

SN 1995N  
P. Chandra +09

Spectral peak shifts to longer  $\lambda$  with time, as SNR becomes less dense & synch. absorption reduces.

SN 1994I

Modeling the rise can distinguish between synchrotron & free-free absorption.

SN 1994 I  
vs. 1993 J  
 $T_b$

Can also measure size of SN with radio VLBI, or infer with measured shock speeds. Can then infer brightness temperature of radio emission.  $T_b$  is fundamentally limited to  $T_b < 3 \times 10^{10} K$ , as higher emission will lead directly to increased IC radiation.

SN 1994I shows  $T_b$  fixed at  $\sim 3 \times 10^{10} K$  until becomes opt. thin, while 1993J shows rising  $T_b$  before becoming optically thin. Suggested to indicate 1994I thick to synch. absorption by same electrons that emit, while 1993J is thick to free-free absorption by electrons outside SNR.

## Synchrotron Self-Comptonization (SSC)

If photon energy density is high enough, IC scattering occurs off same population of rel. electrons emitting synch.

Effect is to boost synch spectrum by  $\gamma^2$ .

Crab's synch. spectrum reaches  $\sim 40$  MeV but peaks around  $\sim 1$  eV (optical)  $\sim 10^{14}$  Hz,  $\gamma \sim 6 \times 10^5$ . Those photons boosted by  $\gamma \sim 6 \times 10^5$  electrons produce  $\sim 3 \times 10^{25}$  Hz gamma-rays — which is the peak of the IC spectrum.

Crab  
SED

This is also the IC emission required to compare  $\Theta$  Pic/Psynch to  $V_{\text{red}}$  & estimate  $U_B$ .

**Crab**  
B estimates

SSC spectra commonly observed in relativistic flows, e.g. jets from accreting objects.

SSC is part of explanation for similarity of Galaxy's appearance in low-freq. radio & hi-E  $\gamma$ -rays.

**Mult-X  
Milky Way**

Low-freq. radio continuum is (opt. thin) synchrotron radiation, Gamma rays produced from several sources.

Consider different photons as bg for IC; first, what are elements producing radiation?

Stars  $\rightarrow$  optical/near-IR (BB,  $\sim 1000$ s K)

Gas  $\rightarrow$  hot ( $10^6$  K)  $\rightarrow$  X-rays

Gas  $\rightarrow$  cool ( $\sim 100$  K) atomic  $\rightarrow$  21-cm atomic HI

Gas  $\rightarrow$  cold ( $\sim 10$  K) molecular  $\rightarrow$  2.6 mm CO

Dust  $\rightarrow$  mid-IR (BB, 100s K)

Cosmic rays  $\rightarrow$  synchrotron  $\rightarrow$  radio

Cosmic rays  $\rightarrow$  IC etc  $\rightarrow$   $\gamma$ -rays

Microwave bg  $\rightarrow$  far-IR (BB, 3 K)

Can calculate total interstellar radiation field by place in galaxy.

**Interstellar  
radiation,  
Strong**

In galactic plane, dominated by starlight, Away from plane, CMB dominates.

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Most common cosmic rays have  $\gamma \sim 10^4$ , typical interstellar B.

what do they produce?

$$\nu_{\text{syn}} = \frac{e^2 q B}{m \pi^2} = \frac{(10^4)^2 (1.6 \times 10^{-19})}{\pi^2 (9.1 \times 10^{-31} \text{ kg})} (3 \times 10^{-10} \text{ T})$$

$$\nu_{\text{syn}} = 5 \times 10^8 \text{ Hz, } 500 \text{ MHz.}$$

That's typical radio continuum.

Now calculate their IC upscatterings:  $\nu_{\text{IC}} = \frac{4}{3} \nu_{\text{syn}}$

$$\text{For CMB, } \nu \sim c/\lambda = \frac{c T}{0.0029 \text{ km}} = 3 \times 10^{14} \text{ Hz,}$$

$$\text{so } \nu_{\text{IC}} \sim 3 \times 10^{19} \text{ Hz, or } \sim 100 \text{ keV (hard X-rays).}$$

$$\text{For starlight, } \nu_{\text{opt}} \sim 5 \times 10^{14} \text{ Hz, } \nu_{\text{IC}} \sim 5 \times 10^{19} \text{ Hz, almost 1 GeV, } \gamma\text{-rays.}$$

So same electrons can produce radio

&  $\gamma$ -ray Galactic background.

So far, have only considered radiation from electrons, for either IC or synchrotron.

Consider our most detailed expression

$$\text{for } P_{\text{synch}} = \frac{e^2 q^2 B^2 v_i^2}{6 \pi \epsilon_0 m^2 c^3} - \text{depends on } m, \gamma.$$

Assume equipartition between protons, electrons  
then  $\gamma_p m_p c^2 = \gamma_e m_e c^2$ , so  $\gamma_p = \gamma_e m_e / m_p$ .

$$\text{So the ratio } \frac{P_{p, \text{synch}}}{P_{e, \text{synch}}} = \left( \frac{m_e}{m_p} \right)^4 = 9 \times 10^{-74}$$

So synchrotron is very inefficient for protons,  
Inverse Compton has similar dependence.

$P_{\text{IC}} \propto \sigma_T \gamma^2$ , but  $\sigma_T \propto \frac{1}{m^2}$ , so

$$\frac{P_{\text{IC}, p}}{P_{\text{IC}, e}} = \left( \frac{m_e}{m_p} \right)^4 = 9 \times 10^{-74} \text{ again.}$$