Soft and Hard
Gradual and Impulsive
Thermal and Non-thermal

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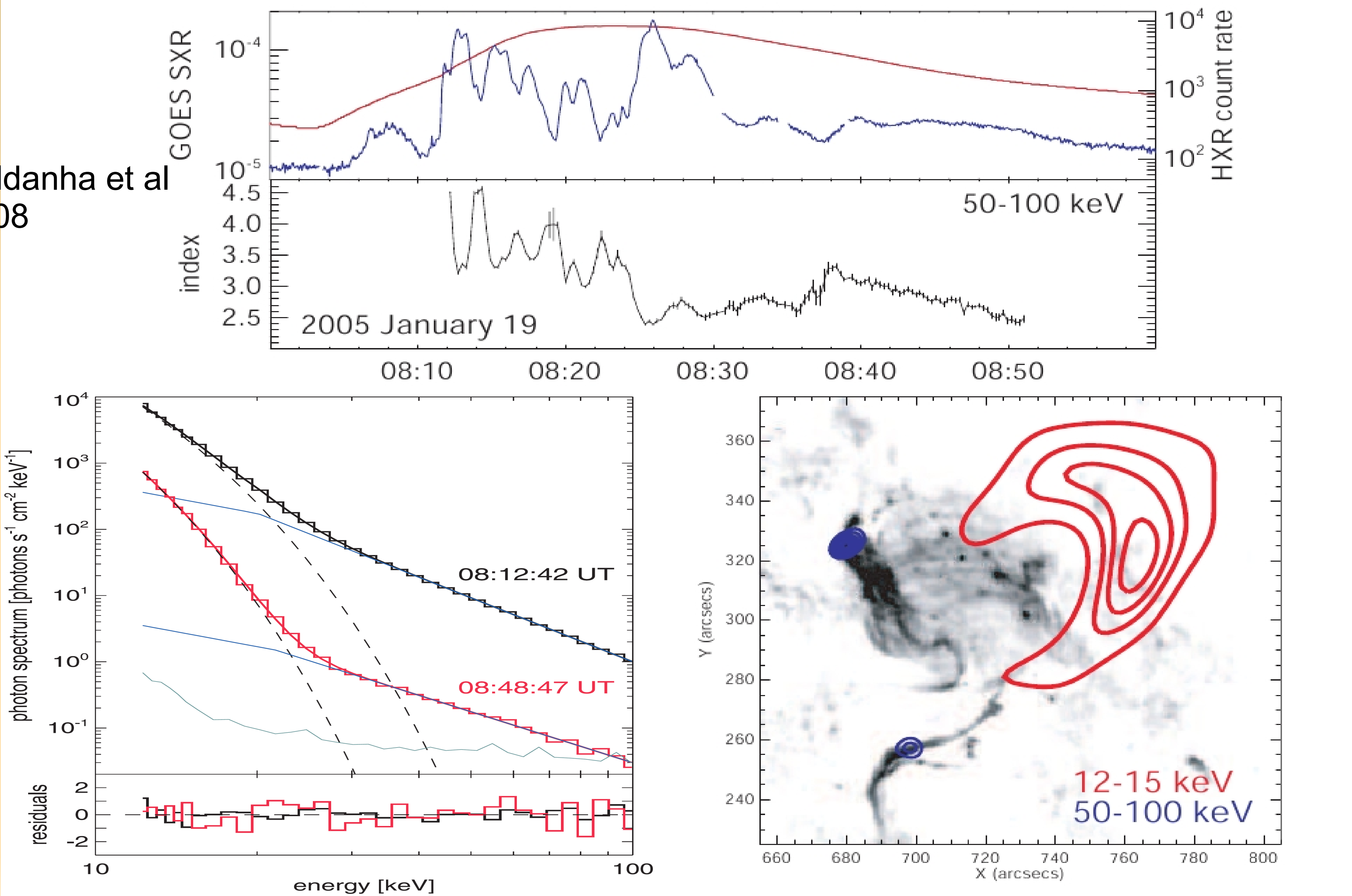
Motivation

- Soft X-ray: gradual light curves as thermal component
- Hard X-ray: impulsive light curves as nonthermal component
- Spectral fitting normally shapes a nice combination of two components, but it doesn't involve the temporal information
- Can we diagnose the thermal and nonthermal information quantitatively from light curves?
- Would the result be consistent with what we get from spectral fits?

An ideal image of a clear seperation of thermal and nonthermal

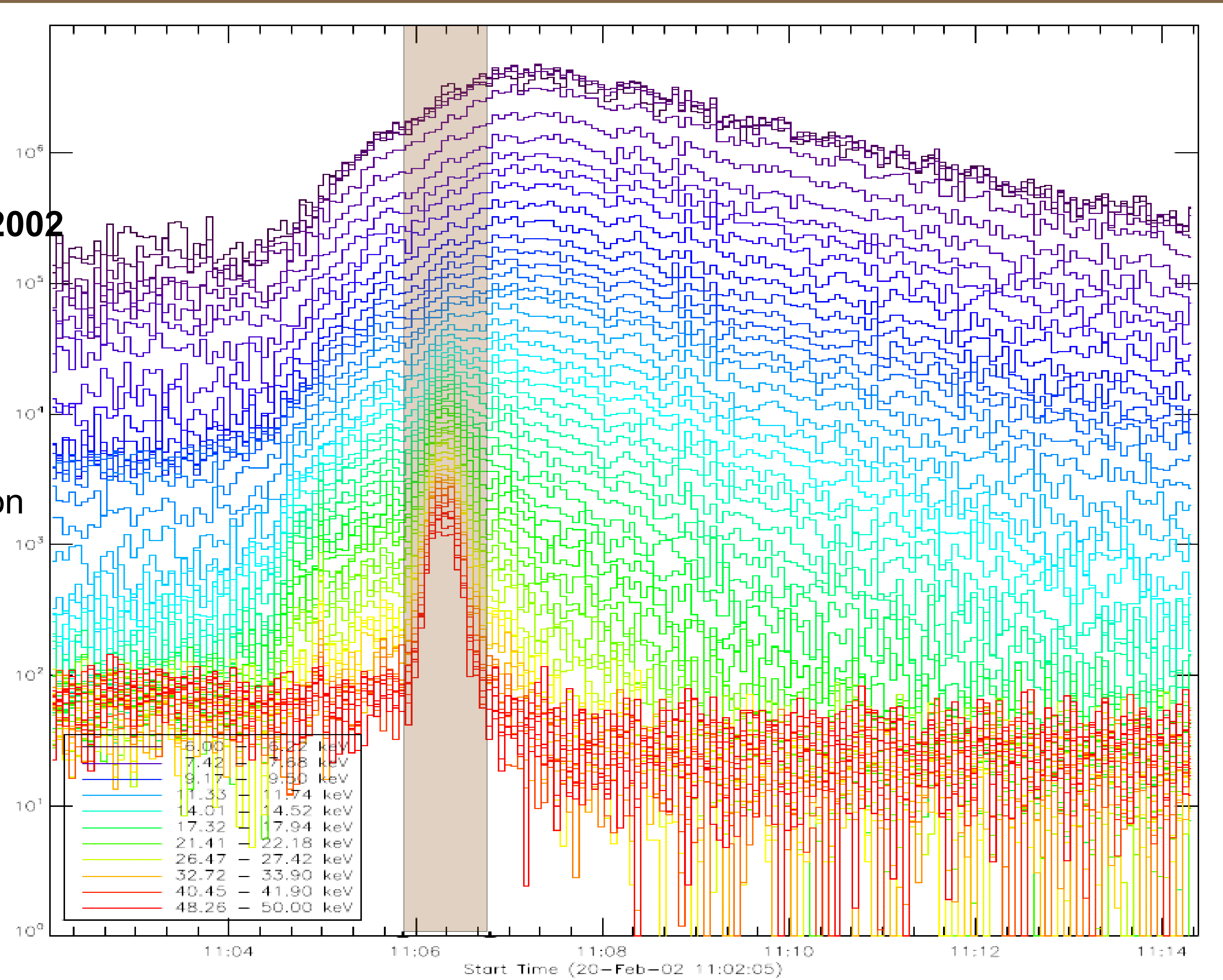
Saldanha et al 2008



Our simple start

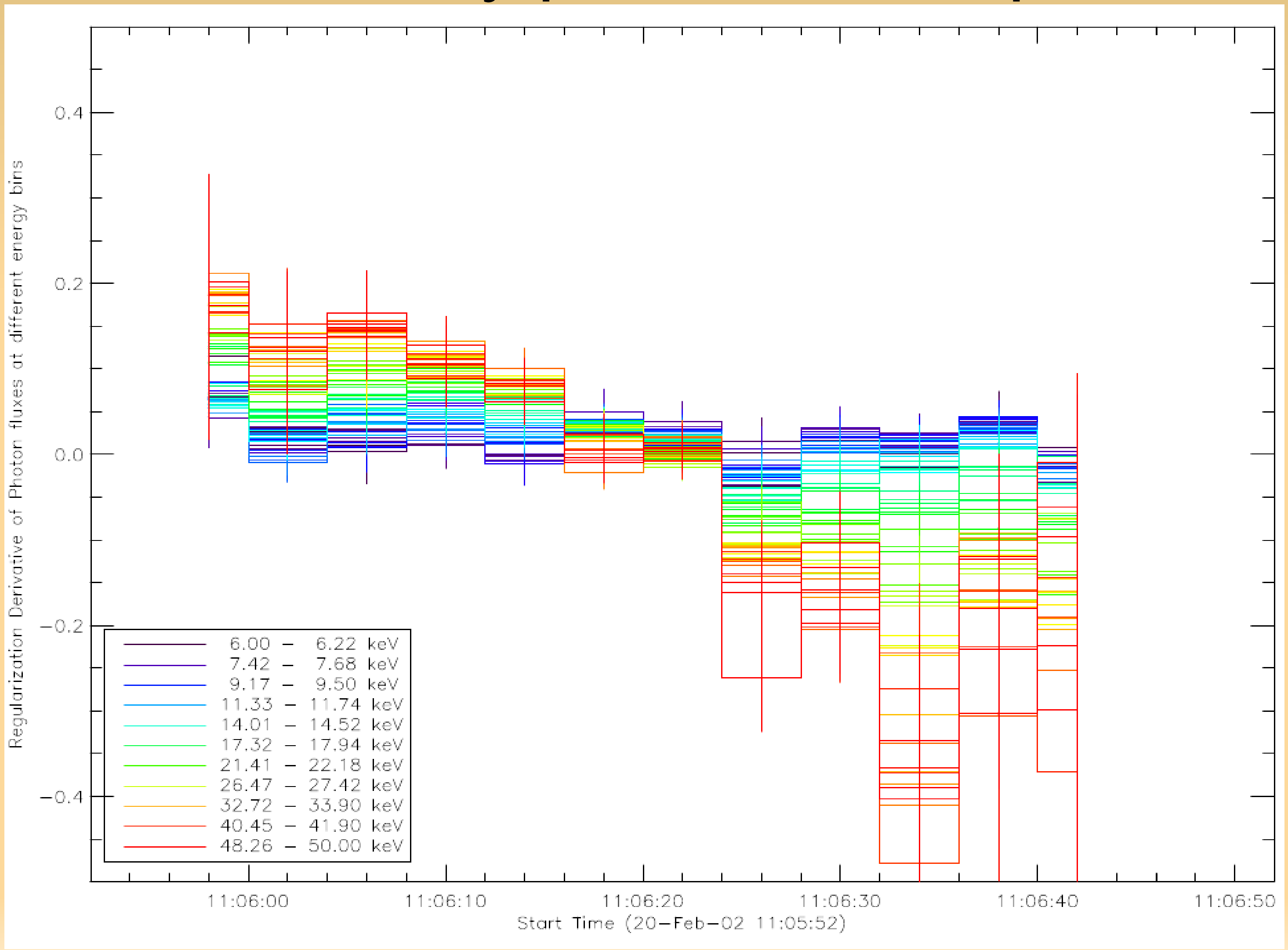
RHESSI 20 Feb 2002

A Clear impulsive single peak at High energies (> ~10 keV)
+
A graudal evolution at low energies (< ~10 keV)

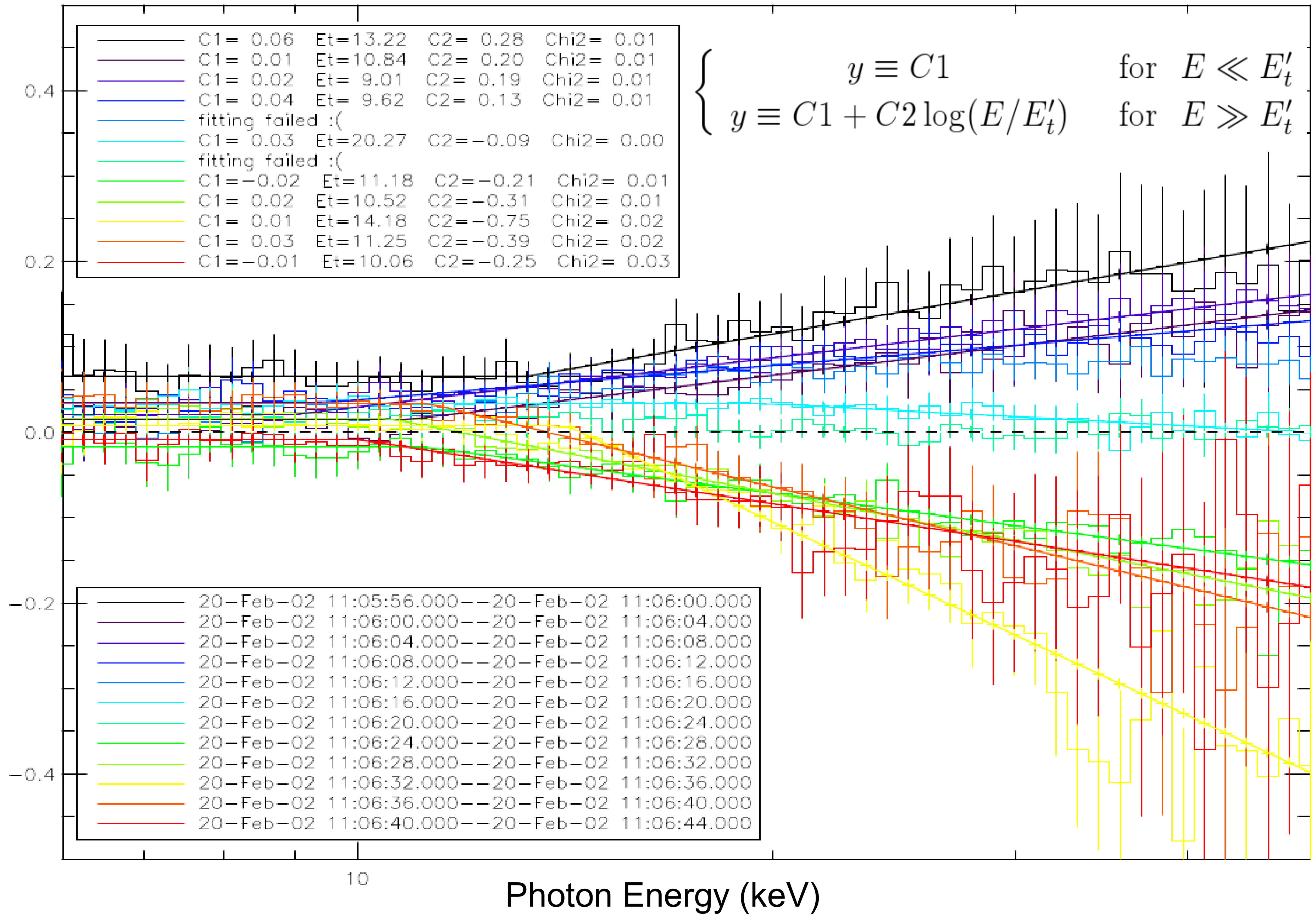


Normalized time derivatives of semi-calibrated flux

- Higher energies have larger derivatives during the rise and decay phases of the peak



Derivatives versus energies



Thermal + Nonthermal Model

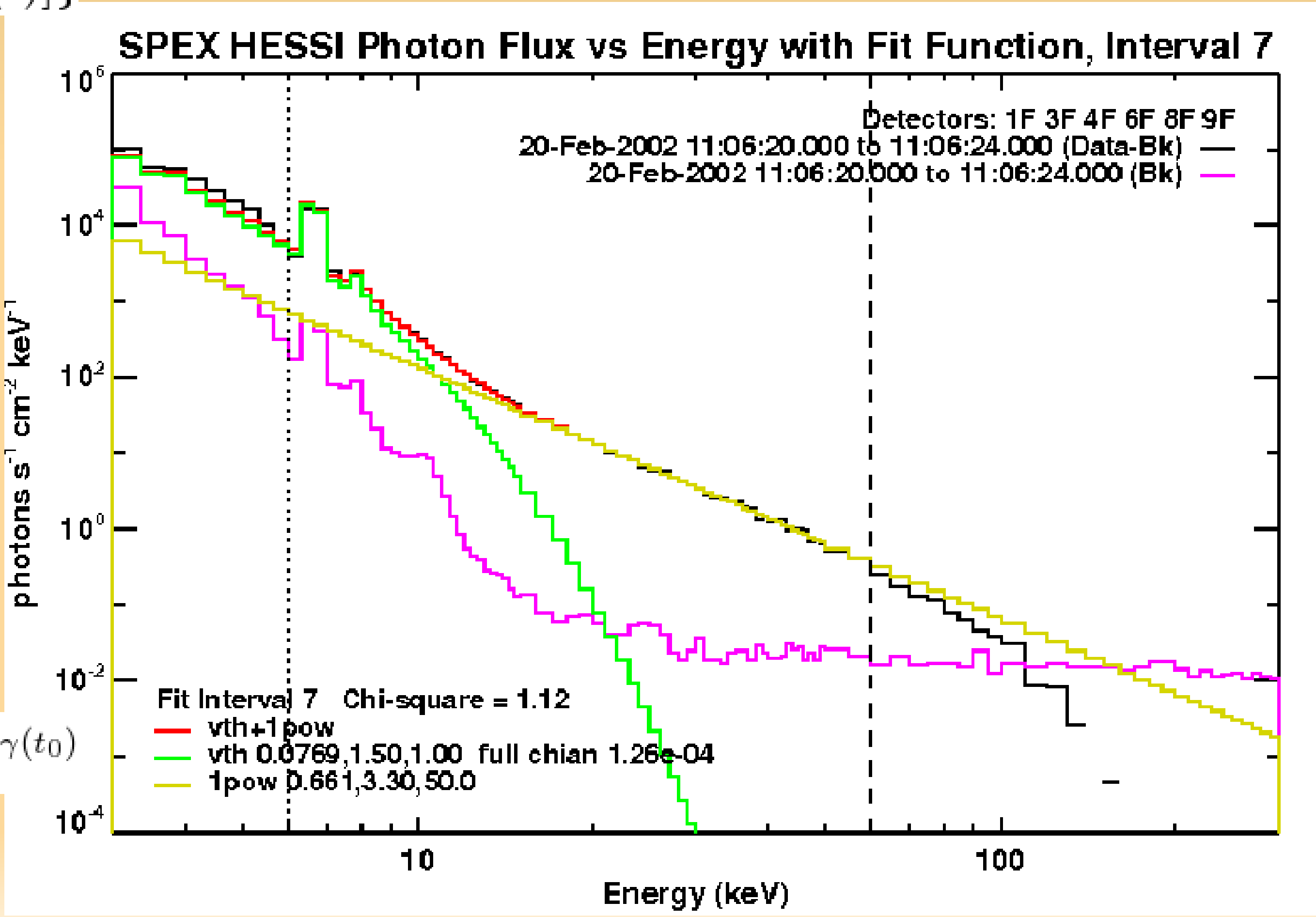
- Isothermal + single power-law

$$N(E,t) = N_{th}(E,t) + N_{nth}(t)\,(E/\mathrm{keV})^{-\gamma(t)}$$

Power-law

$$EM(t)/\ \{E\,T(t)^{1/2}\exp[E/k_{\rm B}T(t)]\}$$

$$EM(t) = n^2V$$

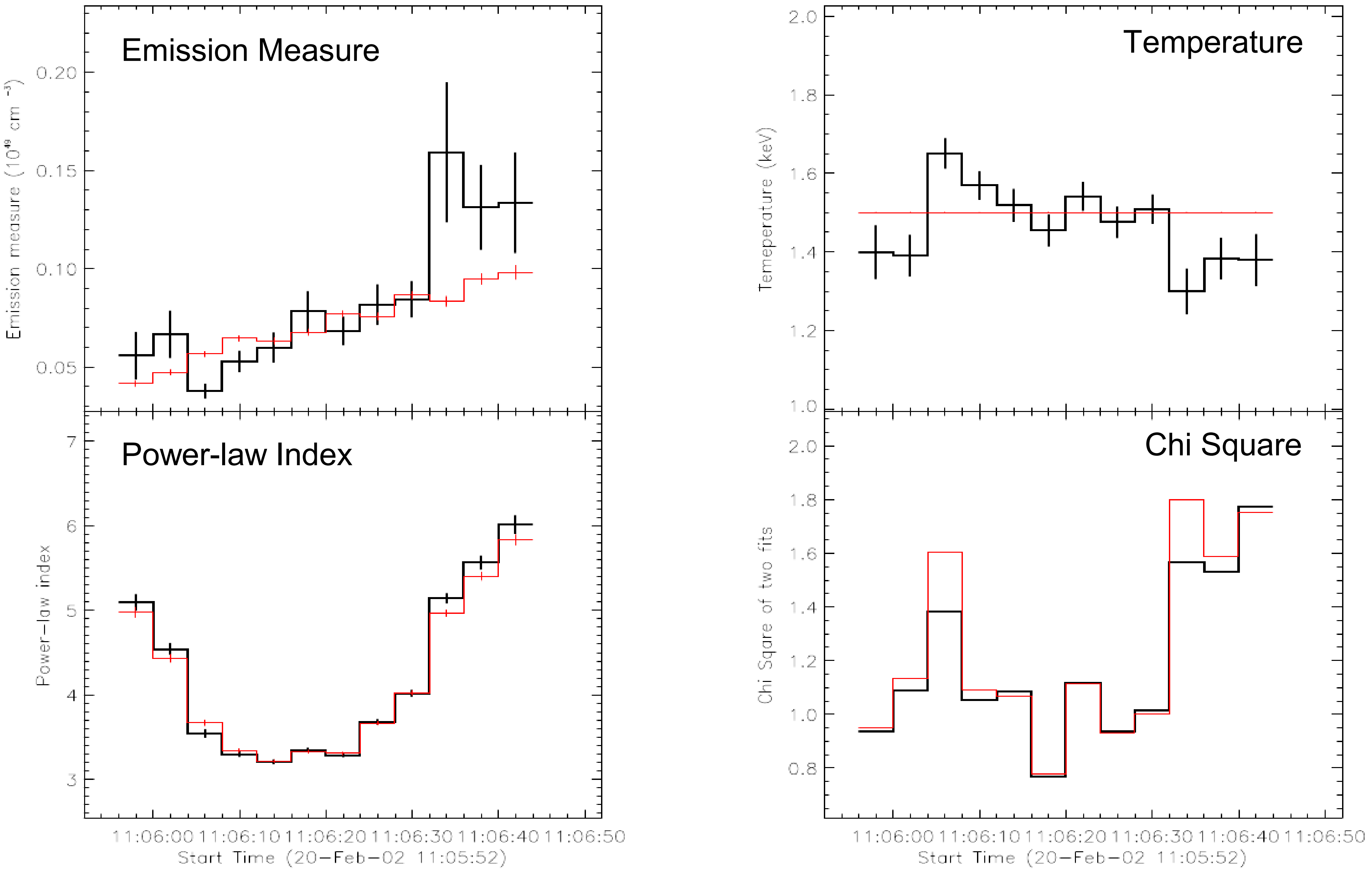


Transition energy Et
is the energy where

thermal emission =
nonthermal emission

$$N_{th}(E_t,t_0) = N_{nth}(t_0)(E_t/\mathrm{keV})^{-\gamma(t_0)}$$

Spectral Fitting



Two-component photon spectral model and its time variation

$$N(E,t) = N_{th}(E,t) + N_{nth}(t)\,(E/\mathrm{keV})^{-\gamma(t)}$$

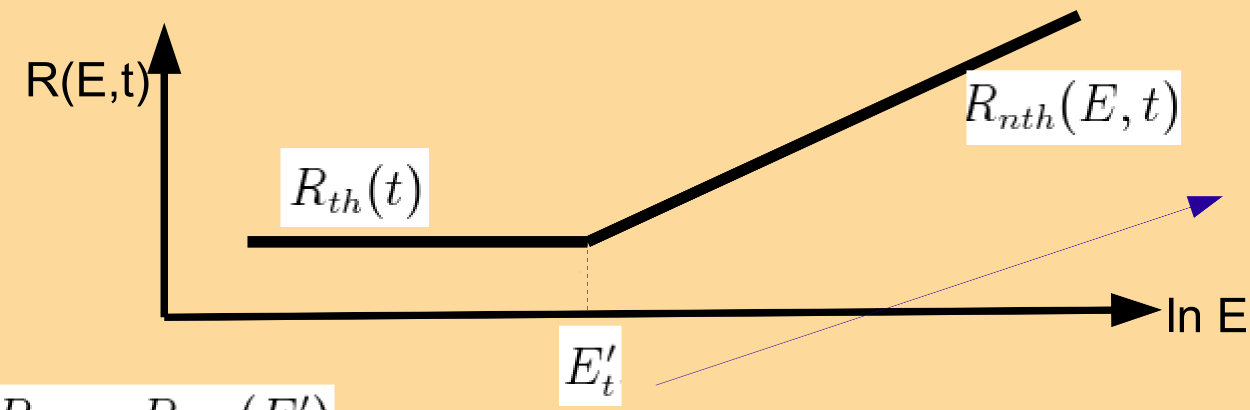
Normalized Derivative

$$R(E,t) \equiv \frac{dN(E,t)}{N(E,t)\cdot dt} = \frac{\dot{N}_{th}(E,t) + \dot{N}_{nth}(t)(E/\mathrm{keV})^{-\gamma} - N_{nth}(t)\dot{\gamma}(t)\ln(E/\mathrm{keV})(E/\mathrm{keV})^{-\gamma}}{N_{th}(E,t) + N_{nth}(t)\,(E/\mathrm{keV})^{-\gamma(t)}}$$

$$\approx \begin{cases} R_{th} \equiv \dot{N}_{th}(E,t)/N_{th}(E,t) & \text{for} \quad E \ll E_t \\ R_{nth} \equiv \dot{N}_{nth}(t)/N_{nth}(t) - \dot{\gamma}(t)\ln(E/\mathrm{keV}) & \text{for} \quad E \gg E_t \end{cases}$$

$$R_{th} = \frac{\dot{N}_{th}(E,t)}{N_{th}(E,t)} = \frac{E\dot{M}(t)}{EM(t)} + \cancel{\frac{E\dot{T}}{k_B T^2}} - \cancel{\frac{\dot{T}}{2T}}.$$

Et comes from spectral fitting

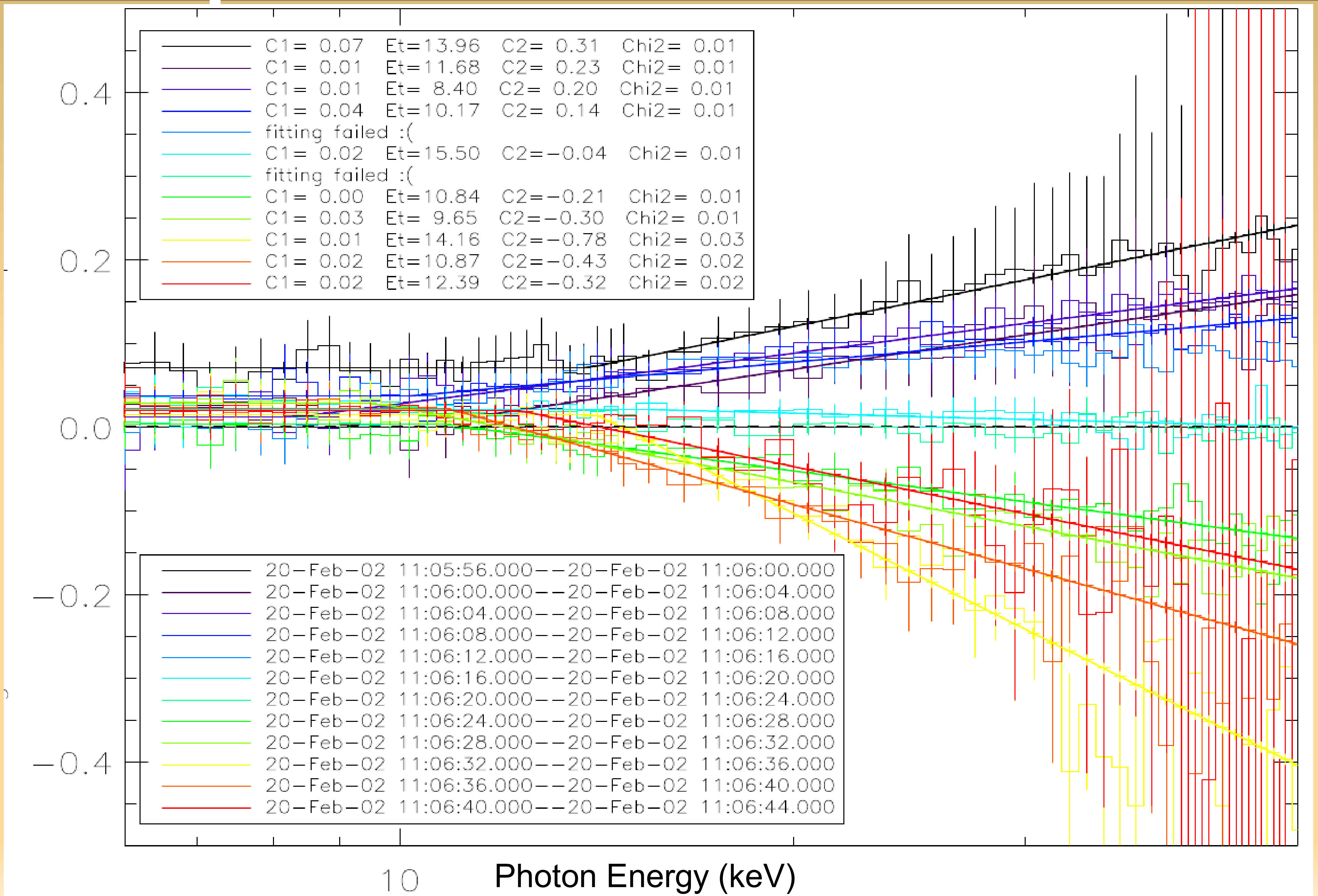


$$R_{th} = R_{nth}(E_t')$$

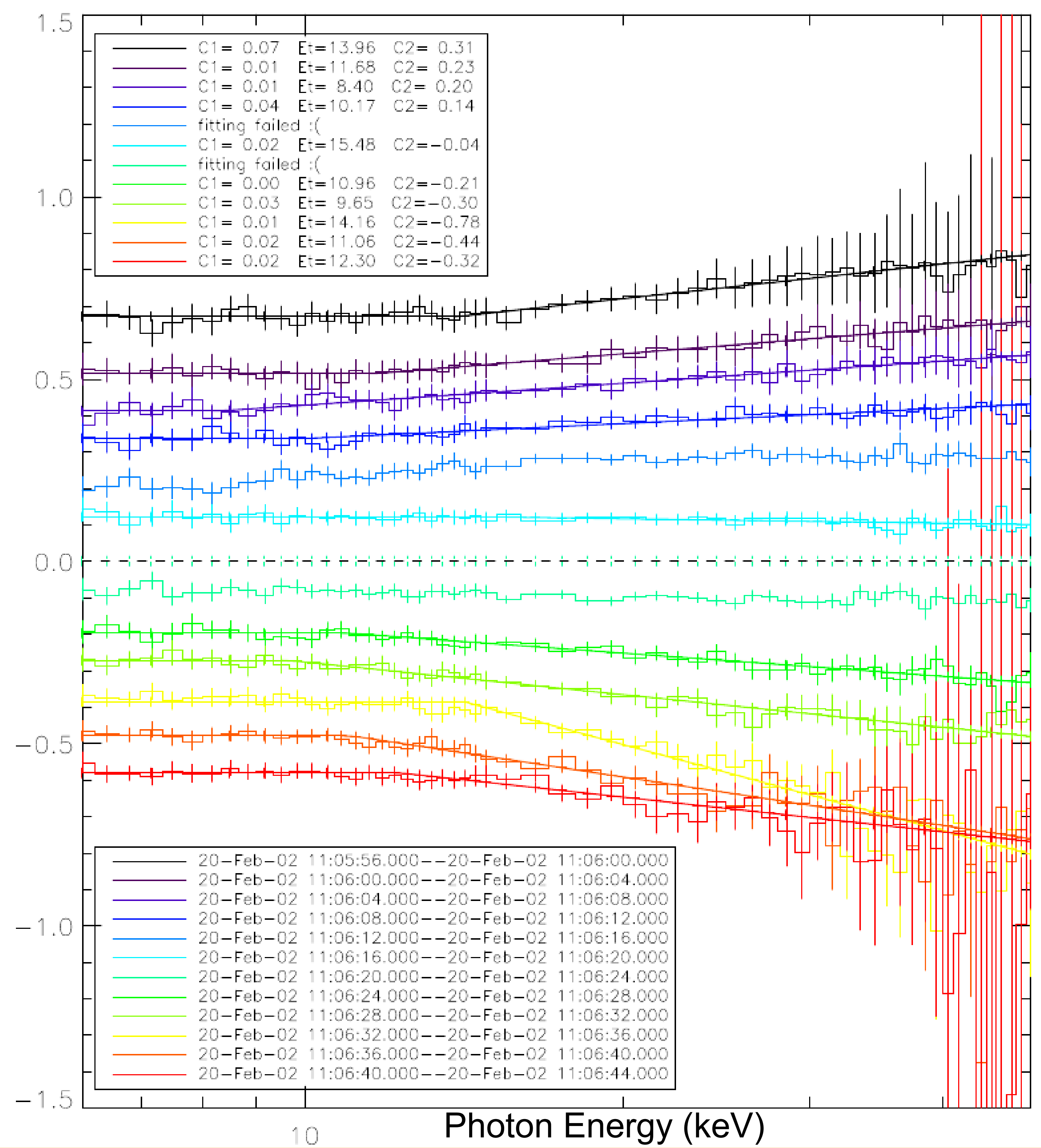
Behavior of time derivatives gives an energy at which rates of change for th/non thermal equal

Are these consistent?

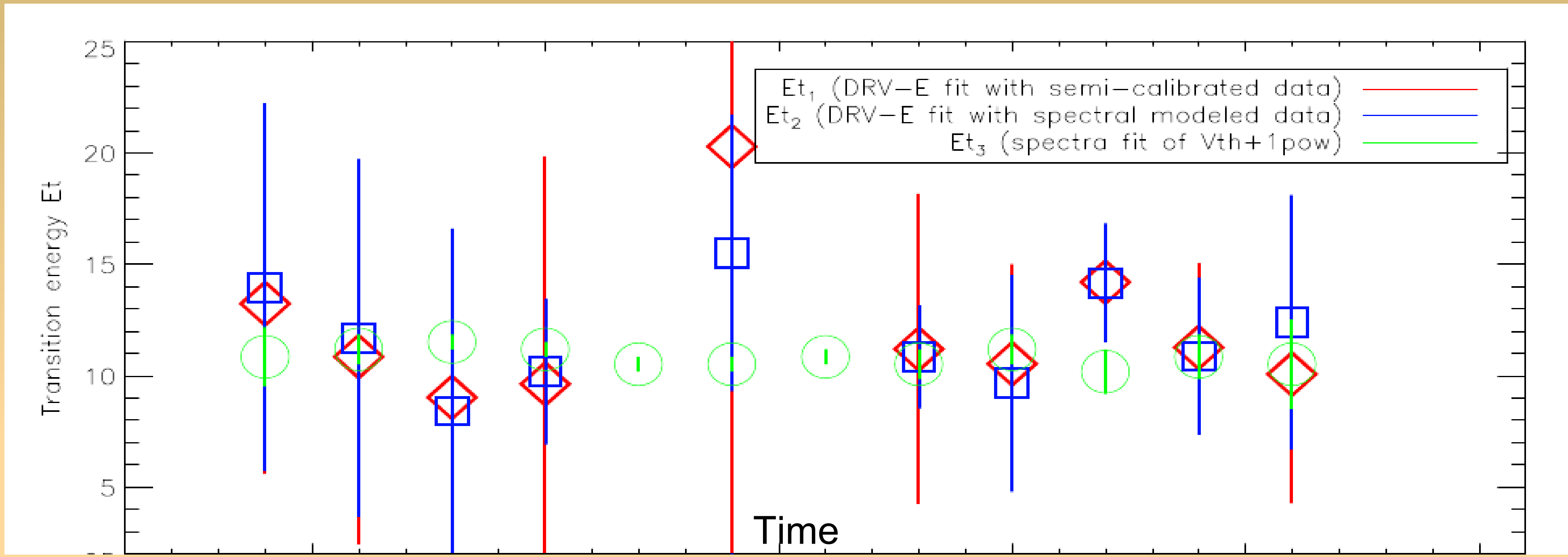
Spectral modeled photon flux derivatives



We shift the lines vertically in y direction with values [0.6, 0.5, 0.4, 0.3, 0.2, 0.1, -0.1, -0.2, -0.3, -0.4, -0.5, -0.6] respectively.



Comparing transition energies Et obtained from both methods



Square & diamonds: Transition energies calculated when $R_{th} = R_{nth}(E'_t)$

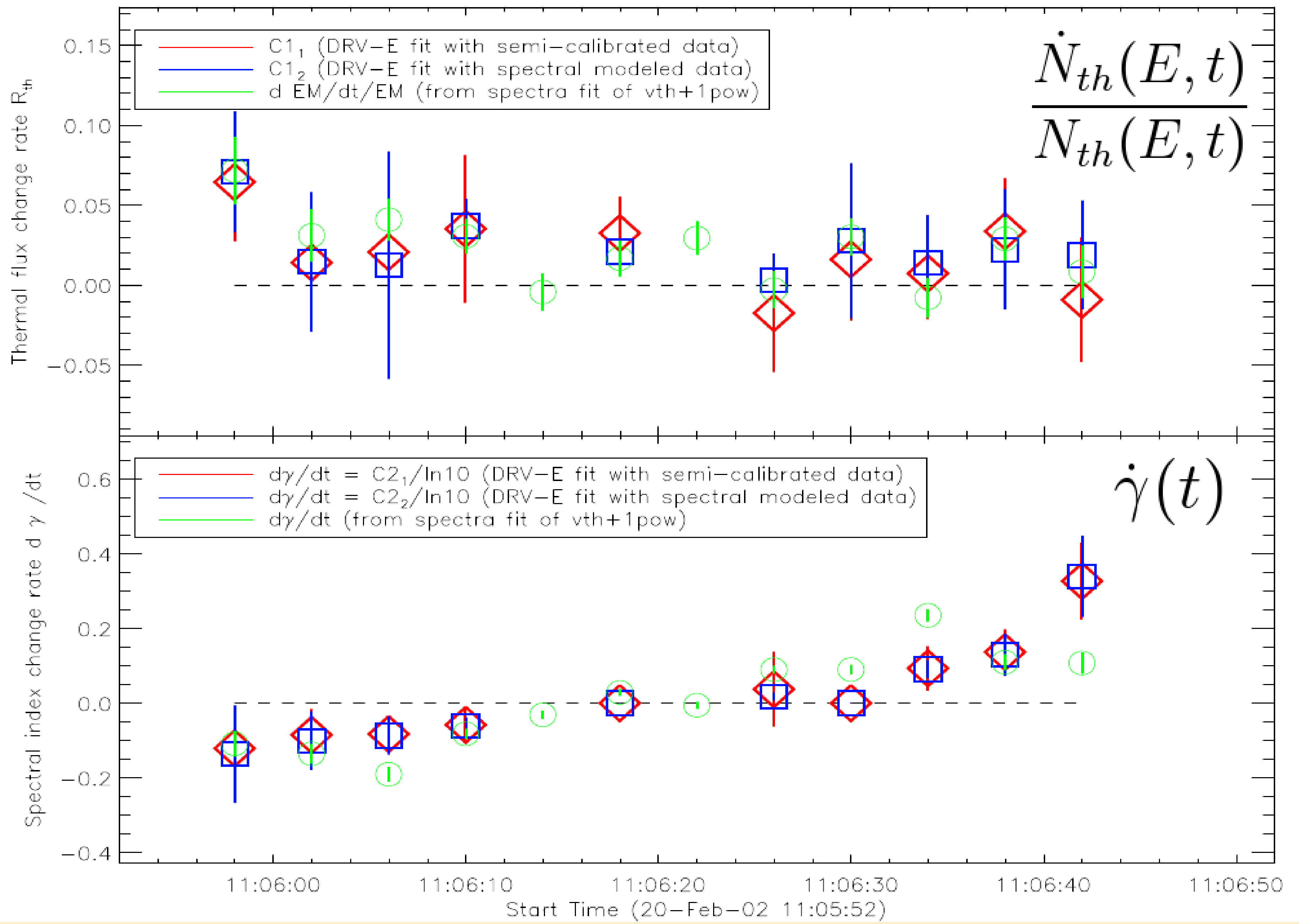
Blue squares: photon fluxes from spectral fitting

Red diamonds: semi-calibrated data

Circles: Transition energies obtained from spectral fitting where f_th = f_nth

The transition energies obtained from different methods are consistent with eachother.

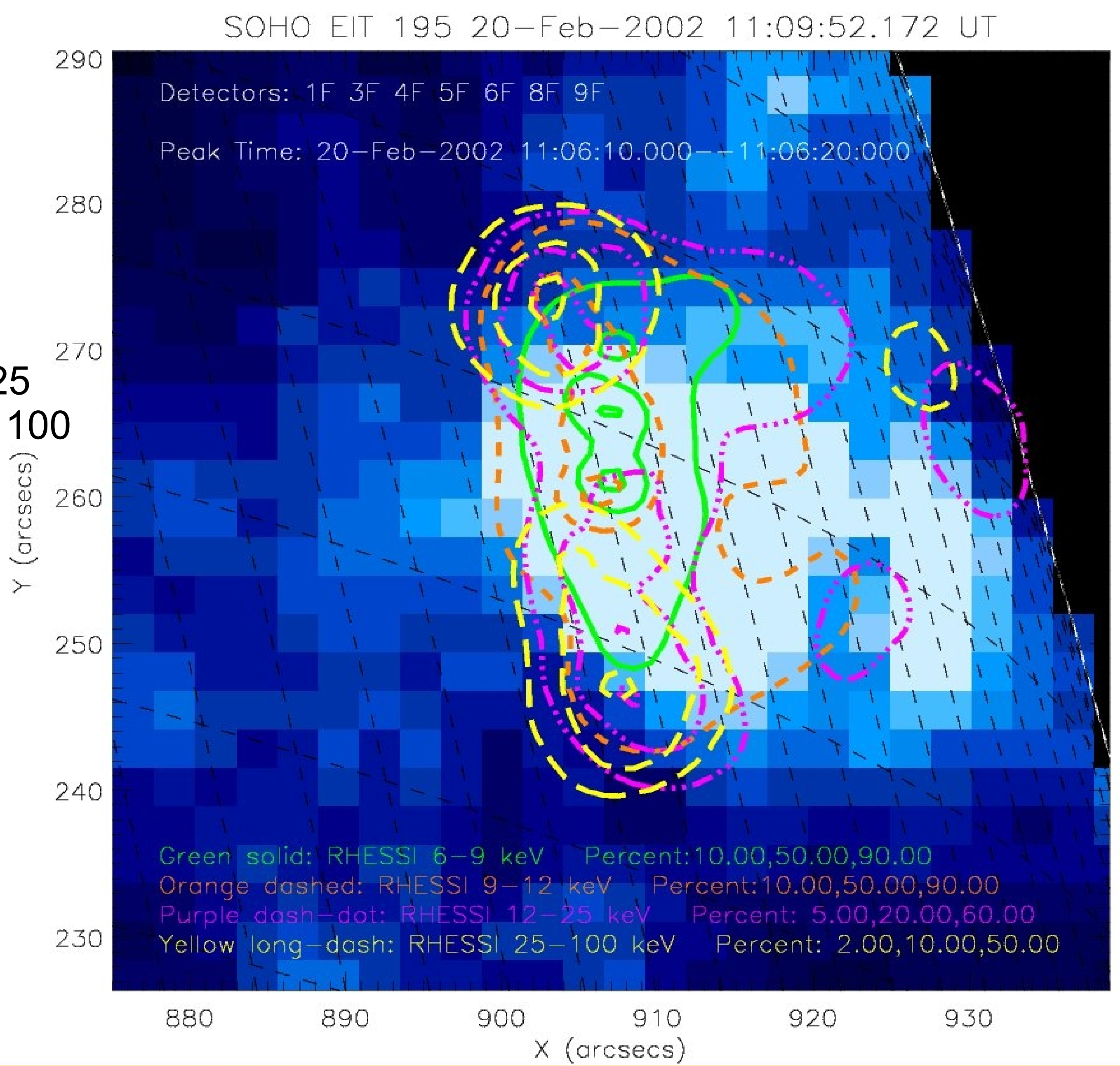
Rate-of-changes of Thermal flux & Spectral Index



Flare Images

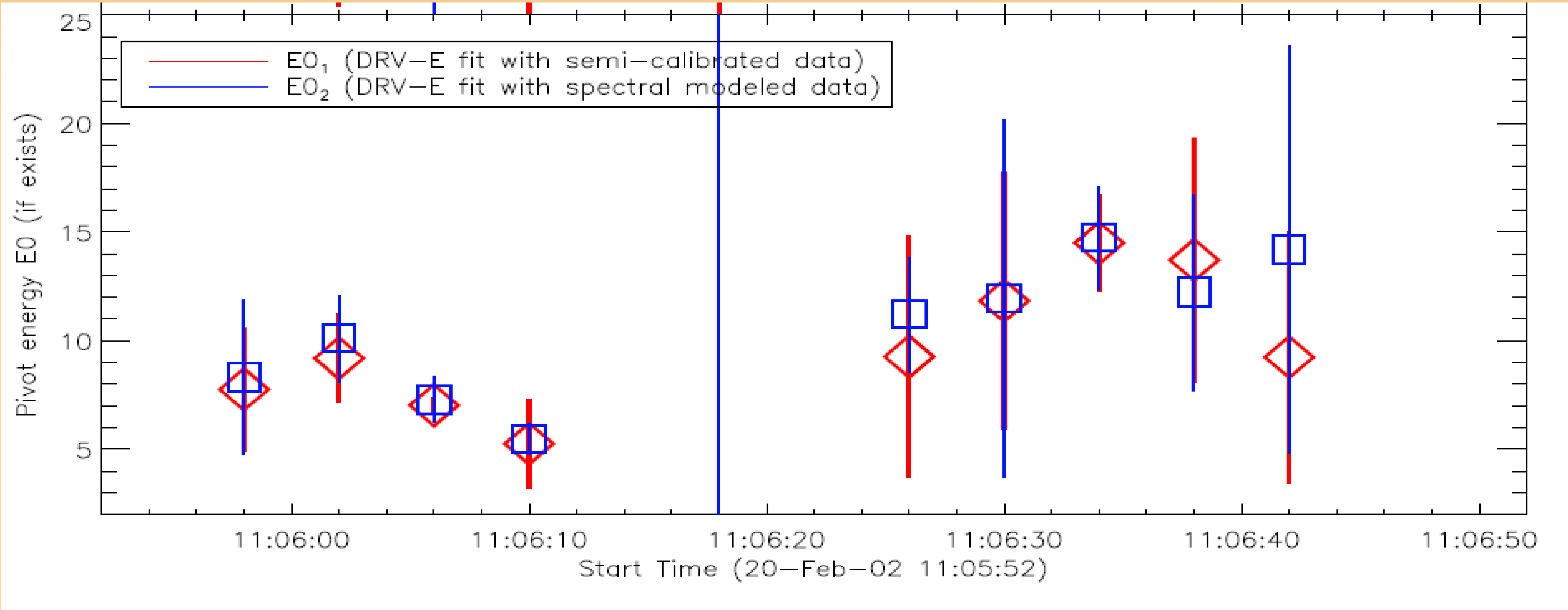
SOHO EIT +
Peak time RHESSI

Green solid: 6-9 keV
Orange dashed: 9-12
Purple dash-dot: 12 -25
Yellow long dash: 25- 100



Pivot energy where $R(E,t) \equiv \dfrac{dN(E,t)}{N(E,t)\cdot dt}$ =0

The soft-hard-soft (SHS) behavior has often been studied to verify the existence of a pivot energy *E*0 where the non-thermal spectrum at different times intersect



Blue squares: photon fluxes from spectral fitting
Red diamonds: semi-calibrated data

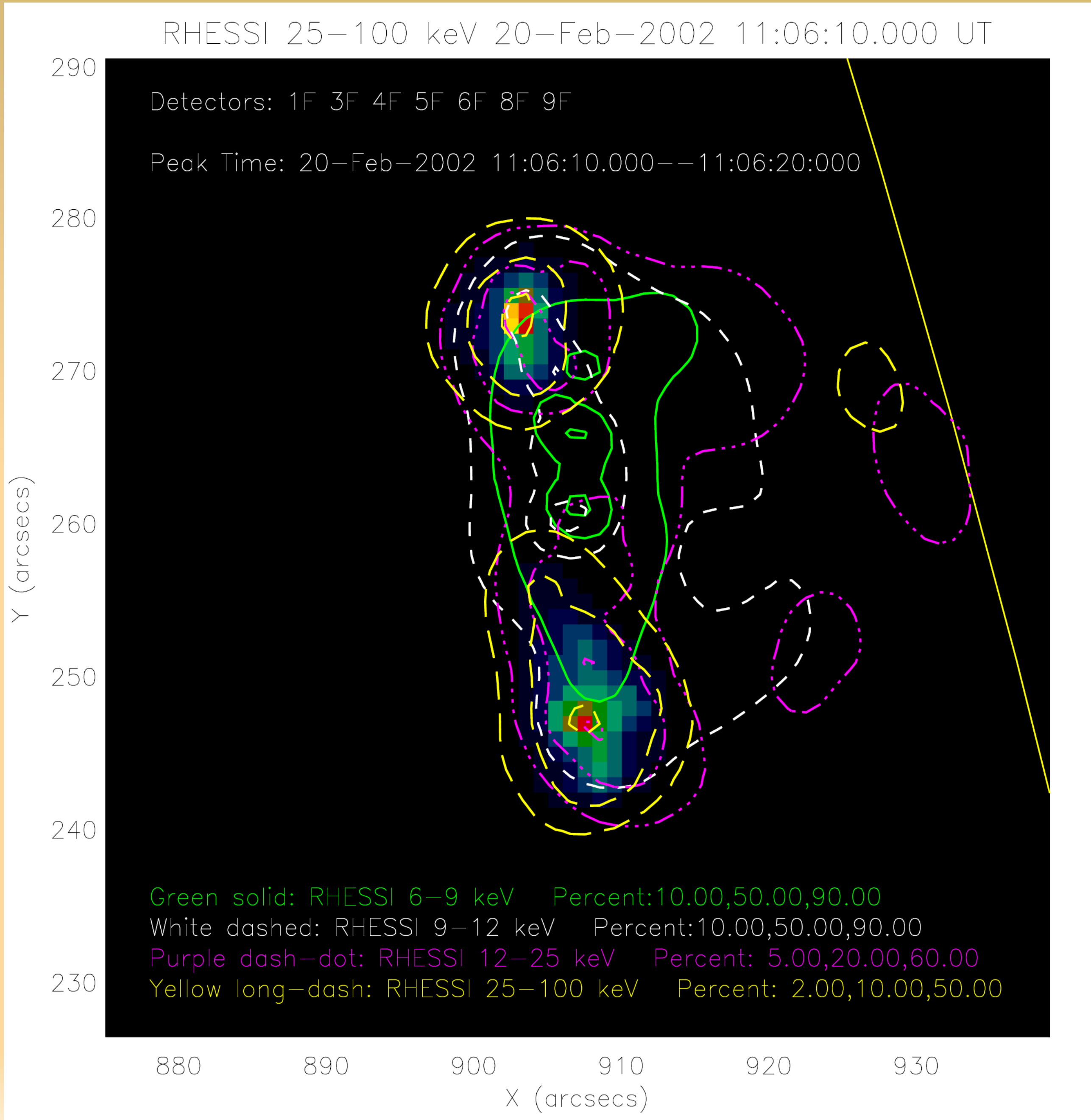
RHESSI image during the peak

Green solid: 6-9 keV
white dashed: 9-12 keV
Purple Dash-dot: 9-12 keV
Yellow long-dash: 25-100 keV

Nonthermal emissions are generated mainly from the footpoints

Thermal source is located Between the footpoints

However, the transition region between thermal & nonthermal energies seems conver both Footpoints and the loop.



Conclusions & Discussions

- The photon flux derivatives contain useful information of the thermal and nonthermal flux
- Different ways to obtain the rates of change of emission measure and power-law index, transition energy and pivot energy
- Big-error-bar issues could be due to
  - Transition energy can be a transition region
  - Instrumental limitation
- Every flare has its own story and we should apply this method to more flares.
- The variation of the temperature can be considered