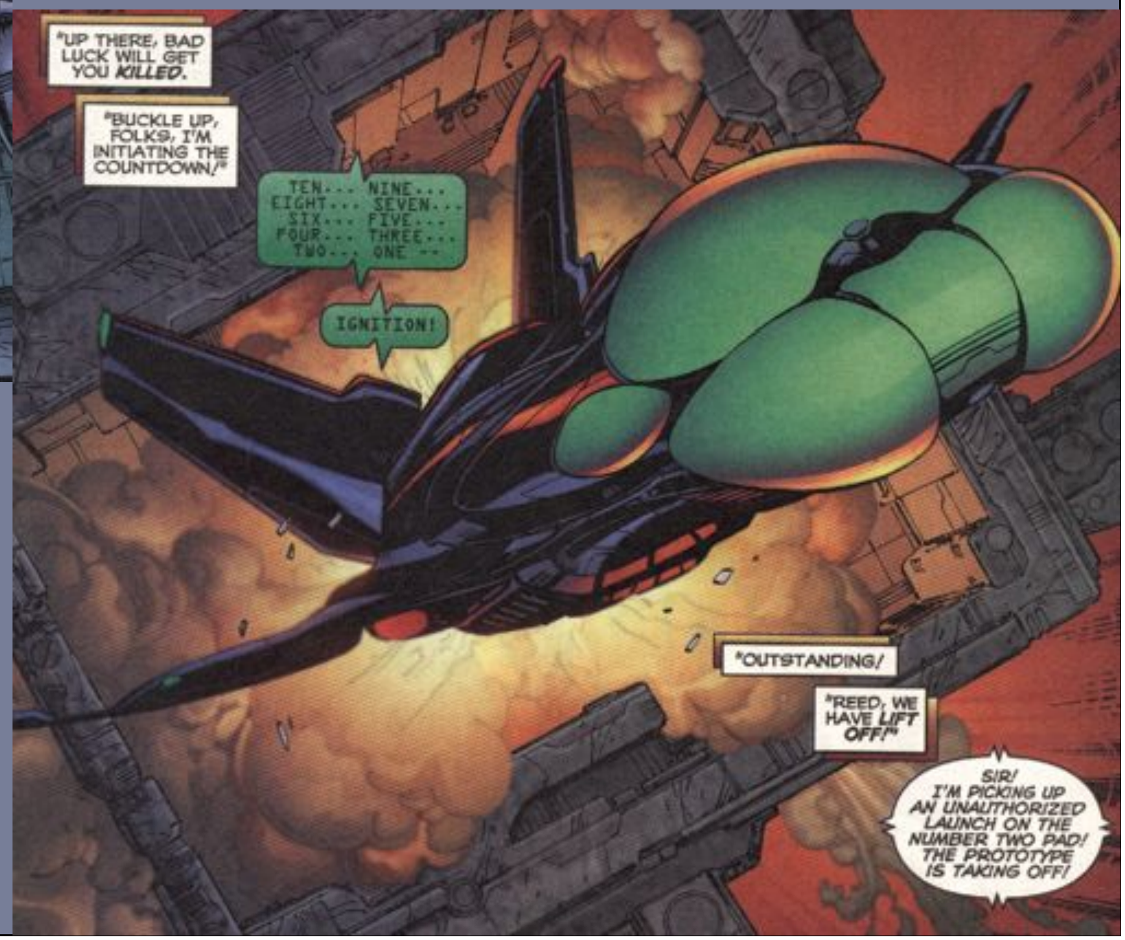
Atmospheric Monitoring with LIDAR Systems at the Pierre Auger Cosmic Ray Observatory

Prof. Gregory Snow

NASA meeting, Omaha: 9/17/2010


MARVEL GRAPHIC NOVEL
SILVER SURFER
STAN LEE


THAT SHOULD HAVE BEEN US UP THERE, SUE.
WE WERE THE ONES WHO WORKED SO HARD TO MAKE THIS DREAM A REALITY.
BUT NOW, SHE'S... GONE.
IT ONLY PROVES THAT YOUR WORK WAS A SUCCESS, REED.
BUT NOW, THE IMPORTANT THING IS TO STOP CONTACT ONE BEFORE WINGFOOT CAN CARRY OUT HIS PLAN.
ENOUGH OF THE WISHFUL THINKIN', PEOPLE. THE PROTOTYPE'S OUR ONLY TICKET OUTTA HERE.
SO LET'S GET MOVIN'!


"UP THERE, BAD LUCK WILL GET YOU KILLED.
"BUCKLE UP, FOLKS, I'M INITIATING THE COUNTDOWN!"
TEN... NINE... EIGHT... SEVEN... SIX... FIVE... FOUR... THREE... TWO... ONE --
IGNITION!
"OUTSTANDING!
"REED, WE HAVE LIFT OFF!"
SIR! I'M PICKING UP AN UNAUTHORIZED LAUNCH ON THE NUMBER TWO PAD! THE PROTOTYPE IS TAKING OFF!


THE DREAM'S ALWAYS THE SAME.
IT BEGINS WITH A PERFECT LAUNCH.
YOU'RE LOOKING GOOD, EXCELSIOR!
BUT THIS TIME IT TAKES A FANTASTIC TWIST.
SUZIE AND JOHNNY?! WHAT'RE THEY DOING HERE?
YOU DID IT, BEN!
IT'S TOO DANGEROUS --
UREEP UREEP UREEP
THAT'S WHEN THE WARNING INDICATORS START LIGHTING UP LIKE A CHRISTMAS TREE!
RADIATION'S FLOODING INTO THE MAIN COMPARTMENT.
OUTTA NOWHERE, REED POPS INTO THE SCENE AND TRIES TO SALVAGE THE SITUATION. BUT EVEN HE RUNS OUT OF ANSWERS.
BEN! YOU'VE GOT TO GET US BACK TO EARTH!
BUT BEFORE I GET A CHANCE TO DO ANYTHING, JOHNNY BURSTS INTO FLAMES BEFORE MY VERY EYES!
MY FRIENDS! MY SHIP!
THEY'RE ALL DYING --
BRREEP BRREEP BRREEP
-- WHEN THERE'S SUDDENLY --
-- A PHONE CALL FOR ME?
MAJOR GRIMM? DO YOU COPY?
HELLO, BEN?

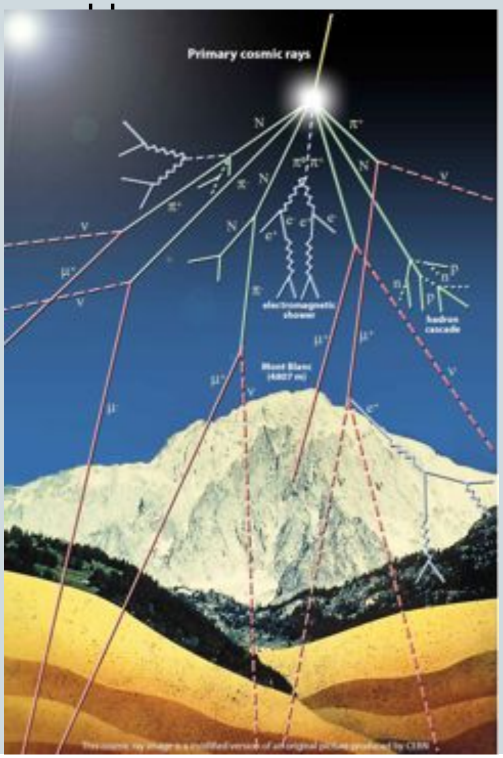

"BEN'S GONNA FREAK WHEN HE GETS A LOAD OF THIS!"
JUST MY LUCK...
SEVENTY FIVE PERCENT OF THE PLANET'S COVERED WITH WATER BUT I STILL MANAGE TO SLAM INTO THE SIDE OF A MOUNTAIN!
LOOKS WORSE THAN MY CRASH IN IRAQ, BUT AT LEAST I'M--
AARGH! HEAD POUNDING! PAIN -- TOO -- INTENSE!
HUH?!
KRRKK
NO! THIS -- THIS CAN'T BE HAPPENING!
MY HANDS -- TURNING INTO -- ROCK!
CAN'T -- FEEL -- ANYTHING!
KRRRKLE
UUNGH! HAR -- HARD -- TO BREATHE!
CAN'T -- STAND -- THE PAIN!
BODY -- FEELS -- LIKE IT'S -- BEING TORN -- APART!
AARRGH!

Outline

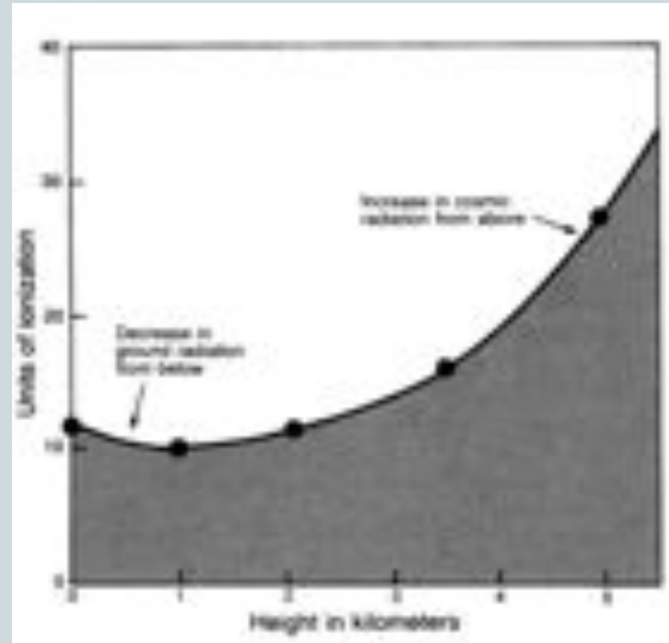
- Cosmic Ray History
  - Discoveries of Cosmic Rays & Extensive Air Showers
- Pierre Auger Cosmic Ray Observatory
  - The experiment & location
  - Surface Detectors & Fluorescence Detectors
- LIDAR Systems
  - Operation and design
- Near-Field Upgrade to LIDAR Systems by UNL Group
  - Detector Designs and Installation
  - Performance Evaluation
- Repaired Laser Study
  - Experimental Procedures
- Enhancements to online Introductory Physics courses using NASA education materials

Cosmic Ray History

- Victor Hess discovered cosmic rays in 1912.
  - “Rays of very great penetrating power are entering our atmosphere from above.” -



Cosmic rays are protons or large nuclei.



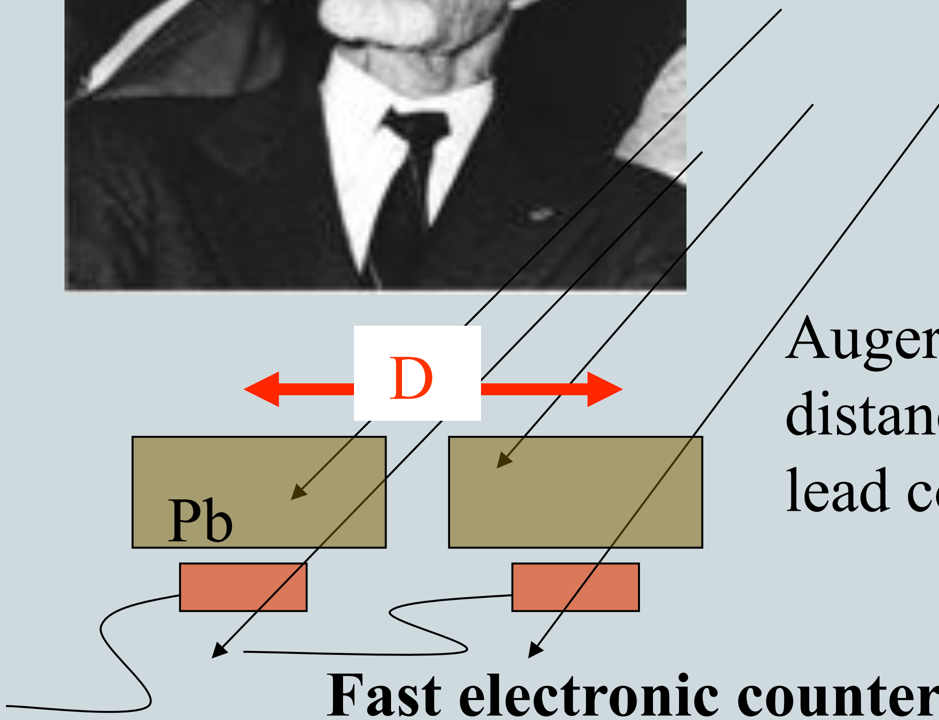
- In 1938 Pierre Auger discovered extensive air showers.
  - Some of the primary cosmic ray energy is converted into mass in the creation of new particles according to $E=mc^2$.

Historical high points

1912
Victor Hess discovers "penetrating radiation" from space

Nobel prize 1936

1938
Pierre Auger discovers extensive air showers



Auger varied distance and lead covering

Fast electronic counters

Snowmass 2001

Replica of
Hess' Electroscope

Portable Geiger
Counters

Wilkes in
Hessian
Outfit

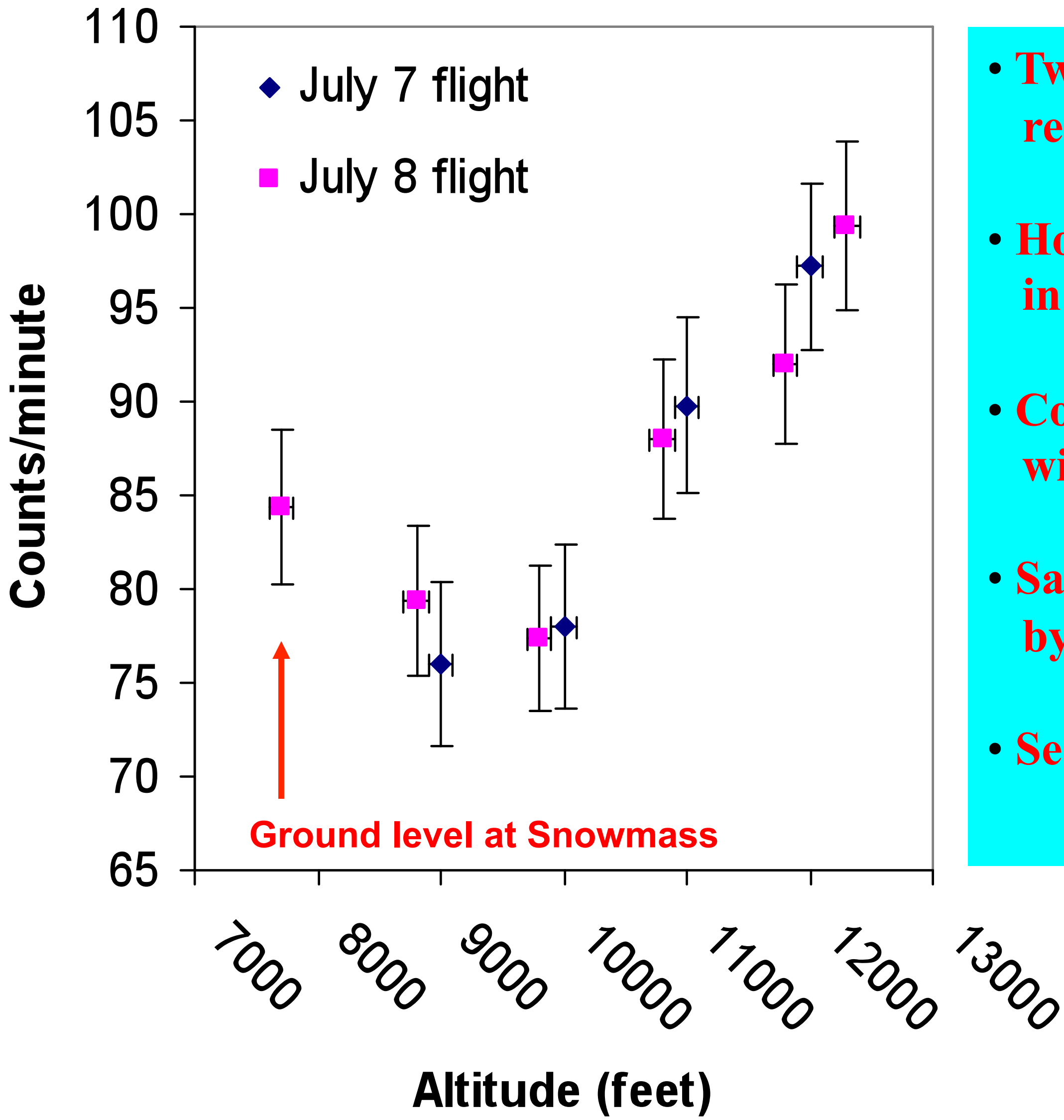
Crowd gathers to watch Victor Hess flight reenactment

Lift off !

Unicorn Balloon Company, Snowmass, CO

Data transmitted live to ground via radio

Snowmass Balloon Flight 2001



- Two flights with consistent results
- Hovered at 1000 ft increments in altitude for 5 minutes
- Cosmic ray rates measured with portable Geiger counters
- Same effects observed by Victor Hess
- See FermiNews, July 27, 2001

Much bigger effect: Northwest airlines at 35,000 feet !

The Pierre Auger Observatory

Auger Observatory is here.

Malargue is a small town on the high plains not far from a ski area in the Andes.

The Auger Collaboration

67 Institutions, 369 Collaborators

Argentina	Netherlands
Australia	Poland
Bolivia*	Portugal
Brazil	Slovenia
Czech Republic	Spain
France	United Kingdom
Germany	USA
Italy	Vietnam*
Mexico	

* *associate*

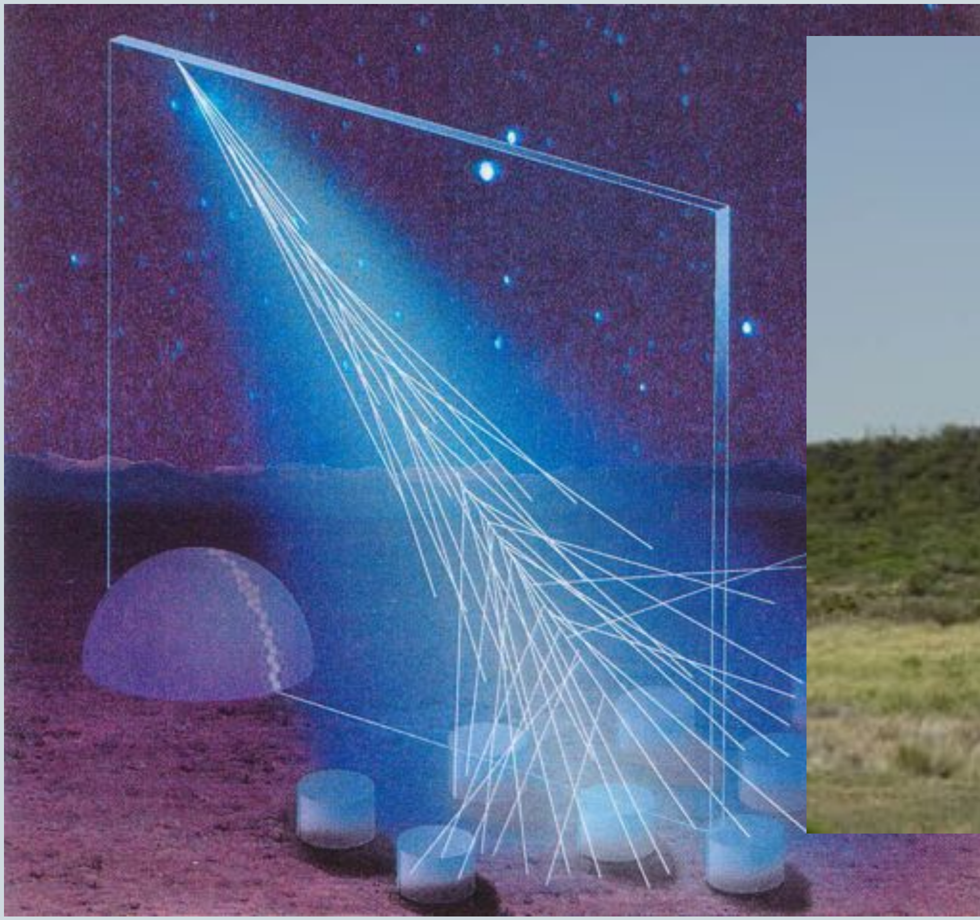
True International Partnership - *by non-binding agreement -*

No country, region or institution dominates – No country contributes more than 25% to the construction.

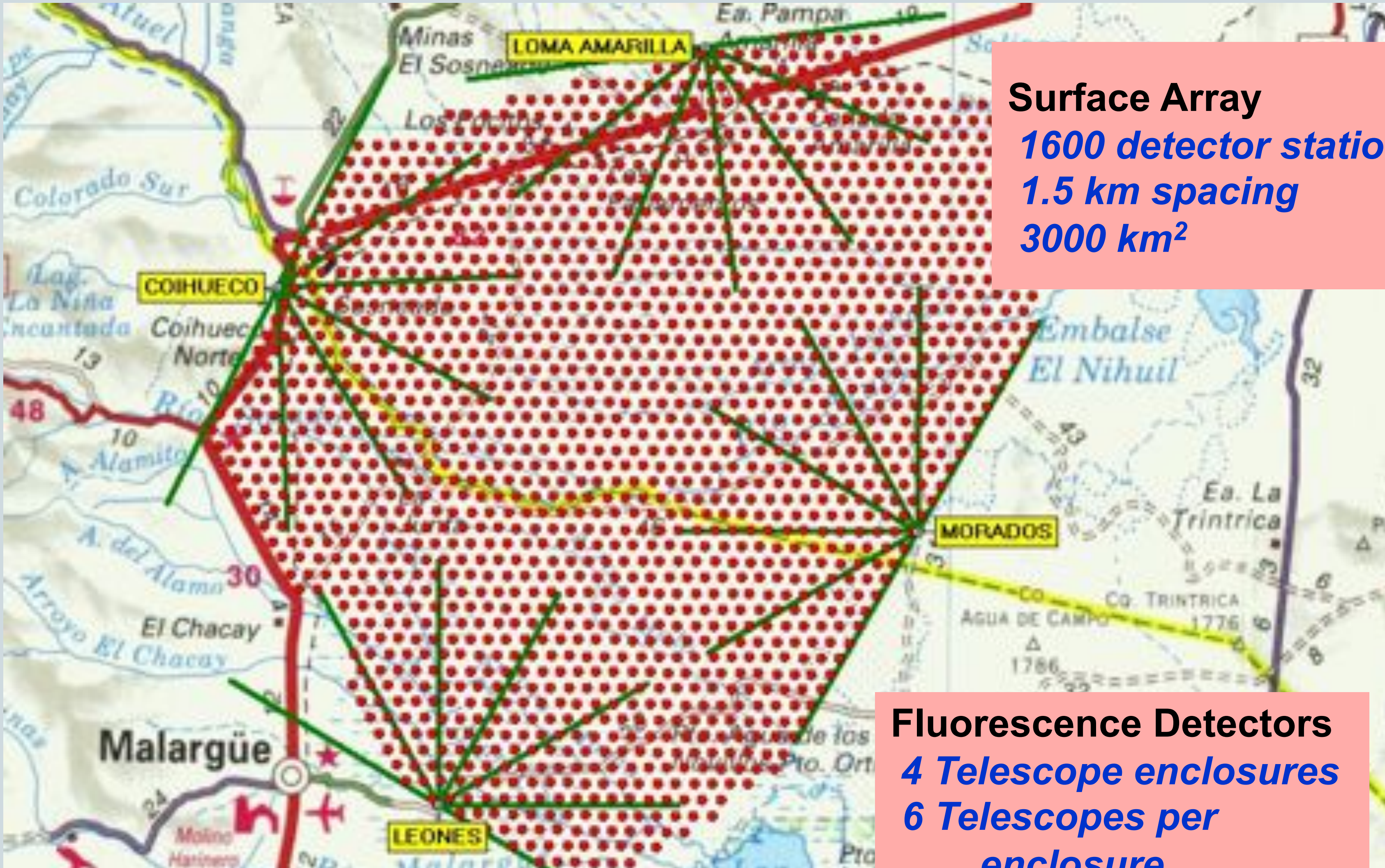
The Hybrid Design

Surface detector array + Air fluorescence detectors

A unique and powerful design



The Observatory Layout



Surface Array

1600 detector stations

1.5 km spacing

3000 km^2

Fluorescence Detectors

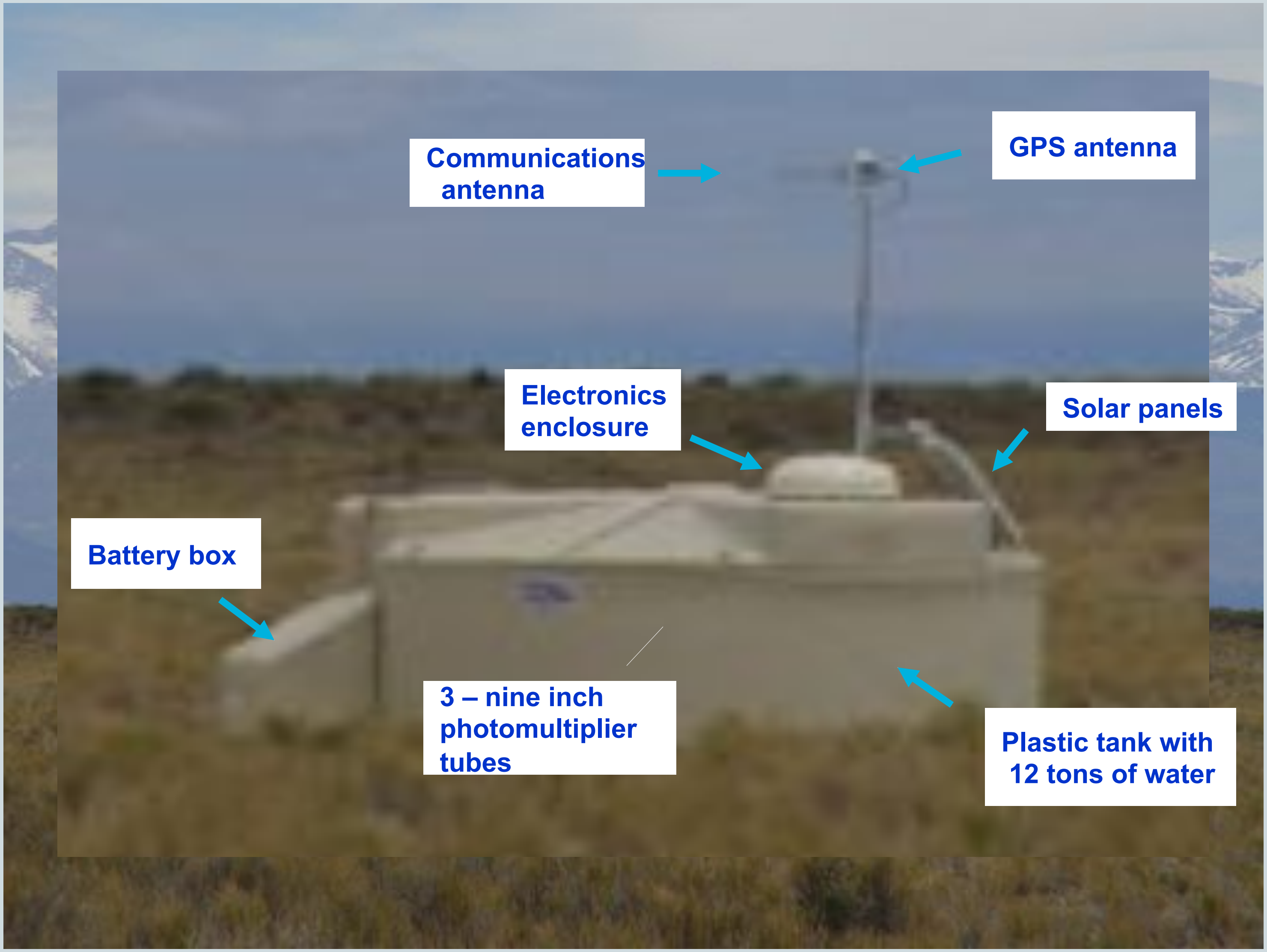
4 Telescope enclosures

6 Telescopes per enclosure

24 Telescopes total

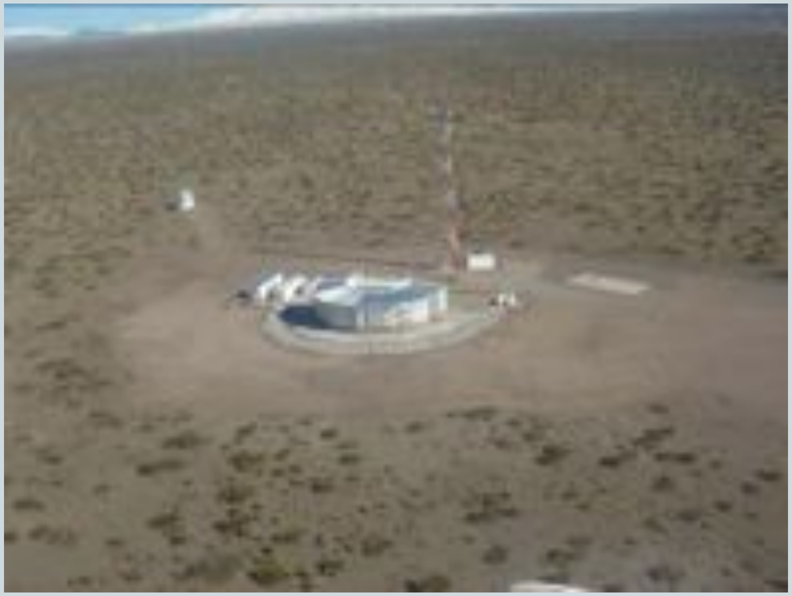
Surface Detectors

Detector Station

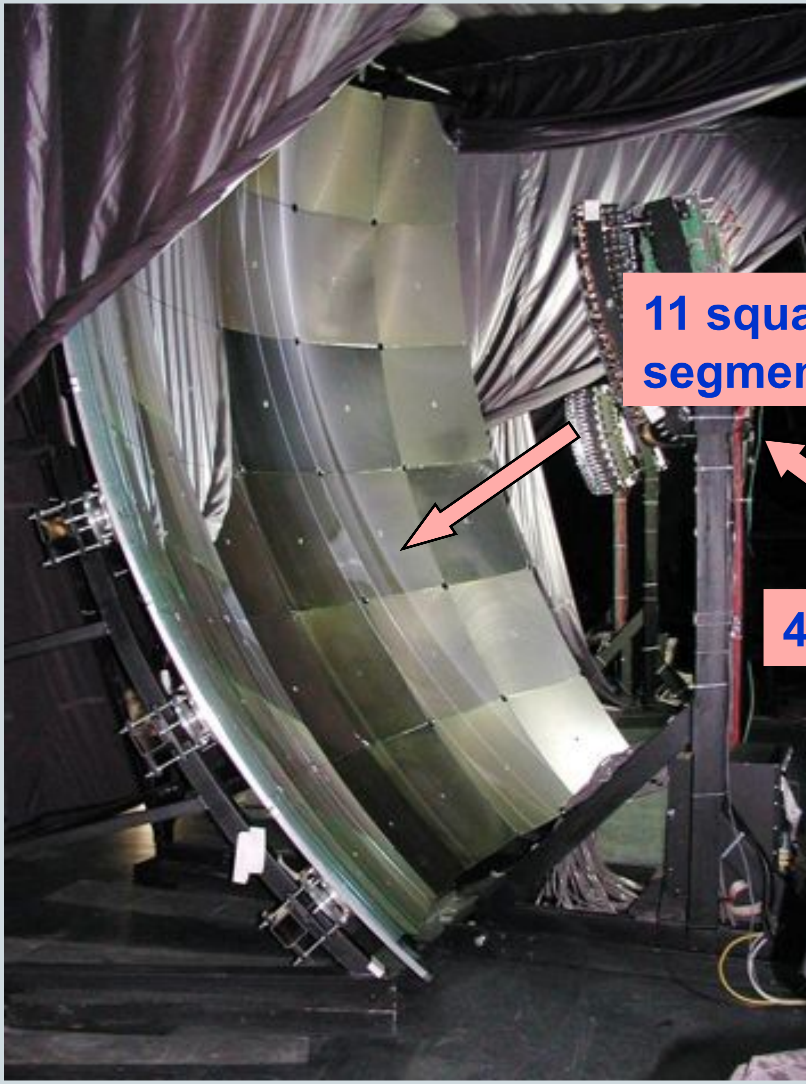


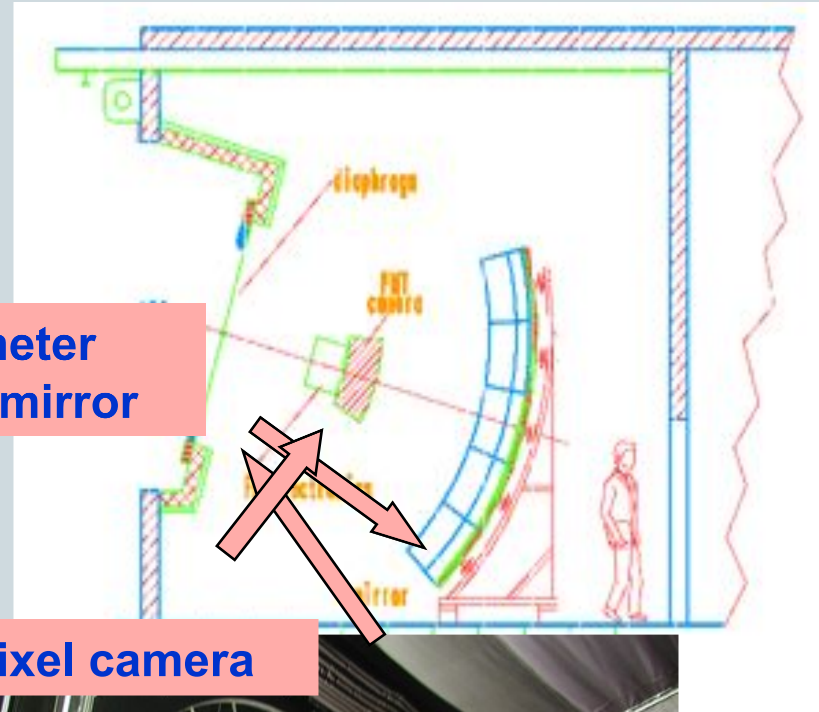
Depl

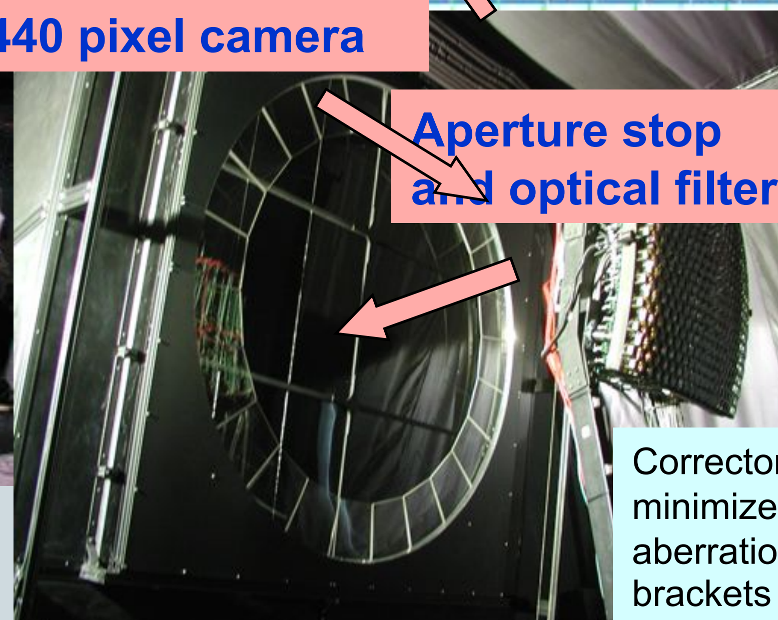
Aerial Photos of Fluorescence Buildings
November 2006



Fluorescence Detectors







11 square meter segmented mirror

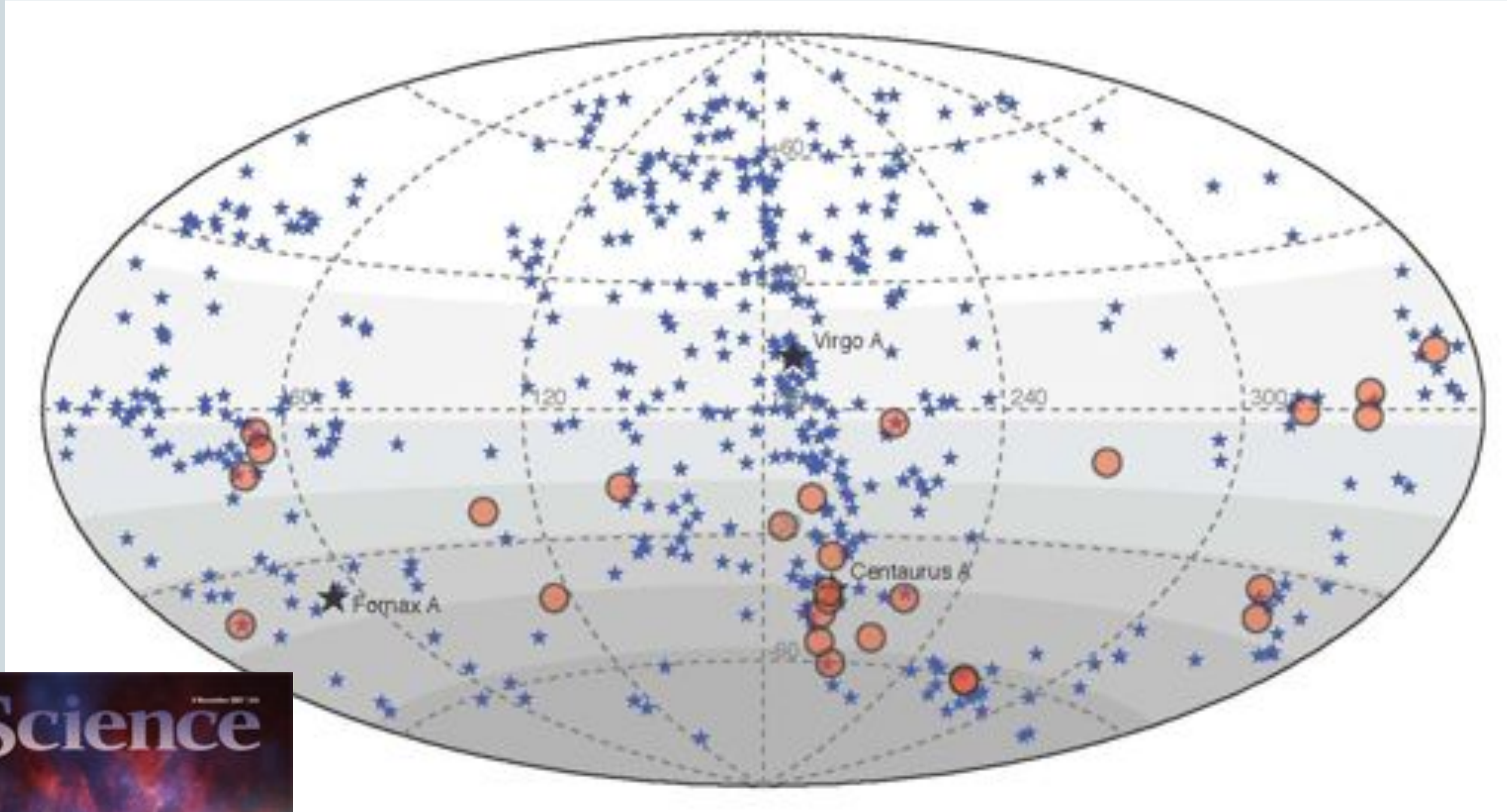
440 pixel camera

Aperture stop and optical filter

Corrector lens minimizes spherical aberrations, filter brackets 350 nm fluorescence light

FD telescopes in closed environment

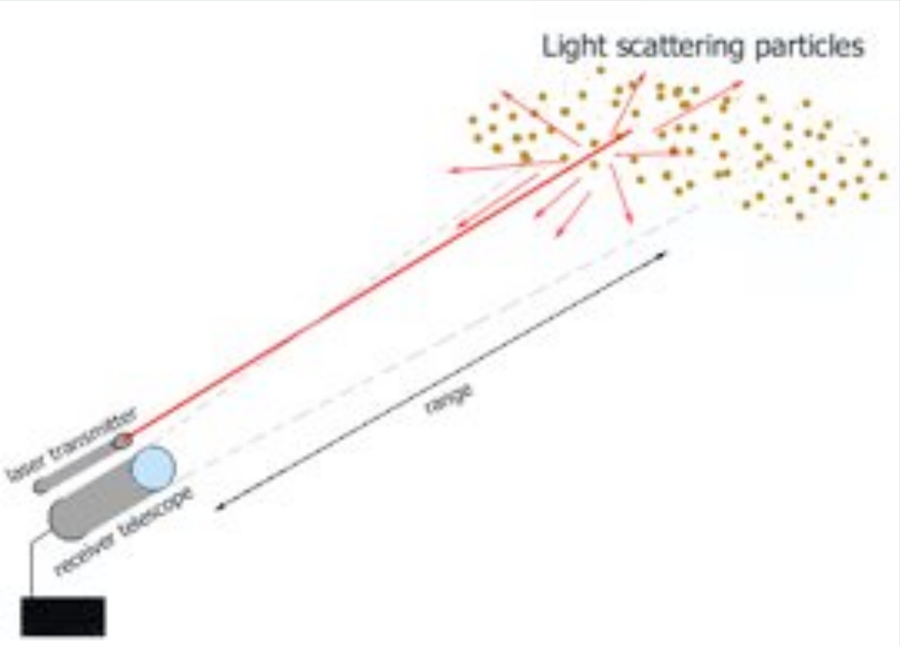
Discovery!



Science, November 2007
Arrival directions of the highest energy cosmic rays point back to certain galaxies with “Active Galactic Nuclei”

Atmospheric Monitoring with LIDAR Systems

- Light Detection And Ranging: "LIDAR"
- LIDAR systems operate as follows:
  - UV laser is triggered to shoot pulses into the atmosphere.
  - Aerosols, molecules, and clouds in the air cause some of the laser light to be backscattered towards the LIDAR station.
  - Spherical mirrors collect backscattered laser light
  - PMT's turn the signal into an electric current signal which is recorded as a function of time.
- Analysis of data allows for the development of atmospheric density profiles.



LIDAR enclosure near Fluorescence Detector building

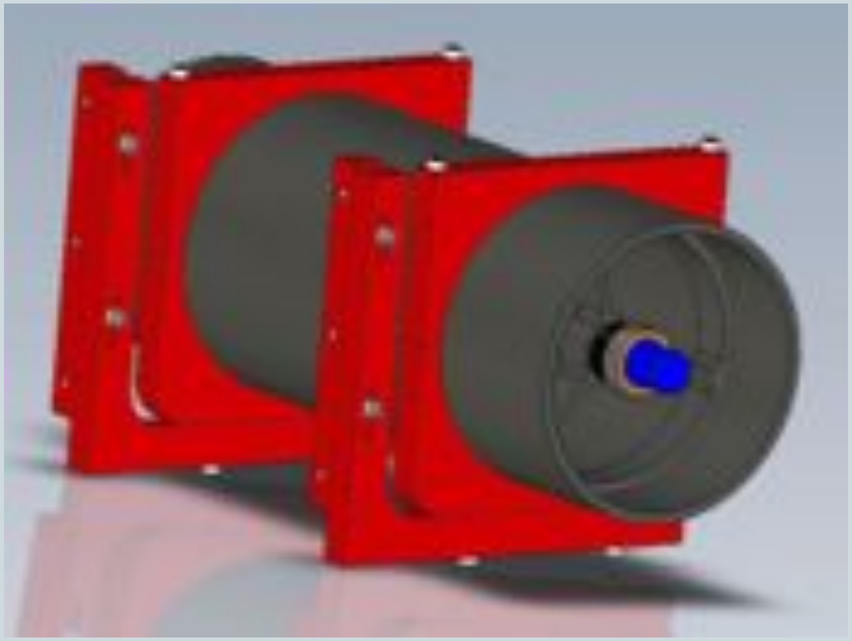
LIDAR Systems at Pierre Auger

- Original LIDAR system design had one laser box surrounded by three mirrors, each with a diameter of 80 cm.
- The mirrors and laser box are mounted to a rigid frame, which is steered and rotated in all directions to scan the entire sky above the observatory.
- After analyzing preliminary data it was determined that upgrades needed to be made in order to improve atmospheric measurements in the near-field, that is, less than 1 kilometer in front of the laser.

- UNL HEP Pierre Auger group:
  - Dr. Greg Snow (faculty)
  - Emily Petermann (graduate student)
  - Maria Becker (undergraduate)

Near-Field Prototype LIDAR Design

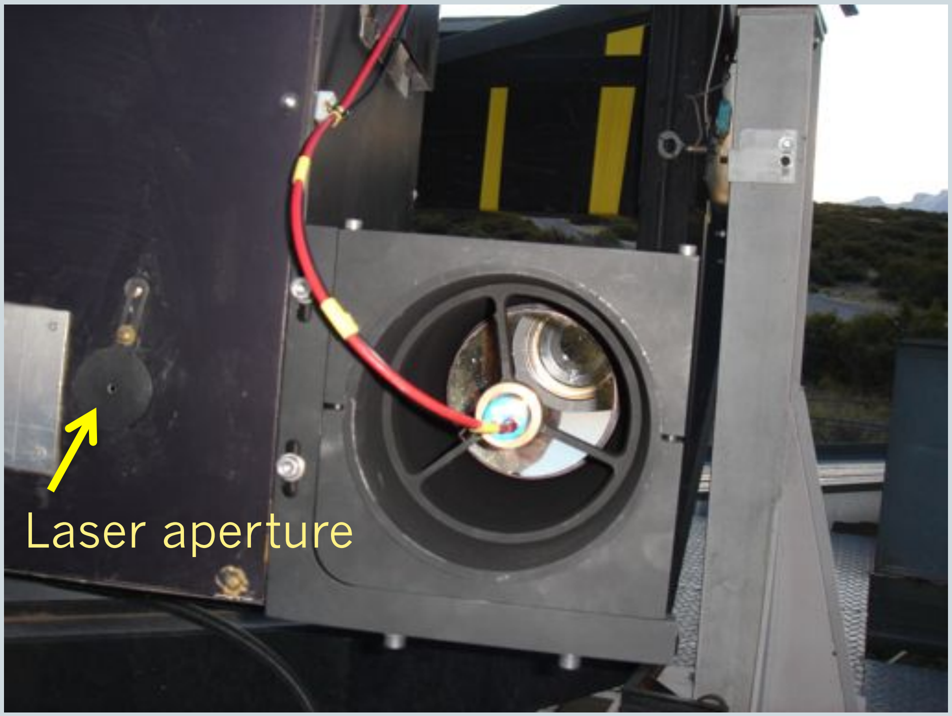
- Weak signal strength in the near-field is due to the large offset between the axis of the laser and the axes of the mirrors
  - 170 cm and 120 cm offsets
- To reduce offset the near-field detectors were designed with smaller-diameter mirrors: 15 cm diameter, focal point: 30 cm
- Simulated several detector designs with a ray-tracing program
- Optimal design was modeled in Solid Works (a 3-D design software package) and constructed by staff in the UNL Dept. of Physics Instrument Shop
- The prototype detector was installed at the Coihueco LIDAR station in Spring 2009



- Aluminum tube houses mirror and PMT
- Mounting support brackets allow for transverse horizontal and vertical adjustment
- Push-pull mechanism for adjusting mirror position

LIDAR enhancement prototype at UNL Physics instrument shop

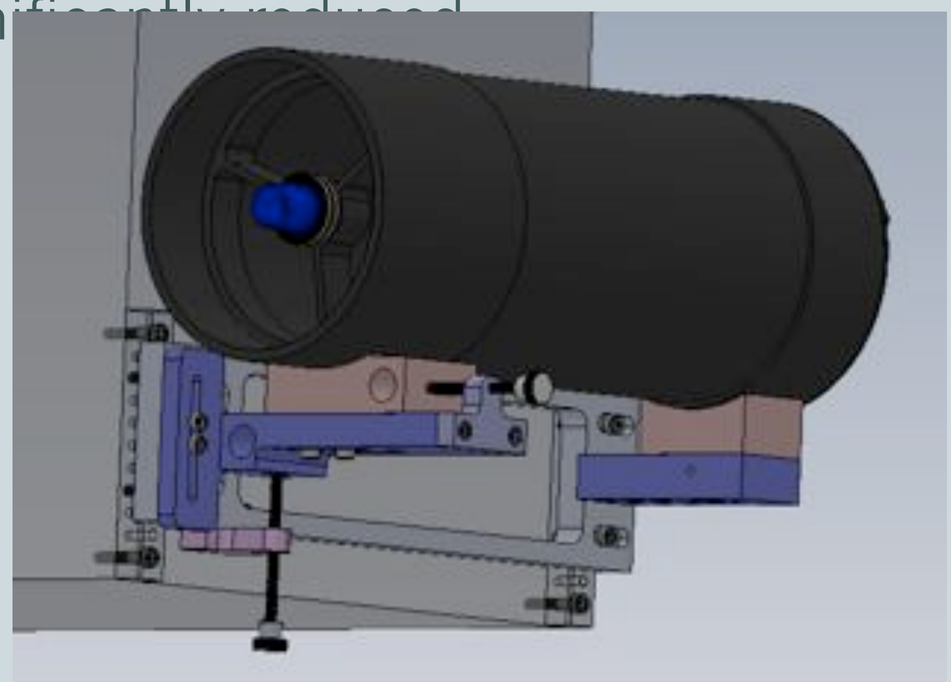
Near-Field Prototype LIDAR Detector Installation at Coihueco



- Offset between laser aperture and mirror axis reduced to ~20 cm

Modified Near-Field Detector Design

- Prototype detector successfully collects atmospheric measurements as close as 200 m from the detector. However, the alignment process was difficult and it was very heavy.
- Re-designed detector’s mounting and positioning structures to have with two rotational degrees of freedom. The weight was also significantly reduced.
- Internal detector components are the same as the for the prototype design.
- One modified near-field detector was completed in November 2009 and installed at the Loma Amarilla LIDAR station in March 2010.

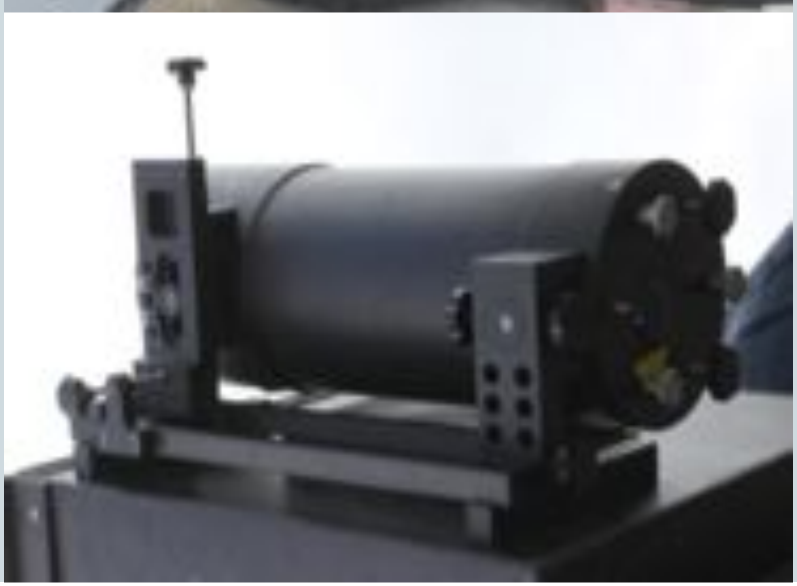


Improved LIDAR Detector

Installation in Argentina

Modified Near-Field Detector Installation at Loma Amarilla





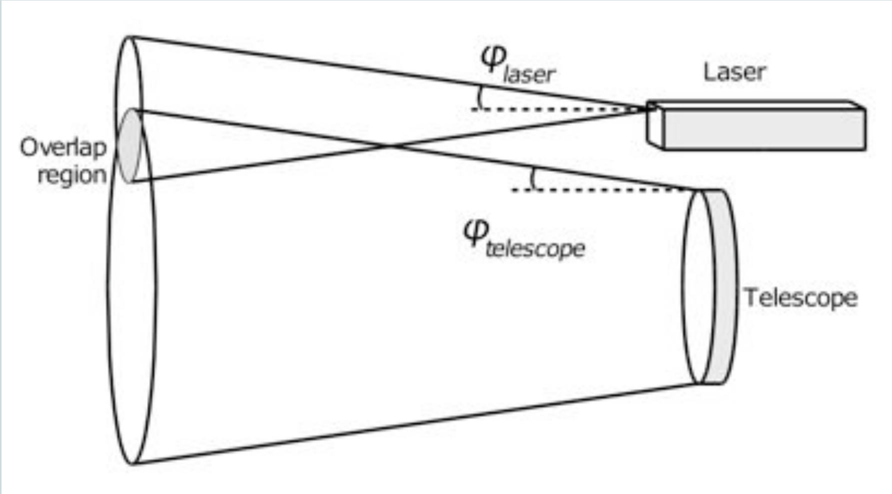

LIDAR Data: Overlap Function

- Data from the near-field LIDAR detector is analyzed to gather specific information about the atmosphere.

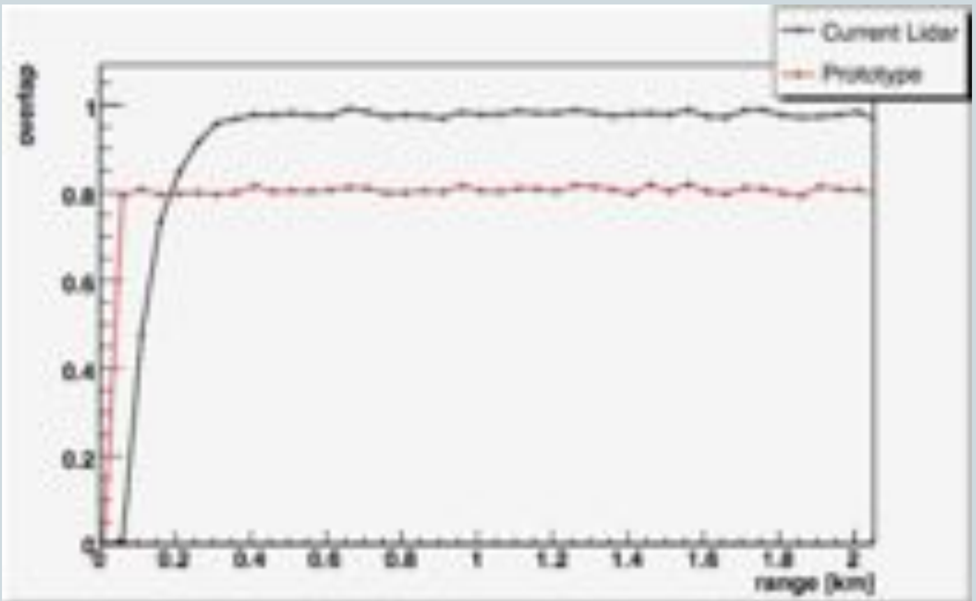
- Evaluate the Overlap function, which serves to indicate proper alignment of the telescope with respect to the laser.

- The overlap function G(r) is a ratio of the effective receiving area of the detector to the total cross-sectional area of the back-scattered laser signal.

$$G(r) = A_{eff}(r) / A_0$$

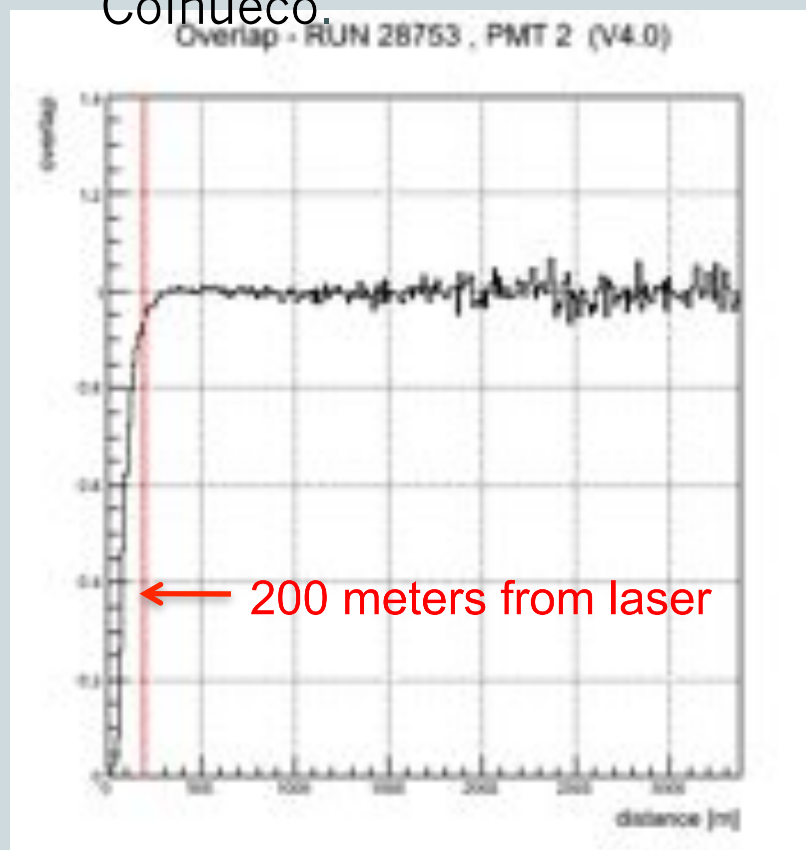


Performance Evaluation



- Comparison of simulated overlap functions for the original LIDAR detectors (black) and the near-field LIDAR detectors (red).
- Near-field detectors achieve complete overlap at much closer range.

- Overlap function generated from atmospheric data collected by the prototype near-field detector at Coihueco.



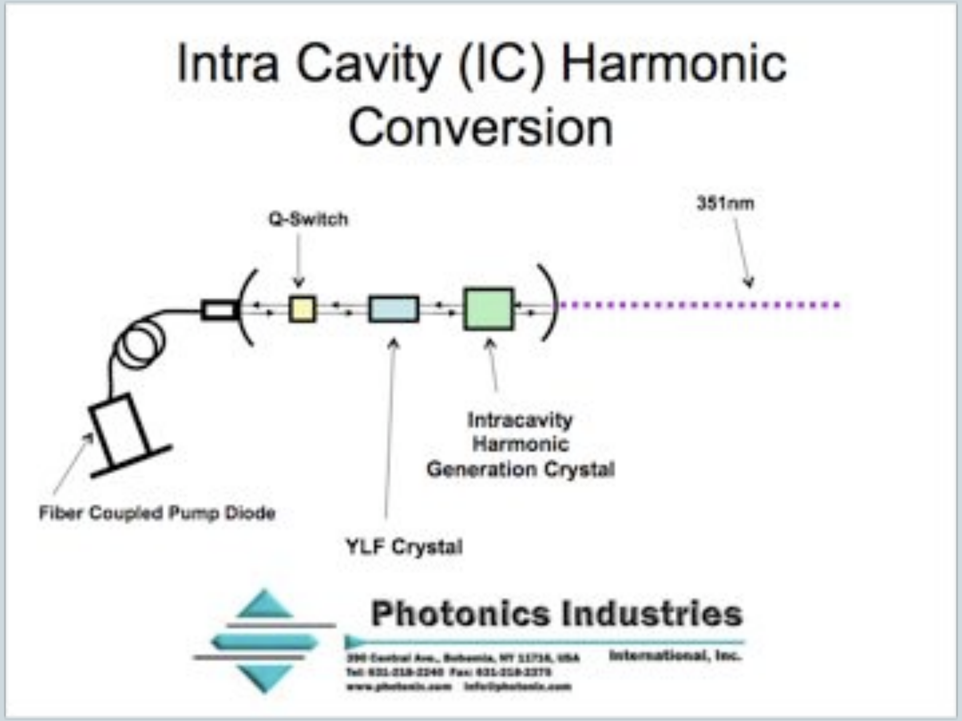
Future Work on Near-Field Upgrade

- Build and install two additional near-field detectors for the remaining fluorescence detector sites, Los Leones and Los Morados
- Analysis of data collected by near-field detectors
- Demonstrate that the addition of near-field atmospheric measurements improves the accuracy of cosmic ray energy calculations

Laser Study

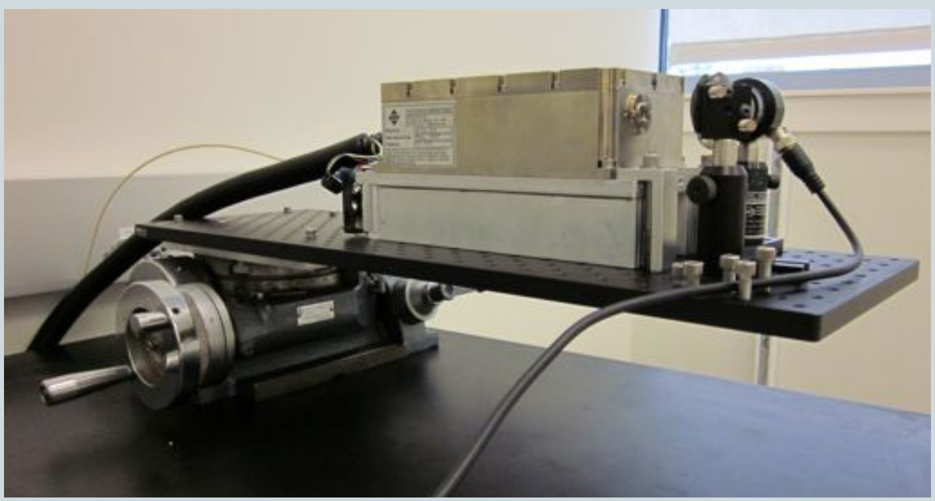
- Objectives:
  - Check stability of laser power over extended periods of operation
  - Check stability of laser power at varying physical orientations

- LIDAR Laser:
  - Diode-pumped, solid state laser: Photonics Industries model #DC30-351
  - 351 nm wavelength
  - Type Nd:YLF (gain medium is a neodymium-doped yttrium lithium fluoride crystal)
  - Average power: 300 mW
  - Average pulse energy: 150 μJ



Experimental Setup & Procedures

- Laser is operated at a rep. rate of 333 Hz to emulate actual operating conditions
- Use a mirror to align laser beam with the photodiode detection area
- Laser, mirror, and photodiode mounted on rotary table
- Photocurrent from photodiode is transferred to the oscilloscope via BNC cable
- Oscilloscope signal is the voltage measured across a 1 MΩ resistor
- Visual Basic program records laser pulse data for analysis
- 1-hour runs at each elevation angle of interest: 0, 30, 60, and 90 degrees
- 10-hour runs in the horizontal position



NASA Education Materials offer New Horizons for Online Physics Courses at UNL[1]

Maria Becker[2], Dr. Gregory Snow[3], and Suhasini Kotcherlakota[4]

http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Optics.Guide.html

NASA Educator Guides provide straightforward explanations and diagrams that demonstrate how mirrors and lenses bend and focus light. Optics is one of the key learning areas of the online course PHYS 212.

Introductory, Calculus-Based Physics Courses:

PHYS 211: Mechanics, Gravitation, Materials, and Waves

PHYS 212: Electricity, Magnetism, Circuits, and Optics

http://www.nasa.gov/mov/150440main_016_intro_newton_laws.mov

http://www.nasa.gov/mov/224269main_122_Gravity.mov

Video Learning Clips provide lecture-style education, not otherwise available with online courses.

These still shots from featured clips show a NASA test pilot explain Newton's Three Laws of Motion and an astronaut in orbit around Earth explain the force of gravity and how it applies to a tethered satellite in space.

Mechanics and gravity are central components of the PHYS 211 curriculum.

Department of Physics & Astronomy, University of Nebraska- Lincoln

1. Work supported by a NASA Nebraska Higher Education Mini-Grant. 2. Maria Becker is an undergraduate Physics major at UNL. 3. Dr. Gregory Snow is an Associate Dean of the College of Arts & Sciences at UNL, as well as a Professor for the Department of Physics & Astronomy. 4. Suhasini Kotcherlakota is an Instructional Design Specialist with EE&O Instructional Design & Development at UNL.

Summary

- Two NASA Nebraska Research Mini-Grants has enabled the University of Nebraska to enhance the atmospheric monitoring capabilities of the Pierre Auger Observatory in Argentina
- The near-field LIDAR detectors (prototype, then improved design) have been shown to work as designed
- This project is half finished and will continue through 2010-2011
- A NASA Nebraska Higher Education Mini-Grant has enabled us to add new dimensions to two online Introductory Physics courses offered by UNL
- Comment on collaborations with NASA scientists (CALYPSO, NASA Langford Laboratory)