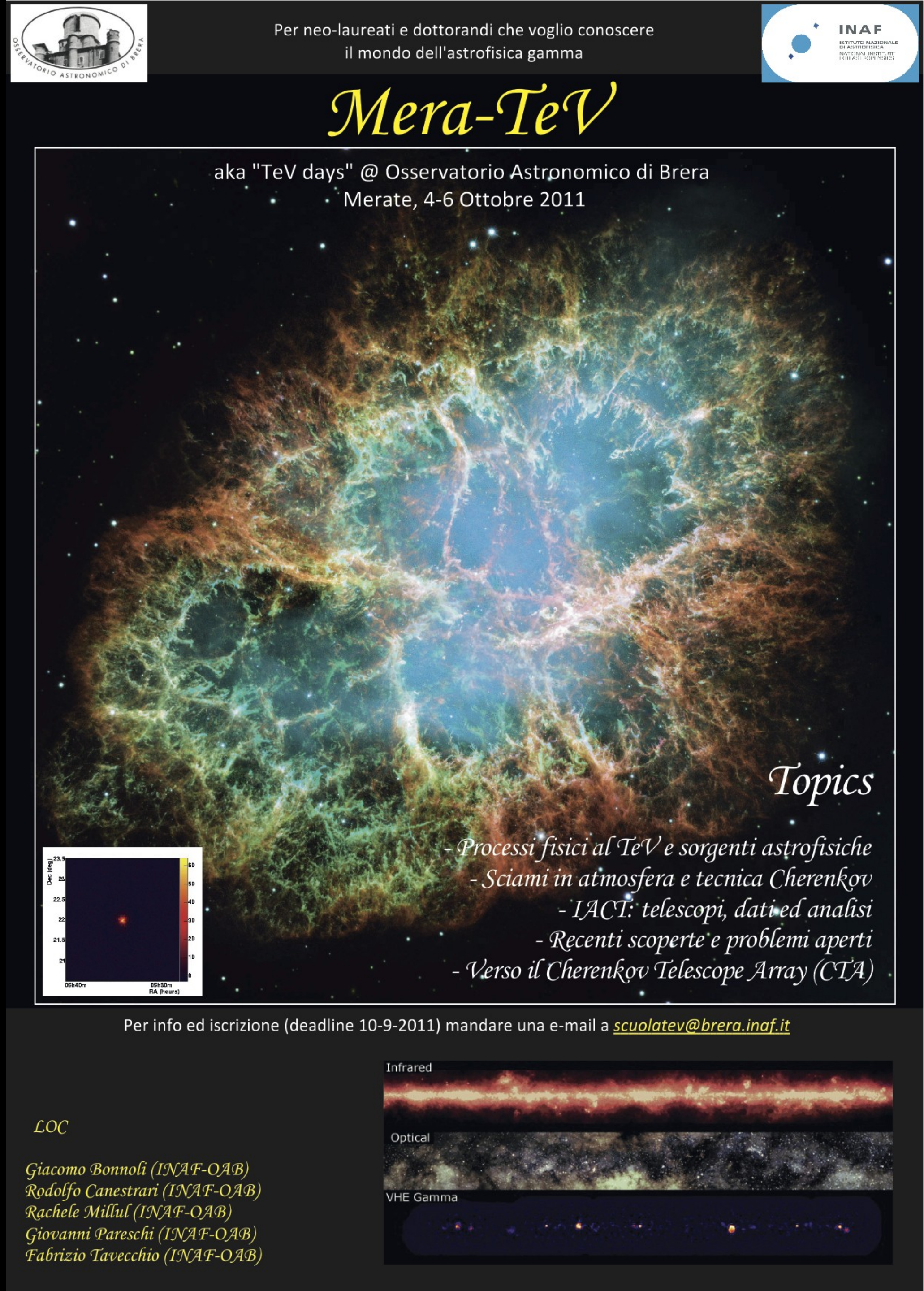
Benvenuti al Mera-TeV!

4-5-6 Ottobre 2011
Sala “POE” di OAB a Merate



Mera-TeV - Calendario

Martedì 4/10 (10.00 -17:30)			Tema	Argomento/Titolo del contributo	Relatore
10:00	-	10:10	Benvenuto		TBD
10:10	-	11:40	Processi fisici al TeV	Processi di emissione, motori astrofisici	Gabriele Ghisellini
11:40	-	12:10	"	Processi di assorbimento	Fabrizio Tavecchio
12:10	-	13:00	Sorgenti Extra-Galattiche	Blazars	Fabrizio Tavecchio
13:00	-	14:30	Pranzo		
14:30	-	15:20	"	Gamma-Ray Bursts	Andrea Melandri
15:20	-	16:20	Sorgenti Galattiche	Processi di accelerazione ed emissione associata in SNRs, PWNe e ammassi di galassie	Giovanni Morlino
16:20	-	16:50	Pausa		
16:50	-	17:30	Altre sorgenti non collimate	Galassie Starburst, Dark Matter	Massimo Persic
Mercoledì 5/10 (9:00 - 18:00)			**Tema**	**Argomento/Titolo del contributo**	**Relatore**
9:00	-	9:40	Rivelazione di raggi Gamma	Rivelazione dallo spazio: Fermi/LAT Survey e monitoring di Fermi LAT come trigger per i puntamenti del CTA	Stefano Ciprini
9:40	-	10:20	"	Rivelazione da Terra	Giacomo Bonnoli
10:20	-	11:00	Telescopi Imaging Atmospheric Cherenkov	Raccogliere la luce Cherenkov	Rodolfo Canestrari
11:00	-	11:30	Pausa		
11:30	-	12:15	Sorgenti Galattiche	Stelle di neutroni e raggi gamma: Fermi e i telescopi Cerenkov vedono lo stesso cielo, ma non le stesse sorgenti	Patrizia Caraveo
12:15	-	13:00	"	Rivelare la luce Cherenkov	Francesco Dazzi
13:00	-	14:30	Pranzo		
14:30	-	15:10	Analisi Dati IACT	Dalla calibrazione alla caratterizzazione degli eventi	Marcos Lopez
15:10	-	16:00	"	Risultati fisici dall'analisi di dati Cherenkov	Elisa Prandini
16:00	-	16:30	Pausa		
16:30	-	17:00	Simulazioni	Aspetti teorici	Piero Vallania
17:00	-	17:30	"	Aspetti tecnici	Federico Di Pierro
17:30	-	18:00	"	Simulazioni MC: prospettive e problemi aperti	Luigi Cossio
Giovedì 6/10 (9:00 - 16:15)			**Tema**	**Argomento/Titolo del contributo**	**Relatore**
9:00	-	9:40	Recenti scoperte, problemi aperti	Gamma-Ray Bursts nel regime VHE	Alessandro Carosi
9:40	-	10:20	"	Principali risultati e problemi insoluti nelle osservazioni VHE di sorgenti extragalattiche	Laura Maraschi
10:20		10:50	"	Narrow Line Seyfert 1 galaxies: una potenziale classe di sorgenti VHE	Luigi Foschini
10:50	-	11:20	Pausa		
11:20	-	12:10	"	Emissione di raggi gamma in sistemi binari	Pol Bordas
12:10	-	13:00	"	Pulsar gamma studiate in banda VHE	Marcos Lopez
13:10	-	14:30	Pranzo		
14:30	-	15:15	CTA	Caso scientifico per CTA	Massimo Persic
15:15	-	16:00	"	ASTRI e CTA in INAF	Bruno Sacco
16:00		16:15	Saluti		Giovanni Pareschi

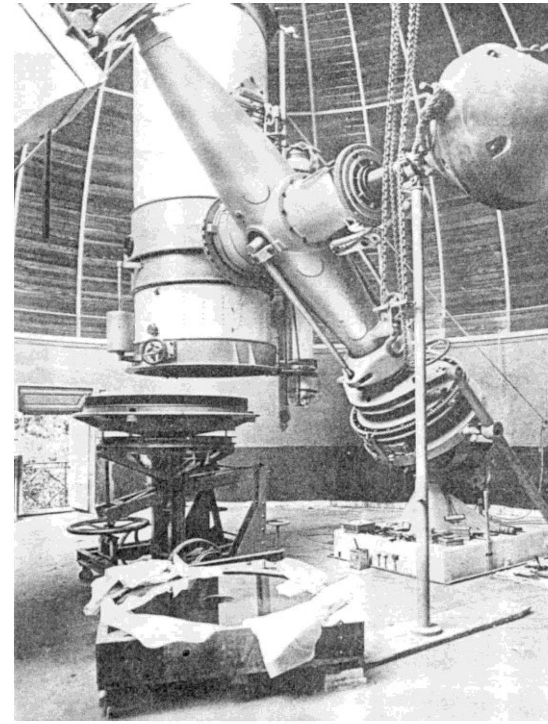
Mera-TeV - Calendario

Martedì 4/10 (10.00 -17:30)			Tema	Argomento/Titolo del contributo	Relatore
10:00	-	10:10	Benvenuto		TBD
10:10	-	11:40	Processi fisici al TeV	Processi di emissione, motori astrofisici	Gabriele Ghisellini
11:40	-	12:10	"	Processi di assorbimento	Fabrizio Tavecchio
12:10	-	13:00	Sorgenti Extra-Galattiche	Blazars	Fabrizio Tavecchio
13:00	-	14:30	Pranzo		
14:30	-	15:20	"	Gamma-Ray Bursts	Andrea Melandri
				Processi di accelerazione ed emissione associata in SNRs, PWNe e	Lorenzo Sironi
16:20	-	16:50	Pausa		
16:50	-	17:30	Altre sorgenti non collimate	Galassie Starburst, Dark Matter	Massimo Persic
Mercoledì 5/10 (9:00 - 18:00)			**Tema**	**Argomento/Titolo del contributo**	**Relatore**
9:00	-	9:40	Rivelazione di raggi Gamma	Rivelazione dallo spazio: Fermi/LAT Survey e monitoring di Fermi LAT come trigger per i puntamenti del CTA	Stefano Ciprini
9:40	-	10:20	"	Rivelazione da Terra	Giacomo Bonnoli
10:20	-	11:00	Telescopi Imaging Atmospheric Cherenkov	Raccogliere la luce Cherenkov	Rodolfo Canestrari
11:00	-	11:30	Pausa		
11:30	-	12:15	Sorgenti Galattiche	Stelle di neutroni e raggi gamma: Fermi e i telescopi Cerenkov vedono lo stesso cielo, ma non le stesse sorgenti	Patrizia Caraveo
12:15	-	13:00	"	Rivelare la luce Cherenkov	Francesco Dazzi
13:00	-	14:30	Pranzo		
14:30	-	15:10	Analisi Dati IACT	Dalla calibrazione alla caratterizzazione degli eventi	Marcos Lopez
15:10	-	16:00	"	Risultati fisici dall'analisi di dati Cherenkov	Elisa Prandini
16:00	-	16:30	Pausa		
16:30	-	17:00	Simulazioni	Aspetti teorici	Piero Vallania
17:00	-	17:30	"	Aspetti tecnici	Federico Di Pierro
17:30	-	18:00	"	Simulazioni MC: prospettive e problemi aperti	Luigi Cossio
Giovedì 6/10 (9:00 - 16:15)			**Tema**	**Argomento/Titolo del contributo**	**Relatore**
9:00	-	9:40	Recenti scoperte, problemi aperti	Gamma-Ray Bursts nel regime VHE	Alessandro Carosi
9:40	-	10:20	"	Principali risultati e problemi insoluti nelle osservazioni VHE di sorgenti extragalattiche	Laura Maraschi
10:20		10:50	"	Narrow Line Seyfert 1 galaxies: una potenziale classe di sorgenti VHE	Luigi Foschini
10:50	-	11:20	Pausa		
11:20	-	12:10	"	Emissione di raggi gamma in sistemi binari	Pol Bordas
12:10	-	13:00	"	Pulsar gamma studiate in banda VHE	Marcos Lopez
13:10	-	14:30	Pranzo		
14:30	-	15:15	CTA	Caso scientifico per CTA	Massimo Persic
15:15	-	16:00	"	ASTRI e CTA in INAF	Bruno Sacco
16:00		16:15	Saluti		Giovanni Pareschi

FATE DOMANDE!

- **Le domande sono gradite, anche prima della fine dei contributi.**
- **L'incontro è volutamente informale, e lo spirito è orientato alla comprensione delle tematiche ed alla interazione tra i partecipanti.**

SOCIAL EVENT



Visita alle Cupole Zeiss e Ruths:
Mercoledì 5, ore 18.15

SOCIAL DINNER

- Taverna dei Cacciatori – Imbersago
- Ore 20.00 Mercoledì
- Partenza da Osservatorio ore 19.45

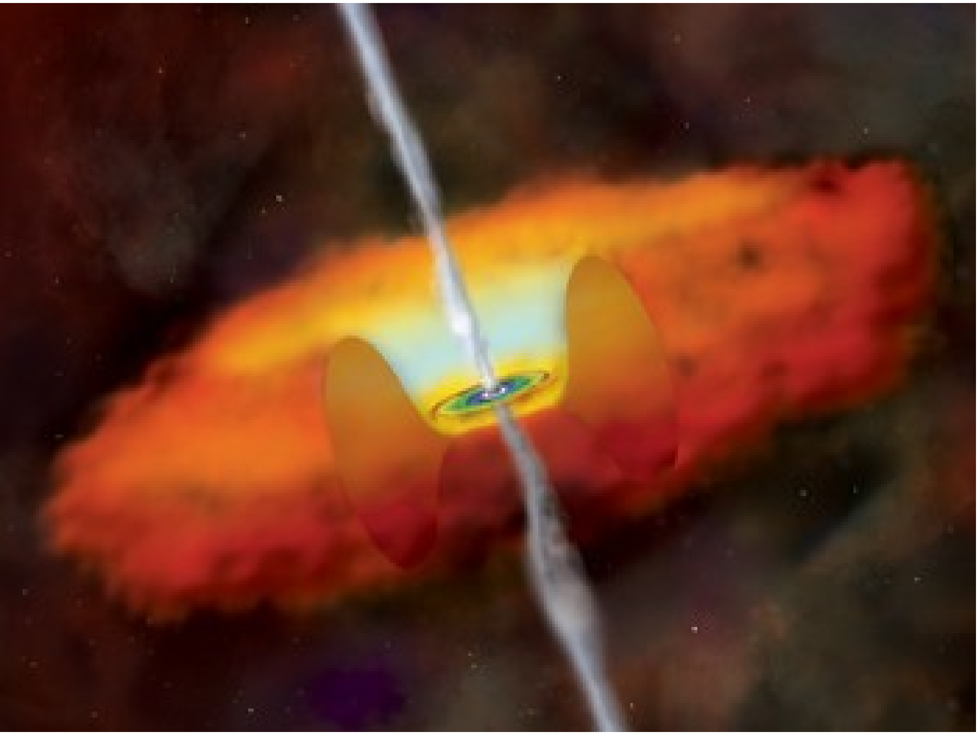
Pranzi e Pause Caffè

- Pranzi: alle 13.00 nel parco, di fronte alla Cupola Ruths
- Coffe Breaks: nella Biblioteca, piano seminterrato edificio principale.

Buon Mera-TeV!!

Beaming

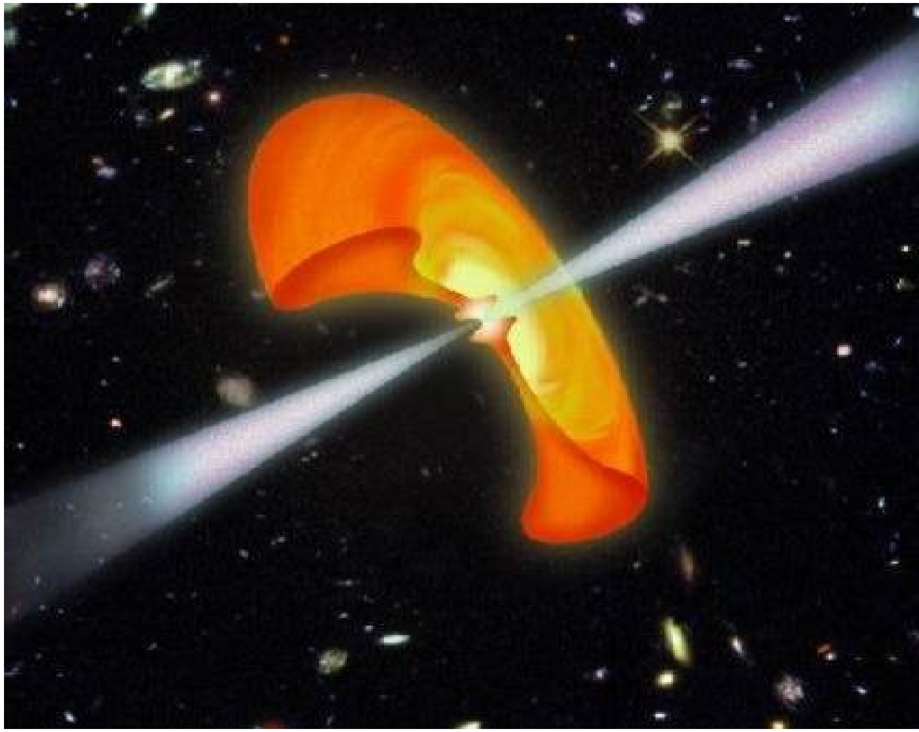
Radio-loud AGNs



~ 0.1 M_o yr^{-1}

Γ~20

Gamma Ray Bursts



~ 10^{-5} M_o
in a few sec

Γ~300

Text book special relativity

Lorentz transformations: $\vec{v}$ along x

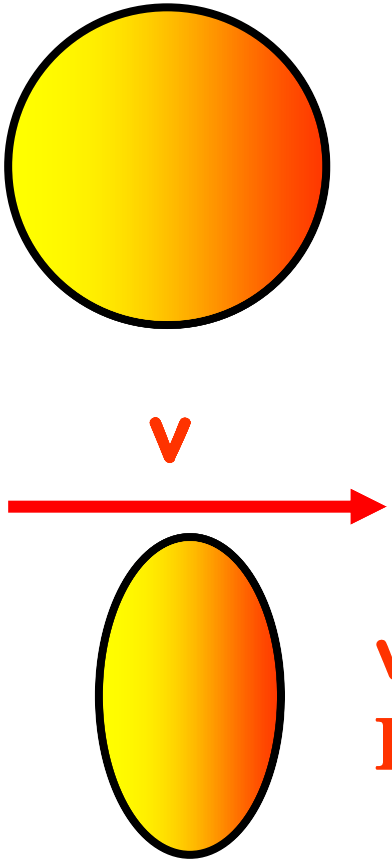
$x' = \Gamma\,(x - vt)$	$x = \Gamma\,(x' + vt')$
$y' = y$	$y = y'$
$z' = z$	$z = z'$
$t' = \Gamma\,(t - v\,x/c^2)$	$t = \Gamma\,(t' + v\,x'/c^2)$

for $\Delta t = 0 \rightarrow \Delta x = \Delta x'/\Gamma$ **Contraction**

for $\Delta x' = 0 \rightarrow \Delta t = \Gamma\,\Delta t'$ **time dilation**

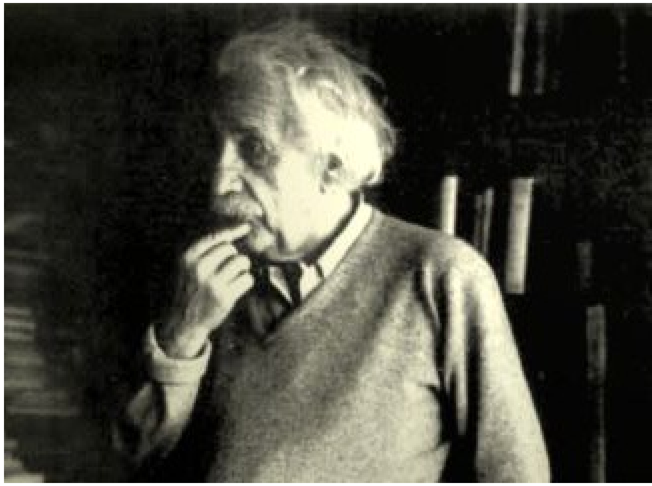
To remember: mesons created at a height of ~15 km can reach the earth, even if their lifetime is a few microsec → ct'_{life}=hundreds of meters.

Can we see contracted spheres?



$v=0$
$\Gamma=1$

$v=0.866c$
$\Gamma=2$



Einstein: Yes!

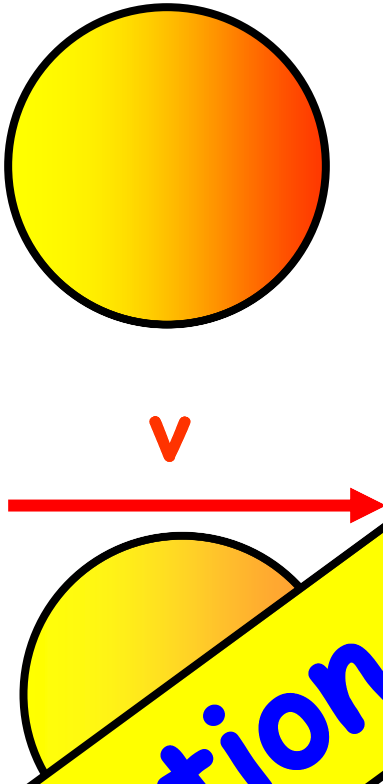
PHYSICAL REVIEW VOLUME 116, NUMBER 4 … 15, 1959

Invisibility of the Lorentz Contr…

JAMES TERRELL

Los Alamos Scientific Laboratory, University of C…

(Received Jun…



v=0

Γ=1

v

…866c

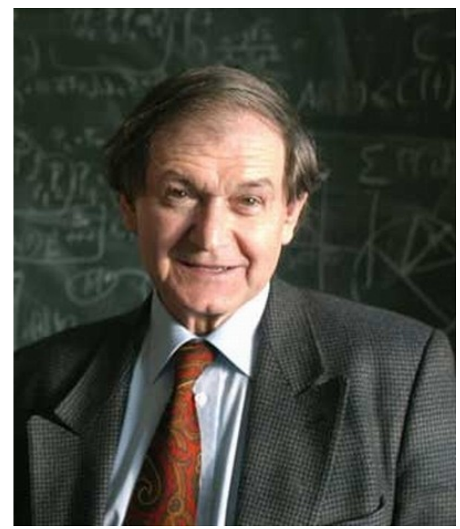
…=2

Ja… 1959

Rotation, not contraction!

NO!

Roger Penrose 1959



Relativity with photons

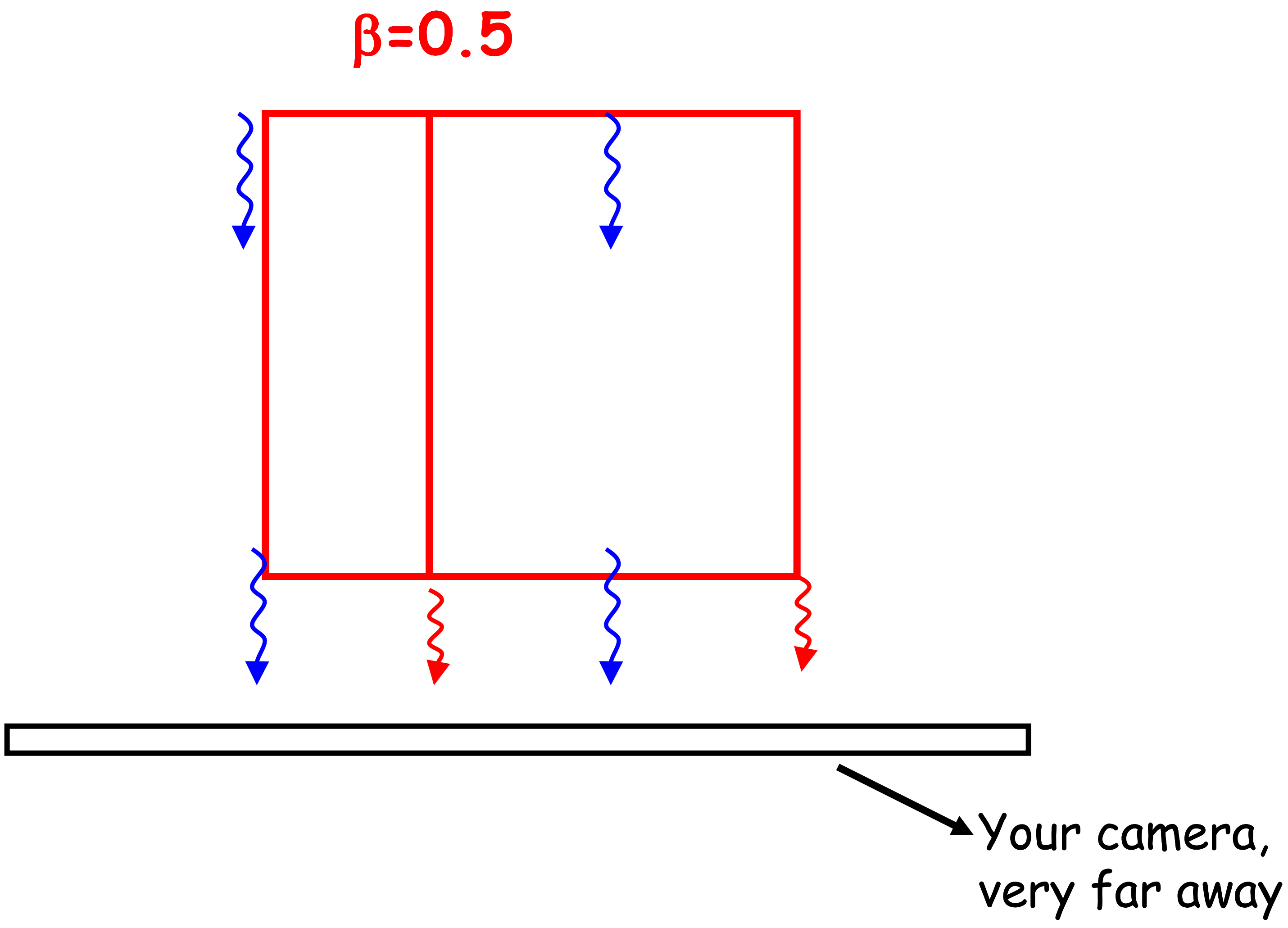
From rulers and clocks

to photographs and frequencies

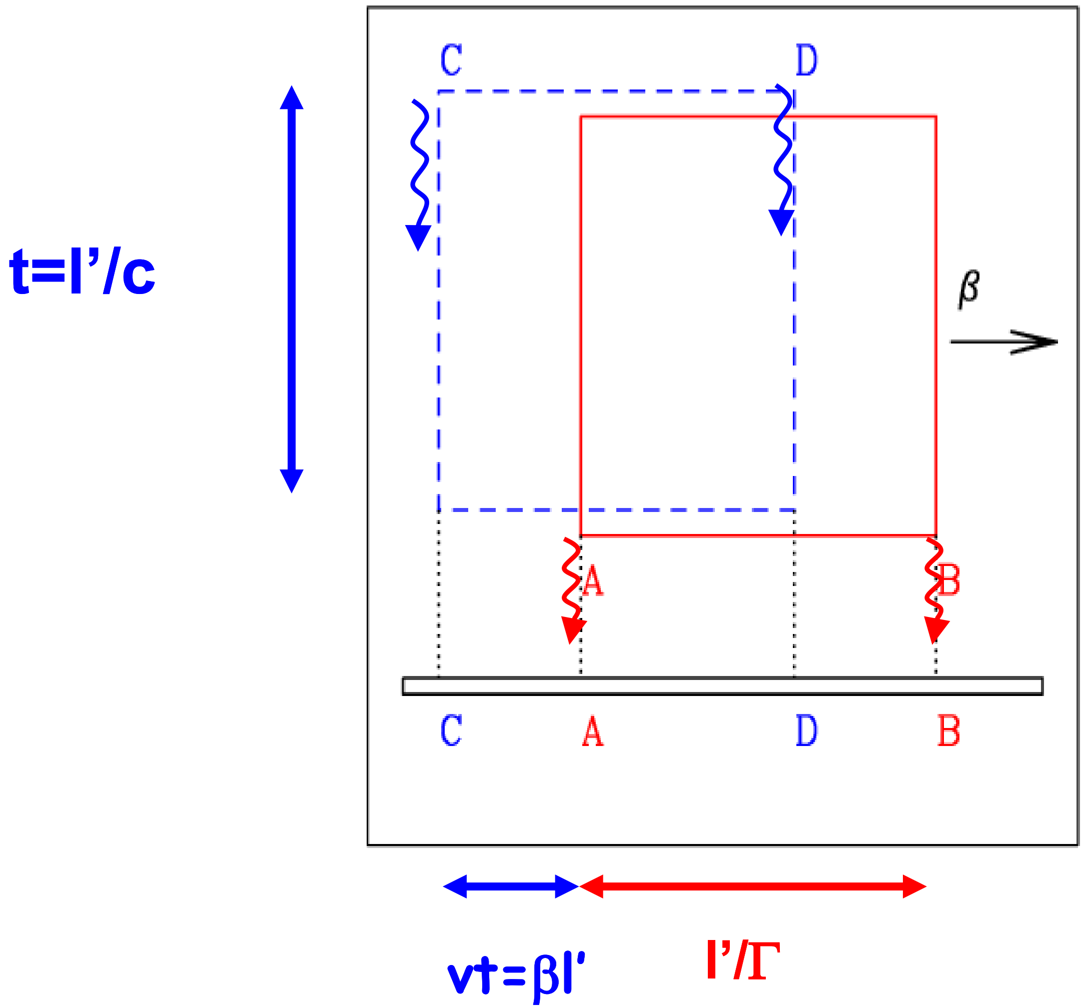
Or:

from elementary particles to extended objects

The moving square



The moving square



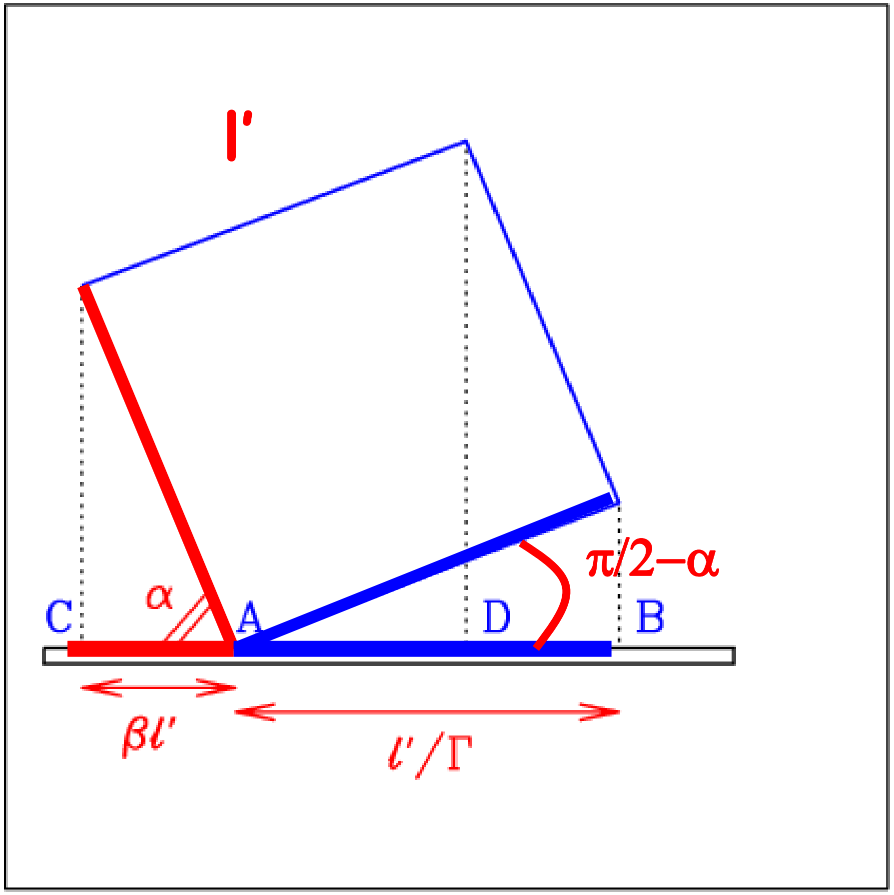
$l_{tot} = l' (\beta + 1/\Gamma)$

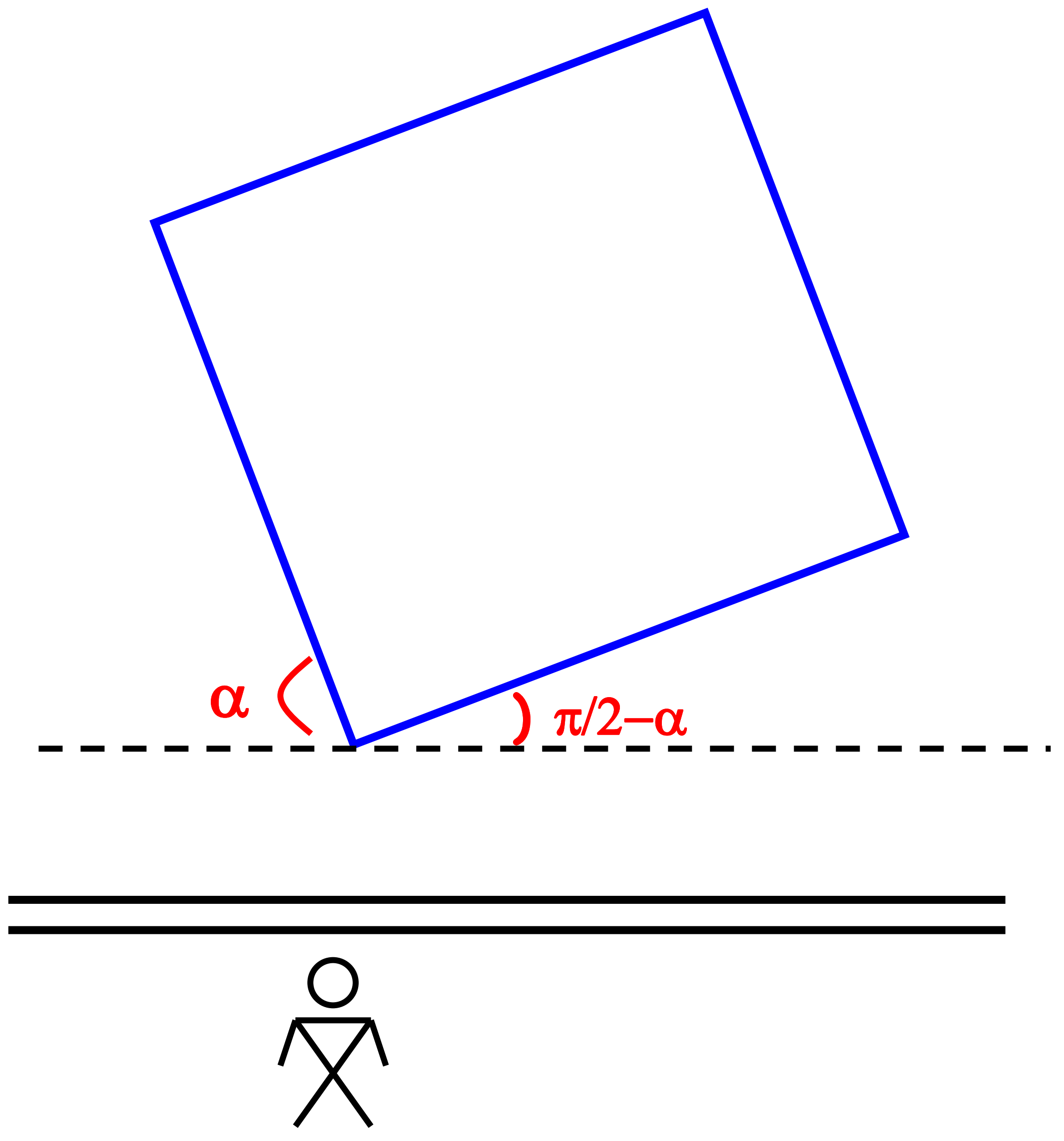
max: $2^{1/2} l'$ (diag)

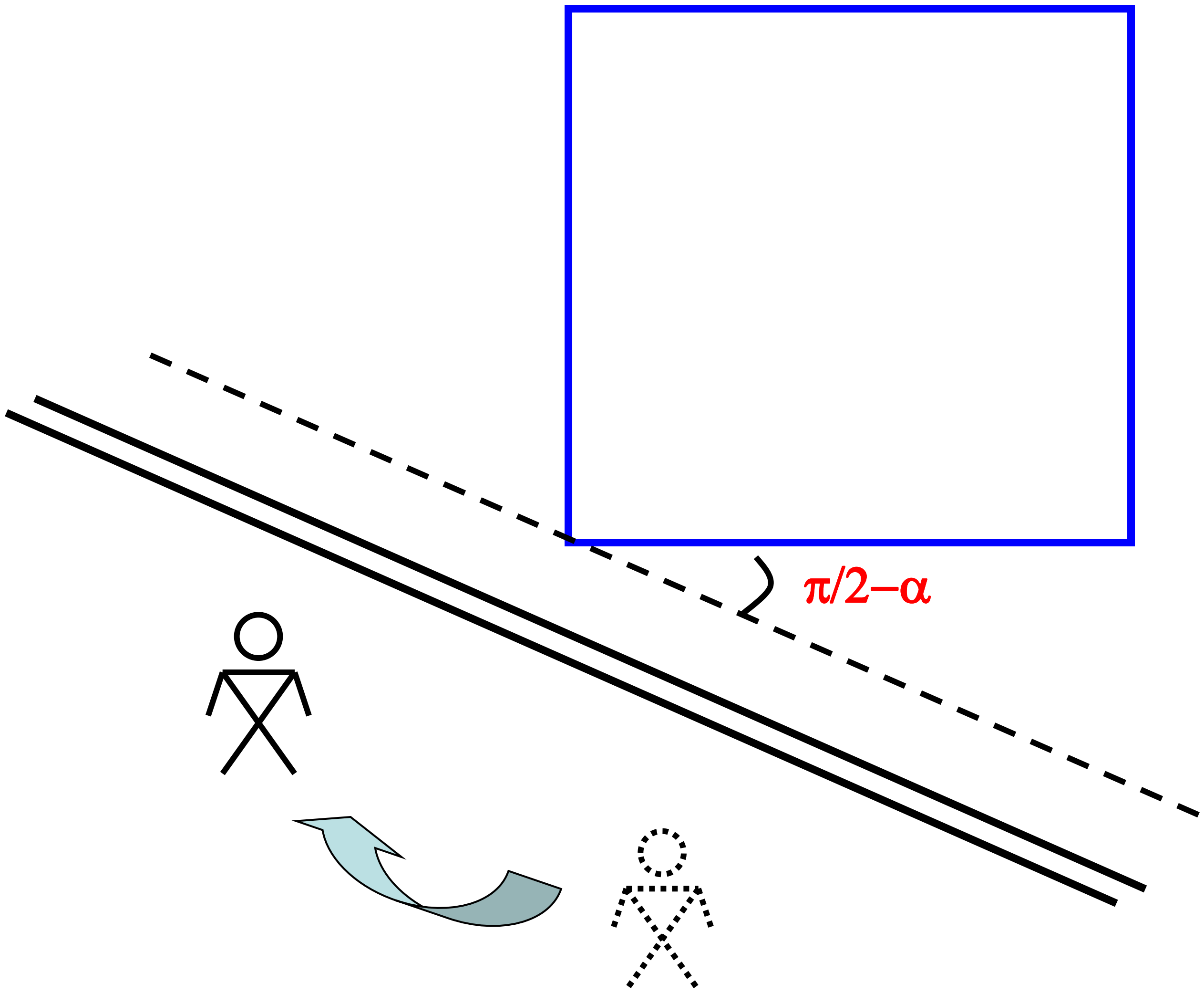
min: l' (for $\beta = 0$)

$l'\cos\alpha = \beta l' \rightarrow \cos\alpha = \beta$

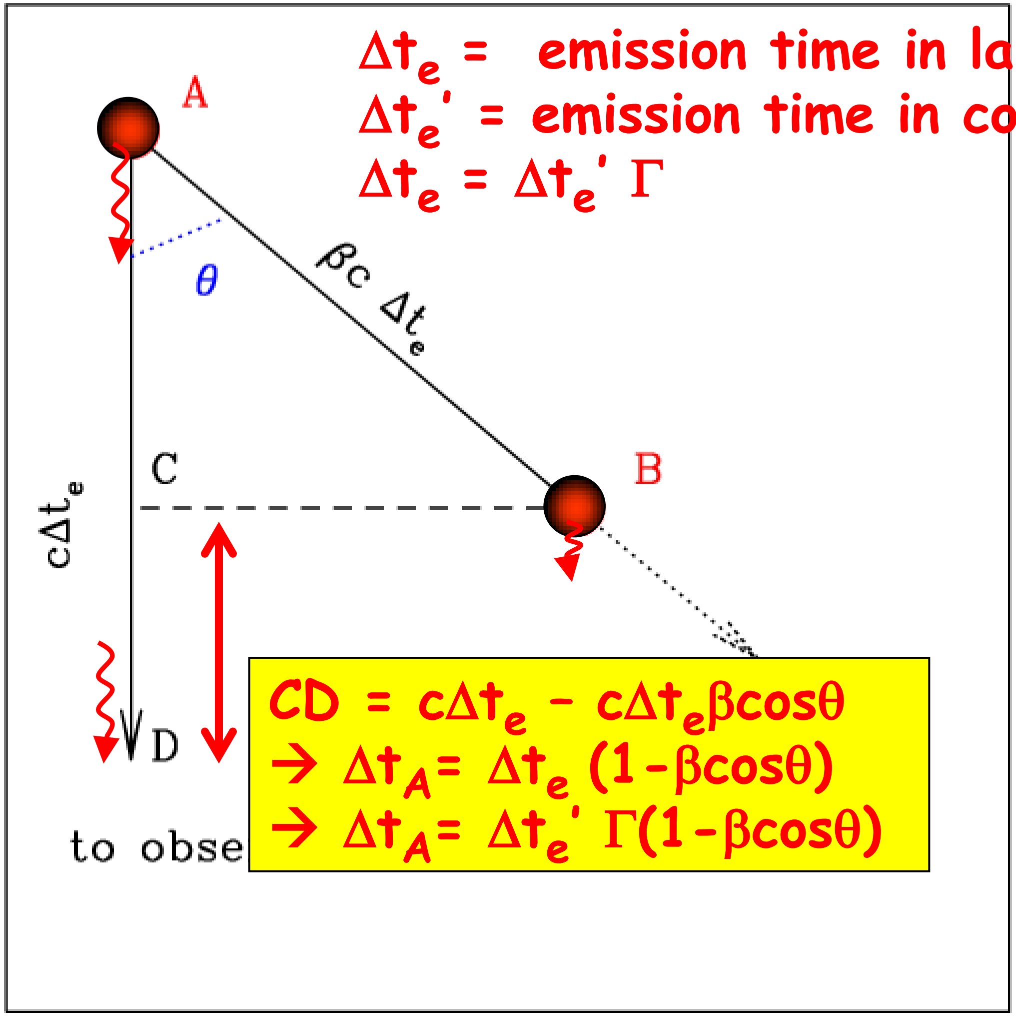
$\cos(\pi - \pi/2 - \alpha) = \sin\alpha = 1/\Gamma$




α
π/2−α


π/2−α

Time



Δt_e = emission time in lab frame

$\Delta t_e'$ = emission time in comov. frame

$\Delta t_e = \Delta t_e' \, \Gamma$

$CD = c\Delta t_e - c\Delta t_e \beta\cos\theta$

→ $\Delta t_A = \Delta t_e \, (1-\beta\cos\theta)$

→ $\Delta t_A = \Delta t_e' \, \Gamma(1-\beta\cos\theta)$

Relativistic Doppler factor δ

$$\Delta t_A = \Delta t_e' \, \Gamma(1-\beta\cos\theta)$$

$$\nu = \nu' \, / \, \Gamma(1-\beta\cos\theta)$$

$$\delta = \frac{1}{\Gamma(1-\beta\cos\theta)}$$

You change frame

Standard relativity (Γ)

Doppler effect ($1-\beta\cos\theta$)

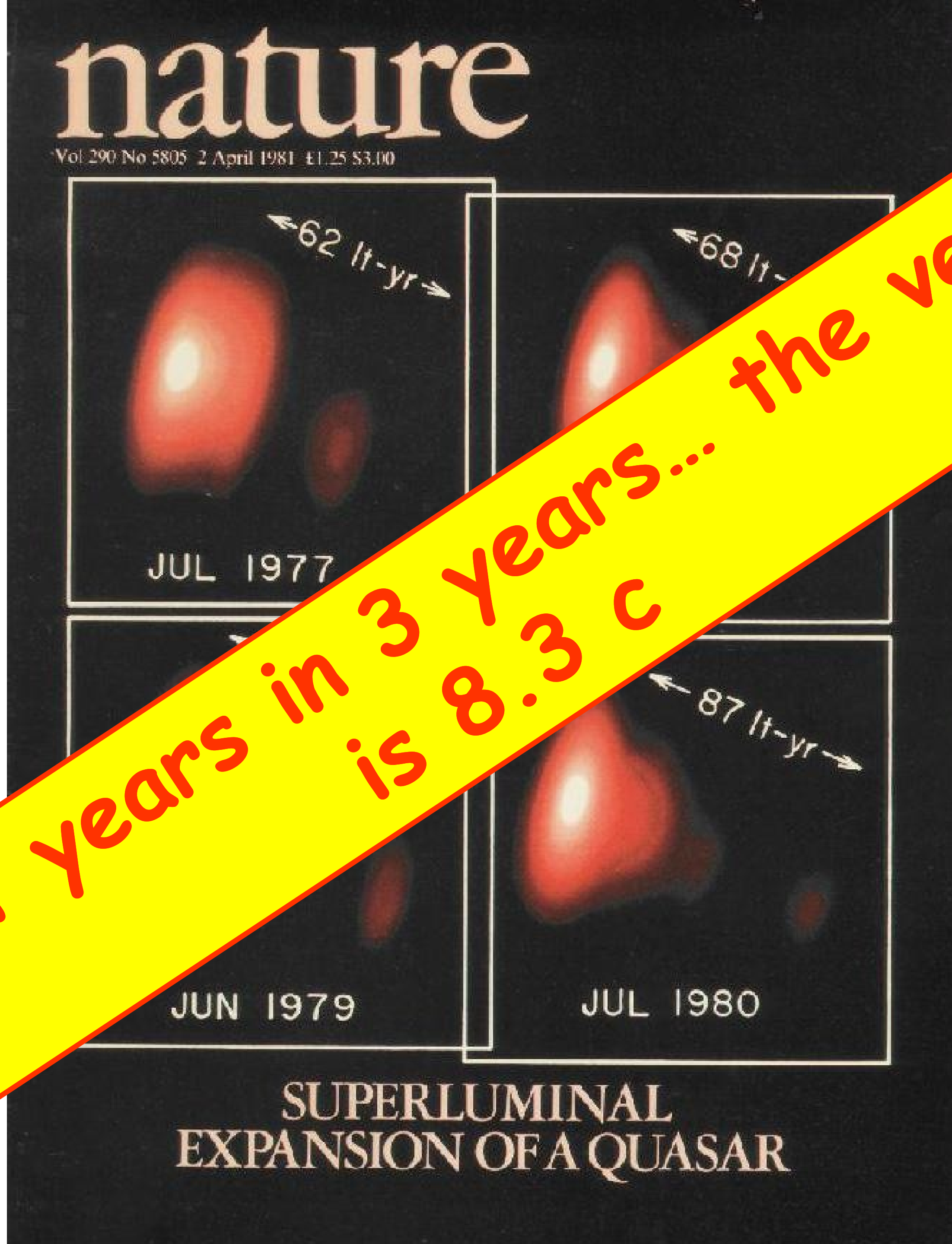
You remain in lab frame

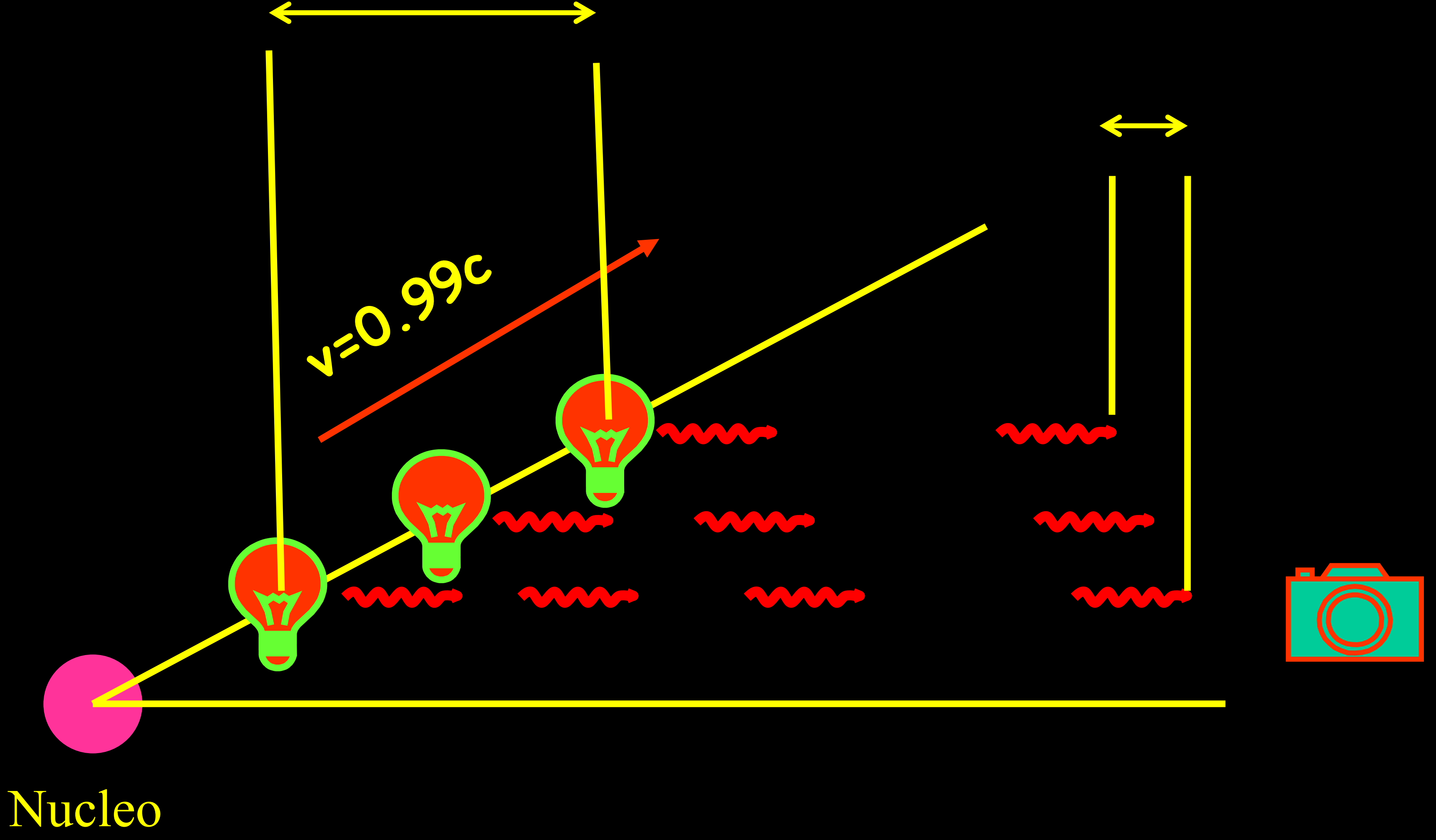
Relativistic Doppler factor δ

$$\delta = \frac{1}{\Gamma(1-\beta\cos\theta)} = \begin{cases} 2\Gamma & \text{for } \theta=0^o \\ \Gamma & \text{for } \theta=1/\Gamma \\ 1/\Gamma & \text{for } \theta=90^o \end{cases}$$

At small angles, Doppler wins over Spec. Relat.

25 light years in 3 years… the velocity is 8.3 c

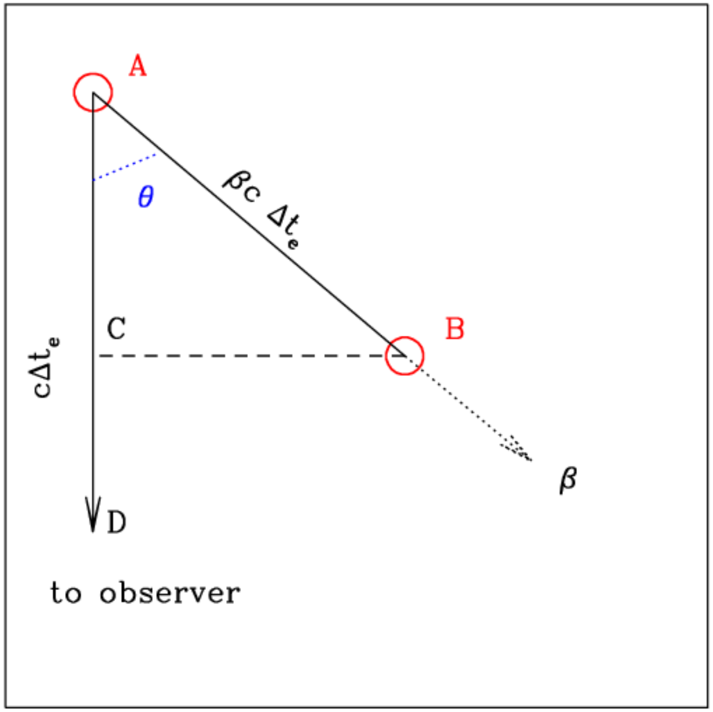



v=0.99c
Nucleo

$$\frac{\Delta s_{app}}{\Delta t_A} = v_{app} = \frac{v\,\Delta t_e \sin\theta}{\Delta t_e\,(1-\beta\cos\theta)}$$

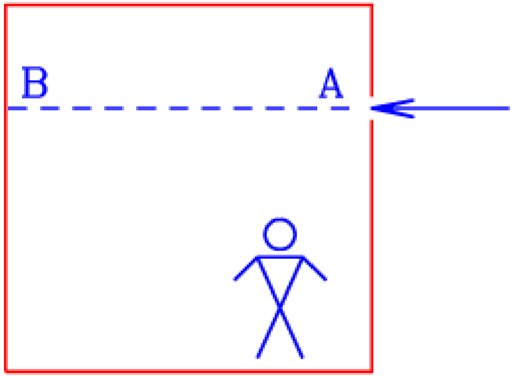
There is no Γ. Correct?

$$\beta_{app} = \frac{\beta \sin\theta}{1-\beta\cos\theta}$$

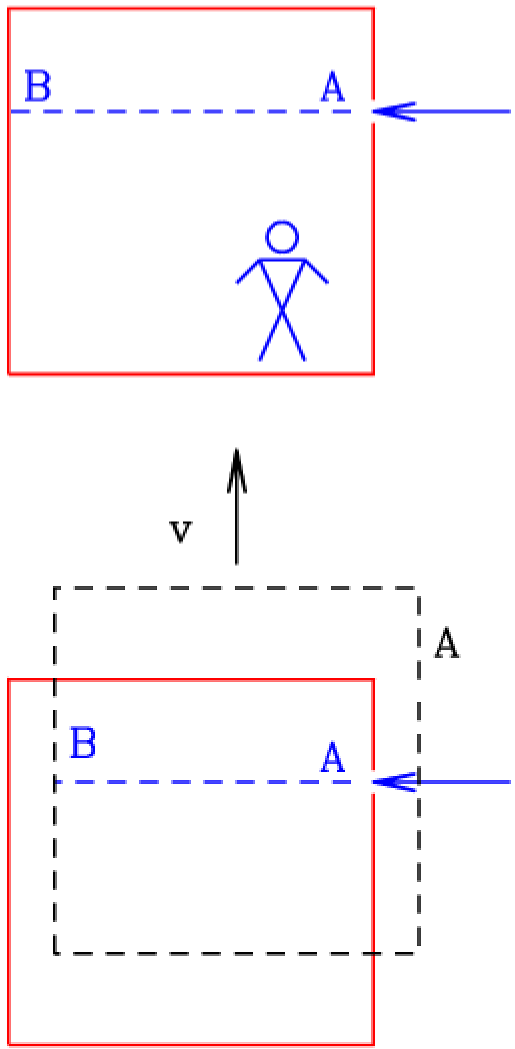


$\beta\Gamma$

Aberration of light

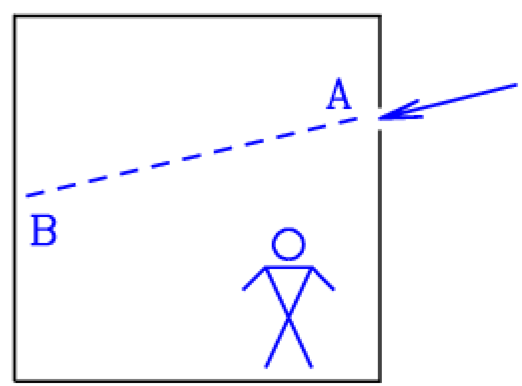


Aberration of light

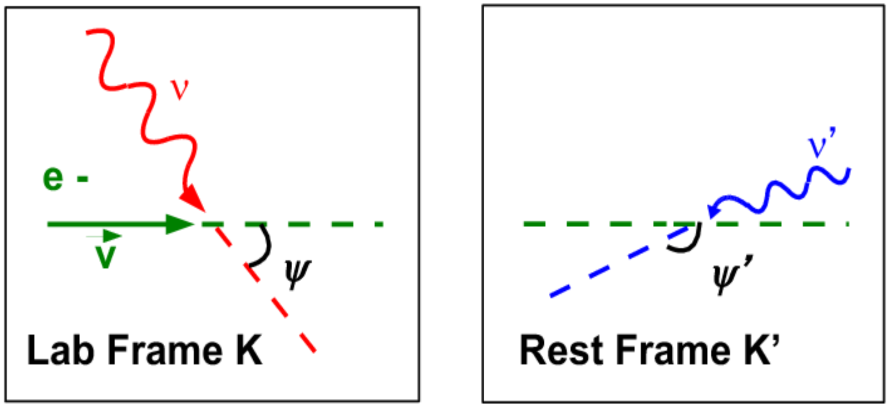


$$\sin\theta = \sin\theta'/\delta$$

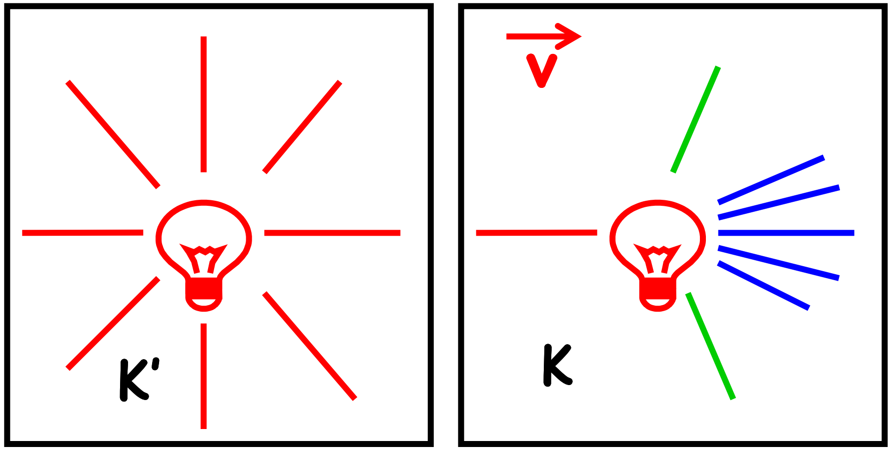
$$d\Omega = d\Omega'/\delta^2$$



Aberration of light



$$\sin\theta = \sin\theta'/\delta$$



$$d\Omega = d\Omega'/\delta^2$$

1

Observed vs intrinsic Intensity

$$\frac{I(\nu)}{\nu^3} = \frac{I'(\nu')}{\nu'^3} = \text{invariant} \Longrightarrow I(\nu) = \delta^3 I'(\nu')$$

$$I(\nu) = \frac{\text{erg}}{\text{cm}^2\ \text{s Hz sterad}} = \frac{E}{dA\ dt\ d\nu\ d\Omega}$$

Observed vs intrinsic Intensity

$$\frac{I(\nu)}{\nu^3} = \frac{I'(\nu')}{\nu'^3} = \text{invariant} \Longrightarrow I(\nu) = \delta^3 I'(\nu')$$

$$I(\nu) = \frac{\text{erg}}{\text{cm}^2 \text{ s Hz sterad}} = \frac{E}{dA\, \cancel{dt}\, \cancel{d\nu}\, d\Omega}$$

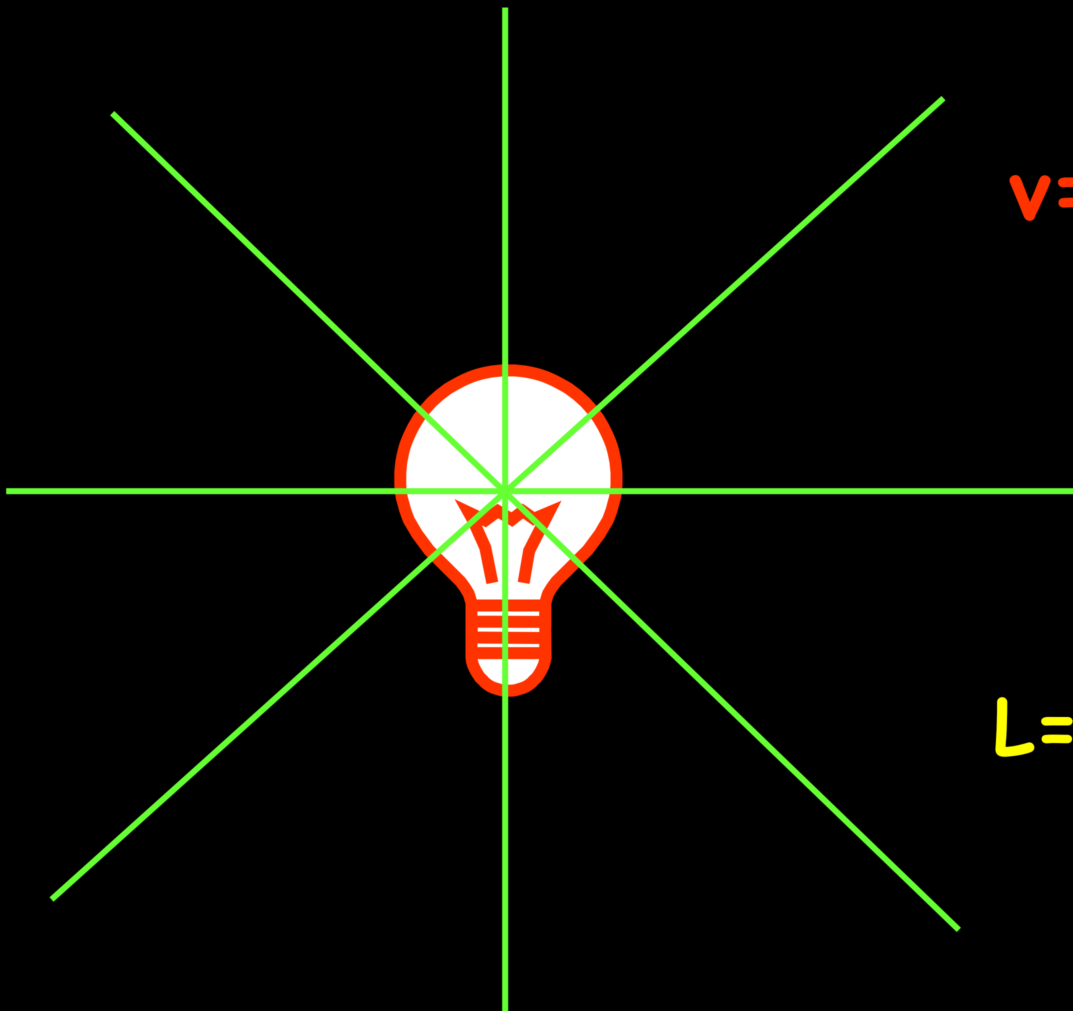
Observed vs intrinsic Intensity

$$\frac{I(\nu)}{\nu^3} = \frac{I'(\nu')}{\nu'^3} = \text{invariant} \Rightarrow I(\nu) = \delta^3 I'(\nu')$$

$$I(\nu) = \frac{\text{erg}}{\text{cm}^2 \text{ s Hz sterad}} = \frac{E'\delta}{dA'\, d\Omega'/\delta^2} = \delta^3 I'(\nu')$$

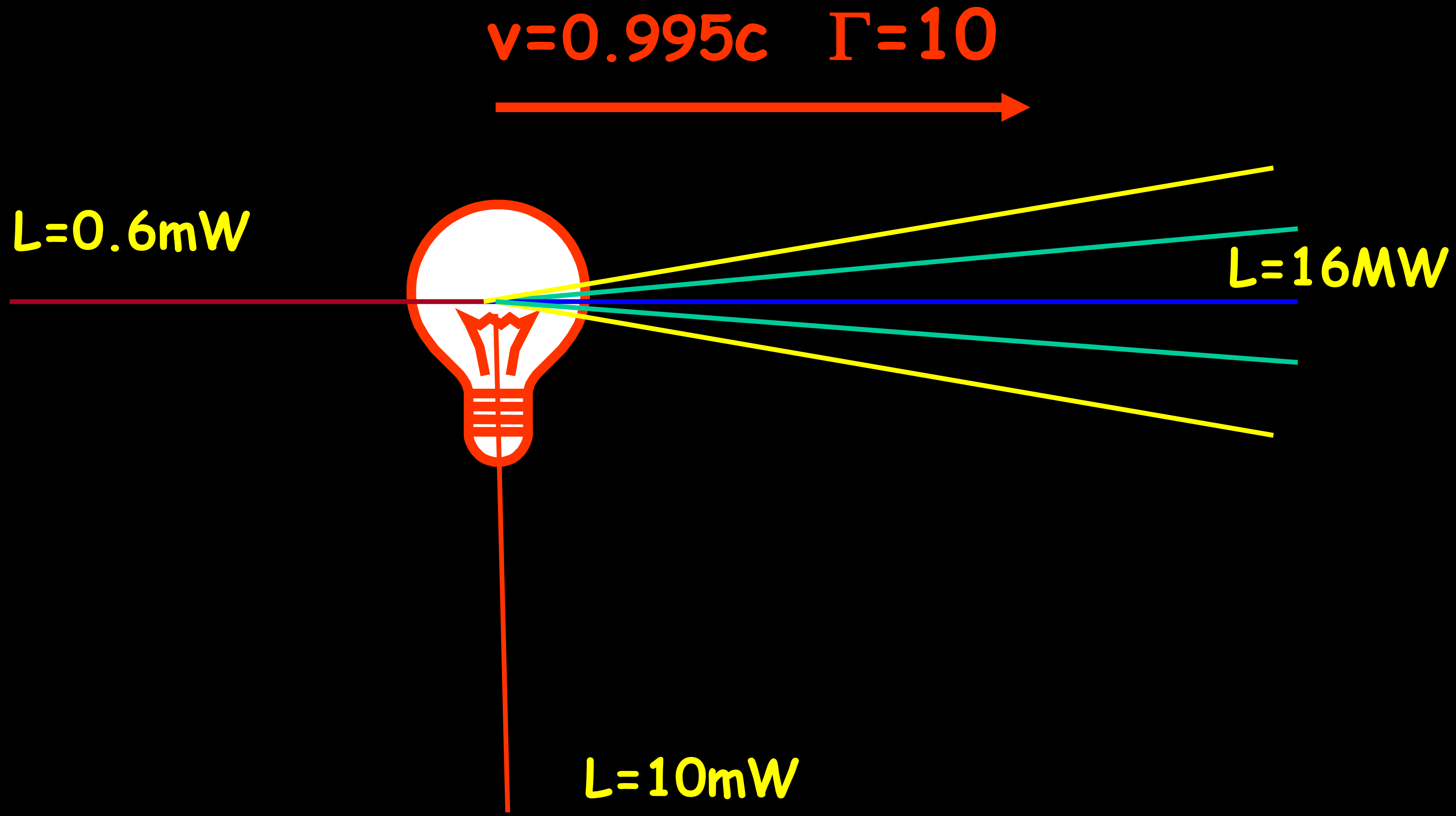
$\Rightarrow$ $I = \delta^4 I'$ $\Rightarrow$ $F = \delta^4 F'$

δ blueshift
δ time
δ^2 aberration

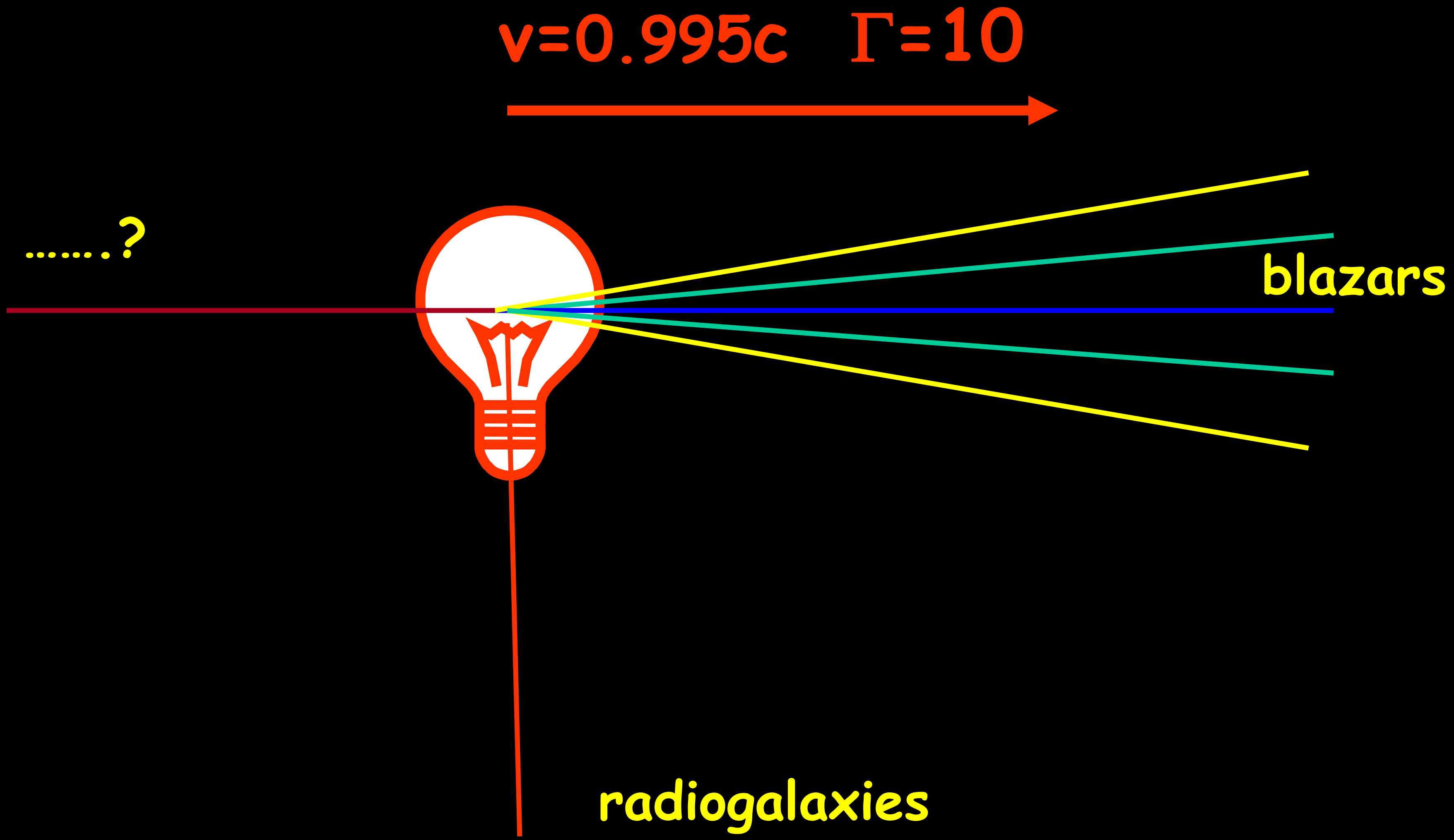


v=0

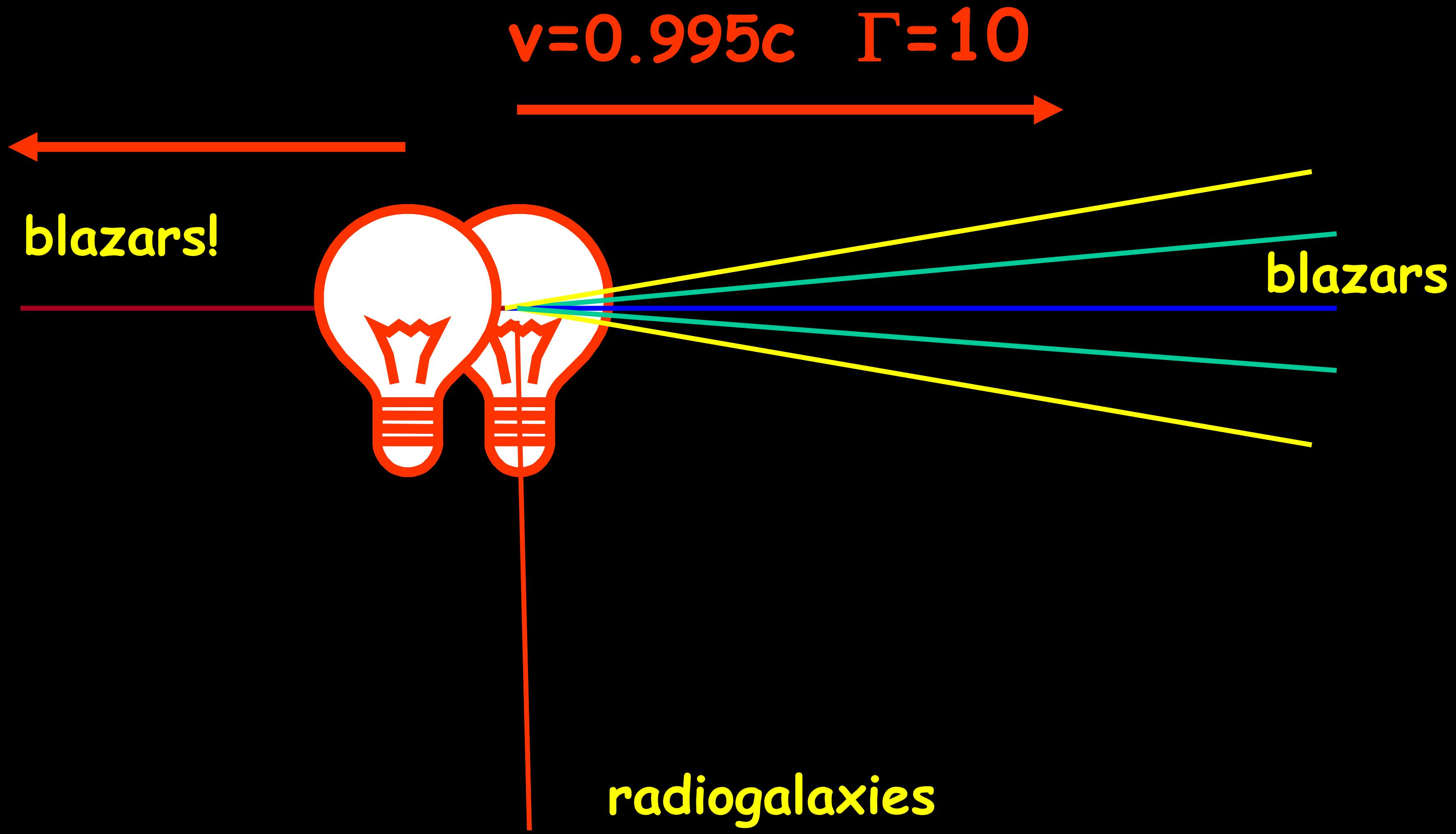
L=100 W

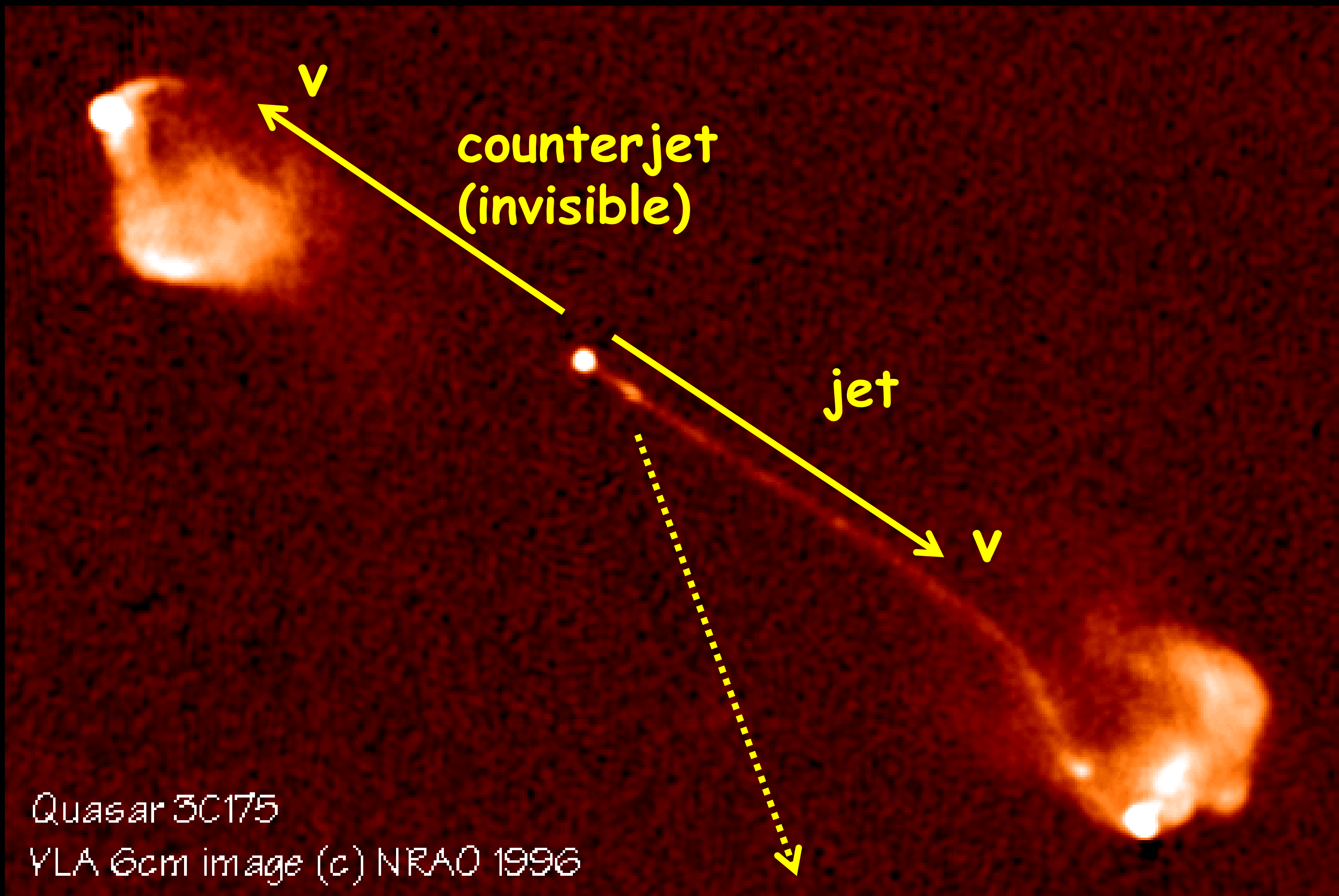


v=0.995c Γ=10
L=0.6mW
L=16MW
L=10mW



v=0.995c Γ=10
blazars
radiogalaxies
.......?


v=0.995c Γ=10
blazars!
blazars
radiogalaxies

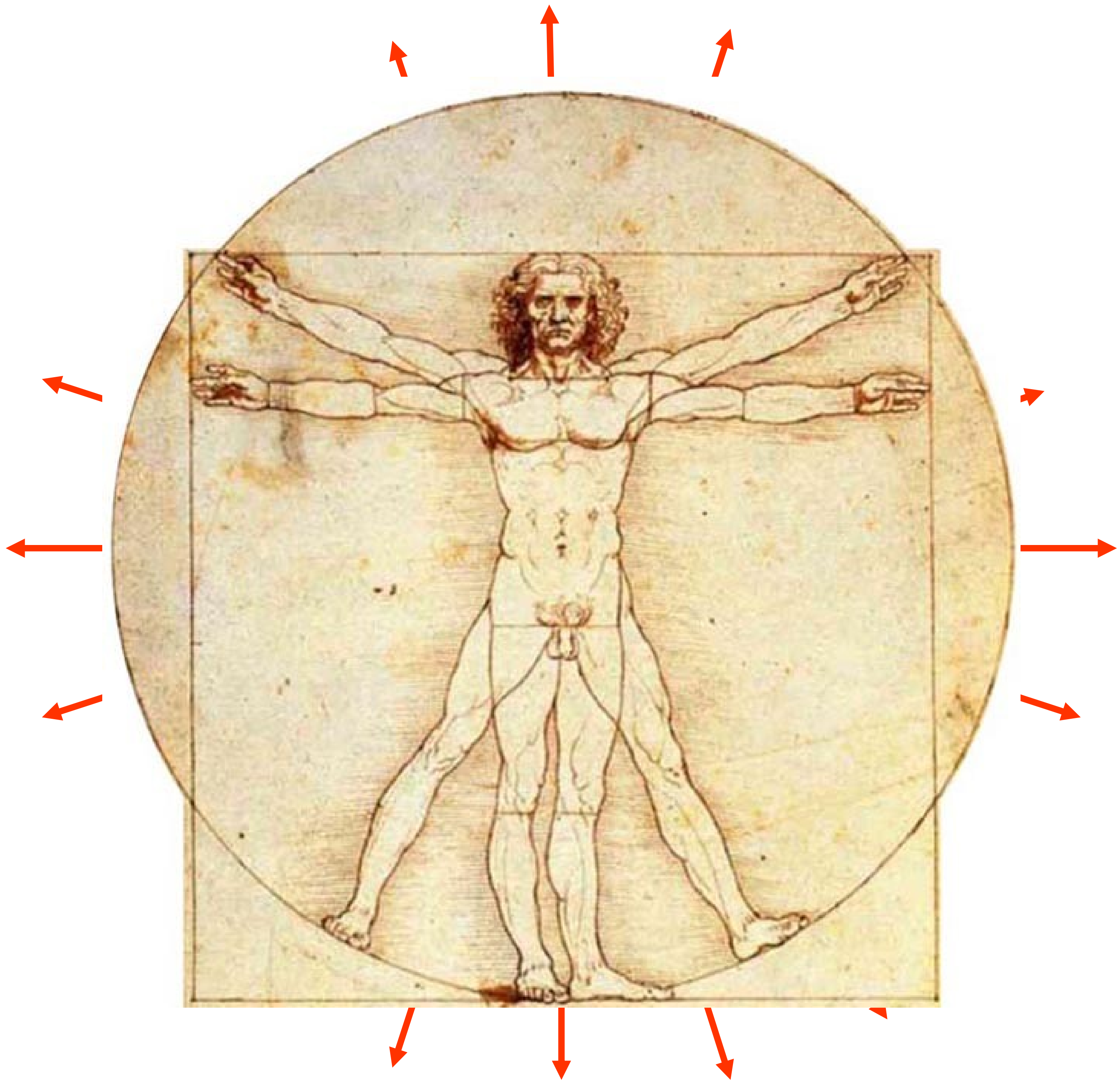

v
counterjet
(invisible)
jet
v
Quasar 3C175
VLA 6cm image (c) NRAO 1996

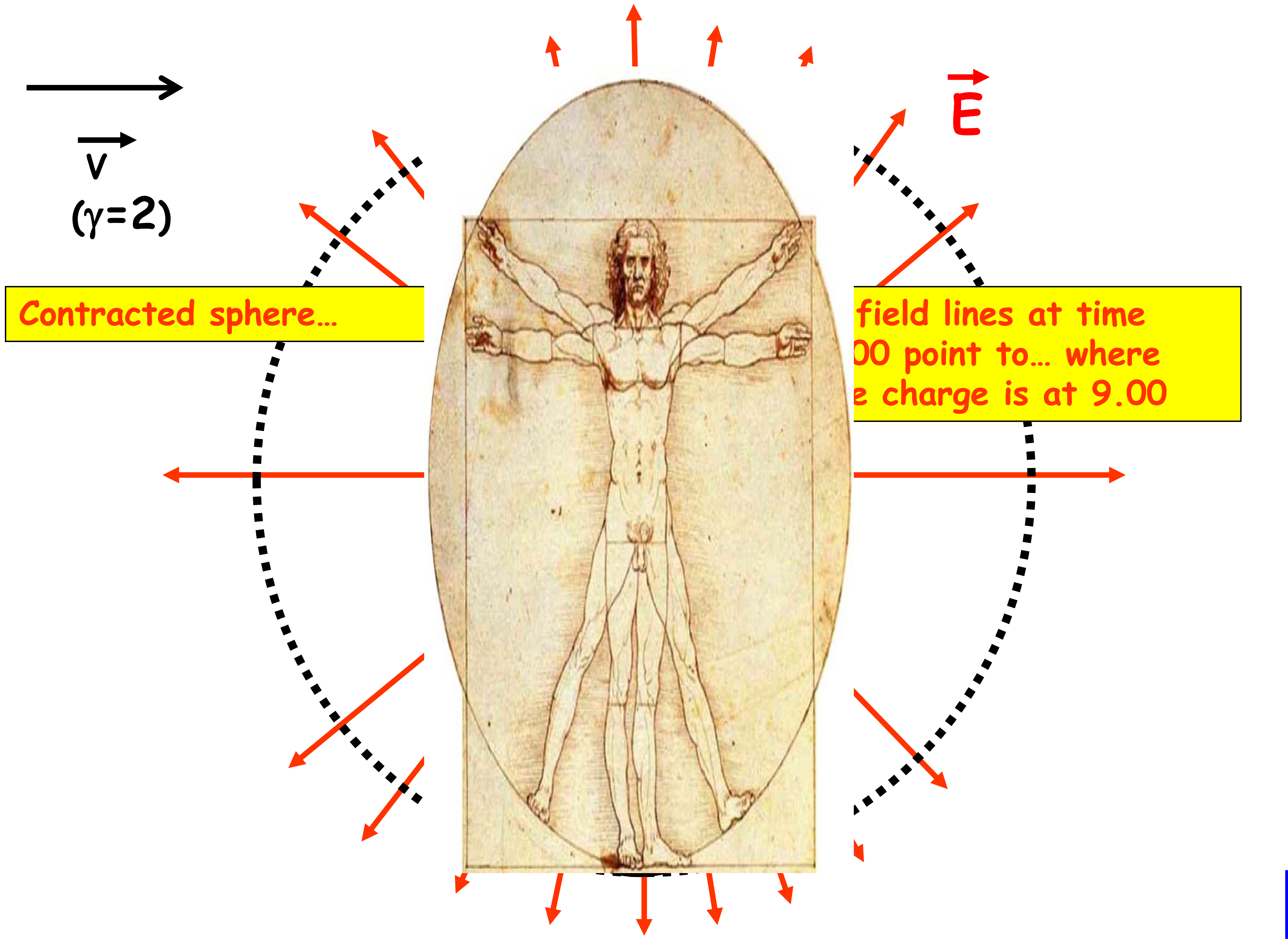
Radiation processes

Radiation processes

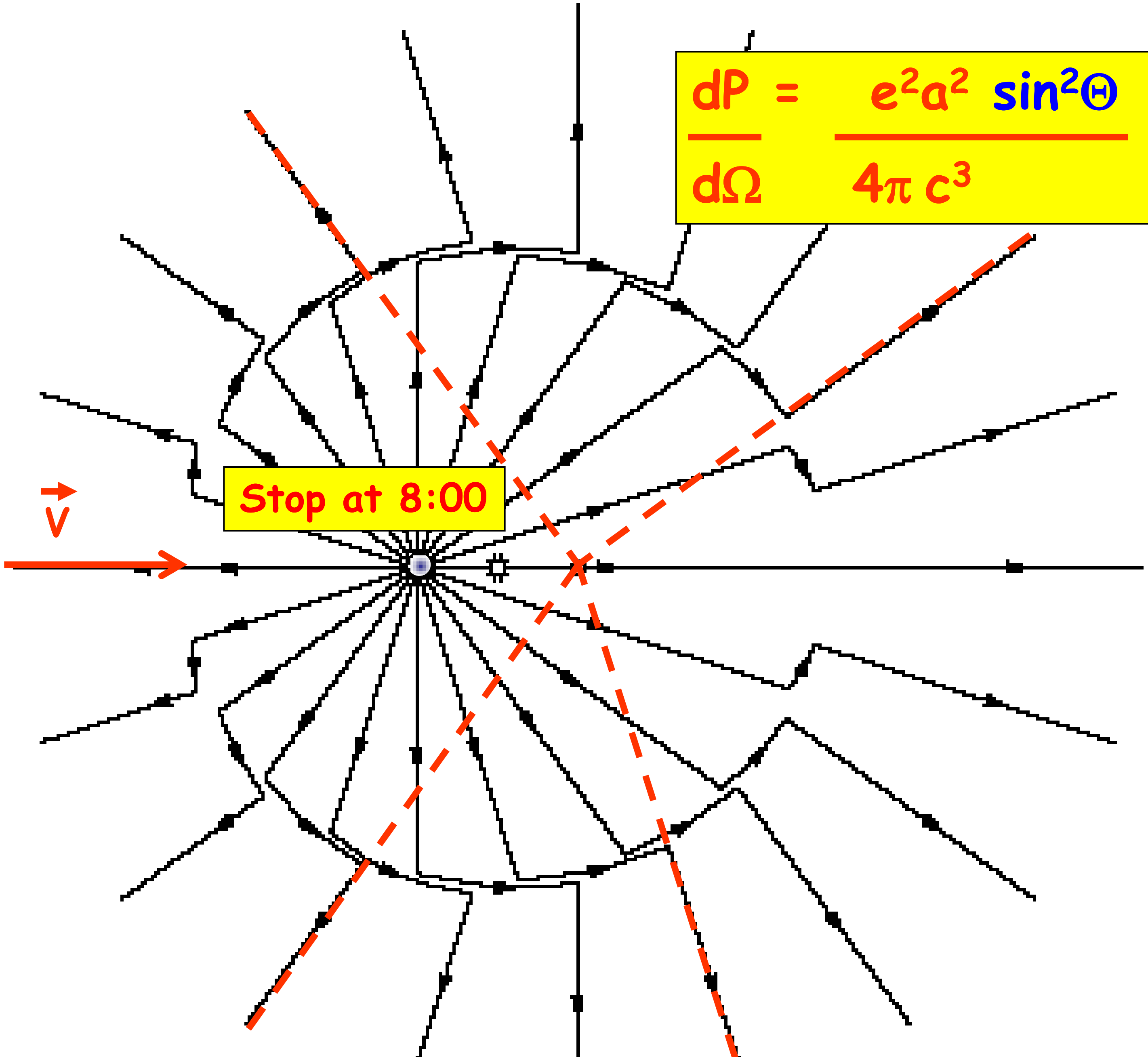
- Line emission and radiative transitions in atoms and molecules
- Breemstrahlung/Blackbody
- Curvature radiation
- Cherenkov
- Annihilation
- Unruh radiation
- Hawking radiation
- Synchrotron
- Inverse Compton

$\vec{V}=0$





v
(γ=2)
E
Contracted sphere...
field lines at time
00 point to... where
e charge is at 9.00



http://www.cco.caltech.edu/~phys1/java/phys1/MovingCharge/MovingCharge.html

$$\frac{dP}{d\Omega} = \frac{e^2 a^2 \sin^2\Theta}{4\pi c^3}$$

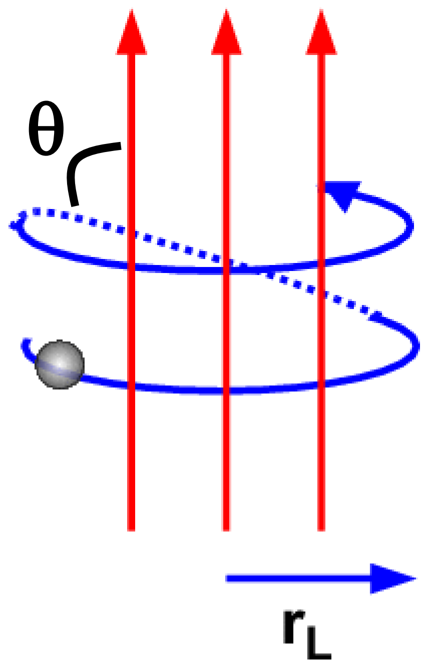
$$P = \frac{2 e^2 a^2}{3 c^3}$$

Synchrotron

Synchrotron

- Ingredients: Magnetic field and relativistic charges
- Responsible: Lorentz force
- Curiously, the Lorentz force doesn't work.

$$\vec{F}_L = \frac{d}{dt}(\gamma m\vec{v}) = \frac{e}{c}\vec{v} \times \vec{B}$$



Total losses

$$P_e = P'_e$$

P=E/t and E and t Lorentz transform in the same way

Please, P_e is not $P_{received}$!!

Total losses

$$P_e = P'_e = \frac{2e^2}{3c^3} a'^2 = \frac{2e^2}{3c^3} (a'^2_{\parallel} + a'^2_{\perp})$$

Total losses

$$P_e = P'_e = \frac{2e^2}{3c^3} a'^2 = \frac{2e^2}{3c^3} (a'^2_{\parallel} + a'^2_{\perp})$$

$$P_e = P'_e = \frac{2e^2}{3c^3} \gamma^2 a^2_{\perp}$$

$$a'_{\perp} = \gamma^2 a_{\perp}$$

$$a'_{\parallel} = 0$$

$$a_{\perp} = \frac{e\, v\, B \sin\theta}{\gamma\, mc}$$

Total losses

$$P_e = P'_e = \frac{2e^2}{3c^3} a'^2 = \frac{2e^2}{3c^3} (a'^2_{\parallel} + a'^2_{\perp})$$

$$P_e = P'_e = \frac{2e^2}{3c^3} \gamma^2 a^2_{\perp}$$

$$a'_{\perp} = \gamma^2 a_{\perp}$$

$$P_S(\theta) = \frac{2e^4}{3m^2c^3} B^2 \gamma^2 \beta^2 \sin^2\theta$$

$$a'_{\parallel} = 0$$

$$a_{\perp} = \frac{e\, v\, B \sin\theta}{\gamma\, mc}$$

Total losses

$$P_e = P'_e = \frac{2e^2}{3c^3} a'^2 = \frac{2e^2}{3c^3} (a'^2_{||} + a'^2_{\perp})$$

$$P_e = P'_e = \frac{2e^2}{3c^3} \gamma^2 a^2_{\perp}$$

$$a'_{\perp} = \gamma^2 a_{\perp}$$

$$P_S(\theta) = \frac{2e^4}{3m^2c^3} B^2 \gamma^2 \beta^2 \sin^2\theta$$

$$a'_{||} = 0$$

$$a_{\perp} = \frac{e\ v\ B \sin\theta}{\gamma\ mc}$$

$$P_S(\theta) = 2\sigma_T c U_B \gamma^2 \beta^2 \sin^2\theta$$

Total losses

$$P_e = P'_e = \frac{2e^2}{3c^3} a'^2 = \frac{2e^2}{3c^3} (a'^2_{\parallel} + a'^2_{\perp})$$

$$P_e = P'_e = \frac{2e^2}{3c^3} \gamma^2 a^2_{\perp}$$

$$a'_{\perp} = \gamma^2 a_{\perp}$$

$$P_S(\theta) = \frac{2e^4}{3m^2c^3} B^2 \gamma^2 \beta^2 \sin^2\theta$$

$$a'_{\parallel} = 0$$

$$a_{\perp} = \frac{e\, v\, B \sin\theta}{\gamma\, mc}$$

$$P_S(\theta) = 2\sigma_T c U_B \gamma^2 \beta^2 \sin^2\theta$$

$$\langle P_S \rangle = \frac{4}{3} \sigma_T c U_B \gamma^2 \beta^2$$

If pitch angles are isotropic

Total losses

$$P_e = P'_e = \frac{2e^2}{3c^3} a'^2 = \frac{2e^2}{3c^3}(a'^2_{\parallel} + a'^2_{\perp})$$

$$P_e = P'_e = \frac{2e^2}{3c^3} \gamma^2 a^2_{\perp}$$

$$a'_{\perp} = \gamma^2 a_{\perp}$$

$$P_S(\theta) = \frac{2e^4}{3m^2c^3} B^2 \gamma^2 \beta^2 \sin^2\theta$$

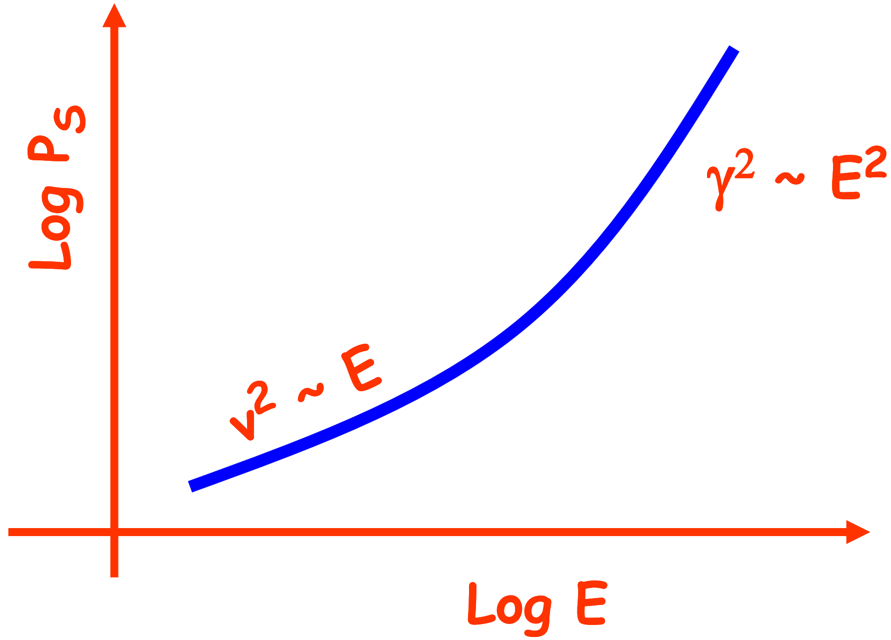
$$a'_{\parallel} = 0$$

$$a_{\perp} = \frac{e\, v\, B \sin\theta}{\gamma\, mc}$$

$$P_S(\theta) = 2\sigma_T c U_B \gamma^2 \beta^2 \sin^2\theta$$

$$\langle P_S \rangle = \frac{4}{3} \sigma_T c U_B \gamma^2 \beta^2$$

If pitch angles are isotropic



Why γ^2??

$$P_S(\theta) = 2\sigma_T U_B \gamma^2 \beta^2 \sin^2\theta$$

What happens when $\theta \rightarrow 0$?

Sure, but what happens to the *received* power if you are in the beam of the particles?

Synchrotron Spectrum

Characteristic frequency

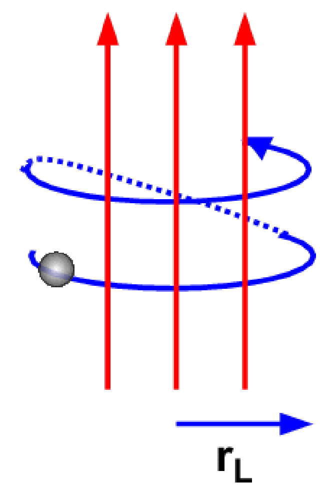
$$r_L = \frac{v_\perp^2}{a_\perp} = \frac{\gamma\, mc^2\, \beta\, \sin\theta}{eB}$$

$$a_\perp = \frac{e\, v\, B\, \sin\theta}{\gamma\, mc}$$

$$\nu_B = \frac{eB}{2\pi\, \gamma mc}$$

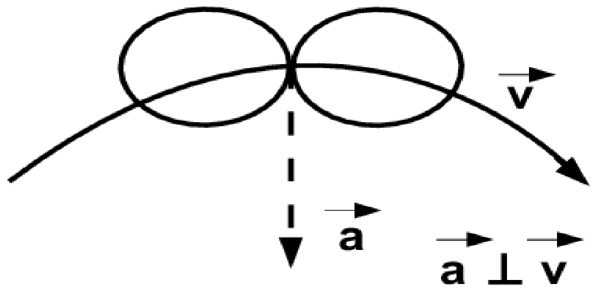
$$\nu = 1/T$$

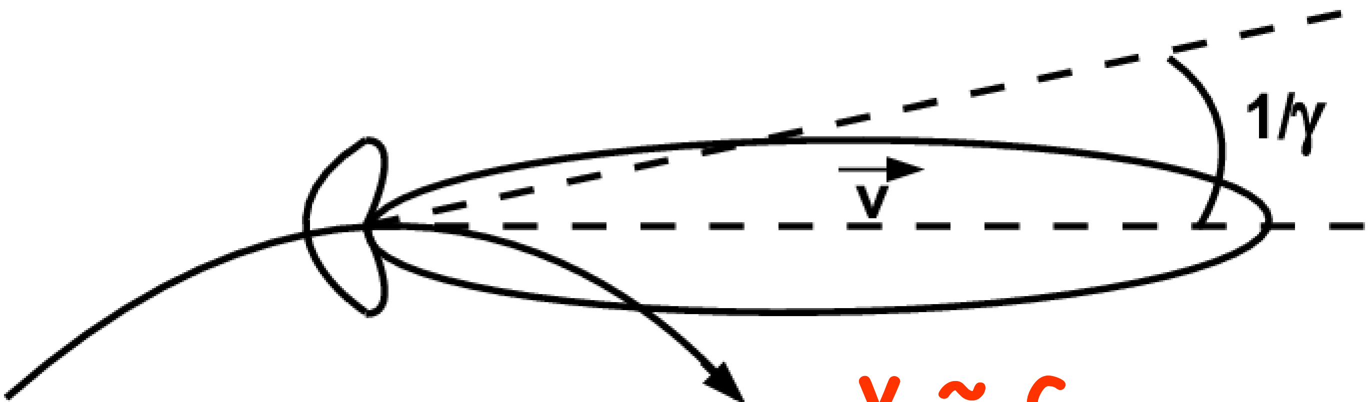
$$T = 2\pi\, r_L / v_\perp$$



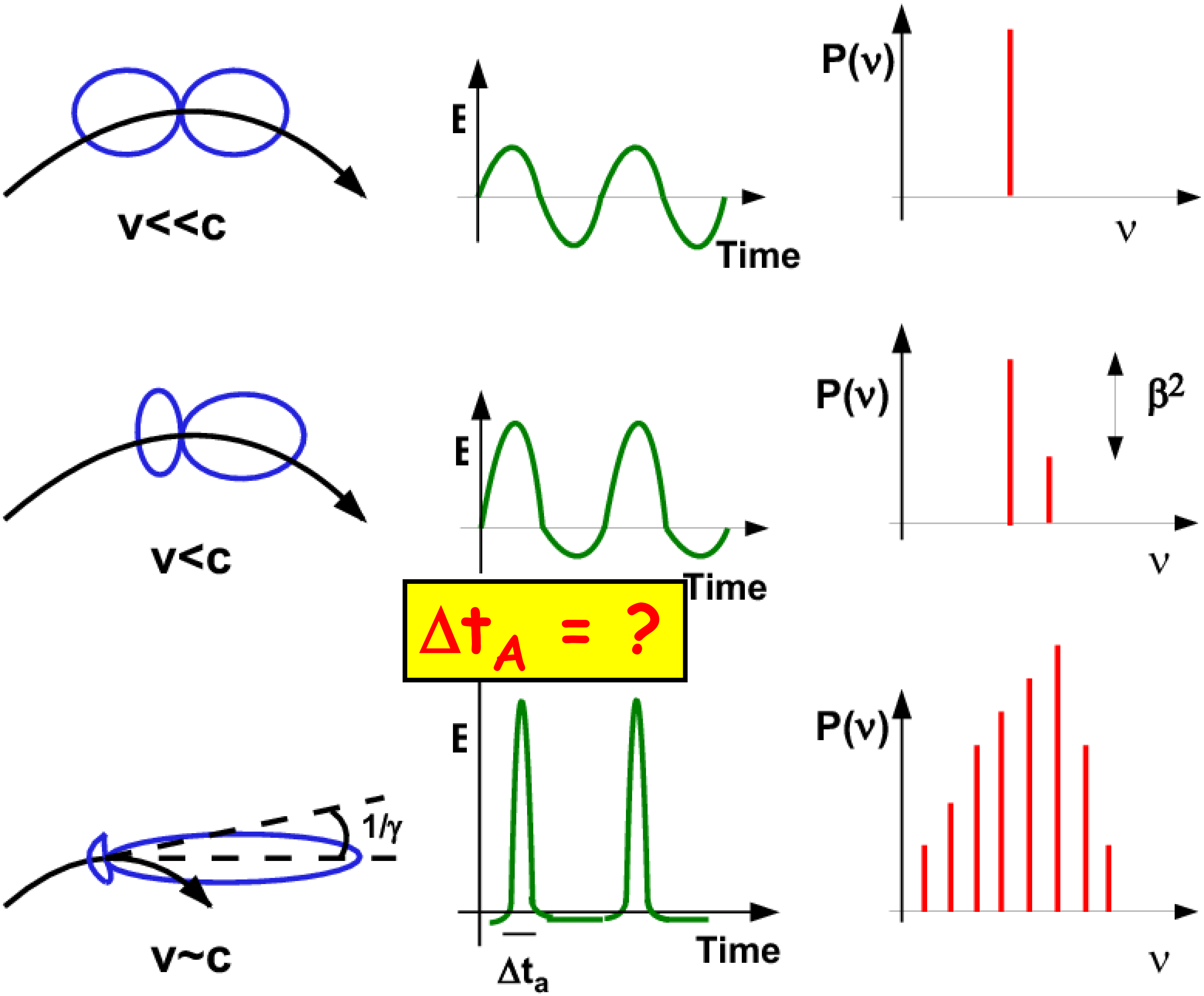
This *is not* the characteristic frequency

V<<c





V ~ c

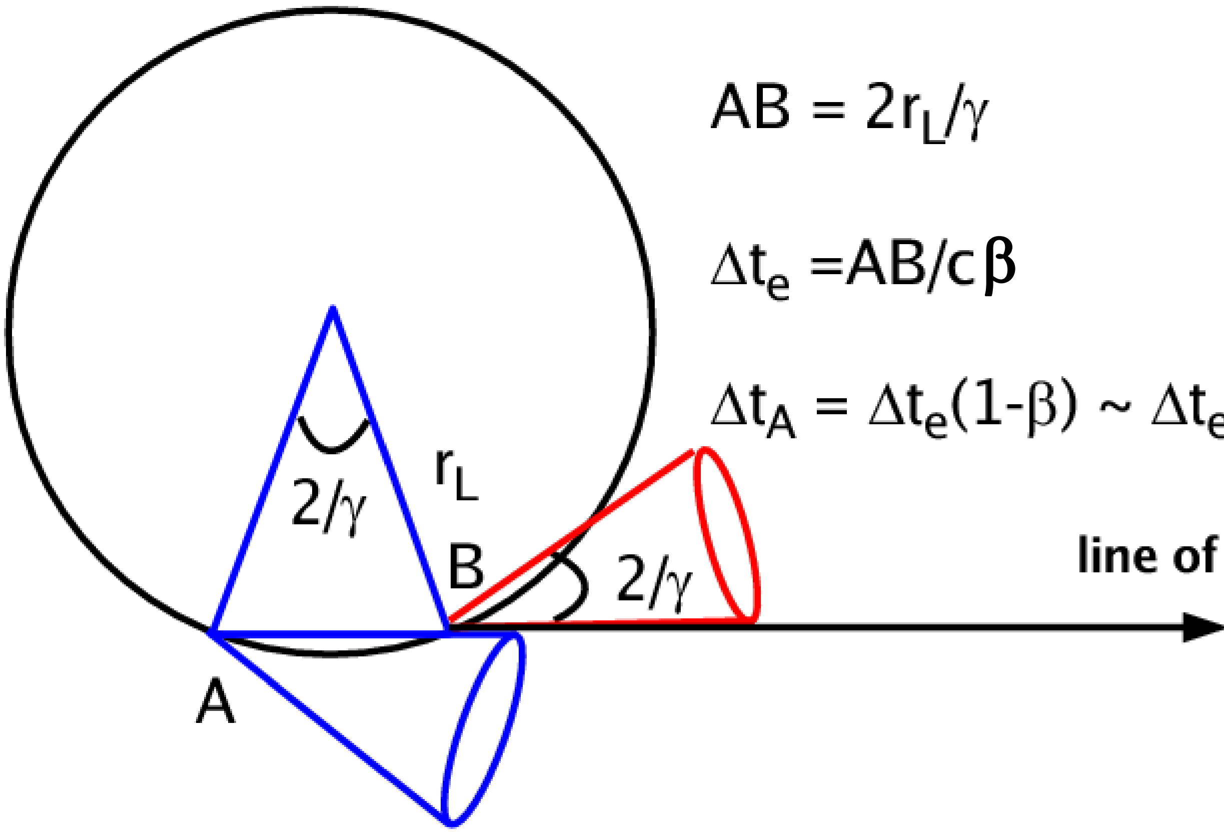


v<<c
E
Time
P(ν)
ν
v<c
E
Time
P(ν)
β²
ν
Δt_A = ?
v~c
1/γ
E
Time
Δt_a
P(ν)
ν

$$\nu_S = \frac{1}{\Delta t_A} = \gamma^2 \frac{eB}{2\pi mc}$$

Compare with ν_B.

$\nu_S = \nu_B\, \gamma^3$

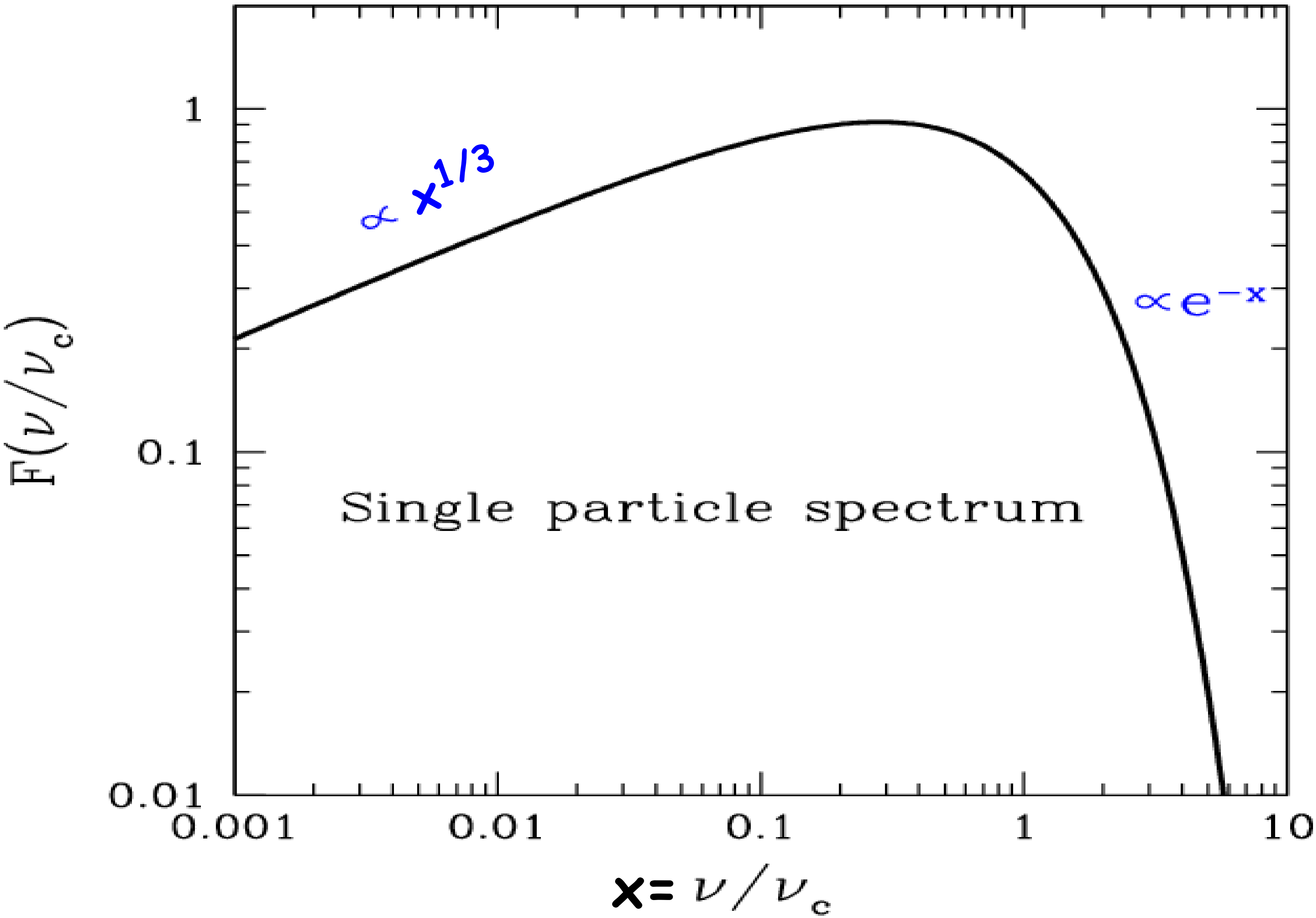


$AB = 2r_L/\gamma$

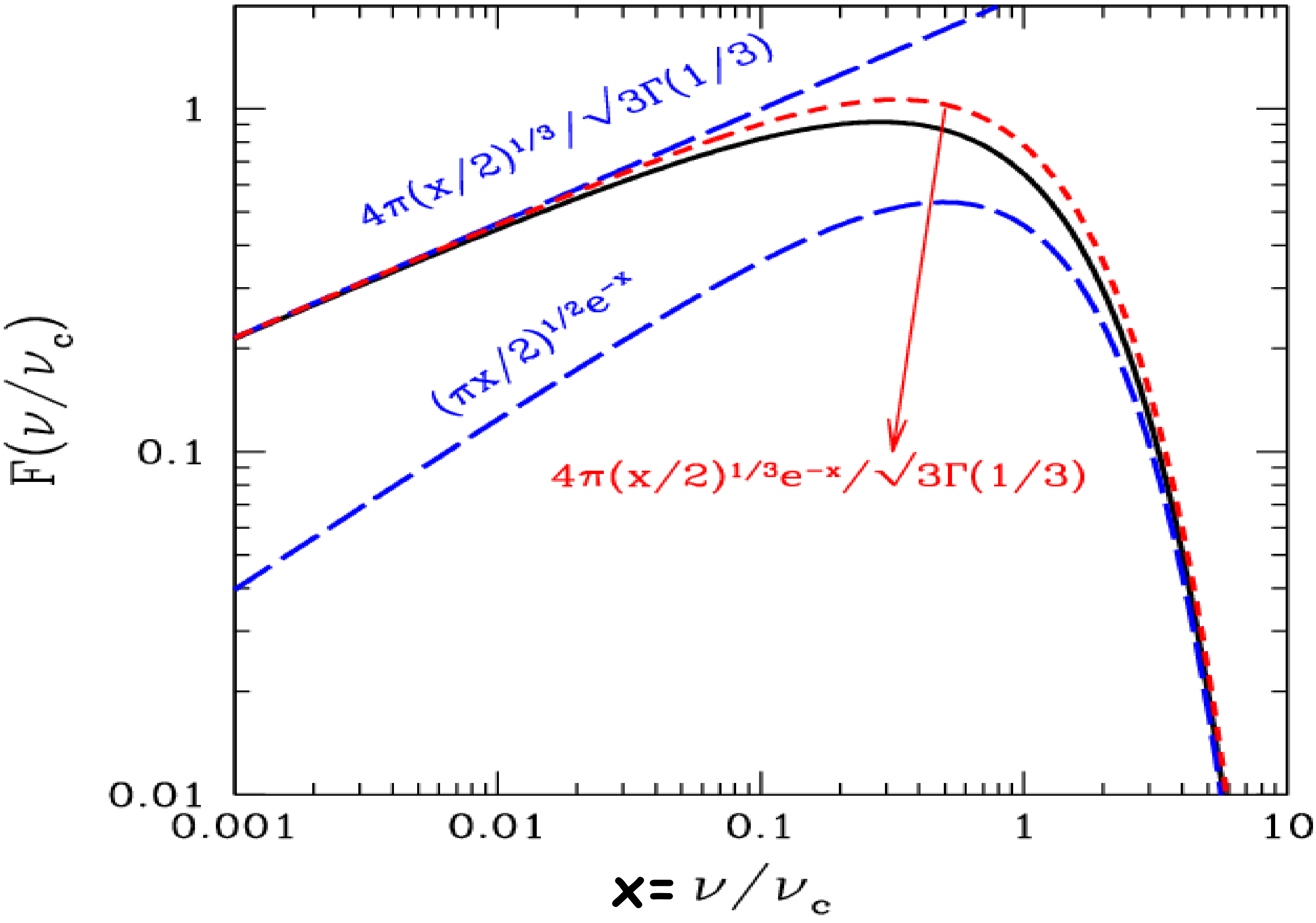
$\Delta t_e = AB/c\beta$

$\Delta t_A = \Delta t_e(1-\beta) \sim \Delta t_e/(2\gamma^2)$

The real stuff

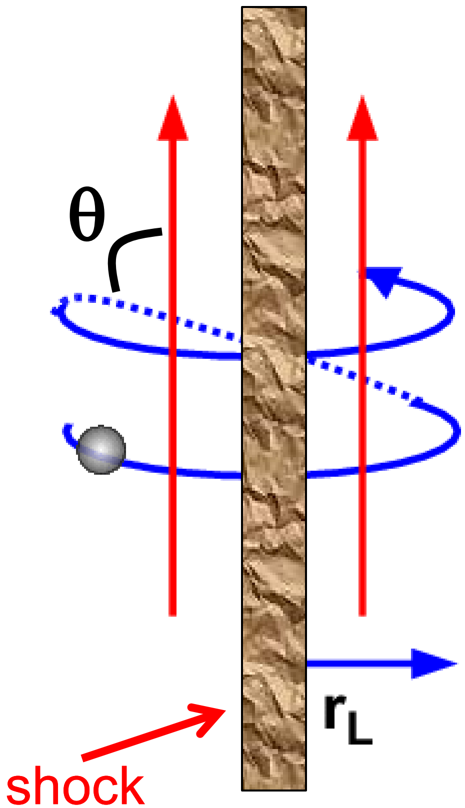


The real stuff



Max synchro frequency

Guilbert Fabian Rees 1983



$$t_{syn} = T \rightarrow \frac{6\pi\,\gamma m_e c^2}{\sigma_T B^2 \gamma^2} = \frac{2\pi\,\gamma\, m_e}{c \quad eB}$$

$$\gamma_{max} \sim \frac{1}{B^{1/2}}$$

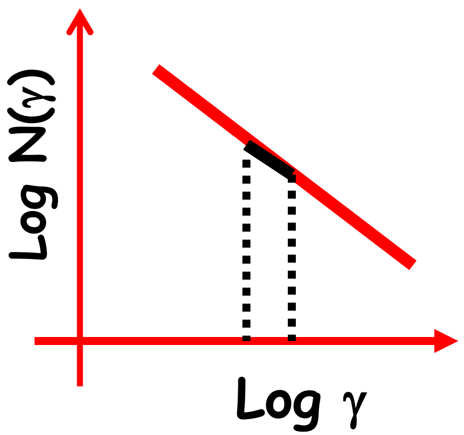
$$h\nu_{S,max} \sim B^2 \gamma_{max} = m_e c^2/\alpha_F = 70\ \mathrm{MeV}.$$

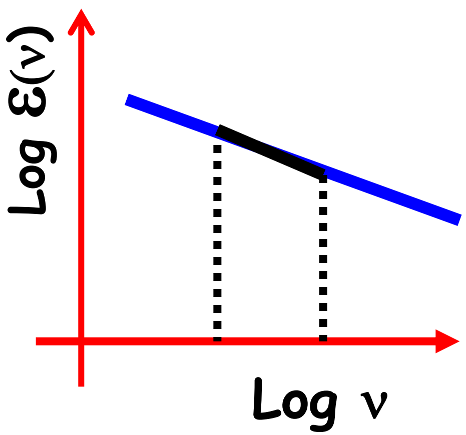
(+ beaming)

Emission from many particles

$$N(\gamma) = K\gamma^{-p}$$

The queen of relativistic distributions

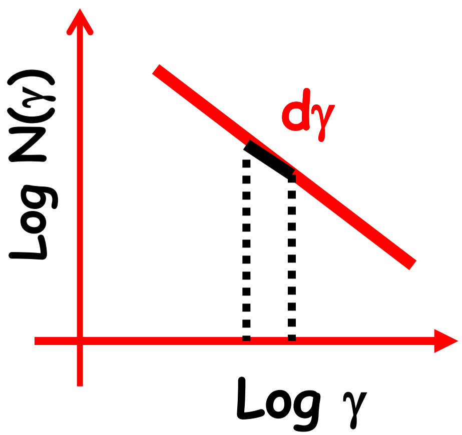


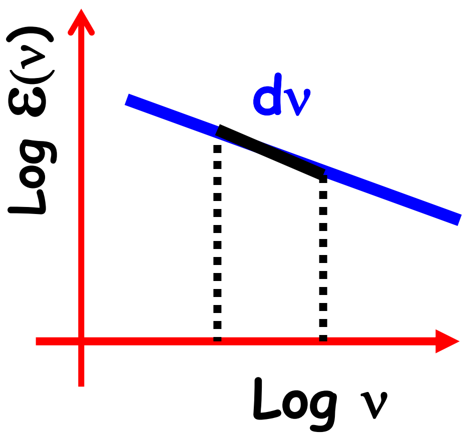


$$\varepsilon(\nu)\, d\nu = \frac{1}{4\pi} N(\gamma)\, P_S\, d\gamma$$

Emission from many particles

$N(\gamma) = K\gamma^{-p}$ The queen of relativistic distributions





$$\varepsilon(\nu) \sim \frac{1}{4\pi} K\gamma^{-p} B^2\gamma^2 \frac{d\gamma}{d\nu}$$

Emission is peaked!

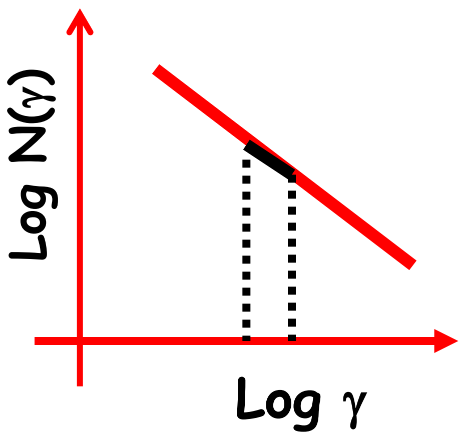
$\gamma \leftrightarrow \nu$

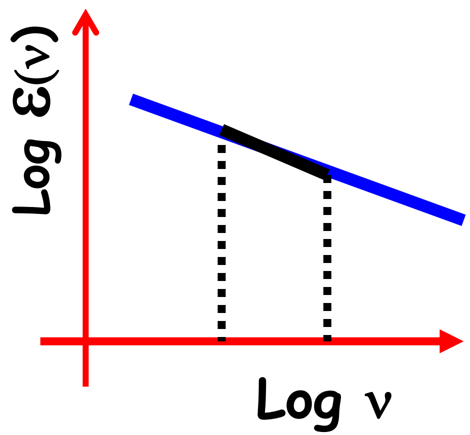
$$\nu_s = \gamma^2 \frac{eB}{2\pi mc}$$

Emission from many particles

$N(\gamma) = K\gamma^{-p}$

The queen of relativistic distributions

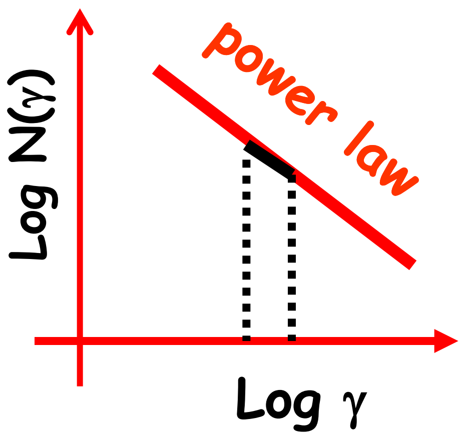


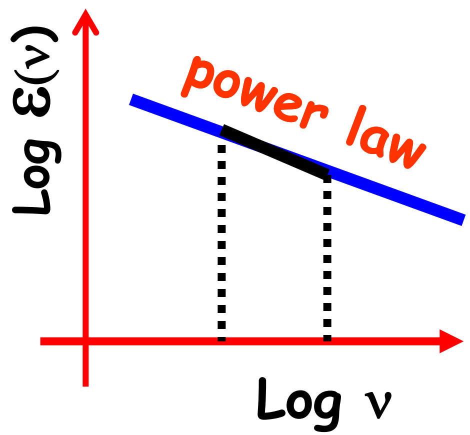


$$\varepsilon(\nu) \sim \frac{1}{4\pi} K\, B^{(1+p)/2}\, \nu^{(1-p)/2}$$

Emission from many particles

$N(\gamma) = K\gamma^{-p}$ The queen of relativistic distributions





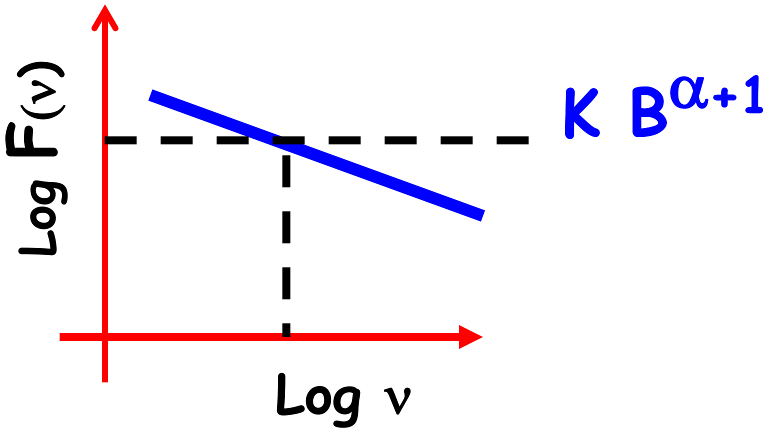
$$\varepsilon(\nu) \sim \frac{1}{4\pi} K B^{\alpha+1} \nu^{-\alpha}$$

$$\alpha = \frac{p-1}{2}$$

So, what?

$$\varepsilon(\nu) \sim \frac{1}{4\pi} K\, B^{\alpha+1}\, \nu^{-\alpha}$$

$$F(\nu) \sim \frac{4\pi \mathrm{Vol}\ \varepsilon(\nu)}{4\pi d^2} \sim \theta_s^2\, R\, K\, B^{\alpha+1}\, \nu^{-\alpha}$$



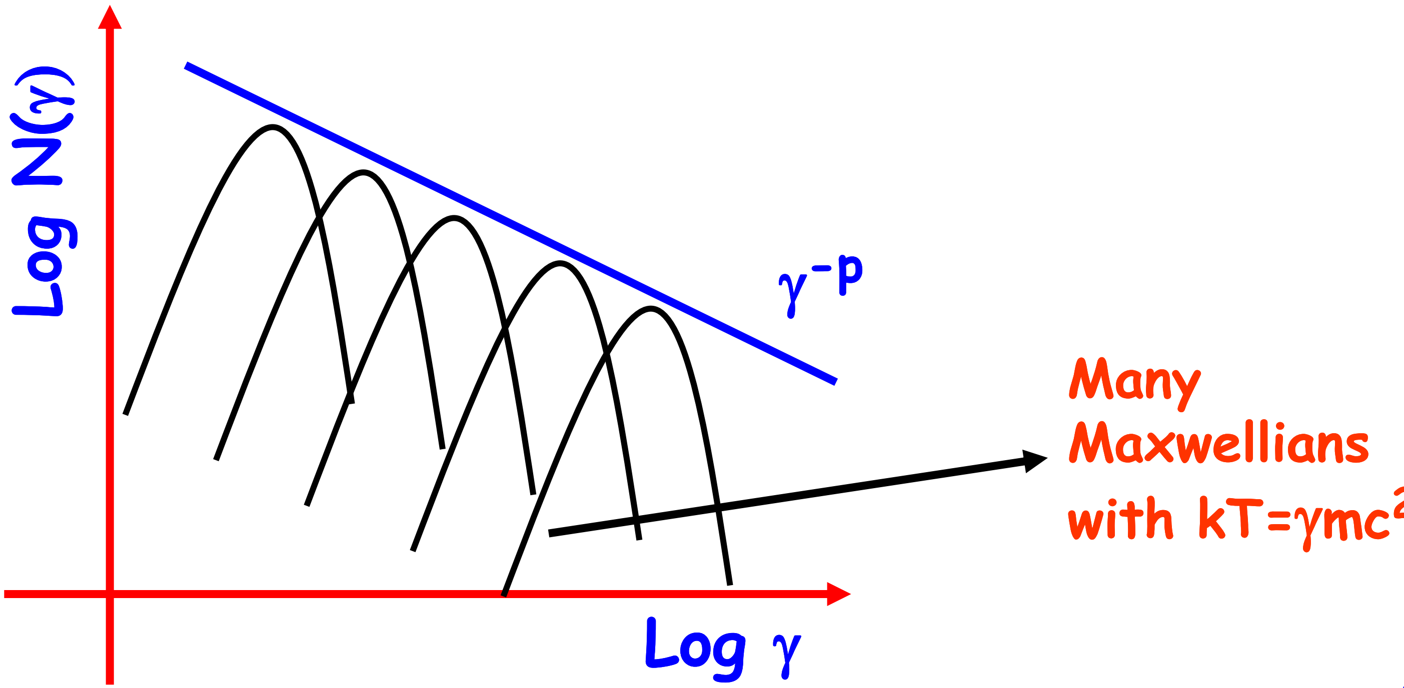
If you know θ_s and R

Two unknowns, one equation… we need another one

Synchrotron self-absorption

- If you can emit you can also absorb
- Synchrotron is no exception
- With Maxwellians it would be easy (Kirchhoff law) to get the absorption coefficient
- But with power laws?
- Help: electrons able to emit ν are also the ones that can absorb ν

A useful trick



$$I(\nu) = 2\ kT\ \nu^2/c^2$$
$$= 2\ \gamma mc^2 \nu^2/c^2$$
$$\sim \frac{\nu^{5/2}}{B^{1/2}}$$

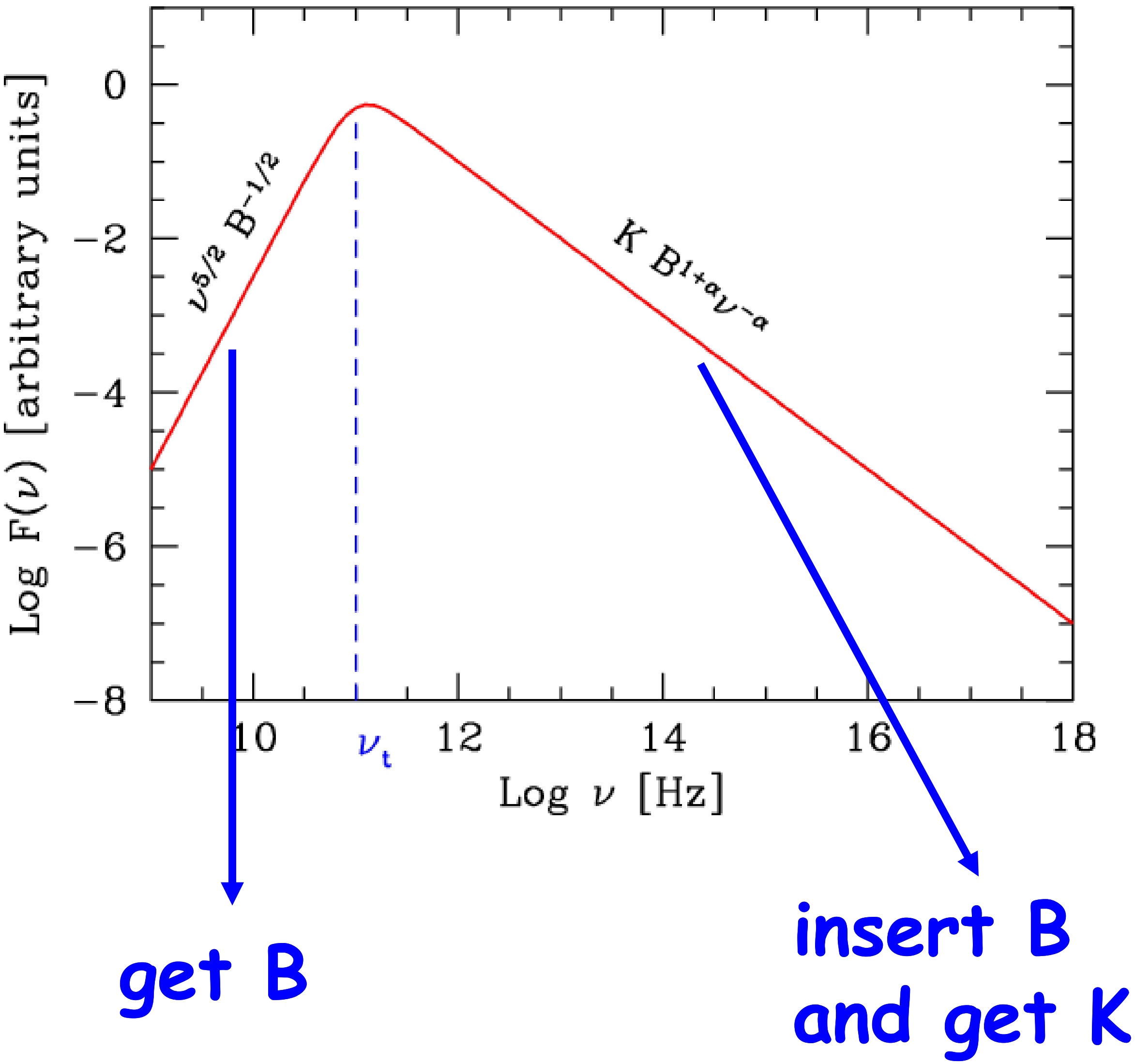
$$\nu = \gamma^2 \frac{eB}{2\pi mc}$$

⬇

$$\gamma \sim (\nu/B)^{1/2}$$

There is no K !

From data to physical parameters



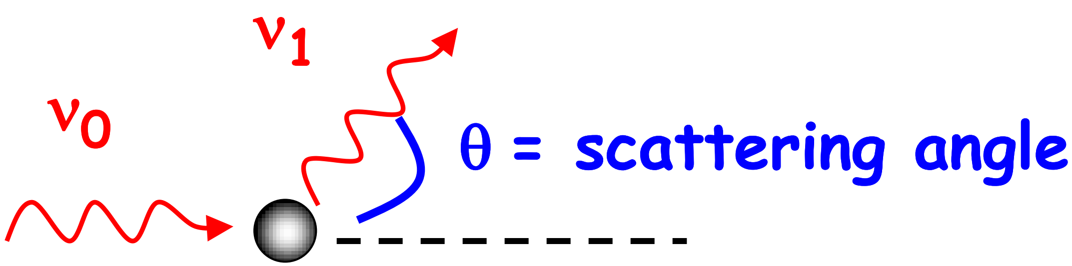
ν_t belongs to thick and thin part. Then in principle one observation is enough

Inverse Compton

Inverse Compton

- Scattering is one the basic interactions between matter and radiation.
- At low photon frequencies it is a classical process (i.e. *e.m. waves*)
- At low frequencies the cross section is called the Thomson cross section, and it is a peanut.
- At high energies the electron recoils, and the cross section is the Klein-Nishina one.

Thomson scattering



- $h\nu_0 << m_e c^2$
- tennis ball against a wall
- The wall doesn't move
- The ball bounces back with the same speed (if it is elastic)

$$\nu_1 = \nu_0$$

Hurry up!

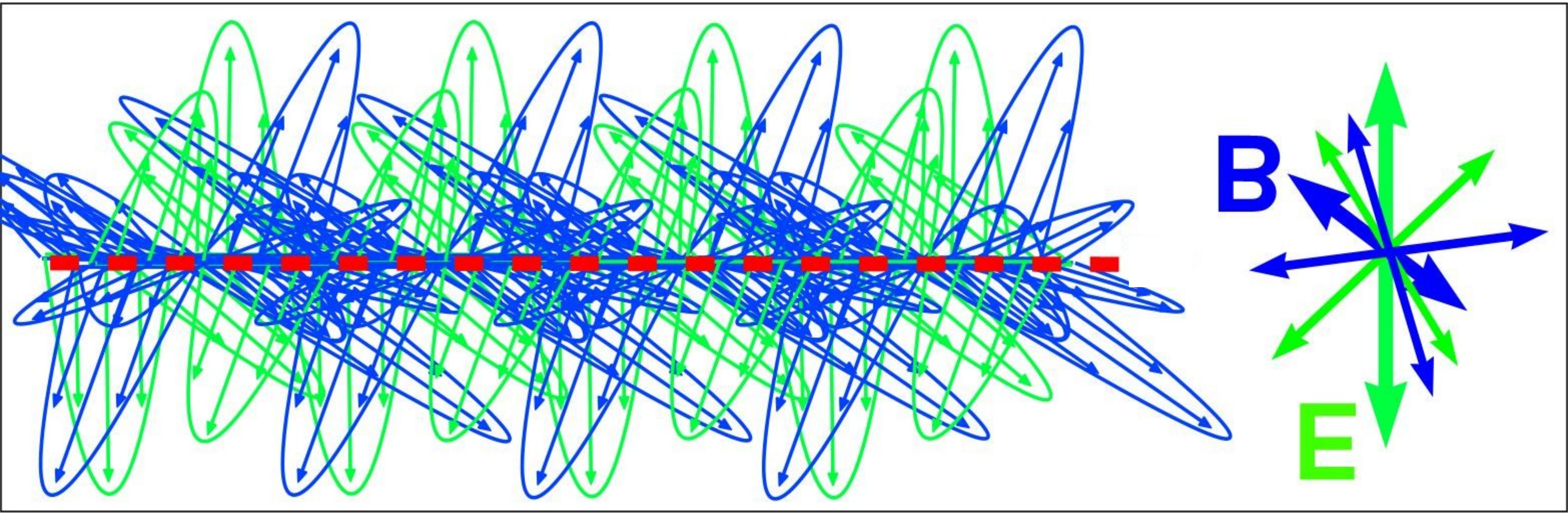
Thomson cross section

$$\frac{d\sigma_T}{d\Omega} = \frac{r_0^2}{2}(1+\cos^2\theta) \Rightarrow \text{a peanut}$$

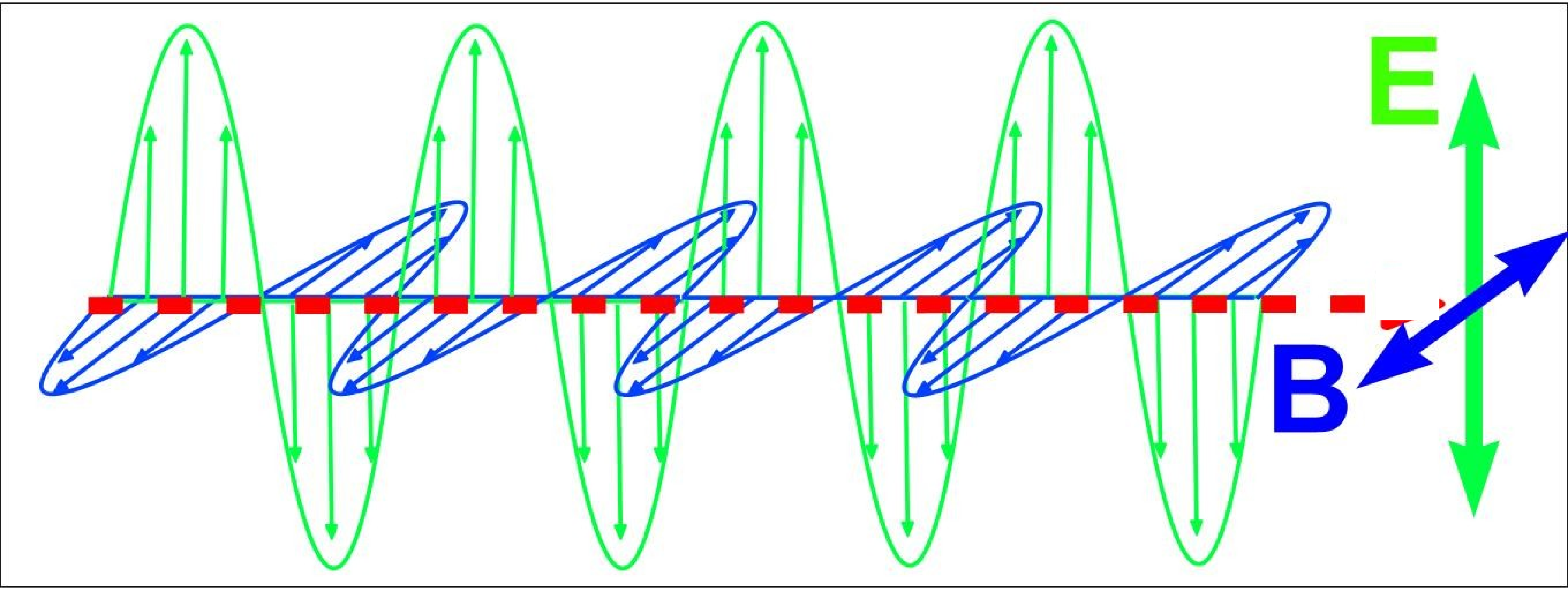
$$\sigma_T = \frac{8\pi}{3} r_0^2$$

$$r_0 = \frac{e^2}{m_e c^2}$$

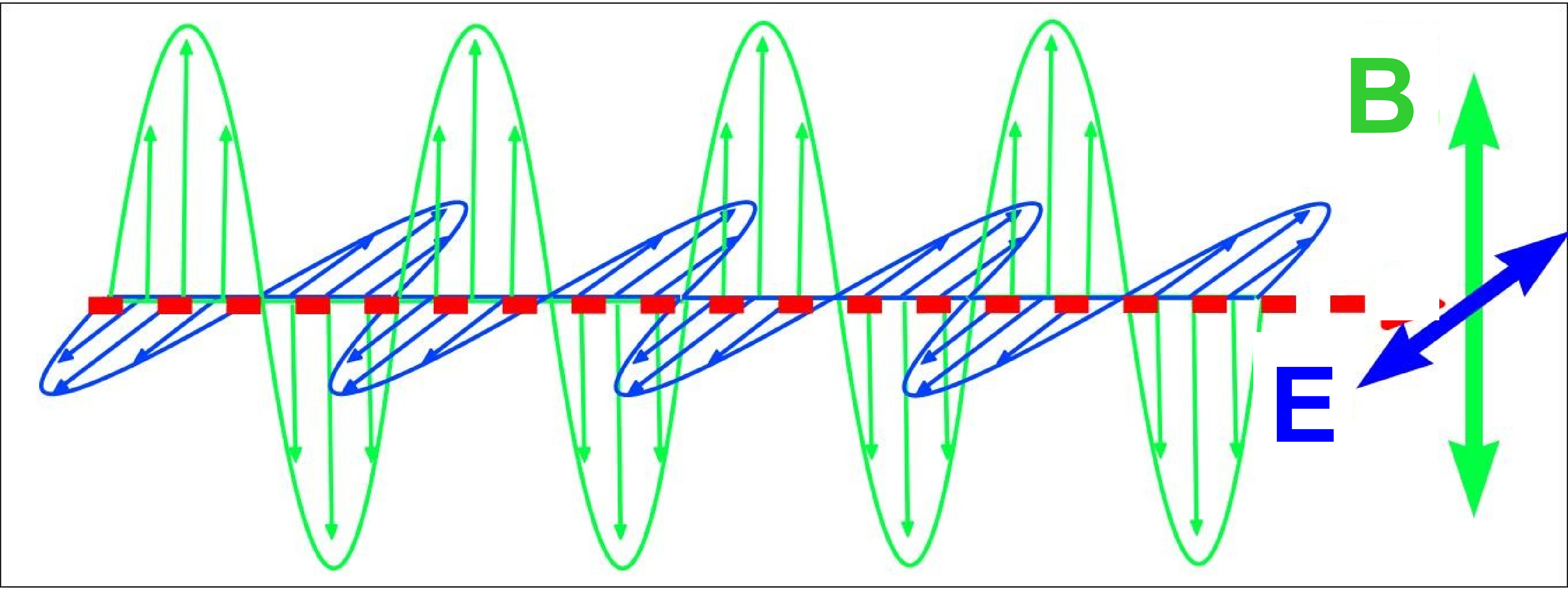
Why a peanut?



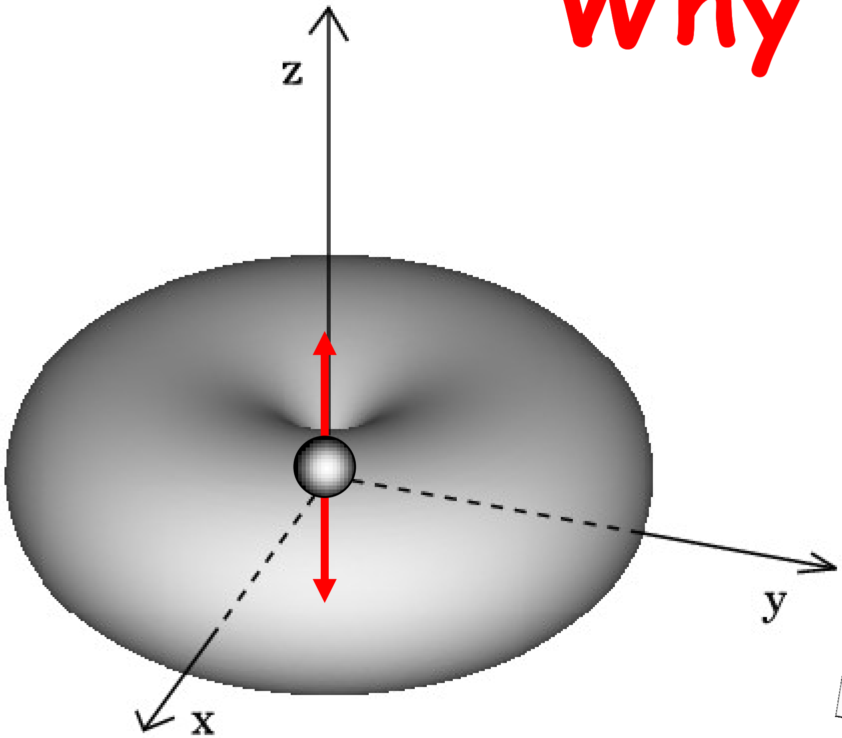
Why a peanut?

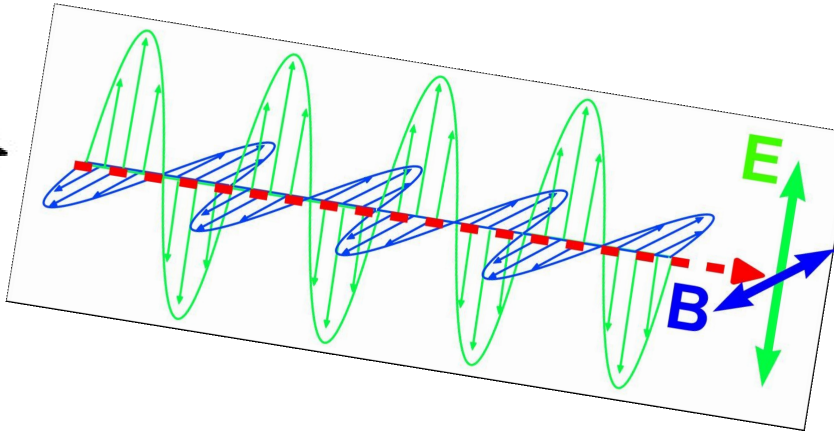


Why a peanut?

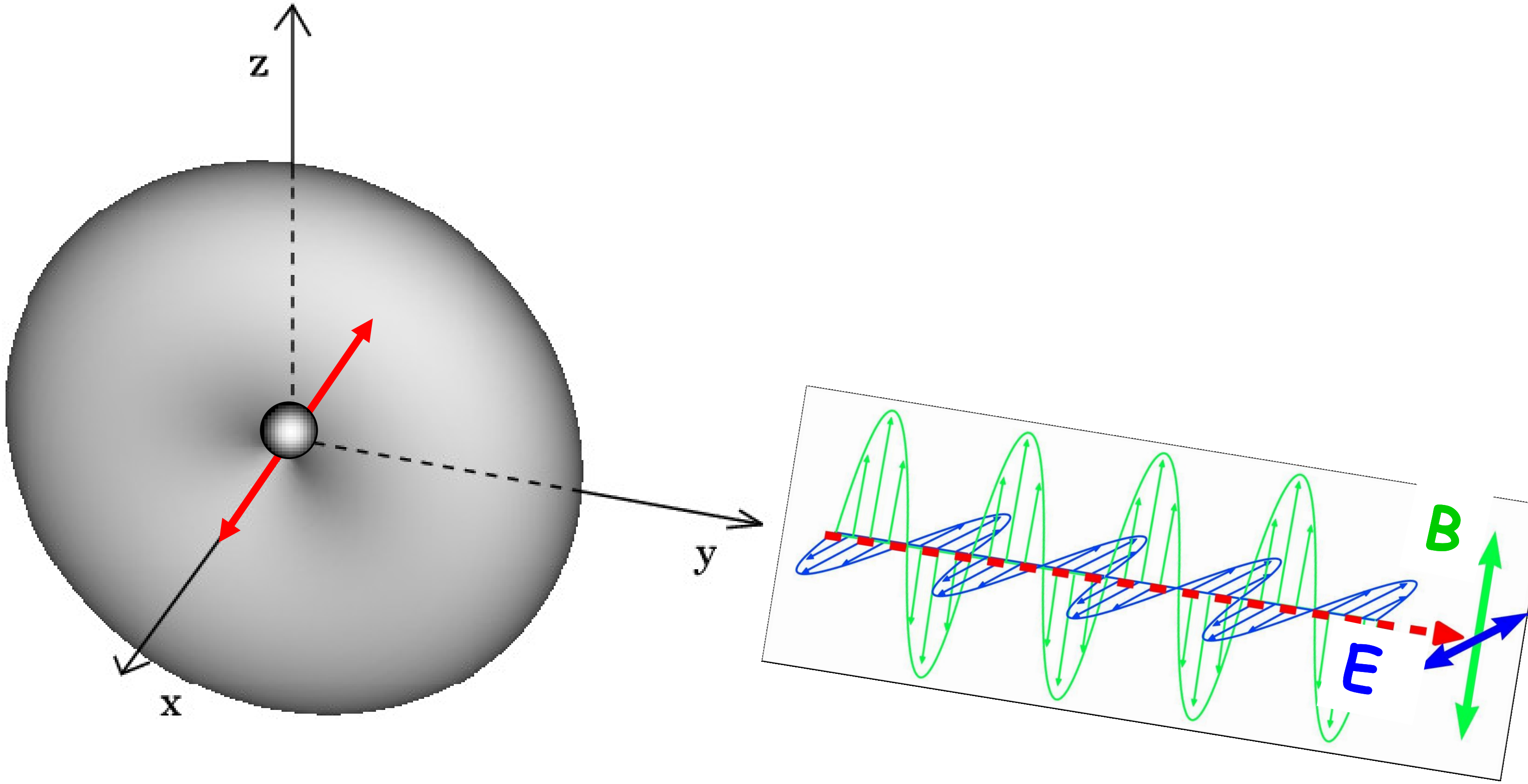


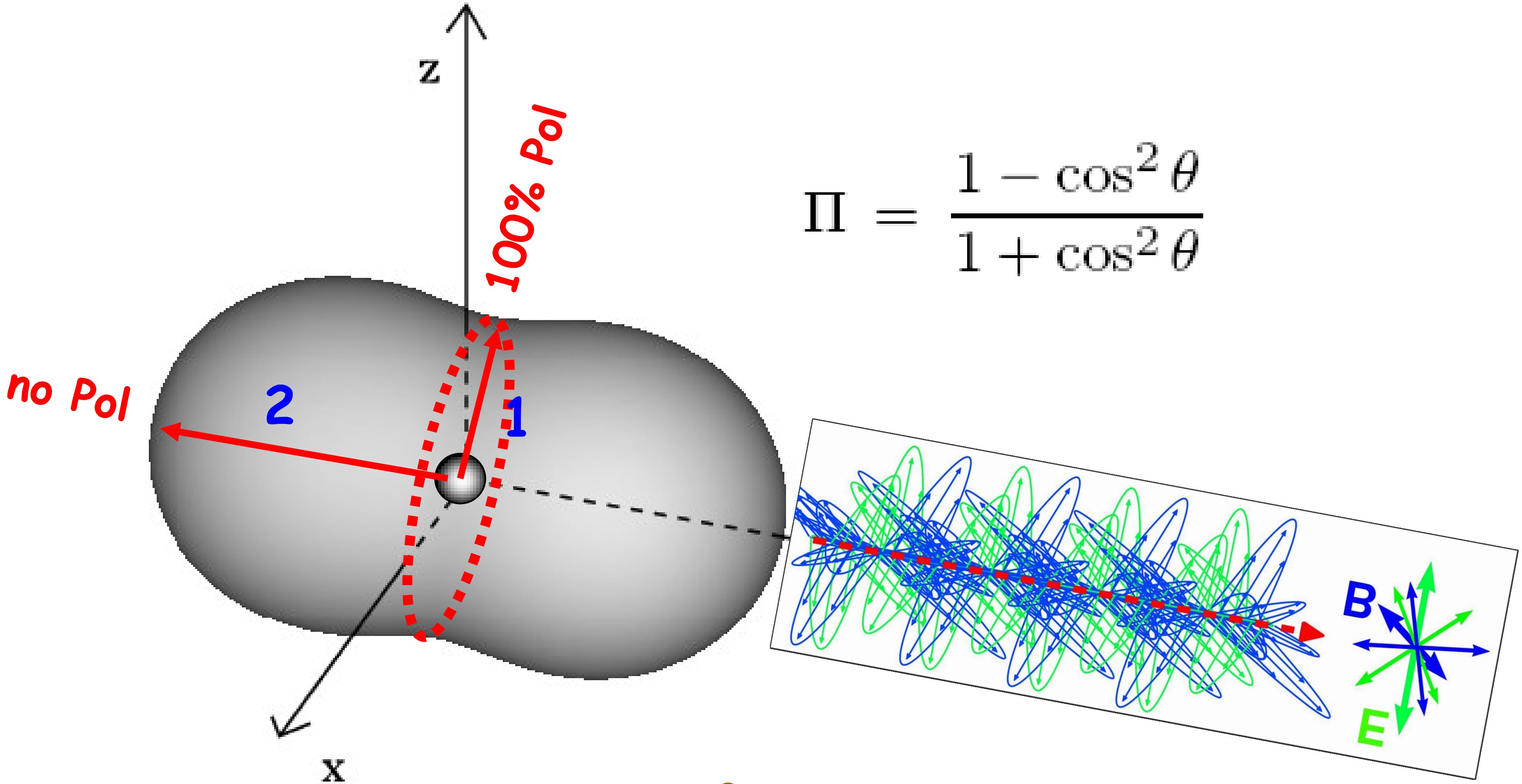
Why a peanut?





Remember: $\frac{dP}{d\Omega} = \frac{e^2 a^2}{4\pi c^3} \sin^2\Theta$

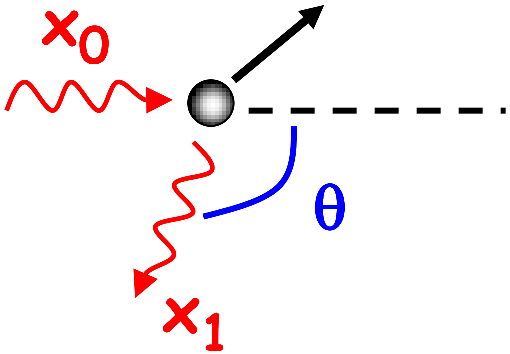

z
y
x
B
E



$$\Pi = \frac{1 - \cos^2\theta}{1 + \cos^2\theta}$$

$$\frac{d\sigma_T}{d\Omega} = \frac{r_0^2}{2}(1+\cos^2\theta)$$

Direct Compton



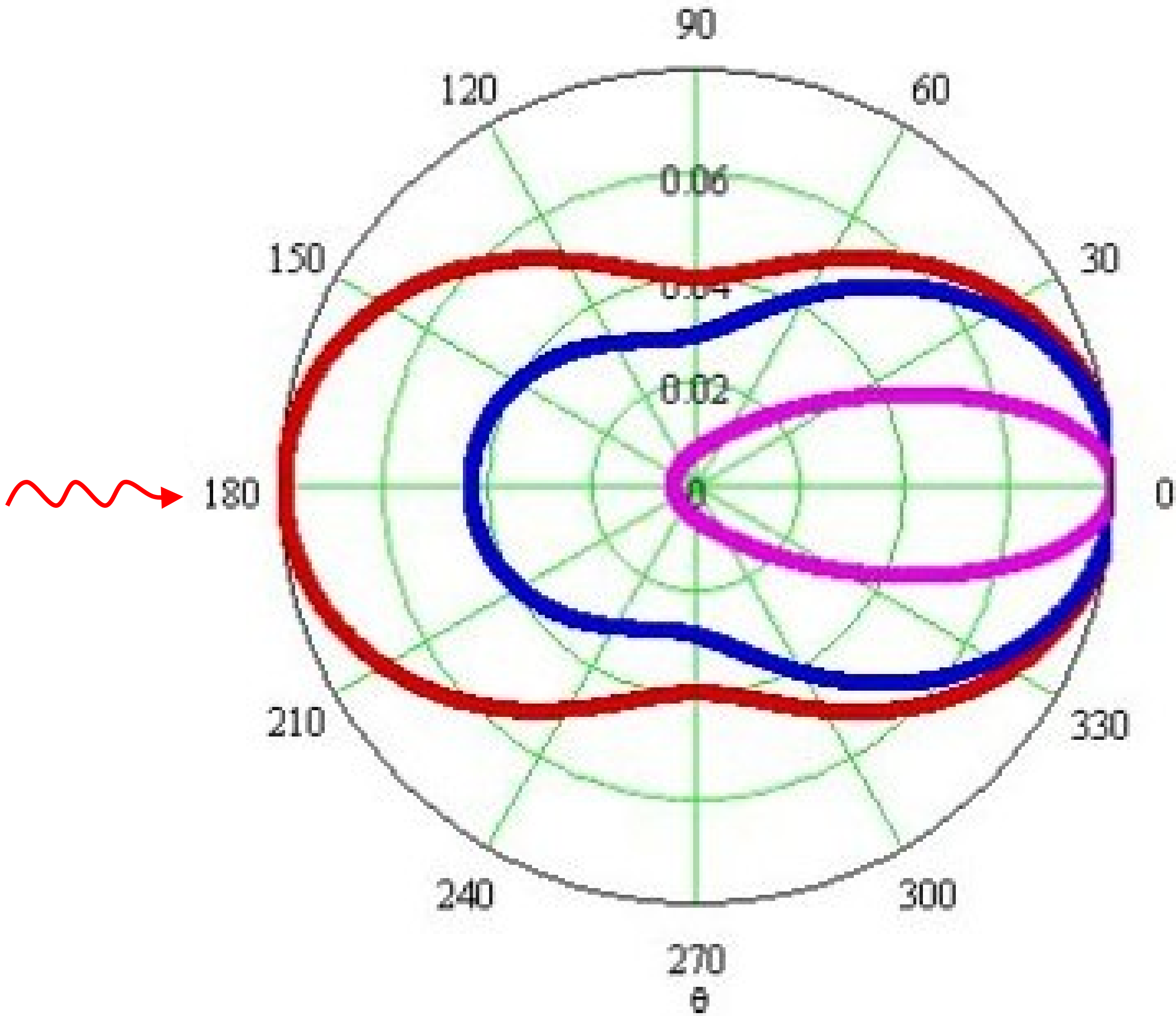
$$x = \frac{h\nu}{m_e c^2}$$

$$x_1 = \frac{x_0}{1 + x_0(1 - \cos\theta)}$$

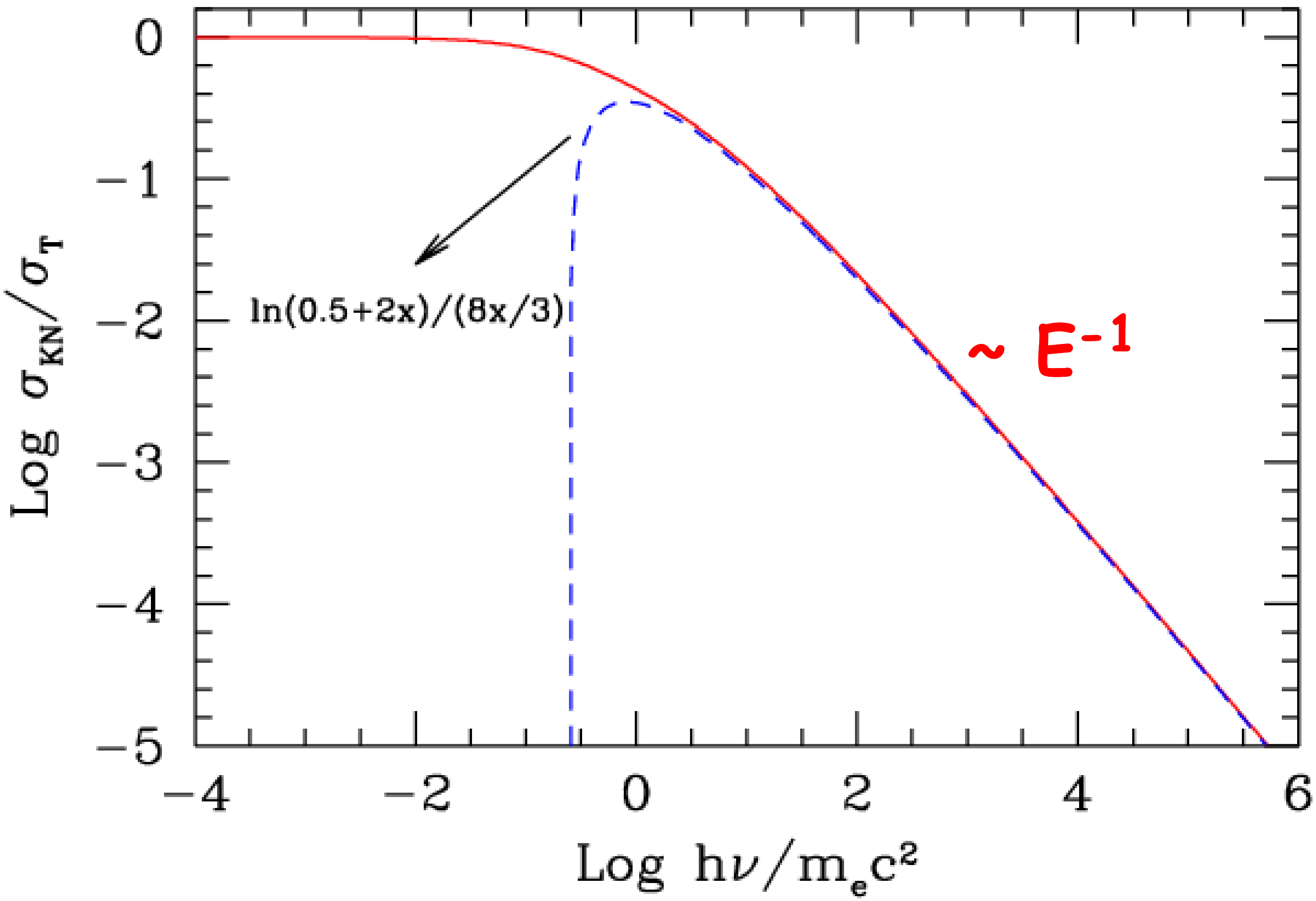
Klein-Nishina cross section

$$\sigma_{\mathrm{KN}} = \frac{3}{4}\sigma_{\mathrm{T}} \left\{ \frac{1+x}{x^3} \left[\frac{2x(1+x)}{1+2x} - \ln(1+2x) \right] + \frac{1}{2x}\ln(1+2x) - \frac{1+3x}{(1+2x)^2} \right\}$$

Klein-Nishina cross section

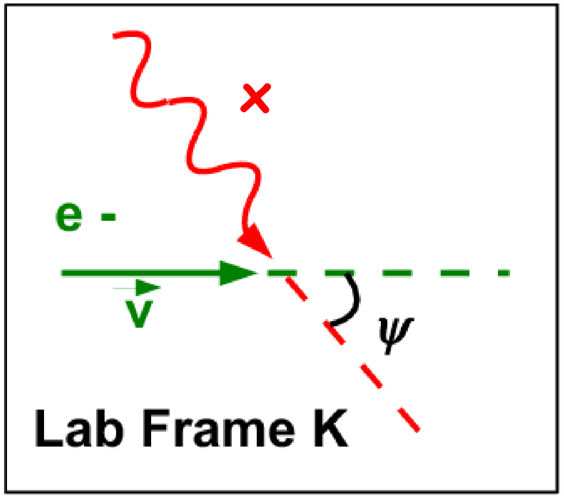


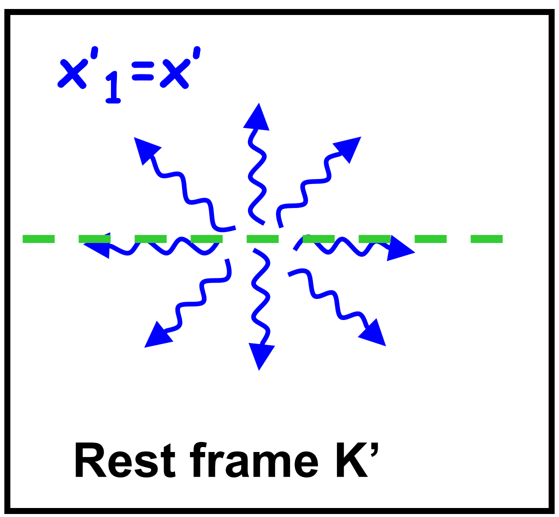
Klein-Nishina cross section

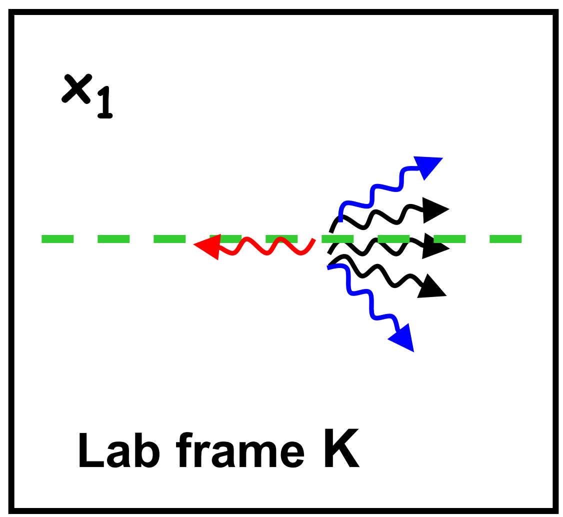


Inverse Compton: typical frequencies

Thomson regime







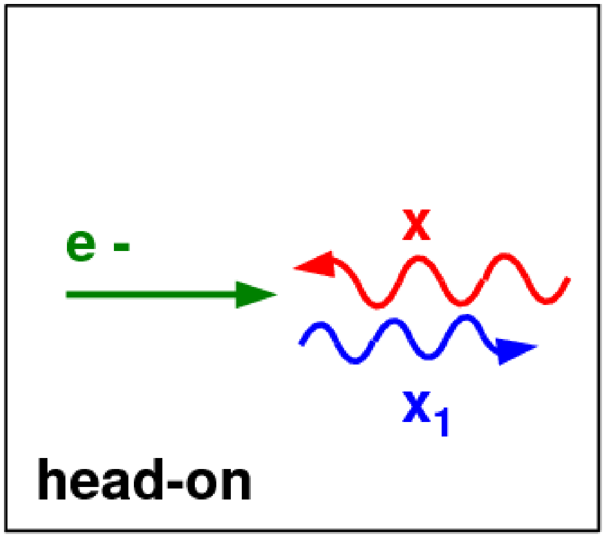
$$x_1 = x'_1\gamma(1+\beta\cos\psi'_1)$$

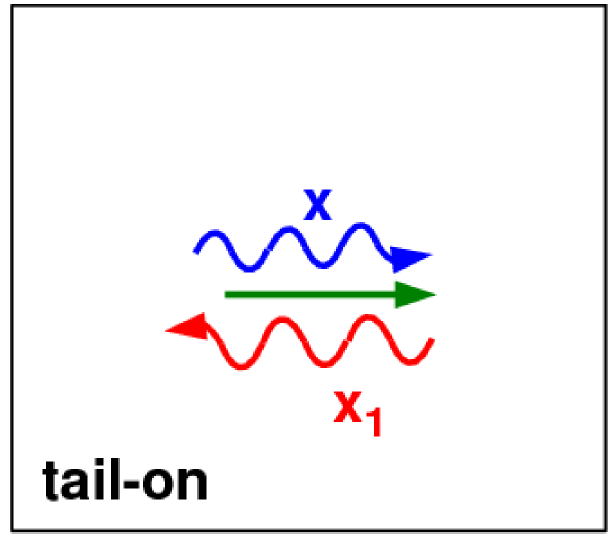
$$\cos\psi'_1 = \frac{\beta+\cos\psi_1}{1+\beta\cos\psi_1}$$

$$x_1 = x\,\frac{1-\beta\cos\psi}{1-\beta\cos\psi_1}$$

Min and max frequencies

$$x_1 = x \frac{1 - \beta \cos\psi}{1 - \beta \cos\psi_1}$$





$\psi = 180^o$

$\psi_1 = 0^o$

$x_1 = 4\gamma^2 x$

$\psi = 0^o$

$\psi_1 = 180^o$

$x_1 = x/4\gamma^2$

Hurry up!

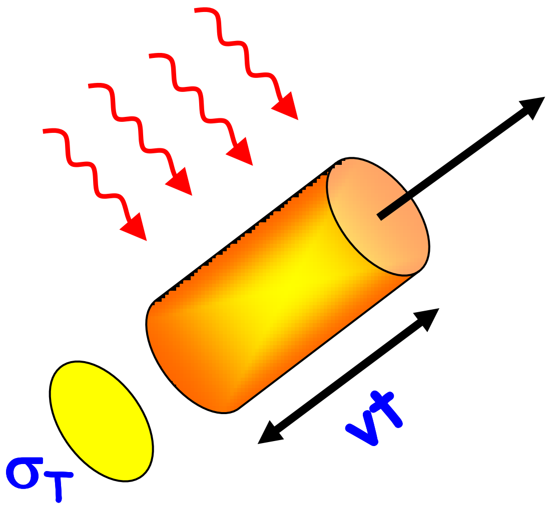
Total loss rate

Everything in the lab frame

$n(\varepsilon)$ = density of seed photons of energy $\varepsilon = h\nu$

v_{rel} = "relative velocity" between photon and electron

$v_{rel} = c - v\cos\psi = c(1-\beta\cos\psi)$

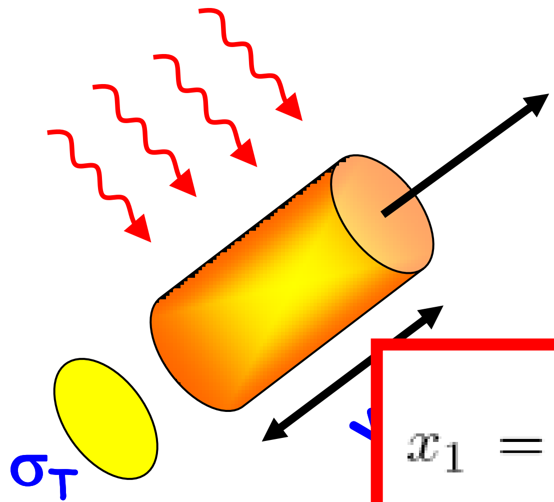


$$\frac{dN}{dt} = \int \sigma_T v_{rel} n(\epsilon) d\epsilon$$

$$\frac{dN}{dt} = \int \sigma_T c(1 - \beta\cos\psi) n(\epsilon) d\epsilon$$

Hurry up!

Total loss rate



$$\frac{dN}{dt} = \int \sigma_{\rm T} v_{\rm rel} n(\epsilon) d\epsilon$$

$$\ldots \sigma_{\rm T} c(1 - \beta\cos\psi) n(\epsilon) d\epsilon$$

$$x_1 = x \frac{1 - \beta\cos\psi}{1 - \beta\cos\psi_1}$$

$$\frac{dE_\gamma}{dt} = \frac{\epsilon_1 dN}{dt} = \sigma_{\rm T} c \int \frac{(1 - \beta\cos\psi)^2}{1 - \beta\cos\psi_1} \epsilon n(\epsilon) d\epsilon$$

There are many ε_1, because there are many ψ_1..
We must average the term $1-\beta\cos\psi_1$, getting

$$\langle 1 - \beta\cos\psi_1 \rangle = 1/\gamma^2$$

Hurry up!

Total loss rate

$$\frac{dE_\gamma}{dt} = \frac{\epsilon_1 dN}{dt} = \sigma_{\rm T} c \int \frac{(1-\beta\cos\psi)^2}{1-\beta\cos\psi_1} \epsilon n(\epsilon) d\epsilon$$

There are many ε_1, because there are many ψ_1..
We must average the term $1-\beta\cos\psi_1$, getting

$$\langle 1-\beta\cos\psi_1 \rangle = 1/\gamma^2$$

$$\boxed{\frac{dE_\gamma}{dt} = \sigma_{\rm T} c \gamma^2 \int (1-\beta\cos\psi)^2 \underbrace{\epsilon n(\epsilon) d\epsilon}_{U_{\rm rad}}}$$

Hurry up!

Total loss rate

$$\frac{dE_\gamma}{dt} = \sigma_T c \gamma^2 \int (1 - \beta \cos\psi)^2 \epsilon n(\epsilon) d\epsilon$$

$\epsilon n(\epsilon) d\epsilon \rightarrow U_{rad}$

If seed are isotropic, average over ψ, and take out the power of the incoming radiation, to get the net electron losses:

$$\langle P_c \rangle = \frac{4}{3} \sigma_T c U_{rad} \gamma^2 \beta^2$$

Compare with synchrotron losses:

$$\langle P_S \rangle = \frac{4}{3} \sigma_T c U_B \gamma^2 \beta^2$$

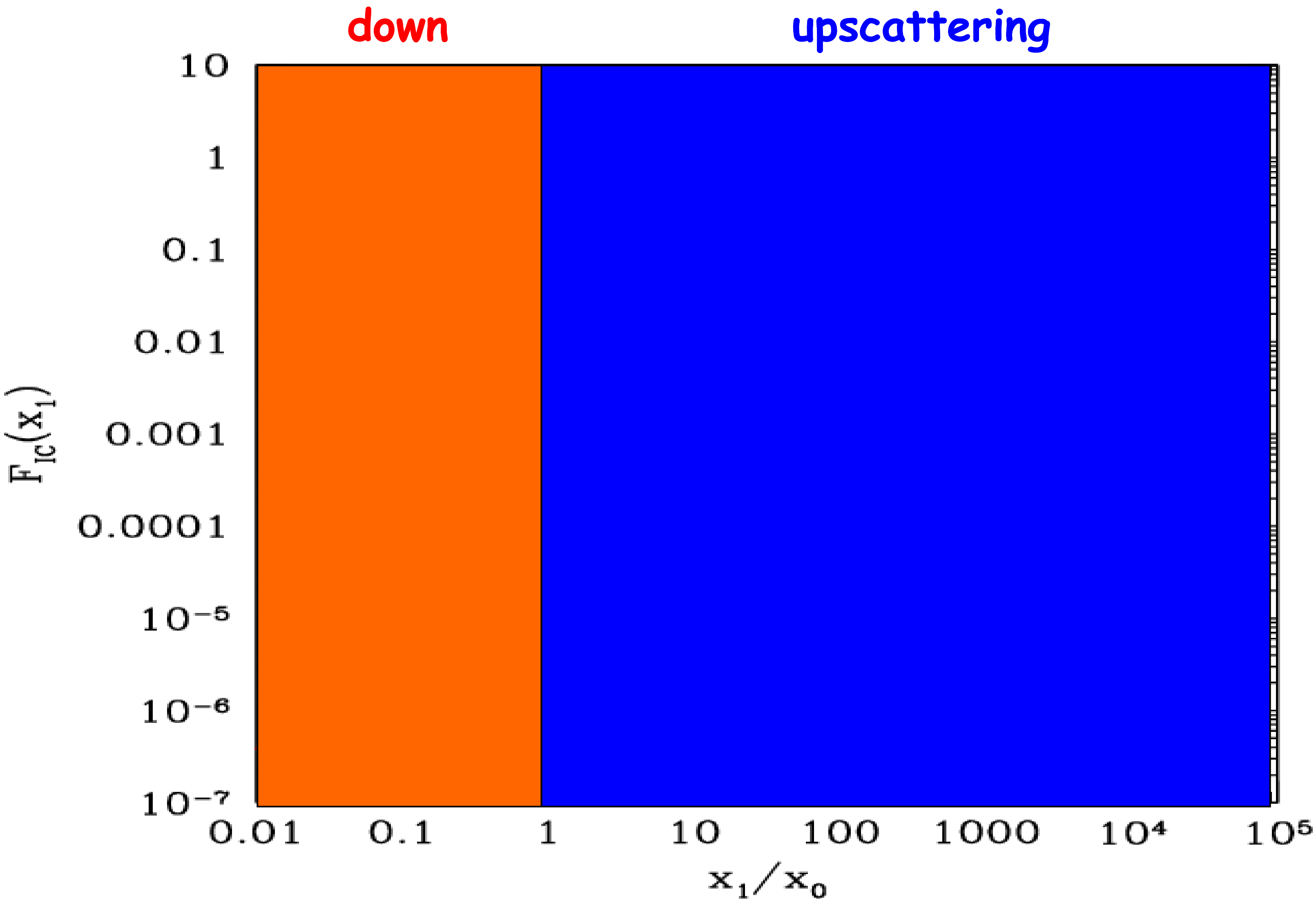
Inverse Compton spectrum

The typical frequency is:

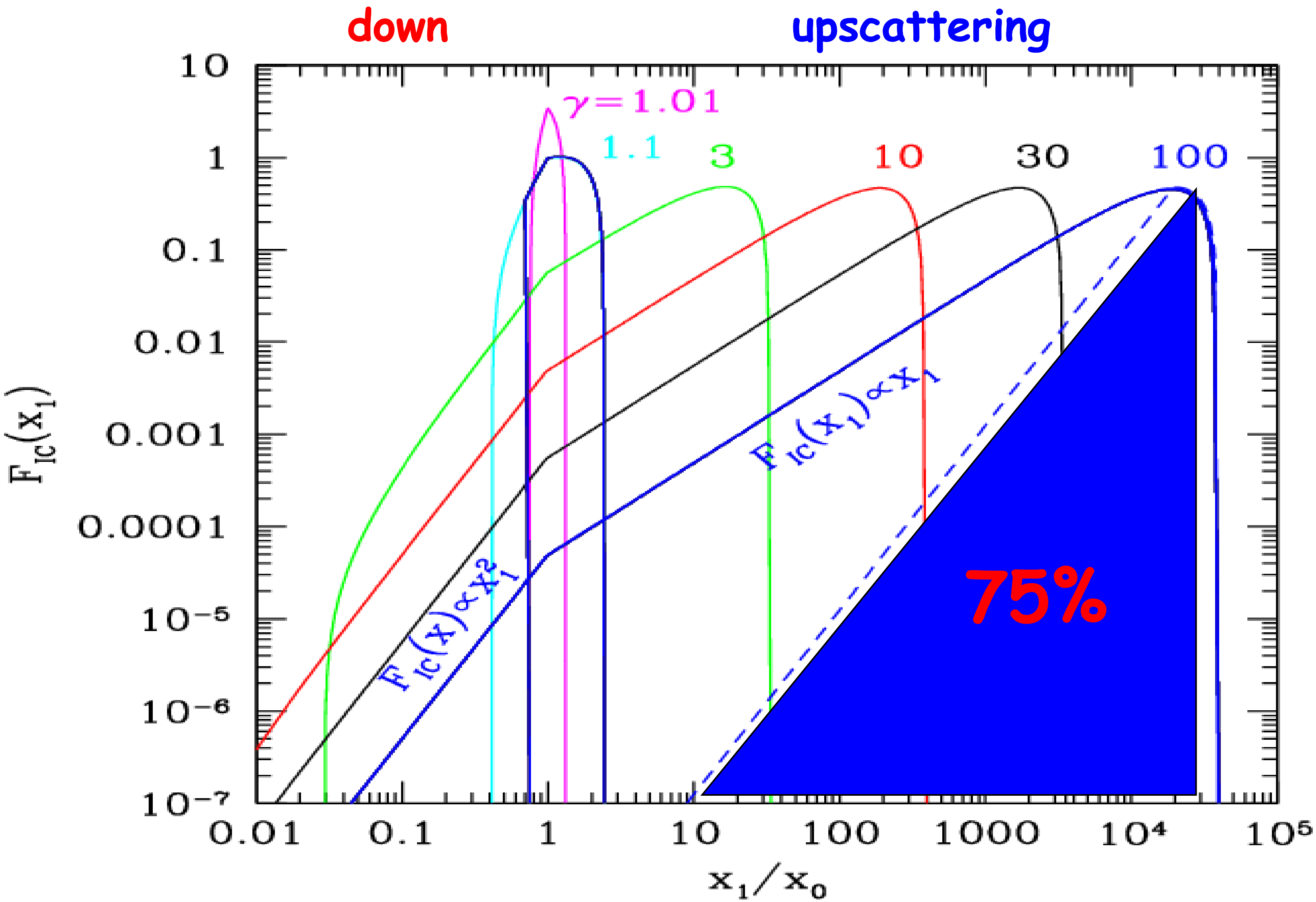
$$\nu = \gamma^2 \nu_0$$

- Going to the rest frame of the e- we see $\gamma\nu_0$
- There the scattered radiation is isotropized
- Going back to lab we add another γ-factor.

The real stuff



The real stuff

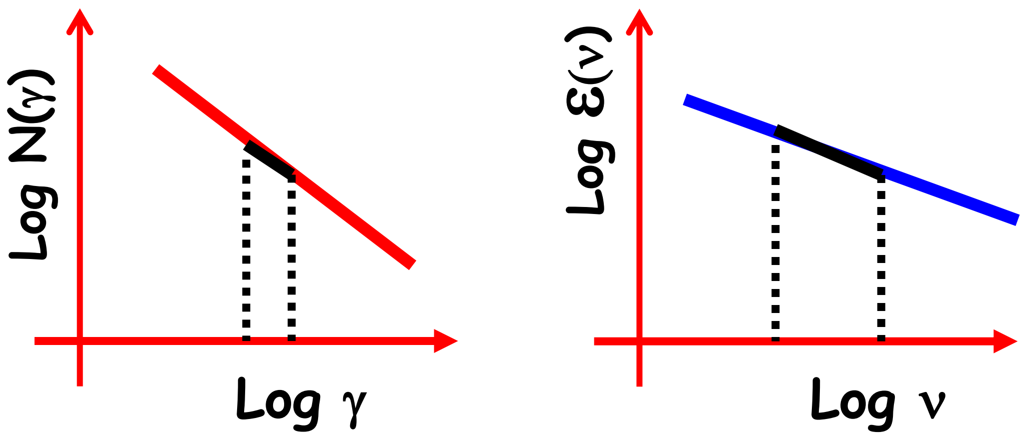


Hurry up!

Emission from many particles

$$N(\gamma) = K\gamma^{-p}$$

The queen of relativistic distributions



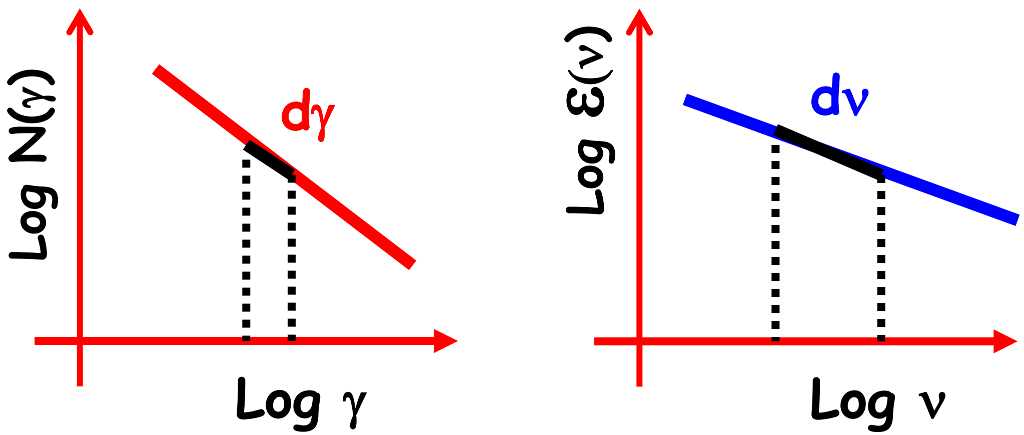
$$\varepsilon(\nu)\, d\nu = \frac{1}{4\pi} N(\gamma)\, P_C\, d\gamma$$

Hurry up!

Emission from many particles

$$N(\gamma) = K\gamma^{-p}$$

The queen of relativistic distributions



$$\varepsilon(\nu) \sim \frac{1}{4\pi} K\gamma^{-p} U_{rad}\gamma^2 \frac{d\gamma}{d\nu}$$

Emission is peaked!

$\gamma \leftrightarrow \nu$

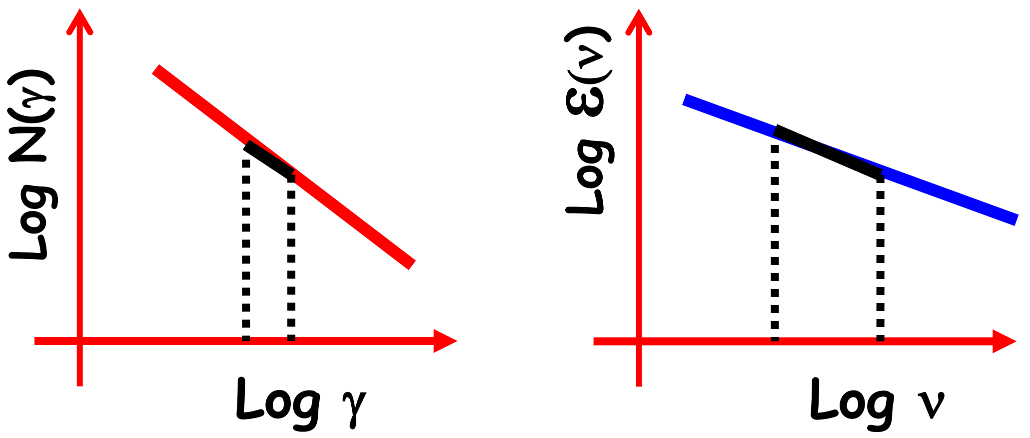
$$\nu = \frac{4}{3}\gamma^2 \nu_0$$

Hurry up!

Emission from many particles

$N(\gamma) = K\gamma^{-p}$

The queen of relativistic distributions

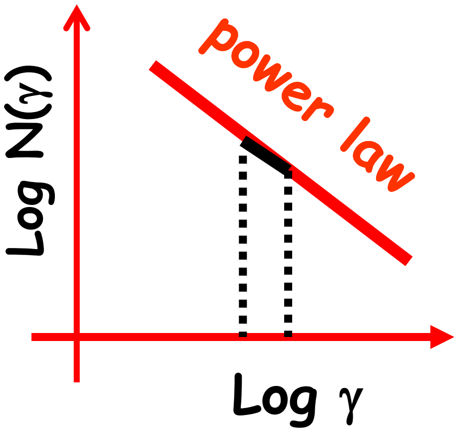


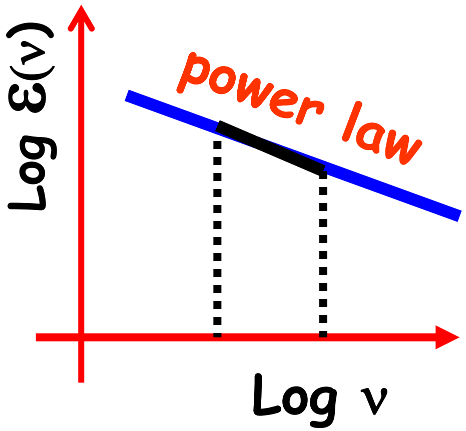
$$\varepsilon(\nu) \sim \frac{1}{4\pi} K U_{rad}\, \nu^{(2-p)/2}\, \nu^{-1/2}$$

Hurry up!

Emission from many particles

$N(\gamma) = K\gamma^{-p}$ The queen of relativistic distributions





$$\epsilon_c(\nu_c) = \frac{1}{4\pi} \frac{(4/3)^\alpha}{2} \sigma_T c K \frac{U_r}{\nu_0} \left(\frac{\nu_c}{\nu_0}\right)^{-\alpha}$$

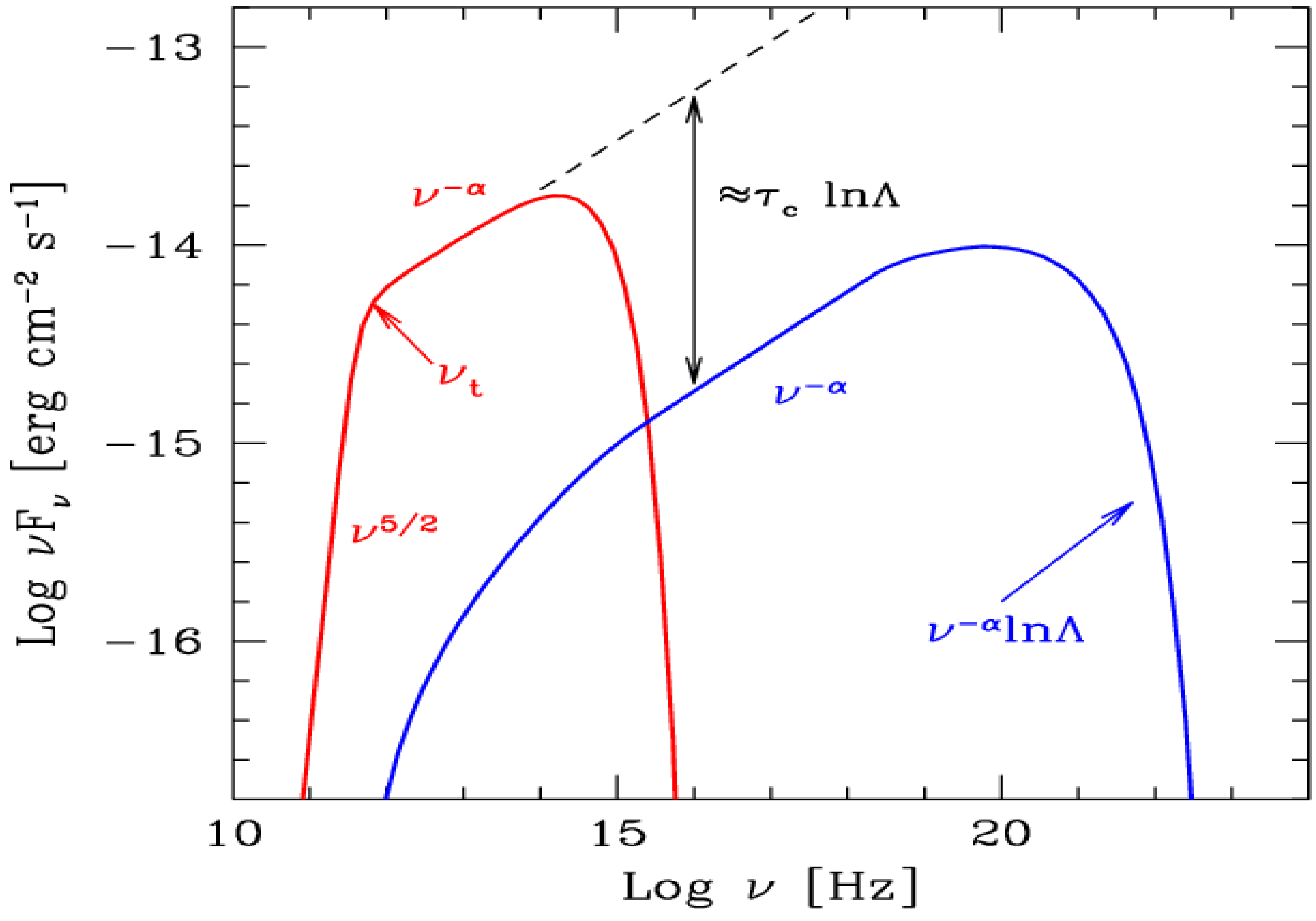
Synchrotron Self Compton: SSC

$$\epsilon_c(\nu_c) = \frac{1}{4\pi}\frac{(4/3)^\alpha}{2}\frac{\tau_c}{R/c}\nu_c^{-\alpha}\int_{\nu_{\min}}^{\nu_{\max}} \frac{\blacksquare}{\nu}\nu^\alpha d\nu$$

Due to synchro, then proportional to: $\tau_c \, B^{\alpha+1} \, \nu^{-\alpha}$

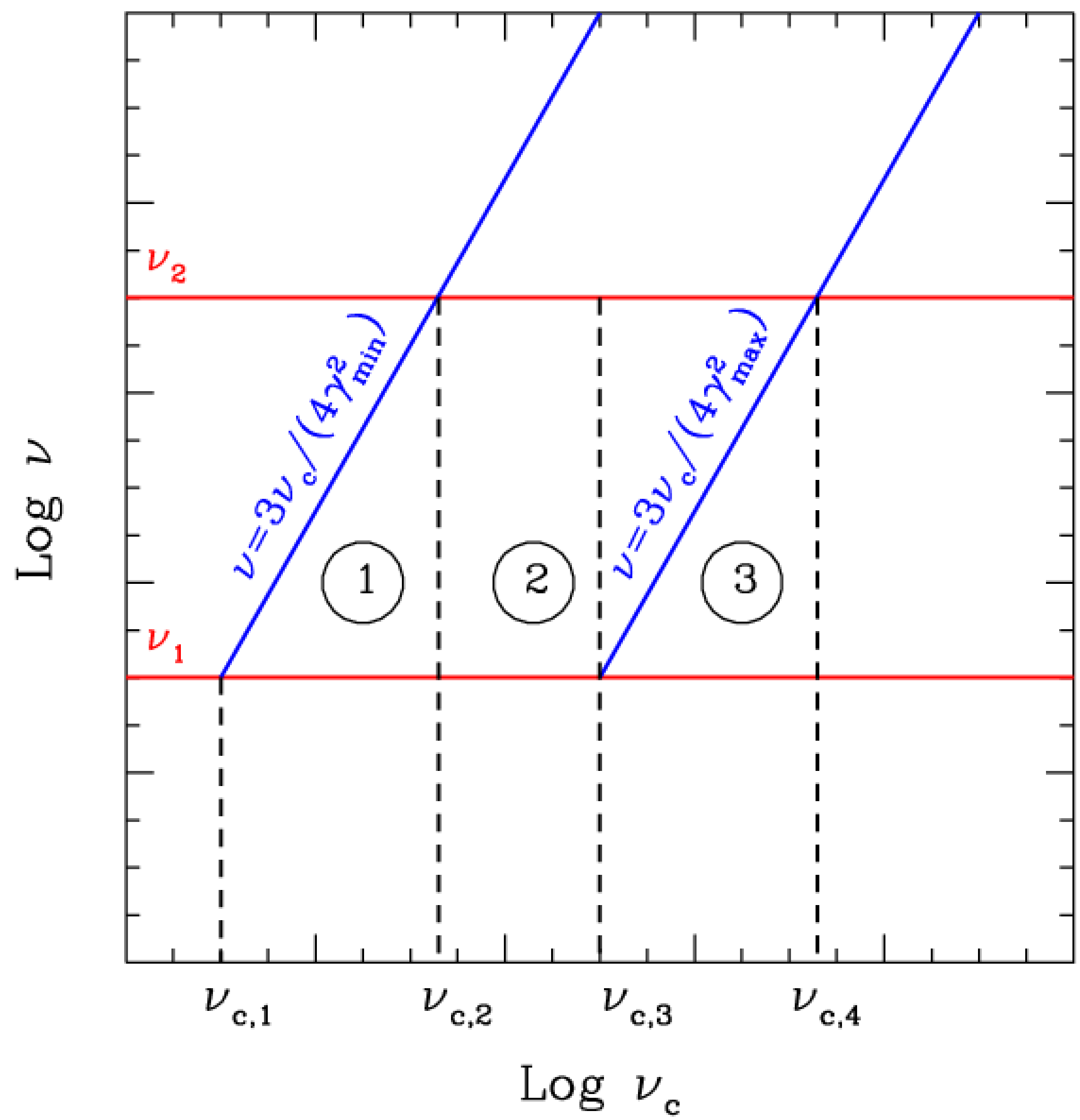
$\varepsilon_c(\nu) \sim \tau^2_c \, B^{\alpha+1} \, \nu_c^{-\alpha}$

Electrons work twice

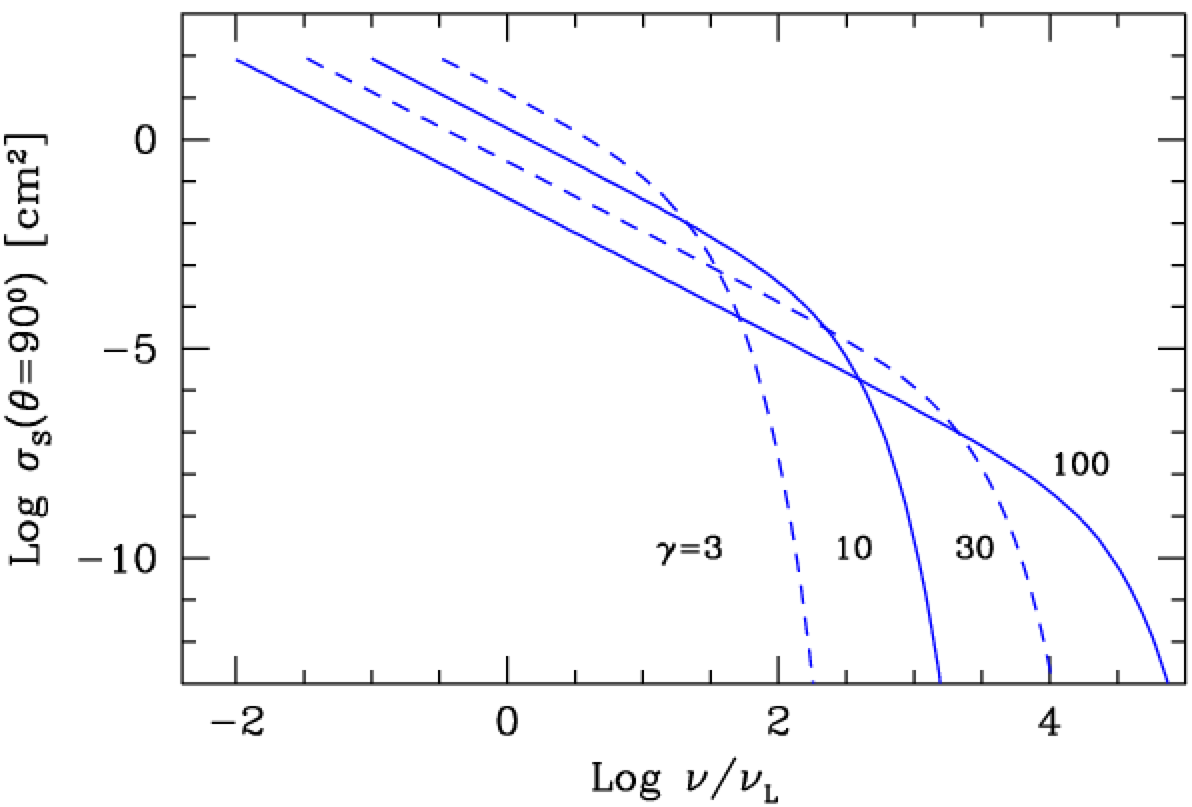


−13
−14
−15
−16
10
15
20
Log νF_ν [erg cm^-2 s^-1]
Log ν [Hz]
ν^-α
ν_t
ν^5/2
≈τ_c lnΛ
ν^-α
ν^-α lnΛ

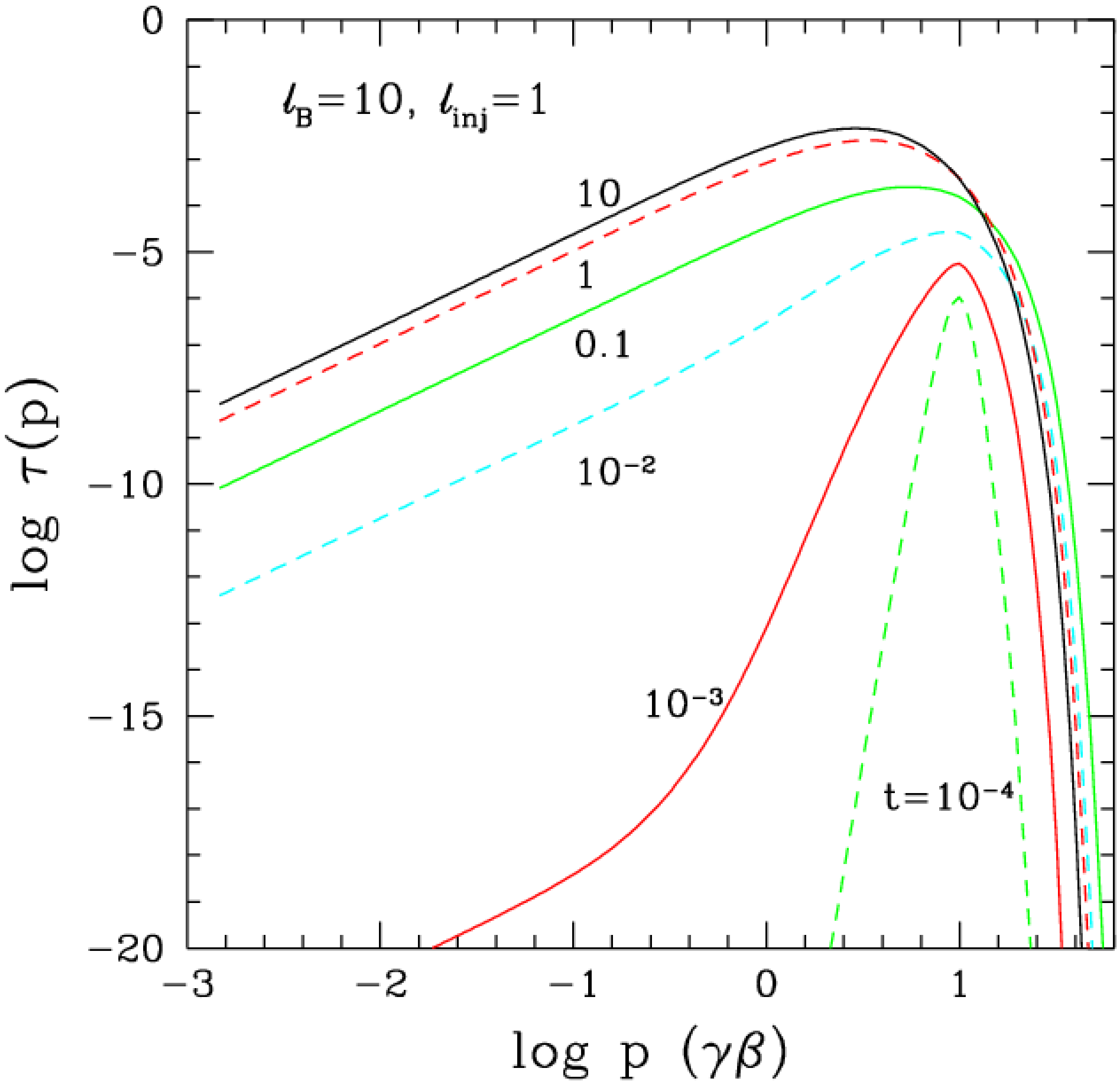
End



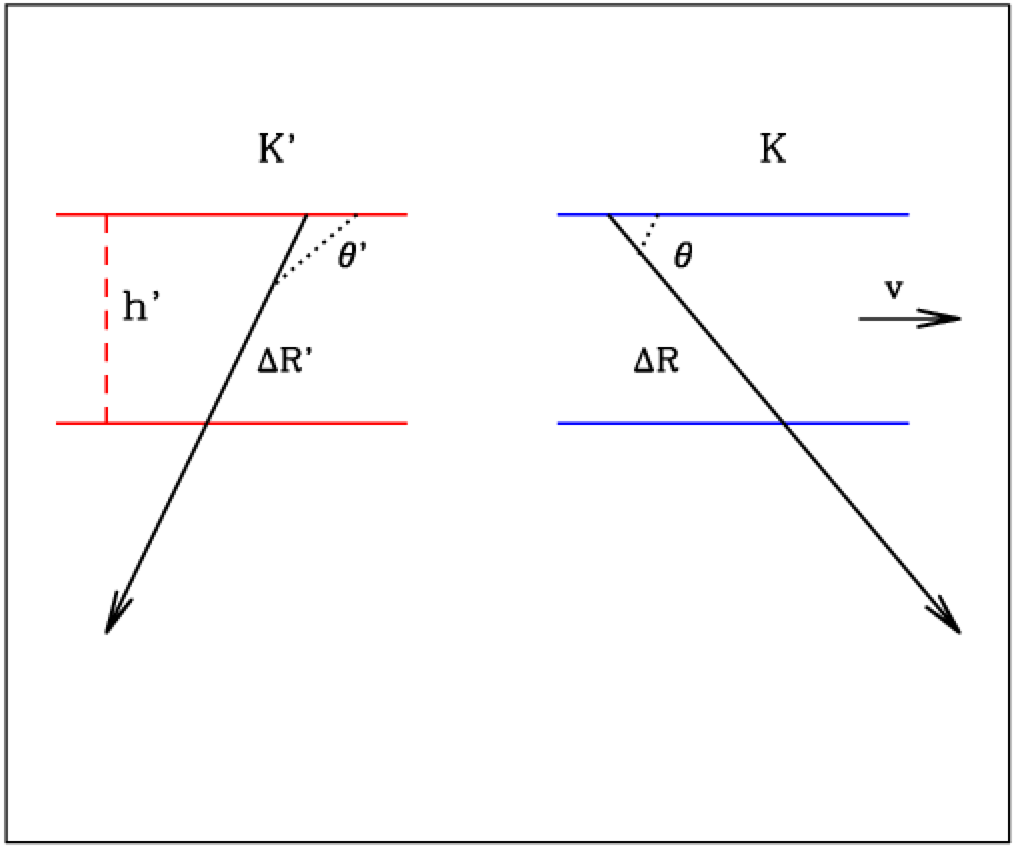
ν_2
ν_1
$\nu=3\nu_c/(4\gamma^2_{min})$
$\nu=3\nu_c/(4\gamma^2_{max})$
1
2
3
Log ν
$\nu_{c,1}$
$\nu_{c,2}$
$\nu_{c,3}$
$\nu_{c,4}$
Log ν_c



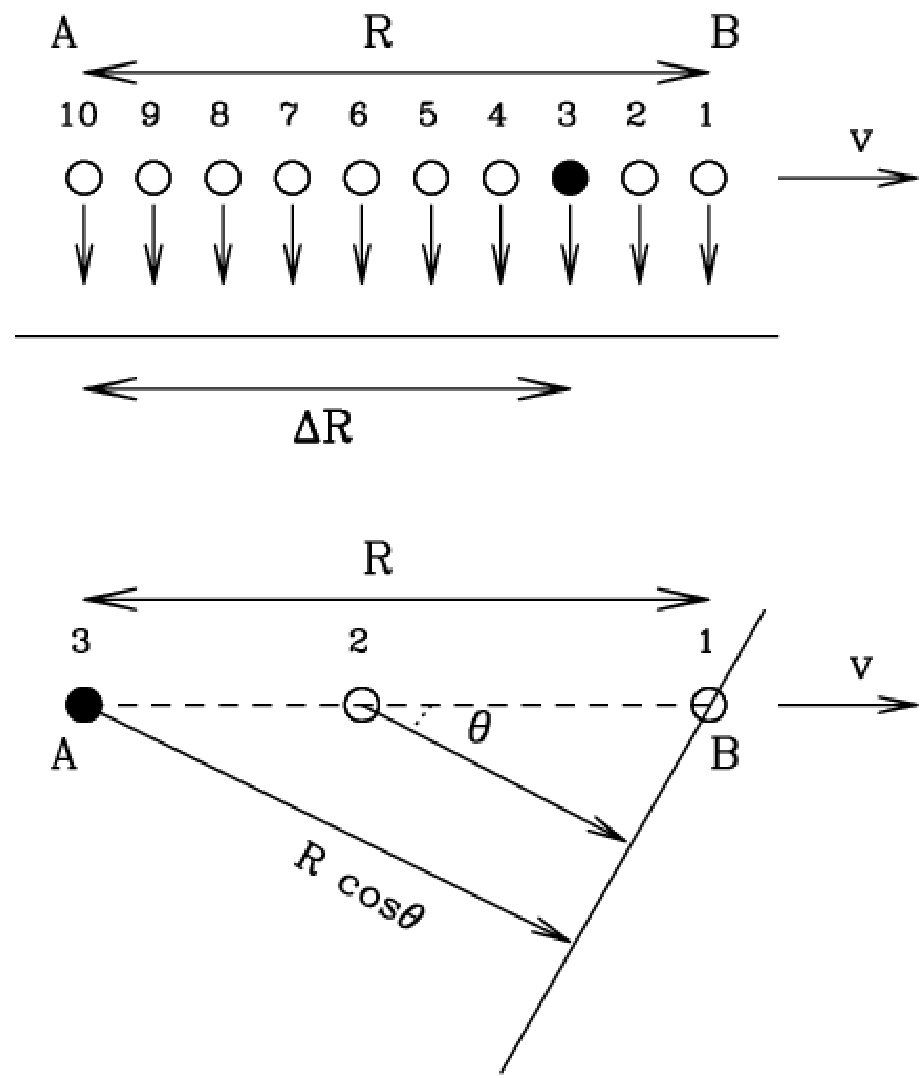
Log $\sigma_S(\theta=90^0)$ [cm²]
Log ν/ν_L
γ=3
10
30
100



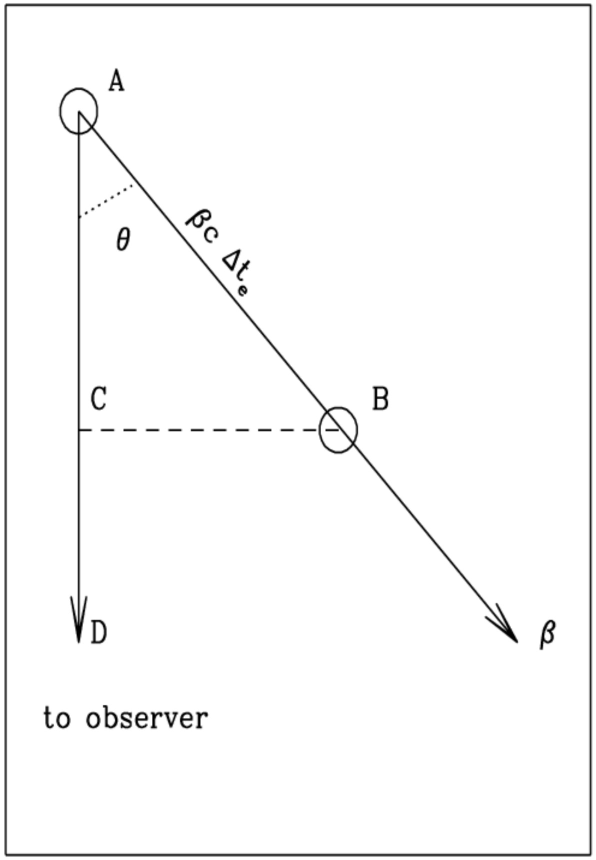
$\ell_B=10,\ \ell_{inj}=1$
10
1
0.1
10^{-2}
10^{-3}
$t=10^{-4}$
0
−5
−10
−15
−20
−3
−2
−1
0
1
log τ(p)
log p (γβ)

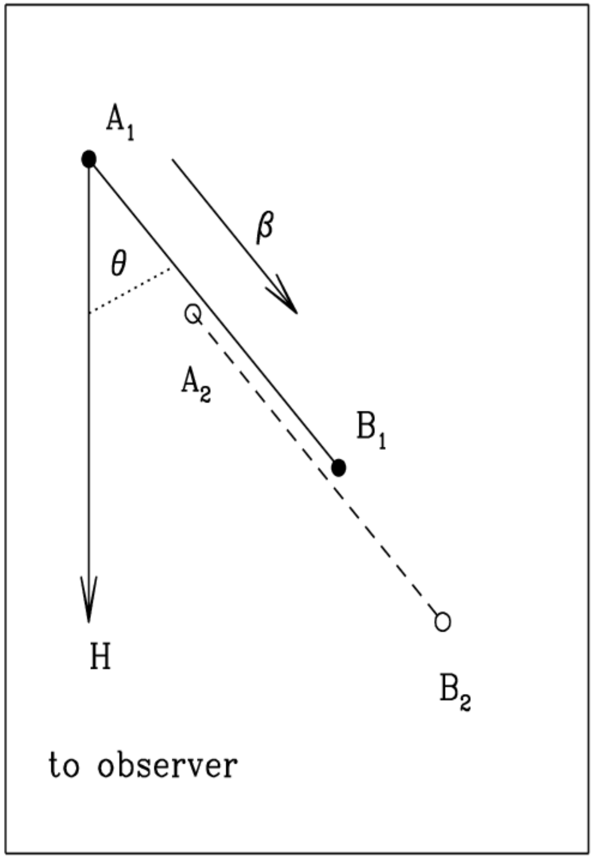


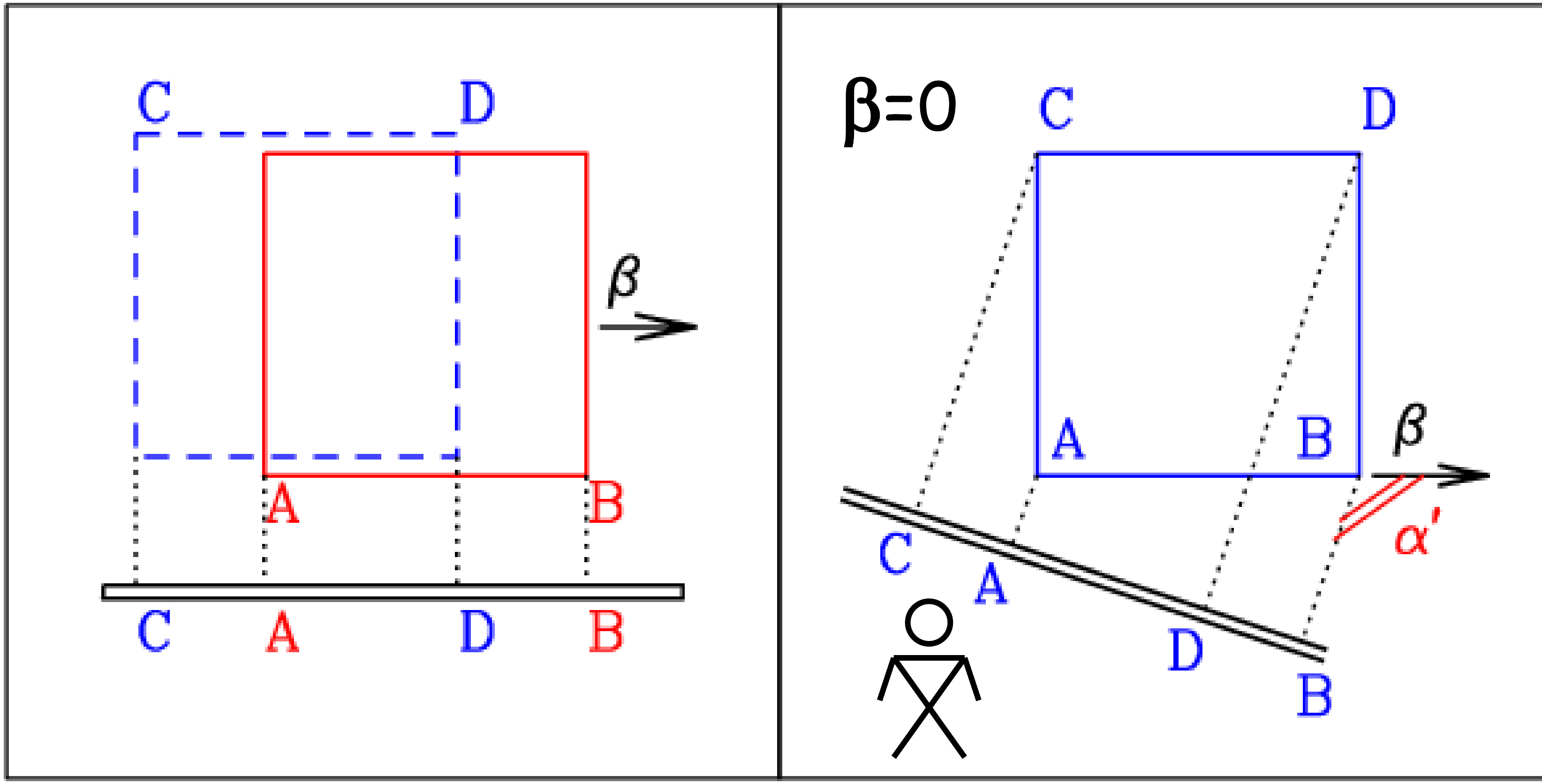
K'
K
θ'
θ
h'
v
ΔR'
ΔR


A
R
B
10 9 8 7 6 5 4 3 2 1
v
ΔR
R
3 2 1
v
θ
A
B
R cosθ

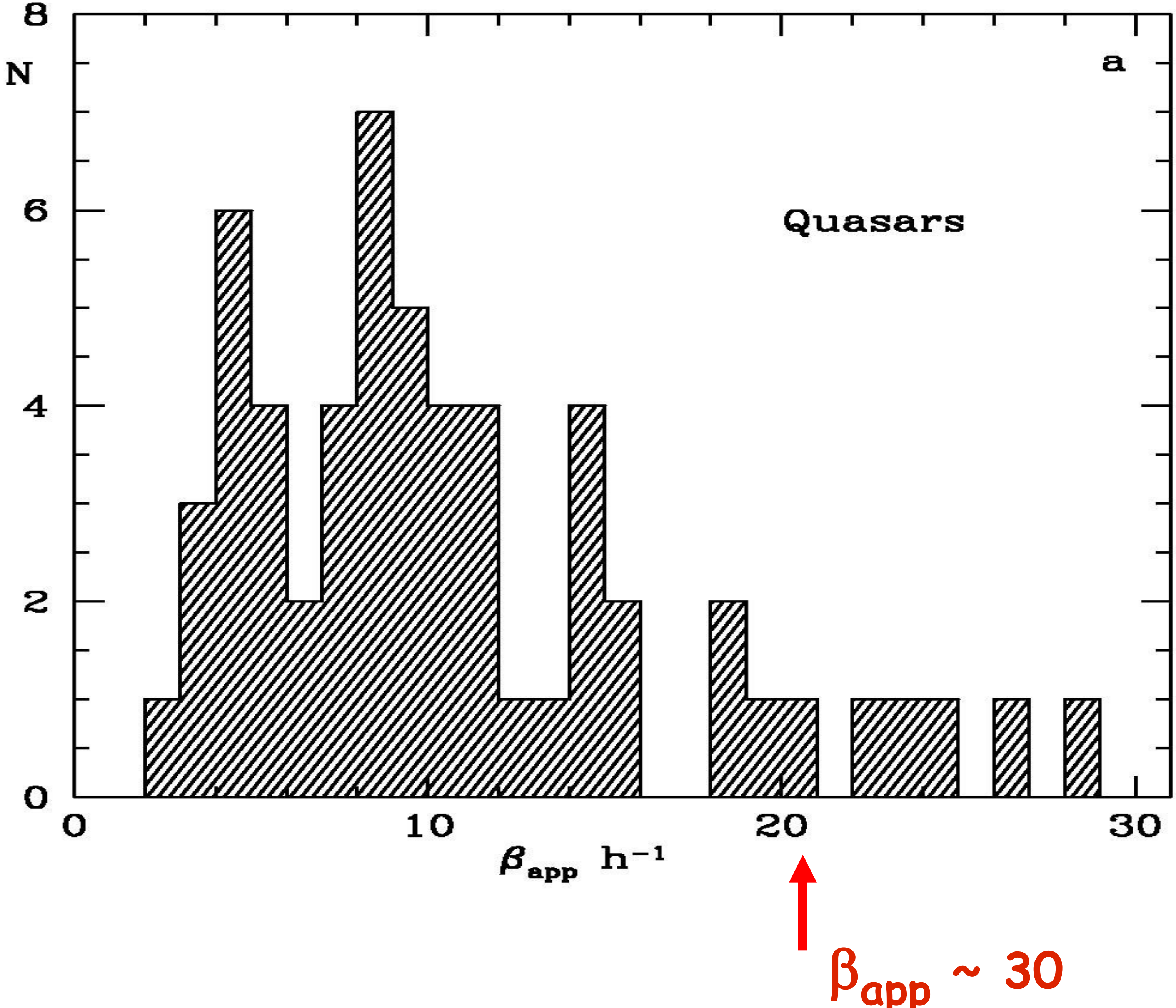
The moving bar



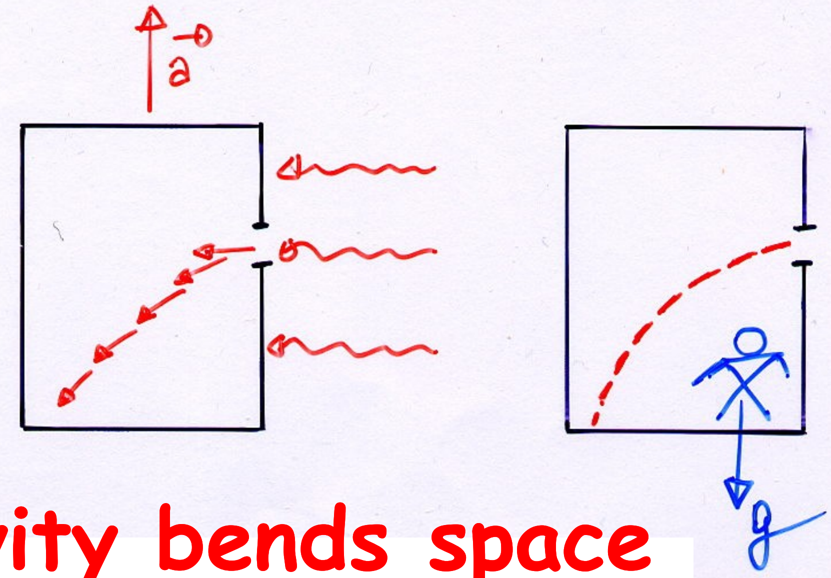




C
D
β
A
B
C
A
D
B
β=0
C
D
A
B
β
C
A
α'
D
B



N
a
Quasars
0
2
4
6
8
0
10
20
30
$\beta_{app}\ h^{-1}$
$\beta_{app} \sim 30$



Gravity bends space

Max synchro frequency

Guilbert Fabian Rees 1983

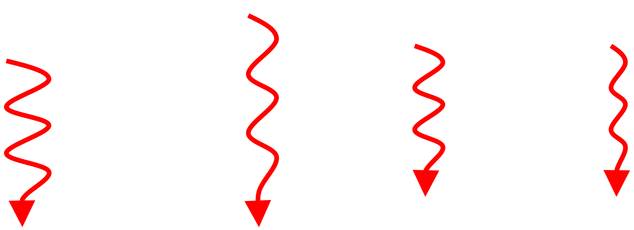
There is max frequency of synchro radiation produced by shock-accelerated electrons. Even if we have relativistic shocks, so that $\Delta\gamma/\gamma$ can be ~1 for each passage through the shock, there is a max energy attainable which corresponds to a γ_e for which

t_{syn} [propto $1/(\gamma_e B^2)$] is comparable to the gyroperiod (propto γ_e/B).

This gives a max γ_e scaling as $1/B^{1/2}$,

so that ν_S becomes independent of B and which corresponds to a wavelength $e^2/m_e c^2$=classical electron radius: i.e. a photon of energy

$$h\nu_{S,max} = m_e c^2/\alpha_F = 70 \text{ MeV}.$$



$$\vec{F}_L = \frac{d}{dt}(\gamma m\vec{v}) = \frac{e}{c}\,\vec{v}\times\vec{B}$$

γ~constant, at least for one gyroradius

$$a_{||} = 0$$

$$a_{\perp} = \frac{e\,v\,B\,\sin\theta}{\gamma\,mc}$$

θ=pitch angle

$$P_S(\theta) = \frac{2e^4}{3m^2c^3}\,B^2\gamma^2\beta^2\sin^2\theta$$

$r_0=e^2/m_ec^2$

$\sigma_T = 8\pi r_0^2/3$

$$P_S(\theta) = 2\sigma_T c U_B \gamma^2\beta^2\sin^2\theta$$

$$\langle P_S\rangle = \frac{4}{3}\sigma_T c U_B \gamma^2\beta^2$$

If pitch angles are isotropic

$$\vec{F}_L = \frac{d}{dt}(\gamma m\vec{v}) = \frac{e}{c}\,\vec{v} \times \vec{B}$$

γ~constant, at least for one gyroradius

$$a_{||} = 0$$

$$a_{\perp} = \frac{e\, v\, B\, \sin\theta}{\gamma\, mc}$$

θ=pitch angle

$$P_S(\theta) = \frac{2e^4}{3m^2c^3} B^2 \gamma^2 \beta^2 \sin^2\theta$$

$r_0 = e^2/m_e c^2$

$\sigma_T = 8\pi r_0^2/3$

$$P_S(\theta) = 2\sigma_T c U_B \gamma^2 \beta^2 \sin^2\theta$$

$$\langle P_S \rangle = \frac{4}{3} \sigma_T c U_B \gamma^2 \beta^2$$

If pitch angles are isotropic

$$\vec{F}_L = \frac{d}{dt}(\gamma m \vec{v}) = \frac{e}{c}\,\vec{v} \times \vec{B}$$

$$a_{\perp} = \frac{e\, v\, B\, \sin\theta}{\gamma\, mc}$$

$$P_S(\theta) = \frac{2e^4}{3m^2c^3}\, B^2 \gamma^2 \beta^2 \sin^2\theta$$

$$r_0 = e^2/m_e c^2$$

$$\sigma_T = 8\pi r_0^2/3$$

$$P_S(\theta) = 2\sigma_T c U_B \gamma^2 \beta^2 \sin^2\theta$$

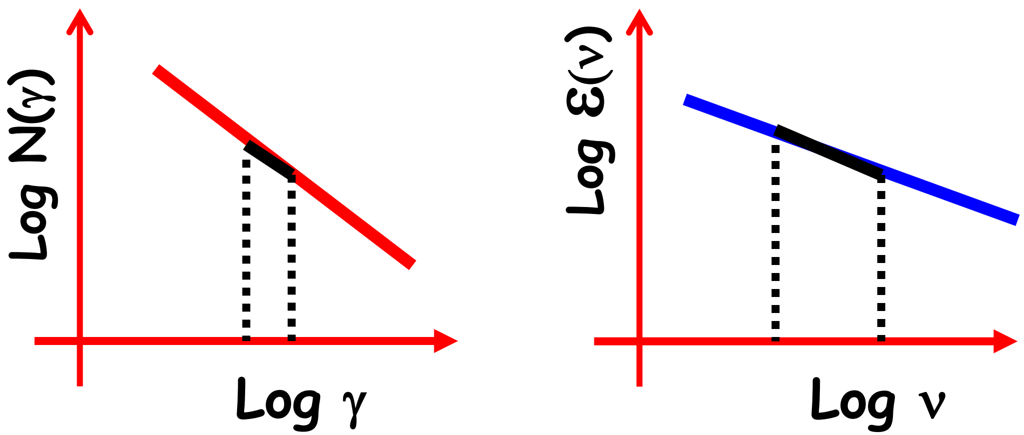
$$\langle P_S \rangle = \frac{4}{3}\sigma_T c U_B \gamma^2 \beta^2$$

If pitch angles are isotropic

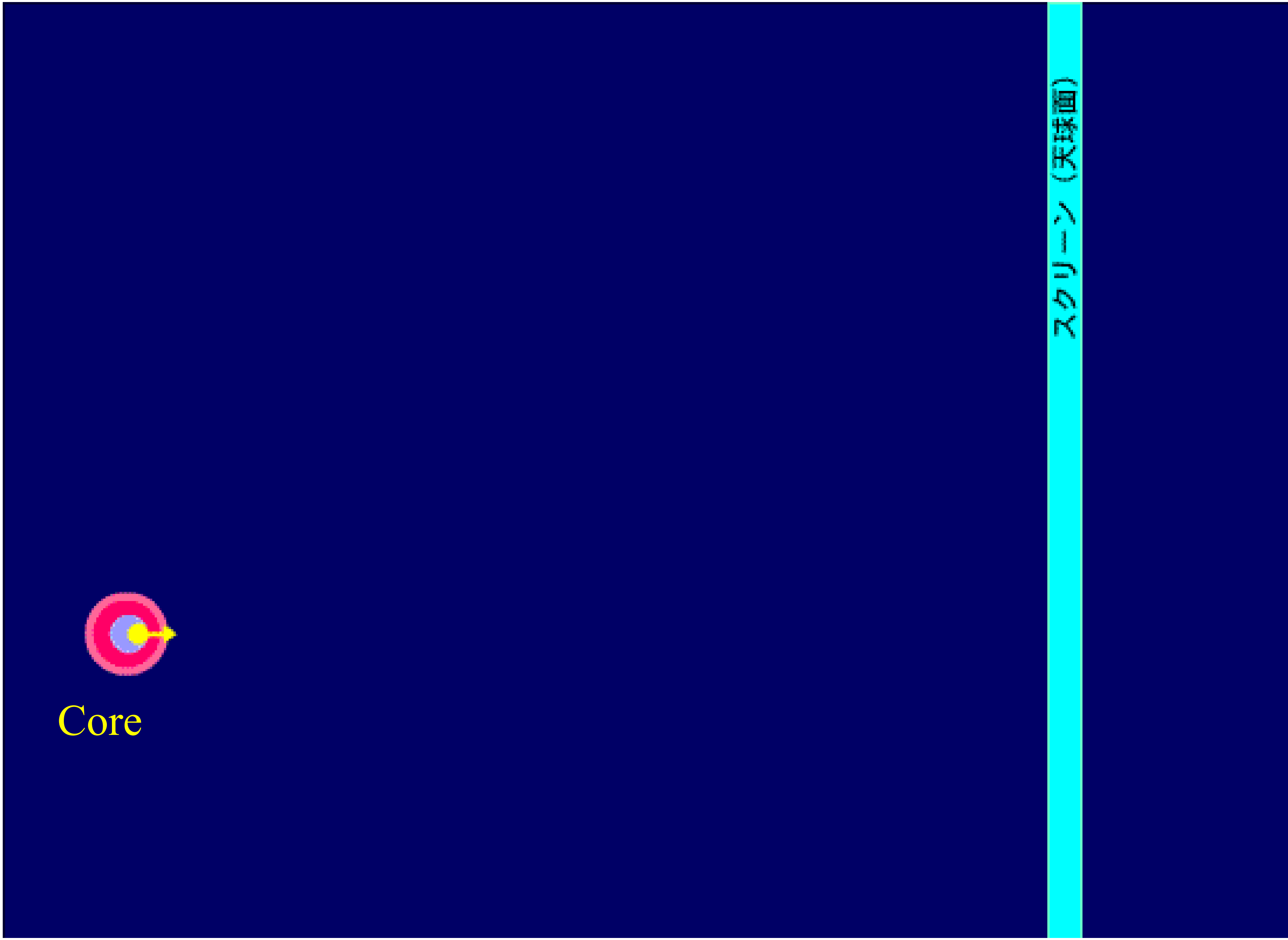
Emission from many particles

$N(\gamma) = K\gamma^{-p}$

The queen of relativistic distributions



$$\varepsilon(\nu) \sim \frac{1}{4\pi} K B^2 \frac{\nu^{(2-p)/2}}{B^{(2-p)/2}} \frac{\nu^{-1/2}}{B^{1/2}}$$


スクリーン（天球面）
Core