Simple Modelling of Synchrotron Emission in High-Energy Astrophysics

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July, 2014

Presentation Outline

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We need to know how this happens ... unintended discoveries comes along!

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- after balancing centrifugal and Lorentz forces we get (in SI units!), the non-relativistic gyrofrequency and the angular gyrofrequency as

$$\nu_{\mathrm{gyro}} = \frac{eB}{2\pi\gamma m_e} \quad \text{and} \quad \omega_{\mathrm{gyro}} = \frac{eB}{\gamma m_e}$$

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- $\Rightarrow$ angular frequency of the electron around the **B**-field is

$$\omega = \left(\frac{eB}{m_e}\right)\frac{1}{\gamma} = \frac{\omega_{\rm crit.n}}{\gamma}$$

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- the energy loss rate of the electrons with pitch angle θ is then

$$\frac{dE}{dt} = -\left(\frac{e^4 B^2}{6\pi\epsilon_0 m_e^2 c}\right)\beta^2\gamma^2 \sin^2\theta$$

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- after averaging over all possible pitch angles and defining $u_B = B^2/2\mu_0$ as **B**-field energy density

$$\frac{dE}{dt} = -\frac{4}{3}\sigma_T c u_B \beta^2 \gamma^2$$

with $\sigma_T = \frac{e^4}{6\pi\epsilon_o^2 c^4 m_e^2} = 6.65 \times 10^{-29}\ \mathrm{m}^2$ the Thomson cross-section

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- the **emissivity** of such a single electron is a function of frequency ω:

$$j(\omega) = -\frac{\sqrt{3}e^3 B \sin\theta}{8\pi^2\epsilon_0 m_e c} F(x)$$

where $F(x)$ are integrals of *modified Bessel functions* of $x = \frac{2\omega r}{3c\gamma^3}$

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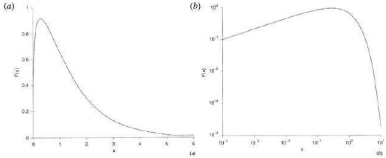

Fig. 8.8 The spectrum of the synchrotron radiation of a single electron shown (a) with linear axes; (b) with logarithmic axes. The function is plotted in terms of $x = \omega/\omega_c = \nu/\nu_c$ where ω_c is the critical angular frequency $\omega_c = 2\pi\nu_c = (3/2)\left(c/v\right)\gamma^2\omega_g \sin\alpha$ where α is the pitch angle of the electron and ω_g is the non-relativistic gyrofrequency, $\omega_g = eB/m_e$.

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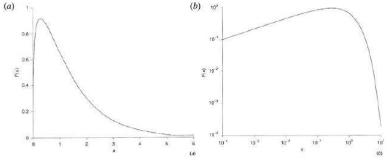

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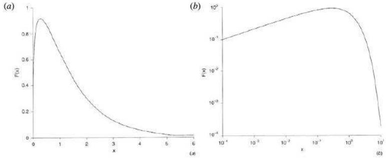

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the asymptotic behaviour of the emissivity is:

$$j(\nu) \propto \begin{cases} \nu^{1/2}, & \text{for high frequencies, i.e } \nu \gg \nu_{\rm crit} \\ \nu^{1/3}, & \text{for low frequencies, i.e } \nu \ll \nu_{\rm crit} \end{cases}$$

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- assume a *power law energy distribution* such that the number of elctrons per unit volume with energies in the range from E to $E + dE$ is

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$$J(\omega) = \frac{\sqrt{3\pi} e^3 B \kappa}{16\pi^2 \epsilon_0 m_e c (p+1)} \left(\frac{\omega m_e^3 c^4}{3eB}\right)^{\frac{-(p-1)}{2}} \frac{\Gamma\left(\frac{p}{4} + \frac{19}{12}\right) \Gamma\left(\frac{p}{4} - \frac{1}{12}\right) \Gamma\left(\frac{p}{4} + \frac{5}{4}\right)}{\Gamma\left(\frac{p}{4} + \frac{7}{4}\right)}$$

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- fair approximation: most of the radiated photons are at $\nu_{\rm crit}$

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2. Radiative Processes
3. Synchrotron radiation
4. Student activity
5. Applications

Getting our hands dirty with a model

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- do a brief parameter study by varrying various input parameters, such as γs, B, p, etc.

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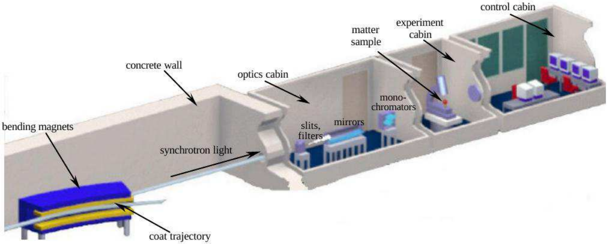
Applications of the synchrotron concept



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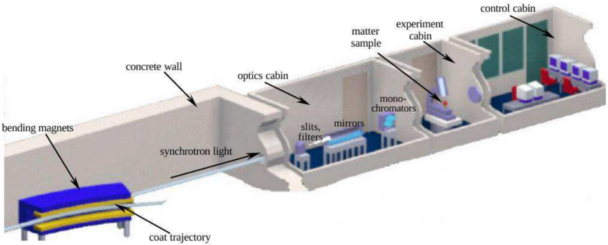

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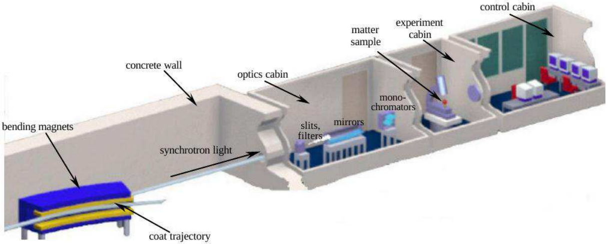

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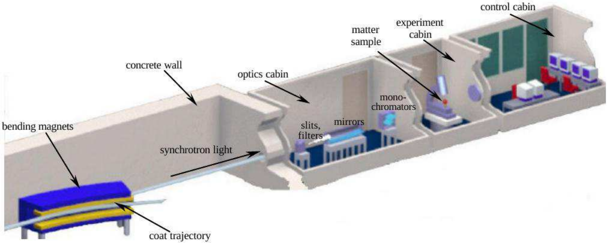

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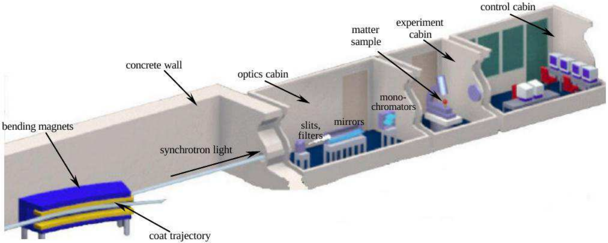

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- man-made circular particle accelerators

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