



Unbiased survey of high-frequency-peaked BL Lacs with VERITAS



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For The VERITAS Collaboration



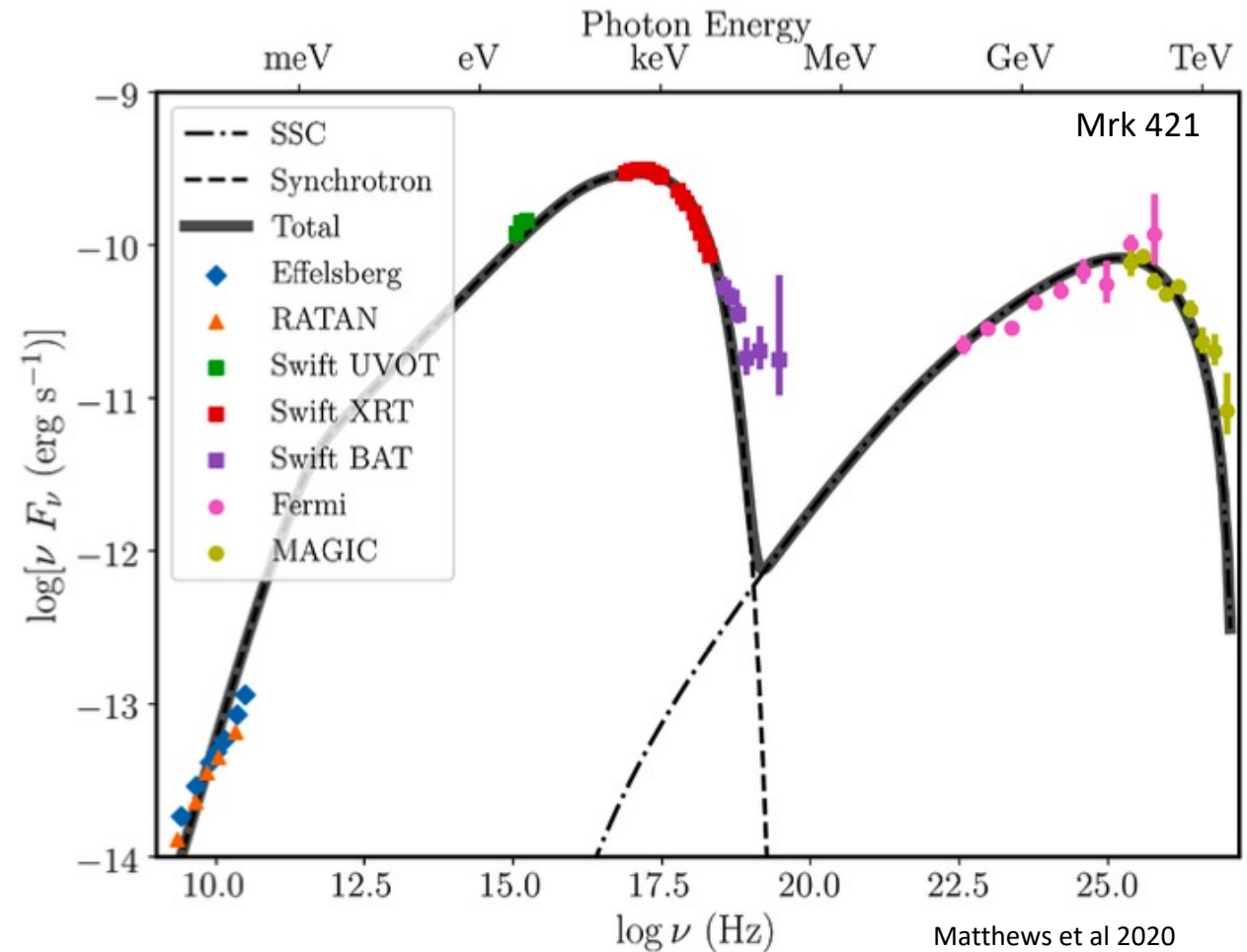
Overview

- VERITAS survey of high-frequency-peaked BL Lacs (HBLs)
- Looking for unbiased estimates of TeV flux of HBLs (reported fluxes often biased towards flares), and new detections of TeV blazars
- Ultimate goal – TeV luminosity function for X-ray selected HBLs



High-frequency peaked BL Lacs (HBLs)

- Double-peaked spectra:
 - Lower-energy peak: Synchrotron
 - Higher-energy peak: Inverse Compton
- BL Lac classification by lower-energy peak
 - HBL synchrotron peak $> 10^{15}$ Hz (UV or X-ray)



VERITAS (Very Energetic Radiation Imaging Telescope Array System)

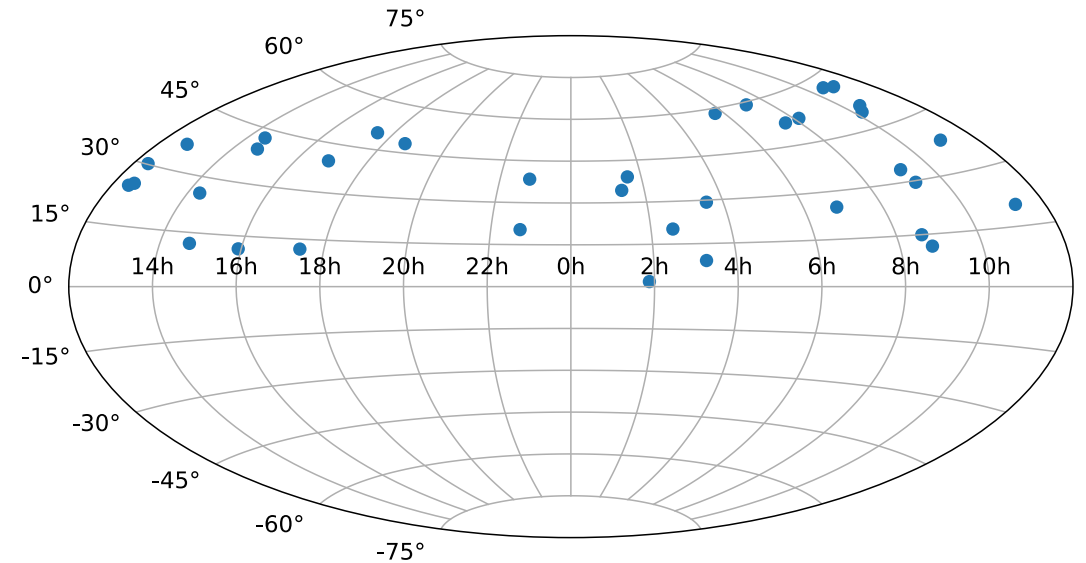
- Began operation in 2007
- Ground-based GeV-TeV gamma-ray observatory in Arizona
- Image Atmospheric Cherenkov Telescope (IACT), four 12-meter optical telescopes
- Most sensitive 100 GeV – 10 TeV



VERITAS

VERITAS HBL Sample

- Based on the 3HSP catalog (Chan et al. 2019):
 - Radio and X-ray selected HBLs
 - Contains 2013 sources with synchrotron peak $> 10^{15}$ Hz (UV to X-ray range)
- Estimated synchrotron peak luminosity $> 6.3 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$.
- Total of 36 sources (21 previously detected at TeV energies)



The VERITAS HBL sample, in celestial coordinates.

Analysis Strategy

- Remove observational bias
 - HBLs generally observed in flaring states
 - Exclude observations triggered by reported high flux states in TeV or other wavelengths
- Combine archive data with new dedicated observations taken in the last three years
 - >2100 archival hours
 - 160 hours of new observations

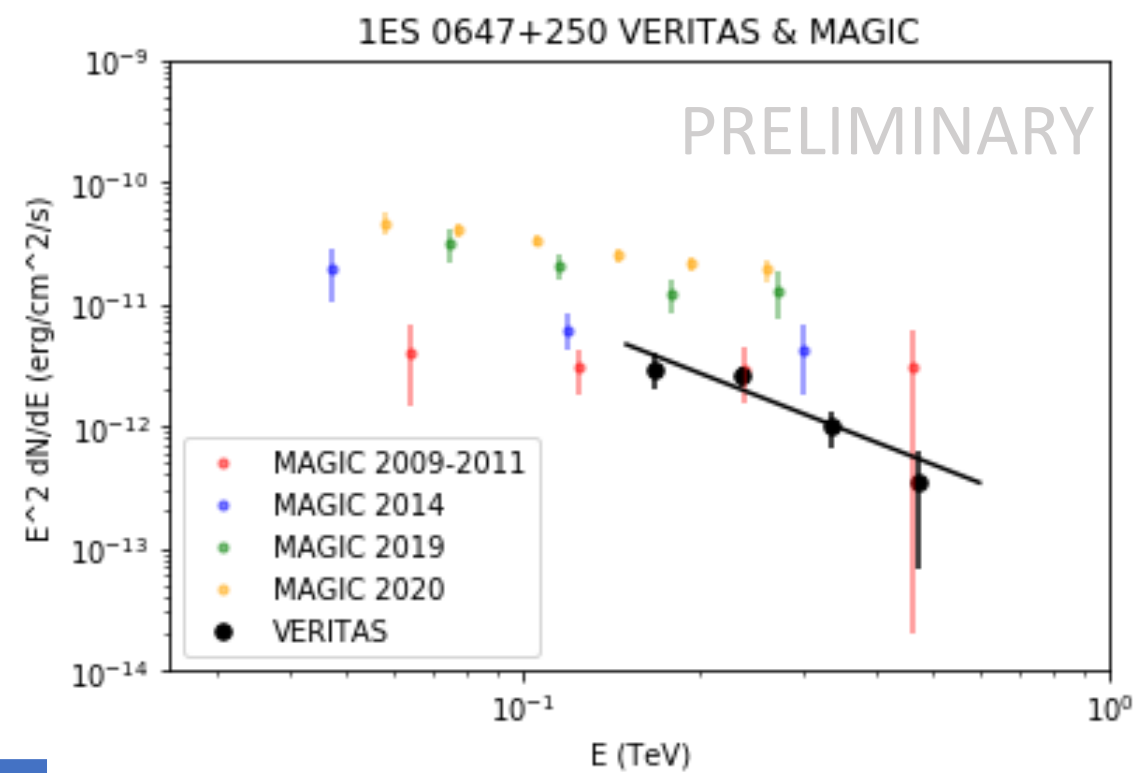


Analysis Status

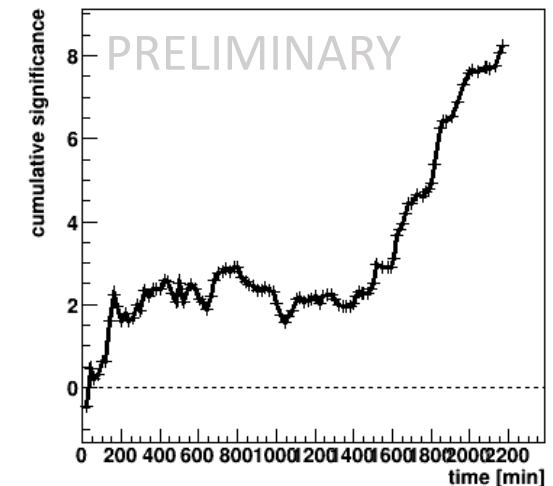
- Completed analysis of 25 of the 36 sources in the HBL sample
 - 15/15 previously non-detected in TeV
 - 10/21 known TeV sources
 - All exposures >7h after quality selection
- 2 sources > 5σ
- 3 sources > 3σ

1ES 0647+250

- MAGIC paper (2023) – low activity detection in 2009-2011, three flares in 2014, 2019, and 2020



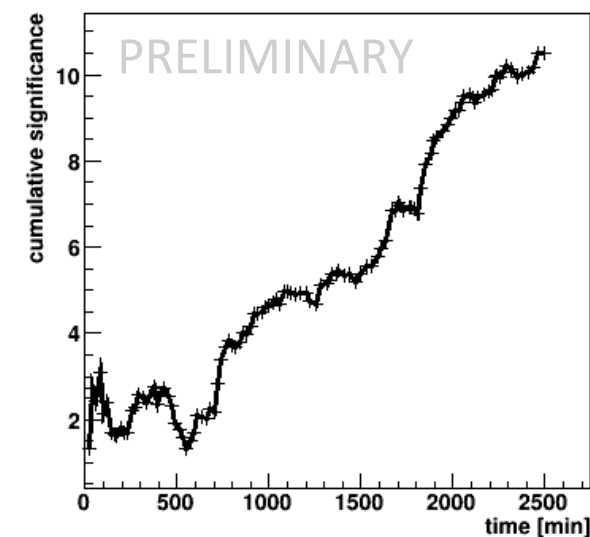
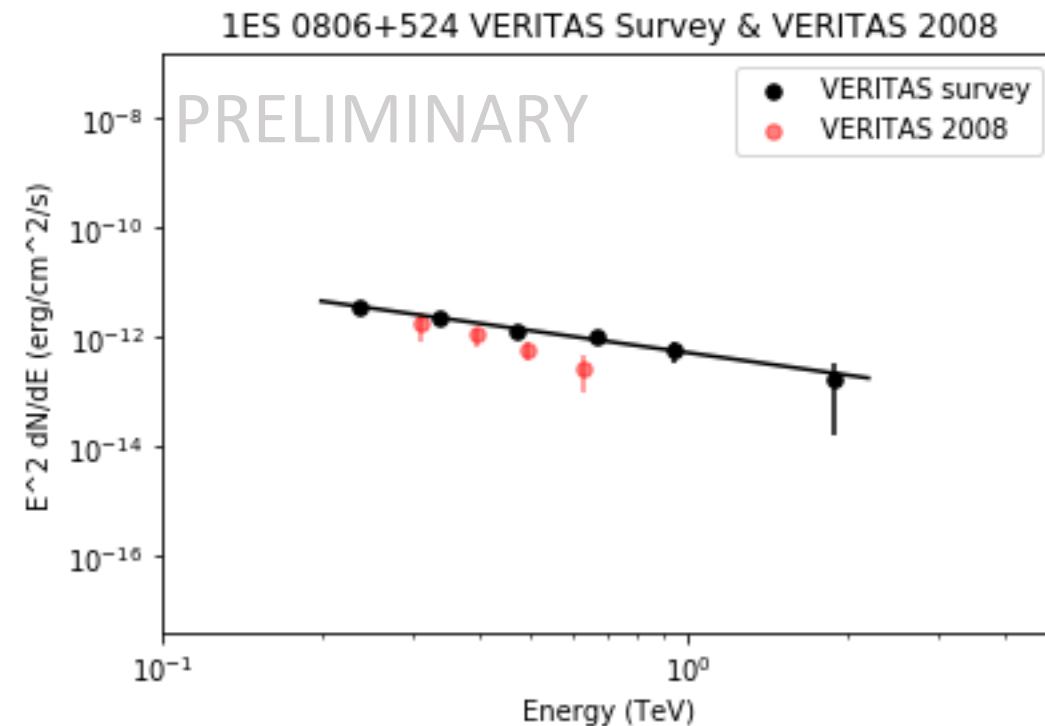
	Significance	Spectral index	Flux > 100 GeV (% C.U.)
VERITAS survey	8.32σ	3.88 ± 0.42	4.61 ± 0.58
MAGIC 2009-2011	5.5σ	3.12 ± 0.37	2.0 ± 0.5
MAGIC 2014	5.3σ	3.25 ± 0.74	3.4 ± 1.6
MAGIC 2019	6.1σ	3.73 ± 0.58	8.0 ± 1.8
MAGIC 2020	22.9σ	3.7 ± 0.21	15.0 ± 1.0



1ES 0806+524

- VERITAS paper (Acciari et al 2008) – first detection from observations in 2006- 2008

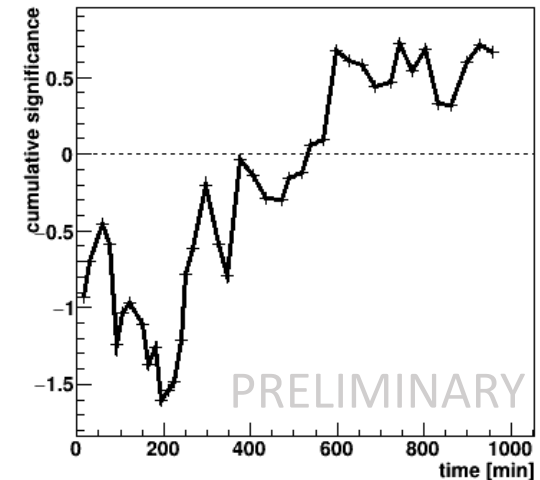
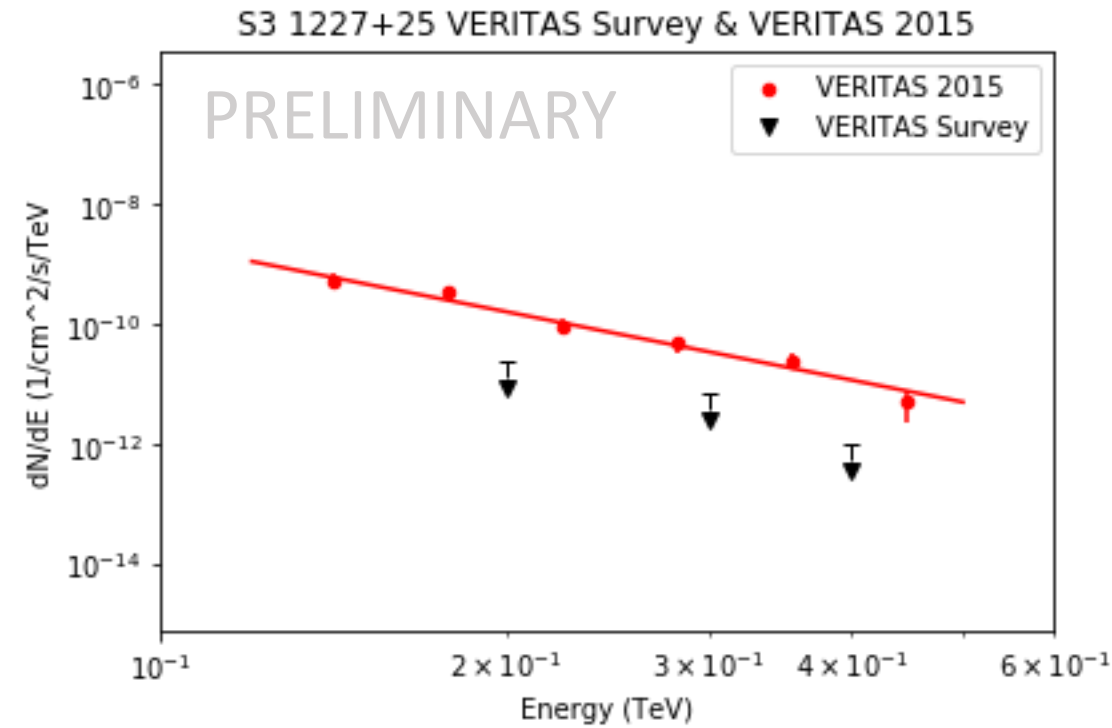
	Significance	Spectral index	Flux > 300 GeV ($10^{-12} \text{ cm}^{-2}\text{s}^{-1}$)
VERITAS survey	10.5σ	3.35 ± 0.21	2.3 ± 0.3
VERITAS 2006-2008	6.3σ	3.6 ± 1.3	2.2 ± 0.9



S3 1227+25

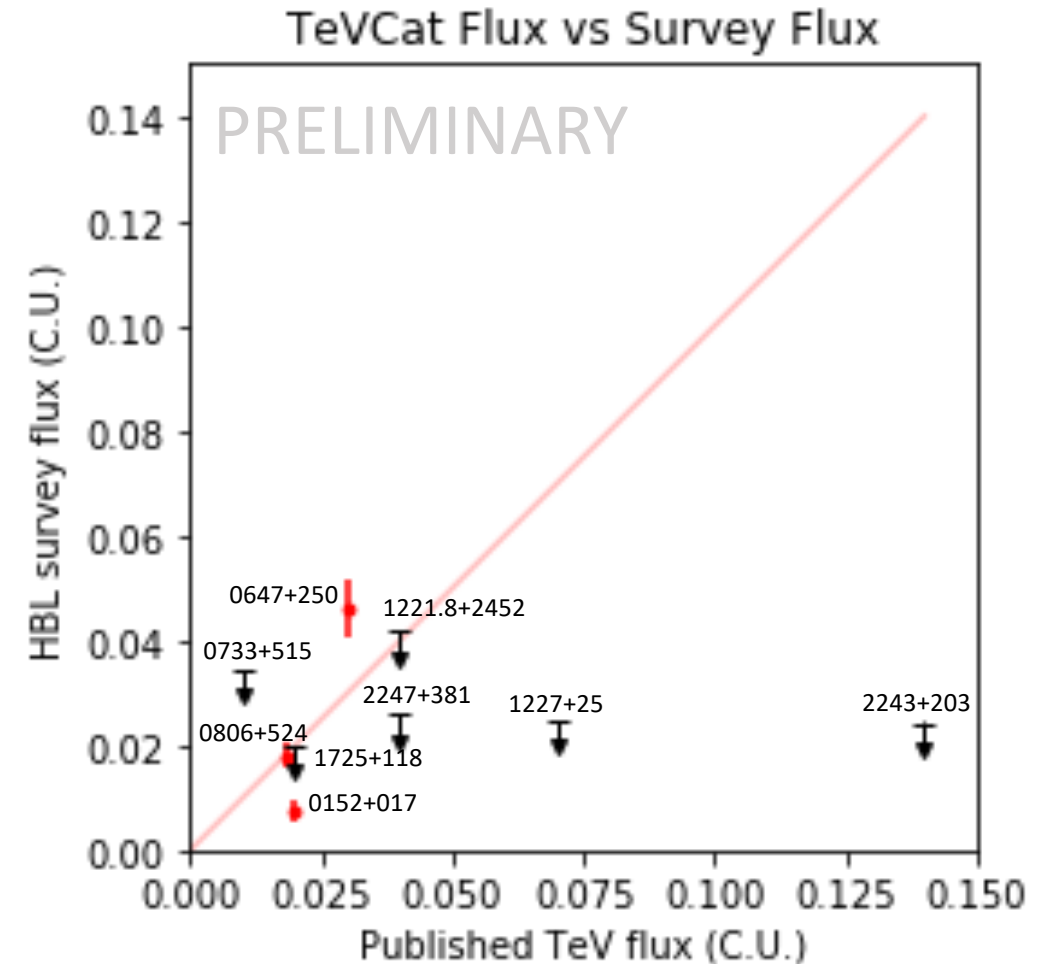
- VERITAS paper (Acharyya et al 2023)
 - detection during flare in May 2015, triggered by Fermi-LAT

	Exposure hours	Significance	Spectral index	Flux > 120 GeV ($10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$)
VERITAS survey	16	0.5σ	3 (assumed)	< 1.25 (99% CL)
VERITAS 2015	5	13σ	3.79 ± 0.4	4.51 ± 0.44



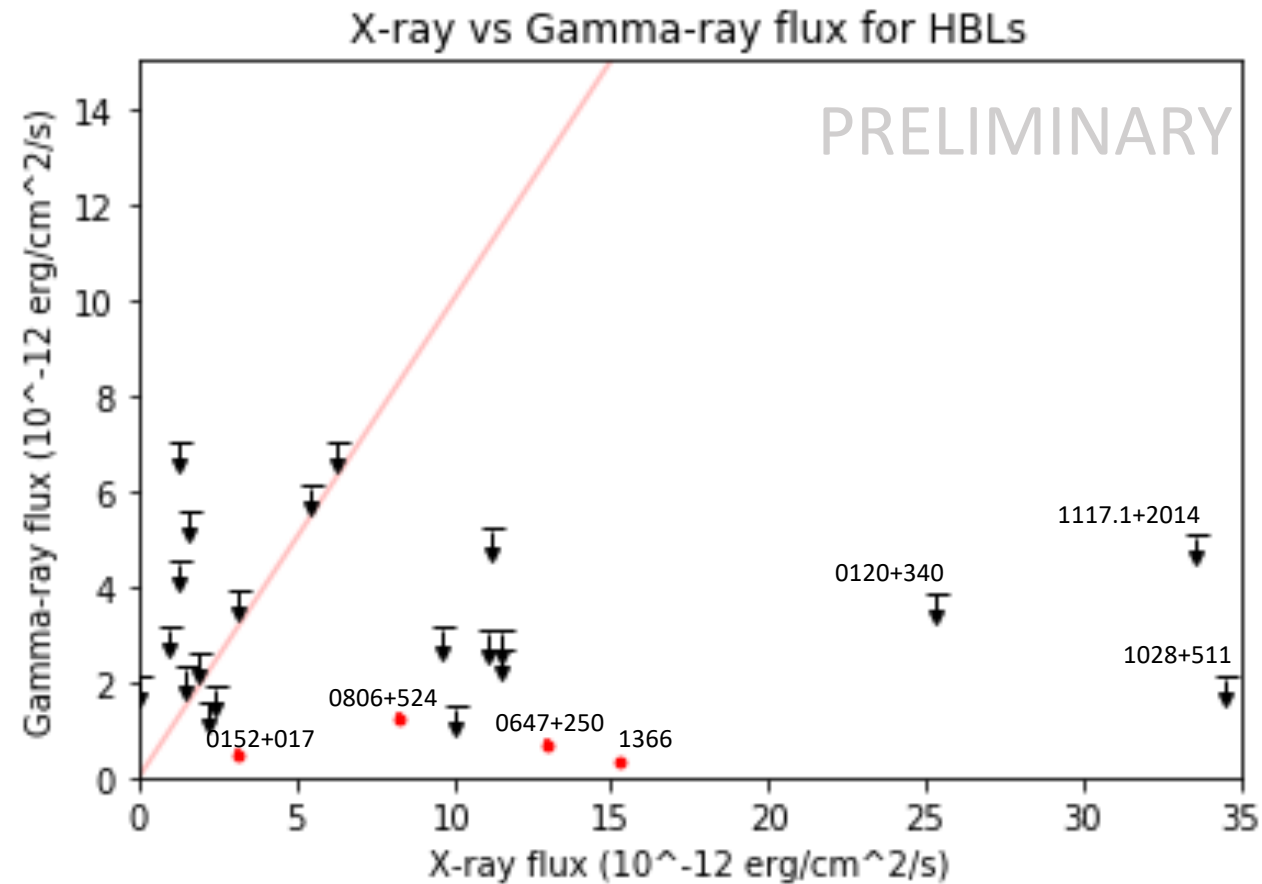
Flux comparisons to published data

- Comparison of published flux values from TeVCat to HBL survey flux values/ULs above the same energies



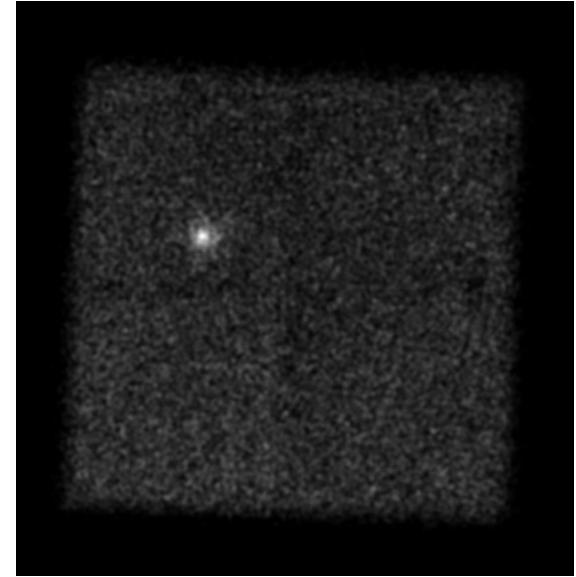
X-ray flux vs TeV flx

- Gamma-ray flux > 200 GeV
(VERITAS data from this survey)
- X-ray flux between 0.1-2.4 keV
(ROSAT data from BZCat)



NuSTAR observations

- NuSTAR proposal accepted for observations of 6 sources from our unbiased survey
 - 1ES 0647+250
 - 1ES 0806+524
 - 1ES 1028+511
 - MS 1221.8+2452
 - RBS 1366
 - RGB J1725+118
- Observations for two sources have already taken place (MS 1221.8+2452 and 1ES 1028+511)



Summary and outlook

- Analysis is underway (>2/3 sources completed)
 - One >4 sigma observation from new TeV blazar
 - Revised unbiased flux estimates for many others
- Will find fluxes or flux upper limits and spectral information when possible for each source
- Survey results will lead to first measurement of luminosity function of TeV blazars
- NuSTAR observations in progress

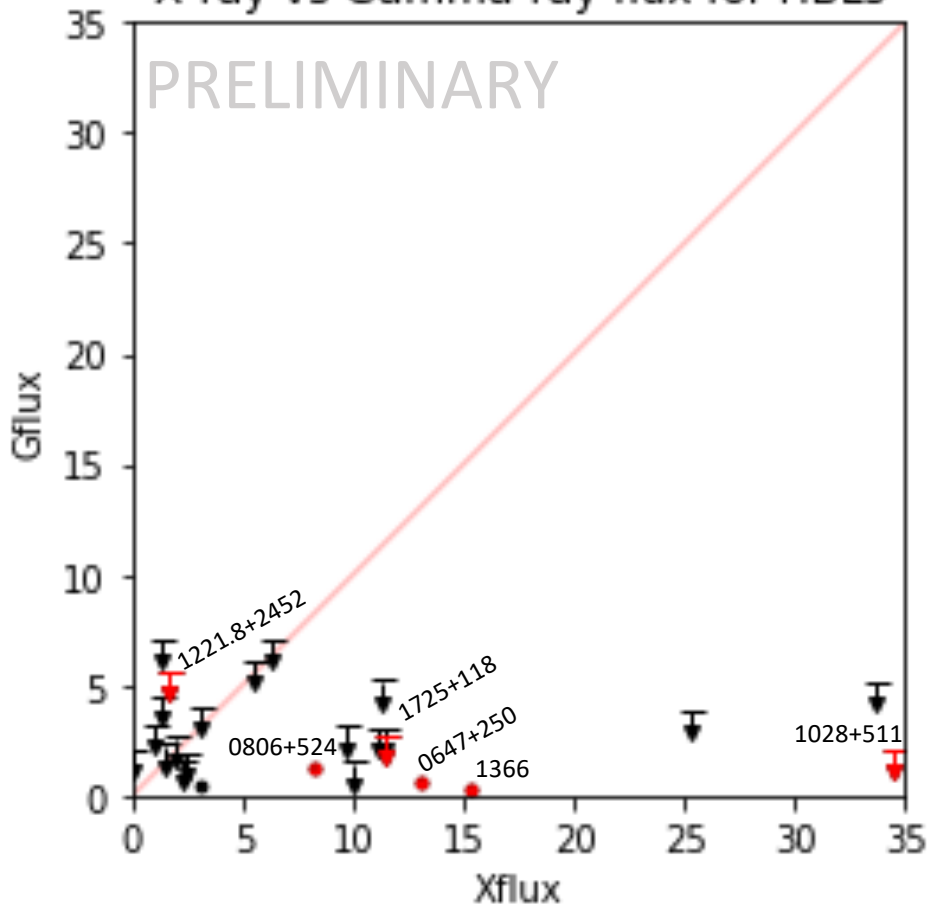


Backup slides

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	
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.

X-ray vs Gamma-ray flux for HBLs



Sources with scheduled NuSTAR observations marked in red and labeled