The luminosity function of TeV-emitting BL Lacs:
observations of an HBL sample with VERITAS

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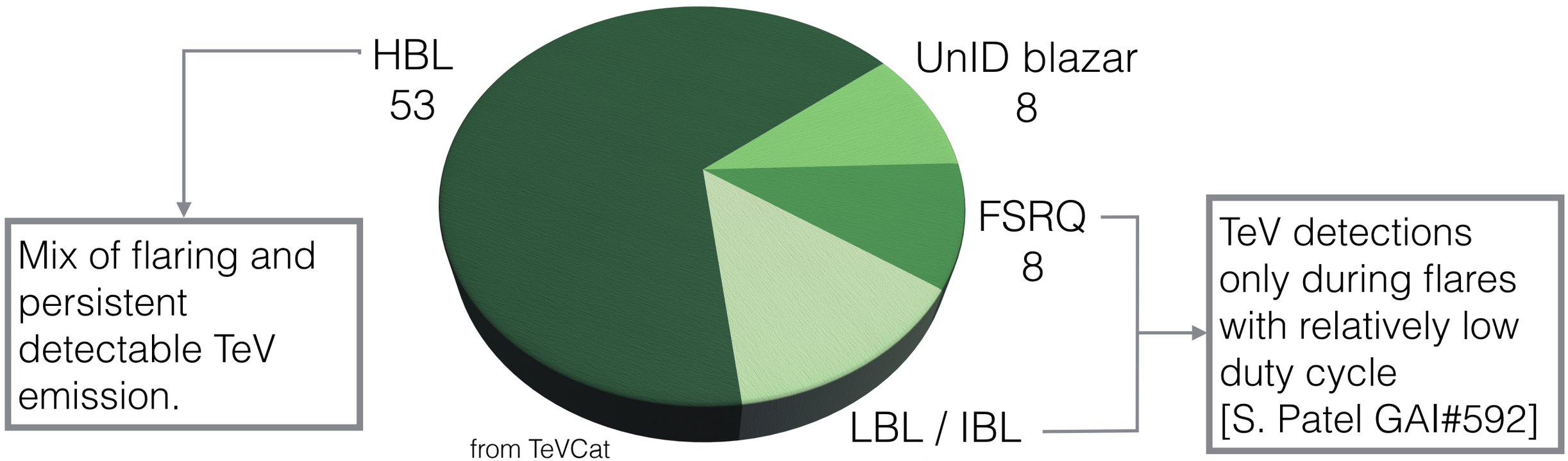
TeV-detected blazars



- There are 82 blazars detected at TeV energies, but their properties as a population (luminosity distribution, redshift distribution, etc) are poorly understood.
- The lack of blind extragalactic surveys combined with observational biases intrinsic to the operation of IACTs do not allow to conduct population studies based on published data.
- There is a need for an unbiased census of TeV-emitting blazars to derive their luminosity function.

Science goals: AGN evolution

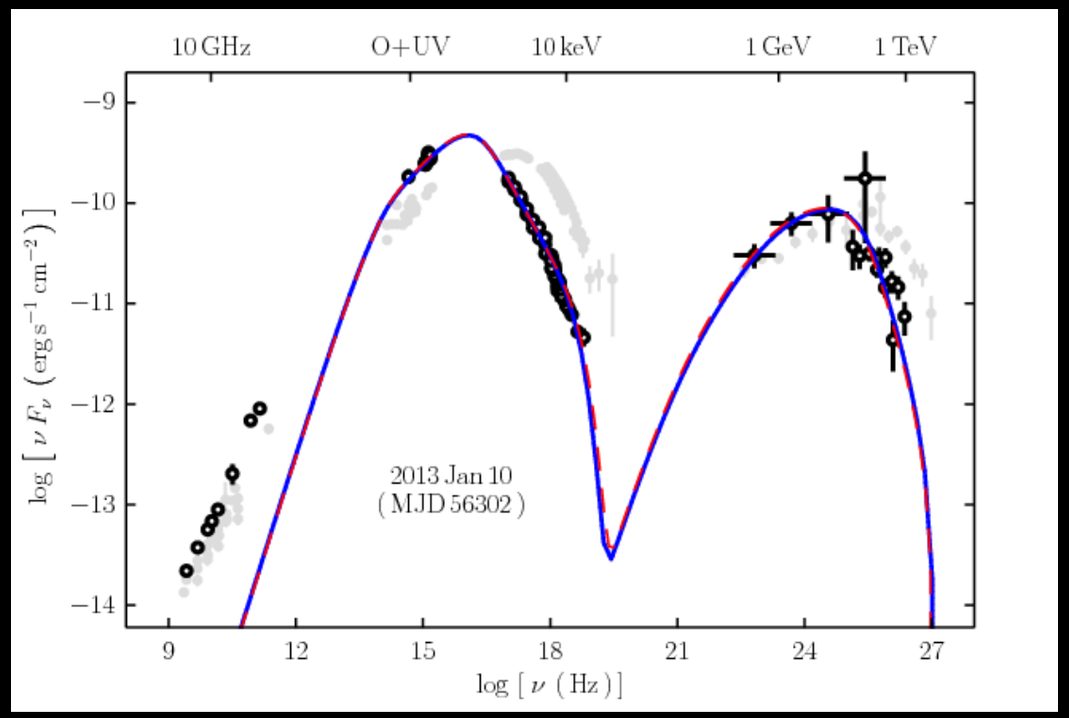
Spiral

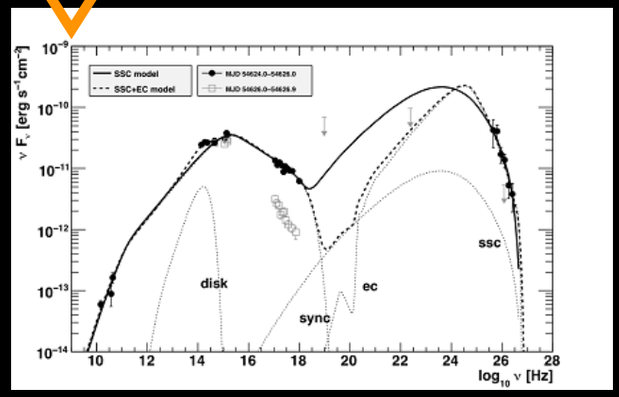
Galaxy **merger**

Elliptical

Accretion ($\dot{m}$) ramps up, starting a luminous **quasar** phase (e.g. 3C 279)

Reduced gas supply, reduced radiative cooling, particle acceleration to TeV energies: **TeV BL Lac** (e.g. Mrk 421)



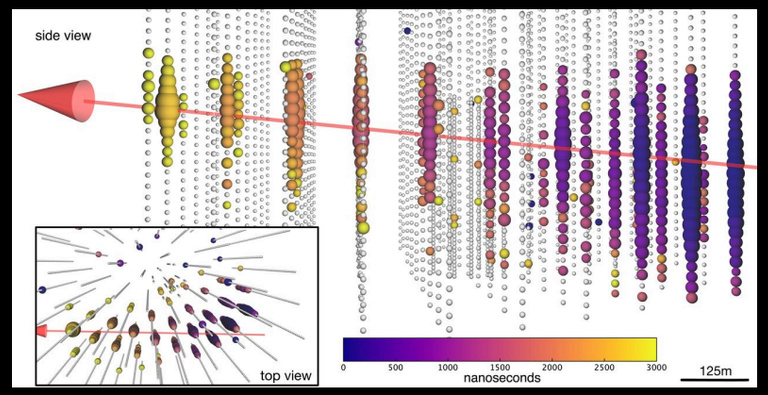


$\dot{m}$ starts to decrease, decreasing luminosity, optically-thick disk: **BL Lac** (e.g. W Comae)

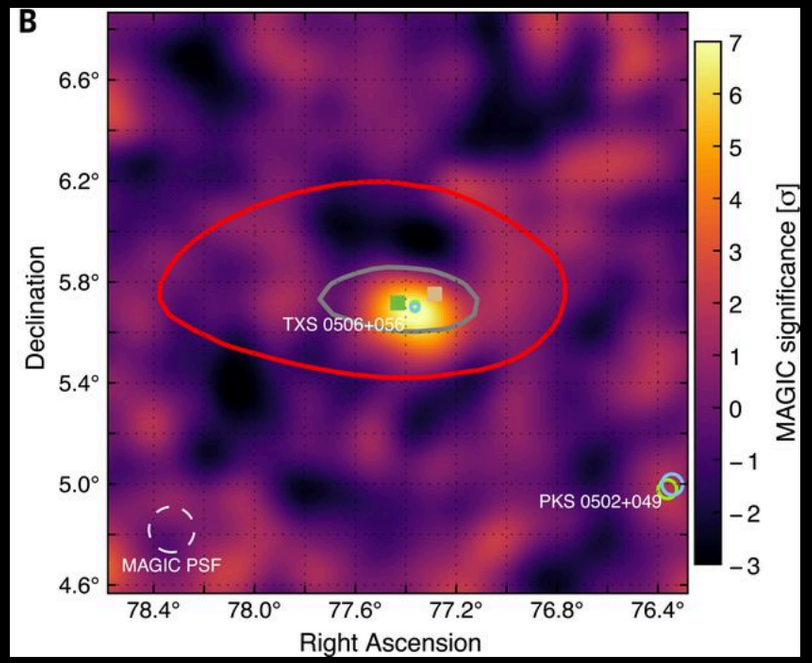
Do TeV BL Lacs represent a late evolutionary phase of AGN?
- Compare redshift evolution of GeV and TeV-selected BL Lacs ($\langle V/V_{max} \rangle$ method)

Science goals: origin of cosmic neutrinos

IceCube + others 2018

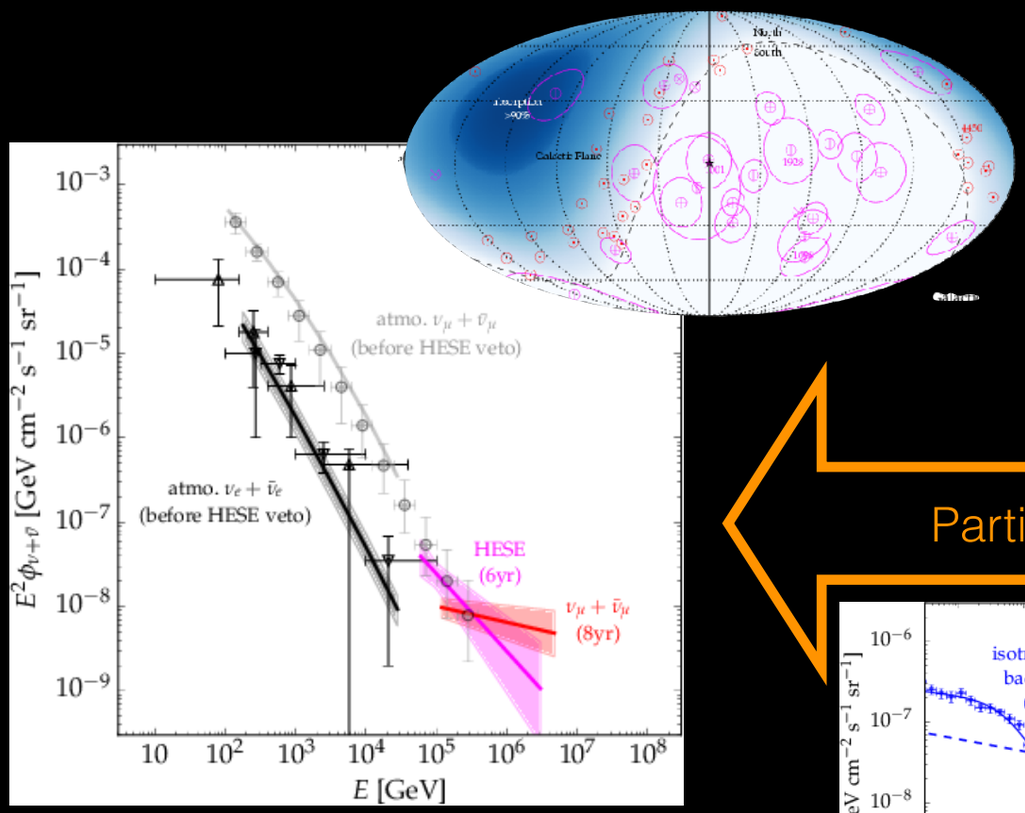


Low-significance correlation



Current link between neutrinos and TeV sources based on correlation of a few neutrino events with blazar flares (small data sample, low significance).

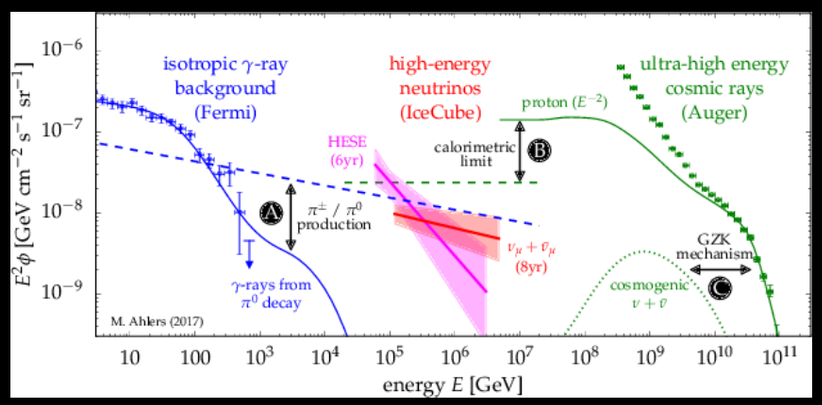
IceCube + others 2018



Ahlers & Halzen 2018

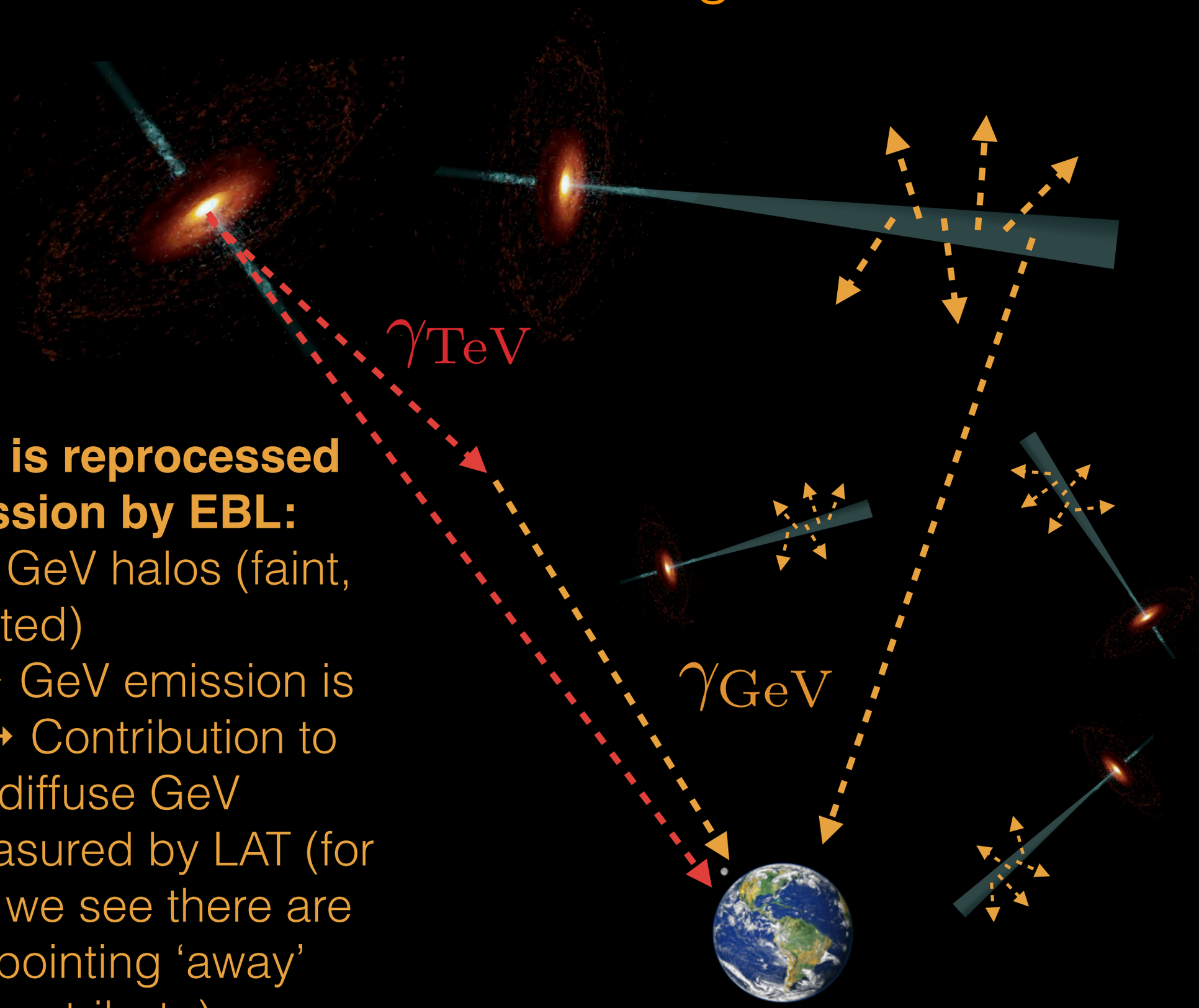
A TeV luminosity function measurement would predict the total neutrino flux measured by IceCube [3]

Particle physics + jet physics



TeV Luminosity Function

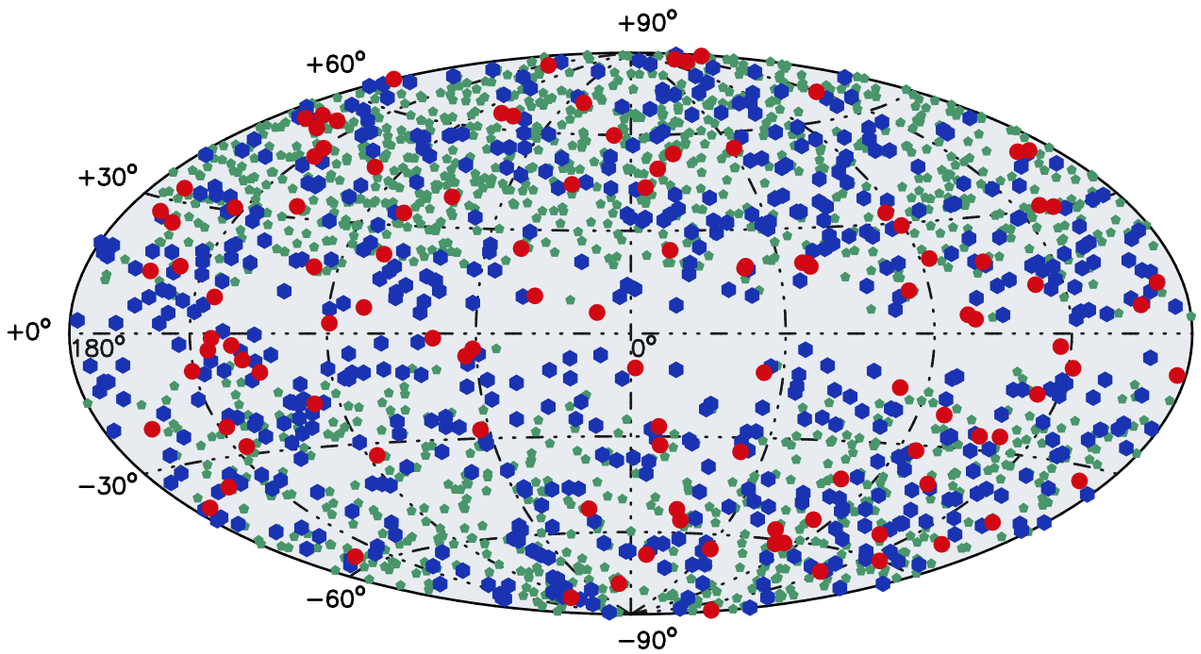
Science: Pair cascades and intergalactic B field



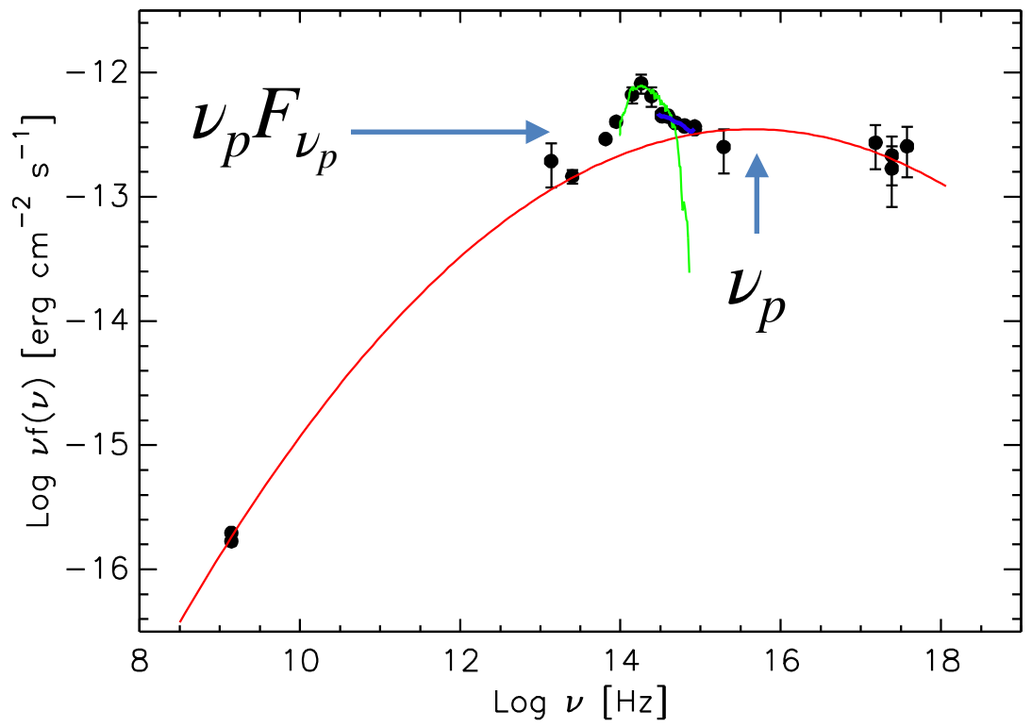
TeV emission is reprocessed into GeV emission by EBL:

- Low B_{IGMF} → GeV halos (faint, not yet detected)
- High B_{IGMF} → GeV emission is isotropized → Contribution to the isotropic diffuse GeV emission measured by LAT (for each BL Lac we see there are $2\Gamma^2$ BL Lacs pointing 'away' from us that contribute).

The 3HSP catalog



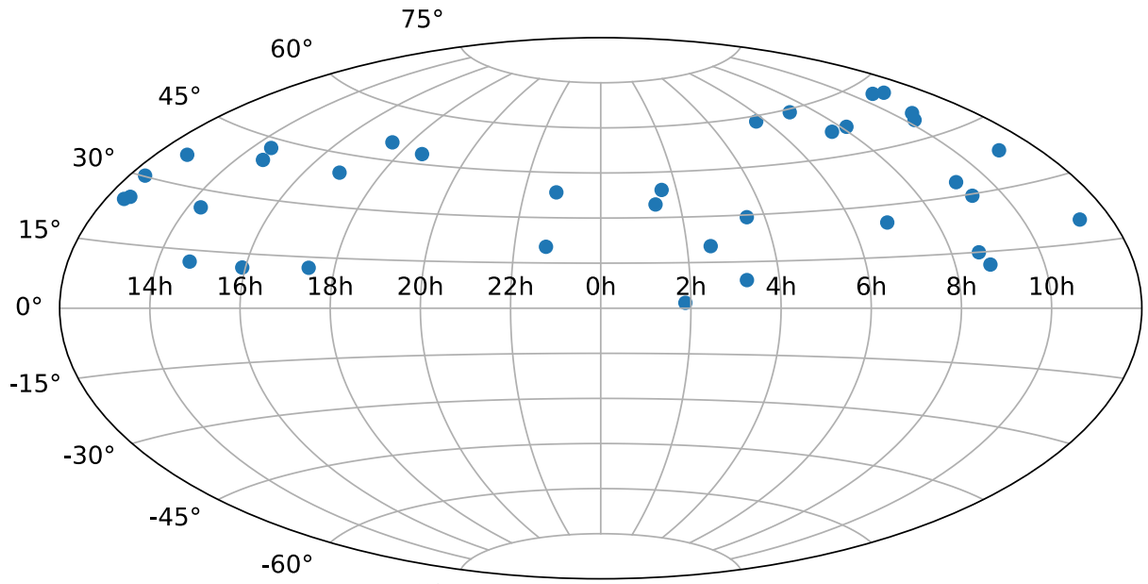
The 3HSP catalog (Chang et al. 2019)



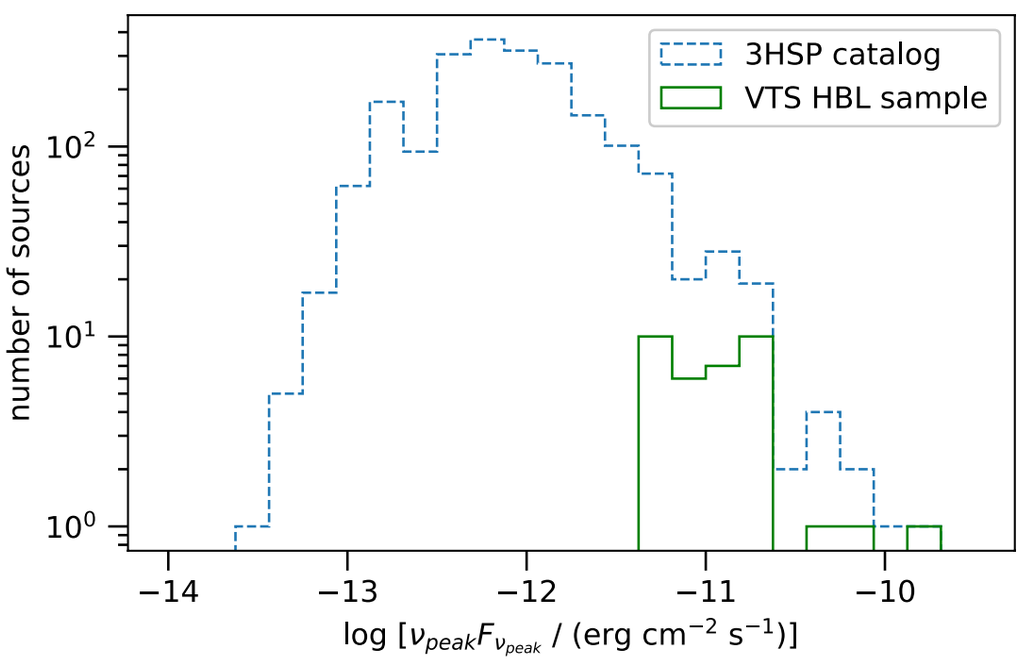
- The 3HSP catalog (Chang et al. 2019, A&A, 632, 77) uses radio and X-ray data to select high-frequency-peaked BL Lacs.
- The catalog includes 2013 sources with synchrotron peak > 10^{15} Hz and high degree of completeness.

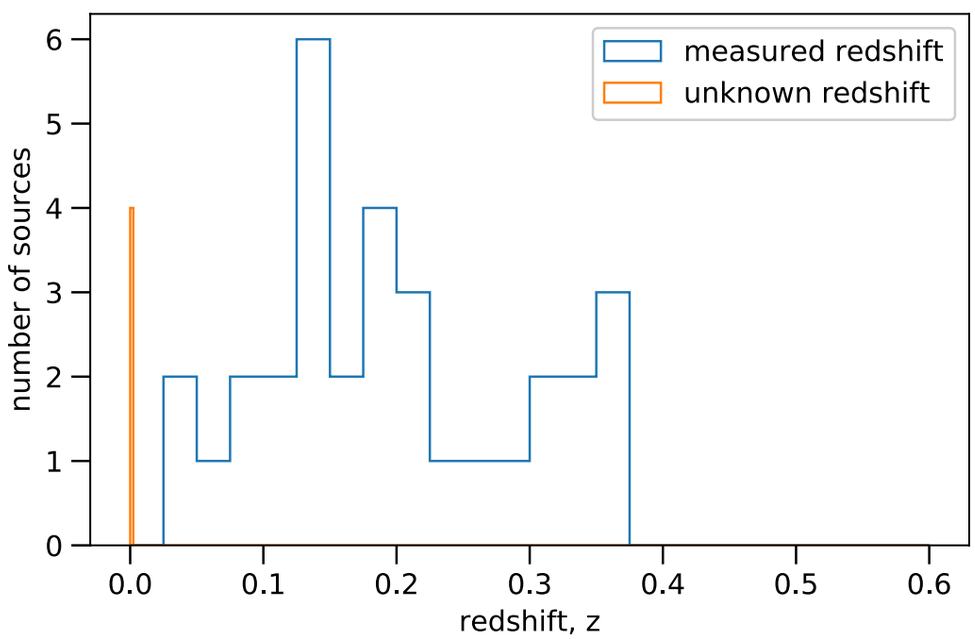
The VERITAS HBL sample

- Based on the 3HSP catalog (Chan et al. 2019): synchrotron peak in the UV to X-ray range.
- Good observing conditions with VERITAS: 1.7° < decl. < 61.7°.
- Off the galactic plane: |b|>10°.
- Estimated synchrotron peak luminosity > 6.3×10^{-12} erg cm^{-2} s^{-1}.
- Total of 36 sources (22 in TeVCat).



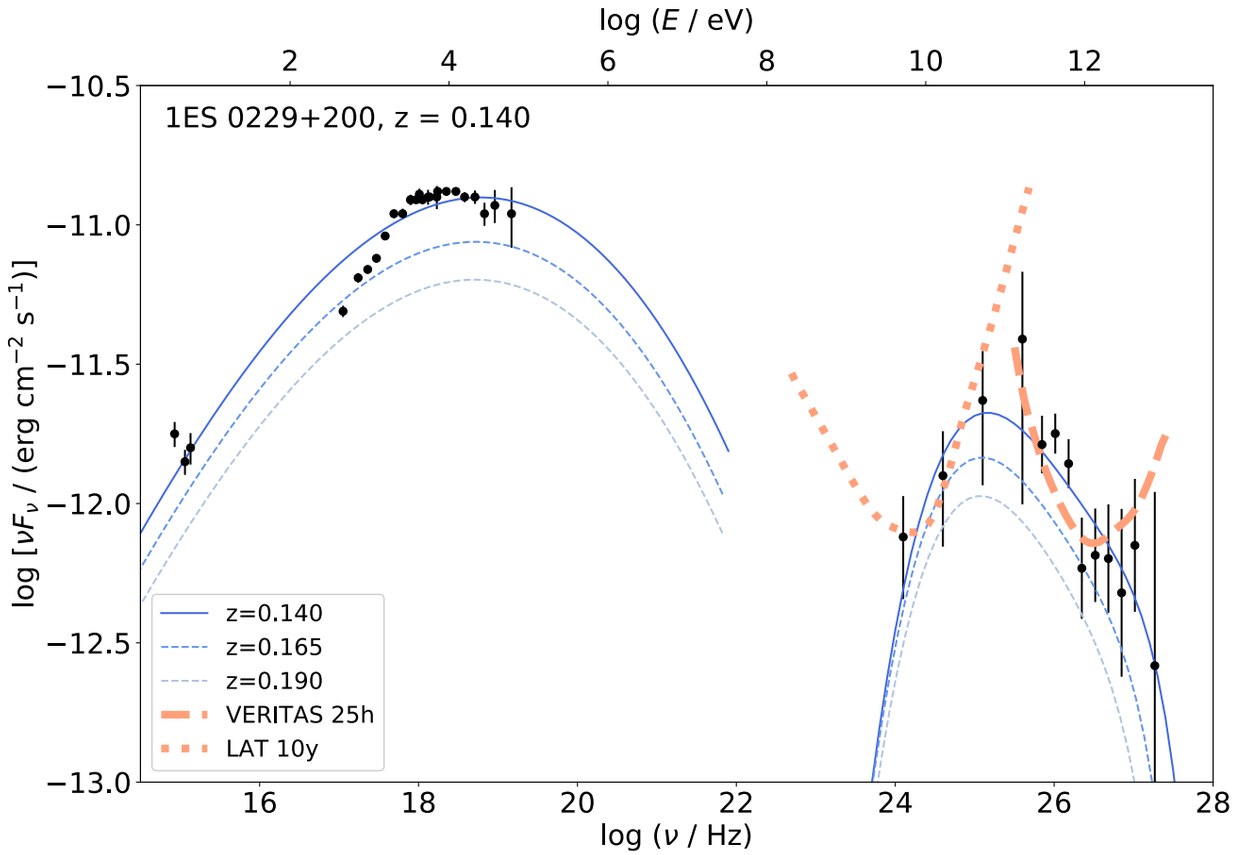
The VERITAS HBL sample, in celestial coordinates.





Observing strategy

- VERITAS has more than 1,800h of exposure on the 36 sources that are included in the VERITAS HBL sample.
- Since 2019, we have obtained an additional 155h of dedicated observations.
- All 36 objects have at least 8h of exposure.



- ToO observations and exposures that were triggered by high flux states reported in the TeV band or at any other wavelength are excluded from analysis to avoid bias towards flaring states.

Summary and outlook

- Observations of a selected sample of 36 HBLs with VERITAS constitute the first attempt of an unbiased characterization of the TeV flux from high-synchrotron-peaked blazars.
- Analysis of ~2,000h of VERITAS data is underway. Additional exposures to be completed by 2022.

Backup slides

Object	RA (J2000)	decl. (J2000)	z	TeVCat?
1ES 0120+340	01:23:08.6	+34:20:48.5	0.270	
RGB J0136+391	01:36:32.6	+39:05:59.2		Y
RGB J0152+017	01:52:39.6	+01:47:17.4	0.080	Y
1ES 0229+200	02:32:48.6	+20:17:17.3	0.139	Y
RGB J0316+090	03:16:12.7	+09:04:43.2	0.372	
1FGL J0333.7+2919	03:33:49.0	+29:16:31.5		
GB6 J0540+5823	05:40:30.0	+58:23:38.4		
1ES 0647+250	06:50:46.5	+25:02:59.5	0.203	Y
RGB J0710+591	07:10:30.1	+59:08:20.5	0.120	Y
PGC 2402248	07:33:26.8	+51:53:55.9	0.090	Y
1ES 0806+524	08:09:49.2	+52:18:58.3	0.137	Y
87GB 083437.4+150850	08:37:24.6	+14:58:20.6	0.278	
RGB J0847+115	08:47:12.9	+11:33:50.2	0.198	Y
RX J0910.6+3329	09:10:37.0	+33:29:24.4	0.350	
B2 0912+29	09:15:52.4	+29:33:24.0	0.190	
1ES 1011+496	10:15:04.1	+49:26:00.8	0.200	Y
1ES 1028+511	10:31:18.5	+50:53:35.9	0.360	
RGB J1037+571	10:37:44.3	+57:11:55.7	0.330	

Table 1: The VERITAS HBL sample. Some of the quoted redshifts are uncertain.

Object	RA (J2000)	decl. (J2000)	z	TeVCat?
RGB J1058+564	10:58:37.7	+56:28:11.2	0.143	
Mrk 421	11:04:27.3	+38:12:31.9	0.030	Y
RX 1117.1+2014	11:17:06.3	+20:14:07.5	0.138	
1ES 1218+304	12:21:22.0	+30:10:37.2	0.180	Y
MS 1221.8+2452	12:24:24.2	+24:36:23.6	0.218	Y
S3 1227+25	12:30:14.1	+25:18:07.1	0.135	Y
RGB J1243+364	12:43:12.7	+36:27:44.0	0.310	
RBS 1366	14:17:56.7	+25:43:25.9	0.240	
H 1426+428	14:28:32.6	+42:40:21.0	0.129	Y
RGB J1439+395	14:39:17.5	+39:32:42.8	0.344	
1ES 1440+122	14:42:48.2	+12:00:40.3	0.160	Y
PG 1553+113	15:55:43.0	+11:11:24.4	0.360	Y
Mrk 501	16:53:52.2	+39:45:36.5	0.030	Y
H 1722+119	17:25:04.3	+11:52:15.5	0.180	Y
1ES 1727+502	17:28:18.6	+50:13:10.5	0.055	Y
RGB J1838+480	18:38:49.1	+48:02:34.4	0.300	
RGB J2243+203	22:43:54.7	+20:21:03.8		Y
B3 2247+381	22:50:05.7	+38:24:37.2	0.119	Y

Table 1: The VERITAS HBL sample. Some of the quoted redshifts are uncertain.