Visokoenergijska astrofizika s Čerenkovljevim teleskopima

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Odjel za Fiziku, Sveučilište Josipa Jurja Strossmayera u Osijeku
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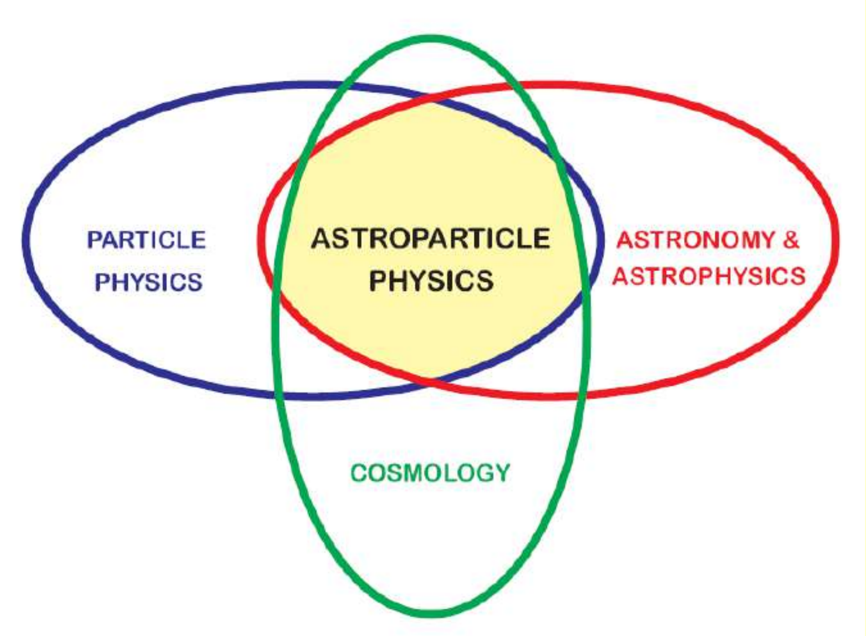
OUTLINE

- VHE astrofizika/astronomija
- Izvori VHE γ-zraka
- Nastank VHE γ-zraka
- IACT
- MAGIC
- CTA

VHE astrofizika/astronomija

VHE astrofizika/astronomija:
Astroparticle physics

the study of particles of astronomical origin



- gamma-ray astronomy
- study of cosmic neutrino
- study of cosmic rays
- gravitational wave searches
- dark matter searches
- nuclear astrophysics

VHE astrofizika/astronomija:
From EM spectrum to VHE γ-rays

Region	Energy	Wavelength
γ-ray	$E > 100$ keV Precisely, $E > m_e c^2 = 511$ keV	$\lambda < 1$ pm Precisely, $\lambda < \lambda^e_{COMPTON} = 2.43$ pm
X-ray	100 eV $< E <$ 100 keV	1 pm $< \lambda <$ 10 nm
ultraviolet	10 eV $< E <$ 100 eV	10 nm $< \lambda <$ 100 nm
visible	1 eV$< E <$ 10 eV Precisely, 1.7 eV $< E <$ 3.2 eV	100 nm $< \lambda <$ 1 μm Precisely, 380 nm $< \lambda <$ 750 nm
infrared	1 meV $< E <$ 1 eV	1 μm $< \lambda <$ 1 mm
microwave	0.1 μeV $< E <$ 1 meV	1 mm $< \lambda <$ 10 cm
radio	$E <$ 0.1 μeV	$\lambda >$ 10 cm

Region	Energy
LE/ME	100 keV $< E <$ 100 MeV
HE	100 MeV $< E <$ 100 GeV
VHE	**100 GeV $< E <$ 100 TeV**
UHE	100 TeV $< E <$ 100 PeV
EHE	$E >$ 100 PeV

VHE astrofizika/astronomija:
X-ray and γ-ray astronomy

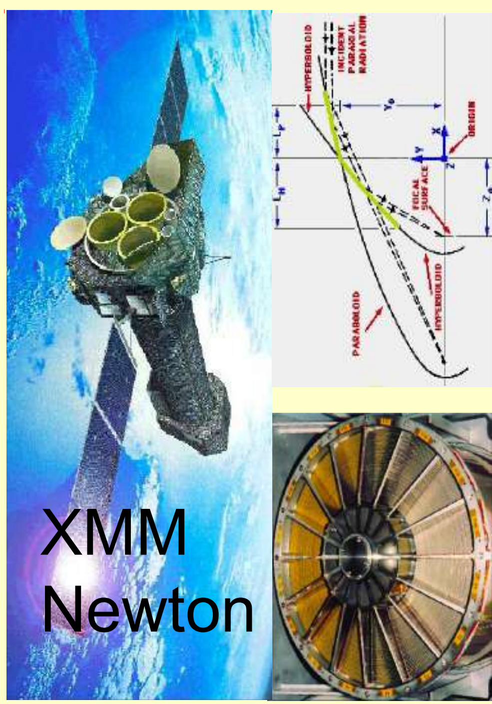
keV MeV GeV

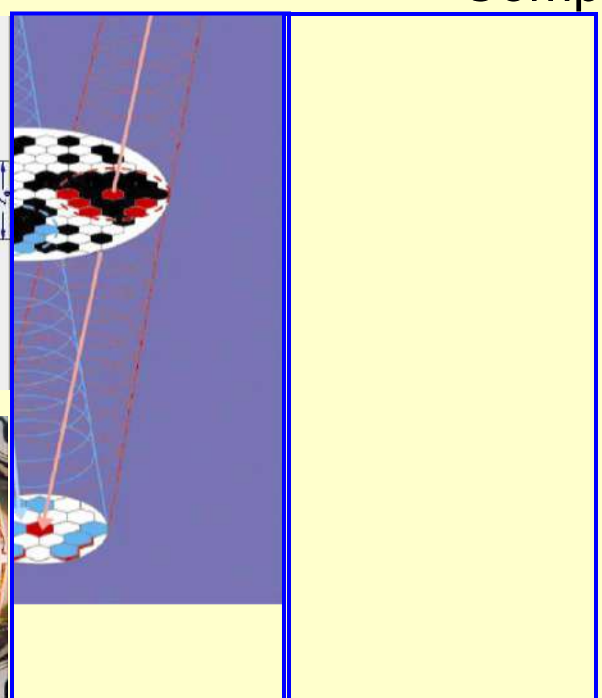
Focusing instruments

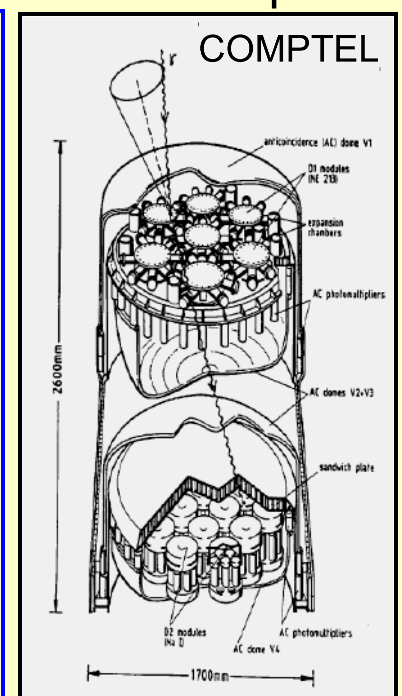
Coded masks, collimators
(i.e. INTEGRAL)

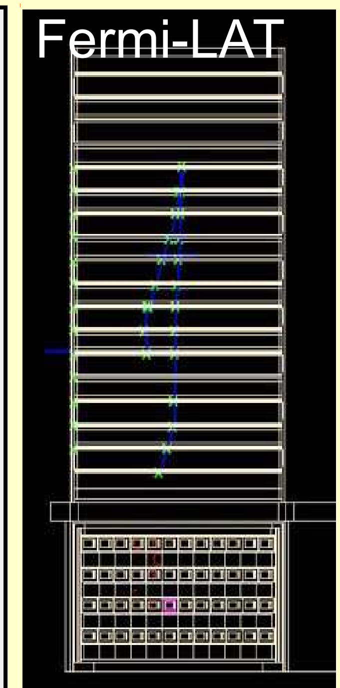
Pair conversion telescopes
(up to ~300 GeV)

Compton telescopes









VHE astrofizika/astronomija:
Limitations of space γ-ray telescopes

Small effective area results in extremely low detection rates above 100 GeV, even for strong sources: flux(Crab,E>100 GeV) <100 photons/m^2/year

Calorimeter depth < 10 radiation lengths (current instruments), which corresponds to 1 ton per m^2 (which is hard to put into orbit)
VHE showers leak out of the calorimeter

VHE astrofizika/astronomija:
Alternative to space γ-ray telescopes

Current satellites are too small to “stop” VHE γ-rays, and, above all, fail to collect enough of them.

Fortunately, the Earth’s atmosphere is thick enough so that the effects of the absorption of a VHE γ-ray in it are detectable from the ground.

The atmosphere acts as tracker & calorimeter.

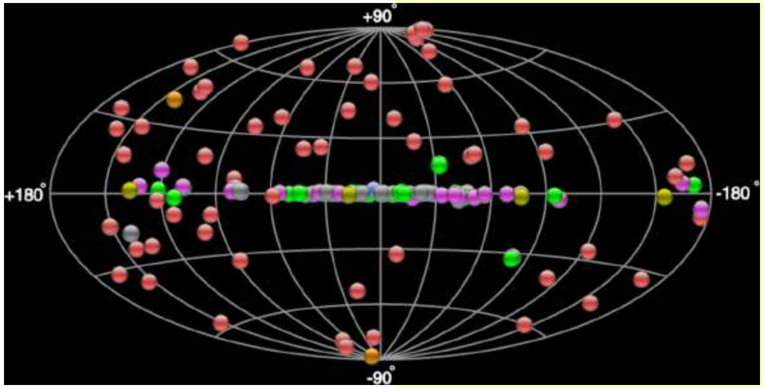
Izvori VHE γ-zraka

Izvori VHE γ-zraka:

>150 sources (galactic and extragalactic)

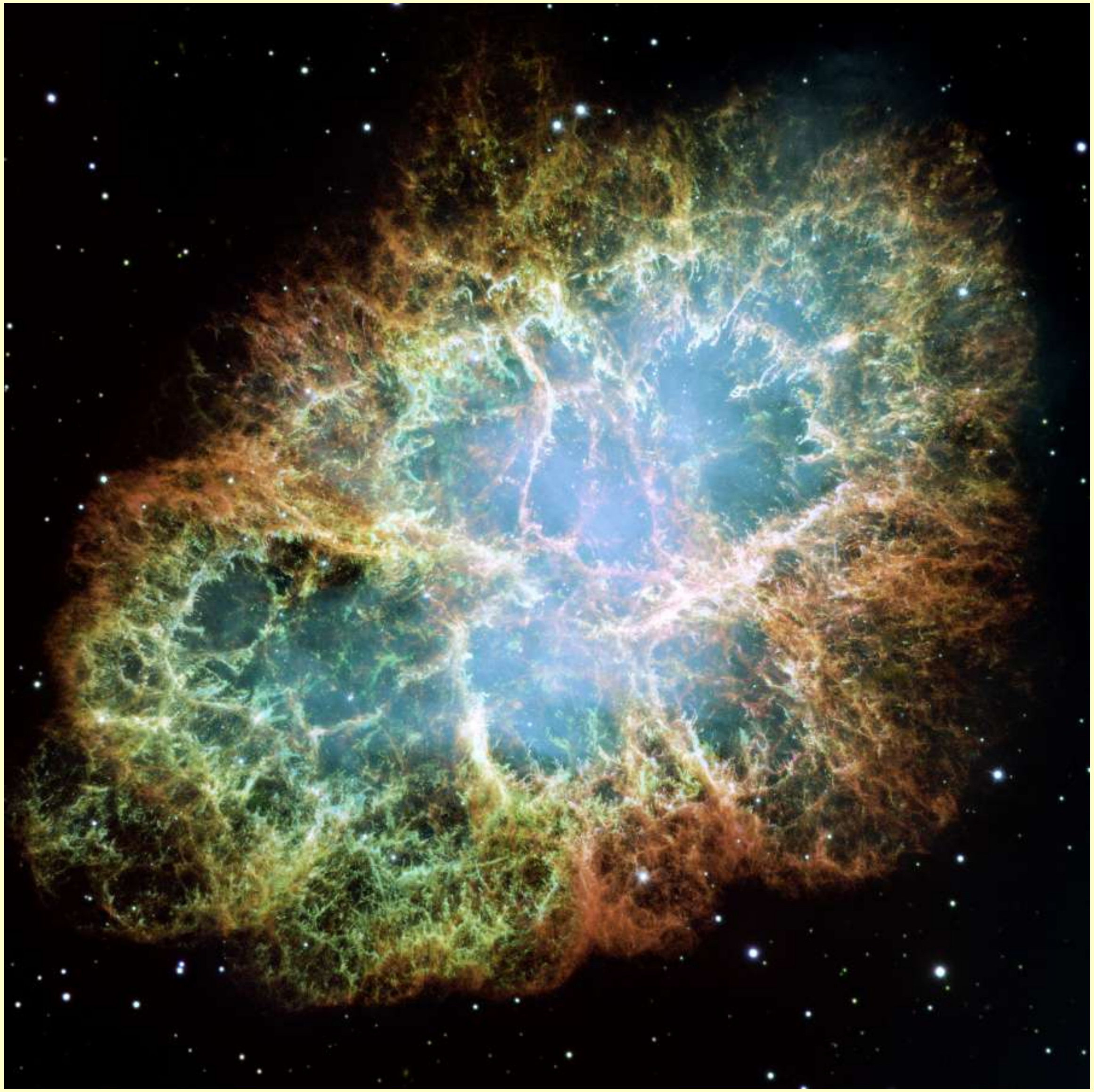
AGNs:

S3 0218+357	**z = 0.944**
3C279	**z = 0.5362**
PG 1553+113	z = 0.5
1ES 0647+250	z = 0.45
4C +21.35	z = 0.432
3C66A	z = 0.41
PKS 1510-089	z = 0.361
1ES 0502+675	z = 0.341
S5 0716+714	z = 0.31
1ES 0414+009	z = 0.287
PKS 0301-243	z = 0.2657
MS 1221.8+2452	z = 0.218
1ES 1011+496	z = 0.212
RBS 0723	z = 0.198
RBS 0413	z = 0.19
1ES 0347-121	z = 0.188
1ES 1101-232	z = 0.186
1ES 1218+304	z = 0.182
RX J0648.7+15	z = 0.179
H 2356-309	z = 0.165
1RXS J101015.9	z = 0.143
1ES 0229+200	z = 0.14
1ES 0806+524	z = 0.138
RX J1136.5+67	z = 0.1342
1ES 1215+303	z = 0.13
H 1426+428	z = 0.129
RGB J0710+591	z = 0.125
B3 2247+381	z = 0.1187
PKS 2155-304	z = 0.116
VER J0521+211	z = 0.108
1ES 1312-423	z = 0.105
W Comae	z = 0.102
SHBL J001355.9	z = 0.095
1ES 1741+196	z = 0.083
RGB J0152+017	z = 0.08
PKS 2005-489	z = 0.071
PKS 0548-322	z = 0.069
BL Lacertae	z = 0.069
1ES 1727+502	z = 0.055
AP Lib	z = 0.049
1ES 1959+650	z = 0.048
Markarian 180	z = 0.045
1ES 2344+514	z = 0.044
Markarian 501	z = 0.034
Markarian 421	z = 0.031
IC 310	z = 0.0189
NGC 1275	z = 0.017559
M87	z = 0.0044
Centaurus A	z = 0.00183

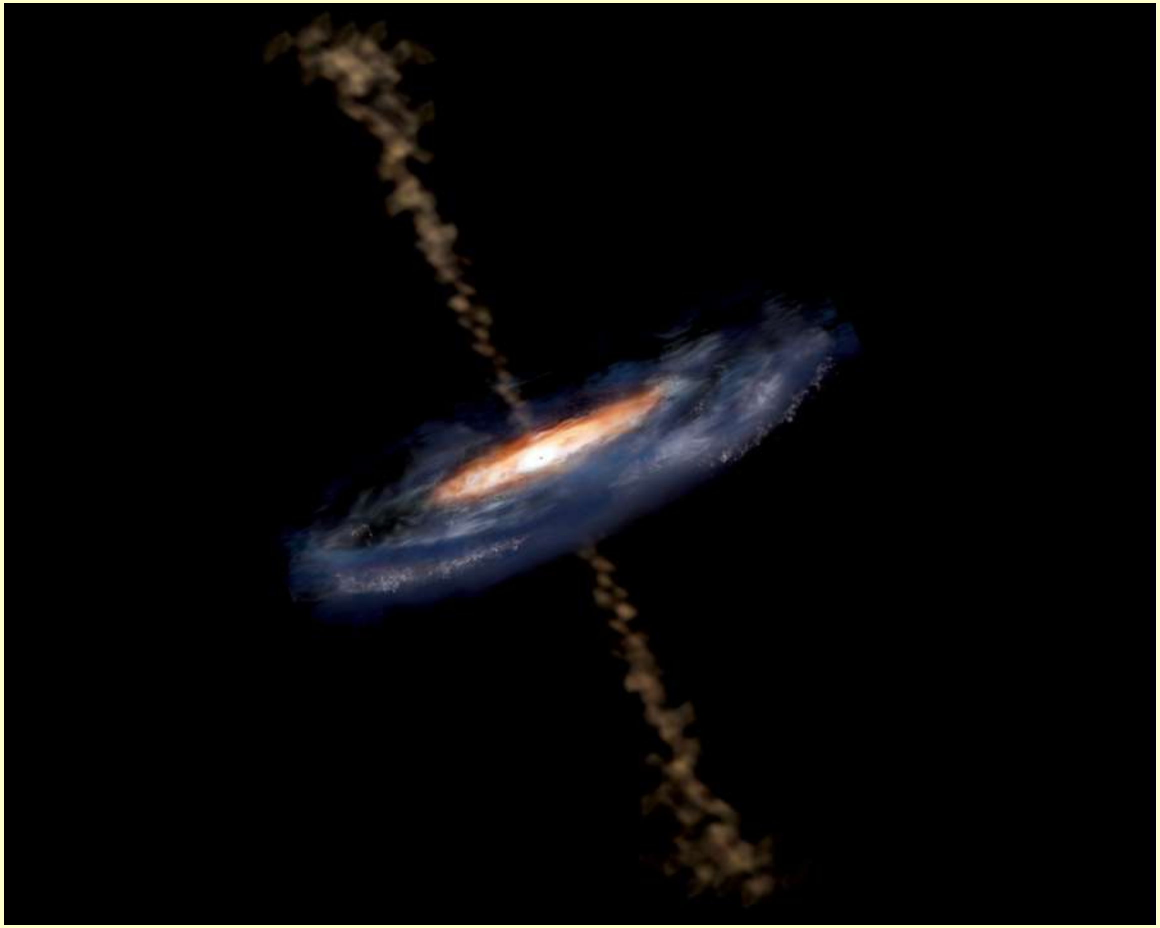


http://tevcat.uchicago.edu/

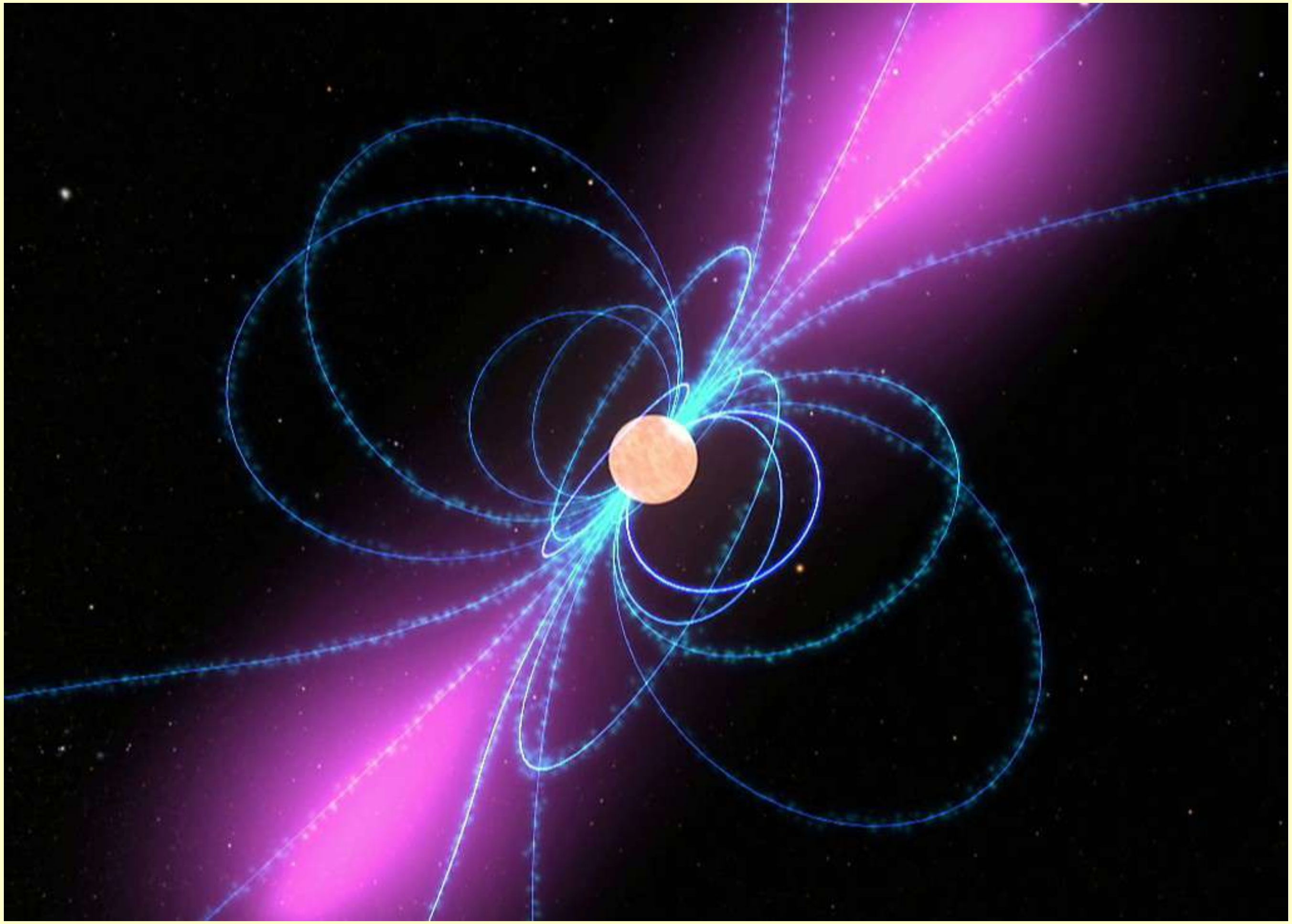
Izvori VHE γ-zraka:
SNR – Supernova remnant



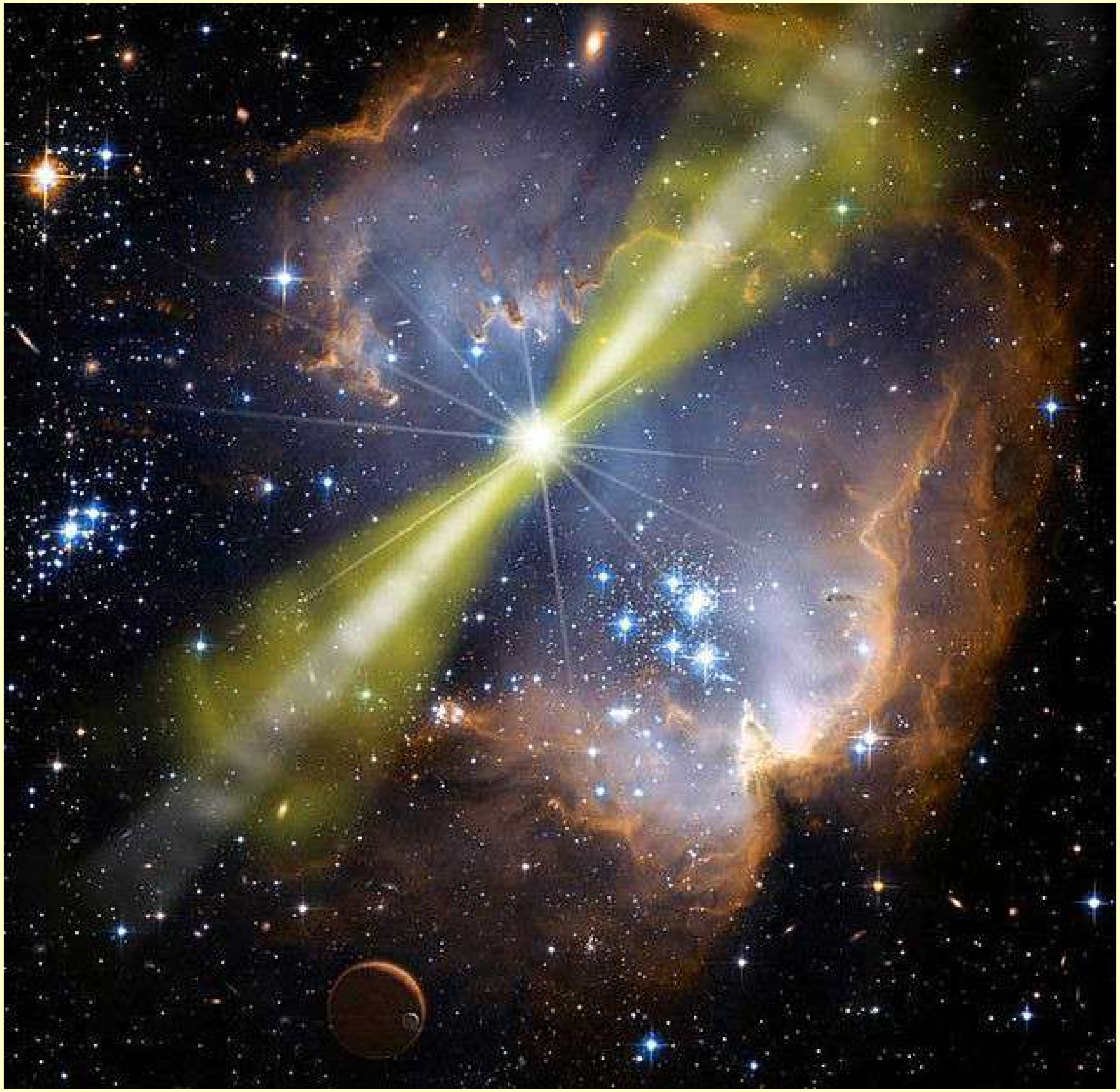
Izvori VHE γ-zraka:
AGN – Active galactic nucleus



Izvori VHE γ-zraka:
Pulsar – fast rotating neutron star

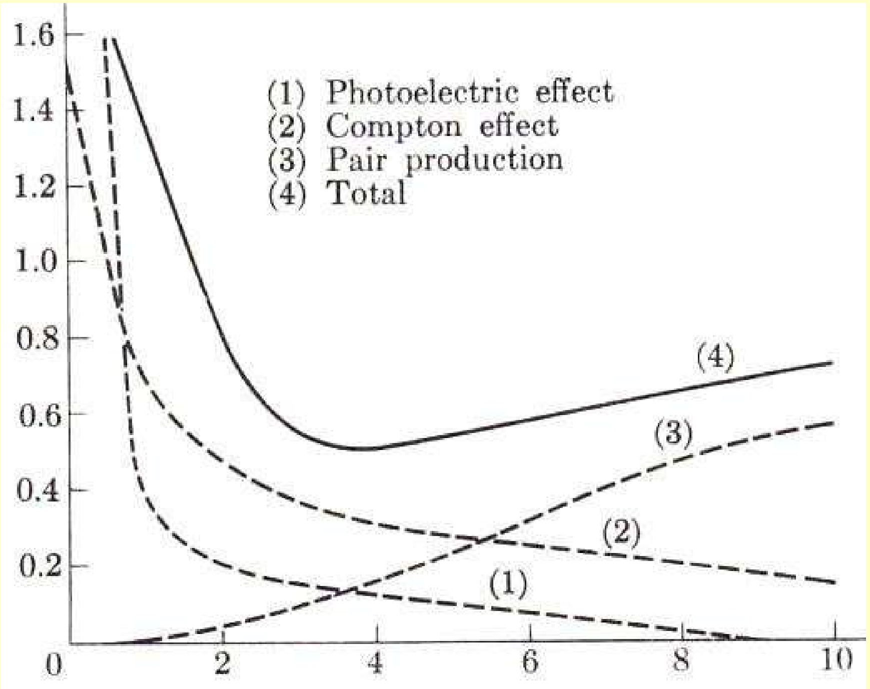


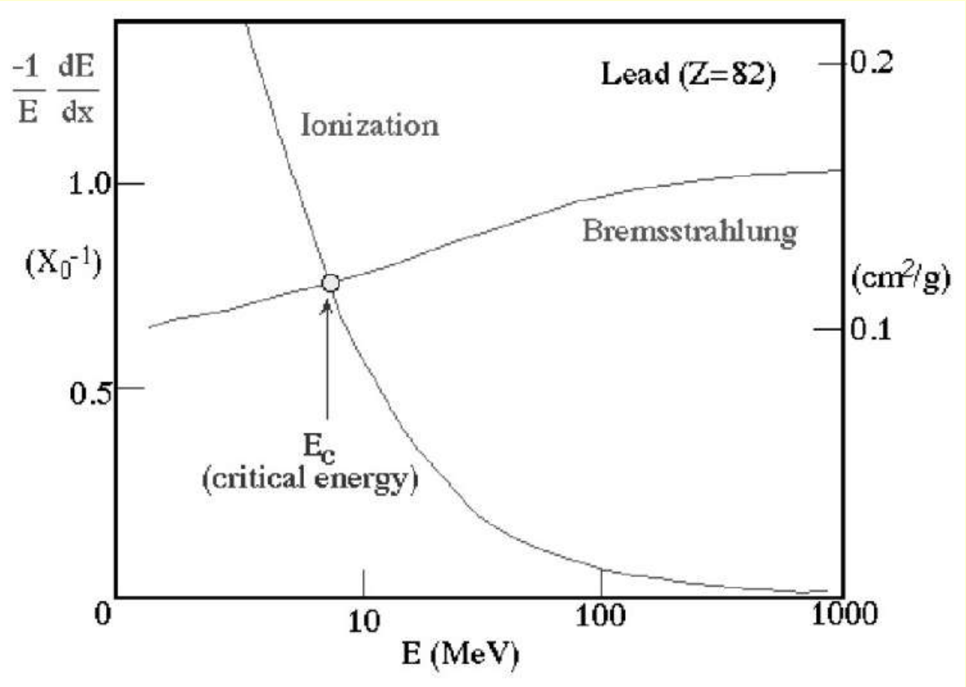
Izvori VHE γ-zraka:
GRB - Gamma-ray burst



Nastank VHE γ-zraka

Nastanak VHE γ-zraka:
Interaction of photons and electrons



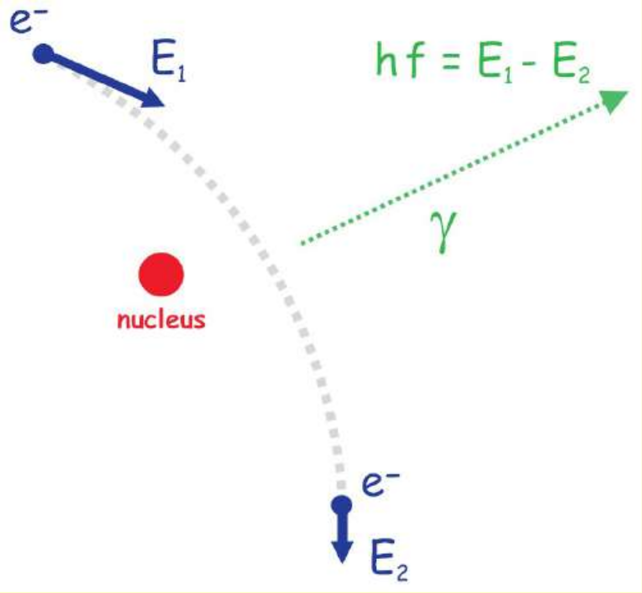


HE photons predominantly lose energy in matter by pair production

HE electrons predominantly lose energy in matter by bremsstrahlung

Nastanak VHE γ-zraka:
Bremsstrahlung

EM radiation produced by a charged particle when it is deflected (decelerated) in *the electric field of a nucleus*



Bremsstrahlung dominates the energy loss of electrons above the critical energy E_c

≈ 700 MeV for hydrogen gas
≈ 70 MeV for the atmosphere
≈ 7 MeV for lead

Nastanak VHE γ-zraka:
Synchrotron radiation

EM radiation produced by a relativistic charged particle which travels through *the strong magnetic field.*

The principal emission mechanism in astrophysical situations

In general:
acceleration of a charged particle ⇒ emisssion of EM radiation

For example:
tangential acceleration (e.g. ***E***) ⇒ bremsstrahlung
centripetal acceleration (e.g. ***B***) ⇒ **magnetic bremsstrahlung (synchrotron radiation)**

Characteristics:
- wide and continuous spectrum (from IR to X-rays)
- very intensive and colimated
- strong polarised

Nastanak VHE γ-zraka:
Emission models of blazars

LEPTONIC models

inverse Comptonov (IC)

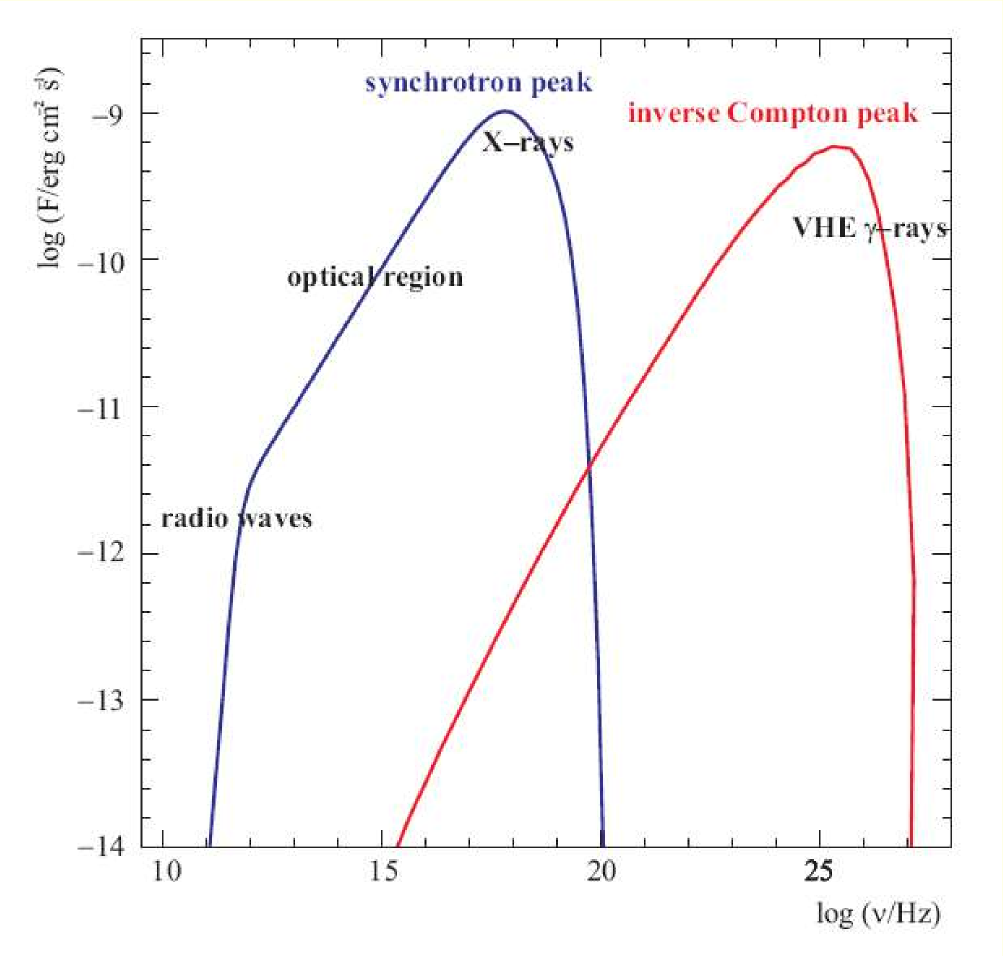
$$e^-_{HE} + \gamma_{LE} \rightarrow e^-_{LE} + \gamma_{HE}$$

HADRONIC models

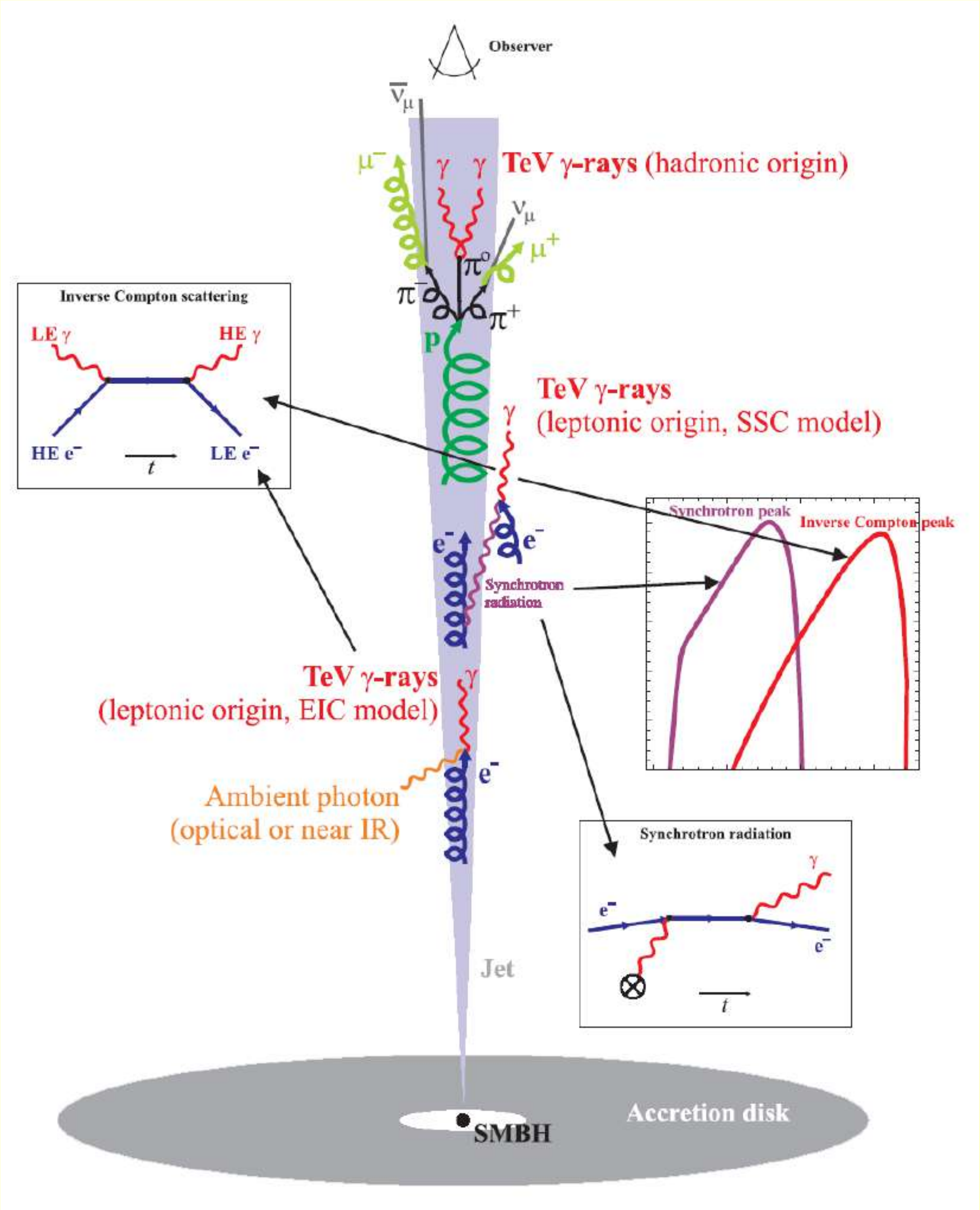
$$p+p \rightarrow N + N + n_1(\pi^+ + \pi^-) + n_2(\pi^o)$$

$$\pi^o \rightarrow \gamma + \gamma$$

$$\pi^\pm \rightarrow \mu^\pm + \nu_\mu$$

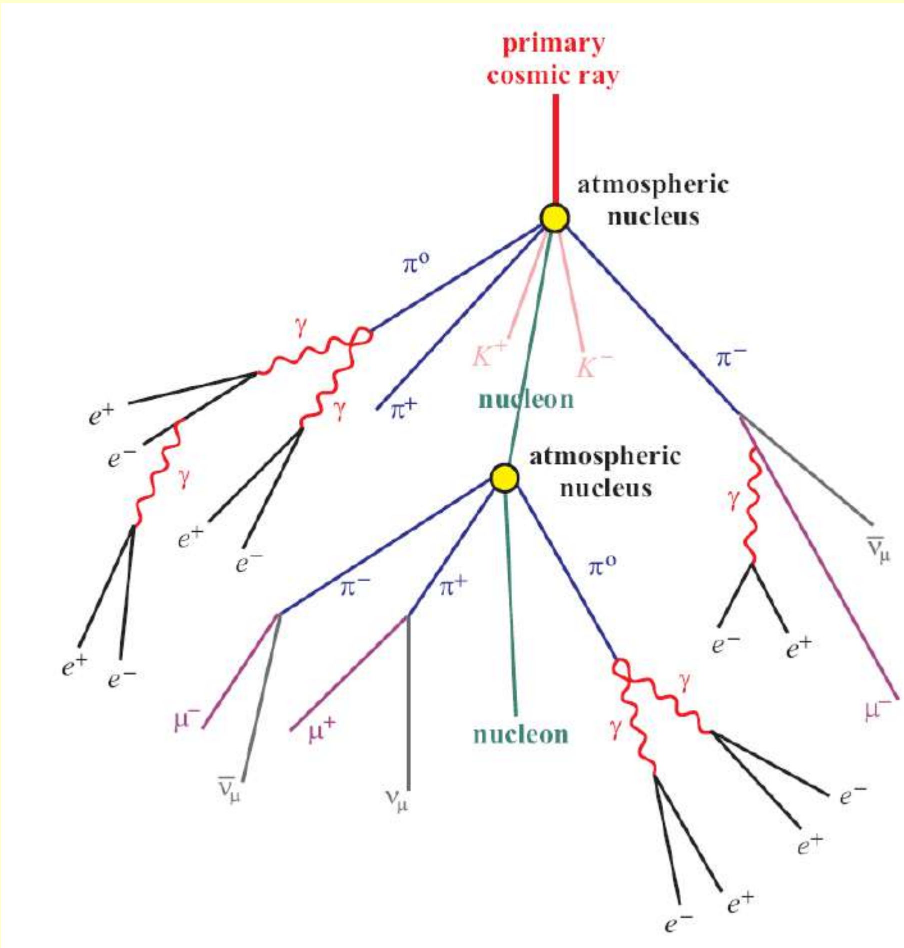


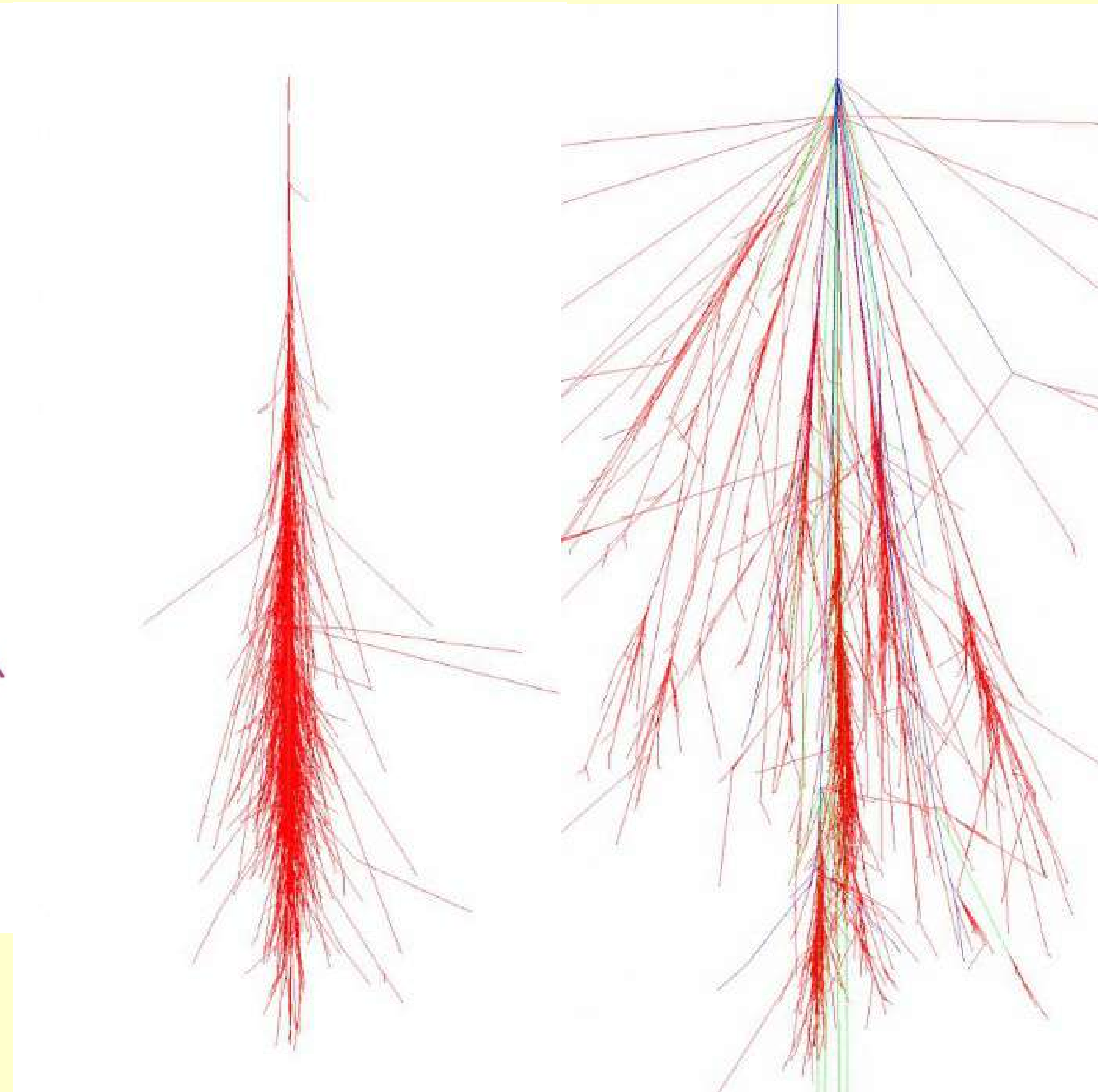
Nastanak VHE γ-zraka:
TeV γ-rays from an AGN jet



IACT

IACT:
EAS - Extensive Air Shower

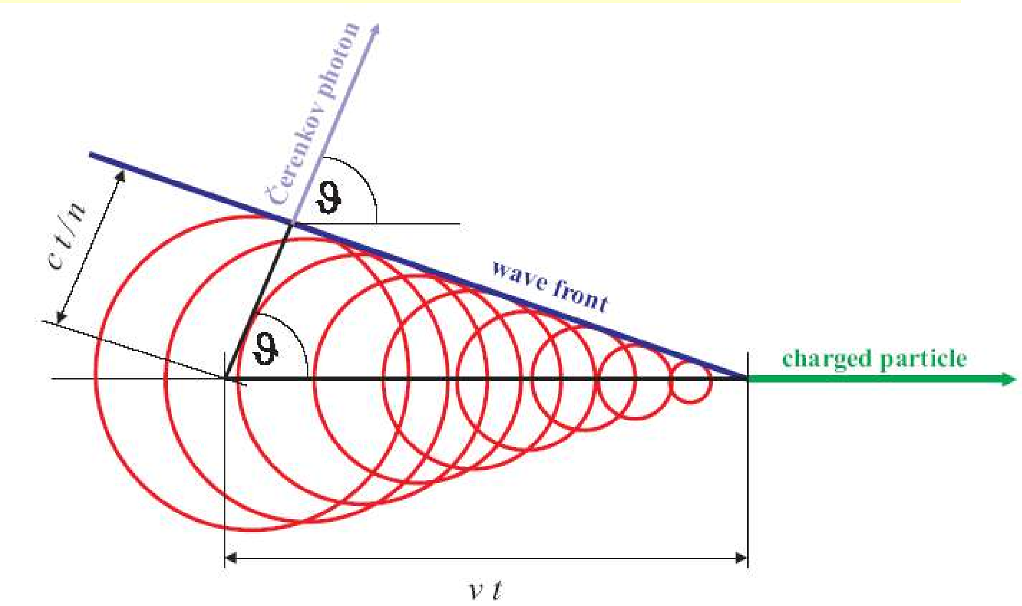


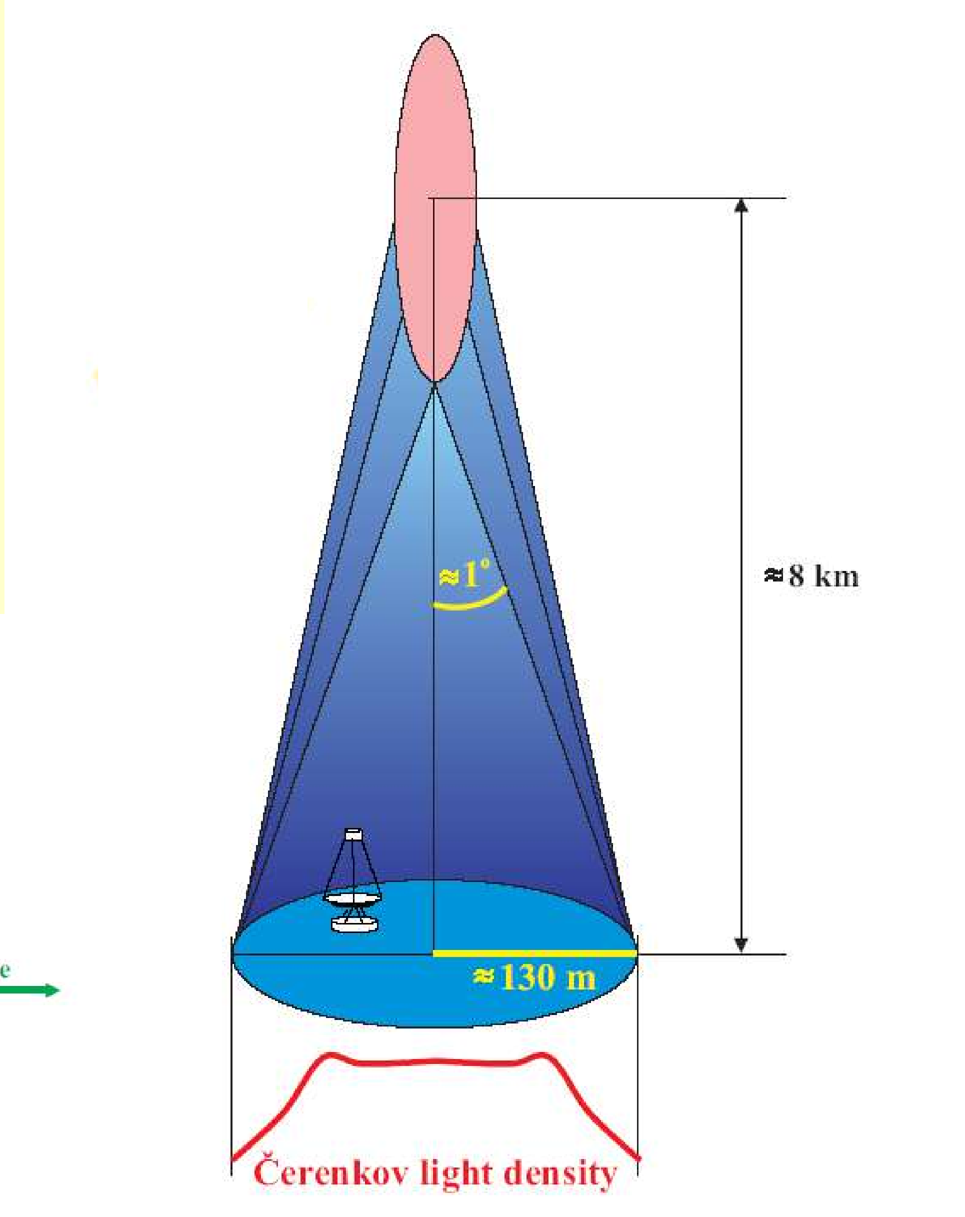


gamma 50 GeV proton 200 GeV

IACT:
Cherenkov light from EAS

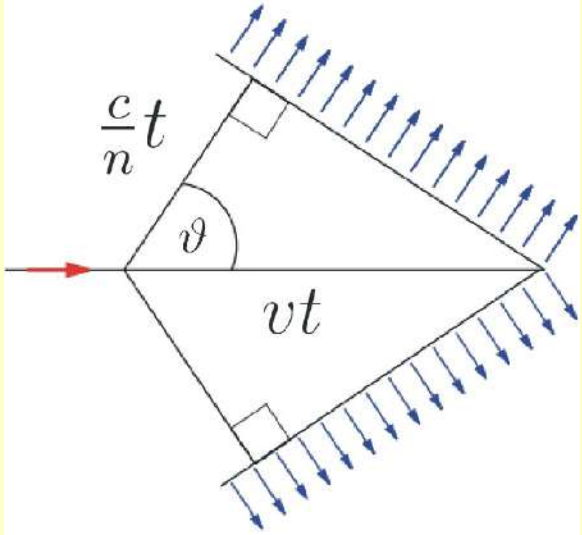
The essential mechanism for the detection of VHE γ-rays at ground





IACT:
Cherenkov radiation

EM radiation *produced by medium* when a relativistic charged particle travels through it with a velocity that **exceeds the velocity of light** in that medium.



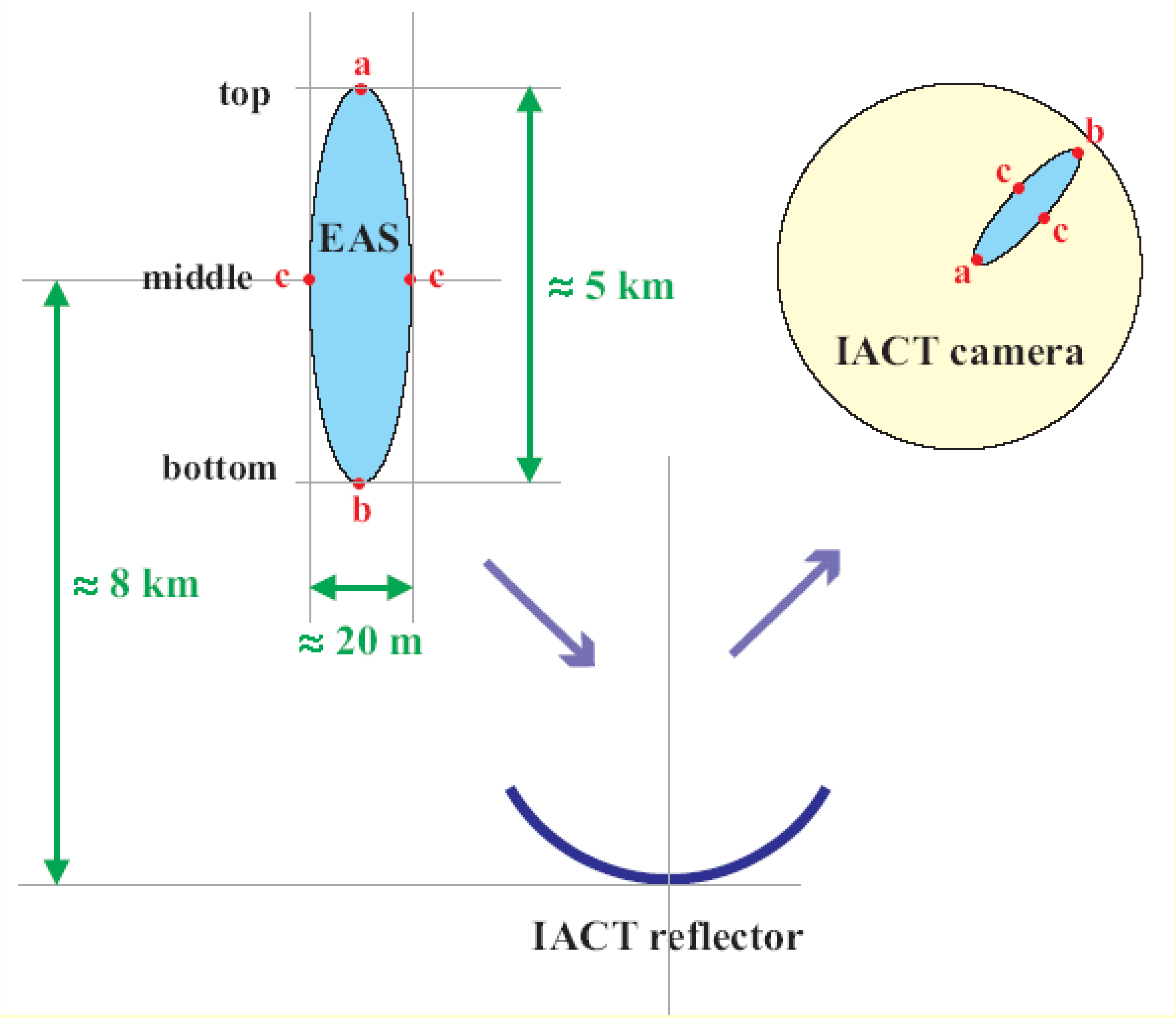
- continuous spectrum (visible & **UV**)
- applications in particle physics (RICH) and astroparticle physics (Čerenkov telescopes and neutrino telescopes)

$$\cos\vartheta = \frac{\frac{c}{n}t}{vt} = \frac{1}{n\beta}$$

In the atmosphere at ground level:

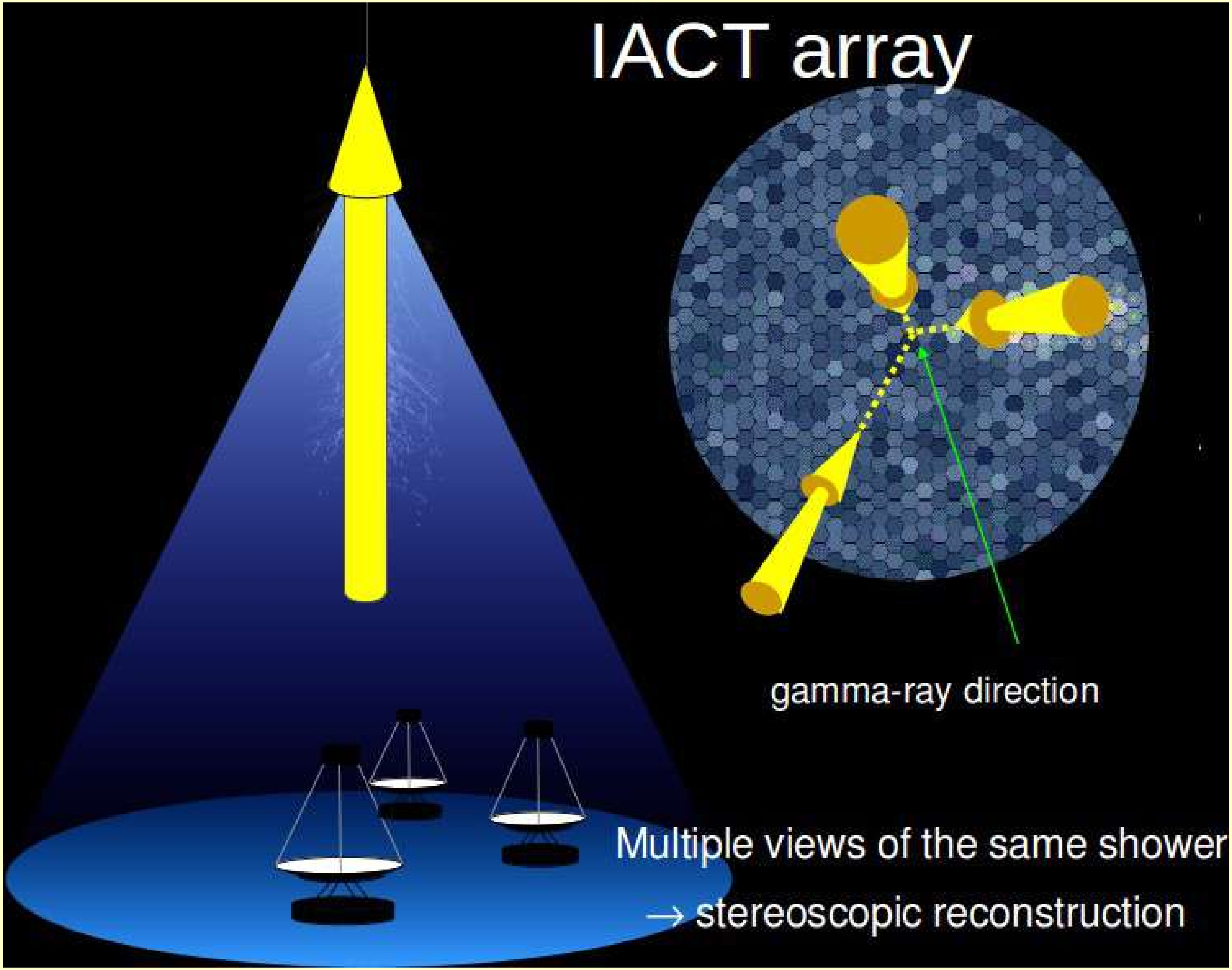
- $n = 1.00029$
- $\theta_{max} = 1.3^{o}$
- $E_{th}(e) = 21$ MeV, $E_{th}(\mu) = 4.4$ GeV, $E_{th}(p) = 39$ GeV,
- light yield (visible) = 30 photons/m (or 10^4 photons/RL)

IACT:
From an EAS to a camera image



IACT (Imaging Atmospheric Cherenkov Technique)

IACT:
Stereoscopic reconstruction



MAGIC

MAGIC:
Basic info

Major Atmospheric Gamma-ray Imaging Cherenkov Telescopes

a system of 2 Cherenkov telescopes situated at the ORM
on La Palma, one of the Canary Islands, at about 2200 m a.s.l.

diameter: 17 m , collecting area: 240 m^2
energy range: 50 GeV do 50 TeV

M1: since 2003
M1+M2: since 2009
Croatian membership: since 2008

- Best flux sensitivity around 400 GeV: 0.6% Crab.
- Angular resolution: 0.1° at 100 GeV ➔0.07° at 1 TeV
- Energy resolution: 20% at 100 GeV ➔ 15% at 1 TeV.

MAGIC:
La Palma, Spain

MAGIC:
The collaboration

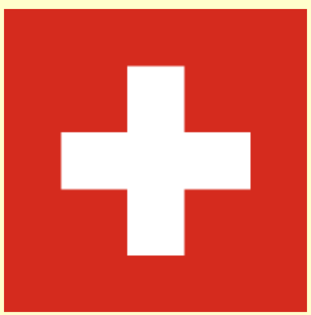

52


48


39


12


10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6

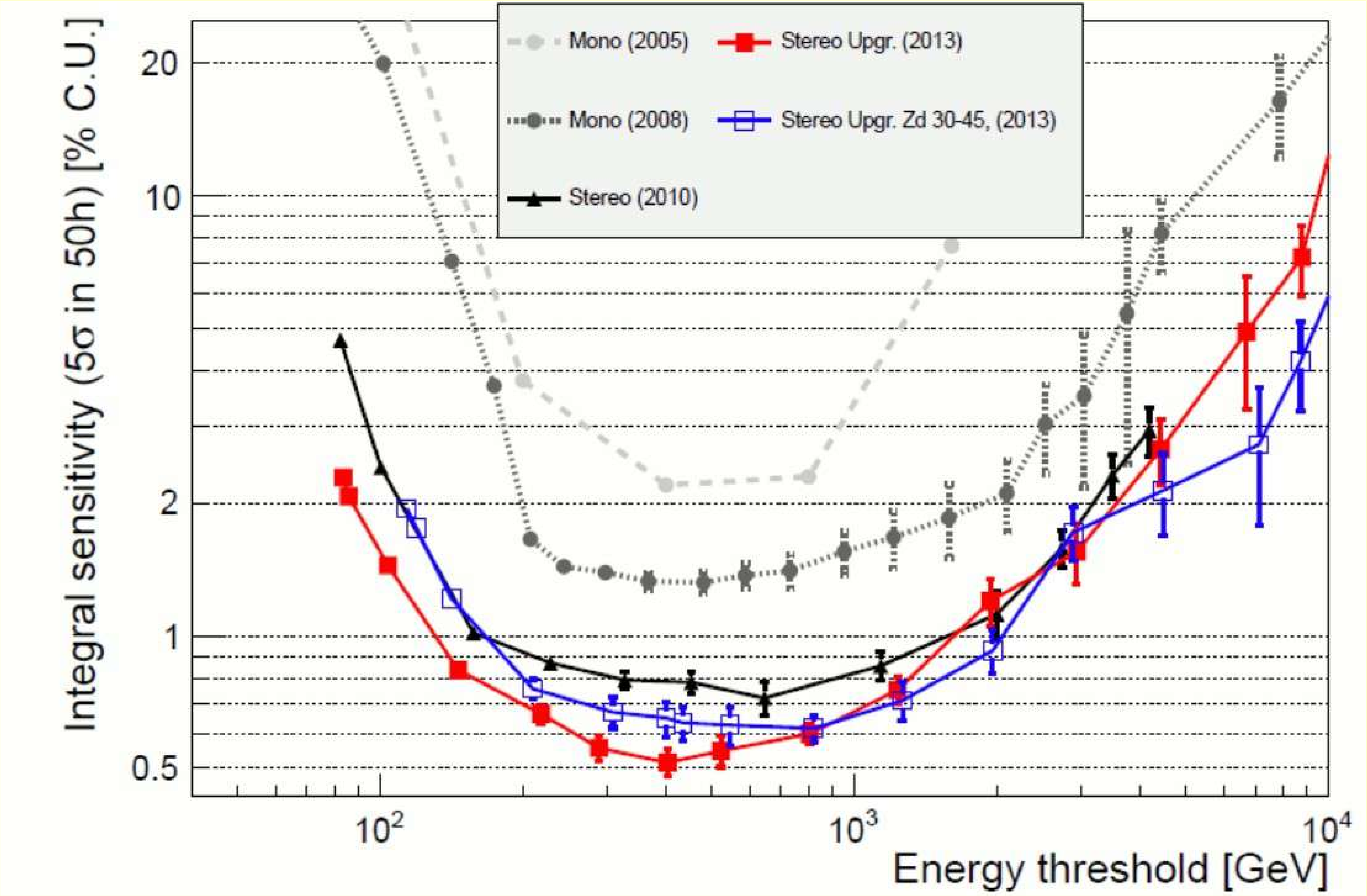

4


4


3

>170 collaboration members

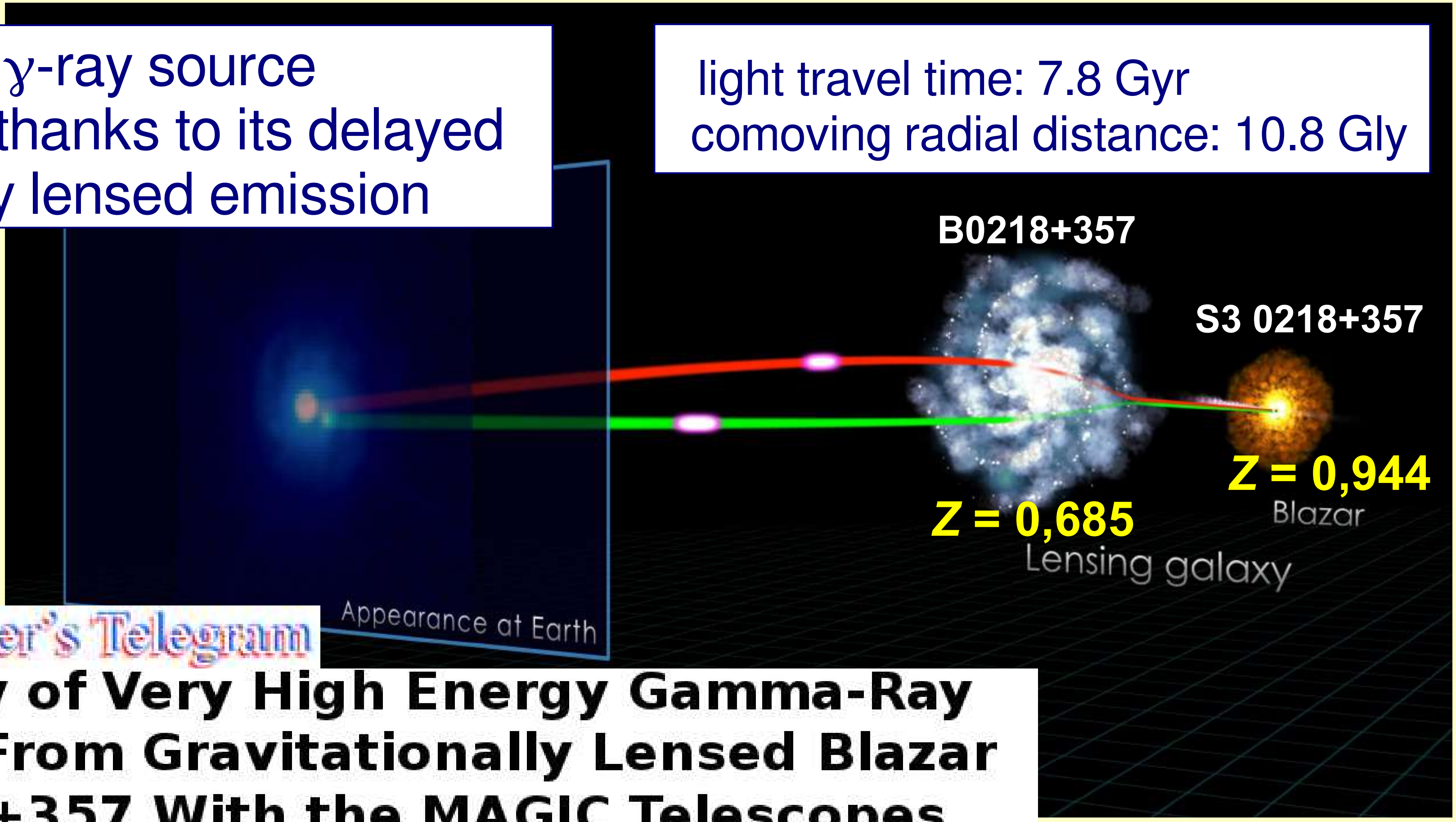
MAGIC:
“The best sensitivity in the world”



MAGIC:
A discovery example: S3 0218+35

farthest VHE γ-ray source
seen in VHE thanks to its delayed
gravitationally lensed emission

light travel time: 7.8 Gyr
comoving radial distance: 10.8 Gly



The Astronomer's Telegram

Discovery of Very High Energy Gamma-Ray Emission From Gravitationally Lensed Blazar S3 0218+357 With the MAGIC Telescopes

ATel #6349; ***Razmik Mirzoyan (Max-Planck-Institute for Physics) On Behalf of the MAGIC Collaboration***
*on **28 Jul 2014; 14:20 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

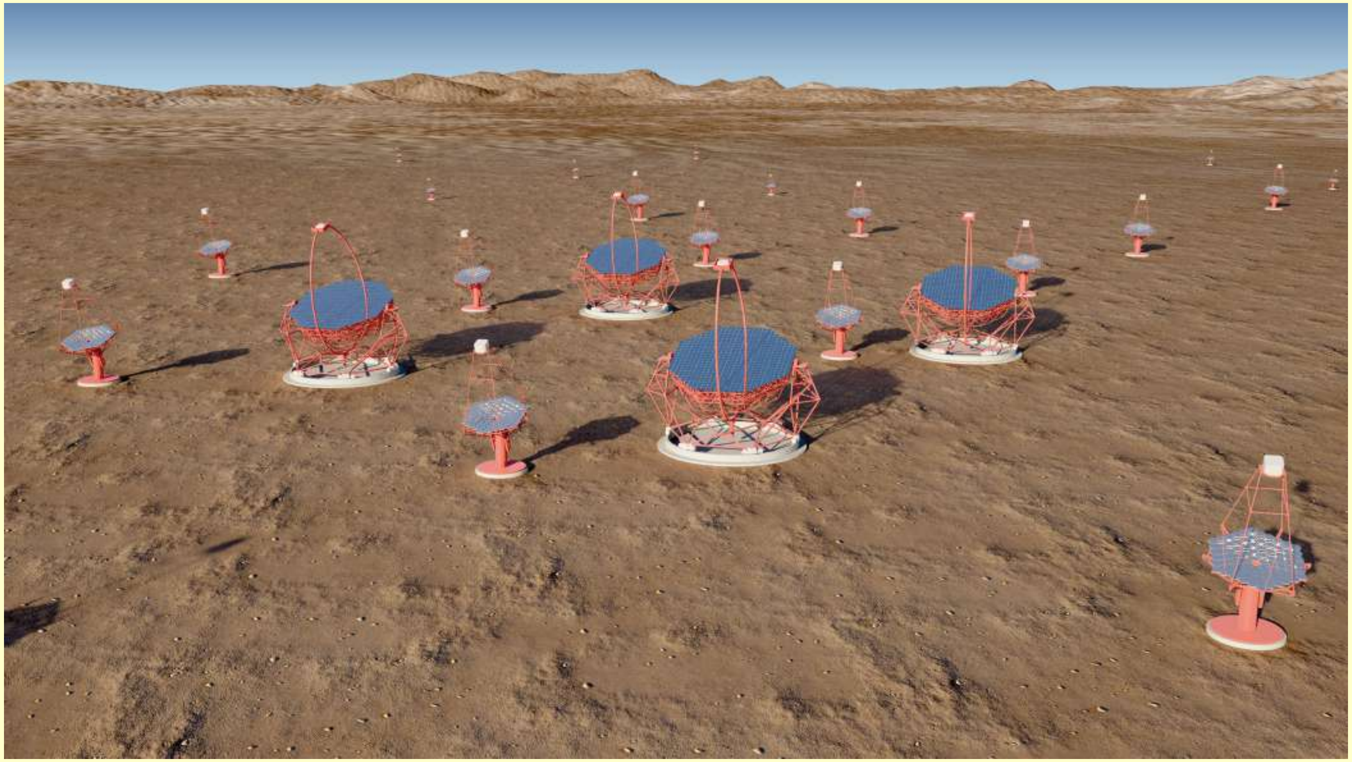
Subjects: Gamma Ray, >GeV, TeV, VHE, UHE, AGN, Blazar, Cosmic Rays, Microlensing Event

CTA

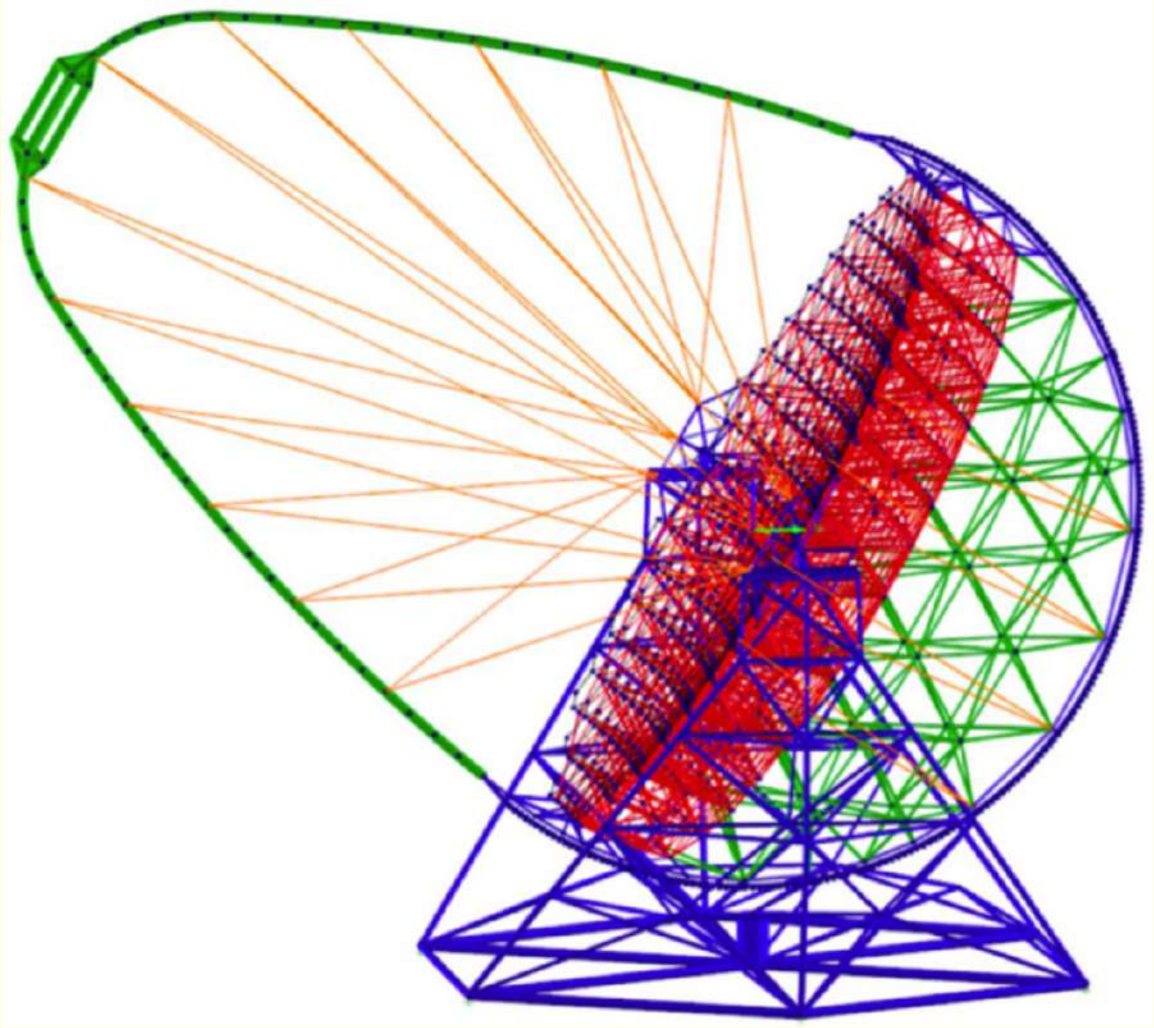
CTA:
Cherenkov Telescope Array

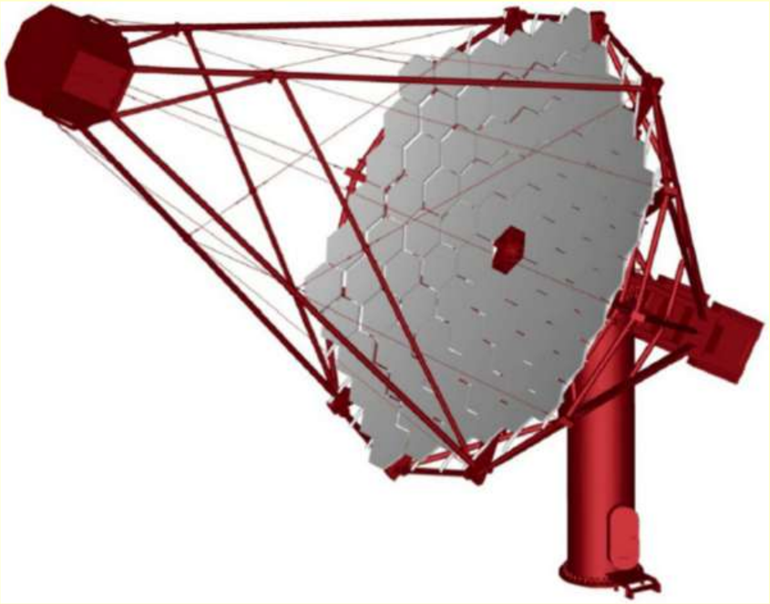
the Cherenkov Telescope Array[1] is a new observatory
for *very high-energy* (VHE[2]) **gamma rays**

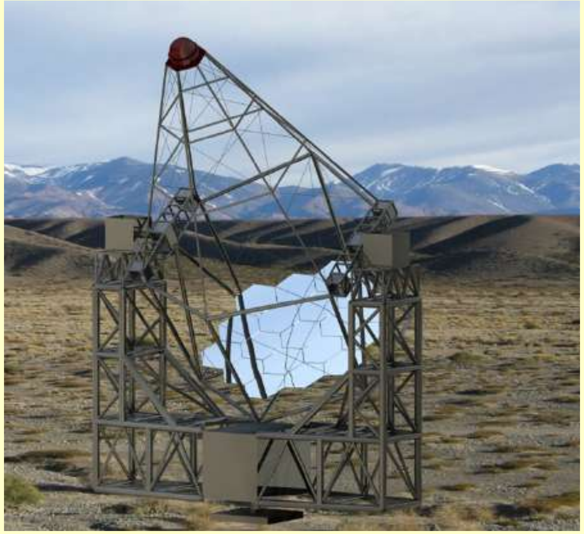
[1] 50–100 telescopes per site
[2] $E > 100$ GeV



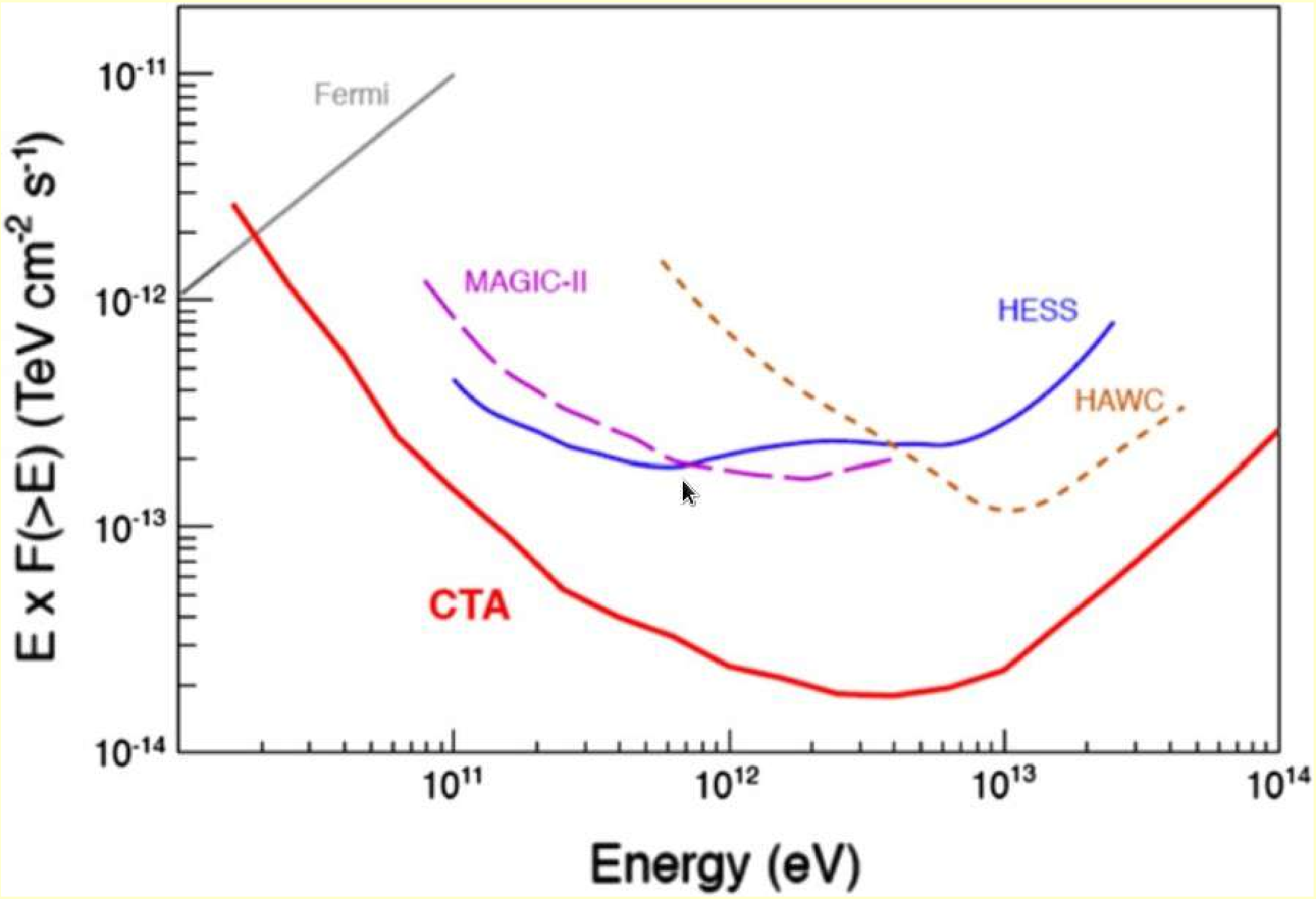
CTA:
LST, MST, SST



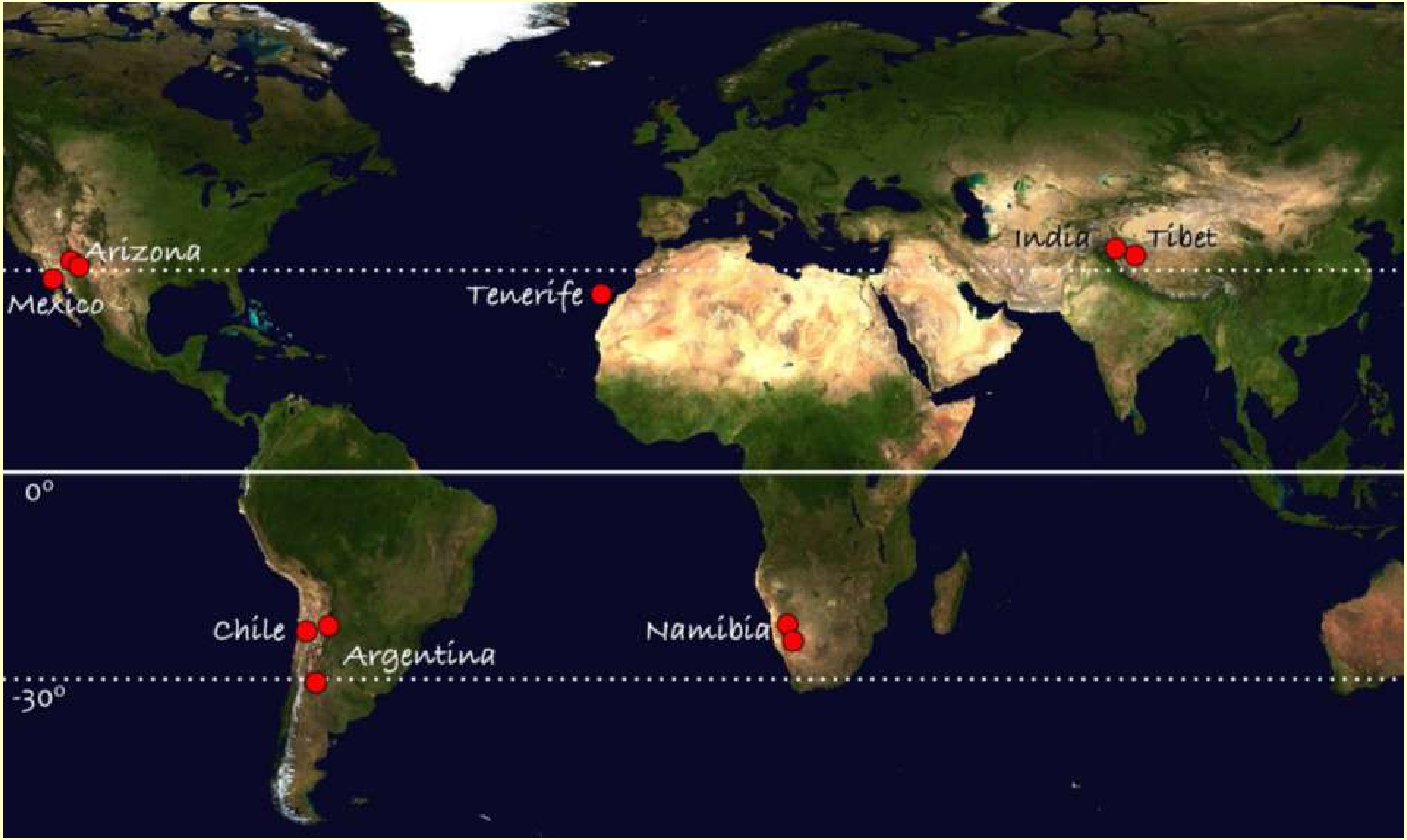




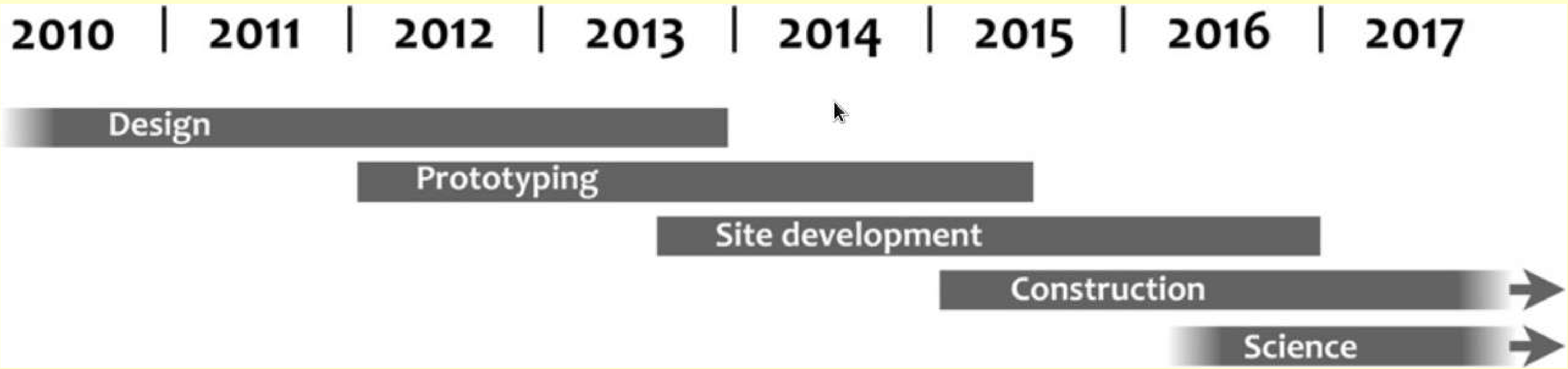
CTA:
Sensitivity



CTA:
Site selection in progress...



CTA:
Into the future...



Introducing the CTA concept
B.S. Acharya et al. (CTA Consortium), Astroparticle Physics **43** (2013) 3-18

Design concepts for the Cherenkov Telescope Array CTA:
an advanced facility for ground-based high-energy gamma-ray astronomy
M. Actis et al. (the CTA Consortium), Experimental Astronomy **32**, 3 (2011) 193-316