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Sub-THz emission processes in solar flares

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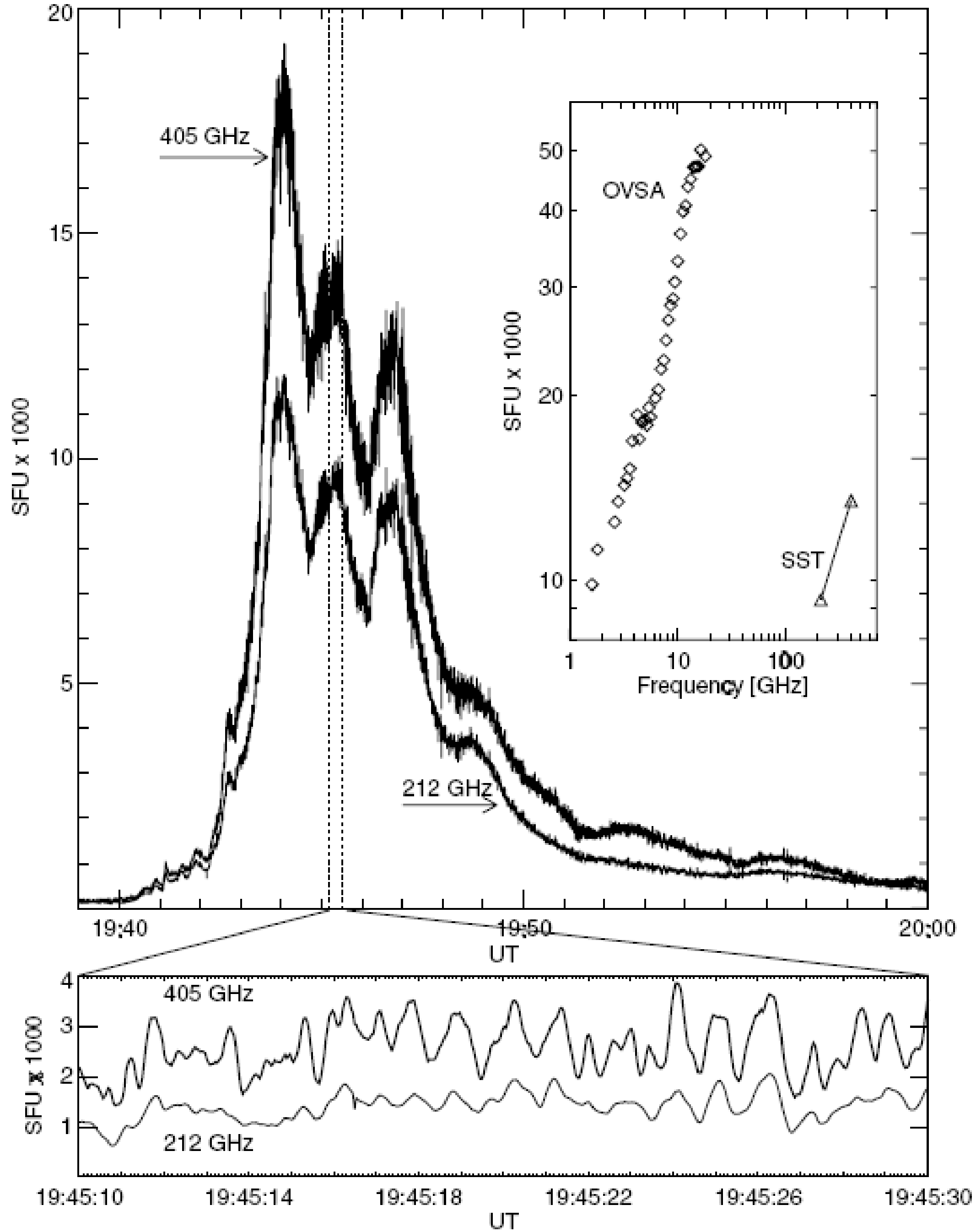
Sub-THz emission mechanisms

The main observational characteristics:

•relatively large radiation peak flux of the order of 10^4 sfu (Kaufmann et al. 2004);
•radiation spectrum rising with frequency $F(f) \propto f^{\delta}$;
•spectral index varying with time within δ ~ 1–6;
•sub-THz component can display a sub-second time variability with the modulation about 5% (Kaufmann et al. 2009);
• the source size is believed to be less than 20’’ (however, it is indirect conclusion) (see also Luthi et al. 2004a, 2004b for large source indications)



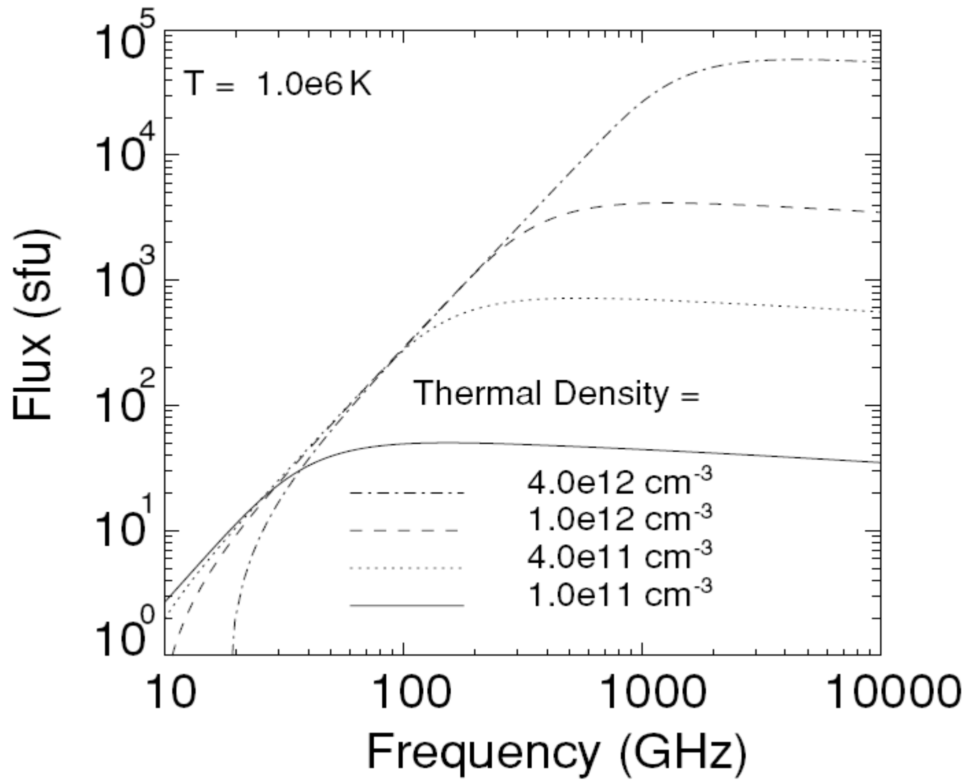
Sub-THz emission mechanisms

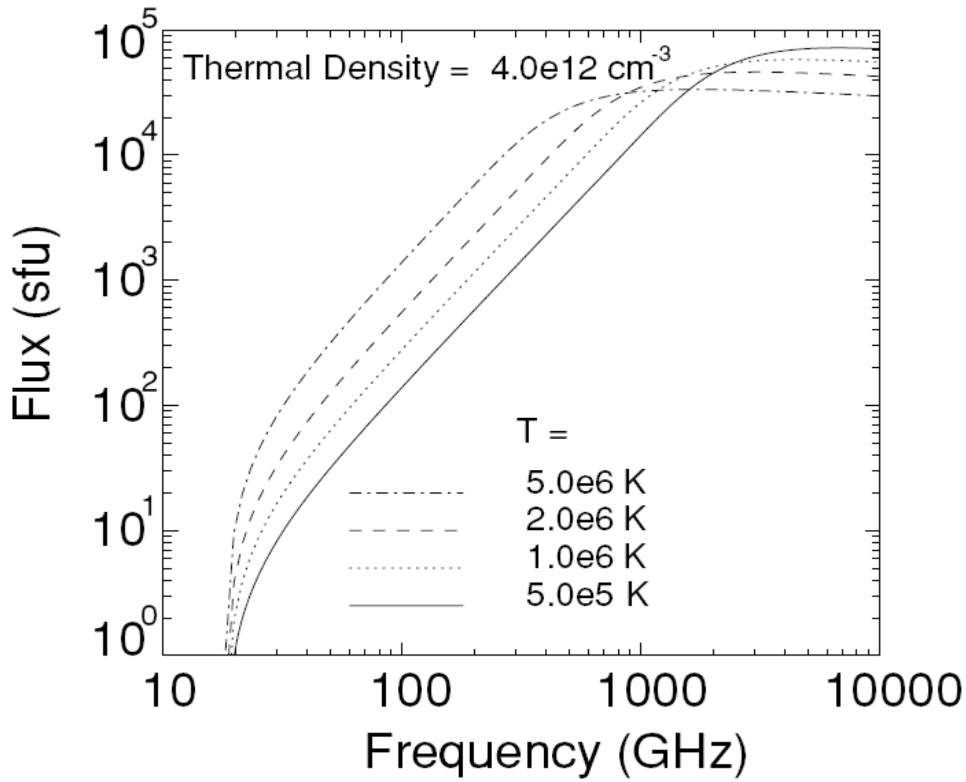
We consider a more complete list of emission mechanisms, capable of producing a sub-THz component, both well known and new in this context, and calculate a representative set of their spectra produced by:

(1) free-free emission;
(2) Gyrosynchrotron emission;
(3) Synchrotron emission from relativistic positrons/electrons;
(4) Diffusive radiation;
(5) Cherenkov emission;

(1) Free-free emission

A rising spectrum from a compact (20'') source requires that the source is relatively **dense** (n_e~10^{11} cm^{-3}) and **hot** (T_e ~10 MK).





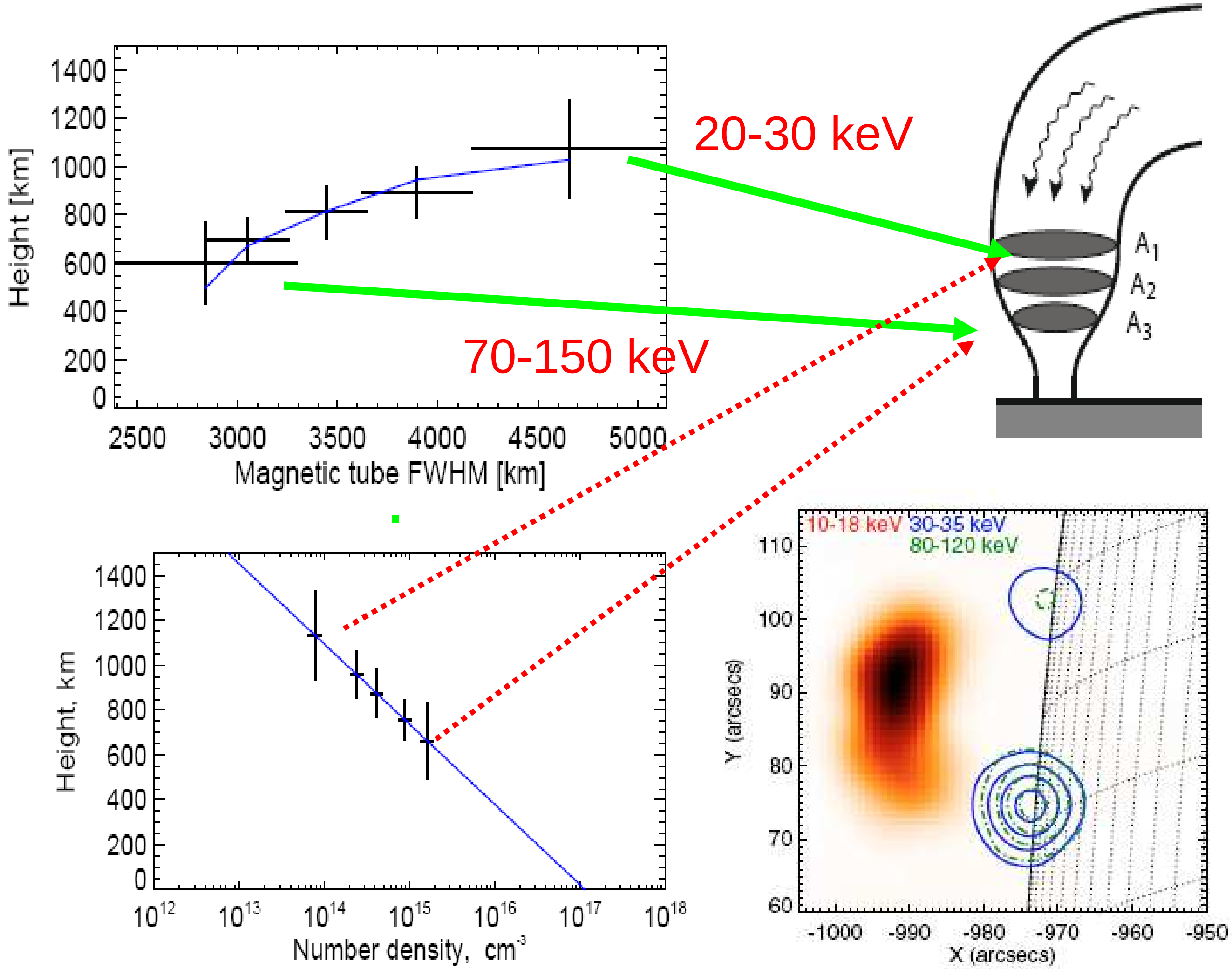
Thermal free-free radio spectra produced from a uniform cubic source with a linear size of 20'' for $n_e = 10^{11}$ to 4×10^{12} cm^{-3} and T_e = 0.5–5 MK.

Note, that from the observations we can exclude the option of a source that is both **dense and hot**, say $n_e \sim 10^{12}$ cm^{-3} and T_e ~ 10 MK, EM = $n_e^2 V \sim 3 \times 10^{51}$cm^{-3}.

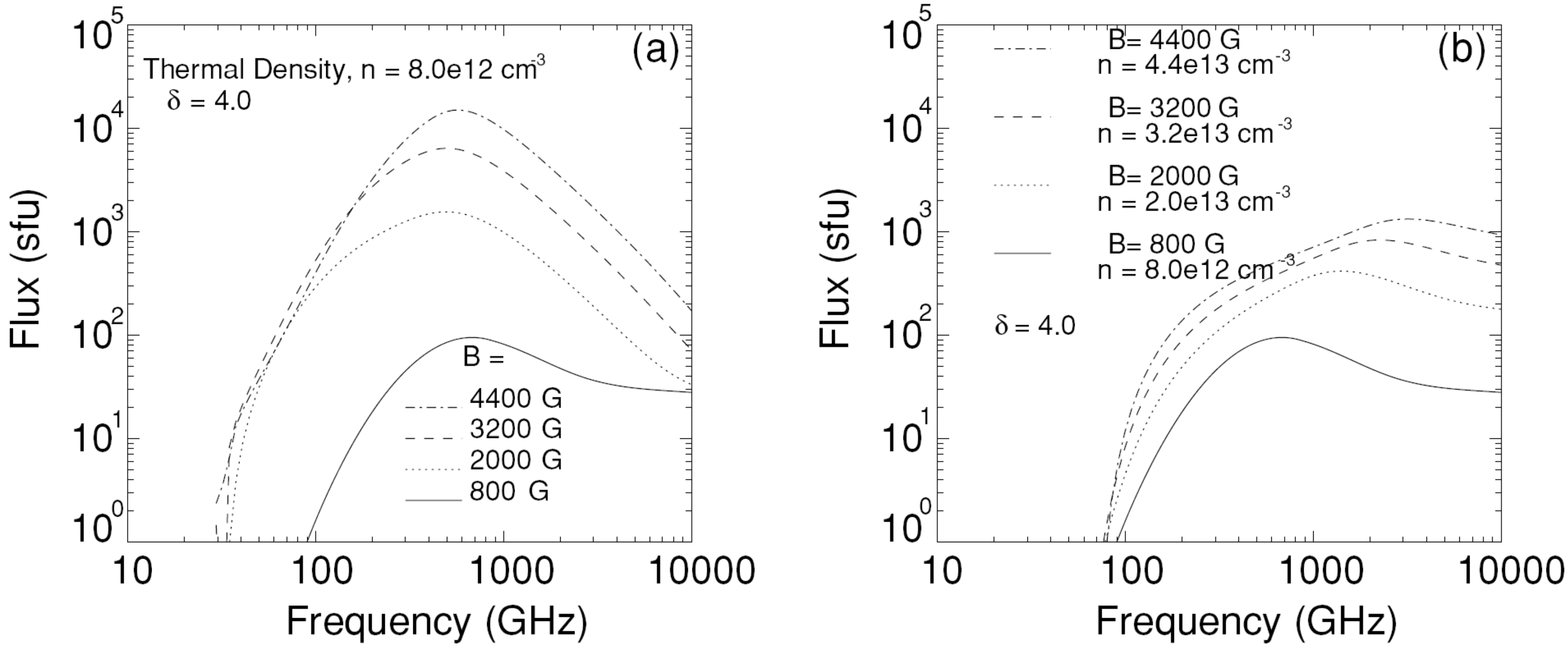
(2) Free-free emission

Temporal pulsations of the free-free emission could be MHD oscillations (e.g. sausage mode) of the corresponding magnetic loop is an attractive scenario (e.g., *Fleishman et al. 2008*).

Sizes: The flux density above the 1000 sfu level requires the thermal electron number density above 10^{12} cm^{-3} or/and the linear size of the source above 20''. While the observations (*Kontar et al, 2008*) suggest that electrons deposit their energy in the chromosphere at the heights 10^8 cm with relatively high density. Therefore, a flare heated chromosphere could contain small (>2'') free-free emitting regions with very high density 10^{13}-10^{15} cm^{-3} with temperatures from 10^4 K up to a few 10^5 K.



(3) Gyrosynchrotron Emission



(a) Radio spectra produced by GS plus free–free contributions from a uniform source with a size of 1 for $n_e = 8 \times 10^{12}$ cm^{-3} and B = 800–4400 G.
(b) Razin-suppressed GS spectra with the Razin frequency 200 GHz plus the free–free component.

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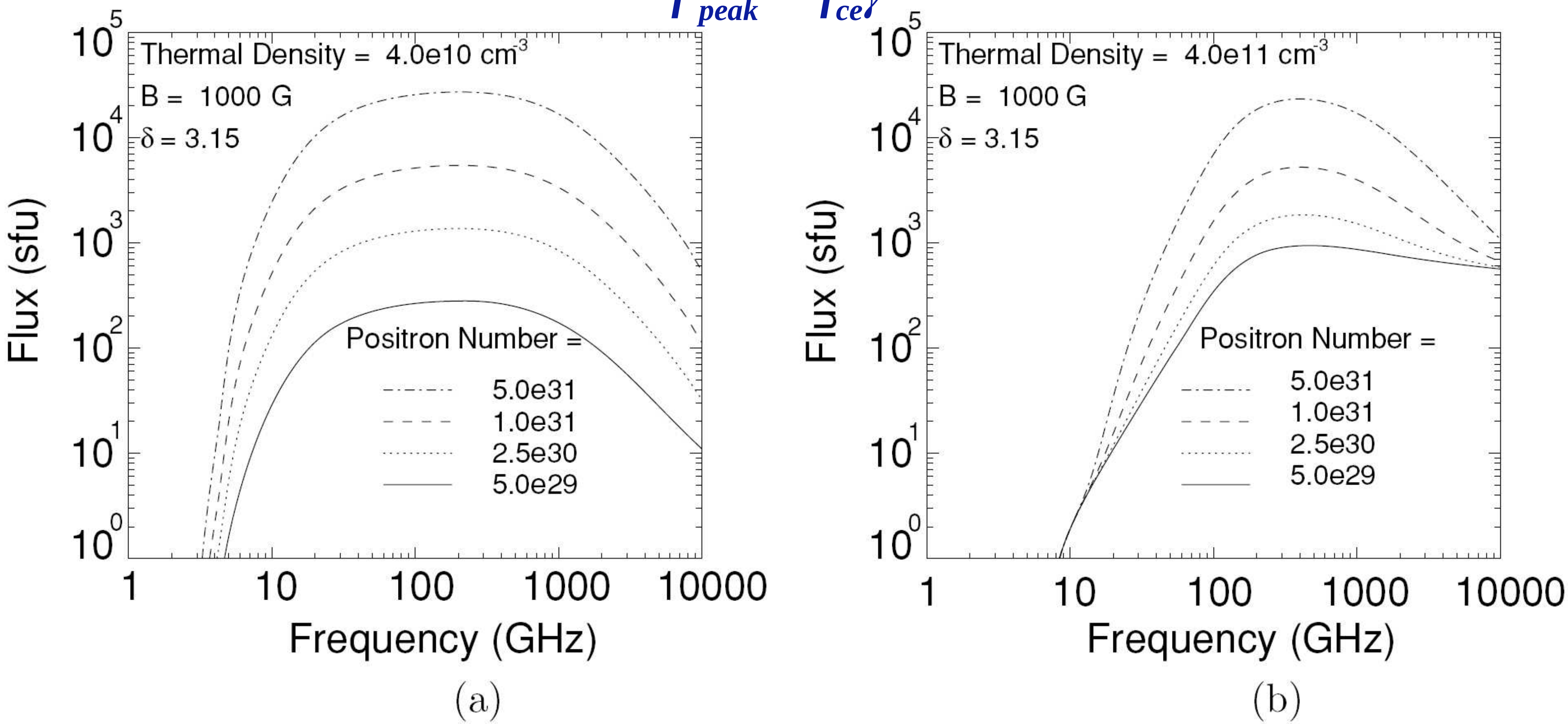
(2) Gyrosynchrotron Emission

Time variability: Due to electrons flux variations (?)

Size: Footpoint size or less (An increase of the source size above 2’’ with the same total number of fast electrons, magnetic field, and thermal electron density results in a spectrum totally dominated by the free–free contribution)

(3) Synchrotron emission from positrons

$f_{peak} \sim f_{ce}\gamma^2$



Radio spectra produced by **synchrotron radiation from relativistic positron plus free–free** contribution from a uniform cubic source with a linear size of 20'' for the total instantaneous positron number $N_{e+} = 5 \times 10^{29}$ to 5×10^{31}, with energy $\gamma = 20$ (~10 MeV), magnetic field $B = 1000$ G, the thermal electron density $n_e = 4 \times 10^{10}$ cm^{-3} (a) and $n_e = 4 \times 10^{11}$ cm^{-3} (b), and $T_e = 1$ MK.

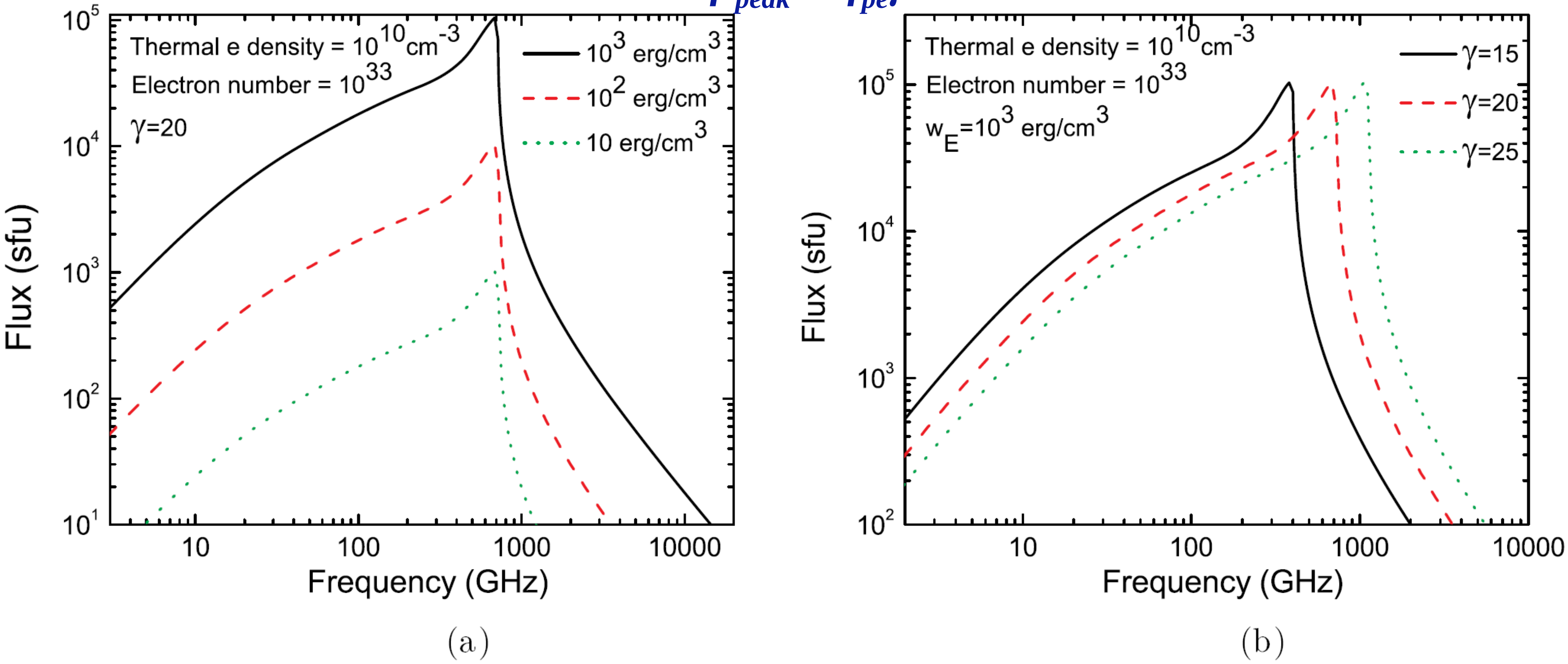
(3) Synchrotron emission from positrons

Time variability: Due to the positron flux variations (?)

Size: footpoints of a flaring loop (~2-7'') or in a moderate-size (<20'') coronal flaring loop

(4) Emission from Langmuir waves

$f_{peak} \sim 2 f_{pe} \gamma^2$



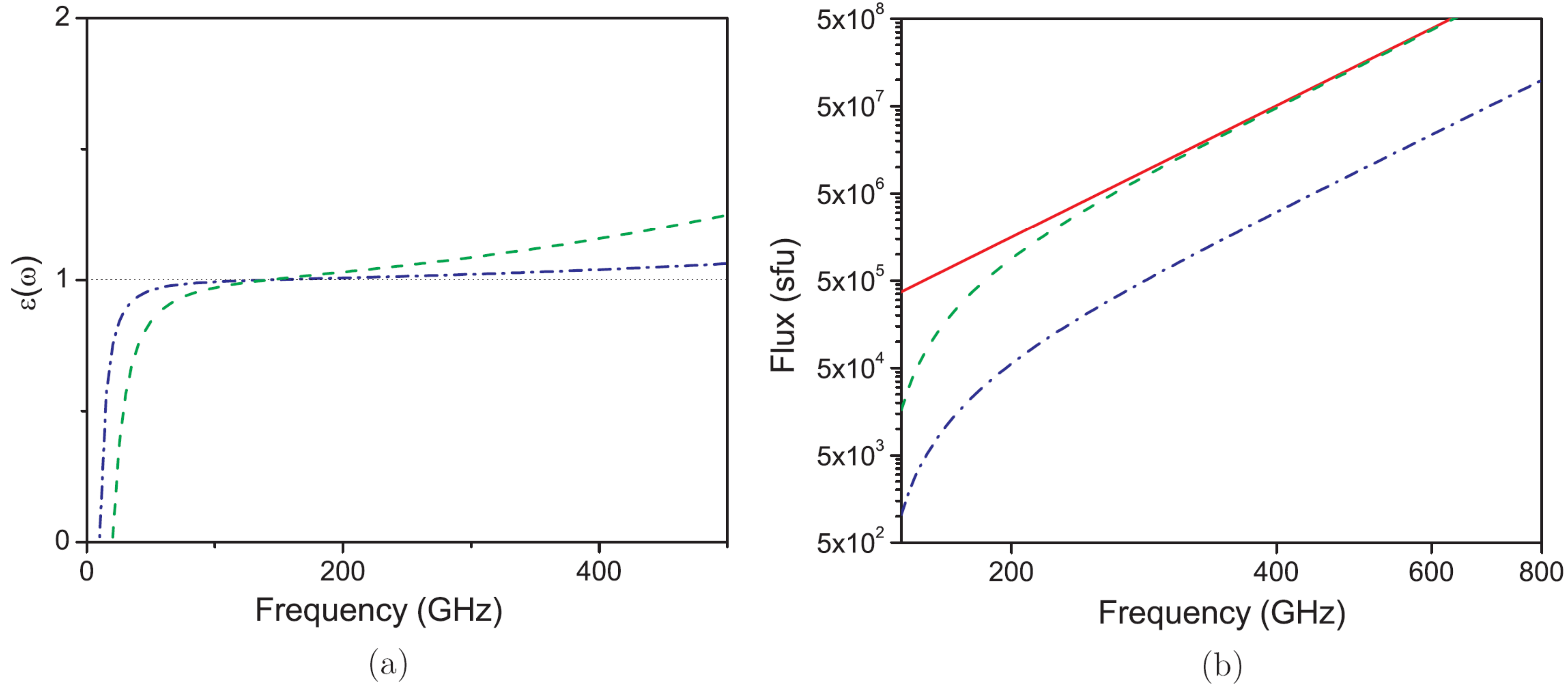
Diffusive Radiation produced by relativistic electrons/positrons in long-wave Langmuir turbulence $\lambda > 2\pi c/\omega_{pe}$. (a) Dependency on Langmuir wave energy density. (b) The spectra for different Lorentz factors.

(4) Emission from Langmuir waves

Time variability: Turbulence variations, electron/positron flux variations

Size: footpoints of a flaring loop (~2-7’’) or in a moderate-size (<20’’) coronal flaring loop

(5) Cherenkov radiation



(a) Model of plasma dielectric permittivity with molecular line contribution included; (b) Vavilov–Cherenkov radiation produced by fast electrons with a power-law distribution over the velocity—blue (dash-dotted) and green (dashed) curves; the red (solid) curve is for $\varepsilon(\omega) = 1 + \omega^2/\omega_0^2$, i.e., without standard plasma contribution.

(5) Cherenkov emission

Time variability: electron flux variations

Size: chromospheric footpoints of a flaring loop (~2-7'')

Sub-THz emission mechanisms

Emission mechanism	Flux, sfu	Spec. index	Time variations, s	Size, arcsec	Advantages	Disadvantages
Free-free	~< 10^4	0-2*	>1	> 20	Explains flux before the flares, large scale sources	no strong compact source possible
Gyrosynchrotron	~< 10^4	< 3†	>0.1	1-2	Flux variations as in HXR	Fields *B*>4000G, spectral index
Synchroton from positrons	~< 10^4	1/3† *	>0.1	arbitrary	Correlation with *gamma*-lines	Number of positrons
DRL	~<10^4	< 2†	>0.01	arbitrary	Flux variations	Strong level of Langmuir waves
Cherenkov emission	~<10^6	arbitrary	>0.1	<10	Large flux values	Uknown chromospheric permitivity
Observations	**~>10^4**	**1…6**	**0.1-100**	**<20-60**		

† -line-of-sight absorption can steepen the spectrum, but will decrease the flux

** - free-free absorption in the source can make spectral index ~<2, but will reduce the flux*