Unraveling the mysteries of blazars with the MAGIC telescopes

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Overview

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- Discovery
- Origin
- Observation

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- MAGIC Telescopes
- Air Showers in the Atmosphere
- Imaging Air Cherenkov Technique

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- Introduction
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- Spectra and Emission Mechanisms
- Open Questions
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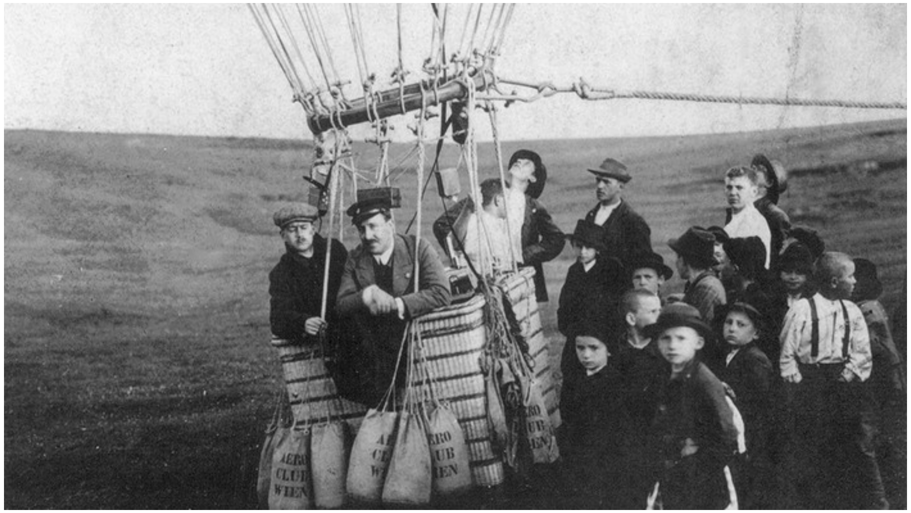
Cosmic Rays
Discovery

Viktor Hess - 1912

„Über Beobachtungen der durchdringenden Strahlung bei sieben Freiballonfahrten“

Physikalische Zeitschrift 13, 1084



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

7. Fahrt (7. August 1912).

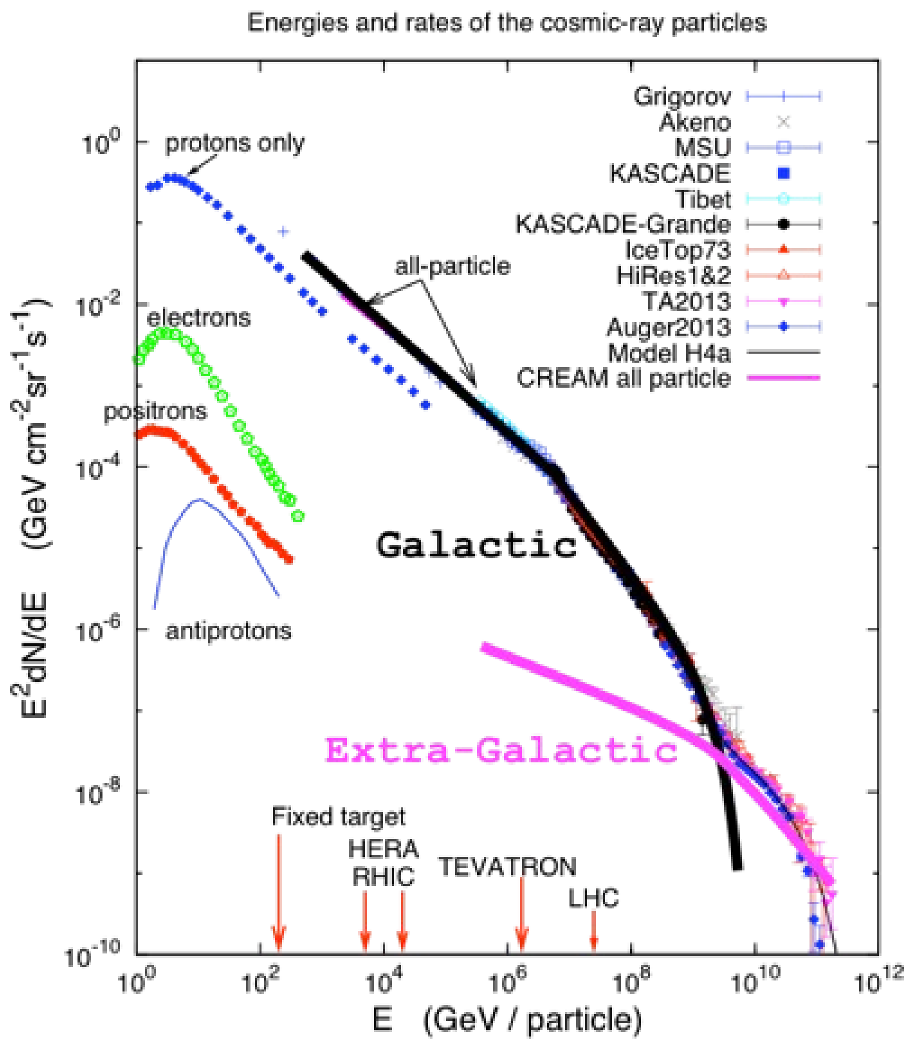
Ballon: „Böhmen“ (1680 cbm Wasserstoff). Führer: Hauptmann W. Hoffory.
Meteorolog. Beobachter: E. Wolf. Luftelektr. Beobachter: V. F. Hess.

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 (4400—5350)	4700	40,7	31,8	—	—	—9,8°	40
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

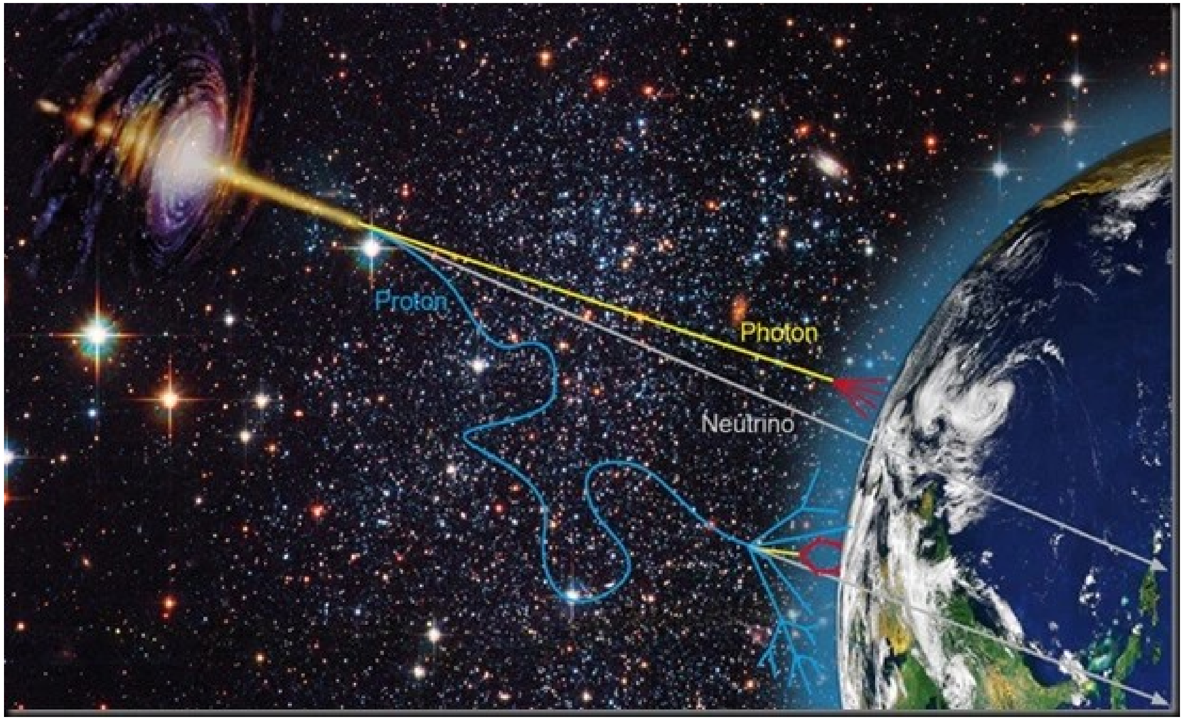


[3] https://masterclass.icecube.wisc.edu/en/analyses/cosmic-ray-energy-spectrum

Galactic
- Pulsars
- Supernova Remnants
- Pulsar Wind Nebula
- Binary Systems
- Young star

Extragalactic
- Active Galactic Nuclei
- Gamma-Ray Bursts
- Starburst galaxies
- Clusters of galaxies

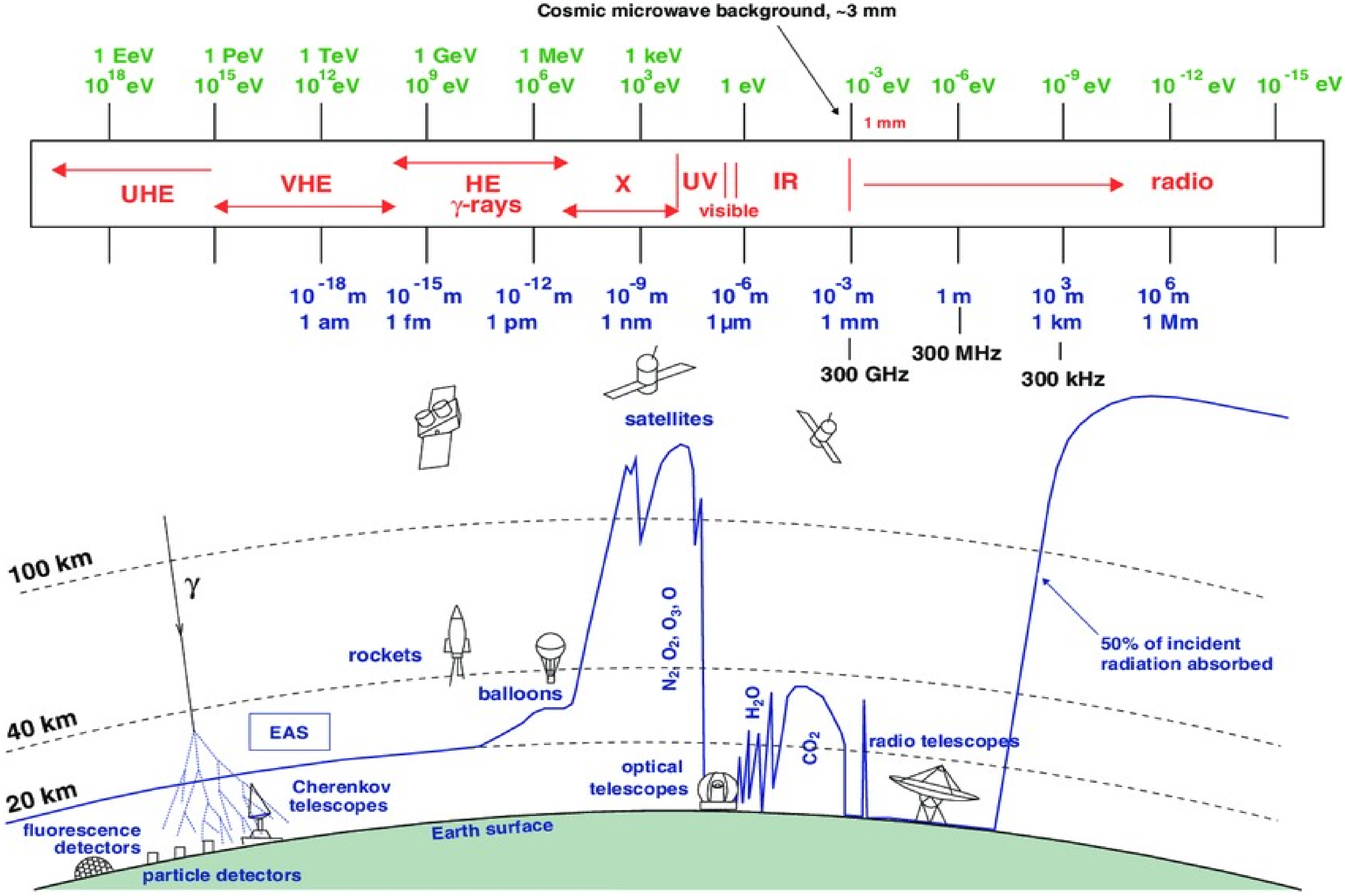
Cosmic Rays
Observation



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

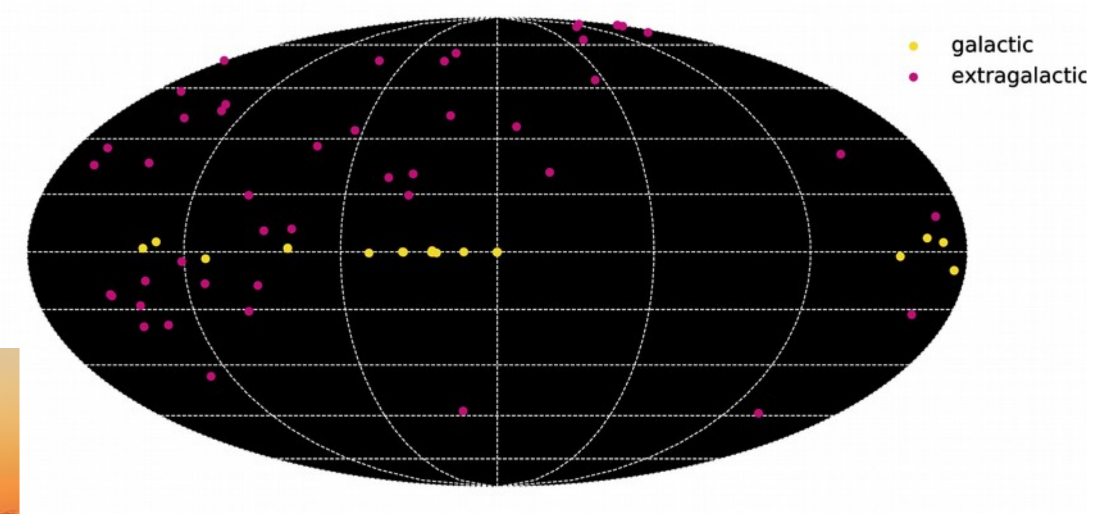
- Charged particles are deflected by the interstellar magnetic field
- Only neutrinos and photons take a direct path to earth

Cosmic Rays
Observation



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

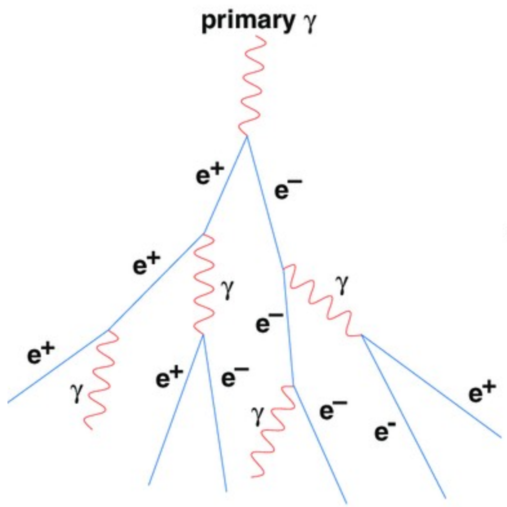
Gamma-Ray Astronomy
MAGIC Telescopes

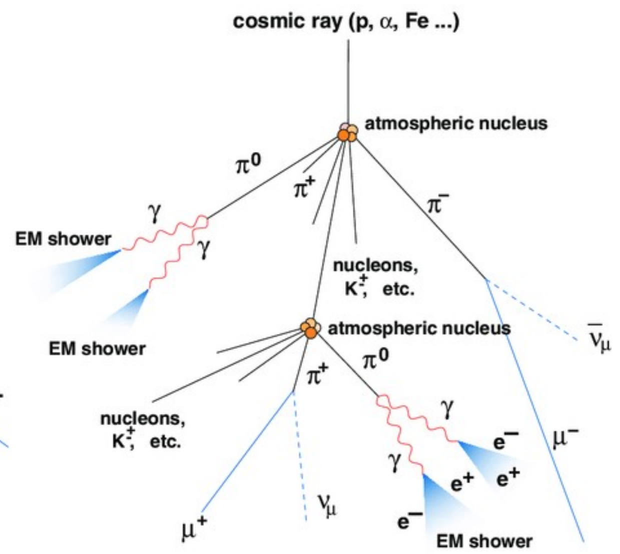


- Two imaging atmospheric air Cherenkov telescopes (IACTs)
- Placed on La Palma (Canary Islands)
- At 2200m above sea level
- Diameter: 17m
- Energy range: 50 GeV to 50 TeV

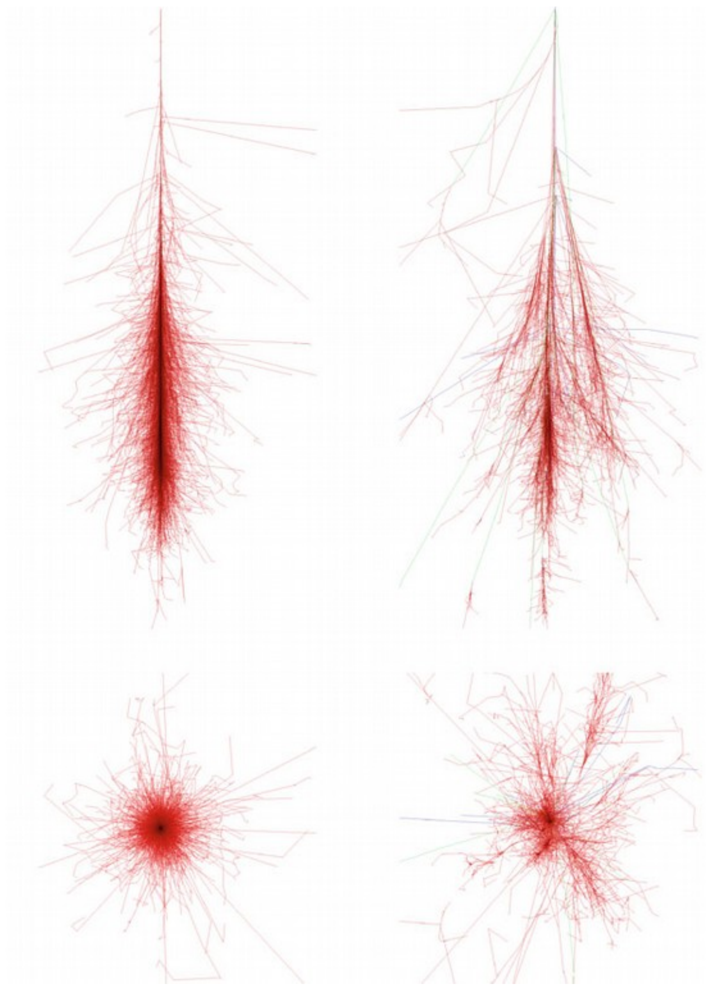
Gamma-Ray Astronomy
Air Shower in the Atmosphere

[9] M. Otte (2007)





[10] R. López Coto (2017)



EM cascades

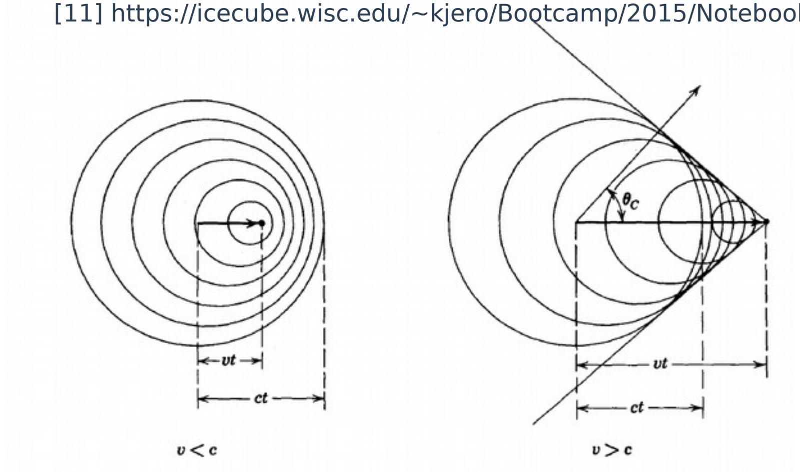
- γ → e^+/e^- pair creation
- e → γ: Bremsstrahlung
- …
- $H_{max} = 1/\ln(E_\gamma)$
- Duration: 3ns

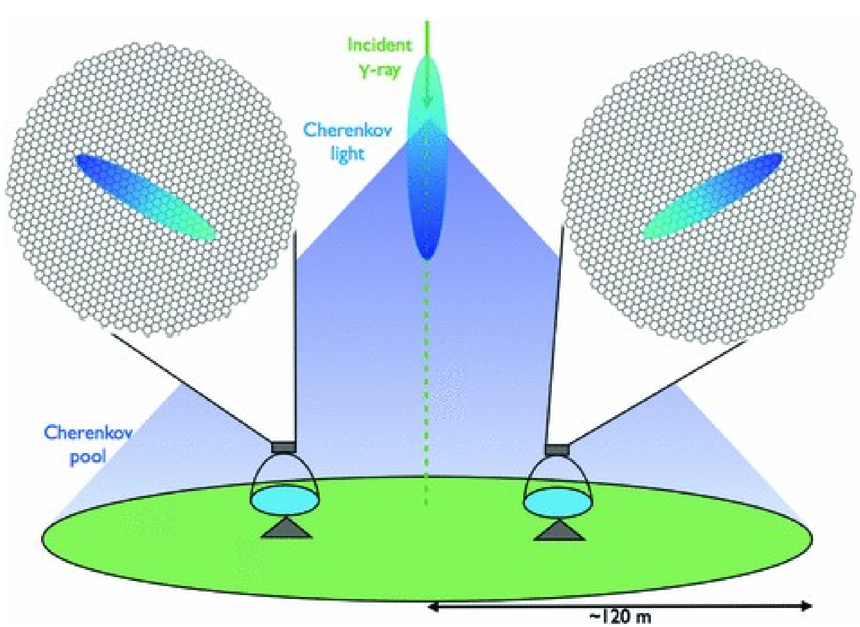
Hadronic cascades

- Mostly π^0, π^+, π^- creation
- Some kaons and light baryons
- Further collisions until Emin 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

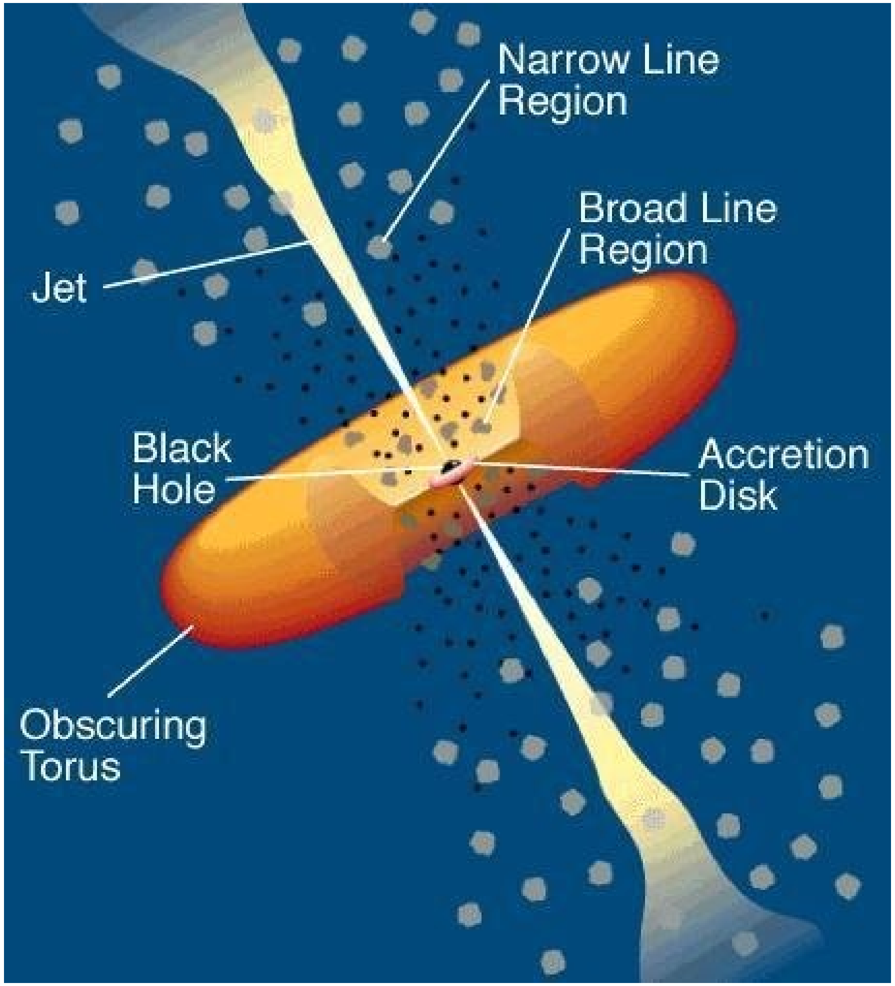
Active Galactic Nuclei (AGN)
Introduction

[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

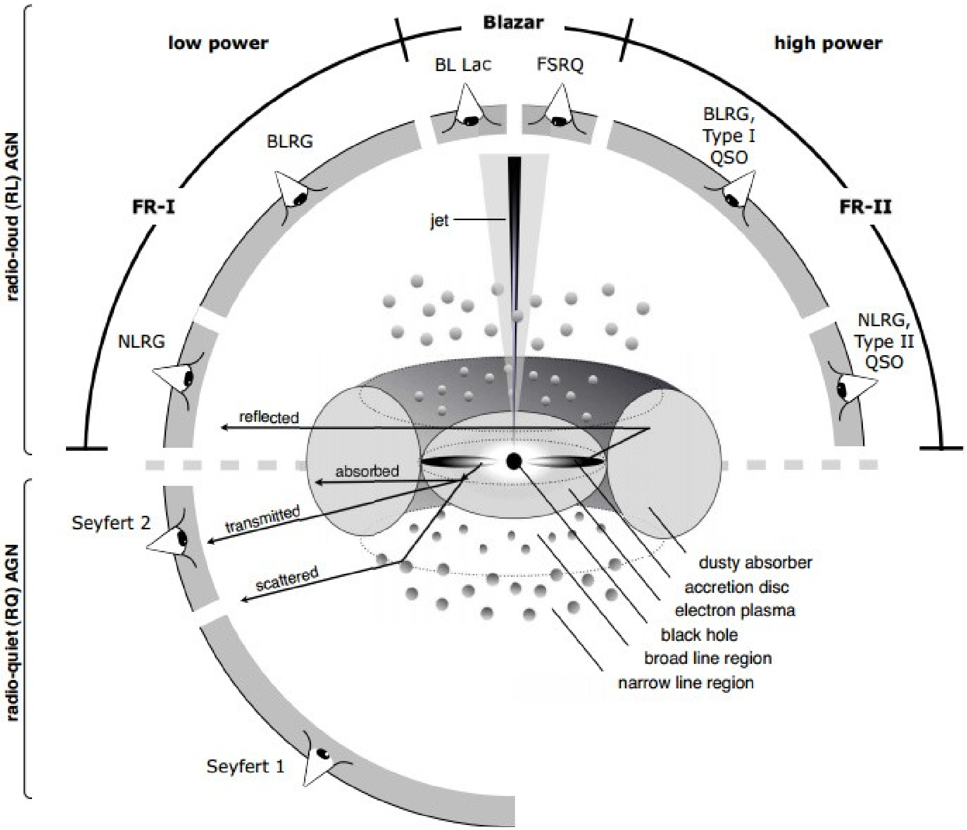


[14] Urry & Padovani 1995

- **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

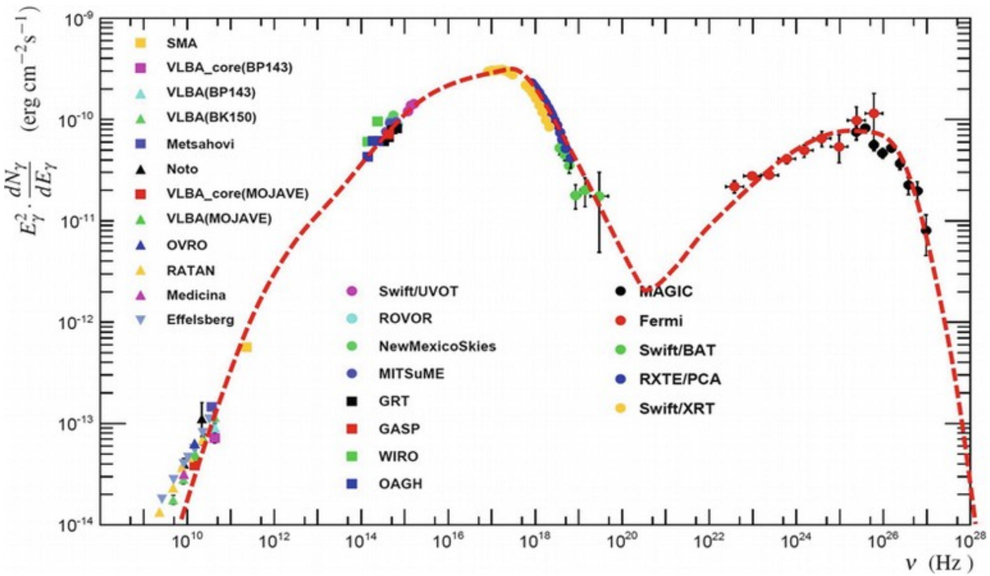
Blazars

- 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

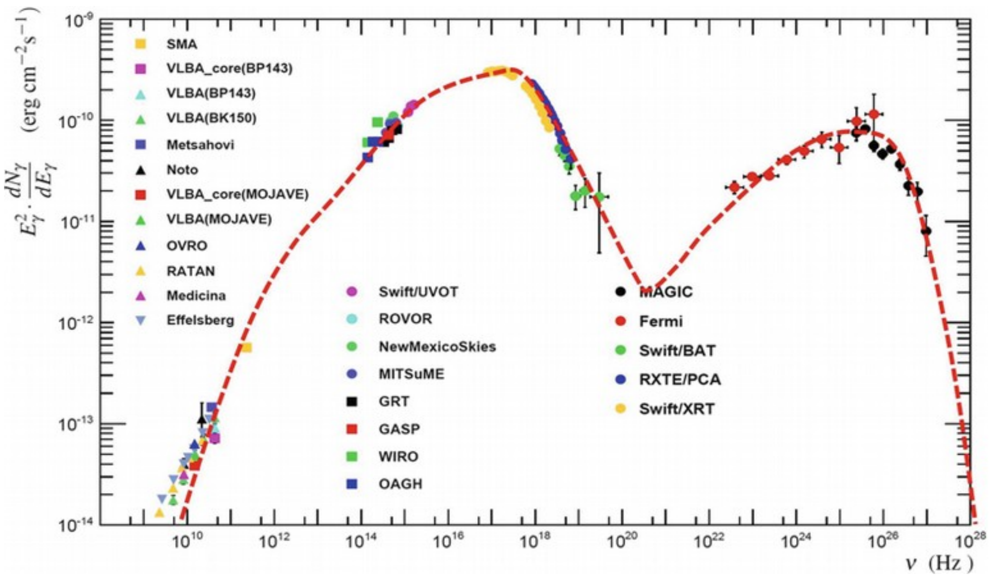
Two component broadband spectra

- 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
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 + magnetic field

  → Synchrotron radiation = first peak
- Radiation field (from Synchrotron) + relativistic electron

  → Inverse Compton scattering = second peak

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?

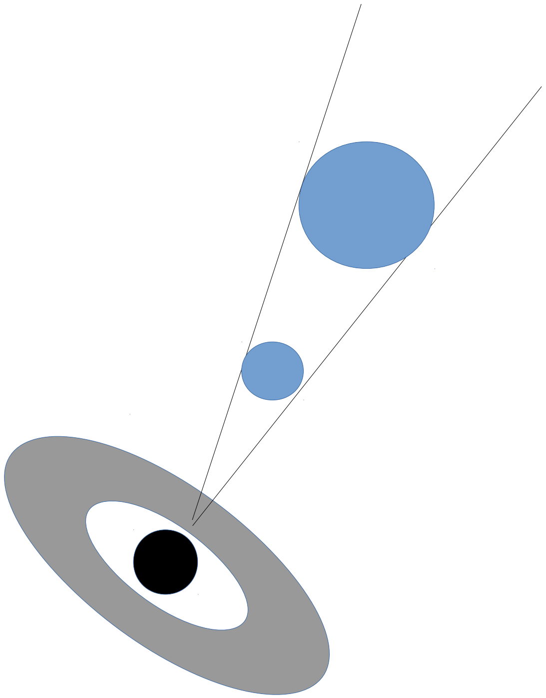
For one period of observation more than one model can explain the spectra satisfactorily

BUT: Different predictions on how it will evolve

Evolution of the spectra with time or flux?

Mrk501 low state

- Markarian 501 is one of the closest blazars for MAGIC
  → We can observed it during quiet and flaring periods
- 2017-2020: regular monitoring in all wavelengths
- Mid 2017 – Mid 2019: lowest very high energy activity observed so far
- Use this low state to find its usual behavior:
  - Model low state spectra with
    - Leptonic scenario
    - Hadronic scenario + prediction for neutrinos
  - Use this baseline emission to model the spectral evolution in the beginning of 2017:
    - Assumption: Baseline emission + flaring region
- Investigate the correlation with other wavelengths
  - Learn which photons are produced in the same regions



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} evV, 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

Thank you for your attention!