TeV Future: APS White Paper

APS commissioned a white paper on the "Status and Future of very high energy gamma ray astronomy. For preliminary information, see http://cherenkov.physics.iastate.edu/wp

Working Groups and leaders:
- Extragalactic - Henric Krawczynski
- Dark Matter - Jim Buckley (WU)
- Gamma-ray Bursts - Abe Falcone & David Williams
- Galactic Diffuse Emission, SNR, and Cosmic Rays - Martin Pohl
- Galactic Compact Objects - Phil Kaaret
- Technology - Karen Byrum

Editorial Board: B. Dingus, H. Krawczynski, M. Pohl, V. Vassiliev, F. Halzen, W. Hofmann, S. Ritz, T. Weekes
Science case being developed through working group interaction and through a series of open meetings

- “Ground-based Gamma-ray Astronomy: Towards the Future”, Oct. 20-21, 2005, Malibu (UCLA)
- “Ground-based Gamma-ray Astronomy: Towards the Future”, May 11-12, 2006, Santa Fe (LANL)
- Satellite meeting at GLAST Symposium, Feb 8, 2007, Palo Alto, CA
Findings

- **F1** - Field was invigorated by initial 1989 detection of Crab nebula, followed by steady progress through finding ~10 new sources throughout 15 years (primarily AGN). In the past ~3 years, the discovery potential has really been shown with ~75 new sources of varying classes, which probe new physics and astrophysics.
Past/Current Success

- Whipple 10m
- Cat
- HEGRA
- MAGIC
- STACEE
- CANGAROO
- H.E.S.S.
- CELESTE
- Milagro
- Tibet AS
- Solar Two
- VERITAS

MAGIC
HEGRA
Motivation

Source classes: Shell-type SNR, PWN, Binary Systems, Star Cluster, Diffuse Emission, Galactic Center, Blazars, Radio Galaxies, Unidentified Sources

Astrophysics topics: nonthermal particle populations, magnetic fields, neutron stars, black holes, jets, dark matter, astroparticle physics.
Findings

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• **F2** - From the plethora of new sources, it is clear that sensitivity improvements could lead to fundamental contributions of TeV astronomy to i) studies of cosmic rays, both galactic and UHE, ii) darkmatter, iii) cosmic history of super-massive black holes and studies of jet formation, iv) stellar mass black holes and binary systems and therefore star formation history and GRBs
Motivation

Extragalactic:
AGN Jets, EBL
Cosmic rays in other galaxies and galaxy clusters

SNR & Cosmic Rays:
Are SNR the dominant source of Cosmic Rays up to $10^{15}$ eV?

Galactic Compact Objects:
Accreting stellarmass black holes

GRBs:
Do GRBs accelerate UHECRs
Probe Lorentz factor and optical thickness.

Dark Matter:
Detect annihilation gamma-rays.
Findings

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- **F2** - From the plethora of new sources, it is clear that sensitivity improvements could lead to fundamental contributions of TeV astronomy to i) studies of cosmic rays, both galactic and UHE, ii) dark matter, iii) cosmic history of super-massive black holes and studies of jet formation, iv) stellar mass black holes and binary systems and therefore star formation history and GRBs.
- **F3** - Large-scale gamma ray observatory would substantially increase science return from existing/planned observatories such as GLAST, LOFAR, LSST, IceCube, ANITA, LIGO, LISA, ...
- **F4** - TeV astronomy was pioneered in the US. For the US to remain in a leadership role, it is mandatory to start the next generation now.
- **F5** - A new observatory, sensitive from 30 GeV - 100 TeV, would be most cost effective and could achieve ~10x sensitivity increase soon.
- **F6** - Imaging Air Cherenkov Telescopes (IACTs) and Water Cherenkov (WCAs) complement one another. IACTs have excellent instantaneous sensitivity and angular resolution, while WCAs can study diffuse objects and bright transients.
- **F7** - If funded adequately, US groups could lead the field.
Recommendations

• **R1** - Based on extrapolations from current instruments, an investment of ~$100M is required to achieve 10x sensitivity improvement that is required to guarantee a rich harvest of science from the existing discovery potential

• **R2** - Next generation observatory should consist of an imaging air Cherenkov array component with 1 km² area, complemented by water Cherenkov array

• **R3** - Timely construction of IACT array requires R&D now

• **R4** - A site, with expansion potential, should be chosen now. It should allow observations of the Galactic center and a significant fraction of the Northern Hemisphere

• **R5** - U.S. should intensify collaboration with European and Japanese colleagues, and should consider option of combining efforts

• **R6** - Broad impact strategies should be considered at all phases of development, and in particular, the U.S. groups should have data access policies that engage full community. They should also involve young scientists to train the future generation, and maintain active outreach efforts
AGIS Design Goal

Differential flux sensitivity of an ideal km² telescope array sensitivity curve (courtesy S. Fegan)
Large IACT arrays

AGIS and CTA are being developed and proposed by US and European collaborations, respectively. Both of these concepts involve a large array of IACTs providing:

- km² effective area
- energy threshold down to ~40 GeV
- flux sensitivity down to $\sim 10^{-13}$ to $10^{-14}$ erg cm$^{-2}$ s$^{-1}$ (~10x better than VERITAS/HESS)
- 10% energy resolution
- angular resolution down to ~1-3 arcmin
Differential Sensitivity of km² IACT
EAS Approach

**HAWC**, a next generation version of Milagro, is also being proposed. This could provide:

- wide FOV -->
  - monitoring of bright sources
  - searches for bright transients
- Searches for diffuse emission
- High duty factor
- 10-15 times Milagro sensitivity
Integral Sensitivity of HAWC to Crab-like Point Sources

- Long integration times lead to excellent sensitivity at highest energies (> few TeV)
- 50 hr observation time assumed for IACTs, HAWC source transit 15° off zenith
- $5\sigma$ sensitivity to:
  - 10 Crab in 3 minutes
  - 1 Crab in 5 hours (1 transit)
  - 0.1 Crab in $\frac{1}{3}$ year
Conclusions

• Since the TeV detection of the Crab in 1989, there has been steady progress in the field, but in the past 3 years a quantum leap in sensitivity has shown that there is a huge region of unexplored discovery space in the TeV gamma ray sky.

• This could be exploited by building large IACT arrays to achieve point source sensitivity increases of ~10x (e.g. AGIS and CTA) with moderately increased FOV and lower energy threshold, while also building an all-sky monitor (e.g. HAWC) to explore the brighter transients and diffuse sources.

• If adequately funded, these efforts could be completed in ~5 years, placing the US in a leading position in the field.