OVERVIEW OF A 3C279's FLARE and SIMULATION OF AGNs

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Outline

- **Overview of 3C279 flare in 1996** ***(Wehrle et al 1996)***
  - **Emission Models**
- **LAT Simulation of 3C279 flare**
  - **Introduction to the method**
- **Data Analysis**
  - **Tutorial**
- **Results and Discussion**
  - **Features of the Likelihood analysis**
- **Summary**

Multiwavelength Light Curve

Gamma rays

flare: High amplitude of the peak

- factor of 10

High variability

- increase of 2.6 in 8h

preflare: no real variability

- 30% from chi-squared

→ **Strong relativistic beaming**

X - rays

High correlation with gamma rays

Lower amplitude

No time lag

- within resolution time (1 day)

→ **Same emission region of gamma rays**

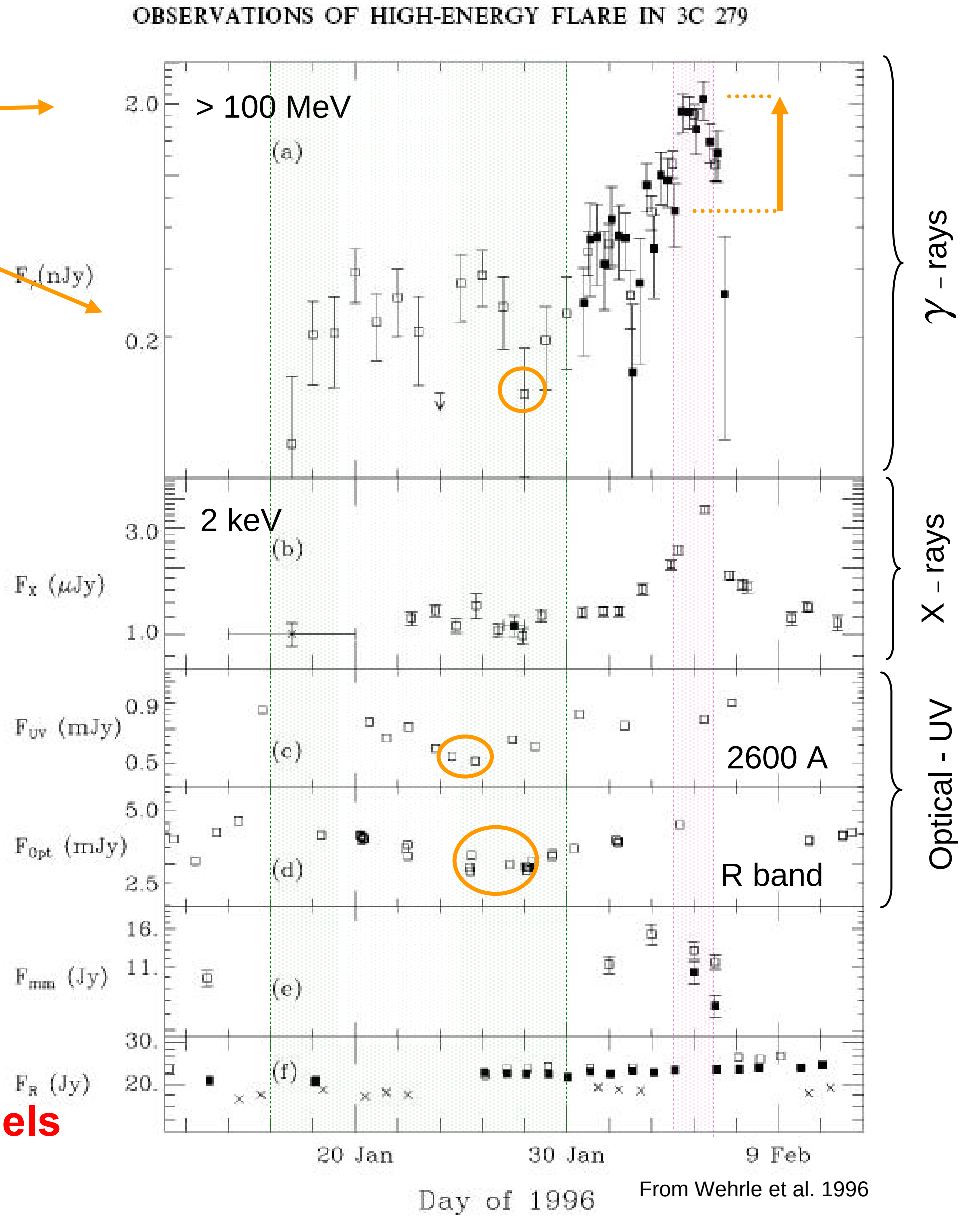
Optical - UV

Possible correlation with gamma rays

Very small amplitude

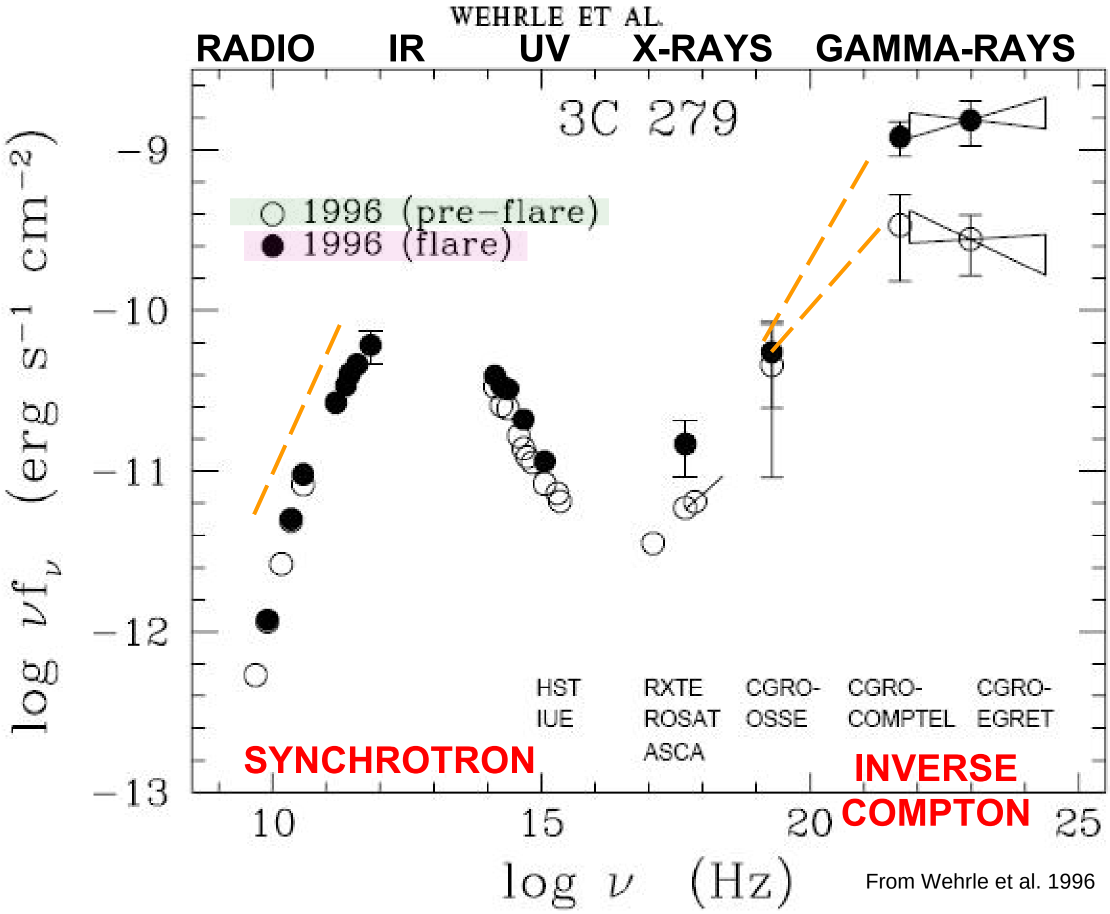
Time lag of 2-3 days

→ **Possible constraints on emission models**



From Wehrle et al. 1996

Spectral Energy Distribution



From Wehrle et al. 1996

The variability amplitude decreases with the decreasing of the energy

The high energy spectrum is harder at the flare peak then at the preflare

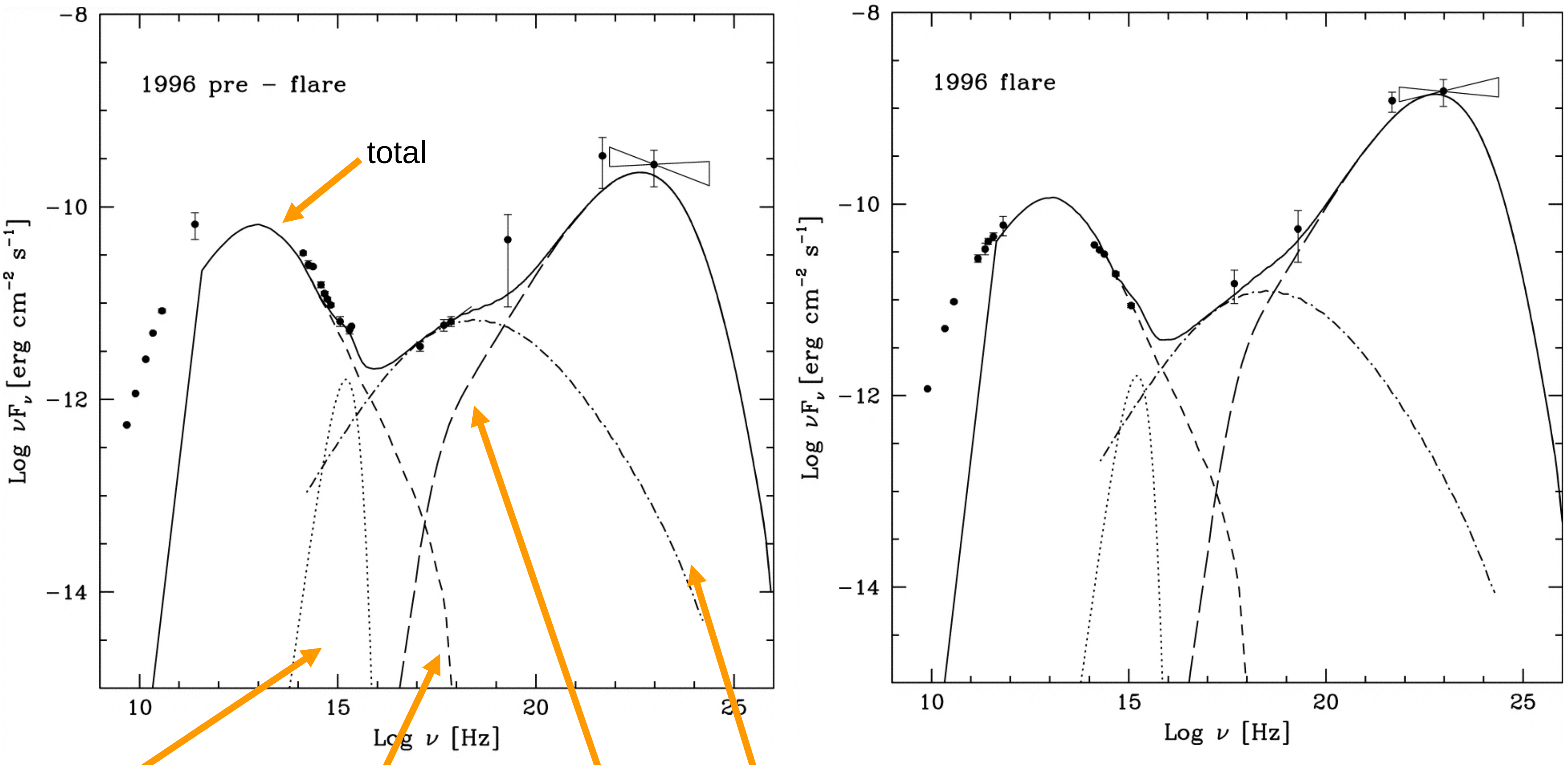
The submillimeter spectral slope during the flare is the same as the X-rays to MeV spectrum

The ratio of the peak fluxes of the inverse Compton distribution to the synchrotron distribution gives constraints to the models that explain the provenience of the seed photons.

- The ratio here is more than quadratic.

Modeling Emission Processes

Ballot et al ApJ, 567, 50-57 (2002)



total

accretion disk

synchrotron

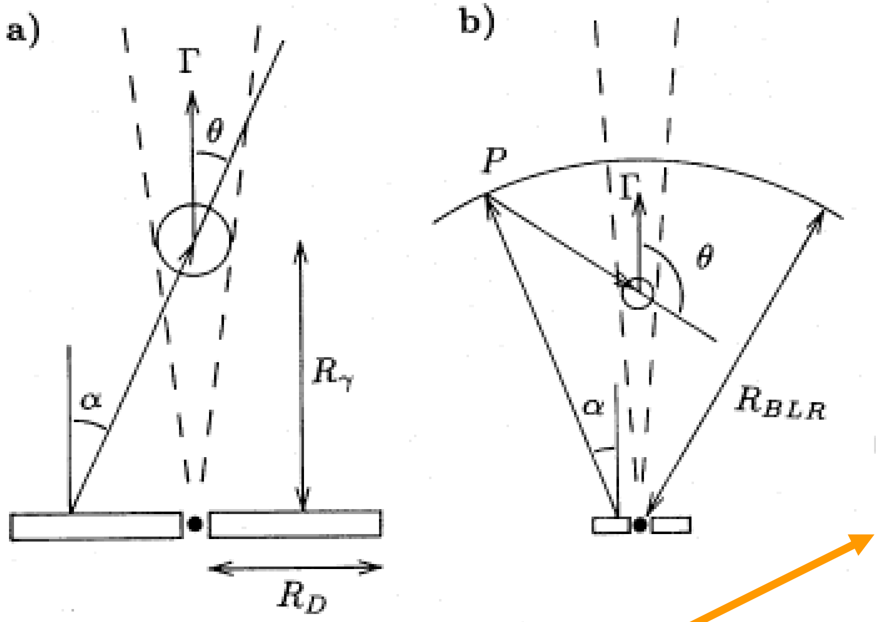
external Compton (mostly BLR)

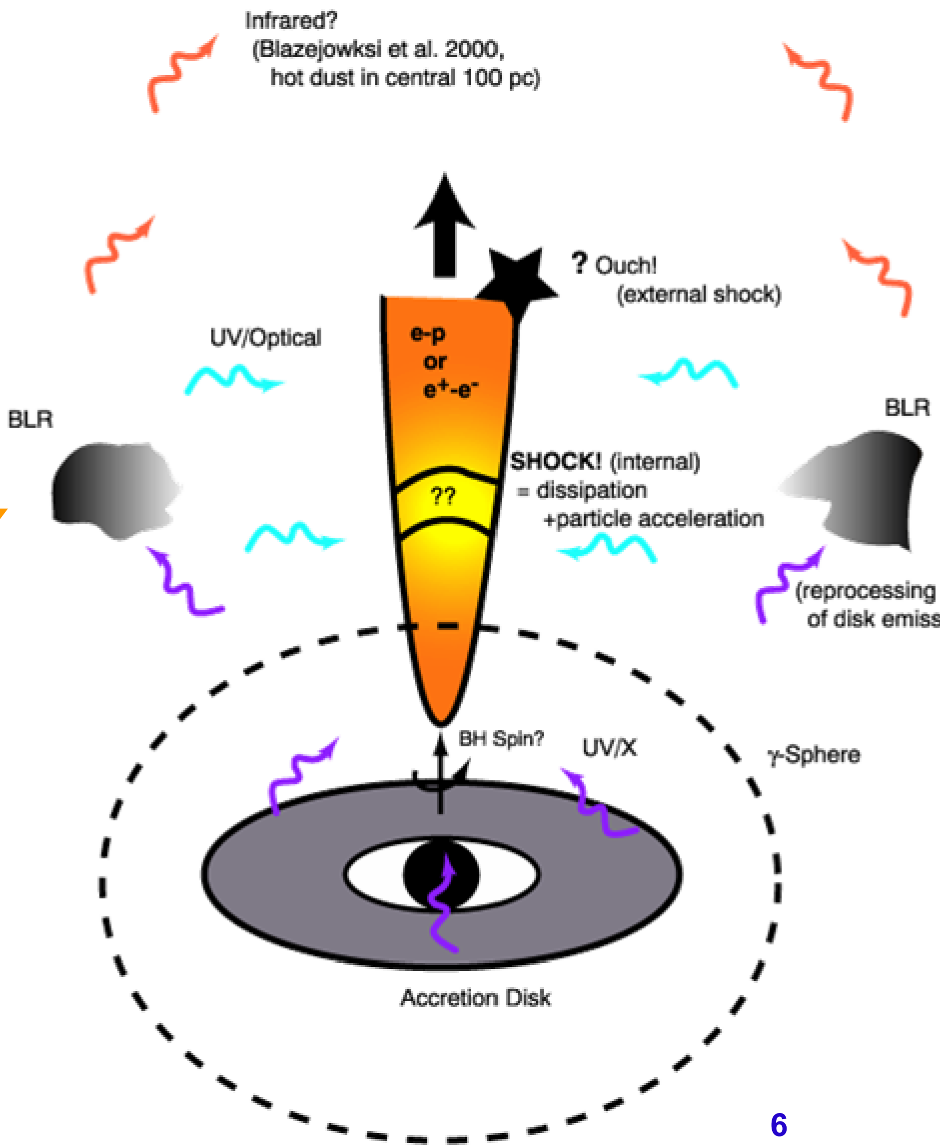
SSC

- **Inverse Compton emission models:**
  - **Synchrotron Self Compton (SSC)**
  - **External Compton**
    - **Mirror Model (BLR)**

External Model: BLR as a mirror

Ghisellini and Madau MNRAS 280, 67-76 (1996)





Wehrle et al (1996)

- **Interaction with gas clouds (BLR) can change the SED**
  - **Clouds act as "mirror" for photons which are scattered into the jet**
  - **Jet can also interact directly with clouds**

Emission Models

Assumption: single active blob in the jet is responsible for the variability

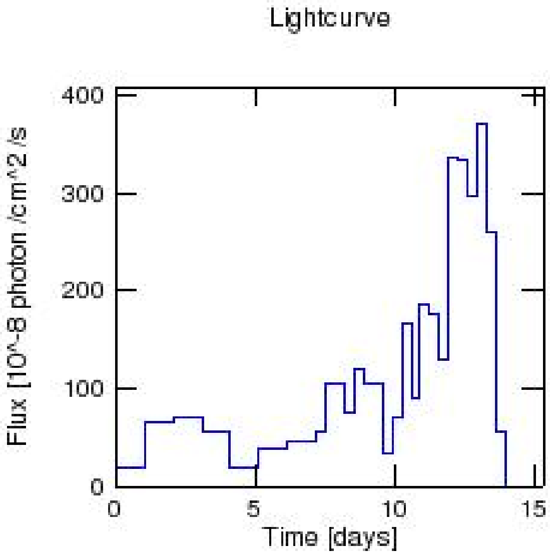
- **Synchrotron Self Compton (SSC)**
  - **Larger variations in synchrotron emission then inverse Compton;**
    - **Energy densities of seed photons and scattering electrons vary in phase;**
  - **In a one-zone model, the ratio is quadratic.**

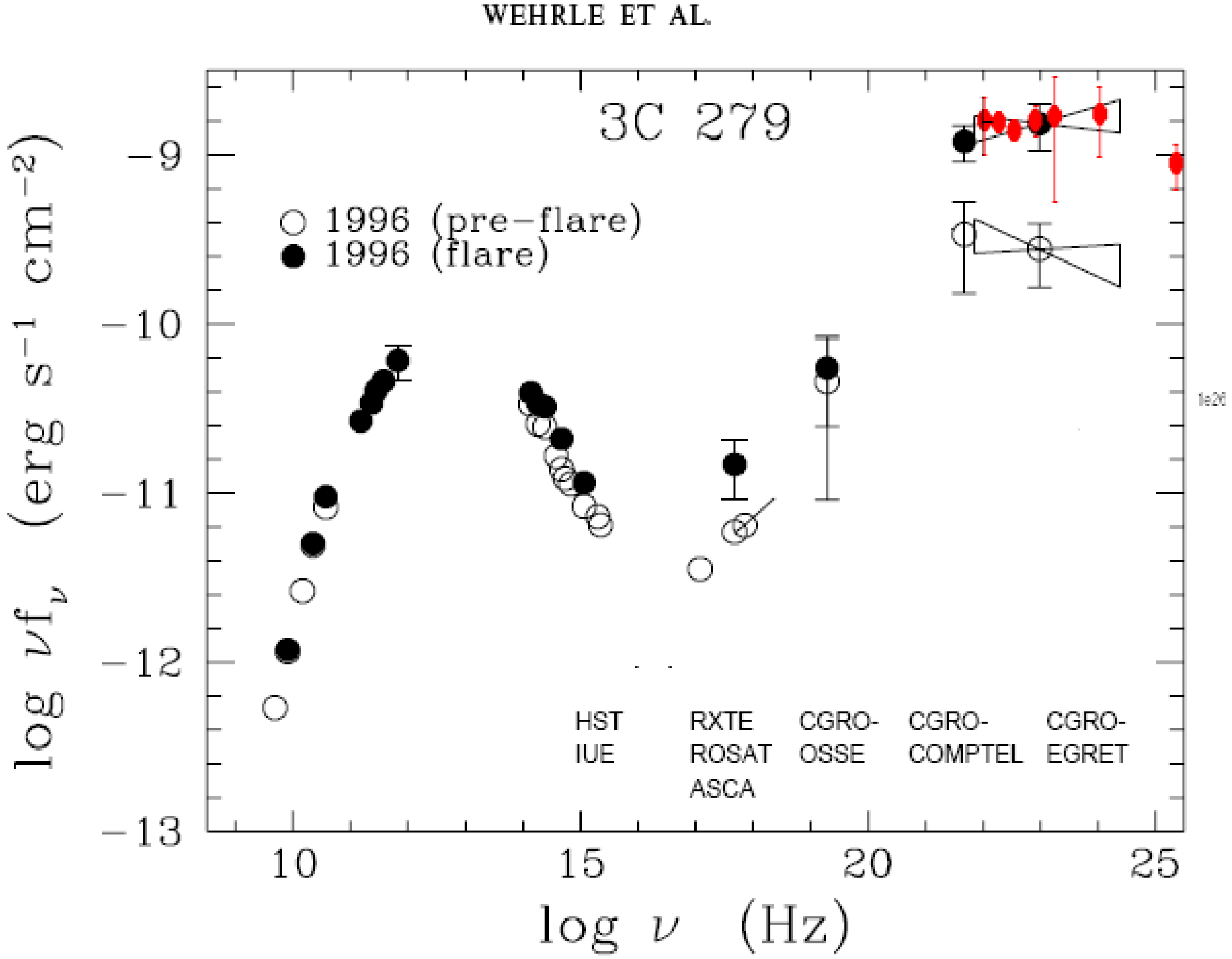
Contribution of photons from different emission zones and lack of data close to the gamma ray peak don’t let us to rule out the SSC model.

- **External Compton (EC)**
  - **The seed photons are external and independent of the jet**
  - **The ratio is linear for changes in the electron spectrum**
  - **It could be more than linear if the bulk Lorenz factor varies together with the electron spectrum**
    - **The entire emission region cannot accelerate and decelerate over such rapid timescales**

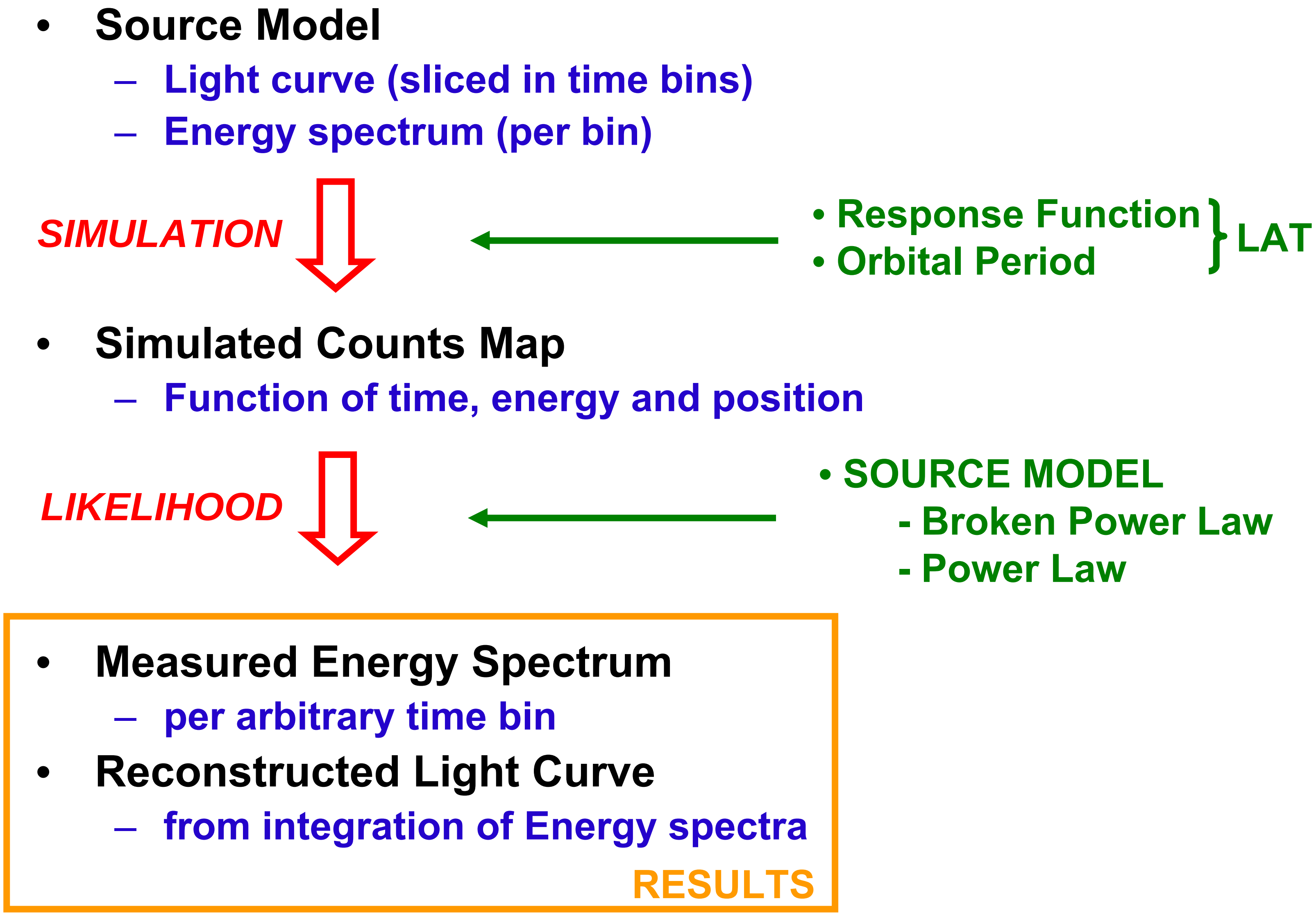
Simulation of the flare

- We do not know yet what is the best model to explain the 3C279 emission
  - Need more data in the SED





Overview of Data Analysis



- Source Model
  - Light curve (sliced in time bins)
  - Energy spectrum (per bin)

SIMULATION

- Response Function
- Orbital Period

} LAT

- Simulated Counts Map
  - Function of time, energy and position

LIKELIHOOD

- SOURCE MODEL
  - Broken Power Law
  - Power Law

- Measured Energy Spectrum
  - per arbitrary time bin
- Reconstructed Light Curve
  - from integration of Energy spectra

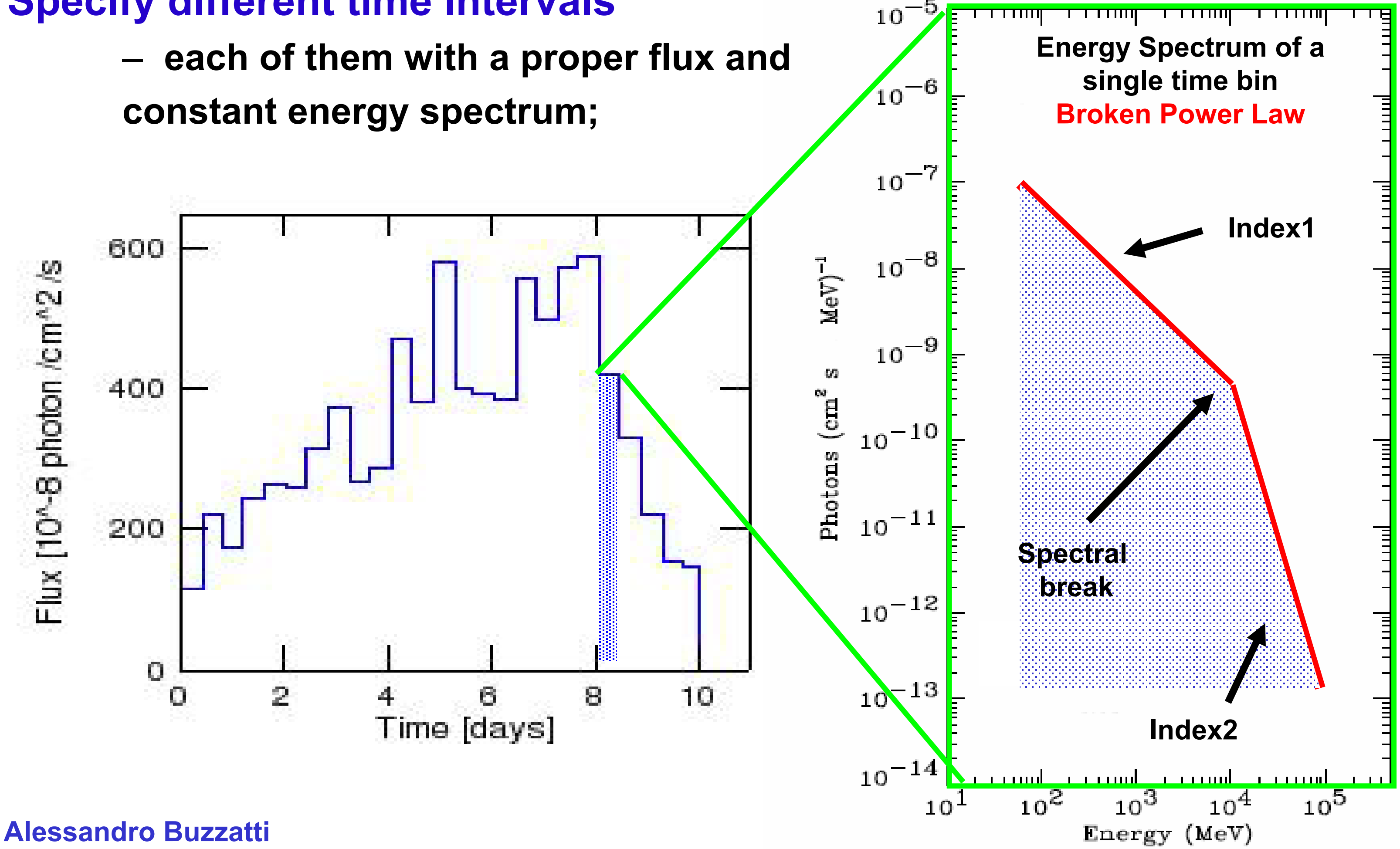
RESULTS

Source Model : flaring AGN

The most flexible model is the Spectral Transient:

- Calculation Steps
  - Define simulation time and overall average flux;
    - choice of parameters is arbitrary
  - Specify different time intervals
    - each of them with a proper flux and constant energy spectrum;

Just an illustration…



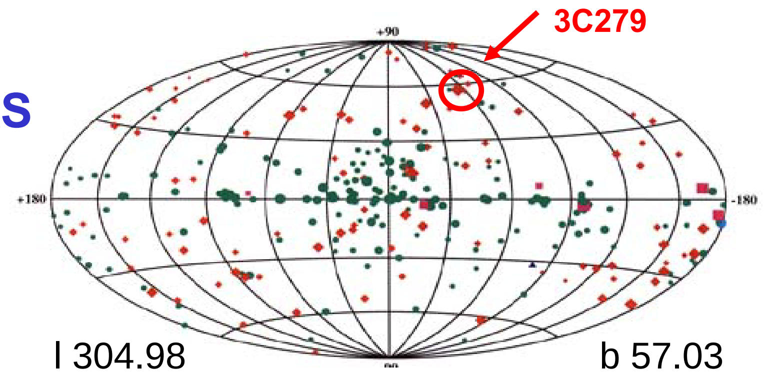
Input to the source model (3C279)

SOURCE MODEL PARAMETERS

Simulation time: 10 days

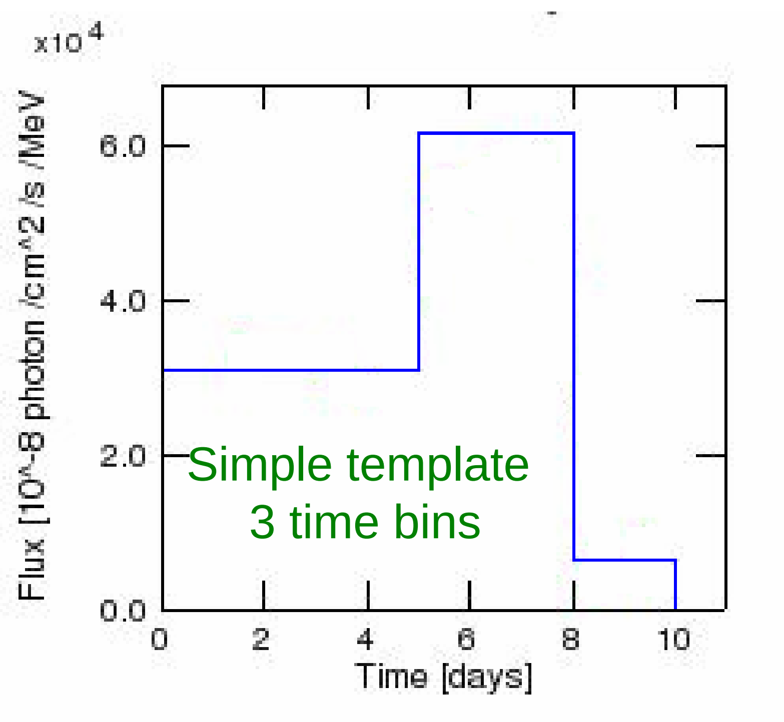
Average Flux: 20000 photons /cm^2 /s

Energy range: 20 MeV to 200 GeV



3C279

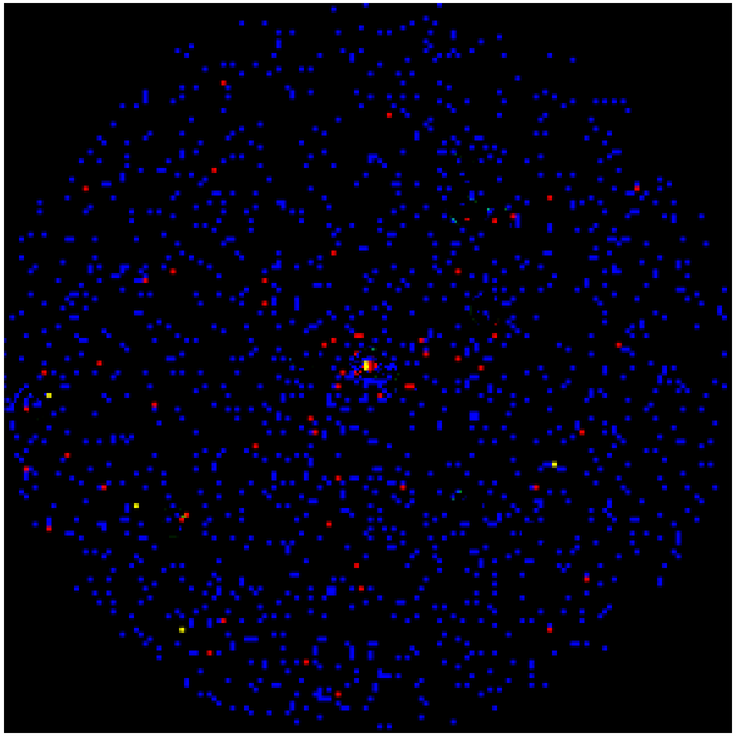
l 304.98 b 57.03



Simple template
3 time bins

	1st bin	2nd bin	3rd bin
Time [days]	**5**	**3**	**2**
Relative Flux	**5**	**10**	**1**
Index1	**1.7**	**1.5**	**2.1**
Index2	**2.5**	**2.2**	**2.1**
Energy Break [MeV]	**300**	**1000**	**1000**

The simulated Counts map



COUNTS MAP

- – integrated over time and energy
- – the colors represent the counts

It will be analyzed with the likelihood test…

- **EGRET used binned Poisson Likelihood (in position space)**
- **We use the unbinned likelihood**

- each event effectively has its own response function

Likelihood Calculation (1)

The unbinned likelihood test is a way to compare measured counts (from a source) with predicted counts (from a model). *I use the ScienceTools v5r6.*

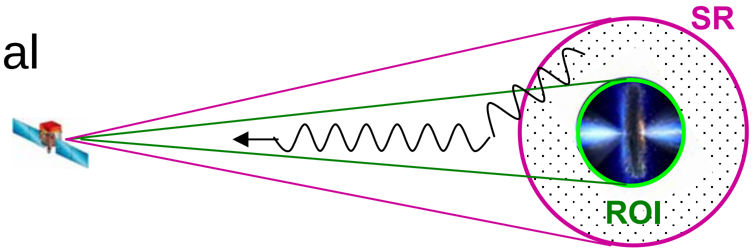
…we start from the measured counts.

STEP 1: SELECTION

- slice the acquisition time (= simulation time) into intervals of constant energy spectrum and flux.

-DON'T CONFUSE WITH THE BINS USED IN THE SIMULATION!!

- define a region that can contribute to the signal (Source Region)
- select the portion of sky to study (Region Of Interest)



STEP 2: MODELING

Create a model of the sources in the ROI (in our case, just one point source)

$$S\,(E,x) = \sum s_i(E)\delta(x - x_i) + S_{bg}(E,x) + \sum S_l(E,x)$$

spectral part

spatial part

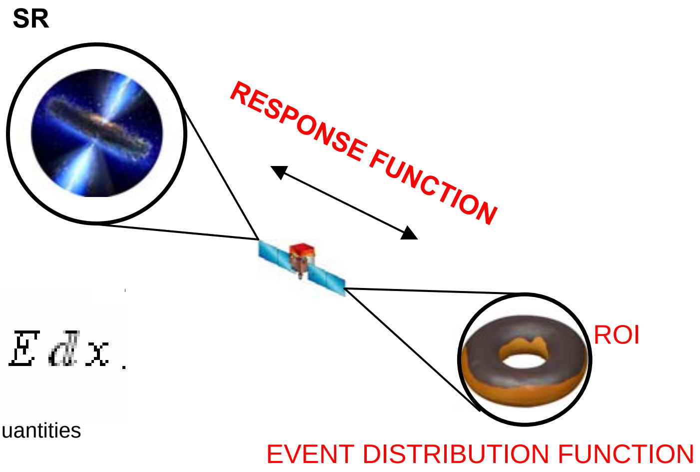
point sources

background

diffuse sources

Spectral models generally used: Power Law and Broken Power Law.

Likelihood Calculation (2)



STEP 3: PREDICTED EVENTS

Compute the Event Distribution Function:

$$M(E',x') = \int_{\mathrm{SR}} R(E',x',E,x)\,S(E,x)\,dE\,dx.$$

*primed quantities are measured quantities

Integrate over the Region Of Interest to get the predicted number of counts:

$$N_{\mathrm{pred}} = \int_{\mathrm{ROI}} M(E',x')\,dE'\,dx'.$$

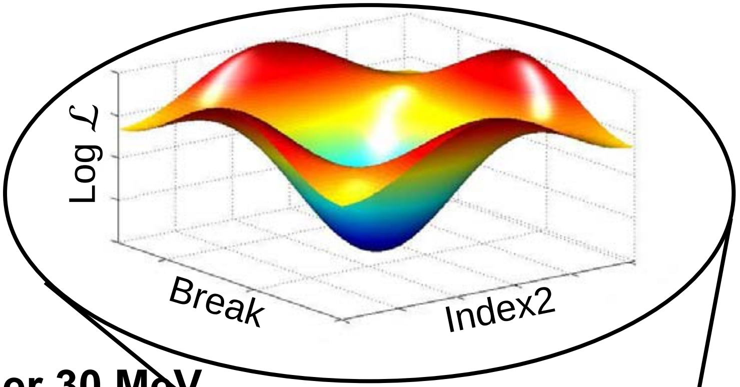
STEP 4: UNBINNED LIKELIHOOD

Maximize the Log-Likelihood. The sum is taken over all the events within the ROI.

$$\log \mathcal{L} = \sum \log M(E_j{}',x_j{}') - N_{\mathrm{pred}}$$

Input to the Likelihood (3C279)

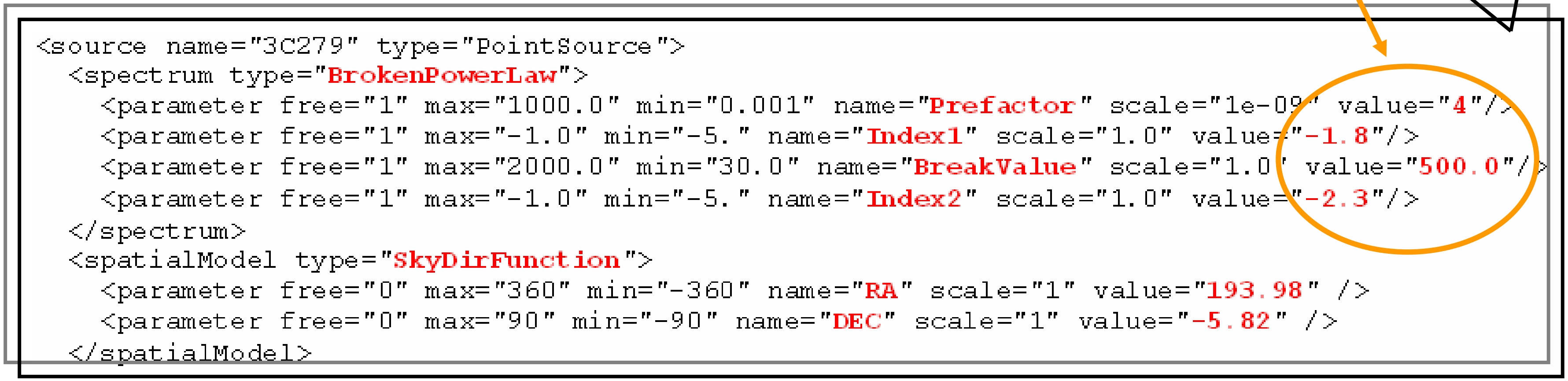
- **Selection on 3C279**
  - Time Intervals = 1 day
  - Region Of Interest = 20°
  - Source Region = 30°
  - Energies = 30 MeV - 200 GeV
    - Response function not reliable under 30 MeV



- **Modeling**
  - Broken Power Law

$$\begin{cases} E < \text{break} & \text{prefactor} * \left(\frac{E}{\text{break}}\right)^{\text{index1}} \\ E > \text{break} & \text{prefactor} * \left(\frac{E}{\text{break}}\right)^{\text{index2}} \end{cases}$$

4 INITIAL VALUES



```
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  <spectrum type="BrokenPowerLaw">
    <parameter free="1" max="1000.0" min="0.001" name="Prefactor" scale="1e-09" value="4"/>
    <parameter free="1" max="-1.0" min="-5." name="Index1" scale="1.0" value="-1.8"/>
    <parameter free="1" max="2000.0" min="30.0" name="BreakValue" scale="1.0" value="500.0"/>
    <parameter free="1" max="-1.0" min="-5." name="Index2" scale="1.0" value="-2.3"/>
  </spectrum>
  <spatialModel type="SkyDirFunction">
    <parameter free="0" max="360" min="-360" name="RA" scale="1" value="193.98" />
    <parameter free="0" max="90" min="-90" name="DEC" scale="1" value="-5.82" />
  </spatialModel>
```

Automation of Data Analysis

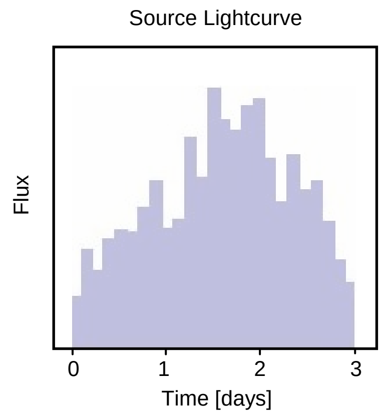
- Science tools require automation…

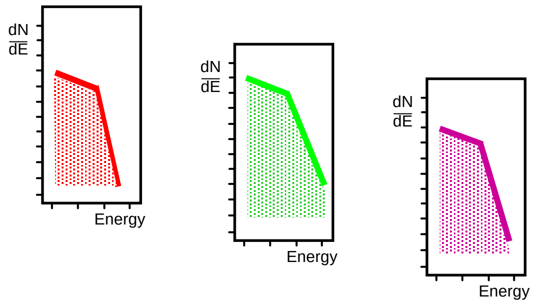
Benoit's macro (c++)

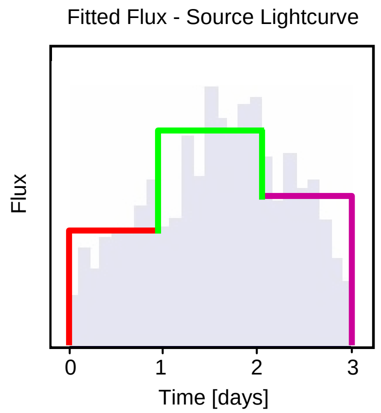
- – Slice the acquisition time
- – Run likelihood test on each bin
  - use the same source model for all

Python macro

- – Compute the fluxes
  - propagation formula for the errors
- – Reconstruct the lightcurve

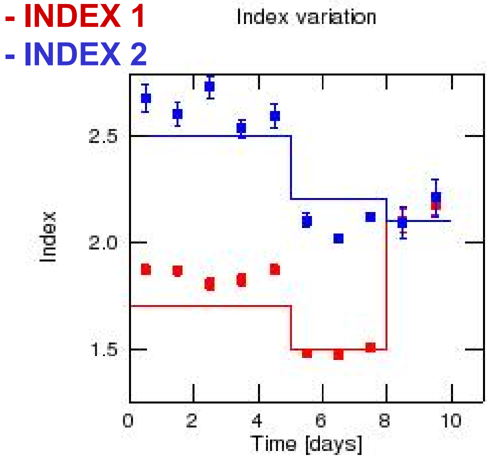


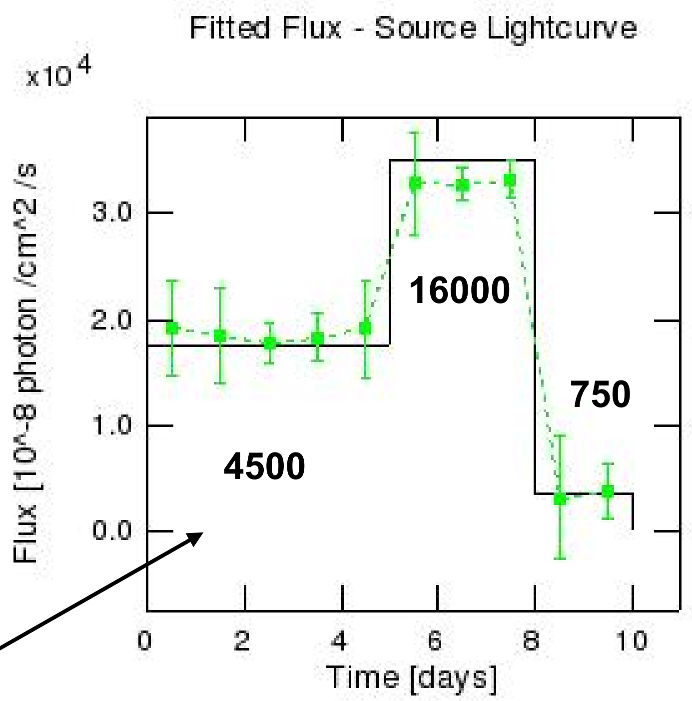


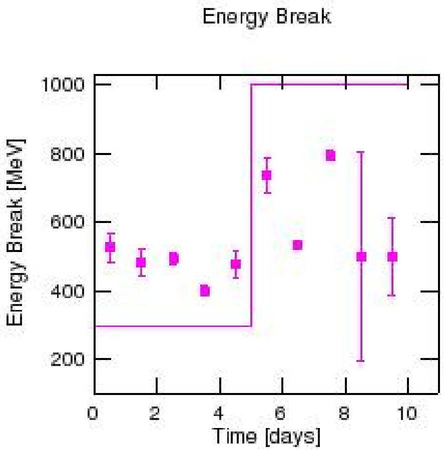


Results for 3C279

- **Results are Spectral Index, Flux, Energy Break, Number of Counts**
  - continuous lines in the plots represent the true parameters







Expected Counts per Day (averaged over each step)
– represent the statistics

The error bars on the flux are propagated without the covariance term
– underestimated

Summary of the Issues

FLUX

- The fit of the light curve depends on the number of counts

- ## ERROR BARS

- The error bars are too big

ENERGY BREAK AND INDICES

- <u>The likelihood cannot converge to the right energy break value</u>
- The indices and the energy break are strongly correlated

Dependencies on Average Flux

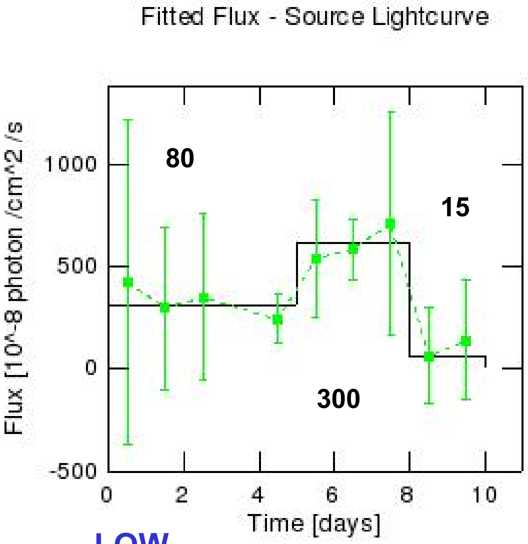
- **Same Parameters – Different Average Flux**

350 | 850 | 3500 | 20000 | 35000

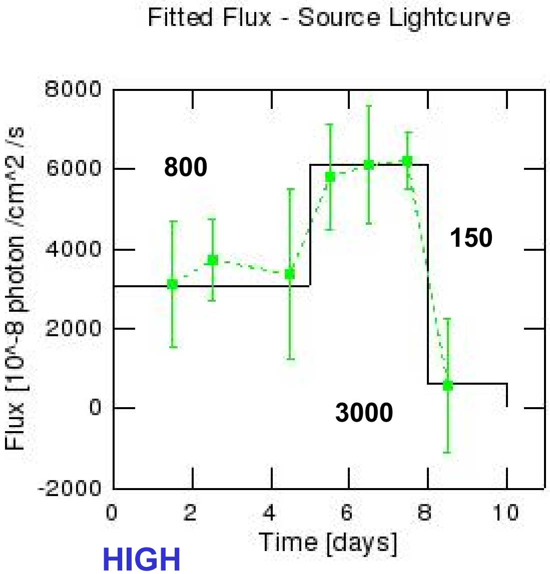
previuous one

10^-8 photons /cm^2 /s

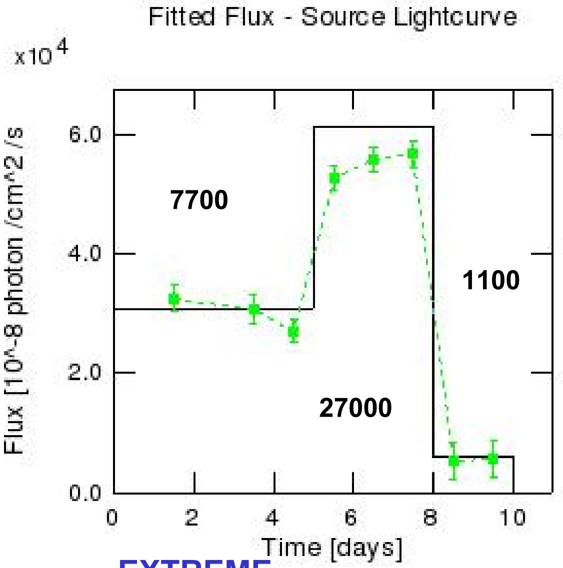
LOW
MEDIUM
HIGH
HUGE
EXTREME



LOW



HIGH



EXTREME

✓ **Counts < 100 → scattered**

✓ **Counts ~ 10^3 → GOOD!**

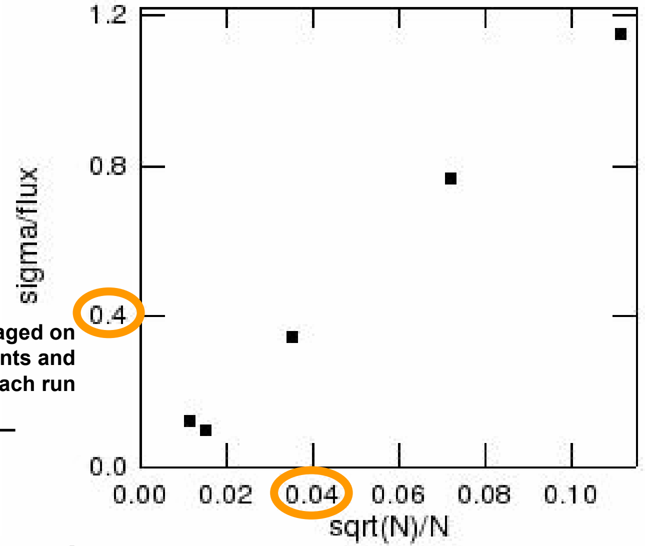
? **Counts > 10^4 → underestimated**

Understanding the uncertainties

Poisson distribution for counts

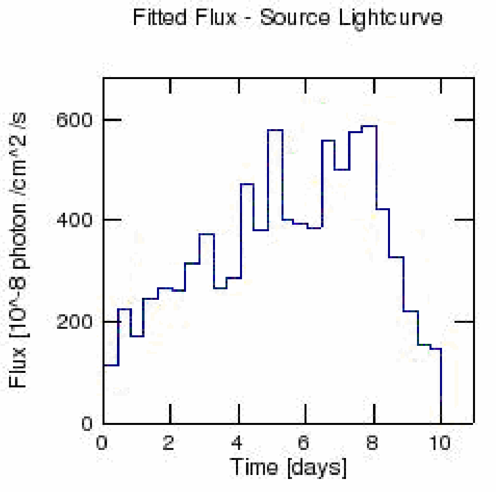
→ We want sigma/flux to be as closest as possible to √N/N

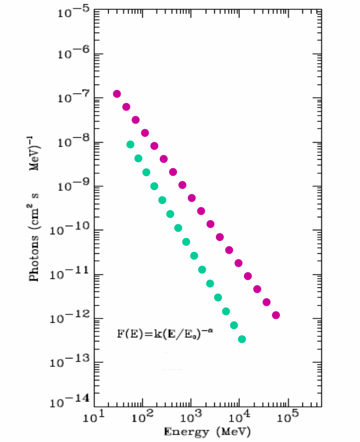
one order of magnitude!

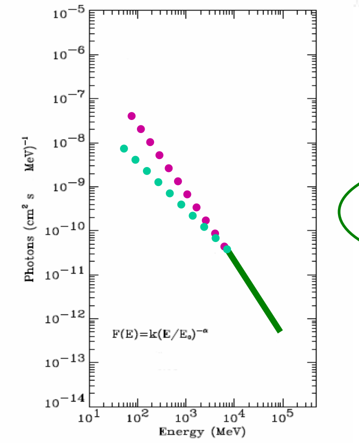


quantities are averaged on the first-step points and plotted for each run

Compare to simple Power Law spectral model







expect more precision

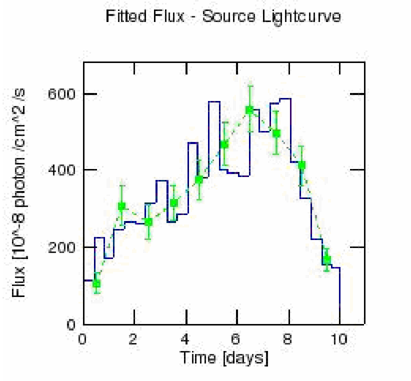
- New source
  - Constant index
  - No Energy break

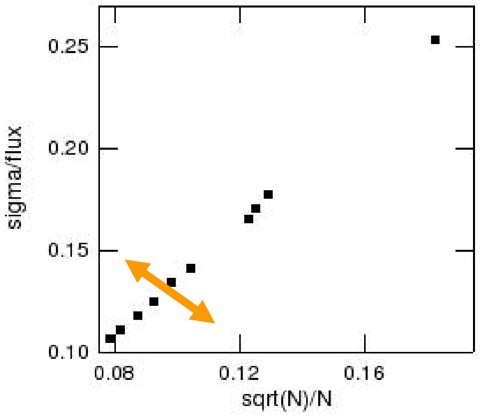
- New models

1. Power Law
2. Broken Power Law
   - 2nd index + Break fixed

Comparison on Error Bars

POWER LAW

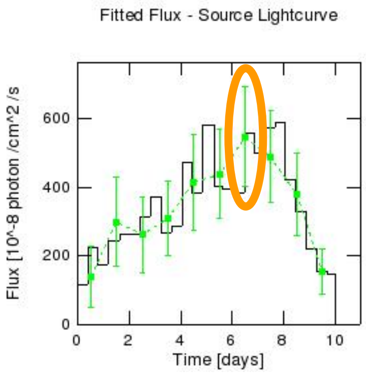


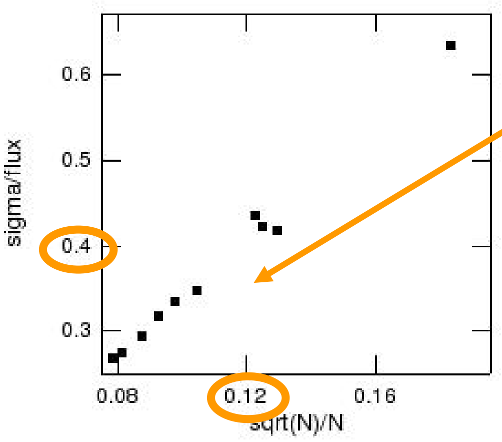


Ratio of almost one to one.

GOOD!

BROKEN POWER LAW



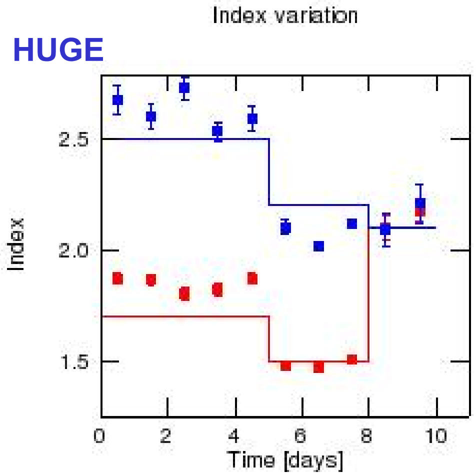


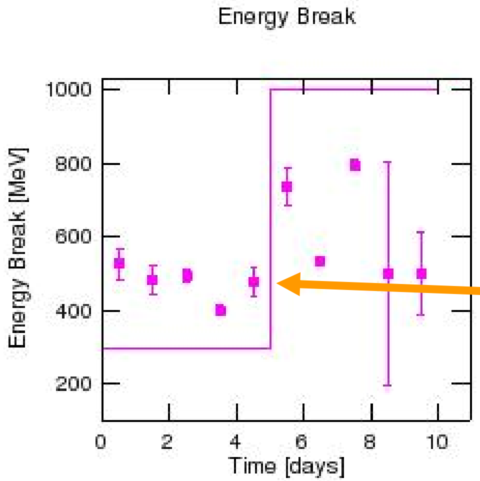
Discrepancy of an order of 3

Something funny is going on here…

Can we fit the energy break?

HUGE





The likelihood test gives back the same value used as initial input (500 MeV)

New run, with initial Break Value at 300 MeV

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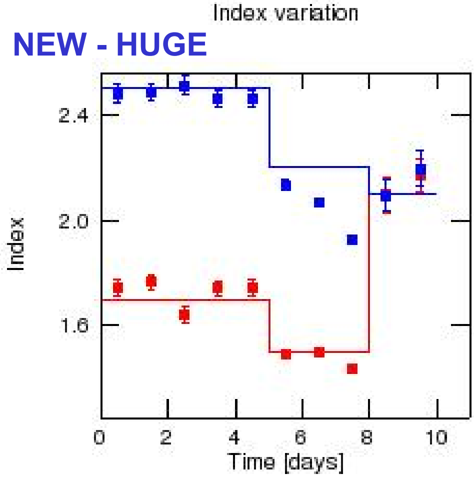
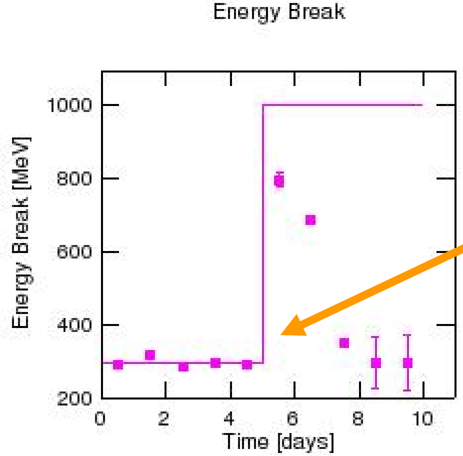
NEW - HUGE



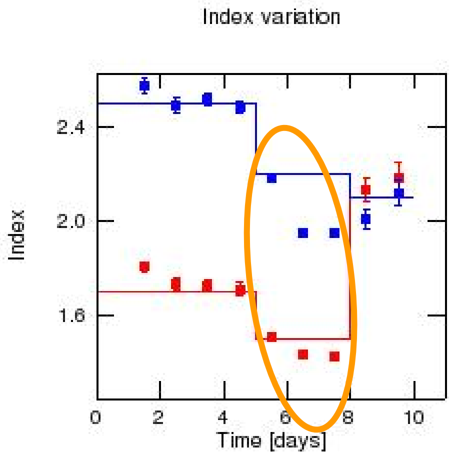


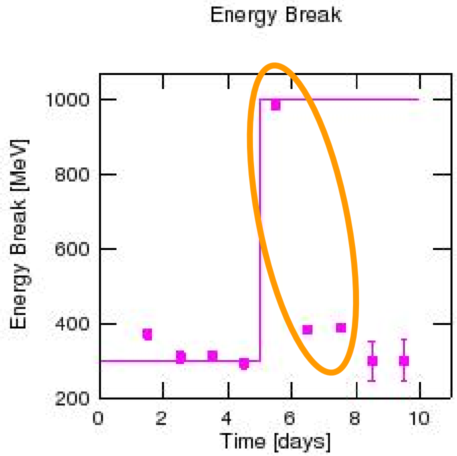
The likelihood now gives back a value around 300 MeV

→ **We are not able to determine the energy break**

Correlation Energy Break – Indices

EXTREME

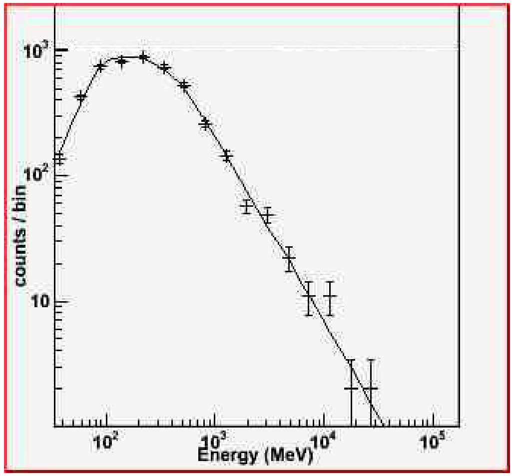




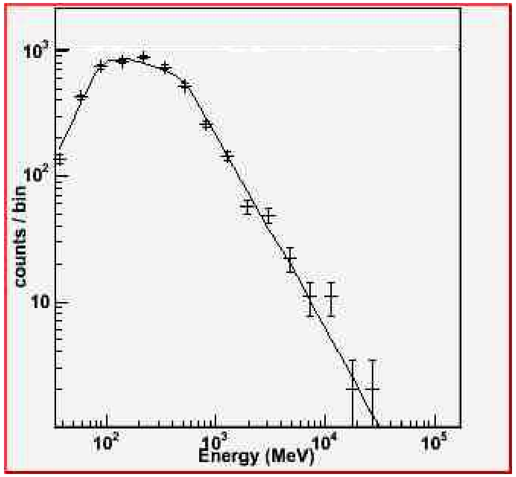
Strong and evident correlation

→ We cannot relay on the fit of the indices

Break at 300 MeV



Break at 500 MeV



Summary

- Overview of the flare of 3C279
  - Described multiwavelength observations
  - Discussed briefly possible emission models

- LAT Simulation and Data Analysis with ScienceTools
  - Simulated a flaring AGN
    - Lightcurve and Energy Spectrum
  - Analyzed with Likelihood tools

- Issues relative to the Likelihood analysis
  - Determination of energy break and spectral indices is not reliable for broken power law models
    - More investigation needed
  - Uncertainties is the likelihood calculations are not yet fully understood
  - Chi squared test is missing

Thanks to...

In order of appearance

Eduardo

Anders

Paul

Jim

Seth

Benoit

Greg

and also…

Luis

all the summer students