GRB observations with H.E.S.S

Jean

Astroparticle school- 05-13, 2021

Obertrubach-Bärnfels

H.E.S.S.

HELMHOLTZ WEIZMANN RESEARCH SCHOOL MULTIMESSENGER ASTRONOMY

DESY

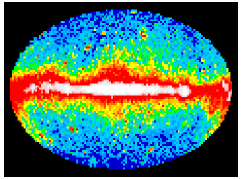
Outline

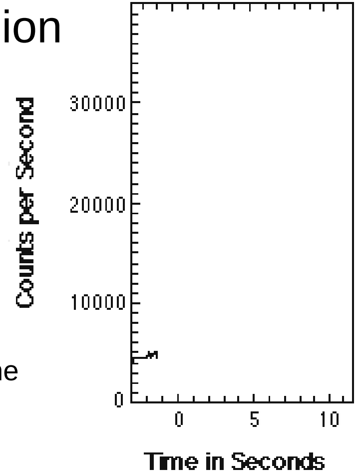
- Basic introduction of GRBs
- H.E.S.S. Telescope
- H.E.S.S. GRB program
- Search for correlation between X-ray and VHE emission from GRBs observed by H.E.S.S.
- Conclusion
- Reference

Gamma-ray Bursts (GRBs)

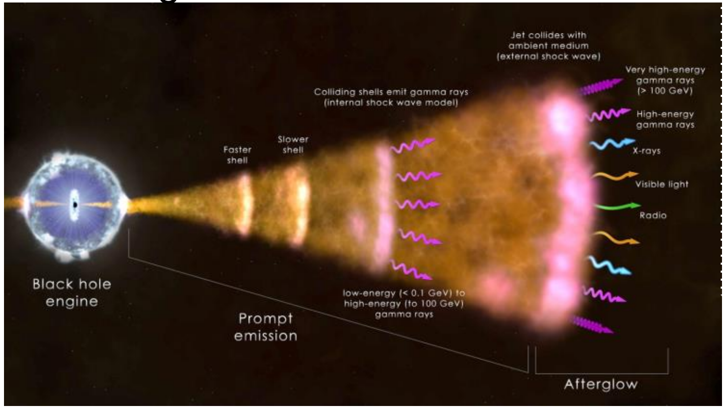
- Extremely bright sources in the universe.
- GRBs have two phases, the prompt phase that last few milliseconds to thousands of seconds and Afterglow phase that last for several days.

Prompt Emission





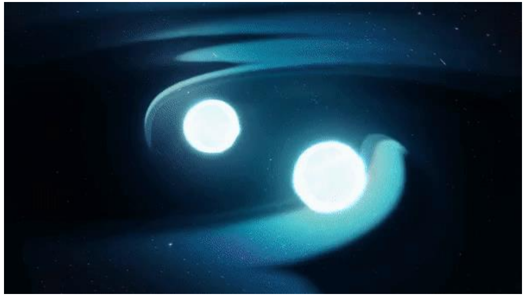
Afterglow emission

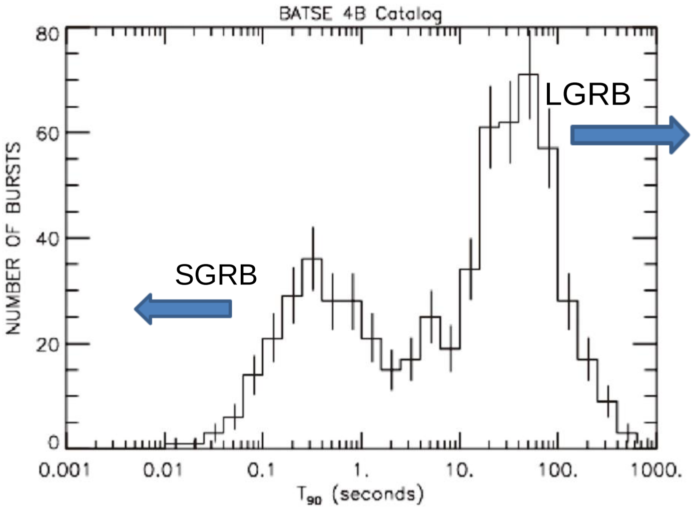


- A relativistic shock would propagate into the ambient medium and accelerate particles
- ➡ EM radiation in all wavelengths lasting for days.
- Several GRBs afterglow emission have been also observed from radio to gamma-ray energies

Question: In the afterglow phase, are GRBs emitting very high energy gamma-rays (VHE; > 100 GeV) ?

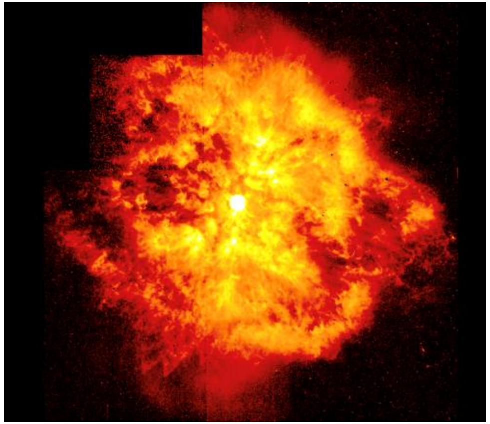
Introduction: Classification and Properties





Duration distribution of GRBs

Ex: WR 124

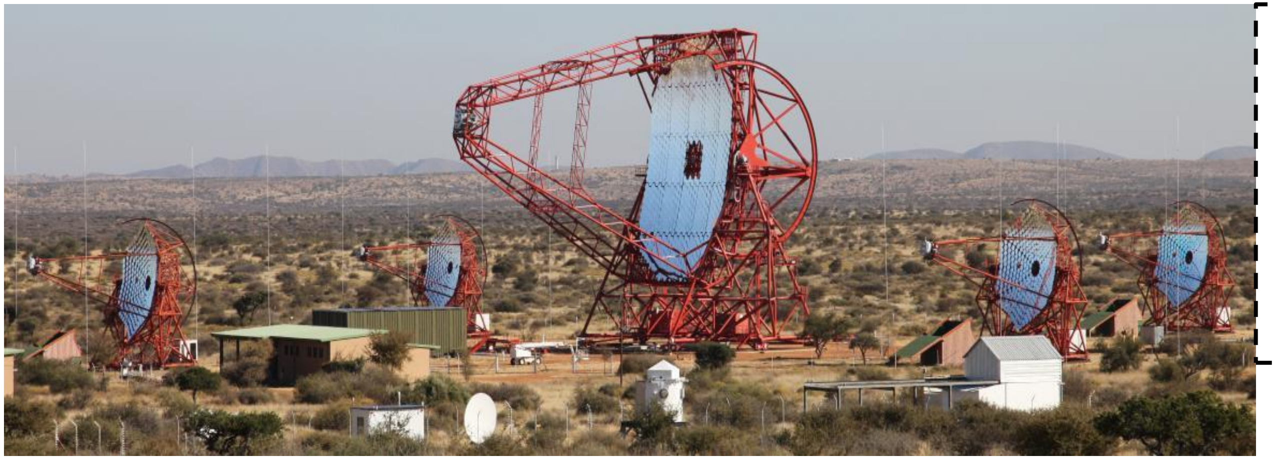


- No link with star forming
- Produced by mergers of compact objects

- Isotropic γ-ray luminosity: $10^{51} – 10^{53}$ erg/s
- Event rate: 1 per Gpc^3 per day

- Majority of observed GRBs
- Linked with core-collapse SN
- Associated with the deaths of massive stars.

High Energy Stereoscopic System (H.E.S.S)



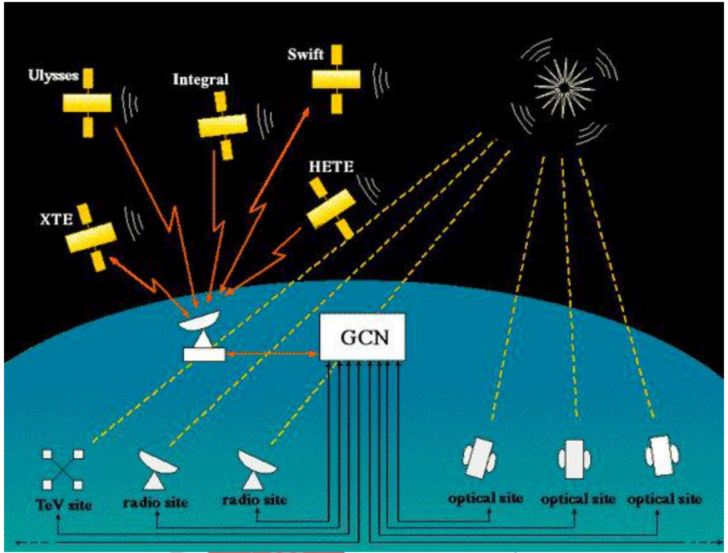
Credit: LSW, Uni. Heidelberg; H.E.S.S.

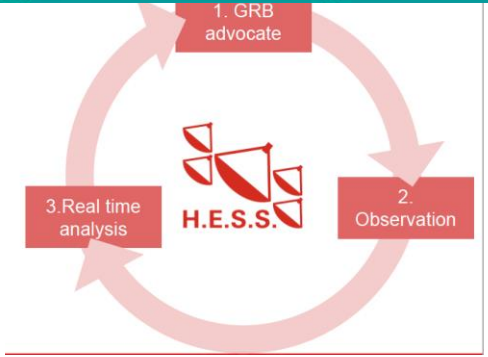
- **Location**: Windhoek, Namibia (1.8 km a.s.l)
- **Technique**: Imaging Atmospheric Cherenkov Technique
- **Telescopes**: 5
- **Key features**: > 50 GeV; slew 100°/minute .

H.E.S.S. has detected VHE gamma-rays from more than 130 sources including 2 TeV GRBs at more than 5 sigma.

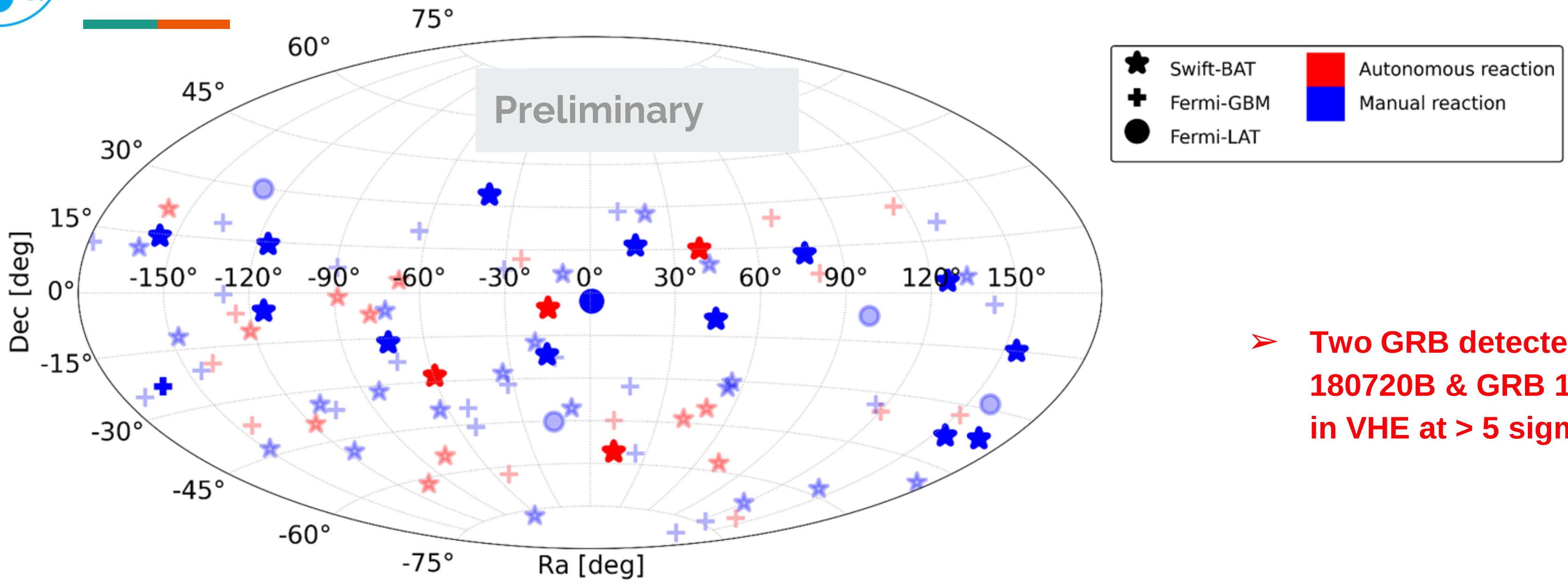
H.E.S.S GRB Program

- An active program within H.E.S.S. collaboration since 2003 (~100 hours / year dedicated for GRB observations).
- The Gamma-ray Coordinates Network (prompt or afterglow alert)
- Most of the GRB observations are automated (to reduce follow-up delay)
- The GRB advocate decides on the continuation of observation (based on real time analysis and available multi-wavelength information).
- Two significant detections are:
  - GRB 180720B
  - GRB 190829A





H.E.S.S GRB Program: Observed GRBs



- Two GRB detected (GRB 180720B & GRB 190829A) in VHE at > 5 sigma

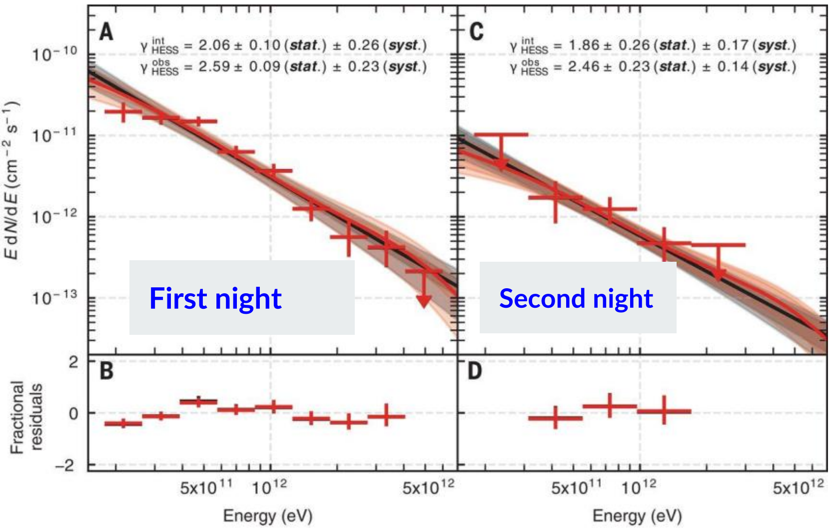
- More than 120 GRBs have been observed till 2021 so far but only two detected.
- Dimmed color are GRBs with no redshift

H.E.S.S GRB Program: Detected GRBs (Cont'...)

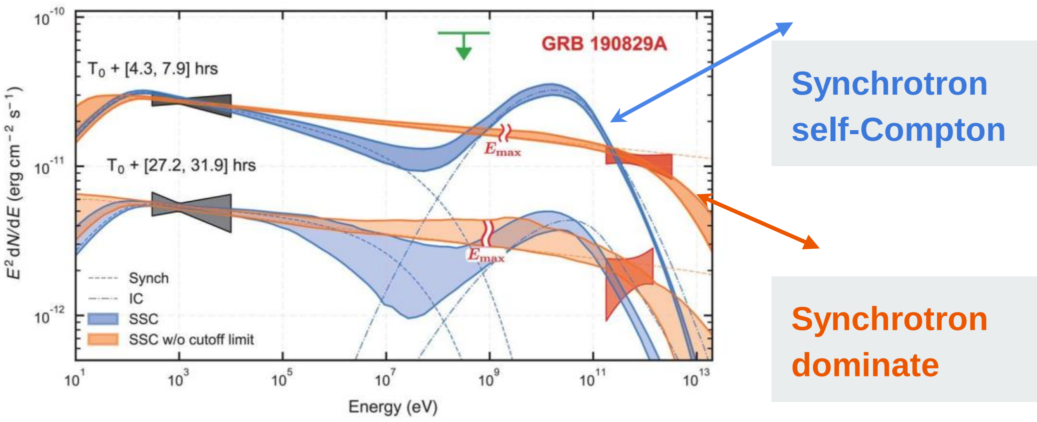
[A cosmic experience - Gamma-ray Burst GRB 190829A]

GRB 190829A

Redshift: z = 0.0785



- This result supports synchrotron dominant emission model



Credit: Science 372, 6546, 1081-1085 (2021)

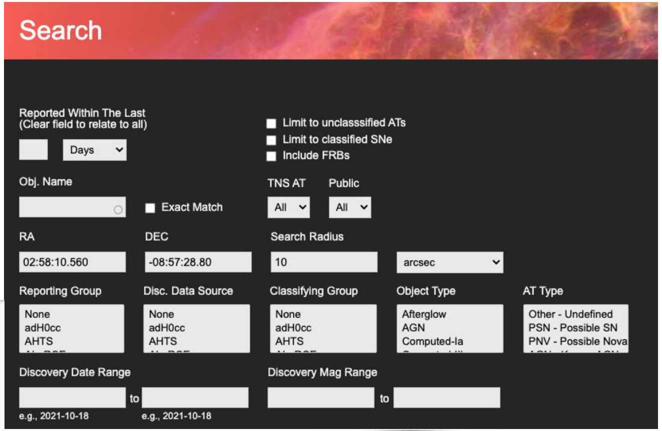
Searching for X-ray/VHE correlation
Sample selection

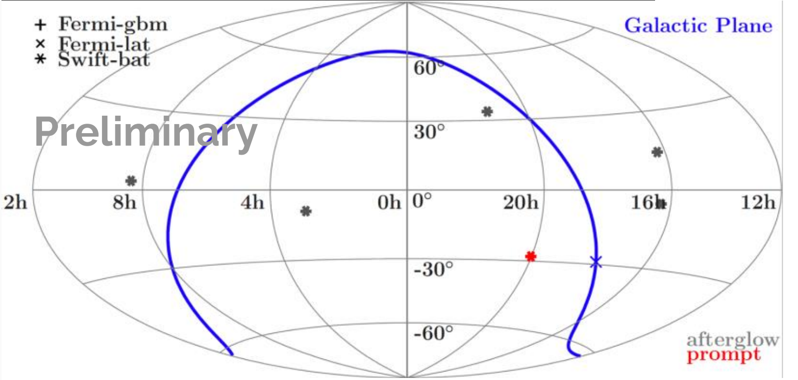
- What can we learn from the simultaneous optical / X-ray data and the VHE upper-limits from H.E.S.S GRBs?

1. HESS observations exists.
2. Have preliminary redshift ($z \lesssim 2$).
3. Reported as transient in the TNS.

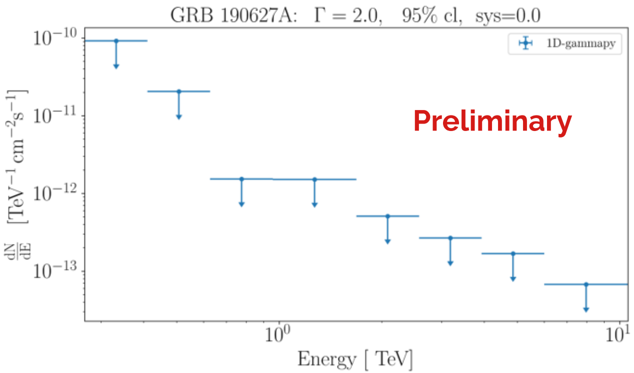
Name	RA	DEC	z	Zenith	$Delay_{HESS}[h]$	$Delay_{opt}[h]$	T_{90}	TransName
GRB 190627A	244.83	-5.29	1.942	44.0	06:21	05:42:29	2.7	AT2019iqz
GRB 190829A	44.544	-8.958	0.0785	23.0	04:20	04:24:16	56.9	AT2019oyw
GRB 201024A	125.95	3.354	0.999	60	22:30	18:14:10	Nan	AT2020yfl
GRB 210610B	243.94	14.39	1.1345	44.0	00:36	00:30:26	69	AT2021qbd
GRB 210619B	319.71	33.86	1.9370	59.8	03:06	2.5	60	AT2021qlb
GRB 210731A	300.31	-28.04	1.2525	6.0	00:02	00:04: 46	26	AT2021umi

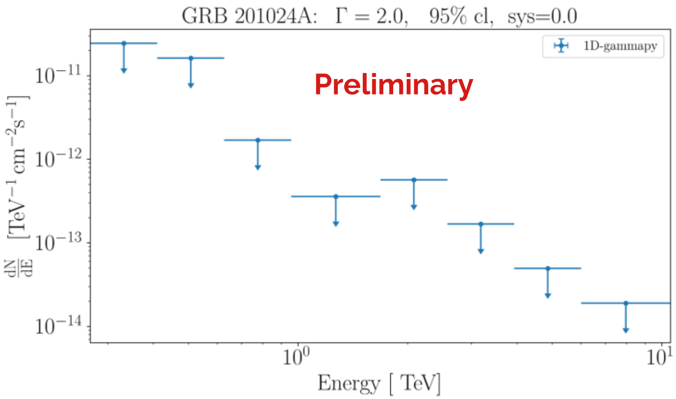
Table 1: The list of selected GRBs.

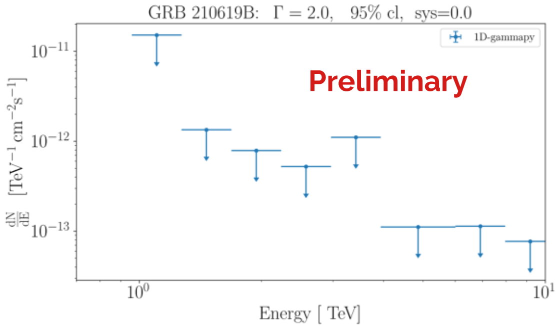


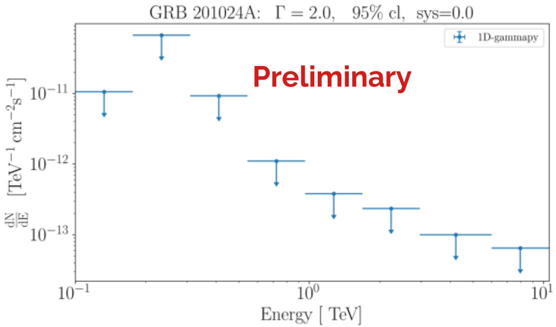


Searching for X-ray/VHE correlation
Differential Upper Limits









Next Steps

- Finish the HESS analysis with all GRBs in the sample (1 remaining)
- Do X-ray analysis for the selected sample.
- Start the modelling of the selected GRBs taking GRB 190829A as a reference.

Conclusions

- In the afterglow phase, GRBs are emitting very high energy gamma-rays but Is it true for all the GRBs?
- The H.E.S.S. GRB observation strategy is successful in observing GeV - TeV afterglow emission from two GRBs so far which motivates to improve the strategy to search for more GRBs.
- The GRB afterglow emission model could be: Synchrotron self-Compton or Synchrotron dominant . More GRBs should be observed to understand the emission model.
- Could this model be used to explain the afterglow emission from GRBs non-detected by H.E.S.S.?

References and Some readings

1. Revealing x-ray and gamma ray temporal and spectral similarities in the GRB 190829A afterglow
2. Extreme emission seen from γ-ray bursts
3. A very-high-energy component deep in the γ-ray burst afterglow
4. The Gamma-ray Coordinates Network (GCN)
5. HESS WG: Multiwavelength Observations
6. TeVCat 2.0
7. Teraelectronvolt Astronomy
8. GMS: A New Era in Gamma-ray Science

End

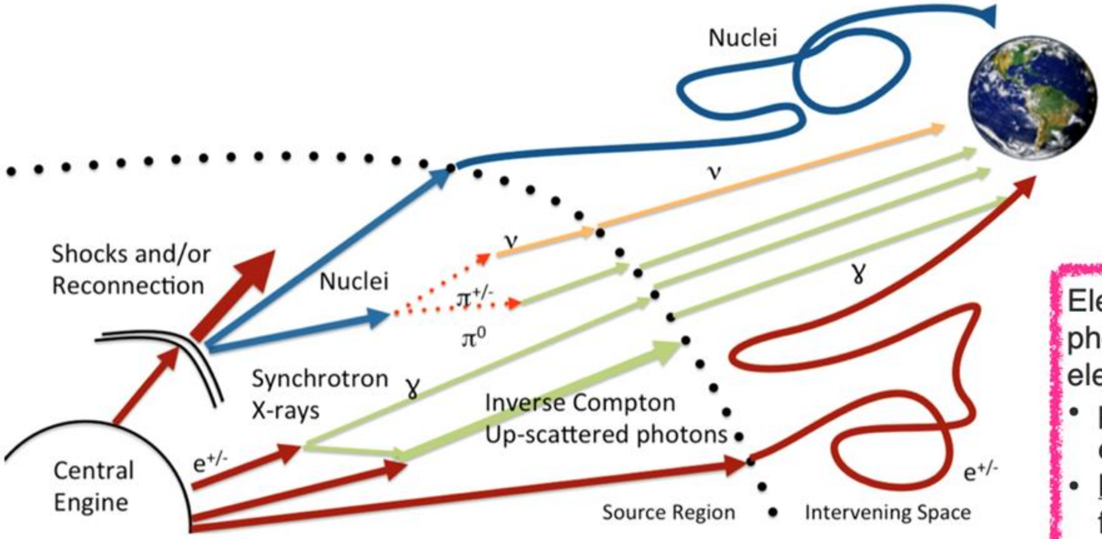
Thank you for your kind attention !

Backup slides

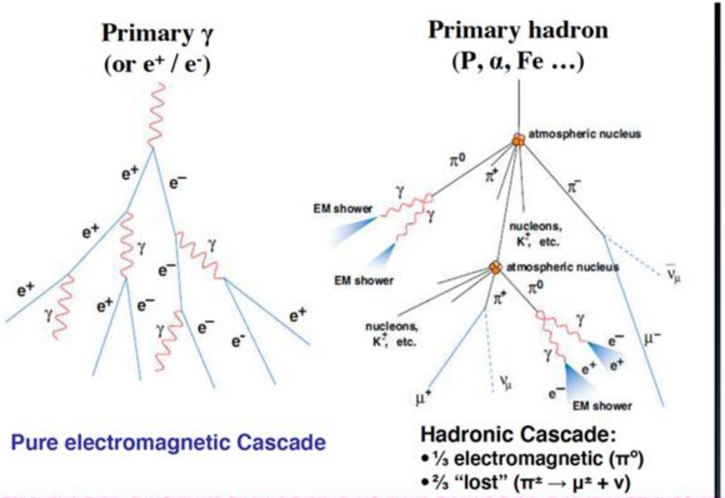
Question: In the afterglow phase, are GRBs emitting very high energy gamma-rays (VHE; > 100 GeV) ?
Note: Due to extragalactic background light (EBL) absorption, VHE gamma-rays tend to have a softer spectrum (Need to be in backup)

Cosmic Ray Accelerators

- Cosmic rays and HE gamma-rays shower in the atmosphere.
- High-energy particle (γ ray or charged nucleus) enters the atmosphere
- Interact with the atmospheric nuclei through various processes,
- Leading to the development of *extensive air shower* (EAS) of particles.



Air shower Cascades



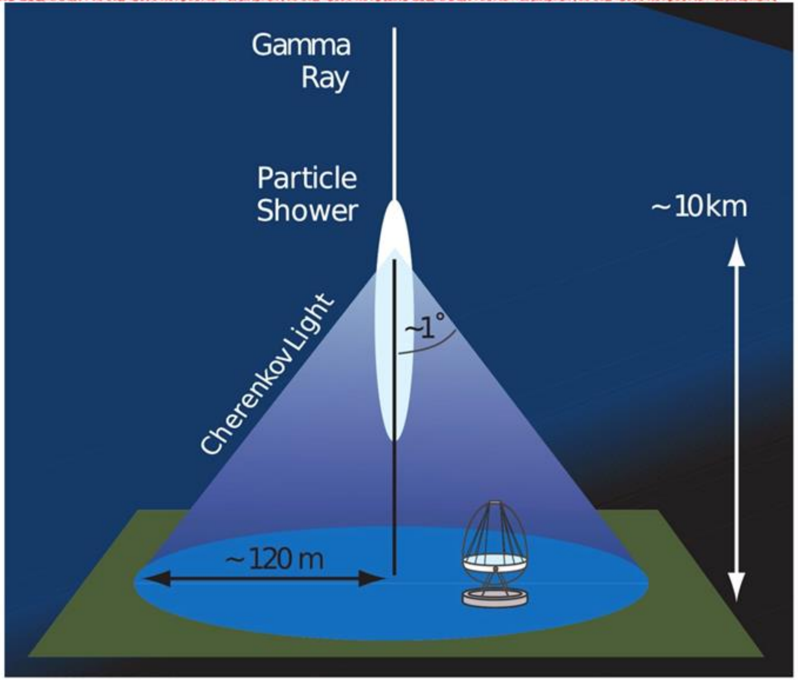
Electromagnetic showers, initiated by high energy photons or electrons are governed by mainly two elementary processes:

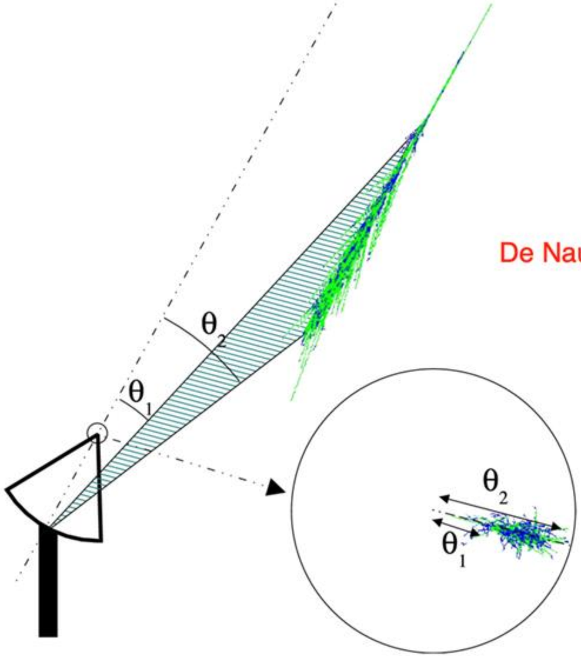
- production of pairs of e± by the conversion of high energy photons in the Coulomb field of the nuclei;
- Bremsstrahlung emission of e± in the same Coulomb field, leading the production of further high-energy photons.

Detection of Air Showers

– multiple scattering of charged particles, leading to shower broadening;
– energy losses of e± by ionization and atomic excitation,
– electron scattering and positron annihilation.
– the Earth's magnetic field, which broadens the shower in the East–West direction.

- Faint pulse of blue light —> Cherenkov radiation
- Pulse lasts a few nanoseconds ~ 5 nsec.
- Effective area = Cherenkov light pool ~10^5 m^2 —> r ~120 m





De Naurois, 2015

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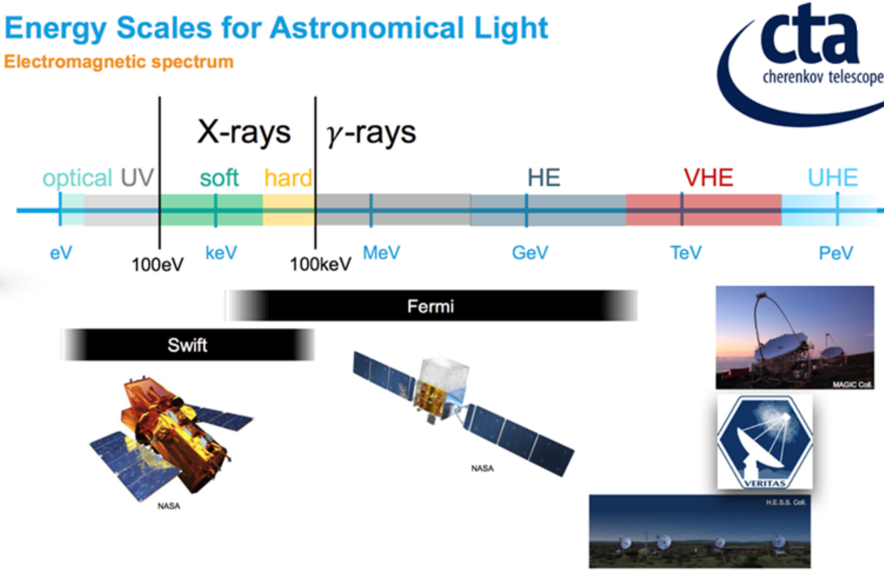
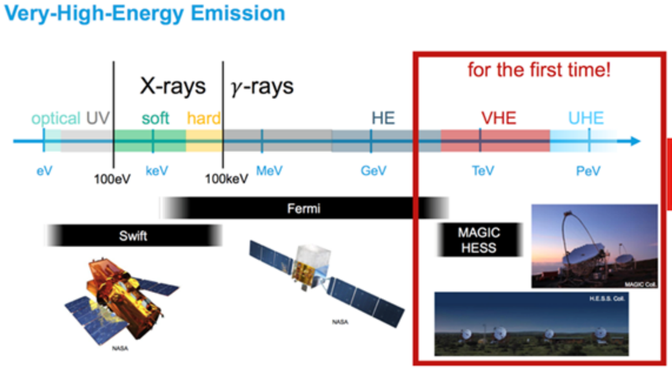
Electromagnetic spectrum

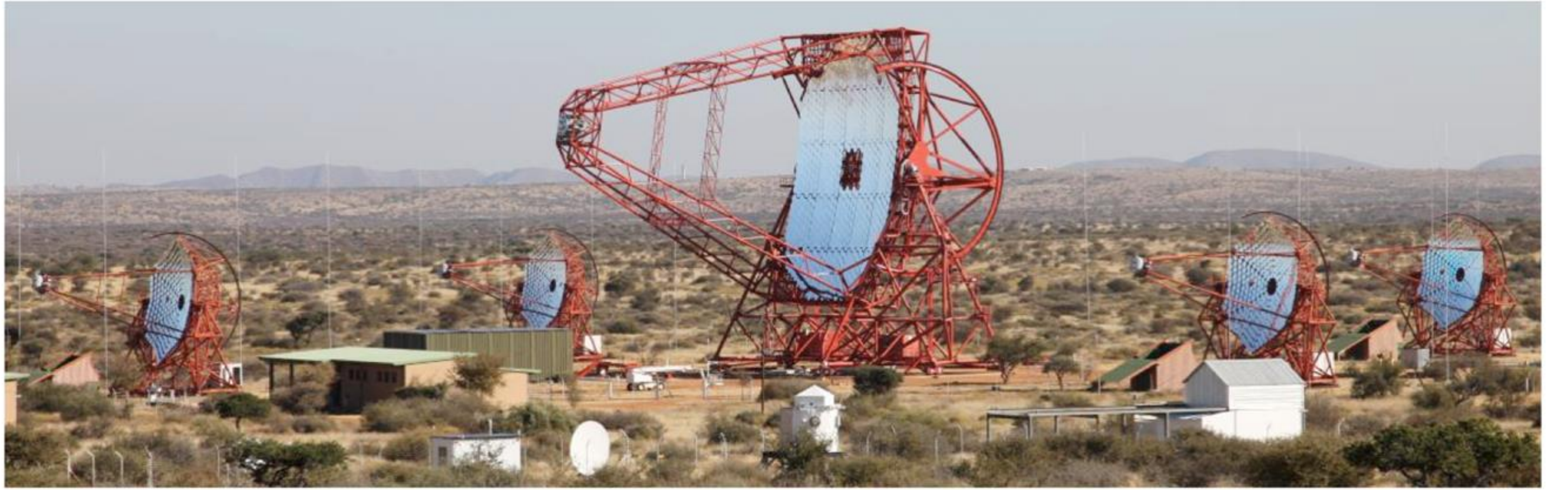
- The Earth's atmosphere is opaque to high energy photons,
- and so the most direct approach to study the gamma-ray sky is to send detectors into space.
- However, astrophysical gamma-ray production mechanisms typically result in steeply falling power-law spectra, leading to a very low photon flux at high energies.





- GRB 190829A and GRB 180720B, by H.E.S.S
- GRB 190114C, by the Magic

H.E.S.S

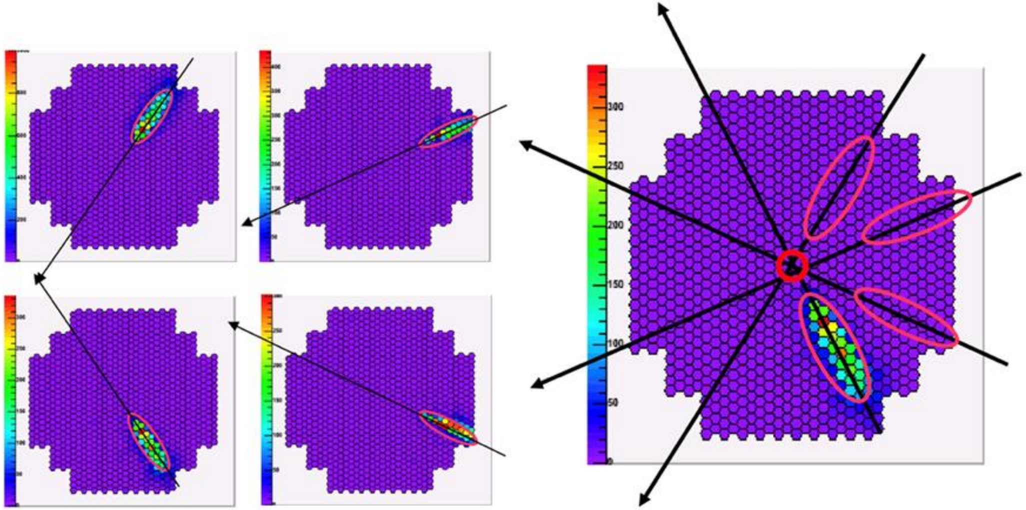


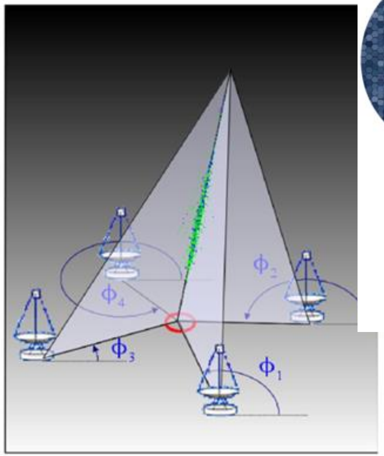
- **H.E.S.S. phase I :**
  - 4 telescopes CT1-4
  - Ø 12 m,107 m^2 for each Camera
  - Stereoscopic reconstruction
  - 960 PMTs/camera, field of view: 5°
  - Source position : ~ 10”
  - Observations : ~1000h/year

- **H.E.S.S. phase II:**
  - Addition of a 5th telescope CT5
  - Ø 28 m, 600 m^2
  - 2048 PMTs, field of view : 3.5°
  - mono and hybrid.
  - Energy threshold (zenith) ~ 30 GeV

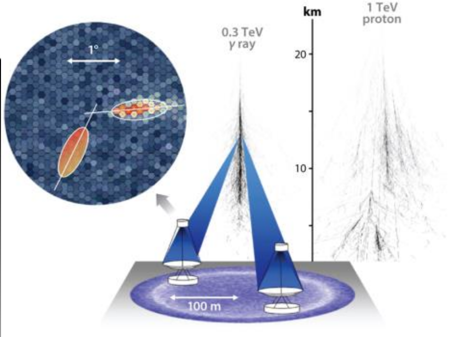
Stereoscopic Techniques

- It is difficult to reconstruct the exact geometry of the air shower in space with a single telescope.
- <u>multiple telescopes are used which view the shower from different points</u> and allow a stereoscopic reconstruction of the shower geometry.





De Naurois, 2015



Credit: Hinton, 2009