Lesson 9 High energy astronomy instruments

2021年6月8日 7:54

X-rays and the atmosphere

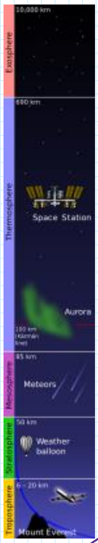
1. What is the common definition of "Space"?

> 100 km   outer space

Jeff Bezos is going to space on first crewed flight of rocket

Blue Origin's flight crewed flight will see the company's six-seater capsule and 59-foot rocket tear toward the edge of space on a 11-minute flight that'll reach more than 60 miles above Earth.

<https://edition.cnn.com/2021/06/07/tech/jeff-bezos-space-blue-origin-new-shepard-flight-scn/index.html>



air friction

Kármán line @ 100 km

https://en.wikipedia.org/wiki/K%C3%A1rm%C3%A1n_line

2. Why do we have to launch artificial satellites to study X-ray astronomy?

Atmospheric absorption of X-rays

above ~100 km
no atmosphere

3. Estimate the "mean free path" [cm] of air for ~ 1keV X-rays, assuming the air density 1.2x 10^{-3} g/cm^3 (at 15 C, sea-level pressure) and Nitrogen/Oxygen photo-electric cross-section 10^{-19} cm^2?

78% N, 21% O → 14, 16

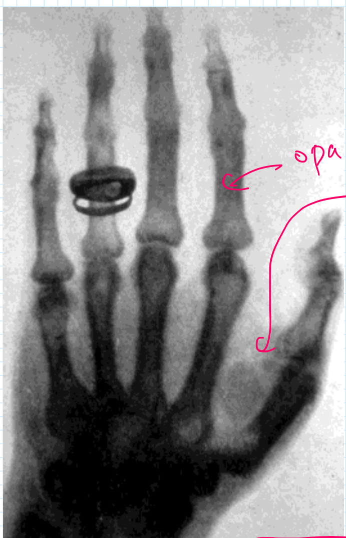
proton mass $\approx 1.67 \times 10^{-24}$ g

N mass, O mass $\binom{14}{16} \times 1.67 \times 10^{-24}$ [g] $\approx \binom{2.3}{2.7} \times 10^{-23}$ [g]

number density $= \frac{1.2 \times 10^{-3} [g/cm^3]}{2.5 \times 10^{-23} [g]} = 5 \times 10^{19}$ [cm^{-3}]

$= \frac{1}{10^{-19} [cm^2] \times 5 \times 10^{19} [cm^{-3}]} = \frac{1}{5}$ [cm] ≈ 2 [mm]

4. We saw that the air in the ordinary condition is "opaque" to ~1 keV X-rays? How can the human-body be "transparent" in the Rontgen image?



opaque

transparent

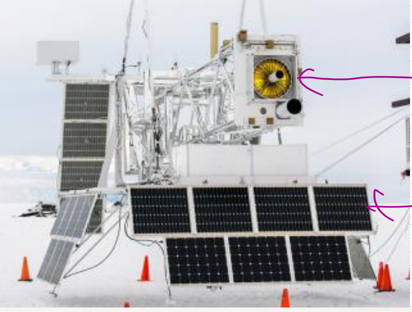
*While **20 keV** is a typical energy for **soft tissue** X-rays, for example mammograms, higher energies (around **150 keV**) are used for **hard tissues**, for example bone.*

<http://nupex.eu/index.php?g=textcontent/nuclearapplications/xraymed&lang=en>

https://commons.wikimedia.org/wiki/File:X-ray_by_Wilhelm_R%C3%B6ntgen_of_Albert_von_K%C3%B6lliker%27s_hand_-_18960123-02.jpg

5. Do we really needs astronomical satellites to study universe in X-rays?

No!!



X-ray telescope

solar panel

Photo Credit: Mike Lucibella
The X-Calibur telescope was designed to study the x-rays emitted by neutron stars and black holes.

<https://antarcticsun.usap.gov/science/4402/>

Hard X-ray Polarimetry with X-calibur https://sites.wustl.edu/xcalibur/

FOXSI : Focusing Optics X-ray Solar Imager http://foxsi.umn.edu/

← ~~sound~~ sounding rockets

https://www.nao.ac.jp/en/news/topics/2019/20190115-solar.html

experimental

6. What is the merit of using balloon or sounding rockets compared to satellites?

Cheap!! Quick!!

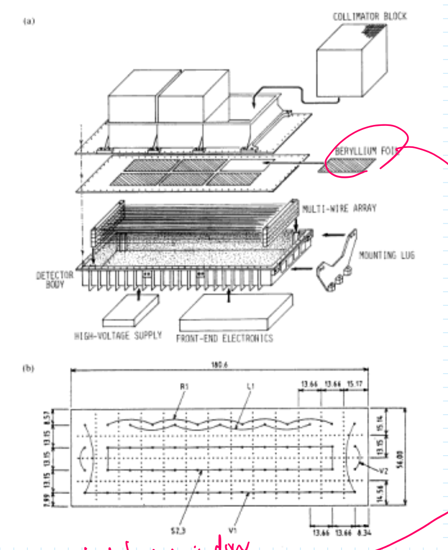
Test new instruments!! → satellites ↓ have to be safe

Principles of X-ray and gamma-ray instruments

Explain principles of X-ray or gamma-ray detections for representative energy ranges

- 2-10 keV

photoelectric absorption → X-rays to photo-electrons → electric signals



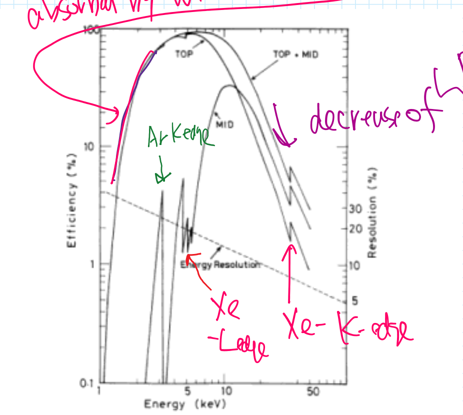


Fig. 8. The photopeak efficiency of the LAC for the top, middle, and top plus middle layers (solid curves) and the energy resolution (dashed line) as a function of energy. The measured energy resolution follows closely the functional form $E^{-0.5}$.

Ginga Large Area counter efficiency: 75 % Ar, 20 % Xe, 5 % CO2

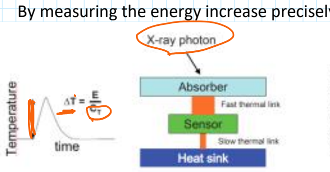
http://articles.adsabs.harvard.edu//full/1989PASJ...41..345T

Number of photo-electrons is proportional to the input X-ray energy

Energy resolution is limited by fluctuation of the number of photo-electrons

X-ray micro-calorimeter: X-rays to heat→measure the temperature increase → electric signal

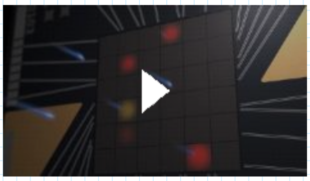
By measuring the energy increase precisely, very high resolution energy resolution is achieved.



https://arxiv.org/ftp/arxiv/papers/1102/1102.2845.pdf

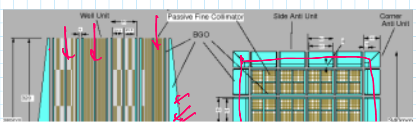
Figure 4.9. Principle of a microcalorimeter. The absorption of an X-ray photon heats both the absorber and the sensor. The resulting signal represents the total energy deposited. The system goes back slowly to its original state through a weak thermal link with a heat sink.

Hitomi Measures Perseus Galaxy Cluster's X-ray Winds

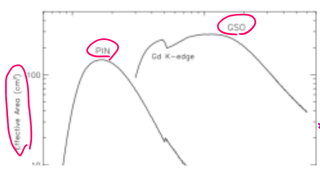


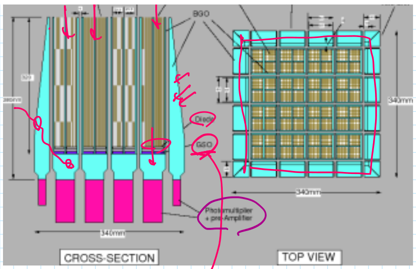
- Tens of keV

Semiconductor (PIN diode, CdZnTe): X-rays → electric signal



https://doi.org/10.1093/pasj/59.sp1.S35





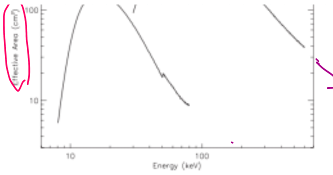


Fig. 9. Total effective area of the HXD detectors, PIN and GSO, as a function of energy. Photon absorption by materials in front of the device is taken into account.

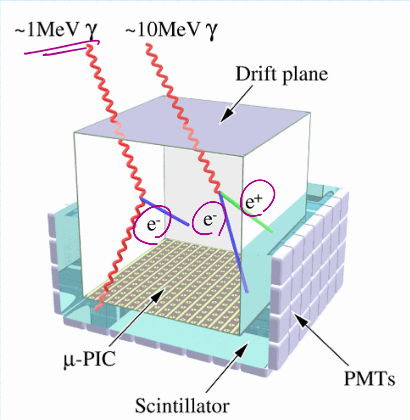
http://www.astro.isas.jaxa.jp/suzaku/doc/suzaku_td/node12.html

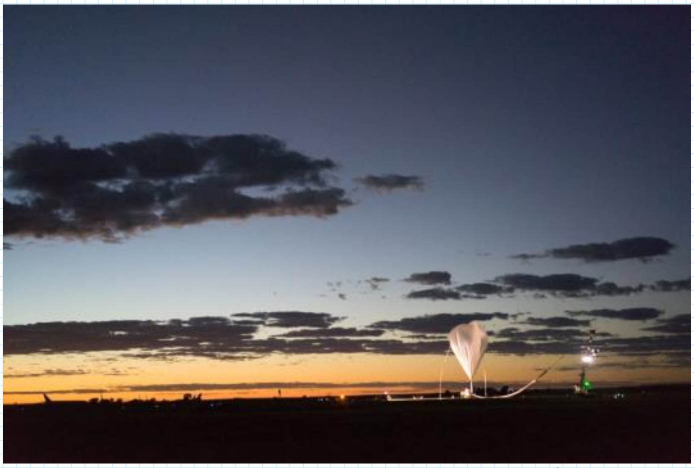
- ~hundrets keV
  Scintillator: gamma-rays → photons → photo-multilir tube (PMT) → electric signal

- ~MeV
gamma-rays → Compton effects → energy transfer to electrons → electric signal

"Sensitivity Gap" at around ~MeV

*However, the number of steadily detected sources was by orders of magnitudes less than those detected in the X-ray and the GeV gamma-ray bands. This is due to lack of the sensitivity at MeV energies compared to other ranges as called "**Sensitivity Gap**".*
<http://www-cr.scphys.kyoto-u.ac.jp/research/MeV-gamma/wiki/wiki.cgi?page=Top_en>

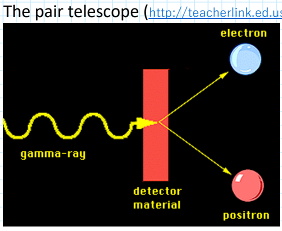




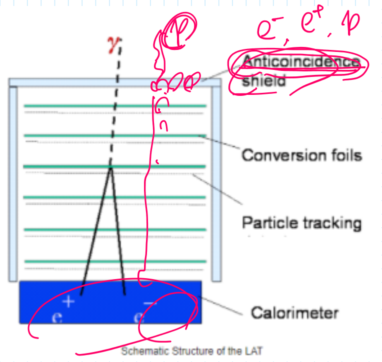
The SMILE-2+ ETCC consisted a gaseous electron tracker, which had a volume of 30x30x30 cm^3 filled by an argon based gas with the pressure of 2 atm, and the surrounding GSO pixel scintillator arrays. …… SMILE-2+ ETCC was launched from Alice Springs, Australia, on April 7, 2018. After the level flight lasted for ~26 hours, the instrument was recovered perfectly. Now, we are analyzing the obtained onboard data.
<http://www-cr.scphys.kyoto-u.ac.jp/research/MeV-gamma/wiki/wiki.cgi?page=SMILE%5F2p%5Fen>

- ~20 MeV to > 300 GeV (Fermi LAT)

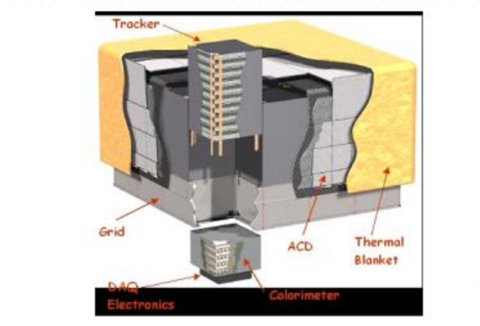
The pair telescope (http://teacherlink.ed.usu.edu/tlnasa/reference/imaginedvd/files/imagine/docs/science/how_l2/pair_telescopes.html)



The Gamma-rays → electron-position pairs → Calorimeter



Schematic Structure of the LAT



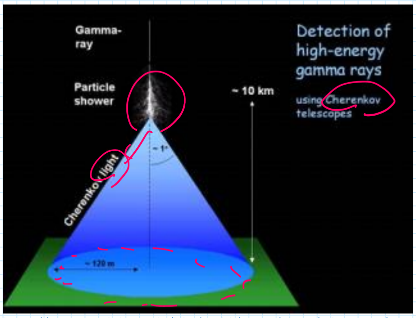
Structure of the LAT

>8000 cm² effective area, 2.4 str Field of View

https://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/Cicerone_Introduction/LAT_overview.html

- ~TeV to ~PeV
  gamma-ray → atomospheric air Cherenkov → Air shower → decttion by ground telescope array

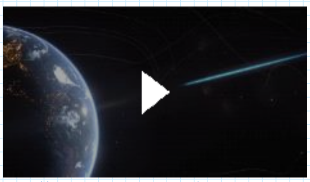
HESS



https://www.mpi-hd.mpg.de/hfm/HESS/pages/about/telescopes/

CTA project

CTA Science: Emission to Discovery



https://www.cta-observatory.org/

Recent big discovery by Chinese gamma-ray telescope

NEWS AND VIEWS | 02 June 2021

Hunting the strongest accelerators in our Galaxy

Twelve candidates for the most powerful astrophysical particle accelerators in the Milky Way have been detected. This advance will help to uncover the nature of these exotic objects.

https://www.nature.com/articles/d41586-021-01377-1

The Large High Altitude Air Shower Observatory (LHAASO)

http://english.ihep.cas.cn/appendix/pic/20190421/201904210948403188.jpg

Article | Published: 17 May 2021

Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 γ-ray Galactic sources

Zhen Cao, F. A. Aharonian, [...]X. Zuo

Nature **594**, 33–36 (2021) | Cite this article

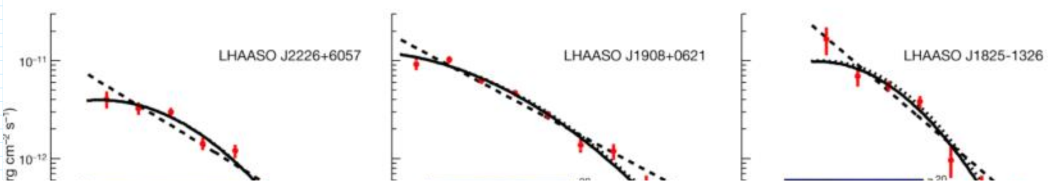
Here we report the detection of more than 530 photons at energies above 100 teraelectronvolts and up to 1.4 PeV from 12 ultrahigh-energy γ-ray sources with a statistical significance greater than seven standard deviations.

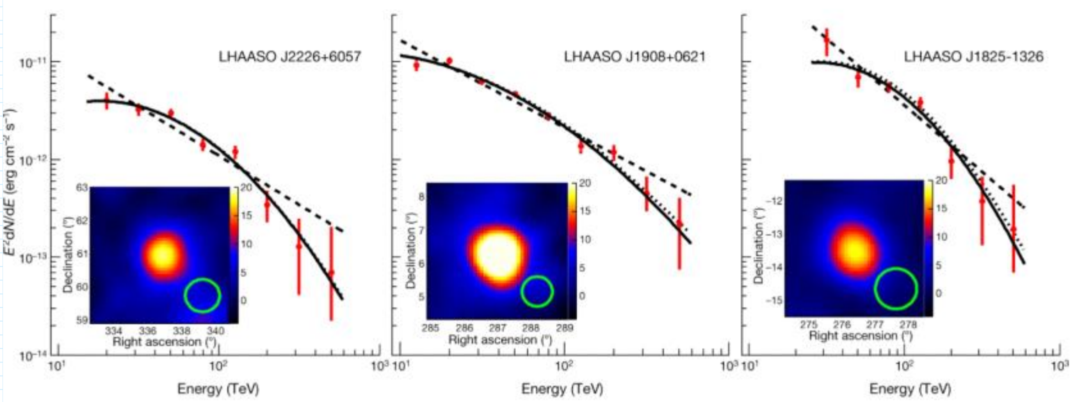
<https://www.nature.com/articles/s41586-021-03498-z>

Table 1 UHE γ-ray sources

From: Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 γ-ray Galactic sources

Source name	RA (°)	dec. (°)	Significance above 100 TeV (×σ)	E_{max} (PeV)	Flux at 100 TeV (CU)
LHAASO J0534+2202	83.55	22.05	17.8	0.88 ± 0.11	1.00(0.14)
LHAASO J1825-1326	276.45	−13.45	16.4	0.42 ± 0.16	3.57(0.52)
LHAASO J1839-0545	279.95	−5.75	7.7	0.21 ± 0.05	0.70(0.18)
LHAASO J1843-0338	280.75	−3.65	8.5	$0.26_{-0.10}^{+0.16}$	0.73(0.17)
LHAASO J1849-0003	282.35	−0.05	10.4	0.35 ± 0.07	0.74(0.15)
LHAASO J1908+0621	287.05	6.35	17.2	0.44 ± 0.05	1.36(0.18)
LHAASO J1929+1745	292.25	17.75	7.4	$0.71_{-0.07}^{+0.16}$	0.38(0.09)
LHAASO J1956+2845	299.05	28.75	7.4	0.42 ± 0.03	0.41(0.09)
LHAASO J2018+3651	304.75	36.85	10.4	0.27 ± 0.02	0.50(0.10)
LHAASO J2032+4102	308.05	41.05	10.5	1.42 ± 0.13	0.54(0.10)
LHAASO J2108+5157	317.15	51.95	8.3	0.43 ± 0.05	0.38(0.09)
LHAASO J2226+6057	336.75	60.95	13.6	0.57 ± 0.19	1.05(0.16)





No known X-ray or gamma-ray (< GeV) sources at these locations. What are these unidenfied PeV sources?

*… researchers studied the surface brightness of the region and connected the emission to the **Cygnus OB2 star cluster**, where powerful shock waves generated by strong stellar winds might accelerate particles to PeV energies.*

<https://www.nature.com/articles/d41586-021-01377-1>