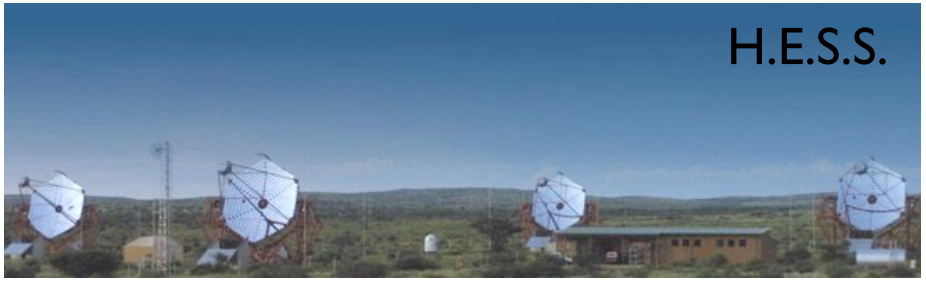
White Paper on the Status and Future of TeV γ-ray Astronomy

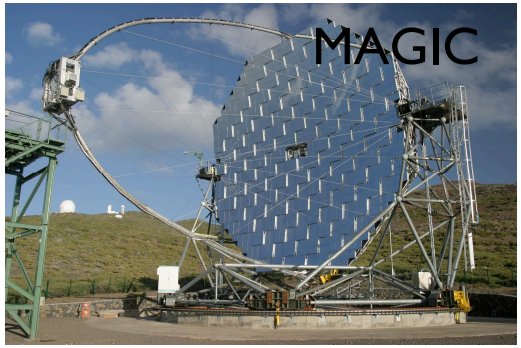
Henric Krawczynski (Washington University in St. Louis)
for the White Paper Team, November 8, 2007

Contents:

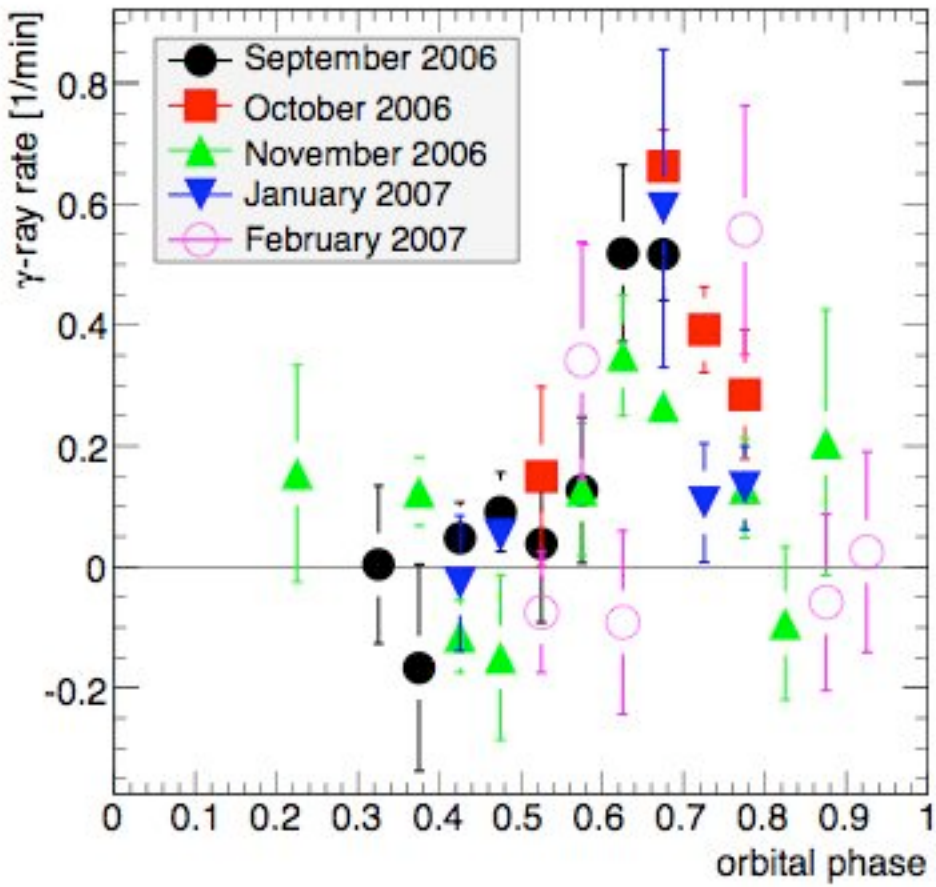
- Motivation and History of White Paper.
- Results of Working Groups.
- Discussion of Findings and Recommendations.

Motivation I





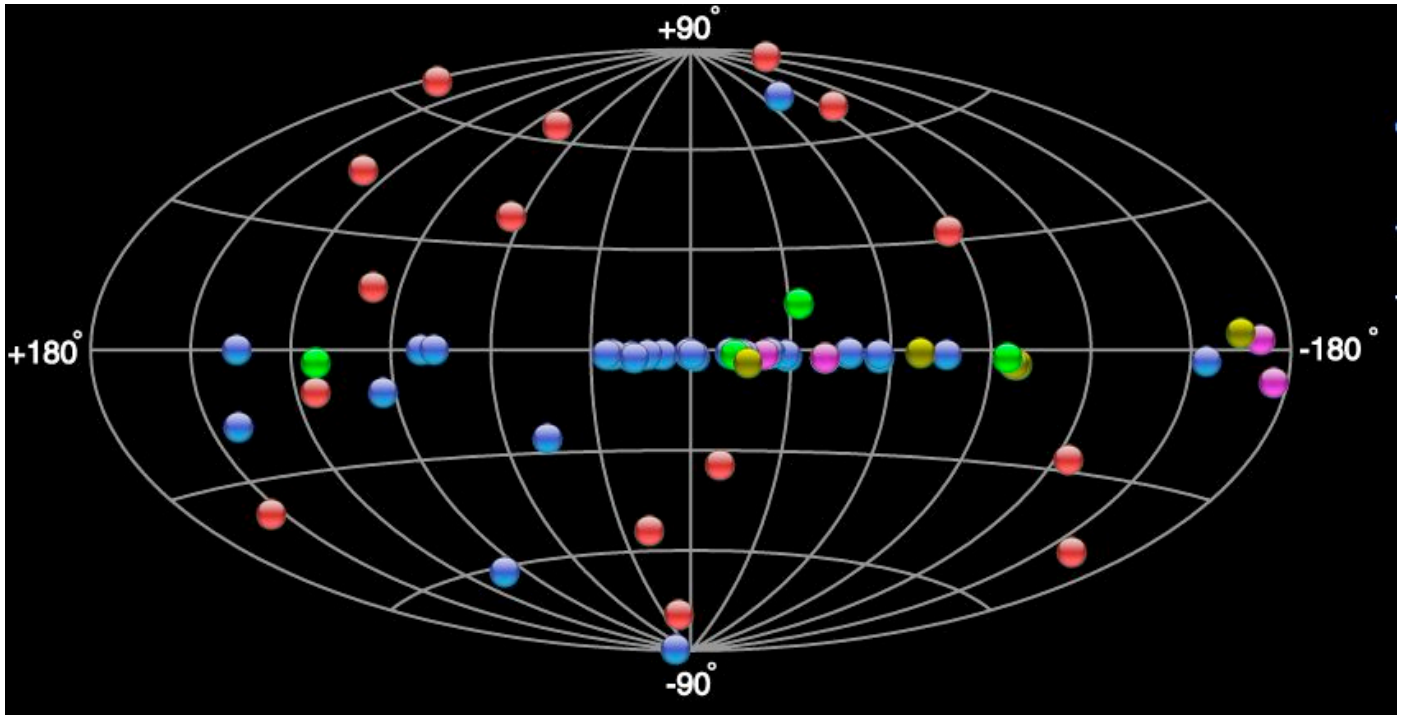
Current instruments meet and exceed high expectations.



VERITAS LSI +61 303

(Maier et al. 2007)

Motivation II



- AGN
- Unident. & Others
- Shell SNR
- PWN
- Microquasar, PSR

TeV sky map by Scott Wakely, Deirdre Horan 2007 (http://tevcat.uchicago.edu/)

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

Astroparticle physics topics: nonthermal particle populations, black holes, accretion physics and relativistic outflows, magnetic fields, neutron stars, dark matter…

Discussion of the Future of TeV γ-Ray Astronomy in the US

Workshops: "Ground-based Gamma-ray Astronomy: Towards the Future":

(1) October 2005, UCLA, Malibu (http://gamma1.astro.ucla.edu/future_cherenkov/)

(2) May 2006, LANL, Santa Fe (http://www.lanl.gov/orgs/p/g_a_d/p-23/gammaworkshop/)

(3) May 2007, Argonne, U. Chicago, Chicago (http://www.hep.anl.gov/byrum/next-iact/)

Objectives:

- Identify emerging science opportunities.
- Clear the way for next-generation experiment.
- Increase involvement of physics and astrophysics community.
- Exchange experience with international γ-ray community.

Initiatives resulting from meetings:

1.) White Paper. 2.) R&D Proposal. 3.) AGIS Collaboration.

White Paper on the Status and Future of Ground Based γ-Ray Astronomy

Commissioned by Division of Astrophysics of the American Physical Society APS in Sept. 2006.

Editorial Board: B. Dingus, H. Krawczynski, M. Pohl, V. Vassiliev, *F. Halzen, W. Hofmann, S. Ritz, T. Weekes*.

Charge:

- Summarize status and potential of γ-ray astronomy with input from all sectors of the astroparticle physics community.
- Describe path for proceeding beyond the near term.

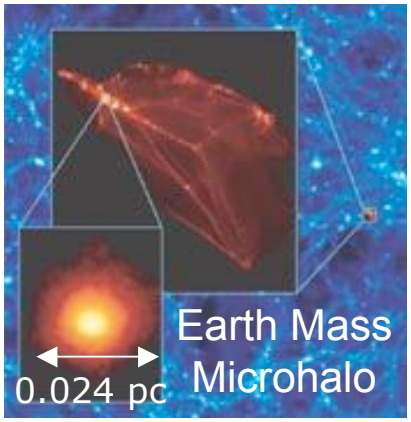
Activities of White Paper Team

- Formation of six working groups:
  - Dark Matter,
  - Compact Galactic Objects,
  - Supernova Remnants and Cosmic Rays,
  - Extragalactic (Non Gamma-Ray Bursts),
  - Gamma Ray Bursts,
  - Technical Working Group.
- Solicitationf of contributions from astroparticle physics community:
  - Via email & special sessions on meetings (First GLAST Symposium, Feb. 2007 (Palo Alto, CF), APS Meeting, April 2007 (Jacksonville, FL)).
- Writing of White Paper in 2006 & 2007:
  - Executive summary (in progress).
  - Detailed discussion (largely finished).
  - Appendices (Glossary…, tbw).

Highlights: Dark Matter

Dark Matter Group:

J. Buckley (chair), T. Baltz, G. Bertone, K. Byrum, B. Dingus, S. Fegan, P. Gondolo, J. Hall, D.Hooper, D. Horan, S. Koushiappas, S. LeBohec, M. Pohl, S. Profumo, J. Ryan, J. Silk, V. Vassiliev, S.P. Wakely, M. Wood, G. Zaharijas.



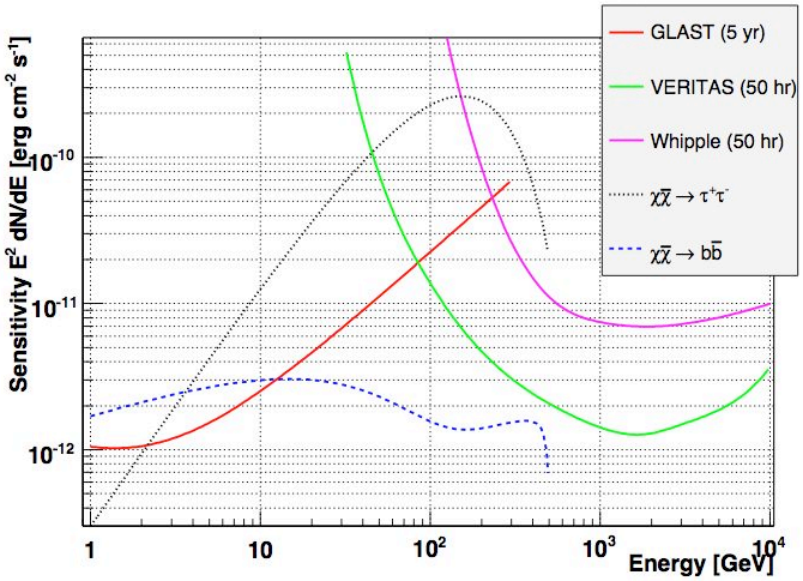
Diemand, Moore, & Stadel, 2005

Unique strength of γ-ray observations:

- Detect dark matter in astrophysical context (microhaloes, galactic substructure, dwarf galaxies, galaxy clusters).

Preferred detection techniques:

- Continuum emission: GLAST & Cherenkov Telescopes.
- Line emission: Cherenkov Telescopes.

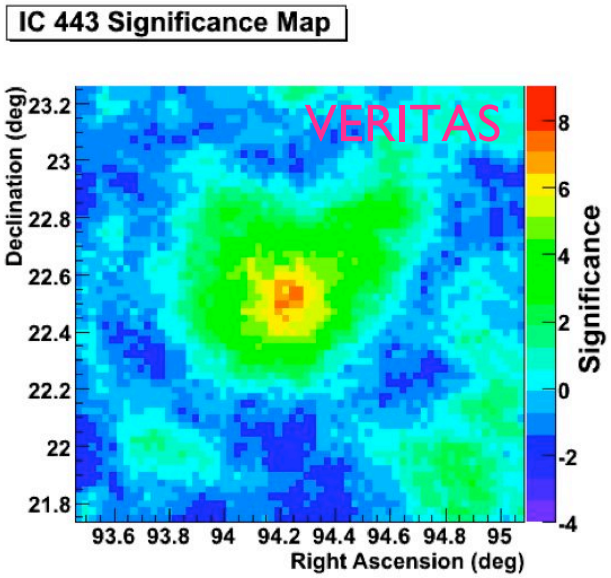


Simulated signal from Globul. Cluster M15

Highlights: Galactic Science

SNR & Cosmic Rays:

M. Pohl (chair), A. Abdo, A. Atoyan, M. Baring, R. Blandford, Y. Butt, D. Ellison, S. Funk, F. Halzen, L. Hays, B. Humensky, T. Jones, P. Kaaret, D. Kieda, S. LeBohec, P. Meszaros, I. Moskalenko, A. Strong, S. Wakely, E. Waxman



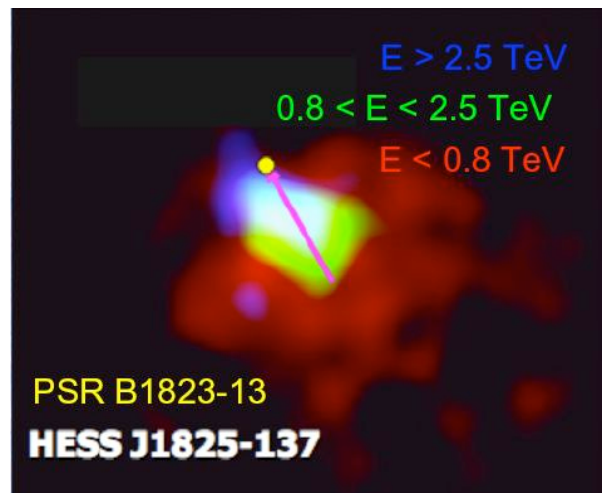
Humensky et al. 2007

SNR Observations.

- Arcmin angular res. observations.
- Census of γ-ray emitting SNRs.

Compact Objects Group:

P. Kaaret (chair), A. Abdo, J. Arons, M. Baring, W. Cui, B. Dingus, J. Finley, S. Funk, S. Heinz, B. Gaensler, A. Harding, E. Hays, J. Holder, D. Kieda, S. LeBohec, A. Levinson, R. Mukherjee, R. Ong, M. Pohl, K. Ragan, P. Slane, A. Smith



Aharonian et al. 2006

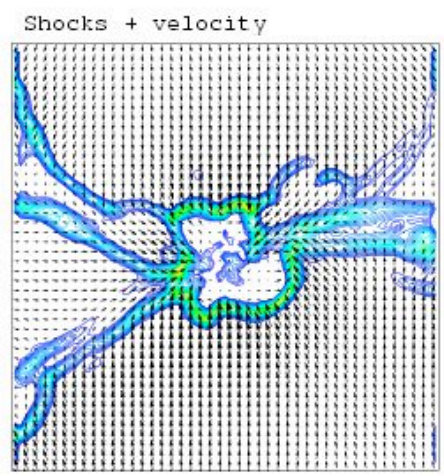
PWN, X-ray binaries: particle acceleration by relativistic winds and jets. TeV Archeology.

Highlights: Extragalactic Science (Non-GRBs)

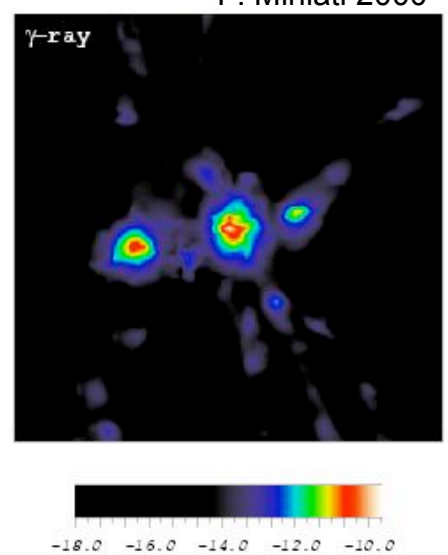
Extragalactic Science:
H. Krawczynski (chair), A. Atoyan, R. Blandford, M. Boettcher, A. Carraminana, P. Coppi, C. Dermer, B. Dingus, I. E. Dwek, J. McEnery, A. Falcone, J. Finley, S. Funk, M. Georganopoulos, J. Holder, D. Horan, T. Jones, I. Jung, P. Kaaret, J. Katz, F. Krennrich, S. LeBohec, R. Mukherjee, R. Ong, E. Perlman, M. Pohl, J. Ryan, G. Sinnis, S. Ritz, M. Urry, V. Vassiliev, T. Weekes, D. A. Williams.

AGNs, Jets, UHECRs,
Pairhaloes, EBL.

Cosmic rays in other starburst galaxies, ultra-luminous infrared galaxoes, AGN, galaxy clusters, large scale shocks.



F. Miniati 2000



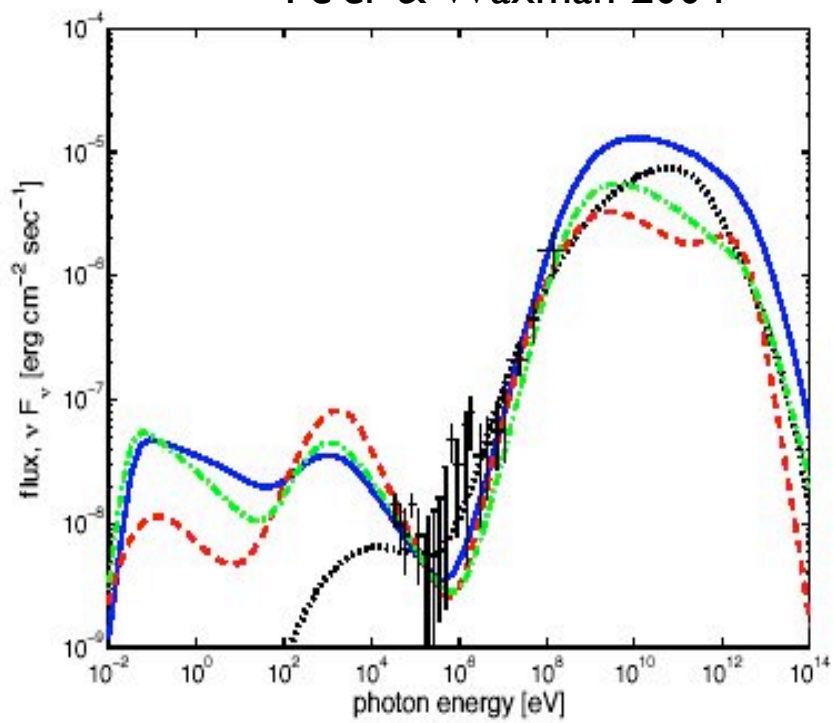
Highlights: GRBs

GRB Working Group:

A. Falcone (chair), D. Williams (co-chair), M. Baring, R. Blandford, V. Connaughton, P.Coppi, C. Dermer, B. Dingus, A. Falcone, C. Fryer, N. Gehrels, J. Granot, D. Horan, J. Katz, K. Kuehn, P. Meszaros, J. Norris, P. Saz Parkinson, A. Pe'er, E. Ramirez-Ruiz, S. Razzaque, X.Y. Wang, B. Zhang

See poster by A. Falcone

Fit to the prompt emission data of GRB 941017 using the SSC model.
Pe'er & Waxman 2004

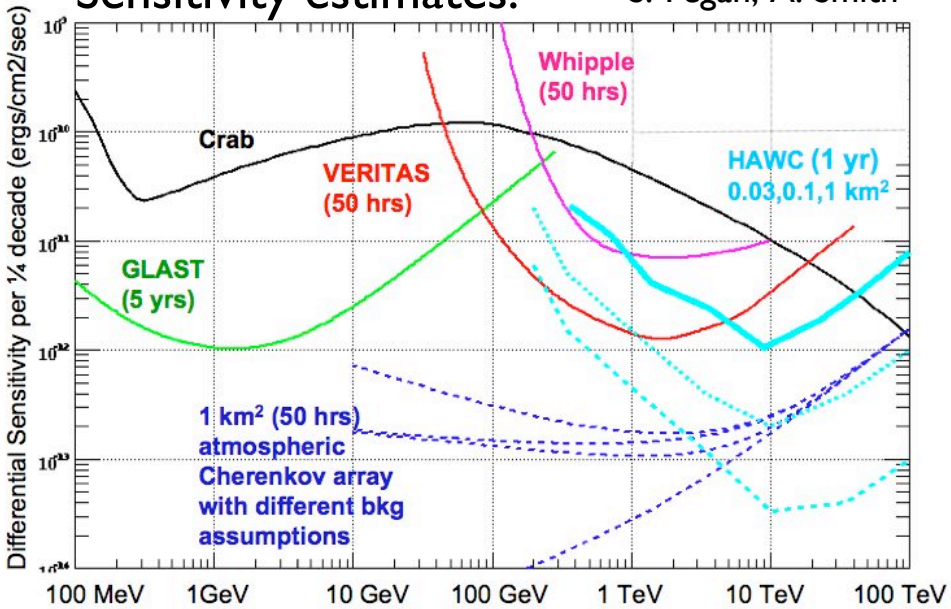


Probe Lorentz factor and optical thickness.

Highlights: Technical Working Group

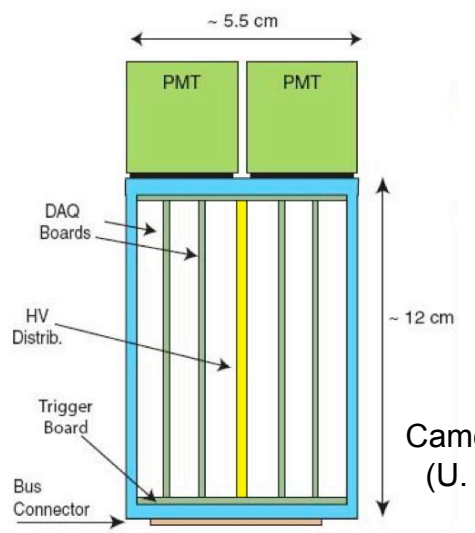
Technical Working Group: K. Byrum (chair), J. Buckley, S. Bugaev, B. Dingus, G. Drake, S. Fegan, J. Finley, L. Hays, J. Holder, D. Horan, A. Konopelko, F. Krennrich, H. Krawczynski, S. Lebohec, A. Smith, V. Vassiliev, S. Wakely

Sensitivity estimates: S. Fegan, A. Smith



Improve sensitivity by factor ~10, angular resolution by factor ~3.

AGIS R&D Proposal (Fall 2007):
(Buckley, Byrum, Swordy, Vassiliev et al.)



Camera Module
(U. Chicago).

Findings & Recommendations

Findings:

(1) Main science drivers.

(2) Timeliness of
Large-Scale Experiment.

(3) Experimental Techniques.

(4) Energy Range.

(5) US Leadership.

Recommendations:

(1) Next-Gen. Experiment.

(2) IACT/WCH Complementarity.

(3) Urgency of R&D Funding.

(4) Establishment of a Site.

(5) International Collaboration.

Findings & Recommendations

Findings:

(1) Main science drivers.
(2) Timeliness of Large-Scale Experiment.
(3) Experimental Techniques.
(4) Energy Range.
(5) US Leadership.

Recommendations:

(1) Next-Gen. Experiment.
(2) IACT/WCH Complementarity.
(3) Urgency of R&D Funding.
(4) Establishment of a Site.
(5) International Collaboration.

(1) Detection of dark matter γ-rays.
(2) Non-thermal particle populations: acceleration,propagation and energy density in SNRs, galaxies, & galaxy cluster and structure formation shocks.
(3) Black Holes and Active Galaxies.
(4) Discovery potential.

Findings & Recommendations

Findings:

(1) Main science drivers.

(2) Timeliness of Large-Scale Experiment.

(3) Experimental Techniques.

(4) Energy Range.

(5) US Leadership.

Recommendations:

(1) Next-Gen. Experiment.

(2) IACT/WCH Complementarity.

(3) Urgency of R&D Funding.

(4) Establishment of a Site.

(5) International Collaboration.

- Imaging Atmospheric Cherenkov Telescopes (IACT) and Water Cherenkov (WCH) experiments: mature techniques.
- Factor of magnitude improvement in sensitivity over current instruments and GLAST possible.

Findings & Recommendations

Findings:

(1) Main science drivers.
(2) Timeliness of Large-Scale Experiment.
(3) Experimental Techniques.
(4) Energy Range.
(5) US Leadership.

Recommendations:

(1) Next-Gen. Experiment.
(2) IACT/WCH Complementarity.
(3) Urgency of R&D Funding.
(4) Establishment of a Site.
(5) International Collaboration.

• Cherenkov telescopes and a Water Cherenkov experiment complement each other:

• Cherenkov telescopes: instantaneous sensitivity, excellent angular and energy resolution, deep observations of point sources and moderately extended sources.

• Water Cherenkov: wide field of view: alerts for Cherenkov telescopes, excellent sensitivity for steady extended sources.

Findings & Recommendations

Findings:

(1) Main science drivers.
(2) Timeliness of Large-Scale Experiment.
(3) Experimental Techniques.
(4) Energy Range.
(5) US Leadership.

Recommendations:

(1) Next-Gen. Experiment.
(2) IACT/WCH Complementarity.
(3) Urgency of R&D Funding.
(4) Establishment of a Site.
(5) International Collaboration.

- Cherenkov telescopes achieve the best νF_ν-sensitivity in the energy range from 50 GeV to 10 TeV.
- Lower energies: high costs, diminishing returns.
- Motivation for lower energies: m_χ<100 GeV/c^2 (++), GRB (+), AGN(-).

Findings & Recommendations

Findings:

(1) Main science drivers.
(2) Timeliness of Large-Scale Experiment.
(3) Experimental Techniques.
(4) Energy Range.
(5) US Leadership.

Recommendations:

(1) Next-Gen. Experiment.
(2) IACT/WCH Complementarity.
(3) Urgency of R&D Funding.
(4) Establishment of a Site.
(5) International Collaboration.

US groups are well positioned to play a leading role in the field:

- Pioneering of IACT technique for 40 yrs.
- Novel and unique concepts: camera design and electronics, intelligent array trigger, and wide field of view optics.
- Unique Water Cherenkov experience.
- Additional strength from GLAST and high-energy particle physics communities.

Findings & Recommendations

Findings:

(1) Main science drivers.
(2) Timeliness of Large-Scale Experiment.
(3) Experimental Techniques.
(4) Energy Range.
(5) US Leadership.

Recommendations:

(1) Next-Gen. Experiment.
(2) IACT/WCH Complementarity.
(3) Urgency of R&D Funding.
(4) Establishment of a Site.
(5) International Collaboration.

Ample guaranteed science, and rich discovery potential:

• The US should work towards the design and construction of a large-scale next-generation ground based gamma-ray experiment.

Findings & Recommendations

Findings:

(1) Main science drivers.
(2) Timeliness of Large-Scale Experiment.
(3) Experimental Techniques.
(4) Energy Range.
(5) US Leadership.

Recommendations:

(1) Next-Gen. Experiment.
(2) IACT/WCH Complementarity.
(3) Urgency of R&D Funding.
(4) Establishment of a Site.
(5) International Collaboration.

The next generation experiment:

- Cherenkov telescopes: ~1 km^2 detection area for instantaneous sensitivity, energy and spatial resolution, and deep observations of key fields.
- Water Cherenkov component for alerts and high sensitivity observations of steady extended (>>1°) sources.

Findings & Recommendations

Findings:

(1) Main science drivers.

(2) Timeliness of Large-Scale Experiment.

(3) Experimental Techniques.

(4) Energy Range.

(5) US Leadership.

Recommendations:

(1) Next-Gen. Experiment.

(2) IACT/WCH Complementarity.

(3) Urgency of R&D Funding.

(4) Establishment of a Site.

(5) International Collaboration.

• To maintain a worldwide leadership role, it is imperative that R&D funding in preparation of a next-generation Cherenkov telescope and Water Cherenkov experiments starts as soon as possible.

Findings & Recommendations

Findings:

(1) Main science drivers.
(2) Timeliness of Large-Scale Experiment.
(3) Experimental Techniques.
(4) Energy Range.
(5) US Leadership.

Recommendations:

(1) Next-Gen. Experiment.
(2) IACT/WCH Complementarity.
(3) Urgency of R&D Funding.
(4) Establishment of a Site.
(5) International Collaboration.

- In parallel to technology R&D, the US groups should work on establishing a site that allows for a step-wise enlargement (space & long-term lease agreement).
- A site that allows to observe the galactic center and galactic plane is scientifically more interesting.

Findings & Recommendations

Findings:

(1) Main science drivers.
(2) Timeliness of Large-Scale Experiment.
(3) Experimental Techniques.
(4) Energy Range.
(5) US Leadership.

Recommendations:

(1) Next-Gen. Experiment.
(2) IACT/WCH Complementarity.
(3) Urgency of R&D Funding.
(4) Establishment of a Site.
(5) International Collaboration.

- The US groups should intensify the collaboration with the European and Japanese/Australian groups.
- It is desirable that the R&D efforts complement each other as efficiently as possible.
- In the long-term,the collaboration should be extended to coordinate the observation program taken with facilities located at different latitudes or longitudes.

Discussion Topics

- Is dark matter the top science driver?
- What is the most efficient way to collaborate with CTA? Should we work towards a G(lobal)TA?
- How do we increase the support:

  -general public,

  -astroparticle physics community,

  -funding agencies,

  -governors, senate, congress.