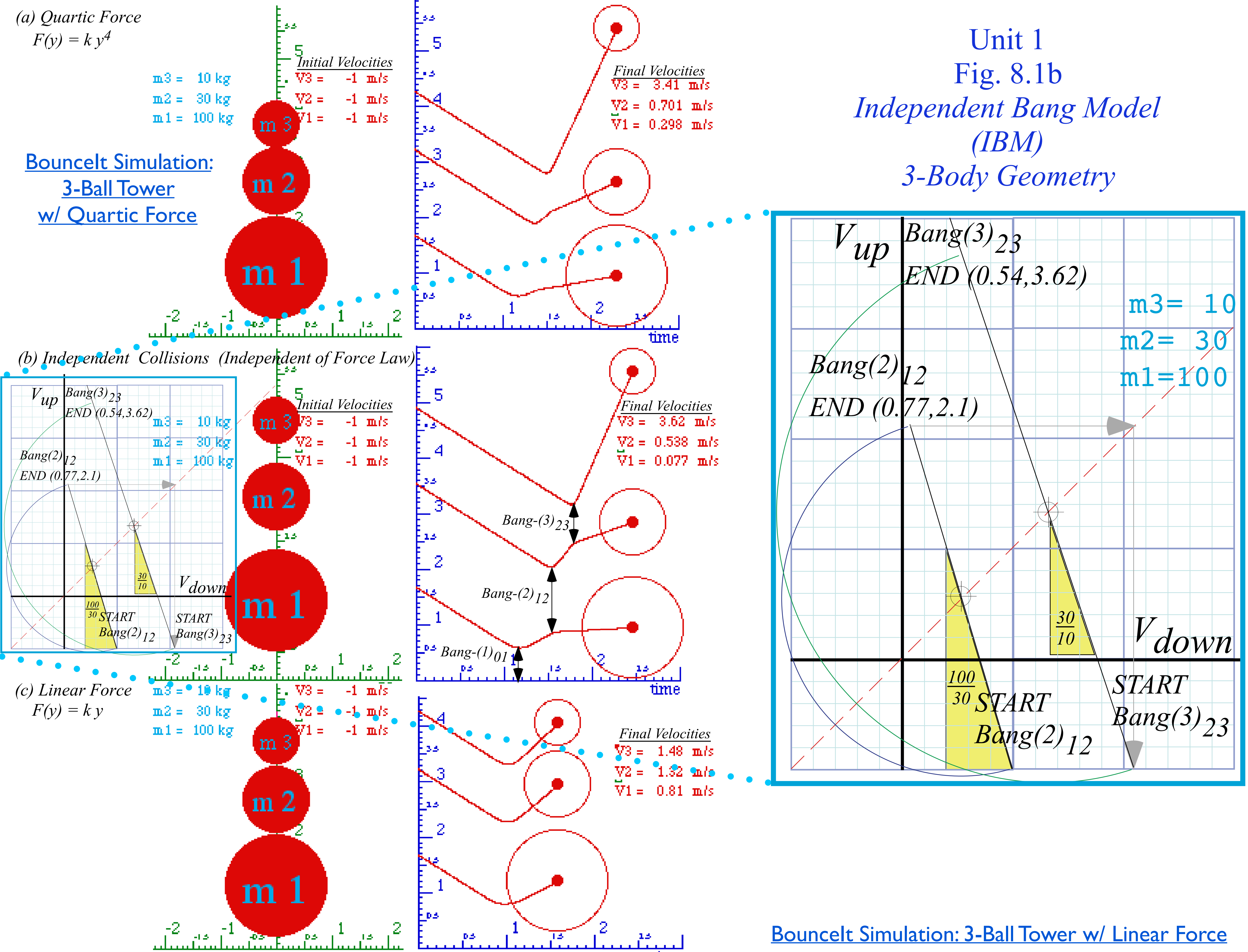
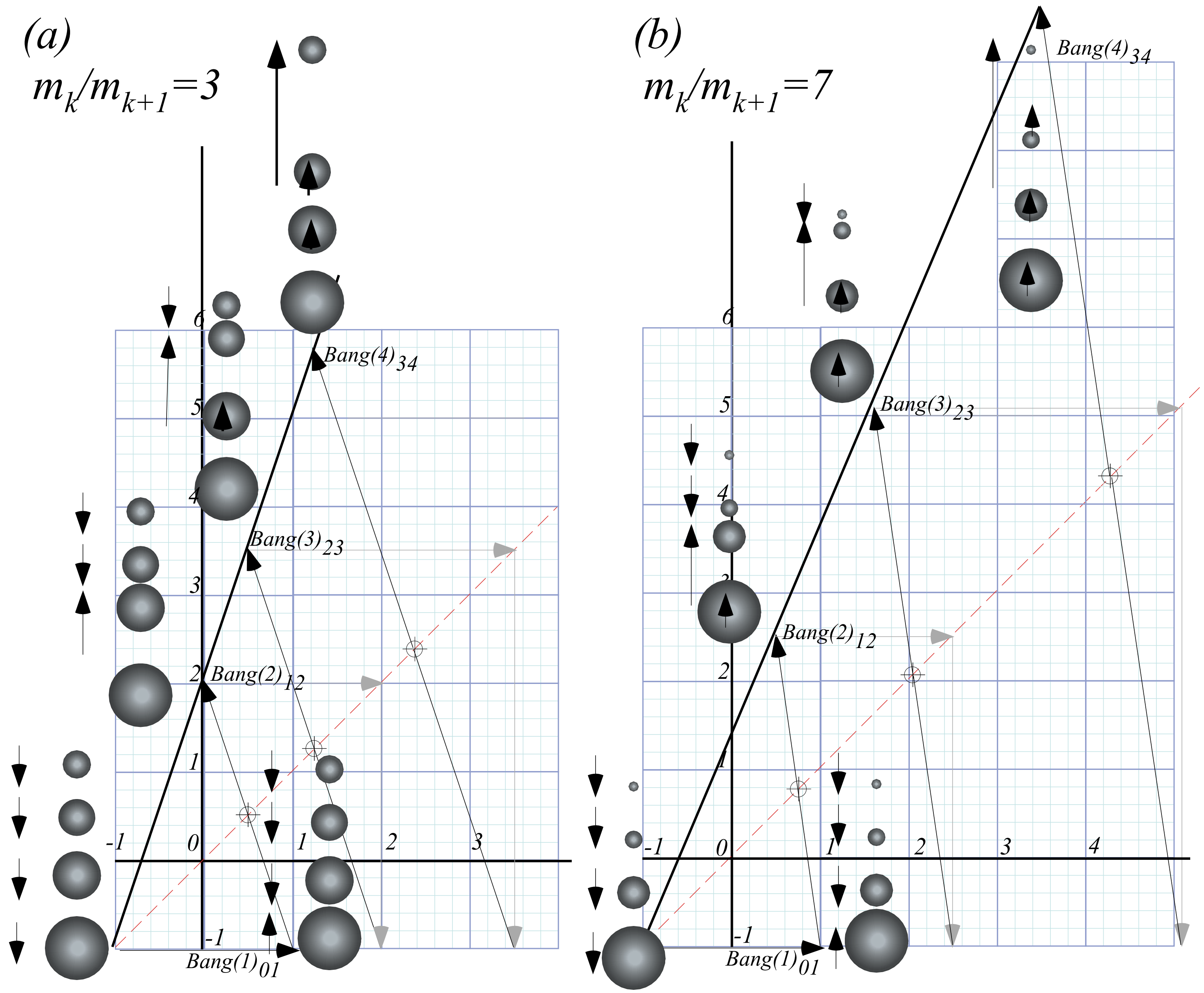
  - Lasers make relativistic (Minkowski) space-time (x,ct)-coordinates and (ω,ck), too

Unit 1
Fig. 8.1b
Independent Bang Model
(IBM)
3-Body Geometry

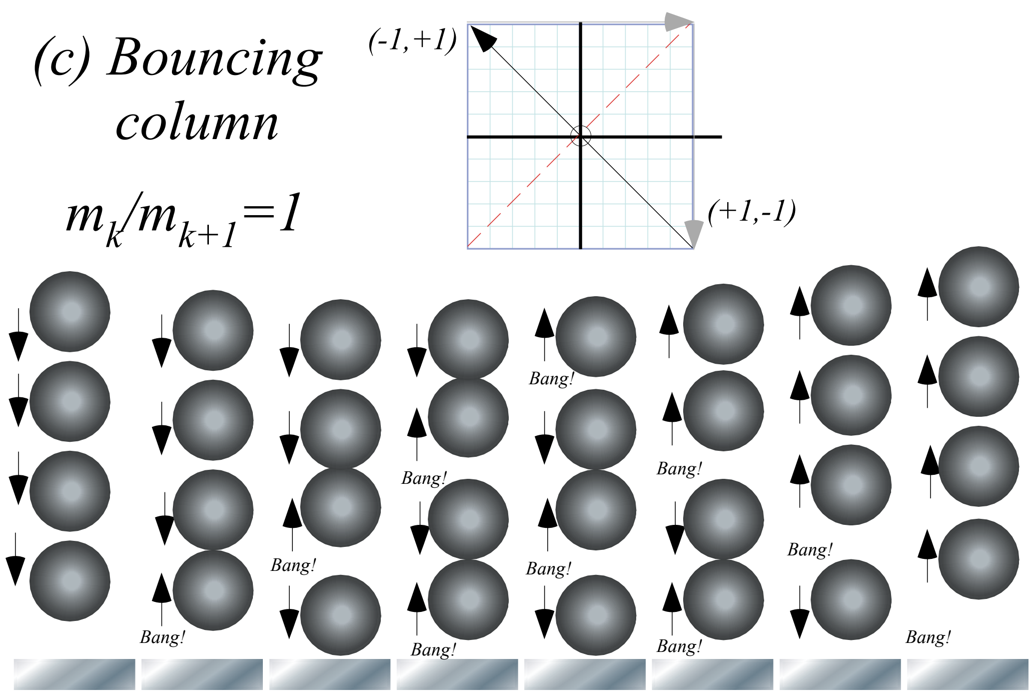


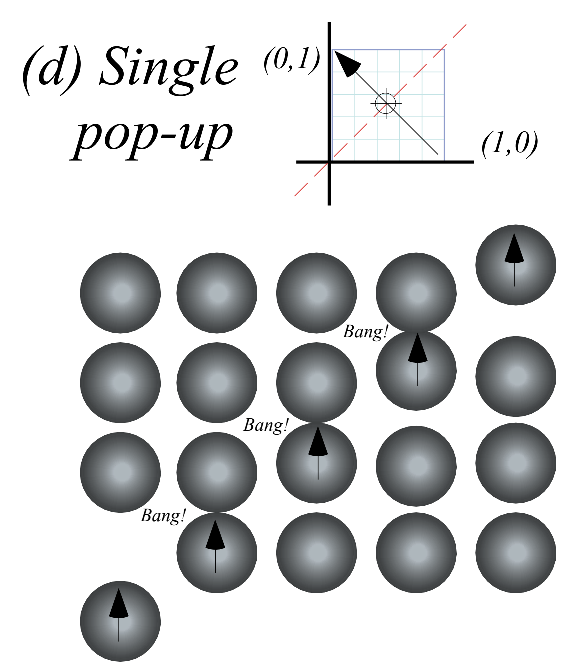
BounceIt Simulation: 3-Ball Tower w/ Linear Force

Unit 1
Fig. 8.2a-b
4-Body IBM Geometry
Fig. 8.2c-d
4-Equal-Body Geometry



[BounceIt Simulation: 4-Ball Tower w/ m_k/m_{k+1} = 3]





4-Equal-Body
"Shockwave" or pulse wave
Dynamics

Opposite of continuous wave dynamics introduced in Unit 2

[BounceIt Simulation: 4-Ball Tower w/ m_k/m_{k+1} = 1]

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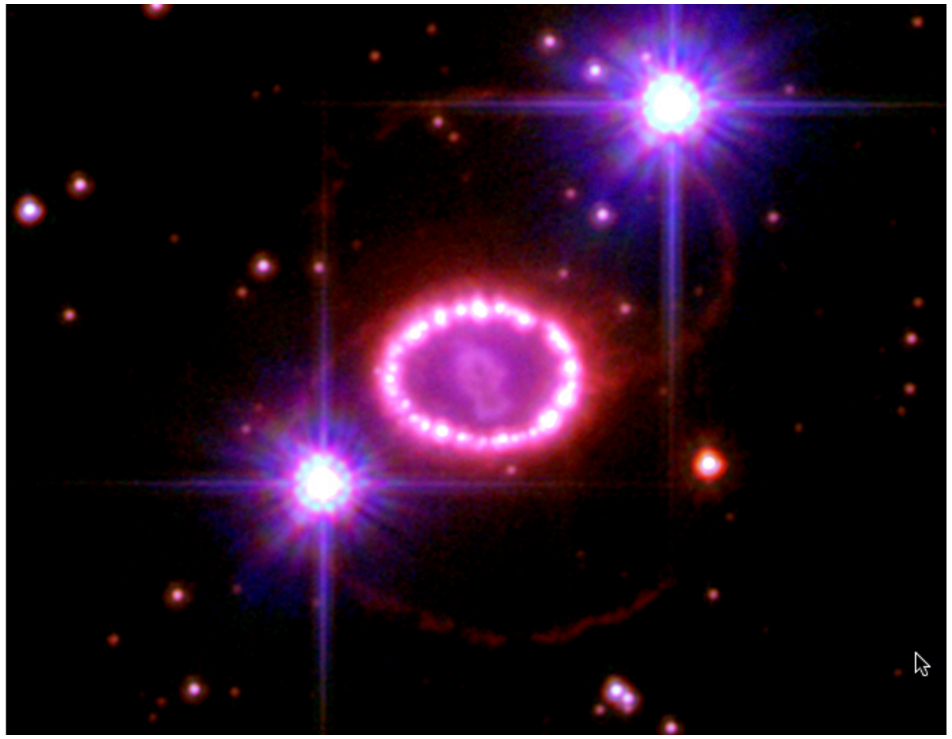
A story of Stirling Colgate (Palmolive) and core-collapse supernovae

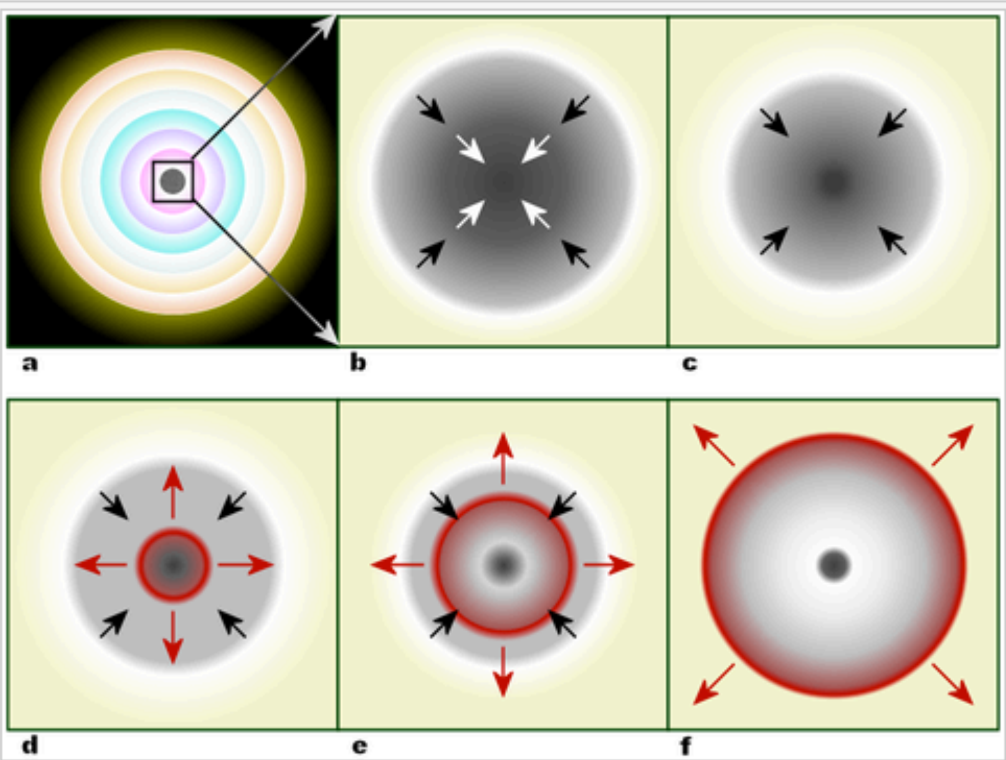


Source

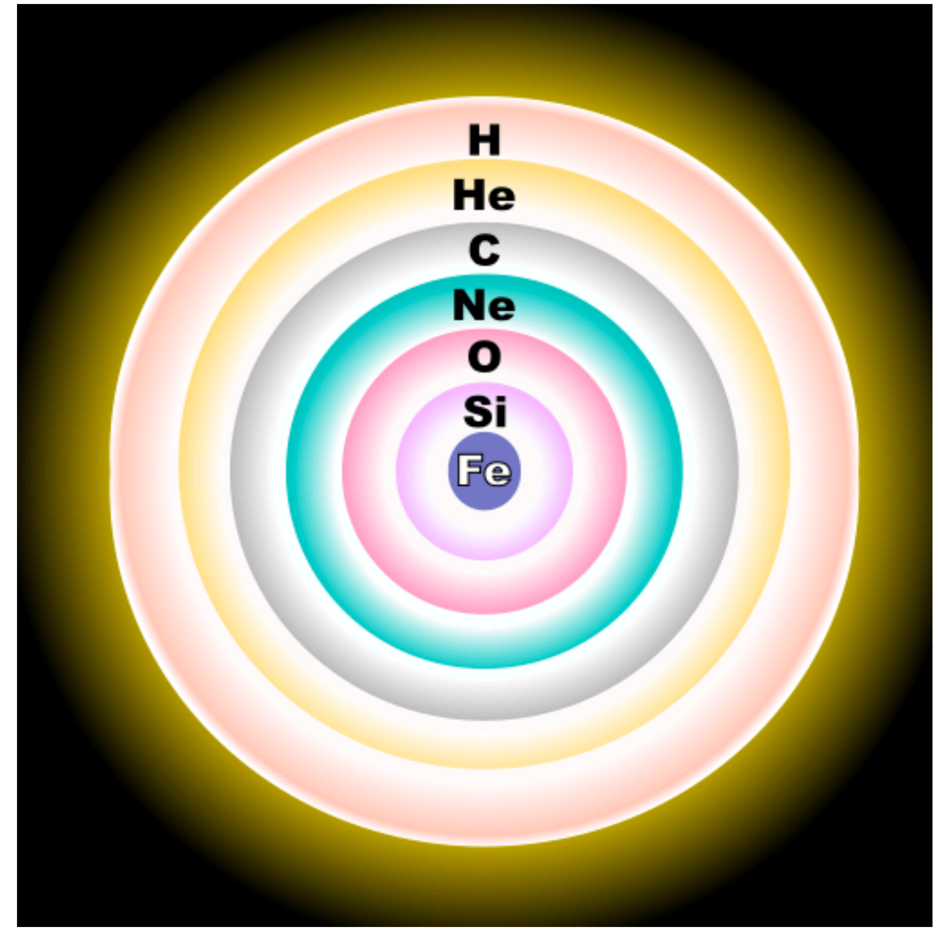
http://hubblesite.org/newscenter/archive/releases/2007/10/image/a/

Author

NASA, ESA, P. Challis, and R. Kirshner (Harvard-Smithsonian Center for Astrophysics)



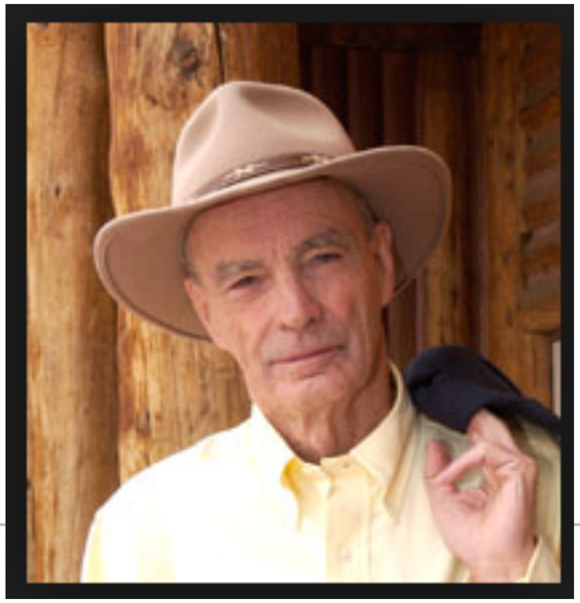
Within a massive, evolved star (a) the onion-layered shells of elements undergo fusion, forming a nickel-iron core (b) that reaches Chandrasekhar-mass and starts to collapse. The inner part of the core is compressed into neutrons (c), causing infalling material to bounce (d) and form an outward-propagating shock front (red). The shock starts to stall (e), but it is re-invigorated by neutrino interaction. The surrounding material is blasted away (f), leaving only a degenerate remnant.



Core-burning nuclear fusion stages for a 25-solar mass star

Process	Main fuel	Main products	25 $M_\odot$ star[6]		
			Temperature (Kelvin)	Density (g/cm^3)	Duration
hydrogen burning	hydrogen	helium	7×10^7	10	10^7 years
triple-alpha process	helium	carbon, oxygen	2×10^8	2000	10^6 years
carbon burning process	carbon	Ne, Na, Mg, Al	8×10^8	10^6	10^3 years
neon burning process	neon	O, Mg	1.6×10^9	10^7	3 years
oxygen burning process	oxygen	Si, S, Ar, Ca	1.8×10^9	10^7	0.3 years
silicon burning process	silicon	nickel (decays into iron)	2.5×10^9	10^8	5 days

Stirling Colgate



From Wikipedia, the free encyclopedia

Stirling Auchincloss Colgate (November 14, 1925 – December 1, 2013) was an American physicist at Los Alamos National Laboratory and a professor emeritus of physics, past president at the New Mexico Institute of Mining and Technology (New Mexico Tech),[1] and an heir to the Colgate toothpaste family fortune.[2] He was America's premier[citation needed] diagnostician of thermonuclear weapons during the early years at the Lawrence Livermore National Laboratory in California. While much of his involvement with physics is still highly classified, he made many contributions in the open literature including physics education and astrophysics.[3] He was born in New York City in 1925, to Henry Auchincloss and Jeanette Thurber (née Pruyn) Colgate.[4]

..an amusing off-color aside
story of Stirling Colgate's NMIMT resignation...

(Not told in Wikipedia!)

Quote

- "*I was always enamored with explosives, and eventually I graduated to dynamite and then nuclear bombs*."

Multiple-collision accelerator assembly

US 5256071 A

ABSTRACT

A device comprising several highly elastic objects is presented whose purpose is to demonstrate an unobvious consequence of fundamental laws of physics--the acceleration of an object to high speed by multiple collisions among a series of heavier objects moving at slower speed. The objects, each of different mass, are arrayed in close proximity in order of decreasing mass with their centers lying along a straight line. This arrangement of the assembly of objects is maintained by a constraining element which permits the assembly axis to be oriented in any desired direction and permits the assembly to be moved or manipulated as a unit in any desired way without destroying the arrangement of objects. In the preferred embodiment the elastic objects are polybutadiene balls (12), the constraining element is an interior guide-pin (10) fastened in the largest ball and extending radially therefrom, on which the remaining balls can slide freely because of diametrical holes formed in them. In use this multiple-collision accelerator assembly is suspended in vertical orientation, with the largest ball downward, by holding the tip-end of the guide-pin which extends beyond the littlest ball. The assembly is then dropped onto a solid surface (14), the striking of which produces a sharp impulse that is transmitted from the largest ball, through the assembly, causing the littlest ball to be projected to a height many times that from which the assembly was dropped.

Publication number	US5256071 A
Publication type	Grant
Application number	US 07/748,804
Publication date	Oct 26, 1993
Filing date	Aug 22, 1991
Priority date ⓘ	Aug 22, 1991
Fee status ⓘ	Paid
Inventors	Edward W. Hones, William G. Hones, Stirling A. Colgate
Original Assignee	Hones Edward W, Hones William G, Colgate Stirling A
Export Citation	BiBTeX, EndNote, RefMan

Patent Citations (3), Referenced by (4), Classifications (7), Legal Events (7)

External Links: USPTO, USPTO Assignment, Espacenet

(Point allowing patent over previous 1973 proposal (4))

1st publication describing theory and experiment of this device 20 years before.

Velocity Amplification in Collision Experiments Involving Superballs

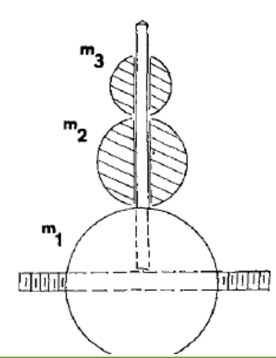
William G. Harter[1] (class of WGH)

– HIDE AFFILIATIONS

[1] University of Southern California, Los Angeles, California 90007

View the Scitation page for University of Southern California (USC).

Am. J. Phys. **39**, 656 (1971); http://dx.doi.org/10.1119/1.1986253



BUY: $30.00

(Now I have to pay APS for my own paper.)

AstroBlaster
Product Code: AstroBlaster
Our Price: $9.95

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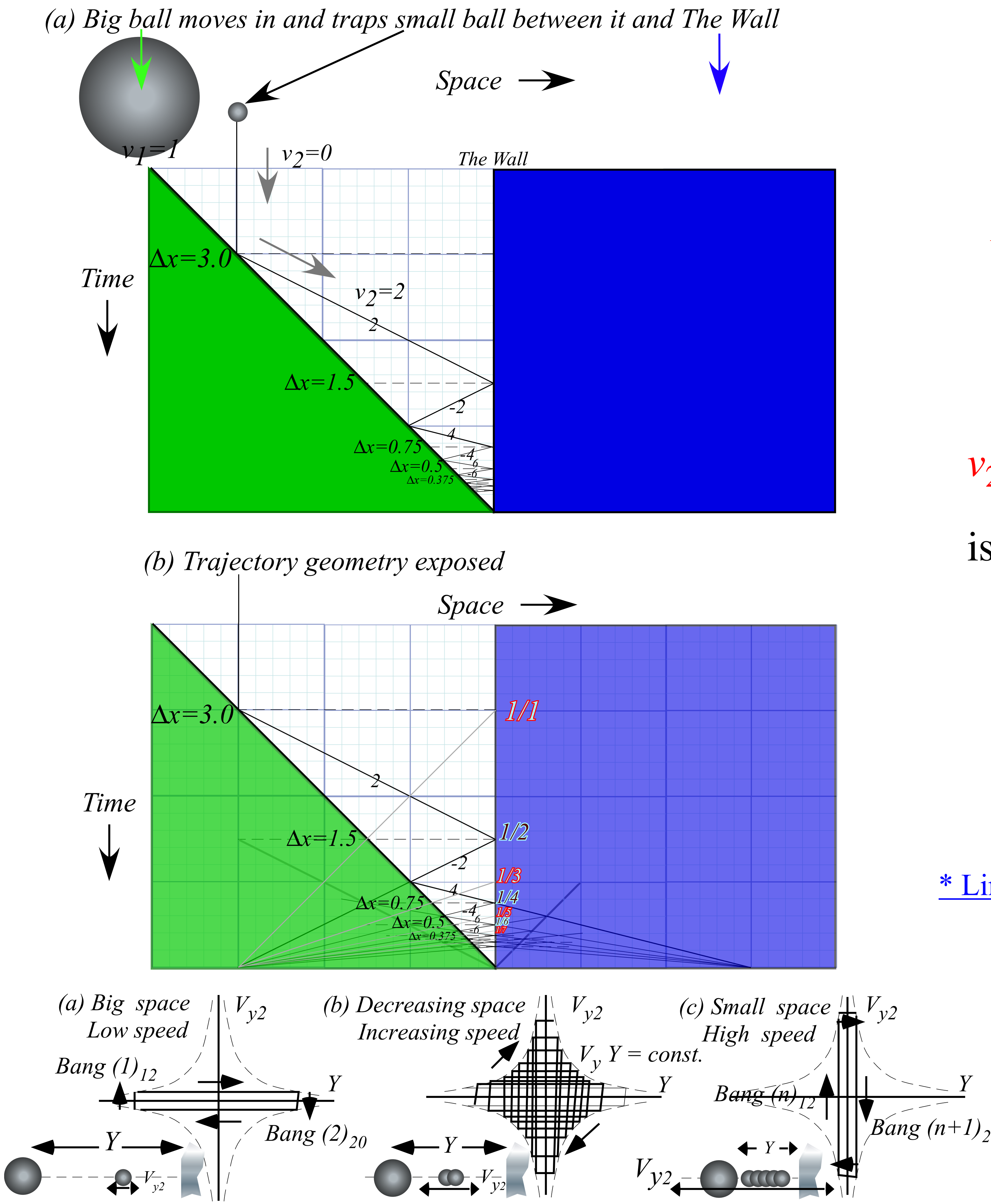


The Classical "Monster Mash"

Classical introduction to

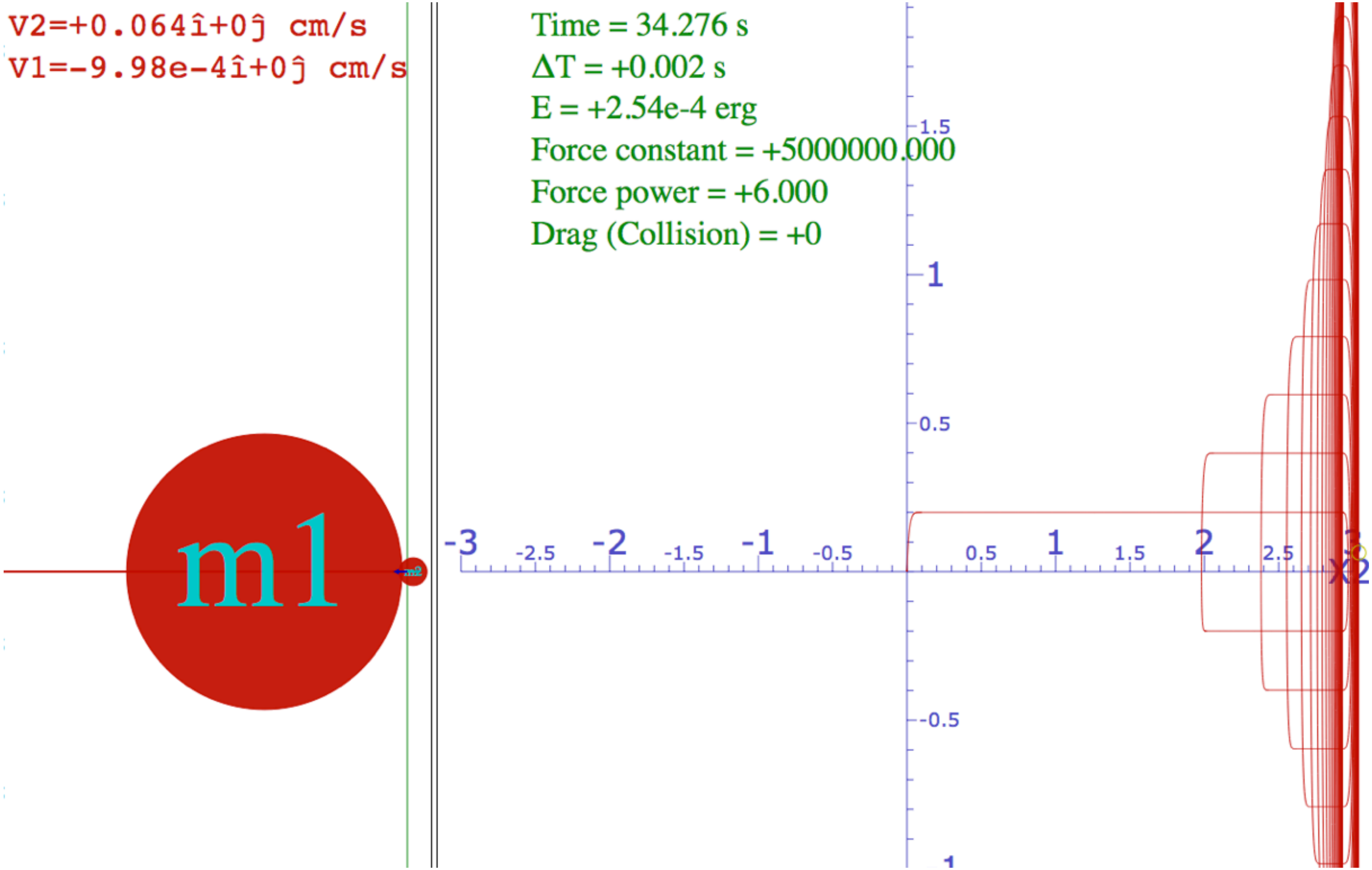
Heisenberg "Uncertainty" Relations

$$v_2 = \frac{const.}{Y} \quad \text{or:} \quad Y \cdot v_2 = const.$$

is analogous to: $\Delta x \cdot \Delta p = N \cdot \hbar$

Unit 1
Fig. 6.4

* Link to BounceIt "*Monster Mash*" $x_2(t)$ animation
(Note: Time sense is inverted)



* [Link to BounceIt "*Monster Mash"* Vx₂ vs x₂ animation]

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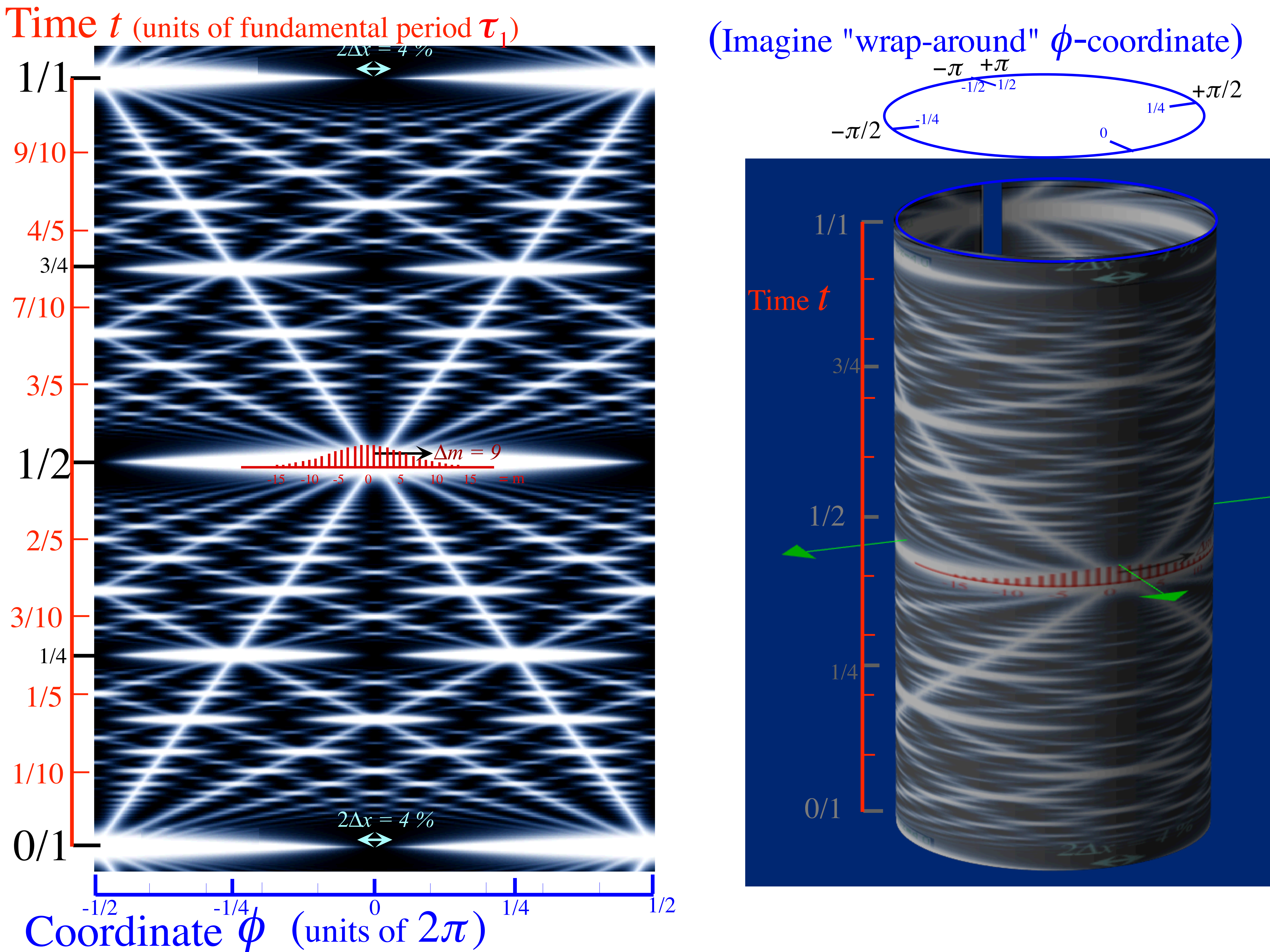


Time t (units of fundamental period τ_1)
1/1
9/10
4/5
3/4
7/10
3/5
1/2
2/5
3/10
1/4
1/5
1/10
0/1
$2\Delta x = 4\ \%$
$\Delta m = 9$
-15 -10 -5 0 5 10 15 = m
-1/2 -1/4 0 1/4 1/2
Coordinate ϕ (units of 2π)
(Imagine "wrap-around" ϕ-coordinate)
$-\pi$ $+\pi$
-1/2 1/2
$+\pi/2$
1/4
$-\pi/2$
-1/4
0
Time t
1/1
3/4
1/2
1/4
0/1

WaveIt Web simulation http://www.uark.edu/ua/modphys/markup/WaveItWeb.html?scenario=Quantum%20Carpet

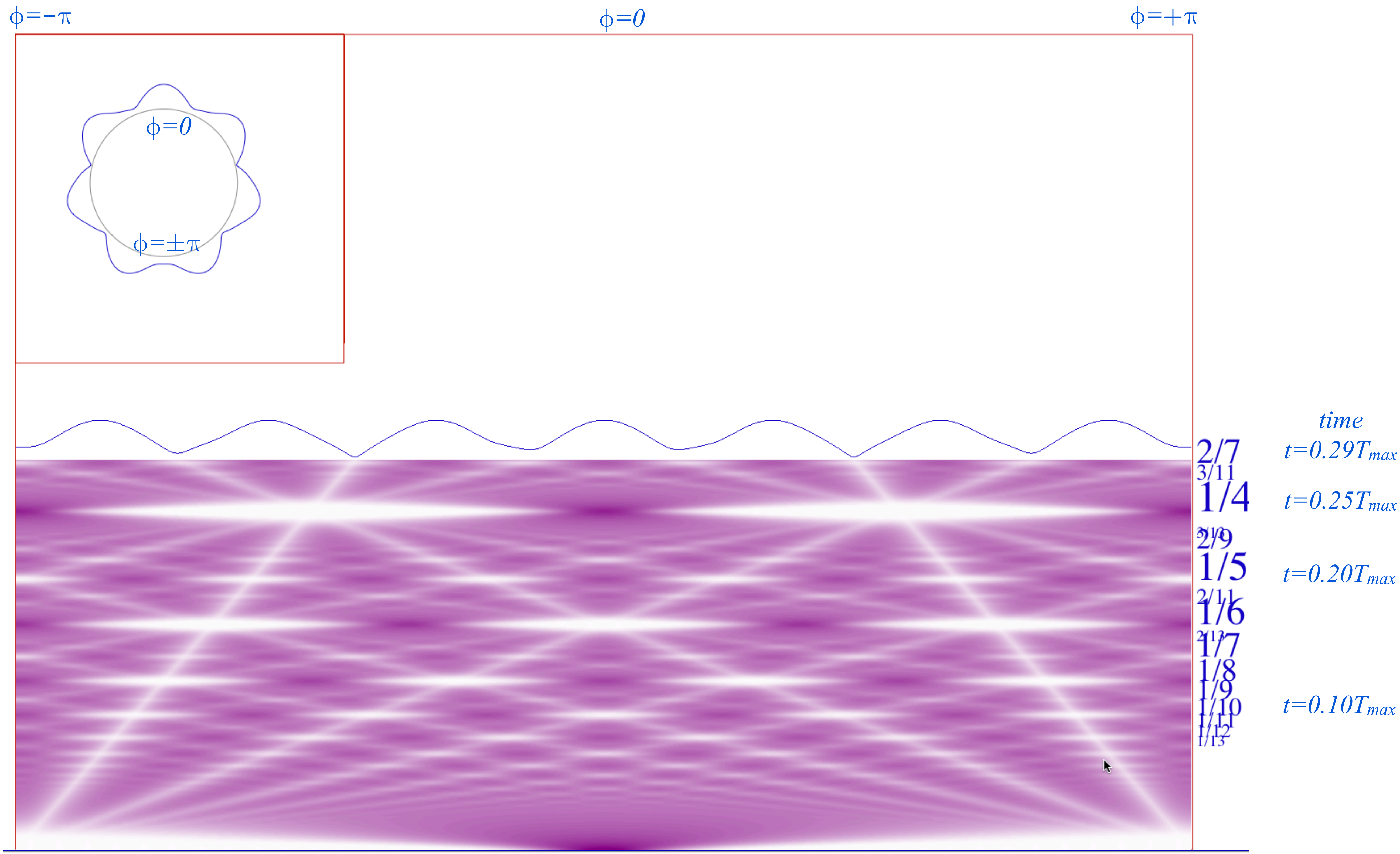
Click here....

Launch | Fourier Control | Scenarios | Pause | Set T=0 | Zero Amps | T-Scale= 1

Twelve (n=12) oscillator
Twelve (n=12) oscillator
Twelve (n=12) oscillator
C(n) Character Table

..then here.... Quantum Carpet

http://www.uark.edu/ua/modphys/pdfs/GTQM_Pdfs/GTQM_Lectures_2017/GrpThLect_14_03.02.17.pdf



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(Farey's sum & Ford's circles)

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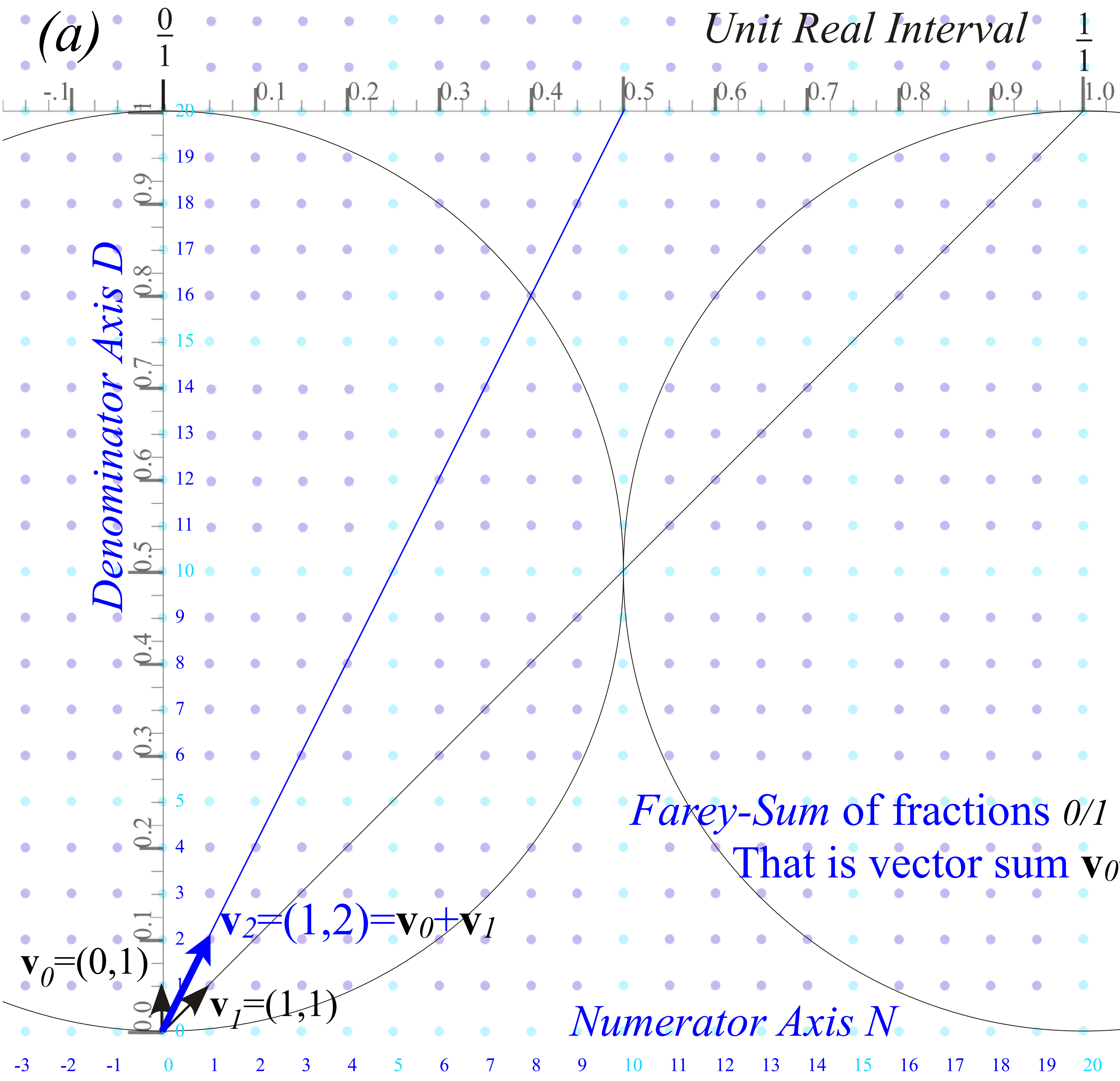
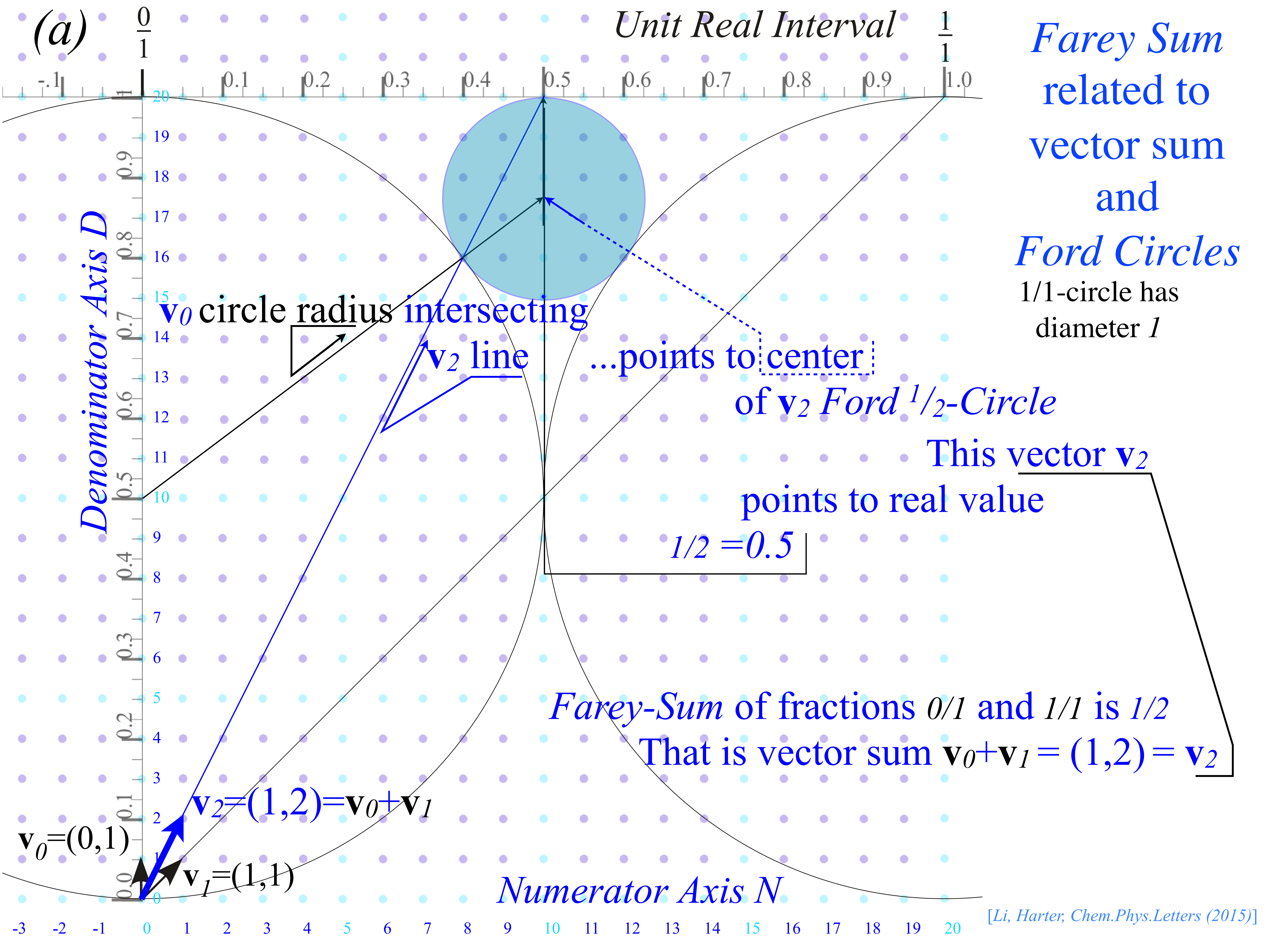
Farey Sum related to vector sum and *Ford Circles*

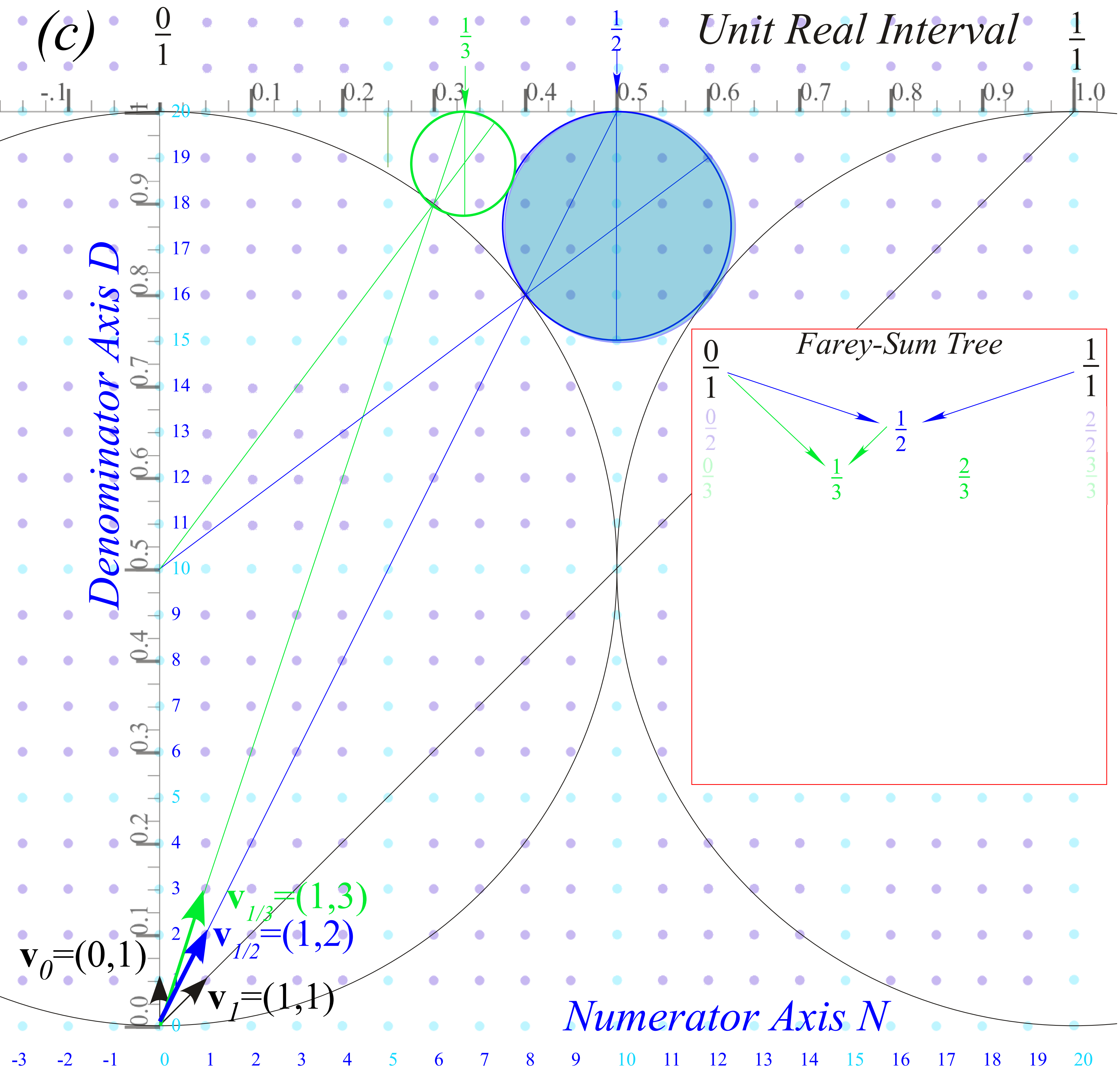
1/1-circle has diameter *1*



[Li, Harter, Chem.Phys.Letters (2015)]



(a)
0/1
Unit Real Interval
1/1
Farey Sum related to vector sum and Ford Circles
1/1-circle has diameter 1
Denominator Axis D
v0 circle radius intersecting
v2 line
...points to center
of v2 Ford 1/2-Circle
This vector v2
points to real value
1/2 =0.5
Farey-Sum of fractions 0/1 and 1/1 is 1/2
That is vector sum v0+v1 = (1,2) = v2
v2=(1,2)=v0+v1
v0=(0,1)
v1=(1,1)
Numerator Axis N
[Li, Harter, Chem.Phys.Letters (2015)]



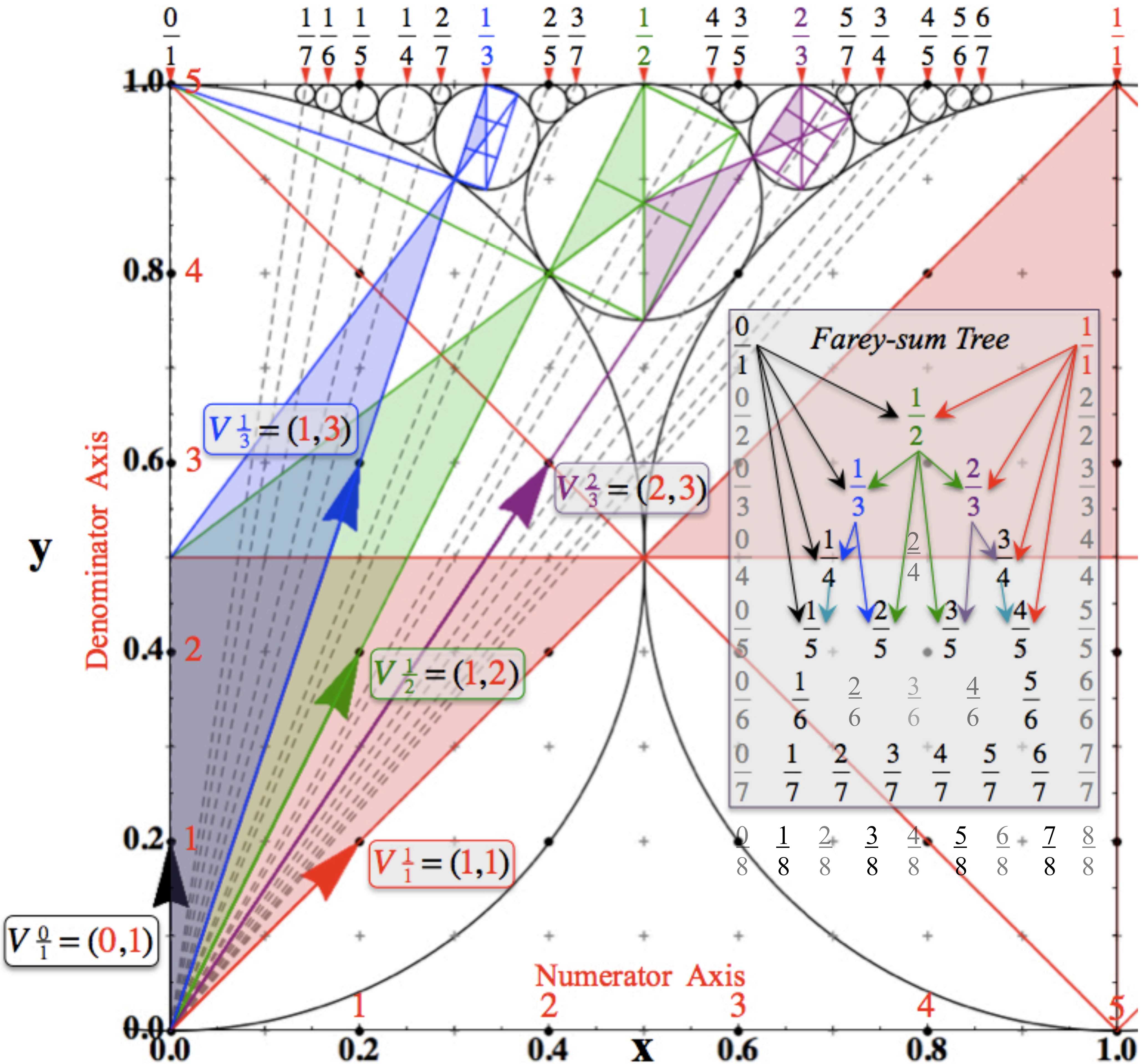
Farey Sum related to vector sum and *Ford Circles*

1/2-circle has diameter $1/2^2=1/4$

1/3-circles have diameter $1/3^2=1/9$

[Li, Harter, Chem.Phys.Letters (2015)]

http://www.uark.edu/ua/modphys/pdfs/GTQM_Pdfs/GTQM_Lectures_2017/GrpThLect_14_03.02.17.pdf



Thales Rectangles

provide
analytic geometry
of
fractal structure

[Li, Harter, Chem.Phys.Letters (2015)]

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Chapter 1. The Trebuchet: A dream problem for Galileo?

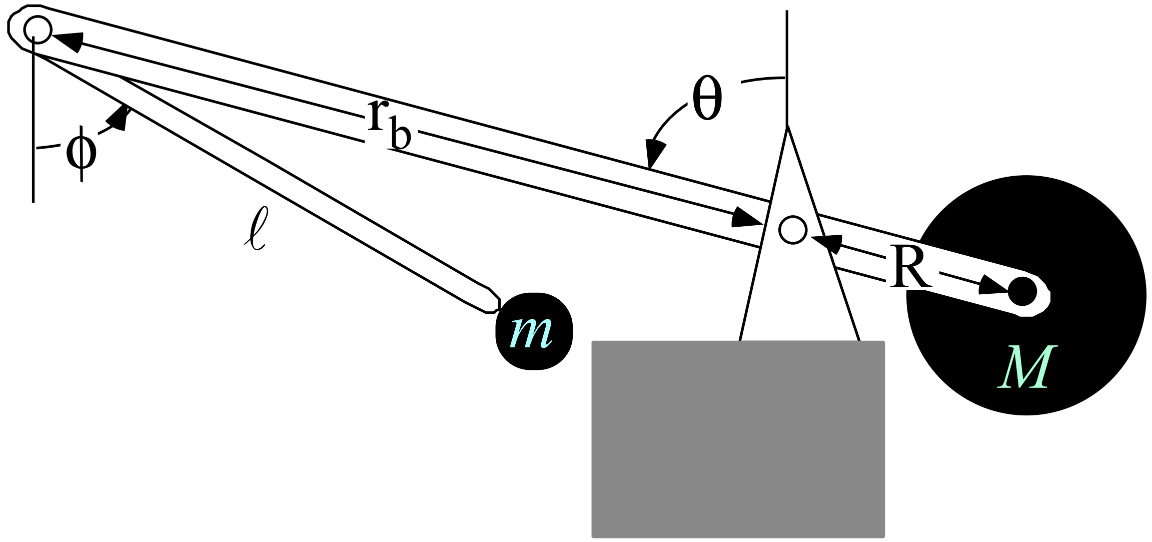
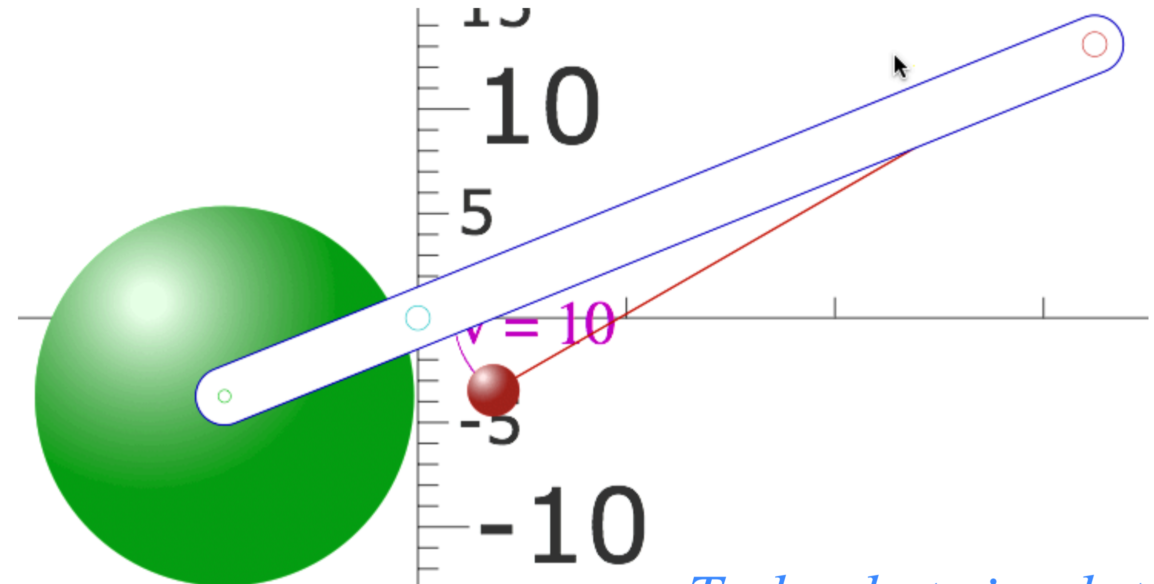
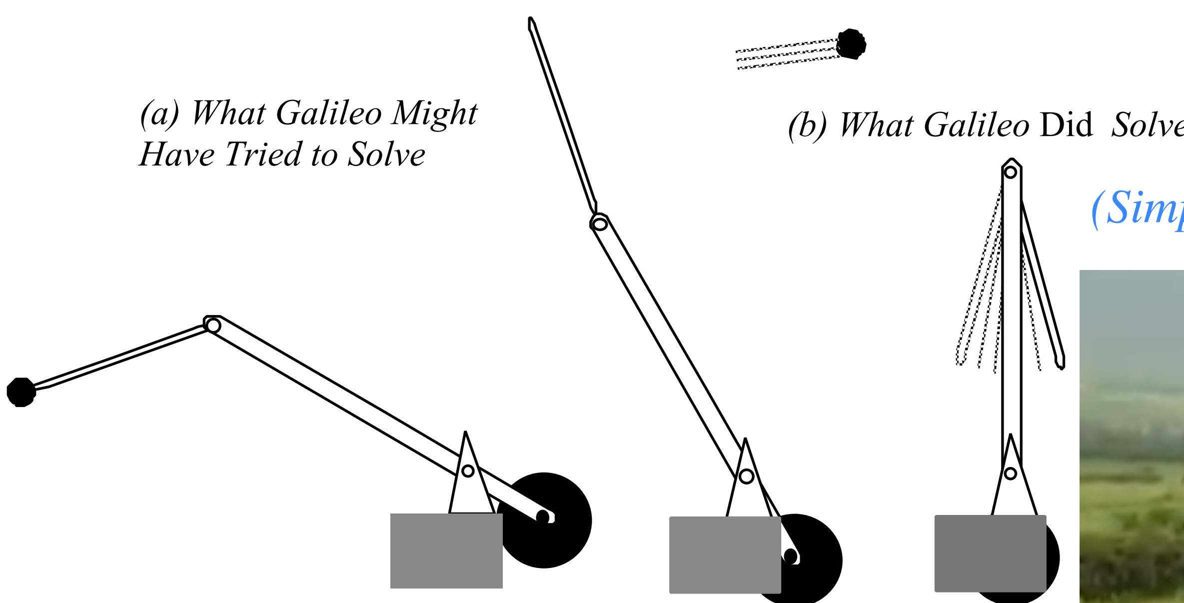


Fig. 2.1.1 An elementary ground-fixed trebuchet



Trebuchet simulator

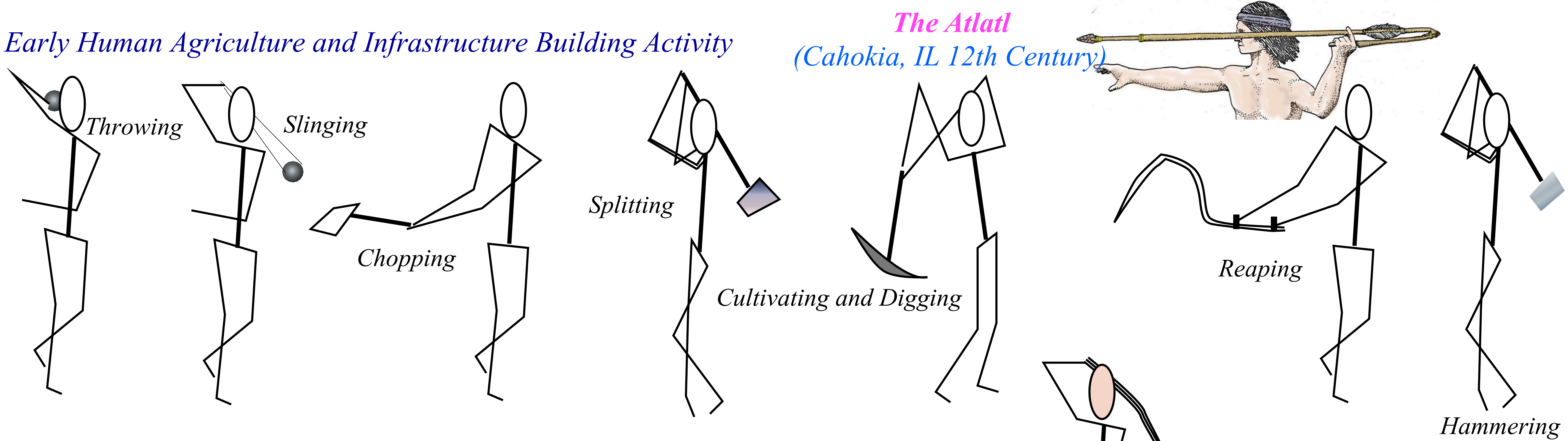
http://www.uark.edu/ua/modphys/markup/TrebuchetWeb.html



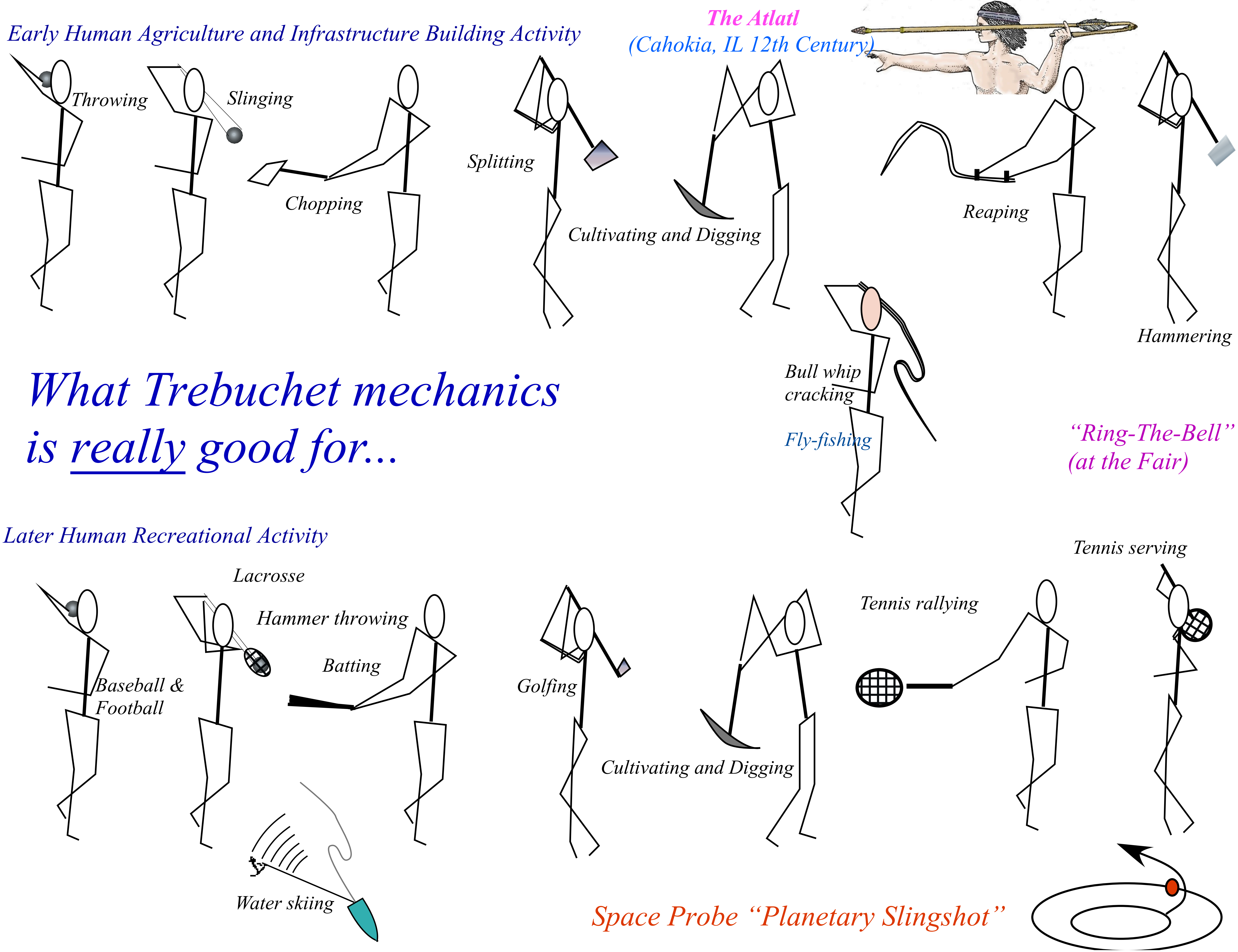
(Simple pendulum dynamics)

Fig. 2.1.2 Galileo's (supposed) problem

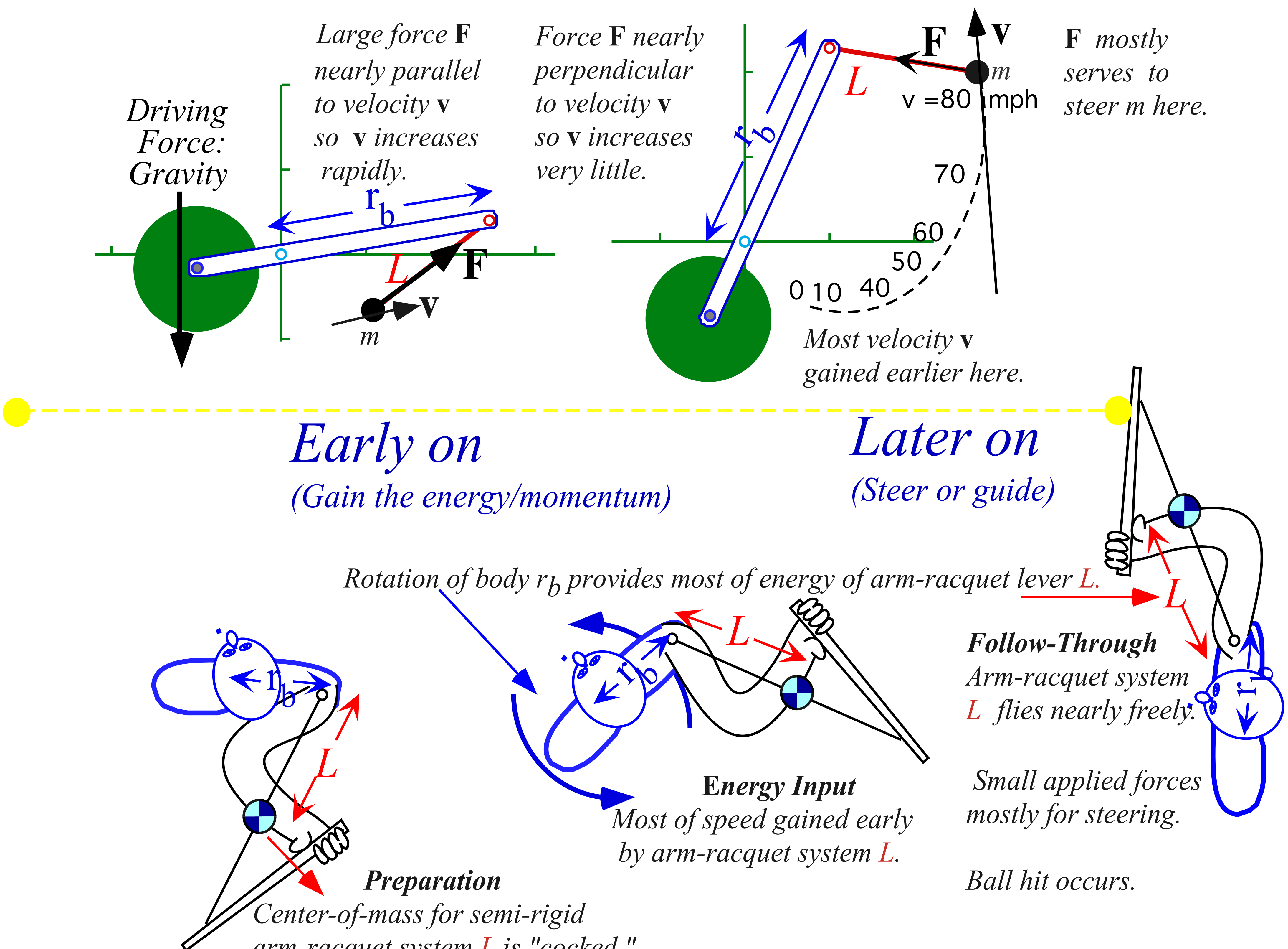
Early Human Agriculture and Infrastructure Building Activity



What Trebuchet mechanics is really good for...


Early Human Agriculture and Infrastructure Building Activity
The Atlatl
(Cahokia, IL 12th Century)
Throwing
Slinging
Chopping
Splitting
Cultivating and Digging
Reaping
Hammering
Bull whip
cracking
Fly-fishing
What Trebuchet mechanics
is really good for...
"Ring-The-Bell"
(at the Fair)
Later Human Recreational Activity
Lacrosse
Hammer throwing
Batting
Baseball &
Football
Golfing
Cultivating and Digging
Tennis rallying
Tennis serving
Water skiing
Space Probe "Planetary Slingshot"

Trebuchet analogy with racquet swing - What we learn

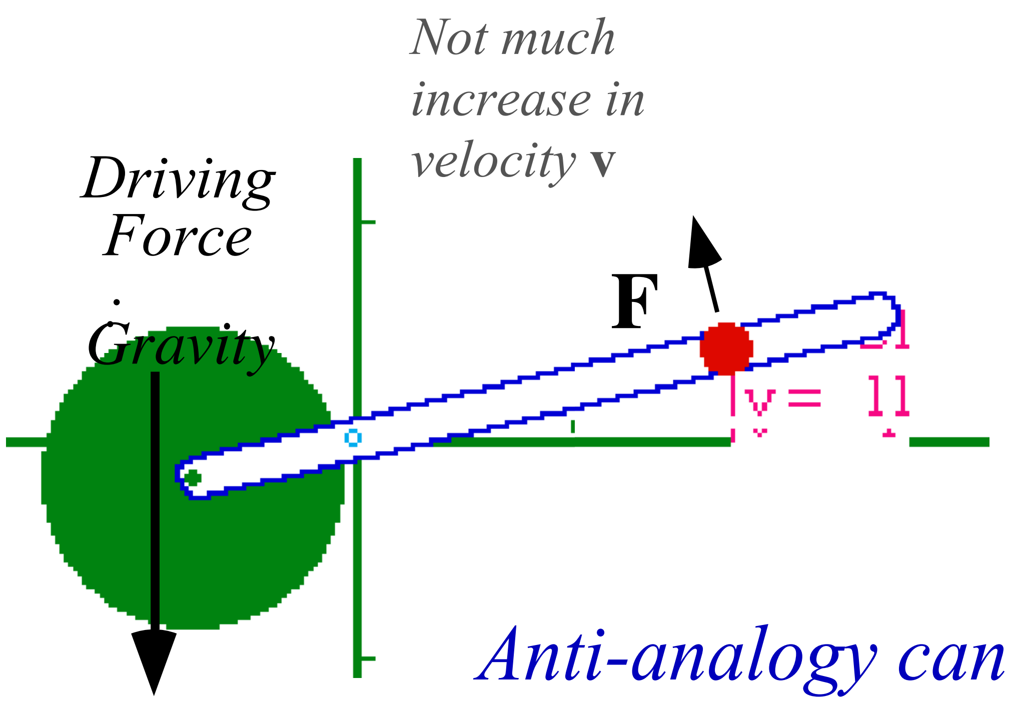


An Opposite to Trebuchet Mechanics- The "Flinger"

Web Simulation: *Trebuchet - "Flinger"*

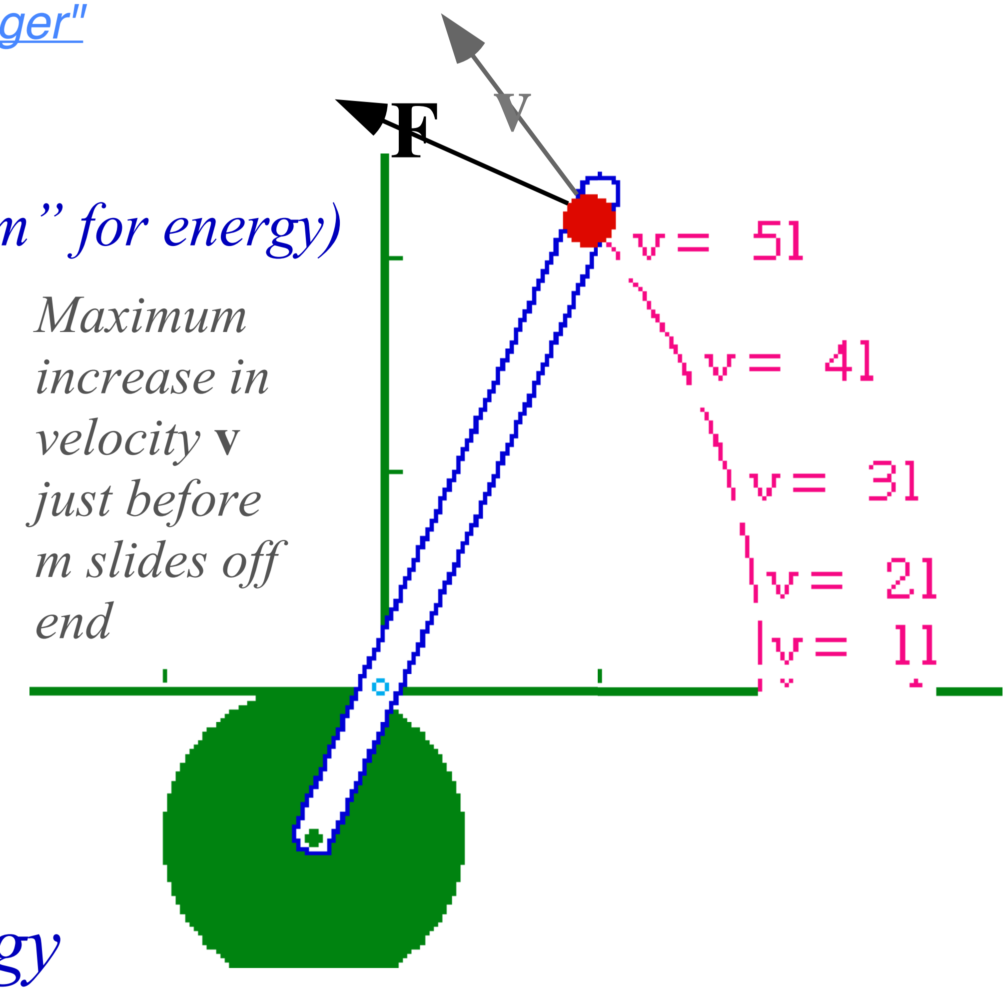
Early on

(Not much happening)



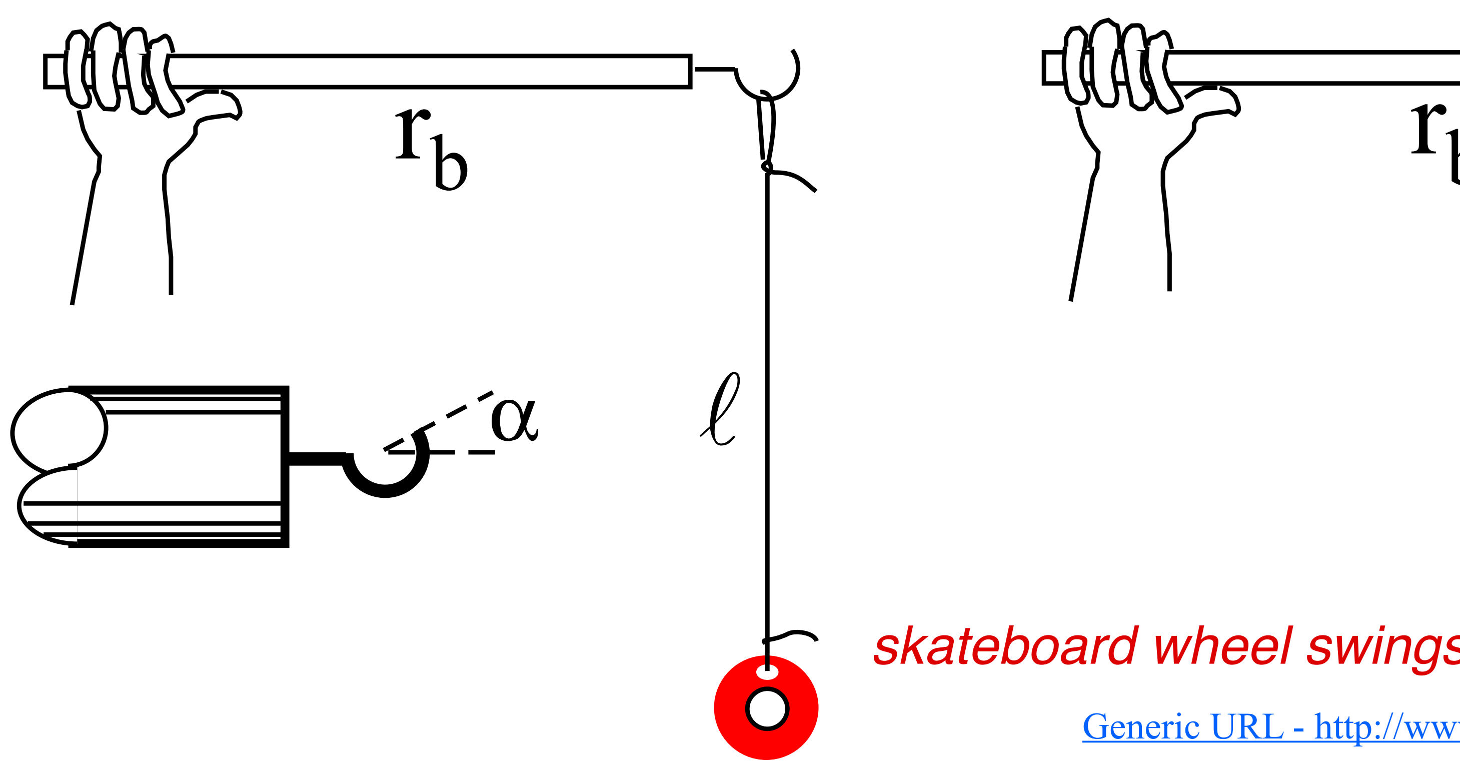
Later on

(Last-minute "cram" for energy)

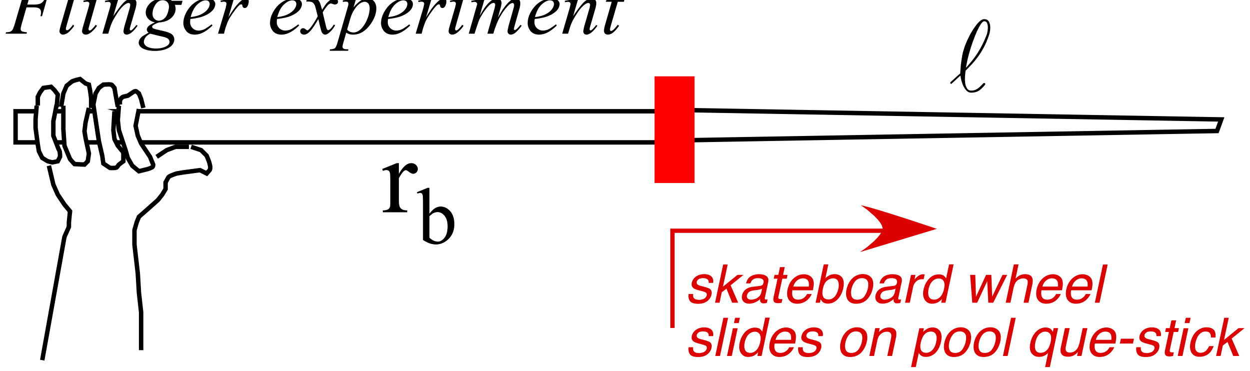


Anti-analogy can be useful pedagogy

Trebuchet-like experiment

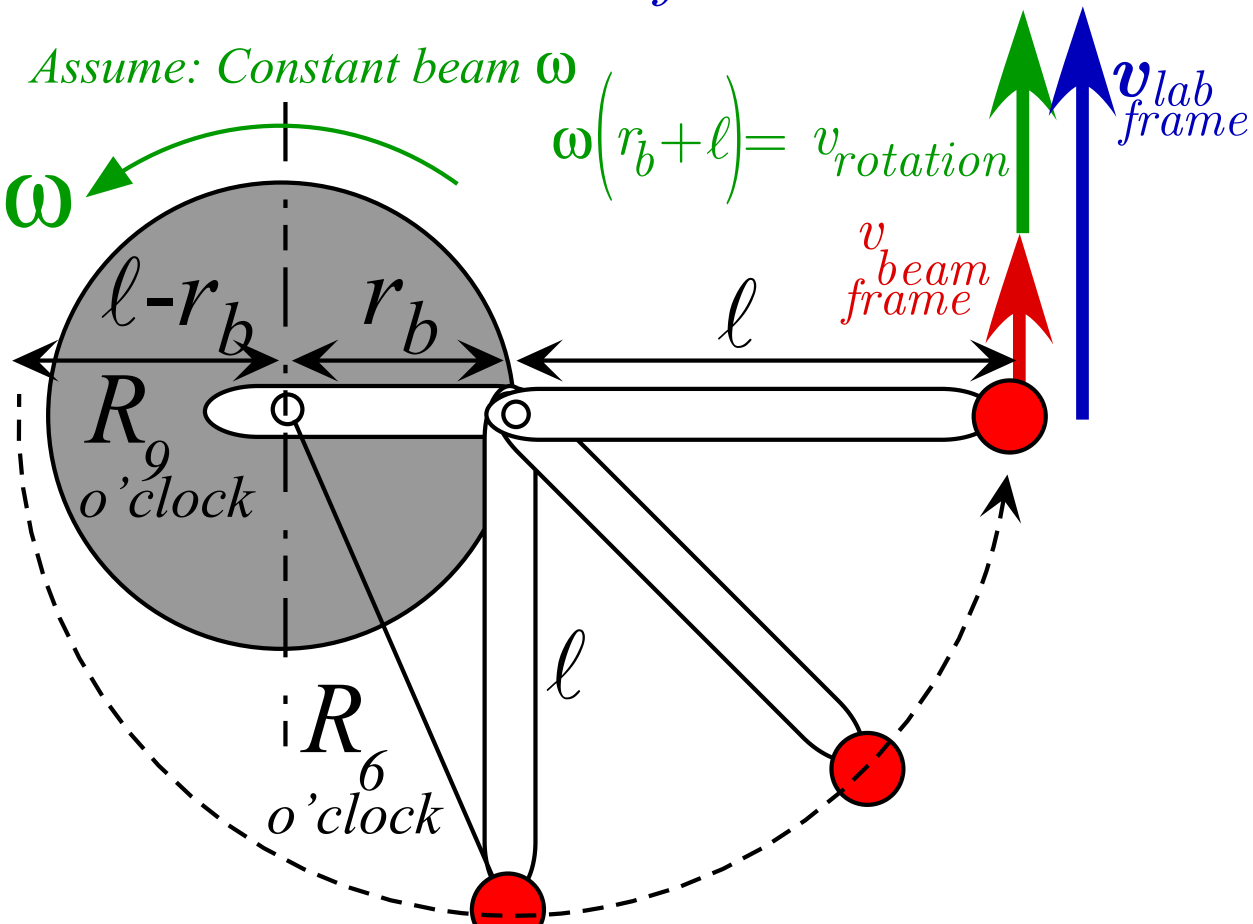


Flinger experiment



Generic URL - http://www.uark.edu/ua/modphys/markup/TrebuchetWeb.html

Trebuchet model in lab frame



$$v^2_{beam\ frame}(trebuchet) = \begin{cases} \omega^2 (2 r_b \ell) & \text{half-cocked 6 o'clock} \\ \omega^2 (4 r_b \ell) & \text{fully-cocked 9 o'clock} \end{cases}$$

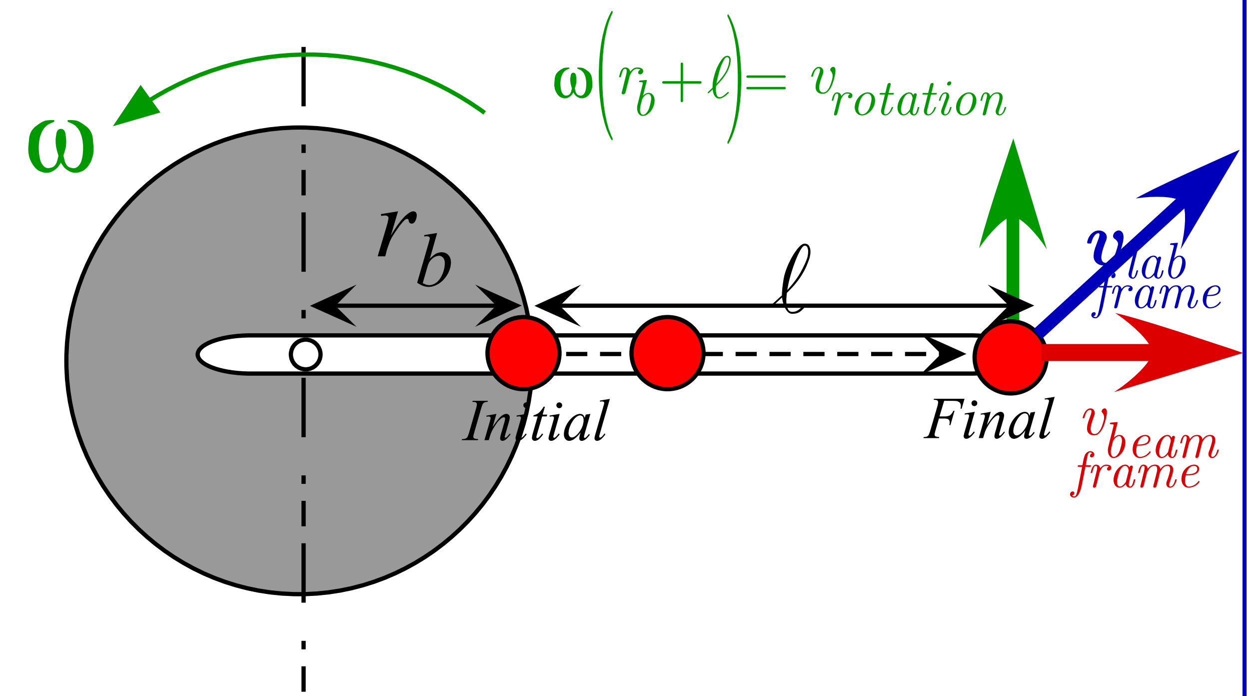
$$v_{lab\ frame}(trebuchet) =$$

$$\begin{cases} \omega\left(r_b + \ell + \sqrt{2\ell r_b}\right) & \text{half-cocked 6 o'clock} \\ \omega\left(r_b + \ell + 2\sqrt{\ell r_b}\right) & \text{fully-cocked 9 o'clock} \end{cases}$$

$$= \begin{cases} 5.00\omega \\ 5.82\omega \end{cases} \qquad = \begin{cases} 5.16\omega \\ 6.00\omega \end{cases} \qquad = \begin{cases} 5.00\omega \\ 5.82\omega \end{cases}$$

$$(r_b = 2, \ell = 1), \quad (r_b = 1.5, \ell = 1.5), (r_b = 1, \ell = 2)$$

Flinger model in lab frame



$$v^2_{beam\ frame}(flinger) = \omega^2 \ell (2 r_b + \ell)$$

$$v_{lab\ frame}(flinger) =$$

$$= \omega\sqrt{(r_b + \ell)^2 + \ell(2r_b + \ell)} = \omega\sqrt{2(r_b+\ell)^2 - r_b^2}$$

(compare)

$$= 3.74\omega \qquad = 3.96\omega \qquad = 4.12\omega$$

$$(r_b = 2, \ell = 1), \quad (r_b = 1.5, \ell = 1.5), (r_b = 1, \ell = 2)$$

Finding spectacular and interesting examples
…and simpler models to explain how they work

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    Galileo's relativity (an approximation)
    Project Ball and problems with selling superball missiles to Whammo Co.

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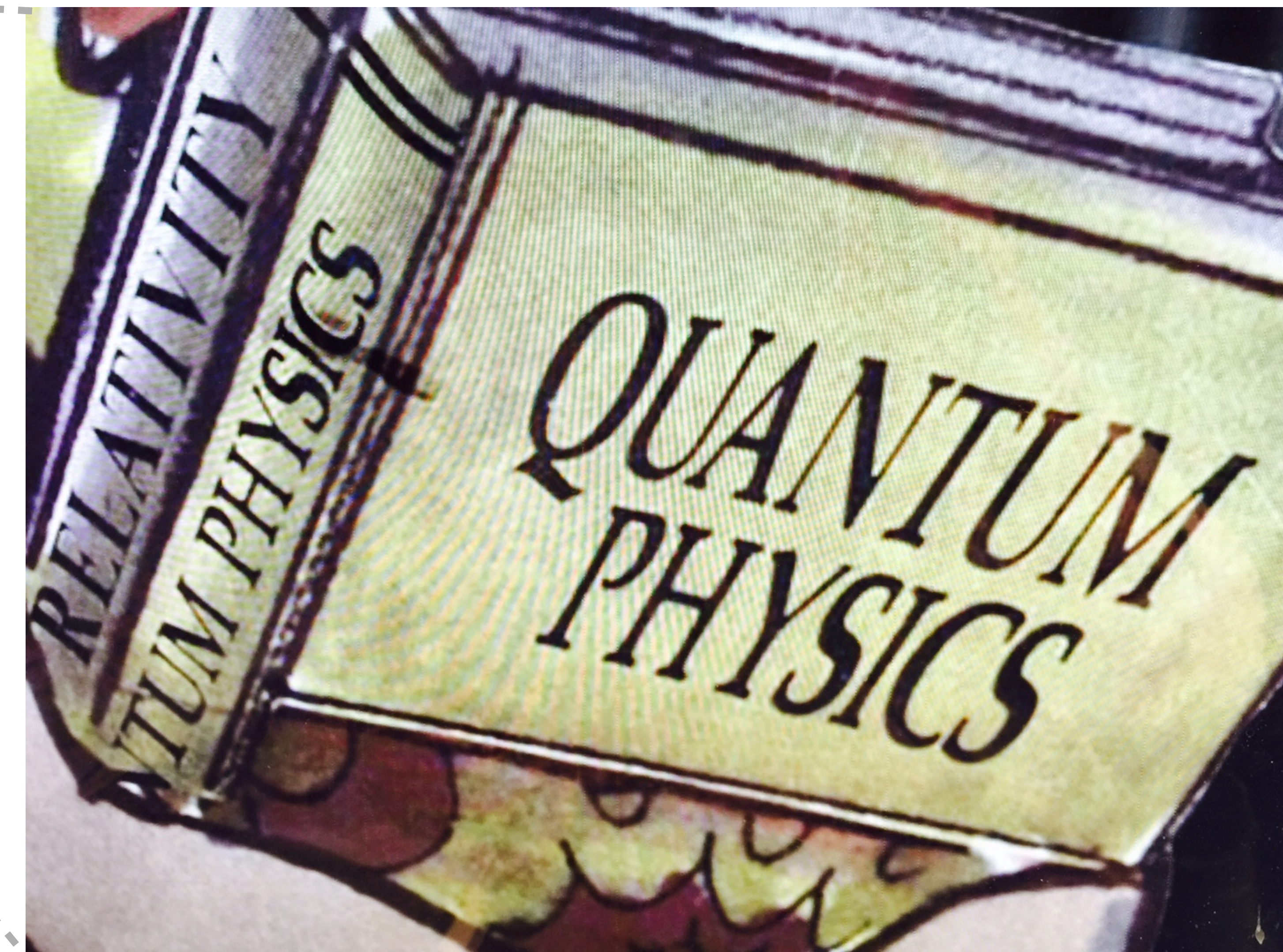
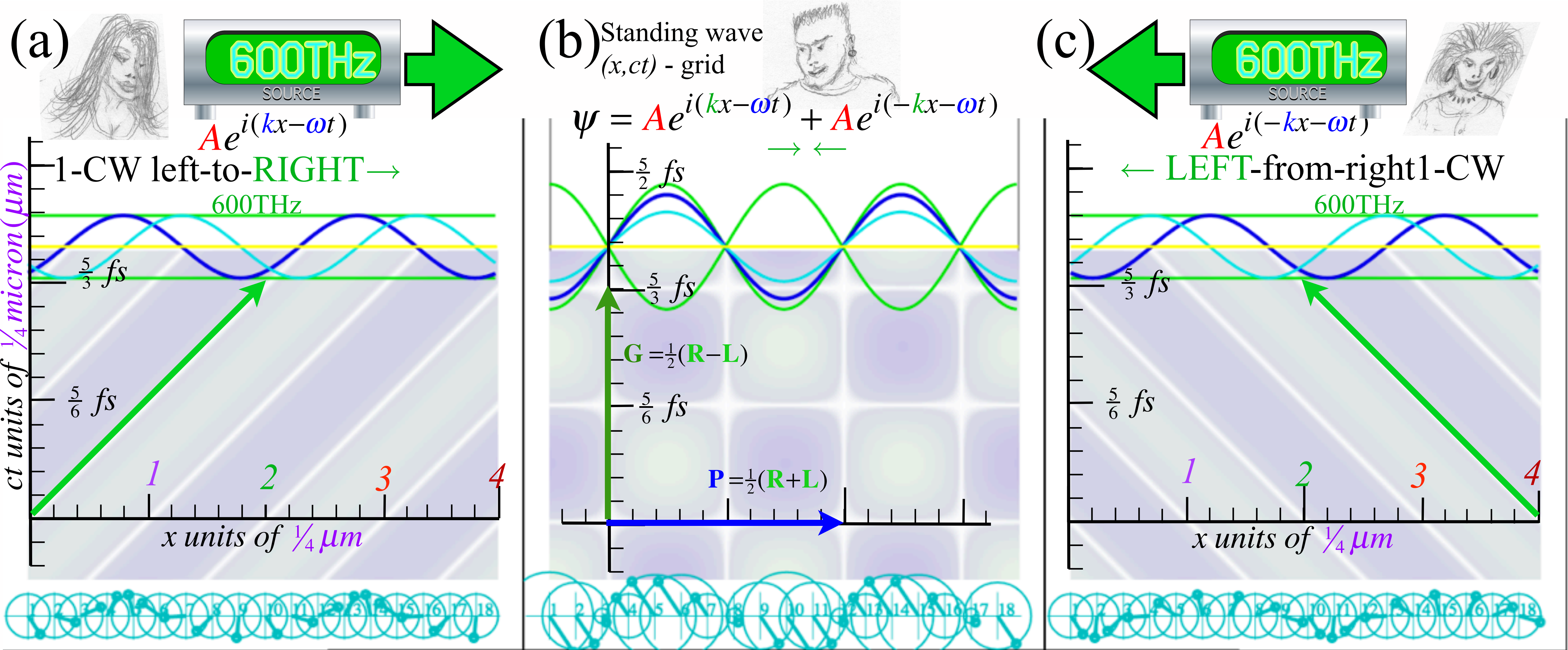
        Lasers make relativistic (Minkowski) space-time (x,ct)-coordinates and (ω,ck), too

Men In Black candidate shot little Suzy



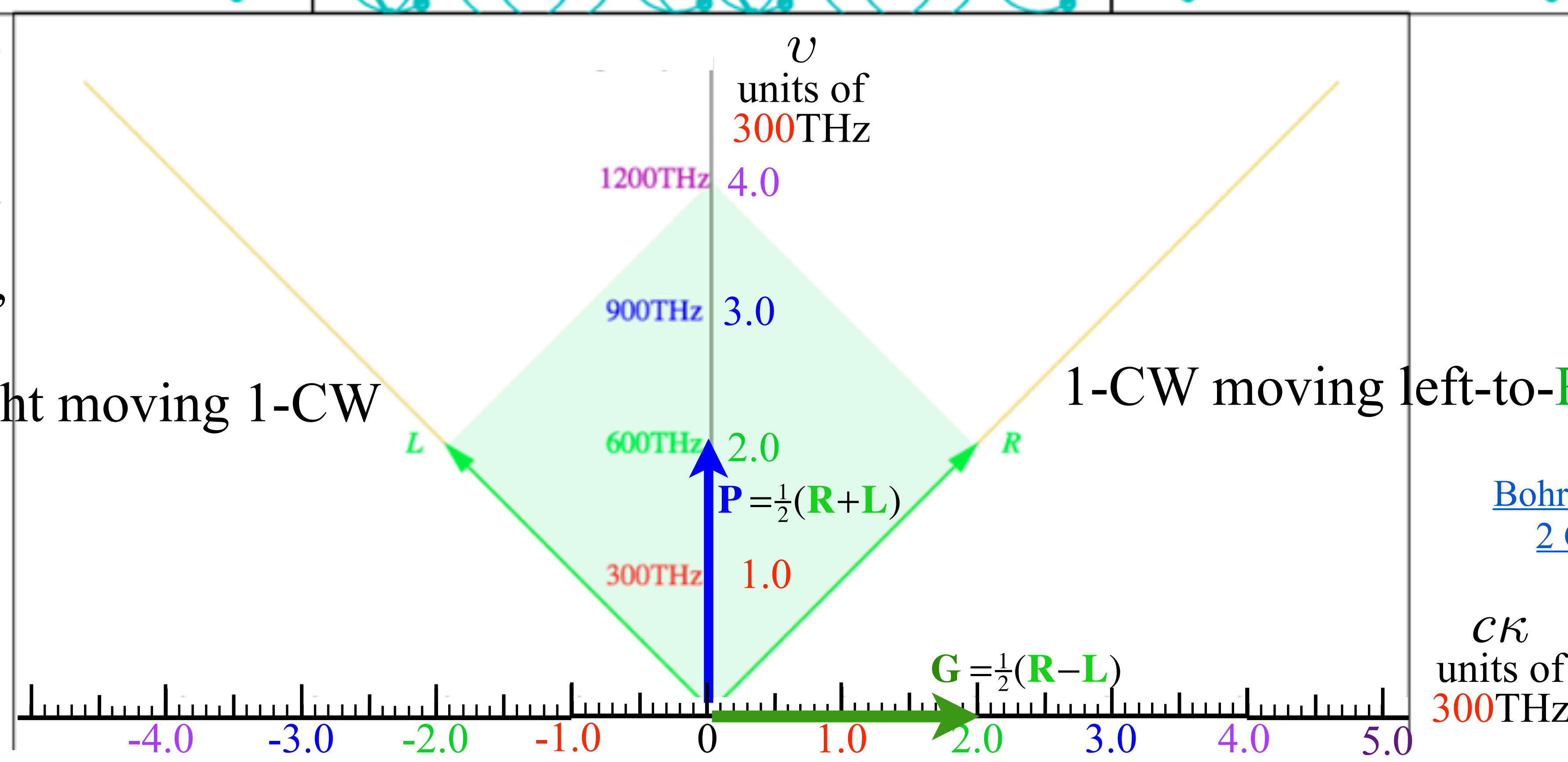
Bad Suzy!
Relativity and Quantum Theory need to be unified in *one* book *half* the size of those old tomes!

It's called ***Relawavity***.

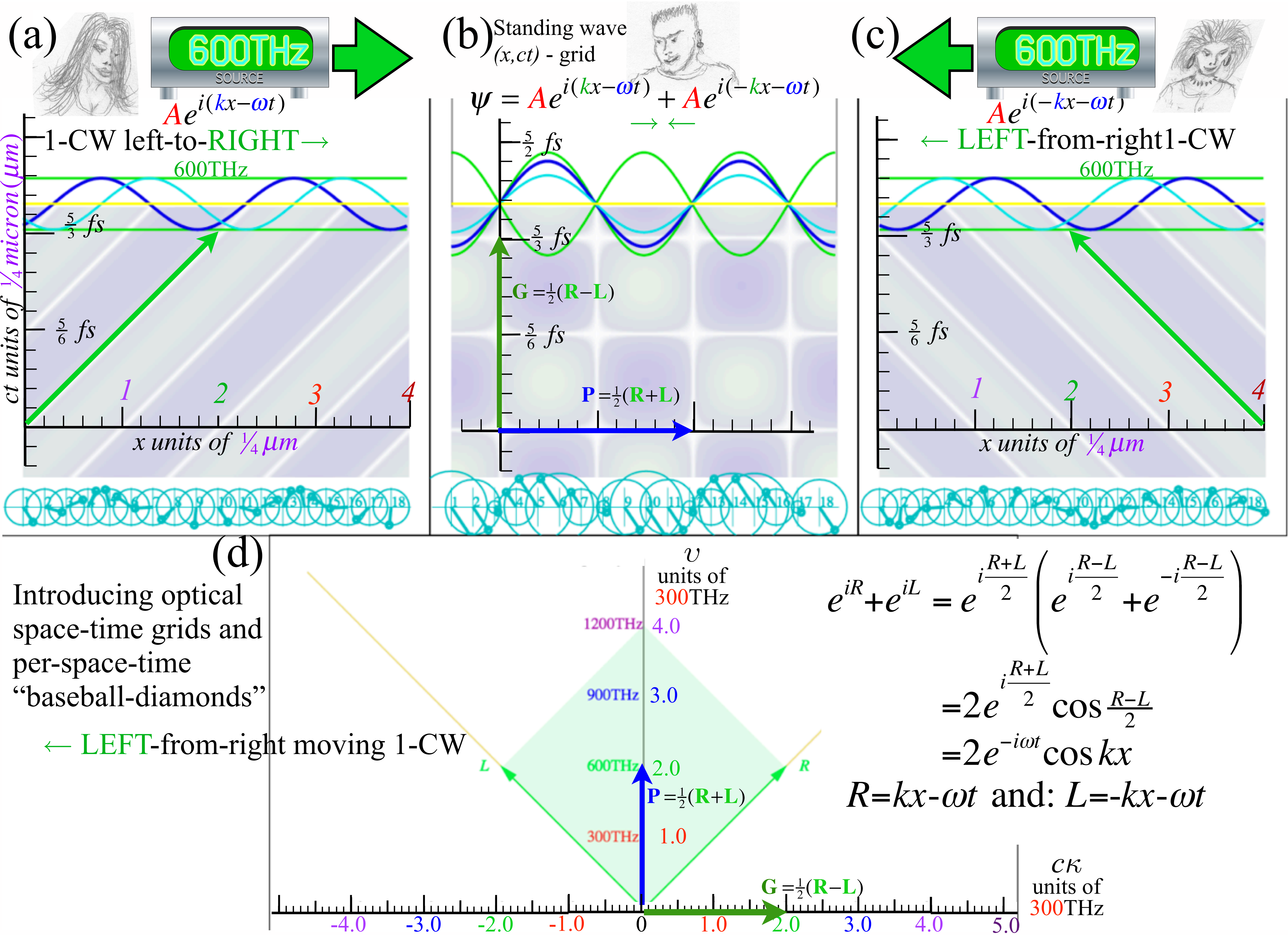


(d)

Introducing optical space-time grids and per-space-time "baseball-diamonds"

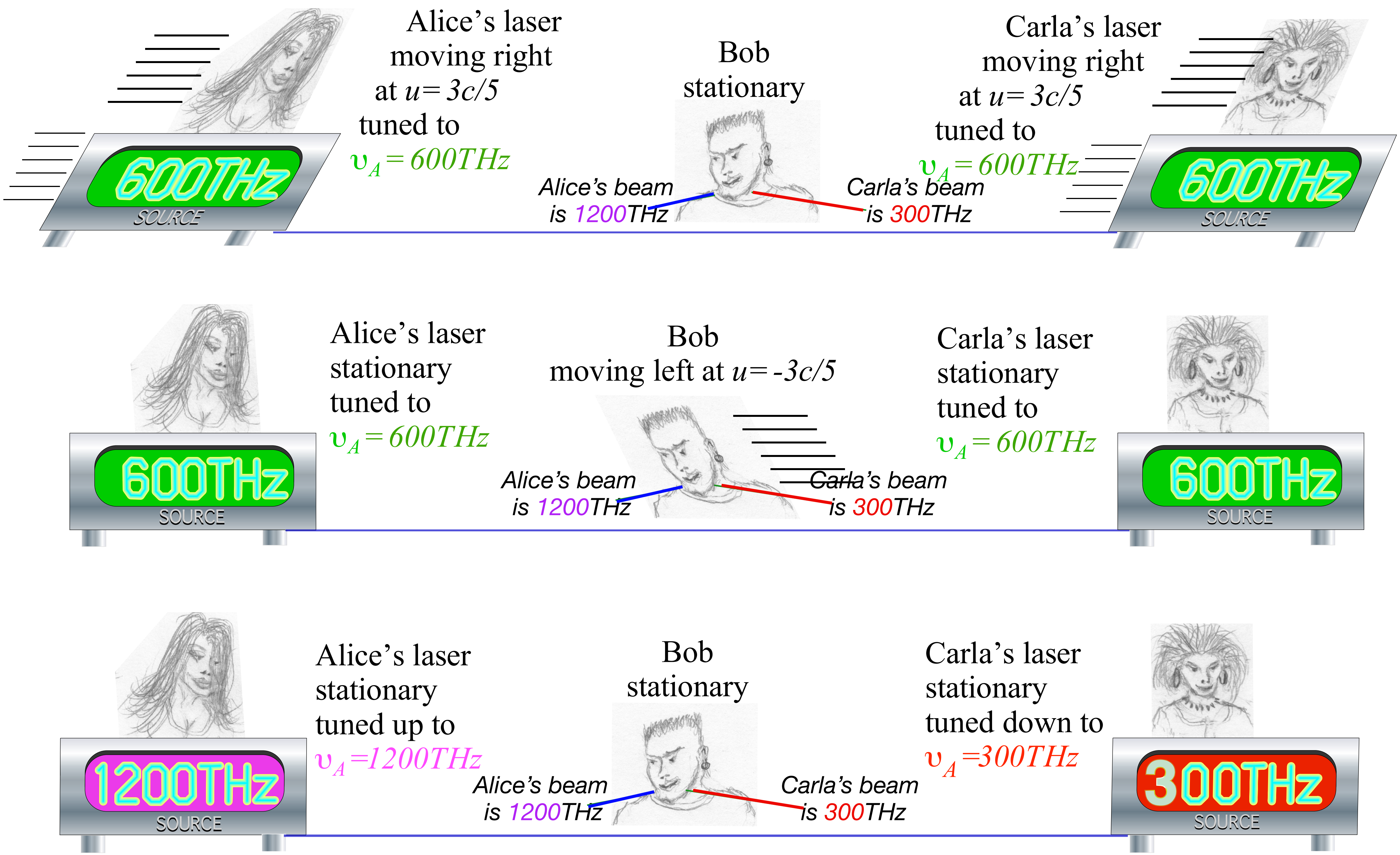


BohrIt Web Simulation
2 CW *ct vs x* Plot
(ck = ±2)



Introducing optical space-time grids and per-space-time “baseball-diamonds”

Three scenarios that look the same to Bob



Much cheaper to do the 3rd scenario!$!

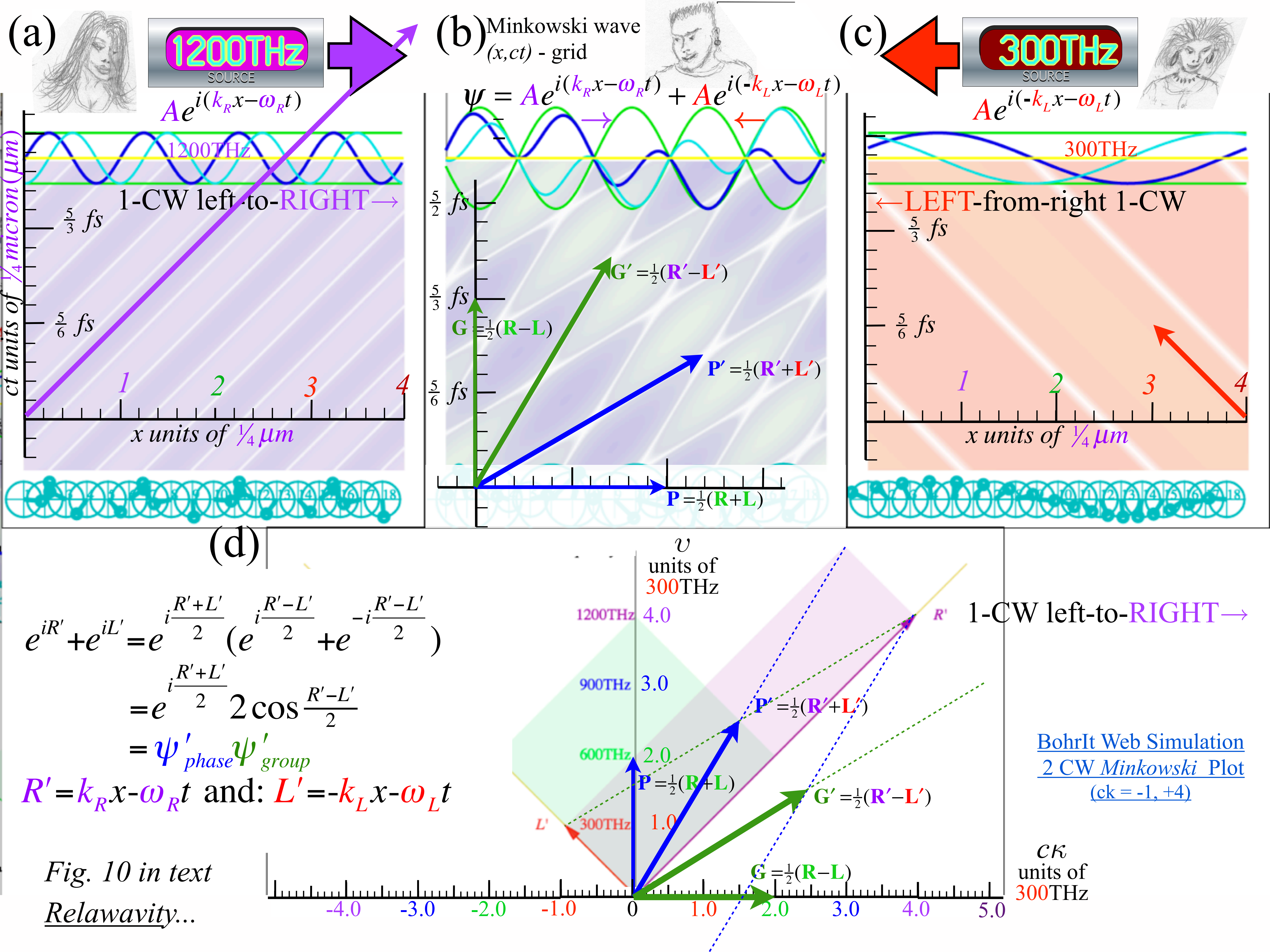


Fig. 10 in text
<u>*Relawavity...*</u>

Lorentz transformations...

write $\mathbf{G}'$ *and* $\mathbf{P}'$ *in terms of* $\mathbf{G}$ *and* $\mathbf{P}$ *using* $\cosh\rho$ *and* $\sinh\rho$

$$\mathbf{G}' = \begin{pmatrix} c\kappa'_{group} \\ \upsilon'_{group} \end{pmatrix} = \upsilon_A \begin{pmatrix} \cosh\rho \\ \sinh\rho \end{pmatrix} = \upsilon_A \begin{pmatrix} 5/4 \\ 3/4 \end{pmatrix}$$

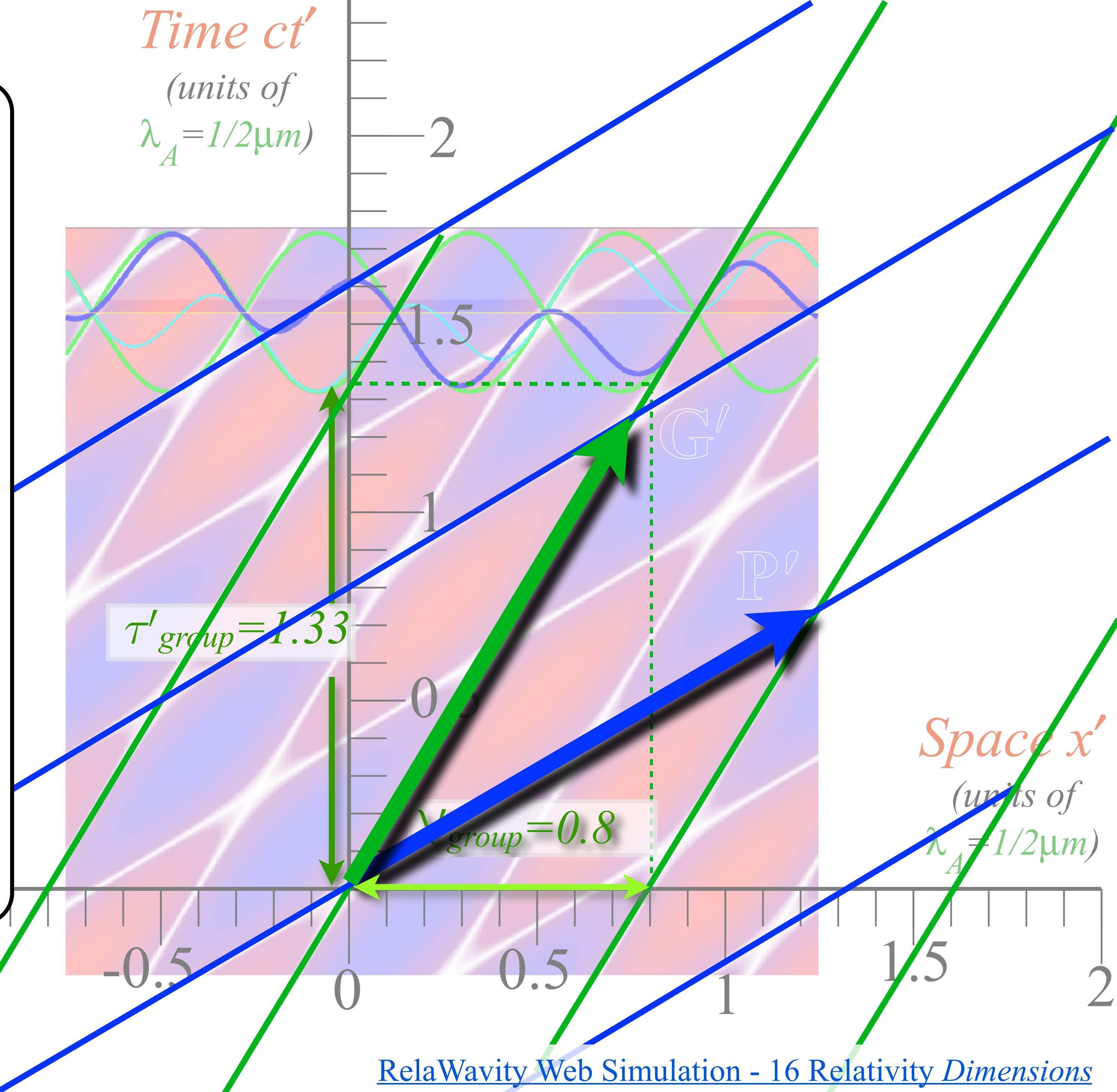
$$= \upsilon_A \begin{pmatrix} 1 \\ 0 \end{pmatrix} \cosh\rho + \upsilon_A \begin{pmatrix} 0 \\ 1 \end{pmatrix} \sinh\rho$$

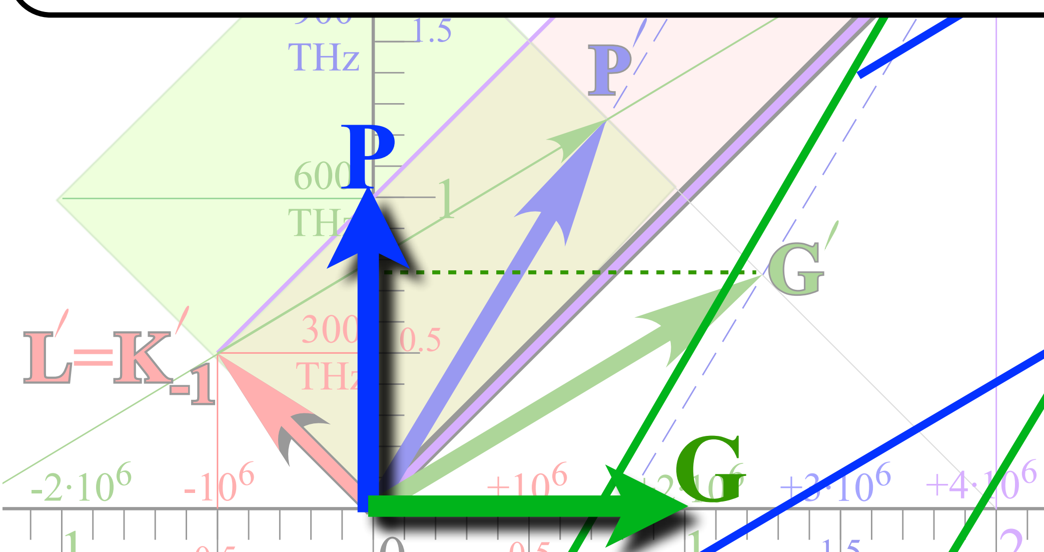
$$\mathbf{G}' = \mathbf{G} \cosh\rho + \mathbf{P} \sinh\rho$$

$$\mathbf{P}' = \begin{pmatrix} c\kappa'_{phase} \\ \upsilon'_{phase} \end{pmatrix} = \upsilon_A \begin{pmatrix} \sinh\rho \\ \cosh\rho \end{pmatrix} = \upsilon_A \begin{pmatrix} 3/4 \\ 5/4 \end{pmatrix}$$

$$= \upsilon_A \begin{pmatrix} 1 \\ 0 \end{pmatrix} \sinh\rho + \upsilon_A \begin{pmatrix} 0 \\ 1 \end{pmatrix} \cosh\rho$$

$$\mathbf{P}' = \mathbf{G} \sinh\rho + \mathbf{P} \cosh\rho$$





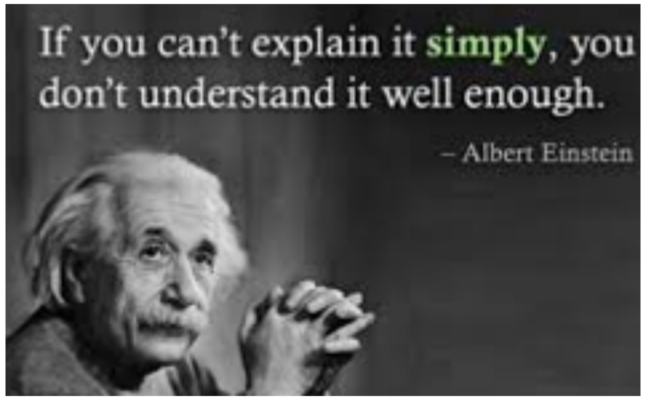
$$\begin{pmatrix} \cosh\rho & \sinh\rho \\ \sinh\rho & \cosh\rho \end{pmatrix}$$ Lorentz transform matrix

RelaWavity Web Simulation - 16 Relativity *Dimensions*

phase	$b_{RED}^{Doppler}$	$\frac{c}{V_{phase}}$	$\frac{\kappa_{phase}}{\kappa_A}$	$\frac{\tau_{phase}}{\tau_A}$	$\frac{\upsilon_{phase}}{\upsilon_A}$	$\frac{\lambda_{phase}}{\lambda_A}$	$\frac{V_{phase}}{c}$	$b_{BLUE}^{Doppler}$
group	$\frac{1}{b_{BLUE}^{Doppler}}$	$\frac{V_{group}}{c}$	$\frac{\upsilon_{group}}{\upsilon_A}$	$\frac{\lambda_{group}}{\lambda_A}$	$\frac{\kappa_{group}}{\kappa_A}$	$\frac{\tau_{group}}{\tau_A}$	$\frac{c}{V_{group}}$	$\frac{1}{b_{RED}^{Doppler}}$
rapidity ρ	$e^{-\rho}$	$\tanh\rho$	$\sinh\rho$	$\text{sech}\,\rho$	$\cosh\rho$	$\text{csch}\,\rho$	$\coth\rho$	$e^{+\rho}$
value for $\beta=3/5$	$\frac{1}{2}=0.5$	$\frac{3}{5}=0.6$	$\frac{3}{4}=0.75$	$\frac{4}{5}=0.80$	$\frac{5}{4}=1.25$	$\frac{4}{3}=1.33$	$\frac{5}{3}=1.67$	$\frac{2}{1}=2.0$

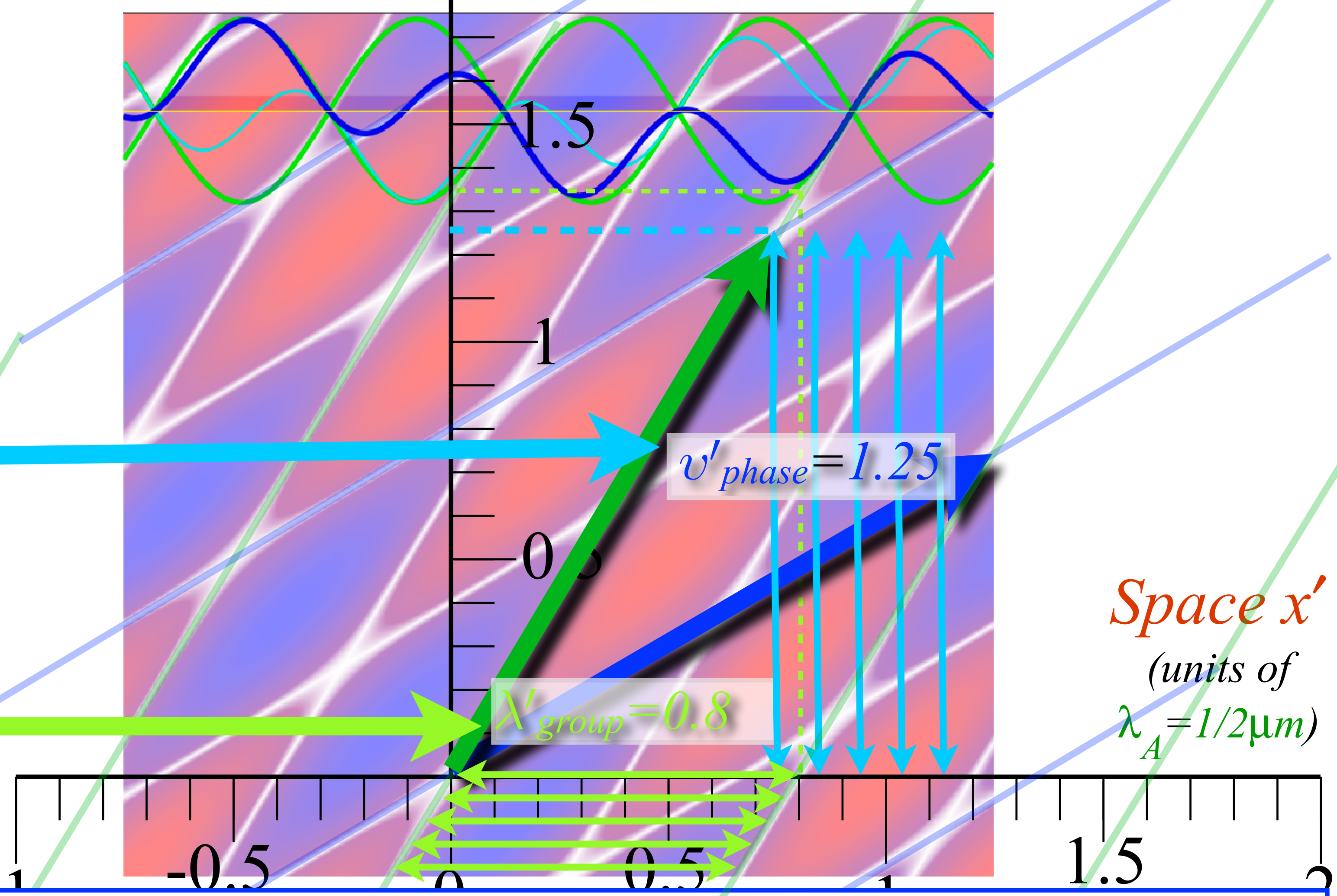
Two Famous-Name Coefficients

Review of Lect. 30 p.106



Albert Einstein 1859-1955

Herman Minkowski 1864-1909



This number is called an: **Einstein time-dilation** (dilated by 25% here)

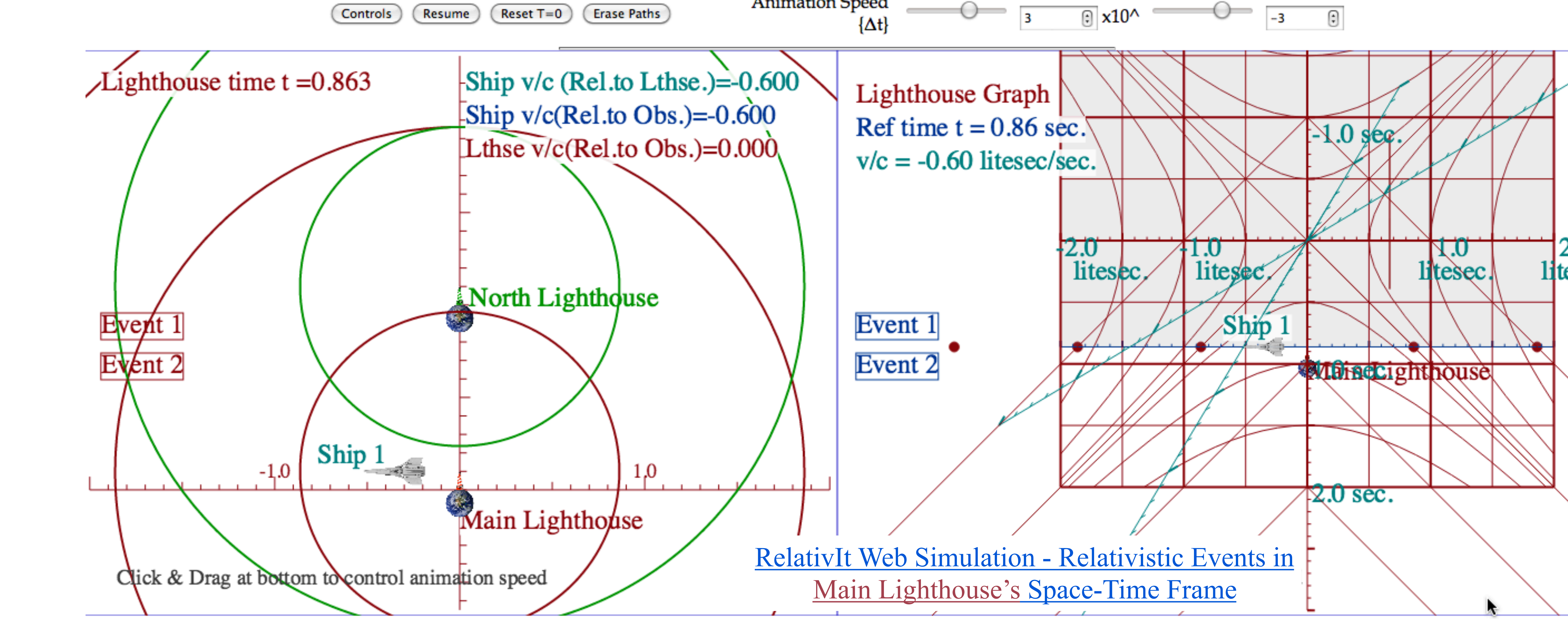
This number is called a: **Lorentz length-contraction** (contracted by 20% here)

Hendrik A. Lorentz 1853-1928

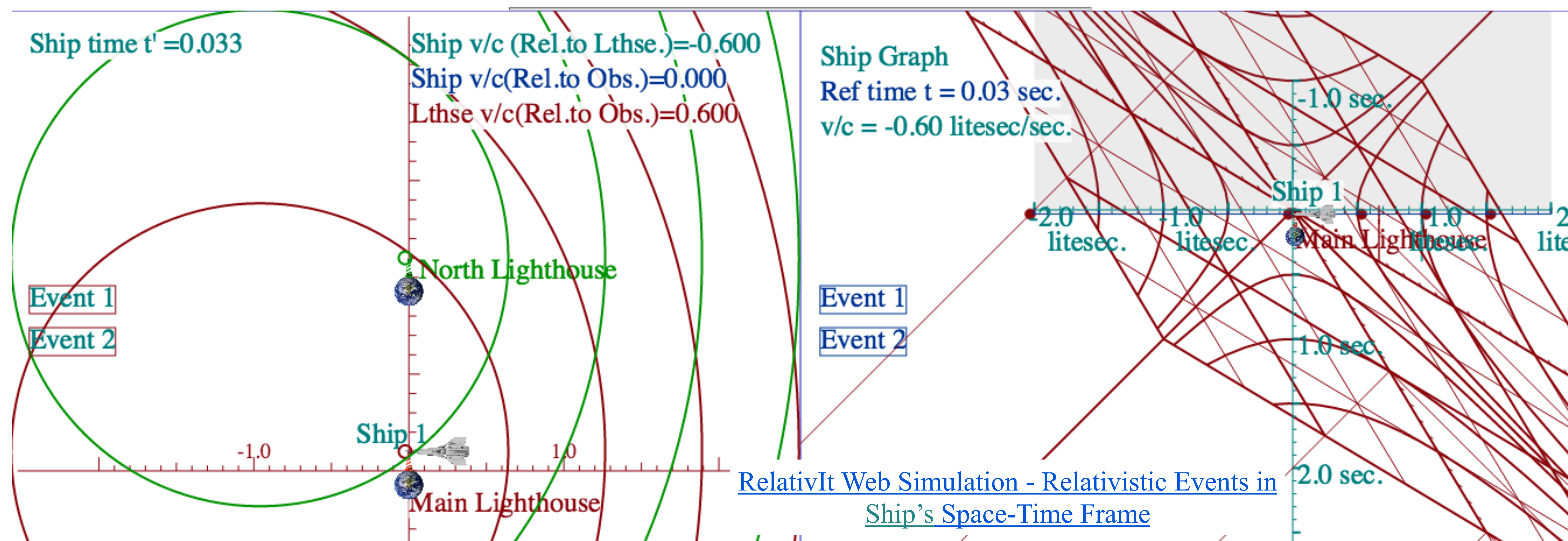
Old-Fashioned Notation

phase	$b^{Doppler}_{RED}$	$\frac{c}{V_{phase}}$	$\frac{\kappa_{phase}}{\kappa_A}$	$\frac{\tau_{phase}}{\tau_A}$	$\frac{\upsilon_{phase}}{\upsilon_A}$	$\frac{\lambda_{phase}}{\lambda_A}$	$\frac{V_{phase}}{c}$	$b^{Doppler}_{BLUE}$
group	$\frac{1}{b^{Doppler}_{BLUE}}$	$\frac{V_{group}}{c}$	$\frac{\upsilon_{group}}{\upsilon_A}$	$\frac{\lambda_{group}}{\lambda_A}$	$\frac{\kappa_{group}}{\kappa_A}$	$\frac{\tau_{group}}{\tau_A}$	$\frac{c}{V_{group}}$	$\frac{1}{b^{Doppler}_{RED}}$
rapidity ρ	$e^{-\rho}$	$\tanh\rho$	$\sinh\rho$	$\text{sech}\,\rho$	$\cosh\rho$	$\text{csch}\,\rho$	$\coth\rho$	$e^{+\rho}$
$\beta \equiv \frac{u}{c}$	$\sqrt{\frac{1-\beta}{1+\beta}}$	$\frac{\beta}{1}$	$\frac{1}{\sqrt{\beta^{-2}-1}}$	$\frac{\sqrt{1-\beta^2}}{1}$	$\frac{1}{\sqrt{1-\beta^2}}$	$\frac{\sqrt{\beta^{-2}-1}}{1}$	$\frac{1}{\beta}$	$\sqrt{\frac{1+\beta}{1-\beta}}$
value for β=3/5	$\frac{1}{2}$= 0.5	$\frac{3}{5}$ =0.6	$\frac{3}{4}$=0.75	$\frac{4}{5}$=0.80	$\frac{5}{4}$=1.25	$\frac{4}{3}$=1.33	$\frac{5}{3}$=1.67	$\frac{2}{1}$=2.0

[RelaWavity Web Simulation - Relativistic *Terms* (Expanded Table)]



RelativIt Web Simulation - Relativistic Events in Main Lighthouse's Space-Time Frame



RelativIt Web Simulation - Relativistic Events in Ship's Space-Time Frame

Finding spectacular and interesting examples
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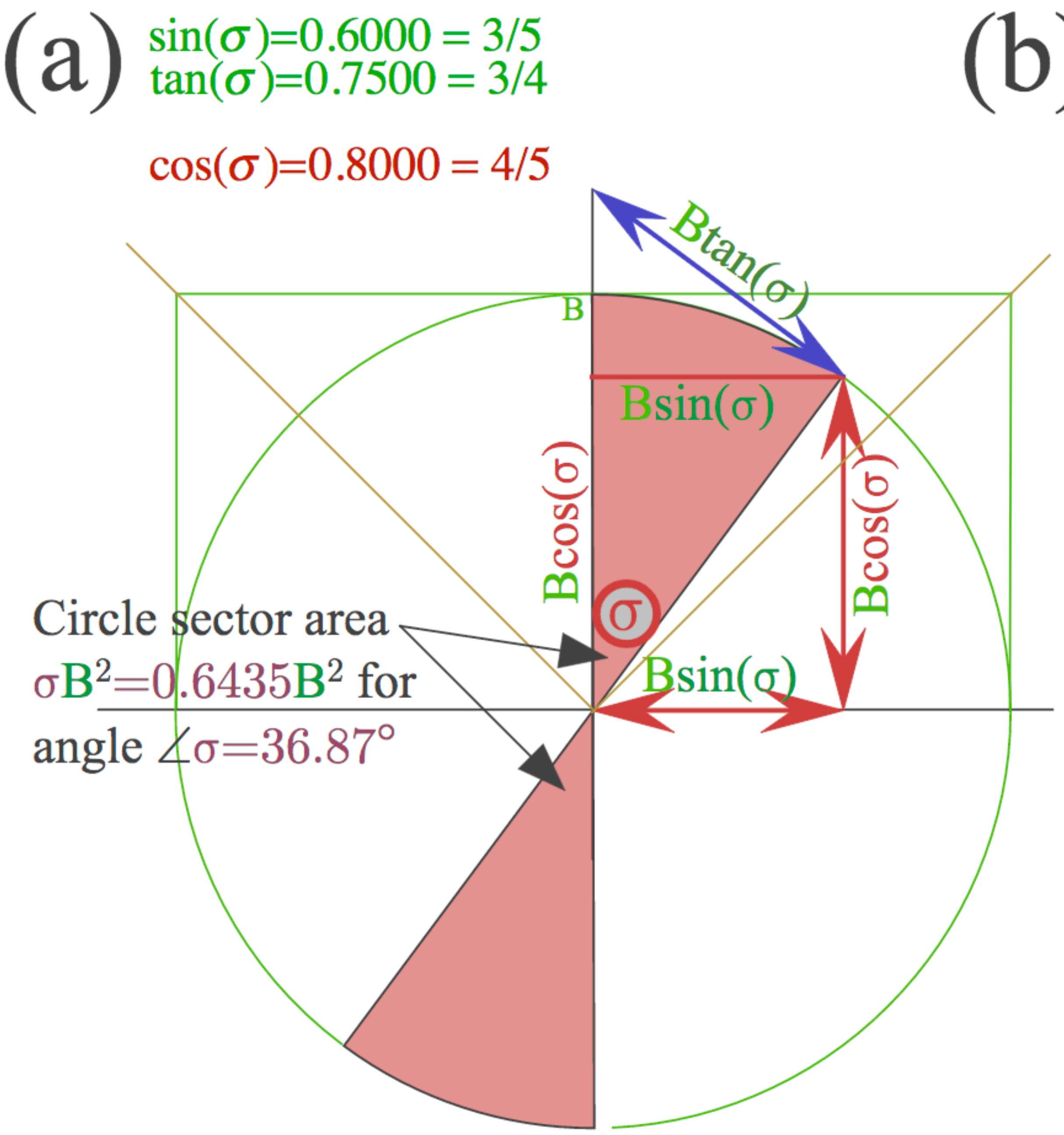
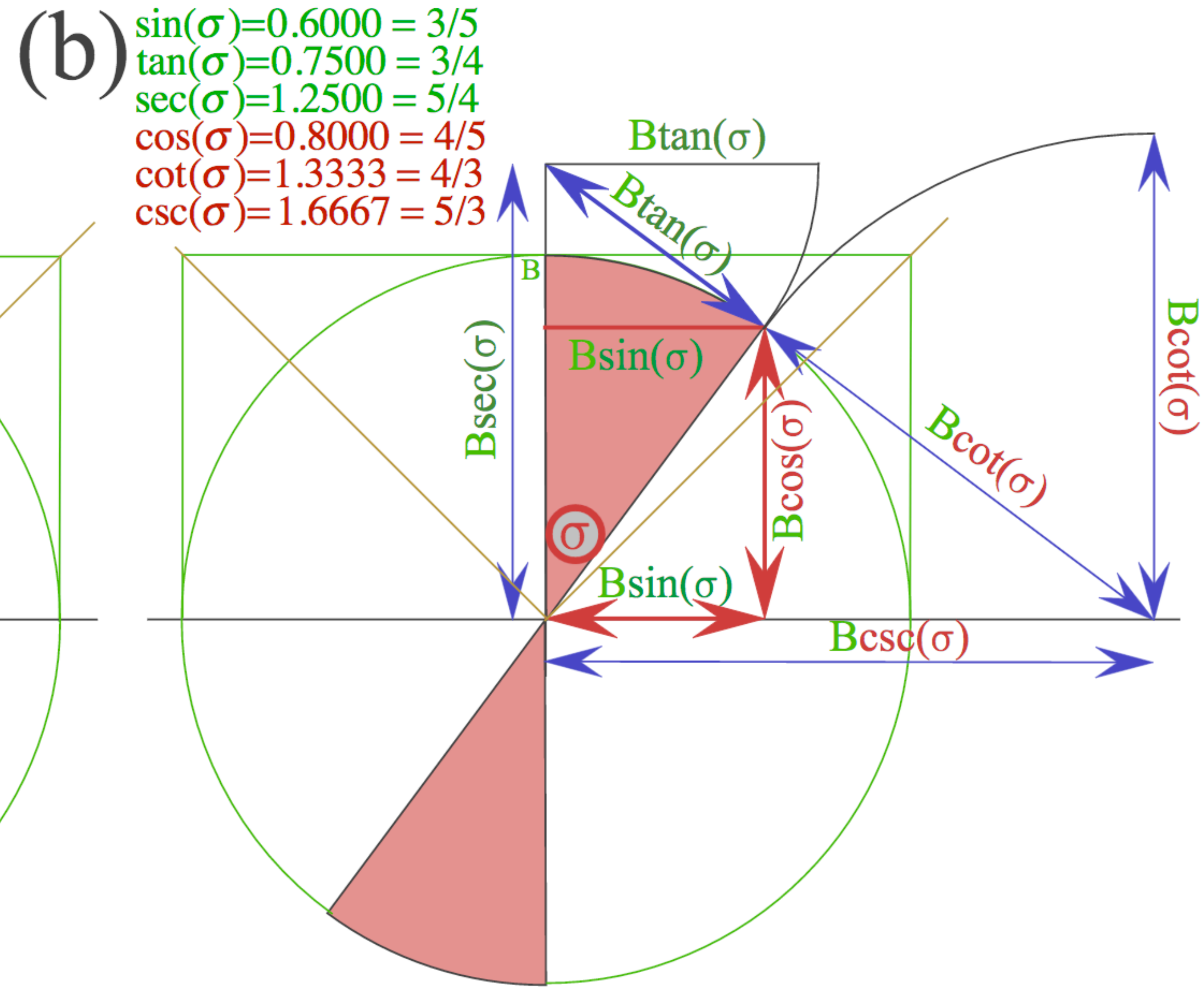
All this physics of relativity
is mostly simple trigonometry
of optical wave interference!

And, it derives fundamentals
of quantum theory, too!

Trigonometric road maps





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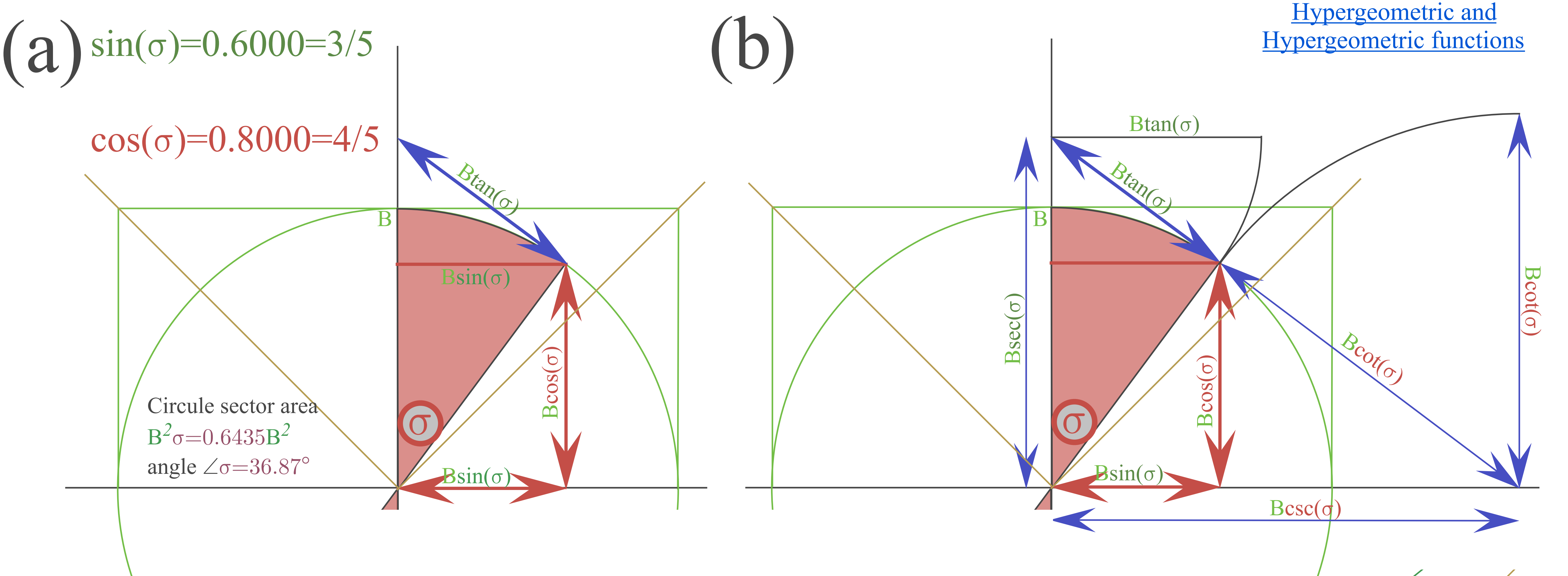
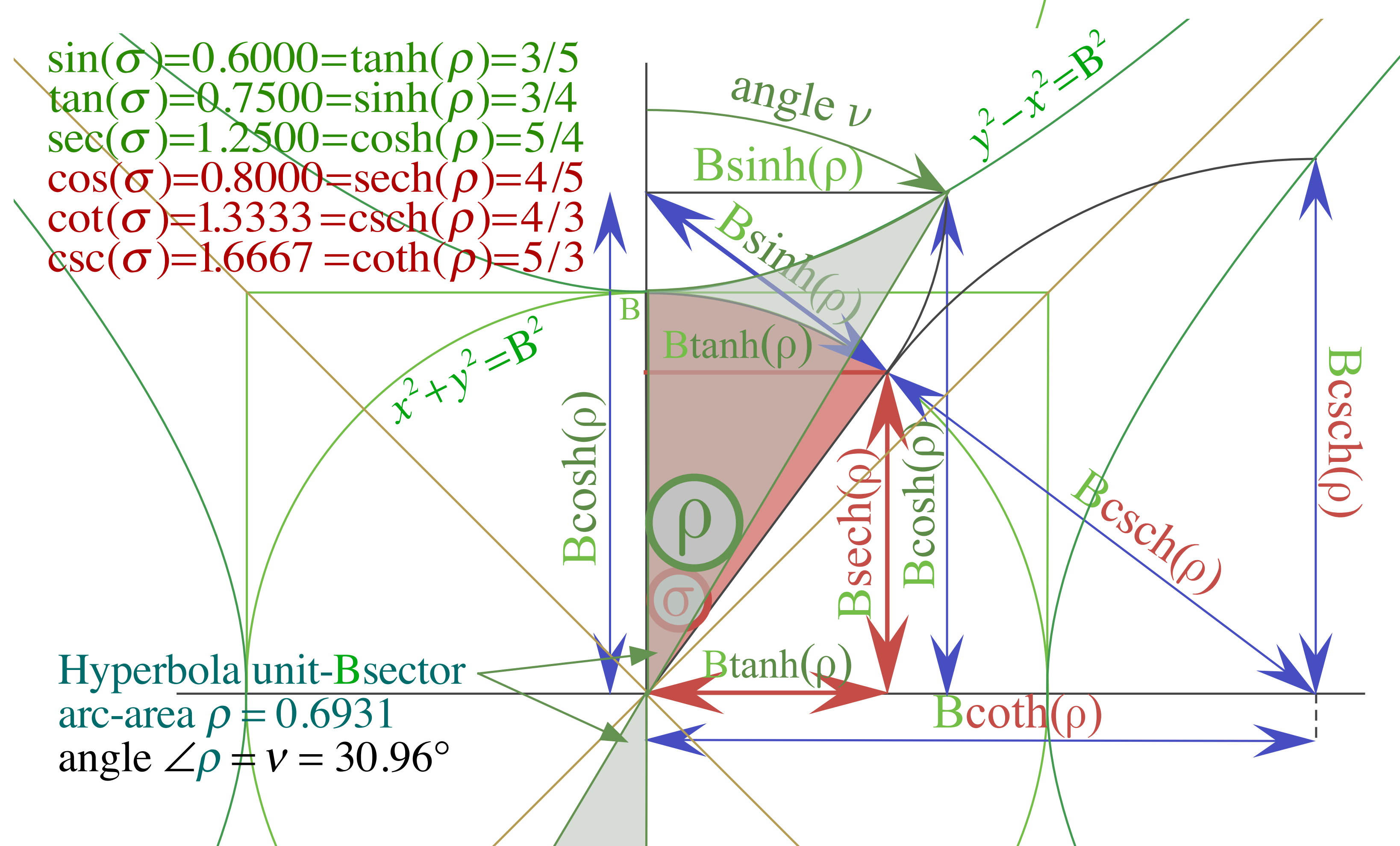
RelaWavity Web Simulation
Relations between
Hypergeometric and
Hypergeometric functions

Trigonometric road maps

RelaWavity Web Simulation
Relations between
Hypergeometric and
Hypergeometric functions





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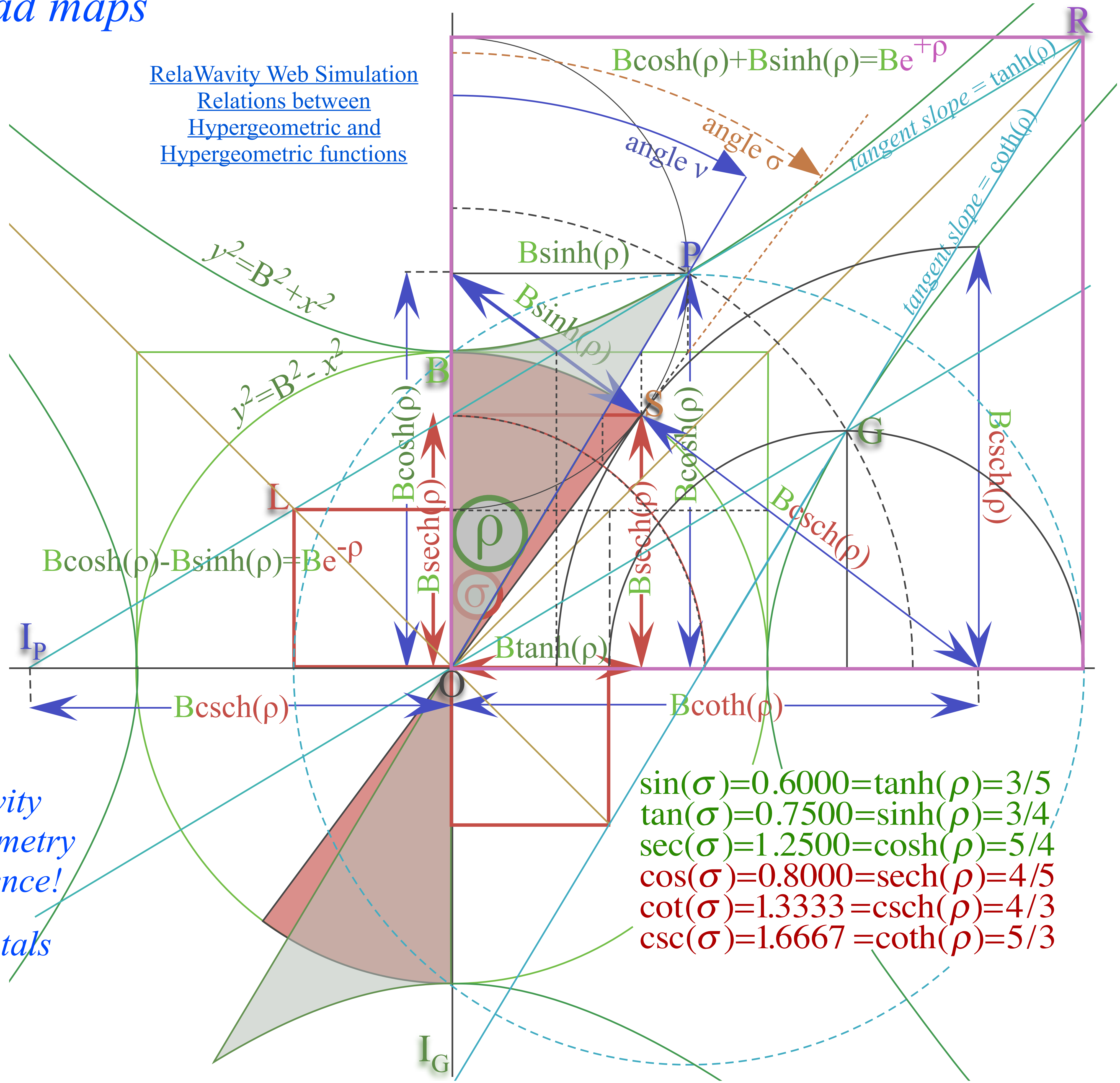
Trigonometric road maps

Need to see how trig road maps match the physical maps on next 2 pages.

[RelaWavity Web Simulation Relations between Hypergeometric and Hypergeometric functions]



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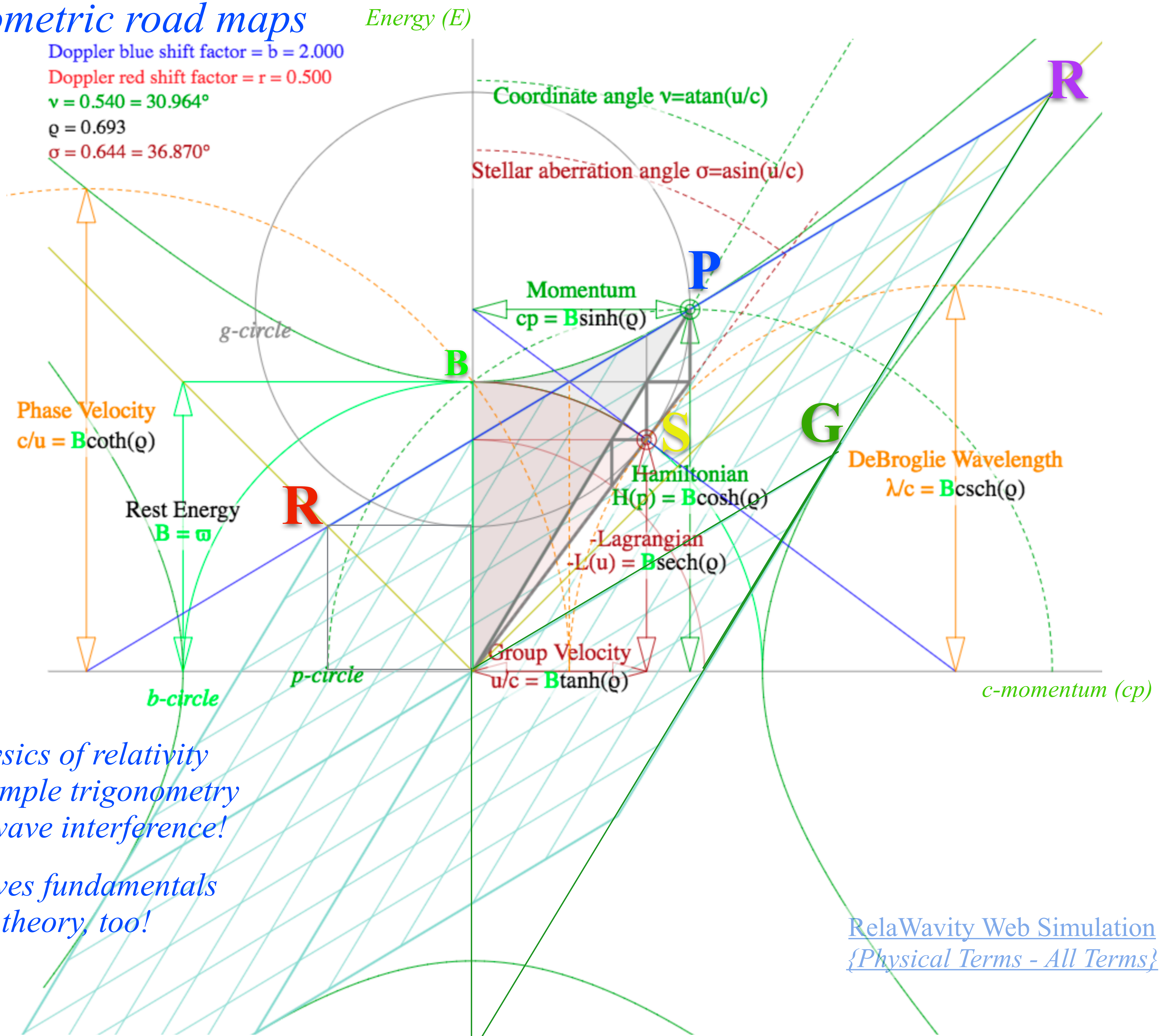

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RelaWavity Web Simulation
{Physical Terms - All Terms}