Unraveling the mysteries of blazars with the MAGIC telescopes

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Overview

Cosmic Rays

- Discovery
- Origin
- Observation

Gamma-ray Astronomy

- A novel Discipline
- MAGIC Telescopes
- Air Showers in the Atmosphere
- Imaging Air Cherenkov Technique

Active Galactic Nuclei

- Introduction
- Unification

Physics in Blazars

- Spectra and Emission Mechanisms
- Open Questions

Cosmic Rays
Discovery

Viktor Hess - 1912

„Über Beobachtungen der durchdringenden Strahlung bei sieben Freiballonfahrten“

Physikalische Zeitschrift 13, 1084

- 7 balloon journeys showed a strong increase in measured ions with altitude not dependent on
  - meteorological parameters
  - day/night cycles
  - the sun (one flight during a partial solar eclipse)

[1] https://www.br.de/themen/wissen/kosmische-strahlung-victor-hess100.html

7. Fahrt (7. August 1912).

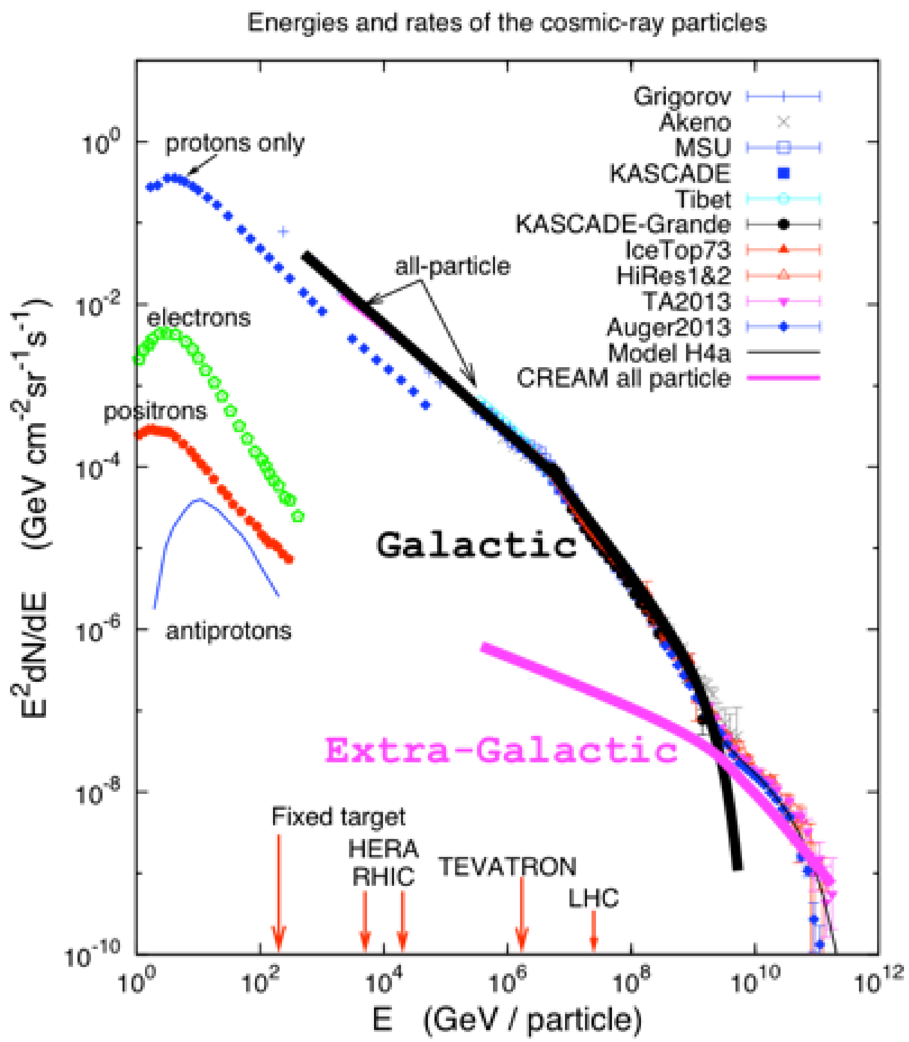
Ballon: „Böhmen“ (1680 cbm Wasserstoff). Führer: Hauptmann W. Hoffory.
Meteorolog. Beobachter: E. Wolf. Luftelektr. Beobachter: V. F. Hess.

Nr.	Zeit	Mittlere Höhe		Beobachtete Strahlung				Temp.	Relat. Feucht. Proz.
		absolut m	relativ m	Apparat 1 q_1	Apparat 2 q_2	Apparat 3 q_3	Apparat 3 reduz. q_3		
1	15^h 15—16^h 15	156	0	17,3	12,9	—	—	—	—
2	16^h 15—17^h 15	156	0	15,9	11,0	18,4	18,4	1½ Tag vor dem Aufstiege (in Wien)	
3	17^h 15—18^h 15	156	0	15,8	11,2	17,5	17,5		
4	6^h 45—7^h 45	1700	1400	15,8	14,4	21,1	25.3	+6,4°	60
5	7^h 45—8^h 45	2750	2500	17 3	12,3	22,5	31,2	+1,4°	41
6	8^h 45—9^h 45	3850	3600	19,8	16,5	21,8	35,2	—6,8°	64
7	9^h 45—10^h 45	4800	4700	40,7	31,8			—9,8°	40
		(4400—5350)				—	—		
8	10^h 45—11^h 15	4400	4200	28,1	22,7	—	—	—	—
9	11^h 15—11^h 45	1300	1200	(9,7)	11,5	—	—	—	—
10	11^h 45—12^h 10	250	150	11,9	10,7	—	—	+16,0°	68.
11	12^h 25—13^h 12	140	0	15,0	11,6	—	—	(nach der Landung in Pieskow, Brandenburg)	

[2] V. Hess (1912)

The Nobel Prize in Physics 1936 was divided equally between Victor Franz Hess **"for his discovery of cosmic radiation"** and Carl David Anderson "for his discovery of the positron."

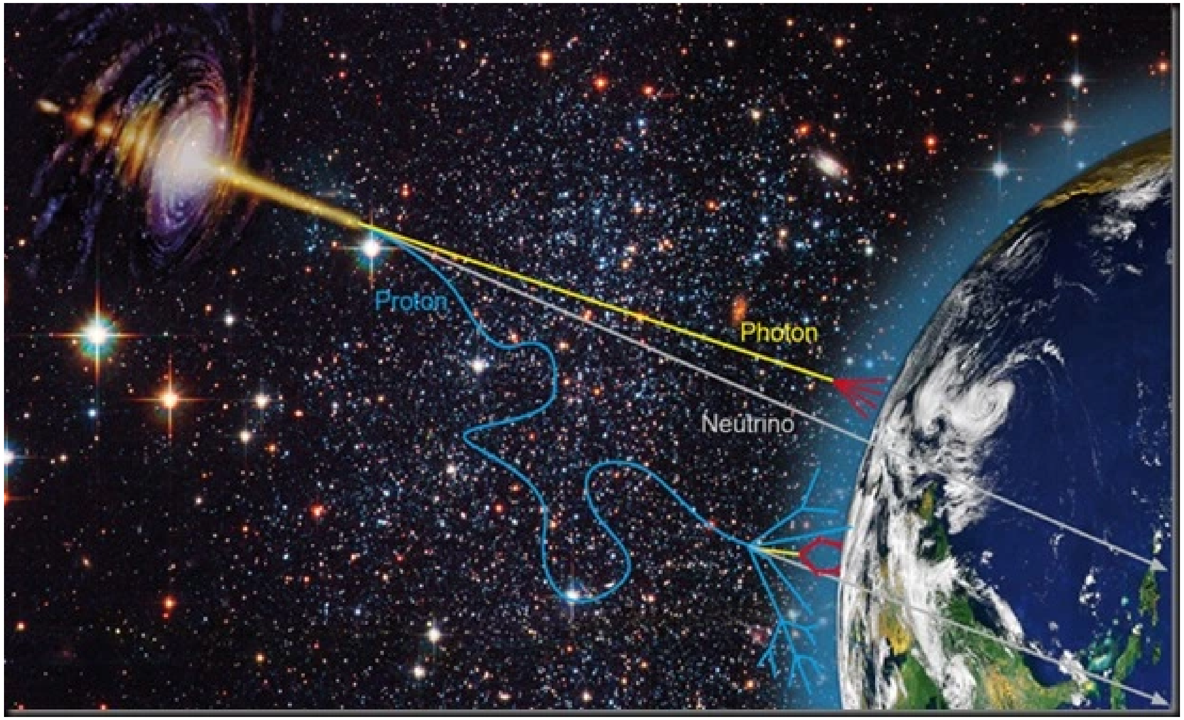
Cosmic Rays
Origin



[3] https://masterclass.icecube.wisc.edu/en/analyses/cosmic-ray-energy-spectrum

- **Galactic**
  - Pulsars
  - Supernova Remnants
  - Pulsar Wind Nebula
  - Binary Systems
  - Young star
- **Extragalactic**
  - Active Galactic Nuclei
  - Gamma-Ray Bursts
  - Starburst galaxies
  - Clusters of galaxies

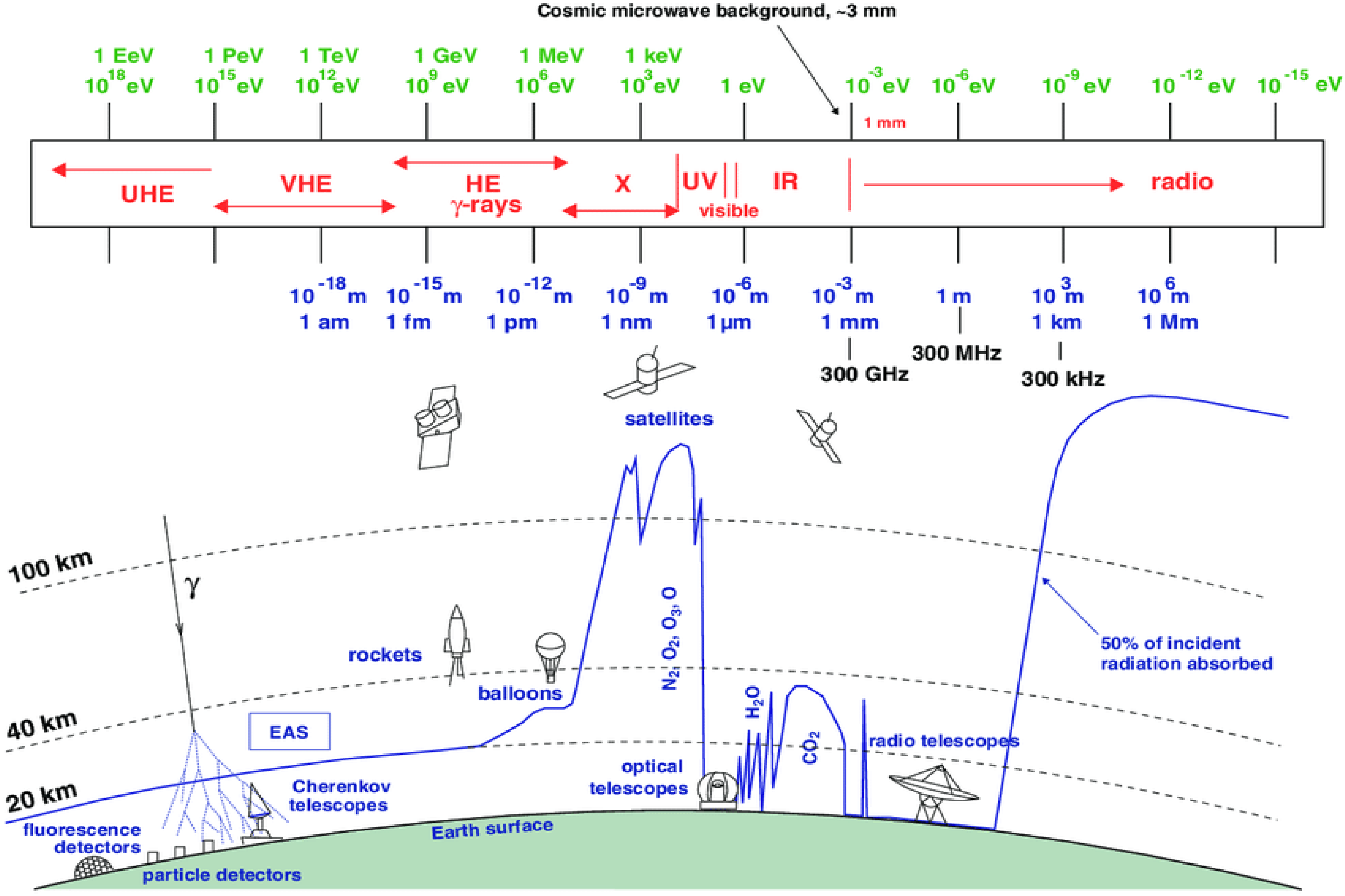
Cosmic Rays
Observation



[4] https://bluexdragon.wordpress.com/2012/04/25/neutrinos-gamma-ray-bursts-and-what-went-wrong-with-our-model/

- Charged particles are deflected by the interstellar magnetic field
- Only neutrinos and photons take a direct path to earth

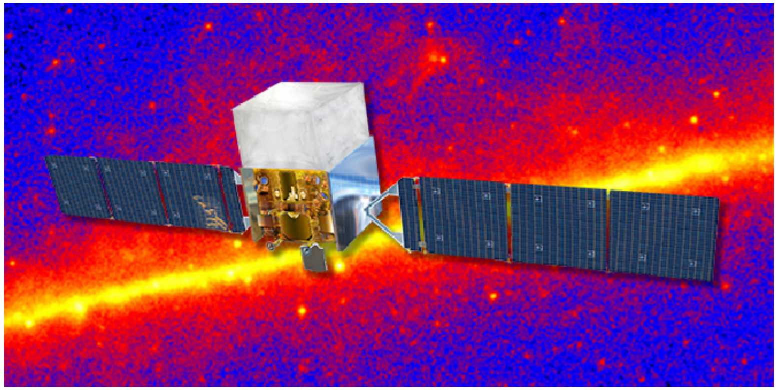
Cosmic Rays
Observation



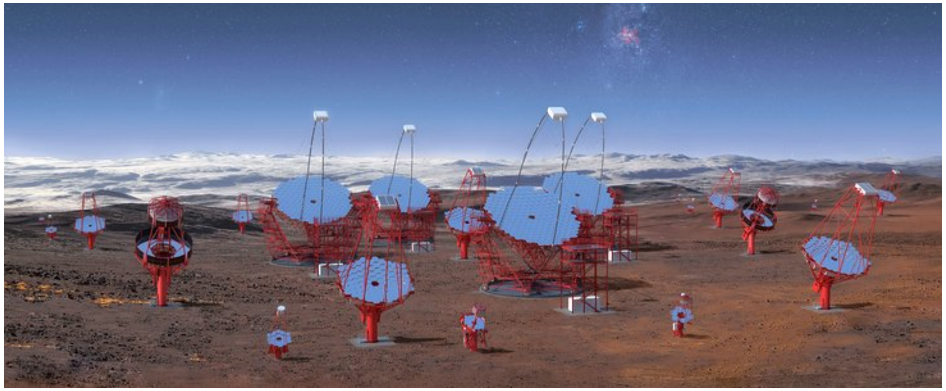
[5] Longair, S. M. (1992)

Gamma-Ray Astronomy
A novel discipline

	Exploration phase ~ 10 Sources	Established Field ~ 100 Sources	"Ultimate" Generation (Population + Precision Studies) ~1.000-10.000 Sources
Space	1970s (SAS-2,COS-B)	1990s (EGRET)	Now (Fermi)
Ground	1980-90s (WHIPPLE, HEGRA,CAT)	2000s (Cangaroo, HESS, MAGIC, VERITAS)	Future (CTA)

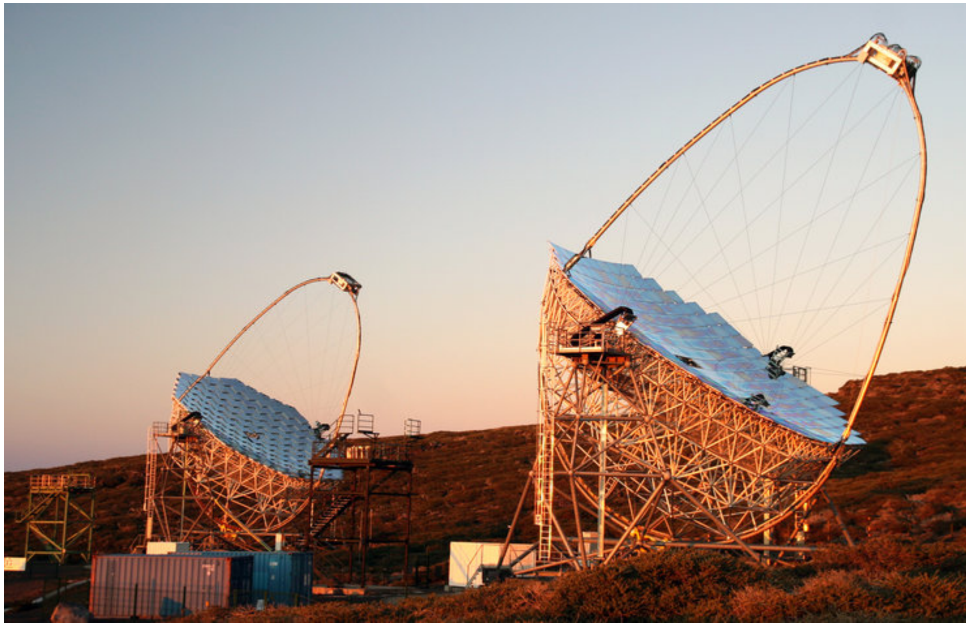


[6] https://fermi.gsfc.nasa.gov/science/constellations/pages/fermi.html

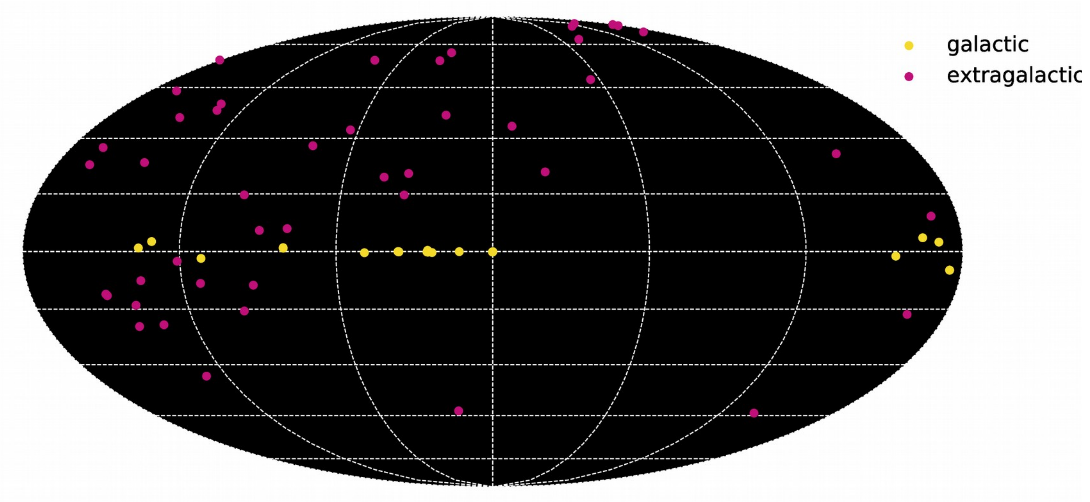


[7] https://www.eso.org/public/news/eso1841/

Gamma-Ray Astronomy
MAGIC Telescopes



[8] Robert Wagner

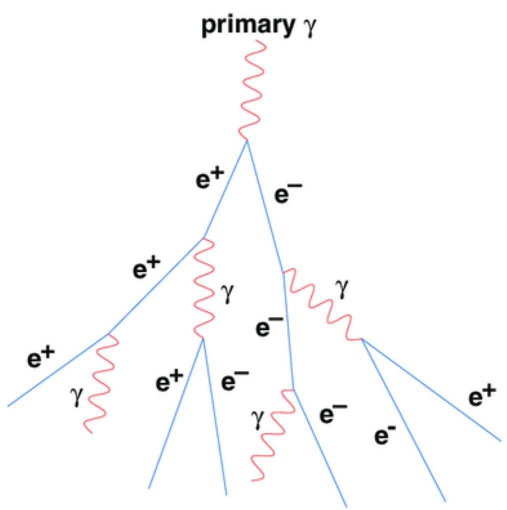


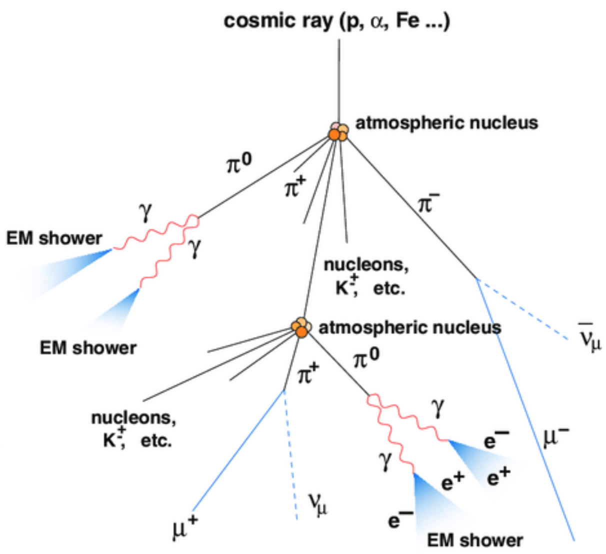
- Two Imaging Atmospheric Air Cherenkov Telescopes (IACTs)
- Placed on La Palma (Canary Islands)
- At 2200m above sea level
- Diameter: 17m
- Energy range: 50 GeV to 50 TeV

Gamma-Ray Astronomy

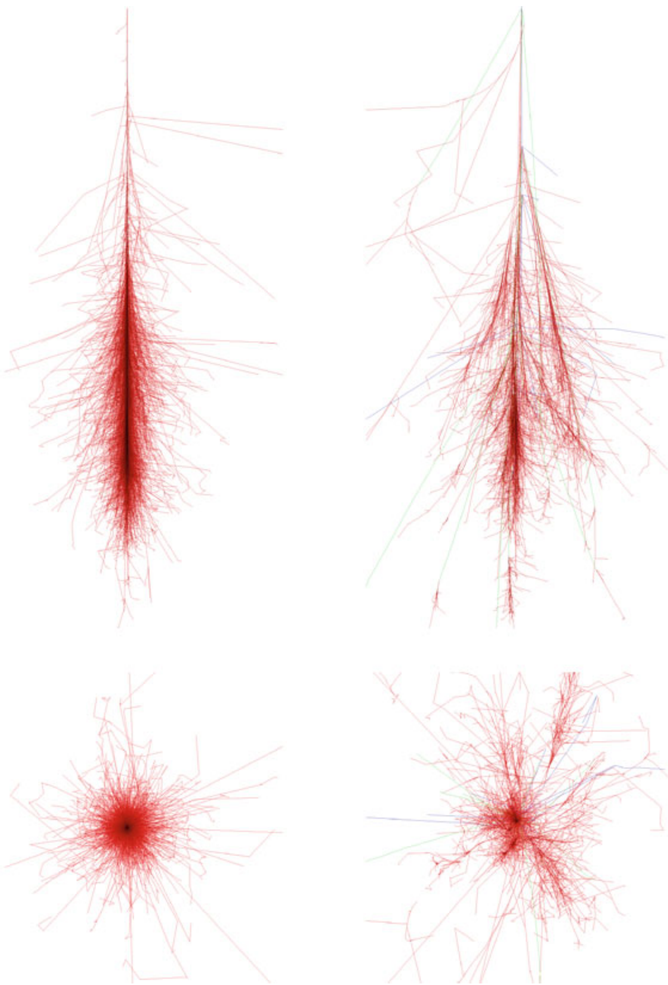
Air Shower in the Atmosphere

[9] M. Otte (2007)





[10] R. López Coto (2017)



EM cascades

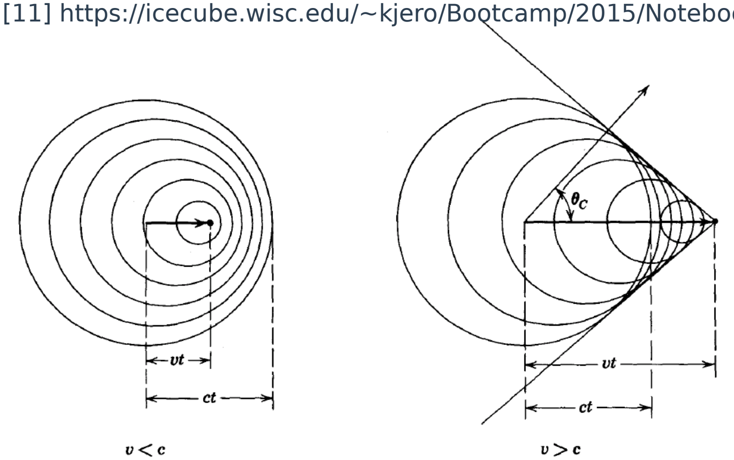
- γ → e+/e- pair creation
- e → γ: Bremsstrahlung
- ...
- $H_{max} = 1/\ln(E_\gamma)$
- Duration: 3ns

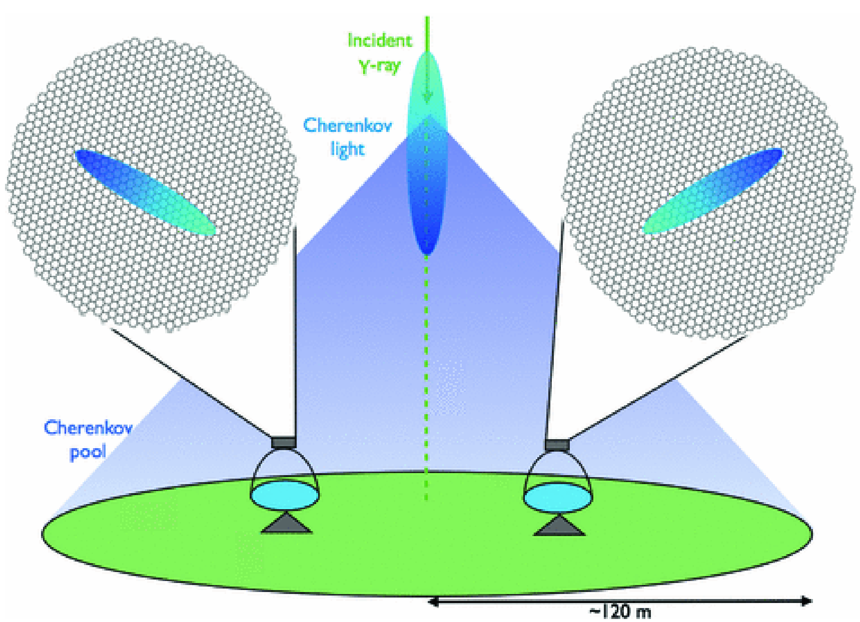
Hadronic cascades

- Mostly π0, π+, π- creation
- Some kaons and light baryons
- Further collisions until Emin for for π production
- Duration: 10ns

Gamma-Ray Astronomy
IACT Technique

[11] https://icecube.wisc.edu/~kjero/Bootcamp/2015/Notebooks/Reconstruction_Introduction.html





[10] R. López Coto (2017)

Cherenkov radiation

- Pavel Cherenkov 1934
- Charged particle with v>c in a medium

  → Electromagnetic shock wave to compensate non-symmetric polarisation in the medium

  → Radiation emitted in form of a cone

In the atmosphere

- One particle produces a ring on the ground
- Superposition → Circle of Cherenkov light
- This is collected by the telescopes

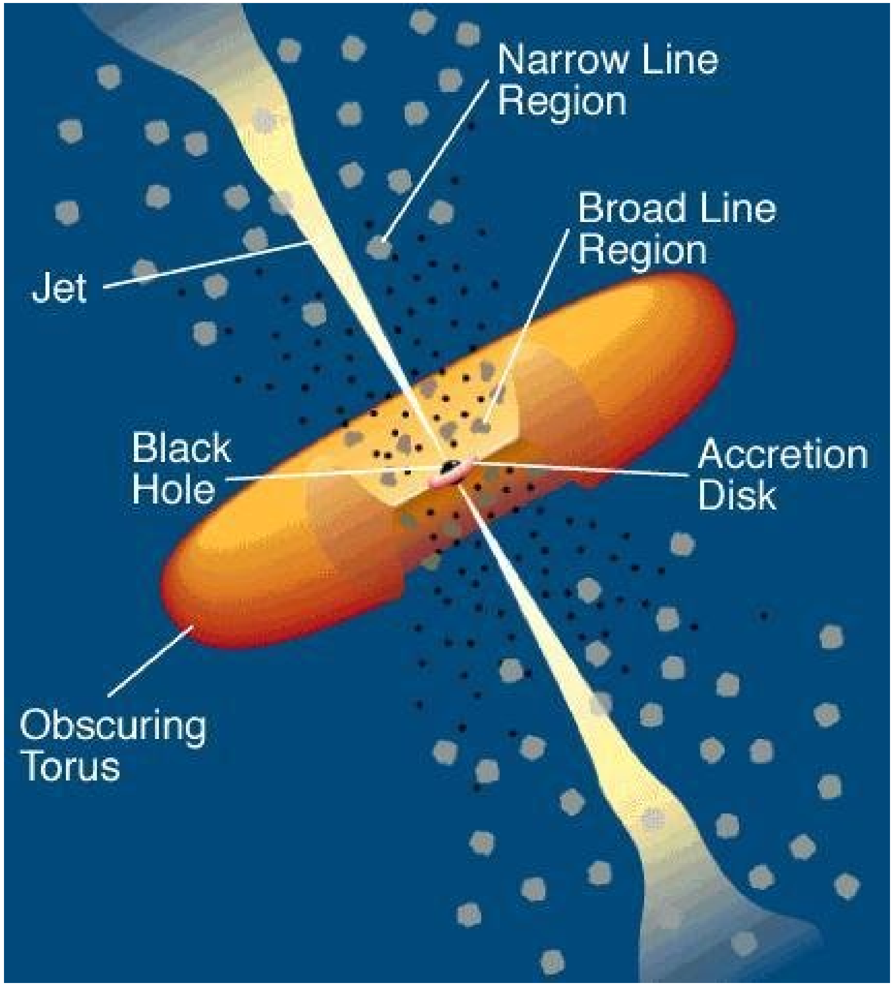
Active Galactic Nuclei (AGN)
Introduction

[13] http://www.astro.princeton.edu/~lilew/

- Extragalactic sources of cosmic rays
- Bright compact nucleus in the center of galaxy
- Most luminous persistent sources in the universe
- Variable in time
- Often accompanied with two jets

- Highly energetic physics laboratories

Active Galactic Nuclei
Model

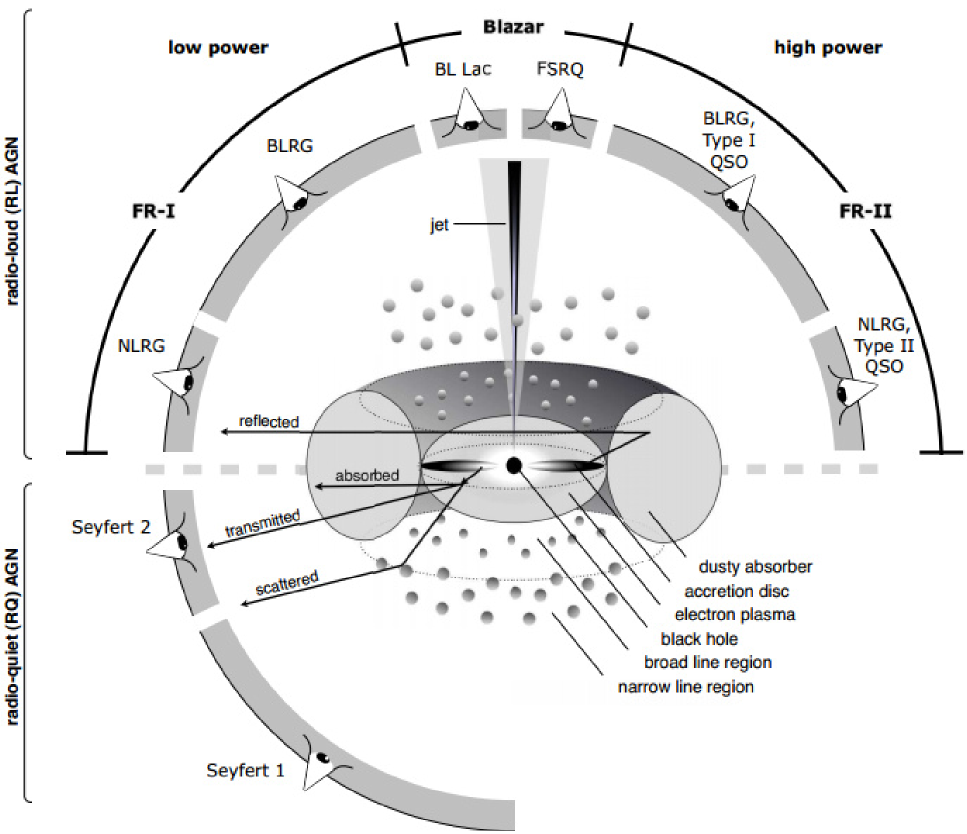


[14] Urry & Padovani 1995

- **Black hole: 10^{-3}-10^{-7} pc**
  - M bigger than 10^5 solar masses
  - Spin
- **Accretion disc: 10^{-7}-1 pc**
- **Broad line region: 0.01-1 pc**
  - High velocity gas (a few 1000km/s)
- **Dusty torus: 0.01-10 pc**
- **Narrow line region: 10-1000 pc**
  - Low velocity gas (300-1000km/s)
- **Jet: 10^{-7}-10^{6} pc**

1 pc = 3,086 · 10^{16} m

Active Galactic Nuclei
Unification Scheme



[15] Beckmann & Shrader 2012

Unification scheme by

- Viewing angle
- Accretion efficient/inefficient
  → high/low power
- Jetted/Non-jetted

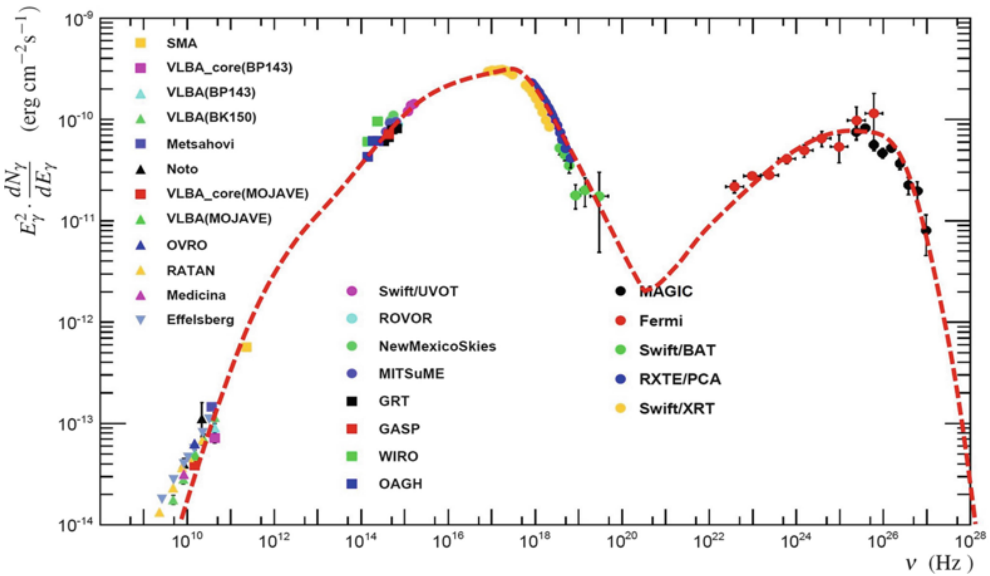
Blazars

- AGNs with jets in our direction
- Strong boosting along the jet
  → High observed luminosities
- Highly variable emission

BL Lacs

- Blazars without broad emission lines in the optical spectra
- Inefficient accretion
  → Gas in the broad line region is not strongly ionised
- Mostly at low redshift, close to us

Physics in Blazars
BL Lac – Spectra



[16] Abdo et al. 2011a

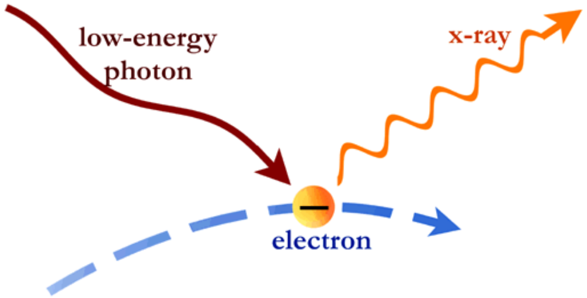
Two component broadband spectra

– Two bumps
– Location and height of the bumps changes with time/flux
– Time variable on scales of minutes, days, months, years

Models

– Leptonic
– Hadronic
– Mixed

Physics in Blazars
Radiative Mechanisms



[17] http://chandra.harvard.edu/resources/illustrations/x-raysLight.html

Synchrotron radiation

- Charged particle moving at a relativistic speed with a magnetic field present

  → Forced on a circular or helical path (Lorentz force)

  → constant acceleration

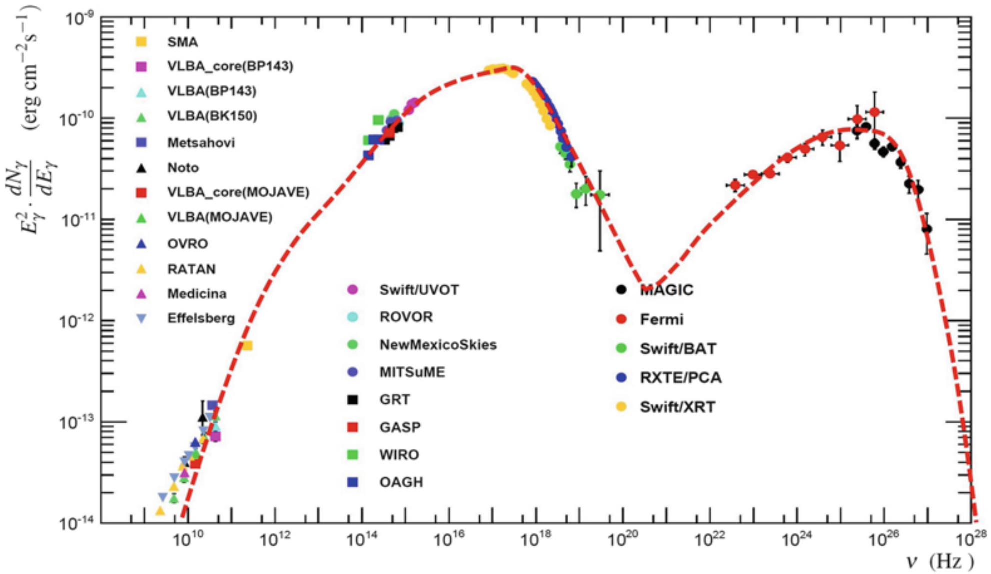
  → emission of radiation
- Beamed in the direction of motion
- Only seen, if the beam is in the direction of the observer

Inverse Compton scattering

- A low energy photon scatters of a relativistic electron

  → It gains the electron loss energy

Physics in Blazars
BL Lac – Spectra



[16] Abdo et al. 2011a

One zone self synchrotron model (SSC)

- Simplest leptonic model for blazars
- One emission zone
- Relativistic electrons in the jet
- Lower energy peak: Synchrotron radiation
- Higher energy peak: Inverse Compton radiation
- Seed photons for the IC are the original synchrotron photons

Physics in Blazars
Open Questions

Which population of particles is producing the radiation?

- Correlation between wavelengths → Same emission location and population of particles
- Delay? → Evolution of particle population (acceleration, cooling,...)
- Spectral models → Leptonic or hadronic particles?

Periodicity

Is there a binary black hole system?

Is there precession taking place?

Which emission mechanisms and models can explain the observed spectra?

- For one period of observation more than one model can explain the spectra satisfactorily
- BUT: Different predictions on how it will evolve
- Evolution of the spectra with time or flux?

Summary

- The origin and mechanisms behind cosmic rays and their acceleration are still unknown
- MAGIC as part of the new multi-messenger era is trying to shed some more light on these mysteries
- Blazars are especially interesting because their jets accelerate particles to extremely high energies (at least 10^{14} eV, maybe up to 10^{20})
- As soon as we have a better understanding of blazars
  - they can be use to probe the interstellar space
  - They can be used as direct probes of black hole physics
  - they can be used as fundamental physics laboratories with higher energies than CERN can ever reach