Time-domain astronomy

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Rough outline

Day 1: Intro

How are gamma rays produced? What do we learn from them?

Day 2: Observations

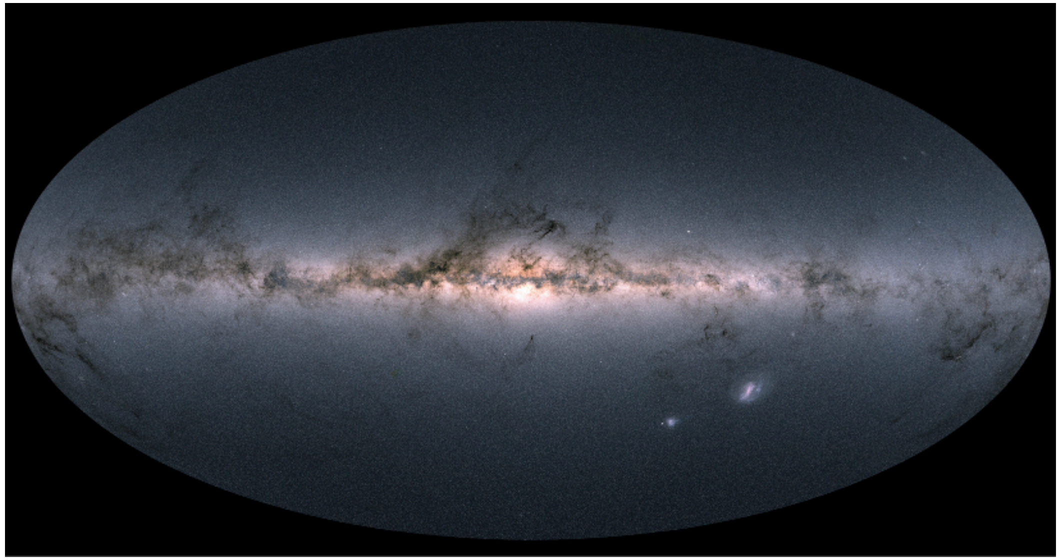
How do we detect gamma rays? How do we decide what/when to observe?

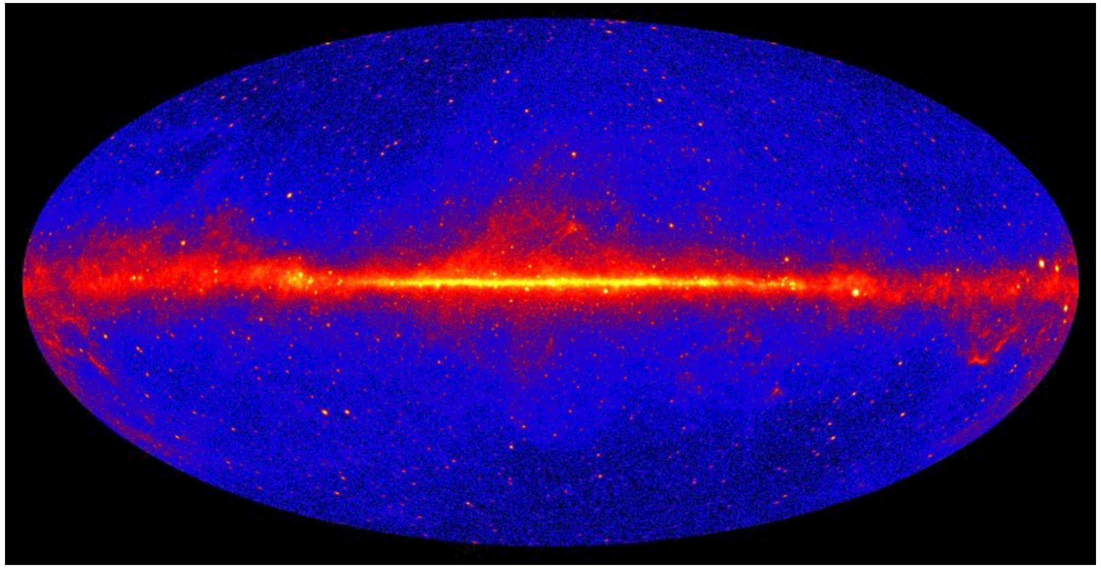
Day 3 + 4: Sources

What astronomical objects do we observe in the time domain?

Returning to the questions

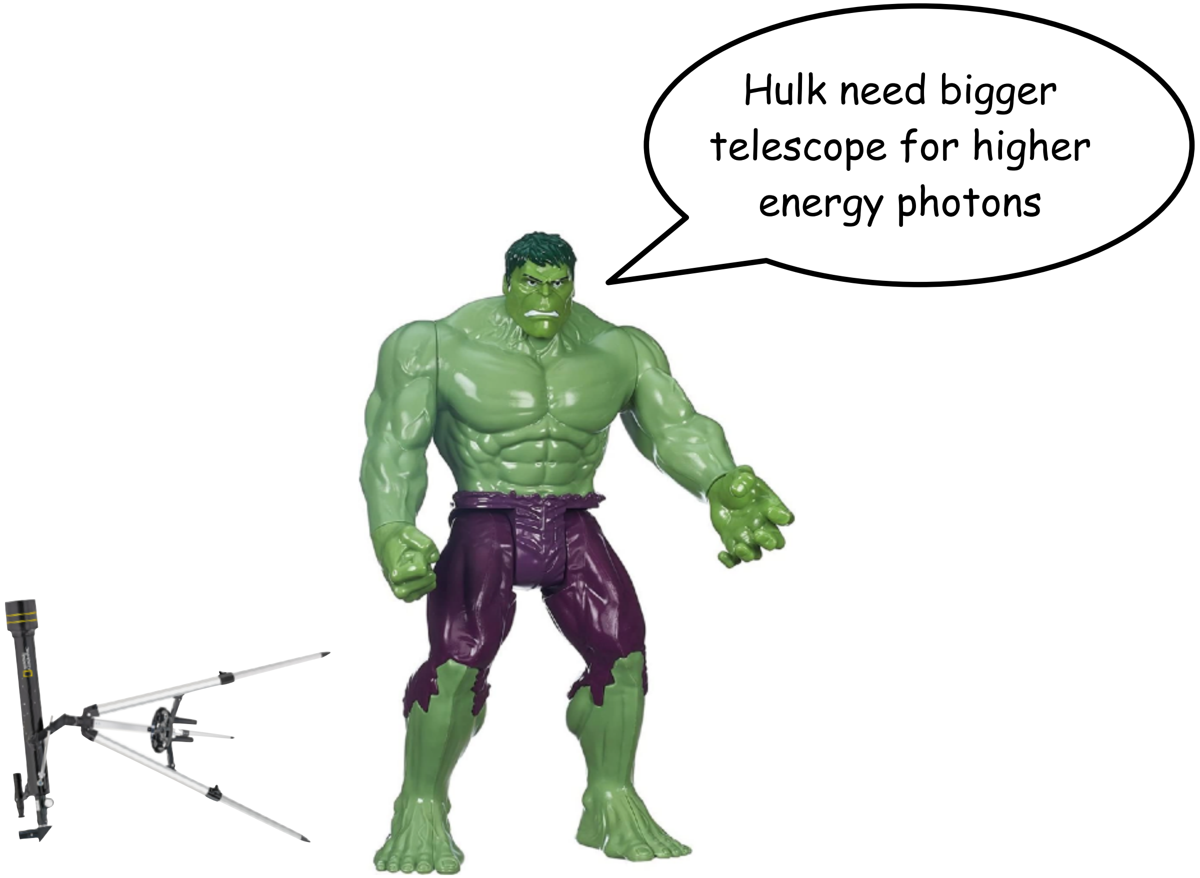
How do we start to find the answers?





Why are some sources bright over a wide energy range, while others are only bright in a narrow range?
How are the photons being produced by these sources?
Are there sources that don't show up on these maps?
How do we detect these sources in the first place?

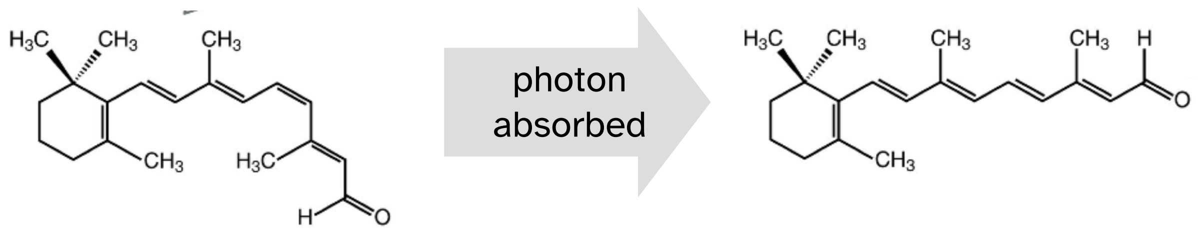
Part 2. How do we detect gamma rays?



How do our eyes detect photons?

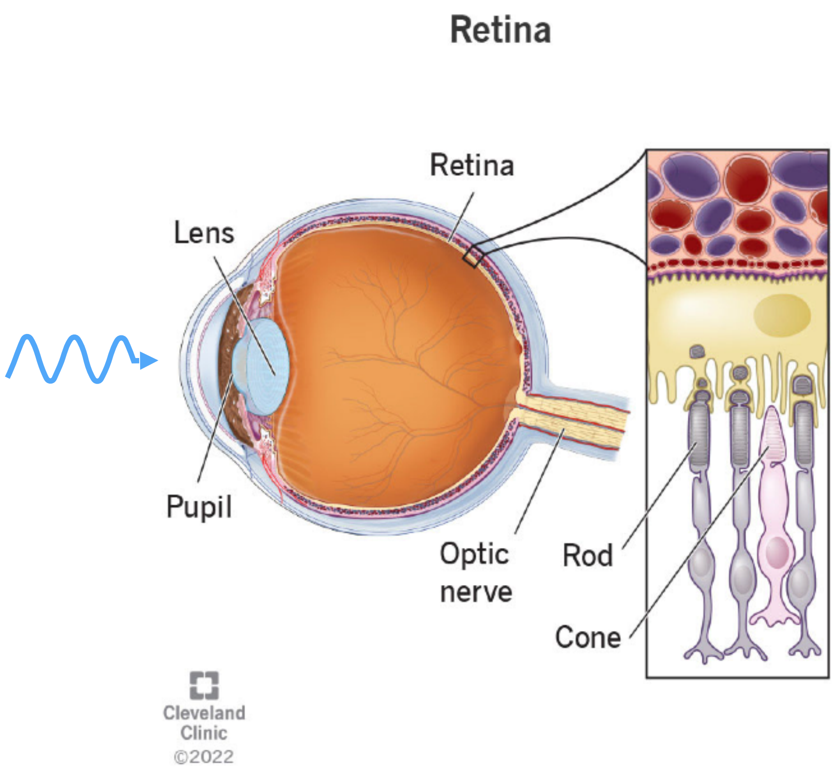
photons -> electric signals

The back of the human eye has photoreceptors that directly **absorb photons** at optical/visible wavelengths and convert them into electric signals



(a) 11-*cis*-retinal (b) all-*trans*-retinal

[Anatomy & Physiology, Connexions]

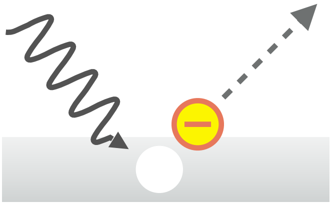


How do we do this for gamma rays?

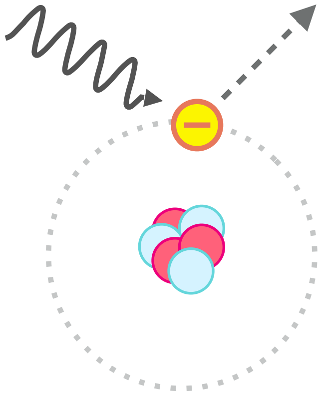
How gamma rays interact with matter

photons -> electric signals

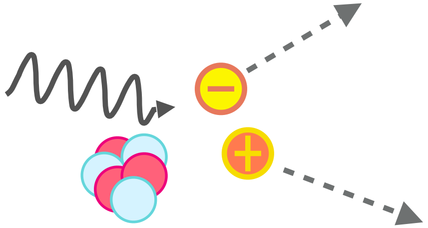
Gamma rays are hard to measure directly, but *electrons* (and positrons) are easy



photoelectric effect



Compton scattering

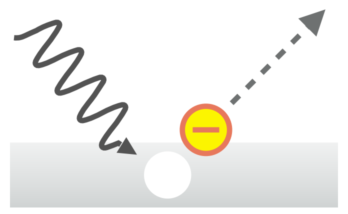


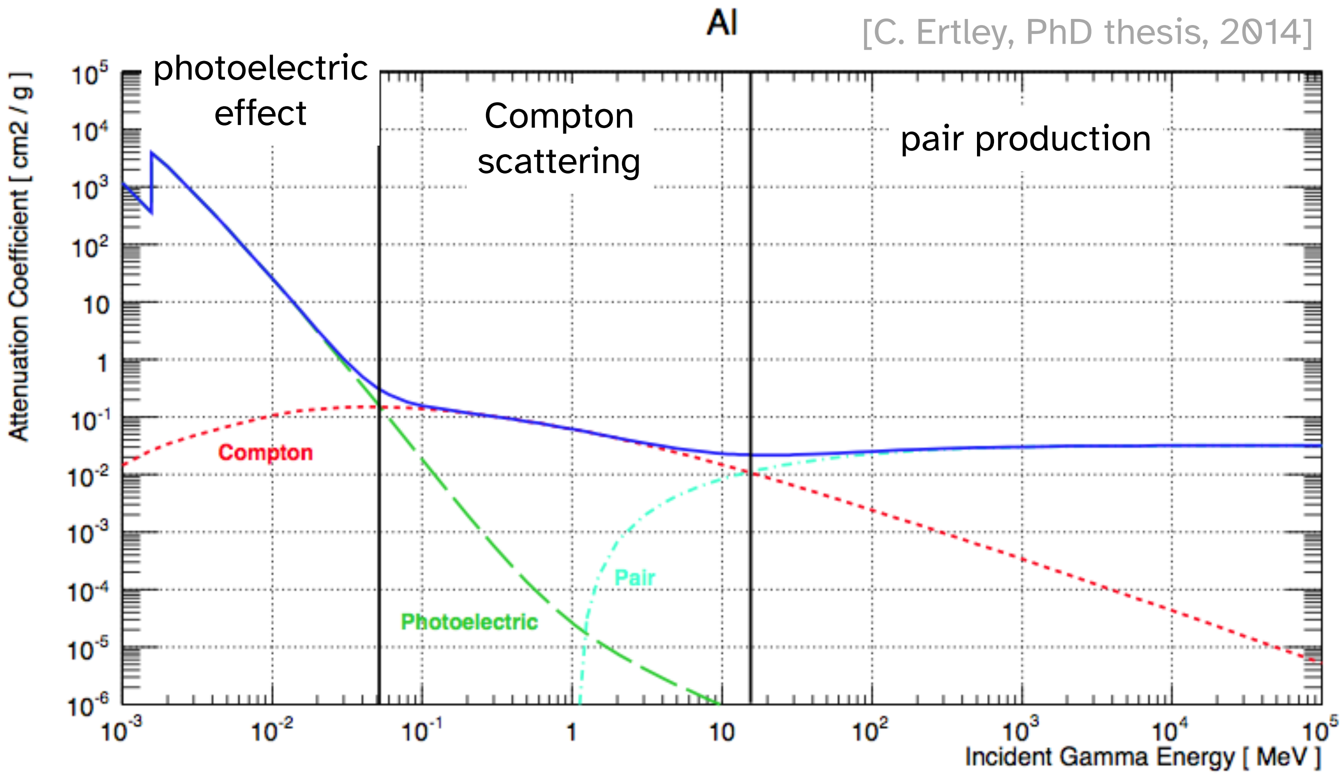
pair production

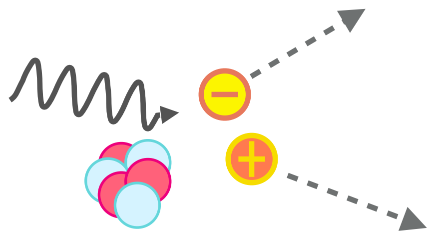
How gamma rays interact with matter

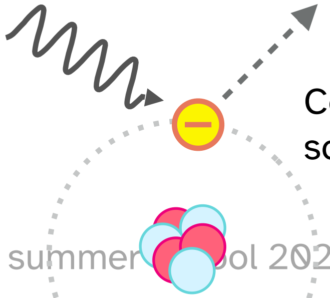
photons -> electric signals

Note: The exact shapes of these curves depend on the target material









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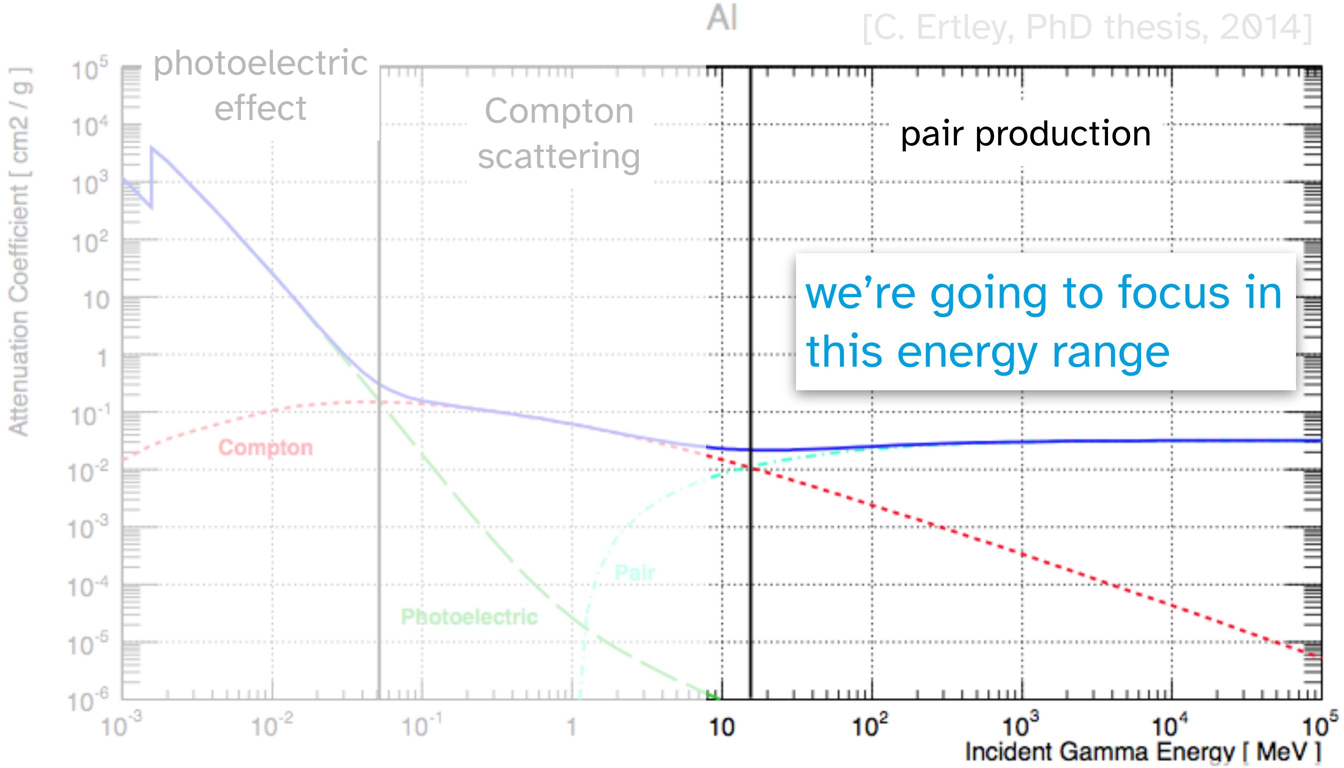
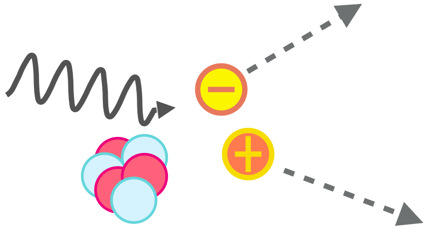
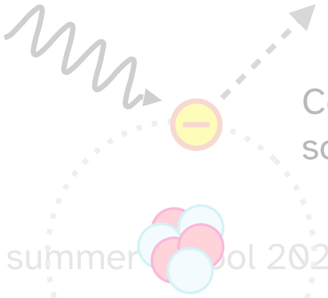
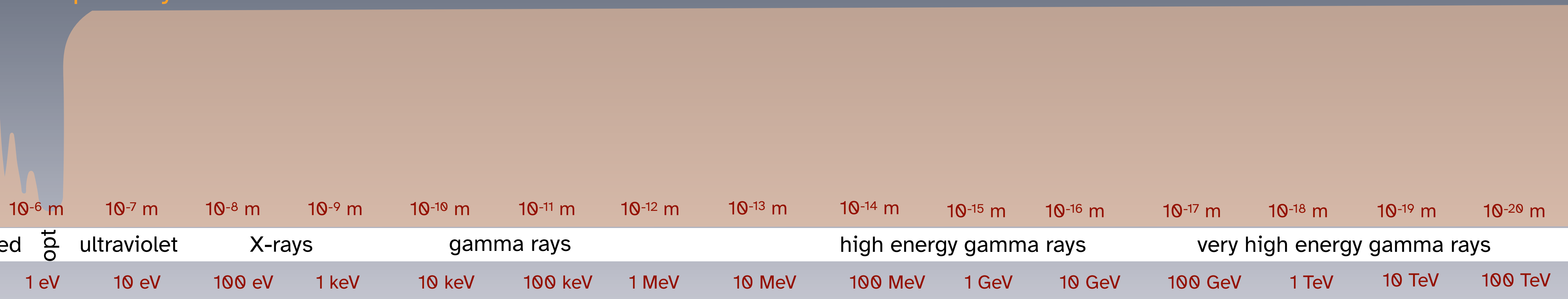






The electromagnetic spectrum, continued

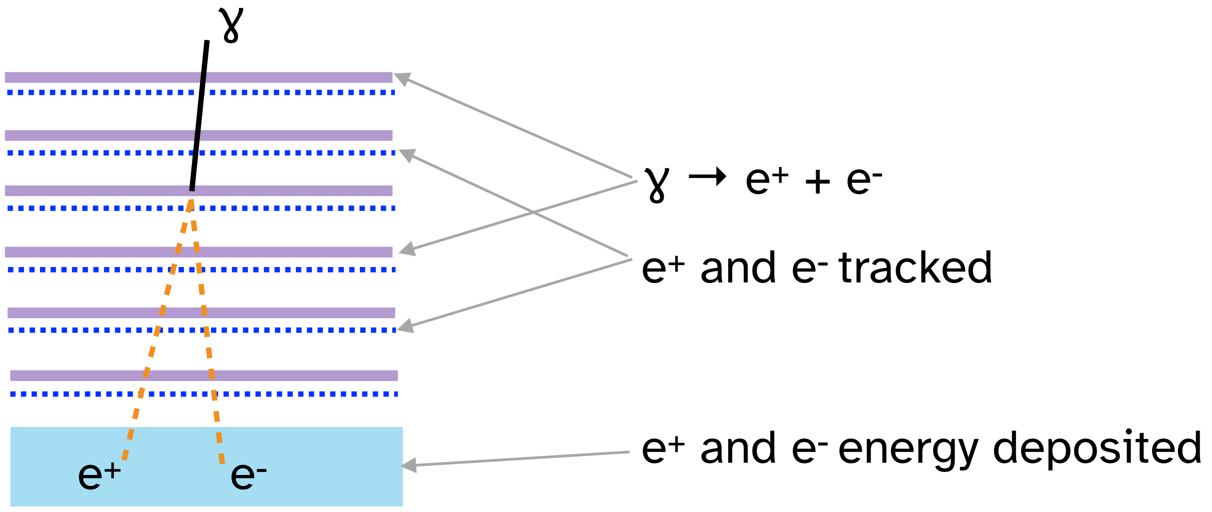
The atmosphere is opaque to gamma rays,
so let's go to space first

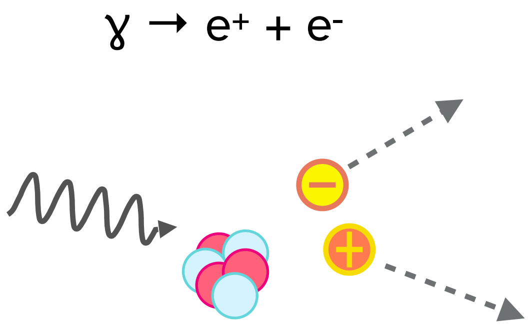


How gamma rays interact with matter: pair production

Pair-conversion telescopes

Gamma rays are hard to measure directly, but *electrons* (and positrons) are easy





In pair-conversion telescopes, the gamma rays are converted into electron-positron pairs, whose trajectories are tracked and energies are measured

How gamma rays interact with matter: pair production

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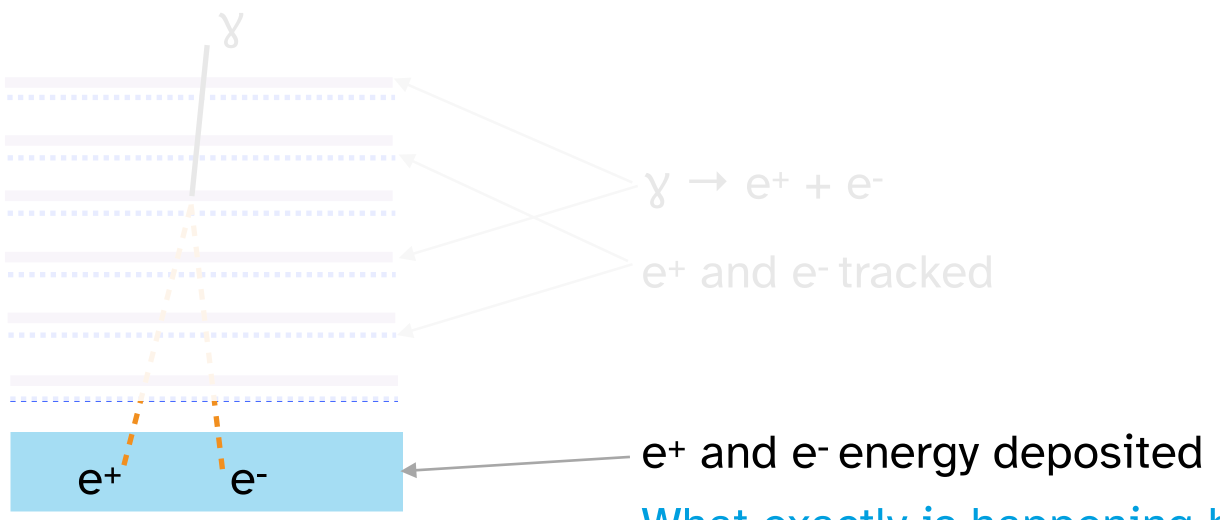

What exactly is happening here?

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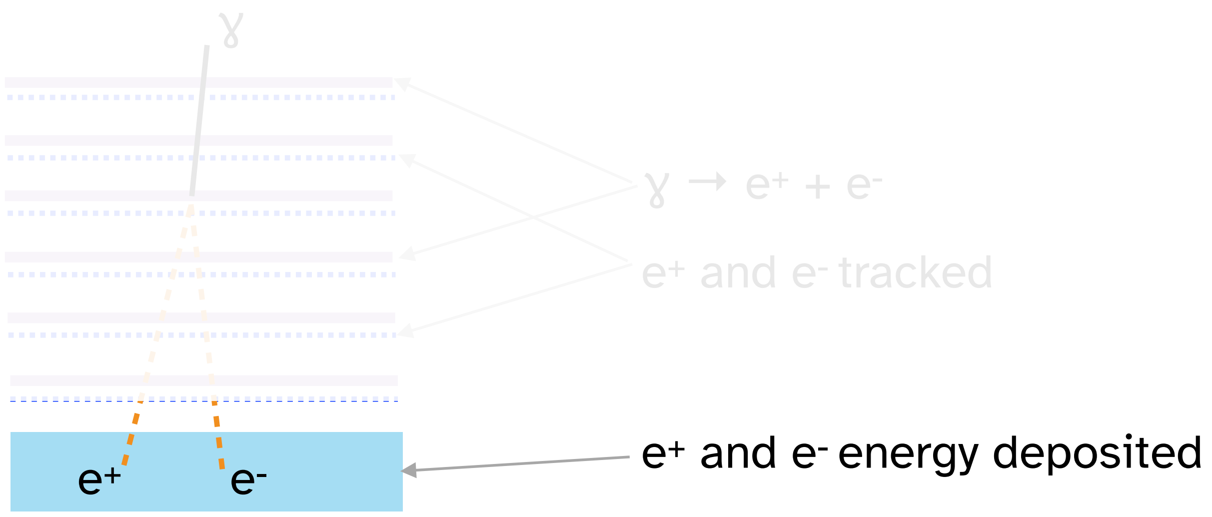
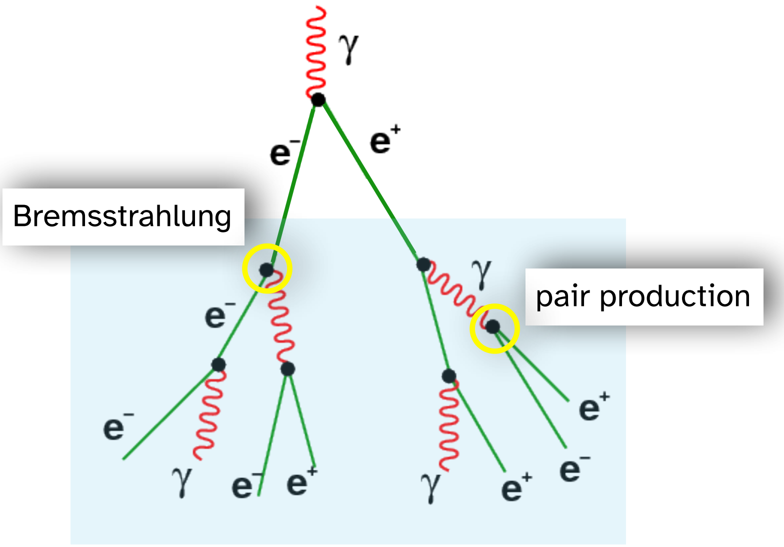


electromagnetic shower



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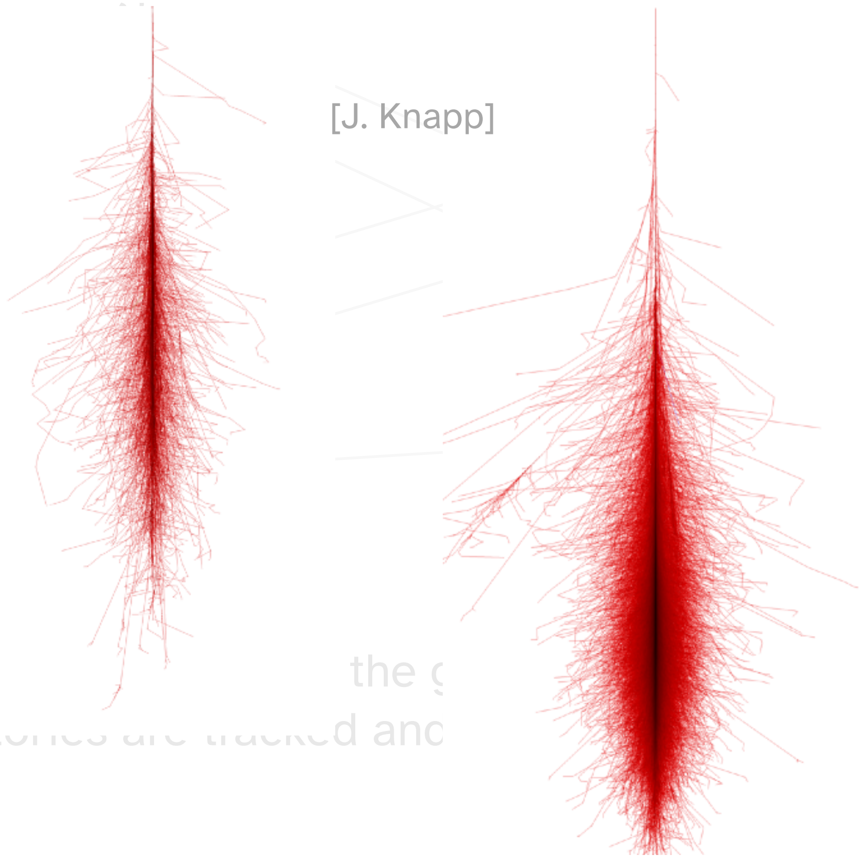
lower energy ɣ higher energy ɣ

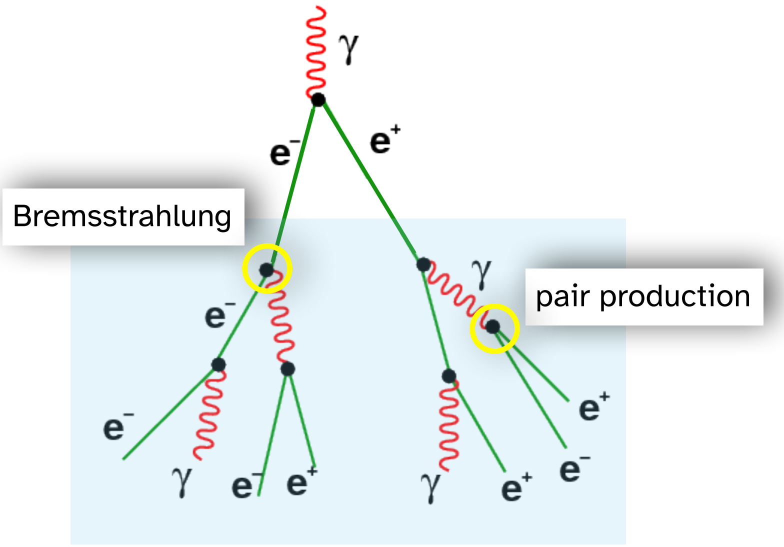


[J. Knapp]

d

/ deposited

electromagnetic shower



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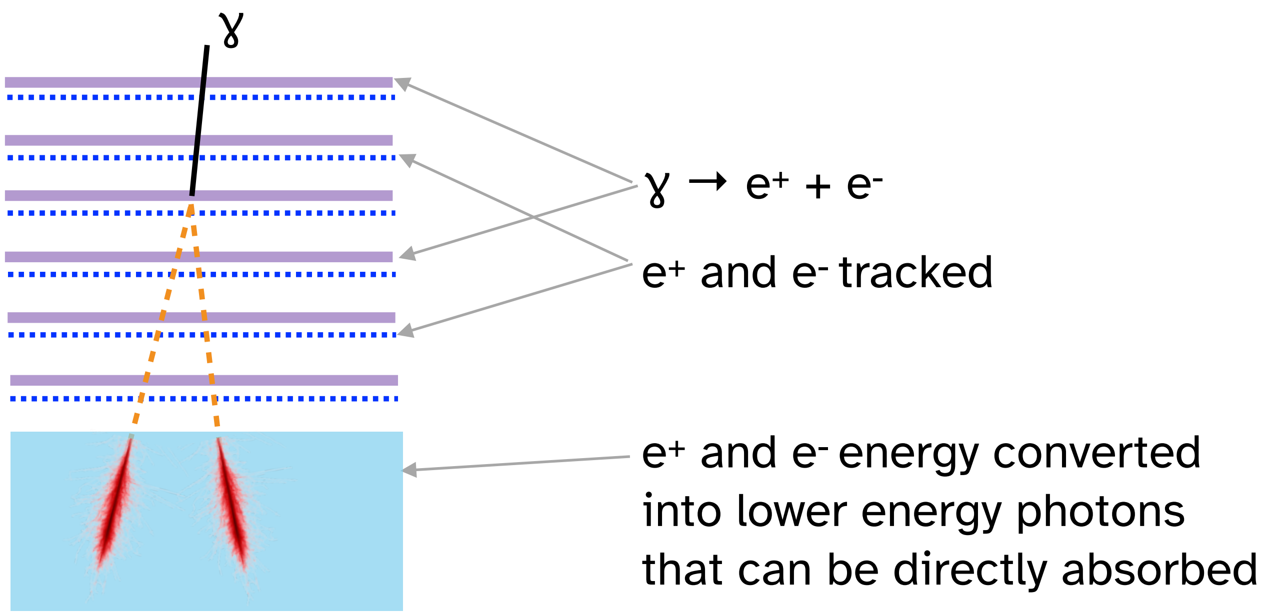

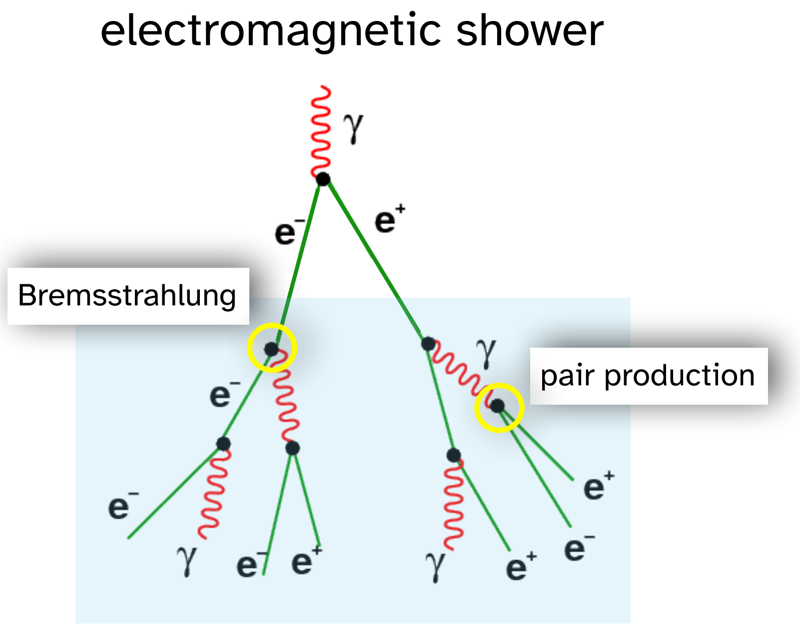

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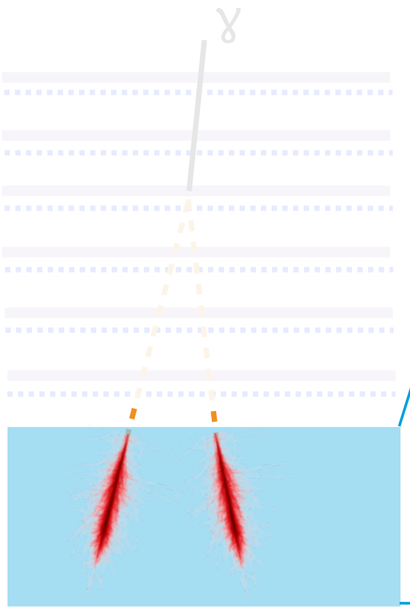
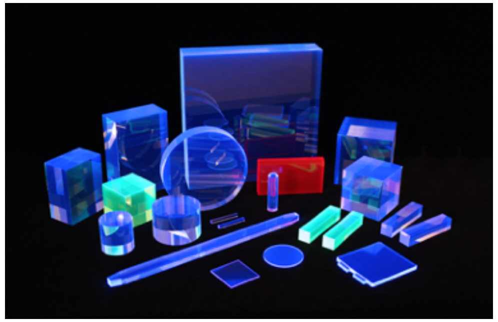
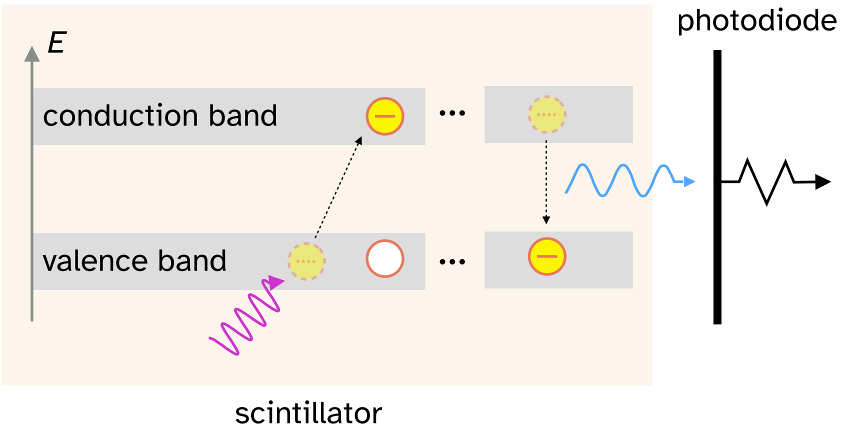


Scintillators absorb higher energy photons or charged particles, then reemit the energy in lower energy (UV, optical) photons



[Eljen Technology]



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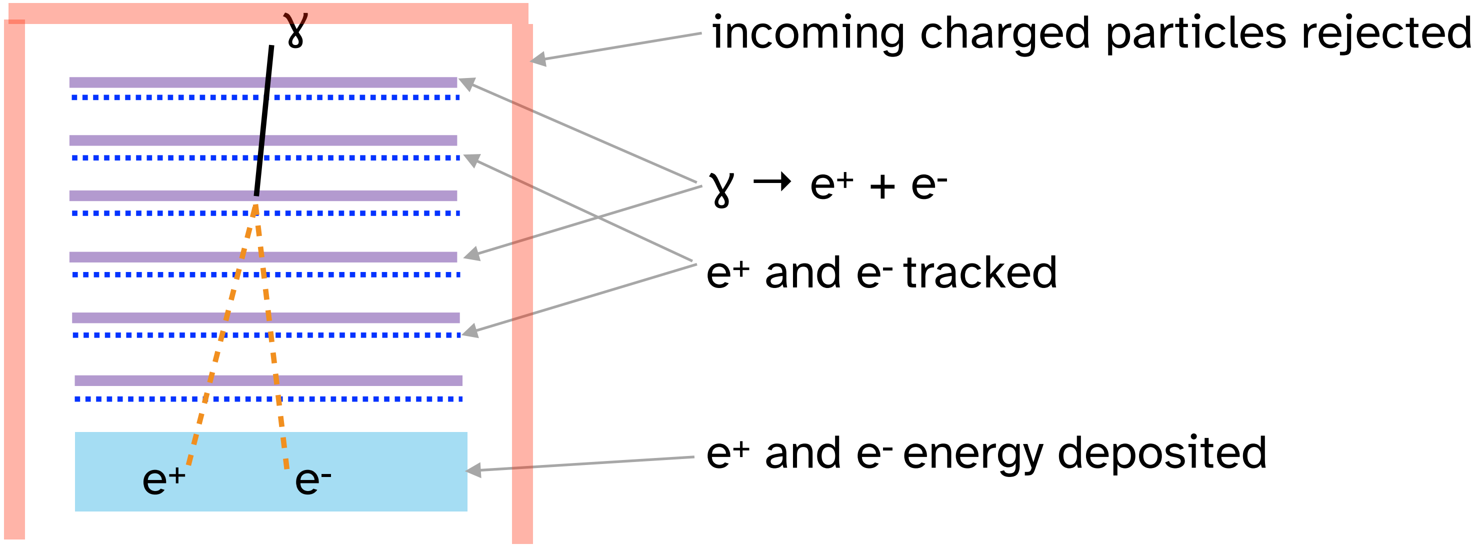

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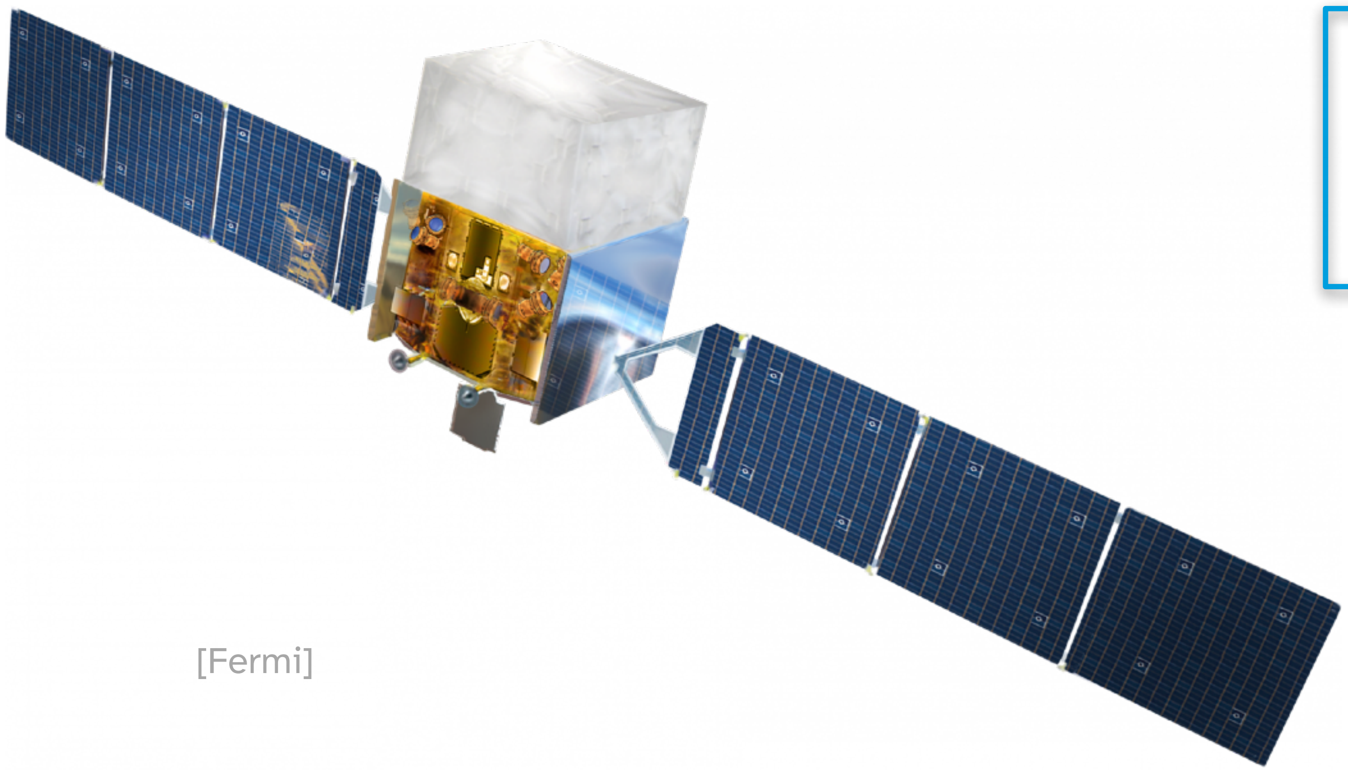

[Fermi]

[NASA/DOE/Fermi-LAT]

Fermi Large Area Telescope

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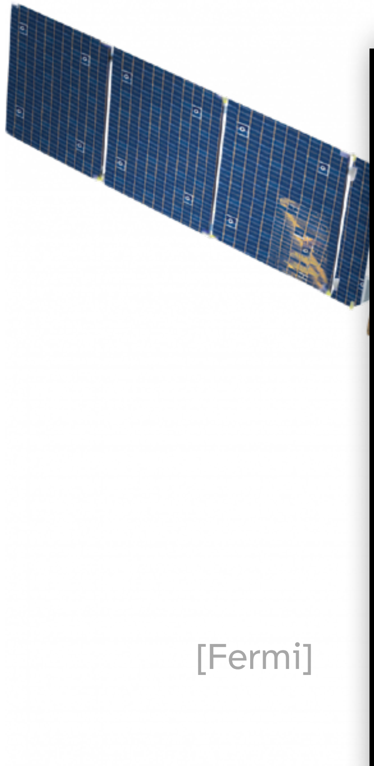

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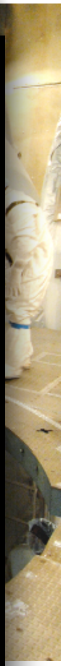
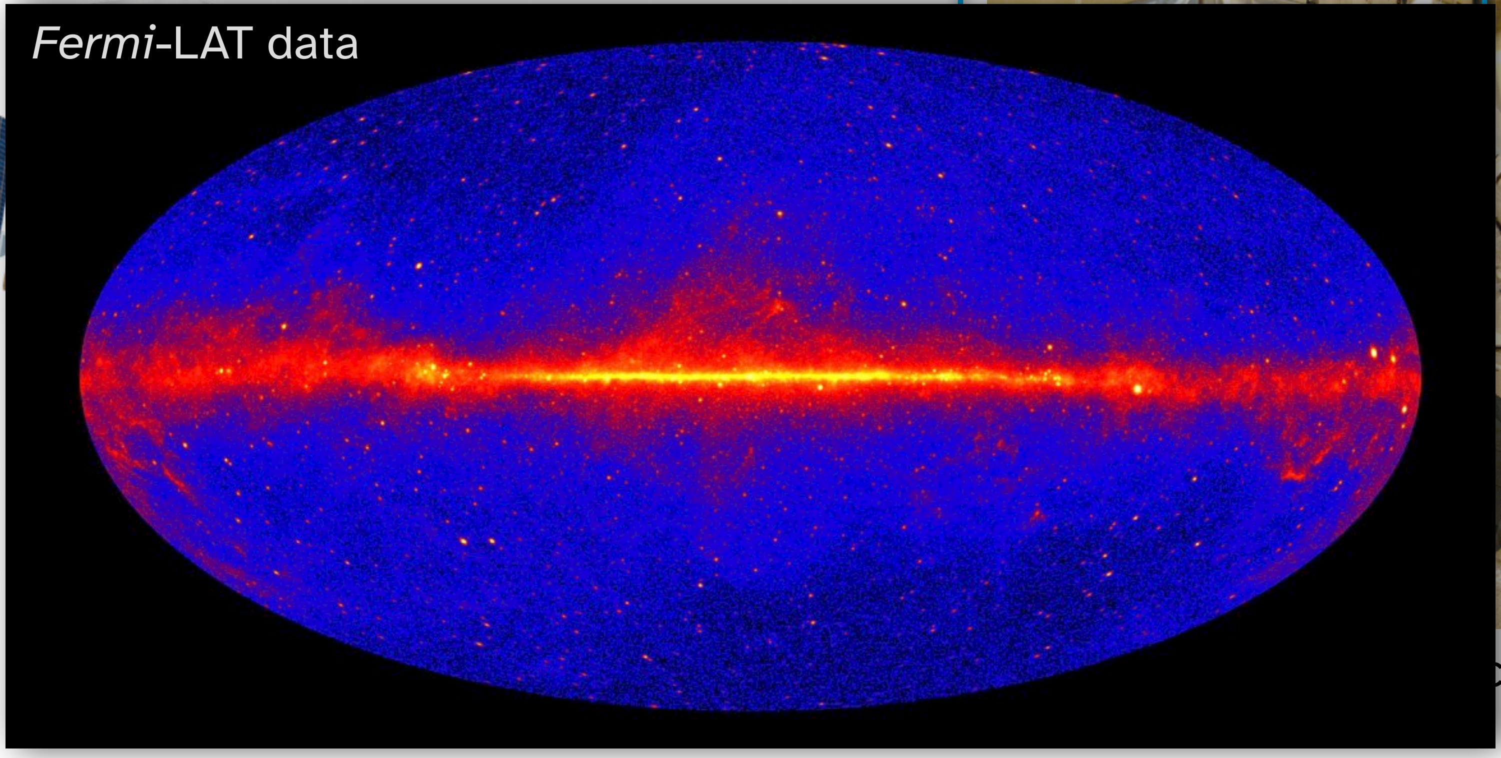


cope



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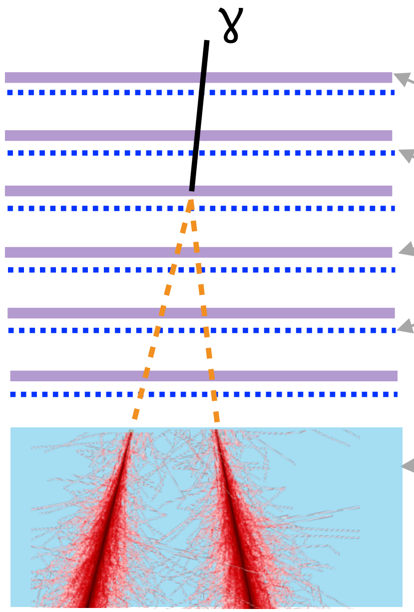
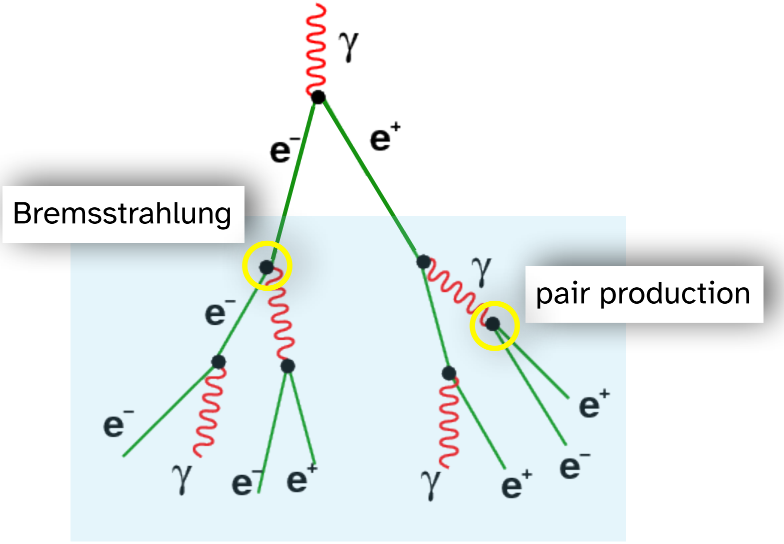


$\gamma \rightarrow e^+ + e^-$

e^+ and e^- tracked

e^+ and e^- energy converted into lower energy photons that can be directly absorbed

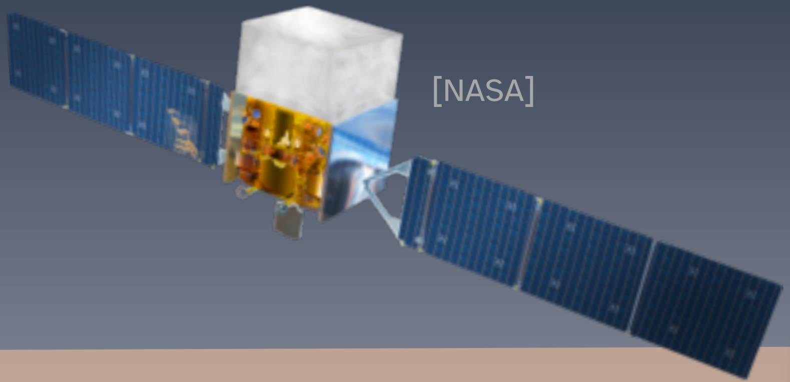
electromagnetic shower

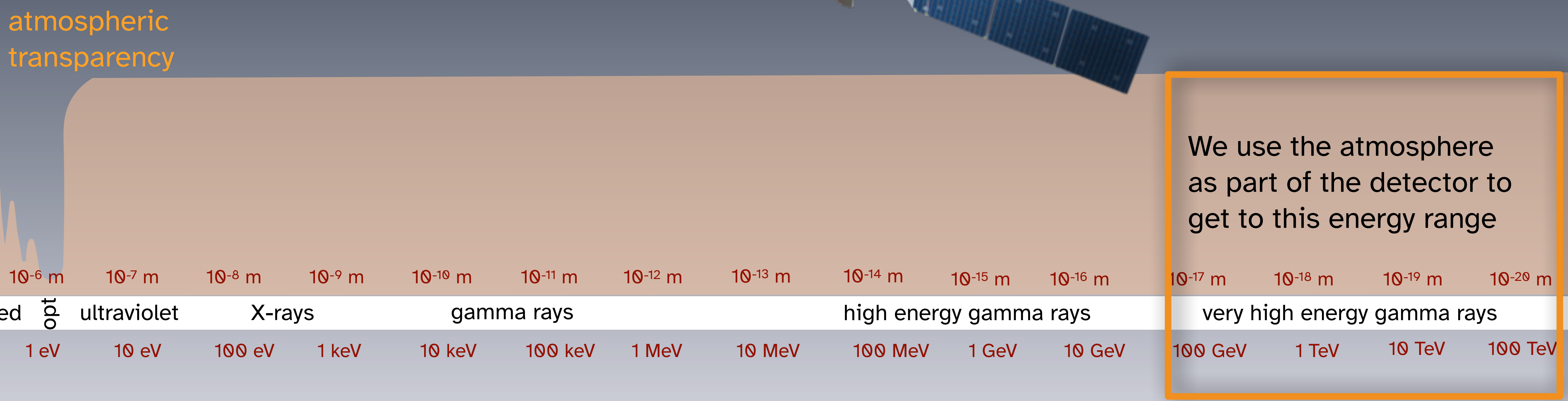


When the initial photon energy is too high, the shower can't be contained within the detector

-> space-based telescopes can't go above ~100s of GeV (plus the issue of collecting area)

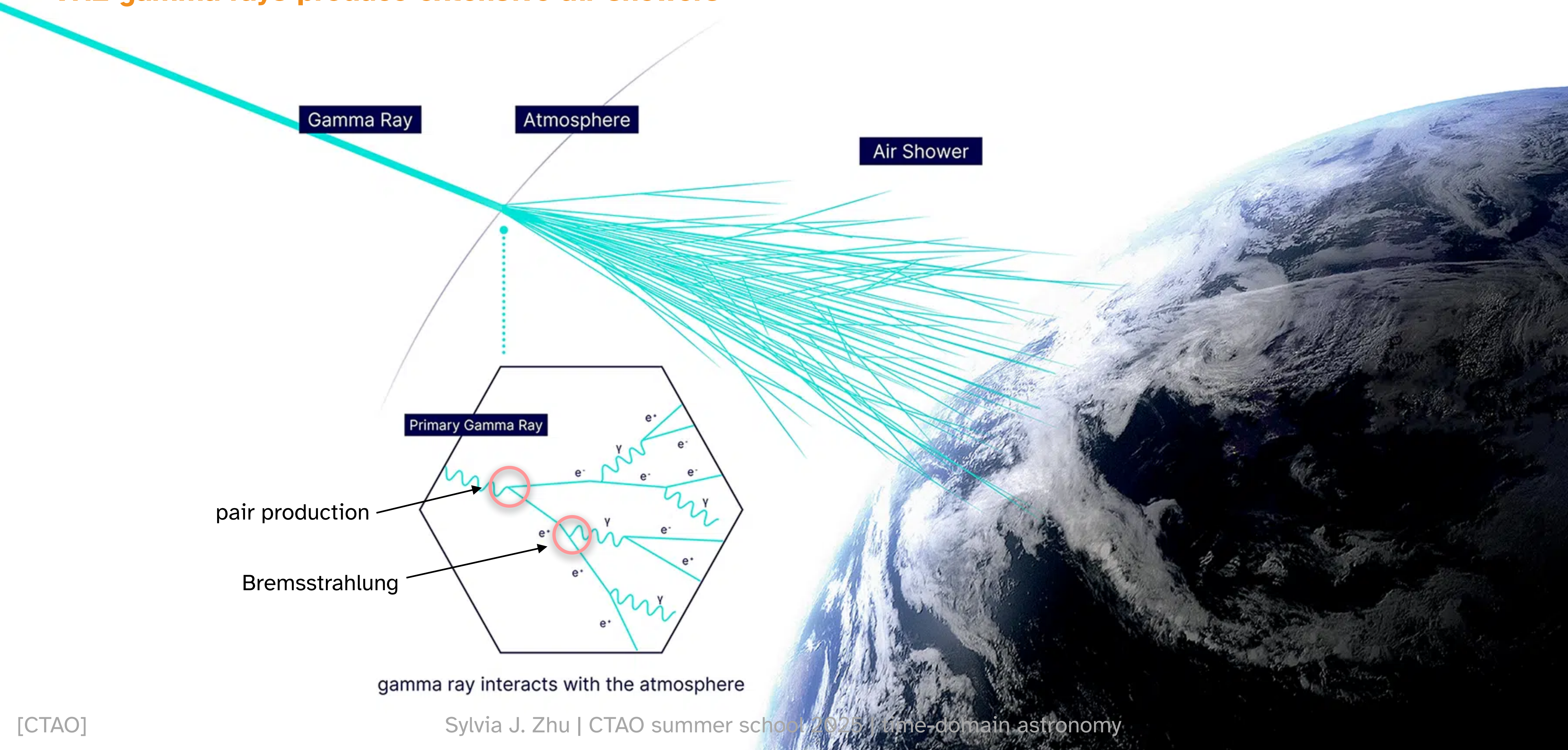
The electromagnetic spectrum, continued





Use the atmosphere as part of the detector

VHE gamma rays produce extensive air showers

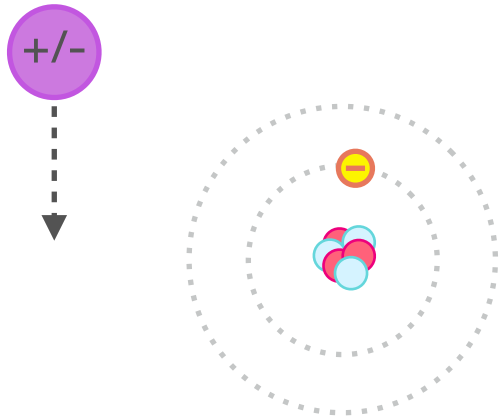


[CTAO]

Use the atmosphere as part of the detector

Particles in the air shower produce Cherenkov radiation

electromagnetic equivalent to a sonic boom



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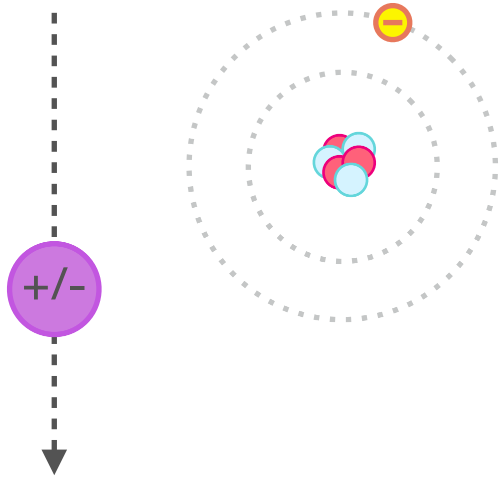

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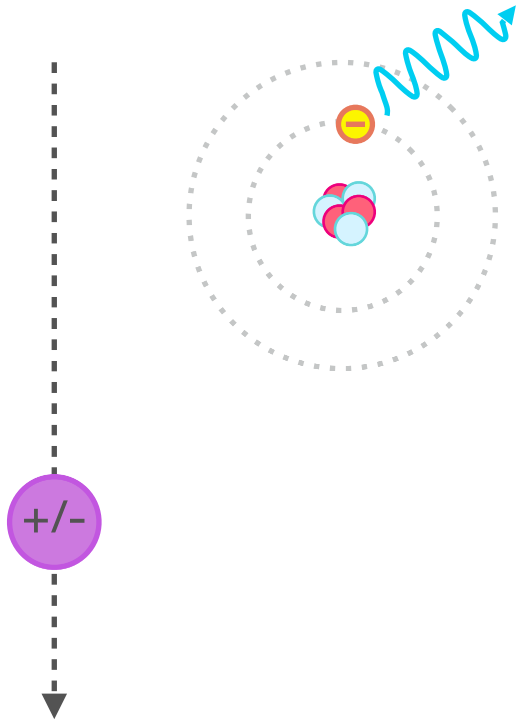

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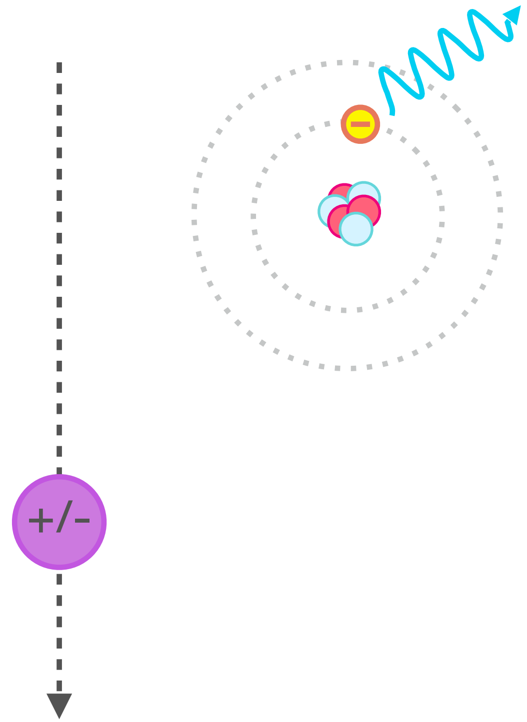
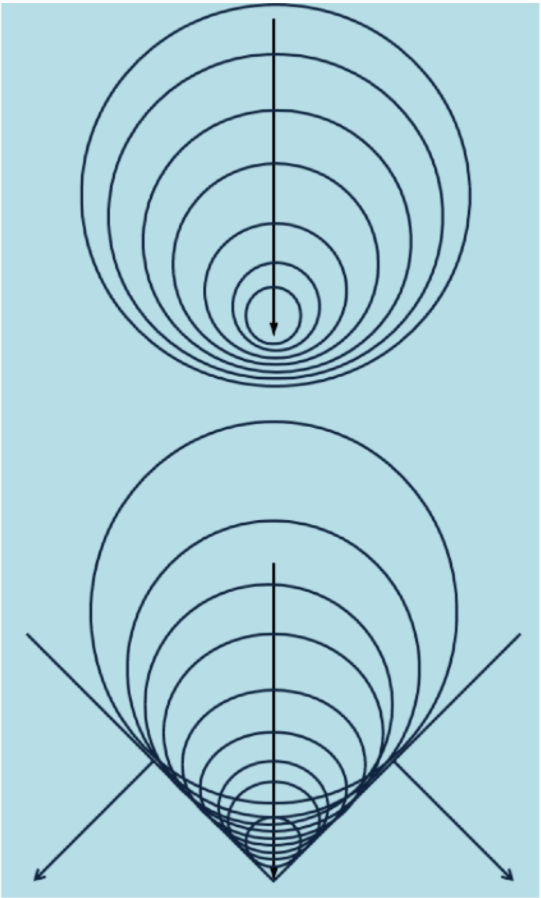


[J. Eckhard]

v < c/n:
no wavefront

v > c/n:
wavefront



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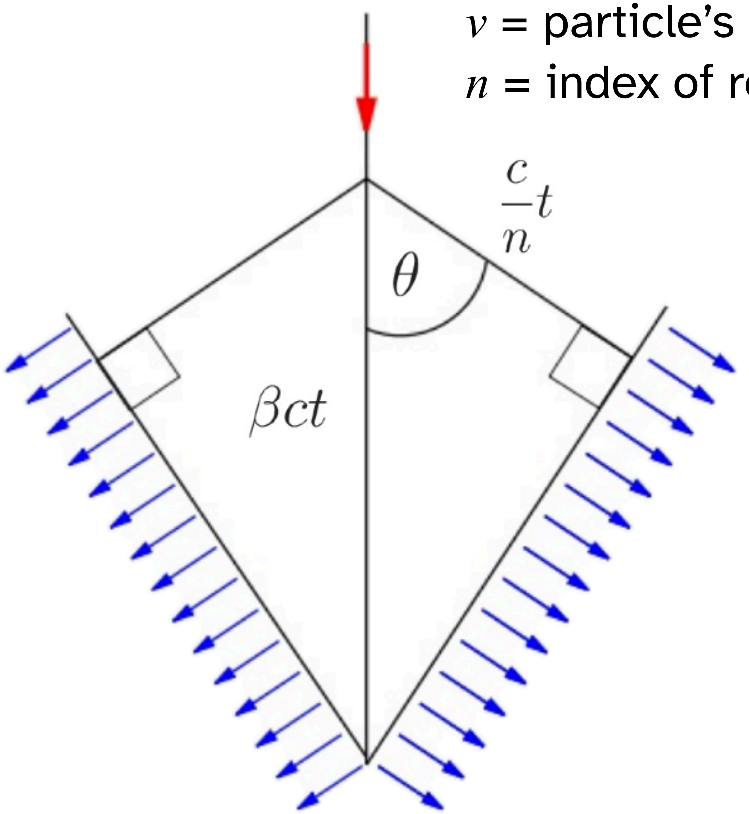


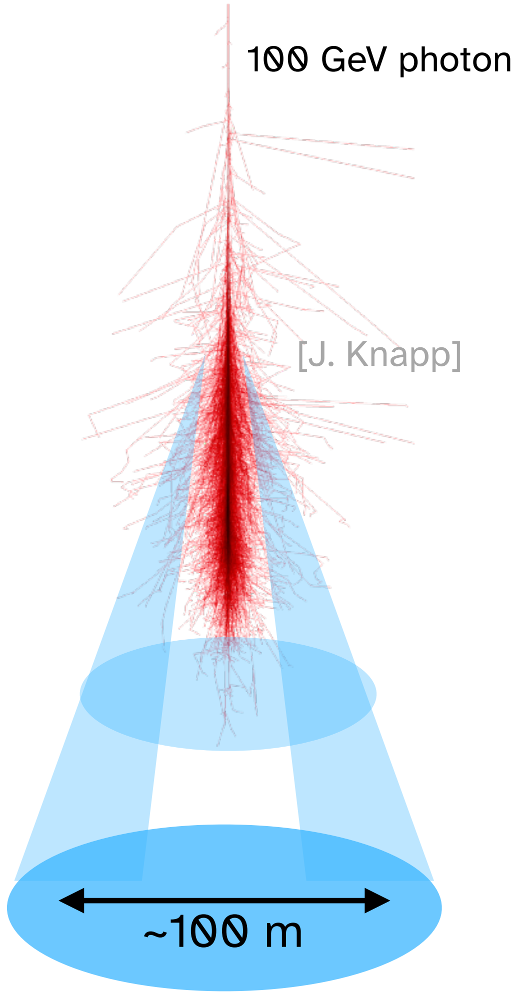
modified from [J. Eckhard]

v = particle's speed
n = index of refraction of air

$$\theta = \arccos \frac{1}{\beta n} \qquad \beta = \frac{v}{c}$$

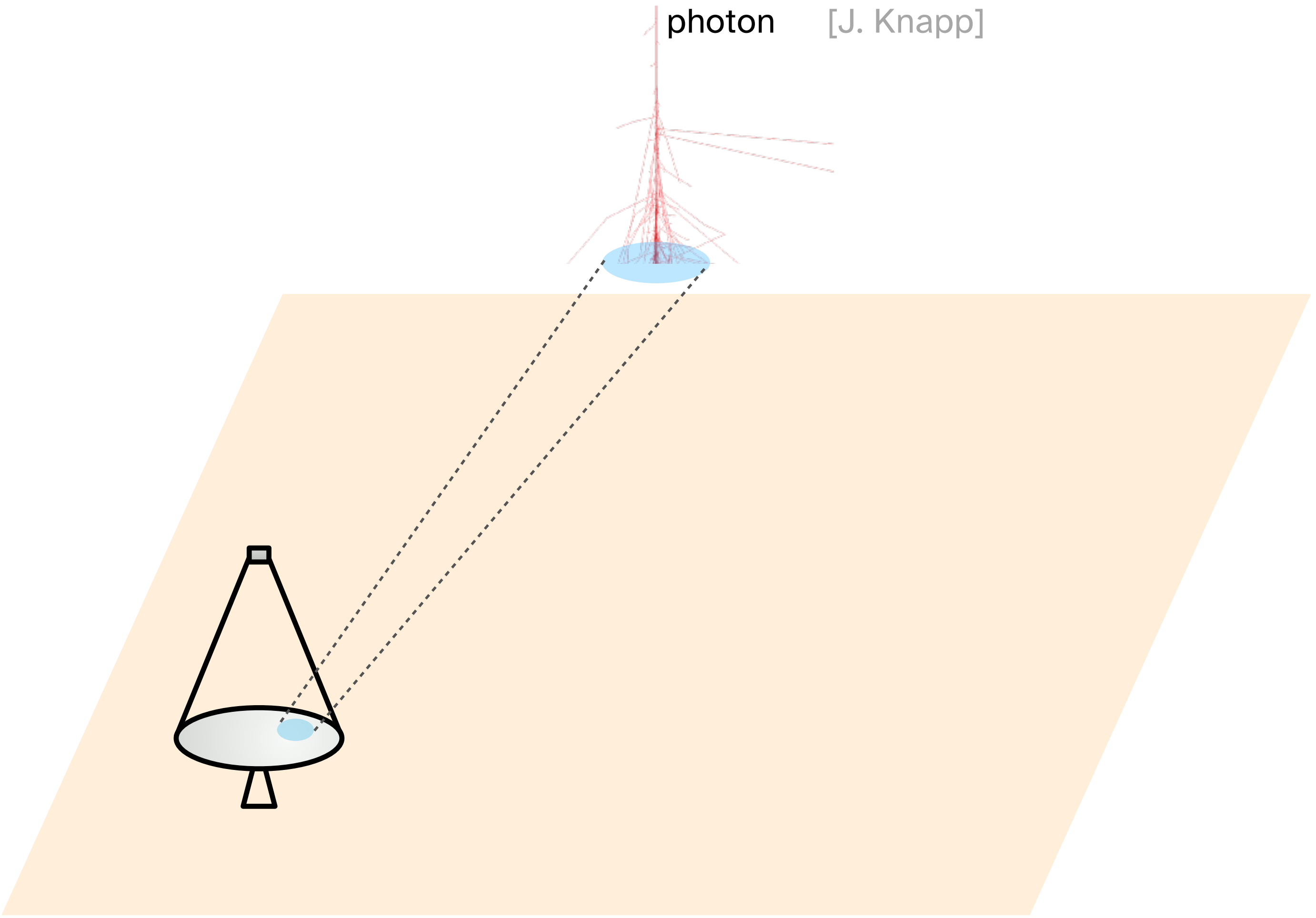
n ~ slightly larger than 1
β ~ 1
=> θ ~ 1°

if shower starts 10 km above ground,
Cherenkov light cone size will be ~100 m



Imaging Atmospheric Cherenkov Telescopes (IACTs)

Take a “snapshot” of the pool of Cherenkov light



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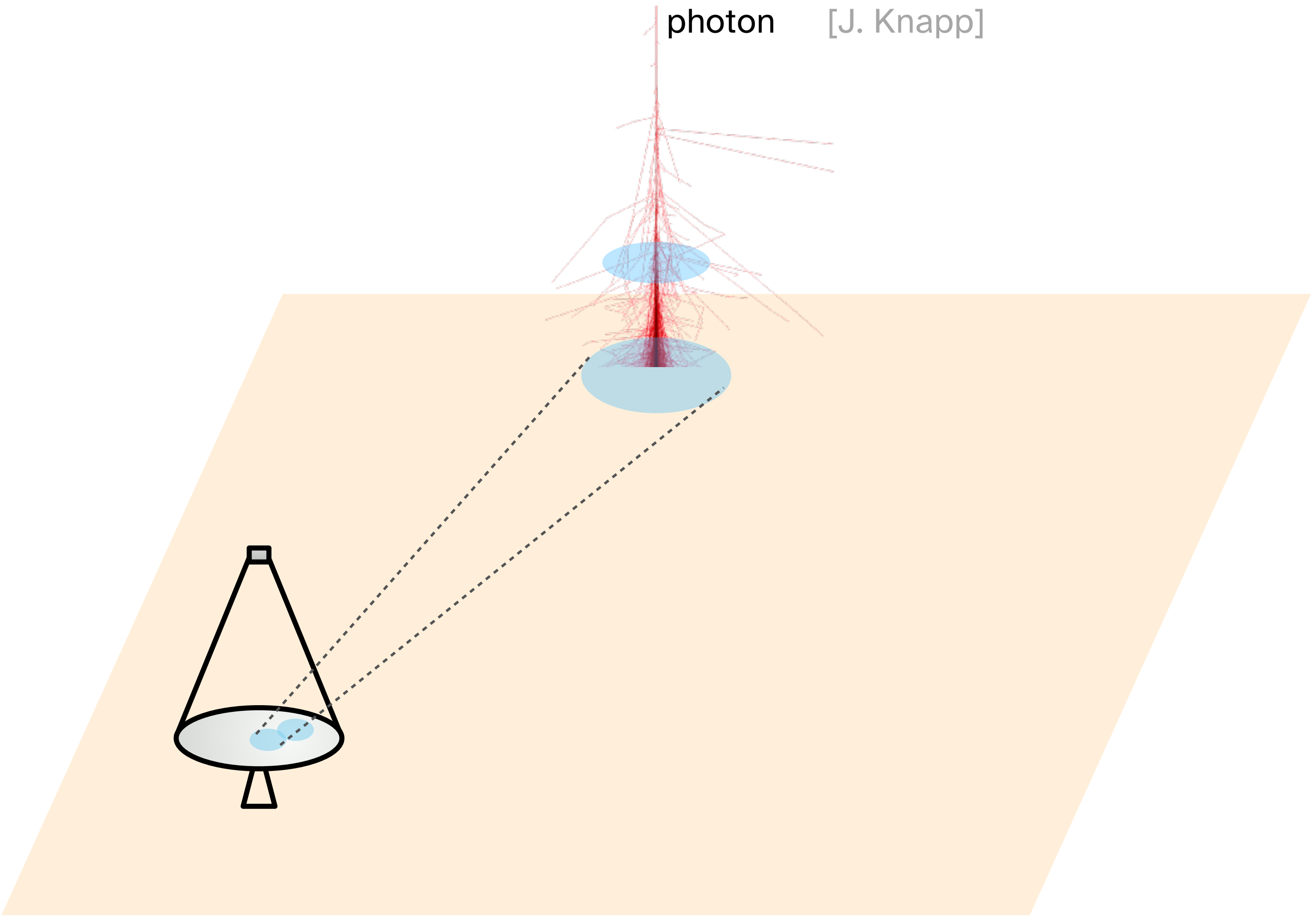

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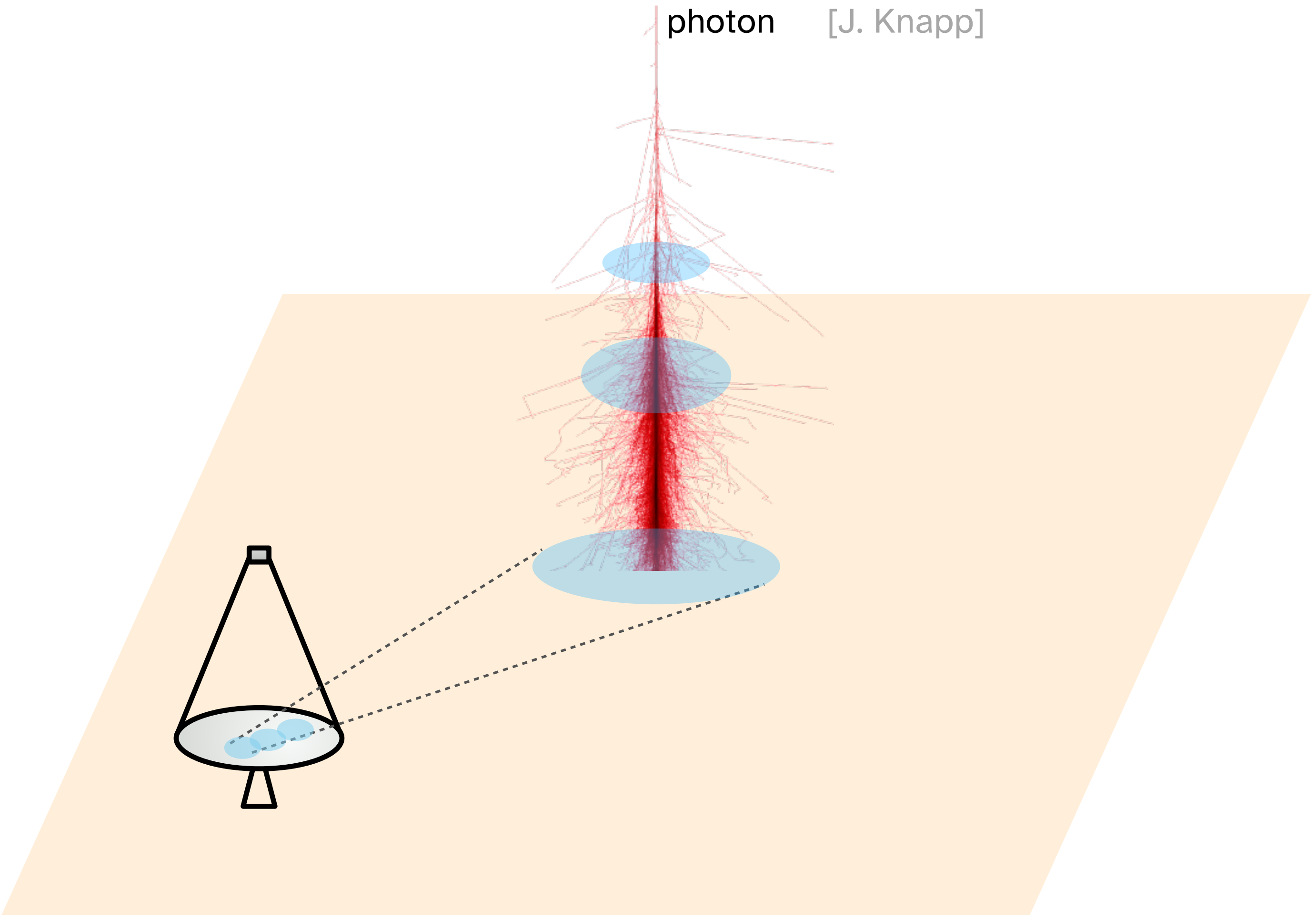

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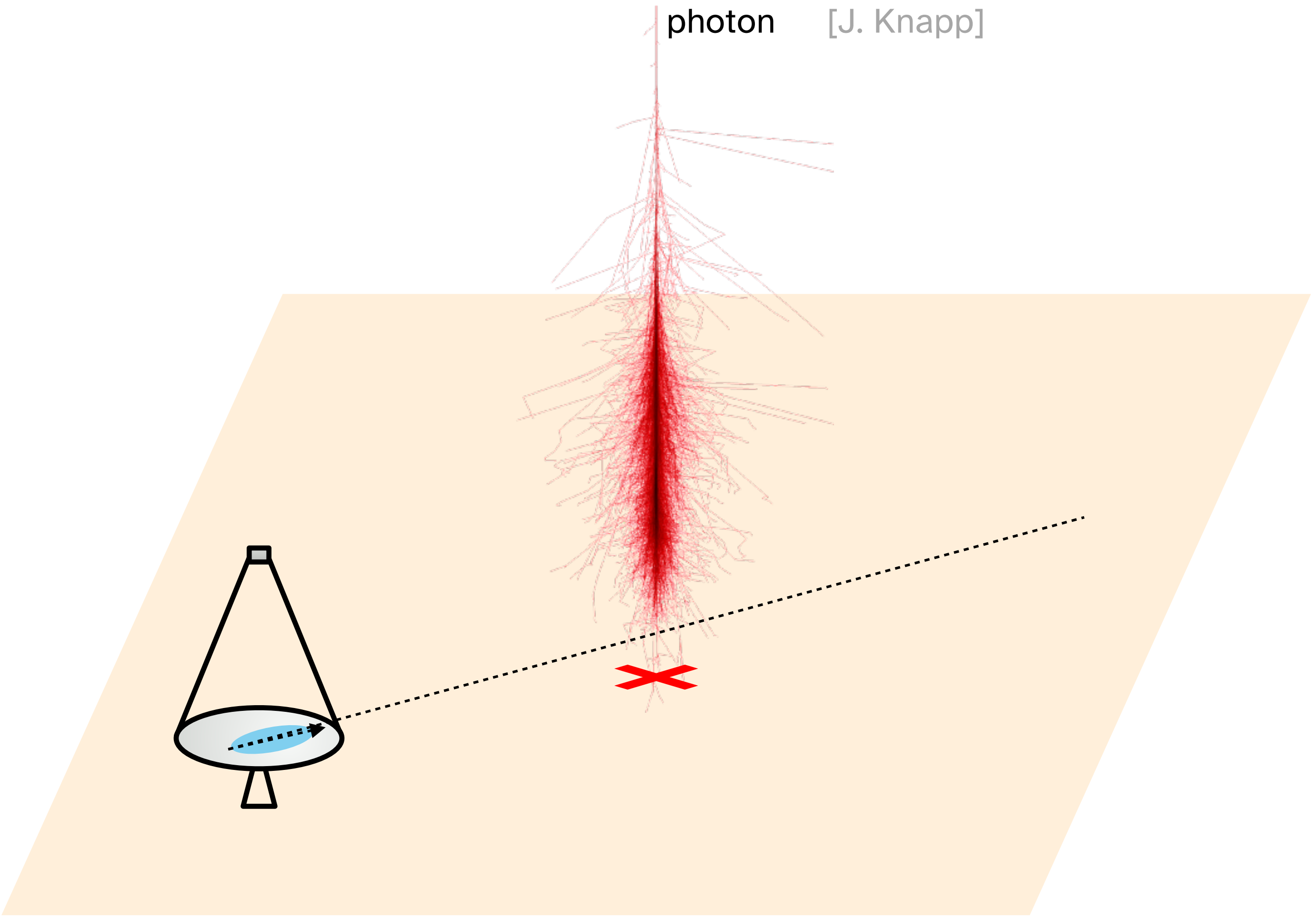

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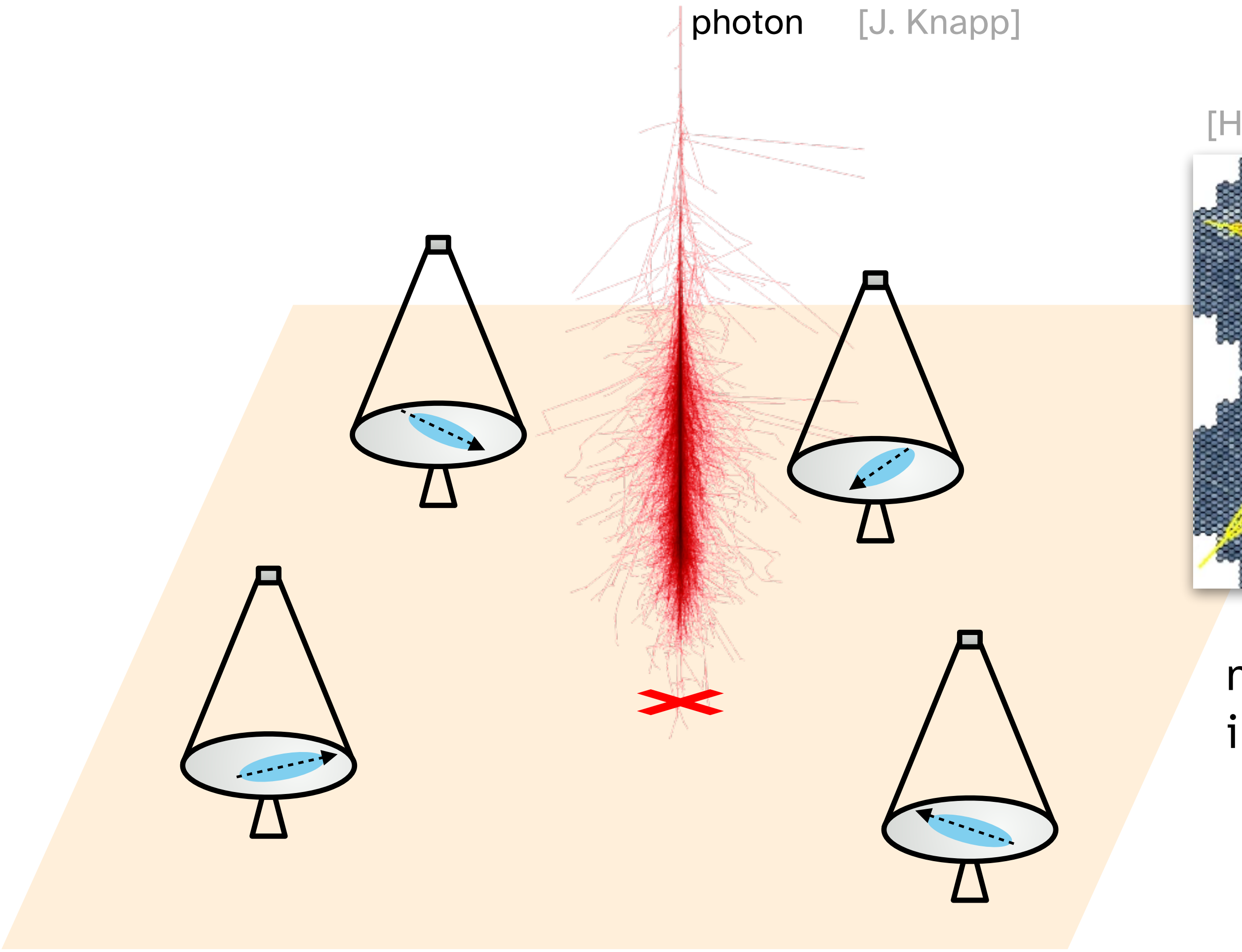
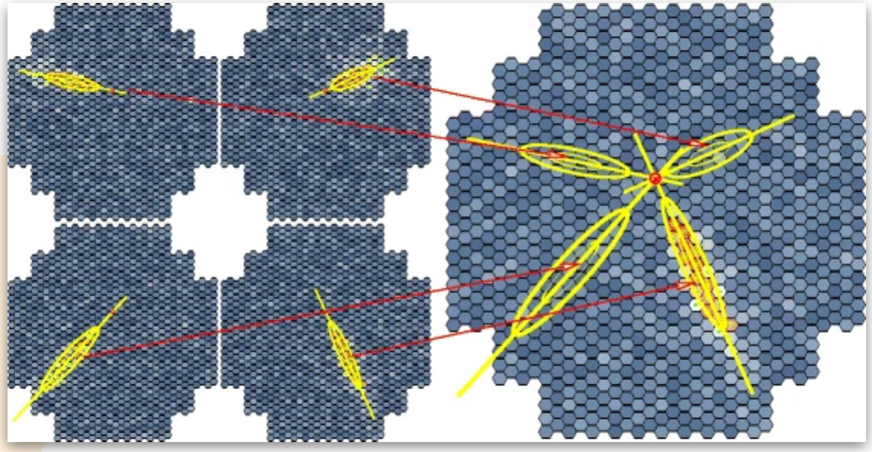


[J. Knapp]

[H. Völk & K. Bernlöhr, ExA 25 (2009)]



main axes -> photon direction
image intensity + geometry -> energy

Imaging Atmospheric Cherenkov Telescopes (IACTs)

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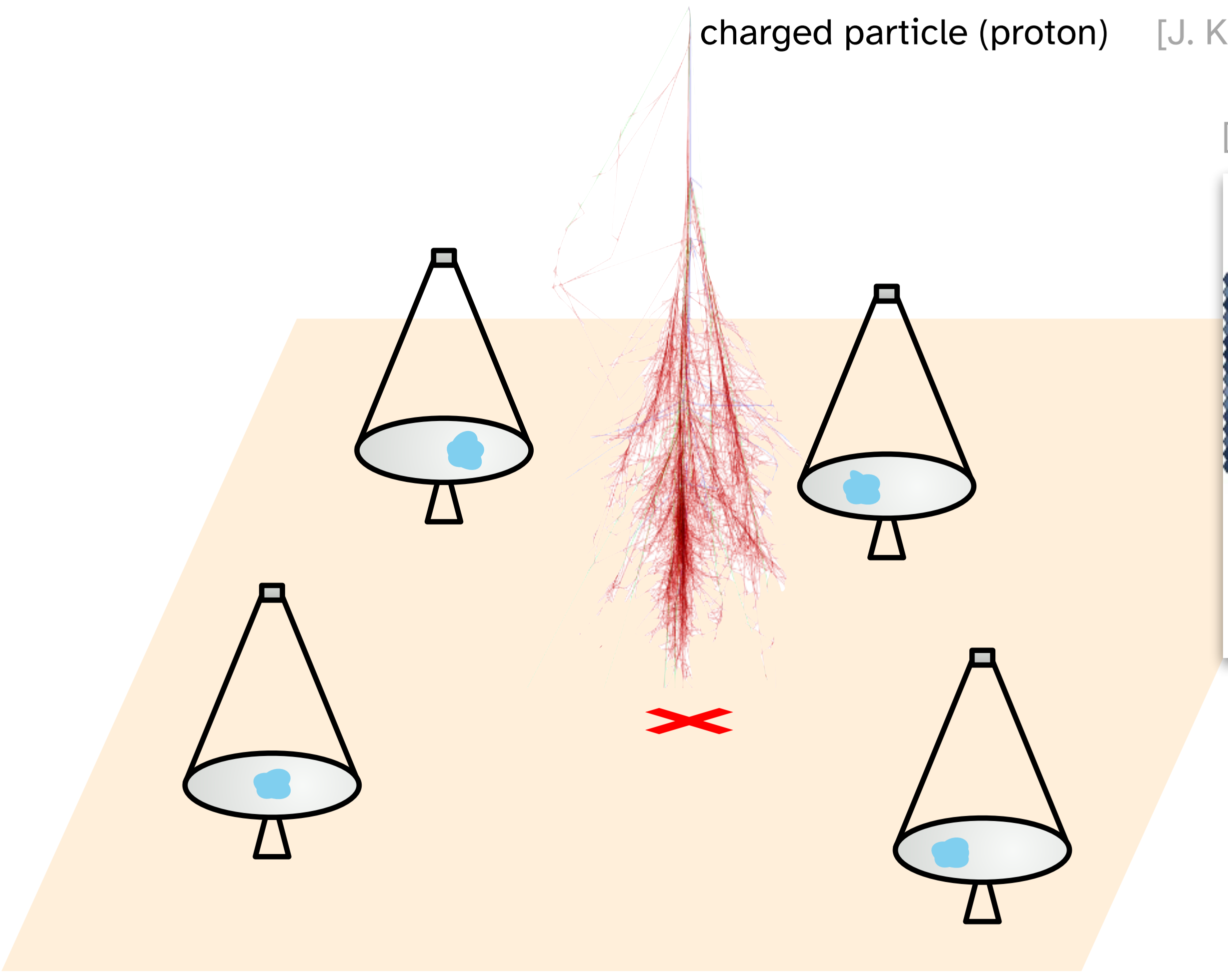
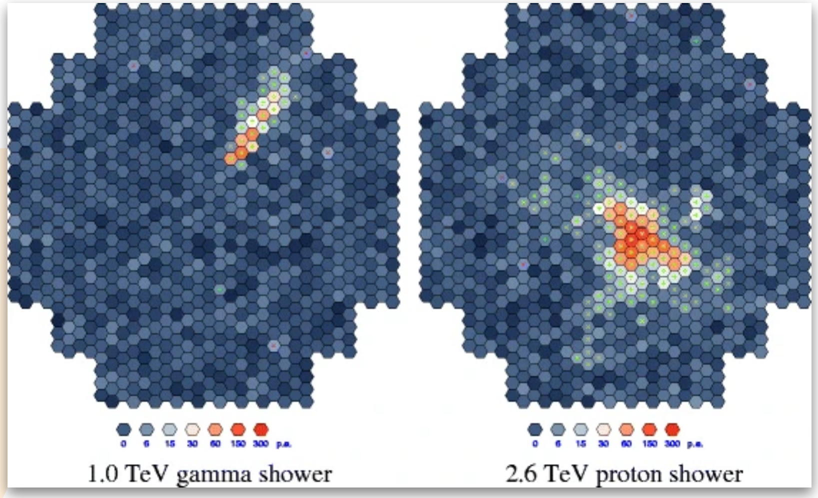


[J. Knapp]

[H. Völk & K. Bernlöhr, ExA 25 (2009)]



main axes -> photon direction

image intensity + geometry -> energy

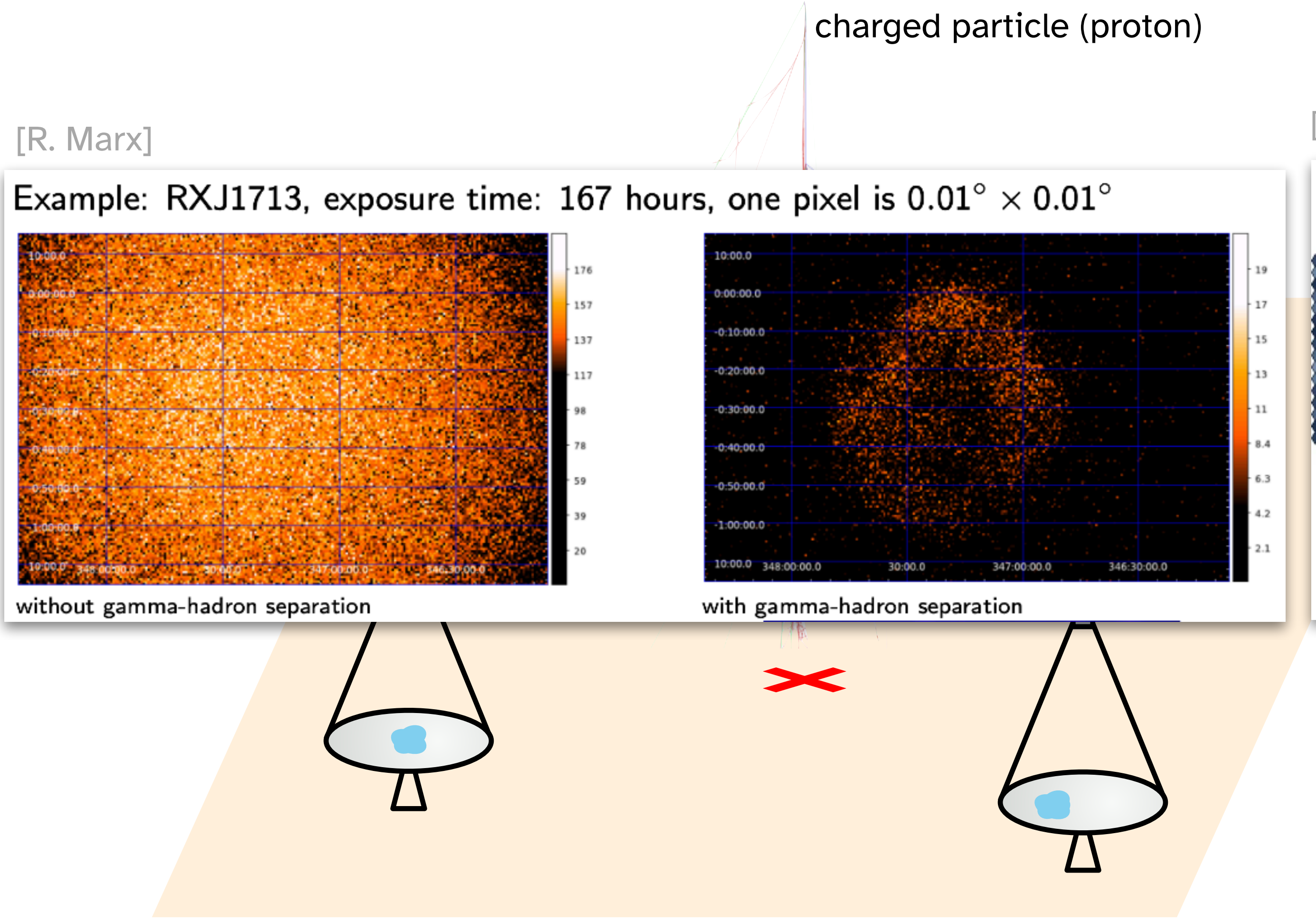
shape -> charged particle rejection

“gamma-hadron separation”

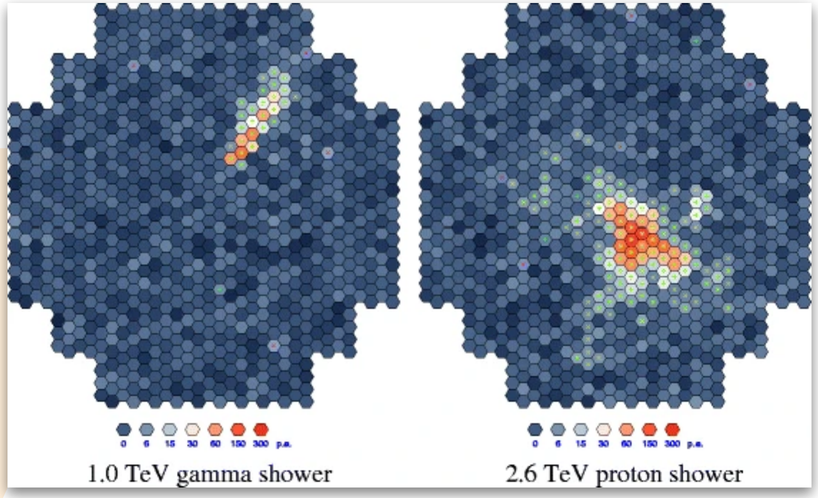
Imaging Atmospheric Cherenkov Telescopes (IACTs)

Take a “snapshot” of the pool of Cherenkov light

[R. Marx]



[H. Völk & K. Bernlöhr, ExA 25 (2009)]



main axes -> photon direction
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“gamma-hadron separation”

Current generation IACT arrays

[Derek Strom, Giovanni Ceribella, MAGIC Collaboration]

VERITAS Collaboration

[H.E.S.S., MPIK/Christian Föhr]

[Daniel R. Strebe]

IACT arrays

MAGIC (La Palma)

[Derek Strom, Giovanni Ceribella, MAGIC Collaboration]

2 x 236 m²
since 2003 / 2009

Major Atmospheric Gamma
Imaging Cherenkov Telescope

VERITAS (Arizona, US)

VERITAS Collaboration

4 x 110 m²
since 2007

Very Energetic Radiation Imaging
Telescope Array System

H.E.S.S. (Namibia)

[H.E.S.S., MPIK/Christian Föhr]

4 x 108 m² since 2007 + 1 x 614 m² since 2012

High Energy Stereoscopic System

H.E.S.S. telescopes

Steel frames

CT5: 600 tons, ~60 m at tallest

[C. Foehr]

CT1-4: 60 tons, ~25 m at tallest

[S. Klepser]

H.E.S.S. telescopes

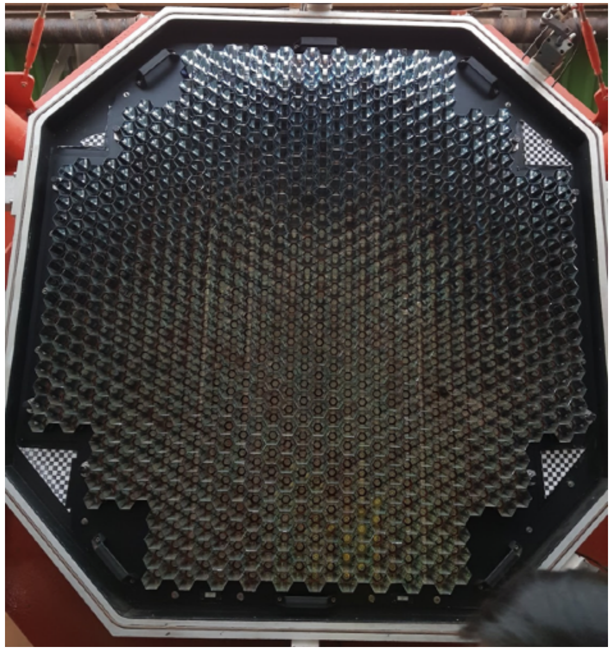
[Helmholtz Alliance for Astroparticle Physics / A. Chantelauze]

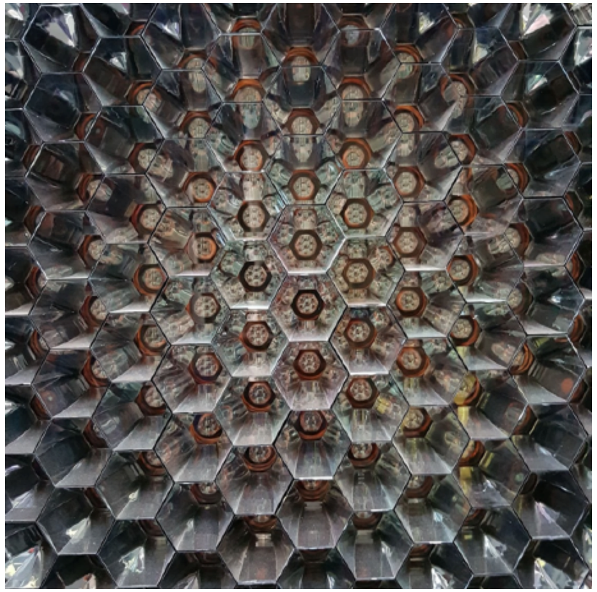
H.E.S.S. telescopes

Cameras (small telescopes)

H.E.S.S. telescopes

Cameras (small telescopes)



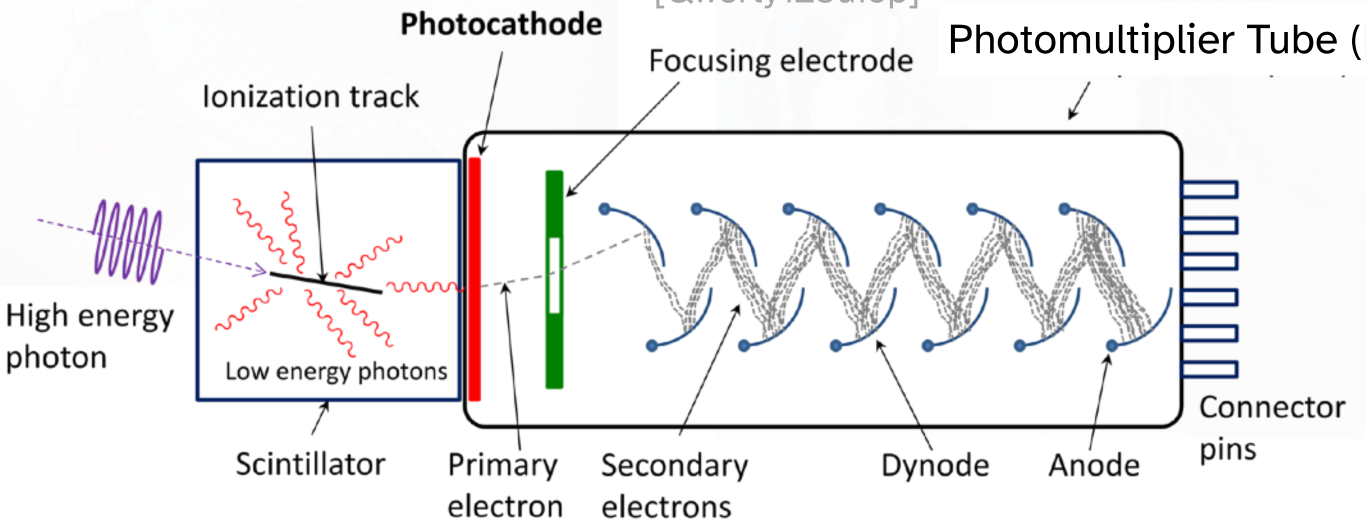


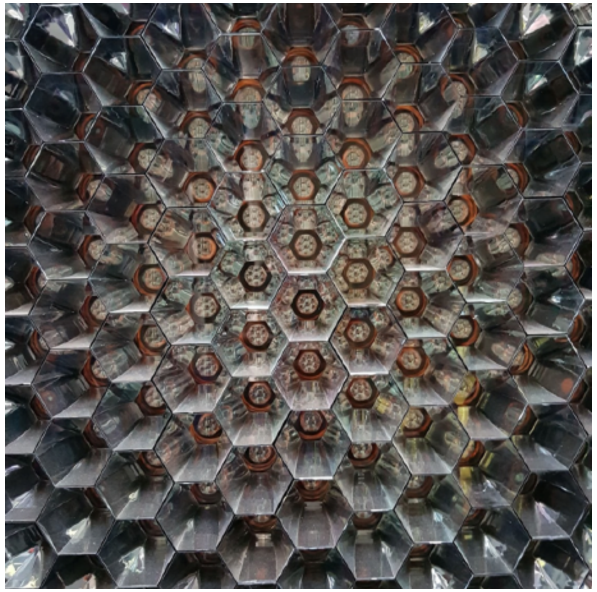
H.E.S.S. telescopes

Cameras (small telescopes)

[Qwerty123uiop]

Photomultiplier Tube (PMT)

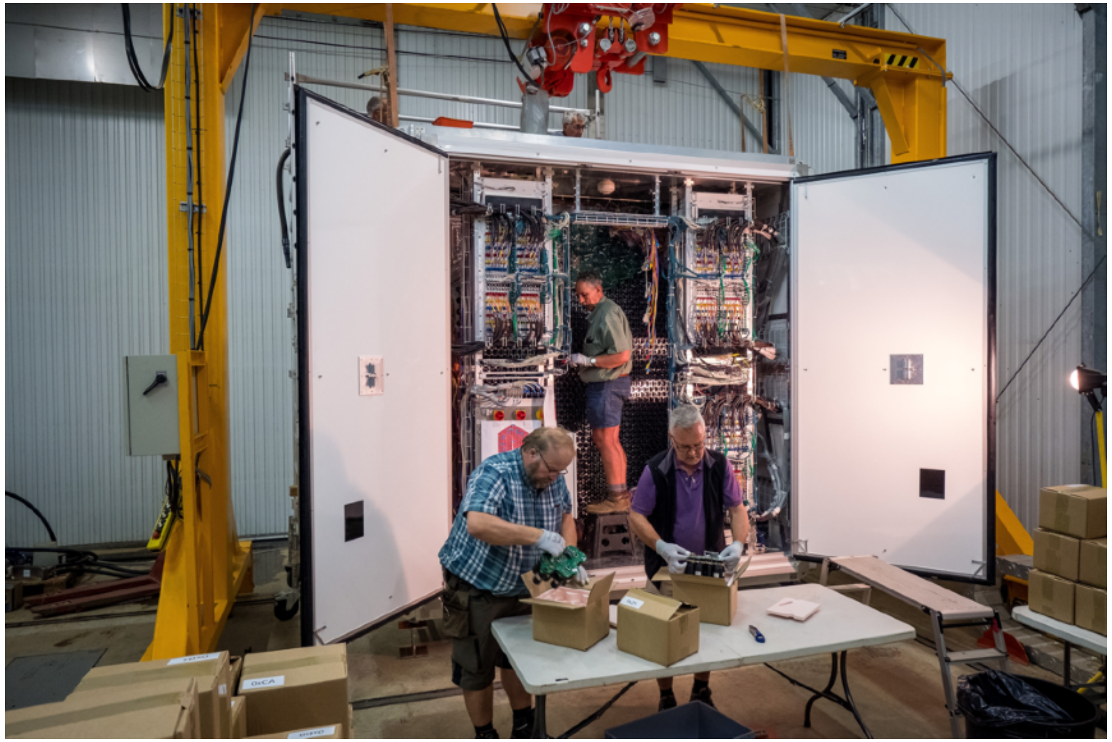




H.E.S.S. telescopes

Camera (big telescope)

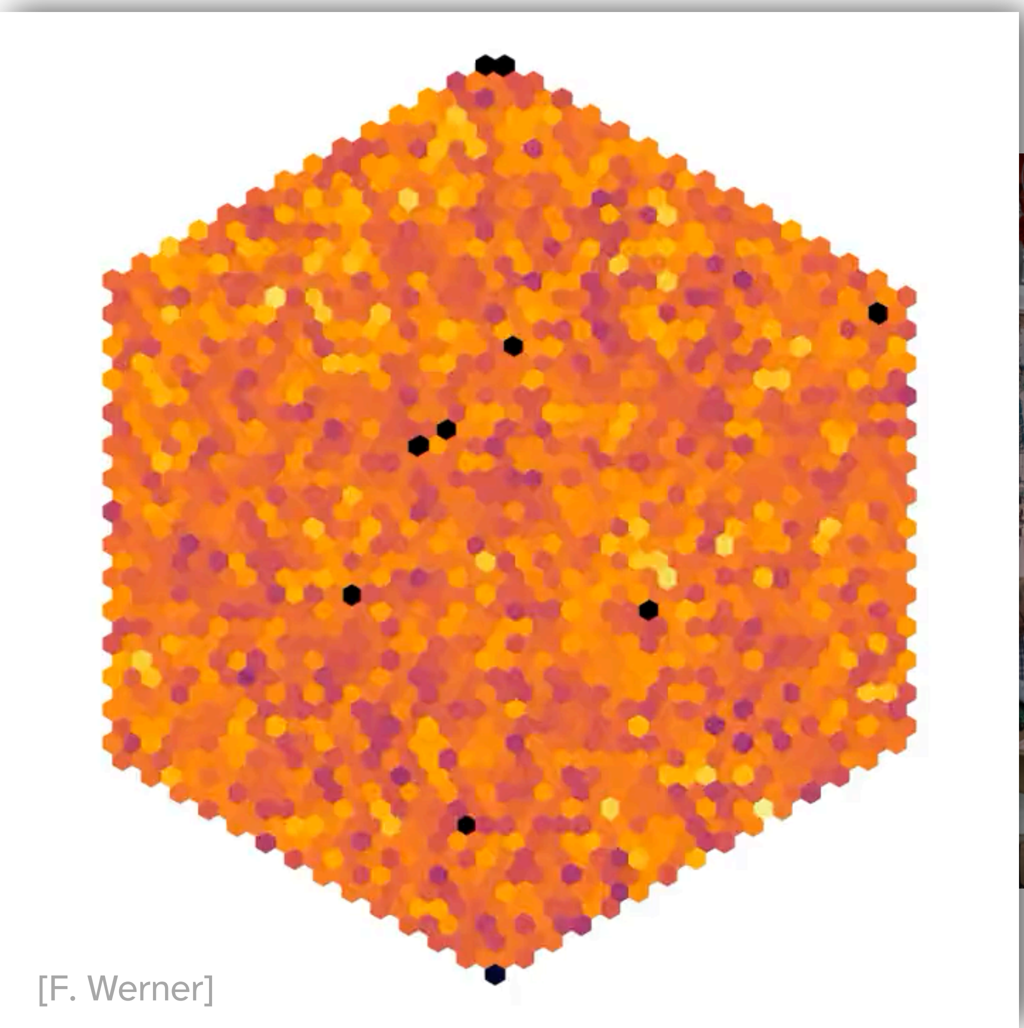
[C. Föhr (MPIK)]



H.E.S.S. telescopes

Camera (big telescope)

[C. Föhr (MPIK)]



[F. Werner]

MAGIC telescopes

Carbon fiber frames

~40 tons, ~30 m at tallest

[MAGIC collaboration]

[S. Schurig]

IACT arrays

When can they observe?

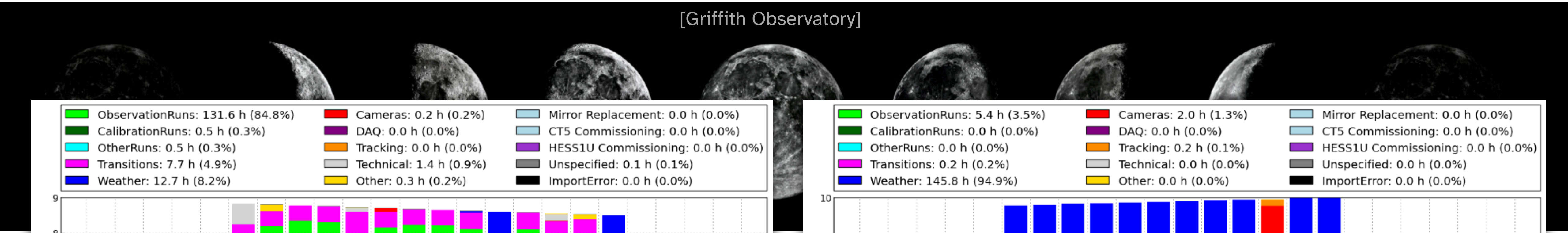
Best for observations | OK for observations | **Can’t observe** | OK for observations | Best for observations

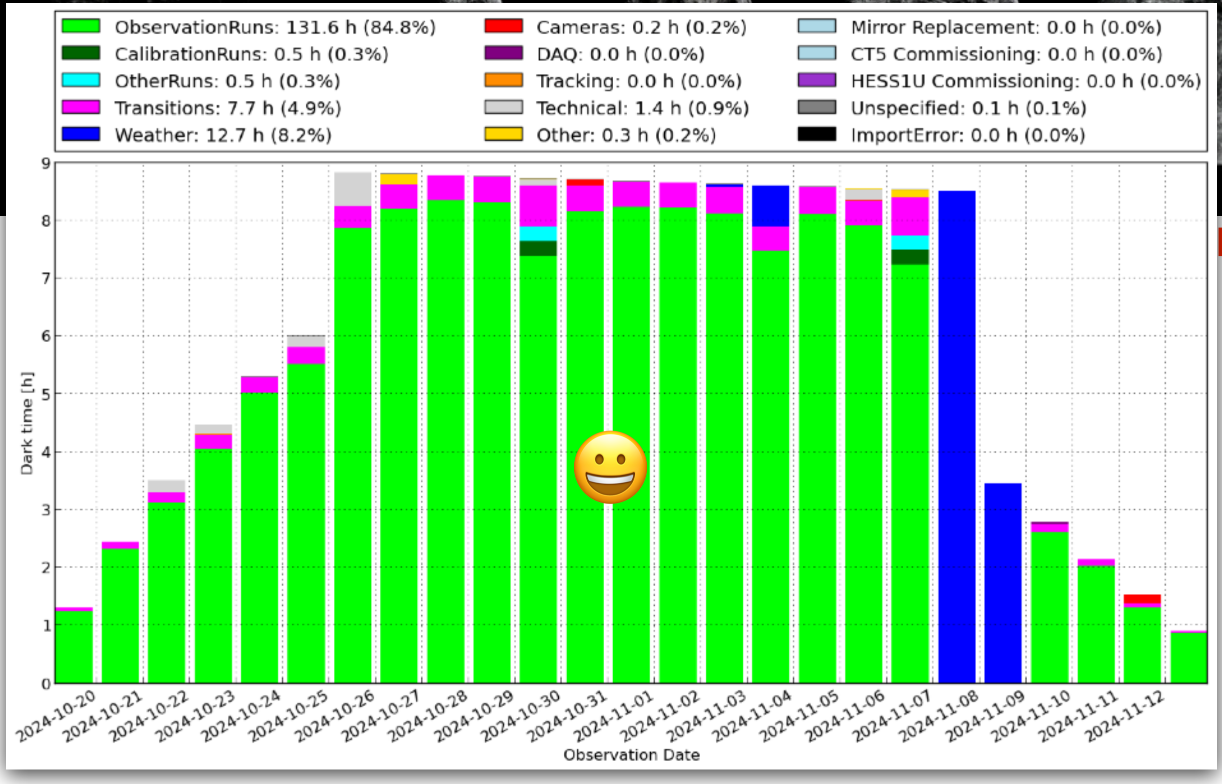
Cherenkov flashes are dim -> cameras are extremely sensitive
If there is too much bright ambient light, cameras could get damaged

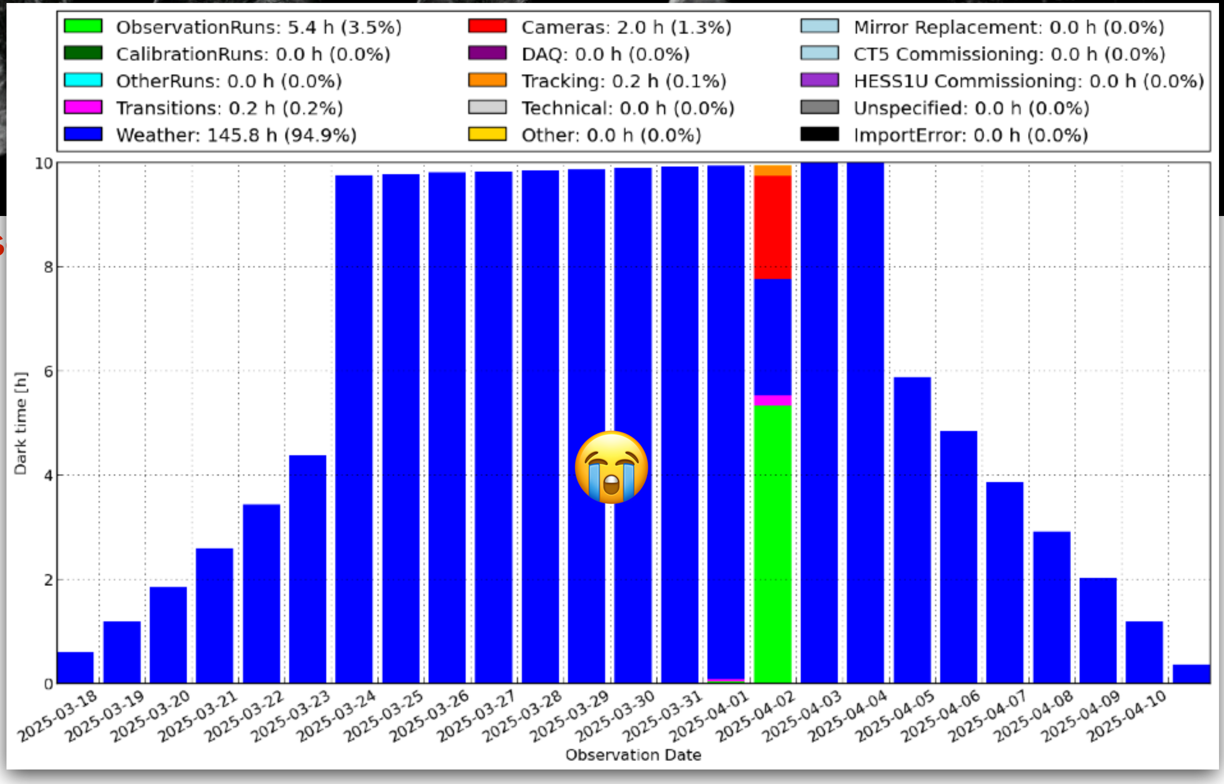
=> IACTs observe ~25 nights during every ~28 day moon cycle **(when weather is good)**

IACT arrays

When can they observe?





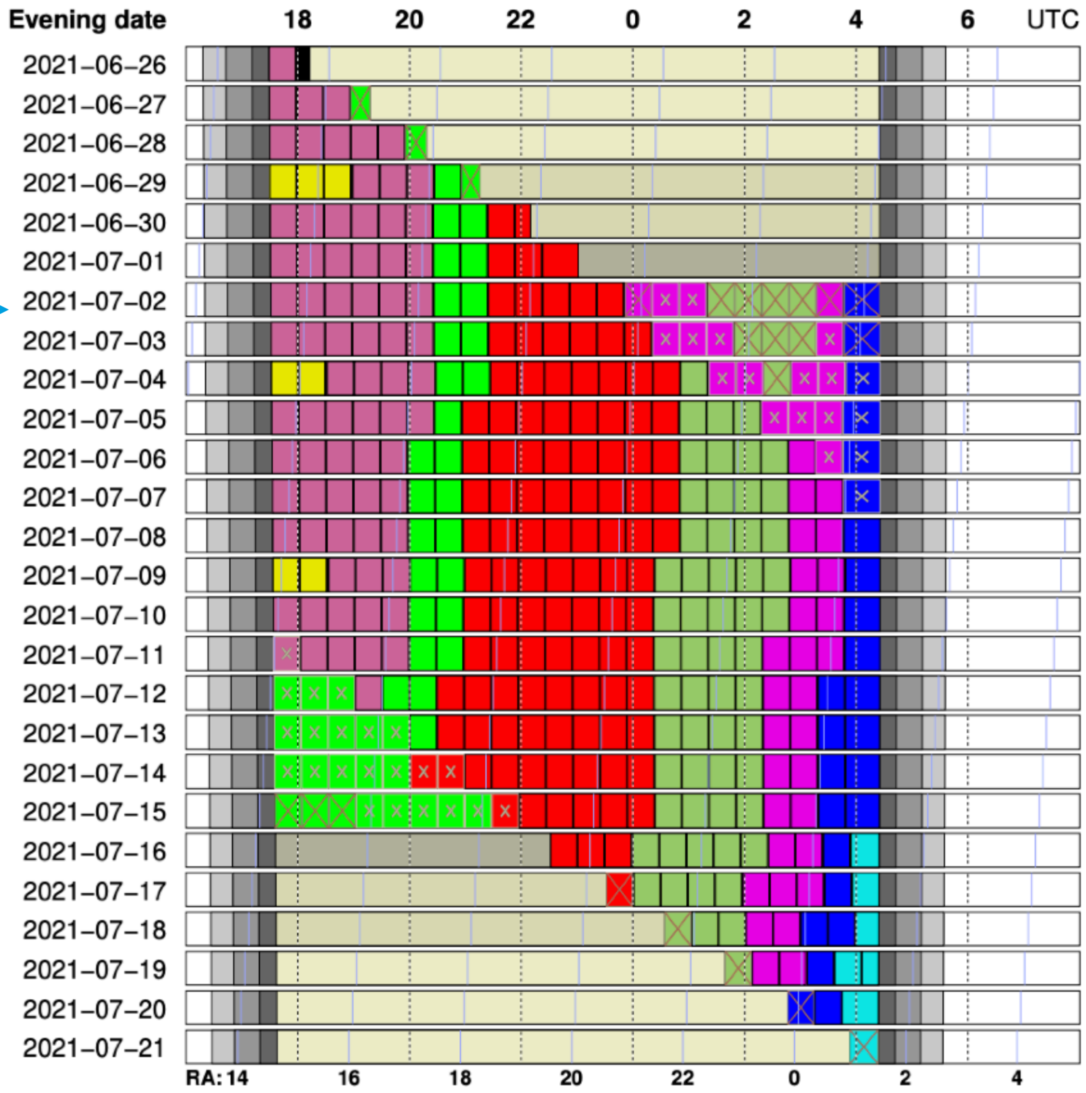


Two very different H.E.S.S. shifts

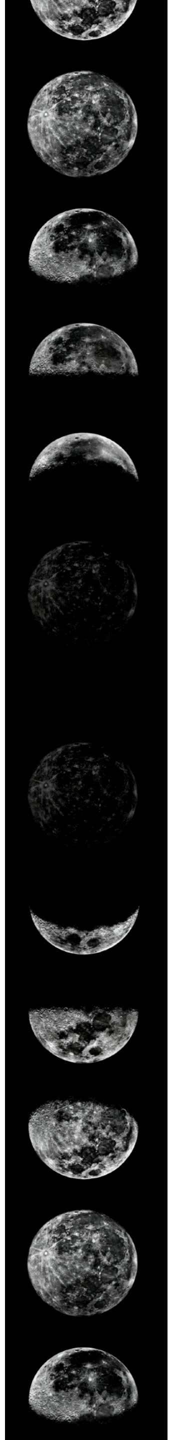
IACT arrays

When can they observe?

An example H.E.S.S. observing schedule

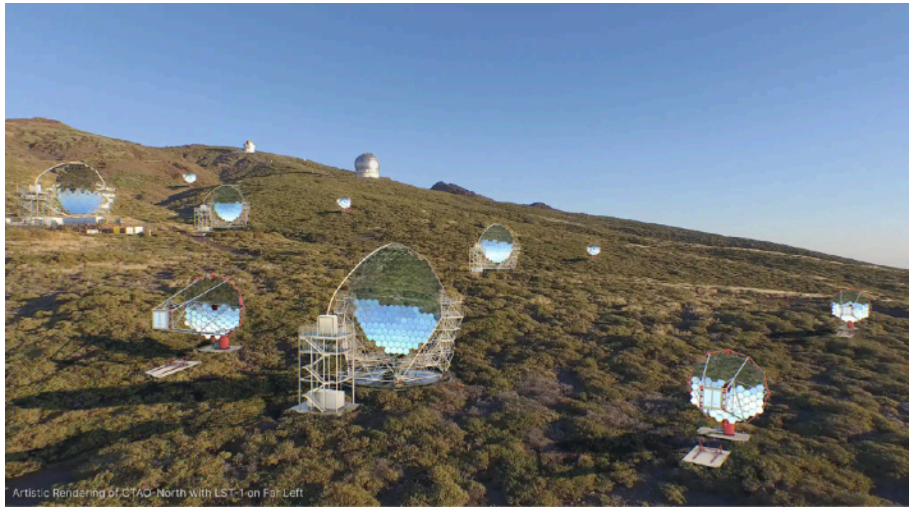


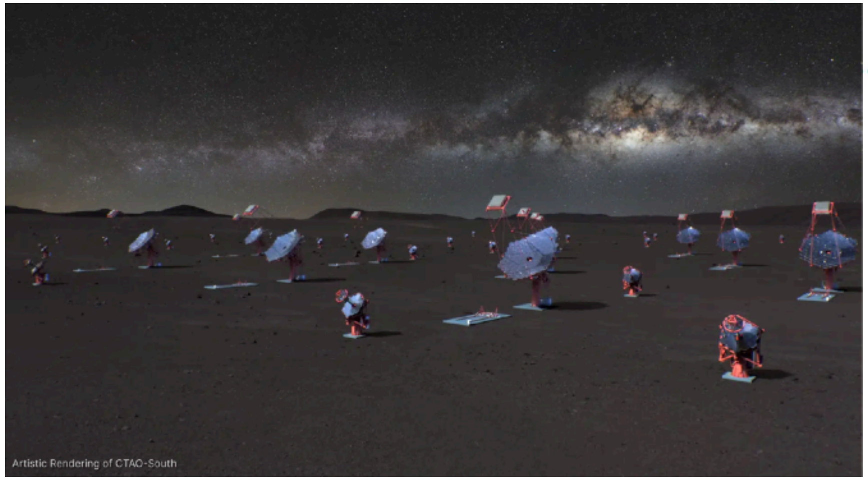
of course, ToOs (Targets of Opportunity) will take precedence over these targets

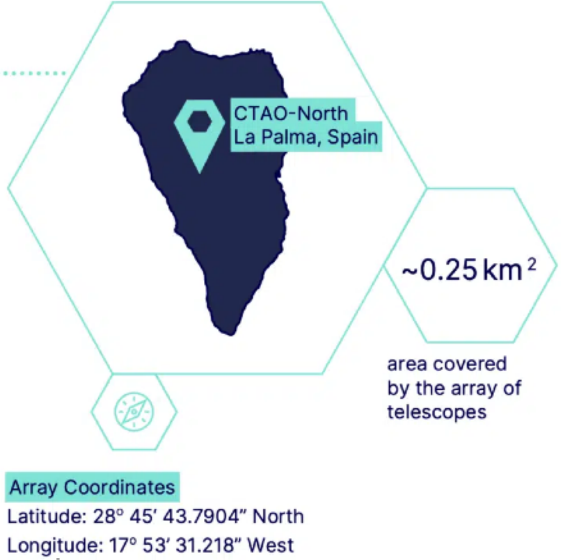


Cherenkov Telescope Array Observatory (CTAO)

Next generation IACT array

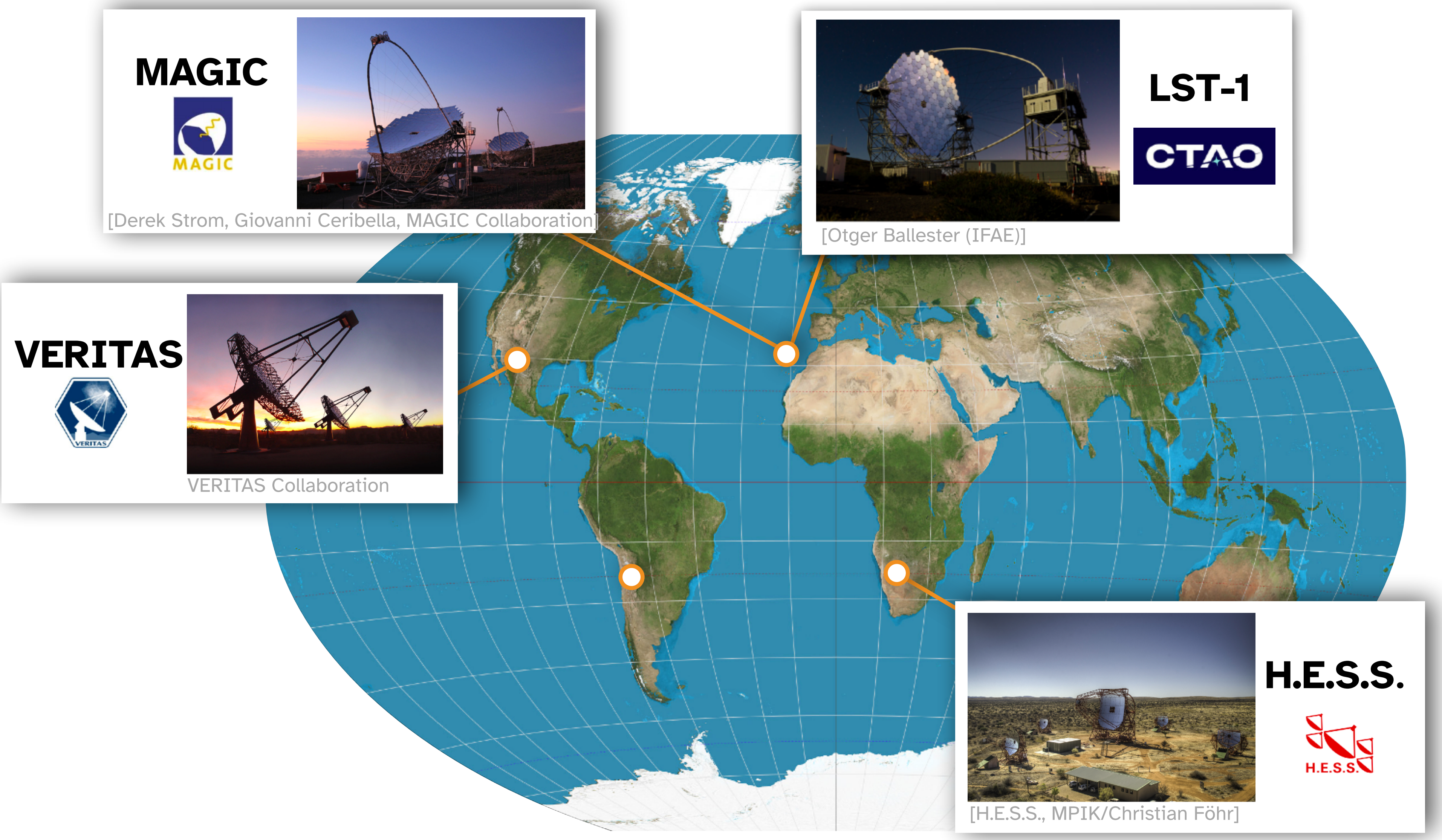






[CTAO]

IACT arrays



[Daniel R. Strebe]

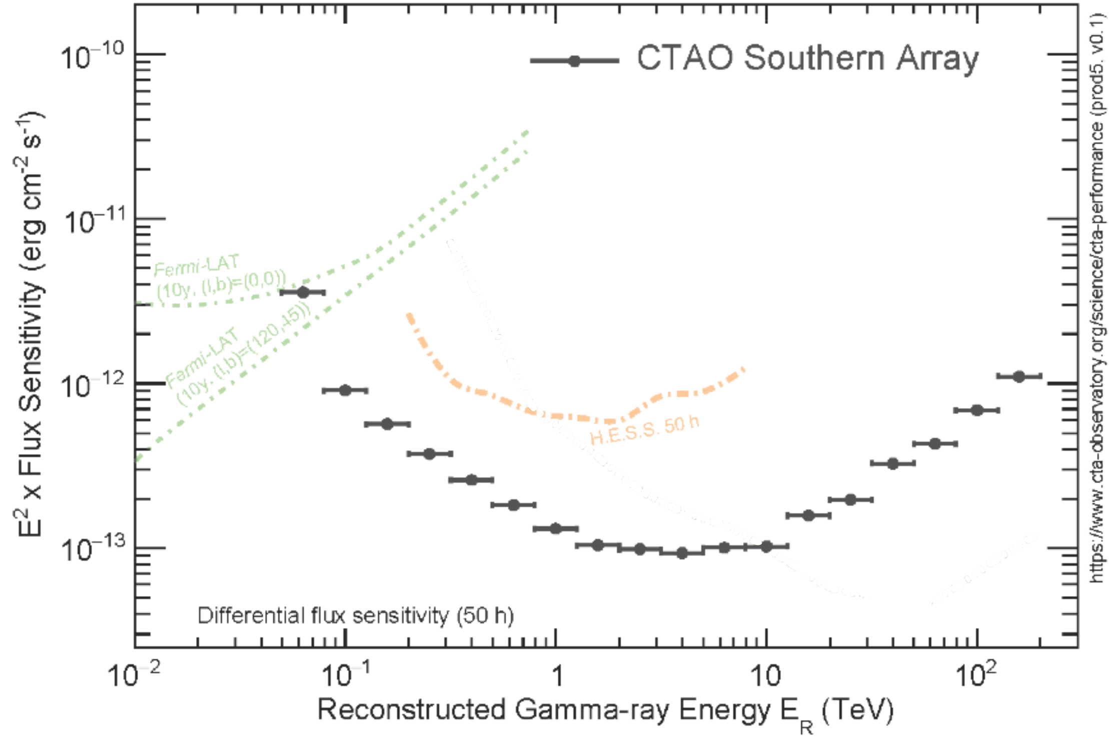
Cherenkov Telescope Array Observatory (CTAO)

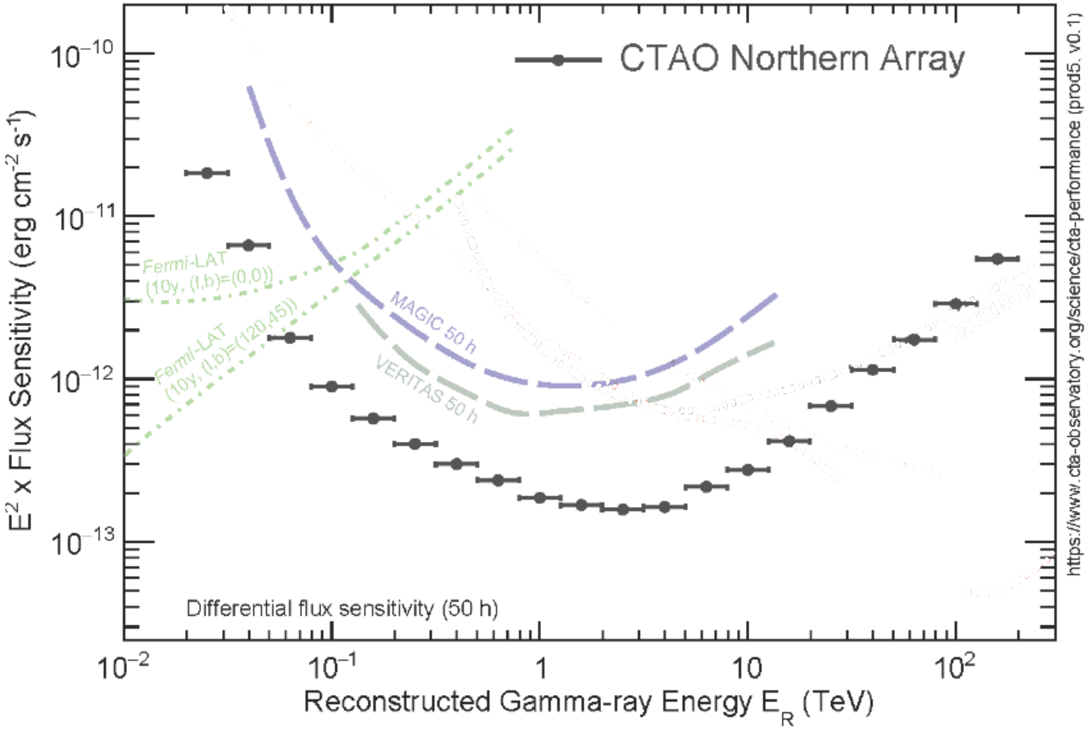
LST-1

Cherenkov Telescope Array Observatory (CTAO)

Next generation IACT array

CTAO will be 10x more sensitive than the current generation of IACT arrays



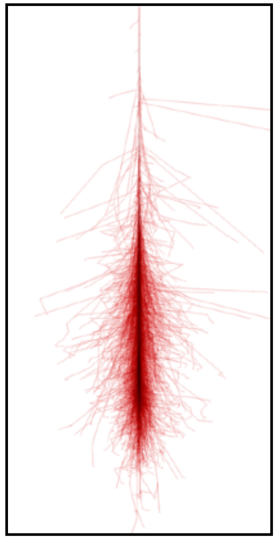


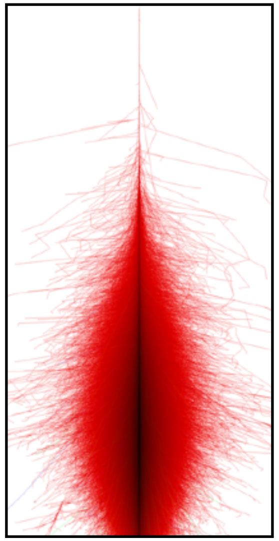
[CTAO]

Use the atmosphere as part of the detector

How do we get to even higher energies?

100 GeV gamma ray vs 100 TeV gamma ray





- most shower particles don't reach the ground
- detect them via Cherenkov light in air

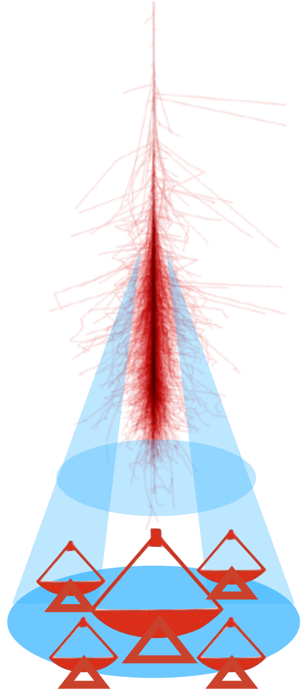
- many shower particles reach the ground
- detect them directly

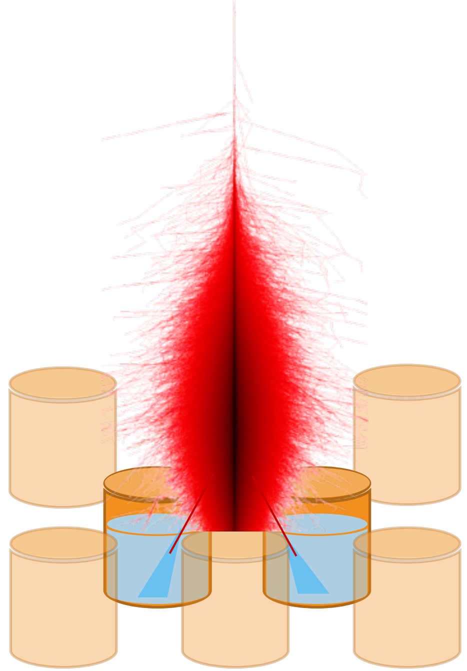
[J. Knapp]

Use the atmosphere as part of the detector

How do we get to even higher energies?

100 GeV gamma ray vs 100 TeV gamma ray





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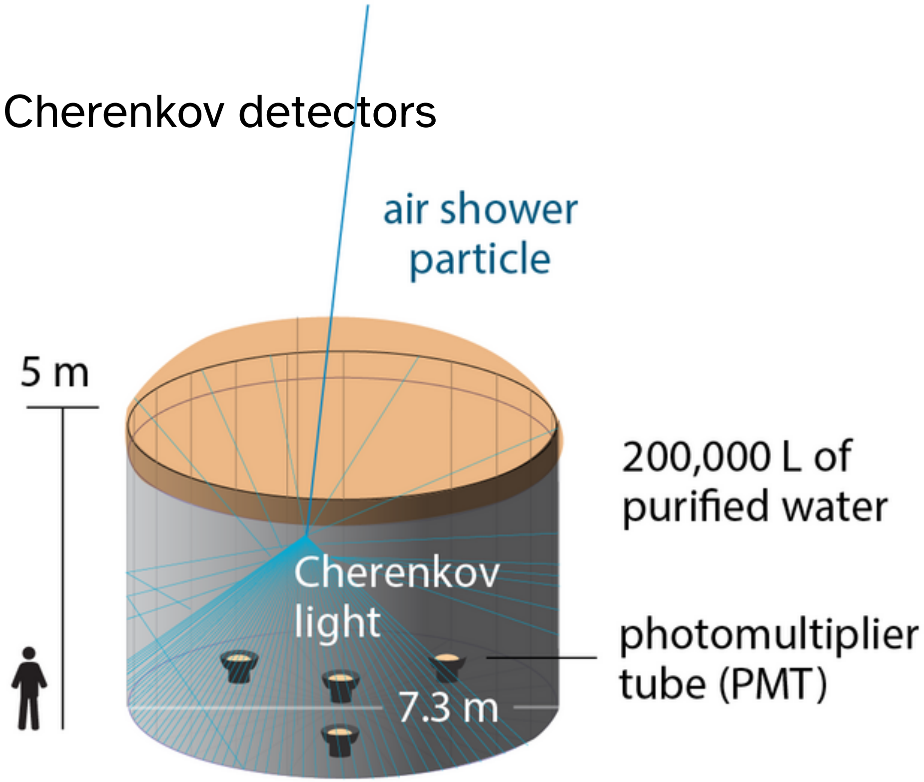
[J. Knapp]

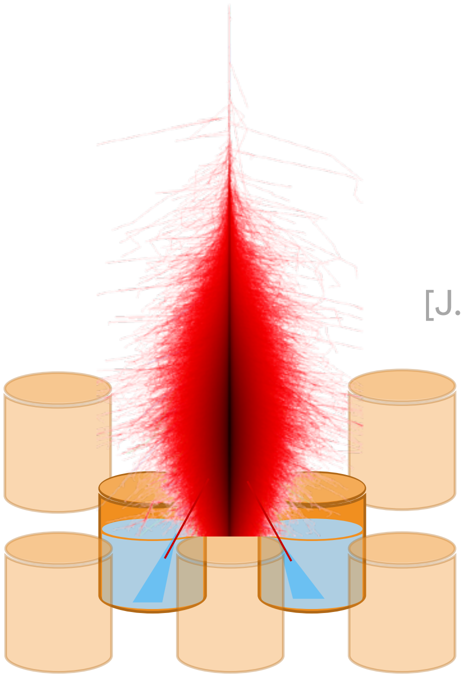
Particle detector arrays

e.g., Water Cherenkov detectors



[U. M. Nisa, HAWC]

100 TeV gamma ray



[J. Knapp]

Particle detector arrays

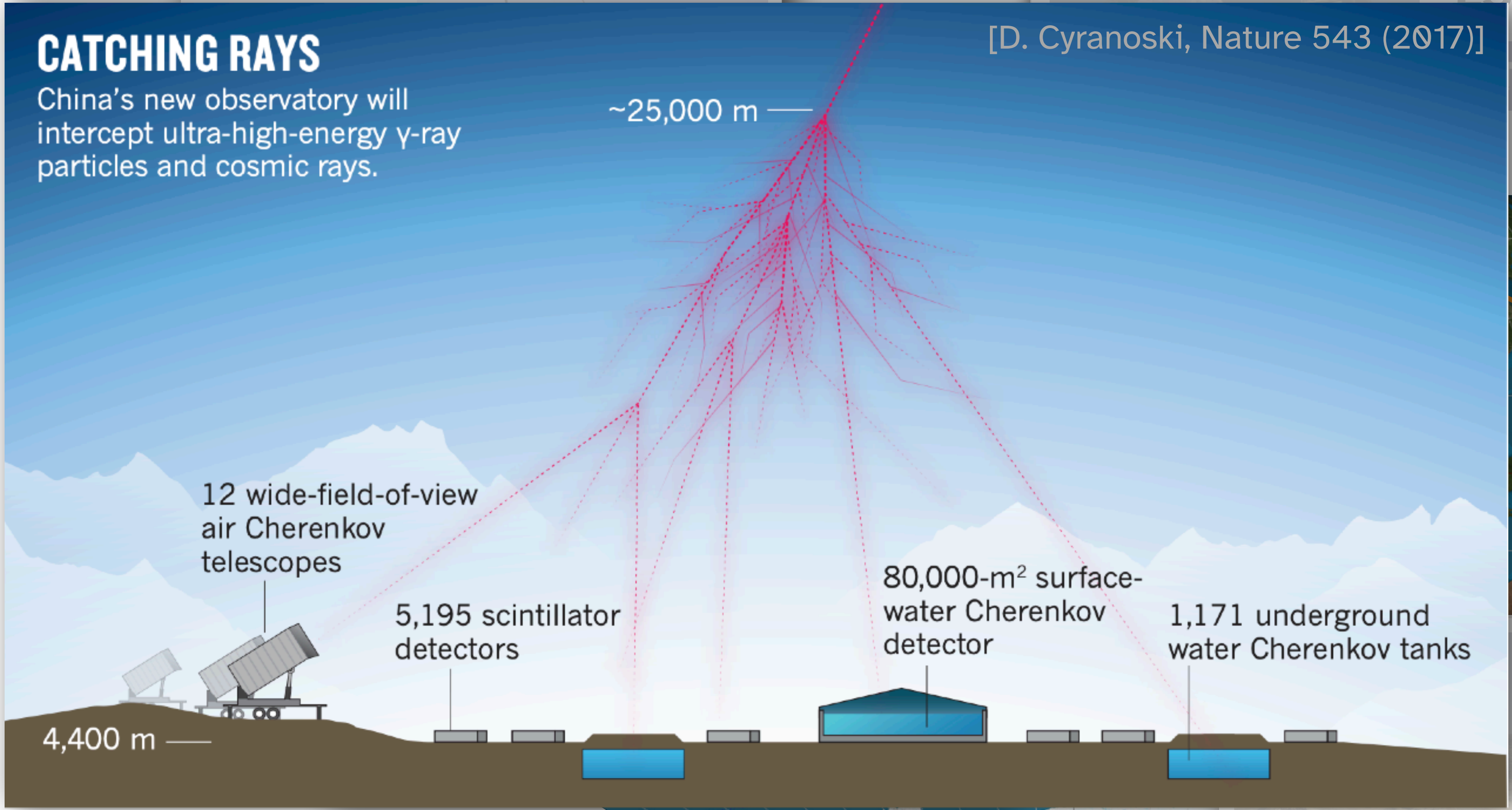
[Daniel R. Strebe]

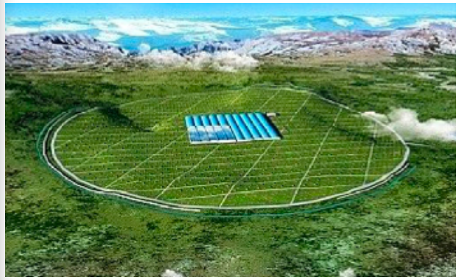
Particle detector arrays

MAGIC

LST-1

CTAO





[IHEP]

LHAASO

LHAASO
高海拔宇宙线观测站

H.E.S.S.

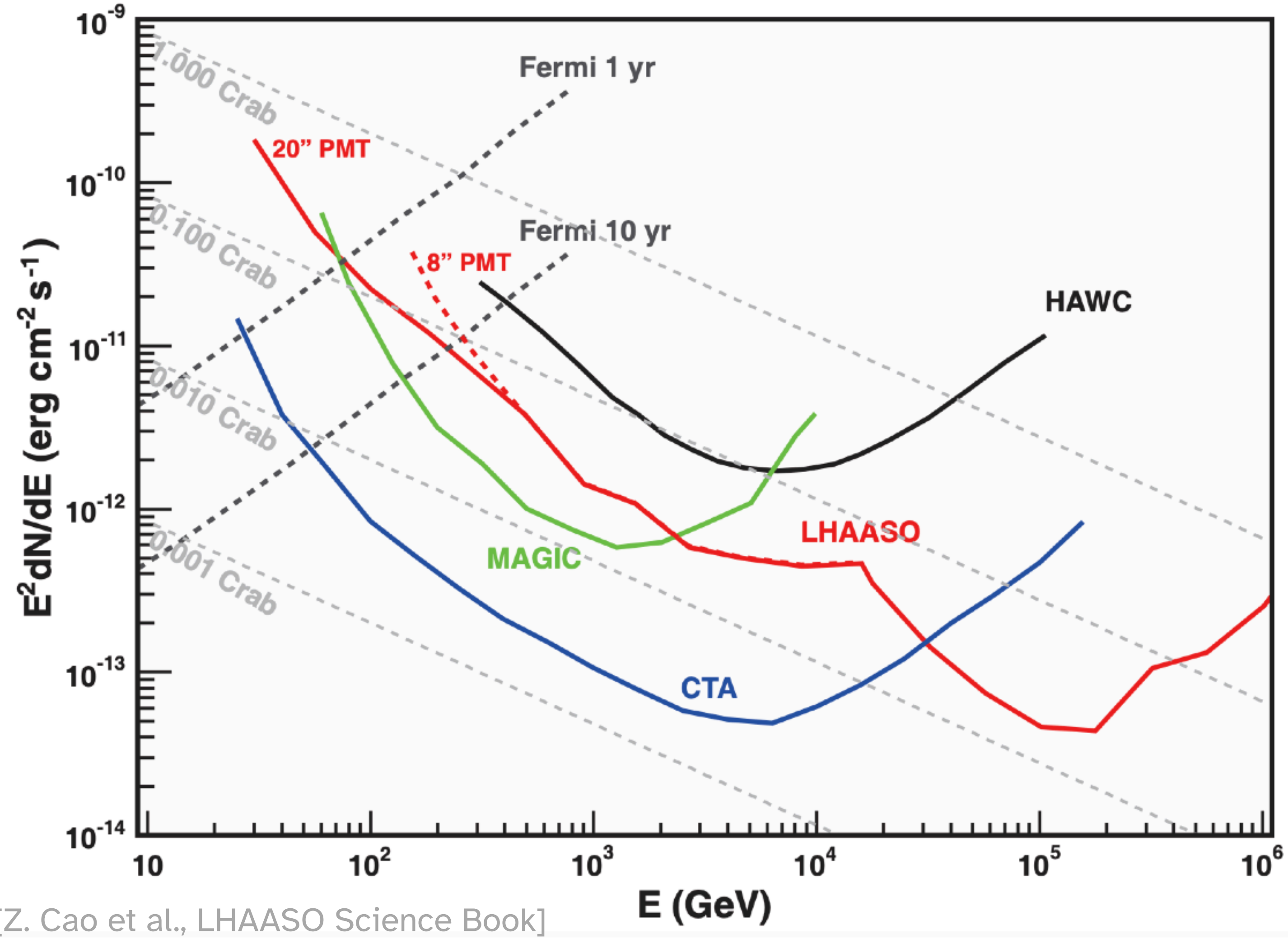
H.E.S.S.

[H.E.S.S., MPIK/Christian Föhr]

[Daniel R. Strebe]

Comparing gamma-ray detectors

Sensitivities

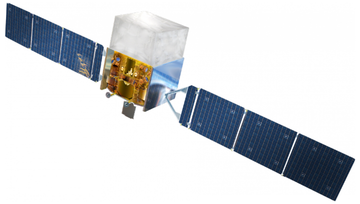


[Z. Cao et al., LHAASO Science Book]

Comparing gamma-ray detectors

Observational properties

	Fermi-LAT	IACT arrays (current gen)	CTAO	particle detector arrays (current gen)
duty cycle	~95%	~15%	~15%	~90%
energy range	[10s of MeV, 100s of GeV]	[~25 to 100 GeV, 100 TeV]	[~20 GeV, >300 TeV]	[100s of GeV, >PeV]
field of view	all-sky	3.5 - 5°	3.5 - 5°	>2 sr
angular resolution	~0.1° - 1°	< 0.1°	< 0.05°	~0.1° - 2°
energy resolution	~5 - 20%	~10 - 15%	~5%	~30 - 50%



H.E.S.S.

CTAO

Comparing gamma-ray detectors

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How do IACTs participate in time-domain astronomy?

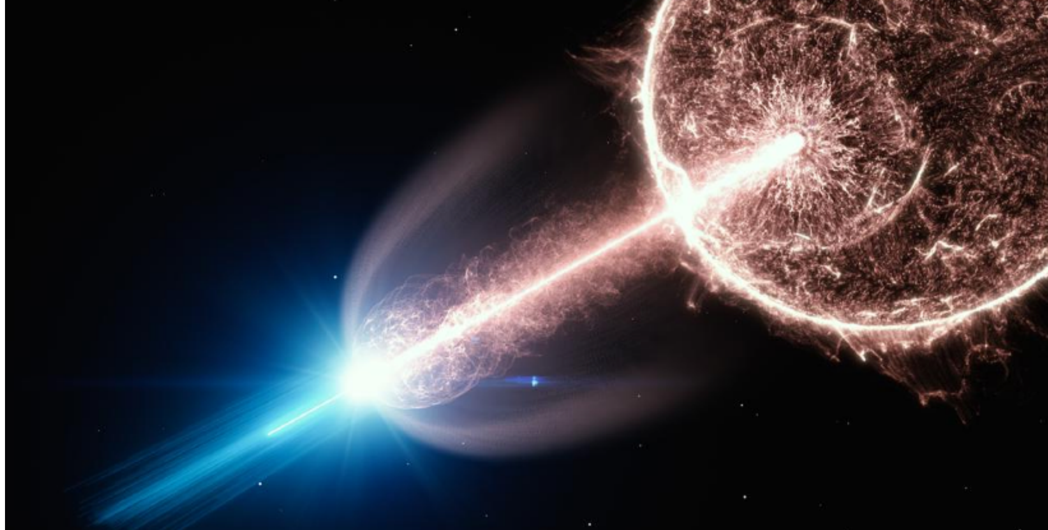
H.E.S.S.

CTAO

I get to talk about gamma-ray bursts now

I'm going to focus on gamma-ray bursts with H.E.S.S. because that's what I know best

CTAO will likely have a slightly different strategy but the broad concepts will be the same

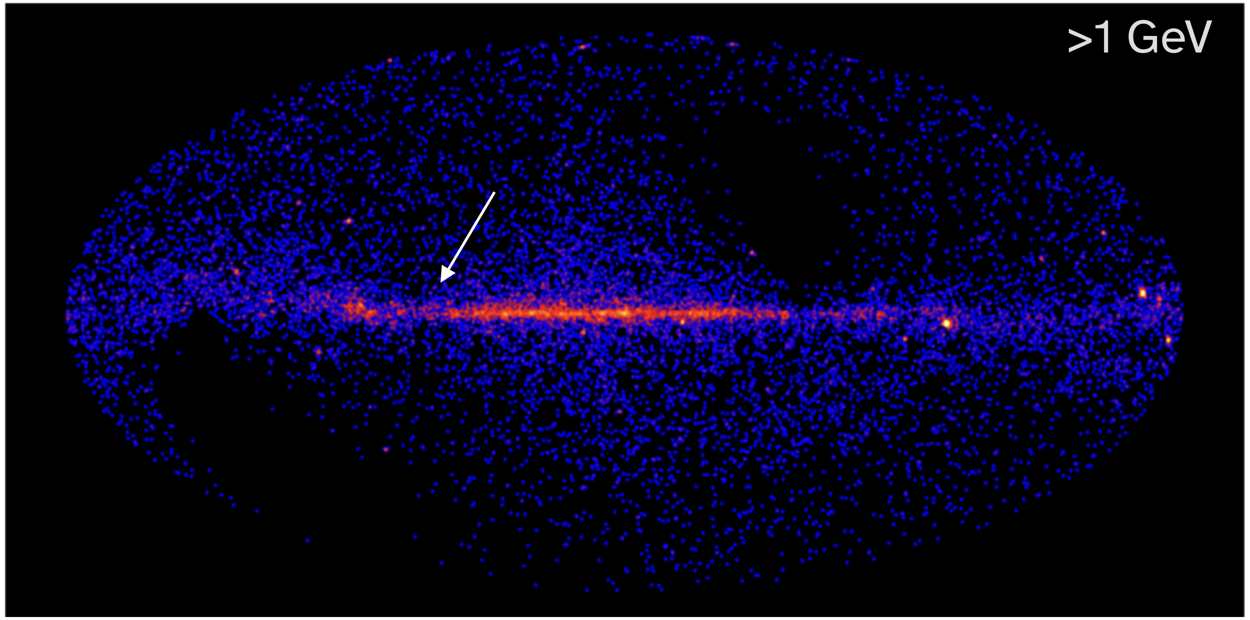


[DESY, Science Communication Lab]

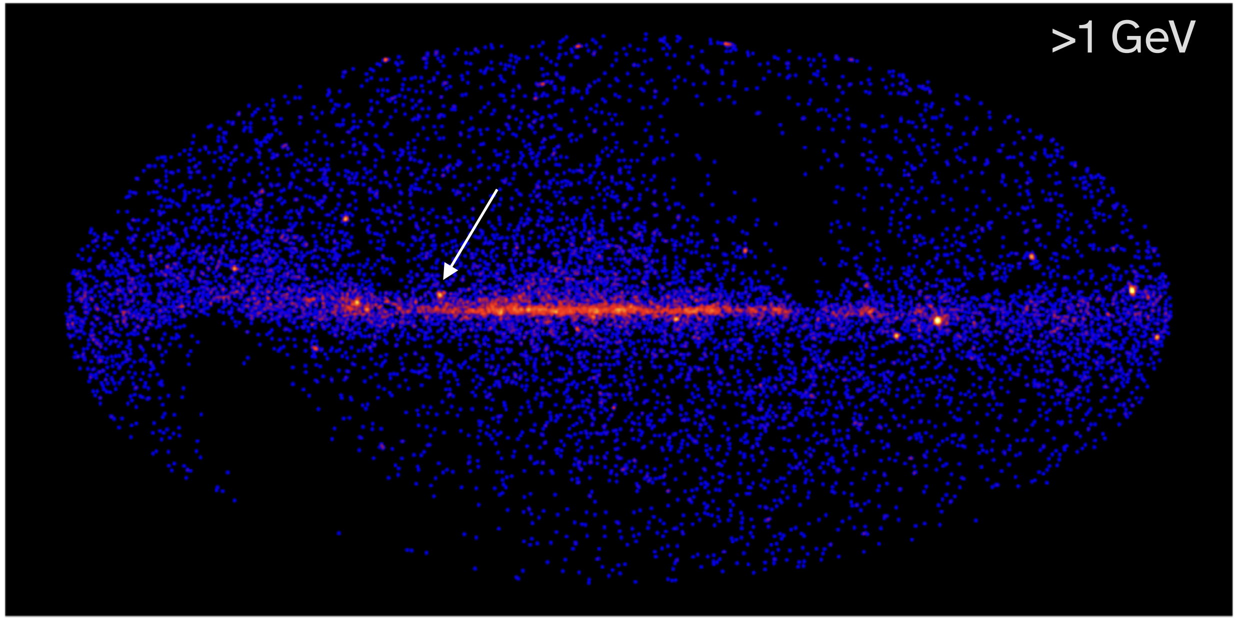
ok but what exactly *is* a “gamma-ray burst”?

Literally, a burst of gamma rays that easily outshines the rest of the gamma-ray sky for their brief existence

[D. Green]



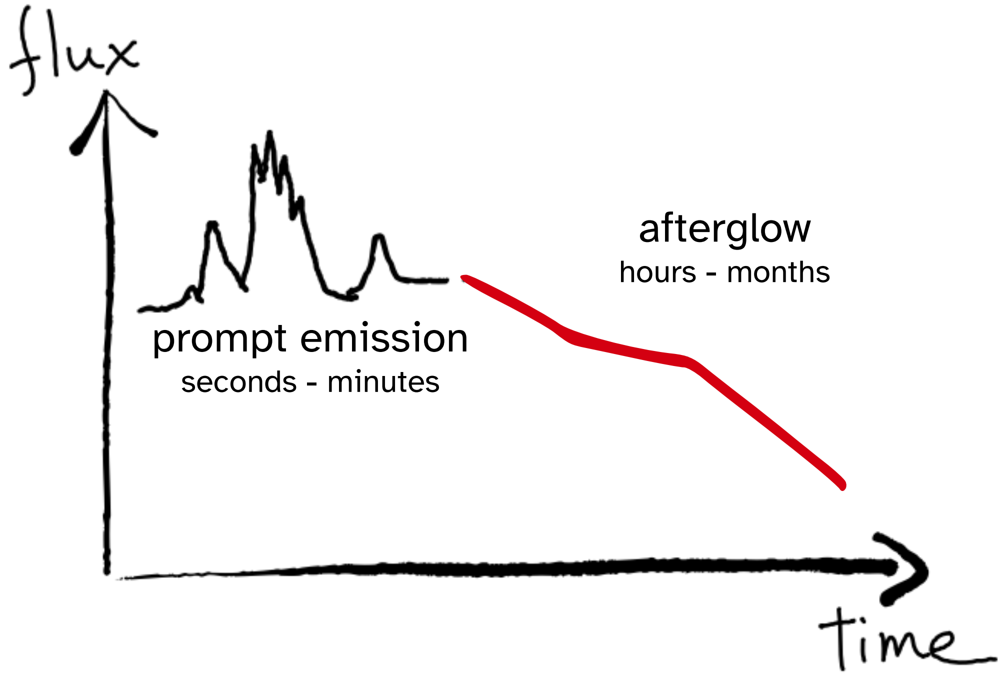
2 days before GRB



GRB + 2 days after

Gamma-ray bursts

What are they?



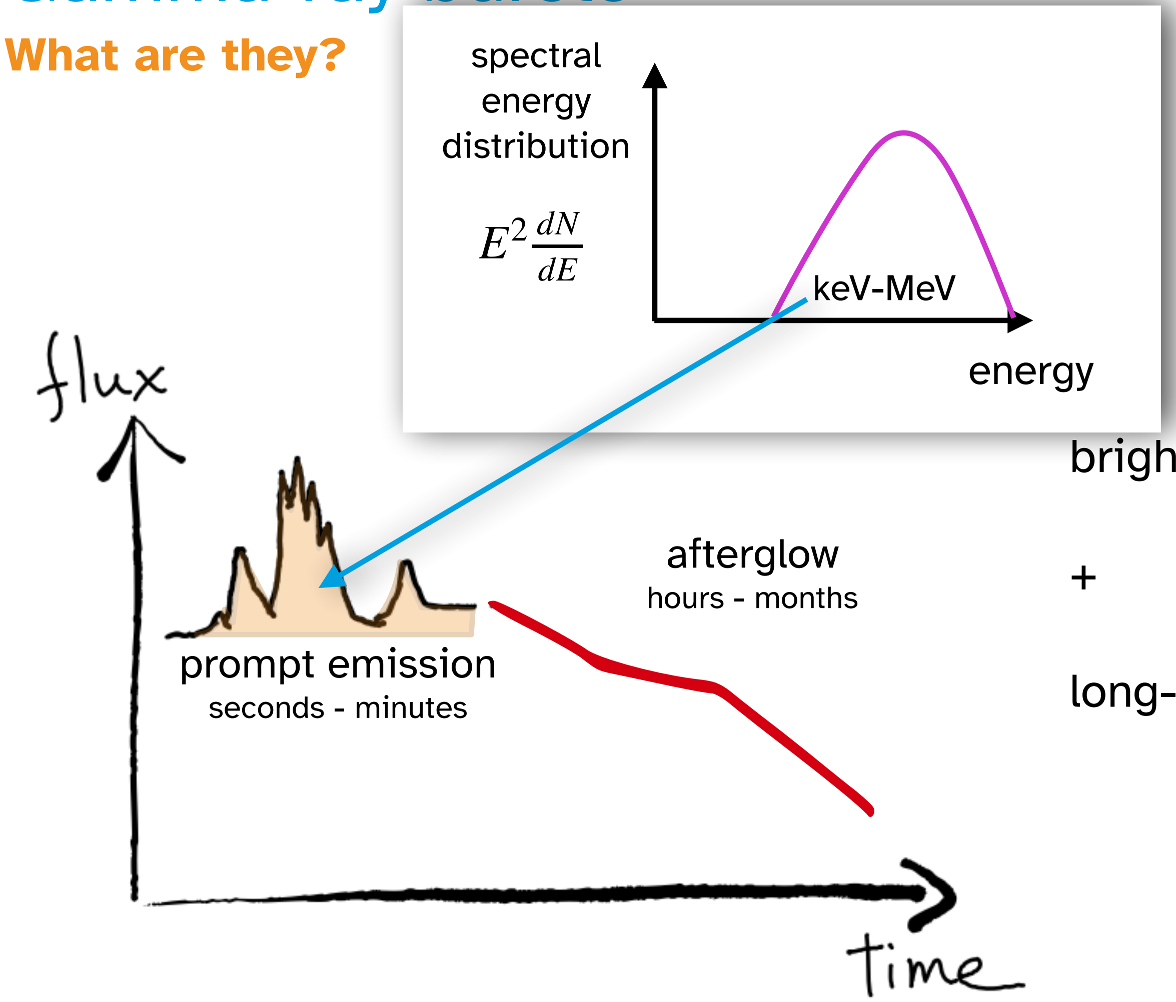
bright flashes of mostly gamma rays (prompt emission)

+

long-lived, slowly fading multiwavelength emission (afterglow)

Gamma-ray bursts

What are they?



bright flashes of mostly gamma rays (prompt emission)

+

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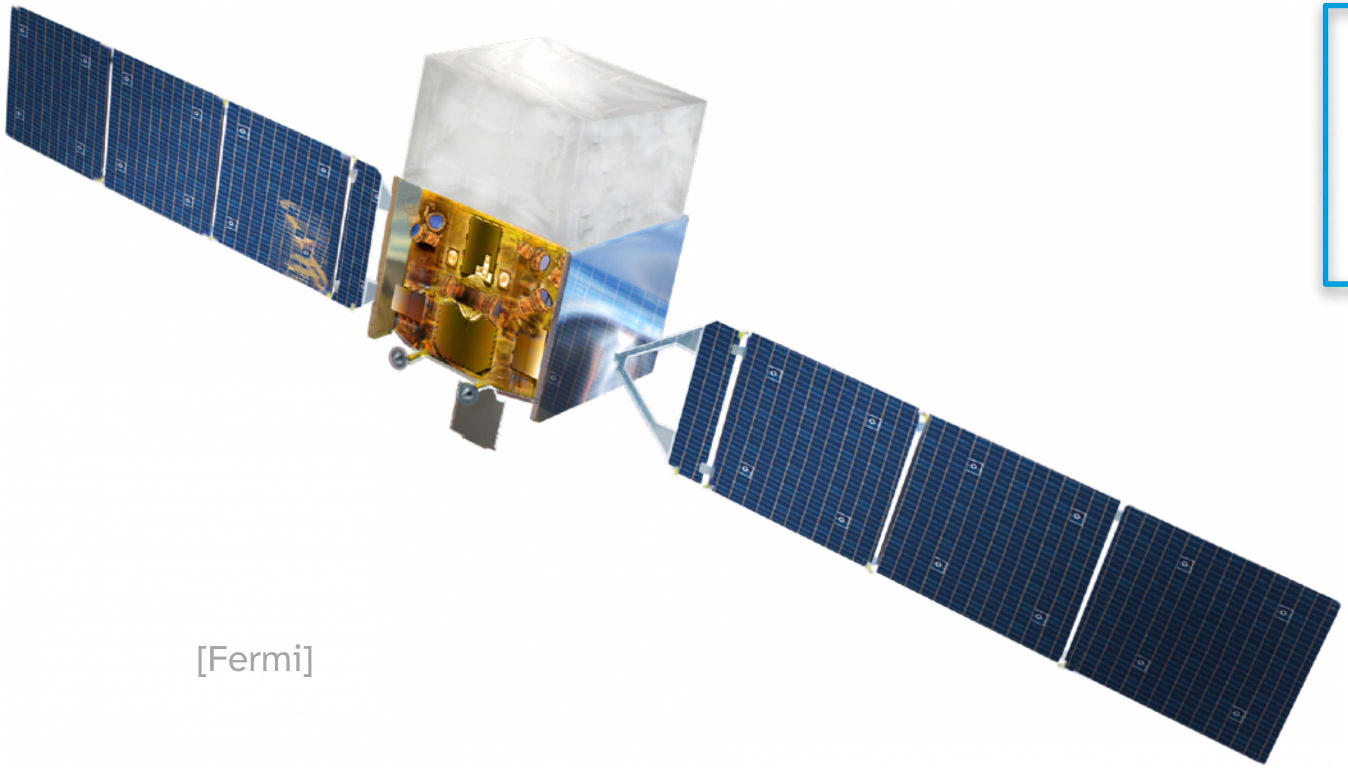
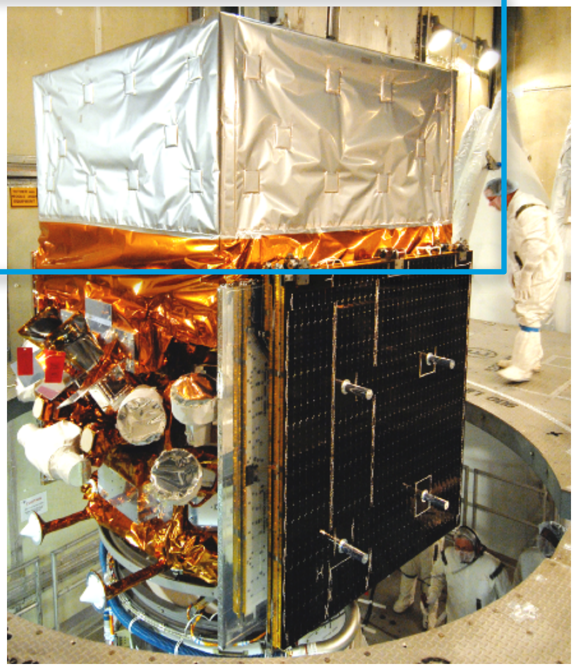
How are gamma-ray bursts detected?

Wide field-of-view gamma-ray monitors



[Fermi]

[NASA/DOE/Fermi-LAT]



Fermi Large Area Telescope

MeV - GeV

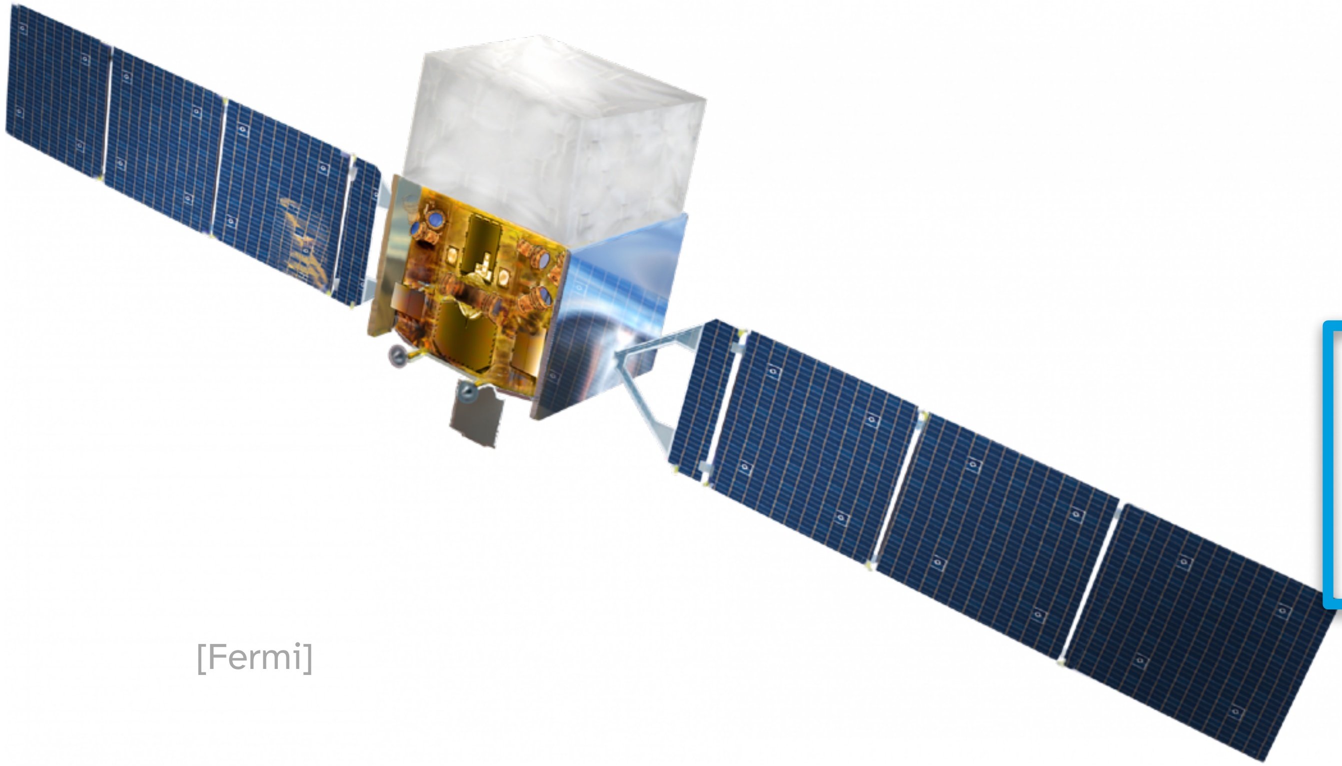
10^{-6} m | 10^{-7} m | 10^{-8} m | 10^{-9} m | 10^{-10} m | 10^{-11} m | 10^{-12} m | 10^{-13} m | 10^{-14} m | 10^{-15} m | 10^{-16} m | 10^{-17} m | 10^{-18} m | 10^{-19} m | 10^{-20} m

ed | opt | ultraviolet | X-rays | gamma rays | high energy gamma rays | very high energy gamma rays

1 eV | 10 eV | 100 eV | 1 keV | 10 keV | 100 keV | 1 MeV | 10 MeV | 100 MeV | 1 GeV | 10 GeV | 100 GeV | 1 TeV | 10 TeV | 100 TeV

How are gamma-ray bursts detected?

Wide field-of-view gamma-ray monitors



[Fermi]

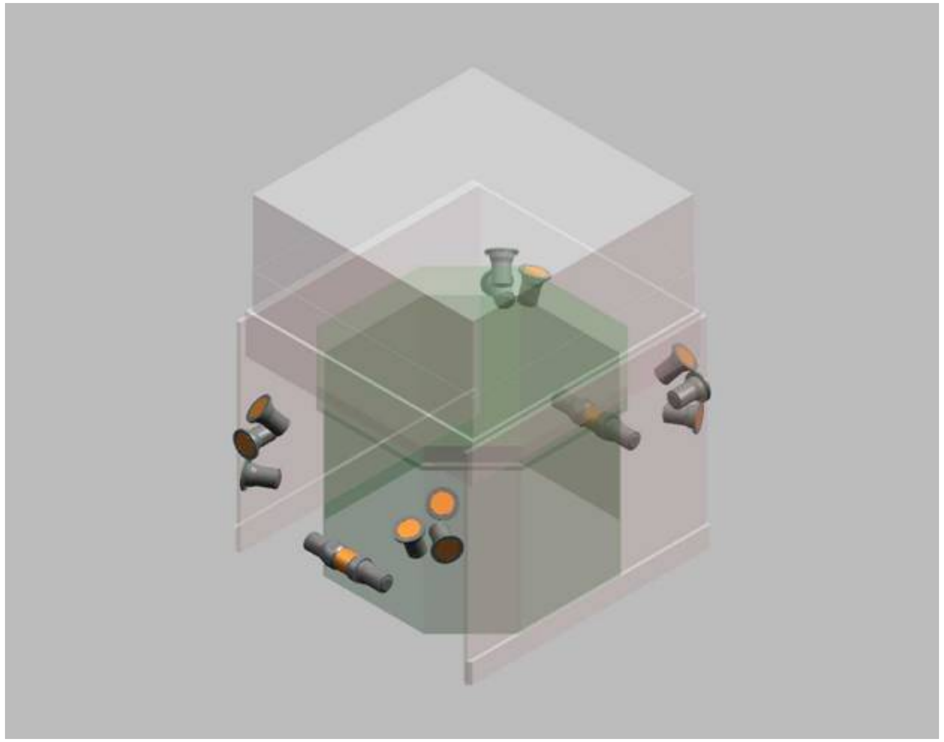
[NASA/DOE/Fermi-LAT]

Fermi Gamma-ray Burst Monitor
keV - MeV

10^{-6} m	10^{-7} m	10^{-8} m	10^{-9} m	10^{-10} m	10^{-11} m	10^{-12} m	10^{-13} m	10^{-14} m	10^{-15} m	10^{-16} m	10^{-17} m	10^{-18} m	10^{-19} m	10^{-20} m
ed opt	ultraviolet	X-rays		gamma rays				high energy gamma rays			very high energy gamma rays			
1 eV	10 eV	100 eV	1 keV	10 keV	100 keV	1 MeV	10 MeV	100 MeV	1 GeV	10 GeV	100 GeV	1 TeV	10 TeV	100 TeV

How are gamma-ray bursts detected?

Wide field-of-view gamma-ray monitors



[NASA/DOE/Fermi-GBM]

[NASA/DOE/Fermi-LAT]

Fermi Gamma-ray Burst Monitor
keV - MeV

10^{-6} m 10^{-7} m 10^{-8} m 10^{-9} m 10^{-10} m 10^{-11} m 10^{-12} m 10^{-13} m 10^{-14} m 10^{-15} m 10^{-16} m 10^{-17} m 10^{-18} m 10^{-19} m 10^{-20} m

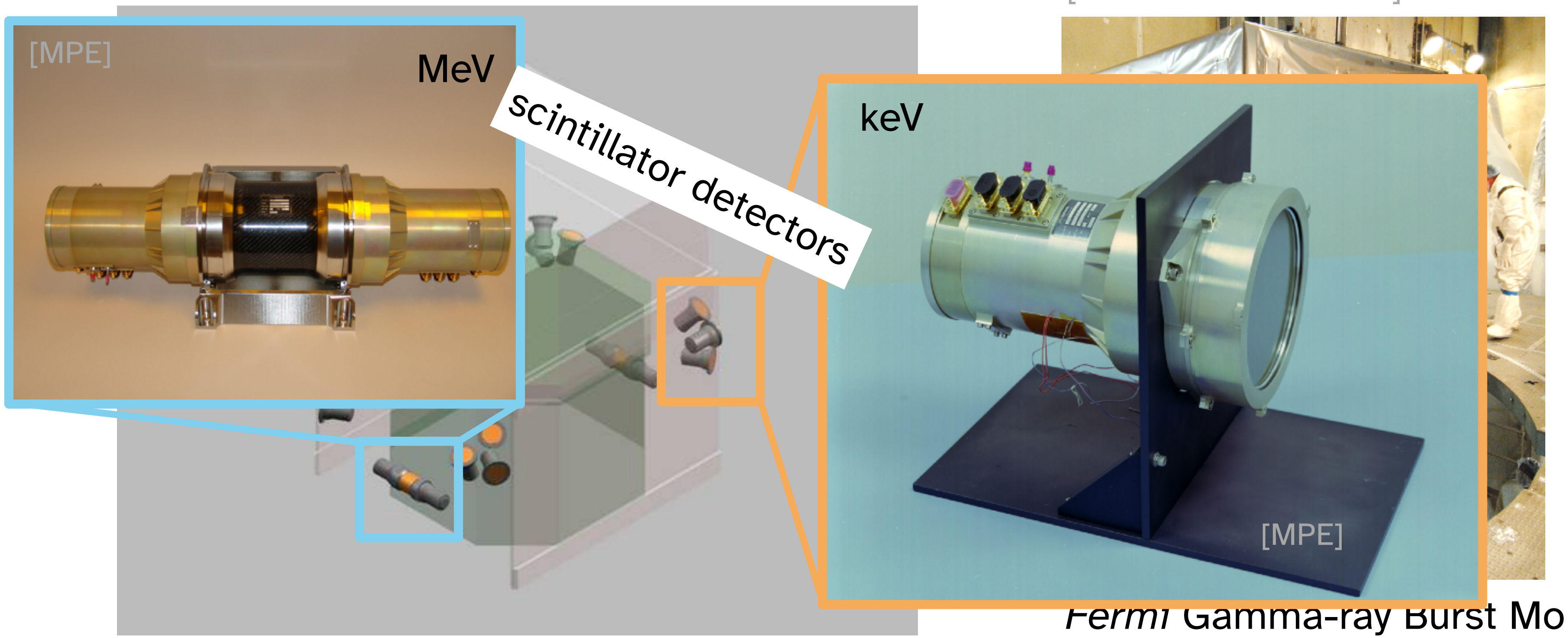
ed opt ultraviolet X-rays gamma rays high energy gamma rays very high energy gamma rays

1 eV 10 eV 100 eV 1 keV 10 keV 100 keV 1 MeV 10 MeV 100 MeV 1 GeV 10 GeV 100 GeV 1 TeV 10 TeV 100 TeV

How are gamma-ray bursts detected?

Wide field-of-view gamma-ray monitors

[NASA/DOE/Fermi-LAT]



[NASA/DOE/Fermi-GBM]

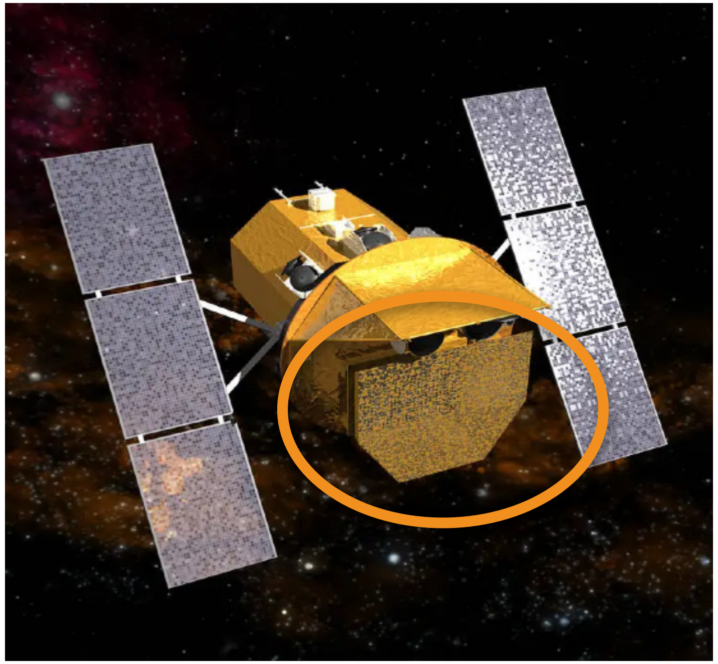
Fermi Gamma-ray Burst Monitor
keV - MeV

10^{-6} m	10^{-7} m	10^{-8} m	10^{-9} m	10^{-10} m	10^{-11} m	10^{-12} m	10^{-13} m	10^{-14} m	10^{-15} m	10^{-16} m	10^{-17} m	10^{-18} m	10^{-19} m	10^{-20} m
ed opt	ultraviolet	X-rays		gamma rays				high energy gamma rays			very high energy gamma rays			
1 eV	10 eV	100 eV	1 keV	10 keV	100 keV	1 MeV	10 MeV	100 MeV	1 GeV	10 GeV	100 GeV	1 TeV	10 TeV	100 TeV

How are gamma-ray bursts detected?

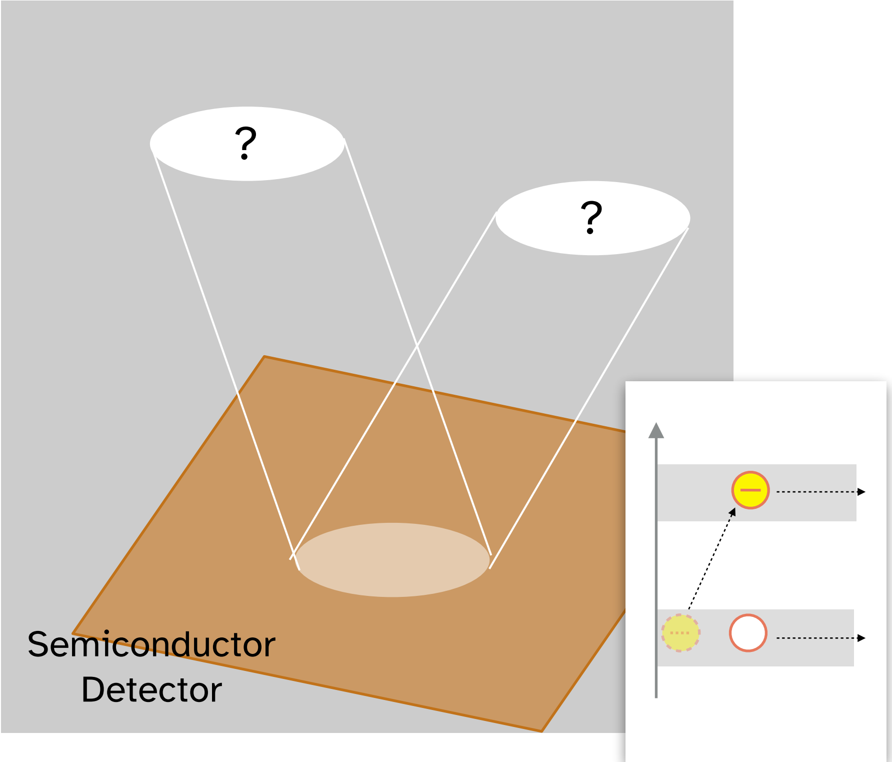
Wide field-of-view gamma-ray monitors

[NASA]



Swift Burst Alert Telescope

keV



10^{-6} m	10^{-7} m	10^{-8} m	10^{-9} m	10^{-10} m	10^{-11} m	10^{-12} m	10^{-13} m	10^{-14} m	10^{-15} m	10^{-16} m	10^{-17} m	10^{-18} m	10^{-19} m	10^{-20} m
ed opt	ultraviolet	X-rays		gamma rays				high energy gamma rays			very high energy gamma rays			
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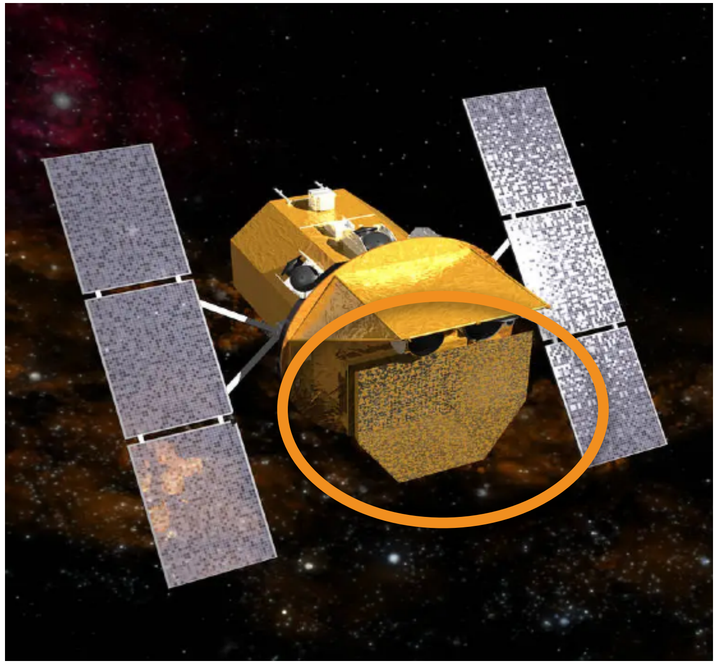
How are gamma-ray bursts detected?

Wide field-of-view gamma-ray monitors

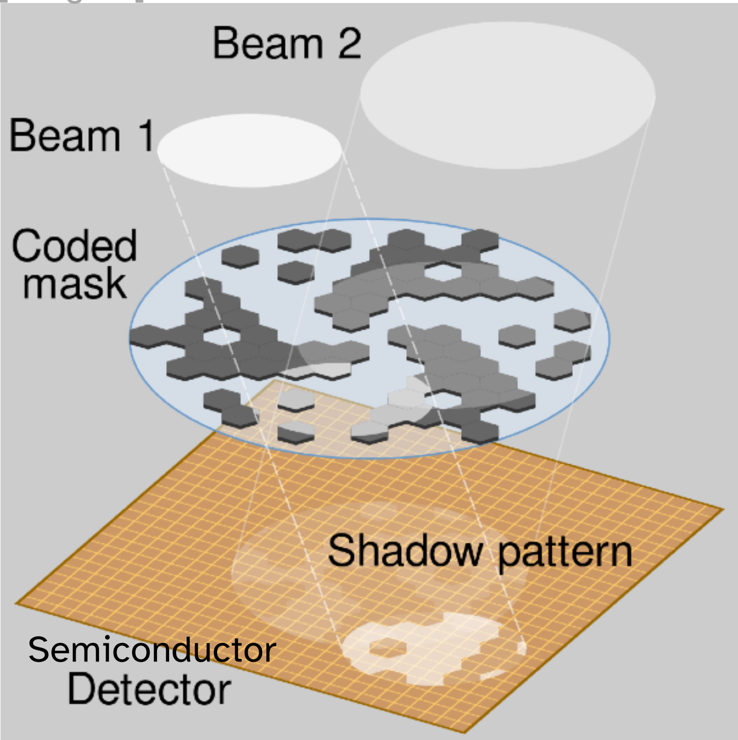
[NASA]



Swift Burst Alert Telescope

keV

[Cmglee]



10^{-6} m	10^{-7} m	10^{-8} m	10^{-9} m	10^{-10} m	10^{-11} m	10^{-12} m	10^{-13} m	10^{-14} m	10^{-15} m	10^{-16} m	10^{-17} m	10^{-18} m	10^{-19} m	10^{-20} m
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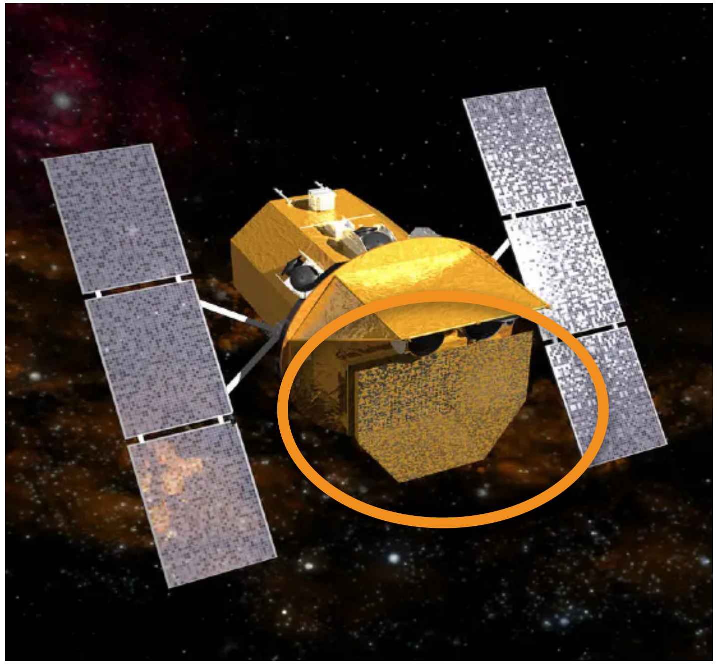
How are gamma-ray bursts detected?

Wide field-of-view gamma-ray monitors

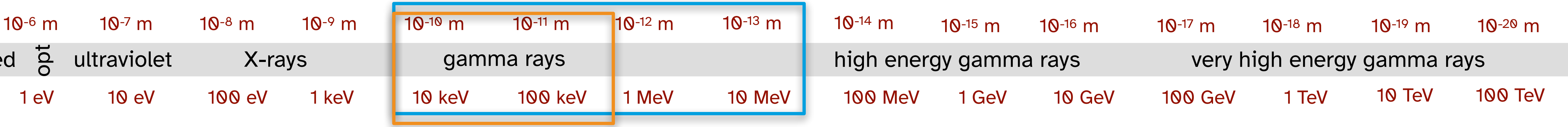
[NASA]



Swift Burst Alert Telescope
keV

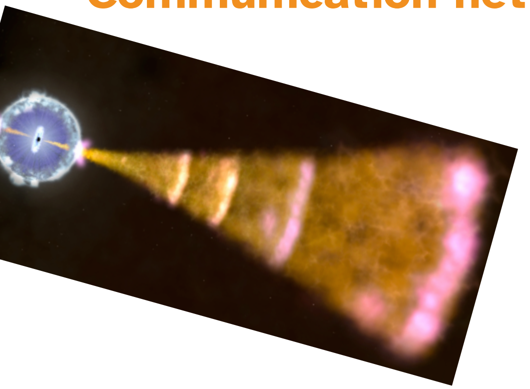
[NASA/DOE/Fermi-LAT]

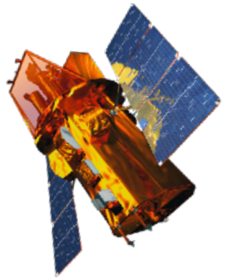
Fermi Gamma-ray Burst Monitor
keV - MeV

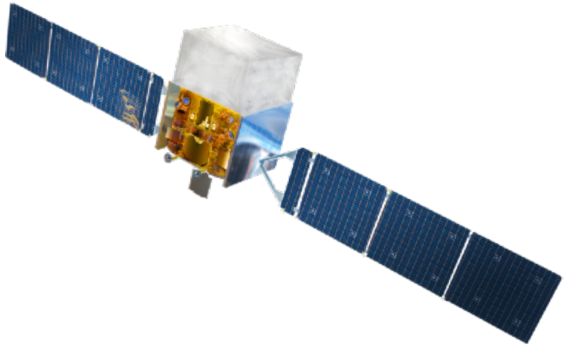


How are gamma-ray bursts detected?

Communication networks







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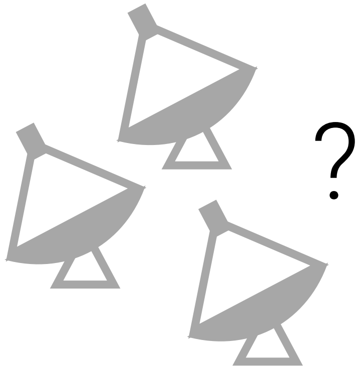
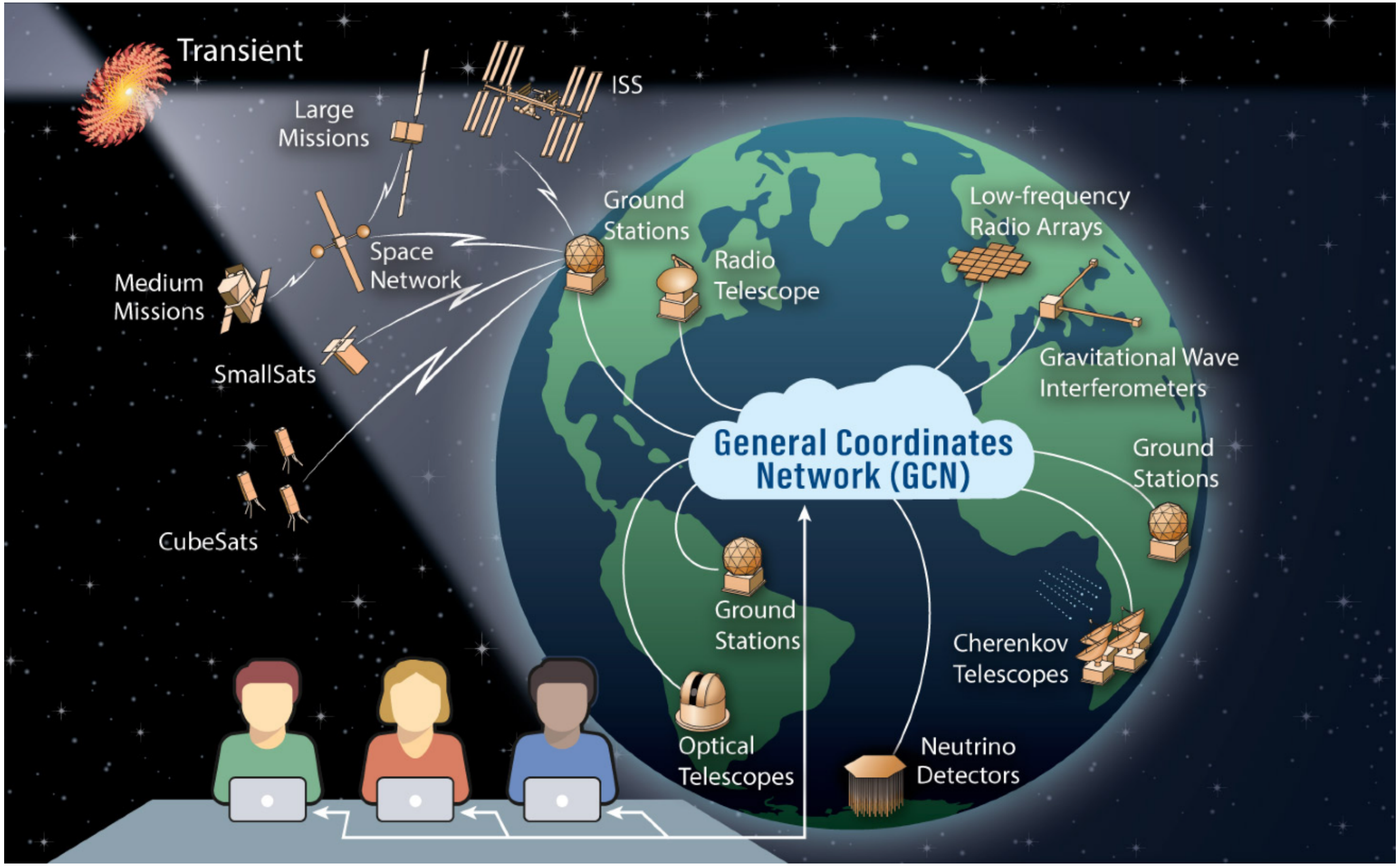


How are gamma-ray bursts detected?

Communication networks

[NASA]



How do IACTs decide what to observe and when?

Transient follow-up systems

alert handling
- decision to observe
- communication with control software

What kind of alerts are we interested in?
From which telescopes?
When are the sources observable?
How do we want to observe them?

control software
- schedule observations

When do we insert the observation into the schedule?
Do the telescopes have to respond immediately?

realtime analysis
- low latency results

Did we detect anything?

How do IACTs decide what to observe and when?

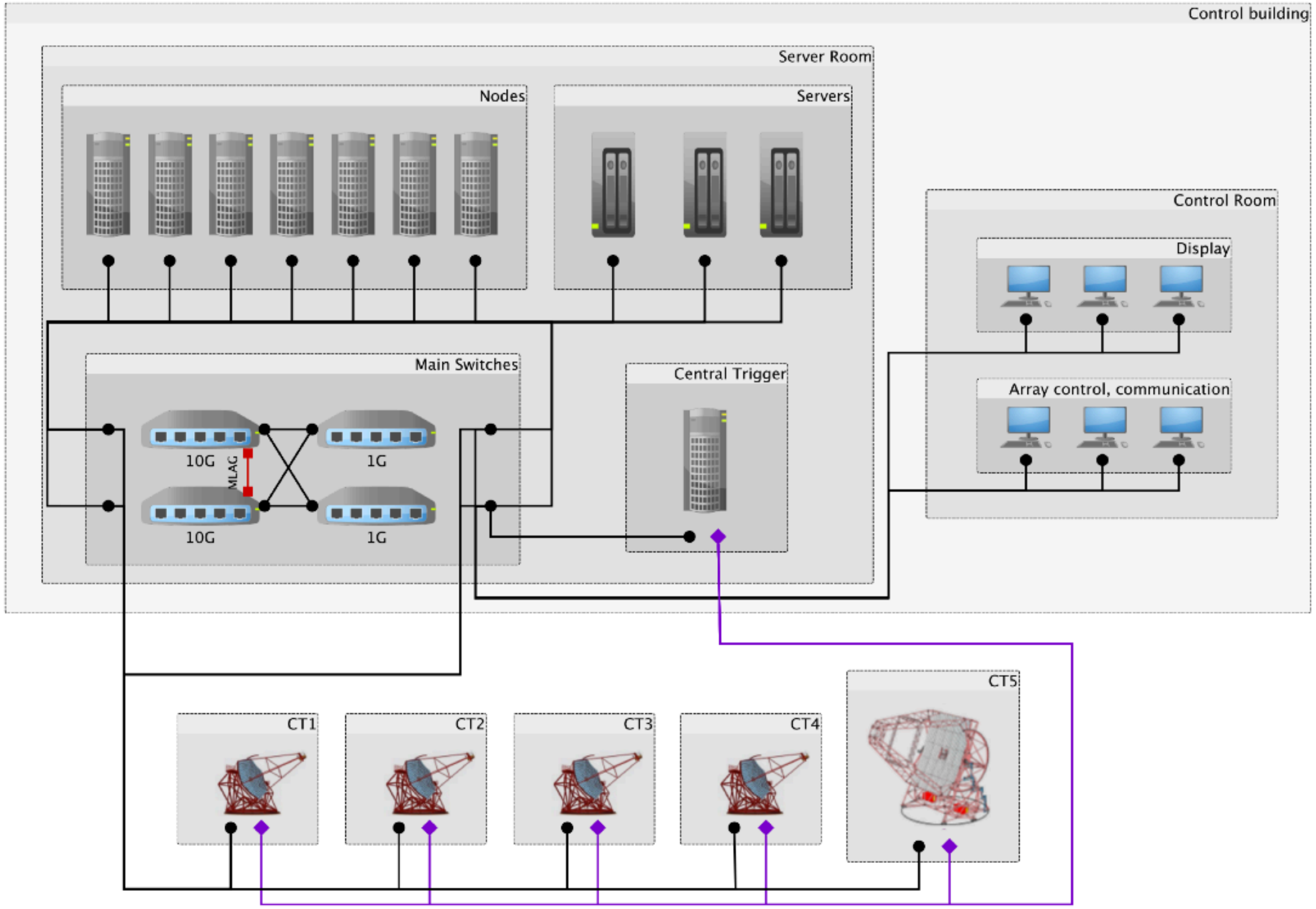
Transient follow-up systems

alert handling
- decision to observe
- communication with control software

control software
- schedule observations

realtime analysis
- low latency results

data acquisition system / DAQ (simplified)



[S. J. Zhu et al., ICRC 2021]

How do IACTs decide what to observe and when?

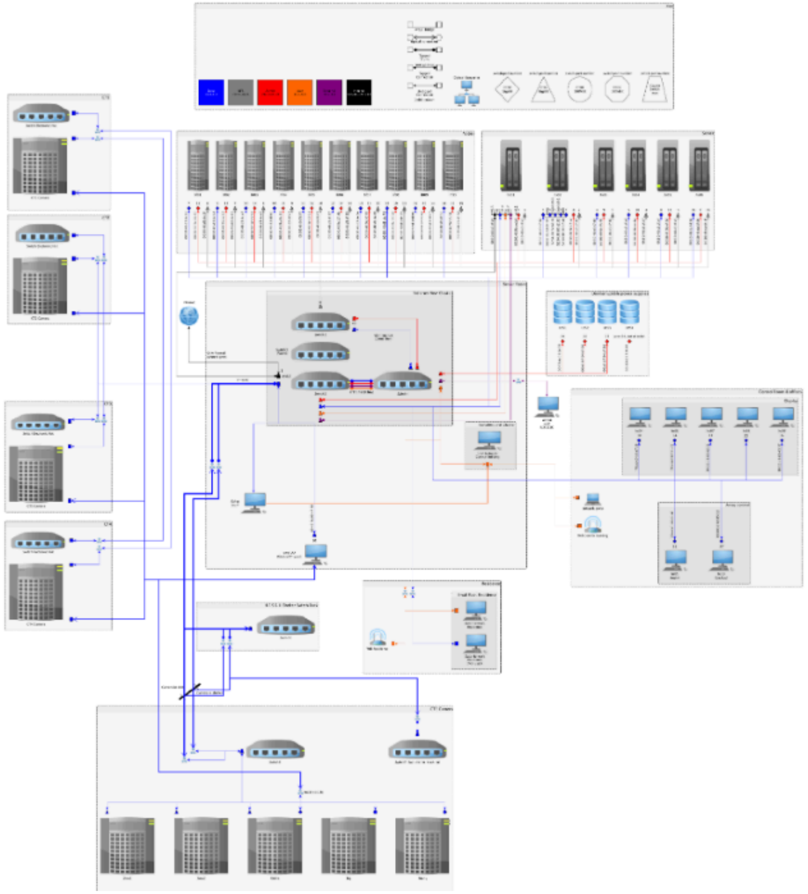
Transient follow-up systems

alert handling
- decision to observe
- communication with control software

control software
- schedule observations

realtime analysis
- low latency results

data acquisition system / DAQ (full)



How do IACTs decide what to observe and when?

Transient follow-up systems

alert handling
- decision to observe
- communication with control software

What kind of alerts are we interested in?
From which telescopes?
When are the sources observable?
How do we want to observe them?

control software
- schedule observations

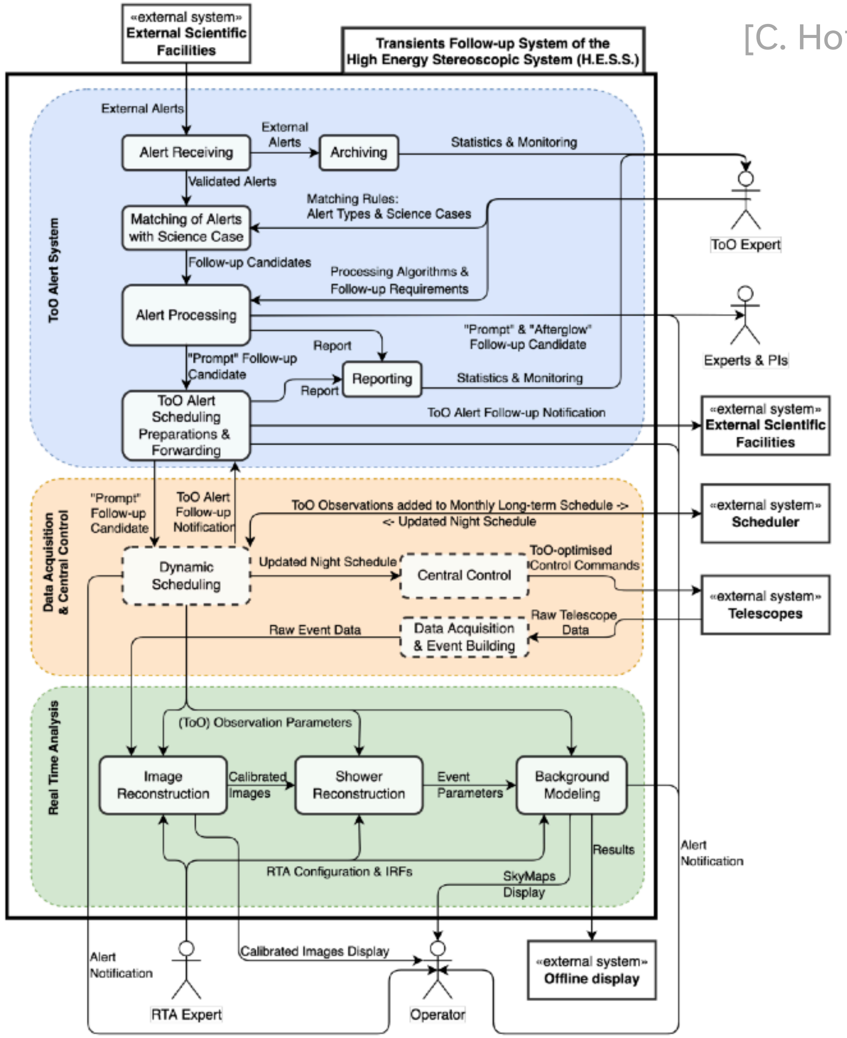
When do we insert the observation into the schedule?
Do the telescopes have to respond immediately?

realtime analysis
- low latency results

Did we detect anything?

How do IACTs decide what to observe and when?

Transient follow-up systems



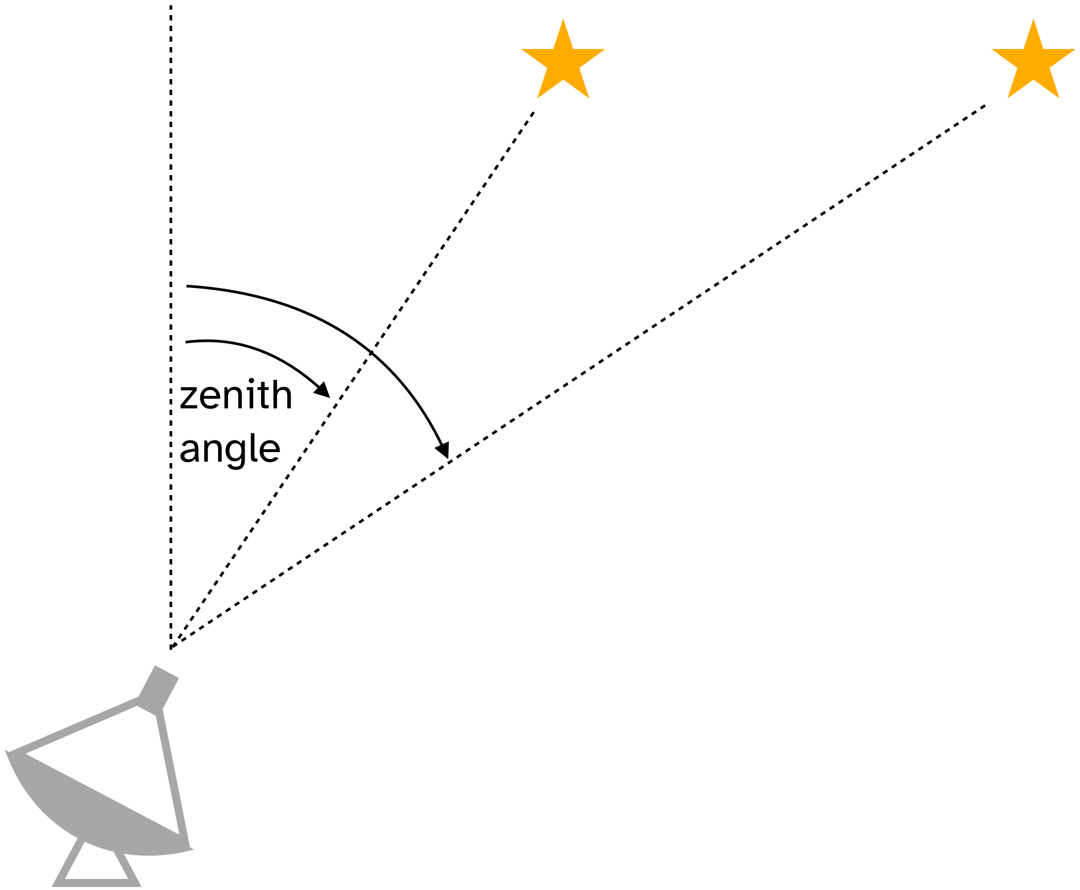
[C. Hoischen et al., A&A 666 (2022)]

Examples of subtleties that we might encounter:

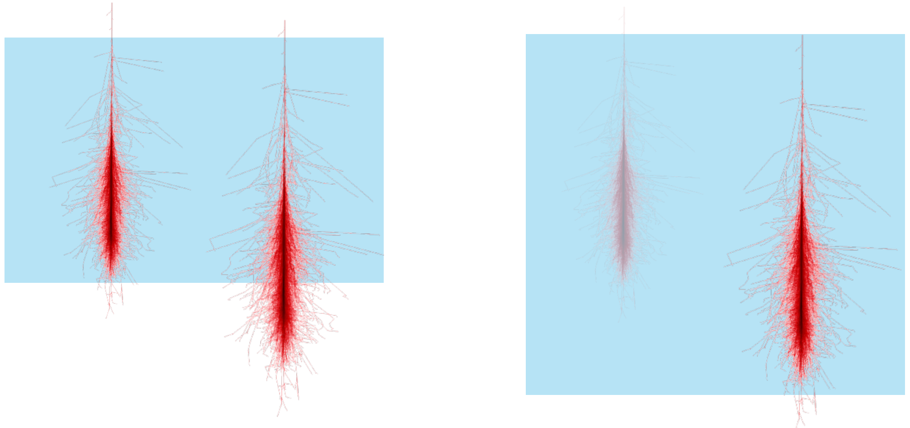
- What cuts might we need to include?
- What happens if two alerts come in at the same time?
- What happens if an alert comes in while the telescopes are taking calibration data?
- What happens if an alert comes in while the telescopes are transitioning between runs?
- If the array reacts automatically: How can we be sure nothing breaks?
- What kind of analysis do we want to run?

How do IACTs decide what to observe and when?

General considerations for IACT observations



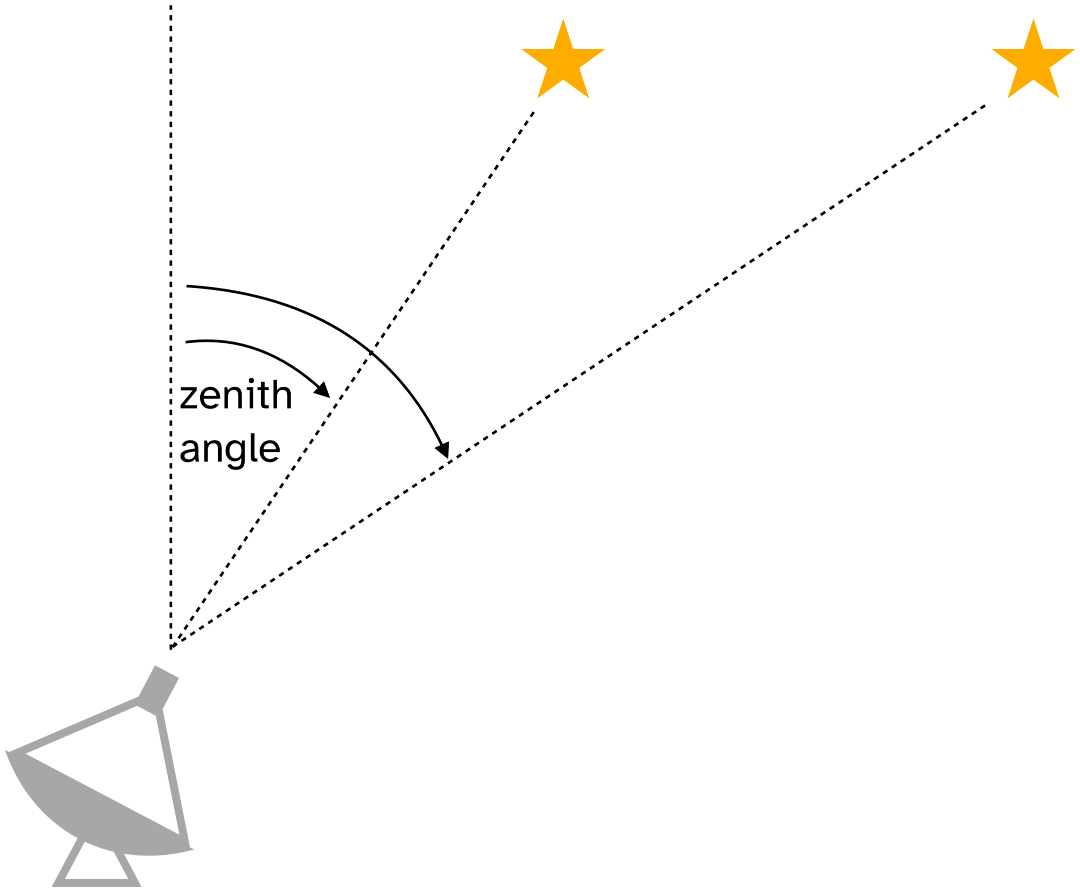
1. When is it dark enough to observe?
2. When is the source high enough in the sky? (i.e., with sufficiently small zenith angle)



larger zenith angle -> more atmosphere to go through
-> more absorption of Cherenkov photons

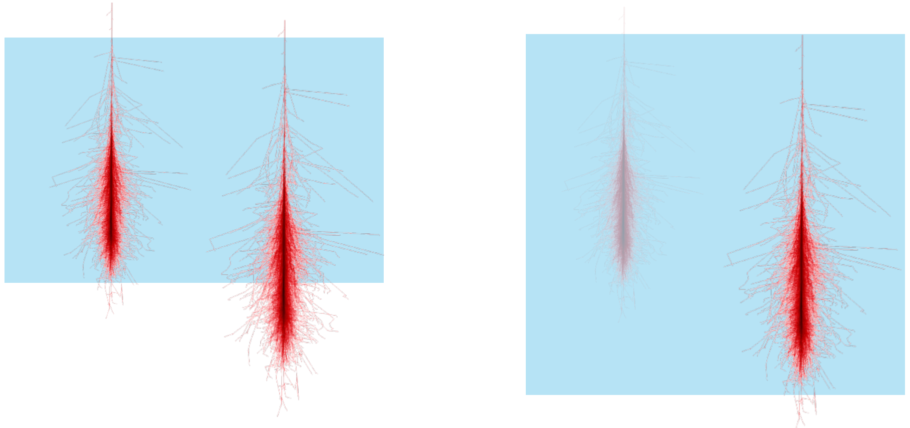
How do IACTs decide what to observe and when?

General considerations for IACT observations



How far below the horizon do the Sun and Moon have to be? How bright can the Moon be? Are there certain parts of the sky that are too bright in general?

1. When is it dark enough to observe?
2. When is the source high enough in the sky? (i.e., with sufficiently small zenith angle)



larger zenith angle -> more atmosphere to go through
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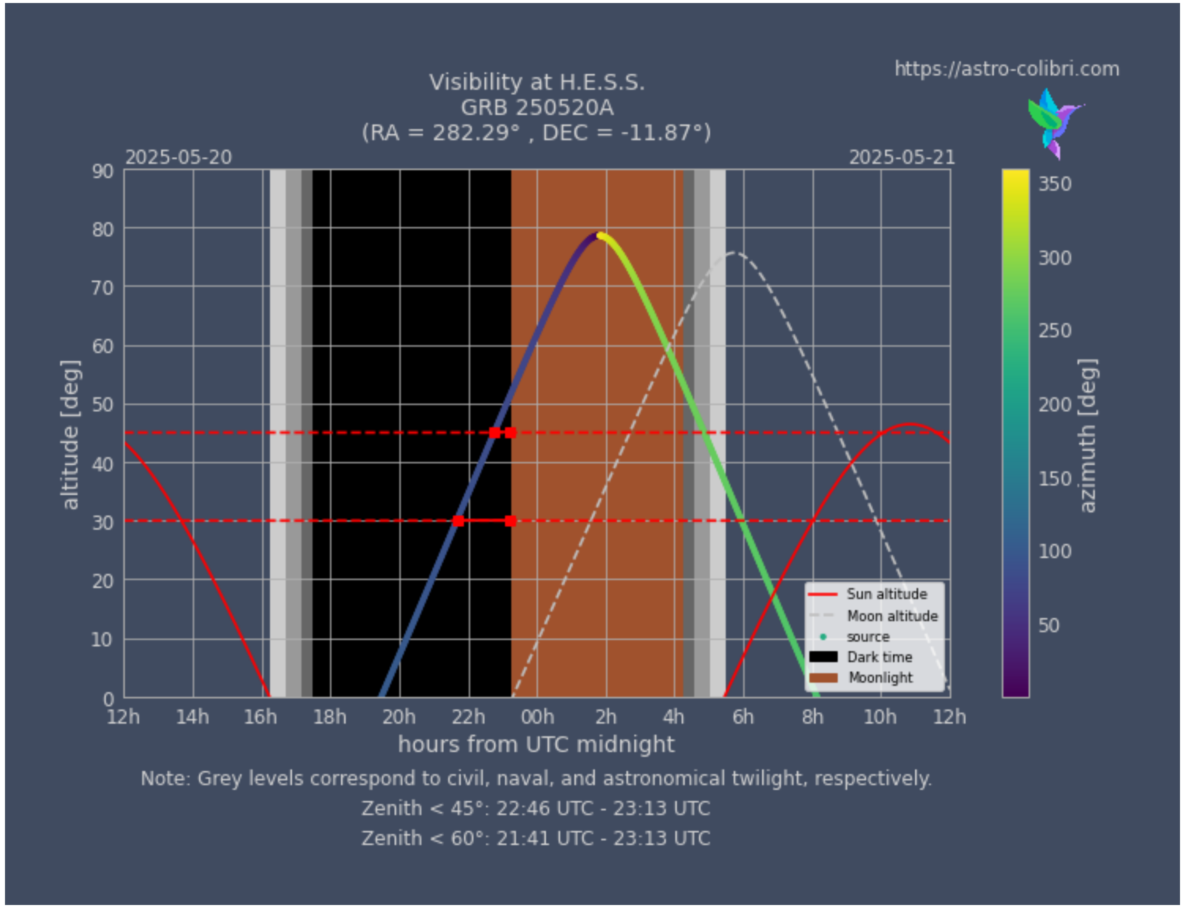
How do IACTs decide what to observe and when?

General considerations for IACT observations

Putting it all together:



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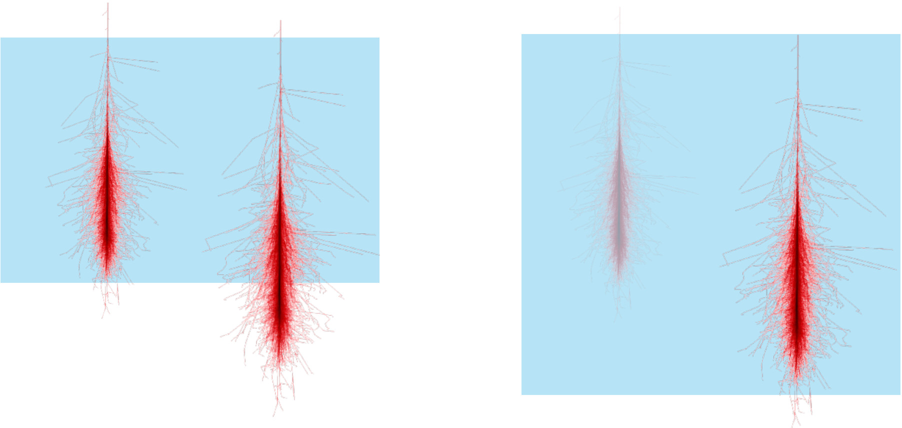
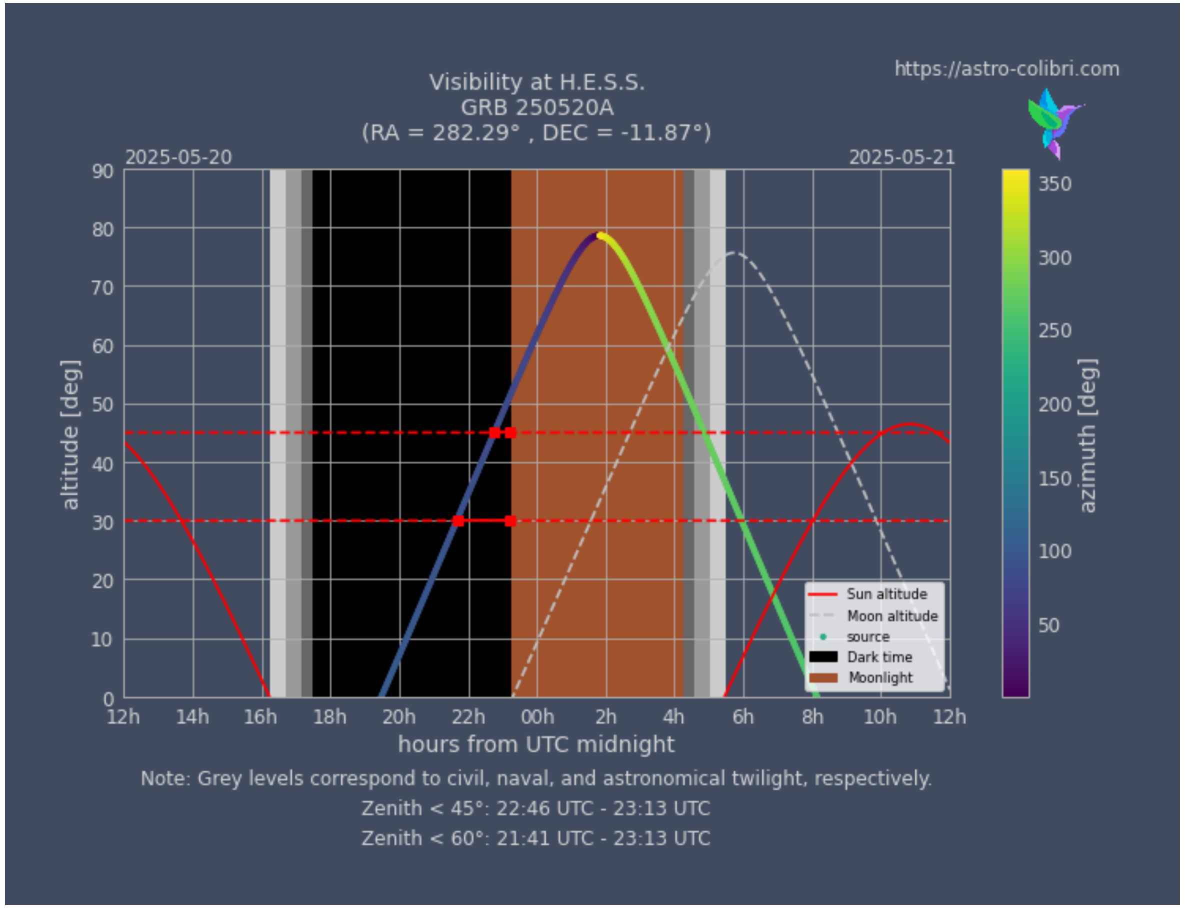


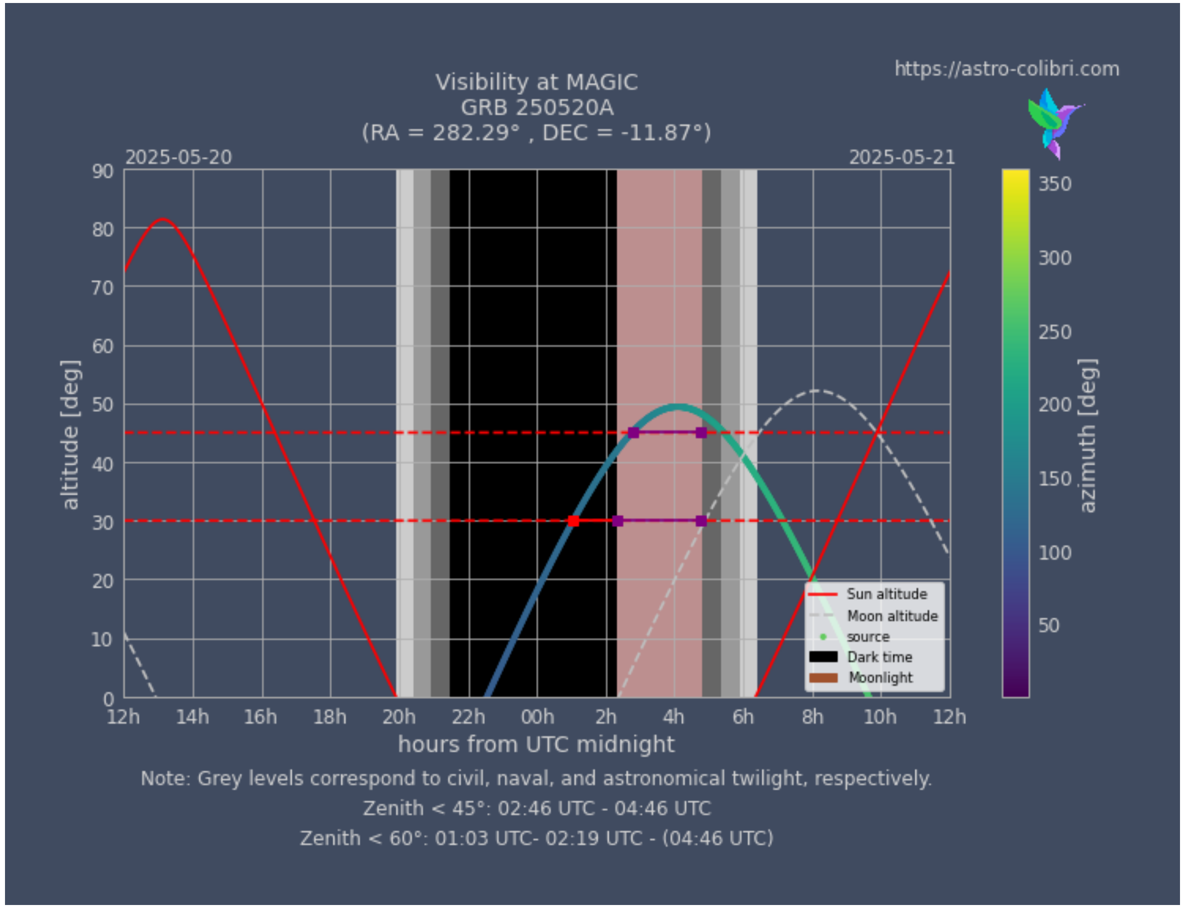
larger zenith angle -> more atmosphere to go through
-> more absorption of Cherenkov photons

How do IACTs decide what to observe and when?

General considerations for IACT observations

Visibility depends on the location of your site

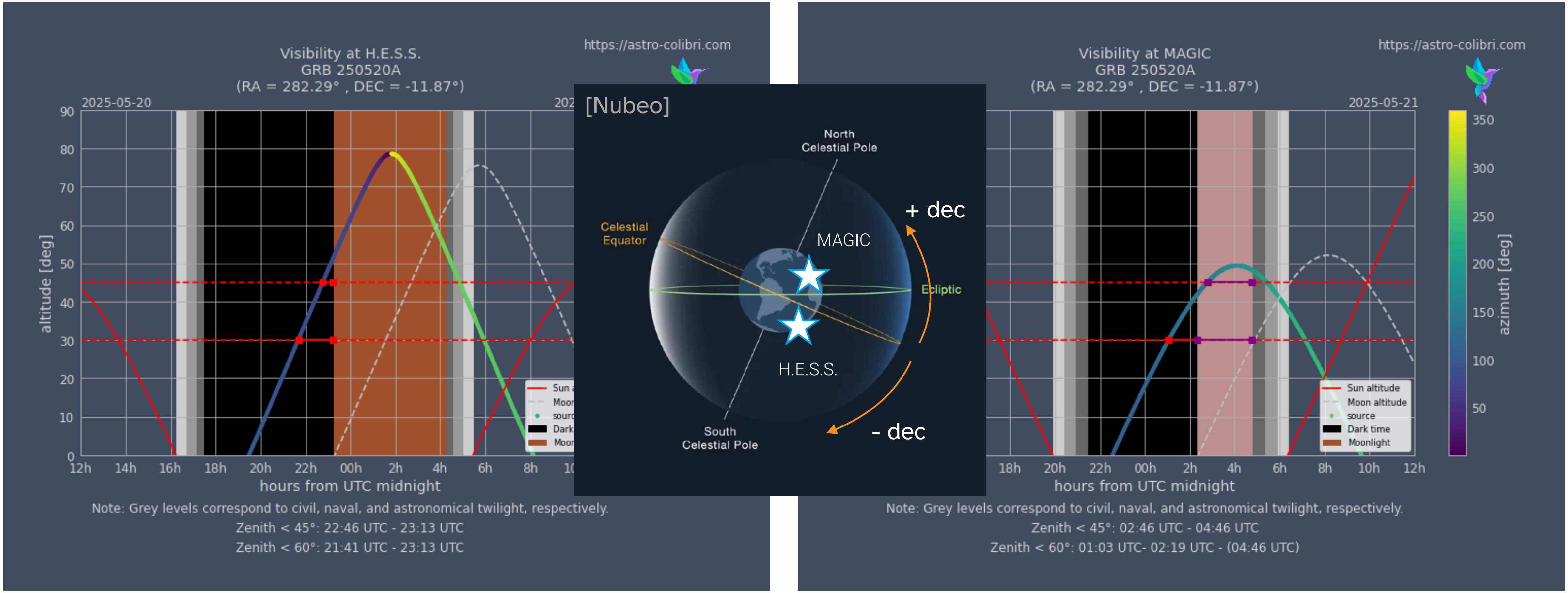




How do IACTs decide what to observe and when?

General considerations for IACT observations

Visibility depends on the location of your site



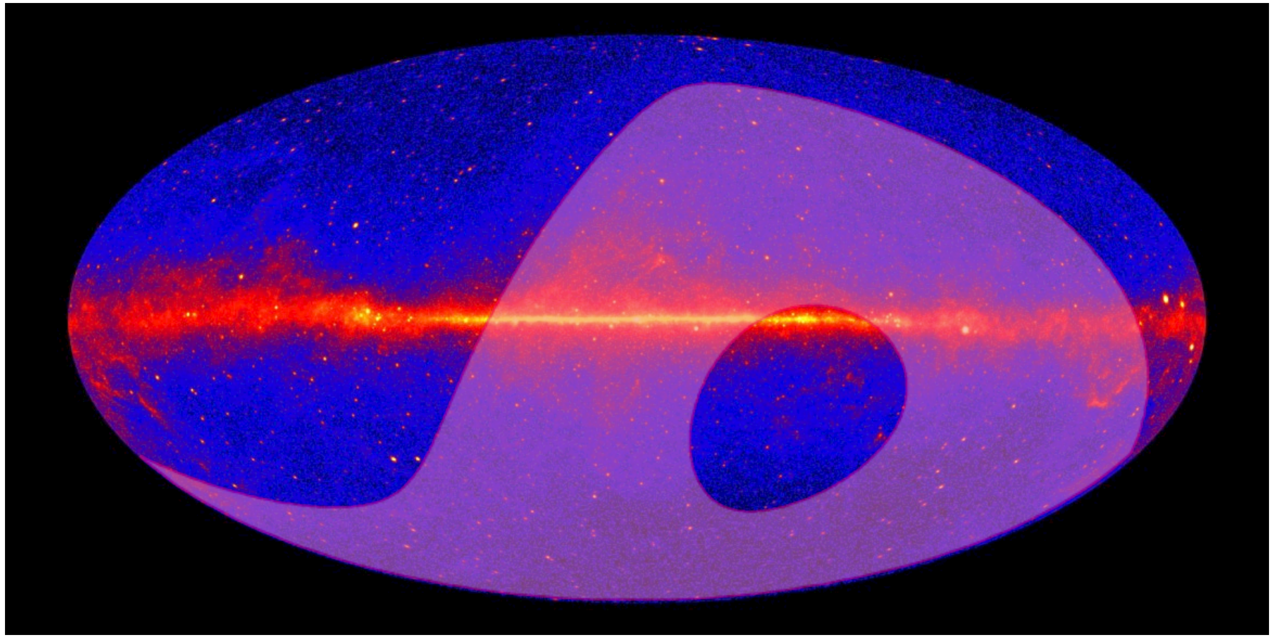
How do IACTs decide what to observe and when?

General considerations for IACT observations

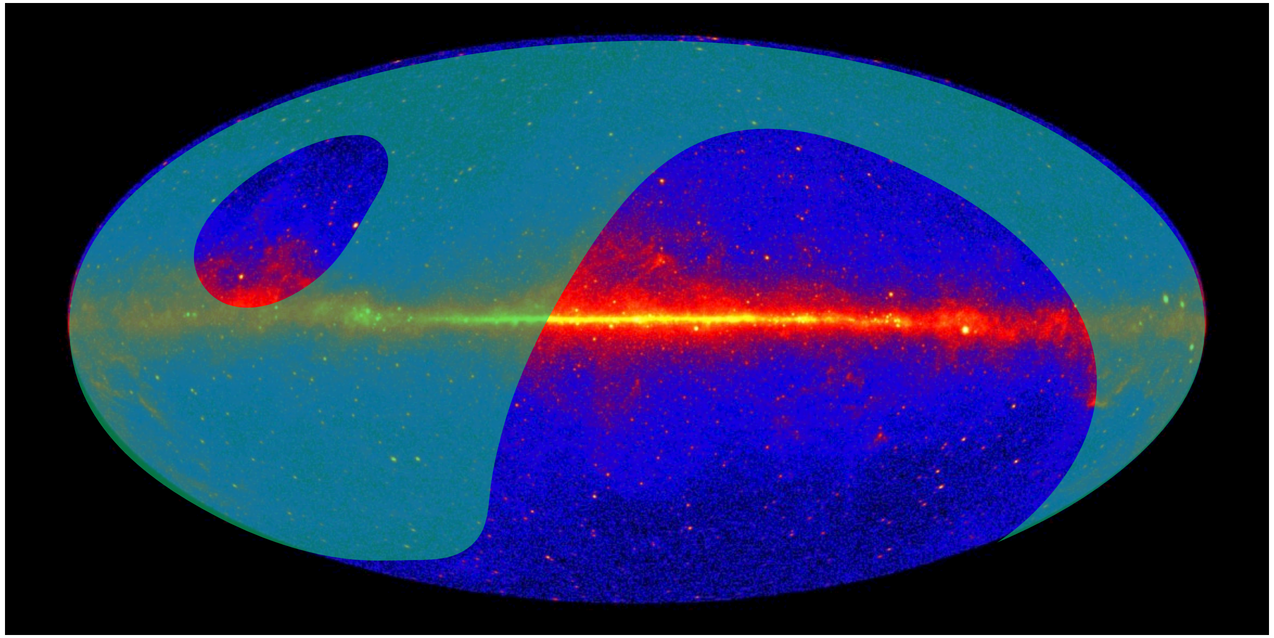
Visibility depends on the location of your site

(note: these particular contours are conservative)

H.E.S.S.



VERITAS/MAGIC



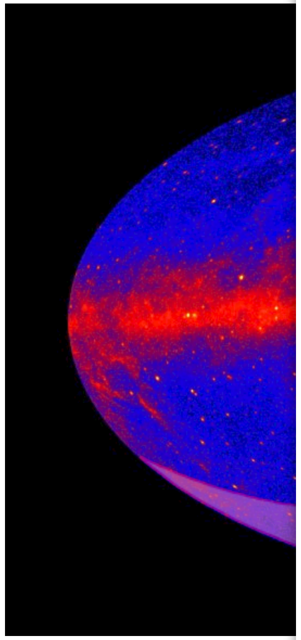
Shown here: Galactic coordinates (≠ ra, dec!)

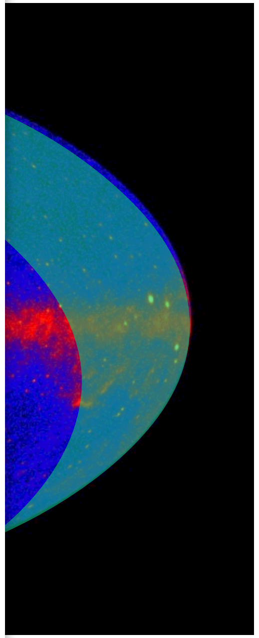
contours made with the aid of [TeVCat]

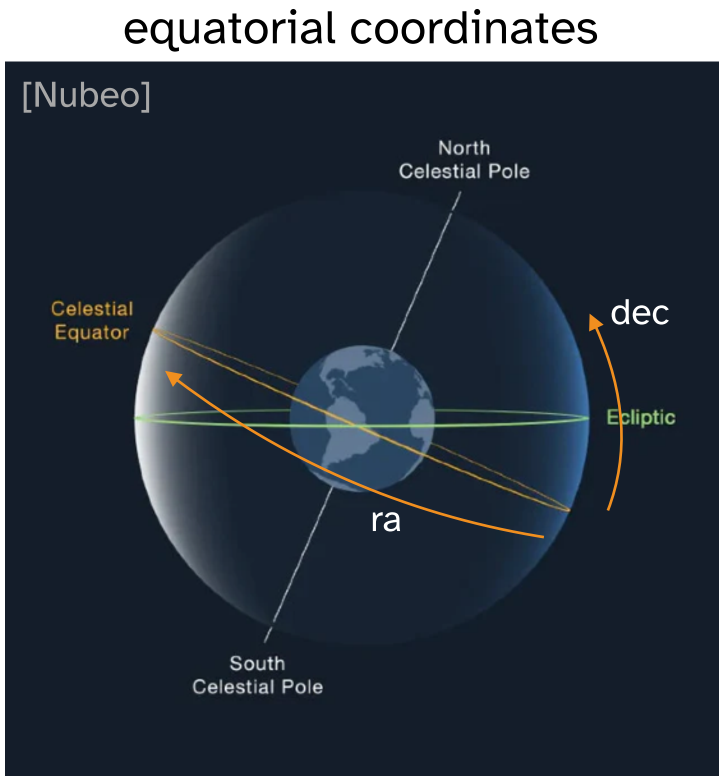
How do IACTs decide what to observe and when?

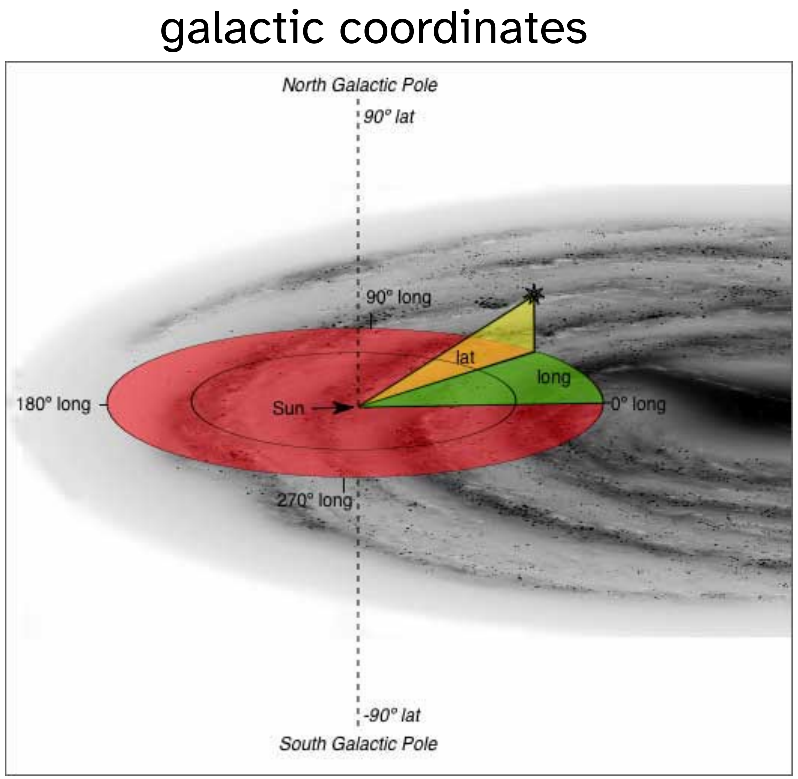
General considerations for IACT observations

Visibility c ... vative)







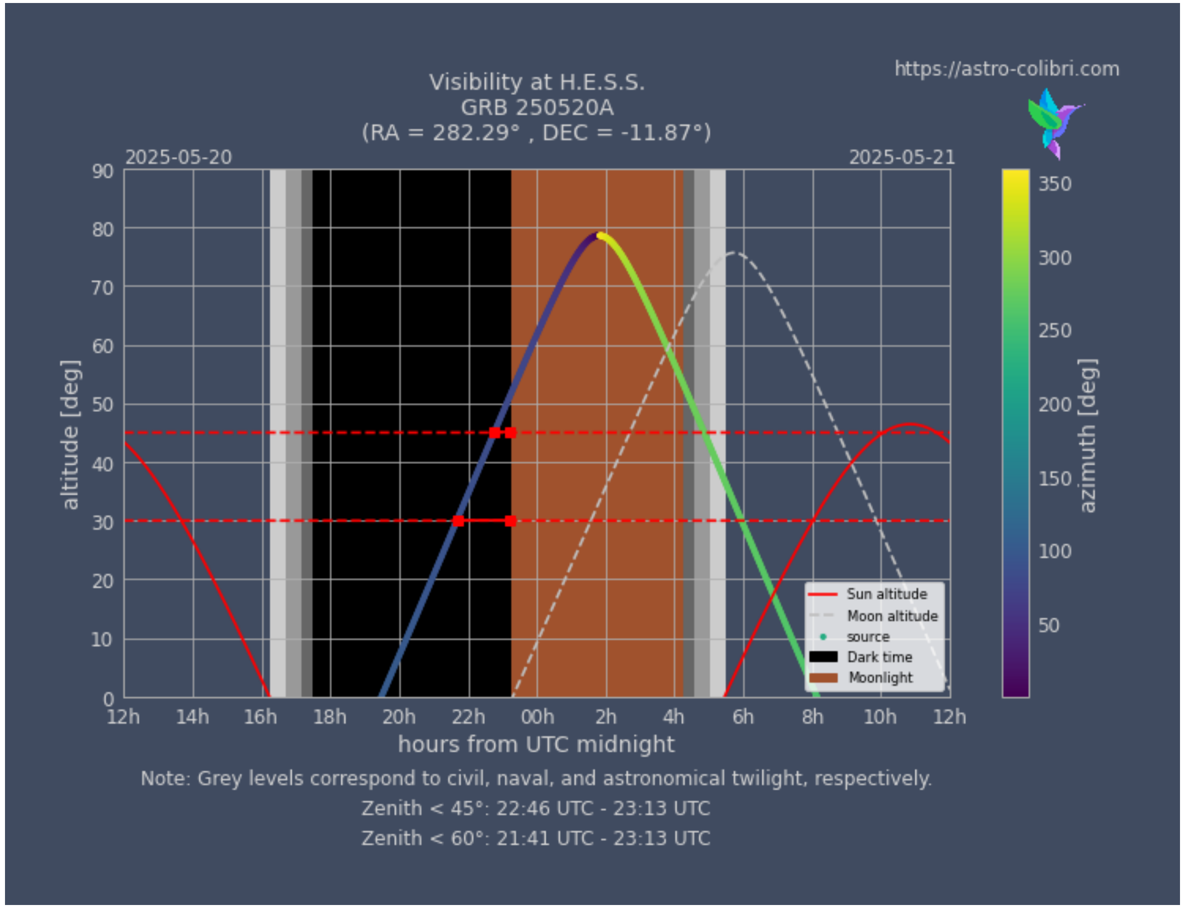


contours made with the aid of [TeVCat]

How do IACTs decide what to observe and when?

General considerations for IACT observations

Putting it all together:



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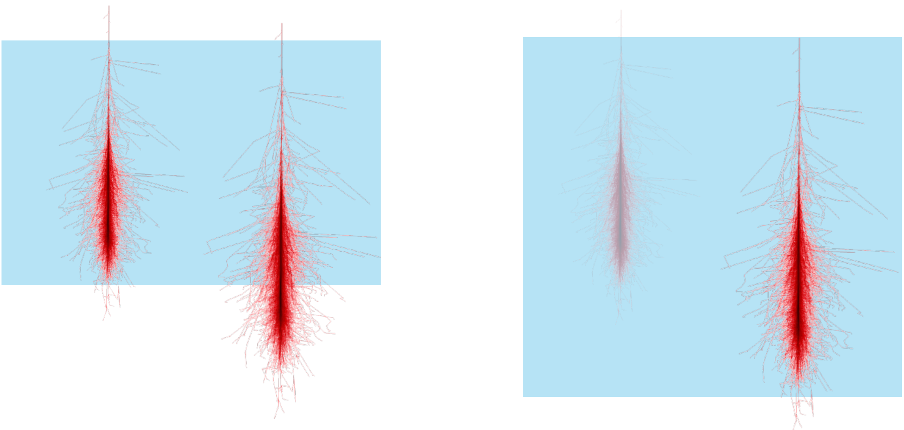
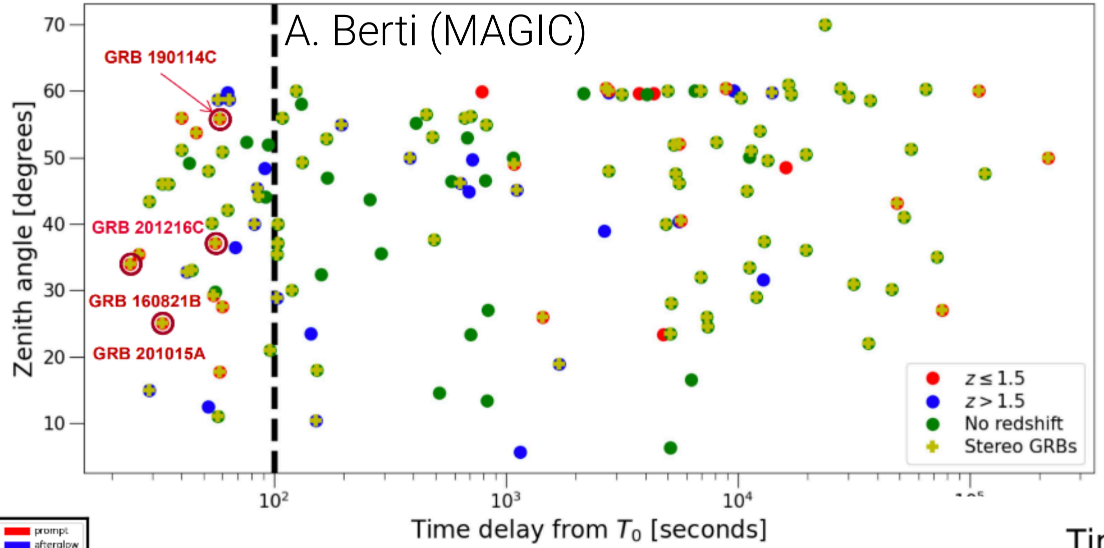
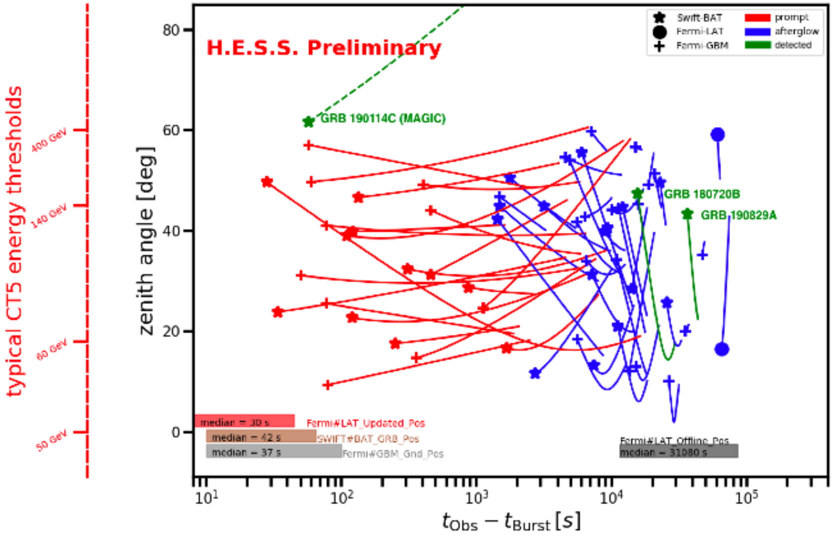


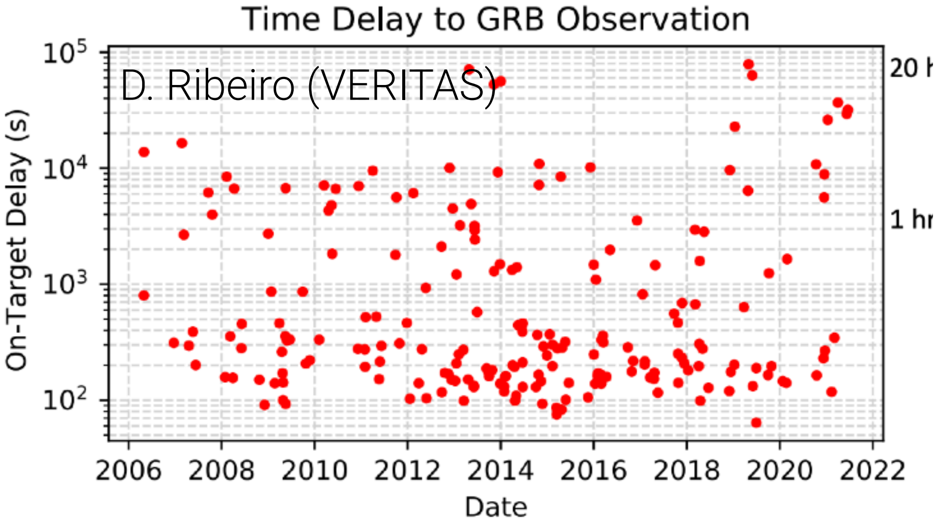
larger zenith angle -> more atmosphere to go through
-> more absorption of Cherenkov photons

IACT GRB observations

(note: these plots are a few years out of date)



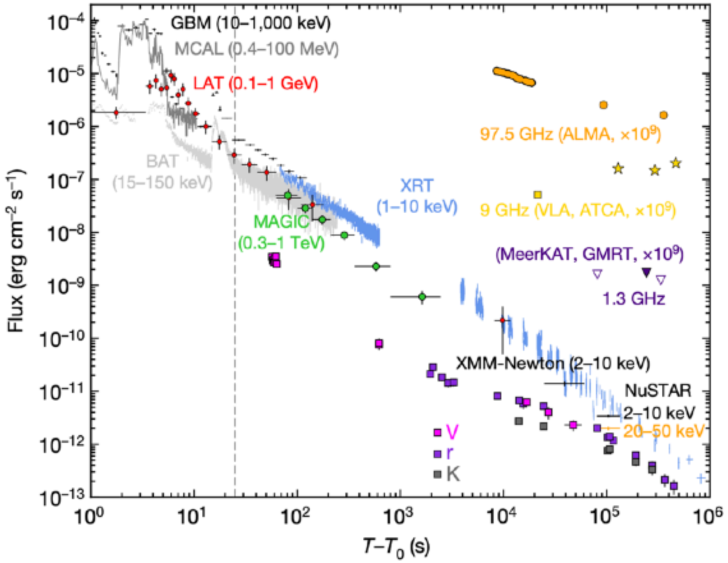




VHE GRB detections

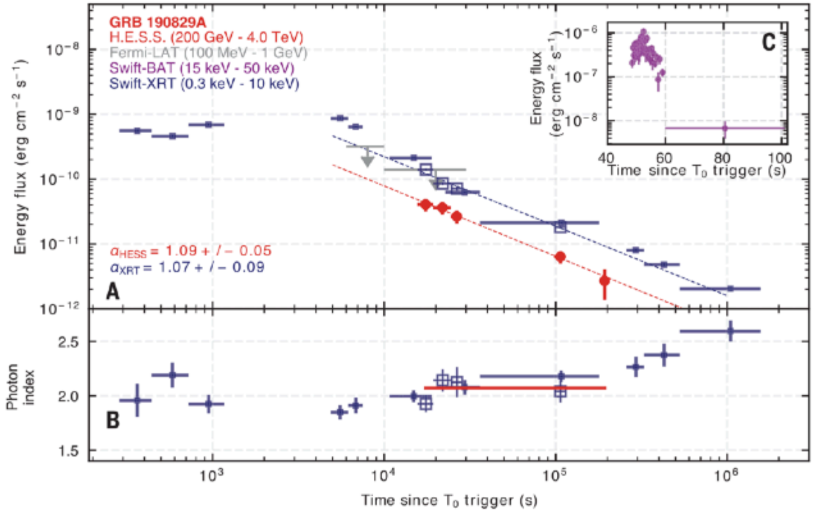
GRB 190114C

[MAGIC, Nature 575 (2019)]



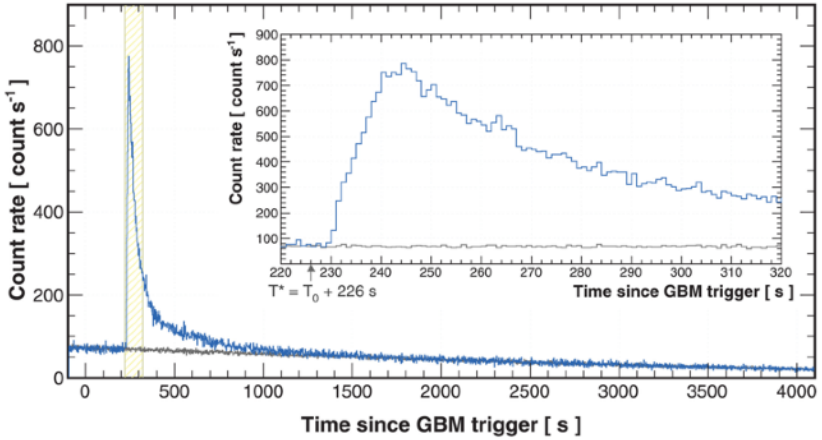
GRB 190829A

[H.E.S.S. et al., Science 372 (2021)]



GRB 221009A

[LHAASO, Science 380 (2023)]



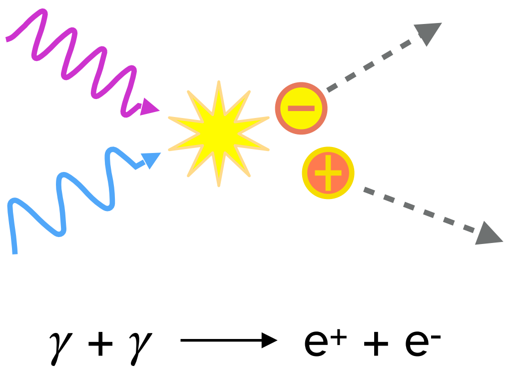
(We'll discuss these briefly later)

(plus a few more)

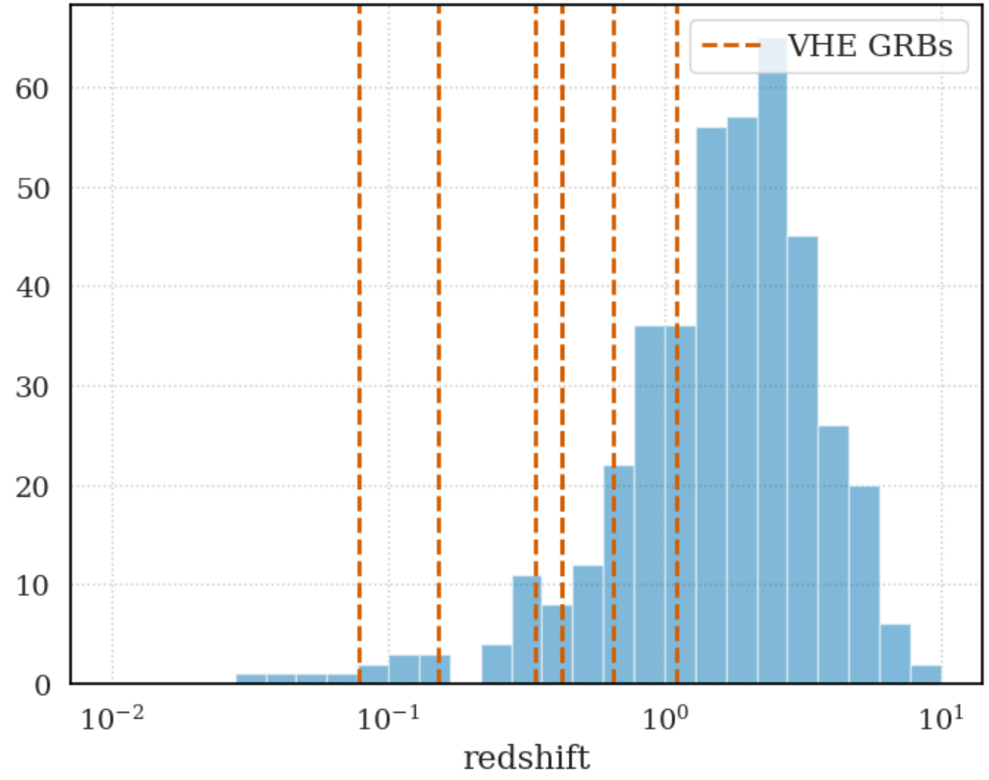
Why haven't we detected more VHE GRBs?

EBL absorption

The GRBs detected at VHE energies have all been very close (all redshifts $z \lesssim 1$)



Gamma rays ≳100 GeV pair produce with the optical/infrared background (from star formation, active galaxies)



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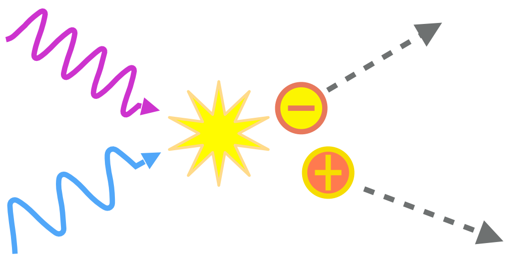
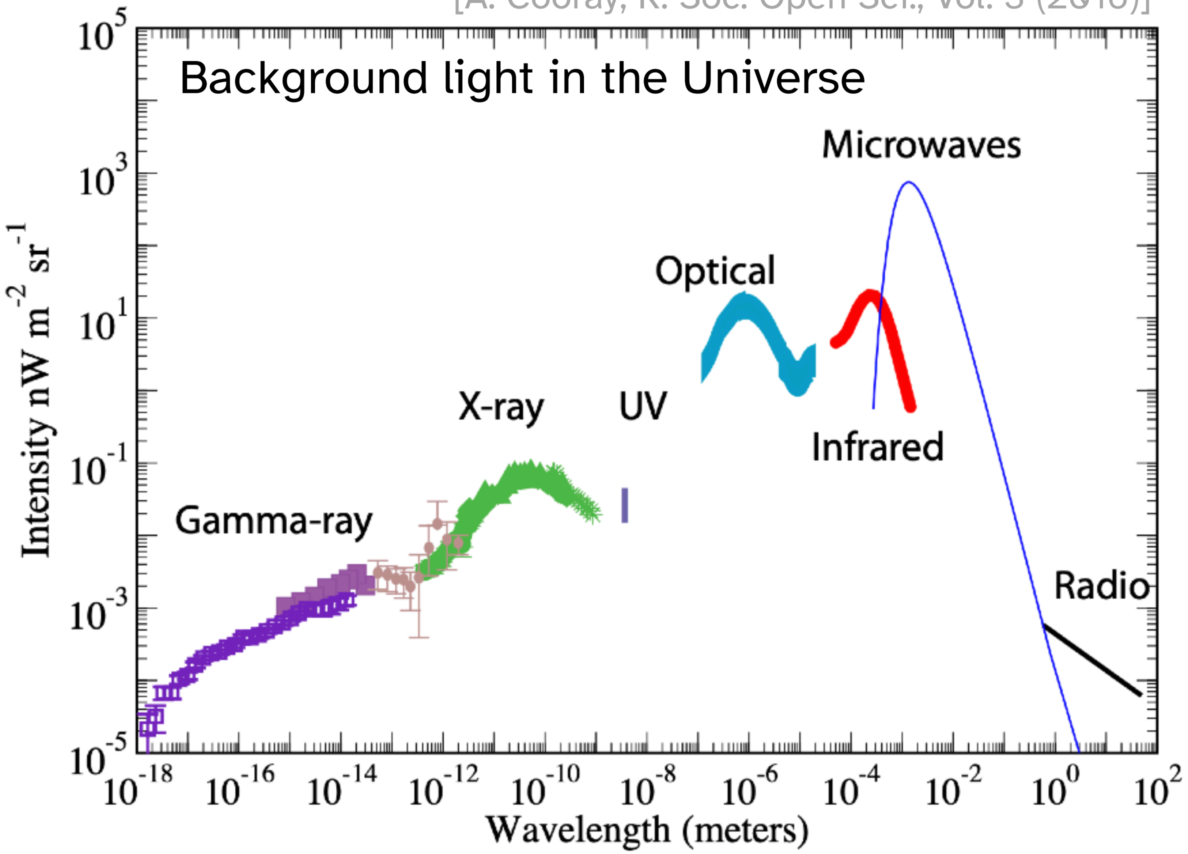


$\gamma + \gamma \longrightarrow e^+ + e^-$

Gamma rays ≳100 GeV pair produce with the optical/infrared background (from star formation, active galaxies)

[A. Cooray, R. Soc. Open Sci., Vol. 3 (2016)]



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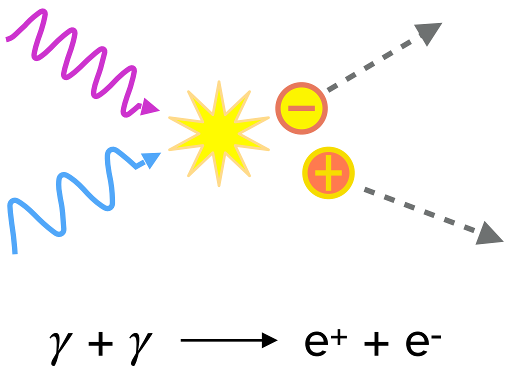
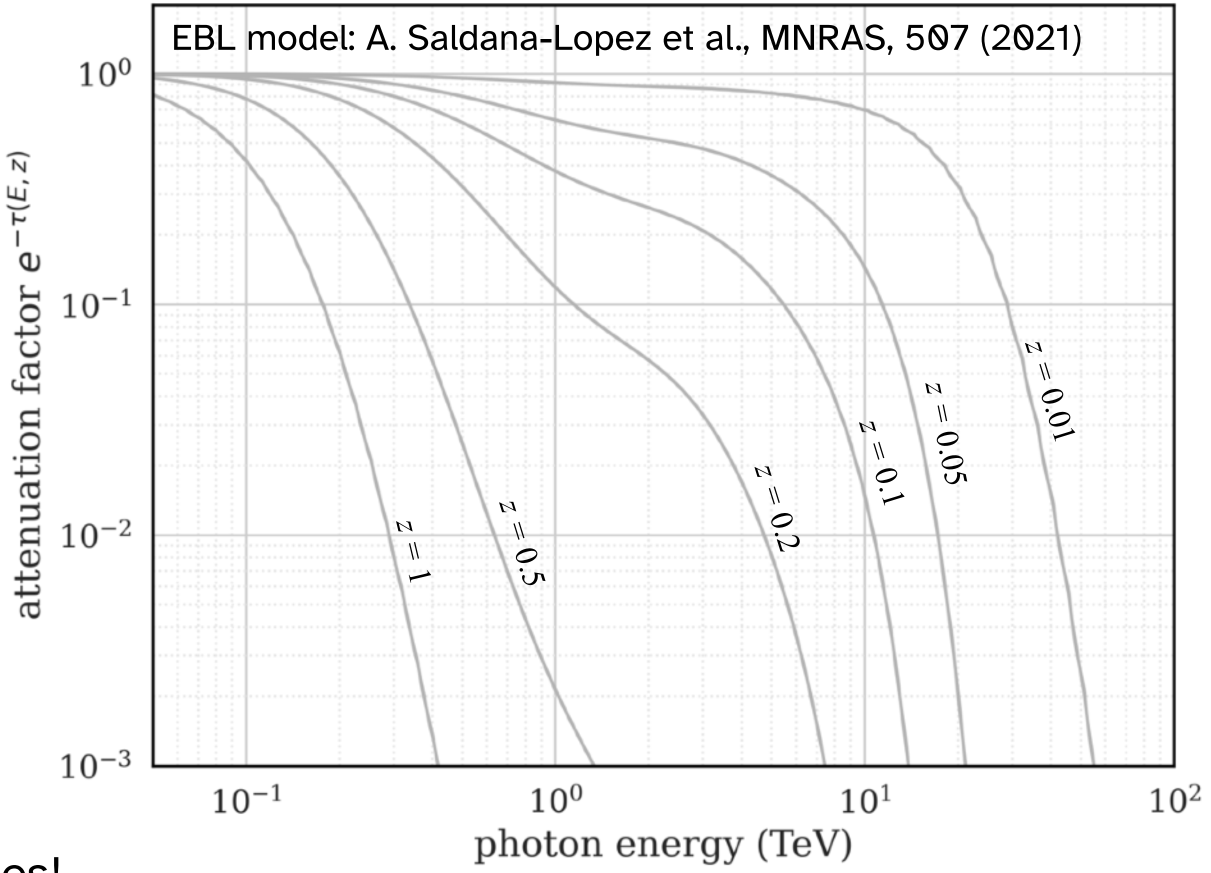




Gamma rays ≳100 GeV pair produce with the optical/infrared background (from star formation, active galaxies)

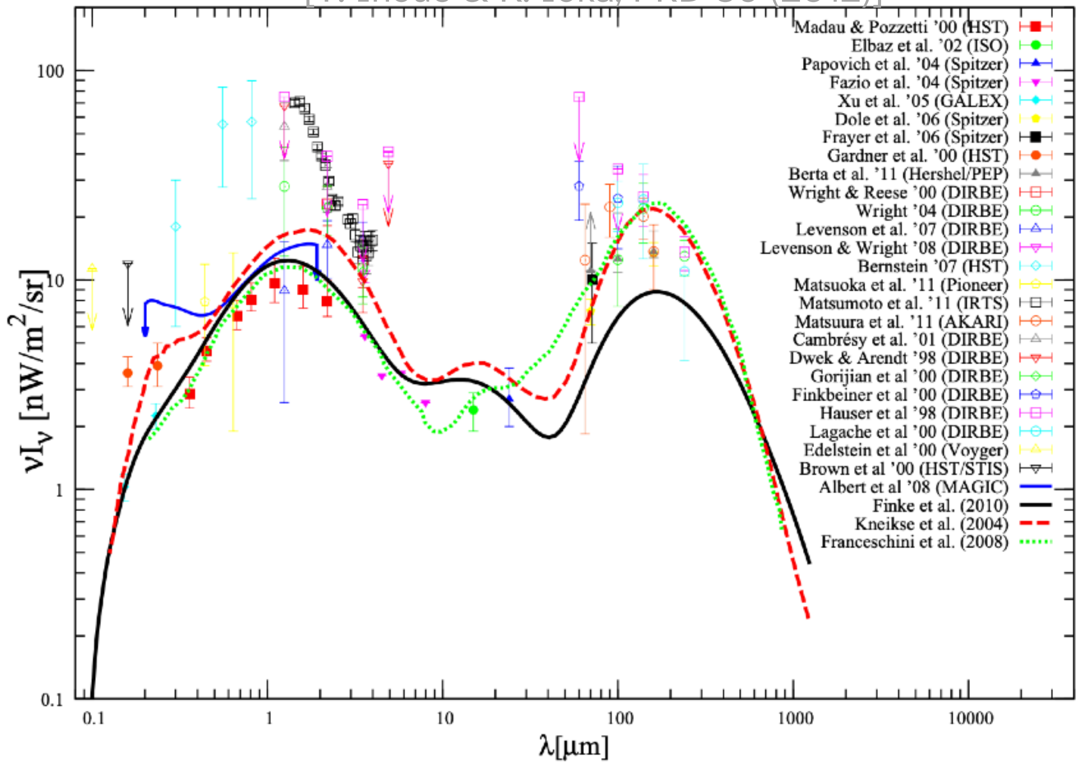
=> EBL is a major limiting factor in extragalactic sources!

Why haven't we detected more VHE GRBs?

EBL absorption

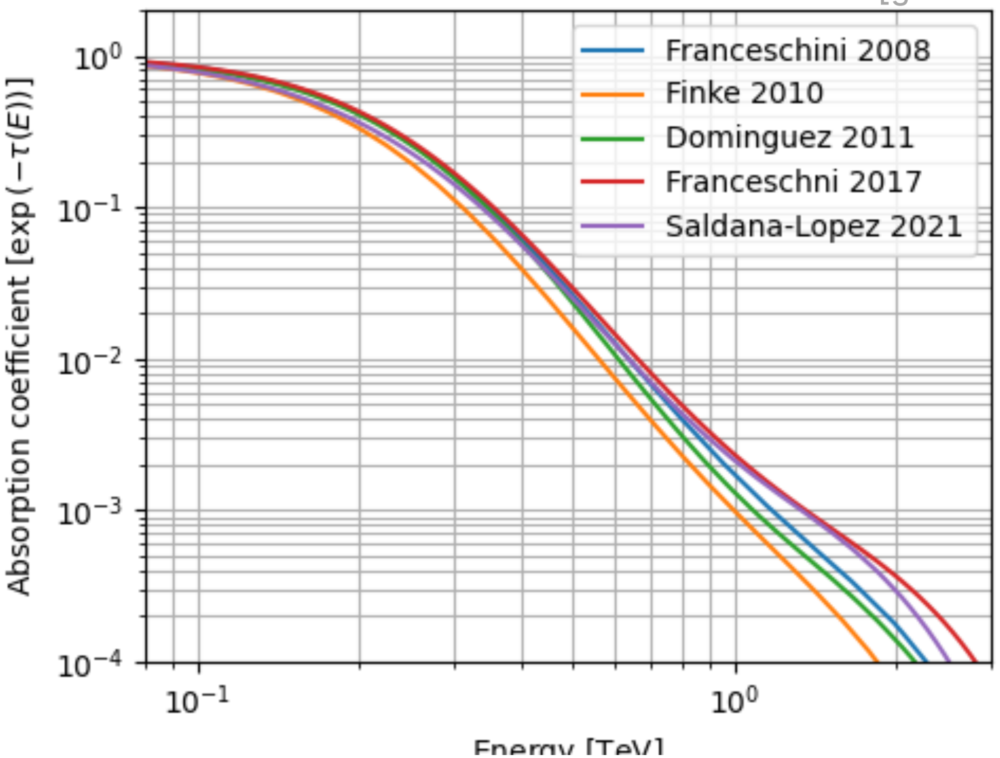
There is a lot of uncertainty still in the EBL spectrum itself

[Y. Inoue & K. Ioka, PRD 86 (2012)]



EBL models (z=0.5)

[gammapy]



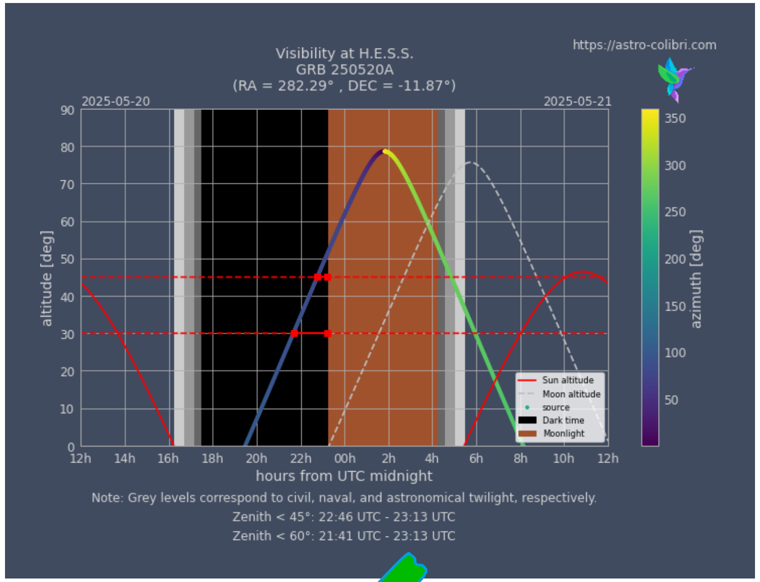
=> EBL is a major limiting factor in extragalactic sources, for both the **detection** and the **analysis**

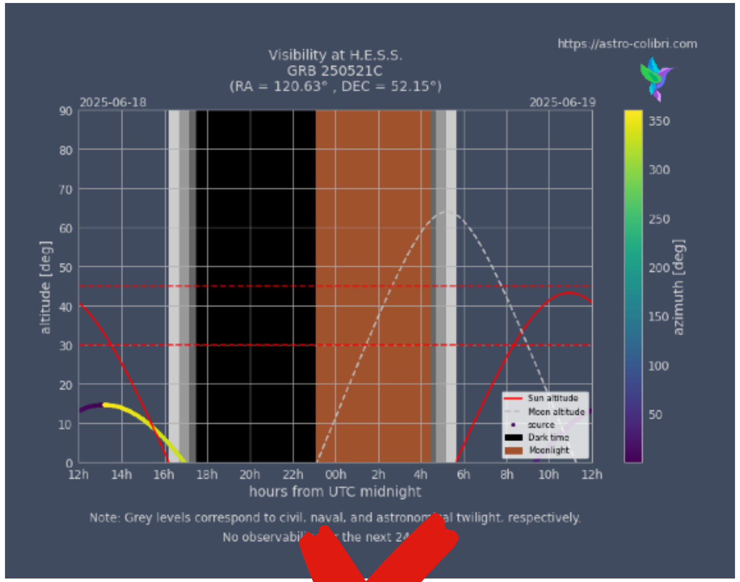
Summarizing observation criteria

1. When is it dark enough to observe?
2. When is the source high enough in the sky? (i.e., with sufficiently small zenith angle)
3. If the redshift is known: Is it close enough?

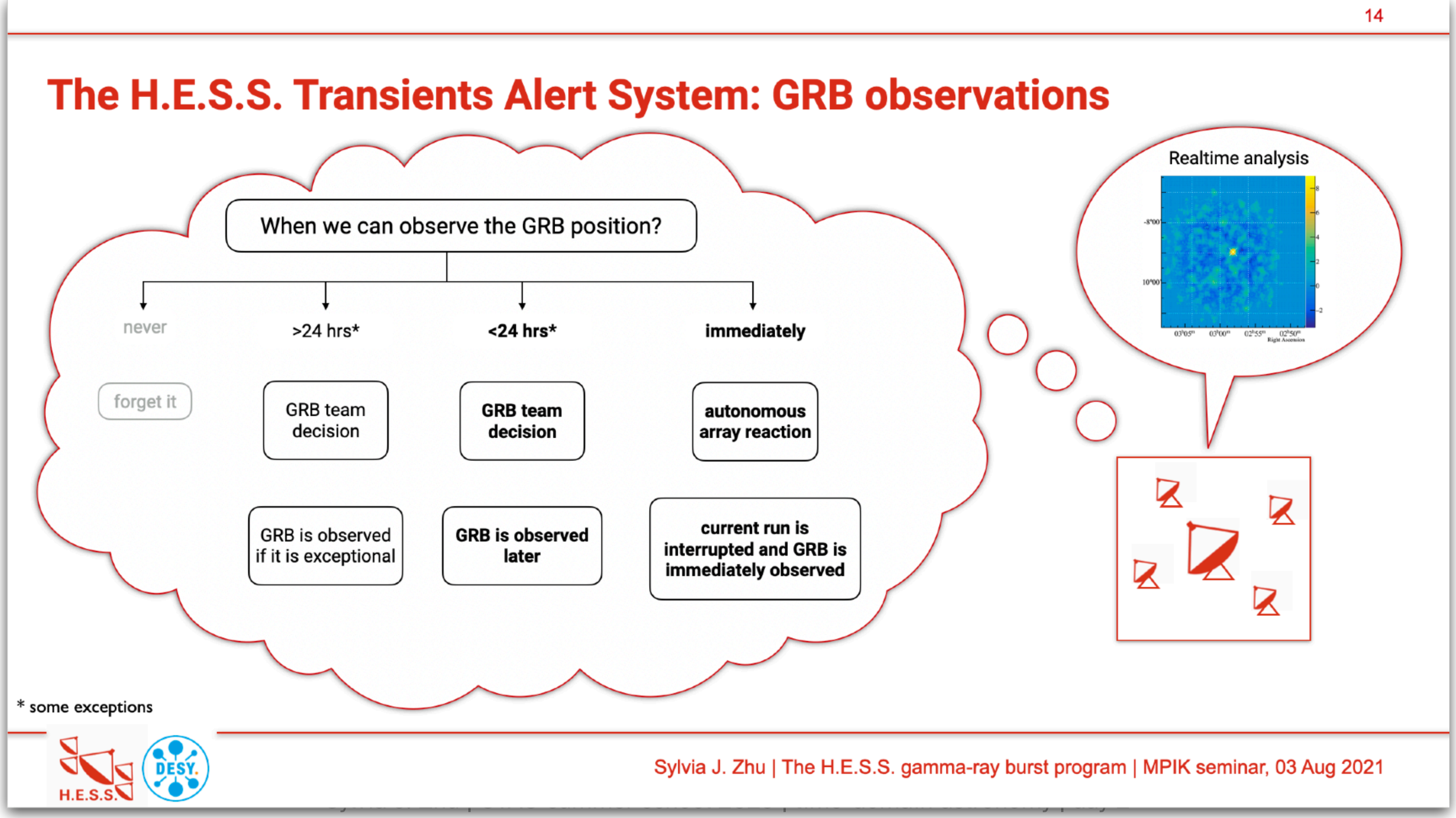
plus:

4. Do we have any MWL information that might indicate it's particularly (un)interesting?
5. When can we start observing it, and for how long?



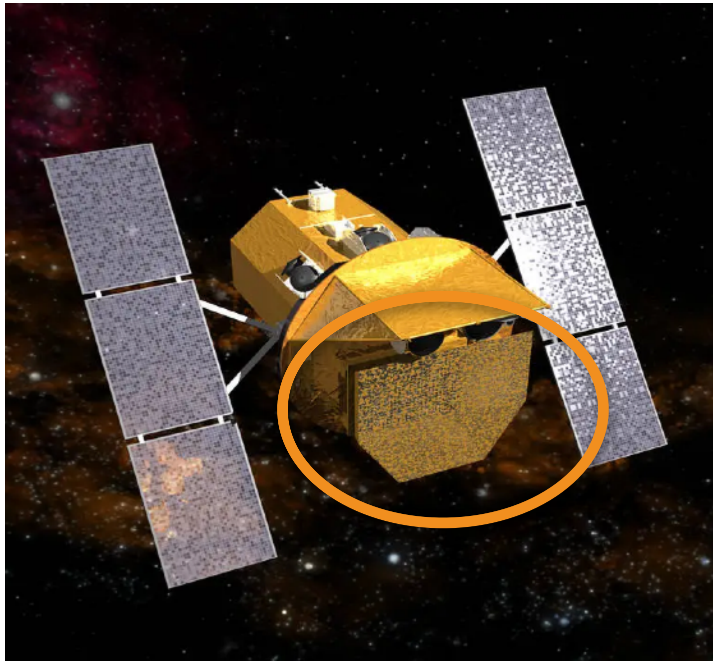


e.g., the H.E.S.S. GRB program



IACTs also observe poorly localized events

[NASA]



Swift Burst Alert Telescope

keV

Smaller field of view and narrower energy range

but

precise localizations

[NASA/DOE/Fermi-LAT]

Fermi Gamma-ray Burst Monitor

keV - MeV

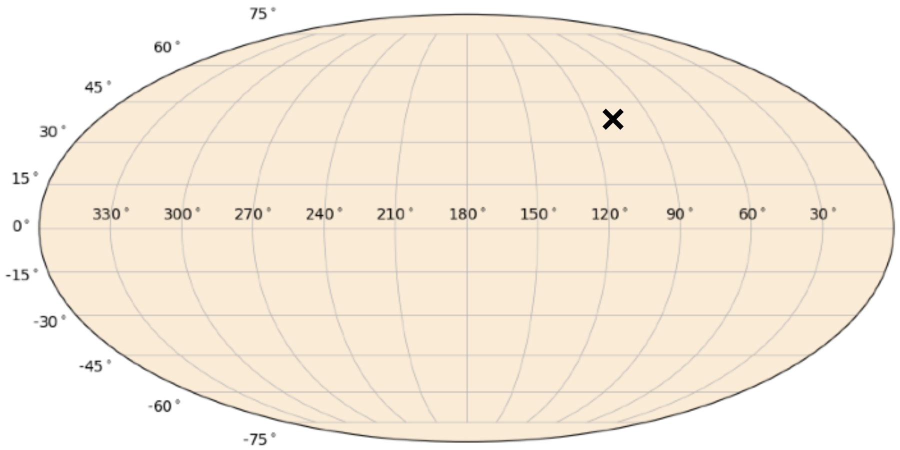
All-sky field of view and wider energy range

but

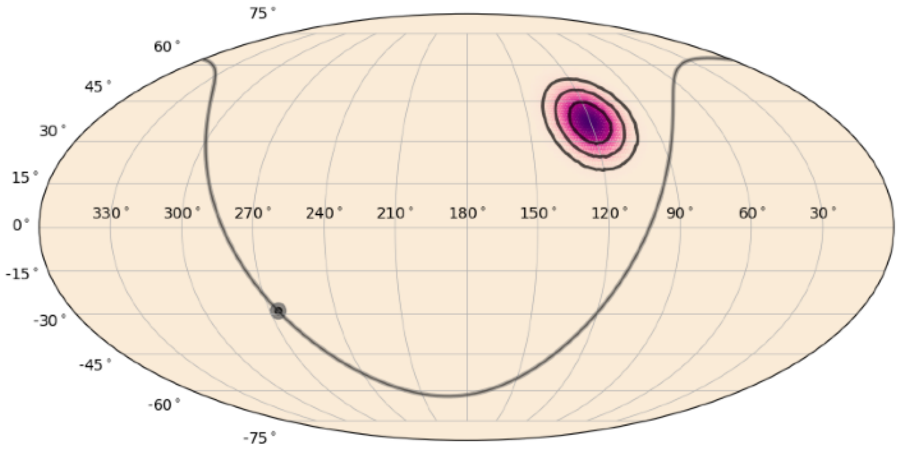
very uncertain localizations

IACT observations of large localization regions

(not just GRBs)



If the localization is smaller than the FoV of our telescope, we can just observe that sky position.

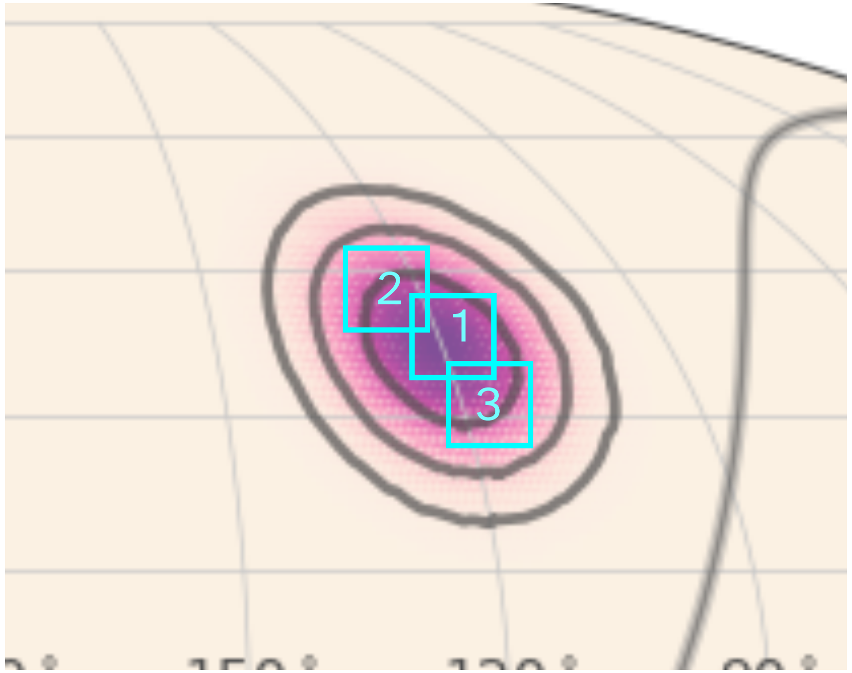


If the localization is *larger* than the FoV of our telescope, we can still **tile** the localization region.

IACT observations of large localization regions

Tiled observations

An example of what the tiling strategy might be for this particular localization region



Simplest: Cover the most probability within the time available

Additional things to potentially consider:

- Zenith angles (source is moving)
- Darkness conditions (moderate moonlight vs complete darktime)
- Prioritize regions where other observatories have found potential counterparts?
- Split up the region between multiple telescopes?
- (For gravitational-wave alerts) Prioritize maximizing the number of known galaxies covered? The most nearby galaxies? The most massive galaxies? see: [H. Ashkar et al., JCAP 2021 (2021)]

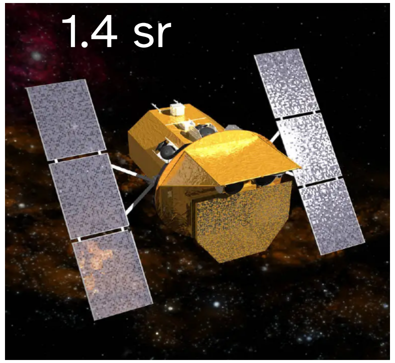
(more about gravitational-wave signals later)

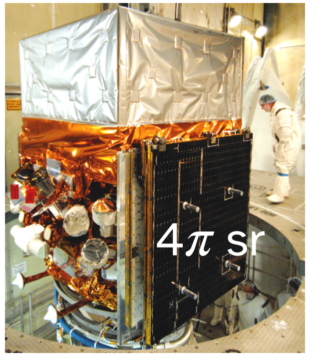
Multiwavelength and multimessenger triggers

a few deg diameter

Ultimately, IACT fields of view are small -> we rely on multiwavelength, multimessenger triggers

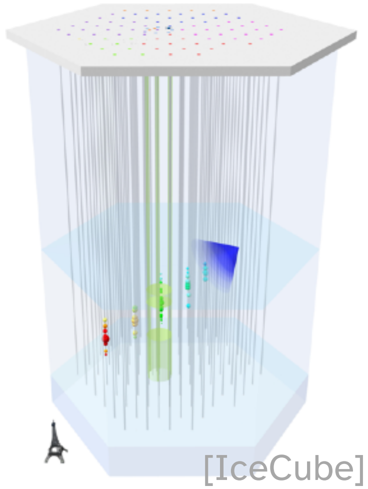
space-based gamma-ray telescopes





gravitational-wave detectors

optical surveys

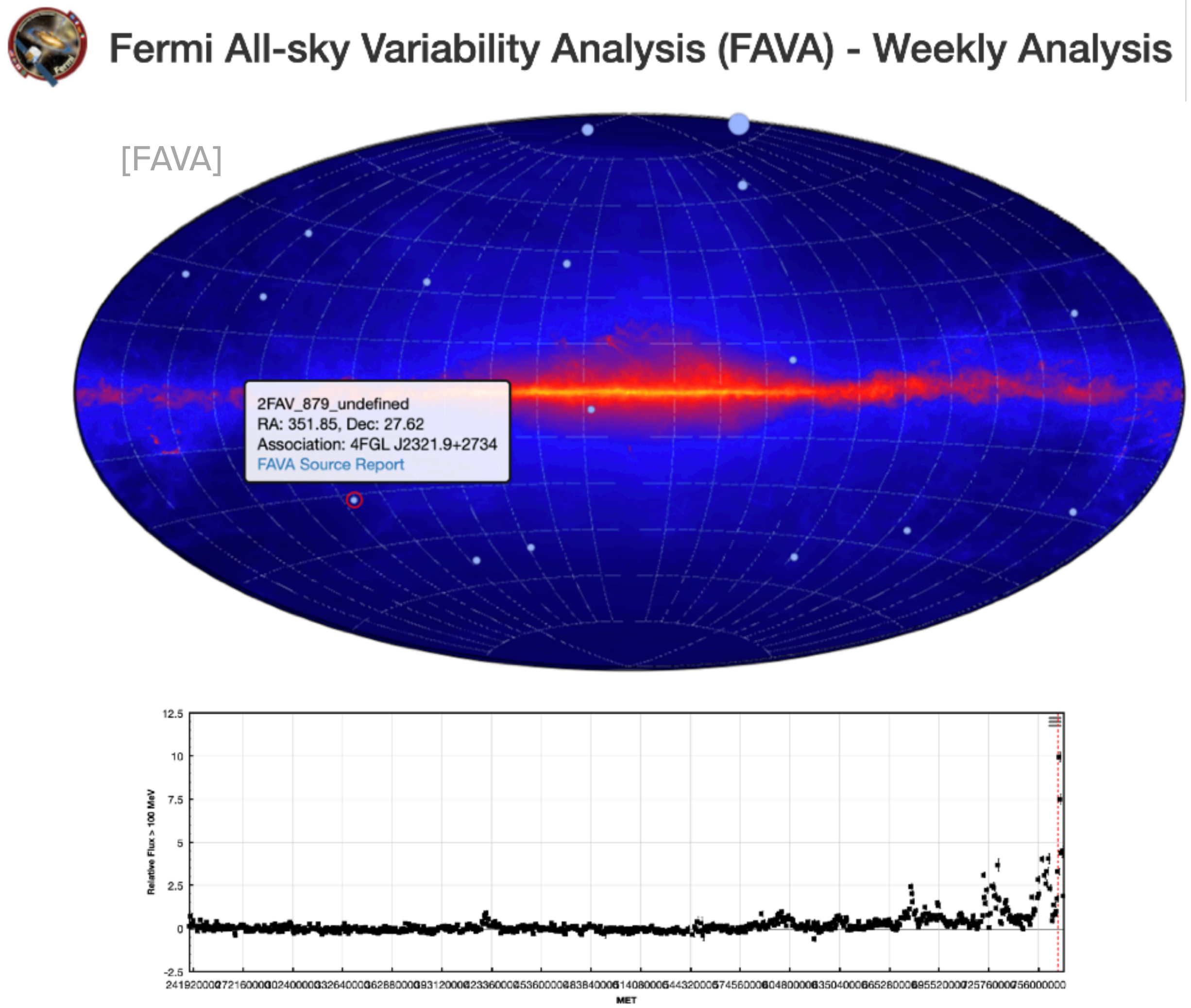


neutrino detectors

Multiwavelength and multimessenger triggers

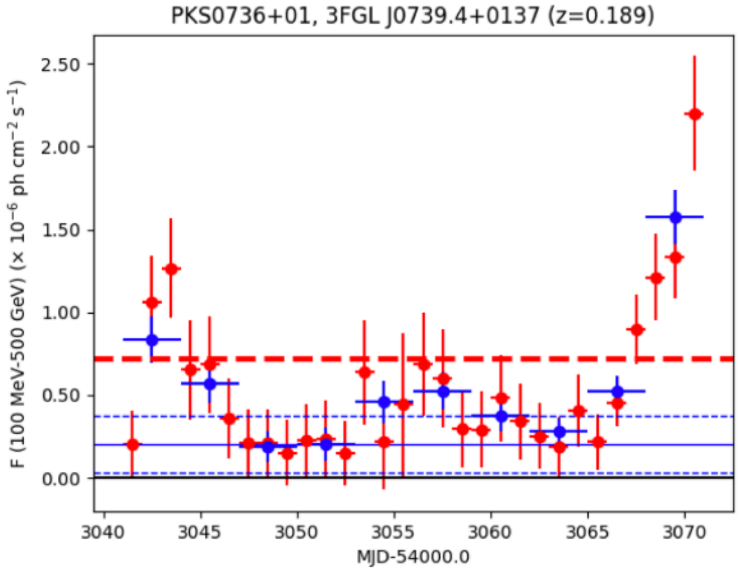
Photometric Fermi-LAT analyses (primarily used for AGN flares)

basically: counting photons



[FAVA]

FLaapLUC: finer time bins, predetermined sources



[J.-P. Lenain, Astronomy & Computing 22 (2018)]

Multiwavelength and multimessenger triggers

The Astronomer's Telegram (ATel)

[ATel]

Human-written summaries of interesting transients or flaring sources

Some examples:

Fermi-LAT detection of enhanced gamma-ray activity from the FSRQ PKS 0907-023

ATel #17133; *Adithiya Dinesh (Universidad Complutense de Madrid), Janeth Valverde (Marquette University) , on behalf of the Fermi Large Area Telescope Collaboration*

Enhanced HE and VHE gamma-ray activity from the FSRQ PKS 0346-27

ATel #15020; *S. Wagner (U. Heidelberg, Germany), for the H. E. S. S. collaboration and B. Rani (KASI, S. Korea), on behalf of the Fermi Large Area Telescope Collaboration*

The MAGIC telescopes detect a very-high-energy gamma-ray flare from OP313

ATel #16977; *David Paneque (Max Planck Institute for Physics), Axel Arbet-Engels (Max Planck Institute for Physics), Mireia Nievas Rosillo (IAC), Giacomo Bonnoli (INAF, Brera Astronomical Observatory), Jorge Otero Santos (INFN Padova) on behalf of the MAGIC collaboration*

VERITAS Follow-up of a Report of Enhanced Emission from 1ES 1727+502

ATel #17099; *Amy Furniss (UC Santa Cruz) for the VERITAS Collaboration*

ATELstream

Recently

17215 NICER sees declined X-ray activity of XB 1732-304 in Terzan 1
G. K. Jaisawal...

17201 SVOM/ECLAIRs detection of a thermonuclear burst in Terzan 1
S. Le Stum ...

Most Viewed

17227 6.7 GHz methanol maser flare in high-mass protostar G85.410+0.003
Ross A. Burns ...

17224 Spectroscopic Classification of PNV J06302516-6955014 as a Classical Nova
Yusuke Tampo ...

17226 Fermi-LAT detection of renewed gamma-ray activity from the FSRQ Ton 599 (4C +29.45)
S. Wagner ...

Fast Radio Burst

17195 Deep JWST/NIRCam Imaging of FRB 20250316A: Detection of Potential IR Counterparts
Peter K. Blanchard...

Supernovae

17225 Spectroscopic Classifications of Optical Transients with the Lick Shane telescope
Kishore C. Patra...

17223 Spectroscopic Classification of Astrophysical Transients with the Lick Shane Telescope
R. Kaur...

17210 Spectroscopic Classifications of Optical Transients with the Lick Shane telescope
Kishore C. Patra ...

17208 Spectroscopic classification of transients with the Lick Shane telescope
P. Arunachalam...

and tons of other source types

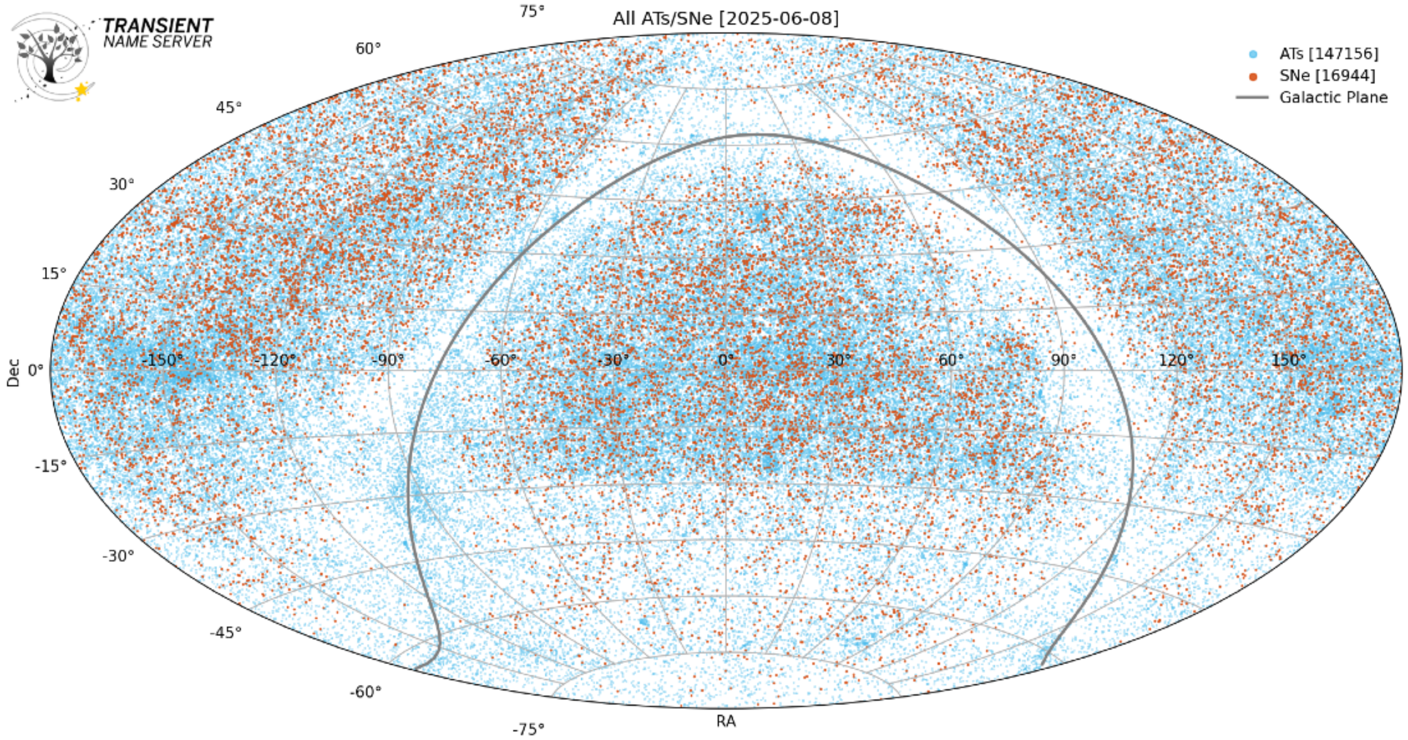
Multiwavelength and multimessenger triggers

Transient Name Server (TNS)

[TNS]

Human-submitted information on new transients

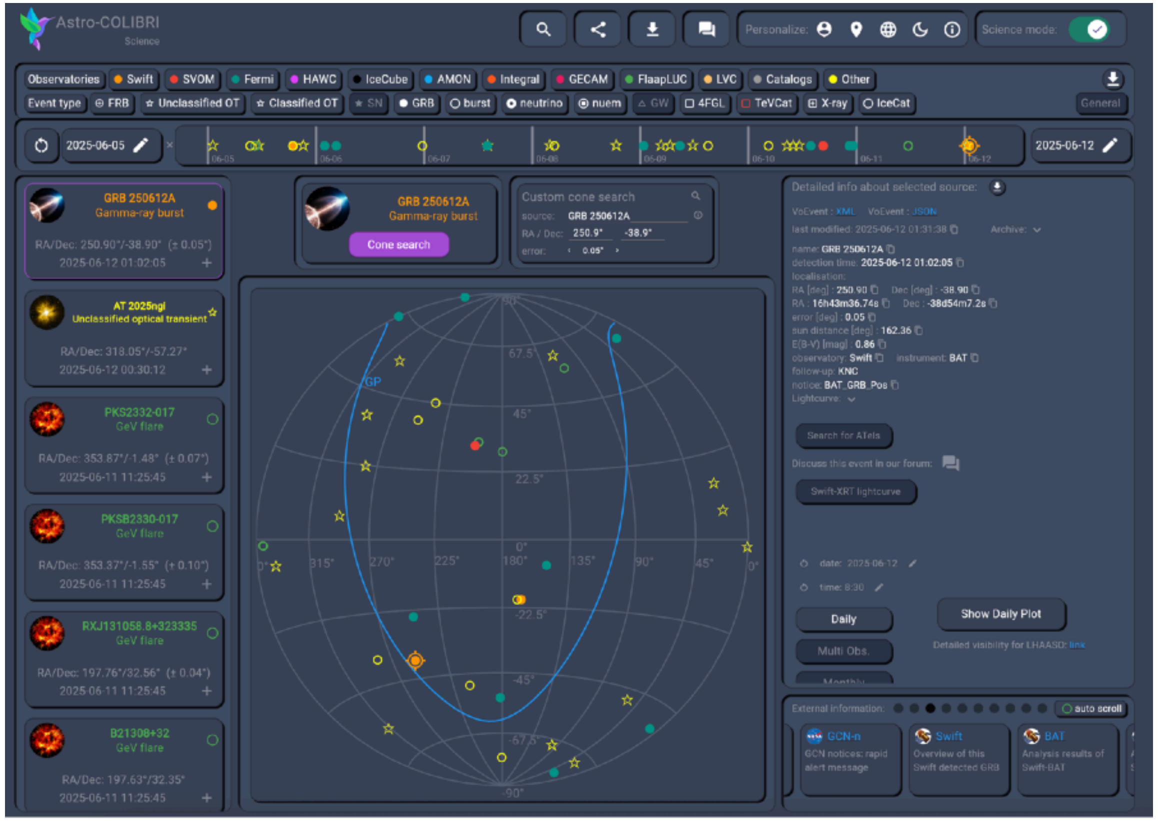
Also: The official way to get a supernova name

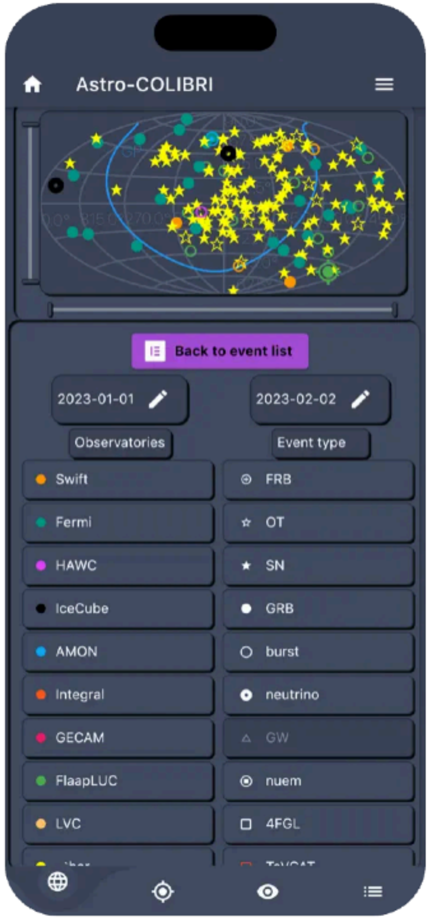


Multiwavelength and multimessenger triggers

Astro-COLIBRI [astro-colibri]

Platform for monitoring and communicating about transients;
also pulls information from other databases like TNS





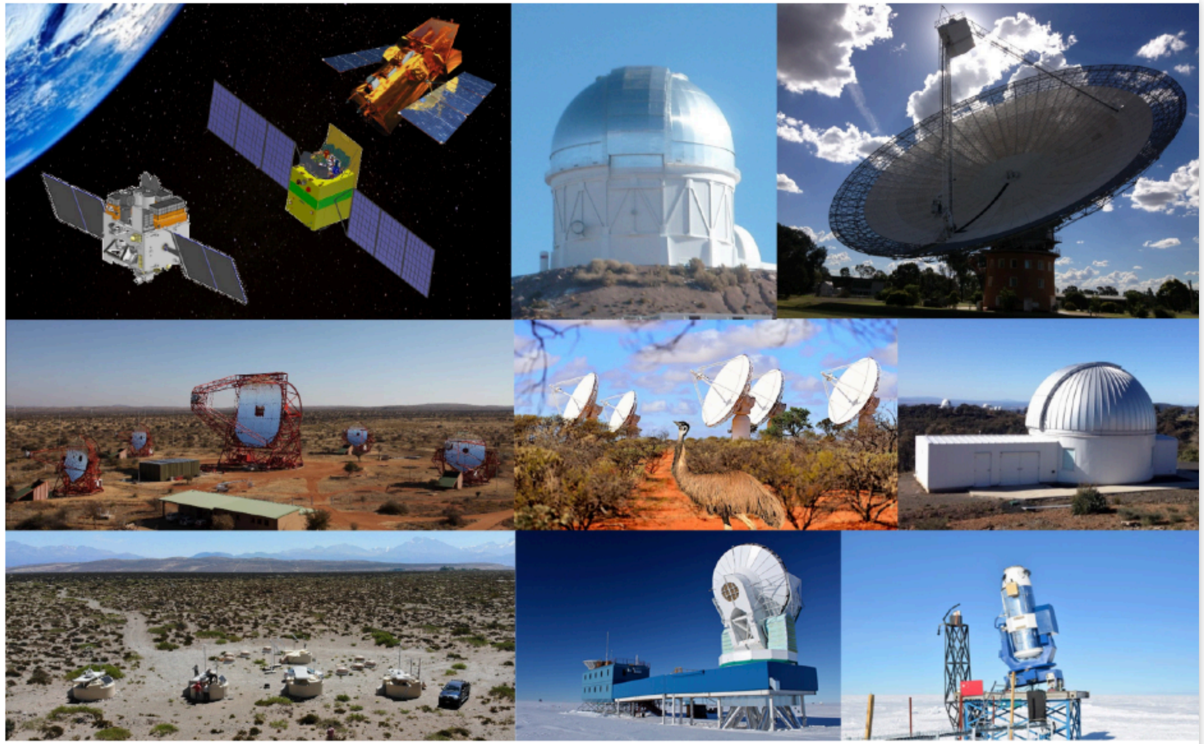
Coordinated observation campaigns

The Deeper, Wider, Faster program

Coordinated observations by ~70 telescopes of the same target fields

Searching for fast transients (ms to hours)

[J. Cooke]



Telescopes wide-field coordinated simultaneously include – *high-energy particles*: Pierre Auger Observatory, HAWC; *gamma-ray*: H.E.S.S., Swift; *X-ray*:, HXMT, Astrosat; *UV*: Astrosat; *optical*: CTIO DECam, Subaru HSC, KMTNet, AST3-2; *mm/sub-mm*: South Pole Telescope; *radio*: Parkes, ASKAP, MeerKAT, MWA; (also *GW*: LIGO/Virgo/KAGRA when online).