Astrophysics in China

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Institute of High Energy Physics
Vulcano, May 23, 2016
Astrophysics in China Since 50’s

Yunnan, 3200m, 50’s

Cloud chamber, 60’s

Tibet, 5500m, 70’s

Tibet, 4200m, 90’s
Yangbajing Cosmic-ray Observatory: \( \text{AS}\gamma \) & ARGO experiment

- \( \sim 3 \text{TeV} \)
- \( \sim 300 \text{GeV} \)

**Sino-Italian ARGO experiment (RPC hall)**

**Sino-Japanese AS\( \gamma \) experiment (scintillation detector array)**

**AS\( \gamma \) scintillation detector**
A new Phase: LHAASO
— Large High Altitude Air Shower Observatory

Sichuan, 4300 m a.s.l.
LHAASO Detector Setup

Main Array:
5195 scintillator detectors every 15 m & 1146 μ–detectors every 30 m

Water Cherenkov Detector
80,000 m²

CR Detectors:
18 Wide field View Cherenkov telescopes & Large Dynamic WCDA++:
precision measurement of CR spectrum
Science at LHAASO

- Unique for 10 TeV $\gamma$ astronomy with the highest sensitivity in the world
- Window for discovering the hadronic origins of cosmic rays
- Crucial CR data covering a very wide energy region of knees
- Exploring for new physics, such as DM or quantum gravity

Complementary to CTA:
- All the time
- All the sky
- Time-variant sources
- Extended sources
- Fast indication for CTA
The knee at 700\(\pm\)230\(\pm\)70 TeV is found

Spectral index:
\(\beta_1=-2.56 \pm 0.05\) below the knee;
\(\beta_2=-3.24 \pm 0.36\) above the knee;

Current Status

- LHAASO is funded for 2016-2020
- Sichuan province provides land & infrastructure
- Construction starts by the end of this year
- The 1st Result with LHAASO prototype & ARGO-YBJ
  - H & He (70% purity)
  - A knee @700 TeV

International Collaboration

- **Italy**
  - INFN approved the LHAASO proposal in Oct. 2015, for one year
  - Torino: gamma ray astronomy, gamma ray burst search, CR spectrum
  - Rome-II: DM search, CRs
  - Natural evolution of 20+yr collaboration (ARGO-YBJ) in HEP between IHEP and INFN
  - The longest & important scientific collaboration between Italy and China

- **Switzerland**
  - Geneva Univ. joined LHAASO as an associated member for collaboration on the SiPM based C-telescope camera
  - They are developing Winston cones for SiPM pixels

- **France**
  - IPN-Orsay and OMEGA group for micro-electronics

- **Russian**
  - neutron detectors

- **Thailand**
  - solar CR group
CMB at Tibet: Ali/BICEPx

- Ali(5100m) is the best observatory in the north hemisphere
  - Moisture in winter: 1.0 mm
  - Nearby(~6000m): 0.5 mm
    - Comparable or even better than South Pole/Chile
- Existing infrastructure
- Good sky coverage

- Collaboration with BICEPx:
  - China participate BICEPx & G4 planning at Chile/South pole
  - US & China establish a new site in Tibet

Thanks to LIGO, Funding suddenly arrived
## Particle & Astro-Particle Physics at IHEP

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<td>XTP</td>
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Space Projects

AMS

Moon exploration

Hard x-ray modulated telescope

To be launched this year

POLAR

To be launched this year
Hard X-ray modulated telescope (HXMT)

- Full sky survey with good angular resolution and sensitivity
- First satellite for astronomy & astrophysics in China
- Construction completed, under final testing
- To be launched around Oct.-Nov., 2016

Total mass: 1021kg
Signal: 1881 Ch.
Power: 350W
Gamma-ray burst polarization experiment onboard China’s Spacelab: POLAR

- Onboard China’s spacelab TG-2: launch time ~2016
- An international collaboration (Switzerland, France, Poland)
- FOV of POLAR: ~½ sky

Instrument concept proposed by N. Produit, et al., NIM (2005)
DArk Matter Particle Explorer (DAMPE) satellite

Energy range: 1 GeV-10 TeV
Particle type: electron, γ-ray, heavy ions
Energy resolution: 1.5%@800GeV
Spatial resolution: 0.1degree@500GeV
Background level: 1%@800GeV
p/e separation: <1%
GF: 0.5m².sr

- Satellite ~ 1900 kg
- Payload ~1340kg
- Power: 840W
- Lifetime > 3 years
- Launched successful on Dec. 18, 2015
HERD @ the China’s Space Station

- Science
  - Dark matter search: \( \gamma \) from 100 – 10,000 GeV
  - \( \gamma \)-ray astronomy: GRBs, microquasars, Blazars and other transients down to 100 MeV
  - Spectral and composition measurements of CRs between 300 GeV to PeV with a large geometrical factor
  - Complementary to LHAASO: directly measured composition & spectrum in space

- Status
  - Groups from China, Italy, Switzerland, Sweden,…
  - Launch in ~2023

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<tr>
<th></th>
<th>( X_0(\lambda) )</th>
<th>( \Delta E/E ) for e</th>
<th>e/p sep</th>
<th>e GF m(^2)sr@200GeV</th>
<th>p GF m(^2)sr@100TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>HERD (2020)</td>
<td>55(3)</td>
<td>1%</td>
<td>10(^{-6})</td>
<td>3.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Fermi (2008)</td>
<td>10</td>
<td>12%</td>
<td>10(^{-3})</td>
<td>0.9</td>
<td>--</td>
</tr>
<tr>
<td>AMS02 (2011)</td>
<td>17</td>
<td>2%</td>
<td>10(^{-6})</td>
<td>0.12</td>
<td>--</td>
</tr>
<tr>
<td>DAMPE (2015)</td>
<td>31</td>
<td>1%</td>
<td>10(^{-4})</td>
<td>0.3</td>
<td>--</td>
</tr>
<tr>
<td>CREAM (2015)</td>
<td>20(1.5)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>0.2</td>
</tr>
</tbody>
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Acceptance & H-energy > 10X all others
China (hardware+data analysis)
- 1 LYSO array
  - 5*5*10 crystals
- Fibers: 2 ICCD + 2 PMT
Geneva: beam coordination
Italy (hardware+data analysis)
- Silicon microstrip tracker
- Plastic scintillator trigger

Conclusion: success
- ICCD performance: OK
- Energy resolution: OK
- Dynamic range: ~OK
- Improved design started
Current team:
- China: IHEP, PMO, USTC, XIOPM
- Switzerland: Geneva
- Italy: Pisa, Florence, IAPS/INAF, Perugia, Trento,
- Sweden: KTH,
Neutrinos: A lot of Progress but still a Lot of Unknowns

- **Neutrino oscillation:**
  - Neutrino mass hierarchy ?
  - Unitarity of neutrino mixing matrix ?
  - $\Theta_{23}$ is maximized ?
  - CP phase ?

- **Absolute neutrino mass ?**

- **Dirac or Majorana ?**

- **Sterile neutrinos?**

- **Magnetic moments ?**

- **Relic neutrinos ?**

$arXiv: 1505.03456; 1603.03549$

$$\sin^2 2\theta_{13} = 0.084 \pm 0.005$$

$$|\Delta M^2_{ee}| = (2.42 \pm 0.11) \times 10^{-3} \text{ eV}^2$$
<table>
<thead>
<tr>
<th>Location</th>
<th>Daya Bay</th>
<th>Huizhou</th>
<th>Lufeng</th>
<th>Yangjiang</th>
<th>Taishan</th>
</tr>
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<tbody>
<tr>
<td>Status</td>
<td>running</td>
<td>planned</td>
<td>approved</td>
<td>Construction</td>
<td>construction</td>
</tr>
<tr>
<td>Power/GW</td>
<td>17.4</td>
<td>17.4</td>
<td>17.4</td>
<td>17.4</td>
<td>18.4</td>
</tr>
</tbody>
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By 2020: 26.6 GW  
arXiv: 1507.05613; 1508.07166;
Largest LS Detector

- LS volume: $\times 20 \quad \Rightarrow \quad$ for more statistics (40 events/day)
- light(PE) $\times 5 \quad \Rightarrow \quad$ for better resolution ($\Delta M_{12}^2/\Delta M_{23}^2 \sim 3\%$)

- Muon detector
- Stainless Steel Structure
- $\Phi35m$ Acrylic tank
- 20 kt LS($A_L > 25$ m)
- 40kt pure water($A_L > 50$ m)
- $\sim18000$ 20” PMTs, $\sim75\%$ coverage; $\sim36000$ 3” PMTs; 3% coverage
- 2000 20” VETO PMTs
Physics Reach

Thanks to a large $\theta_{13}$

- Mass hierarchy
- Precision measurement of mixing parameters
- Supernova neutrinos
- Geoneutrinos
- Sterile neutrinos
- ……

MH sensitivity with 6 years' data:

Ref: Y.F Li et al, PRD 88, 013008 (2013)

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<th>Relative Meas.</th>
<th>(a) Use absolute $\Delta m^2$</th>
</tr>
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<tbody>
<tr>
<td>Ideal case</td>
<td>4$\sigma$</td>
<td>5$\sigma$</td>
</tr>
<tr>
<td>(b) Realistic case</td>
<td>3$\sigma$</td>
<td>4$\sigma$</td>
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<tr>
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<th>JUNO</th>
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<tr>
<td>$\Delta m^2_{12}$</td>
<td>4%</td>
<td>0.6%</td>
</tr>
<tr>
<td>$\Delta m^2_{23}$</td>
<td>4%</td>
<td>0.6%</td>
</tr>
<tr>
<td>$\sin^2 \theta_{12}$</td>
<td>6%</td>
<td>0.7%</td>
</tr>
<tr>
<td>$\sin^2 \theta_{23}$</td>
<td>10%</td>
<td>N/A</td>
</tr>
<tr>
<td>$\sin^2 \theta_{13}$</td>
<td>6% $\Rightarrow$ 4%</td>
<td>$\sim$ 15%</td>
</tr>
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</table>
Schedule & Current Status

Schedule:

- Civil preparation: 2013-2014
- Civil construction: 2014-2017
- Detector component production: 2016-2017
- PMT production: 2016-2019
- Detector assembly & installation: 2018-2019
- Filling & data taking: 2020

Groundbreaking on Jan. 10, 2015

- A 600m vertical shaft
- A 1300m long tunnel (40% slope)
- A 50m diameter, 80m high cavern
JUNO collaboration established

Europe (27)

Armenia (1)
Yerevan Phys. Inst.
Belgium (1)
ULB
Czech (1)
Charles U
France (5)
APC Paris
CPPM Marseille
IPHC Strasbourg
LLR Paris
Subatech Nantes
Finland (1)
U. Oulu
Italy (8)
INFN-Catania
INFN-Frascati
INFN-Ferrara
INFN-Milano
INFN-Mi-Bicocca
INFN-Padova
INFN-Perugia
INFN-Roma 3

USA (1)

Germany (7)
FZ Jülich
RWTH Aachen
TUM
U. Hamburg
IKP FZI Jülich
U. Mainz
U. Tübingen

Russia (3)
INR Moscow
JINR
MSU

America (4)

US (2)
UMD
UMD-Geo

Chile (2)
Catholic Univ. of Chile
BISEE

Asia (31)

BJ Nor. U.
CAGS
Chongqing U.
CIAE
DGUT
ECUST
Guangxi U.
HIT
IHEP
Jilin U.
Ninan U.
Nanjing U.
Natl. Chiao-Tung U.
Natl. Taiwan U.
Natl. United U.

Nankai U.
NCEPU
Pekin U.
Shandong U.
Shanghai JT U.
Sichuan U.
SYSU
Tsinghua U.
UCAS
USTC
U. Of South China
Wuhan U.
Wuyi U.
Xi’an JT U.
Xiamen U.
Future of JUNO?

- Insert a Balloon into the JUNO detector, and fill the balloon with $^{136}$Xe-loaded LS
- Benefit from great experience of KamLAND-Zen
- Benefit from good energy resolution of JUNO
- Too shallow? Cut active volume around the muon track

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<th>Isotopes</th>
<th>Mass(t)</th>
<th>$&lt;m_\nu&gt;$,meV</th>
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<tr>
<td>nEXO</td>
<td>$^{136}$Xe</td>
<td>5</td>
<td>10-50</td>
</tr>
<tr>
<td>GERDA</td>
<td>$^{76}$Ge</td>
<td>1</td>
<td>10-40</td>
</tr>
<tr>
<td>Majorana</td>
<td>$^{76}$Ge</td>
<td>1</td>
<td>10-40</td>
</tr>
<tr>
<td>SNO+</td>
<td>$^{130}$Te</td>
<td>8</td>
<td>20-60</td>
</tr>
<tr>
<td>KamLAND-D-Zen</td>
<td>$^{136}$Xe</td>
<td>1</td>
<td>30-80</td>
</tr>
<tr>
<td>JUNO-bb</td>
<td>$^{136}$Xe</td>
<td>50</td>
<td>4-13</td>
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Very preliminary!  
Muon tracking is important!
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