Leibniz-Institut für Astrophysik Potsdam

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Thermal-nonthermal energy partition in solar flares: current state and first results from STIX

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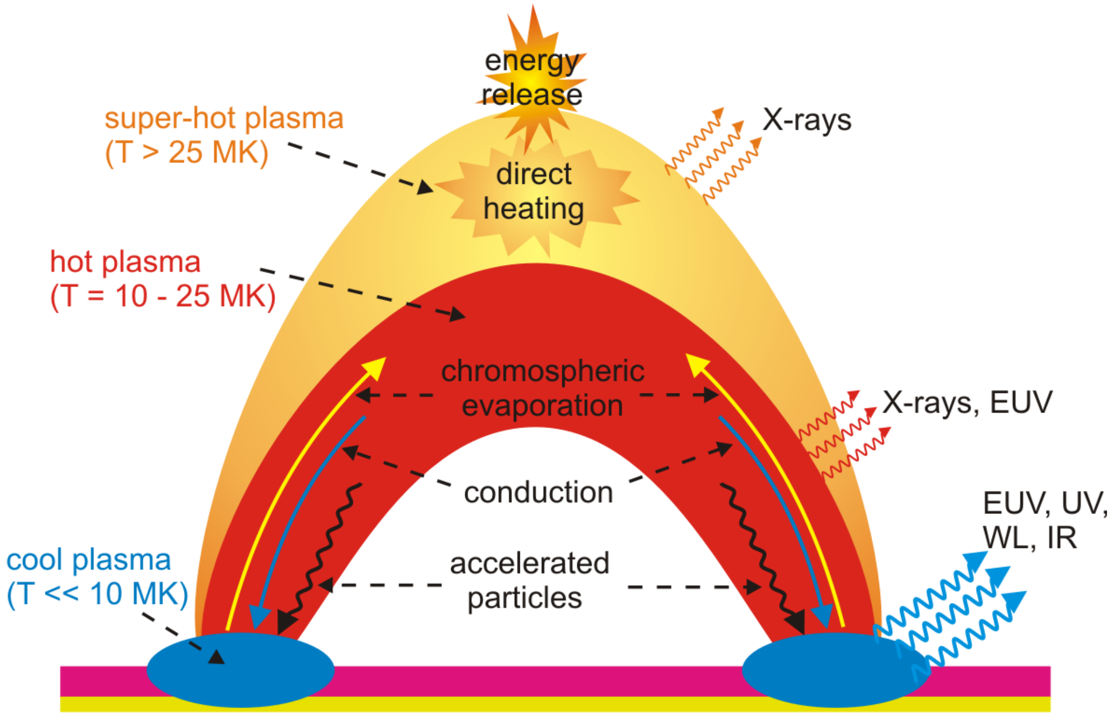
Solar flare energetics: nonthermal and thermal component

- energy in nonthermal electrons
- energy in nonthermal ions

- thermal energy of hot plasma
- radiative energy losses
- conductive energy losses
- kinetic energy in plasma flows
- gravitational energy of plasma



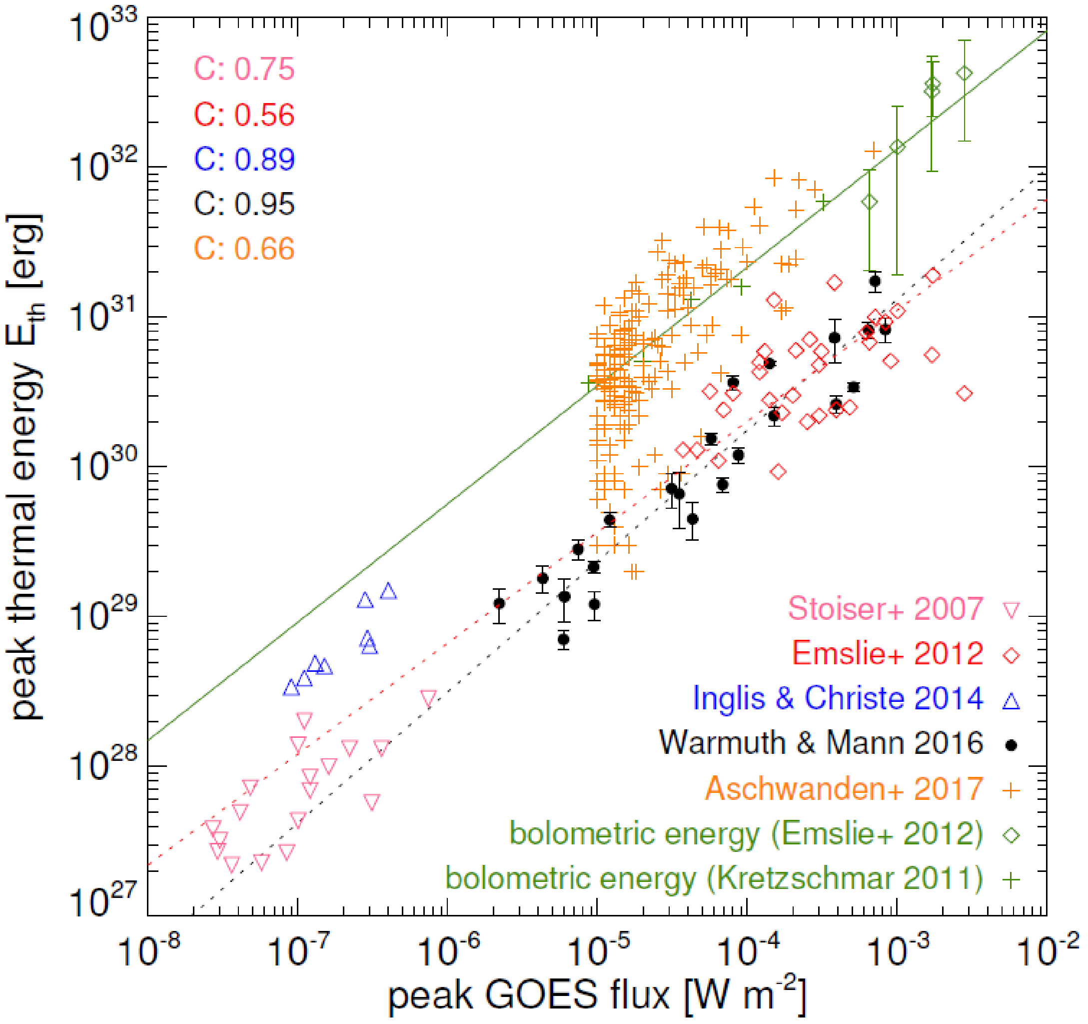
- standard scenario: energy input by nonthermal particle beams
  → nonthermal input has to balance thermal requirements

Recent results on energy partition

- electrons can account for thermal plasma
  (Emslie et al. 2012)
- electrons cannot account for thermal plasma
  (Inglis & Christe 2014)
- electrons can account for thermal plasma only in stronger events
  (Warmuth & Mann 2016)
- electrons can easily account for thermal plasma
  (Stoiser et al. 2009, Aschwanden et al. 2015/2016/2017)

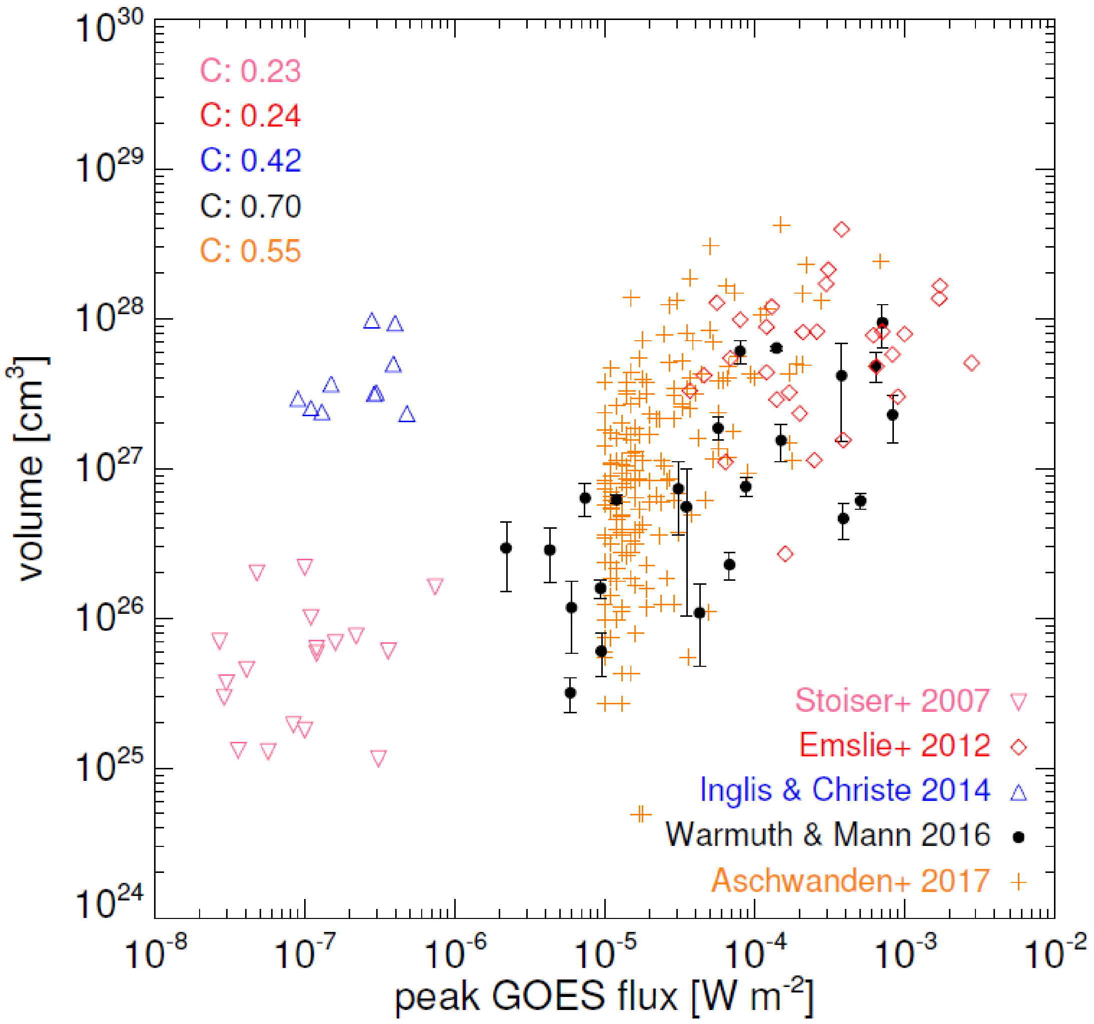
→ discrepancies resulting from limitations in these studies
(Warmuth & Mann 2020)

Peak thermal energy



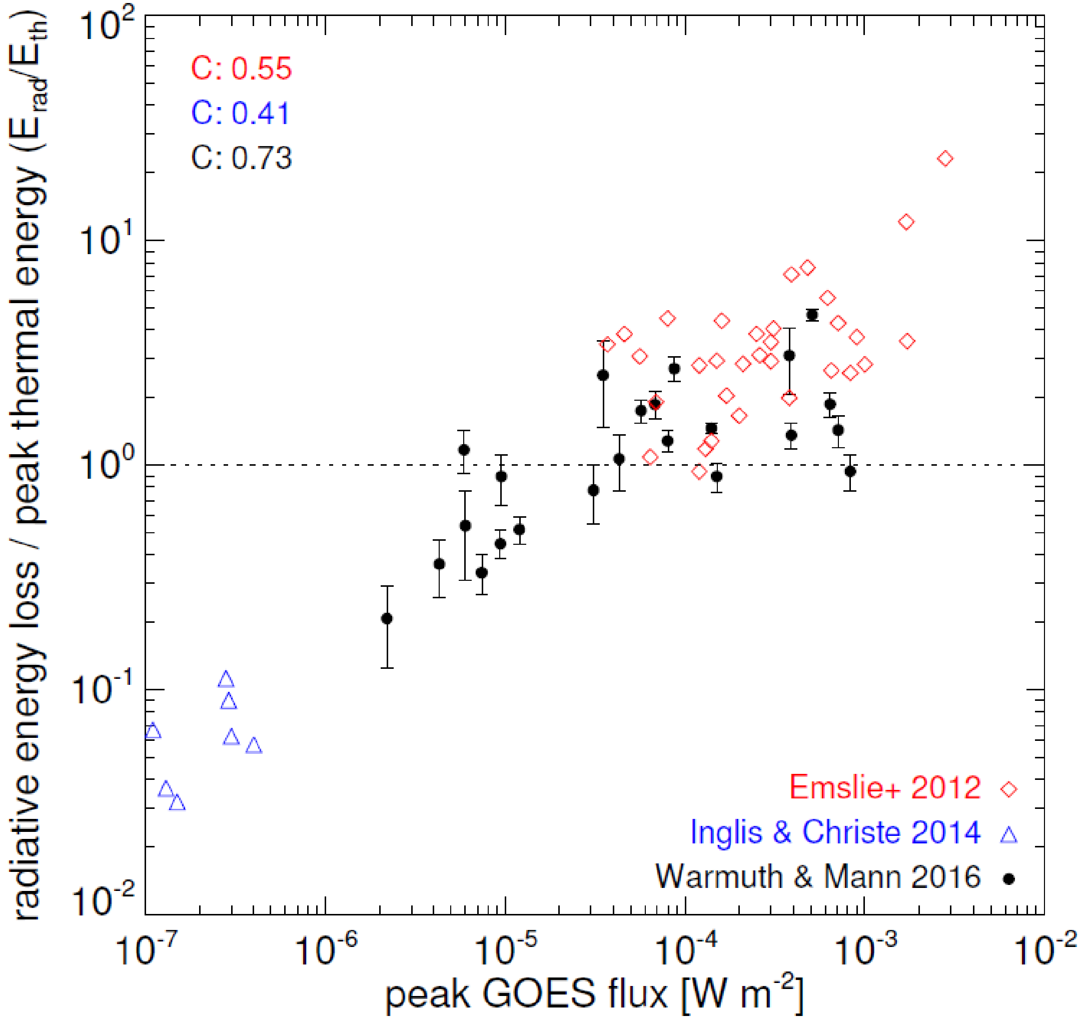
- correlation with GOES peak flux
- discrepancies by up to an order of magnitude
- bolometric energy shown as a proxy for total released energy
- reasons for discrepancies?

Thermal source voulumes



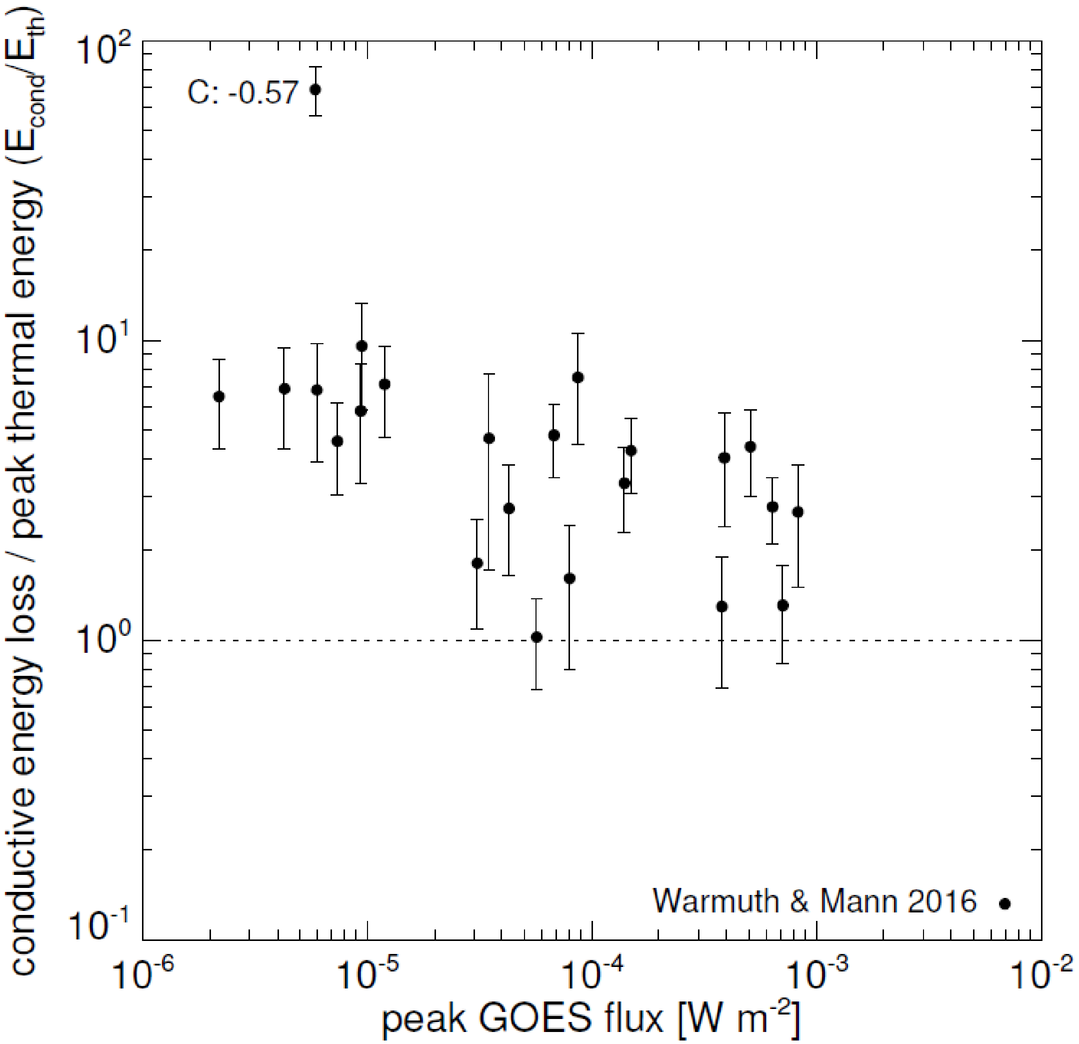
- volumes derived from RHESSI and AIA are consistent

Radiative losses of hot plasma normalized by peak thermal energy



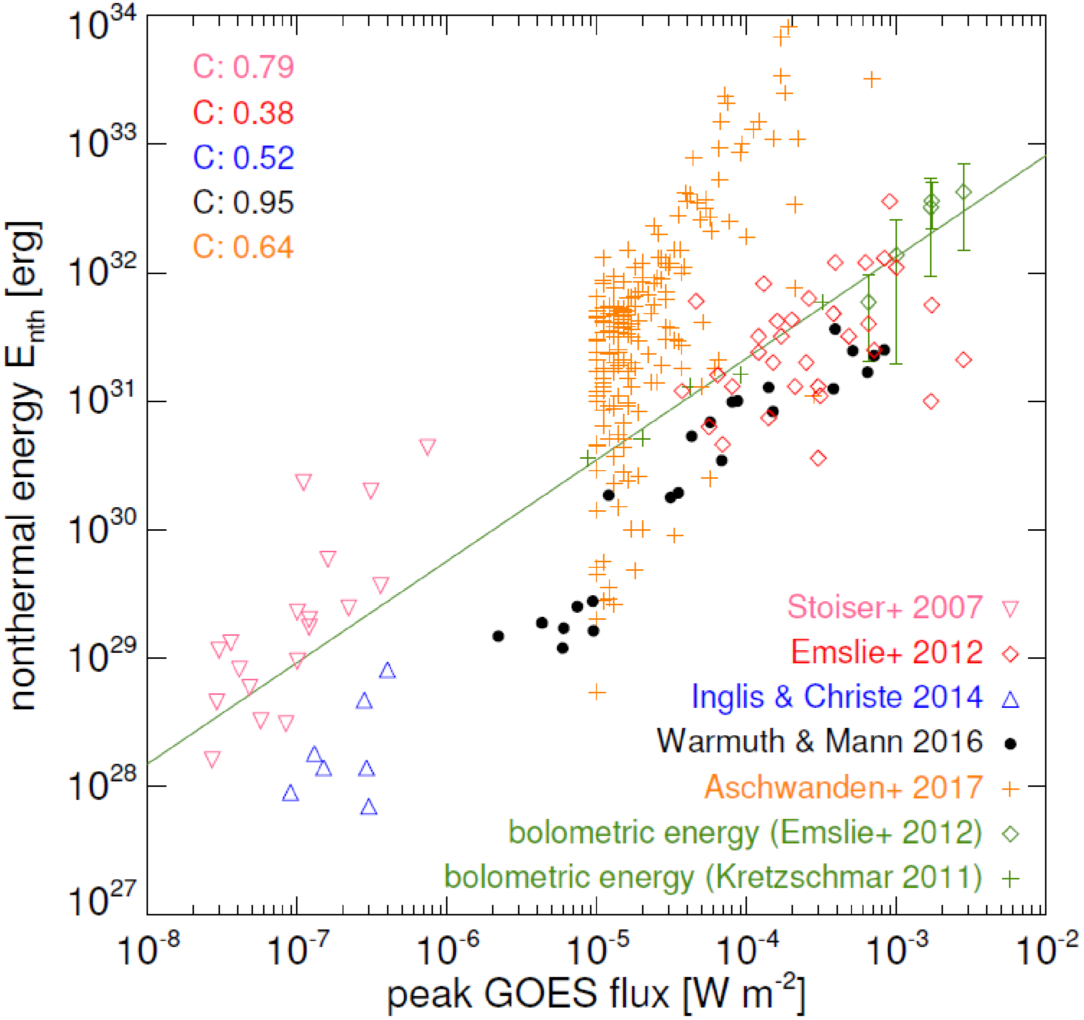
- radiative losses are energetically important for larger events

Conductive losses of hot plasma normalized by peak thermal energy



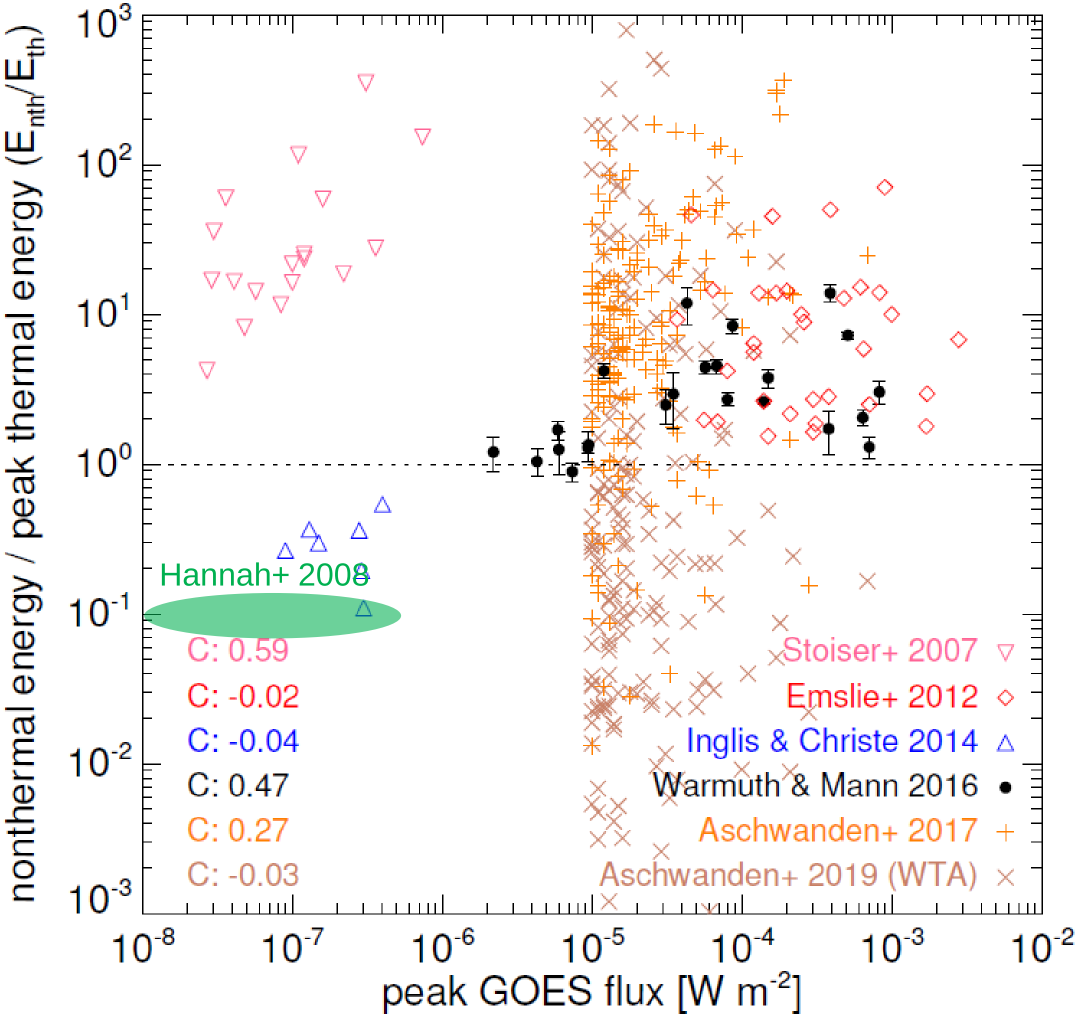
- conductive losses energetically important, especially for smaller events
- however, conduction may be suppressed

Energy in nonthermal electrons



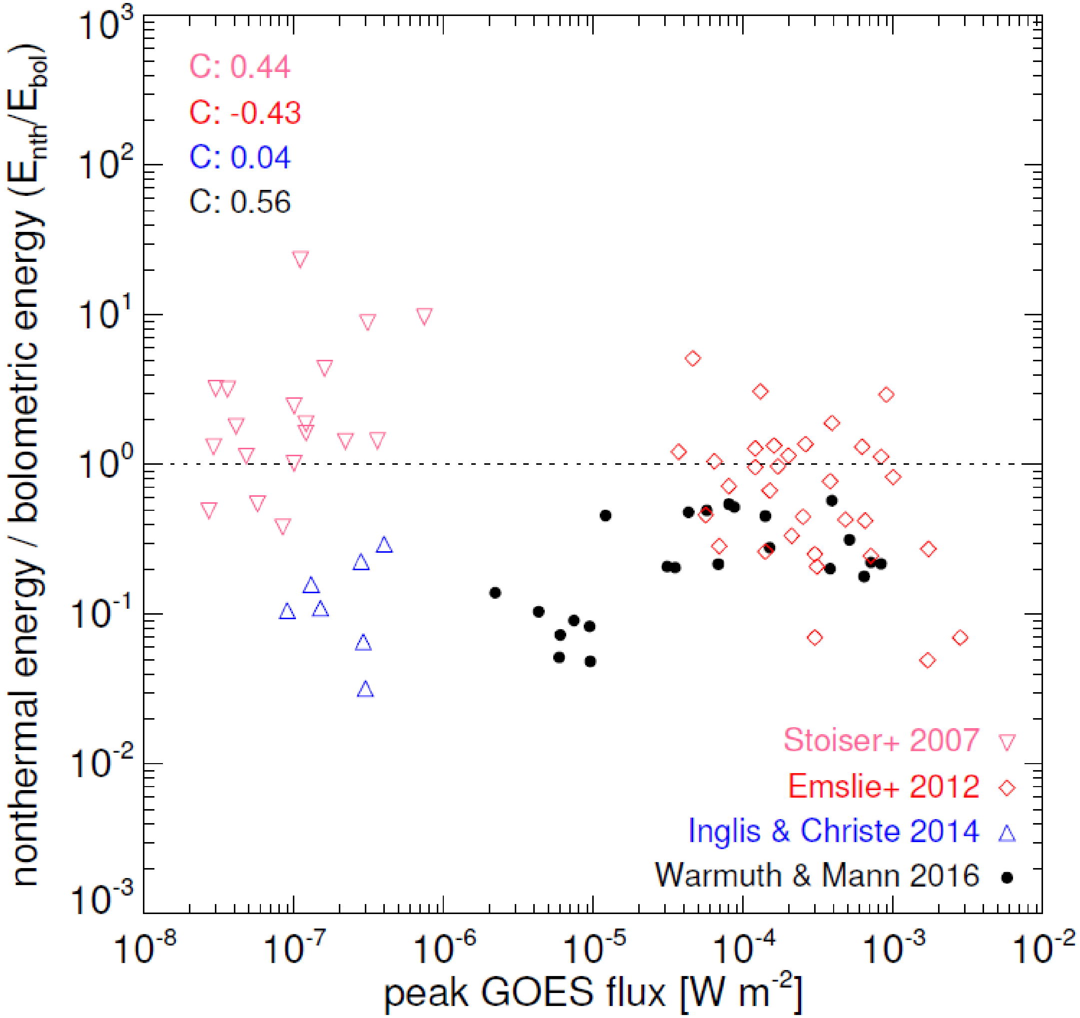
- energy input correlates with GOES class
- large discrepancies between studies
- partly orders of magnitude larger than bolometric energy
- problem: low-energy cutoff

Nonthermal fraction: nonthermal / peak thermal energy



- nonthermal energy larger than thermal energy in most events and studies
- energy in nonthermal ions not considered

Nonthermal fraction: nonthermal / bolometric energy



- sufficient energy to power thermal flare component only in larger events (X class)
- additional energy transport mechanism required to explain bolometric loss (conduction, waves)

Explanation for different results on energy partition

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- electrons can account for thermal plasma *(Emslie et al. 2012)*
- electrons cannot account for thermal plasma *(Inglis & Christe 2014)*
- electrons can account for thermal plasma only in stronger events *(Warmuth & Mann 2016)*

} energy partition changing with flare importance

- electrons can easily account for thermal plasma *(Stoiser et al. 2009, Aschwanden et al. 2015/2016/2017)*

} nonthermal energy overestimated

Spectrometer/**T**elescope for **I**maging **X**-rays (STIX)

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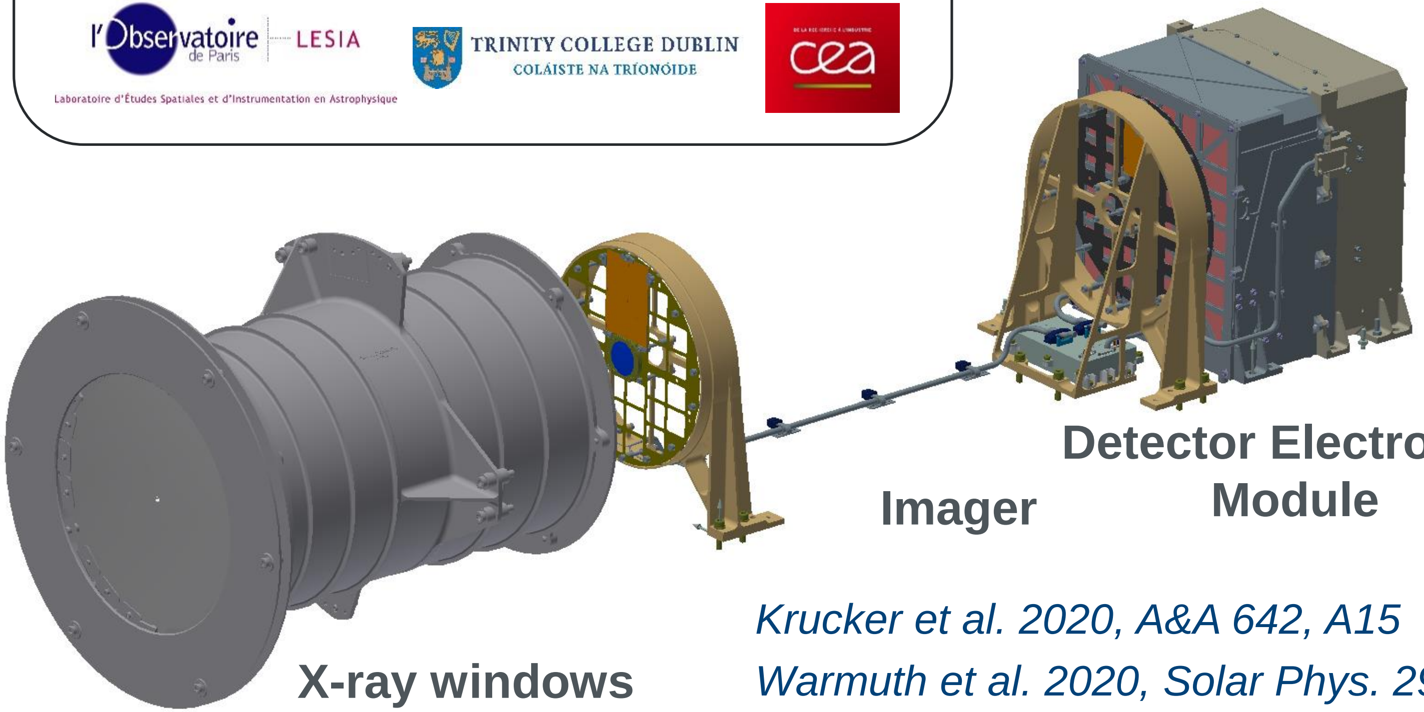
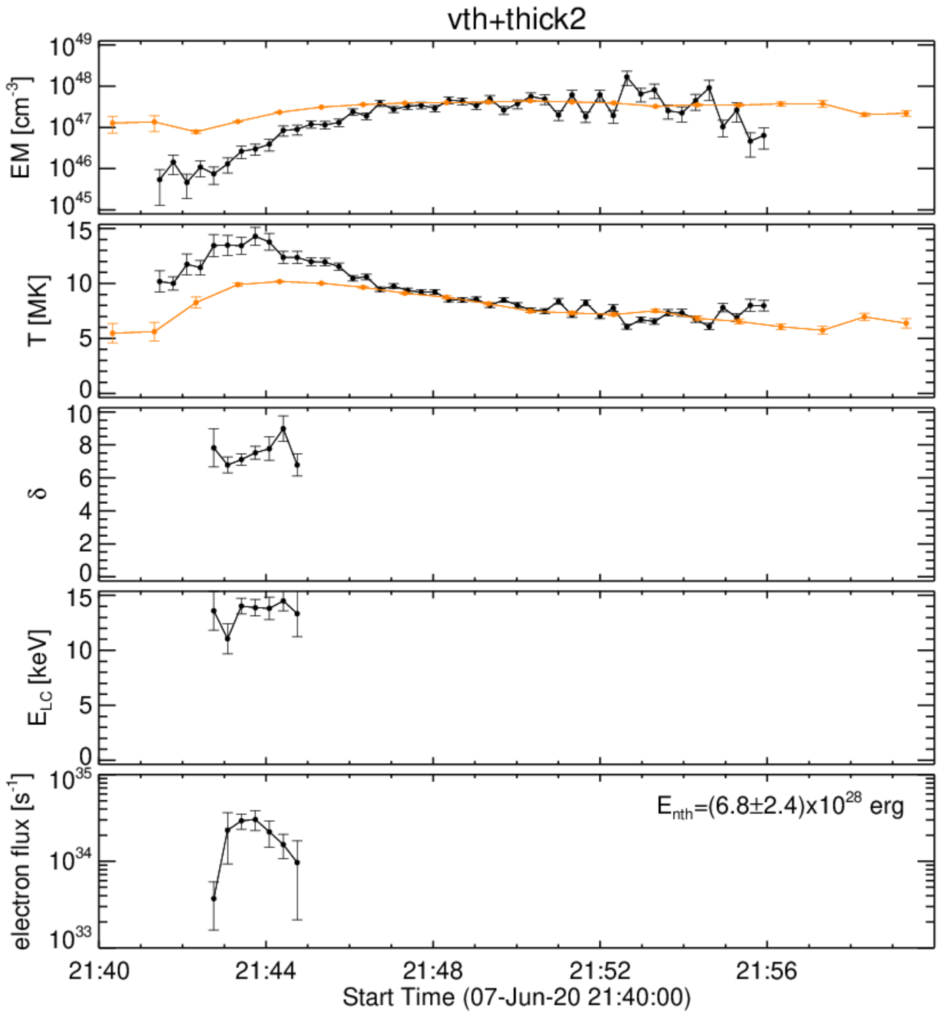
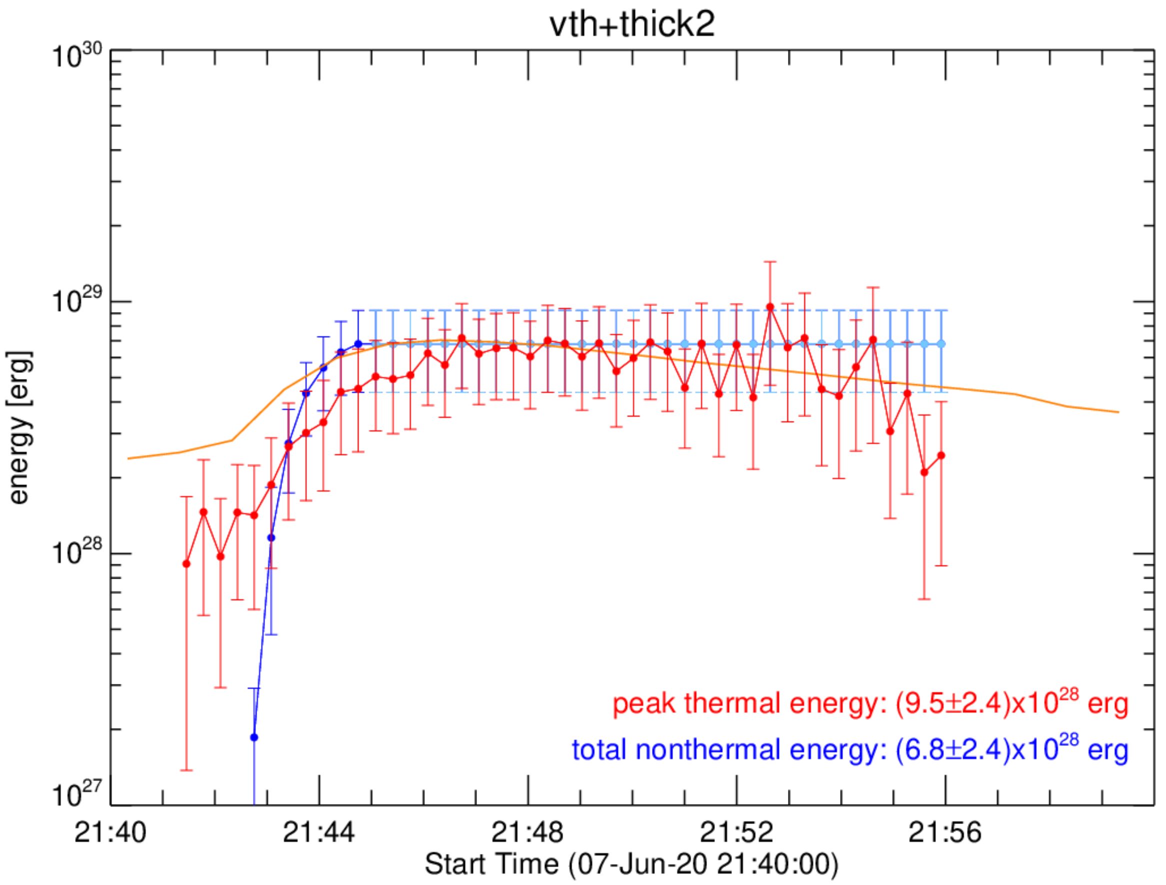


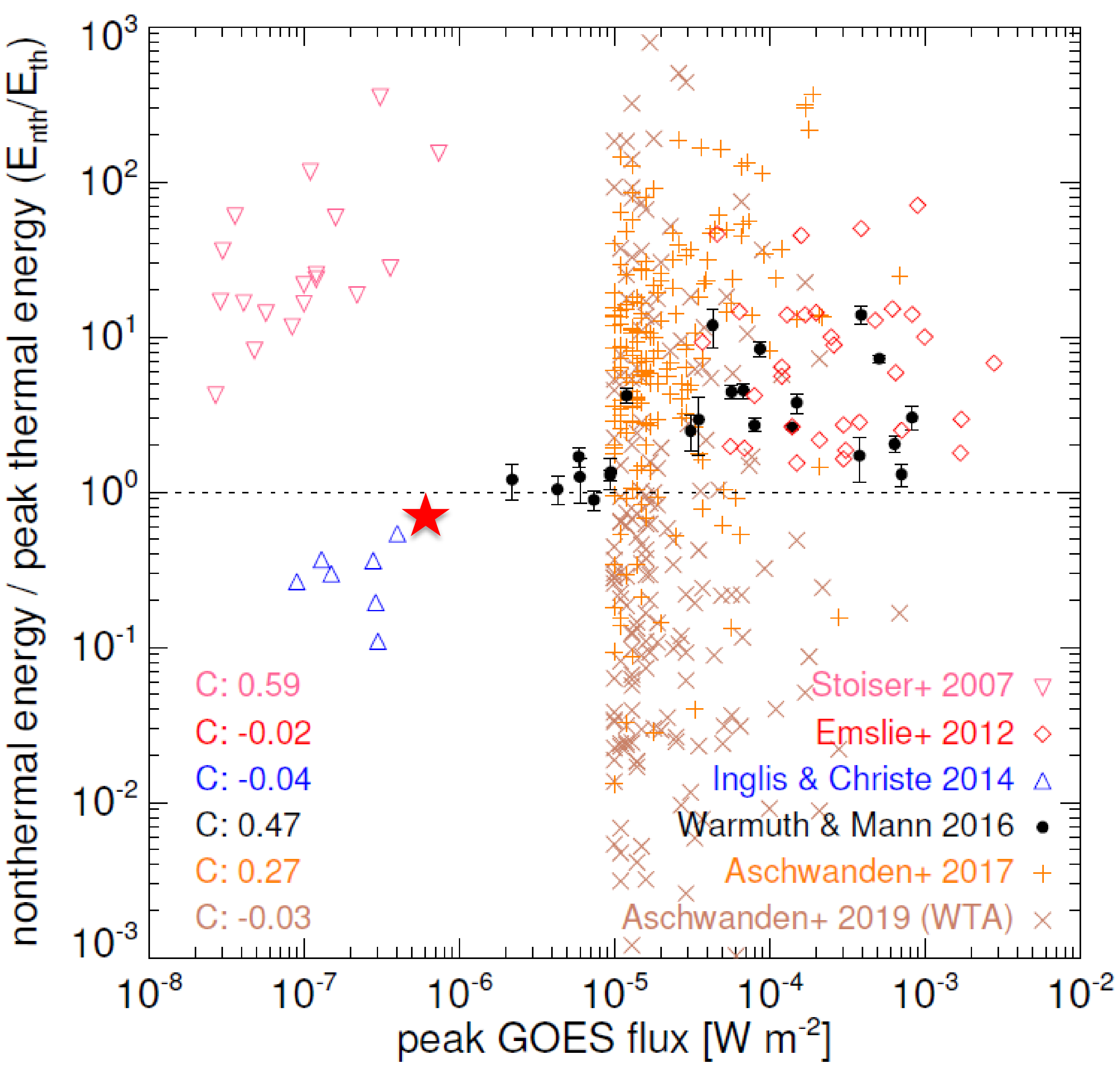
Krucker et al. 2020, A&A 642, A15
Warmuth et al. 2020, Solar Phys. 295, 90
Battaglia et al. 2021, A&A, in review

RESOURCES	• 6.6 kg • 8 W
SPECTRAL	• 4-150 keV • 1 keV at 6 keV • 32 energy bins
IMAGING	• full disk • 7” angular resolution (perihelion: equivalent to 2”) • 30 visibilities
TIME RESOLUTION	• counts are binned to statistically significant numbers • minimum bin size <1 s
SENSITIVITY	• 6 cm^2 effective area (perihelion: equivalent to 70 cm^2) • low background

B6 flare seen from from 0.5 AU: isothermal & thick-target fit







nonthermal energy / peak thermal energy (E_{nth}/E_{th})
peak GOES flux [W m^{-2}]
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
C: 0.59
C: -0.02
C: -0.04
C: 0.47
C: 0.27
C: -0.03
Stoiser+ 2007
Emslie+ 2012
Inglis & Christe 2014
Warmuth & Mann 2016
Aschwanden+ 2017
Aschwanden+ 2019 (WTA)

Conclusions

- largest uncertainties in energy partition: determination of DEM distribution and low-energy cutoff
- bolometric energy provides an important constraint on both thermal and nonthermal energetics
- thermal losses of hot plasma are energetically important
- decreasing nonthermal fraction in smaller events
- need for additional heating and energy transport mechanisms

Outlook

- application of warm-target model to get upper limit on energy in accelerated electrons
- prospects for more reliable results on partition in microflares with STIX