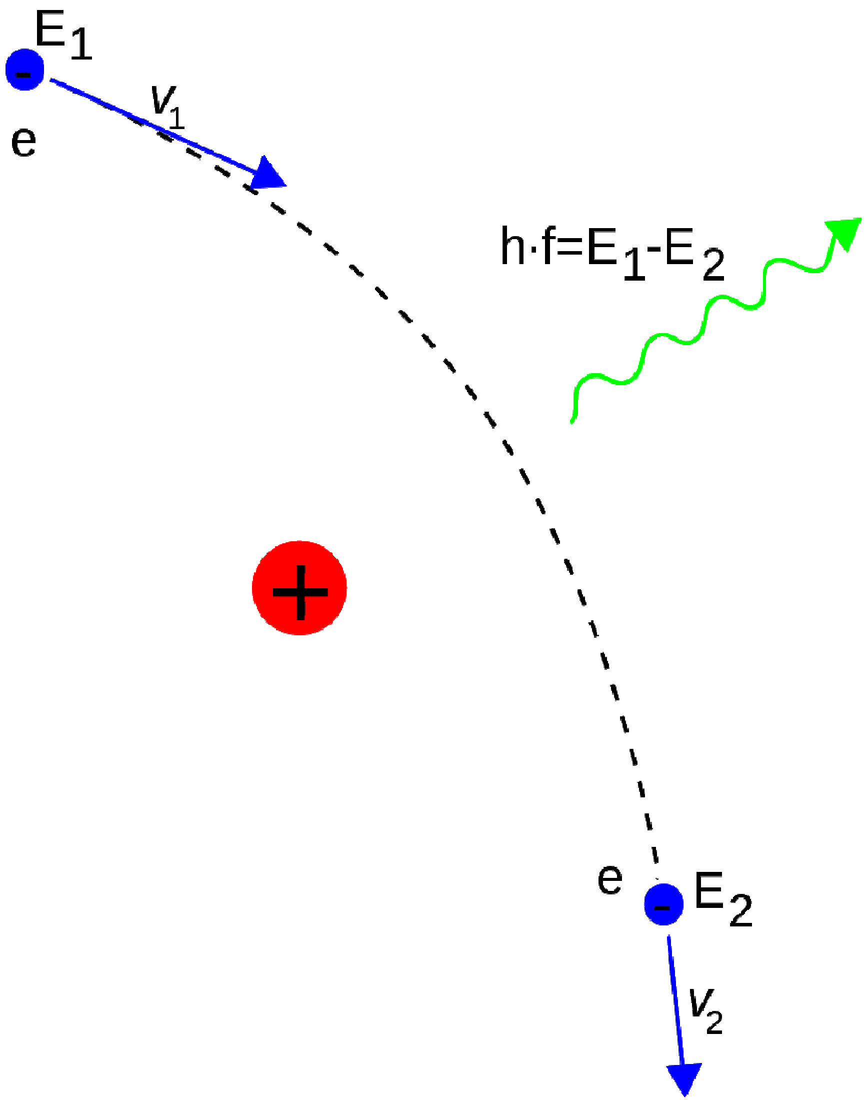
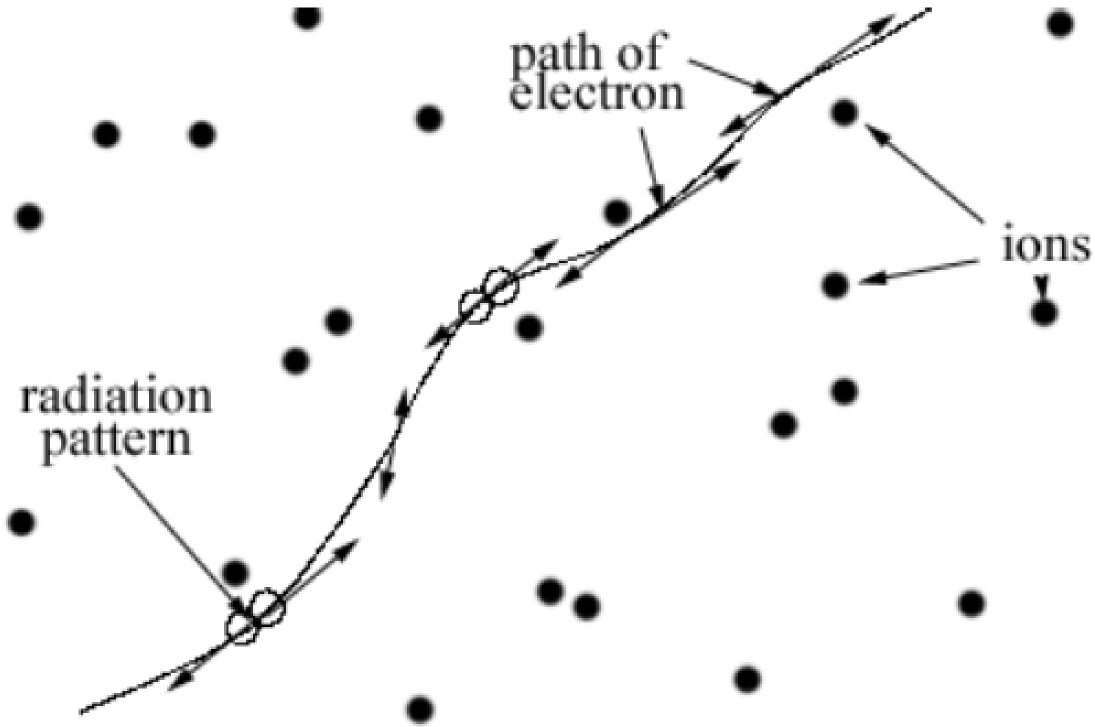
Bremsstrahlung





https://en.wikipedia.org/wiki/Bremsstrahlung https://web.njit.edu/~binchen/phys780/

Thin-target Bremsstrahlung:

incident electron distribution is nearly unchanged, evolves slowly under the influence of collisions

Thick-target Bremsstrahlung:

incident electrons are completely stopped or thermalized in the high-density target

substantial change in incident electron distribution

much quicker energy loss from electrons → lots of X-ray photons emitted → intense X-ray emissions (~10 keV–300 keV)

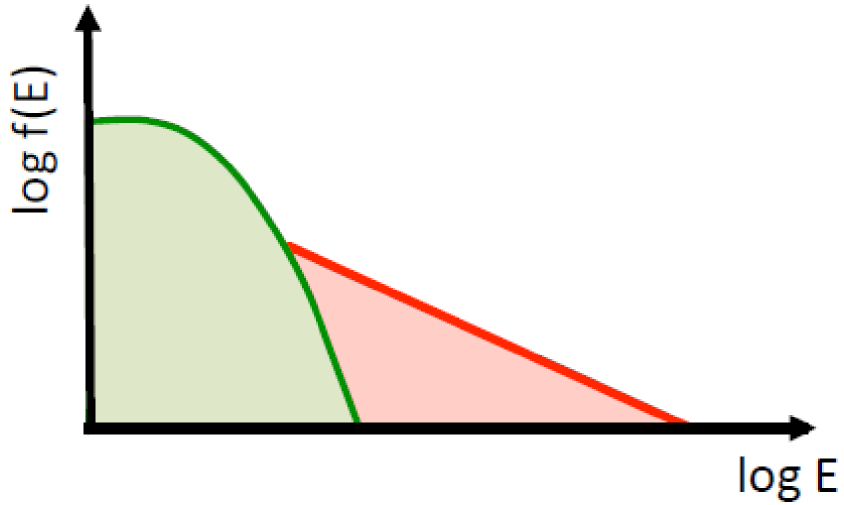
The photon flux emitted per unit energy observed at a distance R is obtained by integrating over the emitting source volume V or, for an imaged source, along the line-of-sight through the source region.

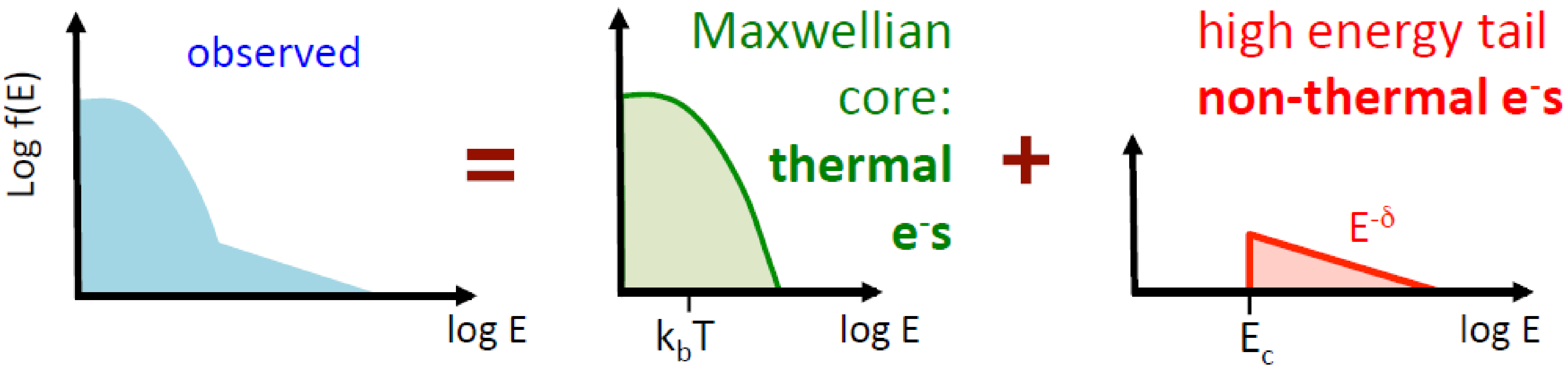
Holman et al. (2011); Kontar et al. (2011); White et al. (2011); Oka et al. (2018)

Collision rate scales inversely with energy.
Collisions "relax" distribution toward a Maxwellian.

Low energy particles relax quickly
→ **Maxwellian core**

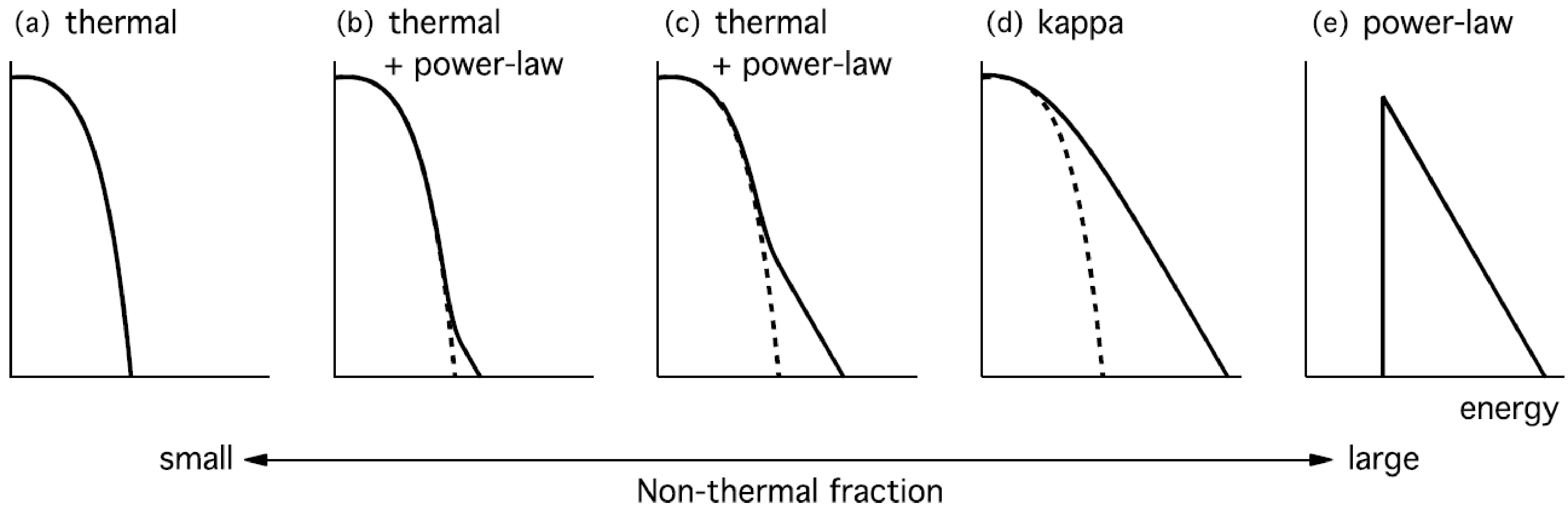
High energy particles fail to relax
→ **tail**

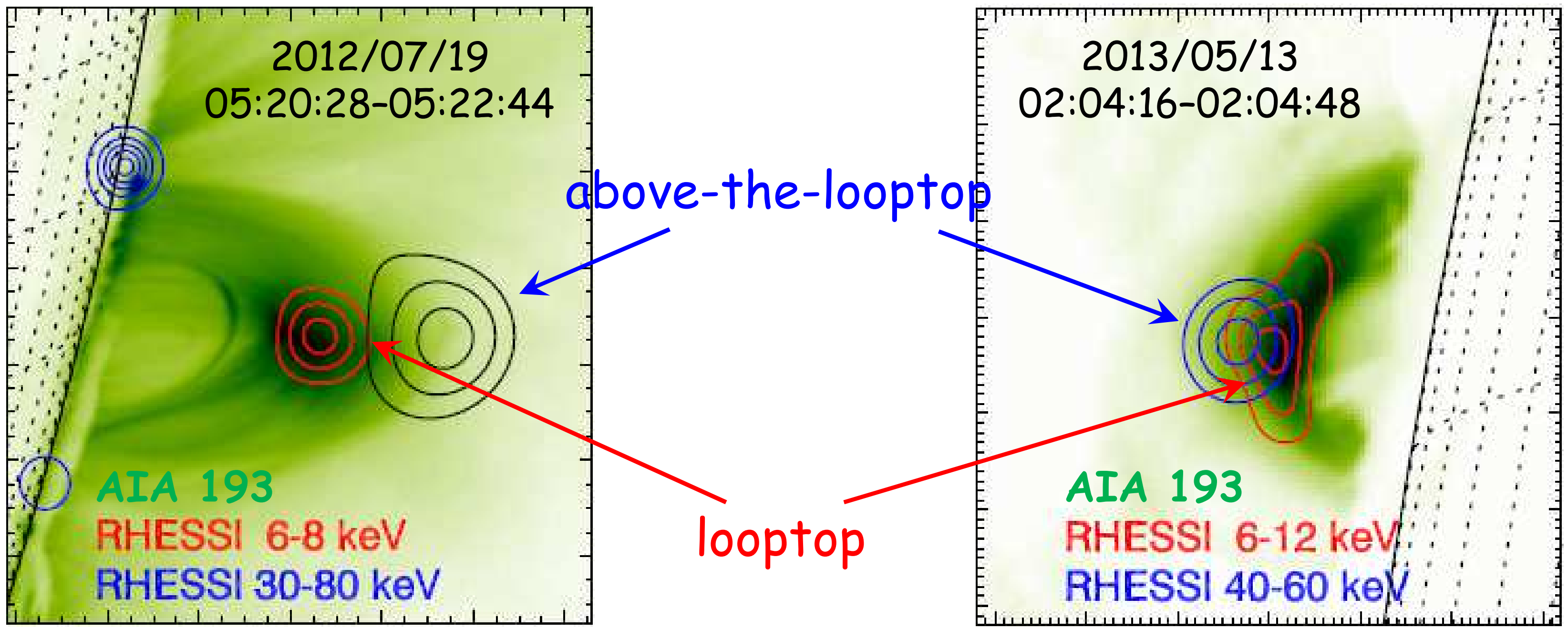




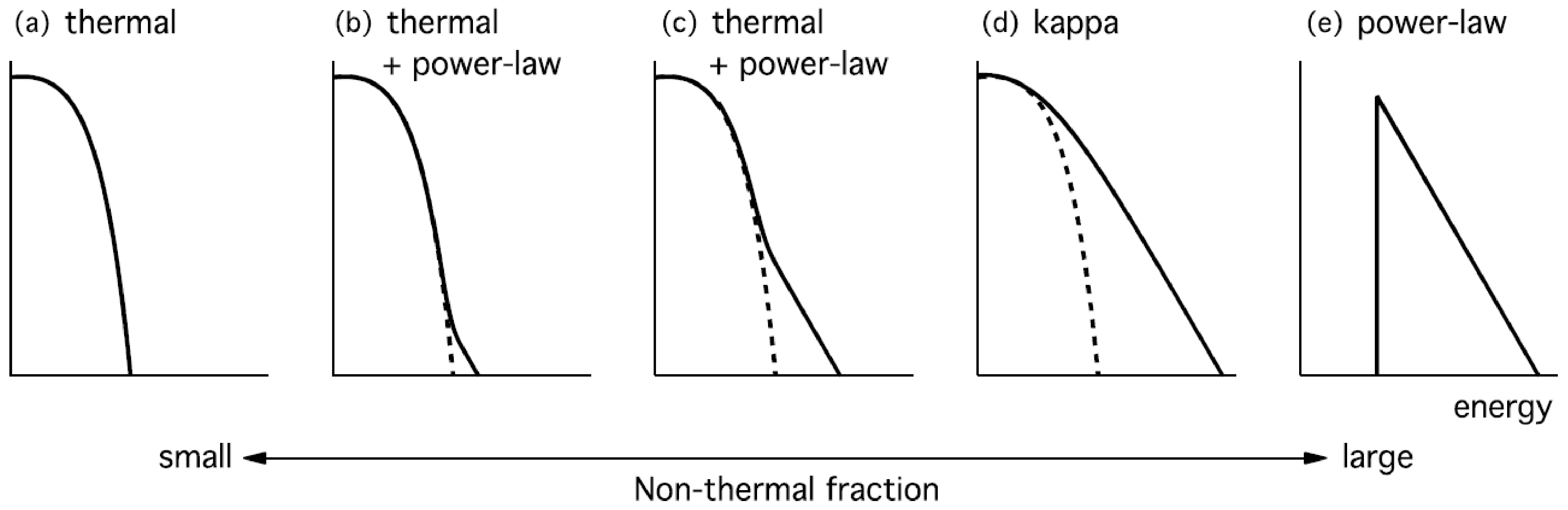
Radiation from a Maxwellian particle distribution is referred to as thermal radiation.
Radiation from a non-Maxwellian particle distribution is referred to as nonthermal radiation.

https://web.njit.edu/~binchen/phys780/LectureNotes/lec20.pdf http://solar.physics.montana.edu/dana/ph591/lec17.pdf





Oka et al. (2015)



Thermal (Maxwellian):

$$F_{\mathrm{M}}(E) = \frac{2N_{\mathrm{M}}\sqrt{E}}{\sqrt{\pi (k_B T_{\mathrm{M}})^3}} \exp\left(-\frac{E}{k_B T_{\mathrm{M}}}\right)$$

Power-law:

$$F_{\mathrm{PL}}(E) = N_{\mathrm{PL}}(\delta - 1) E_{\mathrm{c}}^{\delta-1} E^{-\delta} \quad (\text{for } E \geqslant E_{\mathrm{c}})$$

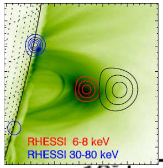
Kappa:

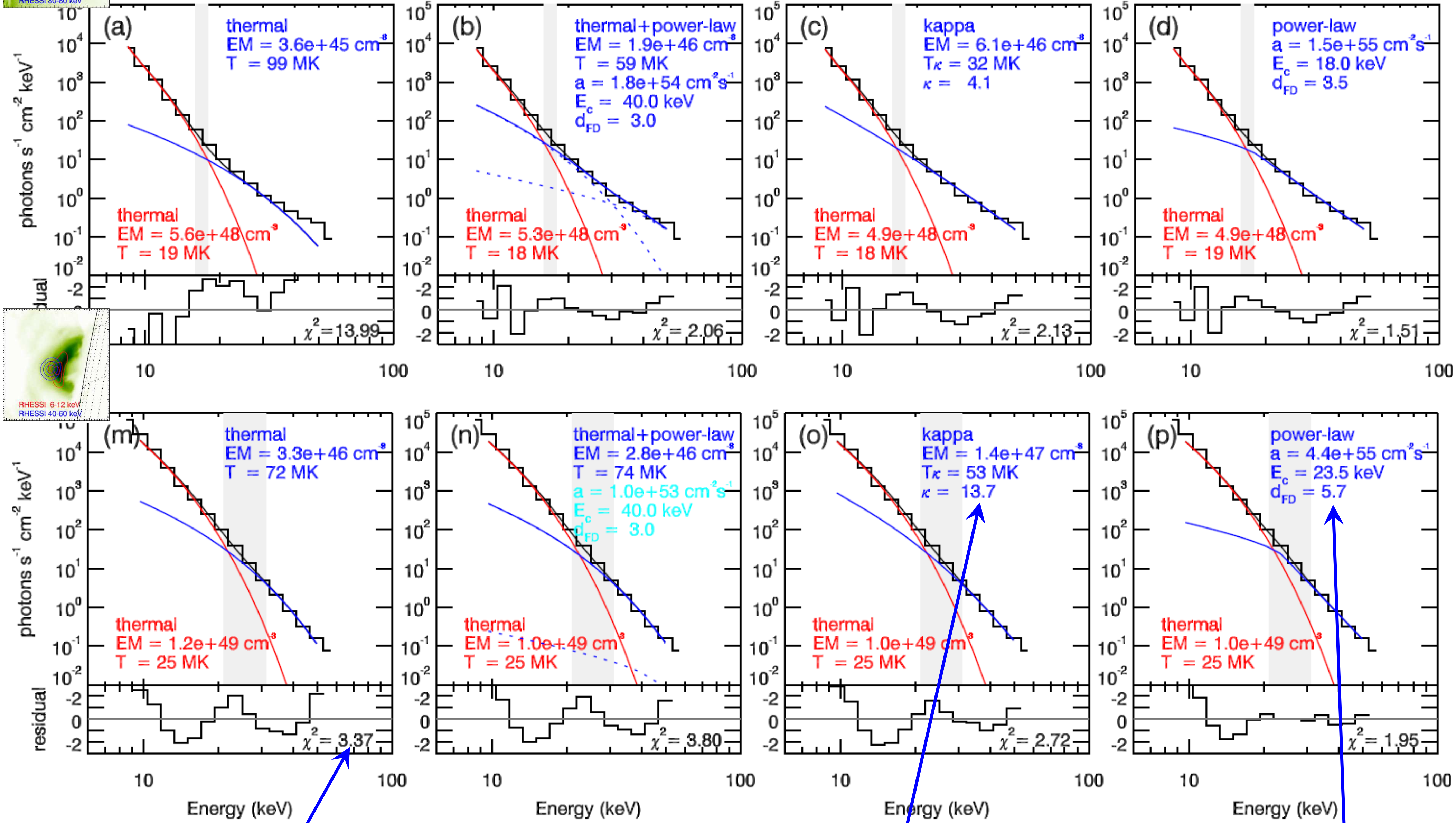
$$F_{\kappa}(E) = \frac{2N_{\kappa}\sqrt{E}}{\sqrt{\pi (k_B T_{\kappa})^3}} \frac{\Gamma(\kappa + 1)}{(\kappa - 3/2)^{3/2}\,\Gamma(\kappa - 1/2)} \left[1 + \frac{E}{k_B T_{\kappa}(\kappa - 3/2)}\right]^{-(\kappa+1)}$$

F: differential density (cm^{-3} keV^{-1})
E: particle energy
N: number density
T: temperature,
E_c: lower-energy cutoff
δ and κ: power-law indices
Γ: Gamma function

Oka et al. (2015)

The thermal+power-law model systematically overestimates and underestimates the temperature and density, respectively, due to the lower-energy cutoff E_c.





less enhanced nonthermal tail

close to Maxwellian

less significant nonthermal component

https://hesperia.gsfc.nasa.gov/ssw/packages/spex/idl/object_spex/fit_model_components.txt

Oka et al. (2015)

$F(E,\mathbf{r})$: electron flux density distribution

electrons cm^{-2} s^{-1} keV^{-1}

$F(E)$: electron flux distribution

electrons s^{-1} keV^{-1}

$f(E,\mathbf{r})$: electron density distribution

electrons cm^{-3} keV^{-1}

$$F(E,\mathbf{r}) = f(E,\mathbf{r})v(E)$$

assume $F(E,\mathbf{r}) \propto E^{-\delta}$, $f(E,\mathbf{r}) \propto E^{-\delta'}$

$$\gamma_{thin} = \delta + 1,\ \gamma_{thick} = \delta - 1$$

$$\gamma_{thin} = \delta' + 0.5,\ \gamma_{thick} = \delta' - 1.5$$

Holman et al. (2011)