How hard are strong Ground Level Enhancement (GLE) events?

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Outline

- Background
- GLE energy spectra
- Evaluation of the Band function use to describe GLE spectra
- Main question of our study
- Results
- Summary

Background knowledge (1)

High fluxes of solar energetic particles (SEPs) are accelerated:

- in the solar corona by flares
- in the interplanetary space by coronal mass ejections (CMEs)

↓

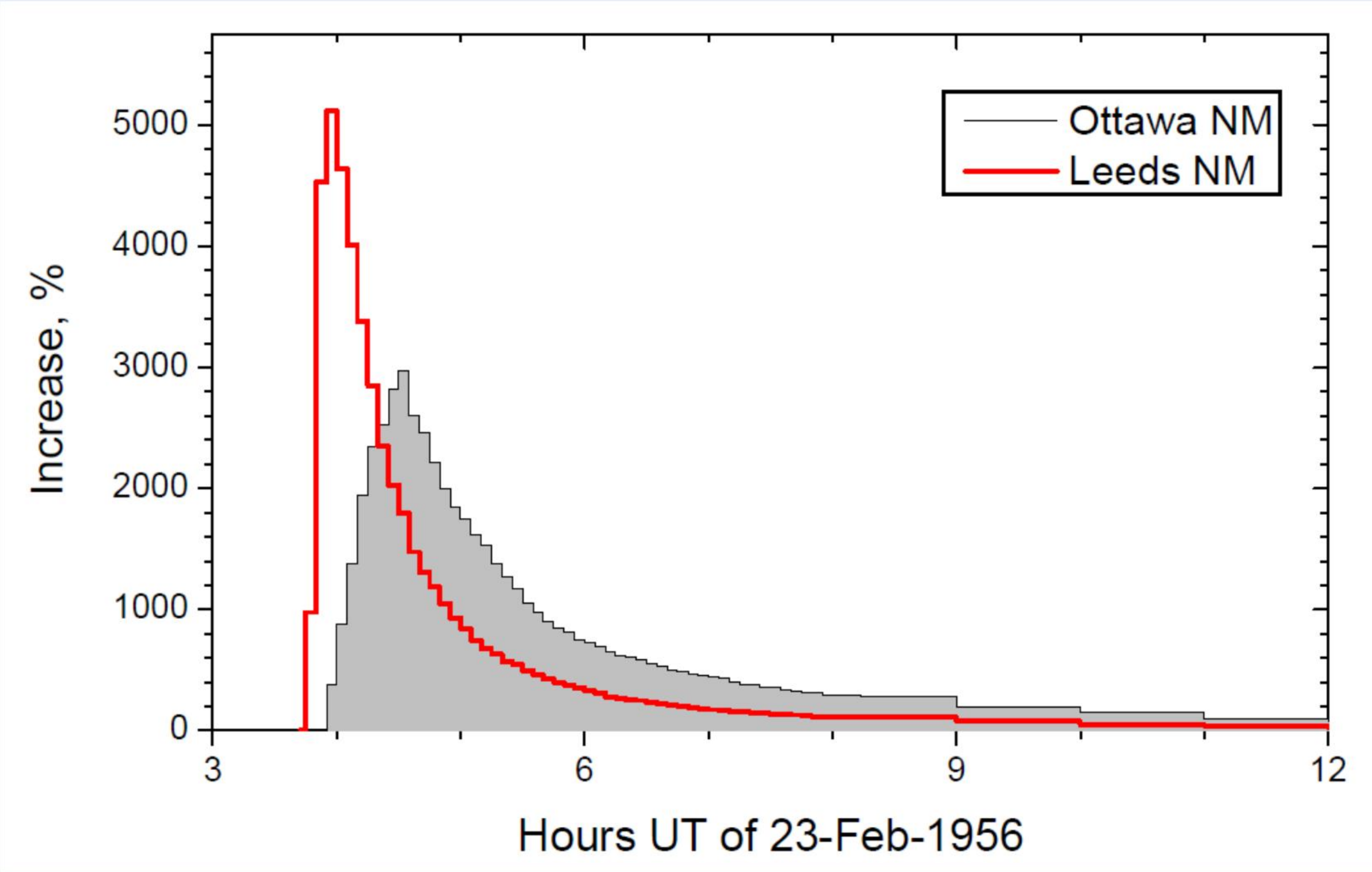
SEPs gain energies high enough to penetrate Earth's atmosphere

↓

Initiate an atmospheric cascade

Background knowledge (2)

Ground-level neutron monitor detectors record the nucleonic component of these cascades.



GLE database: http://gle.oulu.fi

GLE energy spectra

a low energy part

assessed by in situ space-born measurements

+

a high energy tail

assessed by ground based NM detectors

Well described by the Band function: a power-law in rigidity with a smooth roll over in-between.

$$J(>R) = \begin{cases} J_o \cdot R^{-\gamma_1} exp(-R/R_o) & \text{for } R \leq (\gamma_2 - \gamma_1)R_o \\ J_o \cdot [(\gamma_2 - \gamma_1)R_o]^{(\gamma_2 - \gamma_1)} exp(\gamma_1 - \gamma_2) R^{-\gamma_2} & \text{for } R > (\gamma_2 - \gamma_1)R_o \end{cases}$$

Tylka and Dietrich (2008, 2009) did a Band-function fit to 59 GLE events

Evaluation of the Band function use

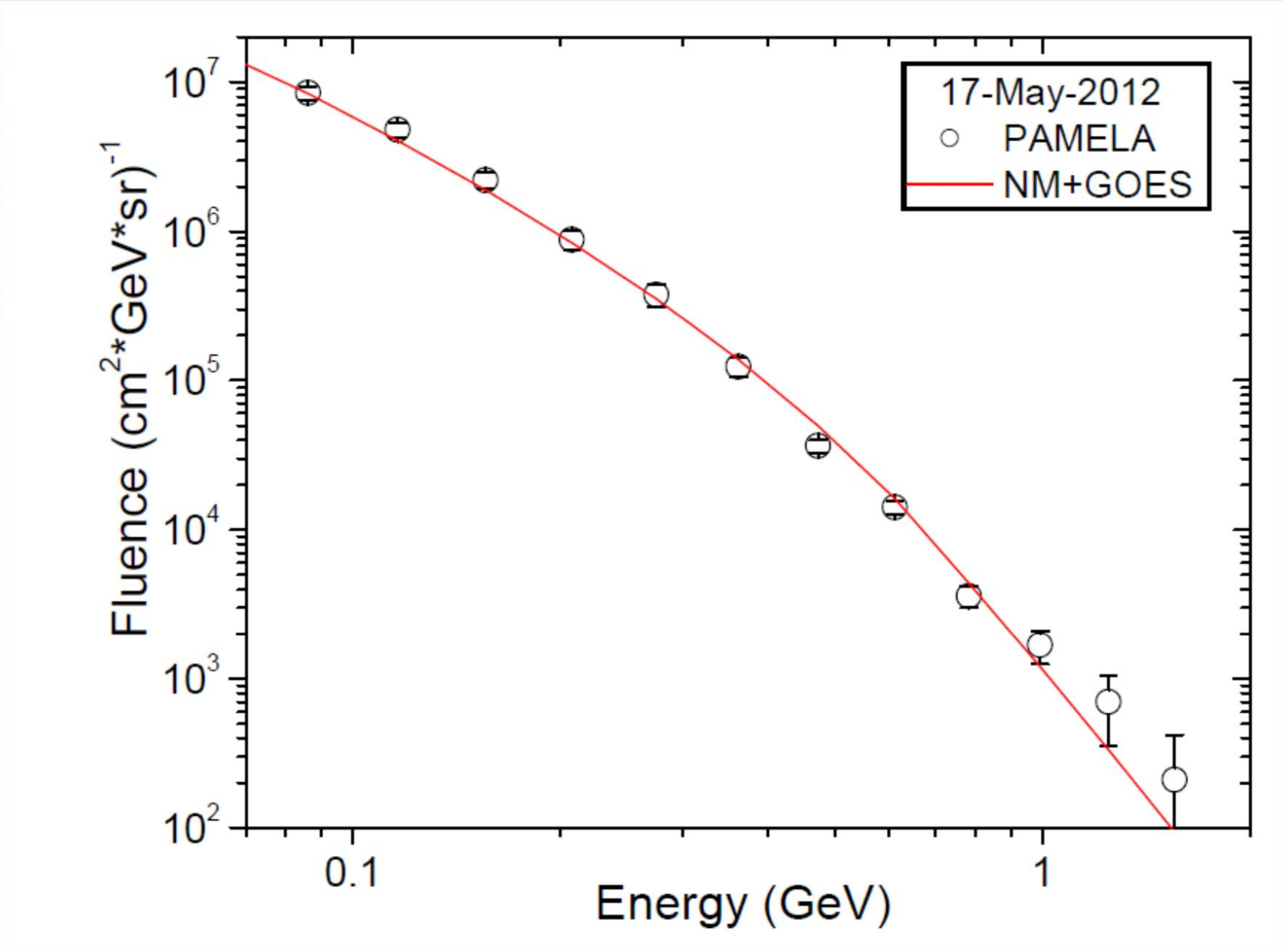
- For GLE 70 (13-Dec-2006) and 71 (17-May-2012) there are direct measurements of SEP energy spectra by space borne magnetic spectrometers such as PAMELA mission (Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics).

- We used them to test the correctness of Band function fits to the energy spectra

Evaluation of the Band function use

- For GLE
  measure
  spectror
  Explorat

- We used
  spectra



Main question of our study

"How hard spectra strong GLE events have?"

A hard spectrum can be simply described as a spectrum with an elevated high energy tail.

For each of the 59 GLE we take the ratio of two fluences, $F_{30} = J(> 30\ \mathrm{MeV})$ and $F_{200} = J(> 200\ \mathrm{MeV})$

Event-integrated intensity I (%*hr): the integral of the excess above the GCR background over the entire duration of the event. It corresponds to the total fluence of SEPs with energy sufficient to cause an atmospheric cascade (several hundred MeV).

Main question of our study

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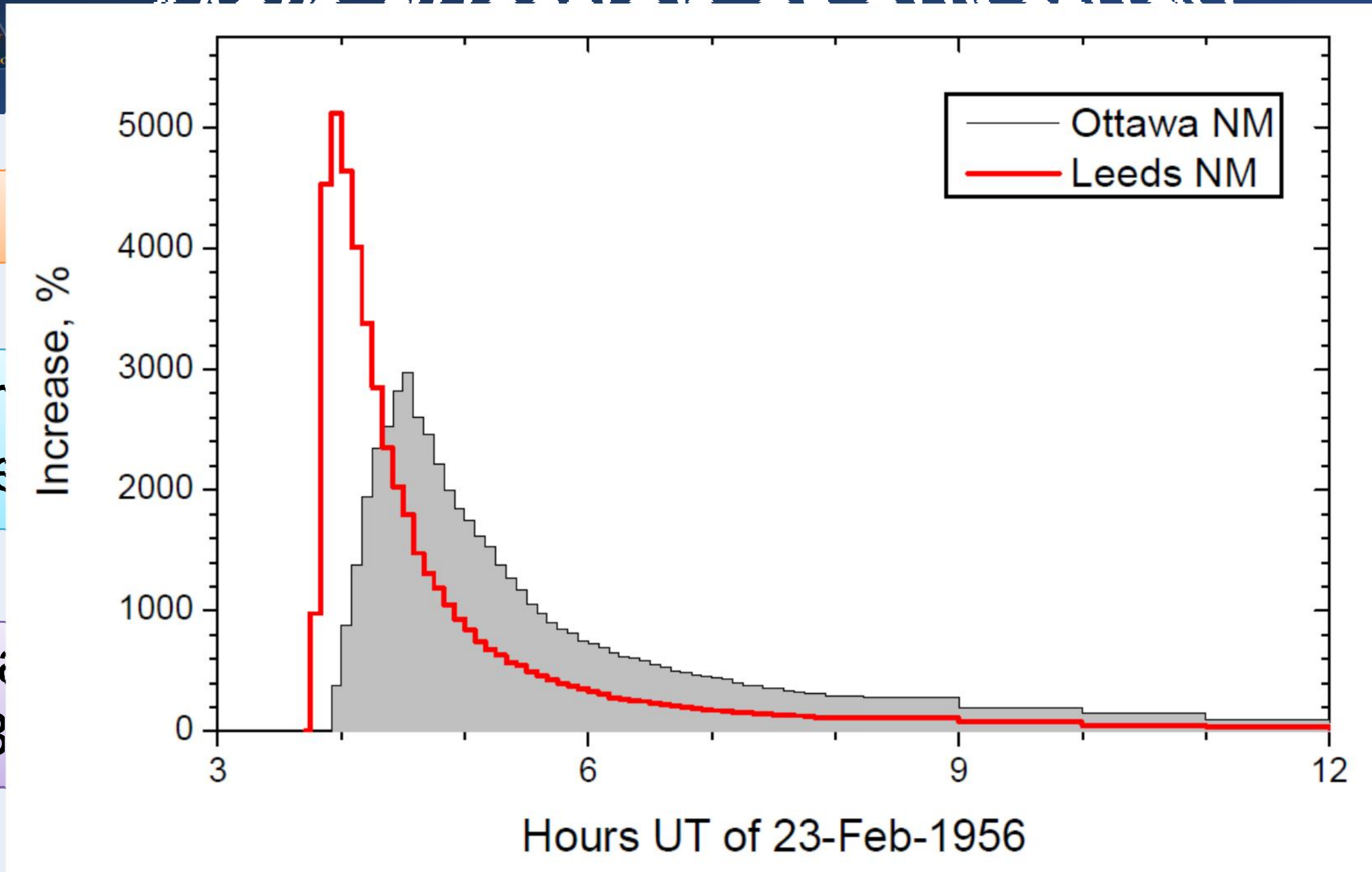
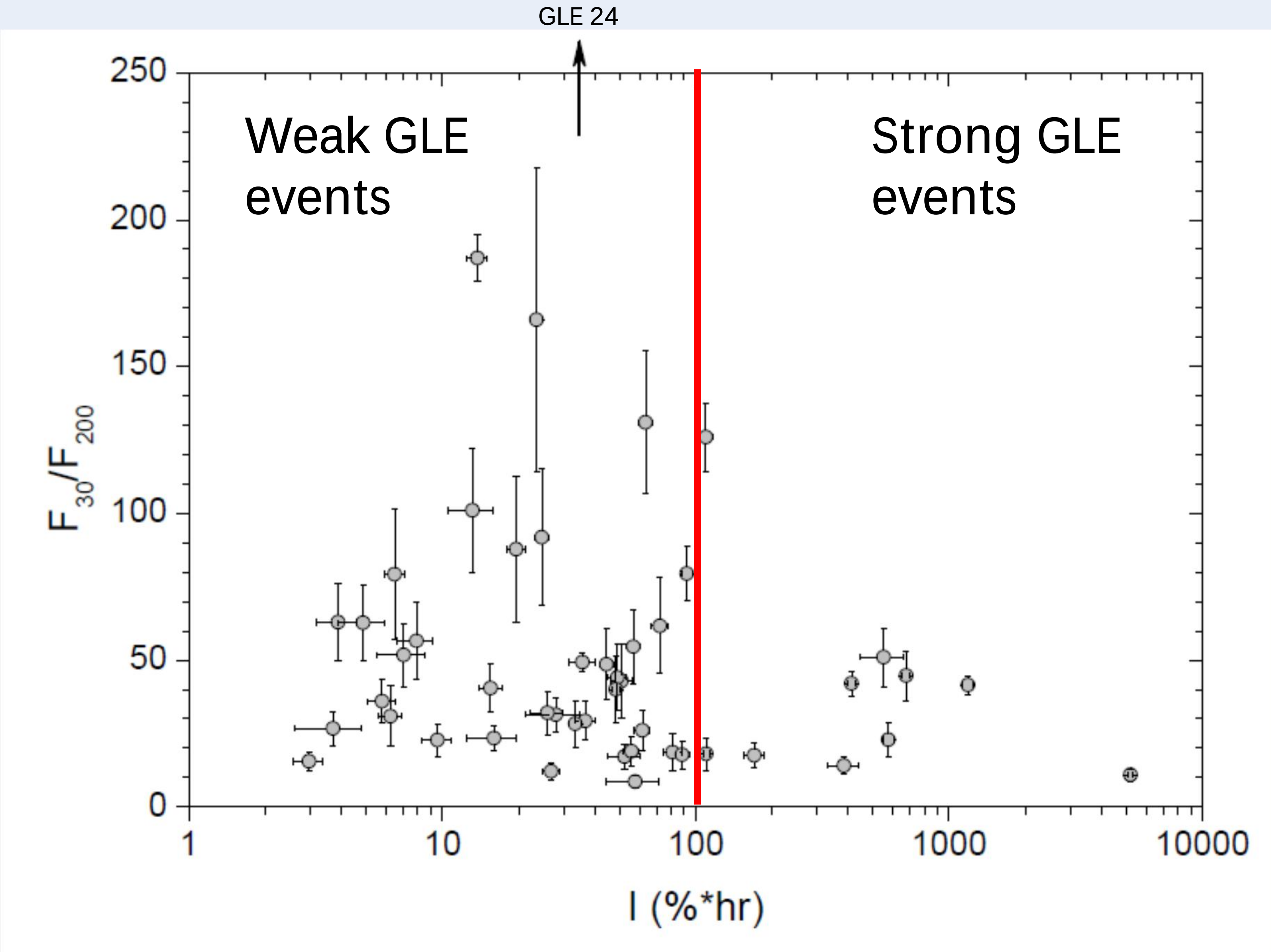
J(> 3...

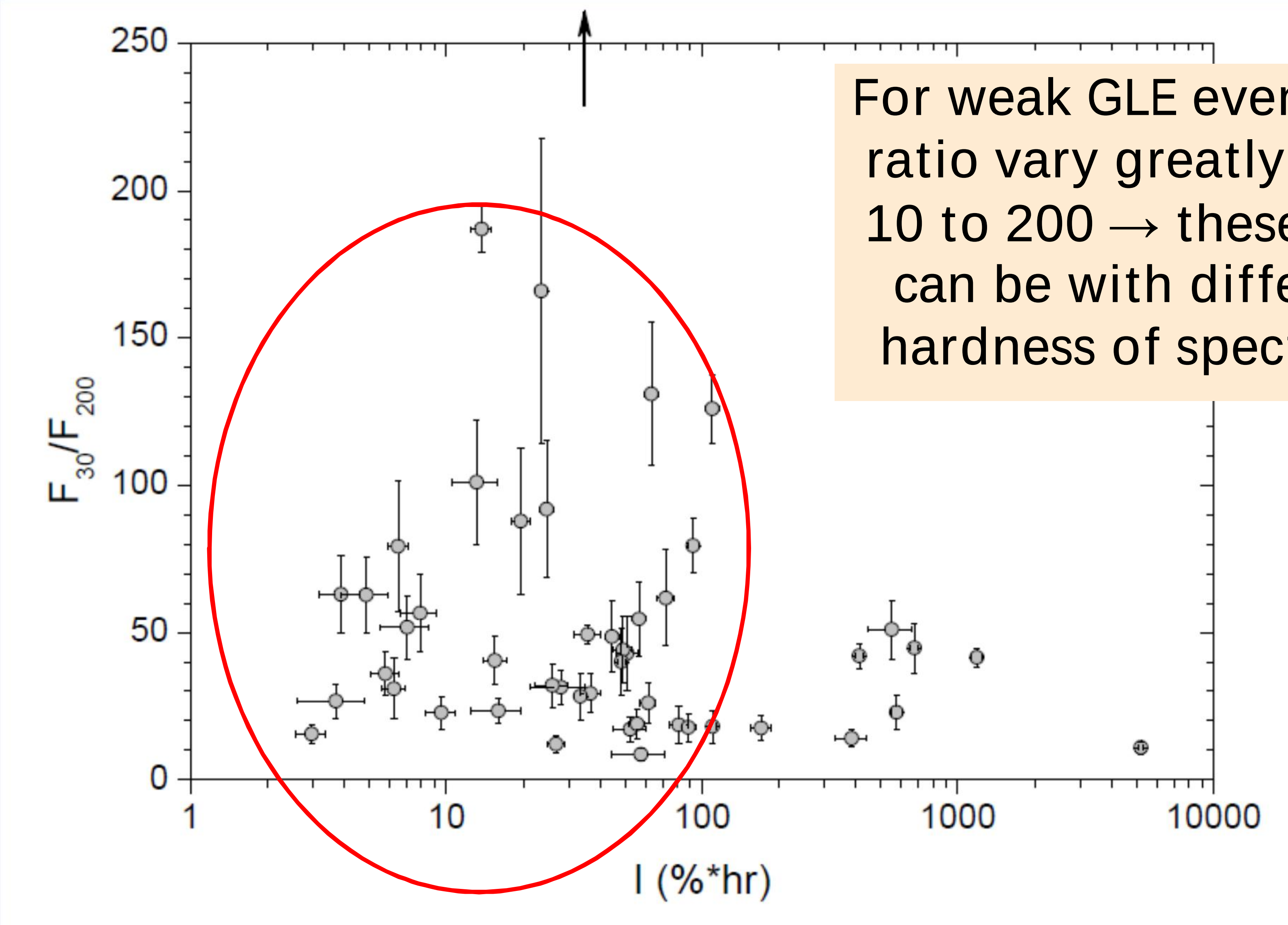


Event-integrated intensity I (%*hr): the integral of the excess above the GCR background over the entire duration of the event. It corresponds to the total fluence of SEPs with energy sufficient to cause an atmospheric cascade (several hundred MeV).

Results (1)

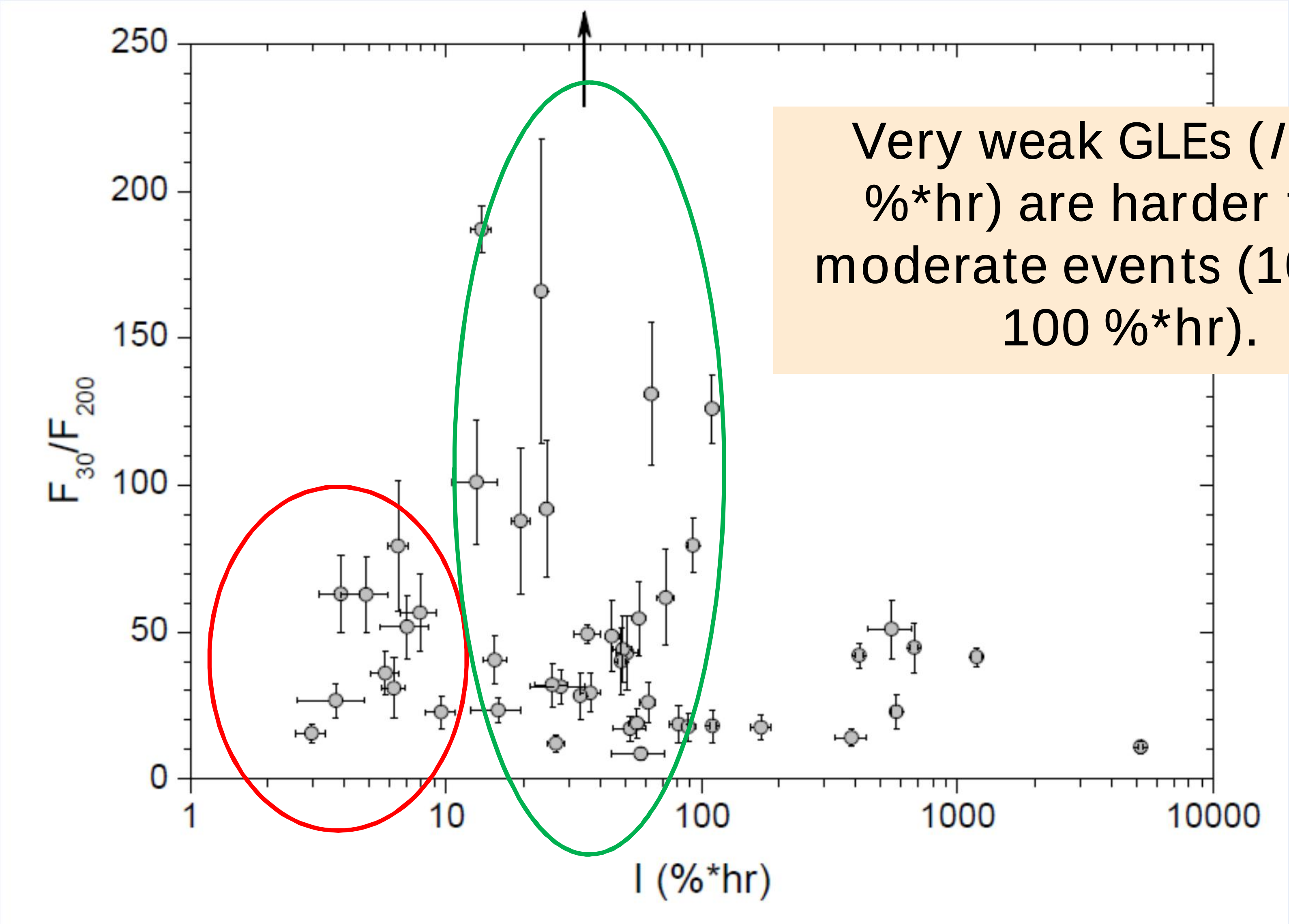

GLE 24
Weak GLE events
Strong GLE events
F_{30}/F_{200}
I (%*hr)
0
50
100
150
200
250
1
10
100
1000
10000

Results (2)



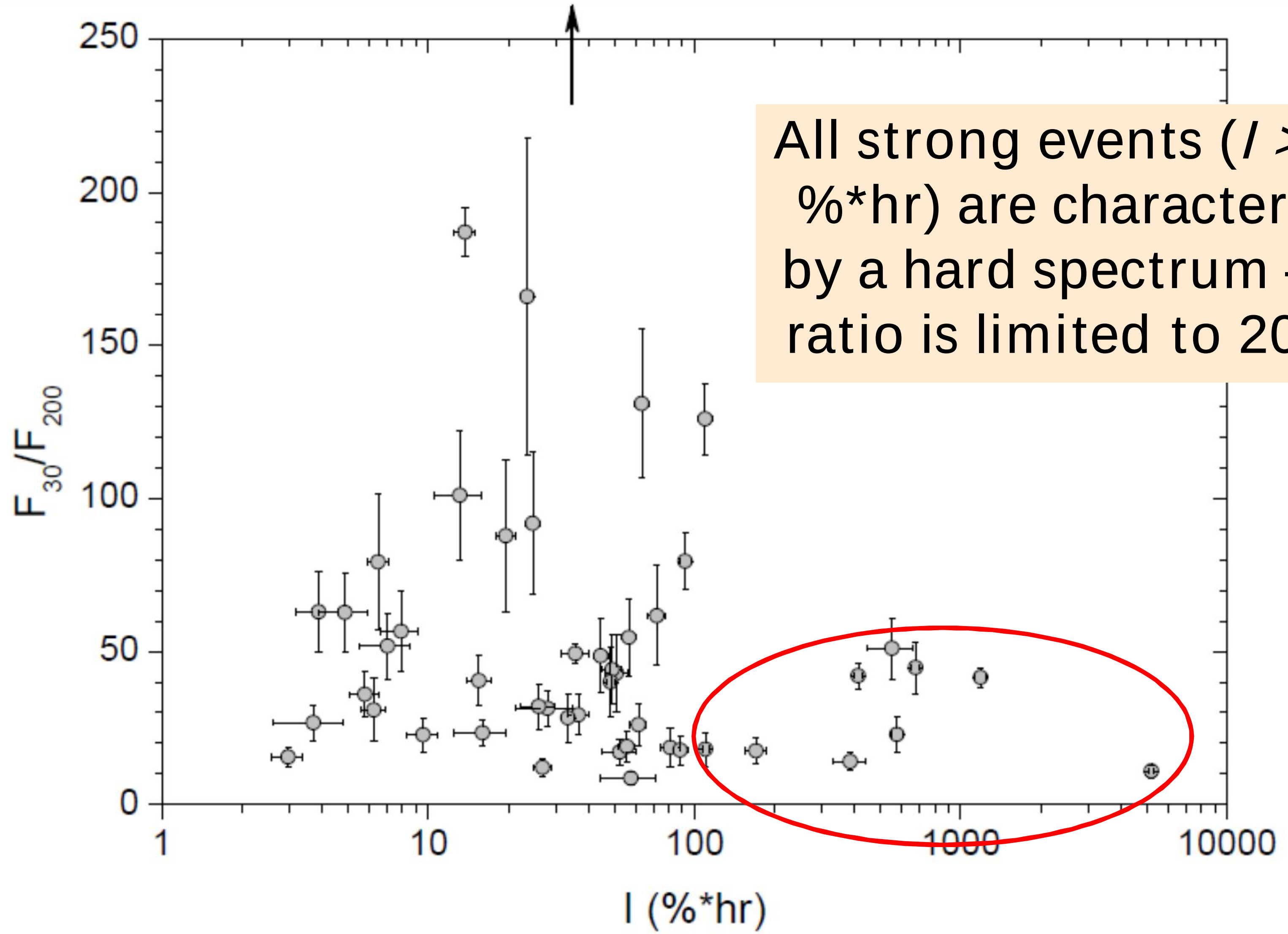
For weak GLE events the ratio vary greatly, from 10 to 200 → these GLEs can be with different hardness of spectrum.

Results (2)



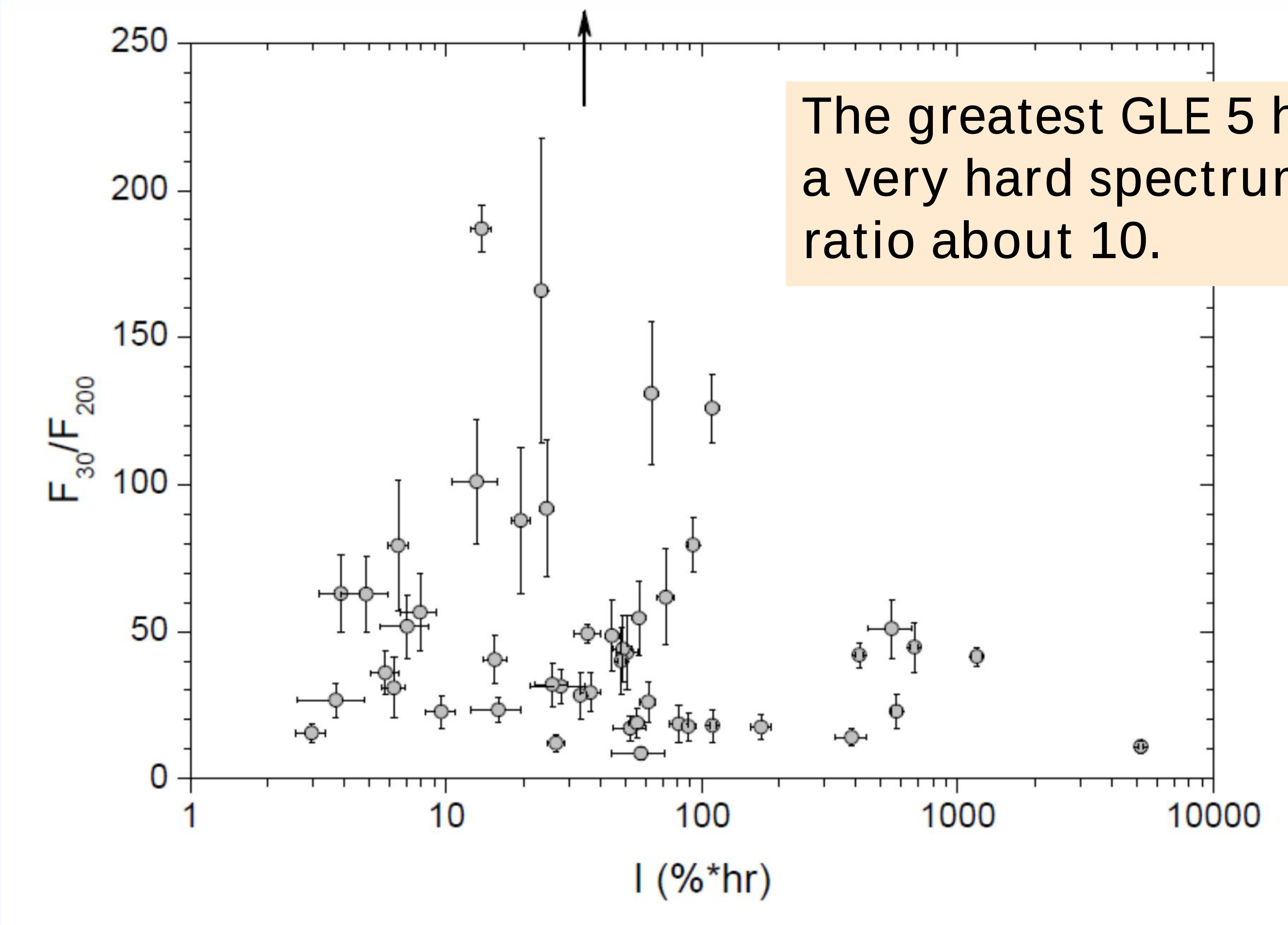
Very weak GLEs (*I* < 10 %*hr) are harder than moderate events (10 < *I* < 100 %*hr).

Results (2)



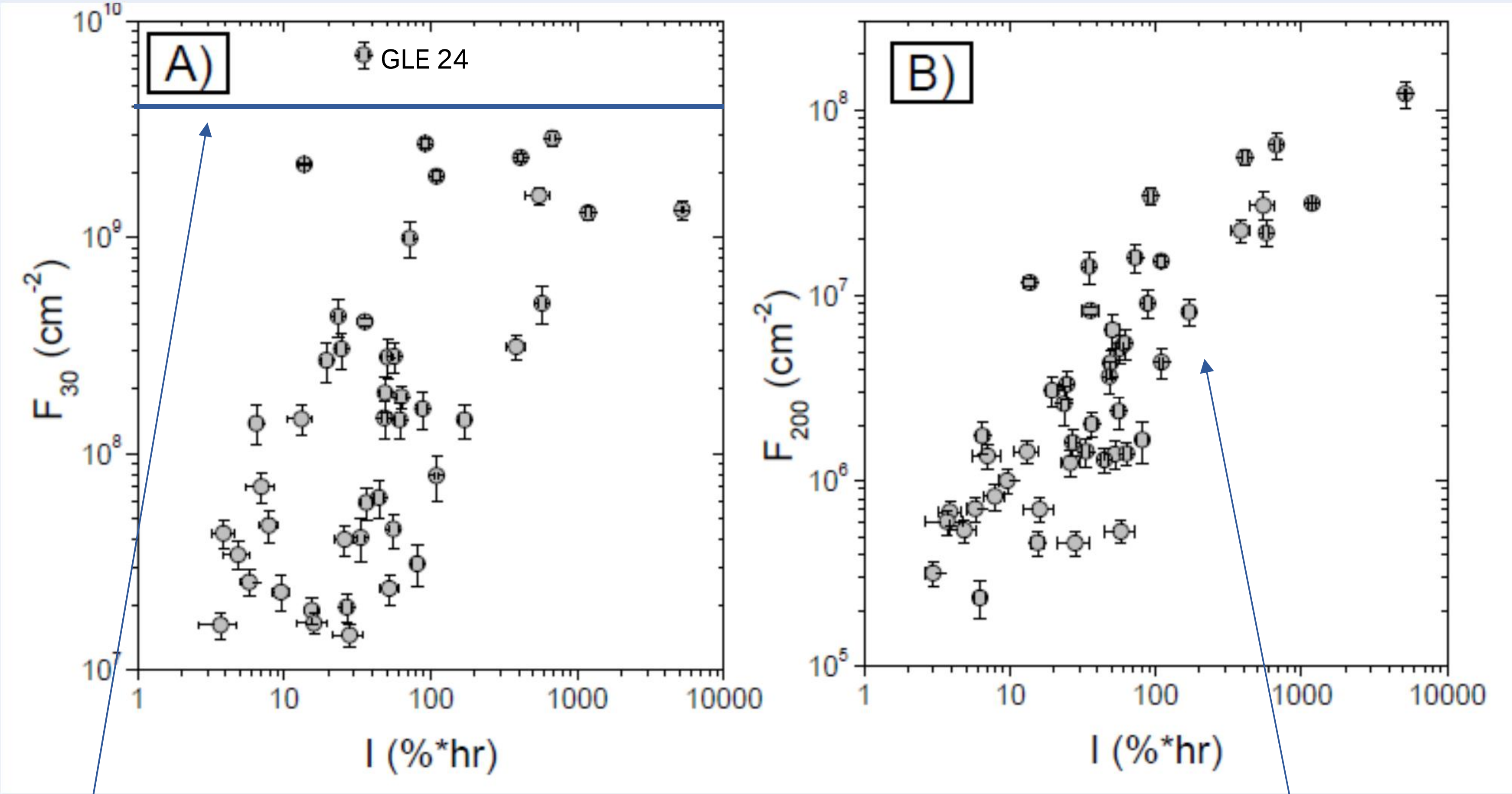
All strong events (*I* > 100 %*hr) are characterized by a hard spectrum – the ratio is limited to 20–50.

Results (2)



The greatest GLE 5 has a very hard spectrum – ratio about 10.

Results (3)



may be related to a saturation, e.g., streaming limit

Vary almost linearly. No saturation

Summary

- We evaluated the use of Band function to describe the GLE events spectra using in situ measurements from the PAMELA experiment and we conclude that the Band function describes well the spectrum.

- We studied the energy spectra of 59 GLE events by considering then fraction of particle fluences F_{30} and F_{200} and the event-integrated intensity I (%*hr) and we found that:

  - ✓ for weak GLE events the ratio vary greatly, from 10 to 200
  - ✓ weak GLEs can be with different hardness of spectrum
  - ✓ very weak GLEs (I < 10 %*hr) are harder than moderate events (10 < I < 100 %*hr)
  - ✓ all strong events (I > 100 %*hr) are characterized by a hard spectrum
  - ✓ the greatest event, GLE 5, has a very hard spectrum
  - ✓ F_{200} varies linearly with I, however F_{30} does not
  - ✓ for F_{30} there is a limit at $3x10^9$ particles/cm^2 which may be related to a saturation

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THANK YOU