



Unveiling the Gamma-Ray Universe with the CTA: the Key Science Projects

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"ti sian lievi le stelle"





The γ -ray sky

The Cherenkov Telescope Array

CTA Key Science Projects

Prospects & discussion



Outline



Talks by

- Pareschi
- de Souza
- Mirzoyan
- Maier
- McEnery

Many topics already covered





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The intersection of major axes on the common FOV gives source position on the sky.

More on the Cherenkov technique, sources and physics in: Hinton & Hofmann, 2009, ARAA, 47, 523





The current IACT status







VHE high-level timeline



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CERENKOV LIGHT IMAGES OF EAS PRODUCED BY PRIMARY GANNA RAYS AND BY NUCLEI Hillas, 1985

A. M. Hillss Physics Department University of Leeds, Leeds LS2 9JT, UK.

4397B4C7

It is shown that it should be possible to distinguish a effectively between background hadronic showers and TeV showers from a point source on the basis of the width. orientation of the Cerenkov light images of the shower, the focal plane of a focusing mirror, even with a relati coarse pixel size such as employed in the Mt. Hopking d.

<u>Detection of point sources of cosmic rays</u> Cortain X-ray binaries, pulsars and active galaxies app

point sources of TeV cosmic rays - presumed to be gamma-rays ces have been detected by observing flashes of Cerenkov radi small showers in the upper atmosphere, but these do not stand against the intense isotropic background of ordinary proton showers. If the appearance of the Cerenkov flashes differs (classes of shower, much of the background might be rejected. paper. Cawley et al. (1) describe the modification of the 107 paper, taxing to all (a) constant and the international to record deta. Cerenkov image on a 0.5 grid, using 37 photomultipliers in (plane of the focusing mirror. (A central photomultiplier is a ring of 6 others, then by a further ring of 12, and another whole forming a baxagonal grid pattern.) Predictions of the this system to air showers will be presented. Even though the widths of shower images are less than 0.5°, the image dimens. measured well enough to provide discrimination between types though the alignment of the short image with the source will clear than with finer angular resolution.

 <u>Simulation of Cerenkov image patterns</u>
 A 3-dimensional Monte-Carlo calculation is used to sis development. The computer program has been used previously
vestigations (2) and is much more detailed than is necessary ting Cerenkov processes, following particles down to an ener (far below the Cerenkov threshold), although "thin sampling" to follow particles below 1/4000 of the primary energy to rea time. The model atmosphere is not isothernal. Madronic coll been simulated both by a radial scaling model with rising eror and by a model with increased production of low-energy second; tive to scaling) at high primary energies (though a less dras' than proposed by Wdowczyk and Wolfendale, for example, as the particles in the fragmentation region - high x - are largel; wever, at TeV energies, there is little difference between constrained by accelerator data, so the simulation result ed together in the presentations below.

hough some loss of Cerenkov light by Rayleigh and a allowed for (2), scattered light is assumed not to 147 the image (size <1°) in a clear mountain atmov the

T - P-ovided by the NASA Astrophysical The basics

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The Astronomycus Research, 342:379-305, 1989 July 1 Restore All rights researed Printed in 118 a

> OBSERVATION OF TAY GAMMA RAYS FROM THE CRAB NEBULA USING THE ATMOSPHERIC CERENKOV IMAGING TECHNIQUE

T. C. WHERE,¹ M. F. CAWLEY,² D. J. FIGAN,³ K. G. GIBBS,¹ A. M. HILLAS,⁴ P. W. KWOE,¹ R. C. LAMP,³ D. A. LEWIS,⁵ D. MACOHR,⁵ N. A. PORTHR,³ P. T. REVNELDS,^{1,3} AND G. VACANTI Revenued 1988 August 1: accepted 1988 December 9

ABSTRACT

The Whipple Observatory 10 m reflector, operating as a 37 pixel camera, has been used to observe the Crab Nebula in TeV gamma rays. By selecting gamma-ray images based on their predicted properties, more than 98% of the background is rejected; a detaction is reported at the 9.0 e level, corresponding to a flux of 1.8 × 10⁻¹¹ photons cm² s⁻¹ above 0.7 TeV (with a factor of 1.5 uncertainty in both flux and energy). Less than 25% of the observed flux is pulsed at the period of PSR 0531. There is no evidence for variability on time scales from months to years. Although continuum emission from the pulsar cannot be ruled out, it seems more likely that the observed flux comes from the hard Compton synchrotron spectrum of the nebula. Subject headings: gamma rays: general - nebulae: Crab Nebula - pulsars - radiation mechanisms

1. INTRODUCTION

The observation of polarization in the radio, optical, and X-ray emission from the Crab Nebula is usually taken as confirmation of the synchrotron origin of the radiation and is a strong indication of the presence in the nebula of a reservoir of relativistic electrons with energies up to 1 TeV. The presence of the radio pulsar, PSR 0531, near the center of the nebula provides a source for the on-going injection of relativistic electrons into this reservoir. The collision of the synchrotron-radiating electrons with synchrotron-radiated photons within the ashula inevitably results in a hard photon spectrum (at some level) that extends from the X-ray into the gamma-ray energy range; the shape of the spectrum mirrors that of the soft photon spec trum but with greatly reduced intensity. The Compton synchrotren model of the nebula was first developed by Gould (1965) and was refined by Ricke and Weekes (1969) and by Grindlay and Hoffmann (1971). A strong flux of gamma rays was predicted with maximum luminosity in the 0.1-1.0 TeV energy range. The gamma-ray flux level depends on the strength of the nebular magnetic field, which is a free parameter in the model and is little constrained by observations at other wavelengths. However, based on equipartition arguments, it is estimated to be ~ 10-1

The observation of a flux of 0.14 TeV gamma rays from the Crab Nebula was reported by the pathsonian group using the atmospheric Cerenkov technique (1972); based on observations that spanned 3 years, tection was still only e weakness of the igue. The detecat the 3 e level. This demonstrates source and the lack of sensitivity of th Source and me acc or activity or my because. The detec-tion of TeV gamma rays from the Crash verse is a confirma-tion of the Compton synchrotron moder of here a direct measure of the magnetic field. This measure each while we conservatively interpreted as an upper limit, the for an ergap TAR magnetic field of 3 × 10⁻⁴ G, or a radially syme with $B_a = 1 \times 10^{-3}$ G at a distance of 0.1 pc from the r (Grindlay 1976).

ard-Smithsonian Center for Aerophysics St. Patrick's College, Mayacoth. University College, Dablas. University of Lends. Rewa State University

Subsequent to the discovery of PSR 0531 in the nebula. gamma-ray observations concentrated on the pulsar beegreater sensitivity could be achieved by the assumption of chronization of the gamma-ray emission with the period radio emission. Several detections were reported at very energies (Grindlay 1972; Jennings et al. 1974; Grind-Helmken, and Workes 1976; Porter et al. 1976; Erick Fickle, and Lamb 1976; Vishwanath 1982; Vishwanath o 1985; Gupta et al. 1977; Gibson et al. 1982b; Douthwaite / 1984; Tumer et al. 1985; Bhat et al. 1986), but the statir sificance was not high, and upper limits were also prese which appeared to be in coeffict with the reported ff. (Helmken et al. 1973; Vishwanath et al. 1986; Bhat et al. 1 At energies above 1 TeV there were also reports of omin from the direction of the Crab (Mukanov 1983; Boone e 1984; Drikowski et al. 1981; Kirov et al. 1985; but, becas the limited angular resolution and the absence of acc timekreping, it was not possible to identify the source of observed signal with the nebula or the pulsar. Again there onflicting upper limits (Craig et al. 1981; Watson 1985 100 MeV energies (which are accessible to study by a chambers on satellites), both a pulsed and steady compwere detected (Kniffen et al. 1977; Hermsen et al. 1977; C er al. 1987); at 1 GeV the strength of the unpulsed compo (which might originate in the nebula or near the pulsar) is 0 times that of the pulsed flux.

Weeks et al. 1989

Using a refined version of the atmospheric Cerenkov te nique, we here report the detection of gamma rays ab, 0.7 TeV from the Crab Nebula at a high level of statistic significance; over the epoch 1986-1988 we find no evidence variability, and the observed flux is in agreement with (reported previously in 1969-1972 and in an earlier observa utilizing this same technique in 1983-5 (Cawley et al. 19 & Gibbs 1987). The observed gamma-ray flux is only 0.2% cosmic-ray background. A periodic analysis using the k radio period of the pulsar indicates that less than 25% of bserved signal is pulsed. The detection of such a weat en a steady (nonpulsed) source with a significance of 9 in the developme ground-based gamma-ray astronom It demonstrate

power of using atmospheric Cerenkov , wer imaging h tinguish gamma-ray initiated air shower from those at

source



Hinton & Hoffmann, 2009

>150 sources

Teraelectronvolt Astronomy

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Annu, Rev. Auron. Assemblys, 2009, 47:573-65. The Annual Review of Astronomy and Astrophysics is online as parts annual reviews.org

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Key Words

gamma-ray astronomy, high-energy astrophysics

Abstract

Ground-based y-ray astronomy, which provides access to the TeV energy range, is a young and rapidly developing discipline. Recent discoveries in this waveband have important consequences for a wide range of topics in astrophysics and astroparticle physics. This article is an attempt to review the experimental status of this field and to provide the basic formulae and concepts required to begin the interpretation of TeV observations.

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100 GeV – 50 TeV sky





The Fermi sky above 50 GeV





Only ~25% of the 2FHL sources have been previously detected by Cherenkov telescopes. **2FHL provides a reservoir of candidates to be followed up at very high energies.**



2FHL Ackermann+16

~25% of Galactic sources (20-30) has a photon index harder than $2 \rightarrow$ high-energy SED peak in the TeV band.

Fermi-LAT detects emission from many Galactic sources well beyond 500 GeV.

360 sources 282 non-IACT 216 |b|>10° 66 |b|<10°





Preliminary *Fermi*/LAT results E>10 GeV



Beyond 2FHL \rightarrow 3FHL

74%

Extragalactic





3FHL, arXiv:1702.00664

10 GeV – 2 TeV 7 years of data 1556 sources 214 brand new (not in 1FHL/2FHL/3FGL)

Beyond 2FHL \rightarrow 3FHL





3FHL Dominguez Gamma2016













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A long time ago in a galaxy far, far away....









Two sites (North and South) for a whole-sky coverage

Operated as on open Observatory

The Cherenkov Telescope Array

A factor of 5-10 more sensitive w.r.t. the current IACTs



Where to find us













- La Palma prototype operational in 2018.
- <u>http://webcam.lst1.iac.es/</u> <u>stream2view.htm</u>

Credits: The CTA Consortium

Medium Size Telescope Prototype





Dual-mirror MST prototype





Credits: The CTA Consortium

Small size telescope prototypes





CTA Telescopes



Telescope	Large	Medium		Small		
	LST	MST	SCT	SST-1M	ASTRI SST-2M	GCT SST-2M
Number North array	4	15	TBD		0	
Number South array	4	25	TBD	70		
Optics						
Optics layout	Parabolic mirror	Davies-Cotton	Schwarzschild- Couder	Davies-Cotton	Schwarzschild- Couder	Schwarzschild- Couder
Primary mirror diameter (m)	23	13.8	9.7	4	4.3	4
Secondary mirror diameter (m)	-	-	5.4	-	1.8	2
Eff. mirror area after shadowing (m ²)	368	88	40	7.4	6	6
Focal length (m)	28	16	5.6	5.6	2.15	2.28
Focal plane instrumentation						
Photo sensor	PMT	PMT	silicon	silicon	silicon	silicon
Pixel size (degr.), shape	0.10, hex.	0.18, hex.	0.07, square	0.24, hex.	0.17, square	0.15-0.2, square
Field of view (degr.)	4.5	7.7/8.0	8.0	9.1	9.6	8.5 - 9.2
Number of pixels	1855	1764/1855	11328	1296	1984	2048
Signal sampling rate	GHz	250 MHz / GHz	GHz	250 MHz	S&H	GHz
Structure						
Mount	alz-az, on circular rail	alt-az positioner	alt-az positioner	alt-az positioner	alt-az positioner	alt-az positioner
Structural material	CFRP / steel	steel	steel	steel	steel	steel
Weight (full telescope, tons)	100	85	~85	9	15	8
Max. time for repositioning (s)	20	90	90	60	80	60

Credits: The CTA Consortium







4 x 23 m Ø Large Size Telescopes (LST) ~20 GeV to ~ 1 TeV range



25 x 14 m Ø Medium Size Telescopes (MST) ~100 GeV to ~10 TeV range



70 x 4 m Ø Small Size Telescopes (SST) few TeV to few 100 TeV range

Effective area for gamma-ray detection



cta

CTA Telescope layout






Differential Sensitivity



A factor of **5-10 improvement** in sensitivity in the domain of **about 100 GeV to some 10 TeV.**

Extension of the accessible energy range from well below 100 GeV to above 100 TeV.

Credits: The CTA Consortium















Angular Resolution

Energy Resolution



Further improvements of shower reconstruction algorithms and optimization of event selection can improve the IRFs.

You can download the Instrument response functions at the following URL:

https://www.cta-observatory.org/science/cta-performance/

Credits: The CTA Consortium

CTA as an *all-sky* Observatory





CTA as a transient factory



- Huge advantage over Fermi in energy range of overlap for ~minute to ~week timescale phenomena
 - Explosive transients
 - AGN flares
 - Binary systems
- Disadvantage over Fermi
 - Limited FoV (compared to Fermi)
 - Prompt reaction to external trigger is critical



CTA Science





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



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?

Adapted from J. Knödlseder.

More information on Astroparticle Physics, Vol. 43, 1-356 (2013) & CTA Contributions to the 2015 ICRC Conference [arXiv:1508.05894]







Project Phases

Pre-Construction Current Phase		Pre-Production 2018-2020	Production 2020-2024							
First Pre-Production Telescopes on Site (earliest 2018)										
Pre-Construction										

CTA as an Open Observatory



The modes of user access to CTA will be:

- The Guest Observer (GO) Programme by which users can obtain access to proprietary observation time, submitting proposals in response to Announcements of Opportunity (AOs).
- The Key Science Projects (KSPs) are large programmes that ensure that some of the key science issues for CTA are addressed in a coherent fashion, with a well-defined strategy.
- Director's Discretionary Time (DDT) a small fraction of observation time may be reserved for, e.g., unanticipated targets of opportunity, or outstanding proposals from non-member countries.
- Archive Access under which all CTA gamma-ray data will be openly available, after a proprietary period.





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CTA Key Science Projects



The criteria used for selection of the baseline KSPs

- 1. Excellent scientific case and clear advance beyond the state of the art;
- 2. Production of legacy data-sets of high value to a wider community;
- **3. Clear added value of doing this as a KSP** rather than as part of the Guest Observer Programme:
 - 1. the **scale of the project** in terms of observing hours very large projects will be difficult to accommodate in the open time early in the lifetime of the observatory;
 - 2. the need of a **coherent approach** across multiple targets or pointings;
 - 3. the **technical difficulty** of performing the required analysis and hence reliance on consortium expertise.



cherenkov telescope array

Science with the Cherenkov Telescope Array



Science with CTA

Will become a regular book / a special issue journal.

KSPs vs. proposal-driven programs

Key Science Projects

- Ensure that important science questions for CTA are addressed in a coherent fashion and with a well-defined strategy,
- Conceived to provide legacy data sets for the entire community



Example: galactic and extragalactic surveys



Deep investigation of known sources

- Follow-up of KSP discovered sources
- Multiwavelength campaigns
- Follow-up of ToOs from other wavebands / messengers
- Search for new sources

Proposal-Driven User Programme

Credits: Hofmann, Gamma 2016

CTA Key Science Projects



- 1. Dark Matter Programme
- 2. Galactic Centre Survey
- 3. Galactic Plane Survey
- 4. Large Magellanic Cloud Survey
- 5. Extragalactic Survey
- 6. Transients
- 7. Cosmic-ray PeVatrons
- 8. Star-forming Systems
- 9. Active Galactic Nuclei
- **10.Cluster of Galaxies**
- 11. Non-Gamma-ray Science

Science questions & KSPs



Theme		Question		Galactic Centre Survey	Galactic Plane Survey	LMC Survey	Extra- galactic Survey	Transients	Cosmic Ray PeVatrons	Star-forming Systems	Active Galactic Nuclei	Galaxy Clusters
Understanding the Origin and Role of Relativistic Cosmic Particles	1.1	What are the sites of high-energy particle acceleration in the universe?		v	~~	~~	~~	~~	v	~	~	~~
	1.2	What are the mechanisms for cosmic particle acceleration?		~	v	v		~~	~~	~	~~	~
	1.3	What role do accelerated particles play in feedback on star formation and galaxy evolution?		~		~				~~	~	~
Probing Extreme Environments	2.1	What physical processes are at work close to neutron stars and black holes?		~	~	~			~~		~~	
	2.2	What are the characteristics of relativistic jets, winds and explosions?		~	~	~	~	~~	~~		~~	
	2.3	How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time?					~	~			~~	
Exploring Frontiers in Physics	3.1	What is the nature of Dark Matter? How is it distributed?	~~	~~		~						•
	3.2	Are there quantum gravitational effects on photon propagation?						~~	~		~~	
	3.3	Do Axion-like particles exist?					~	~			~~	









Hubble Space Telescope image of the inner region of the galaxy cluster Abell 1689.

The blue overlay shows the dark matter distribution reconstructed by gravitational lensing using the multiple galaxy images seen in the telescope image.





Galaxy cluster Abell 1689 Credits: The CTA Consortium

The existence of dark matter as the dominant gravitational mass in the Universe is by now established but the detailed nature of dark matter is at present still unknown.

The priority for the CTA dark matter program is to **discover** the nature of dark matter with a positive observation.

The principal target for dark matter observations in CTA **is the Galactic halo**.

Observations will be taken within several degrees from the Galactic Centre.

500 hours in this region provide sensitivities below the thermal cross-section and give a significant chance of discovery in some of the most popular models for **WIMPs**.





The Galactic Plane Survey





Credits: The CTA Consortium

CTA will carry out a **survey of the full Galactic** plane using both the southern and northern CTA observatories.

The Survey will provide a **complete and systematic view of the Galaxy** to facilitate our understanding of Galactic source populations and diffuse emission, and **a comprehensive data-set and catalogue**.

The CTA GPS will be a factor of 5 – 20 more sensitive than surveys carried out by earlier or existing atmospheric Cherenkov telescopes.

In the Northern Hemisphere, the CTA will complement/extend observations made by HAWC at much lower energy and with substantially better angular resolution.

Galactic Plane Survey





J. Knödlseder and CTA Consortium

Galactic Plane Survey





Expected results

- Discovery of new and unexpected phenomena in the Galaxy
- Discovery of PeVatron candidates → origin of cosmic rays
- Detection of many new VHE sources O(300 500), particularly PWNe and SNRs
- Measurement of the large-scale diffuse VHE gamma-ray emission
- Discovery of new VHE gamma-ray binaries
- Production of a multi-purpose legacy data set
- The GPS will produce and periodically release sky maps and catalogues

The Galactic Centre Survey





The region within a few degrees from the **Galactic Centre** is full of a **wide variety of high-energy emitters.**

The central VHE source has been well studied with H.E.S.S., VERITAS, and MAGIC, but still remains unidentified due to source confusion and limited sensitivity to variability and small-scale morphology.

Credits: The H.E.S.S. Collaboration

Deep observations of this object with CTA will provide

- **an optimal angular resolution** to image the arcminute scale VHE source
- the possibility to search for **variability** of the central source
- sufficient **spectral sensitivity and energy coverage** to determine the maximum energy reached by accelerated cosmic rays in this region.

Galactic Centre Survey





Expected results

The CTA Consortium

- Determination of the nature of the central source
- A detailed view of the VHE diffuse emission
- Resolving new, previously undetectable sources
- Search for variability in the VHE source near Sgr A*
- Studying the interaction of the central source with neighbouring clouds

LMC Survey





Credits: Schaefer 2015

The Large Magellanic Cloud (LMC) is one of the nearest star-forming galaxies, at a distance of 50 kpc ($\pm 2\% \rightarrow$ important for source energetics).

Its activity is attested by more than 60 supernova remnants, dozens to hundreds of HII regions, bubbles and shells observed at various wavelengths.

It is a unique place to obtain a resolved, global view of a star-forming galaxy at TeV energies.







LMC Survey





Simulation includes currently detected sources, plus ten point-like sources with $L_{(E > 1 \text{ TeV})} \sim 10^{34} \text{ erg s}^{-1}$, and a handful of regions enriched in cosmic rays.

Credits: The CTA Consortium

Extra-galactic Survey





The aim is to perform a blind survey of 25% of the sky, and to construct an unbiased VHE extragalactic source catalogue with an integral sensitivity limit of ~5 mCrab.

CTA will combine the **deep MSTs sensitivity** for E > 100 GeV and the **wide SSTs field of view** (>9°).

Credits: The CTA Consortium

We expect the **discovery of extreme BL Lac objects** peaking in the 0.1 – 1 TeV region, thanks to the good spectral coverage provided by MSTs and SSTs in the 0.1 – 10 TeV energy range.

Extra-galactic Survey





The survey would connect with the Galactic Plane Survey (|b| < 5°) over Galactic longitude –90° < l < 90°.

Several highly interesting regions such as the Virgo & Coma clusters, the Fermi Bubbles (North) and Cen A (South) will be covered by the proposed survey. The EGAL survey will be useful to investigate dark matter sub-halos.

Current simulations suggest that a wide-field, shallow survey should detect more sources than a narrow-field, deep survey (given an equal survey time).

Extra-galactic Survey





Padovani & Giommi (2015) derived the expected number of blazars on the sky in the GeV–TeV domain.

With the 5 mCrab sensitivity during the proposed survey, **CTA should detect around 100 sources in 10,000 deg**².

Transients





Credits: The LIGO Scientific Collaboration **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, multimessenger 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

Transients





Assuming that the Crab nebula high-energy flares are due to synchrotron emission, to detect the **variable inverse-Compton component at multi-TeV energies**, we would need to monitor the source for **4 h/night during approximately 10 nights.** With this strategy we could unveil the nature of these flares.

Inverse-Compton component of the 2011 April Crab flare assuming Γ =70. The variable tail from 10 to 100 TeV is clearly detectable.

CTA is potentially capable of **resolving GRBs light curve in exquisite detail** for such bright bursts. The assumed GRB template is the measured Fermi-LAT light curve above 0.1 GeV, extrapolating the intrinsic spectra to VHE with power-law indices as determined by Fermi-LAT.

We expect to detect ~1 GRB yr⁻¹ site⁻¹.

Cosmic-ray PeVatrons





Credits: The H.E.S.S. Collaboration

Supernova remnants might be able to satisfy the cosmic-ray energy requirement if they can somehow convert ~10% of the supernova kinetic energy into accelerated particles.

CTA will perform **deep observations of known sources with particularly hard spectra**. Moreover, it will search for **diffuse gamma-ray emission from the vicinity of prominent gamma-ray bright SNRs**.

The interactions of such runaway **PeV particles** with the ambient gas produce **gamma rays** with a characteristic hard spectrum extending **up to ~100 TeV.**

Cosmic-ray PeVatrons




Cosmic-ray PeVatrons





Evidence of the acceleration of PeV protons in the Galactic Centre (GC).

The 1/r profile (red line) of the cosmicray density up to 200 pc indicates a quasi continuous injection of protons into the central molecular zone from a centrally located accelerator (located in the inner 10pc region from the GC).



The best fit to the data: a power-law extending with a photon index of ~2.3 to energies up to tens of TeV, without a cut-off or a break in the central tens of pc.

The SMBH Sgr A* is the most plausible supplier of ultra-relativistic protons and nuclei that could have been accelerated either in the accretion flow, or at the site of termination of an outflow during phases of enhanced accretion rate.

Active Galactic Nuclei





Credits: ESA/NASA

AGNs are known to emit **variable radiation** across the entire electromagnetic spectrum up to multi-TeV energies, with fluctuations **on time-scales** from **several years** down to **a few minutes**.

VHE observations of active galaxies harbouring super-massive black holes and ejecting relativistic outflows represent a unique tool to probe the physics of extreme environments, to obtain precise measurement of the extragalactic background light (EBL) and to constrain the strength of the intergalactic magnetic field (IGMF).

AGNs will be useful to investigate fundamental physics phenomena such as the **Lorentz invariance violation** and signatures of the existence of **axionlike particles**.

Active Galactic Nuclei



Testing emission scenarios



A set of **high-quality spectra** from different blazar types and different redshifts is needed to **unambiguously distinguish intrinsic spectral features**, such as shown here, from **external absorption**.

Active Galactic Nuclei



Testing variability in AGNs



Such measurements put strong constraints on the bulk Doppler factor, as well as on particle acceleration and cooling processes.





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Synergies during CTA operation





These are just a few of the MWL facilities available during the CTA era.

Next slide shows...

Synergies during CTA operation



2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
(←	CTA I	Prototypes	⇒			Science V	erification =	⇒ User Oper	ation		
Low Free	uency Rad	dio			:						
LOFAI	R										j
MWA			[MWA	(upgrade))					
	VLITE on J	VLA	>	(~2018? LO	BO)						
Mid-Hi Fr	equency F	Radio		FASI							
JVLA,	VLBA, eMer	lin, ATCA, EV	'N, JVN, KV	N, VERA, L	BA, GBT(1	nany other sn	naller facilitie	s));
ASKA Kat7 -	P -> MoorKAT .	-> SKA Phase	.1			\neg					
	-> MEETINAT	-> SIXA I llast				SKA	1&2 (Lo/Mid	;	:		- · · · · ·
(sub)Mill	imeter Rad	lio						;	;	:	
JCMT	, LLAMA, LN	IT, IRAM, NO	DEMA, SMA	, SMT, SPT,	Nanten2, Mo	pra, Nobeyaı	na (many	other smaller	facilities))
ALMA			. 0 11								
	EHI	(prototy	pe —> full o	ps)							
Optical T	ransient F	actories/Tr	ansient Fi	inders							
iPalom	ar Transient l	Factory	-> (~2017)	Zwicky TF			T (buildup to	full survey n	node)		
PanST	ARRSI -> P	anSTARRS2	CEM (Mee	rlight single	dich prototyp	a in 2016)					
		Diac	:	:	aisii prototyp	e m 2010)	;				
Optical/II	R Large Fa	cilities	:				:	:		:	
VLT, K	eck, GTC, G	emini, Magella	an(many o	ther smaller	facilities)					(WFIRST
					C						
	:	:	:	:	JWST					`	(GMT)
X-ray					JWST		e	ELT (full ope	ration 2024)	& TMT (time)	GMT line less clear)?)
X-ray Swift (incl. UV/optic	al)			JWST		e	ELT (full ope	ration 2024)	& TMT (time	GMT line less clear)?)
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RX J1713.7-3946 – a multi-wavelength view



Ideal laboratory for particles propagation studies (see Abdalla+16)



RX J1713.7-3946 over time



Chaves 2016



2004

18 h livetime E_{min} = 1 TeV γ-ray excess: 1430 PSF (R_{68%}) = 4.8' 2006

2016

63 h livetime E_{min} = 0.3 TeV γ-ray excess: 6700 PSF (R_{68%}) = 3.6' 164 h livetime $E_{min} = 0.25 \text{ TeV}$ γ -ray excess: 31000 PSF ($R_{68\%}$) = 2.9' Better err_{svs} control

The "Fab-four" pion-bumbers



Pion-decay signature in the AGILE & Fermi-LAT data



PWN – the "violently quiet" Crab









Blazar monitoring at HE/VHE





Lauer+16

FSRQs – PKS 1441+25





The location of the emitting region:

- in the jet outside the BLR during the period of high activity
- partially within the BLR during the period of low (typical) activity



CTA PHYS Working Group



The **PHYS WG is composed of ~340 members**, while SWGs are composed as follows (note that one can register for more than one SWG and numbers are rounded)

Registrations are always open for CTA Consortium members!

<u>https://portal.cta-observatory.org/_layouts/people.aspx?</u> <u>MembershipGroupId=989</u>

Galactic	~160
Cosmic Rays	~130
Extra-galactic	~150
Transients	~150
Dark matter and exotic physics	~100
Intensity Interferometry	~ 25
MWL Transverse WG	~ 70

CTA PHYS SWGs



1. Galactic

- 1. Jamie Holder (Coordinator)
- 2. Roberta Zanin (Deputy)

2. Cosmic-rays

- 1. Stefan Ohm (Coordinator)
- 2. Sabrina Casanova (Deputy)

3. Extra-galactic

- 1. Elina Lindfors (Coordinator)
- 2. Fabrizio Tavecchio (Deputy)

4. Transients

- 1. Catherine Boisson (Coordinator)
- 2. Daniela Hadasch (Deputy)

5. Dark matter and exotic physics

- 1. Fabio Zandanel (Coordinator)
- 2. Aldo Morselli (Deputy)

6. Intensity interferometry

- 1. Dainis Dravins (Coordinator)
- 2. Michael Daniel (Deputy)

Multi-wavelength and synergies

- 1. Sera Markoff (Coordinator)
- 2. Emma de Oña Wilhelmi (Deputy)

Collaborations/Contributions



Among others, collaborations and contributions may be on

- Science activities

- We have established the PHYS Science Working Groups and several activities are ongoing
 - Computation of the KSPs performance metrics
 - Data Challenge
 - Simulations and theoretical activities for the science Consortium papers
 - Multi-wavelength transverse group studies

Software development

- CTA low-level pipelines (e.g., Monte Carlo, and reconstruction/analysis pipelines)
- Specific analysis tools are being developed by the Consortium (e.g., Ctools, GammaPy...).
 - Might be important to familiarize with the CTA analysis tools





https://www.cta-observatory.org/

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CTA Library webpage



https://www.cta-observatory.org/science/library/

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Library

Hundreds of papers have been published about CTA science and technology. Several publications detailing CTA's science goals and potential are available for download here. Visit the News & Media page for links to see the latest articles published about CTA.

Questions concerning the publication of CTA-related materials should be directed to the Chair of the Speakers and Publications Office (SAPO): Jean-Pierre Ernenwein.

CTA Performance webpage



Expected Baseline Performance Plots https://www.cta-observatory.org/science/cta-performance/ ~ Sensitivity ста м ~ Angular Resolution Home About Science Project News & Media Energy Resolution and Energy Dispersion Matrix ~ Collection Area **CTA's expected baseline CTA Performance** ✓ Background Rate performance ~ Off-Axis Sensitivity **CTA Performance** ASCII files CTA will provide very wide energy range and excellent angular resolution and sensitivity in comparison to any CTA-Performance-South-20150511.ASCII.tar.gz existing gamma-ray detector. Energies up to 300 TeV will push CTA beyond the edge of the known electromagnetic spectrum, providing a completely new view of the sky. Here is how CTA's energy range will compare to some of the existing astronomical instruments: CTA-Performance-North-20150511.ASCII.tar.gz ROOT format: CTA-Performance-South-20150511.tar.gz

CTA-Performance-North-20150511.tar.gz

References



Teraelectronvolt Astronomy

- Hinton and Hofmann, Annual Review of Astronomy and Astrophysics, 47, 523 (2009)
- Seeing the High-Energy Universe with the Cherenkov Telescope Array - The Science Explored with the CTA
 - Edited by Hinton, Sarkar, Torres and Knapp, Astroparticle Physics Volume 43, Pages 1-356 (March 2013)
- CTA Contributions to the 2015 ICRC Conference
 - [arXiv:1508.05894]
- Science with the Cherenkov Telescope Array
 - Edited by Hinton, Ong and Torres, to appear soon !

Conclusions



- CTA will be an observatory open to the scientific community.
- Science will focus on cosmic particle acceleration, extreme environments, and physics beyond the standard model.
- Proprietary time (significant fraction in the first years) will be articulated in Key Science Programs.
- Synergies with current and planned MWL facilities will allow us to investigate source properties across several decades in energy.
- Contributions on the PHYS working group activities and on more technical activities (e.g., SW pipelines, Monte-Carlo,...) are welcome!

Title of the Proposal

Group 1

1. Abstract

Type a concise (less than 5 lines) abstract of your proposal.

2. Scientific Rationale

Here you can give the scientific background of your proposed study.

3. Immediate Objectives

Here you should state what you are proposing to observe and what the goals of the proposed study are.

4. Justification of Requested Observing Time and Feasibility

The requested observing time, intrument modes, and any constraints have to be explained in detail here.

Proposers must clearly describe how their proposal capitalizes on the unique capabilities of CTA. If more than one target is proposed, give the priority of each target in case only some of your targets are accepted.

If this is a monitoring program, give the cadence of observations and all time constraints.

If this is a ToO proposal, explain and justify the trigger criteria and give a realistic estimate of the probability that the ToO will be triggered.

5. Report on Previous and Related Programs

Here you can report on your previous studies that are related to this proposal.





Feel free to contact me during this days, I will be around for the whole period !

e-mail: stefano.vercellone@brera.inaf.it