Elisa Bete de Gouveia Dal Pino (IAG-USP)
On behalf of the CTA Collaboration

UFES, Vitória, 8 de Outubro, 2018
The High-Energy Gamma Ray Sky (1989)

E > 100 GeV

(Galactic coordinates)
TeV sky today (~212 sources, 62 unidentified)
Detecting very high energy gamma rays on the ground: Cherenkovov telescopes
Cherenkov Image

Cherenkov “light pool” on the ground:
area $\sim 10^5 \text{ m}^2$

250 m
$50 \text{ GeV to } \sim 50 \text{ TeV}$, collecting area $\sim 10^5 \text{m}^2$, $\sim 4^\circ \text{ FoV}$, angular res. $\sim 0.1^\circ$ (TeV)
CTA: What one can (hopefully) afford

Key design goals:
- 10-fold increased sensitivity at TeV energies
- 10-fold increased effective energy coverage
- Larger field of view for surveys
- Improved angular resolution
- Full sky coverage: an array in each hemisphere
CTA Design (S array)

Science Optimization under budget constraints

**Low energies**
Energy threshold 20-30 GeV
23 m diameter
4 telescopes
(LST’s)

**Medium energies**
100 GeV – 10 TeV
9.7 to 12 m diameter
25 telescopes
(MST’s/SCTs)

**High energies**
Up to > 300 TeV
10 km² eff. area @ 10 TeV
4m diameter
70 telescopes
(SST’s)
CTA Consortium

CTA is being developed by the CTA Consortium:

31 countries, 92 parties, 202 institutes, 1466 members (513 FTE)
Where to find us
CTA PERFORMANCE
CTA ANGULAR RESOLUTION

Angular Resolution (°) vs. Energy $E_R$ (TeV)

- CTA South
- MAGIC
- VERITAS
- HAWC
- Fermi LAT Pass 8

CTA SCIENCE CASE
Science with the CTA: book to be published soon. Contains most of the plots in this talk.

CTA is an open observatory with 40% of its time reserved for Key Science Projects.

(http://adsabs.harvard.edu/abs/2017arXiv170907997C)
CTA Main Scientific Themes

Cosmic Particle Acceleration
- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

Probing Extreme Environments
- Processes close to neutron stars and black holes
- Processes in relativistic jets, winds and explosions
- Exploring cosmic voids
- Probing IGMFs

Physics frontiers – beyond the Standard Model
- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high-energy photons?
- Do axion-like particles exist?
Discovery Potential

adapted from
Horan & Weekes 2003

Distance
kpc
Mpc
Gpc

SNR/PWN
Binaries
Radio Gal.
Blazars

Pulsed

Current
Sensitivity
Future

Colliding Winds
Starbursts
Clusters
GRBs
+Dark Matter
+UHECR Sig.
Key Science projects

Galactic Centre
Galactic Plane Survey
Cosmic Ray PeVatrons
Star Forming Systems
LMC Survey
Extragalactic Survey
Active Galactic Nuclei
Transients
Clusters of Galaxies
Dark Matter Programme
Current Galactic VHE sources (with distance estimates)
EXAMPLE: GALACTIC PLANE SURVEY

H.E.S.S.

CTA, for same exposure

expect ~500 detected sources
COSMIC ACCELERATORS
TEVS -> PEVATRONS:

- Black Hole Binaries (Microquasars)
- AGNs (blazars, radio-galaxies, seyferts)
- Supernovae
COSMIC RAY PEVATRONS ($\sim 10^{15}$ EV)

**Figure 1.6** – Simulated CTA images of the TeV-bright supernova remnant RXJ1713--3946 for different emission scenarios, showing the power of CTA to differentiate between these scenarios. Reproduced from [21].


Detection gammas up to $E \sim 100$ TeV will imply:

- **✓** emission is hadronic
- **✓** SNR is PeVatron (because $\sim 100$ TeV photons are produced by $\sim$PeV protons)
Global view of a near star-forming galaxy at TeV energies
More than 60 SNRs
CTA EXTRAGALACTIC TARGETS

- Other galaxies
- GRBs
- Blazars
- Radio galaxies
- Star forming regions
- Survey / deep field
- Galaxy clusters
- EBL / IGMF

Thanks to D. Mazin
Galactic Plane and Extragalactic Survey
Location of Gamma Emission in Radio Galaxies

origin of variability at all scales?

location of emission region?

duty cycle?

PKS2155-304
arXiv:0706.0797
H.E.S.S.

2 min. bin
Resolving Complex Sources

Example: Cen A

0.1°
Typical
HESS/MAGIC/VERITAS
Resolution

2'
CTA > 1 TeV
Transients are a diverse population of astrophysical objects. Some are known to be prominent *emitters of high-energy gamma-rays*, while others are sources of non-photonic, multi-messenger signals such as cosmic rays, *neutrinos and/or gravitational waves*.

Possible classes of targets
- Gamma-ray bursts
- Galactic transients
- High-energy neutrino transients
- Gravitational wave transients
- Radio, optical, and X-ray transients
- Serendipitous VHE transients

Credits: The LIGO Scientific Collaboration
BLACK HOLE SOURCES: PEVATRONS, TRANSIENTS

AGNs (blazars, radio-galaxies, seyferts)

Black Hole Binaries (Microquasars)

GRBs
TRANSIENTS WITH CTA

Huge opportunity for short-timescale phenomena: GRBs, AGN/Microquasar flares ...

Differential Flux Sensitivity $E^2dN/dE$ (erg cm$^{-2}$ s$^{-1}$)

- **Fermi**
- **CTA**

Time (s):
- 1 min
- 10 min
- 1 hour

$10^2$ $10^1$ $10^0$ $10^{-1}$ $10^{-2}$ $10^{-3}$ $10^{-4}$ $10^{-5}$ $10^{-6}$ $10^{-7}$ $10^{-8}$ $10^{-9}$ $10^{-10}$ $10^{-11}$ $10^{-12}$ $10^{-13}$
CTA WILL RESOLVE GRB LIGHT CURVES!

CTA is potentially capable of resolving GRBs light curve in exquisite detail.

GRB template is the measured Fermi-LAT light curve above 0.1 GeV extrapolating the intrinsic spectra to VHE.

We expect to detect ~1 GRB/yr / site.
**AGN: ORIGIN OF VARIABILITY AT ALL SCALES? LOCATION AND SIZE OF EMISSION REGION?**

**PKS 2155-304 flare**

*arXiv:0706.0797 H.E.S.S.*

- TeV Flux

- Isotropic luminosity $10^{46}$ erg/s (luminosity of Milky Way: $10^{44}$ erg/s)

**CTA:** flares should be detectable within seconds rather than minutes

**200 s variability -> emitting zone $<R_s$ or very high Lorentz factor $\Gamma > 100$**

The data are binned in one minute intervals.

(Aharonian et al. 2007)
SEARCHING FOR DARK MATTER ANNIHILATION

Does dark matter annihilate producing gamma rays?

What is the (dark) matter content?

CTA prospects for CDM signatures:
- Around the Galactic center
- In dwarf galaxies
- In clusters of galaxies
DARK MATTER ANNIHILATION

- Canonical cross section
- 500 h, $W^+W^-$
- Aar, 30 GeV threshold
- Statistical errors only

- HESS GC halo (112 h)
- Fermi dSph stacking (10 dSphs, 4 yrs)
- Galactic Halo
- Sculptor dwarf
- LMC

DM mass (TeV)
Studies of Extragalactic Background Light with CTA

Lebedev Physical Institue

Gamma-rays from jet of Quasar

Observed spectrum

Emitted spectrum

Background light

Energy Flux

Energy

high absorption

low absorption
The Gamma Ray Horizon  \( \gamma + \gamma \rightarrow e^+e^- \)

- Whole universe visible
- Beamed sources, time variability
- Precision study of local EG sources, resolved morphology
- Precision study of galactic CR sources, up to the knee

1 pc = \(3 \times 10^{16}\) m
Probing Intergalactic Magnetic Fields

Probed Intergalactic Magnetic Fields

Axion conversion ??

$B_{\text{sim}} > 10^{-15} \text{ G}$

(Sol et al. 2013)
Quantum gravity effects -> arrival time delays between photons of different energies travelling large distances -> **variation of light speed** (non-trivial refractive index of the vacuum)
Complex, structured VHE source (BH)
Gas clouds illuminated by Pevatron?

Dark matter halo emission?
Launch of Fermi bubbles?
GALACTIC CENTER REGION

- wealth of VHE diffuse emission & sources, including the only known PeVatron
- giant particle outflow (Fermi bubbles)
- ideal region for dark matter searches
GALACTIC CENTER REGION IN GAMMA RAY
Brazilian Involvement
CTA Brazil

12 Institutions
25 Scientists
16 Students
5 Technicians

CTA - Rio

- CBPF
  - Prof. Ulisses de Almeida
  - Prof. Ronald Shellard
  - Bruno Arsioli
  - Bernardo Fraga
  - Rodrigo Cardoso
  - Amanda Carvalho

CTA - SP - MST

- IFSC-USP
  - Prof. Vitor de Souza
  - Prof. Manuela Vecchi
  - Prof. Cibelle Celestino
  - Dr. Humberto Huerta
  - Dr. Aion Viana
  - Edyvania Martins
  - Rodrigo Lang
  - Luan Arbeletche
  - Andres Delgado
  - Rodrigo Guedes Lang
  - Danielle Kaori
- IF-USP
  - Prof. Edivaldo Moura
  - Douglas Pimentel
- UFABC
  - Prof. Marcelo Leigui
  - Raquel de Almeida
- UFSCar
  - Dr. Gustavo Rojas
- UFPR
  - Prof. Rita de Cássia
- EEL/USP
  - Prof. Fernando Catalani
  - Prof. Carlos Todero
- SAIFR/IFT-UNESP
  - Dr. Fabio Iocco
  - Dr. Ekaterina Karukes
  - Maria Benito

CTA - SP - SST

- IAG-USP
  - Prof. Elisabete dal Pino
  - Prof. Rodrigo Nemmen
  - Dr. Rafael Batistai
  - Dr. Chandra Singh
  - Dr. Grzegorz Kowal
  - Dr. Reinaldo Lima
  - Dr. Paramita Barai
  - Dr. Luis Kadowki
  - Dr. Claudio Melioli
  - Dr. Juan Ramirez
  - Tania Torrejon
  - Renato Gimenes
  - Pankaj Kushwaha
  - Saib Hussain
  - Carlos Fermino
  - Raniere Menezes
  - William Bohórquez
  - Lucas Santos
- UNICSuI
  - Prof. Anderson Caproni
- EACH/USP
  - Prof. Diego Falceta-Gonçalves
  - Mohammad Ali

(Slide by V. de Souza)
BRAZILIAN BUDGET FOR CTA SO FAR

- FAPESP: total budget awarded: R$ 17.3M

- Thematic Project (Elisabete de Gouveia Dal Pino, IAG-USP): 12,2 M R$ + 2,7 M R$ (posdoc scholarships and international school)

- JP Grant (Paramita Barai, IAG-USP): 618 K R$

- Thematic Project (Vitor de Souza, IFSC-USP): 1,8 M R$

- FAPERJ: total budget awarded: ~ R$ 500 K
The ASTRI Mini-Array: CTA precursor

Mini-array with 9 SST-2M telescopes at the CTA south site (Chile): our 3 telescopes are currently in construction -> in 2019
Brazilian engineers @ ASTRI: structure/software development

Active optics tests (Torino)
- With Daniele Gardiol & Federico Russo

Performed task:
- Segment motion
- Data collection and calibration
- Repeatability verification

M1 Interface elaboration (Catania)
- W/ Matteo Munari, Salvo Scuderi, Enrico Giro, Luca Stringhetti, Elisa Antolini

Performed task:
- Actuator configuration as in CANopen
- Screens preparation for driving motors
- Interface implementation with users, scheduling tests, etc.
- Teaching on operation of logics for future change and implementation
- Teaching hardware & software Beckhoff
CTA-BR NEEDS

- Shareholder in CTA-Observatory on behalf of Brazil (under negotiation with MCT-C)
- Increase the current investments at least 10 MEuro
- Country wide participation
- Currently mainly FAPESP
- Partners in national industries (currently a few involved)
CTA Phases & Timeline

1 Design

2 Pre-Construction

3 Pre-Production

4 Production

5 Operations

- 2017-8: Hosting agreements, site preparations start
- 2019: Start of construction
- Construction period of ~6 years
- Initial science with partial arrays possible before construction end

Slide by Rene Ong.