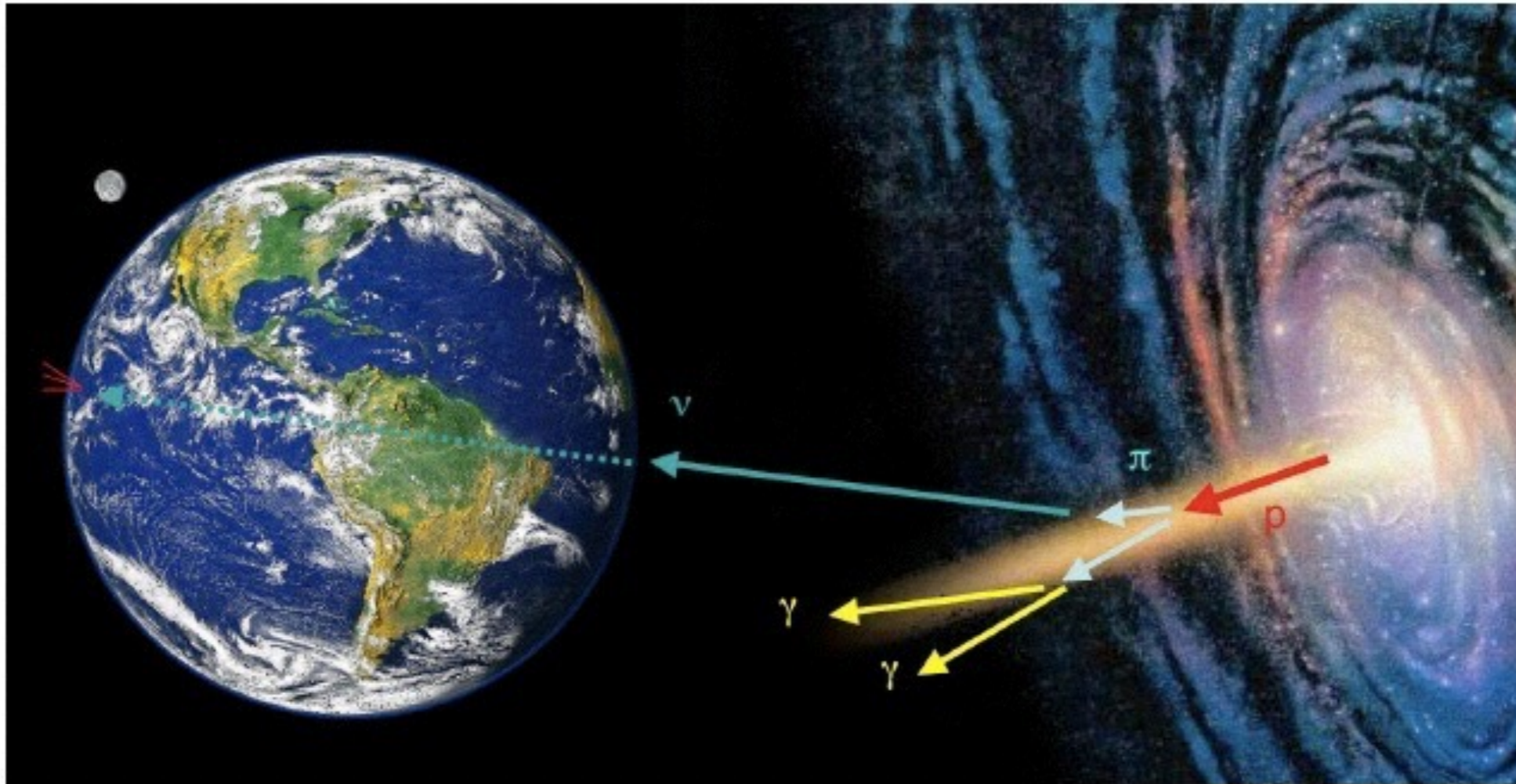


# Teilchenphysik mit kosmischen und mit erdgebundenen Beschleunigern



## 01. Einführung/Introduction

13.04.2015



# Goal of the Lecture

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- Current and future accelerators
- Particle detection in high energy and astroparticle physics
- The Standard Model of particle physics
- Precision measurements in particle physics
- Dark Matter and Dark Energy
- Cosmic acceleration mechanisms
- The physics of charged and neutral cosmic particles
- Neutrino physics
  
- We are open to other topics as well - just let us know!

# Organisational Matters

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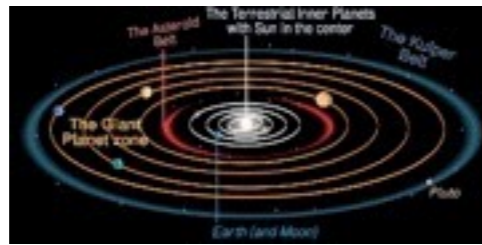
- Time: Mondays, 14:00 to 16:00
- Place: PH 127 , TUM Physik-Departement I
- Background
  - if possible: KTA (Introduction to nuclear, particle and astro physics)
  - in addition: Quantum field theory, theoretical particle physics
  - does not hurt: Teilchenphysik mit höchstenergetischen Beschleunigern (Higgs & Co)
- Exercise classes: none
- Exams: Yes, if asked for
- Material: The slides will be posted after the lectures on the MPP web site:  
[www.mpp.mpg.de](http://www.mpp.mpg.de) → Veranstaltungen → Vorlesungen



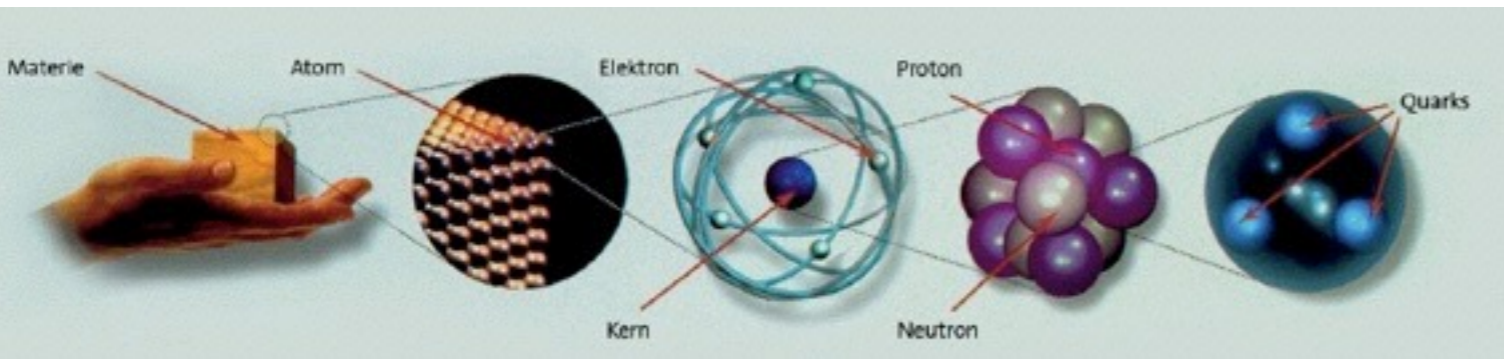
# Themenübersicht

13.04.	Einführung / Introduction
20.04.	<b>Achtung - keine Vorlesung! No Lecture!</b>
27.04.	Erdgebundene Beschleuniger / Accelerators
04.05.	Detektoren in der Nicht-Beschleuniger-Physik / Detectors
11.05.	Das Standardmodell / The Standard Model
18.05.	QCD und Jet Physik an Lepton Beschleunigern
27.05.	<b>Pfingsten - Keine Vorlesung! No Lecture</b>
03.06.	Kosmische Beschleuniger / Cosmic Accelerators
10.06.	Kosmische Strahlung I / Cosmic Rays I
17.06.	Kosmische Strahlung II / Cosmic Rays II
24.06.	Präzisionsexperimente (g-2) / Precision Experiments
01.07.	Dunkle Materie & Dunkle Energie / Dark Matter & Dark Energy
08.07.	Neutrinos I
15.07.	Neutrinos II

# From the very big to the very small

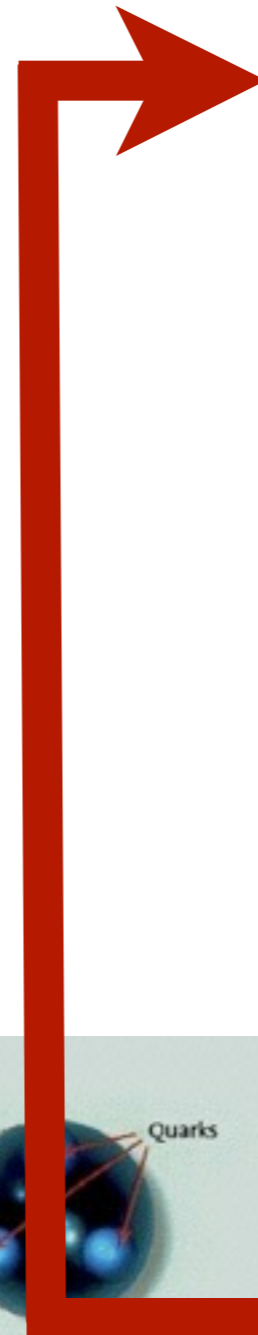
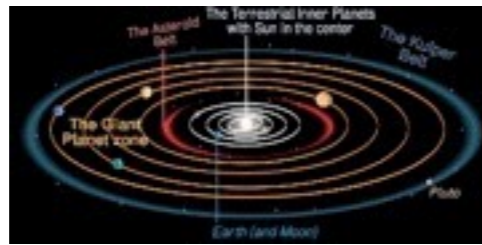


	Size	Mass
Universe	$10^{26}$ m	$10^{52}$ kg
Galaxy	$10^{21}$ m	$10^{41}$ kg
Solar system	$10^{13}$ m	$10^{30}$ kg
Earth	$10^7$ m	$10^{24}$ kg
Man	$10^0$ m	$10^2$ kg
Atom	$10^{-10}$ m	$10^{-26}$ kg
Nucleus	$10^{-14}$ m	$10^{-26}$ kg
Nucleon	$10^{-15}$ m	$10^{-27}$ kg
Quarks, Leptons	$<10^{-18}$ m	$10^{-30}$ kg

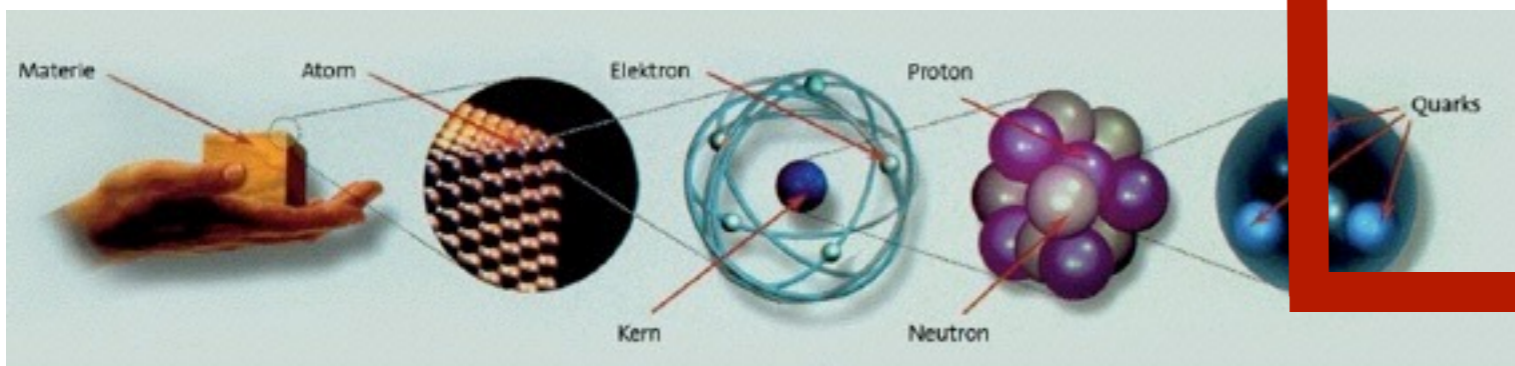


“Astroteilchenphysik in Deutschland”, <http://www.astroteilchenphysik.de/>, und darin angegebene Referenzen

# From the very big to the very small

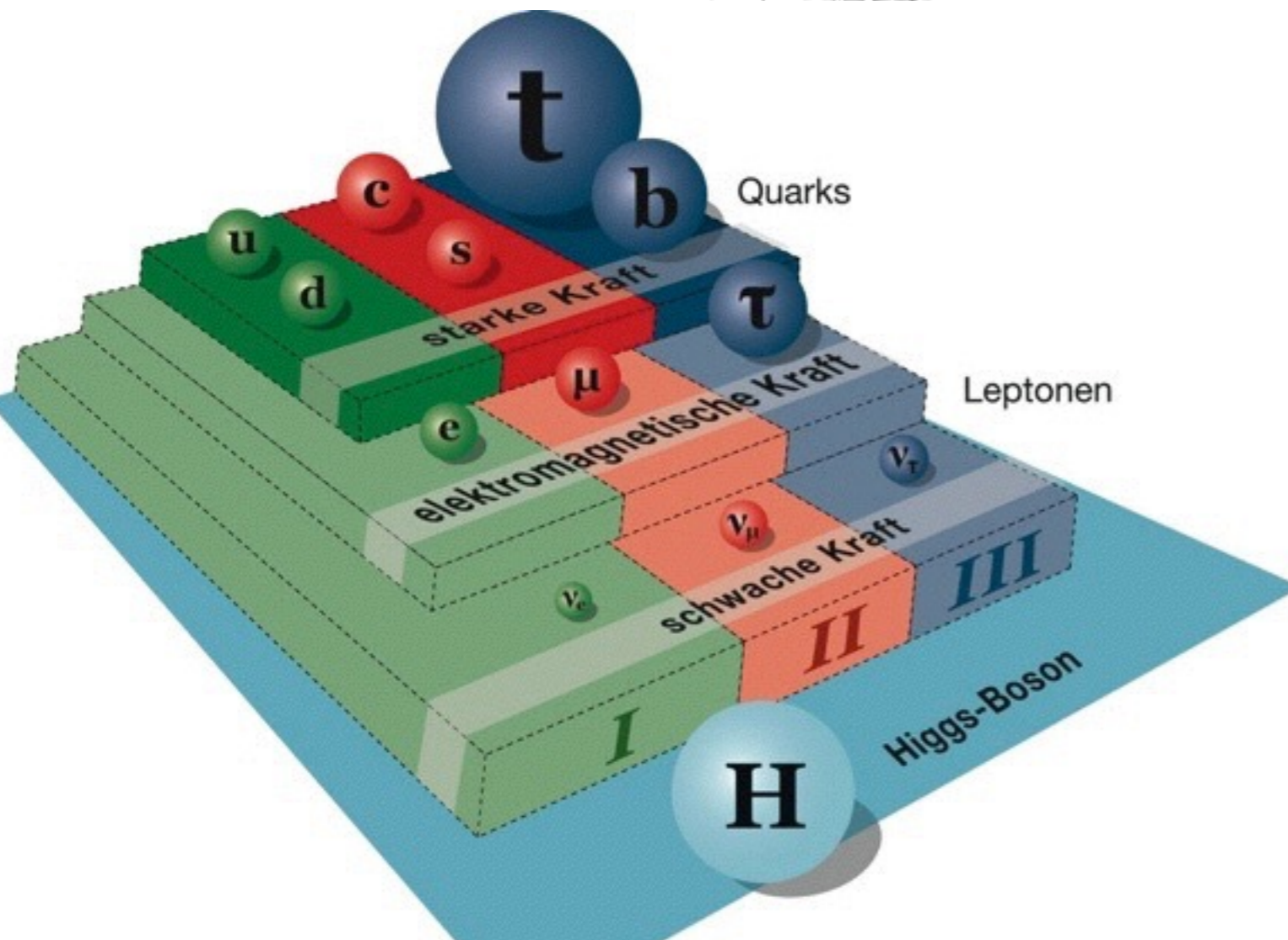


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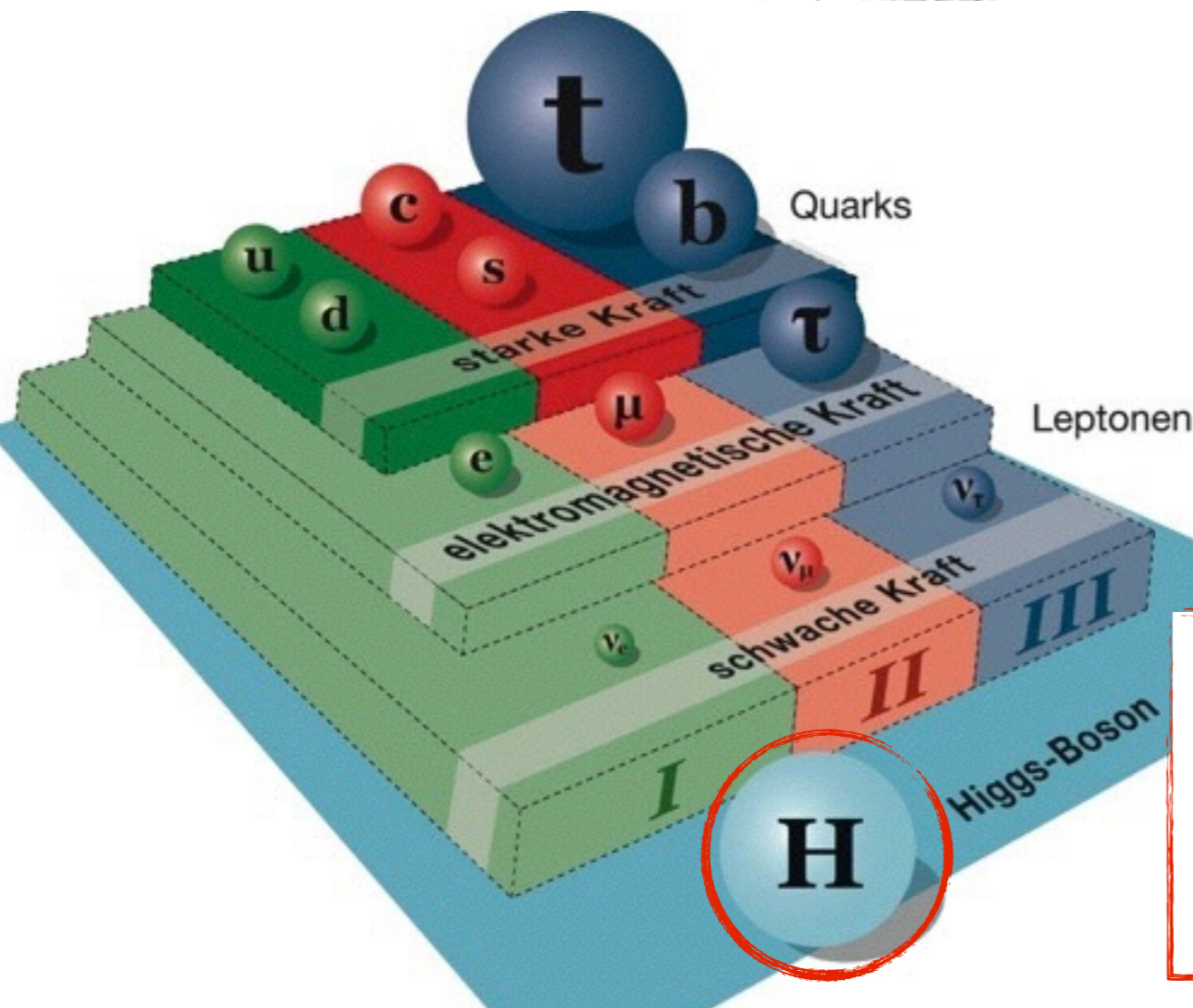
# The Standard Model of Particle Physics



Interaction	Range	relative strength
Strong	subatomic	1
Electromagnetic	infinite	1/137
Weak	subatomic	$10^{-14}$
Gravitation	infinite	$10^{-40}$

Gravitation	elektromag. Kraft	schwache Kraft	starke Kraft
	1 Photon 	3 Bosonen 	8 Gluonen 

# The Standard Model of Particle Physics



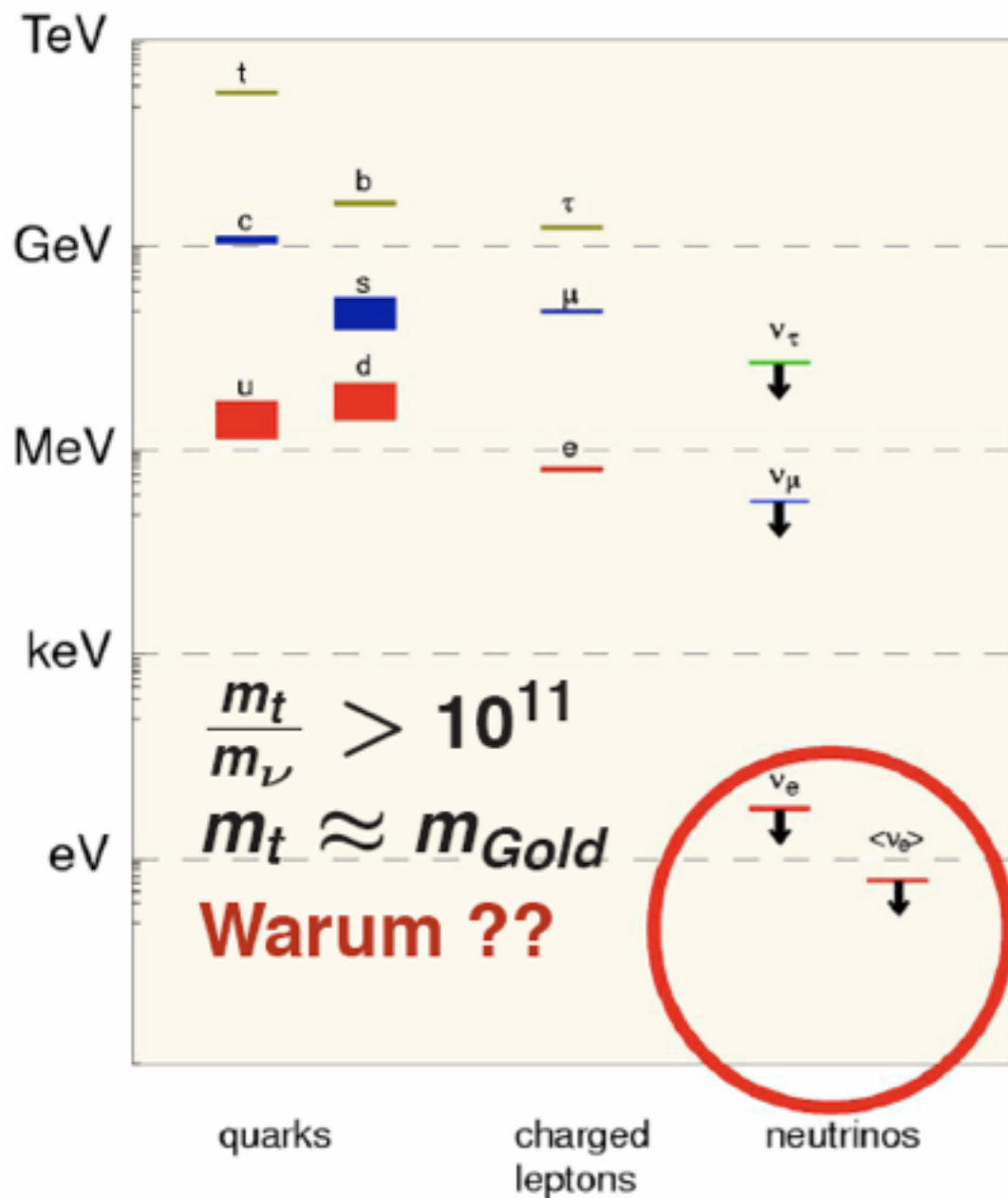
Interaction	Range	relative strength
Strong	subatomic	1
Electromagnetic	infinite	1/137
Weak	subatomic	10 <sup>-14</sup>

The last missing piece  
discovered at LHC: July 4th, 2012

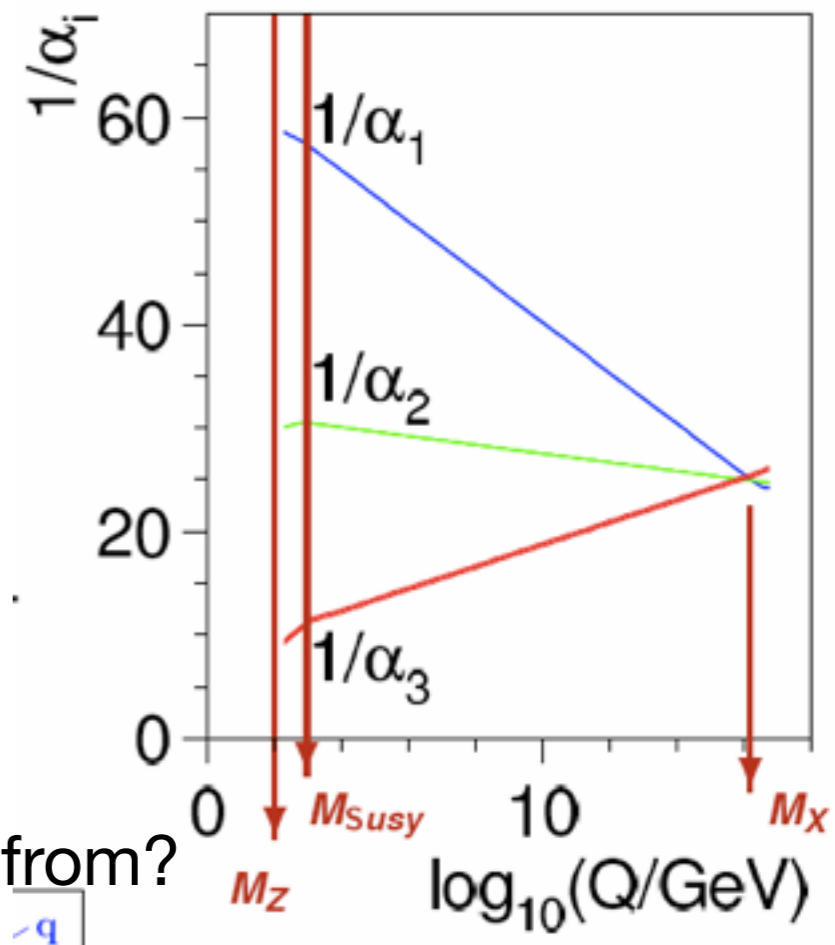
Gravitation	elektromag. Kraft	schwache Kraft	starke Kraft
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# The Standard Model: Open Questions



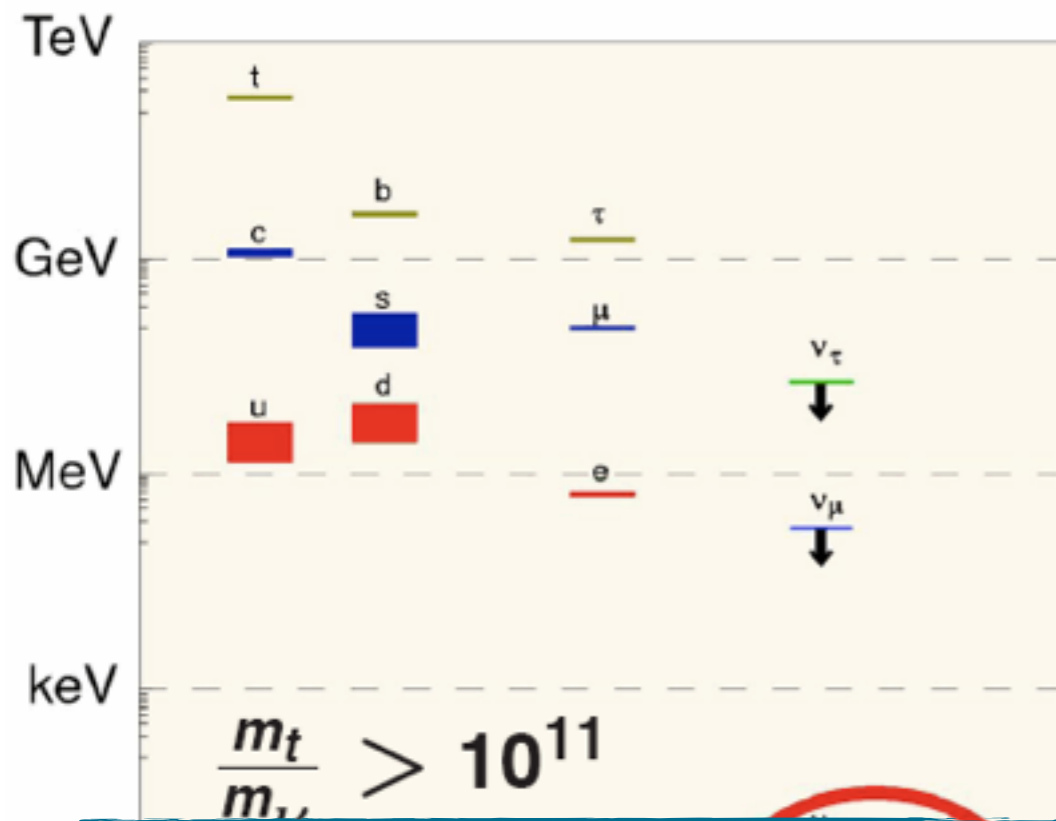
- Where does the mass hierarchy of particles come from?
- Why are there exactly 3 families of fermions?
  - known from the measurement of the Z Boson width: Only three light neutrinos!
- Is there a unification of forces (not possible in the SM)?
  - ▶ Super-Symmetry?
  - ▶ ...



Questions connected to cosmology / astrophysics

- What is Dark Matter? Dark Energy
- Where does the matter / antimatter asymmetry come from?

# The Standard Model: Open Questions

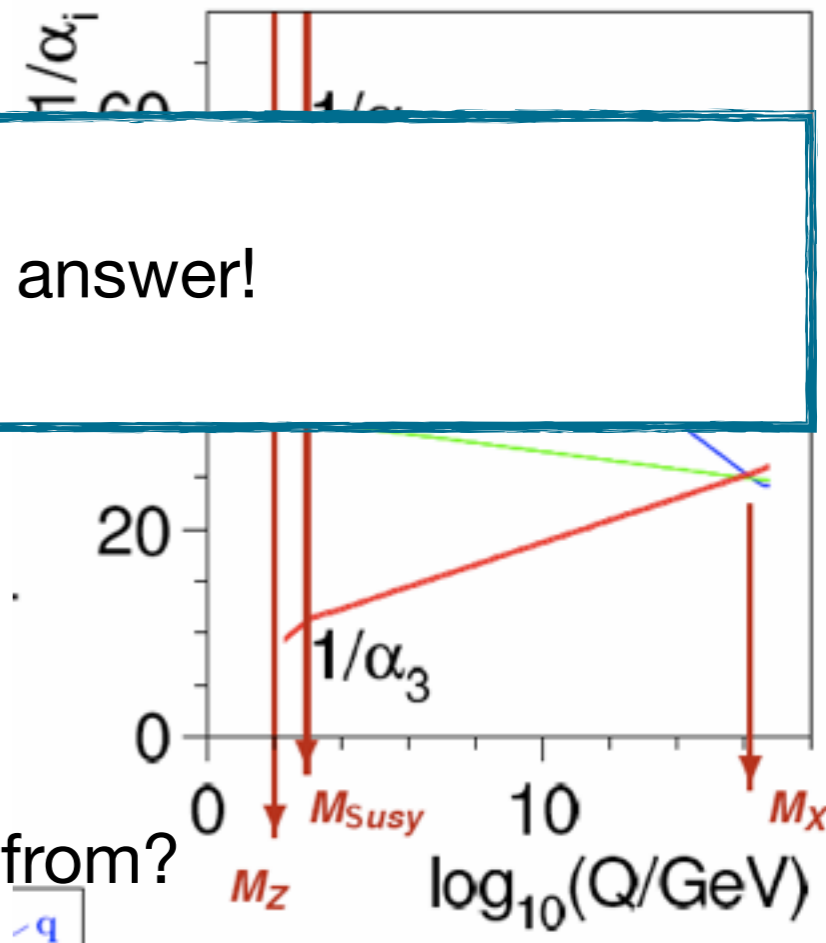


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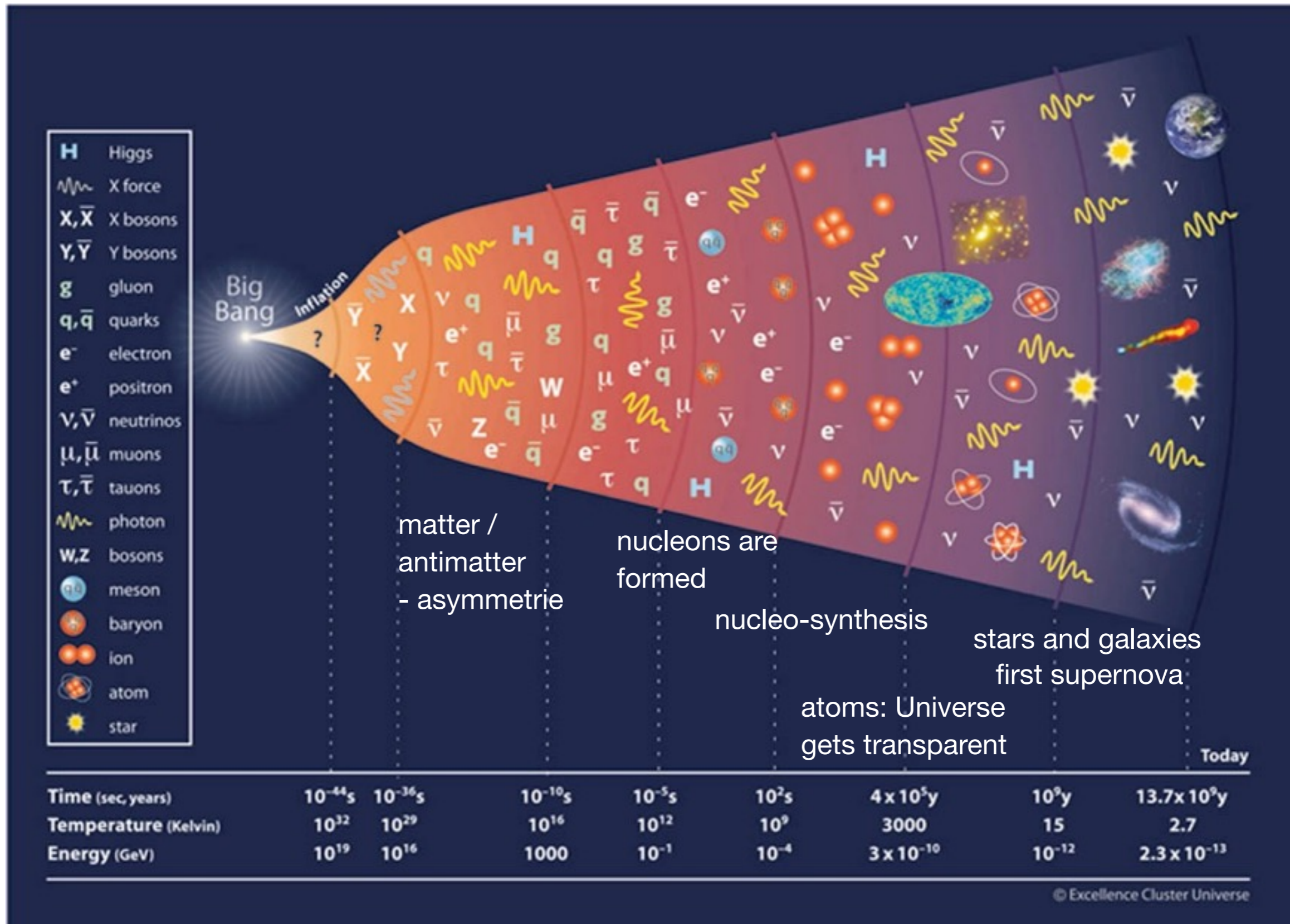
The Standard Model cannot be the final answer!

Questions connected to cosmology / astrophysics

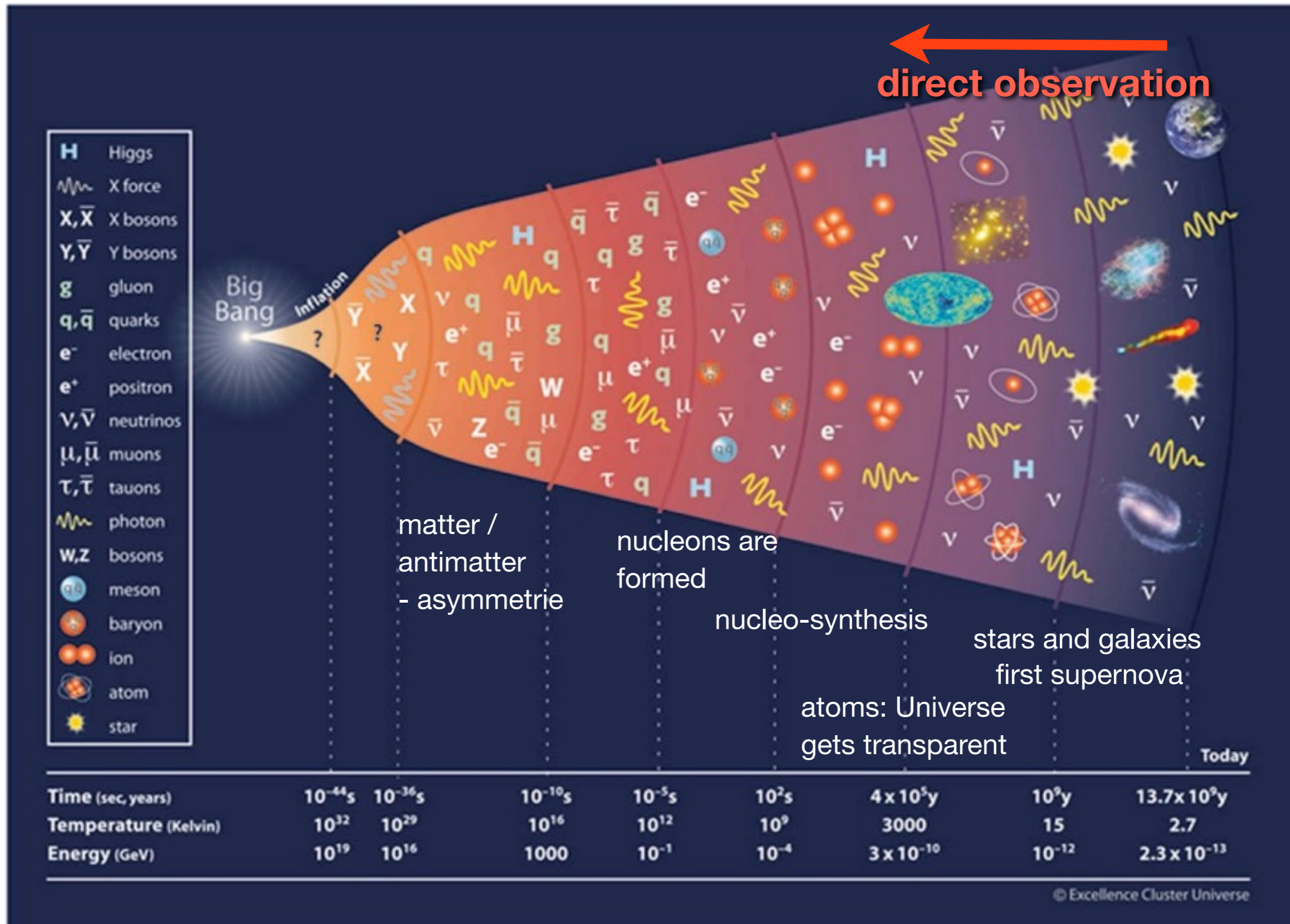
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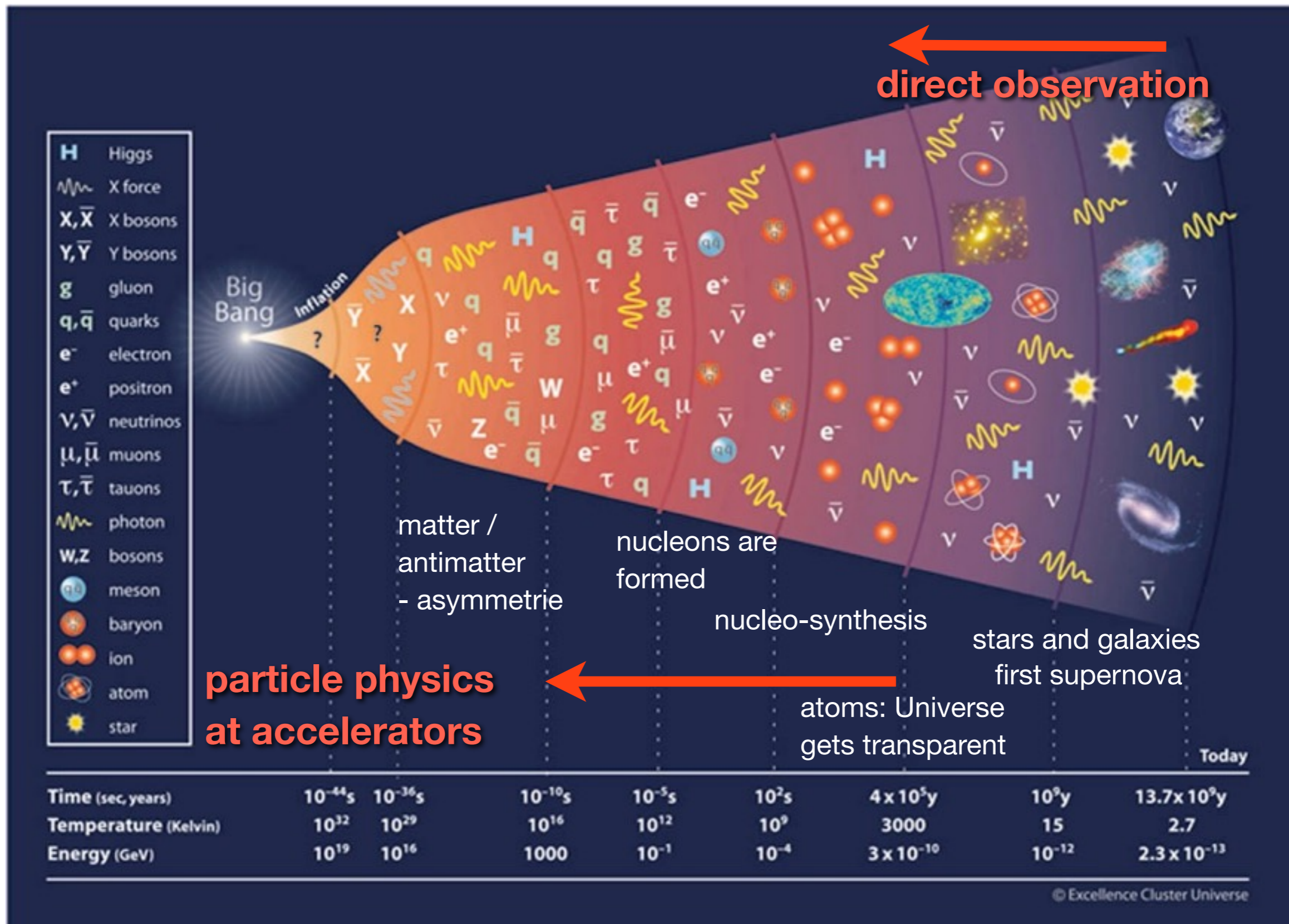
# The Evolution of the Universe



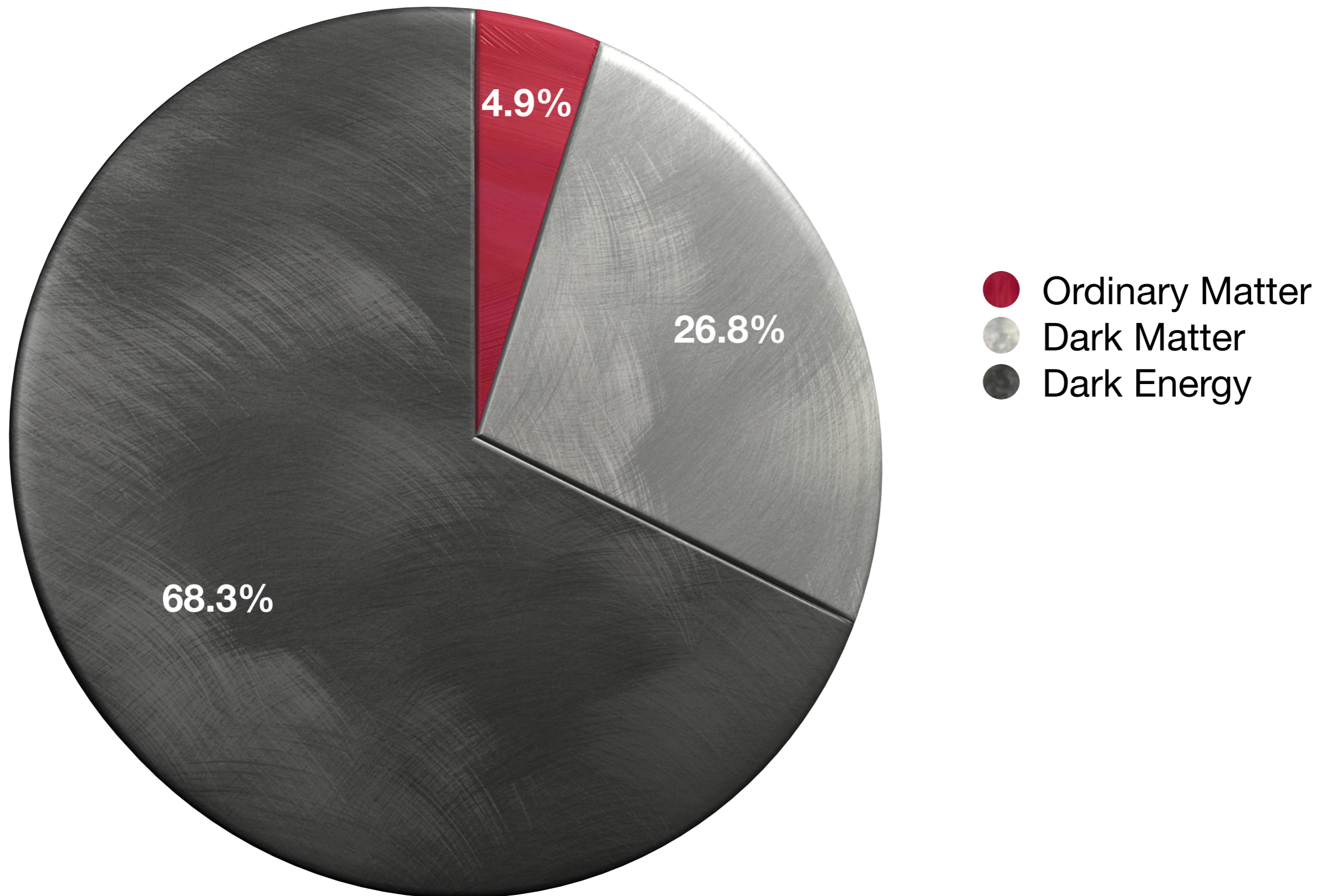
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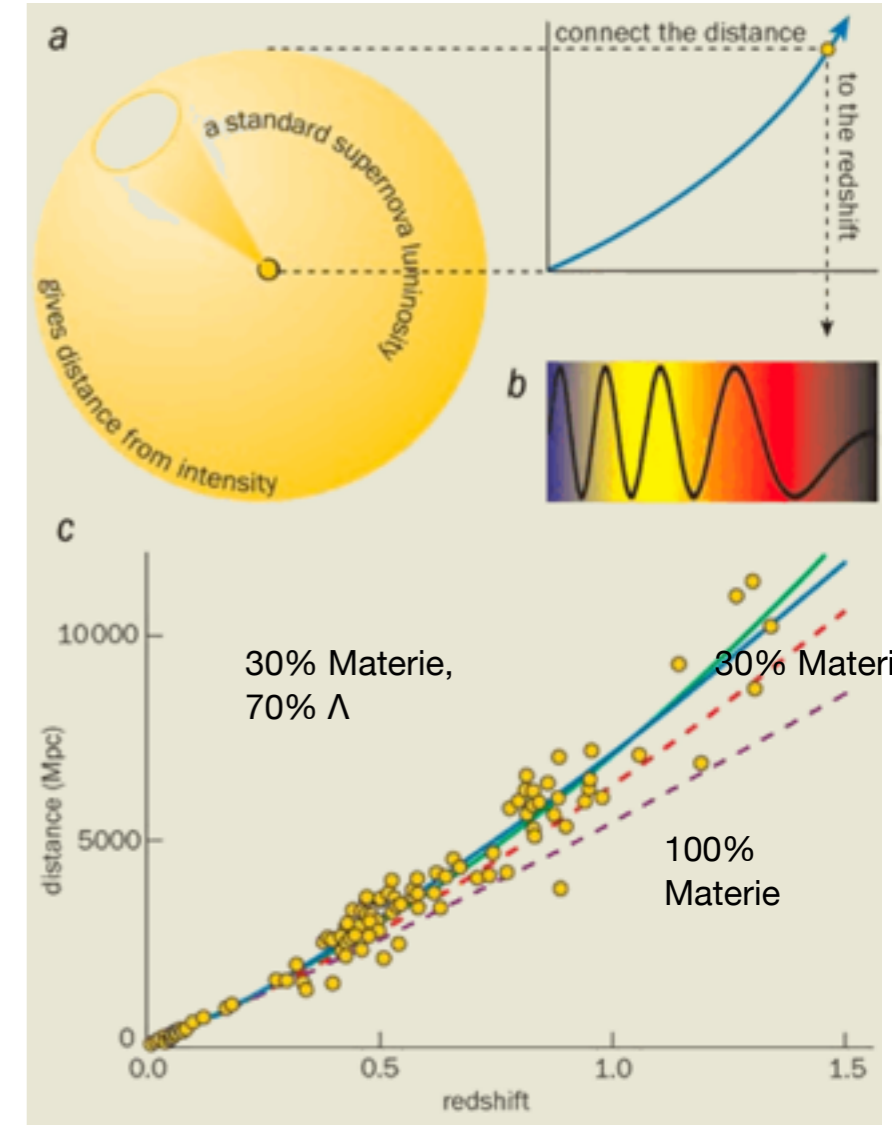
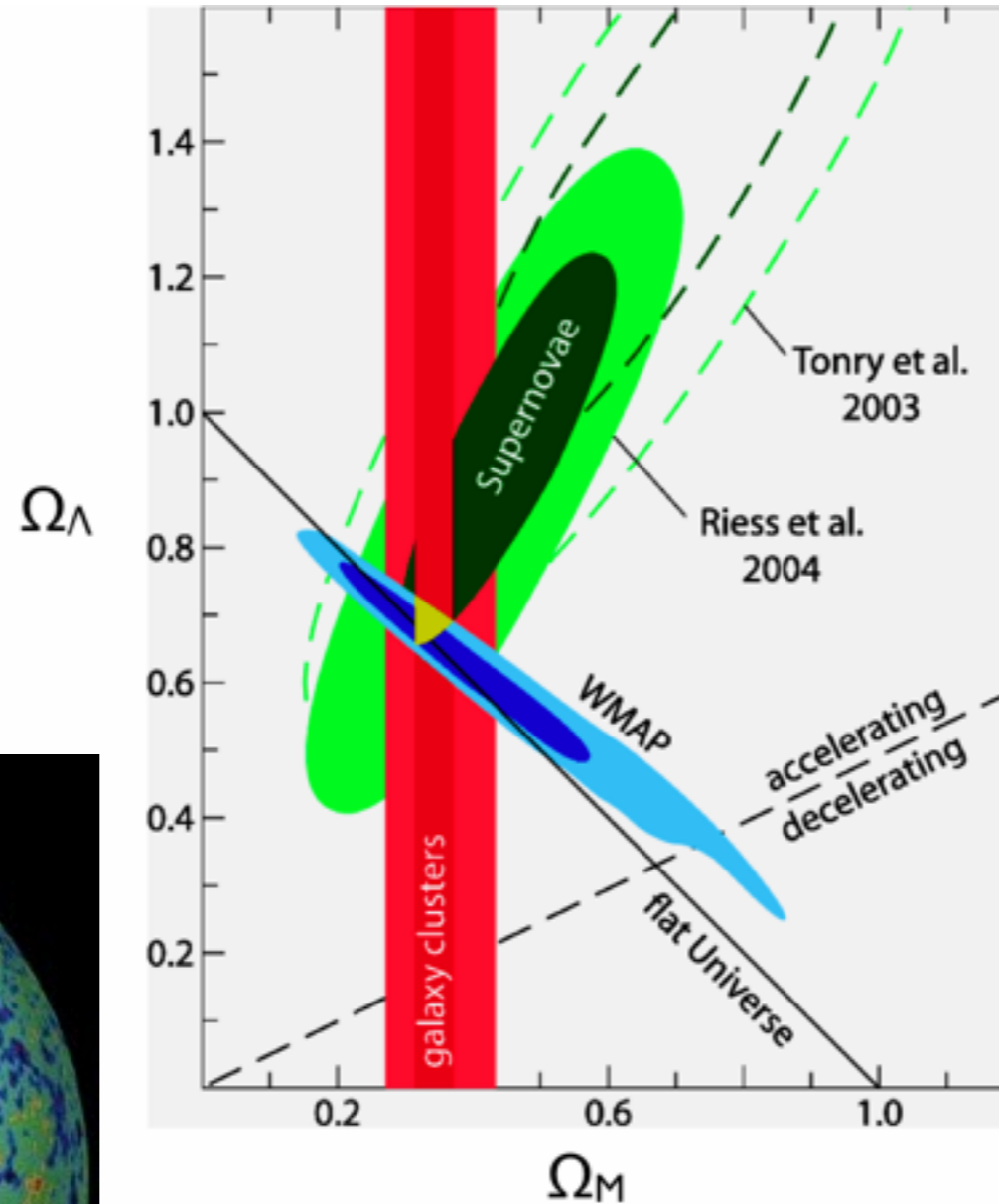


# The Composition of the Universe



# How do we know the composition?

- The movement of galaxy clusters shows the matter density

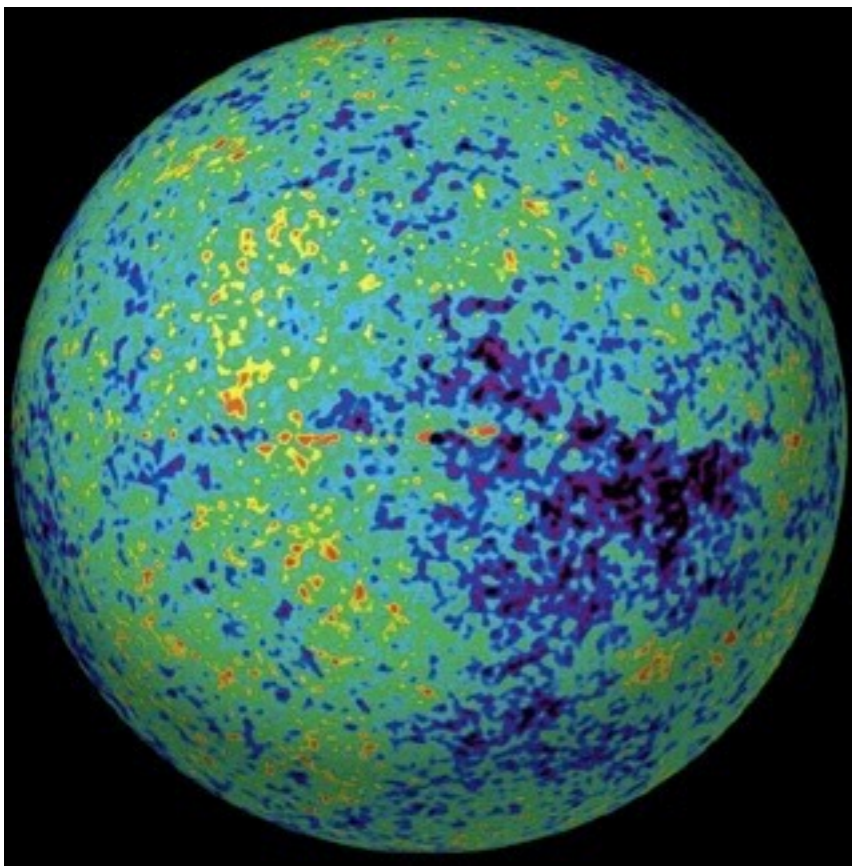


- CMB - fluctuations show that the universe is "flat":  

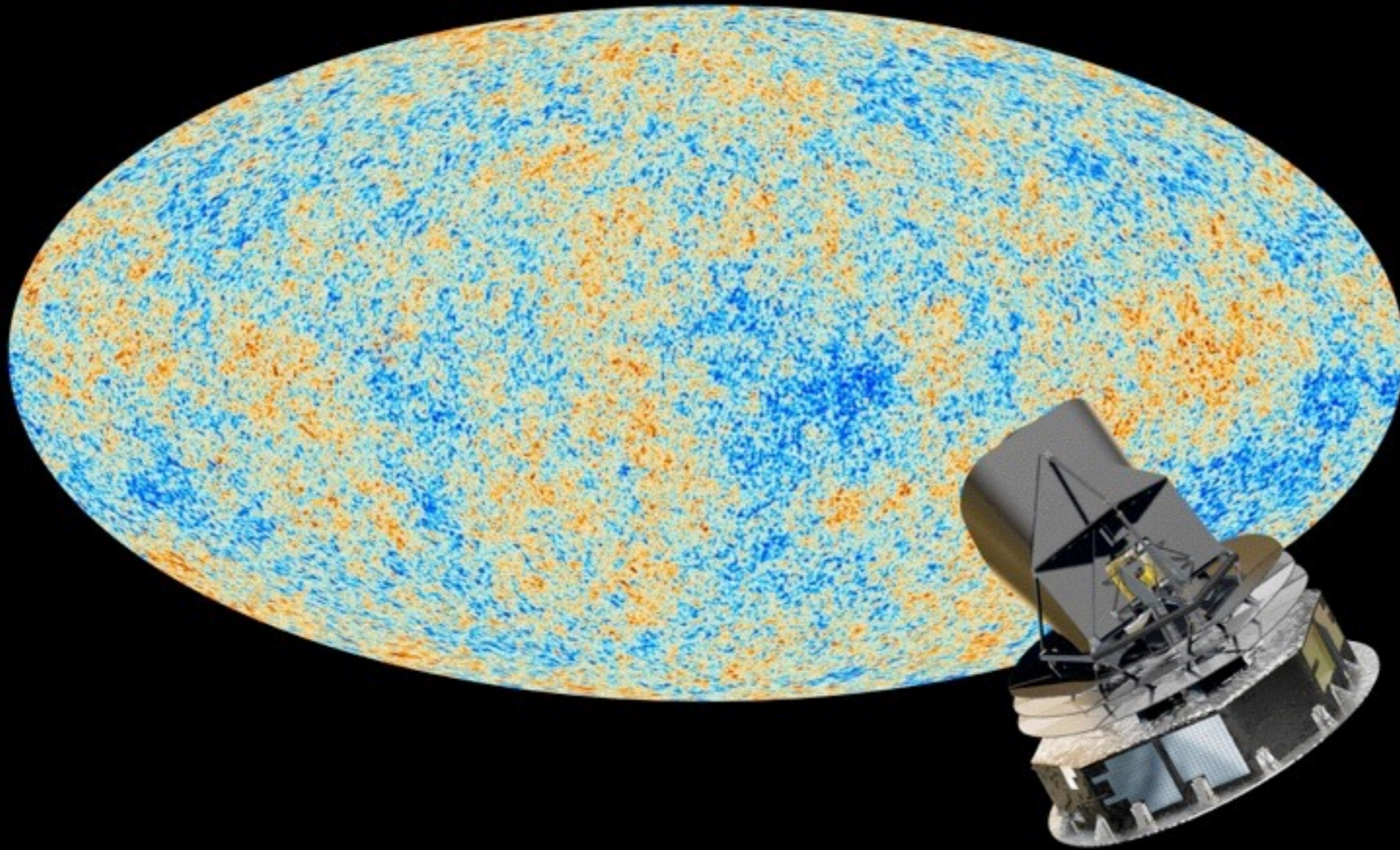
$$\Omega_\Lambda + \Omega_M = 1$$

- Supernova data show that the expansion is accelerating

<http://physicsworld.com/cws/article/print/19419>



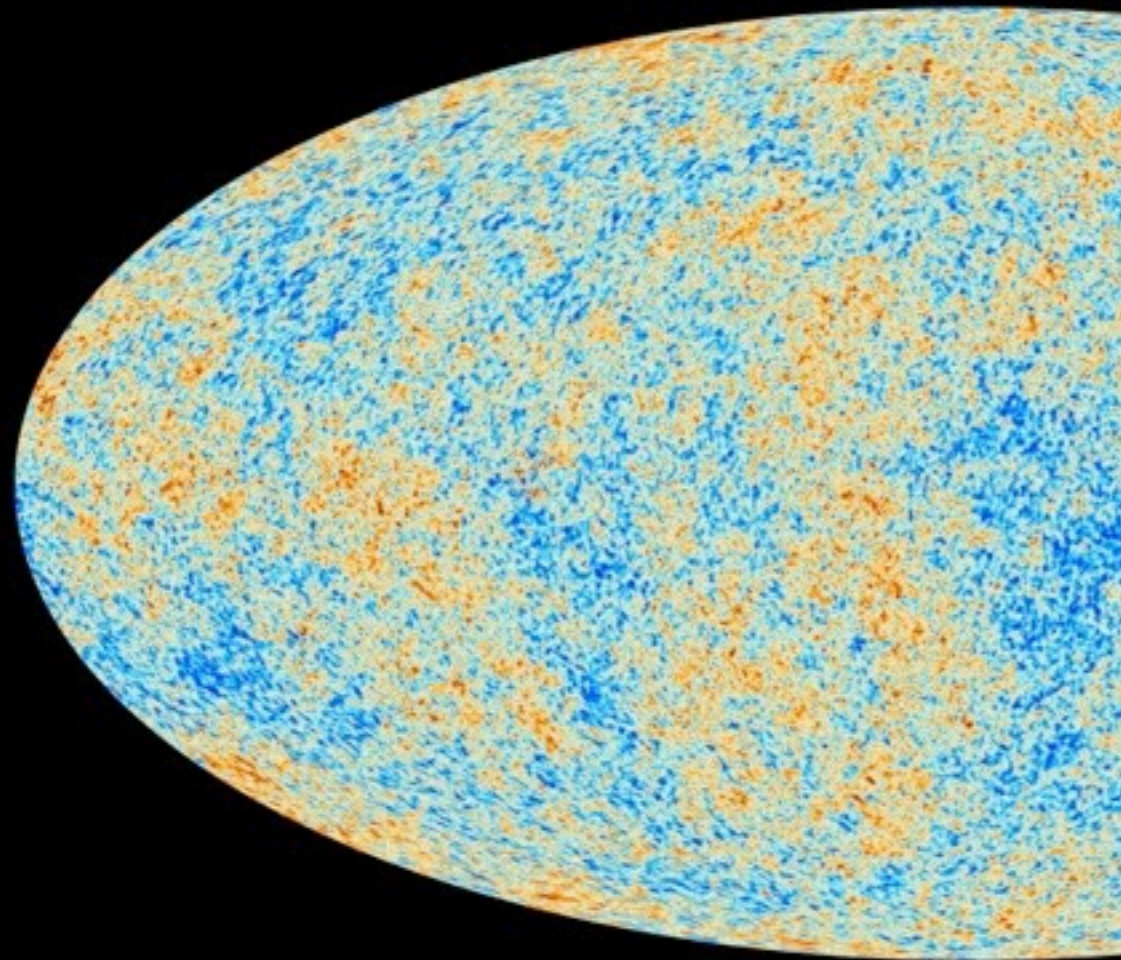
# New Instruments - Better Results



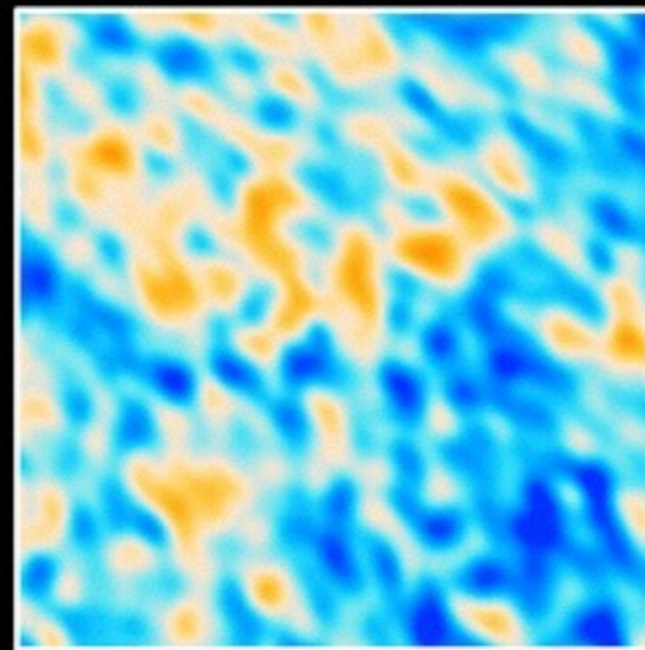
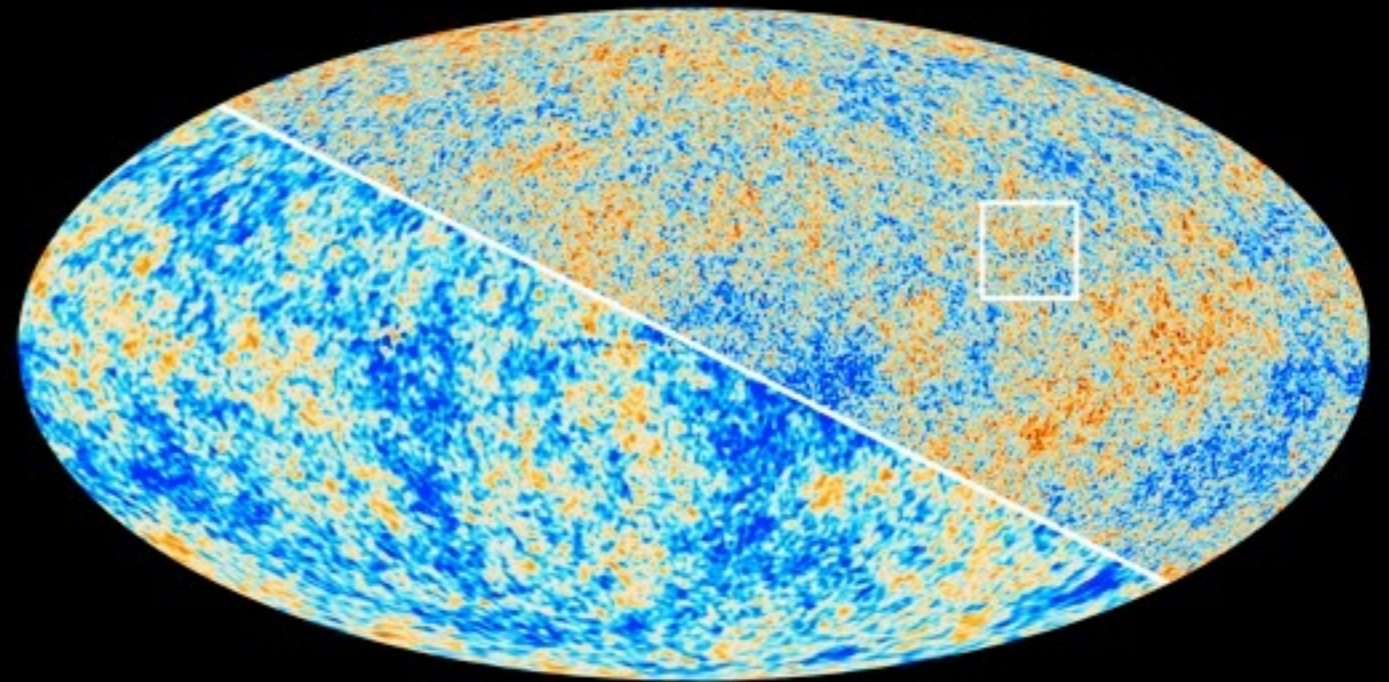
- Planck satellite (ESA) - First results in 2013, most precise picture of the Universe at 400 000 years



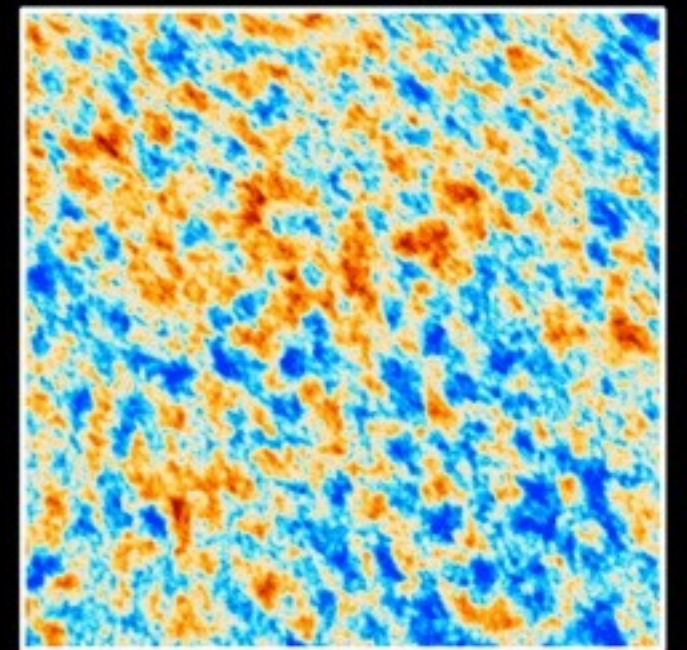
# New Instruments - Better Results



*The Cosmic Microwave Background as seen by Planck and WMAP*



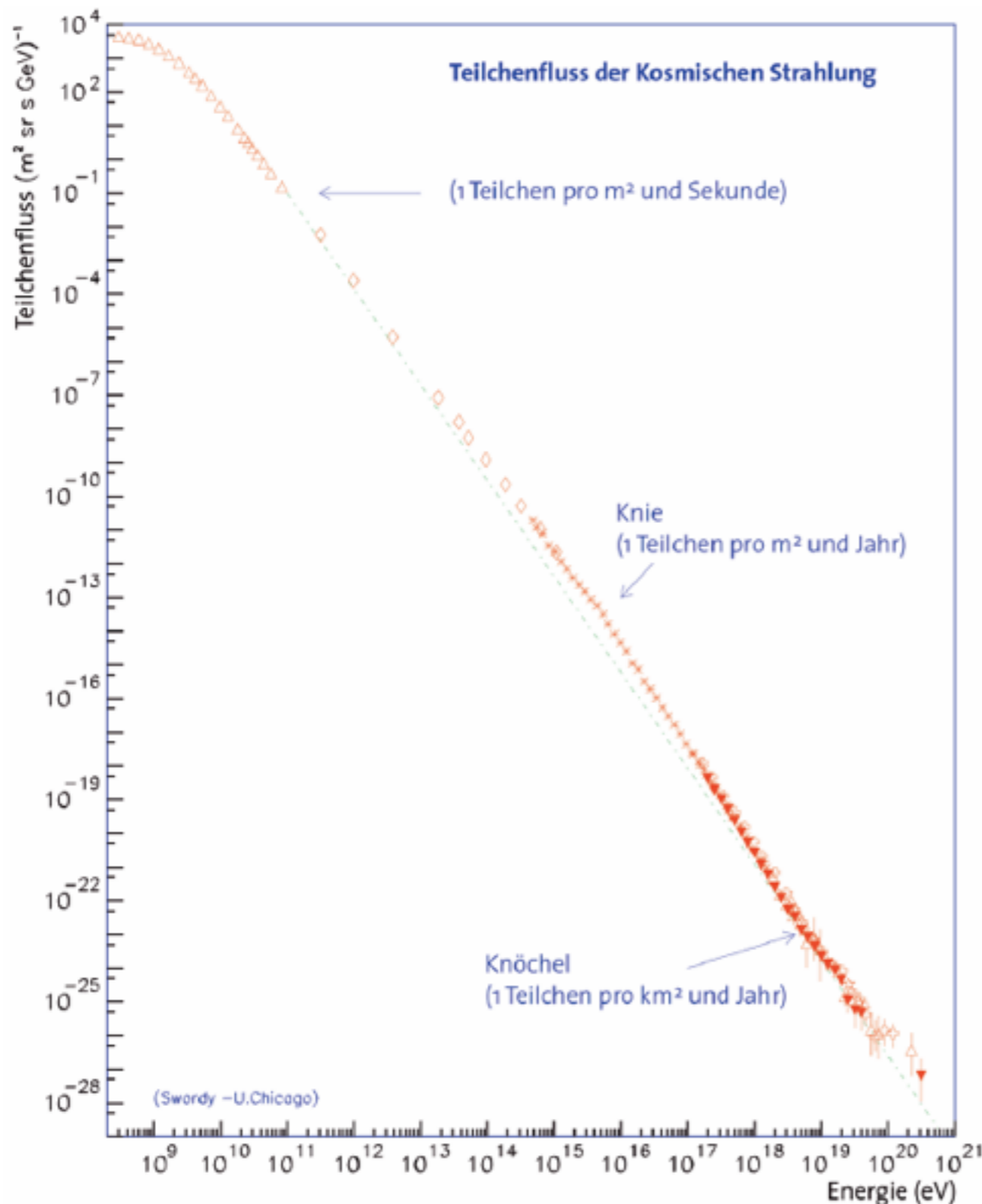
*WMAP*



*Planck*

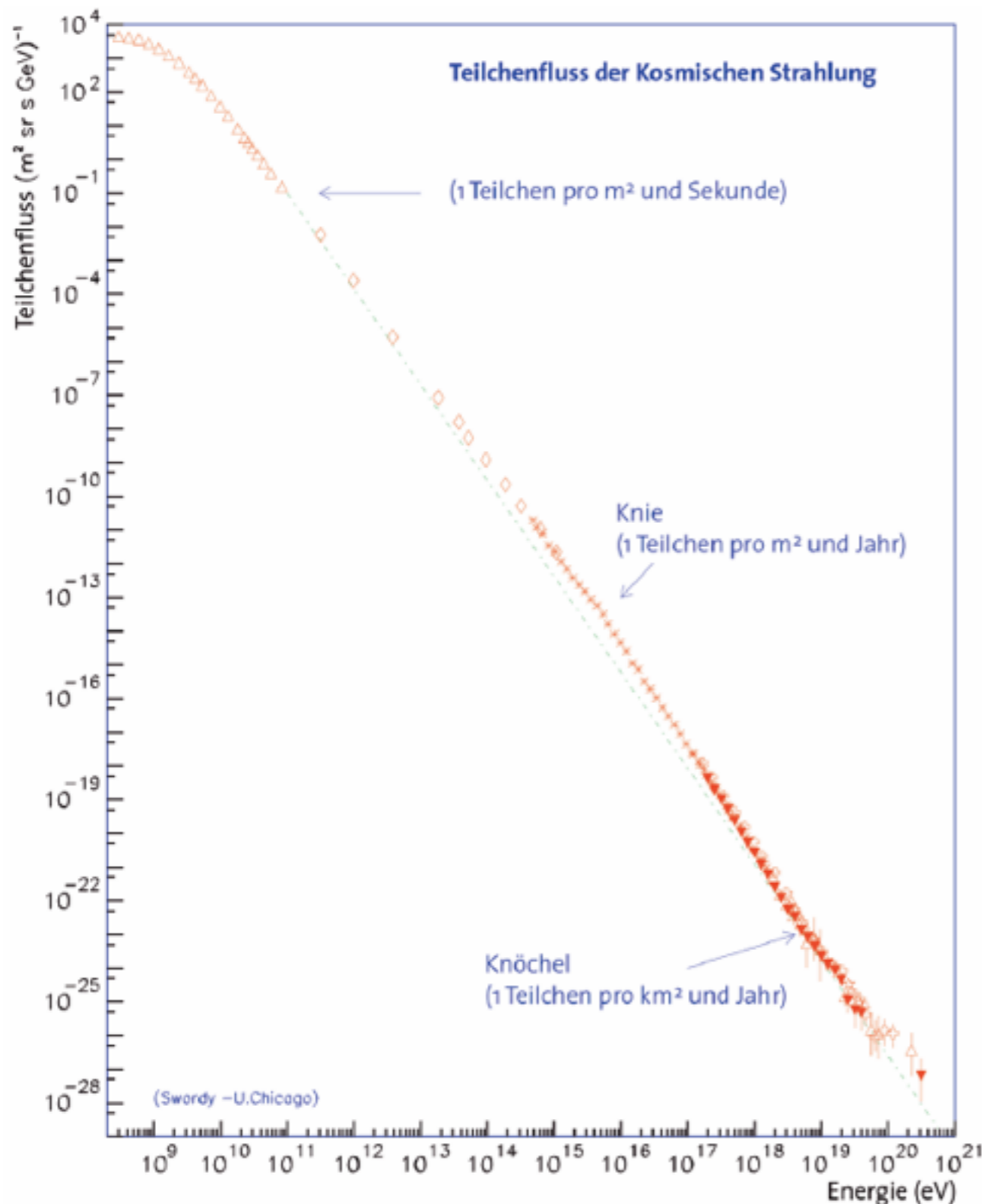
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# Cosmic Rays: Energy Spectrum



- Particle flux described by power law:
  - $\sim E^{-2.7}$  up to  $E \sim 10^{15}$  eV
  - $\sim E^{-3}$  from  $10^{15}$  to  $10^{18}$  eV
  - $\sim E^{-2.7}$  above  $E \sim 10^{18}$  eV
- ▶ Transition from galactic to extragalactic sources?
- ▶ Cut-off effect at highest energies?

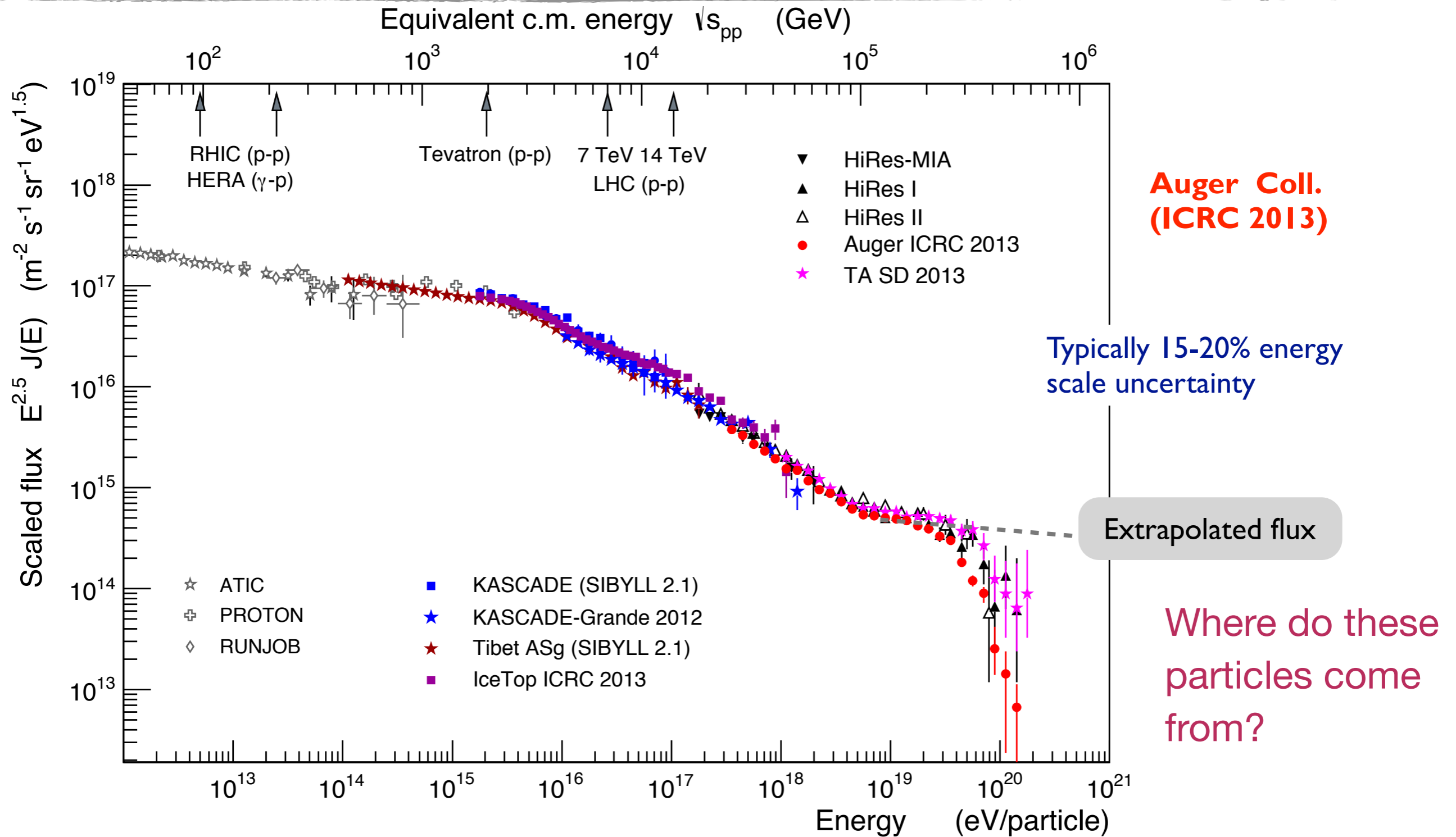
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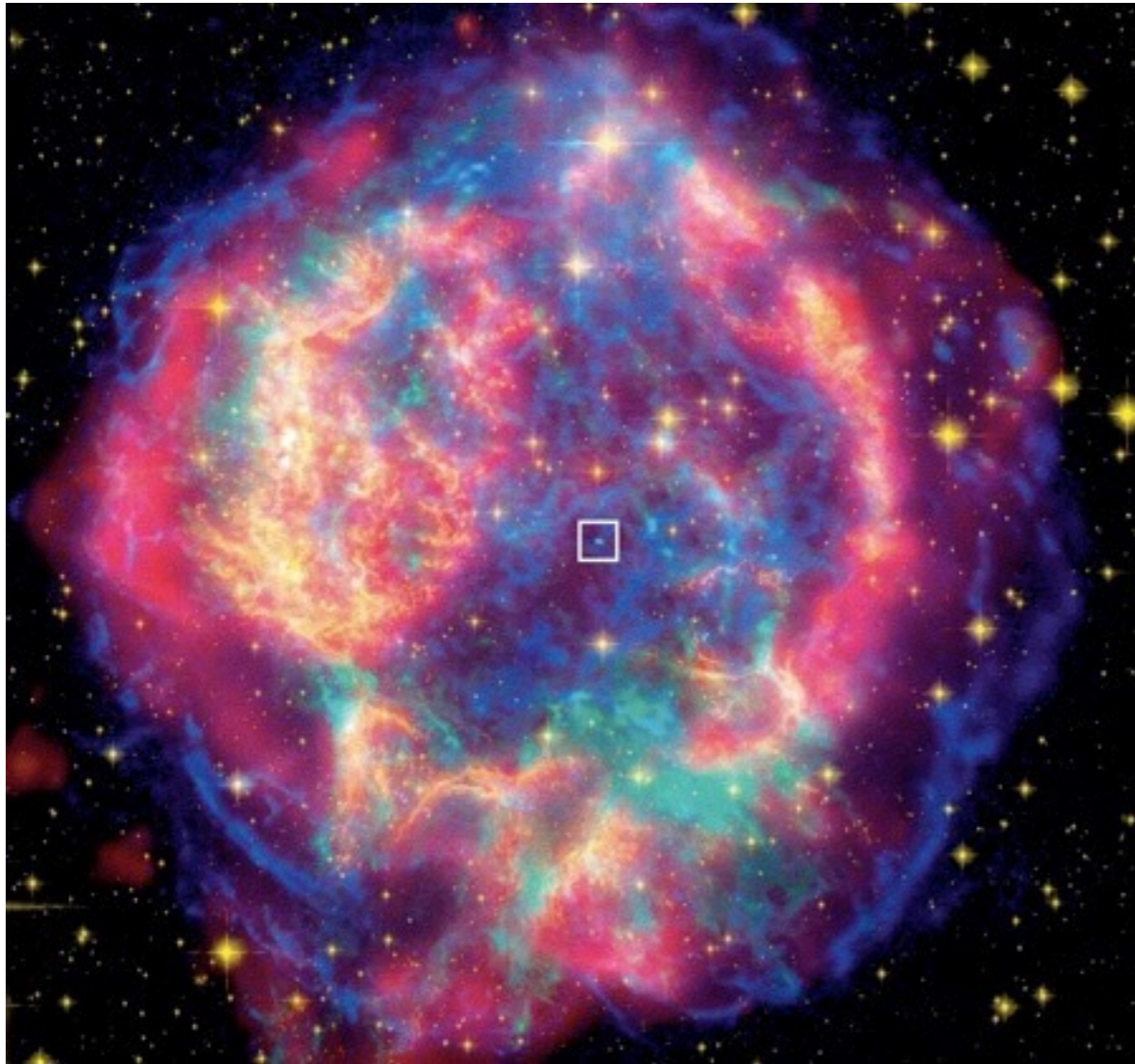
How are the particles accelerated?  
Which astrophysical objects are responsible?

# Cosmic Rays at Highest Energies



► Strong indications for a cut - off at  $\sim 10^{20}$  eV - Interactions with CMB

# Cosmic Accelerators

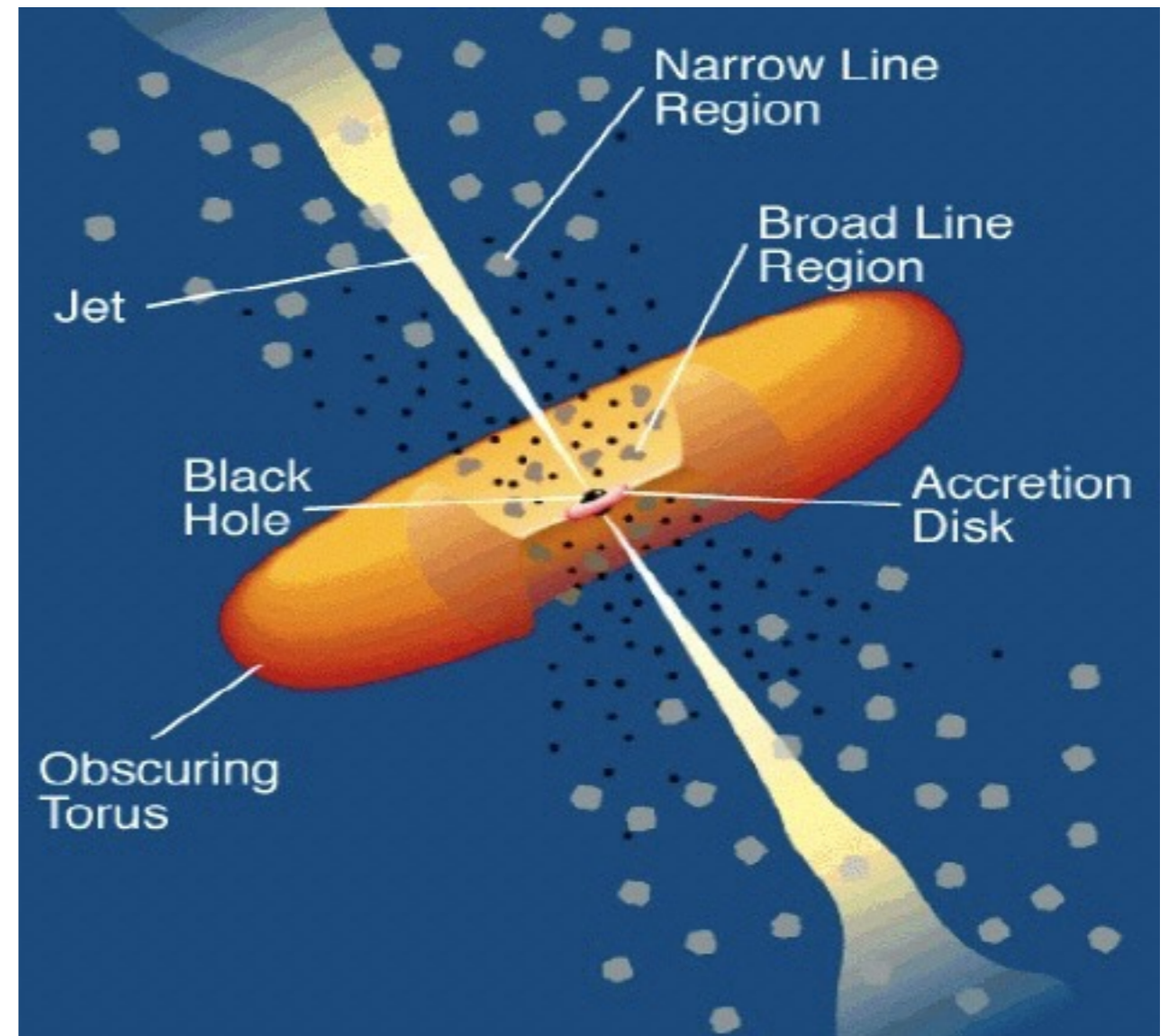
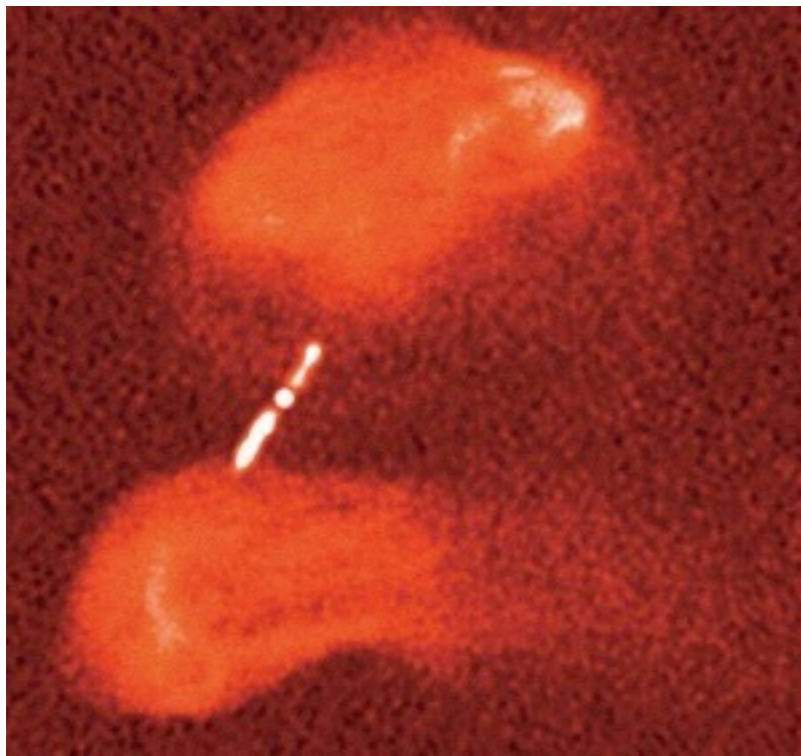
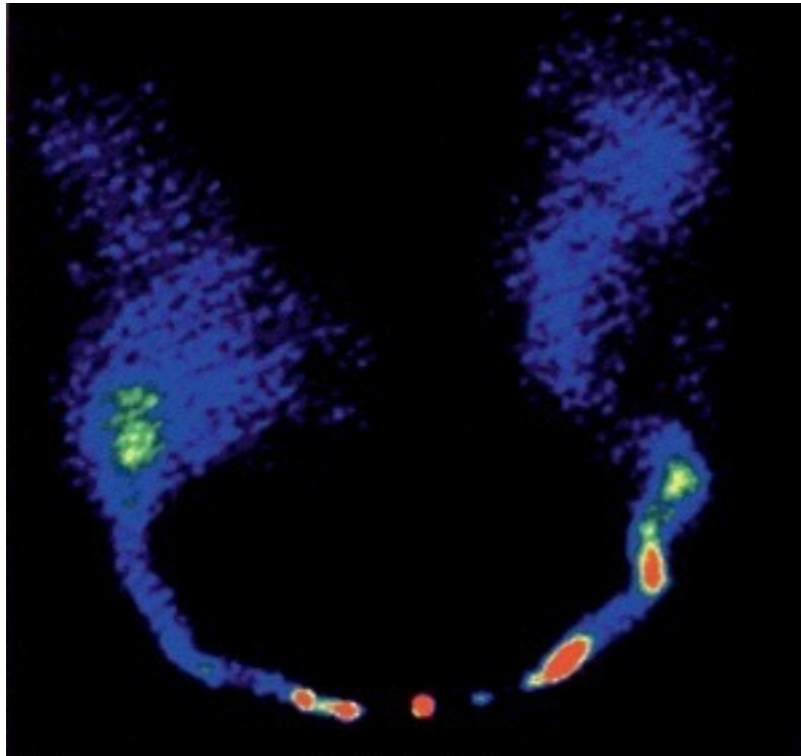


“Astroteilchenphysik in Deutschland”, <http://www.astroteilchenphysik.de/>, und darin angegebene Referenzen

- Supernova explosion: Acceleration in shock waves
- Pulsars: Acceleration in very strong magnetic fields

▶ Galactic sources for highly energetic particles

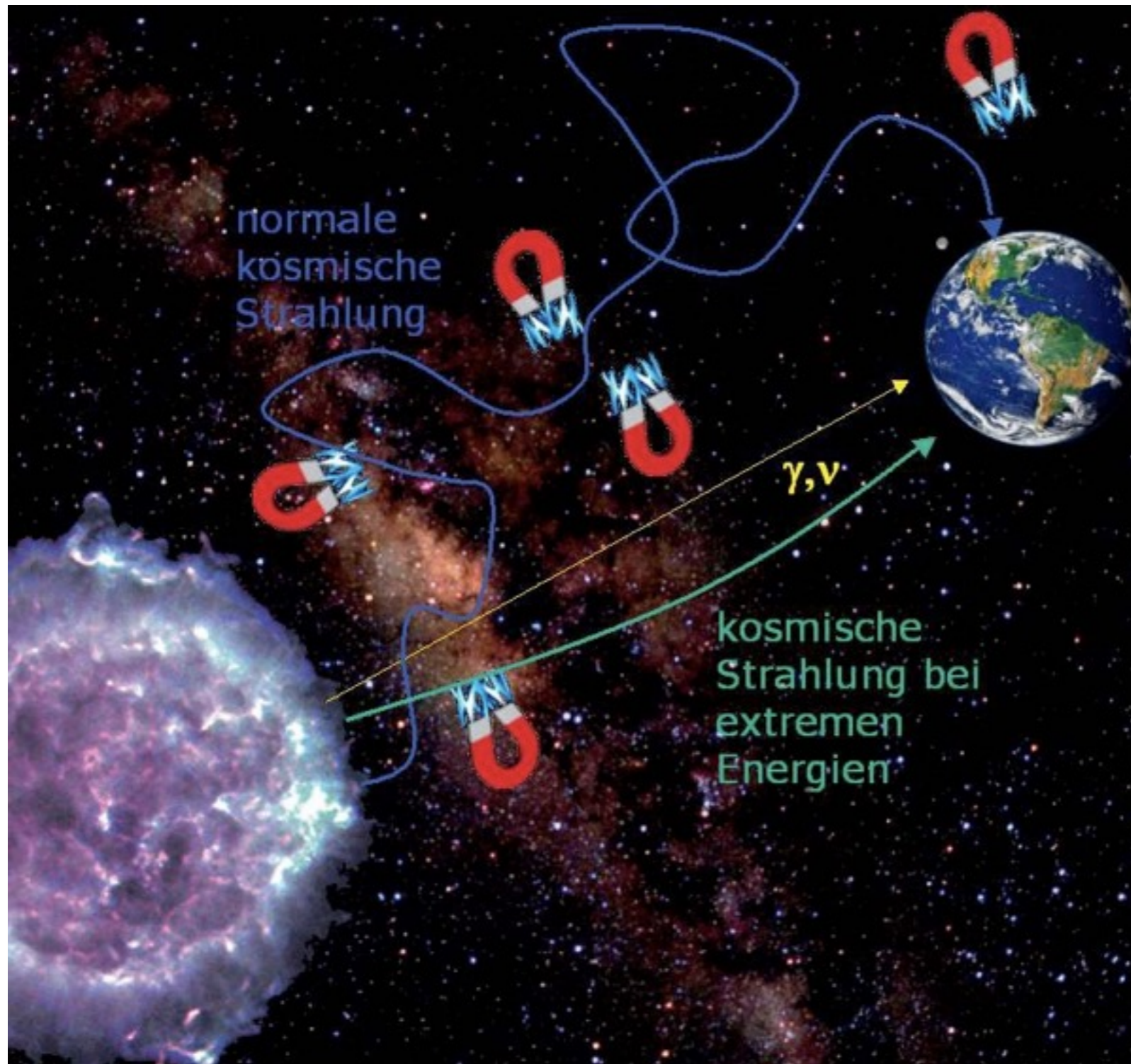
# Cosmic Accelerators



- Nuclei of active galaxies (AGN)
- ▶ There are first indications that the highest-energy particles come from AGNs

“Astroteilchenphysik in Deutschland”, <http://www.astroteilchenphysik.de/>, und darin angegebene Referenzen

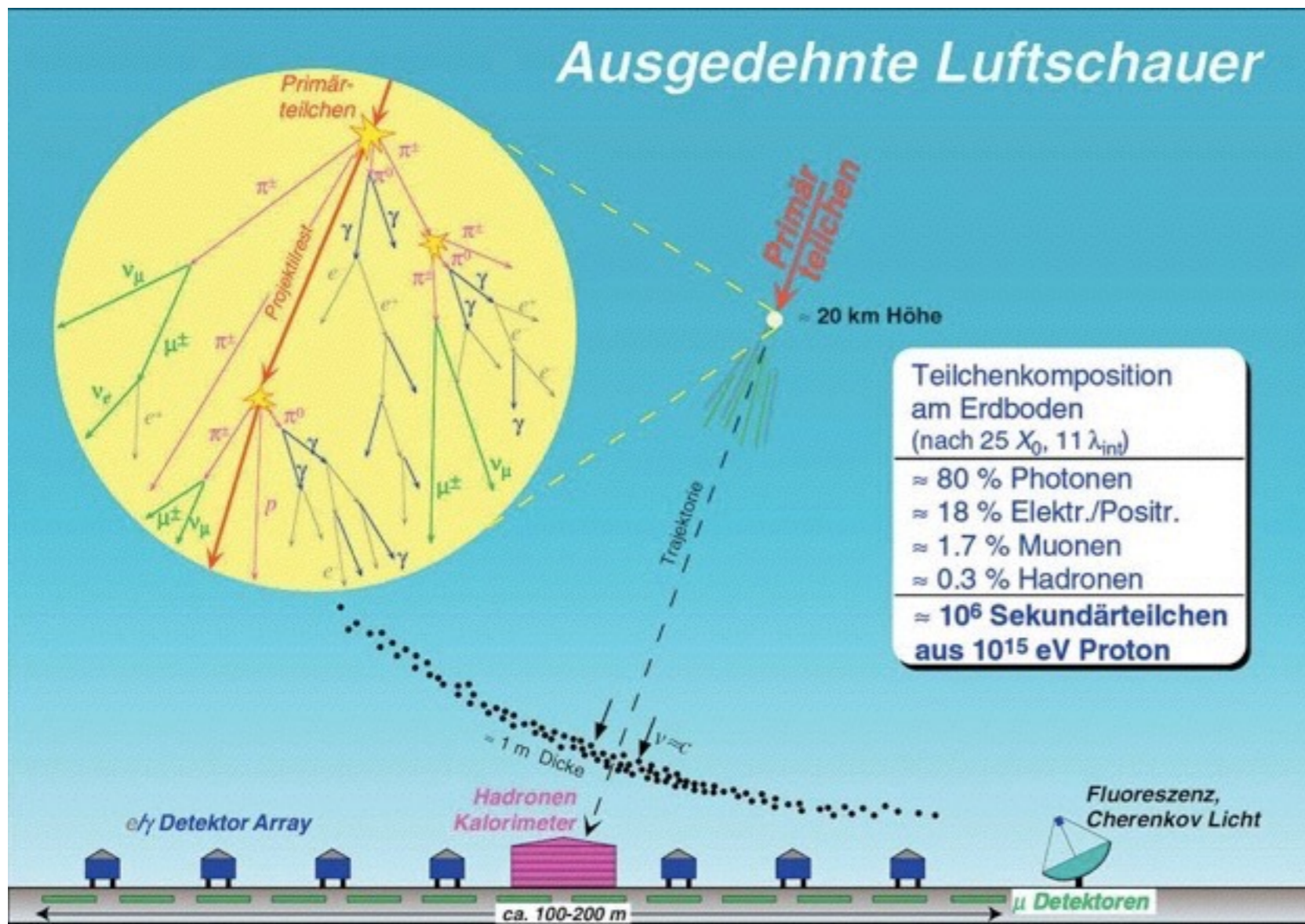
# The Path to Earth



- strong deflection of charged particles in cosmic magnetic fields
- ▶ neutral particles and highest energies can provide information on their sources
  - ▶ Highly energetic photons and charged particles have limited range!

“Astroteilchenphysik in Deutschland”, <http://www.astroteilchenphysik.de/>, und darin angegebene Referenzen

# Cosmic Rays on Earth: Air Showers



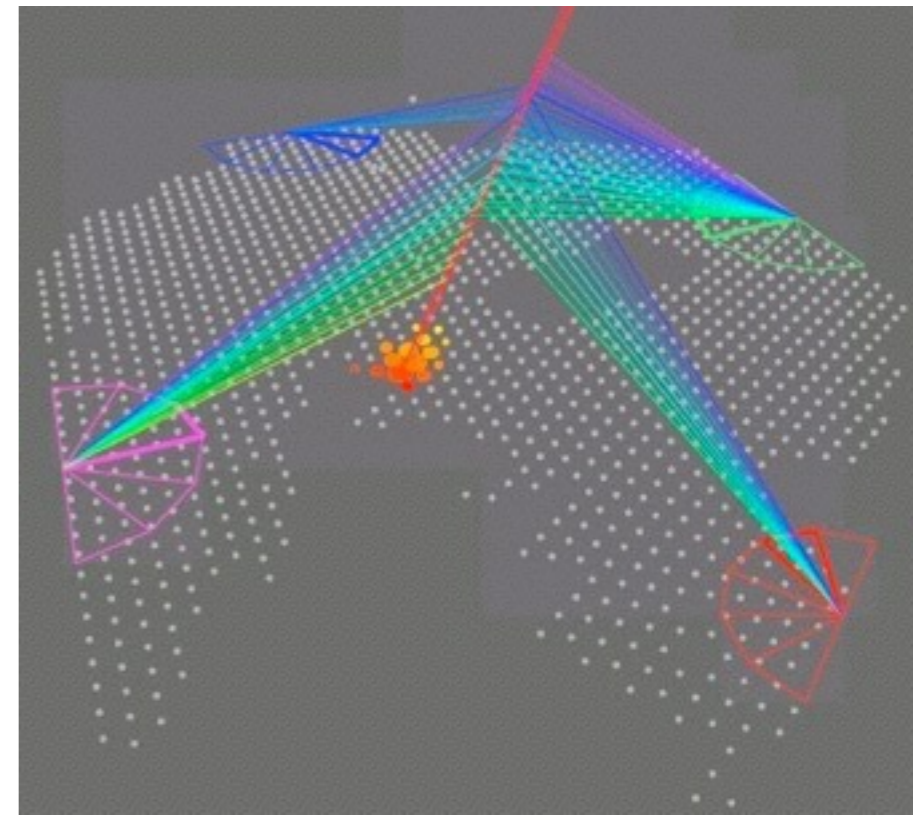
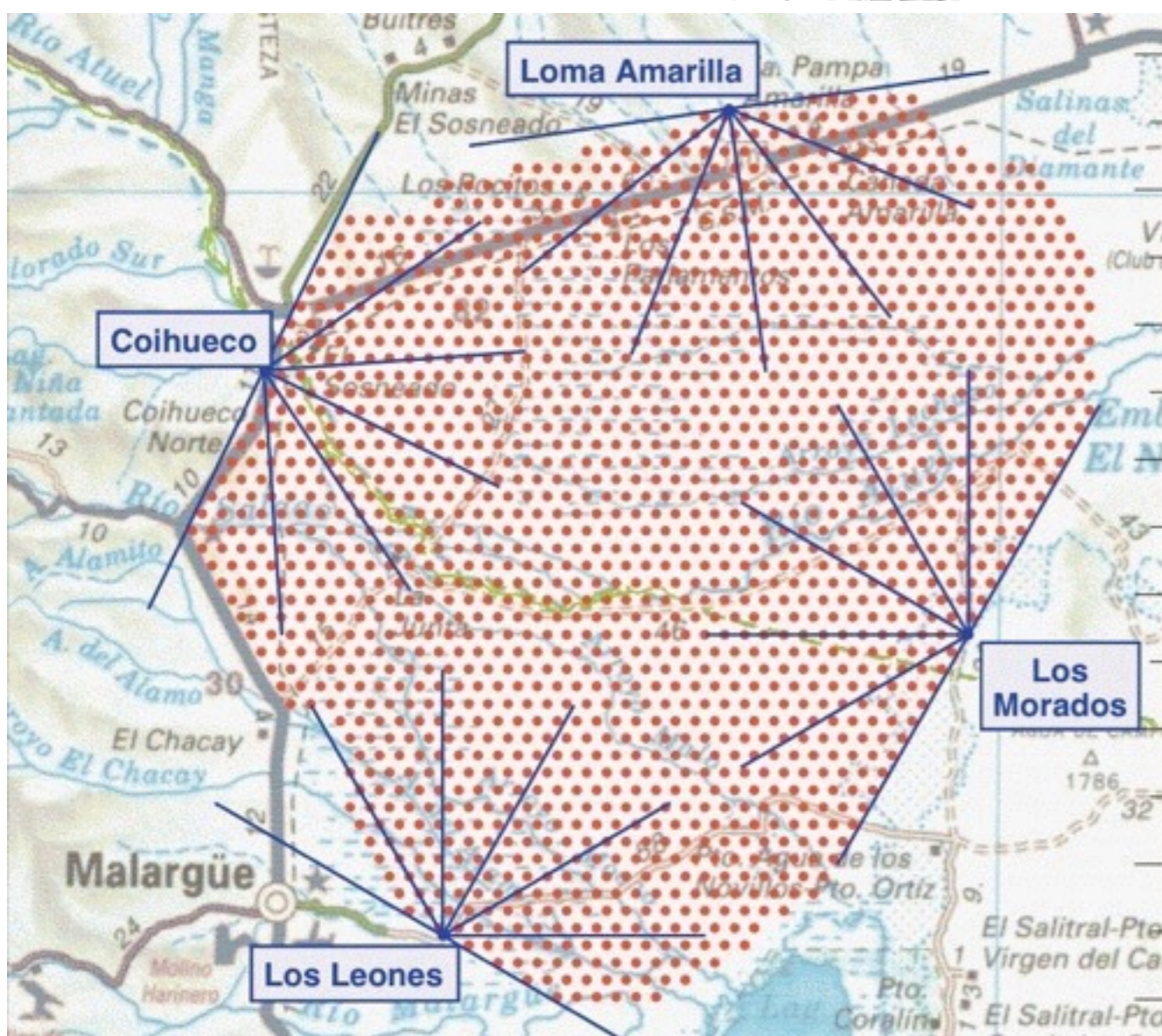
- Highly energetic particles create “extended air showers”
- numerous nuclear interactions in the atmosphere
- Energy measurement by using the atmosphere as a calorimeter: Detection of charged particles, photons, fluorescence and Cherenkov light

“Astroteilchen-Physik in Deutschland”, <http://www.astroteilchenphysik.de/>, und darin angegebene Referenzen

(KASCADE - Experiment, Karlsruhe)

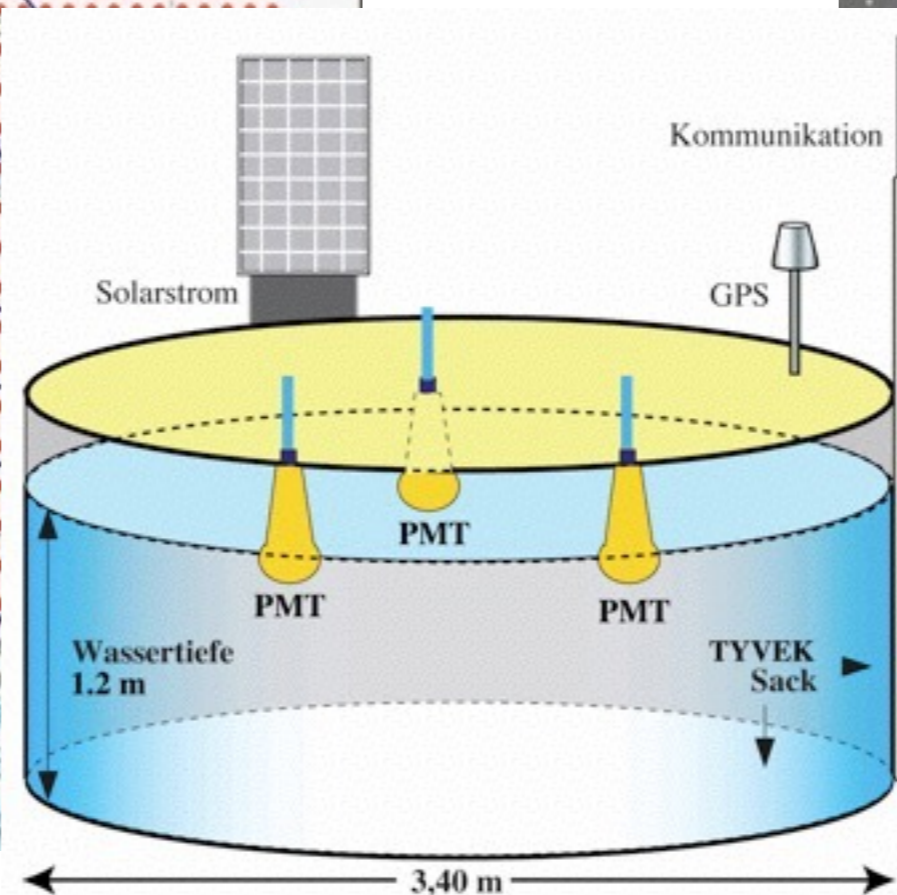
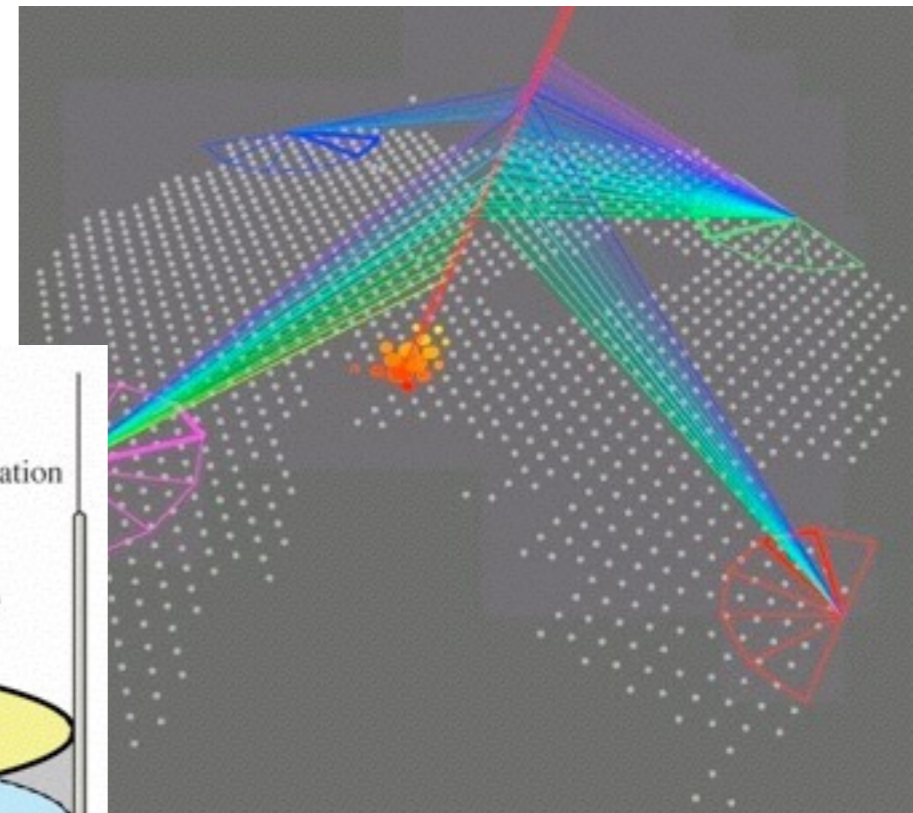
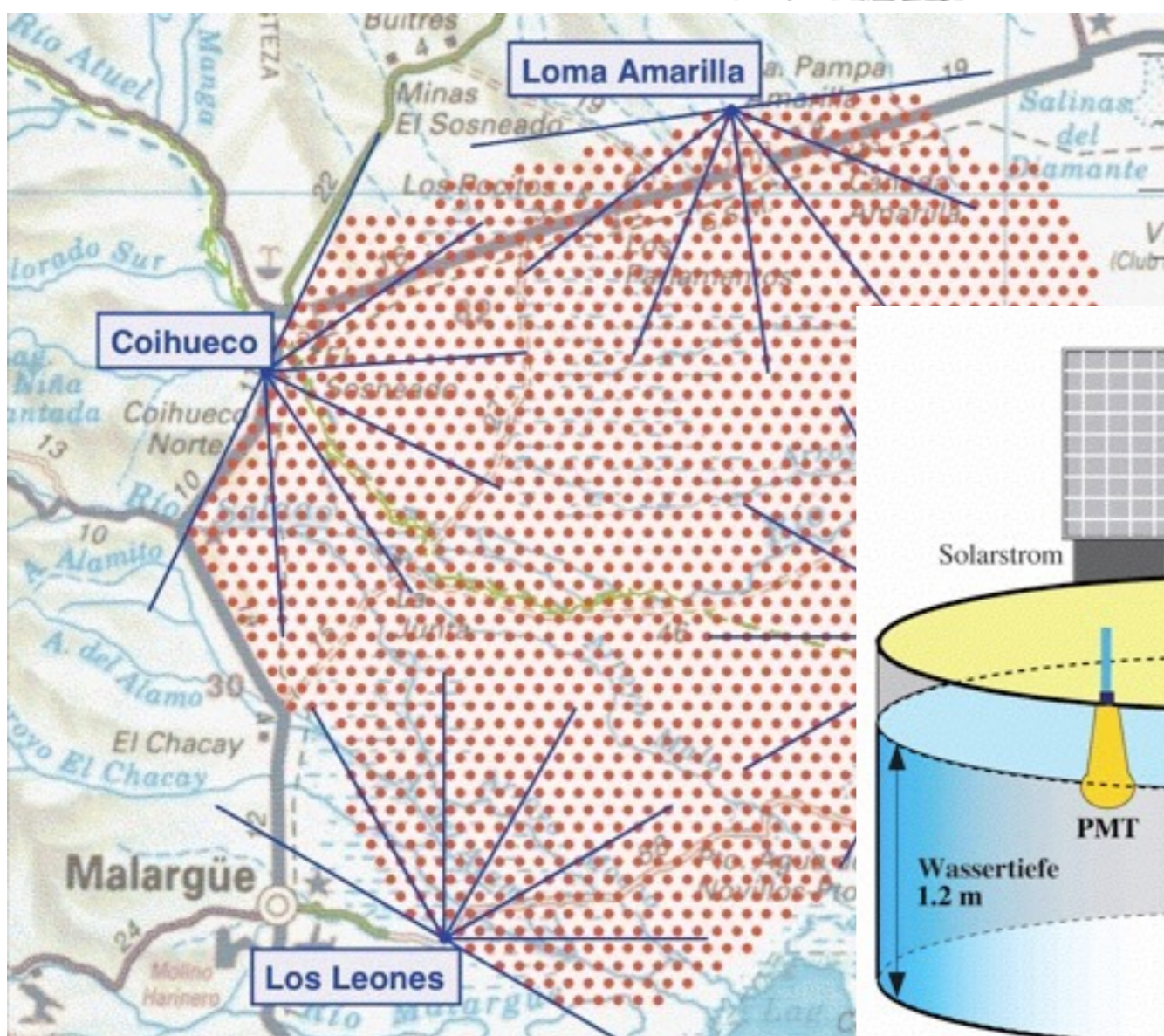


# Detector for Highest Energies: AUGER Experiment



- 2 detector-types:
  - 1600 shower detectors (water-Cherenkov)
  - 24 fluorescence telescopes
  - Total area: 3000 km<sup>2</sup> (~10 x Munich)

# Detector for Highest Energies: AUGER Experiment



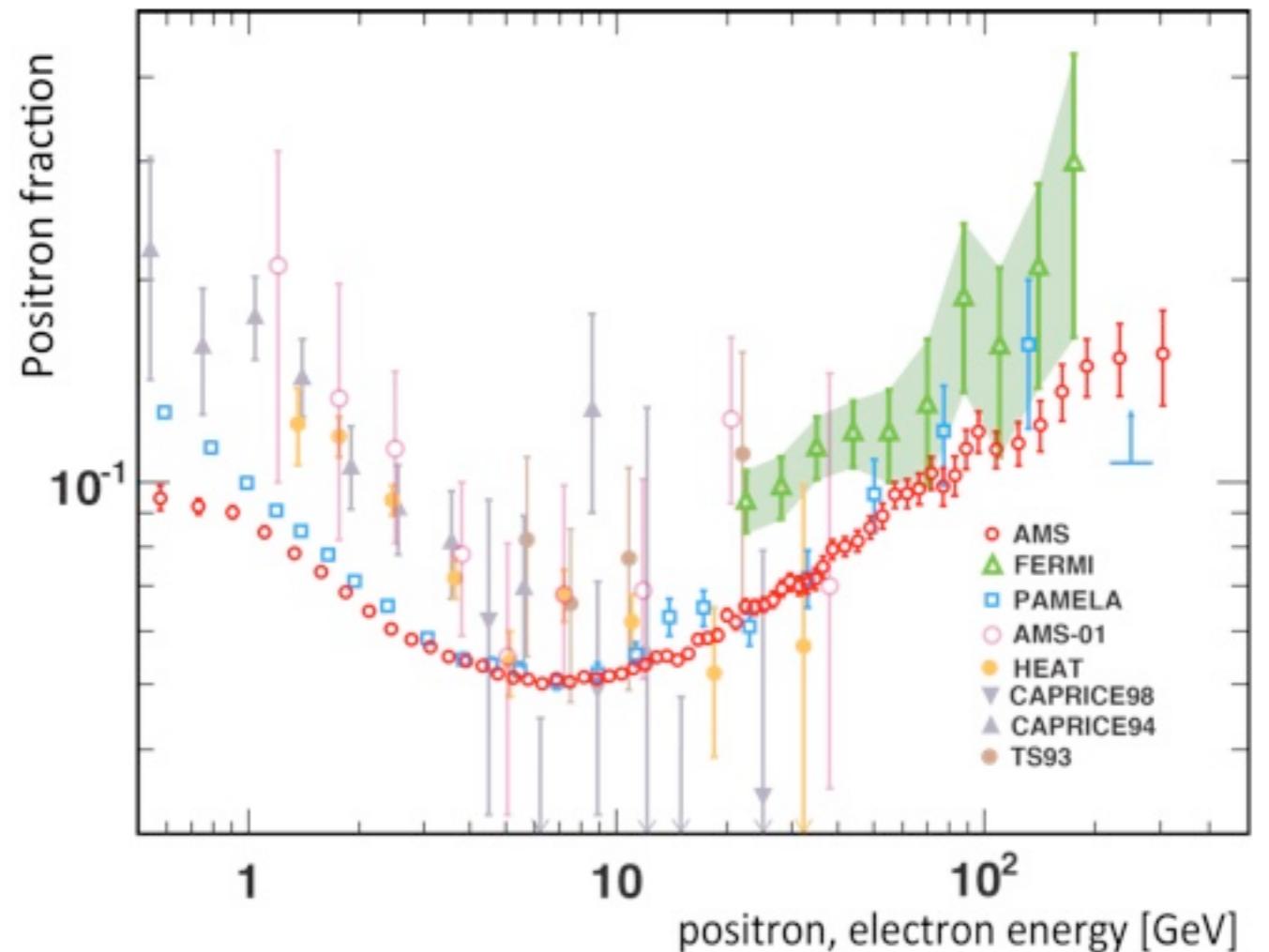
- 2 detector-types:
  - 1600 shower detectors (water-Cherenkov)
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# Spectacular Experiments in Space - AMS



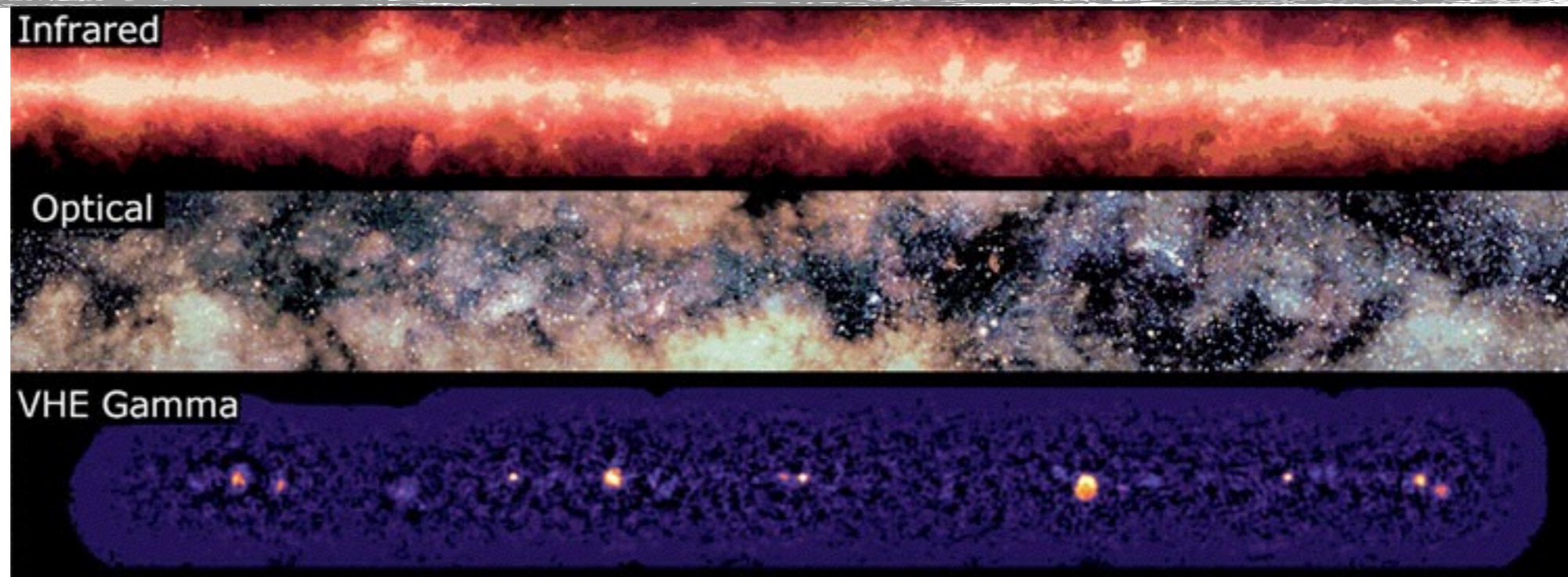
- A complete particle detector on the International Space Station

- Interesting first results: Too many positrons - confirms earlier measurements with higher precision!
  - Astrophysical phenomenon?
  - New Physics - Dark Matter?



# Neutral Cosmic Rays

Photons  
originating from  
the Milky Way



- Photons:
  - Decay of neutral pions
  - Black holes, AGNs, supernova explosions
  - Gamma-Ray-Bursts (GRB)
  - Pulsars
- Neutrinos
  - Solar neutrinos
  - Supernova explosions
  - pion decay
  - atmospheric neutrinos from air showers

# Gamma und X-Ray—Astronomy: Satellites



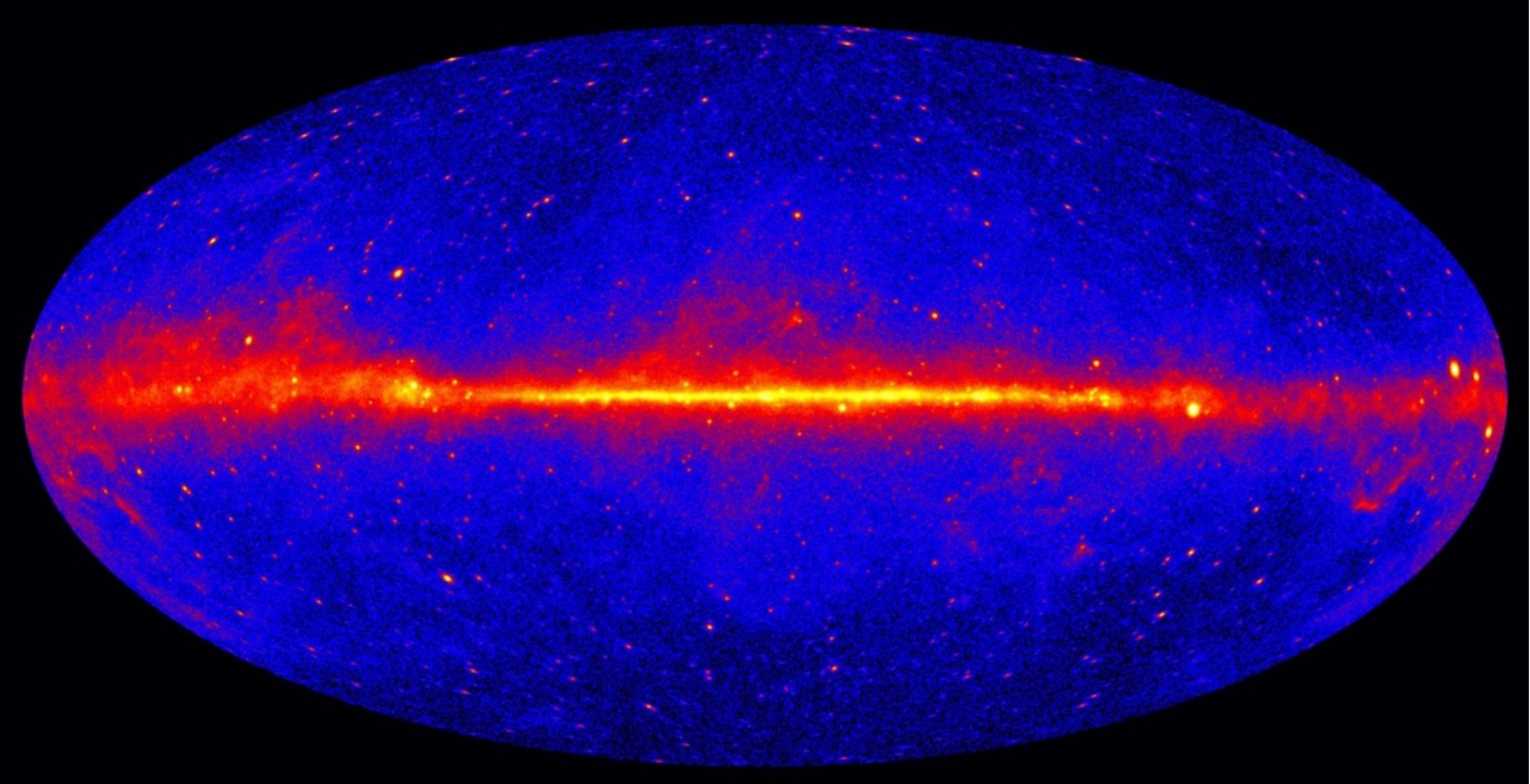
- FERMI - data taking since August 2008
  - Energy range: 10 keV to 300 GeV
  - Data catalog ( $\gamma$  - spectra, sources) available



# Gamma und X-Ray—Astronomy: Satellites



- FERMI - data taking since August 2008
- Energy range: 10 keV to 300 GeV



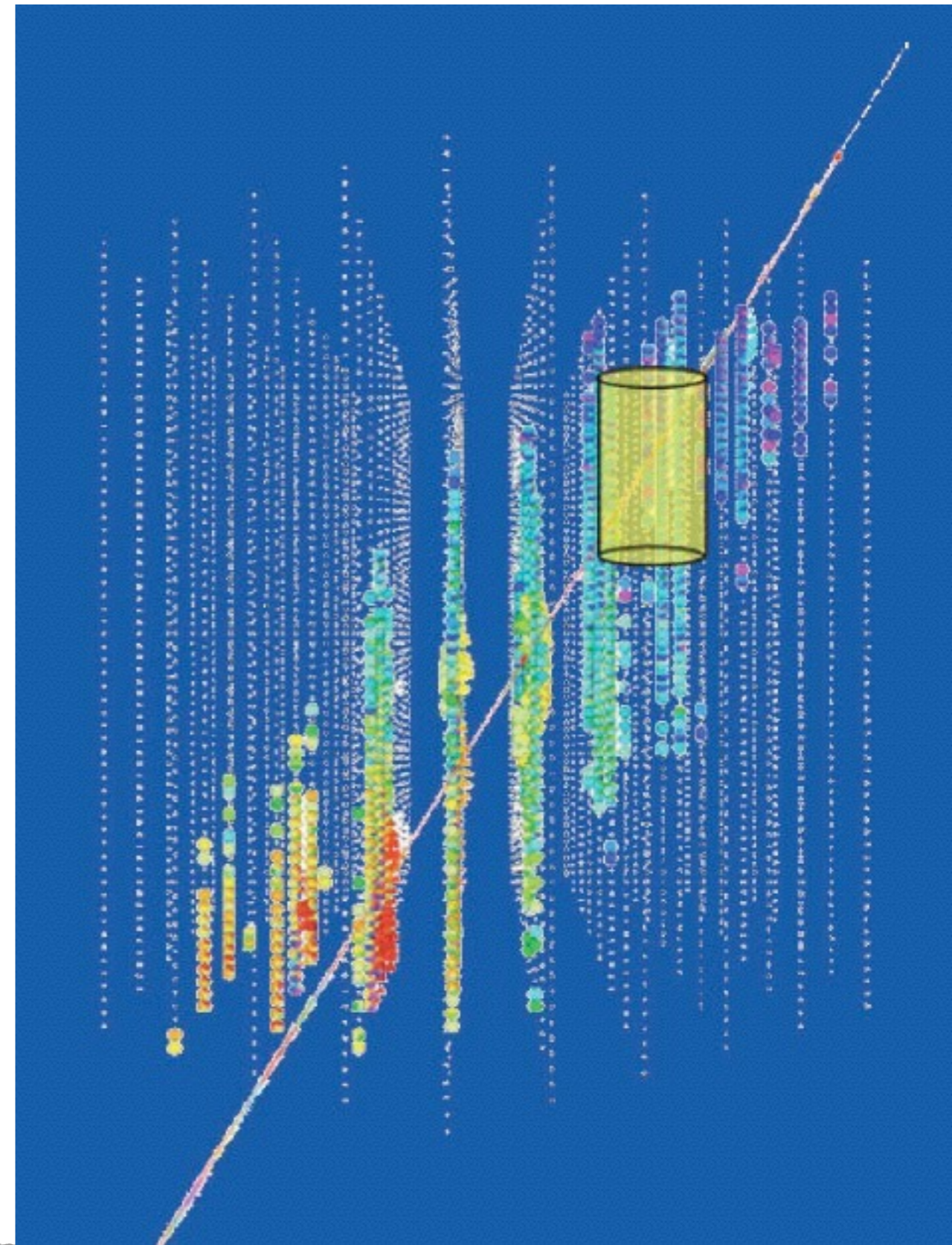
# Detector for Cosmic Gamma Rays: MAGIC



- Detection of highly energetic photons via air showers in the atmosphere
- Two telescopes with high-resolution cameras, each with 234 m<sup>2</sup> mirror surface
- Ultralight construction to allow fast repositioning

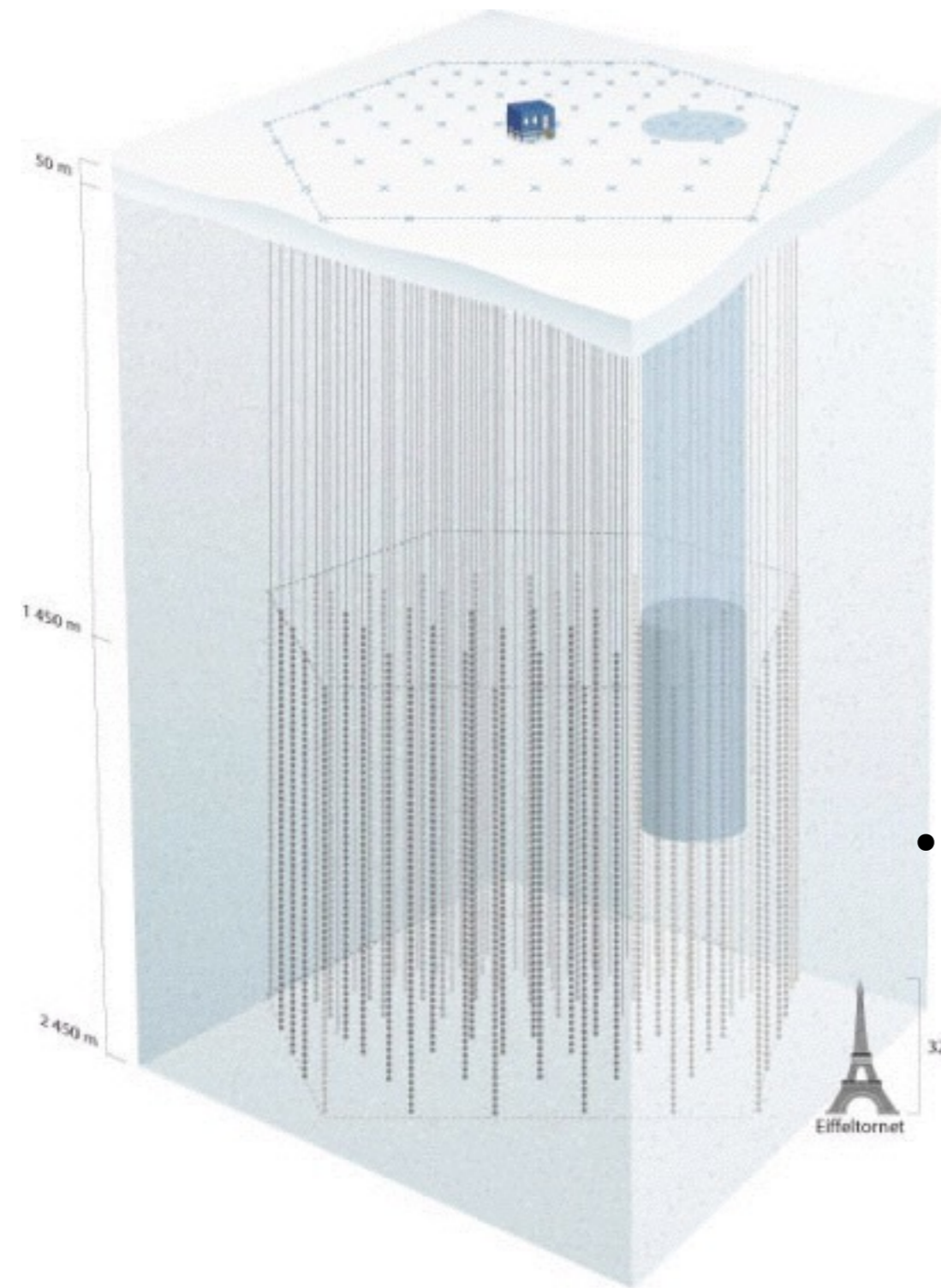
# Highly energetic Neutrinos

- Detection in deep underground detectors via Cherenkov light of muons or electrons produced in charged current reactions  
Example: Muon in IceCube
- Atmospheric neutrinos:
  - Are produced in air showers via pion and muon decay
  - Observation of neutrino oscillations
- Cosmic neutrinos
  - Supernovae
  - Other cosmic sources?



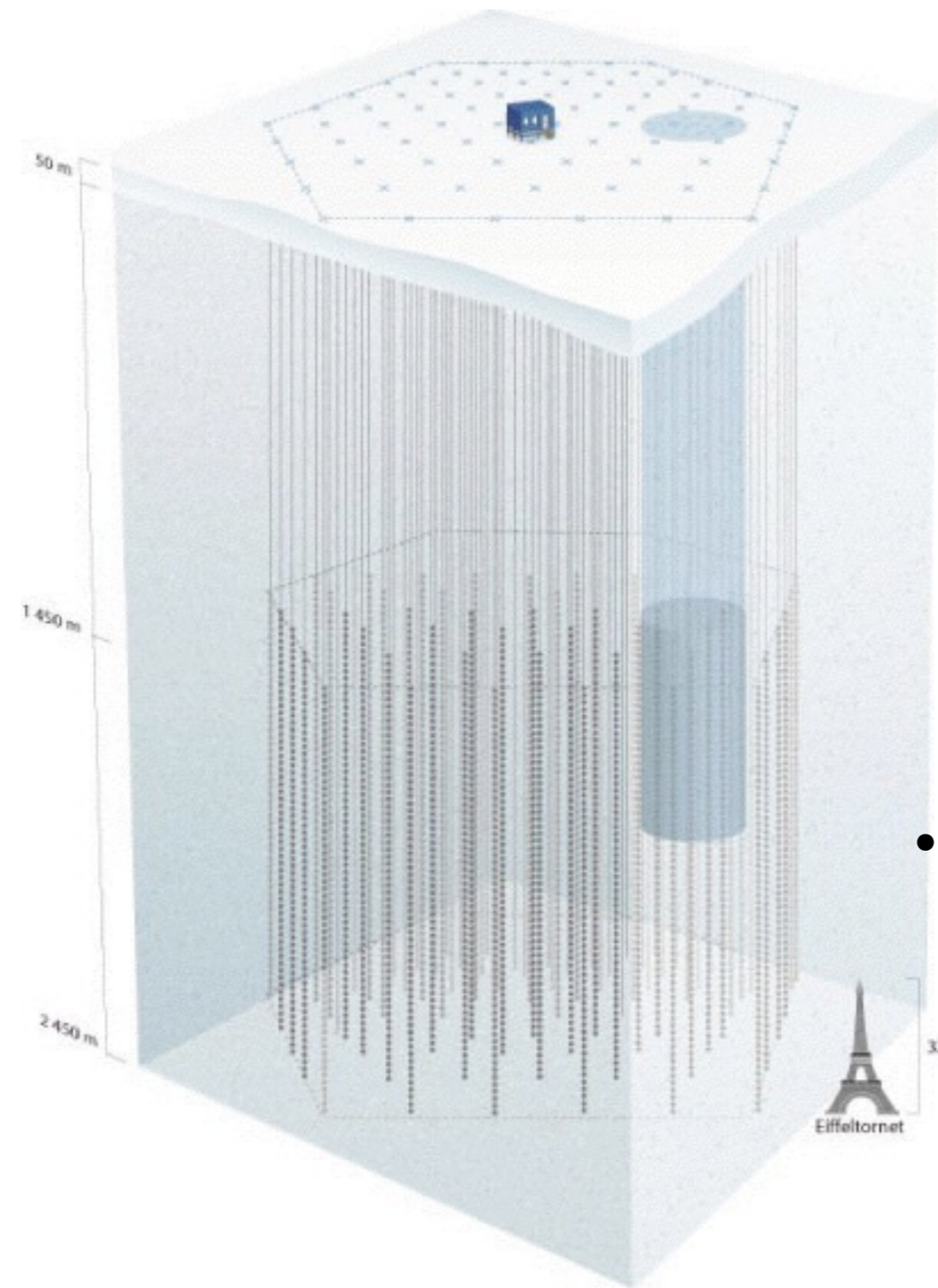


# Neutrino Astrophysics: IceCube



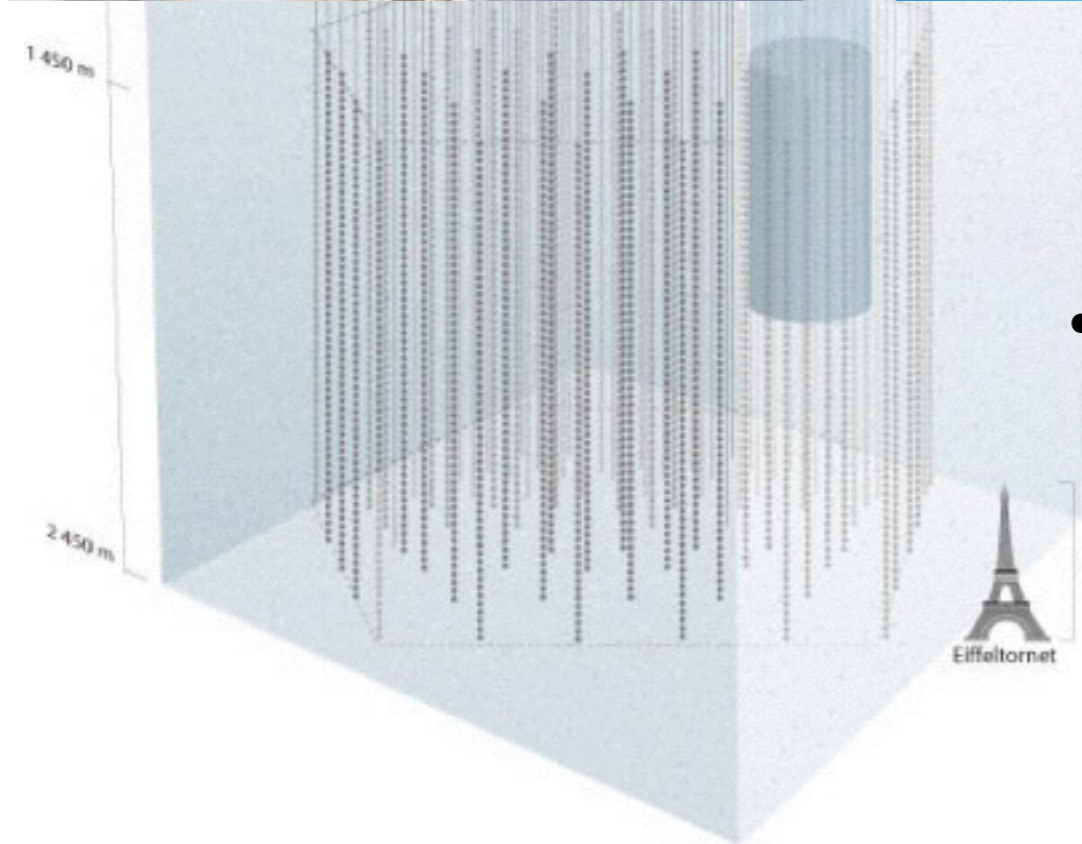
- 1 km<sup>3</sup> instrumented volume in the ice sheet at the south pole

# Neutrino Astrophysics: IceCube



- 1 km<sup>3</sup> instrumented volume in the ice sheet at the south pole

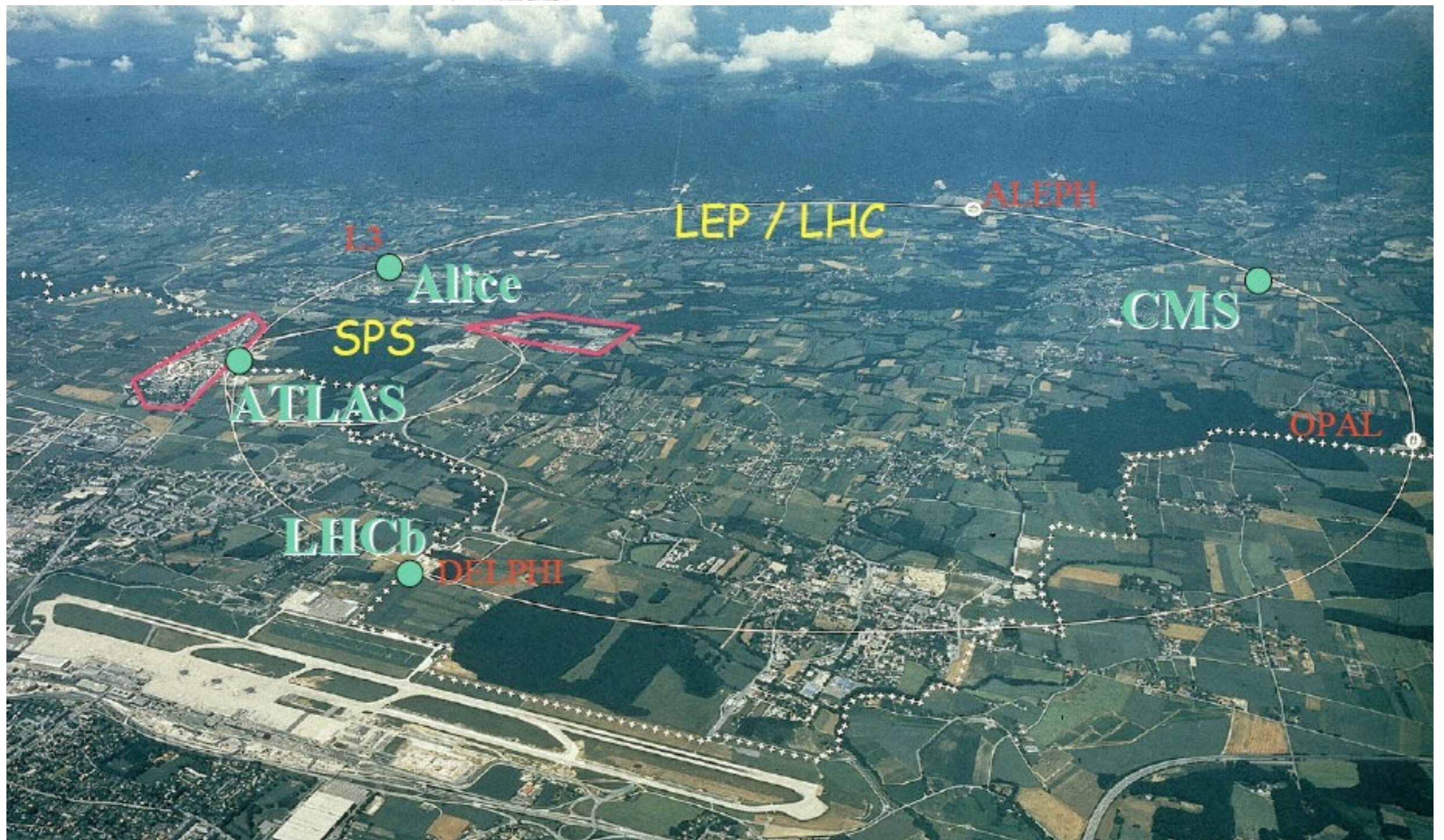
# Neutrino Astrophysics: IceCube



- 1 km<sup>3</sup> instrumented volume in the ice sheet at the south pole



# Accelerators on Earth: LEP/LHC



- Electron-Positron Collider (200 GeV, until 2000),  
now: LHC - with data at 8 TeV, in a few weeks starting again at 13 TeV

# LEP: The highest-energy $e^+e^-$ Collider to Date

- Circular collider: Magnets keep particles on their track
- Quadrupole: focussing
- Dipole: circular orbit




Foto: CERN

# Future Lepton Colliders

- Linear electron-positron colliders to reach energies substantially above those reached by LEP - potentially up to several TeV



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- Linear electron-positron colliders to reach energies substantially above those reached by LEP - potentially up to several TeV



- Even larger rings: Up to 100 km circumference for extremely high luminosity at energies up to  $\sim 350$  GeV

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- As far future project: A muon collider



# Future Lepton Colliders

- Linear electron-positron colliders to reach energies substantially above those reached by LEP - potentially up to several TeV



- Even larger rings: Up to 100 km circumference for extremely high luminosity at energies up to  $\sim 350$  GeV
- As far future project: A muon collider
- Ultimate acceleration gradients for leptons in plasmas - first promising R&D steps

# Summary

---

- Particle physics with accelerators and astroparticle physics are complementary
- Accelerator-based experiments provide detailed understanding of the most fundamental constituents of matter and their interactions
- Highly energetic cosmic particles provide information on violent processes in the universe
  - Where do the particles with the highest energies come from?
  - Photons and neutrinos may point the way to interesting sources
- The combination of different measurements may provide new discoveries

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Next Lecture: **27.04**, “Accelerators”, F. Simon

# Summary

---

- Particle physics with accelerators and astroparticle physics are complementary
- Accelerator-based experiments provide detailed understanding of the most fundamental particles and interactions

- High energy experiments provide detailed understanding of the most fundamental particles and interactions

**Attention !**  
**No lecture next week!**  
**The next lecture will take place on Monday, April 27!**

- Various experiments provide detailed understanding of the most fundamental particles and interactions
- Photons and neutrinos may point the way to interesting sources
- The combination of different measurements may provide new discoveries

Next Lecture: **27.04**, “Accelerators”, F. Simon