Max Planck Institute for Physics
The MAGIC Telescope

Ringberg Young Scientist Workshop 2012

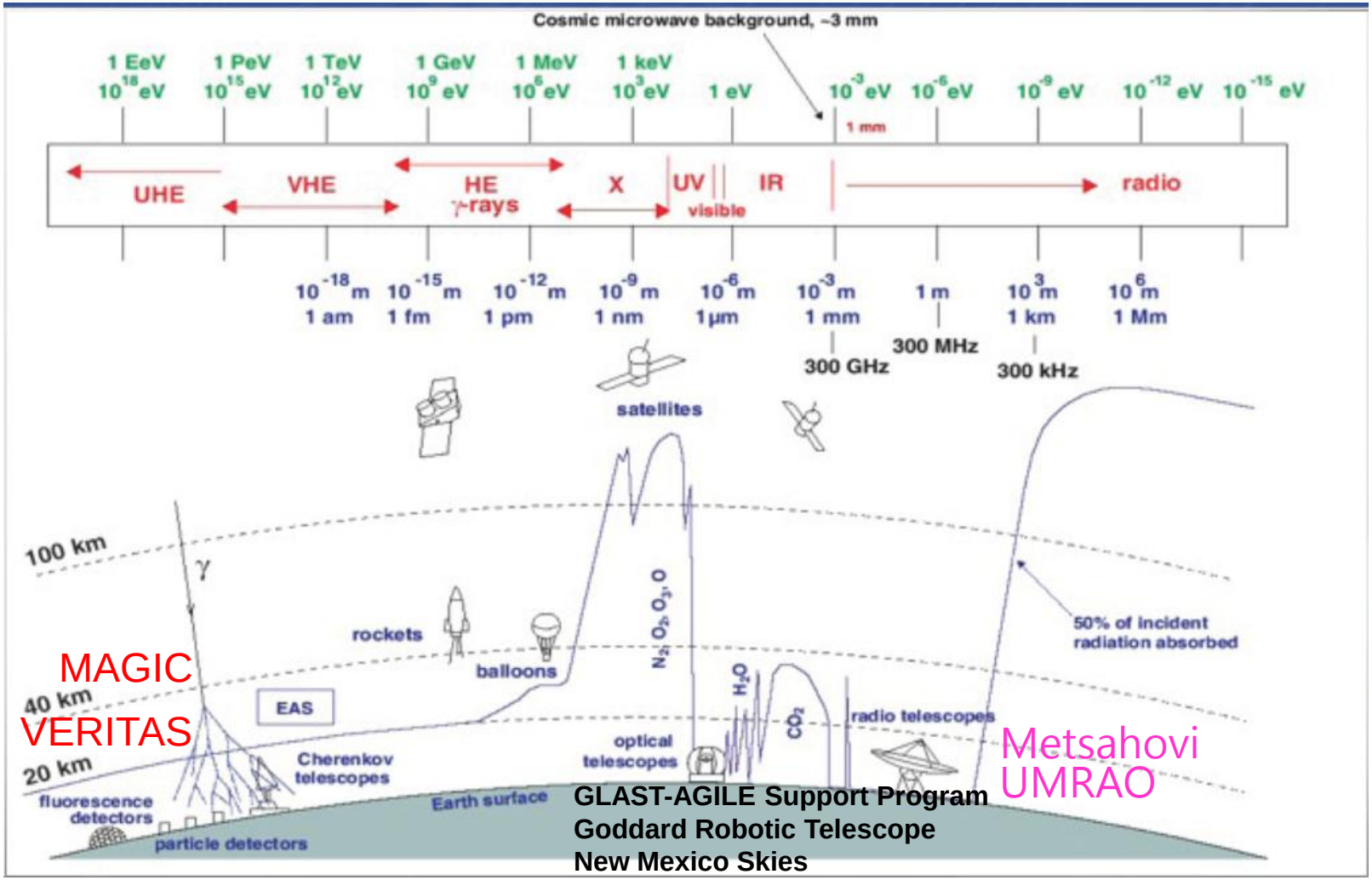
Detailed characterization and scientific interpretation of the broadband emission of Mrk421 during flaring activity in 2010

ShangYu Sun

A. Boller, L. Fortson, N. Galante, D. Paneque and B. Steinke On behalf of the Fermi, MAGIC, VERITAS collaborations and the participants/groups of the MW campaign on Mrk421 in 2010, which include GASP-WEBT, F-GAMMA and many others

24_07_2012

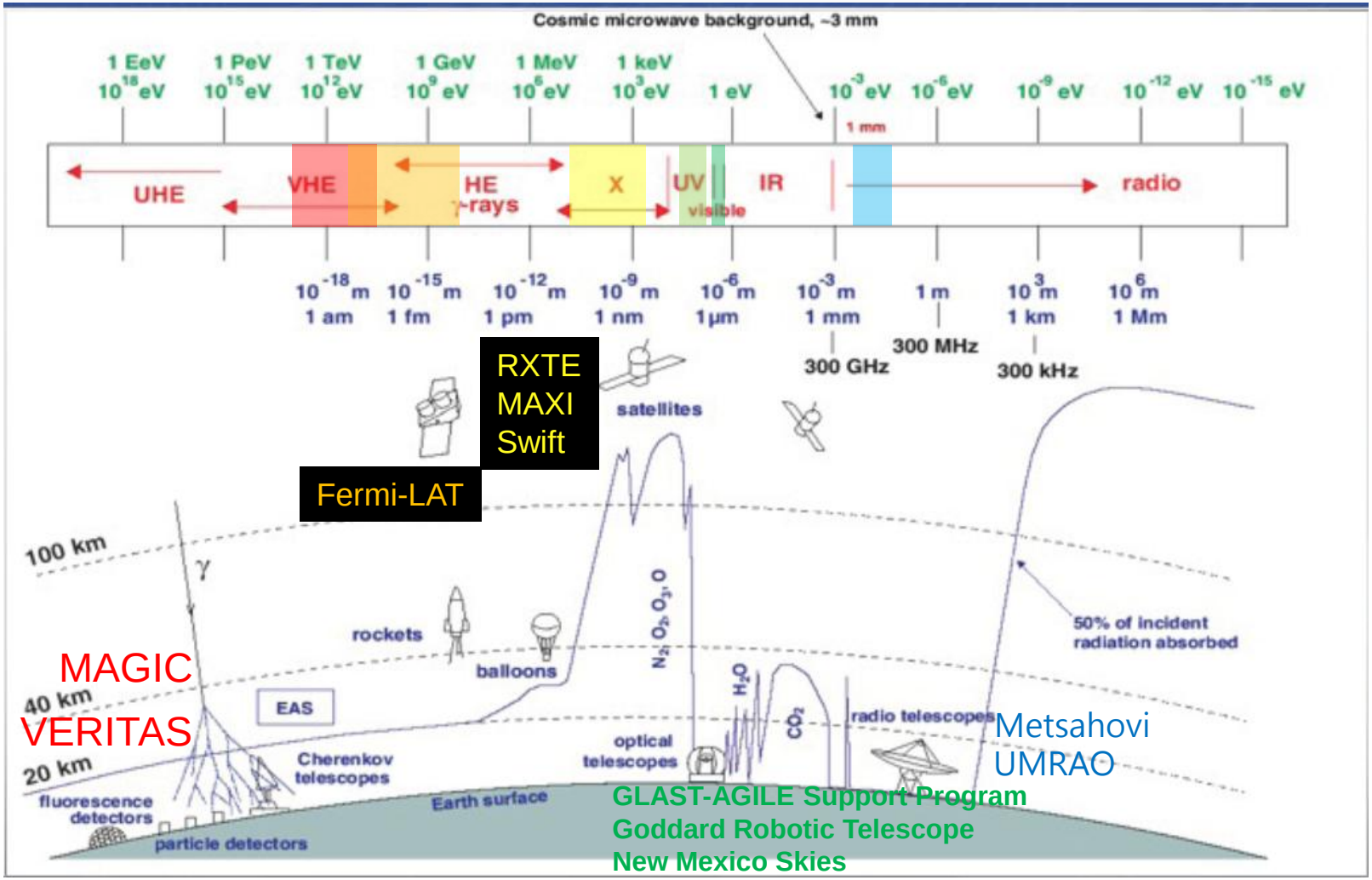
2010 Multi-wavelength Campaign for Mrk 421



GLAST-AGILE Support Program
Goddard Robotic Telescope
New Mexico Skies
ROVOR
St.Petersburg ……

2010 Multi-wavelength Campaign for Mrk 421

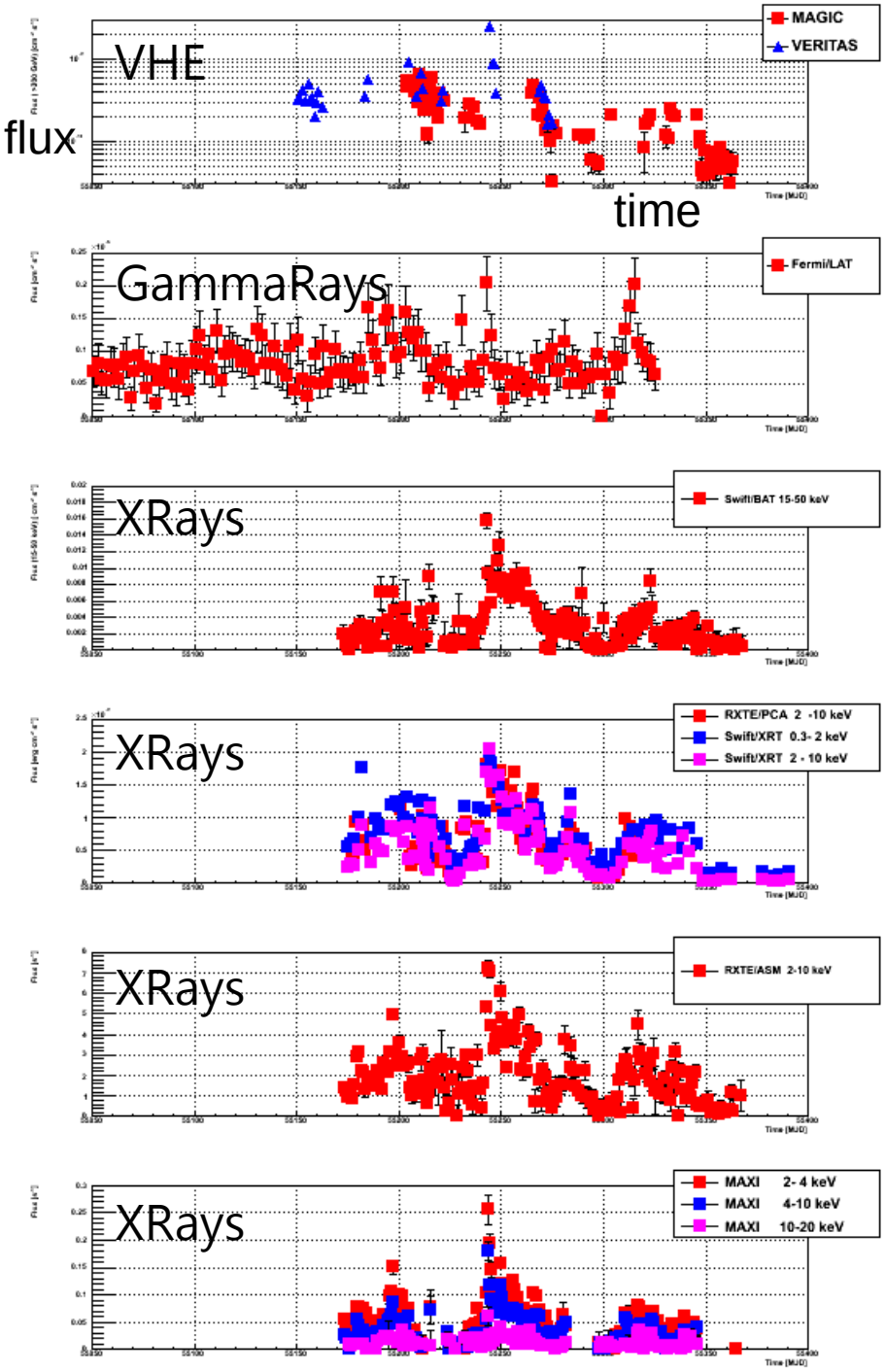
50TeV-50GeV | 300GeV-300MeV | 50keV-300 eV



GLAST-AGILE Support Program
Goddard Robotic Telescope
New Mexico Skies
ROVOR
St.Petersburg …….

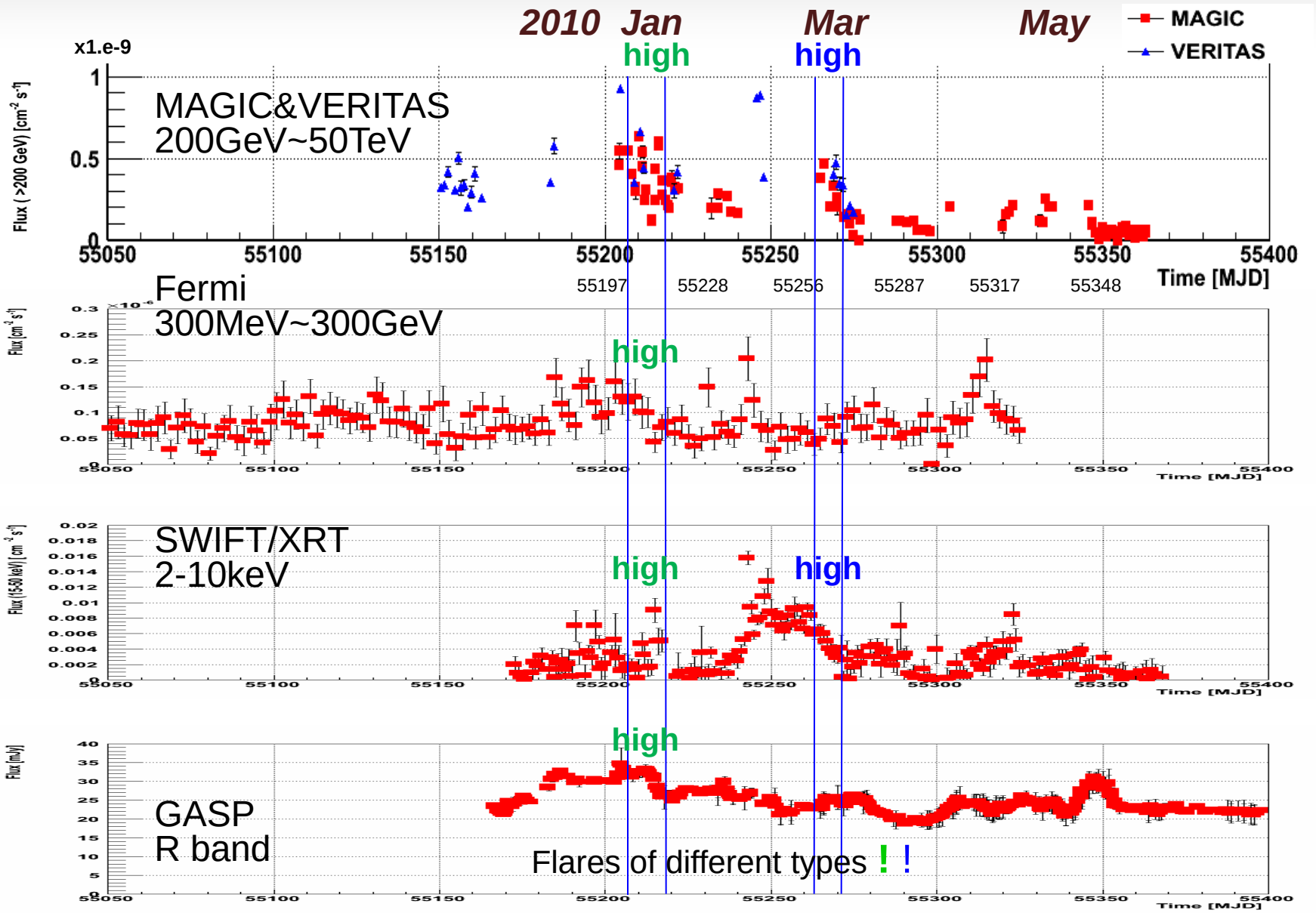
MW Light-Curve Frequency-Bands

Wave band	instrument	flux unit	mean freq. Hz	low freq. Hz	high freq. Hz	low energy	high energy
VHE	MAGIC	count/cm^2/s		4.84E+025	1.21E+028	200GeV	
VHE	VERITAS	count/cm^2/s		4.84E+025	1.21E+028	200GeV	
GammaRays	Fermi	ph/cm2/s		6.06E+022	6.06E+025	300MeV	300GeV
XRays	RXTE/PCA	erg/cm2/s		4.84E+017	2.42E+018	2.00keV	10.0keV
Xrays	SWIFT/BAT	count/cm2/s		3.63E+018	1.21E+019	15keV	50keV
Xrays	SWIFT/XRT	erg/cm2/s		4.84E+017	2.41E+018	2keV	10keV
Xrays	SWIFT/XRT	erg/cm2/s		7.25E+016	4.84E+017	0.3keV	2keV
Xrays	RXTE/ASM	ph/s		4.84E+017	2.41E+018	2keV	10keV
XRays	MAXI	ph/s		9.67E+017	2.41E+018	4keV	10keV
UVW2	SWIFT/UVOT	mJy	1.60E+015	1.37E+015	1.93E+015		
UVM2	SWIFT/UVOT	mJy	1.38E+015	1.24E+015	1.55E+015		
UVW1	SWIFT/UVOT	mJy	1.19E+015	1.05E+015	1.37E+015		
b	ROVOR	mJy	6.81E+014	6.14E+014	7.66E+014		
b	Bradford Robotic Telescope	mJy	6.81E+014	6.14E+014	7.66E+014		
v	New Mexico Skies	mJy	5.45e14	5.04e14	5.92e14		
v	ROVOR	mJy	5.45e14	5.04e14	5.92e14		
v	Bradford Robotic Telescope	mJy	5.45e14	5.04e14	5.92e14		
r	New Mexico Skies	mJy	4.68E+014	4.20E+014	5.29E+014		
r	ROVOR	mJy	4.68e14	4.20e14	5.29e14		
r	Bradford Robotic Telescope	mJy	4.68e14	4.20e14	5.29e14		
r	GLAST-AGILE Support Program	mJy	4.68e14	4.20e14	5.29e14		
r	Goddard Robotic Telescope	mJy	4.68e14	4.20e14	5.29e14		
r	Perkins	mJy	4.68e14	4.20e14	5.29e14		
r	Steward	mJy	4.68e14	4.20e14	5.29e14		
r	Crimean	mJy	4.68e14	4.20e14	5.29e14		
r	St.Petersburg	mJy	4.68e14	4.20e14	5.29e14		
I	ROVOR	mJy	3.79e14	3.47e14	4.19e14		
Radio	Metsahovi	Jy	37GHz	3.63E+010	3.87E+010	1.5e-4eV	1.6e-4eV
Radio	UMRAO	Jy	14GHz	1.26E+010	1.64E+010	5.2e-5eV	6.8e-5eV
Radio	UMRAO	Jy	8GHz	7.25E+009	8.70E+009	3.0e-5eV	3.6-5eV



Mrk421 2010
MW light curves

Mrk421 2010 Flares
VHE, HE, Xray, Optical light curves



Mrk421 Broadband Spectral Energy Distribution

2009 data

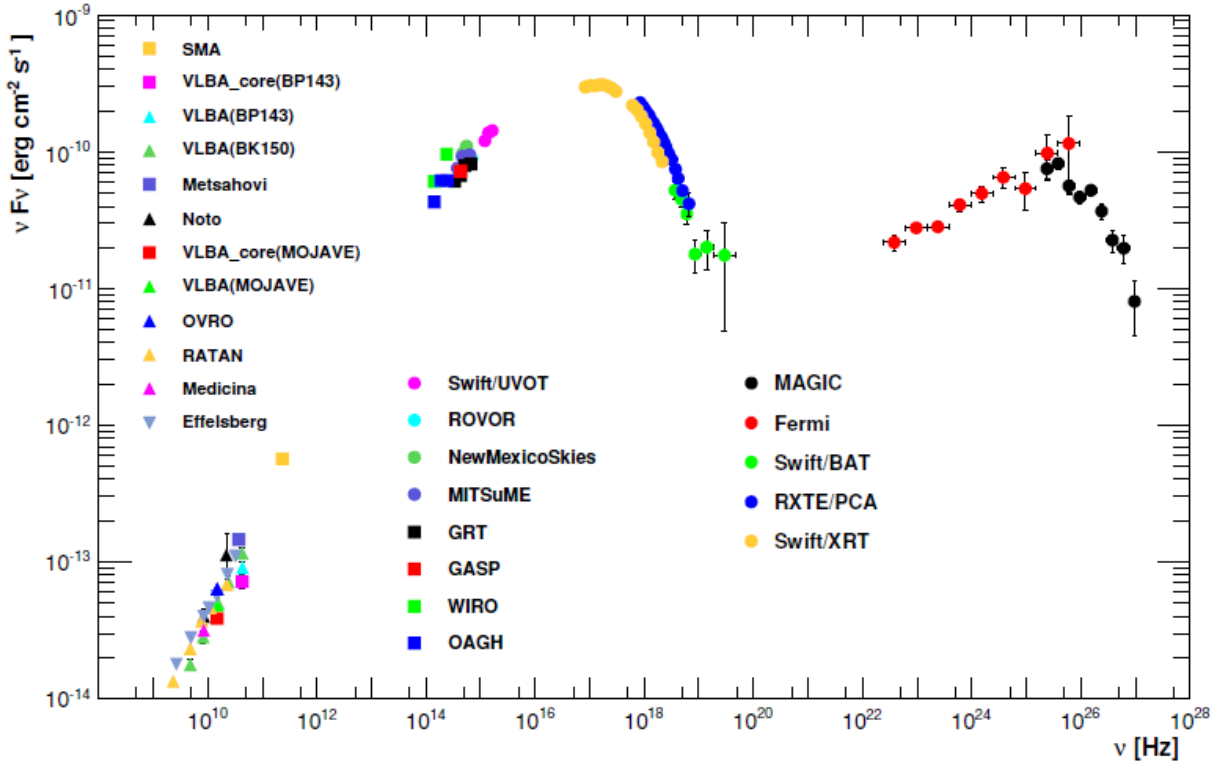


Figure 8. Spectral energy distribution of Mrk 421 averaged over all the observations taken during the multifrequency campaign from 2009 January 19 (MJD 54850) to 2009 June 1 (MJD 54983). The legend reports the correspondence between the instruments and the measured fluxes. The host galaxy has been subtracted, and the optical/X-ray data were corrected for the Galactic extinction. The TeV data from MAGIC were corrected for the absorption in the EBL using the prescription given in Franceschini et al. (2008).

Mrk421 2010 MW Light Curve Variability

Variability: the quantity showing how much each light curve fluctuates

Variability

(S. Vaughan et al. Mon.Not.Roy.Astron.Soc.345:1271,2003)

$$F_{\mathrm{var}} = \sqrt{\frac{S_f^{\,2} - \overline{\sigma_i^{\,2}}}{\bar{f}^{\,2}}}$$

$$S_f^{\,2} = \frac{\sum_i^{N_f} (f_i - \bar{f})^2}{N_f - 1}$$

$S_f^{\,2}$ Variance of Flux

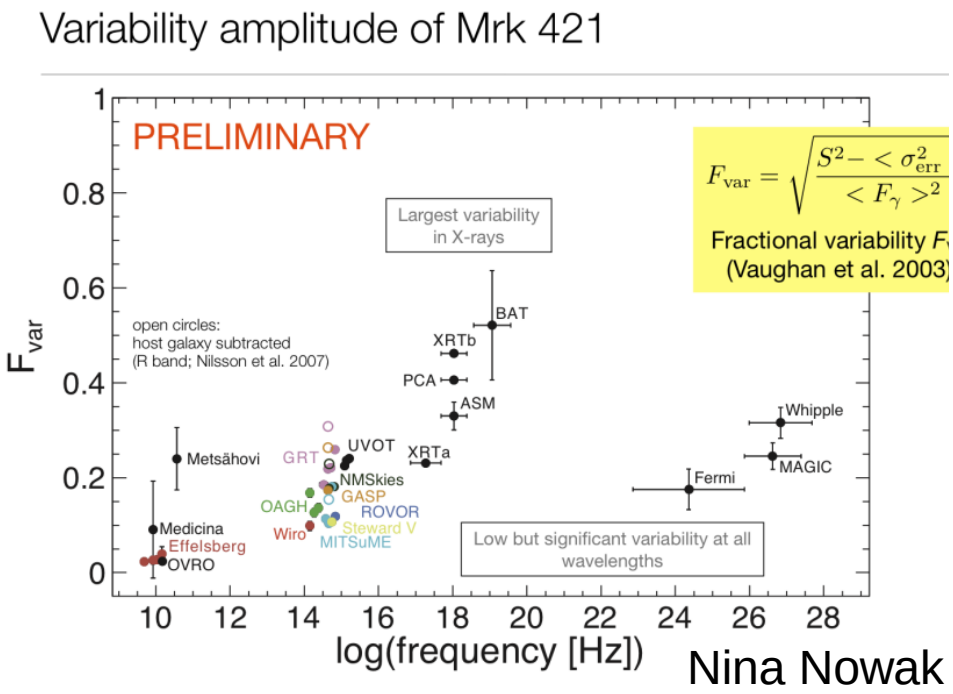
$\overline{\sigma_i^{\,2}}$ Mean of error sq.

$\bar{f}$ Mean of Flux

Mrk421 2010 MW Light Curve Variability

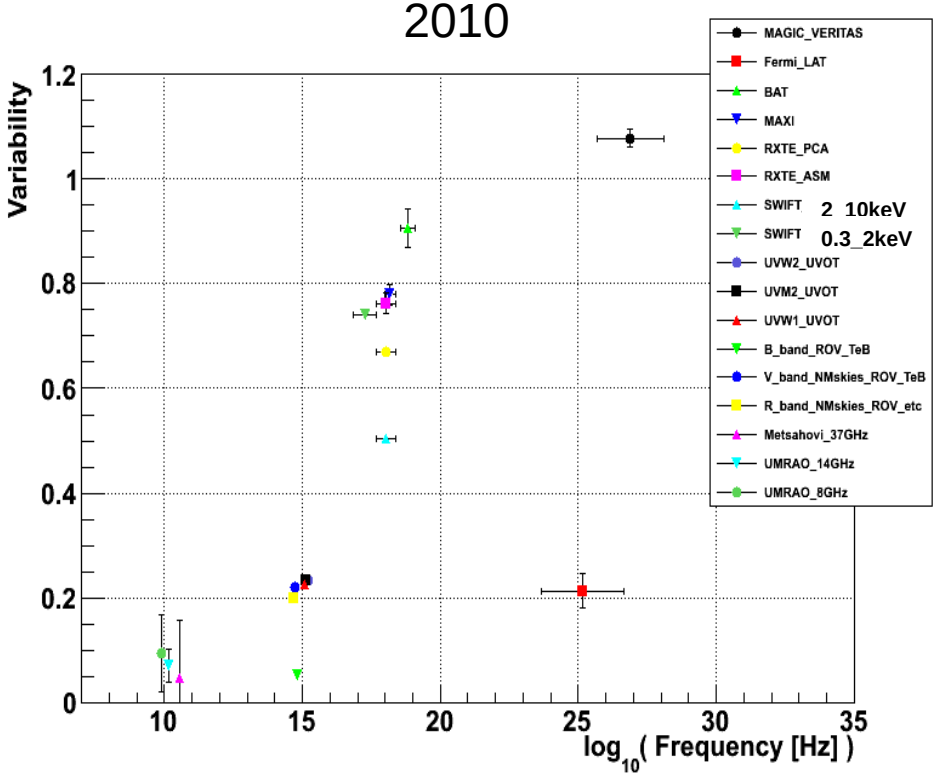
Variability: the quantity showing how much each light curve fluctuates

2009



Nina Nowak

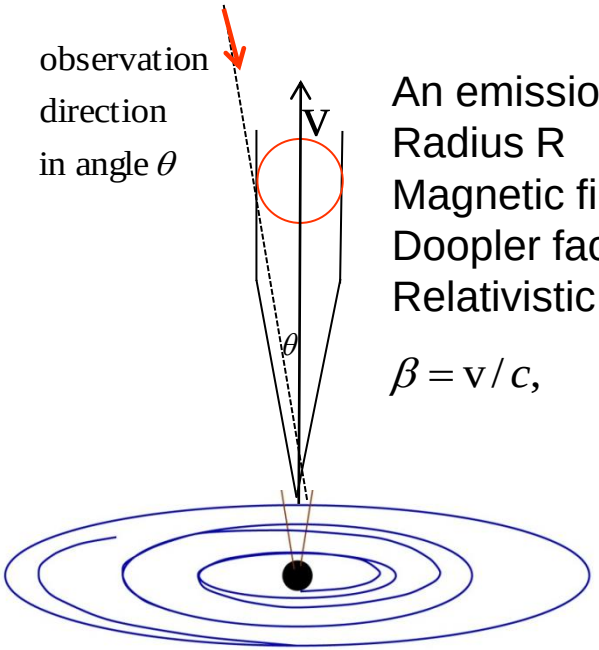
2010

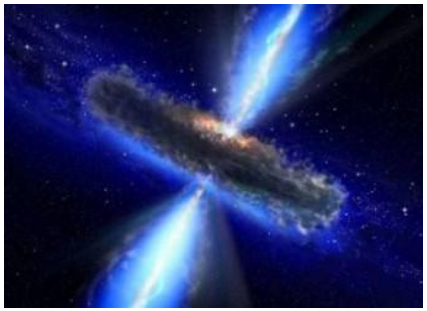


Opt 0.2 X 0.45 GeV 0.2 TeV 0.25

Opt 0.2 X 0.7 GeV 0.2 TeV 1.1

Describe Spectra with One-Zone Synchrotron Self-Compton Model





An emission blob with:
Radius R
Magnetic field B
Doopler factor δ
Relativistic electrons

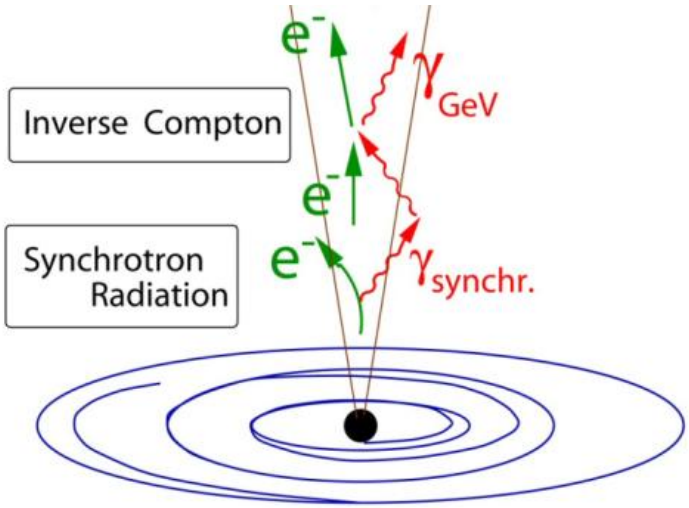
$$\beta = \mathrm{v}/c, \qquad \gamma = (1-\beta^2)^{-1/2}, \qquad \delta = \gamma^{-1}(1-\beta\cos\theta)^{-1}$$

electron injection spectrum $(n_e, s_1, s_2, \gamma_{\min}, \gamma_{break}, \gamma_{\max})$

$$\frac{dN}{d\gamma} = \begin{cases} (\text{for } \gamma_{\min} < \gamma < \gamma_{break1})\ n_e\gamma^{-s_1} \\ (\text{for } \gamma_{break1} < \gamma < \gamma_{break2})\ n_e\gamma^{-s_2}\gamma_{break}^{s_2-s_1} \end{cases}$$

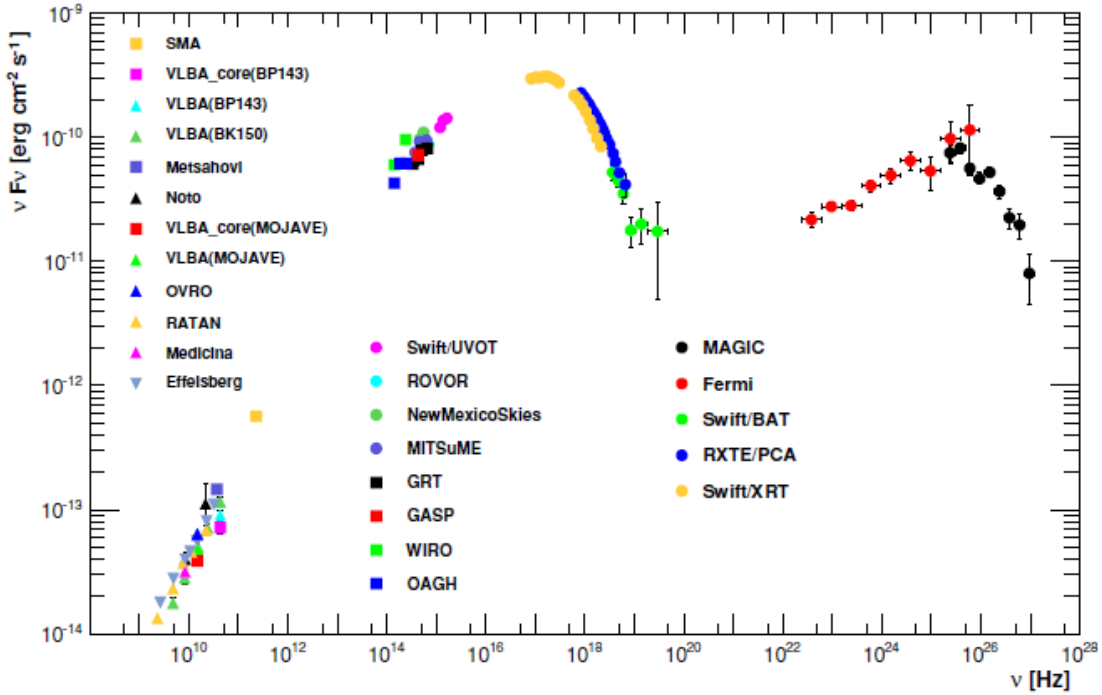
Using Hajime Takami 's SSC code
Monthly Notices of the Royal Astronomical Society, Volume 413, Issue 3, pp. 1845-1851

Describe Spectra with One-Zone Synchrotron Self-Compton Model



synchrotron radiation
=>Xray

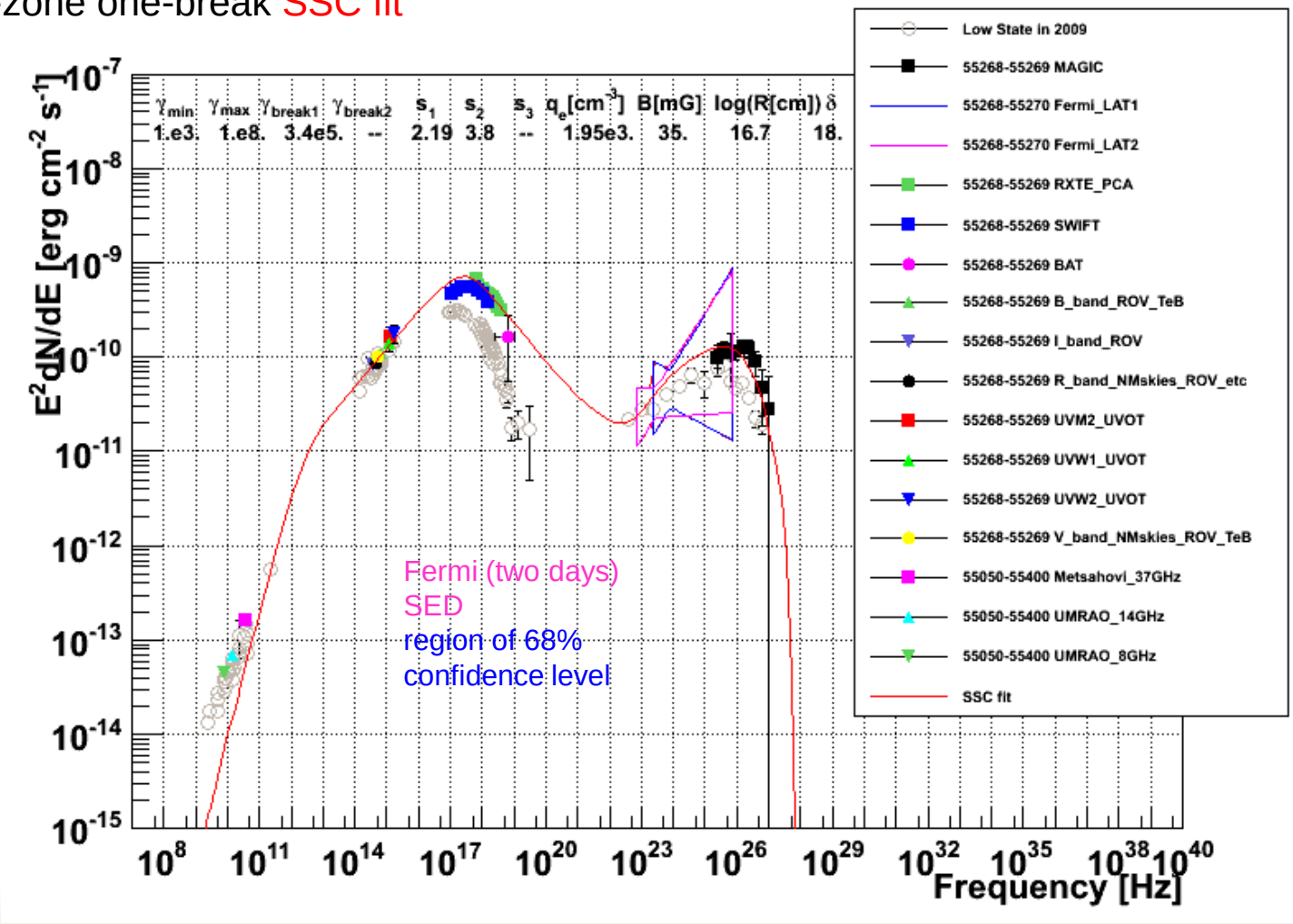
inverse Compton
=>GammaRay



Mrk421 Broadband SED and SSC Modeling

Content of this plot:

1. 2009 average SED (low state)
2. 2010_03_14(high state) SED
3. one-zone one-break SSC fit

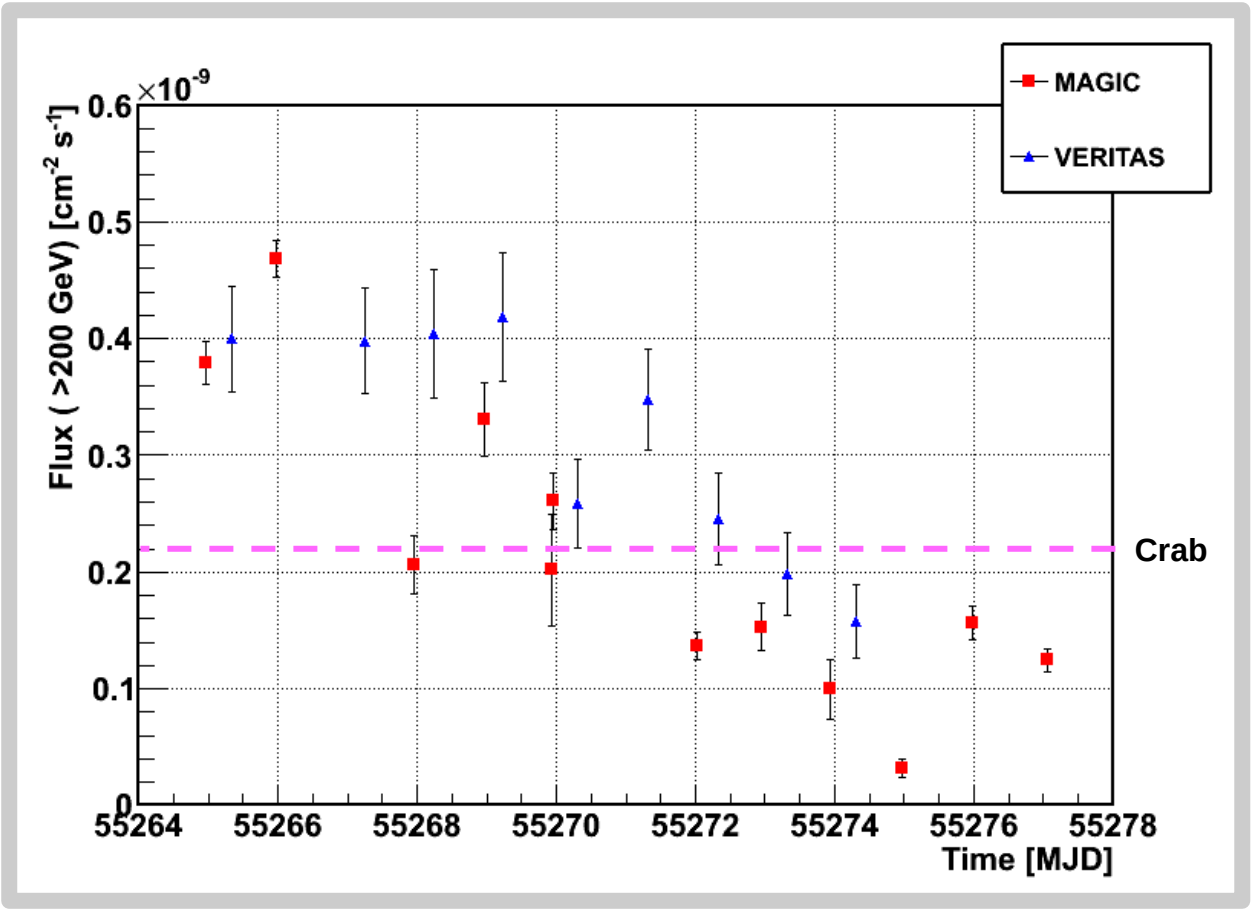


Mrk421 2010 March
Very High Energy Light Curve

March 10 12 14 16 18 20 22

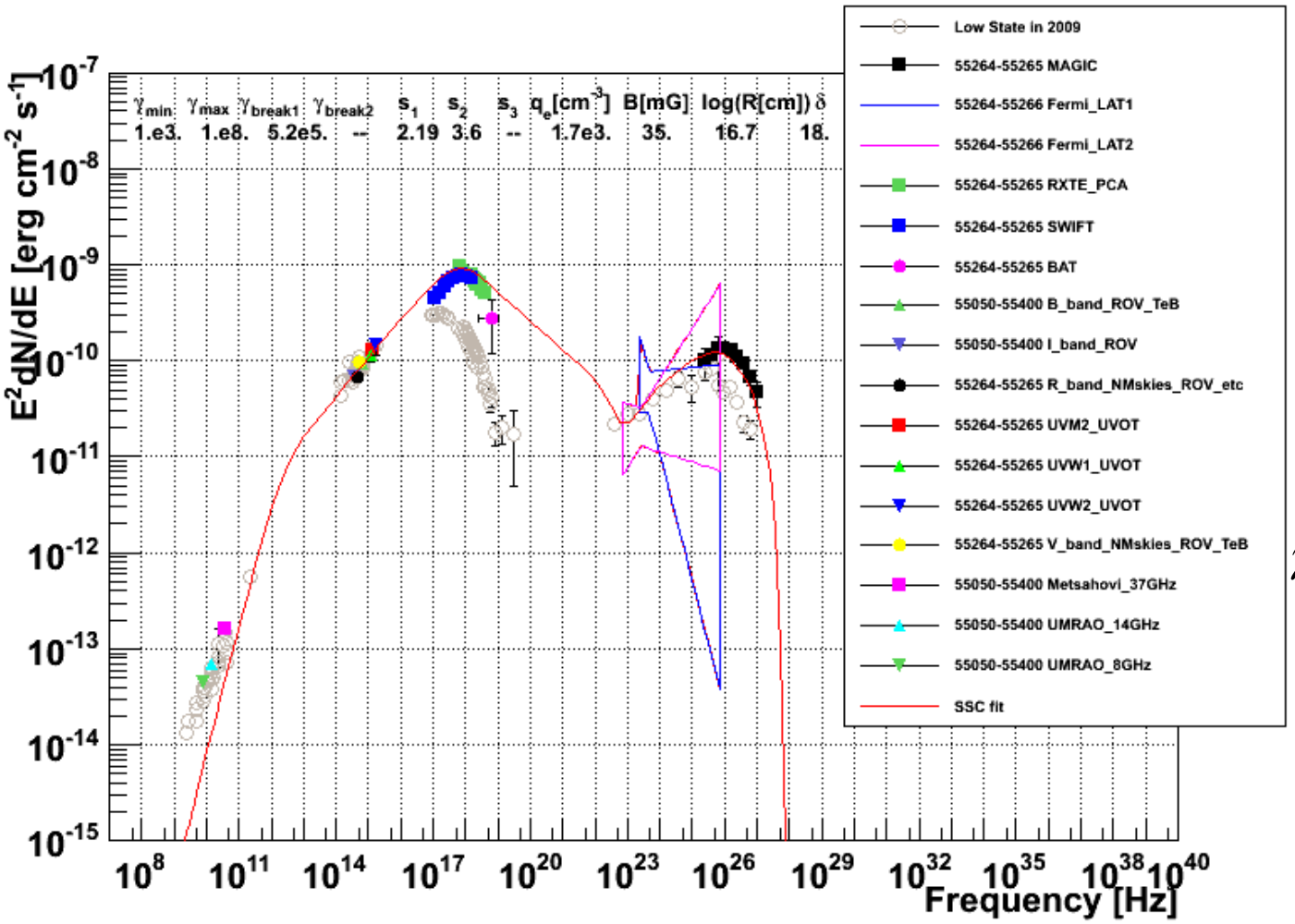
- A decaying flare in Mrk 421 was observed by MAGIC and VERITAS in March (peak ~2 Crab). (Low state around 50% Crab)

- 10/03/2010 (55255) - 22/03/2010 (55267) ; MAGIC 11 nights (10~80 min obs.) VERITAS 6 nights (~10 min obs.)



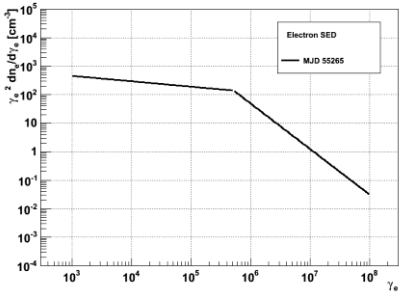
Next: unprecedented data for blazar study:
day-by-day broadband Mrk421 SEDs in flaring activity

Mrk421 MW 2010_03_10 (55265)



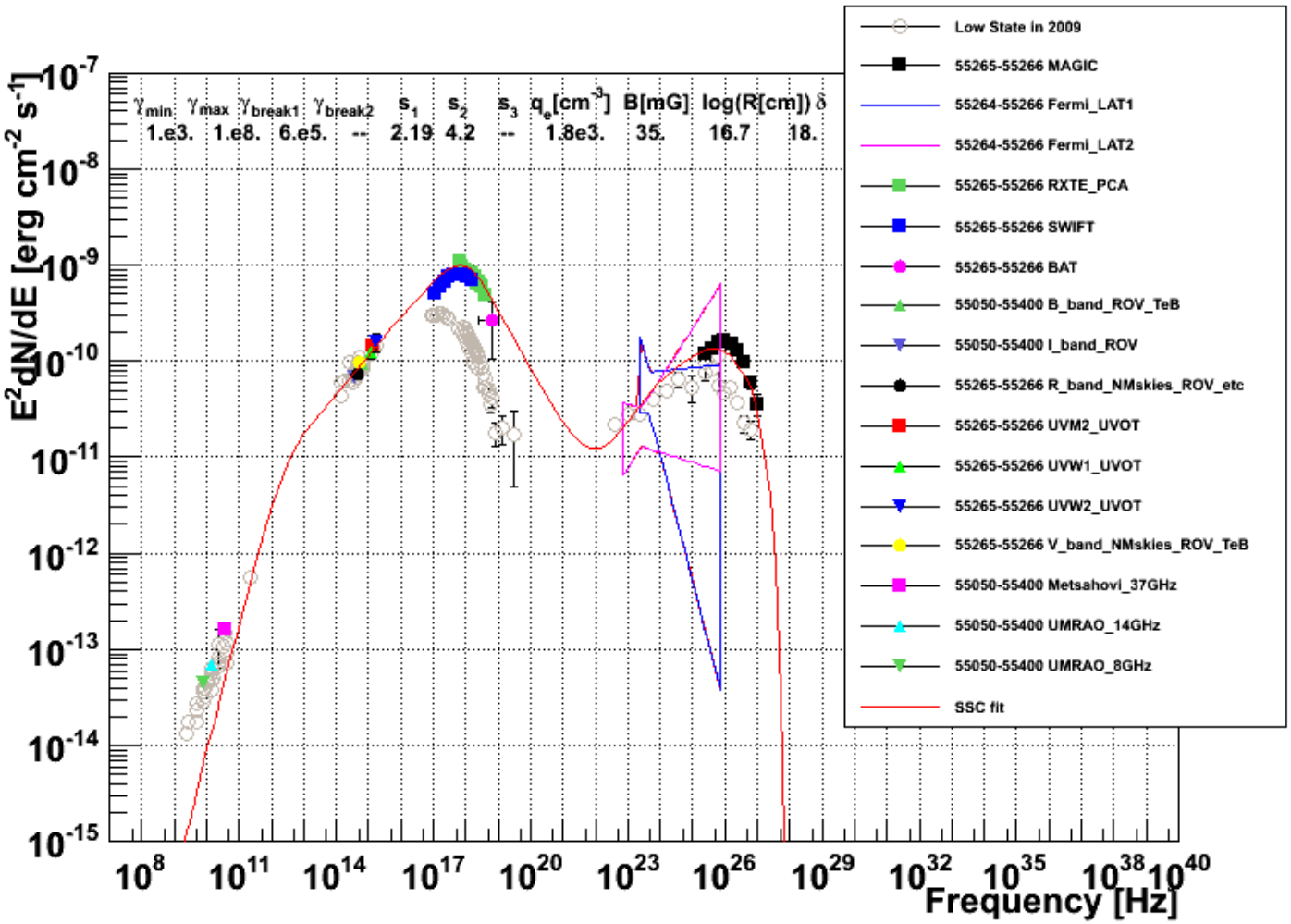
$\gamma^2 \frac{dN}{d\gamma}$

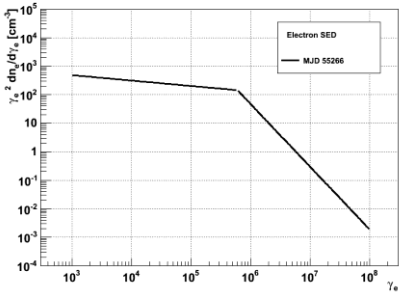
Electron Energy Spectrum



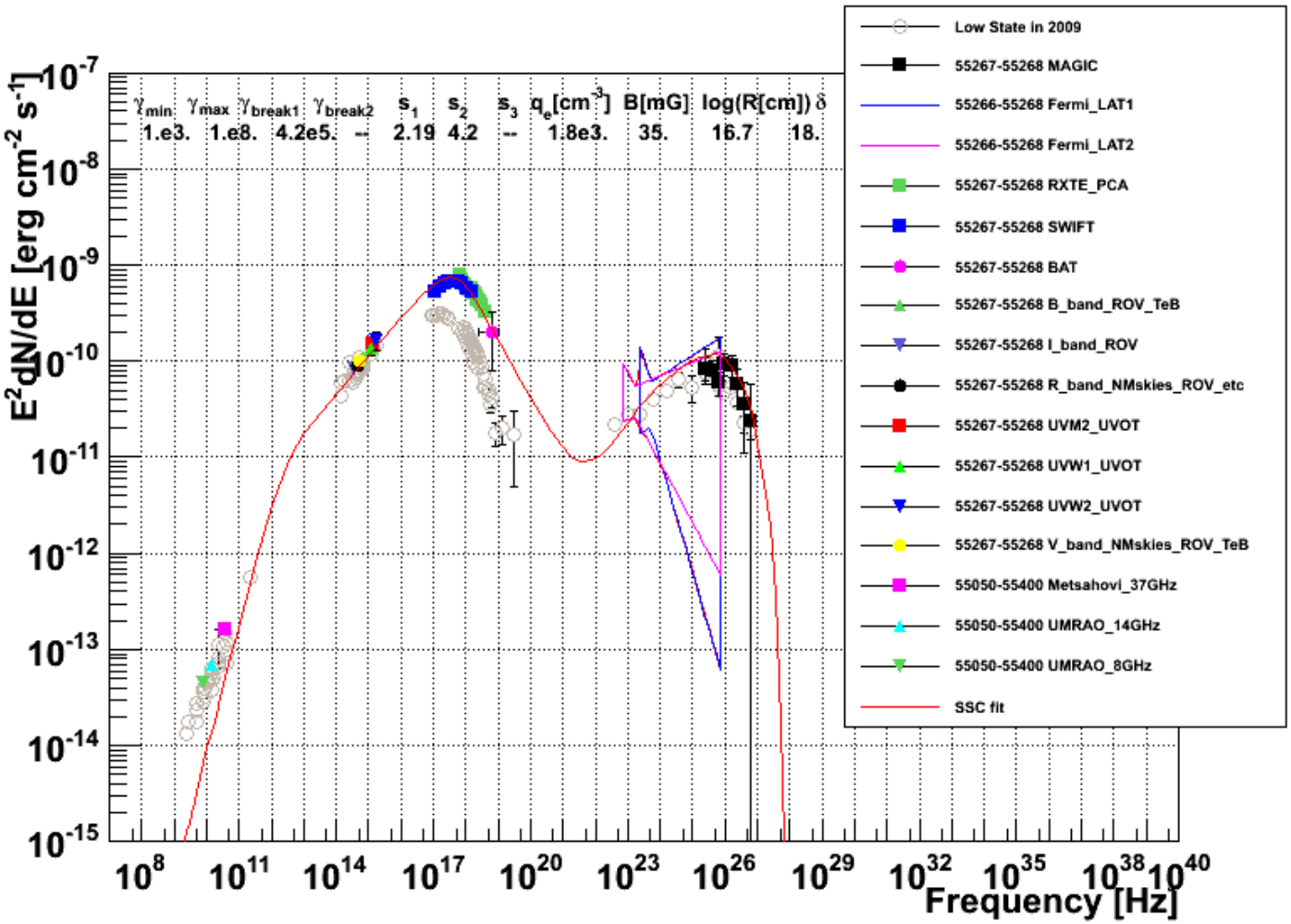
γ

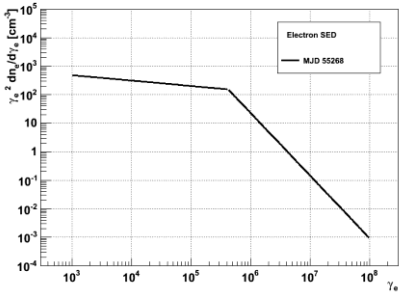
Mrk421 MW 2010_03_11 (55266)



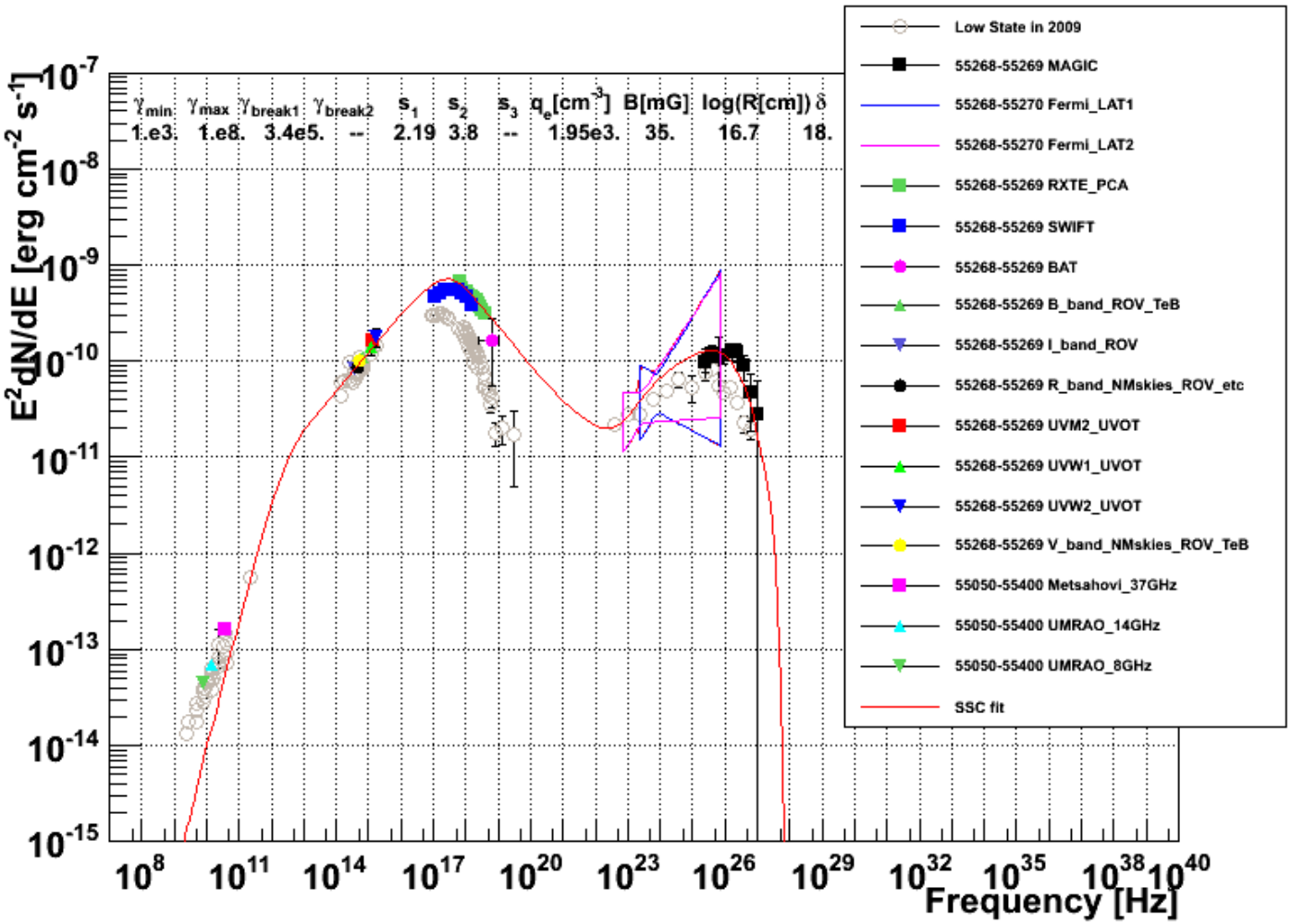


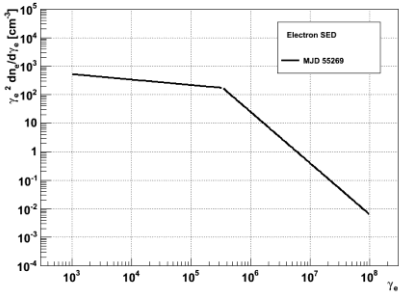
Mrk421 MW 2010_03_13 (55268)



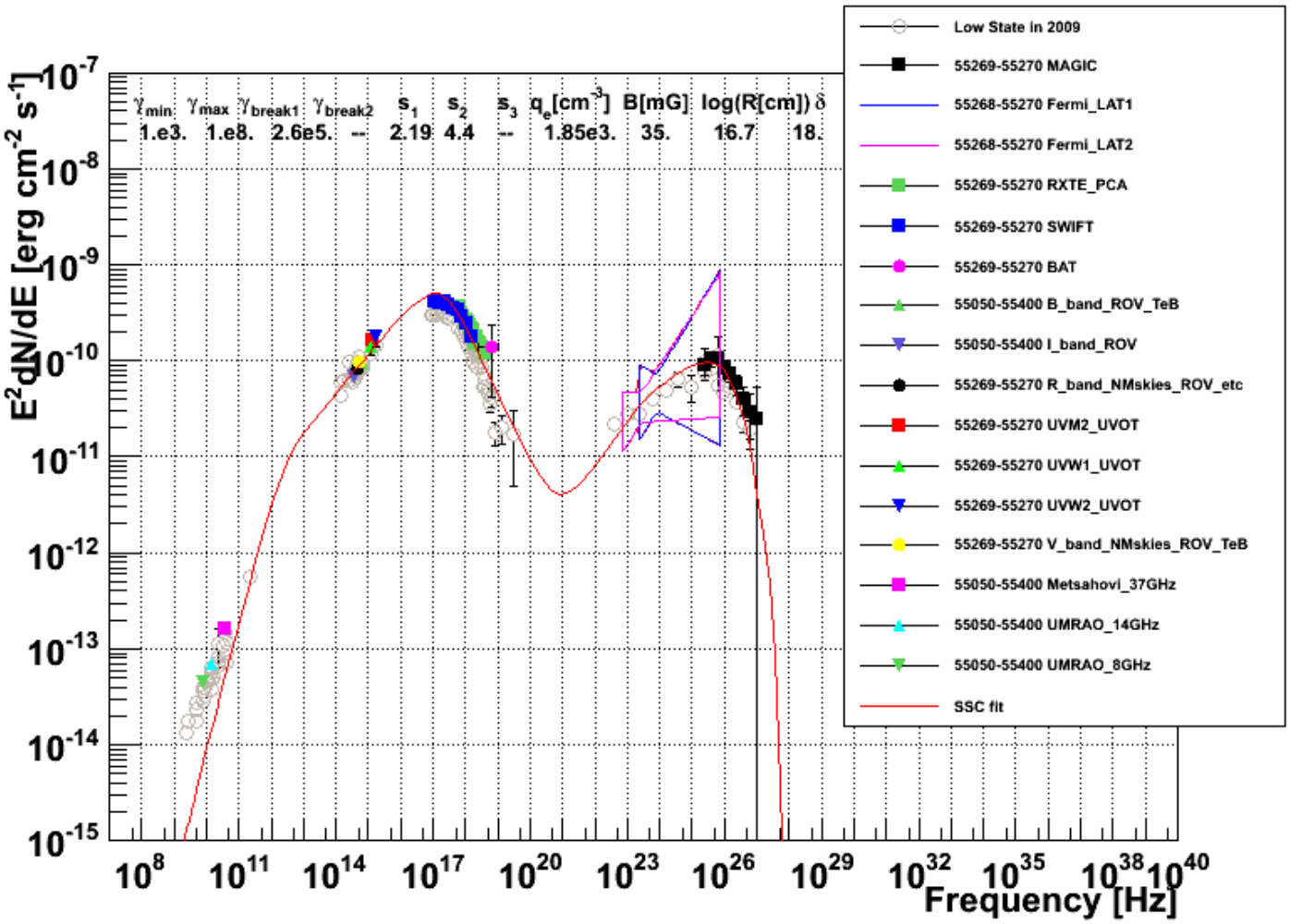


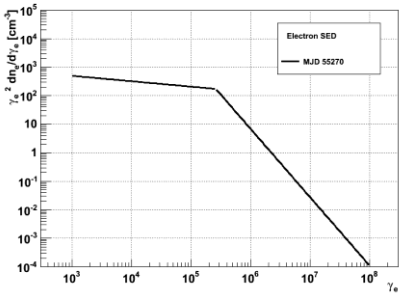
Mrk421 MW 2010_03_14 (55269)



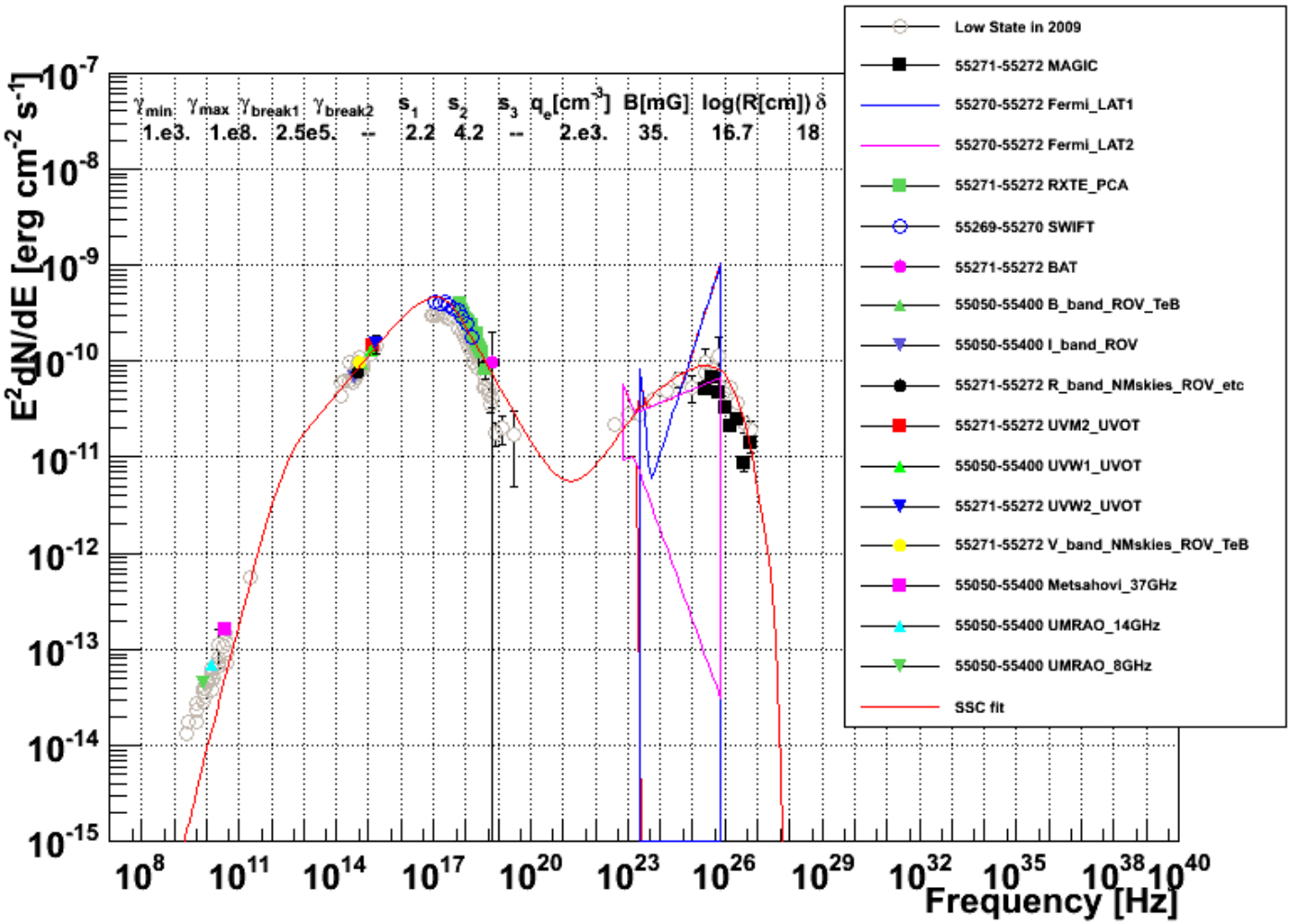


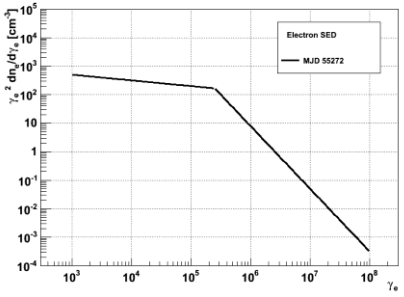
Mrk421 MW 2010_03_15 (55270)



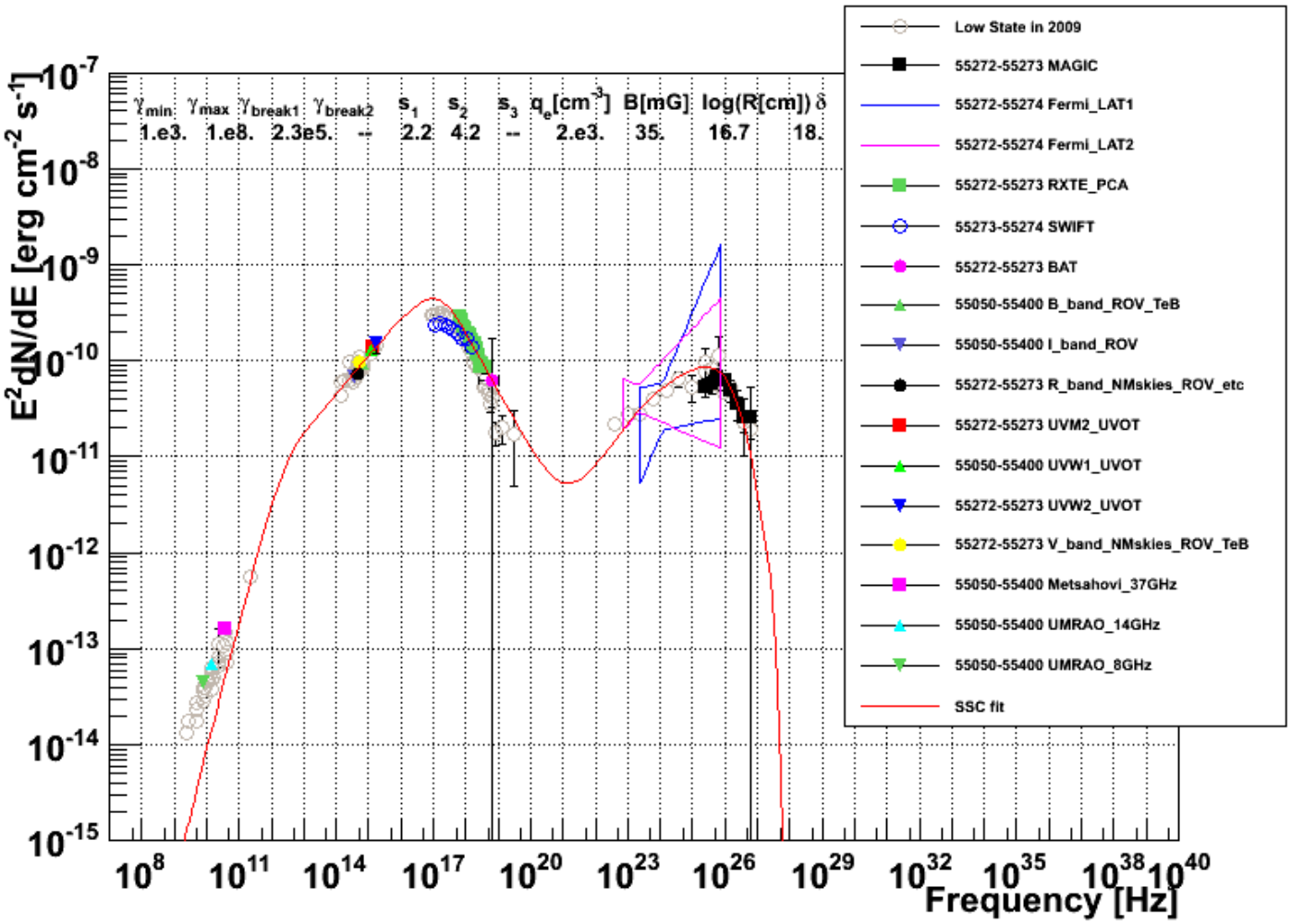


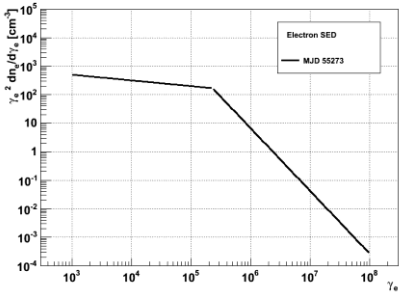
Mrk421 MW 2010_03_17 (55272)



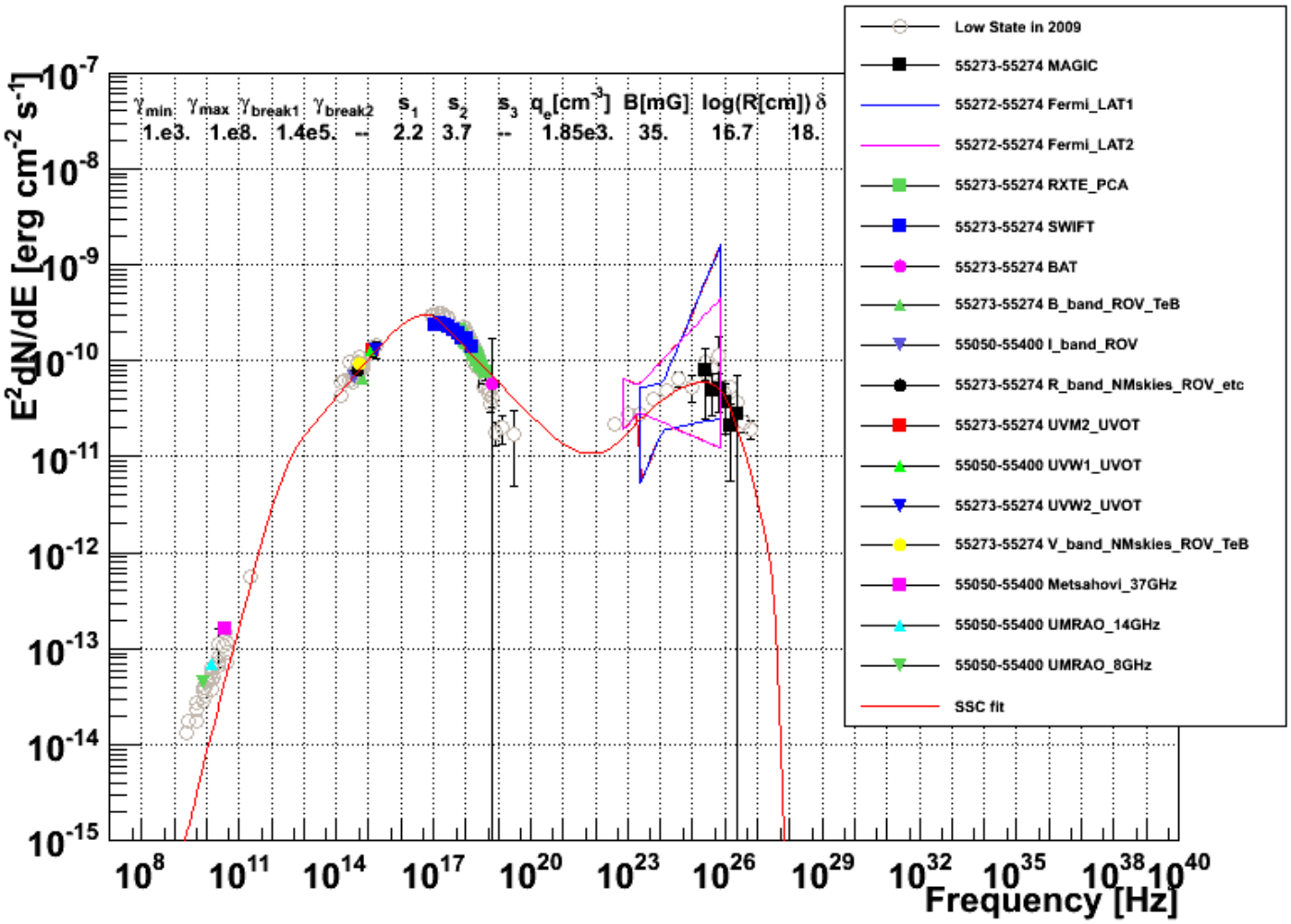


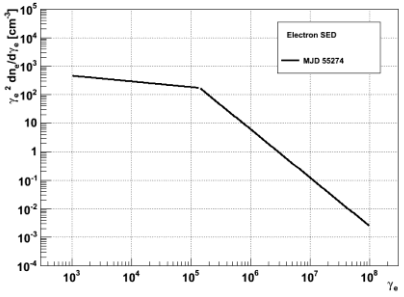
Mrk421 MW 2010_03_18 (55273)



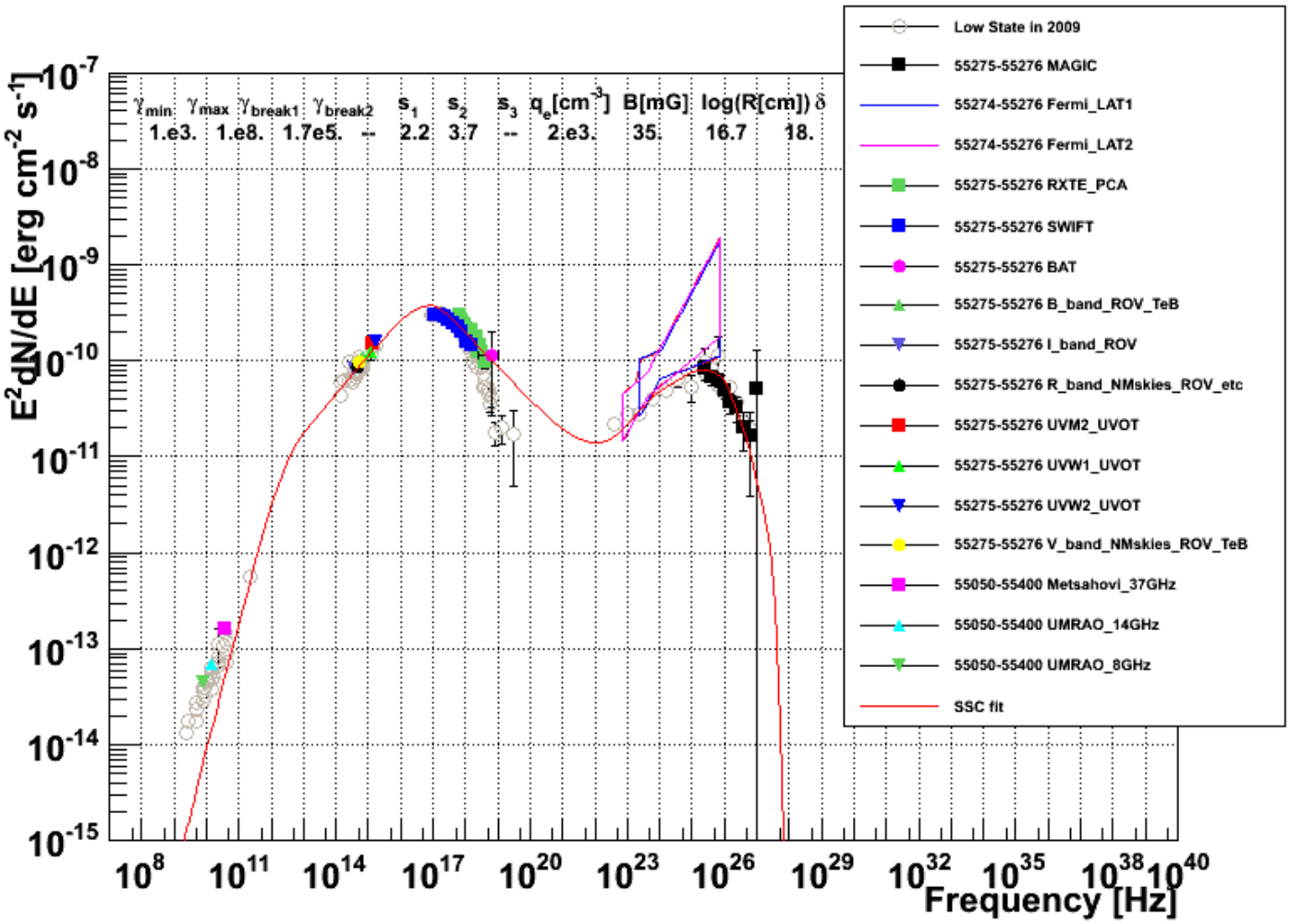


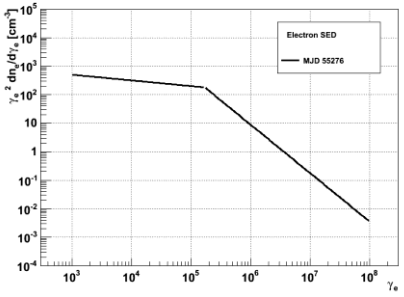
Mrk421 MW 2010_03_19 (55274)



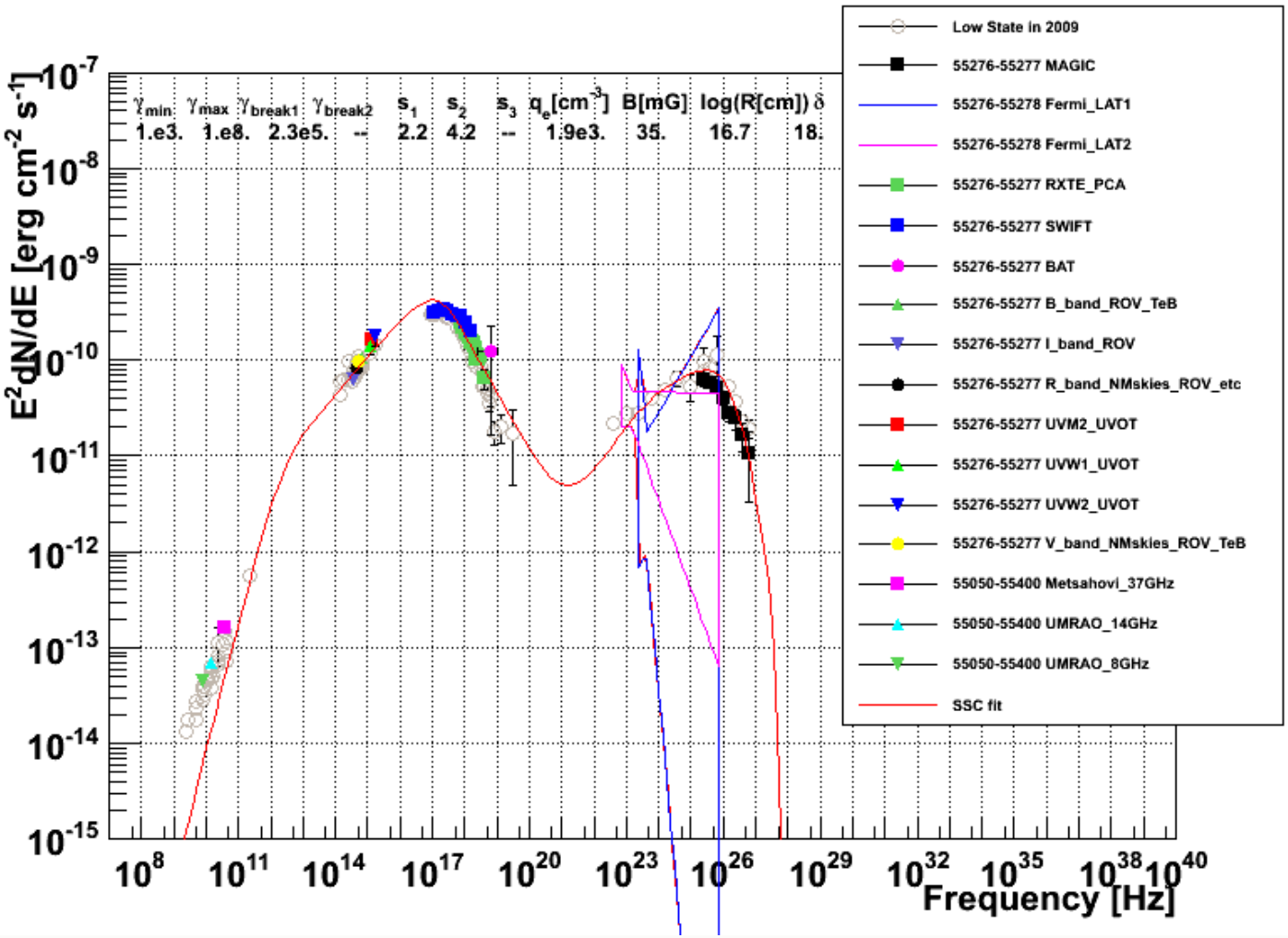


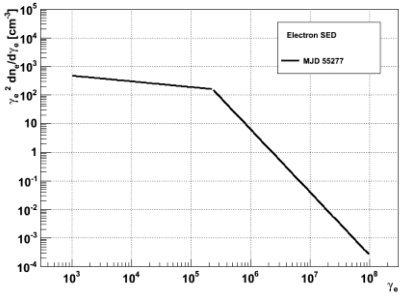
Mrk421 MW 2010_03_21 (55276)





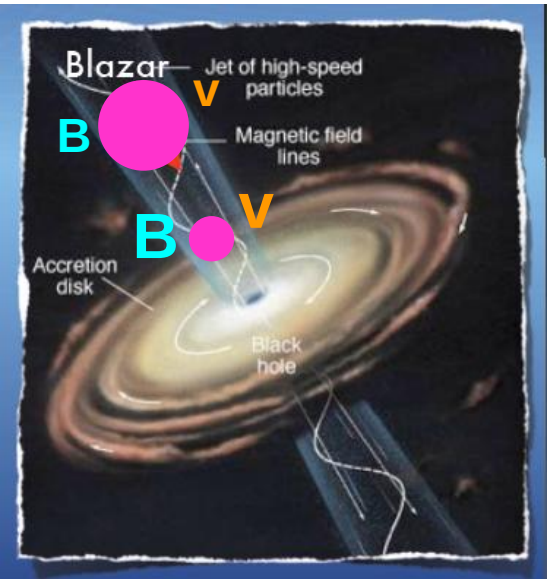
Mrk421 MW 2010_03_22 (55277)



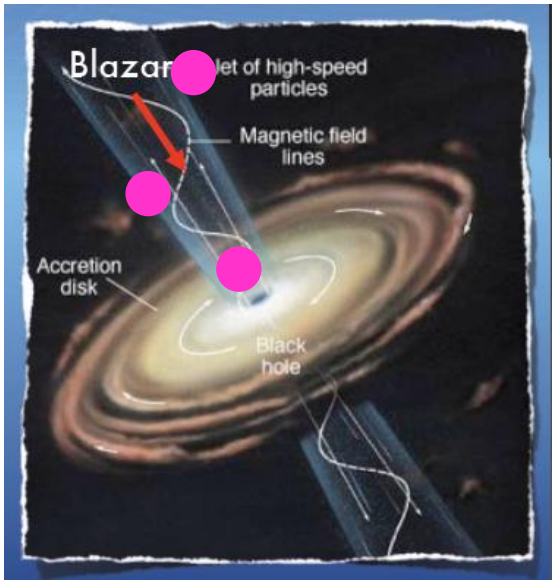


Which parameter changes during flaring acyivity?

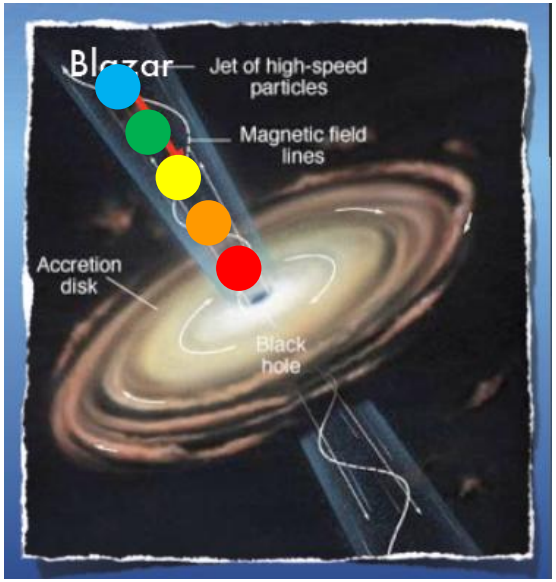
Magnetic field ?
Blob speed ?
Blob size?



Blob bouncing in the jet?

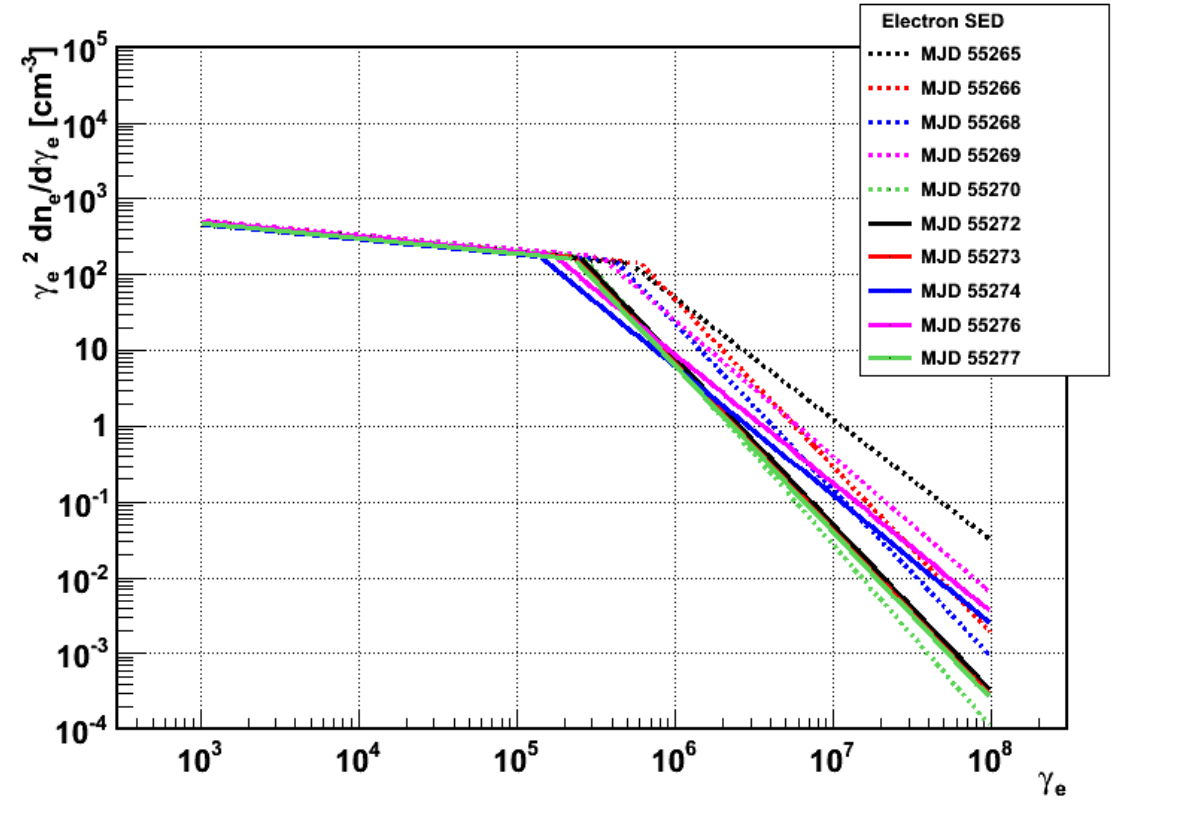


Electron energy ?



Describe Variation of Spectra with Electron SEDs

The evolution of the SED during the flare can be explained, within the one-zone Synchrotron Self-Compton scenario, with variations in the high-energy part of the electron energy distribution, rather than the environment parameters (B,R, Doppler factor).

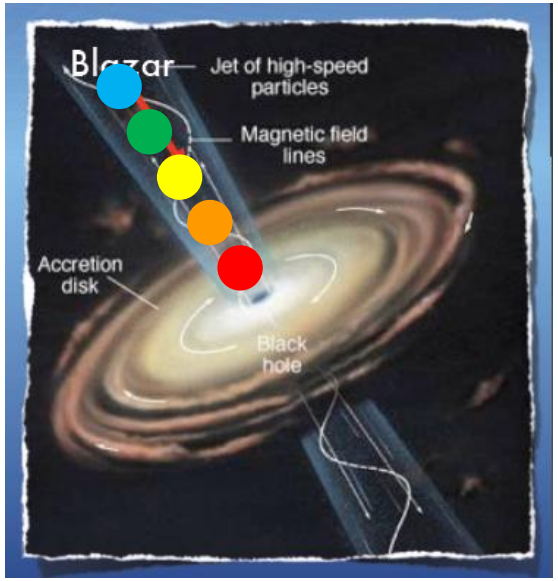


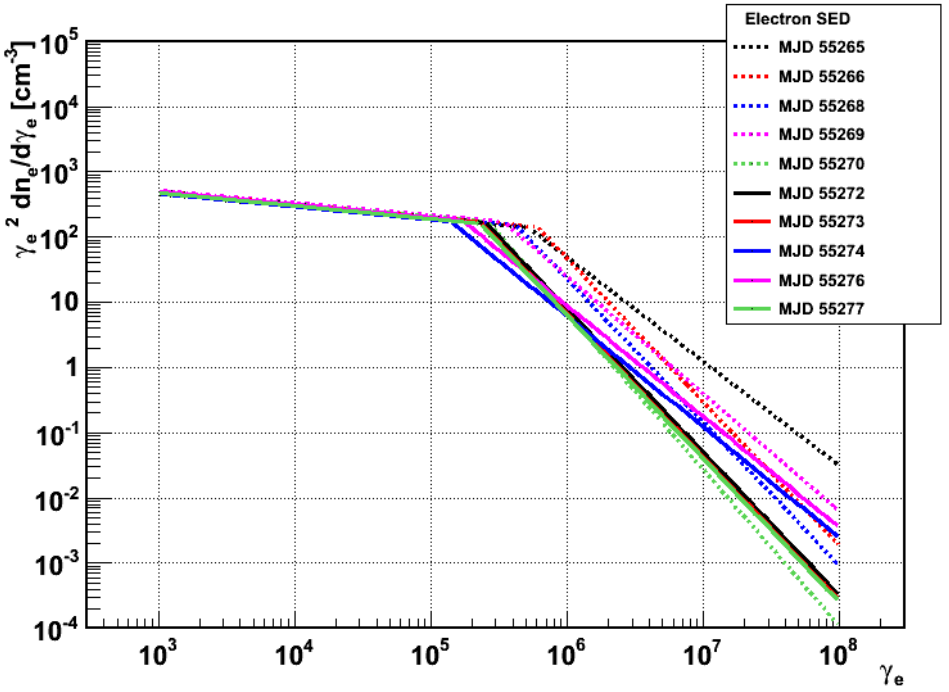
Fixed Parameters

γ_{min}	1.e3.
γ_{max}	1.e8.
B[mG]	35.
log(R[cm])	16.7
δ	18.

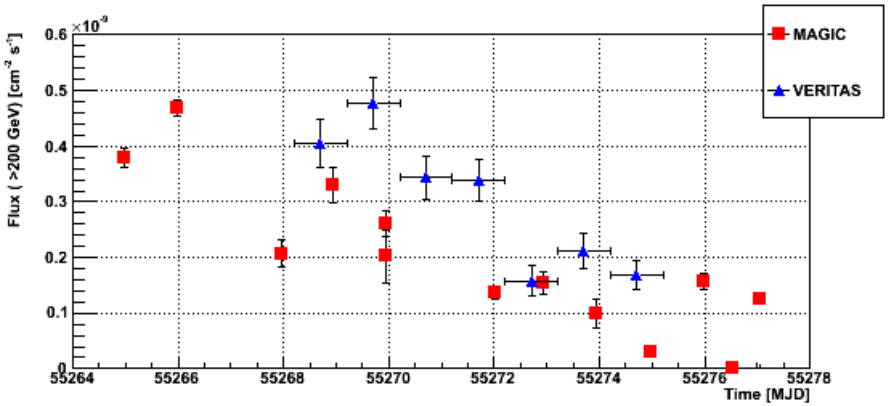
Conclusion

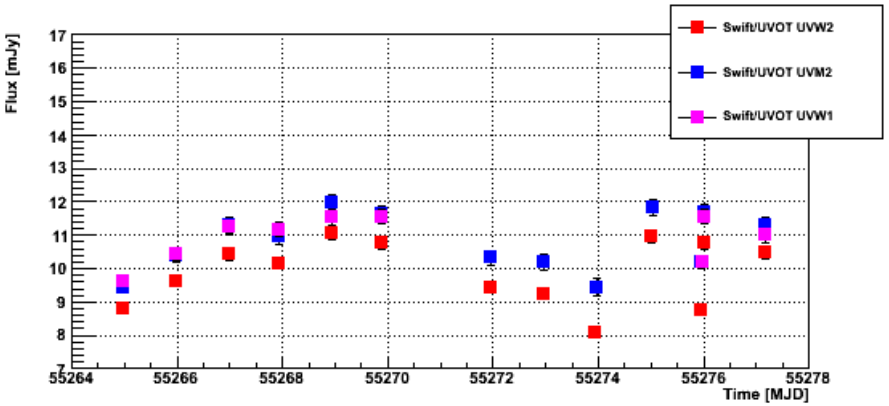
We found that the Mrk 421 flaring activity in 2010 could be explained within a one-zone Synchrotron Self-Compton Emission Model by only changing the shape of electron energy distribution

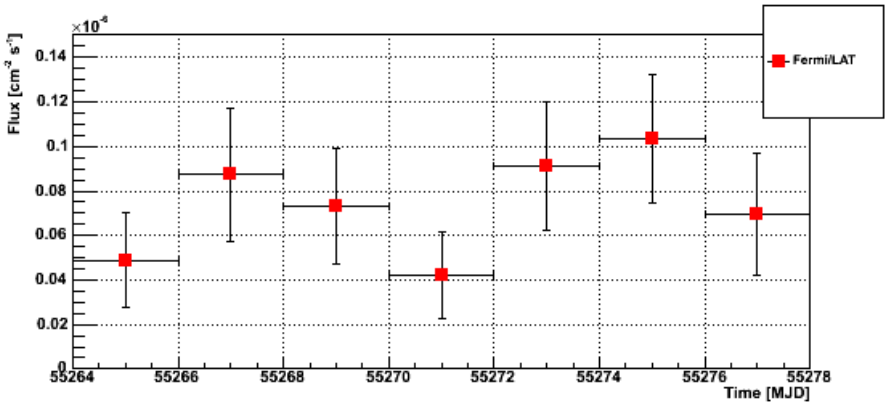


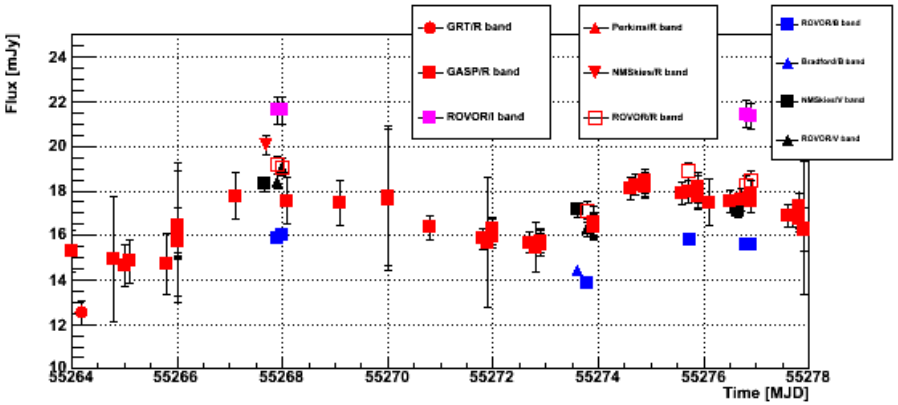


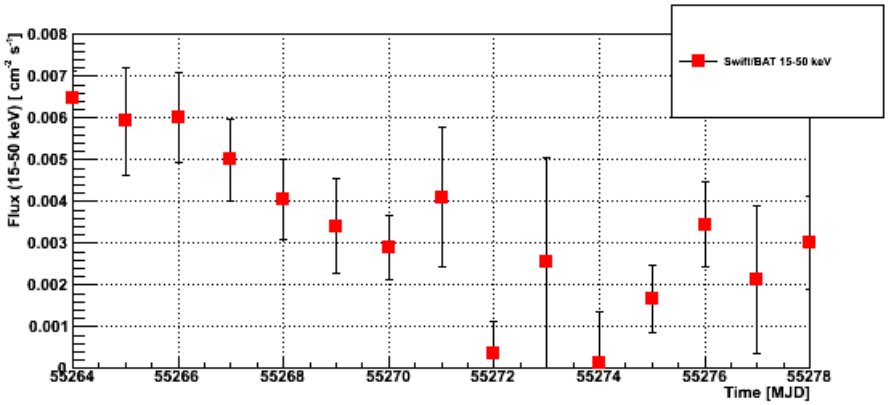
Backup Slides

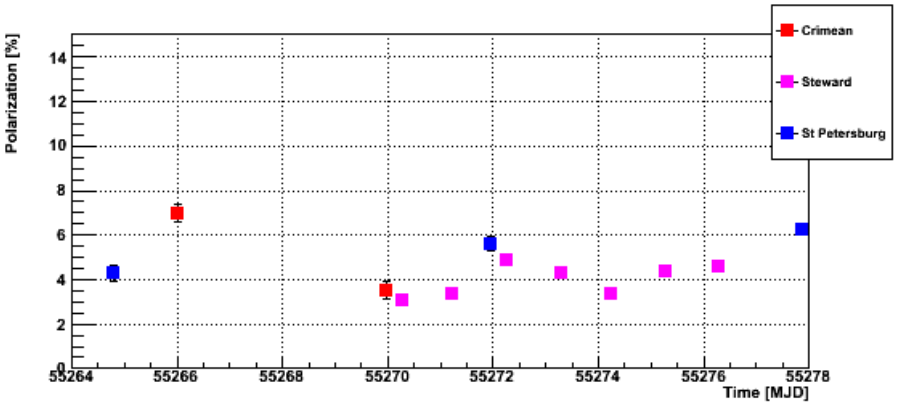

MAGIC
VERITAS
Flux (>200 GeV) [cm^{-2} s^{-1}]
Time [MJD]

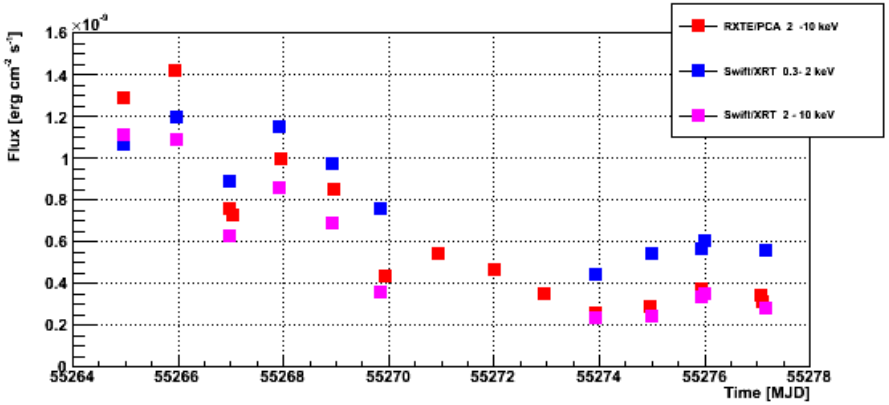

Swift/UVOT UVW2
Swift/UVOT UVM2
Swift/UVOT UVW1
Flux [mJy]
Time [MJD]

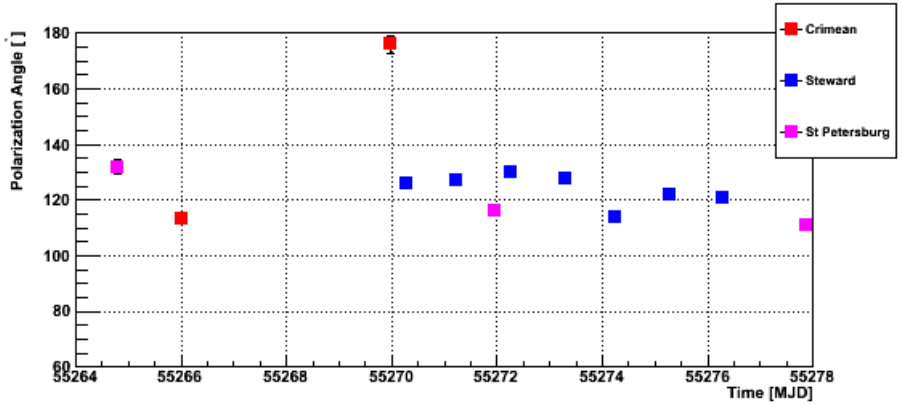

Fermi/LAT
Flux [cm^{-2} s^{-1}]
Time [MJD]

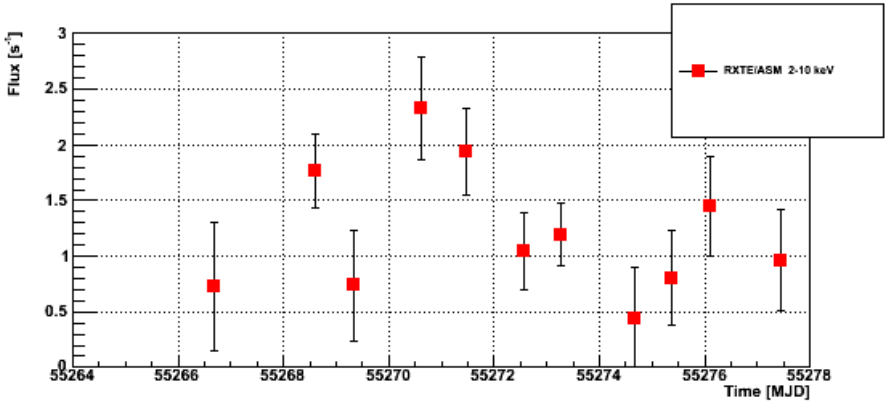

GRT/R band
GASP/R band
ROVOR/I band
Perkins/R band
NMSkies/R band
ROVOR/R band
Flux [mJy]
Time [MJD]

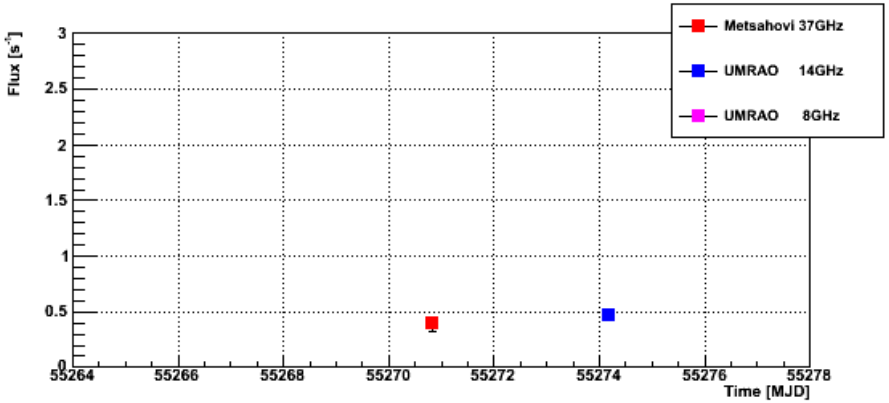

Swift/BAT 15-50 keV
Flux (15-50 keV) [cm^{-2} s^{-1}]
Time [MJD]

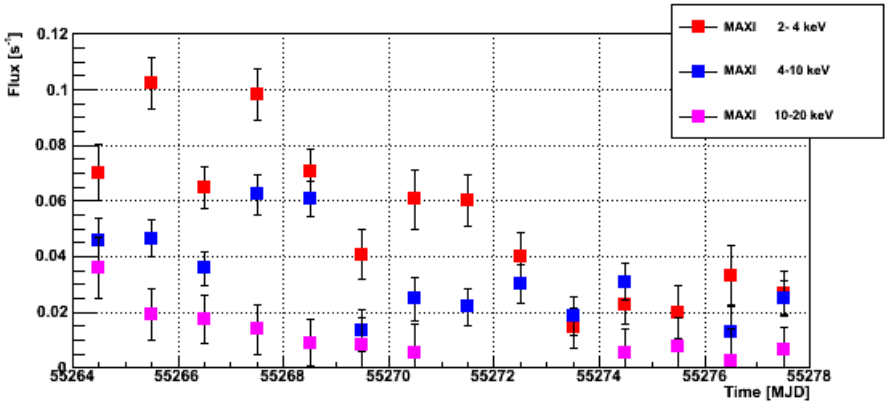

Crimean
Steward
St Petersburg
Polarization [%]
Time [MJD]


RXTE/PCA 2 -10 keV
Swift/XRT 0.3- 2 keV
Swift/XRT 2 - 10 keV
Flux [erg cm^{-2} s^{-1}]
Time [MJD]


Crimean
Steward
St Petersburg
Polarization Angle [°]
Time [MJD]

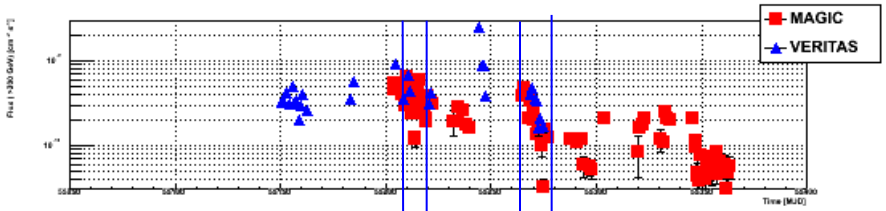

RXTE/ASM 2-10 keV
Flux [s^{-1}]
Time [MJD]

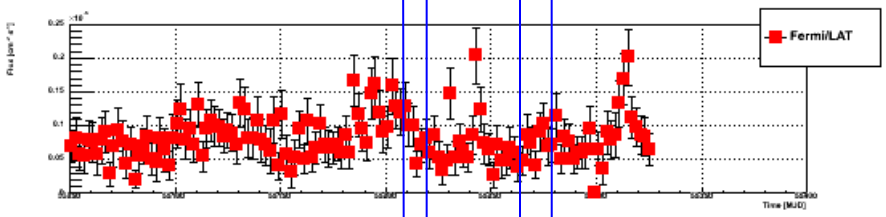

Metsahovi 37GHz
UMRAO 14GHz
UMRAO 8GHz
Flux [s^{-1}]
Time [MJD]

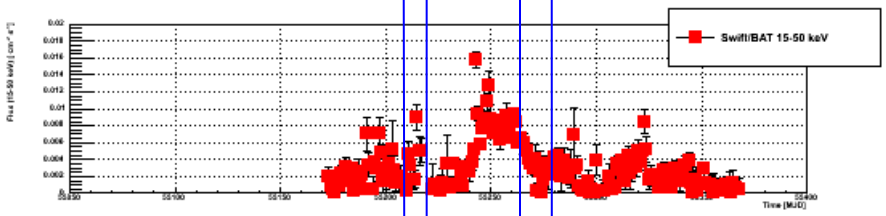

MAXI 2- 4 keV
MAXI 4-10 keV
MAXI 10-20 keV
Flux [s^{-1}]
Time [MJD]

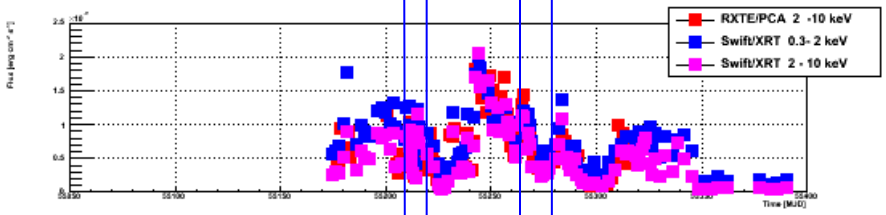
- The GLAST-AGILE Support Program (GASP) was organized within the Whole Earth Blazar Telescope (WEBT: 43 radio to optical)to provide optical-to-radio long-term continuous monitoring of a list of selected gamma-ray-loud blazars during the operation of the AGILE and GLAST satellites.

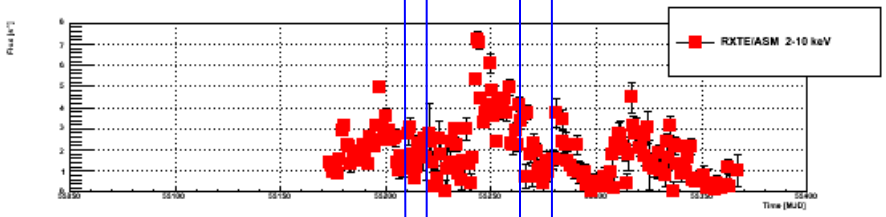
- **AGILE** (**Astro-rivelatore Gamma a Immagini LEggero**) is an X-ray and Gamma ray astronomical satellite of the Italian Space Agency (ASI).

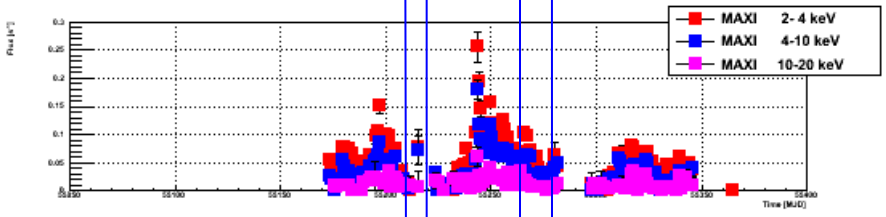


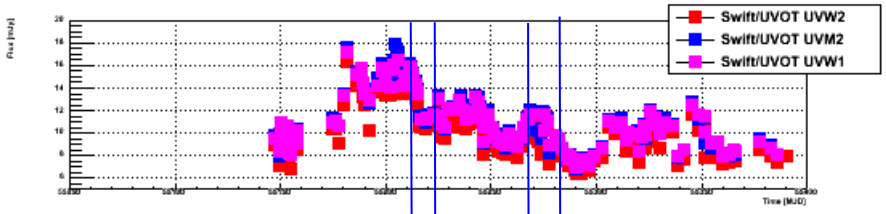


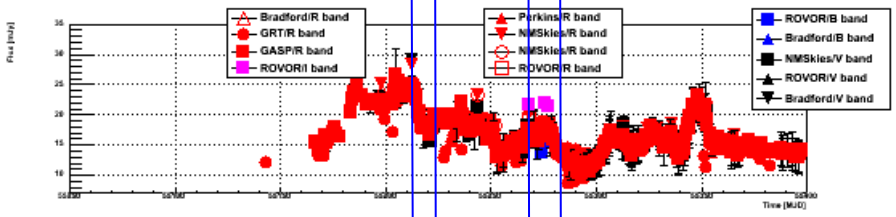


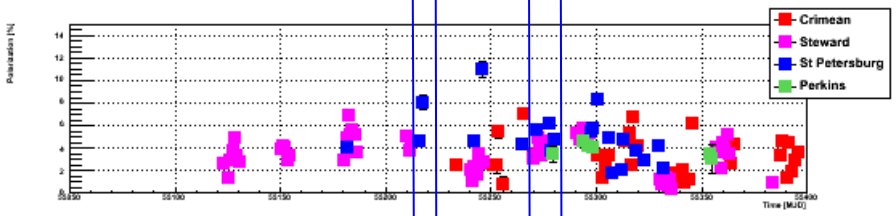


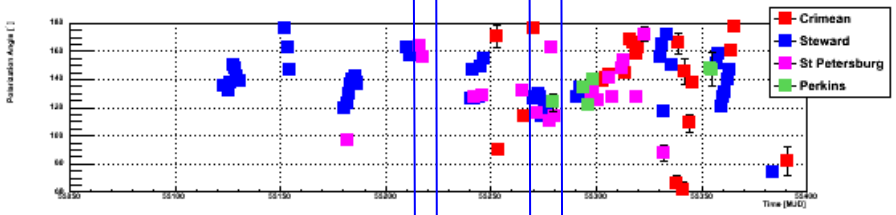


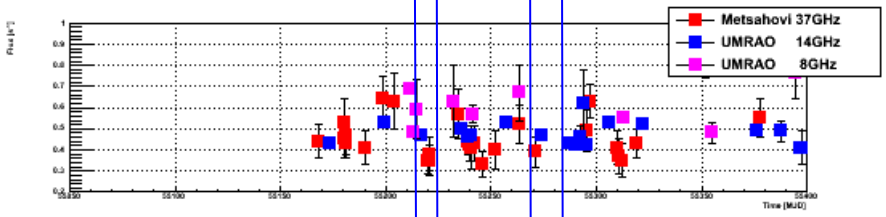










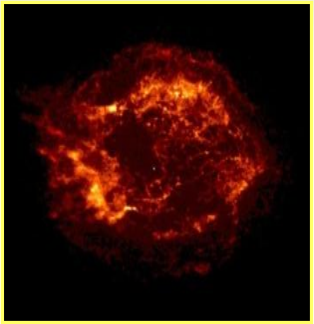


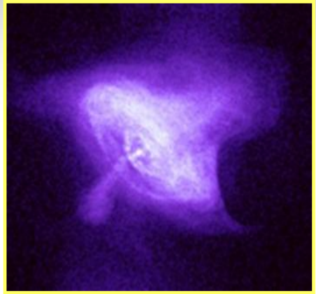
Mrk421 2010
MW light curves

TeV Sources

extragalactic sources

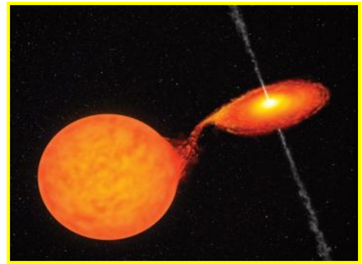
Supernova Remnant

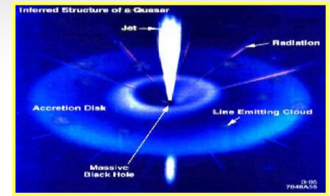




Pulsar
Pulsar Wind Nebula

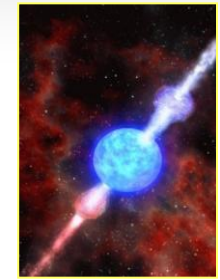
Micro quasar
X-ray binary





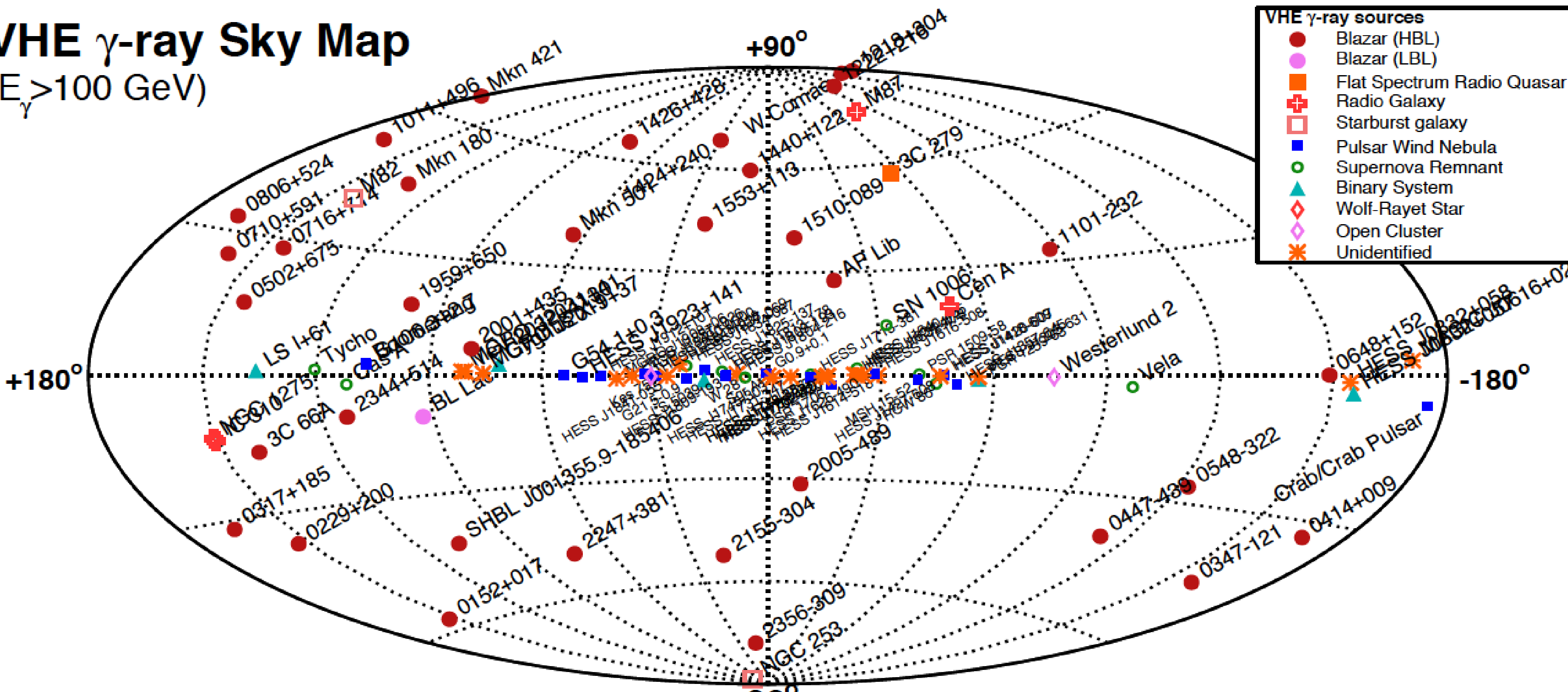
Active Galactic Nuclei

Gamma Ray Burst



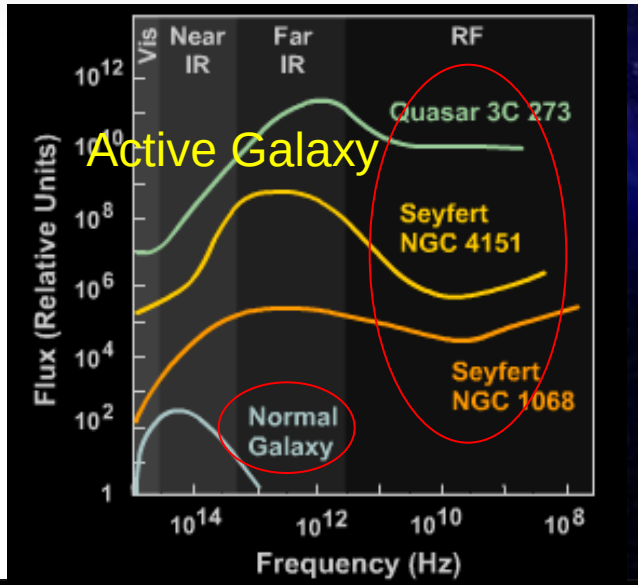
VHE γ-ray Sky Map

(E_γ>100 GeV)

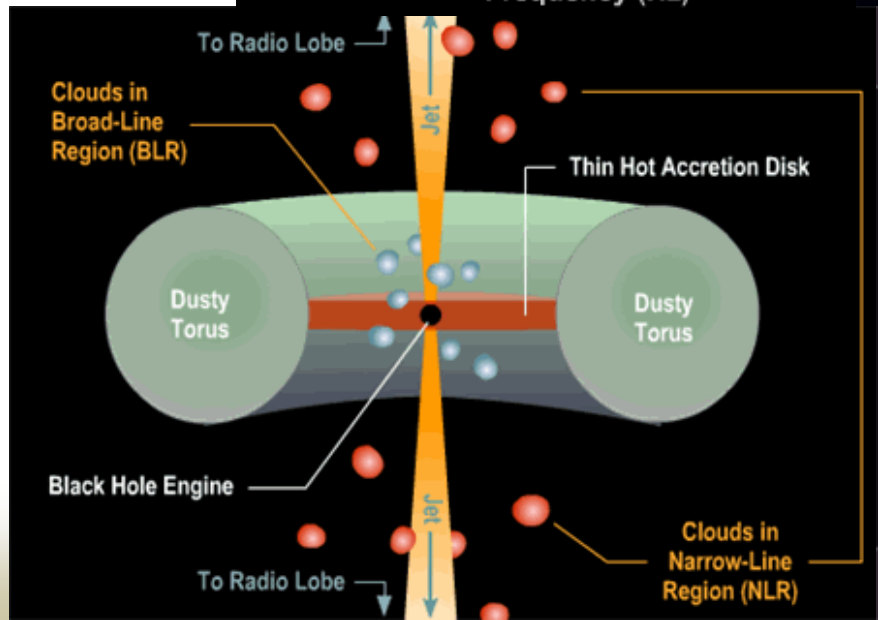


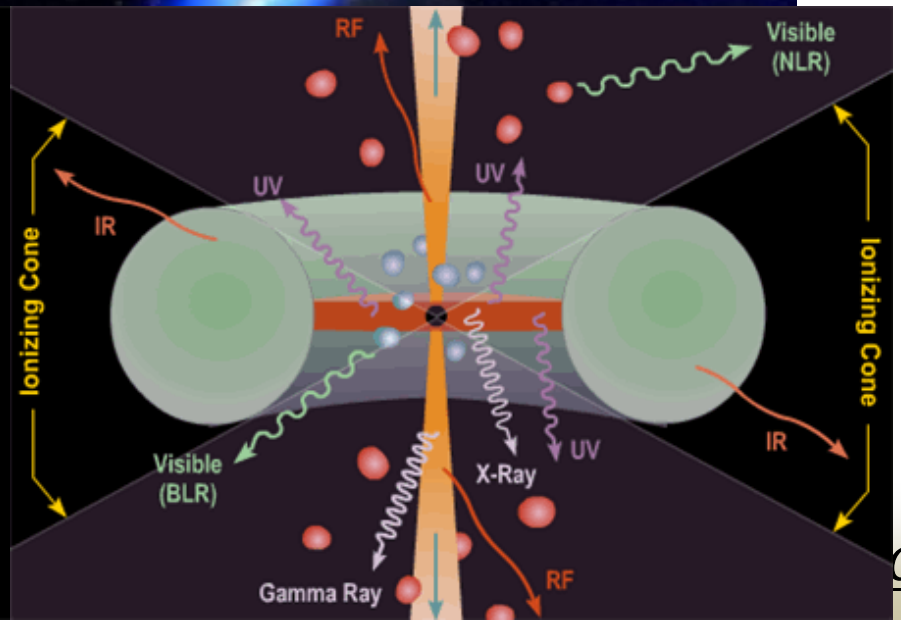
2010-11-11 - Up-to-date plot available at http://www.mpp.mpg.de/~rwagner/sources/

Active Galactic Nuclei(AGN) of Active Galaxies



Credits from Brooks/Cole Thomson Learning





TeV Extragalactic Sources

Credits from R. Wagner

Name	redshift	reference
NGC 253	3.3 Mpc	Aharonian, et al., Science Express (09/2009)
Centaurus A	3.8 Mpc	Raue et al., arXiv0904.2654 (2009)
M 82	4.0 Mpc	Benbow et al., proc of ICRC (2009)
M 87	16.7 Mpc	Aharonian et al., A&A, 403, L1 (2003)
3C66B(?)	0.022	Aliu et al., ApJ, 692, L29 (2009)
Markarian 421	0.030	Punch et al., Nature, 358, 477 (1992)
Markarian 501	0.034	Quinn et al., ApJ, 456, L83 (1996)
1ES 2344+514	0.044	Catanese et al., ApJ, 501, 616 (1998)
Markarian 180	0.045	Albert et al., astro-ph/0606630 (2006)
1ES 1959+650	0.047	Nishiyama et al., 29th ICRC, 3, 370 (1999)
PKS 548-322	0.067	Superina et al., Proc. Of ICRC (2007)
BL Lacertae	0.069	Albert et al., astro-ph/0703084 (2007)
PKS 2005-489	0.071	Aharonian et al., A&A, 436, L17 (2005)
W Comae	0.102	Swordy et al., ATel #1422 (2008)
PKS 2155-304	0.116	Chadwick et al., ApJ, 513, 161 (1999)
RGB J0710+591	0.125	Ong et al., Atel#1941 (2009)
H 1426+428	0.129	Horan et al., ApJ, 571, 753 (2002)
1ES 0806+524	0.138	Swordy et al., ATel #1415 (2008)
1ES 0229+200	0.139	Proc. Of ICRC 2007
PKS 1424+240	0.16(?)	Ong et al., Atel#2084 (2009)
H 2356-309	0.165	Aharonian et al., Nature, 440, 1018 (2006)
1ES 1218+304	0.182	Albert et al., ApJ, 642, L119 (2006)
1ES 1101-232	0.186	Aharonian et al., Nature, 440, 1018 (2006)
1ES 0347-121	0.188	Proc. Of ICRC 2007
RBS 0413	0.190	Ong et al., Atel#2272 (2009)
PKS 0447-439	0.200	Raue et al., Atel #2350 (2009)
1ES 1011+496	0.212	Albert et al., ApJ, 667, L21 (2007)
1ES 0414+009	0.287	Hofmann, Fegan, et al., Atel #2293 (2009)
1ES 0502+675	0.341	Ong et al., Atel#2301 (2009)
VER J0521+211	???	Ong et al., Atel#2260 (2009)
PG 1553+113	>0.09?	Aharonian et al., A&A, 448, L19 (2006)
S50716+714	???	Teshima et al., Atel #1500 (2008)
3C 66A	>0.096	Swordy et al., ATel #1753 (2008)
3C 279	0.54	Errando et al., ArXiv preprint (2008)

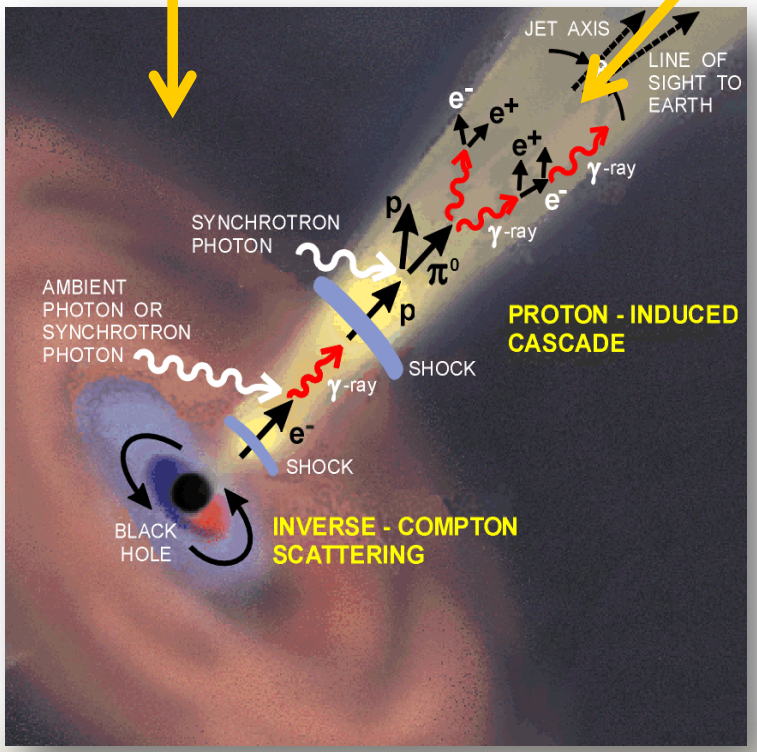
Star burst galaxies
Radio galaxies
Unclear
Blazars

46 TeV extragalacic sources

3 x FR-I,
2 x Starburst galaxies,
4 x FSRQs,
37 x BL Lacs

FRI, FRII (Radio Galaxies)

BL Lac, FSRQ (Blazars)



MAGIC

Summary

1. MAGIC in its first year(2010) of stereo observation on Mrk 421 caught three TeV flares: January (~3 Crab), March (~2 Crab)
   high state: TeV,GeV,X,Opt TeV,X

2. Mrk 421 2010 MW light curves:
   Variability of (TeV, GeV, X, Opt)~(1.1, 0.2, 0.75, 0.2)

3. MAGIC stereo had 10 observation on Mrk421 in March 2010, catching a decaying flare, with fluxes of 4 observations > 1 Crab, with simultaneous spectra from Optical, SWIFT/XRT*BAT, RXTE/ASM, Fermi, MAGIC .

4. 1-zone Synchrotron Self-Compton Emission Model can describe well Mrk 421 spectrum evolution. The physical properties which changes during decaying flare might be the intrinsic characteristics of electrons, rather than the environment parameters(B,R).