LAGO International Project

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PI

Outline

Science

- TeV Gamma-Ray Astronomy
- Cosmic Rays and Their Sources

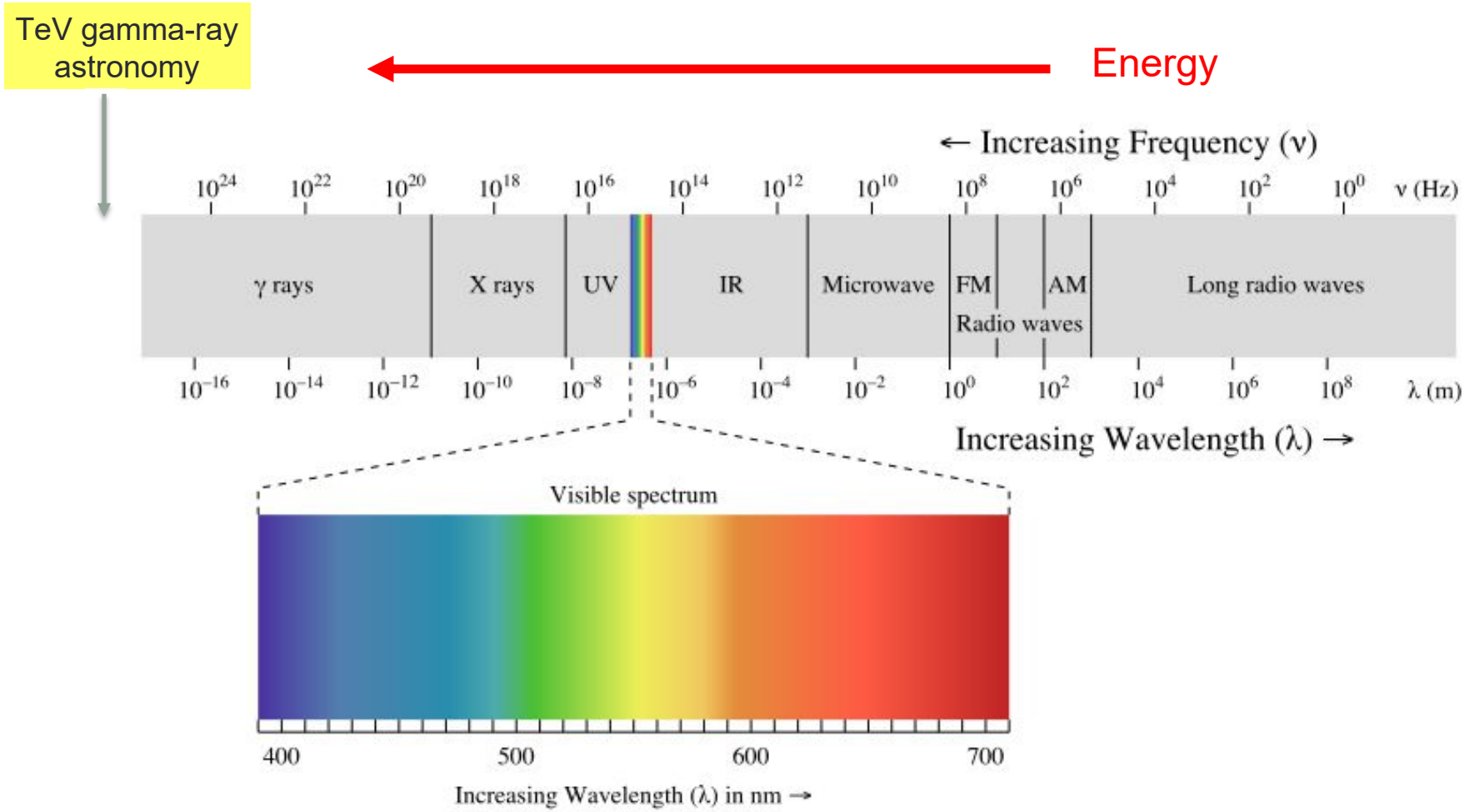
Detection techniques

- Air Showers
- The LAGO International Project

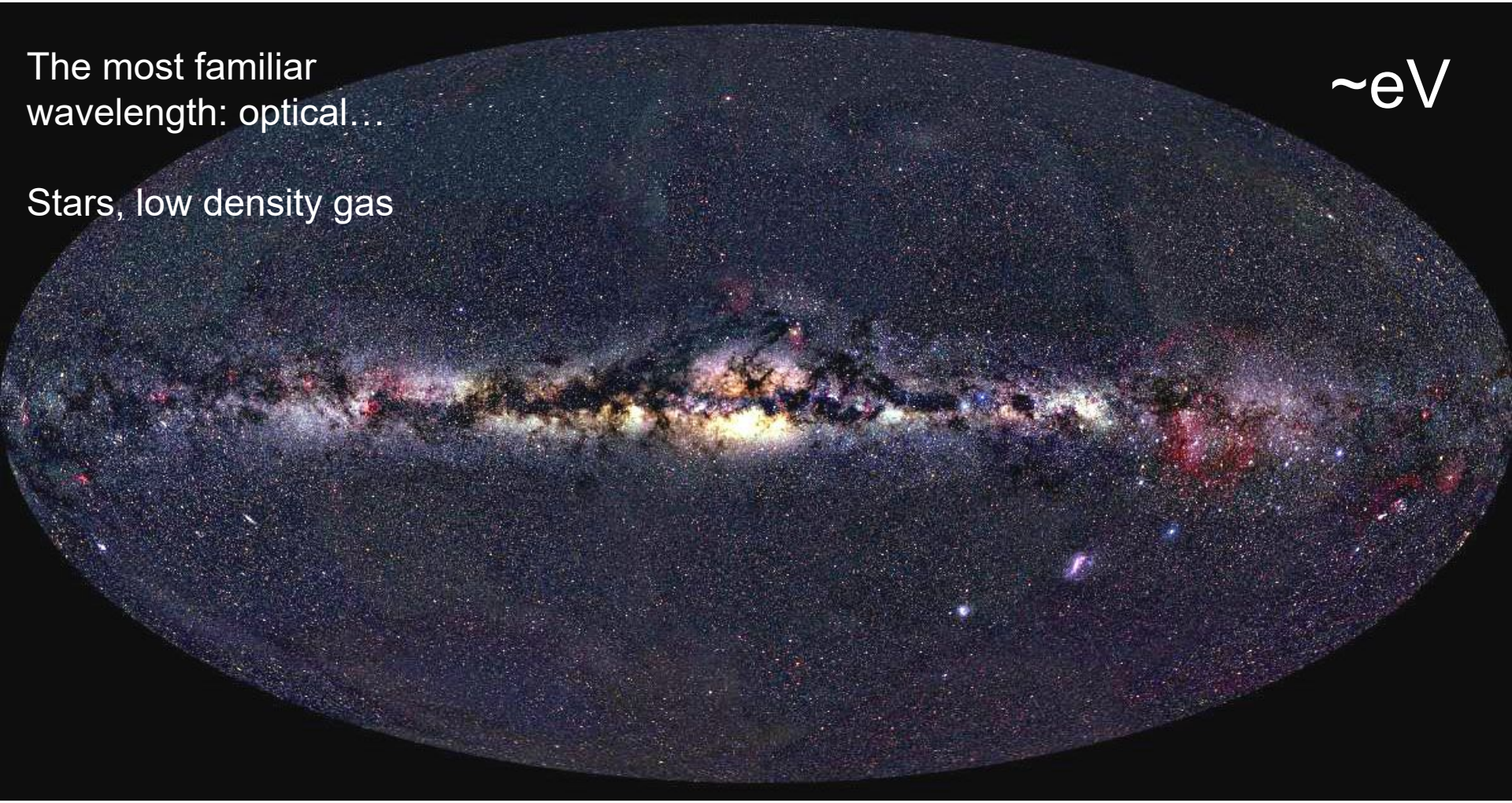
Particle Astrophysics

- "Classical" Astronomy – electromagnetic spectrum from radio to X-rays.
- Gamma-Ray Astronomy – photons (light particles) with energies 10^{10} larger than optical light.
- Cosmic Rays – protons and heavier nuclei with energies up to several Joule, the highest particle energies observed in the Universe.
- Neutrinos – tightly connected to cosmic rays and their sources, but neutral and not subject to deflection in magnetic fields (= easier for "astronomy").

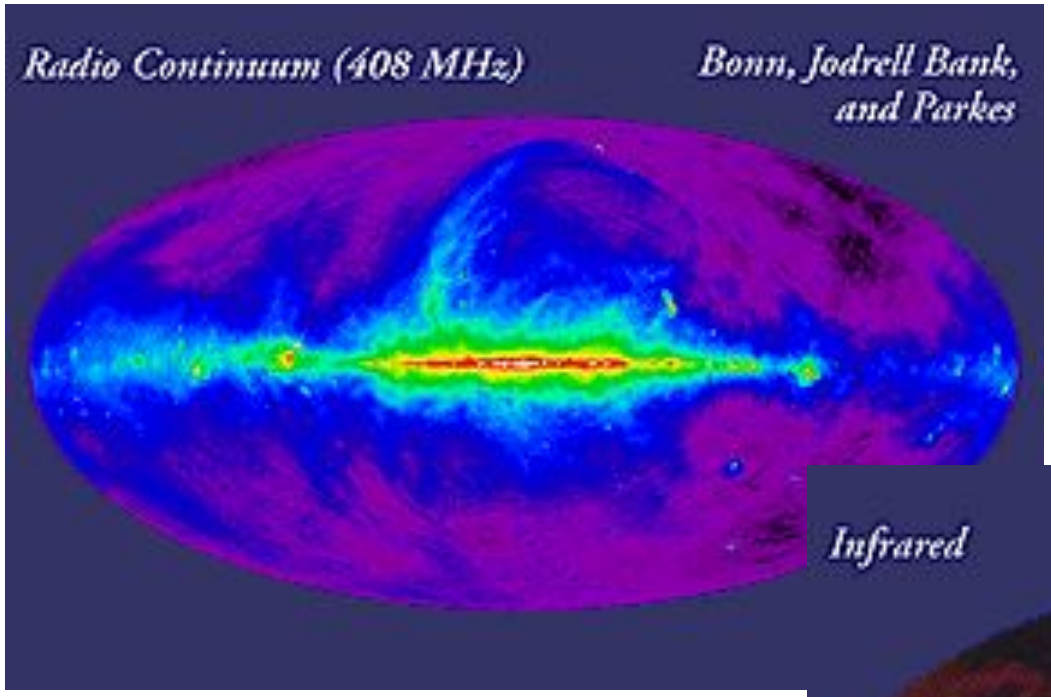
Electromagnetic Spectrum



The Multiwavelength Sky

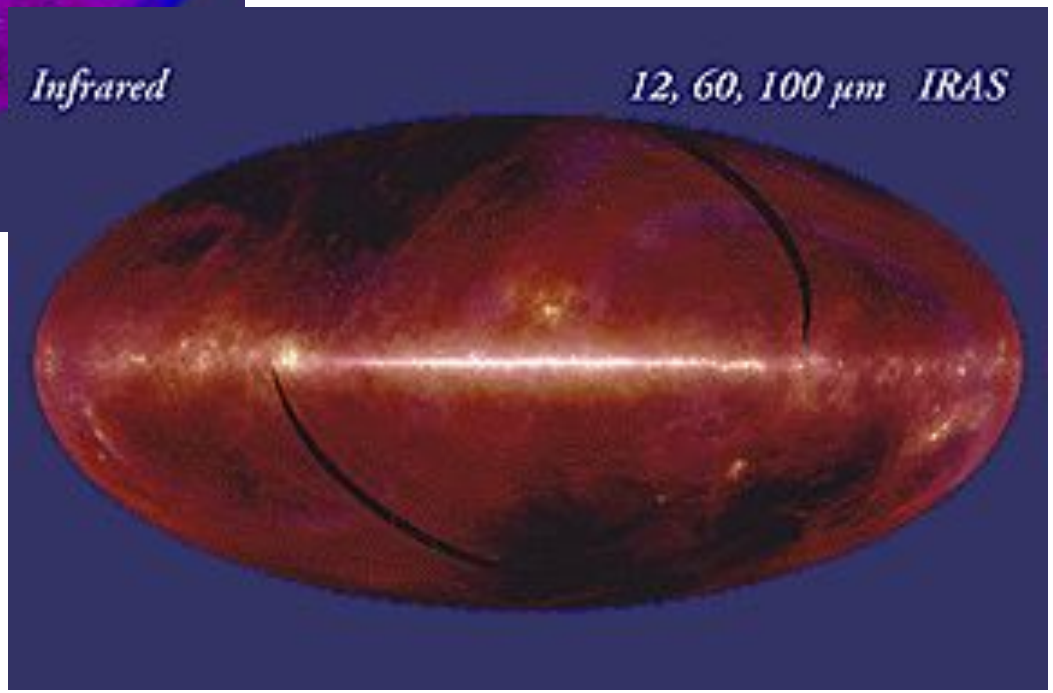


Going to *Lower* Energy…



radio
0.002 eV = 2 meV

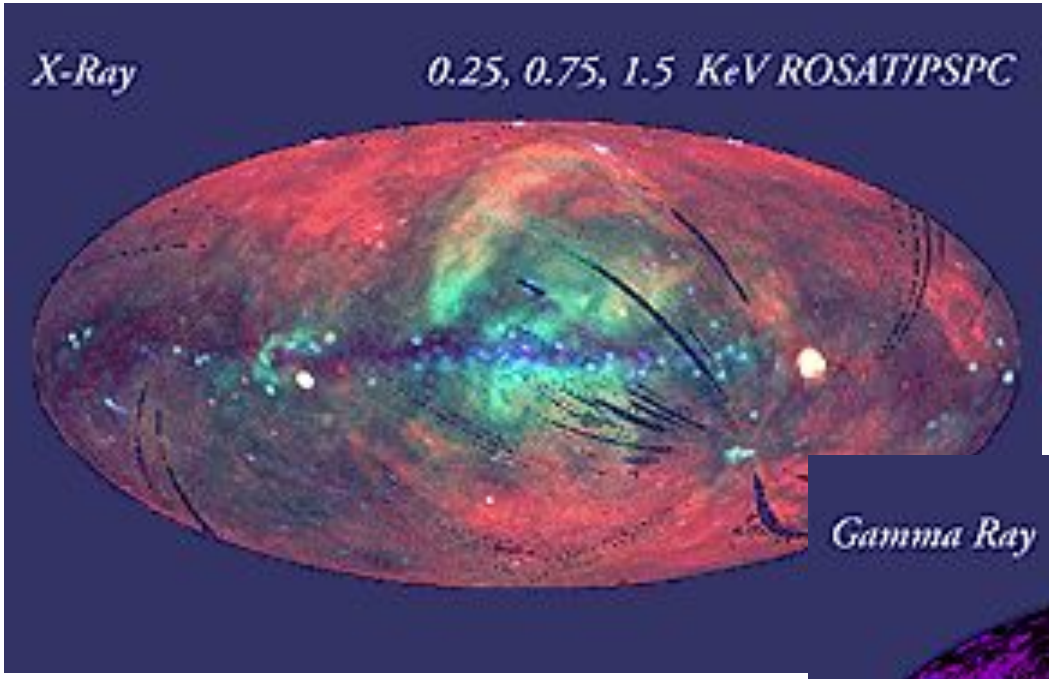
Scattering of free electrons in ionized interstellar gas



Interstellar dust warmed by absorbed starlight, starforming regions

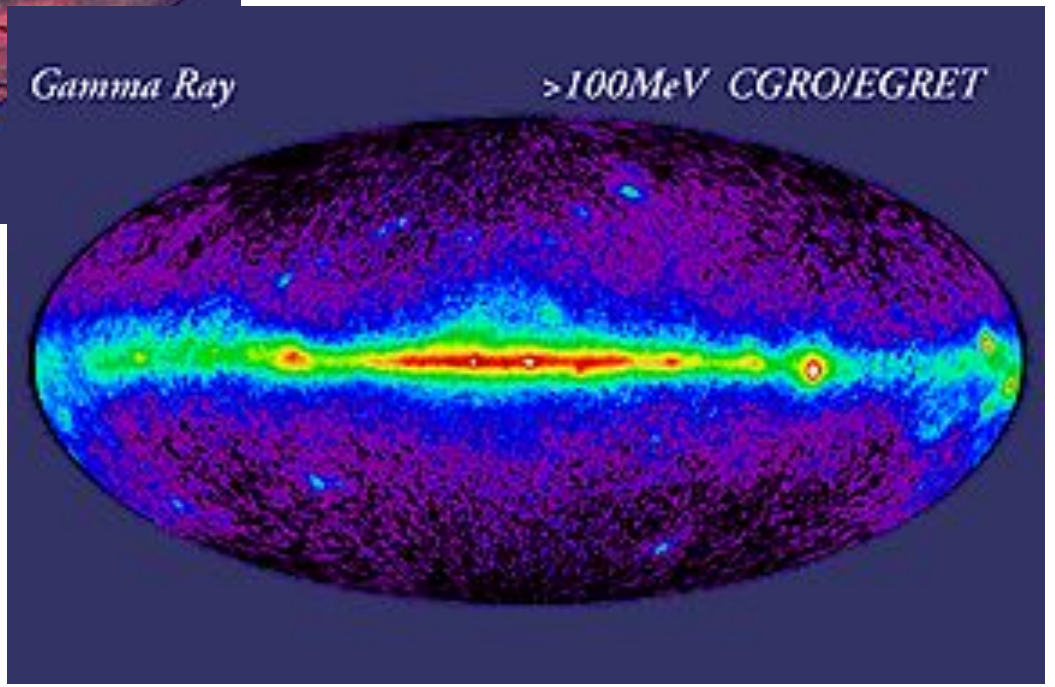
infrared
0.01 – 2 eV

Going to *Higher* Energy



X-ray
1000 eV = 1 keV

Hot gas

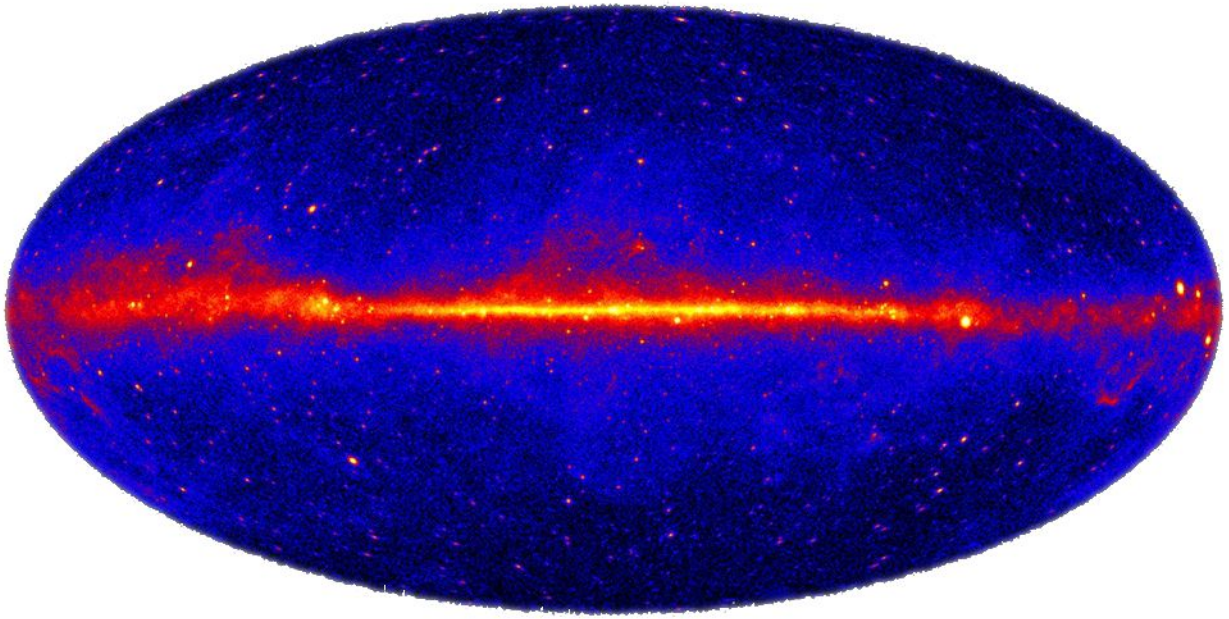


Collisions of cosmic rays with nuclei in interstellar clouds

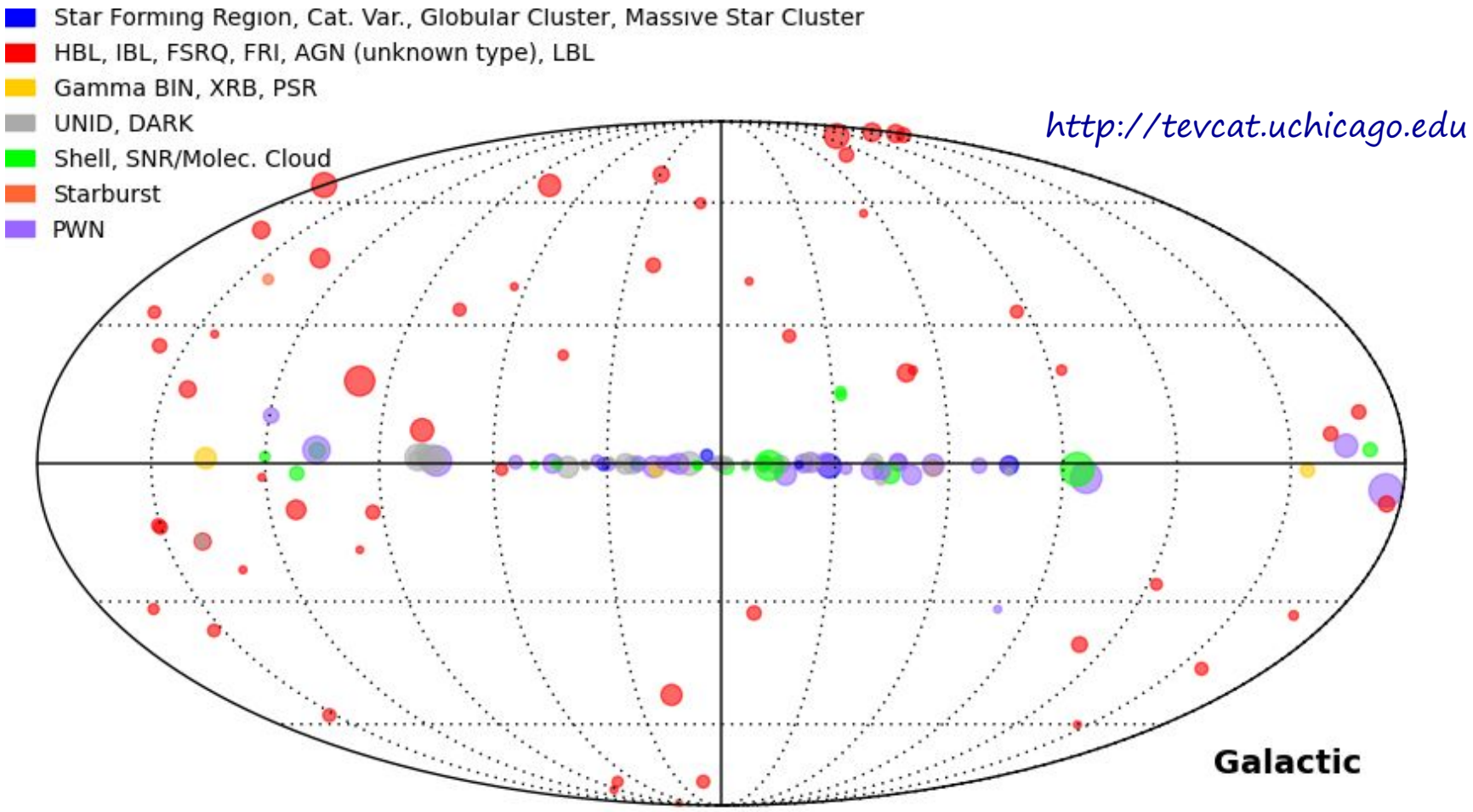
Gamma ray
>100 MeV

GeV Sky (10^9 eV) sources of Gamma Rays

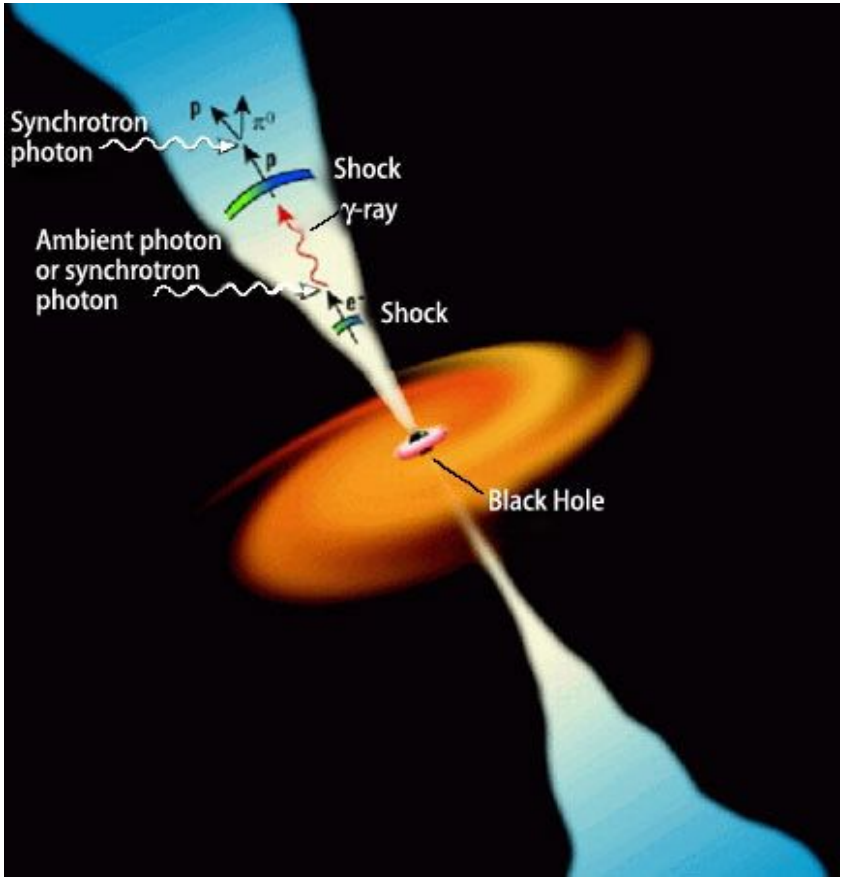
- Most gamma rays with energy > 100 MeV originate in collisions of *cosmic rays* with nuclei in interstellar clouds (so the Milky Way is a diffuse source of gamma-ray light).
- Superimposed are several *gamma-ray pulsars*, e.g., the Crab, Geminga, and Vela pulsars along the Galactic plane.
- Away from the plane, many of the sources are known to be *active galactic nuclei.*



TeV Sky (10^{12} eV)



TeV Sources



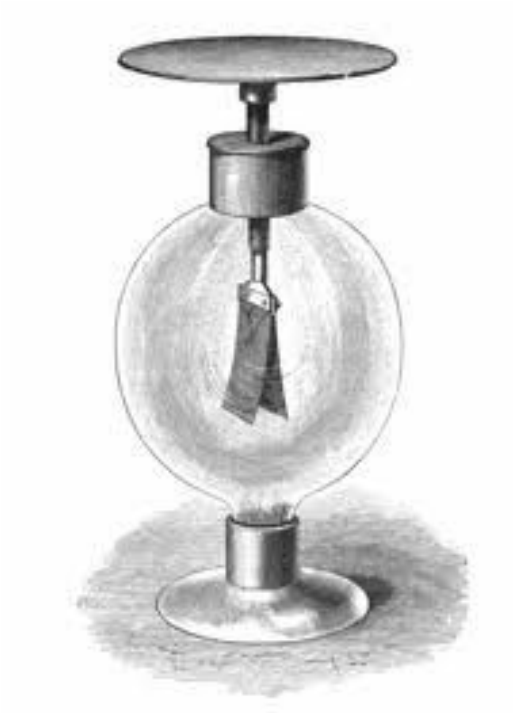
Galactic Sources:
Supernova Remnants, pulsars,…

Extragalactic Sources:
Active Galactic Nuclei,…

Why Study the TeV Band?

- TeV gamma rays are the highest energy gamma rays observed so far – this is the *energy frontier* of astronomy!
- TeV sources emit radiation over more than 15 orders of magnitude in energy, from radio to TeV!
- Historically, opening new windows in astronomy always results in major, *unforeseen discoveries.*
- Among the most tantalizing possibilities: the TeV window might help to identify the *sources of cosmic rays* and solve a hundred year old mystery…!

Victor Hess, 1912

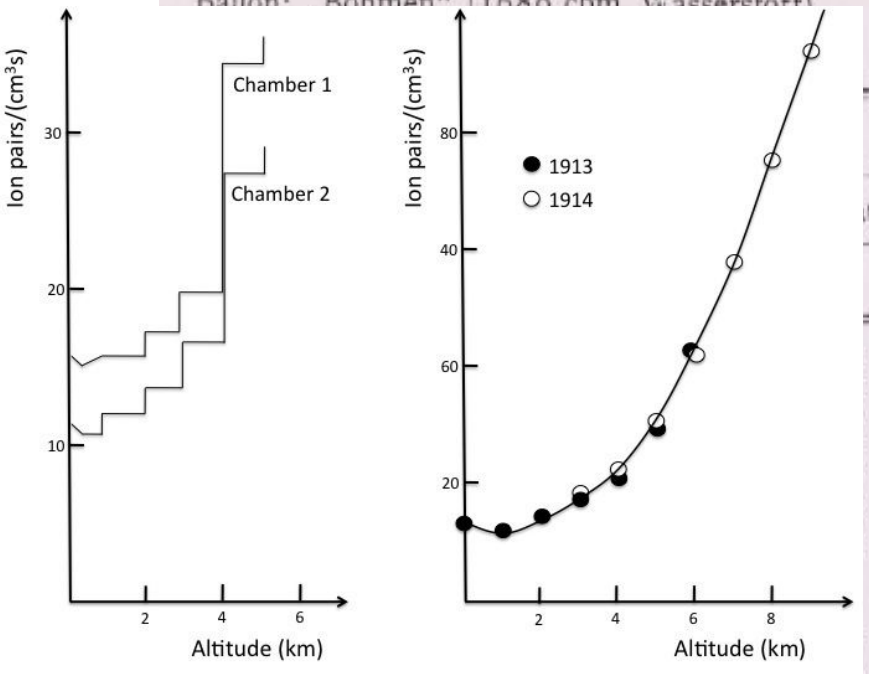


- Electroscopes discharge slowly even if no radioactive material is around - does the Earth radiate?

Victor F. Hess

Discovery of “Cosmic Rays”

- Going up as high as 17,500 feet, Hess showed that the radiation level *increases* with altitude!



7. Fahrt (7. August 1912).

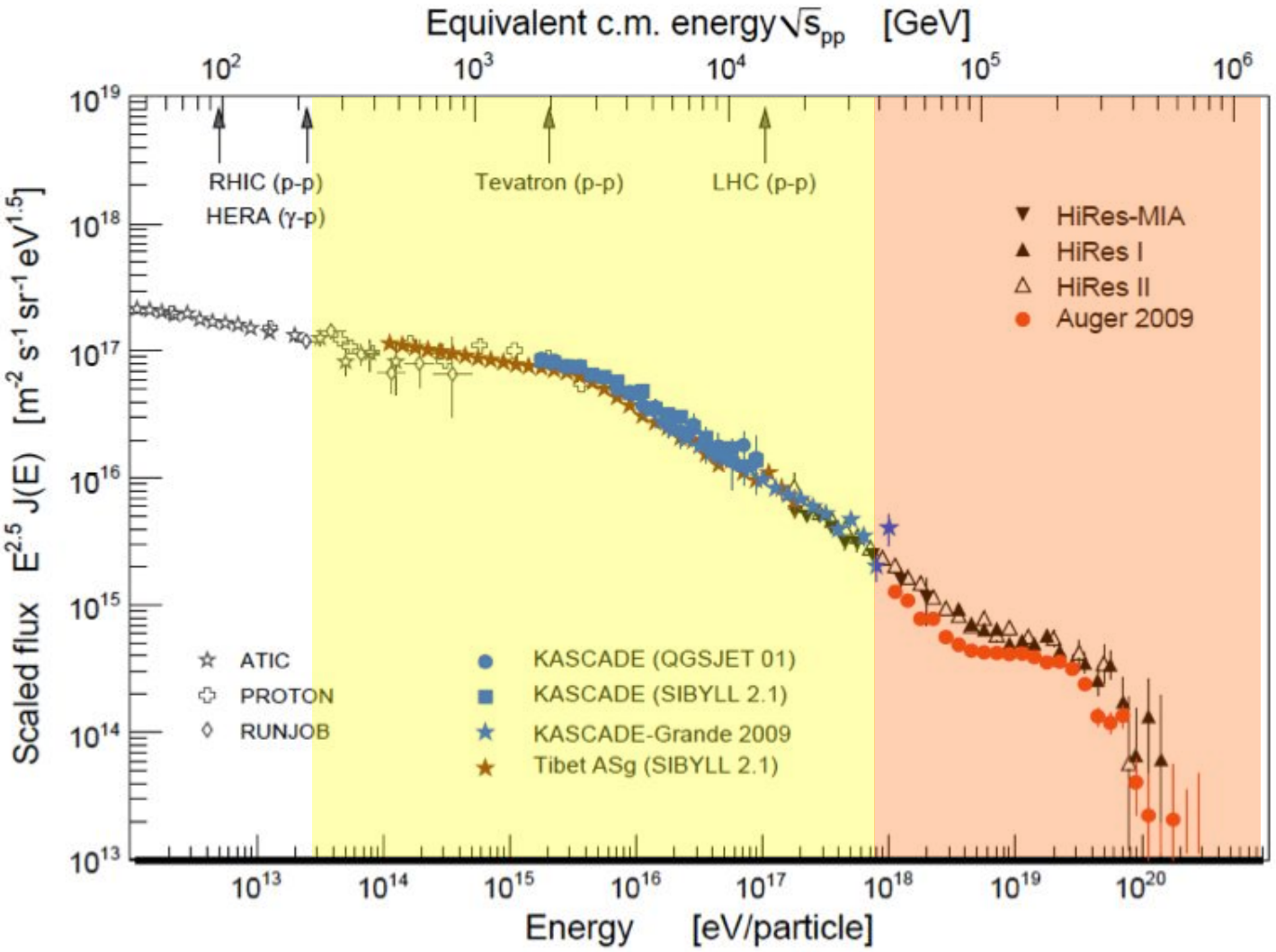
Führer: Hauptmann W. Hoffory.
Luftelektr. Beobachter: V. F. Hess.

Beobachtete Strahlung

10	11h 45—12h 10	250	150	11,9
11	12h 25—13h 12	140	0	15,0

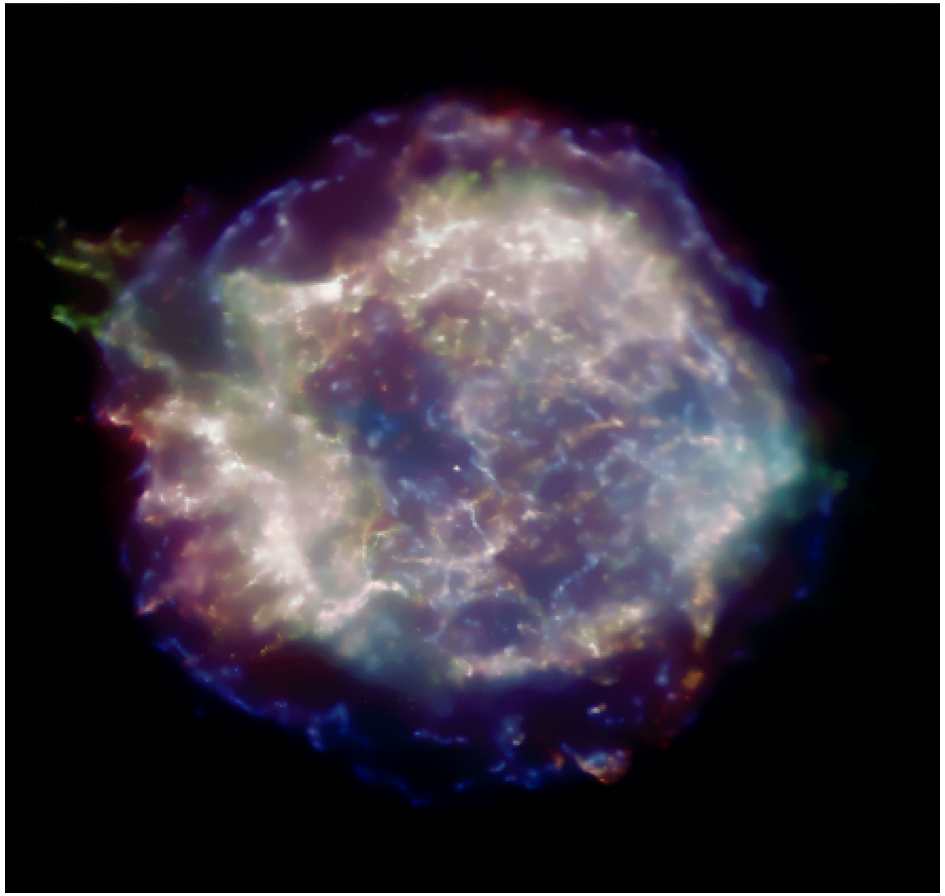
Pieskow, Brandenburg)

Cosmic-Ray Energy Spectrum

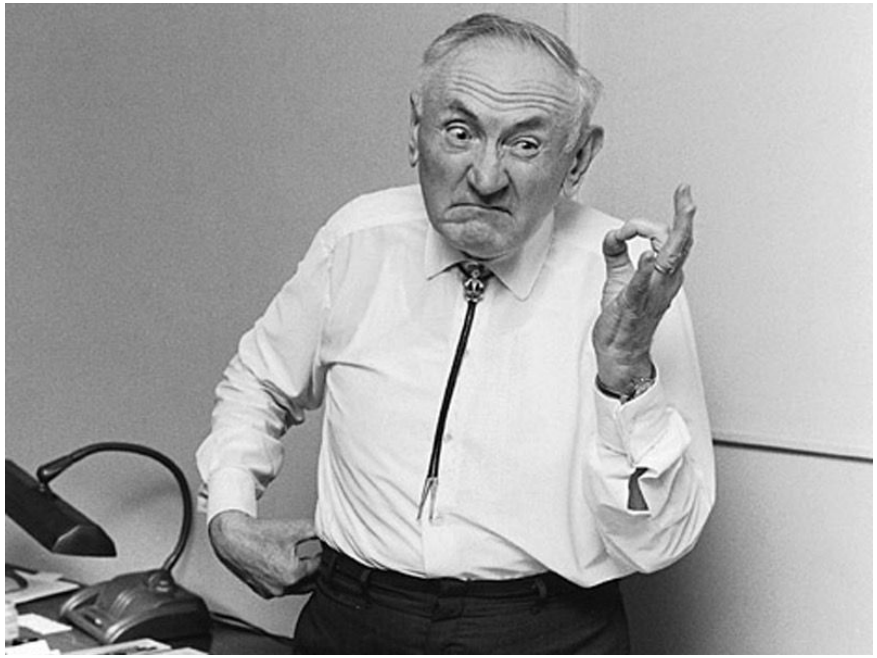


Galactic Cosmic Rays

- Baade and Zwicky suggested in 1934 that *supernova remnants* could be the sources of Galactic cosmic rays.



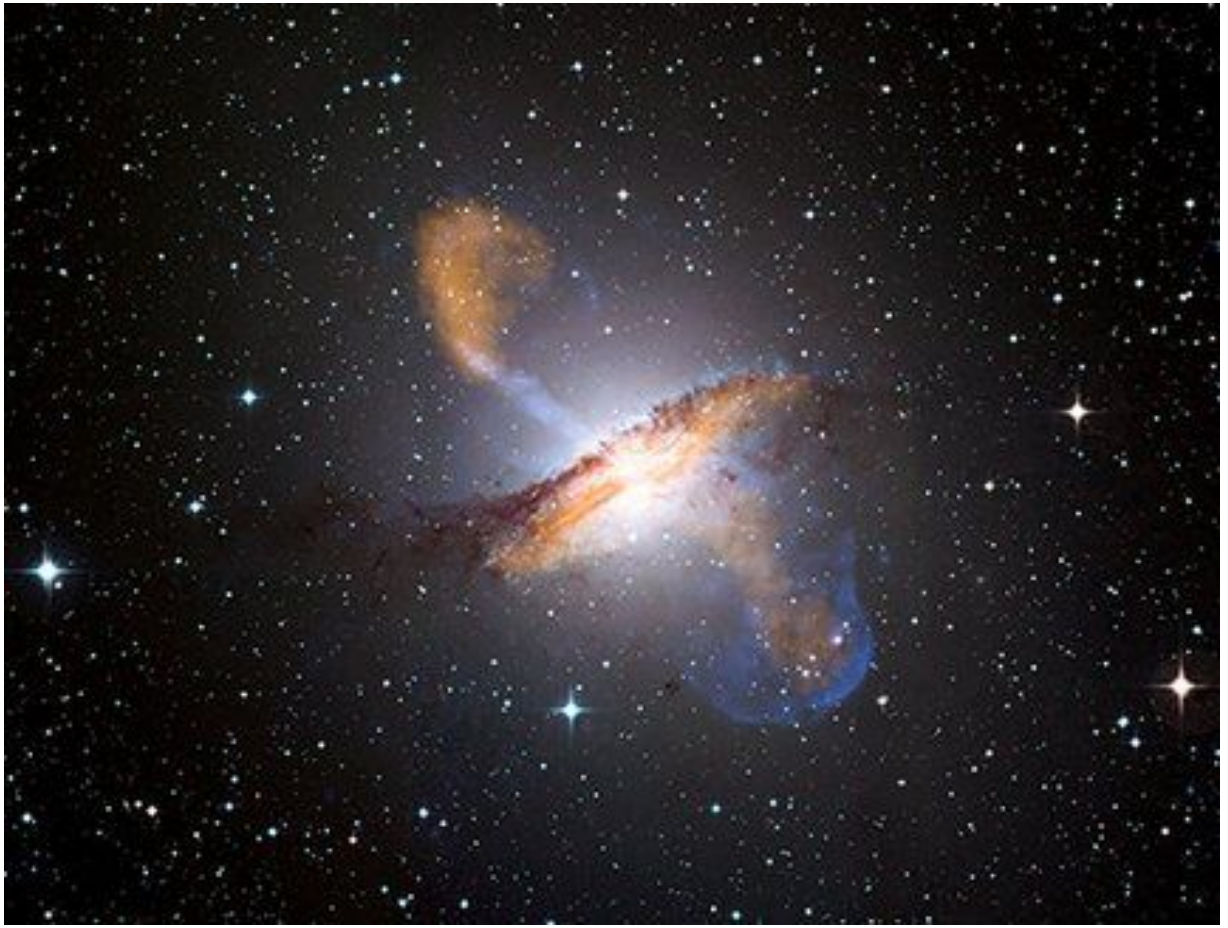
Cas A, Chandra (NASA)



Fritz Zwicky

Extragalactic Sources

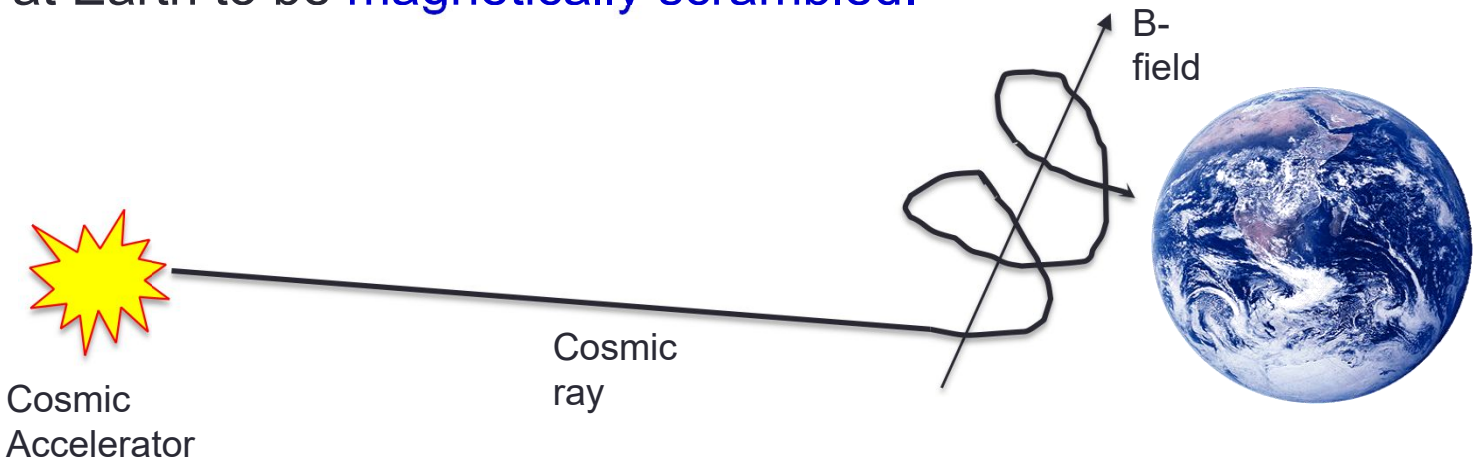
- *Active Galactic Nuclei* (AGN) are possible sources for the highest energy cosmic rays.
- AGN consist of a supermassive black hole, an accretion disk, and two jets in which shocks move outward.



Centaurus A (ESO 2.2 m WFI + APEX + Chandra)

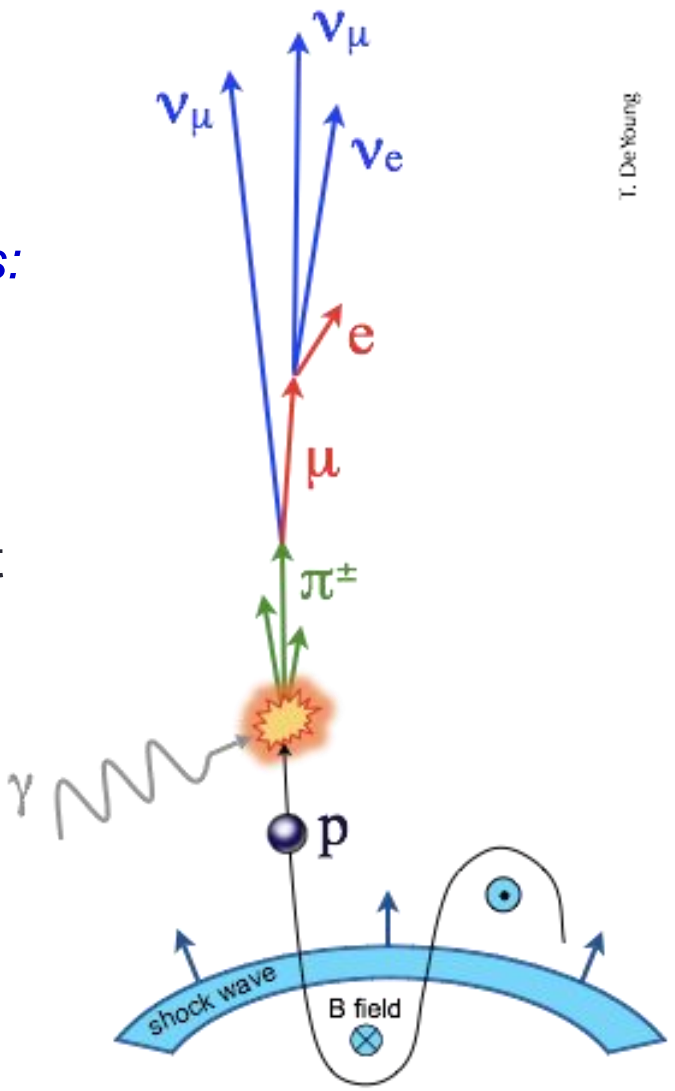
Cosmic-Ray Astronomy?

- No source of Galactic or extragalactic cosmic rays has been identified so far.
- The problem: cosmic rays are charged, and the universe is full of magnetic fields.
- Below 10^{19} eV (*at least*) we expect the arrival directions of cosmic rays at Earth to be magnetically scrambled.



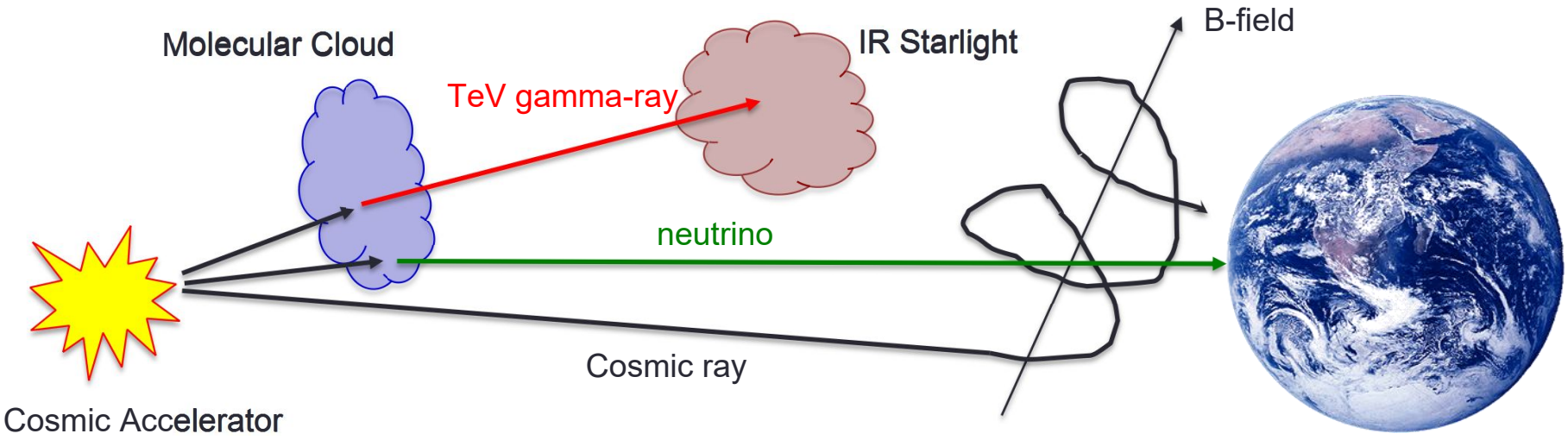
Gamma Rays

- Cosmic rays *interact* with their surroundings.
- The interactions will produce *decay products:*
  - Gamma rays
  - Neutrinos
- Both are neutral and come to us in a straight line!
- Energy escaping the source is distributed among *cosmic rays, gamma rays,* and *neutrinos.*

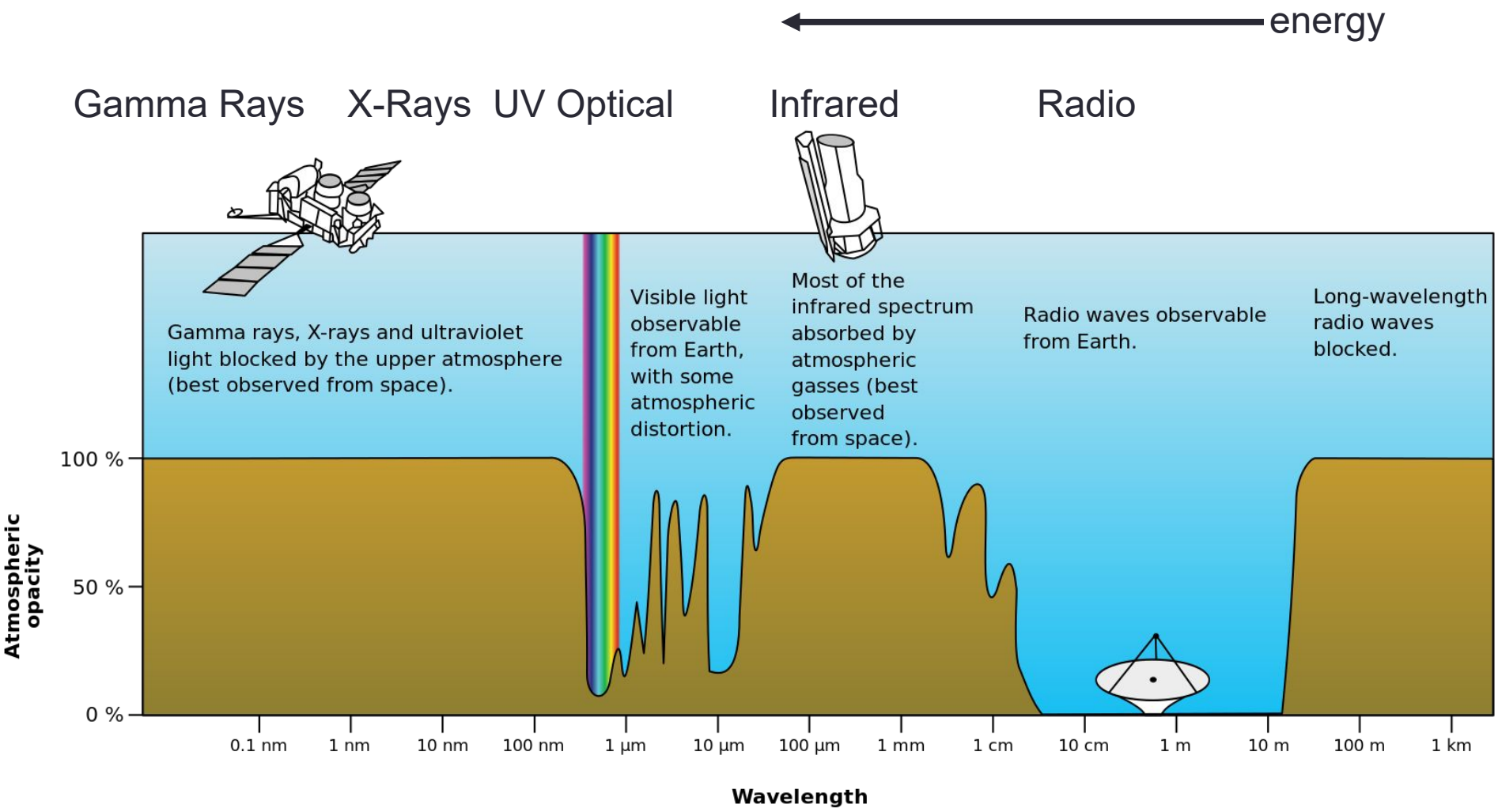


Multi-Messenger Astrophysics

- Each channel has relative strengths and weaknesses:
  - Cosmic rays: ✓ largest flux, ✗ deflected by magnetic fields
  - Gamma-rays: ✓ undeflected, ✗ attenuated
  - Neutrinos: ✓ undeflected, ✓ unattenuated, ✗ difficult to observe



Observation Techniques



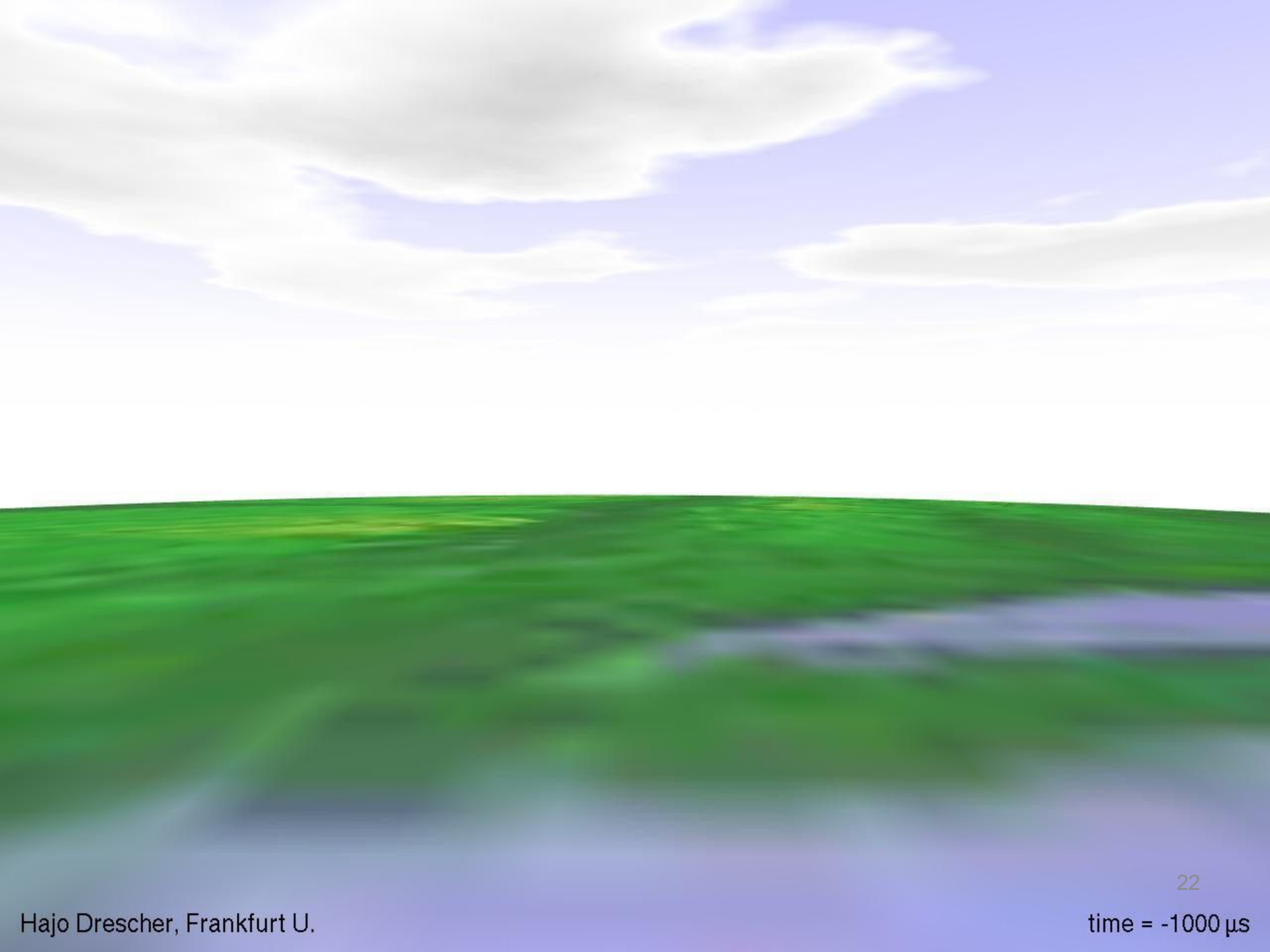
Detecting TeV Gamma Rays

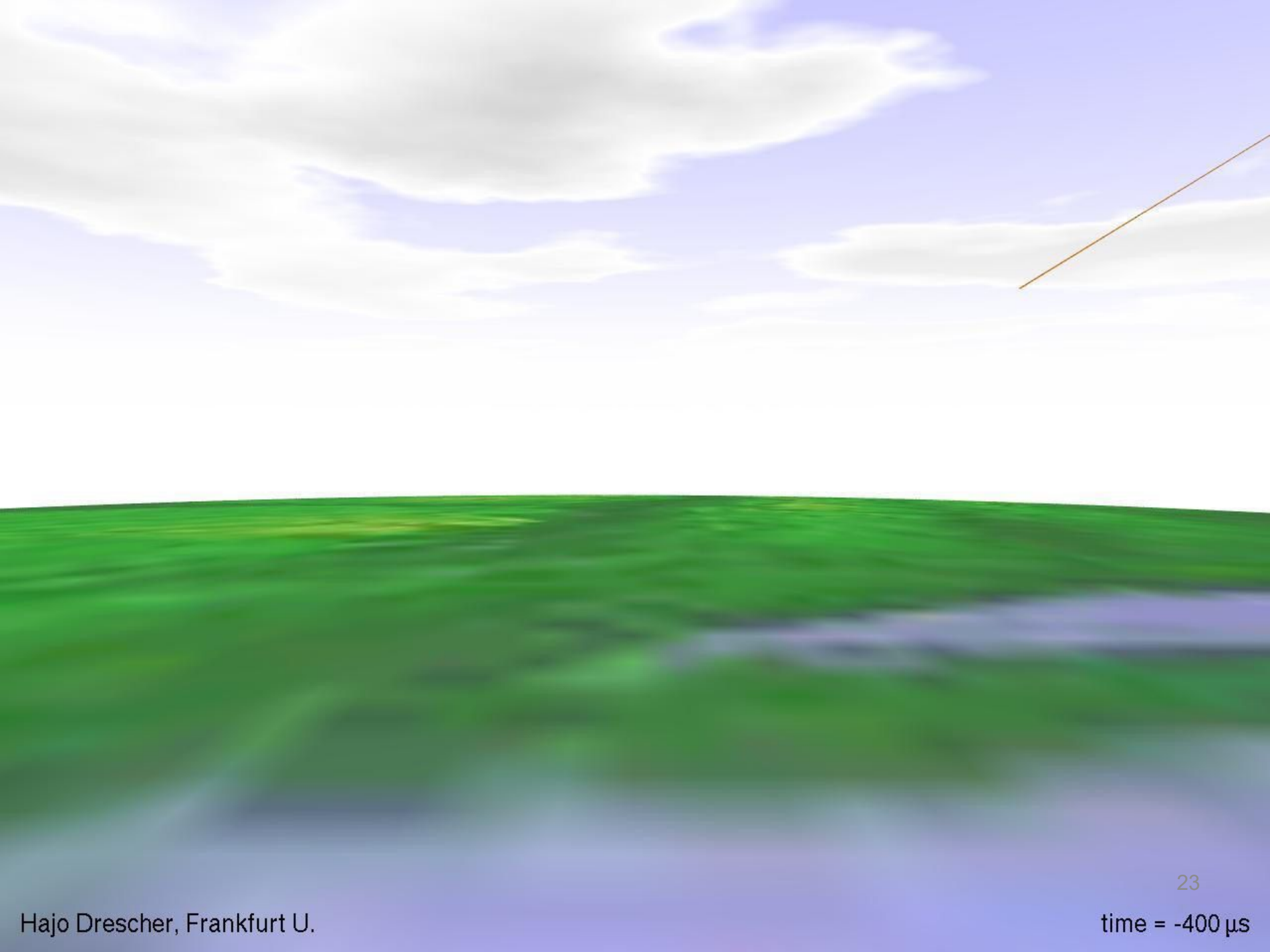
- The flux of TeV (= 10^{12} eV) gamma rays is more than 6 orders of magnitude smaller than at GeV(= 10^{9} eV) energies, where the Fermi satellite operates. To get sufficient flux, the experiment must cover a large area, at least soccer field size…

- … so the experiment must be Earth-bound.

- The Earth's atmosphere is 100% *opaque* to gamma rays at TeV energies.

- Gamma rays and cosmic rays interact with air molecules and develop cascades of secondary particles, so-called *air showers.* The atmosphere acts as a giant calorimeter. We can use this to our advantage!


22
Hajo Drescher, Frankfurt U.
time = -1000 µs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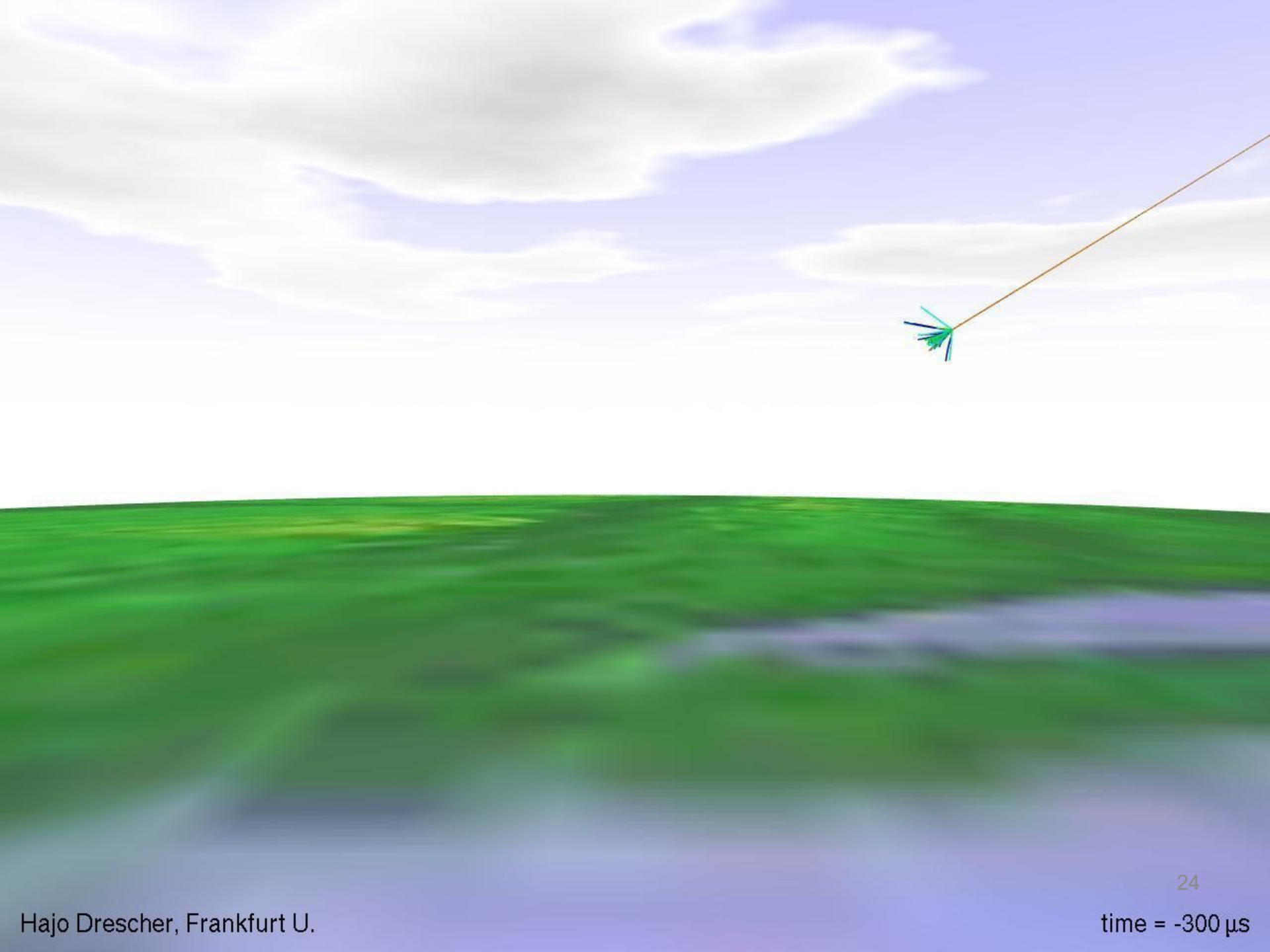
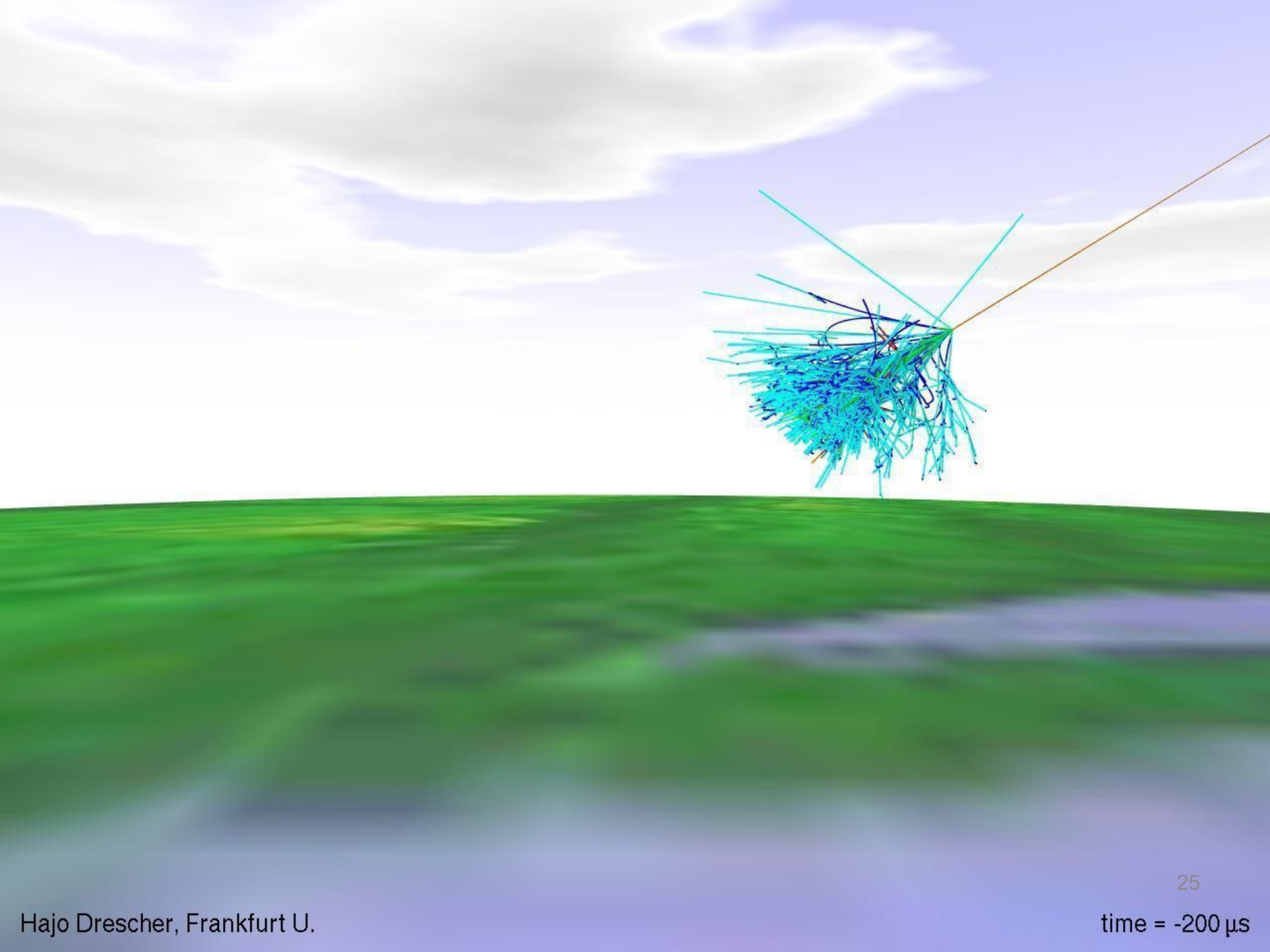
Hajo Drescher, Frankfurt U.
time = -400 µs


Hajo Drescher, Frankfurt U.
time = -300 µs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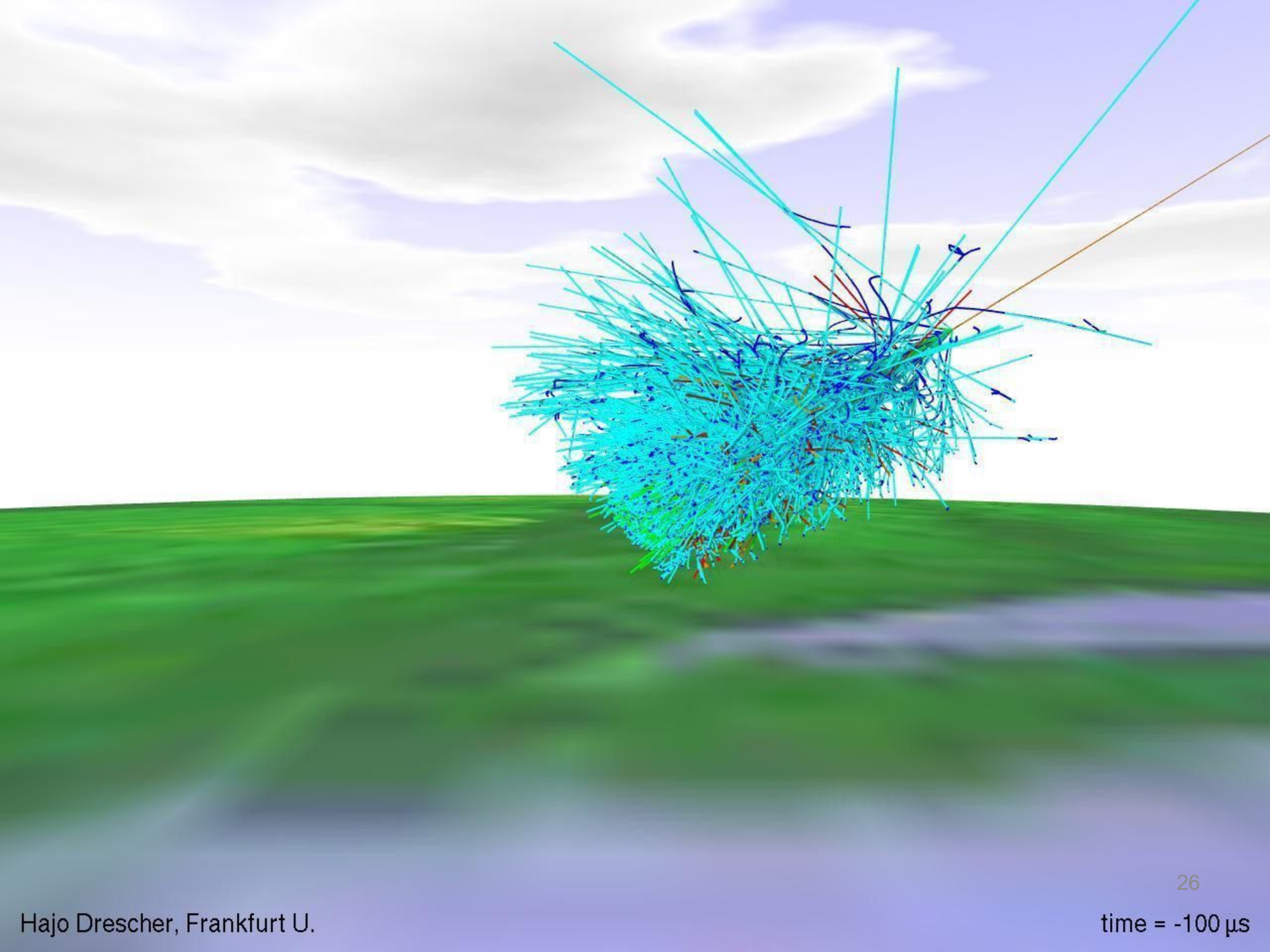
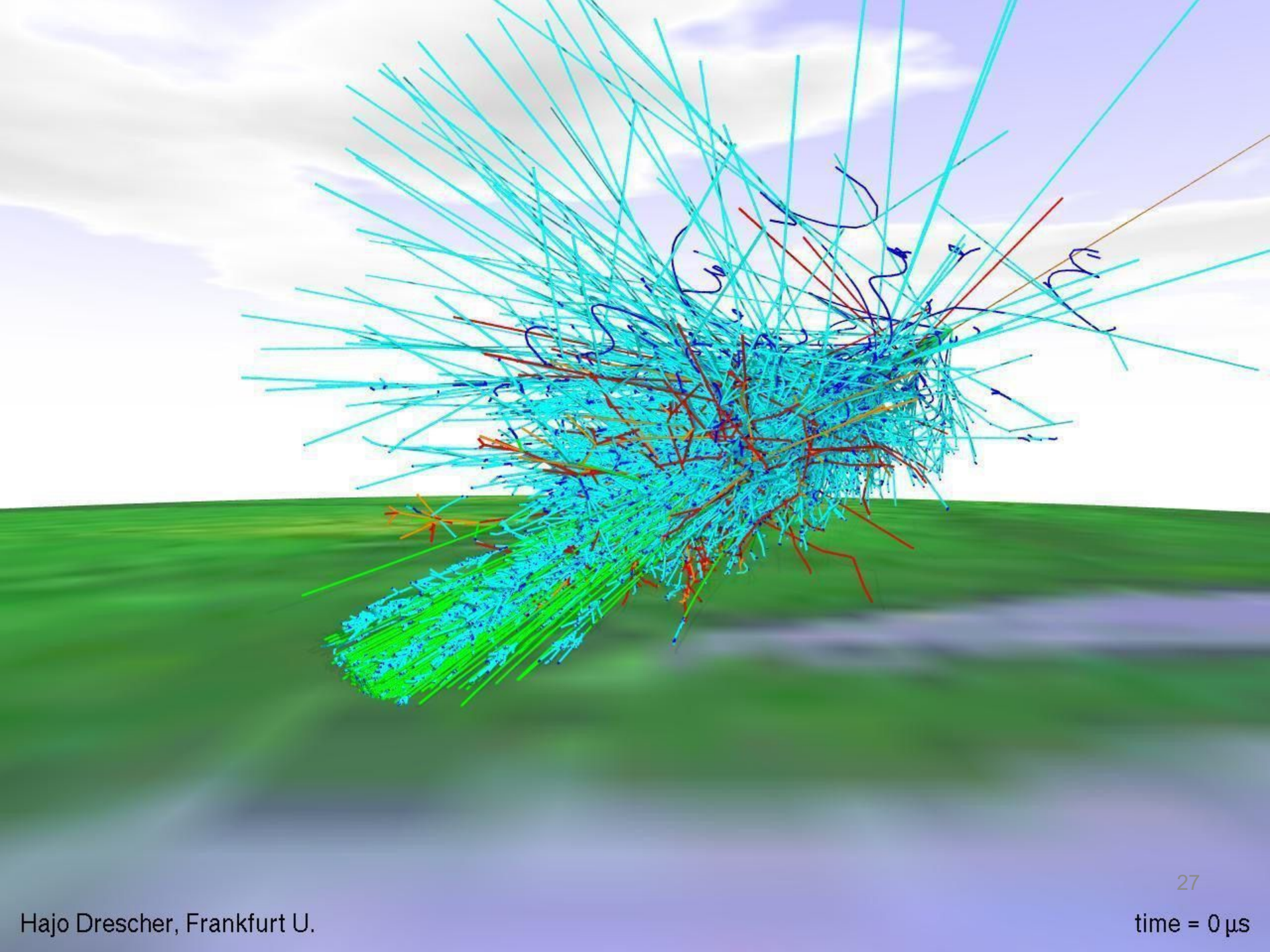
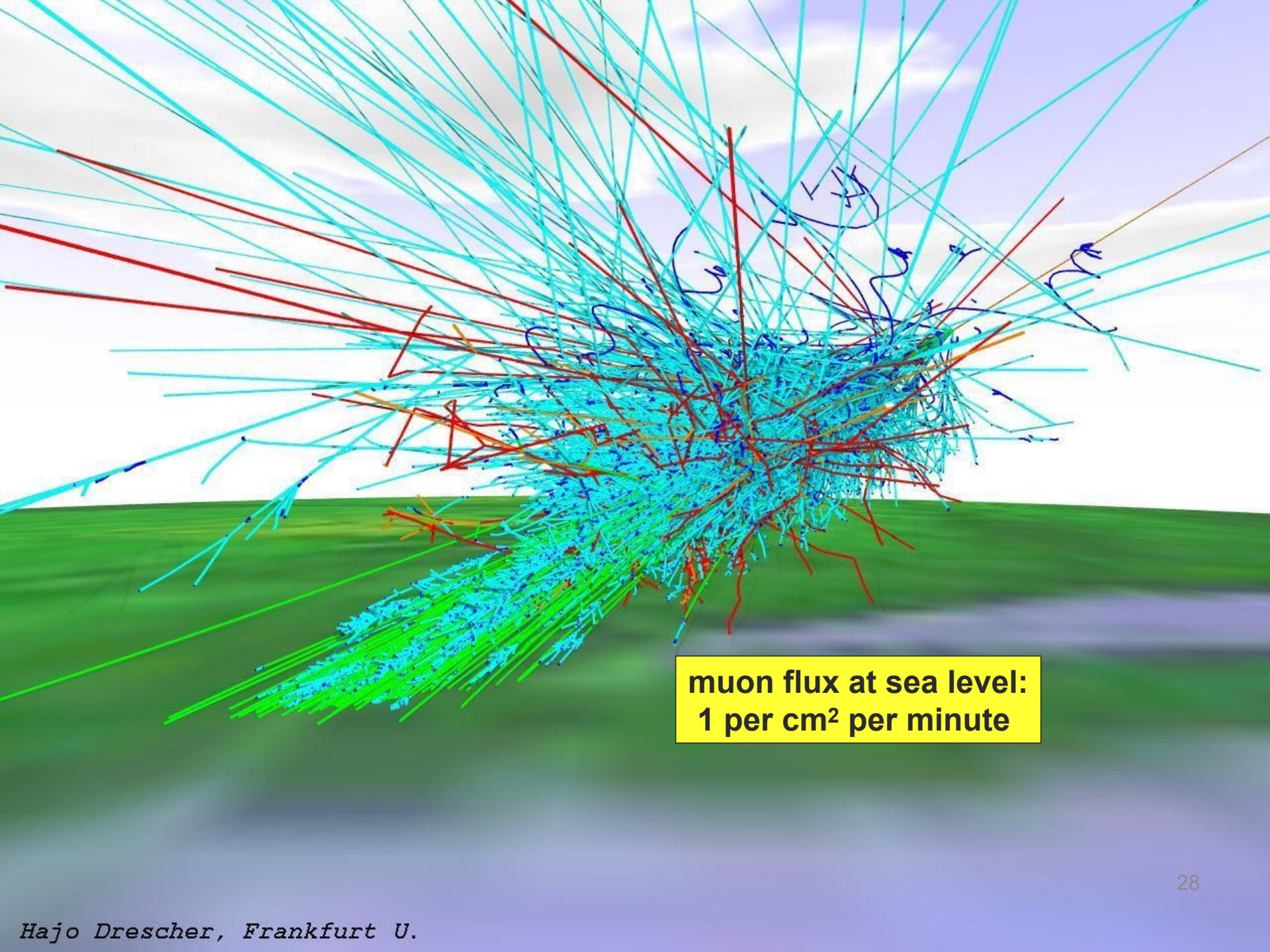
time = -200 µs

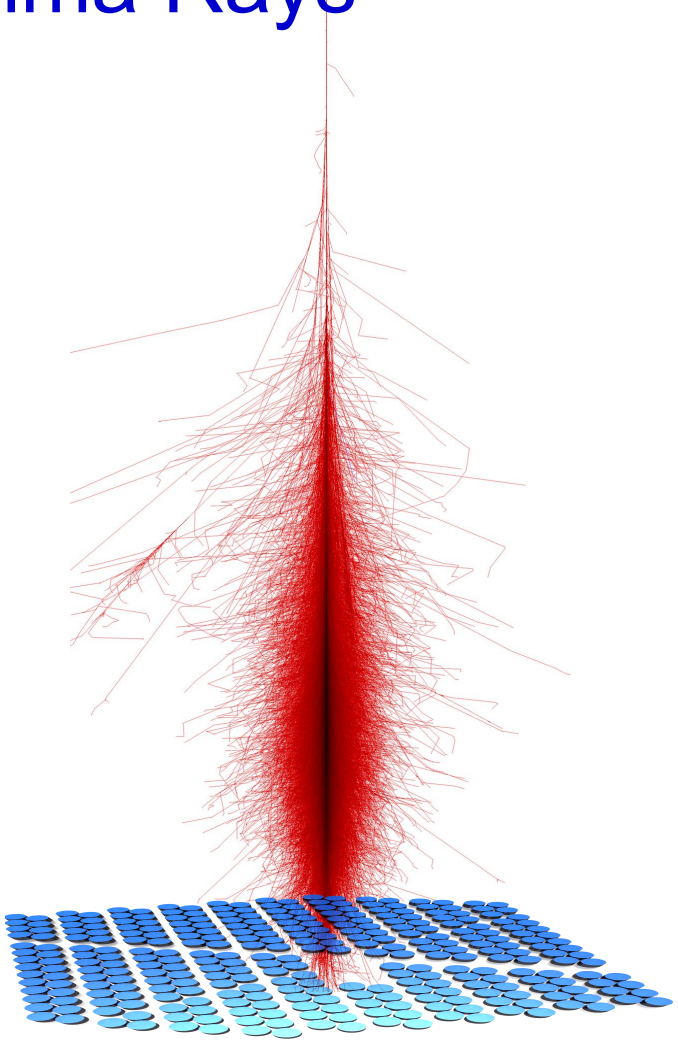

Hajo Drescher, Frankfurt U.
time = -100 µs


Hajo Drescher, Frankfurt U.
time = 0 µs


muon flux at sea level:
1 per cm² per minute

Detecting TeV Gamma Rays

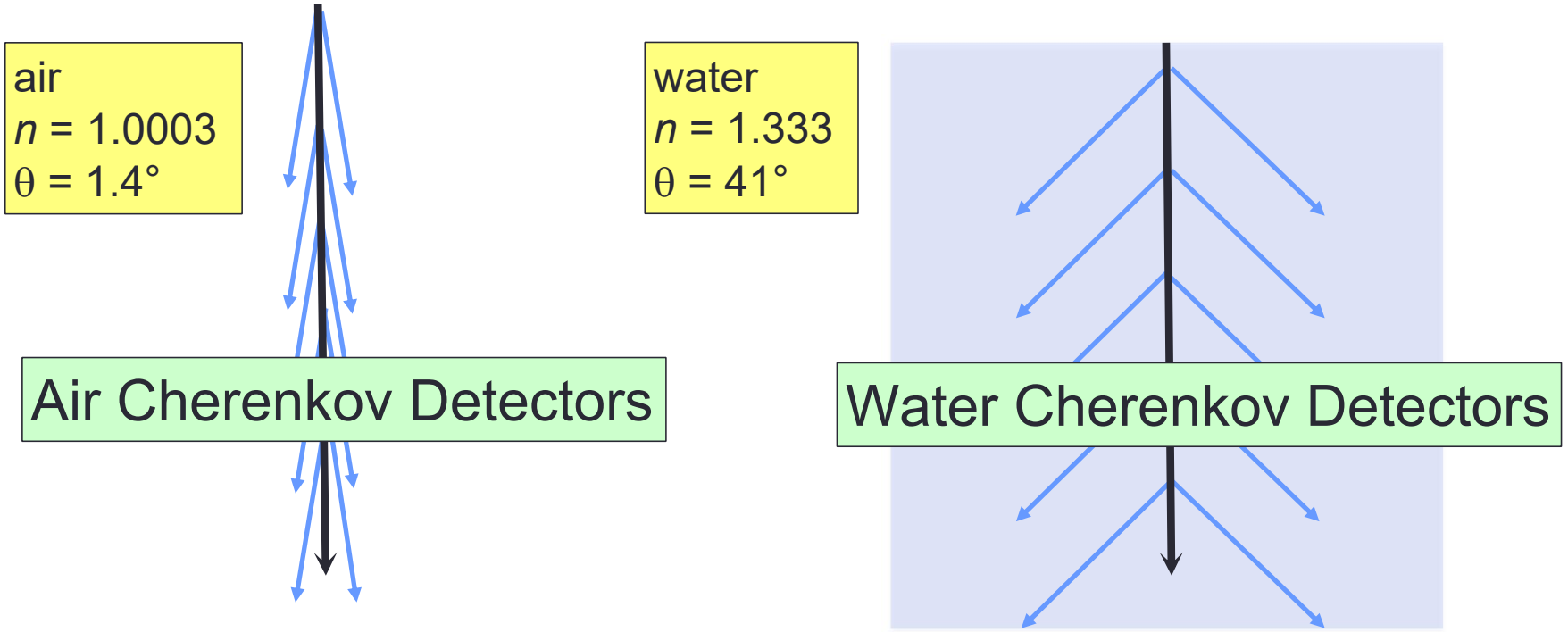
- (Two) methods for detecting air showers:
  - A fraction of the secondary particles hits the ground and can be detected by arrays of particle counters.
  - The air shower particles are relativistic and produce *Cherenkov light* which can be picked up by light detectors.
  - Both techniques use Cherenkov light and photomultiplier tubes…



Cherenkov Light

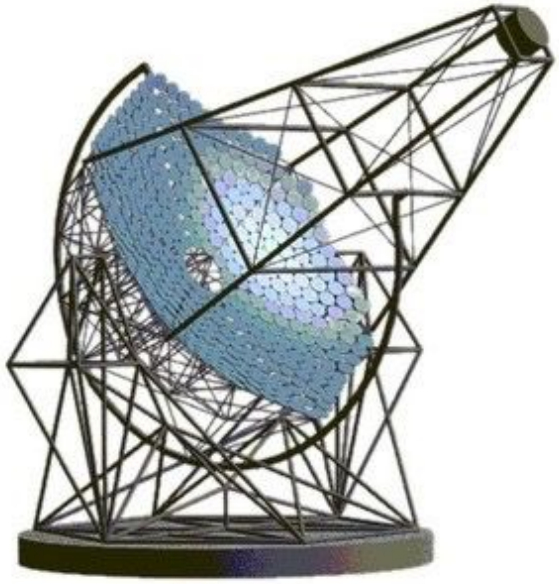
- Cherenkov light is produced when particles travel through a medium (air, water,…) at a speed *faster* than the speed of light *in the medium.*

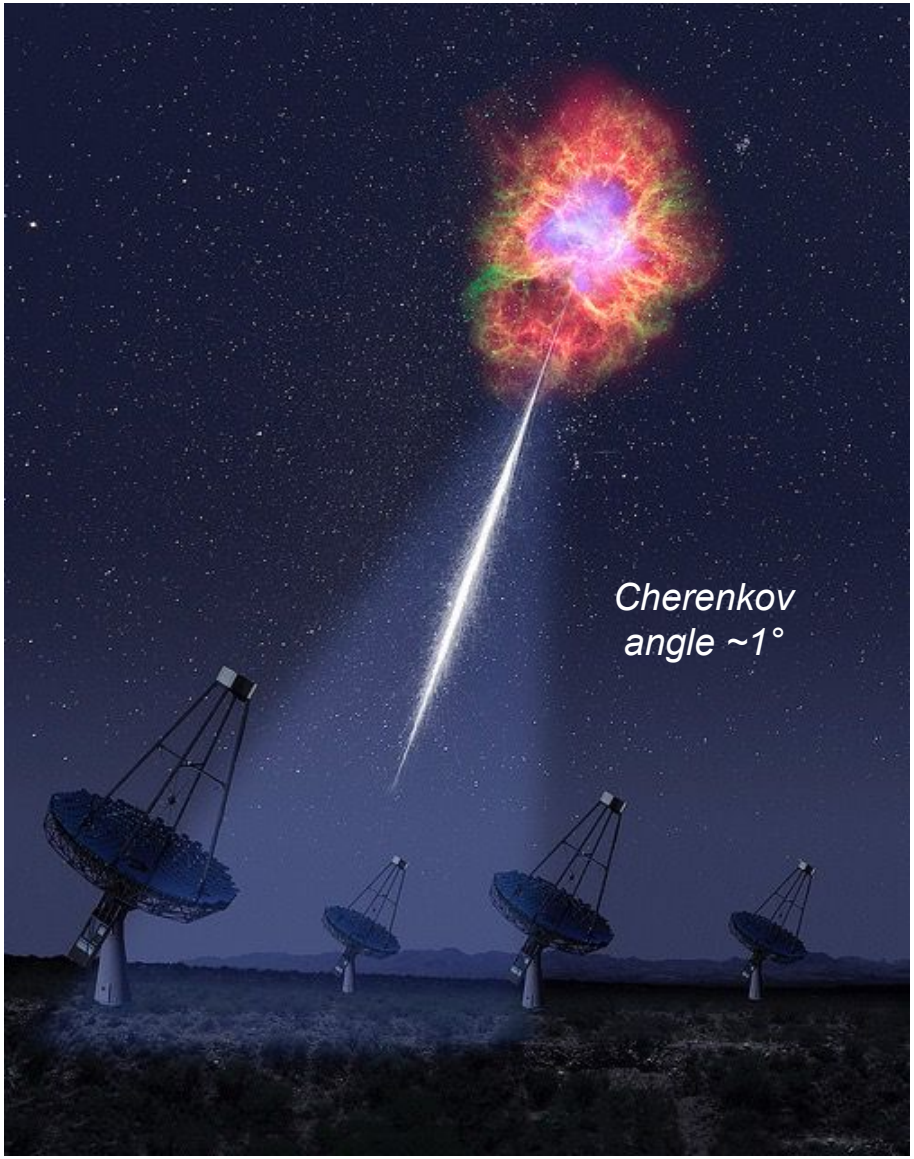
- Cherenkov light is emitted in the forward direction, and the emission angle depends on the index of refraction *n* of the medium.



Air Cherenkov Telescopes

- Air Cherenkov telescopes detect the *Cherenkov light cone* produced by the particle shower.
- They consist of systems of small mirrors that reflect the light into cameras made of arrays of photomultipliers





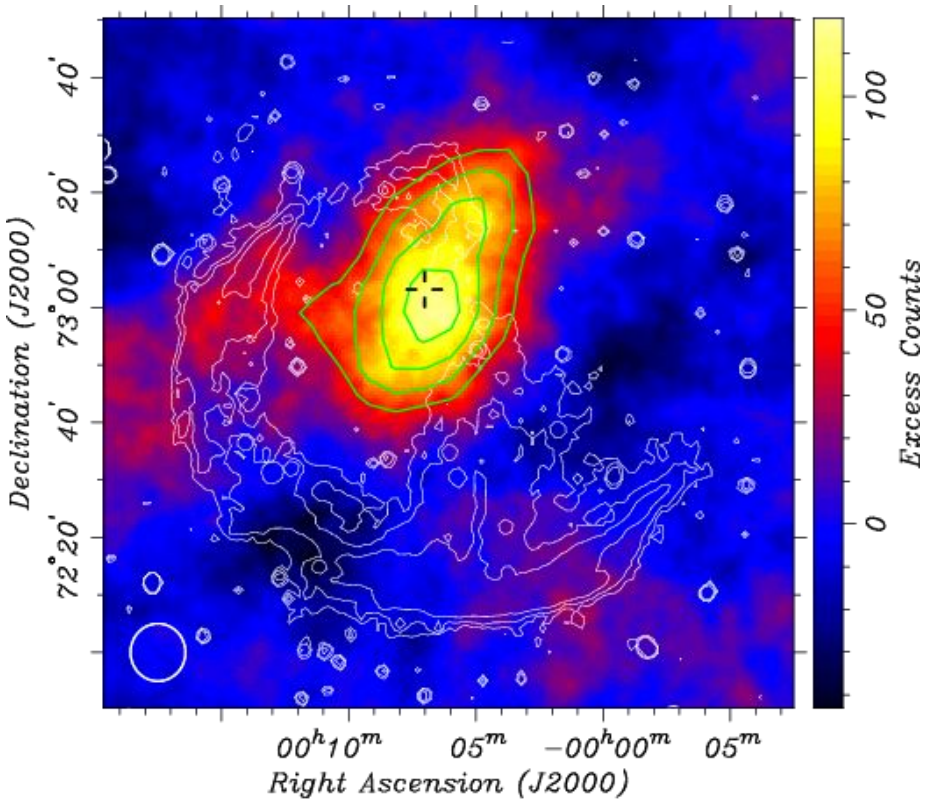
Air Cherenkov Telescopes

Pros:

- *Excellent sensitivity,* with a typical angular resolution of about 0.1°.
- They produce detailed pictures of individual sources.

Cons:

- They are *pointed* instruments that can only observe one object at a time.
- Only operate during dark nights and have a *limited duty cycle* (~1000 hours/year).

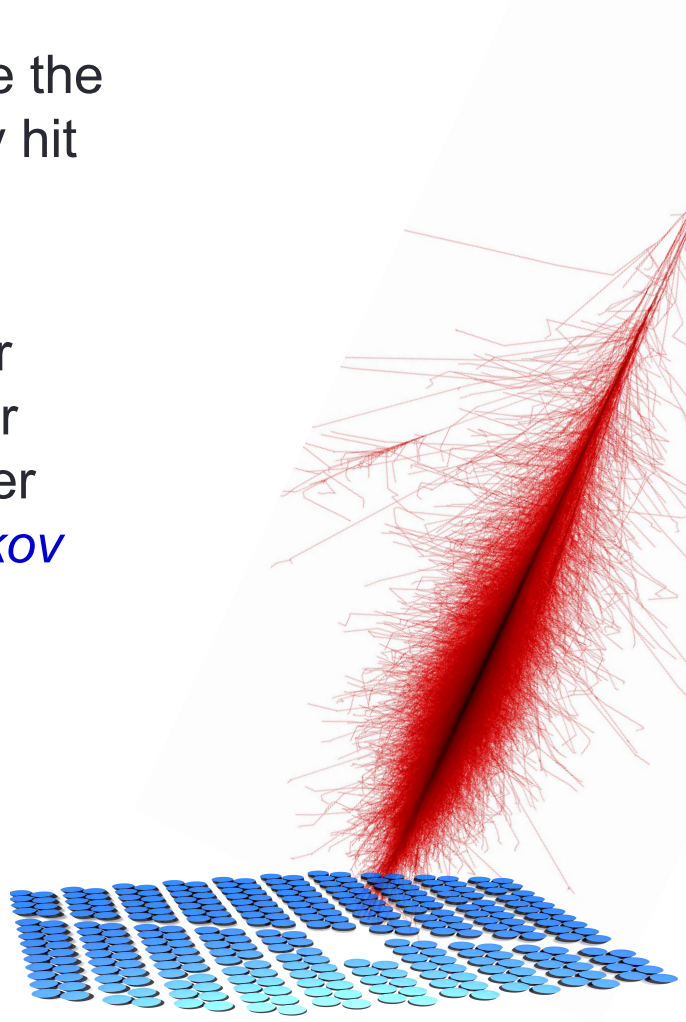


VERITAS image of the SNR CTA1

Water Cherenkov Detectors

- Alternative approach: measure the *air shower particles* when they hit the ground.

- *Water* is the cheapest detector material: the particles of the air shower move through the water volume and generate *Cherenkov light* that is captured by photomultipliers.



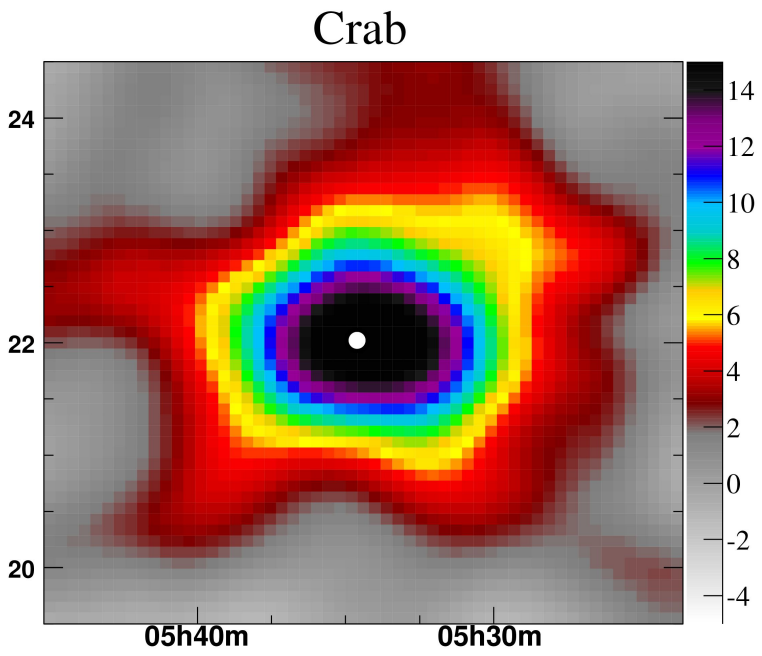
Water Cherenkov Technique

Pros:

- *Large duty cycle* (>95%), independent of weather and daylight.
- *Large field-of-view.*
- *Large effective area.*

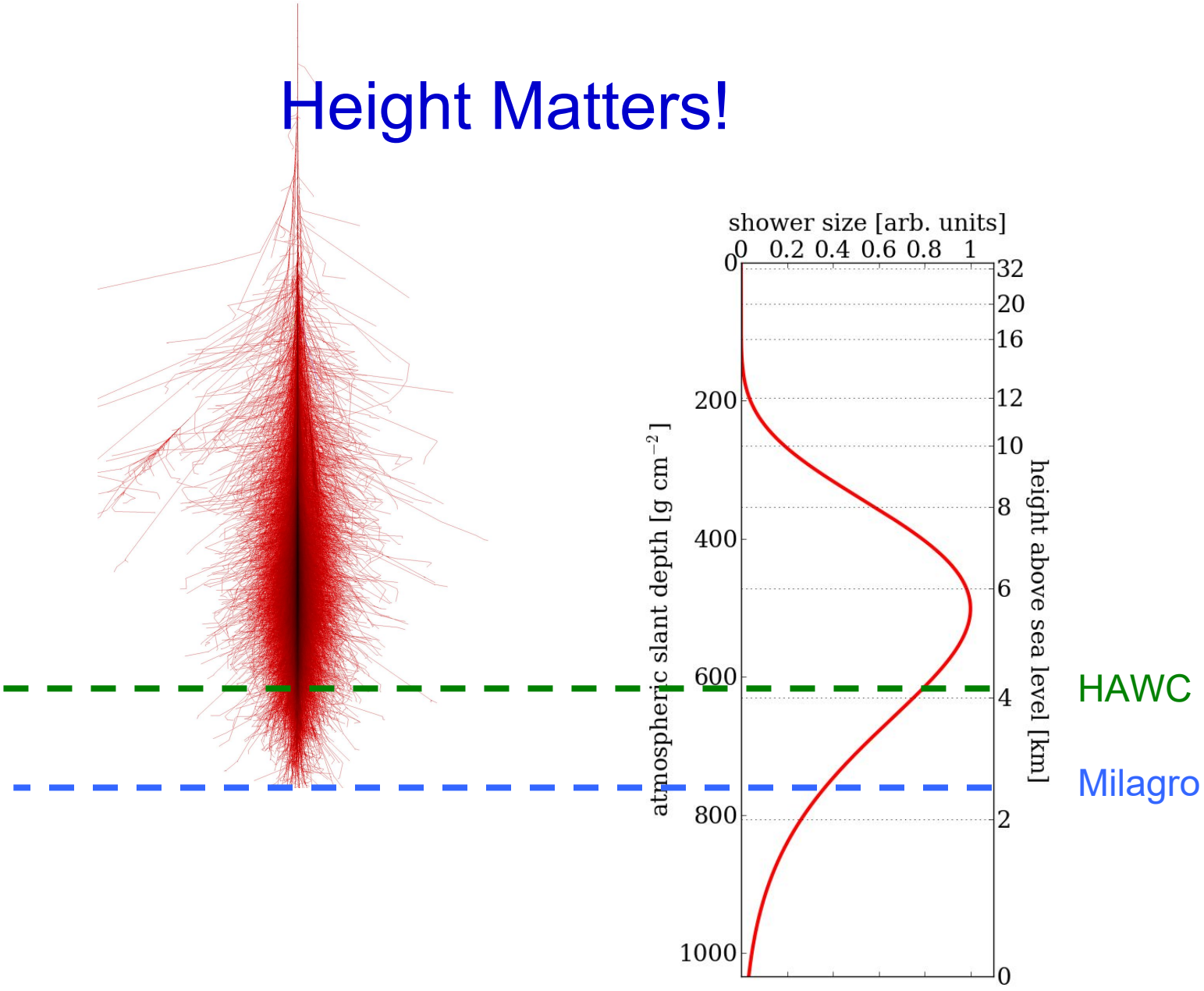
Cons:

- Much *lower sensitivity* for point sources.
- Angular resolution ~1°.



Significance of Milagro Crab signal in ~8 years of data

Height Matters!



The Latin American Giant Observatory (LAGO) Project

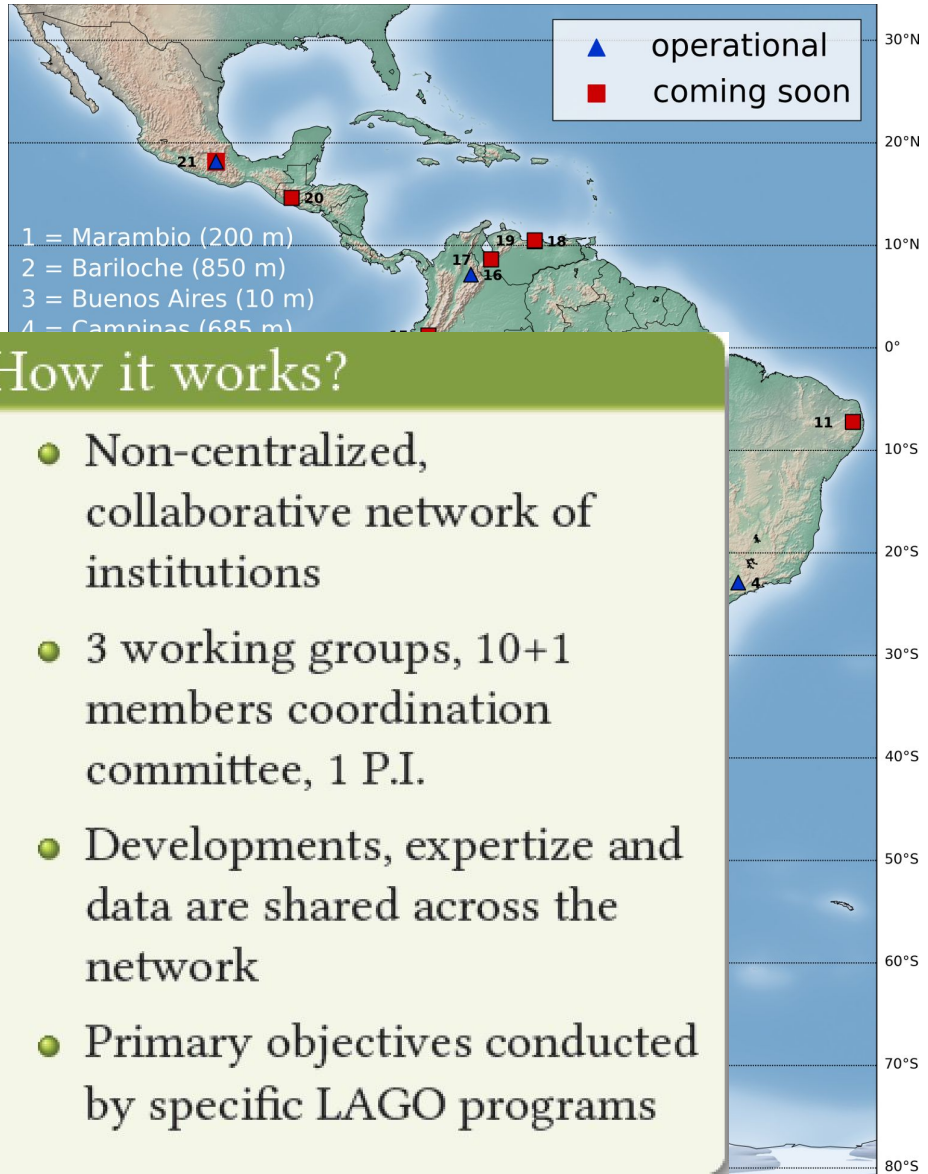
A very long baseline “array” of water Cherenkov detectors (WCD)

- 87 members from 26 institutions, 10 countries
- Scientifics goals:
  - Study High Gamma events at high altitude sites
  - Transient and long term Space Weather phenomena trough Solar modulation of CR
  - Measurement of background radiation at ground levels at different rigidity, continental level

- Academic goals:
  - Train Latin American students in Astroparticle physics
  - Build a Latin-America network of Astroparticle researches

LAGO Sites

- Network goes from México to Patagonia (Bariloche)
- One station will be installed at Marambio Base (200 m.a.s.l), Antarctic

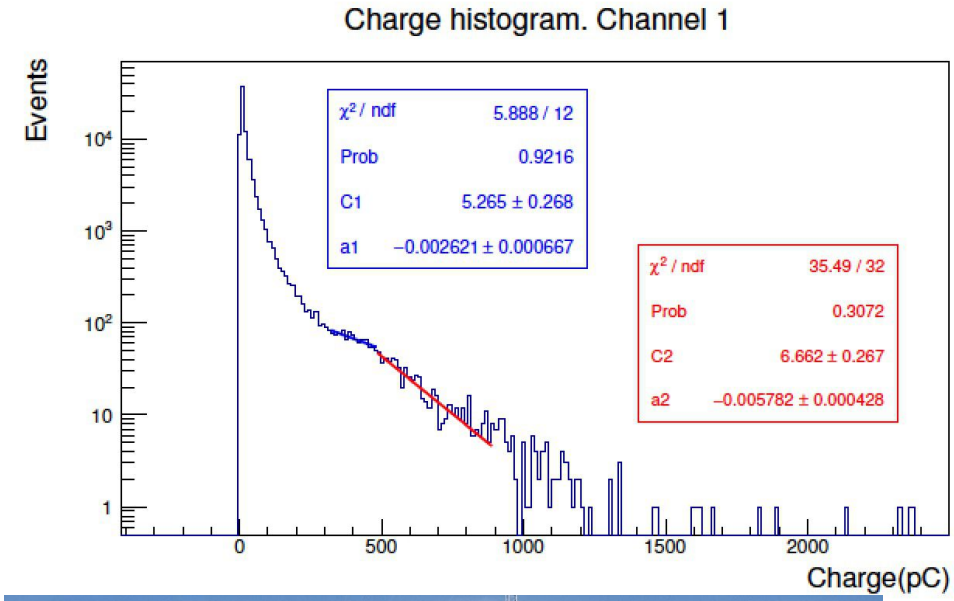


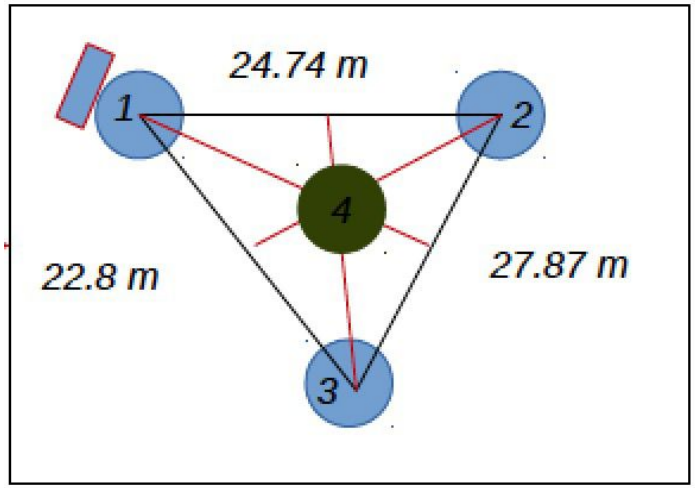
- Sites at nine LA countries: Argentina, Bolivia, Brazil, Colombia, Ecuador, Guatemala, Mexico, Peru & Venezuela

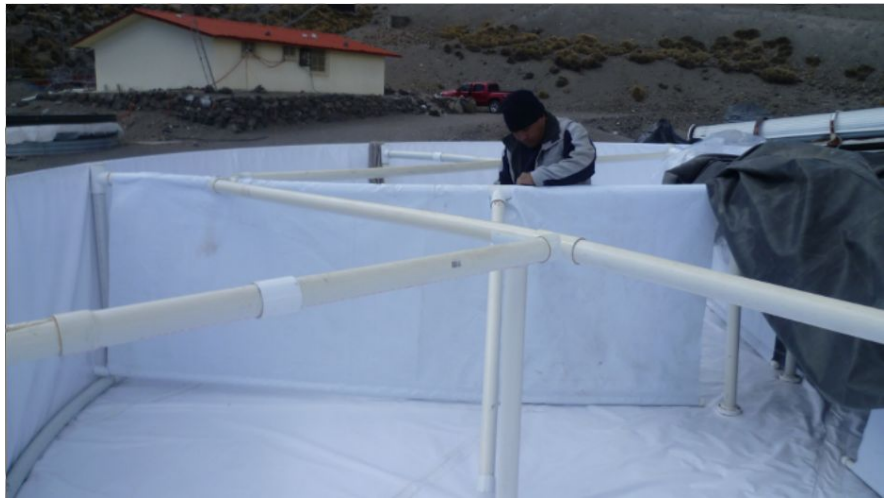
How it works?

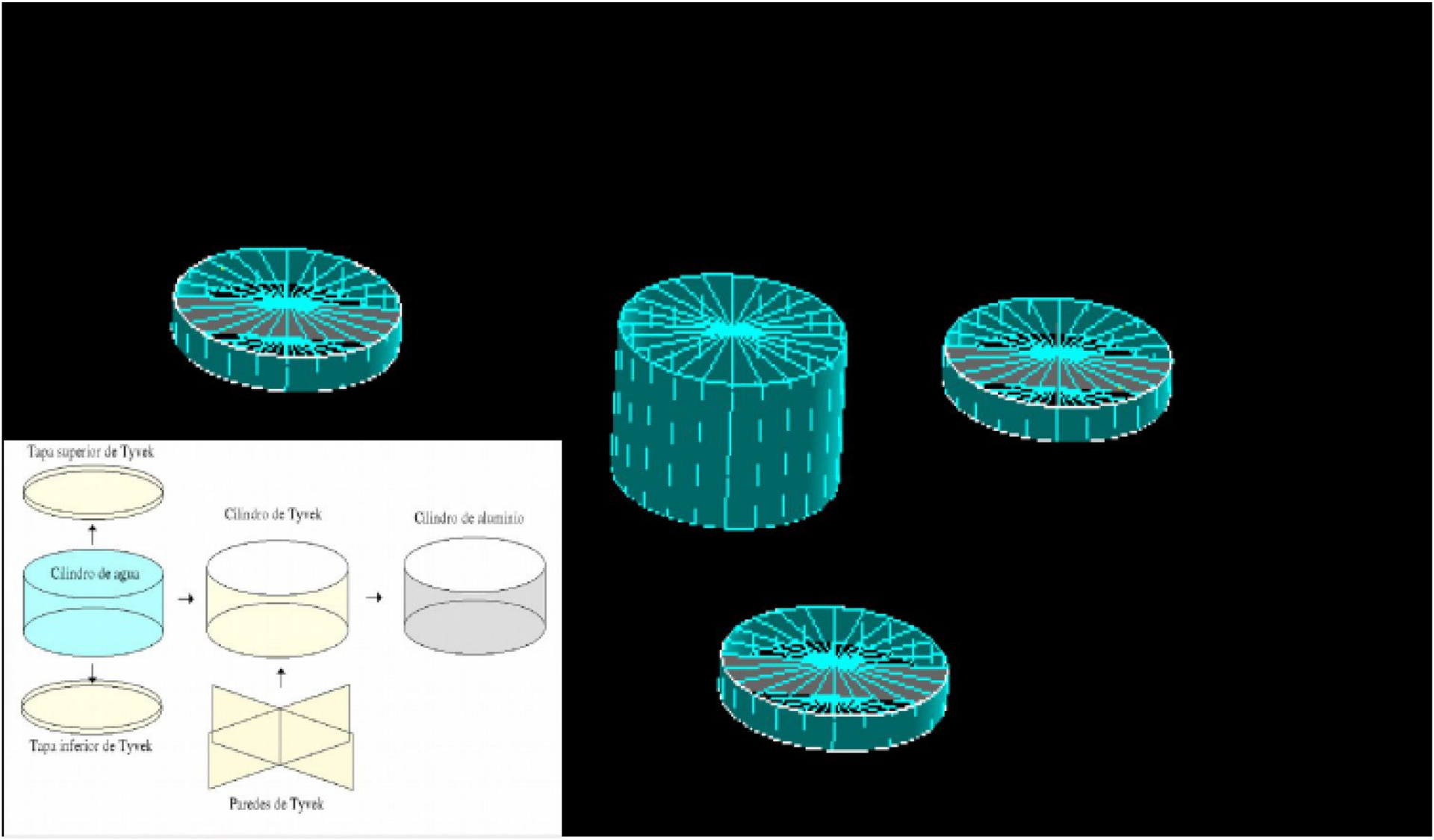
- Non-centralized, collaborative network of institutions
- 3 working groups, 10+1 members coordination committee, 1 P.I.
- Developments, expertize and data are shared across the network
- Primary objectives conducted by specific LAGO programs

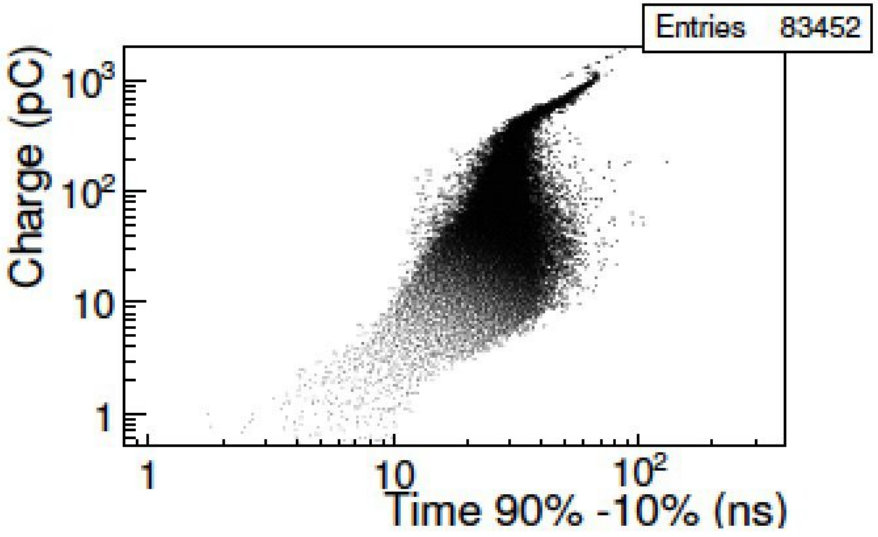
- Sites similar longitudes but different latitudes and altitudes (different rigidity cutoff)
- All based on WCD
- Placed at remote places and no infrastructure, every node would be autonomous
- Every node have other sensors and comercial GPS
- To increase electromagnetic-muon separation at single pulse level in high altitude sites, a method based on the total charge and pulse rise time analysis is also implemented
- Improving the search for possible GRB candidates


Charge histogram. Channel 1
Events
χ^2 / ndf 5.888 / 12
Prob 0.9216
C1 5.265 ± 0.268
a1 −0.002621 ± 0.000667
χ^2 / ndf 35.49 / 32
Prob 0.3072
C2 6.662 ± 0.267
a2 −0.005782 ± 0.000428
Charge(pC)

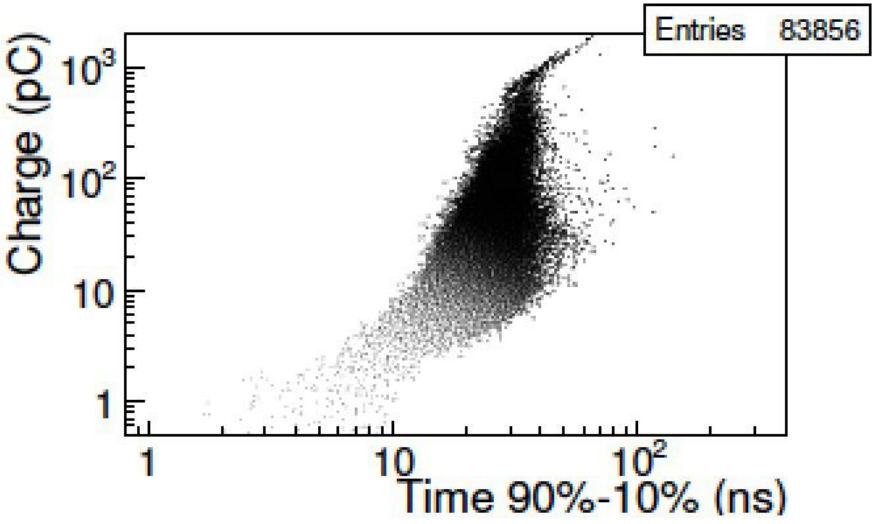

24.74 m
1
2
4
3
22.8 m
27.87 m



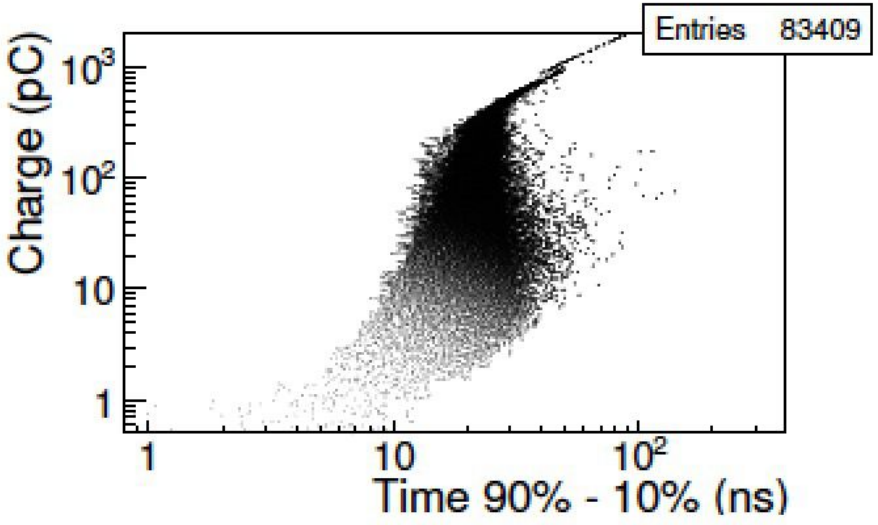

Tapa superior de Tyvek
Cilindro de Tyvek
Cilindro de aluminio
Cilindro de agua
Tapa inferior de Tyvek
Paredes de Tyvek



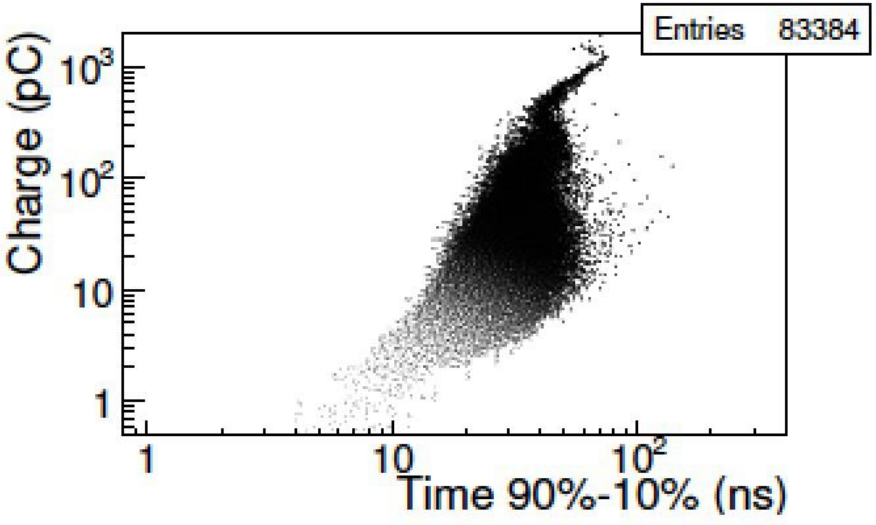
(a) Channel 1. PMT 7066.



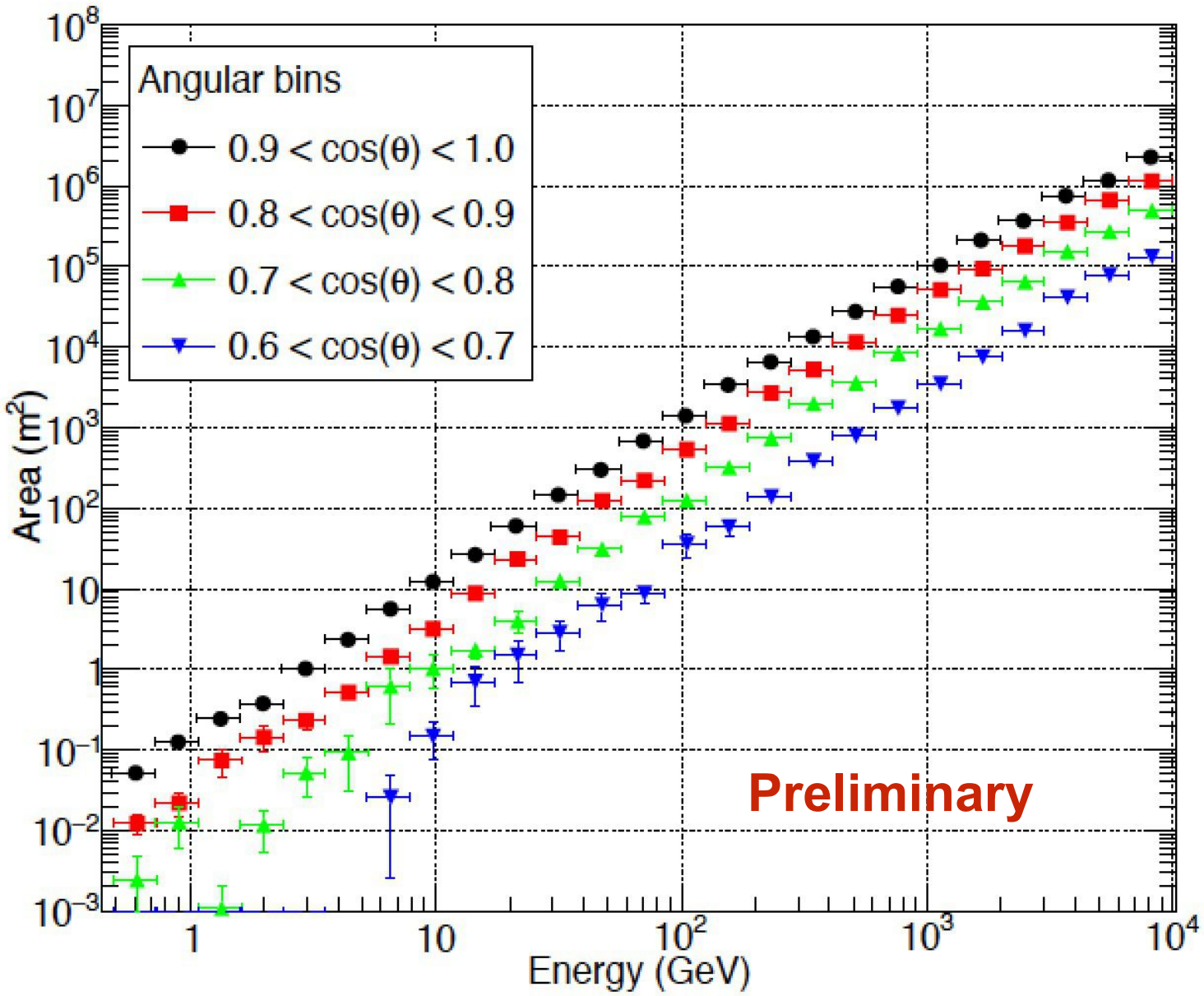
(b) Channel 2. PMT 7089.



(c) Channel 3. PMT 7025.



(d) Channel 4. PMT 7077.



A. Galindo et al, submitted to NIM

LAGO Simulations

- MC simulations to compute the specter flux for every site
  - Different energies, arrival directions, primary particles
- Simulations for every site last some months!
- Use of cluster is mandatory
- Use of data centers are also mandatory, every site produce some Gb per month

Summary

- TeV gamma-ray astronomy is the energy frontier of astronomy.

- LAGO is designed to perform a *wide field of view synoptic survey* of the TeV sky.
  - Large field of view: unbiased survey.
  - Large uptime: increased sensitivity to transients.
  - High-energy response: will help identify cosmic ray sources.
- It is an exciting time: *a new window on the Universe is opening!*