Unraveling the mysteries of the non-thermal universe using γ-ray observations of Active Galactic Nuclei

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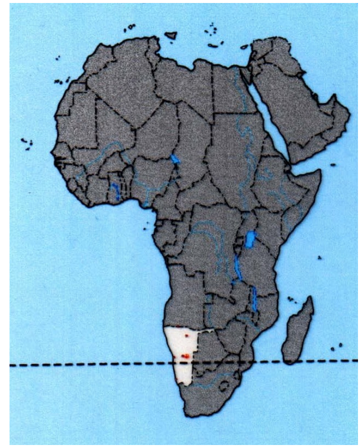
The H.E.S.S. Phase-I Telescopes



Location:

- Namibia (1800 m asl)

Telescope:

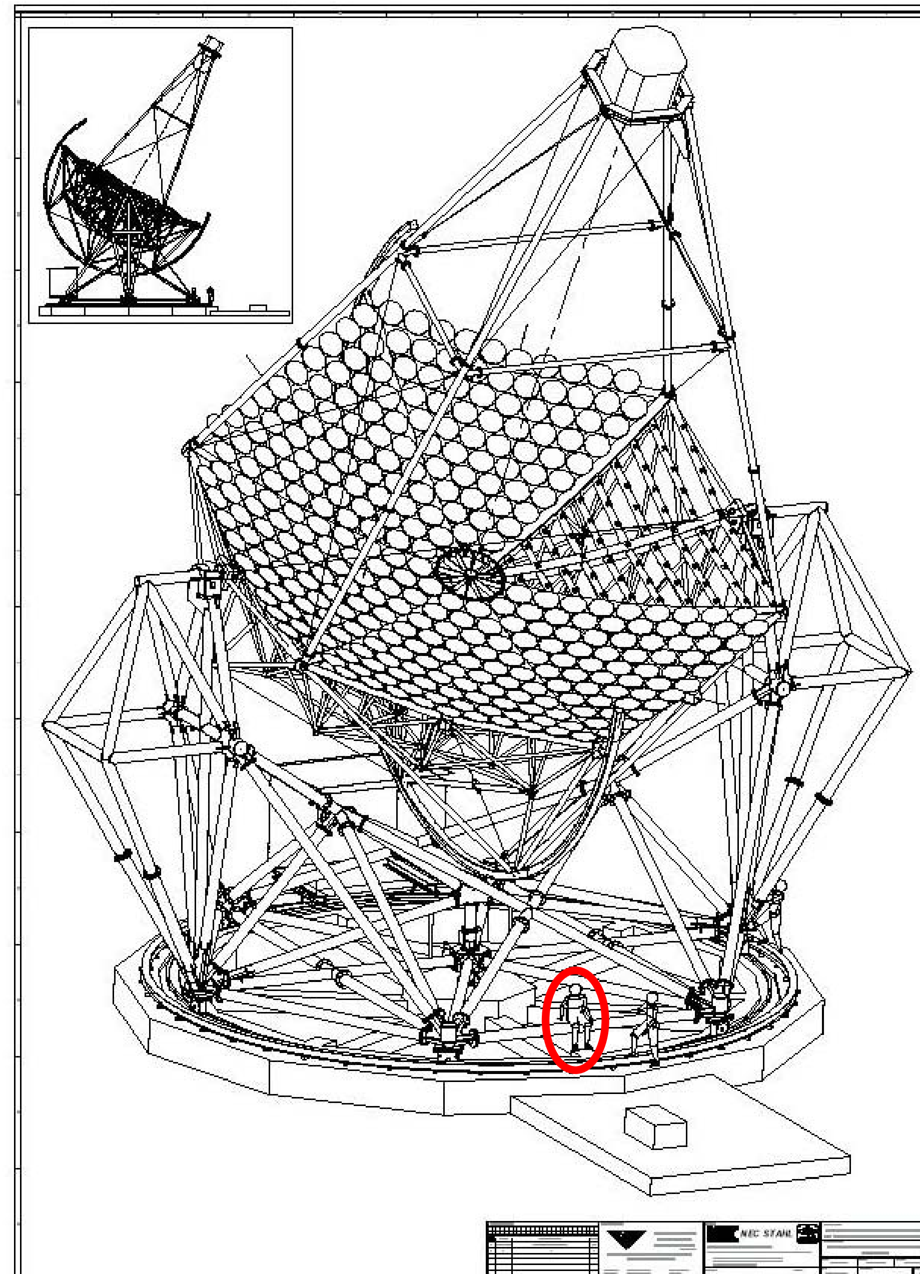
- Altitude-azimuth mount
- Davies-Cotton reflector
- Rigid steel structure
- Diameter: 12 m
- Focal length: 15 m (f/d ~1.2)
- **4 telescopes separated by 120 m**

Mirror:

- Mirror area ~107 m^2
- 380 individual mirrors (60 cm diameter)
- **Image of a star focused to 1/3 of camera pixel**

Central Trigger System:

- **Require a 2-telescope conicidence**
  - Removes muons
  - Lower threshold
  - Enables stereoscopic techniques

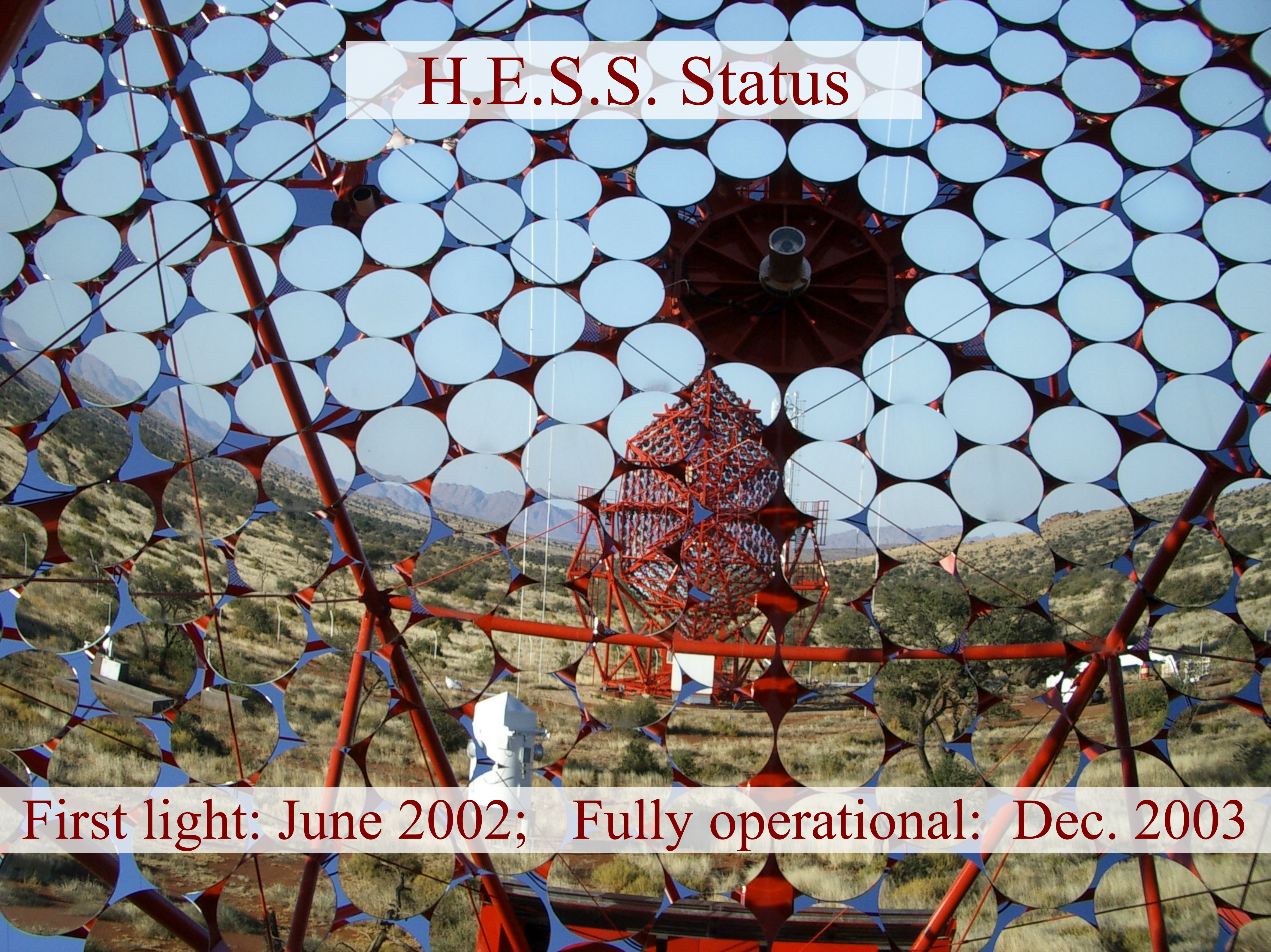


The H.E.S.S. Cameras

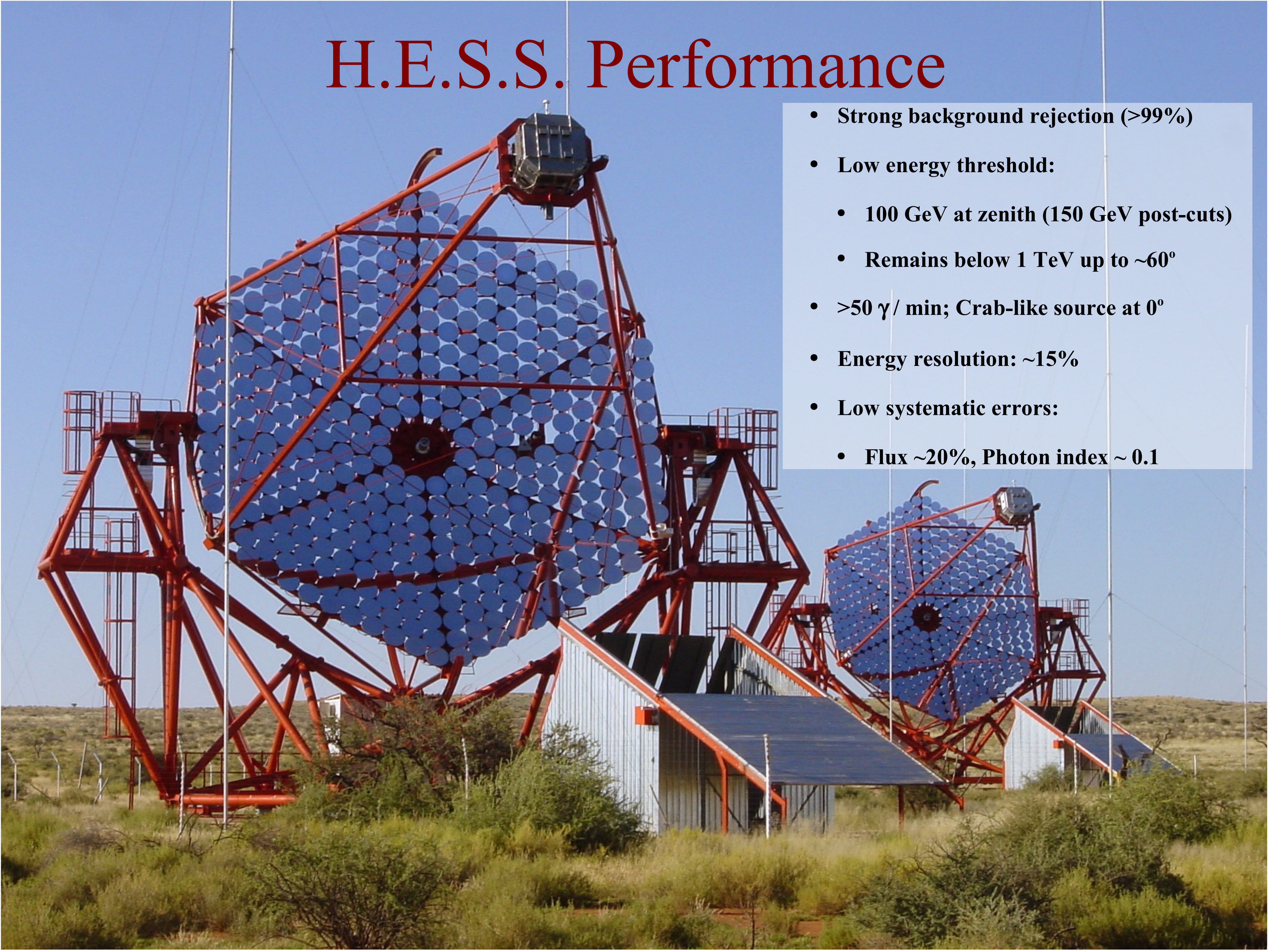
- 960 pixels of 0.16^{o}
- 5^{o} field of view (1.4 m)
- Readout integrated in camera body
- 16 ns integration, 1 GHz sampling

"Light in,
light out"

H.E.S.S. Status



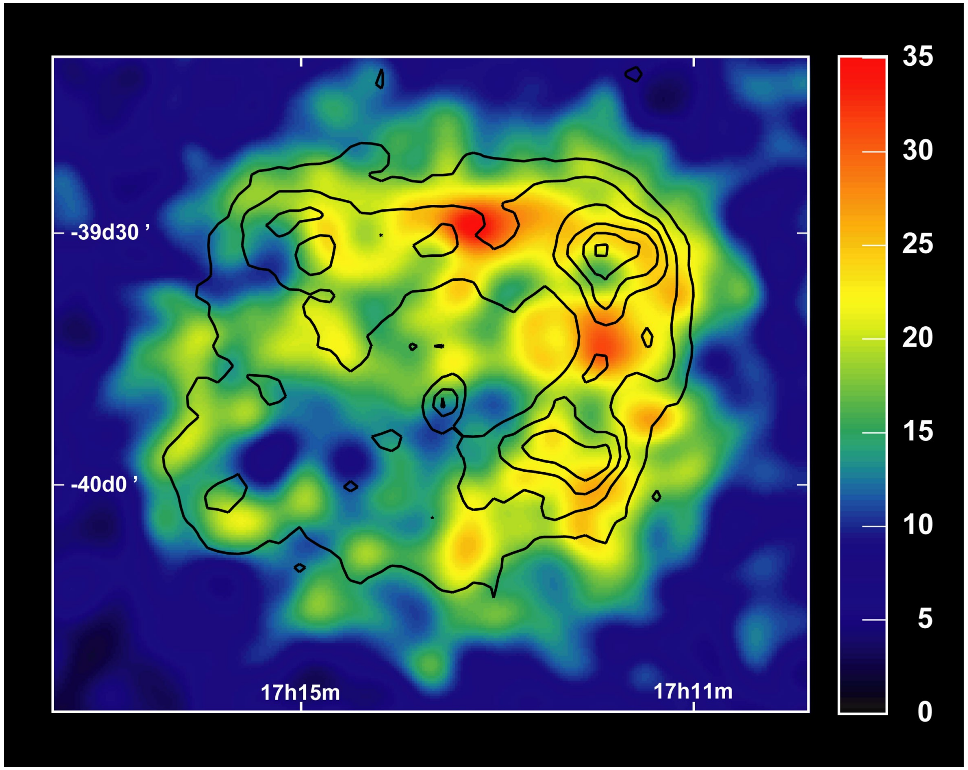
First light: June 2002;   Fully operational: Dec. 2003



H.E.S.S. Performance

- Strong background rejection (>99%)
- Low energy threshold:
  - 100 GeV at zenith (150 GeV post-cuts)
  - Remains below 1 TeV up to ~60^{o}
- >50 γ / min; Crab-like source at 0^{o}
- Energy resolution: ~15%
- Low systematic errors:
  - Flux ~20%, Photon index ~ 0.1

H.E.S.S. Performance

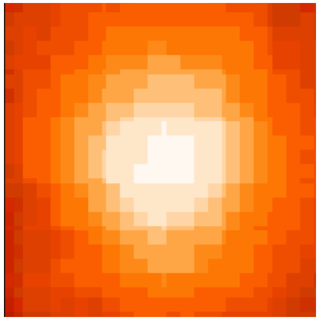


- **Small point spread function**
  - Width < 0.1°,
  - Comparable to ASCA
- **Large field of view (5°)**
- **Pointing error < 20''**
- **Great for surveys:**

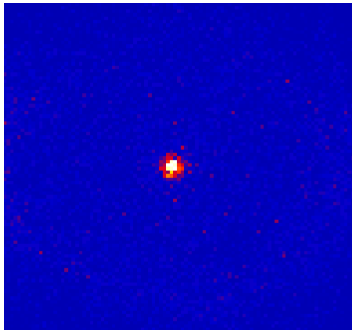
Aharonian et al., 2005, *Science*, **307**, 1938

Resolve γ-ray morphology of extended objects (e.g. SNR) like RXJ 1713.7-3946

Aharonian et al., 2004, *Nature*, **432**, 75



Crab with EGRET



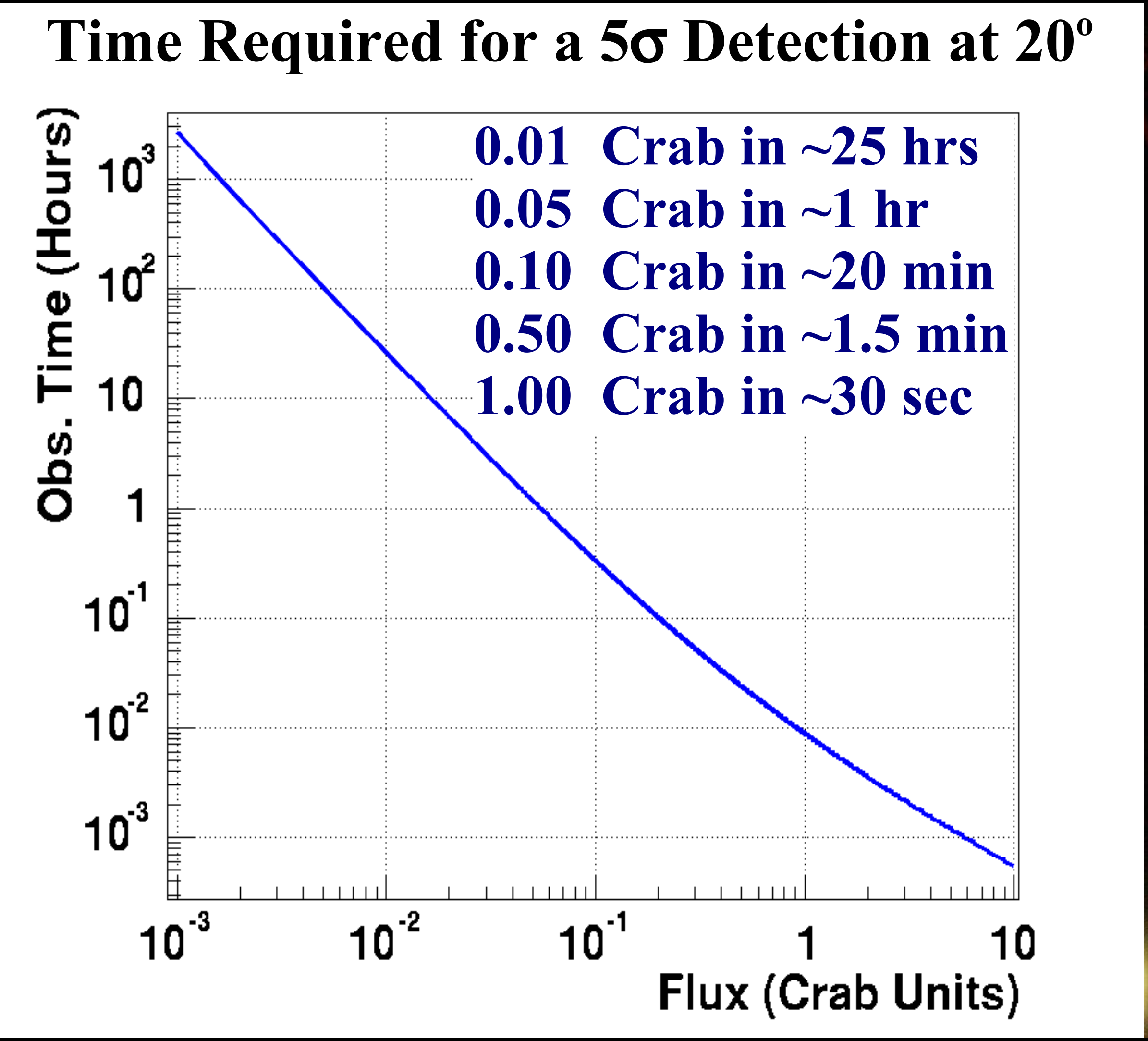
Crab in TeV

Many Analysis Chains
All agree well!

- **2 independent simulations**
- **Camera calibration:**
  - ***Astropart Phys*, 22, 109 (2004)**
  - **2 independent methods**
- **Geometrical reconstruction:**
  - **3 independent methods**
- **Backgroud rejection**
  - **4 different methods**
- **Background estimation (>5 methods)**
- **Energy estimation (5 methods)**
- **Spectrum (2 techniques)**

Standard Analysis:
W. Benbow, Proc. of Towards a Network of Atmospheric Cherenkov Detectors VII (Palaiseau), 2005

H.E.S.S. Sensitivity

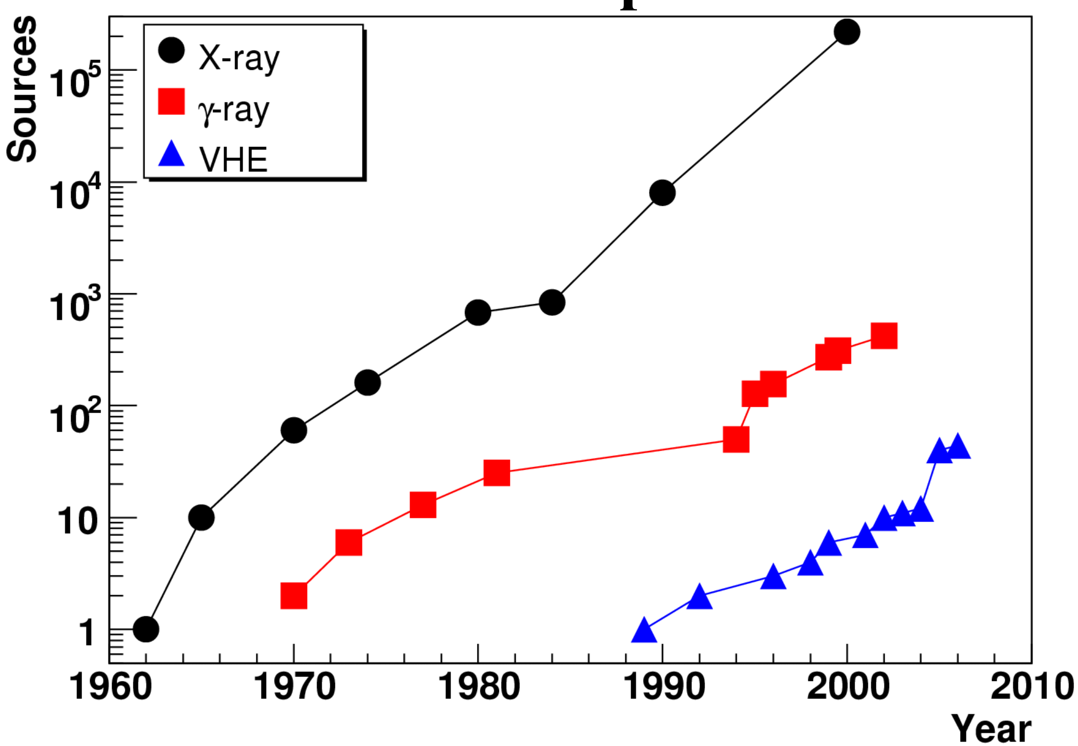


For comparison: HEGRA needed ~100 hrs to detect 5σ from a 5% Crab source

The Rapidly Increasing VHE Catalog

(& some shameless propaganda)

"Kifune plot"



- 46 total VHE sources
  - 12 extragalactic (AGN)
- 37 are H.E.S.S. sources
  - 7 extragalactic (AGN)
- 30 are H.E.S.S. discoveries
  - 4 extragalactic (AGN)
- Many more to come....

30 scientific H.E.S.S. publications in refereed journals

3 Nature letters & 2 Science letters

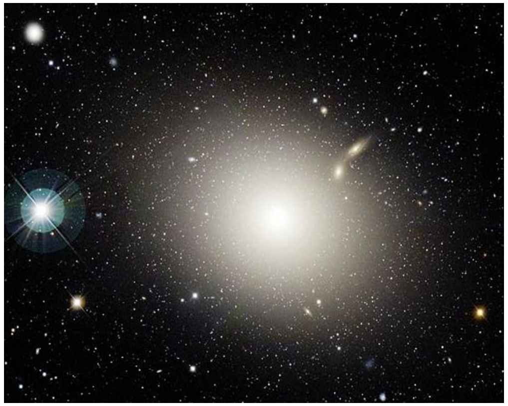
www.mpi-hd.mpg.de/hfm/HESS/

What is an AGN?

Spiral Galaxy

Spitzer Image (NASA)

Elliptical Galaxy

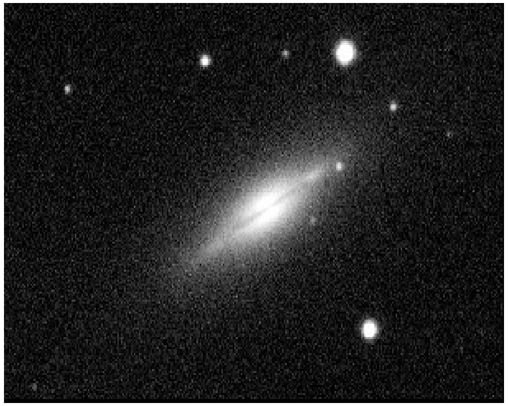


Cuillandre (CFH Telescope)

Irregular Galaxy

Hunter (Lowell Observatory) & Levay (STScI)

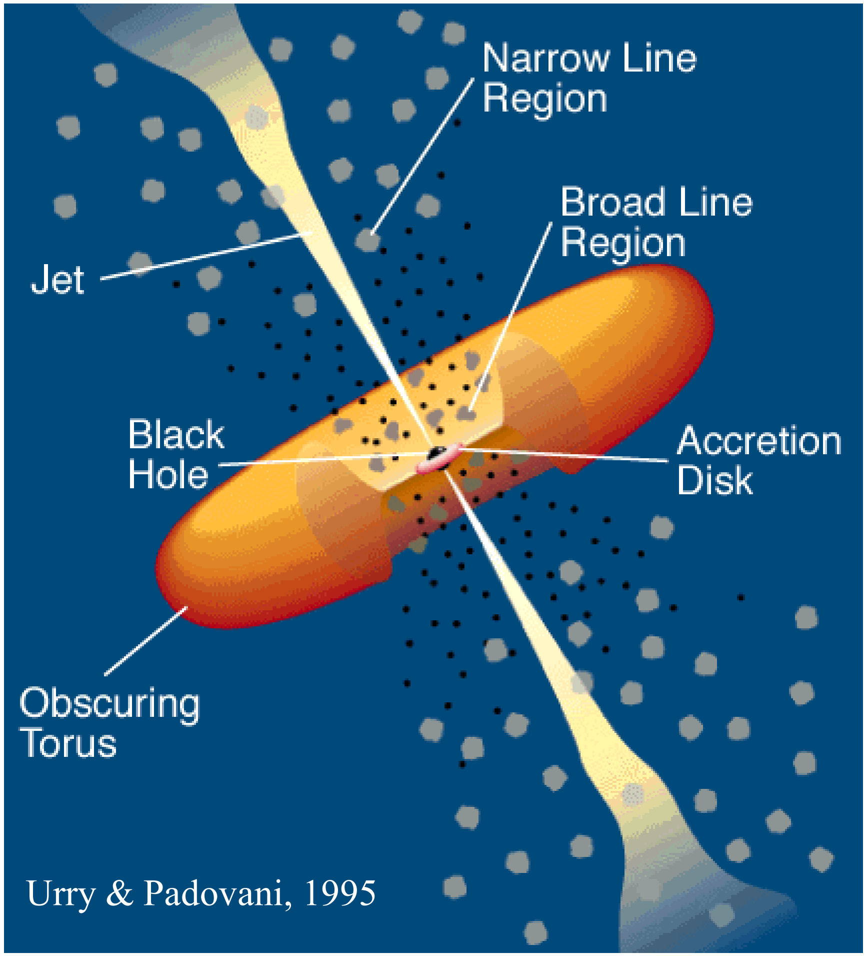
Lenticular Galaxy

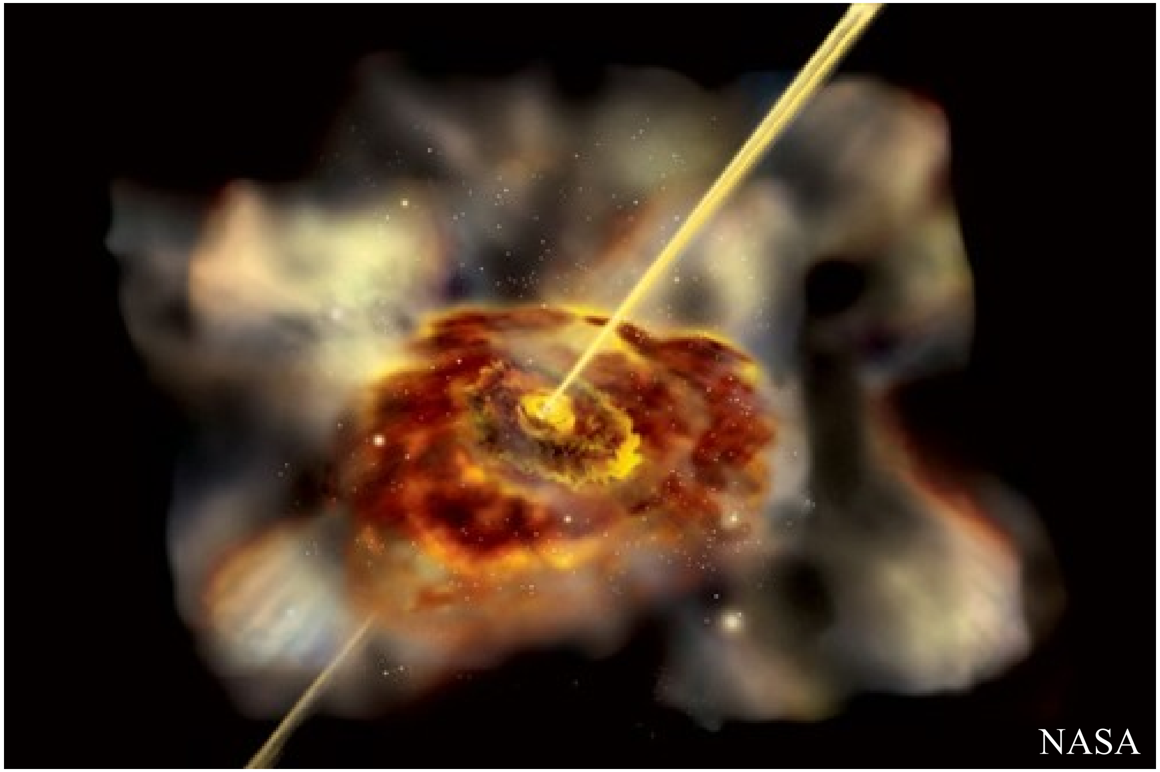


Korth (Sternwarte Aufderhöhe)

- Galaxy: A collection of gas, dust & $>10^6$ stars held together by gravity
  - Usually a super massive black hole at the center (~10^6 to 10^9 x solar mass)
- At least 5% of all galaxies are active galaxies
  - Active galaxies: small "bright" core of emission in otherwise typical galaxy
  - AGN = Active Galactic Nucleus (i.e. the core)
- AGN are highly variable & very bright compared to rest of galaxy
  - Bulk of emission is non-thermal (not just sum of lots of stars)
  - Emission at wavelengths other than optical (e.g. radio, x-ray & **γ-ray**)
- Basic model: Matter accreting onto supermassive black hole
- Why are some galaxies active & others not? Central matter already "eaten"

Unified Model of AGN





About 10% of AGN (Radio-loud population) have jets = highly relativistic outflow of energetic particles approximately perpendicular to the accretion disk

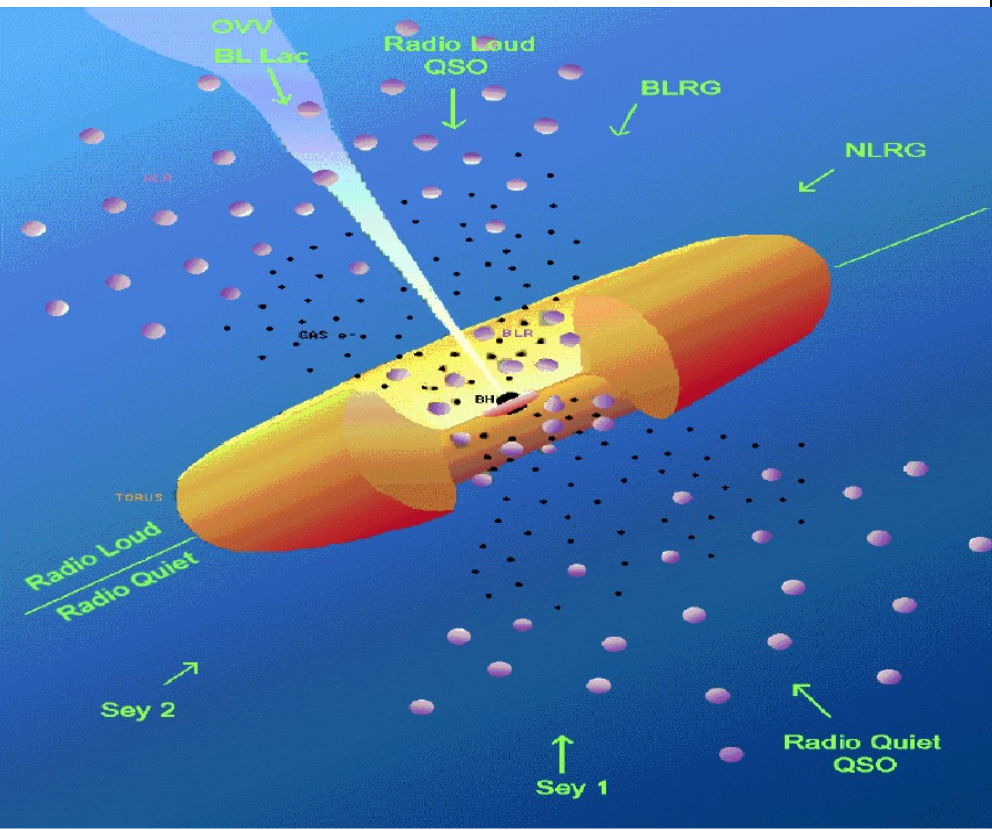
VHE emission is believed to be generated by these collimated radio-emitting jets

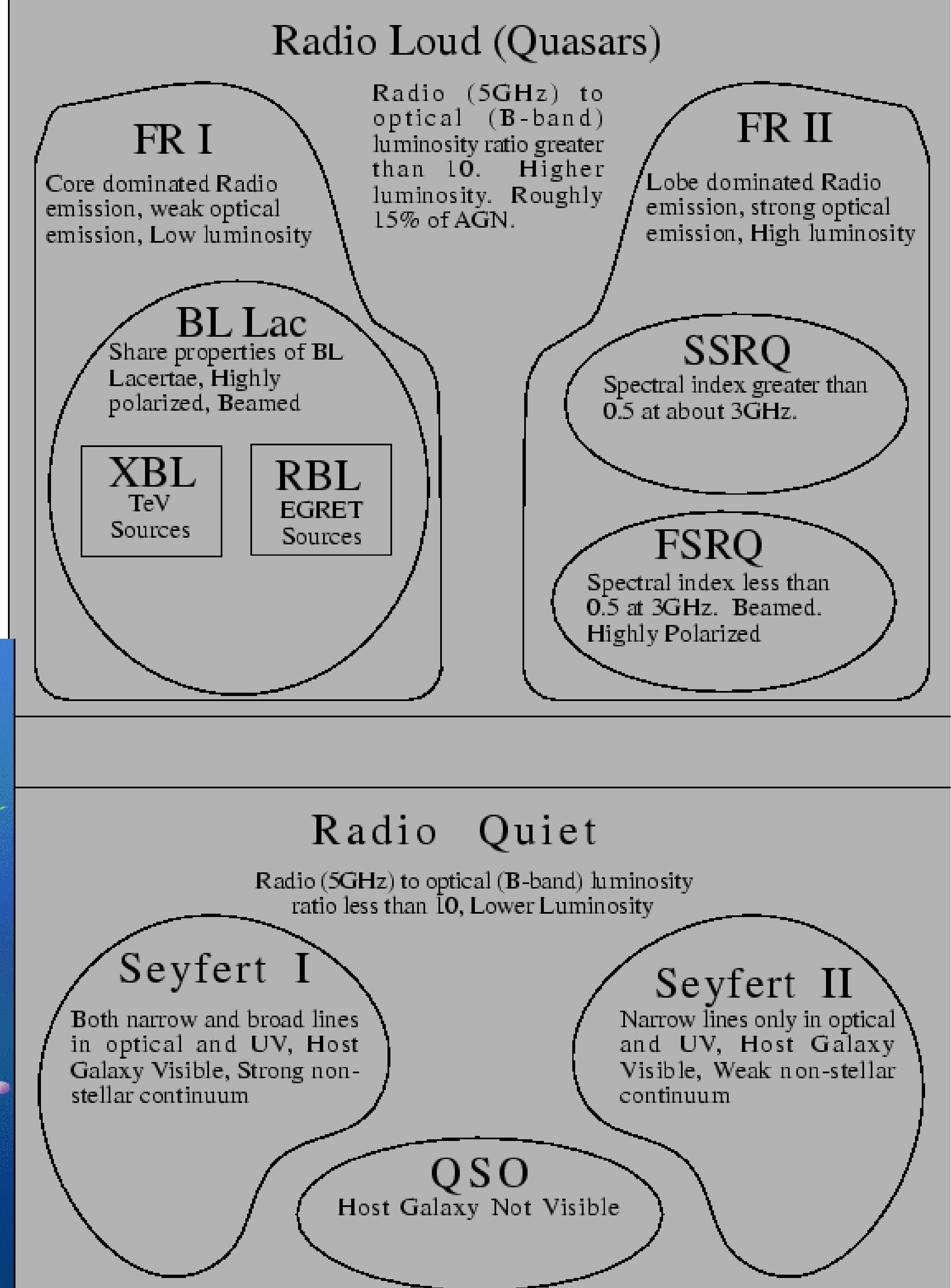
Taxonomy of AGN

Many, many subclasses of AGN

Due to viewing "same" objects at various angles with respect to the torus plane

~All VHE AGN are BL Lacs



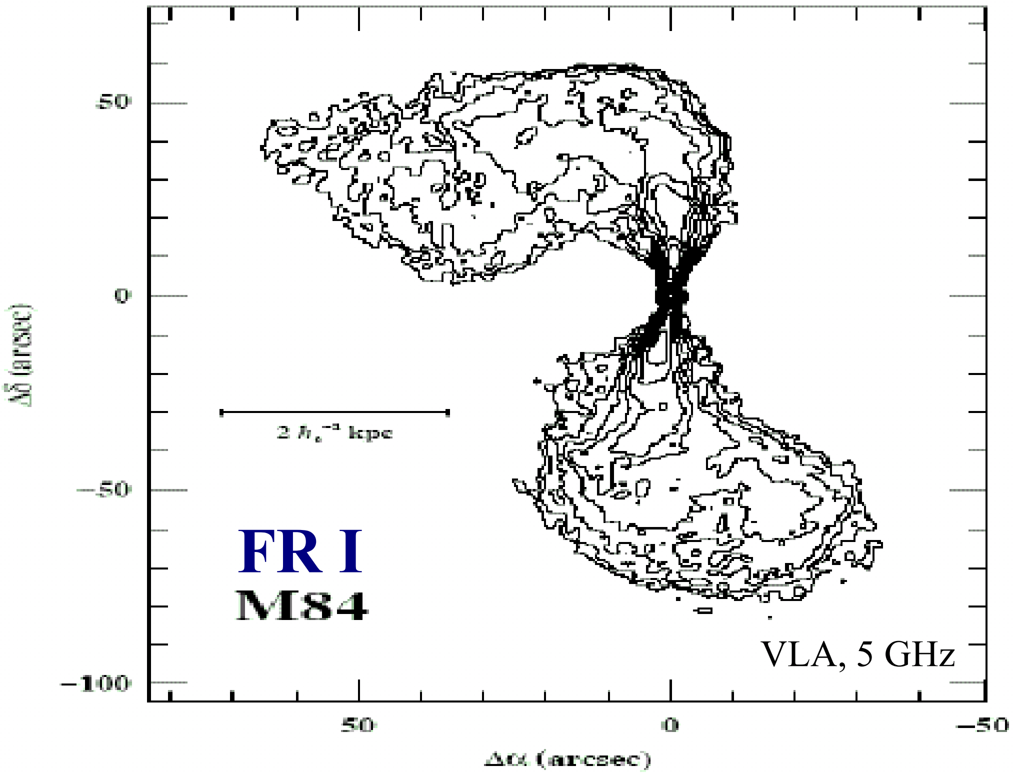


Venn Diagram from Lowell Boone

Fanaroff-Riley Galaxies

FR I: extended jets, no distinct termination point, core dominated

- Small angle => BL Lacs



Blazars: BL Lacs + FSRQ

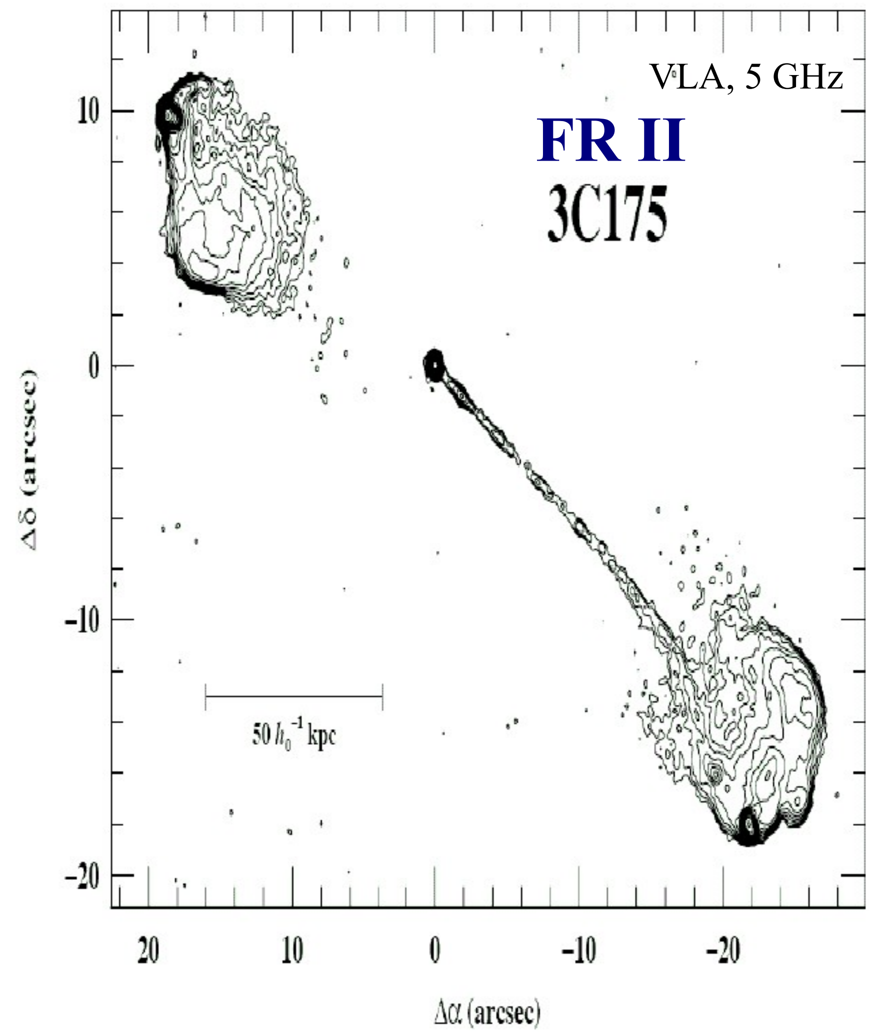
Low-energy (EGRET) γ-ray AGN :

- 66 definite + 27 possible blazars
- Cen A (the FR I prototype)

VHE γ-ray AGN: 11 blazars + M 87 (FR I)

FR II: Narrow, collimated jets with terminal "hot spots", lobe dominated, more luminous

- Small angle => FSRQ



Blazars: The VHE Bread & Butter

Jet oriented close to line of sight:

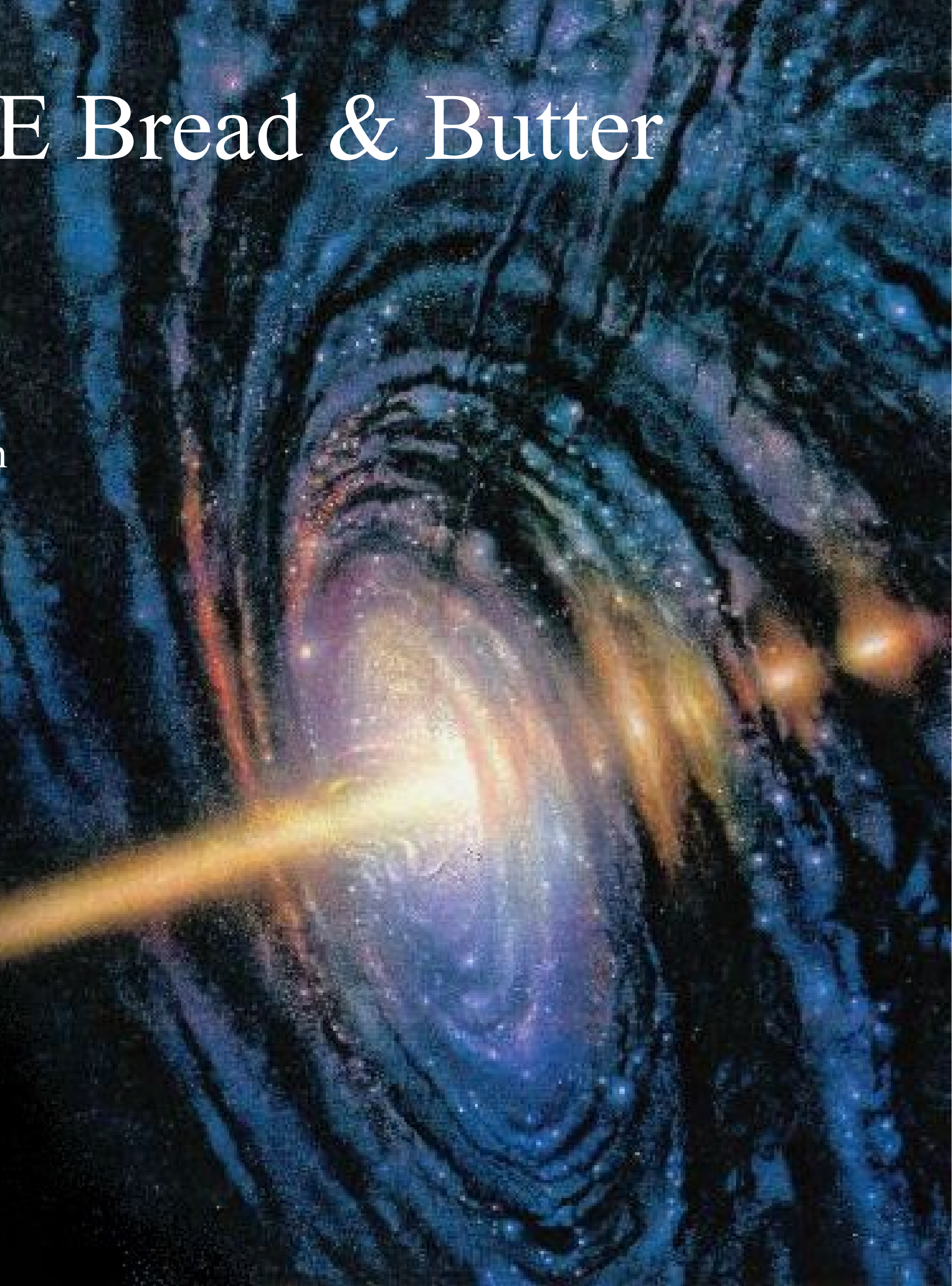
- Emission is Doppler boosted ("relativistically beamed")
- Large variations in luminosity
- "Decreased size" of emission region
- Reduces variability time-scale
- Allows VHE photons to escape high radiation fields

Low-emission quiescent states with bright flares (orders of mag.)

Emission is polarized

- Reflected light from torus

BL Lacs = no/weak optical lines
FSRQ = broad optical lines



Blazar Properties

SED: Power vs energy

2 populations: “Not really”

Blazar SEDs have 2 bumps:

- Low-energy from synchrotron radiation of relativistic electrons in B-fields of Jets
- High-energy bump: controversial

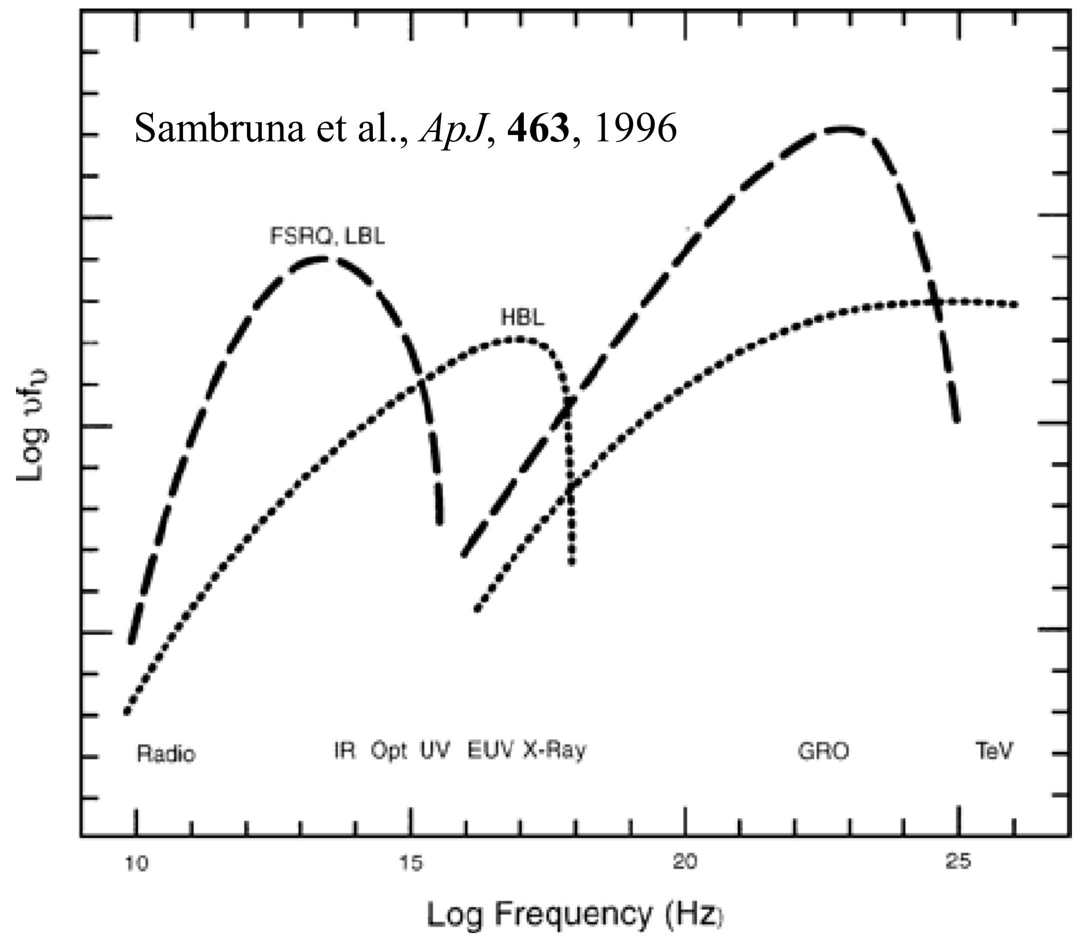
Leptonic Models:

- Electrons upscatter photons (via inverse-Compton scattering) to high energies
- Seed photons: SSC vs EC

Hadronic Models:

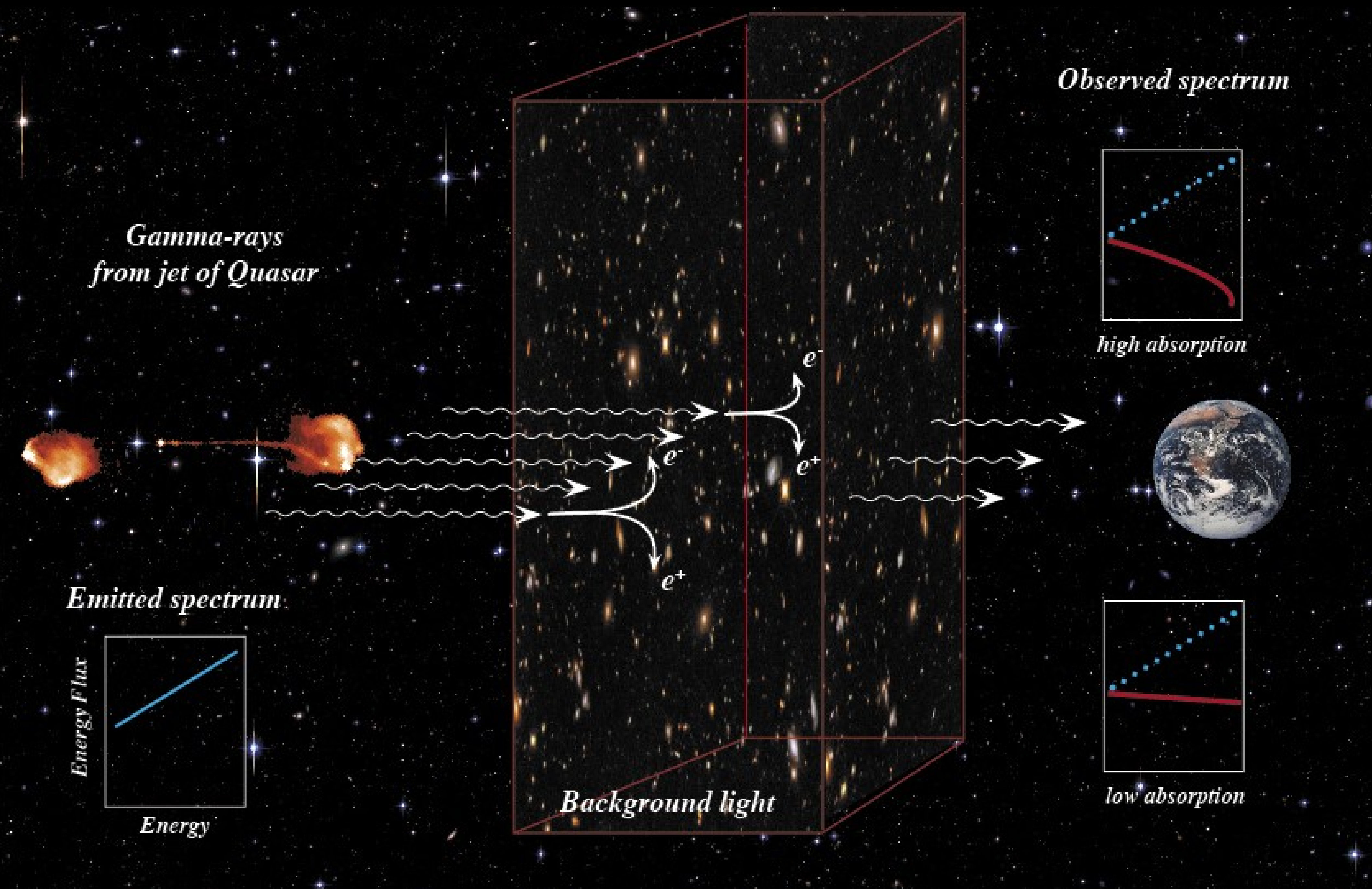
- Interaction of relativistic protons with matter, ambient photons, B-field, or photons & B-field

Average Spectral Shape of Blazars



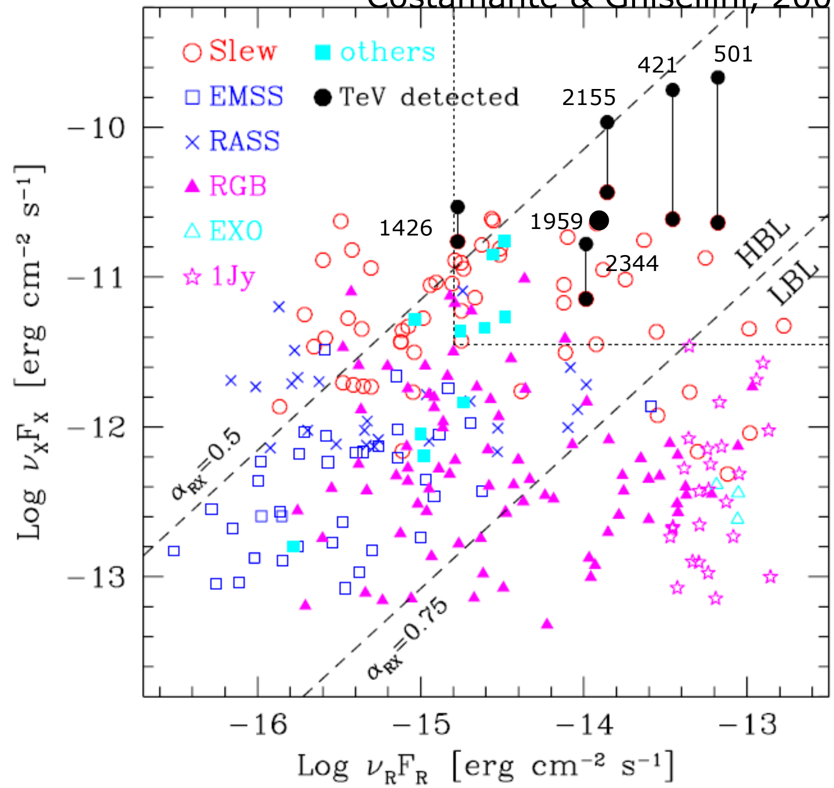
“All” EGRET AGN are LBL & FSRQ
“All” VHE AGN are HBL

One "Small" Complication!



7 VHE AGN in 2002

Costamante & Ghisellini, 2002



Object	Redshift	Type	1st Detection	Confirmation
M 87	0.004	FR I	HEGRA	None
Mkn 421	0.030	BL Lac	Whipple	Many
Mkn 501	0.034	BL Lac	Whipple	Many
1ES 2344+514	0.044	BL Lac	Whipple	HEGRA
1ES 1959+650	0.047	BL Lac	7-Tel. Array	Many
PKS 2155-304	0.116	BL Lac	Mark VI	None
H 1426+428	0.129	BL Lac	Whipple	Many

2 are “dubious”, Only 2 very well studied

Only upper limits from other AGN in the X-ray/Radio flux box

The H.E.S.S. AGN Program

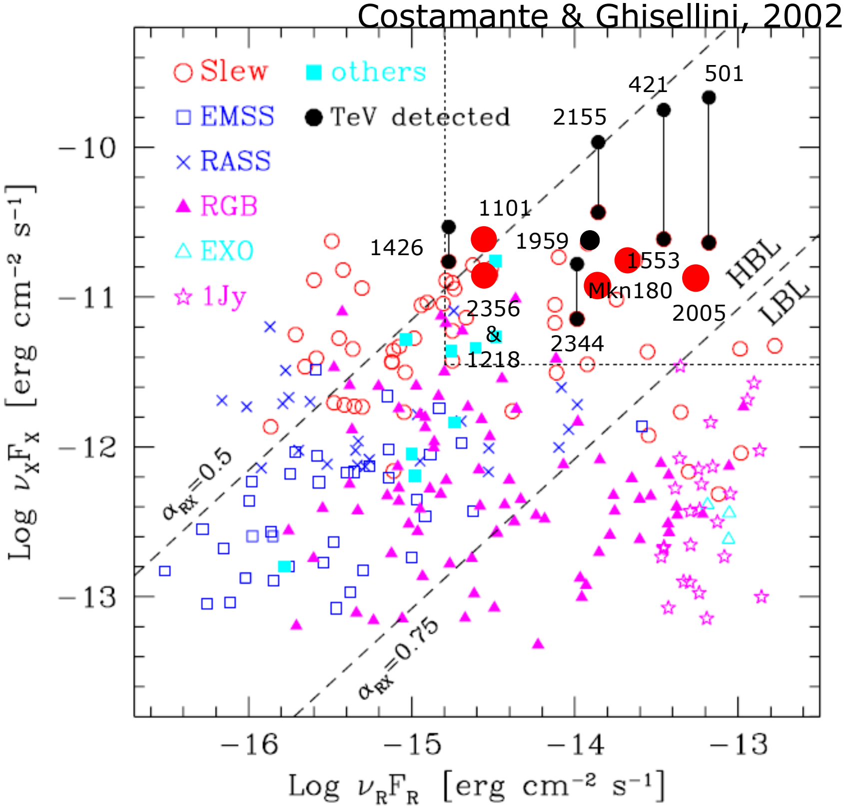
- **Usually ~1000 total hrs of observations per year**
  - **Can only observe on moonless, cloudless nights**
  - **~1700 total hrs are possible**
- **~300 hrs per year for AGN program**
  - **~300 hrs in 2003**
  - **~400 hrs in 2004**
  - **~300 hrs in 2005**
  - **~100 hrs so far in 2006 (target is ~300 hrs)**
- **Focus: Monitor known VHE AGN, observe candidate objects, MWL studies**
  - **Initially observe ~10 hrs on a target (~1.5% Crab flux sensitivity)**
  - **Then increase to ~50 hrs if something interesting is seen!**

Goal #1: Identify New VHE AGN

13 Known VHE AGN in 2006

Object	Redshift	Type	1st Detection	H.E.S.S. Reference
M 87	0.004	FR I	HEGRA	astro-ph/0504395
Mkn 421	0.030	HBL	Whipple*	A&A, 437, 95, 2005
Mkn 501	0.034	HBL	Whipple*	---
1ES 2344+514	0.044	HBL	Whipple*	---
Mkn 180	0.046	HBL	MAGIC	---
1ES 1959+650	0.047	HBL	7-Tel. Array*	---
PKS 2005-489	0.071	HBL	H.E.S.S.	A&A, 436, L17, 2005
PKS 2155-304	0.116	HBL	Mark VI	A&A, 430, 865, 2005
H 1426+428	0.129	HBL	Whipple*	---
H 2356-309	0.165	HBL	H.E.S.S.	Nature, 440, 1018, 2006
1ES 1218+304	0.182	HBL	MAGIC	---
1ES 1101-232	0.186	HBL	H.E.S.S.	Nature, 440, 1018, 2006
PG 1553+113	>0.25	HBL	H.E.S.S.	A&A, 448, L19, 2006

Costamante & Ghisellini, 2002



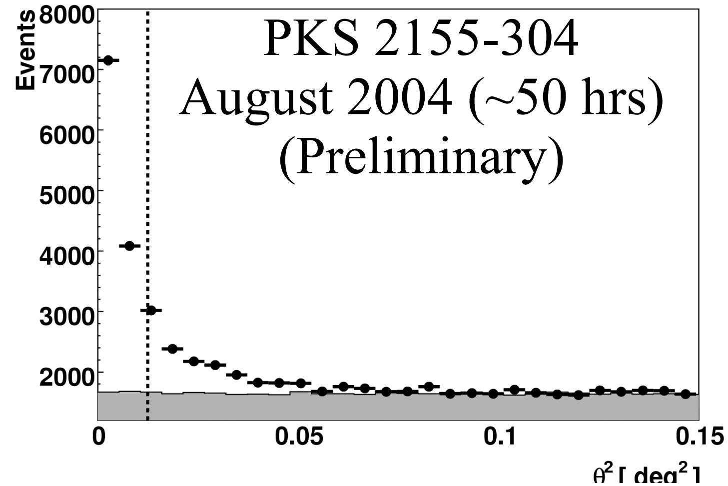
* = detected by many (>2) observatories

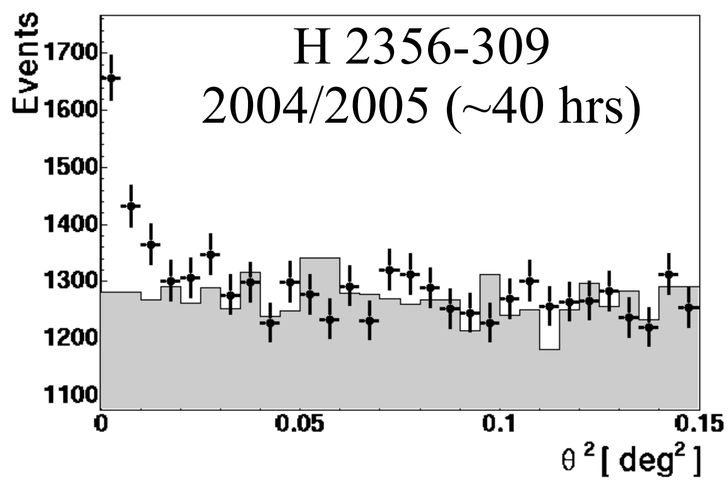
H.E.S.S has detected 7 AGN at VHE energies!

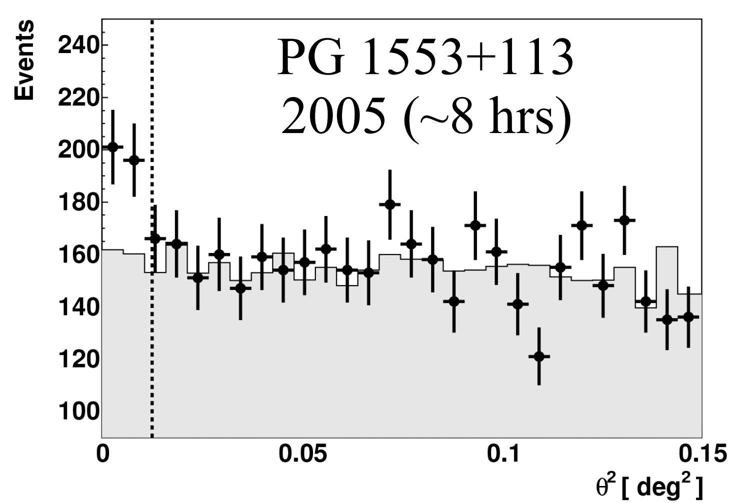
4 are "discoveries", 2 are 1st confirmations of "weak" detections

H.E.S.S. BL Lacs

- 2 objects with >100σ
  - PKS 2155-304 & Mkn 421
- 3 objects with >10σ
  - 1ES 1101-232, H 2356-309, PKS 2005-489
- 1 object with "Evidence for"
  - 4.0σ on PG 1553+113
  - >7σ including 2006 obs.
- All seen in multiple epochs
  - PKS 2155-304: 2002-2005
  - PG 1553 in 2005 & 2006
  - Others: 2004 & 2005
- All are HBL!

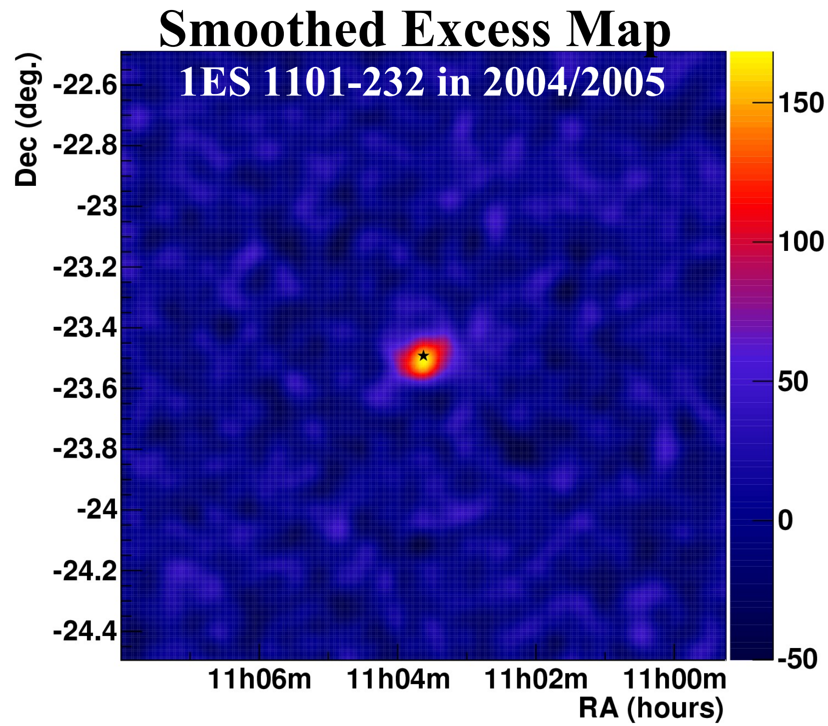


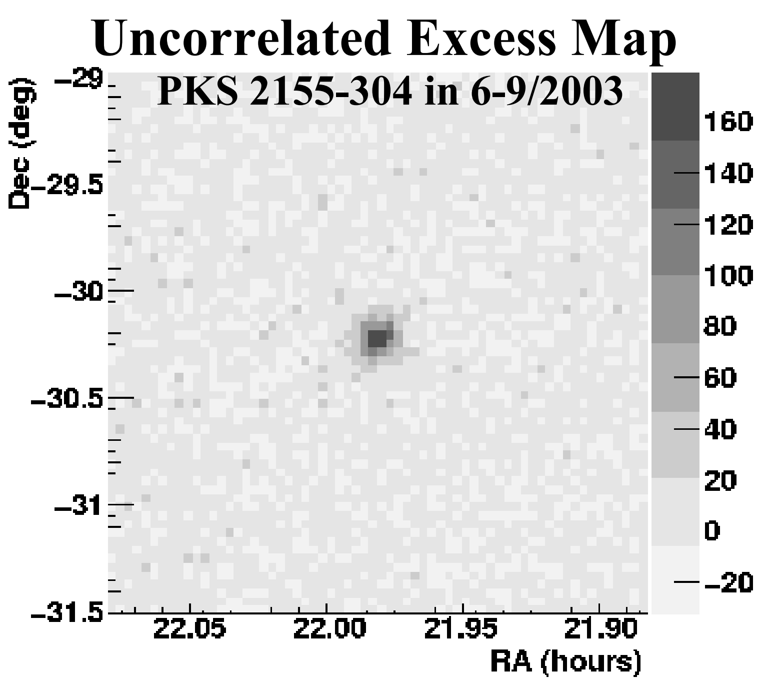


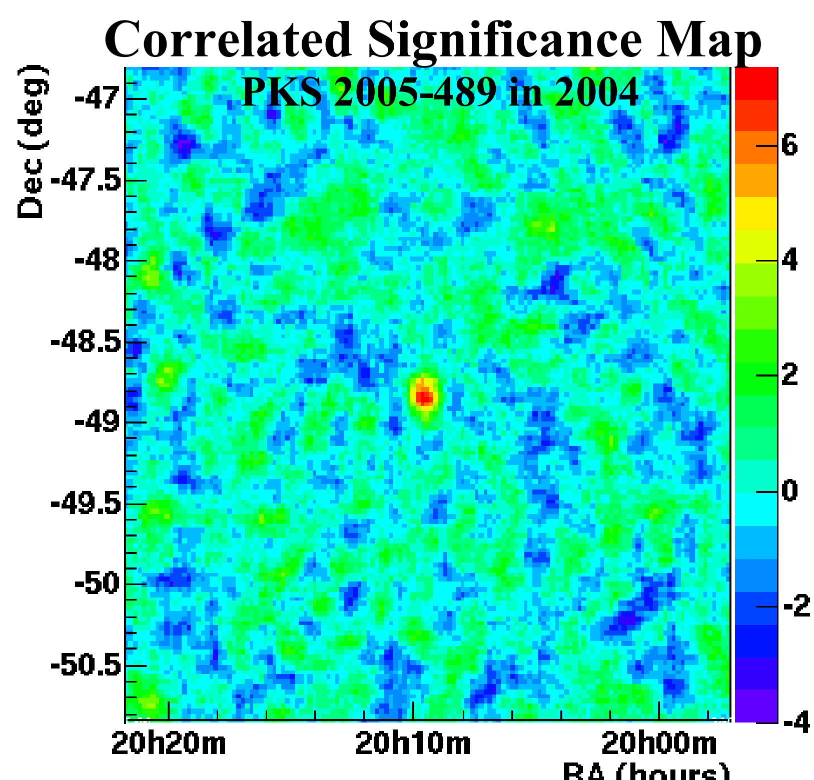


BL Lac Signals in 2D

- Fit a 2D Gaussian to a sky map of the uncorrelated excess for each H.E.S.S. AGN
- Location of all AGN excesses are **coincident with nucleus**
- Width of Gaussian is always **point-like** for AGN excesses
- Galactic sources typically extended







M 87: non-blazar

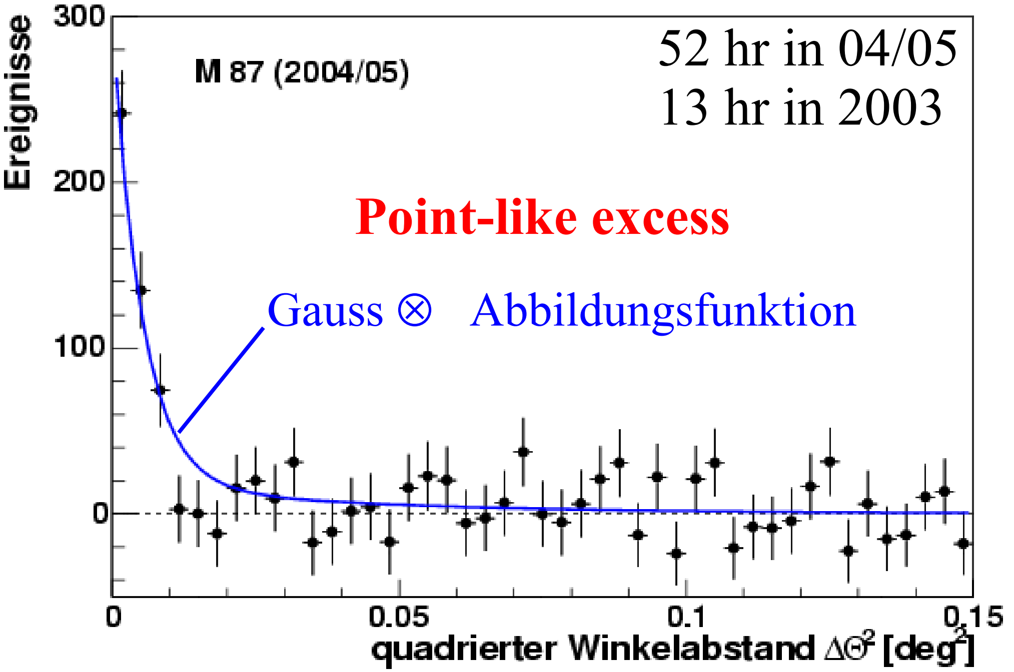
Fanaroff-Riley Type-I Galaxy:

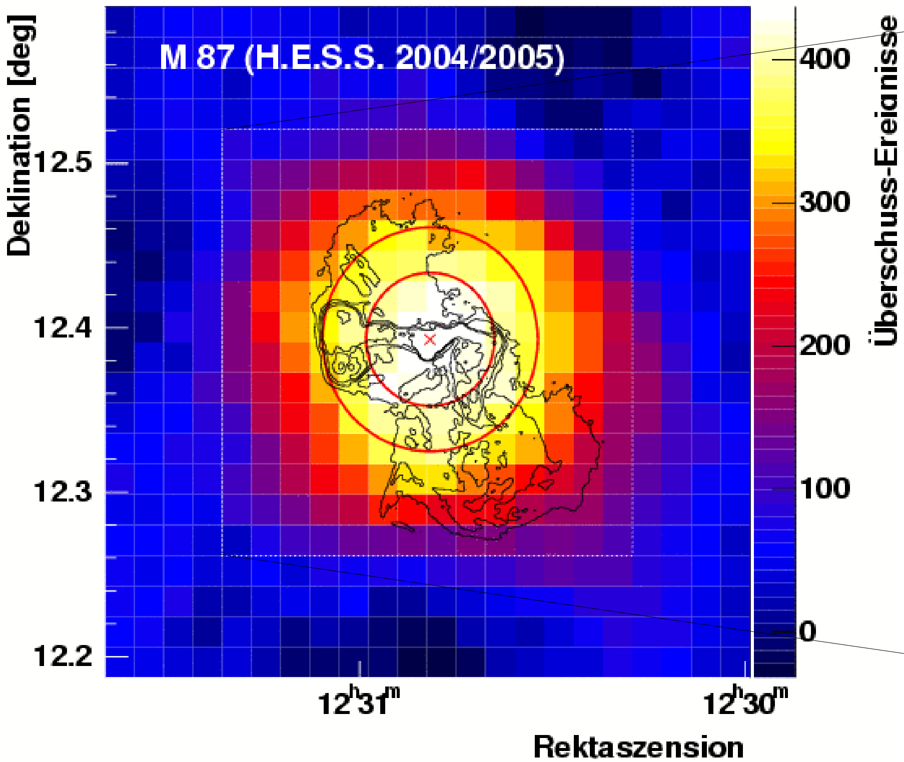
- A mis-aligned BL Lac?
- Jet angle: 20° to 40°
- Distance: ~16 Mpc

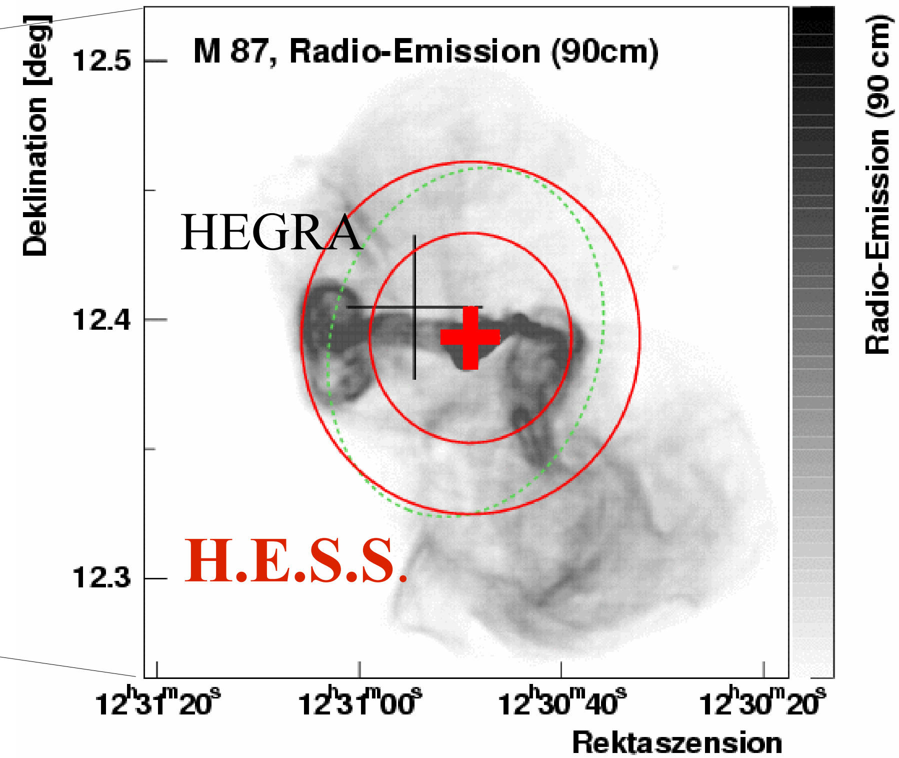
HEGRA: 4.7 σ in 77 hrs (1998-99)

Whipple: Upper limits in 2000-03

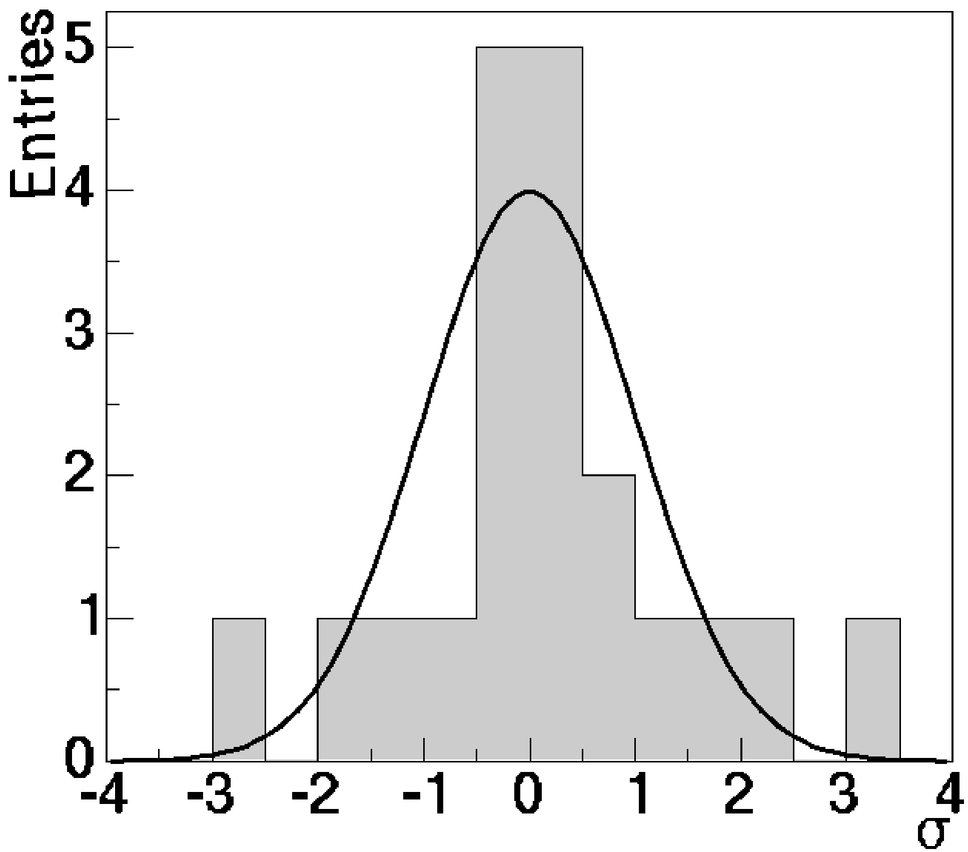
H.E.S.S.: ~11 σ (471 γ-rays)







AGN Upper Limits



20 other AGN observed

- 13 BL Lacs (mostly HBL)
  - 7 from Costamante & Ghisellini 2002
- 4 Radio-loud objects
  - FR I: Pictor A, Cen A (prototype)
  - FR II: 3C 120
  - FSRQ: 3C 273
- 3 Seyferts
  - Type I: NGC 3783 (brightest), NGC 7469
  - Type II: NGC 1068 (prototype)

No significant signal

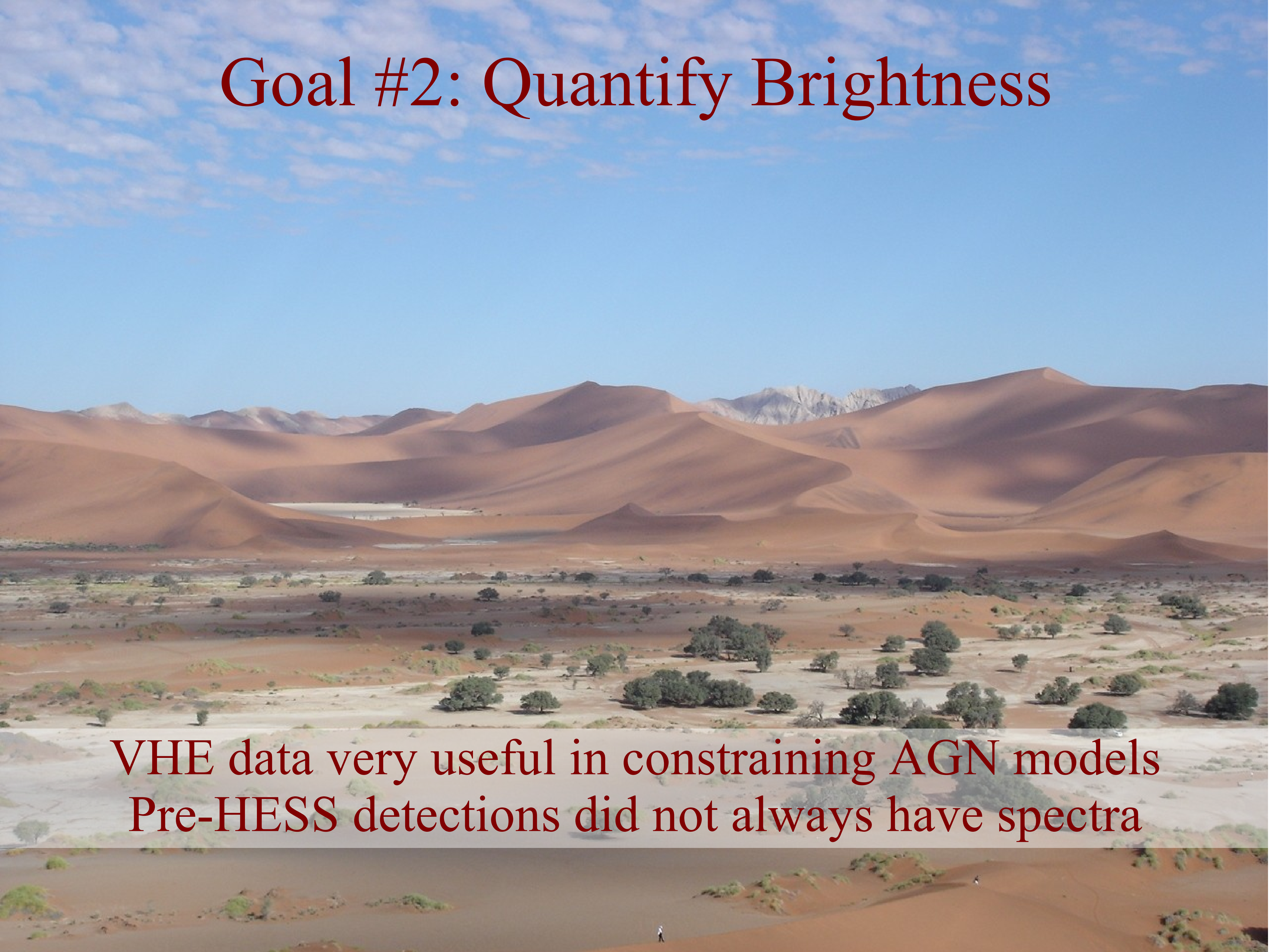
- Mkn 501 (3.1 σ, ~15% Crab flux)

Exposure: 1 to 8 hrs each (avg 3.2 h)

99.9% Upper limits: 0.4 to 5.1% Crab

A&A, **441**, 465 (2005)

Goal #2: Quantify Brightness



VHE data very useful in constraining AGN models
Pre-HESS detections did not always have spectra

H.E.S.S. BL Lac Fluxes are low!

Mkn 421 is exceptional case: ~3 Crab above 2 TeV

- H.E.S.S. Observations triggered by communication from Whipple

Average Observed Flux for H.E.S.S. BL Lacs:

- **PKS 2155-304: ~15% Crab above 200 GeV**
- **PKS 2005-489: ~2.5% Crab above 200 GeV**
- **1ES 1101-232: ~2% Crab above 200 GeV**
- **H 2356-309: ~2% Crab above 200 GeV**
- **PG 1553+113: ~2% Crab above 200 GeV**
  - 1 Crab above 200 GeV = 2.3×10^{-10} cm^{-2} s^{-1}

H.E.S.S. Observation time required for a 5σ detection:

15 minutes for PKS 2155-304

~10 hrs for PKS 2005, 1ES 1101, H 2356 & PG 1553

Essentially impossible for earlier instruments to detect!

- A “Southern” Whipple (~300 GeV threshold):
  - 10 hrs for PKS 2155 & ~500 hrs for other sources
- A “Southern” HEGRA (~1 TeV threshold):
  - 100 hrs for PKS 2155, ~2500 hrs from 1ES 1101 & H 2356, & >20000 hrs for PKS 2005 & PG 1553

BL Lac Energy Spectra

Most spectra follow a pure power-law with no features

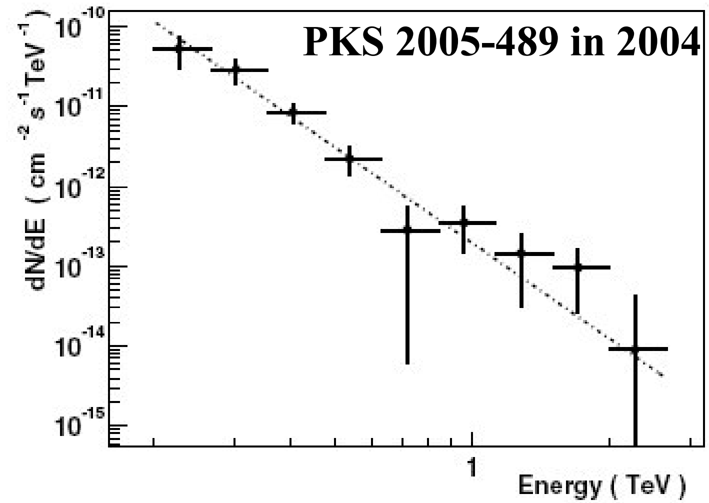
- $dN/dE \sim E^{-\Gamma}$

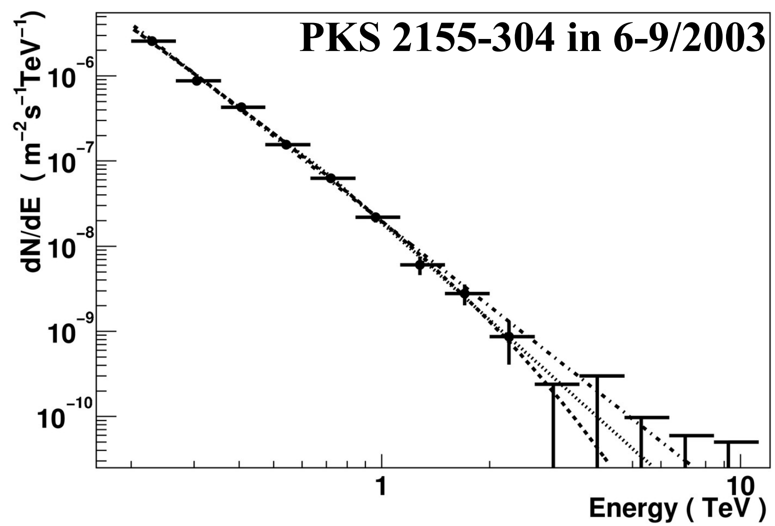
Soft spectra measured for all the H.E.S.S. BL Lacs:

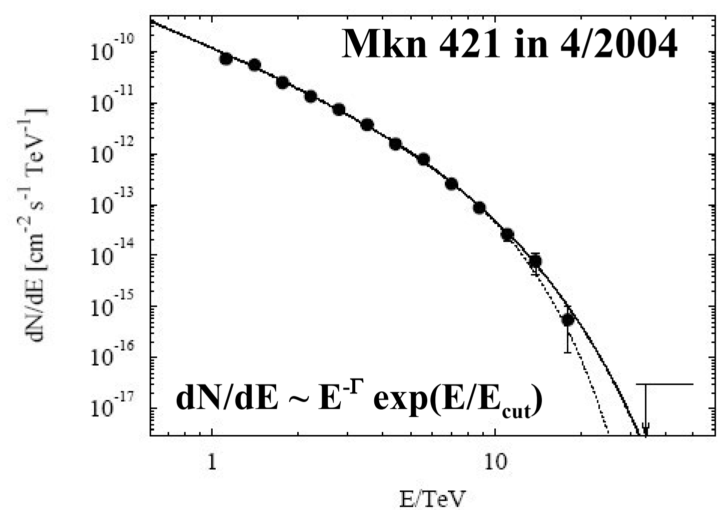
- 1ES 1101-232: $\Gamma = 2.88 \pm 0.17$
- H 2356-309: $\Gamma = 3.06 \pm 0.21$
- PKS 2155-304: $\Gamma = 3.32 \pm 0.06$
- PKS 2005-489: $\Gamma = 4.0 \pm 0.4$
- PG 1553+113: $\Gamma = 4.0 \pm 0.6$
- Systematic Error: 0.1

- Mkn 421: $\Gamma = 2.1 \pm 0.1 \pm 0.3$
    - $E_{cut} = 3.1\ (+0.5,-0.4) \pm 0.9$ TeV

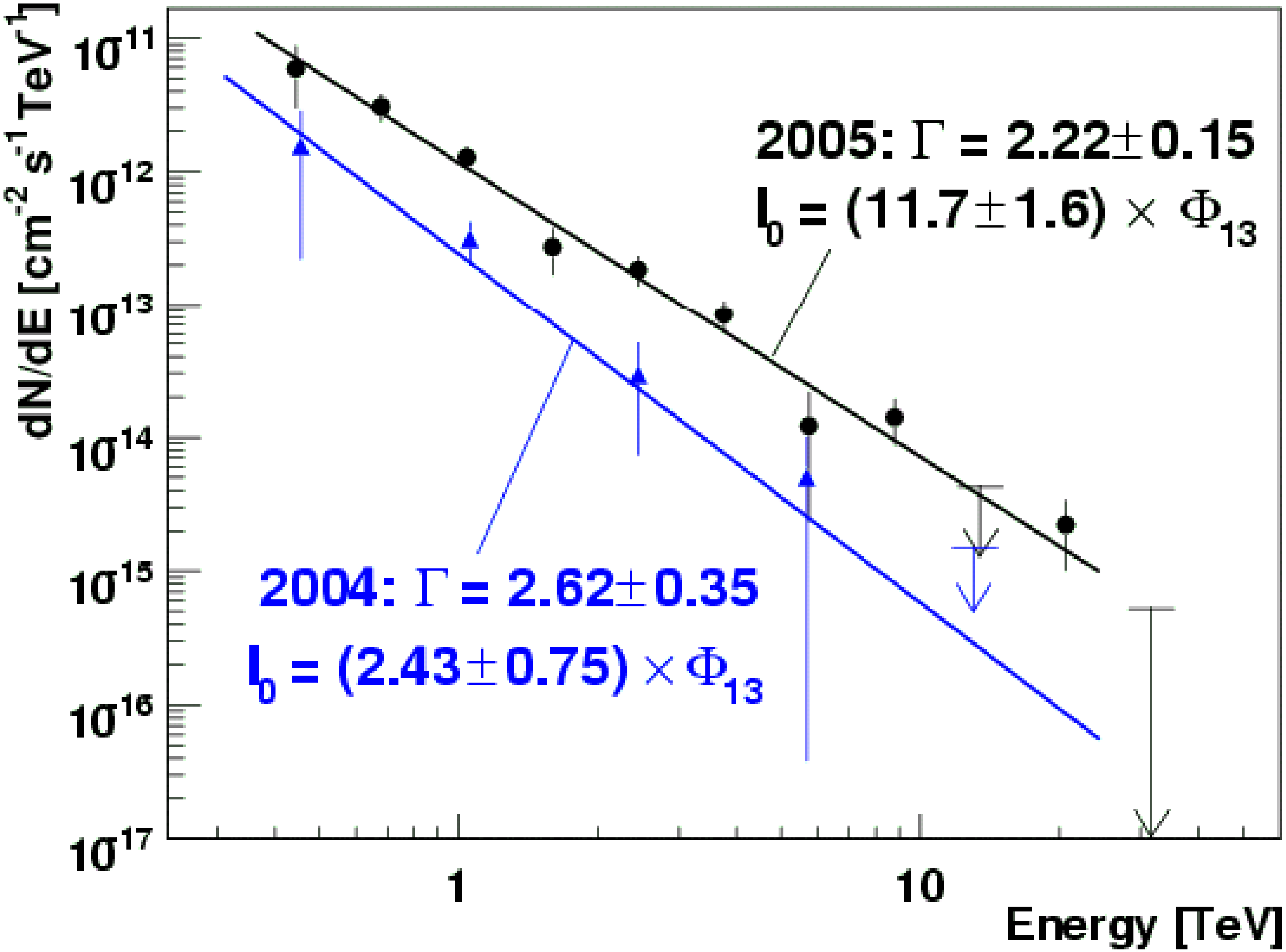
Note: Galactic sources typically have hard ($\Gamma \sim 2.3$) spectra







M 87 Spectrum is Hard



Annual spectra:

- 2004 (5σ)
- 2005 (10σ)

Both spectra follow a pure power-law:

- $dN/dE = I_o\,(E/TeV)^{-\Gamma}$
- $\Phi_{13} = 10^{-13}$ cm^{-2} s^{-1} TeV^{-1}

Photon index similar

Flux is less in 2004

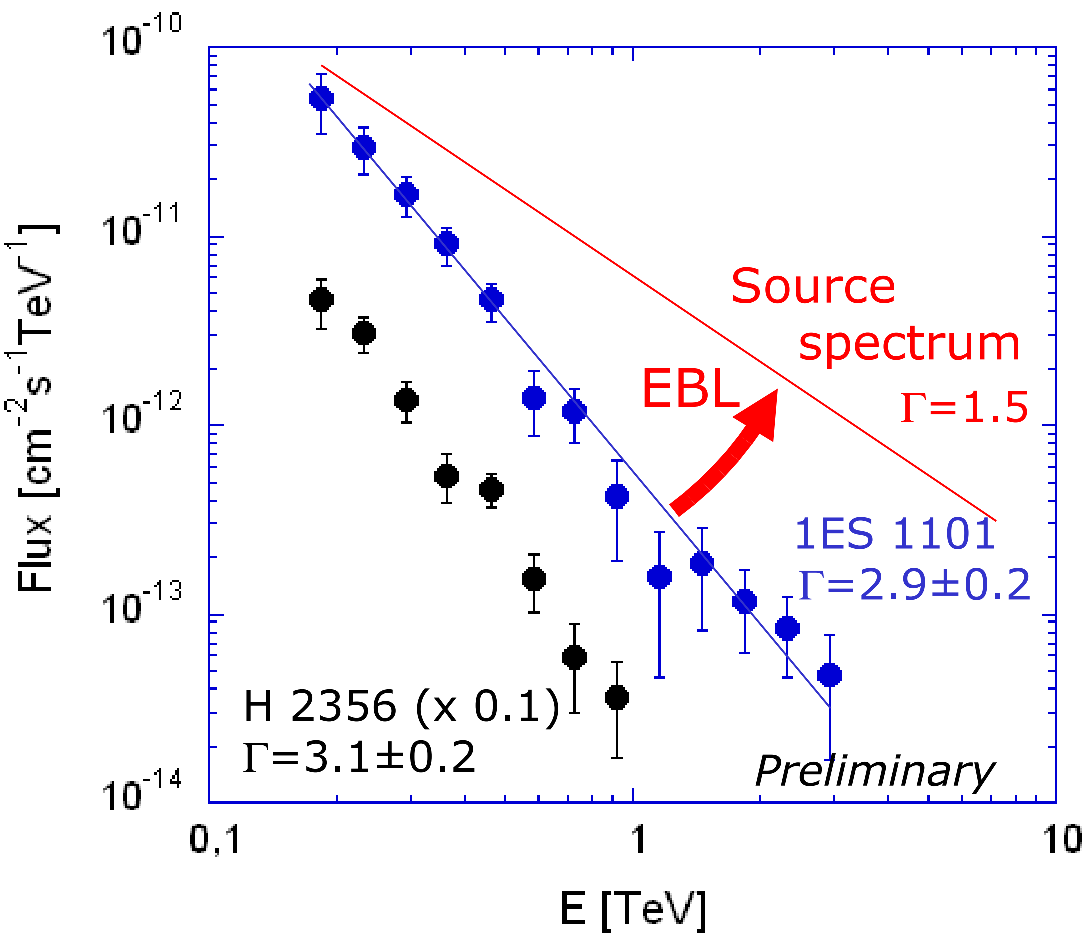
Goal #3: Constrain EBL

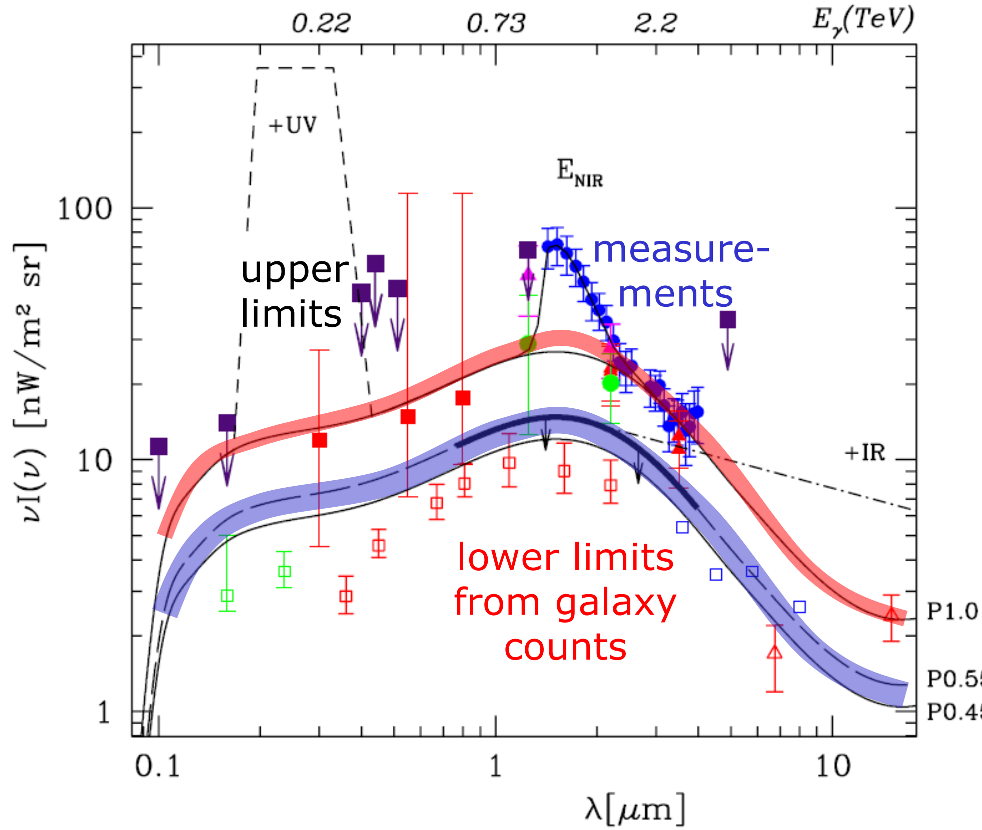
Use features in observed spectra of distant VHE AGN

Establish VHE gamma-ray horizon

Distant BL Lacs

- VHE γ-rays absorbed by EBL
- Absorption increases with E & z
- Large z => Softer observed spectra
- More EBL = More absorption





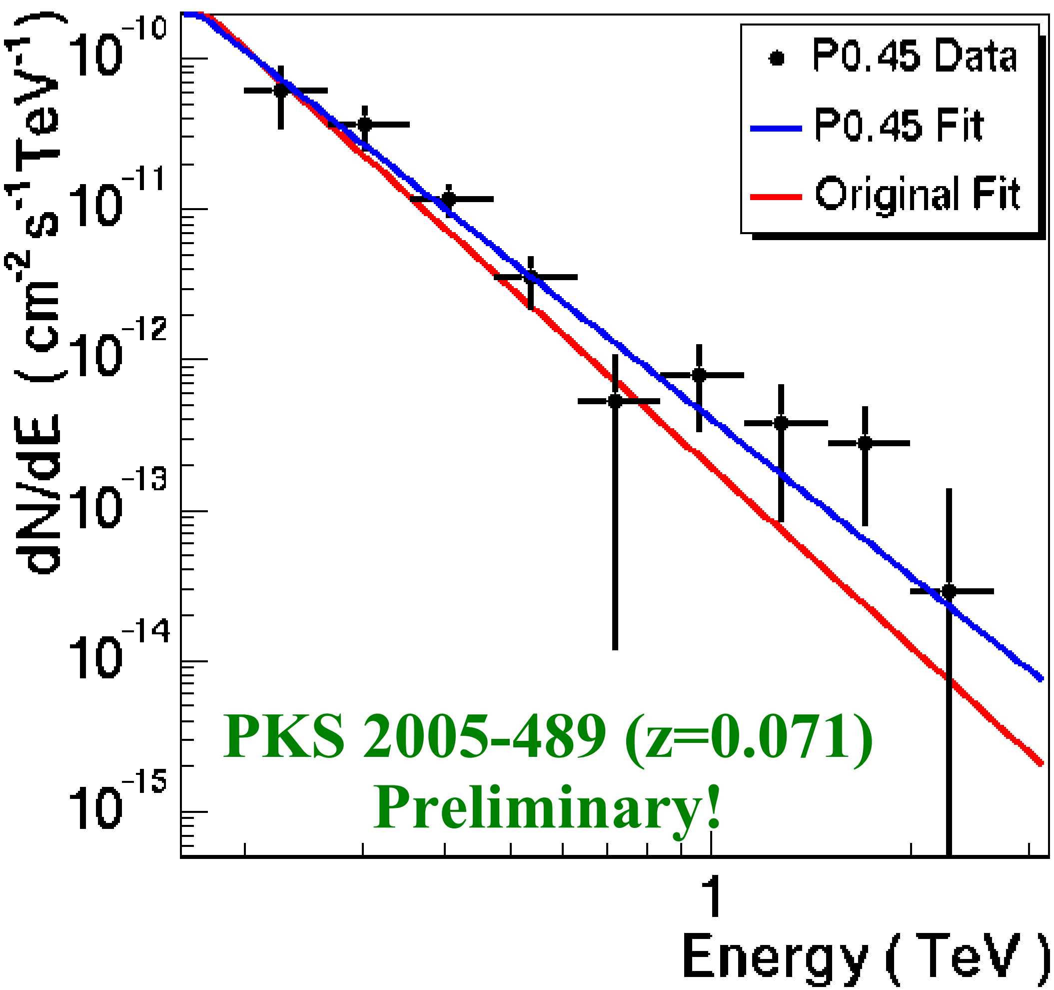
EBL less than previously thought!

- Density must be less than 0.45x shape
- Account for errors, etc => 0.55x
- Within a factor of 2 of lower limits

We can see much further in VHE!

Nature 440, 1018, 2006

Soft spectra not "only" from EBL



Observed spectrum:

- $\Gamma = 4.0 +/- 0.4$
- I(>200 GeV) ~ 6.9 x10^{-12} cm^{-2} s^{-1}

High EBL Flux:

- $\Gamma = 3.0 +/- 0.4$

H.E.S.S. EBL Limit (P0.45):

- $\Gamma = 3.5 +/- 0.4$
- I(>200 GeV) ~ 7.8 x 10^{-12} cm^{-2} s^{-1}

Softness of spectrum is mostly intrinsic to PKS 2005-489
Inverse-Compton peak <100 GeV

The Case of PG 1553+113

VHE candidate:

- Costamante & Ghisellini (2002)
- VHE upper limits from Whipple & Milagro
- Catalog redshift is 0.36

HESS detected in 2005

Catalog redshift (z=0.36) incorrect!

- Falomo & Treves, 1990
- No lines found in ~10 attempts

No host galaxy in HST images:

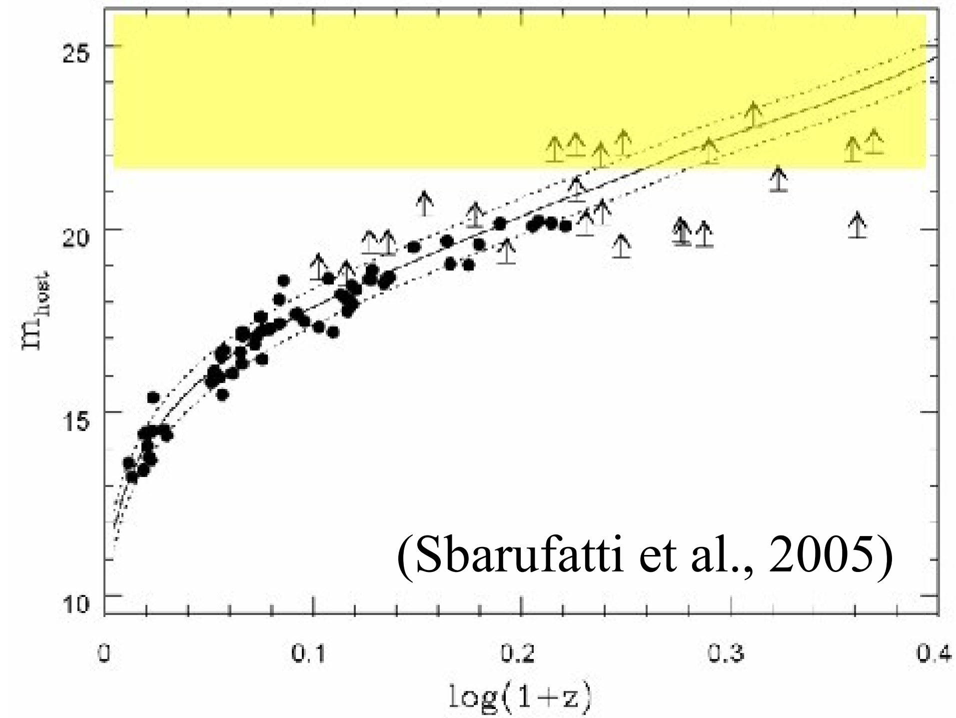
- All HST BL Lacs with z<0.25 have resolved hosts
- ~75% of HST BL Lacs with 0.25 < z < 0.6 have resolved hosts

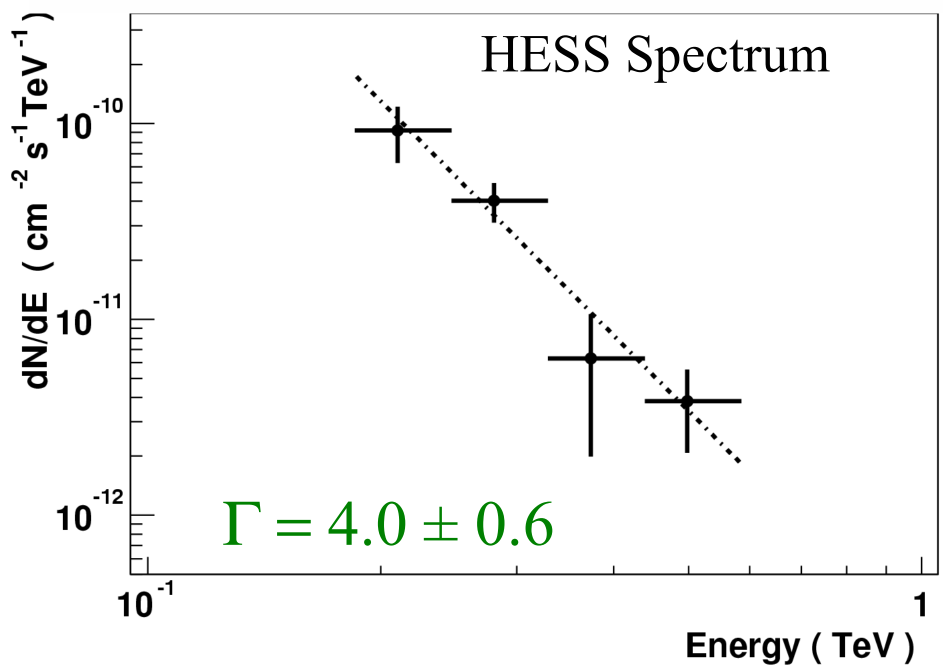
z>0.78 (Sbarufatti et al., 2005)

- Recently z>0.09 (astro-ph/0601506)

Determining redshift is important!

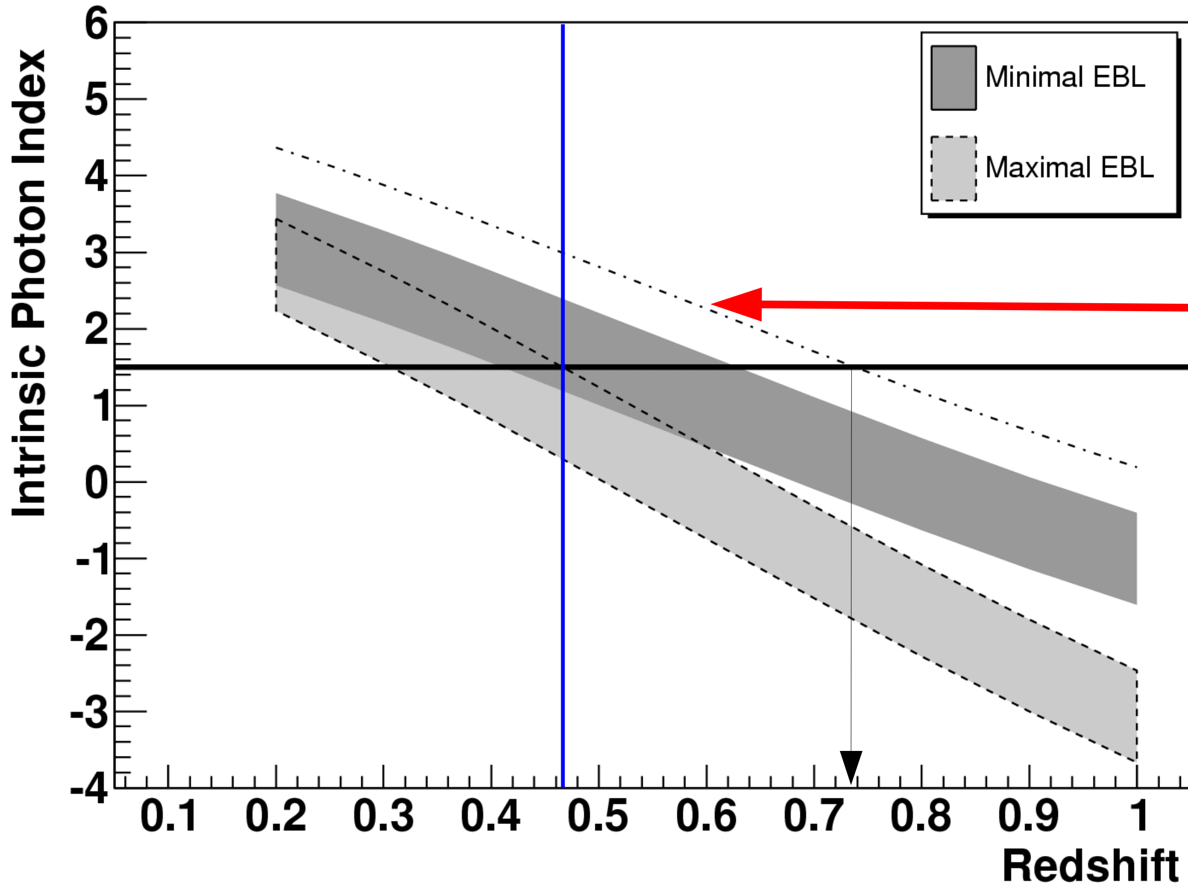
- H.E.S.S. received 5 hrs of VLT time on PG 1553+113 (IR to mid-IR) in early 2006
- Analysis on going





Cosmological Interpretation

If z > 0.47:
Spectrum is more constraining than HESS EBL limit!



Minimal EBL
+2σ errors

z < 0.74

Minimal EBL = Deabsorbed with 0.6x Primack 2001 EBL; Galaxy Counts

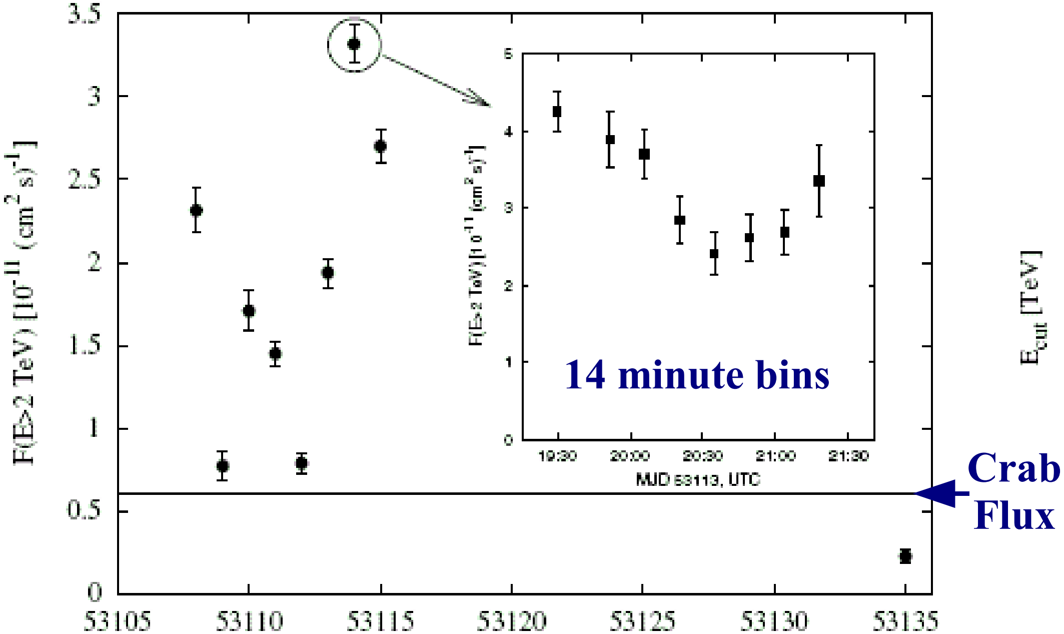
Maximal EBL = Deabsorbed with 0.85x Primack 2001 EBL; HESS EBL Limit

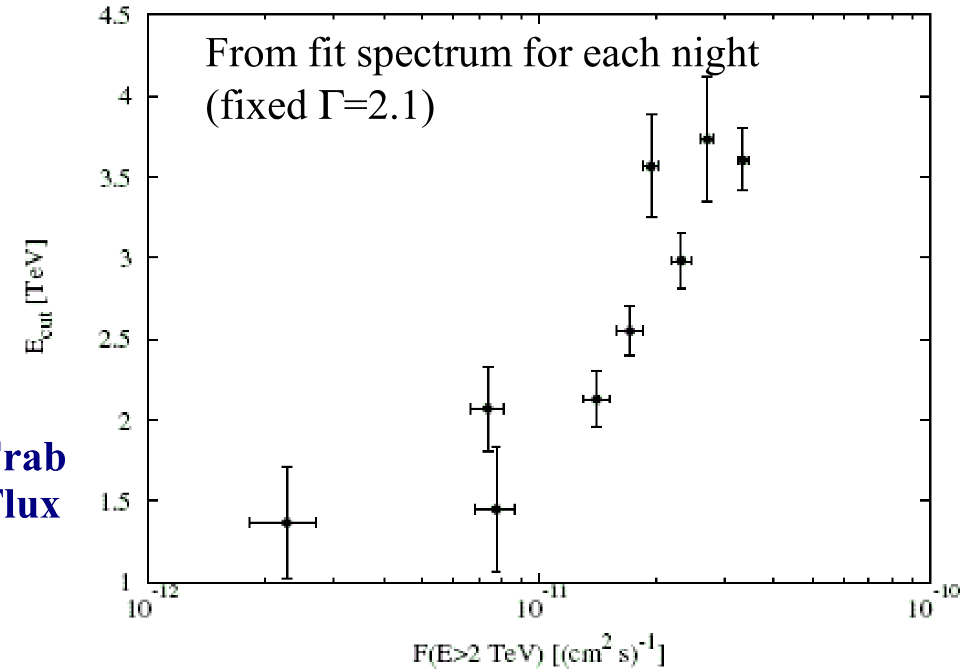
Why Primack 2001 EBL? Includes effects of galaxy evolution

Goal #4: Study VHE Variability

Establish variability time scales
Search for temporal spectral evolution (i.e. hardening)

Extreme Flux Variability: Mkn 421





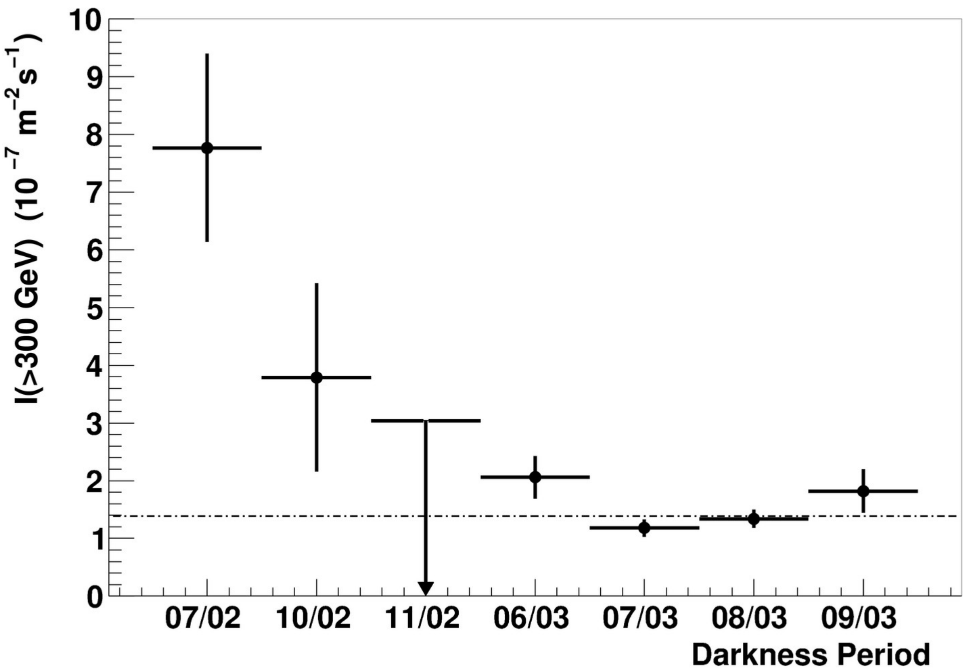
Flux (>2 TeV) varies by factor of 4.3; Average value ~3 Crab

Doubling time-scale less than 1 hour

Clear evidence for spectral hardening with increased flux!

Note: Data taken at extremely large zenith angle

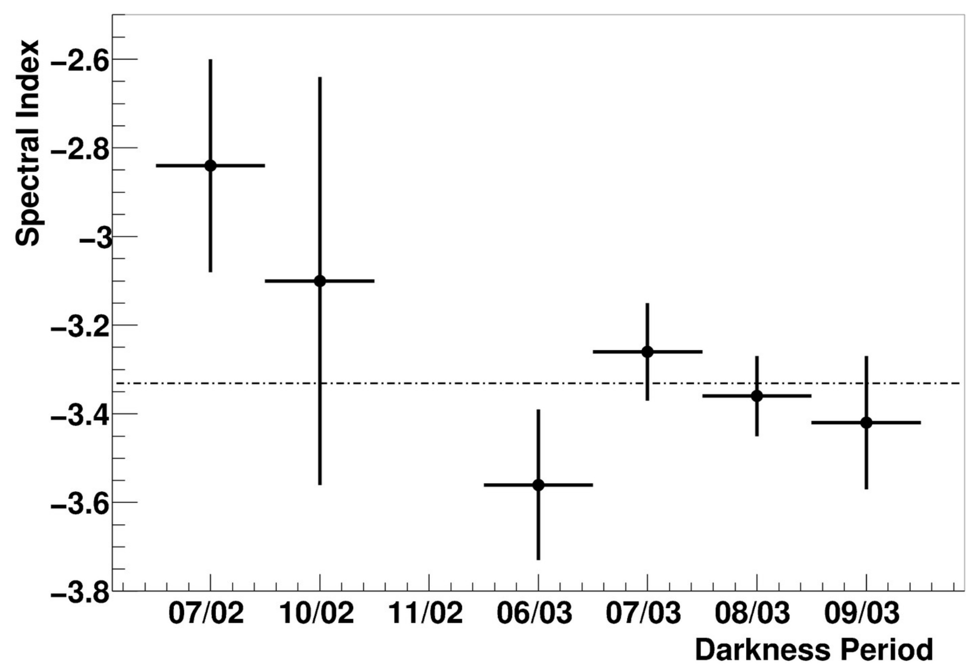
Variability of PKS 2155-304



VHE flux is clearly variable on monthly time-scales

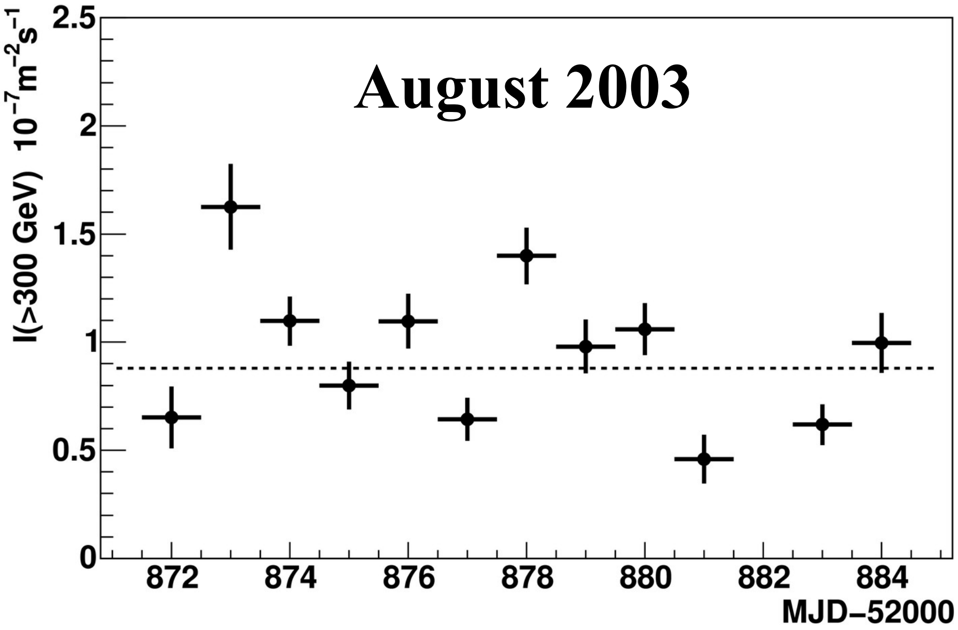
I(>300 GeV) ranges from 0.1 Crab to 0.6 Crab

No evidence for variability of photon index or spectral hardening with increased flux, but it is not ruled out either



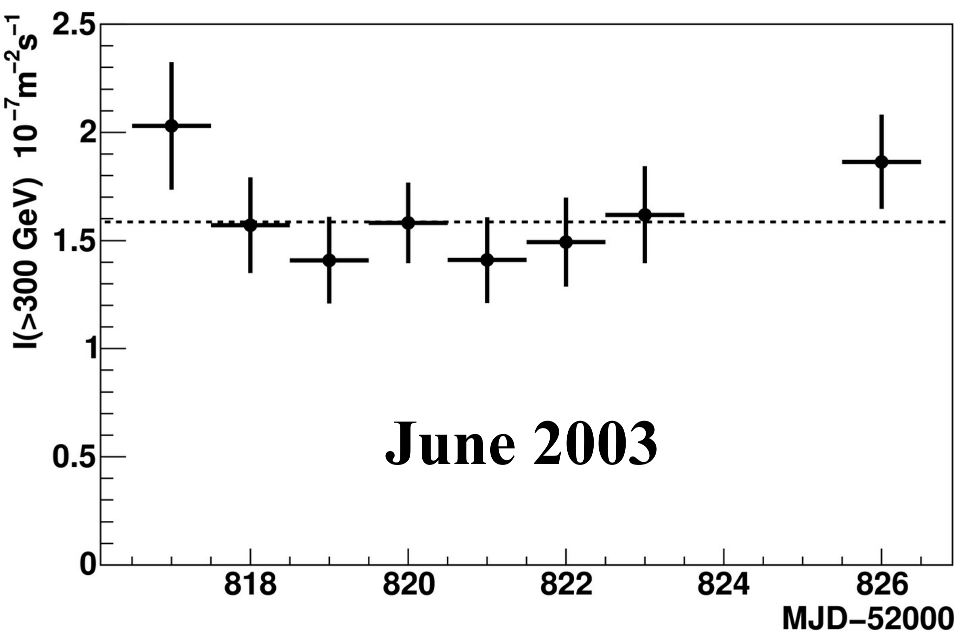
PKS 2155-304 VHE flux & spectrum ~same in late 2003, all 2004 & all 2005 data

Nightly VHE Flux Variability

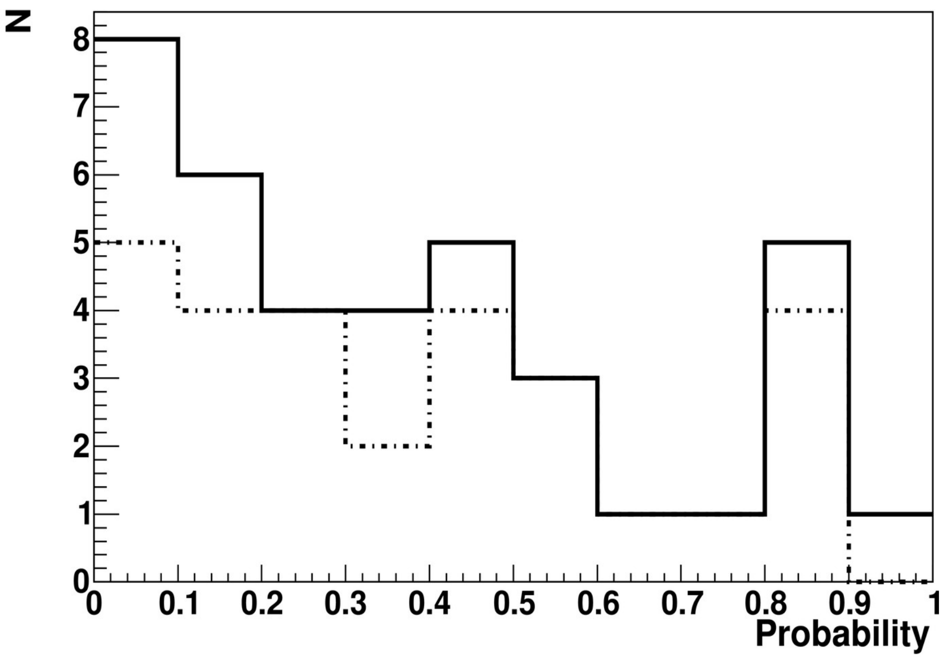


Clear evidence for VHE flux variability on nightly time-scales in some dark periods

However, the flux is also stable in some dark periods



Intra-Nightly Flux Variability



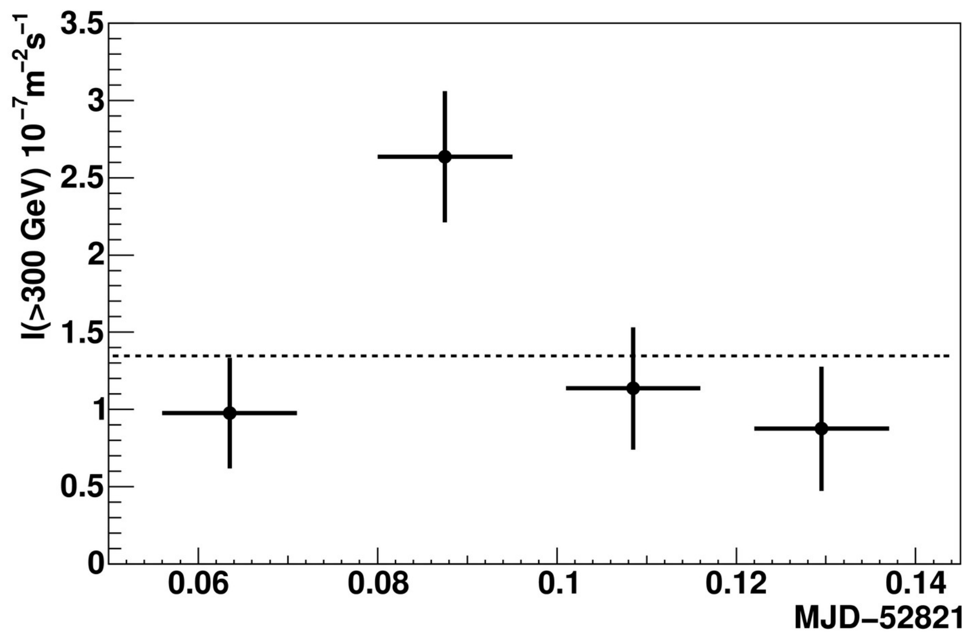
Fit a constant to theVHE flux (~30 min intervals) within each night

- Dashed line is for >1 d.o.f.

Population of nights with a low χ^2 probability

Sub-hourly changes on the night with the most significant flux variability:

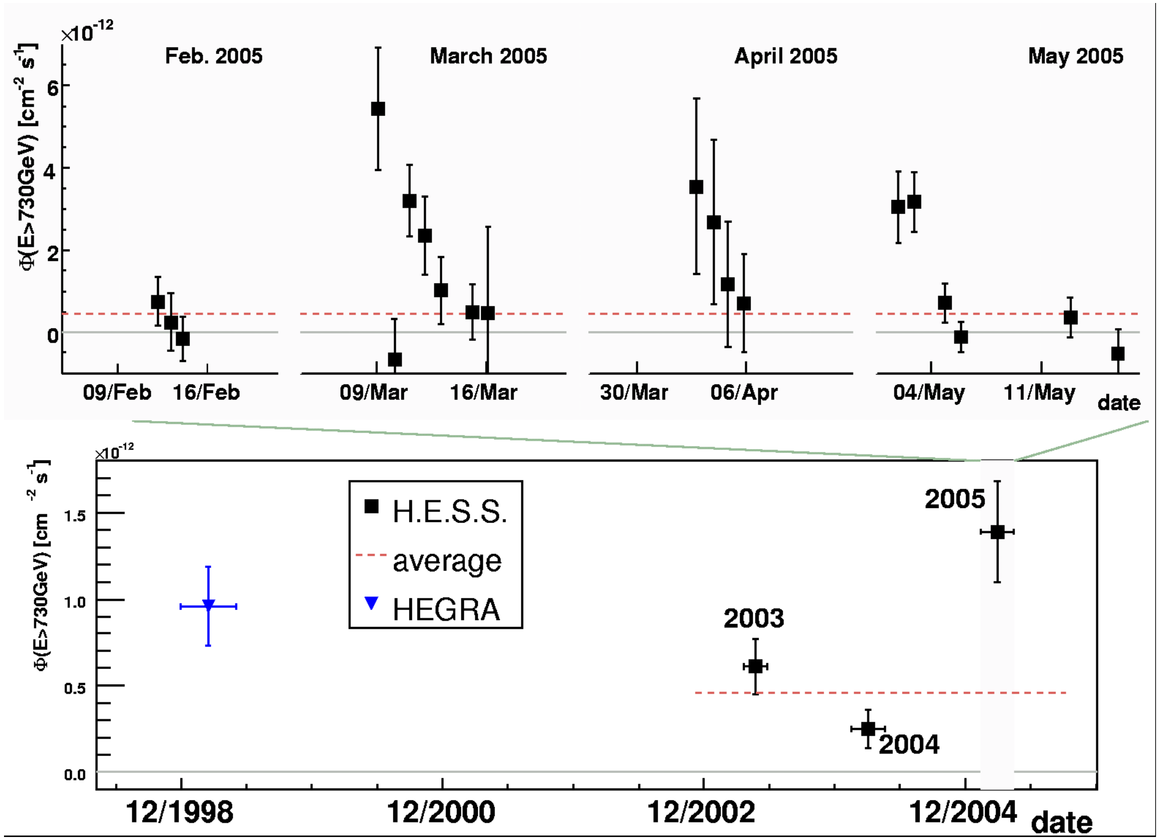
- Increase by a factor of 2.7 ± 0.7 in 30 minutes
- Decrease by a factor of 2.3 ± 0.9 in the next 30 minutes

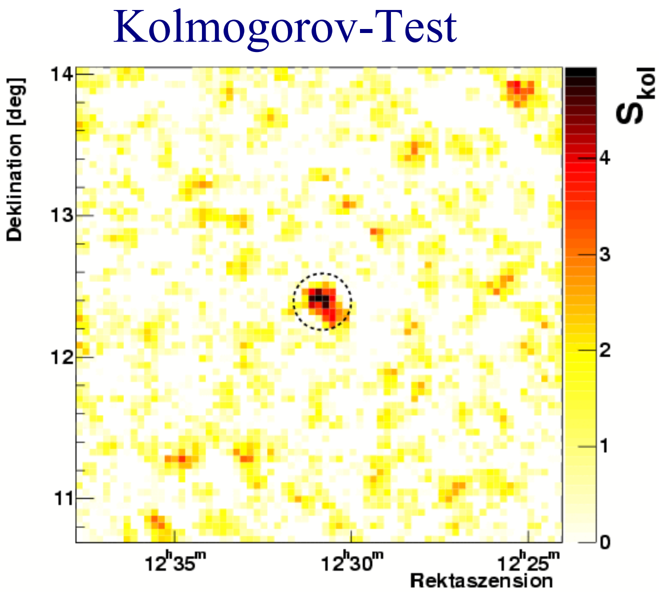


Generally Limited VHE Flux Variability

- **PKS 2005-489:**
  - Marginal indications that source was brighter in 2004 than 2003
  - No short-term (< 1 yr) flux or spectral variability in 2003 or 2004
  - ~60 hrs of good quality H.E.S.S. data in 2005 (source detected)
- **H 2356-309:**
  - No short-term flux or spectral variability in 2004 data
  - ~60 hrs of good quality H.E.S.S. data in 2005 (source detected)
- **1ES 1101-232:**
  - No flux or spectral variability on any time scale (2004 & 2005 same)
  - ~15 hrs of unknown quality in 2006 (source detected)
- **PG 1553+113:**
  - No evidence for short-term variability in 2005 H.E.S.S. data
  - ~10 hrs of unknown quality in 2006 so far... (source detected)
  - MAGIC: Factor of 3 in flux between 2005 & 2006 (astro-ph/0606161)

> 730 GeV Flux Variability from M 87





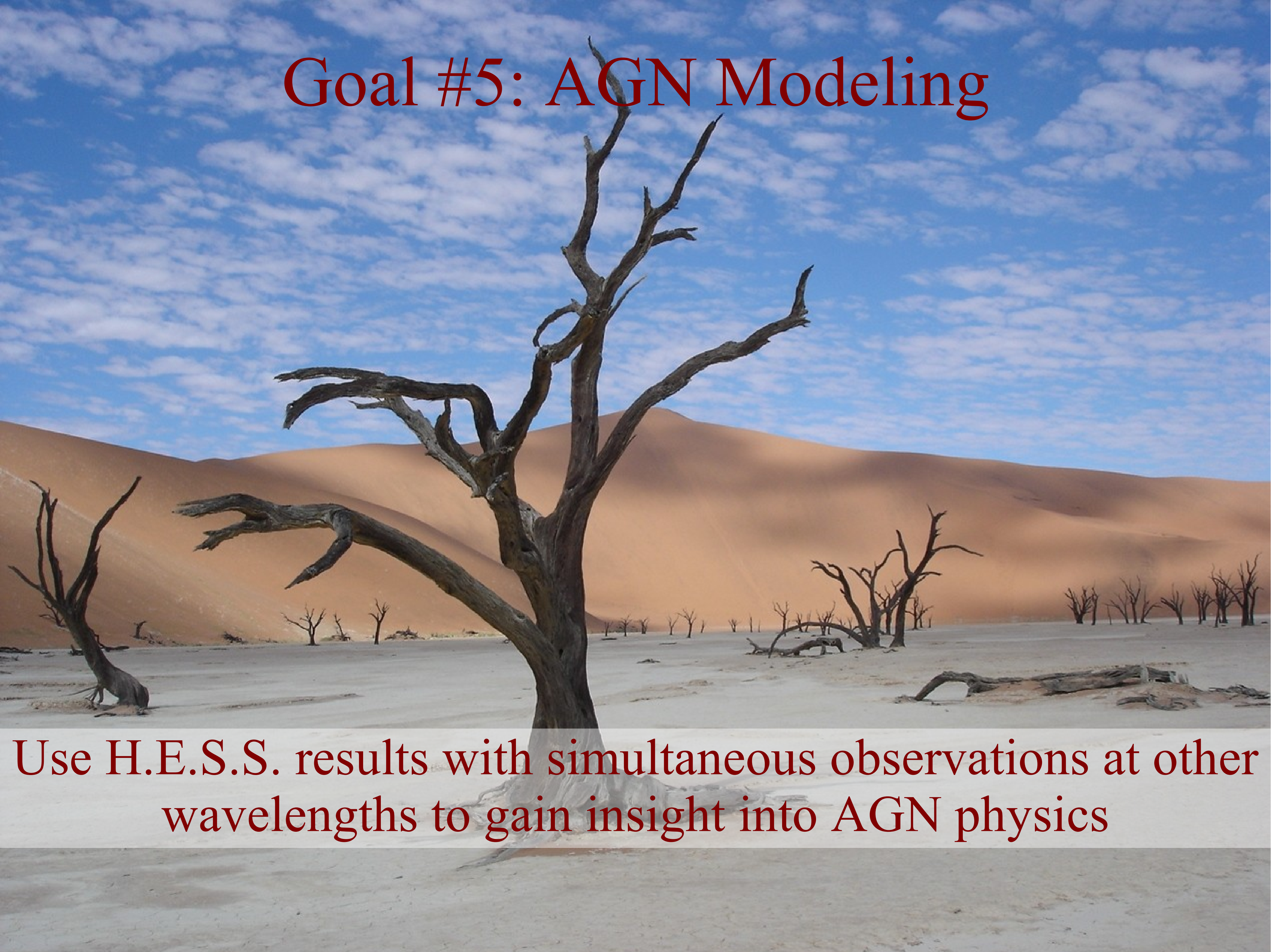
Apply Kolmogorov test to distribution of photon arrival times: 4σ variability

Fit a constant to annual HESS data: 3.2σ variability

Surprise: Fit of a constant to 2005 nightly flux shows >4σ variability

Fast variability, hard spectrum & point-like emission from core is very difficult to model: Excludes most!

Goal #5: AGN Modeling



Use H.E.S.S. results with simultaneous observations at other wavelengths to gain insight into AGN physics

AGN Multi-wavelength Campaigns

Blazars highly variable

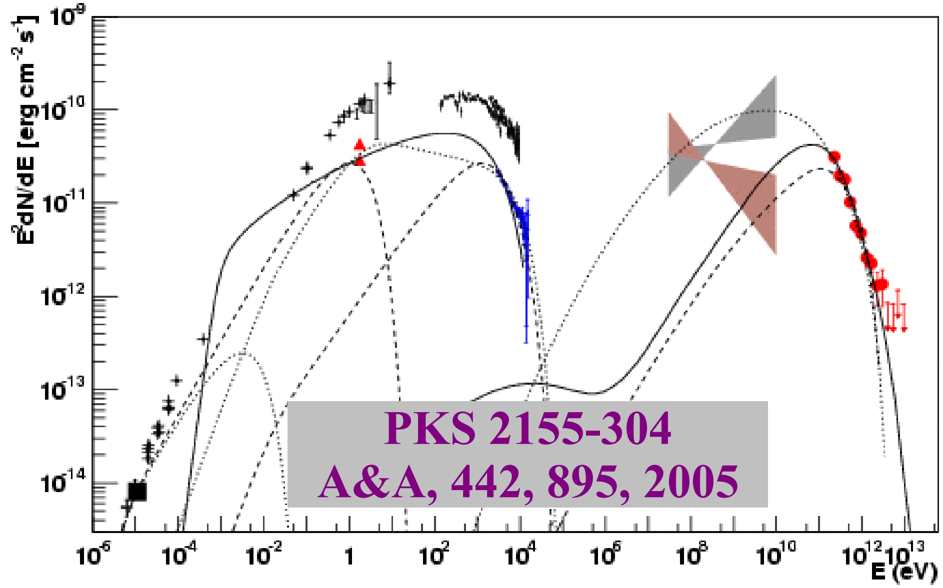
- Complications using VHE data to model archival measurements

Need: Simultaneous radio, optical, X-ray & VHE observations

- Model the SED
- Search for correlated variability & orphan flares

H.E.S.S. has 12 total (so far...)

- 3 for PKS 2155-304
  - 2 XTE, 1 XTE + Spitzer
- 3 for PKS 2005-489
  - 1 XTE, 2 XMM
- 3 for 1ES 1101-232
  - 1 XMM, 1 XTE, 1 Suzaku
- 2 for H 2356-309
  - 1 XTE, 1 XMM
- 1 for Mkn 421 (MAGIC & Suzaku)



Leptonic (dashed & dotted lines) & Hadronic (solid line) models

1 more scheduled for 2006:

- PG 1553+113 with Suzaku, MAGIC & H.E.S.S.

Several ToO proposals:

- Chandra, XTE, Suzaku

PKS 2155-304 MWL Campaign

Simultaneous observations in October & November 2003

- VHE: H.E.S.S. (2-tels.)
- X-ray: RXTE
- Optical: ROTSE
- Radio: NRT

Clear flux variability

- VHE, X-ray, optical

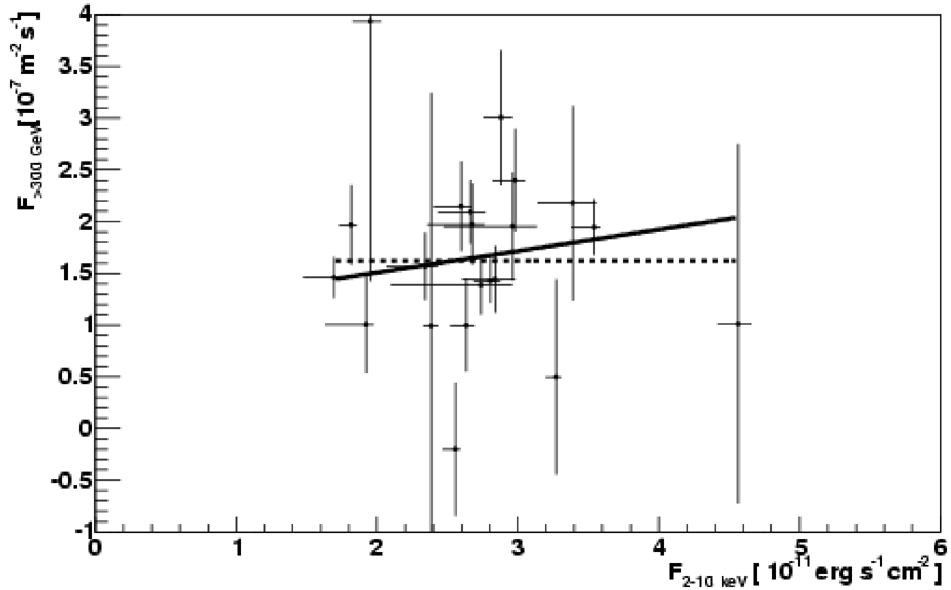
No evidence for correlated flux variability

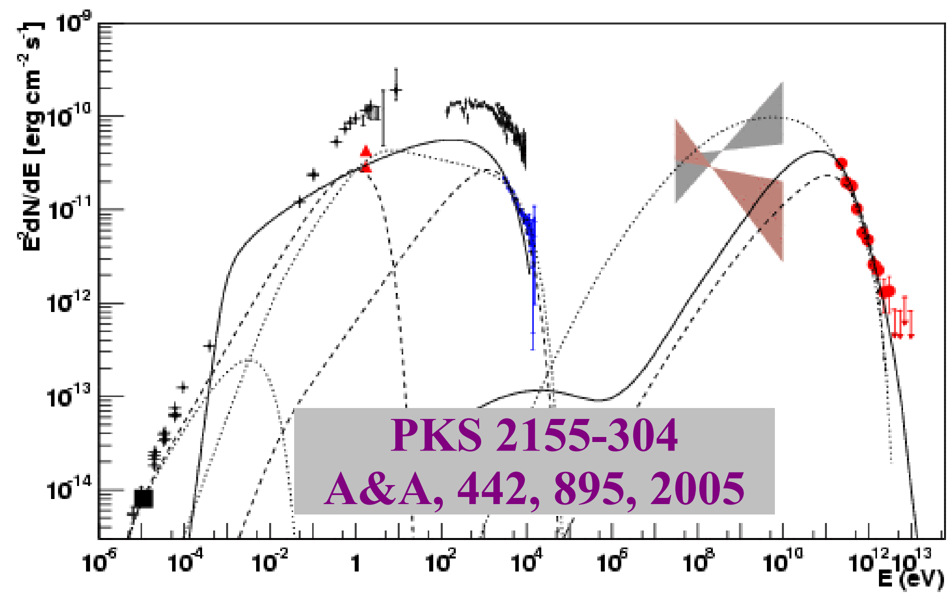
- Smaller data set (~11 hrs)

X-ray & optical fluxes are historical lows

Reasonable fits in hadronic & leptonic scenarios

- Parameters in normal ranges with low EBL level



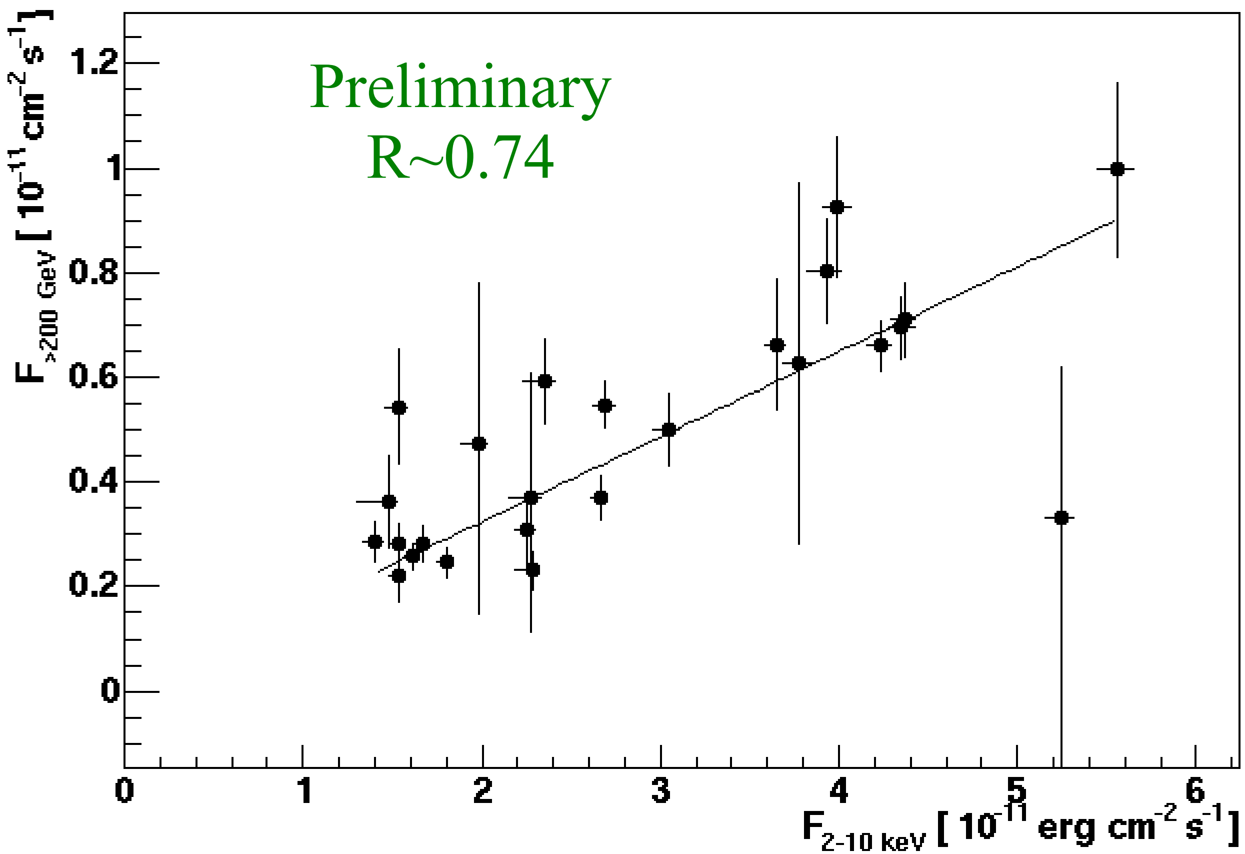


Leptonic (dashed & dotted lines) & Hadronic (solid line) models

MWL: Correlated X-ray/VHE Variability

Largest MWL campaign "ever" with VHE: PKS 2155-304 in 2004

H.E.S.S.: ~130 hours; RXTE, Spitzer, Radio, Optical

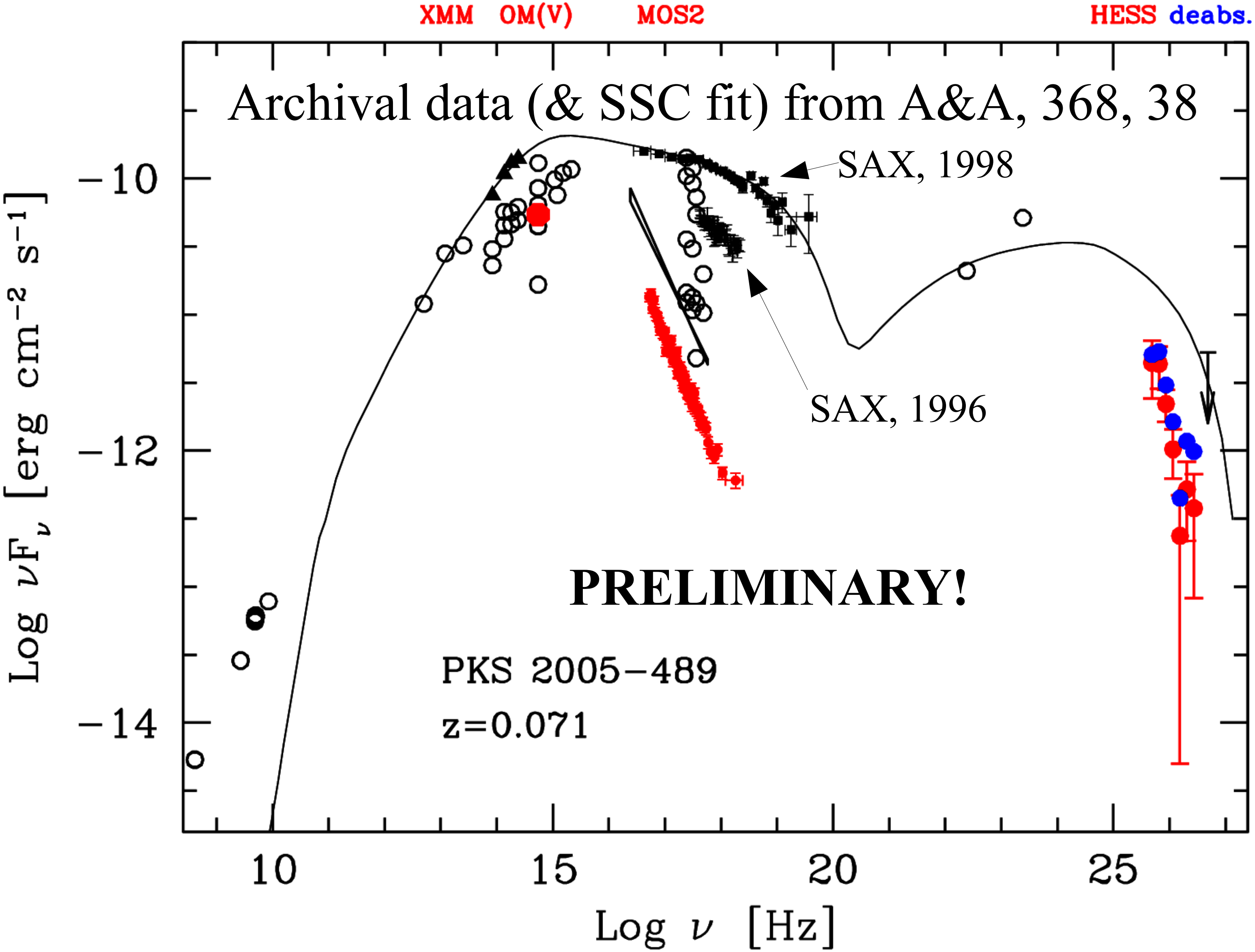


Clear indication for correlated X-ray/VHE flux variability

Only strictly simultaneous data shown!

Implies: Same particle population responsible for X-ray/VHE flux

PKS 2005-489 SED from 2004



X-ray & VHE spectra are steep!

XMM: Oct 4, 2004

Γ = 2.98 +/- 0.03

χ^2_{red} = 0.94 (150 d.o.f.)

H.E.S.S.: 2004

Γ = 4.0 +/- 0.4

Γ_{deabs} = 3.5 +/- 0.4

H.E.S.S. detection in lowest "ever" X-ray state!

No optical, X-ray, or VHE flux variability!

H 2356-309 MWL Campaign in 2004

VHE: H.E.S.S. (~40 hrs)
X-ray: RXTE (5.4 ks)
Optical:ROTSE
Radio: NRT

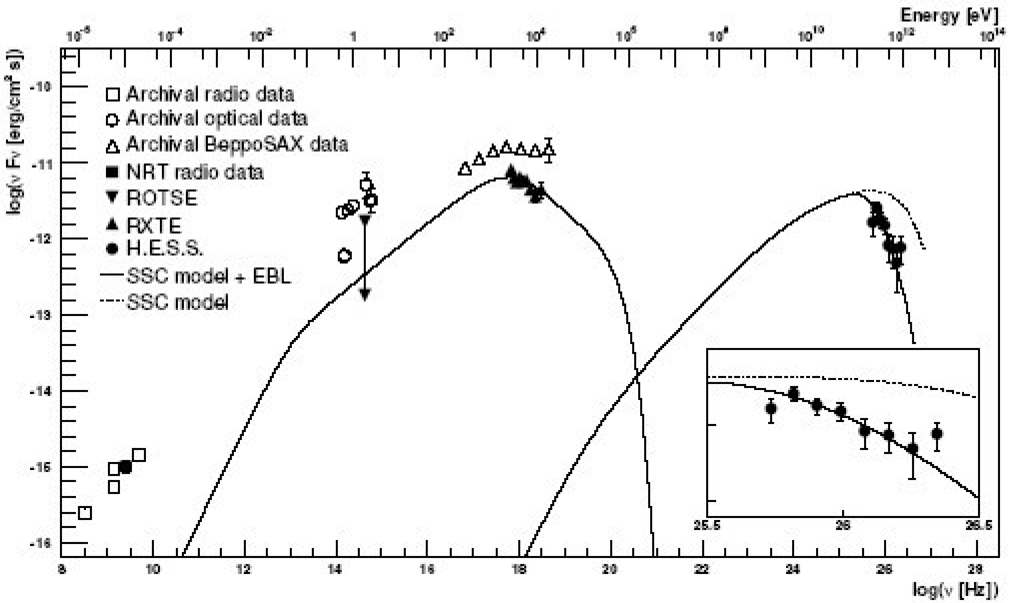
No VHE, X-ray, optical variability!

X-ray: Γ=2.43 ± 0.11

- Lowest flux & softest spectrum ever

Fit SED: A "simple", 1-zone, time-independent, homogeneous SSC model

- Radio from elsewhere
- Optical treated as UL



Reasonable parameters give good fit:

- Spherical emission region: R=3.4x10^{15} cm
- B = 0.16 G
- Doppler factor = 18
- Electron distribution = BPL

Aharonian et al., *A&A*, in press, 2006

Cooperation with MAGIC

VHE threshold increases with zenith angle

- Northern object => HESS LZA & MAGIC SZA; & vice versa

Use both instruments to simultaneously observe an object (e.g. Mkn 421):

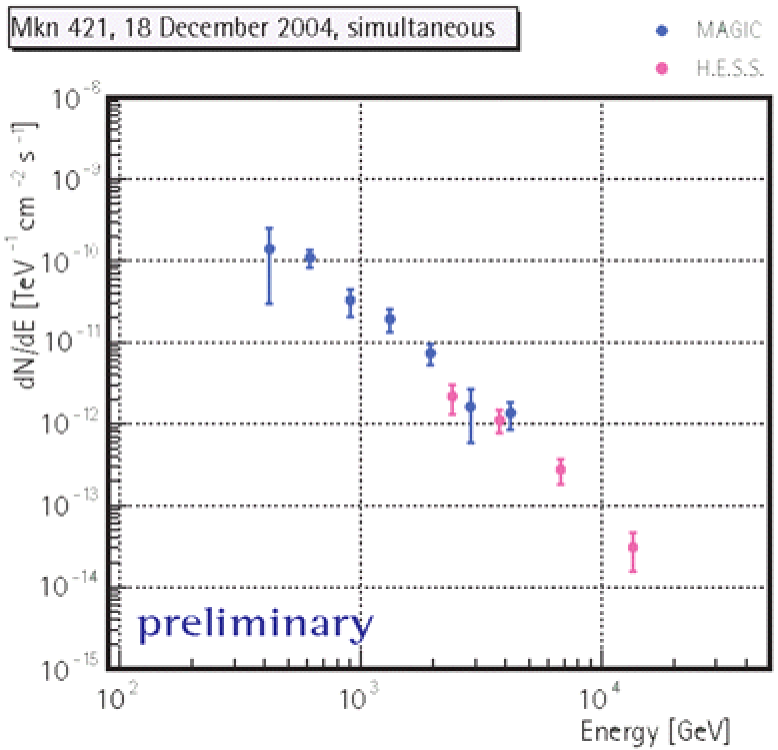
- Spectral measurement at different energy ranges
- Cross calibration

December 2004: Mkn 421 met proposed trigger threshold (flux)

- ~1 hr of simultaneous obs.

Agreement to perform similar campaign on other objects:

- PG 1553+113 in July 2005



D. Mazin et al., poster at 29th Int. Cosmic Ray Conf., Pune, 2005

Another ~2 hr Mkn 421 campaign in April 2006 also with Suzaku!

2006 AGN Program

Monitor known VHE AGN (10 hrs each)

"All" C&G HBL ($\delta < 20^{o}$, 10 hrs each)

- New candidates (new surveys & larger z)

Extend VHE classes

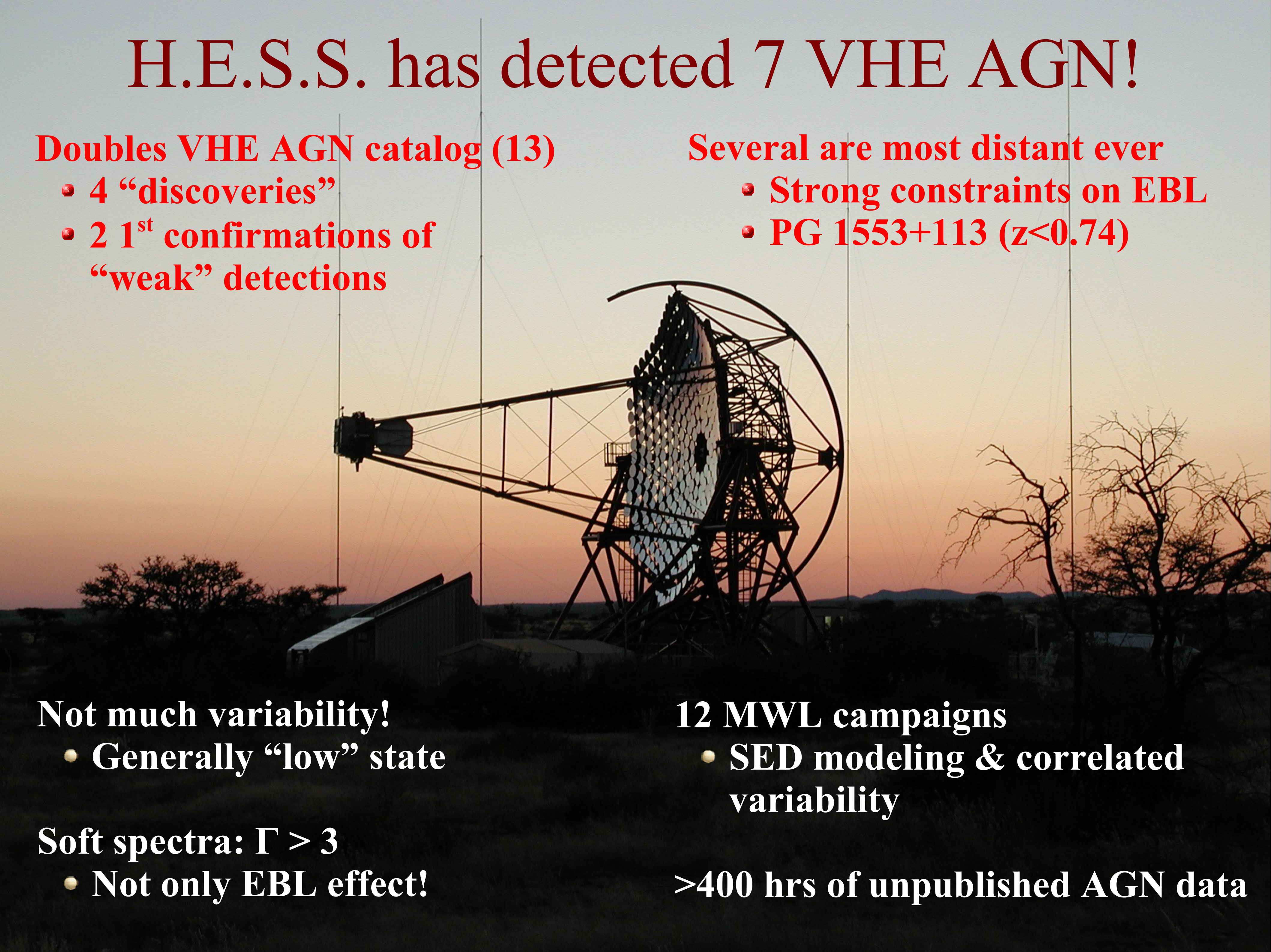
- 3 Seyfert galaxies (10 hr each)
- 3C 273 (FSRQ, 30 hrs)
- Pictor A (FR I, 30 hrs)
- Cen A (FR I, 50 hrs)

New ideas (10 hrs each):

- Some EGRET LBL, a unique IBL, a unique HFSRQ

Continue MWL efforts

H.E.S.S. has detected 7 VHE AGN!



Doubles VHE AGN catalog (13)

- 4 “discoveries”
- 2 1st confirmations of “weak” detections

Several are most distant ever

- Strong constraints on EBL
- PG 1553+113 (z<0.74)

Not much variability!

- Generally “low” state

Soft spectra: $\Gamma > 3$

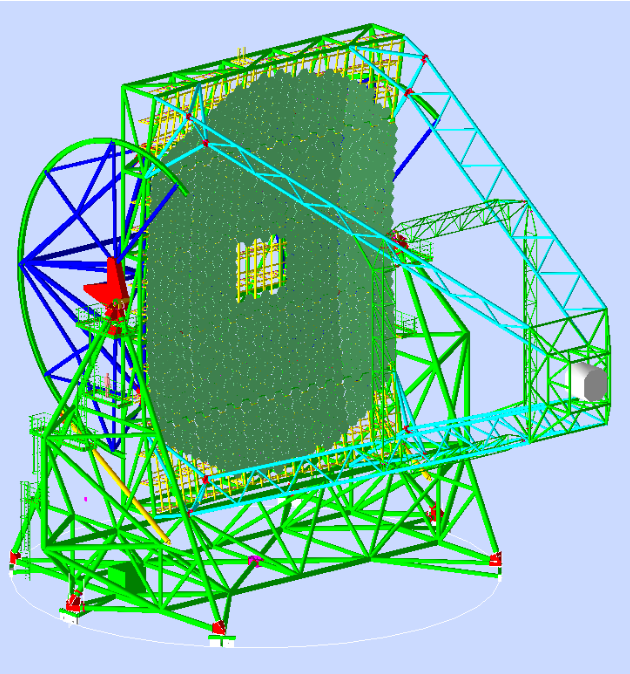
- Not only EBL effect!

12 MWL campaigns

- SED modeling & correlated variability

>400 hrs of unpublished AGN data

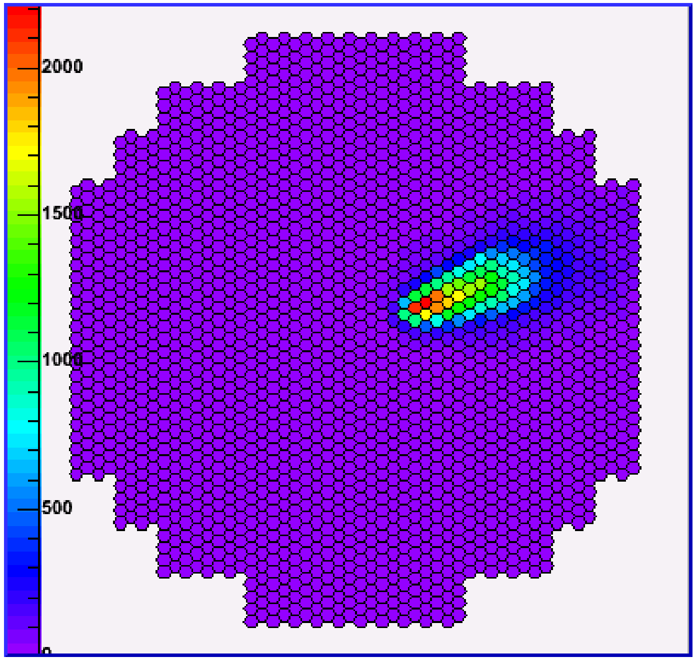
The Future: H.E.S.S. Phase-II



- Diameter = 30 m
- Focal length = 36 m
- Rigid steel structure: ~560 tons

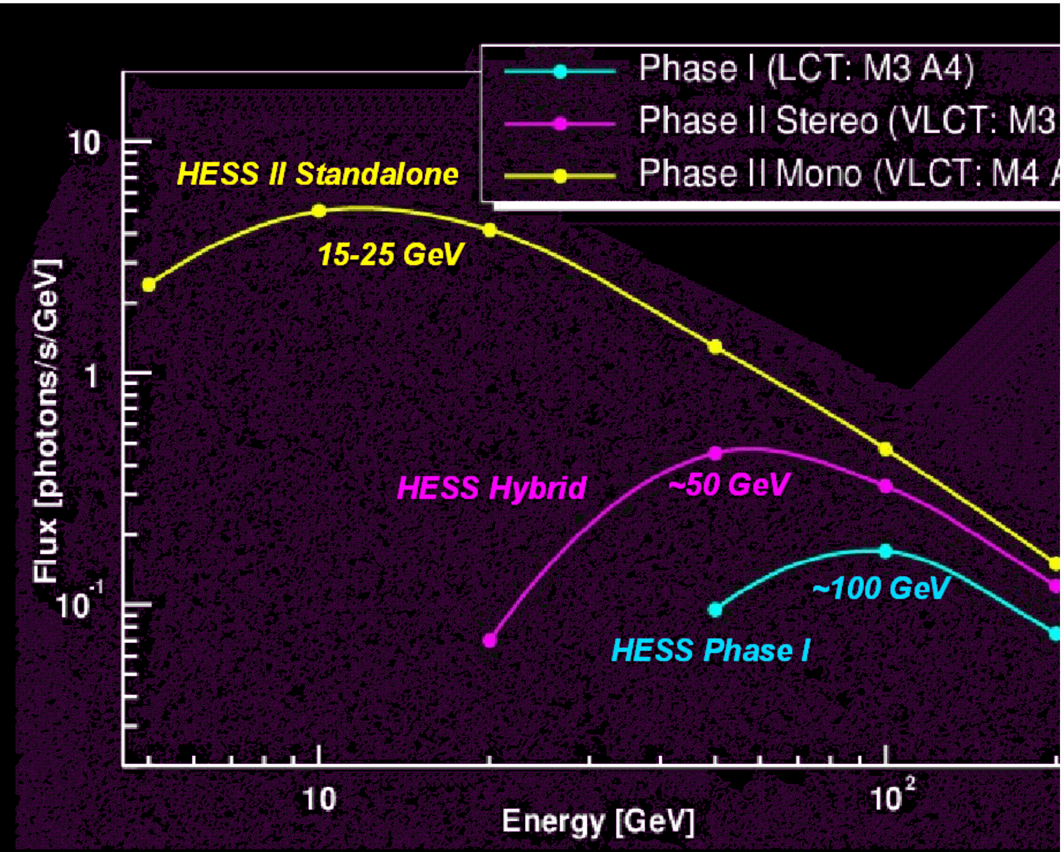
- 851 mirrors
- Mirror area = ~600 m^2

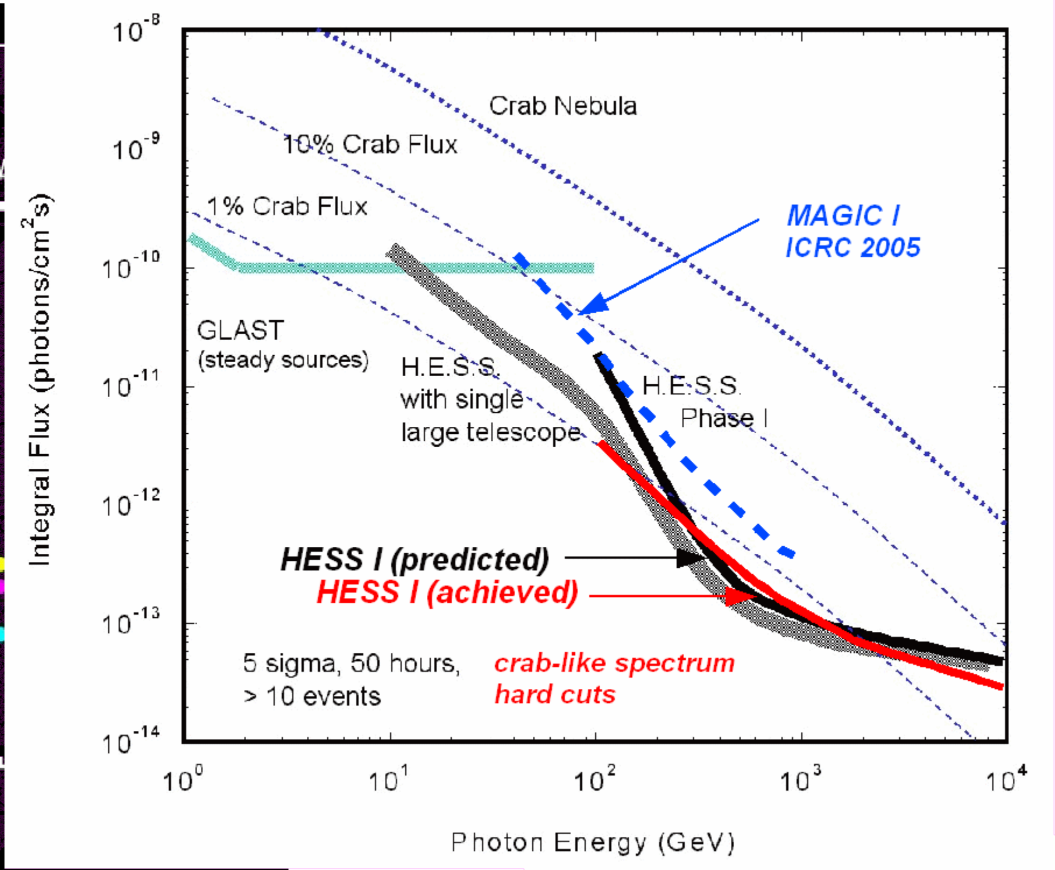
- 2048 pixel camera
- Pixel size: 0.07°
- 3.6° field of view



Telescope: 2007; Camera & Mirrors: 2008; Data: 2009

Phase II: Threshold & Sensitivity





Let's see and learn

Guaranteed new window

Improved Sensitivity

Thank you for your time!

How does H.E.S.S. detect high-energy gamma rays?