Status and Highlights of VERITAS

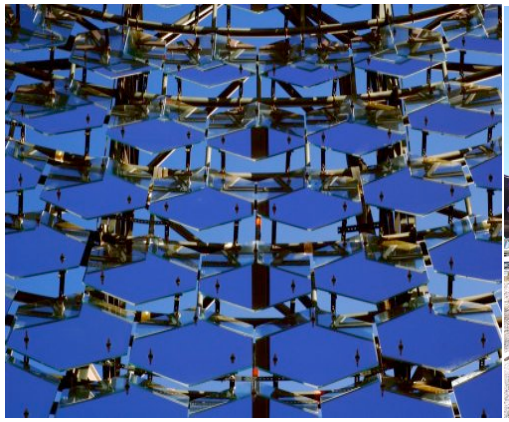
Harvard-Smithsonian
Center for Astrophysics

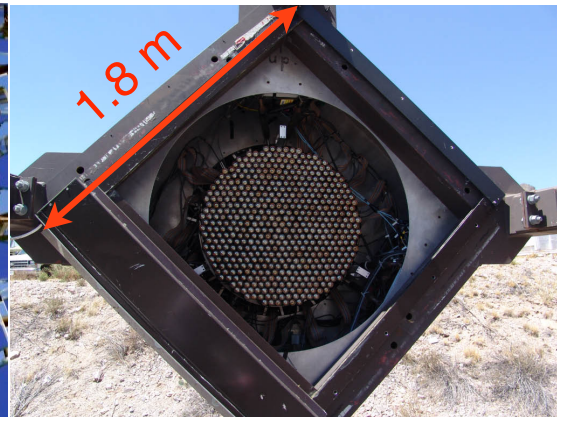
Nicola Galante for the VERITAS collaboration
ngalante@cfa.harvard.edu

VERITAS

Very Energetic Radiation Imaging Telescope Array System

- Arizona: ~32° N, ~111° W, ~1300m a.s.l
- Array of four 12m ∅ IACTs
  - D = 12 m; f = 12 m; f/D = 1
  - Segmented mirror reflective surface: 4 x 350 mirrors, ~110 m^2 each Tel.
  - Camera: 499 PMTs (0.15°), ~3.5° FoV
  - 3-level topological trigger
  - DAQ: <10% dead time @ 300 Hz
- Metrics:
  - Energy range: ~100 GeV to ~30 TeV
  - Energy resolution 15% - 20%
  - Angular resolution: r_{68} < 0.1°
  - Pointing accuracy: < 50”
  - Systematic uncertainty: ΔΓ ~0.1°, ΔF ~20%
  - Sensitivity: 1% Crab Nebula (5σ) ~25 hr





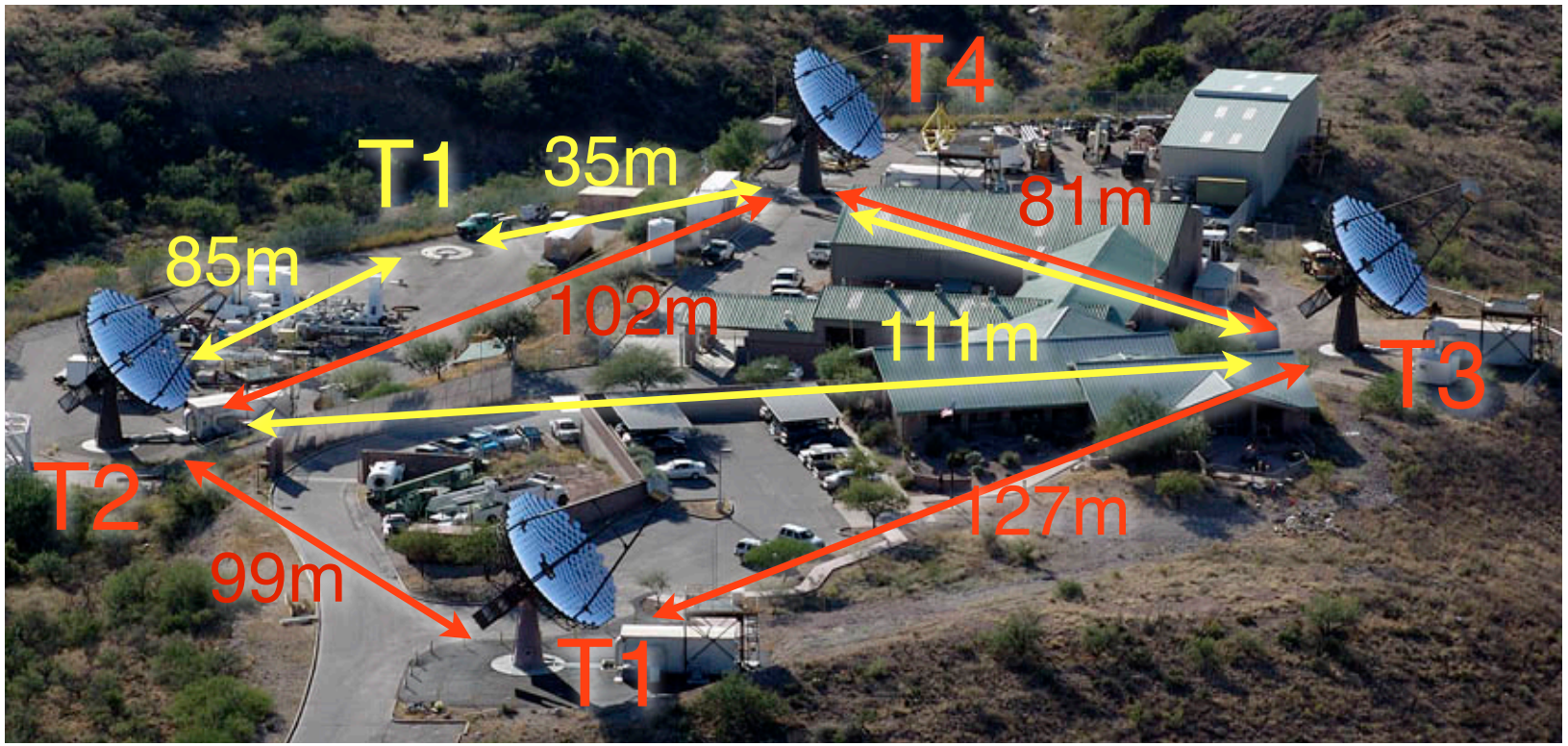
Past Upgrades

Relocation of T1 (Summer 2009)

- Array more "square" (~97 m)
- 30% sensitivity improvement!

Topological L2 trigger (Nov. 2011)

- Shorter coincidence: Less NSB
- Enables diagnostics
- Potential 4L trigger

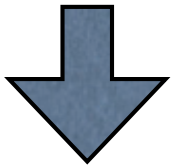


Current Upgrade

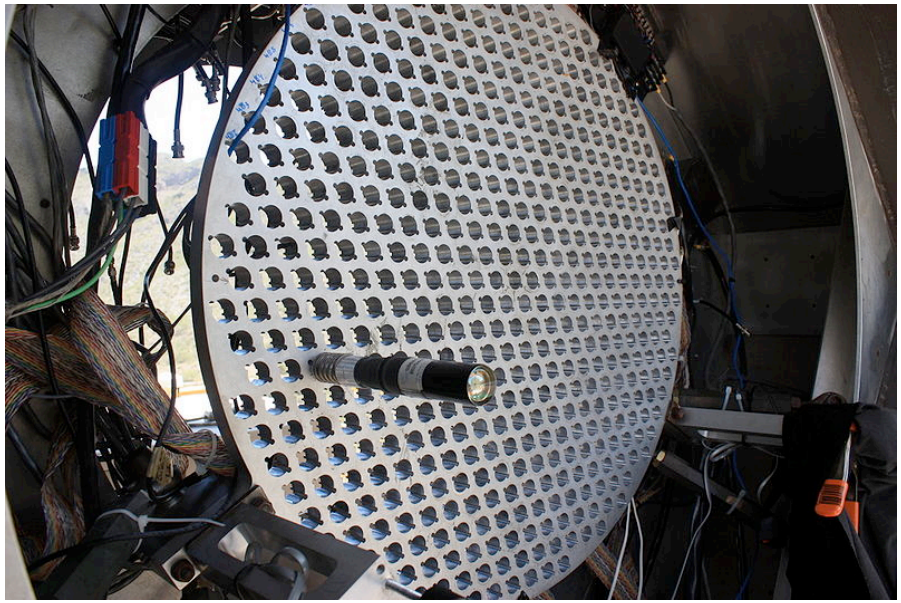
High-QE PMTs (Summer 2012)

Higher QE sensitivity
lower trigger energy threshold

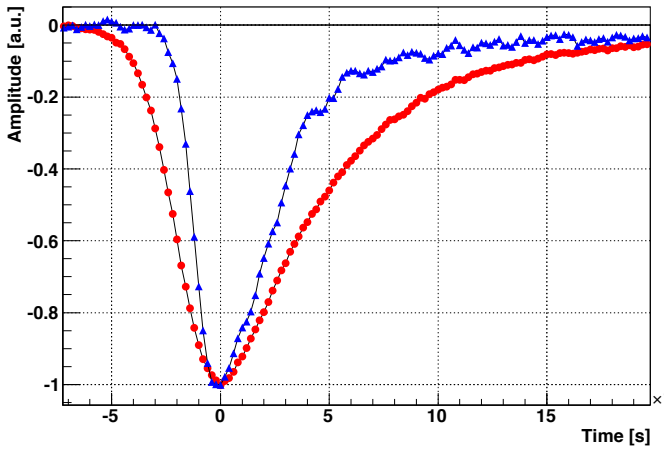
Photonis XP2970 PMTs

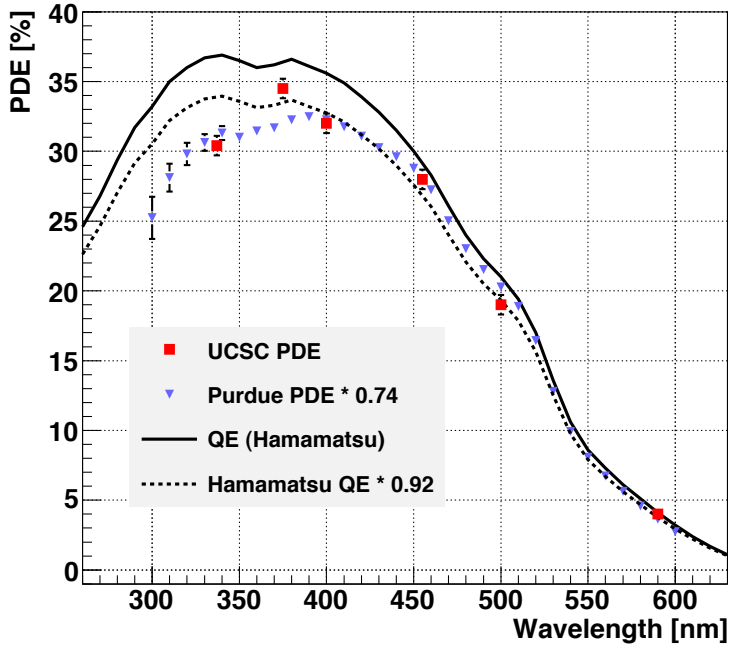


Hamamatsu R10560-100-20
super-bialkali PMTs

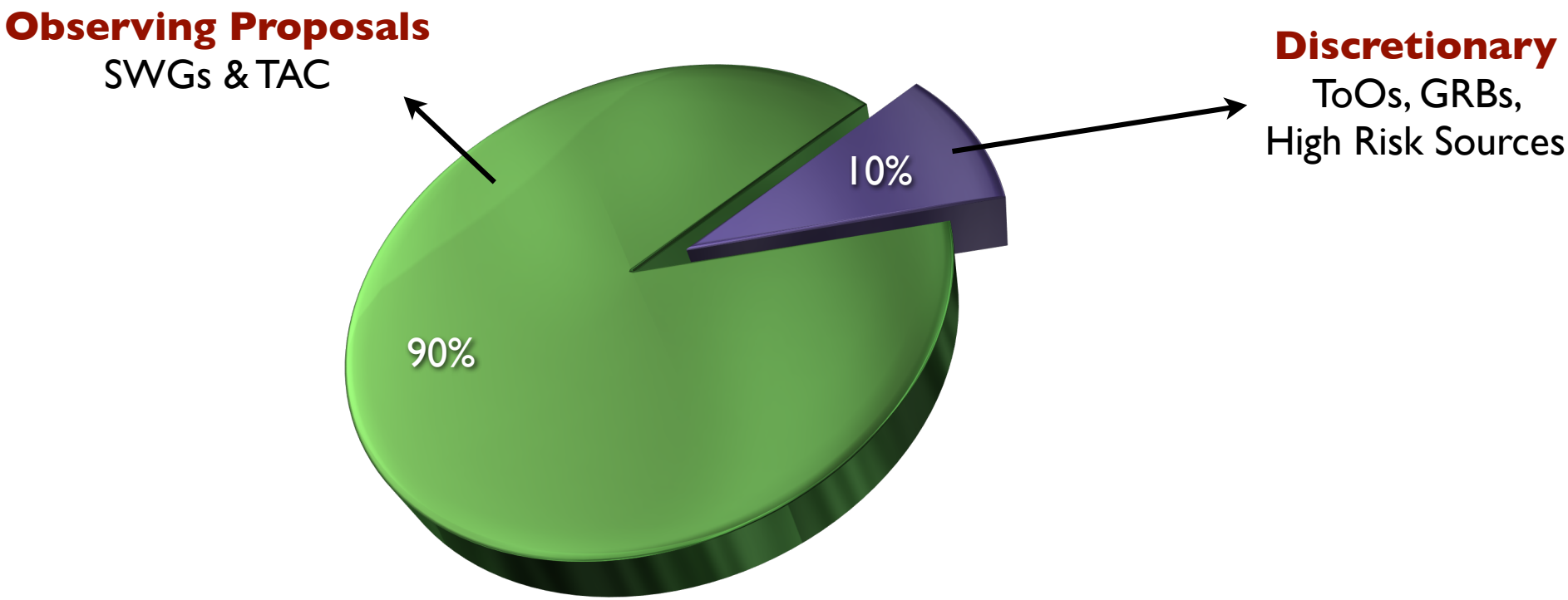


- FWHM 4.2 ns
- PDE 35% > Photonis
- ~23% Cherenkov eff.



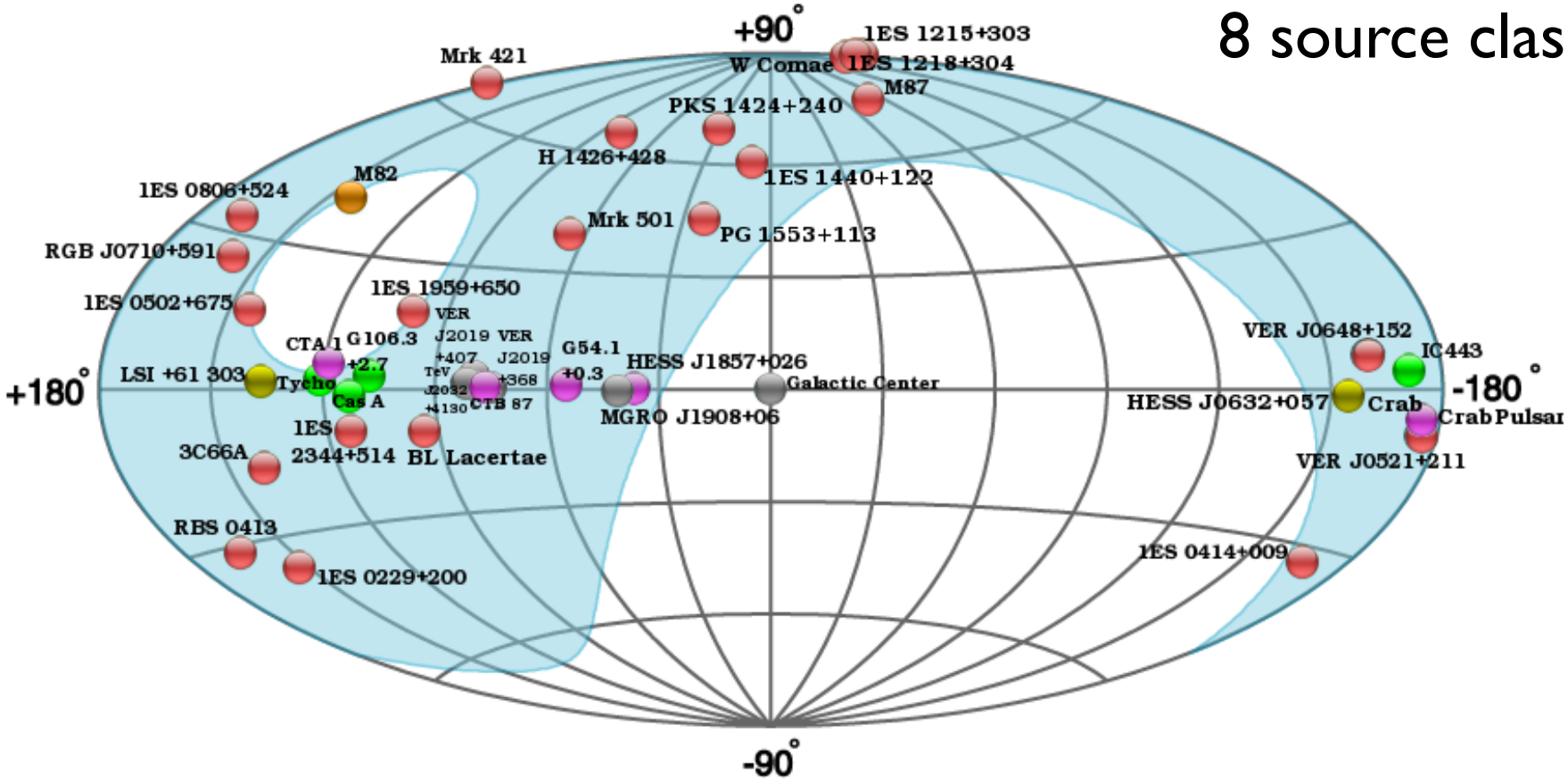


VERITAS Observation Strategy



- 800 hours/year Dark Time + 30% Moonlight = ~1100 hours total
- >90% data taken with all 4 telescopes operating
- >90% data taken with good weather conditions

VERITAS Sky



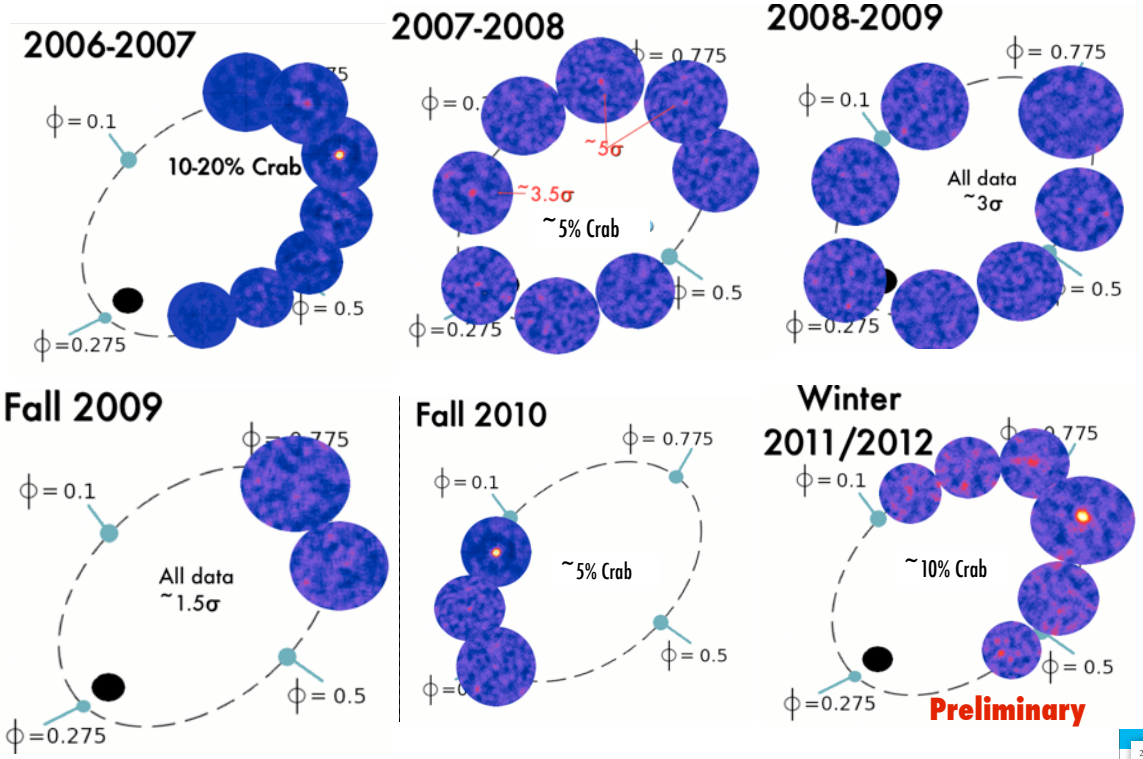
8 source classes

Detected: 40 (21 blazars; 12 galactic; 2 extragalactic; 5 unidentified)

Discovered: 25 > 1/2!!!

GALACTIC PROGRAM

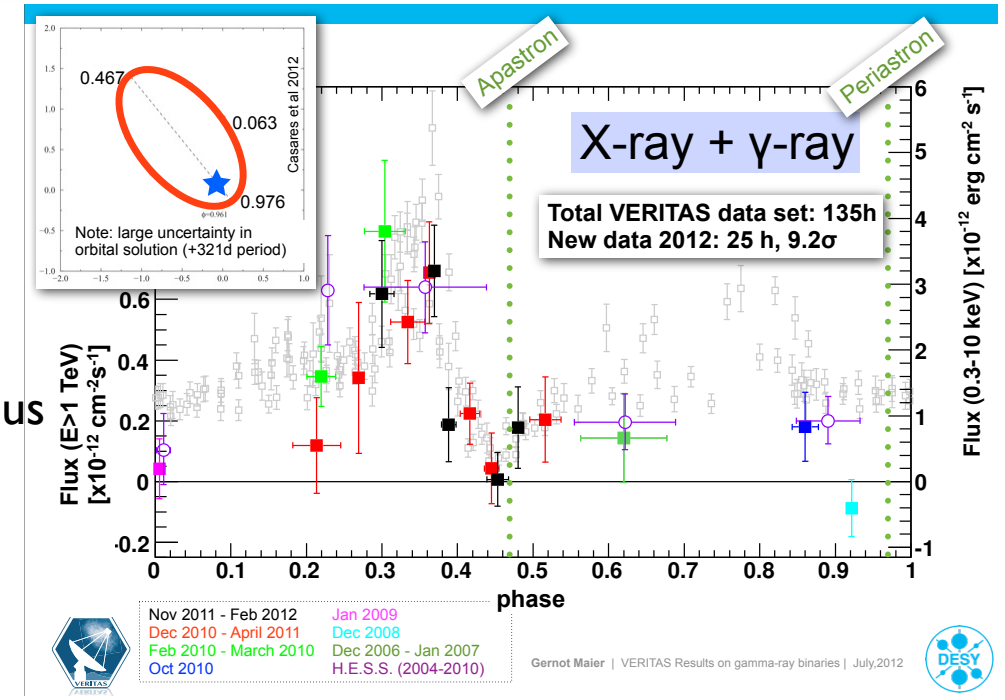
Binary Systems: LSI 61+303 & HESS J0632+057



G. Maier talk, Monday 9th, 4:20pm

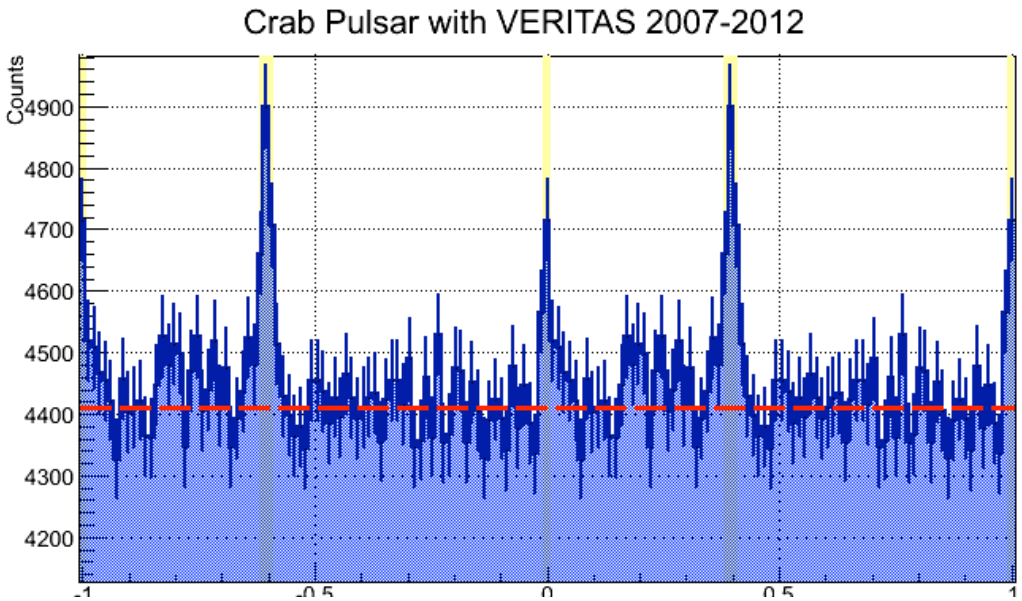
- Monitored since 2006
- Coverage of large fraction of orbit
- Not always detected
- Not detected in 2008-2009
- **Stochastic** process superimposed to **periodic** process?

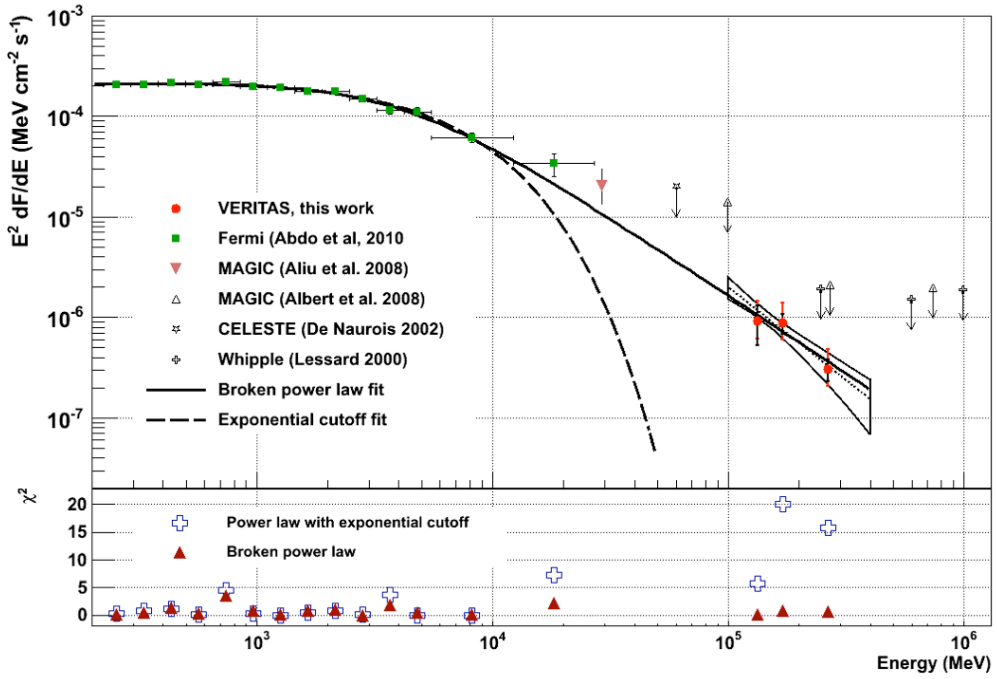
- 2004: discovered by HESS
- 2009: evidence for variability (VERITAS)
- No binary companion resolved
- Until 2011 unidentified point source without obvious companion



Nicola Galante for the VERITAS coll.

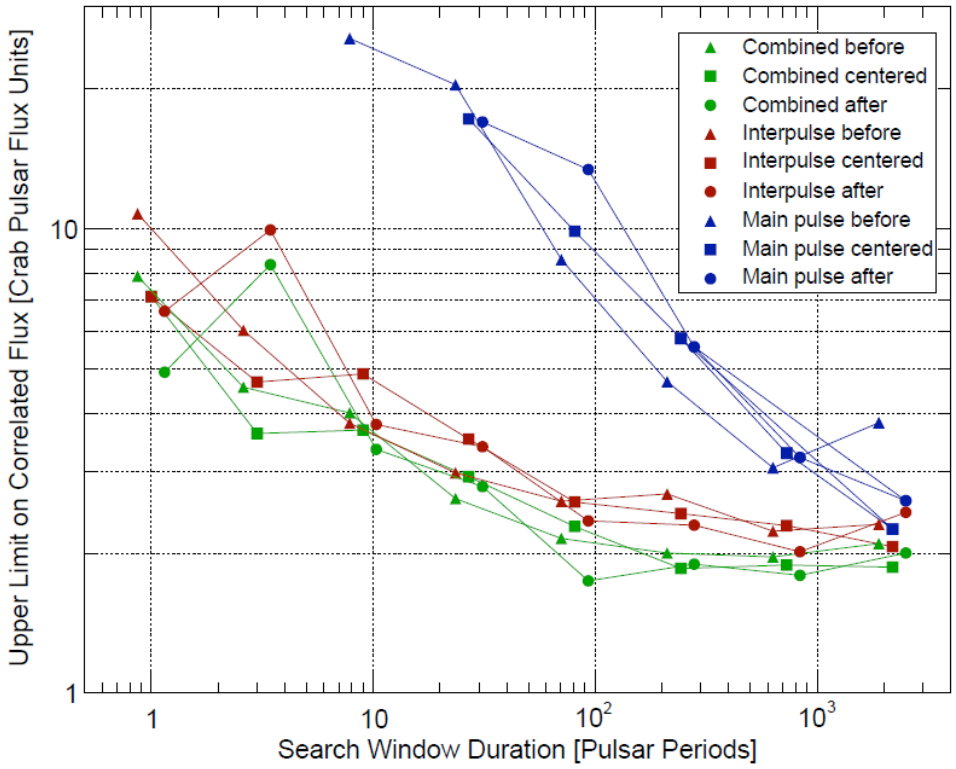
Crab Pulsar



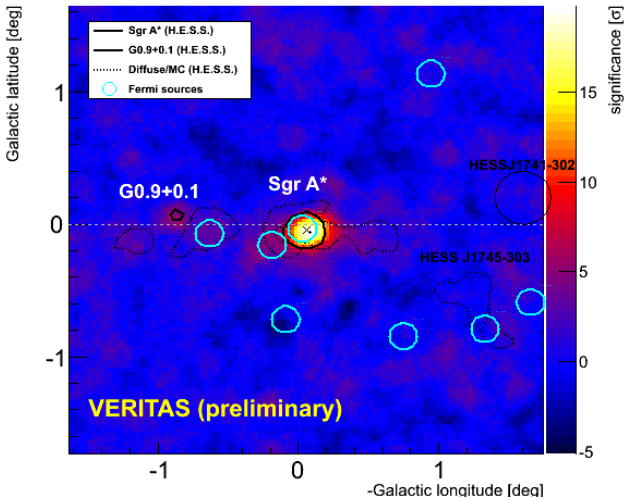


B. Zitzer talk, Monday 9th, 11:46am

- 130 hr total observation time, >10σ Li&Ma
- Search for correlation with Giant Radio Pulses, no correlation found



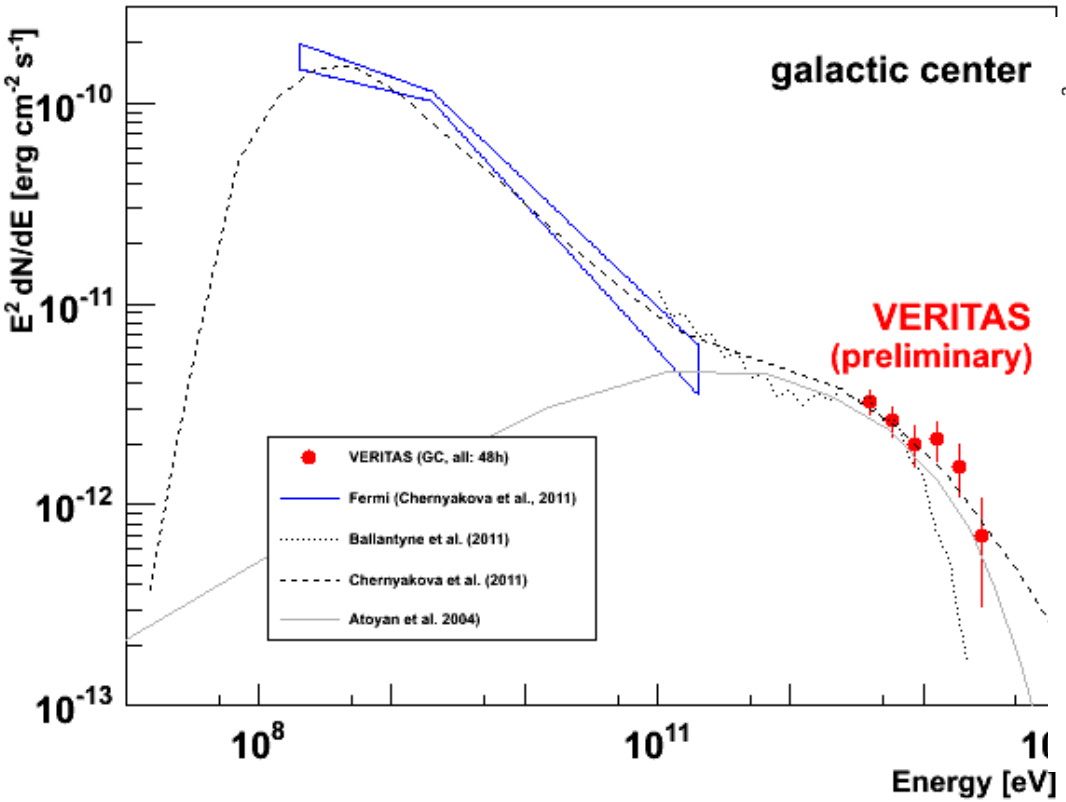
Galactic Center

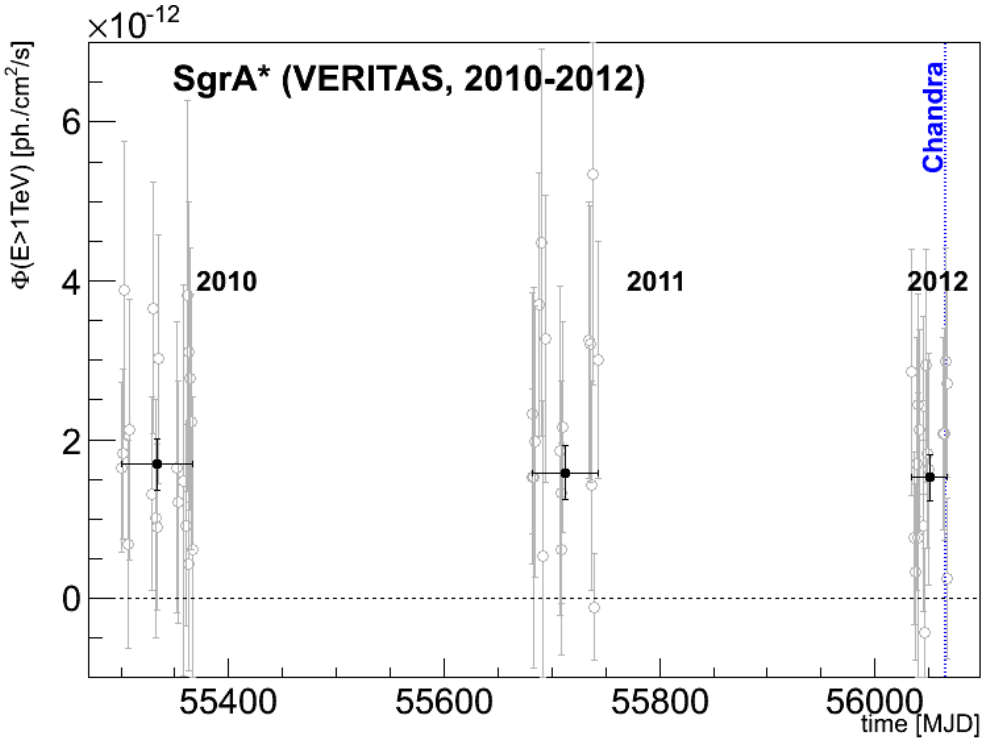


1. Hadron acceleration around BH
2. Hadron acceleration close to BG
3. Leptonic wind

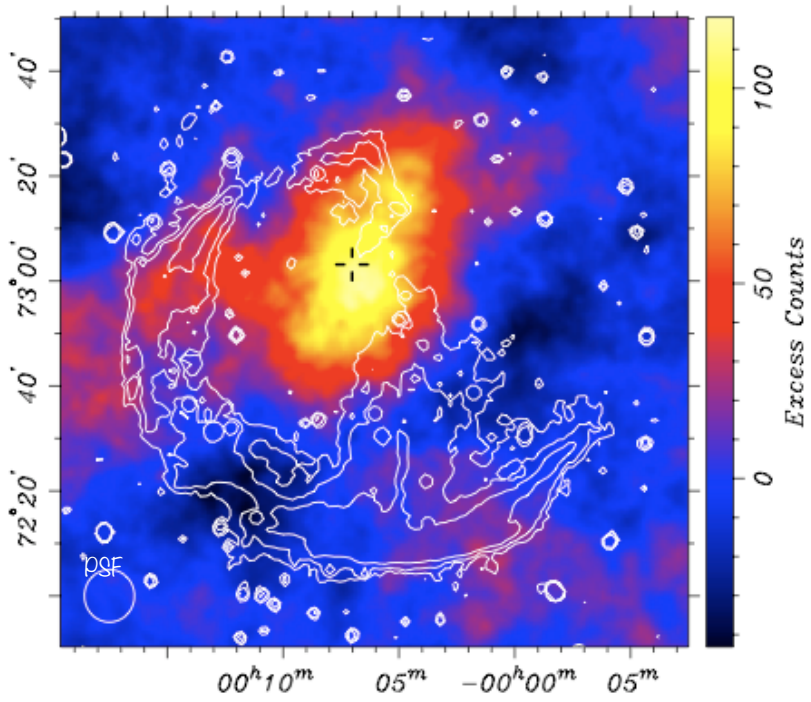
IMPORTANT INPUT TO MODELS:
- Cutoff
- Variability E>10 TeV

M. Beilicke talk, Thursday 12th, 12:26pm



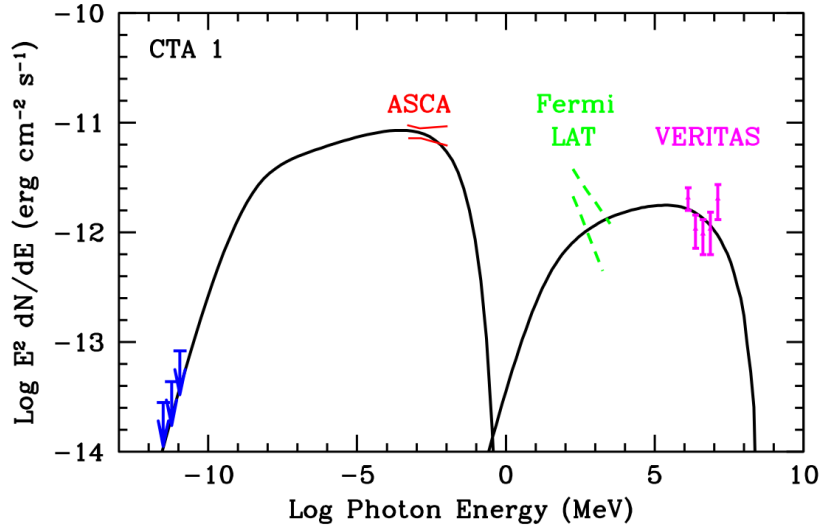


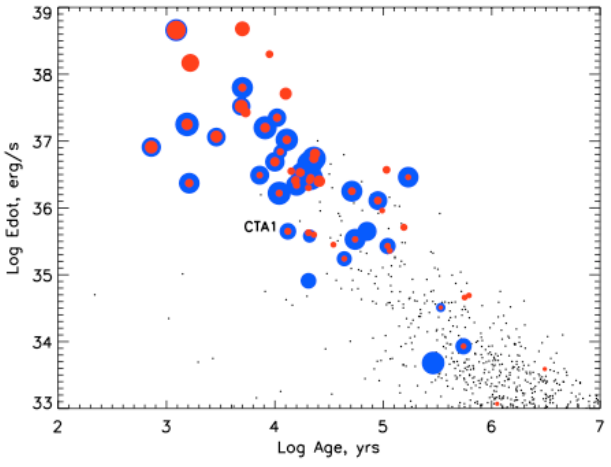
SNR: CTA1

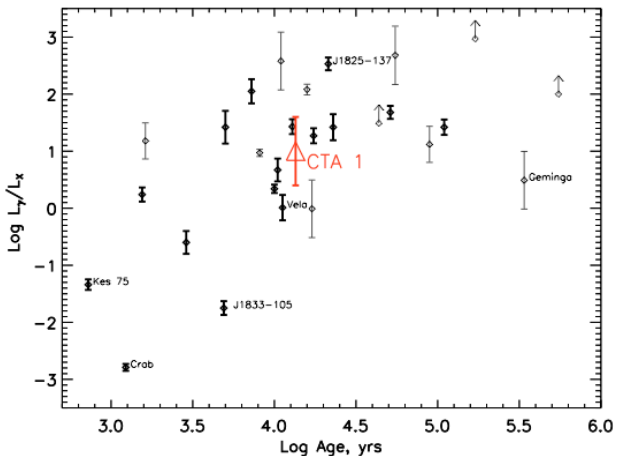


N. Park, poster

- Composite SNR, shell-type structure
- VERITAS VHE discovery **VER J0006+729**
- TeV emission in broadband SED compatible with synchrotron IC
- Comparison with other relic PWNe: typical TeV PWN around pulsar with age < 100kyr and E ≲ 10^{35} erg s^{-1}



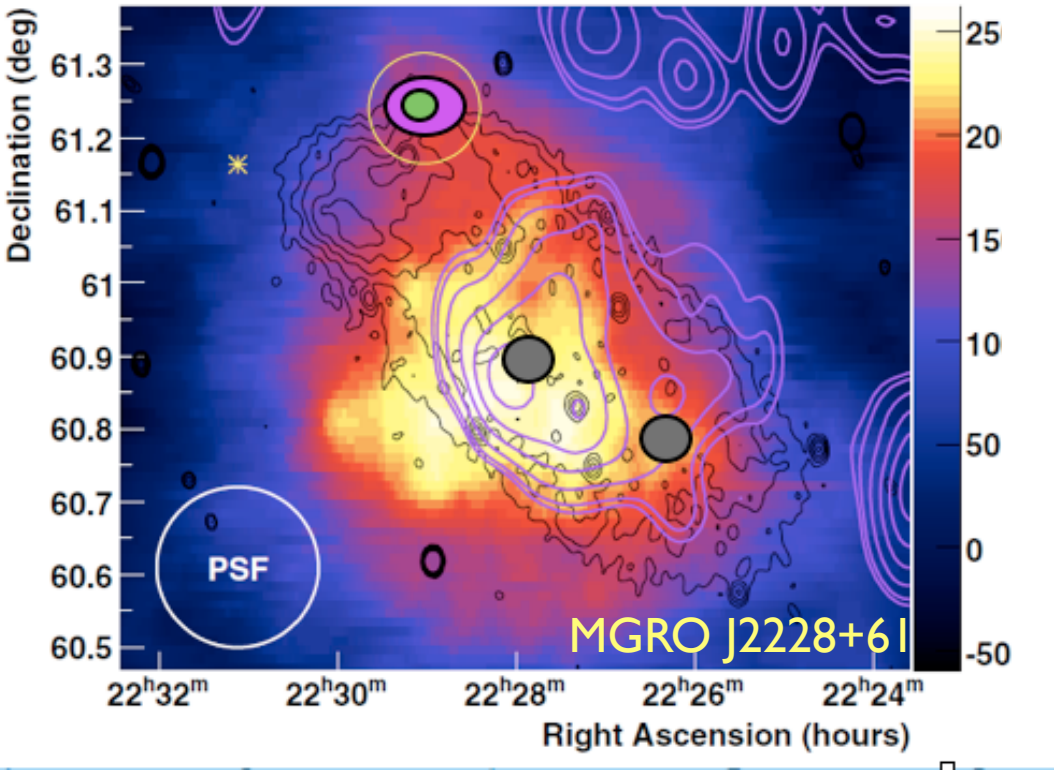


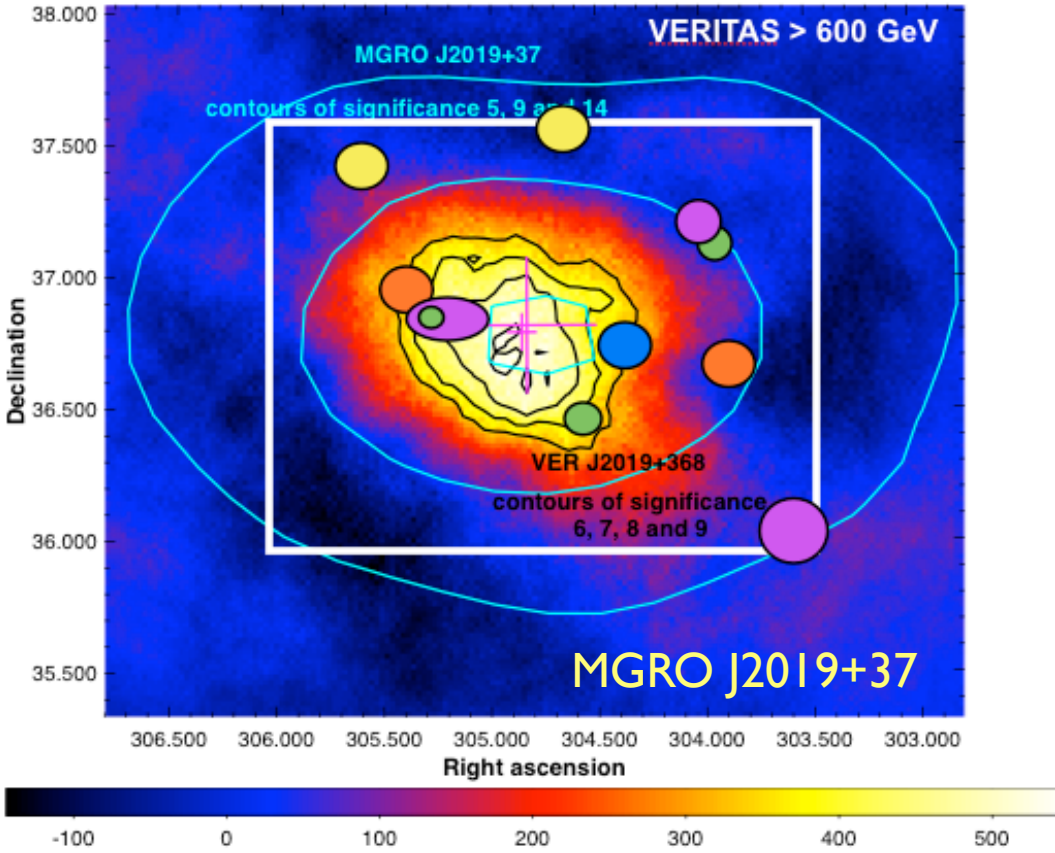


MILAGRO Diffuse TeV Sources

E. Aliu talk, Tuesday 10th, 3:15pm

VERITAS improves location
of 2 MGRO TeV sources





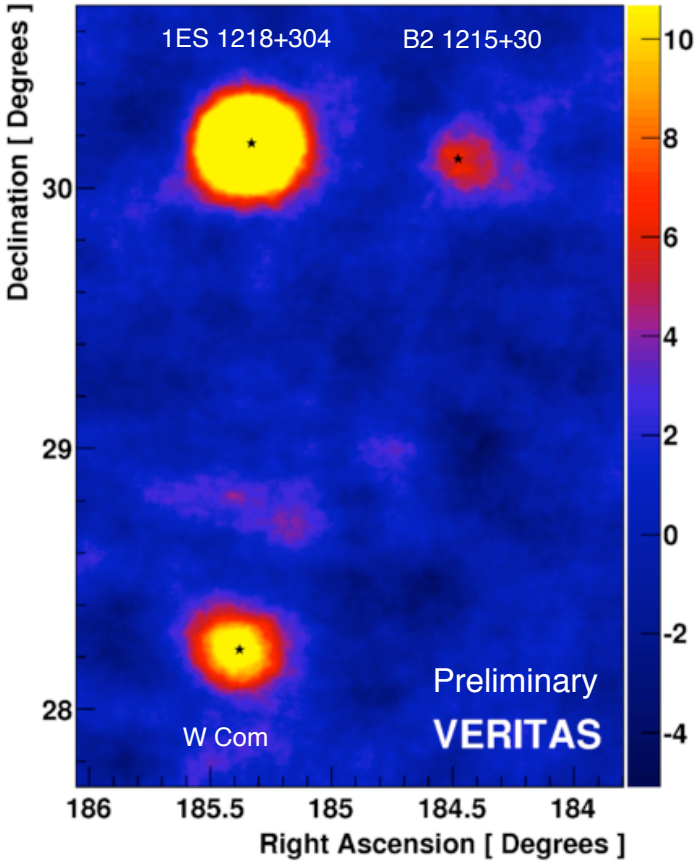
VERITAS + MWL suggest that emission is **overlap of several sources** although PWN might be dominant

AGN PROGRAM

~2000 hr since Sept. `07, ~420 hr/yr

W. Benbow, poster
L. Fortson, poster
H. Prokoph, poster

- VERITAS detected 22 AGNs
  - 21 blazars (15 HBL, 5 IBL, 1 LBL), 1 RG, no FSRQs so far (~25% without z)
  - 14 discovered (Whipple: 4 HBL - VERITAS: 6 HBL + 4 IBL)
- All observations in MWL
  - Monitoring & ToO
  - VHE (HESS/MAGIC), HE (Fermi), X-ray (Chandra, XMM, Swift, XTE, Suzaku), Optical (MMT, MDM, Super-LOTIS, other FLWO: 48"), Radio (VLA, VLBA)
- Strategy
  - `07-10: 80% discovery, 20% known sources
  - `10-11: 40% discovery, 60% known sources



Moving from discovery mode to a detailed characterization of the source
Discovery program moving to a ToO (incl. Optical!) strategy

The VERITAS AGN Science Program

VER J catalog started

SOURCE	TYPE	REDSHIFT	DATE	EXTRA
Markarian 421	HBL	0.031	Whipple	
Markarian 501	HBL	0.034	Whipple	
1ES 2344+514	HBL	0.044	Whipple	
1ES 1959+650	HBL	0.048	Whipple	
H 1426+428	HBL	0.129	Whipple	
M 87	FR I	0.004	07/2007	
1ES 1218+304	HBL	0.182	03/2008	
1ES 0806+524	HBL	0.138	03/2008	ATel #1415
W Comae	IBL	0.102	03/2008	ATel 1422
3C 66A	IBL	0.444 ?	10/2008	ATel #1753
RGB J0710+591	HBL	0.125	02/2009	ATel #1941
PKS 1424+240	IBL	-	06/2009	ATel #2084
RGB J0521.8+2112	HBL	-	10/2009	ATEL #2260, ATel #2309. We confirmed HBL designation.
RBS 0413	HBL	0.190	10/2009	ATel #2272
1ES 0502+675	HBL	-	11/2009	ATel #2301
1ES 0229+290	HBL	0.140	11/2009	
RX J0648.7+1516	HBL	0.179	03/2010	ATel #2486; We measured z & confirmed an HBL
1ES 0414+009	HBL	0.287	03/2010	
PG 1553+113	HBL	-	05/2010	HST reports a rock-solid z > 0.43 based on Lyman alpha observations
1ES 1440+122	IBL	0.162	08/2010	ATel #2786
B2 1215+30	IBL	-	05/2011	
BL Lac	LBL	0.069	06/2011	ATel #3459

VERITAS AGN Discoveries

SOURCE	TYPE	REDSHIFT	$Log_{10}(\nu_{sync})$	Flux [% Crab]	Γ_{VER}	Γ_{2FGL}
1ES 0806+524	HBL	0.138	16.6	2%	3.6 ± 1.0	1.94 ± 0.06
W Comae	IBL	0.102	14.8	Flares (9%-23%)	3.8 ± 0.4	2.02 ± 0.03
3C 66A	IBL	0.444 ?	15.6	Variable, avg. 6%	4.1 ± 0.4	1.85 ± 0.02
RGB J0710+591	HBL	0.125	21.1	3%	2.7 ± 0.3	1.53 ± 0.12
PKS 1424+240	IBL	-	15.7	5%	3.8 ± 0.5	1.78 ± 0.02
RGB J0521.8+2112	HBL	-	HBL	Variable, avg. 5%	3.5 ± 0.2	1.93 ± 0.03
RBS 0413	HBL	0.190	17.0	2%	3.2 ± 0.7	1.55 ± 0.11
1ES 0502+675	HBL	-	19.2	6%	3.9 ± 0.4	1.49 ± 0.07
RX J0648.7+1516	HBL	0.179	HBL	2%	4.4 ± 0.8	1.74 ± 0.11
1ES 1440+122	IBL	0.162	16.5	1%	3.4 ± 0.7	1.41 ± 0.18
AVERAGE				**4%**	**3.6 (EBL effect)**	**1.7**

pre-1FGL: observations motivated by EG, bright X-ray component, observability, z<0.5
post-1FGL: emphasis on LAT-extrapolated spectra
Identification of object through VHE-motivated observations

All discoveries triggered MWL follow-up and published (or are in the process) SEDs including data from MWL partners

IBLs & LBLs

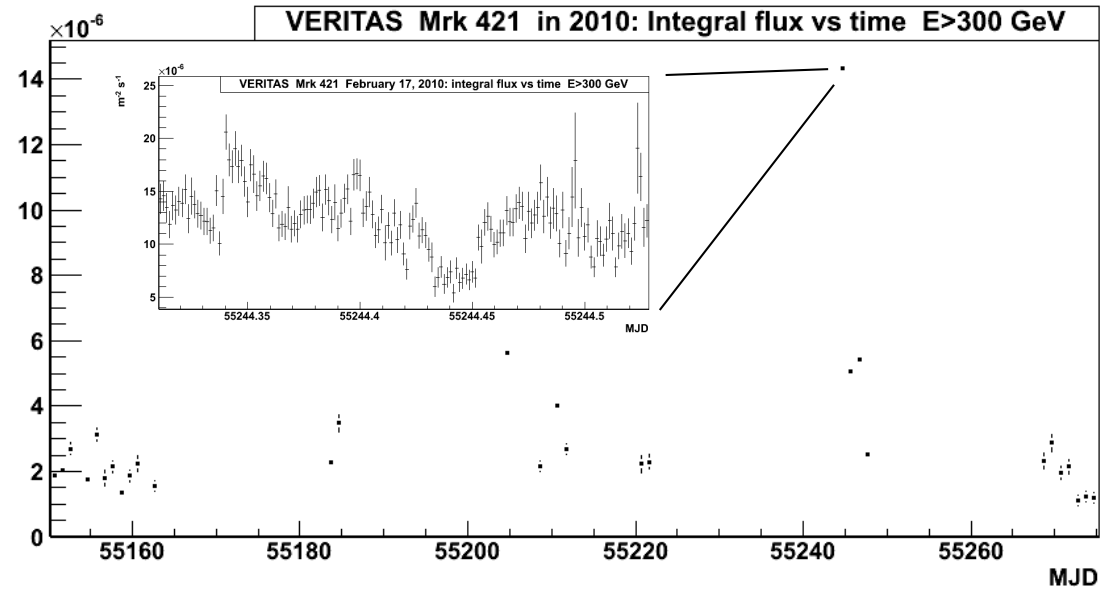
- 5 IBLs: 3C 66A, W Com, PKS 1424+240, B2 1215, 1ES 1440
- Average of requested observation time: **>100 hr each**
- Taken ~20-25 hr/each since 2010
- All blazars detected
- Fluxes significantly lower than initial discovery: low/quiescent state?

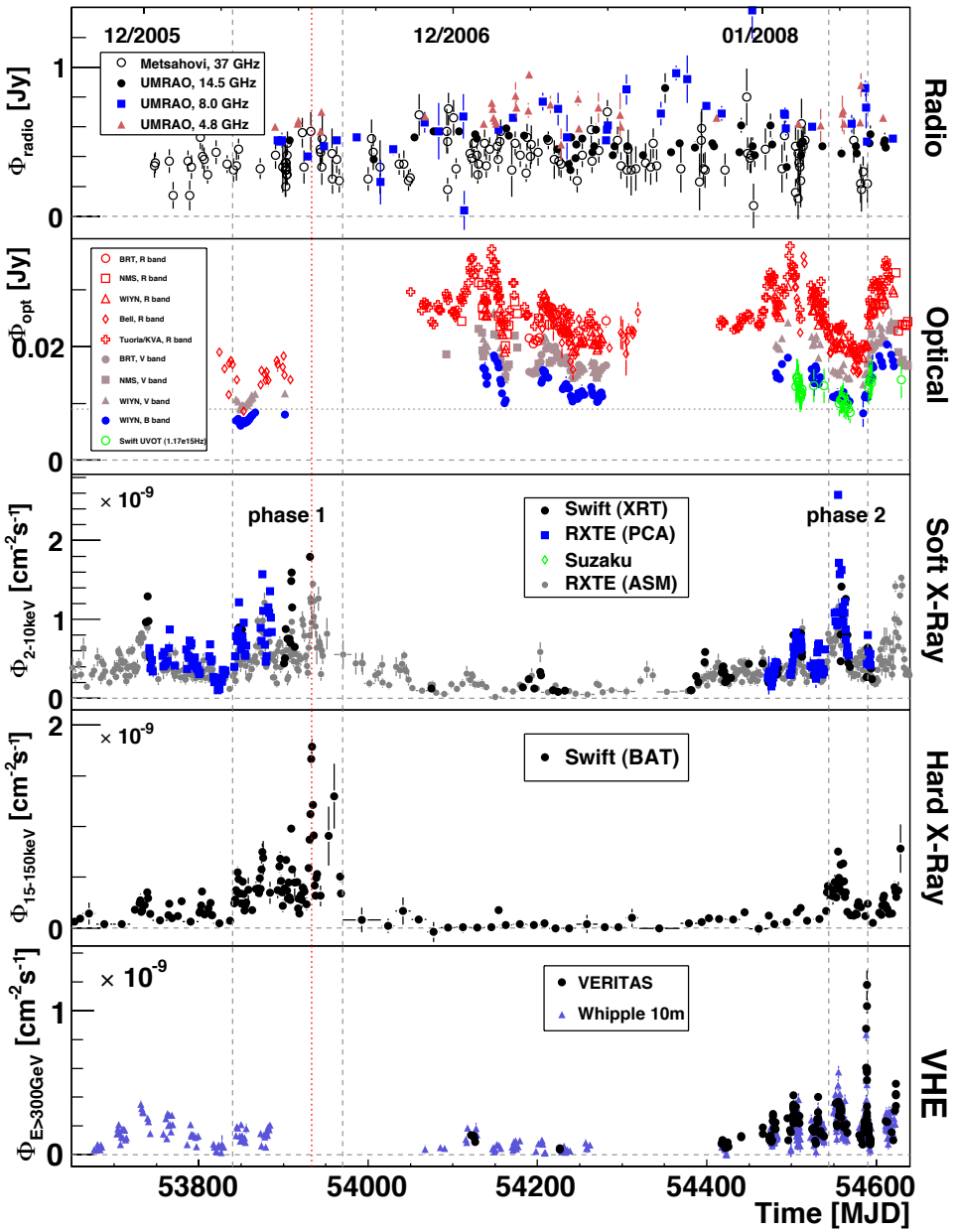
IBL-VHE catalog started!

- 2 LBLs: BL Lacertae, S5 0716+714
- Average of requested observation time: **>100 hr each**
- Taken ~25-30 hr/each since 2010
- Neither of them detected in low state
- BL Lacertae flare detected in June 2011

Other Classical Blazars: Mrk 421

- Large MWL observational campaign since 2006 (Whipple & VERITAS)
- Two phases of increased X-ray activity (2006 & 2008)
- Good X-ray/TeV coverage in second phase
- Spectral evolution in TeV: correlation between Flux vs. Γ

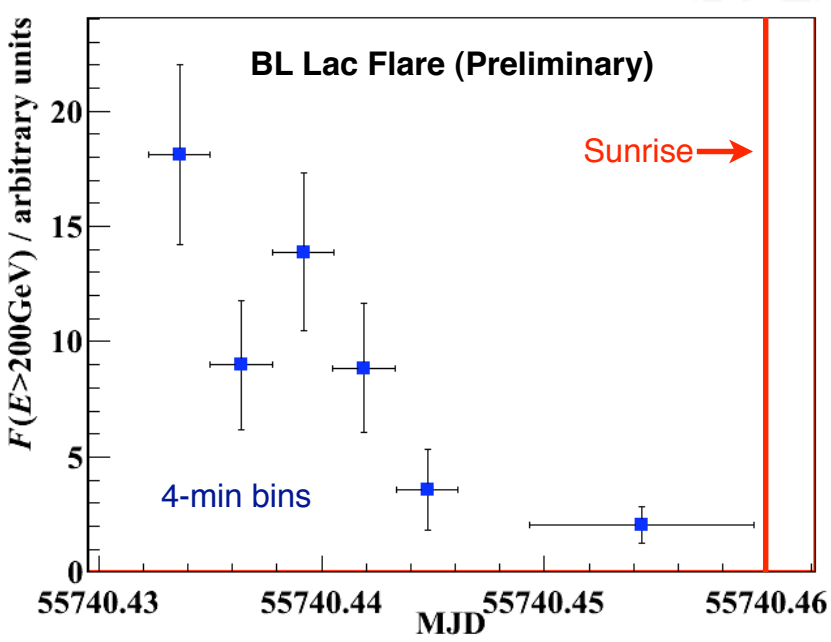


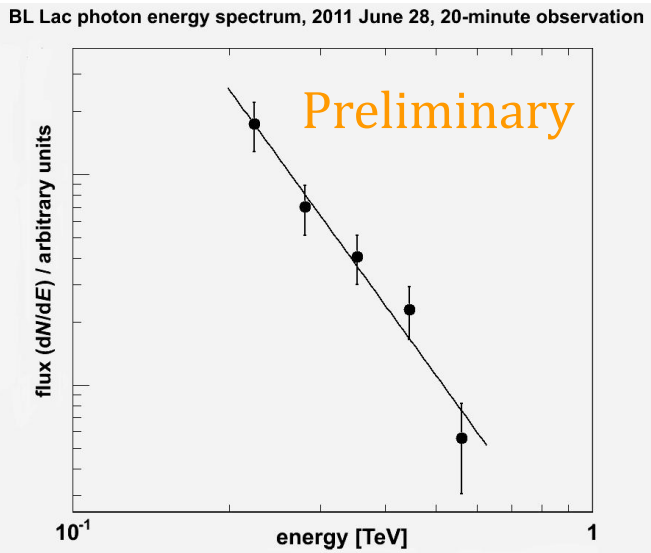


Rapid Flare of BL Lacertae

- MAGIC discovery 2005-2006, flux ~3% Crab, no variability, Γ ~3.6

- VERITAS Monitoring started in 2010
- No detection, UL < 3% Crab
- May 2011 several observatories reported increase in activity





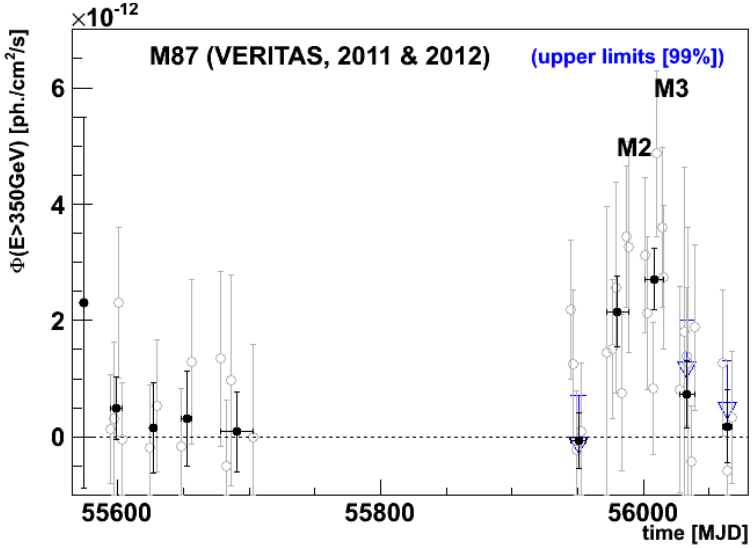
- June 28th VERITAS (3T, twilight) observed a flare on a 40 min observation
- Run #1: 20σ, ~50% Crab (E > 300 GeV)
- Run #2: 5σ, ~10% Crab (E > 300 GeV)
- Soft spectrum Γ = 3.4 ± 0.4

Non-Blazar AGNs: M 87

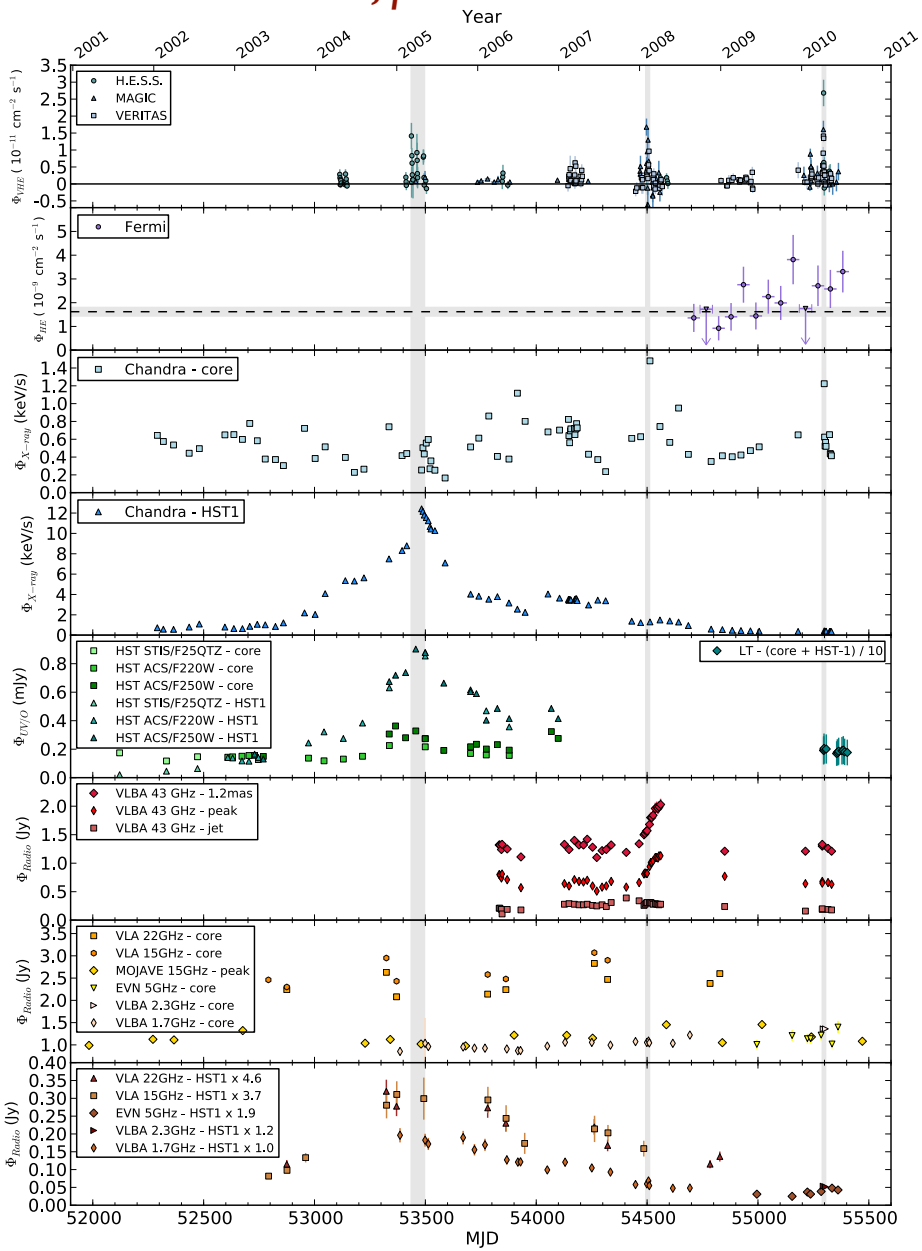
Extensive MWL campaign over several years:
VHE:VERITAS, MAGIC, HESS (80 hr tot)
HE: Fermi
X-ray: Chandra
Optical: HST, Liverpool Telescope
Radio:VLBA (43 GHz, 2.3 GHz, 1.7 GHz),VLA (22 GHz), EVN (5 GHz), Mojave (VLBA 15 GHz)

3 flaring episodes (maybe 4)

Acciari et al. (VERITAS collab.), ApJ, 679, 397 (2008)
Acciari et al. (VERITAS, HESS, MAGIC collab.), Science, 325, 444 (2009)
Acciari et al. (VERITAS collab.), ApJ, 716, 819 (2010)
HESS, MAGIC, VERITAS ApJ, 746, 151 (2012)



M. Beilicke, poster



DARK MATTER PROGRAM

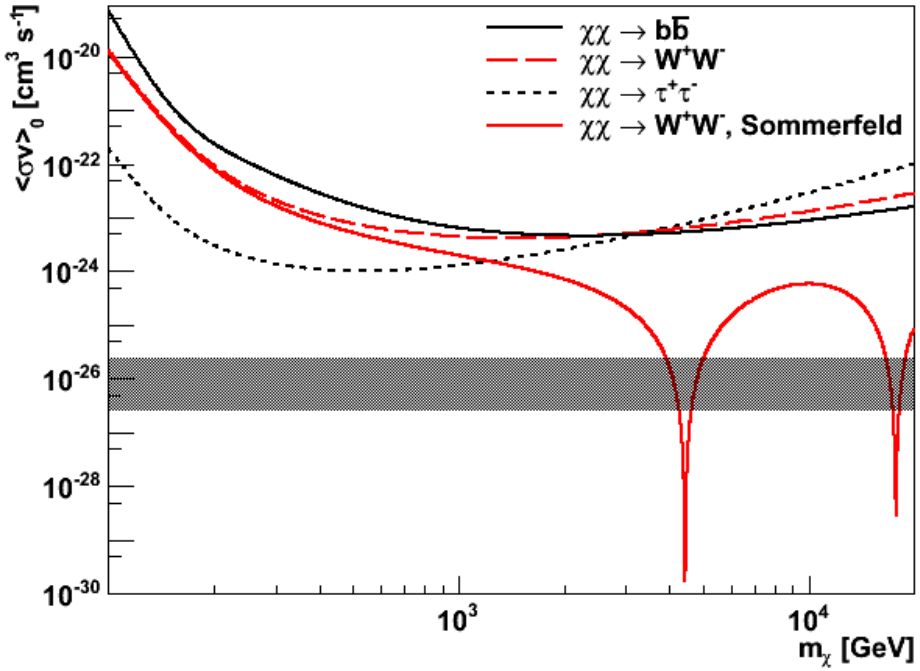
Nicola Galante for the VERITAS coll.

Gamma2012, Heidelberg, July 9-13, 2012

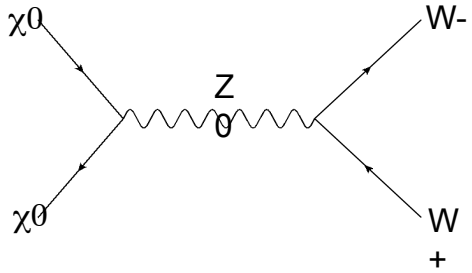
Segue I

· Upper limits on the number of gamma rays in the signal search region can be translated into upper limits on the DM-annihilation cross-section:

$$\langle \sigma v \rangle_{min}^{95\%\,CL} = \frac{8\pi}{\bar{J}_{ann}(\Delta\Omega)} \times \frac{N_\gamma^{95\%CL} m_{DM}^2}{T_{obs} \int_0^{m_{DM}} \mathcal{A}_{eff}(E) \frac{d^3\Phi_\gamma}{dE dA dt} dE} \qquad [\mathrm{cm^{-3}\ s^{-1}}]$$



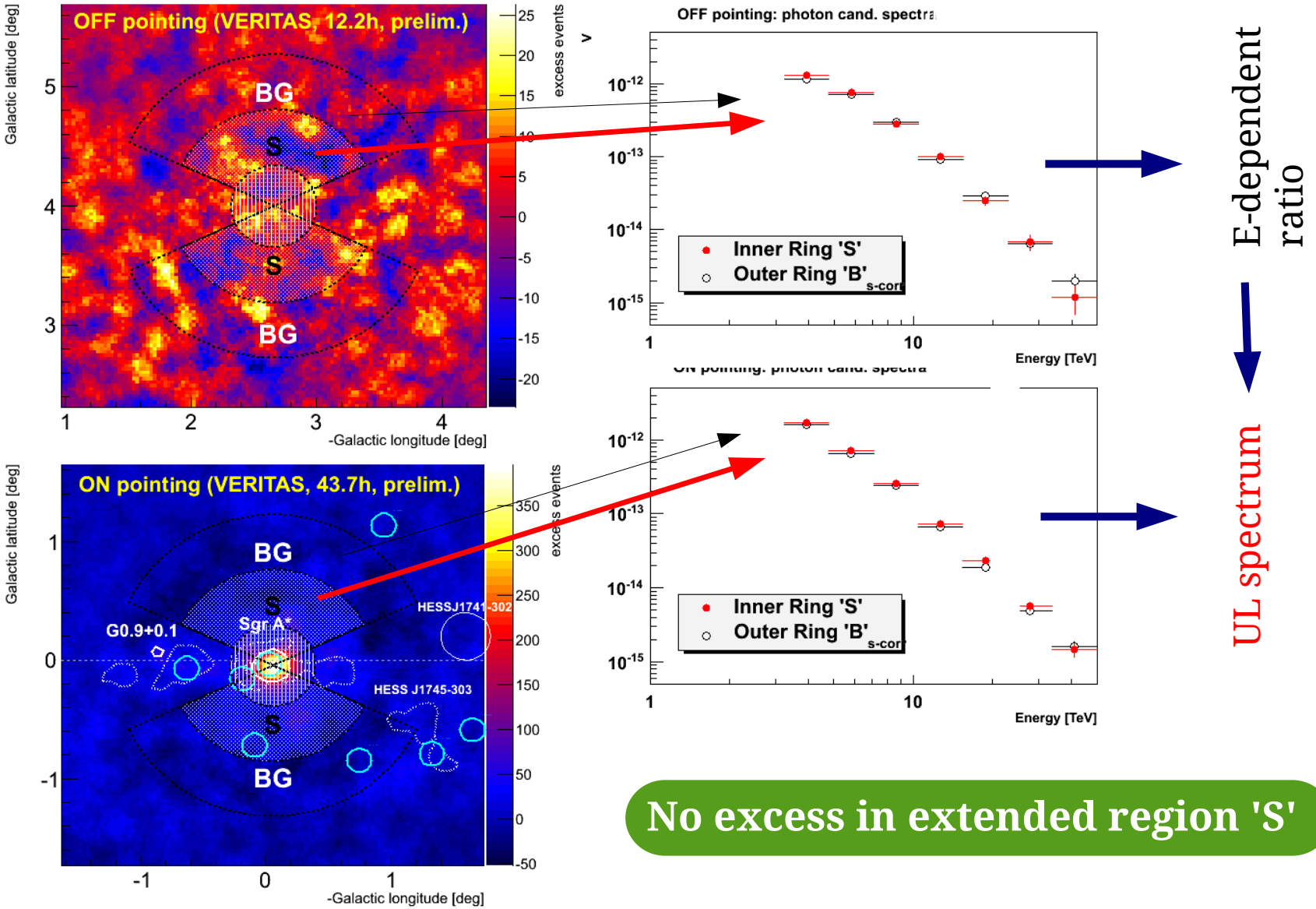
J. Grube, poster



- $\langle\sigma v\rangle_{min} \leq 1^{-8} \times 10^{-24}$ cm^3 s^{-1}, 95 % c.l.
- Still two orders of magnitude away from the interesting parameter space (grey band area)
- First resonances excluded when considering the Sommerfeld enhancement in the W^+W^- channel (see the proceeding, and the soon-to-be published paper for further information)

Galactic Center

M. Beilicke talk, Thursday 12th, 12:26pm



No excess in extended region 'S'

FUNDAMENTAL PHYSICS

Nicola Galante for the VERITAS coll.

Gamma2012, Heidelberg, July 9-13, 2012

LIV from Crab Pulsar

N. Otte, ICRC 2011

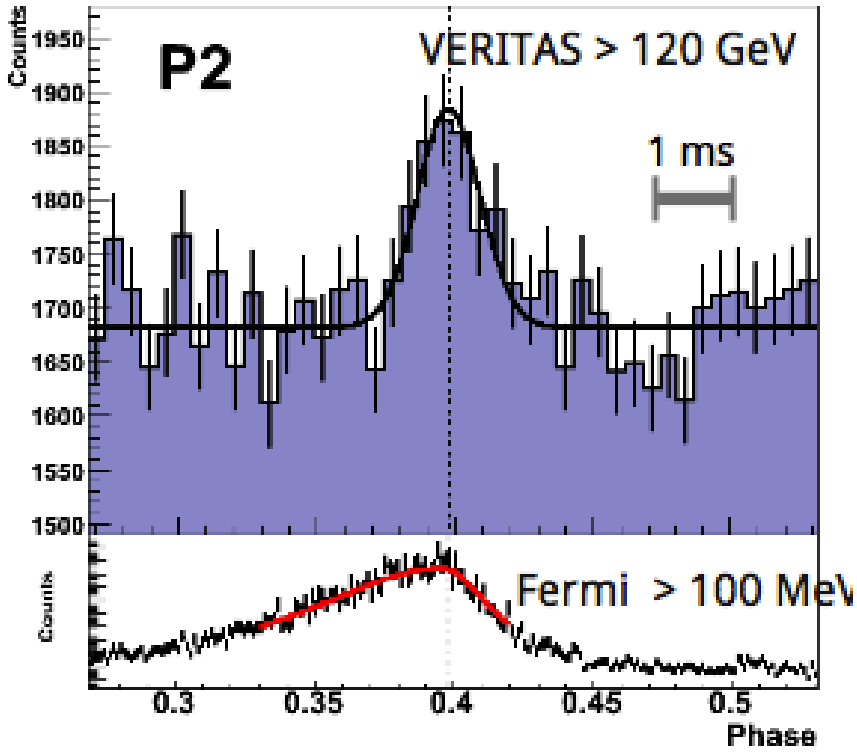
Quantum Gravity suggests:
$c = c_0(1 - (E/E_{LIV})^n)$ n =1,2 & $E_{LIV} \sim M_{pl}$

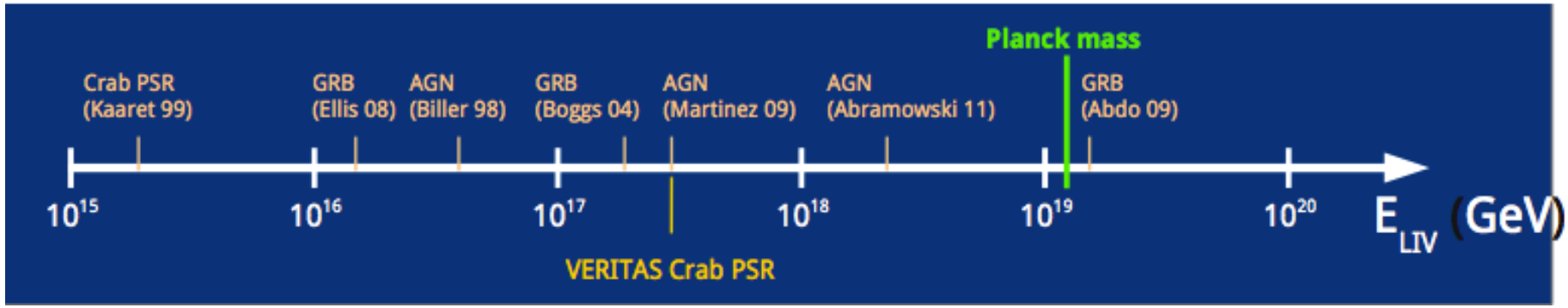
Effects small, requires fast variability, high energies and astronomical distances

Limit calculated from P2 peaks differences of FERMI and VERITAS

$E_{LIV} \sim 3 \times 10^{17}$GeV

B. Zitzer talk, Monday 9th, 11:46am





Conclusions

- **VERITAS** is **operating well** and is matching its scientific goals
- VERITAS has been **upgraded** over the years (past and present) with successful **increases in sensitivity** and performances
- The VERITAS **science** program is well structured, rich and **balanced**
- **Variability** study of **binary system**
- First measurement of **VHE power law** in **pulsars**, limits on **LIV**
- Probing the inner **composition** of MILAGRO **extended regions**
- VERITAS started the IBL catalog at VHE, **new VHE sub-class of blazars**
- Huge flare on Mrk 421 triggered by VERITAS monitoring to **MWL** partners, **variability and spectral evolution** study on progress
- Hint from VERITAS catalog: HBL ➔ SSC IBL ➔ SSC+EC
- **Limits on redshift** from VHE observations
- Radio Galaxy program provides insights of the **sub-structures** of the jet and core
- **Strongest limits** on **WIMP** annihilation cross section from dSph