The future of multi-wavelength studies

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The virtual radio sky: A fresh view of the radio sky, Heidelberg, Germany, September 21-22, 2011

Outline

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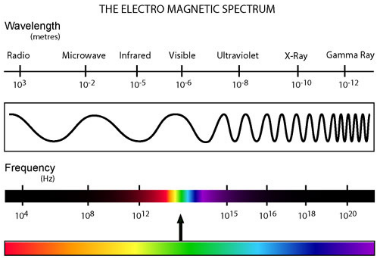
Introduction to gamma-ray astronomy

What are gamma-rays?



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Introduction to gamma-ray astronomy

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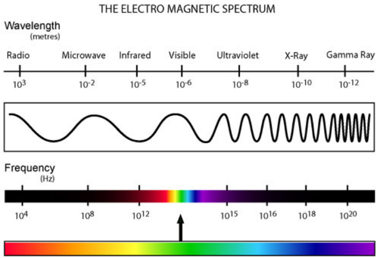

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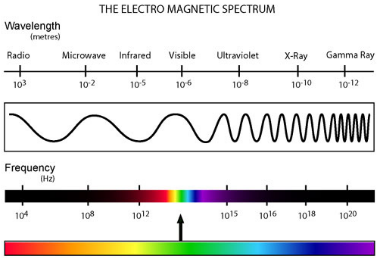

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- The change-over from X-rays to gamma-rays is at about 100 keV. (1 keV$=10^3$ eV$\sim 1.6 \times 10^{-9}$ erg.)
- High energy (HE) gamma-rays are $100\ \mathrm{keV} < E < 1$ MeV and very high energy (VHE) gamma-rays are $E > 1$ MeV.

Introduction to gamma-ray astronomy

Where are gamma-rays produced?

- (VHE) gamma-rays are produced by charged particles which are accelerated in extreme environments and interact either in the source, or on their way to earth, to produce gamma-rays.

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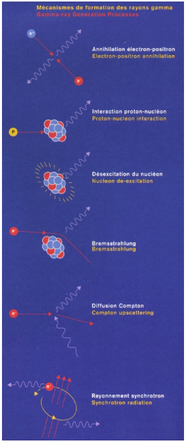
- The charged particles are *cosmic-rays* (CRs), which were discovered about a century ago.
- We don't know exactly where CRs come from, but generally it is thought that they are accelerated – at least in our galaxy – in objects such as supernovae (SNRs).

Introduction to gamma-ray astronomy

How are gamma-rays produced?

Astrophysical gamma-rays are produced in three main ways:



Picture credit:

ESA/INTEGRAL.

1. Proton-proton collisions (via $p + p \rightarrow \pi^0 \rightarrow 2\gamma$) of hadronic (meaning protons and – strictly – heavier ions) CRs and the ambient interstellar matter.

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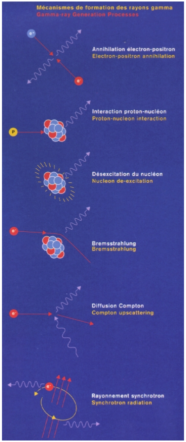

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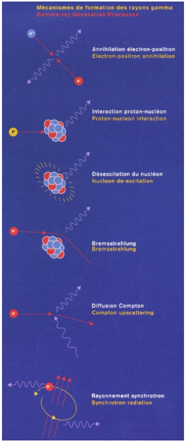

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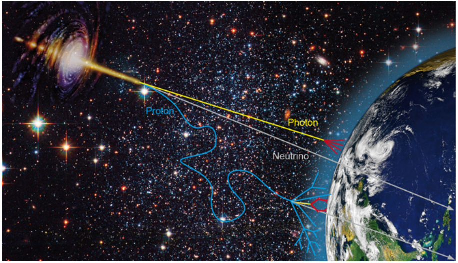
2. Electron up-scattering of ambient photons (via $e + \gamma \rightarrow e' + \gamma$) to VHE energies: Inverse Compton.
3. Emission of photons through bremsstrahlung (via $e + p \rightarrow p + e'$) radiation of electrons.

Introduction to gamma-ray astronomy

Why observe gamma-rays? I



Picture credit: http://nuastro-zeuthen.desy.de/.

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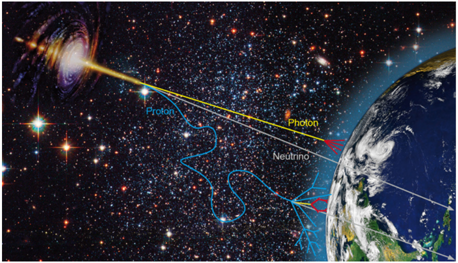

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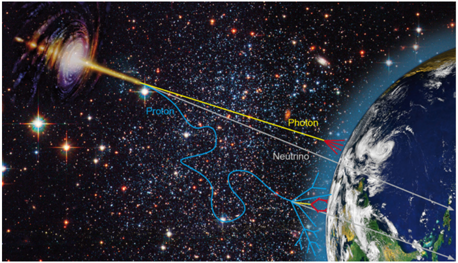

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2. Neutrinos may also be produced, however, their low cross-sections prevent (so-far) us from developing a mature astronomy with neutrino detection.
3. Thus gamma-rays are the best way to observe VHE source.

Introduction to gamma-ray astronomy

Why observe gamma-rays? II

The observation of astrophysical gamma-rays can reveal many secrets about the universe:

Introduction to gamma-ray astronomy

Why observe gamma-rays? II

The observation of astrophysical gamma-rays can reveal many secrets about the universe:

- What are the origin of Galactic cosmic-rays? This is one of the oldest questions in modern astrophysics:
  - Are they accelerated in SNRs? In molecular clouds? Colliding winds? Pulsars? Something else?
  - Since their discovery by Victor Hess in 1912, we still know of no clear origin for cosmic-rays...

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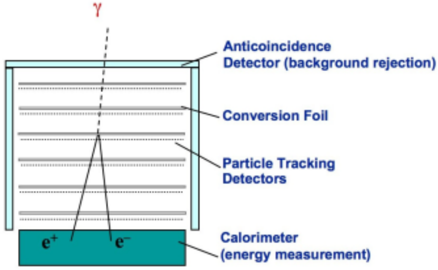
- Where do Galactic cosmic-rays end and extra-galactic cosmic-rays become dominant?
- Examining large-scale structures; galaxy clusters.
- Indirect dark matter searches: dark matter halos.

Detection of astrophysical gamma-rays

Spaced based gamma-ray detectors



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http://www-glast.stanford.edu/instrument.html.

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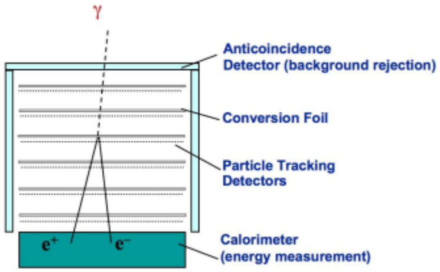

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1. Between 100 keV and 1 MeV, photo-electric absorption is the primary absorption mechanism, whilst $E \lesssim 0.1$ TeV, Compton scattering and $e^{\pm}$ pair production are dominant.
2. Thus at the lower energies, gamma-ray astronomy needs to be performed in space, limiting the effective area of any telescope (such as Fermi (right); $A_{eff} \sim 1$ m^2).

Detection of astrophysical gamma-rays

The Imaging Atmospheric Cherenkov Technique (IACT) I

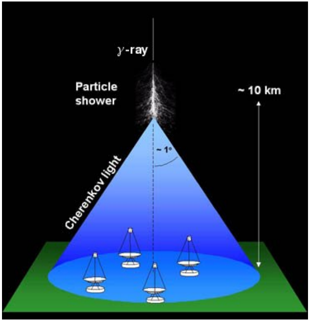

Image credit: http://www.dur.ac.uk/~dph0www4/images/

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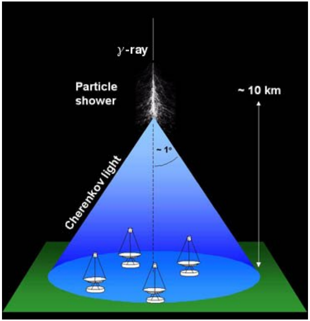

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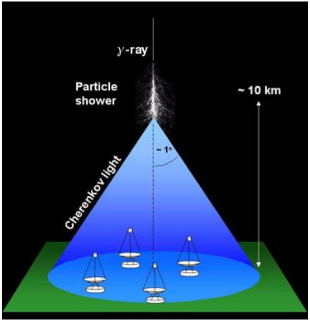

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- When a gamma-ray impinges on the Earth's atmosphere, it produces a particle cascade.
- In a cascade, the original gamma-ray pair produces in the Coulomb field of an (atmospheric) atomic nuclei.
- These positrons and electrons then produce more gamma-rays via bremsstrahlung. The gamma-rays then pair-produce.
- In this way, an *electromagnetic particle shower* results.

Detection of astrophysical gamma-rays

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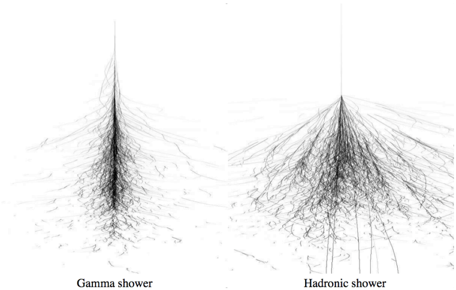

Image Credit: Völk & Bernlohr (2008)

- A shower initiated by a gamma-ray is fundamentally different to one initiated by a proton (hadron).

Detection of astrophysical gamma-rays

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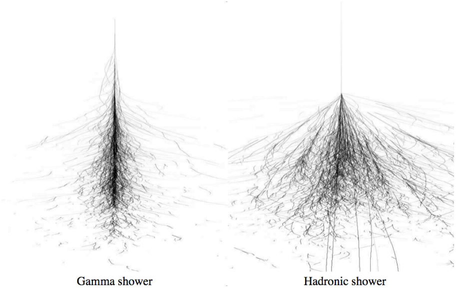

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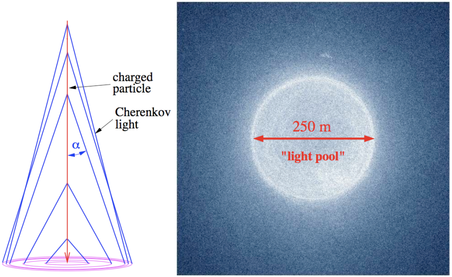
- A shower initiated by a gamma-ray is fundamentally different to one initiated by a proton (hadron).
- Hadronic showers produce a wider profile and produce additional particles, such as pions, kaons and nucleons.

Detection of astrophysical gamma-rays

The Imaging Atmospheric Cherenkov Technique (IACT) III



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Detection of astrophysical gamma-rays

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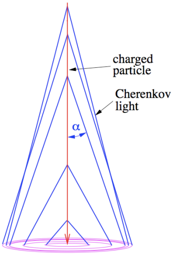


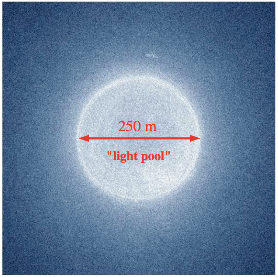


Image Credit: Völk & Bernlohr (2008)

- The particles in an air-shower possess a velocity with is greater than the (local) speed of light.
- Thus they emit *Cherenkov photons*, which can be observed by (ground-based) detectors.

Detection of astrophysical gamma-rays

The Imaging Atmospheric Cherenkov Technique (IACT) IV

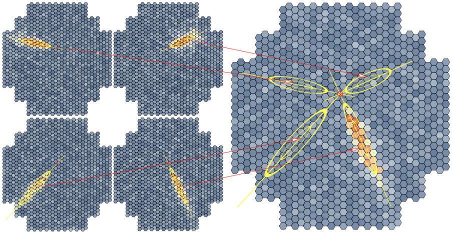


Image Credit: Völk & Bernlohr (2008)

- Reflectors collect this Cherenkov light and process it into an image.

Detection of astrophysical gamma-rays

The Imaging Atmospheric Cherenkov Technique (IACT) IV

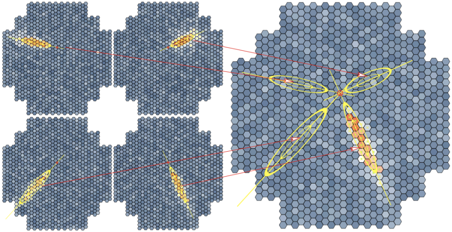


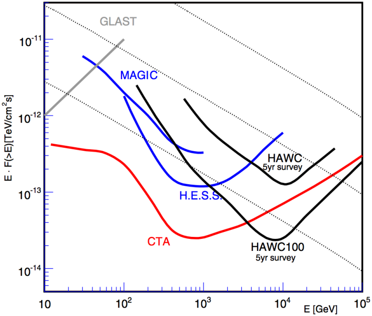
Image Credit: Völk & Bernlohr (2008)

- Reflectors collect this Cherenkov light and process it into an image.
- Using more than one dish allows a better direction determination (i.e., like HESS below).

Outline

Current instruments

Sensitivity of current instruments



- The figure shows the sensitivities for current and planned gamma-ray observatories.

Current instruments

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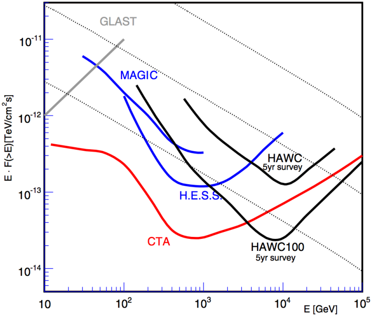


- The figure shows the sensitivities for current and planned gamma-ray observatories.
- This is based on (for all instruments) 50 hours of observation time for the IACTs. The dotted lines are 1, 0.1 and 0.01% of the flux of the Crab pulsar.

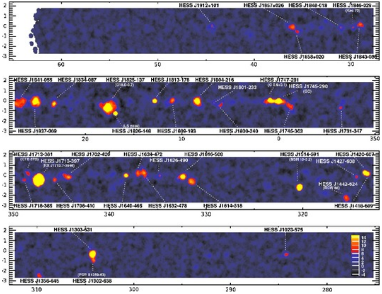
Current instruments

The High Energy Stereoscopic System (HESS) Telescope

- HESS is a 4-element IACT arranged in form of a square with 120 m side length, to provide multiple stereoscopic views of air showers.
- The total mirror area is 108 m^2 per telescope, with each camera possessing a 5° field of view (FoV).
- Each camera has 960 photon detector elements ("pixels"), each subtending 0.16° angle.

Current instruments

HESS Galactic plane survey



- Being located in the Southern Hemisphere (Namibia), means that HESS has a great view of the Galactic plane

Current instruments

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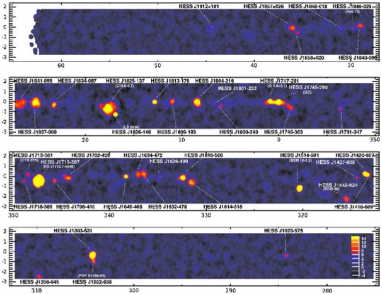
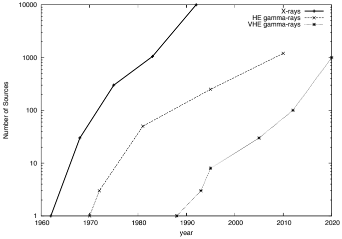


- Being located in the Southern Hemisphere (Namibia), means that HESS has a great view of the Galactic plane
- The main results from the HESS telescope comes from their Galactic plane survey (in addition to targeted observational campaigns).

Future instruments

The maturation of an observational science



- Plot on the right is known as a 'Kifune' plot of time versus the number of discovered sources.
- A comparison to other wavebands, gamma-ray astronomy is becoming a mature observational astronomy.
- Future experiments will (and has) – as it did in other wavebands – reveal(ed) many new and interesting sources.

Future instruments

Cherenkov Telescope Array

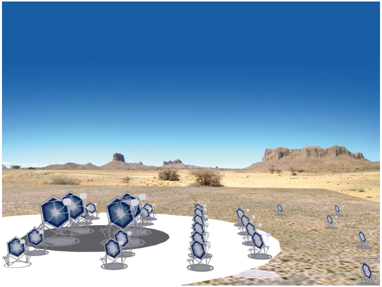
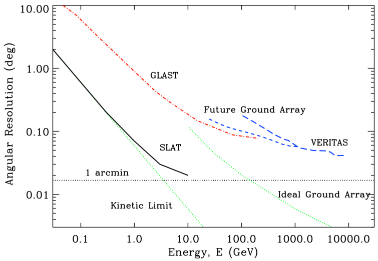


Image credit: ASPERA / D.Rouable

- The Cherenkov Telescope Array (CTA) is the next generation of IACT.
- It will work over a wide range of energies – from 10 GeV to 100 TeV (!)
- It will improve on the angular and energy resolution and sensitivity of present day telescopes (i.e., HESS, VERITAS).

Future instruments

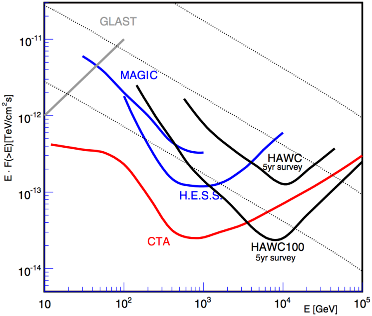
The angular resolution of future instruments



- The angular resolution of an IACT is limited to $\sim 1'$ due to uncertainties in shower processes, etc.
- This limits the "usefulness" of gamma-ray astronomy in a way that other wavebands don't experience (i.e., diffraction limits).
- Sensitivity, then, is a must to compete with other wavebands.

Future instruments

Sensitivity of Future instruments



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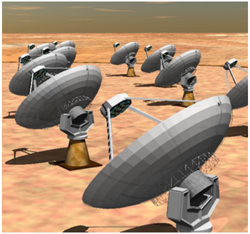
Outline

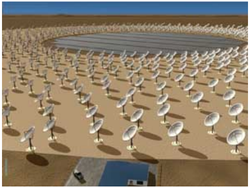
Future radio telescopes
LOFAR/ASKAP/SKA

- A common phrase today is the radio astronomy is entering a second 'Golden Age'.
- This refers to the new, low-frequency radio telescopes which will come on-line in the next decade.

LOFAR



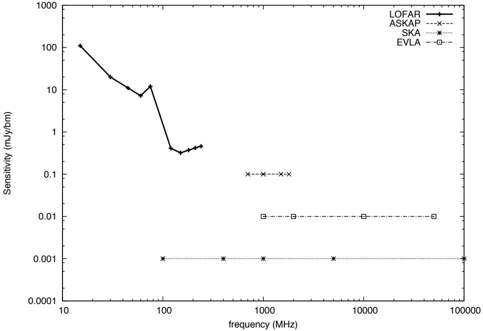
ASKAP



SKA

Future radio telescopes

Sensitivity



Sensitivity of current/planned radio telescopes, assuming a 1 hr integration time.

Given the frequency coverage and sensitivity of current radio telescopes (such as (E)VLA, ATCA, etc), the next generation of radio telescopes will be much more powerful

Outline

Galactic surveys in the the SKA/CTA era

New Radio Telescopes

Telescope	Elements (#)	$\Delta\nu$ (GHz)	Res. ($''$)	Sens. (erg/cm^2/s)	FoV ($^\circ$)
EVLA	27	1–50	1	10^{-18}	0.5
ATCA	6	1–50	1	10^{-17}	0.5
ASKAP	36	0.7–1.8	10	10^{-19}	30
SKA	3000	0.07–10	$\ll 1$	10^{-20}	200
HESS	4	0.1–10	~ 600	10^{-13}	5
CTA	50	0.001–100	~ 120	10^{-14}	3–4

A comparison of present and future radio telescopes to the present/future gamma-ray telescope, HESS/CTA. This shows that radio telescopes still have an appreciable edge over gamma-ray telescopes in terms of sensitivity.

Galactic surveys in the the SKA/CTA era

EMU and ASKAP

- The **E**volutionary **M**ap of the **U**niverse is a survey to map $\sim 30^\circ$ of the southern sky down to $1 - 10$ μJy/beam at 1.4 GHz.

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- Together with instruments such as the CTA, this will mean that radio and gamma-ray astronomy will be much more closely related than they are currently.

Galactic surveys in the the SKA/CTA era

The search for Galactic SNRs in the (near) future

- The canonical supernova remnant (SNR) for the gamma-ray community is RXJ1713-390.

Galactic surveys in the the SKA/CTA era

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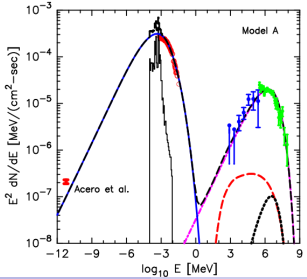
Galactic surveys in the the SKA/CTA era

The search for Galactic SNRs in the (near) future

- The canonical supernova remnant (SNR) for the gamma-ray community is RXJ1713-390.
- As can be seen from the spectral energy distribution (SED) below, RXJ1713-390 is *under-luminous* in the radio band.
- The estimated age for this remnant is $\sim$ 300 years, which is used to argue that the radio emission low because the GeV particles take longer to cool than TeV particles.



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- This, as I have (hopefully) shown, will be matched by similar (both instrumentally and temporally) in the GeV–TeV gamma-ray domain with CTA.
- One of the immediately obvious applications of surveys, such as the EMU survey with ASKAP, is the multi-waveband survey of the Galaxy for supernova remnants.
- CTA will be able to – due to the particle physics – sample one part of the SNR phase-space: the young, close SNRs that perhaps are very radio-dim, given the loss times of the $\sim$GeV particles that make up the radio-band.