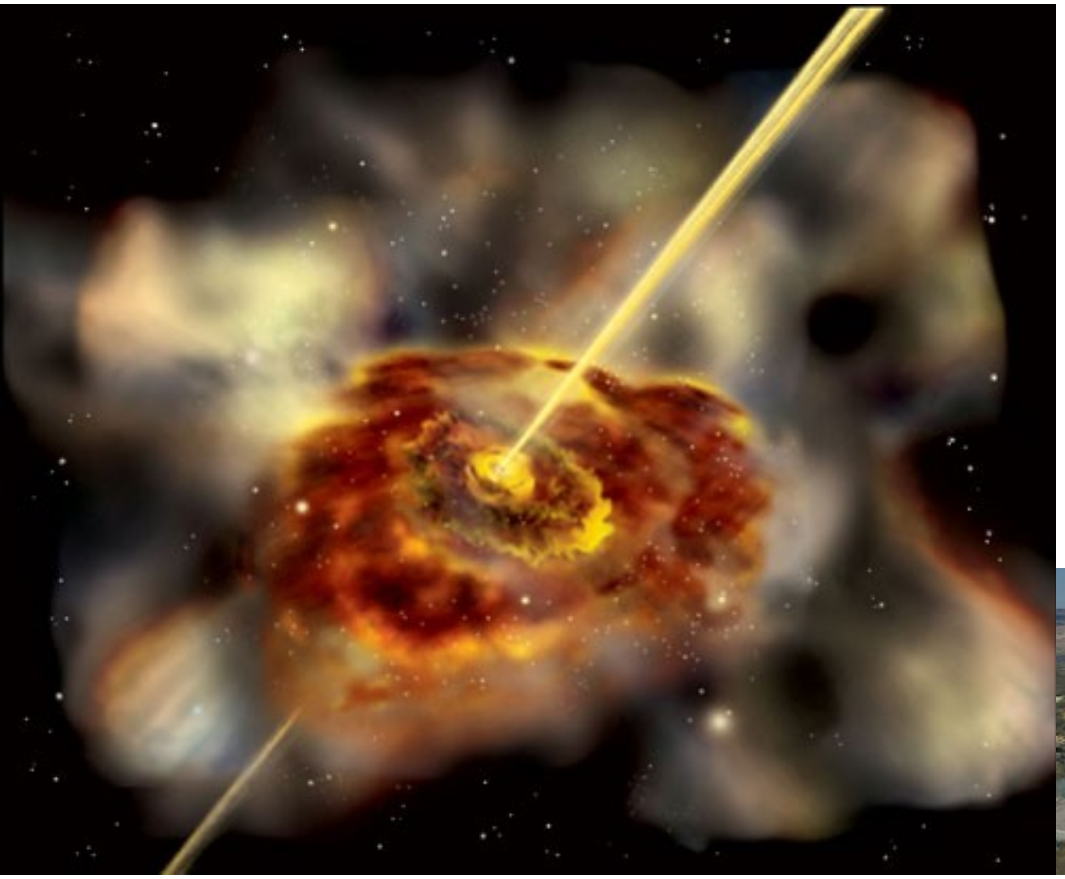
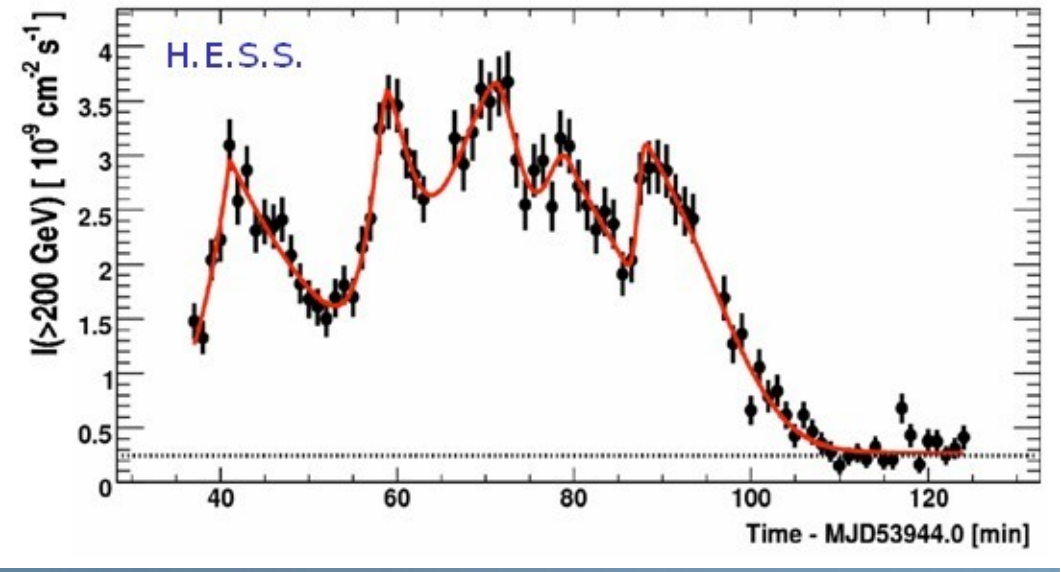
Variability of VHE γ-ray Blazars

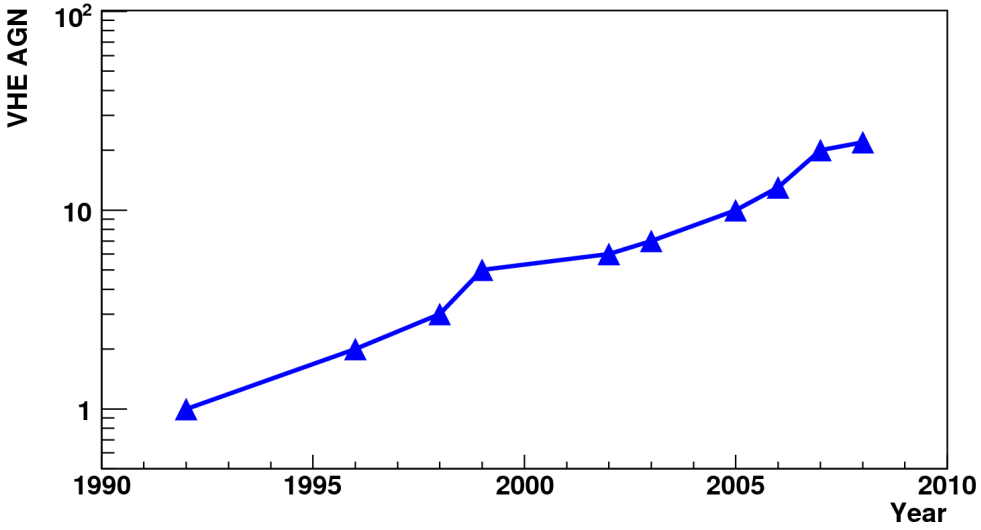
Wystan Benbow
Harvard-Smithsonian Center for Astrophysics

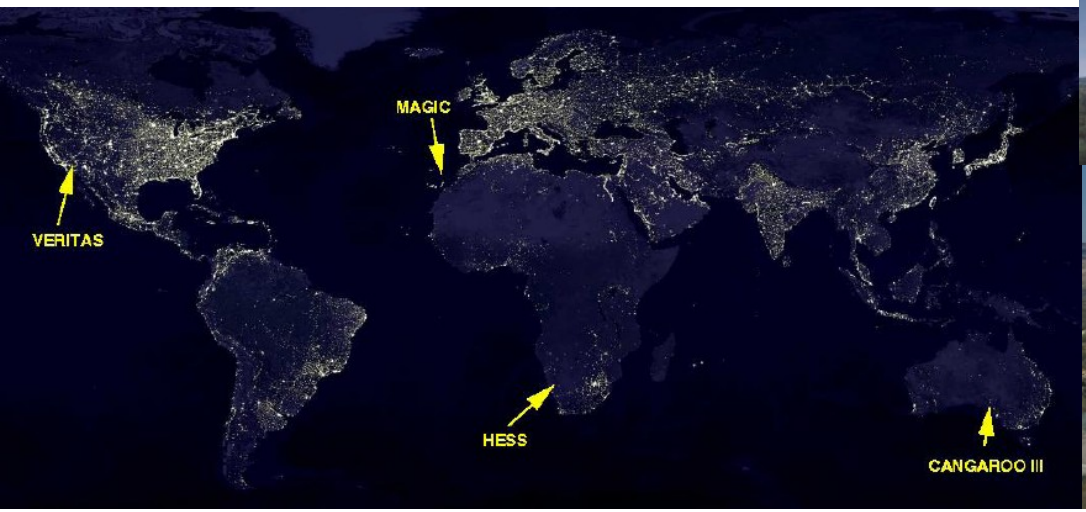


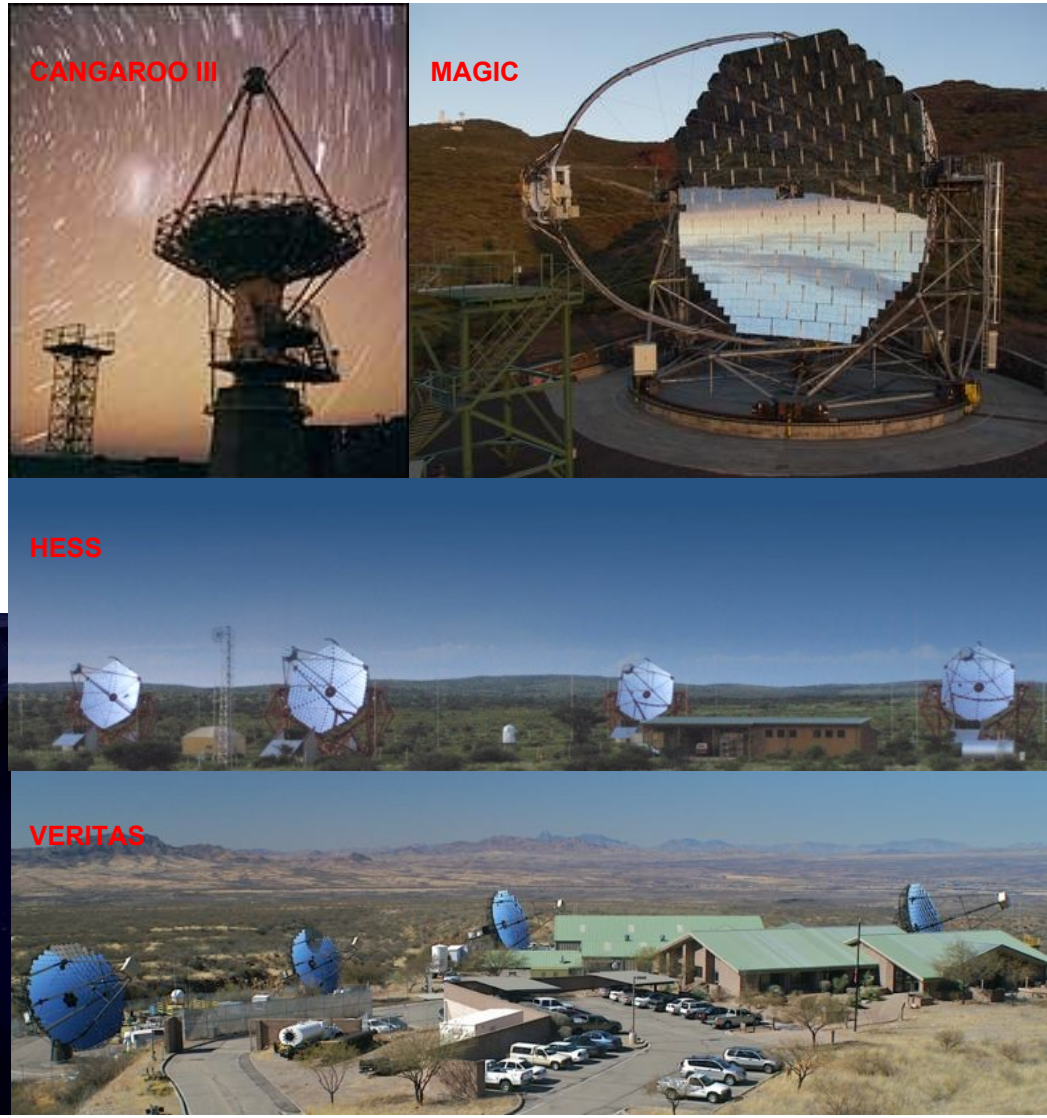


22 VHE AGN & Counting...

Four sensitive VHE instruments with AGN discovery programs



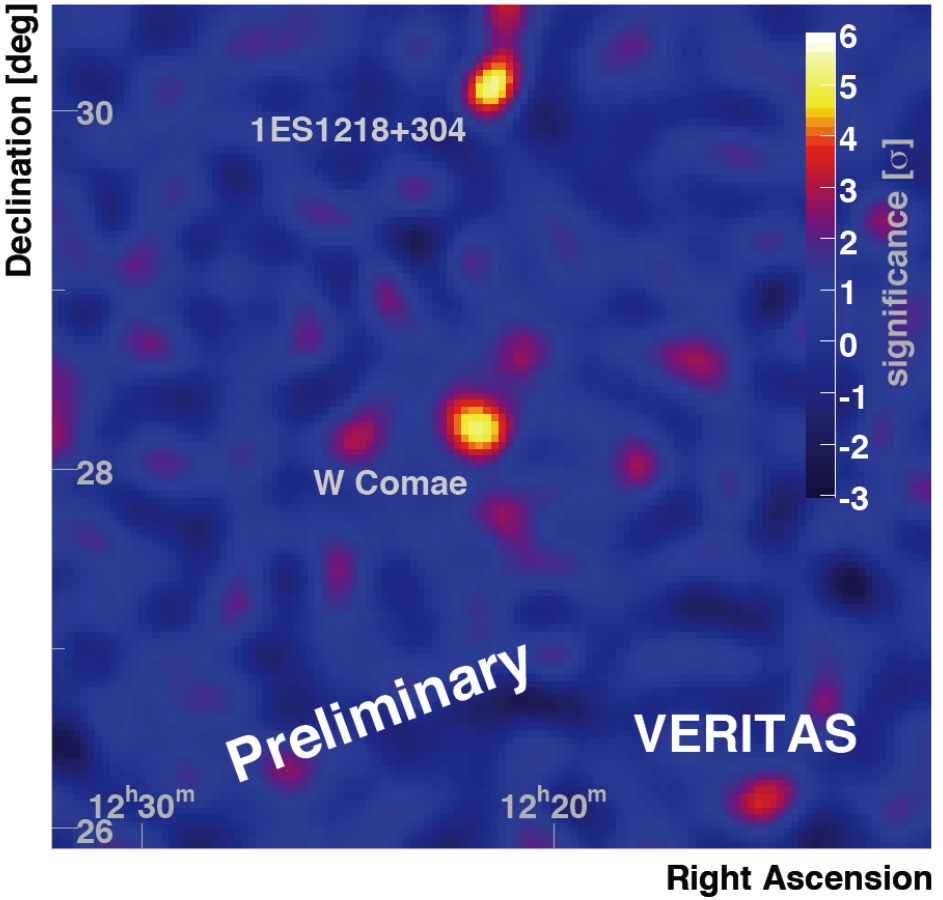




The VHE AGN Catalog

Object	Redshift	Type	1st Detection	EGRET
M 87	0.004	FR I	HEGRA*	N
Mkn 421	0.030	HBL	Whipple*	Y
Mkn 501	0.034	HBL	Whipple*	Y
1ES 2344+514	0.044	HBL	Whipple*	N
Mkn 180	0.046	HBL	MAGIC	N
1ES 1959+650	0.047	HBL	7-Tel. Array*	N
BL Lac	0.069	LBL	MAGIC	Y
PKS 0548-322	0.069	HBL	H.E.S.S.	N
PKS 2005-489	0.071	HBL	H.E.S.S.	N
RGB J0152+017	0.080	HBL	H.E.S.S.*	N
W Comae	0.102	IBL	VERITAS	Y
PKS 2155-304	0.116	HBL	Mark VI*	Y
H 1426+428	0.129	HBL	Whipple*	N
1ES 0806+524	0.138	HBL	VERITAS	N
1ES 0229+200	0.139	HBL	H.E.S.S.	N
H 2356-309	0.165	HBL	H.E.S.S.	N
1ES 1218+304	0.182	HBL	MAGIC*	N
1ES 1101-232	0.186	HBL	H.E.S.S.	N
1ES 0347-121	0.188	HBL	H.E.S.S.	N
1ES 1011+496	0.212	HBL	MAGIC	N
PG 1553+113	>0.25	HBL	H.E.S.S.*	N
3C 279	0.536	FSRQ	MAGIC	Y

* = detected by ≥2 observatories



VHE spectra generally soft (Γ>3.0)

"High"-z AGN harder than expected

- e.g. 1ES 0229 (Γ=2.5) & 1ES 1101 (Γ=2.9)
- Limits EBL density to low values
- VHE horizon has expanded

VHE Milestones

1992: 1st VHE AGN (Mkn 421)

1994: 1st VHE flare; 1st simultaneous SED

1995: 2nd VHE AGN (Mkn 501)

- 1st "serious" MWL campaign (Mkn 421)
  - Apparent VHE/X-ray/UV correlations
- 1ES 2344+514 discovered during flare

1996: 10 Crab flare of Mkn 421

- Sub-hour flux variability
- 1st indications of VHE spectral hardening

1997: Mkn 501 flares; 1st non-ACT detection

1998: VHE/X-ray correlated on time scales of hours

2001: 1st clear VHE spectral variability

2002: "Orphan flare" of 1ES 1959+650

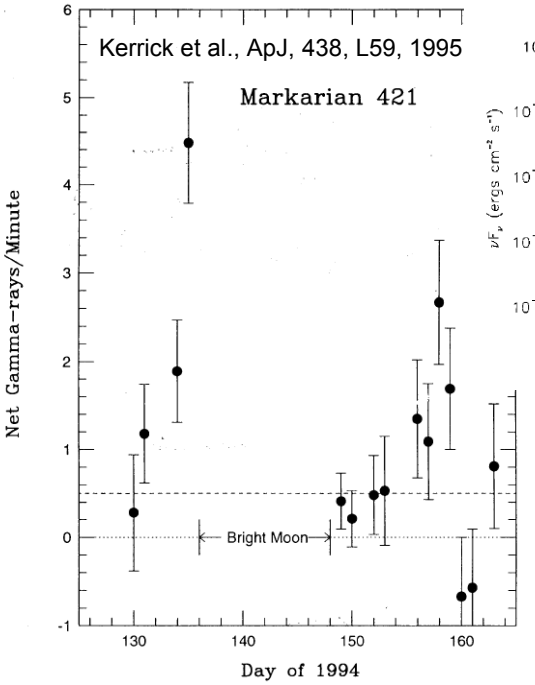
2003: 1st VHE emitting non-blazar (M 87) published

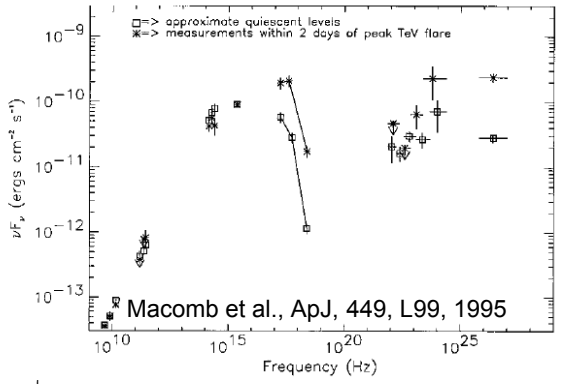
2005: Day-scale variability of M 87

- ~2 minute doubling time in Mkn 501

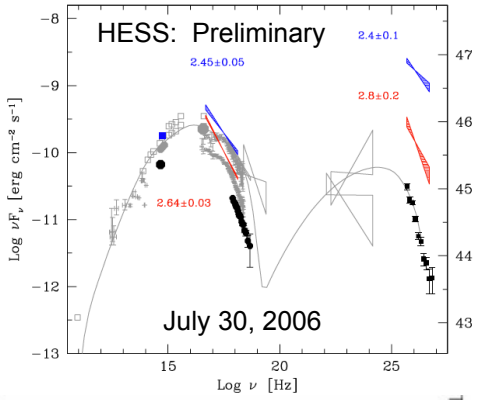
2006: HESS detects amazing PKS 2155-304 flare

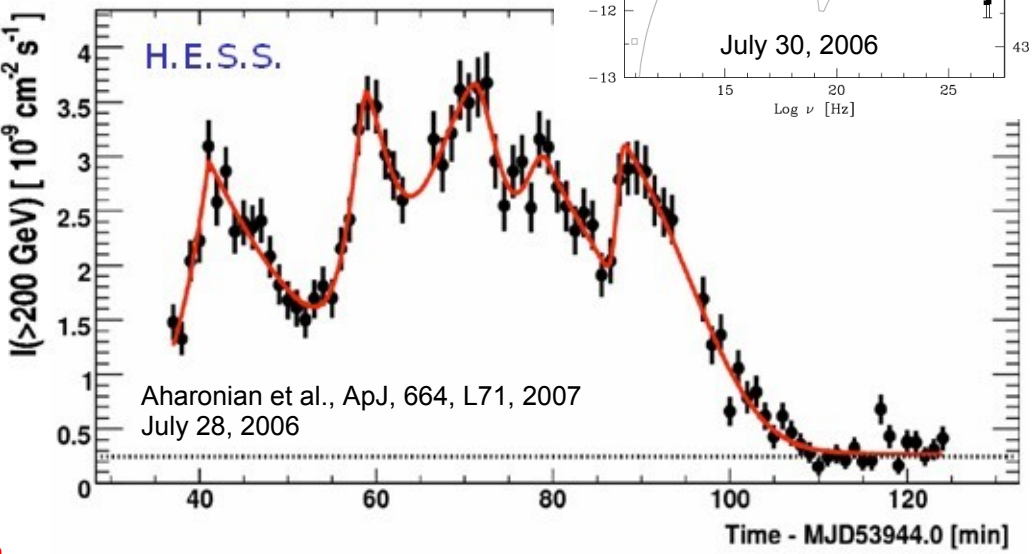
- Minute-scale VHE spectra with simult. X-ray data





Costamante et al., Proc. High Energy Phenomena in Relativistic Outflows (Dublin), 2007





No Variability for ~1/3 of VHE Blazars

- **1ES 0806+524** (1% Crab, VERITAS)
  - 5.8σ in 46 h (0.9σ $h^{-0.5}$), 2 years
  - Swordy et al., ATel #1415, 2008
- **1ES 0229+200** (1.8% Crab, HESS)
  - 6.6σ in 42 h (1.0σ $h^{-0.5}$), 2 years
  - Aharonian et al., A&A, 475, L9, 2007
- **PKS 0548-322** (1.4% Crab, HESS)
  - 5.8σ in 24 h (1.2σ $h^{-0.5}$), 3 years
  - Superina, Benbow et al., Proc 30th ICRC, 2007
- **Mkn 180** (11% Crab, MAGIC)
  - 5.5σ in 11 h (1.7σ $h^{-0.5}$), 7 days
  - Albert et al., ApJ, 648, L105, 2006
- **RGB J0152+017** (2% Crab, HESS)
  - 6.6σ in 15 h (1.7σ $h^{-0.5}$), 2 months
  - Aharonian et al., A&A, in press, 2008
- **1ES 0347-121** (2% Crab, HESS)
  - 10.1σ in 25 h (2.0σ $h^{-0.5}$), 5 months
  - Aharonian et al., A&A, 473, L25, 2007

All of these blazars have only 1 VHE detection article

All prior VHE limits are well above the reported flux

Low flux => Only 3 of these are detectable in 1 night

These 3 have limited sampling of the VHE light curve

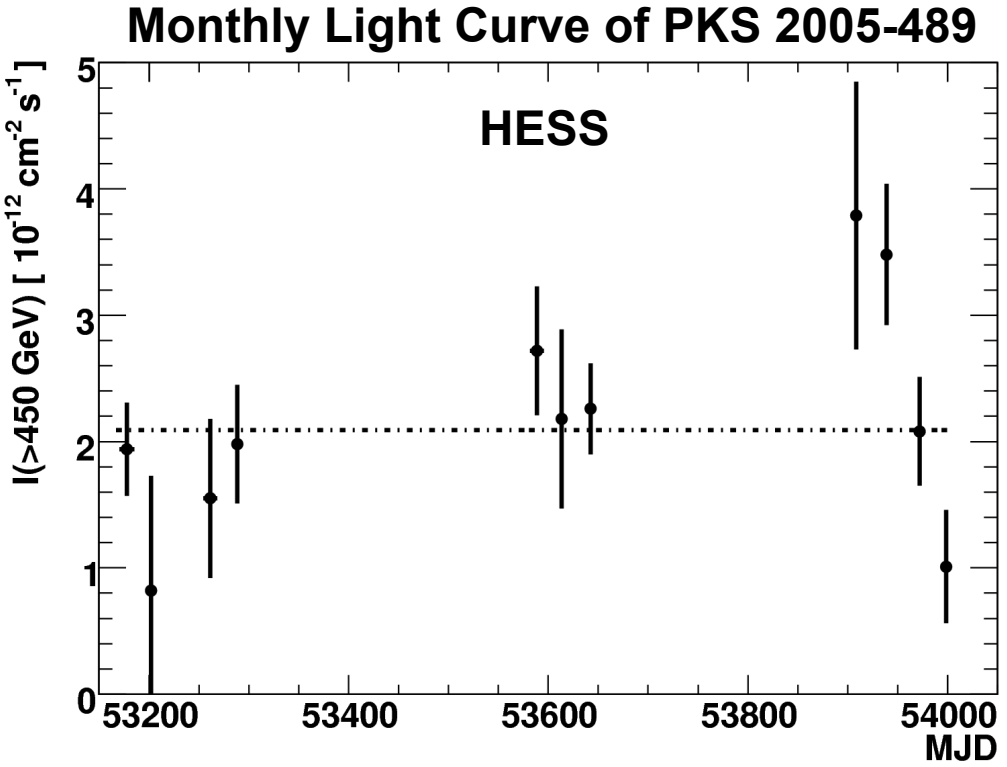
Even variability with a factor of a few would probably be missed

Weak Evidence for 4 VHE Blazars

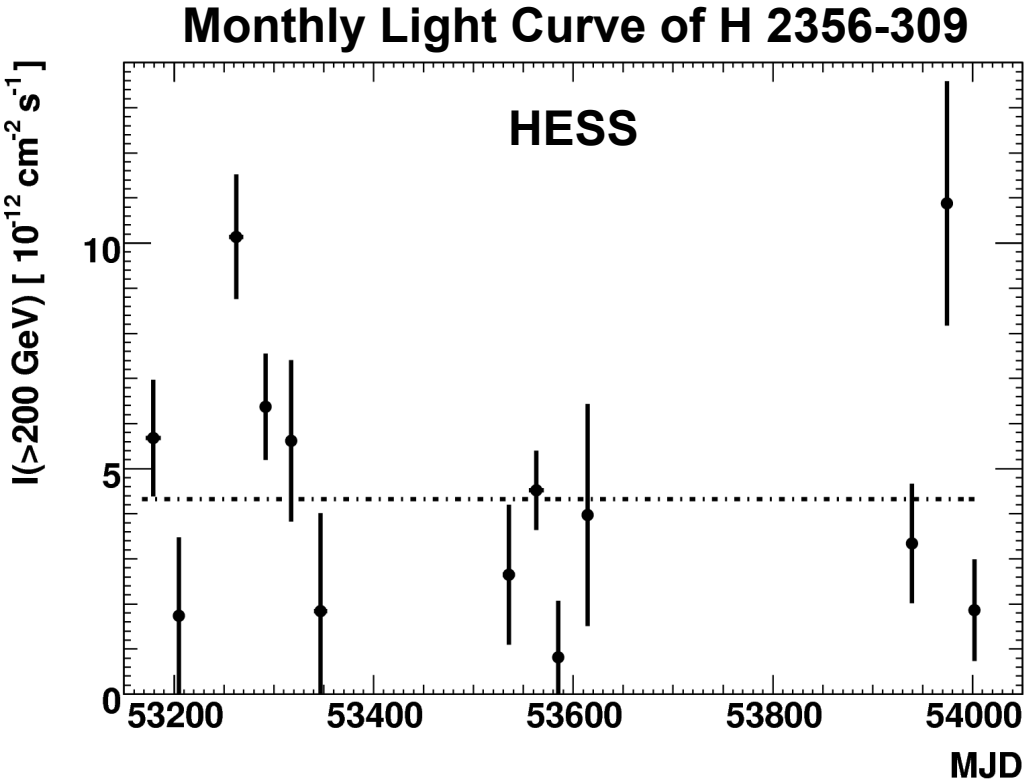
- **1ES 1218+304** (MAGIC & VERITAS)
  - MAGIC: 13% Crab in 1/2005
    - 6.4σ in 8.2h
    - Albert et al., ApJ, 642, L119, 2006
  - MAGIC: 9% Crab in 1-3/2006
    - 4.6σ in 14.6h, Within errors of 2005 flux
    - Albert et al., ApJ, in press, 2008
  - VERITAS: 8% Crab in 12/2006-3/2007
    - 10.4σ in 17.4h, ~2.5σ less than MAGIC '05
    - Fortin et al, HEAD 2008 presentation
- **1ES 1101-232** (HESS)
  - 10.6σ in 61h of 2004-2007 data
  - ~2% Crab from 2004-2006, 2007 limit
    - '07 limit (99.9%) ~1σ less than 04-06 avg.
    - A&A, 470, 475, 2007; A&A, 478, 387, 2008
- **1ES 1011+496** (MAGIC)
  - 6.5% Crab in 03-05/2007 (6.2σ in 18.7h)
    - Albert et al., ApJ, 667, L21, 2007
  - <8.6% Crab Limit from 03-04/2006
    - 2.5σ in 14.5h; special analysis => 3.6σ
    - "Flux" ~40% lower than '07 flux, but <2σ diff.
    - Albert et al, ApJ, in press, 2008
- **PG 1553+113** (HESS & MAGIC)
  - HESS: 3.4% Crab in 2005-06
    - 10.2σ in 24.8h, No variations
    - Aharonian et al., A&A, 477, 481, 2008
  - MAGIC: 8.8σ in 18.8 h in 2005-06
    - 2005 flux consistent with HESS
    - 2006 flux is ~1/3 of 2005 flux; ~2.3σ diff.
    - '06 data not same epoch as HESS
    - Albert et al, ApJ, 654, L119, 2007

Weak Variability for 2 VHE blazars

Costamante, Benbow, et al., Proc 30th ICRC, 2007



	t (h)	Sign. (σ)	I(>450 GeV)	Γ
2004	24.2	7.7	1.81±0.26	3.65±0.39
2005	32.6	11.0	2.38±0.27	3.15±0.30
2006	21.5	8.8	2.20±0.26	2.89±0.20
Total	**78.3**	15.9	2.08±0.15	3.18±0.16



	t (h)	Sign. (σ)	I(>200 GeV)	Γ
2004	39.9	9.6	5.97±0.61	2.97±0.19
2005	46.7	5.9	3.28±0.65	2.99±0.39
2006	23.2	5.1	3.49±0.82	3.43±0.41
Total	**109.8**	12.1	4.47±0.39	3.09±0.16

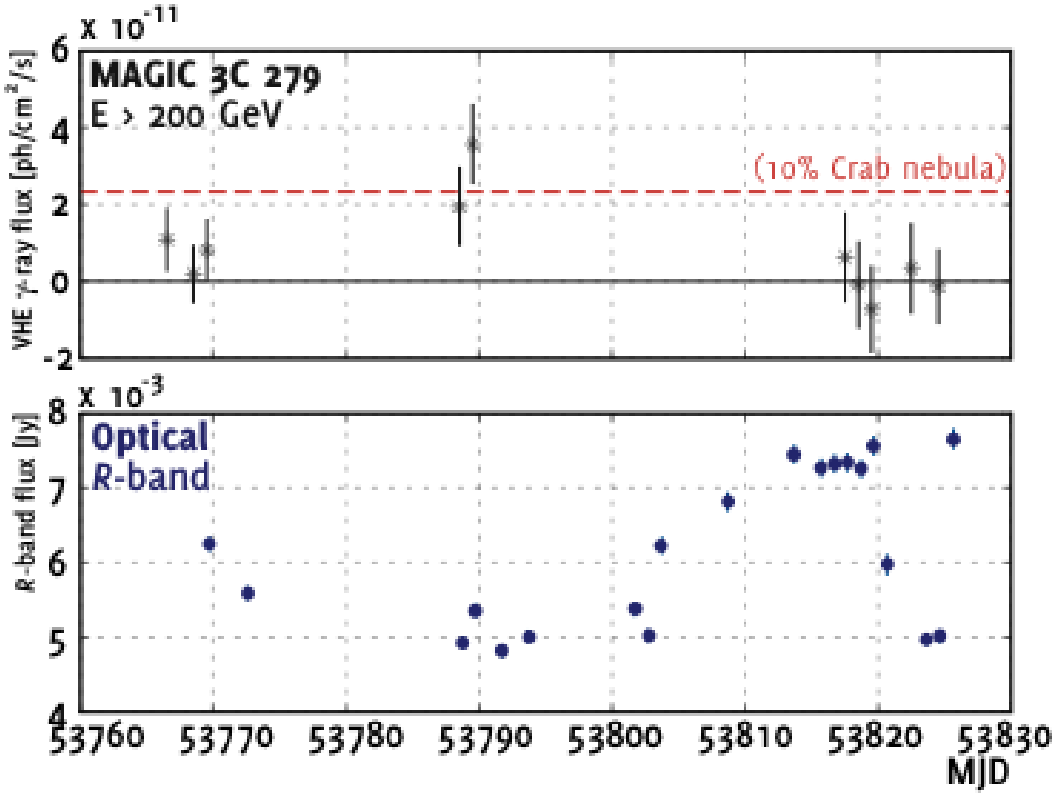
PKS 2005-489: Monthly flux variations in 2006; Γ hardens (1.8σ) between 2004 & 2006

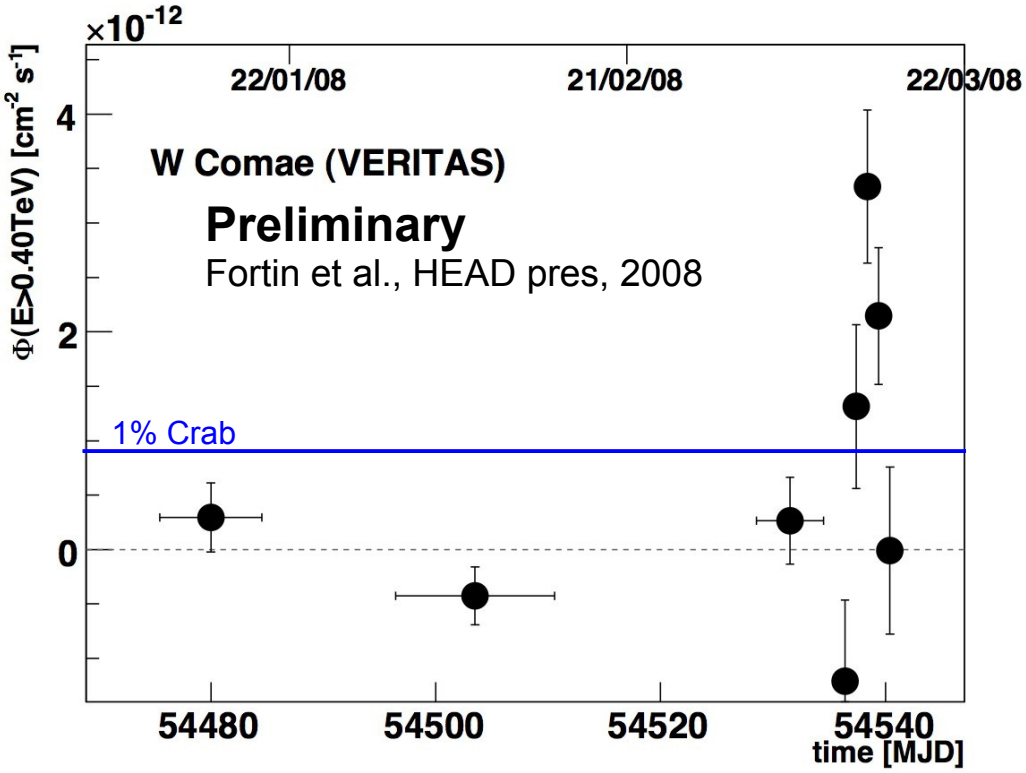
3 X-ray campaigns: Flux increases (x10) & Γ hardens by 0.7 between 2004 & 2005; 2004 is lowest/softest state "ever"

H 2356-309: Clear month-scale variability; No spectral variations

3 X-ray campaigns: Flux & Γ are ~constant between 2004 & 2005; Low-state SED

The only 3 non-HBL VHE blazars





3C 279: MAGIC claims VHE detection

Teshima et al., Proc 30th ICRC, 2007

~5σ in 62 minutes of data from only 1 night

No signal in other MAGIC data or HESS data

W Comae: VERITAS claims VHE detection

Swordy et al., ATel #1422, 2008

Signal effectively from 3 nights

Only strong VHE limits prior

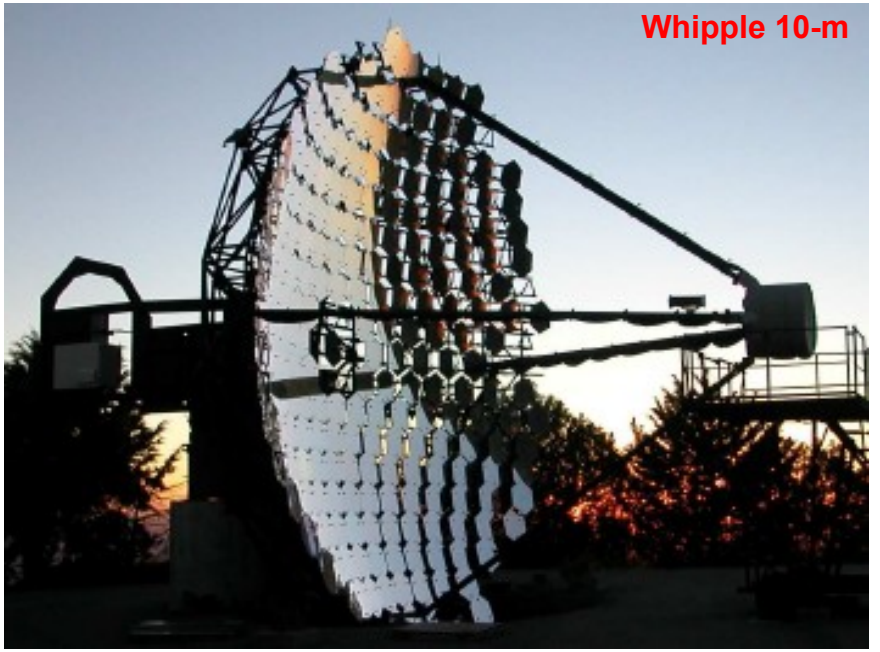
BL Lac: Magic detect (5.1σ in ~22 h; 3% Crab) constant signal in August 2005

Not detected by MAGIC in 2006 (~26 h) & only strong limits prior to 2005

Albert et al., ApJ, 666, L17, 2007

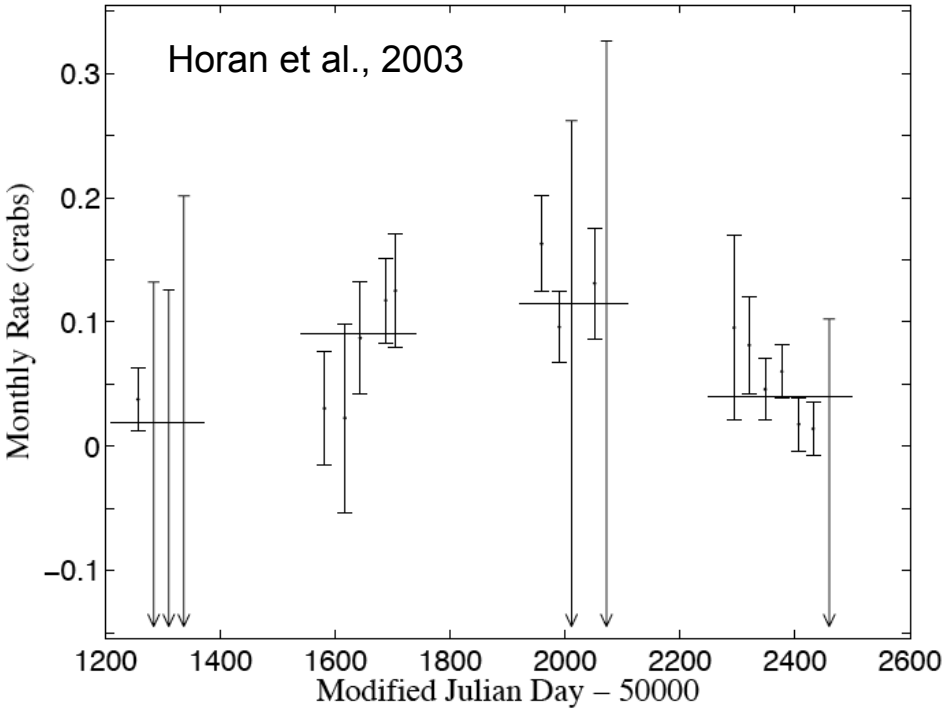
What's left? The original 7 AGN

- Not much variability from new blazars
  - Flux near current sensitivity limit
  - Many sources very new
- The original 7 AGN:
  - North: Mkn 421, Mkn 501, 1ES 2344+514, H 1426+428, 1ES 1959+650, M 87
  - South: PKS 2155-304
    - M 87, Mkn 421, Mkn 501 viewable at LZA
- HESS: PKS 2155-304 detected immediately
  - 1st light in June 2002
  - 4-telescopes in January 2004
- MAGIC: Mkn 421 detected immediately
  - Fully operational in February 2004
- VERITAS: Mkn 421 detected with prototype
  - "1st" data in 2006
  - 4-telescopes in ~April 2007
- CANGAROO-III: PKS 2155-304 detected in 2006
  - Fully operational in March 2004
- Whipple 10-m: Still operating
  - Primary purpose is blazar monitoring (since 2005)
    - Long-term study of original 5 Northern blazars
    - Flaring alerts



H 1426+428

Whipple 10-m Light Curve (1999-2002)

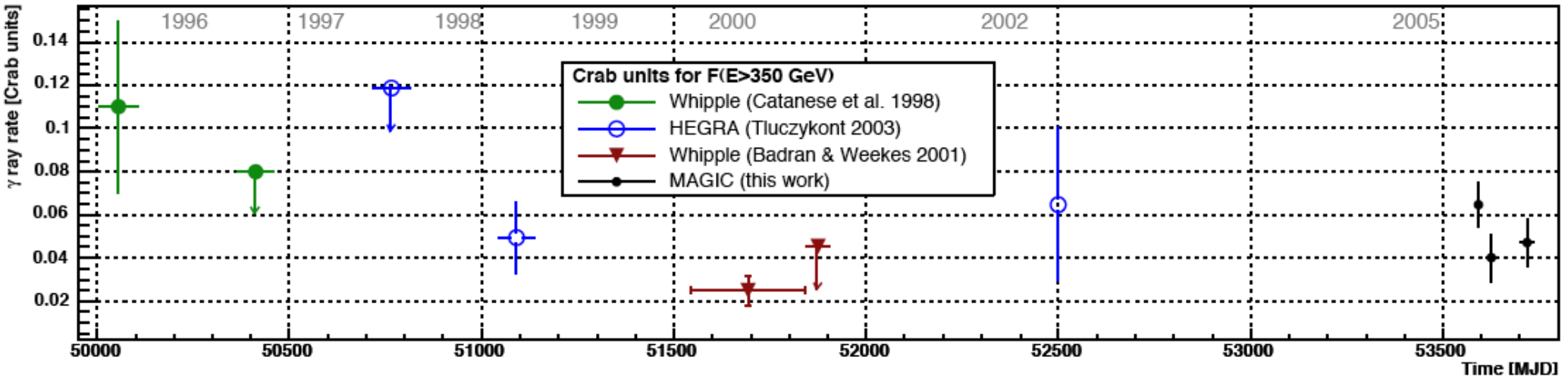


"Bright" period (2000-2001) otherwise nothing...

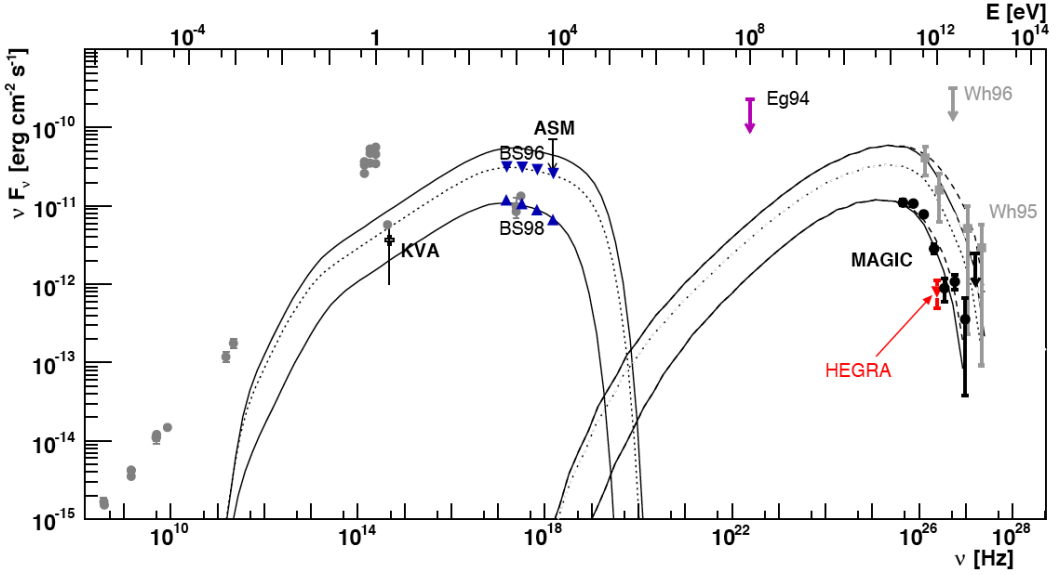
Not detected by 3rd generation instruments

- Whipple: Horan et al., ApJ, 571, 753, 2002
  - 1995-98: VHE limits from monitoring (18 h)
  - 1999: VHE limit (0.9σ in 24h); <3% Crab
  - 2000: Marginal (3.1σ in 40 h): ~10% Crab
  - 2001: Discovery (5.5σ in 38 h): ~13% Crab
  - 2002: Marginal (2.4σ in 111 h): ~3% Crab
    - Horan et al., Proc 28th ICRC, 2003
  - 2003-07: No detection (>150 h)
    - J. Grube, PhD Thesis, 2007
    - Kildea et al., HEAD Pres., 2008
- HEGRA: Aharonian et al., A&A, 403, 523, 2003
  - 1999-2000: 5.8σ in 44h; ~10% Crab
  - 2002: 5.3σ in 220 h; ~4% Crab
- CAT: Djannati-Atai et al., A&A, 391, L25, 2002
  - 1998-2000: 5.2σ in 26h, ~20% Crab
- MAGIC: Albert et al., ApJ, in press, 2008
  - 2005: VHE Limit (-0.1σ in ~6h); <5% Crab
- VERITAS: Krawcynski et al, Proc 30th ICRC, 2007
  - 2006-07: 3.2σ in 12.5h, <2.9% Crab

1ES 2344+514: The 3rd VHE blazar



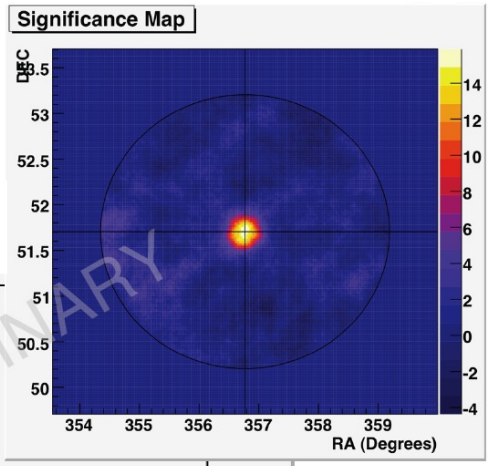
- Discovered during flaring episode
  - Catanese et al., ApJ, 501, 616, 1998
  - 6σ, 63% Crab on Dec 20, 1995 (not shown)
  - 4σ, 11% Crab during rest of 1995-96 season
- Only limits or weak detections until MAGIC late-2005 data (11σ in 23 h)
- No flaring detected by Whipple 10-m telescope from 2005-07 (122 h)
  - Kildea et al., HEAD Presentation, 2008

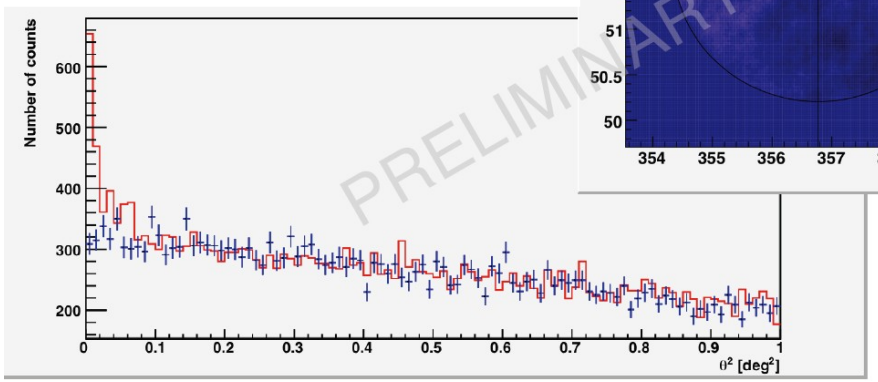


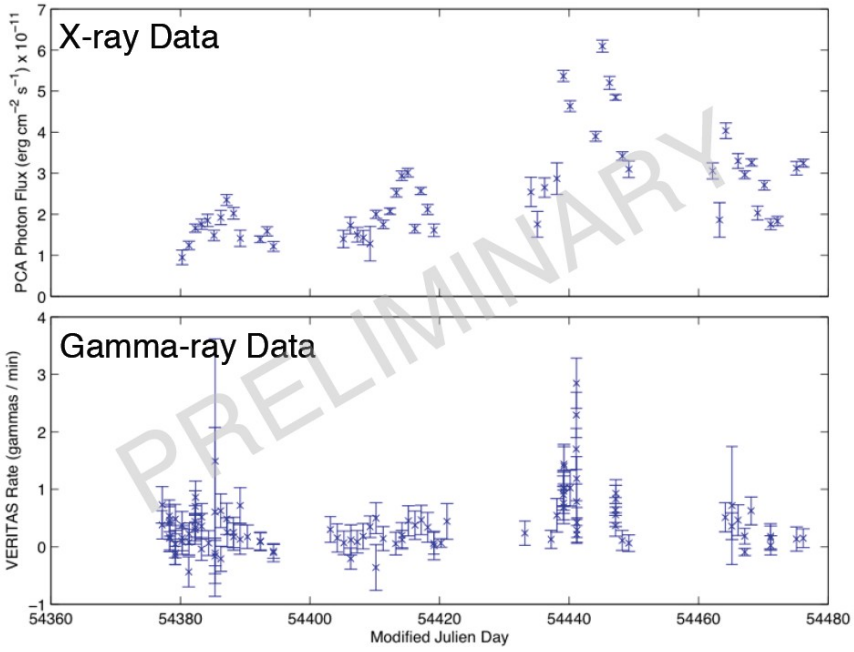
Plots from Albert et al, ApJ, 662, 892, 2007

VERITAS detects 1ES 2344+514:
VHE flaring during the 2007-08 season

- 23.5 hours of good data (28.9 total)
- Standard analysis performed
- Significance: 14.7 σ
- Mean rate: 0.35 γmin^{-1}







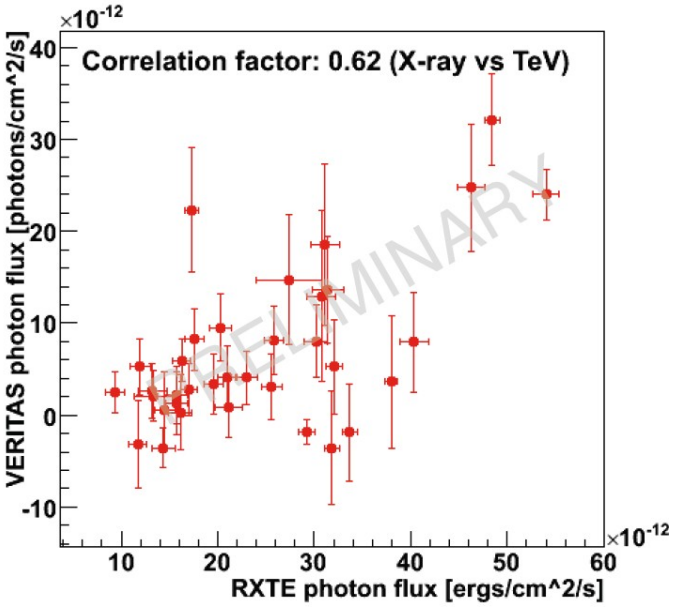
40% Crab flare on December 7, 2007

Correlated variability: X-rays & VHE γ-rays

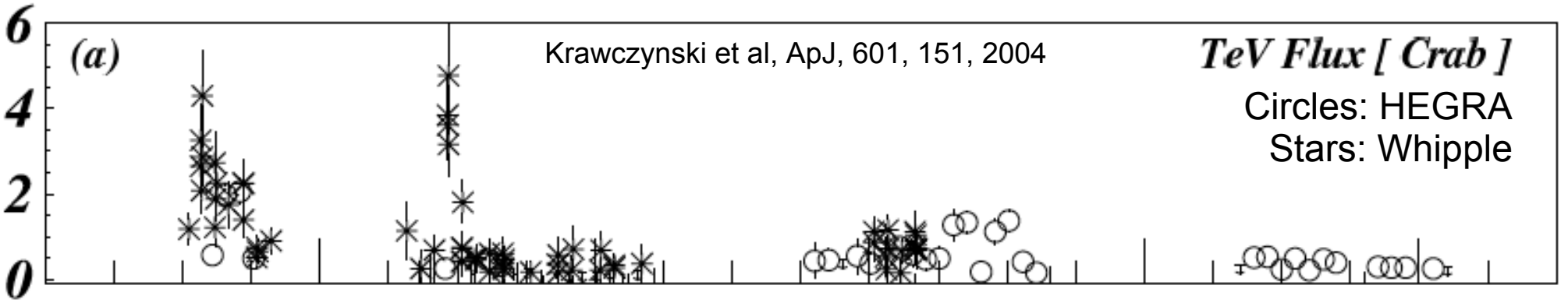
X-ray: Spectral hardening with increased flux

Simultaneous optical & radio data taken

From Horan et al., HEAD presentation, 2008



1ES 1959+650: The VHE history



Marginal (3.9σ) discovery by 7-Telescope Array

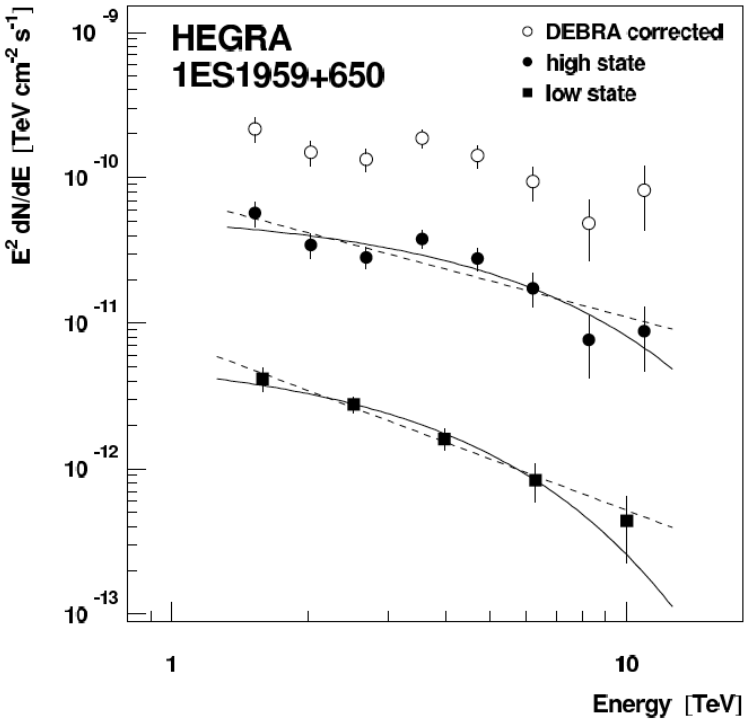
- 1998 data; Variability claimed
  - Nishiyama et al., Proc 26th ICRC, 1999

Low-state detected by HEGRA in 2000-2001

- 5.2σ in ~108h; 5.3% Crab; No variability
  - Aharonian et al., A&A, 406, L9, 2003

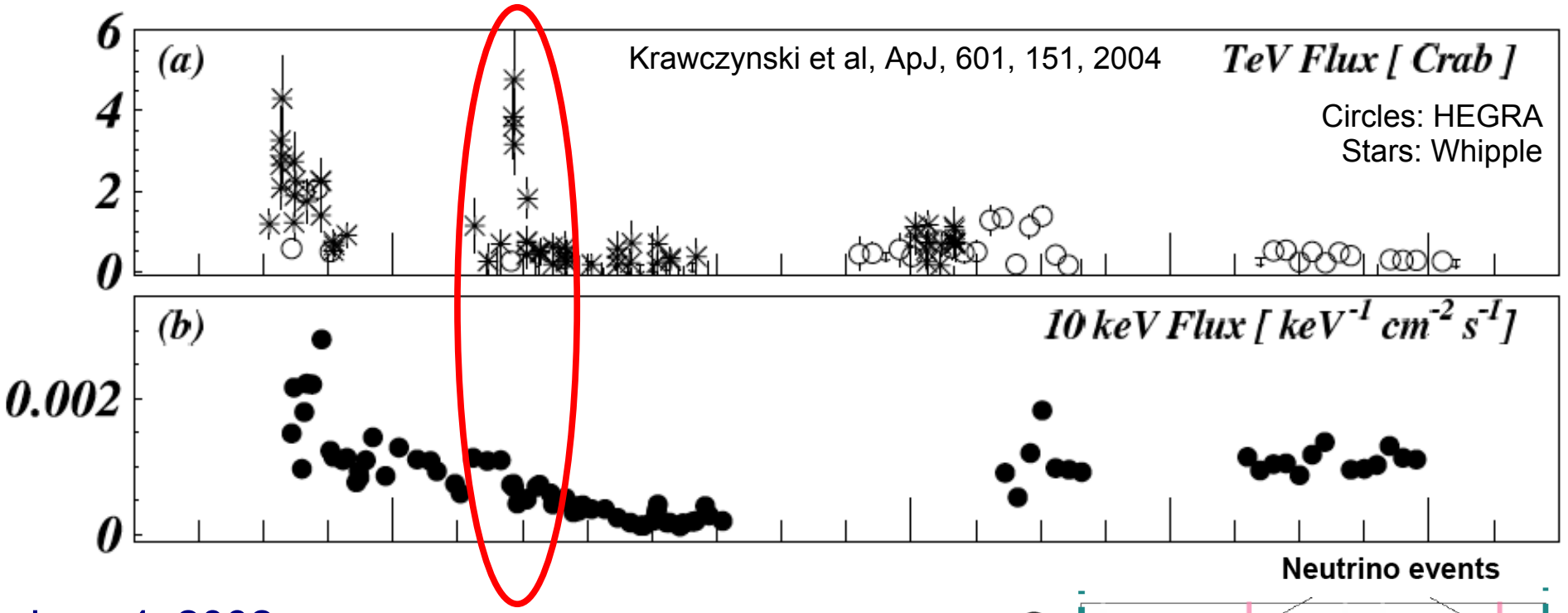
Major outburst detected in 2002

- Whipple:
  - Peak fluxes >5 Crab; Mean flux ~0.6 Crab
    - Holder et al., ApJ, 583, L9, 2003
  - No spectral variability (Γ~2.8)
    - Daniel et al., ApJ, 621, 181, 2005
- HEGRA: Aharonian et al., A&A, 406, L9, 2003
  - Peak fluxes >2.2 Crab; Hint of spectral variability
- CAT: Khelifi, PhD Thesis, 2002



HEGRA high state Γ=2.83±0.14±0.08
HEGRA low-state Γ=3.18±0.17±0.08

1ES 1959+650: The Orphan Flare

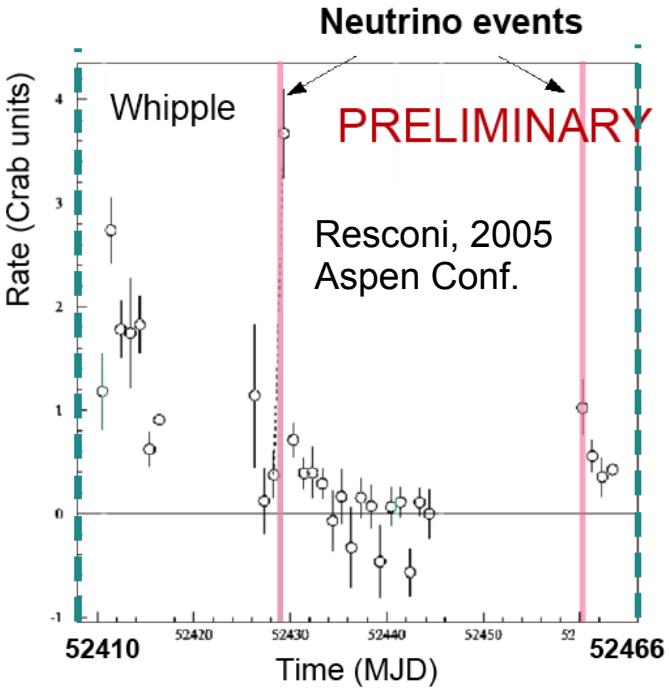


June 4, 2002:

- Whipple 10-m observes a VHE flare
- No corresponding variability in X-ray band
- Challenges 1-zone SSC model

Interesting, but not significant, AMANDA result:

- 2 neutrinos detected during flare period
- 1 coincident with the orphan flare
- Unfortuantely not a “blind analysis” => Trials
- Neutrino detection implies hadronic process



1ES 1959+650: Quiet since 2002

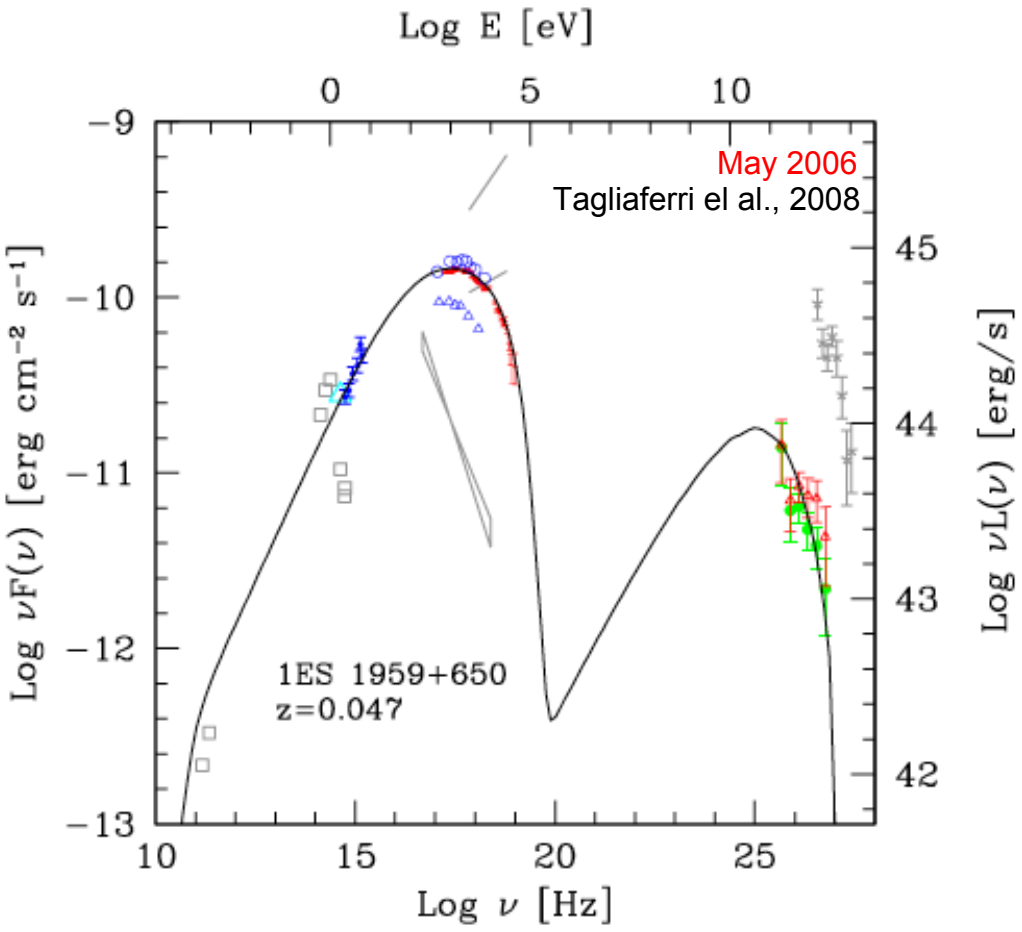
Whipple 10-m telescope:

- 2003: Marginal detection (3.3σ);
  - 24±11% Crab
  - Guitierrez et al., ApJ, 644, 742, 2006
- 2005-2007: No flares in 147 h
  - Kildea et al., HEAD Presentation, 2008

MAGIC:

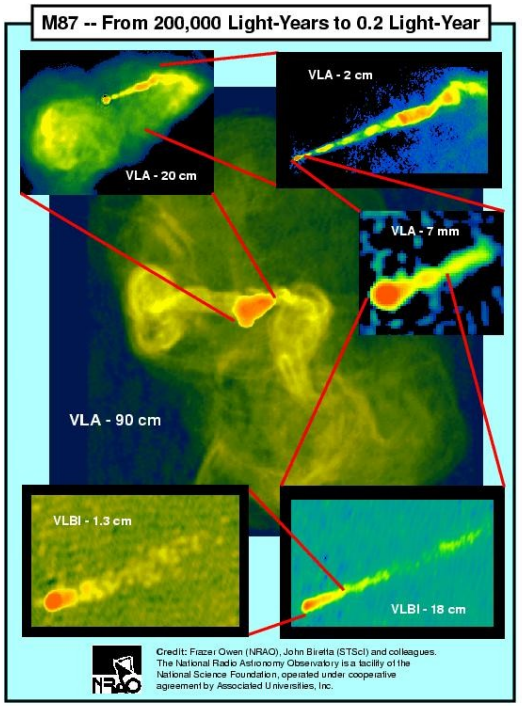
- 2004: ~20% Crab; Constant signal
  - Albert et al., ApJ, 639, 761, 2006
- 2006: ~12% Crab; Constant signal
  - Tagliaferri et al., ApJ, in press, 2008
  - Goebel et al., Proc 30th ICRC, 2007

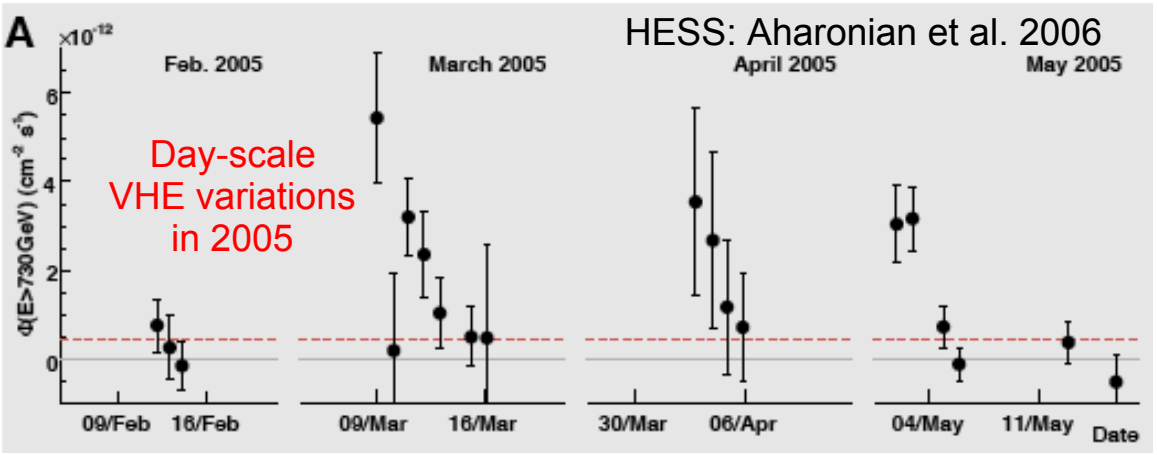
"No" VERITAS data

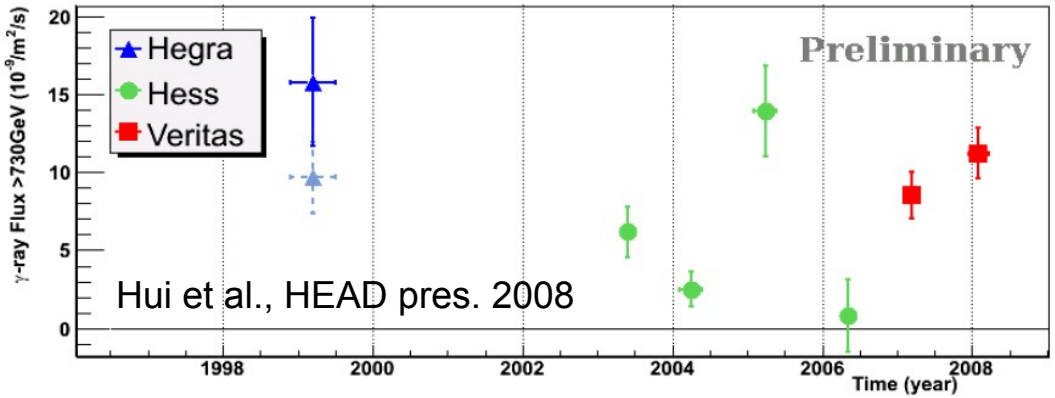


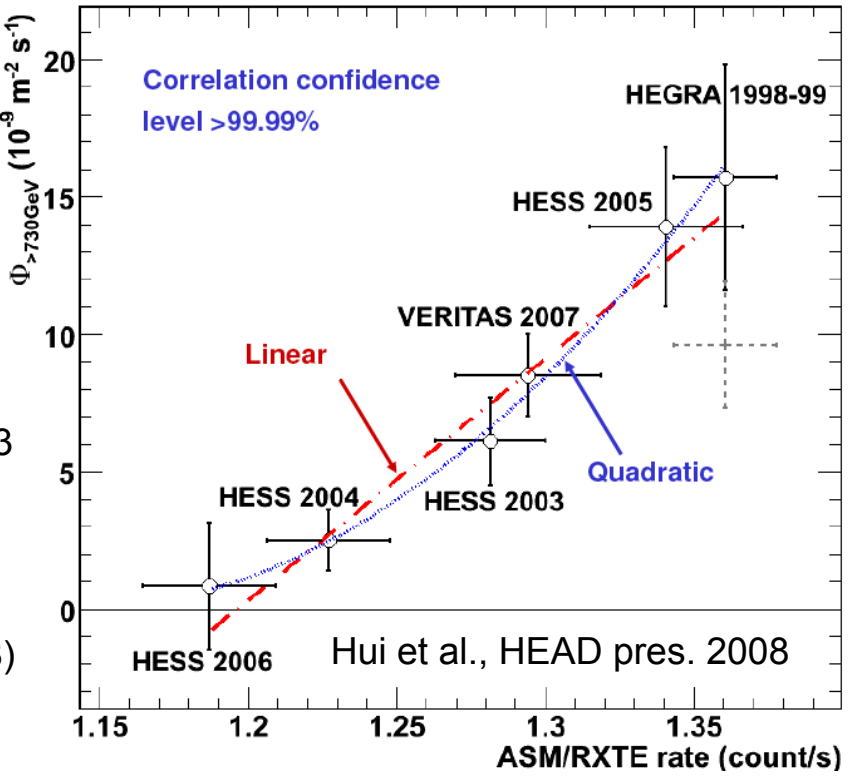
May 2006 SED: High X-ray state, but low VHE state

M 87: A “misaligned” blazar









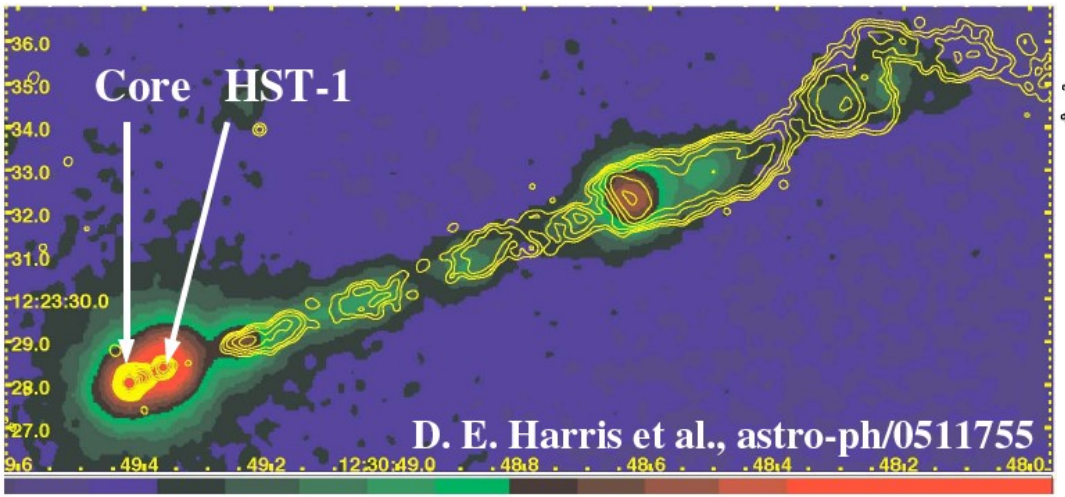
HEGRA discovers VHE emission: Aharonian et al., A&A, 403, L1, 2003

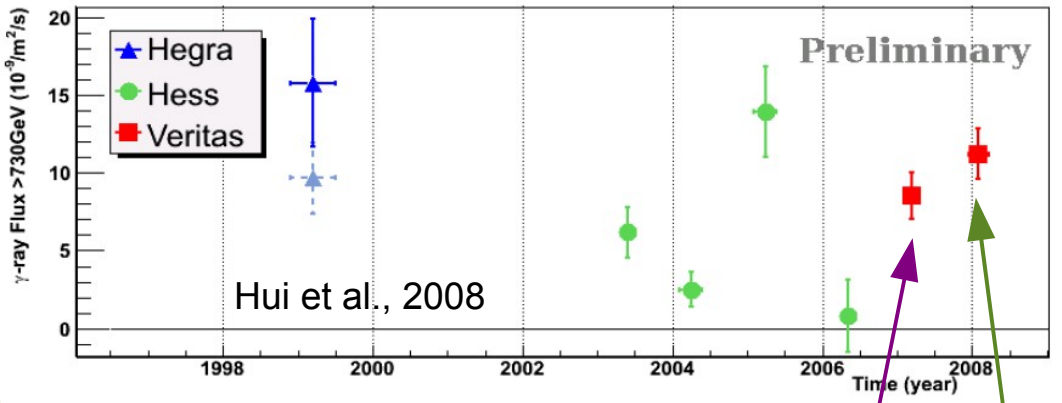
HESS detects variable, point-like, hard spectrum excess from core: Aharonian et al., Science, 314, 1424, 2006

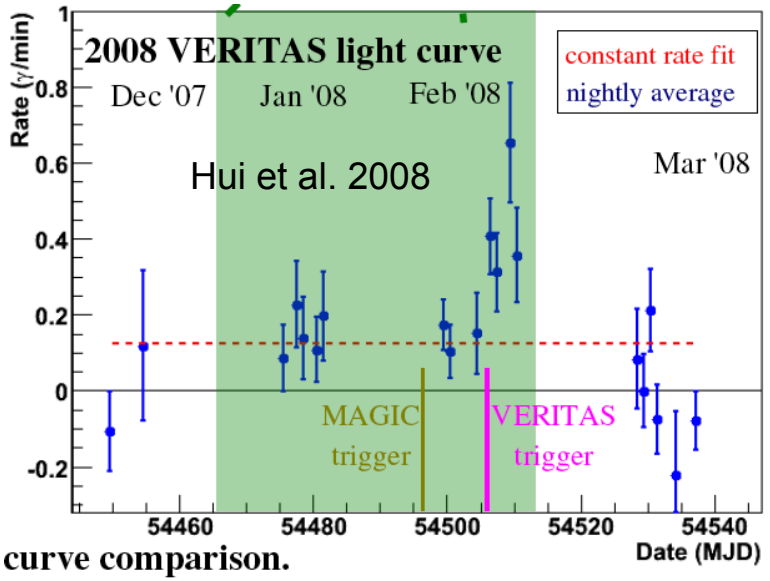
VERITAS detects steady flux in 2007 (Acciari et al., ApJ, in press, 2008)

Detected by VERITAS & MAGIC in 2008 (Hui et al., HEAD pres. 2008)

M 87: Is it the Nucleus or HST-1?

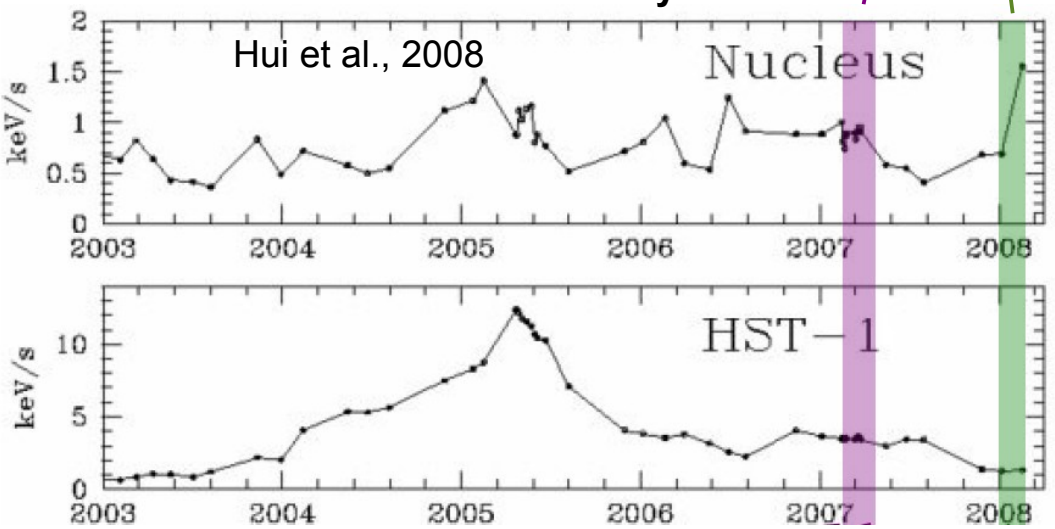






curve comparison.

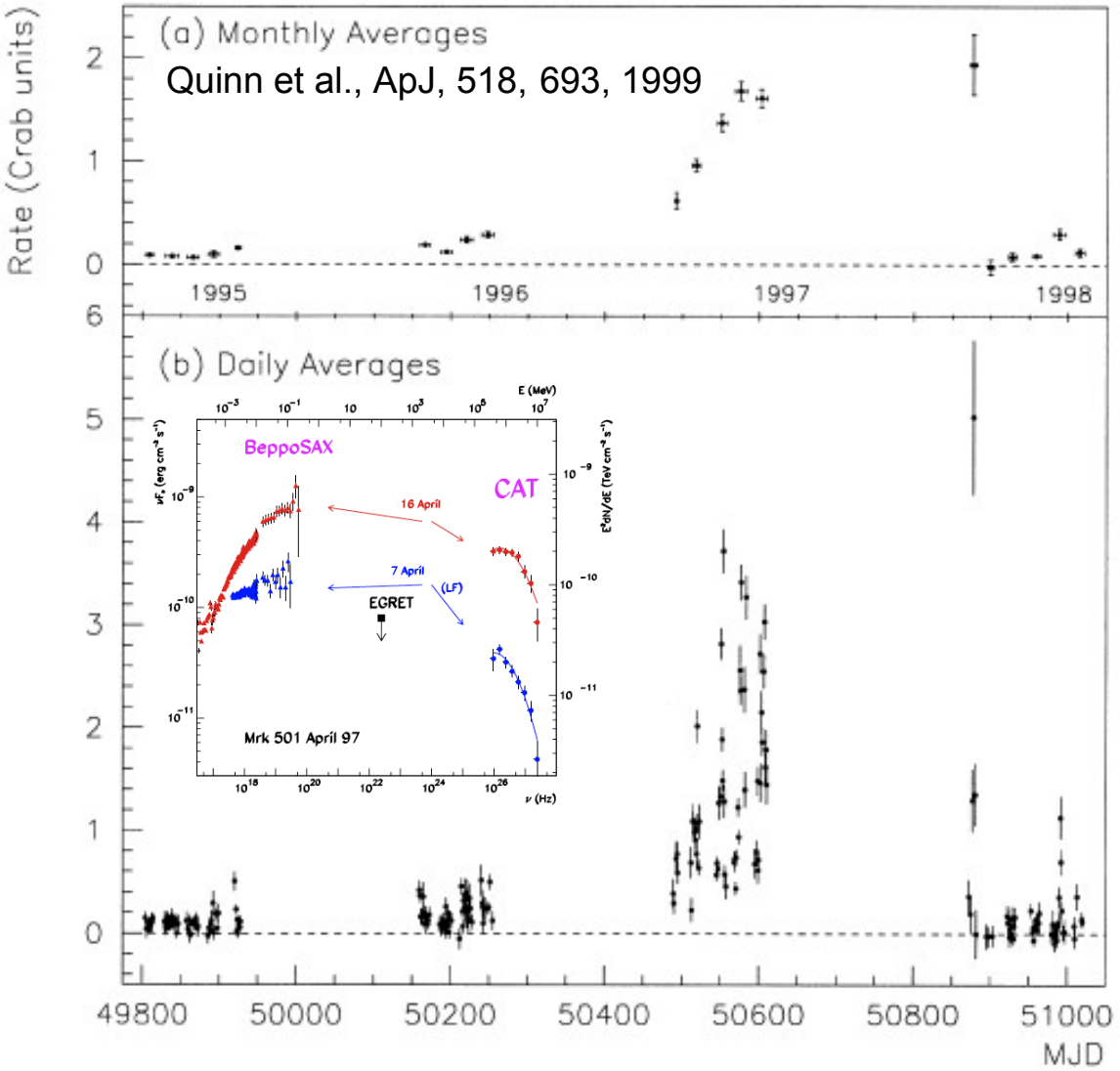
CHANDRA X-ray Data



VERITAS confirms day-scale VHE variations in 2008 data!
Increase in VHE & Nucleus' X-ray flux; Decrease in HST-1 X-ray flux!

Mkn 501

1995-98 Whipple 10-m Light Curve



CAT/SAX SED: Djannati-Atai et al., A&A, 350, 17, 1999

Discovered by Whipple

- Quinn et al., ApJ, 456, L 83, 1995

•1997: Huge VHE flare

- Whipple 10-m: ApJ, 518, 693, 1999
  - Mean=1.4 Crab; ~2 h doubling
  - No spectral variations
- HEGRA: A&A, 342, 69, 1999
  - Mean=~3 Crab; ~10 Crab peaks
  - ~5 h rise/decay time
  - Weak VHE/X-ray correlation
  - No spectral variations
- CAT: A&A, 350, 17, 1999
  - Mean=~2 Crab; ~8 Crab peaks
  - Weak VHE/X-ray correlation
  - SED peak in VHE, Varies with flux
- Milagrito & Tibet: Weak detections

Brief VHE flares in June 1998

- HEGRA: ApJ, 538, 127, 2000
  - Sub-hour variability
  - Softening during flare decay

•Well-studied by 2nd generation ACTs

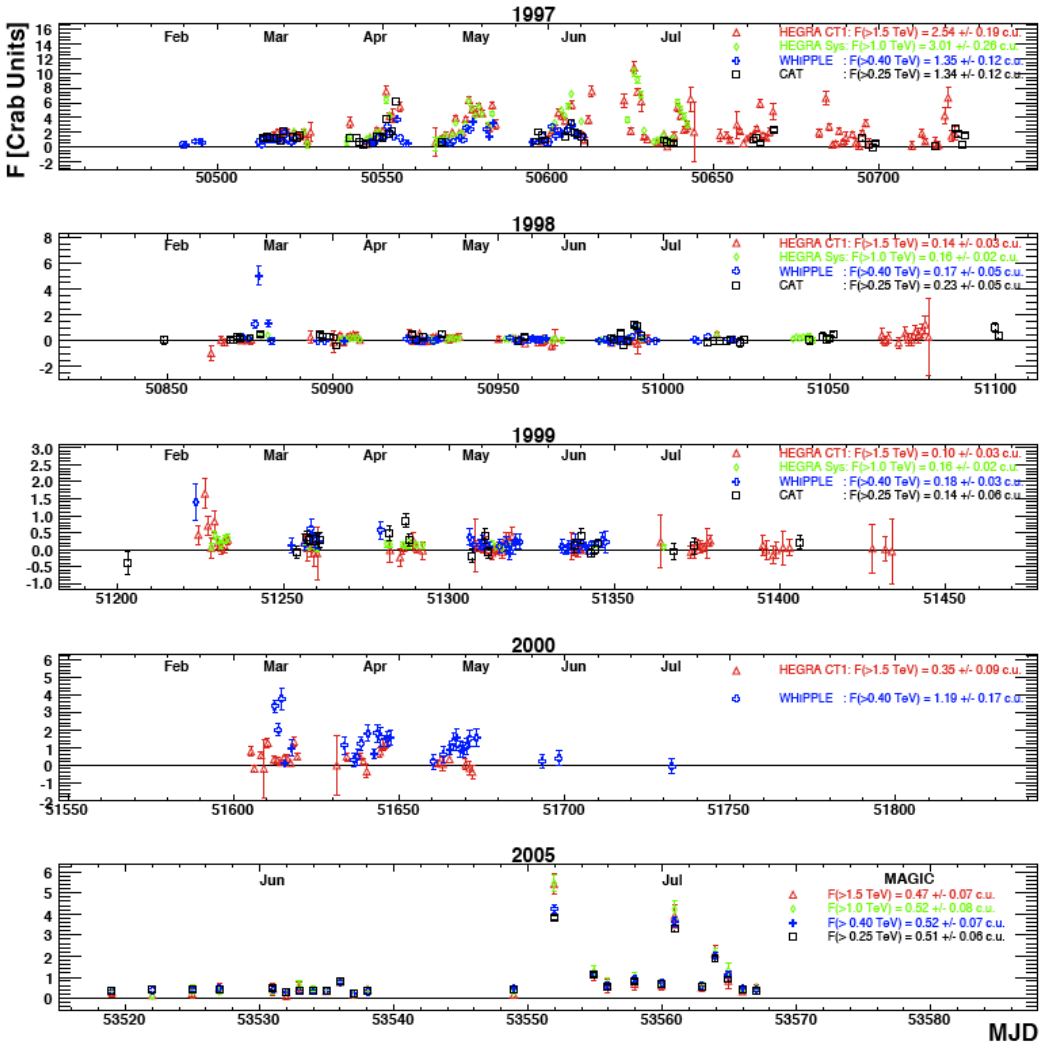
- Whipple: 15% of 33 AGN publications
- HEGRA: 50% of 22 AGN publications

•Detected by MAGIC & VERITAS

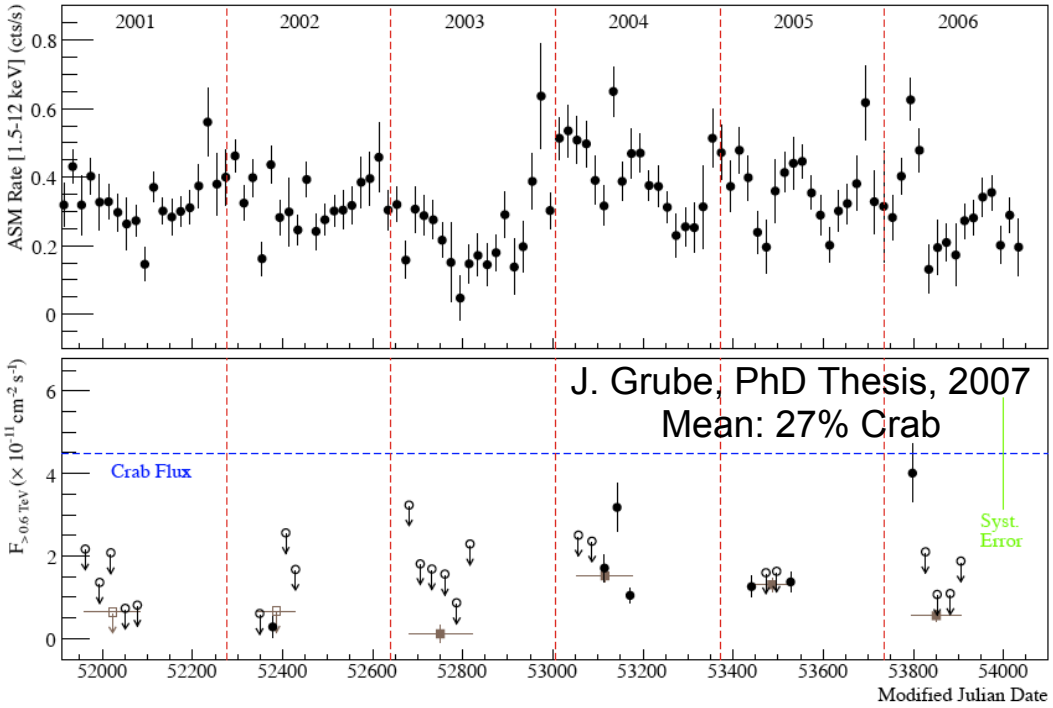
Long-term Monitoring of Mkn 501

1997-2000 Light Curve Compilation

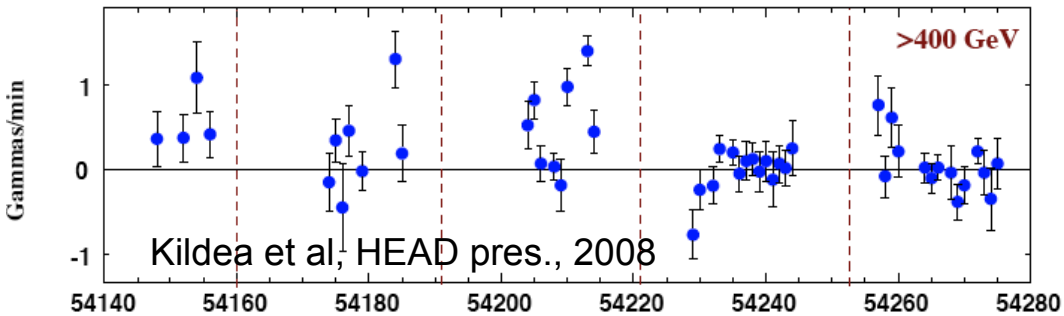
Albert et al., ApJ, 669, 862, 2007



2001-2006: Whipple/ASM Light Curve



2007 Whipple 10-m Light Curve

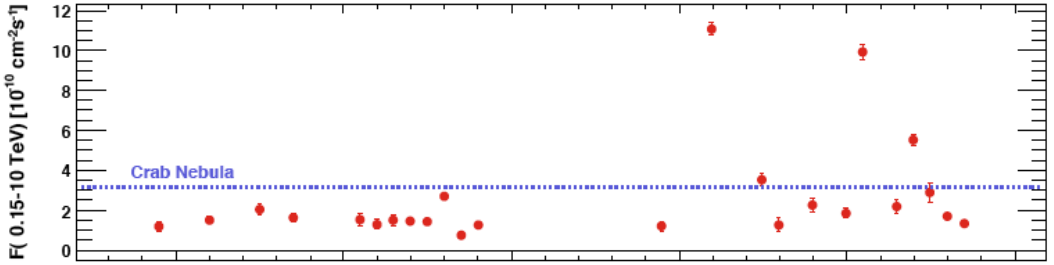


Relatively quiet outside of Whipple 10-m Crab-level episode in 2000
MAGIC: Flares in July 2005 (after Whipple 10-m season ended)

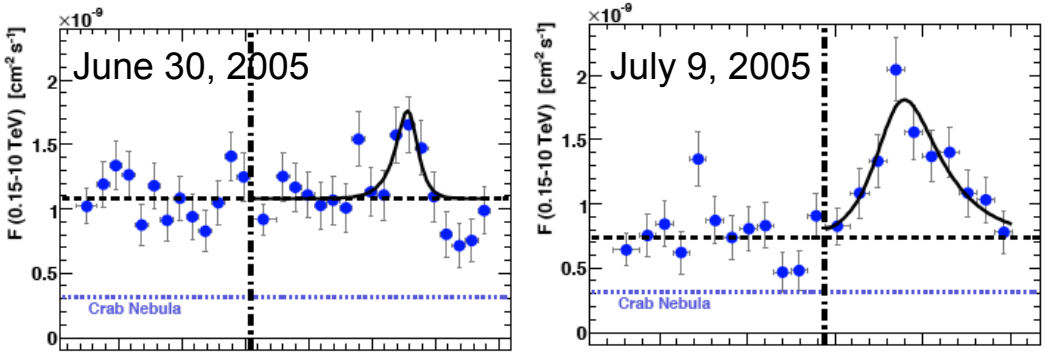
Mkn 501: MAGIC Flare in 2005

Albert et al., ApJ, 669, 862, 2007

2005 Nightly Light Curve



Brightest Nights Light Curve (2 min bins)



Doubling time scales of ~2 minutes

- Variations are largest at higher energies

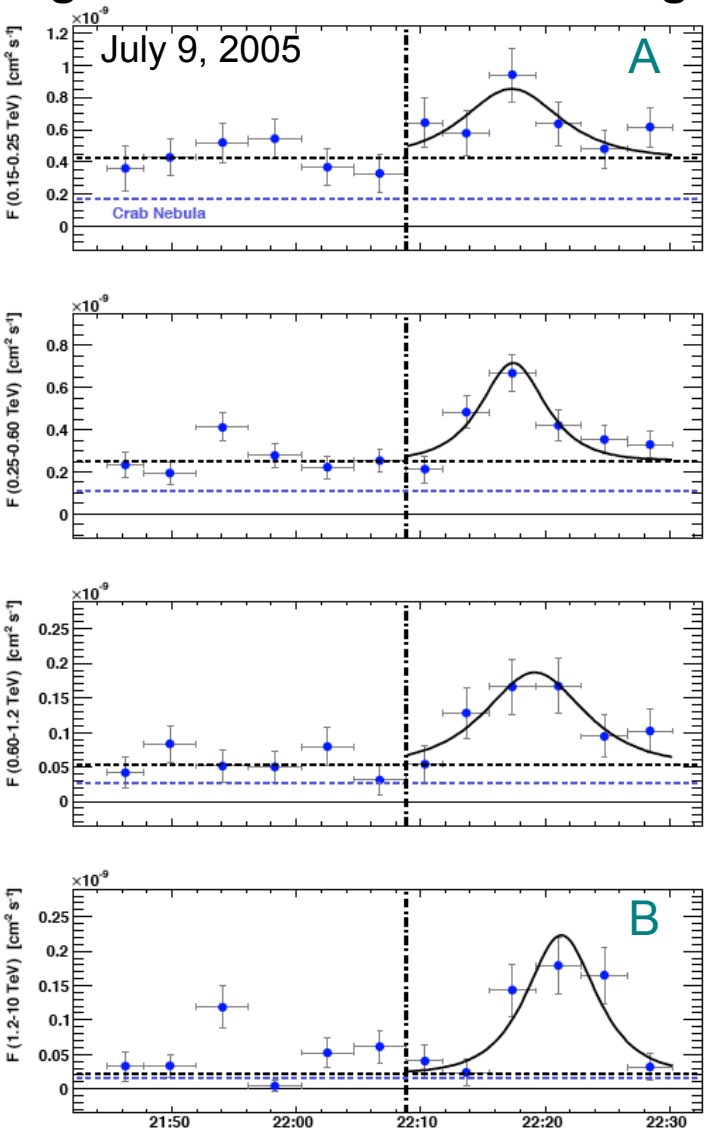
Spectrum hardens with increasing flux

- VHE spectrum for every night

SED peak seen on 2 brightest nights

- June 30, 2007: 430 GeV
- July 9, 2005: 250 GeV

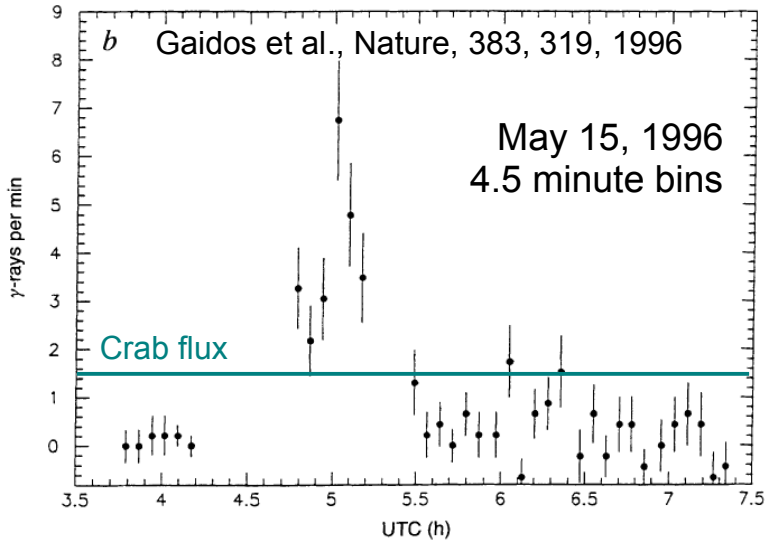
Light Curve at Different Energies

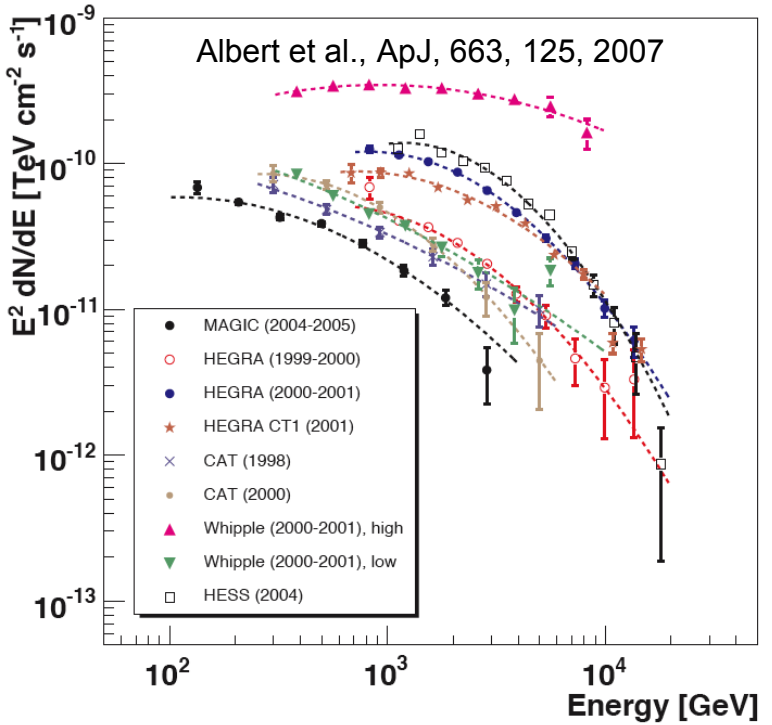


4±1 min delay between peaks (A & B)

Quantum gravity implications: astro-ph/0708.2889

T.C. Weekes: “Thank god for Mkn 421...”





1992: Whipple 10-m discovery (>500 GeV)
- Punch et al., Nature, 358, 477, 1992

1994: 1st VHE flares of Mkn 421
- Weak day-scale VHE/X-ray correlations

1996: 1st Major VHE Flare
- May 9, 1996: 10 Crab only 1 day after 0.3 Crab
- May 15, 1996: ~15 minute VHE variations
- Indications of VHE spectral hardening

1998: 1st hour-scale VHE/X-ray correlation

2000-2001: Major flaring episode
- VHE hardening, spectral curvature, MWL correlations
  - Beautiful results from HEGRA & Whipple 10-m
- Milagro, Tibet, STACEE & Celeste also see...

2004: HESS detects Mkn 421 flare
- >100σ in 15 h at 63° zenith angle
- 15 minute variations above 2 TeV
- Clear VHE spectral hardening
- Variability amplitude larger at higher energy

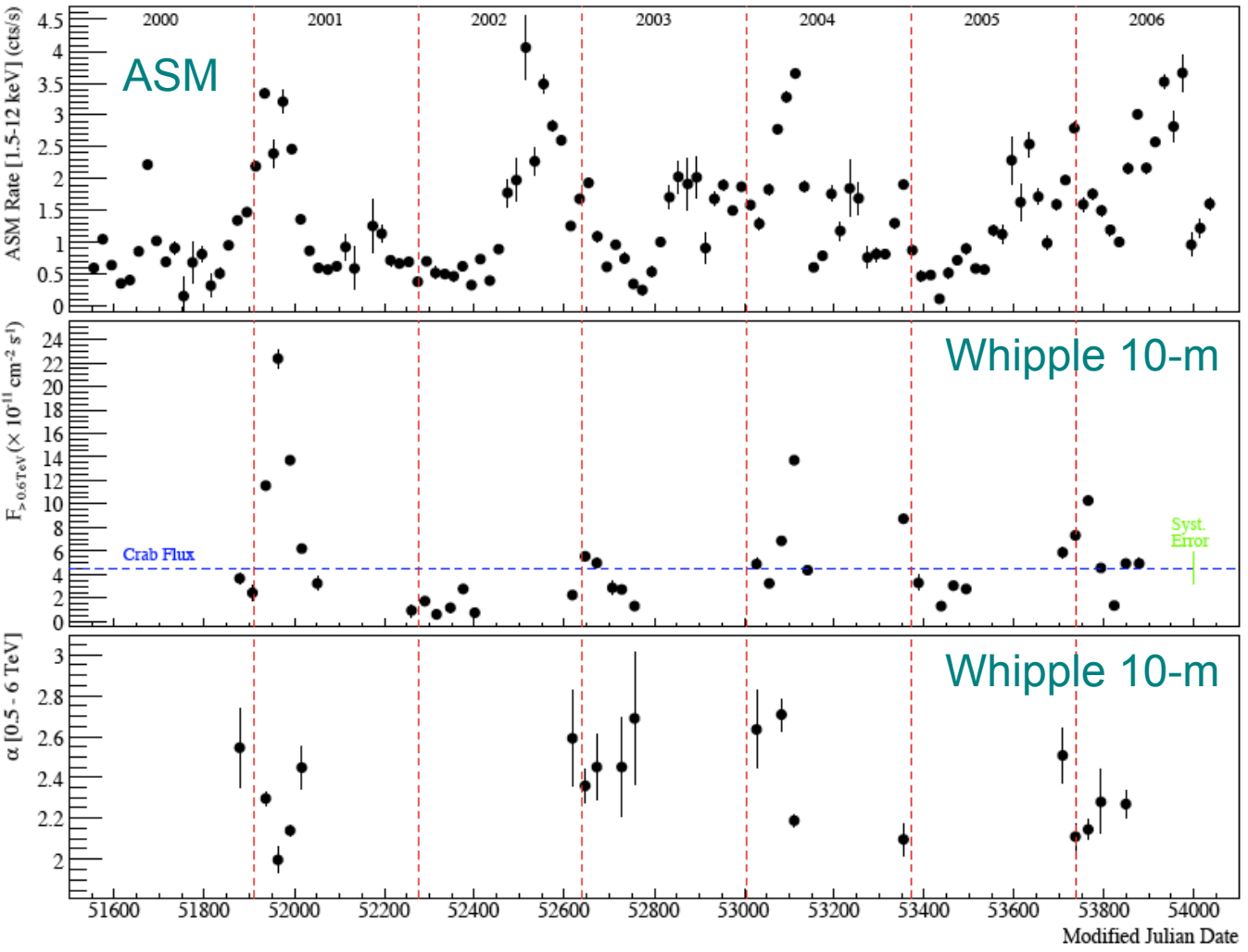
Now: HESS, MAGIC & VERITAS detections
- Simultaneous HESS/MAGIC spectrum

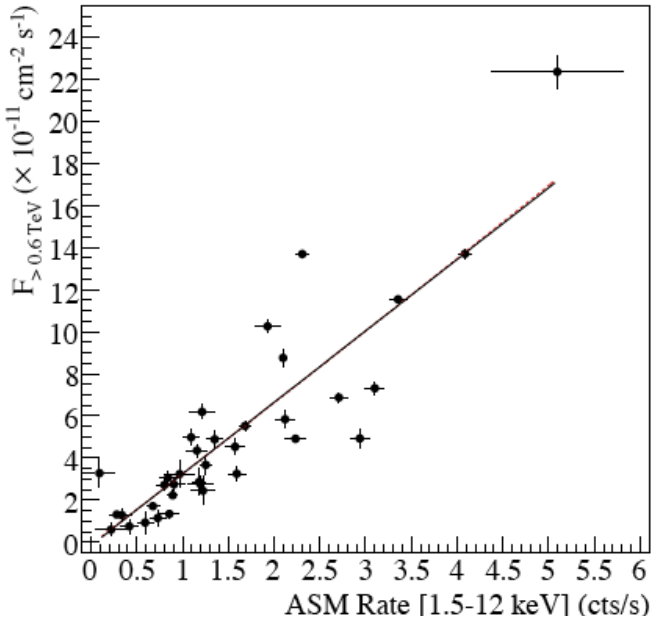
“Everyone” saw Mkn 421:
- 52% of 33 Whipple AGN ref. publications
- 23% of 22 HEGRA AGN ref. publications

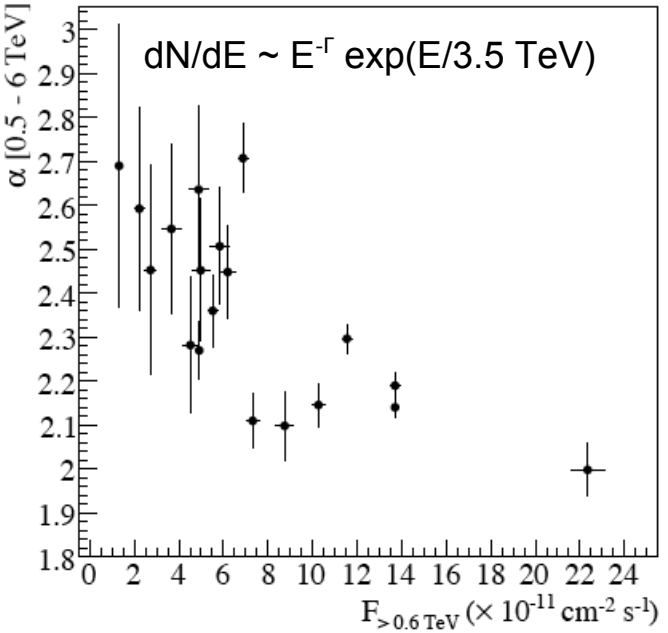
Long Term Monitoring of Mkn 421

J. Grube, PhD Thesis, 2007

Monthly X-ray flux, VHE flux & VHE Index vs Time





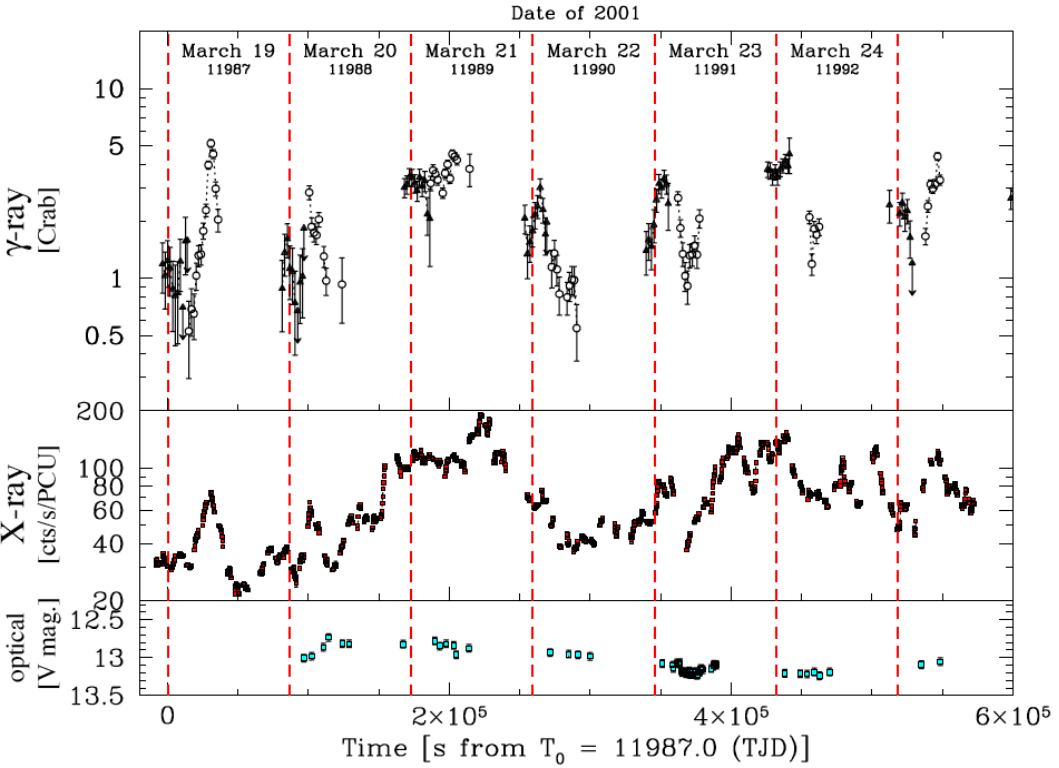


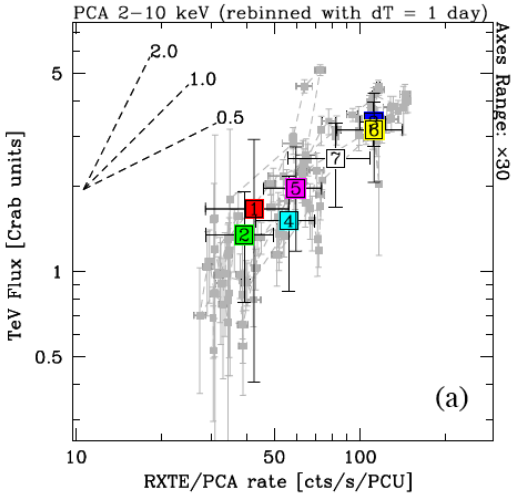
VHE & X-ray flux are well correlated

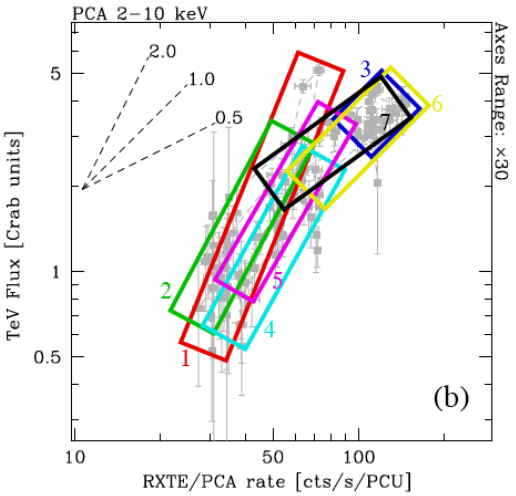
VHE spectrum hardens with increased flux

Mkn 421: The VHE/X-ray Connection

Fossati et al., ApJ, in press, 2008







Week-long multi-wavelength campaign during the 2001 Mkn 421 flare

VHE: HEGRA & Whipple; X-ray: RXTE; Optical: Mount Hopkins 48” telescope

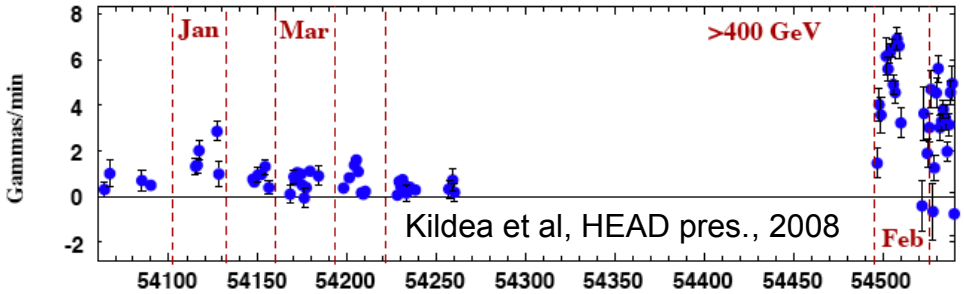
A linear X-ray/VHE flux correlation overall

The shorter time-scale dependence (i.e. on some nights) is quadratic

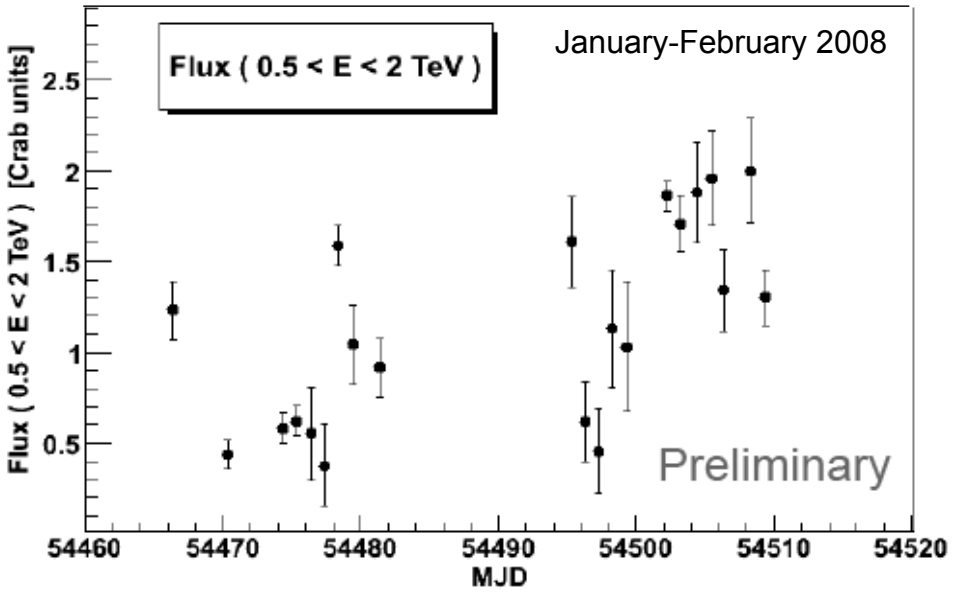
Mkn 421 Flares Again in 2008

VERITAS plots from Reyes et al., HEAD pres., 2008

2007-08 Whipple 10-m Nightly Light Curve

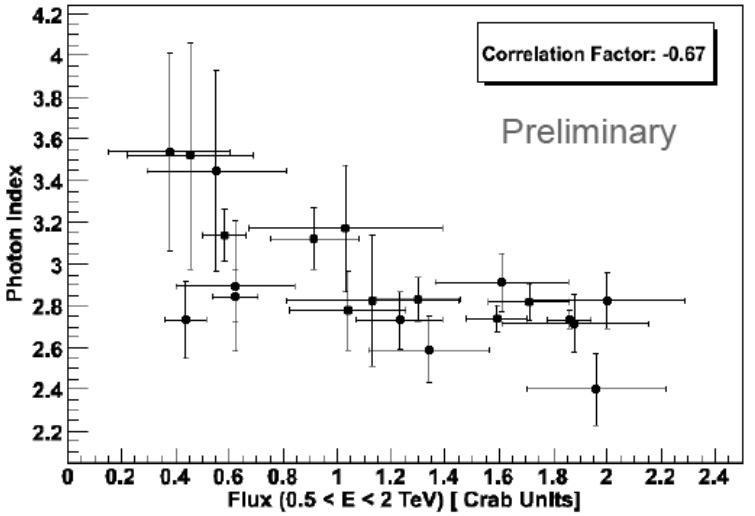


2008 VERITAS Nightly Light Curve



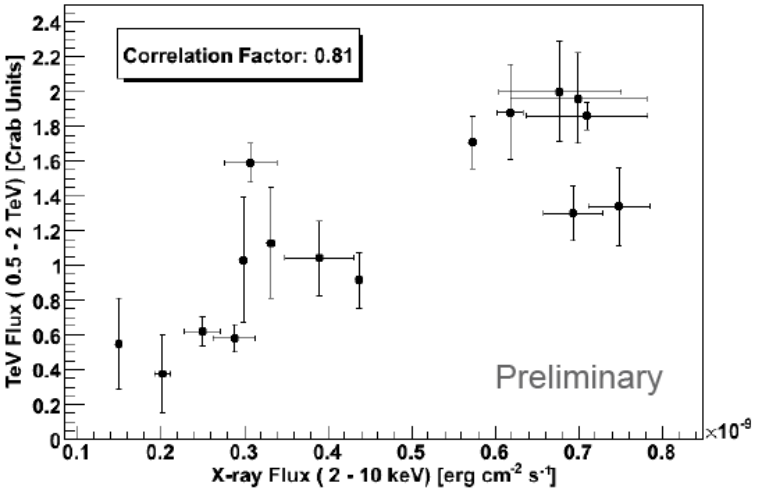
VERITAS: VHE Flux vs VHE Index

2008 Swift/RXTE X-ray data show similar correlation



VERITAS VHE Flux vs X-ray Flux

Simultaneous X-ray data from SWIFT & RXTE



On-going VHE + SWIFT/RXTE X-ray campaign

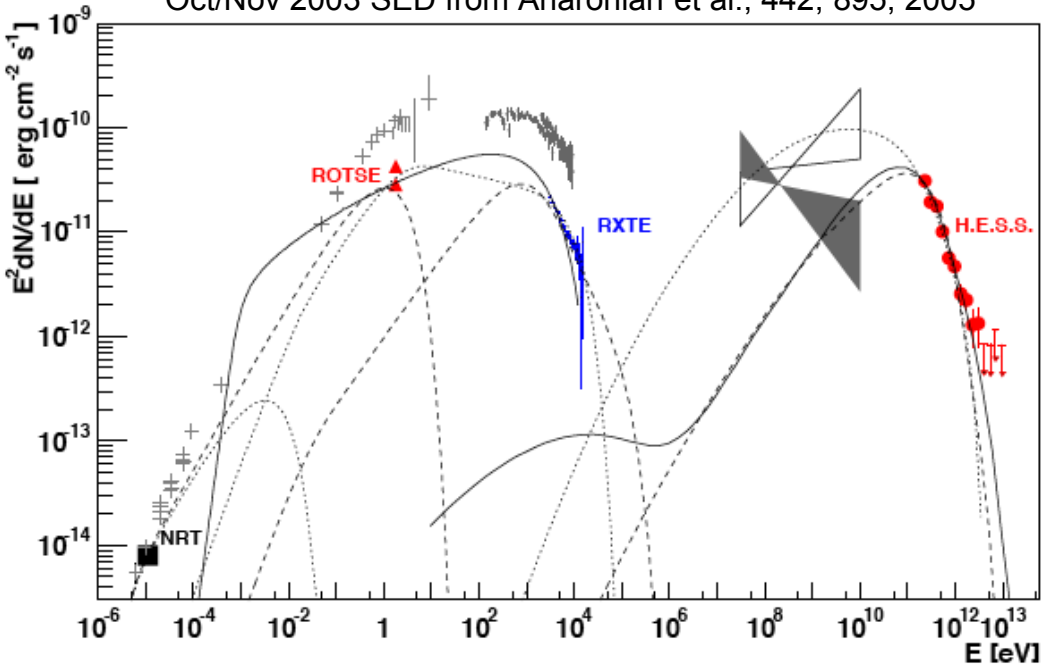
VERITAS/MAGIC: >4 Crab flux in 03-04/2008

MAGIC/HESS/VERITAS: Coordinated alerts

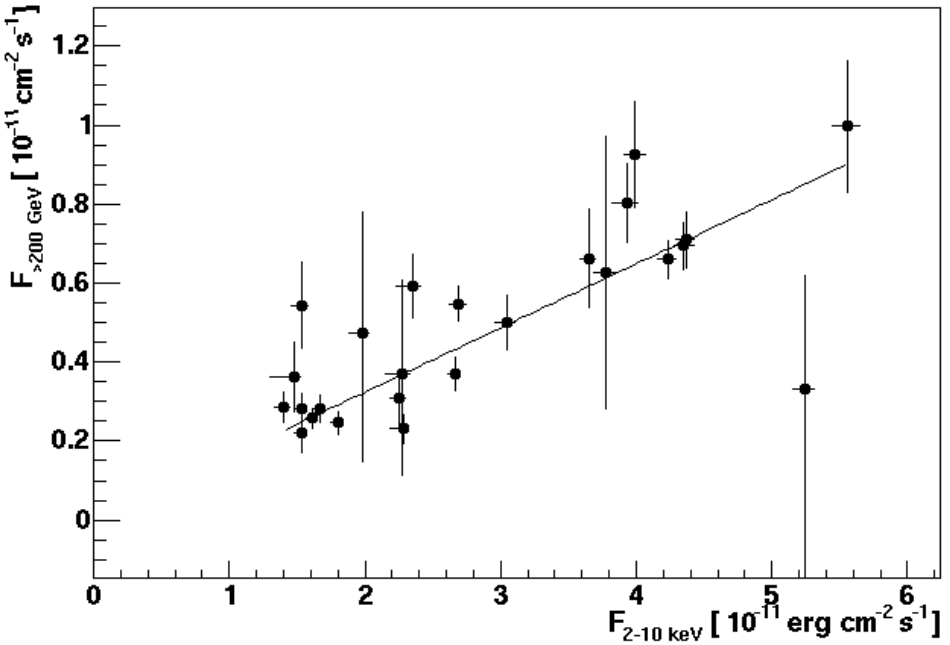
PKS 2155-304: Prior to 2006

Summary from Punch et al., Proc 30th ICRC, 2007

Oct/Nov 2003 SED from Aharonian et al., 442, 895, 2005



HESS vs RXTE flux from Giebels et al., Proc. SF2A, 2005



Discovered by Durham Mark VI in 1998; Always detected by HESS since 2002

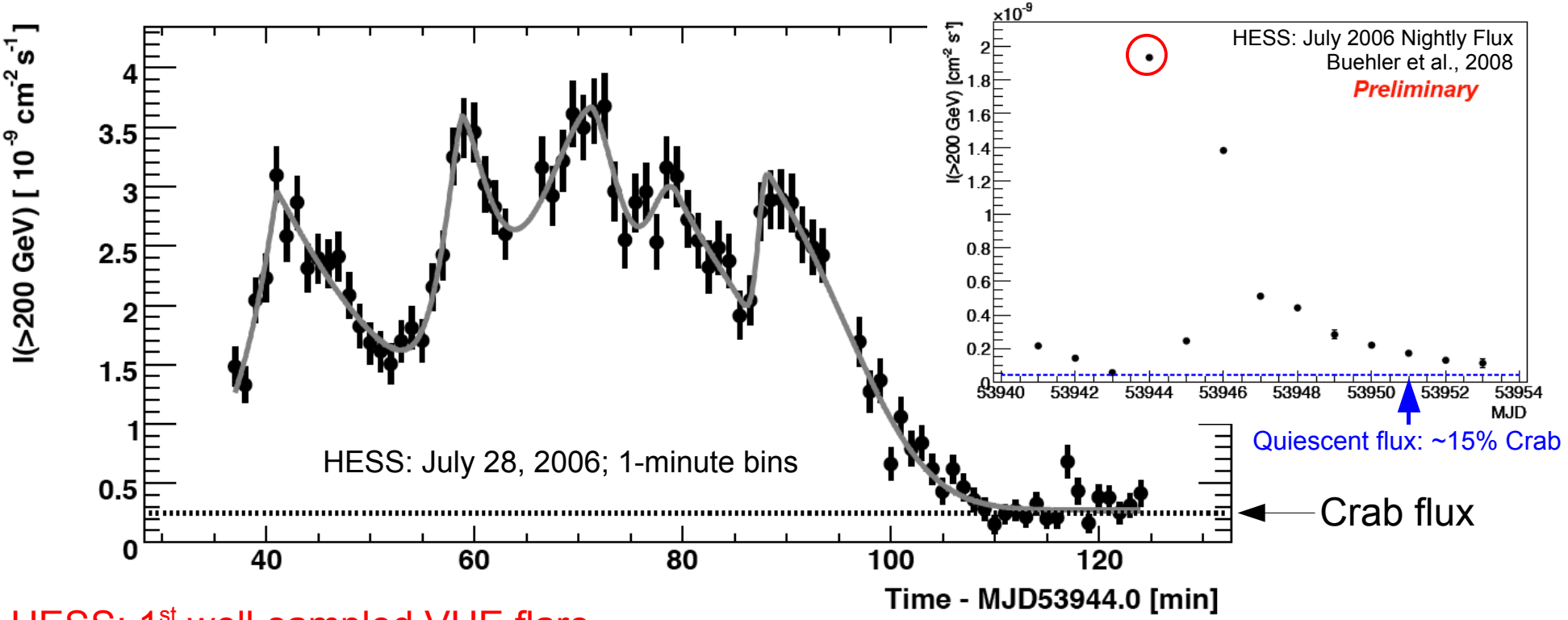
Weak yearly, monthly, daily flux variations seen, but no spectral variations observed

1st MWL campaign with VHE data in 2003: Historical lows in SED

Enormous MWL campaign in 2004: HESS (130 hours), RXTE, Spitzer, Optical, Radio
Clear VHE/X-ray correlation using purely simultaneous data
VHE state comparable to 2003

PKS 2155-304: The Big Flare

Aharonian et al., ApJ, 664, L71, 2007



HESS: 1st well-sampled VHE flare

- Mean flux: ~ 7 Crab; Range: 0.65 Crab to 15.1 Crab in ~90 min
- Fit generalized burst function ("GRB-like")
  - Best τ_{rise}=173±23s; Fastest: τ_{rise}=67±44s

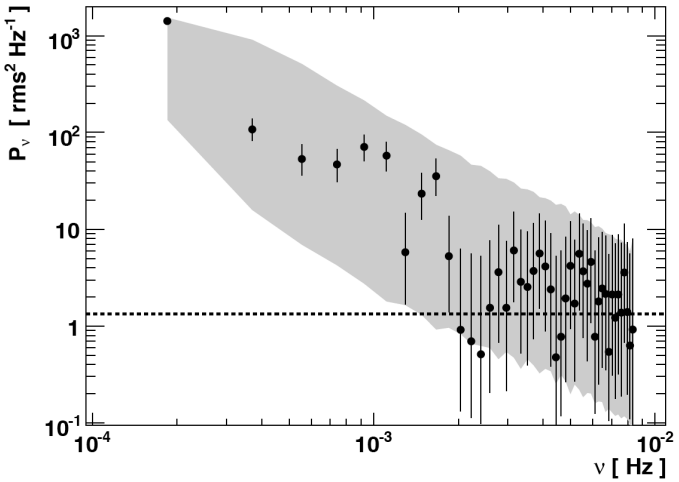
τ_{rise}=173s => δ > 60-120 R/Rs for 1-2 x 10^9 $M_\odot$ SMBH

Energetics + VHE photon escape: Γ > 50

- Begelman, Fabian & Rees, MNRAS, 384, L19 2008

Fourier PDS compatible with red-noise of index $\nu \leq 2$

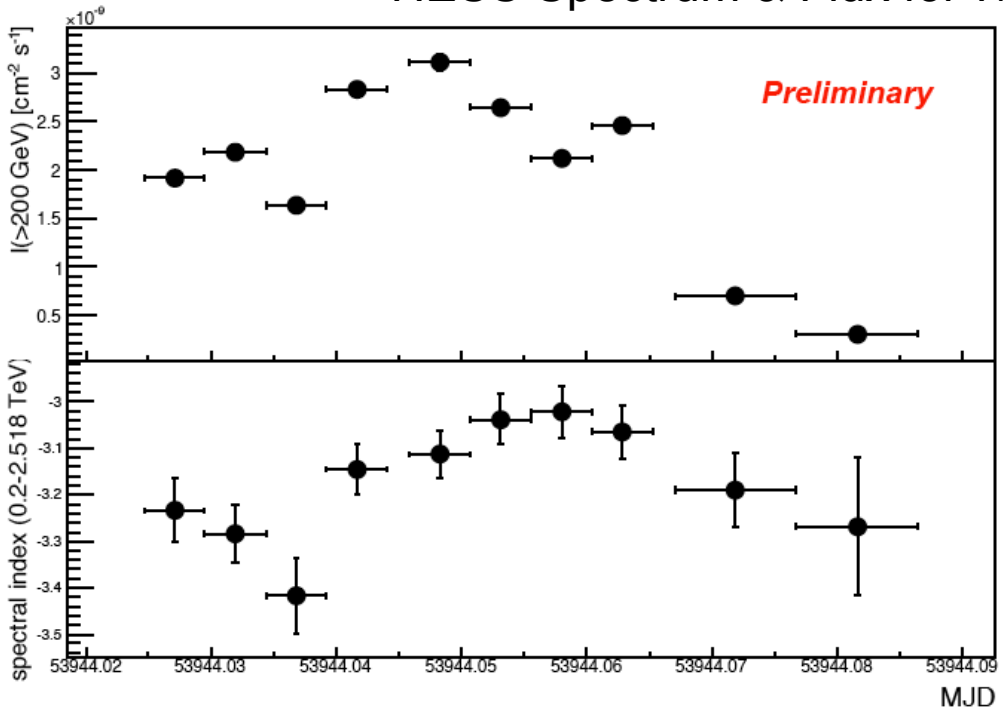
- More power than in X-rays

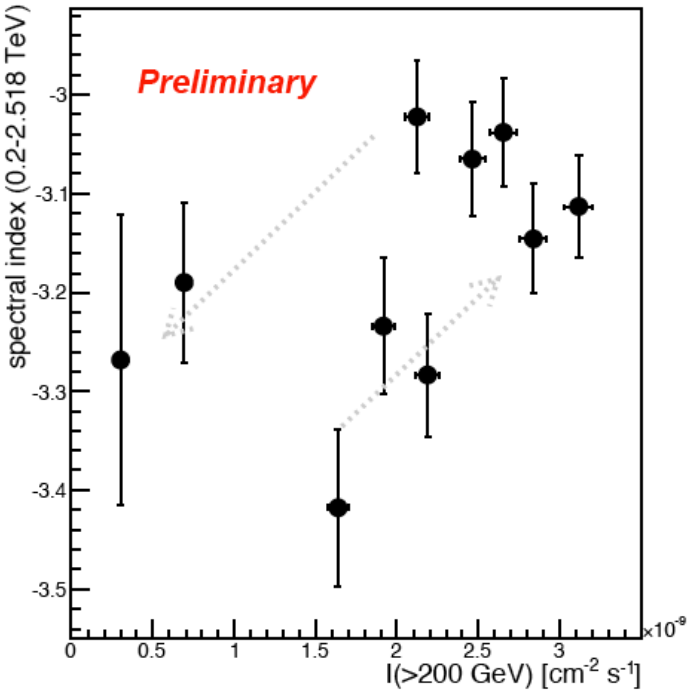


The Big Flare: Spectral Variations

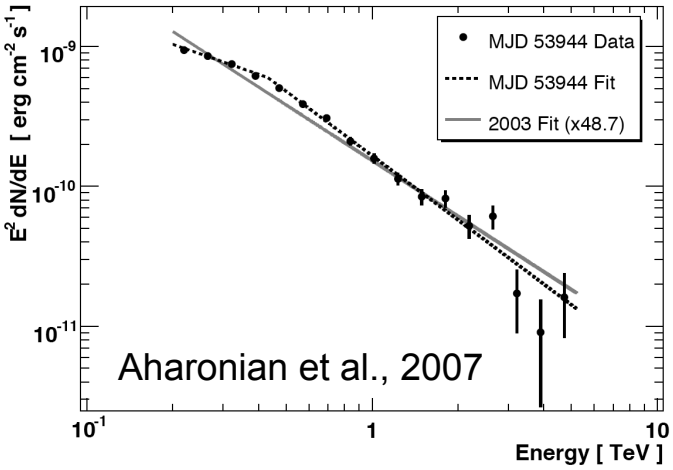
Plots from Buehler et al., Proc of High Energy Phenomena in Relativistic Outflows (Dublin), 2007

HESS Spectrum & Flux for 7/14 minute bins



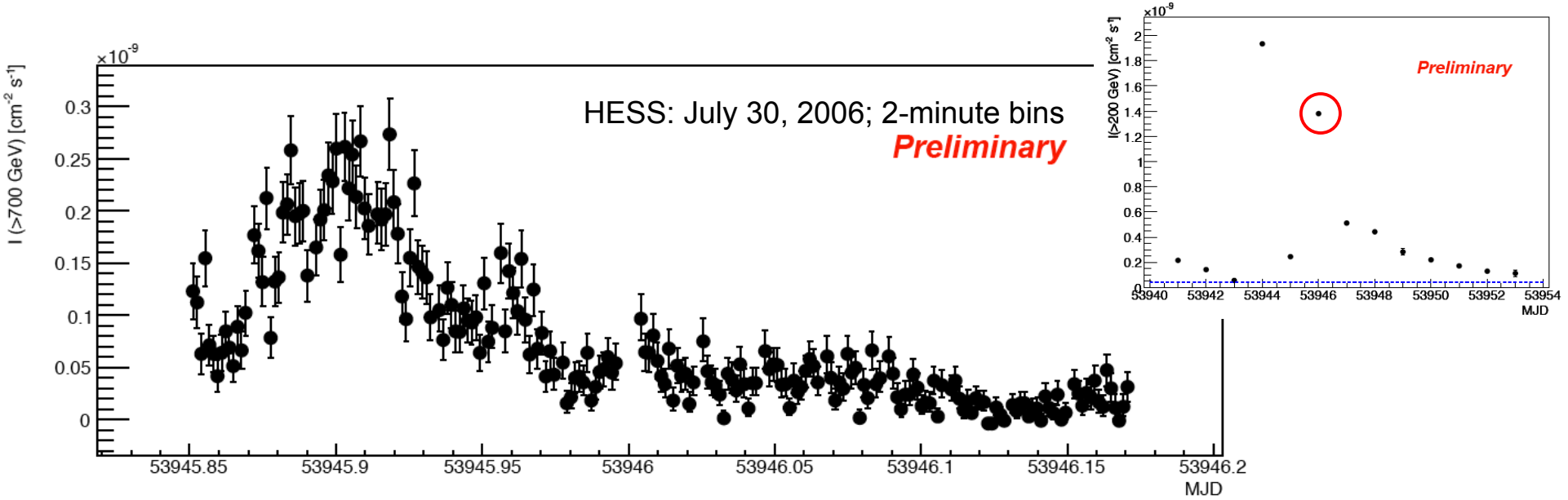


- Time-average flare spectrum is soft (Γ~3.18)
  - Better fit by broken power-law; E_{break}~430 GeV
  - Similar to 2003 spectrum outside of flux
- Only weak temporal variations: ΔΓ±0.2
  - Slight hardening with increased flux
- No energy-dependent time-lags in light curve
  - Strong quantum gravity limits
  - Wagner, Benbow et al, Proc. 30th ICRC, 2007



PKS 2155-304: The 2nd Big Flare

Plots from Buehler et al., Proc of High Energy Phenomena in Relativistic Outflows (Dublin), 2007



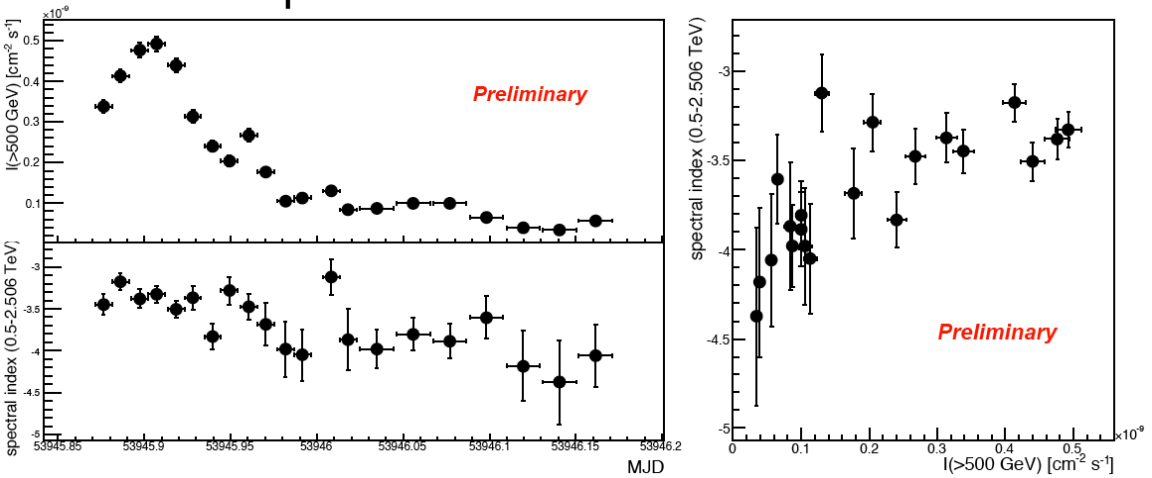
HESS detects 2nd VHE flare

- July 29-30, 2006
- 6.6h exposure => Some LZA data

Compared to 1st flare

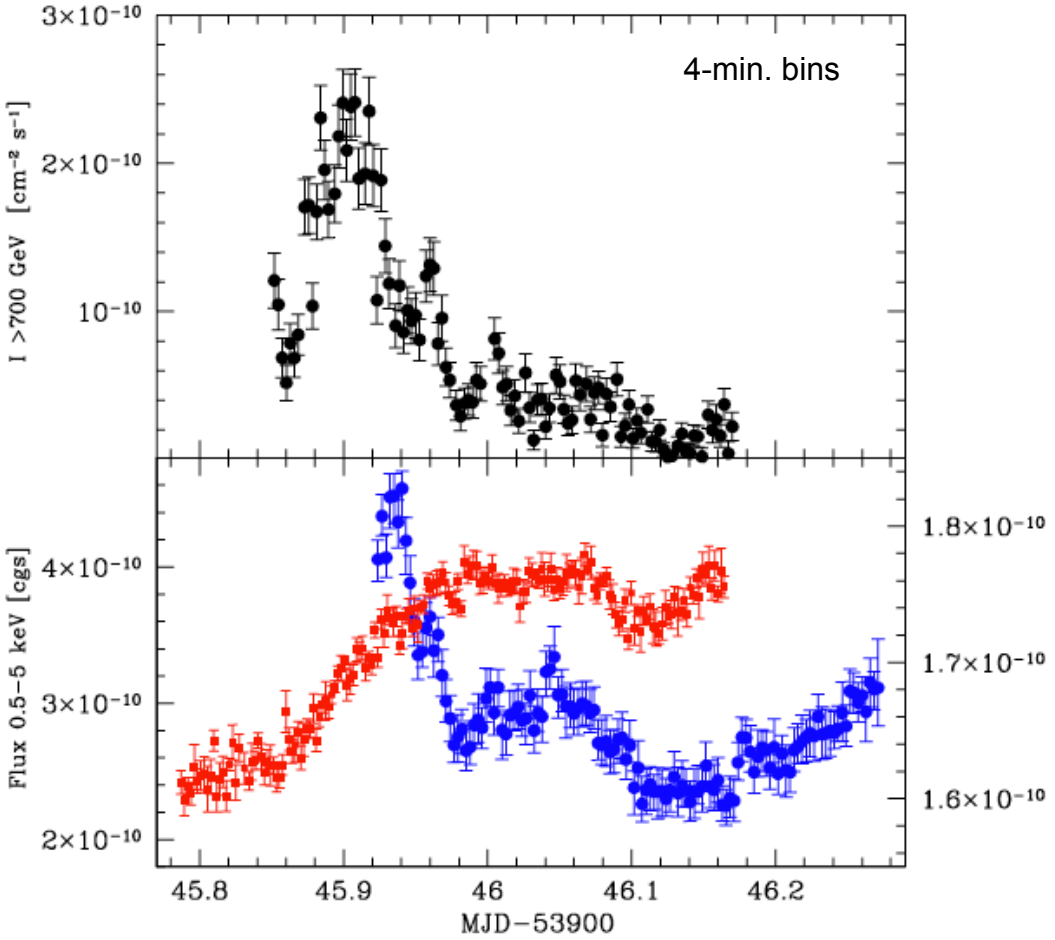
- Variability slower; ~500 s
- Mean flux lower
- Peak flux higher
- Larger spectral variations: ΔΓ ~0.5
  - Interesting plateau in Γ vs Flux

HESS Spectrum & Flux for 7/14 minute bins

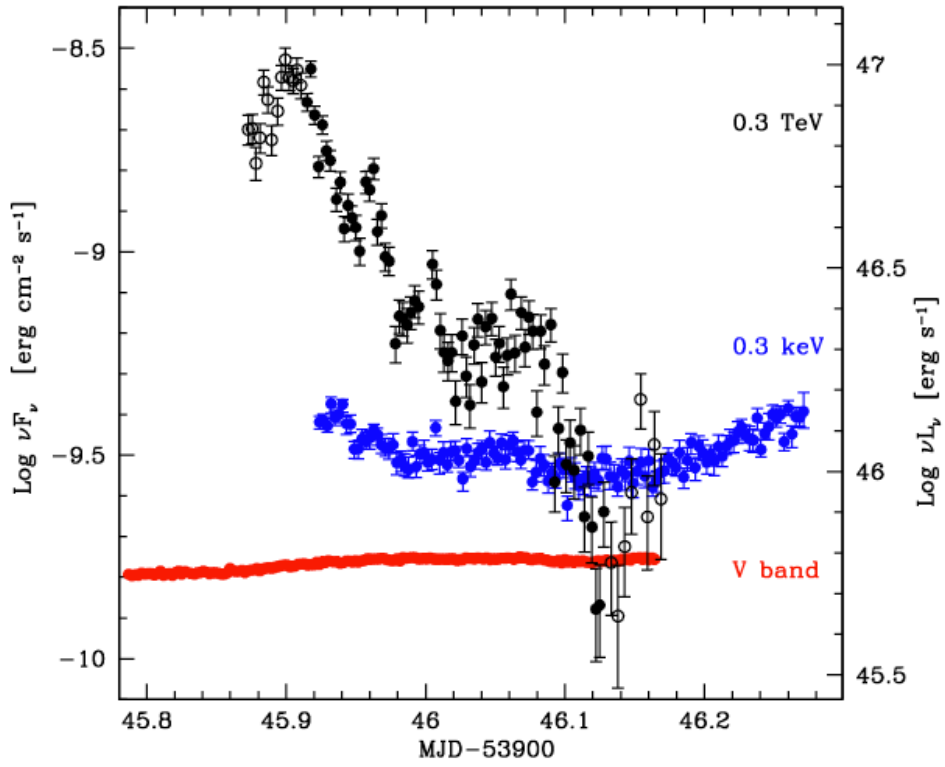


The 2nd Flare = "Chandra Night"

Plots from Costamante et al., Proc of High Energy Phenomena in Relativistic Outflows (Dublin), 2007



HESS VHE, Chandra X-ray & Bronberg Optical Light Curve



VHE (1.4 orders of mag.) flux variations much larger than X-ray (x2) & optical (15%)

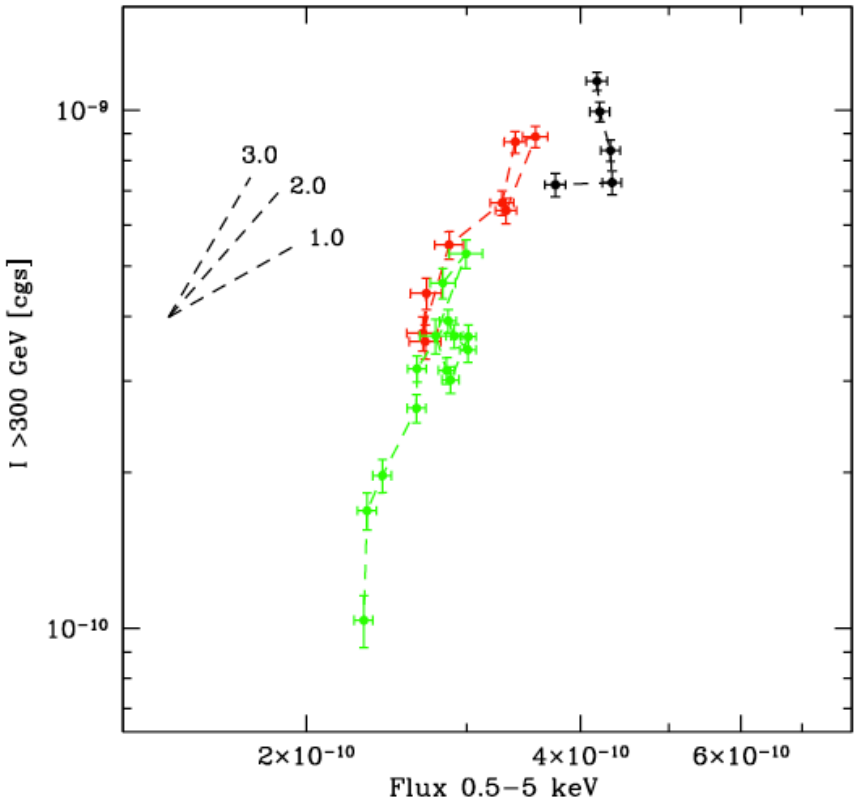
VHE spectral variability ($\Delta\Gamma \sim 0.5$) larger than X-ray ($\Delta\Gamma \sim 0.3$)

VHE/X-ray flux variability strongly correlated with no lags, but optical uncorrelated

Rapidly evolving SED is initially extremely Compton dominated (L_c/L_s ~10)!

The “Chandra Night”

Plots from Costamante et al., Proc of High Energy Phenomena in Relativistic Outflows (Dublin), 2007

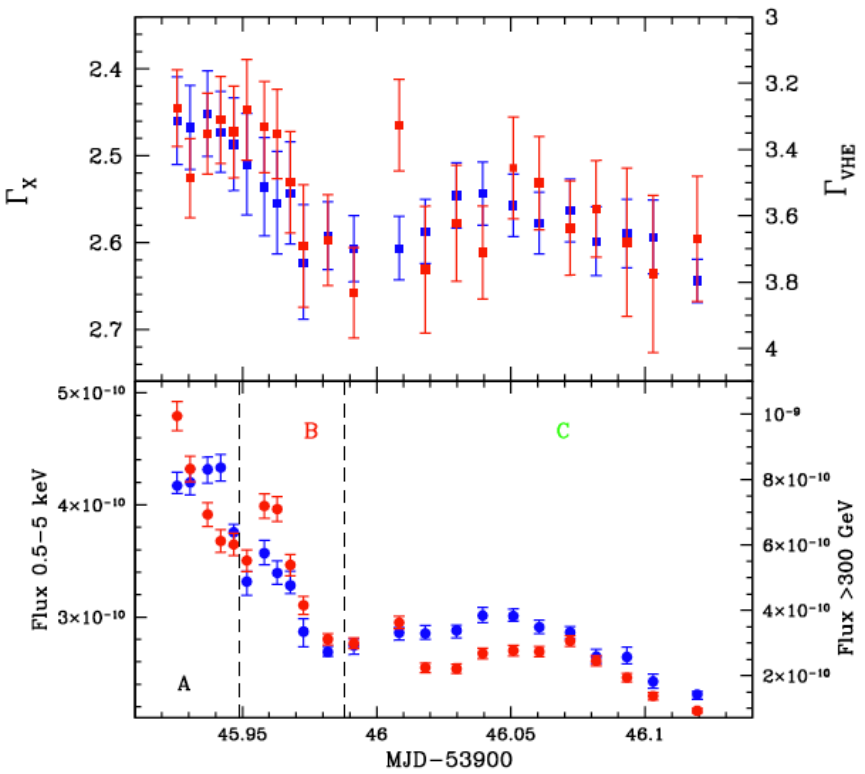


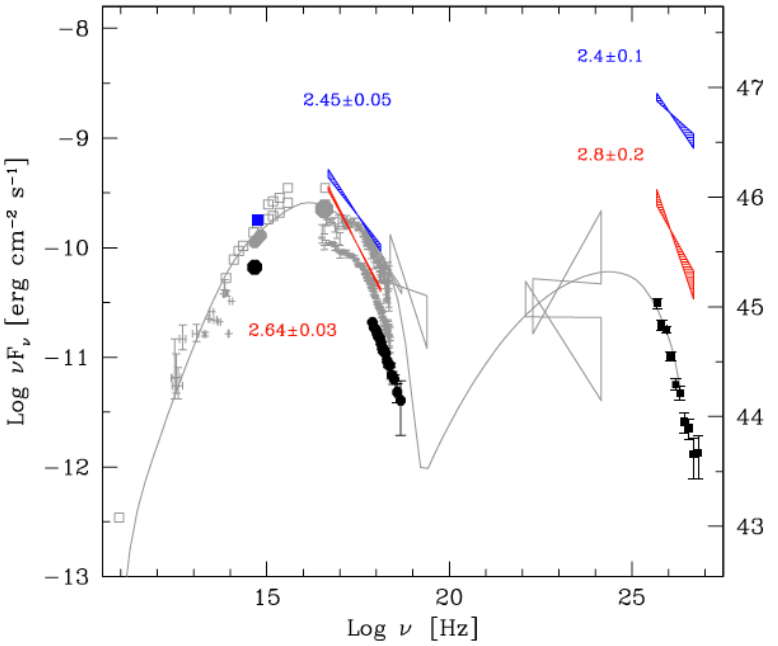
Cubic correlation for VHE/X-ray flux during the flare decay!

SED shown for highest & lowest VHE state

Black points simultaneous archival data (Aharonian et al., 2005)

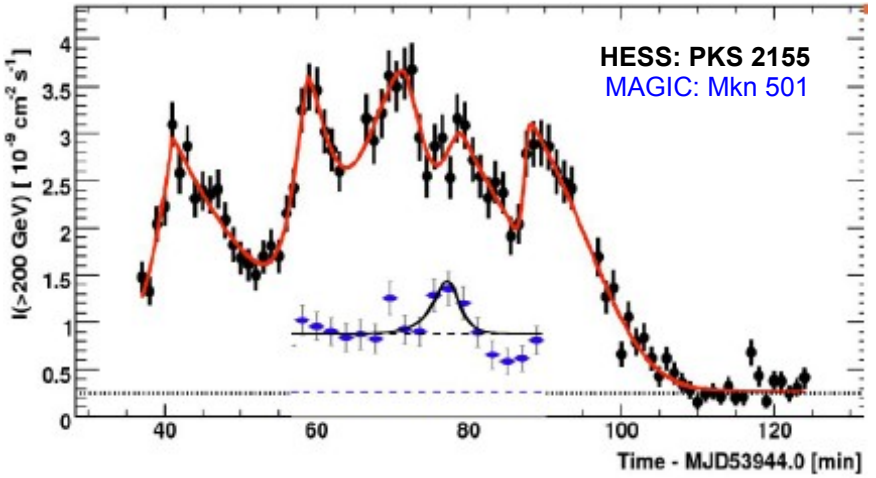
HESS/Chandra data in 7/14 minute bins





Conclusions

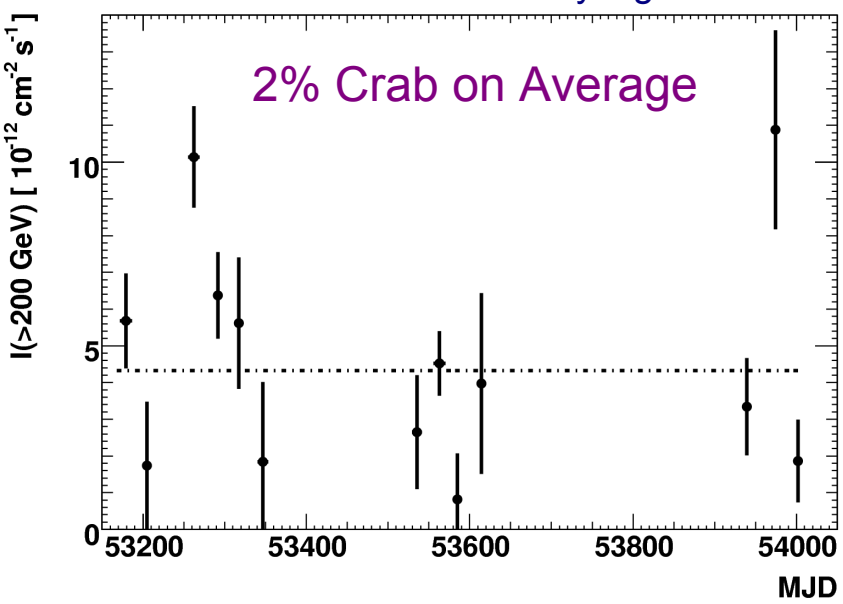
Fastest VHE Flare Comparison: Hinton, ICRC 2007



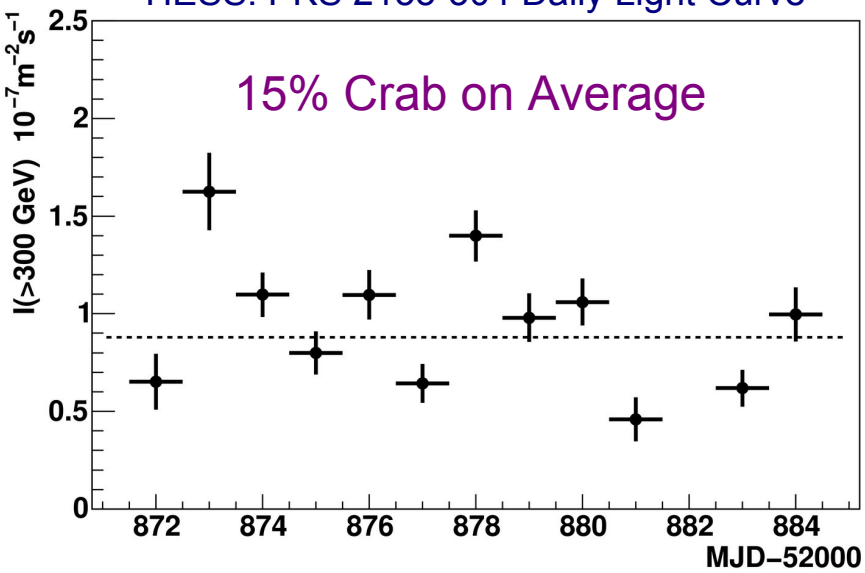
- 22 AGN at VHE energies
  - 21 are blazars; 18 are HBL
  - 15 discovered with 3rd generation IACTs
- Not much variability from the new blazars
  - 6 HBL have no variability & 4 HBL have marginal indications of weak variability
  - 2 HBL have weak variability & 3 non-HBL only seen during brief flares
- Lessons learned primarily from the original 7 AGN
  - Minute-scale flux variations observed & light curves no longer under-sampled
    - Light curves for several energy binnings & powerful statistical studies are now possible
    - The HESS PKS 2155-304 flares in July 2006 are an incredibly rich data set
  - Spectral variability studies possible on time-scales of a few minutes; Hardening with increased flux
  - Generally clear VHE/X-ray flux & index correlations
    - Is the correlation linear? What about "orphan flares? Lags or leads? Optical correlations?
  - **VHE flaring is not the norm:** Only Mkn 421 has regular, long-duration, Crab-flux scale outbursts
- Further progress expected:
  - Northern: VERITAS fully operational & MAGIC II in Fall 2008; Southern: HESS II begins ~2010
  - Planning for the 4th generation instrument (CTA/AGIS) ongoing

VHE Variability: An Impression...

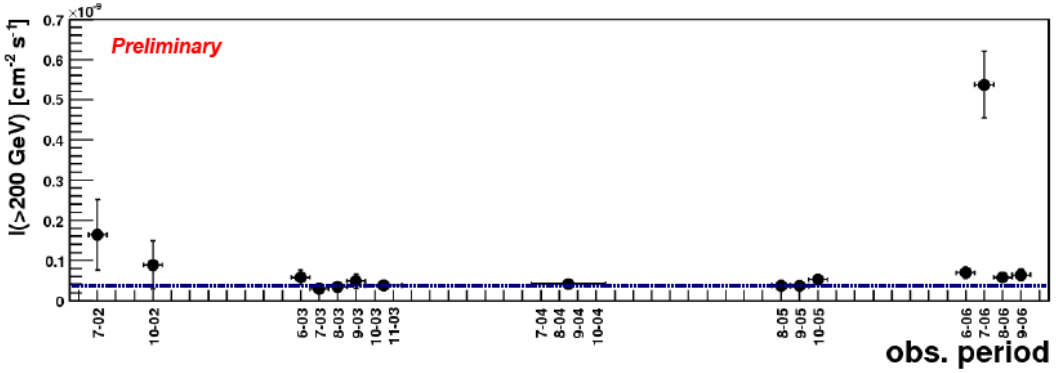
HESS: H 2356-309 Monthly Light Curve



HESS: PKS 2155-304 Daily Light Curve



HESS: PKS 2155-304 5-year Light Curve



Mkn 421 is not the norm!

HESS: PKS 2155-304 90 Minute Flare