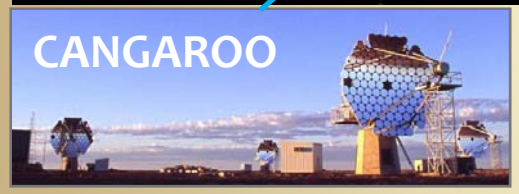
White Paper
Status and Timeline

Vladimir Vassiliev
UCLA

On behalf of WP editorial board and S&T WGs

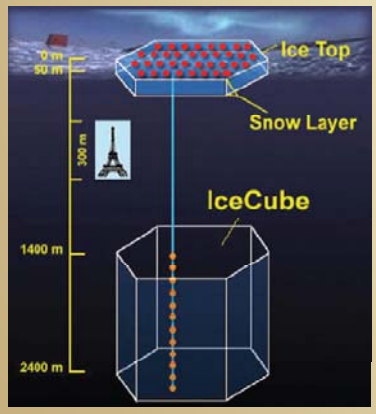
Globalization



Multi-wavelength / messenger Astronomy

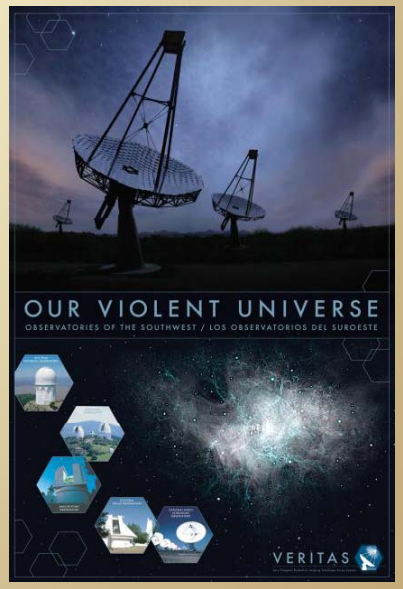
UHE Cosmic Rays
Auger Observatory,
2005-

X-ray and γ-ray
satellites
GLAST,
Launch late 2007



Neutrinos
IceCube, 2010

VHE γ-rays
VERITAS, April 2007



Multiple Scientific Objectives

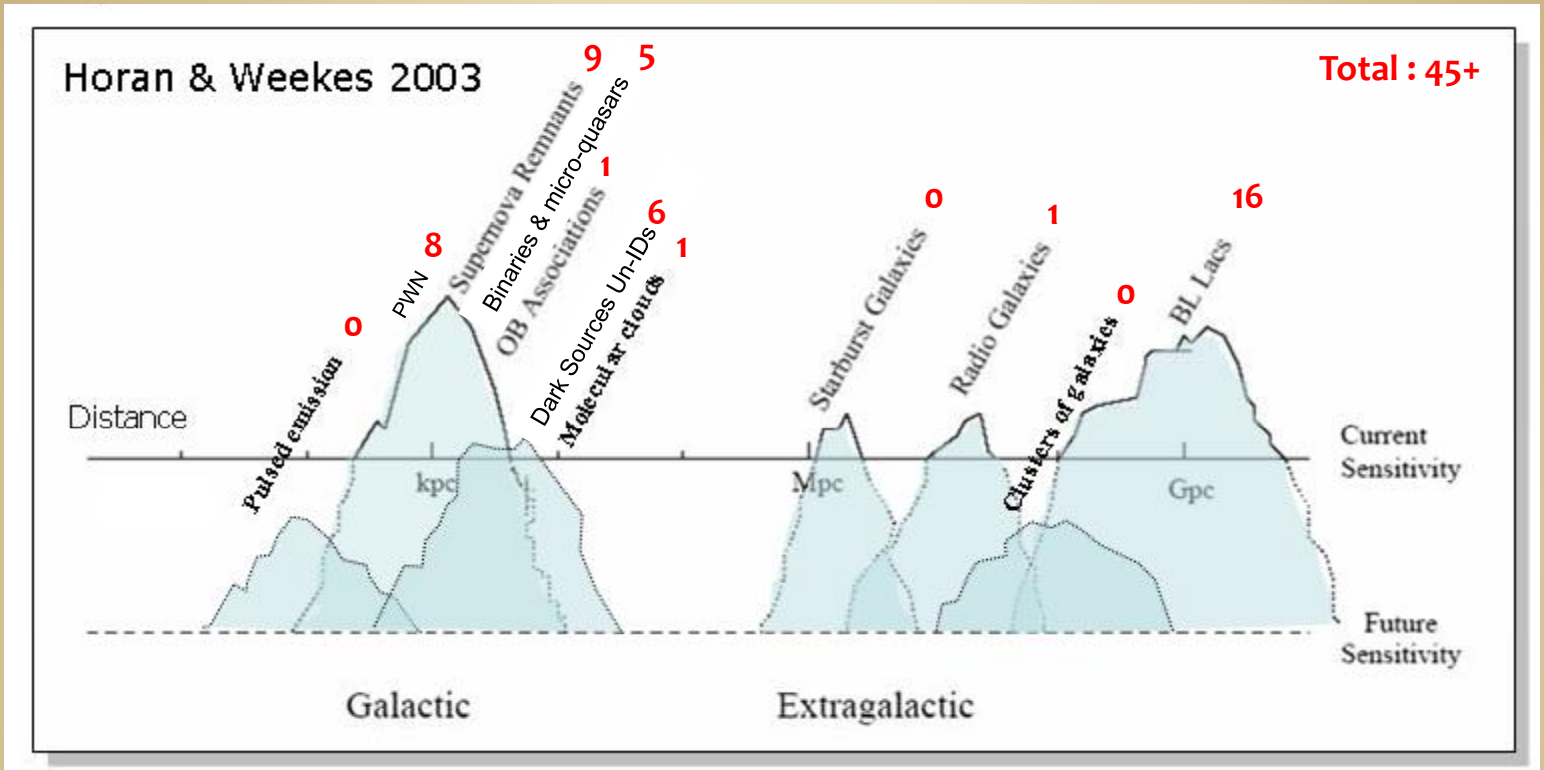
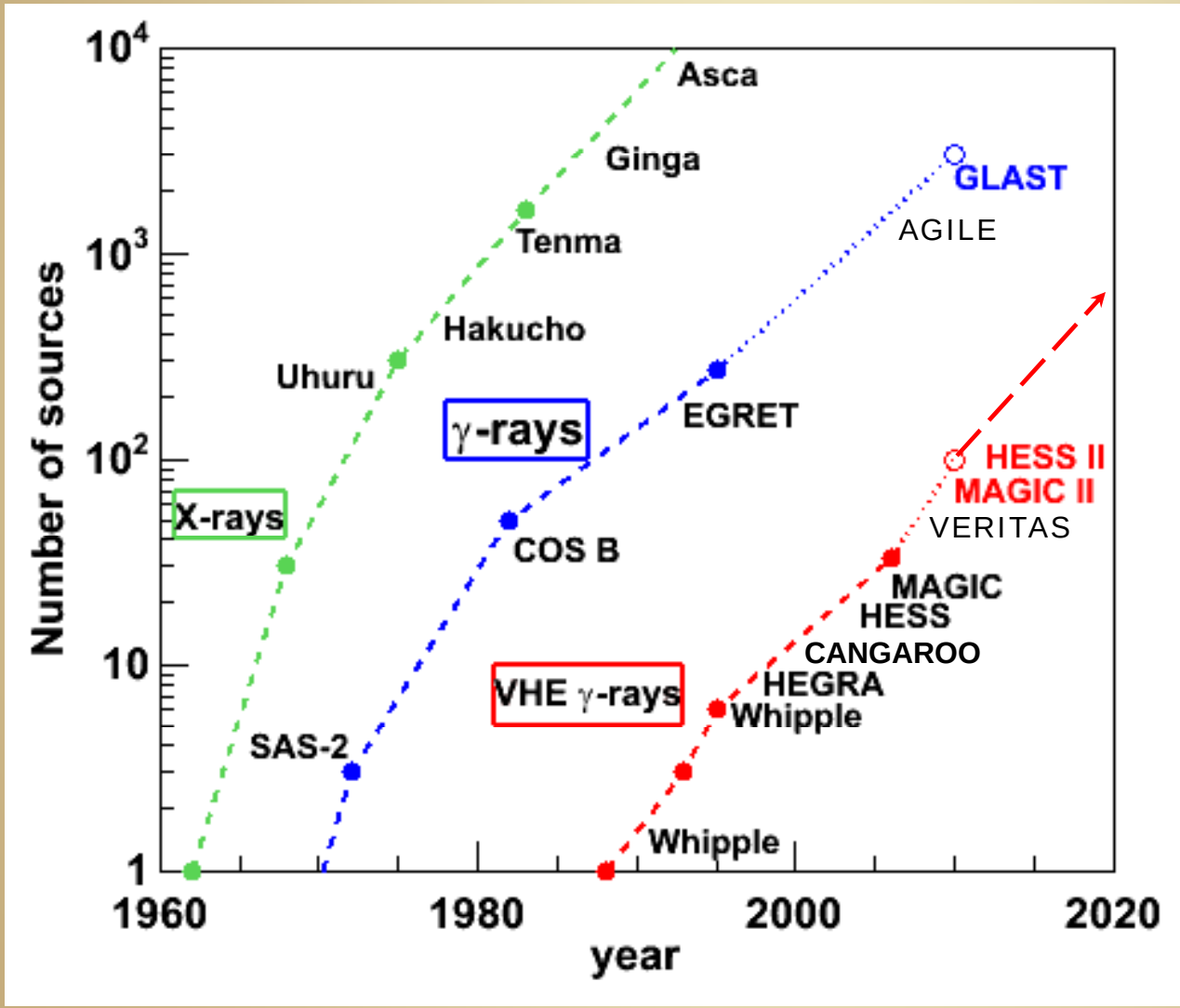


Fig. 2. Tips of the Icebergs in the TeV Universe.

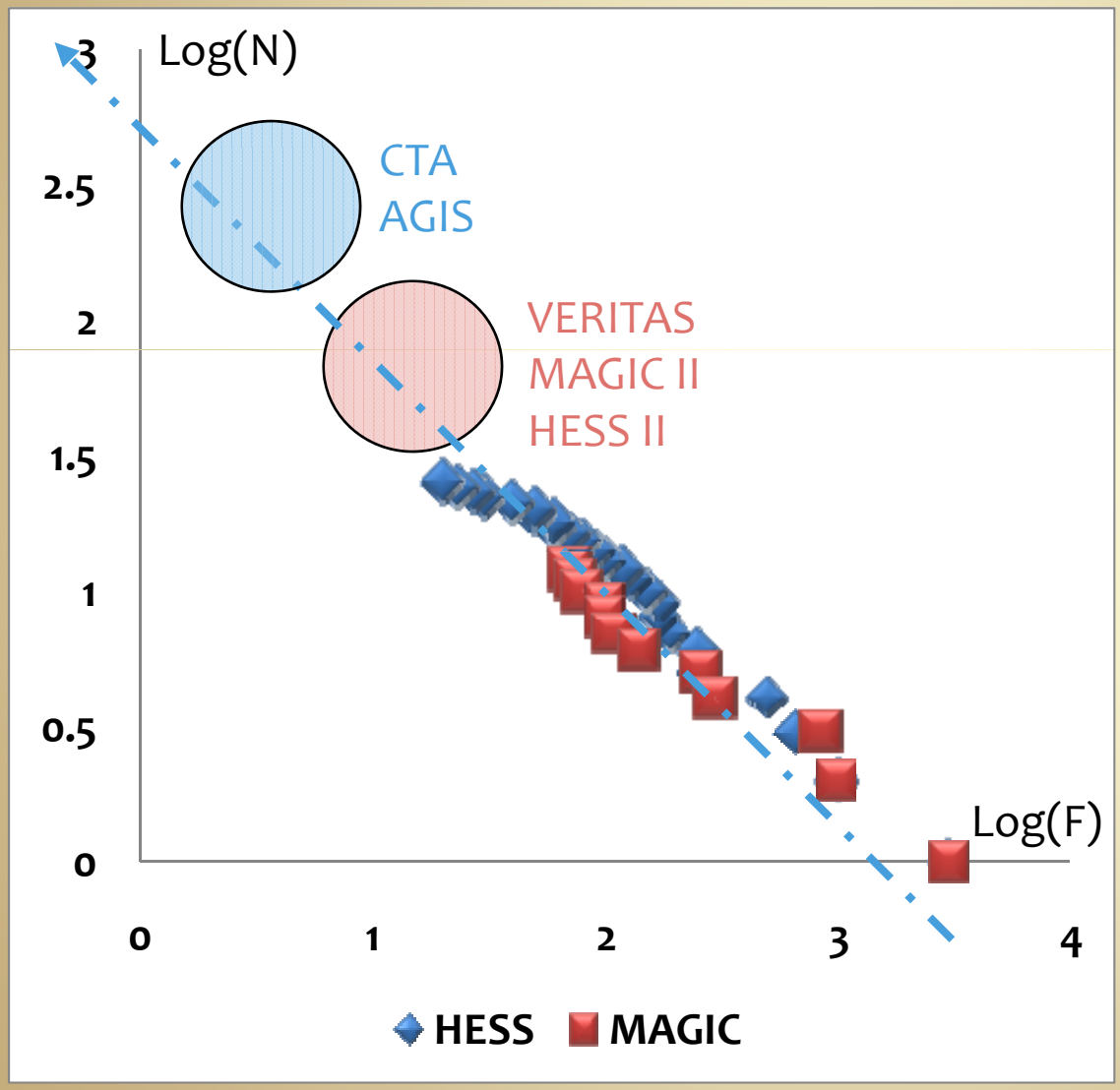
…As we discuss below, not only has the number of detected objects increased (and with this the depth of the universe that is probed) but the number of kinds of extra-galactic sources has also increased; this is a prediction of good things to come as the sensitivity and range of the telescopes is improved.

Kifune's Plot



- ~10^0 in 1990 by Whipple
- ~10^1 in 2000 by Whipple, HEGRA, CANGAROO
- ~ 10^2 in 2010 by HESS I&II, MAGIC I&II, VERITAS, CANGAROO III
- ~ 10^3 in 2020 by CTA AGIS

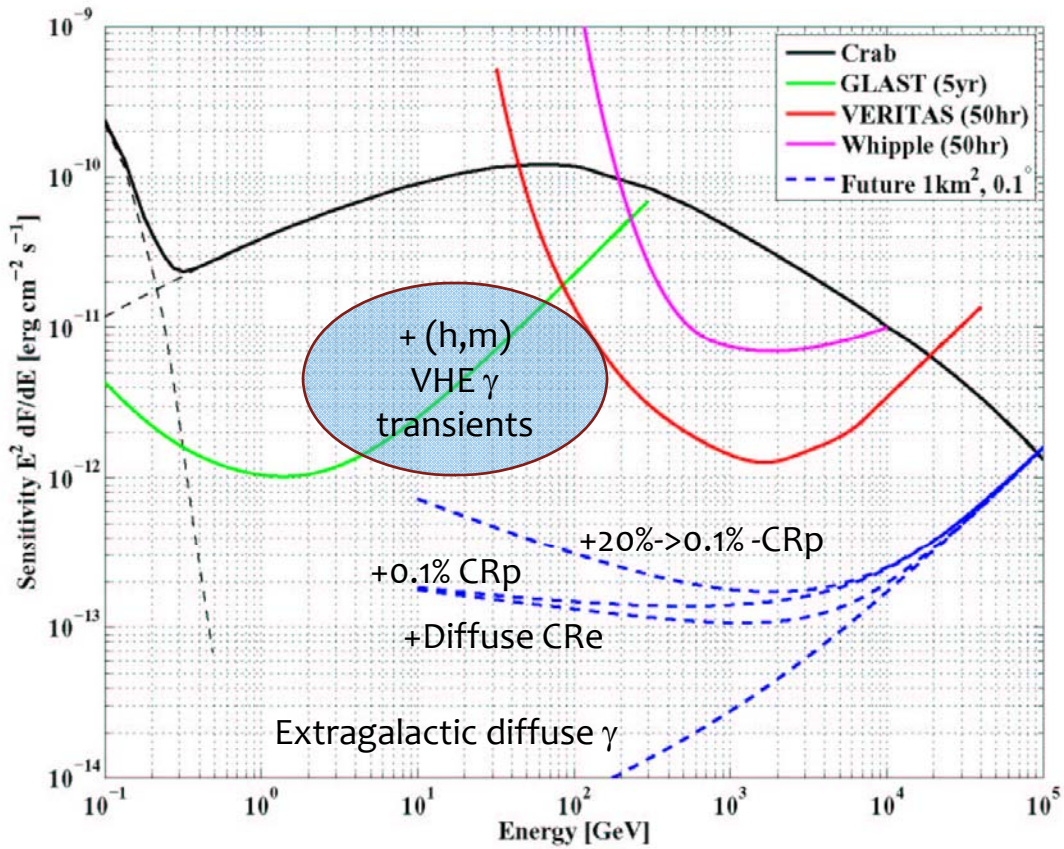
VHE: Log(N) ~ -1.0 (2d?) Log(F)



- VHE (>100 GeV) γ-ray astronomy is firmly established as a division of astronomical sciences (45+sources)
- GLAST, AGILE are expected to advance the field dramatically

Modified from original by M. Teshima

Future Science Opportunities



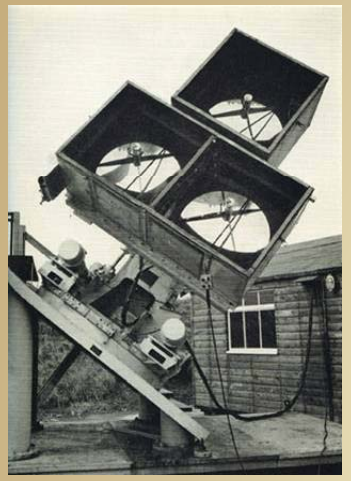
(S. Fegan & V. Vassiliev)

Area: 1 km^2
Angular resolution: 0.1°
$\Delta E/E$=0.58 (4 bins per decade)

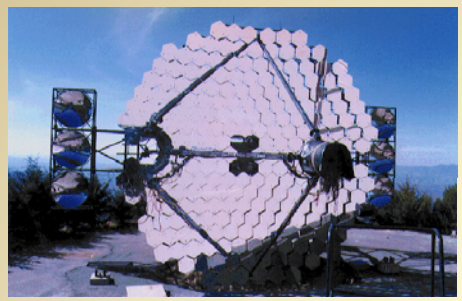
Differential sensitivity of ideal 1km^2 IACT array

- **Full Sky Survey (>100 GeV) with 10x sensitivity of present day instrumentation**
- **Indirect DM Searches**
- **Cosmologically distant Universe (>10 GeV)**
- **VHE transient Universe (>10 GeV)**
- **GLAST, AGILE GeV catalogue studies**

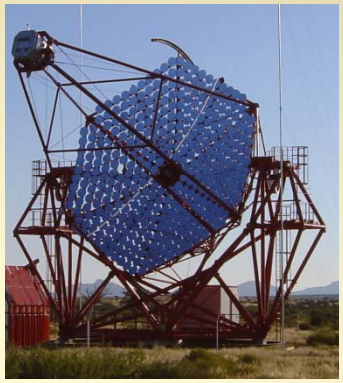
Costs

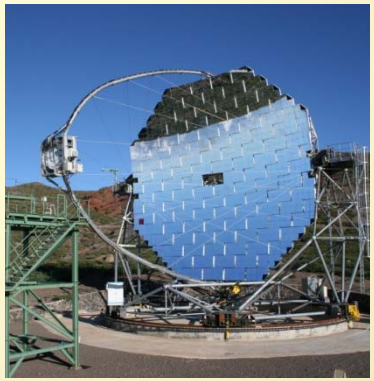


Early British-Irish, and Russian Observatories, 1960-1970
Recycled military hardware
~50K$

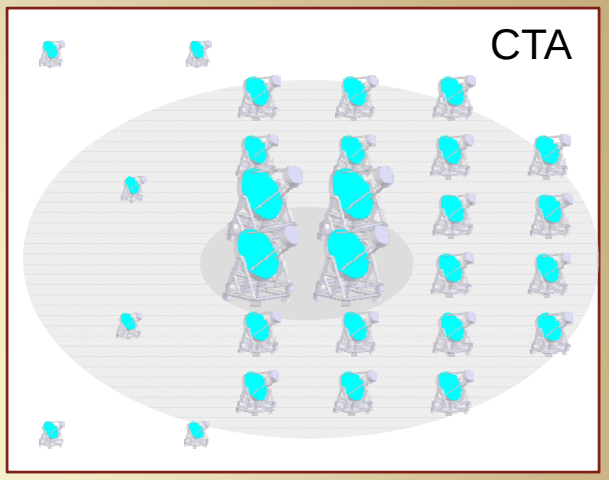


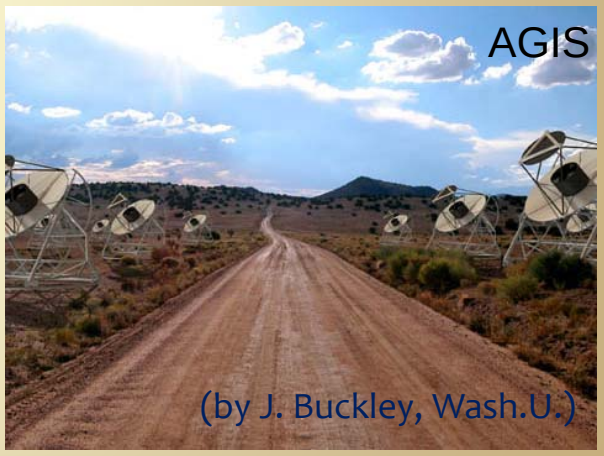
Whipple 10m, HEGRA
1980-2000
~1-3M$





HESS, MAGIC, VERITAS
2000 --, ~30M$

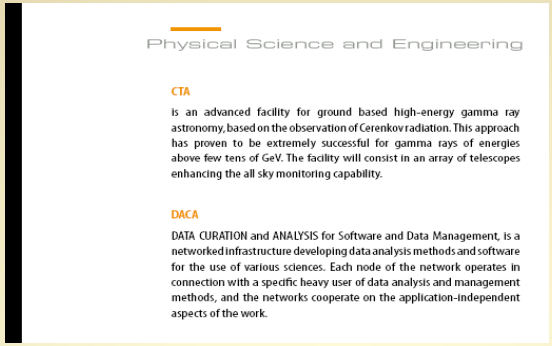




CTA, AGIS
2010 --,
~150 -200 M$

Next step clearly requires global international effort !

Europian Initiative (CTA)



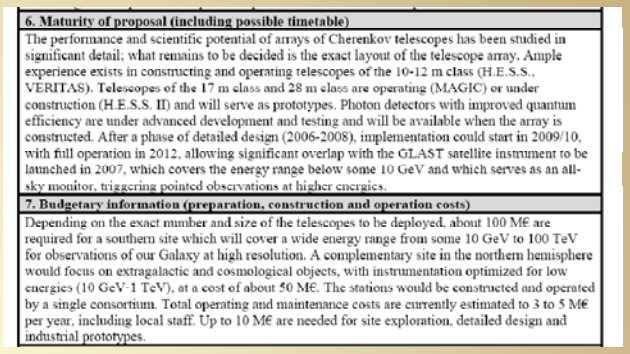
Physical Science and Engineering

CTA

is an advanced facility for ground based high-energy gamma ray astronomy, based on the observation of Cerenkov radiation. This approach has proven to be extremely successful for gamma rays of energies above few tens of GeV. The facility will consist in an array of telescopes enhancing the all sky monitoring capability.

DACA

DATA CURATION and ANALYSIS for Software and Data Management, is a networked infrastructure developing data analysis methods and software for the use of various sciences. Each node of the network operates in connection with a specific heavy user of data analysis and management methods, and the networks cooperate on the application-independent aspects of the work.



6. Maturity of proposal (including possible timetable)

The performance and scientific potential of arrays of Cherenkov telescopes has been studied in significant detail; what remains to be decided is the exact layout of the telescope array. Ample experience exists in constructing and operating telescopes of the 10-12 m class (H.E.S.S., VERITAS). Telescopes of the 17 m class and 28 m class are operating (MAGIC) or under construction (H.E.S.S. II) and will serve as prototypes. Photon detectors with improved quantum efficiency are under advanced development and testing and will be available when the array is constructed. After a phase of detailed design (2006-2008), implementation could start in 2009/10, with full operation in 2012, allowing significant overlap with the GLAST satellite instrument to be launched in 2007, which covers the energy range below some 10 GeV and which serves as an all-sky monitor, triggering pointed observations at higher energies.

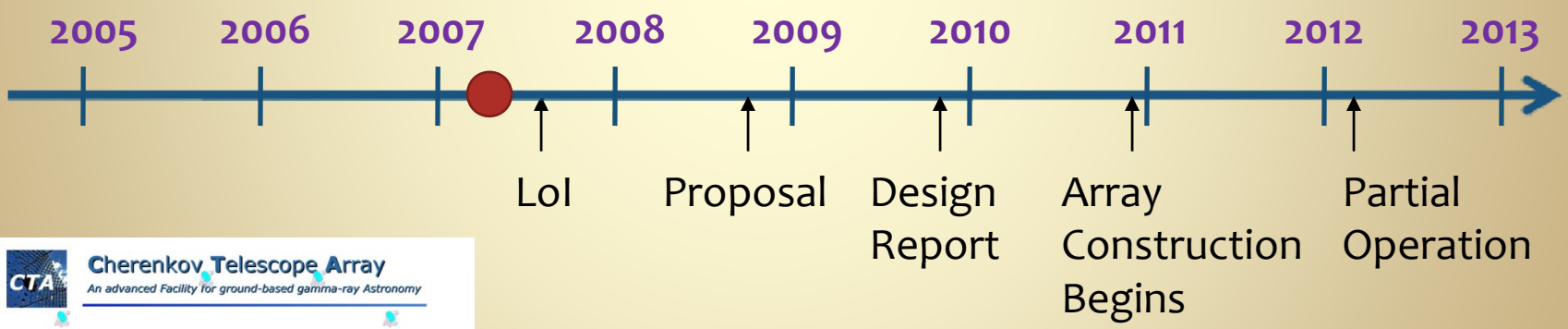
7. Budgetary information (preparation, construction and operation costs)

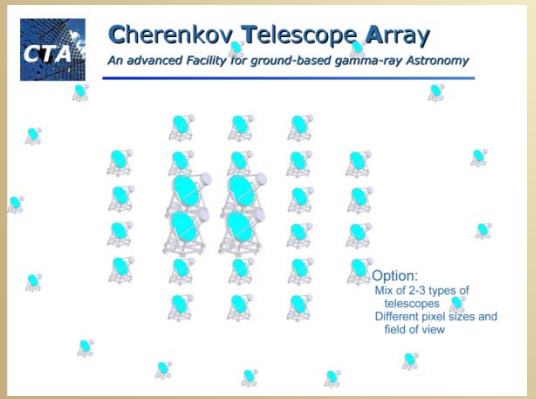
Depending on the exact number and size of the telescopes to be deployed, about 100 M€ are required for a southern site which will cover a wide energy range from some 10 GeV to 100 TeV for observations of our Galaxy at high resolution. A complementary site in the northern hemisphere would focus on extragalactic and cosmological objects, with instrumentation optimized for low energies (10 GeV-1 TeV), at a cost of about 50 M€. The stations would be constructed and operated by a single consortium. Total operating and maintenance costs are currently estimated to 3 to 5 M€ per year, including local staff. Up to 10 M€ are needed for site exploration, detailed design and industrial prototypes.

Emerging Proposal: CTA
The Cherenkov Telescope Array facility

ESFRI LoI defines CTA baseline

(W. Hofmann Presentation, Paris 2007)



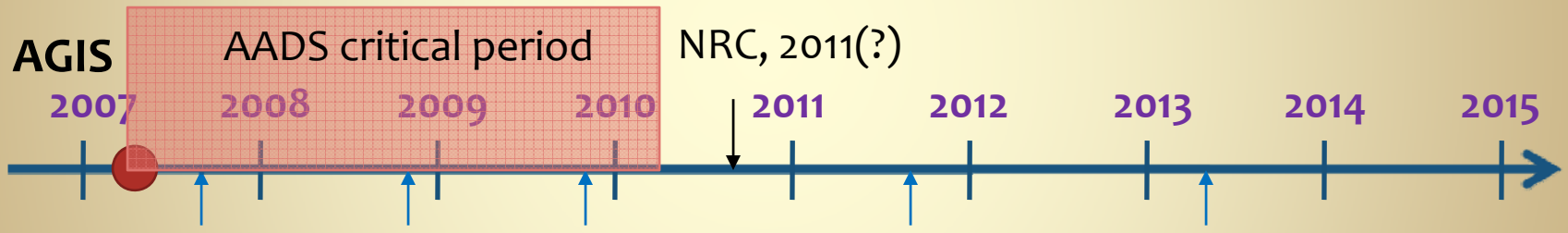


Telescope type	Cost/Unit	Units
Large (30 m class) telescope	10 – 15 M€	~ 3-4
Medium (15 m class) telescope	2.5 –3.5 M€	~ 15-20
Small (<10 m class) telescope	0.5– 1.5 M€	~ many

100M € (SS) +50M € (NS) +5M € (OC/y)

Emerging US Initiative (AGIS)

(artist view by J. Buckley, Wash.U.)



R&D Prop. D&C +1 Tel. AGIS Prop. Construction Partial Operation

Budget: ~130M$, "Moderate Initiative"
Observatory: ~1km^2 array of mid-IACTs
IACTs: 150-50 identical telescopes (+…)
CT Aperture: 5-15 m (#CTs & aperture TBD)
Technology: demonstrated AC technique
Field of View: 5-12° (TBD)

R&D: Novel Camera, OS , Trigger, DAQ
Telescope & Array Trigger: (TBD)
Site Elevation: ~1500-4200

A number of novel technologies is required to improve performance and reduce cost

“Towards the Future…” series

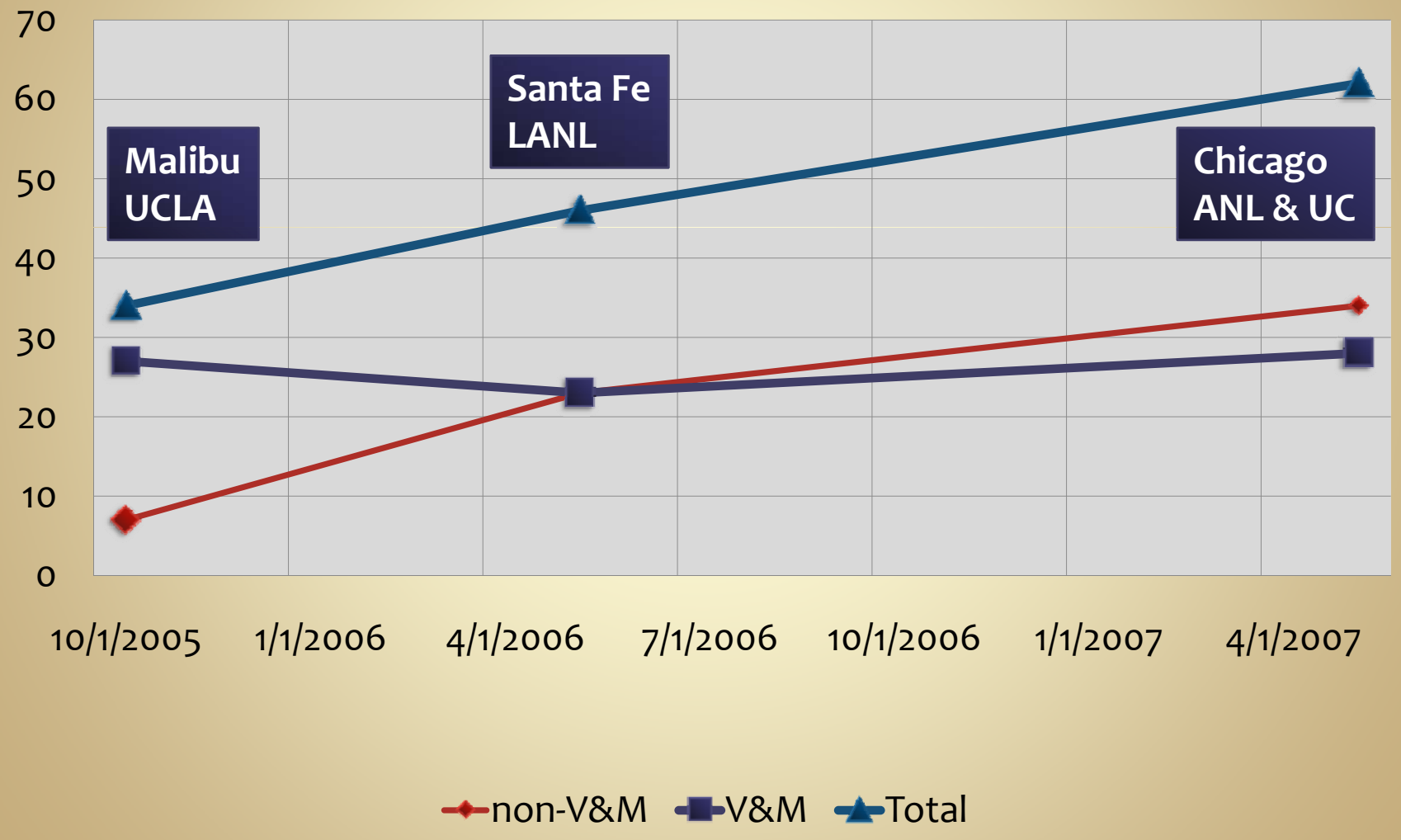
- "Ground-based Gamma-ray Astronomy: Towards the Future", October 20-21, 2005, UCLA, Mays' landing, Malibu, CA http://gamma1.astro.ucla.edu/future_cherenkov/

- "Ground Based Gamma Ray Astronomy: Towards the Future", May 11-12, 2006, LANL, Santa Fe, NM, http://www.lanl.gov/orgs/p/g_a_d/p-23/gammaworkshop

- "Ground Based Gamma Ray Astronomy: Towards the Future", May 13-14, 2007, ANL & UC, Chicago, IL, http://www.hep.anl.gov/byrum/next-iact/index.html

"Towards the Future…"

Participation



White Paper

Extensive discussions of the status of VHE γ-ray Astronomy with James Ryan, Chair of the APS DAP, took place during the Santa Fe meeting. As a result the APS solicited a White Paper with the following official charge:

"The Division of Astrophysics of the American Physical Society invites you **to prepare a review or white paper on the status and future of ground based TeV gamma-ray astronomy**. With the upcoming commissioning of VERITAS and the success of HESS and others in this emerging field, **a review of the science accomplishments and potential** would be welcome. Furthermore, given the long lead time for designing, developing and deploying new instruments, we **need a clear path for proceeding beyond the near term**."

Dear Colleagues,

The Division of Astrophysics of the American Physical Society invites you to prepare a review or white paper on the status and future of ground based TeV gamma-ray astronomy. With the upcoming commissioning of VERITAS and the success of HESS and others in this emerging field, a review of the science accomplishments and potential would be welcome. Furthermore, given the long lead time for designing, developing and deploying new instruments, we need a clear path for proceeding beyond the near term.

Understanding that this is a significant task, we would ask you to do the following:

- Consider yourselves the editorial board for this white paper. This entails being ultimately responsible for the drafting, formatting and distribution of the report.
- Recruit, as necessary, a very small number of other people to augment you as an editorial board. These people might be important players in TeV gamma-ray astronomy or astrophysics who might lend their expertise and stature to the preparation of the report. Please ensure that a spectrum of researchers is represented on the board to promote objectivity and avoid the appearance of advocacy.
- Delegate, as necessary, to willing and knowledgeable people in the field the collection and synthesis of information necessary for drafting this report. These people would likely draft sections of the report that you would, in turn, edit and merge with other sections.

There is little time to prepare this report for release at the April 2007 APS meeting, however, it would fitting if this report could be released at the April 2008 meeting. If is available a sufficient time before the April 08 meeting, we should consider releasing it by other means for the benefit of the community.

We suggest that as soon as possible you begin soliciting financial support from interested agencies, institutions and parties. The costs for travel and production of the report will not be trivial.

Although, I am in no position to offer financial support from the DAP you are free to ask for such support, but as members you know the limitations of our resources and the difficulty of maintaining them.

The Executive Committee appreciates your investment of time and energy into the future directions of this important field. If we, the Executive Committee, can be of help, please feel free to ask.

On Behalf of the DAP Executive Committee,
Sincerely Yours,

James Ryan
Chair

B. Dingus (LANL / MILAGRO)
H. Krawczynski (WU / VERITAS, EXIST)
M. Pohl (ISU / Theory, GLAST)
V. Vassiliev (UCLA / VERITAS)

W. Hofmann (MPI / HESS)
S. Ritz (GSFC, NASA / GLAST)
F. Halzen (U. W-M / Ice Cube)
T. Weekes (CfA / VERITAS)

Formed in Sep – Nov, 2006

WP goals

- Define the science goals and instrument requirements for a future experiment. Build a strong science case to justify the project budget.
- Describe relevant performance specifications and identify areas of required technology development.
- Estimate the timeframe and the budget required to complete the project.
- Increase interest and involvement of broader scientific community
- Prepare for "decadal survey" (AADS)

WP History / Timetable

- Editorial board formed (Sep 27, 2006)
- Wash U meeting defined WP scope, key topics, organizational structure, timetable (Oct 27, 2006)
- Advisory board formed (Dec, 2006)
- AAS HEAD and APS communities are invited to contribute to WP effort, formation of S&T WGs (Jan, 2007)
- WP satellite meeting associated with the First GLAST Symposium at Stanford University, California (Feb 8, 2007)
- First SWG reports: draft of "The Appendices" (Mar, 2007)
- WP session at the American Physical Society meeting, Jacksonville, Florida (April 15,2007)
- WP "Towards the Future" meeting, Chicago (May 13-14, 2007)
- "The Appendices" final draft (July 23, 2007)
- First draft of WP / (late summer, 2007)
- WP release (late fall, 2007)

WP Structure

Wash U. meeting (St. Louis, 10/27/2006)

- Executive summary (2 pages , E&A boards)
- Extended summary (10 pages , E&A boards)
- "The Appendices" (<12 pages each, WG reports)
  - Compact objects
  - GRBs
  - SNRs
  - Extragalactic CRs
  - AGN & BH
  - Astroparticle Physics (EBL, B-field, PBH, Lorentz-invariance)
  - Dark Matter
  - Technology

WP Working Groups/Web page

- Extragalactic Astrophysics [32] – (Henric Krawczynski, Wash. U.)
- Galactic Compact Objects [22] – (Phil Kaaret , U. Iowa)
- Galactic Diffuse Emission, SNR and Cosmic Rays [19]– (Martin Pohl, ISU)
- Dark Matter [18] – (Jim Buckley ,Wash. U.)
- Gamma-ray bursts [20] – (David Williams/Abe Falcone, UCSC)
- Technology [15] – (Karen Byrum, ANL)

Participation of 60+ people, e.g.
Atoyan, Baltz, Böttcher, Coppi, Dermer, Dwek, Georgonopulous, Jon es, Koushiappas, Perlman, …

WP Web Site: http://cherenkov.physics.iastate.edu/wp/

"The Appendices" status

Reports of Working Groups

1 Extragalactic VHE Astrophysics

Observations of extragalactic objects cover four major science topics: (i) exploring astrophysical black holes, (ii) the study of Gamma Ray Bursts, (iii) exploring cosmic rays in extragalactic systems, (iv) the search for dark matter in extragalactic systems, and (v) measuring extragalactic r
magnetic fields.

1.1 Gamma-ray observations of astrophysical bla

There are two types of extragalactic back holes that are emitters of GeV/T
black holes (SMBH) with masses between a million and several billion sol
black holes with masses between 3 and several 10 solar masses.
SMBH linger at the centers of galaxies. Some supermassive black holes a
galactic nuclei (AGN): they accrete matter. Powered either by the gravitati
matter, or, by the rotational energy of the black hole, the accretion system
in the Universe. Blazars, AGN with fast collimated outflows (jets) along th
gamma-ray sourc
and thus beaming
MeV/GeV emitter
the first extragala
(Punch et al. 199
2005), only a sing
of writing this doc
the gamma-ray ba
rapid flux variabili
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most likely even i
which moves with
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describing a rang
improve on the G
sources.
The observations
estimates of the p

Galactic diffuse emission, Supernova remnants, and the Origin of Cosmic Rays

The origin of cosmic rays and the mechanisms of their acceleration are among the most challenging problems in astroparticle physics and also among the oldest. Cosmic rays are energetically important in our understanding of the interstellar medium (ISM) because they contain at least as much energy as the other phases of the ISM. Yet, the origin of cosmic rays remains uncertain 93 years after their discovery by Victor Hess in 1912 (for a recent review, see [1]). Improving our knowledge of the interaction between highly energetic particles and the other elements of the ISM could help understand other systems, such as infant galaxies where there are strong outflows of high energetic
ear to directly affect the formation and
between nuclear black hole mass and

n shell-type supernova remnants (SNR)

f the main unsolved, yet fundamental,
t particle acceleration proceeds in
c Nuclei, Gamma-ray Bursts, and
to perform spatially resolved studies

mately linked to the interaction
he question of cosmic-ray acceleration
of turbulence in a non-equilibrium
, energetic particles, and colliding
remnants, for which observations in
efficient particle acceleration to at
field that is much stronger than a

smic rays. An understanding of particle
hety years old question of the origin
ection between some aspects beyond
ery high-energy gamma rays and
arios of cosmic-ray origin.
nterstellar medium of galaxies, thus
. In particular when our results
s of massive stars, they will help
evolution of the interstellar medium

0.1 Dark Matter

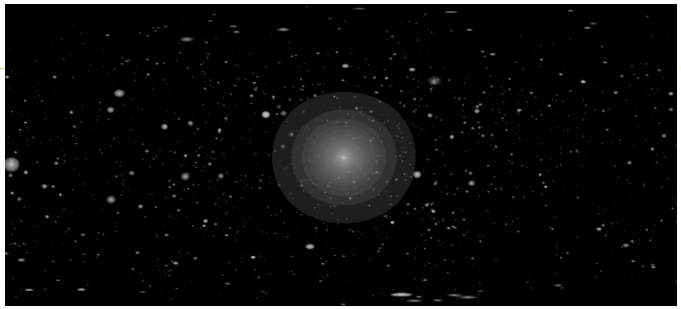


Figure 1: Appearance of the gamma-ray sky from neutralino annihilation, plotted as the intensity in galactic coordinates [Baltz (2006)]. The galactic center appears as the bright object at the center of the field of view. If the sensitivity were high enough, a number of other galactic substructures could become visible.

The gravitational effects of Dark Matter have been observed in the Universe on all spatial scales, ranging from the size of the inner parsec of our own Galaxy to the Hubble radius. The Dark Matter (DM) paradigm was first introduced by Zwicky [2] to explain anomalous velocity dispersion in galaxy clusters. In ??? Vera Rubin and ??? found dramatic evidence for dark matter in the rotation curves of nearby galaxies. The latest compelling evidence for DM,
which severely limits explanation based on modifications of gravitational force at large scale, has been demonstrated in a unique cluster merger event 1E0657-558 [3]. In this system X-ray emitting plasma, which dominates the mass of the visible matter, appears to be spatially segregated from the DM mass component acting as the main source of gravitation producing weak lensing effect. Ample astrophysical evidence derived from observations of the large scale structure formation in the Universe, gravitational lensing, primordial nucleosynthesis, observations of CMB temperature fluctuations, luminosities of distant supernovae, etc. all indicate that the critical density composed of the DM is 0.238 ± 0.019, the second largest contribution to the energy density of the Universe [4].
In spite of the overwhelming astrophysical evidence for DM, its nature has remained elusive for three quarters of a century. It is remarkably coincident, however, that if DM is composed of a hypothetical elementary particle with an approximate mass on the scale of the weak bosons (! 100 GeV), one could naturally produce the required cosmological density through thermal decoupling of the DM component from the baryons, leptons, and radiation during the early phase of expansion of the Universe if its characteristic interaction cross section, "!v#, is on the same scale of as that of the weak interactions. The decay of such a particle must be forbidden by some conservation number associated with an, as yet, undiscovered symmetry of Nature so that the lifetime of the particle is longer than the Hubble time. The only non-trivial extension of space-time symmetry known to date is supersymmetry (SUSY), a theory which provides the mathematical foundation for the potential resolution of several outstanding problems of quantum field theories. SUSY offers

Initial drafts with various degree of completion exist (typically 5-10 pages).

All drafts require additions for completeness, editing, citations, etc.

Some drafts (e.g. Technology) are in a very early stage.

WP FAQ (1)

- Is this effort national or international?
  - **WP will be focused on science and to a lesser extent on appropriate technologies. As such this effort doesn't preclude, but instead encourages, international participation. The majority of people involved so far are US scientists. "The Neutrino Matrix" is an example of a WP with a significant component of international participation.**
- Does it address the science that can be done at energies above 10 GeV or is it solely concerned with what science can be done from the ground?
  - **It will address the science which can be done above 10 GeV since we see scientific opportunities in this energy regime which will not be addressed by GLAST or by present day ground based IACTs & WCD.**
- Is WP to address the US policy on Very High Energy Gamma Ray Astronomy?
  - **WP goal is to identify scientific opportunities and in this sense it may influence the direction of VHE gamma-ray Astronomy. WP will avoid all political discussions which could be originated in different experimental approaches, or in different national polices affecting science funding.**

WP FAQ(2)

- Is WP intended to endorse a particular experiment?
  - **WP will present scientific case, define required performance specifications, and outline possible technologies and the needs for their development. It will not endorse any particular experiment.**
- Is WP effort endorsed by the VERITAS/Milagro Collaborations or related to them?
  - **WP effort is not formally endorsed by VERITAS/Milagro collaborations and is independent from them. However, there are many VERITAS/Milagro members who participate in this work. The White Paper is intended to be helpful to anybody proposing an experiment in VHE regime.**
- Will WP be peer reviewed?
  - **WP will not be peer reviewed, instead, it will be endorsed by all scientists who contributed to it, and who will become its authors.**

Primary goals of this meeting

- Finalize work of SWGs and provide input to "The Appendices." All contributions to this meeting by speakers and by participants in the discussions will be incorporated into S&T WG reports (unless there is an objection)

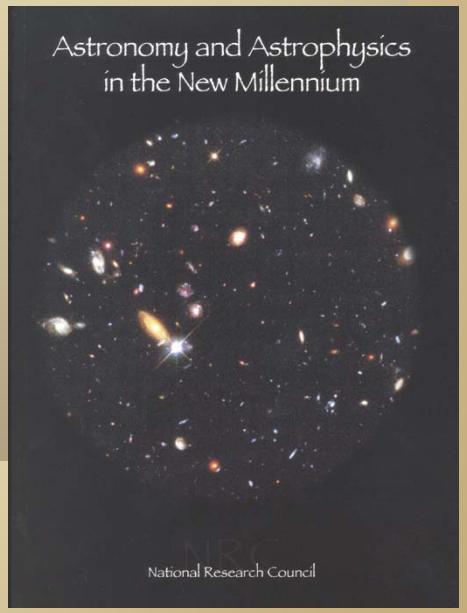
- Identify science areas which might have been overlooked and not included in the WP (e.g. multi-messenger / multi-wavelengths interface)

- Discuss and plan the most efficient way of gathering input, writing, and editing the "The Appendices" (e.g. Sky survey sub-group, DM small scale structure sub-group, etc.)

Main Science Questions

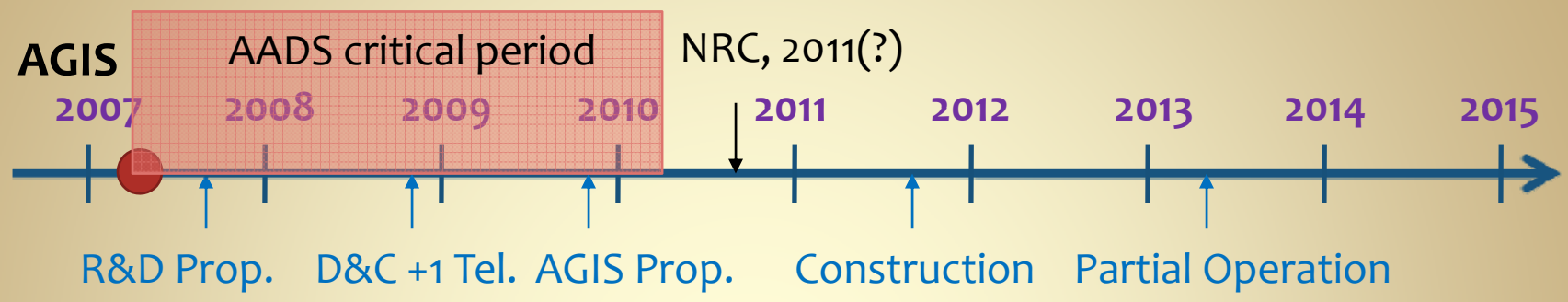
…it is clear that for the foreseeable future, the defining questions for astronomy and astrophysics will be these:

- **How did the universe begin, how did it evolve from the soup of elementary particles into the structures seen today, and what is its destiny?**
- **How do galaxies form and evolve?**
- **How do stars form and evolve?**
- **How do planets form and evolve?**
- **Is there life elsewhere in the universe?**



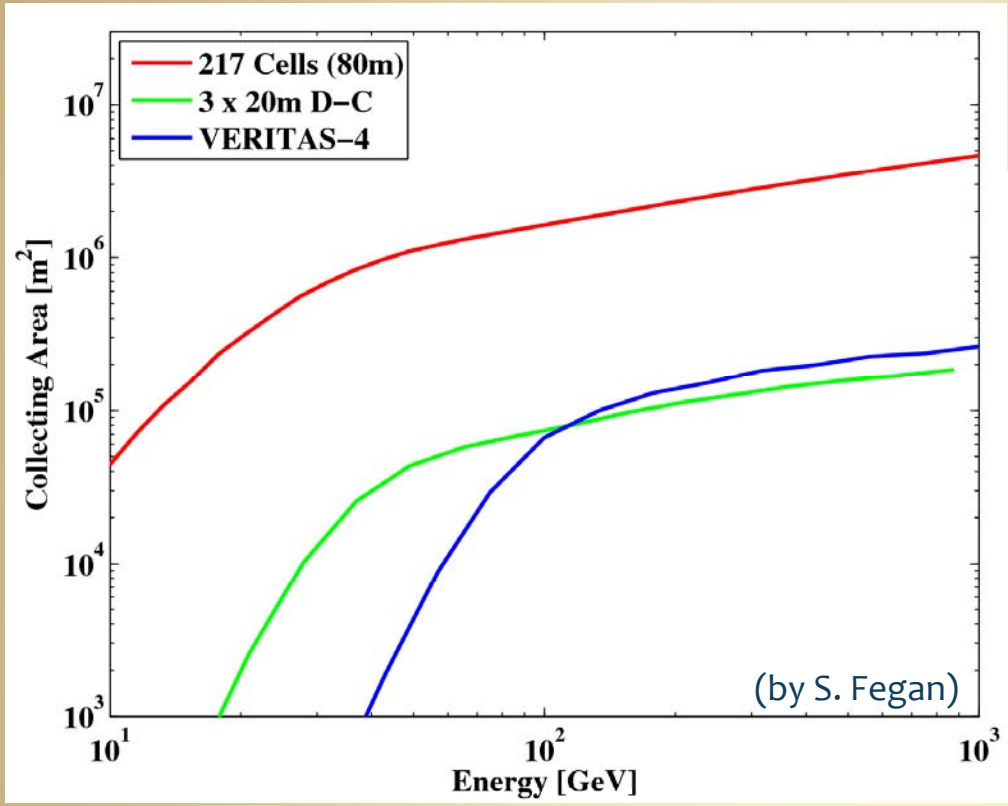
NRC, 1991 (Bahcall report); NRC 2001 (A&ANM); NRC 2008-2011 (?)

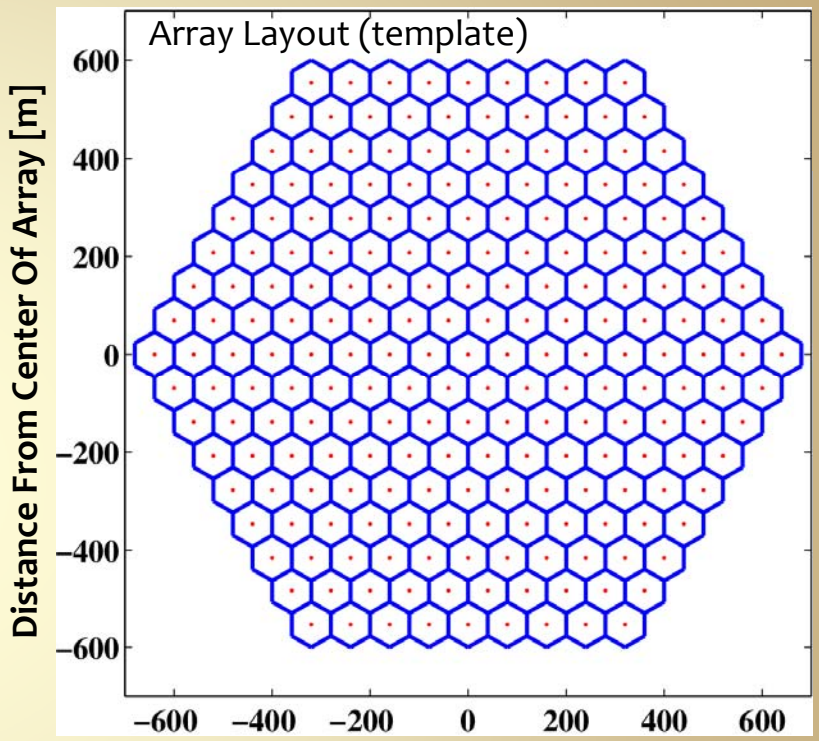
Technology WG



- Need to identify technologies with the promise of significant enhancement of performance, reliability, and/or cost reduction.
- The timescale available for R&D is very short (imposed by AADS timeline); reality must be taken into account.
- WP doesn't have a charge to endorse a particular experiment and/or place it onto the roadmap of VHE γ-ray astronomy progress. A yet-to-be-established Particle Astrophysics Scientific Assessment Group (PA SAG) will have this responsibility.

Test of ACT array performance at low energy

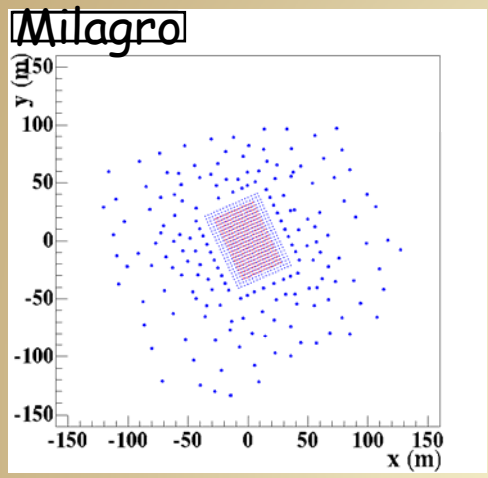




Large array of 7-10m aperture ACTs can operate efficiently at low energies: "cell" -effect

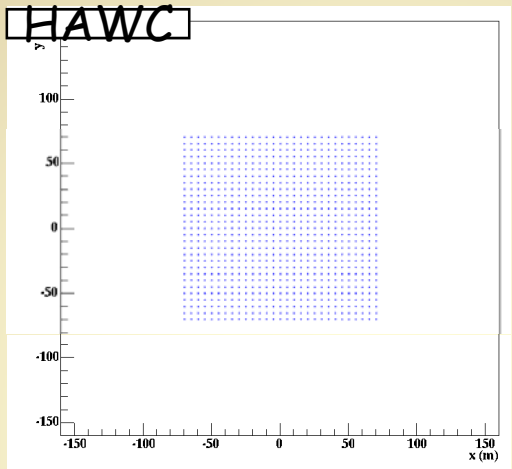
Can/will be tested (at least partially) by VERITAS / HESS through event selection

Test of WC technology performance at high energy



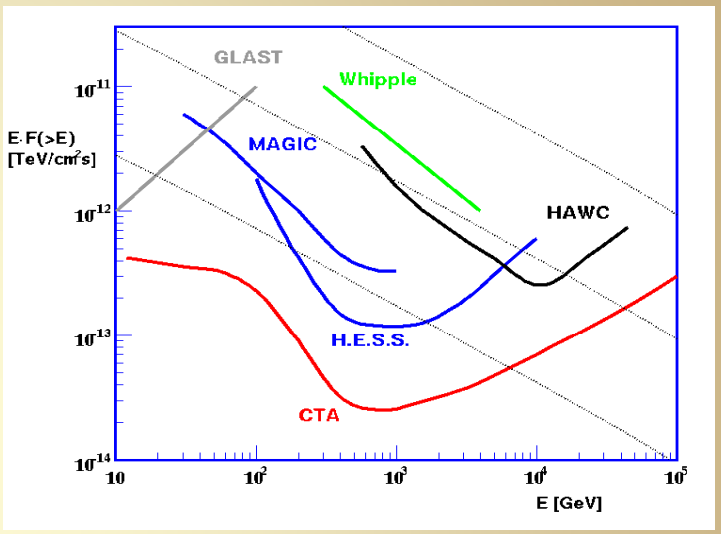
Milagro

Altitude: 2610m
Dense Area: 4,000m^2
μ det Area: 2,200m^2
No optical isolation
PMT spacing: 2.8m



HAWC

Altitude: >4,000m
Dense Area: 22,500m^2
μ det Area: 22,500m^2
Optical Isolation
PMT Spacing: 5.0m



Crab transit (4 hr)	~5 σ
Crab 1 year	~100 σ
Median Energy	700 GeV
Energy Resolution	~30% (>med)
Angular Resolution	0.25^{O}-0.5^{O}

Concept of optical isolation and consequent dramatic bg rejection power needs verification…; perhaps by HAWC

15x Sensitivity increase over Milagro

~3x from Altitude+Area

~3x from γ/hadron separation

~1.5x from Angular resolution

(from presentation by Gus Sinnis)

Focal plane / Electronics / Trigger

- There is growing number of options for photon detectors (SiPMs, MAPMTs, IIs, APDs, HPDs, traditional PMTs, etc.). Advantages and costs of these options have to be evaluated on the time scale of 3-5 years.

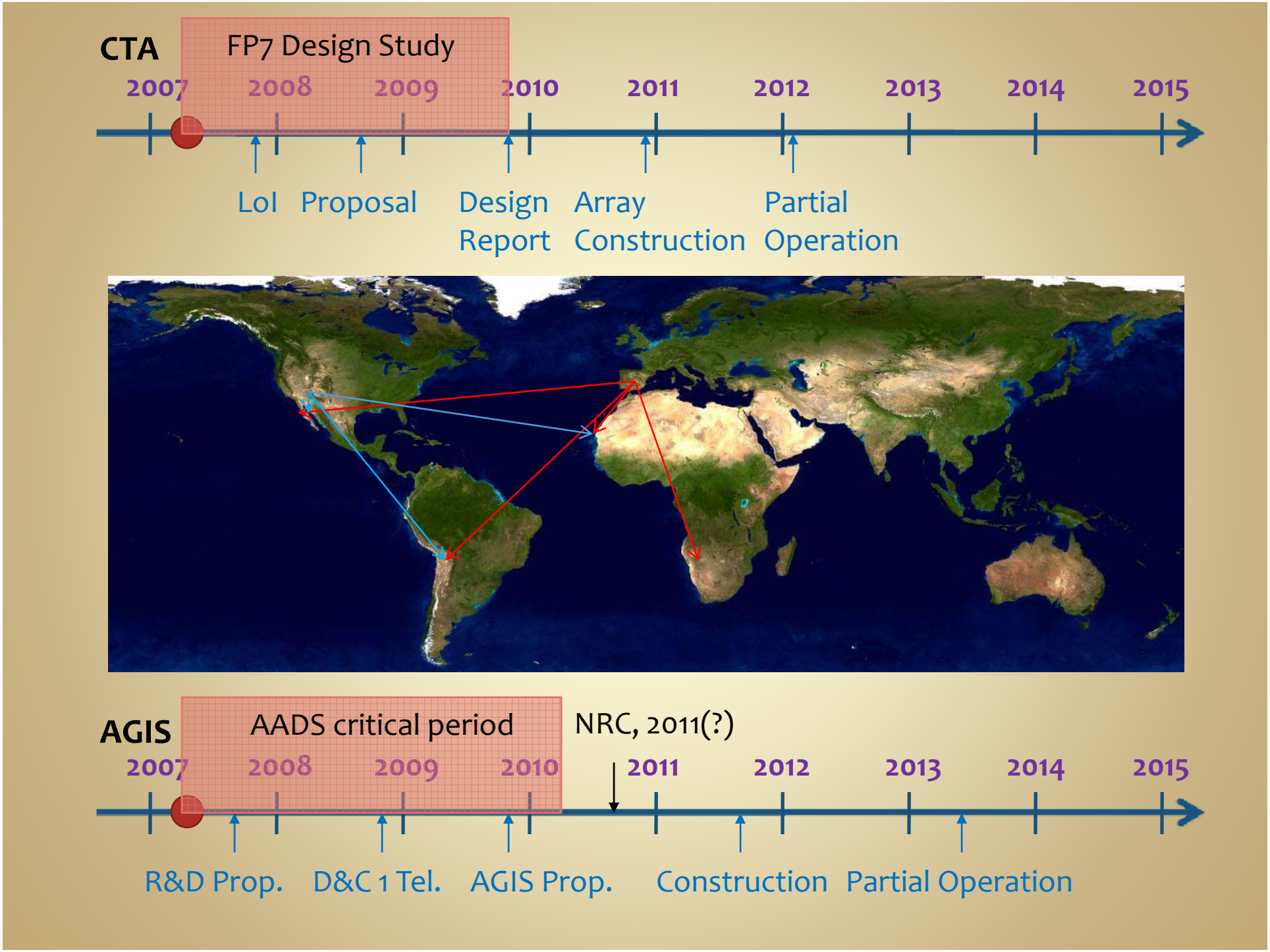
- Feasibility of these technologies may also be coupled with the requirement of having non-traditional telescope designs and therefore with significant R&D, which must be possible within a rather limited period of time.

- Even larger number of options exists for DAQ electronics. Somehow we need to come up with criteria to evaluate and limit discussion of them within the (hopefully!) finite size of the technology section of the WP.

- With these realities a discussion of benchmark technologies which can be used "tomorrow" appears necessary.

Summary

- The goal of this meeting is to contribute to the White Paper for the purposes of planning of the next generation VHE γ-ray instrumentation. The timescale before AADS is short.
- Science is first…
- Technology is second…
- Planning of the next meeting (late fall 2007) to accomplish the task of AGIS collaboration formation is third…


CTA
FP7 Design Study
2007
2008
2009
2010
2011
2012
2013
2014
2015
LoI
Proposal
Design Report
Array Construction
Partial Operation
AGIS
AADS critical period
NRC, 2011(?)
2007
2008
2009
2010
2011
2012
2013
2014
2015
R&D Prop.
D&C 1 Tel.
AGIS Prop.
Construction
Partial Operation