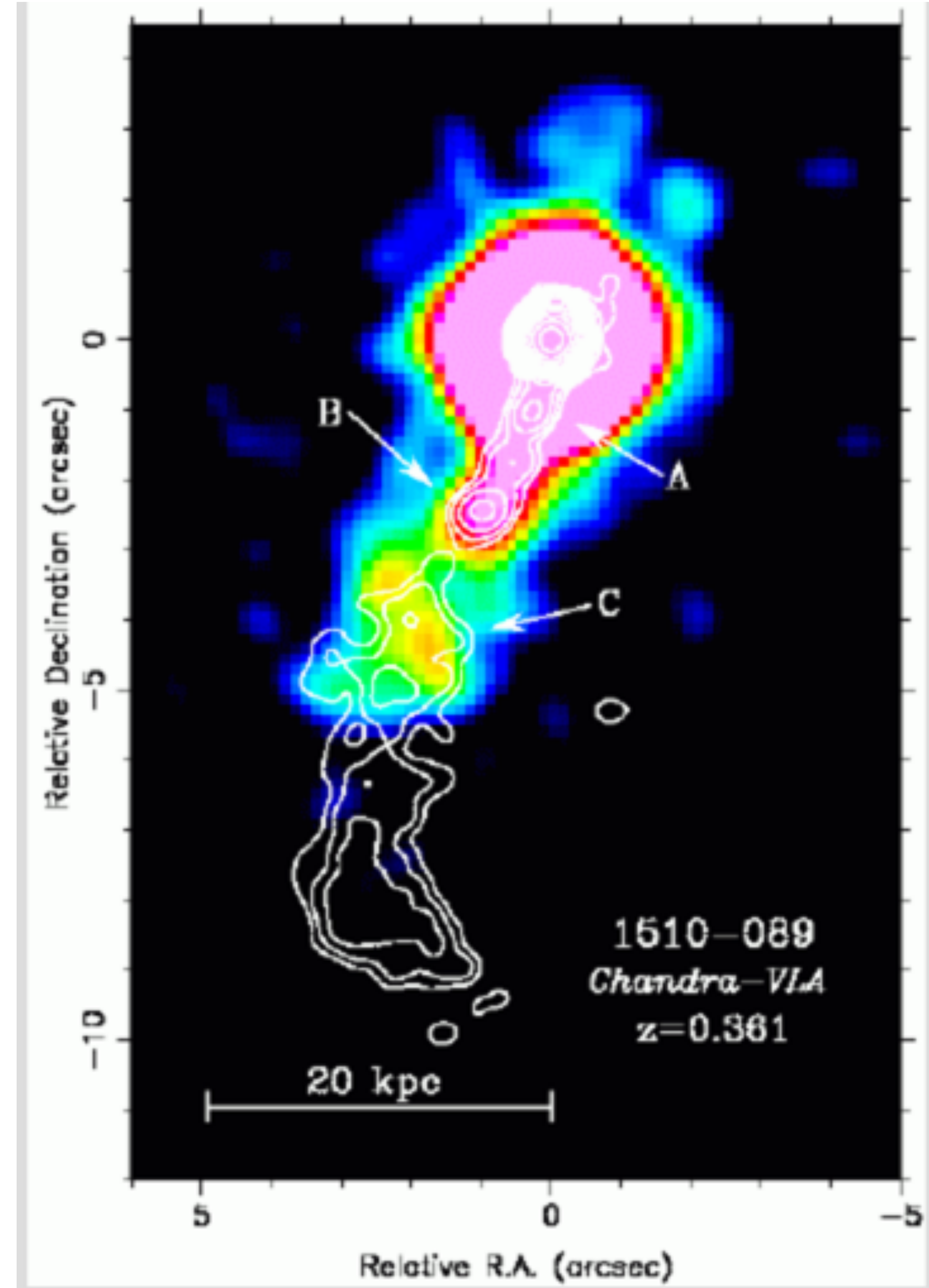
PKS 1510-089



X-ray (color), Radio (contours)
From: Sambruna et al. (2004)

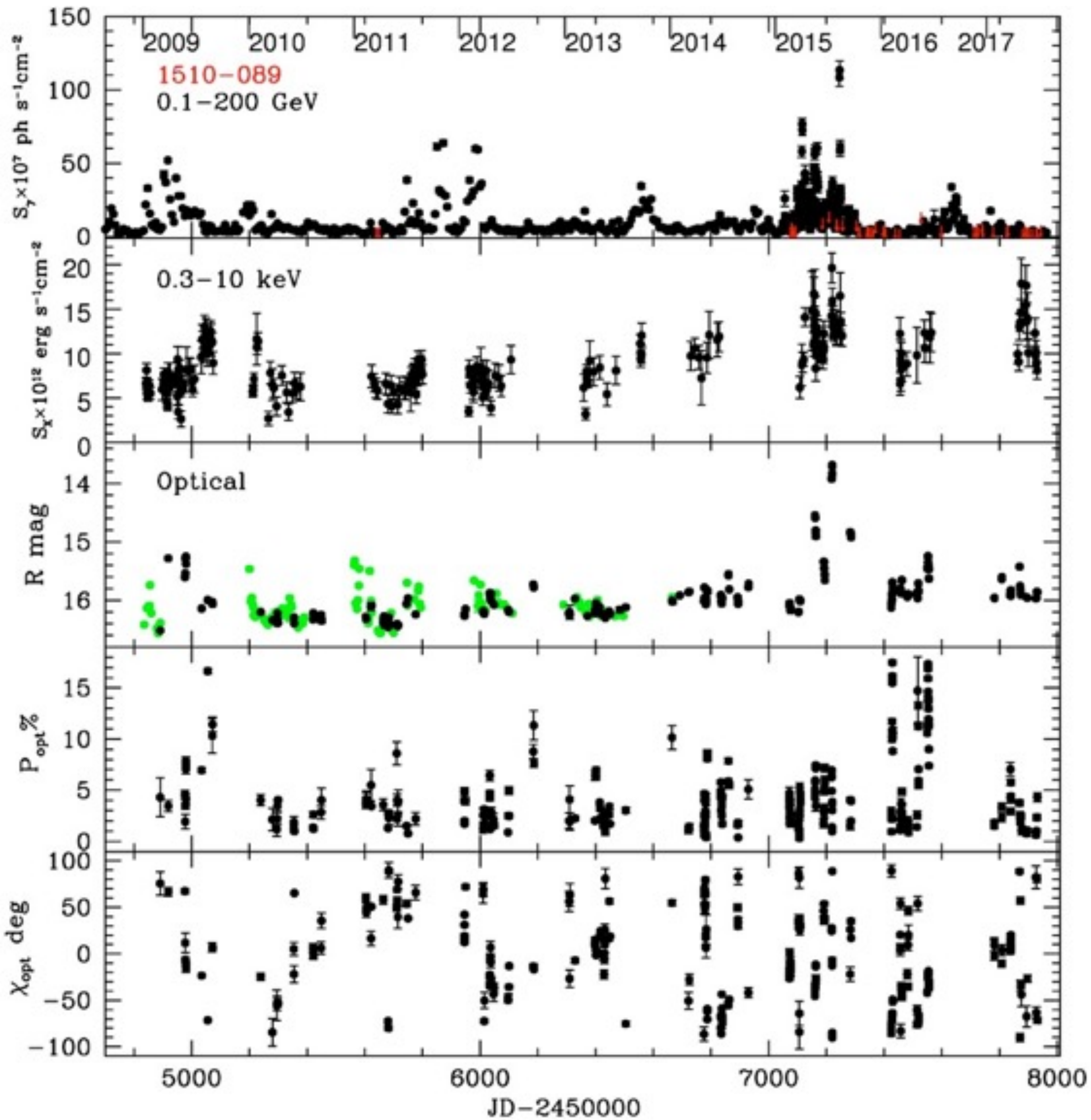
FSRQ

z=0.361

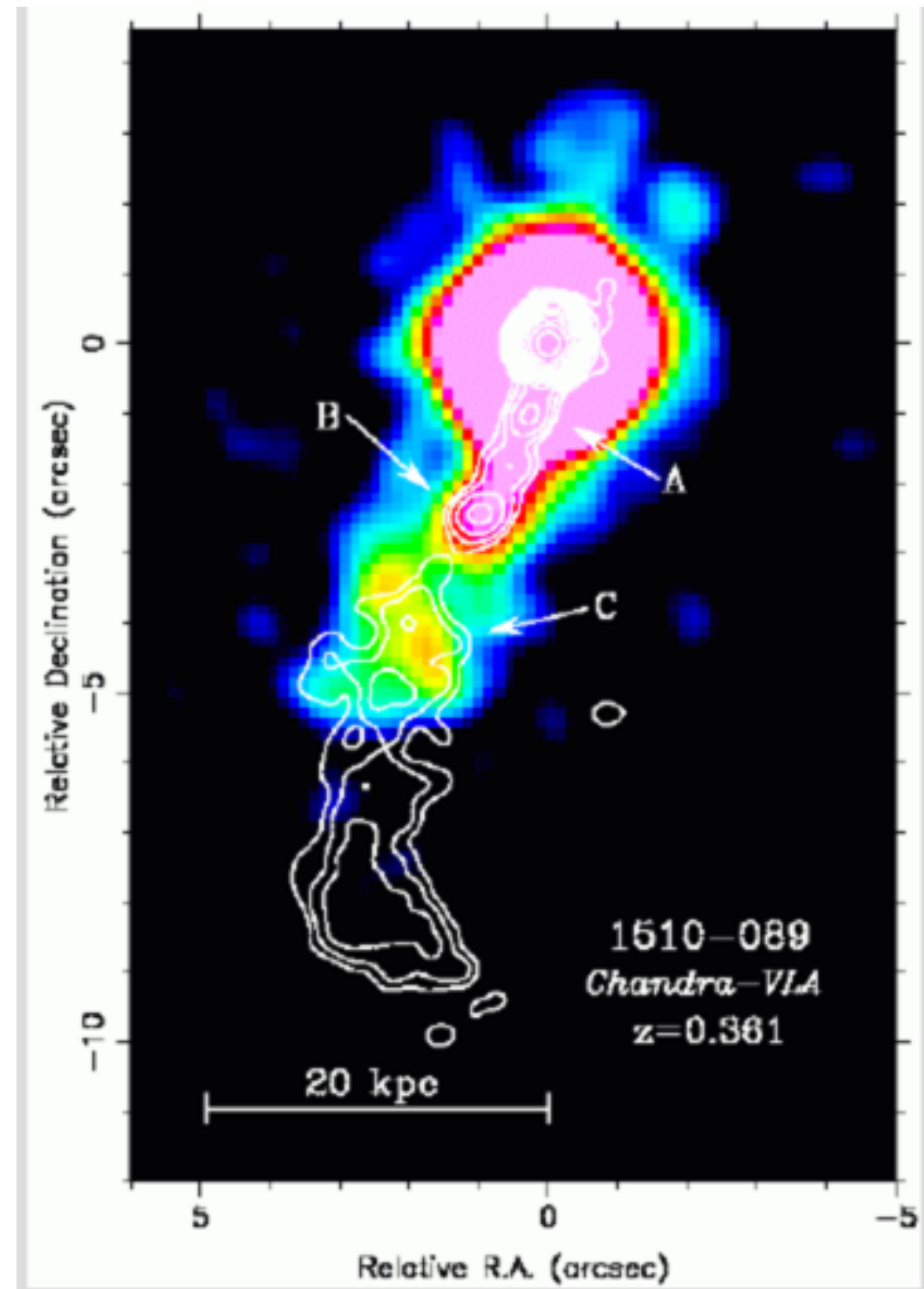
Nh(Gal)=6.99e20 cm-2
(Kalberla et al. 2005)

Apparent velocity: 1263 ± 27 μas/y ; 28.00 c
(Lister et al. 2013, AJ, 146, 120)

Variable



Jet resolved in X-ray



X-ray (color), Radio (contours)
From: Sambruna et al. (2004)

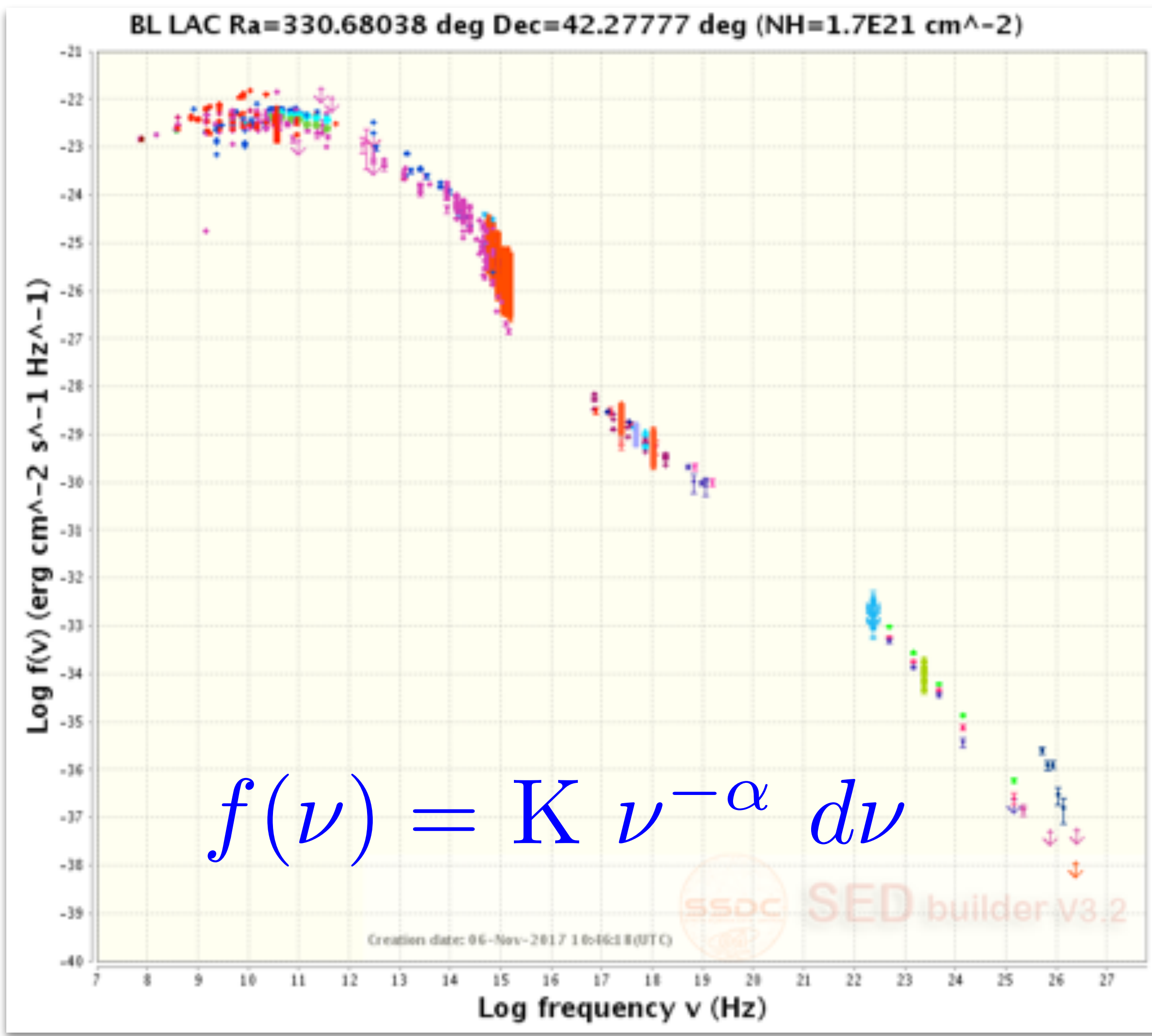
Spectral and Imaging Analysis

- Chandra: Superposition X-ray and Radio images (DS9) to individuate the regions to be analyzed in the jet
- Chandra: Knot B and C - extraction of the spectra and production of rmf and arf files(CIAO). Analysis with XSPEC. Definition of the best model: parameter uncertainties, confidence (68%, 90% and 99%) contour plots, flux and luminosity
- Chandra: Nucleus - extraction of the spectrum using a circle. Extraction of a new spectrum using an annulus. Check for possible pile up effects.
- Swift/XRT- Spectral analysis of the nucleus with XSPEC Definition of the best model: parameter uncertainties, confidence (68%, 90% and 99%) contour plots, flux and luminosity.
- Construction of the Spectral Energy Distribution

- Optional: AGILE: Spectral analysis (spectral slope and flux); time variability of the gamma-ray counterpart of PKS1510-089

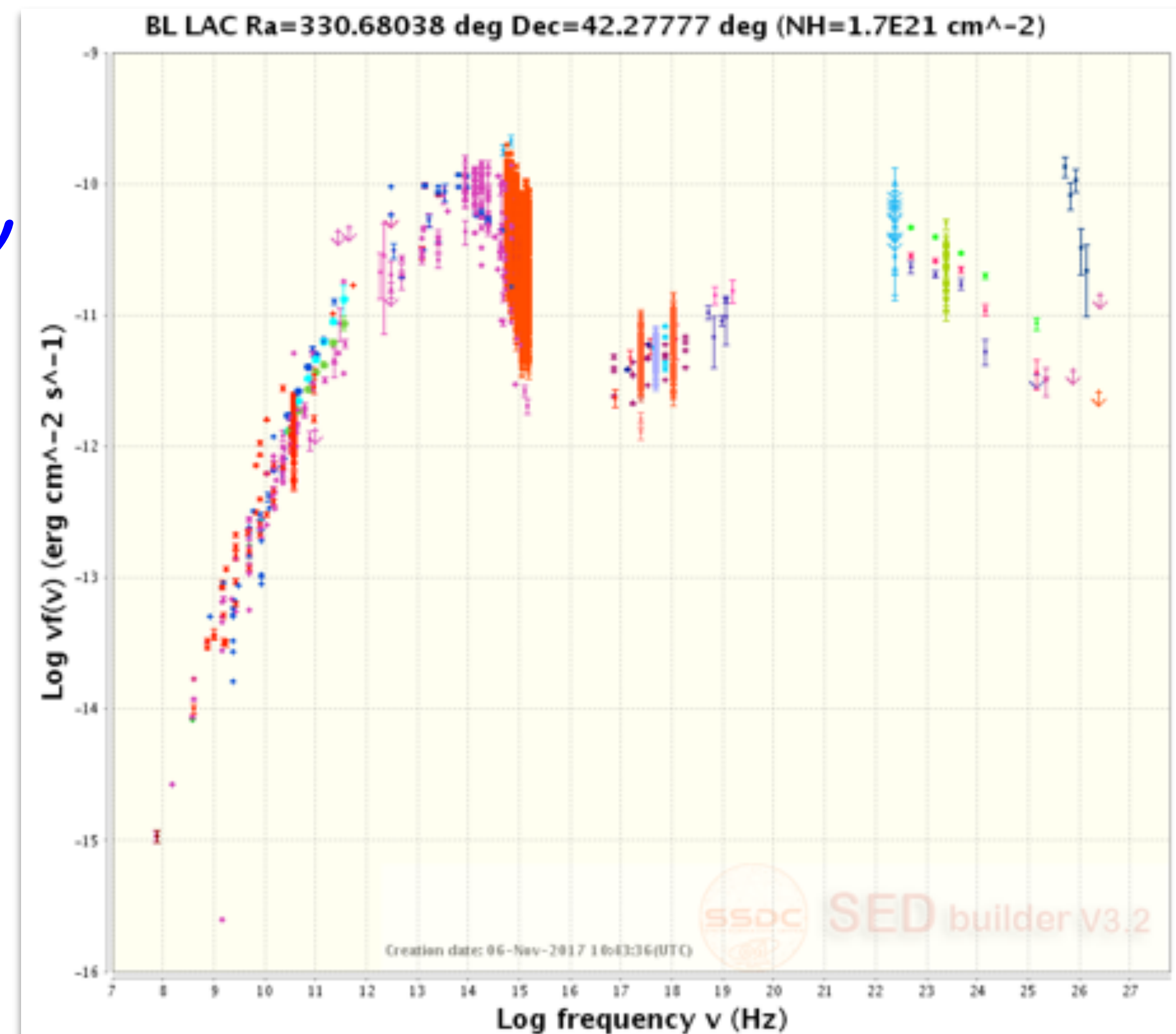
Construction of the Spectral Energy Distribution

Why a SED?



$$f(\nu) = \mathrm{K}\ \nu^{-\alpha}\ d\nu$$

$$\times \nu$$

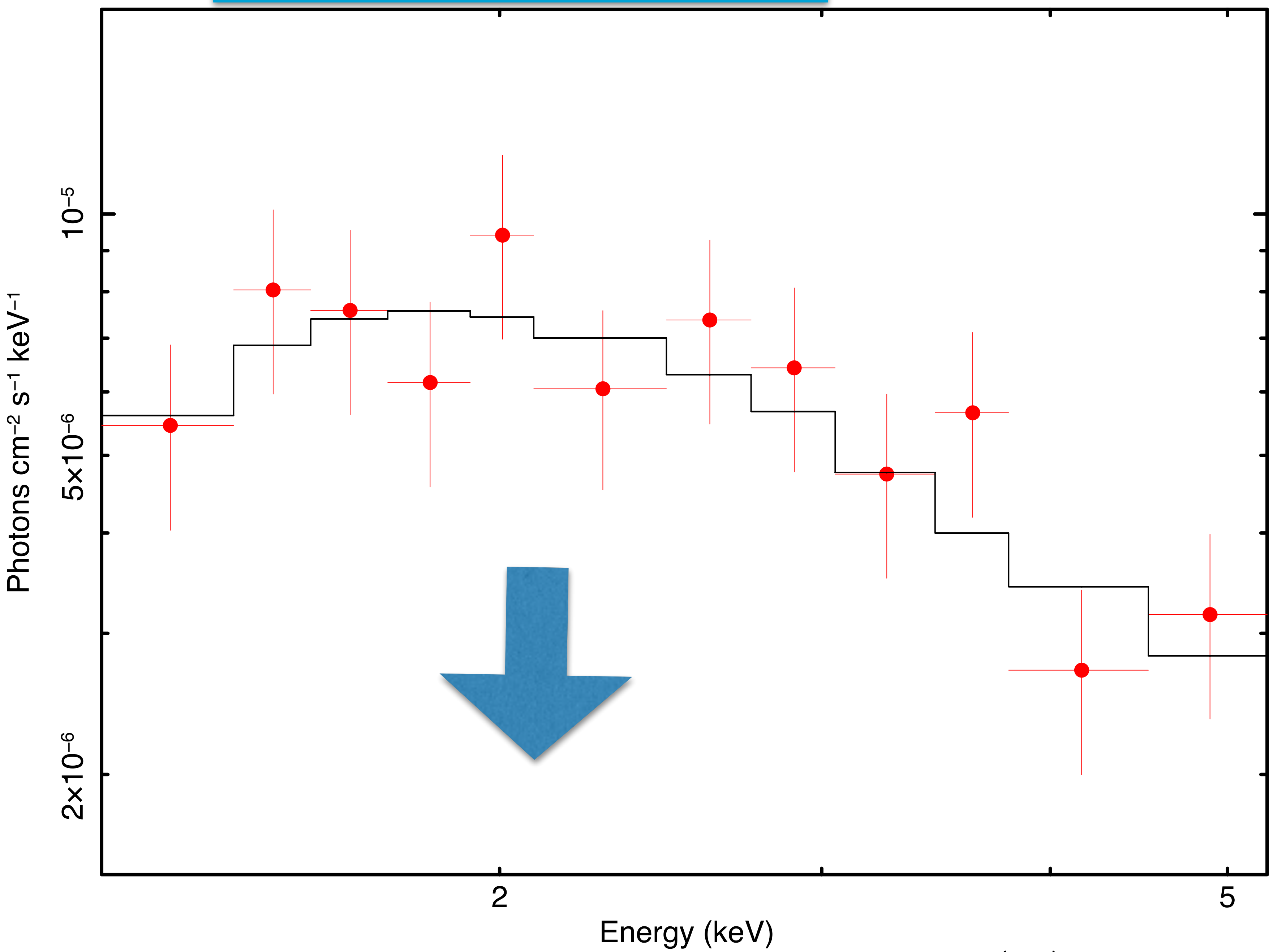


$$(\mathrm{erg\ cm^{-2}\ s^{-1}\ Hz^{-1}})$$

$$(\mathrm{erg\ cm^{-2}\ s^{-1}})$$

$$F(E) = K_E E^{-\Gamma}$$

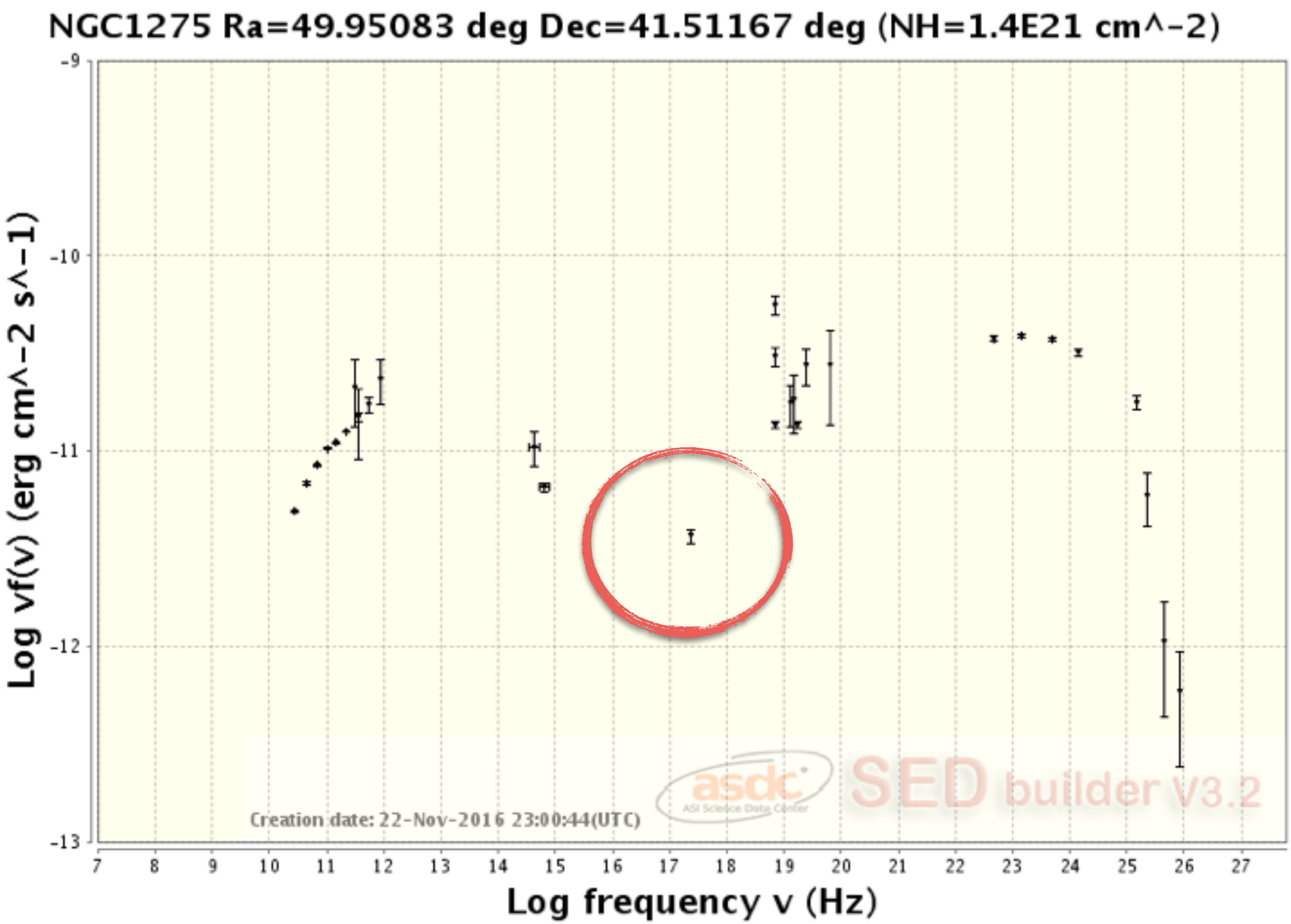
K_E (phot $cm^{-2} s^{-1} keV^{-1}$)



$$F(\nu) = K_\nu \nu^{-\alpha}$$

K_ν (erg $cm^{-2} s^{-1} Hz^{-1}$)

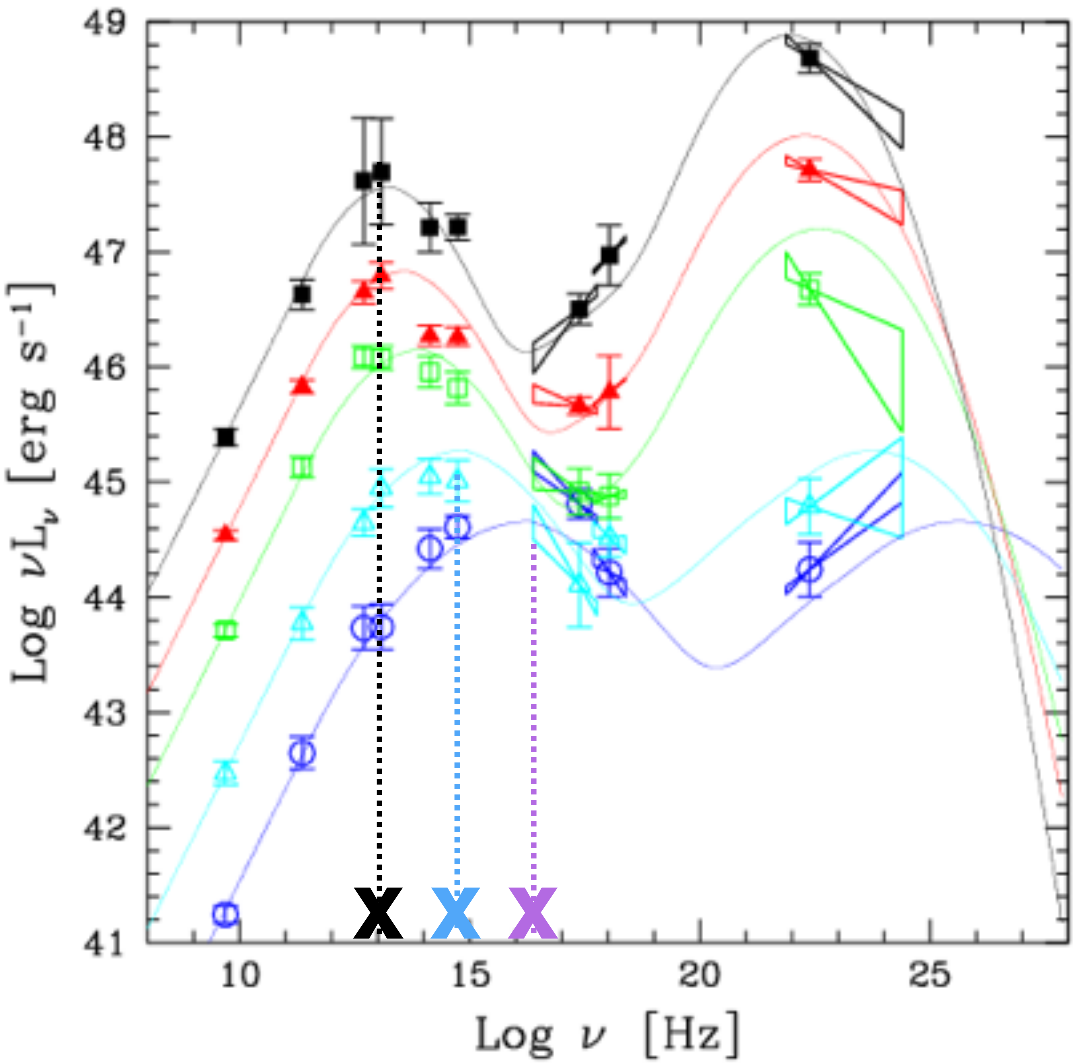
SED



1. black point are already in a file in the work directory
2. points inside the red circles (swift and agile) provided by your direct data analysis

SED Physical Interpretation

- Synchrotron peak position: ν_S



High synchrotron-peaked (HSP) blazars: ν_S $>10^{15}$ Hz

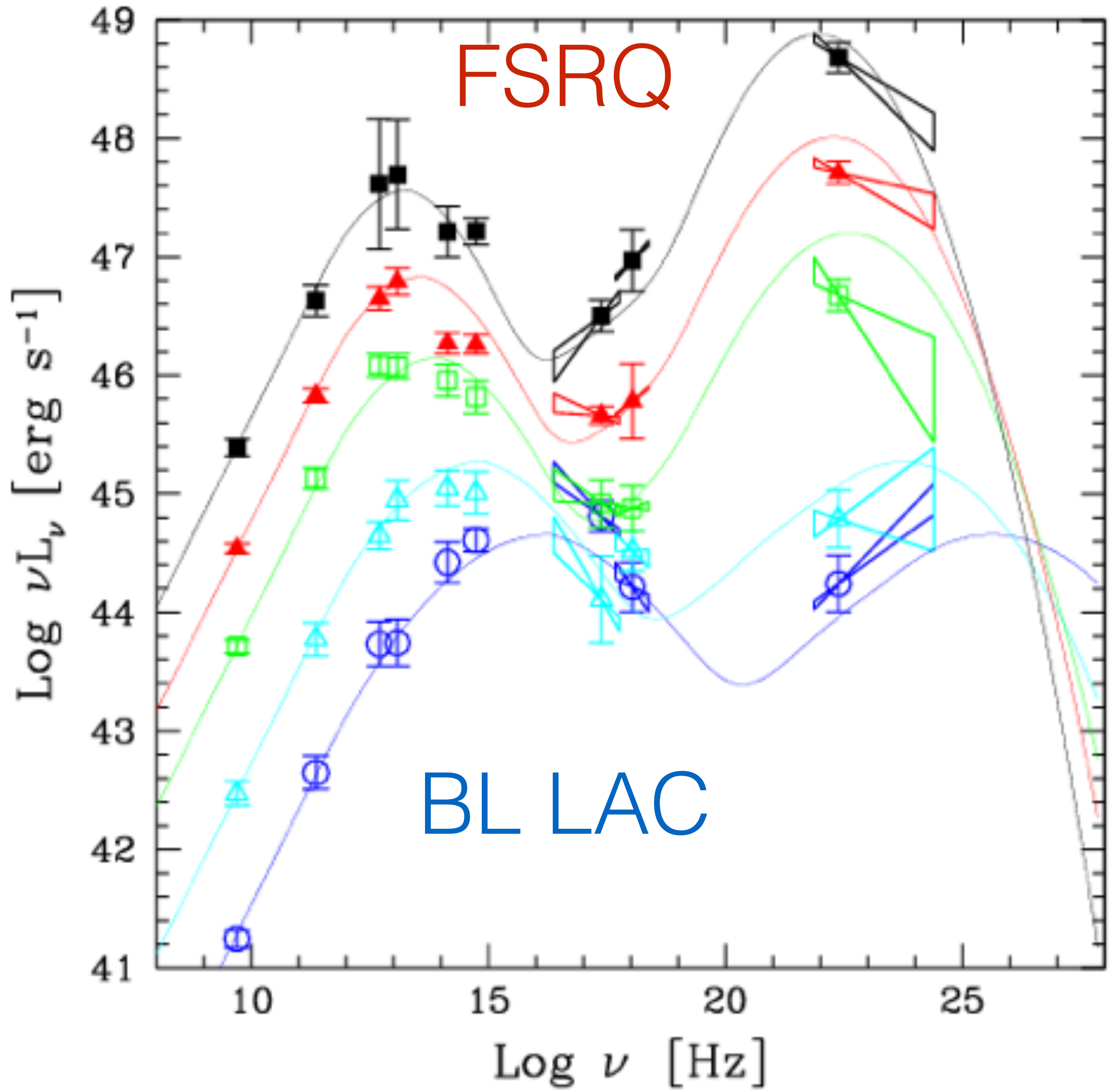
Intermediate synchrotron-peaked (ISP): $10^{14} <$ ν_S $<10^{15}$ Hz

Low synchrotron-peaked (LSP) blazars : ν_S $< 10^{14}$ Hz

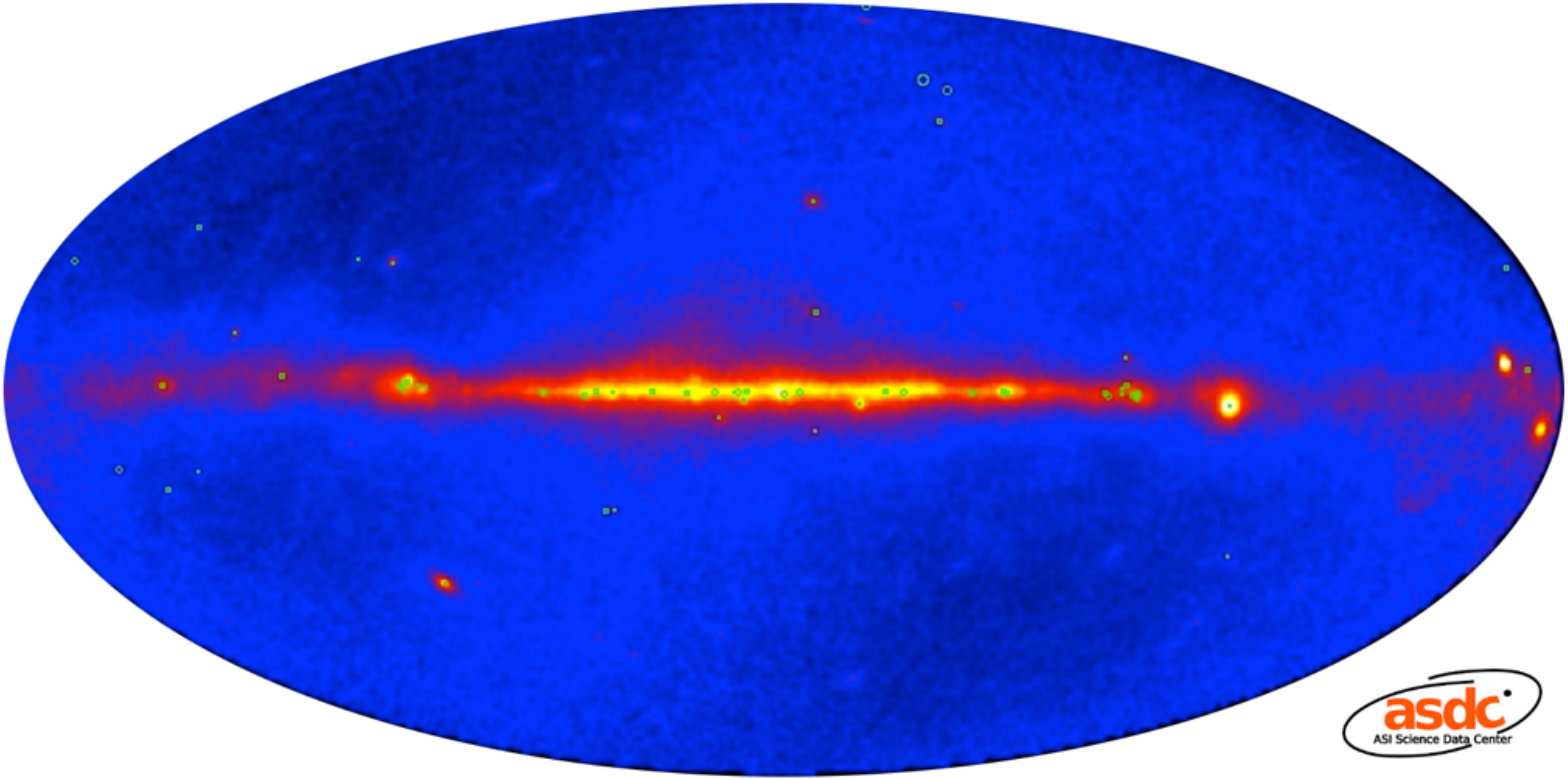
- Compton Dominance (CD): $\mathrm{CD} = \frac{L_{IC}}{L_S}$

FSRQ → CD >1

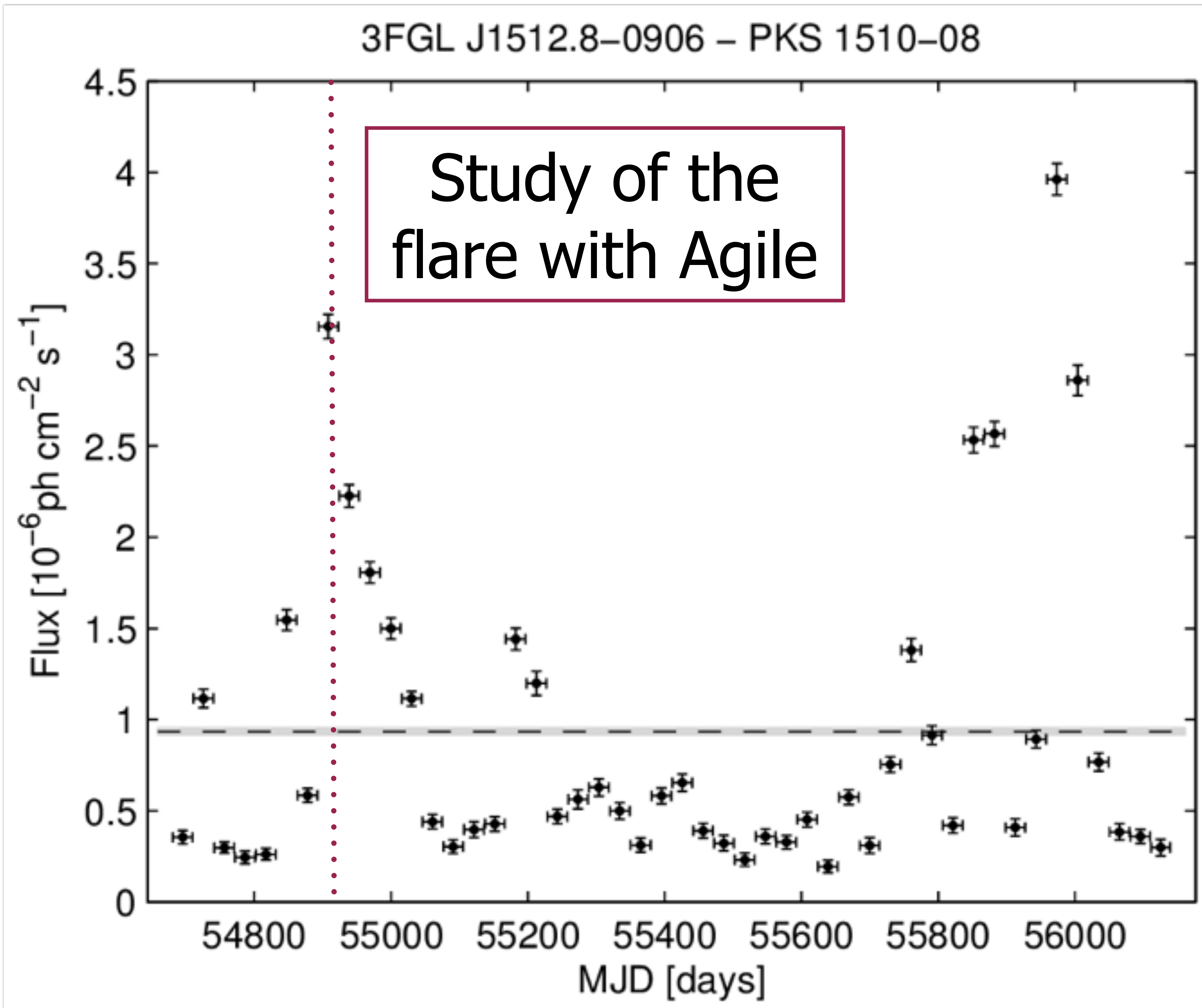
BL LAC → CD~ 1



Optional: AGILE analysis



Extremely variable source in the gamma-ray band



temporal bin = 1 month

AGILE data collected in the time interval:
2009-02-28T12:00:00 (MJD* 54894.50) -- 2009-03-31T12:00:00 (MJD54921.50)

1) calculate flux, best-position and spectral index

2) generate a "counts map" in the energy range 100-50000 MeV

3) generate a light curve

4) Compute the dimension (upper limit) of the emitting region from the flux variability

* Il giorno giuliano (Julian Day, JD) è il numero di giorni passati dal mezzogiorno del lunedì 1º gennaio 4713 a.C . MJD = JD - 2400000.5

X-ray	Gamma-ray
File data File housekeeping Response matrix Background	File data File housekeeping Response matrix (instrumental Response Function IRF) Background
i) light curve; ii) image; iii) spectrum	i) light curve; ii) count map (image); iii) spectrum
source spectrum, bkg spectrum arf + rmf => XSPEC model fit (chi square, Cstat)	Region of interest (ROI) ~ several degrees centered on the target Spectral model and position of all the sources in the Roi + background + IRF ==> Likelihood analysis

Because of the paucity of data, the large errors associated with detecting gamma-rays and a bright background, analysis and interpretation of the data require complex statistical techniques

We need a likelihood analysis

The likelihood L is the probability of obtaining your data given an input model.

In our case, the input model is the distribution of gamma-ray source on the sky and include their intensity and spectra (+background).

One will maximize L to get the best match of the model to the data.

BINNED LIKELIHOOD ANALYSIS

· **POISSON DISTRIBUTION**: describes the probability of a number of events ocurring in a given pixel.

$$p_i = \frac{\theta_i^{n_i} e^{-\theta_i}}{n_i!}$$

n_i = number of observed counts in pixel i

θ_i = number of predicted counts in pixel i

· The likelihood for the model will be the product of the probabilities for all pixels.

$$L = \prod_i p_i$$

· And taking the logarithm,

$$\mathrm{Log}L = \sum n_i \mathrm{Log}(\theta_i) - \sum \theta_i - \sum \mathrm{Log}(n_i!)$$

Npred = total number of predicted counts

Model independent: neglected

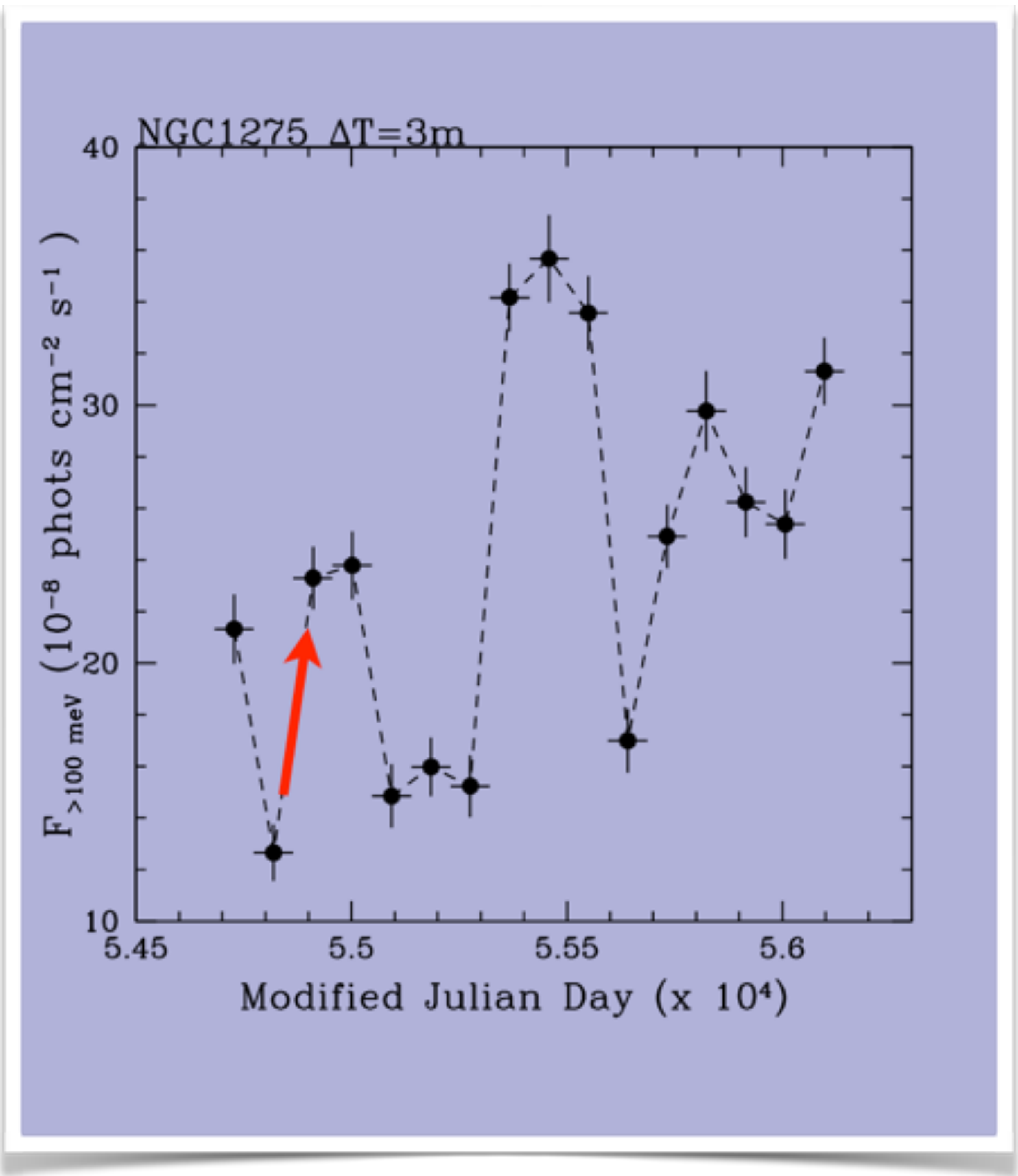
The Test Statistic is defined as:

$TS=-2 \ln (L_{max,0}/L_{max,1})$

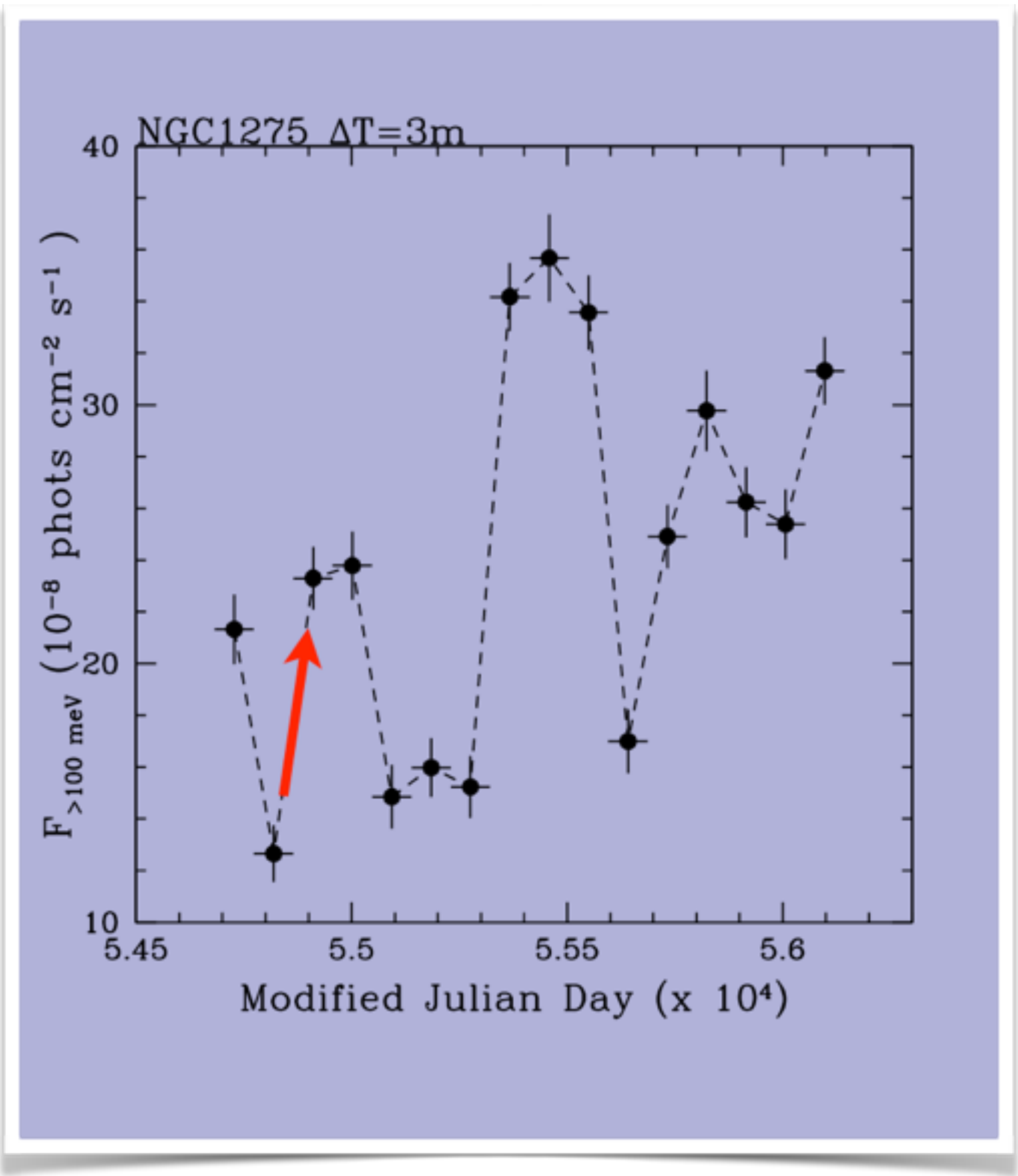
- Where $L_{max,0}$ is the maximum likelihood value for a model without an additional source (the 'null hypothesis') and $L_{max,1}$ is the maximum likelihood value for a model with the additional source at a specified location.

- As a basic rule of thumb, the square root of the TS is approximately equal to the detection significance for a given source. $TS \sim \sigma^2$

Light curve in gamma-ray

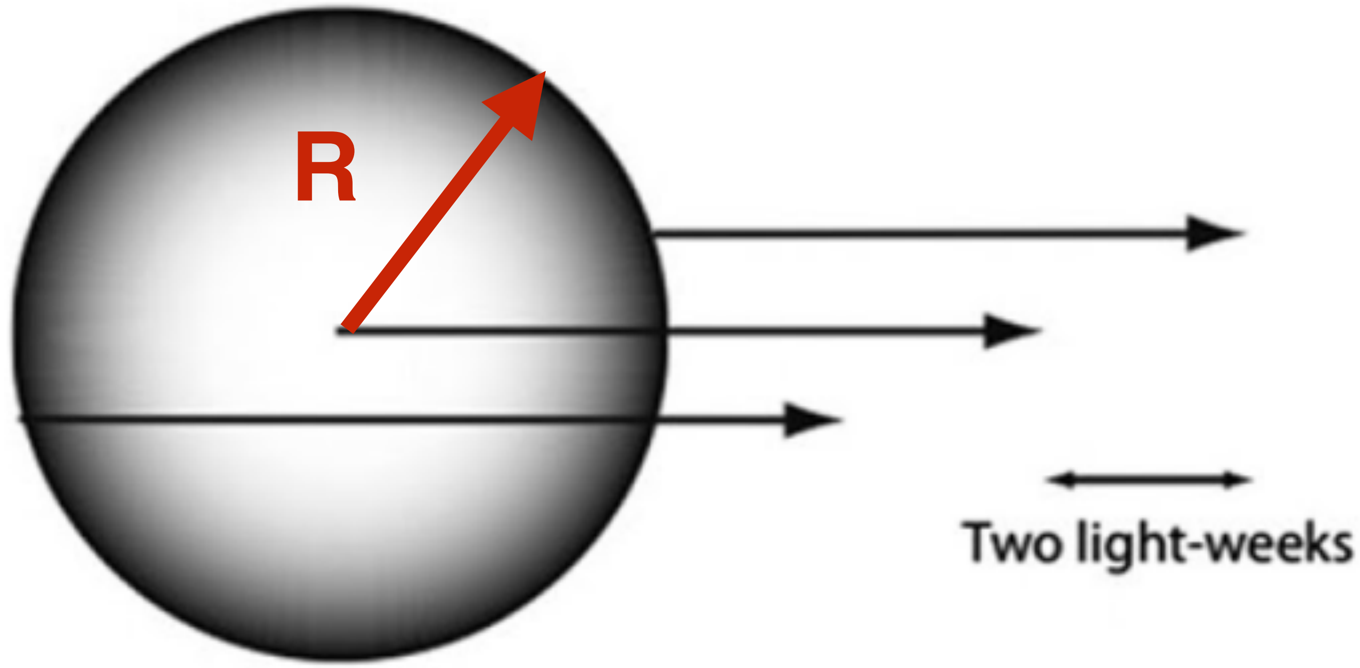


Likelihood analysis is performed in each temporal bins



upper limit on the source size

$$R < \frac{c\Delta t_{obs}\delta}{1+z}$$



$$R < \frac{c\Delta t_{obs}\delta}{1+z}$$

The best way to describe this concept is like this: Imagine an AGN that measures 4 light-weeks across (2 light-week in radius) Now suppose that the entire AGN emits a brief flare (~1 s) of light coming from a volume of hot gas or plasma. Photons from the part of the AGN nearest to Earth arrive at the telescope first.

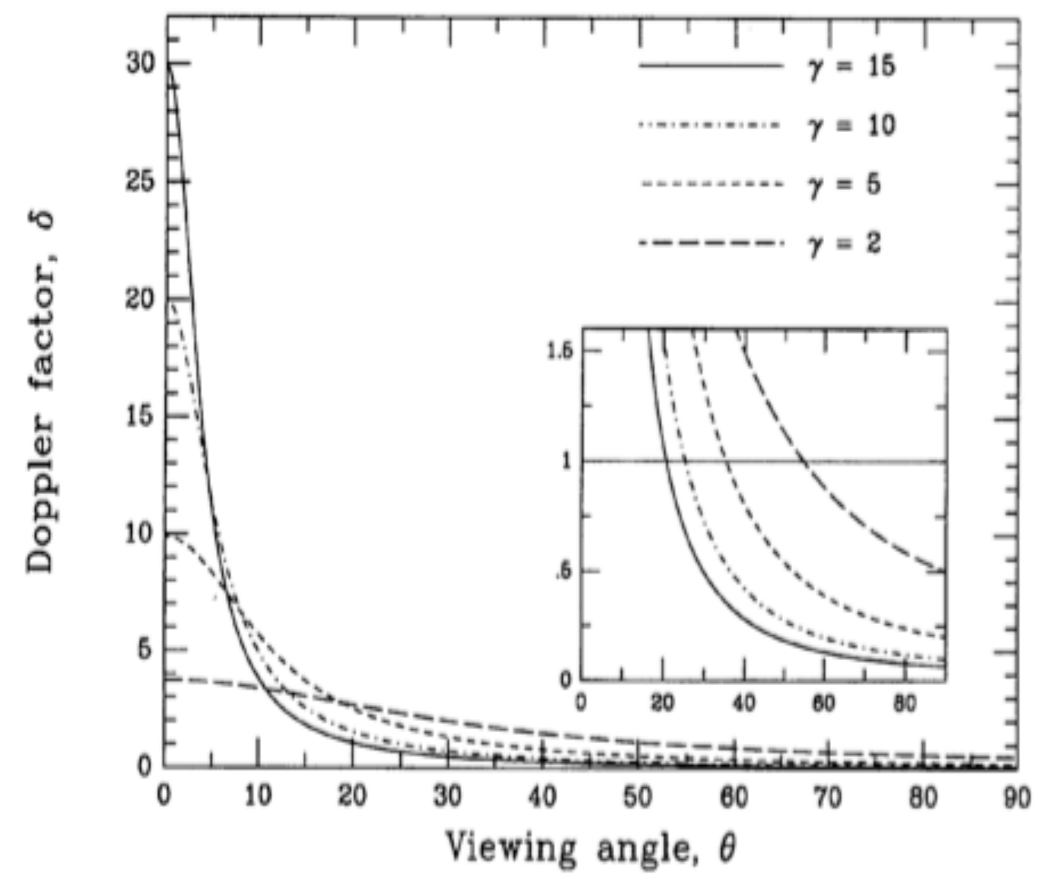
Photons from the middle of the AGN (the largest part if spherical) arrive on Earth, and telescopes, sometime later.

Finally, light from the far side of the AGN arrives after a measurable time difference from the arrival of the first photons.

Although the object emitted a sudden flash of light, what is observed is a gradual increase in brightness that lasts, in this case, a full 4 weeks from the first recorded incident. In other words, the flare is stretched out over a time interval equal to the difference in the light travel time between the nearest and most remote observable regions of the AGN.

$$R < \frac{c\Delta t_{obs}\delta}{1+z}$$

$$\delta = [\gamma(1-\beta cos\theta)]^{-1}$$



The Doppler factor relates intrinsic and observed flux for a moving source at relativistic speed v=β c.

For an intrinsic power law spectrum: $F'(\nu') = K\,(\nu')^{-a}$
the observed flux density is

$F_\nu(\nu) = \delta^{3+\alpha} F'_{\nu'}(\nu)$

$$\Delta t = \Delta t'/\delta$$

PKS1510-089 $\quad \delta \sim 39$

Jordstat et al. 2005
iopscience.iop.org/article/10.1086/444593/pdf