LHAASO对河外伽马源的实时监测与预警

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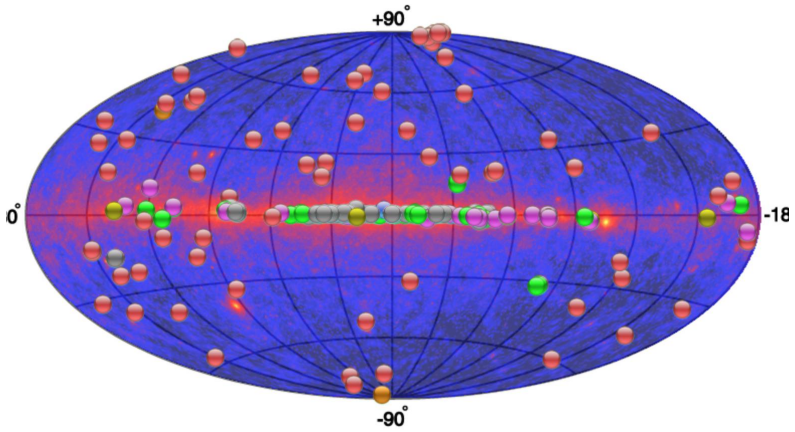
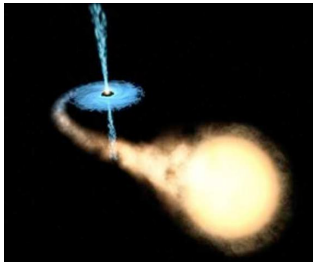
LHAASO合作组会议
15/08/16-18/08/16

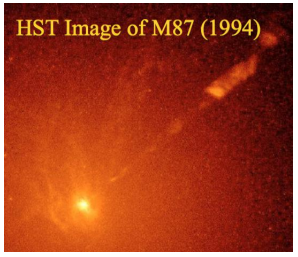
The VHE gamma-ray sky

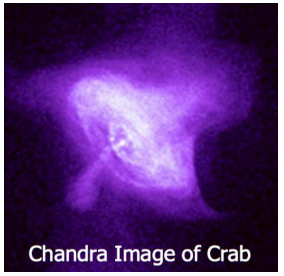
- Aug. 2016, 177 sources in TevCat;
- Flux range: 0.1% - 20 crab;
- Many different sources;
  - Active Galactic Nuclei
  - Pulsar wind Nebular
  - Supernova Remnants
  - x-ray Binaries,microquasar
  - Nearby Starbust, Galaxies, milky way
  - Molecular clouds
  - Galactic center
- 67 extragalactic VHE sources
  - 2 starburst galaxies:
    - M82 & NGC 253
  - 4 FR I radio galaxies:
    - M87, Cen A, NGC1275 & PKS 0625-35
  - 61 Blazars (with jets pointed us)

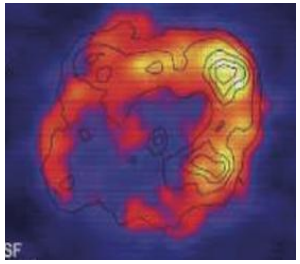
VHE r-ray sky map with Fermi-LAT sky map





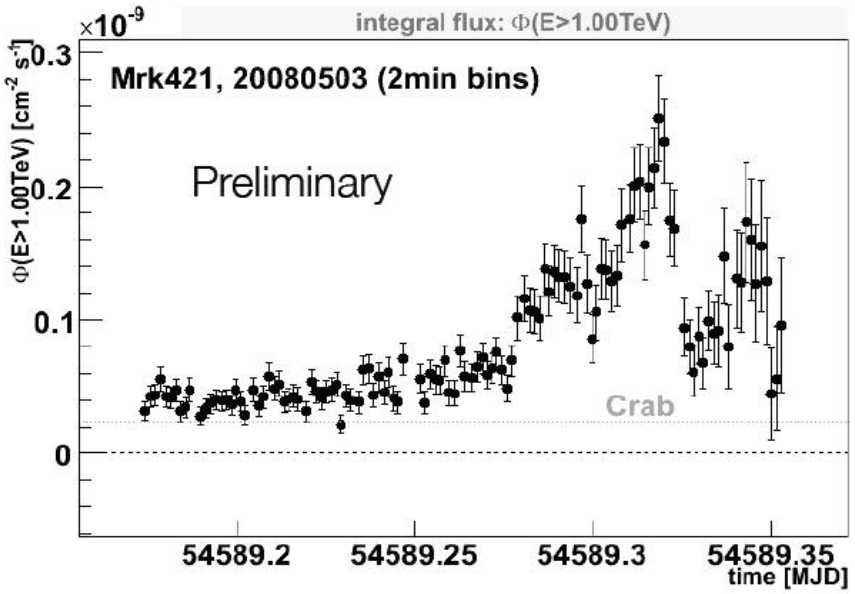


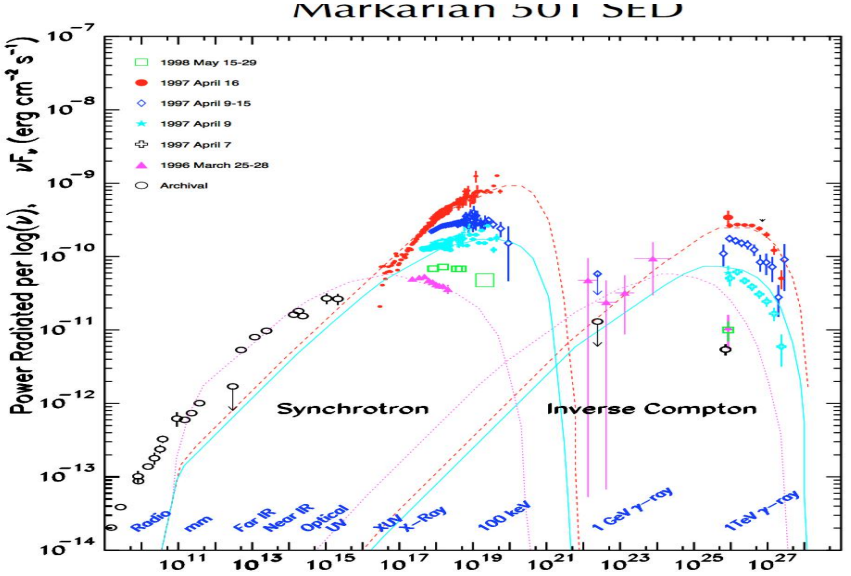




AGN source characteristics

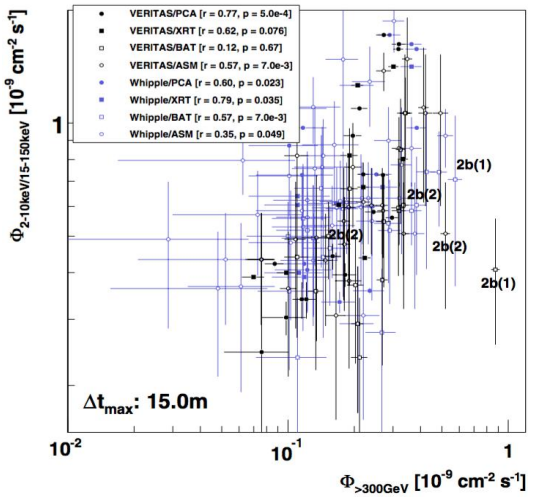
- Rapid variability
  - Time: from minutes,hours to month;
  - Flux: even tens times flux of Crab.
- SED: typicaly two-bump
  - radio – hard xray: synchrotron emission
  - High energy bump
    - Leptonic .vs. hadronic scenario
- Simultaneous variability of x-ray and TeV γ -rays supports SSC model and/or inverse compton with external photons



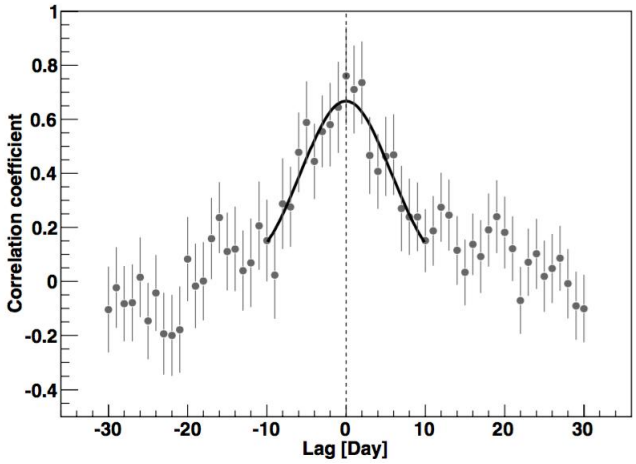


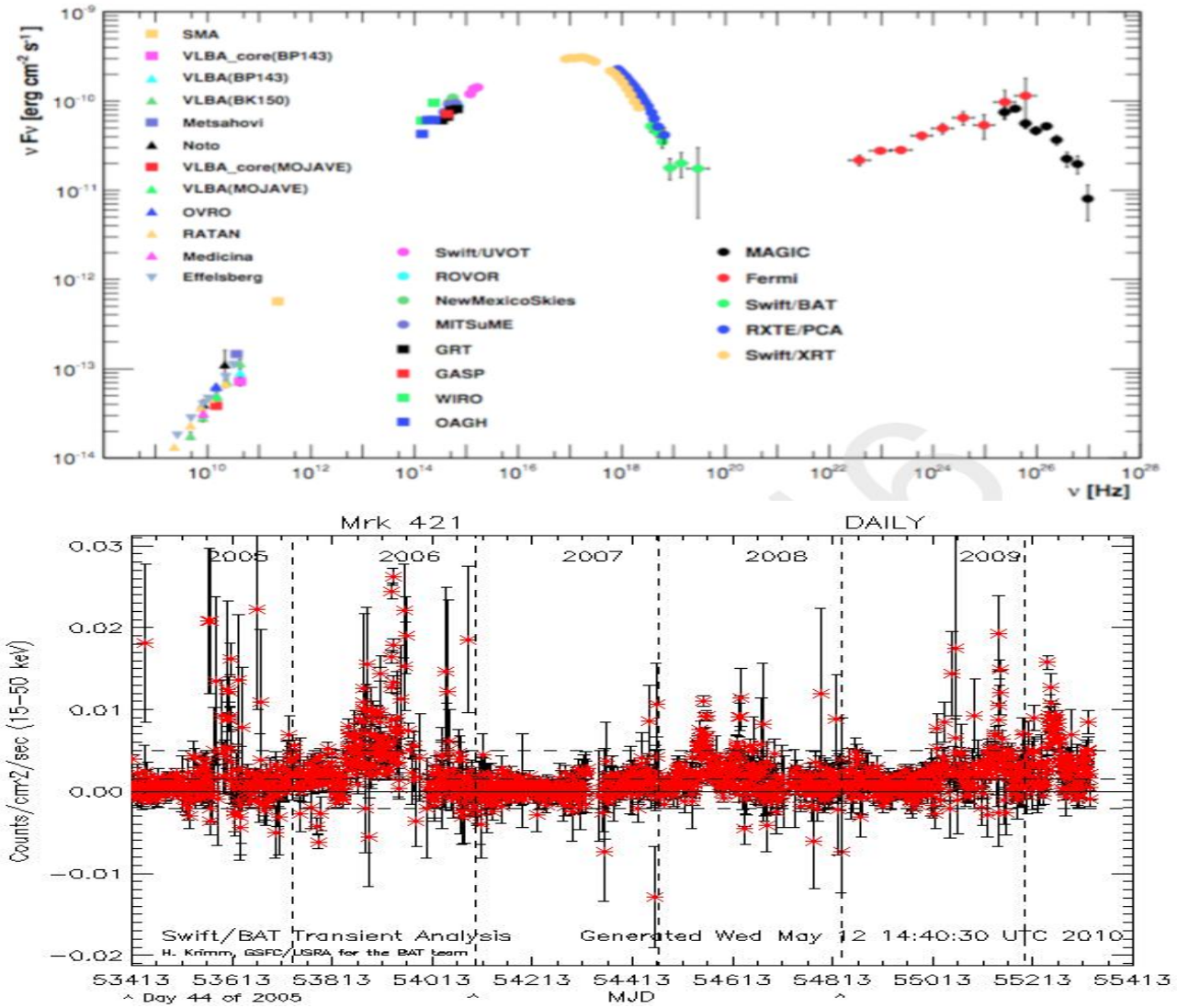
Physics from AGN alert and monitoring

- To collect many unbiased flare data;
- Flare alert can trigger multi-wavelength following-up observation;
- Correlation flares with other energy bands:
  - Correlations with x-rays, optical, radio, neutrinos to determine emission model;
  - Orphan flare search is a good probe for leptonic or hadronic emission model;
  - Role of external photon fields;
  - Intrinsic spectra vs. EBL-affected spectra
  - Extends TeV spectrum to high energies
- Cosmological feature from bright flare emission
  - Extragalactic background light
  - A good probe of exotic physics
    - To test Lorentz invariance violation;
    - ……



Acciari et al. 2011, ApJ, 738, 25

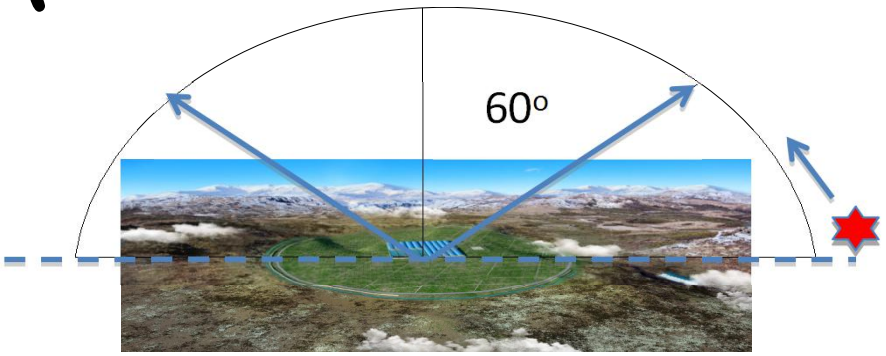


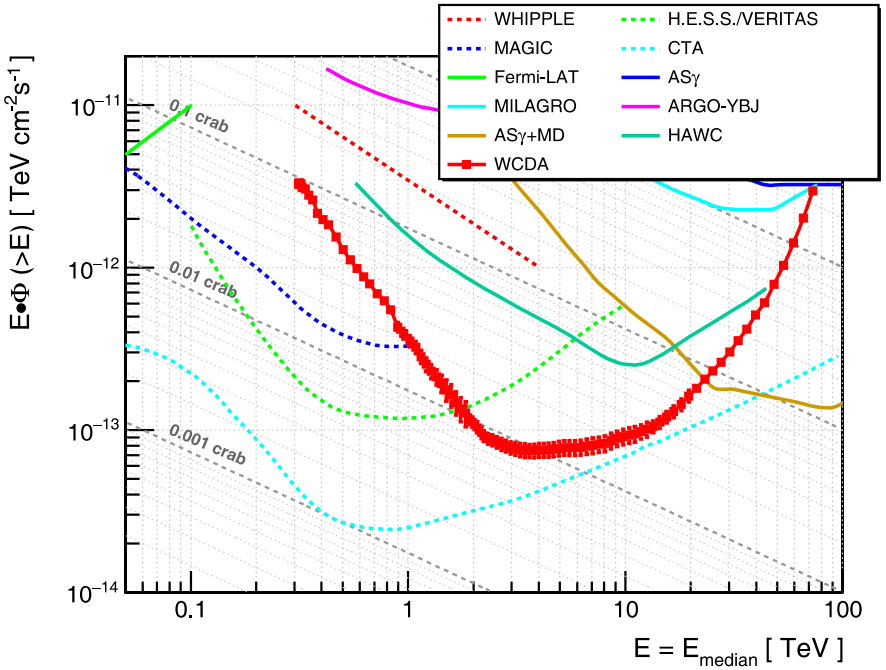


- 对高能耀变现象的监测、研究和预警的最佳的观测手段是具有较高灵敏度的能够24小时连续监测整个天空的大型地基的粒子探测器。
- 全景式的高精度的多波段能谱的演化行为AGN辐射研究可以提供重要线索。

LHAASO-WCDA

- IACT has limited duty cycle and usually only 1 source per observation dependent on sun, moon
- WCDA can monitoring over 2/3 sky for 6 hours per day regardless of sun, moon or weather
- WCDA can monitor most of the 60 known TeV emitting AGN and WCDA will rapidly notify multi-wavelength observation

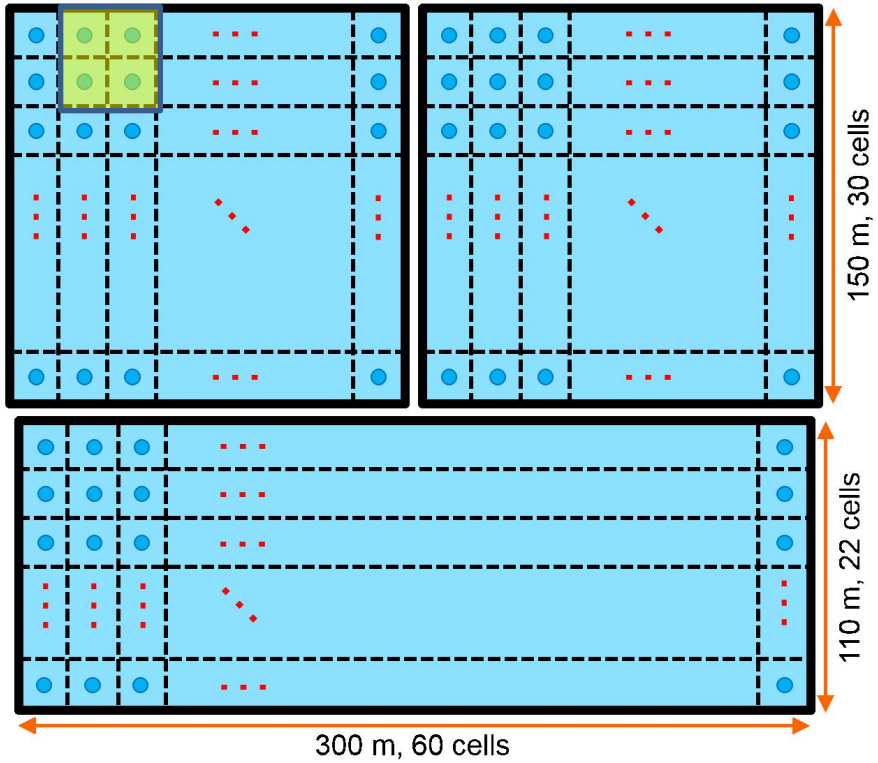


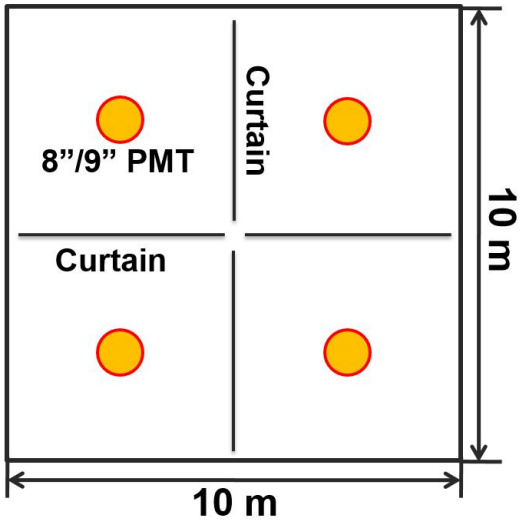


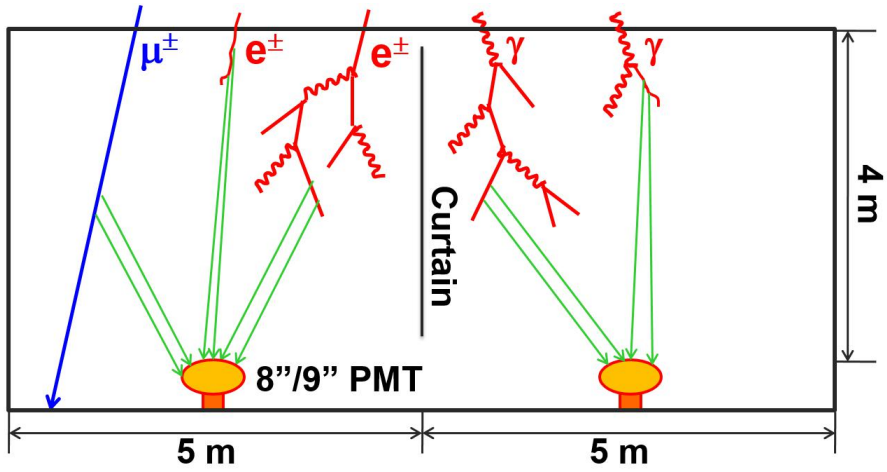
- WCDA @Haizi mountain;
  - long duty cycle;
  - large view field;
  - high altitude;
  - capable for observing flare;
  - complementary with IACTs;
  - WCDA's 5 sigma sensitivity is (5, 1, 0.1,0.04) Crab in (1h, 1d, 10d, 1M)

Cells of WCDA

- 3 water ponds:
  - 78,000 m^2 in total;
  - 4 m effective depth;
  - 3120 cells, with an 8"/9" PMT in each cell;
  - Cells are partitioned with black curtains.







Analysis chain

- 候选源的选定
  - HAWC: TeVCat + 2FGL blazar (z<1) +30 galactic TeV binaray candidates
  - @ARGO-YBJ: 40 objets
  - @WCDA: on-line /off-line
- 事例筛选和在线重建
  - 遍举法: 王晓洁报告
  - 速度的提高和优化: GPU
- 背景估计方法的研究
  - Surrounding/Equi-zenith/ Direct integration
- 时间、空间窗口的选取
- 预警的设置
- 实时搜寻结果的网页发布
- 超出结果的后续分析

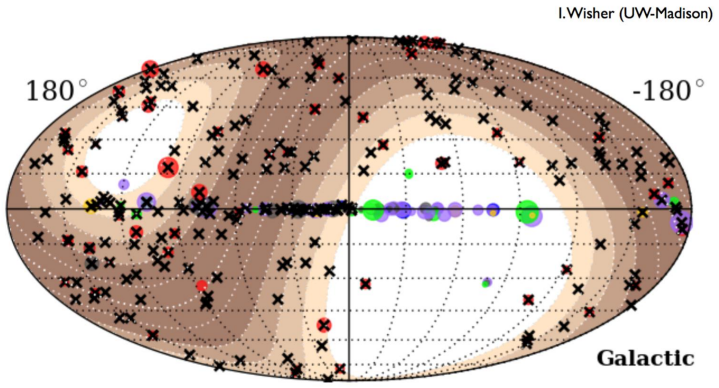


Table 1: List of selected candidates.

Nr.	Name	RA (degree)	DEC (degree)	E_{th} (GeV)	Flux($>E_{th}$) (crab)	index
0	Mrk 421	166.114	38.209	500	3.00×10^{-1}	-2.00
1	Mrk 501	253.468	39.760	300	6.60×10^{-2}	-2.20
2	1ES 2344+514	356.653	51.708	350	6.90×10^{-1}	-2.15
3	1ES 1959+650	299.995	65.151	600	2.00×10^{0}	N/A
5	1H 1426+428	217.136	42.672	280	1.40×10^{-1}	-3.55
6	M87	187.706	12.391	880	4.00×10^{-2}	N/A
8	1ES 1218+304	185.341	30.177	250	4.80×10^{-1}	-3.00
10	1ES 1101-232	165.907	-23.492	160	2.20×10^{-2}	-2.88
11	PG 1553+113	238.929	11.190	200	2.00×10^{-2}	-4.00
12	Mrk 180	174.110	70.158	200	2.50×10^{-2}	-3.60
14	BL Lacertae	330.680	42.278	200	2.50×10^{-2}	-3.60
15	1ES 0229+200	38.203	20.288	580	2.20×10^{-2}	-2.50
16	1ES 0347-121	57.347	-11.991	250	2.00×10^{-2}	-3.10
17	1ES 1011+496	153.767	49.434	200	6.70×10^{-2}	-4.00
18	3C 279	194.047	-5.789	100	7.07×10^{-1}	-4.10
19	RGB J0152+017	28.165	1.788	300	2.20×10^{-2}	-2.95
20	1ES 0806+524	122.455	52.316	300	1.80×10^{-2}	-3.60
21	W Comae	185.382	28.233	200	8.40×10^{-2}	-3.81
22	S5 0716+71	110.473	71.343	400	1.30×10^{-1}	N/A
23	3C 66A	35.665	43.036	200	5.50×10^{-2}	-4.10
26	RGB J0710+591	107.625	59.139	300	1.60×10^{-2}	N/A
27	PKS 1424+240	216.752	23.800	200	2.00×10^{-2}	N/A
28	NGC 253	11.890	-25.288	220	3.00×10^{-3}	-2.20
29	M82	148.843	69.661	700	1.20×10^{-2}	-2.60
30	VER J0521+211	80.480	21.190	200	5.00×10^{-2}	N/A
31	RBS 0413	49.966	18.759	200	2.00×10^{-2}	N/A
32	1ES 0414+009	64.218	1.090	200	5.00×10^{-3}	N/A
33	1ES 0502+675	76.985	67.650	350	4.00×10^{-2}	N/A
34	PKS 0447-439	72.353	43.836	N/A	N/A	N/A
35	PKS 1510-089	228.210	-8.900	N/A	N/A	N/A
36	RGB 0648+152	102.207	15.273	200	2.00×10^{-2}	N/A
37	IC 310	49.179	41.325	300	2.50×10^{-2}	N/A
38	VHE L3+C	172.530	-1.190	36	4.86×10^{5}	-6.31
39	Crab	83.633	22.014	200	1.00×10^{0}	-2.62

CPU、GPU计算时间对比计算速度对比

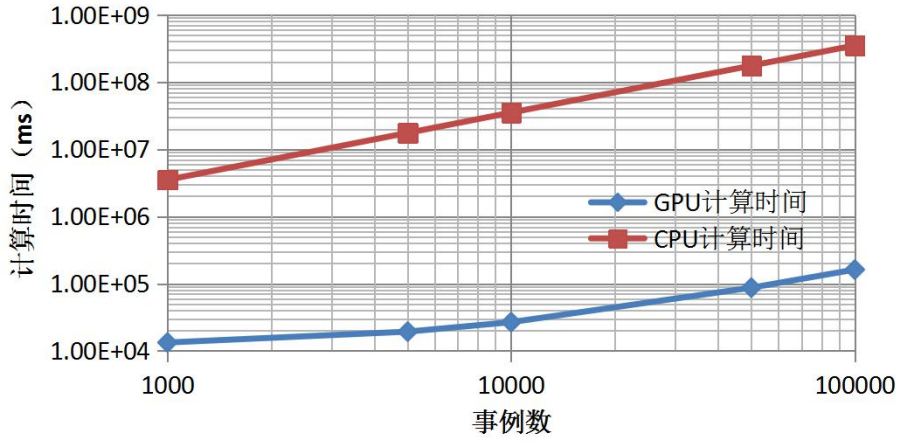
国台：张建立

- MC event
- Proton 5TeV +382hits Zenith=30deg + Azimuth=80deg
- 事例重复使用。

- 方法
  - 天区划分：
  - 天顶角：[0-75]，step 5deg，15bins
  - 方位角：[0-360]，step 5deg ， 72bins
  - 逐个格子对事例pad着火时间排序

事例数	GPU@NAOC(ms)	CPU@IHEP(ms)	CPU@IHEP/Tmath
1000	13310	3.51E+06	2.52E+06
5000	19310	1.75E+07	1.26E+07
10000	26740	3.51E+07	2.52E+07
50000	87060	1.75e+08	1.26e+08
100000	161710	3.50e+08	2.52e+08

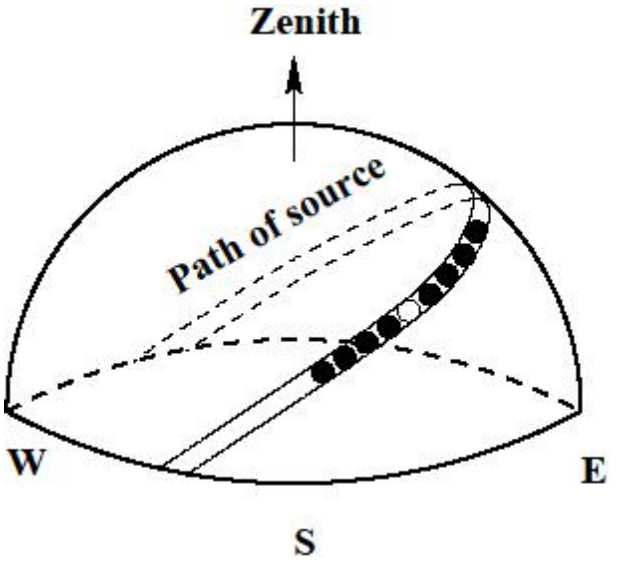
第2、3列GPU、CPU排序算法相同，
第4列与ROOT Tmath排序算法进行对照。



在目前**数据结构和程序框架下**，GPU加速显著

RA scan

- Source/background see identical sky region
- Symmetric background bins
  - averages out the effect of changes in event rate that is linear in time;
- Limitation
  - Stability of event rate: R(t) = constant !
  - Equal exposure is required to correct some interrupt changes by discarding data;
  - Less background bins retreve more time with increasing background uncertainty
  - Loss of significance;
  - Background region is limited, its statistics fluctuation will affect the background determination

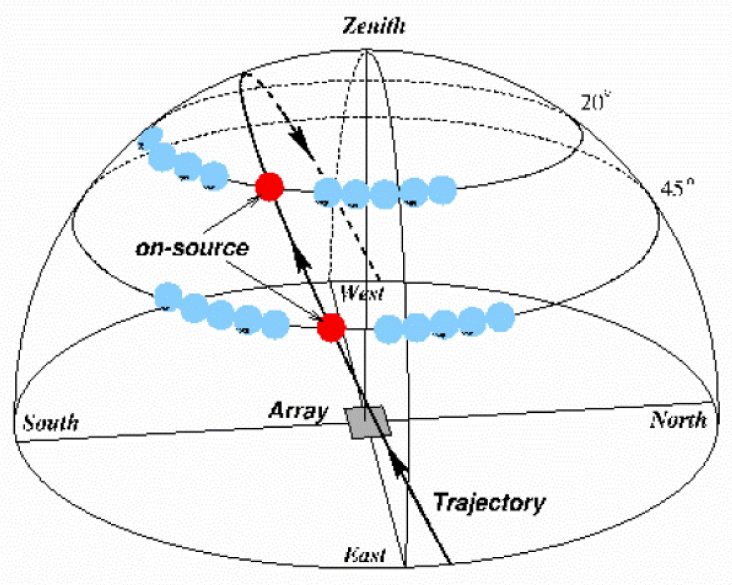


$$N_{BG} = \frac{\sum_{i=1}^{8} N_i^{OFF}}{8}$$

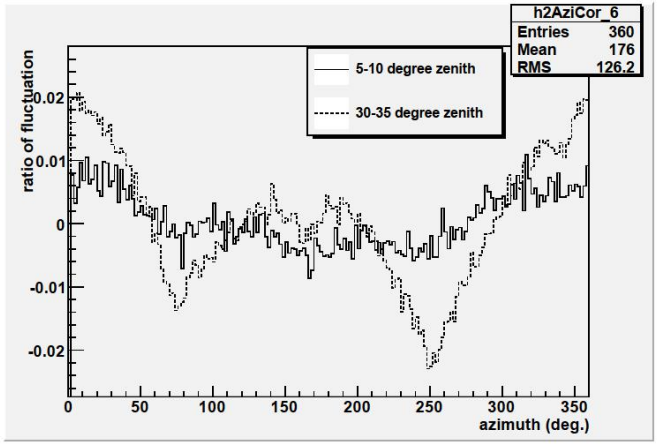
$$\alpha = \frac{1}{8}$$

Equi-zenith

- Simultaneously collected events in the same zenith angle belt can be used to estimate the background of a possible point source located in the same zenith angle.
- Free of zenith dependence;
- Minimize the detecting factors from detector and environmental variation
  - See Source/background at the same time;
  - Free from acceptance/ efficiency changes;
  - Free from Pressure and tempreture;
- Limitation:
  - Giving up small zenith angle data due to off windows
  - non-uniformity distribution for the azimuth angle
  - Hard to form a formula, it is from a experimental data

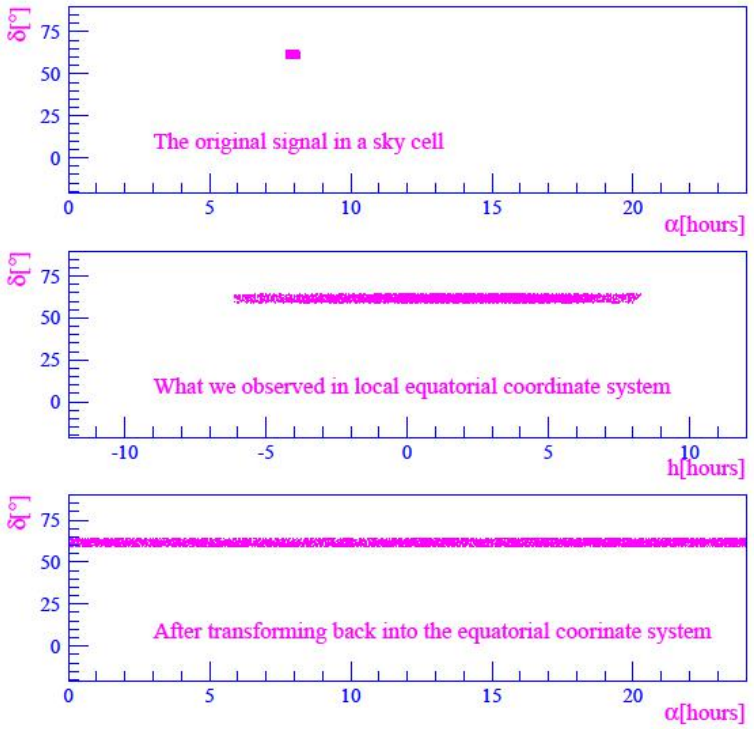


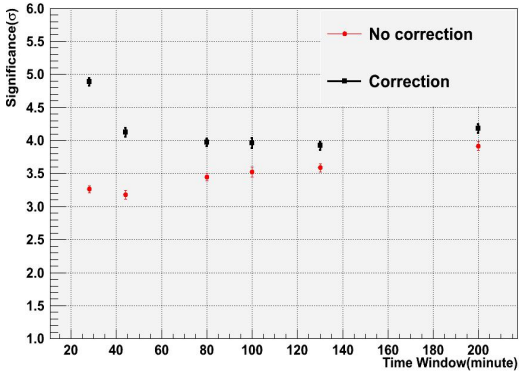
$$N_{BG} = \frac{\sum_{i=1}^{10} N_{OFF} i}{10}$$



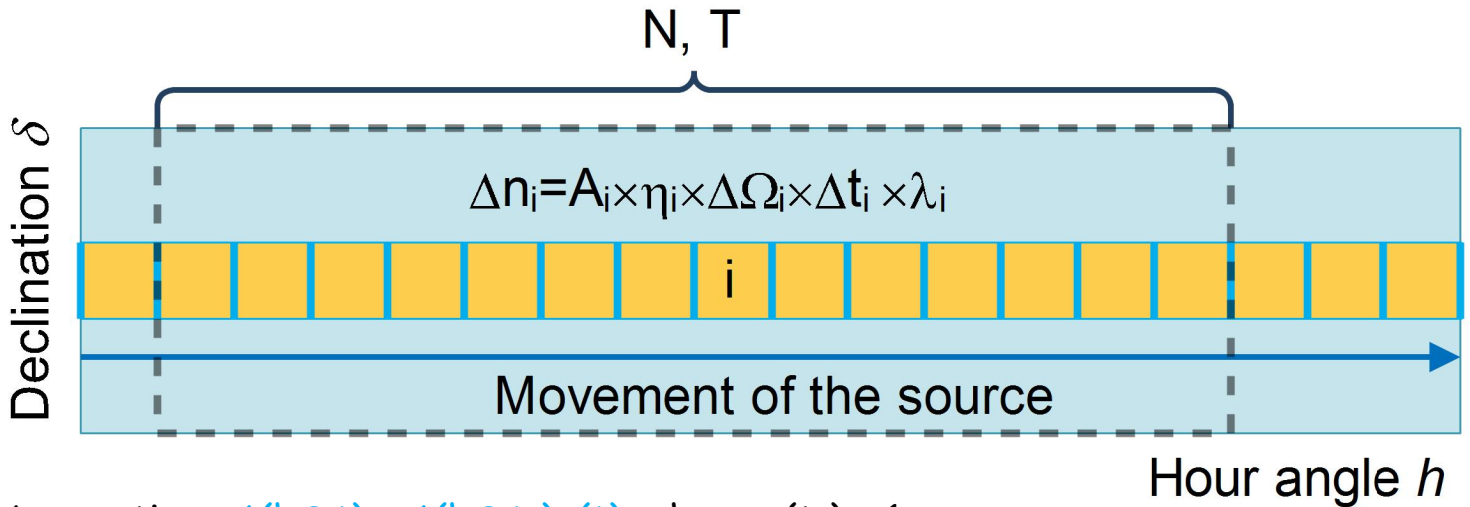
Time swapping

- implemenation
  - Effective acceptance map in local coordinate is tabulated within certain time period (T_w)
  - Artificial background events are created with the randomly combination of above map and arriving time within this time period;
- advatage
  - Keep most properties of background
  - Naturally compensate event rate variations including any length interruptions;
- limitation
  - Conservative result
  - Not applicable to the investigation of high declination sky.
  - Time-shuffling length?
  - Swapping times?
  - Possible correction?





Direct Integral

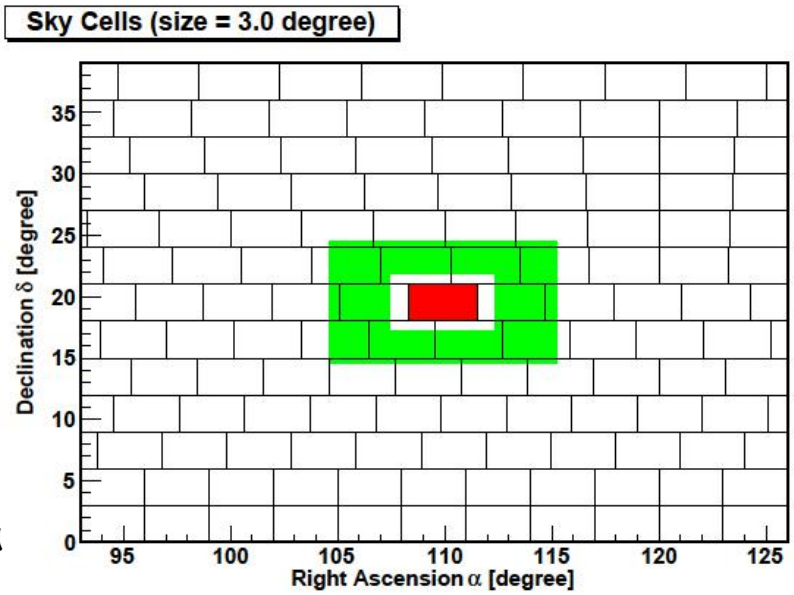


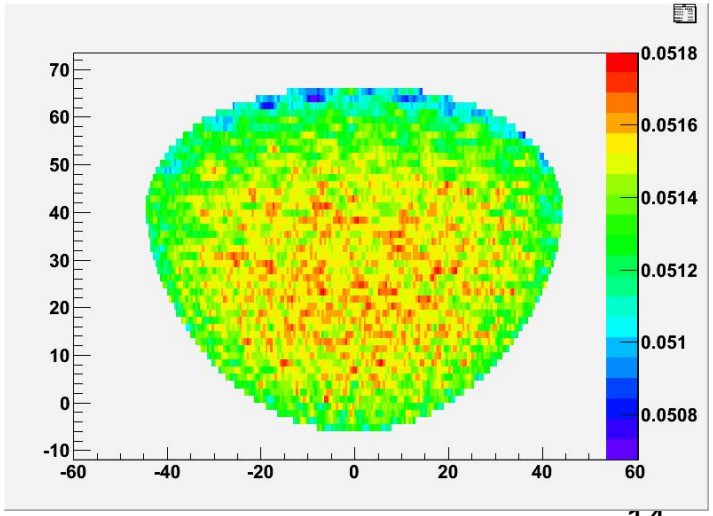
- Assumption: $A(h,\delta,t) = A(h,\delta,t_0)\eta(t)$, where $\eta(t_0) = 1$;
- Total *effective* live-time of a duration: $T = \Sigma_k \eta_k \lambda_k \Delta t_k$;
- Total number of events in a sky region during T: N;
- Number of background events when the source passing through cell i: Δn_i;
- $\eta_i \Delta t_i \lambda_i \approx [\Delta N(\Delta t_i)/N] \times T$; $A_i \Delta\Omega_i T \approx \Delta N_i(T)$; $N_B = \Sigma_i \Delta n_i \approx \Sigma_i [\Delta N(\Delta t_i)/N] \times \Delta N_i(T)$.

- The acceptance distribution in local equatorial coordinates for certain period is first established.
- For a particular period, the event distribution as a function of sidereal time is analyzed.
- The expected background distribution in equatorial coordinates for a given period, can be calculated by convolving the event distribution with the established acceptance distribution
- Time Integration period
  - As long as possible to minimize the statistics fluctuation;
  - Short enough to minimize the systematic errors
- Limitation
  - The final significance or upper limit of a signal is a little conservative
  - The change of the acceptance must be "isotropical";
  - Not applicable for the source near the North/South pole;

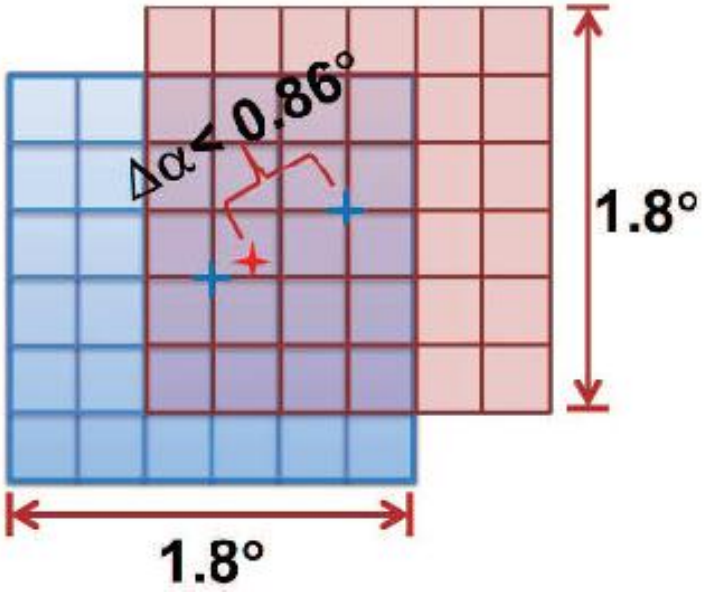
Surrounding window method

- Rectangular cells of equal solid angle
  - $\Delta\delta \times \Delta\alpha_i$
  - $\Delta\alpha_i = \Delta\delta / \cos\delta_I$
  - Every sky cell has a corresponding background region surrounding it;
  - Calibrate the acceptance ratio in the local equatorial coordinate system every hour angle bin (e.g. 0.5°), with a stable period's data;
- also 36 cells shift mode;
  - Shift on Dec. in 6 bins
  - Shift on RA. in 6 bins
    - 0/6, 1/6, 2/6, 3/6, 4/6, 5/6
  - S_{max} among the closest 36 cells

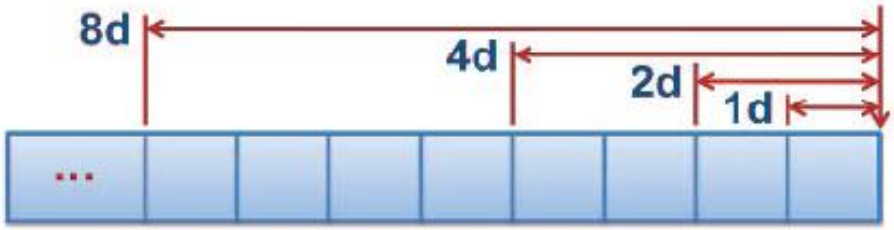




Shifting Sky Cells &Running Windows



- A same grid of sky cells are defined, sources may not exist in the center of any sky cell;
- 6×6 shifts with a step of 0.3°;

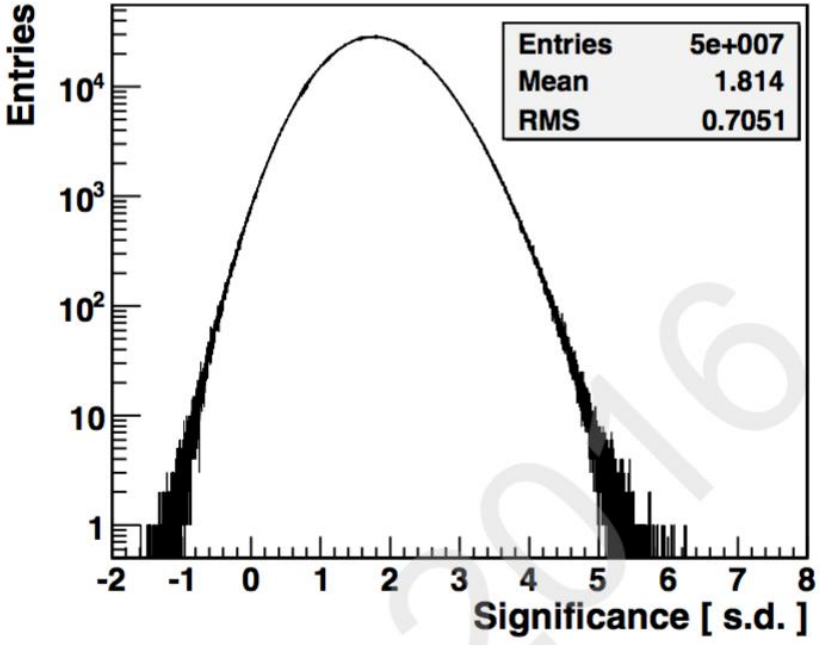


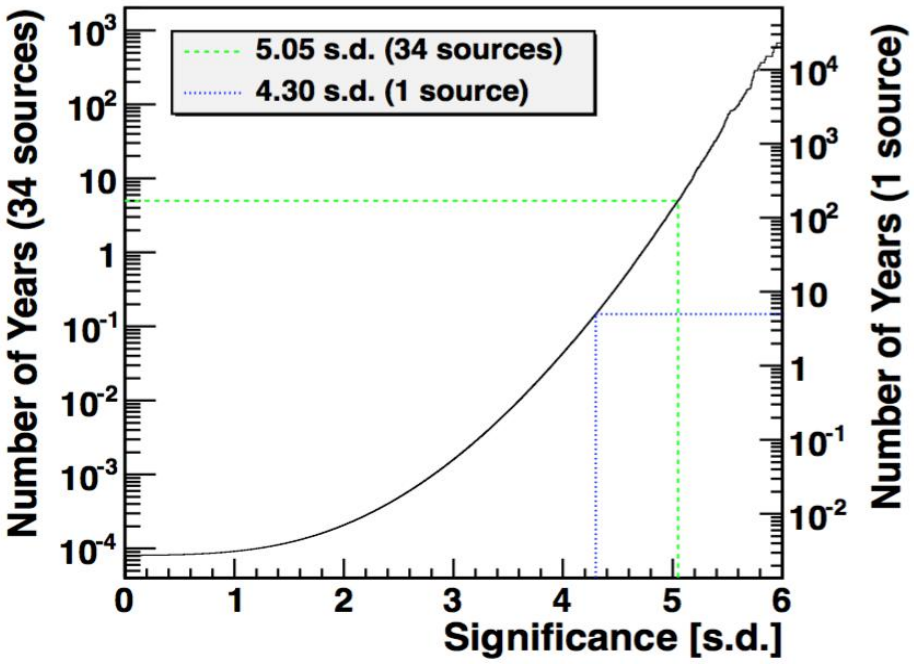
+ 1 h, 2 h, 4 h, 1 d ……

- When a source just left the field of view (zenith >60°):
  - Excesses of 1, 2, 4, 8 transits of this source are calculated.

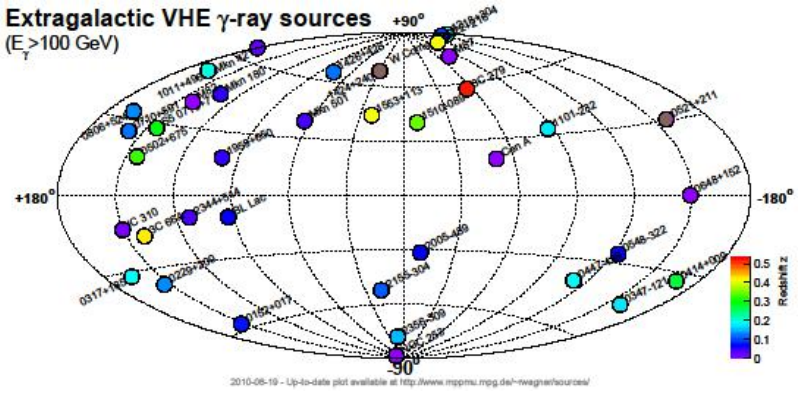
Alarm setting @ARGO-YBJ

- MC simulation techniques to sort out the correlated trials:
  - Distribution does not depends on statistics.
- Alarming thresholds for two scenario:
  - Once per 5 years for 34 sources: 5.05 s.d.
  - Once per 5 years for 1 single source: 4.30 s.d.





Real-time flare monitoring & alert @ARGO-YBJ



- 40候选源: 39 + Crab 候选源
- 数据的实时传输（10分钟）；
- 实时分析,Nhit>100,延迟<2小时；
- 邮件实时预警；
- 预警的设置
  - $S_{max} \geq 4.30$
- 运行于2010/01-2013/02。

Gmail by Google

Min Zha <zha.min@gmail.com>

20080402: Found an excess: 4.5004 (center 2.9824) s.d. from s000@d004

1 message

zham@ihep.ac.cn <zham@ihep.ac.cn> Thu, Feb 10, 2011 at 4:08 AM
To: min.zha@ihep.ac.cn, yao.chen@ihep.ac.cn, zhiguo.yao@ihep.ac.cn

Dear Colleagues,

Found an excess in nearby cells of Mkn_421!

I am happy to announce that we found an excess of 4.5004 s.d.
with Non = 31516 and Nb = 30698.735 from
the monitored source number 000 (Mkn_421: 166.1136, 38.2088)
in a total duration of 4 transits
(MJD 54555.46666 - 54558.90069, 2008/03/30 09:27 - 2008/04/02 21:23 UTC).

The center of this sky cell is 0.490 degree away from the source position.

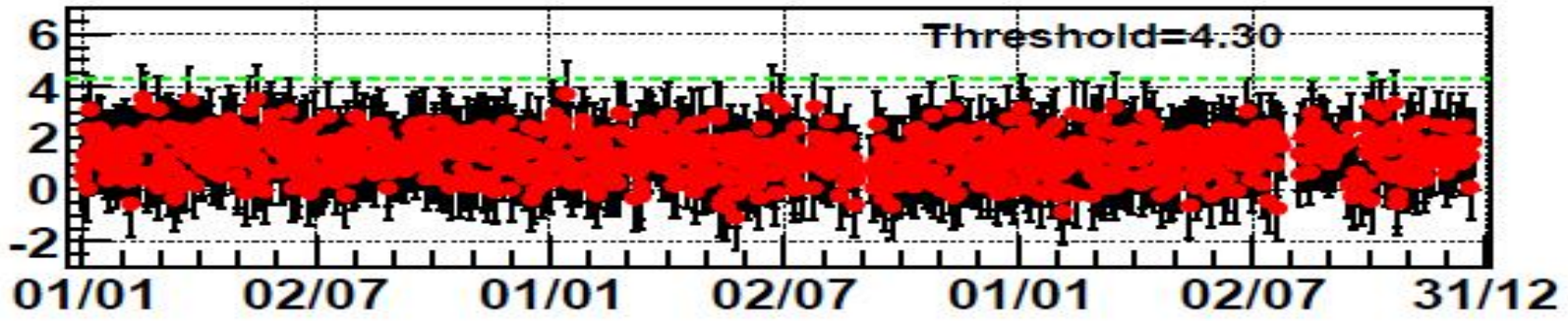
The significance of the center cell (0.150 degree away) is 2.9824 s.d.
with Non = 31416 and Nb = 30873.729.

The used data (362 files) are

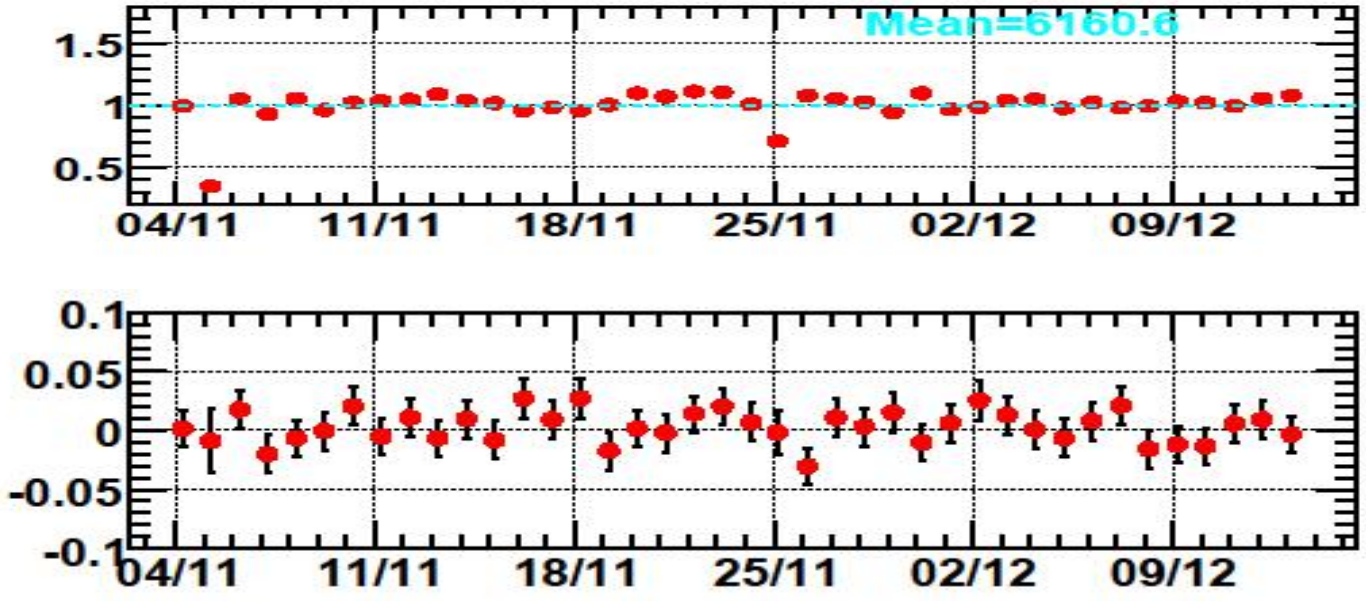
20080900927.015
..... (skipped)
20080932123.002

Note: Some runs may still be missing in this period, attributed to this specific fast alerting mechanism.

cheers,
Robot



Daily summary by sending email



Summary of Date 20100912 (MJD: 55451)

Date: 20100911, Source = 000 (Mkn_421: RA = 166.1136, DEC = 38.2088)

Ndays	MJD1	MJD2	Sigma	Non	Nb	Dis	Sigma_X	Non_X	Nb_X	Dis_X	N_N	Seq
001	55450.05069	55450.42500	-1.0150	2916	2972.898	0.150	0.7964	3020	2975.068	0.970	36	7
002	55449.02777	55450.42500	-1.2124	6071	6168.964	0.150	1.5964	6297	6167.193	0.970	75	8
004	55447.18263	55450.42500	0.1619	10311	10294.050	0.150	2.8015	10574	10279.508	0.970	134	2
008	55443.03472	55450.42500	-0.1137	13274	13287.519	0.150	2.0479	13590	13345.161	0.970	181	4
016	55435.05625	55450.42500	-0.4542	35153	35240.917	0.150	1.7732	35629	35284.790	0.970	510	6
032	55419.10277	55450.42500	-0.2258	89500	89569.701	0.150	1.4040	89470	89037.452	0.730	1260	5
064	55387.19097	55450.42500	-0.0132	220234	220240.396	0.150	1.4598	219476	218771.205	0.970	3090	3
128	55323.36597	55450.42500	0.7438	672310	671681.066	0.150	1.9771	673531	671858.458	0.510	8667	1

Date: 20100911, Source = 001 (Mkn_501: RA = 253.4674, DEC = 39.7604)

Ndays	MJD1	MJD2	Sigma	Non	Nb	Dis	Sigma_X	Non_X	Nb_X	Dis_X	N_N	Seq

Dear Colleagues,

I am happy to announce that we found an excess of 3.3449 s.d.
with Non=12140 and NB=11777.010 from 1ES_0347-121 (57.3468, -11.9909) in a total duration of 11.23403 days (269.61667 hours, MJD 55240.37152 - 55251.60555, 201002130820 - 201002241144).

The number of transits is 16, i.e. 16 sidereal days.

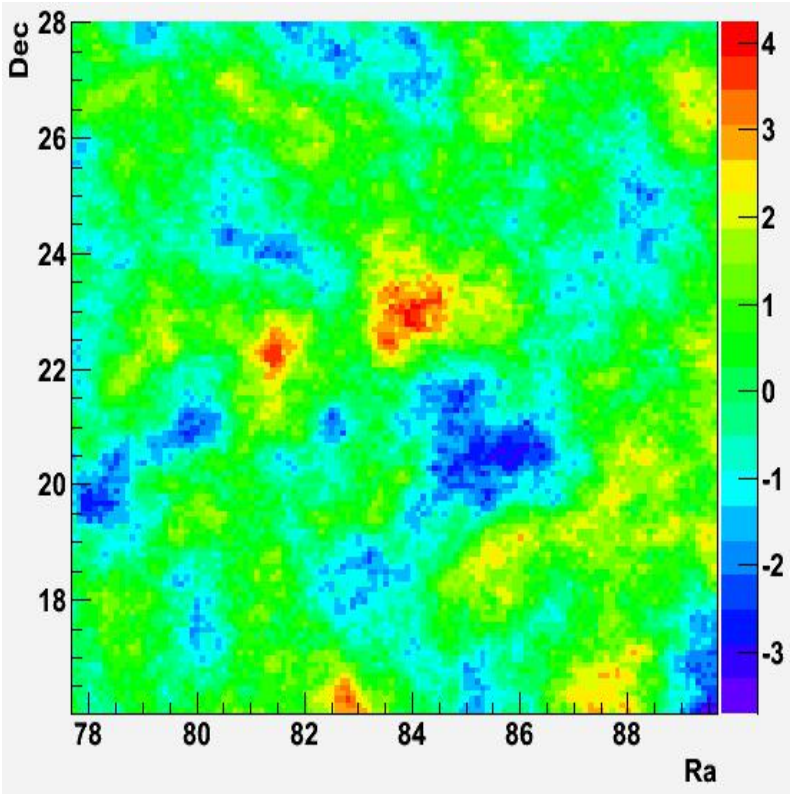
The data (669 files) we used are

20100440820.005
..... (skipped)
20100551144.023

Note: Some runs may still be missing in this period, attributed to this

Monitor result (Nhit>100)

- 3.8569 20101012_summary_sent.txt:20101012 004 039 Crab
- MJD 55478.73194__55481.99583
- 3.9054 20101013_summary_sent.txt:20101013 004 039 Crab
- MJD 55478.73194_55482.12222
- 4.0329 20101017_summary_sent.txt:20101017 008 039 Crab
- MJD 55478.73194_55486.10972



- No flares except MKN421 have been found;
- The biggest excess is 5.035 s.d. from M82.

Summary and outlook

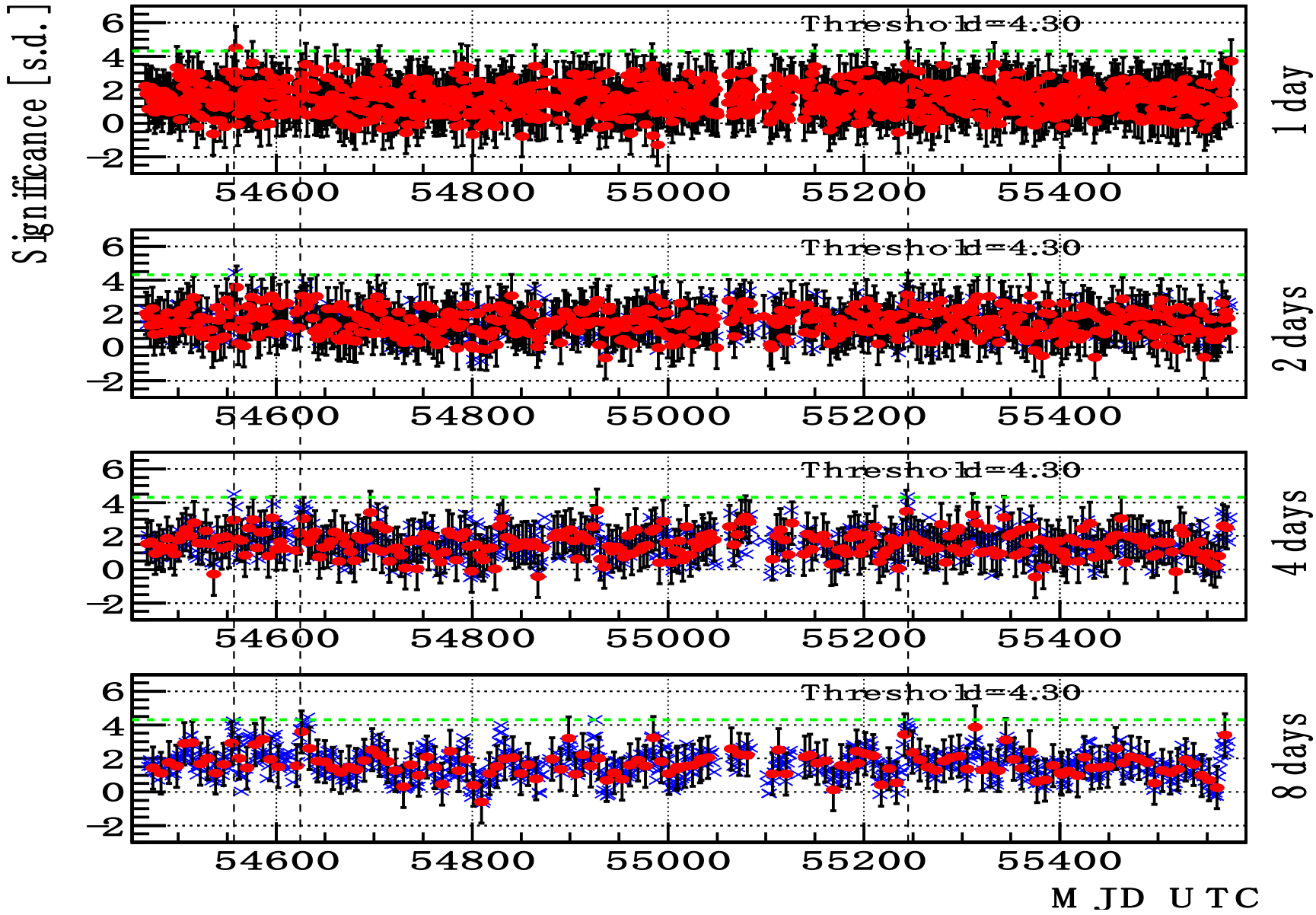
- LHAASO-WCDA实验将会提供足够多的耀变事件样本从而为深入、统计研究河源耀变现象奠定基础。

- 基于LHAASO-WCDA数据建立一套针对河外候选耀变源的在线监测、预警与分析系统。

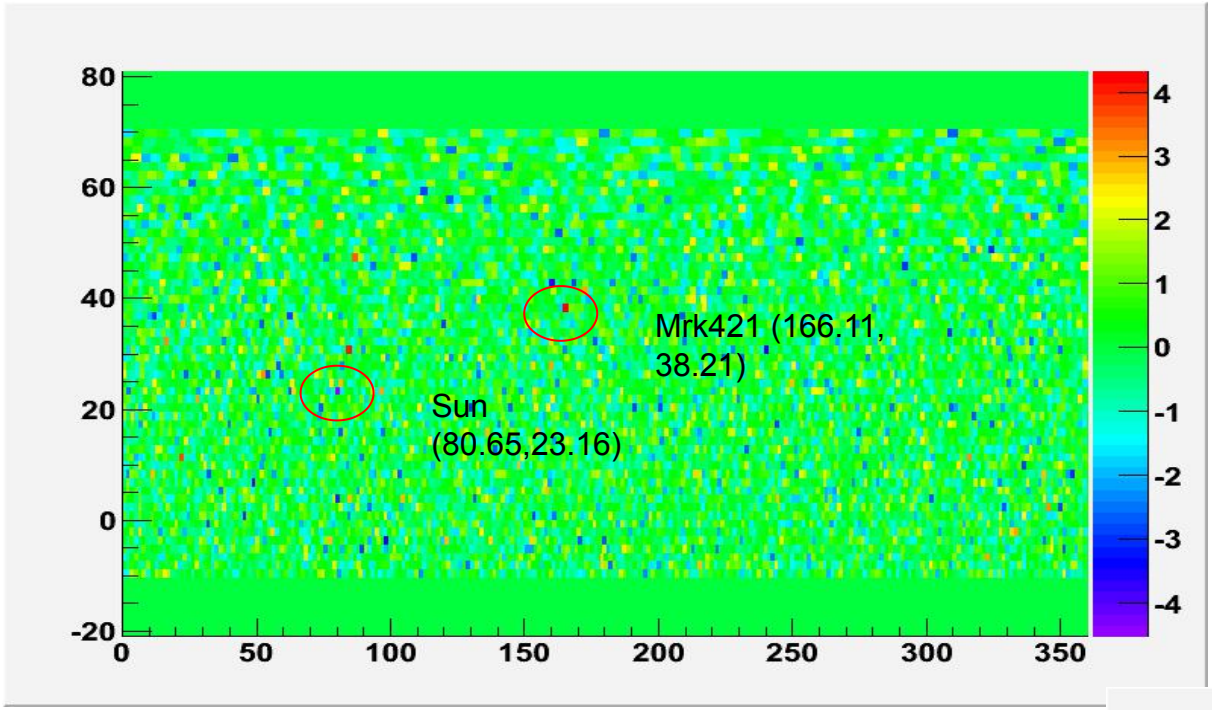
- 开展与其它能段的实验(如Fermi-LAT)的多波段观测,协同位于西半球的同类型的HAWC实验实现对同一耀变现象的全时段观测,并提供条件使得IACT实验能够对转瞬即逝的耀变现象开展深度观测。

backup

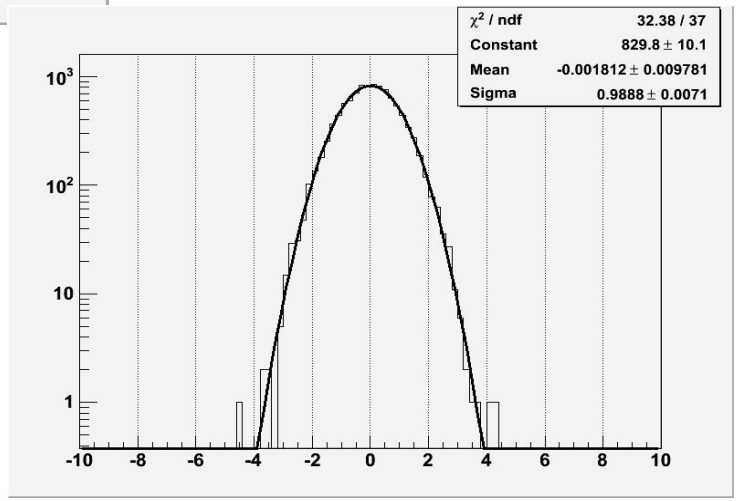
Mrk421 monitoring



Re-Observation of Mrk421's flare with surrounding window method (2008163-165)

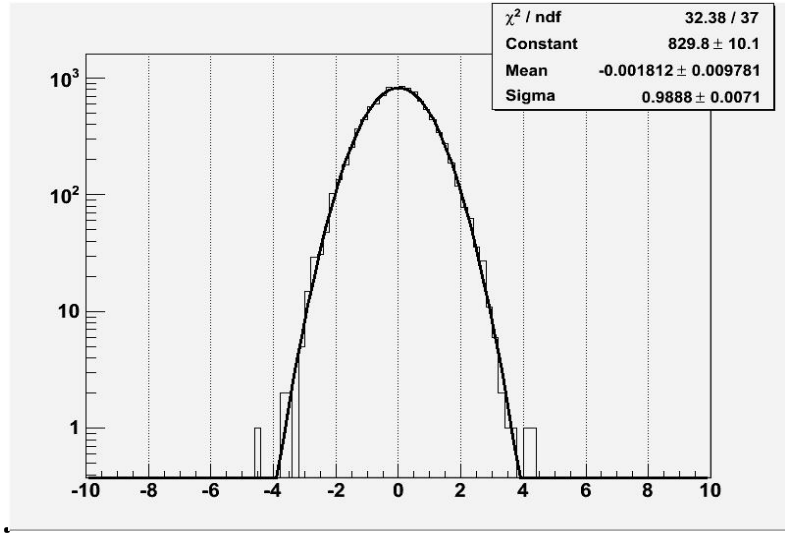


Time swapping ~ 4.25 σ ;
Surrounding window ~ 4.2 σ ;
Direct integral ~ 4.2 σ

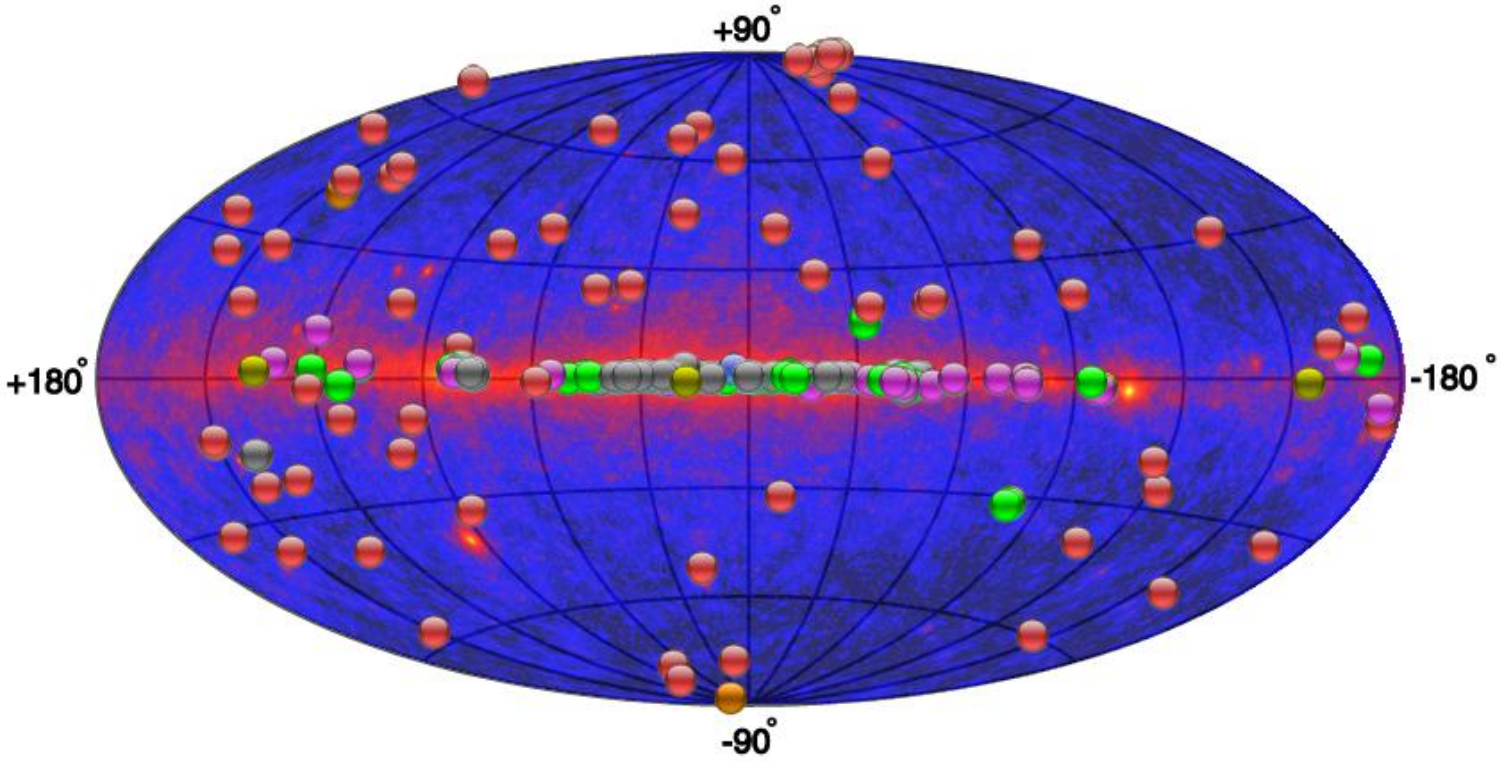


Analysis

- background estimation:
  - surrounding window method;
  - why not others:
    - equi-zenith: affected by non-uniformity distribution of the azimuth angle; Not applicable in small zenith angle data due to limited solid angle;
    - time-swapping: affected by variations in the event rate; may in principle overestimate background;



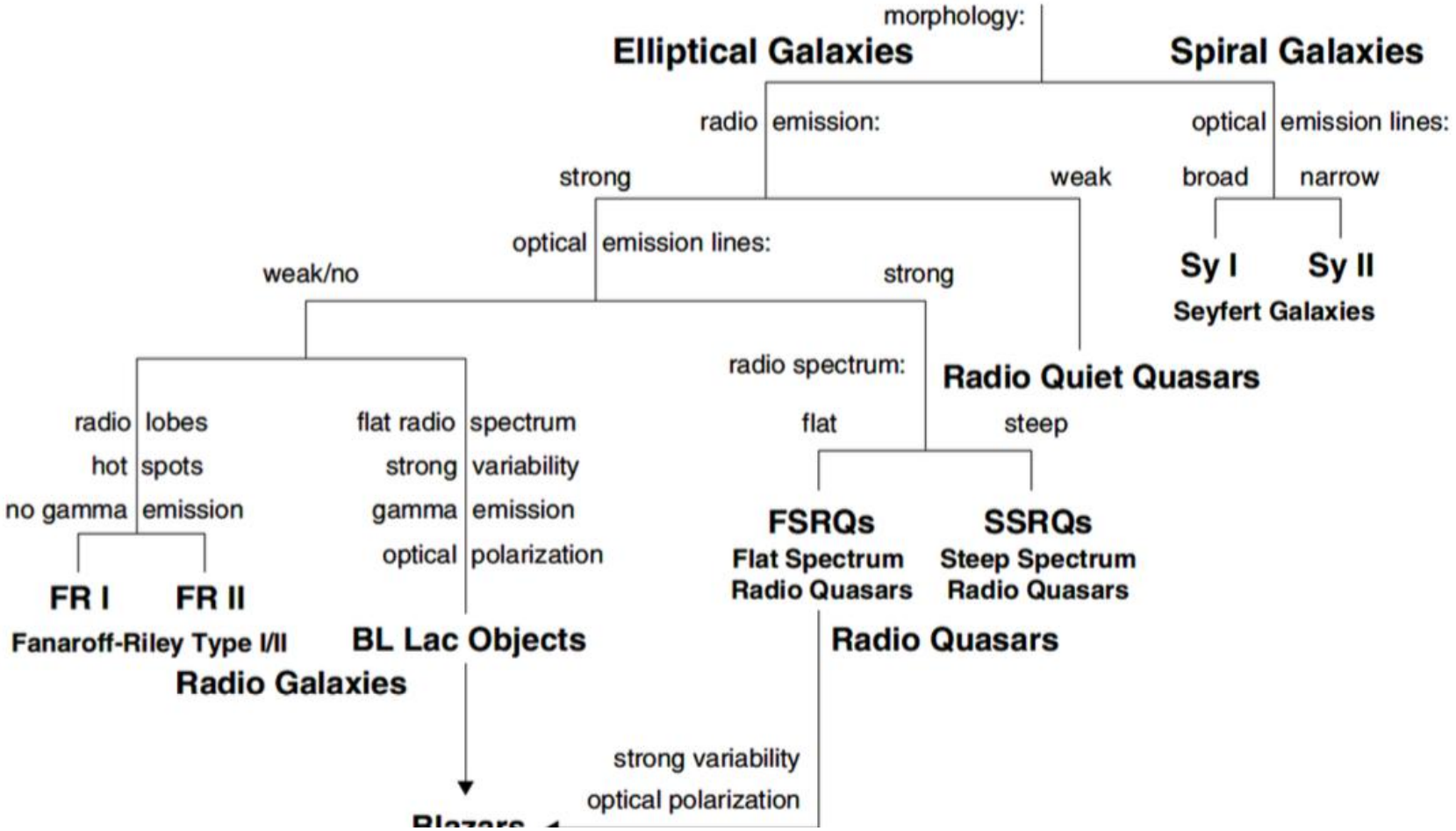
Real-time flare monitoring & alert to known sources



Source Types

- PWN
- Binary XRB PSR Gamma BIN
- HBL IBL FRI FSRQ Blazar LBL AGN (unknown type)
- Shell SNR/Molec. Cloud Composite SNR Superbubble
- Starburst
- DARK UNID Other
- uQuasar Star Forming Region Globular Cluster Cat. Var. Massive Star Cluster BIN BL Lac (class unclear) WR

AGN class


morphology:
Elliptical Galaxies
Spiral Galaxies
radio emission:
optical emission lines:
strong
weak
broad
narrow
optical emission lines:
weak/no
strong
Sy I
Sy II
Seyfert Galaxies
radio spectrum:
Radio Quiet Quasars
radio lobes
hot spots
no gamma emission
flat radio spectrum
strong variability
gamma emission
optical polarization
flat
steep
FSRQs
Flat Spectrum Radio Quasars
SSRQs
Steep Spectrum Radio Quasars
FR I
FR II
Fanaroff-Riley Type I/II
Radio Galaxies
BL Lac Objects
Radio Quasars
strong variability
optical polarization