Coronal vs chromospheric heating through co-spatial return currents during the 19 and 20 Jan 2005 solar flares

Meriem Alaoui[1,2]
Gordon Holman[2]

[1]Department of Physics
Catholic University of America

[2]Goddard Space Flight Center, NASA
Solar Physics Laboratory

RHESSI meeting, 2016

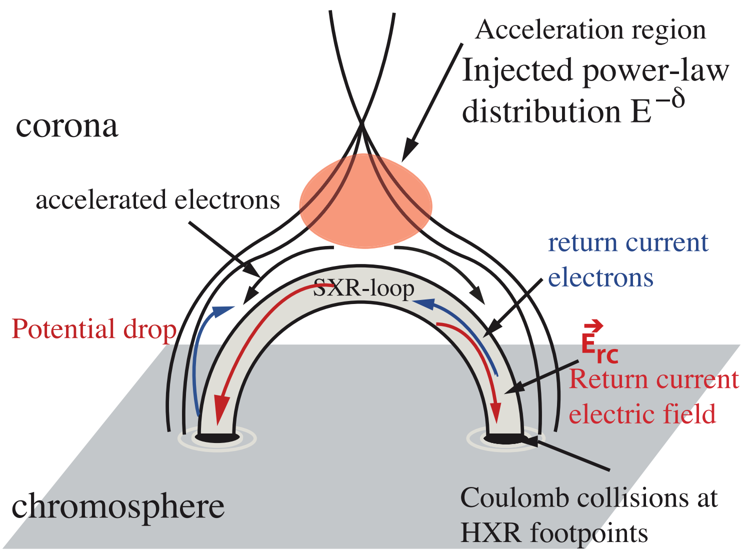
Outline of Topics

Why study return currents?

- They heat the corona and modify the shape of x-ray spectra
- They solve the electron number and associated current stability "problems"
  High electron fluxes on the order 10^{36} electrons/s (e.g. Hoyng et al. 1976)
  => charge separation and high induced magnetic field, at least 3 orders of magnitude higher than coronal magnetic field

Standard collisional thick-target model with return currents

Beam propagates in a conducting plasma => charge displacement by the beam will create a current
(e.g. Knight & Sturrock 1977; Emslie 1980,1981; Rowland & Vlahos 1985; Litvinenko & Somov 1991; Zharkova & Gordovskyy 2006, Holman 2012)



Alaoui & Holman (in preparation)

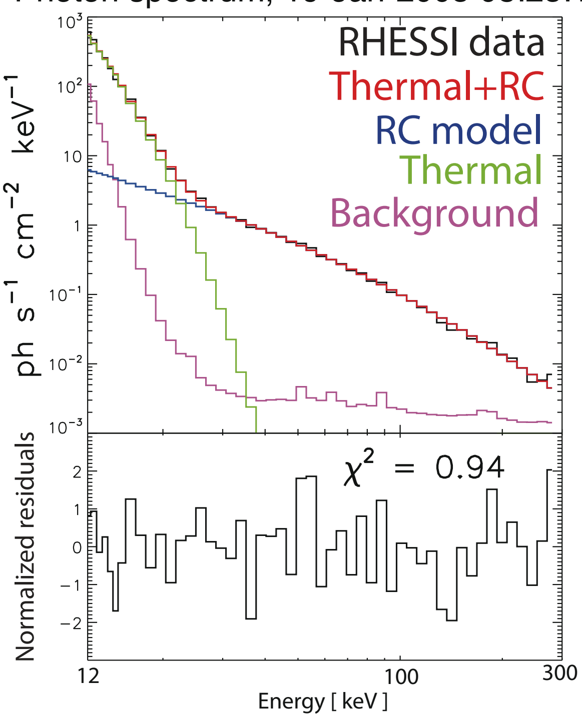
Return current collisional thick-target model: Assumptions

Adapted from Holman 2012

- 1D and J parallel to B
- Injected power law electron distribution $E^{-\delta}$ with sharp low-energy cutoff at the loop top
- J_{RC} has had the time to reach the steady state and $J_{RC} = J_{direct}$
- Electrons are thermalized and lost from the beam when their energy decreases to δk_B T (from Kontar et al. 2015)
- All the spectral flattening is due to potential drop associated with return currents

Spectral fits using the return current model

Photon spectrum, 19-Jan-2005 08:25:12 UT



Fit parameters

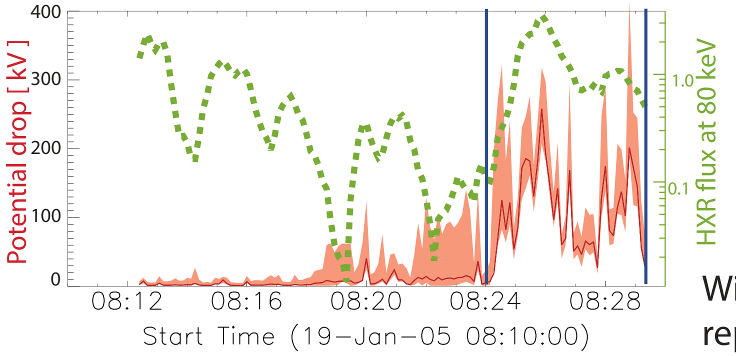
Non-thermal parameters

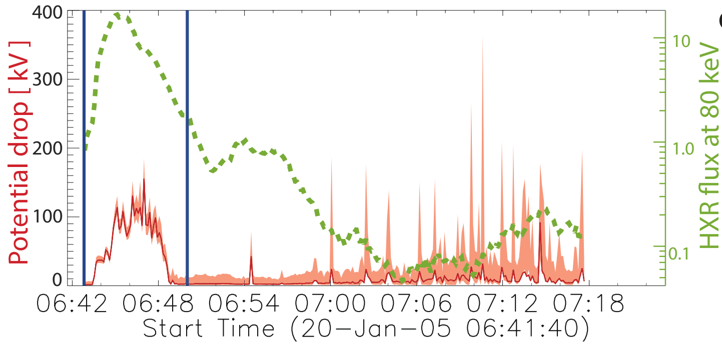
Total electron flux 5×10^{32} e^-/s
Potential drop 160 kV
Spectral index $\delta = 5.2$
Max. low-energy cutoff 58 keV
High-energy cutoff (fixed) 32 MeV

Thermal parameters

Temperature 27 MK
Emission measure 10^{49} cm^{-3}

HXR light curve and potential drop time evolution



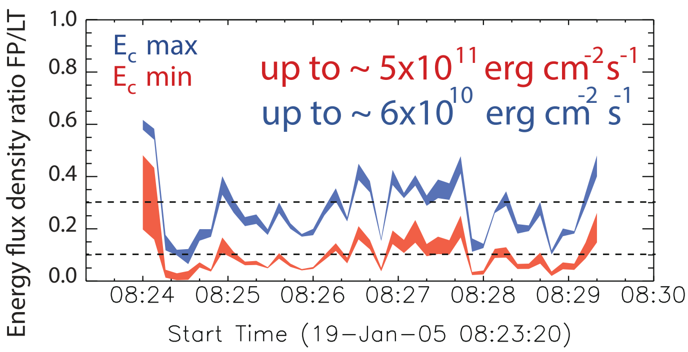


Width of the curves represents the 67 % confidence interval from 1000 Monte Carlo runs

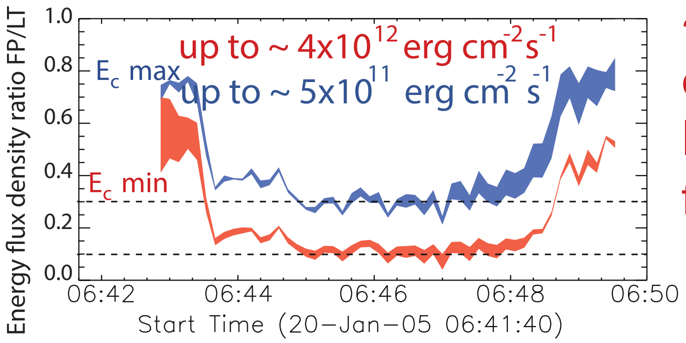
Co-spatial return current model
Spectral fits with co-spatial return current model
Heating due to return-current losses
Deduced plasma and beam parameters
Conclusions

How much energy flux density reaches the footpoints?
What is the total energy deposited in the corona?

How much energy flux density reaches the footpoints?

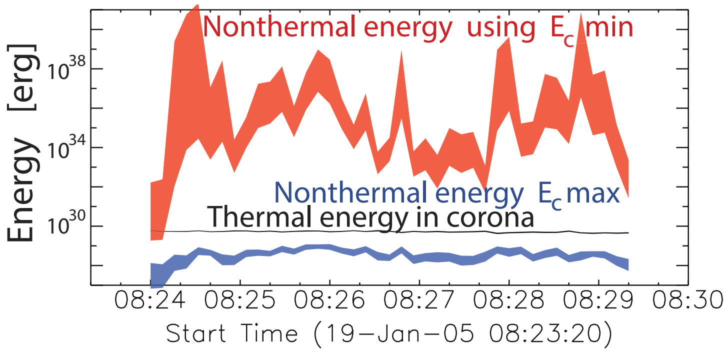


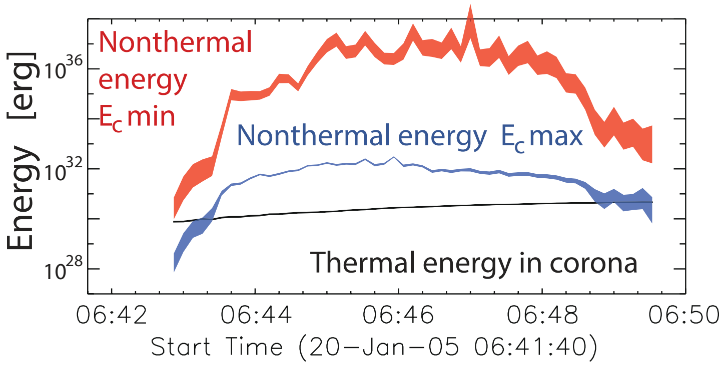
~30% of energy flux density injected at loop top reaches footpoints (E_c max)



~10 % of energy flux density injected at loop top reaches footpoints ($E_c$min)

How much energy is lost in corona due to RC losses?

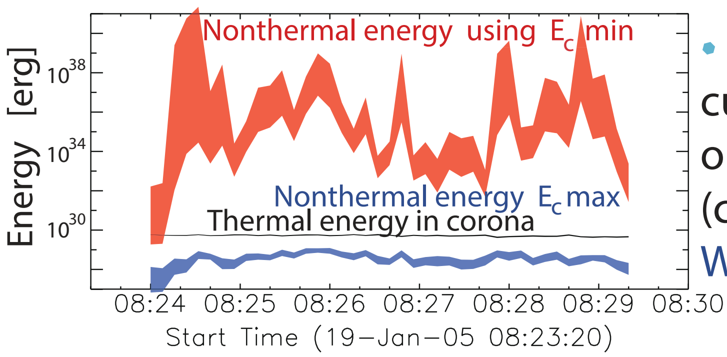




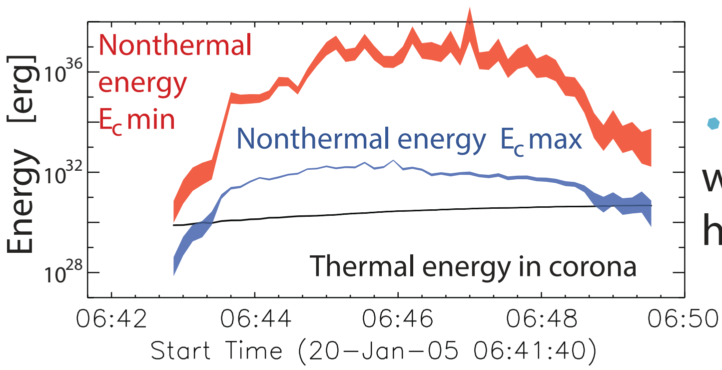
Co-spatial return current model
Spectral fits with co-spatial return current model
Heating due to return-current losses
Deduced plasma and beam parameters
Conclusions

How much energy flux density reaches the footpoints?
What is the total energy deposited in the corona?

How much energy is lost in corona due to RC losses?



- Value of low-energy cutoff should be high, on the order of E_c max (consistent with Warmuth et al. 2009)



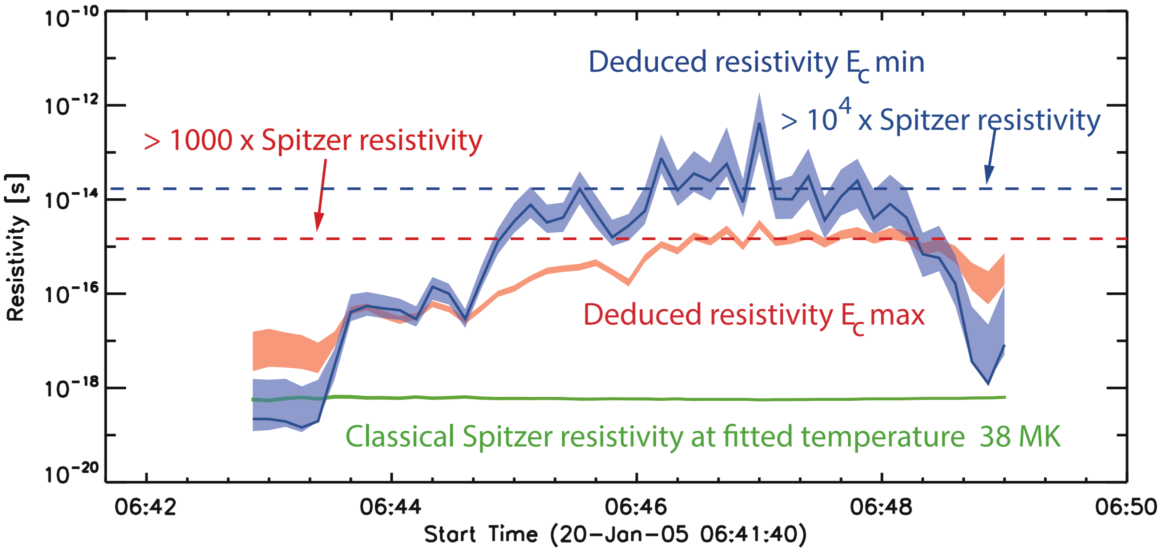
- Result consistent with return current heating

Intermediate summary

- δ k T is too low a low-energy cutoff
- It is possible to discriminate between a spectral flattening due to a high value of the low-energy cutoff and a potential drop
- 19-Jan-2005 better explained with a high value of the low-energy cutoff 120 keV rather than a potential drop
- 20-Jan-2005 is consistent with a potential drop flattening

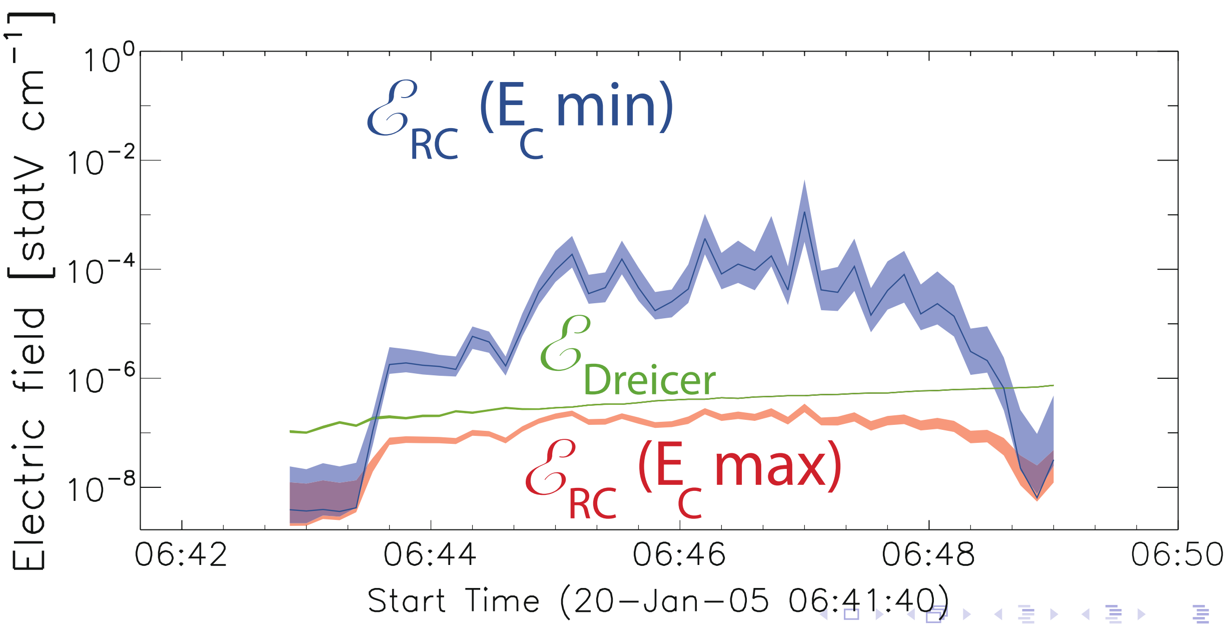
When return-current losses are the better explanation for the spectral flattening, what can be deduced about plasma and beam parameters?

Is the resisitivity classical or anomalous?



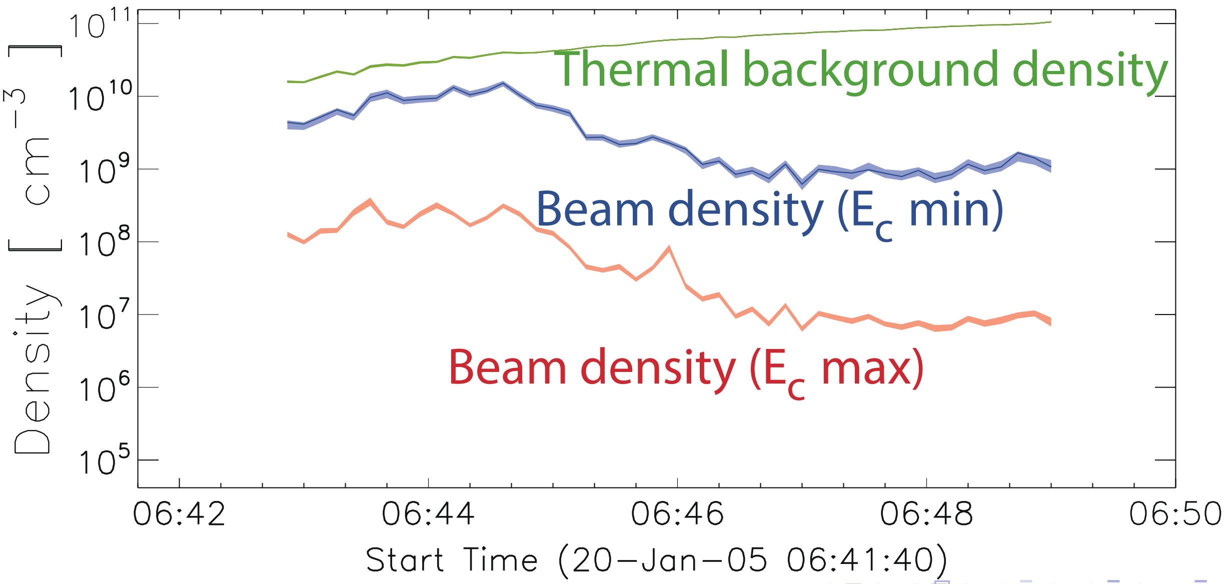
Co-spatial return current model
Spectral fits with co-spatial return current model
Heating due to return-current losses
Deduced plasma and beam parameters
Conclusions
Is the resistivity classical or anomalous?
Return current electric field vs. Dreicer field in the corona?
Background density vs. beam density

How does the return current electric field compare to Dreicer field in the corona?



Alaoui, Holman
Return currents in solar flares

Are there enough electrons in the background plasma to form the return current?



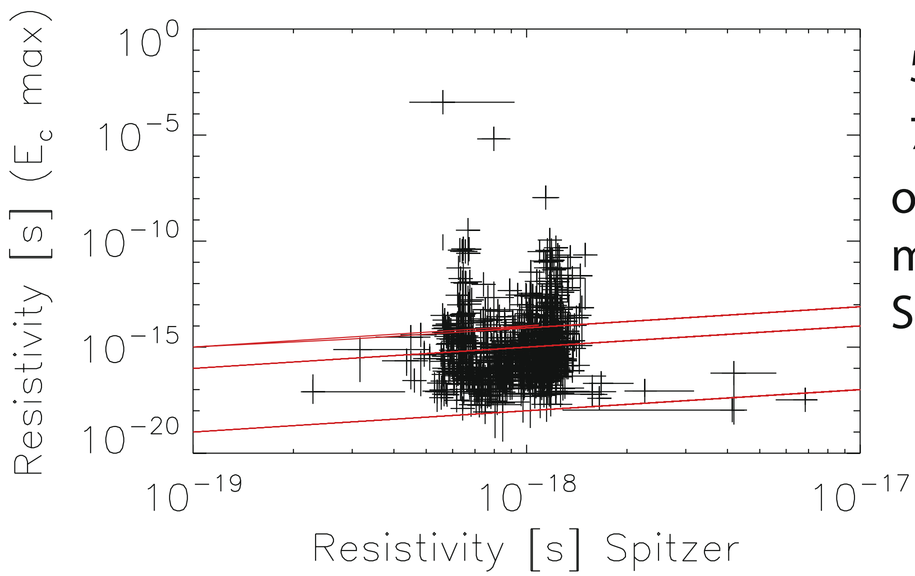
Conclusions

- Return current collisional thick-target model provides good fits to x-ray spectra with *strong* breaks
- Energy flux density in footpoints is 10% to 30% the injected energy flux density at loop top when potential drop is significant
- Thermal response of the plasma gives an indication of the plausibility of return currents being significant and observable
- Resistivity in the corona is up to 3 orders of magnitude higher than classical Spitzer resistivity at loop top temperature at E_c max

Other collaborators:
Brian Dennis, Kim Tolbert, Richard Schwarz, Joel Allred

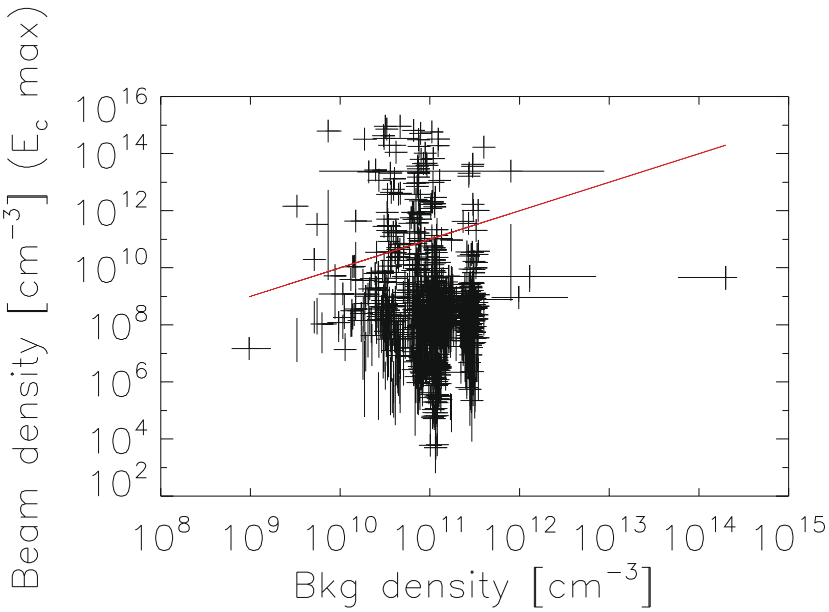
meriem.alaouiabdallaoui@nasa.gov

All other spectra with significant potential drop



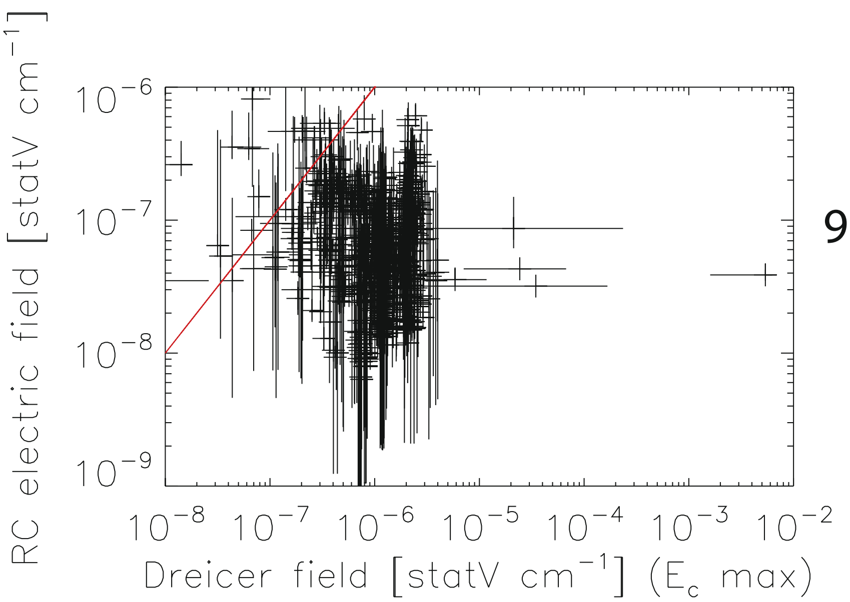
56%<3
78% <4
orders of magnitude Spitzer resistivity

All other spectra with significant potential drop



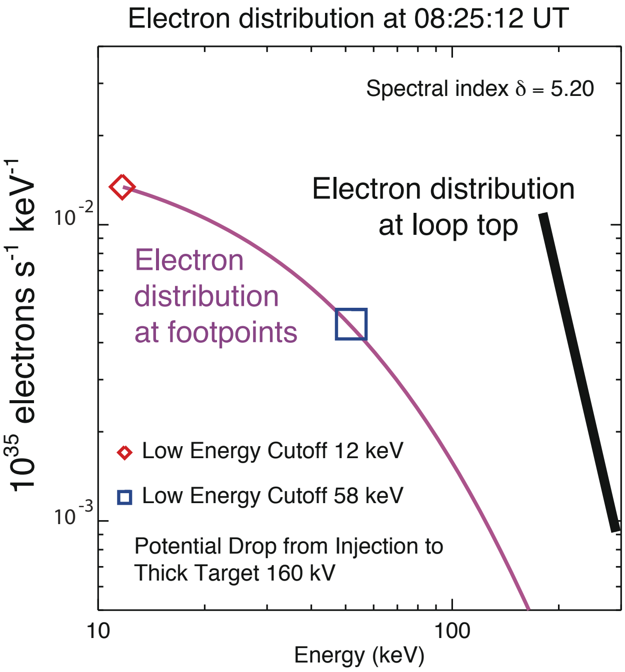
84% $n_{beam} \lesssim n_{bkg}$

All other spectra with significant potential drop



97% $E_{RC} < E_{Dreicer}$

Limits on the low-energy cutoff



Lower limit on low-energy cutoff 12 keV at the footpoints: $E_c = \delta k T$

Upper limit on low-energy cutoff 58 keV at the footpoints: $E_c = E_c \max$ (fitted)

E_c (loop top) = E_c (fitted) + V

↓ Potential drop