Modelling the γ–ray Emission of the Supernova Remnant G330.2+1.0

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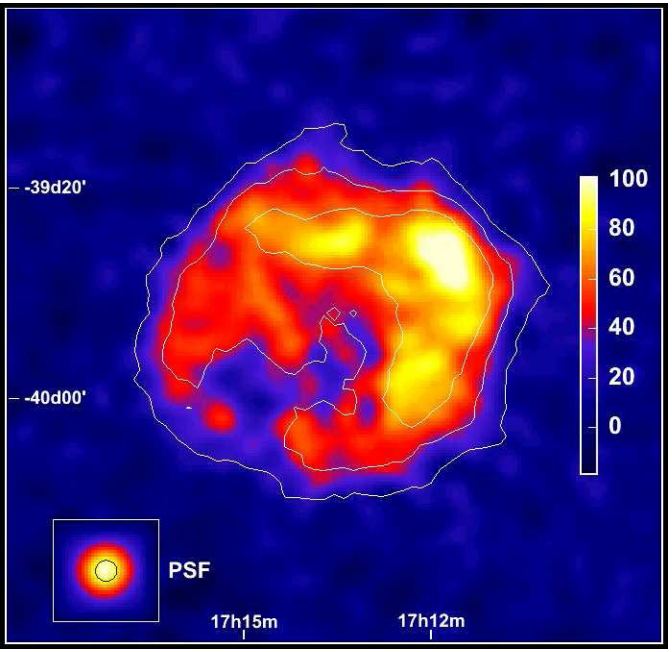
EUROPEAN COMMISSION
Erasmus Mundus,
"External Cooperation Window"

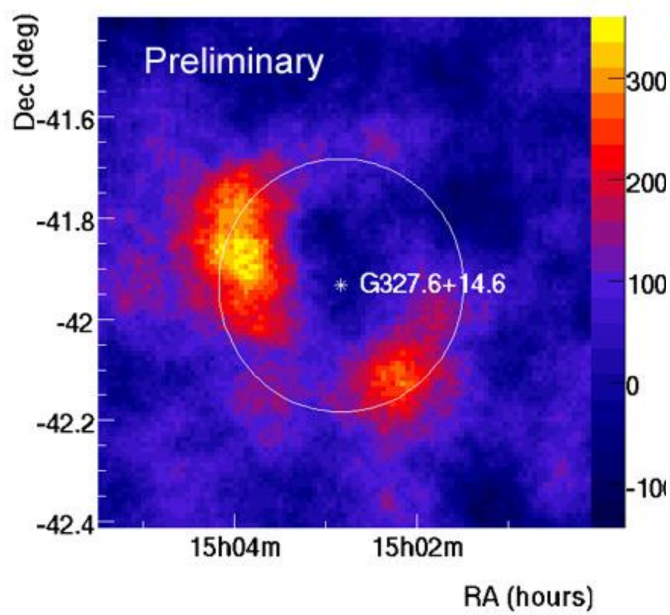
H.E.S.S. telescopes

- Array of four imaging atmospheric Cherenkov telescopes (IACTs)
- Energy range from ~ 100 GeV to 20 TeV
- Angular resolution ~0.1

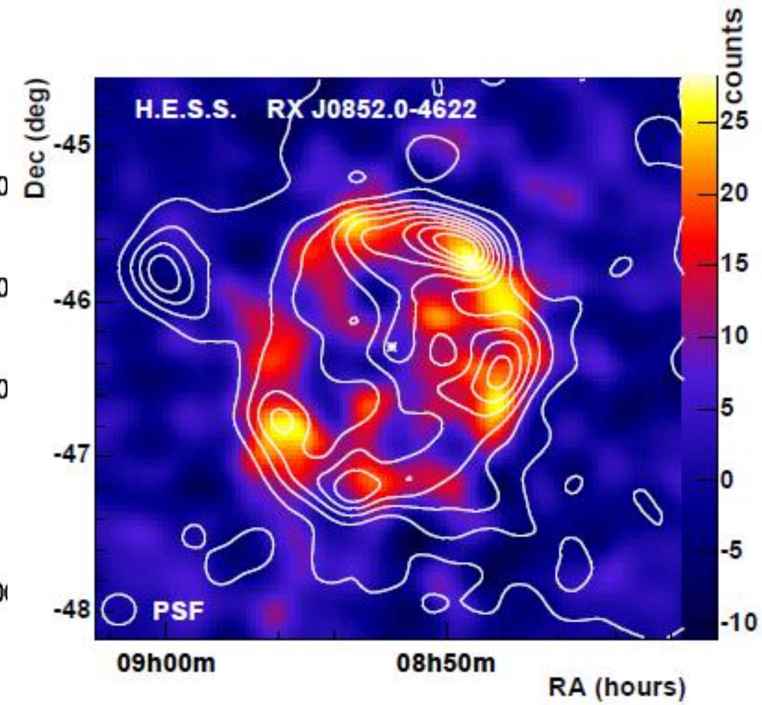
SNRs with H.E.S.S.



RX J1713.7−3946



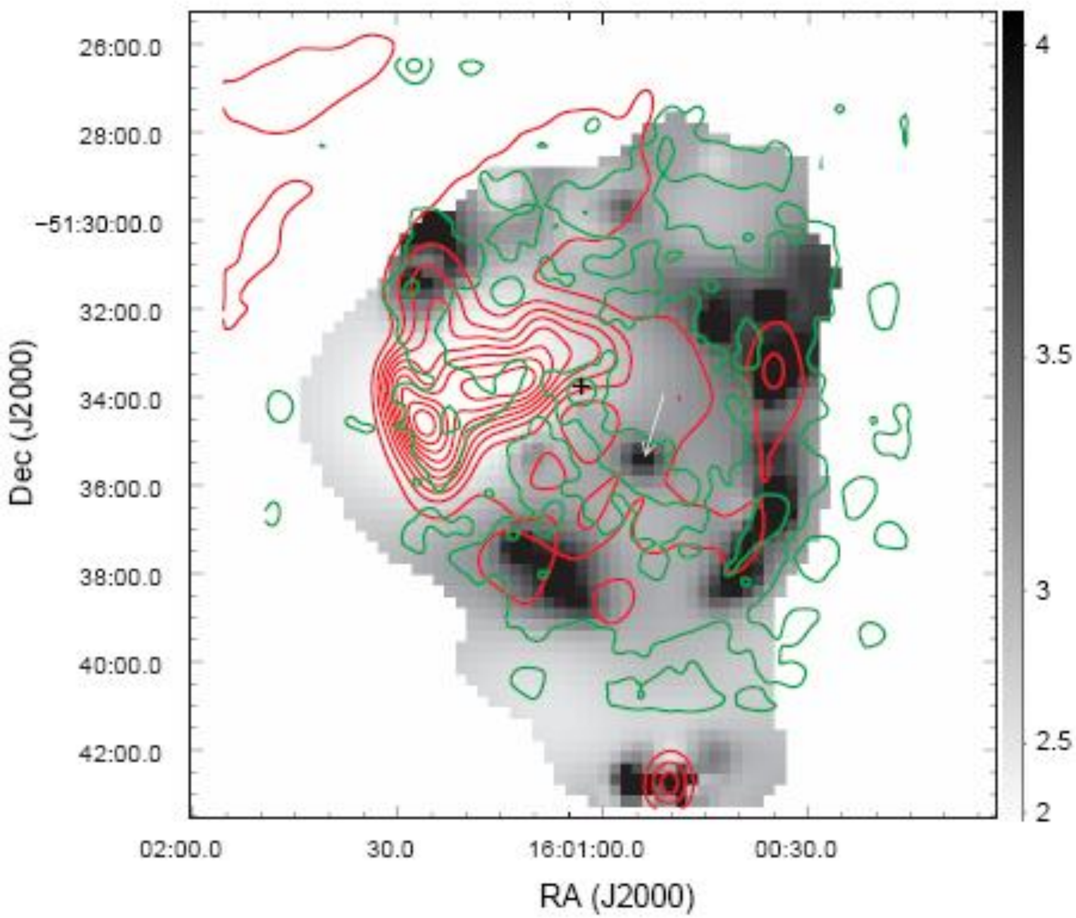
SN 1006



RXJ0852.0−4622

Some of detected by H.E.S.S. SNRs with resolved shell structure, what indicates the particle acceleration in the shock

G330.2+1.0



2-8 to 1-2 keV XMM-Newton hardness ratio map of G330.1+2.0. The green contours are taken from an 1-8 keV image of the same data. The red contours depict the 843 MHz radio image taken from the MOST SNR Catalog (Whiteoak & Green 1996).The black cross marks the position of the CCO J1601. (Park et al., 2008)

SNR G330.2+1.0 properties

- Right Ascension: 16h 01m 06s
- Declination: −51º 34'
- Size: 11 arcmin
- Type: Shell (in radio clumpy distorted)
- Distance: >4.9 kpc (from the HI absorbtion (McClure-Griffiths et al., 2001))
- ISM density is $n_{ISM} \sim 0.1\ f^{-1/2}\ d_5^{-1/2}\ cm^{-3}$, where f – is a X-Ray emitting volume filling factor (Park et al., 2008)
- Due to Sedov solution, minimum distance 5 kpc, explosion energy normalized to 10^{51} ergs and ISM density normalized to 0.1 cm^{-3} the minimum age is

$$t = 10^3\ (E_{51}/n_{0.1})^{-1/2}\ d_5^{5/2}\ \mathrm{yr.}$$

- X-ray spectrum (Torii et al. 2006) :

Photon index: 2.82 0.21

Unabsorbed 0.7-10 keV flux: 1.6 10^{-11} erg s^{-1} cm^{-2}

Inverse Compton scattering model

(according to de Jager et al. 1995)

$$\frac{dN}{dt\,d\epsilon_1} = S(\epsilon_1)/\epsilon_1 = \frac{r_o^2}{\pi\hbar^3 c^2} K_e (kT)^{(p+5)/2} F(p) \epsilon_1^{-(p+1)/2} \quad \text{for } (\epsilon_1 kT)^{1/2} \ll mc^2$$

$dN/d\gamma = K_e \gamma^{-p}$ ⟶ electron spectrum

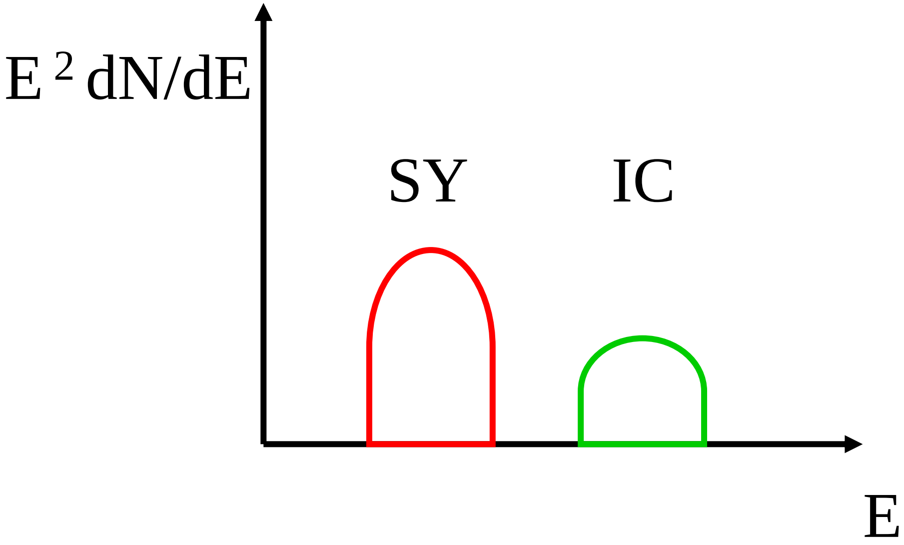
$p = 2a_x + 1$ ⟶ electron spectral index

X-ray energy index

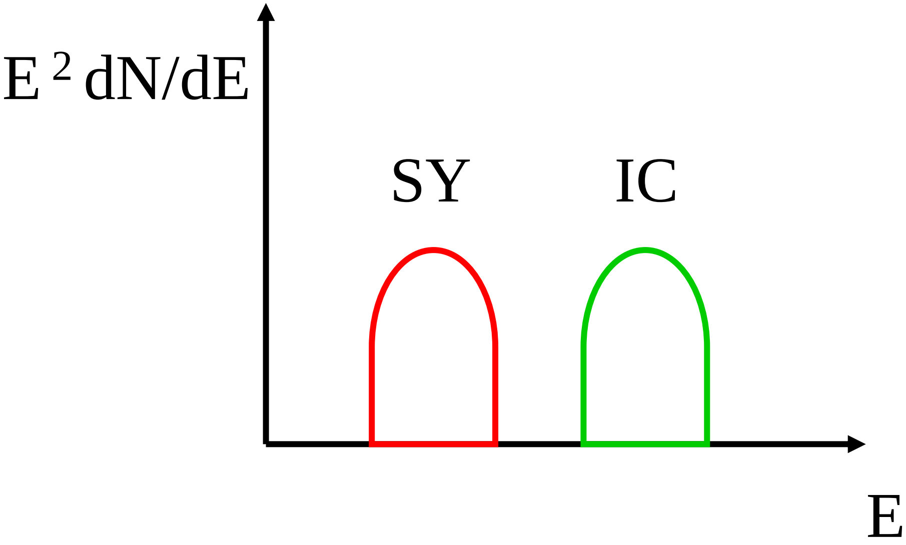
$S(\epsilon_{keV}) = S_{1keV}\,\epsilon_{keV}^{-a_x}$ ⟶ X-ray spectrum

$$S(\epsilon_{TeV}) = 6.6 \times 10^{-17} (1.4 \times 10^{-5})^{a_x} \exp(2.2 a_x - 0.126 a_x^2) B_\perp^{-(a_x+1)} S_{1keV}\, \epsilon_{TeV}^{-a_x}$$

Dependance on B-Field



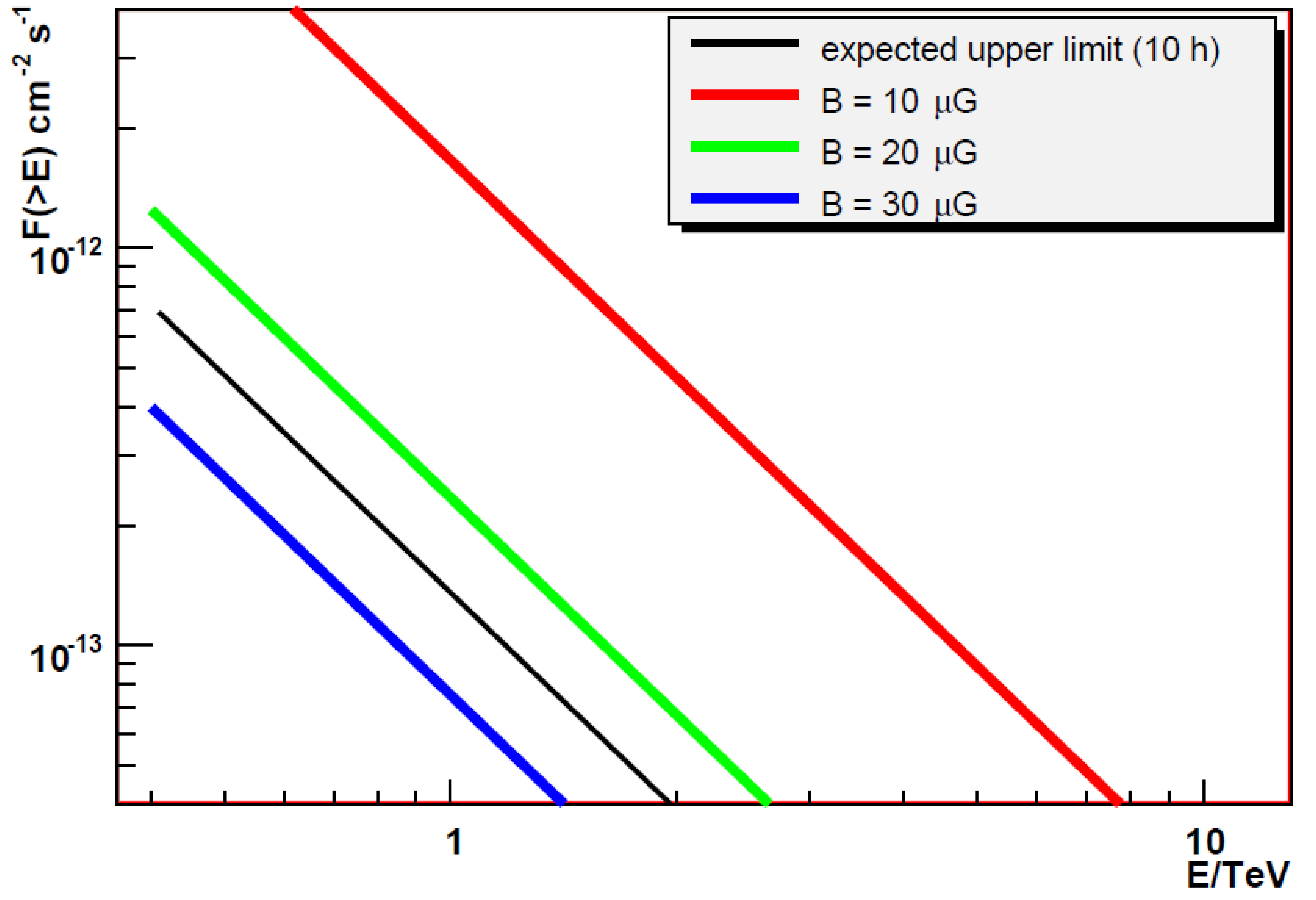
- Higher B-Field, lower electron injection $\rightarrow$ lower IC



- Lower B-Field, higher electron injection $\rightarrow$ higher IC

Estimates on expected gamma-ray flux

Using the simple model of IC scattering of electrons on CMB photons (de Jager et al. 1995) and X-ray data we can estimate the expected gamma-ray flux depending on the magnetic field



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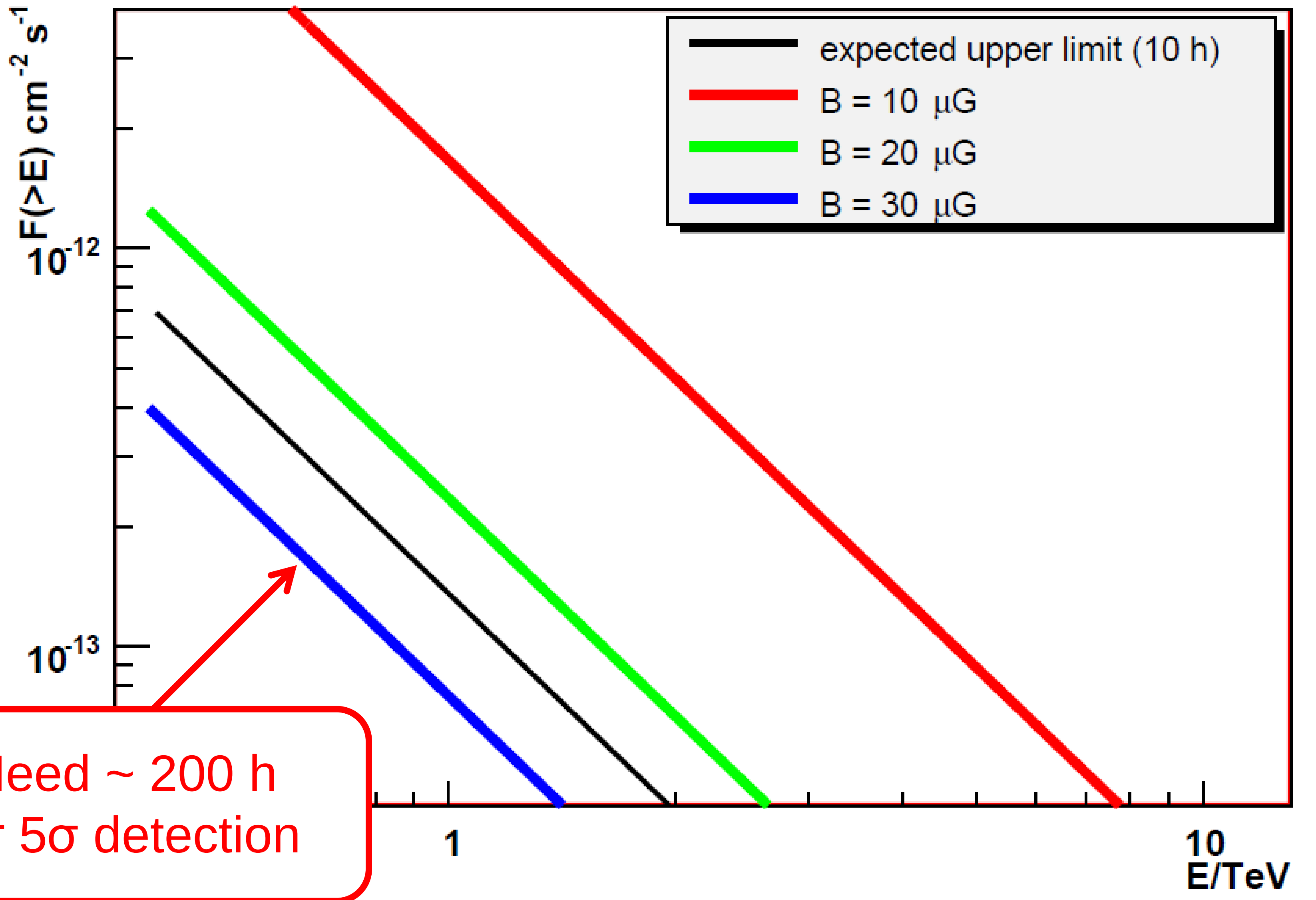


Need ~ 200 h
for 5σ detection

Lower limit on magnetic field

The expected 99 % confidence upper limit on the integrated TeV flux above 0.18 TeV threshold energy with respect to 10 hours observation

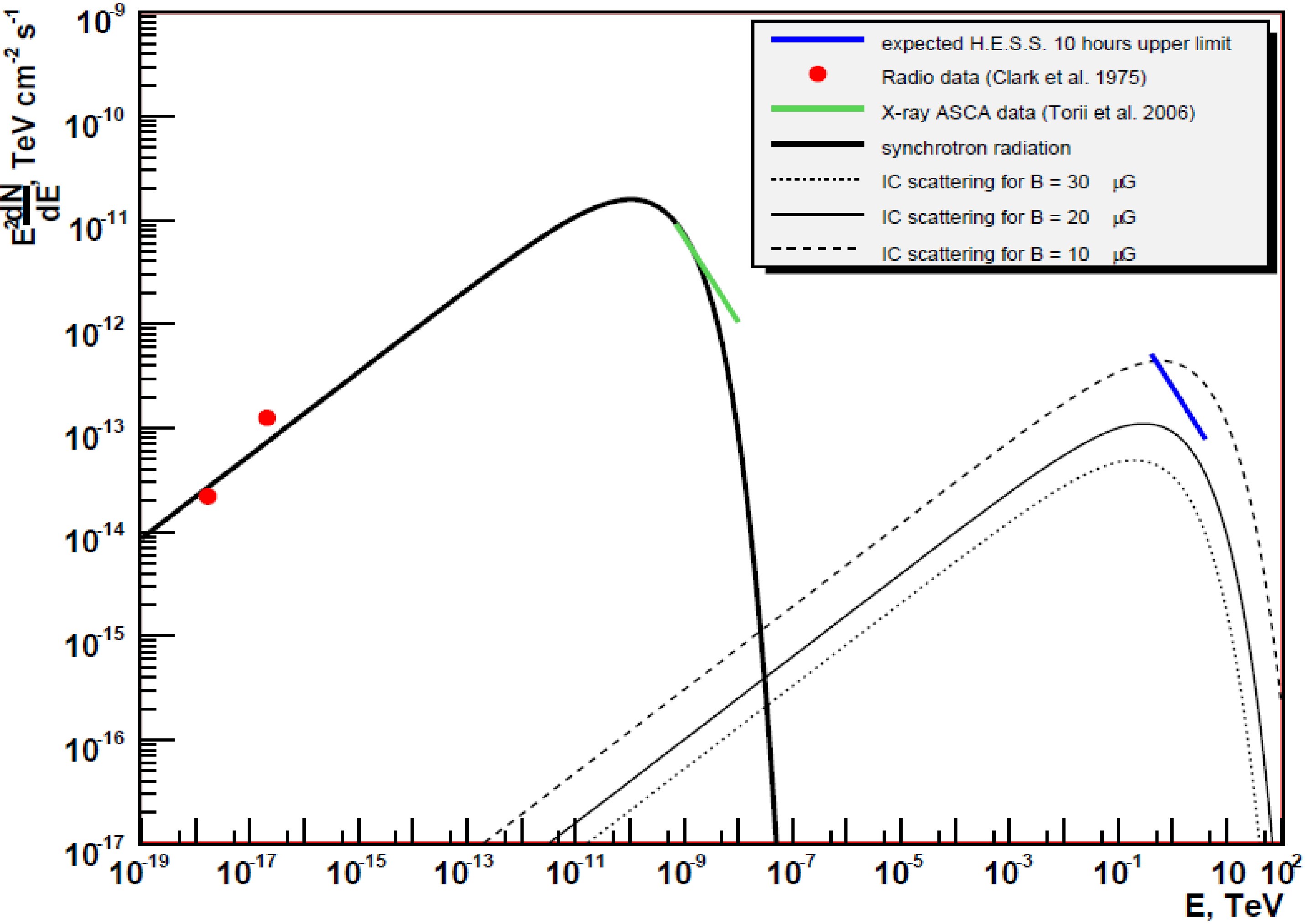
$$f_{\text{max } 99\%} = 3.08 \;\; 10^{-12} \;\; s^{-1}\, cm^{-2}$$

Using de Jager et al. 1995 IC model and X-ray data we calculate the 99 % confidence lower limit on the magnetic field

$$B_{\text{min } 99\%} = 20\ \mu G$$

SED broadband model (analytical)

In the model is used the electron injection spectra of the form of power law with the exponential cut-off with the spectral index of 2.2 and cut-off energy of about (5 – 9) TeV



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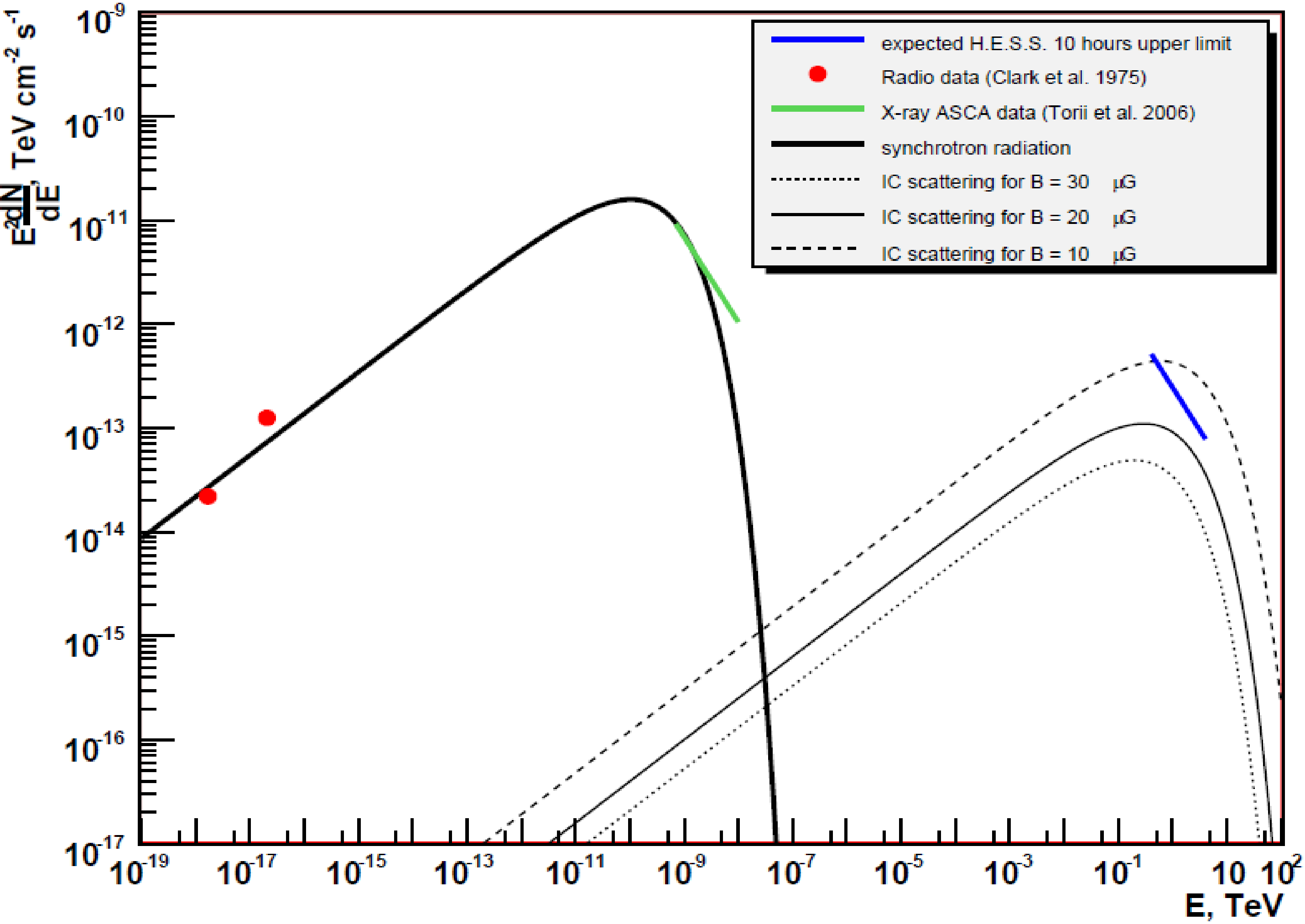
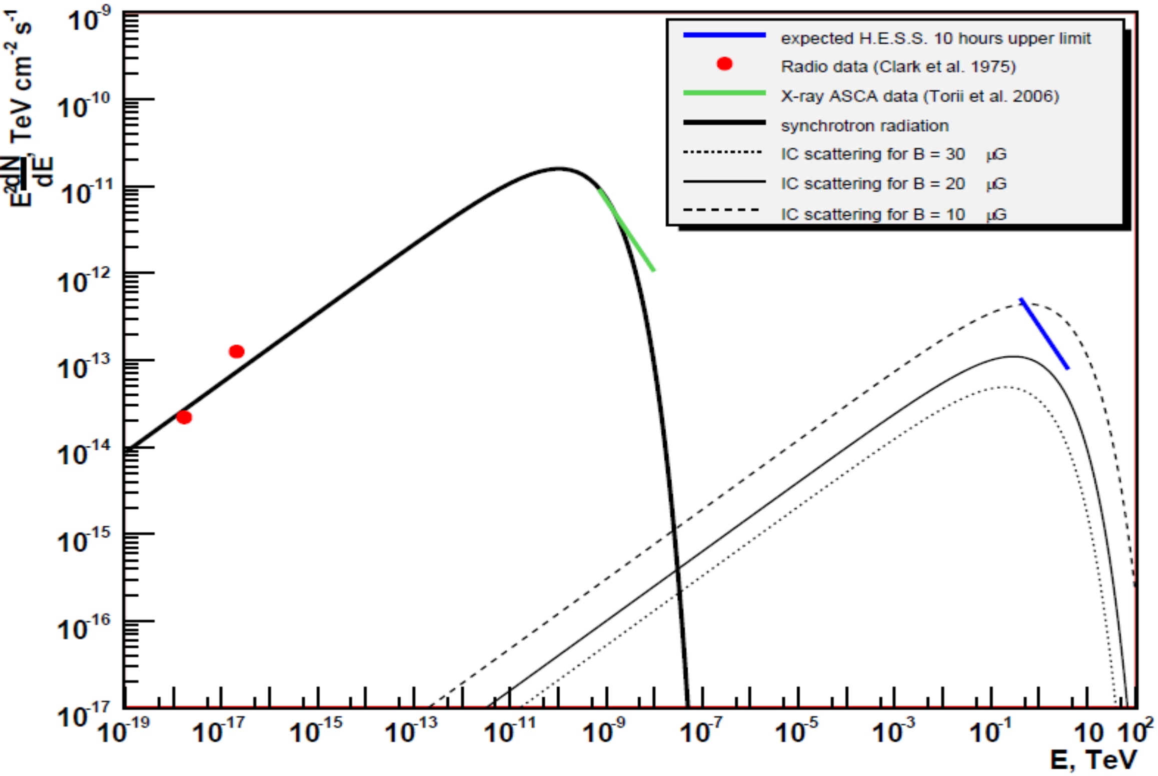


PROBLEM!!!

Anticorrelation of radio and X-ray intensities can mean that X-ray and radio emissions are spatially separated and we can not use the assumption that they are from the same electron population!!!

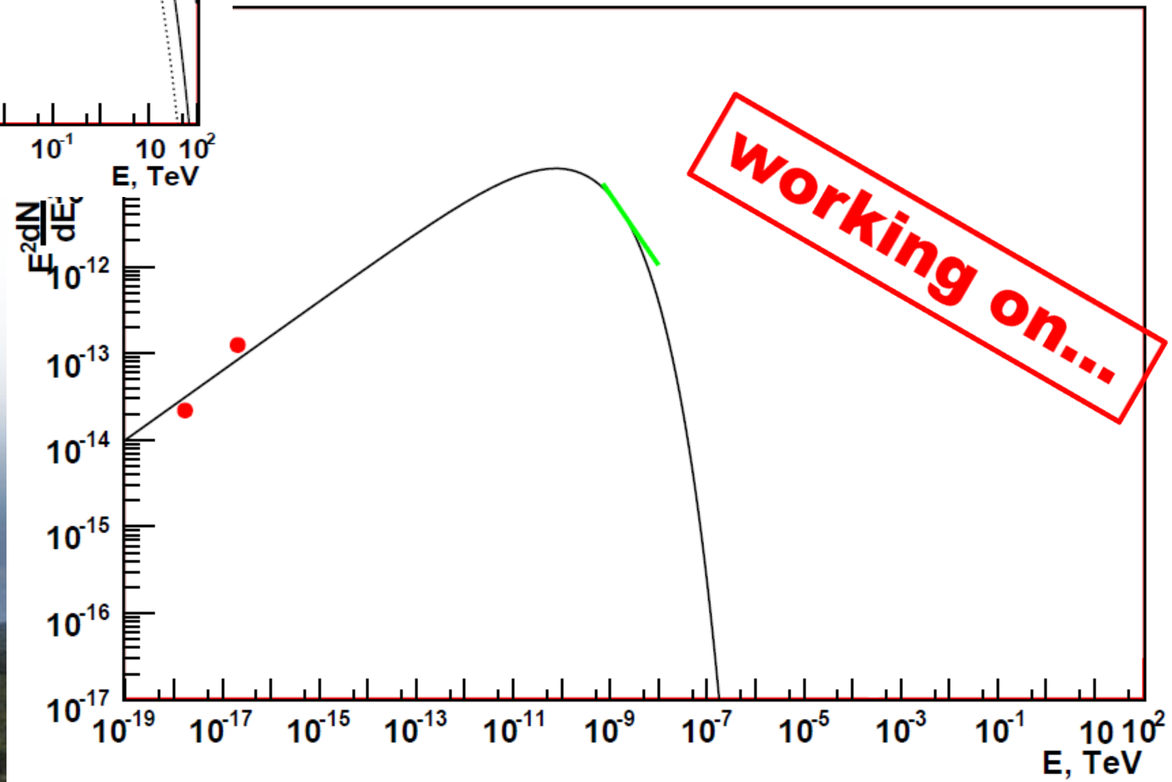
How dramatic can it be for the modelling?

Comparison of the analytical and numerical model



Analytical model

Numerical model



Summary

- Assuming IC scenario we estimated the lower limit on the magnetic field of 20μG
- There was built the analytical SED broadband model for G330.2+1.0 taking into account the synchrotron radiation and IC scattering on CMB photons. I’m still working on the numerical one
- How dramatic can be the influence of the anticorrelation of the radio and X-ray data on the broadband model???

BACKUP SLIDES

Analytical broadband model (synchrotron)

$$N_e(\gamma)\,d\gamma = K_e \gamma^{-p} e^{-\frac{\gamma}{\gamma_{\max}}} d\gamma$$ Electron energy distribution

Synchrotron emission:

$$P_{tot}(\omega) = \int_{\gamma_1}^{\gamma_2} P(\omega)\,N_e(\gamma)\,d\gamma = \int_{\gamma_1}^{\gamma_2} \frac{\sqrt{3}}{2\pi} \frac{q^3 B \sin\alpha}{mc^2} F\left(\frac{\omega}{\omega_c}\right) K_e \gamma^{-p} e^{-\frac{\gamma}{\gamma_{\max}}} d\gamma$$

$$F(x) = x \int_x^{\infty} K_{5/3}(\xi)\,d\xi \qquad x = \frac{\omega}{\omega_c} \qquad \omega_c = \frac{3qB\sin\alpha}{2mc}\gamma^2 \qquad \omega_{c\ \max} = \frac{3qB\sin\alpha}{2mc}\gamma_{\max}^2$$

$$P_{tot}(\omega) \propto \omega^{-\frac{p-1}{2}} \int_{x_1}^{x_2} F(x)\,x^{\frac{p-3}{2}} e^{-x^{-1/2}\left(\frac{\omega}{\omega_{c\ \max}}\right)^{1/2}} dx$$

Analytical broadband model (synchrotron)

$$N_e \;\gamma\; d\gamma = K_e \gamma^{-p} e^{-\frac{\gamma}{\gamma_{\max}}} d\gamma$$ Electron energy distribution

Synchrotron emission:

$$P_{tot} \;\omega\; = \int_{\gamma_1}^{\gamma_2} P \;\omega\; N_e \;\gamma\; d\gamma = \int_{\gamma_1}^{\gamma_2} \frac{\sqrt{3}}{2\pi} \frac{q^3 B \sin\alpha}{mc^2} F\left(\frac{\omega}{\omega_c}\right) K_e \gamma^{-p} e^{-\frac{\gamma}{\gamma_{\max}}} d\gamma$$

$$F \;x\; = x \int_x^{\infty} K_{5/3} \;\xi\; d\xi \qquad x = \frac{\omega}{\omega_c} \qquad \omega_c = \frac{3qB\sin\alpha}{2mc}\gamma^2 \qquad \omega_{c\ \max} = \frac{3qB\sin\alpha}{2mc}\gamma_{\max}^2$$

$$P_{tot} \;\omega\; \propto \omega^{-\frac{p-1}{2}} \int_{x_1}^{x_2} F \;x\; x^{\frac{p-3}{2}} \boxed{e^{-x^{-1/2}\left(\frac{\omega}{\omega_{c\ \max}}\right)^{1/2}}} dx$$

$$\boxed{x = \frac{\omega}{\omega_c} \approx \frac{\omega_c}{\omega_c} = 1}$$

Analytical broadband model (IC)

$$N_e \quad \gamma \quad d\gamma = K_e \gamma^{-p} e^{-\frac{\gamma}{\gamma_{\max}}} d\gamma$$ Electron energy distribution

IC emission:

$$\frac{dN_{tot}}{dtd\varepsilon_1} = \int_0^{\infty} \int_{\frac{1}{2}\left(\frac{\varepsilon_1}{\varepsilon}\right)^{1/2}}^{\infty} N_e \quad \gamma \quad d\gamma \left(\frac{dN_{\gamma,\varepsilon}}{dtd\varepsilon_1} \right) = K_e \int_0^{\infty} \int_{\frac{1}{2}\left(\frac{\varepsilon_1}{\varepsilon}\right)^{1/2}}^{\infty} \gamma^{-p} e^{-\frac{\gamma}{\gamma_{\max}}} d\gamma \left(\frac{dN_{\gamma,\varepsilon}}{dtd\varepsilon_1} \right)$$

$$\frac{dN_{\gamma,\varepsilon}}{dtd\varepsilon_1} = \frac{\pi r_0^2 c}{2\gamma^4} \frac{n \quad \varepsilon \quad d\varepsilon}{\varepsilon^2} \left(2\varepsilon_1 \ln \frac{\varepsilon_1}{4\varepsilon\gamma^2} + 4\varepsilon\gamma^2 + \varepsilon_1 - \frac{\varepsilon_1}{2\varepsilon\gamma^2} \right)$$

$$\frac{dN_{tot}}{dtd\varepsilon_1} \approx \pi r_0^2 c K_e 2^{p+3} \frac{p^2 + 4p + 11}{p+3 \quad ^2 \quad p+5 \quad p+1} \int_0^{\infty} \varepsilon^{\frac{p-1}{2}} n \quad \varepsilon \quad e^{-\frac{\varepsilon^{-1/2}}{2\gamma_{\max}} \varepsilon_1^{1/2}} d\varepsilon$$

Analytical broadband model (IC)

$$N_e(\gamma)\,d\gamma = K_e \gamma^{-p} e^{-\frac{\gamma}{\gamma_{\max}}} d\gamma$$ Electron energy distribution

IC emission:

$$\frac{dN_{tot}}{dt\,d\varepsilon_1} = \int_0^{\infty} \int_{\frac{1}{2}\left(\frac{\varepsilon_1}{\varepsilon}\right)^{1/2}}^{\infty} N_e(\gamma)\,d\gamma \left(\frac{dN_{\gamma,\varepsilon}}{dt\,d\varepsilon_1}\right) = K_e \int_0^{\infty} \int_{\frac{1}{2}\left(\frac{\varepsilon_1}{\varepsilon}\right)^{1/2}}^{\infty} \gamma^{-p} e^{-\frac{\gamma}{\gamma_{\max}}} d\gamma \left(\frac{dN_{\gamma,\varepsilon}}{dt\,d\varepsilon_1}\right)$$

$$\frac{dN_{\gamma,\varepsilon}}{dt\,d\varepsilon_1} = \frac{\pi r_0^2 c}{2\gamma^4} \frac{n(\varepsilon)\,d\varepsilon}{\varepsilon^2} \left(2\varepsilon_1 \ln\frac{\varepsilon_1}{4\varepsilon\gamma^2} + 4\varepsilon\gamma^2 + \varepsilon_1 - \frac{\varepsilon_1}{2\varepsilon\gamma^2}\right)$$

$$\boxed{\varepsilon \approx 2.7kT}$$

$$\frac{dN_{tot}}{dt\,d\varepsilon_1} \approx \pi r_0^2 c K_e 2^{p+3} \frac{p^2 + 4p + 11}{(p+3)^2 (p+5)(p+1)} \int_0^{\infty} \varepsilon^{\frac{p-1}{2}} n(\varepsilon)\, e^{-\frac{\varepsilon^{-1/2}}{2\gamma_{\max}}\varepsilon_1^{1/2}} d\varepsilon$$