A project for a new generation of Cherenkov telescopes

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Outlines

• Short review of current techniques
  • technological aspects
  • selected results
Outlines

- Short review of current techniques
  - technological aspects
  - selected results

- A next generation IACTs
  - Physical motivations
  - CTA consortium
  - Technical solutions
  - Calendar
Current IACTs
Technologies and selected results
Detecting Very High Energy Gamma-Rays with Cherenkov Light

~ 120 m Focal Plane

~ 100 m Particle Shower

~ 10 km Primary γ-ray

Atmosphere

Telescope focal plane

Courtesy J.Hinton
Current major experiments

VERITAS (Arizona, USA)
Array 4 telescopes of 12m diam.
Central mast mounting
1800 m asl
>2007

MAGIC (Canary Island, Spain)

HESS (Namibia)
HESS I: Array 4 tel. of 12m
HESS II: 28m diameter (>2009)
1800 m asl
>2003

Array 2 telescopes
17m diameters
2200 m asl
>2004
Well-proven technology...

- **Mounting**
  - Alt-azimuth mounting
  - Central mast or circular rail
  - Spherical or parabolic reflector (12-17m)

- **Mirror**
  - Tessellation of the surface
  - Extreme optical precision non required
  - Solid glass, aluminum, glass-aluminum replica

- **Camera**
  - ~1000 pixels
  - Photomultipliers (now...)
  - most expensive part of the telescope

- **Electronics/trigger**
  - Cherenkov signal lasts few ns, fast electronics
  - Tbytes/night
  - Topological triggers for single telescopes
  - Central trigger for stereoscopy
...and well-proven scientific outcome
...and well-proven scientific outcome

See also talks by Brun, Foerster, Krennrich, Egberts, De Angelis, Stamerra, this conference
...and well-proven scientific outcome

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- **Galactic targets**
  - Y-morphology SNR
  - Pulsed Y from pulsars
  - Periodic Y from binaries
  - Diffuse and punctual Y from GCs

- **Extragalactic targets**
  - Growing catalog of blazar
  - Radiogalaxy M87

- **Fundamental/CR physics**
  - Delay vs energy
  - Electron-Positrons

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Towards a precision gamma-ray astronomy

Physics motivations / technical demands
Scientific targets
Scientific targets

- Galactic targets

- Pulsar
- Supernova Remnants
- Pulsar wind nebulae
- Micro-quasars
- Galactic center
Scientific targets

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• Extragalactic targets
  - Active Galactic Nuclei
  - Galaxy Cluster
  - Starburst galaxies
  - Merging Galaxies
  - Gamma-ray Bursts
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- **Fundamental physics**
  - CR physics
  - Lorentz invariance
  - Quantum gravity
  - Axion-photons obsc
  - Dark Matter annihilation
  - Universe transparency

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CTA sensitivity

Crab spectrum
CTA sensitivity

- Low-Energy
- Hi-Energy

10x sensitivity

Crab spectrum

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- Low-Energy
- High-Energy

Background limits

10x sensitivity
CTA sensitivity

- **Low-Energy**
- **Hi-Energy**
- **Background limits**
- **Statistics limits**

10x sensitivity
CTA sensitivity

- Low-Energy
- Hi-Energy

Background limits

10x sensitivity

Statistics limits

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Low-energy physics (<50 GeV)

- **Galactic objects**
  - Investigate Pulsar models: pulsars have different cutoffs (below ~60 GeV) according to acceleration close or far from surface
  - VERY FERMI DEPENDENT!
  - Synchrotron emission from PWNs: PWNs emit synchrotron ~50 GeV gamma-rays from ultra-relativistic winds
    - Investigate acceleration mechanisms
    - hadronic/leptonic acceleration at SNRs: there are spectral differences below 100 GeV
- **Extragalactic objects**
  - Steep-spectrum blazars.
  - Complete Fermi catalog at VHE
- **Other**
  - overlap with Fermi on all unidentified >GeV sources
  - increase probability of observation of low-mass DM candidates
High-energy physics

• Galactic sources
  • Acceleration mechanism in SNRs (again):
    Above 50 TeV, hadronic/leptonic acceleration mechanism at SNRs differ
  • the nature of ultra-relativistic jets of micro-quasars
  • the nature of binary-systems
• Extragalactic
  • Understand FSRQs

• Other
  • Lorentz invariance between HE/LE photons
  • Probing the knee in cosmic-ray spectrum
Improve sensitivity

- The most fundamental of all tasks
- Give birth to precision VHE TeV astronomy

- Morphological studies on galactic targets
  - local interaction with gas/matter
  - discrimination hadronic/leptonic mechanisms
  - interaction with globular clouds

- Variability studies
  - sub-min scale variation (pulsar, binaries, AGNs, Lorentz invariance)
  - possibility to make follow-up obs. (binaries, blazar)

- Consolidate TeV astronomy
  - ~1000 new sources expected
  - acceleration sites of extragal. CRs (gal. merges, gal. clusters, IR gal., ...)
  - VHE model for AGNs
  - GRBs...
**Improve angular resolution**

- Both at the center and on the entire FOV
- Galactic objects
  - avoid source confusion due to the improved sensitivity.
  - hadrons and leptons have different free-streaming lengths and gamma-emission is strongly shaped by local interactions
- Improved angular resolution (arcsec scale) coupled with MW campaign will give key information to discriminate acceleration mechanisms
- SNRs, PWNs, Binaries, Micro-quasar, GC
- Complete a precise multi-wavelengths scenario
Improve energy resolution

- Increase capability to observed cutoffs
- Pulsar,
- EBL-absorbed AGNs
- DM spectral features
- Lorentz invariance
Improve energy resolution

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  - EBL-absorbed AGNs
  - DM spectral features
  - Lorentz invariance
CTA

Technical demands
**General design**

- **DESIGN**
  - Increase the array from 4 to ~100 telescopes
  - Distribute them over large area (~1 km$^2$)
  - Telescopes of 2-3 different sizes

- **DEVELOPMENT**
  - Use well-proven technology of current IACTs
  - High automatization

- **OBSERVATORY**
  - Open to external astronomer
Concept

- Few **Large Size Telescopes** should catch the sub-100 GeV photons
- Large reflective area
- Parabolic profiles to maintain time-stamp
- Contained FOV
- Challenging technology on all sides
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- Several **Medium Size Telescopes** perform 100 GeV-50 TeV search
  - well-proven techniques (HESS, MAGIC)
  - goal is to reduce costs and maintenance
  - core of the array
  - act as VETO for LSTs
Concept

• Few **Large Size Telescopes** should catch the sub-100 GeV photons
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• Several **Medium Size Telescopes** perform 100 GeV-50 TeV search
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• Several **Small Size Telescopes** perform ultra-50 TeV search
  • very simple construction
  • price should be small compared to full observatory
  • (maybe use only MST with larger FOV)
One observatory with two sites operated by one consortium

**Northern Array (50 ME)**
- complementary to SA for full sky coverage
- Energy range some 10 GeV .... ~1 TeV
- Small field of view
  Mainly extragal. Sources

**Southern Array (100 ME)**
- Full energy and sensitivity coverage
  some 10 GeV .... 100 TeV
- Angular resolution:
  0.02 ... 0.2 deg
- Large field of view
  Galactic + Extragal. Sources
Observation modes
Observation modes

Deep field

Highest sensitivity observation
Observation modes

1/3 array
Deep field

1/3 array
Deep field

Permanent monitoring
of some AGN

1 telescope
Monitor

4 telescopes
Monitor

--> ToO-triggers
on huge flares
Observation modes

Wide FOV Scan

Systematic scan of some good part of the sky

4 telescope Monitor
Observation modes

1/3 array Deep field

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Permanent monitoring of some AGN

---> ToO-triggers on huge flares

Wide FOV Scan

Systematic scan of some good part of the sky

Deep field

Highest sensitivity observation.
CTA Project
Structure, ideas, calendar
Members and structure
Members and structure

- **Partners:**
  - HESS+MAGIC collaborations + European (all) + world interest (Japan, Argentina)
  - coordination/discussions with US AGIS (Advanced Gamma-ray Imaging System) scientists, who work on a project
  - already ~50 institutes, ~14 countries (~ 300 scientists)
  - Regular meetings since 2007.
  - Project run as observatory

- **Structure**
  - Spokesman: **W. Hoffman** (MPI-K, Heidelberg),
  - Co-spokesman: **M. Martinez** (IFAE, Barcelona)
  - Work-Packages:
    - Physics,
    - MC,
    - Telescope and Mirrors,
    - Focal Plane Instrumentation,
    - Electronics,
    - etc.
Telescopes

- **Small Size Telescope (SST)**
  - 2 projects
  - MPI-K
  - MPI-M
- **Medium Size Telescope (MST)**
  - 4 projects
  - BASELINE
  - ANL/DESY
  - Saclay
  - MPI-K
  - Meudon
- **Large Size Telescope (LST)**
  - 1 project
  - MPI-M

Different designs under competition
Mirrors

- Sizeable part of costs
- Challenges
  - 10,000 m²
  - Produce them in time!
  - Replica techniques to be proven
Mirrors

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- Aluminum-sandwich
  - Maintain optical properties
  - Costly

- Foam glass replica
  - Dew formation?
  - Cheap

- Composites
  - technology not proven

- Cold-slumped glass replica
  - MAGIC II
  - Not proven technology
Camera/pixels

- Expensive
- Camera composed of 1000-2000 pixels
- Electronic inside the camera
- Keep low weight
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PMT = 40% PDE
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**Use of PMTs is baseline design**

PMT = 40% PDE

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GaAsP HPD = 50% PDE

PMT = 40% PDE
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Use of PMTs is baseline design

GaAsP HPD = 50% PDE

G-APD 60% PDE

PMT = 40% PDE
### Calendar of activities

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Very funding dependent!
System fully operational in 2018
Summary

• In 5+ years from now,
  • CTA will open the era of precision gamma-ray astronomy
    • Galactic and extragalactic objects
  • CTA may answer long-standing questions on cosmic-rays:
    • Where galactic and extra-galactic CR are accelerated
    • How CR are accelerated (hadrons/leptons, jets, magnetic irregularities, etc....)
  • CTA may answer fundamental physics
    • DM (see next talk by Fornasa),
    • Lorentz invariance,
    • Universe transparency,
    • photon-axion oscillation,

• For a new generation of IACTs, it is mandatory to:
  • Extend energy range from few tens of GeV to 100 TeV
  • Improve sensitivity and energy resolution
  • Larger FOV and better angular resolution
  • Operate as observatory
  • Multi-wavelength observations
Thanks!
Gamma-ray astronomy
Gamma-ray astronomy

- Galactic targets
  
  Pulsar
  Supernova Remnants
  Pulsar wind nebulae
  Micro-quasars
  Galactic center
Gamma-ray astronomy

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  - Quantum gravity
  - Axion physics
  - ....

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  - .....
Supernova Remnants

- **RX J1713.7-3946 (HESS, 2004)**
  - from 190 GeV to 40 TeV
  - shell radiating gamma rays
  - homogeneous spectral index quasi power-law
  - flux differences factor 2

- **Present tense:**
  - proven electron accelerators <100 TeV
  - prove existence of turbulent magnetic fields
  - provide acceleration mechanisms and energy budget
  - not conclusive results for hadronic/leptonic emission

- **Demands:**
  - Hadronic/leptonic emission depends on local ambient gas/radiation/magnetic field...
    - improve sensitivity to scan entire FOV
    - improve angular resolution to make morphology (down to 0.02?)
    - Extend sensitivity up to 100 TeV (where models differ)
  - Multi-wavelength campaigns (X-radio)
Pulsar Wind Nebulae

- PWNs give unique insights on relativistic winds acceleration
  - The magnetic field of the PWN drives a relativistic winds
  - Termination shocks is formed
  - HE particles diffuse into the nebula and emit X-ray (synchrotron) and g-ray (IC)

- Open questions:
  - maximum particle energy,
  - particle injection rate,
  - strength of the nebular magnetic field.

- Many open questions

- Demands:
  - Multi-wavelenghts (ratio X-ray and g-ray)
  - Angular resolution (morphology, interaction with ambient gas/radiation)
  - Lower energy threshold (catch synchrotron emission)
  - Sensitivity (morphology studies)
Pulsars

- Present tense:
  - 2000 pulsars known
  - 7 pulsars at HE gamma-rays with EGRET, n with FERMI
  - only 1 pulsar observed at VHE gamma-ray (<60 GeV) with MAGIC

- Facts
  - cutoff in gray spectra depends on model
    - polar cap (low-en cutoff)
    - outer gap (hi-en cutoff)

- Demands
  - Low threshold as possible toward 10 GeV
Diffuse gamma-ray emission

- Diffuse gamma-ray of galactic origin:
  - SNRs, PWNs, superbubbles, globular clusters....
  - DM?
- Hadrons travel more than electron and therefore account more for diffuse emission
- It is known since EGRET
  - < 50 GeV Fermi is currently the best experiments (has perhaps ruled-out the gamma-ray excess at 10 GeV)
  - > 200 TeV also Milagro

- The combination of the results from MeV-PeV allows for definition of scenario
- Demands
  - large FOV to get large sky
  - good angular resolution to exclude point-like sources
  - increased sensitivity to scan the FOV
**Double-objects**

- Systems of a compact object (neutron star, BH) and a massive star
  - spin together (orbital emission)
  - ultrarelativistic jets observed (micro-quasar)
  - highly unsteady

- Unknown:
  - jet composition (hadrons, leptons)
  - jet mechanism
  - energies
  - interaction with ambient matter/radiation

- Demands:
  - *angular resolution to shape ejection region*
  - *good sensitivity to sample orbital motion*
  - *sensitivity up to 100 TeV to disentangle mechanism*
  - *multi-wavelengths campaigns during orbit*