Experimental Facilities in Latin America

Claudio O. Dib
Universidad Técnica Federico Santa María, Valparaíso, Chile
Content:

- **Brief introduction** to Particle Physics experiments.
- **Accelerator Facilities in L.A.**
- **Astronomical Observatories in L.A.** (current and future)
  - VLT, ALMA, DSA3, DES, LSST, GMT, ELT, LLAMA.
- **Current Astroparticle Facilities in L.A.**
  - Auger
  - Parenthesis on Cosmic Rays and Extensive Air Showers.
  - LAGO, HAWC
- **Future Astroparticle Facilities in L.A.**
  - CTA, ALPACA, LATTES, SGSO, ANDES
- **Summary**
Particle Physics experiments:

- Table top experiments

- Cosmic ray detection (Astroparticle Physics)

- Accelerators and colliders: (cyclotrons, synchrotrons, linacs; fixed target collisions, colliding beams)
Past table-top experiments

1895: J.J Thomson
  -> electron

1911: E. Rutherford
  -> nucleus & proton

1932: J. Chadwick
  -> neutron
Cosmic ray experiments

- **Cosmic rays:**
  radiation that comes from outer space.

- Discovered in 1912 by Victor Hess:
  - Went up a Balloon up to 5300 m:
    → Radiation is higher further above.

- Named **cosmic rays** by R. A. Millikan.

**Cosmic rays are actually... particles!**
(mainly protons & heavier nuclei)
Cosmic ray experiments

1932: C. Anderson discovers the **positron**.

1947: C. Powell, G. Occhialini, C. Lattes
- the **pion** and the **muon**.

Emulsion tracks show a pion decaying to muon and the latter to electron

Cosmic Physics Observatory, mount Chacaltaya, Bolivia
Accelerator facilities (fixed target & colliders)

Bevatron, Berkeley 1954-1971

(it fits in a big room...)

LHC, CERN, 2008-

(...it fits under a city and a few towns)

Many particles discovered in accelerators and colliders:
- baryons and antibaryons, mesons, tau, quarks, mu and tau neutrinos...

and the Higgs boson
Facilities in L.A.
Accelerator Facilities

• Pelletron (USP, Brasil) 1972-
  – Tandem electrostatic acceleration of ions through 8 MV

• TANDAR (B.A., Argentina) 1985-
  – Tandem electrostatic acceleration of ions through 20 MV

• Sirius (Synchrotron light source, LNLS, Campinas, Brasil) 2020-
  – Synch. 518 m perim., 3GeV electrons
  – Synch. radiation from IR to X-ray.
Briefs on Astronomy in LA
(current and near future)
Briefs on Astronomy (current)

- **VLT (Very Large Telescope)**
  - Cerro Paranal, Chile
    - 24°37’38” S
    - 2,635 m a.s.l.
  - 4 LT 8.2 m + 4 movable aux. T 1.8 m
  - Visible and IR
  - Interferometry & adaptive optics
  - First to get image of an exoplanet
  - Tracked stars around Super Massive BH at the Galactic Center
  - Afterglow of furthest known GRB (Gamma Ray Burst)
  - Currently the most productive Observatory
Alpha Orionis (Betelgeuse)

Without adaptive optics

With adaptive optics at VLT

Credit: ESO and P. Kervella
Briefs on Astronomy (current)

- **ALMA (Atacama Large Millimeter Array)**
  
  Chajnantor plateau, Chile  
  23°01’09” S  
  5,059 m a.s.l.

- 66 movable antennas, 12 m and 7 m
- 9.6 mm to 0.3 mm wavelength
- See through dust into star-forming regions
- Chemical compounds in stellar medium
- Disk and structures around stars
- Most expensive ground-based Observatory.

8 to 10
• **DSA 3 (Deep Space Antenna)**

  Malargüe, Argentina  
  35°46’34’’S  69°23’53’’W  
  1,550 m a.s.l.

  - Parabolic antenna 35 m.
  - VLBI with Australia & Spain.
  - 8 GHz / 32 GHz (200 MHz bw).

**Two uses:**

- Track and comm. with deep space probes
- Radio astronomy: Gamma ray sources, radio Galaxies, AGNs, nebula chemistry, etc.
Briefs on Astronomy (current)

- DES (Dark Energy Survey) 2013-2018
  Cerro Tololo, Chile
  30°10′11″S , 2,200 m a.s.l.

- DECam: hi sensitivity 570 Mpix
  Mounted on the 4 m Telescope
  (Victor Blanco Telescope)

To observe:
- Deep wide-area survey (5000 deg^2)
- Observe thousands of Supernovae
  and ≈ 300 M galaxies
Briefs on Astronomy (future)

- **LSST (Large Synoptic Survey Telescope)**
  
  2022-

  Cerro Pachón, Chile
  30°14’00” S, 2,682 m a.s.l.

  - Wide field 8.4 m Telescope.
  - 3.2 Gpix camera.

  - Map the sky every 3 nights, 45 Tb of data.
  - 10 year survey of the sky.

**To study:**

  - Explore the changing sky
  - Milky Way structure and formation
  - Nature of DM and understand DE
  - Catalog the Solar System
LLAMA (Large Latin American Millimeter Array)

202X?

Alto Chorrillos, Argentina
24°11′31″ S, 66°28′29″ W
4,820 m a.s.l.

- 12 m single radio telescope.
- mm and sub mm wavelength.
- 1 millisecond of arc resolution by very long baseline interferometry with ALMA & others.

To study:

- The Solar atmosphere, ...
- Exo planetary systems,...
- Intergalactic medium (molecules, ...)
- Spacetime distorsions near black holes,...
Briefs on Astronomy (future)

• GMT (Giant Magellan Telescope) 2024-
  Cerro Las Campanas, Chile
  29°00′57″ S, 2,550 m a.s.l.

  - Seven mirrors of 8.4 m in an array
    of 24.5 m diam → 368 m²
  - 10 times the resolving power of HST.
  - Adaptive optics.

To study:
  - Extrasolar planets
  - Galaxy formation and evolution
  - Universe evolution, DM, DE, ...

3 to 10
• **ELT (Extremely Large Telescope)**
  
  **2025-**
  
  Cerro Armazones, Chile
  
  $24^\circ35'52''$ S, 3,046 m a.s.l.

  - 39.3 m segmented primary mirror.
  - 4.2 m secondary mirror 978 m$^2$.
  - 16 times the resolving power of HST.
  - Adaptive optics.

**To study:**

- Exoplanets, water, etc
- Planetary systems formation
- First galaxies formation and evolution
- Universe evolution

2 to 10
Astroparticle Facilities

- **Pierre Auger Observatory** (UHE Cosmic rays)
- **LAGO** (CR)
- **HAWC** (Gamma rays)

**Future**

- **CTA** (Gamma rays)
- **ALPACA** (gamma rays)
- **LATTES** (Gamma rays)
- **SGSO** (Gamma rays)
- **ANDES** (Underground Lab: neutrinos, DM, ...)

Pierre Auger Observatory

Malargüe, Argentina
Parenthesis on CR and EAS
COSMIC RAYS (CR):

• **Primary Cosmic Rays** (direct from outer space):
  – **Charged CR**: protons, heavier nuclei, electrons
  – **Gamma Rays**: photons (lower flux: $< 10^{-3}$ flux of charged CR)
  – **Neutrinos** (weaker interactions)

• **Secondary particles** (produced by collisions of CR with the atmosphere)
  – Photons, e+, e−, muons, protons,...
CR Composition:

Similar to the solar composition

→ Stellar origin?

This is the galactic CR composition.

... We also need to know the extragalactic composition!
CR Spectrum and Composition:

Credit: J. Aguilar, UL Bruxelles
**CR spectrum:**

- Most primary CR: \( E < 10 \text{ GeV} \)
  - Spectrum decreases sharply for \( E > 10 \text{ GeV} \):
    \[
    \frac{d\Phi}{dE} \sim E^{-a}
    \]
  - \( E < 1 \text{ PeV} \): \( a \approx 2.7 \)
  - \( E > 1 \text{ PeV} \) (knee) \( a \approx 3.1 \)
  - \( E > 1 \text{ EeV} \) (ankle) \( a \approx 2.6 \)
  - \( E > 50 \text{ EeV} \): GZK cut...

Ref: S. Mollerach & E. Roulet, arXiv 1710.11155
HOW TO STUDY COSMIC RAYS:

• Primary Cosmic Rays:

  Measured in **Satellites or high altitude balloons** (h > 15 km)
  – CR with E < 100 GeV: absorbed by the atmosphere.
  – With E > 1 PeV: flux too low to be measured.

...but:

• Extensive Air Showers:

  – For E > 100 TeV, the CR cause **extended air showers** by collisions with atmosphere molecules.

  – Secondary particles can reach the ground.

  – Also charged particles cause **Cerenkov light** and **Fluorescence light**
EXTENSIVE AIR SHOWERS (EAS):

- Two types: **electromagnetic** (caused by gamma, e-, e-)
  **Hadronic** (caused by ions – e.g. protons)

- e.m. shower: (more collimated)
  $e^+, e^-, \gamma$ by a succession of
  - bremsstrahlung $e^\pm \rightarrow e^\pm \gamma$
  - pair production $\gamma \rightarrow e^+ e^-$

- Hadronic: (more messy ! ! !)
  lots of pions $\rightarrow$ muons from $\pi^\pm \rightarrow \mu \nu_{\mu}$
  and e.m. Components from $\pi^0 \rightarrow \gamma\gamma$
  $\mu \rightarrow e \nu_{\mu} \nu_{\e}$

Credit: S. Mollerach & E. Roulet, arXiv 1710.11155
Credit: J. Stachel, U. Heidelberg
Extensive Air Showers (cont.)

- **Shower develops:**
  - producing more and more particles...
    ... each with less and less energy
  - Multiplicity $N$ reaches a maximum at $x = X_{max}$
  - $N$ and $X_{max}$ depend on primary energy $E_0$
  - Surface spread is also a function of $E_0$
    ... but with large statistical fluctuations

- Hadronic showers are muon-rich, and with soft e.m. part reaching the ground.
- Lateral spread is broad and irregular, reaching $\sim$ km for $E > 1$ EeV  (UHECR)

Protons: interaction length in air: $\ell_H \approx 90 \, g/cm^2 \ (\approx 750 \, m \ at \ NTP)$
  (shorter for heavier nuclei: $\sim A^{-2/3}$
Total atmosphere thickness: $\approx 1kg/cm^2 \ (\approx 11 \ times \ \ell_H)$
Extensive Air Showers (cont.)

- **Electromagnetic showers** (part of a CR shower, or from a primary gamma):
  - Electrons, positrons and gamma.
  
  - Two processes: pair production: $\gamma \rightarrow e^+ e^-$ and Bremsstrahlung: $e^\pm \rightarrow e^\pm + \gamma$
  
  - Energy per particle degrades as: $\frac{dE}{dx} = -\frac{E}{X_r}$

  - Radiation length: $X_r \approx 37 \text{ g/cm}^2 \ (\sim 300 \text{ m at sea level NTP})$

  - Whole atmosphere $\sim 30$ radiation lengths (quite thick!)

  - Shower reaches maximum when energy reaches $E_c \approx 80 \text{ MeV in air}$. Then, **ionization loss** dominates over **bremsstrahlung**, and the shower dissipates.

$$\Rightarrow X_{max} \sim X_r \ln\left(\frac{E_0}{E_c}\right)$$
SIMPLE MODEL of an AIR SHOWER:

- **Heitler model:**
  - Only one kind of particle.
  - After every interaction length, particle splits in two, each with half the energy.
  - Continue until the particle energy is $E_c$ (when ionization loss and absorption win)

<table>
<thead>
<tr>
<th>$x = 0$</th>
<th>$\ell_H$</th>
<th>$2\ell_H$</th>
<th>$\ldots$</th>
<th>$n\ \ell_H$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N = 1$</td>
<td>2</td>
<td>4</td>
<td>$\ldots$</td>
<td>$2^n$</td>
</tr>
<tr>
<td>$E_0$</td>
<td>$E_0/2$</td>
<td>$E_0/4$</td>
<td>$\ldots$</td>
<td>$E_0/2^n$</td>
</tr>
</tbody>
</table>

\[ N(x) = 2^{x/\ell_H} \quad E(x) = E_0 \cdot 2^{-x/\ell_H} \]

\[ \therefore X_{max} = \ell_H \ \log_2(E_0/E_c) \quad \text{and} \quad N_{max} = E_0/E_c \]

(...but in the real case the dependence on $E_0$ is more complicated, with large fluctuations.)
HOW TO DETECT EAS:

- **Surface detectors (SD):**
  (water Cerenkov detectors, resistive plate chambers, scintillators)

- **Cerenkov telescopes**
  (detect Cerenkov light produced by the e.m. shower)

- **Fluorescence telescopes**
  (detect light emitted by excited Nitrogen)

- **Radio signals**
  (new technique for UHECR)
On CERENKOV RADIATION

• Charged particles moving in a medium with \( v > c/n \) emit a shock wave of radiation.

• Radiation propagates at an angle: \( \cos \theta_C = \frac{1}{n \beta} \)

• For \( \beta \to 1 \):
  - in water: \( \theta_C \simeq 41^\circ \), yield \( \sim 500 \text{ photons/cm} \)
  - in air: \( \theta_C \simeq 1.4^\circ \), yield \( \sim 40 \text{ photons/m} \)

• Continuous spectrum, grows with frequency.
  -> more blue, violet and UV
WHAT WE CAN LEARN from UHE CR and VHE GR:

Lots of issues in Particle Physics and Astrophysics:

- The most energetic processes in the Cosmos!
- CR acceleration mechanisms and sources
- Galactic nuclei: AGN, blazars, ...
- Propagation in the cosmic medium (GZK cutoff?)
- Magnetic fields in cosmic media
- Tests for relativity (Lorentz invariance)
- Dark Matter (indirect by decay or annihilation)
- And of course, the unexpected.
Pierre Auger Observatory

Air Shower Array + Fluorescence Telescopes
- Malargüe, Argentina
- 35º28’00”S, 69º18’41”W
- 1330 – 1620 m a.s.l.

- Detection of Ultra High Energy Cosmic Rays (UHECR), E > 10^{18} eV

- Largest CR detector array:
  - 3000 km^2 with 1600 WCD tanks,
  - 27 fluorescence telescopes in 4 sites.
Pierre Auger Observatory

- **The Surface detectors (SD):**
  Water Cerenkov Detectors (WCD) 1600 tanks, spread 1.5 km, covering a total terrain of 3000 km²

  Each tank:
  - 12 m³ of ultrapure water in a diffusive bag
  - Cerenkov light collected by three 9 in. PMTs.
  - 40 MHZ FADC digitization
  - GPS time
  - Radio communication
  - Solar panel + battery
Pierre Auger Observatory

• The Surface detectors (SD):
The Fluorescence detectors (FD):

- 27 Telescopes in 4 groups
- 3.5 m diam spherical mirror
- 440 PMTs per camera
- UV filters
- 180° x 30° FoV
- 10% duty cycle (moonless nights)

Atmospheric N₂ fluorescence:
- low yield (\( \sim 1 \text{ photon/m per } e^\pm \))
- isotropic emission

Observes longitudinal development
Calorimetric measurement (energy)
Composition measurement (\( X_{\text{max}} \))
The Fluorescence detectors (FD):

- Intensity + arrival time allows full reconstruction of the shower.
- Better resolution with info of two FD and SD.
- Integral of intensity profile along the shower = energy of primary.
- In addition with $X_{\text{max}} = \text{composition}$. 

Pierre Auger Observatory

from A.N. Bunner, MSc thesis 1964
Pierre Auger Observatory

Hybrid events

Event: 1364365

Los Morados

Ig(E/eV)~19.2
(θ,φ)=(63.7, 148.4) deg

Los Leones

Ig(E/eV)~19.3
(θ,φ)=(63.7, 148.3) deg

SD array: Ig(E/eV)~19.1
(θ,φ)=(63.3, 148.9) deg

Credit: X. Bertou
Main results from Auger:

– UHECR are nuclei (H to Fe). No gammas, no neutrinos.
– UHECR seem to be heavy elements at the highest energies
– High energy cut is not necessarily the GZK cutoff
– Current focus in on UHECR composition measurements
– No excess from Galactic Center
– Produced by astrophysical sources

• Other results:
  – High energy interaction model studies, atmospheric studies, solar physics, Lightning physics.

• Upgrades: (Auger Prime)
  – Add scintillator plates on top of each WCD, and muon detector underground; add radio detection of EAS.

• The website:  https://www.auger.org
LAGO

From Mexico to Patagonia
1 = Marambio (200 m)
2 = Bariloche (850 m)
3 = Buenos Aires (10 m)
4 = Campinas (685 m)
5 = La Paz (3630 m)
6 = Cota Cota (3917 m)
7 = Chacaltaya (5240 m)
8 = Cusco (3400 m)
9 = Lima (150 m)
10 = Huancayo (3370 m)
11 = Campina Grande (550 m)
12 = Riobamba (2750 m)
13 = Quito-SF (2800 m)
14 = Quito-PO (2800 m)
15 = Pasto (2530 m)
16 = Bucaramanga (956 m)
17 = Merida-ULA (1893 m)
18 = Caracas-USB (1200 m)
19 = Caracas-UCV (900 m)
20 = Guatemala-USC (1490 m)
21 = Sierra Negra (4550 m)
LAGO (Latin American Giant Observatory)  
(former Large Aperture Gamma Ray Observatory)

**Type:** Surface WCDs distributed all along the Continent,

- Ultra long baseline array of WCDs.
- One tank per site.
- High and low altitude sites along the Andes Mountains

**From Mexico to Patagonia:**
Mexico, Guatemala, Venezuela, Colombia, Brazil, Ecuador, Bolivia, Peru, Argentina and recently Chile.

Sierra Negra, Mexico | Pico Espejo, Venezuela
Marcapomacocha, Peru | Chacaltaya, Bolivia
LAGO (Latin American Giant Observatory)
(former Large Aperture Gamma Ray Observatory)

• The Detector: a Water Cerenkov tank.
  – Reliable, simple and cheap.
  – Commercial tanks with 1.5 m² – 10 m² detection area.
  – Filled with purified water.
  – Tyvek inner coating for UV light diffusion.
  – PMT + digitizer board (design available).
  – FPGA + Raspberry Pi: control, telemetry, DAQ, and on-board preanalysis
  – Time synch with GPS in PPS mode.
LAGO (Latin American Giant Observatory) (former Large Aperture Gamma Ray Observatory)

• Science goals:
  – The Universe:
    • Gamma Ray Bursts HE monitoring
    • High Energy Astroparticles
    • CR towards the knee
  
  – Space Weather:
    • CR Solar modulation
    • Atmosphere studies
    • Radiation background at sea level and higher altitudes.
LAGO (Latin American Giant Observatory)
(former Large Aperture Gamma Ray Observatory)

“Forbush decrease” of CR due to solar activity in a single WCD:

From X. Bertou
LAGO (Latin American Giant Observatory)
(former Large Aperture Gamma Ray Observatory)

• **Other purposes:**
  
  – **Education and training of students in LA**
    
    • Astrophysics,
    
    • Particle physics experiments and instruments,
    
    • Data Analysis + Statistics,
    
    • Muon Decay studies,
    
    • Interaction of particles with matter.

  – **Build an LA network of Collaboration in HEP**
    
    • Both among local institutions and international
LAGO (Latin American Giant Observatory)  
(former Large Aperture Gamma Ray Observatory)

• Organization:
  – Non centralized collaborative network of institutions;
  – Three working groups
  – A coordination Committee: 9 members + 1 P.I.
  – 75 members from 24 institutions in 10 LA countries

LAGO members in Marcapomacocha, Peru. from: L. Villaseñor
Sierra Negra, Mexico
HAWC (High Altitude Water Cerenkov)

Type: Air Shower Array

- Side of Sierra Negra, near Puebla, Mexico
- $18^\circ 59'41''N, 97^\circ 18'28''W$,
- 4100 m a.s.l. (need the high altitude to get the e.m. Shower: for 1 TeV gamma, $X_{\text{max}} \approx 8$ km a.s.l.)
- Detection of Very High Energy Gamma Rays (1 TeV to 100 TeV)

- 300 steel tanks, 7.3 m diam, 4.5 m high
- Cover area 22,000 m$^2$
- 4 PMT on bottom of each tank.

- HAWC is an improvement from MILAGRO (Los Alamos, NM, USA)

www.hawc-observatory.org
Brief on MILAGRO (Multi Institution Los Alamos Gamma Ray Observatory)

- Near Los Alamos, NM, USA
- 2530 m a.s.l.

- Pond 80 m x 60 m x 8 m, lined on bottom, filled with water and covered on top.
- 723 PMTs in two layers: 1.5 m and 5 m below surface
- 200 small WCD tanks added around the pond to select showers with core outside the pool.

- Detection of VHE gammas (100 GeV to 100 TeV)
Brief on MILAGRO (Multi Institution Los Alamos Gamma Ray Observatory)

- Detect e+ and e- from the e.m. atmospheric showers: they produce Cerenkov light in the water.
- Timing gives the direction
- Large field of view and duty cycle
- Poor energy resolution (> 50%)

- SOME RESULTS:
  - First TeV GR from Galactic plane
  - Map of diffuse galactic TeV GR
  - Discovers source of TeV GR in Cygnus
  - TeV GR from Crab Nebula and AGN’s

- Shut down in 2008, PMTs went to HAWC.

https://physics.nyu.edu/experimentalparticle/milagro.html
So... back to HAWC

- 15 times more sensitive than MILAGRO
- Why separate tanks: PMT optical isolation (less noise)

- The shower detection in water tanks:
  - 4 PMTs at the tank bottom:
    - 3 PMT of 8 in. (from MILAGRO)
    - 1 PMT of 10 in. at center, of high quantum efficiency for better sensitivity at $E < 1$ TeV

- Cerenkov radiation in water
- Direction of primary obtained from timing
- Angular resolution $\approx 1^\circ - 2^\circ$
Satellite view of the HAWC Observatory (Google Earth, 2016) showing the layout of the 300 water Cherenkov tanks in the array.
**HAWC (High Altitude Water Cerenkov)**

- **CR vs. Gamma separation:**
  - CR are $10^3$ times more frequent than Gamma-Rays

- **CR rejection by:**
  a) muon detectors or
  b) shower shape

3 to 43

www.hawc-observatory.org
HAWC (High Altitude Water Cerenkov)

- Sensitivity (1 yr)

![Graph showing sensitivity of different experiments](image)
HAWC (High Altitude Water Cerenkov)

- What HAWC can study:

  (take advantage of large FoV and duty cycle)

- Galactic CR sources: up to 100 TeV gamma (point to sources)
- Extreme galactic accelerators (unfrequent events)
- Extended TeV sources (most sources are extended)
- Diffuse emission from galactic plane (most CR interaction is w/ gas and dust)
- Extragalactic CR sources: AGNs and GRB (not seen at TeV ..but high output)
- Multimessenger and multiwavelentgth searches
  (early detection of most transient sources due to large FoV and Duty Cycle can warn other observatories with better resolution)

More on the website:  www.hawc-observatory.org
Future facilities

- CTA
- ALPACA
- LATTES
- SGSO
- ANDES
CTA

North: La Palma, Canary Is., Spain
South: Paranal, Atacama desert, Chile
CTA (Cerenkov Telescope Array)

Array of Imaging Air Cerenkov Telescopes (IACT)

- The largest array of IACT by far.

On two sites:

- **South Site (20 GeV – 300 TeV)**
  - Cerro Paranal, Chile
  - $24^\circ41'00''S, 70^\circ18'58''W$
  - 4 Large Size (LST) for low energies
  - 25 Medium Size (MST) for core range
  - 70 Small Size (SST) for highest energies

- **North Site (20 GeV – 20 TeV)**
  - La Palma, Canary Islands
  - 4 LST and 15 MST

12 to 53
CTA observatory sites:

CTA-North: La Palma, Canary Is.

CTA-South: Paranal, Chile

4 LST
15 MST

4 LST
25 MST
70 SST

(20 GeV - 150 GeV)
(150 GeV – 5 TeV)
(1 TeV – 300 TeV)

11 to 53
CTA: A consortium of 31 countries

Locations:

Agreements for both sites signed in 2018!

CTA-North array site (19 telescopes)

CTA-South array site (99 telescopes)
Several possible SST designs:

- **SST-2M GCT**
- **SST-2M ASTRI**
- **SST-1M**

Schwarzchild-Couder double mirror 4m & 2m app.

Davis-Cotton single mirror.

Credits: Akira Okumura
The MST designs:

**Modified Davis-Cotton**
- 12 m diam, f= 16 m
- FoV = 7.5°

**SCT 2M**
- 10 m / 5m diam,
- f= 5.6 m
- FoV = 7.6°

SCT prototype at Whipple Observatory, Arizona
The LST design:

Parabolic 23 m diam,
f= 28 m
FoV = 4.3º

103 tons!
CTA: how it works

γ-ray enters the atmosphere

Electromagnetic cascade

10 nanosecond snapshot

0.1 km² "light pool", a few photons per m².
CTA: how it works

- Cerenkov from e.m. shower in air: $\theta_C \approx 1^\circ$ at 10 km a.s.l.
- Angular spread of e.m. shower: $< 0.5^\circ$
  
  → Cone opening is dominated by Cerenkov.
- For 1 TeV gamma: maximum emission at $\approx 8$ km a.s.l.

- Light pool := ground area illuminated by Cerenkov. at 2000 m a.s.l., pool radius $\approx 120$ m.
- Pool photon density (quite uniform):
  
  For 1 TeV gamma: $\approx 150$ photons/m$^2$
  For 100 GeV gamma: $\approx 10$ photons/m$^2$
  
  → much thinner for lower energy GR.
Question:

• Why are the **LST** so large and so few, while the **SST** are small but many, and spread over a much larger area?
- Why is CTA South more sensitive at higher energies than CTA North?
- Why is HAWC more sensitive than CTA at very large energies?
Science with CTA:

• The Origin and role of relativistic cosmic particles:
  – Where are high-energy particles accelerated?
  – What are the mechanisms for CR acceleration?
  – What role do the CR play on star formation and galaxy evolution?

• Exploration of Extreme environments:
  – What physical processes occur near neutron stars and black holes?
  – What are the characteristics of relativistic jets, winds and explosions?
  – How are radiation and magnetic fields in cosmic voids?

• Exploration of Frontiers in Physics:
  – What is Dark Matter?
  – Are there quantum gravity effects on photon propagation?
  – Are there axion-like particles?
CTA (Cerenkov Telescope Array)

CTA operation: KSP + open to proposals.

- KSP 1: Galactic Center (GC)
- KSP2: Galactic Plane Survey
- KSP3: Large Magellanic Cloud (LMC) Survey
- KSP4: Extragalactic Survey
- KSP5: Transient Phenomena
- KSP6: Cosmic Ray PeVatrons
- KSP7: Star Forming Systems
- KSP8: Active Galactic Nuclei (AGN)
- KSP9: Clusters of Galaxies

See their website: www.cta-observatory.org
and the article: “Science with CTA” (arXiv:1709.07997v2)
ALPACA

Air shower array

Near Chacaltaya, Bolivia
ALPACA (Andes Large area Particle detector for Cosmic ray physics and Astronomy)

**Type:** **Air Shower Array** with muon detectors underground

- Estuquería plateau, near Mt. Chacaltaya, Bolivia.
- 16°23’S, 68°08’W, 4740 m a.s.l.

- Detection of UHECR and GR
- 401 SD (1m² scintillator) in 82,800 m²
- 96 Underground WCD (56 m²) in 5,400 m²

www.alpaca-experiment.org
ALPACA (Andes Large area Particle detector for Cosmic ray physics and Astronomy)

- Air Shower Array: 83,000 m²
- 1 m² plastic scintillation detector
- Muon Detector Array: 5,400 m²
- 56 m² underground water-tank muon detector

1 to 56
Scientific goals:

- Galactic sources of UHECR
- Nearby extragalactic sources
- CR composition around the knee to understand acceleration mechanisms
- UHECR energy distribution
- Solar Coronal Magnetic Field
- Cosmic Ray Anisotropy

Sensitivity to $\gamma$-ray Point Source

$\sim 15\%$ Crab/yr @30 TeV

10 – 1000 TeV

Energy (eV)
LATTES

Surface array for VHE gammas

Chajnantor plateau, near ALMA, Chile
LATTES (Large Array Telescope for Tracking Energy Sources)

**Type: Surface Detector Array for Gamma Ray Showers**
- Chajnantor plateau, near ALMA, Chile
- 23°01’09” S
- 5200 m a.s.l. (high altitude)

- Detection of GR 100 GeV – 100 TeV
- To cover gap in sensitivity between satellites and VHE ground arrays.
- To have a large FoV observatory (important for transient phenomena) in the South.
LATTES @ ALMA site

Large Array Telescope for Tracking Energetic Sources

- Planned site:
  - Atacama Large Millimeter Array site
    - Chajnantor plateau
    - 5200 meters altitude in north Chile
    - Good position to survey the Galactic Center
LATTES (Large Array Telescope for Tracking Energy Sources)

- High altitude (5200 m a.s.l.):
- Detection of GR 100 GeV:
  \[ \rightarrow \text{e.m. shower must reach the ground.} \]
A hybrid detector:
- Lower energy showers:
  Photons are $5-7$ times more than $\text{e}^+ \text{e}^-$
  $\rightarrow$ trigger on the photons.

- $5.6$ mm lead plate on top
  (to convert the photons)

- Two $1.5 \times 1.5$ m$^2$ RPC
  (resistive plate chamber) for good timing and geometry reconstruction

- WCD (water Cerenkov) $3 \times 1.5 \times 0.5$ m$^3$
  for calorimetric measurement
LATTES

The array:

• Core array: 20,000 m$^2$
  (improved sensitivity at low E)

• Towards a Full array: additional array of sparse detectors
  100,000 m$^2$.
LATTES (Large Array Telescope for Tracking Energy Sources)

Summary:

• Surface array for Gammas of relative low energy to fill gap between Satellite – EAS arrays

• In the Southern hemisphere Large FoV to detect transients and variable sources

• Provides trigger to IACT observatories like CTA
SGSO

A large surface detector array somewhere in South America
**SGSO (Southern Gamma-ray Survey Observatory)**

A. Albert et al., arXiv:1902.08429

**Motivation:**
- Currently no wide FoV (field of view) in the Southern Hemisphere
- Ground view of the Galactic Center is only from the South
- Will greatly help CTA to find transient events and variable sources

**Proposal:**
- A Surface array in the South (wide FoV and large duty cycle)

The two techniques:
- Surface detectors at high altitude to catch the shower particles
- IACT at lower altitude to detect the Cerenkov light
SGSO

Improve from HAWC:
- larger size + higher altitude
- larger number of channels
- larger “fill factor”
→ lower E threshold
→ better angular resolution & bkgnd rejection

Current work:
- Simulations to find optimal design (Strawman detector with larger size and at higher altitude than HAWC)
SGSO (Southern Gamma-ray Survey Observatory)

The science: Four pillars of SGSO:

• Unveil galactic and extragalactic **particle accelerators**:  
  – Galactic center + plane, Star-forming regions, Pulsars, Fermi bubbles,...

• Monitoring **transients** of VHE GR:  
  – AGNs & Blazars, GRBs, G Waves, HE neutrinos,...

• Probing **Particle Physics** BSM:  
  – Dark Matter?, Axion-like particles? Lorentz invariance?

• Characterize the **Cosmic Ray flux**  
  – CR Spectrum + Composition, CR flux anisotropies  
  – Space weather and Heliosphere physics
...and last: SGSO as part of a multi-messenger network: **AMON** (Astrophysical Multi-messenger Observatory Network)
Where to build: several options

- High altitude, access, services, water.

- **Argentina:**
  - e.g. Cerro Vecar, near LLAMA & QUBIC 4800 m a.s.l., 24° S.

- **Chile:**
  - e.g. Chajnantor, near ALMA 5100 m a.s.l., 23° S.

- **Perú:**
  - e.g. Lake Sibinacocha, Cuzco region 4870 m a.s.l., 13° S

Want to join the team?

www.sgso-alliance.org
ANDES
First Int’l Underground Lab in LA

Inside the Agua Negra tunnel
at Chile-Argentina border
ANDES

Deepest point of the Agua Negra Tunnel (to be built)
- $33^\circ11’34”S, 69^\circ49’25”W$, 3900 m a.s.l.
- 1700 m rock overburden
- Tunnel 14 km long, two tunnels, two lanes each.
- 220 km from La Serena, Chile
- 250 km from San Juan, Argentina
- Lab: 2 large caverns,
  - 1 large pit,
  - several smaller caverns
  - 1 geoscience tunnel

San Juan, Argentina

La Serena, Chile
ANDES

- Deepest point (1750 m)
  ≈ 3.5 km from Chile entrance
ANDES

- Third deepest Lab in the world
- First in Latin America
- First in Southern Hemisphere
- Low neutrino bkgnd from Reactors
- Special geophysical region
Science in ANDES:

- **Neutrino Physics:**
  - Large size detector (geoneutrinos, SN, etc)
  - Double beta decay

- **Dark Matter searches:**
  - New technologies for Low Mass DM
  - South-North oscillation comparison
  - Beyond the neutrino floor?

- **Nuclear Astrophysics**
- **Biology** in extreme environments
- **Geophysics, Geology**
- **Environmental science**
ANDES

ANDES Design

• Current status: engineering design by Lombardi
ANDES Design: Main cavern
- 50 m long, 23 m wide, 25 m high
- 40 ton curved bridge crane
- Fluid spill repository 500 m³
- To fit several large experiments
- Mechanics workshop
ANDES Design: Main pit

- 35 m diam, 38 m high
- Access from top and bottom
ANDES

ANDES Biology Lab

- 24 m long, 8 m wide
- Two floors
ANDES Geoscience cavern

- 200 m long, 4m x 4 m section
- Restricted access (no ventilation)
Two Support Labs:
• La Serena (Chile)
• Rodeo (Argentina)
• Includes Visitor Center

Current Status:
pending approval from Chile

Support from
more than 40 institutions

Organization:
an International Consortium.

from: Lab. S. de Modane, France
Summary:

• A lot of Astronomy Observatories (optical and radio) in the South
• Some accelerators for applications
• Most HEP Facilities in L.A. are in Astroparticles!
  — Cosmic Rays, Cosmic Gamma Rays... and soon underground: DM and neutrinos.
• The largest CR Observatory in history is in L.A. (Argentina)
• The largest IACT array in history will be in L.A. (Chile)
• A new prospect: the first Underground Lab in the Southern Hemisphere ...
  will be in L.A. (Argentina-Chile border).

• Several plans for the near future (you should join in!)

Thank you

Nations prosper when they dare to face great challenges together.