EAS Arrays

- Provide synoptic view of the sky
- See an entire hemisphere every day
- Large fov & high duty cycle
  - Gamma ray bursts
  - Transient astrophysics
  - Extended objects
  - New sources
- Excellent complement to GLAST
  - With >1000 sources need an all-sky instrument in VHE
- Current EAS arrays lack sensitivity to complement GLAST
- What can be done?
  - Need low threshold (GLAST overlap) < 100 GeV
  - High sensitivity
Existing Arrays

- **Milagro**
  - Dense sampling
  - Moderate altitude (2650m)
  - Background rejection

- **Tibet Array**
  - Sparse sampling
  - High altitude (4300m)
  - No background rejection

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Milagro TeV Sky Map


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5.9 $\sigma$ detection at (79.8°, 26°) using 2.9° bin
Angular extent 0.8° ± 0.4°

5.5 $\sigma$ detection at ~(308°, 42°) using 5.9° bin
Brightest region in Northern hemisphere (EGRET)
GRBs: High Energy Emission

GRB 970417a – Milagrito
10^{-3} chance probability
>650 GeV photons
HAWC
High Altitude Water Cherenkov

- 200m x 200m water Cherenkov detector
- Two layers of 8” PMTs on a 2.7 meter grid
  - Top layer under 1.5m water (trigger & angle)
  - Bottom layer under 6m water (energy & particle ID)
  - ~11,000 PMTs total (5,000 top and 5,000 bottom)
  - Trigger: >50 PMTs in top layer
- Two altitudes investigated
  - 4500 m (~Tibet, China)
  - 5200 m (Atacama desert Chile)
Event Reconstruction

Angular resolution ~0.75 degrees
Background Rejection Bottom Layer

Gammas

30 GeV (a)
70 GeV (b)
230 GeV (c)

Protons

20 GeV (d)
70 GeV (e)
270 GeV (f)

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Background Rejection

Uniformity Parameter
nTop/cxPE > 4.3
Reject 70% of protons
Accept 87% of gammas
1.6x improvement in sensitivity
D.C. Sensitivity: Galactic Sources

- Crab Spectrum: $\frac{dN}{dE} = 3.2 \times 10^{-7} E^{-2.49}$
  - Milagro 0.002 (0.001) Hz raw (cut) rate
  - HAWC 0.220 (0.19) Hz raw (cut) rate
  - Whipple 0.025 Hz
  - VERITAS 0.5 (0.12) Hz raw (cut) rate
- Background rate 80 (24) Hz raw (cut)
- $4 \sigma/\sqrt{\text{day}}$ raw data
- $6 \sigma/\sqrt{\text{day}}$ cut data
  - $120 \sigma/\sqrt{\text{year}}$
- 40 mCrab sensitivity (all sky) in one year
  - Whipple: 140 mCrab per source
  - VERITAS: 7 mCrab per source (15 sources/year)
Gamma Ray Burst Sensitivity

50 events

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Gamma Ray Burst Sensitivity

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Point Source Sensitivity

Flux Sensitivity of Gamma-Ray Telescopes

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Time Domain Sensitivity

Solid Angle/Sensitivity

FOV (sr) / Sensitivity (Crab Units)

COS-B  EGRET  GLAST  Whipple  Veritas  Milagro  HAWC

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Conclusions

- Water Cherenkov technology has been proven with Milagro
- An EAS array with > 20x the sensitivity of Milagro can be built
- A sensitive EAS array is needed to extend GLAST measurements to >100 GeV energies
- Detect prompt emission from GRBs above 100 GeV (~10/year)
  - Provide valuable information on maximum energy of GRB
  - Better sensitive than GLAST above 50 GeV
- Monitor AGN flaring above 100 GeV
- Explore time-domain astrophysics in VHE band
- Discover extended sources at VHE energies
- Discover new VHE sources
Gamma-Ray Telescopes

High Sensitivity
Whipple(1965)/VERITAS(2006, $18M)

Low Energy Threshold
EGRET/GLAST(2007 $330M)

Large Aperture/High Duty Cycle
Milagro(2000)/HAWC(2010?, $30M?)

Large Effective Area (~100,000 m²)
Excellent Background Rejection (>99%)
Low Duty Cycle/Small Aperture

Space-based (small area)
“Background Free”
Large Duty Cycle/Large Aperture

Sky Survey (<10 GeV)
1000’s of AGNs
Transients (GRBs) <100 GeV
Dark Matter & Quantum Gravity

Moderate Area/Large Area (HAWC)
Good Background Rejection
Large Duty Cycle/Large Area

Sky Survey > 3 TeV/100 GeV
New Sources
Transients (GRB’s) > 100 GeV/20 GeV
Time Domain VHE Astrophysics

Studies of known sources
Distribution of Excess in the Cygnus Region:

Gaussian Weighted Excess

2 regions of excess give rise to the observed signal.
Excess Coincident with EGRET source 3EG J0520+2556

3EG J0520+2556

Source Reported twice before by Milagro:

1) APS Meeting: April 2002
   Reported as a Hot Spot. A Larger than optimal bin size was used in that initial survey.

2) Location of one of the top excesses in our published point source All Sky search.

5.5 σ detection at (79.8°, 42°) using binsize= 2.9°

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EGRET Unidentified Source 3EG 0520+2556

Distribution of the significance of measured excesses for the entire northern sky (Crab and Mrk421 regions removed)
Tail due to excess coincident with 3EG J0520+2556.

Growth of Excess vs days of exposure.
No evidence of flaring or episodic emission.

Binsize = 2.9°

Distribution of sigmas with Crab and Mrk 421 regions removed. The E0520 excess contributes the tail to the Gaussian distribution.

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3EG 0520_2556 Before and After Initial Report

(465 days of exposure)

Before: 4.4σ
After: 3.7σ peak at 4.4σ

12/10/2001 – 05/05/2004
(840 days of exposure)

Data reported on at April 2002 APS Meeting.

Independent data set collected since the 2002 report.

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GRB 941017 (pre-Milagro)

- This burst is the first observation of a distinct higher energy spectral component in a GRB
- Lower energy component decays faster than higher energy component
- Peak of higher energy component is above the energy range of the detector
- Power released in higher energy component is more than twice the lower energy component
Theories of the High Energy Component of GRB941017

- Requires GRBs to more energetic phenomena
- Different timescale of low and high energy implies an evolving source environment or different high energy particles
- Shape of high energy component applies tight constraints to ambient densities and magnetic fields
- Or evidence of origin of Ultra High Energy Cosmic Rays
- More high energy observations are needed

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Pe’er & Waxman (astroph/0310836) constrain source parameters for Inverse Compton emission of GRB941017

Milagro Sensitivity

\( z = 0.2 \)

\( z = 0.02 \)
The Need for HAWC

• GLAST
  – Will discover 1000’s of sources
  – Many variable
  – ACTs can monitor ~15/year at stated sensitivity
• GRBs
  – Detect highest energy photons in prompt phase
• AGNs
  – Detect/Monitor AGN at redshift < 0.3
  – Study AGN transients in VHE regime
  – Populations studies
• Fundamental Physics
  – Lorentz violation at high energies (quantum gravity?)
  – Dark matter
• VHE sky surveyed to 40% of Crab flux
  – Sensitive Sky Survey < 1% of Crab flux
• Time Domain Astrophysics in the VHE Regime
  – Extreme states of extreme systems
Effect of Altitude

Approximation B

Low Energy Threshold Requires High Altitude

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Energy Distribution After EBL
AGN Sensitivity

1 Year

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Site Visit: YBG 4/1-6

- Excellent location
  - Land available
  - many km² available at 4300m
  - Room at ~4800m
  - Power available (3 MWatts generated in YBJ)
  - Water available
  - Dormitories (“Western rooms”)
- Existing gamma ray detectors
  - ASγ array
  - ARGO detector
Site Visit: IHEP Beijing

- Scientists excited by project (IHEP and Tibet University)
  - Would like full-scale collaboration
  - Have experience with ASγ and ARGO
- IHEP Director Hesheng Chen enthusiastic about project
  - Committed to provide land, power, water, and people
    - Will provide letter to NSF on request
  - Funds for infrastructure (building, etc) can not be promised at this time
    - They paid ~$2M for ARGO building/infrastructure
CORSIKA: Energy Resolution

Primary Energy vs. Number of Particles

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CORSIKA: Energy Resolution

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CORSIKA: Energy Resolution

Delta E/E (>50 GeV)

- ede50
  - Entries: 5098
  - Mean: 0.006335
  - RMS: 0.4522
  - $\chi^2 / \text{ndf}$: 139.9 / 26
  - Constant: 3862 ± 79.5
  - MPV: -0.2811 ± 0.0042
  - Sigma: 0.137 ± 0.002

Delta E/E (>300 GeV)

- ede300
  - Entries: 343
  - Mean: -0.04854
  - RMS: 0.2725
  - $\chi^2 / \text{ndf}$: 36.03 / 14
  - Constant: 349.1 ± 27.0
  - MPV: -0.2289 ± 0.0123
  - Sigma: 0.09641 ± 0.00565

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Background Rejection

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EAS Particle Content

Low Energy Threshold Requires Detection of Gamma Rays in EAS

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Detecting Extensive Air Showers

**Air Cherenkov Telescope**
- Low energy threshold (300 GeV)
- Good background rejection (99.7%)
- Small field of view (2 msr)
- Small duty cycle (< 10 %)

**Extensive Air Shower Array**
- High energy threshold (100 TeV)
- Moderate background rejection (50%)
- Large field of view (~2 sr)
- High duty cycle (>90%)

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HAWC Performance Requirements

- Energy Threshold < 50 GeV
  - GRBs visible to redshift ~1
  - Near known GRB energy
  - AGN to redshift ~0.3
- Large fov (~2 sr) / High duty cycle (~100%)
  - GRBs prompt emission
  - AGN transients
  - Time domain astrophysics in VHE regime
- Large Area / Good Background Rejection
  - High signal rate
  - Ability to detect Crab Nebula in single transit
- Moderate Energy Resolution (~40%)
  - Measure GRB spectra
  - Measure AGN flaring spectra
Event Reconstruction

Particle Arrival Time Distribution vs. Core Distance

Particle Arrival Time Distribution vs. Energy

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Angular Resolution
Energy Distribution of Fit Events

Median Energy 180 GeV
(Milagro ~3 TeV)
Effect of EBL on Distant Sources

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