Cosmology and Particle Astrophysics

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Talk Outline

- Part I 8:10-9:30am
  - Introduction to Cosmology
    - From Quarks to Cosmos
    - Origin of Universe
    - Remaining Questions
- Part II 10:00-11:00am
  - Particle Astrophysics
    - Messengers from the Earliest and the Extreme Universe
- Discussion 11:00-11:30am

Part I

Introduction to Cosmology

Central Theme

- Why are we here?
  - Origin of Ourselves
  - Origin of Life
  - Origin of the Solar System
  - …
  - Origin of the Universe
- What is the most fundamental law in nature?

History of Life and the Human beings

Time

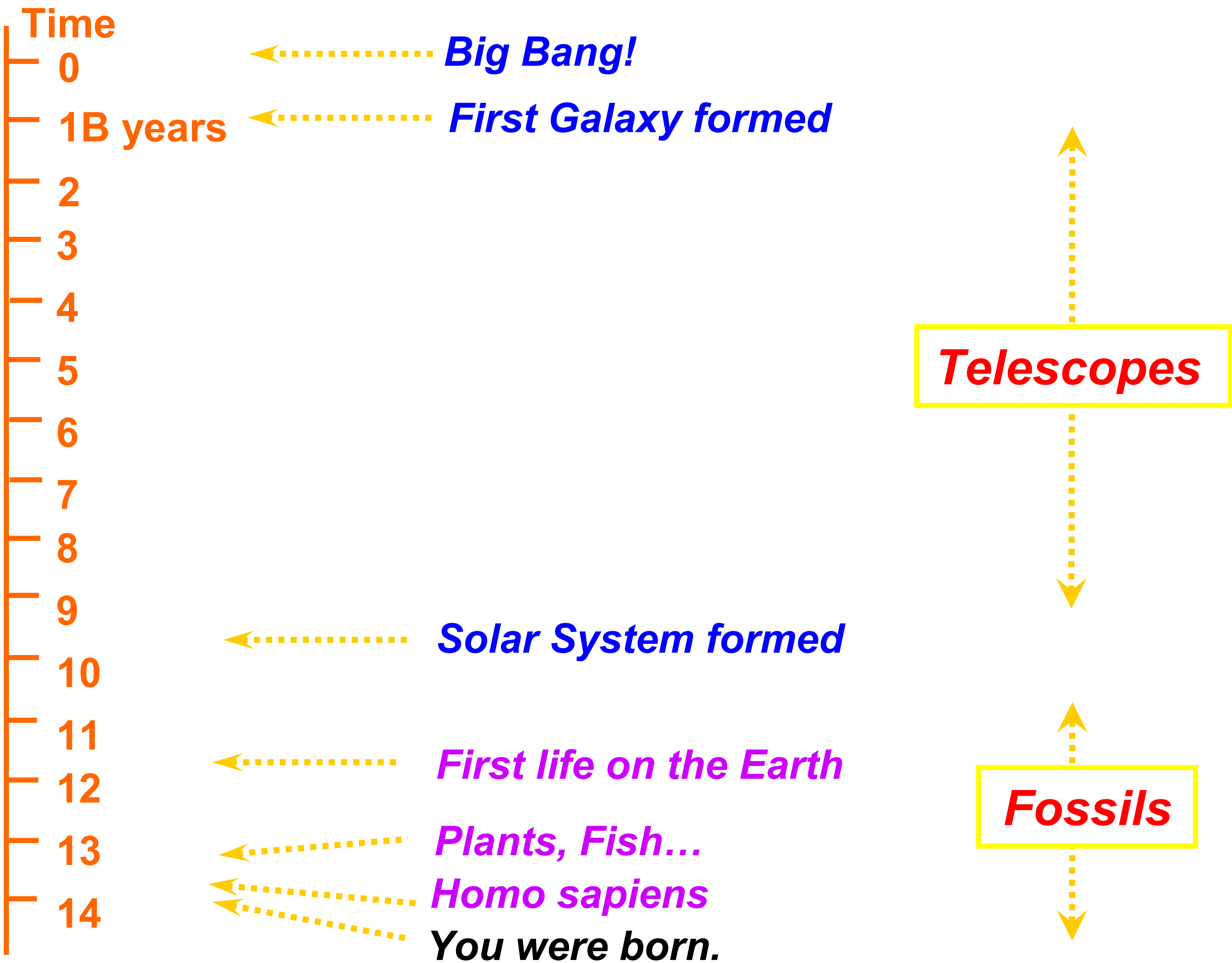
- 10B years ← *Big Bang!*
- ← *Solar System formed*
- 1Billion ← *First life on the Earth*
- ← *Plants, Fish…*
- 100M
- 10M ← *Mammals*
- 1Million ← *Homo sapiens*
- 100,000
- 10,000
- 1,000 ← *Jesus Christ was born.*
- 100 ← *Einstein was born.*
- ← *You were born.*
- 10
- 1 year
- 100 days
- 10 days
- 1 day
- 10 hours
- 1 hour ← *You woke up this morning.*
- 10 minutes
- 1 minute ← *You saw this viewgraph.*

Fossils

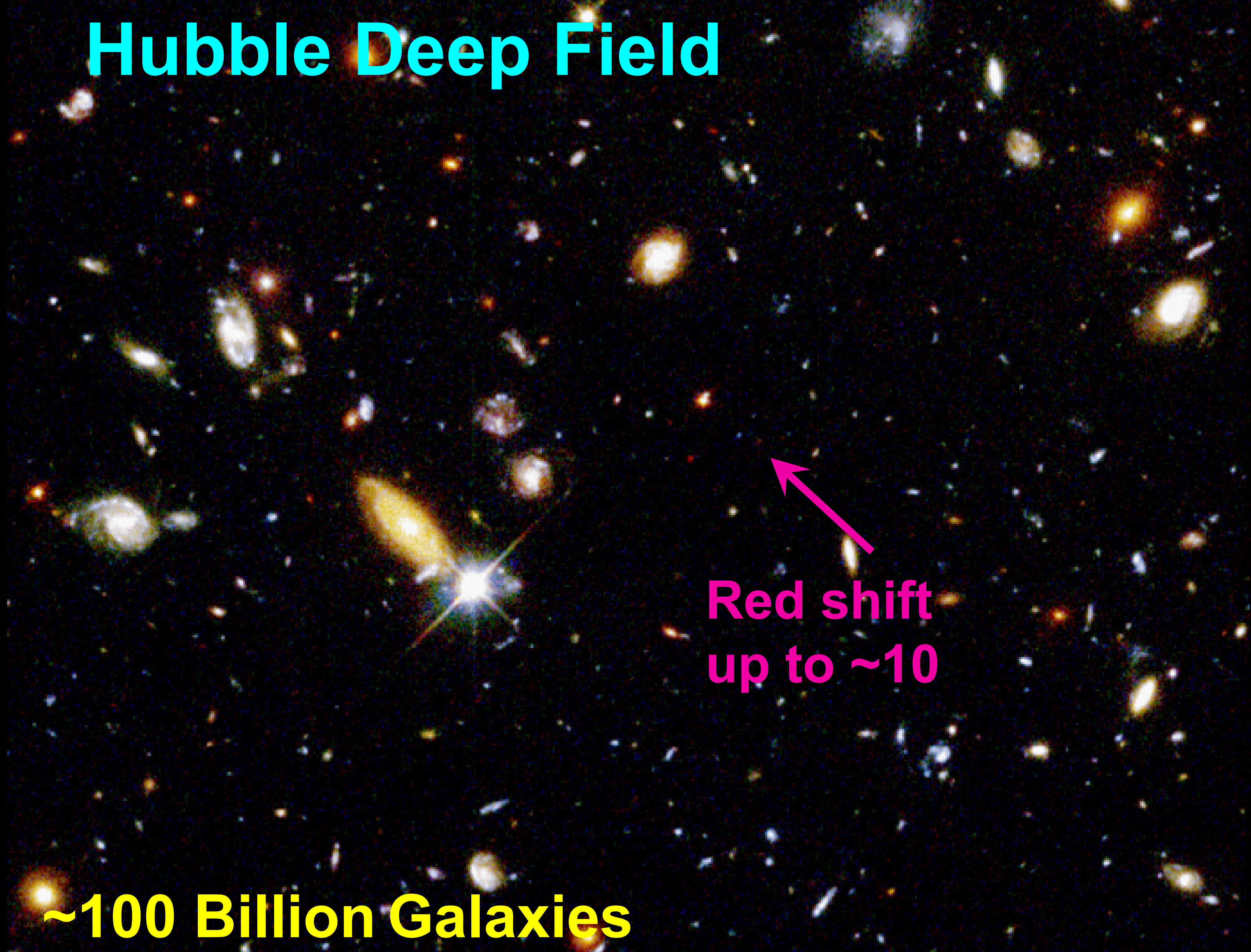
Written Documents

Videos, Pictures

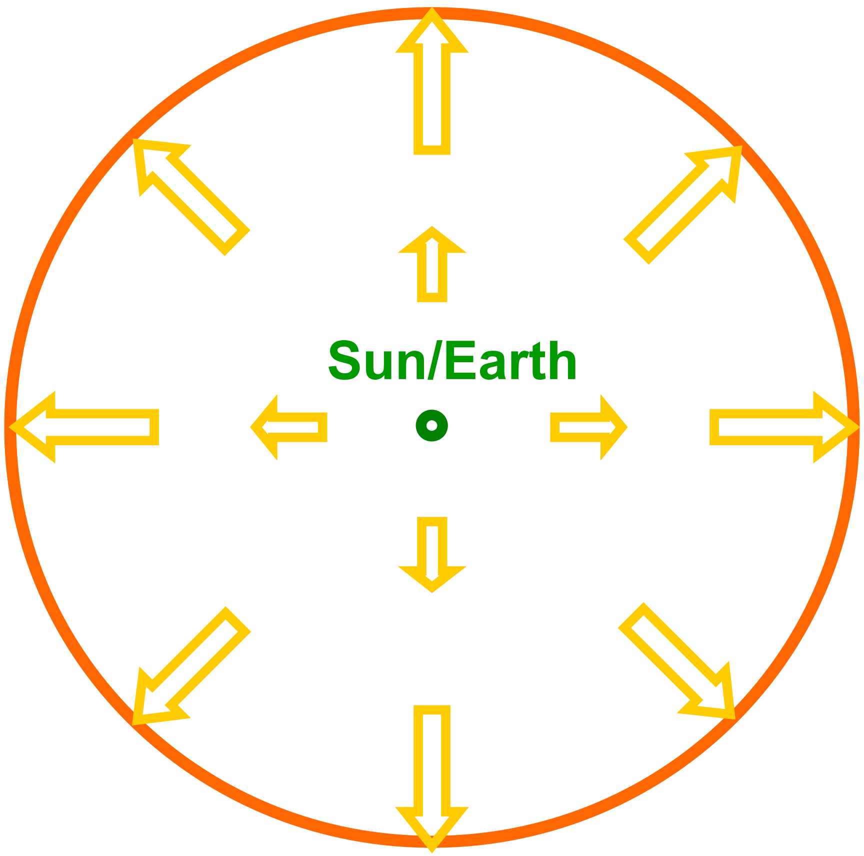
Brief History of Universe and Life




ANDROMEDA
GALAXY
~100 Billions Stars in a Galaxy


Hubble Deep Field
Red shift
up to ~10
~100 Billion Galaxies

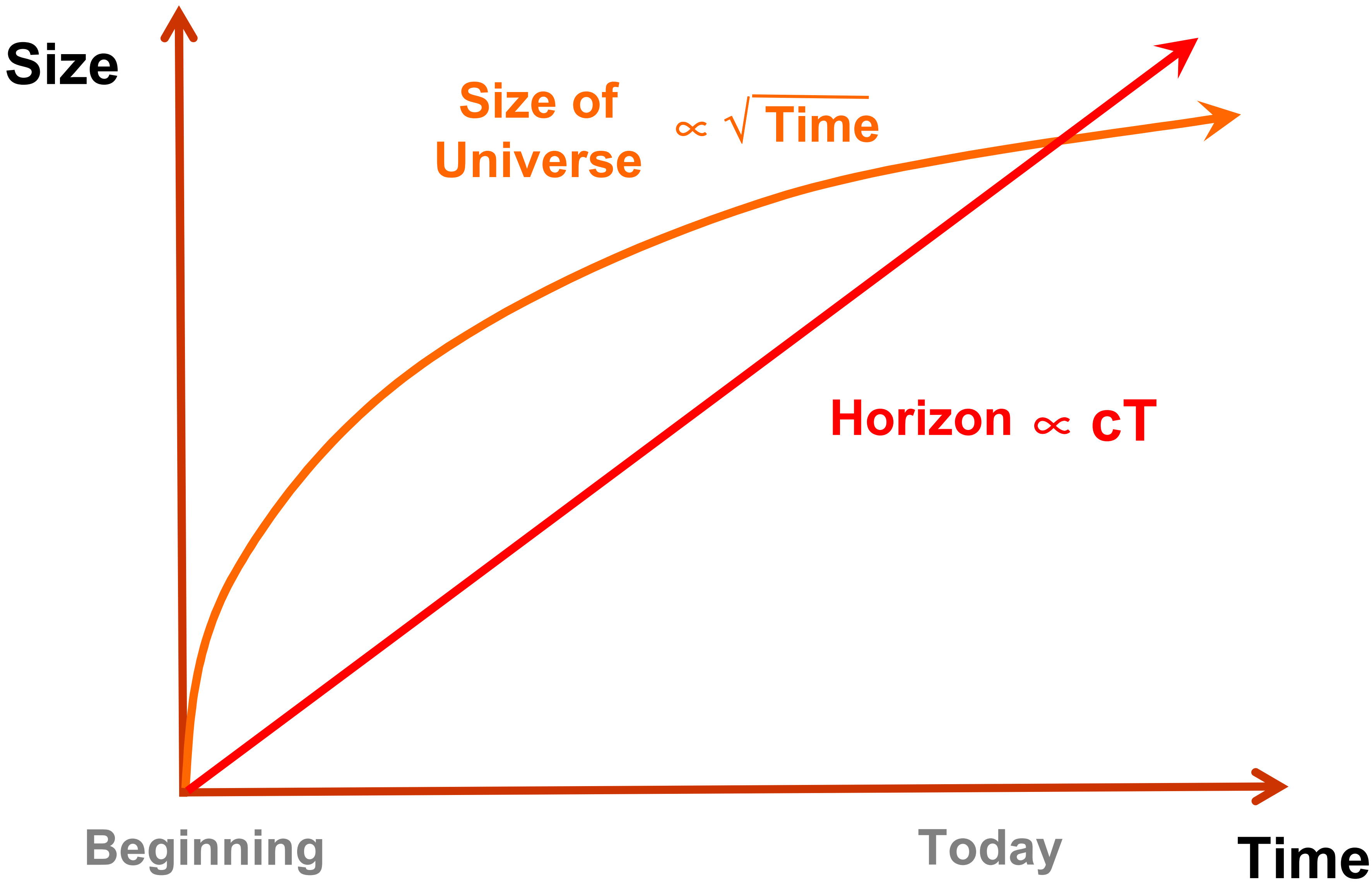
Hubble's Law: Expansion of the Universe



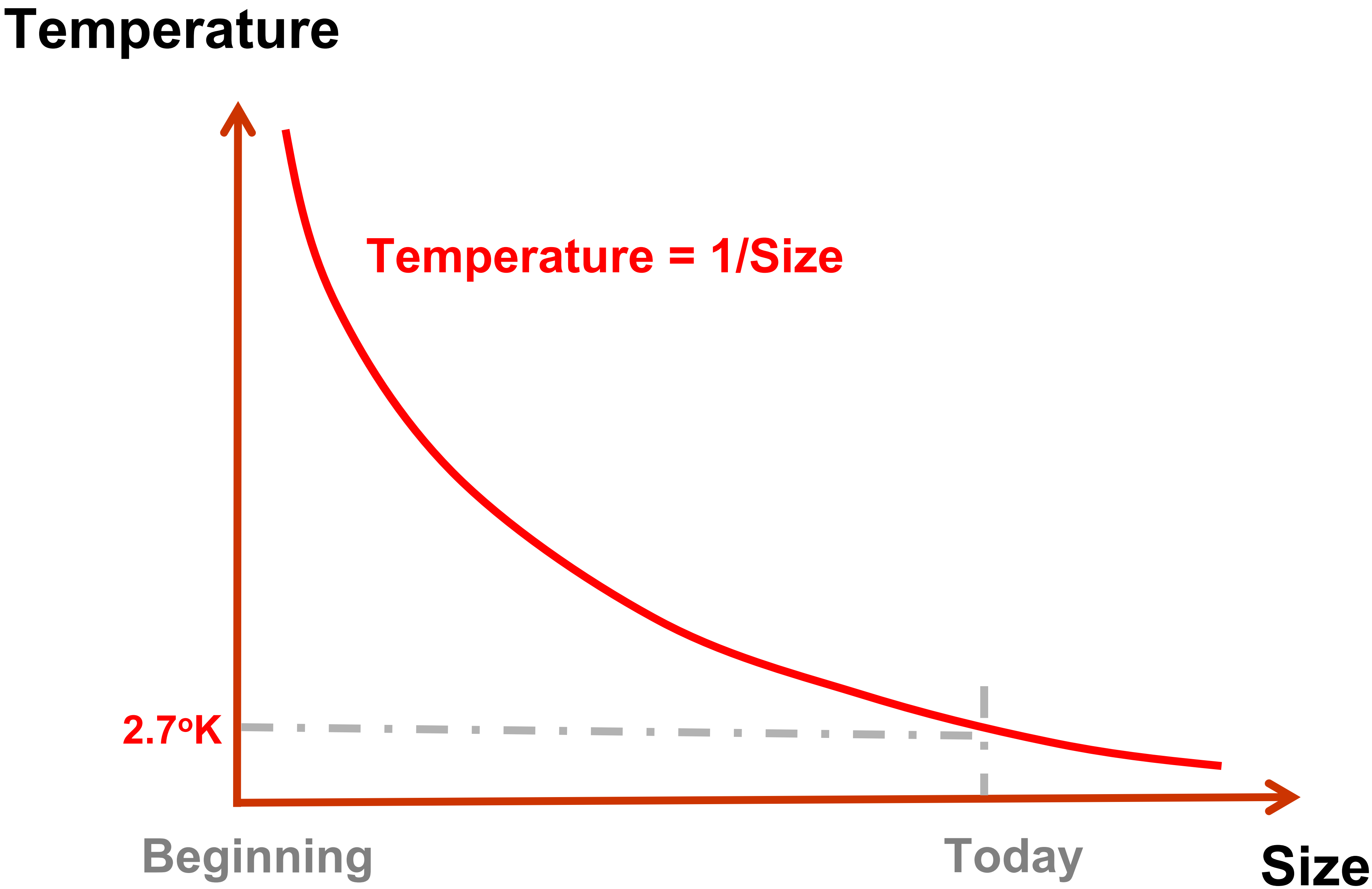
**1.4 Billon
Light Years**

**Moving Away
at Speed of Light**

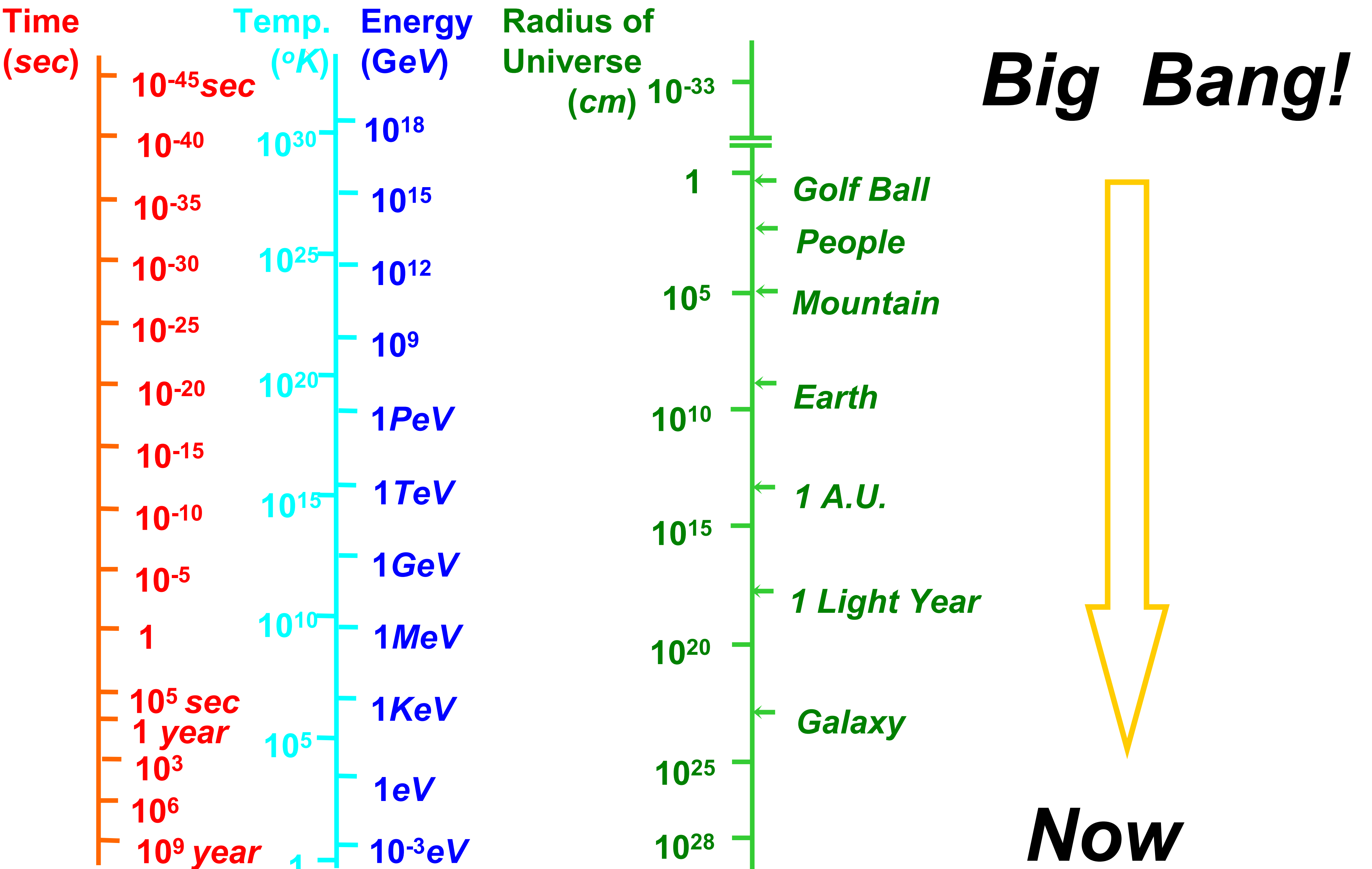
Expansion of Universe



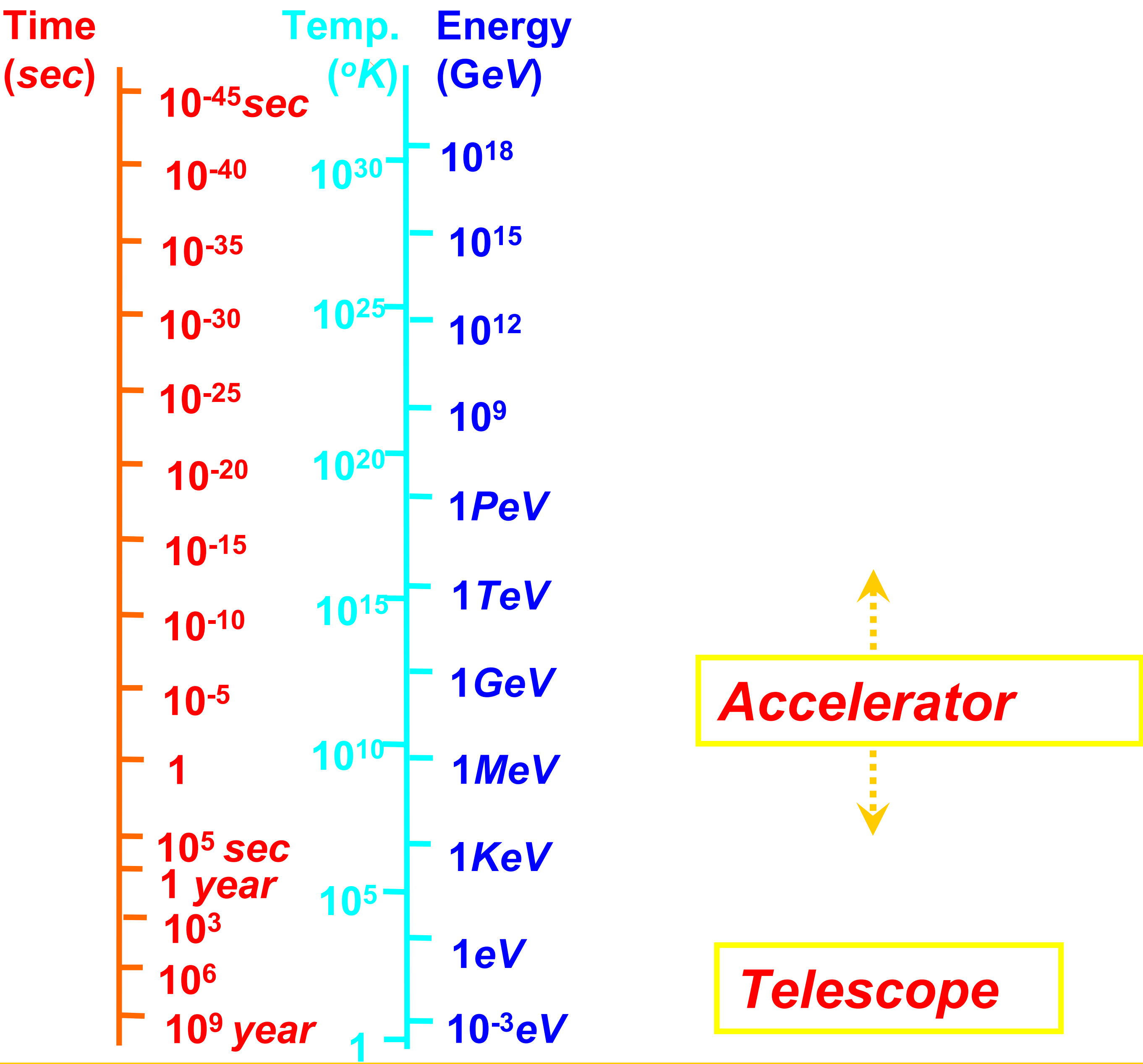
Temperature of Universe



Evolution of the Early Universe

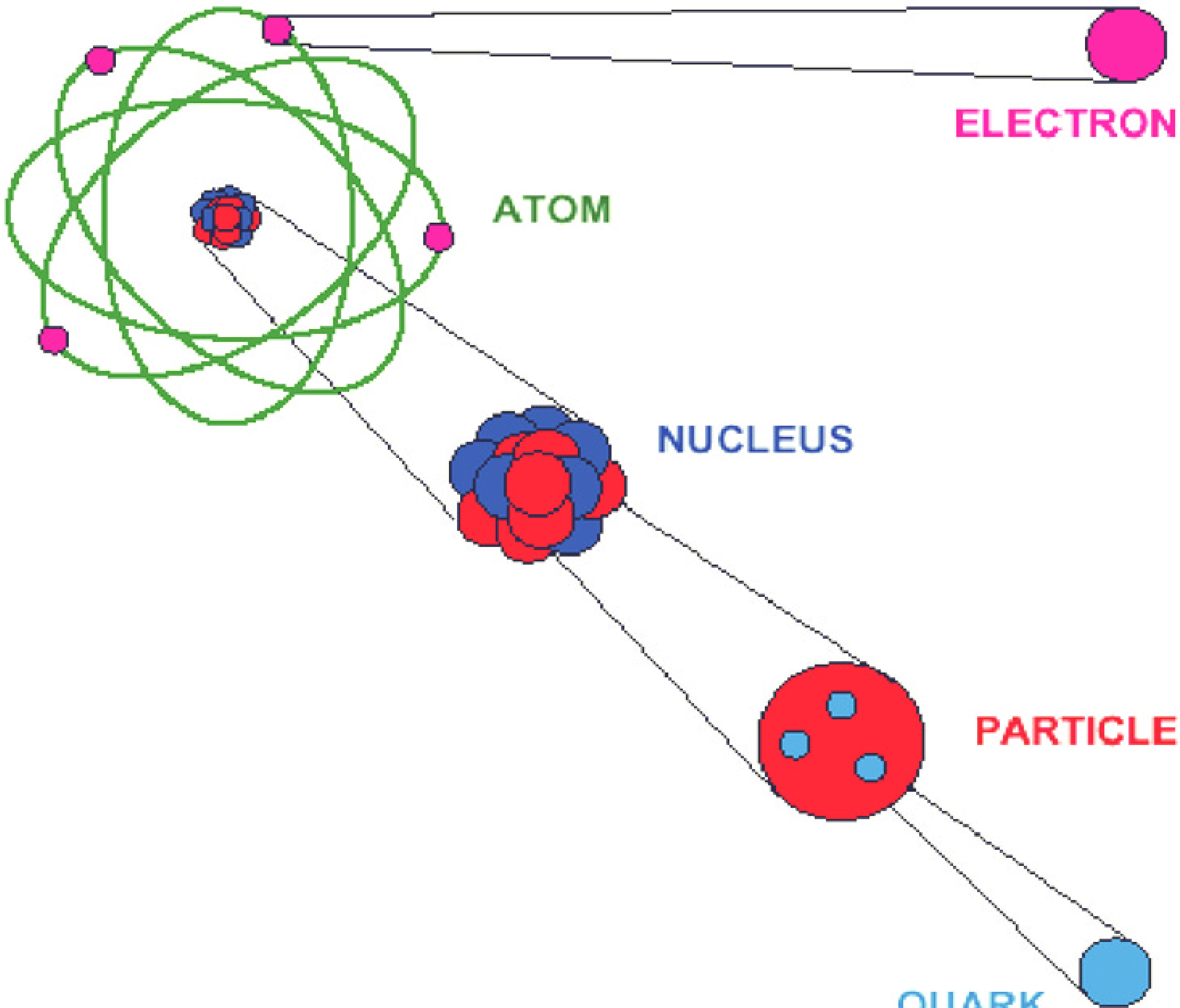


Tools to explore the Early Universe

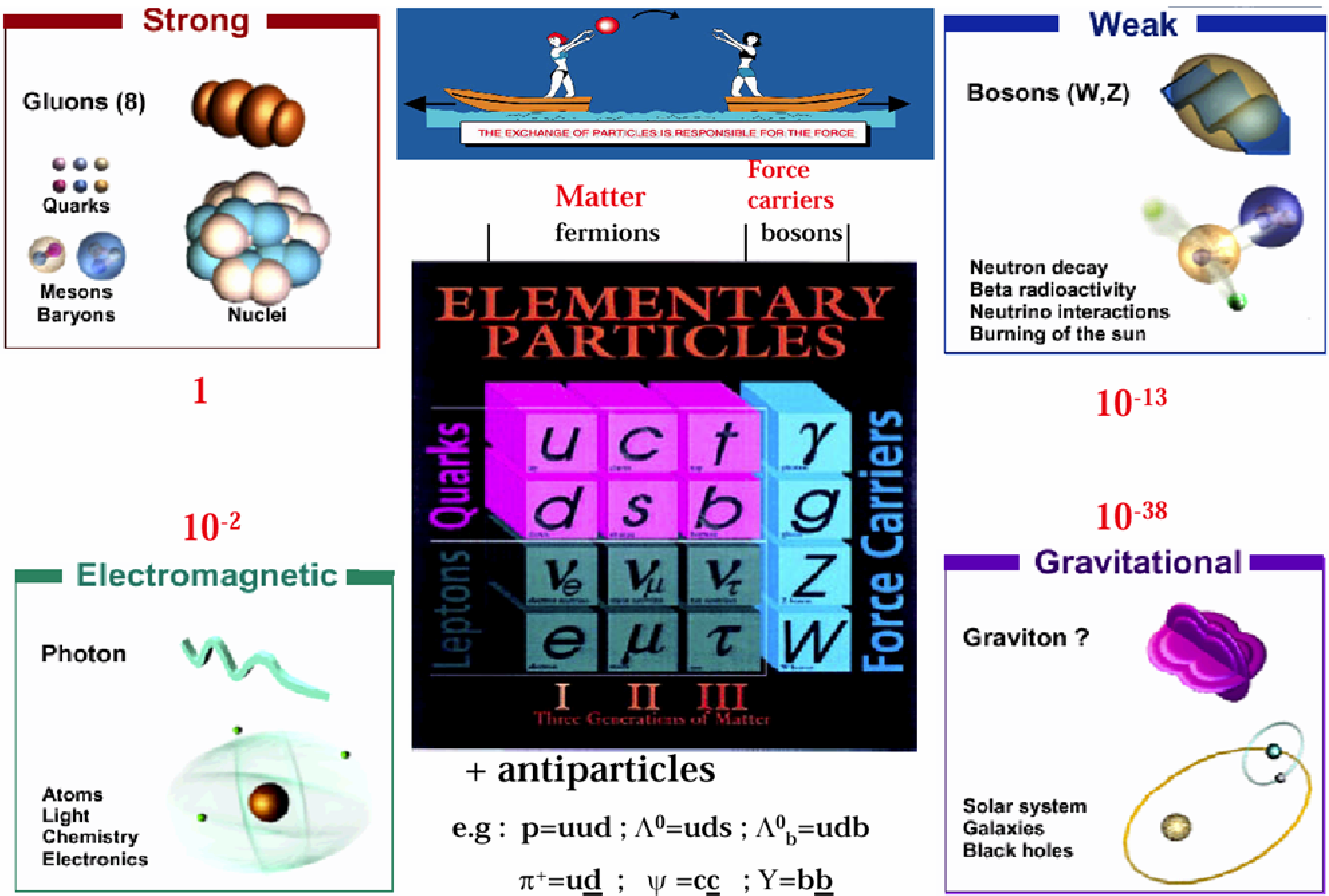


Fermi Lab near Chicago

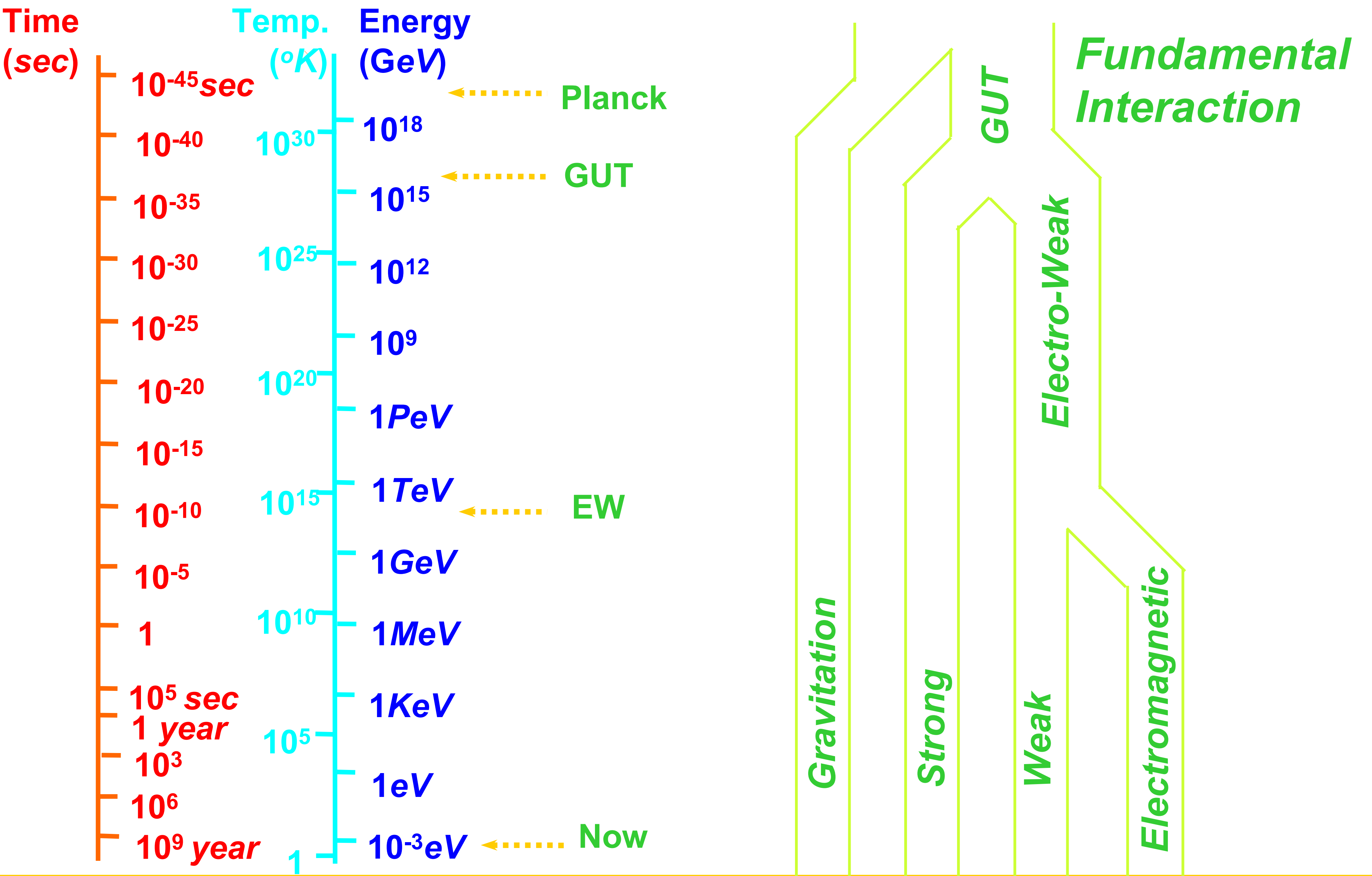
Elementary Particles (~1970)



Elementary Particles and Forces



Unification of Fundamental Forces (~1975)

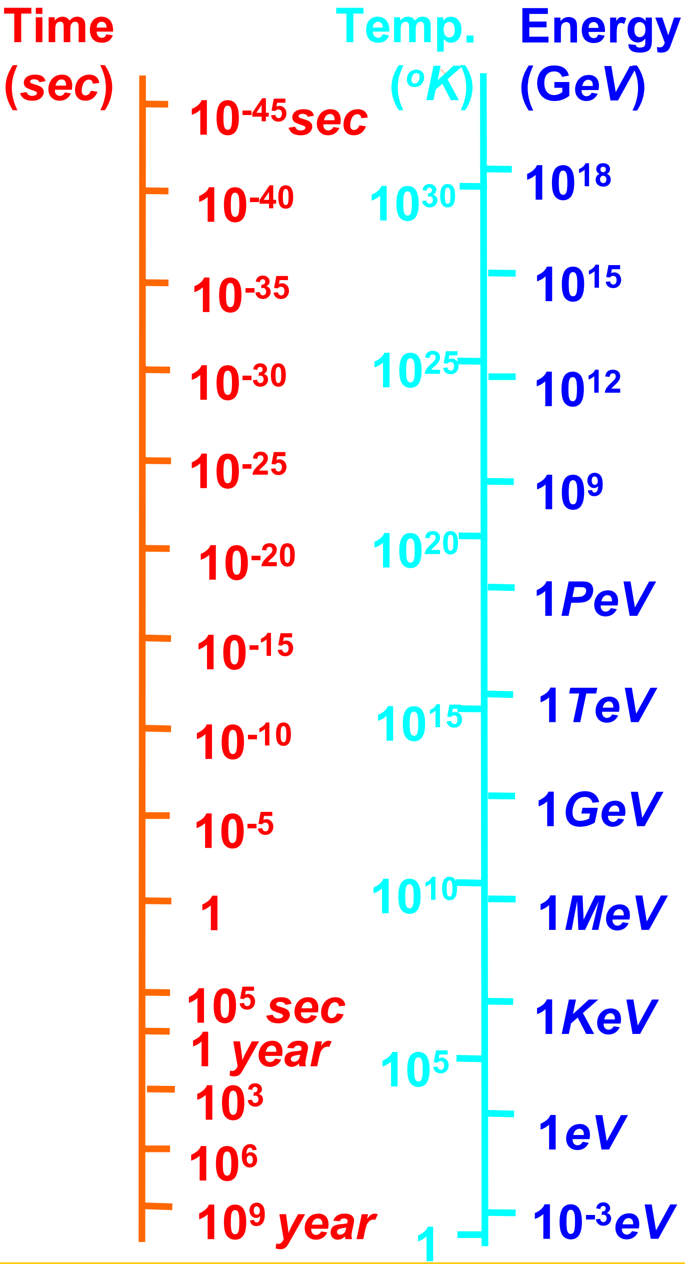


Physicists' View of Early Universe

Lorentz Invariance

Local Gauge Invariance

Symmetry Breaking

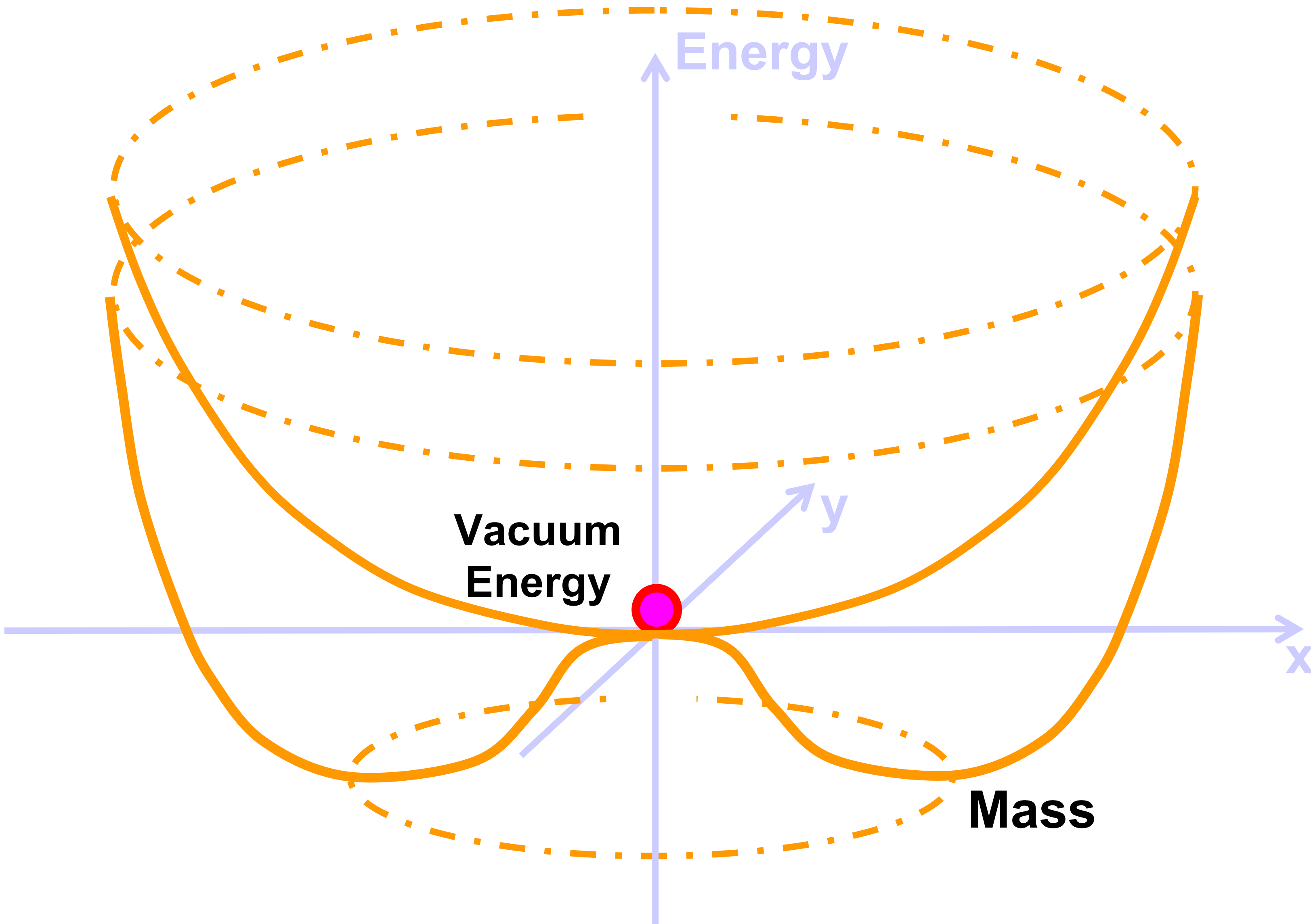


Simple

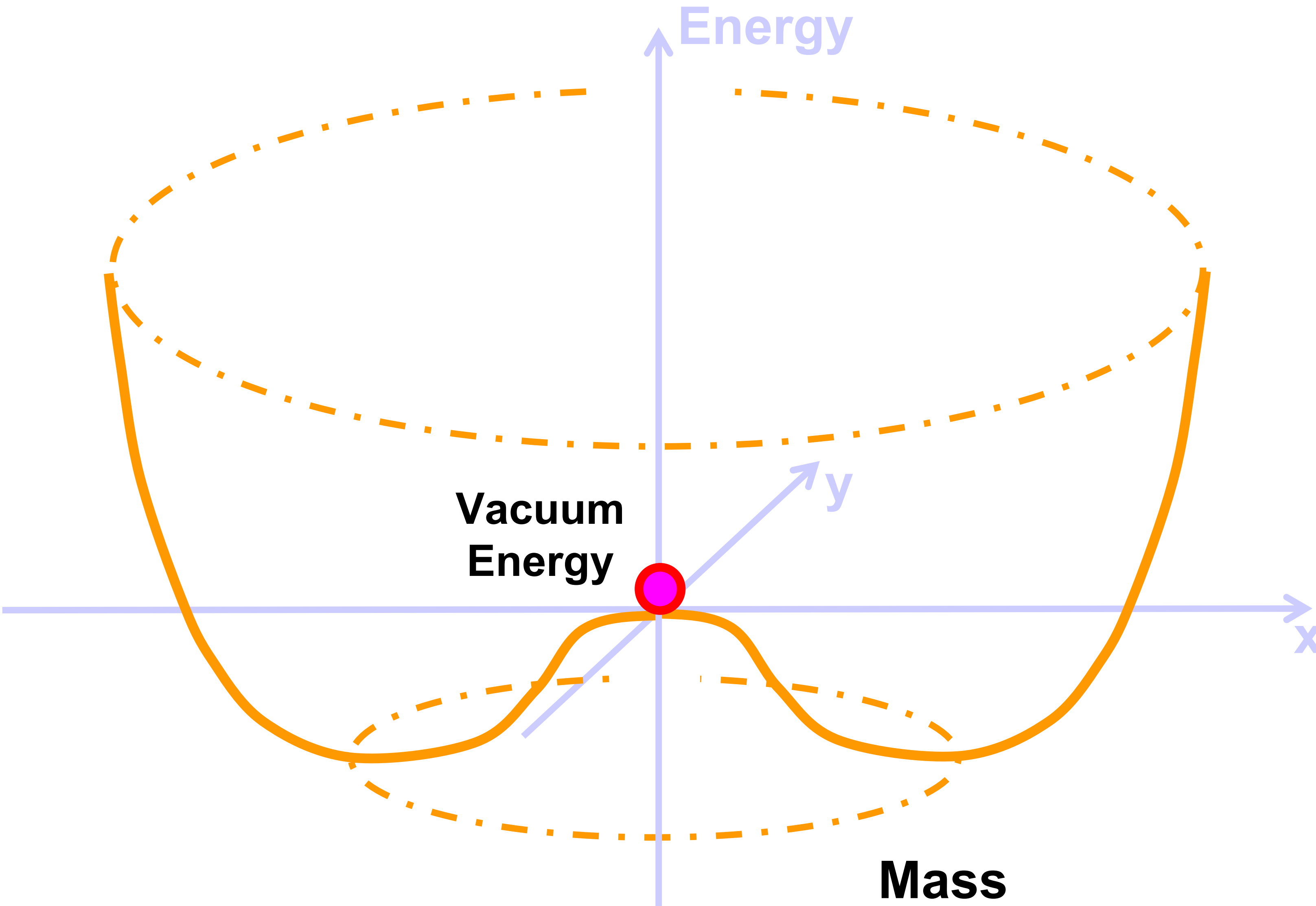
Symmetry Break Down

Complex

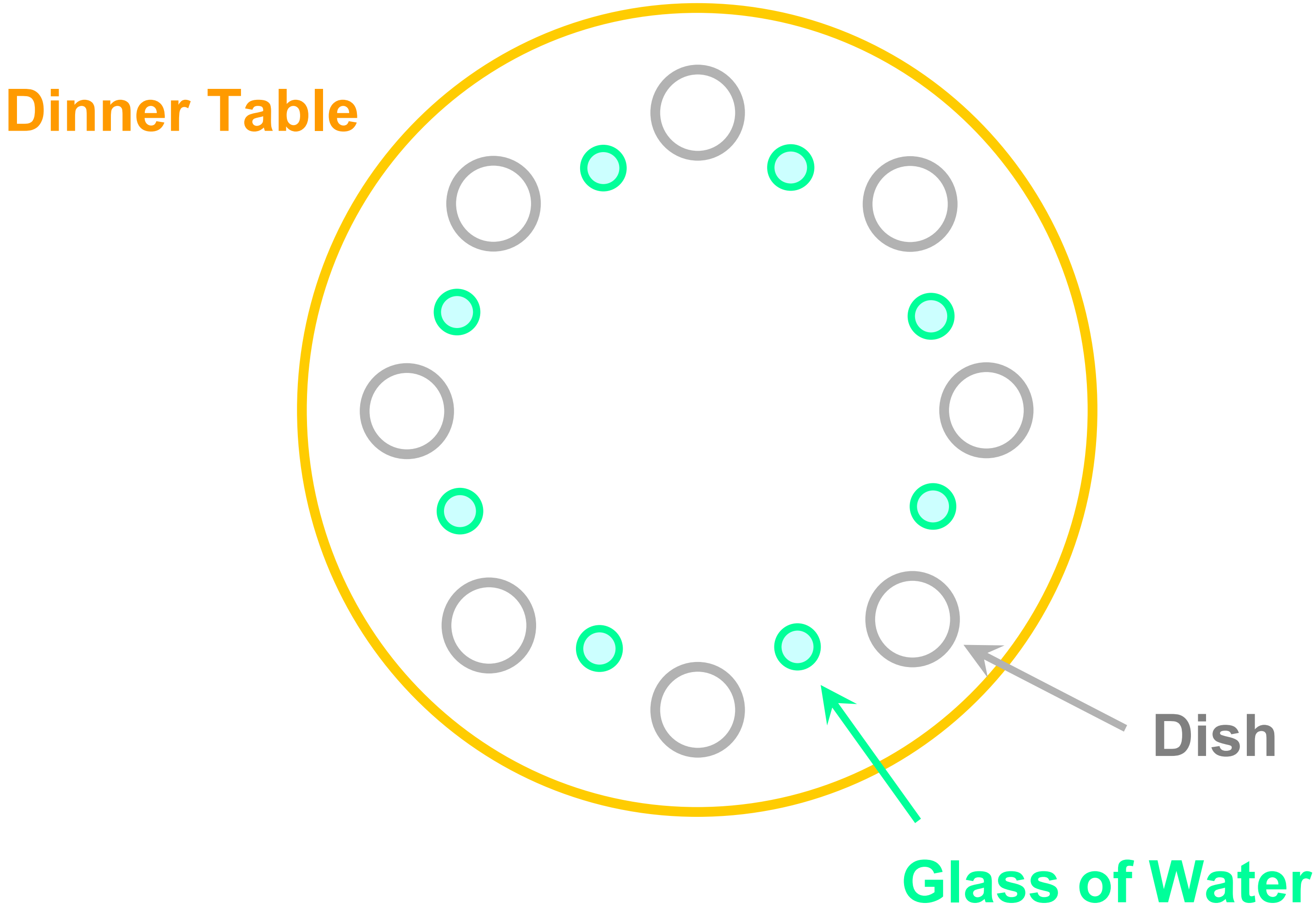
Spontaneous Symmetry Breaking
- Higgs Mechanism -



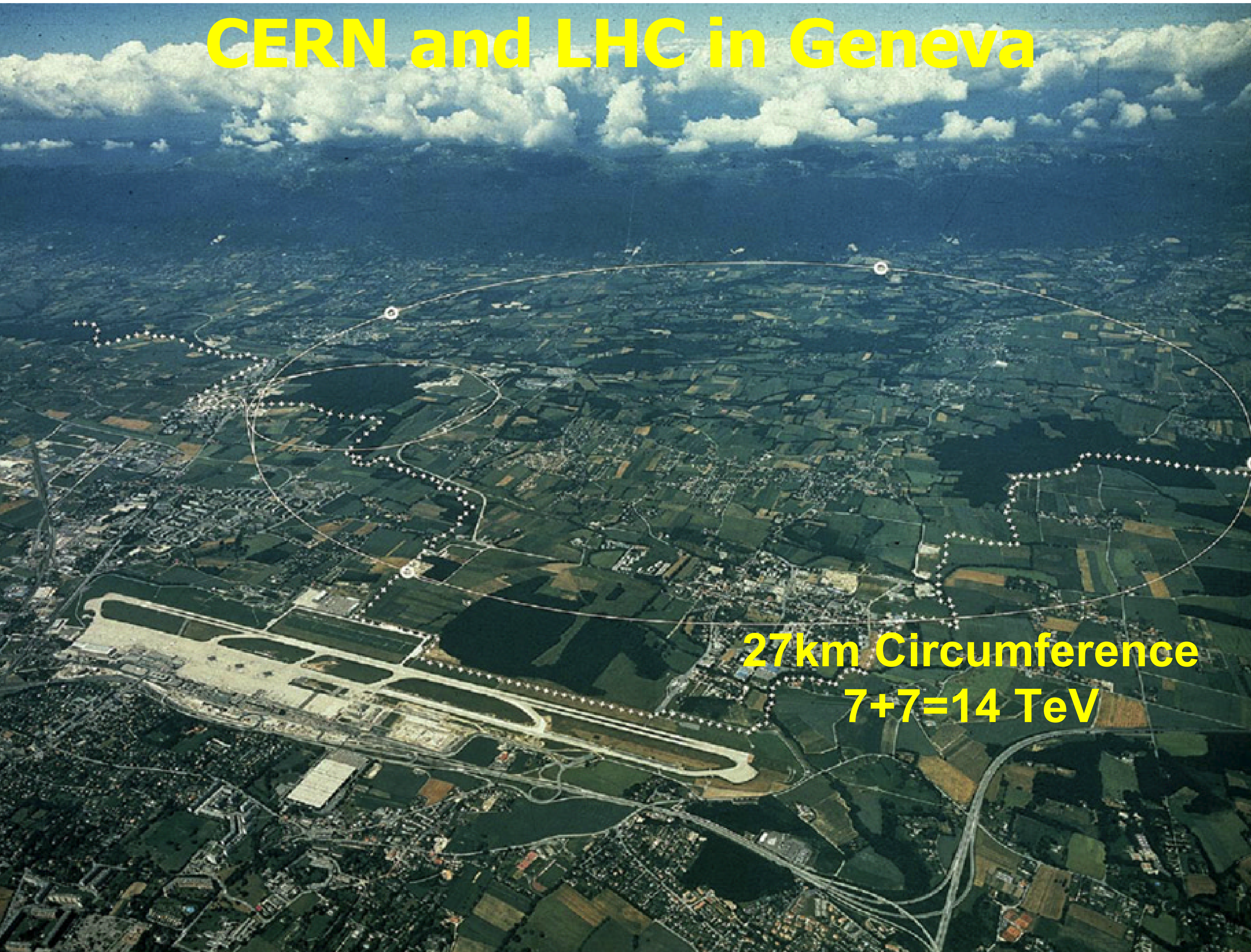
Spontaneous Symmetry Breaking - Higgs Mechanism -

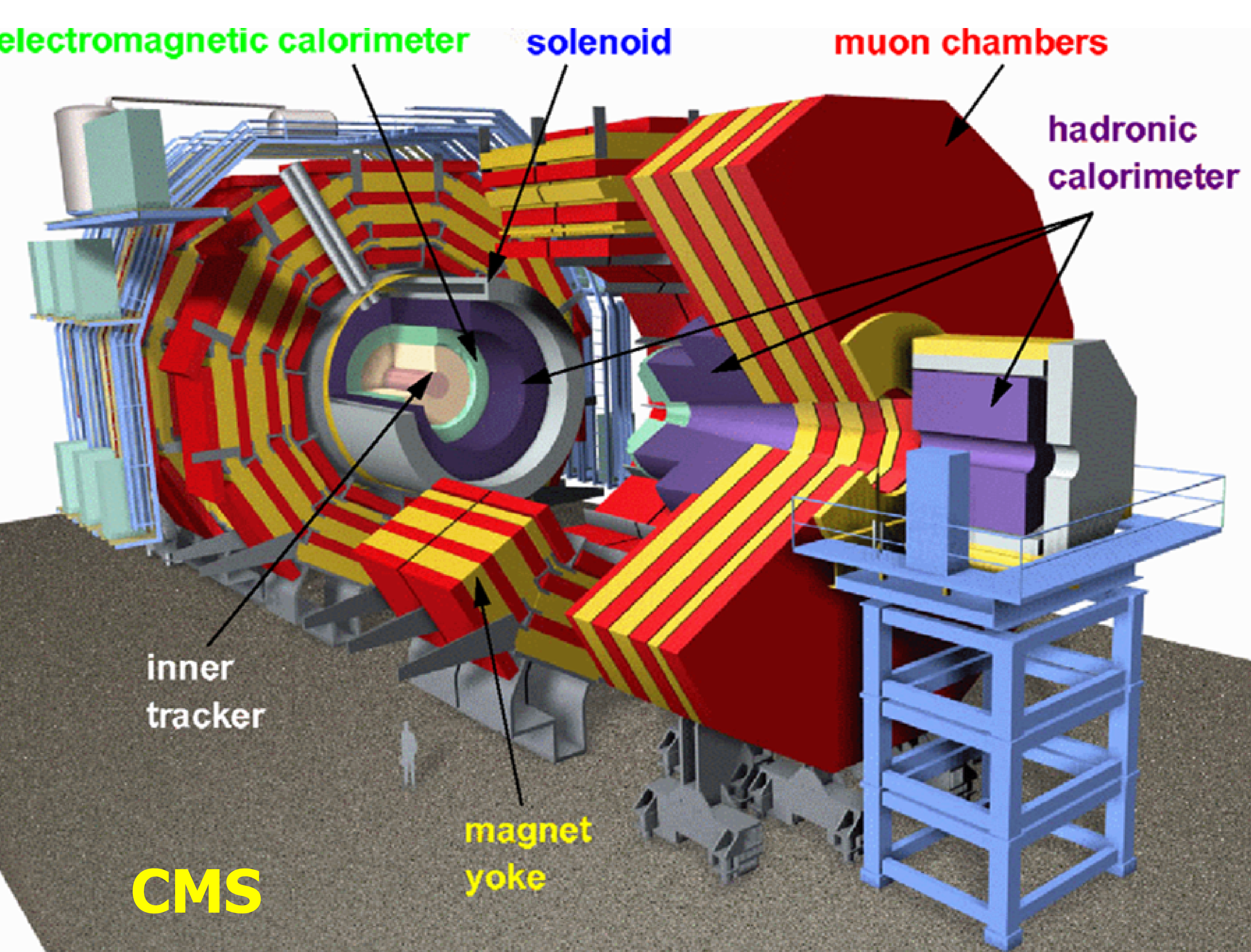


Spontaneous Symmetry Breakdown at a Dinner Table



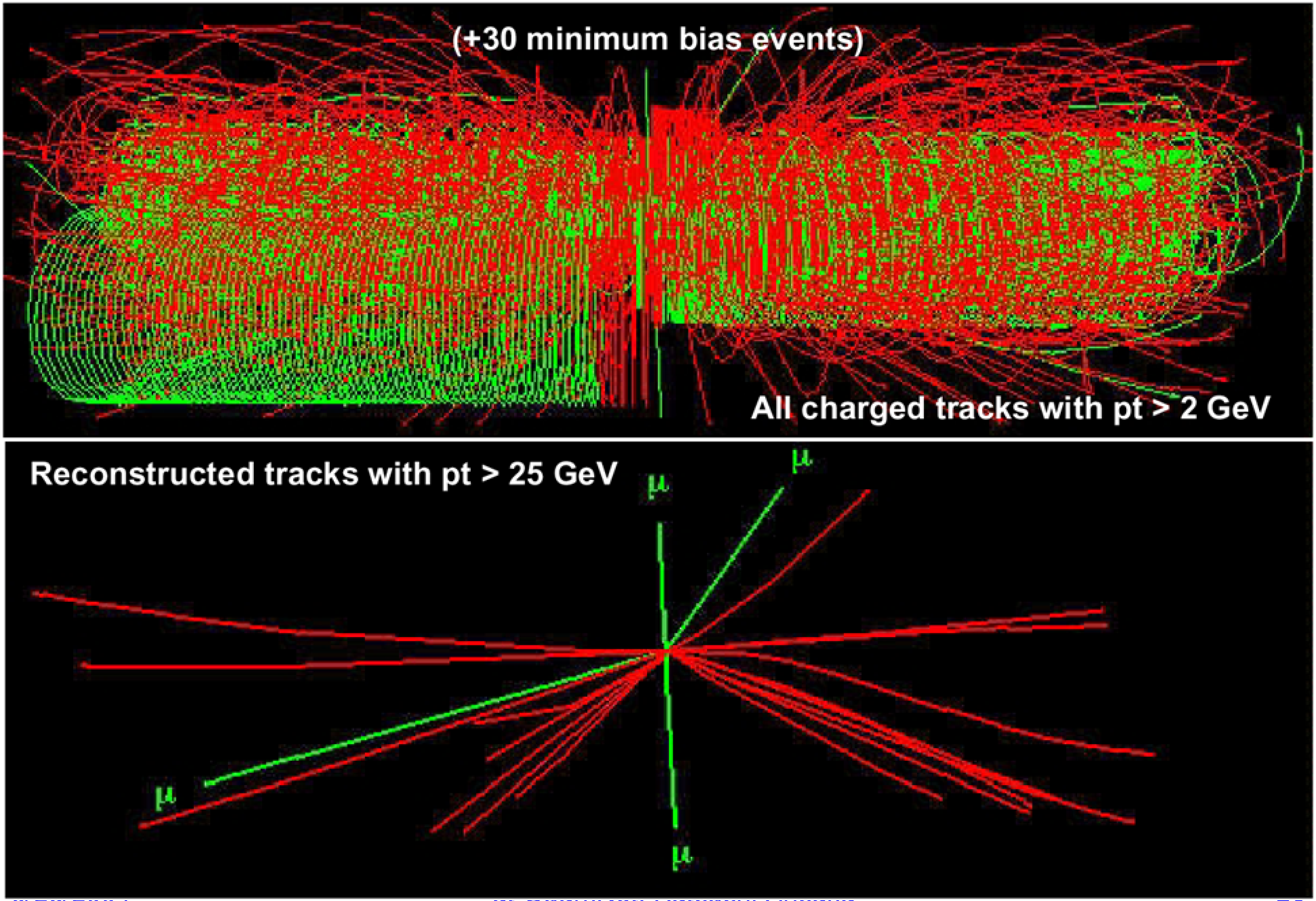
by Nambu Yoichiro


CERN and LHC in Geneva
27km Circumference
7+7=14 TeV

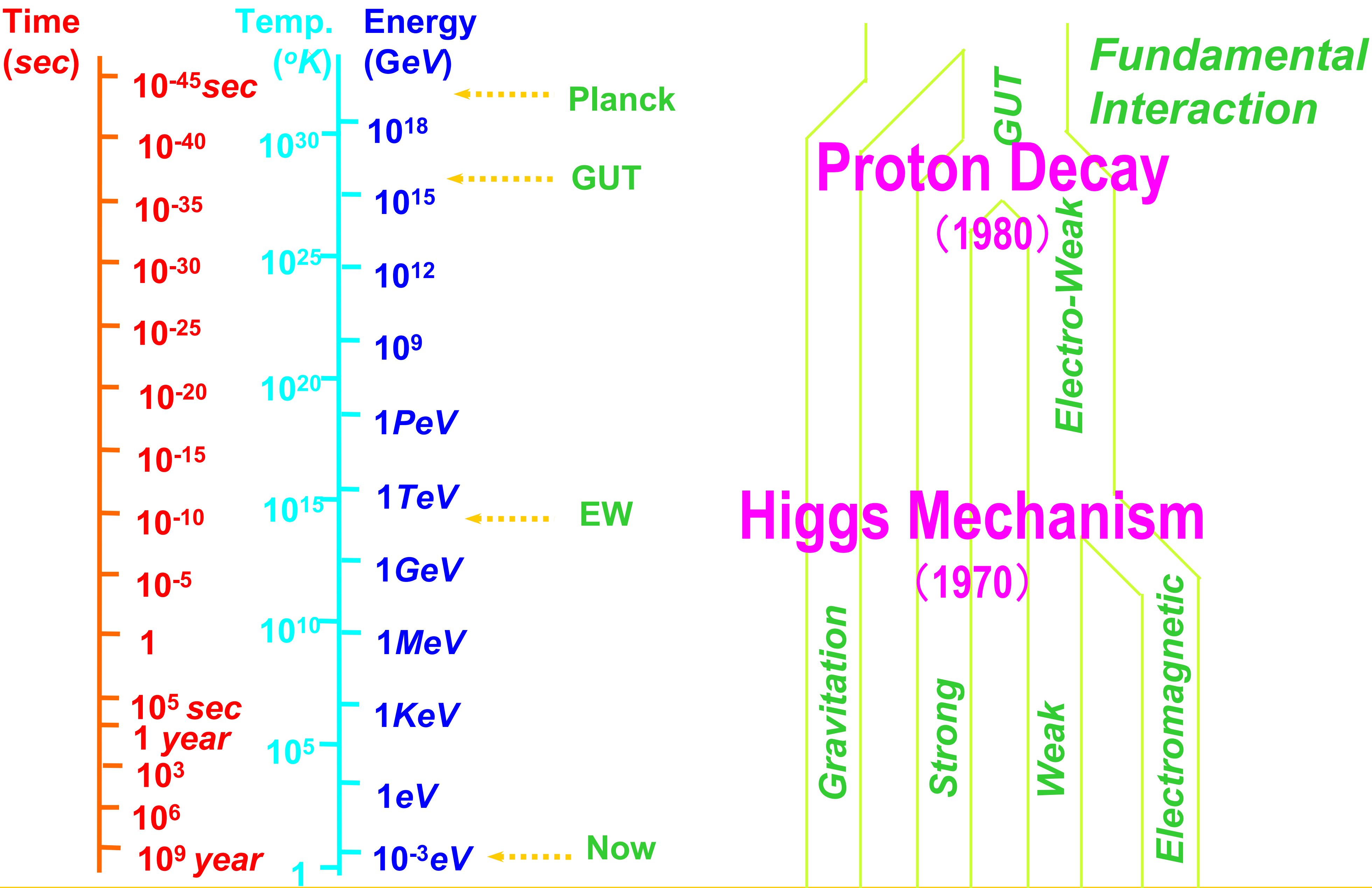

electromagnetic calorimeter
solenoid
muon chambers
hadronic
calorimeter
inner
tracker
magnet
yoke
CMS

CMS Barrel Yoke

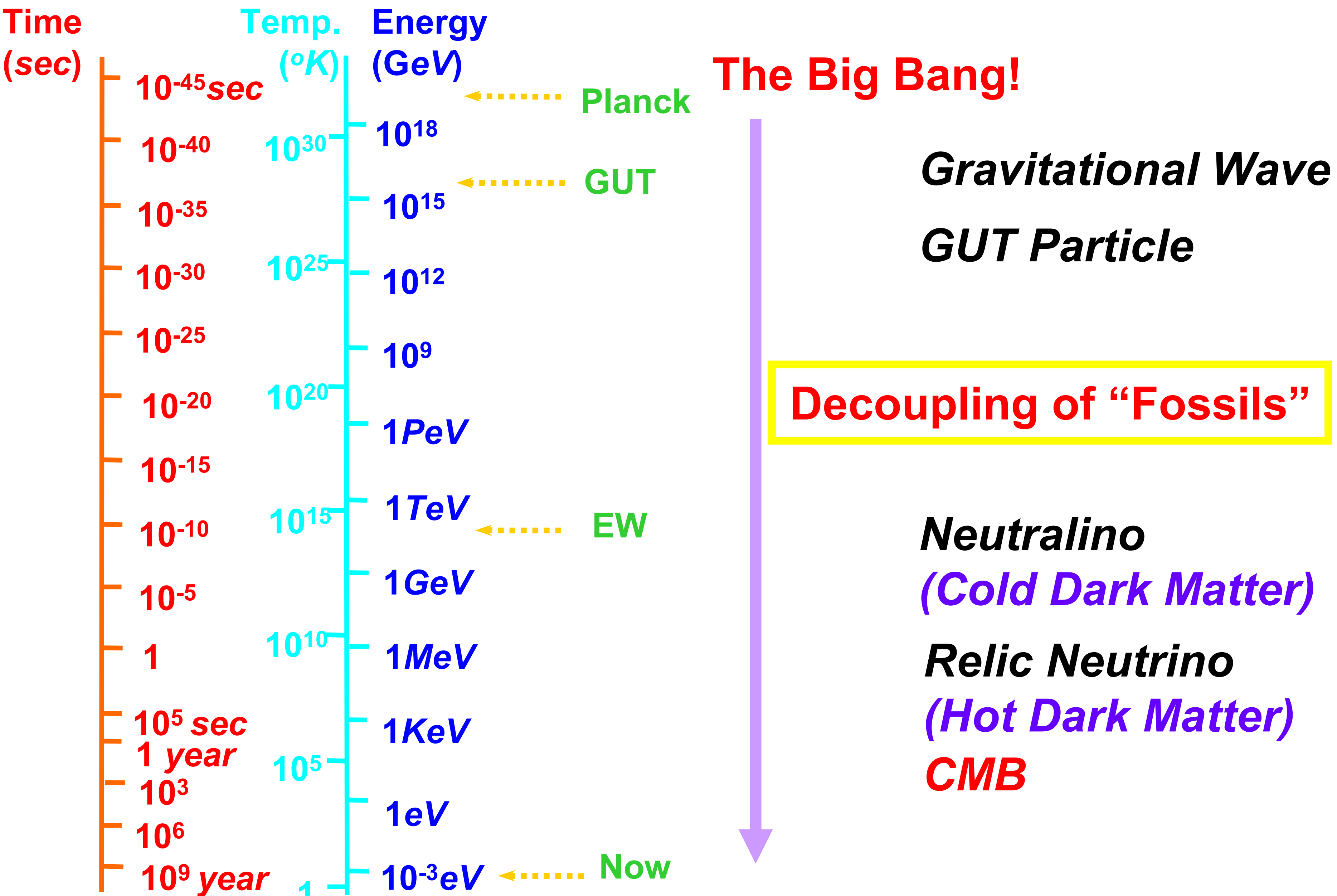
Higgs Decay into 4 muons (2008?)



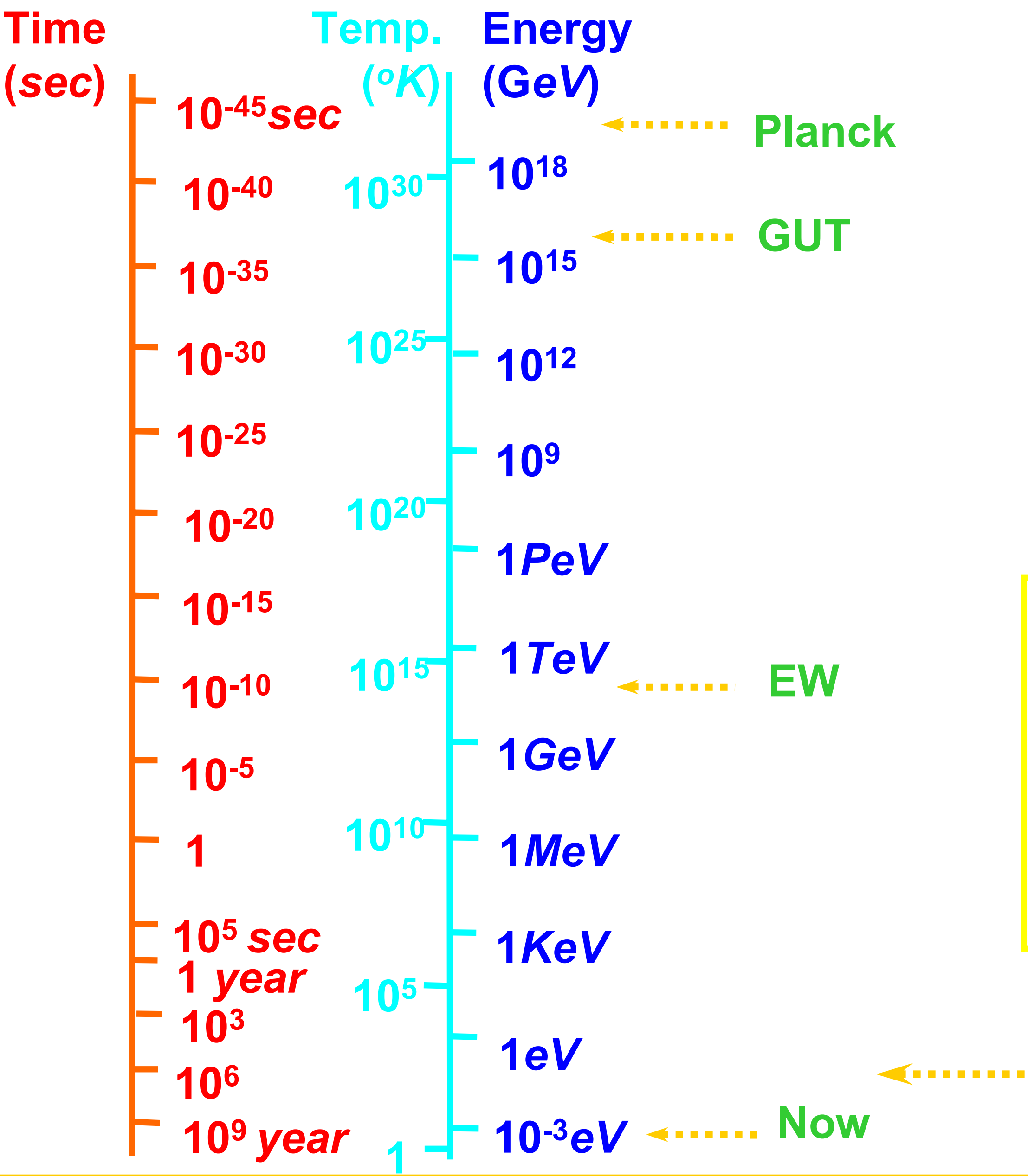
Unification of Fundamental Forces



"Fossils" from the Earliest Universe



Cosmic Microwave Background (CMB)
Matter-Radiation Decoupling



Time = 300,000 *years*

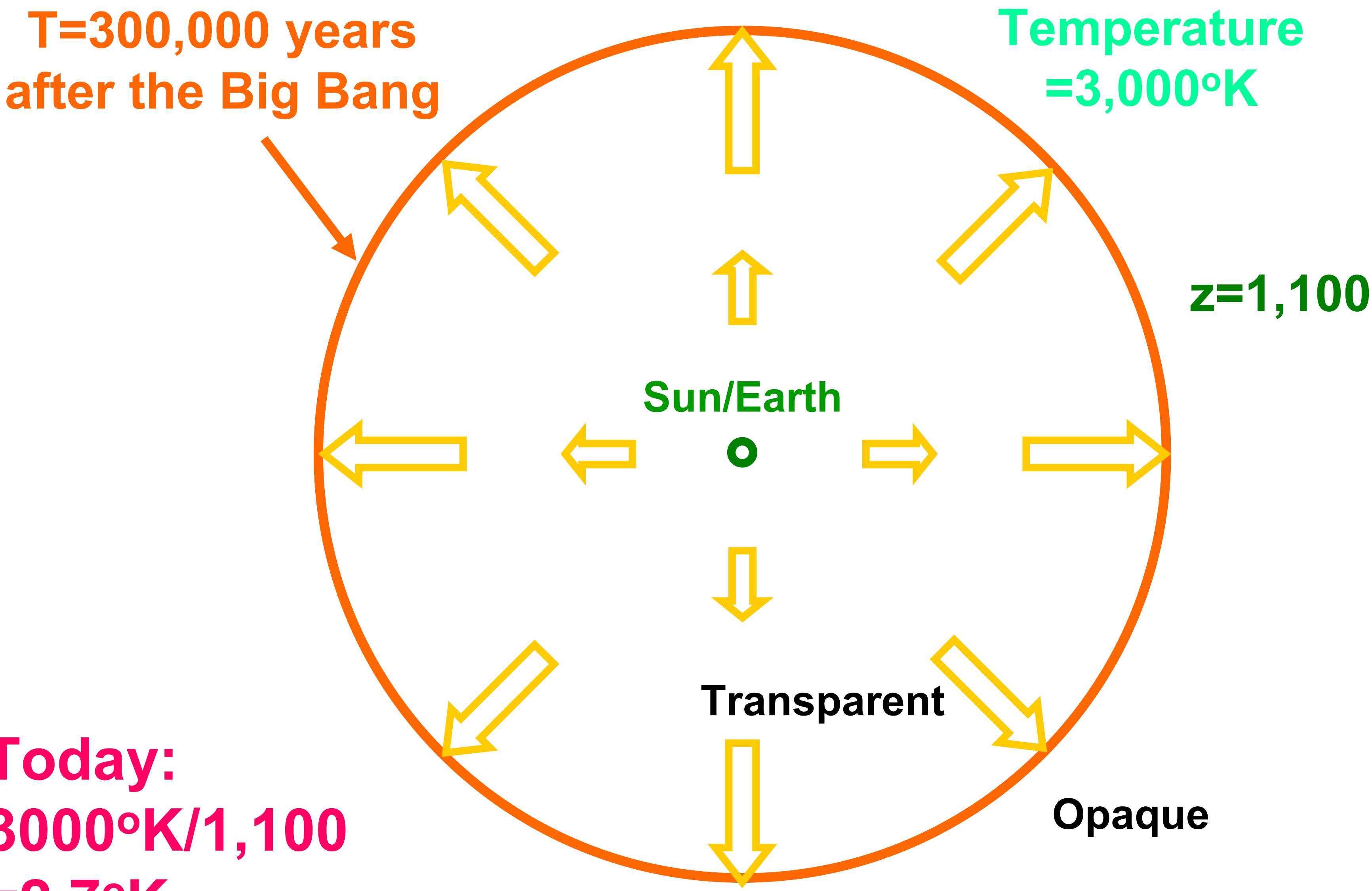
Temperature = 3,000 °*K*

Energy = 0.3 *eV*

Z = 1,100

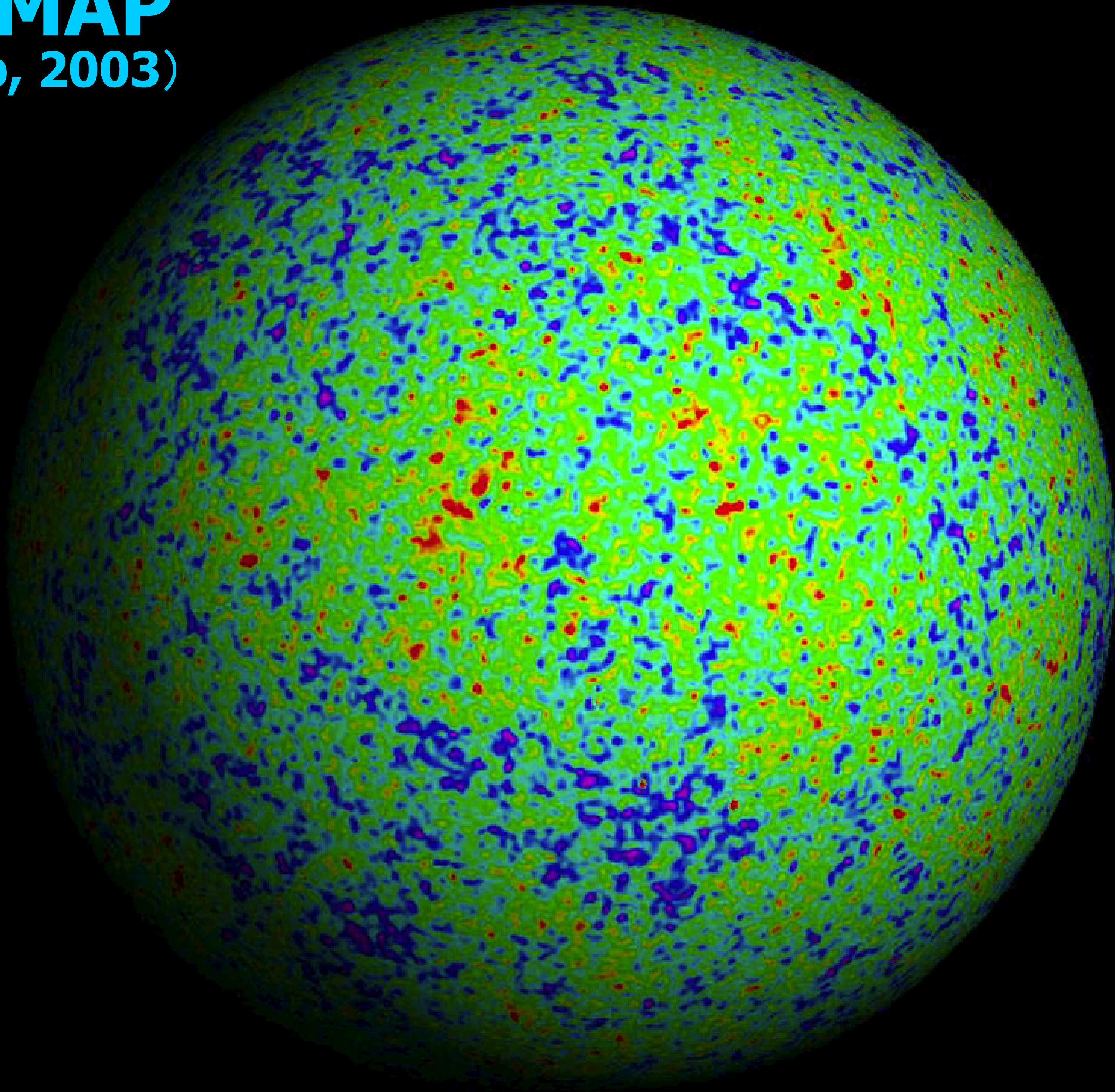
Matter-Radiation Decoupling ⇒ ***CMB***

Cosmic Microwave Background
(Discovered in 1964)



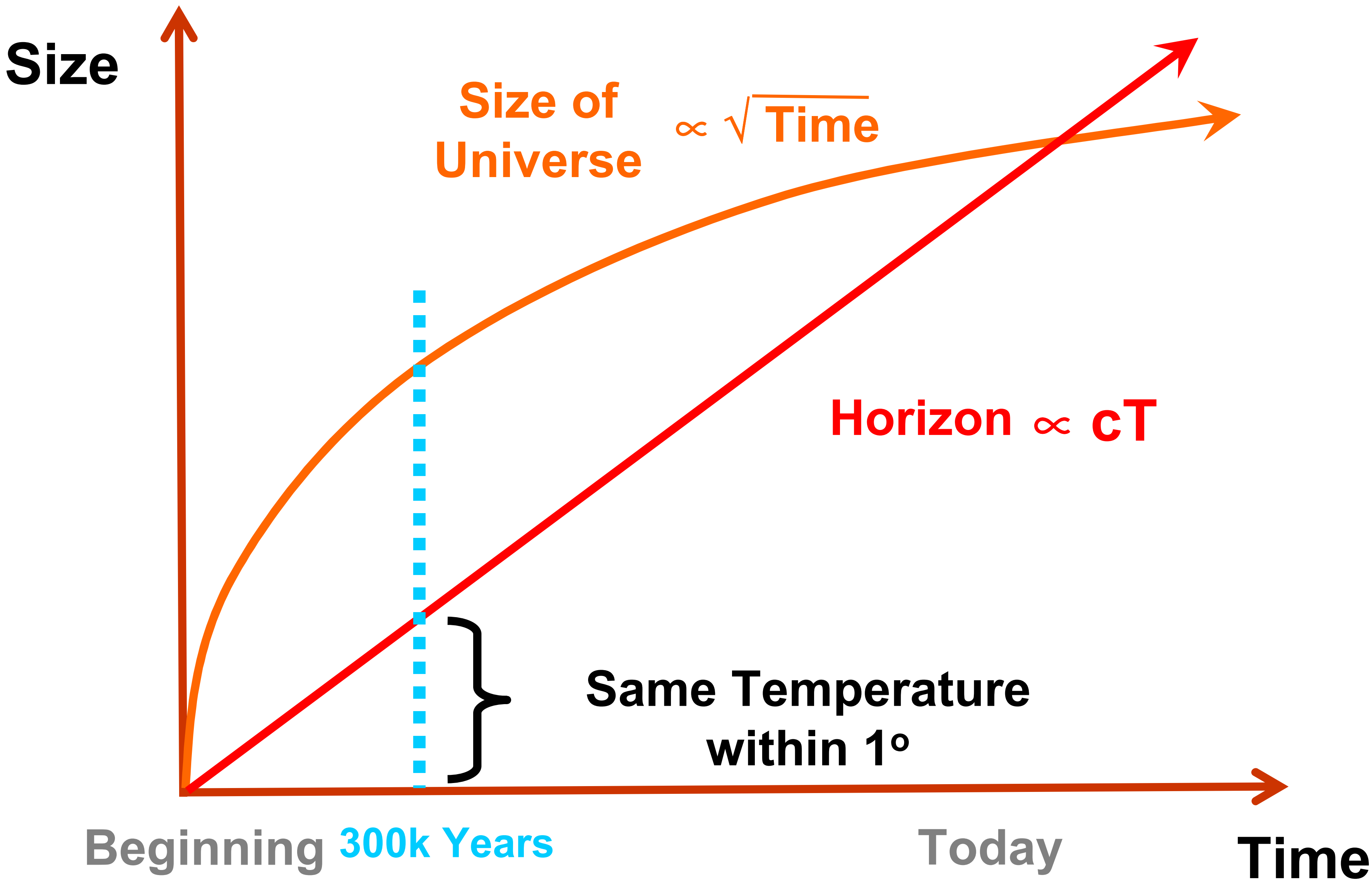
Today:
3000°K/1,100
=2.7°K

WMAP
(Feb, 2003)

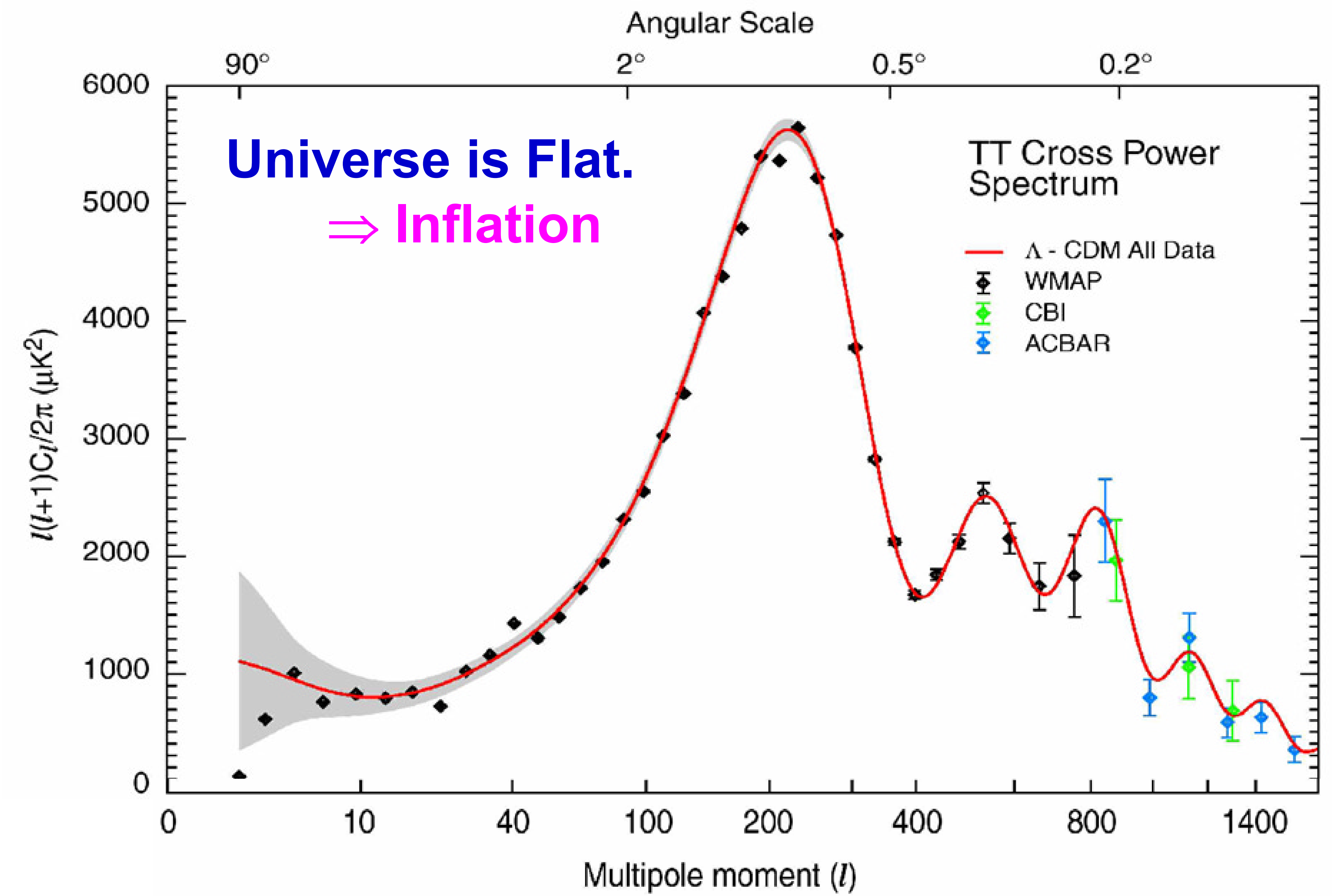


Foreground-cleaned WMAP map from Tegmark, de Oliveira-Costa & Hamilton, astro-ph/0302496

Expansion of Universe

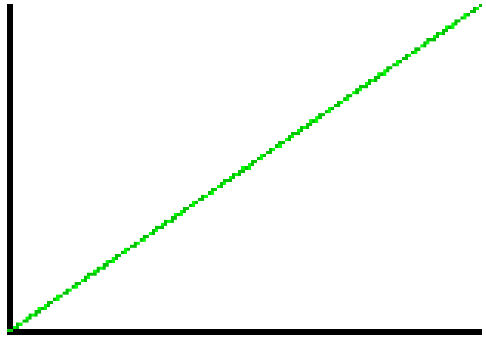


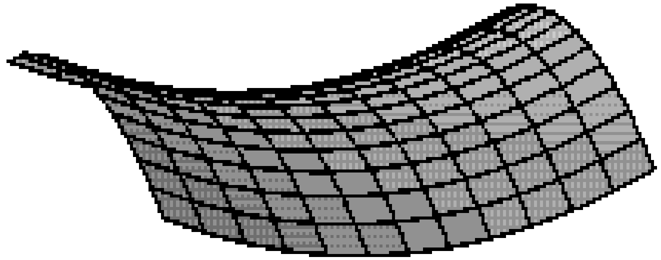
WMAP Power Spectrum



Geometry of the Universe

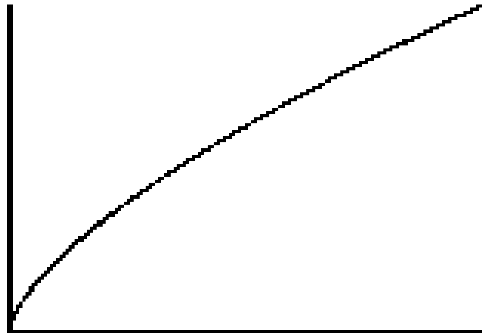
Open $\Omega<1$

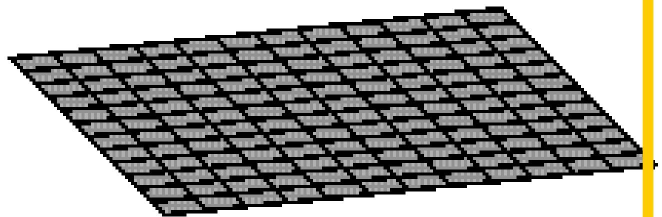




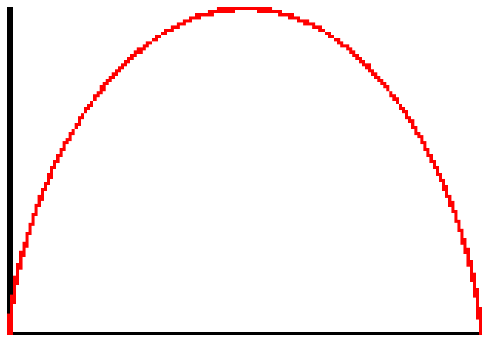
Flat $\Omega=1$

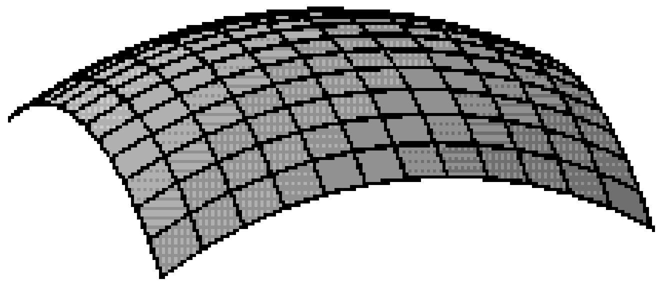
(predicted by Inflation)





Closed $\Omega>1$





Two Fundamental Problem of Big Bang Cosmology

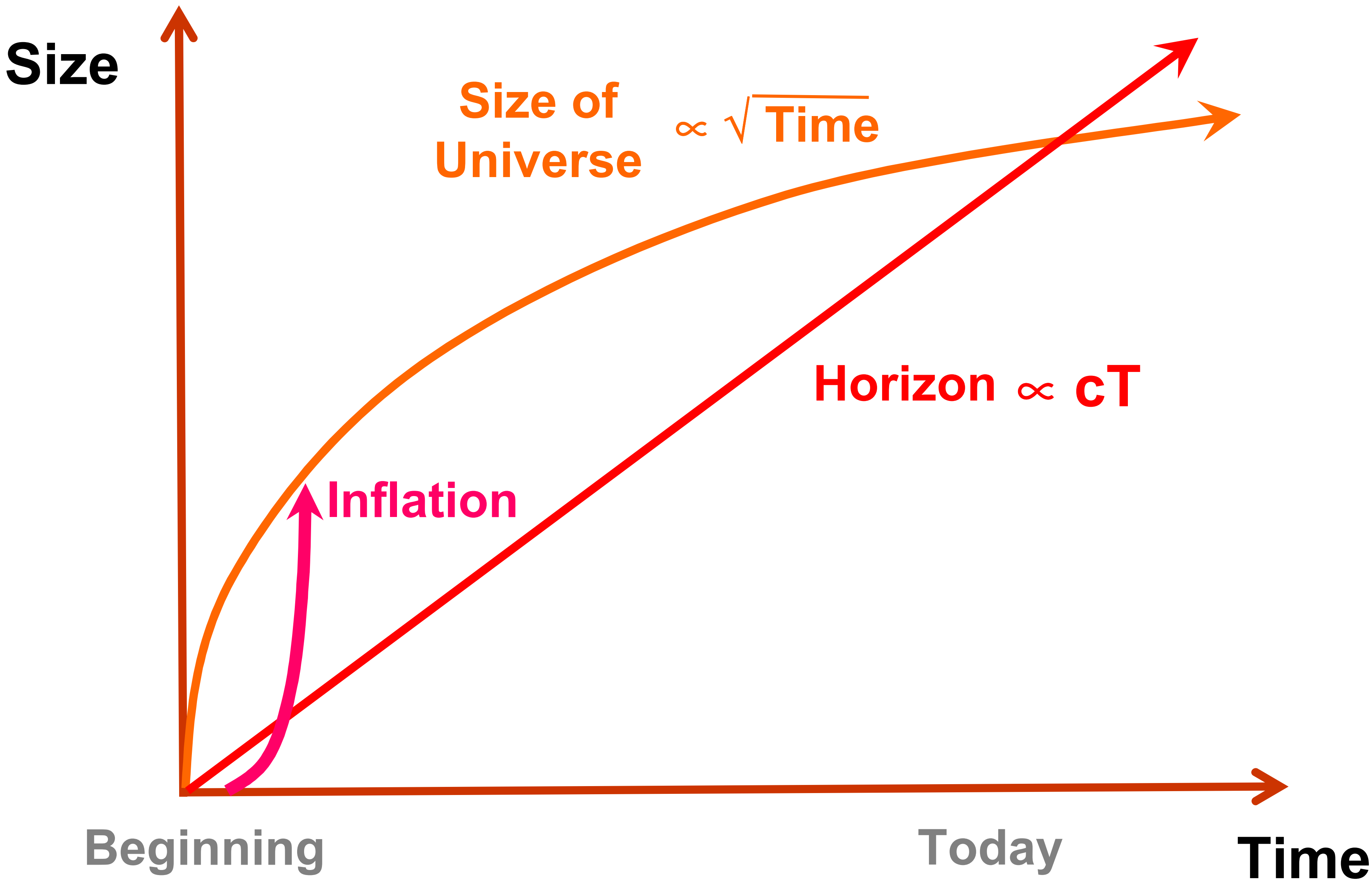
➢ Horizon Problem

- At early Universe, Size >> Horizon.
- Why is CMB so uniform in every direction?

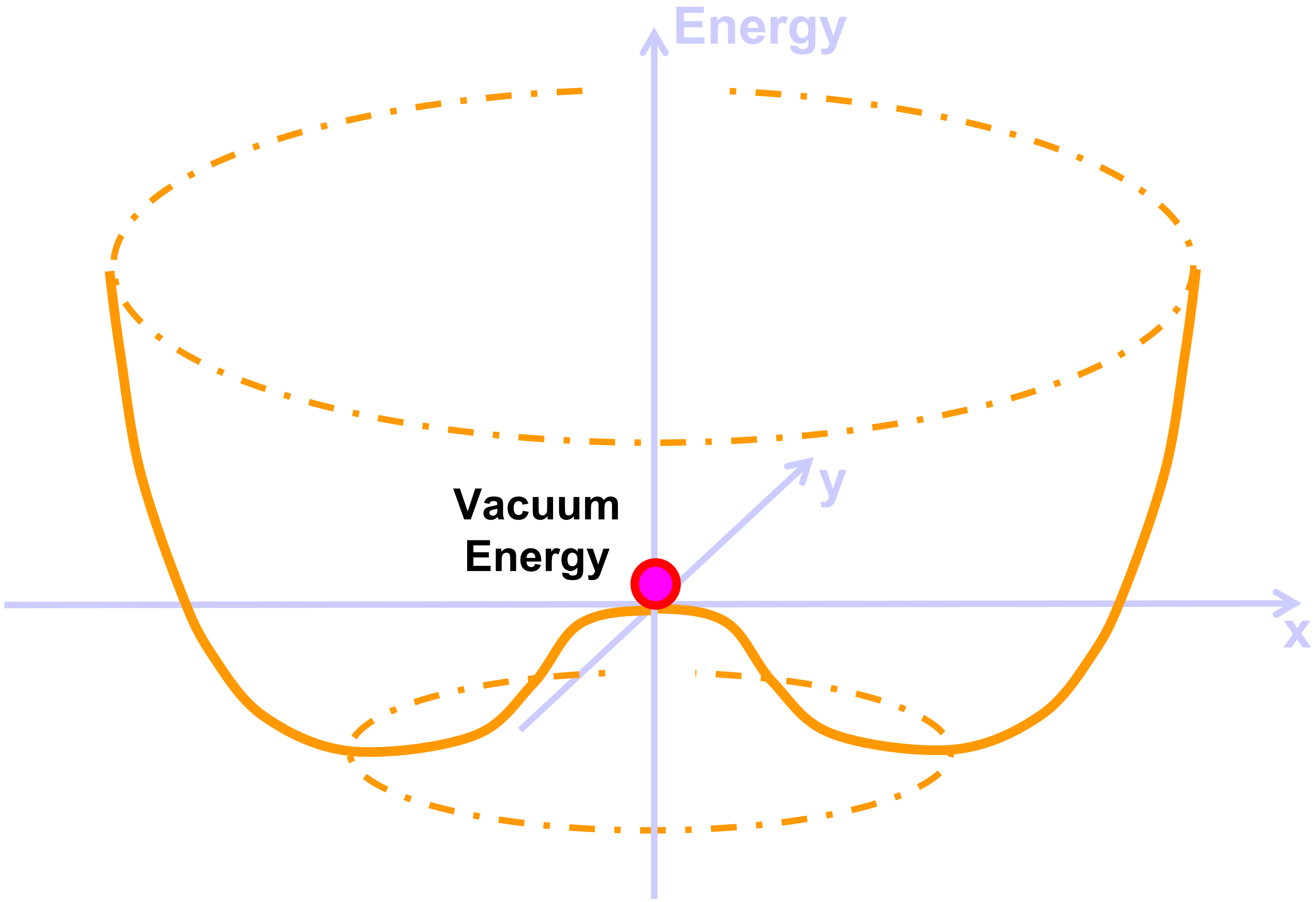
➢ Flatness Problem

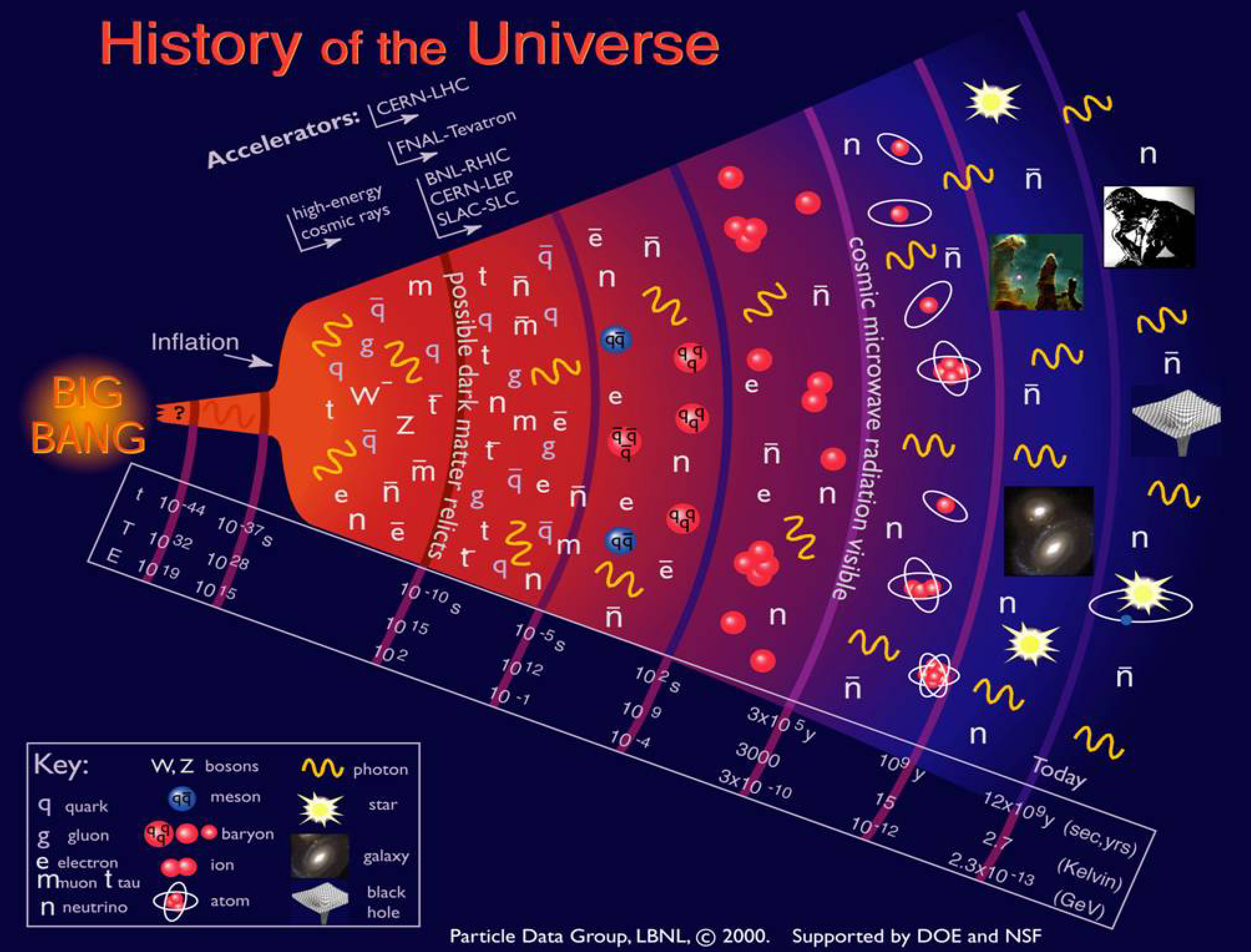
- $|\Omega\text{-}1|$ grows promotional to the size of the Universe.
- Why is Ω of today close to 1?

Inflation in Early Universe

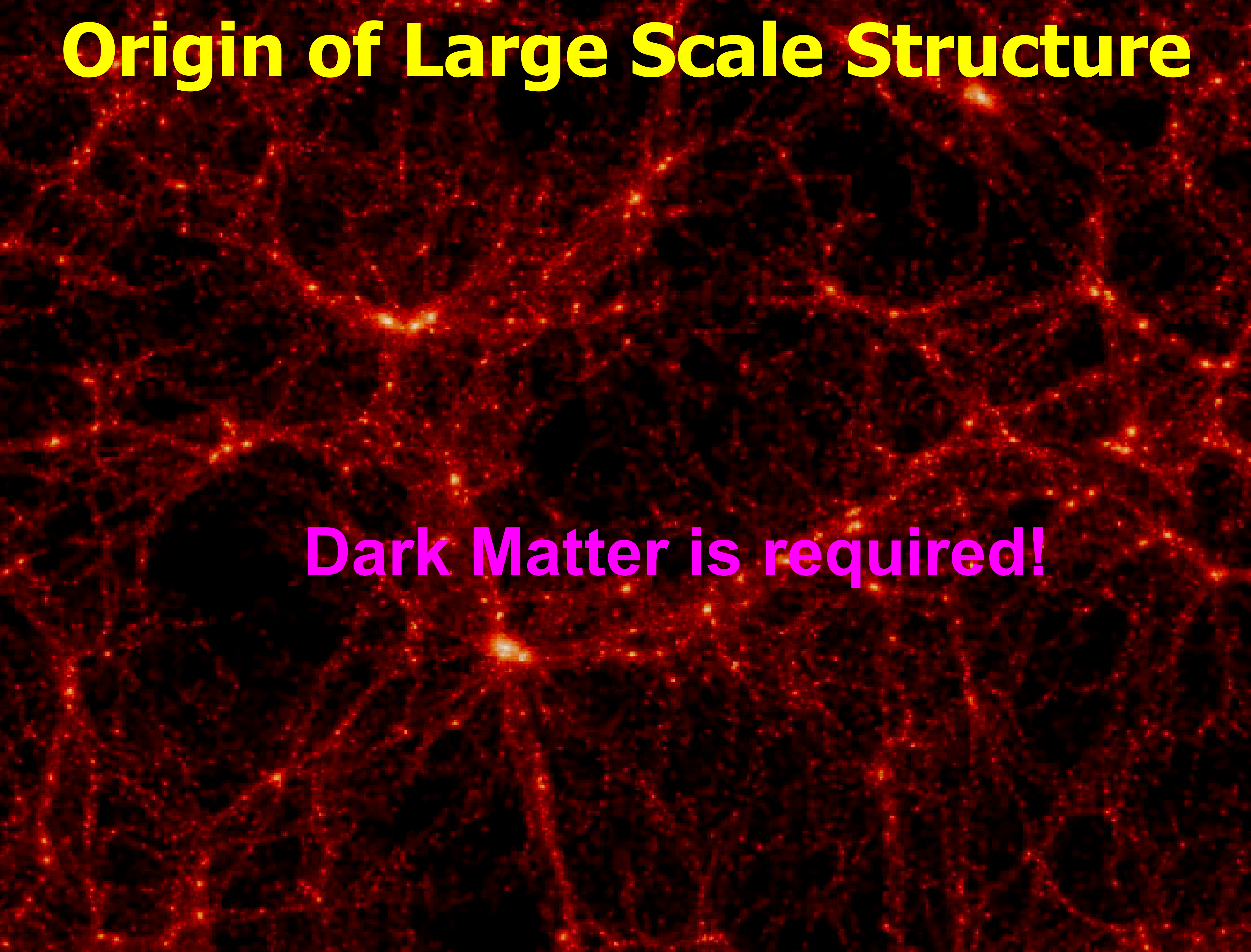


Origin of Inflation

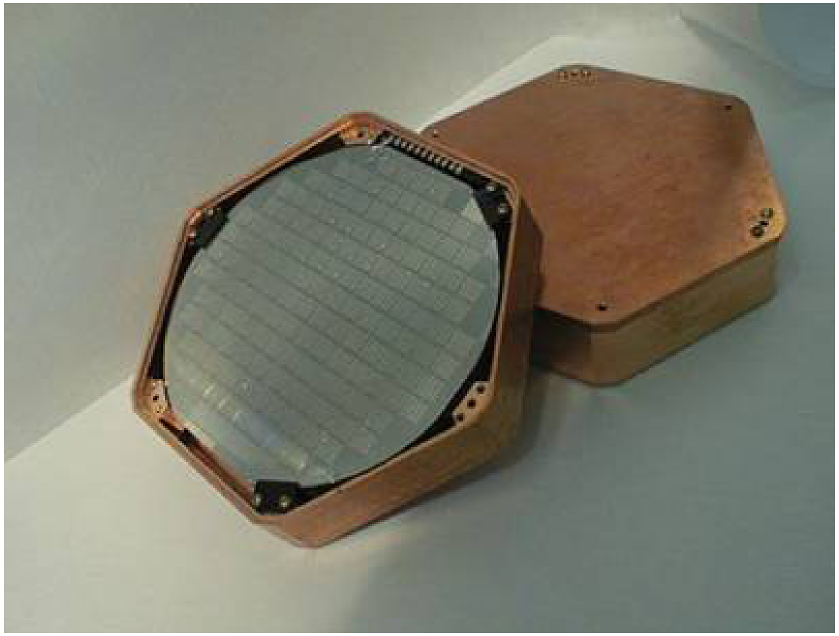


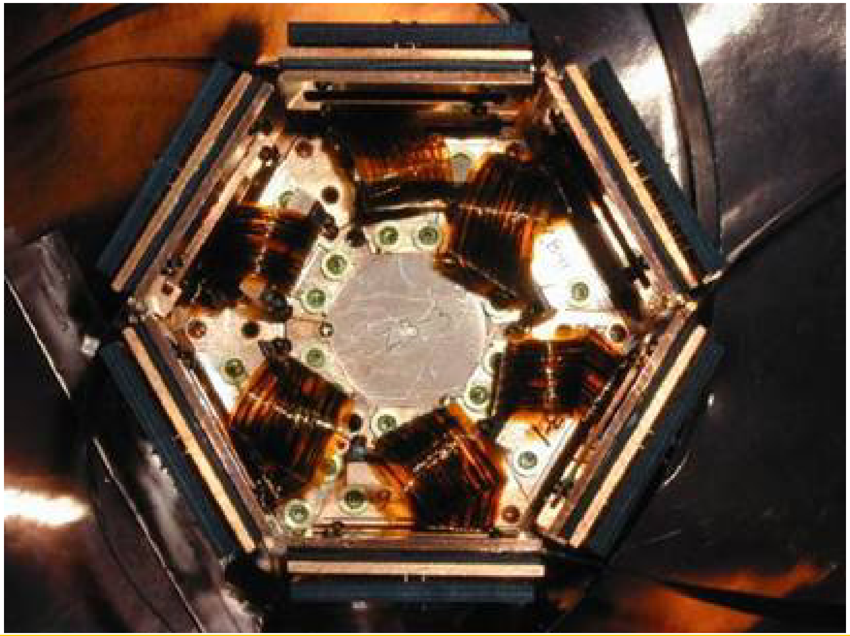


History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
?
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37s 10-10 s 10-5 s 102 s 3x105 y 109 y 12x109 y (sec,yrs)
T 1032 1028 1015 1012 109 3000 15 2.7 (Kelvin)
E 1019 1015 102 10-1 10-4 3x10-10 10-12 2.3x10-13 (GeV)
Today
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

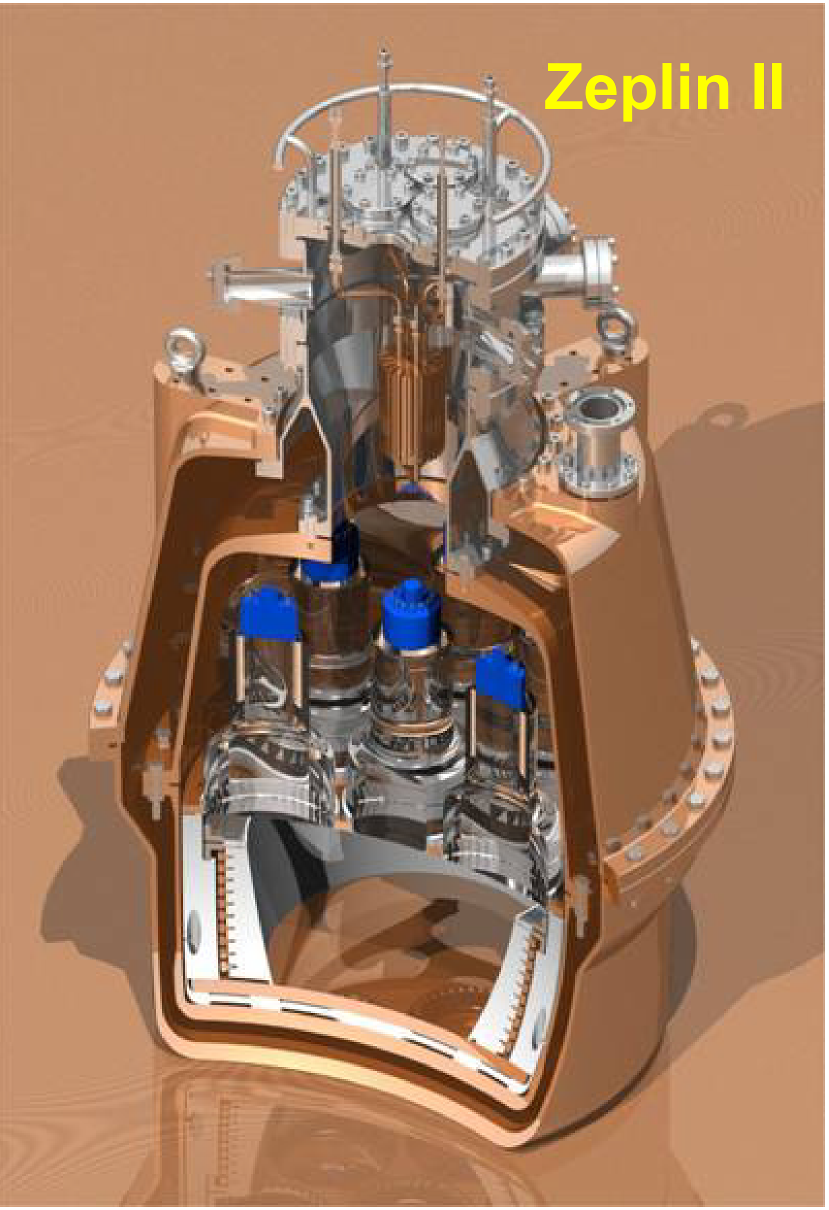

Origin of Large Scale Structure
Dark Matter is required!

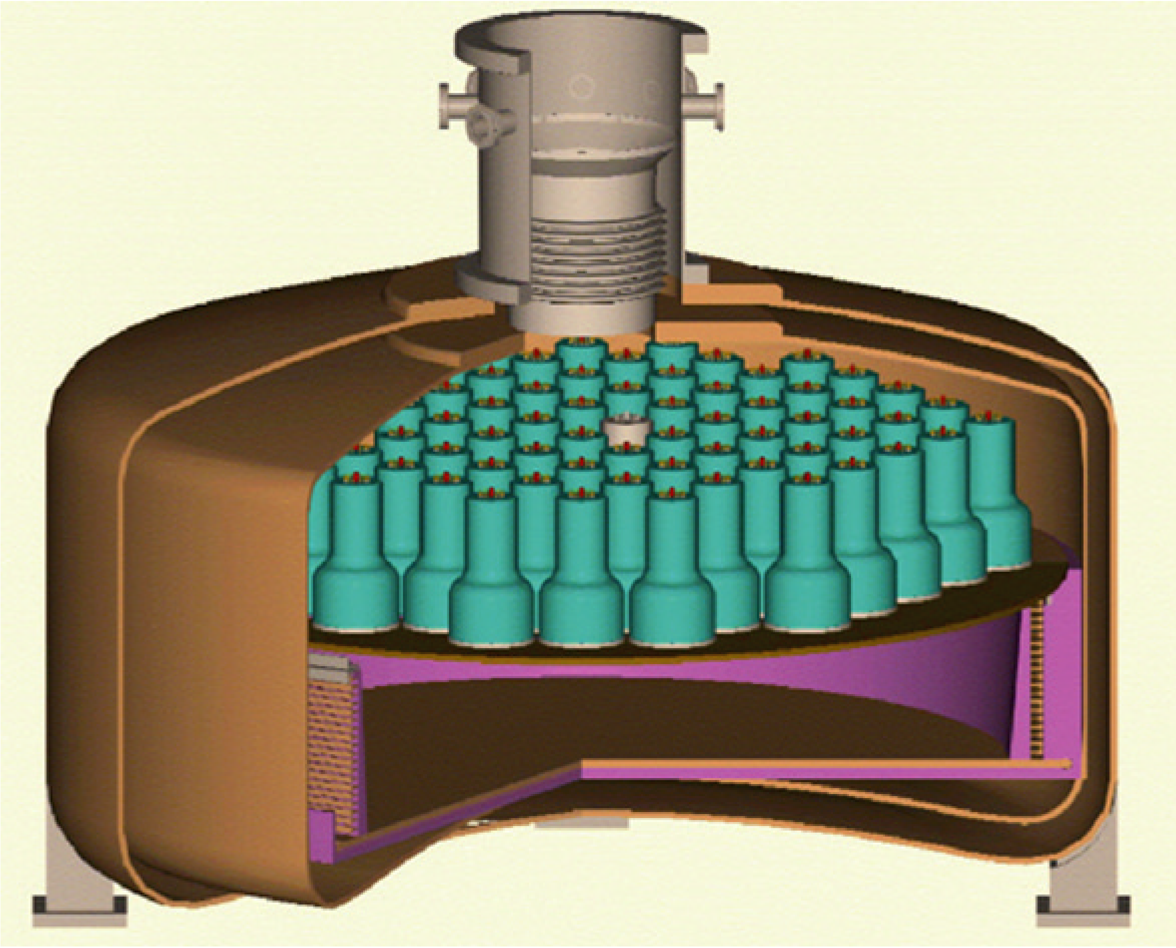
CDMS Dark Matter Detector





Zeplin Dark Matter Detector

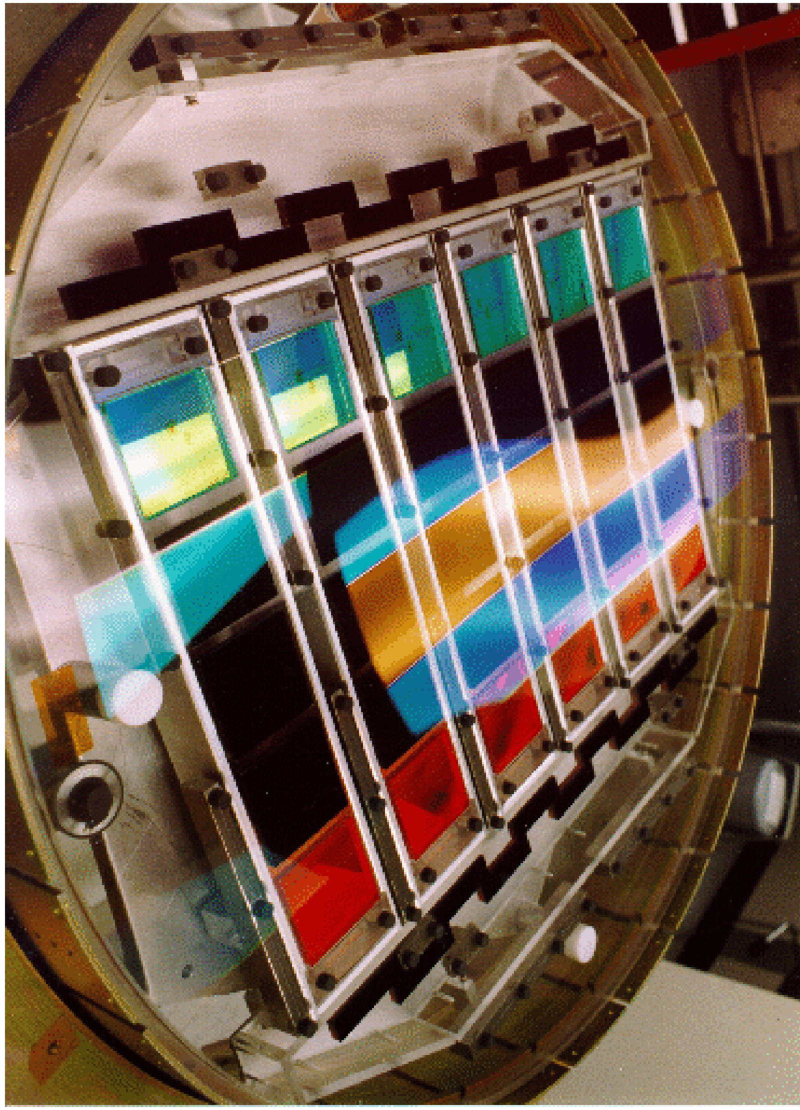




Liquid Xenon Scintillator

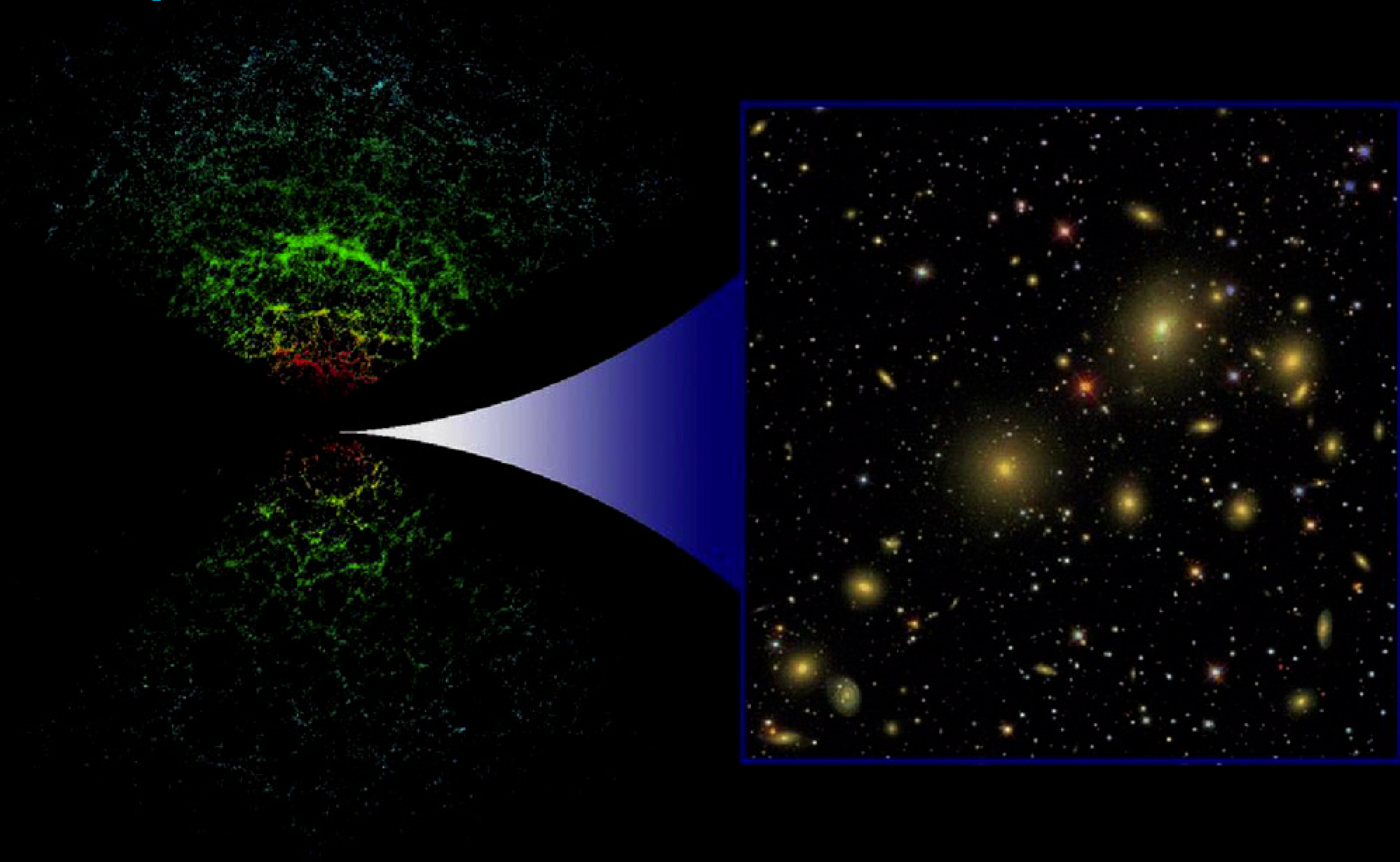
SDSS (Sloan Digital Sky Survey)

- 2.5m Diameter
- 3° x 3° FOV
- f/2.25
- 30 x 4Mega-pixel CCD

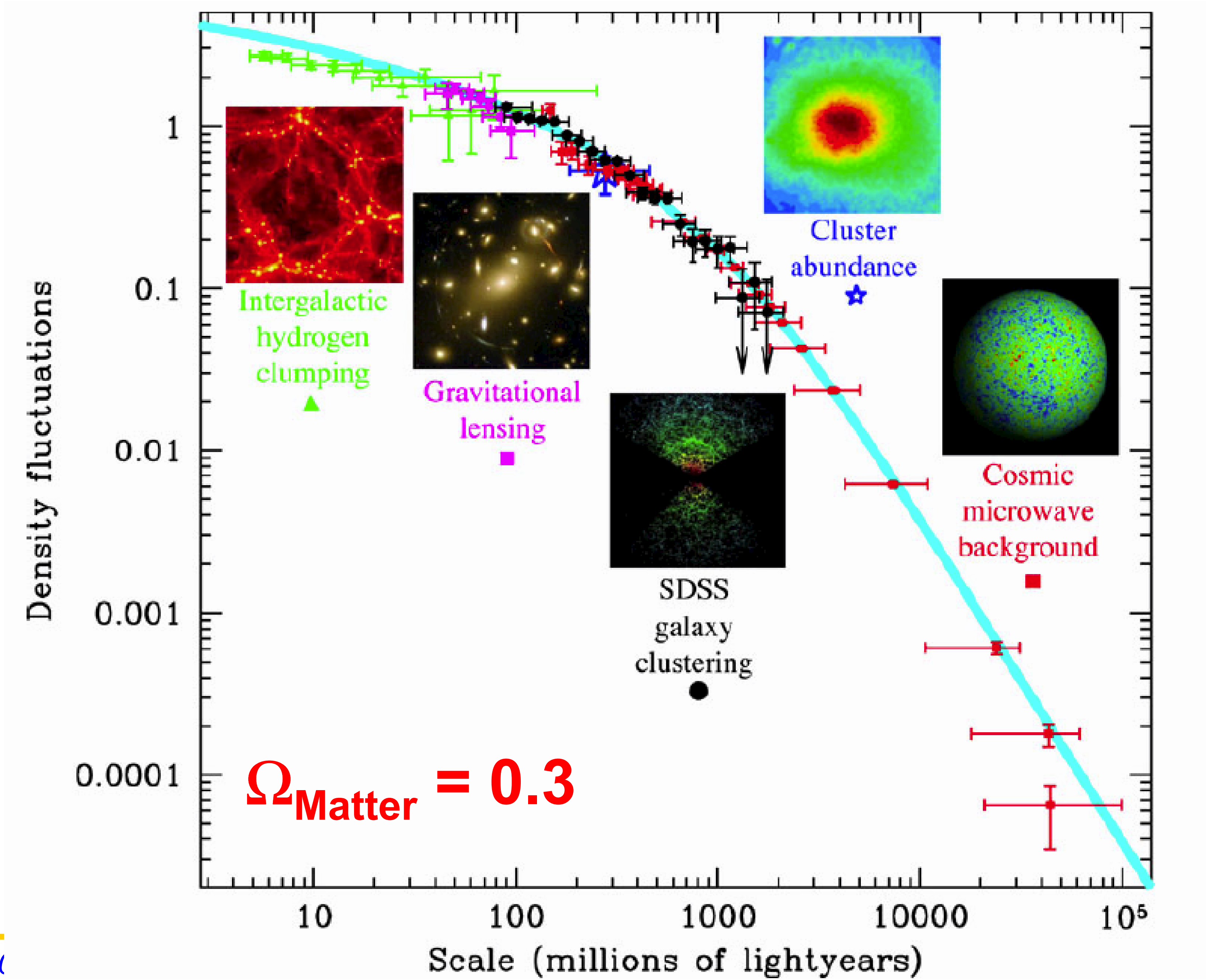


Focal Plane

SDSS
(Nov, 2003)

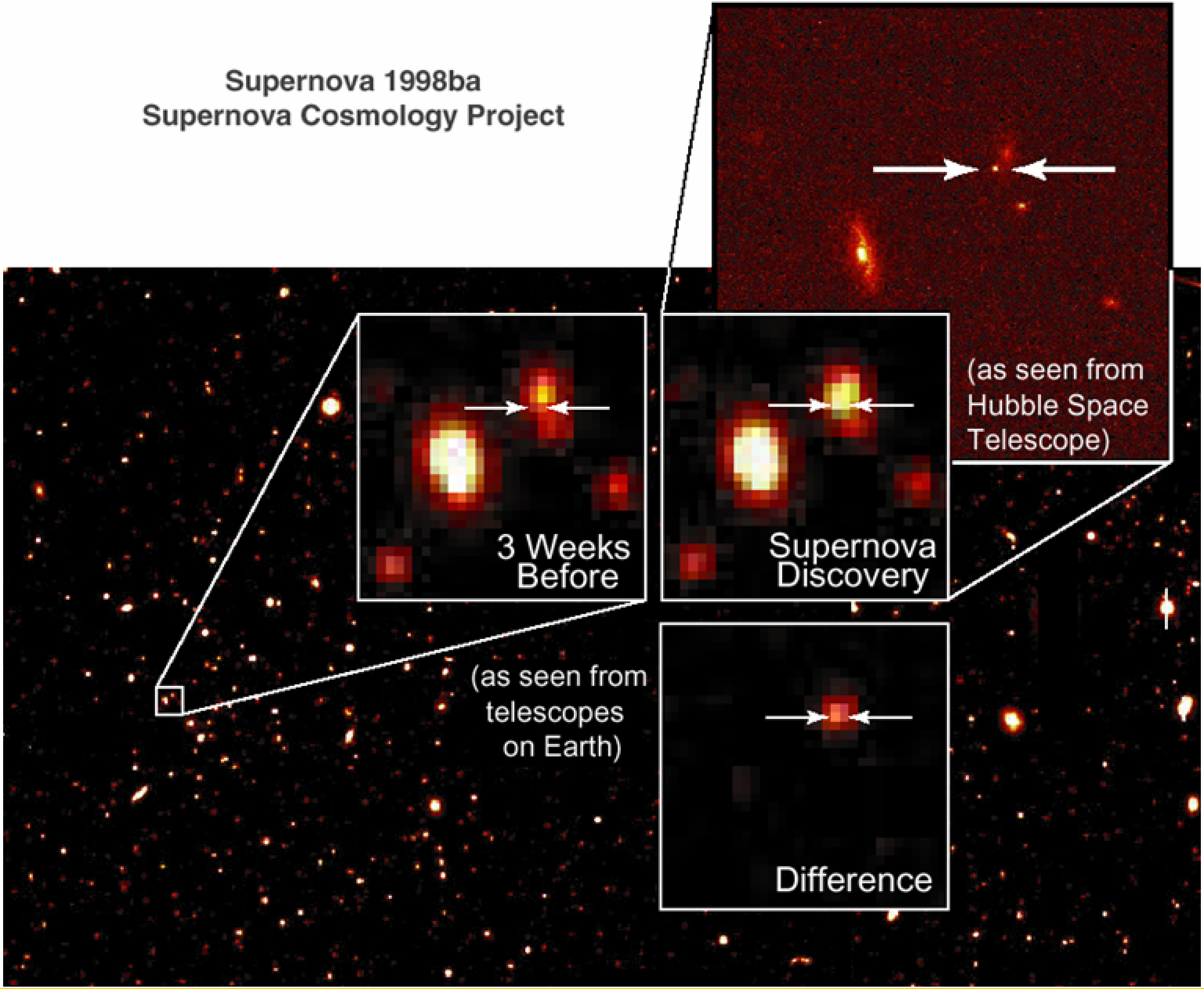


Density Fluctuations

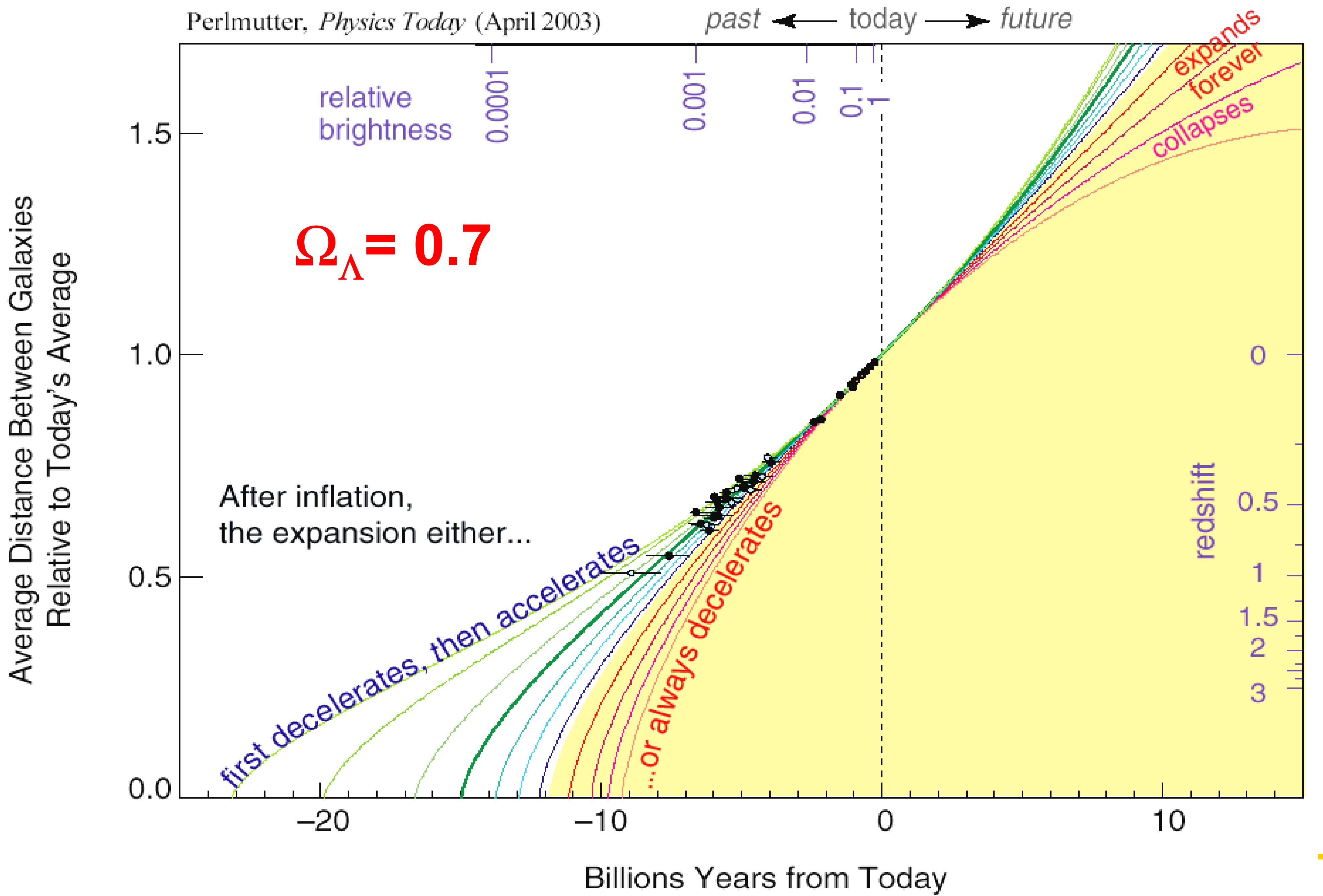


$\Omega_{Matter} = 0.3$

Supernova as a Standard Candle

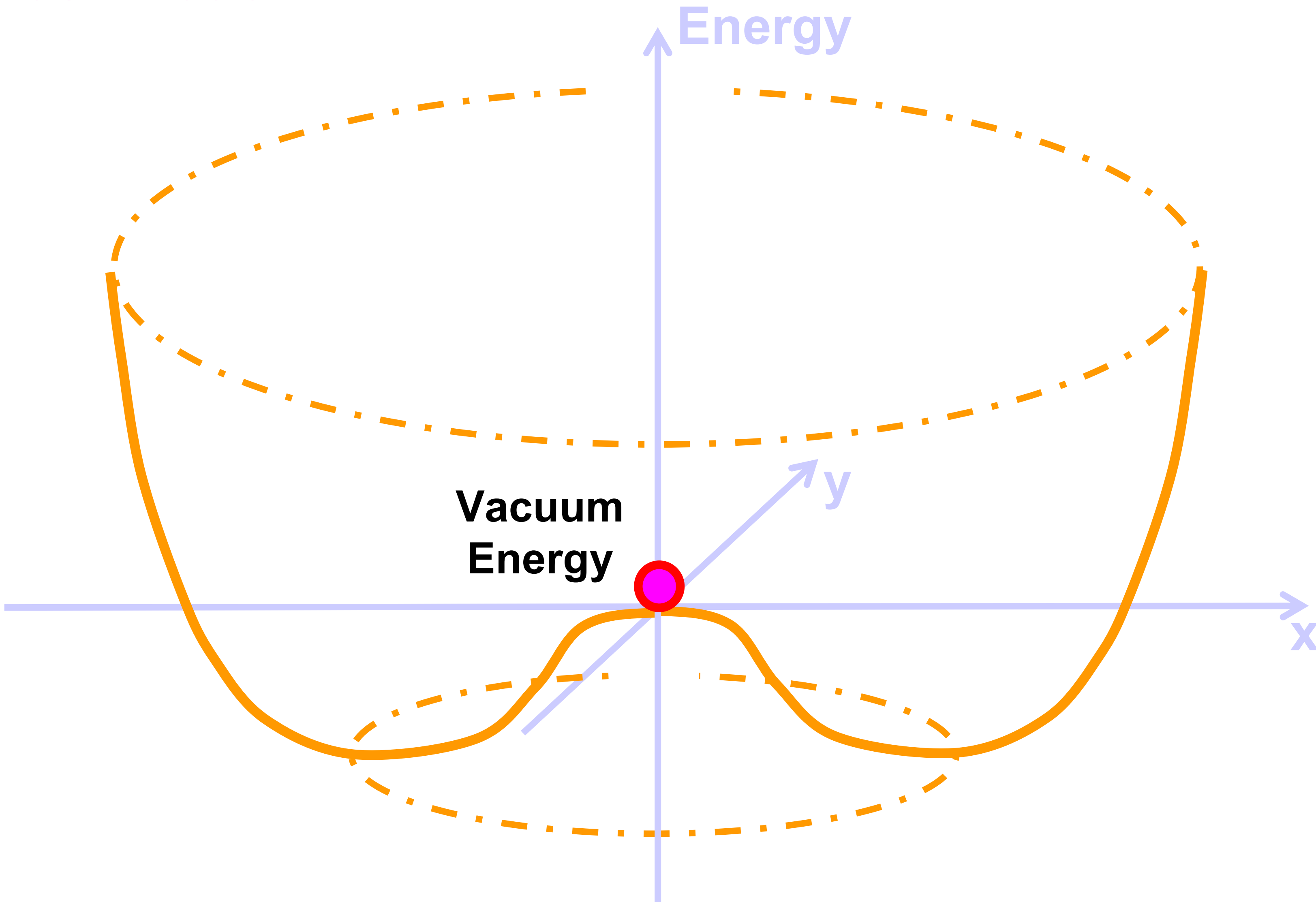


The Accelerating Universe （1998）



Origin of Dark Energy

Same as Inflation

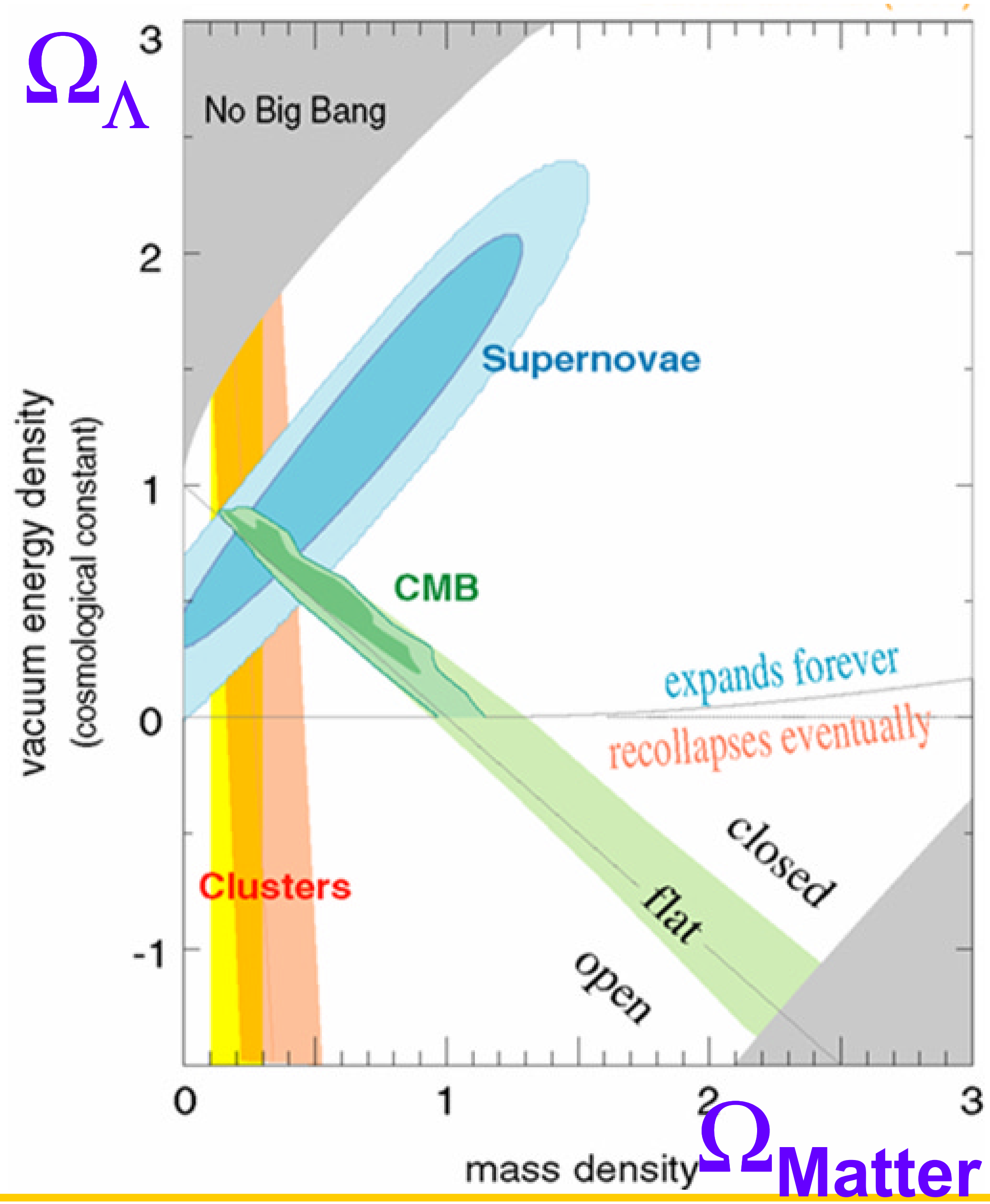


Density of Our Universe

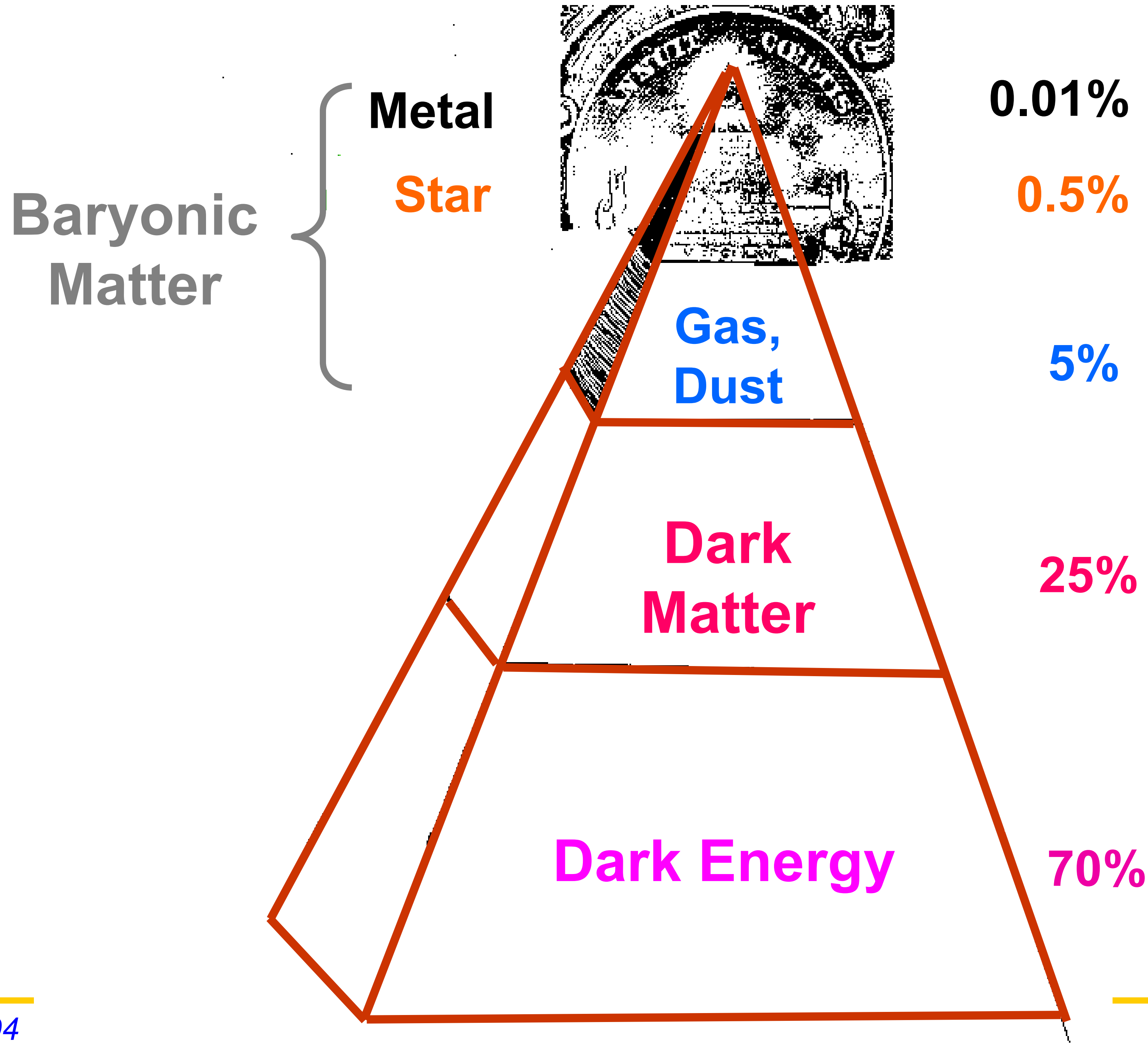
- $\Omega_{Total} = \Omega_{\Lambda} + \Omega_{Matter}$
  $= 1.0$

- Universe is Flat.
  $\Rightarrow$ Inflation

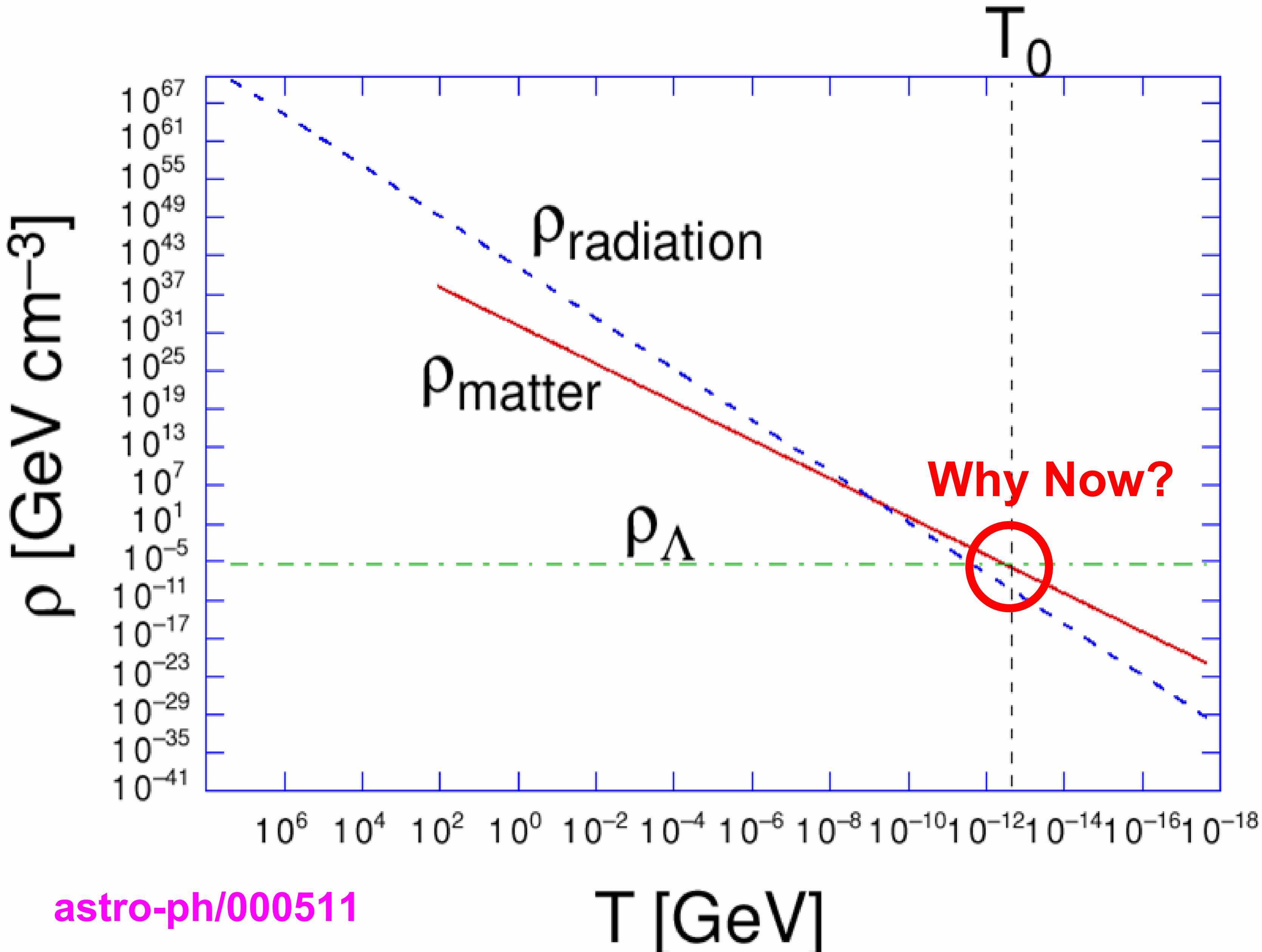
- 70% is Dark Energy.
  $\Rightarrow$ Accelerating



Cosmic Pyramid （2003）

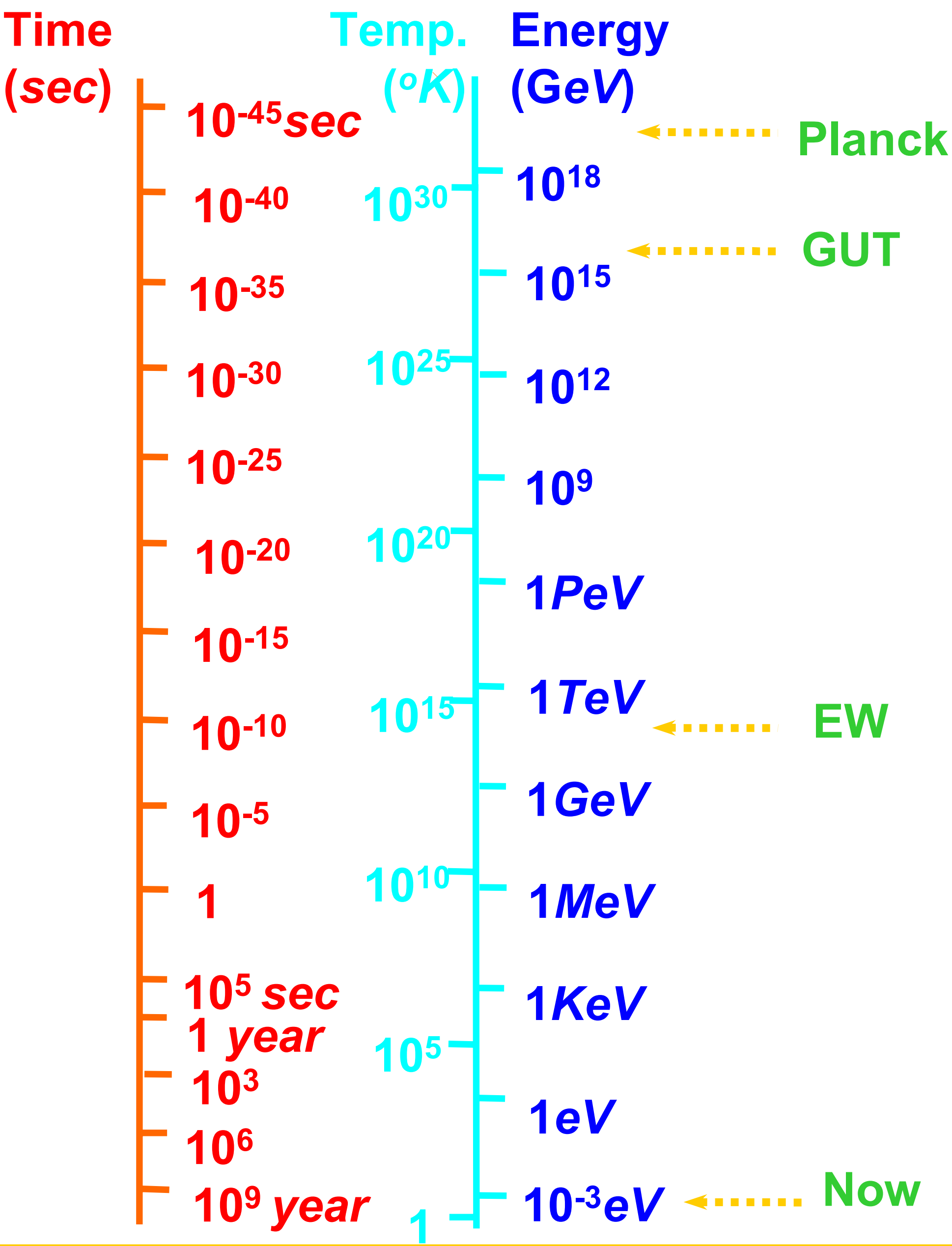


Cosmic Triple Coincidence



astro-ph/000511

Cosmic Coincidence

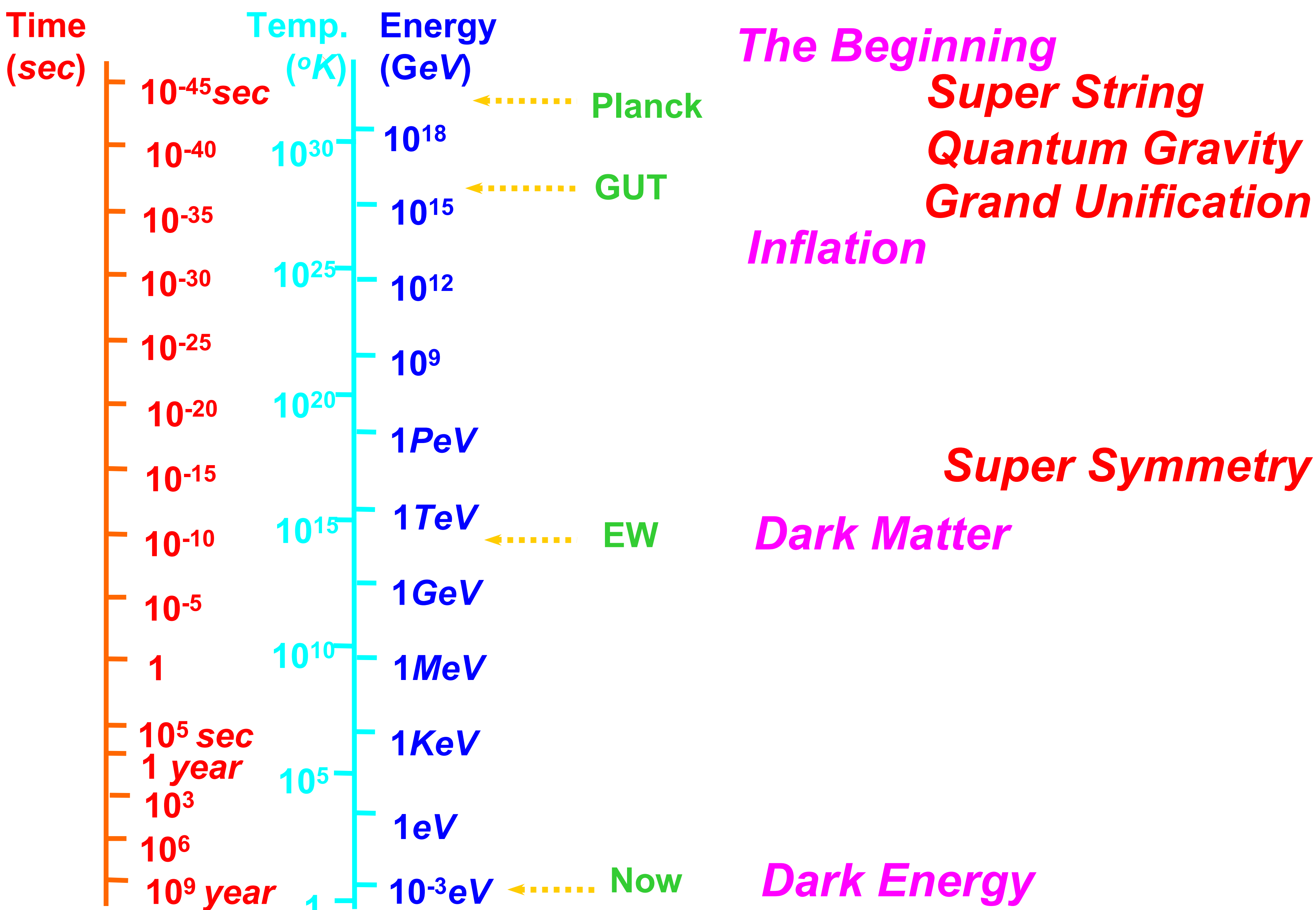


$$\alpha_{Gravity} \approx \alpha_{Strong} \approx \alpha_{EM} \approx \alpha_{Weak}$$

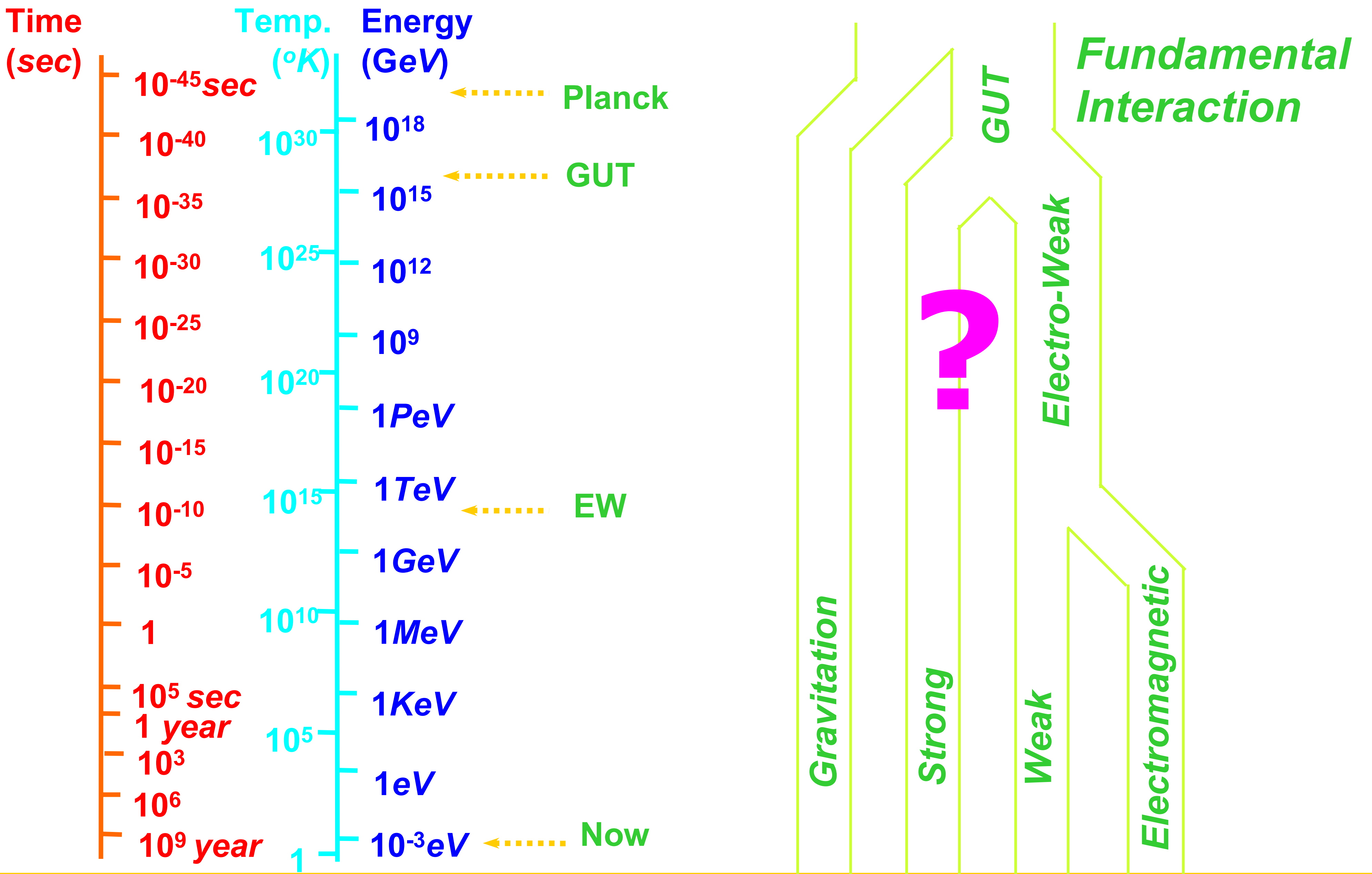
$$\frac{E_{EW}}{E_{Planck}} \approx \frac{E_{Now}}{E_{EW}} \approx 10^{-15}$$

$$\Omega_{Rad} \approx \Omega_{\nu} \approx \Omega_{CDM} \approx \Omega_{B} \approx \Omega_{\Lambda}$$

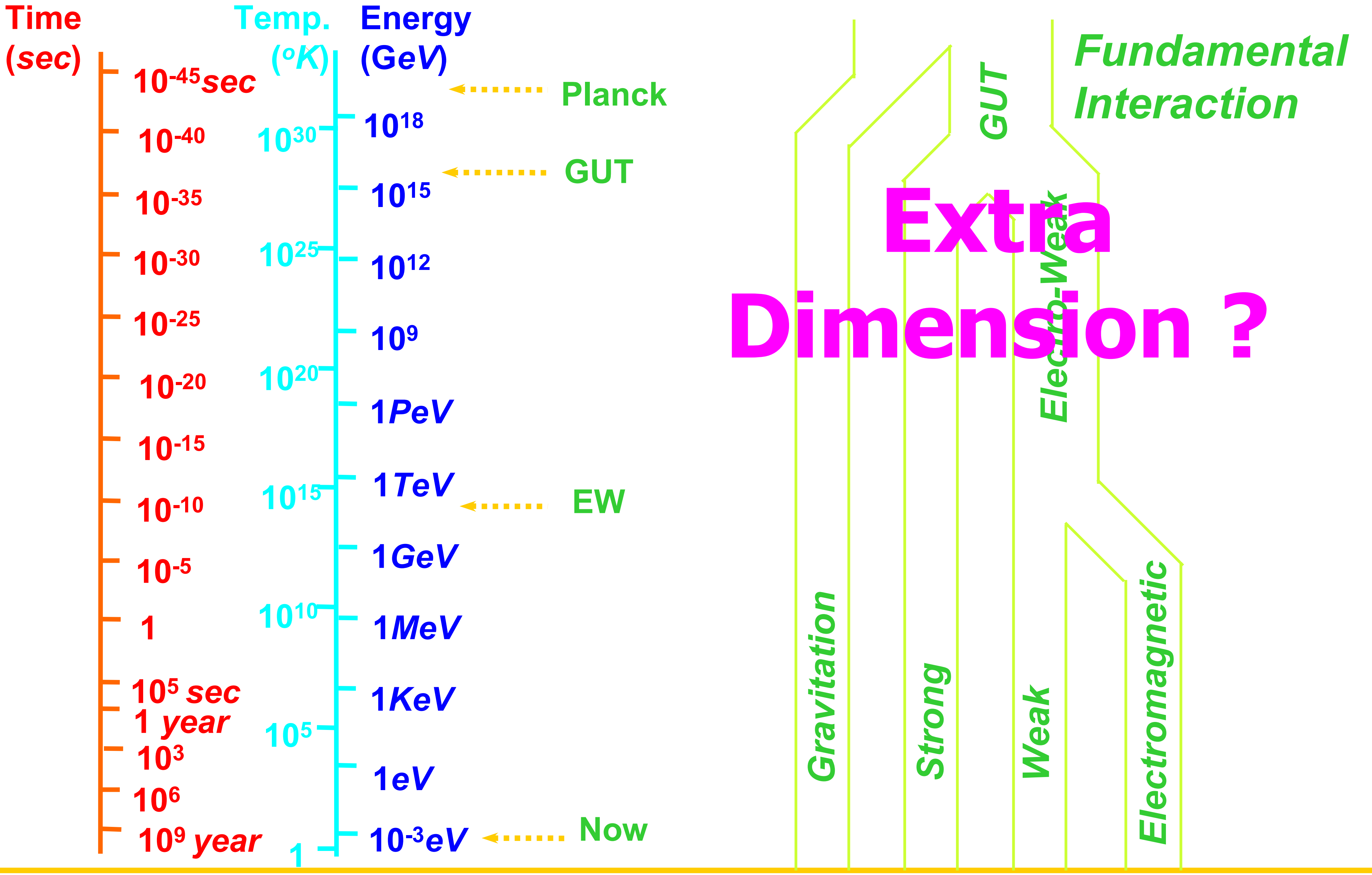
Unsolved Evidence & Untested Theories



Is there the Unification of Fundamental Forces?



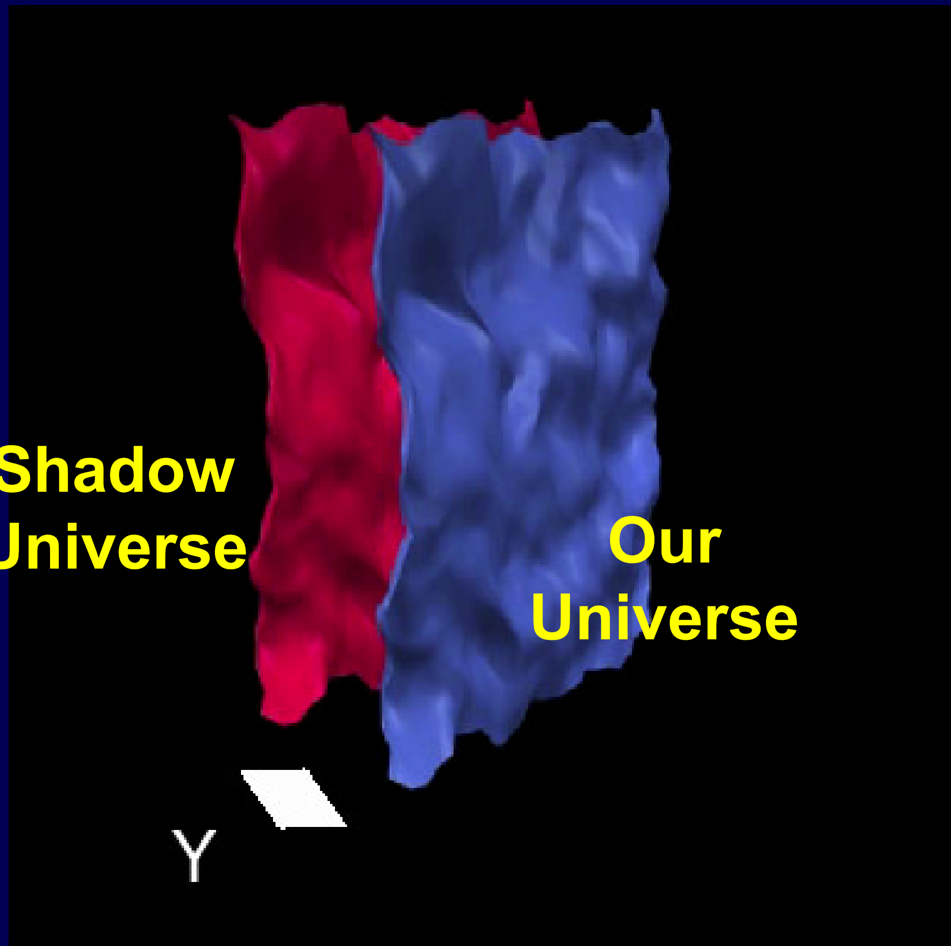
Is there the Unification of Fundamental Forces?



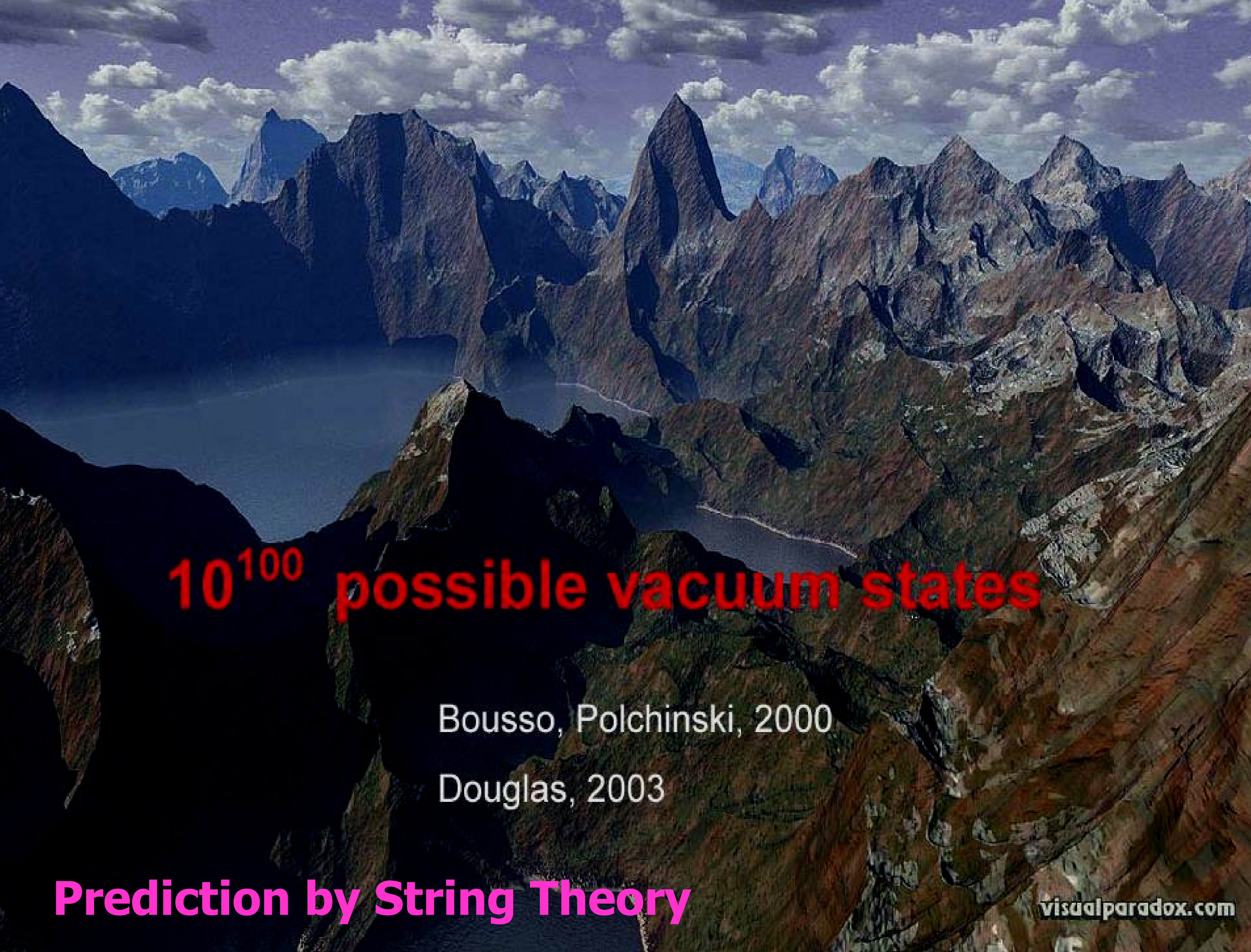
Cyclic Model

“bang”
radiation
matter
dark energy
“contraction”
“crunch”

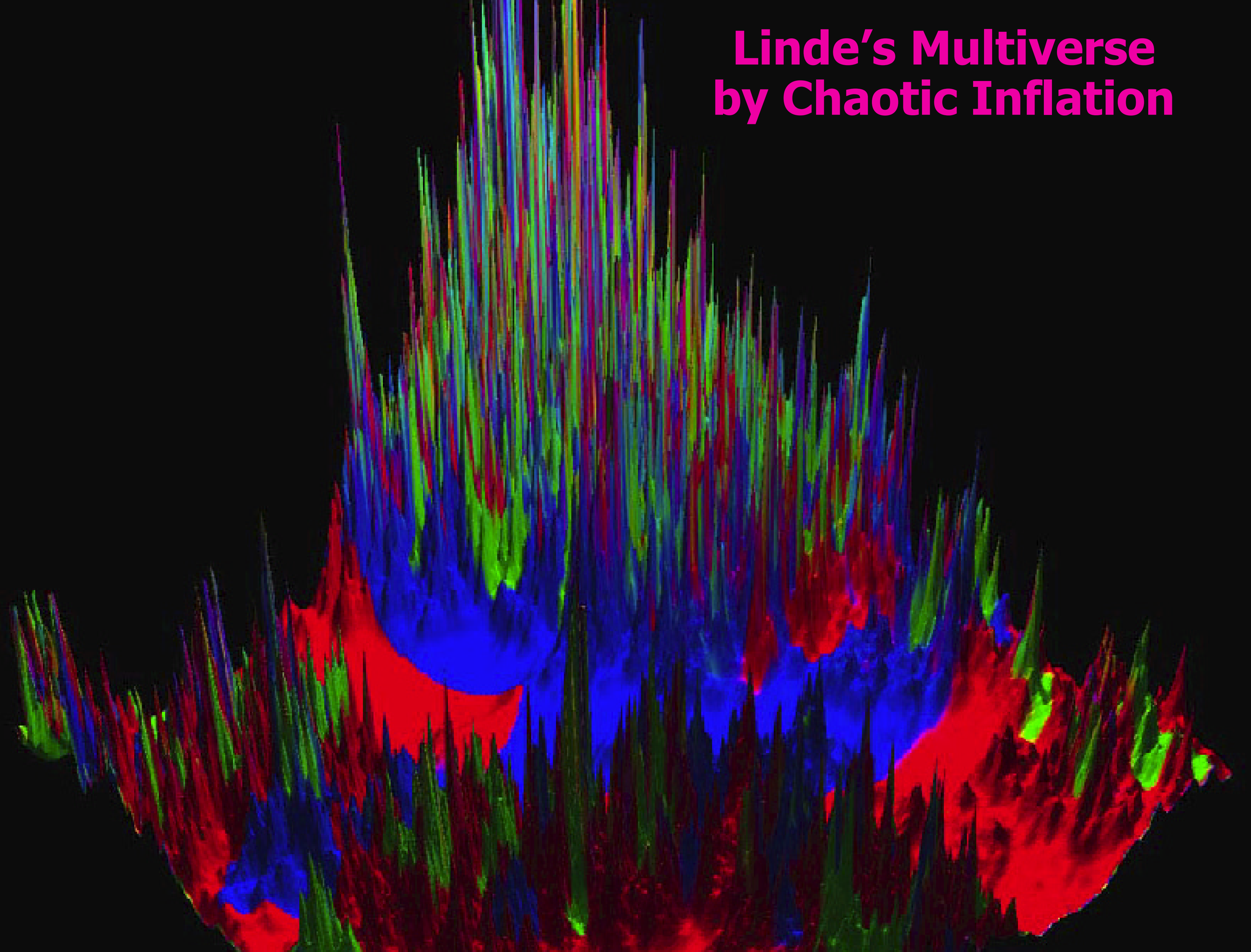
M theory



Are there more than one Universe?


10^{100} possible vacuum states
Bousso, Polchinski, 2000
Douglas, 2003
Prediction by String Theory
visualparadox.com

Linde's Multiverse by Chaotic Inflation

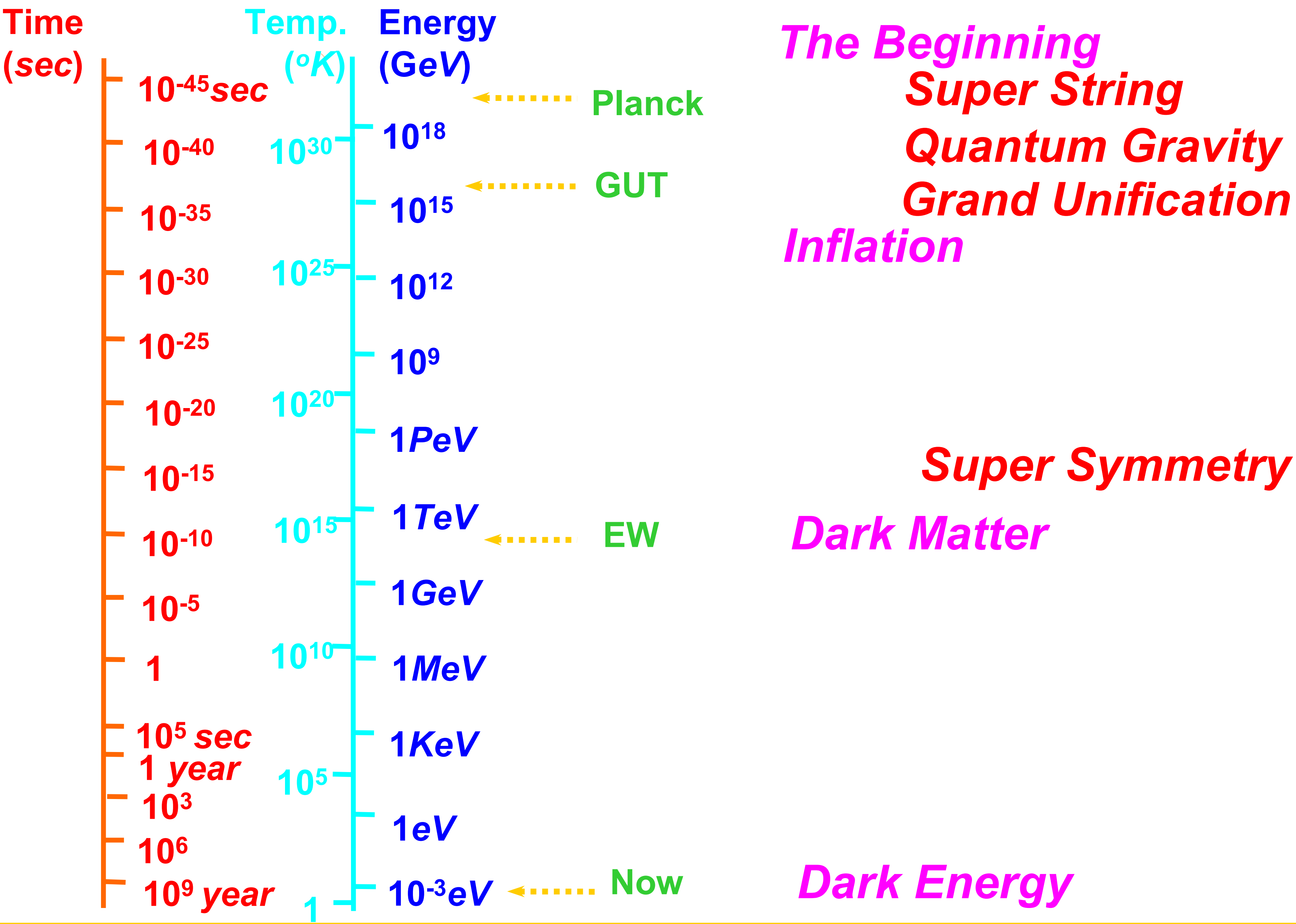



There may be ~100 Billion Universes.

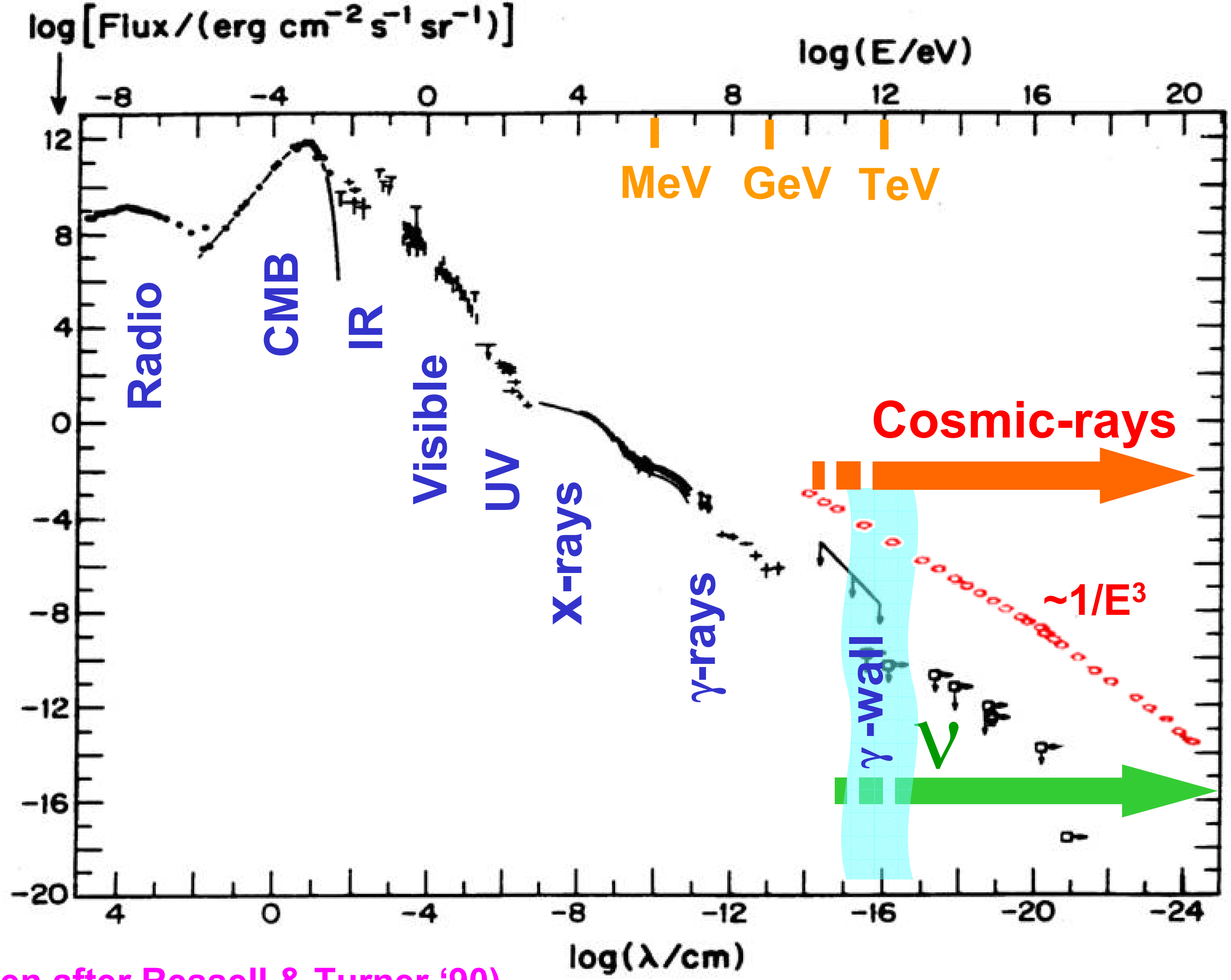
Part II

Particle Astrophysics

Unsolved Evidence & Untested Theories



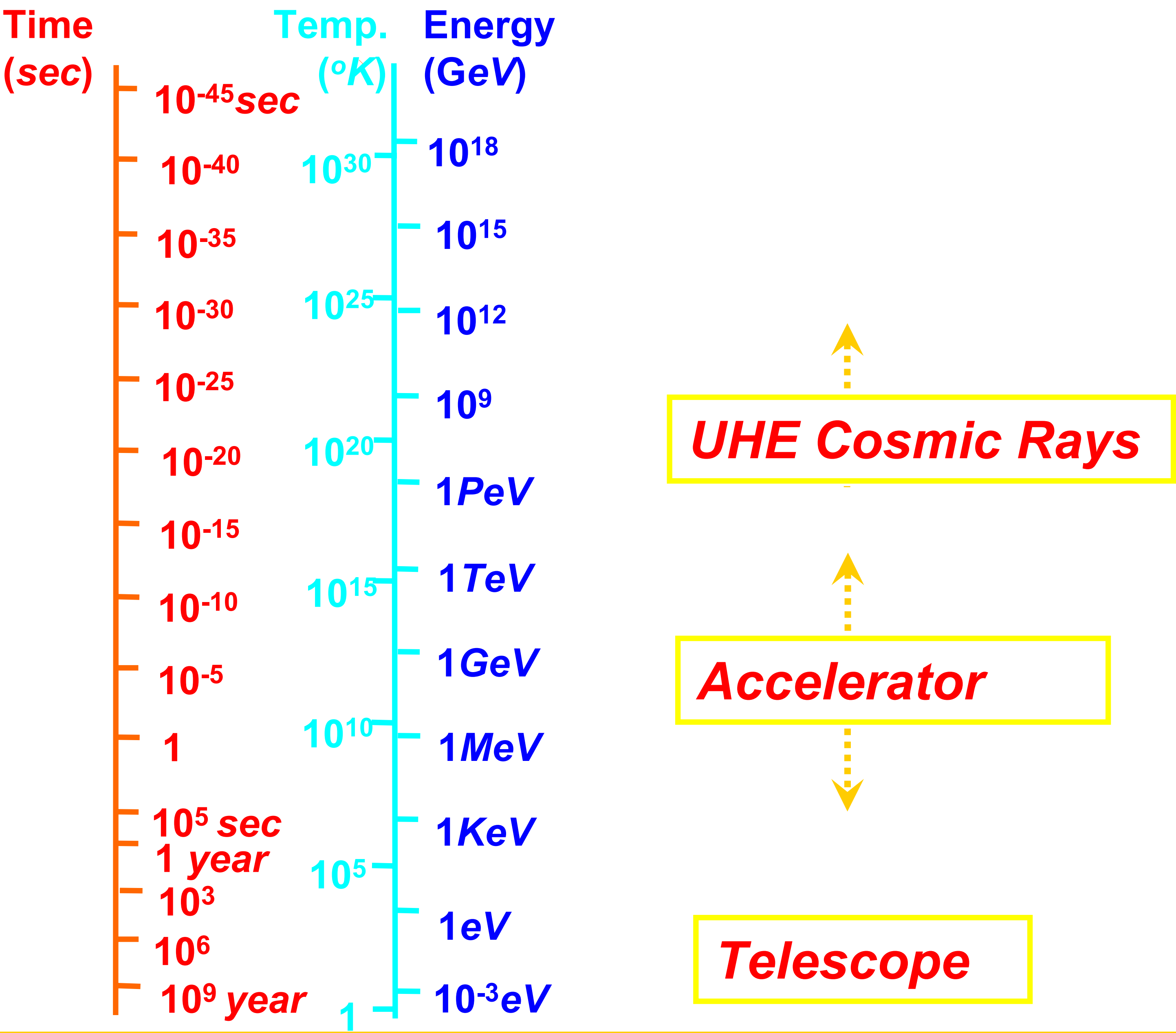
Cosmic Radiation



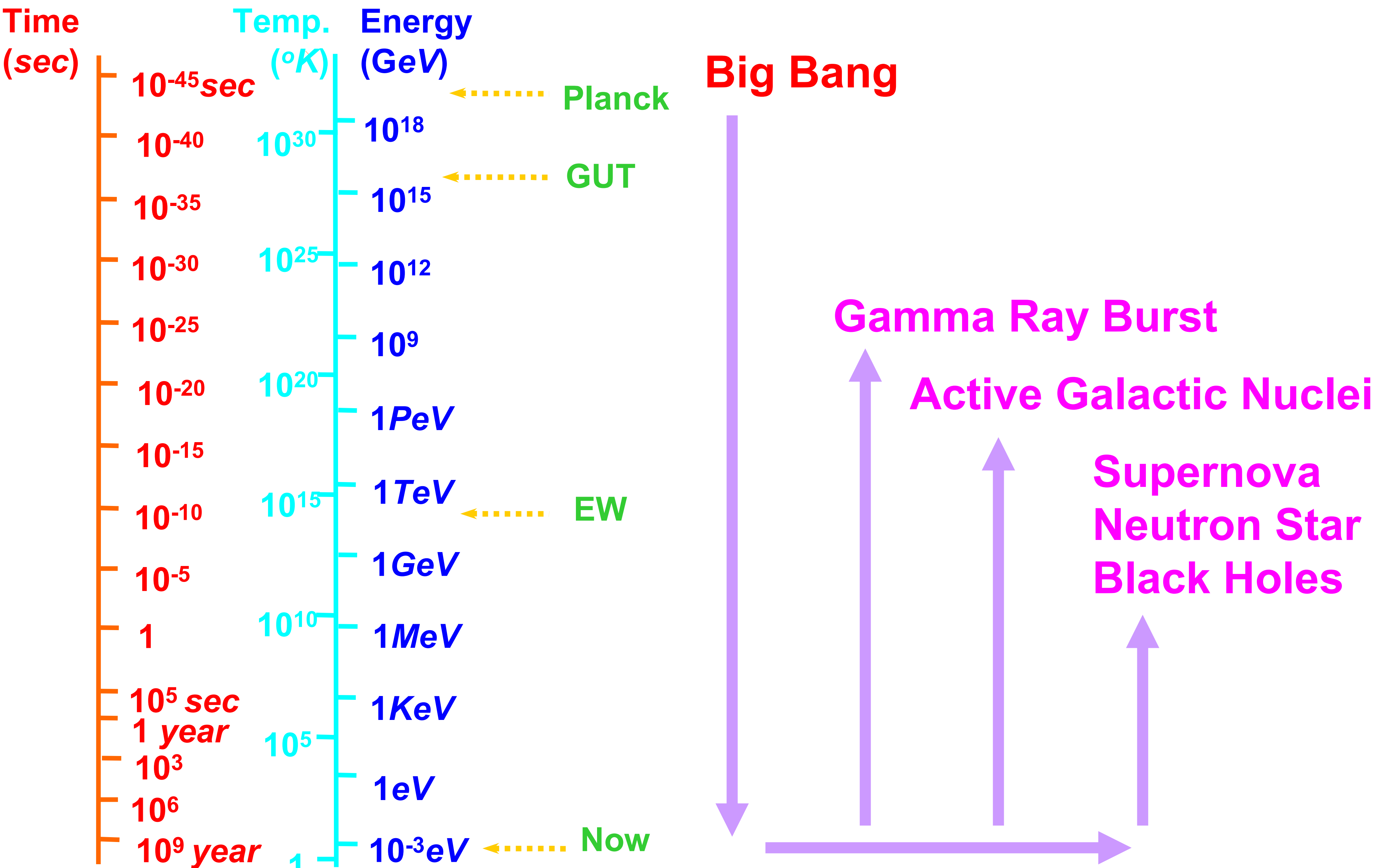
(by Halzen after Ressell & Turner '90)

2

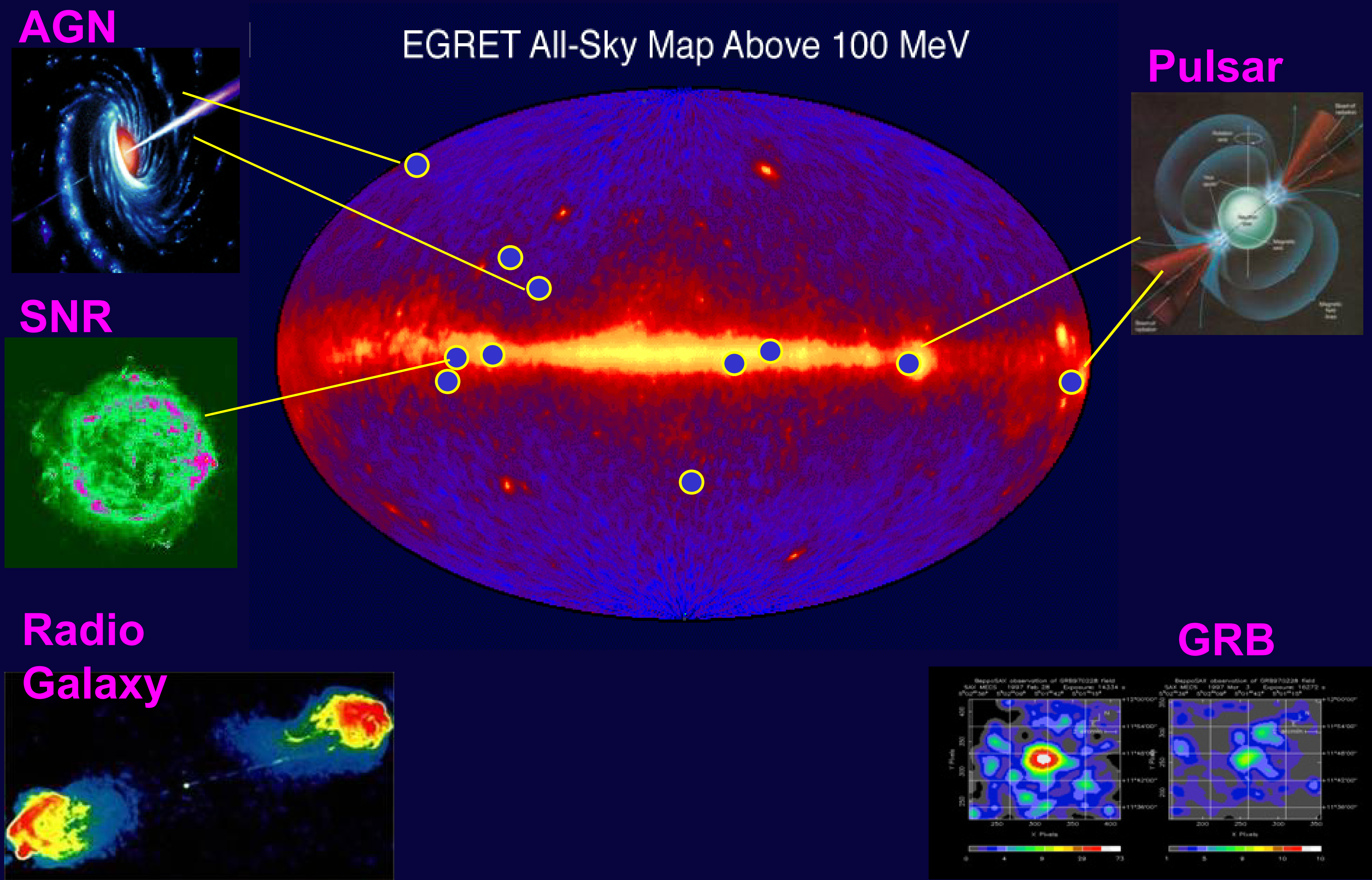
Tools to Explore the Early Universe



The Extreme Universe



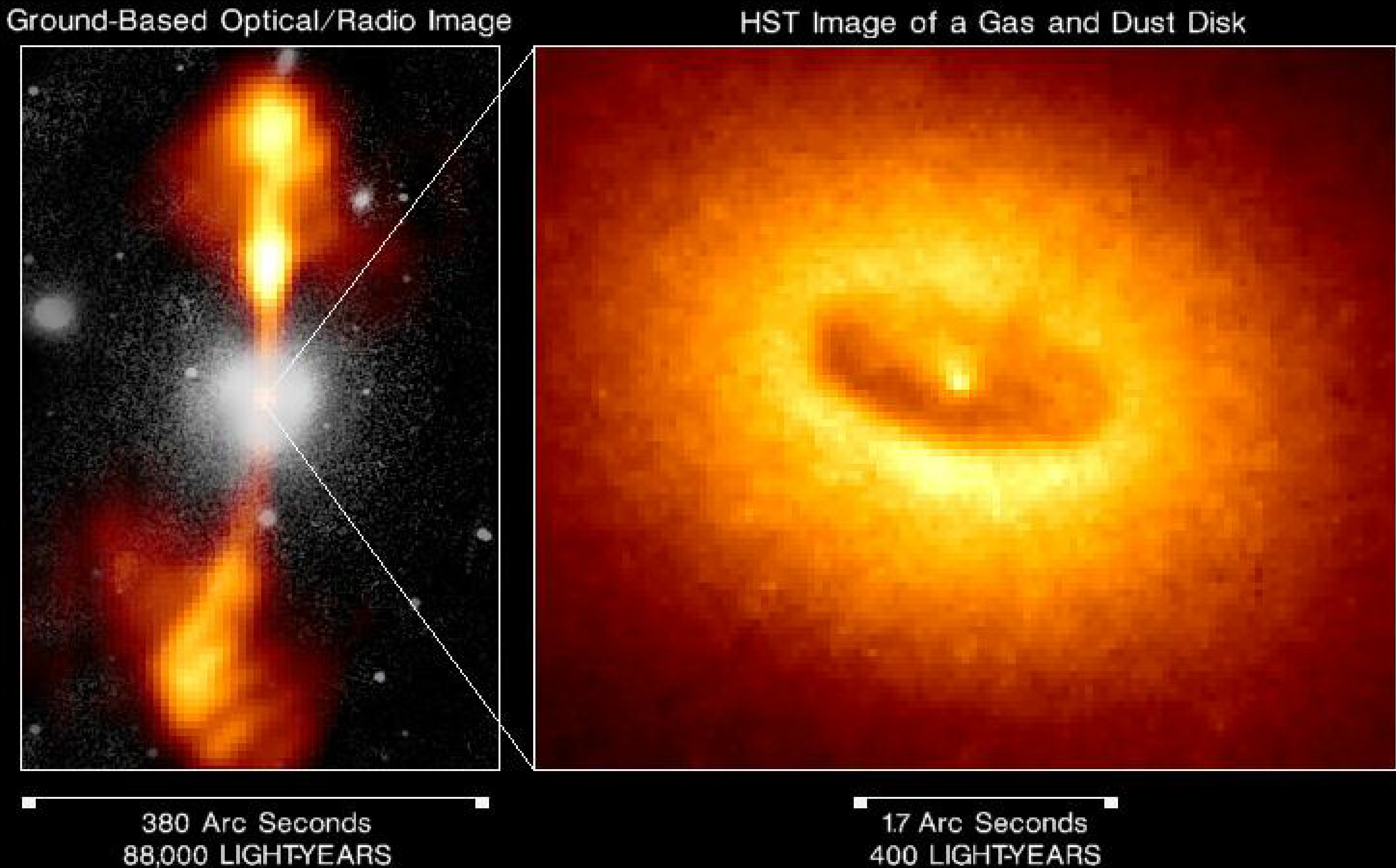
The Extreme Universe



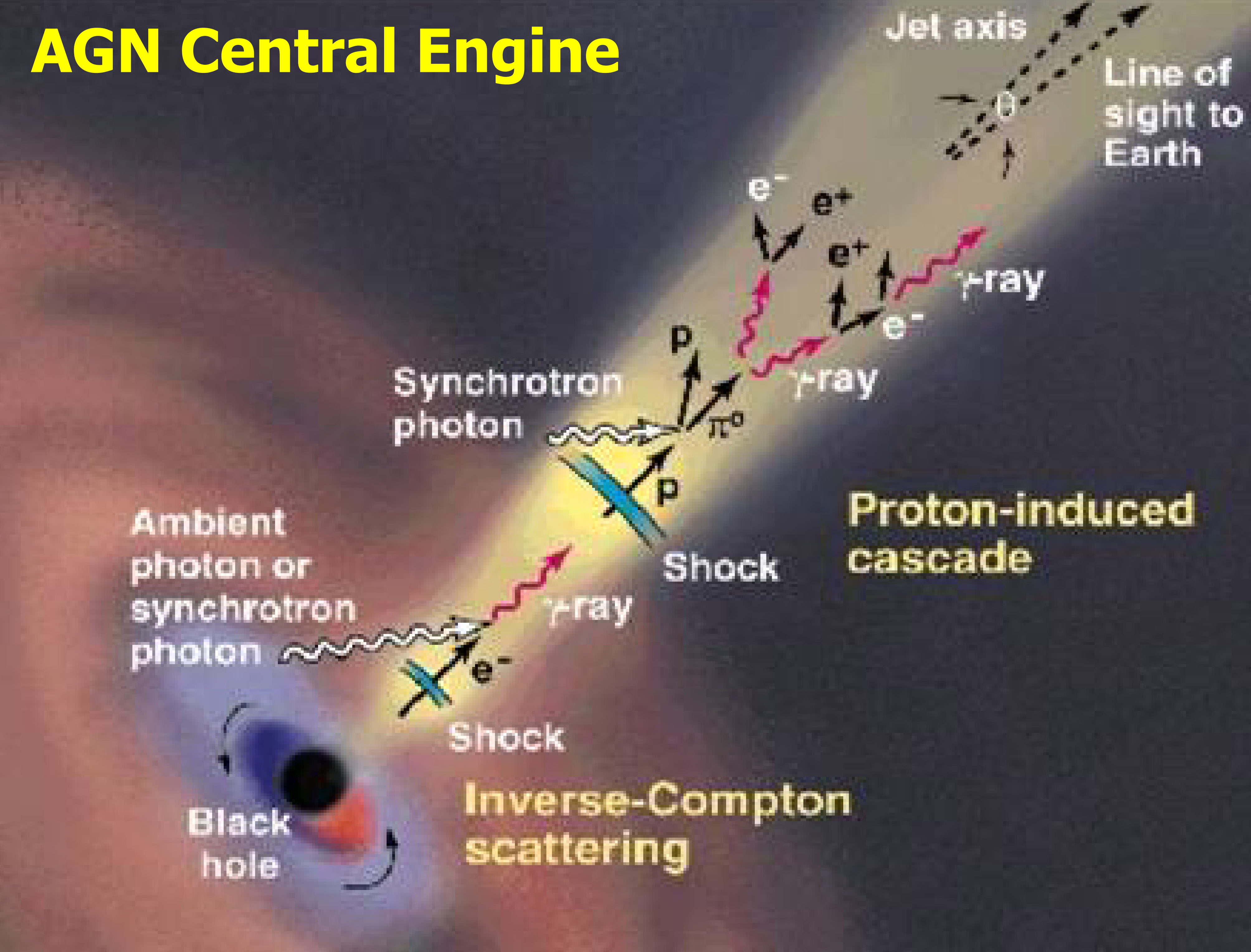
Core of Galaxy NGC 4261

Hubble Space Telescope

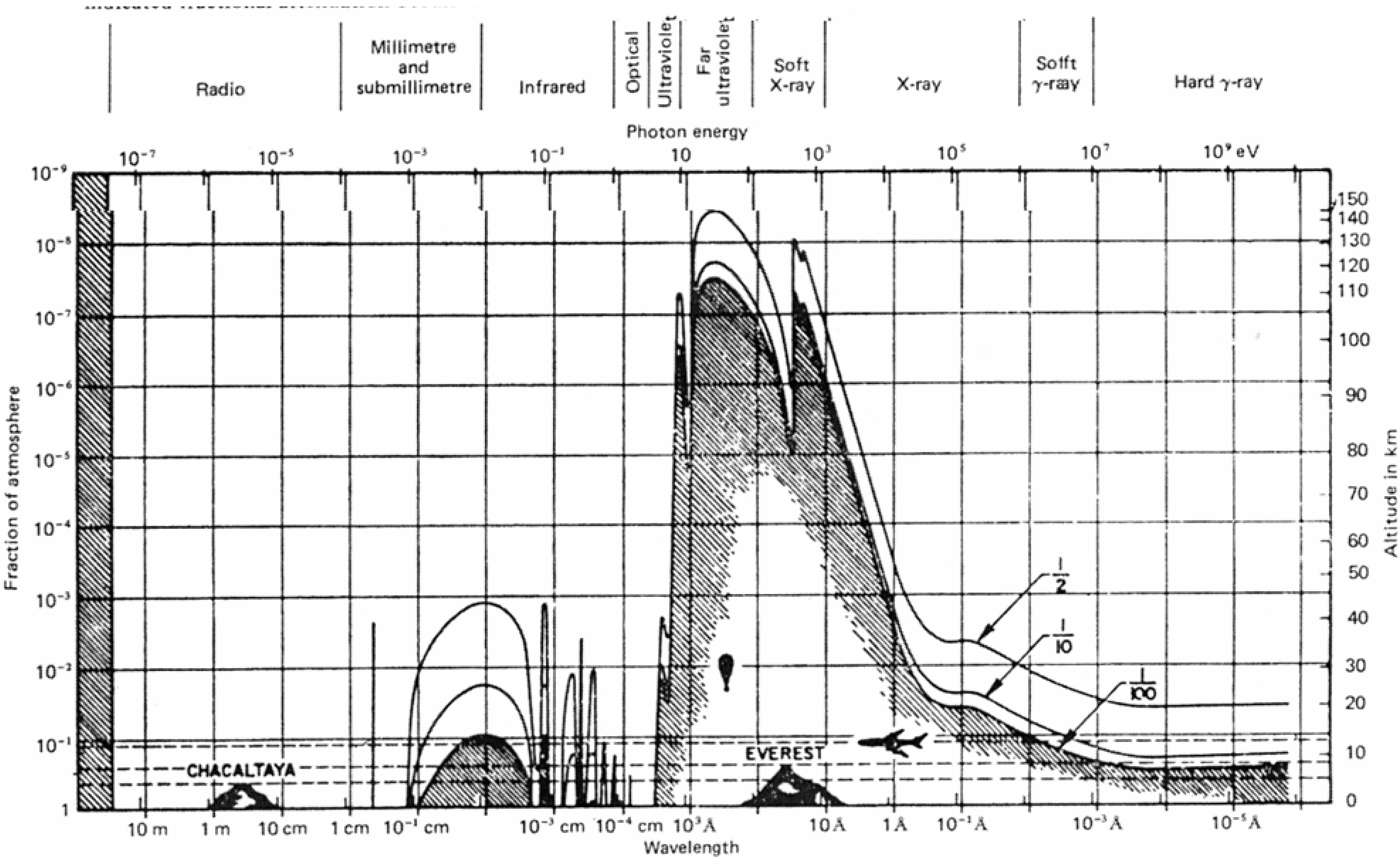
Wide Field / Planetary Camera



AGN Central Engine

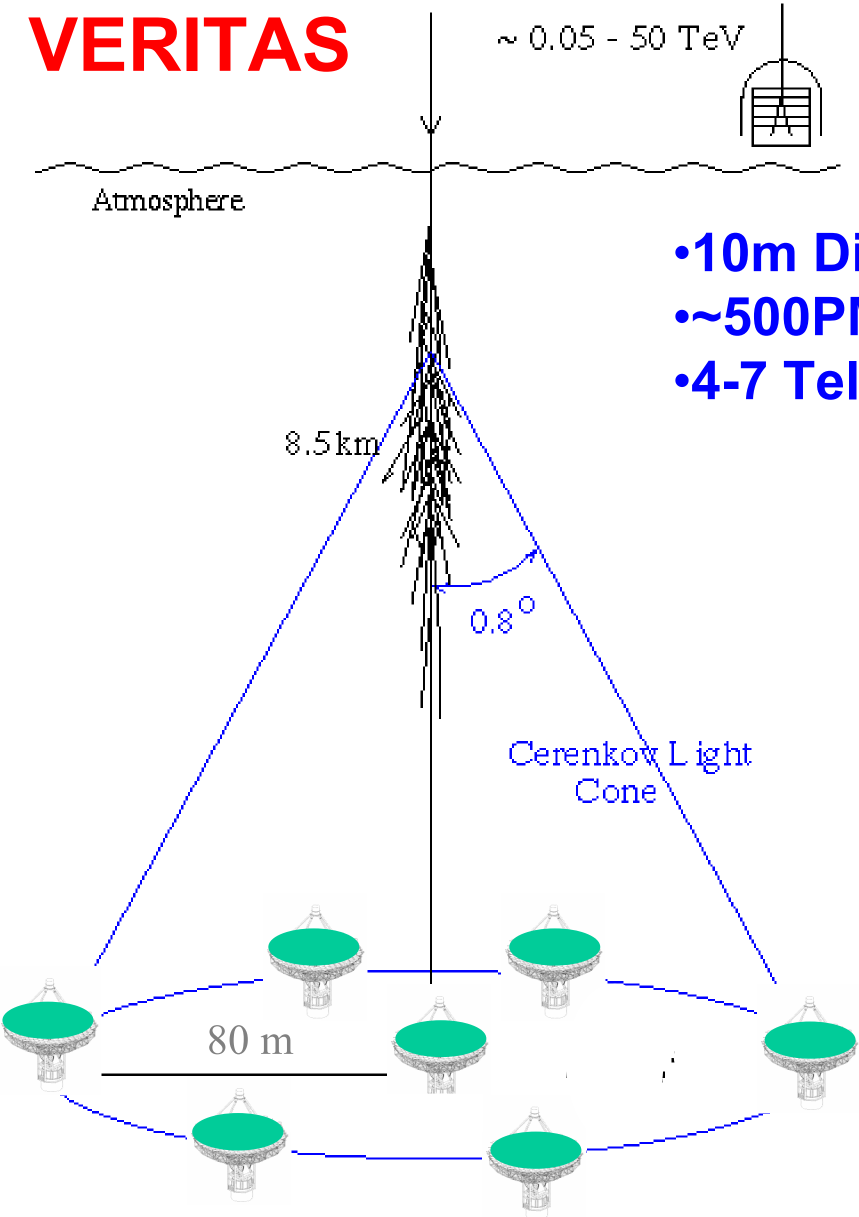


Absorption of photons by Atmosphere



Gamma ray Telescopes

VERITAS

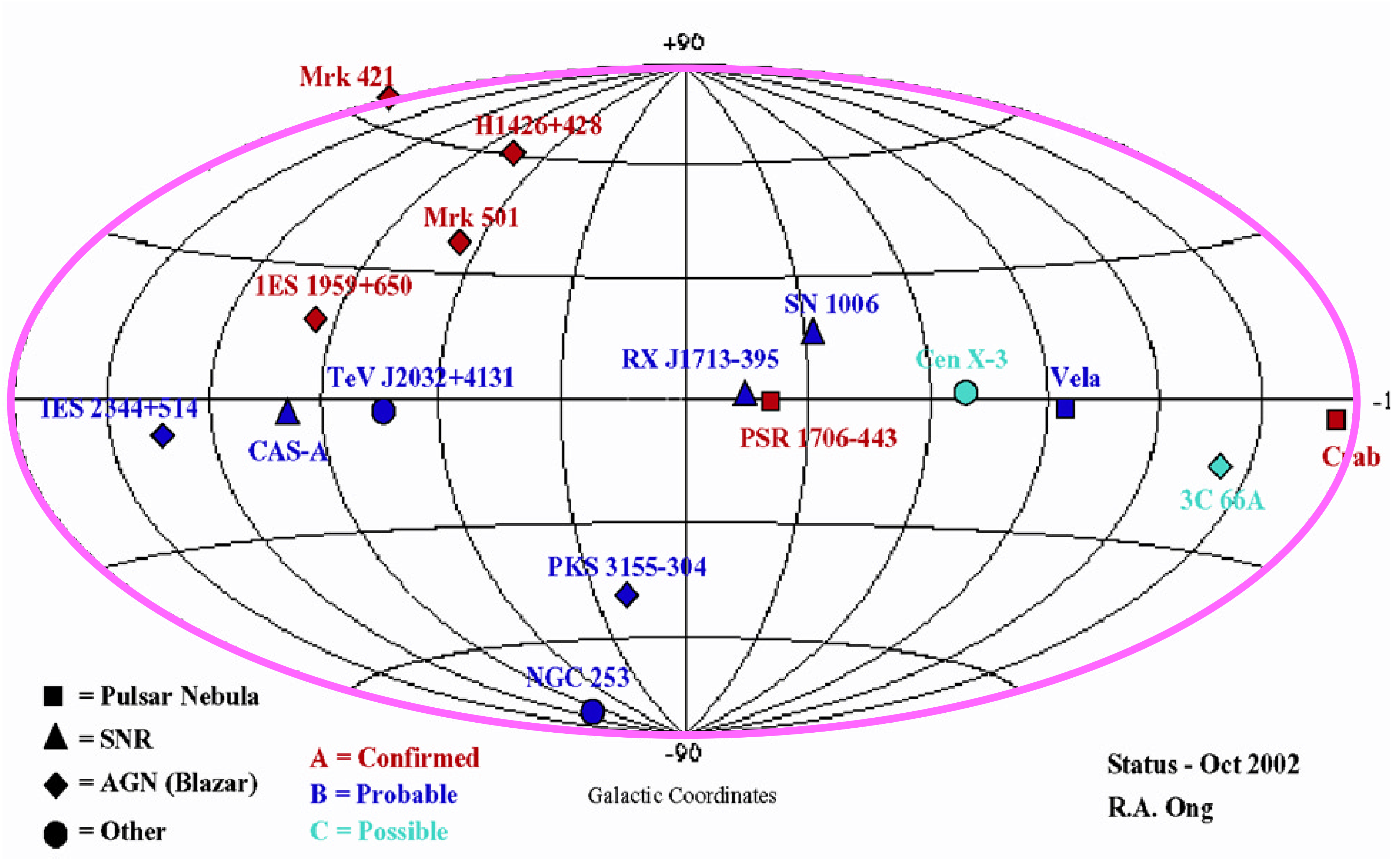


Prof. Rene Ong

- 10m Diameter
- ~500PMT/Camera
- 4-7 Telescopes

HESS

TeV Gamma Rays



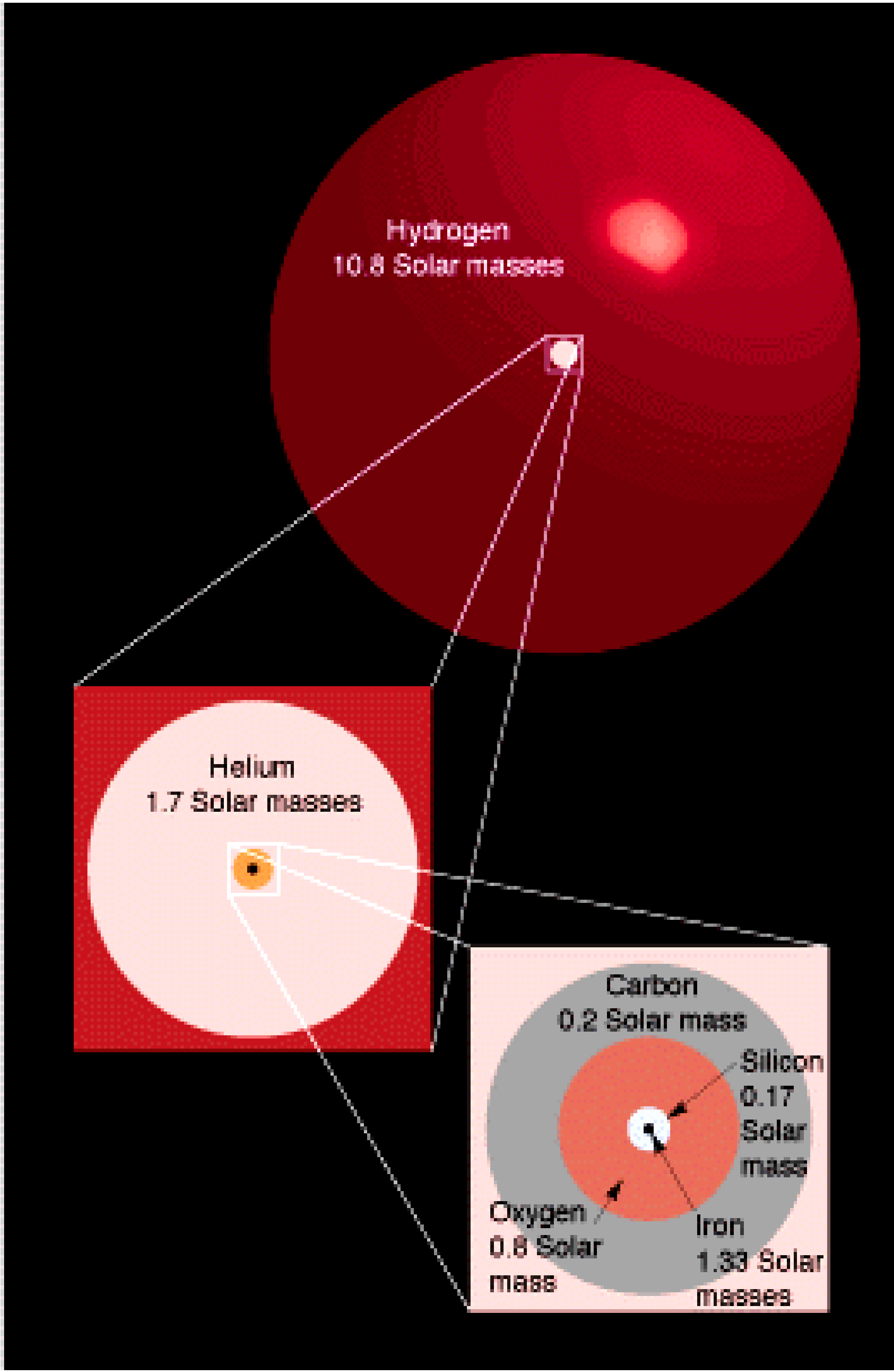
Super-Kamiokande

•11,200 of 20” PMTs

Nuclear Burning in High Mass Stars

(times for a 20 M_o star)

Hydrogen	*10^7 yr*
Helium	*10^6 yr*
Carbon	*10^3 yr*
Oxygen	*1 yr*
Neon	
Magnesium	
Silicon	*1 week*
Iron	*< 1 day*

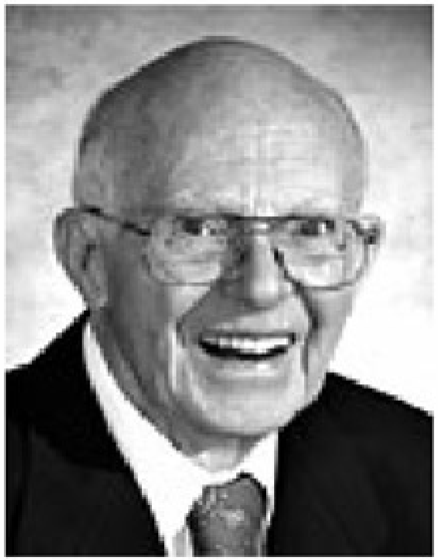


Nobel Prize in 2002

The Nobel Prize in Physics 2002

"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos"

"for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources"

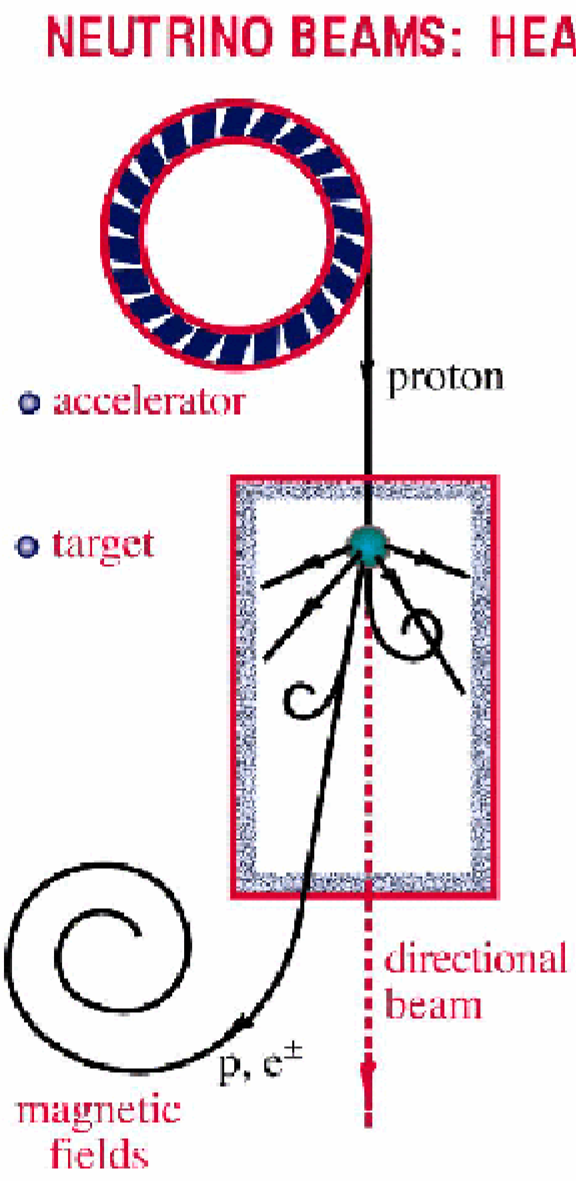


Raymond Davis Jr.

Masatoshi Koshiba

Riccardo Giacconi

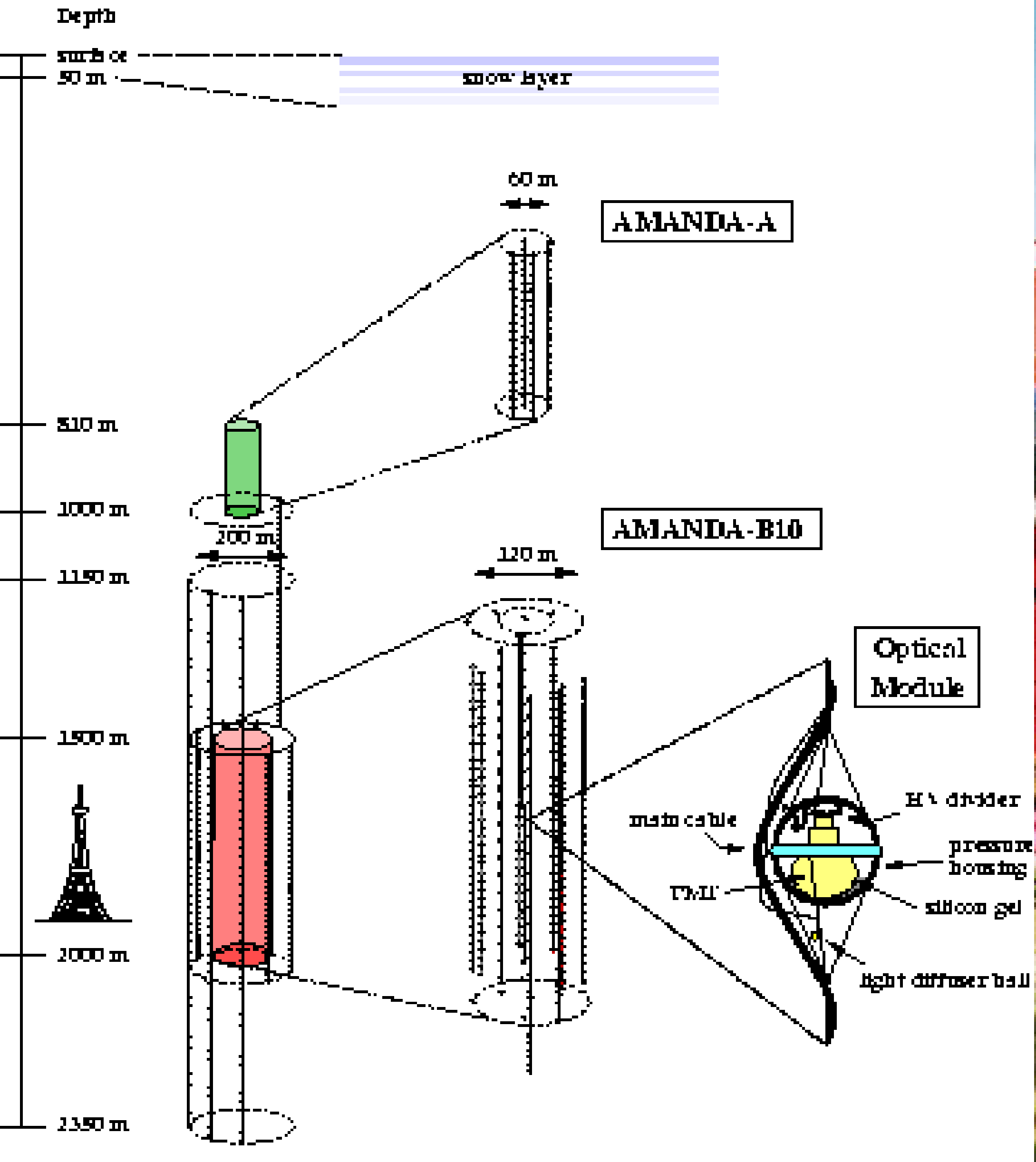
Neutrino Astronmy



black hole

radiation enveloping black hole

AMANDA



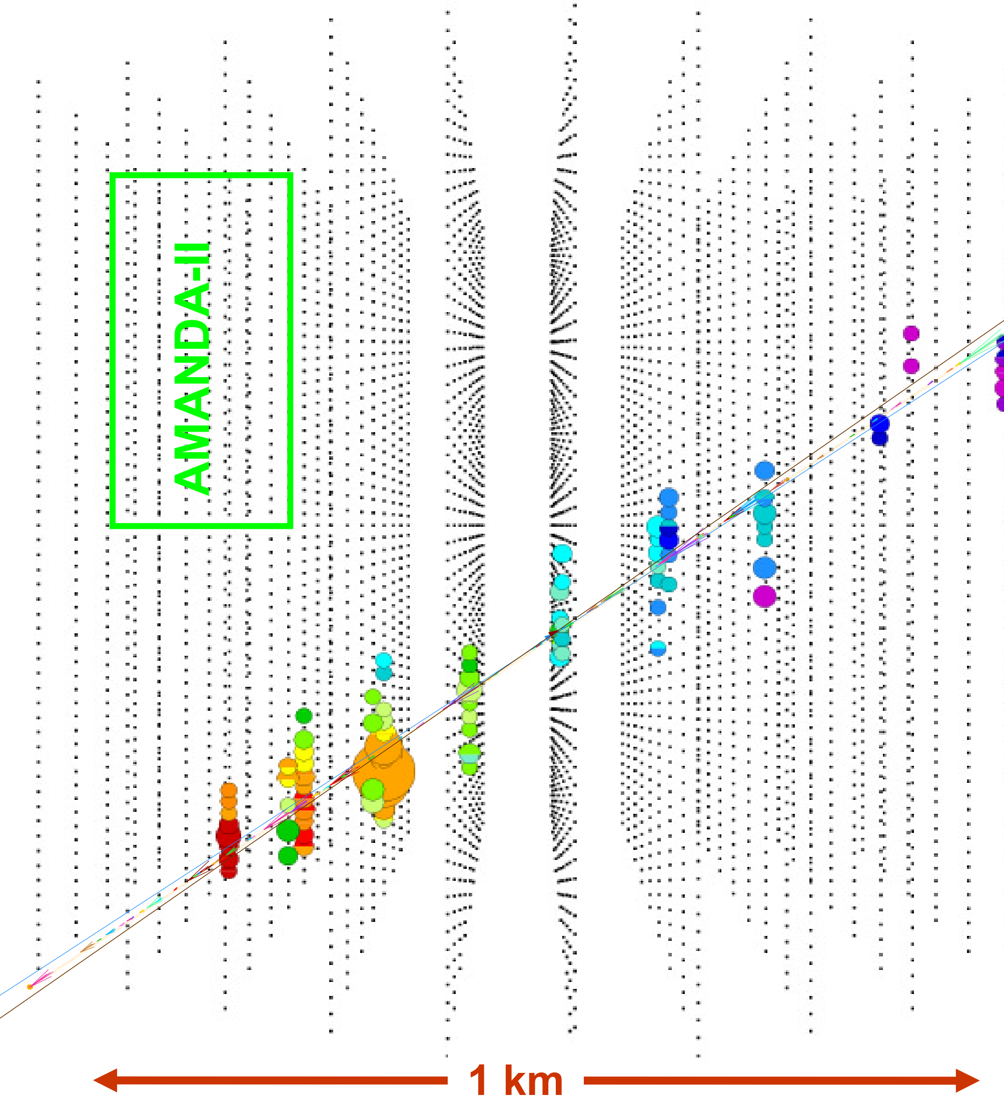
AMANDA as of 2000
Eiffel Tower as comparison
(true scaling)

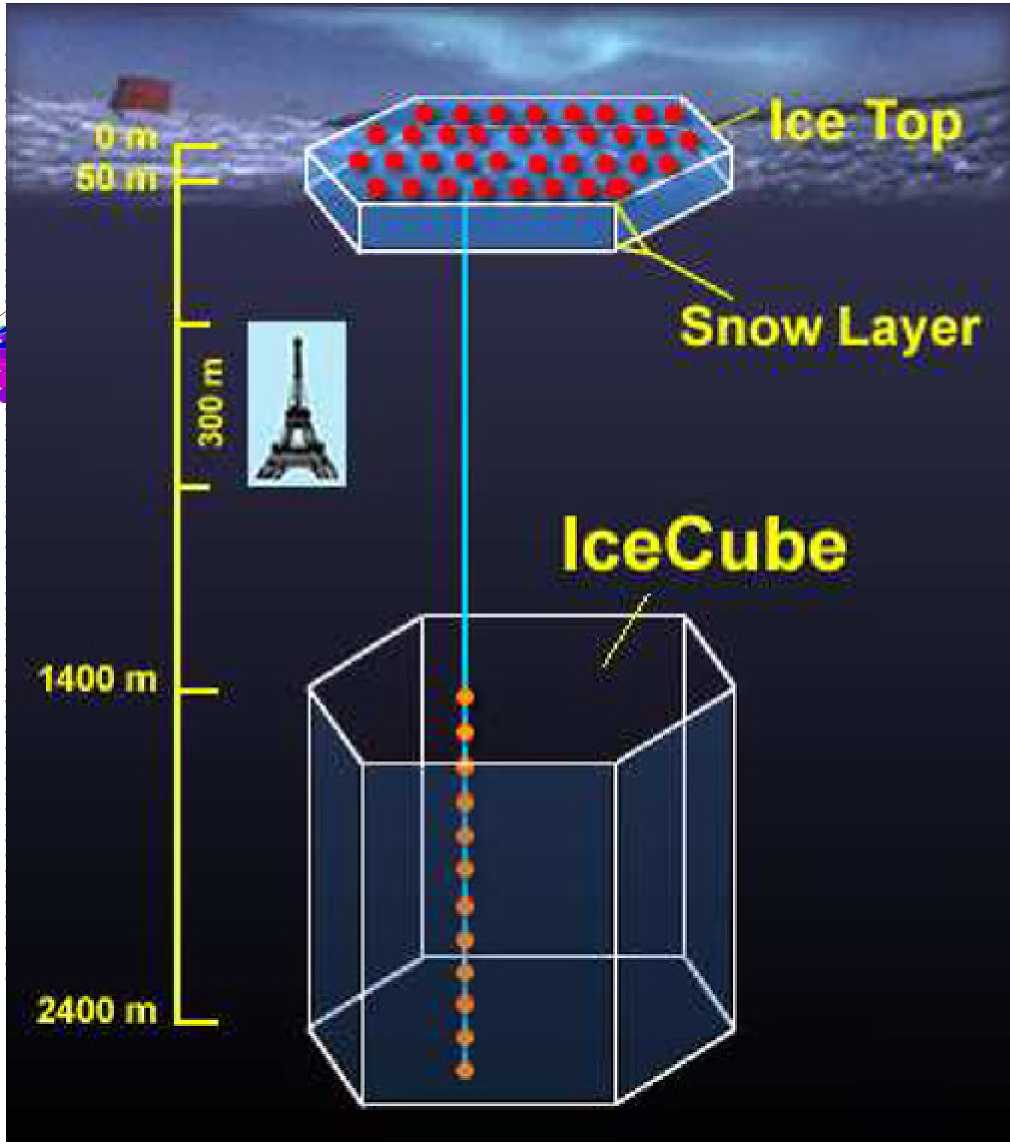
zoomed in on
AMANDA-A (top)
AMANDA-B10 (bottom)

zoomed in on one
optical module (OM)

ICECUBE

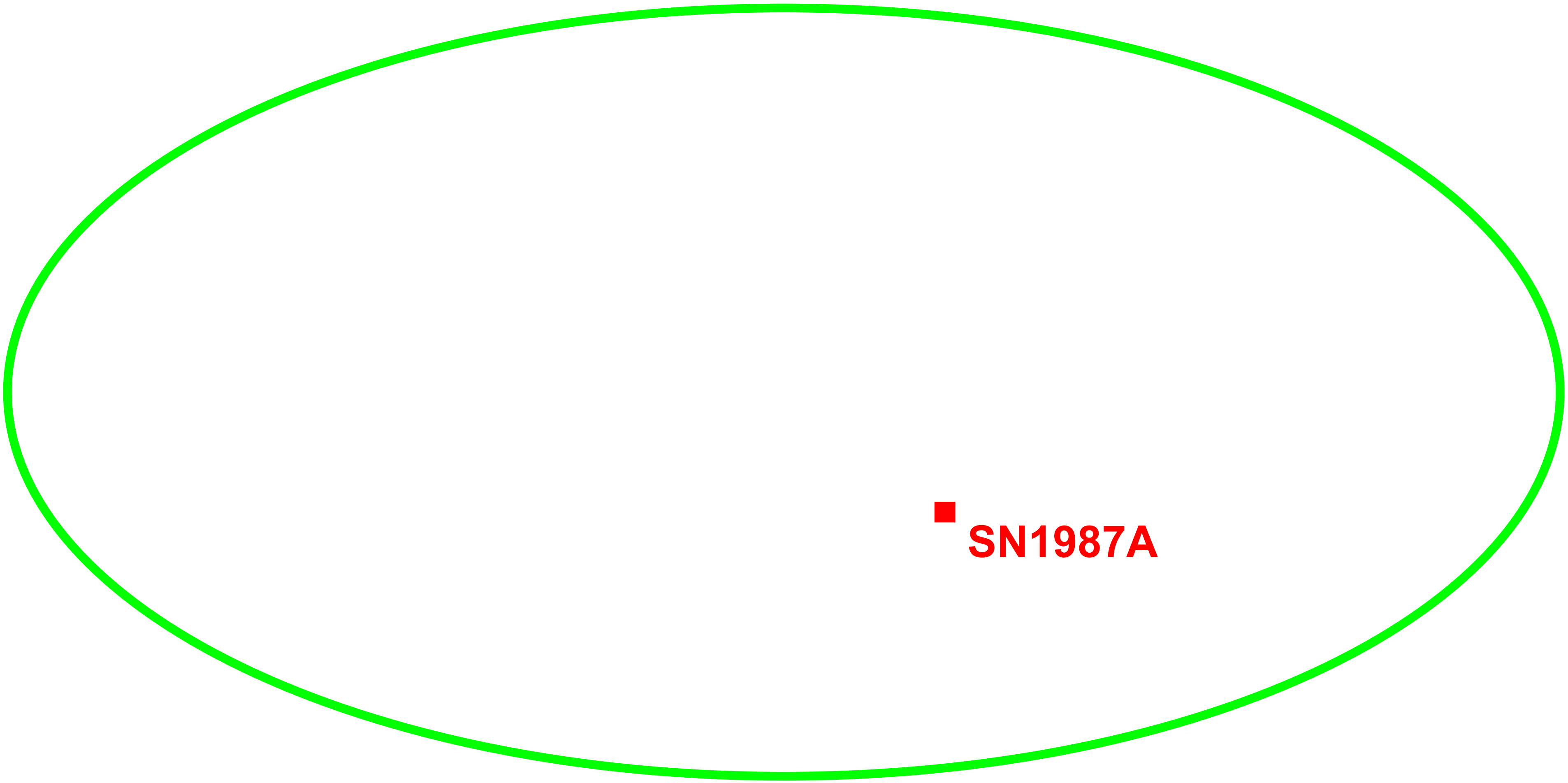
10 TeV Muon Event





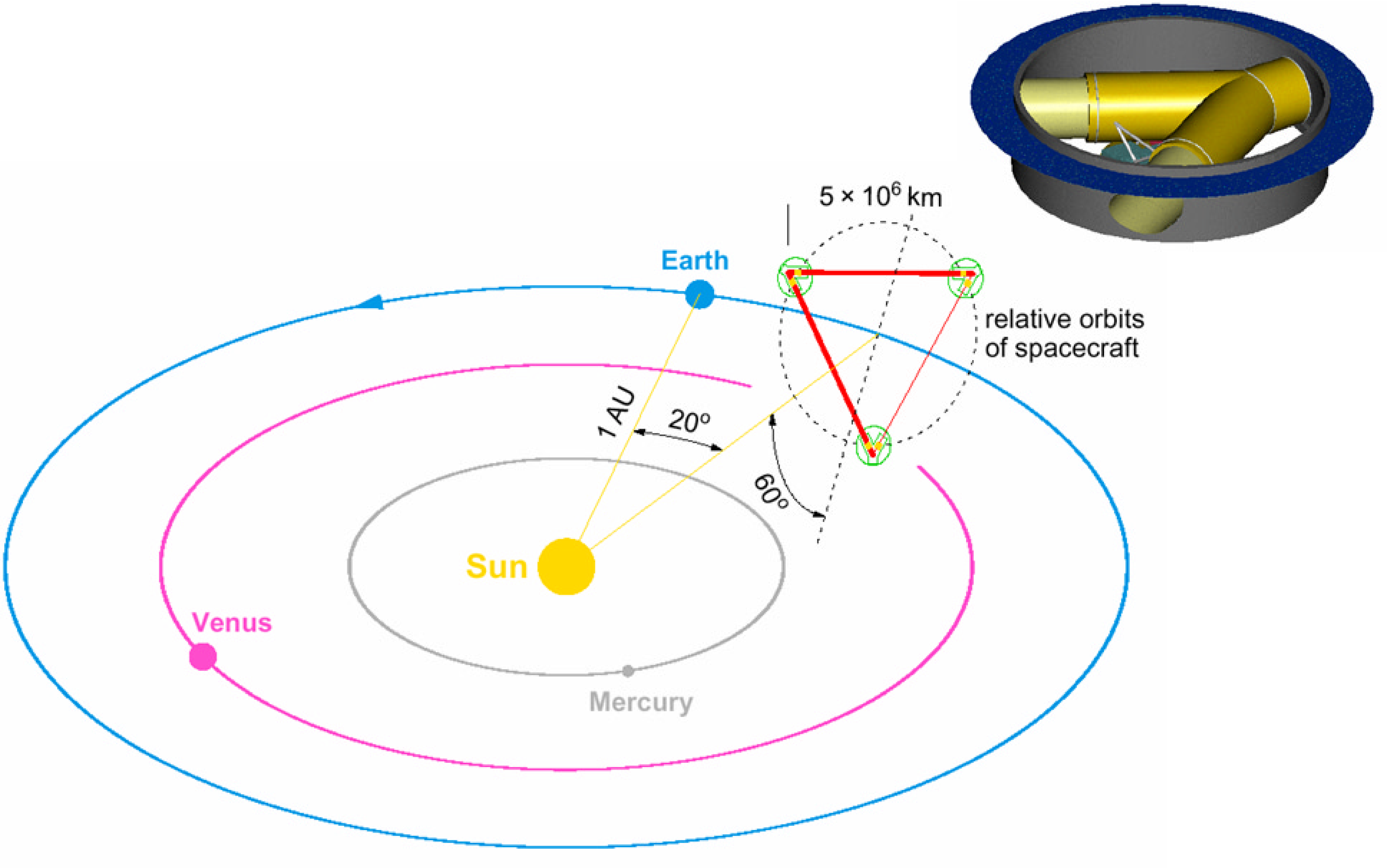
High Energy Neutrino

Prof. David Saltzberg

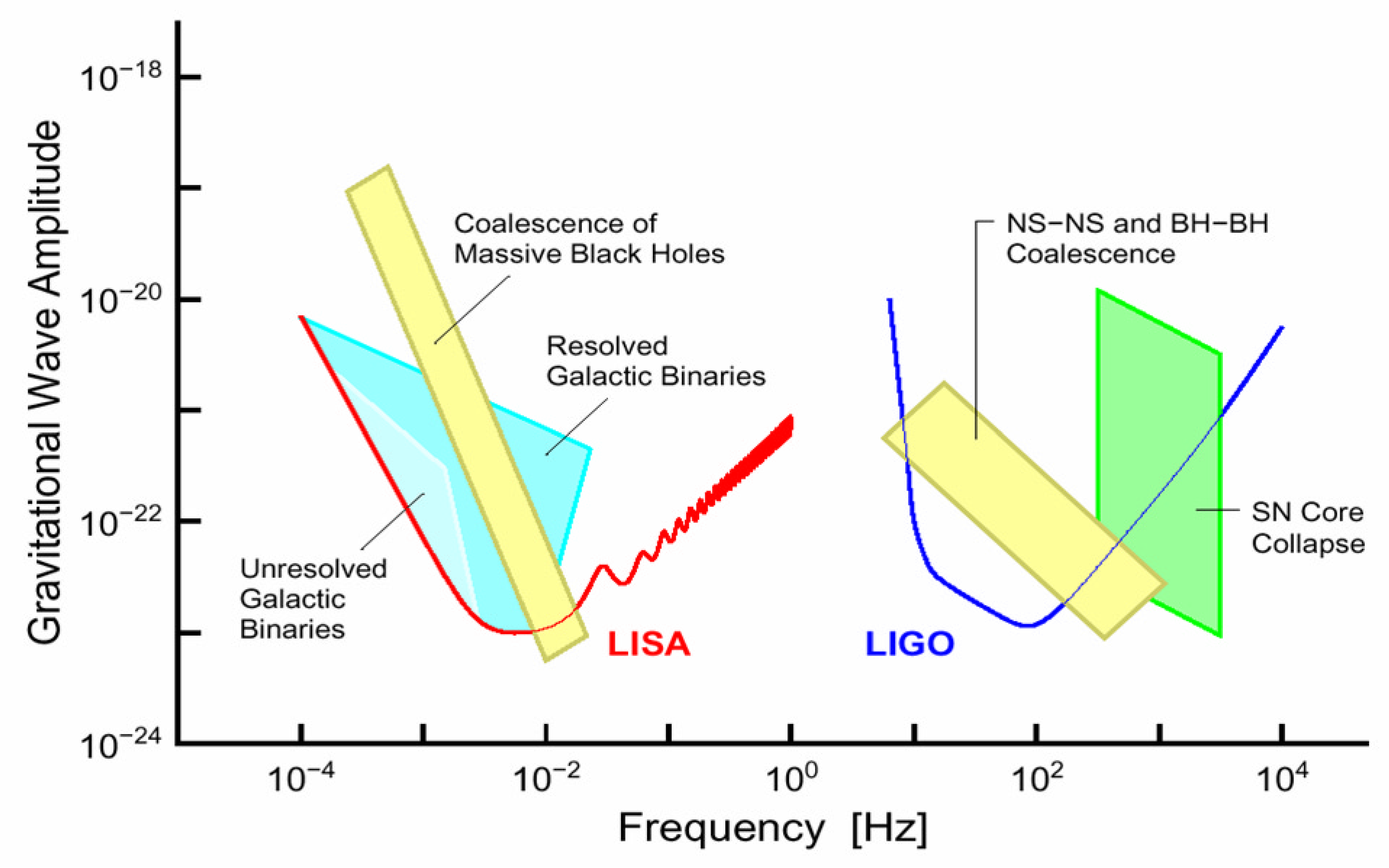


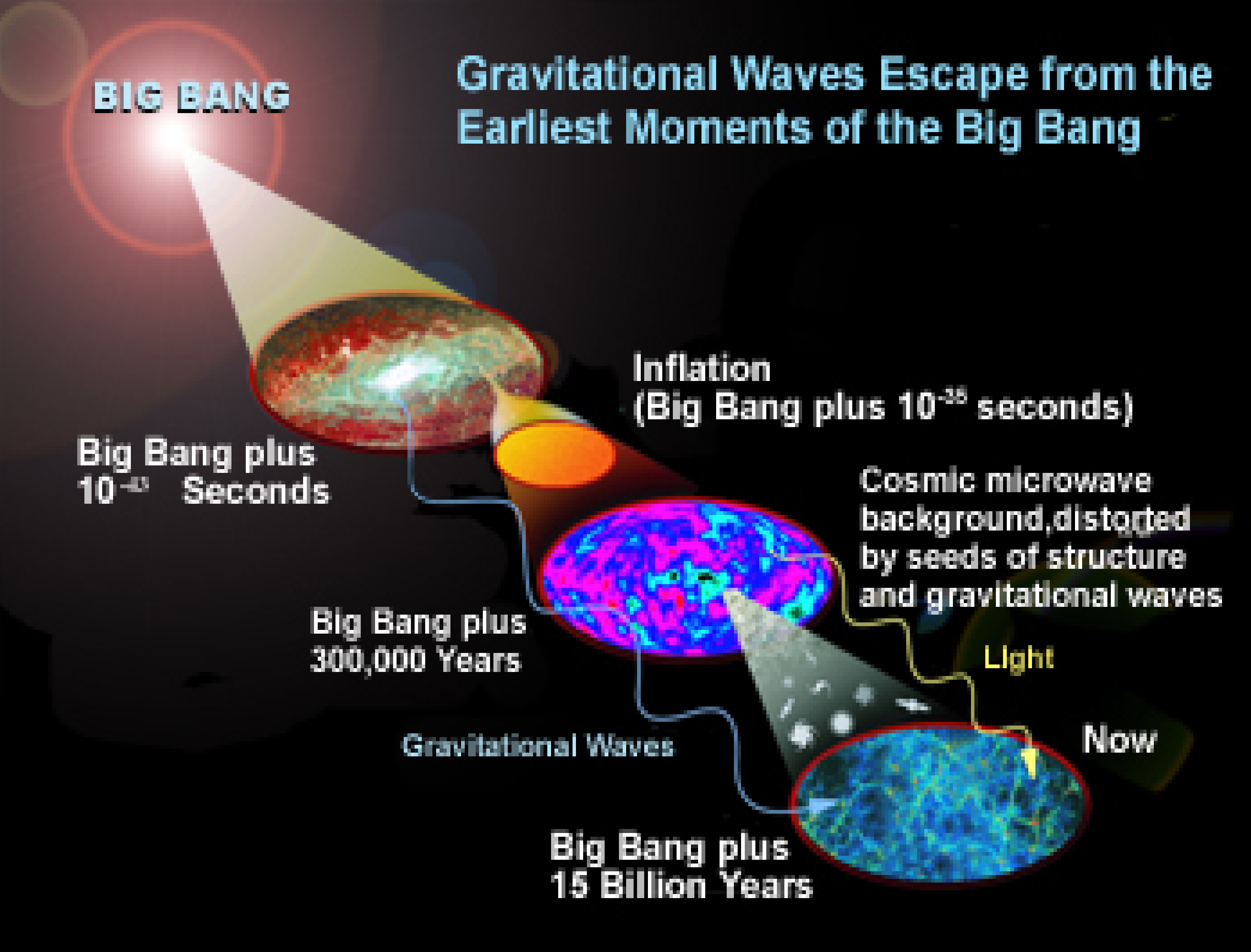
LIGO Hanford Observatory

LISA Detector Concept



Sensitivity of LIGO and LISA



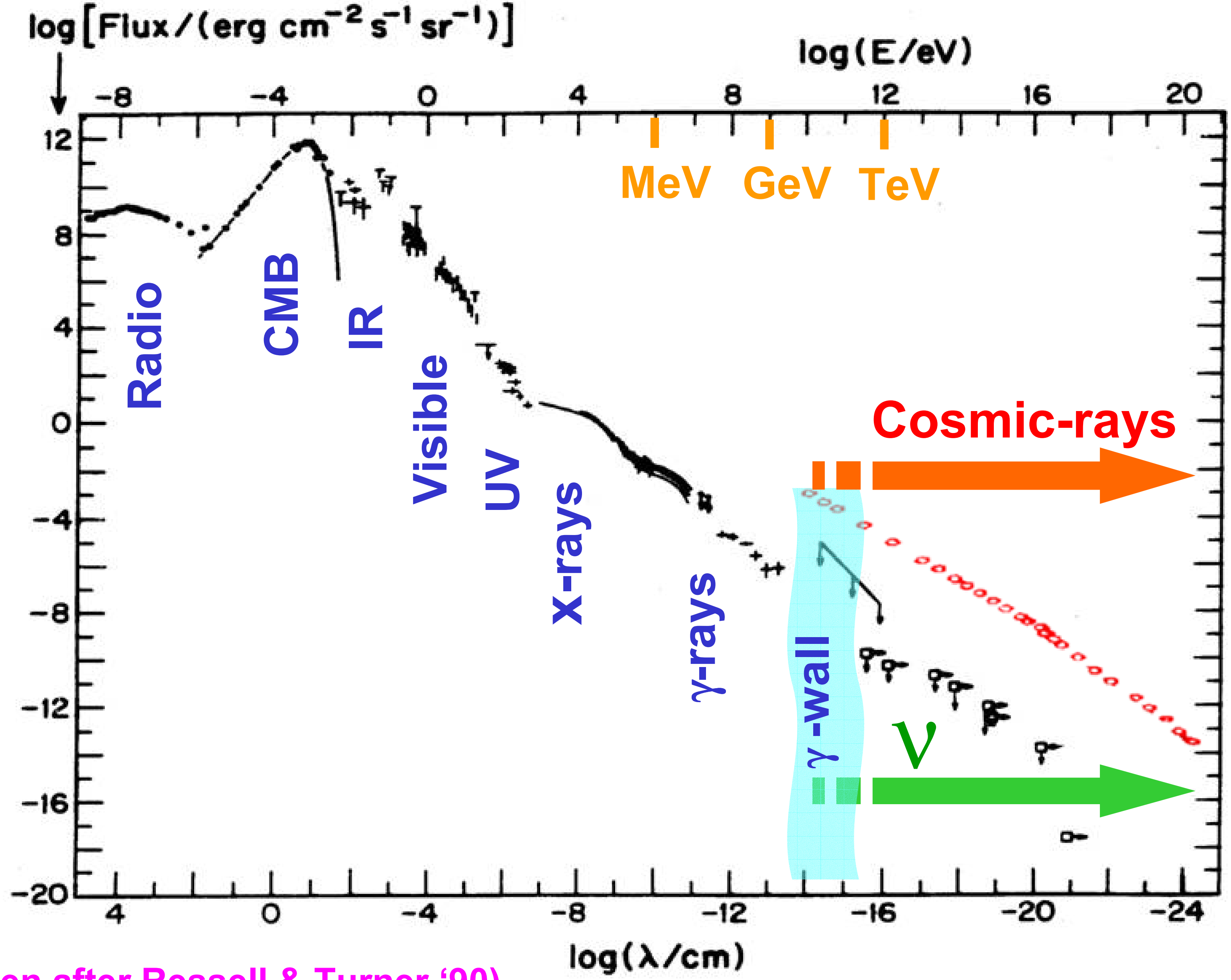

Gravitational Waves Escape from the Earliest Moments of the Big Bang
BIG BANG
Inflation
(Big Bang plus 10^{-35} seconds)
Big Bang plus
10^{-43} Seconds
Cosmic microwave background,distorted by seeds of structure and gravitational waves
Big Bang plus
300,000 Years
Light
Gravitational Waves
Now
Big Bang plus
15 Billion Years

Gravitational Wave

Ultimate Goals

- **Energy Frontier of Particle Physics, Cosmology and Astronomy**
  - Earliest Universe: Inflation, Planck Scale …
  - Extreme Universe: AGN, GRB …
- **Need for Multi-Messenger Approach**
  - Gamma ray Veritas, GLAST …
  - Charged Particle Auger, EUSO …
  - Neutrino Icecube, Auger …
  - Gravitational Wave LIGO, LISA …

Cosmic Radiation

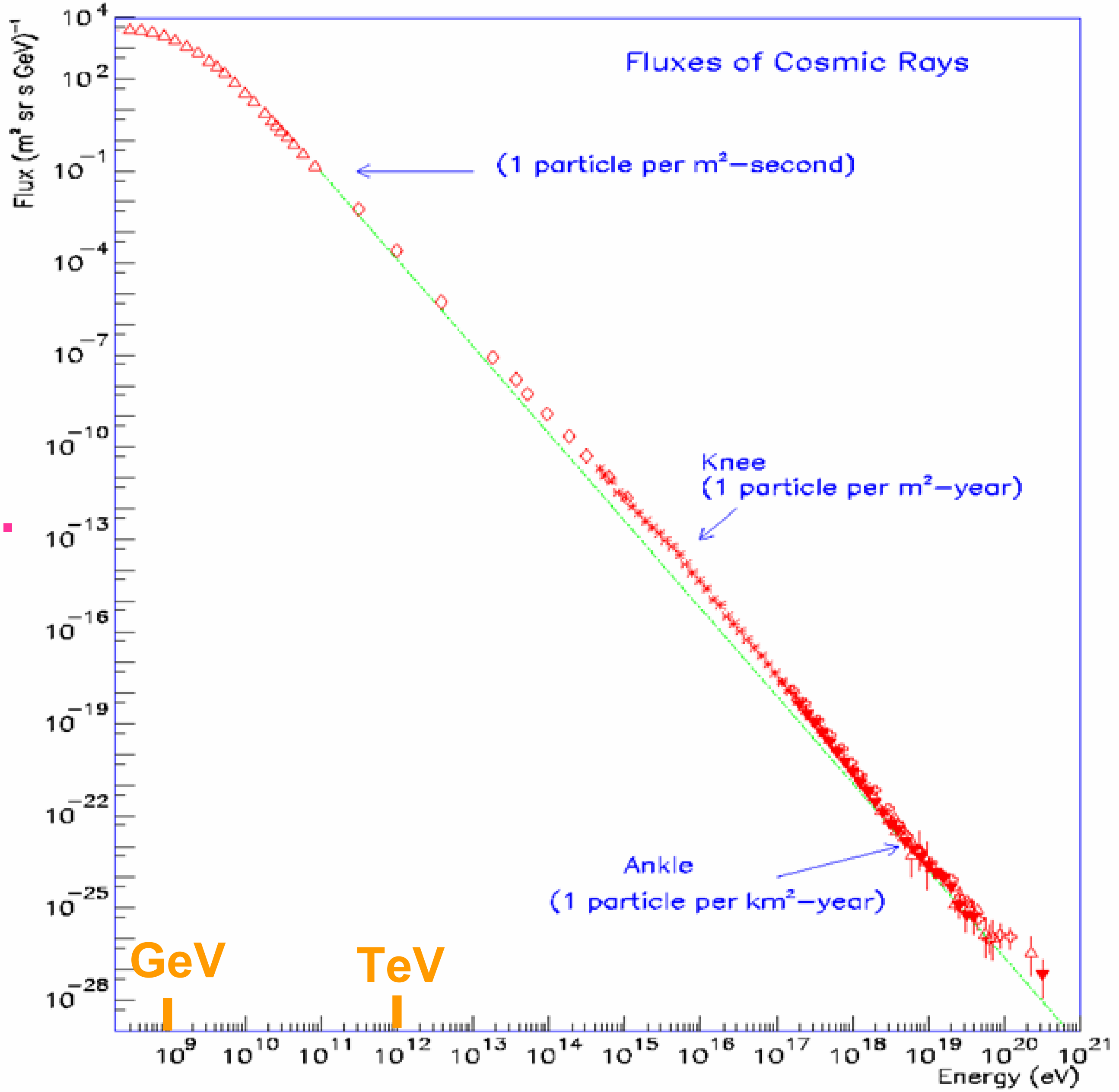


(by Halzen after Ressell & Turner '90)

2

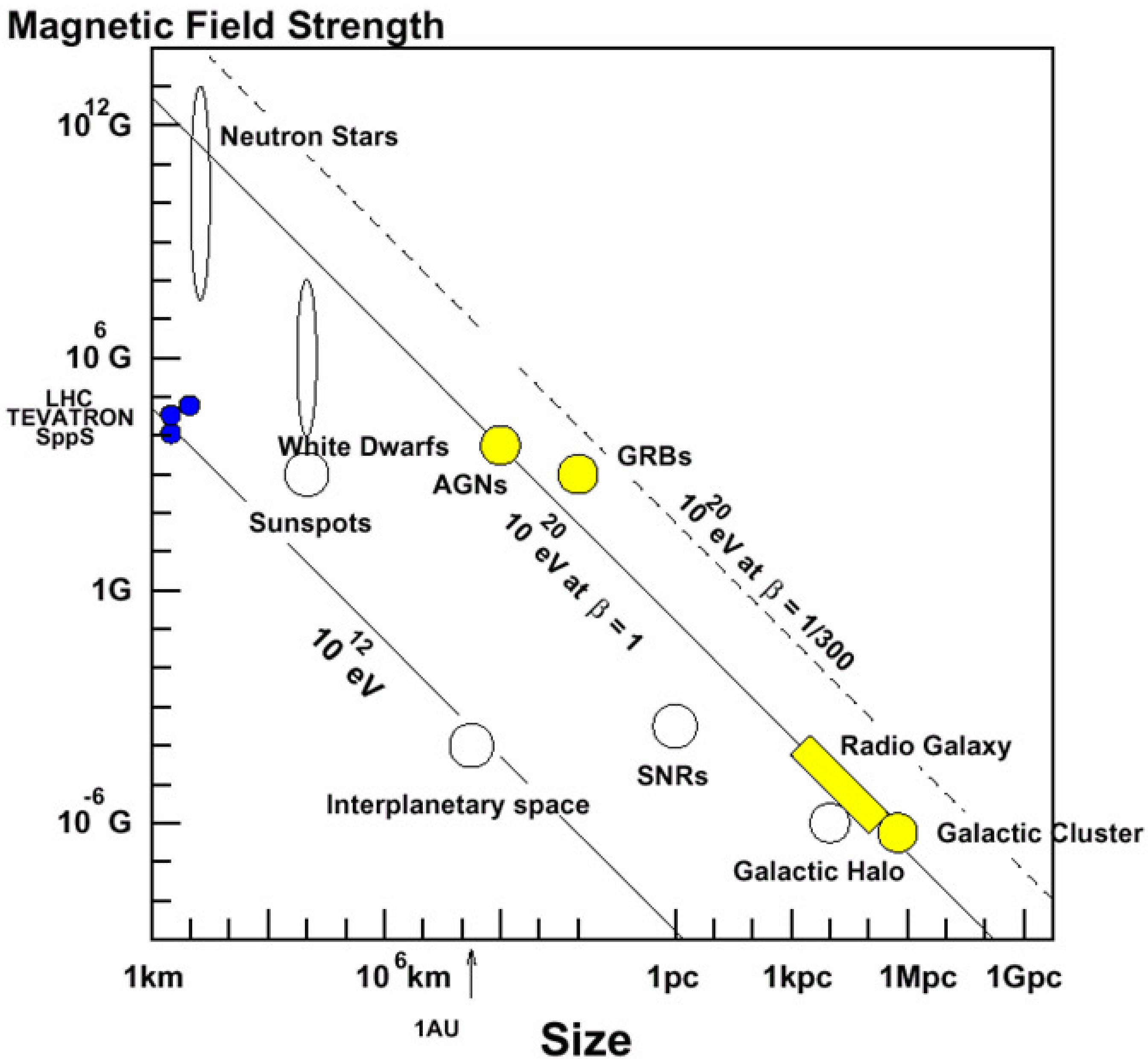
Energy Spectrum of Cosmic Rays

- **Energy Spectrum** **~ E^{-3}**
- **The spectrum extends beyond** **10^{20}eV (=10^{11}GeV).**
- **Beyond 10^{20}eV, Flux is only** **one particle per km^2-century.**



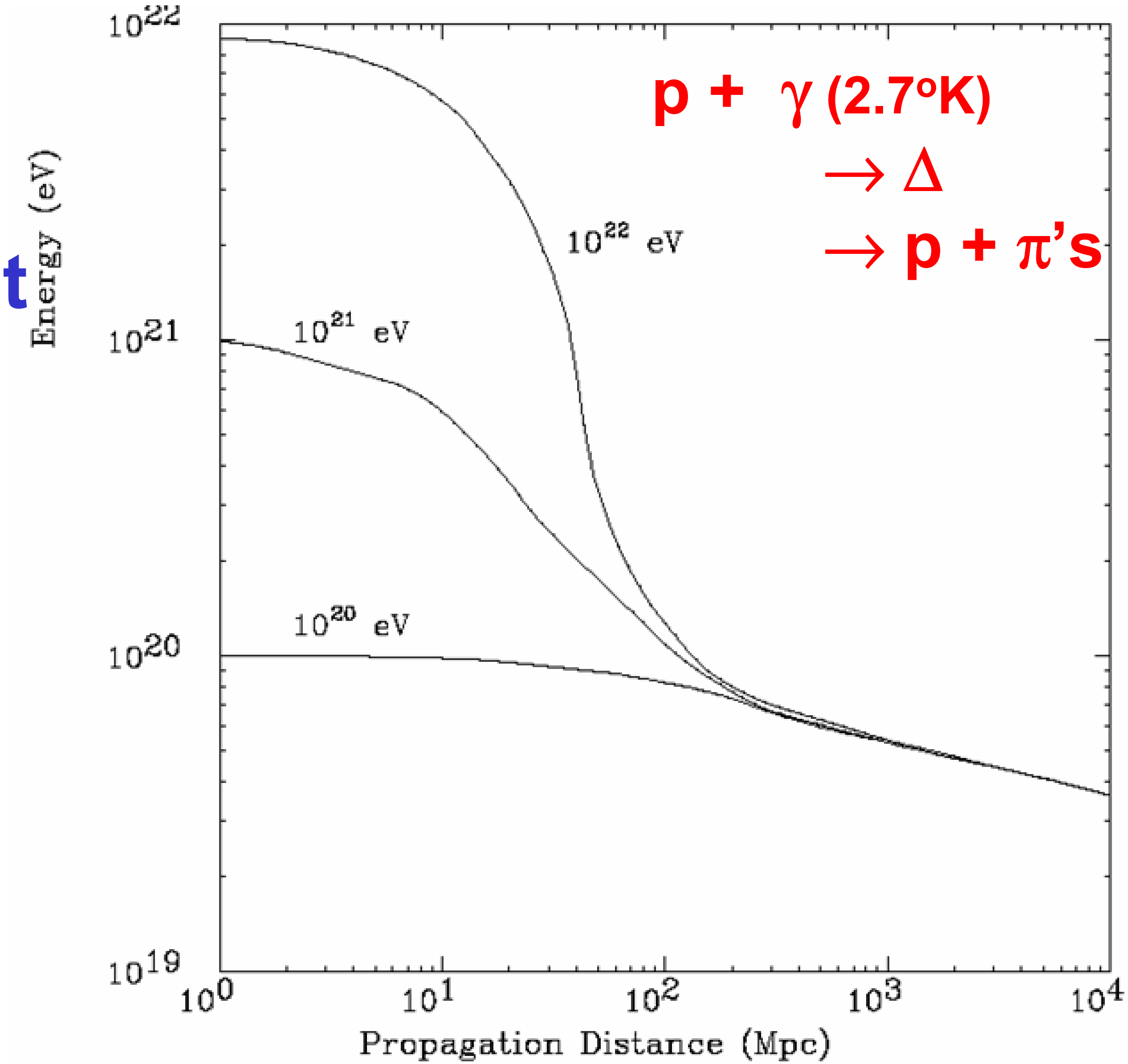
Possible Acceleration Sites

- Several possible accelerators in nature up to 10^{20}eV.
- Extremely difficult to accelerate above 10^{20}eV.

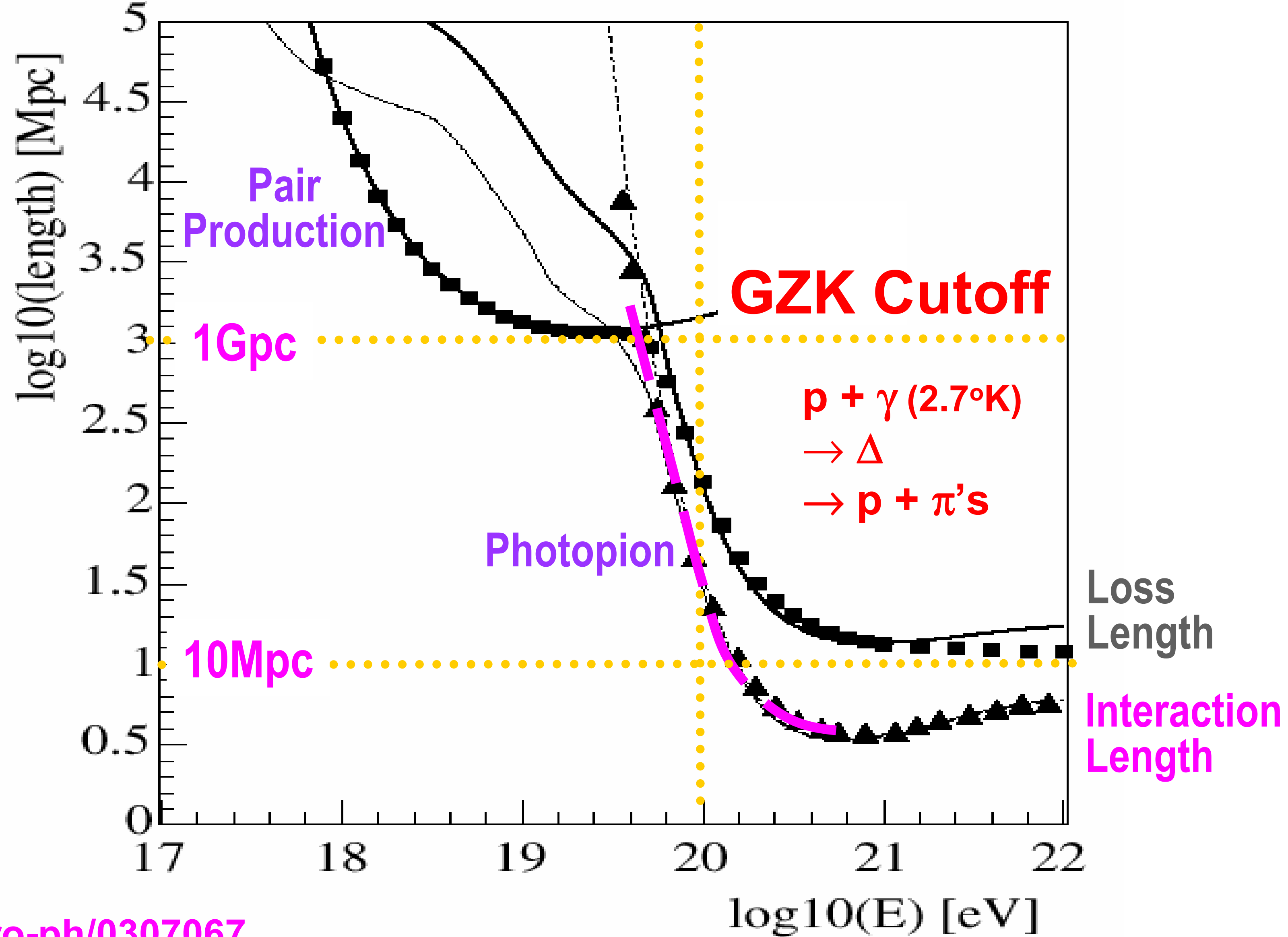


Effect of GZK Cut-off

- Protons above ~10^{20}eV can not travel more than ~50Mpc (~1% of the Horizon of the Universe.)

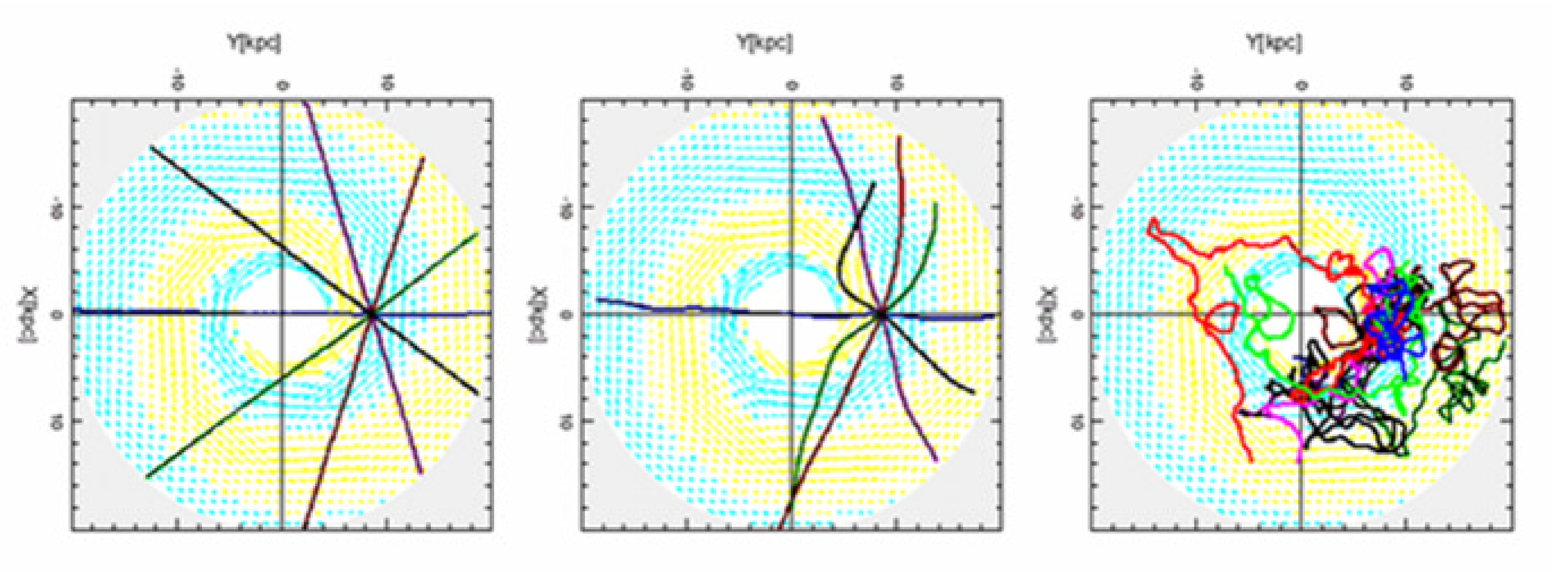


Interaction Length of UHE Protons



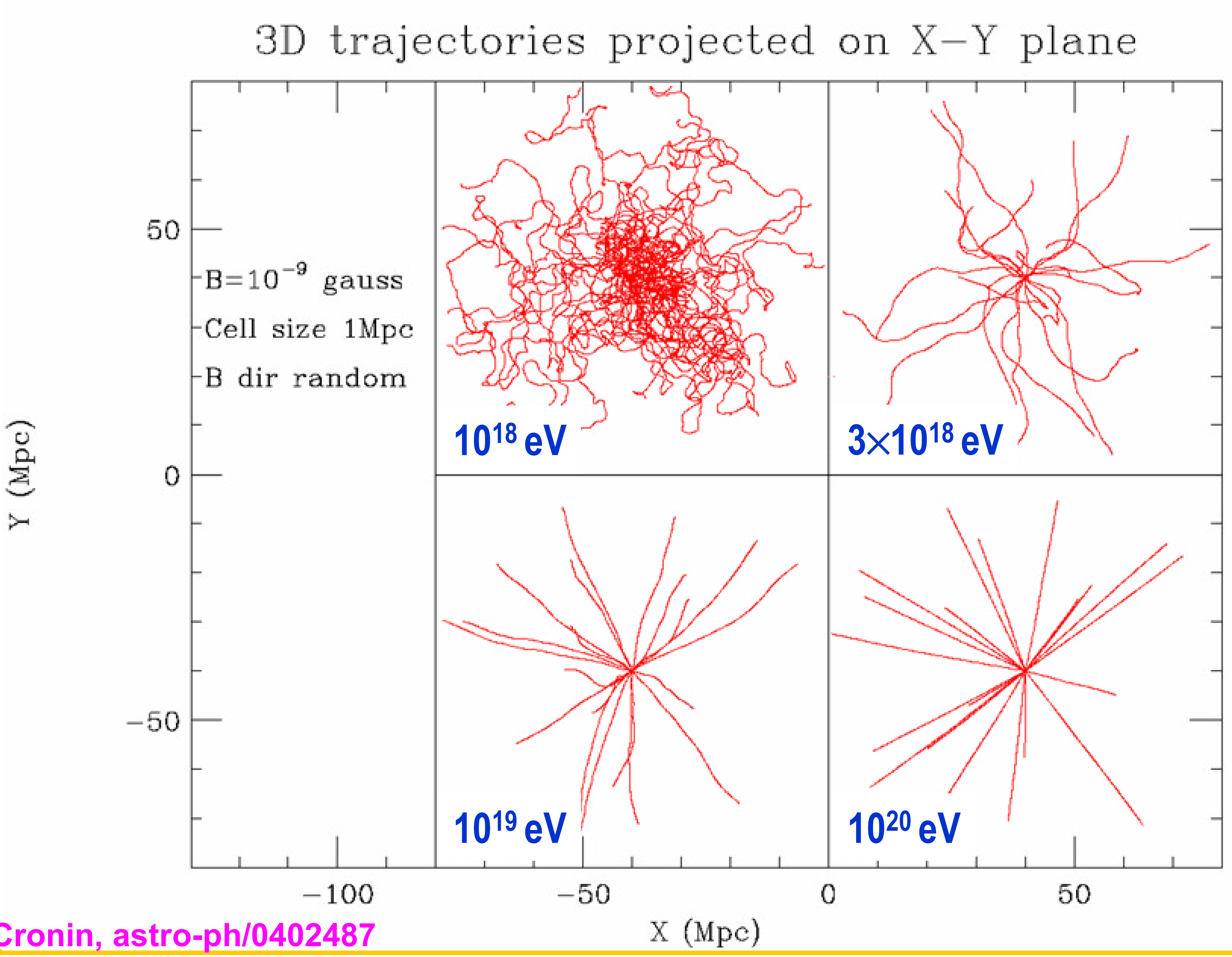
Blasi, astro-ph/0307067

Trajectory of Cosmic Ray Protons in the Galaxy



E=10^{20}eV **E=10^{19}eV** **E=10^{18}eV**

Trajectories of Protons in inter Galactic Space

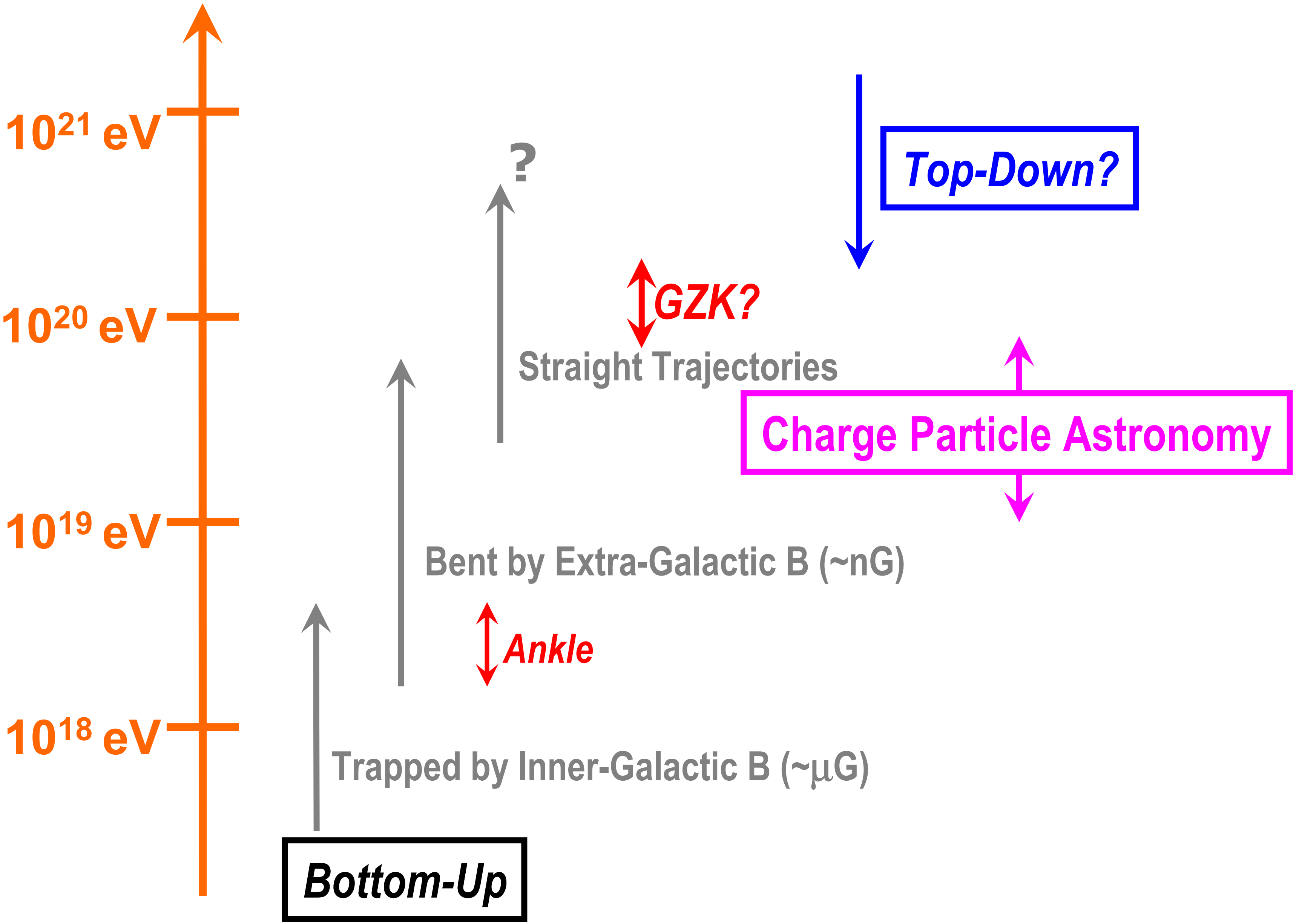


Jim Cronin, astro-ph/0402487

Why is ~10^{20} eV so special?

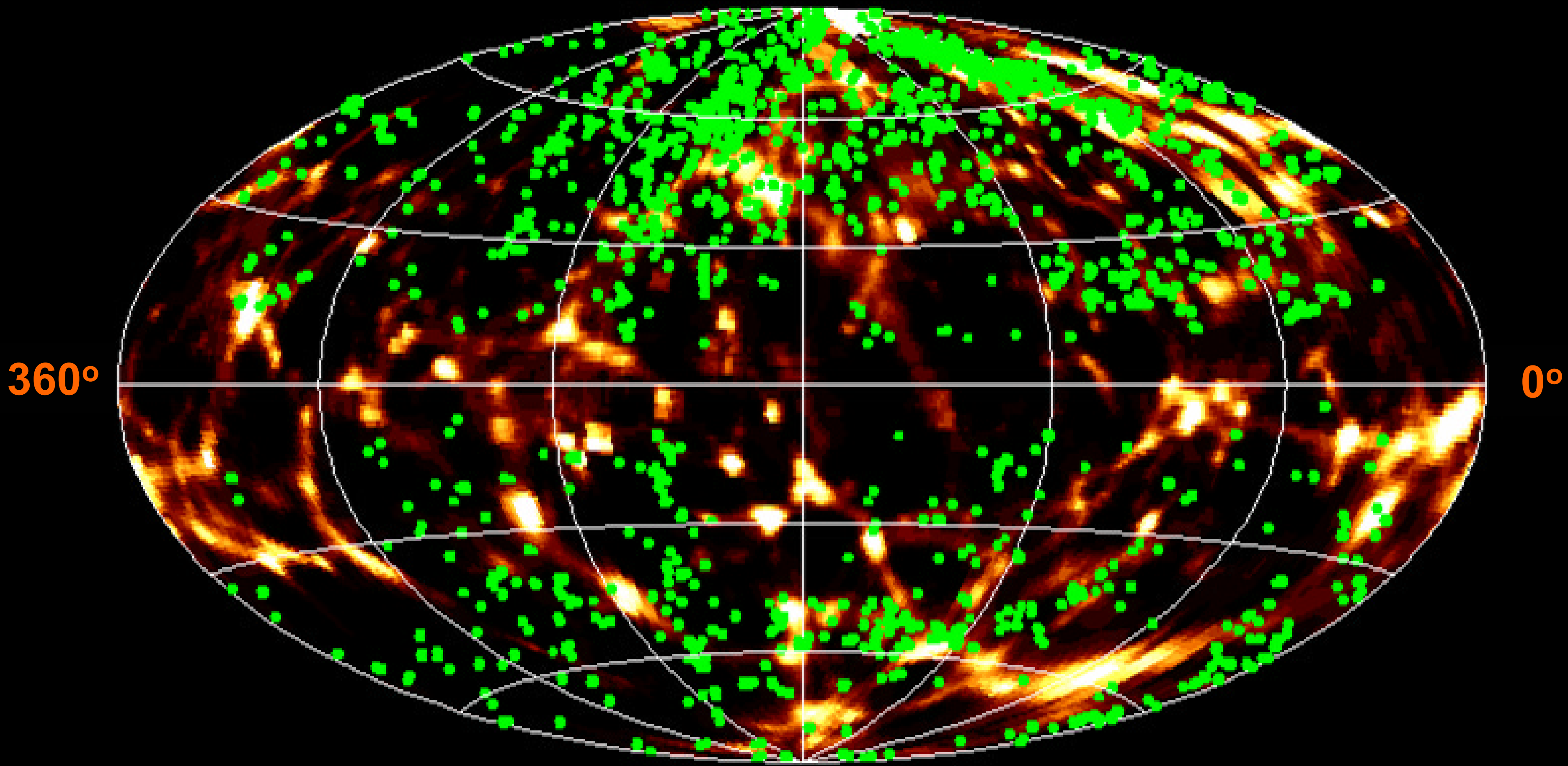
- Protons can not travel beyond ~100Mpc at E > 10^{20}eV due to interaction with CMB.
  - GZK Cut-off
- Protons can travel straight at E > ~4×10^{19}eV.
  - Charged-Particle Astronomy
  - New Window of Extreme Universe
- Difficult to accelerate beyond 10^{20}eV.
  - Top-down Mechanism?

Rich Physics and Astronomy



Galaxies (R < 45 Mpc)

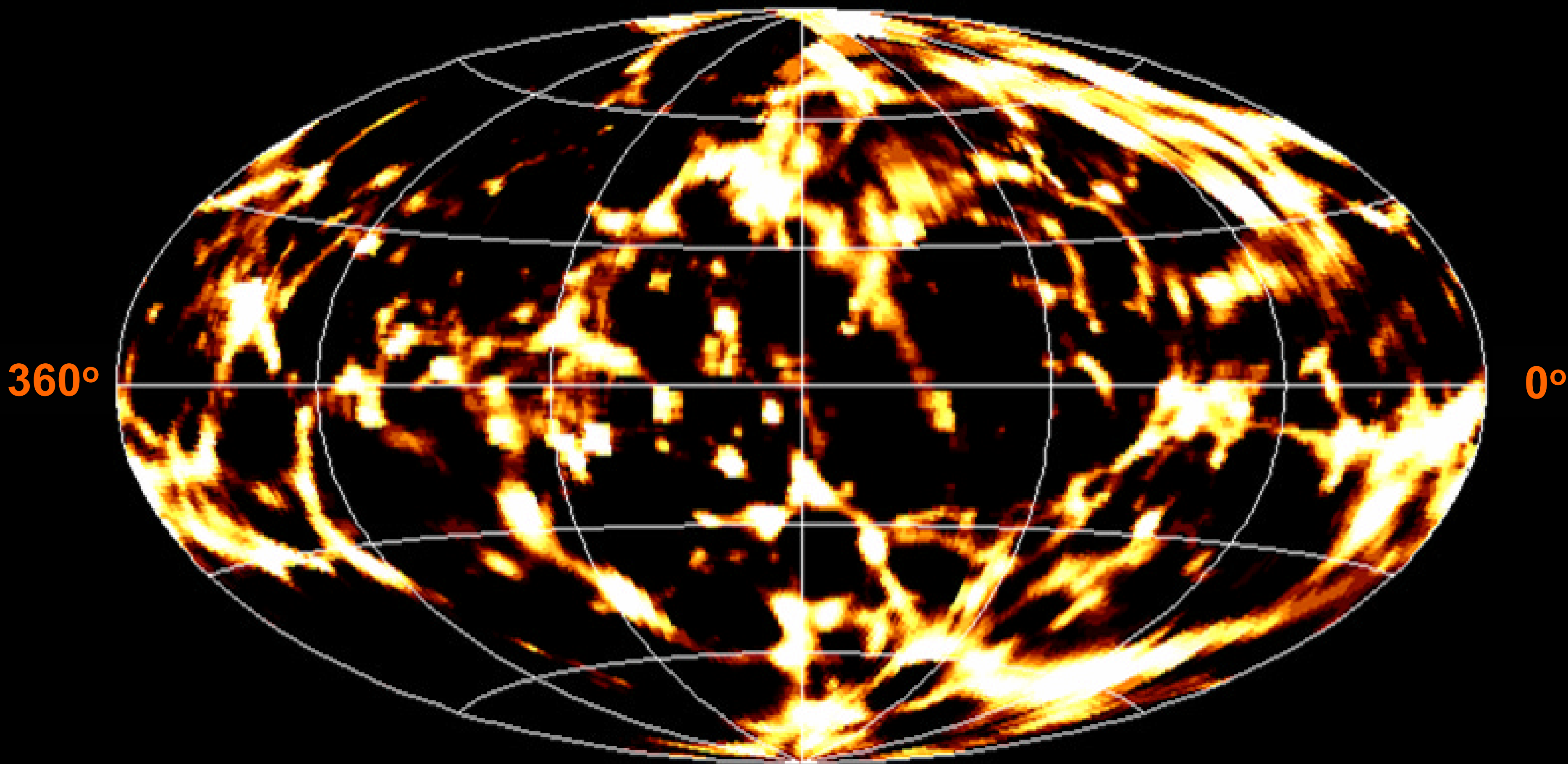
Matter (7 < R < 93 Mpc)



Andrey Kravtsov

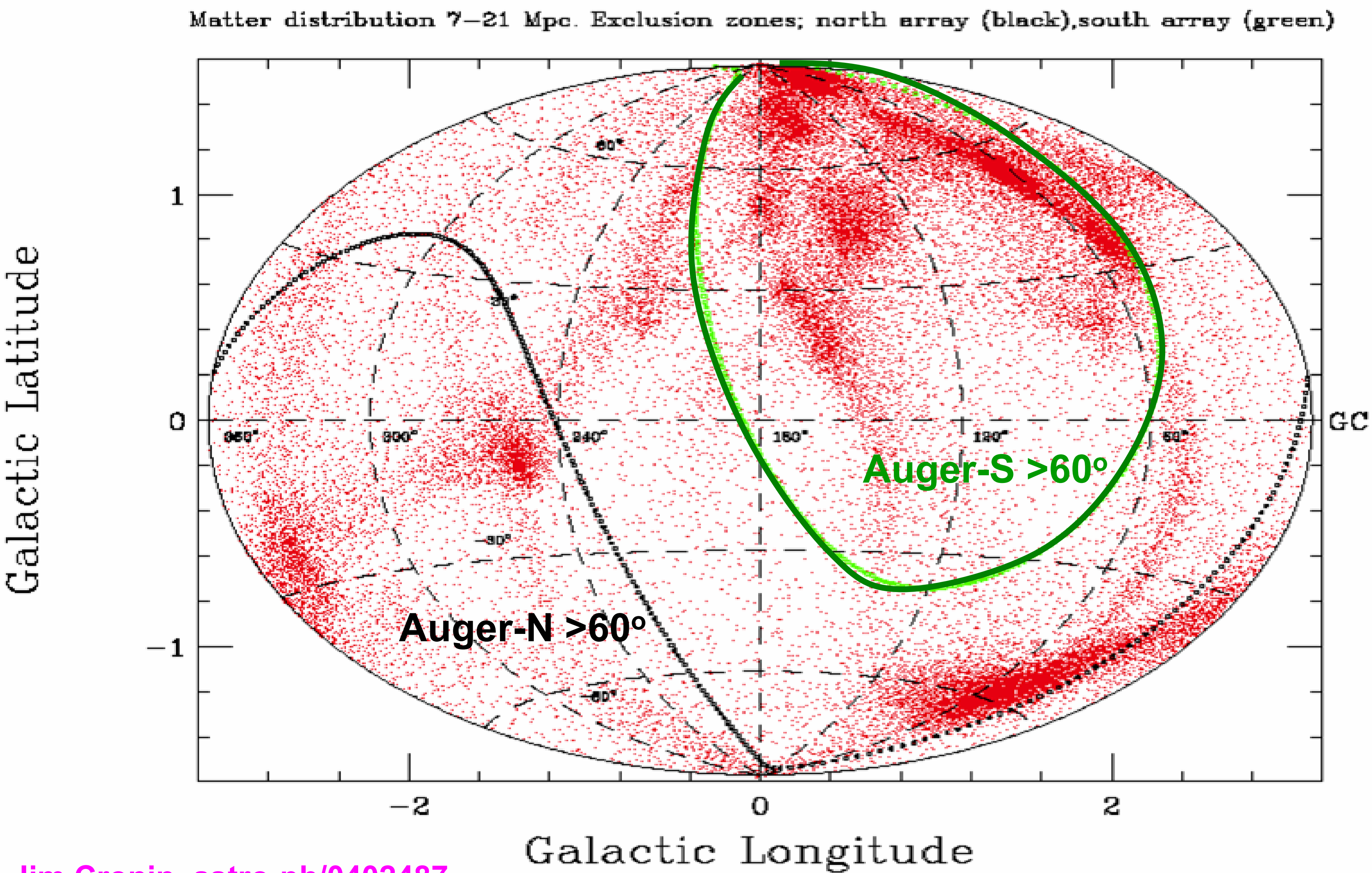
Matter Distribution
(7 < R < 93 Mpc)

Projected matter distribution in a constrained realization (7 < R < 93 Mpc)



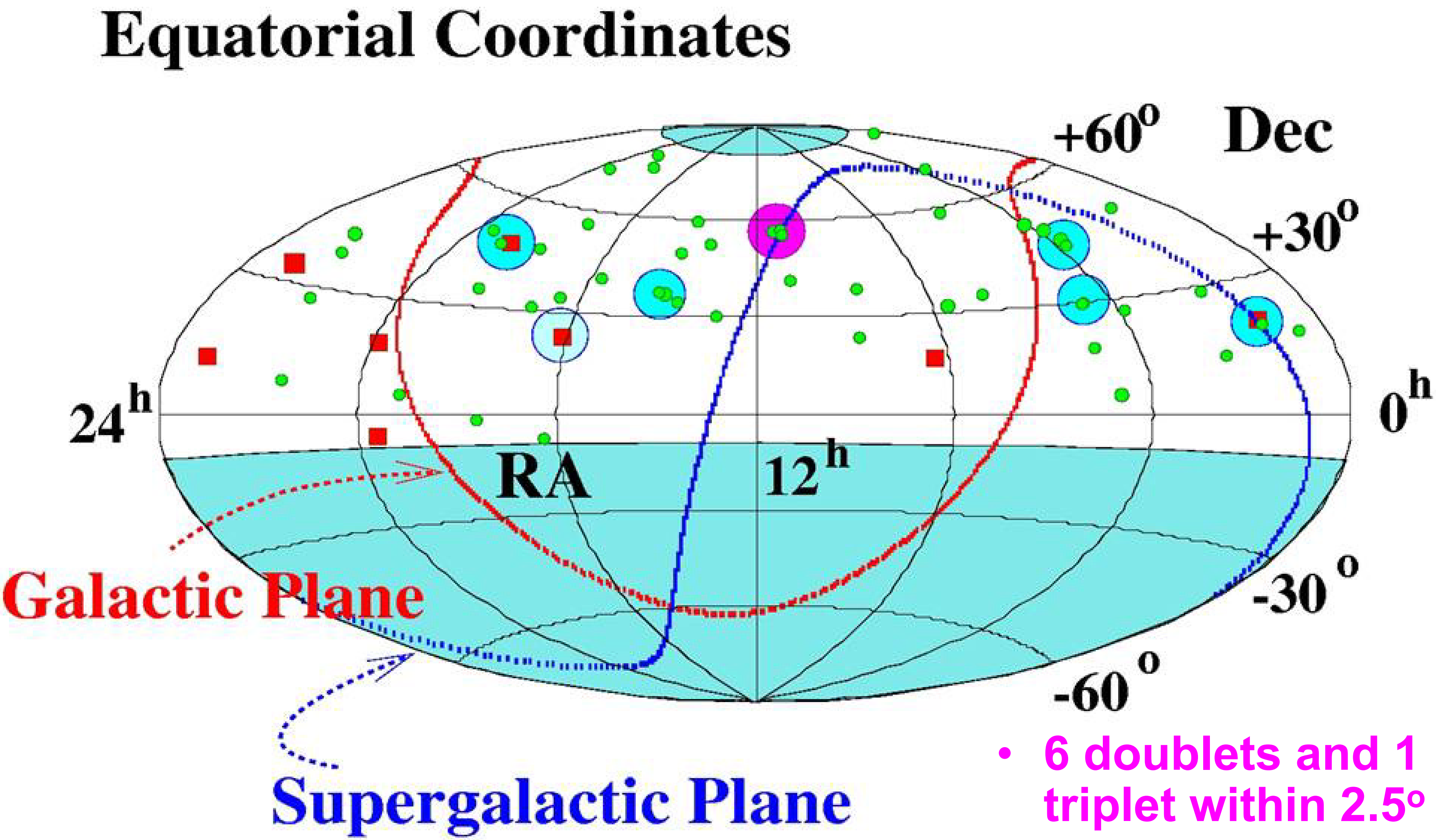
A. Kravtsov

Distribution of Matter
(7-21Mpc)



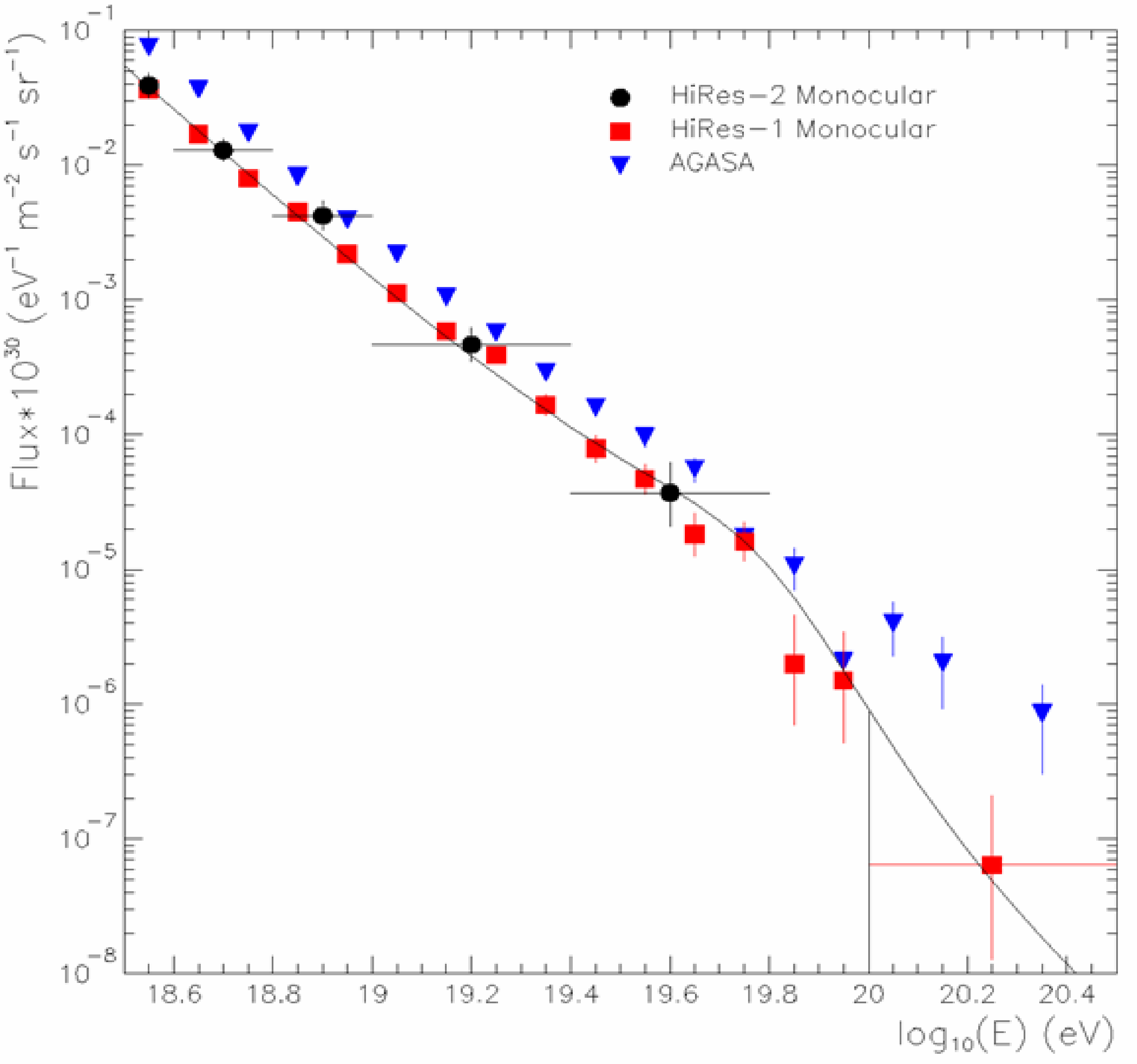
Jim Cronin, astro-ph/0402487

Arrival Direction of UHECR (>4×10^{19}eV) by AGASA



- 6 doublets and 1 triplet within 2.5° cone.

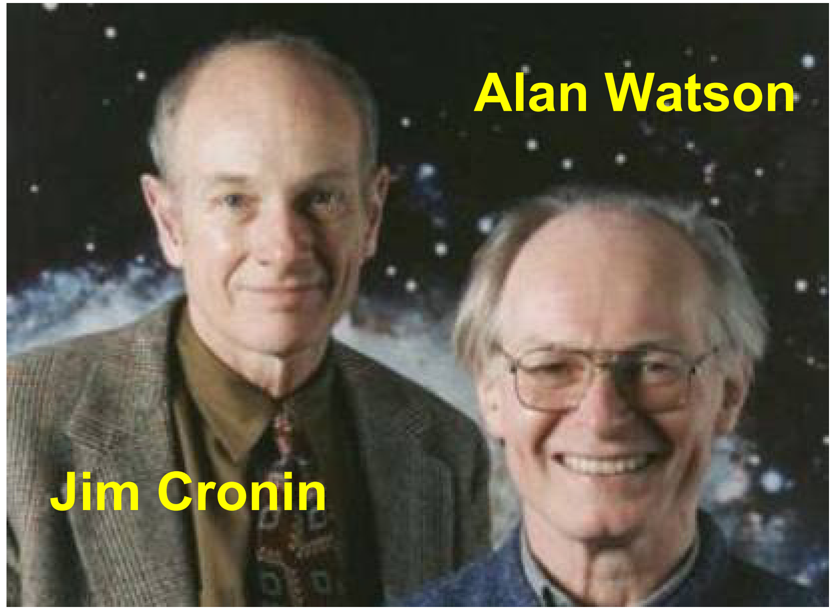
HiRes vs. AGASA

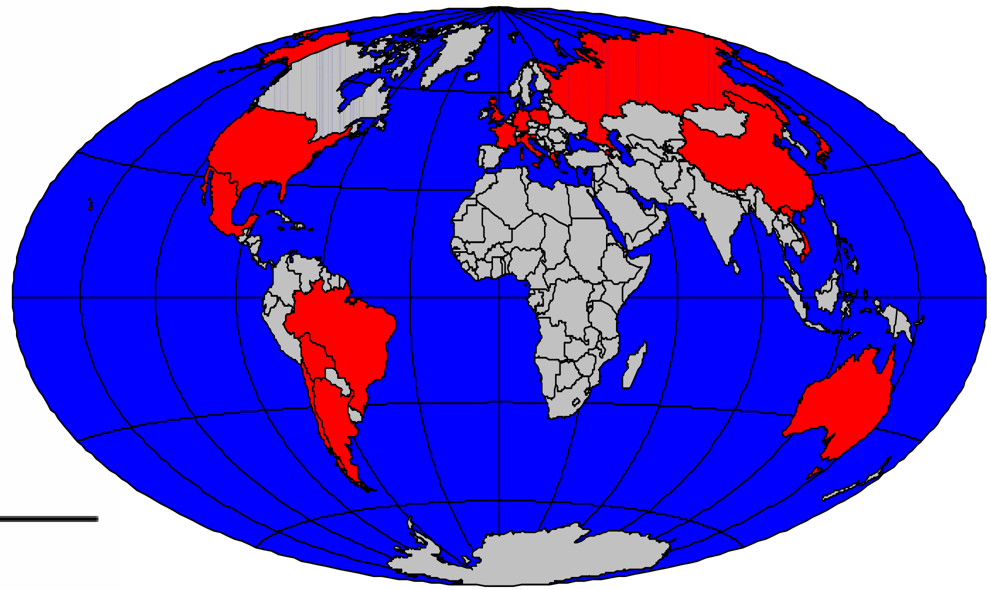


?

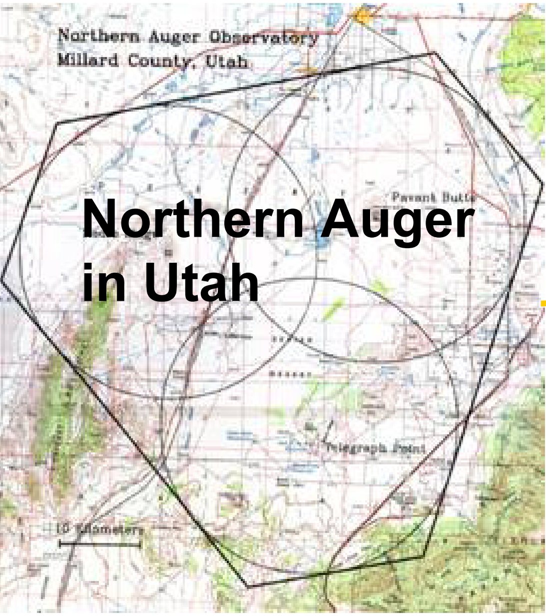
Pierre-Auger Collaboration

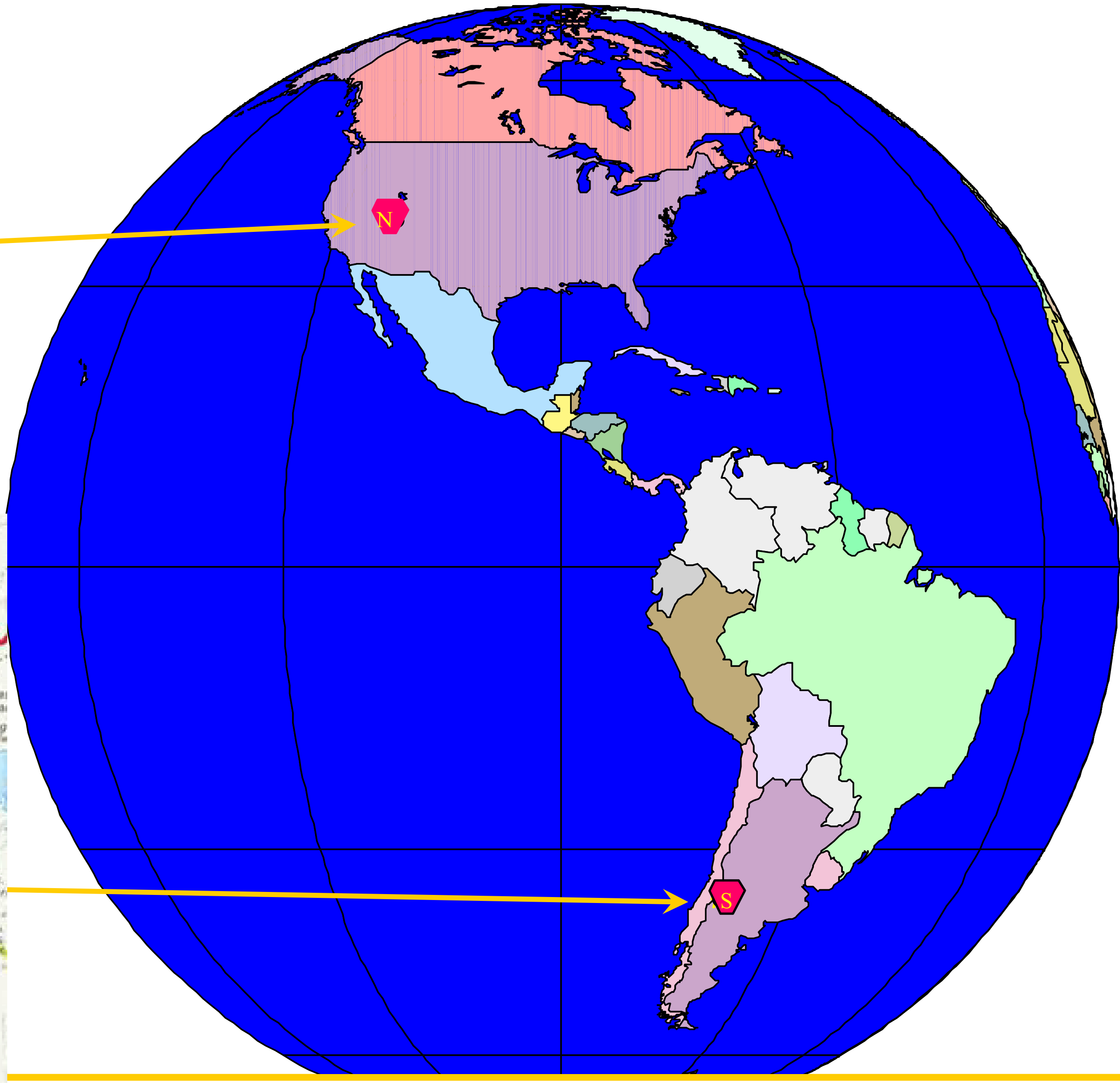
	Country	Institutions	Phys.+Eng.
	Armenia	1	6
EUROPE	France	6	29
EUROPE	Greece	1	15
EUROPE	Germany	1	3
EUROPE	← Italy		
EUROPE	Poland	2	8
EUROPE	Slovenia	1	3
EUROPE	Russia	1	4
EUROPE	United Kingdom	1	6
ASIA	China	1	11
ASIA	Japan	1	6
ASIA	Vietnam	2	9
	Australia	1	3
LATIN AMERICA	Argentina	6	38
LATIN AMERICA	Bolivia	1	4
LATIN AMERICA	Brazil	4	26
LATIN AMERICA	Chile	1	3
LATIN AMERICA	Mexico	4	43
	USA	11	62
	TOTAL	**46**	**279**



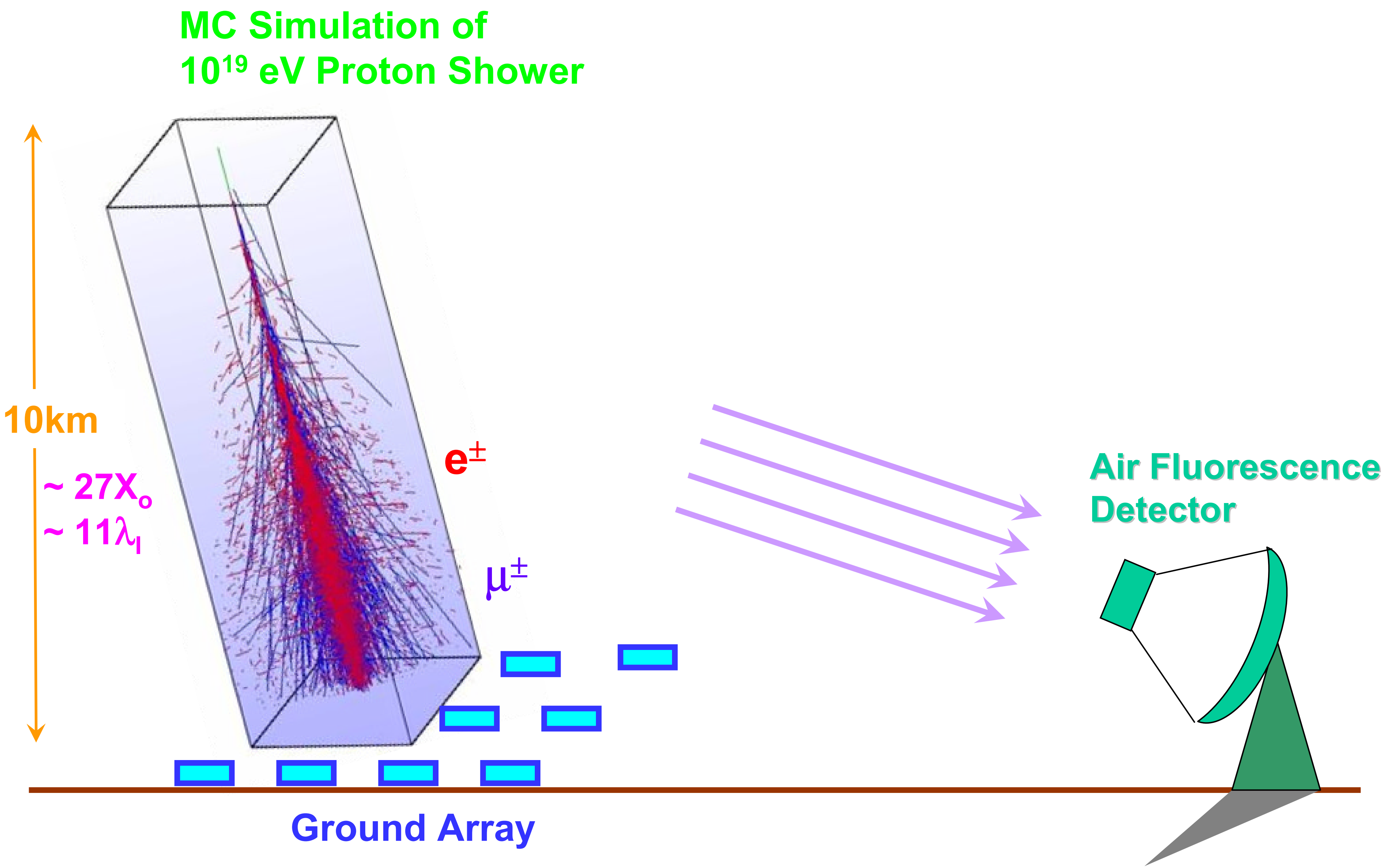


Pierre-Auger Observatory

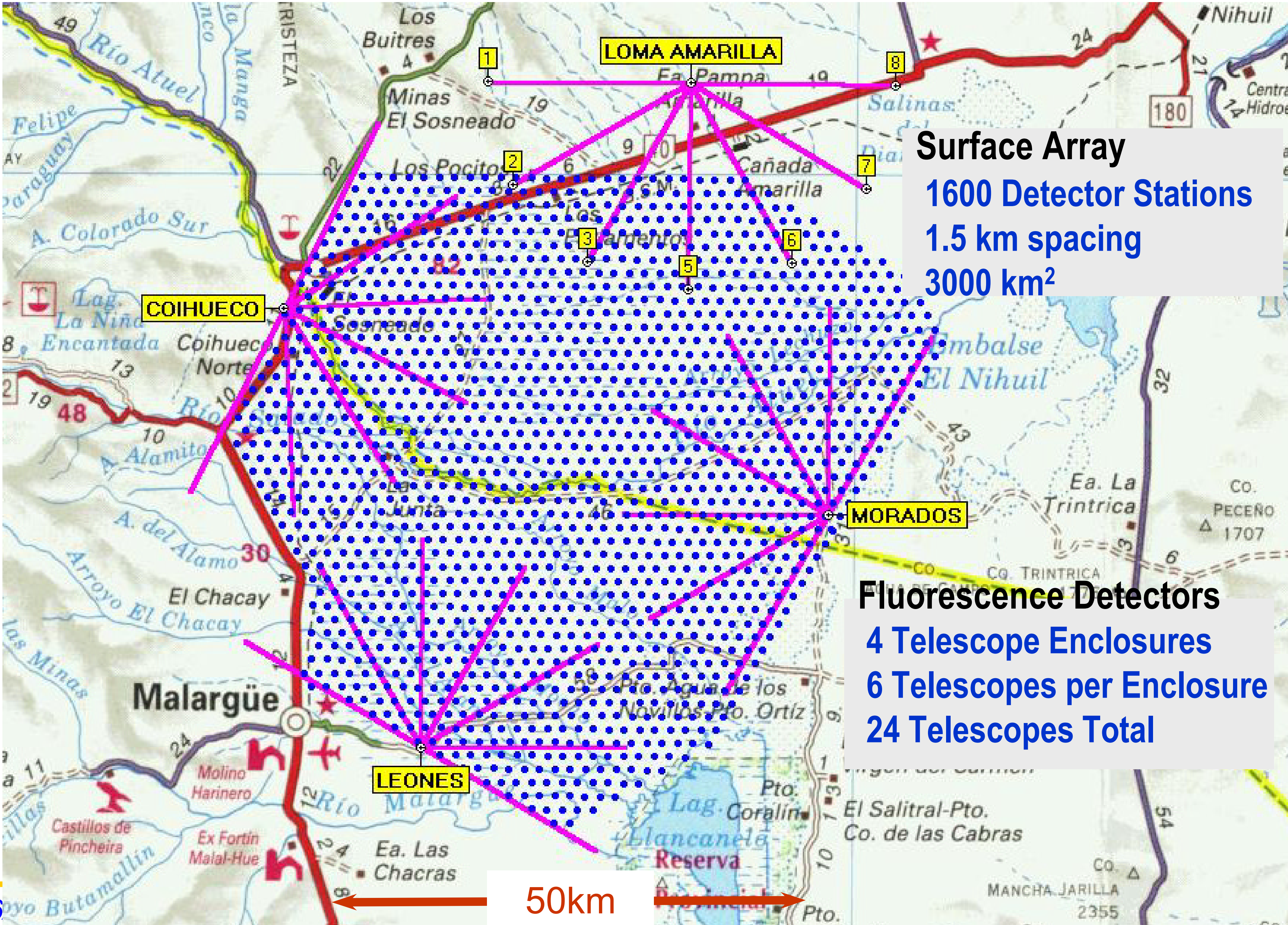




Principle of Hybrid Detection



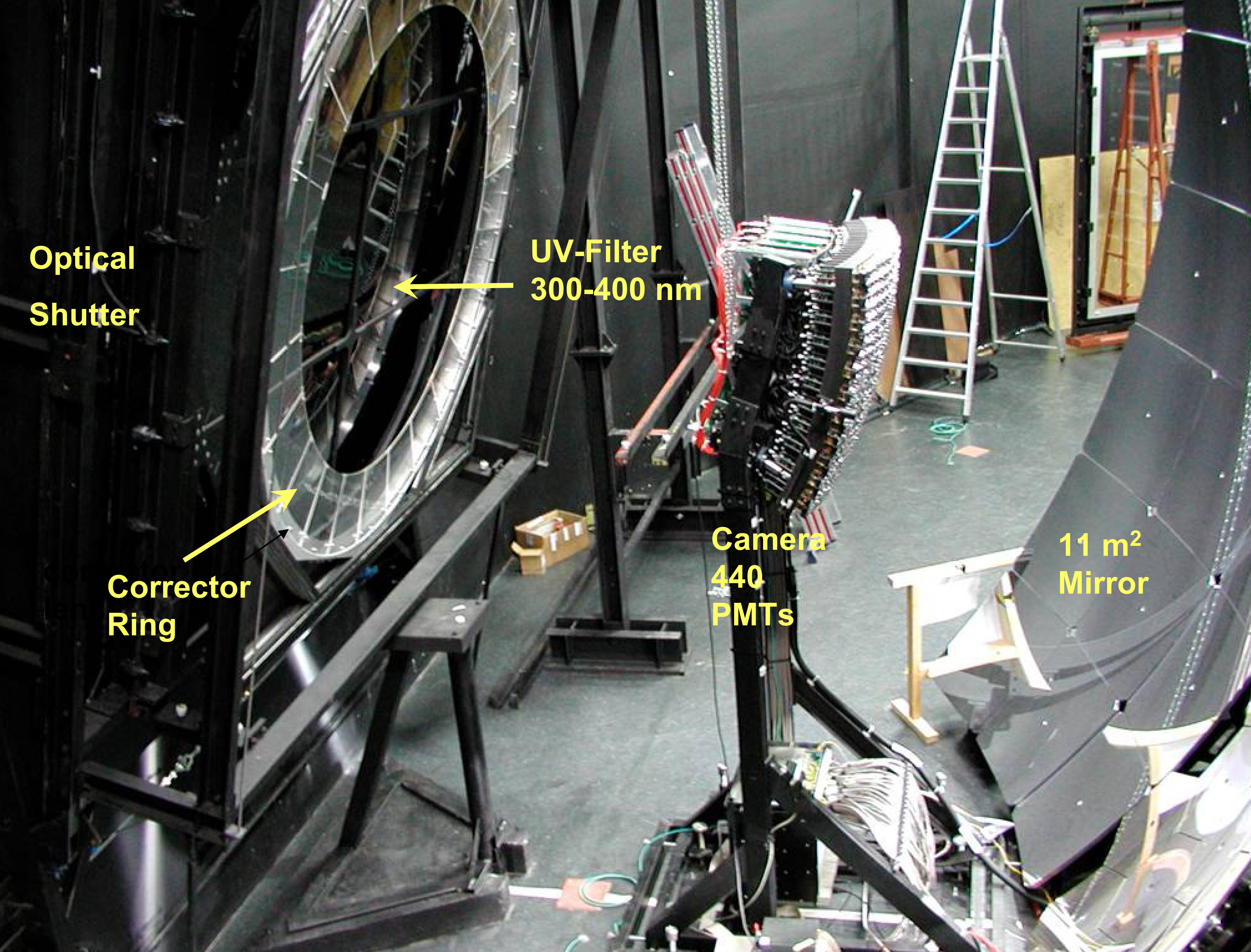
Southern-Auger in Argentina



Surface Array
- 1600 Detector Stations
- 1.5 km spacing
- 3000 km^2

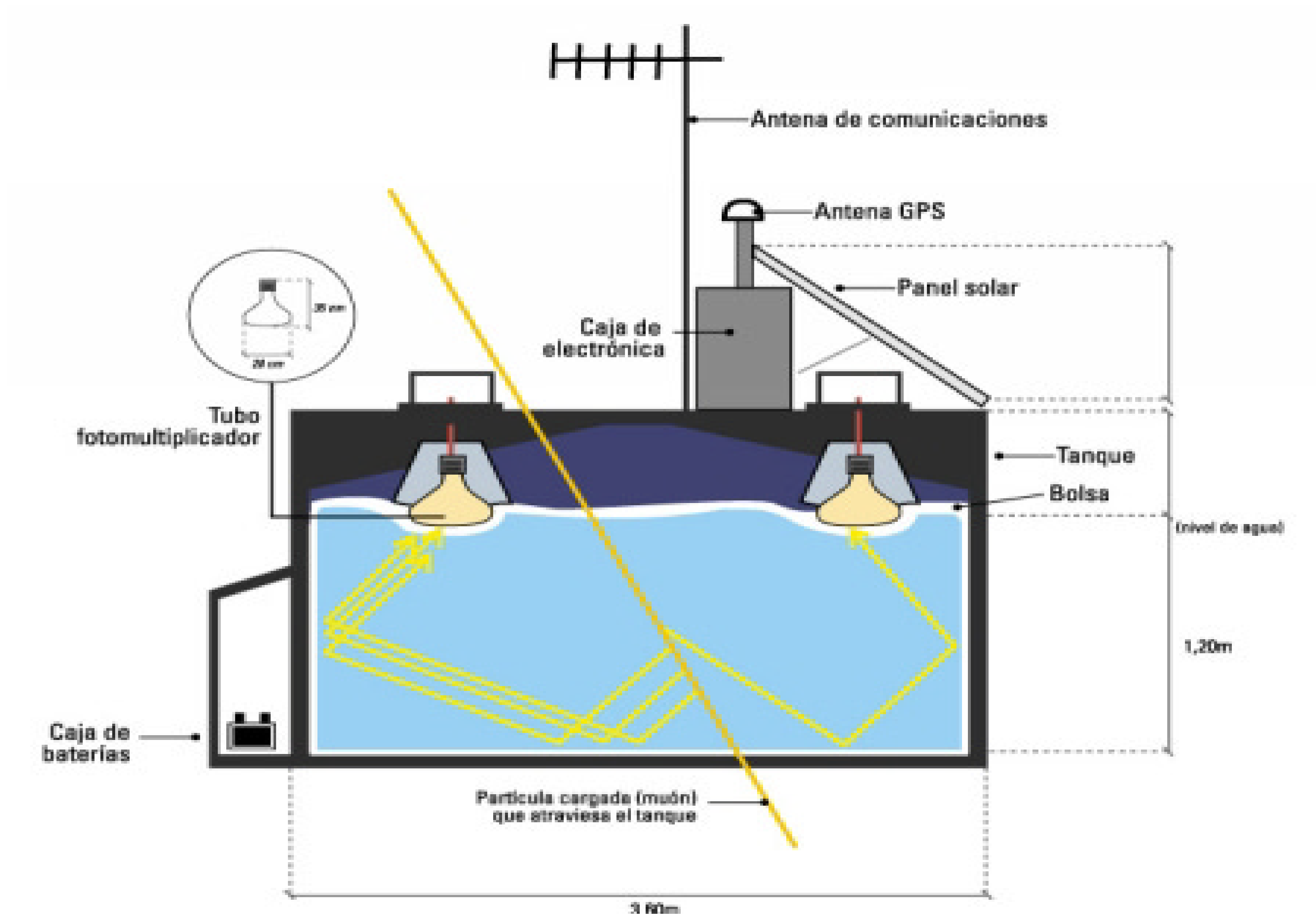
Fluorescence Detectors
- 4 Telescope Enclosures
- 6 Telescopes per Enclosure
- 24 Telescopes Total


The First Fluorescence Detector

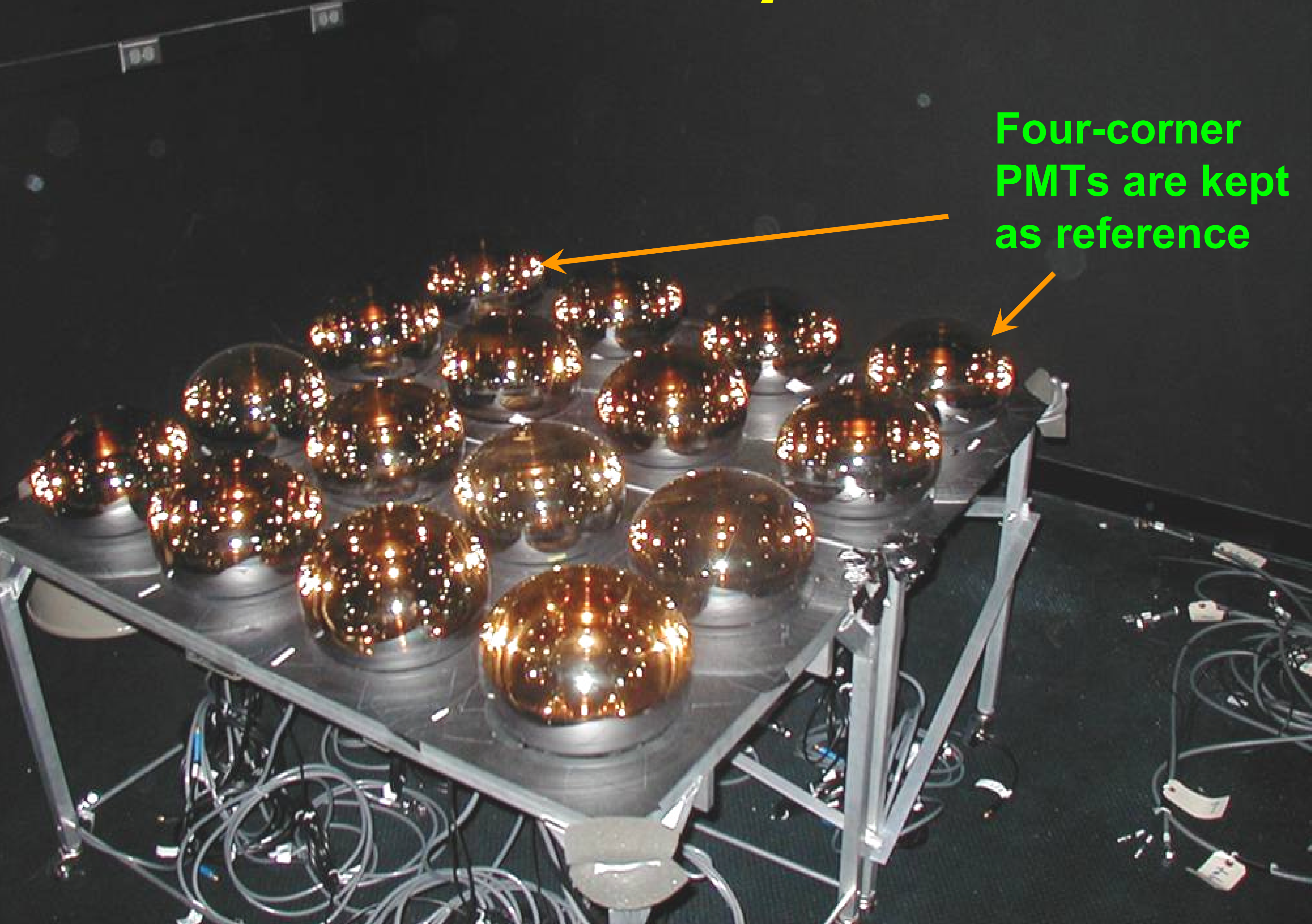

Optical
Shutter
UV-Filter
300-400 nm
Corrector
Ring
Camera
440
PMTs
11 m²
Mirror

Surface Detector and the Andes

Pierre-Auger Shower Detector Tank



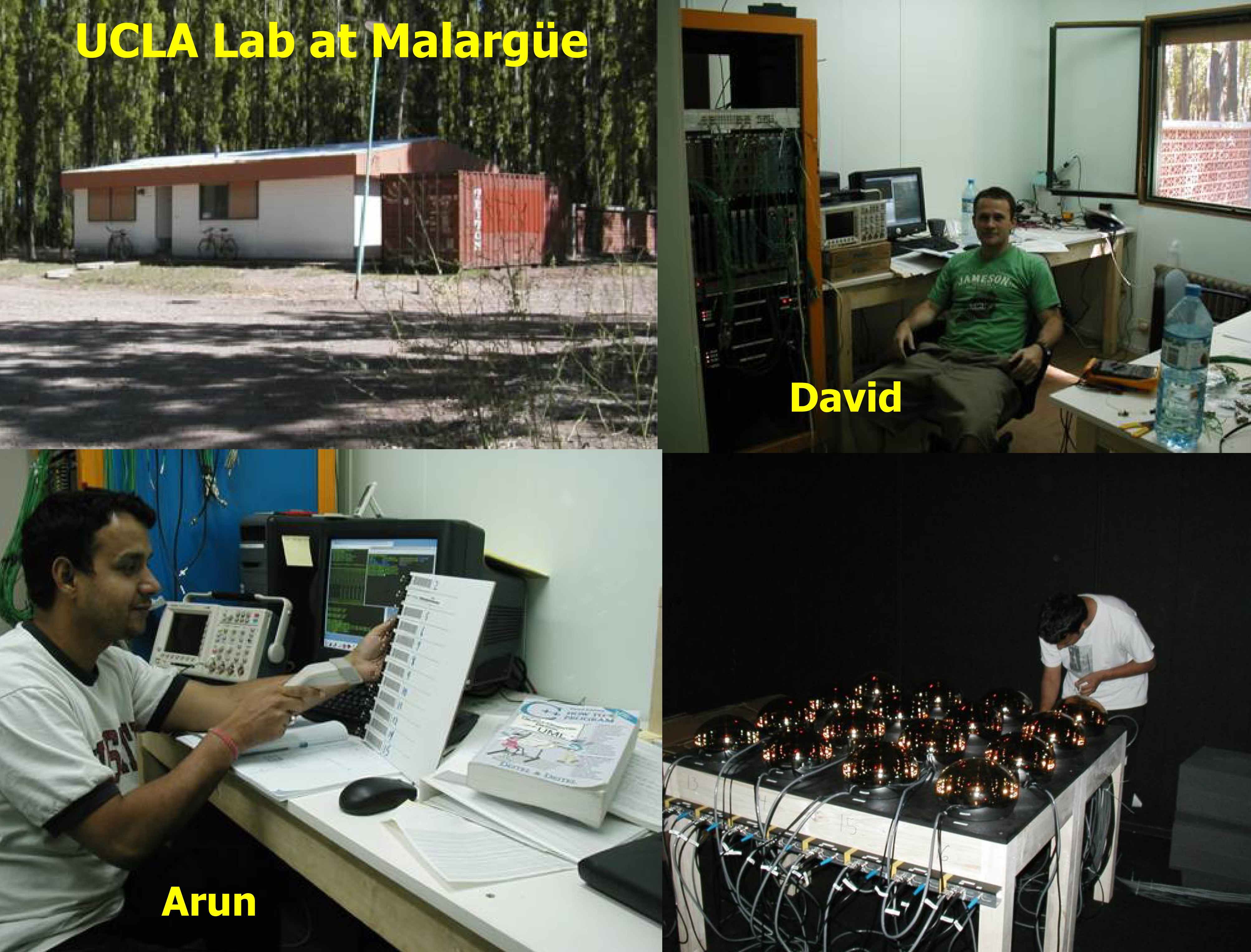
UCLA PMT Test Facility at STRB




PMT Potting Underway at UCLA

UCLA Auger Group

Katsushi Arisaka	Professor
William Slater	Professor
Arun Tripathi	Research Scientist
Tohru Ohnuki	5th year grad.
David Barnhill	4th year grad.
Joong Lee	3rd year grad.
Matt Healy	2nd year grad.
…	


UCLA Lab at Malargüe
David
Arun

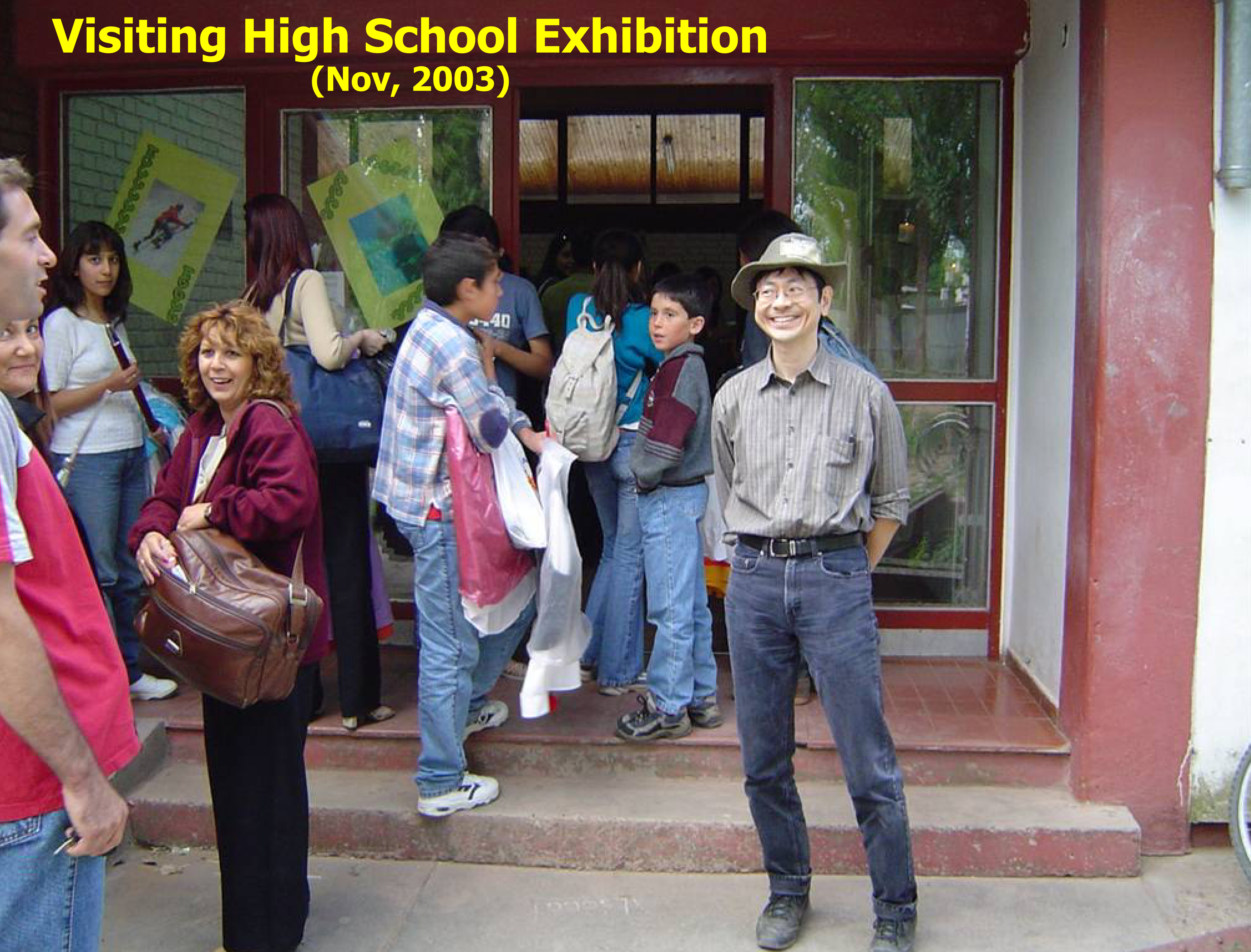
Office Building

Annual Festival of Malargue City
(Nov, 2003)


VS
05
133


Regalería
Summer
EQUIPOS DE MUSICA - REGALOS
JUGUETES - BAZAR - HERRAMIENTAS
ARMERIA y PESCA
PESCA
ARTICULOS DE LIBRERIA
minutas
OBSERVATORIO DE RAYOS COSMICOS PIERRE AUGER
Malargüe, Provincia de Mendoza, Argentina
PIERRE AUGER OBSERVATORY
PIERRE AUGER OBSERVATORY

Visiting High School Exhibition
(Nov, 2003)




ARGENTINA
Japon
Nihon
BOLIVIA
JAPON

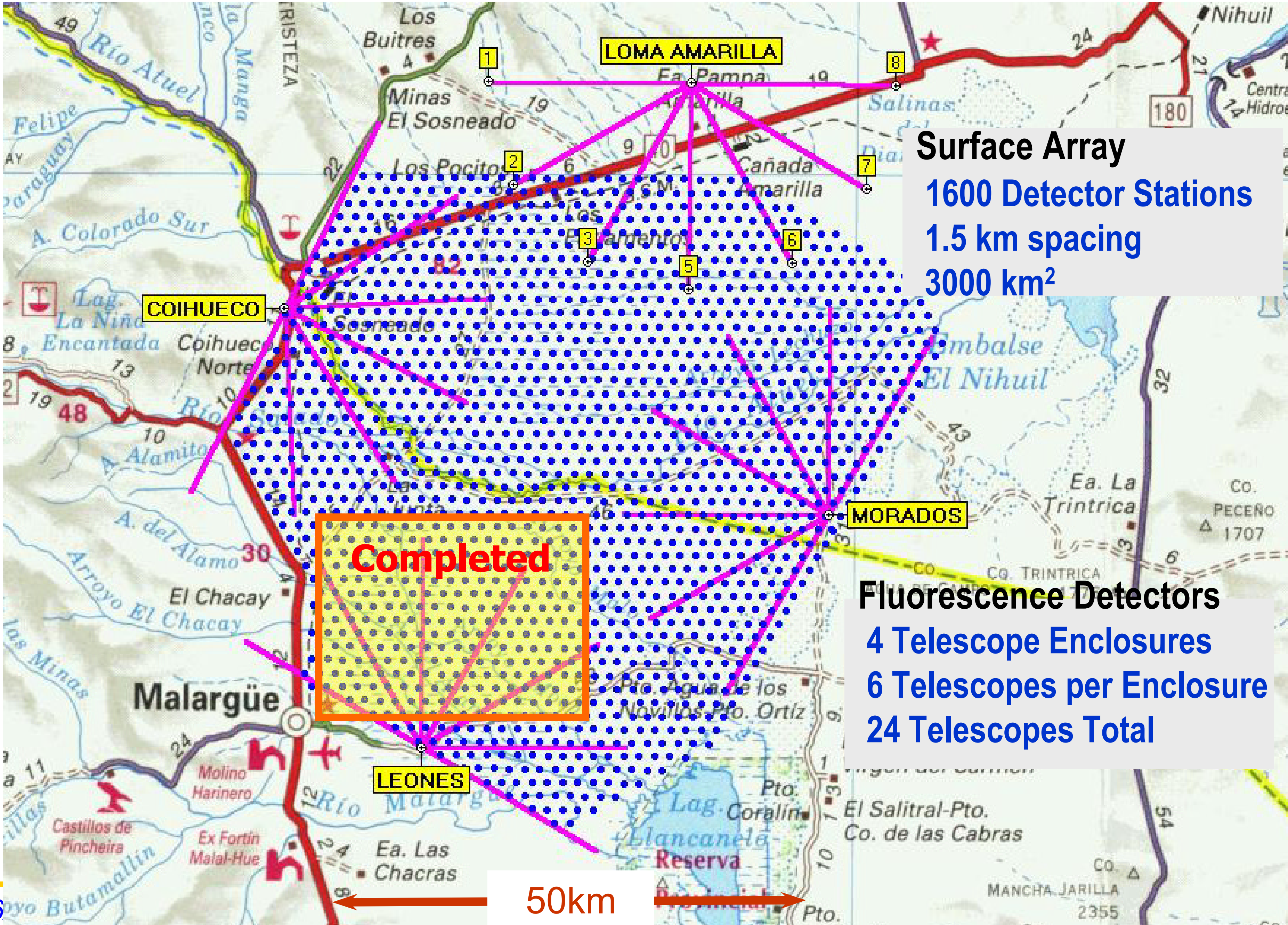
Receiving 10 tanks per week

Checking Electronics

Don’t get stuck!

Surface Detector inspection by residents of the Pampa

Southern-Auger in Argentina



Status of Construction

Coihueco

Deployed Stations

Los Morados

Los Leones

Surface Array

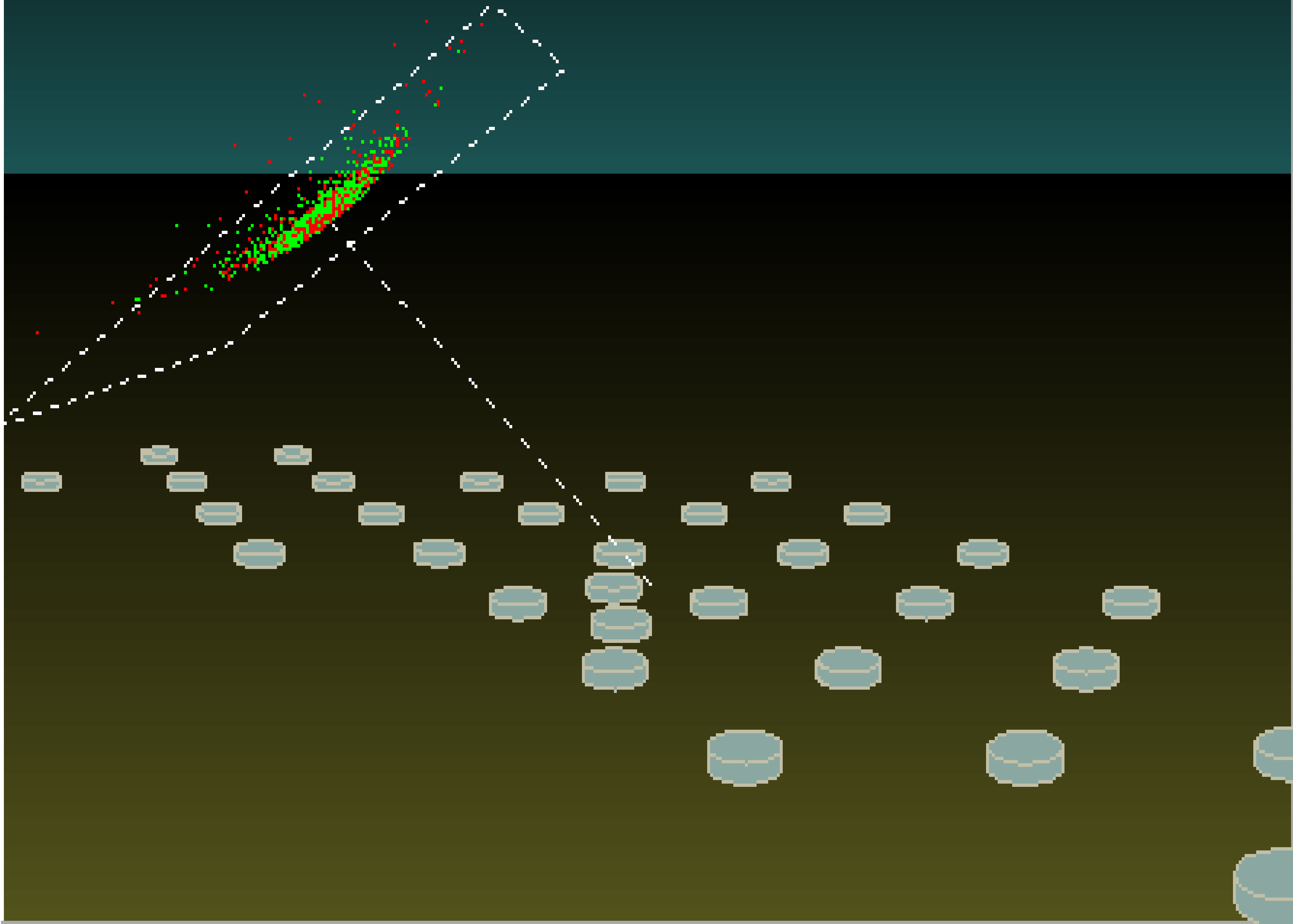
- **350 surface detector stations deployed**
- **270 surface detector stations have electronics and are operational –** ***World's largest array!***

Fluorescence detectors

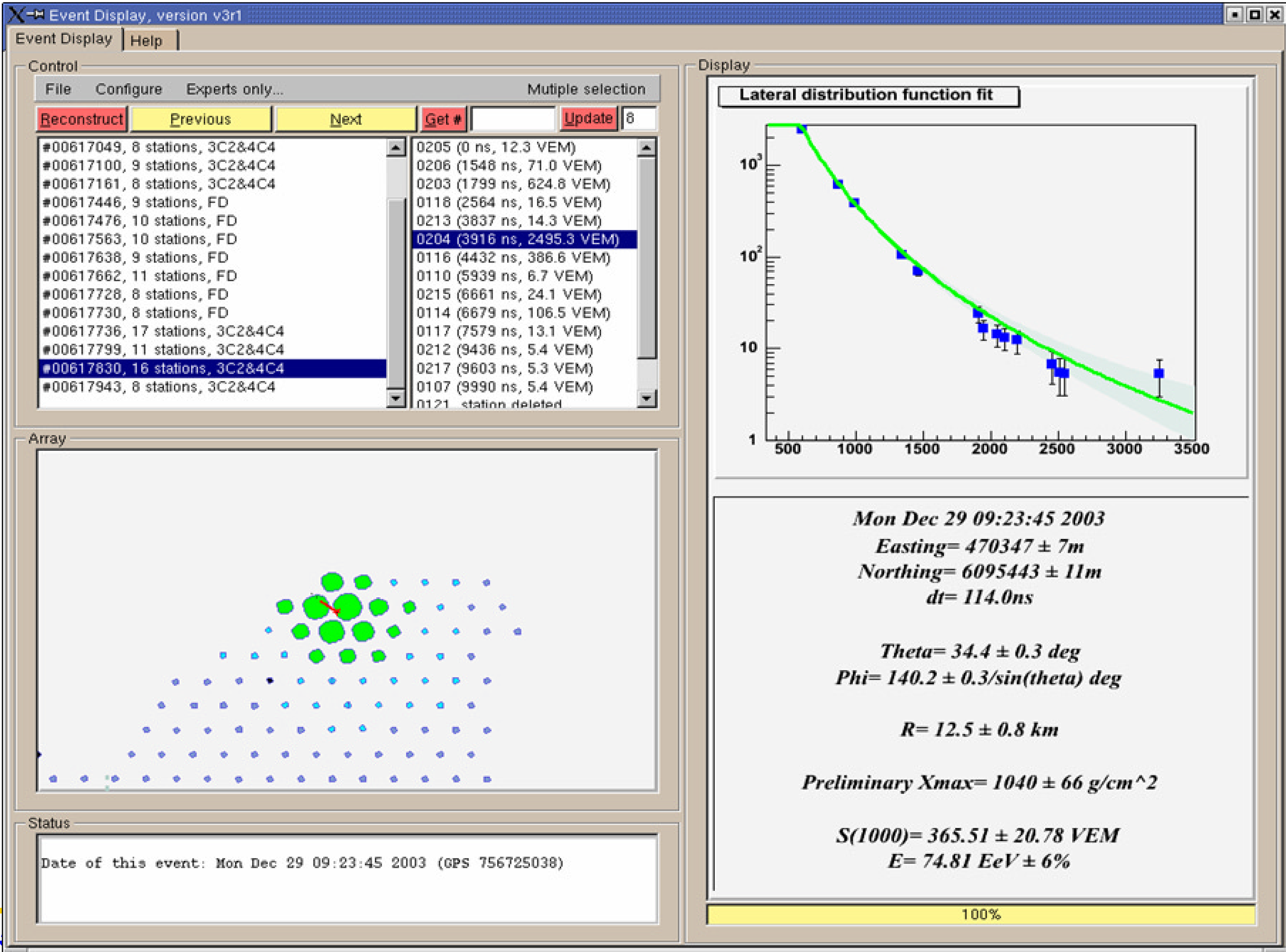
- **6 telescopes operational in Los Leones**
- **2 telescopes operational in Coihueco**

Paul Mantsch at SAGENAP

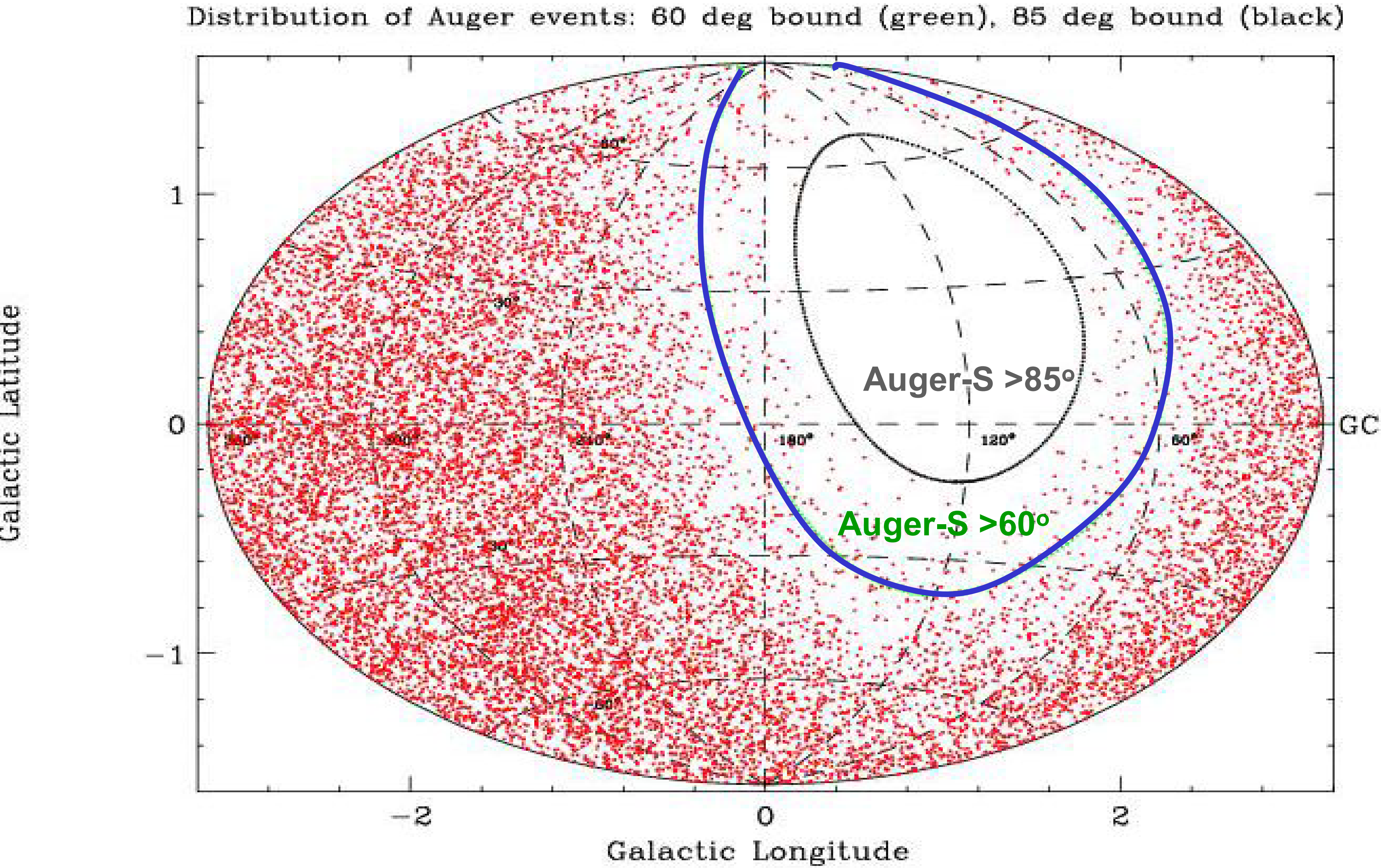
Event Simulation based on Real Event



~7x10^{19} eV Event



Angular distribution of UHECR by Pierre-Auger (Preliminary, No energy cut)



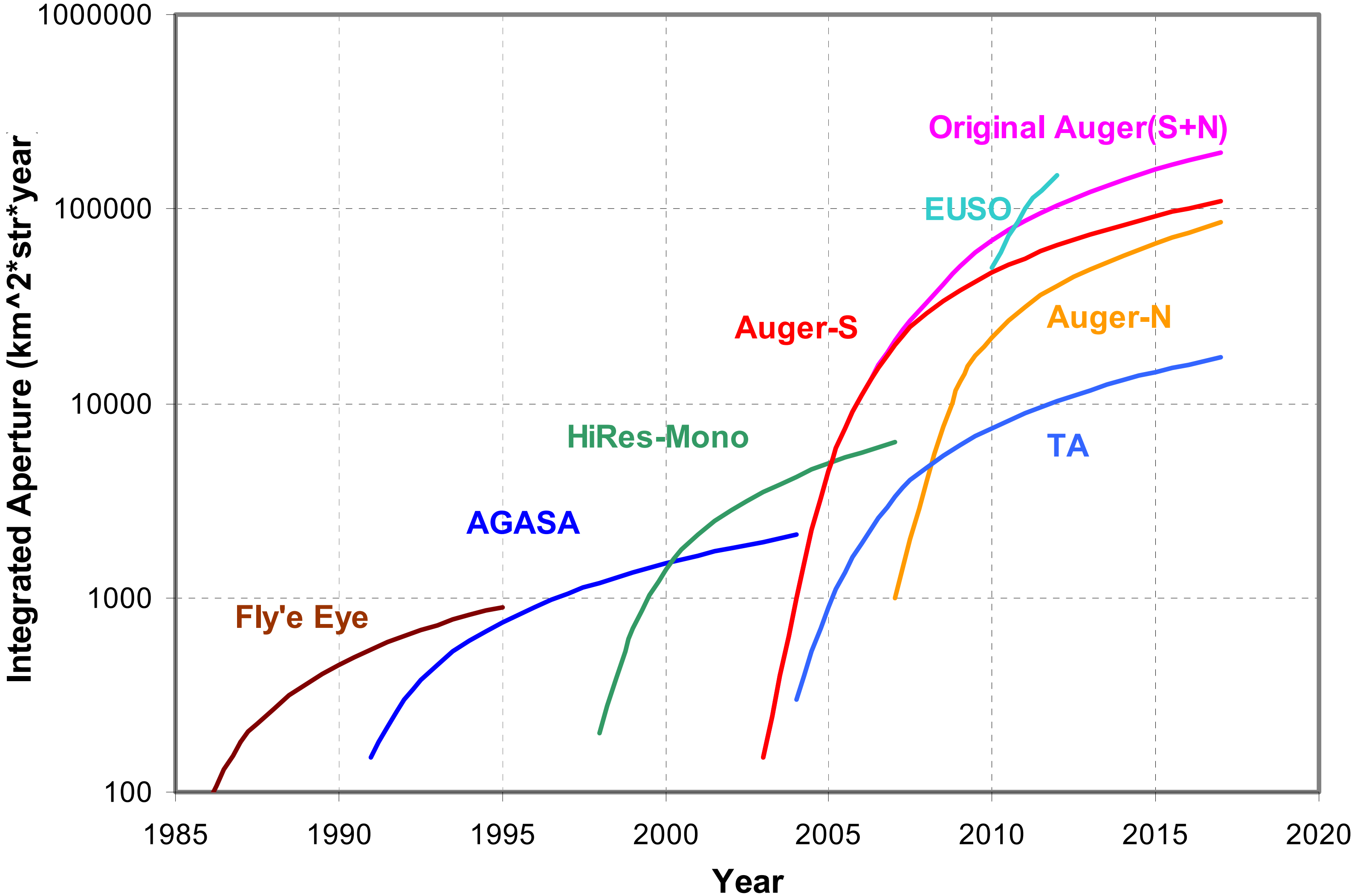
Two Candidate Sites for Northern Site

Utah Site

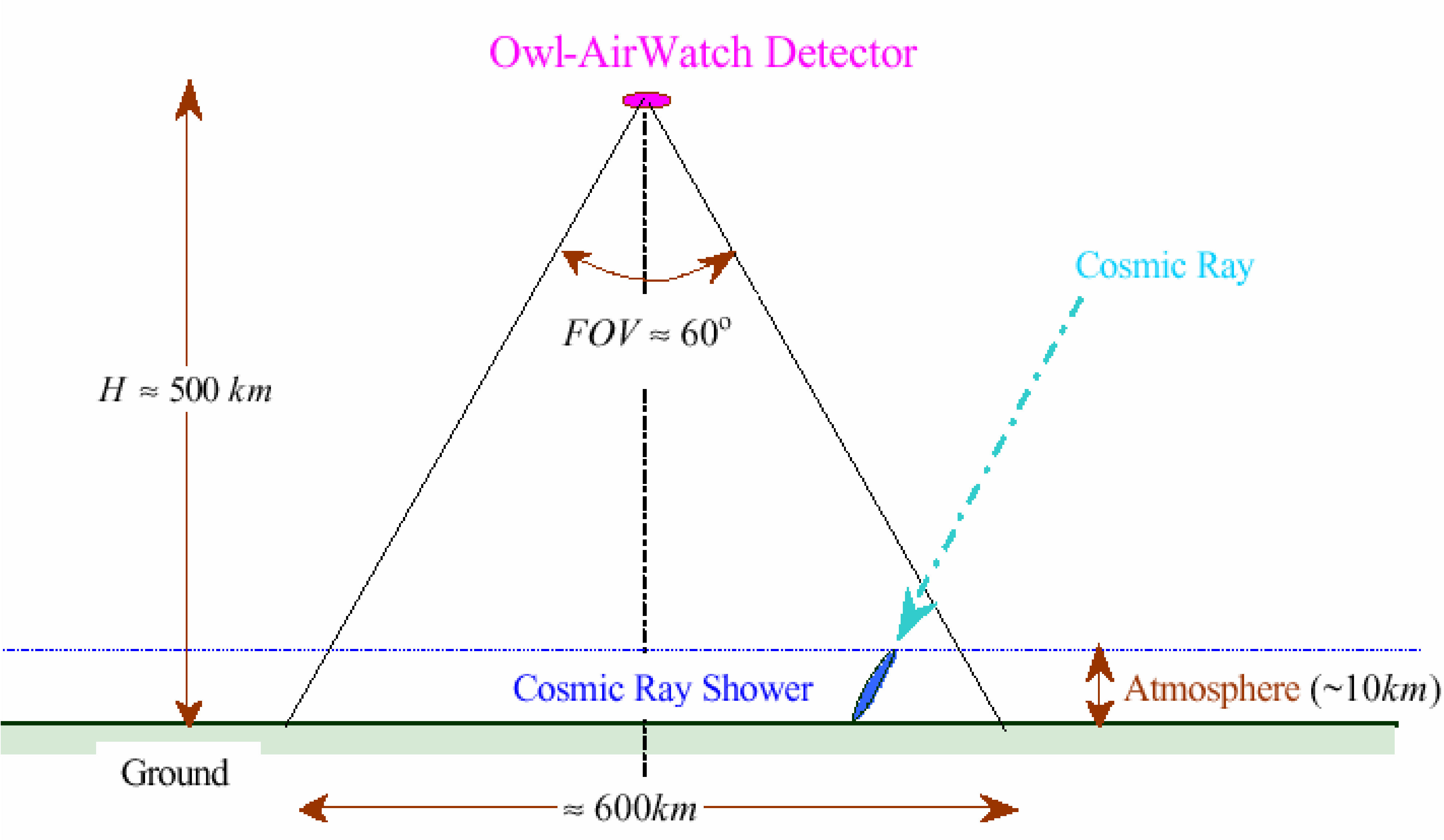

Colorado Site
View to west, Sept 23, 2003

Integrated Sensitivity (at 10^{20} eV)

updated on 4/24/2004

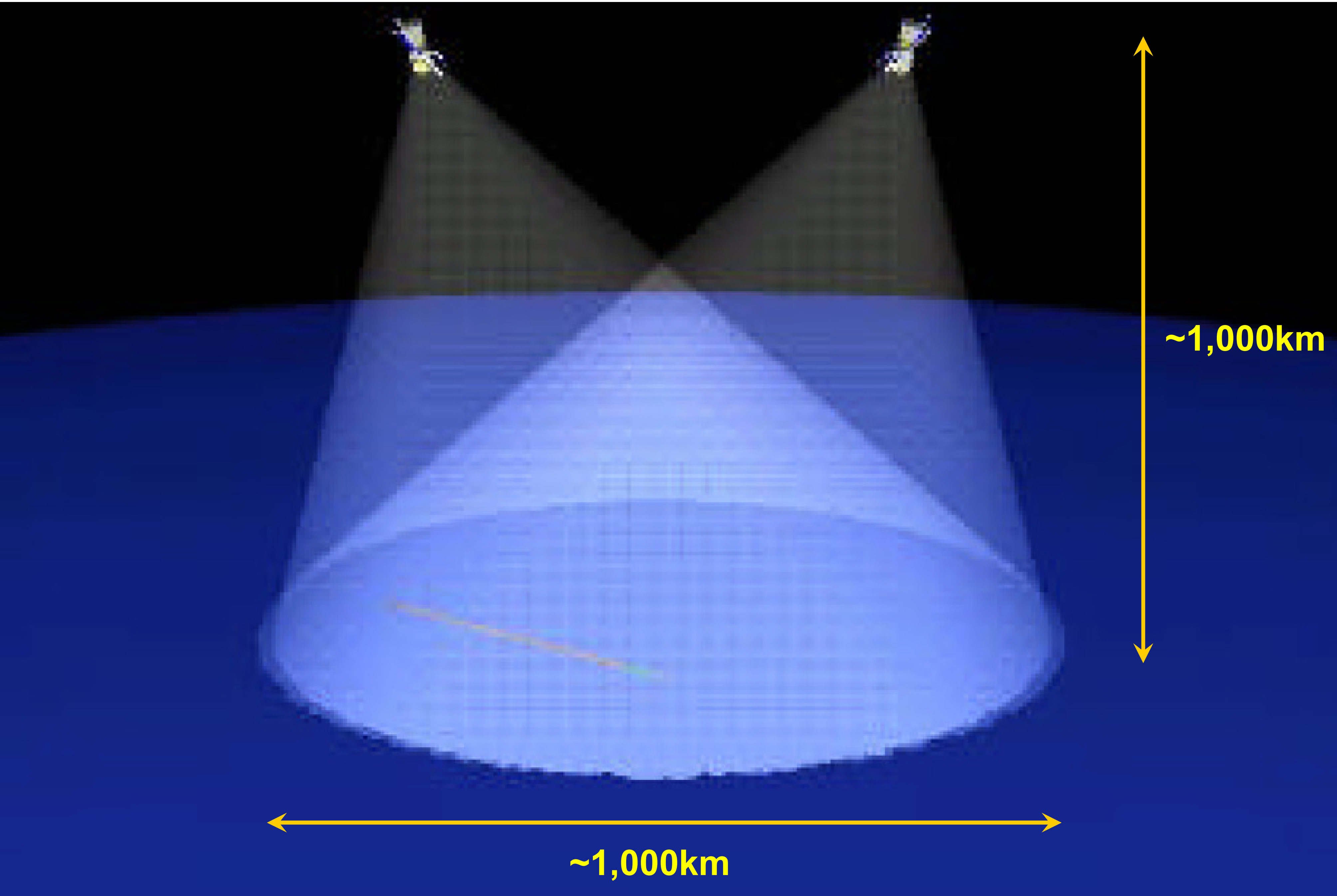


EUSO/OWL Detector Concept



EUSO on International Space Station

OWL Stereo View from Space



Multi-Messenger Exploration

Messenger	Experiment	Energy (eV)	Stage			Year Starts	Total Budget (M$)
			Pro-posal	Construction	Physics Run		
Gamma Rays	Veritas/Hess/Magic…	$10^{10} - 10^{14}$		Y	Y	2004	~50
	GLAST	$10^{7} - 10^{11}$		Y		~2006	~400
	Swift			Y		~2006	~200
Cosmic Rays	HiRes	10^{18} -			Y	1998	5
	Auger (South)	10^{19} -		Y	Y	2004	50
	Auger (N+S)	10^{19} -	Y			~2008	~150
	EUSO	10^{20} -		Y		>2010	~200
Neutrinos	Super-K	$10^{7} - 10^{10}$			Y	1996	100
	Hyper-K/UNO…	$10^{7} - 10^{10}$	Y			~2010	~500
	Amanda	10^{10} -			Y	2000	20
	Icecube	10^{11} -		Y		~2007	~200
Gravitational Wave	LIGO/Virgo…			Y	Y	2000	~500
	LISA		Y			>2010	~500

Summary

- Why are we here?
- What is the most fundamental law in nature?

⇓

- Observation of the extreme universe by cosmic radiations may tell us something totally unexpected.

Thank you!

- Feel free to stop by my office any time.
  - Katsushi Arisaka
  - Knudsen 4-145
  - (310) 825-4925
  - arisaka@physics.ucla.edu

- This talk available at: http://www.physics.ucla.edu/~arisaka/quarknet