



The Swift Perspective of Very High Energy Sources Observed with VERITAS



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On behalf of the VERITAS Collaboration

VERITAS: Ground-based γ -ray Observatory



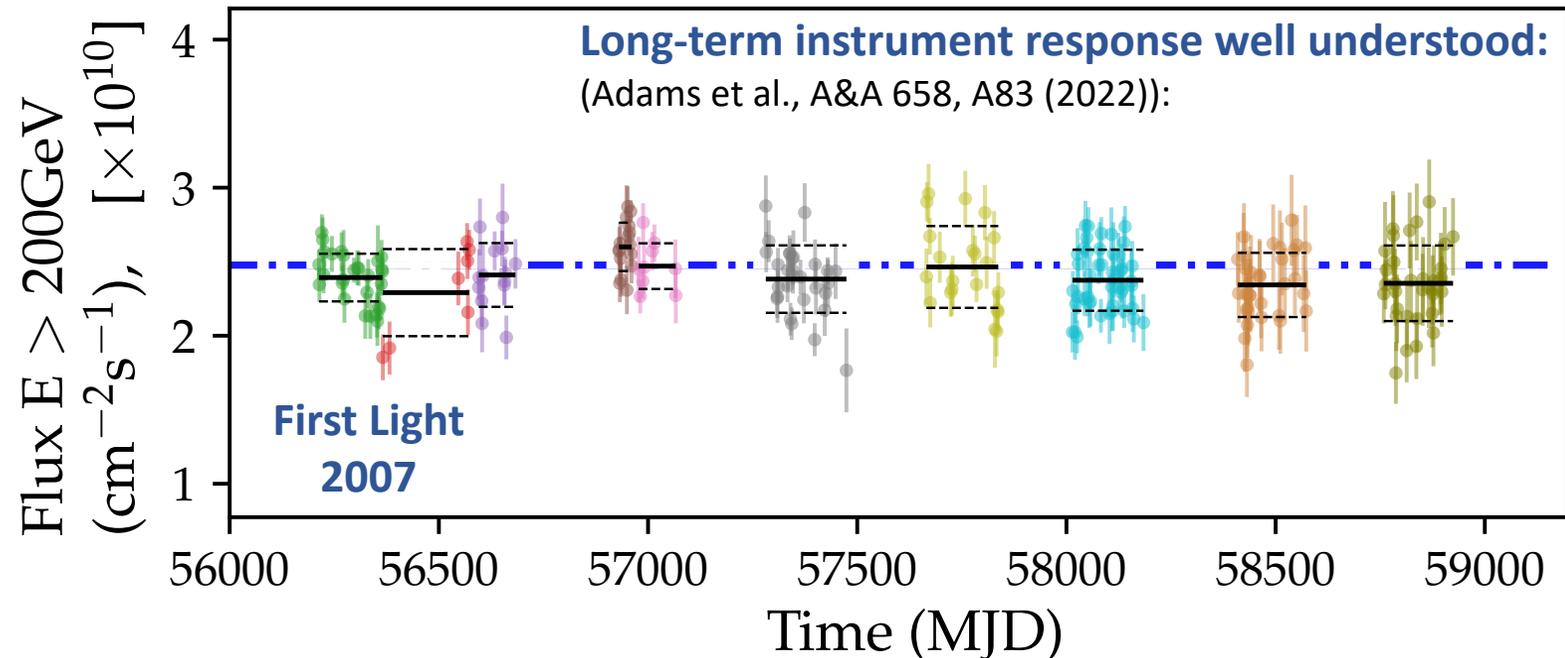
Photo credit: John Quinn

Aurora Interruptions, 5th May 2024

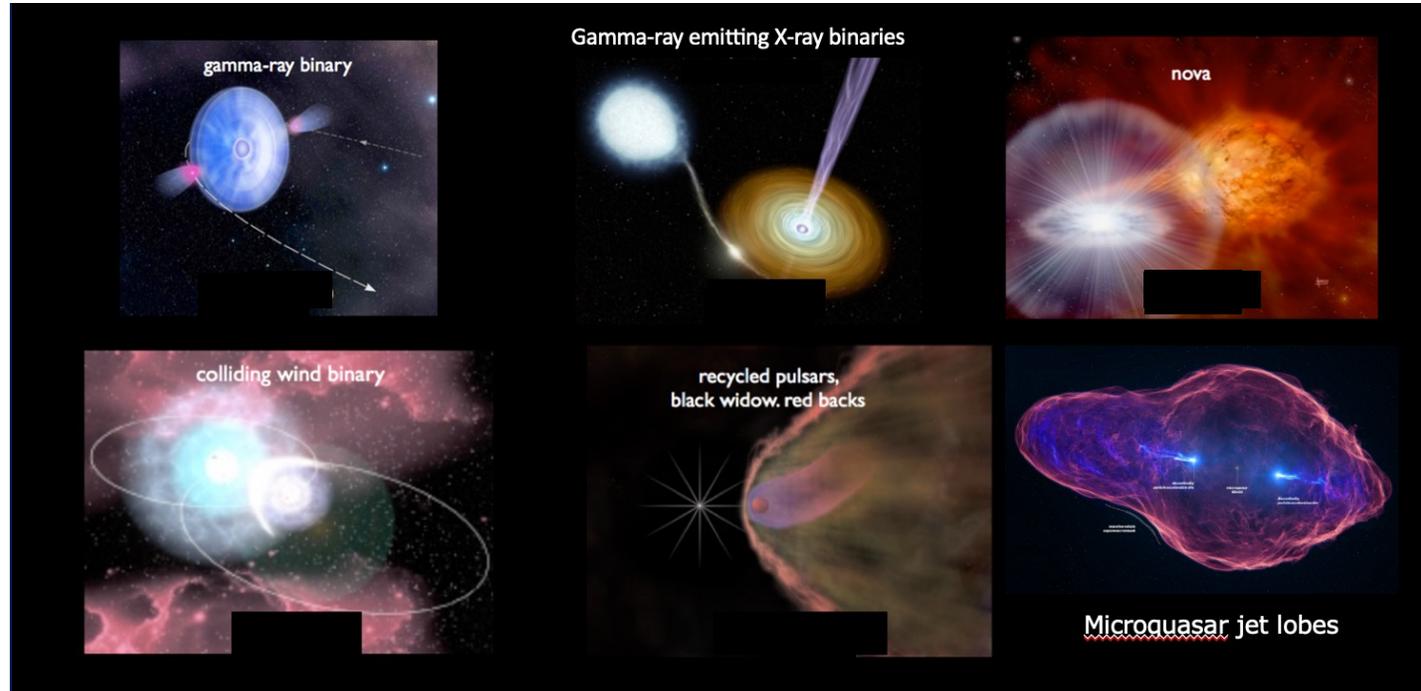
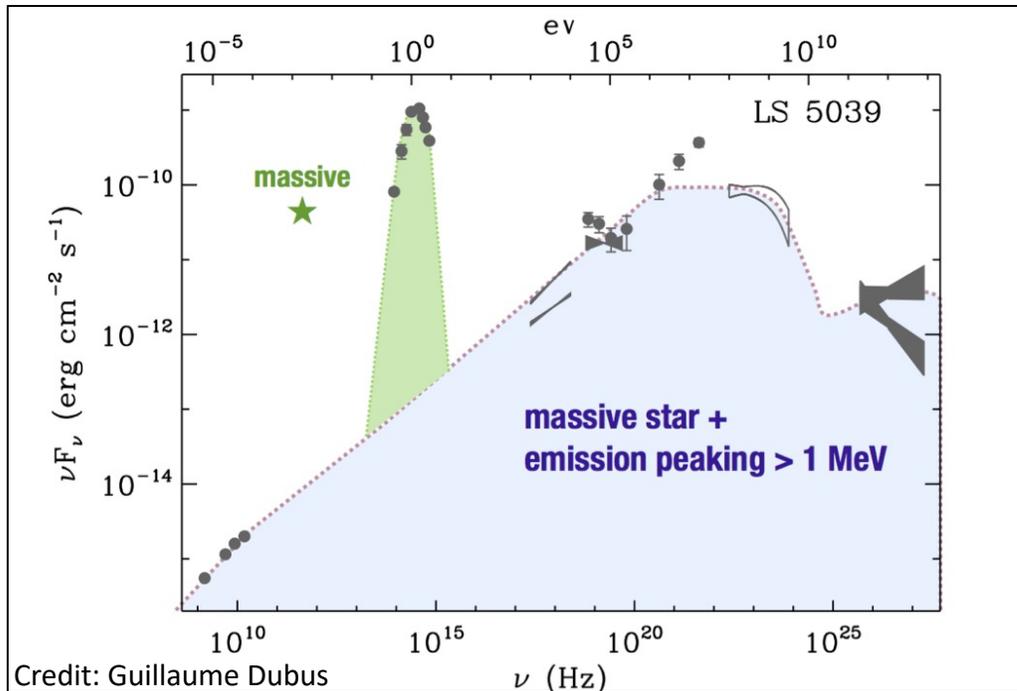
Field of View	3.5° diameter	Angular Resolution (r_{68})	$\sim 0.08^\circ$ @ 1 TeV
Energy Range	~ 85 GeV to ~ 30 TeV	Energy Resolution	$\sim 17\%$
Effective Area	$\sim 10^5$ m ² at 1 TeV	Sys. Errors: Flux	$\sim 20\%$
Sensitivity	1% Crab in < 25 h	Sys. Errors: Spectral Index	~ 0.1

Lifelong Swift Coordination

- **Swift data in 63 of VERITAS' peer-reviewed publications**
- Swift observations regularly matched with VERITAS
 - Monitoring
 - Single-exposure
 - Preplanned and ToO

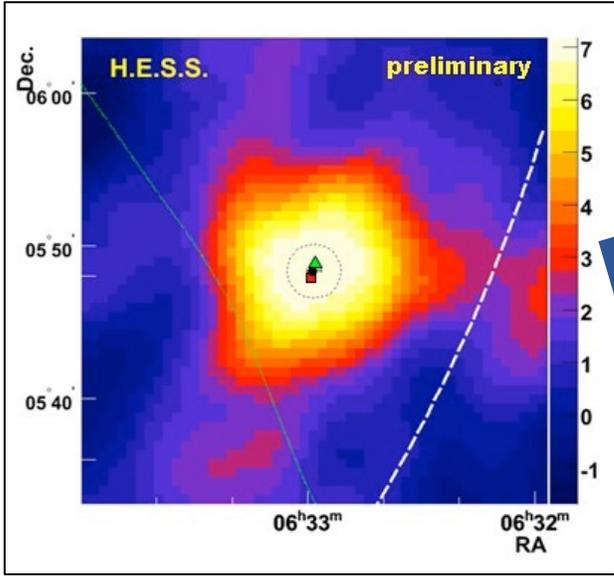


- Massive star + compact object (BH or NS)
- Periodic emission peaking $> 1\text{MeV}$.
- Natural particle accelerators with changing but regularly repeating environmental conditions.
- Provide a laboratory for particle acceleration, and gamma-ray production, emission and absorption processes.
- Each system unique – the population, as well as the data quality, is increasing.

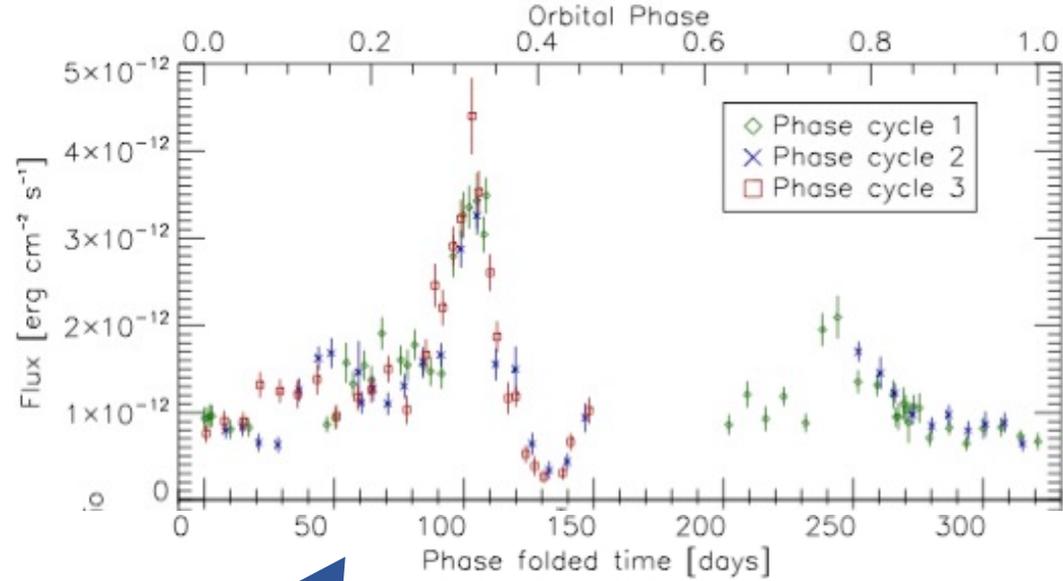




Predicting TeV Emission From HESS J0632+057

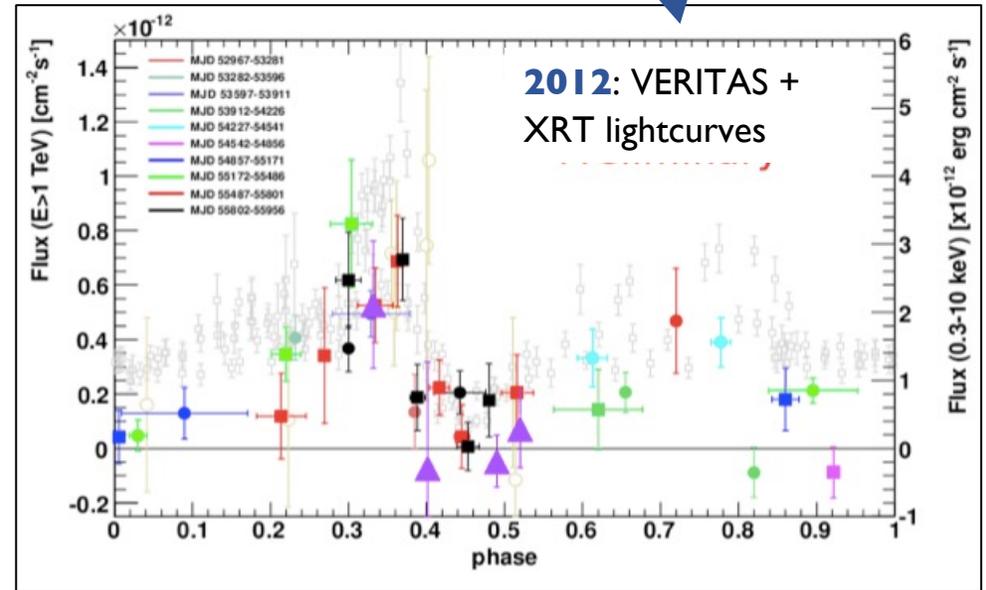
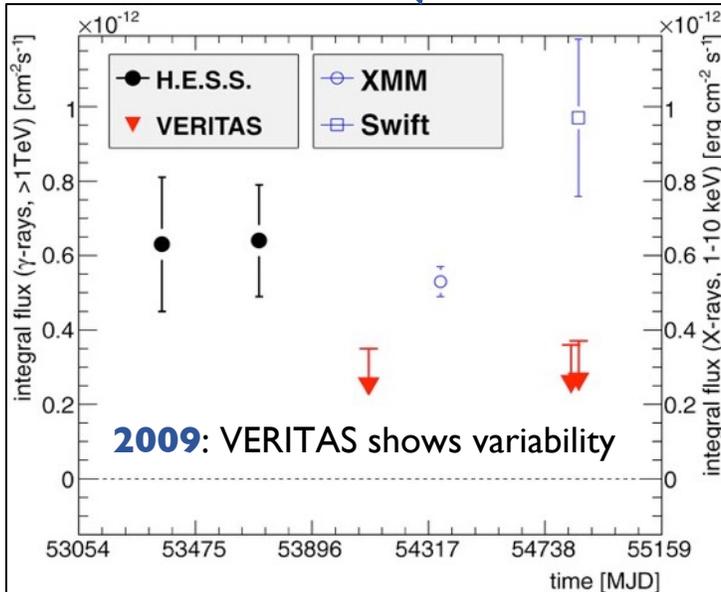


2007:
HESS discovers
TeV point
source



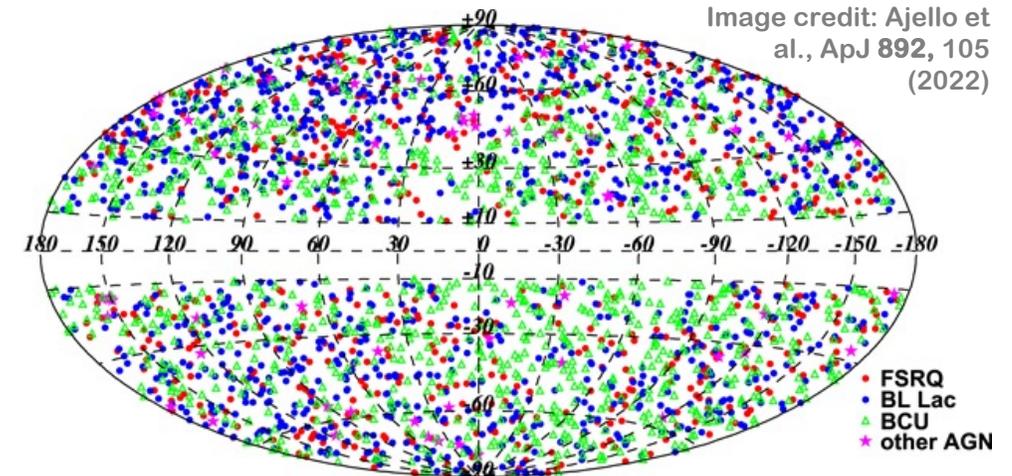
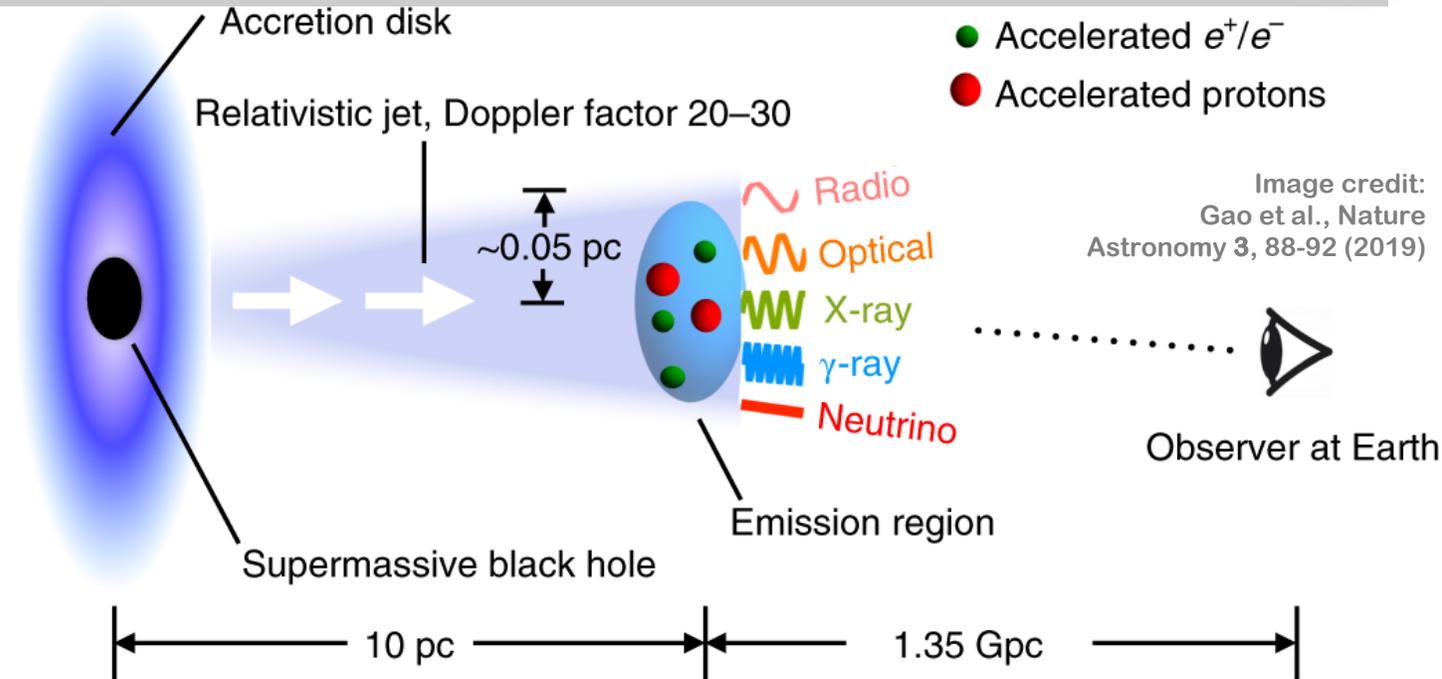
2009-2011:
Swift provides good
coverage to
understand variability

2011:
With Swift, a 315-
day period in X-
rays identified.



Gamma-ray Blazars

- Geometrically-selected jetted quasar.
- Powered by supermassive black holes at center.
- Produce beamed non-thermal emission
- Potential progenitors of neutrinos and ultra-high-energy cosmic rays.
- Most commonly detected type of gamma-ray emitter.



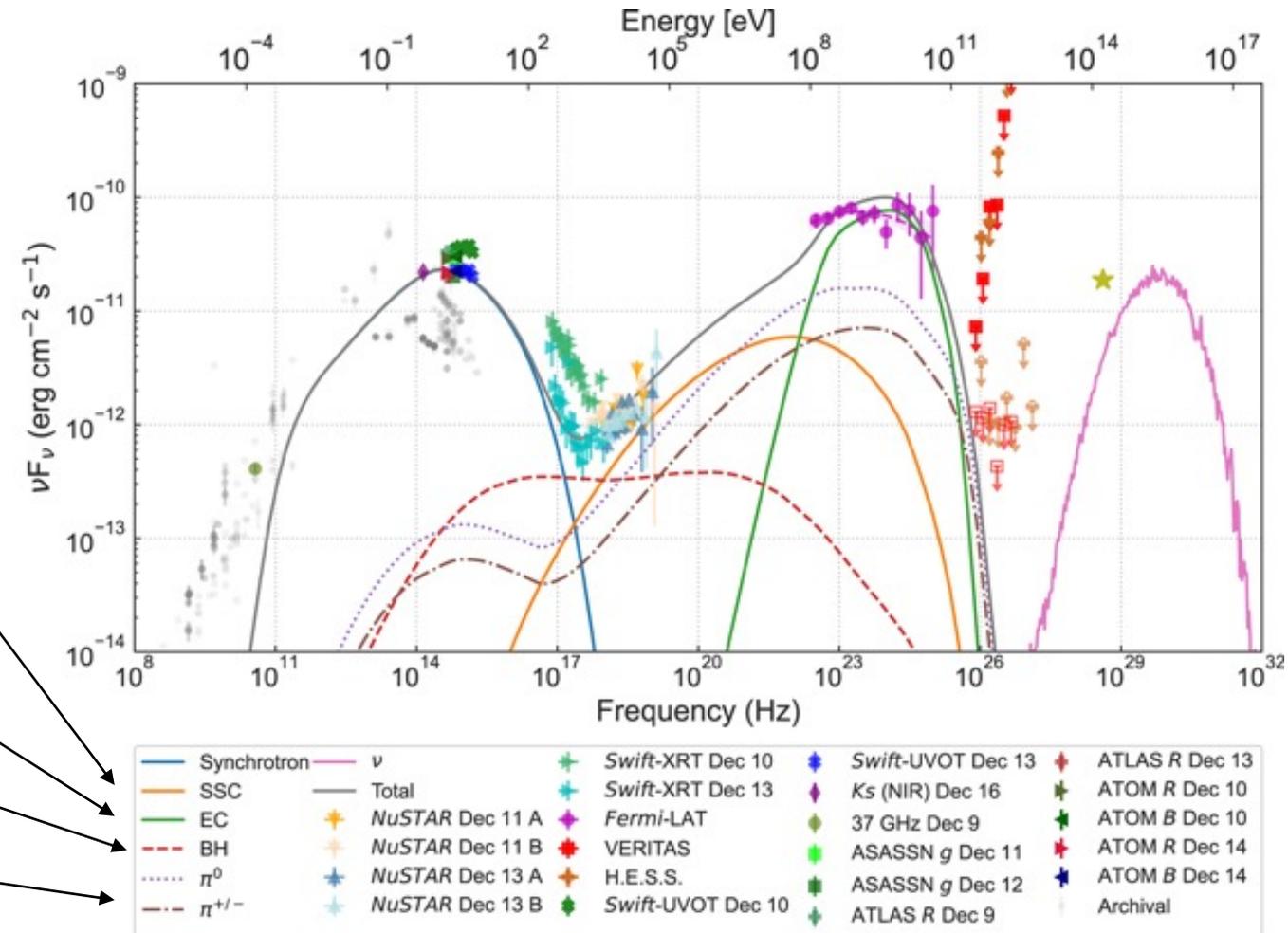
How are TeV photons made in blazars?

Synchrotron Self-Compton (SSC)

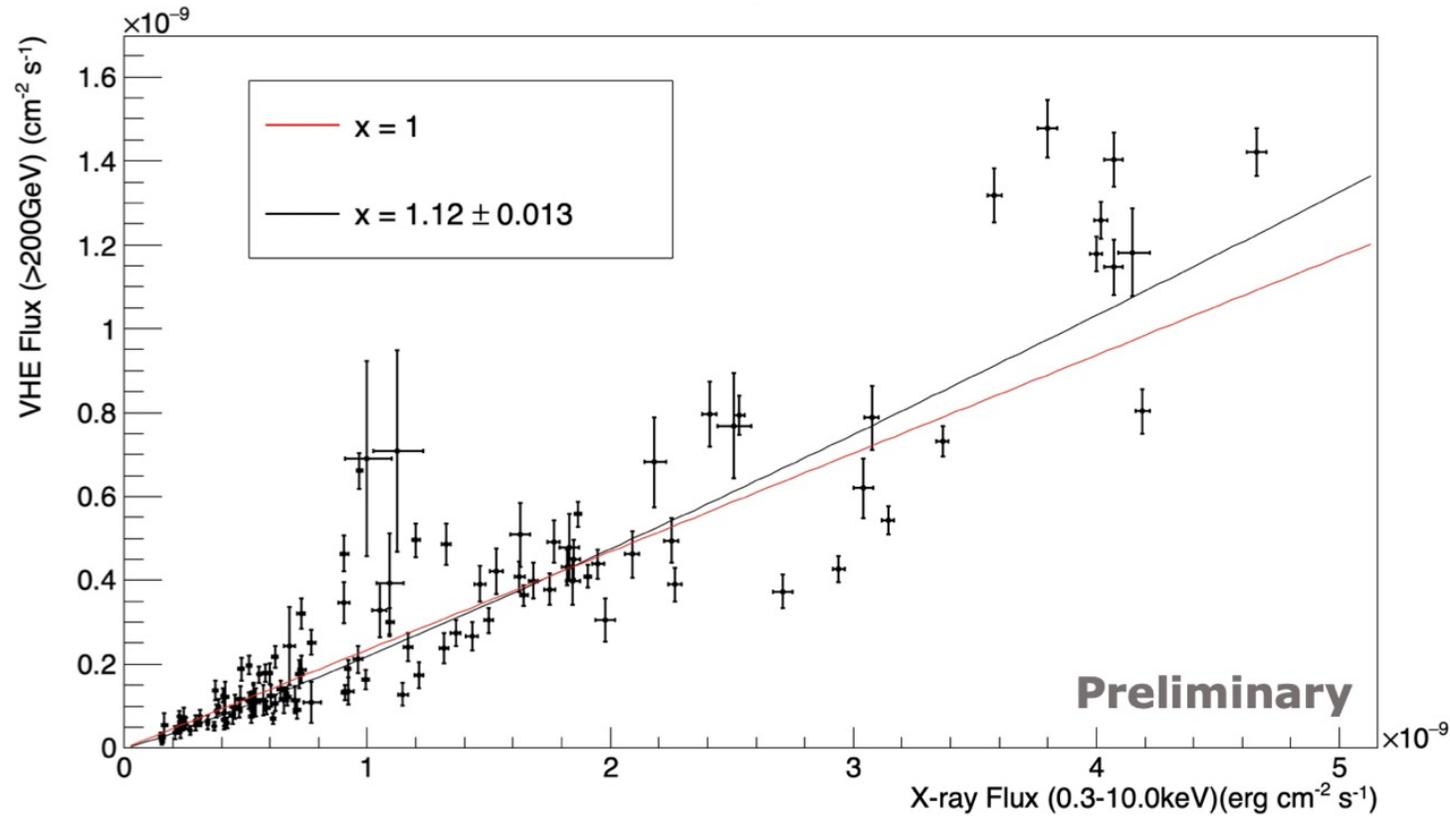
External- Compton (EC)

Bethe-Heitler process

Photomeson processes

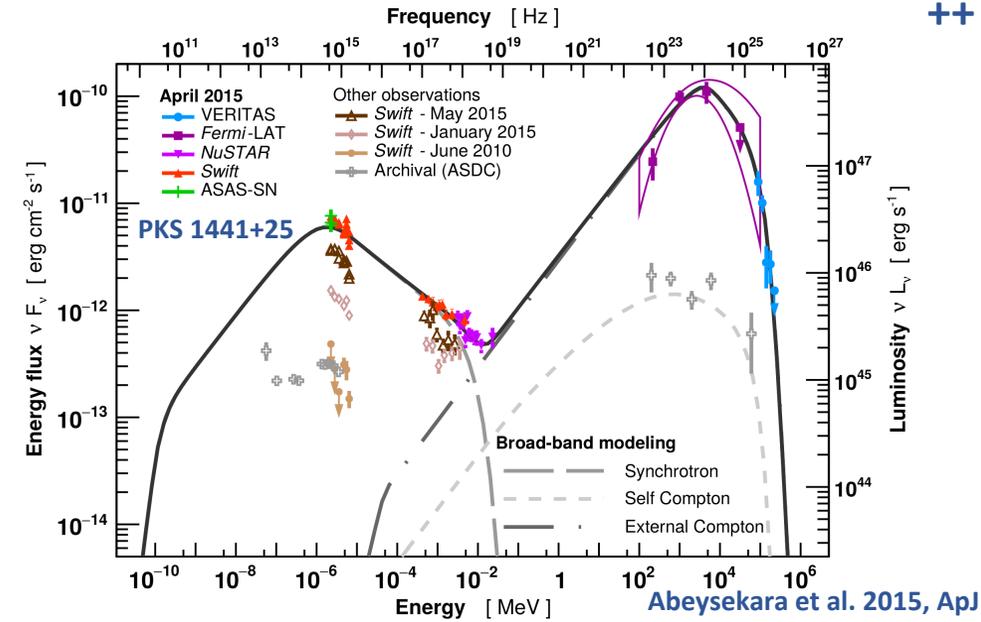


- Nearly 20 years of VERITAS +Swift coordination
- Provides broadband perspective on gamma-ray blazars
- VERITAS observations made to match Swift exposures, e.g. Mrk 421
 - 26 hours *simultaneous* data of Mrk 421
 - Strong evidence that the X-ray and TeV photons result from the same population (SSC)



- Gamma-ray photons likely derived from X-ray photons
 - Necessitates contemporaneous X-ray-TeV observations for emission modeling
- **Many** ToO observations with Swift GO
 - PI D. A. Williams: 17 published, 3 in prep
 - VERITAS discovery of blazar gamma-ray emission → Swift ToO
 - Constrain emission zone size with variability
 - Model optical + Swift + Fermi + VERITAS broadband SED
- **Many** Swift ToO requests outside of GO
 - A. Falcone provides regular coordination
 - ++ VERITAS members requesting 1-6 exposures per month

Name	Date	z	Class	Swift Observations
1ES 0806+524	Mar '08	0.138	HBL	6 ks XRT / 6 ks UVOT
W Com	Mar, Jun '08	0.102	IBL	29 ks XRT / 29 ks UVOT
3C 66A	Oct '08	$\geq 0.3347^2$	IBL	13 ks XRT / 12 ks UVOT
RGB J0710+591	Feb '09	0.125	HBL	15 ks XRT / 15 ks UVOT
PKS 1424+240	Jun '09	0.6035 ²	IBL/HBL	16 ks XRT / 16 ks UVOT
RGB J0521+212	Oct, Nov '09	?	HBL	17 ks XRT / 17 ks UVOT
RBS 0413	Oct '09	0.19	HBL	2 ks XRT / 2 ks UVOT
1ES 0502+675	Nov '09	0.34?	HBL	4 ks XRT / 4 ks UVOT
RX J0648.7+1516	Mar '10	0.179 ²	HBL	11 ks XRT / 11 ks UVOT
1ES 1440+122	Aug '10	0.16	HBL	2 ks XRT / 2 ks UVOT
B2 1215+30	Jan, Apr '11	0.131 ²	IBL	31 ks XRT / 31 ks UVOT
1ES 0647+250	Dec '12	?	HBL	19 ks XRT / 19 ks UVOT
RGB J2243+203	Dec '14	$>0.39?$	HBL	5 ks XRT / 5 ks UVOT
PKS 1441+25	Apr–May '15	0.939	FSRQ	21 ks XRT / 22 ks UVOT
S3 1227+25	May '15	0.135	IBL	17 ks XRT / 17 ks UVOT
RGB J2056+496	Nov '16	?	blazar	6 ks XRT / 6 ks UVOT
OJ 287	Feb–Mar '17	0.306	LBL	36 ks XRT / 35 ks UVOT
TXS 0506+056	Sep '17–Feb '18	0.337	IBL	74 ks XRT / 74 ks UVOT
Ton 599	Feb–Mar '17	0.725	FSRQ	11 ks XRT / 10 ks UVOT
3C 264	Jan–Apr '18	0.0217	FR I radio galaxy	27 ks XRT / 28 ks UVOT

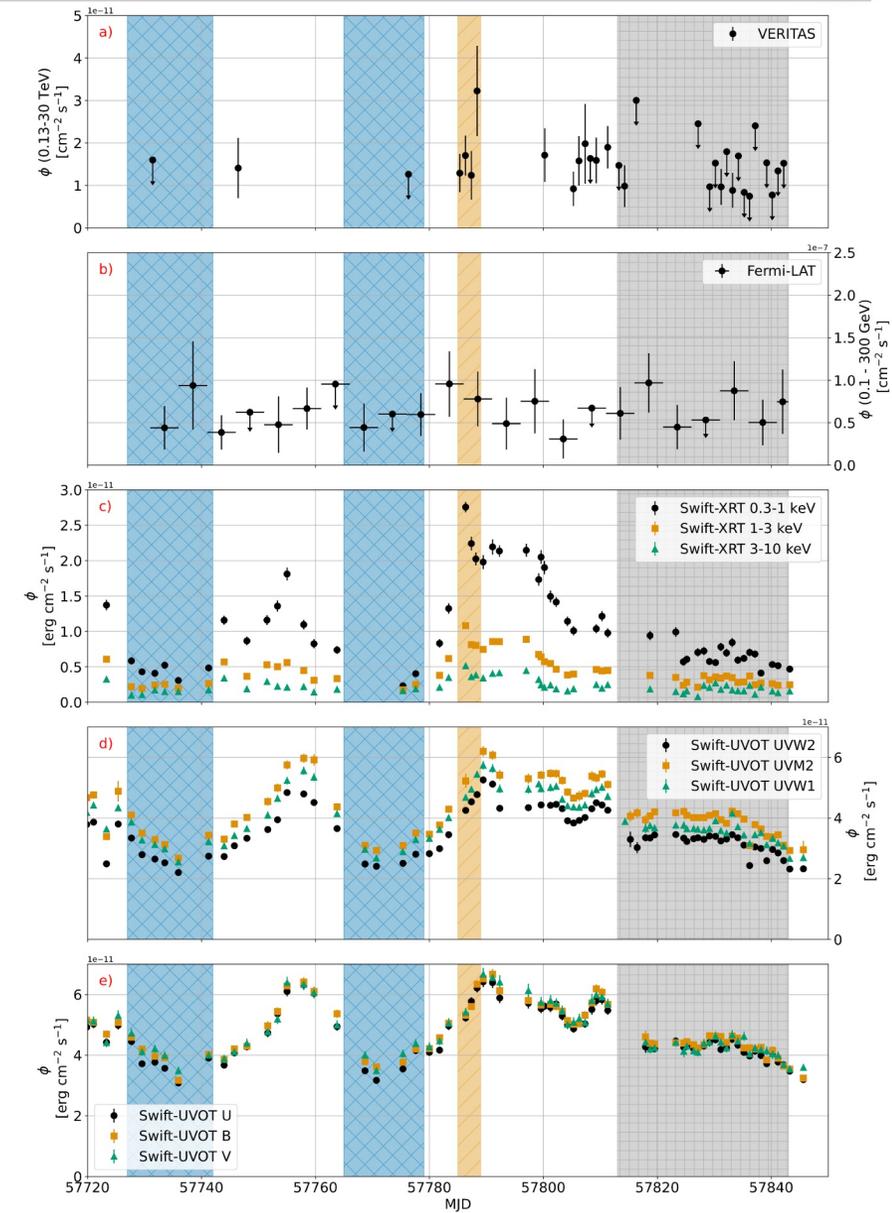




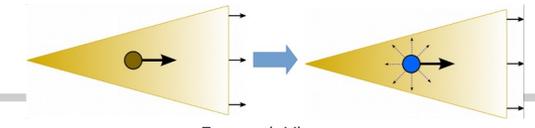
A multi-wavelength Study to Decipher the 2017 Flare of the Blazar OJ 287



- **Gamma-ray discovery triggered by XRT**
 - Strong signs of activity in UV/X-ray starting in middle of 2016
- VERITAS observed for months starting 2016
- TeV discovery by VERITAS in February 2017, coincident with Swift detected X-ray flare
- Three states investigated
 - **Low state:** MJD 57731-57740 & MJD57765-57777
 - **Flare:** MJD 57785-57789
 - **Post-flare:** MJD 57813-57843

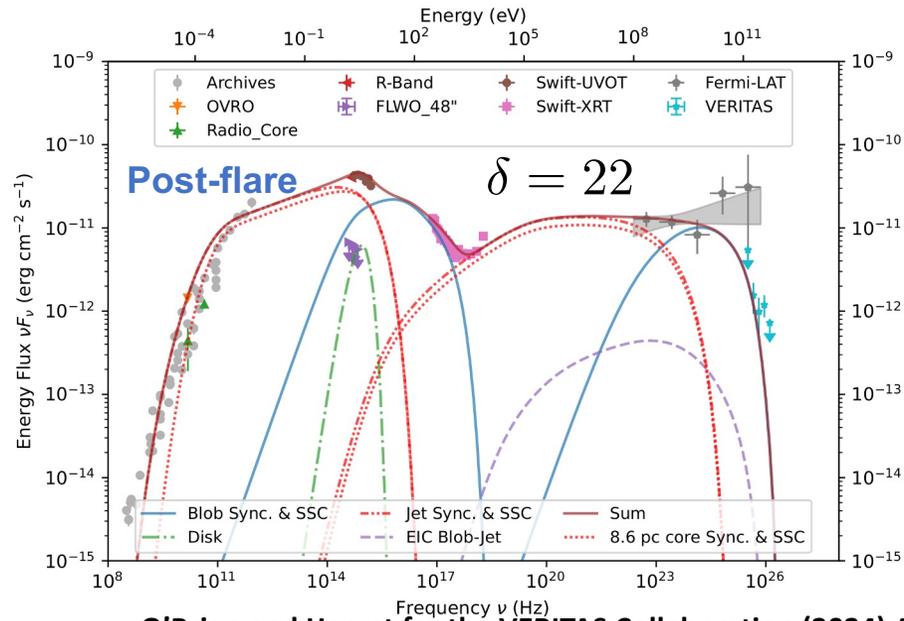


A multi-wavelength Study to Decipher the 2017 Flare of the Blazar OJ 287

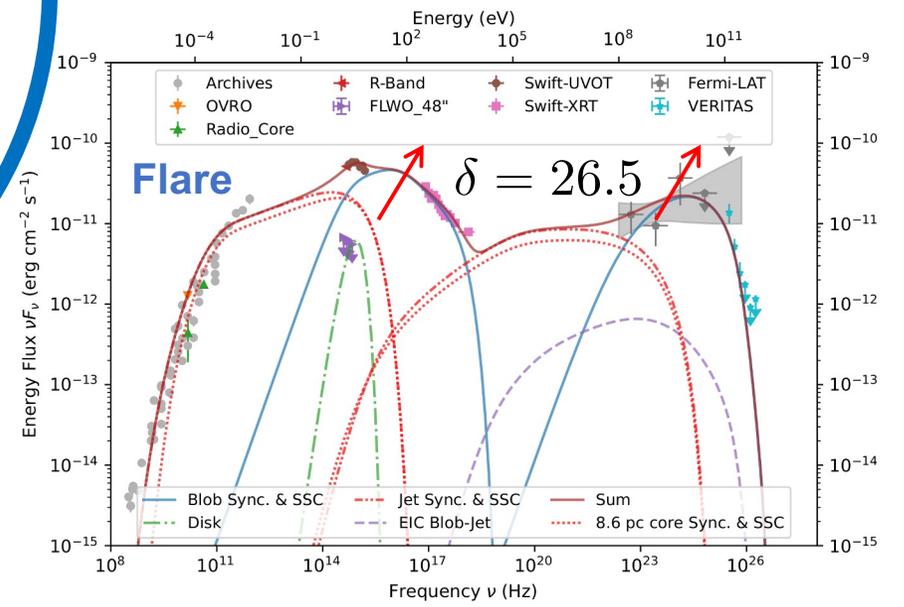
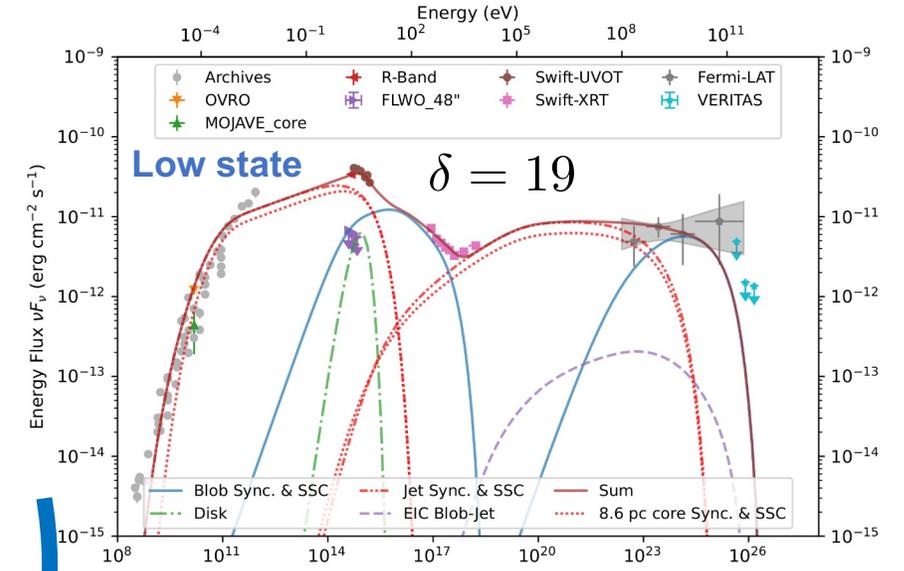


A flaring blob in a steady jet

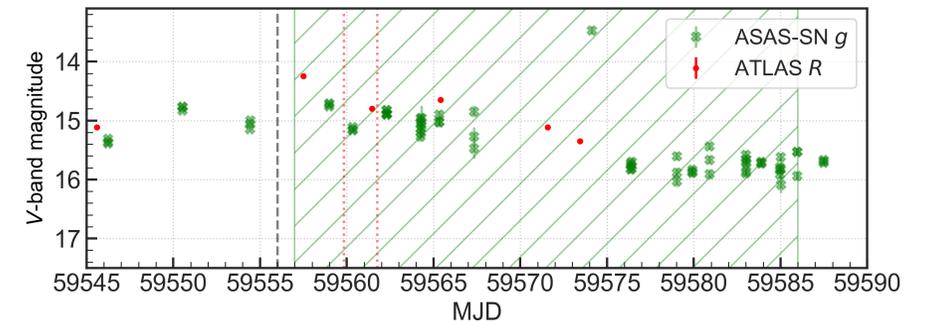
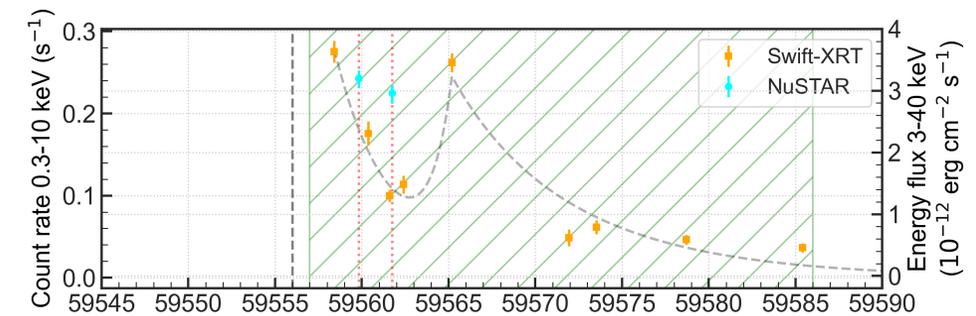
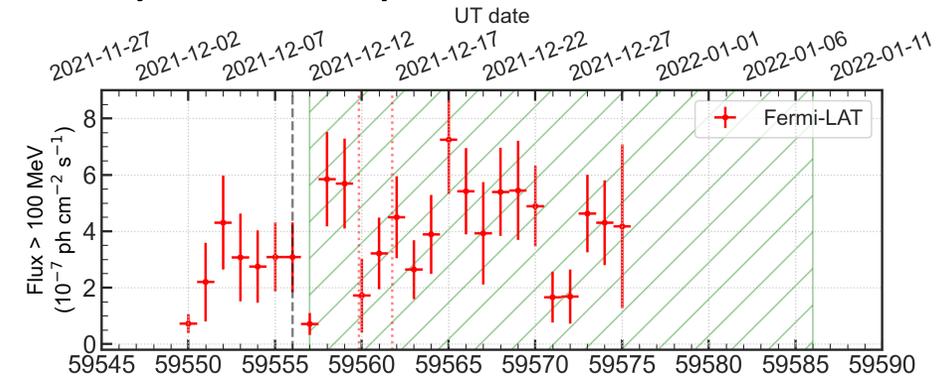
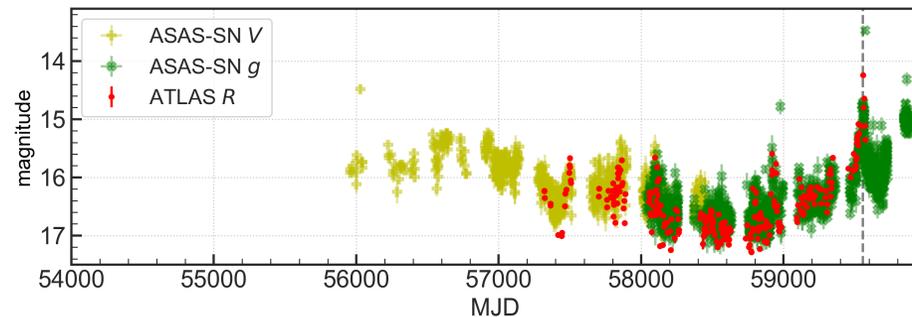
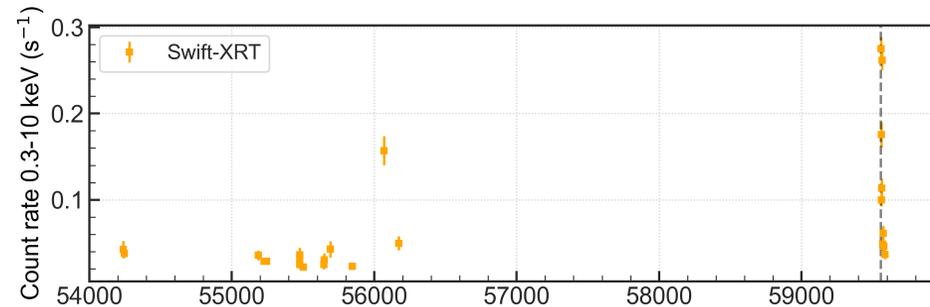
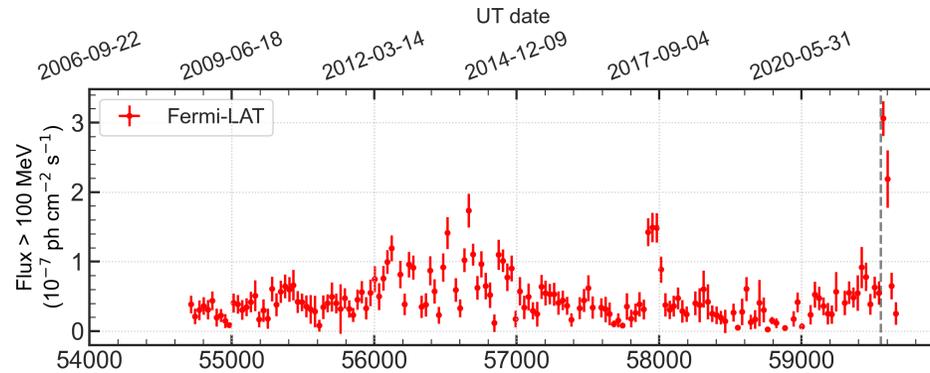
- Variability can be explained by a variation of the blob's Doppler factor δ
- The abrupt change of δ is consistent with a strong recollimation shock (e.g. *Hervet+ 2017*)
- Contemporaneous radio observations suggest the flare originates within a radio knot ~ 10 pc from the core (*Lico+ 2022*)



O'Brien and Hervet for the VERITAS Collaboration (2024) ApJ, 973



- Possible association with IceCube-211208A ($E_\nu=171$ TeV; Dec 2021).
- Swift, NuSTAR, LAT and optical show historically high flux and daily variability.
- Swift provides measurement in quiescence + flare
- Year timescale
 - Historic high fluxes coincident with the neutrino.
- Day timescale
 - Swift observed X-ray variability constrains $R < \sim 5e16$ cm

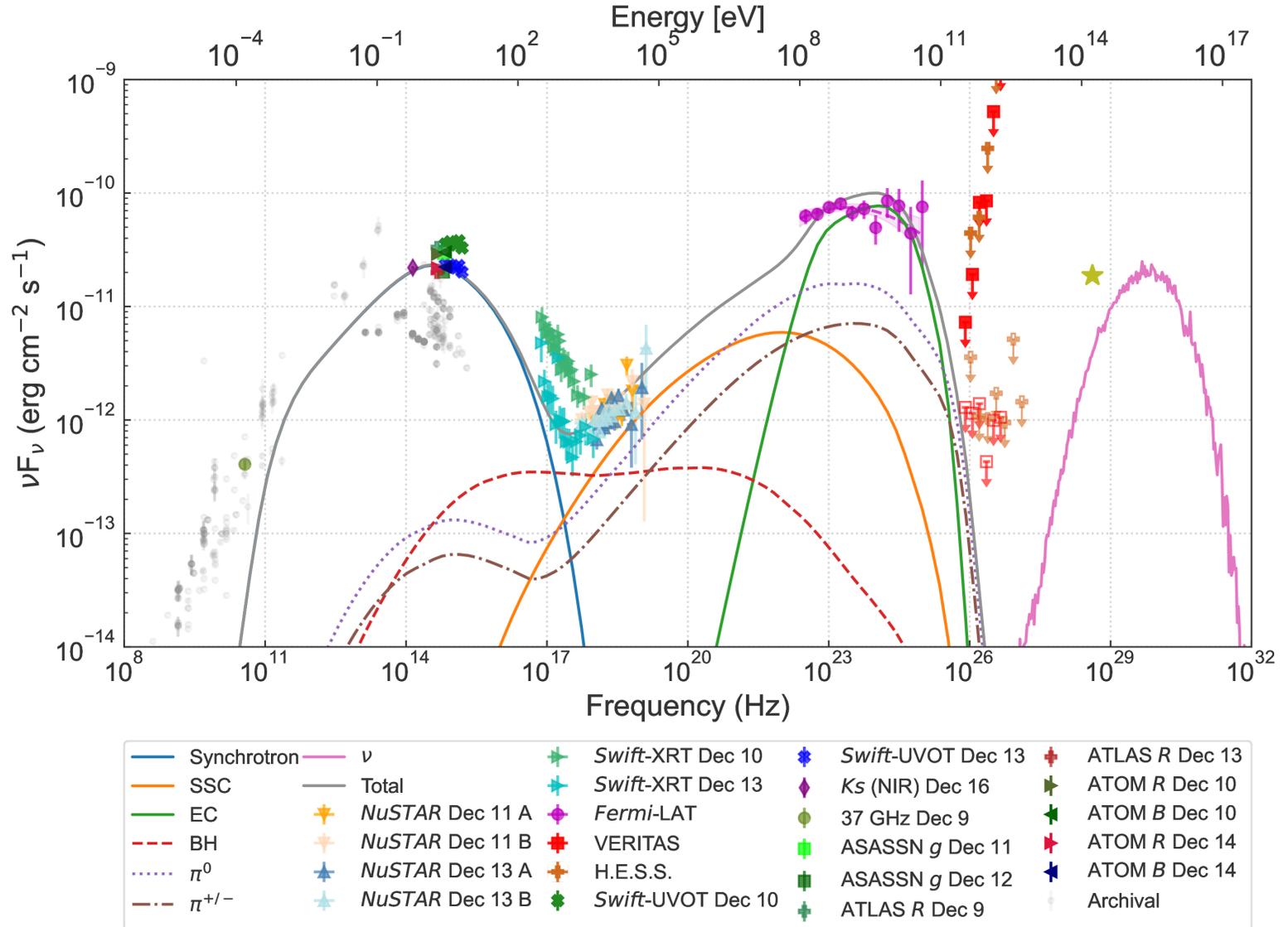




Multiwavelength Observations of the Blazar PKS 0735+178 in Spatial and Temporal Coincidence with an Astrophysical Neutrino Candidate IceCube-211208A



- Upper limits from H.E.S.S. and VERITAS indicate cutoff at 100 GeV.
- Swift XRT provide constraint at transition from synchrotron bump to inverse-Compton bump
- External soft photon field is necessary to explain SED
- With BLR photon field:
 - purely leptonic external inverse-Compton model can explain the photon emission.
 - dominate at multi-GeV and cutoff above 100 GeV.
- Lepto-hadronic with external target photons also explain neutrino rate





Nearly 20 Years of High Impact Collaboration



- Swift continues to provide critical insight on the particles that are responsible for TeV emission
 - Gamma-ray binaries
 - Blazars
 - MM studies involving possible neutrino association with gamma-ray emission
 - Follow up of Swift GRBs [[1](#), [2](#), [3](#)]
- VERITAS triggers Swift + Swift triggers VERITAS + MM facilities trigger both
- Contemporaneous Swift exposures have been an integral part of the VERITAS observing plan for nearly 20 years
 - Benefit from both GO Program and accommodating ToO coordination
- VERITAS looks forward to continued coordination with Swift



A thank you from VERITAS to the Swift team!



VERITAS Collaboration Meeting, Oxford UK, July 2024