HE, UHE Gamma-Ray astronomy

Masahiro Teshima
ICRR, University of Tokyo
Max-Planck-Institute for Physics
Cherenkov Telescope Array (CTA Project)

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>1100 scientists from 27 countries
Current Status
Cherenkov Telescope Arrays

MAGIC-II
VERITAS
HESS-II
Imaging Atmospheric Cherenkov Telescope

- Energy range: $50\text{GeV} \sim 10\text{TeV}$
- CR Rejection: $\sim 99.5\%$
- Angular Res.: $\sim 0.07$ degrees
- Energy Res.: $\sim 20\%$
- Effective Area: $\sim 10^5\text{m}^2$
- Sensitivity: $\sim 0.6\%$ Crab Flux ($10^{-13}\text{erg/cm}^2\text{s}$)

# of Photons: 50 photons/m$^2$ at 1TeV
>100GeV Gamma Ray Sources
155 sources (>100GeV) ➔ >1,000 sources with CTA
Cherenkov Telescope Array
High Energy Gamma Ray Astronomy

- Origin of Cosmic Rays
- Study of High Energy Astronomical Objects
- EBL Study → Cosmology (Star formation rate)
- Search for Dark Matter
- Space and Time (test of Relativity) High Precision
Cosmic Ray Energy Spectrum

Observation of accelerators in the Universe with HE/VHE gamma rays

- SNRs (Cas-A)
- Large Structure in our galaxy (Fermi bubble)
- AGNs (M87)
Gamma Ray emission from Shell type SNRs

H.E.S.S. Observation
IC443 and W44

FERMI Collaboration in Science
Different stages of SNRs as cosmic ray accelerator
CTA will deliver more information on SNRs as cosmic ray accelerators
We can survey most of SNRs in our galaxy ➔ C.R. energetics
Cosmic Ray Origin

SNRs

$E^2 \frac{dN}{dE} \text{ [eV m}^{-2} \text{s}^{-1} \text{sr}^{-1}]$

$10^{12}$

$10^{10}$

$10^{8}$

$10^{6}$

$10^{4}$

$10^{2}$

$12$ $14$ $16$ $18$ $20$

$\log E \text{ [eV]}$

ATIC

PROTON

RUNJOB

Tibet ASg (SIBYLL 2.1)

KASCADE (QGSJET 01)

KASCADE (SYBILL 2.1)

KASCADE-Grande (2009)

HiRes I

HiRes II

Auger (2010)
Cen A is a hadron accelerator?

Distance: 3.8Mpc
Flux: 0.8% in Crab Unit
Spectral Index: -2.7

Evidence of P-\(\gamma\) ?
Sahu et al 2012

Moskalenko et al.

\(L_{\text{VHE}} \sim 2.6 \times 10^{39} \text{ erg s}^{-1}\)
\(L_{\text{UHECR}} \sim 10^{40} \text{ erg s}^{-1}\)
Cosmic Ray Origin

SNRs

AGNs, GRBs

\[ E^2 \frac{dN}{dE} \text{ [eV m}^{-2} \text{s}^{-1} \text{sr}^{-1}] \]

\[ \log E \text{ [eV]} \]

- HiRes I
- HiRes II
- Auger (2010)

ATIC
PROTON
RUNJOB

Tibet ASg (SIBYLL 2.1)
KASCADE (QGSJET 01)
KASCADE (SYBILL 2.1)
KASCADE–Grande (2009)
Large structure in our galaxy
Fermi bubble

Symmetry suggests relation to Galactic Center
Hard Energy Spectrum (dN/dE ~ E^{-2})
Extends up to 10kpc above the disk (cooling time problem)
Edges are not clear

Source for Cosmic rays above knee??
Re-acceleration of CR?
\sim 10^{52}\text{erg} / 30,000\text{yrs}

Chernyshov et al. 2011
Cosmic Ray Origin

Large Structure at GC??

AGNs, GRBs?

$E^2 \frac{dN}{dE} \left[ \text{eV m}^{-2} \text{s}^{-1} \text{sr}^{-1} \right]$
From current arrays to CTA

light pool radius
R ≈ 100-150 m
≈ typical telescope spacing

Sweet spot for best triggering and reconstruction:
most showers miss it!

large detection area
more images per shower
lower trigger threshold
The ideal solution
Science-optimization under budget constraints:

- Array area increases with $\gamma$ energy
- Mirror area decreases with $\gamma$ energy

- Few large telescopes for lowest energies, for 20 GeV to 1 TeV
- ~km$^2$ array of medium-sized telescopes for the 100 GeV to 10 TeV domain
- Large array of small telescopes, sensitive about few TeV, 7 km$^2$ at 100 TeV

Base budget (2006):
- 100 M€ capital inv. (S)
- 50 M€ capital inv. (N)

4 LSTs

~25 MSTs plus
~36 SCTs extension

~70 SSTs
# Telescopes

<table>
<thead>
<tr>
<th></th>
<th>SST “small”</th>
<th>MST “medium”</th>
<th>LST “large”</th>
<th>SCT “medium 2-M”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number</strong></td>
<td>70 (S)</td>
<td>25 (S)</td>
<td>4 (S)</td>
<td>36 (S)</td>
</tr>
<tr>
<td></td>
<td>15 (N)</td>
<td>4 (N)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spec’d range</strong></td>
<td>&gt; few TeV</td>
<td>200 GeV to 10 TeV</td>
<td>20 GeV to 1 TeV</td>
<td>200 GeV to 10 TeV</td>
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<tr>
<td><strong>Eff. mirror area</strong></td>
<td>&gt; 5 m²</td>
<td>&gt; 88 m²</td>
<td>&gt; 330 m²</td>
<td>&gt; 40 m²</td>
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<tr>
<td><strong>Field of view</strong></td>
<td>&gt; 8°</td>
<td>&gt; 7°</td>
<td>&gt; 4.4°</td>
<td>&gt; 7°</td>
</tr>
<tr>
<td><strong>Pixel size ~PSF θ₈₀</strong></td>
<td>&lt; 0.25°</td>
<td>&lt; 0.18°</td>
<td>&lt; 0.11°</td>
<td>&lt; 0.075°</td>
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<tr>
<td><strong>Positioning time</strong></td>
<td>90 s, 60 s goal</td>
<td>90 s, 60 s goal</td>
<td>50 s, 20 s goal</td>
<td>90 s, 60 s goal</td>
</tr>
<tr>
<td><strong>Availability</strong></td>
<td>&gt; 97% @ 3 h/week</td>
<td>&gt; 97% @ 6 h/week</td>
<td>&gt; 95% @ 9 h/week</td>
<td>&gt; 97% @ 6 h/week</td>
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<tr>
<td><strong>Target capital cost</strong></td>
<td>420 k€</td>
<td>1.6 M€</td>
<td>7.4 M€</td>
<td>2.0 M€</td>
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</table>
LARGE 23 M TELESCOPE
OPTIMIZED FOR THE RANGE BELOW 200 GEV

400 m² dish area
27.8 m focal length
1.5 m mirror facets

4.5° field of view
0.1° pixels
Camera Ø over 2 m

Carbon-fibre structure

Active damping of oscillations, active mirror control

4 LSTs on each site

Masahiro Teshima

Expand gamma ray horizon up to z = 4.0
1510mm LST MIRROR prototype at Sanko
2.7mm Glass + 60mm Al.Honeycomb + 2.7mm Glass

Specifications
- F2F: 1510mm
- Area: 2m²
- R: 56.0 – 58.4 m
- D80: 15mm (1/3 pixel)
- Weight: 45kg
- Honeycomb with Slits
- Water drains

- Sputtering multi layer coat
  - Cr + Al + SiO₂ + HfO₂ + SiO₂
- Reasonably High reflectivity
- Strong protective surface
  - Long life time
PMD system is installed at ICRR, U-Tokyo

No.007, R = 57.02m

Deviation from ideal sphere

20μm

-20μm

PMD - Measurement Principle

2f-PSF @ 57.02m; PMD d80 = 16.4mm

D80 @1F = 8.2mm
LST-Camera  265 clusters/1855 pixels
(0.1°pixel, FOV 4.5°, Weight< 2 ton)

- Clusters 1.33kg x 265 <400kg
- Two cooling plates  <500kg
- Plex glass < 70kg
- Cables, Switching hub < 100kg
- Power module <150kg
- Supporting frame < 100kg
- Skin of Camera < 200kg
- Interface with Arch < 100kg
- Garage door < 200kg

Total <1820 kg

W = 68kg
HPK Photomultiplier (R11920)

Very High QE

R11920-100-20 Q.E. peak Histogram

- Ave. = 40.6%
- Min. = 36.4%
- Max. = 44.6%

R11920-100-20 Quantum Efficiency

- Peak 45%
- High Q.E.
- Good Consistency
MEDIUM-SIZED 12 M TELESCOPE
OPTIMIZED FOR THE 100 GEV TO ~10 TEV RANGE

100 m² dish area
16 m focal length
1.2 m mirror facets

7-8° field of view
~2000 x 0.18° pixels

25 MSTs on South site
15 MSTs on North site

→ Stefan Schlenstedt

Achieve the best sensitivity of 1mCrab at 1TeV and survey our galaxy
Look for PeVatron in our galaxy

SMALL TELESCOPE
OPTIMIZED FOR THE RANGE ABOVE 10 TEV

ASTRI Design
4.3 m mirror
9.6° foV
0.25° pixels

Multiple options under study:
Conventional single mirror, PMT camera
Single mirror, silicon sensor camera
Dual mirror optics, silicon & MAPMT camera

70 SSTs on Southern site

→ Tim Greenshaw

Look for PeVatron in our galaxy
Look for gamma rays from D.M. annihilation at G.C. and Dwarf Sph. Galaxies
Possible array configuration

Reference Layouts

South

North

1 km

LST 23m

MST 10-12m

SST 4.3m

LST

MST

SST

SCT
CTA (Cherenkov Telescope Array) covering 20GeV-100TeV

- An order of magnitude better sensitivity
- Wide energy coverage
- More than 1000 sources will be discovered

Simulation Galactic Plane scan (HESS and CTA)
Current Galactic VHE sources (with distance estimates)

CTA as ultimate survey machine

CTA as ultimate flare machine
at 25 GeV, for flares 10000 times more sensitive than Fermi

Coherent full-sky coverage from two sites
Cover 6 decades of Energy!!

After long observation, Crossing Energy is ~40GeV

CTA-LSTs give a significant sensitivity for transient sources,

GRBs, AGNs, and Galactic Transients
GRB: Simulated light curve (template: GRB080916C)
CTA Project office made a proposition and CB agreed during the CTA meeting in Warsaw on 23-27 September.

**SITE CANDIDATES**  Sites will be selected in the end of 2013

1st: Teide (Canaries, Spain), Meteor Crater (USA), Yavapai (USA)

1st: Aar (Namibia)
2nd: Armazones (Chile), HESS
3rd: Leoncito (Argentina)
4th: San Antonio (Argentina)

Warning: map not quite accurate

two sites to cover full sky at 20°-30° N, S
FOR THE FIRST TIME IN THIS FIELD: OPEN OBSERVATORY

Scientific community

Observer

Data products

Virtual Observatory

Proposal

CTA observatory

Science Operation Centre

Evaluation + selection, preparation

Science Data Centre

Data dissemination and reduction

Validation

Scheduling

Execution

Array Operation Centre

Center 30 pers.
South 30 pers.
North 20 pers.
Galactic Center observation by HESS in PRL 2011
Deep observation of Segue-1 by MAGIC

Segue 1: Dwarf Sph. Galaxy
Discovered by SDSS in 2006

Distance = 23kpc
M/L = 3400 M⊙/L⊙
M = 600,000 M⊙

\[
\frac{d\Phi_\gamma}{dE_\gamma} = \frac{1}{4\pi} \left< \sigma v \right> \frac{dN_\gamma}{dE_\gamma} \times J(\Delta \Omega),
\]
\[
J(\Delta \Omega) = \int_{\Delta \Omega} \int \rho^2(l, \Omega) \, dl \, d\Omega.
\]

<table>
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<tr>
<th>Name</th>
<th>l deg.</th>
<th>b deg.</th>
<th>d kpc</th>
<th>(\log_{10}(J))</th>
<th>(\sigma)</th>
<th>ref.</th>
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<td>358.08</td>
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<td>17.7</td>
<td>0.34</td>
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<tr>
<td>Carina</td>
<td>260.11</td>
<td>-22.22</td>
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<td>241.9</td>
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<td>0.53</td>
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<td>Ursa Major II</td>
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<td>Ursa Minor</td>
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<td>44.80</td>
<td>66</td>
<td>18.5</td>
<td>0.18</td>
<td>[16]</td>
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</tbody>
</table>
CTA sensitivity for G.C. Halo (50hrs)
CTA Sensitivities for G.C. Halo in 100 h (J. Conrad)
130GeV Line feature in gamma rays from Galactic Center in Fermi-LAT data (43 months), C. Weniger in 2012

4.6 sigma excess (50 photons)
Flux $\sim 2 \times 10^{-10} \text{ cm}^{-2} \text{ s}^{-1}$
$\langle \sigma v \rangle = 1.27 \times 10^{-27} \text{ cm}^3 \text{ s}^{-1}$
Analysis with 2D Energy Dispersion Model (Fermi team)

Fit to a gamma-ray line at 133 GeV in the P7REP CLEAN R3 data using the 2D model including a scale factor for the width of the energy dispersion.
Discovery potential for DM Line (50hrs) by T. Buanes

50hrs
NFW profile
Summary

• CTA is the next generation high-energy gamma ray observatory
  – Researchers from HESS, MAGIC, VERITAS, and high energy astrophysics field
  – More than 1100 scientists from 27 countries

• CTA is now in the preparatory phase and will move to the construction phase in the late 2014 or 2015
  – Several projects ➔ reviews, reviews, reviews,,
  – Design reports, Technical reports ➔ doc, doc, doc,,
  – Prototyping / preproduction ➔ Verification, Validation,,

• CTA will be the first open observatory in the field of Astroparticle Physics

• Good News: Germany (BMBF, MPG, Helmholtz) has decided the finance of about 50MEuro for the CTA construction
Thanks