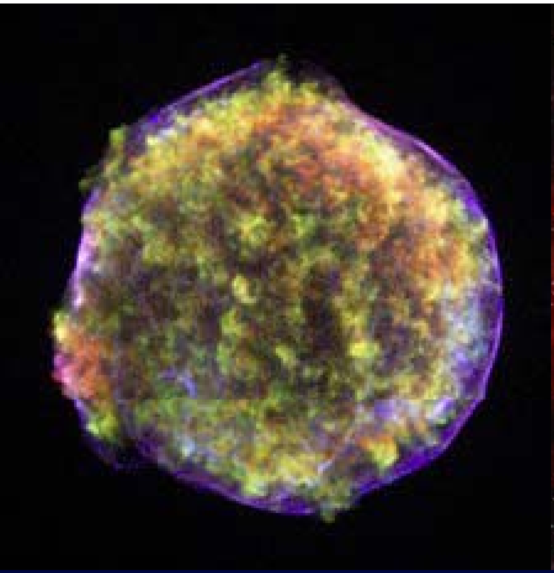
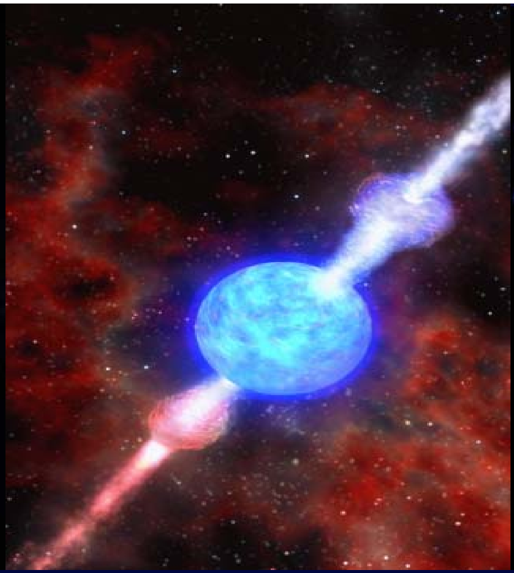
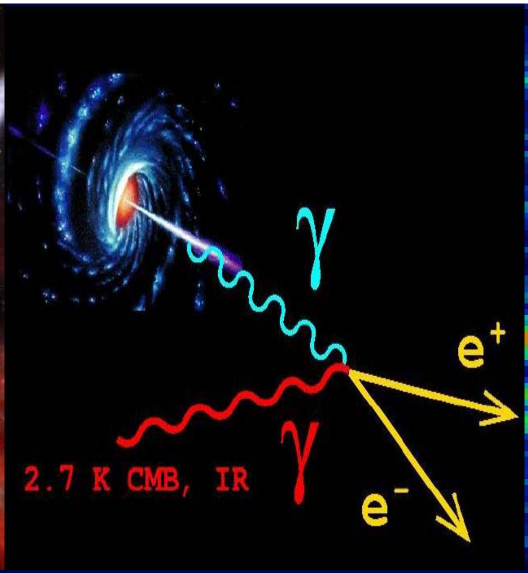
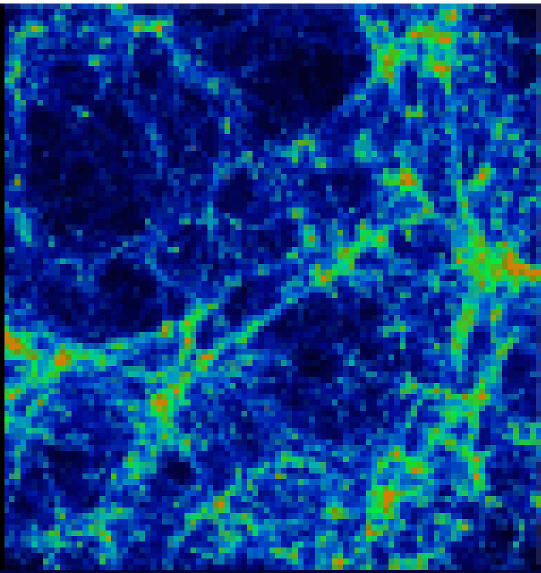








The High-Energy Universe

Rene A. Ong (UCLA)

SLAC 50th Anniversary Celebration, 24 September 2012

Cosmic Messengers

We learn about the universe (outside the solar system) from four messengers:

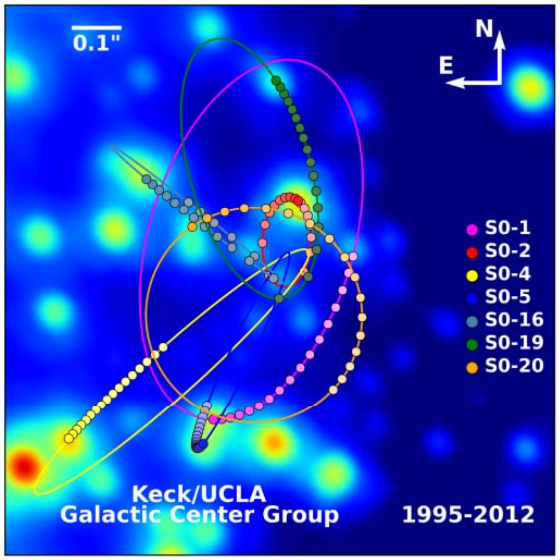
Messenger		**Strength**	**Weakness**
Photons	γ	neutral	absorbed
Cosmic Rays	p, He^{++}, …	copious	deflected
Neutrinos	ν	neutral	hard to detect
Gravitational Waves		neutral	very hard to detect

This talk will summarize our understanding and goals of messengers 1-3 at high energies (E > 1 GeV).

New wavebands = New insight

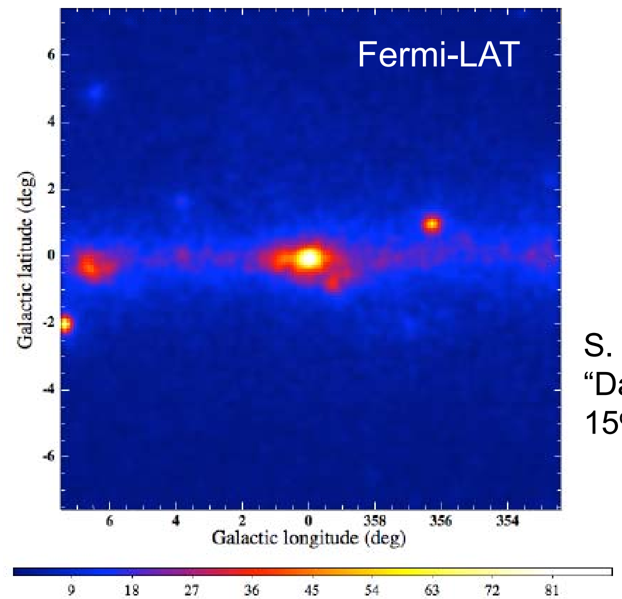
Milky Way Galactic Center region

Infrared



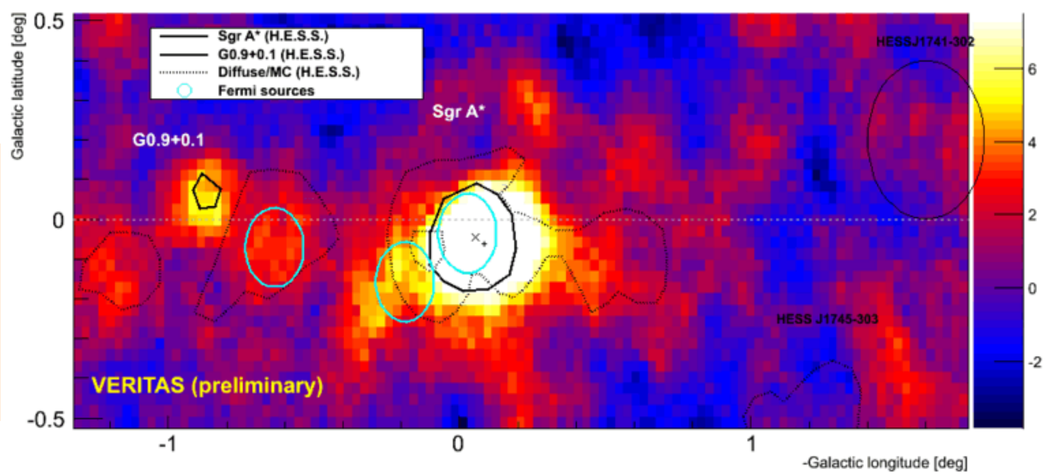
Ghez et al., 2012
1″ x 1″

GeV γ-rays



S. Murgia,
"Dark Attack 2012"
15° x 15°

TeV γ-rays



M. Beilicke et al.
"Gamma 2012"
1° x 3°

GeV & TeV emission is:

- Intense & non-thermal
- totally unexpected
- not understood

Outline

Introduction

- The study of high-energy particles in the cosmos
- Detection techniques, first detectors
- Main scientific motivations

Present Landscape

- Survey of existing experiments, SLAC program
- (A few) recent scientific highlights: γ's, CR's, ν's

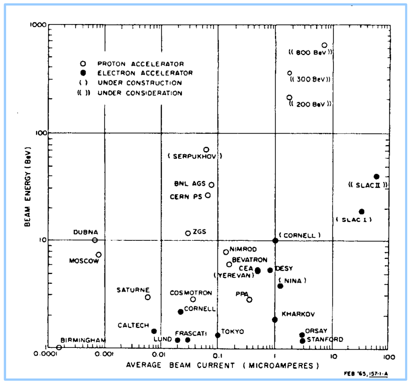
Future

- Key science goals for future
- New instruments & new ideas
- Science results presented at SLAC's 75th Anniversary !

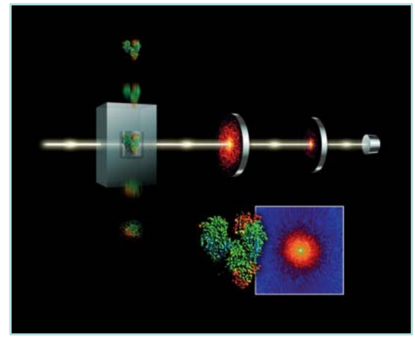
Summary, Acknowledgements

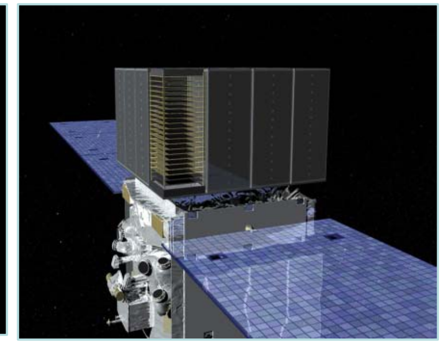
We celebrate two great anniversaries in 2012:

50th Anniversary of SLAC



50 years

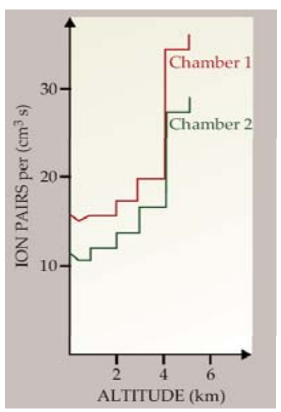




W. Panofsky, SLAC BL, May 1983

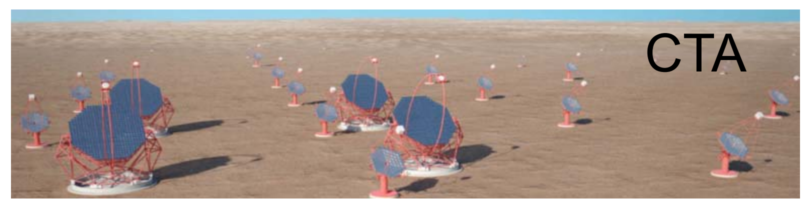
100th Anniversary of Cosmic Rays

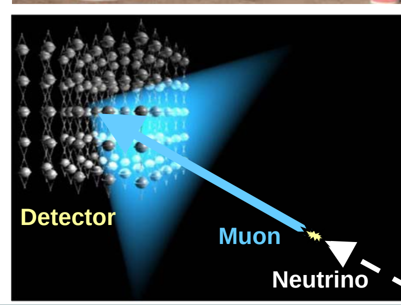
Victor Hess in 1912

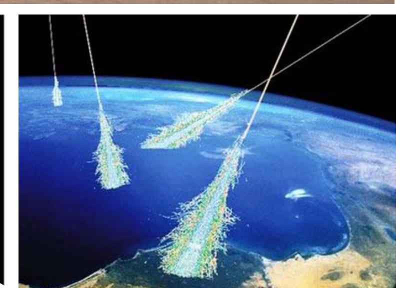


P. Carlson,
Phys. Today, Feb. 2012

100 years





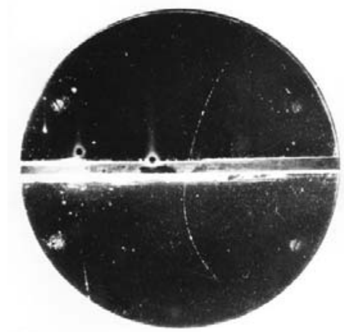


Cosmic Rays: First 50 Years

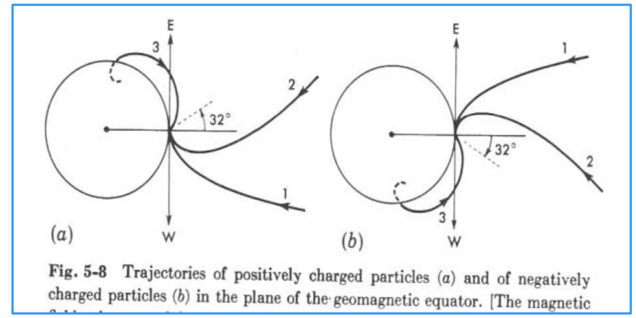
1912 V. Hess discovery

1920-40 Identification as protons

1930-55 New Particles (e^+,μ,π, etc.)
Birth of "high-energy physics"



C.D. Anderson, 1933



B. Rossi, "Cosmic Rays", 1964

1939 Extensive air showers discovered by P. Auger
$E_{cr} > 10^{15}$ eV

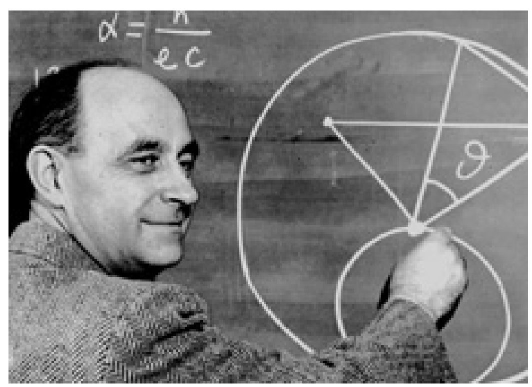
ACADÉMIE DES SCIENCES - SÉANCE DU 18 JUILLET 1938

PHYSIQUE NUCLÉAIRE.- *Les grandes gerbes cosmiques de l'atmosphère.* Note[1] de MM. **PIERRE AUGER** et **ROLAND MAZE**, présentée par M. Jean Perrin.

1. Nous avons montré[2] l'existence de gerbes de rayons cosmiques produites dans l'atmosphère et dont les branches peuvent être distantes de plusieurs mètres. Nous avons pu étendre cette étude jusqu'à des distances de plusieurs dizaines de mètres et mettre ainsi en évidence les effets de corpuscules de très haute énergie dans leur traversée de l'atmosphère. La mesure du pouvoir pénétrant des particules contenues dans ces gerbes montre l'existence d'un groupe présentant un parcours maximum d'environ 15 cm dans le plomb, groupe auquel on peut attribuer le second maximum de la courbe de gerbes de Rossi, et l'anomalie d'absorption contestée par Kuhlenkampff.

P. Auger & R. Maze, Comptes Rendus, 1938

1949 E. Fermi proposes "shock" accelerator



1962 J. Linsley discovery of UHECRs
$E > 10^{20}$ eV !

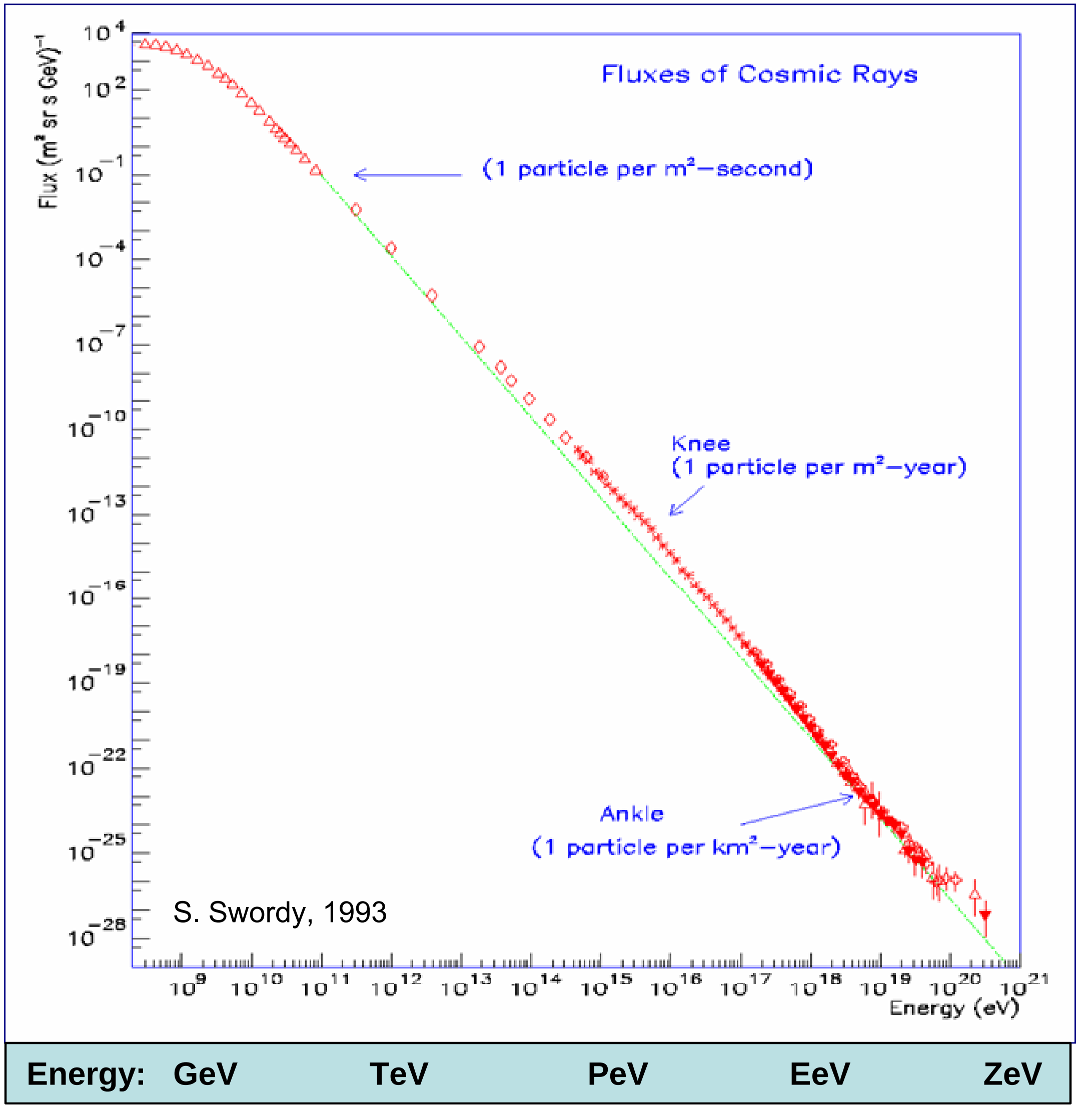
EVIDENCE FOR A PRIMARY COSMIC-RAY PARTICLE WITH ENERGY 10^{20} eV†

John Linsley
Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received 10 January 1963)

J. Linsley looking for rattlesnakes at Volcano Ranch (NM)

At Founding of SLAC

By 1962, we knew that cosmic rays were mostly charged protons & nuclei and that they covered a very large dynamic range > 10^{12}.



Cosmic rays:

- cover an enormous energy range
- have energy density ~ 1 eV/cm^3
- have mysterious origin(s) – bent by galactic B field

Photons, Neutrinos:

- are un-deflected by B fields
- can be used to directly image astrophysical sources

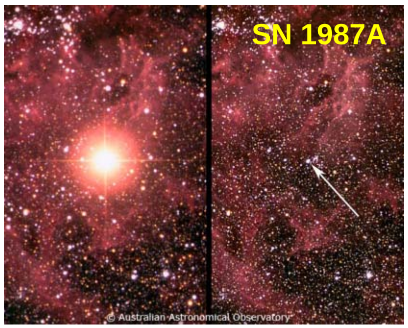
1962:

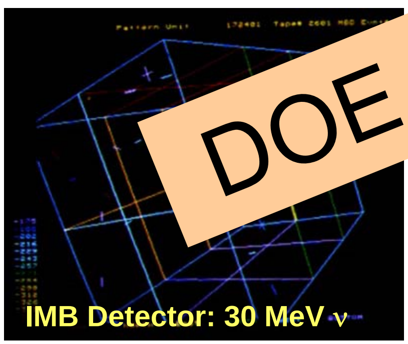
Ideas for γ-ray and ν astronomy existed – but it took another 25 years to bear fruit … skipping forward ...

γ–ray and Neutrino Astronomy

The few years following 1987 were critical ones for γ-ray and ν astronomy:

1987





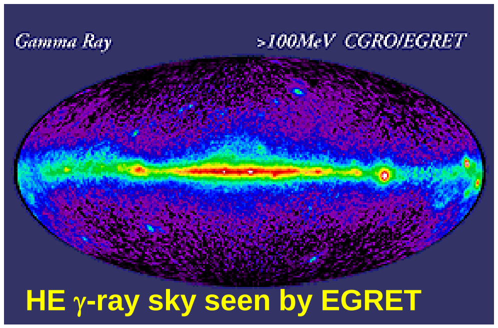
Detection of ν's from SN 1987A

1989

Crab Nebula: First TeV γ-ray source

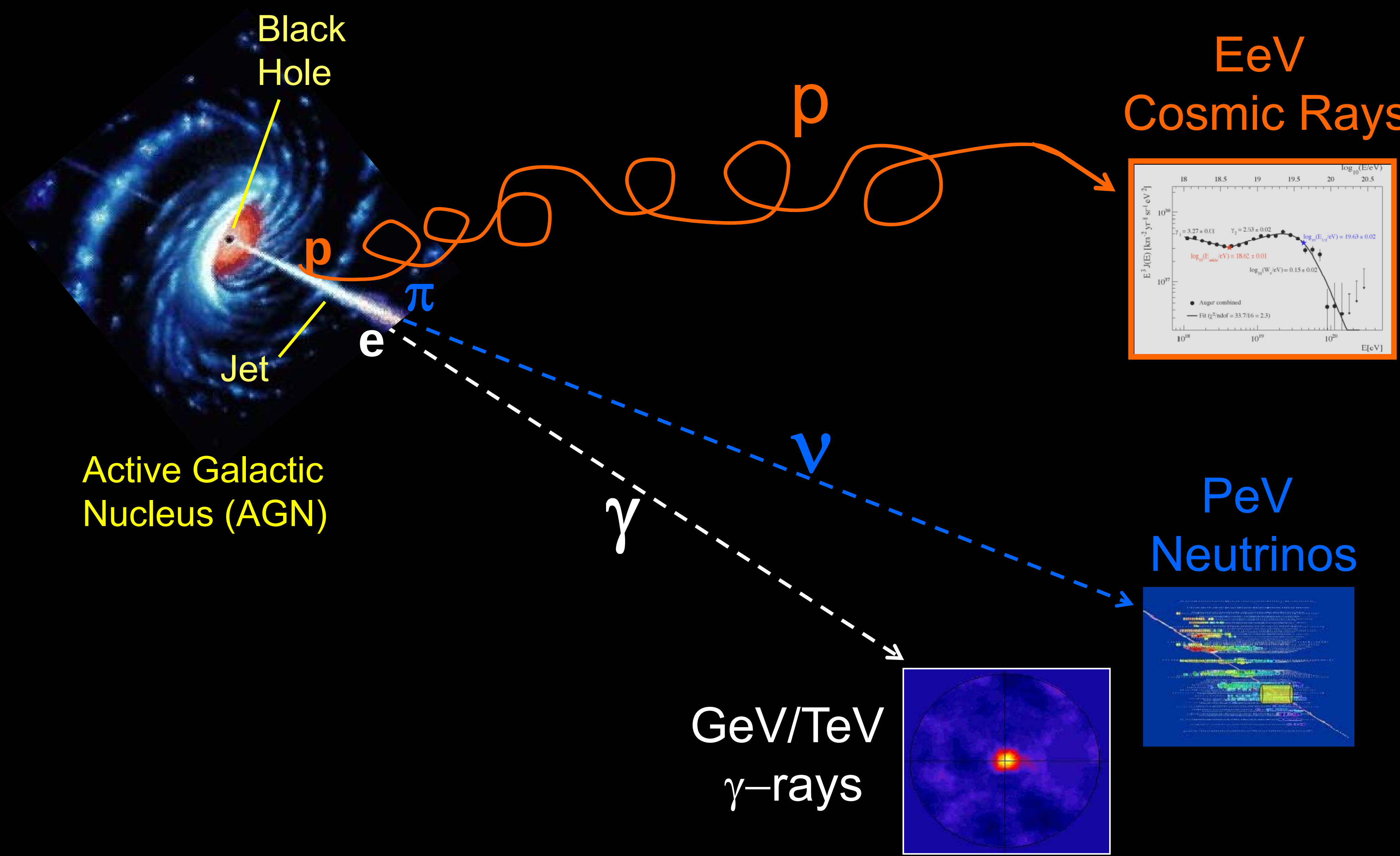
DOE Supported !

1991



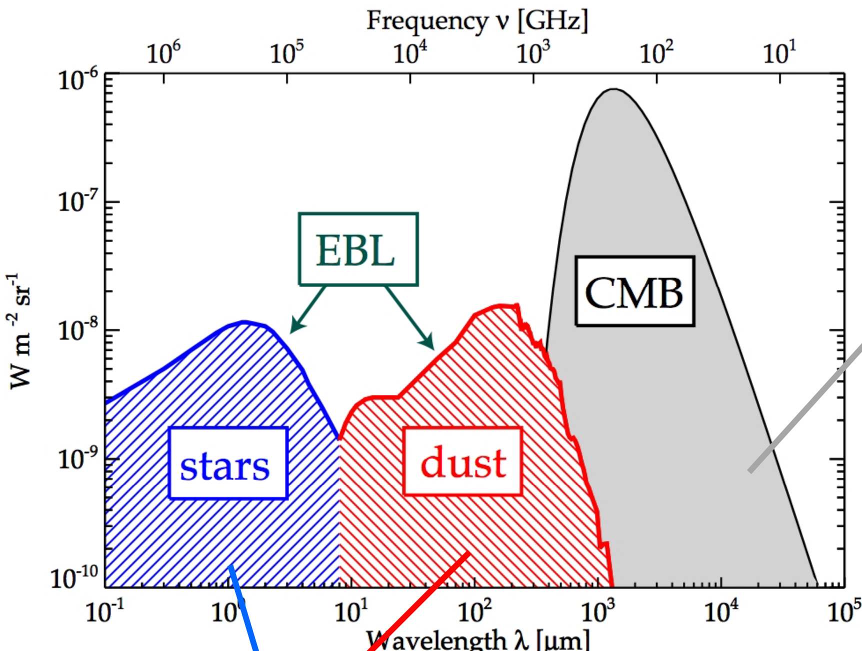
Launch of Compton γ-ray Observatory

Multi-Messenger Science



γ-ray & Cosmic Ray Horizon

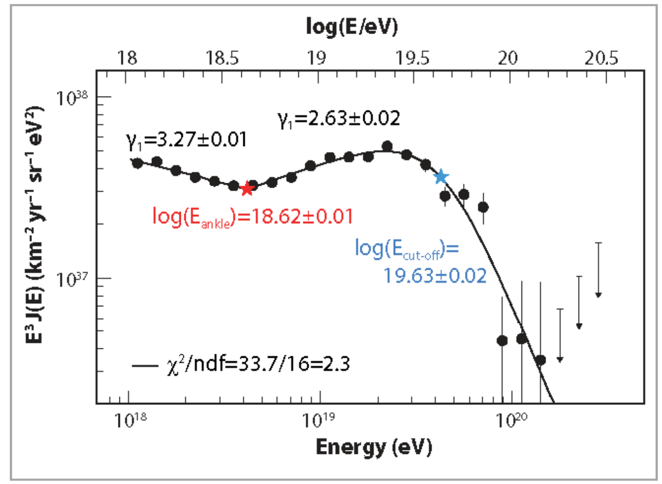
Intergalactic radiation fields limit the range of γ-rays and cosmic rays:



$P\ \gamma_{CMB} \rightarrow \Delta^+ \rightarrow N\pi$

"GZK Effect"

Suppression $E_p > 6\ x10^{19}eV$

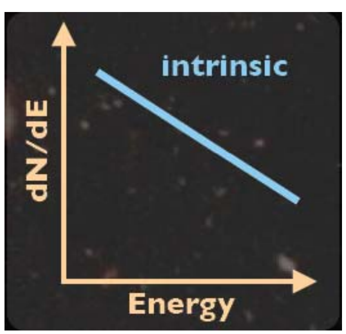


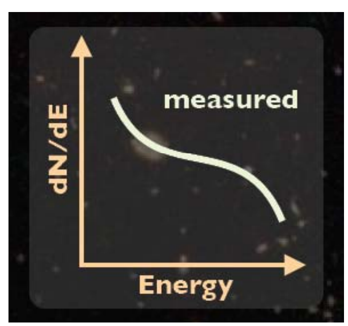
Limits the distance to sources to < ~150 Mpc.

→ Diffuse "GZK" neutrinos.

$\gamma\ \gamma_{EBL} \rightarrow e^+\ e^-$

Spectral Distortion





Main Scientific Motivations

1. A New Window on the Cosmos

- → Discovery of new astrophysical phenomena (e.g. GRBs, Fermi bubbles, Galactic center …).
- → Understanding the sources of high-energy particles: Tevatrons/Pevatrons involving "extreme astrophysics".
- → Multi-messenger astronomy: cosmic rays, γ-rays and ν's providing complementary views.

"You can observe a lot by just watching." (Yogi Berra)

2. Connection of "Inner-Space" ←→ "Outer-Space"

- → New physics/new particles → detectable HE signatures (e.g. dark matter, primordial black holes, etc.).
- → HE beams over long distances → tests of cosmology and the nature of space-time.

"The universe is … an elementary particle physics laboratory." (David Schramm)

A New Window on the Cosmos

Key points on "extreme astrophysics":

→ **The universe is <u>filled</u> with luminousTevatrons/Pevatrons. We are just starting to understand how they work.**

→ **The energy supply for these sources harnesses gravitational/EM potentials in a wide variety of astrophysical situations.**

→ **Charged particles are accelerated to ultra-relativistic energies with diverse mechanisms/parameters.**

The Many Faces of Particle Acceleration

Pulsars

NS dynamo

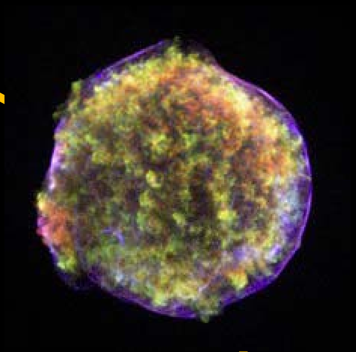
AGN

Jets powered by accretion or unipolar Induction. UHECR's ?

Star Forming Regions

SNRs, cosmic rays, molecular clouds.

Supernova Remnants

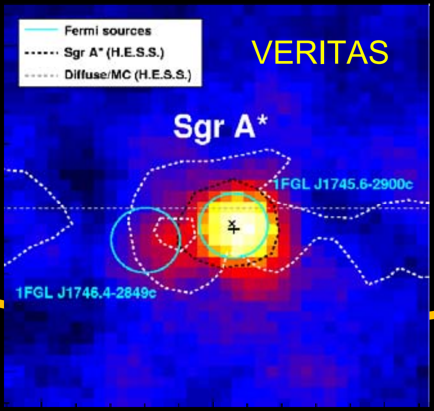


Fermi Acceleration

Gamma-Ray Bursts

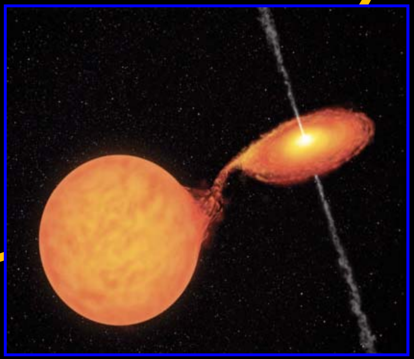
Star collapse→ relativistic jets

Unidentifieds



???

Binary Systems



Accretion jets or stellar winds

Outline

Introduction

- The study of high-energy particles in the cosmos
- Detection techniques, first detectors
- Main scientific motivations

Present Landscape

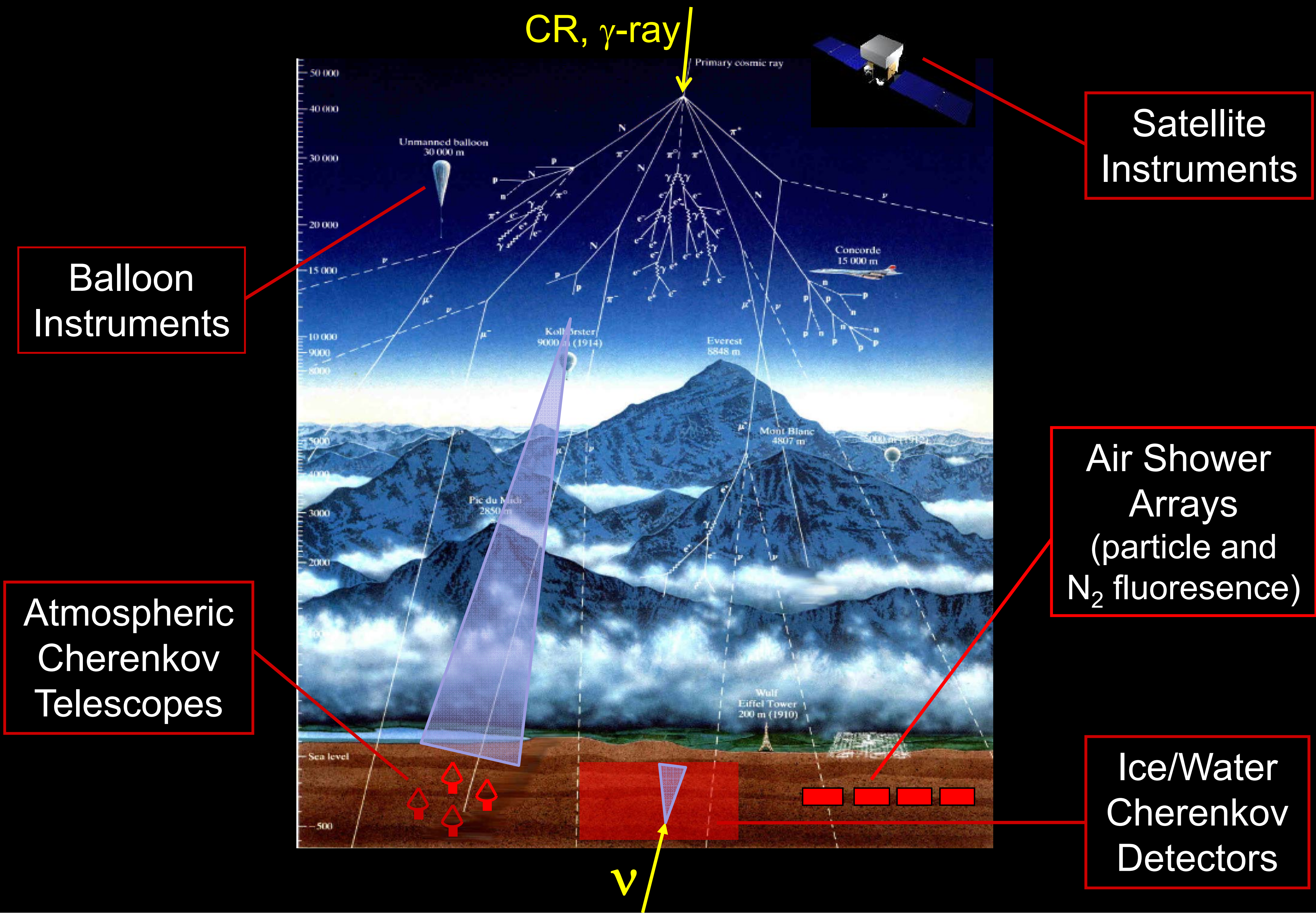
- Survey of existing experiments, SLAC program
- (A few) recent scientific highlights, : γ's, CR's, ν's

Future

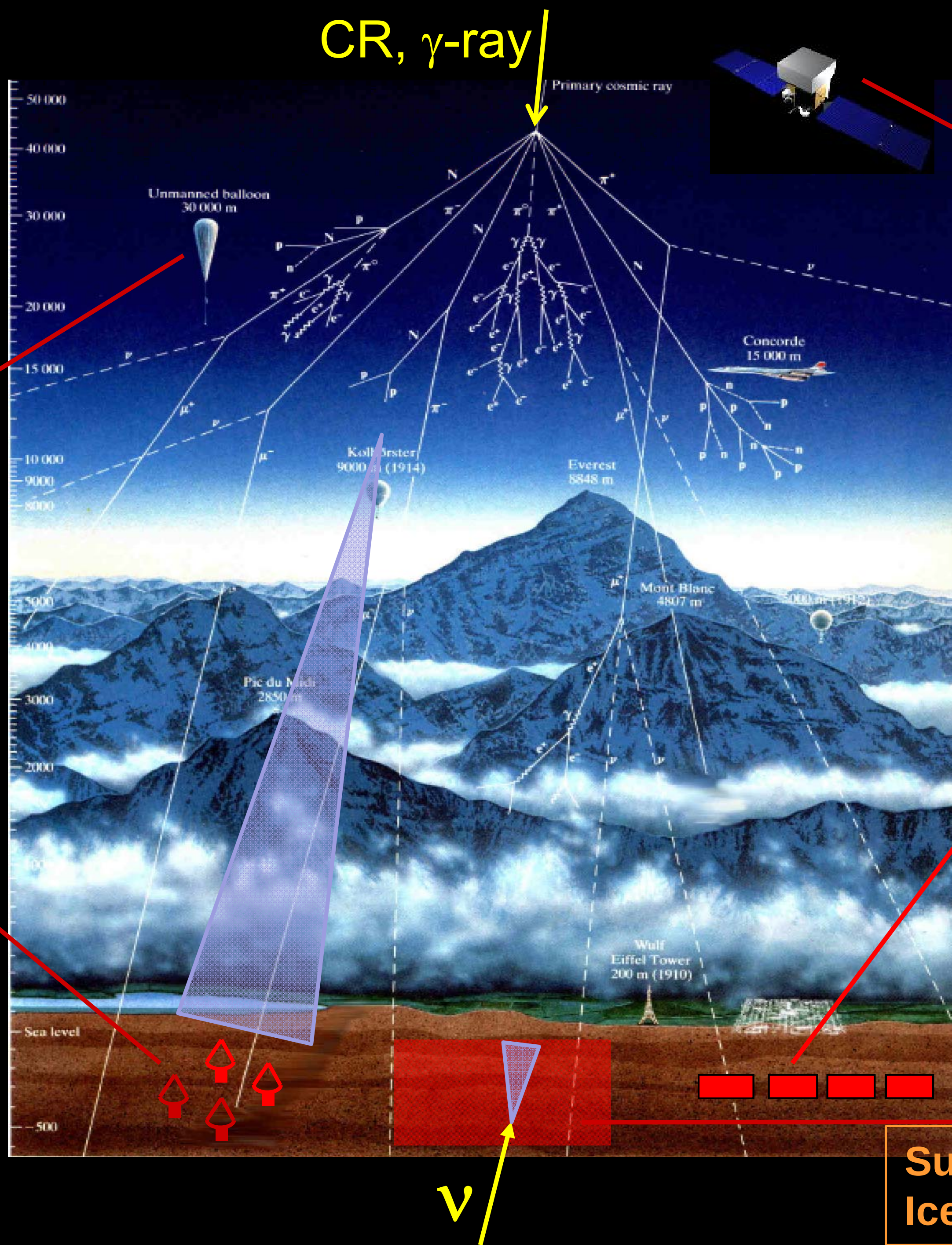
- Key science goals for future
- New instruments & new ideas
- Science results presented at SLAC's 75th Anniversary

Summary, Acknowledgements

CR, γ-ray, & Neutrino Detectors



CR, γ-ray, & Neutrino Detectors (2012)



Satellite Instruments

Fermi Space Telescope

Balloon Instruments

ANITA

Air Shower Arrays (particle and N_2 fluoresence)

Auger
Telescope Array
(HAWC)

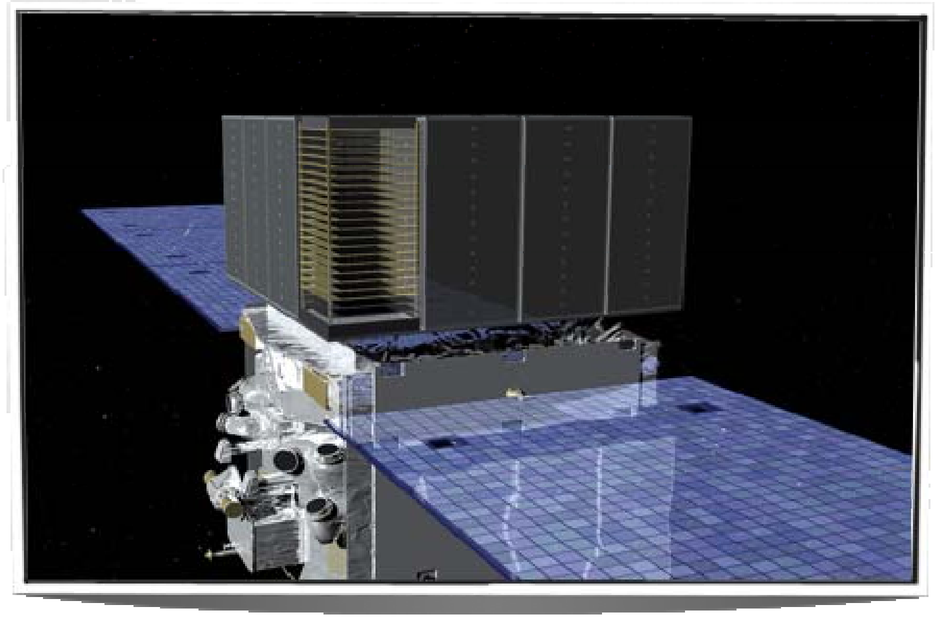
Atmospheric Cherenkov Telescopes

HESS
MAGIC
VERITAS

Ice/Water Cherenkov Detectors

Super-K
IceCube

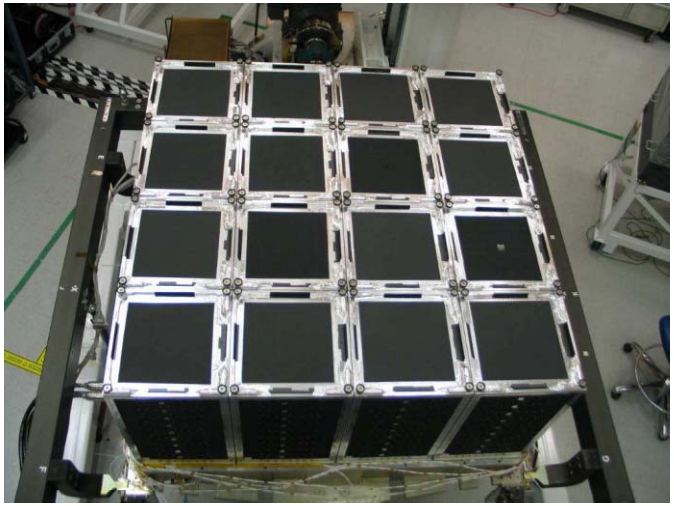
Fermi Large Area Telescope (LAT)



Fermi-LAT Conceptual Picture

Particle detector in space

- γ-rays by pair conversion
- E range: 20 MeV to >300 GeV
- Large field of view
- Launched 11 June 2008

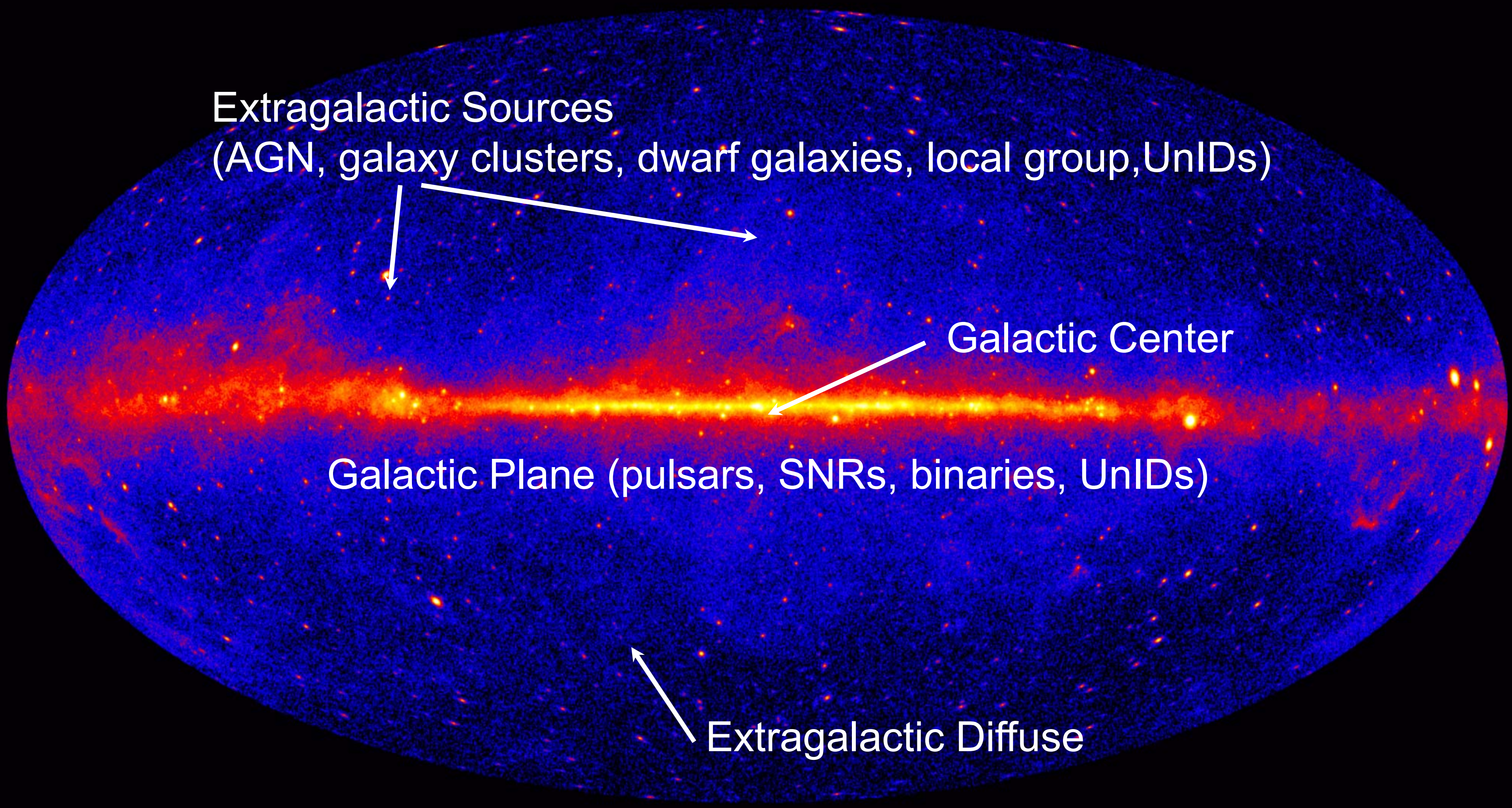


Completed LAT tracker before integration with spacecraft

SLAC's Key Role

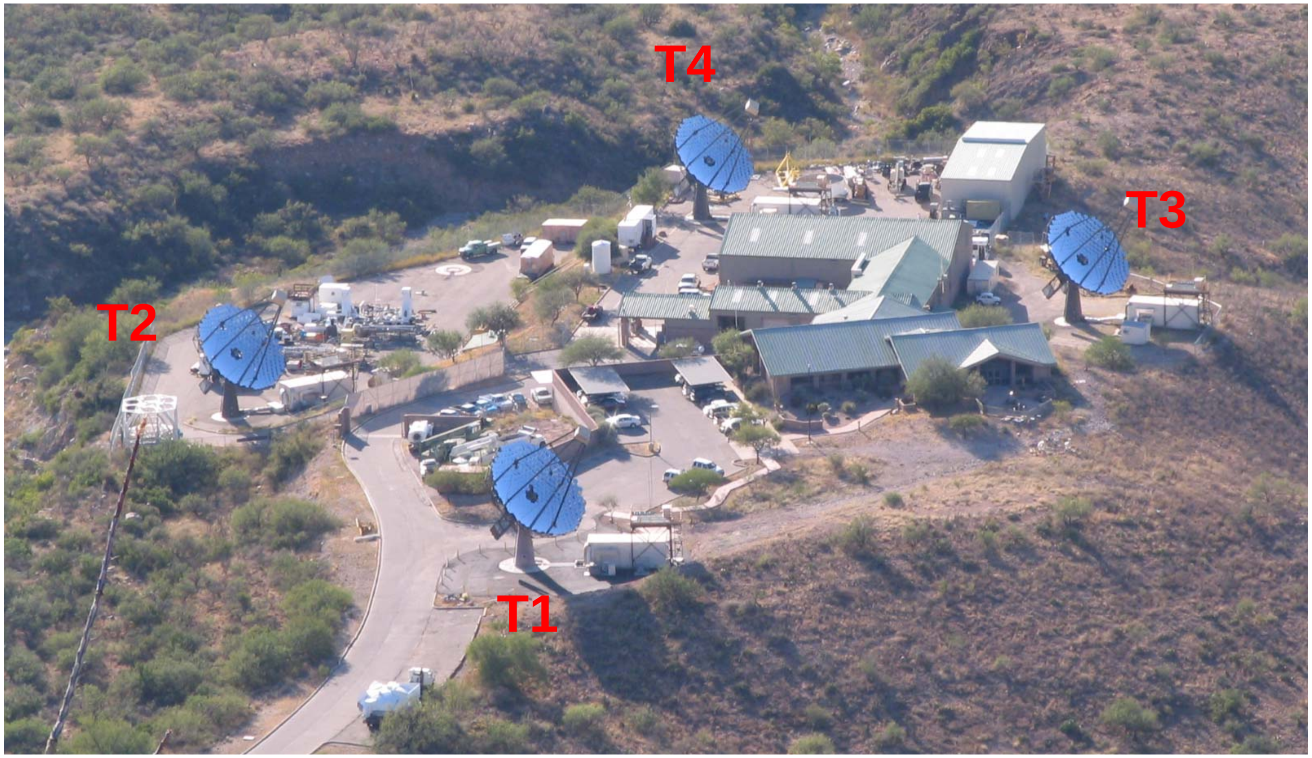
- LAT electronics, flight software
- Beam tests & integration of LAT
- Operations and data processing
- Central in LAT analysis & science
- Host laboratory for collaboration

The GeV Sky (c 2012)

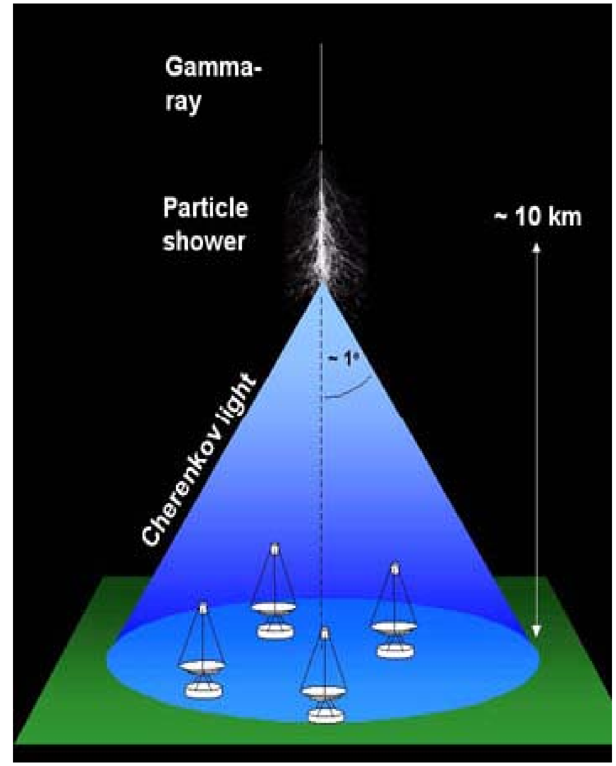


- **Three-year γ-ray sky seen by Fermi-LAT**

VERITAS: Ground-Based γ-ray Detector



VERITAS at Mt. Hopkins, AR, USA



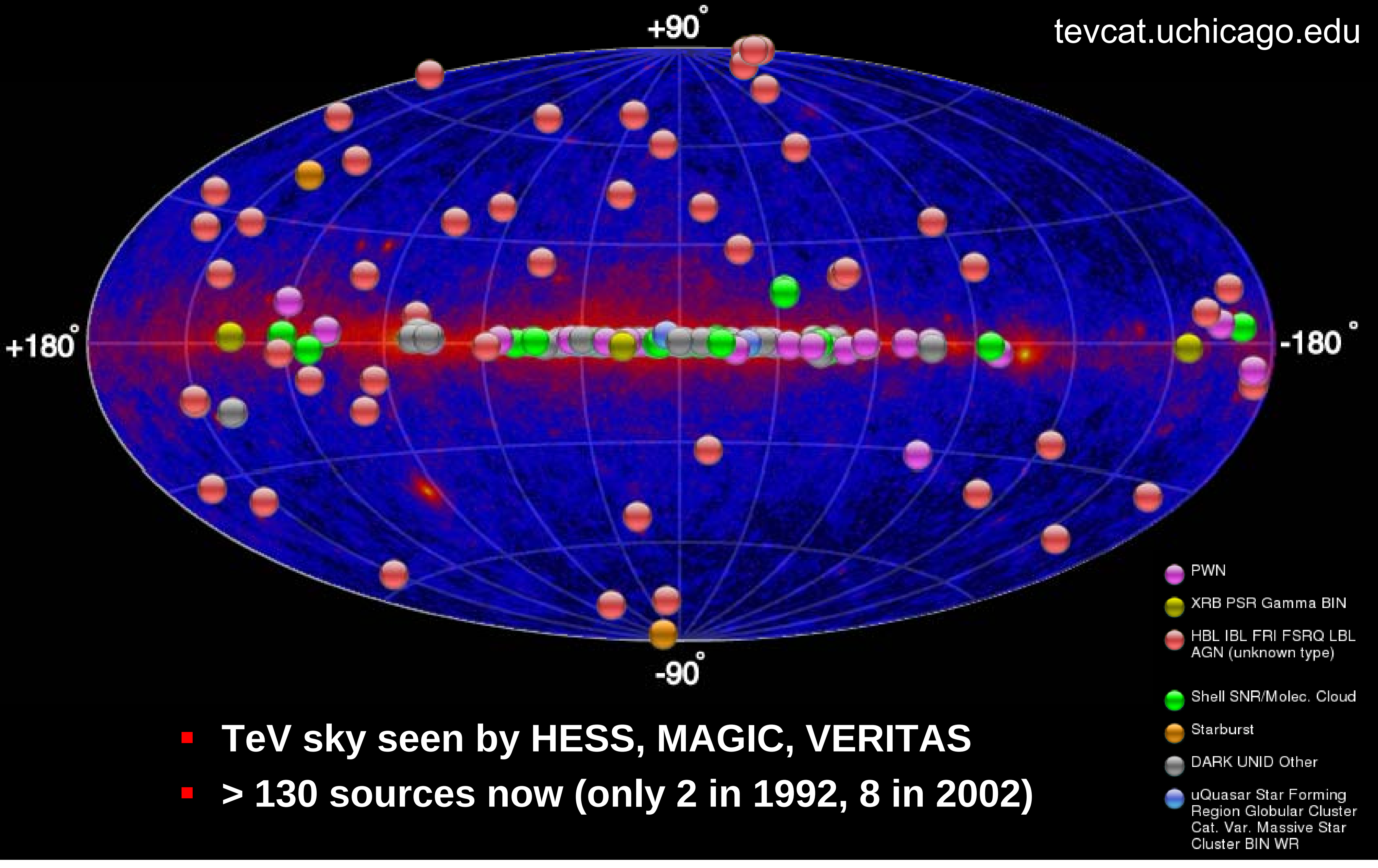
Atmospheric Cherenkov Technique

A premier TeV γ-ray instrument

- Four x 12m atmospheric Cherenkov telescopes
- Energy range: 50 GeV-100 TeV
- Very sensitive, but narrow field of view
- Completing (Sept 2012) camera upgrade

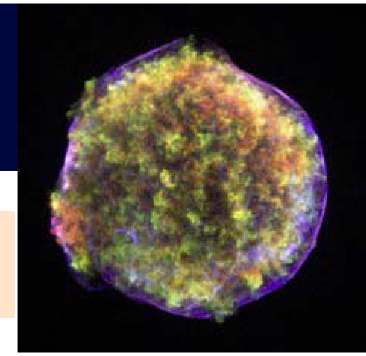
A VERITAS Telescope

The TeV Sky (c 2012)



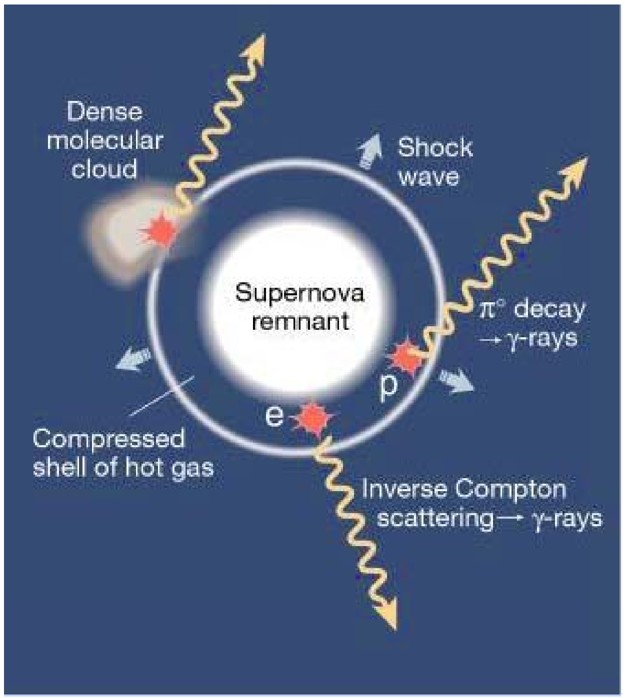
- **TeV sky seen by HESS, MAGIC, VERITAS**
- **> 130 sources now (only 2 in 1992, 8 in 2002)**

SNRs: Origin of Cosmic Rays



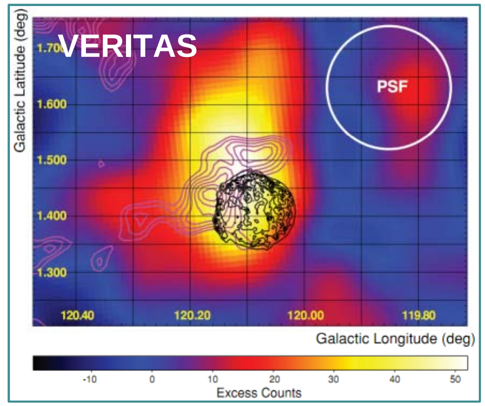
Tycho, age = 440y,
D = 2-5 kpc

General Picture



Recent Data from Tycho's SNR

V. Acciari et al., 2011



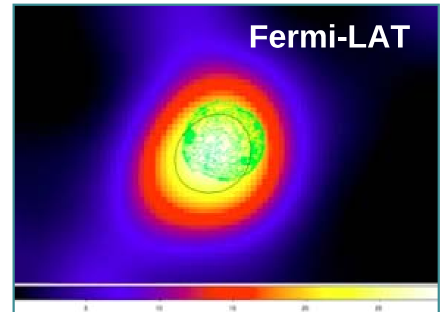
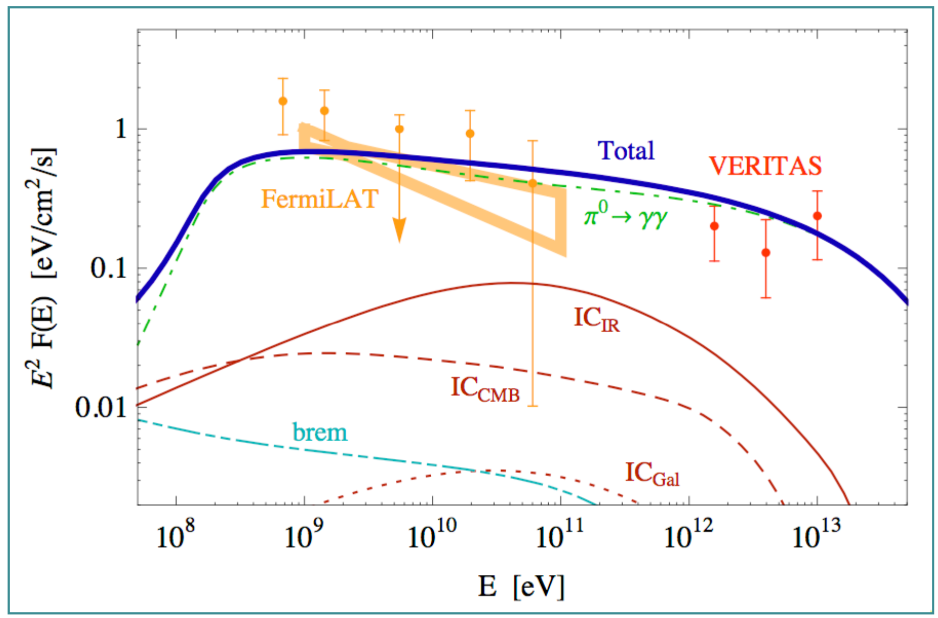


Figure 2: *Fermi TS map of Tycho in the 1 GeV – 100 GeV energy range. The green contours are from XMM-Newton and the black line denotes the 95% confidence area for the FERMI position.*

F. Giordano et al., 2011

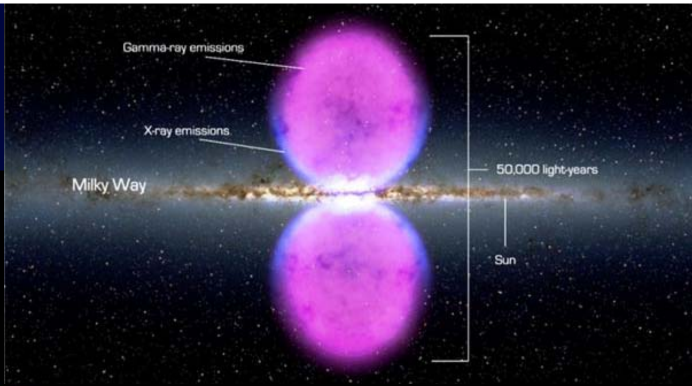


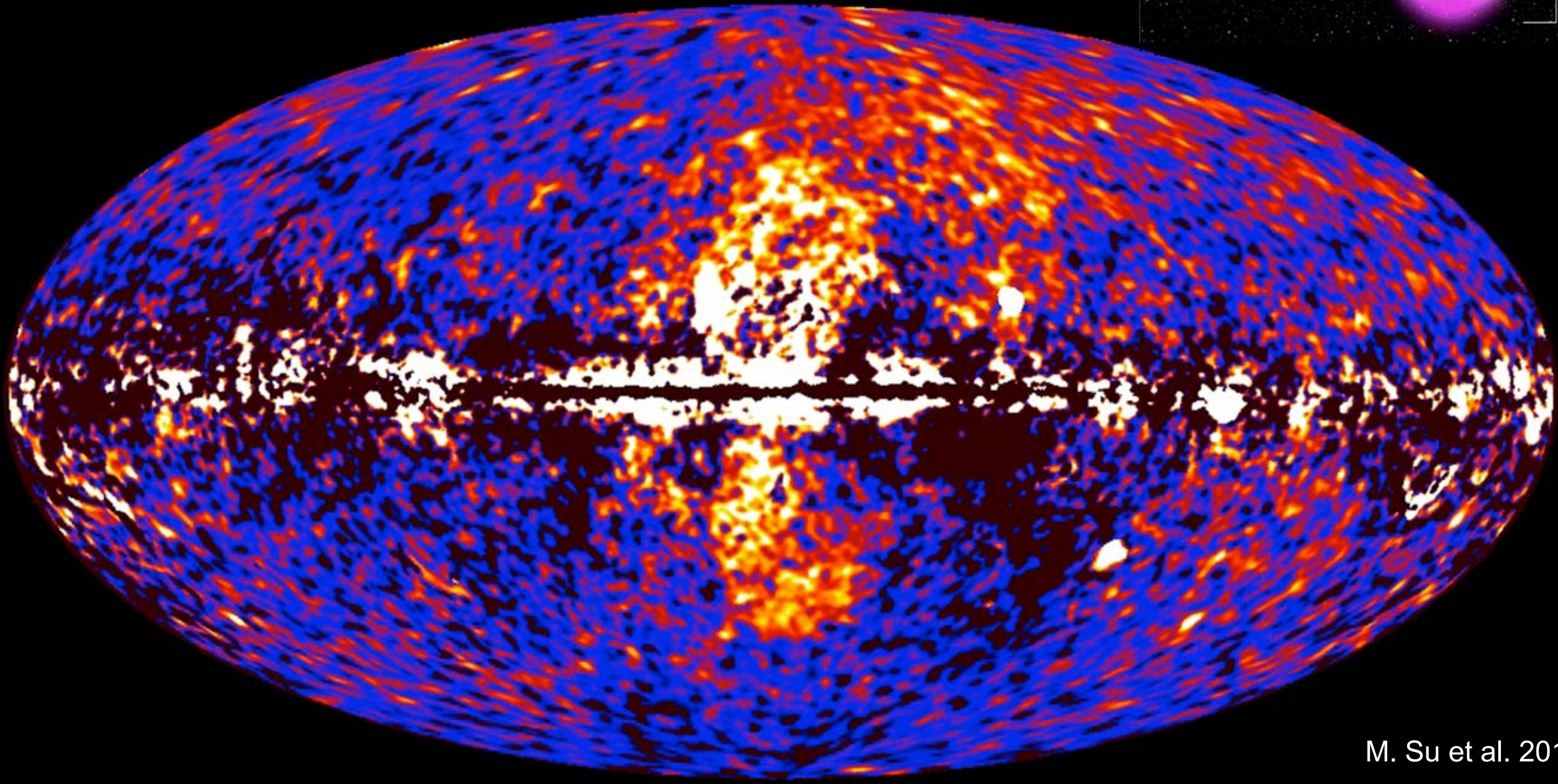
Morlino & Caprioli, 2011

Standard paradigm for CR's

- Gives luminosity, spectral shape.
- Several SNRs now provide evidence for hadron acceleration.
- but … more evidence needed.

Fermi Bubbles



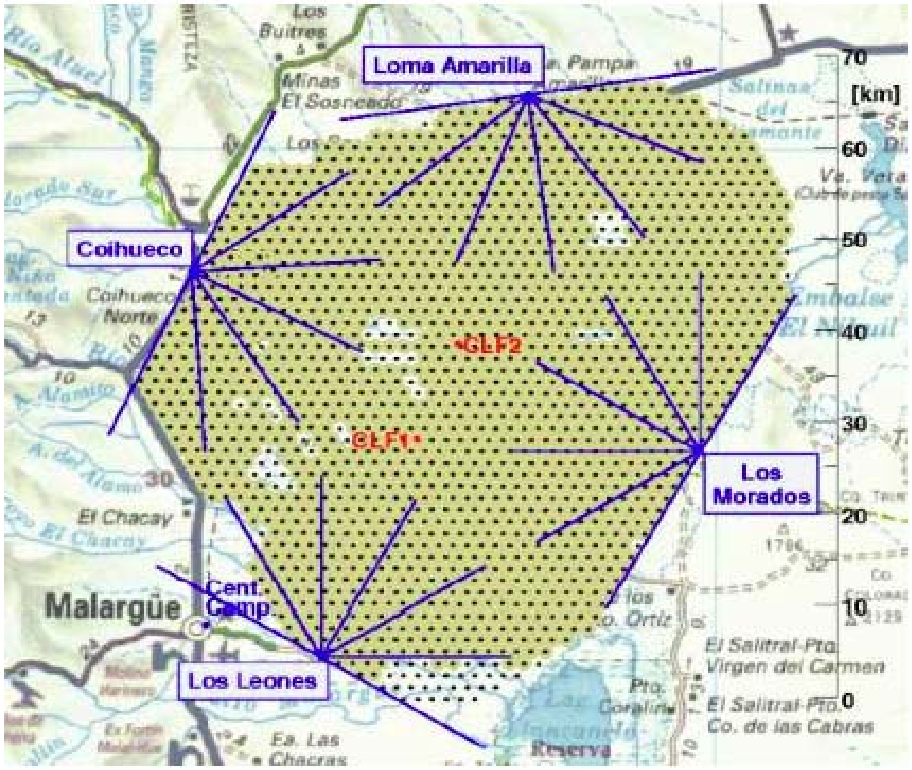


M. Su et al. 2010

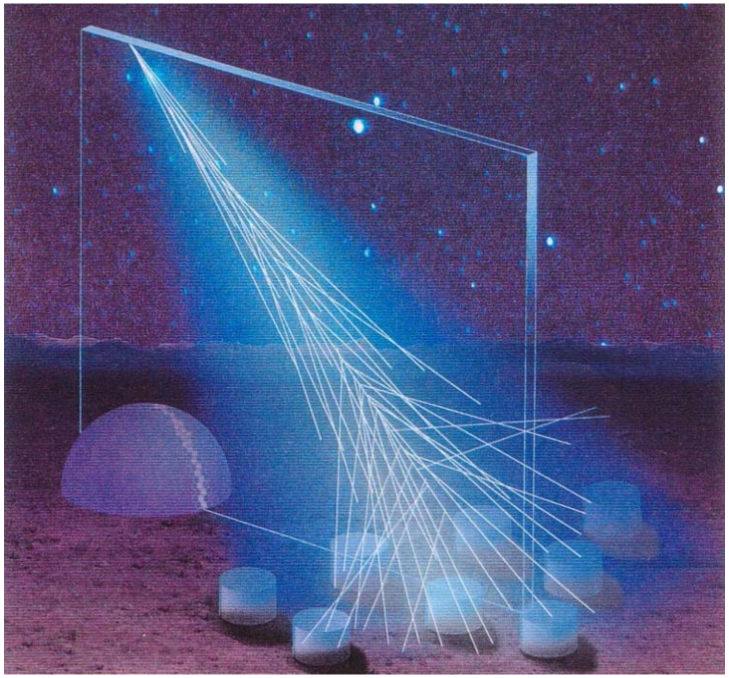
Complete Surprise !

- Very extended (10 kpc) with hard spectrum.
- Related to earlier history of Galactic center ?

Auger Project: 3000 km^2 Detector



Auger Project in Mendoza, Argentina



Surface array & fluorescence detection

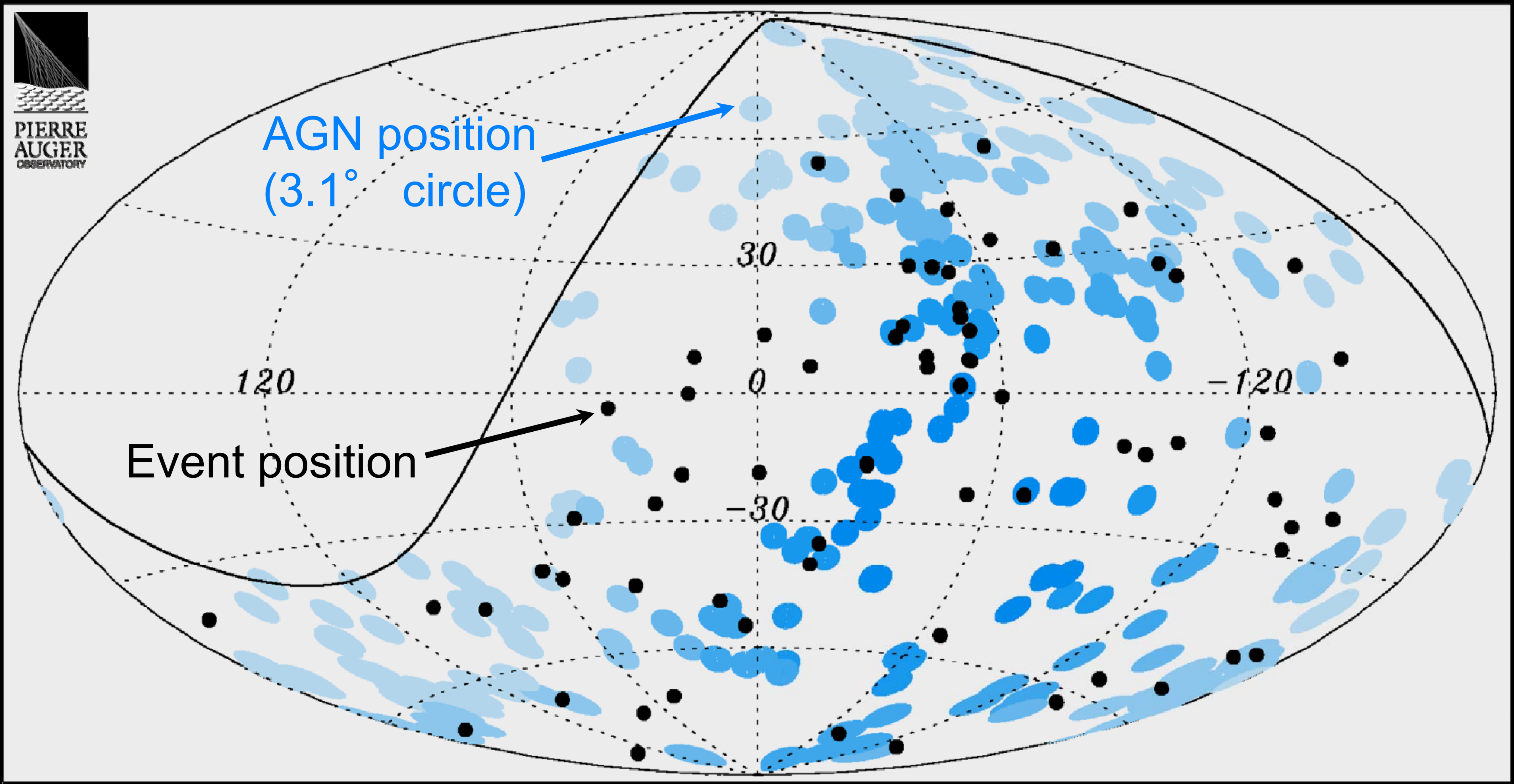
A surface detector & fluorescence station

World's largest particle detector

- 3000 km^2 area covered
- Energy range: E > 10^{17} eV
- Surface array of 1600 detectors
- 24 fluoresence detectors, 4 locations

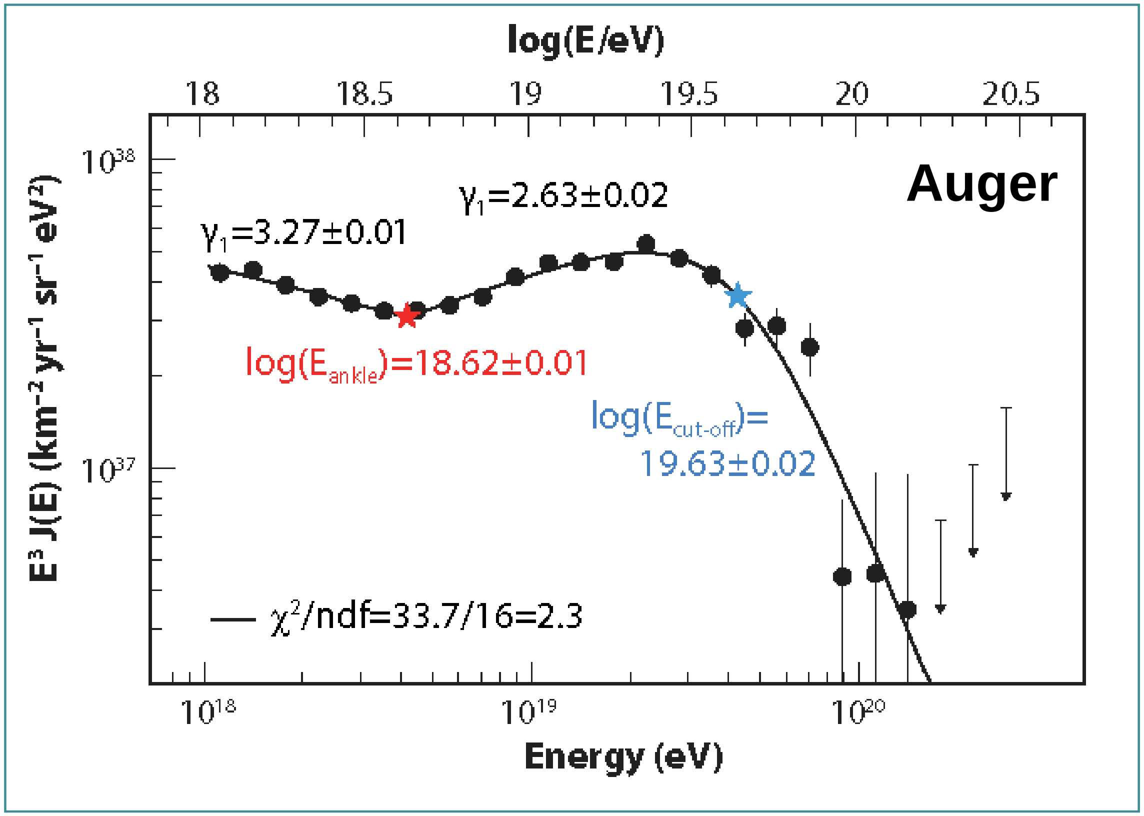
The 10^{19} eV Sky (c 2012)

P. Abreu et al., 2010

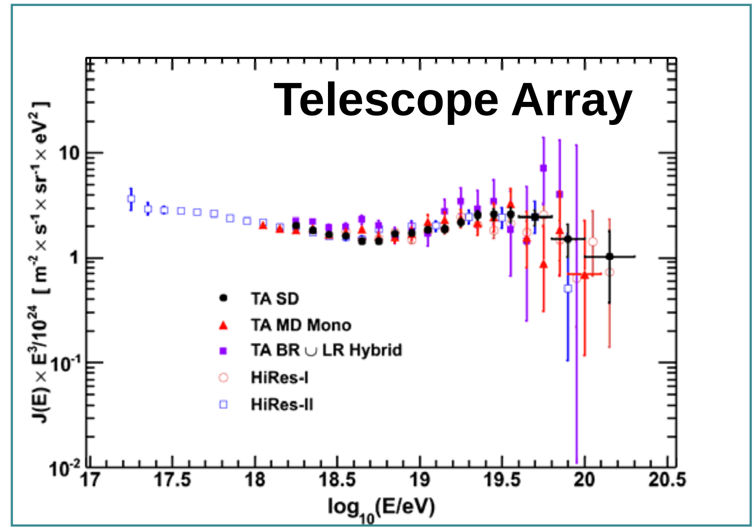


- **EeV sky seen by Auger (E > 55 EeV), 69 events.**
- **Additional 25 events from Telescope Array (E>57 EeV).**

CR's at the Highest Energies



S. Westerhoff, "COSPAR 2012"

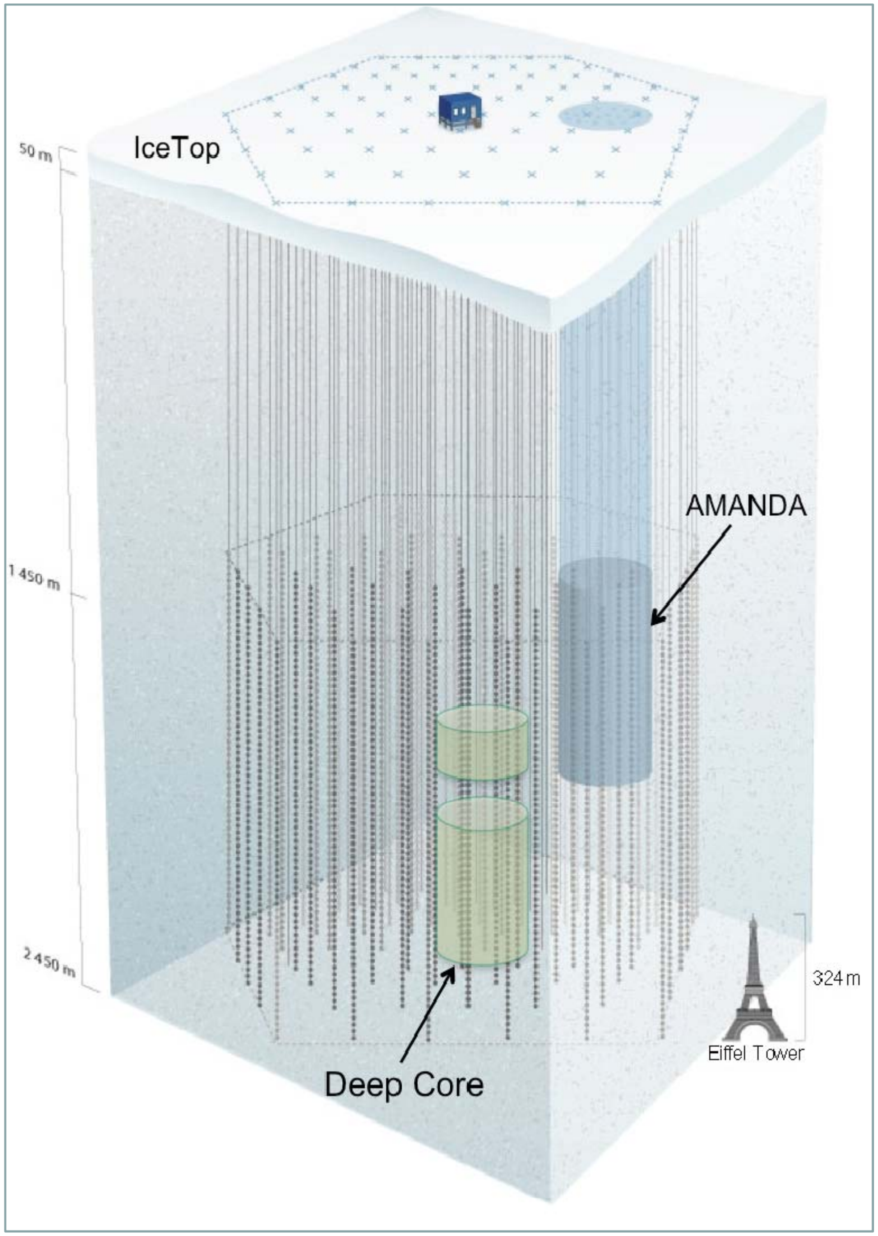


S. Westerhoff, "COSPAR 2012"

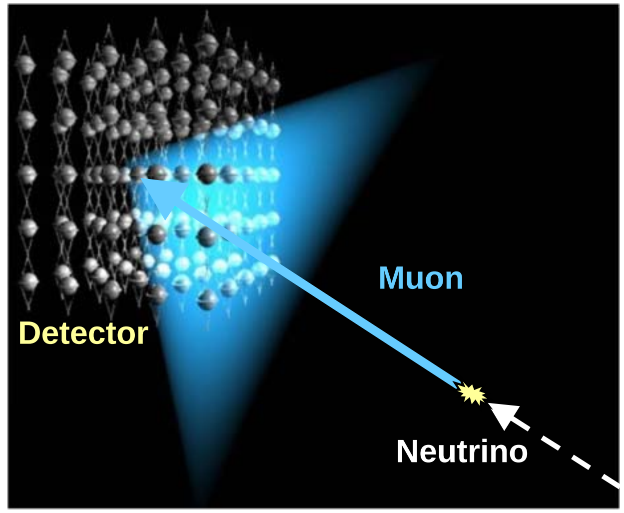
Origin is still unknown

- Auger and Telescope Array agree on spectrum – clear cutoff ~$6x10^{19}$eV
  → Unclear if GZK effect or source acceleration limit
- Weakly correlated with nearby AGN/matter

IceCube: ν Detector at South Pole



Schematic of IceCube at South Pole



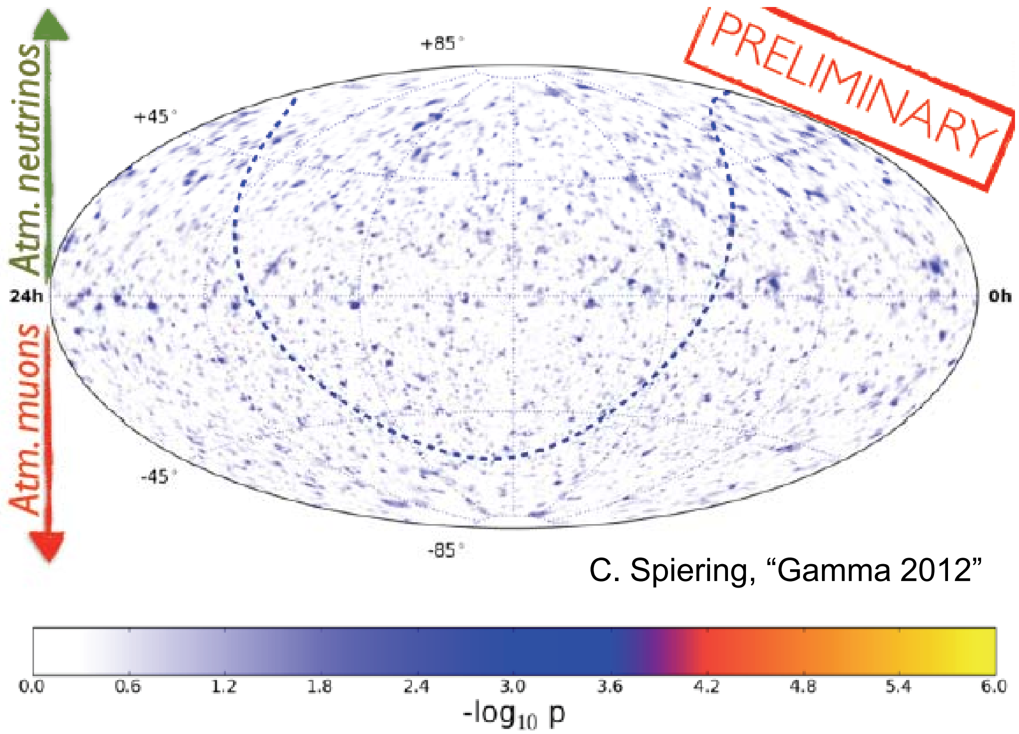
TeV muon-neutrino detection

Installing an IceCube string

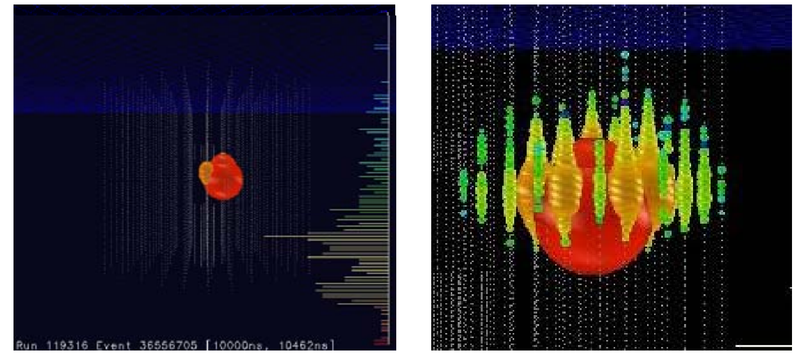
km^3 Neutrino Detector

- Ice-Cherenkov technique
- Energy range: 10^{11}-10^{17} eV
- 86 strings x 60 optical modules
- IceTop for air showers
- Deep Core for low energies

Latest Neutrino Results



IceCube neutrino sky map (probability)



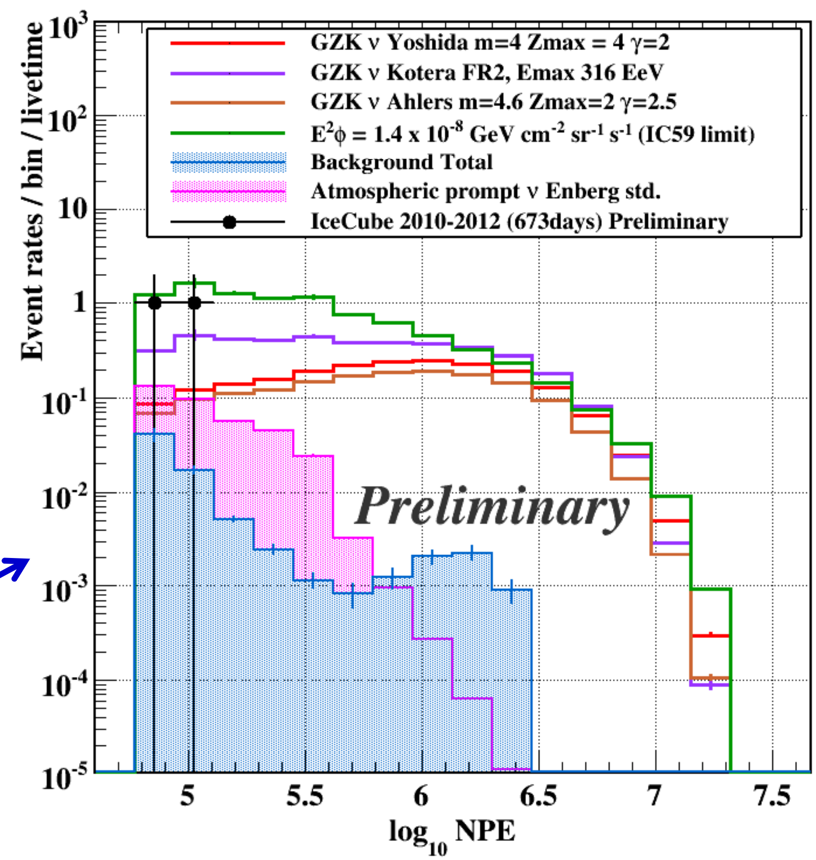
Event displays of one PeV diffuse neutrino event

No ν's detected from point sources.

- Limits now well below initial estimates.

Diffuse Search: 2 detected events

- 0.14 expected from background
- $E > 10^{15}$ eV



Number of photoelectrons detected by IceCube for two shower events, with models/bkgfn.

A. Ishihara, "Neutrino 2012"

Inner Space ←→ Outer Space

New Physics:

- Dark matter annihilation/decay → γ-rays, ν's.
- Exotic particle interactions/decay
  (e.g. axion-like particles, primordial BH's).
- Neutrino properties.
- p-p cross-section at UHE.
- … your item here …

Passage of HE Beams through space:

- Measurement of cosmic radiation fields (EBL, IGMF).
- Lorentz invariance violation.
- "GZK neutrinos" from UHECR interactions.

Dark Matter Detection

γ–ray Signals

Gamma rays from DM annihilation:

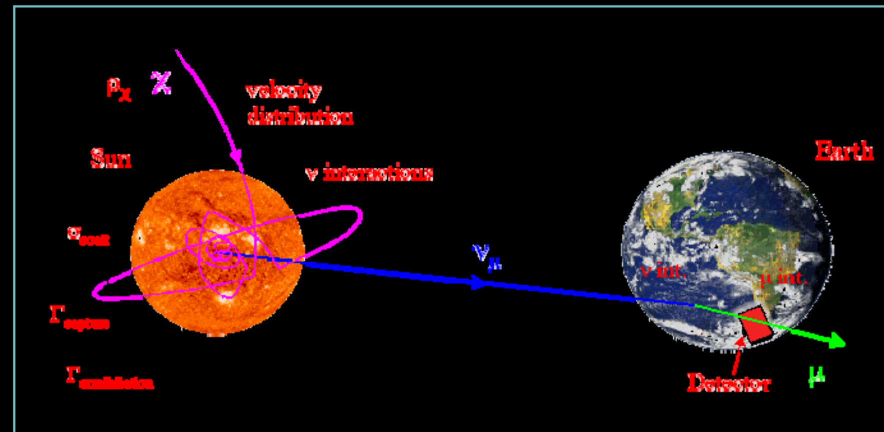
particle physics

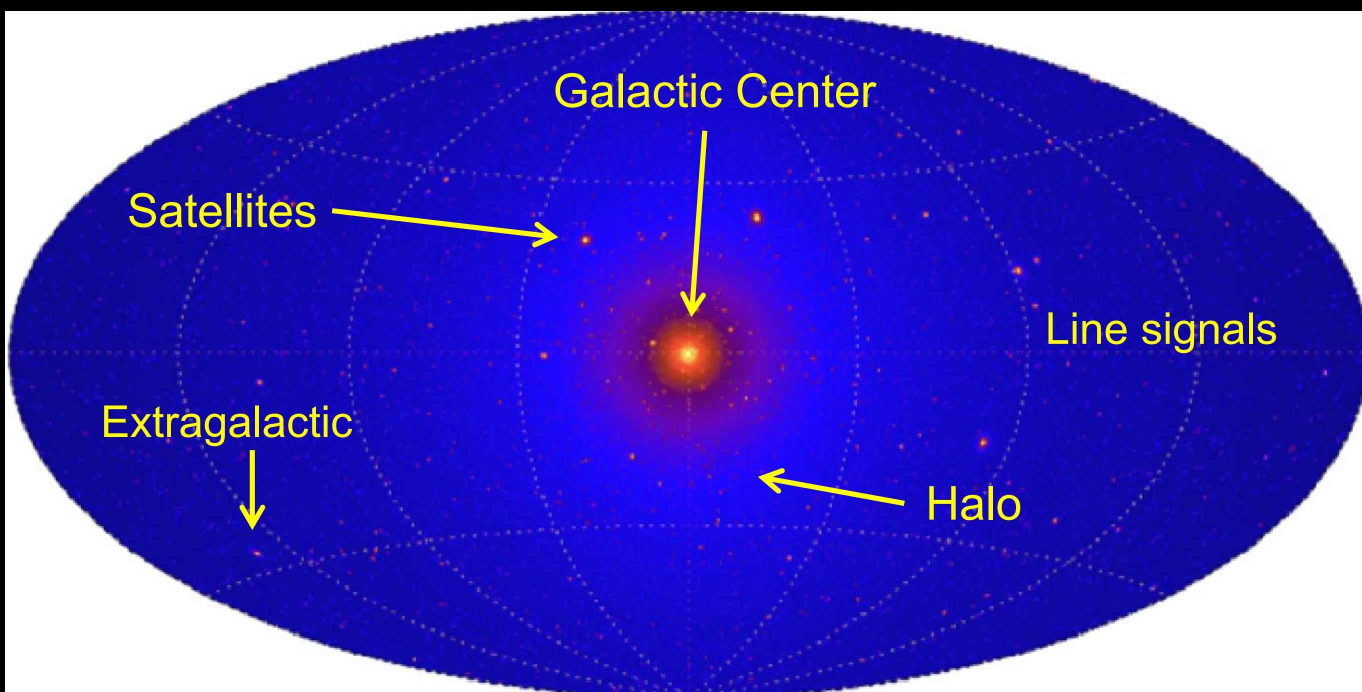
$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\phi,\theta) = \frac{1}{4\pi}\frac{<\sigma_{ann}v>}{2m^2_{WIMP}}\sum_f \frac{dN^f_\gamma}{dE_\gamma}B_f \times \int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{los} \rho^2(r(l,\phi'))dl(r,\phi')$$

DM distribution

S. Murgia,
“Dark Attack 2012”

Neutrino Signals





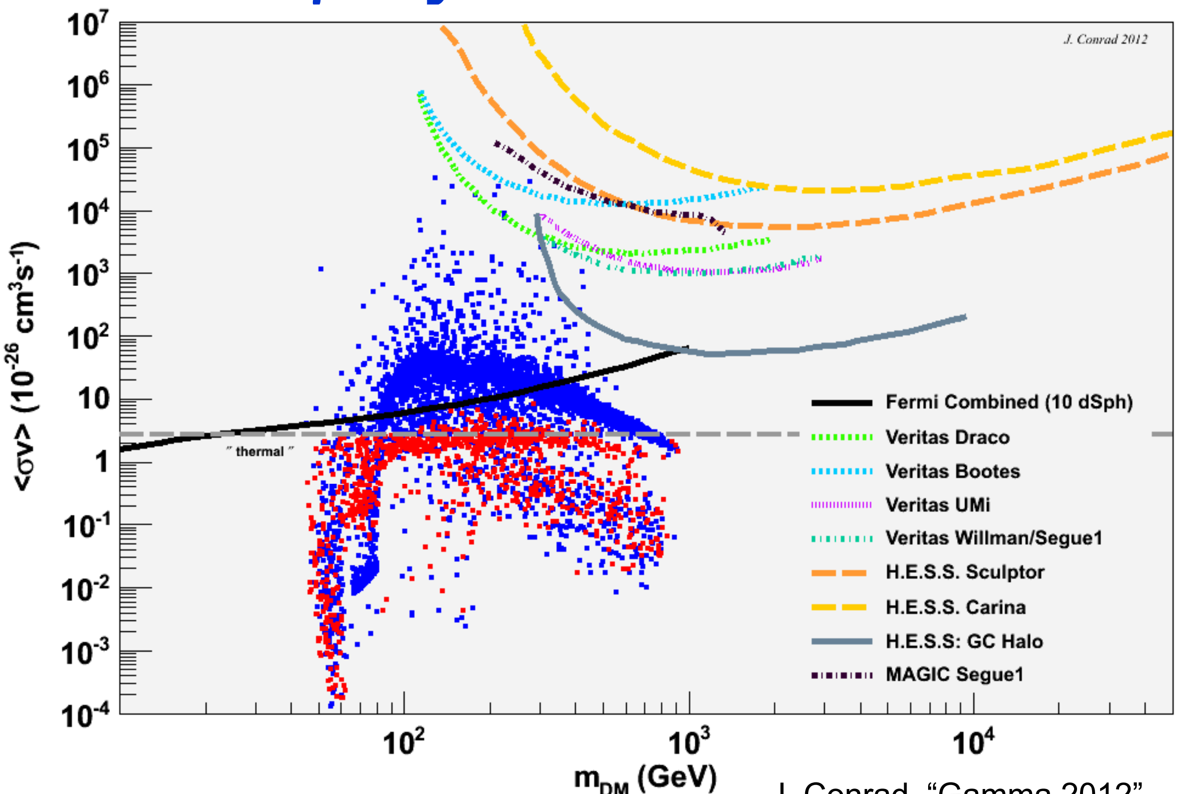
DM simulation (Pieri et al., 2011)

Also charged particles:

- positrons
- anti-protons
- anti-deuterons

Current DM Limits

γ-ray DM limits



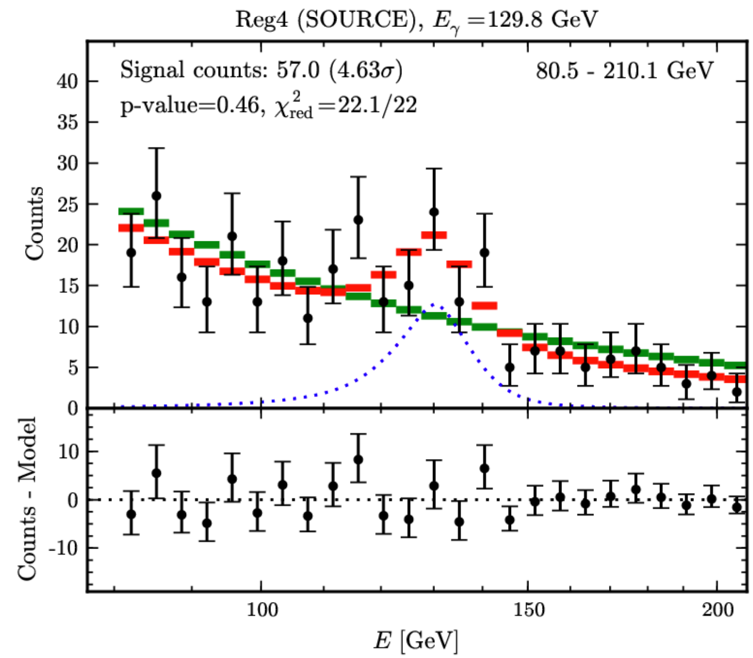
J. Conrad, "Gamma 2012"

No signal (yet)

- Limits at or approaching thermal relic cross section.

But …

C. Weniger, "Gamma 2012"



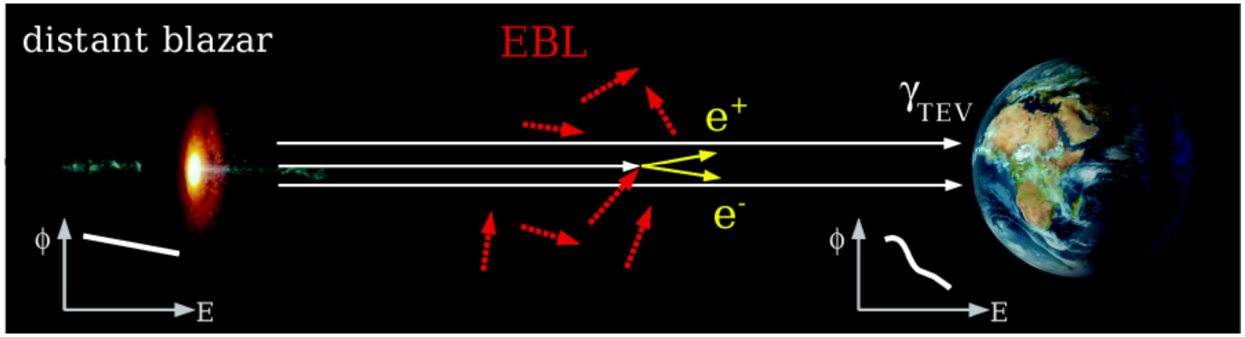
Evidence for line at ~130 GeV

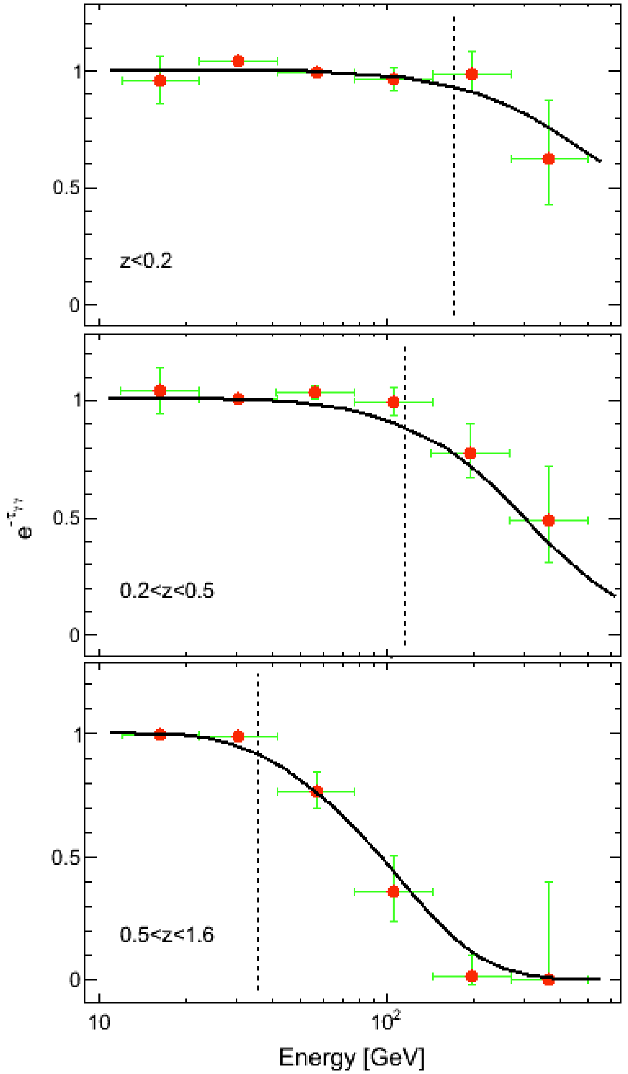
- ~3σ (post trials).
- seen by several authors.
- close to Galactic center.
- systematic effect ?
- can be confirmed or refuted.

Extragalactic Background Light (EBL)

Use γ-ray beam to probe EBL – cosmic O/IR background from history of star formation

M. Ajello, “Gamma 2012”





Previously only upper limits on EBL density.

2012 results by Fermi and HESS provide the first actual determinations of EBL

- Density close to that predicted by resolved galaxy counts → impacts on the star formation history.

SLAC Program

Starting in early 1990’s:

- USA X-ray mission (E. Bloom).
- 1992: Convergence of W. Atwood, E. Bloom, & P. Michelson.
- 1994: GLAST existed (Stanford workshop, Snowmass 94).
- Then SLAC developed a very strong program
  → establishment of LAT Collaboration
- SLAC Directors (Richter, Dorfan, & Drell) gave invaluable support.
- Important connection to Stanford (& establishment of KIPAC).

Some of the significant impacts (so far):

1. Origins of LAT and successful operations & science from Fermi.
2. Critical work to demonstrate Askaryan Effect → ANITA ν Experiment.
3. Theoretical work.
4. Development of Cherenkov Telescope Array (CTA).
5. (Large Synoptic Survey Telescope – important HEP expertise).

1992 Talk (Transparencies!)

SLAC 3/24/92
RENE ONG

PHYSICS AND ASTROPHYSICS

AT PeV ENERGIES

INTRODUCTION

PHYSICS – ORIGIN OF COSMIC RAYS

ASTROPHYSICS – VERY HIGH ENERGY ACCELERATION
DIFFUSE γ-RAYS
COSMOLOGY

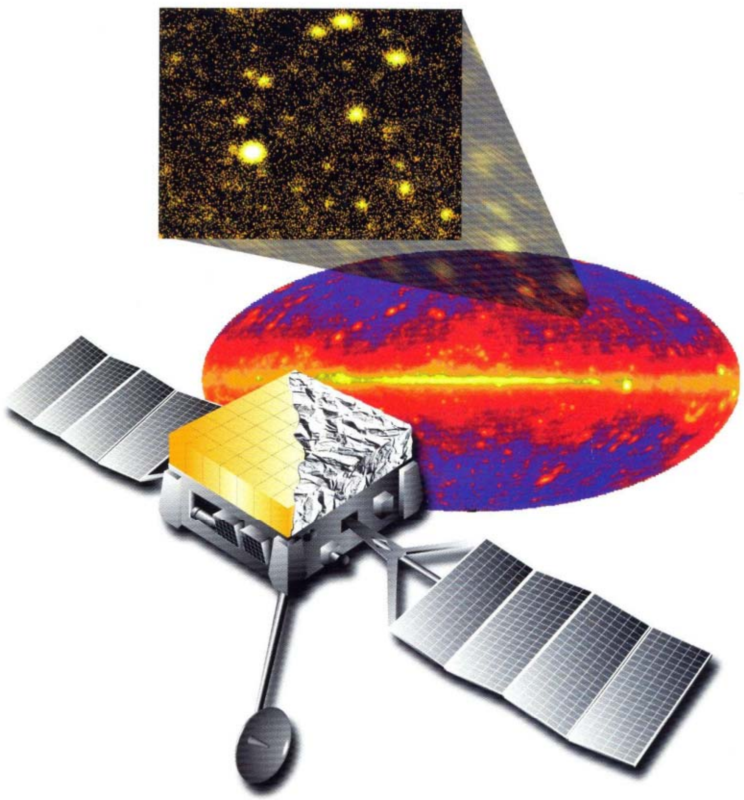
PREVIOUS RESULTS / EXPERIMENTS

CASA – STATUS AND RESULTS

PeV = 10^{15} eV (10^{6} GeV)
EeV = 10^{18} eV (10^{9} GeV)

LAT Development

Towards a Next-Generation High-Energy Gamma-Ray Telescope



STANFORD UNIVERSITY • AUGUST 22–24, 1994

(ed. Elliott Bloom)

Table of Contents

iii

Askaryan Effect at SLAC

LINAC beam tests

- 2000: Sand (silica)
- 2004: Rock salt
- 2007: Ice – ANITA calibration

Dawn Williams, Al Odian,
& Peter Gorham

Dieter Walz

PHYSICAL
REVIEW
LETTERS

Articles published week ending
26 OCTOBER 2007

Volume 99, Number 17

Published by The American Physical Society

ANITA in ESA in 2007

Outline

Introduction

- The study of high-energy particles in the cosmos
- Detection techniques, first detectors
- Main scientific motivations

Present Landscape

- Survey of existing experiments, SLAC program
- (A few) recent scientific highlights, : γ's, CR's, ν's

Future

- Key science goals for future
- New instruments & new ideas
- Science results presented at SLAC's 75th Anniversary

Summary, Acknowledgements

Big Science Questions for Future

(NB: subjective)

Question
What is dark matter ? Can it be detected in the cosmos through its particle interactions ? Measure the properties and distribution of DM.
What new physics/interactions can be identified by HE particles from space ?
What is the origin of the cosmic rays, from TeV to 10^{20} eV scale ? What is the maximum energy of cosmic particle acceleration ?
What are the intergalactic radiation fields (EBL and IGMF) and how are they produced ? What is the source of the isotropic γ-ray flux ? Is there an isotropic neutrino flux ?
How do cosmic accelerators (e.g. GRB's and Supernovae) work ? What *is* going on at the Galactic center ?

Big Science Questions for Future

(NB: subjective)

Question	Particle	Requirement
What is dark matter ? Can it be detected in the cosmos through its particle interactions ? Measure the properties and distribution of DM.	γ, ν (CR)	Sensitivity (E resolution, E range)
What new physics/interactions can be identified by HE particles from space ?	γ, ν, CR	Sensitivity, E resolution,
What is the origin of the cosmic rays, from TeV to 10^{20} eV scale ? What is the maximum energy of cosmic particle acceleration ?	γ, ν, CR ν, CR	Sensitivity, E resolution, ang. resolution, sky coverage, MWL data
What are the intergalactic radiation fields (EBL and IGMF) and how are they produced ? What is the source of the isotropic γ-ray flux ? Is there an isotropic neutrino flux ?	γ γ, ν	Sensitivity, E range Sensitivity, E range
How do cosmic accelerators (e.g. GRB's and Supernovae) work ? What *is* going on at the Galactic center ?	γ, ν, CR	Sensitivity, E resolution, angular resolution, sky coverage, MWL data

Future Major (>10 yr) Efforts*

	Present	Future	Key Features
γ	Fermi HESS MAGIC VERITAS	Cherenkov Telescope Array Space mission ?	10x better sensitivity Wider FOV Higher & lower E
CR	Auger	Expanded Array ?	
	Tel Array	JEM-EUSO	Larger aperture Higher E reach
ν	IceCube	ARA, ARIANNA, EVA	Higher E coverage
	ANTARES ANITA	KM3NET	Greater sensitivity S sky coverage
		PINGU	Lower E coverage

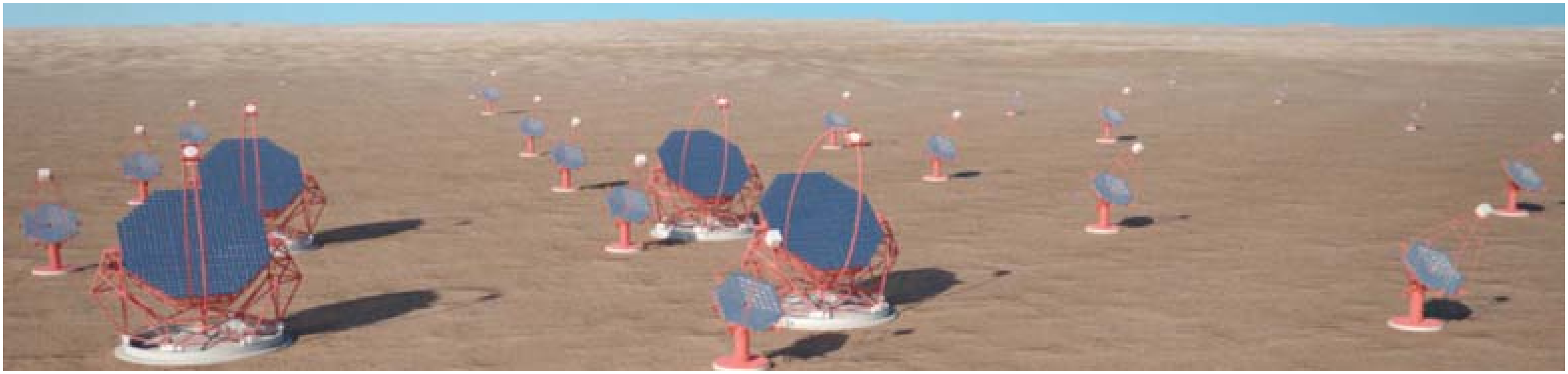
(*not necessarily complete)

Future Major (>10 yr) Efforts*

	Present	Future	Key Features
γ	Fermi HESS MAGIC VERITAS	Cherenkov Telescope Array Space mission ?	10x better sensitivity Wider FOV Higher & lower E
CR	Auger Tel Array	Expanded Array ? JEM-EUSO	Larger aperture Higher E reach
ν	IceCube ANTARES ANITA	ARA, ARIANNA, EVA KM3NET PINGU	Higher E coverage Greater sensitivity S sky coverage Lower E coverage

(*not necessarily complete)

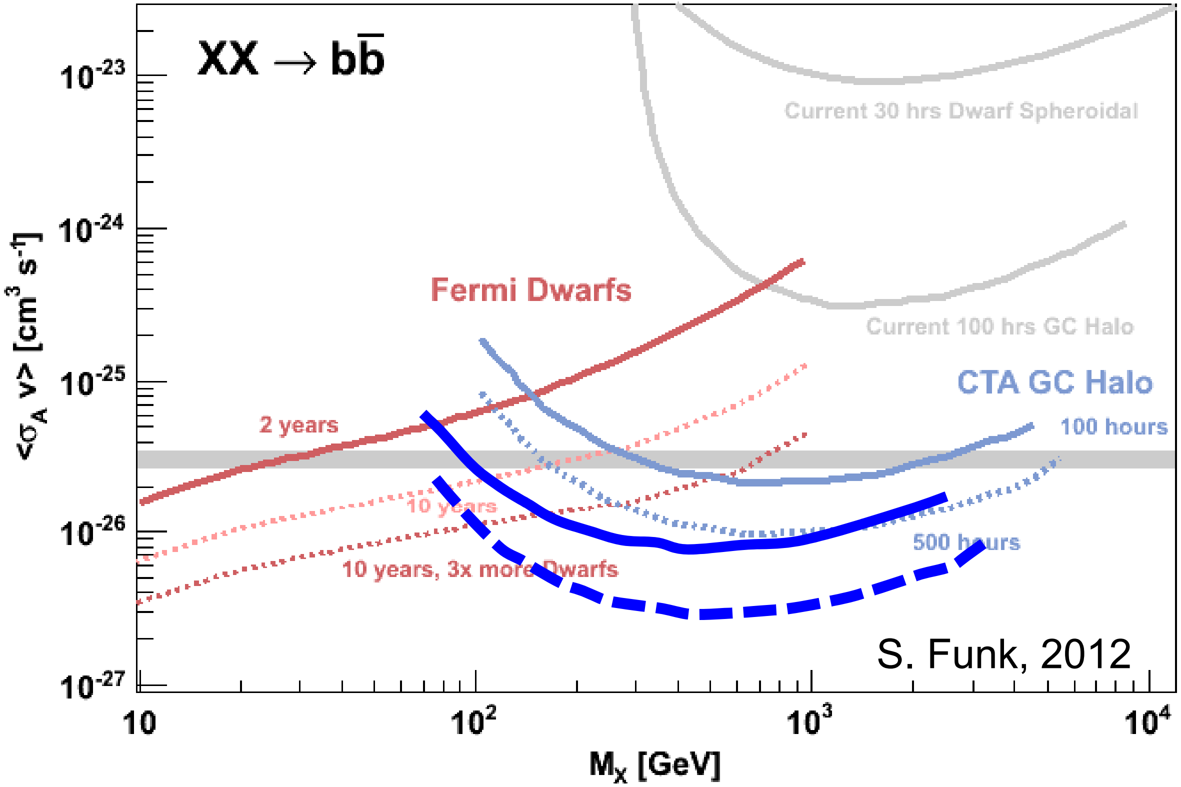
Cherenkov Telescope Array (CTA)



CTA: artist's conception

Key features of CTA:

- Factor of 10 more sensitive, better σ_{ang} and σ_E than HESS/VERITAS.
- Wide E range: 25 GeV – 100 TeV.
- Wide field-of-view (>6°).
- Two sites: S (10 km^2), N (1 km^2)
- 40-80 Cherenkov telescopes/site.
- Open observatory.
- Complemented by HAWC (wide-field, high duty cycle) in N.



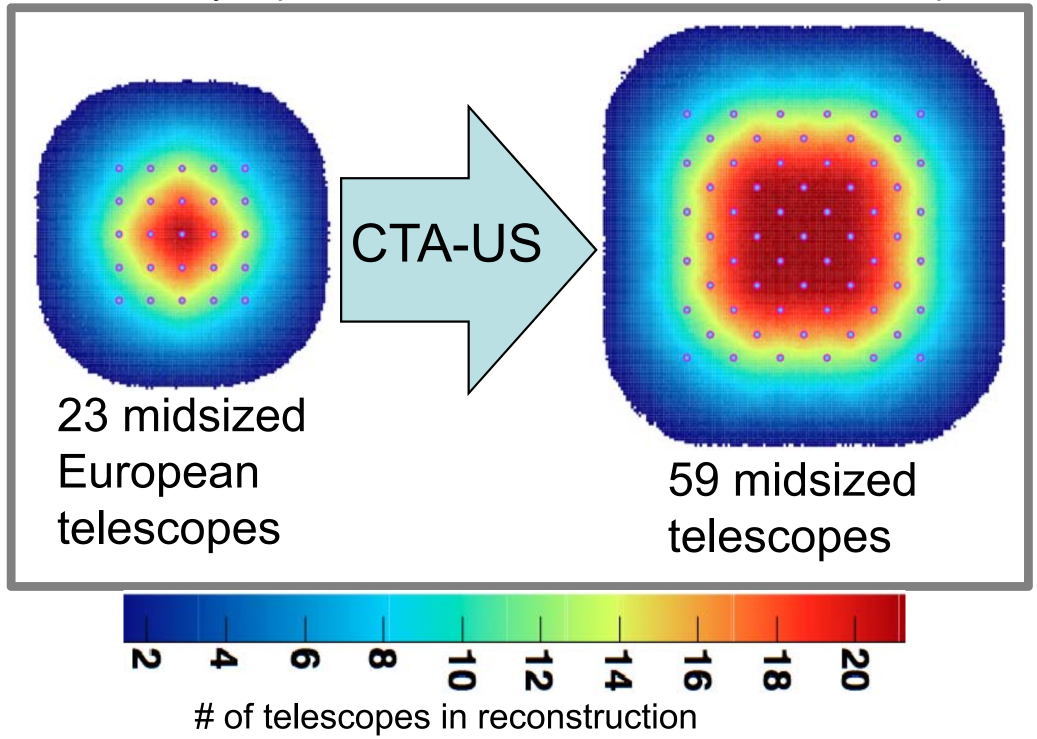
CTA and Fermi dark matter sensitivity

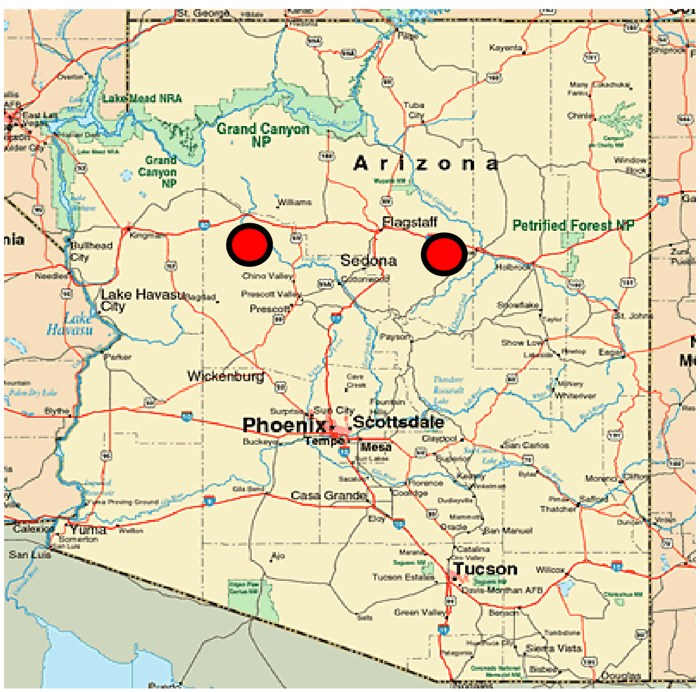
Proposed US Contributions to CTA

- Boost core array by 36 telescopes.
- 3x better sensitivity.
- High resolution imaging.
- Wider field of view.
- Spatially resolve (arc-min) sources to map dark matter profiles.

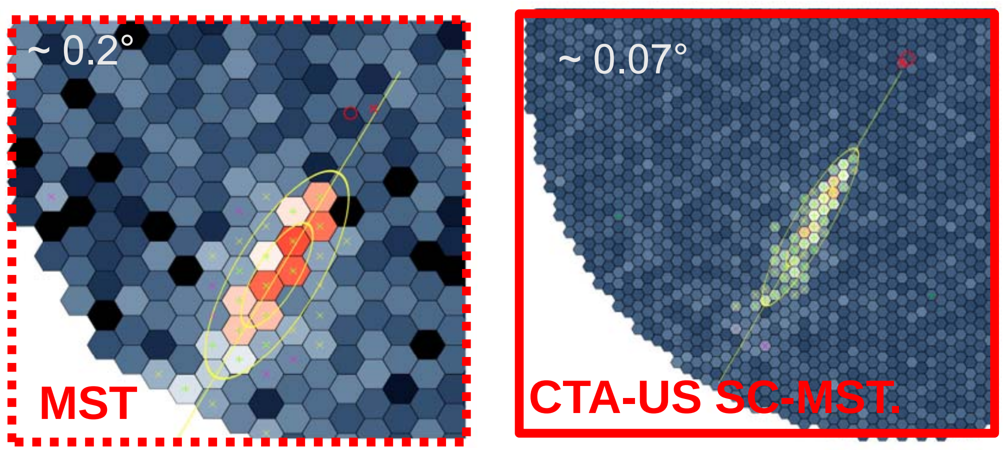
- Potential sites for CTA in N. Arizona.

Greatly improved effective area with CTA-US telescopes





Proposed sites for CTA N in Arizona, USA

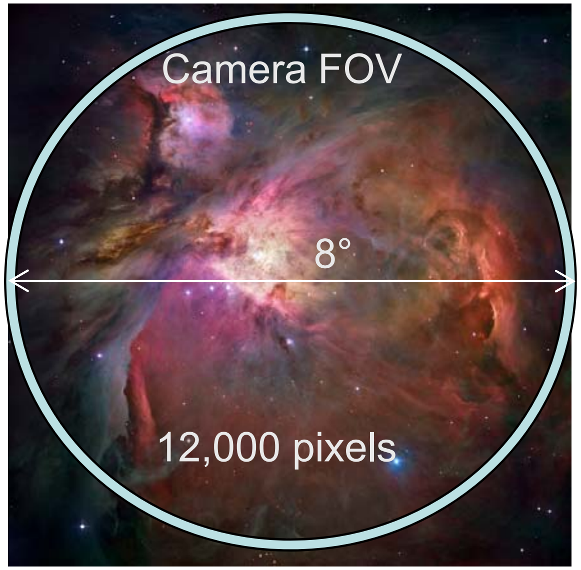


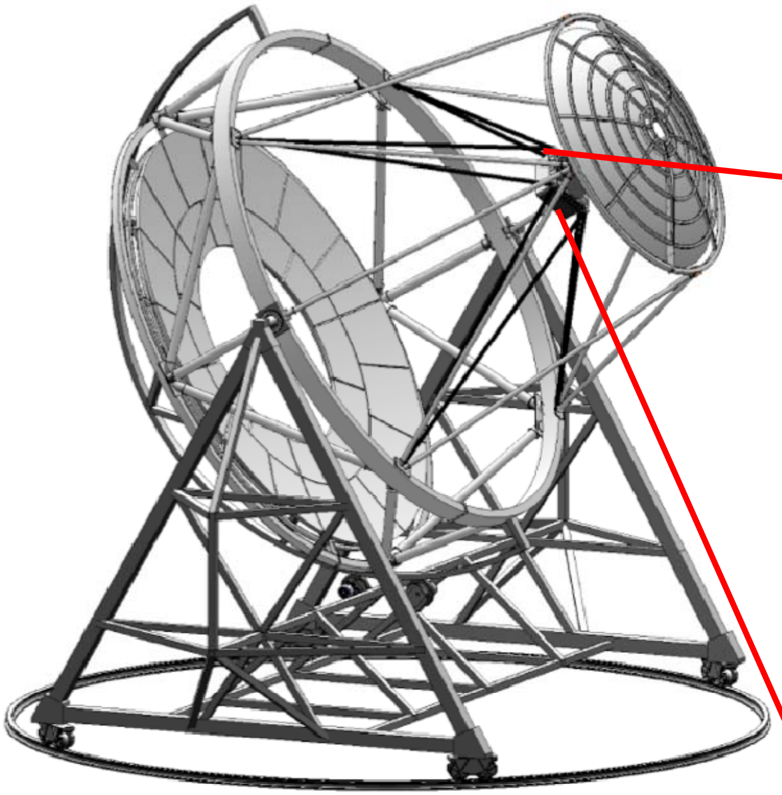
Improved image resolution with CTA-US

CTA-US Telescope & Camera

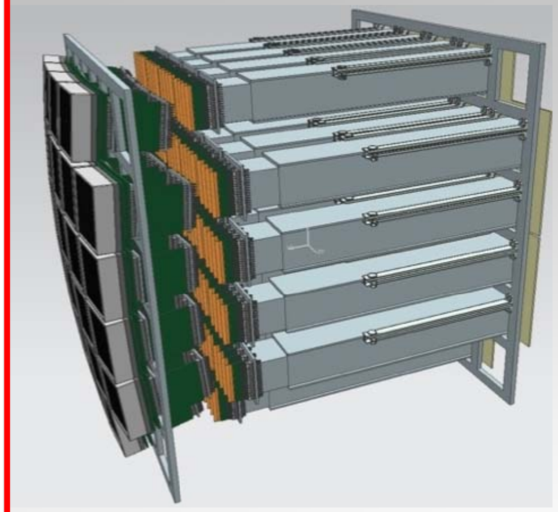
Innovative two-mirror telescope design:

- Corrects aberrations – wide FOV.
- Reduces place scale – compact camera.
- High channel count/density require HEP expertise.
- Prototype telescope construction 2012-2015.





Schwarzschild-Couder telescope design



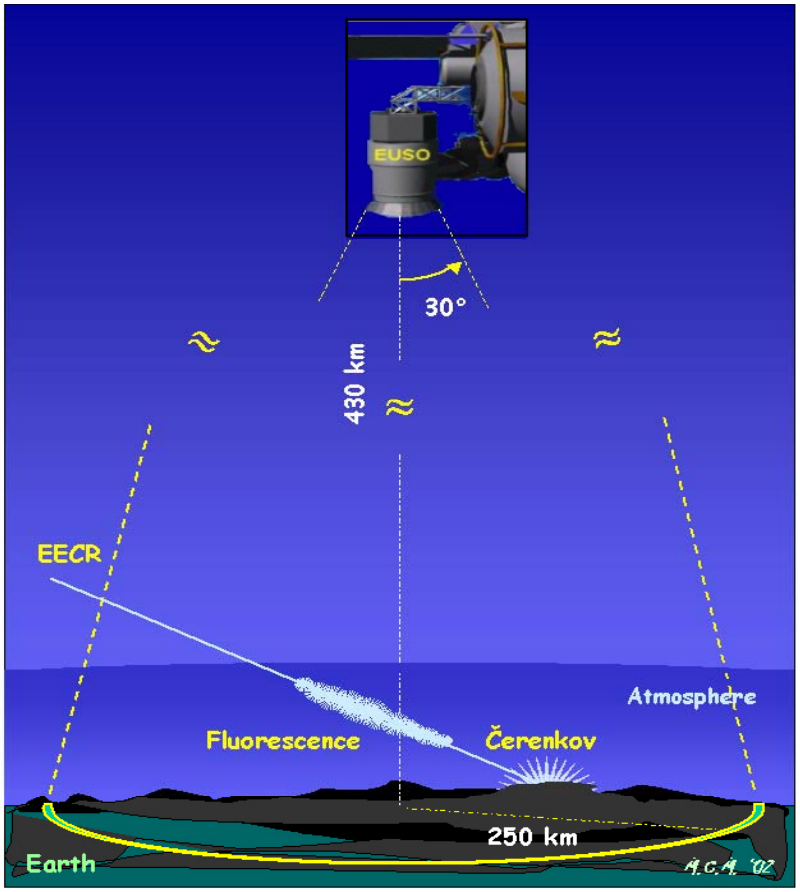
Camera

- Development at **SLAC**
- ASIC design
- New photodetector technology (Si-PMs)
- Cost effective
- Compact (< 1m)

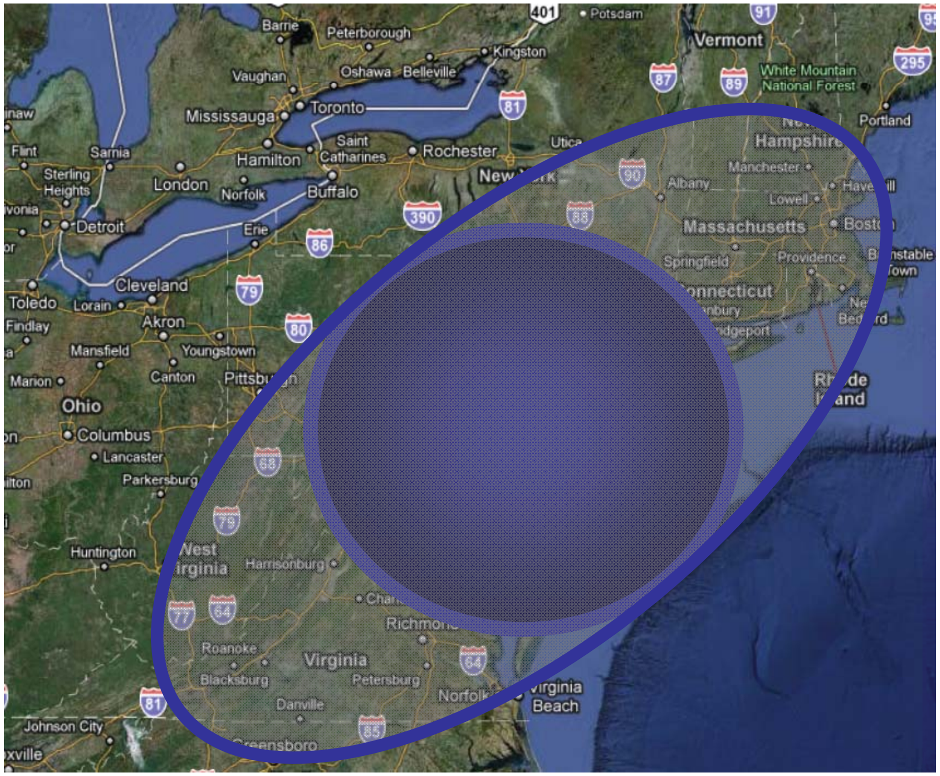
JEM-EUSO: UHECRs in Space

JEM-EUSO:

- N_2 fluorescence detector on ISS.
- Exposure/year is x10 Auger.
- Proposed launch in 2017.



JEM-EUSO concept

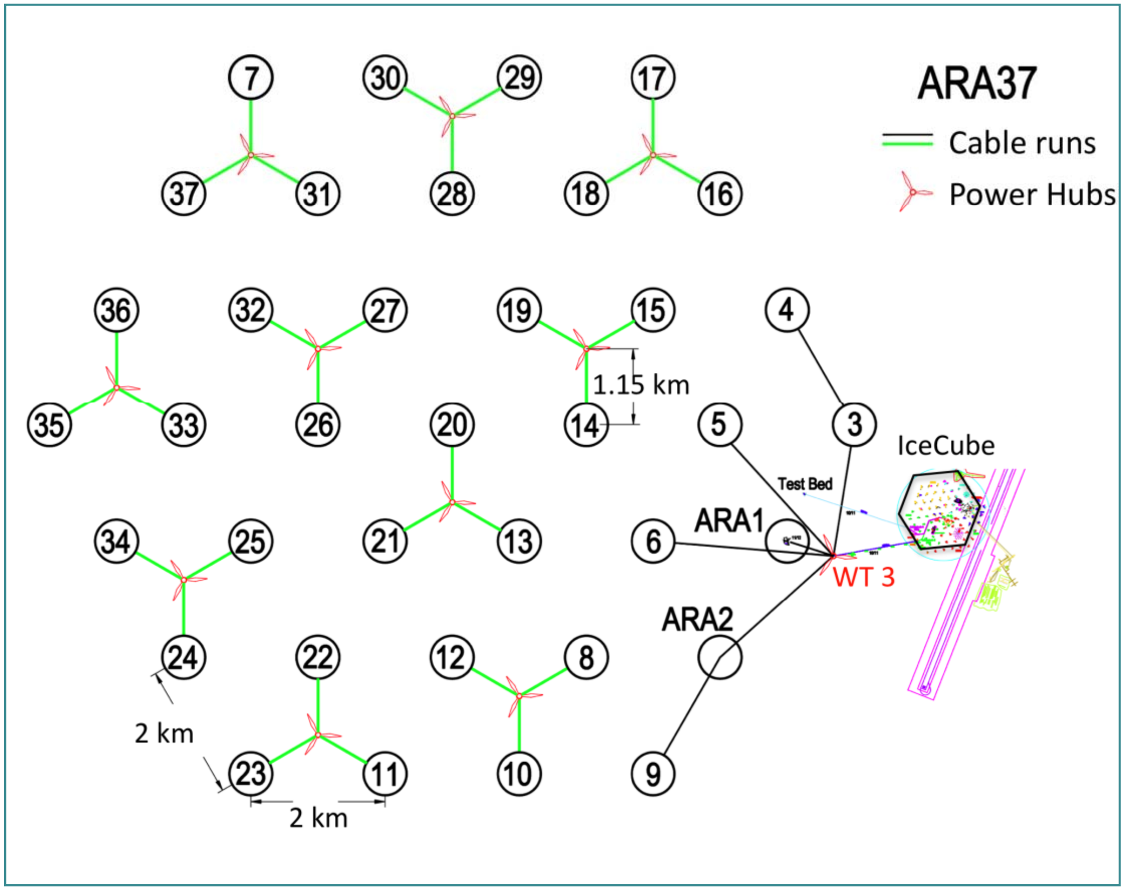

JEM-EUSO effective area in nadir & tilt modes.


JEM-EUSO on ISS (nadir).

Askaryan Radio Array (ARA)

ARA:

- Very large (~150 km^2) radio neutrino detector at South Pole.
- Uses Askaryan effect to detect radio Cherenkov signal.
- Main science goal: GZK neutrinos, $E > 10^{17}$ eV.



Possible layout for ARA at South Pole

The Future Role for SLAC

SLAC has an important role to play in this area:

- → Very strong science base: faculty, students, researchers.
- → Excellent interdisciplinary approach (e.g. Fermi-LAT and in future with LSST → important for CTA follow-ups).
- → Unique HEP technical expertise: mechanical, electronic, computing.
- → BEAMS – still very important.
- → Facilities for construction and testing of large instruments.
- → Managerial expertise for large projects.

And now …

Science Results at SLAC's 75th

- **Dark matter discovered in VHE γ-rays!**

  Discovery followed by mapping of the Galactic DM distribution through its γ-ray signature and detection of proper motion of nearby clump.

- **Detection of 25,000 neutrinos from a Supernova in our Galaxy.**

  The neutrinos from a supernova in Cygnus at a distance of 7.5 kpc provide confirmation of the neutrino hierarchy, as well as unparalleled information about supernova dynamics.

- **Three local sources of positrons identified**. This solves the mystery of the excess positron flux at high energies.

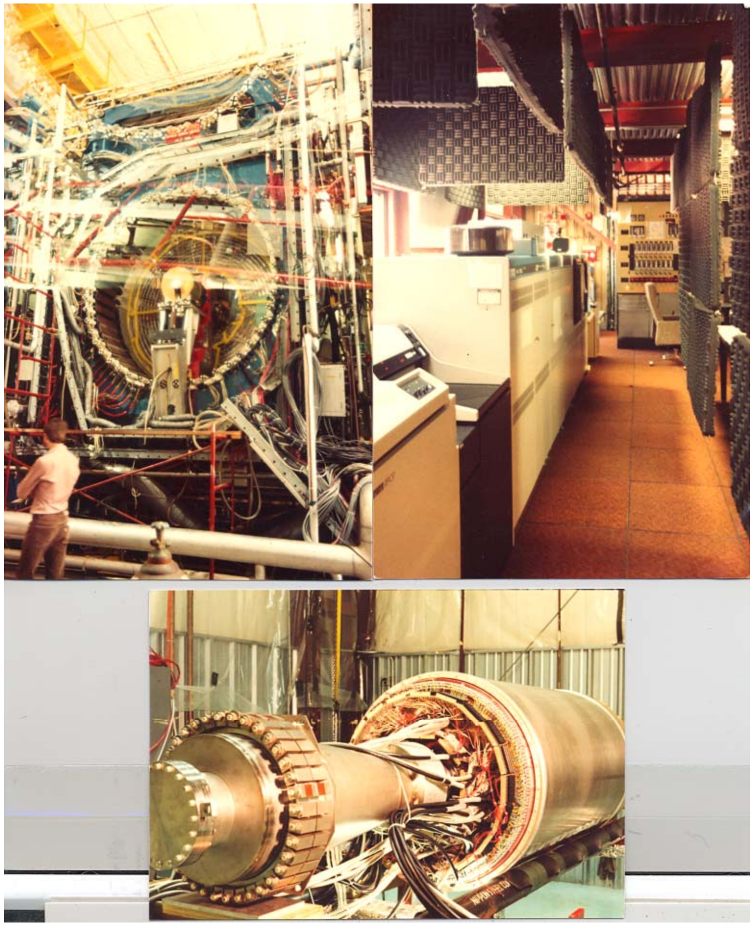
- **Measurement of the intergalactic magnetic field (IGMF).** The IGMF density and distribution argues for a primordial B field, confounding the cosmologists.

Science Results at SLAC's 75th

- **GKZ effect and upper limit to cosmic particle acceleration established. Sources of UHECRs found.** Precise measurements of the UHE cosmic ray spectrum and anisotropy, combined with the detection of GKZ neutrinos confirmed the identification of starburst galaxies as the source of $E>10^{18}$ eV particles.
- **Origin of cosmic rays solved.** A census of 300 Galactic sources detected in γ-rays and 40 sources detected in neutrinos provide accurate measurements of proton acceleration fraction. In conjunction with the identification of several local sources, the origin of ~90% of the cosmic ray flux has been established.
- **Precise determination of extragalactic background light (EBL).** Measurement of EBL spectrum versus redshift provides strong constraint on star-formation rate density.

N.B. these are "known" topics; there will almost certainly be completely unexpected discoveries.

SLAC provides outstanding training



Mark II Detector at PEP
Mark II Vertex Chamber
(group led by John Jaros)

Rene Ong, Nigel Lockyer, Mark Nelson, Larry Gladney

Pat Burchat with someone's baby

Dave Bennett, Robert Johnson

Elliott Bloom, Harry Nelson

Summary

- **High energy (HE) particles probe astrophysics of TeV/PeV/EeV particle acceleration in the cosmos not tested or understood by other means.**
- **Equally important is using HE probes to search for new physics beyond the standard model.**
- **The current suite of γ-ray, cosmic ray and neutrino detectors provides an unparalleled view of the universe. However, many important questions remain !**
- **SLAC has developed a world-leading program in HE particle astrophysics. Development of the Cherenkov Telescope Array (CTA) and leadership in this project is an integral component of a strong program in particle astrophysics at SLAC.**

"The real voyage of discovery consists, not in seeking new landscapes, but in having new eyes."

Marcel Proust (1871-1922)

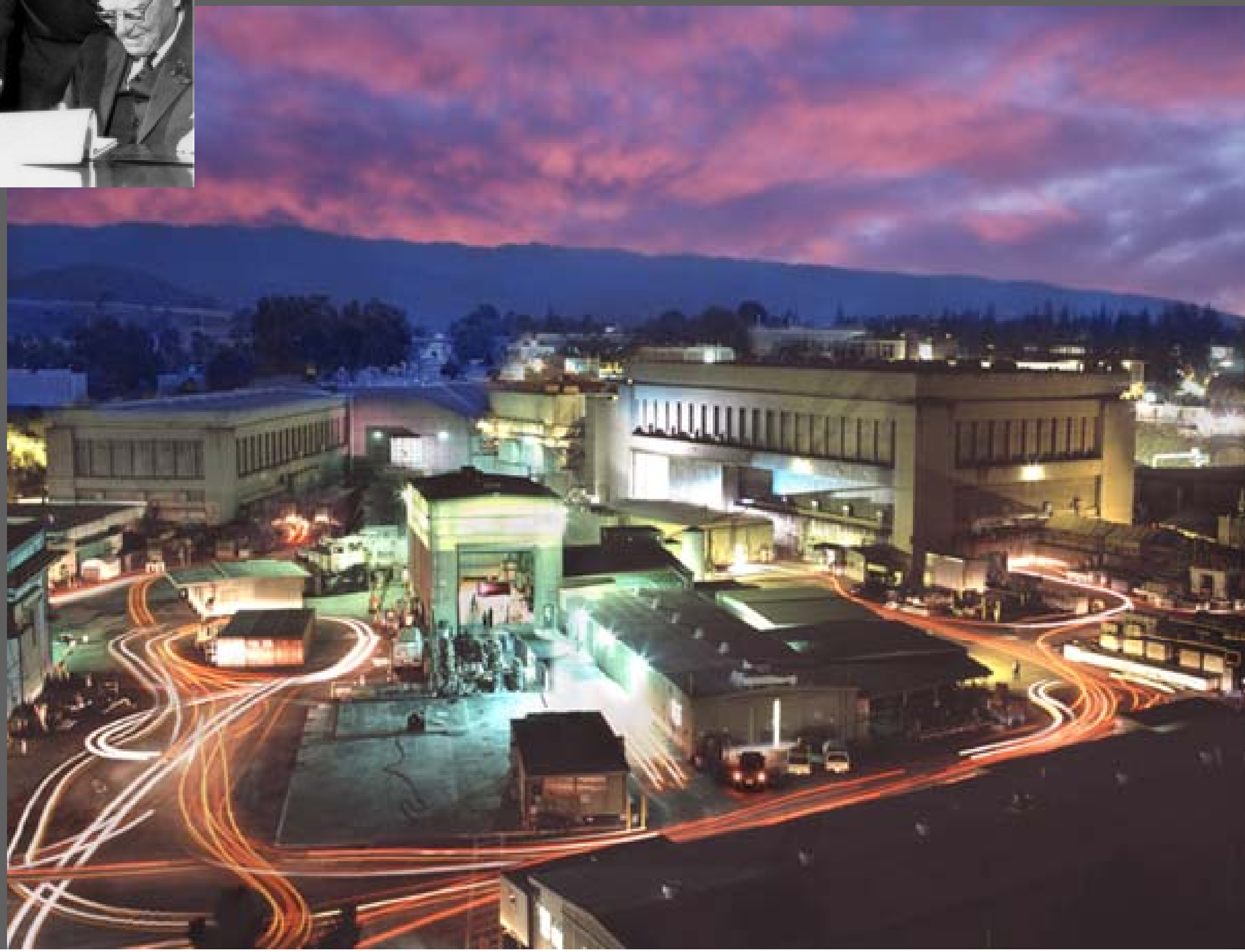
Acknowledgements

The following provided useful advice and/or information:

- Jim Adams
- Roger Blandford
- Elliott Bloom
- Markus Boettcher
- Jan Conrad
- Seth Digel
- Jonathan Feng
- Stefan Funk
- Peter Gorham
- Francis Halzen
- Werner Hofmann
- Karl-Heinz Kampert
- Albrecht Karle
- Spencer Klein
- Frank Krennrich
- Manel Martinez
- Jim Matthews
- Peter Michelson
- Simona Murgia
- Angela Olinto
- David Saltzberg
- Pierre Sokolsky
- Christian Spiering
- Stefan Westerhoff

Much thanks to John Jaros, Michael Peskin and the organizers !

Congratulations SLAC !



50th
Anniversary