Detection of Extra-galactic sources and Transients from LHAASO-WCDA

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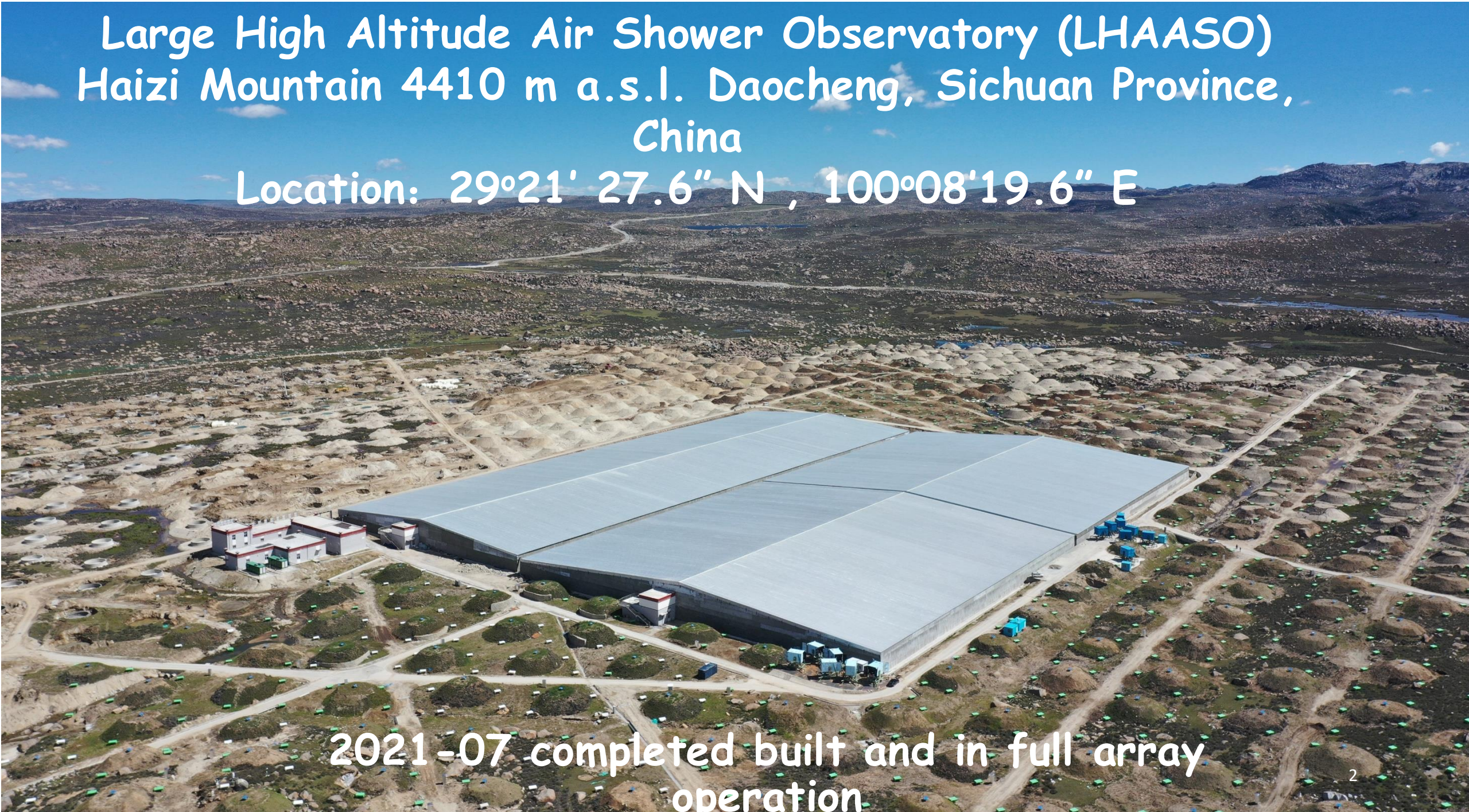
On behalf of LHAASO Collaboration

TeVPA2025 Valencia
2025/11/03-2025/11/07

Large High Altitude Air Shower Observatory (LHAASO)

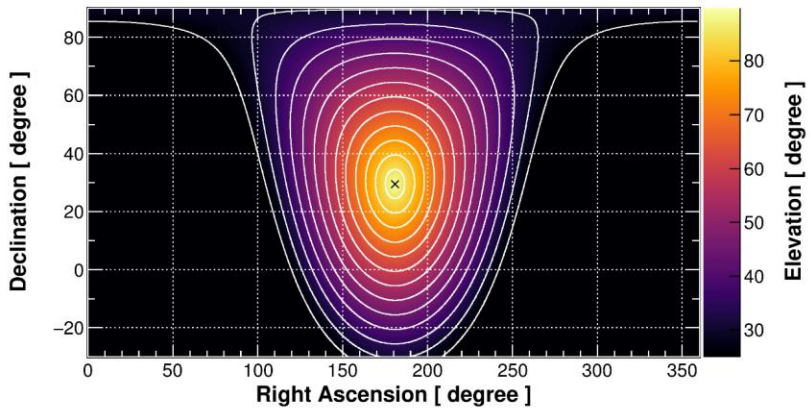
Haizi Mountain 4410 m a.s.l. Daocheng, Sichuan Province, China

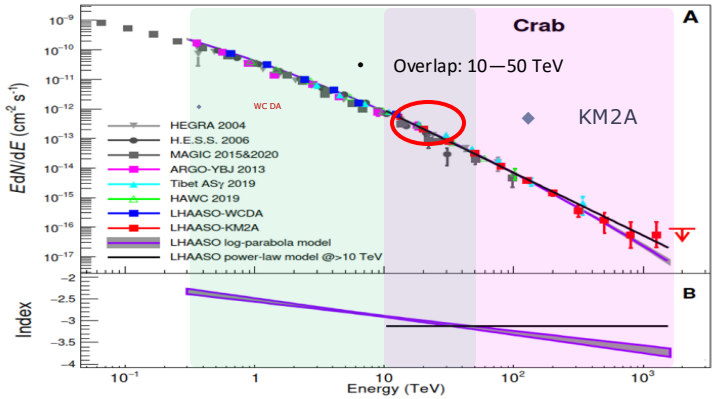
Location: 29°21′ 27.6″ N , 100°08′19.6″ E

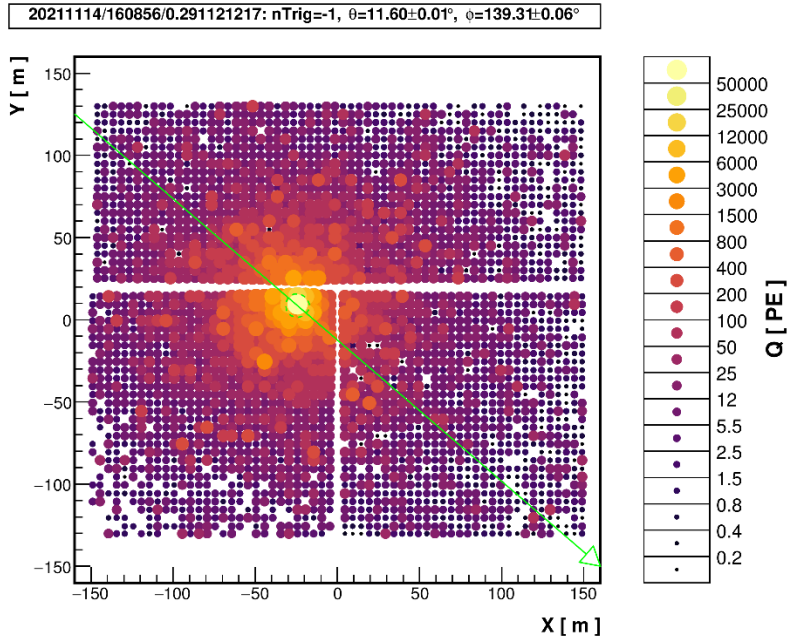


2021-07 completed built and in full array operation

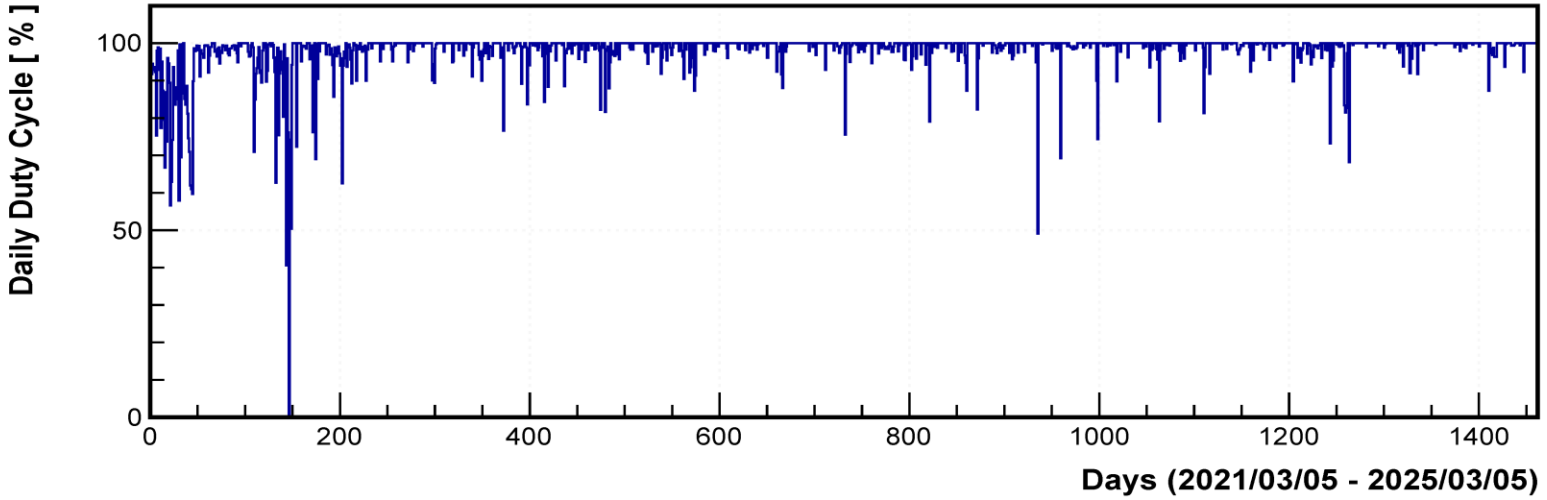
A good facility to do sky survey and monitor transient phenomena







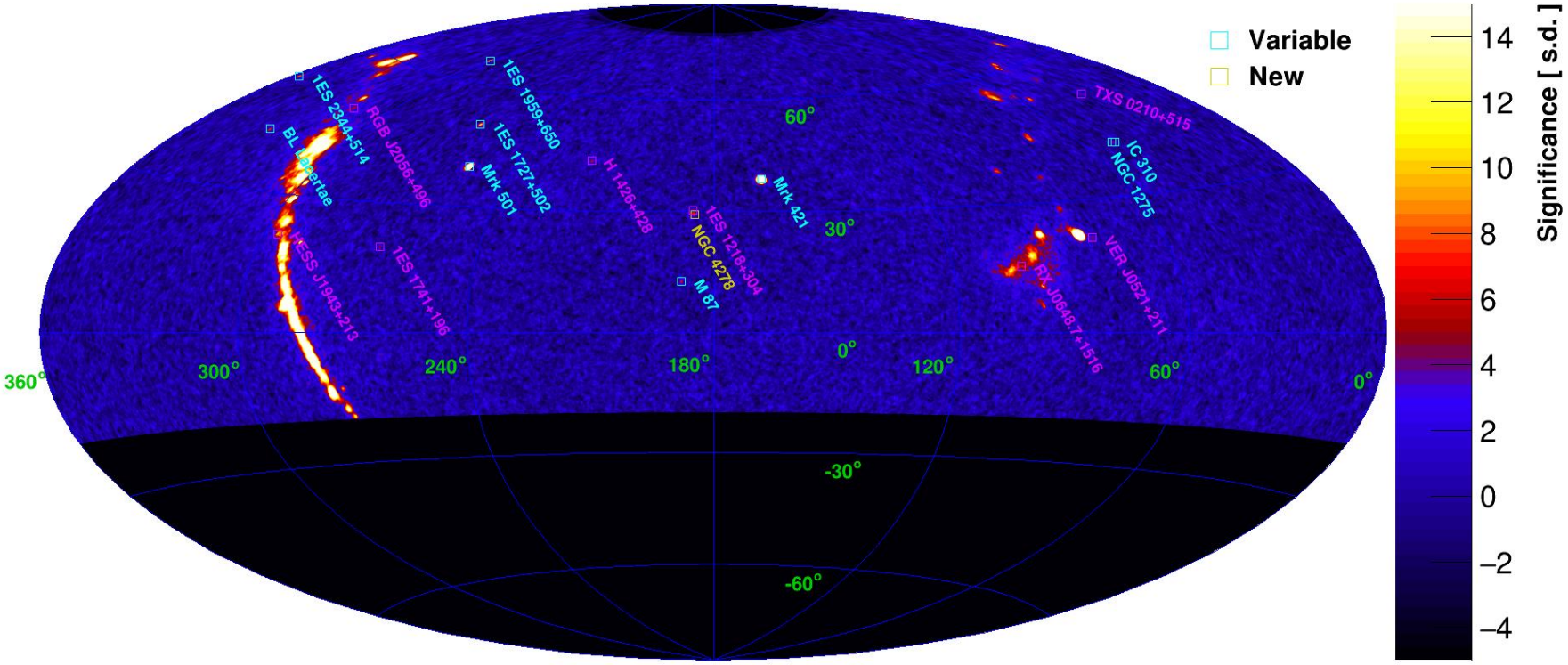
Overall Duty Cycle = 97.96%



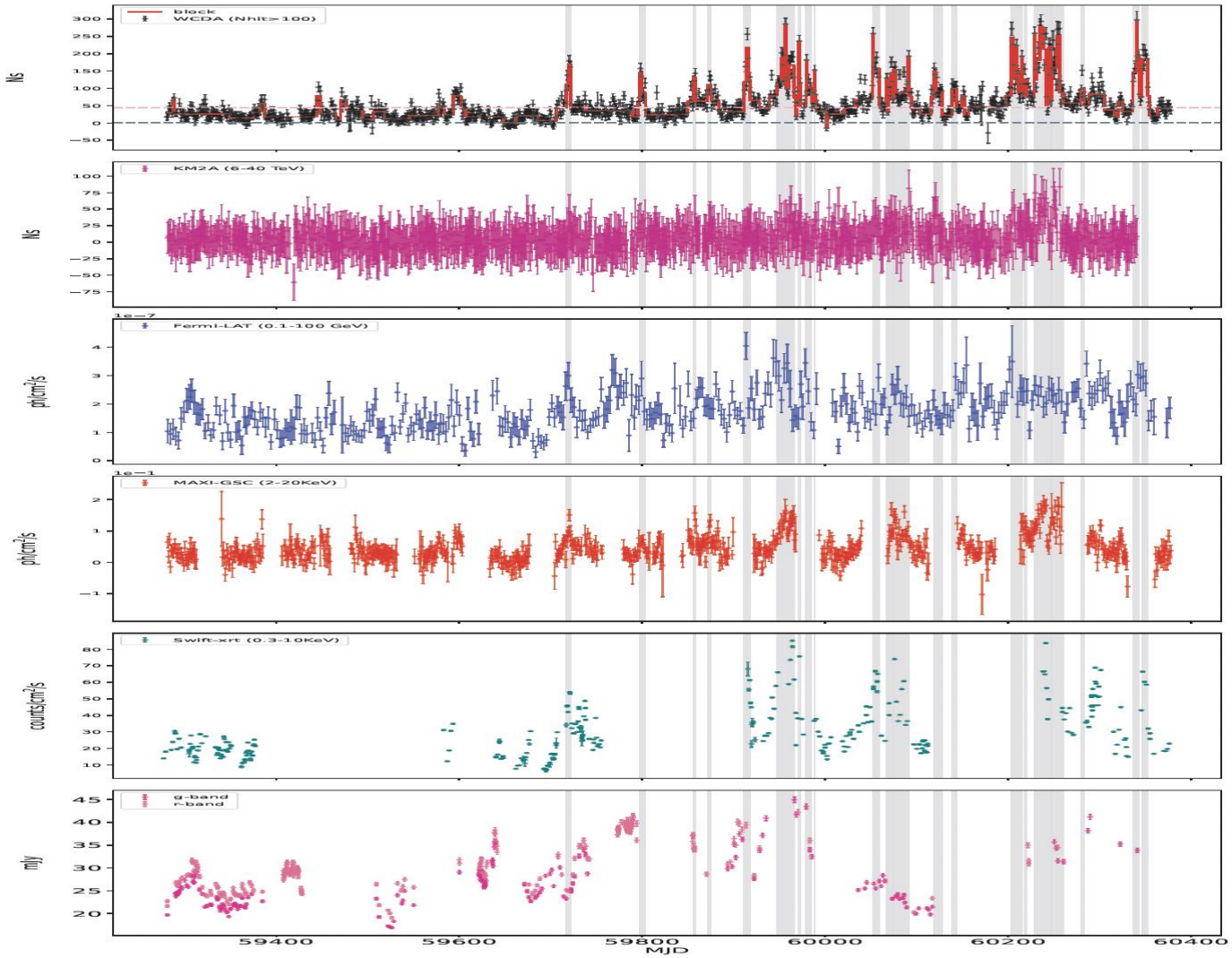
- Wide field of view
- Full duty cycle (>98%);
- Good sensitivity;
- Low threshold (>100GeV).

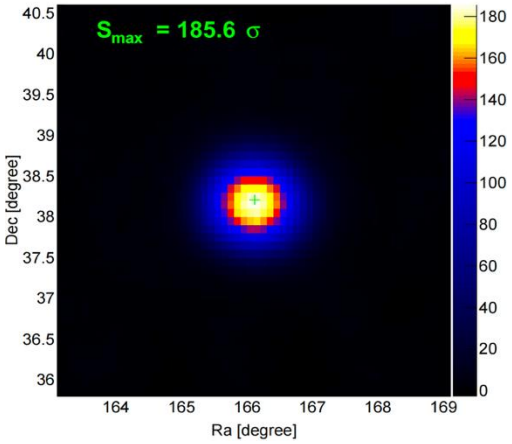
- Unbiased more samples collections;
- Early alert to the community;
- Muti-wavelength follow-up observation;
- Physics behind phenomena.

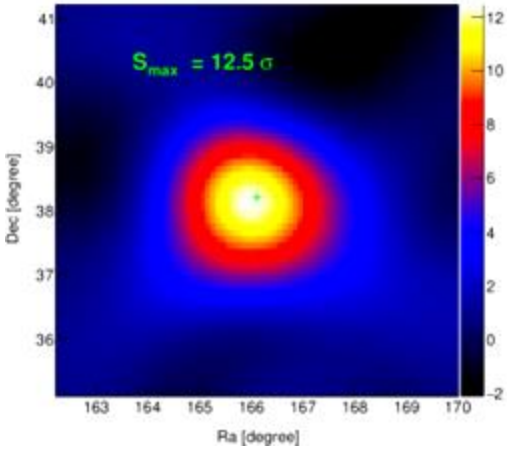
LHAASO Extragalactic Sky Map @ 1180 days observation

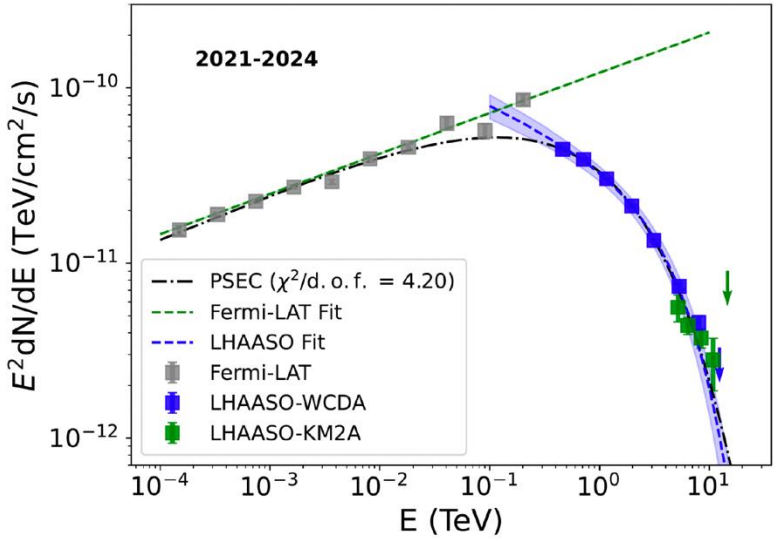


Mrk 421 @ LHAASO

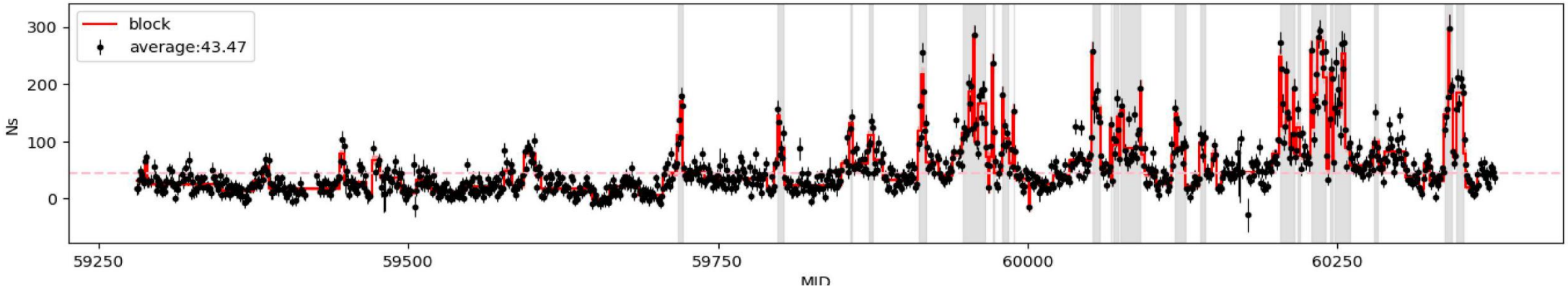


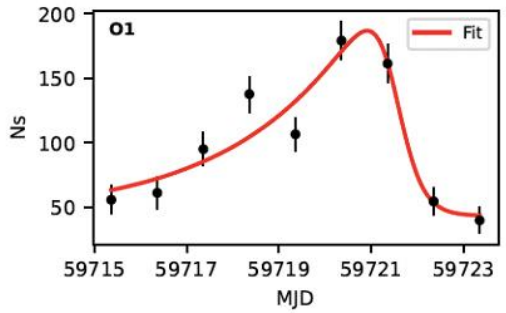


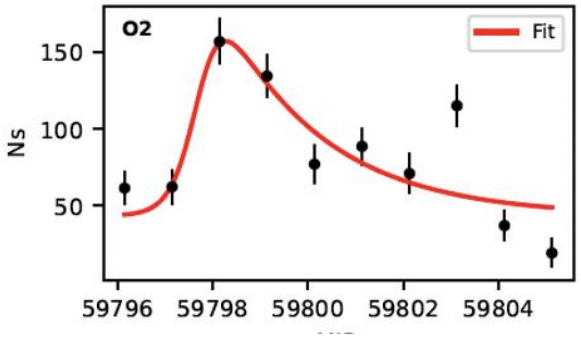


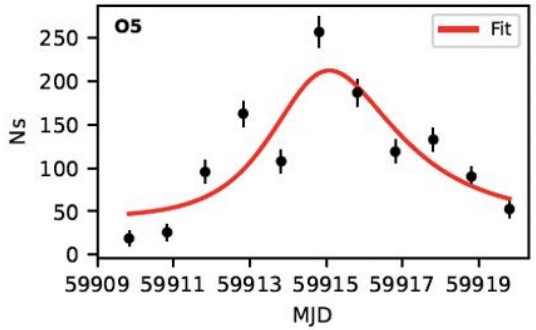


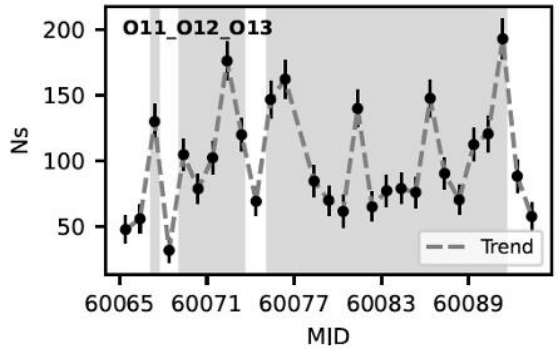
Mrk 421 @ LHAASO-WCDA





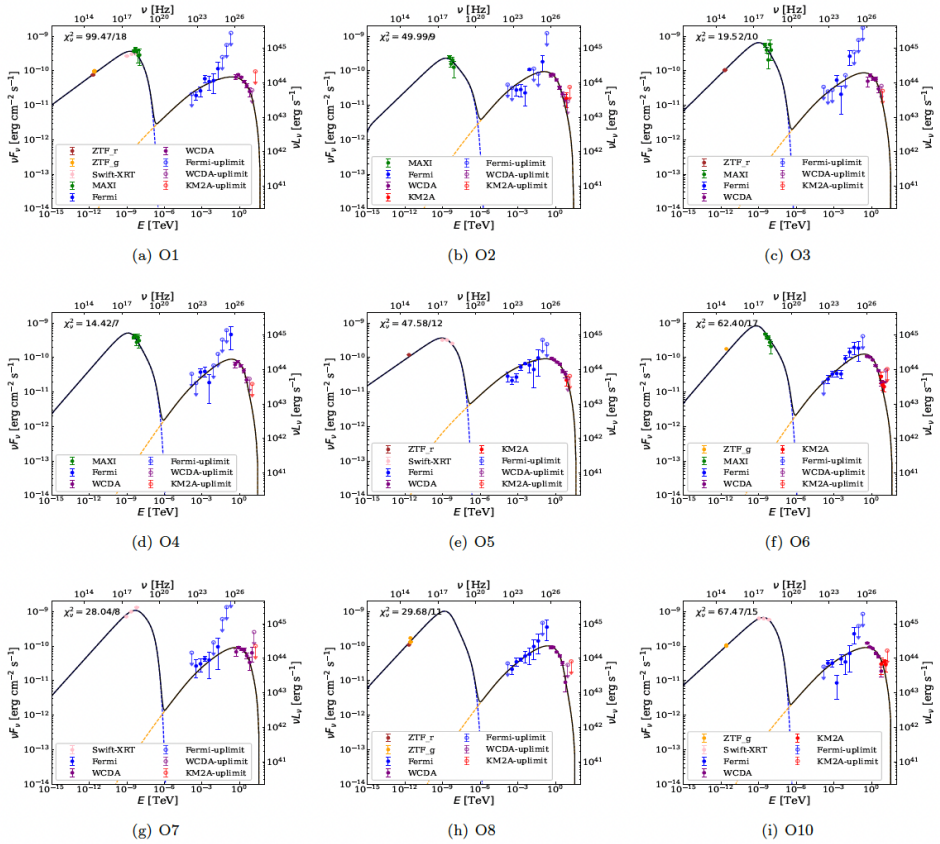




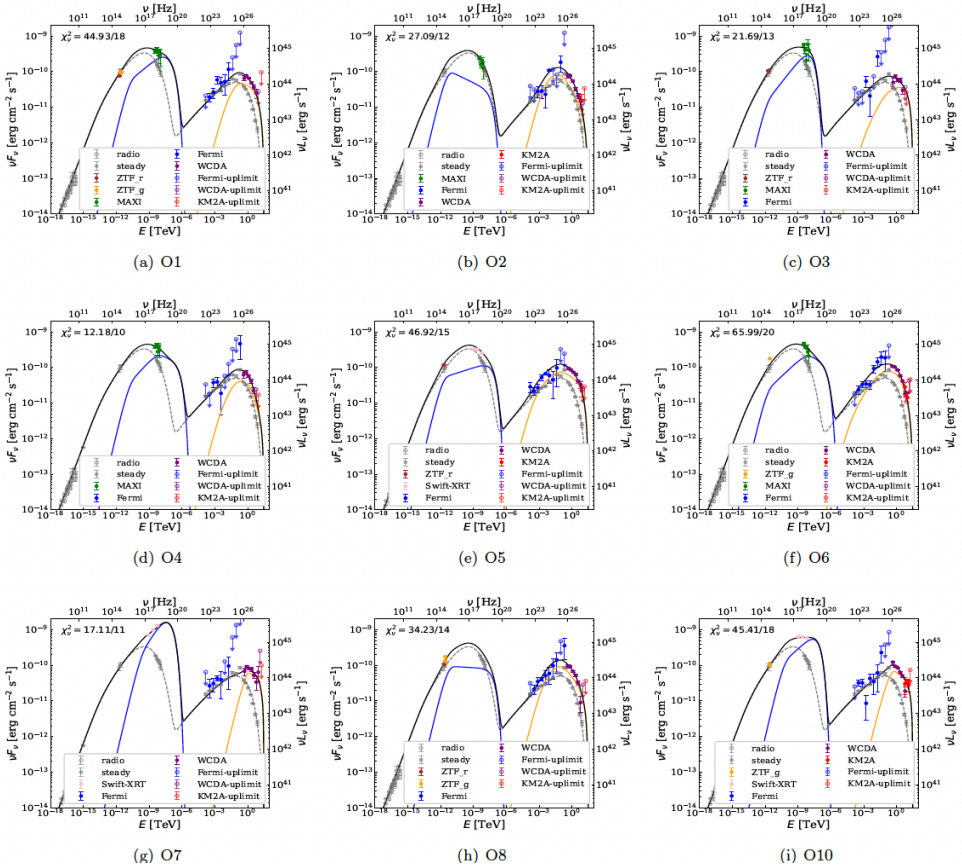


- 23 flares @ 05/03/2021– 05/03/2024
- Flaring duty cycle: 14%
- 4 groups @ variability timescale
  - A: longer risetime + shorter decay time;
  - B: shorter risetime + longer decay time;
  - C: symmetric distribution;
  - D: "flaring forest"

modelling @ one zone .vs. multi-zone



χ^2/d.o.f ~ 2.7



χ^2/d.o.f ~ 1.9

Draft is ready for submission !

Perseus Galaxy Cluster

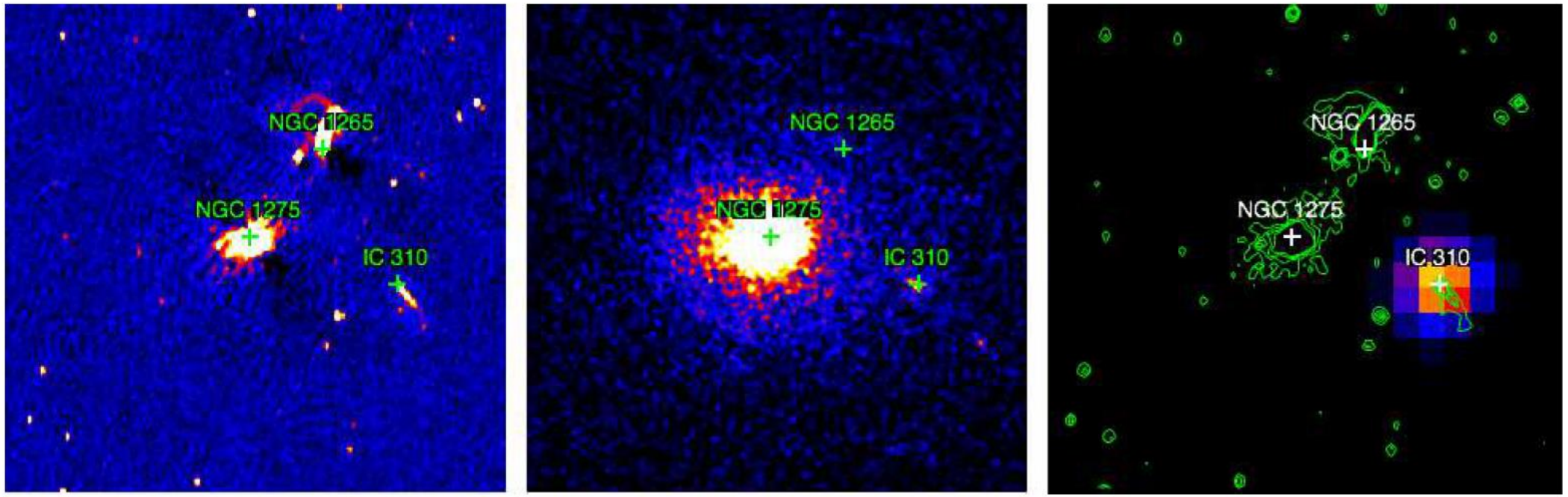
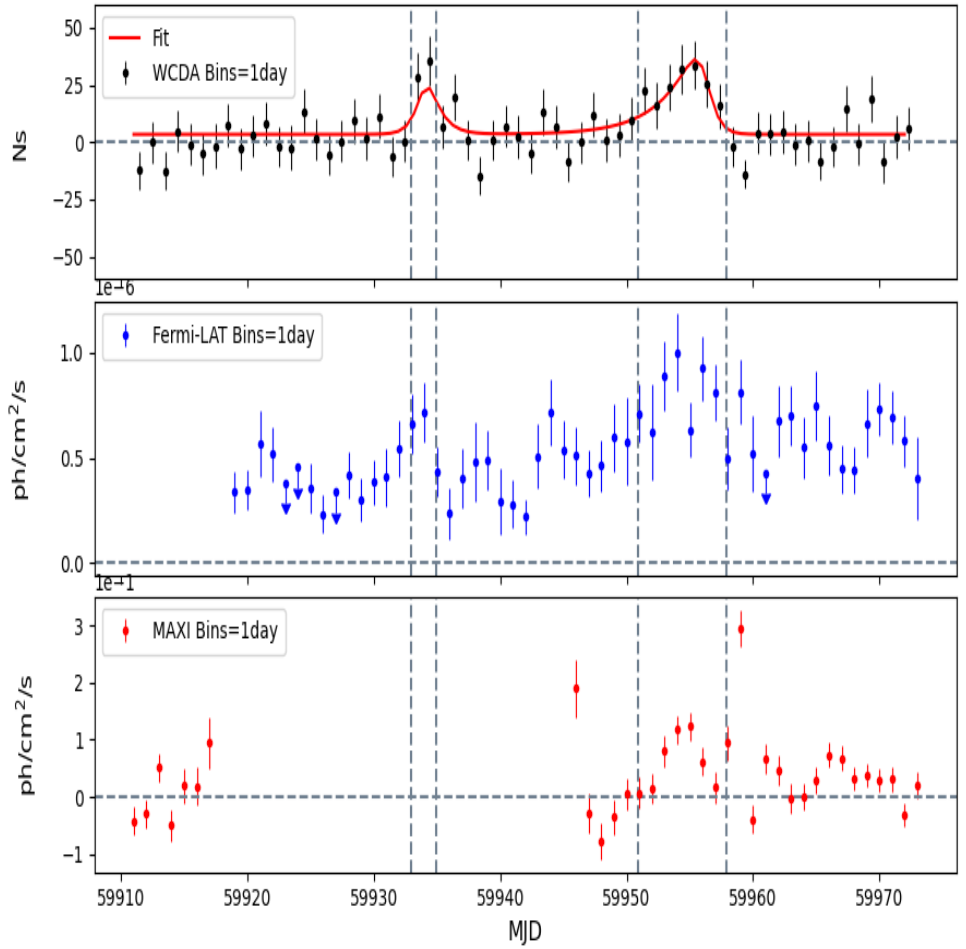
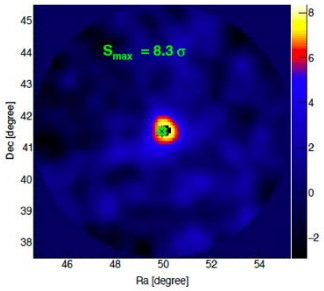
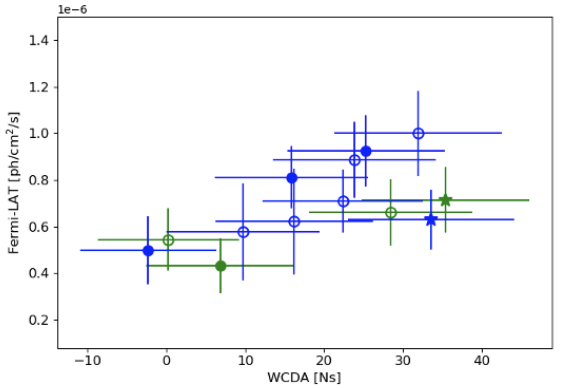


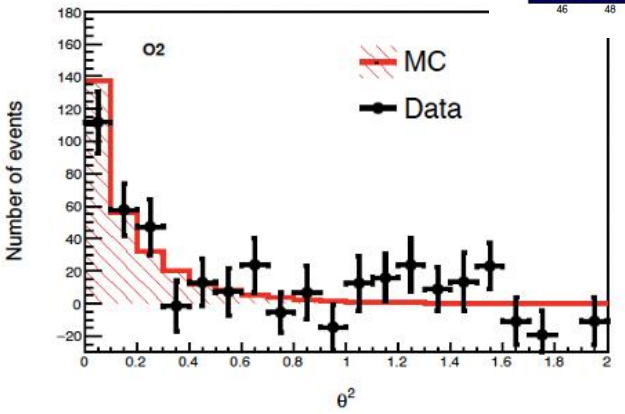
Fig. 3. Image of Perseus galaxy cluster in radio band from WENSS sky survey (left), in the X-ray band from the *ROSAT* all sky survey (middle) and the *Fermi* image in the 100-300 GeV energy band (right). The green contours on the right panel correspond to the radio image from the left panel.

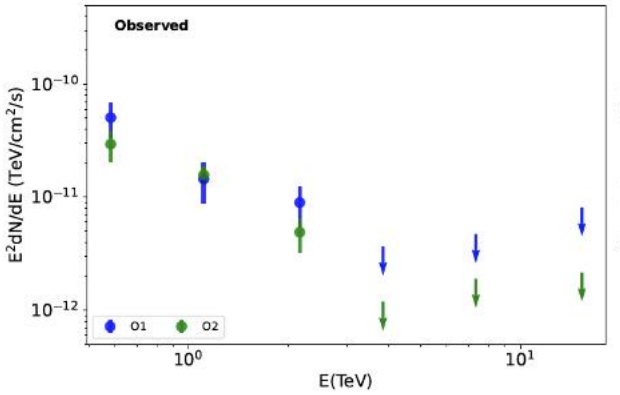
NGC 1275 @ Dec. 2022 - Jan. 2023

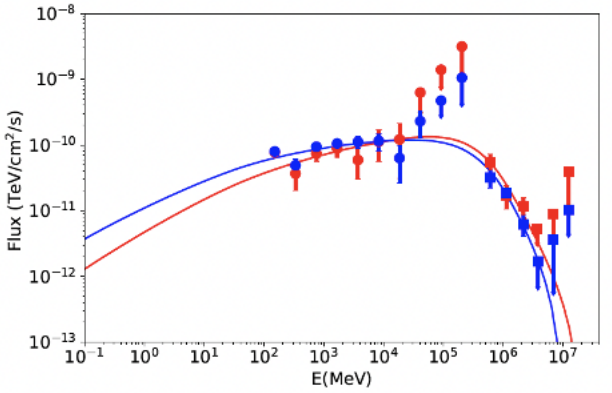








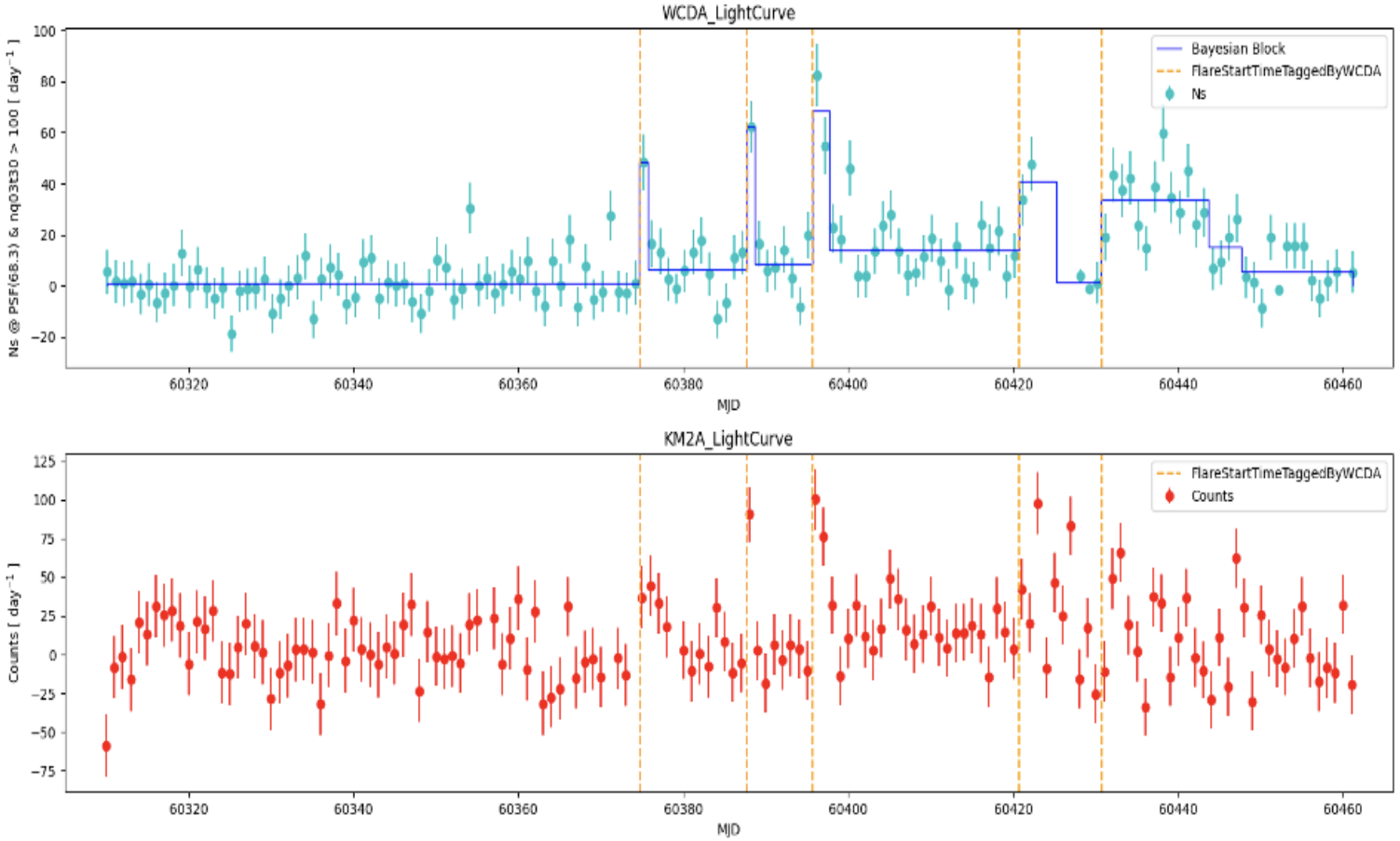


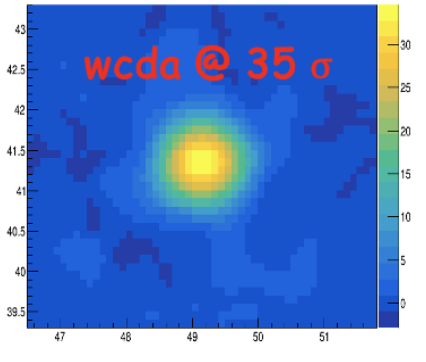


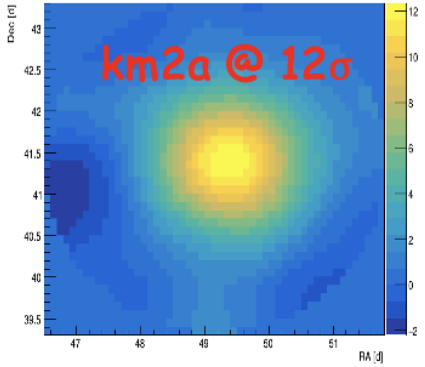
- very soft spectrum to several TeV.
- the lack of any noticeable diffuse gamma-ray structure within the cluster.

LHAASO Coll. MNRAS (2025)

IC 310 flaring during March – May in 2024

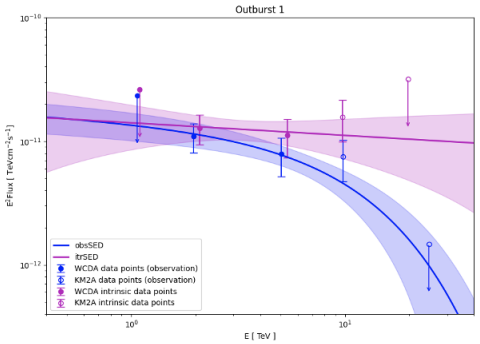


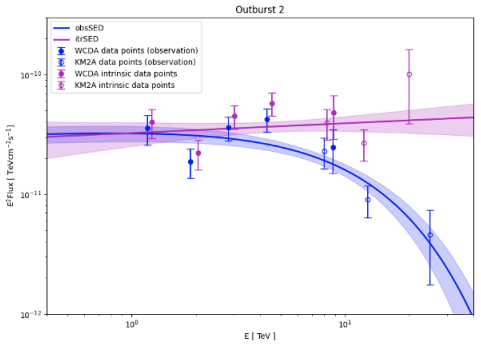


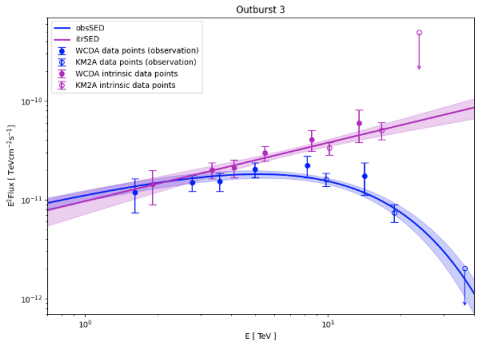


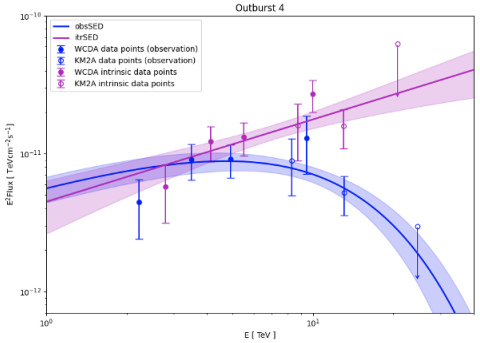
- Flare 1 @ 7.5 σ
- Flare 2 @ 15 σ
- Flare 3 @ 22 σ
- Flare 4 @ 13 σ
- Flare 5 @ 23 σ

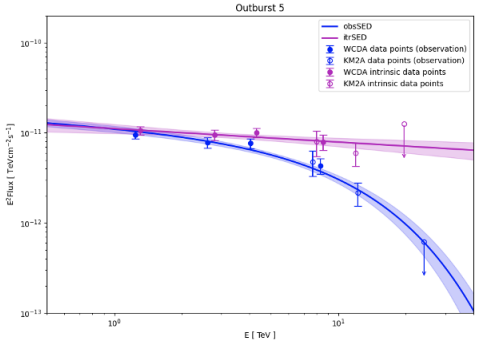
Flaring SEDs and time revolution

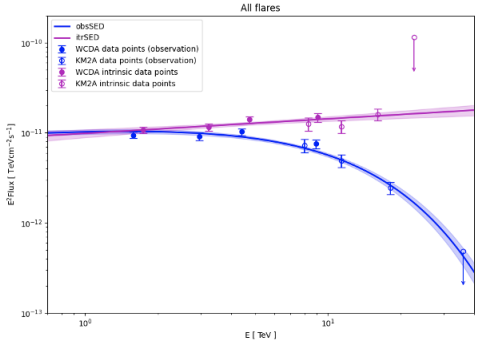


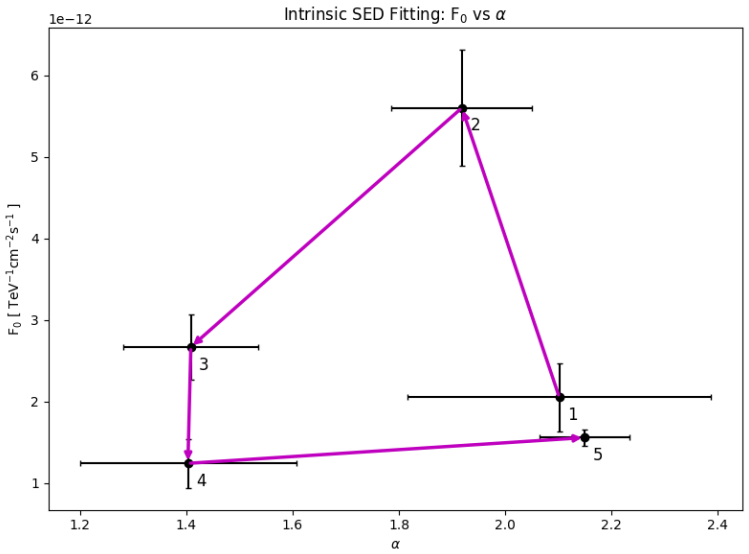






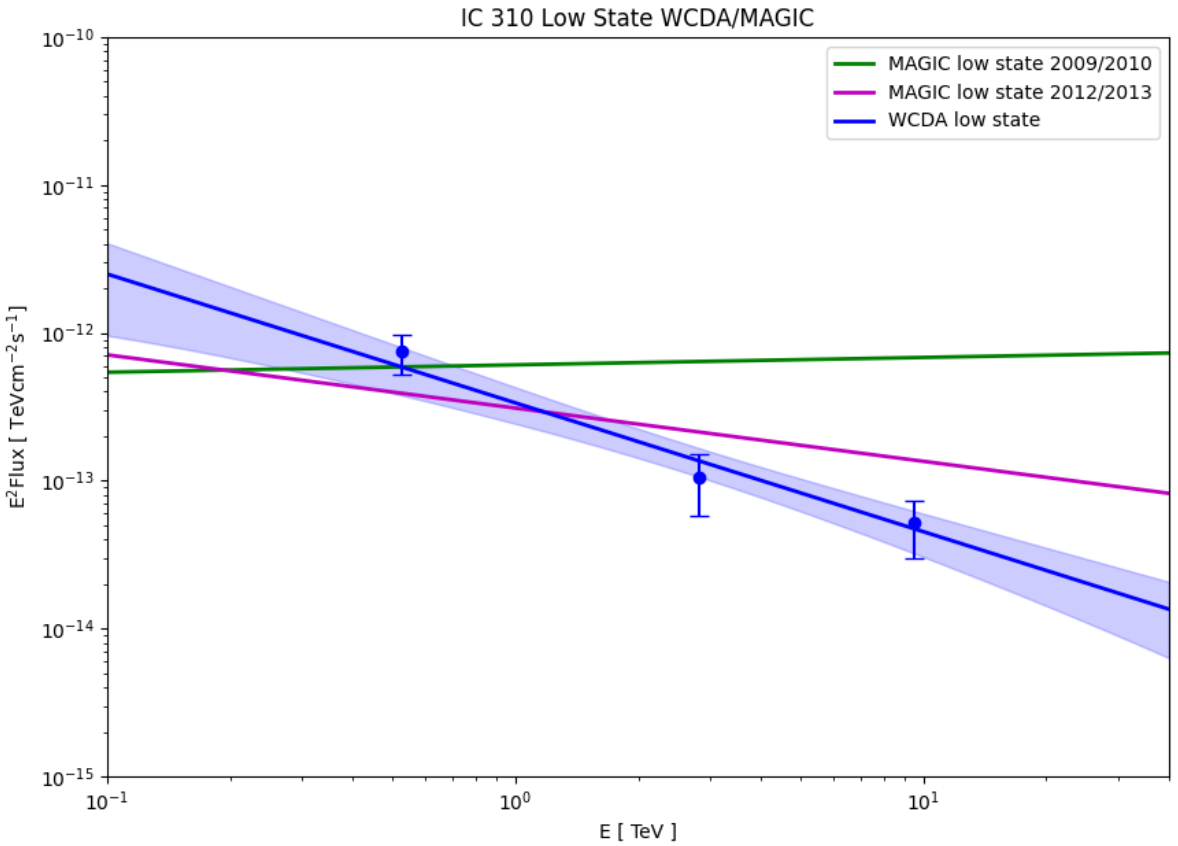






- Very hard spectrum @ VHE → Modeling → hadronic components?

Long-term observation

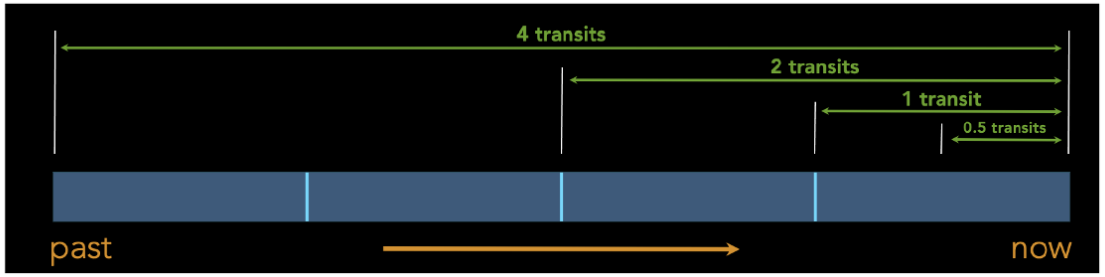


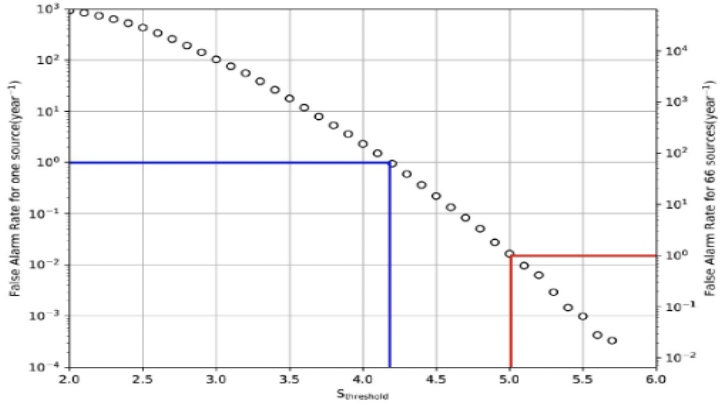
- A "quiescent" state @ VHE band with more than 9000 hours data;
- MAGIC 35.3h around flare 2012 and 38.8h around flare 2009

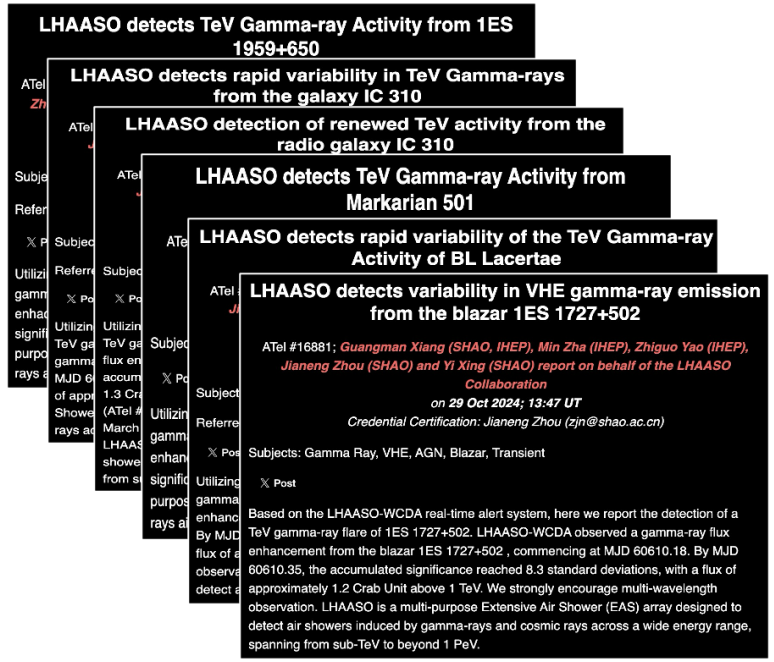
Period	Energy	Index
WCDA 3 yrs	0.5-9.5 TeV	2.87 ± 0.18
MAGIC 2009	0.12-8.1 eV	1.95 ± 0.23
MAGIC 2012	0.08-2.1 TeV	2.36 ± 0.34

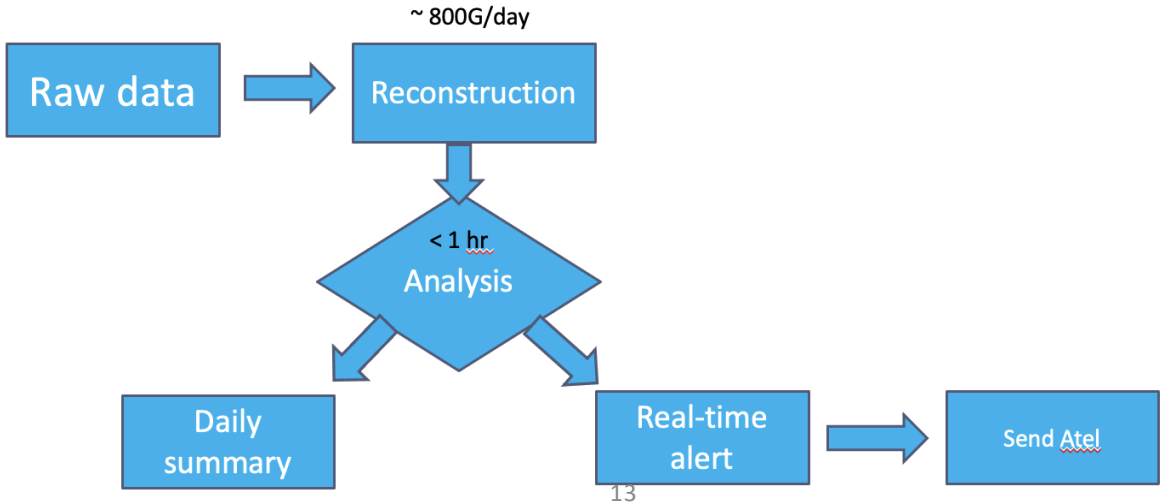
A real-time monitoring @ selected AGN

Category	number	$TS_{Threshold}$
Mkn 421,Mkn501	2	18.79
TeVCat Extragalactic sources	65	26.37
Nearby 3FHL Extragalactic sources($z < 0.2$)	85	27.03
Total	152	









→ **Real-time full sky monitoring in debuging**

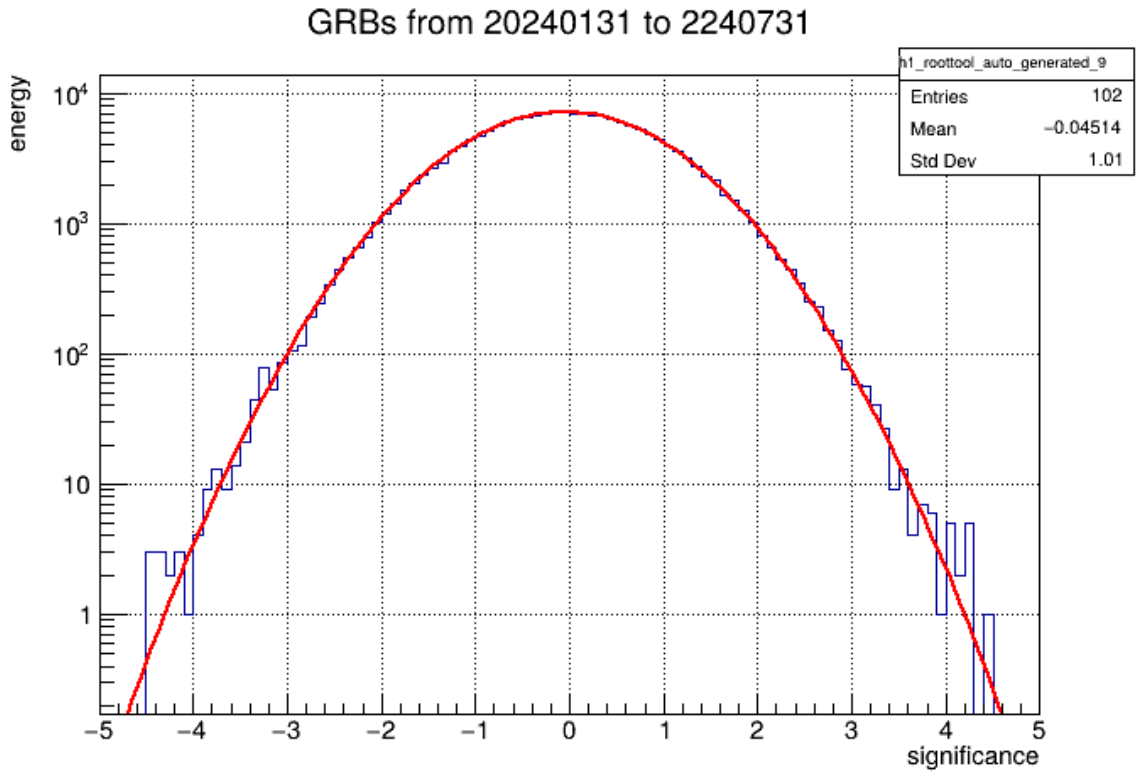
GRB follow-up observation @ trigger data

Short time scale

- T_{range}: -64 sec → 64 sec
- T_{width}: 2^{-3}, 2^{-2}, …, 2^{5} sec, half sliding

Long time scale

- T_{range}: T_0 → out of FOV
- T_{width}: 2^{6}, 2^{7}, …, 2^{15} sec, half sliding



GRB follow-up observation @ triggerless data

GCN alert inside LHAASO FOV

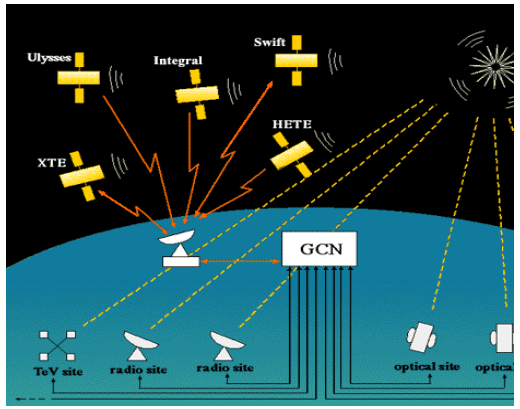
- rate: 2.5/week

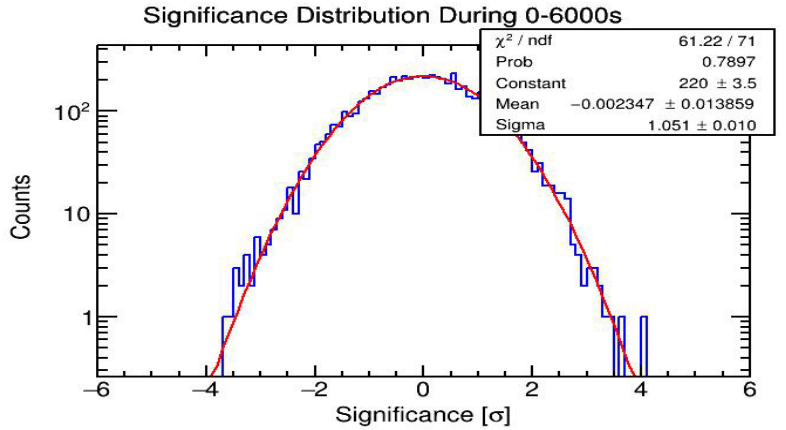
Save (T0-0.5 h, T0 + 2 h) data

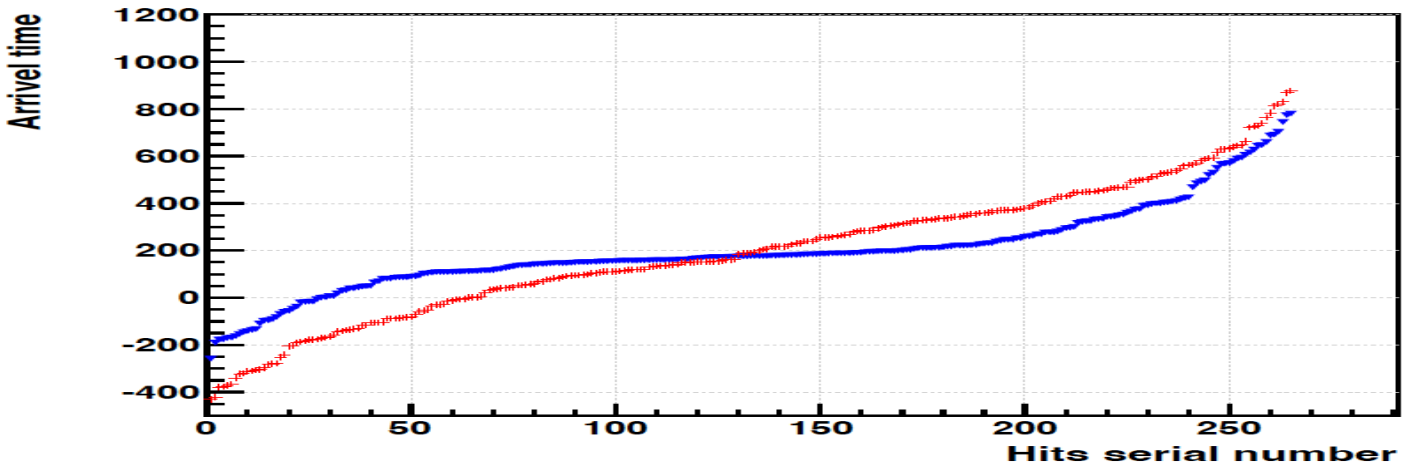
- (Npe, T) of 3120 detector units
- Big data size → 7 TB/alert
- Touching low energy band

Analysis pipeline

- Hits-to-Events re-trigger
  - Time & window selection
  - Twin=1000 ns + half overlap
- Background estimation
- Searching excess



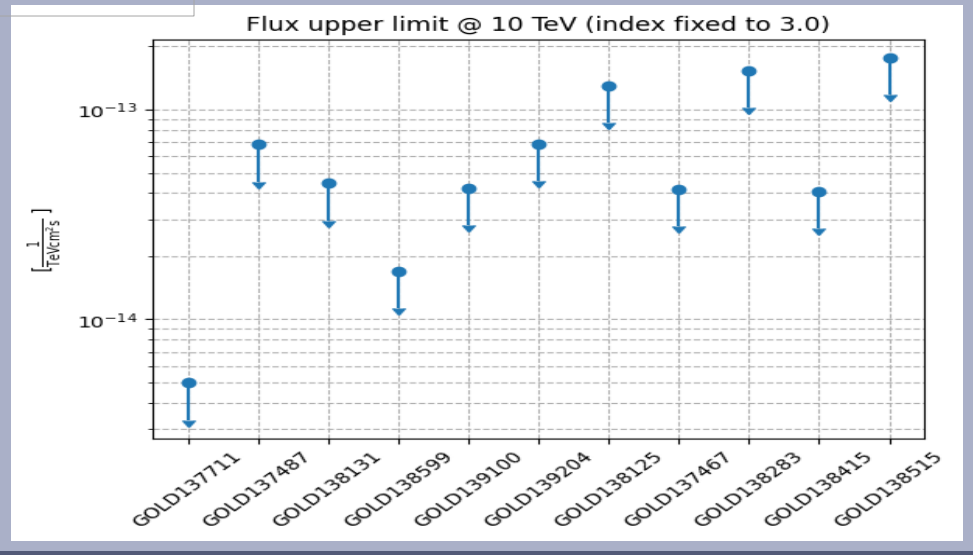




Multi-messenger astrophysics

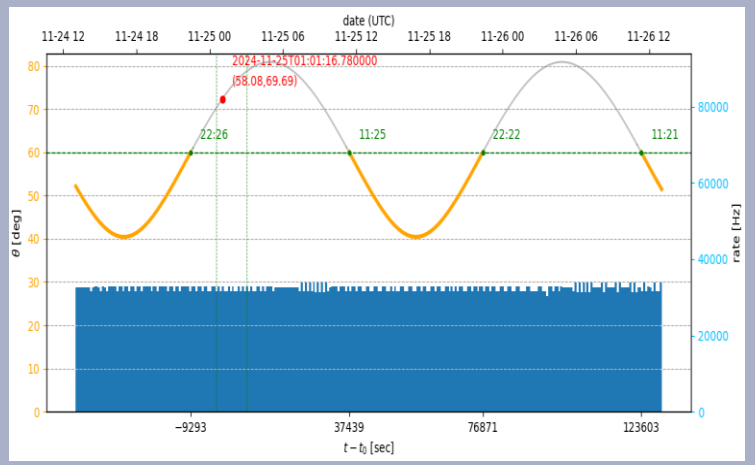
Neutrino alert

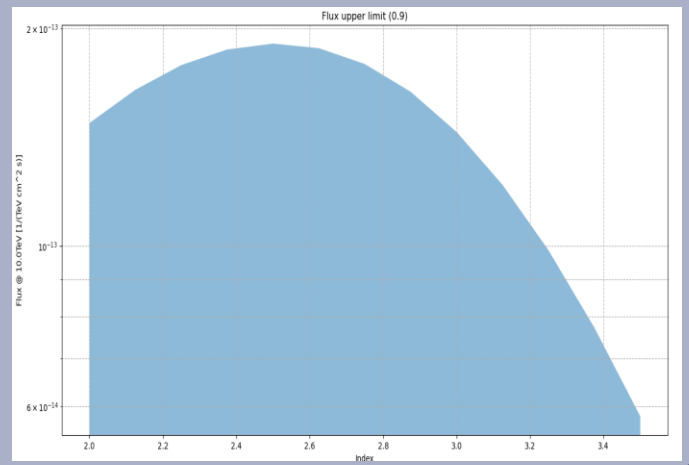
139315_50057906	1	24/04/24	01:49:26.00	GOLD	327.0799	+3.0600	96.89	54.60	1.9235e+02	5.0816e-01	1.2243	IceCube Gold event. The position error is statistical only, there is no systematic added.
139315_50057906	0	24/04/24	01:49:26.00	GOLD	326.5299	+3.1619	76.22	29.69	1.9235e+02	5.0816e-01	1.2243	IceCube Gold event. The position error is statistical only, there is no systematic added.
139303_27647445	1	24/04/19	23:25:41.04	BRONZE	73.1700	+1.6399	130.49	77.54	1.2084e+02	3.1477e-01	3.4261	IceCube Bronze event. The position error is statistical only, there is no systematic added.
139303_27647445	0	24/04/19	23:25:41.04	BRONZE	74.1535	+1.0796	55.67	21.68	1.2084e+02	3.1477e-01	3.4261	IceCube Bronze event. The position error is statistical only, there is no systematic added.
139279_10803235	1	24/04/12	05:33:46.89	BRONZE	102.4399	+6.3499	42.29	26.70	1.2126e+02	3.0910e-01	3.4096	IceCube Bronze event. The position error is statistical only, there is no systematic added.
139279_10803235	0	24/04/12	05:33:46.89	BRONZE	103.7861	+5.8716	69.22	26.96	1.2126e+02	3.0910e-01	3.4096	IceCube Bronze event. The position error is statistical only, there is no systematic added.
139204_39158985	2	24/03/27	11:04:49.92	GOLD	25.3999	+7.7800	257.99	68.99	1.9966e+02	5.3864e-01	1.0306	IceCube Gold event. The position error is statistical only, there is no systematic added.
139205_9784024	1	24/03/27	16:12:30.47	BRONZE	89.2099	+0.9300	84.15	46.34	1.5269e+02	3.7111e-01	2.4194	IceCube Bronze event. The position error is statistical only, there is no systematic added.
139204_39158985	1	24/03/27	13:44:38.00	GOLD	25.3999	+7.7800	257.99	68.99	1.9966e+02	5.3864e-01	1.0306	IceCube Gold event. The position error is statistical only, there is no systematic added.



L/V/K alert

- GCN - Circulars - 38443 - LIGO/Virgo/KAGRA S241125n: gamma-ray upper limits from joint observations by the LST-1 and MAGIC telescopes
- GCN - Circulars - 38308 - LIGO/Virgo/KAGRA S241125n: Swift/BAT-GUANO candidate counterpart
- GCN - Circulars - 38305 - LIGO/Virgo/KAGRA S241125n: Identification of a GW compact binary merger candidate
- ...
- RA = 58.079, DEC=69.689 degree from SWIFT





Summary and prospects

- **WCDA will continue to survey northern sky;**
- **A real-time AGN flaring monitoring system has been operated since July of 2023;**
  - Mrk421 / NGC 1275 / 1ES 1959+60 / IC310/ BL Lac/ 1ES 1727 + 502 …..
- **Two independent GRB analysis packages of triggerless and trigger data have been operated;**
  - No signifiant excess were detected besides GRB221009A.
- **Mutli-topics follow-up observation has been operated since July of 2024;**
  - Neutrino alert + L/V/K alert + FRB alert + Novae + TDE alert + ….
- **To-do-list**
  - Further analysis of the variablity;
  - Full sky searching + sub-threshold @ real-time flaring monitoring;
    - further improvement to minimize process time;
  - Further optimization on LHAASO data performance.

backup

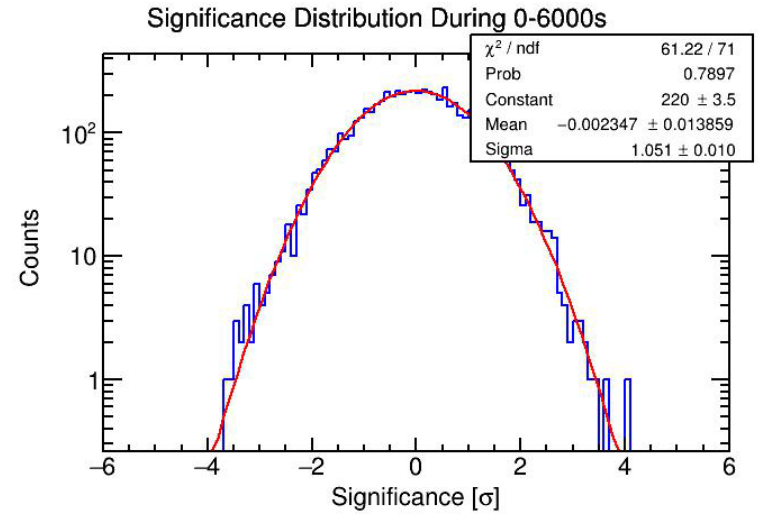


表 4.2 不同红移下T_0-T_{90}和T_{90}−6000s时间范围内低能和高能流强上限列表

取数日期	天顶角	T90	T_{90}, nfitc < 60		T_{90}, nfitc ≥ 60		0 – 6000s, nfitc < 60		0 – 6000s, nfitc ≥ 60	
			F (zs=0.1)	F (zs=0.5)	F(zs=0.1)	F (zs=0.5)	F (zs=0.1)	F(zs=0.5)	F(zs=0.1)	F (zs=0.5)
	[o]	[s]	[erg cm^{-2}]	[erg cm^{-2}]	[erg cm^{-2}]	[erg cm^{-2}]	[erg cm^{-2}]	[erg cm^{-2}]	[erg cm^{-2}]	[erg cm^{-2}]
20190619	27.73	/	5.20E-05	1.23E-02	8.08E-07	1.91E-04	3.27E-04	7.71E-02	3.23E-06	7.63E-04
20190620	24.92	/	4.74E-04	1.08E-01	3.84E-06	8.74E-04	2.86E-03	6.52E-01	1.58E-05	3.59E-03
20190703	4.48	/	2.36E-04	1.18E-02	1.85E-06	9.18E-05	1.08E-03	5.38E-02	1.08E-05	5.39E-04
20191004	31.43	/	1.20E-03	5.49E-01	7.87E-06	3.60E-03	4.53E-03	2.07E+00	3.75E-05	1.72E-02
GRB191011A	31.33	/	1.09E-03	4.98E-01	4.15E-06	1.90E-03	5.46E-03	2.50E+00	4.38E-05	2.00E-02
GRB191017C	36.1	/	1.95E-03	1.57E+00	1.17E-05	9.42E-03	2.05E-02	1.65E+01	9.96E-05	8.01E-02
GRB191101B	47.09	/	1.14E-03	9.13E-01	1.67E-06	1.35E-03	9.42E-03	7.57E+00	7.20E-05	5.79E-02
GRB191115A	29.23	/	1.17E-03	5.16E-01	8.11E-06	3.59E-03	4.81E-03	2.13E+00	2.10E-05	9.29E-03
GRB191122A	25.29	/	3.14E-04	7.16E-02	3.45E-06	7.87E-04	3.25E-03	7.41E-01	2.44E-05	5.55E-03
GRB191125A	33.42	/	7.70E-04	3.52E-01	3.58E-06	1.64E-03	3.89E-03	1.78E+00	1.89E-05	8.65E-03
GRB200903C	34.93	/	5.25E-03	4.22E+00	2.41E-06	1.94E-03	2.89E-02	2.32E+01	5.62E-06	4.52E-03
GRB200906A	39.13	67.3	1.20E-02	1.59E+01	/	/	5.78E-02	7.67E+01	2.15E-05	2.85E-02
20200913	38.93	/	6.27E-03	8.32E+00	4.00E-06	5.31E-03	9.07E-02	1.20E+02	2.00E-05	2.66E-02
20200915	40.9	/	7.35E-03	9.87E+00	/	/	6.34E-02	8.53E+01	2.80E-05	3.77E-02
GRB200916A	35.49	76	1.72E-03	1.38E+00	/	/	4.71E-03	3.78E+00	8.20E-07	6.59E-04
GRB200919A	36.39	/	8.05E-03	6.47E+00	2.54E-06	2.04E-03	3.73E-02	3.00E+01	2.37E-05	1.90E-02
GRB201021A	31.73	/	3.15E-03	1.44E+00	1.41E-06	6.45E-04	1.10E-02	5.03E+00	1.32E-05	6.02E-03
20201030	26.48	/	1.26E-03	2.98E-01	7.70E-07	1.82E-04	2.24E-02	5.28E+00	1.03E-05	2.42E-03
GRB201031B	29.06	/	2.74E-03	1.21E+00	2.56E-06	1.13E-03	1.80E-02	7.97E+00	8.42E-06	3.72E-03
GRB201116A	34.09	/	1.50E-03	6.88E-01	1.59E-06	7.27E-04	1.23E-02	5.65E+00	4.77E-06	2.18E-03
20201119	37.75	/	4.23E-03	3.47E+00	3.03E-06	2.48E-03	2.28E-02	1.87E+01	6.06E-06	4.96E-03
20201123	41.47	/	6.90E-03	9.27E+00	/	/	6.87E-02	9.23E+01	4.05E-05	5.45E-02
GRB201128A	36.47	/	1.05E-02	8.47E+00	3.39E-06	2.73E-03	5.00E-02	4.02E+01	5.93E-06	4.77E-03
20201213	35.91	/	6.50E-03	8.62E+00	8.17E-06	1.08E-02	1.34E-01	1.78E+02	1.36E-05	1.81E-02