Spectral Evolution of the 11 June 1991 Solar Flare:
The Transition from the Impulsive to the Extended Phase

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• We use the 2.2 MeV and 4-7 MeV time profiles to investigate the spectral hardness of the accelerated proton spectrum during the flare:
We calculate the expected flux in the delayed 2.2MeV neutron capture line by using the prompt 4-7 MeV flux as an indicator of the neutron production. The free parameters of this model

— 2.2MeV/4-7MeV fluence ratio R
— neutron capture time λ

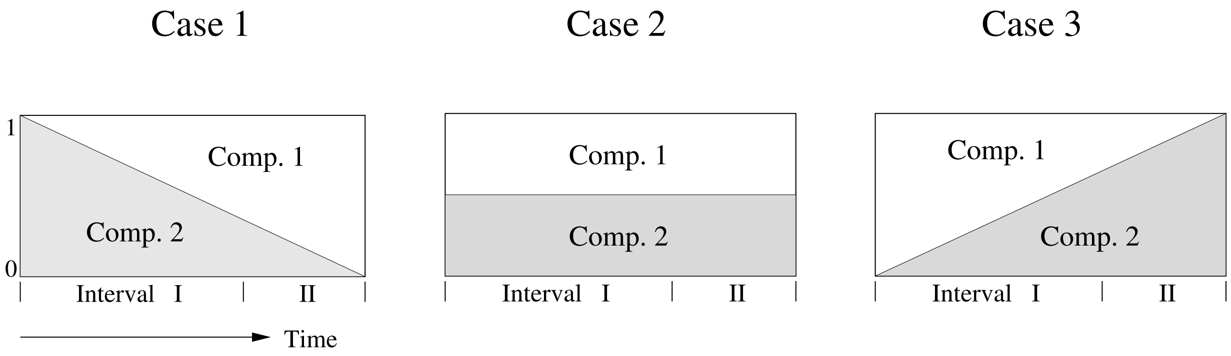
are adjusted by comparing the calculated flux to the actually measured flux.

• Approach 1: As the time intervals of the telescope data are quite long we do not fit the λ values, but set $\lambda = 70$s. This capture time can be derived from the PBS or from PHEBUS data for the time of the peak emission during the impulsive phase.
Result: to describe the measurements with sufficient accuracy, different values for R are necessary. This is an indication of a spectral evolution.
Problem: interval II, situated after the impulsive and before the extended phase shows nearly no ongoing neutron production and therefore requires a very high R value to explain the maintained 2.2 MeV emission. This would indicate a very hard spectrum, which is in conflict with the fact, that we measure no high energy γ-rays and also EGRET measures no substantial $>$ 50MeV flux during this period.

• Approach 2: Is it possible to 'feed' interval II with neutrons remaining from the impulsive phase? As interval II streched out for $\sim$ 7min this will require uncommonly long capture times λ.
Result: it is possible to fit the data with similar accuracy. The value for R has decreased, but remains high. Note, that intervals I and II do not require different parameter sets now.
Problem: The required capture time is much too long to be in agreement with the 70s derived from PBS and PHEBUS.

Situation so far:
— Both approaches are statistically compatible with the dataset.
— If λ is short, then R has to be high: indicates hard spectrum which contradicts with missing indication for pion production.
— Long capture times can be understood if large numbers of low energy neutrons are produced. This could be the case for a very soft spectrum. But even when allowing a large λ, R remains very high.

• Approach 3: Up to now **one** spectral component was taken into account. Is it possible to explain the measurements by assuming that the emission originates from **two independent particle populations**? Component 1 is assumed to be of normal spectral hardness with short capture time. Component 2 is assumed to have a very soft spectrum, that produces a lot of low energy neutrons. They stay at the top of the photosphere, where the hydrogen density is low and it takes long to be captured. We use λ =70s for the first component. We vary both R ratios and the second (long) capture time. Interval III is not changed. We do not allow for changes in each of the components during intervals I and II, but instead vary the relative contribution of both components with time. We study three cases of relative contributions:



Result: The third case of the two-component model offers the best fit to the data. The relative contribution shows that the short λ dominates in the beginning, the long λ at later times.
Problem: Contrary to our expectations, the long capture time of component 2 does not yield a very low, but again a very high R value.

SUMMARY AND CONCLUSIONS:

The impulsive phase of the 11 June 1991 flare can not be understood using the normal approach of the 2.2 MeV line production. We have tried several methods of fitting the data:

— a changing spectral hardness (Appr 1)
— different neutron capture times (Appr 2)
— a two-component model (Appr 3).

Statistically, the relative variations of two components during the impulsive phase plus a third component of the extended phase explain the data best. But in all cases it turned out, that R needs to be very high at the end of the impulsive phase.

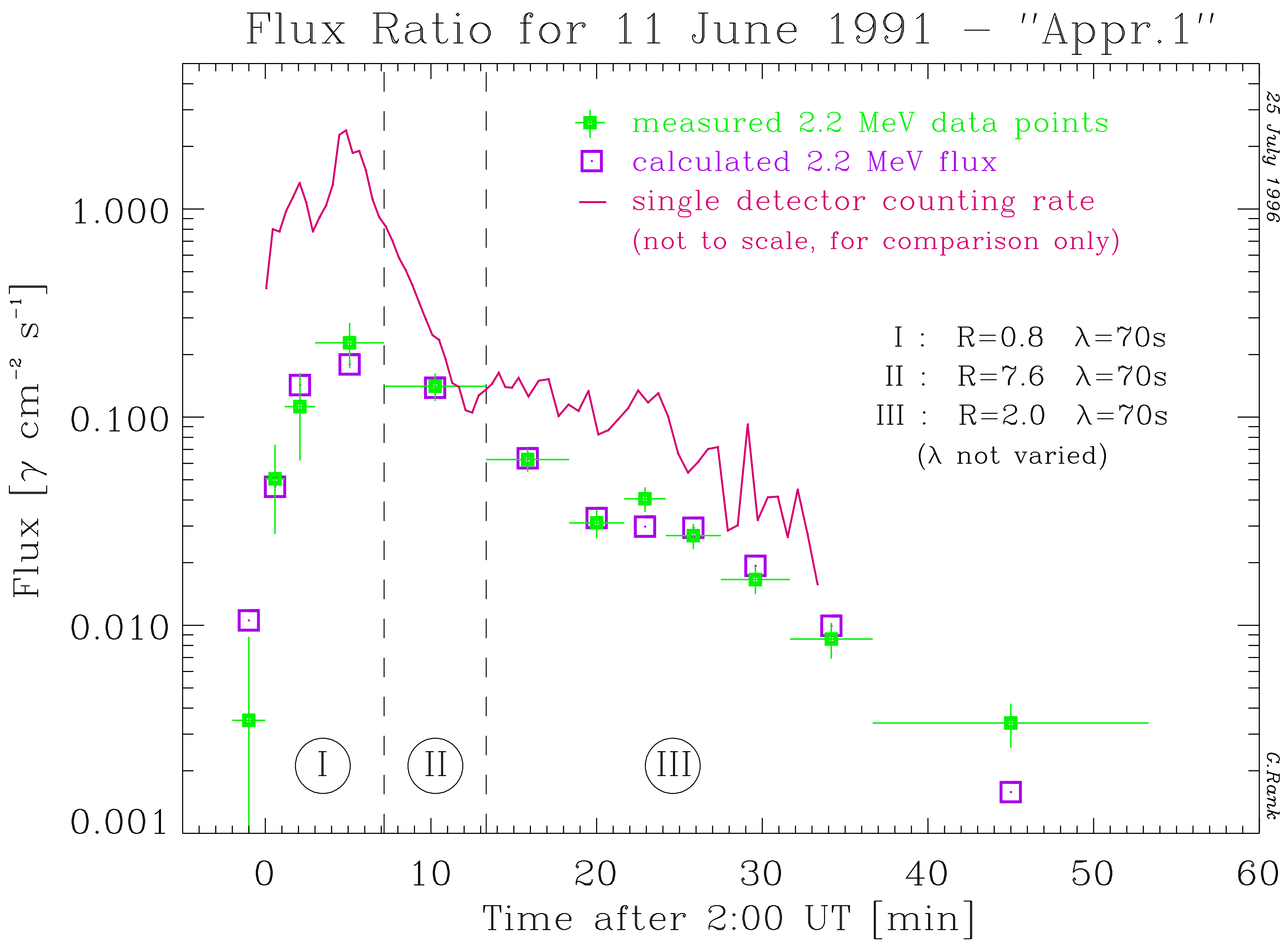
The dependence of the 2.2MeV/4-7MeV ratio of spectral hardness used in our interpretation so far is based on the work of Hua & Lingenfelter (1987). This work takes neutrons with energies $>$ 1 MeV into account. In this context, a high value of R indicates a hard spectrum.

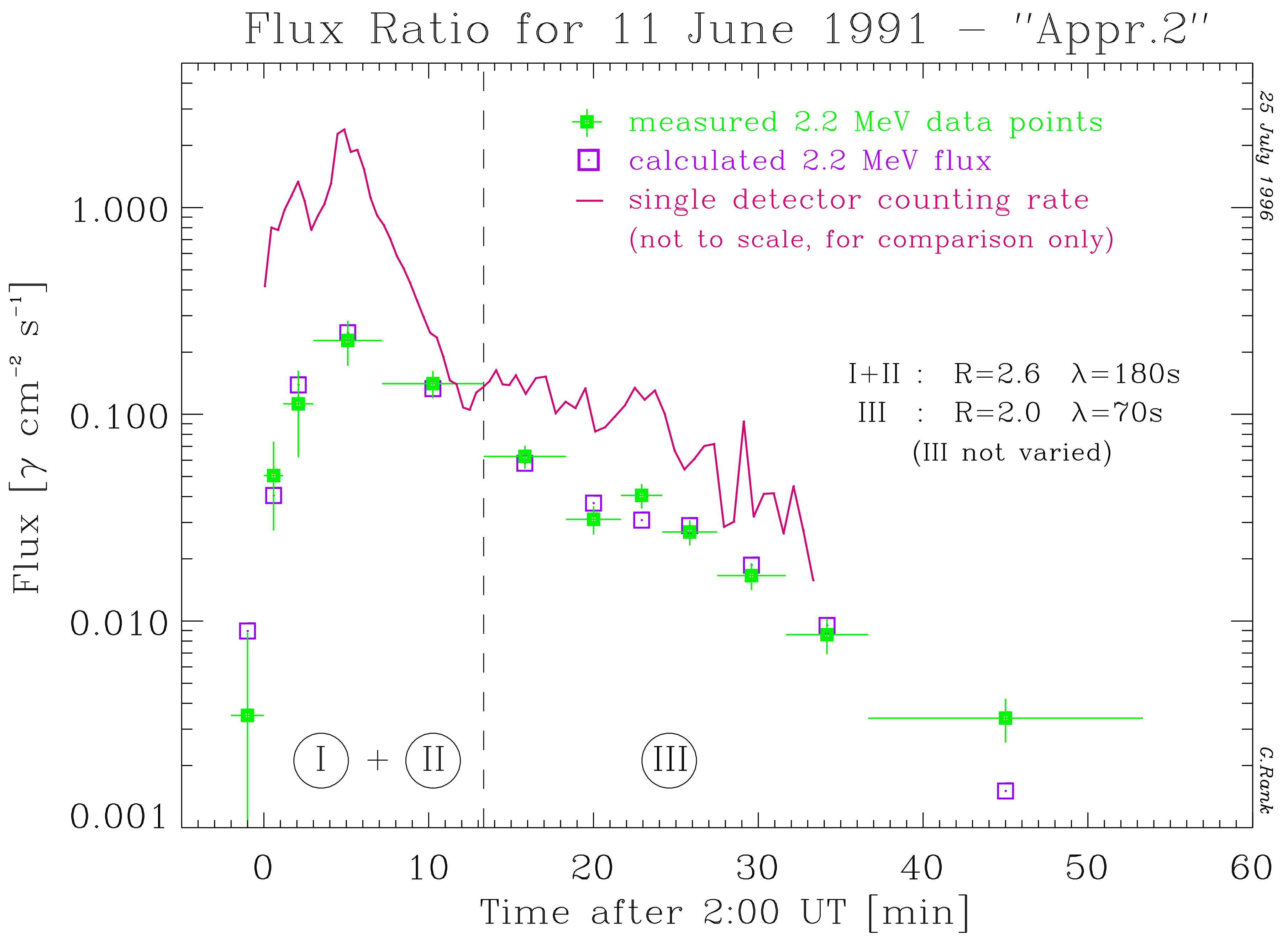
In order to understand the impulsive phase of the 11 June 1991 flare, it seems to be necessary to include also lower energy neutrons in this study. Such work is done by Alex Young at UNH presently. The question to investigate is, whether **the contribution of low-energy neutrons is sufficient to produce a high value of the 2.2MeV/4-7MeV ratio also for a very soft spectrum.** Then a large R could be indicating a hard spectrum (the high 2.2 MeV emission caused by $\sim$ 100 MeV neutrons) or a very soft spectrum (the high 2.2 MeV emission caused by $<$ 1 MeV neutrons).

FUTURE WORK:

Investigate, what spectral hardness (e.g. for a power law) would be necessary to produce a detectable pion signal for EGRET.

Check if the developed models are consistent with the PBS and PHEBUS data.


Flux Ratio for 11 June 1991 – "Appr.1"
measured 2.2 MeV data points
calculated 2.2 MeV flux
single detector counting rate
(not to scale, for comparison only)
I : R=0.8 λ=70s
II : R=7.6 λ=70s
III : R=2.0 λ=70s
(λ not varied)
I
II
III
1.000
0.100
0.010
0.001
Flux [γ cm⁻² s⁻¹]
0
10
20
30
40
50
60
Time after 2:00 UT [min]
25 July 1996
G.Rank


Flux Ratio for 11 June 1991 – "Appr.2"
measured 2.2 MeV data points
calculated 2.2 MeV flux
single detector counting rate
(not to scale, for comparison only)
I+II : R=2.6 λ=180s
III : R=2.0 λ=70s
(III not varied)
I + II
III
Flux [γ cm^{-2} s^{-1}]
1.000
0.100
0.010
0.001
0
10
20
30
40
50
60
Time after 2:00 UT [min]
25 July 1996
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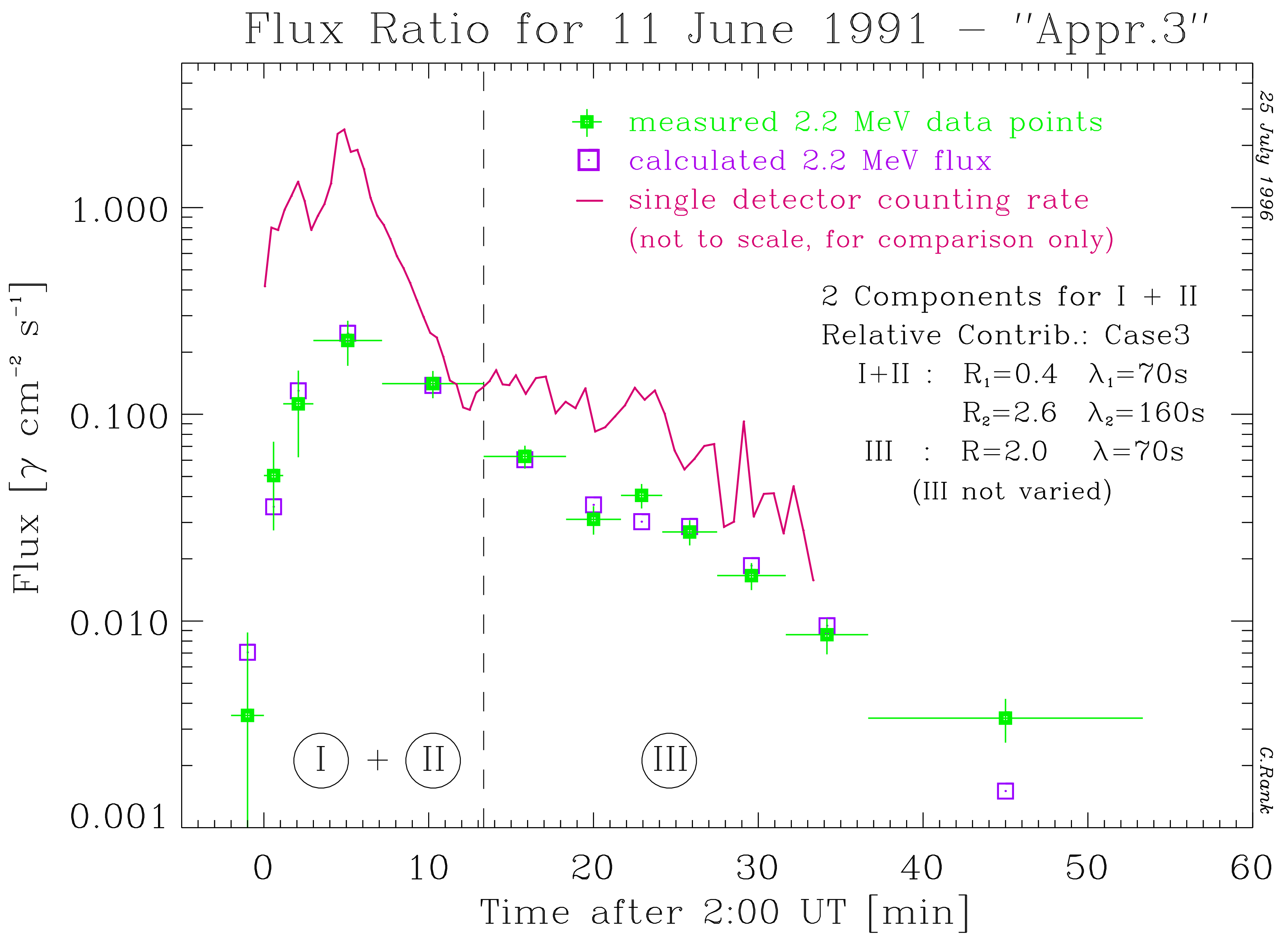

Flux Ratio for 11 June 1991 – "Appr.3"
measured 2.2 MeV data points
calculated 2.2 MeV flux
single detector counting rate
(not to scale, for comparison only)
2 Components for I + II
Relative Contrib.: Case3
I+II : R₁=0.4 λ₁=70s
R₂=2.6 λ₂=160s
III : R=2.0 λ=70s
(III not varied)
I + II
III
1.000
0.100
0.010
0.001
0
10
20
30
40
50
60
Time after 2:00 UT [min]
Flux [γ cm⁻² s⁻¹]
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