KIAA Workshop on *Astroparticle* Physics

KIAA@Peking University; Sept. 28-29, 2015 — http://kiaa.pku.edu.cn/aph2015/

TOPICS

COSMIC RAYS
DARK MATTER DETECTION
PARTICLE COSMOLOGY
PARTICLE PHYSICS IN STARS

The long-standing quest for understanding the fundamental laws of Nature has motivated the new field of **Astroparticle Physics** where observations of the Universe are used to probe particle interactions. This small workshop will bring together AstroParticle Physics experts to provoke discussion and foster collaboration especially between members of Kavli Institutes.

Organizers

Ke Fang (U Chicago)
Zhaosheng Li (PKU)
Angela V. Olinto (U Chicago)
Meng Su (MIT)
Renxin Xu (PKU)

KIAA – PKU

KICP
Kavli Institute for Cosmological Physics at The University of Chicago

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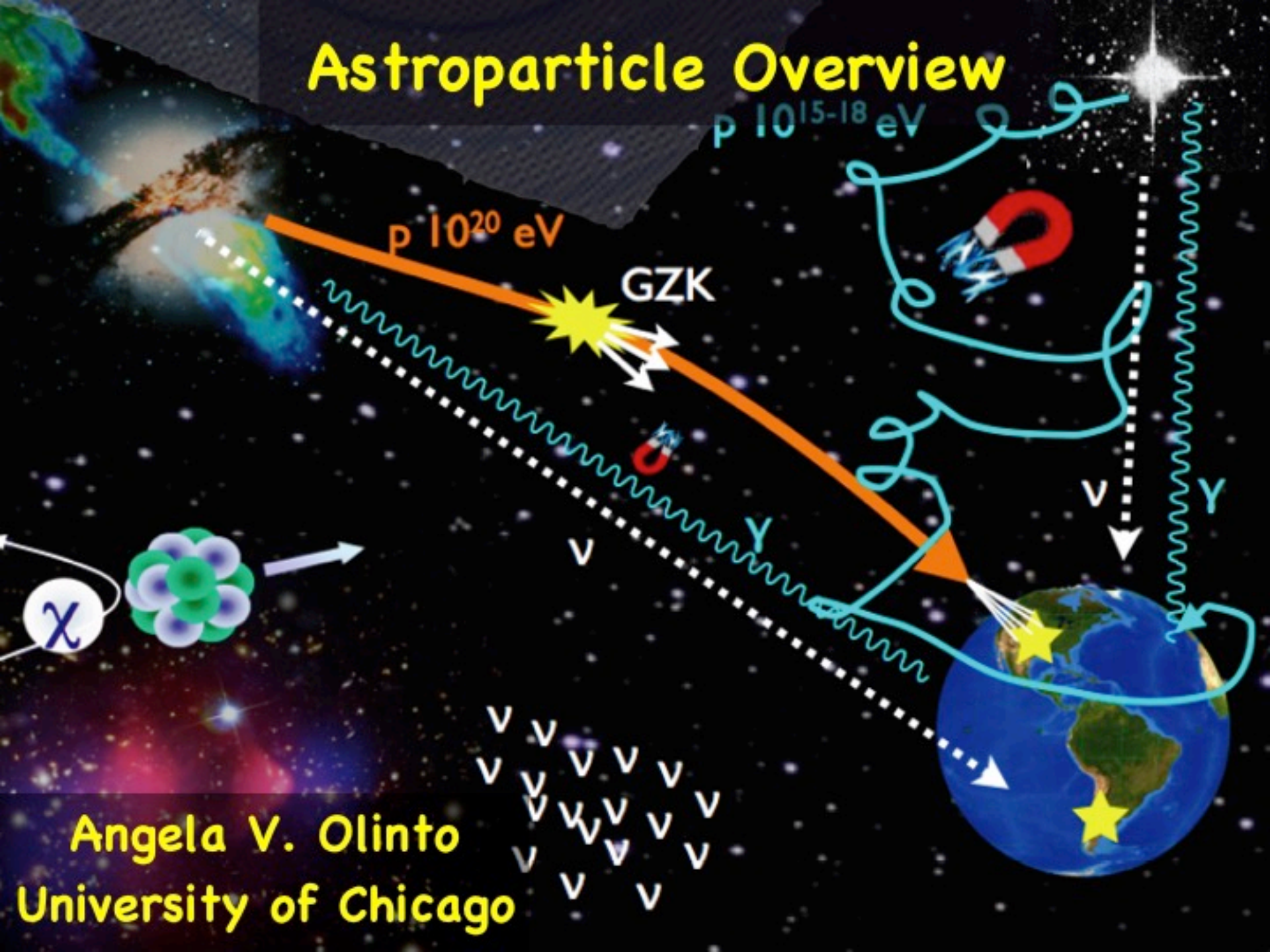
Jie Yau

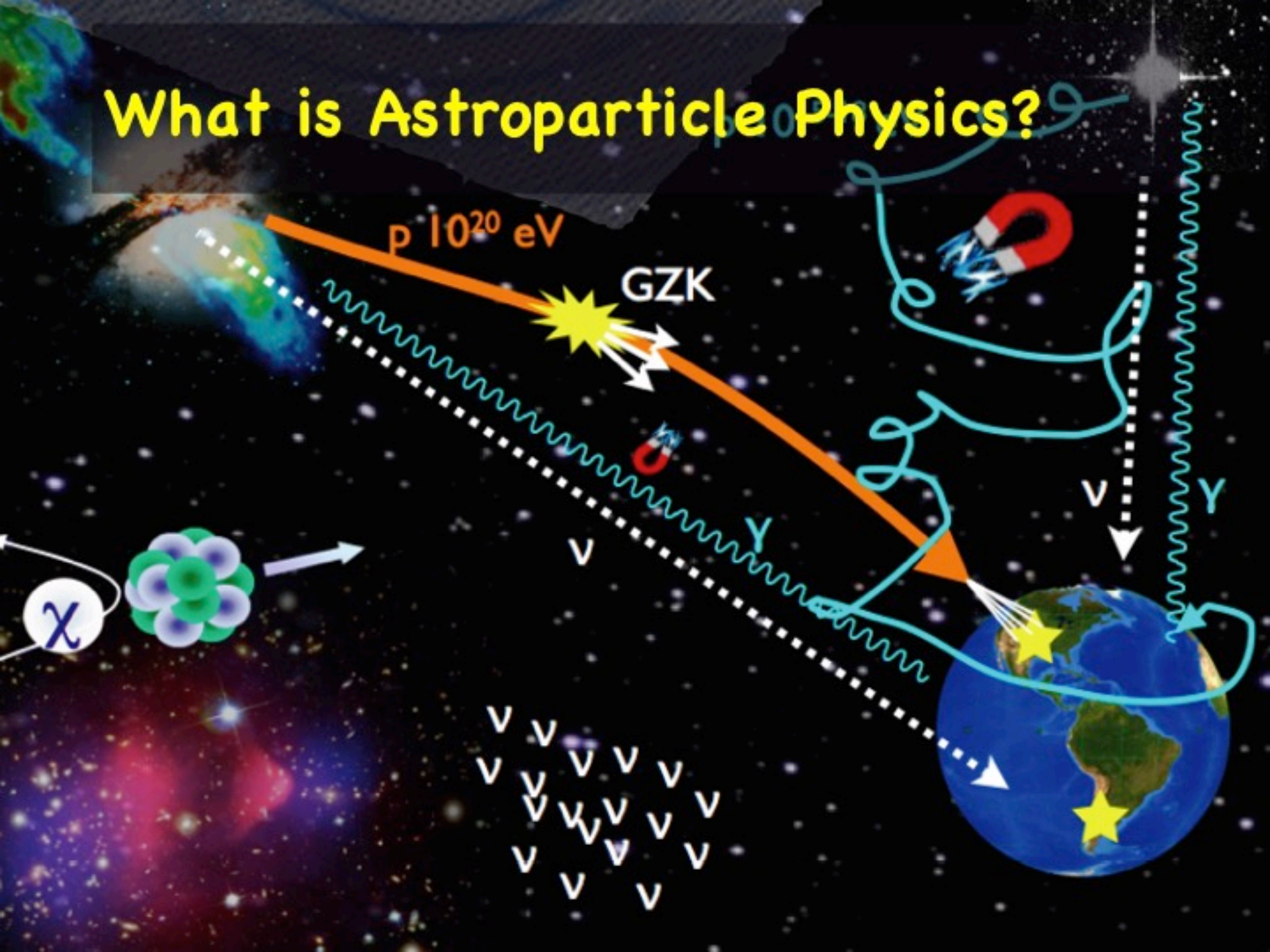
Zhaosheng Li

MIT
Kavli Institute

Ke Fang
Kavli Institute for Cosmological Physics

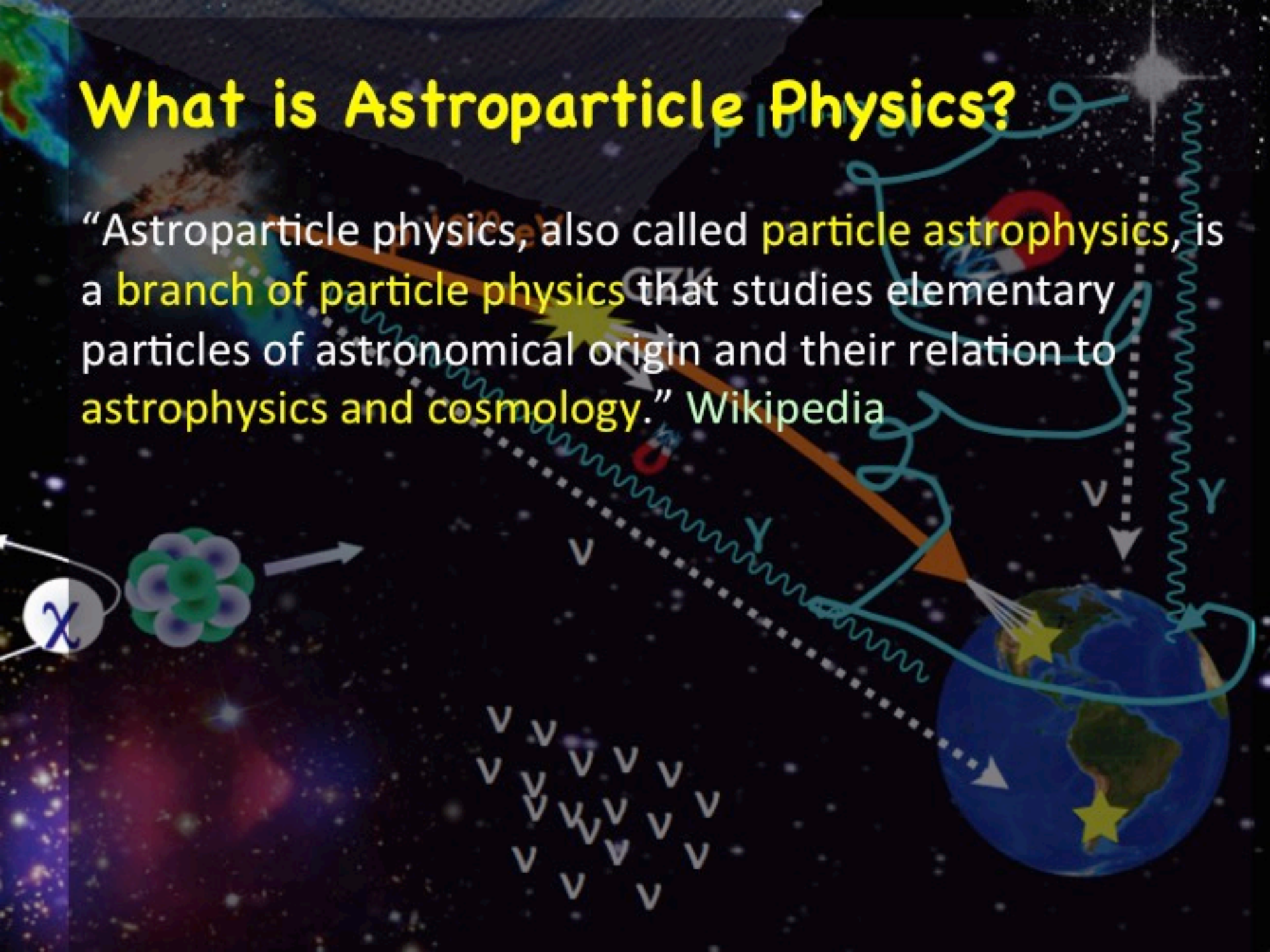

Astroparticle Overview
p $10^{15\text{-}18}$ eV
p 10^{20} eV
GZK
ν
γ
ν
γ
χ
ν ν ν ν ν
ν ν ν ν ν
ν ν ν ν
ν ν ν
Angela V. Olinto
University of Chicago

What is Astroparticle Physics?



What is Astroparticle Physics?

"Astroparticle physics, also called particle astrophysics, is a branch of particle physics that studies elementary particles of astronomical origin and their relation to astrophysics and cosmology." Wikipedia



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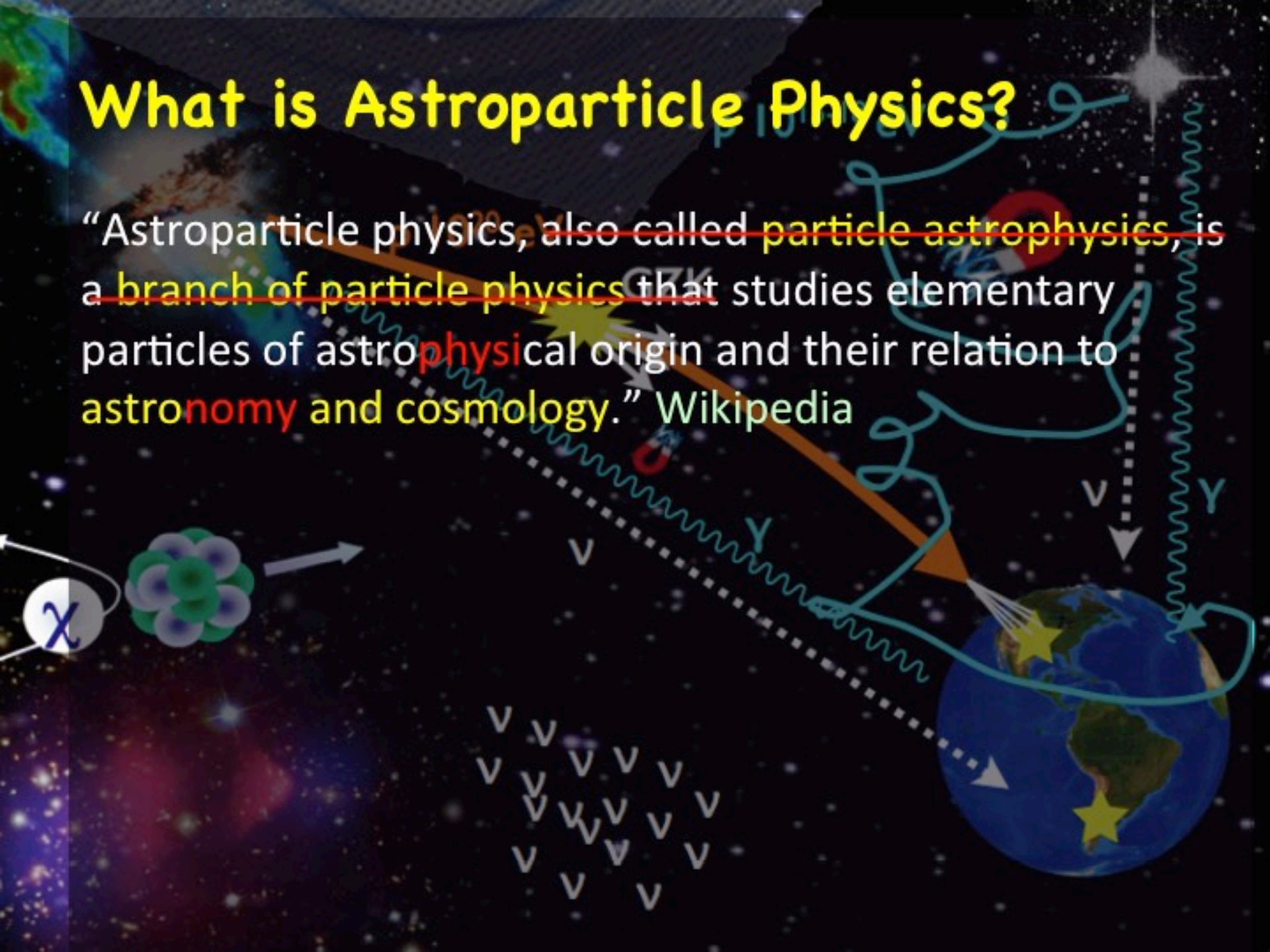

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"Astroparticle Physics is a new field of research emerging at the intersection of **particle physics, astronomy, and cosmology**.

http://www.astroparticle.org

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"Astroparticle Physics is a new field of research emerging at the intersection of **particle physics, astronomy, and cosmology**. It aims to answer fundamental questions related to the story of the Universe such as: What is the Universe made of? What is the origin of cosmic rays? What is the nature of gravity?"
http://www.astroparticle.org

AStroParticle ERAnet

What is Astroparticle Physics?

"Astroparticle Physics is a ~~new~~ field of research ~~emerging~~ at the intersection of **particle physics, astronomy, and cosmology**. It aims to study the fundamental laws of Nature using the Universe as a laboratory. Current questions include: What is the Universe made of? What is the origin of cosmic PARTICLEs (Gamma-rays, cosmic rays, neutrinos)? What is the nature of gravity?"
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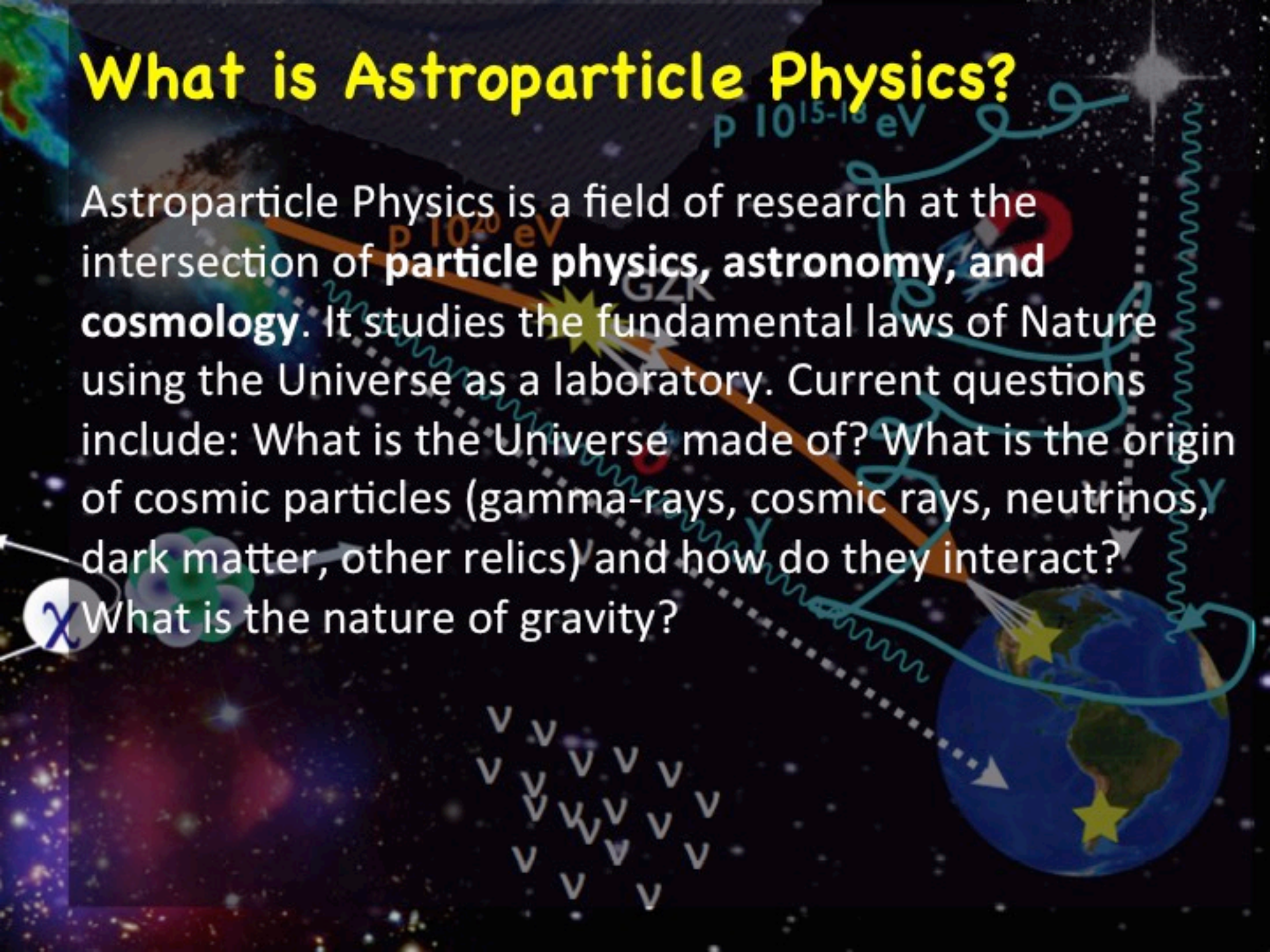
What is Astroparticle Physics?



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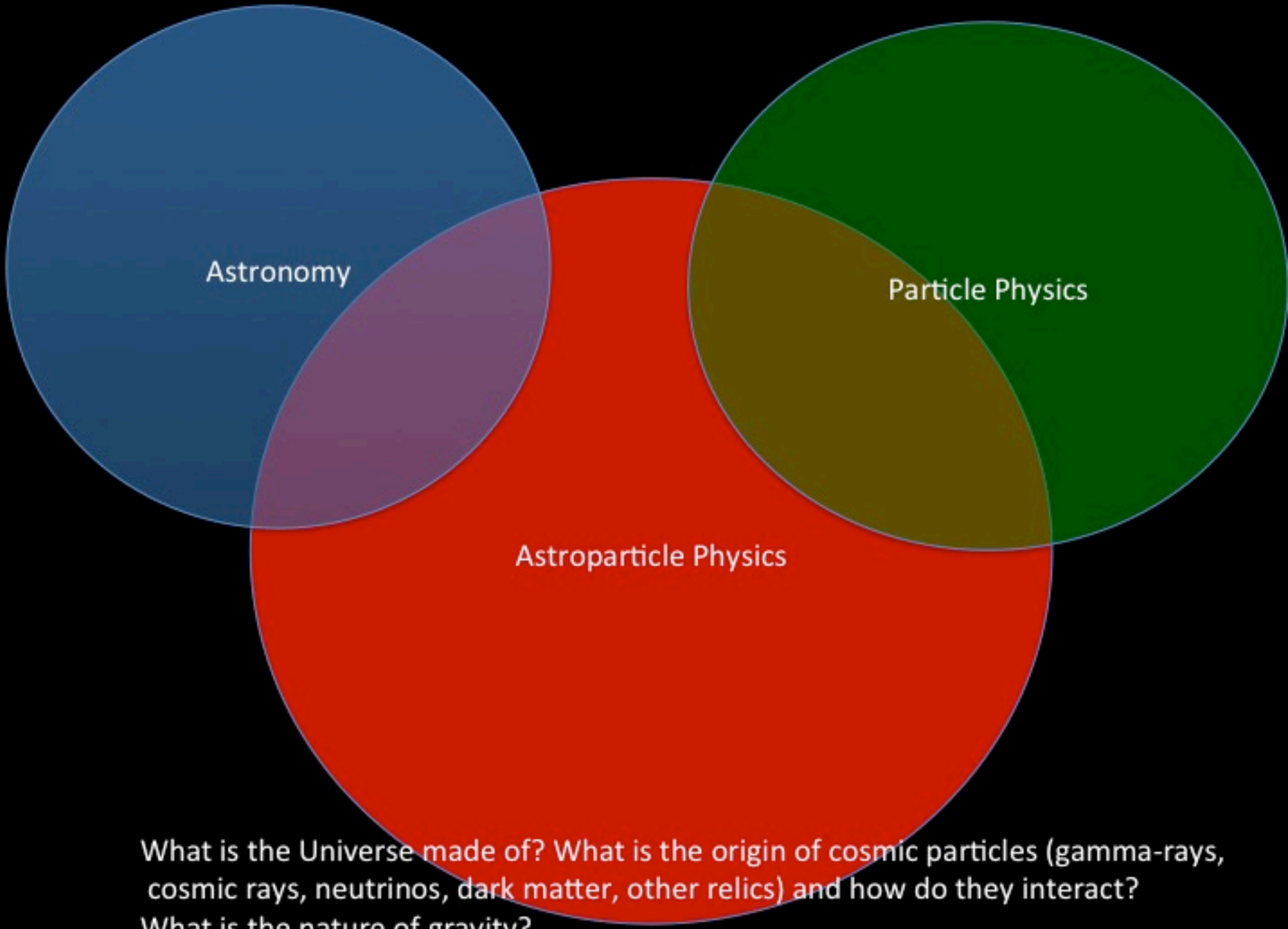

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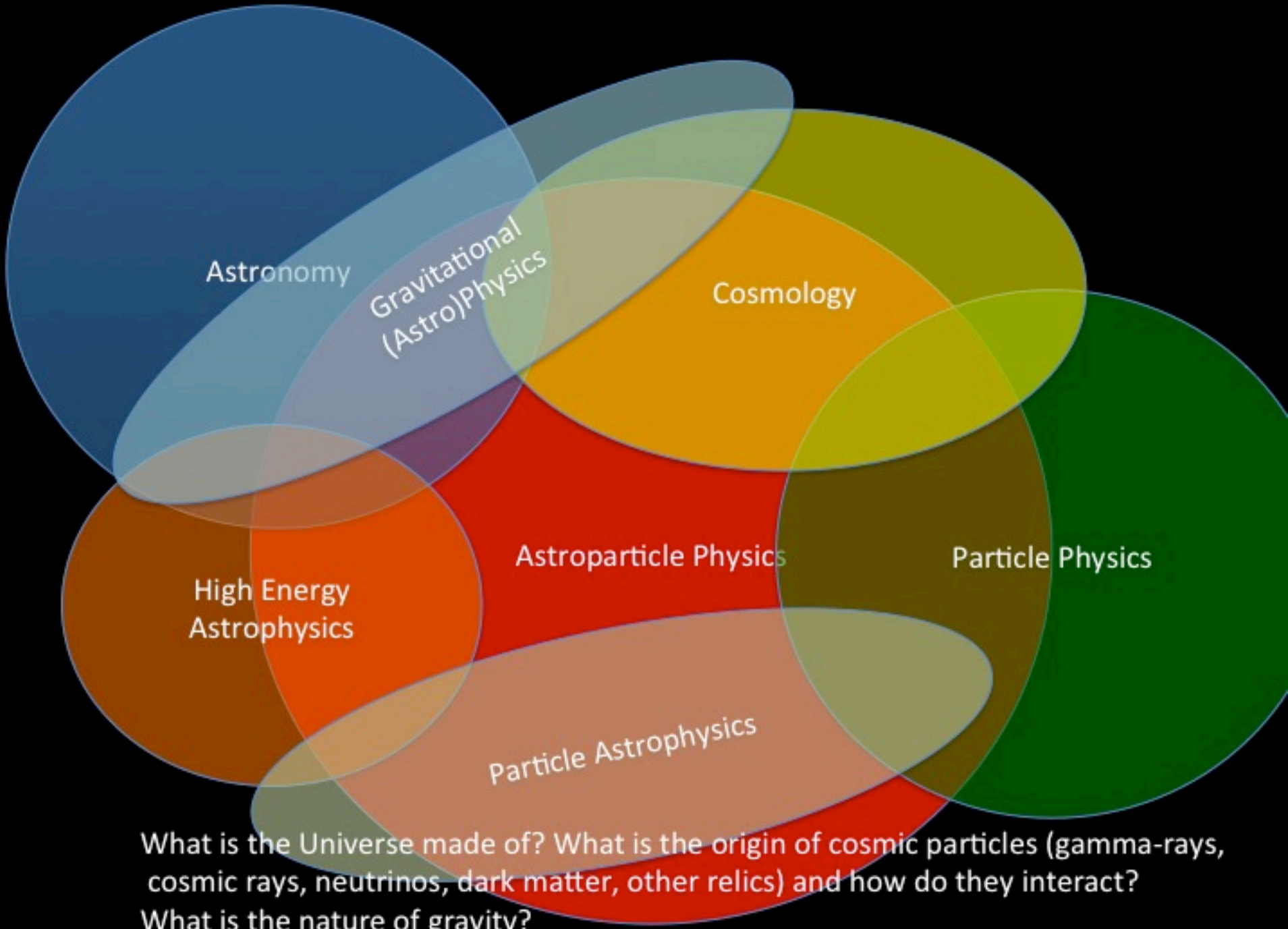

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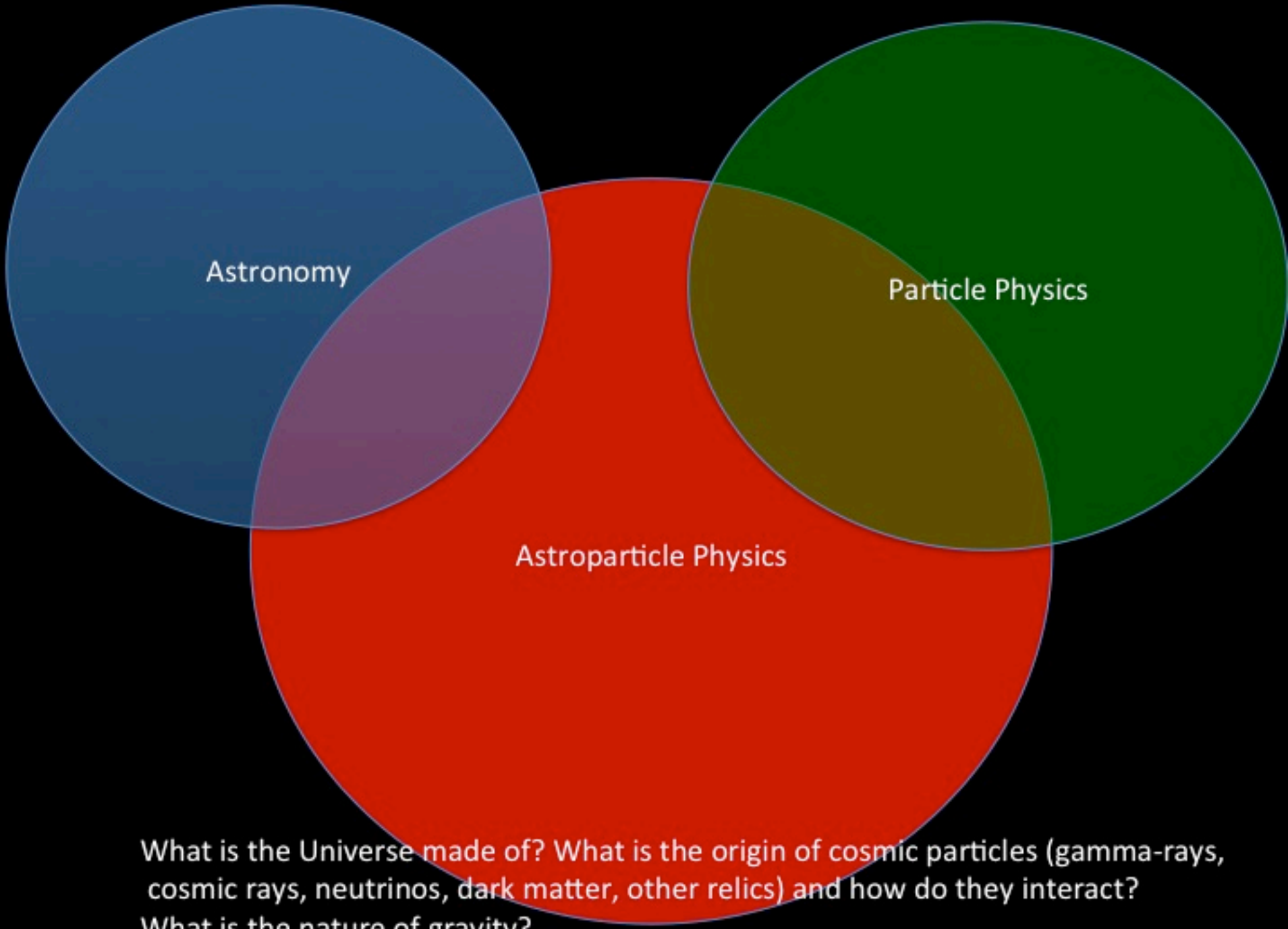

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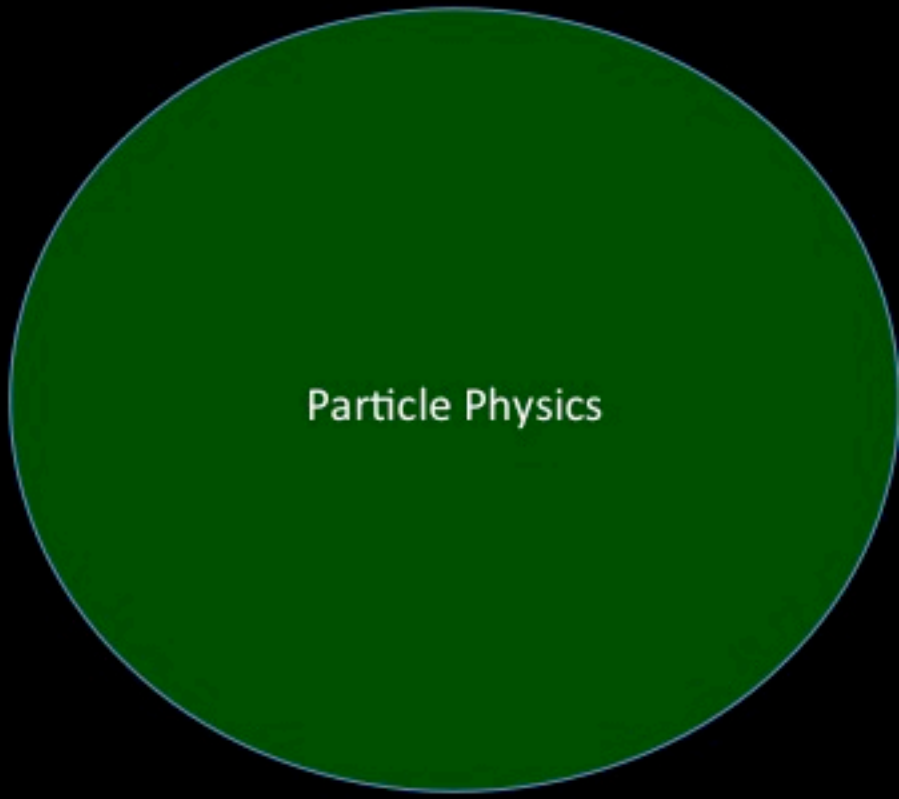
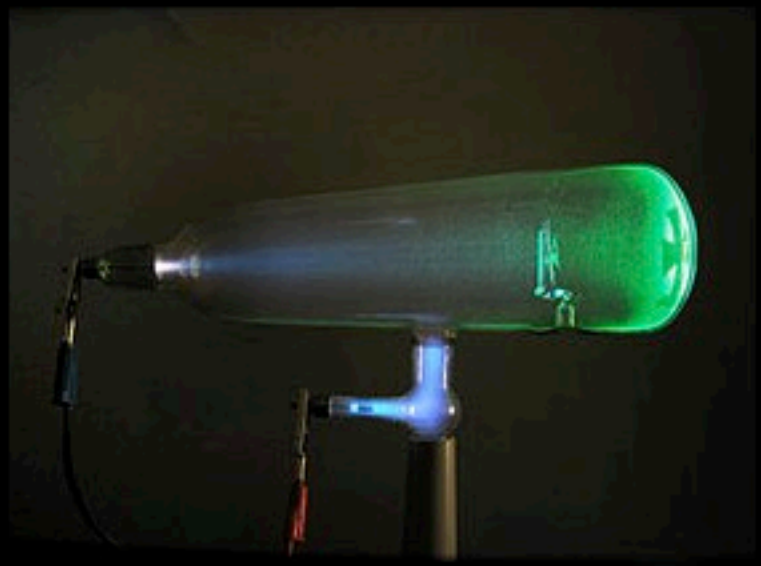

Particle Physics

Particle Physics

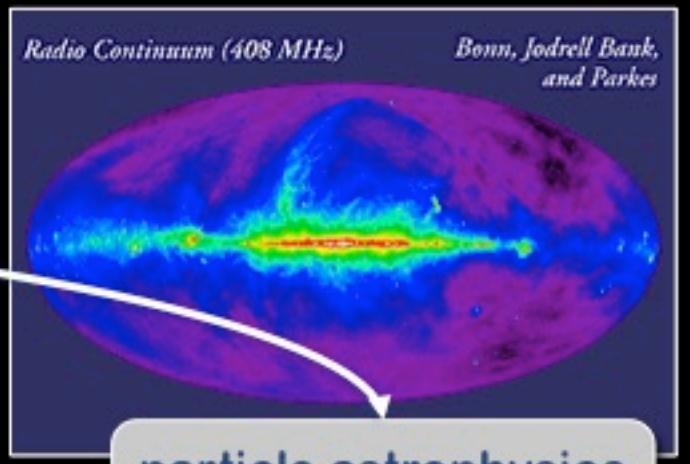
Begins with
1897 Discovery of the electron
J. J. Thompson et al.,
Crookes' cathode ray tube



Joint Development of Particle Physics & Particle Astrophysics

Study of cosmic rays

1953



particle astrophysics

1932 Positron

1936 Muon

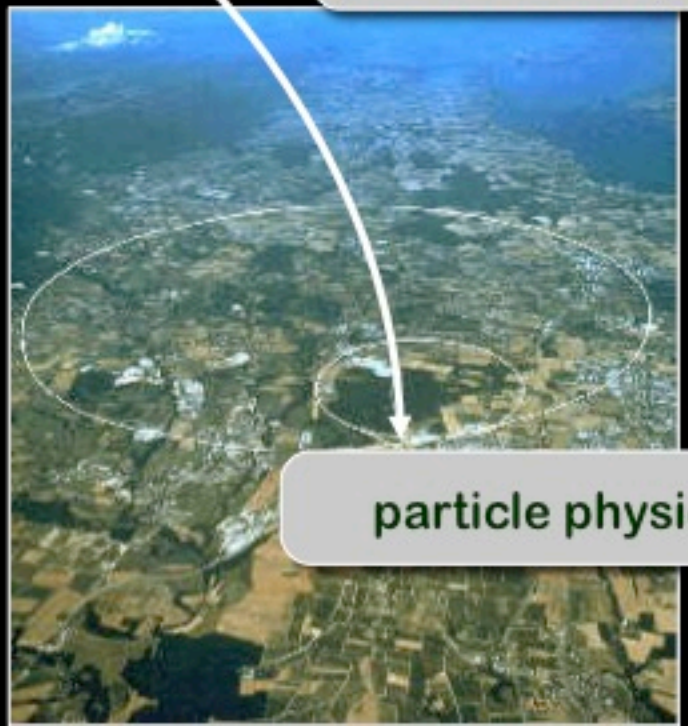
1947 Pions : π^0, π^+, π^-

1949 Kaons (K)

1949 Lambda (Λ)

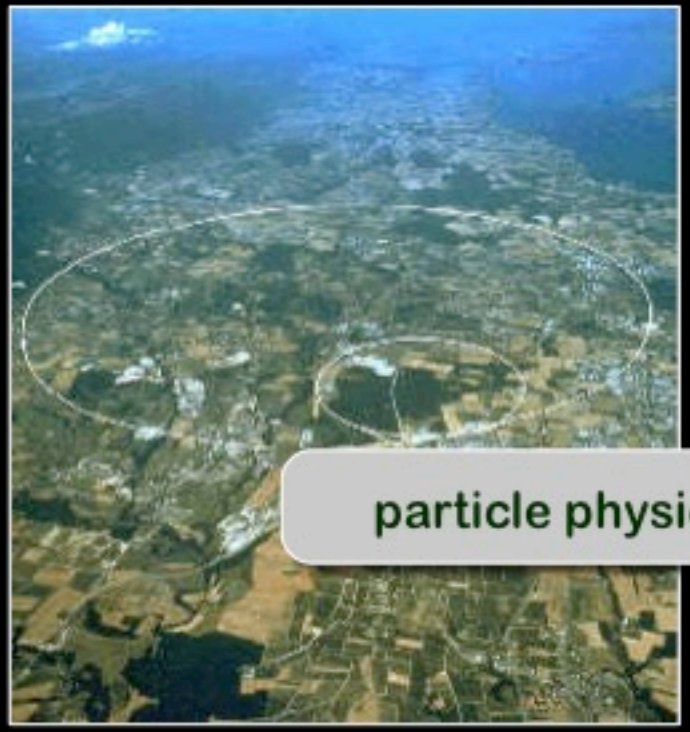
1952 Xi (Ξ)

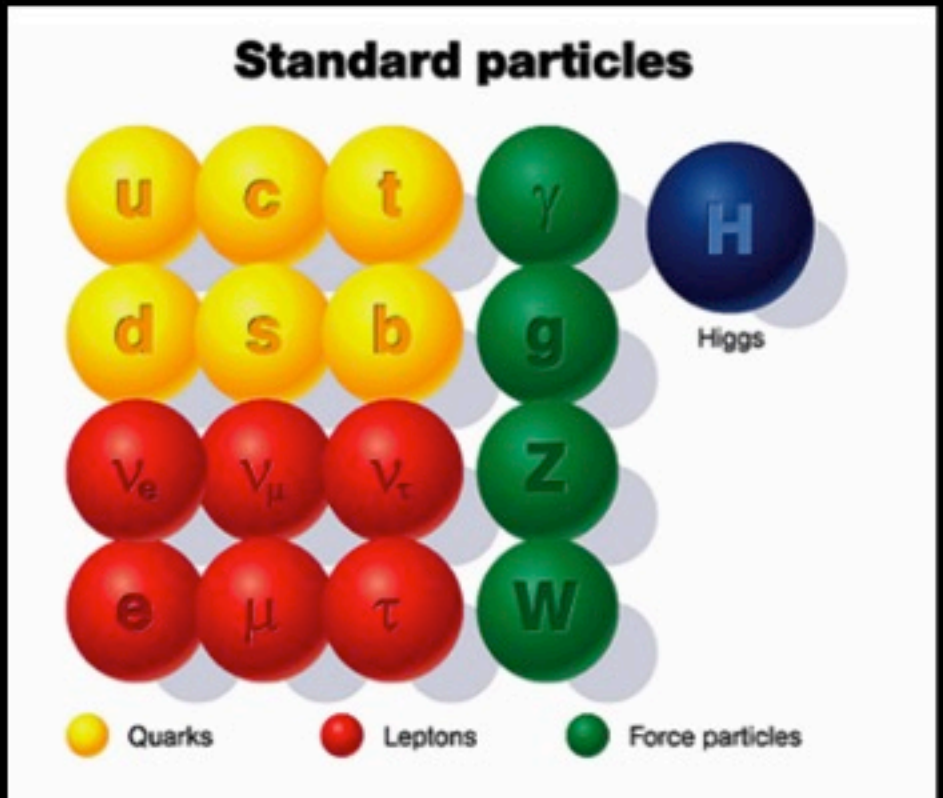
1953 Sigma (Σ)



particle physics

Particle Physics

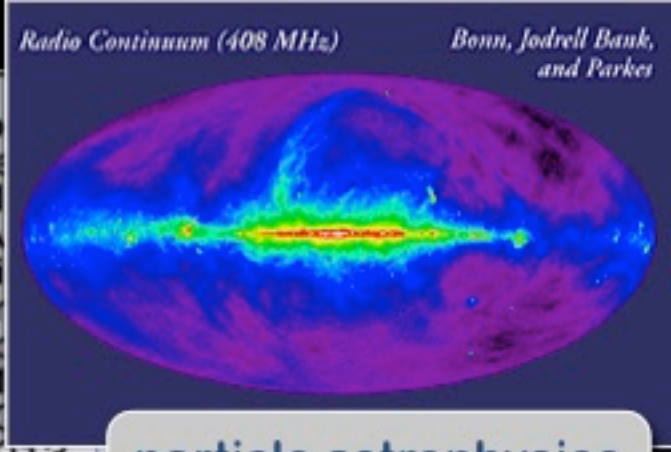




In 2013,
The Standard Model
is complete!!

Precise description of nature up to ~10 TeV

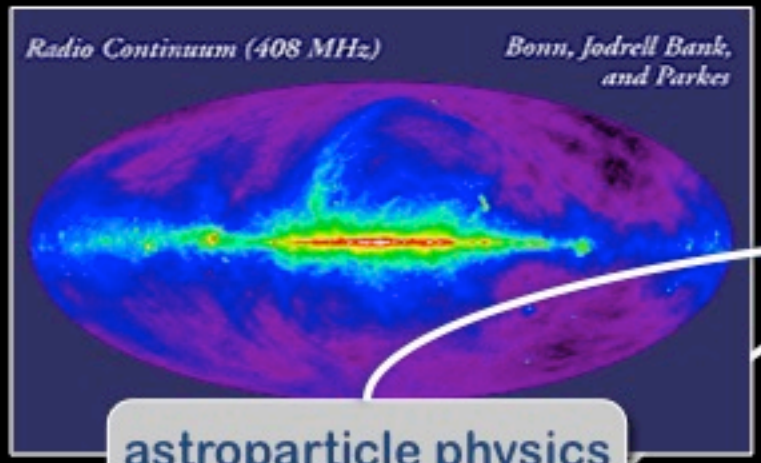
Cosmic Ray Spectrum



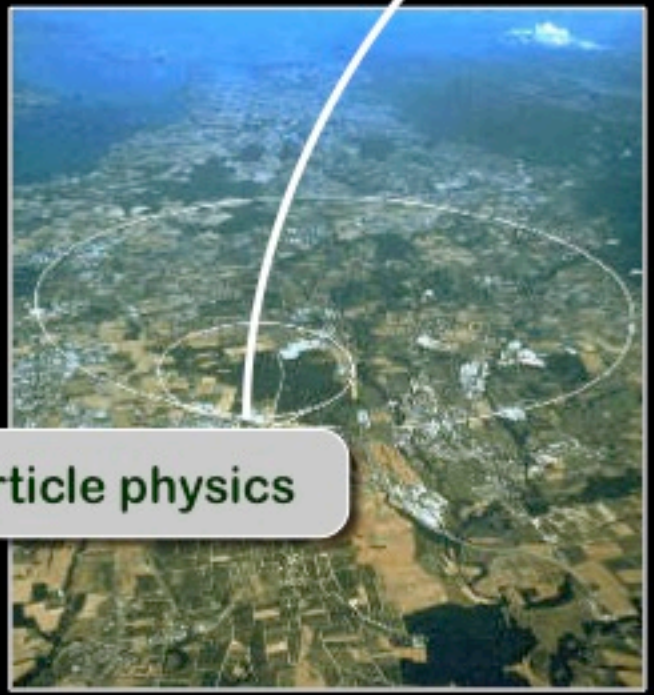
particle astrophysics

protons only
all-particle
electrons
positrons
antiprotons
Grigo
Ake
M
KASCA
Ti
KASCADE-Gra
IceTo
HiRes
TA2
Auger2013
Model H4a
CREAM all particle
Fixed target
HERA
RHIC
TEVATRON
LHC
$E^2 dN/dE$ (GeV cm^{-2} sr^{-1} s^{-1})
E_{tot} (GeV / particle)
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{0}
10^{2}
10^{4}
10^{6}
10^{8}
10^{10}
10^{12}

Joining forces again
Particle Physics & AstroParticle Physics

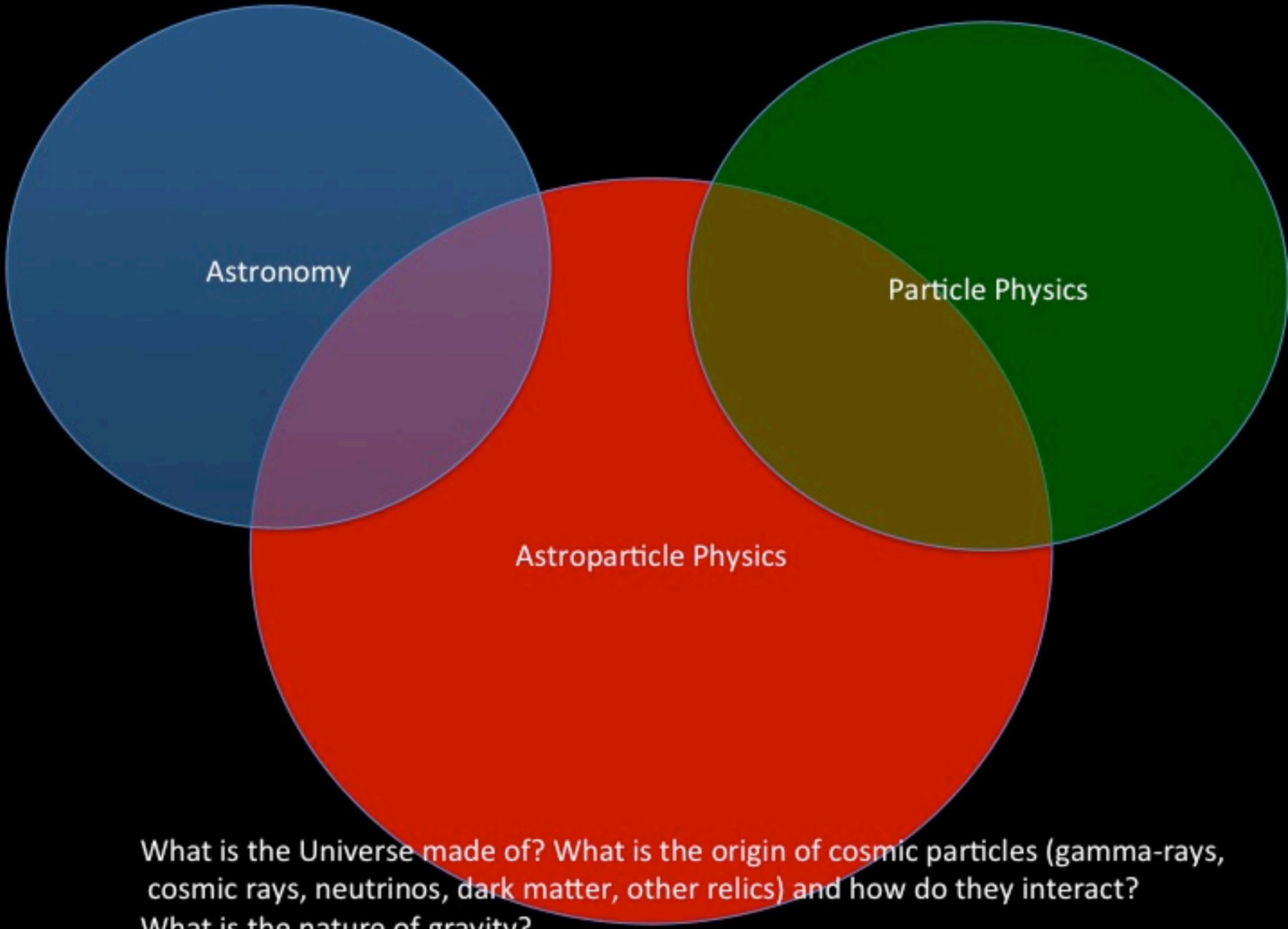


astroparticle physics



particle physics

- Cosmic particles (CRs, ν's, γ's) with E > LHC
- Neutrino Properties: masses, symmetries,...,
- Dark Matter: WIMPS, axions, SHDM,...
- Dark Energy: ????
- Inflation and GUT scale physics (e.g., CMB polarization)
- Gravitational Waves
- Other Early Universe Relics...



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What is the nature of gravity?


Astronomy

1933
Coma cluster
~ 70 Mpc

M_{dark} ~ 400 $M_{visible}$

Fritz Zwicky

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Coma cluster
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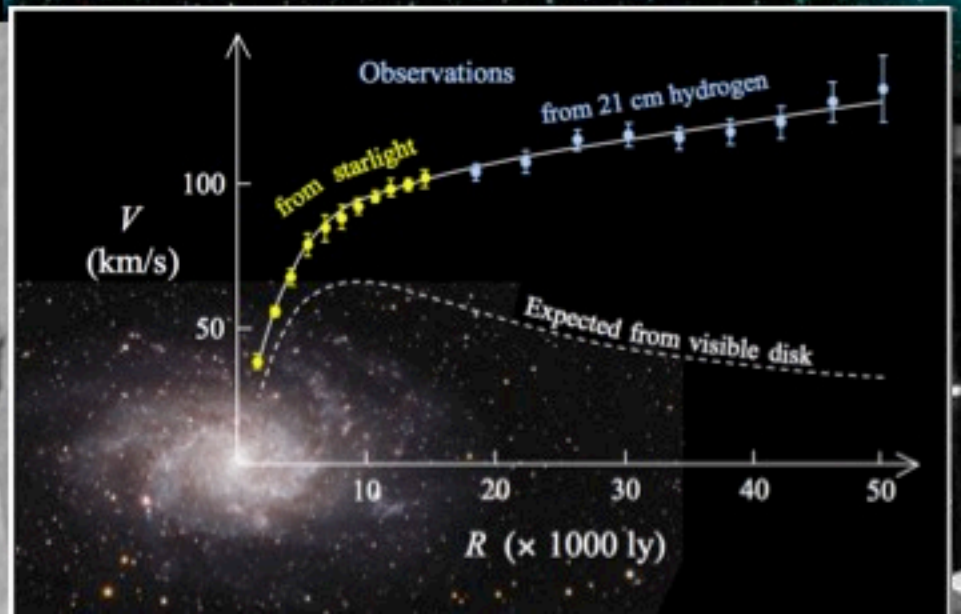
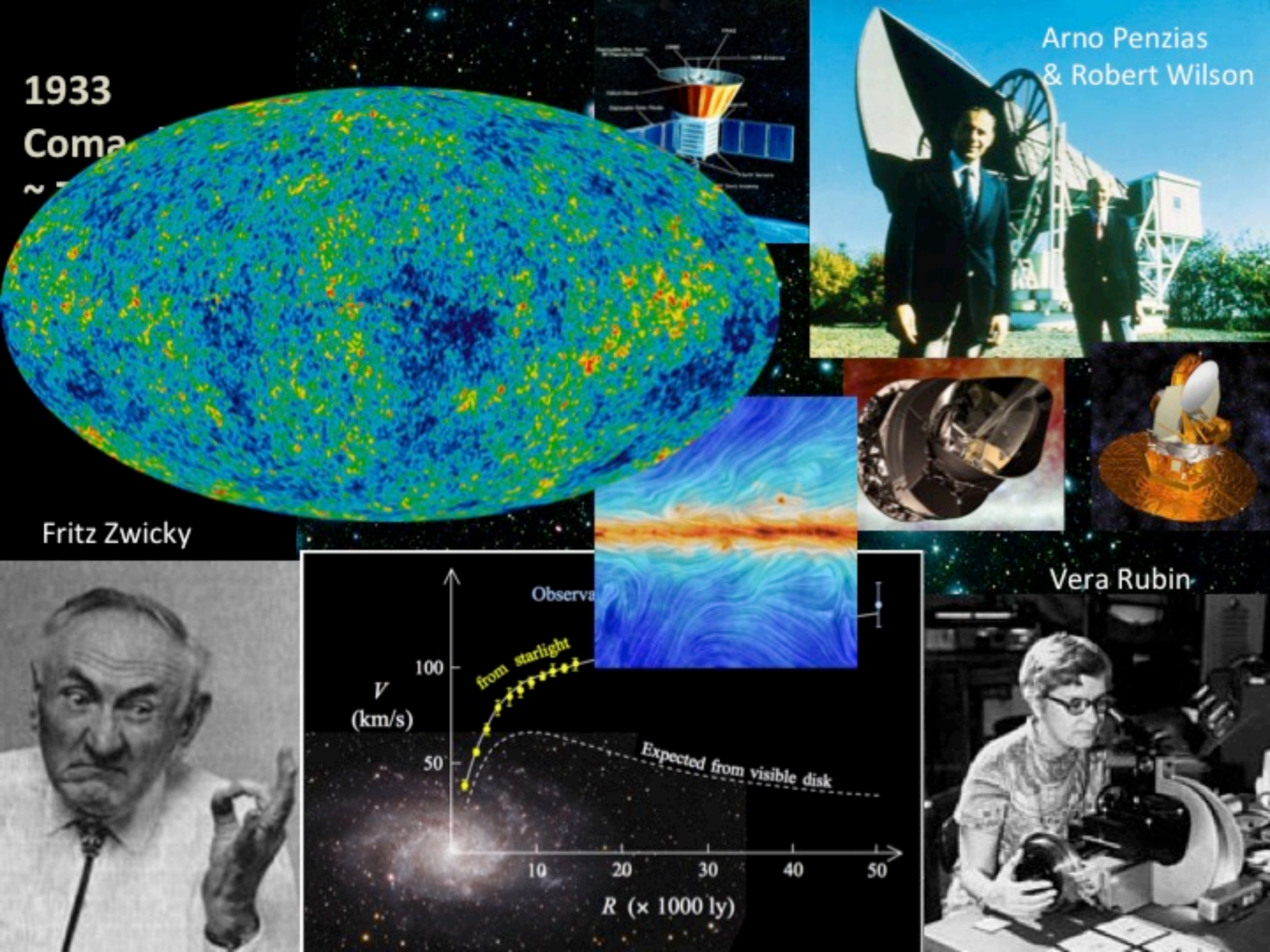
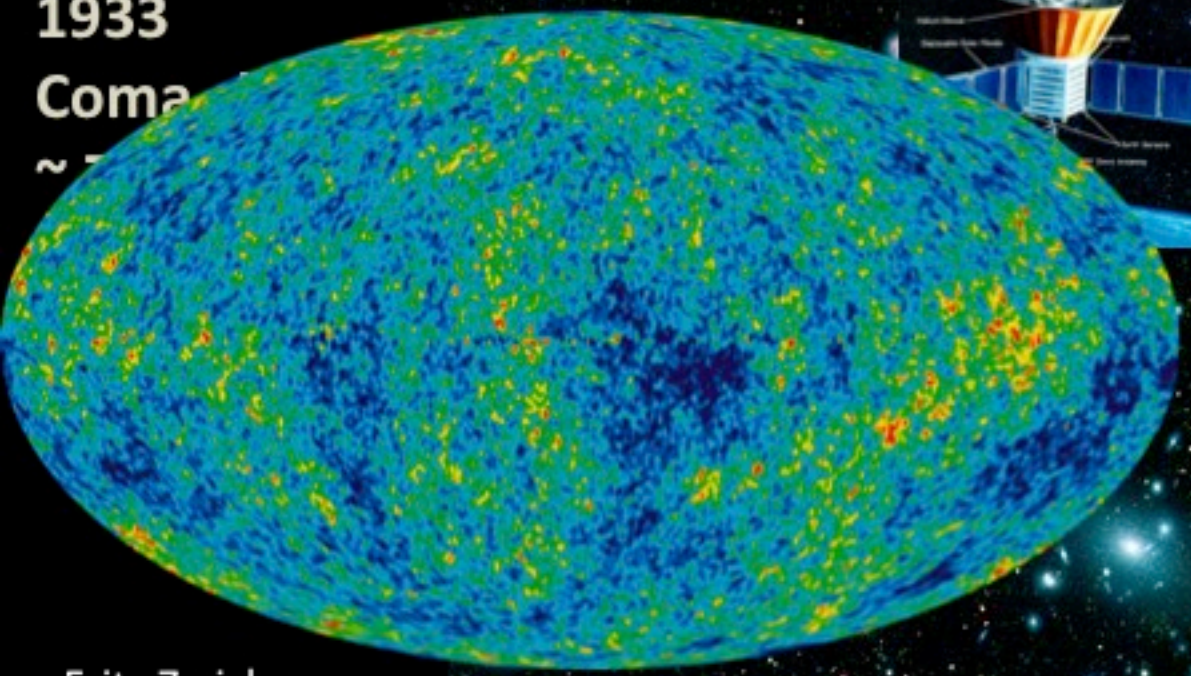


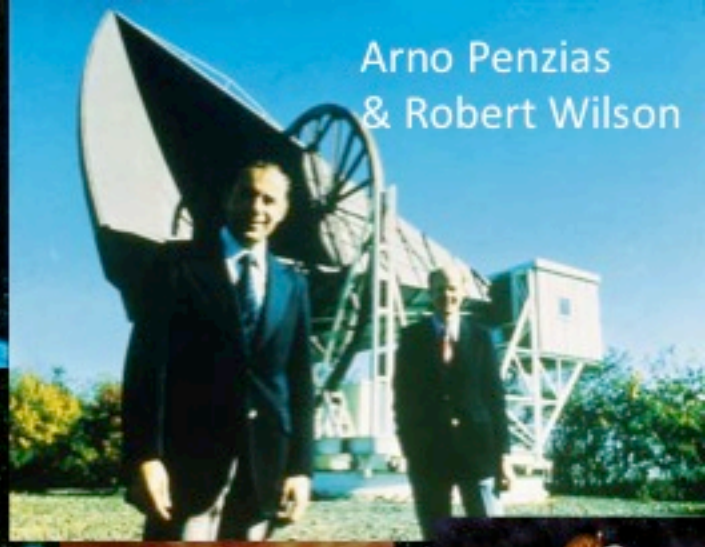
Vera Rubin


1933
Coma
~
Fritz Zwicky
Arno Penzias
& Robert Wilson
Vera Rubin
Observa
from starlight
100
V
(km/s)
50
Expected from visible disk
10
20
30
40
50
R (× 1000 ly)

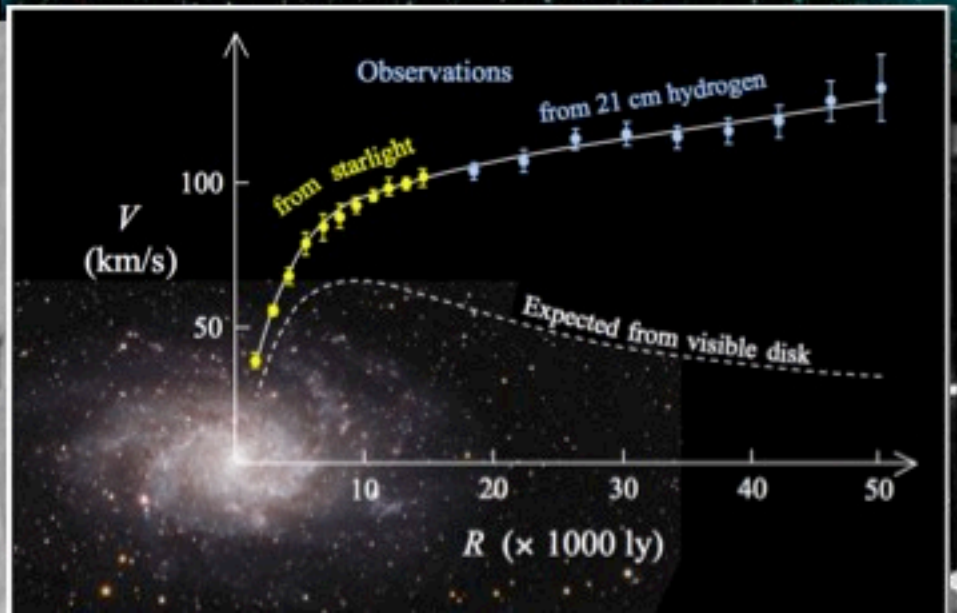
1933
Coma
~



Arno Penzias
& Robert Wilson



Fritz Zwicky

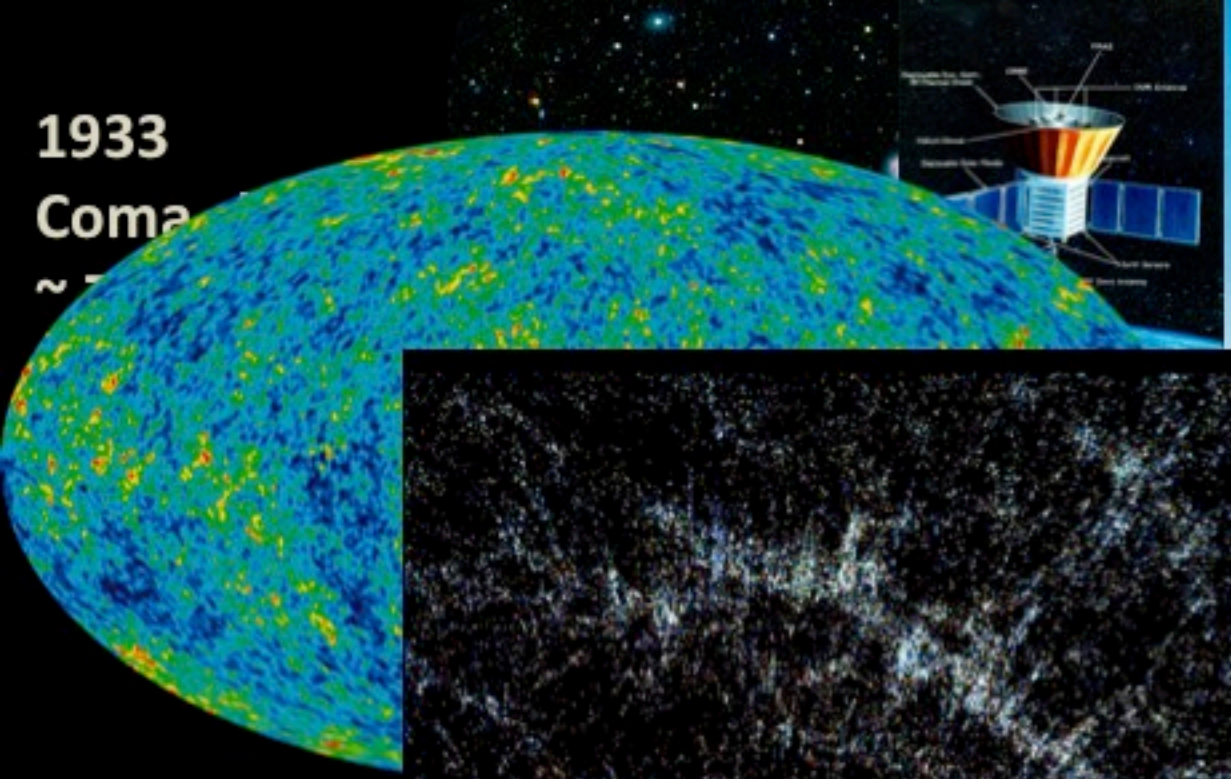


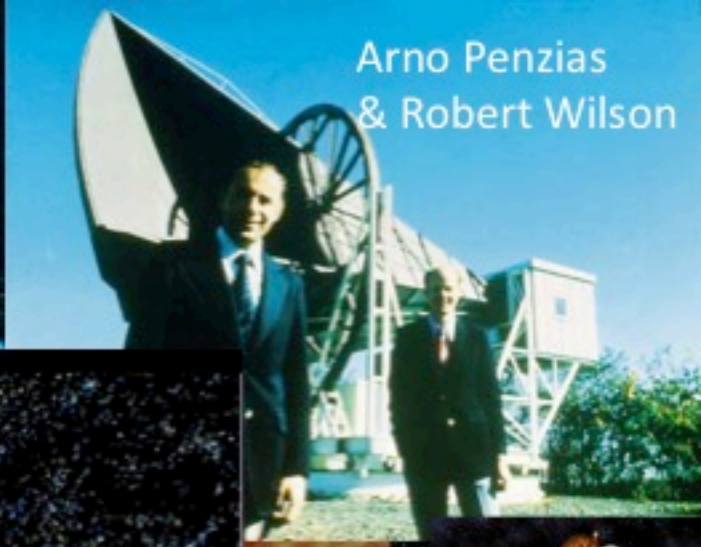
Vera Rubin

1933

Coma

~





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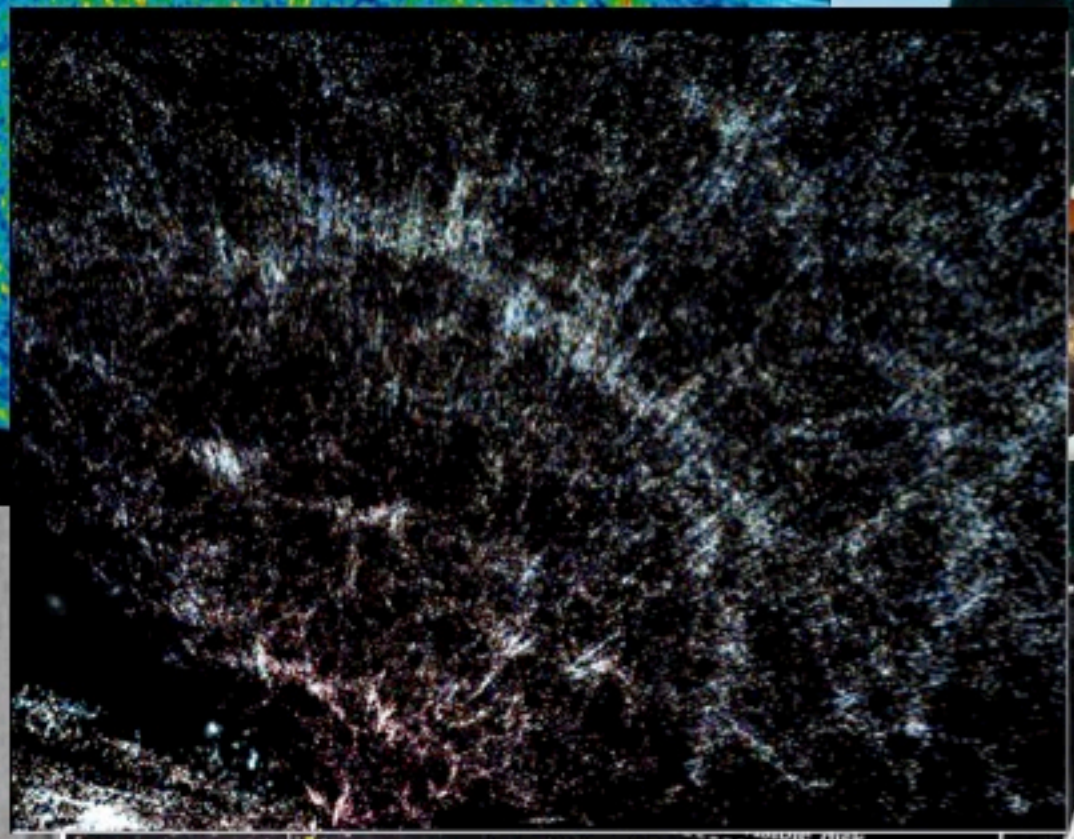

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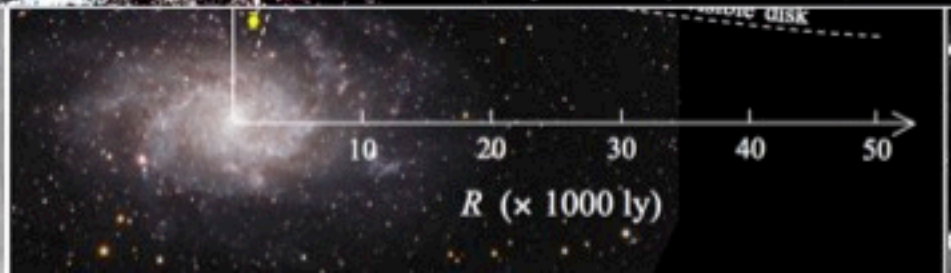
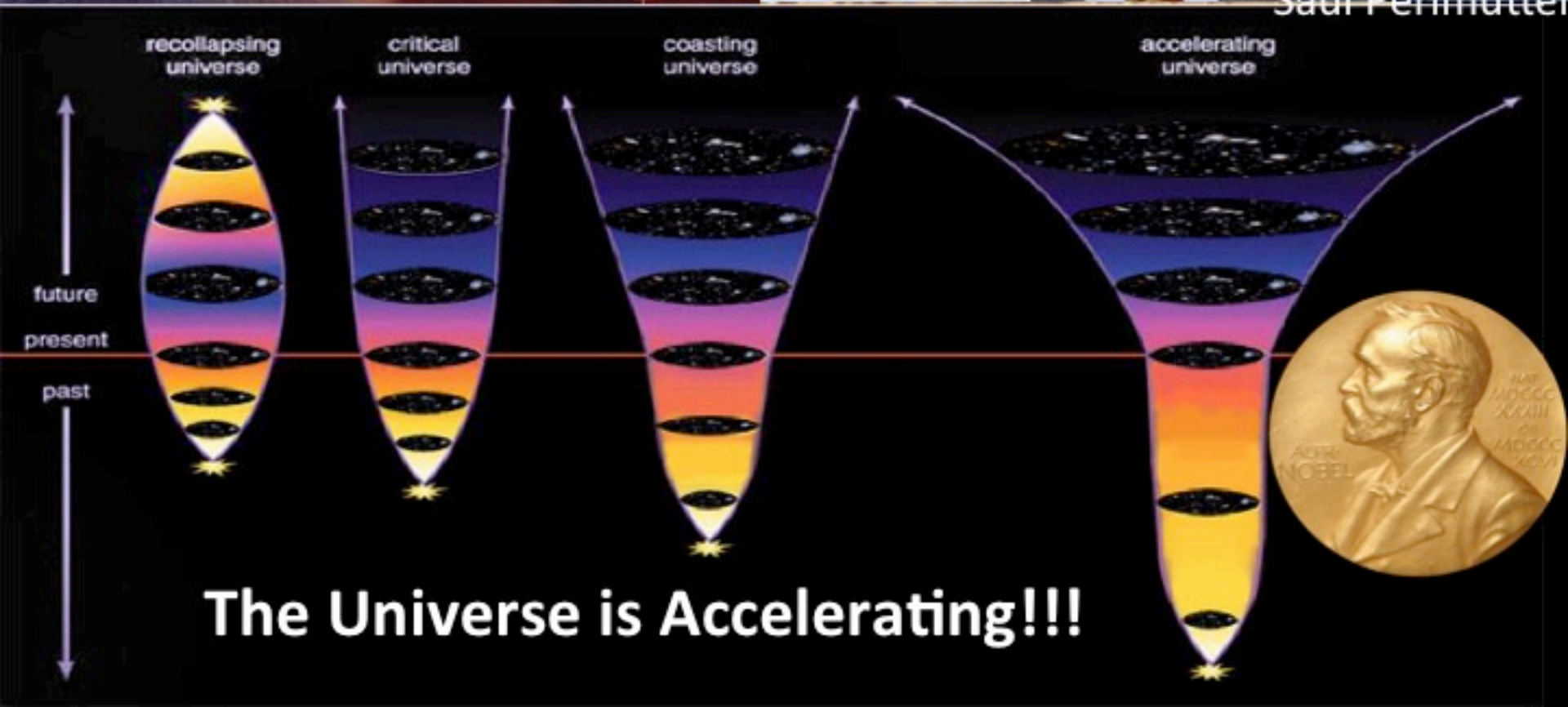


Physics Nobel Prize 2011

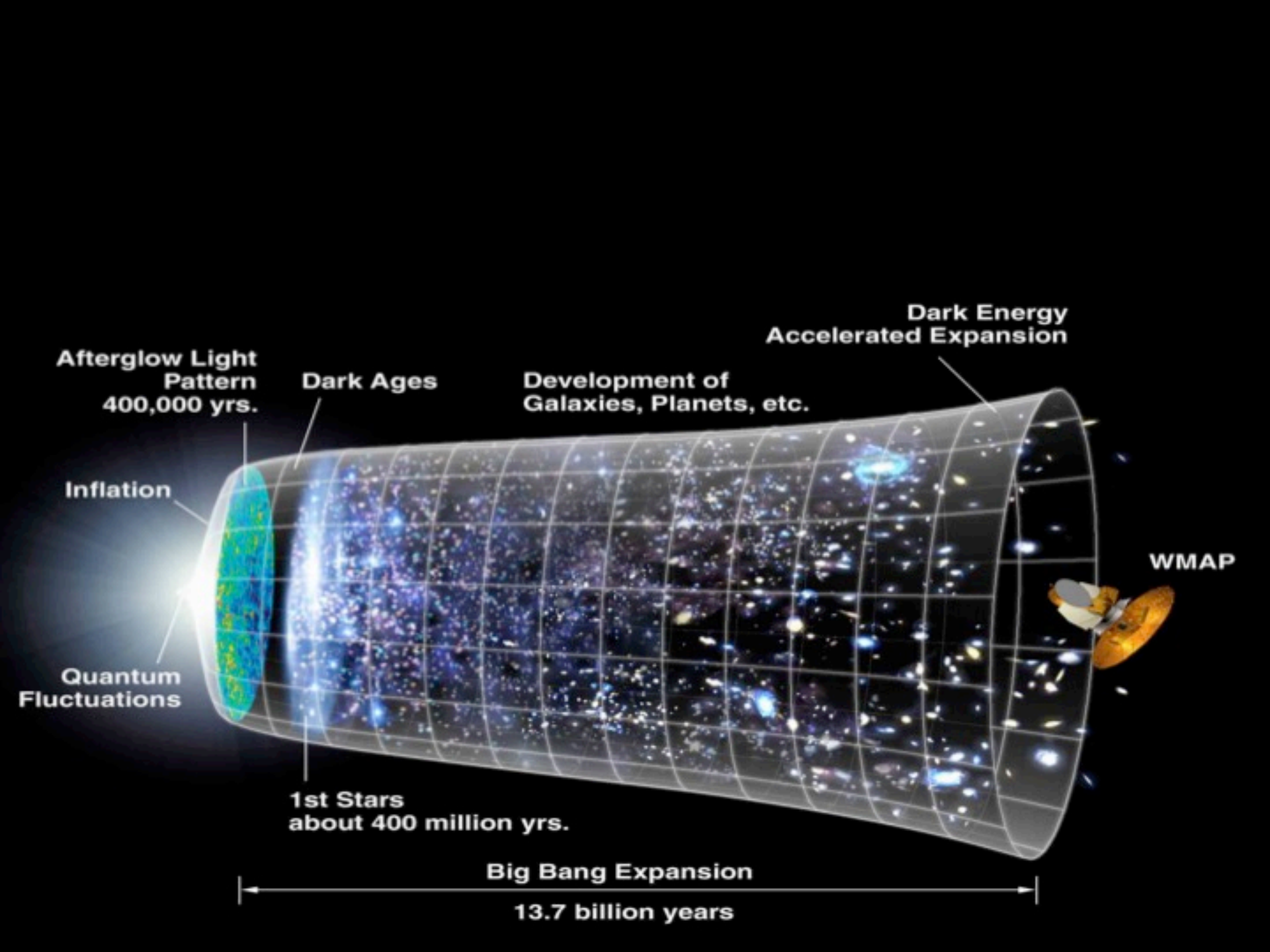
Adam G. Riess

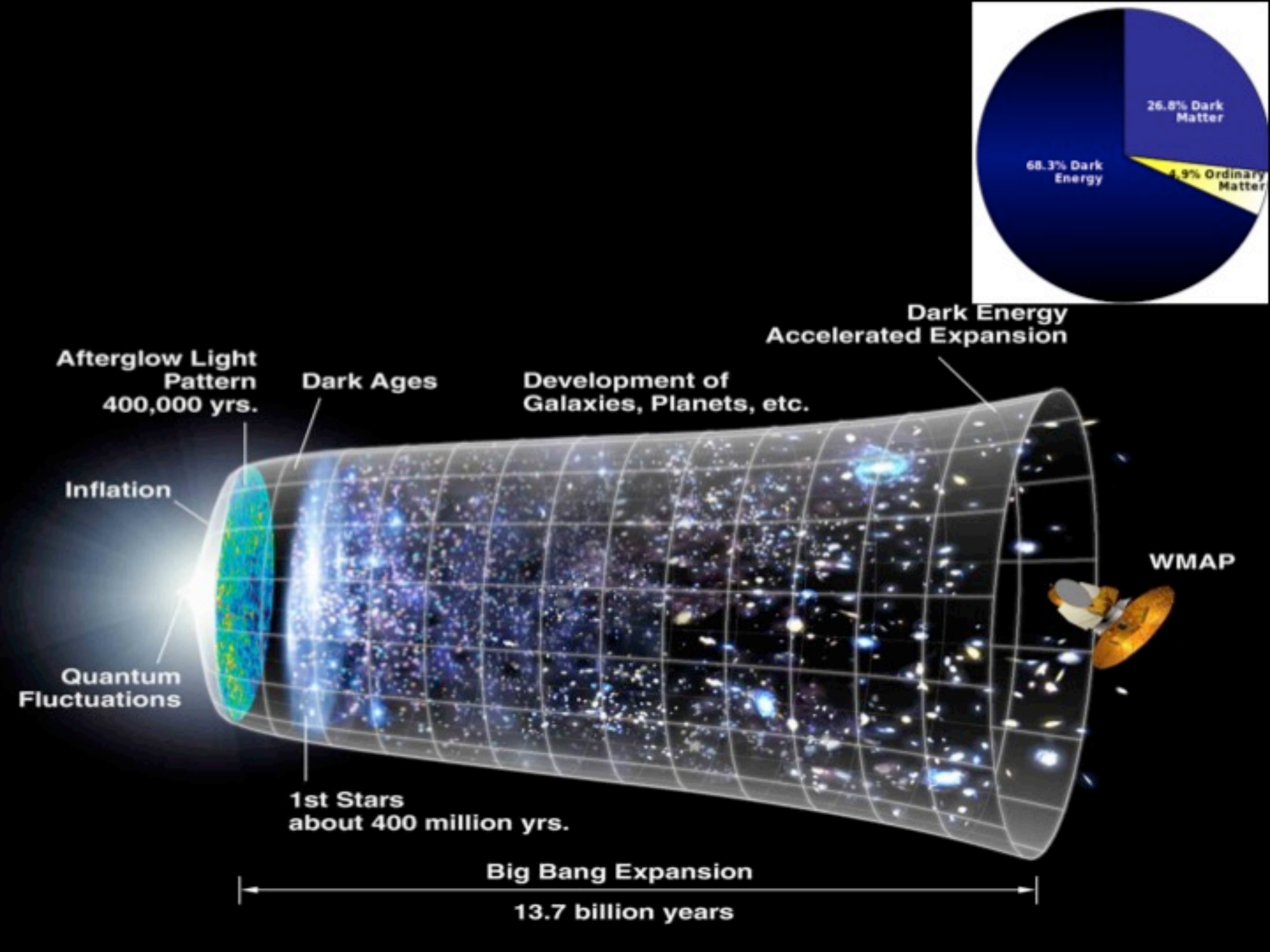
Brian P. Schmidt

Saul Perlmutter



The Universe is Accelerating!!!


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years


26.8% Dark Matter
68.3% Dark Energy
4.9% Ordinary Matter
Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
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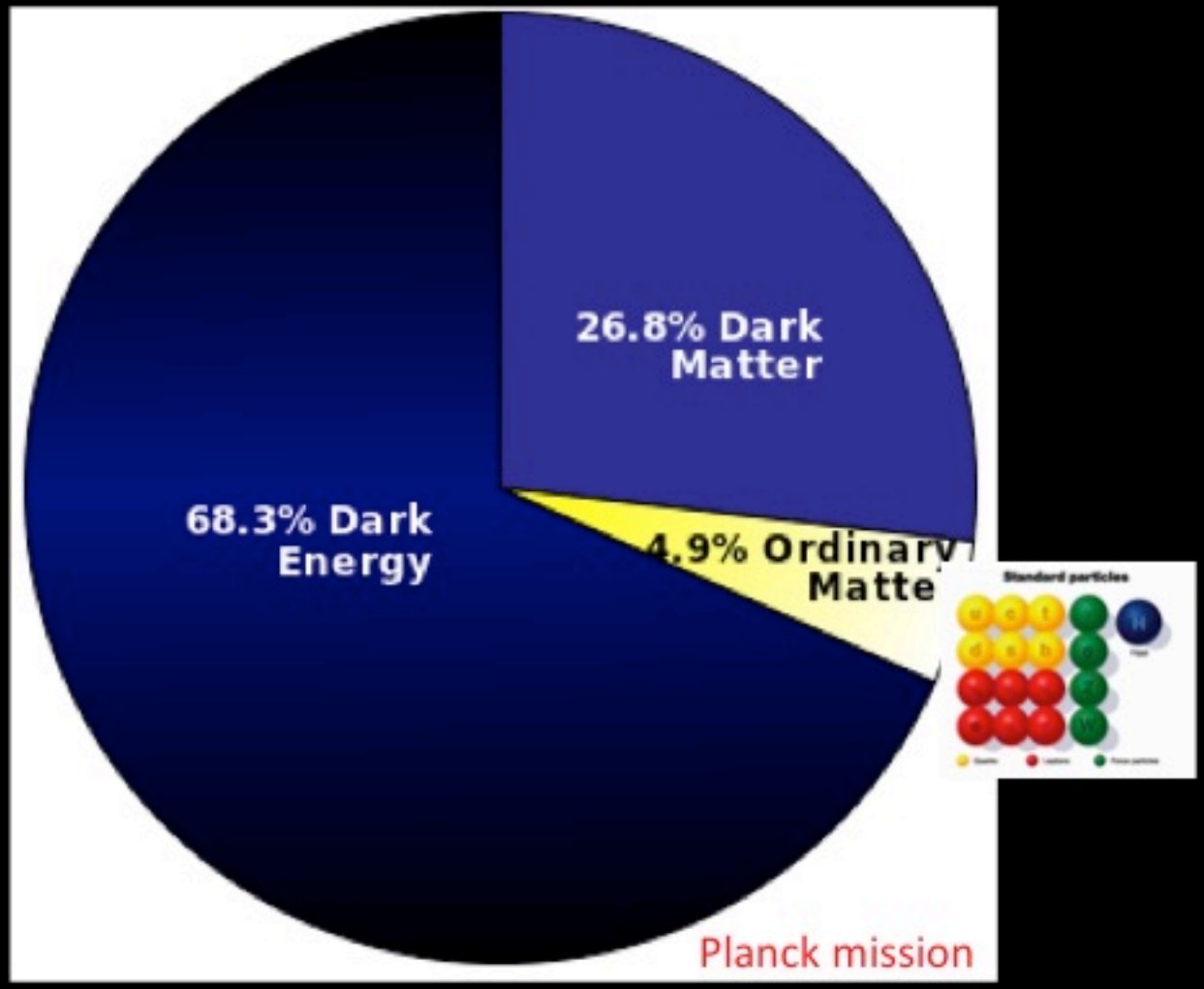
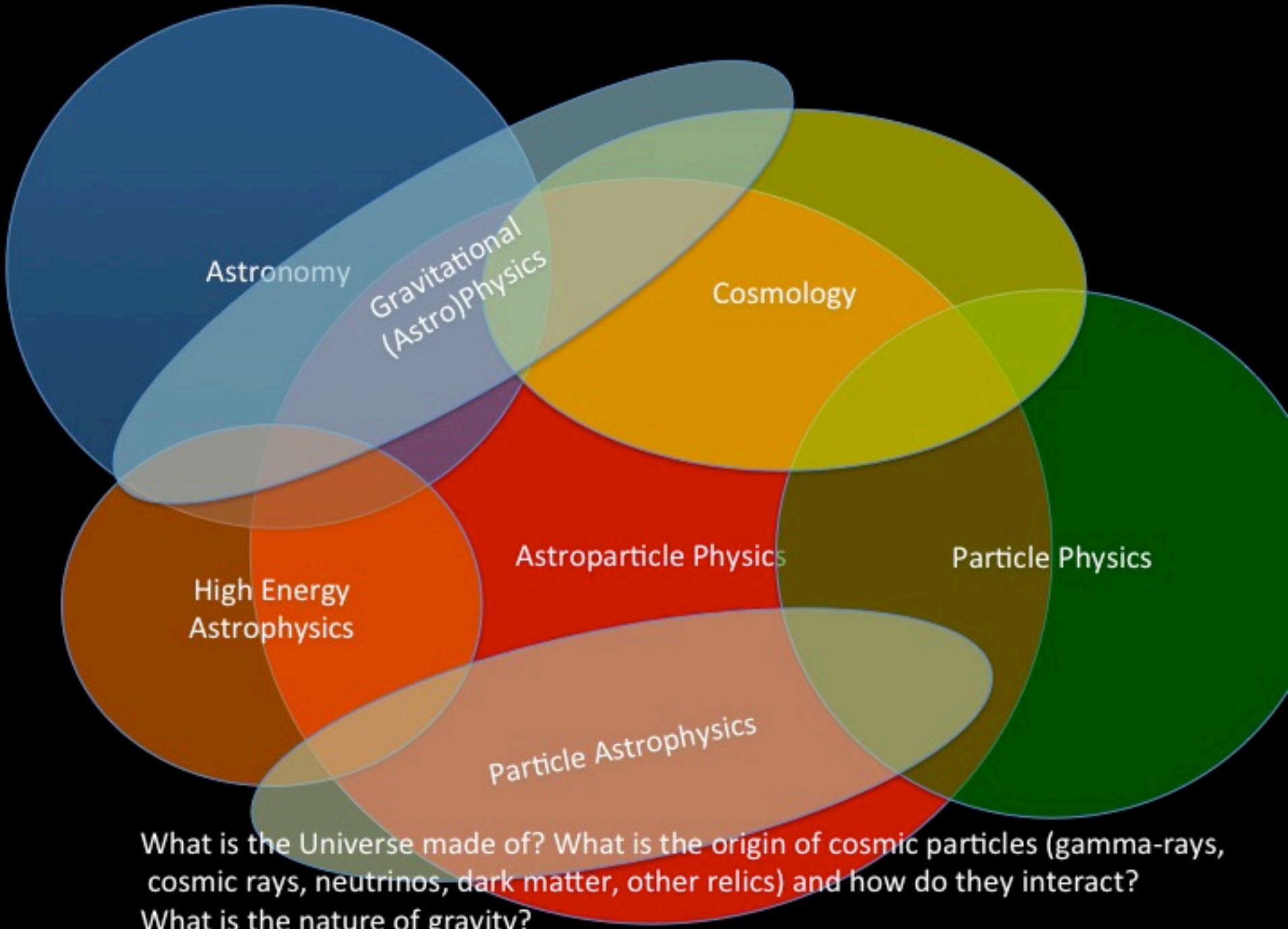
Cosmological Surprises:



Standard Model explains ~5% of the universe, 27% Dark Matter, & 68% named Dark Energy!



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Astroparticle Physics

The Universe as a Particle Physics Laboratory

Astroparticle Physics

Neutrinos:

Solar Neutrino problem - oscillations

$N_\nu < 4$ from Big Bang Nucleosynthesis

Atmospheric Neutrinos - oscillations

Supernova 1987A – mass limits, SN theory

CMB – neutrino masses

High Energy Neutrinos

Ultra-high Energy neutrinos?

Astroparticle Physics

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High Energy Neutrinos

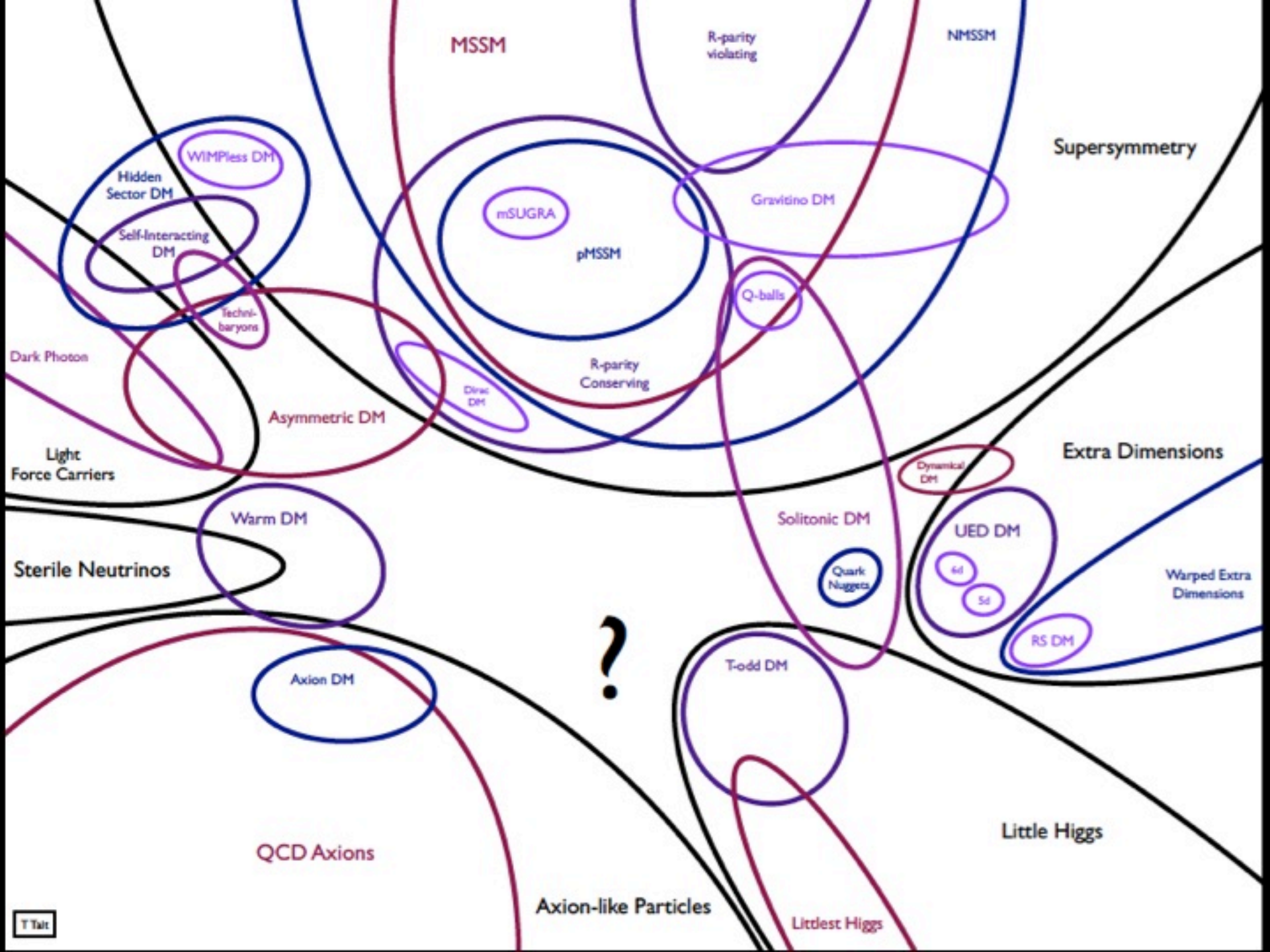
Ultra-high Energy neutrinos?

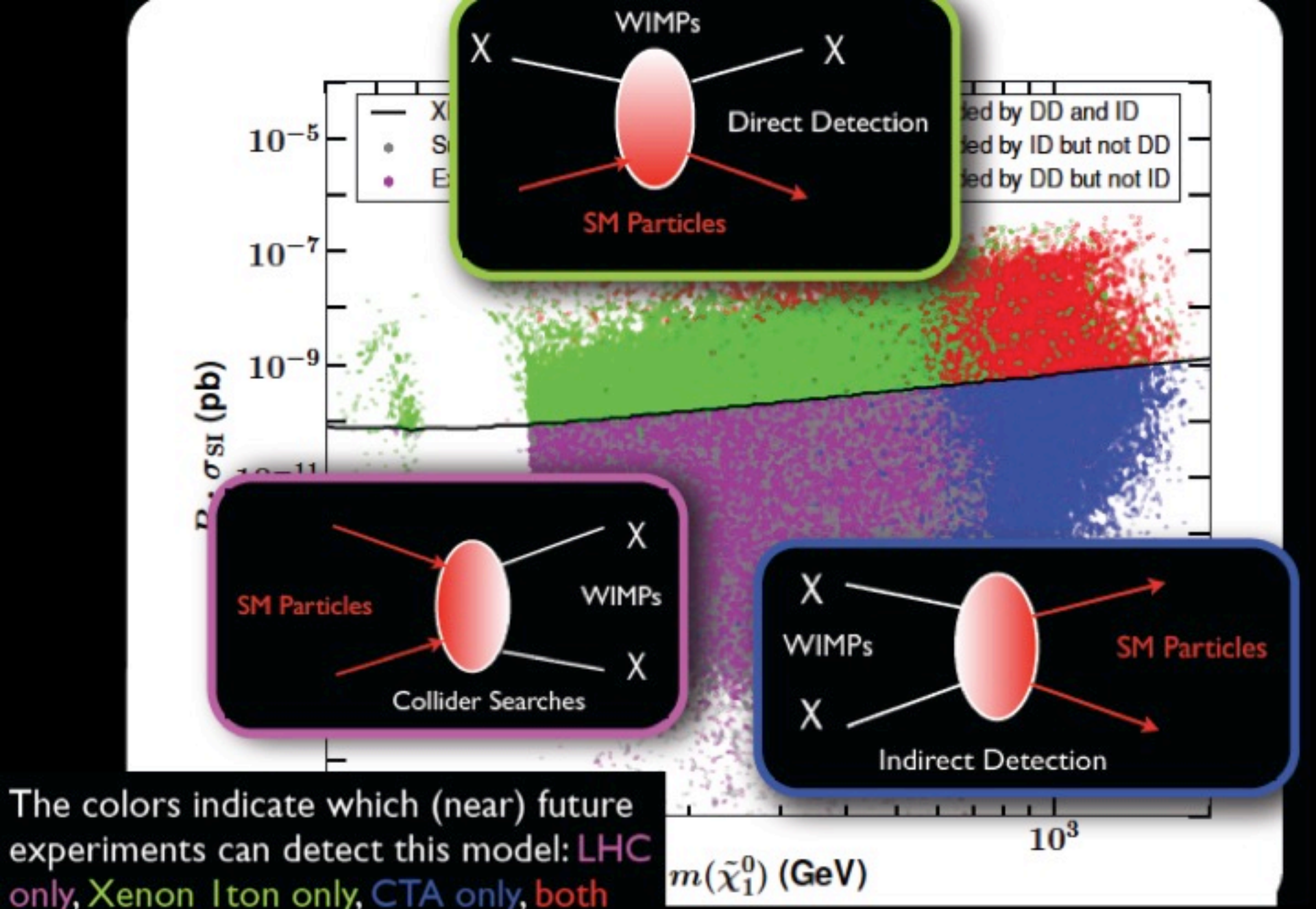
Xinhua Bai
Daniele Fargion
Ke Fang
Xiangyu Wang
Kumiko Kotera
Xiang-Ping Wu
Angela Olinto

Astroparticle Physics

Dark Matter

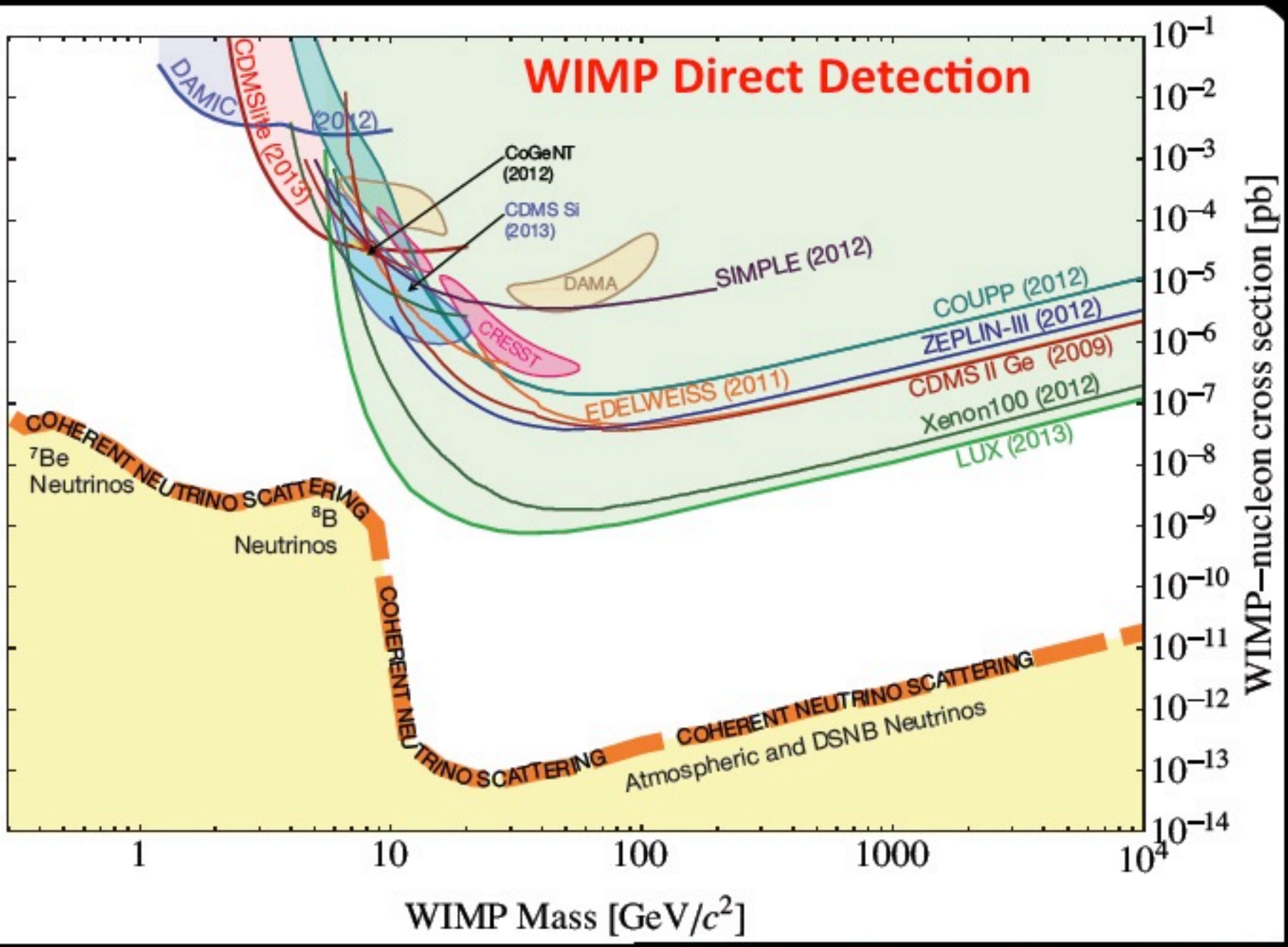
- Astronomical Evidence
- Cosmological Evidence
- **Direct Detection (WIMPs, Axions)**
- **Indirect Detection (WIMPs, Axions, SHDM, other relics?)**
- Production at LHC (WIMPs)


MSSM
R-parity violating
NMSSM
Supersymmetry
WIMPless DM
Hidden Sector DM
Self-Interacting DM
Techni-baryons
mSUGRA
pMSSM
Gravitino DM
Q-balls
Dark Photon
R-parity Conserving
Dirac DM
Asymmetric DM
Light Force Carriers
Extra Dimensions
Dynamical DM
Warm DM
Solitonic DM
UED DM
Sterile Neutrinos
Quark Nuggets
6d
5d
Warped Extra Dimensions
RS DM
?
Axion DM
T-odd DM
Little Higgs
QCD Axions
Axion-like Particles
Littlest Higgs
T Tait



The colors indicate which (near) future experiments can detect this model: LHC only, Xenon 1ton only, CTA only, both Xenon and CTA, or can't be discovered.

Cahill-Rowley et al, 1305.6921



Billard, Figueroa-Feliciano, Strigari 1307.5458

Astroparticle Physics

Dark Matter

- Astronomical Evidence
- Cosmological Evidence
- ***Direct Detection (WIMPs, Axions)***
- ***Indirect Detection (WIMPs, Axion***
  SHDM, other relics?)
- Production at LHC (WIMPs)

Joao Torres de Mello Ne
Xiaojun Bi
Chen Wang
Dong Lai
Hao Zheng
Lie-Wen Chen
Meng Su
Lei Feng
Yizhong Fan

Astroparticle Physics

Early Universe

- BB Nucleosynthesis
- Baryogenesis
- Inflation – CMB B-modes
- Phase Transitions
- Relics: cosmic strings, monopoles, primordial black holes, strangelets...

Astroparticle Physics

Early Universe

- BB Nucleosynthesis
- Baryogenesis
- Inflation – CMB B-modes
- ***Phase Transitions***
- ***Relics: cosmic strings, monopoles, primordial black holes, strangelets...***

Xiaoyu Lai
Angela Olinto

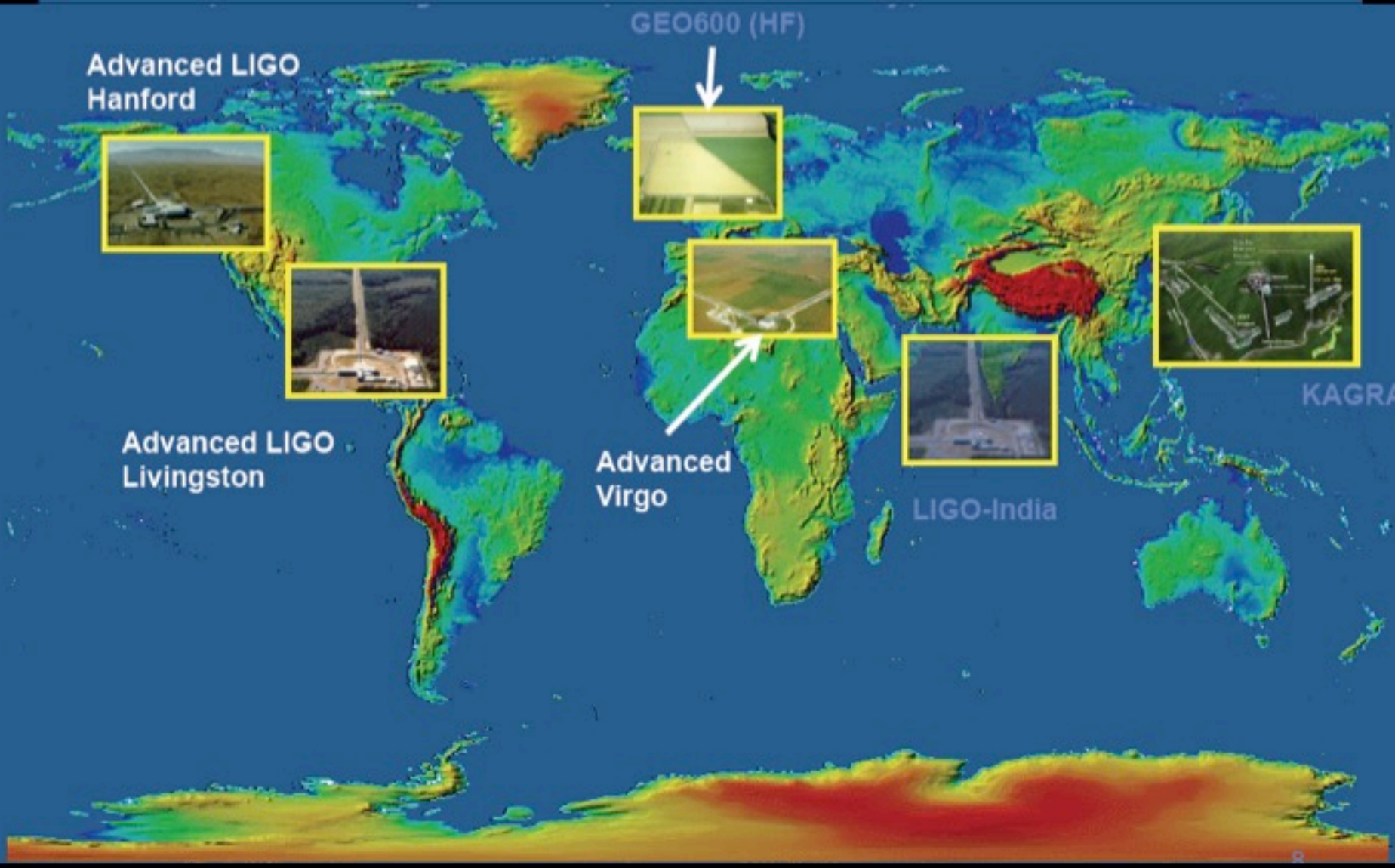
Astroparticle Physics

Dark Energy

- Acceleration of the Universe
- Modify Gravity or Stress-Energy Tensor?
- Expansion rate vs. Growth of Structure probes

Gravitational Waves

The Advanced GW Detector Network



Astroparticle Physics

Universe's Accelerators

- Compact Objects: Neutron / Quark Stars
- Black Holes
- Energetic Transient Events
- Cluster Shocks

Astroparticle Physics

Universe's Accelerators

Compact Objects: Neutron/Quark St

Black Holes

Energetic Transient Events

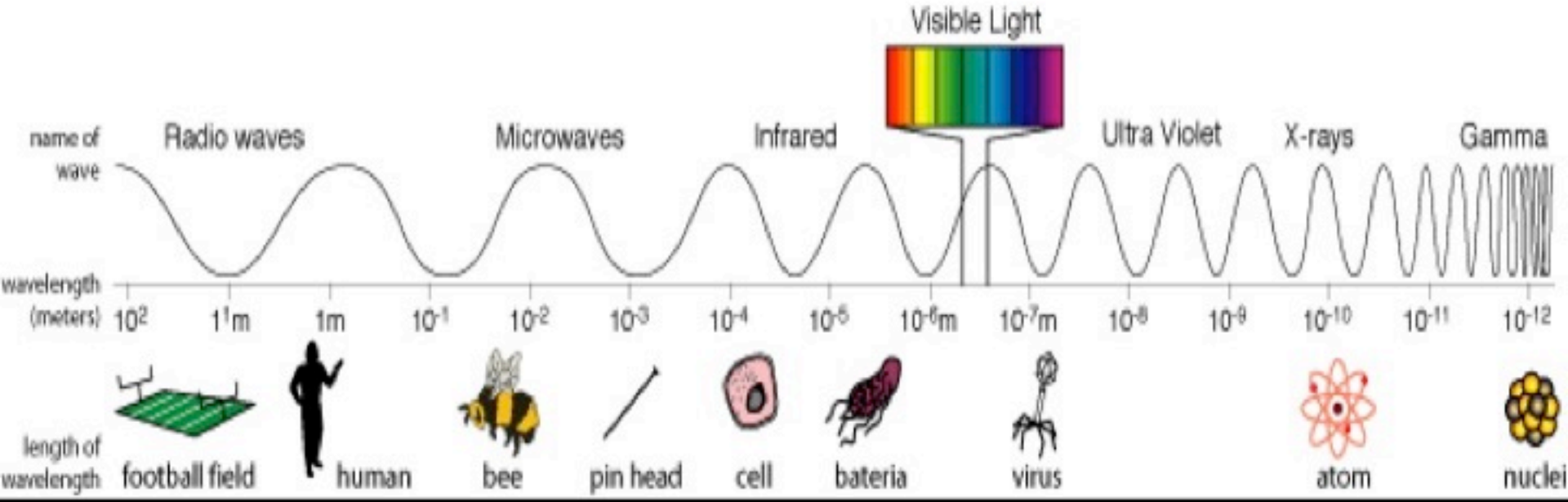
Cluster Shocks

Xinhua Bai
Martin Pohl
Kumiko Kotera
Vahe Petrosian
Igor Moskalenko
Xiaojun Bi
Ke Fang
Jonathan Zrake
Zhuo Li
Daniele Fargion
Xiangyu Wang
Jon Arons
Xiangdong Li
Chen Wang

Dong Lai
Hao Zheng
Lie-Wen Chen
Renxin Xu
Xiaoyu Lai
Zhaosheng Li
Shuangnan Zhang
Angela Olinto
Meng Su
Hua Feng
Shoushan Zhang
Zhen Cao
Xiang-Ping Wu
Jianrong Deng

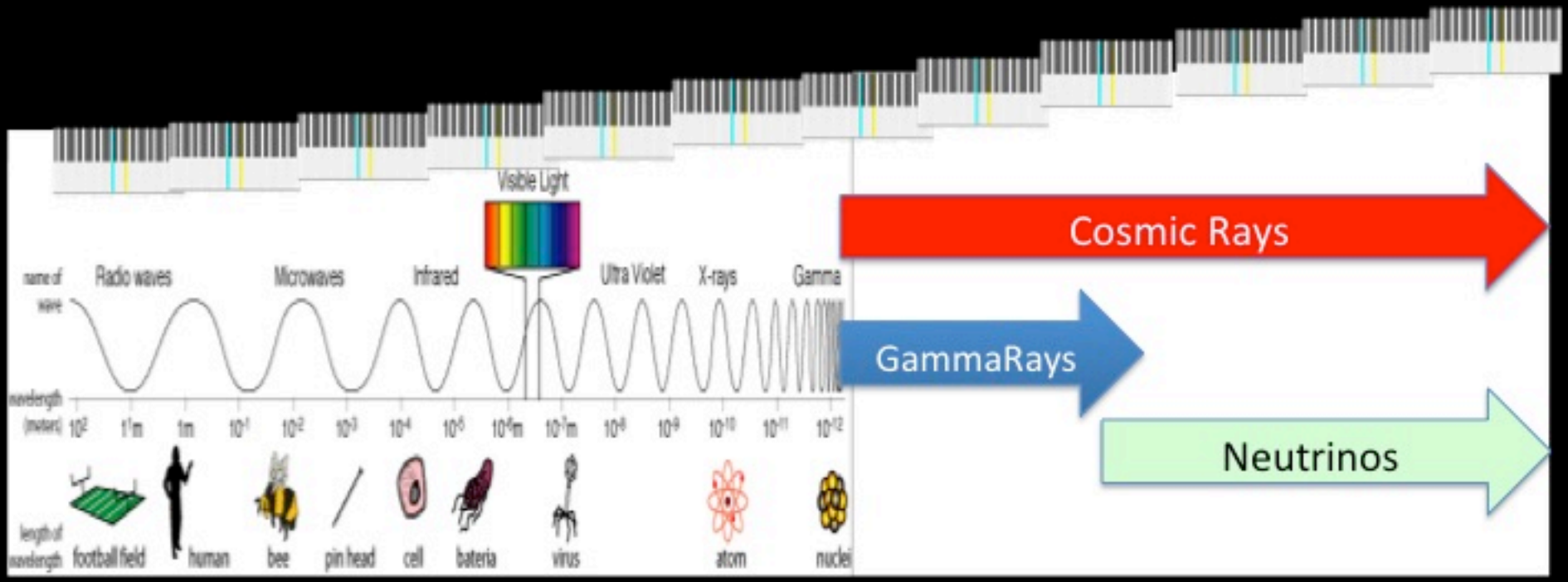
Astronomer's view of energy scales

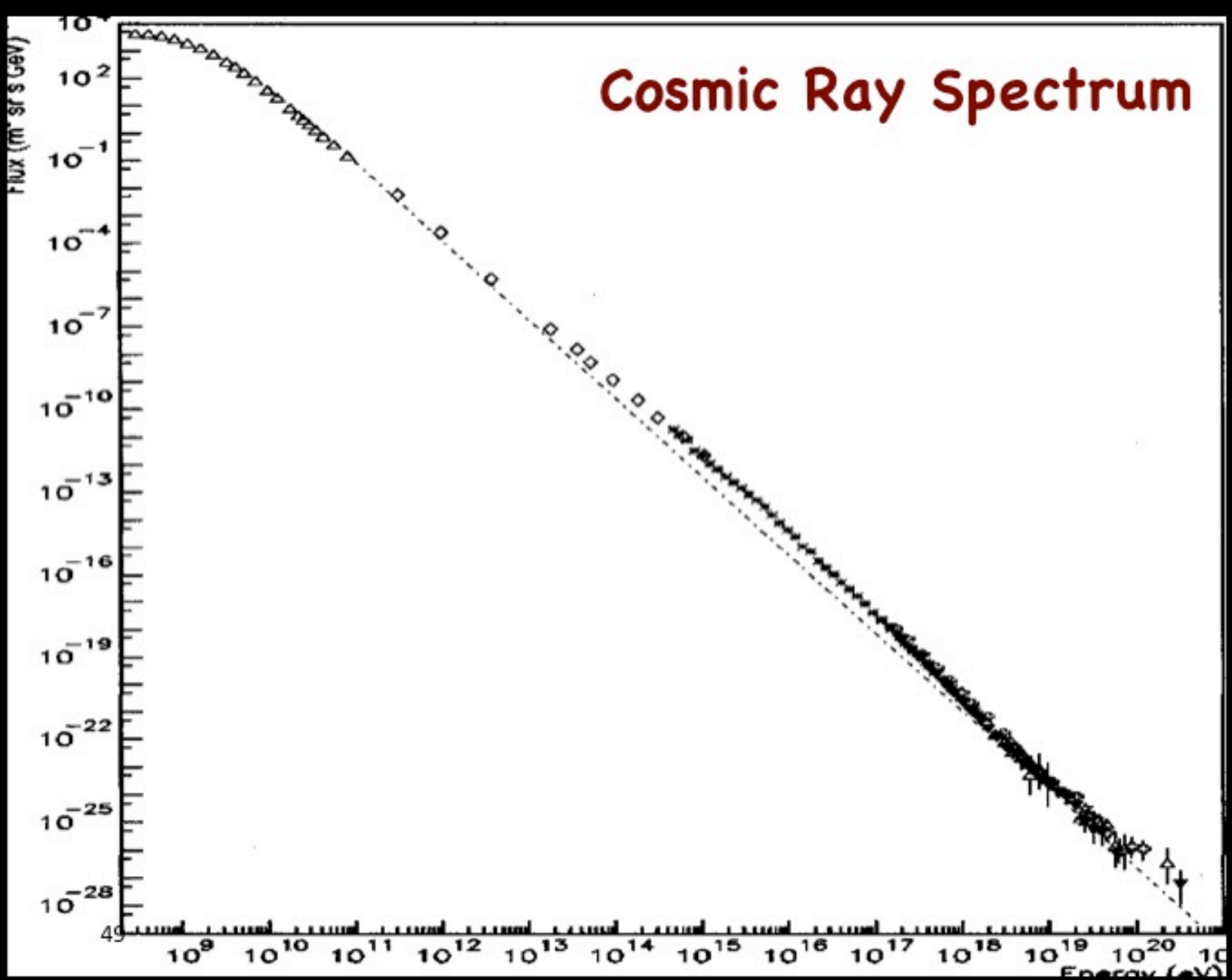
Photon "energy range"

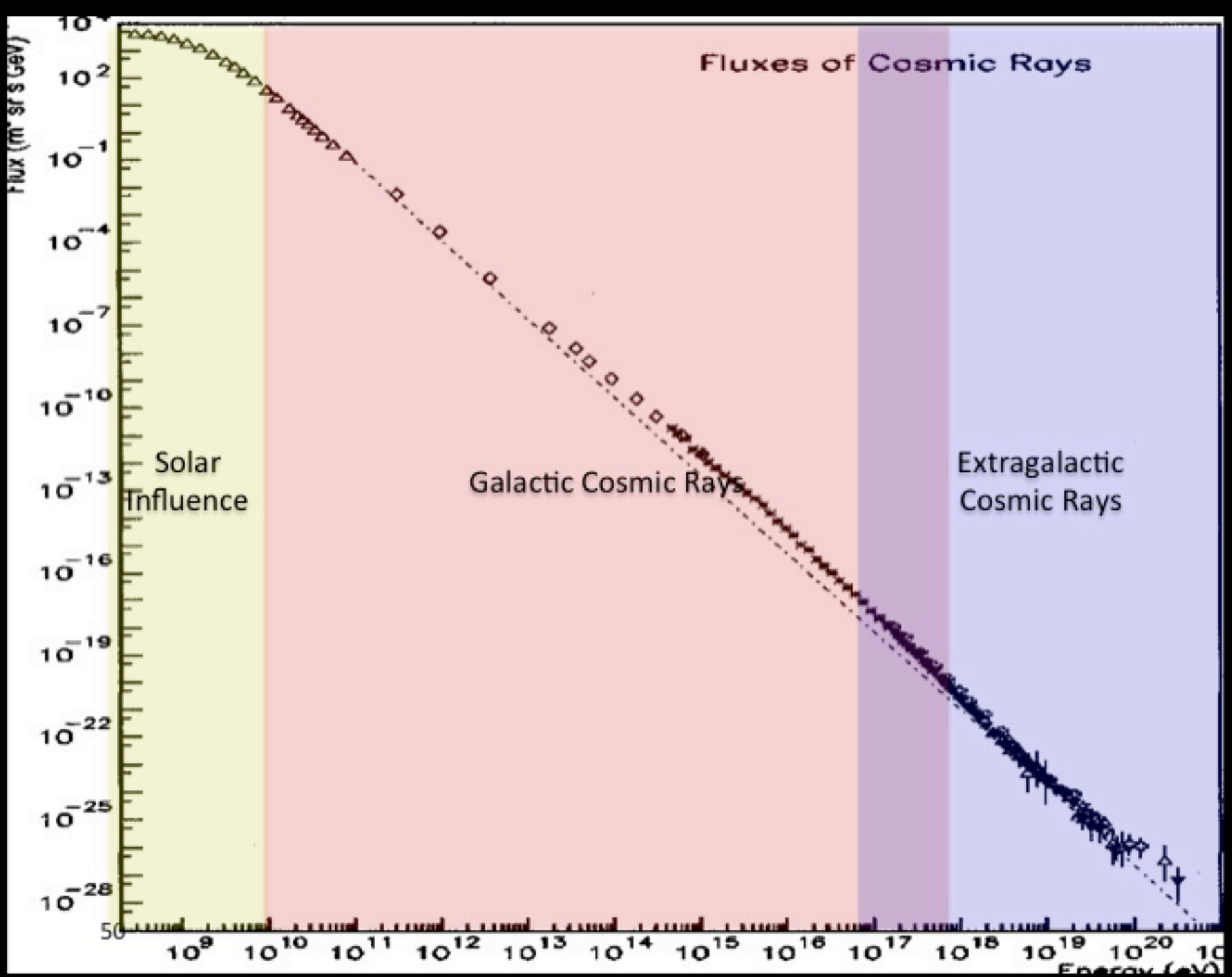


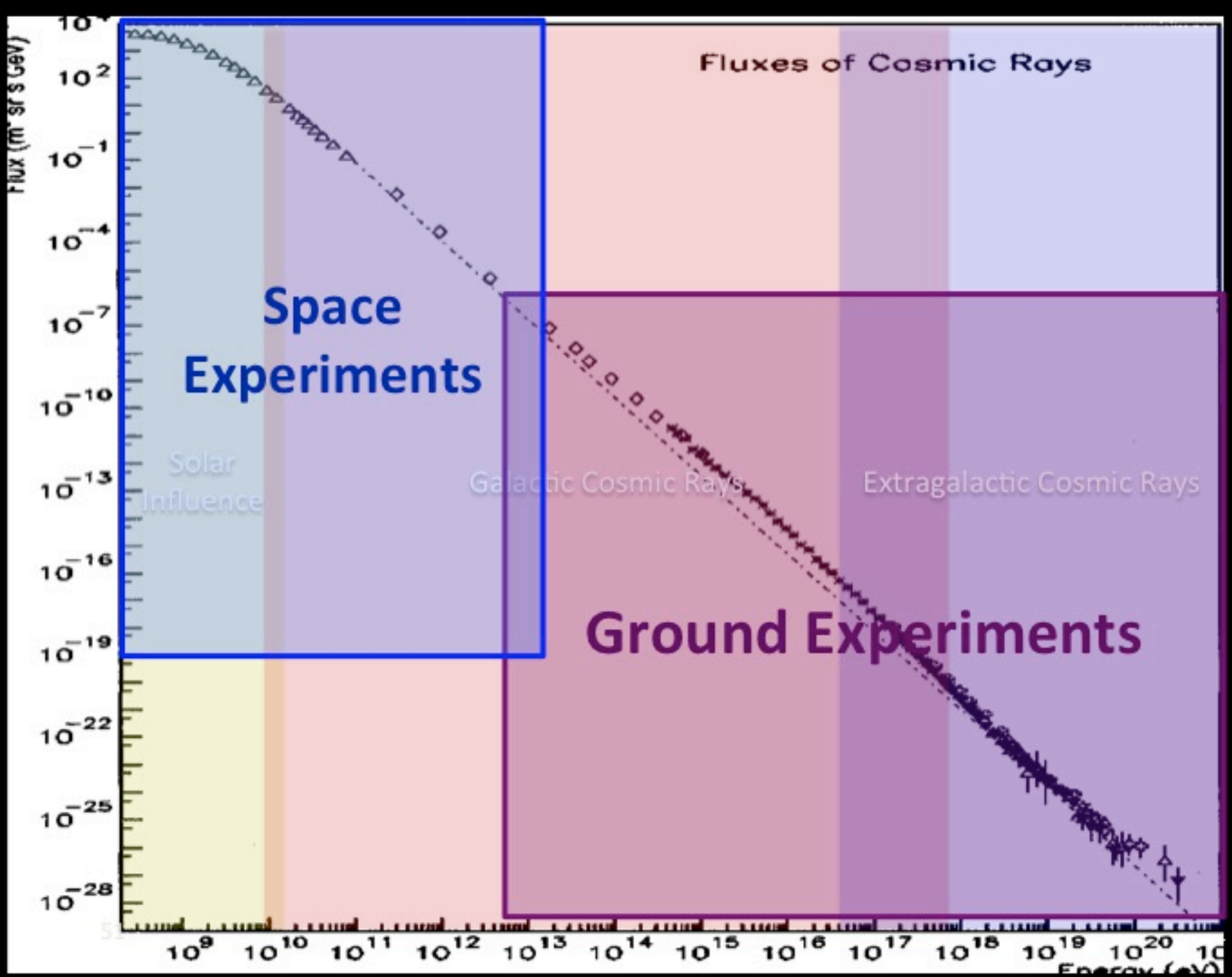
High Energy Particles

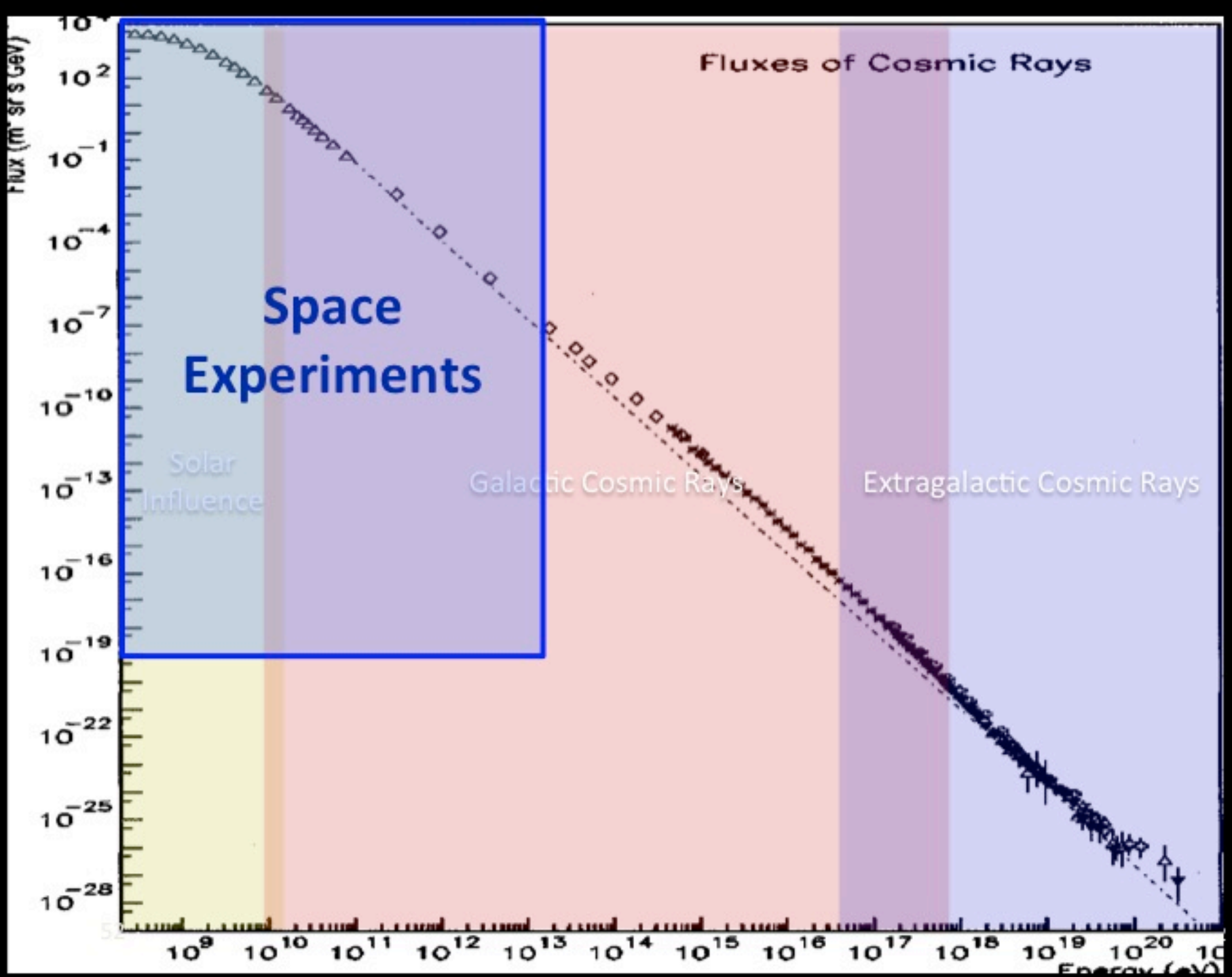
~ double the energy range for Astrophysics



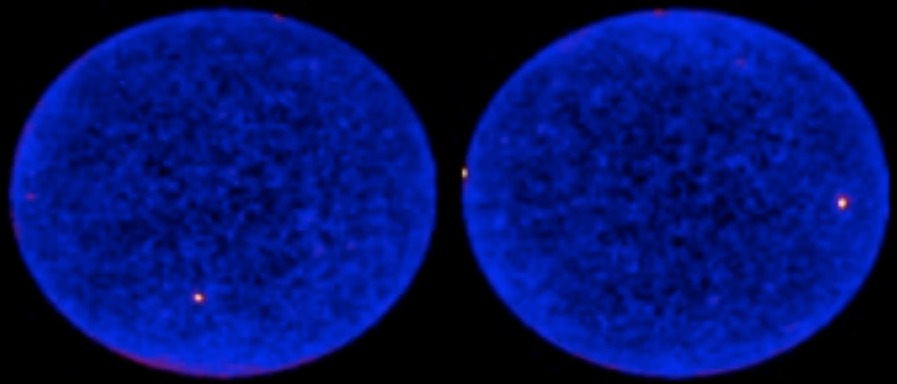

Cosmic Ray Spectrum
Flux (m² sr s GeV)
10²
10⁻¹
10⁻⁴
10⁻⁷
10⁻¹⁰
10⁻¹³
10⁻¹⁶
10⁻¹⁹
10⁻²²
10⁻²⁵
10⁻²⁸
10⁹ 10¹⁰ 10¹¹ 10¹² 10¹³ 10¹⁴ 10¹⁵ 10¹⁶ 10¹⁷ 10¹⁸ 10¹⁹ 10²⁰
Energy (eV)

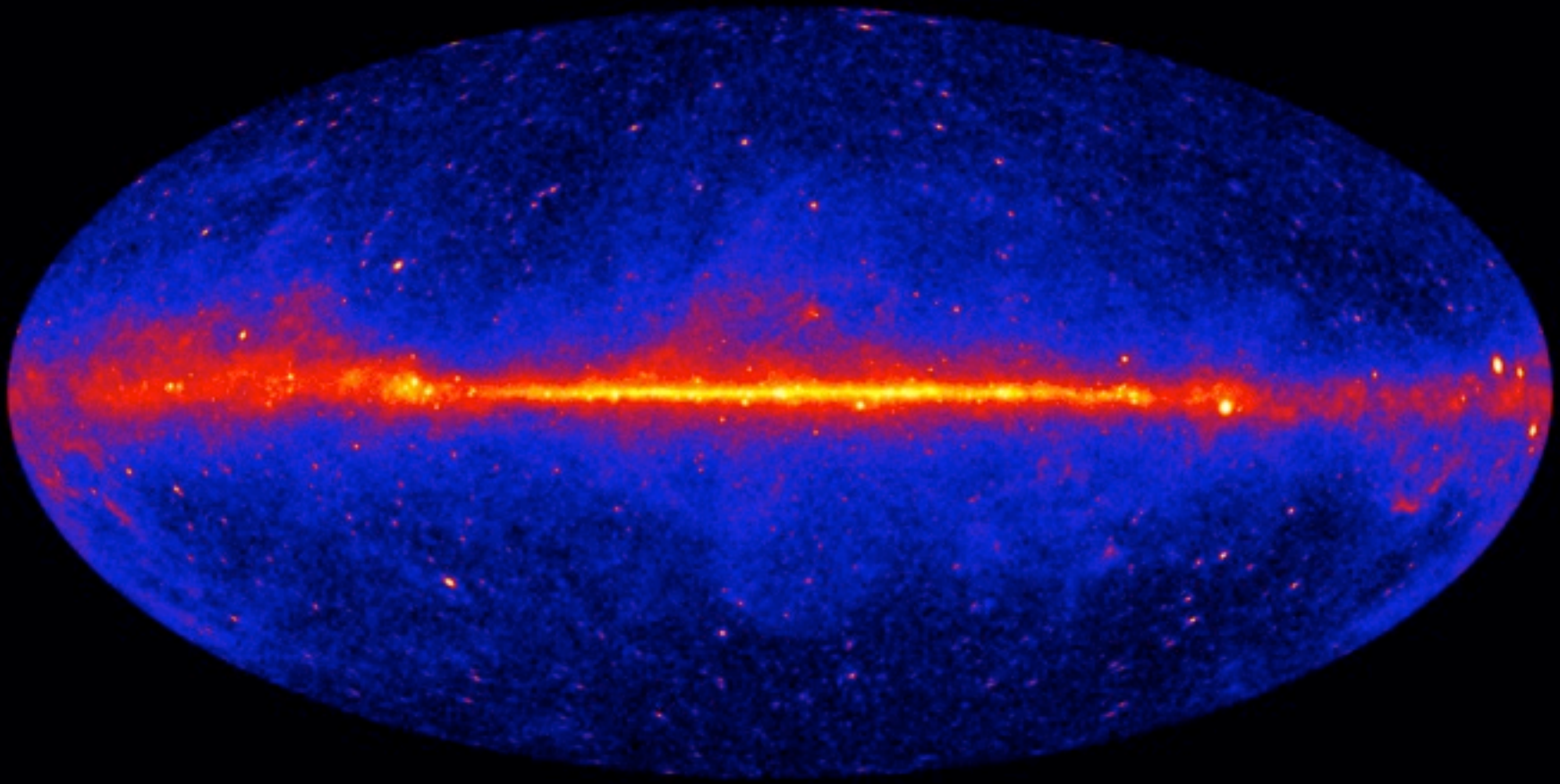

Fluxes of Cosmic Rays
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)


Fluxes of Cosmic Rays
Space Experiments
Ground Experiments
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays


Fluxes of Cosmic Rays
Space Experiments
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)

Fermi



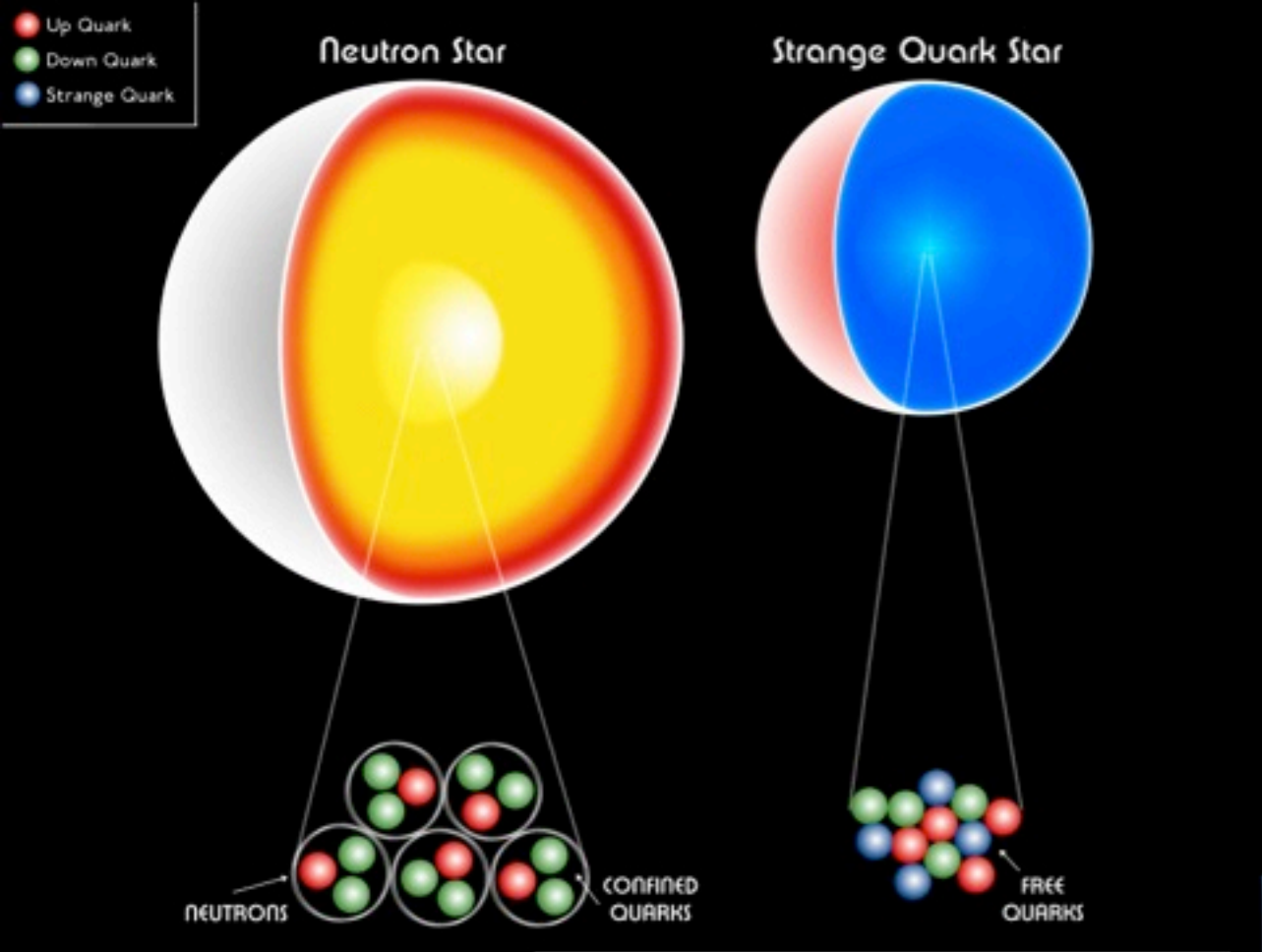


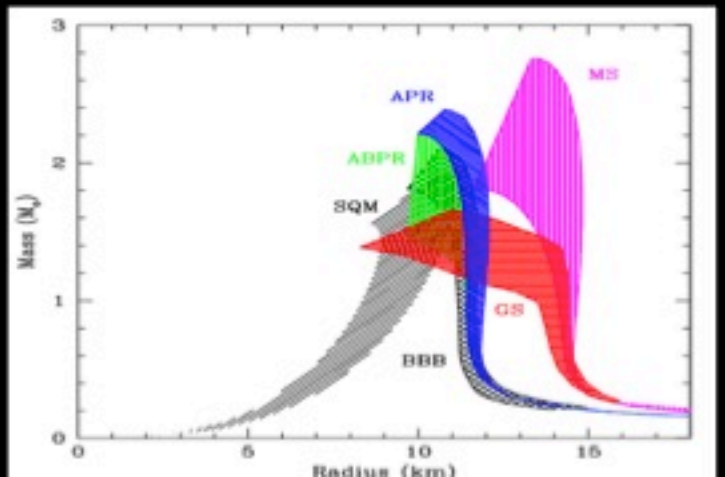
What has Fermi found: The LAT two-year catalog

Limits on DM in GC, Dwarf Galaxies, etc…
Limits on LIV to ~ M_{pl}
Limits on Large Extra Dimensions stronger LHC

Credit: NASA/Goddard Space Flight Center

Neutron Stars
Strange Stars

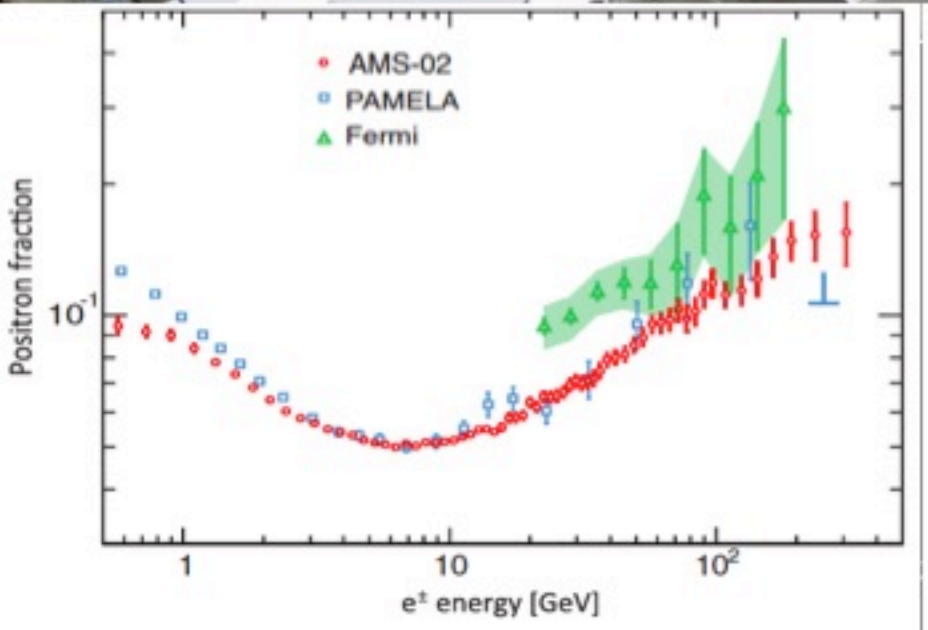


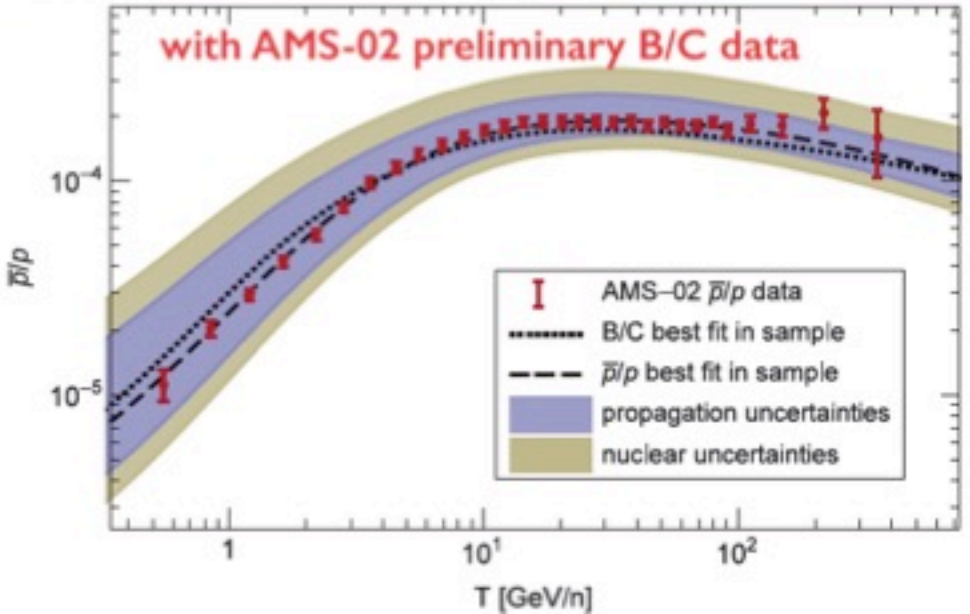


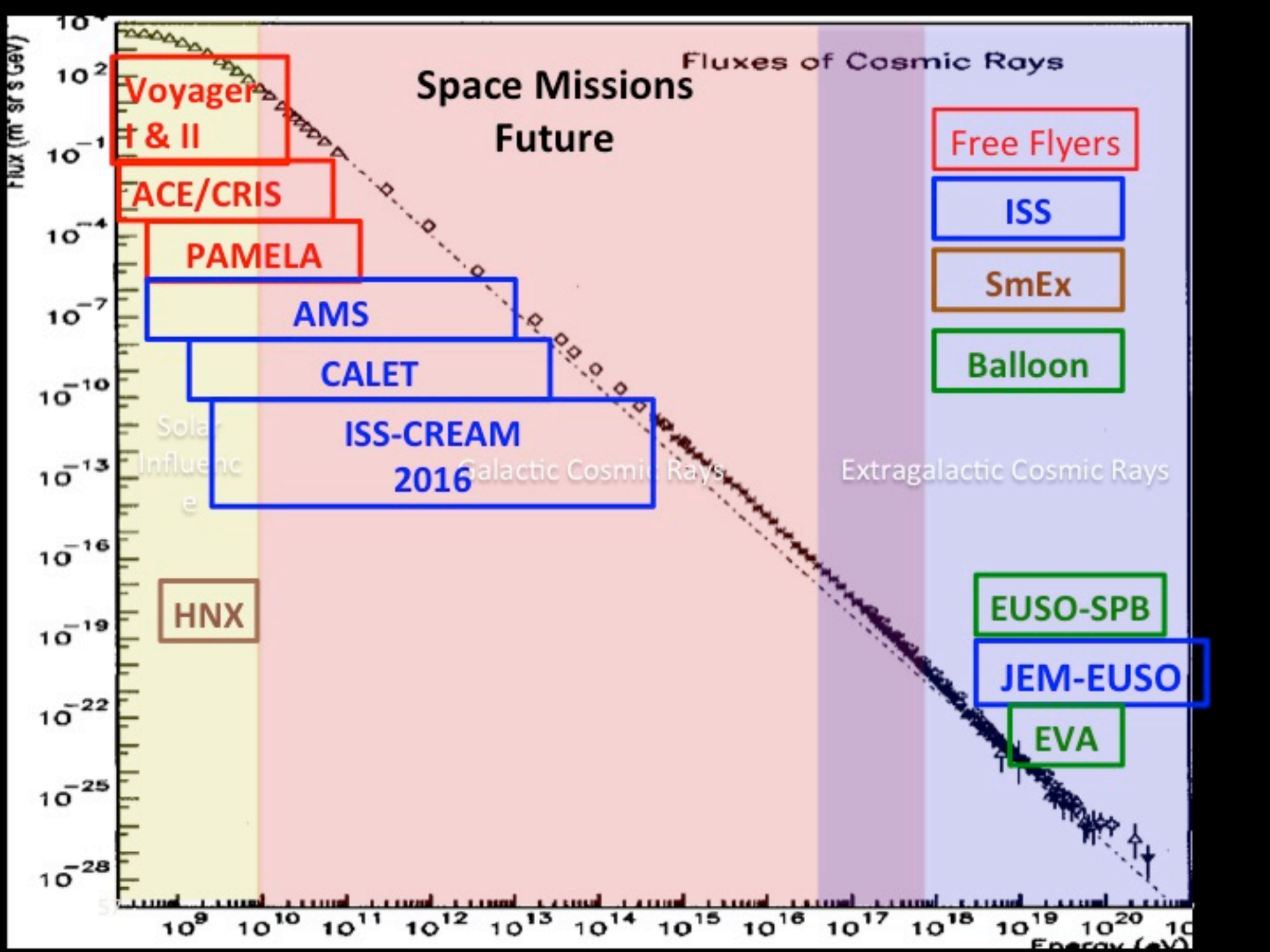
Ultra-dense matter probe through soft X-ray timing

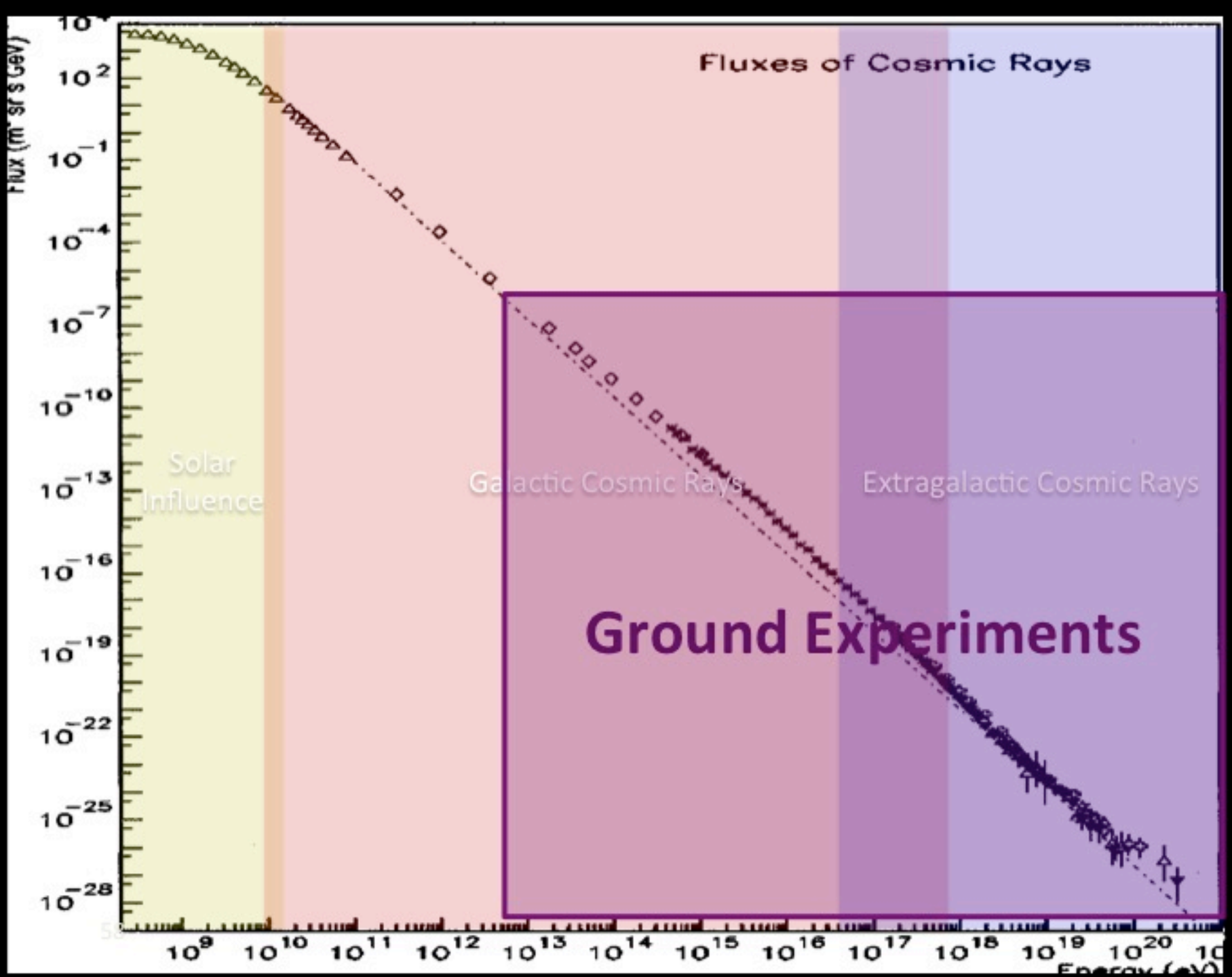
Alcock, Farhi, AVO ’86
Haensel et al ‘86

AMS on the ISS

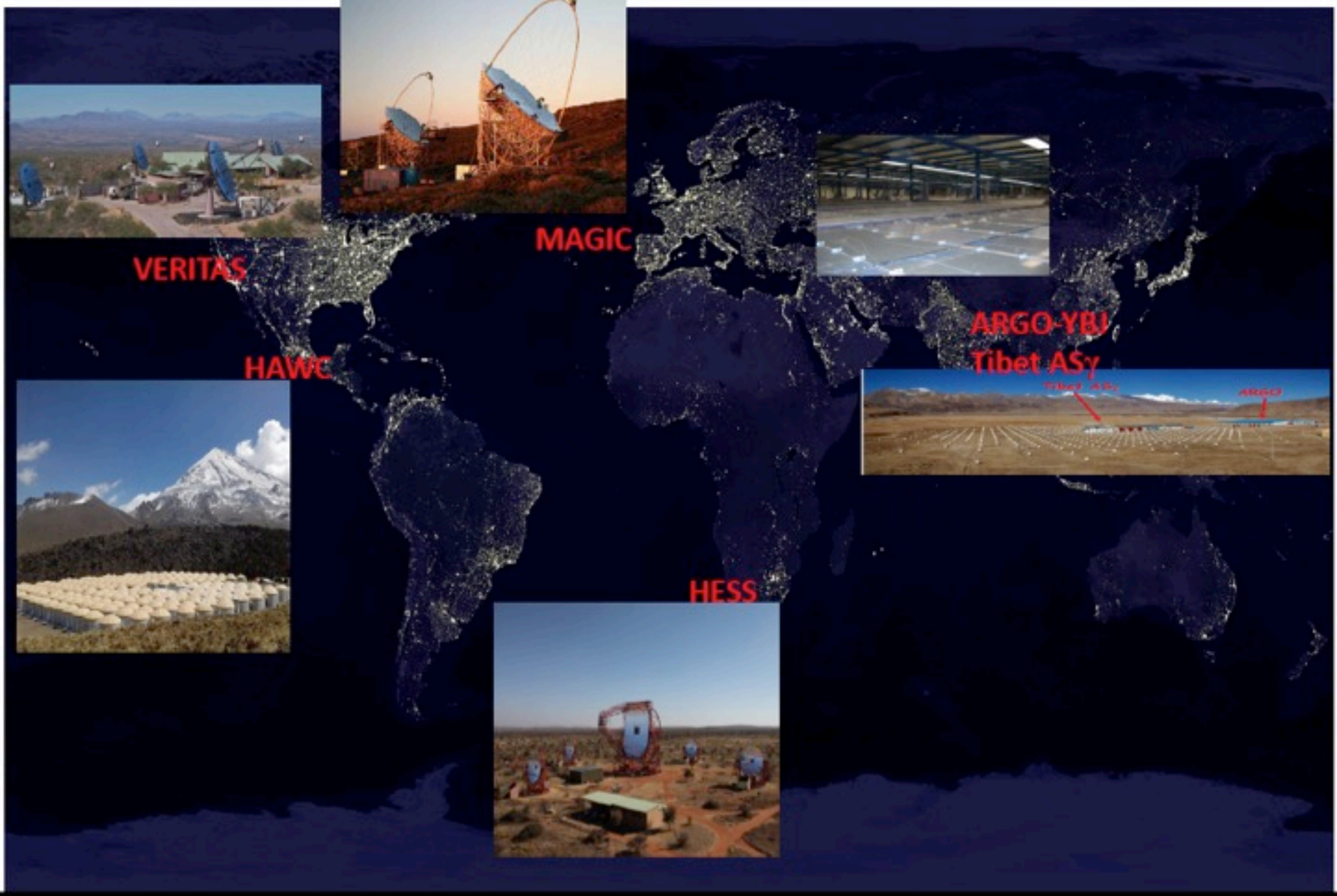




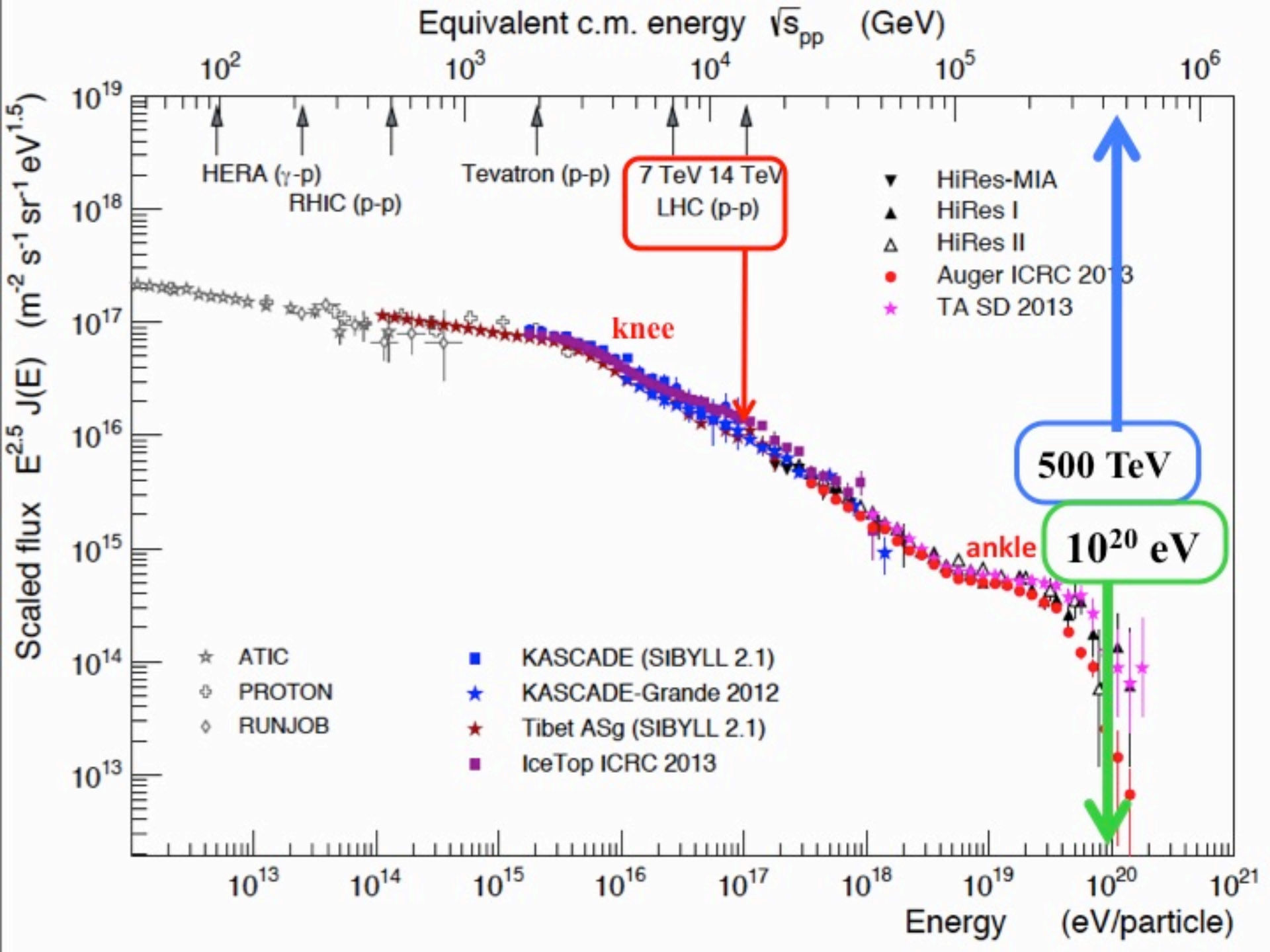

Fluxes of Cosmic Rays
Space Missions
Future
Voyager I & II
ACE/CRIS
PAMELA
AMS
CALET
ISS-CREAM 2016
HNX
Free Flyers
ISS
SmEx
Balloon
EUSO-SPB
JEM-EUSO
EVA
Galactic Cosmic Rays
Extragalactic Cosmic Rays


Fluxes of Cosmic Rays
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Ground Experiments

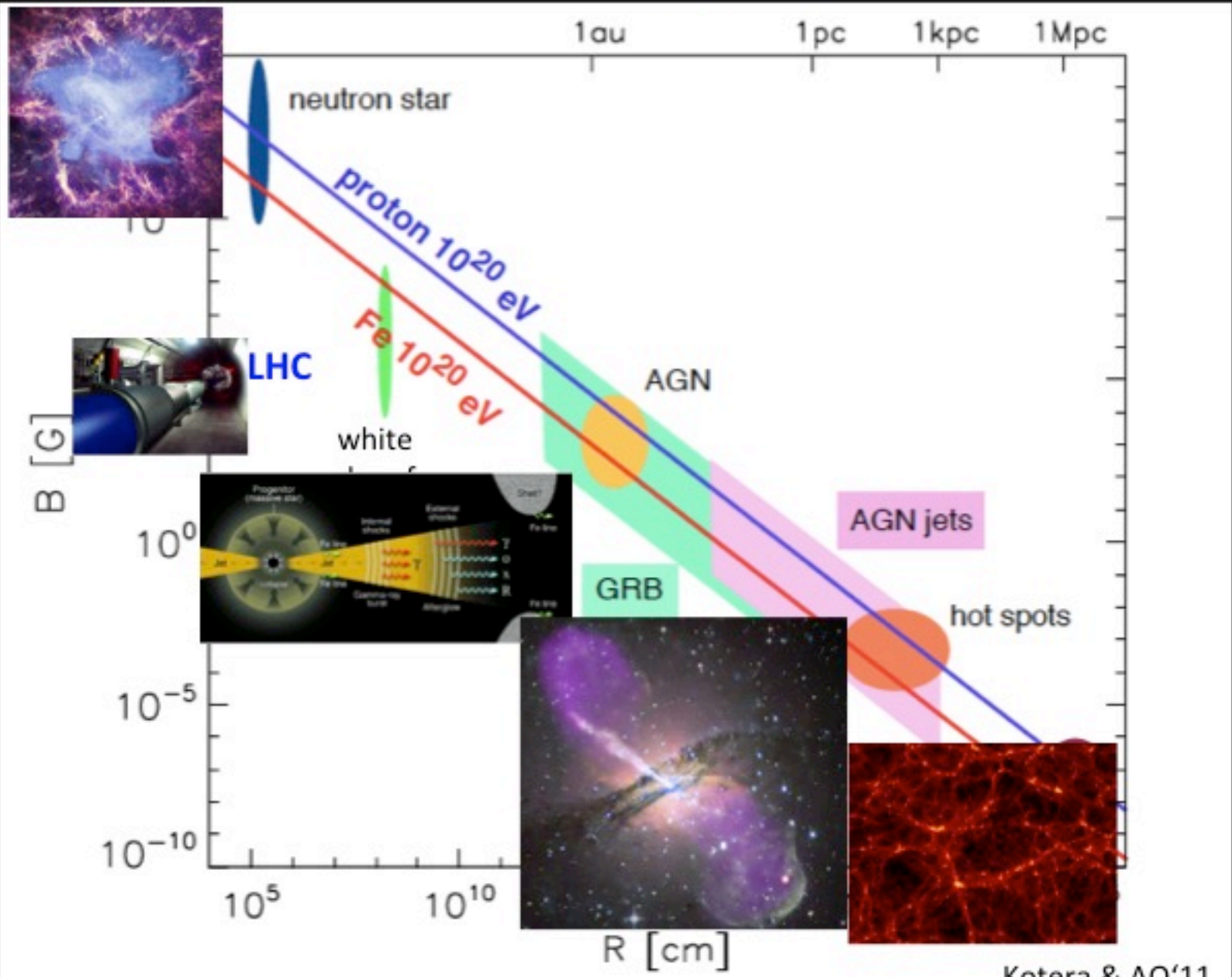
Global Instruments of VHE Gamma Ray Astronomy



Global Instruments of VHE Gamma Ray Astronomy


Equivalent c.m. energy $\sqrt{s_{pp}}$ (GeV)
10^2
10^3
10^4
10^5
10^6
HERA (γ-p)
RHIC (p-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
ankle
500 TeV
10^{20} eV
ATIC
PROTON
RUNJOB
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
IceTop ICRC 2013
Scaled flux $E^{2.5}$ J(E) (m^{-2} s^{-1} sr^{-1} $eV^{1.5}$)
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
Energy (eV/particle)

Hillas Plot: E_{max} required



Kotera & AO'11

Observatories of Ultrahigh Energy Cosmic Rays

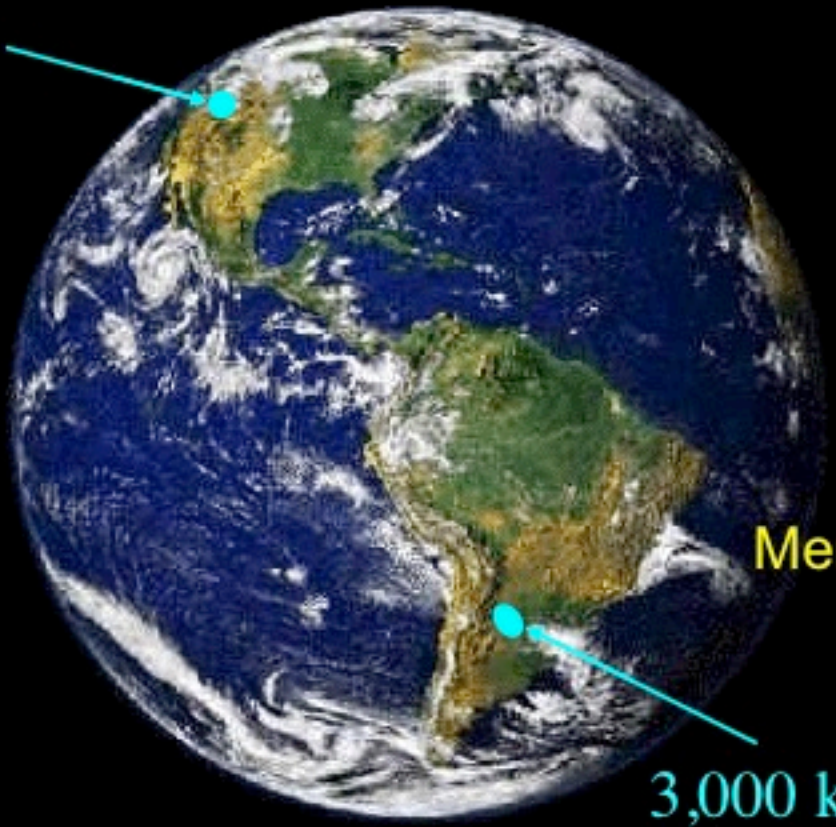
Telescope Array

Utah, USA

(5 country collaboration)

700 km^2 array

3 fluorescence telescopes



Pierre Auger Observatory

Mendoza, Argentina

(19 country collaboration)

3,000 km^2 array

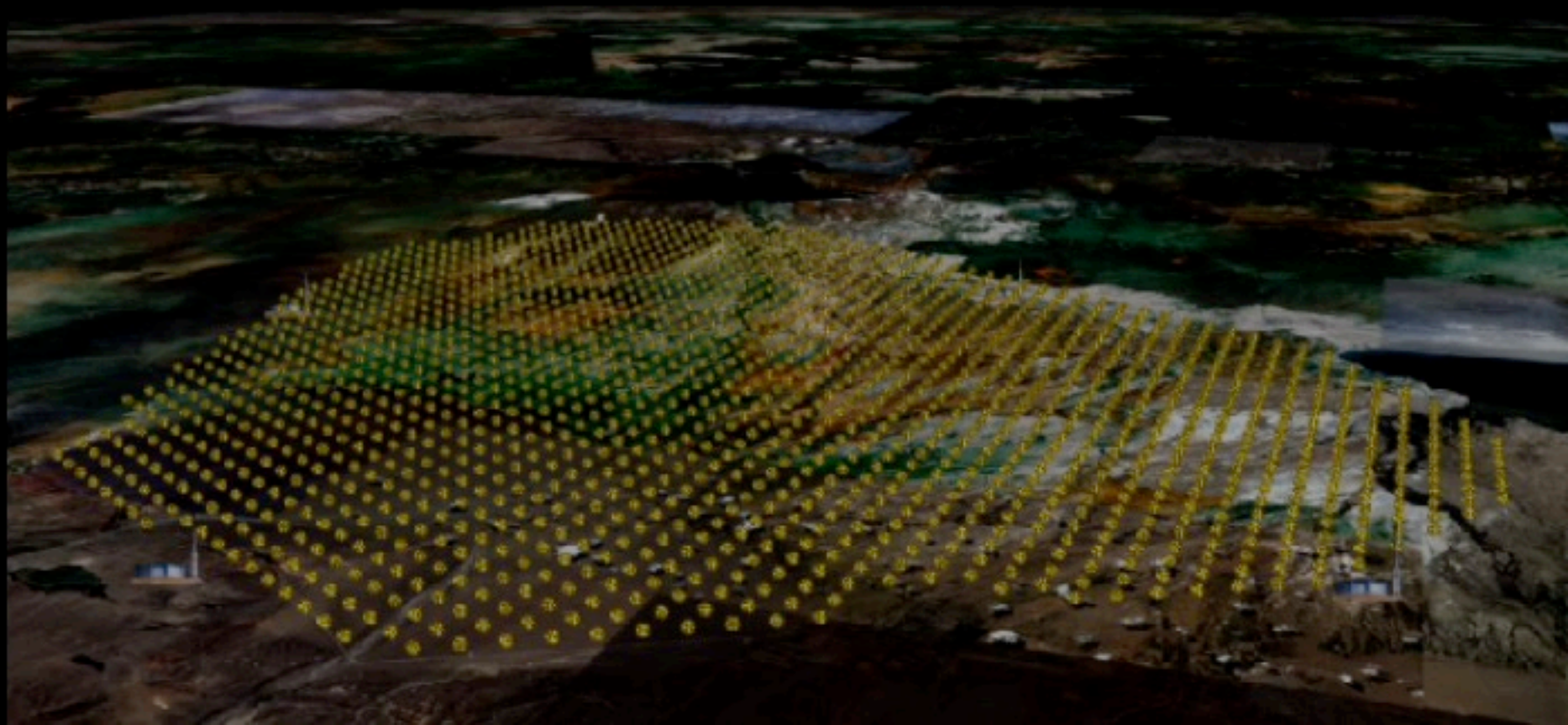
4 fluorescence telescopes

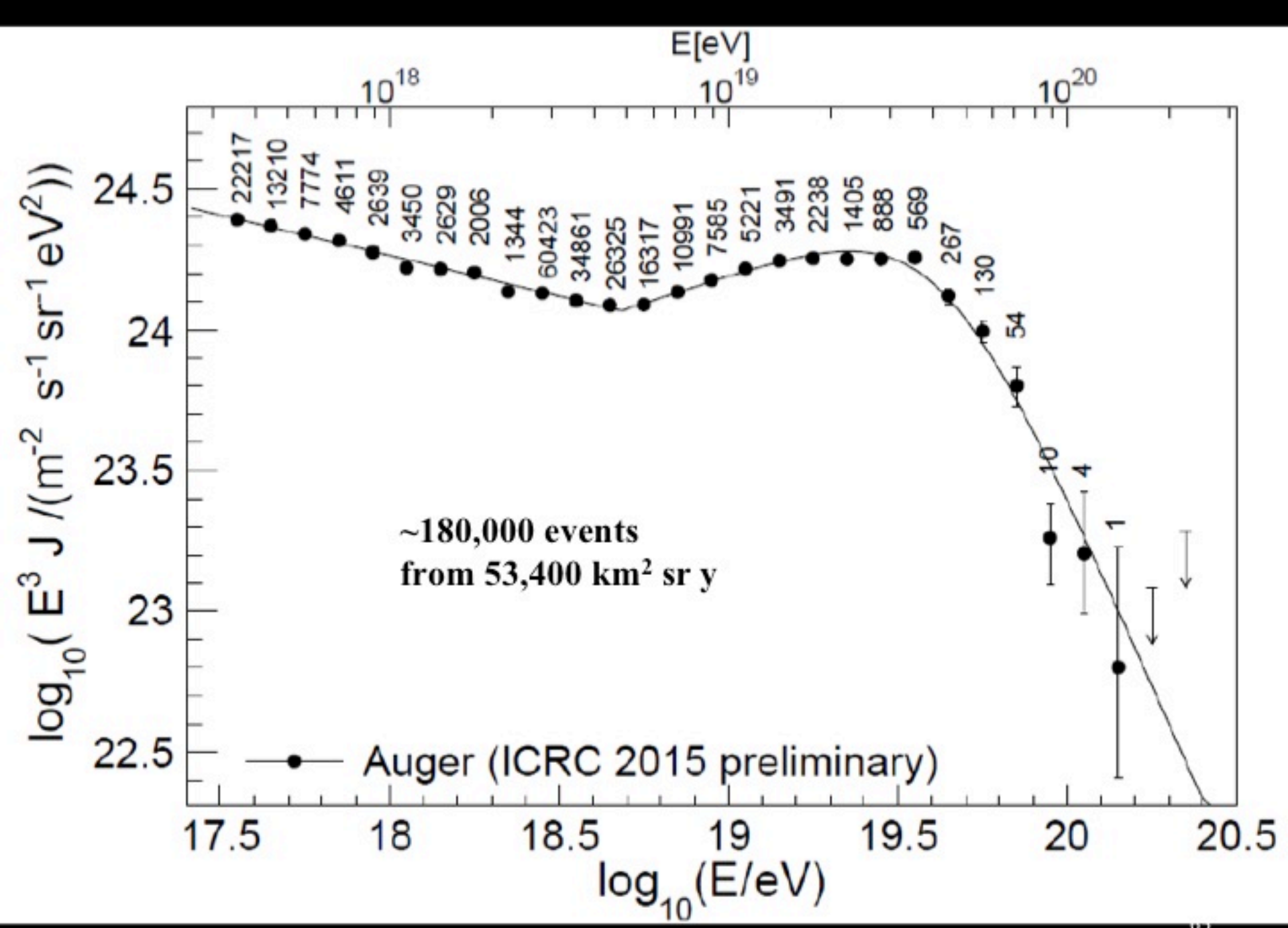
Pierre Auger Observatory

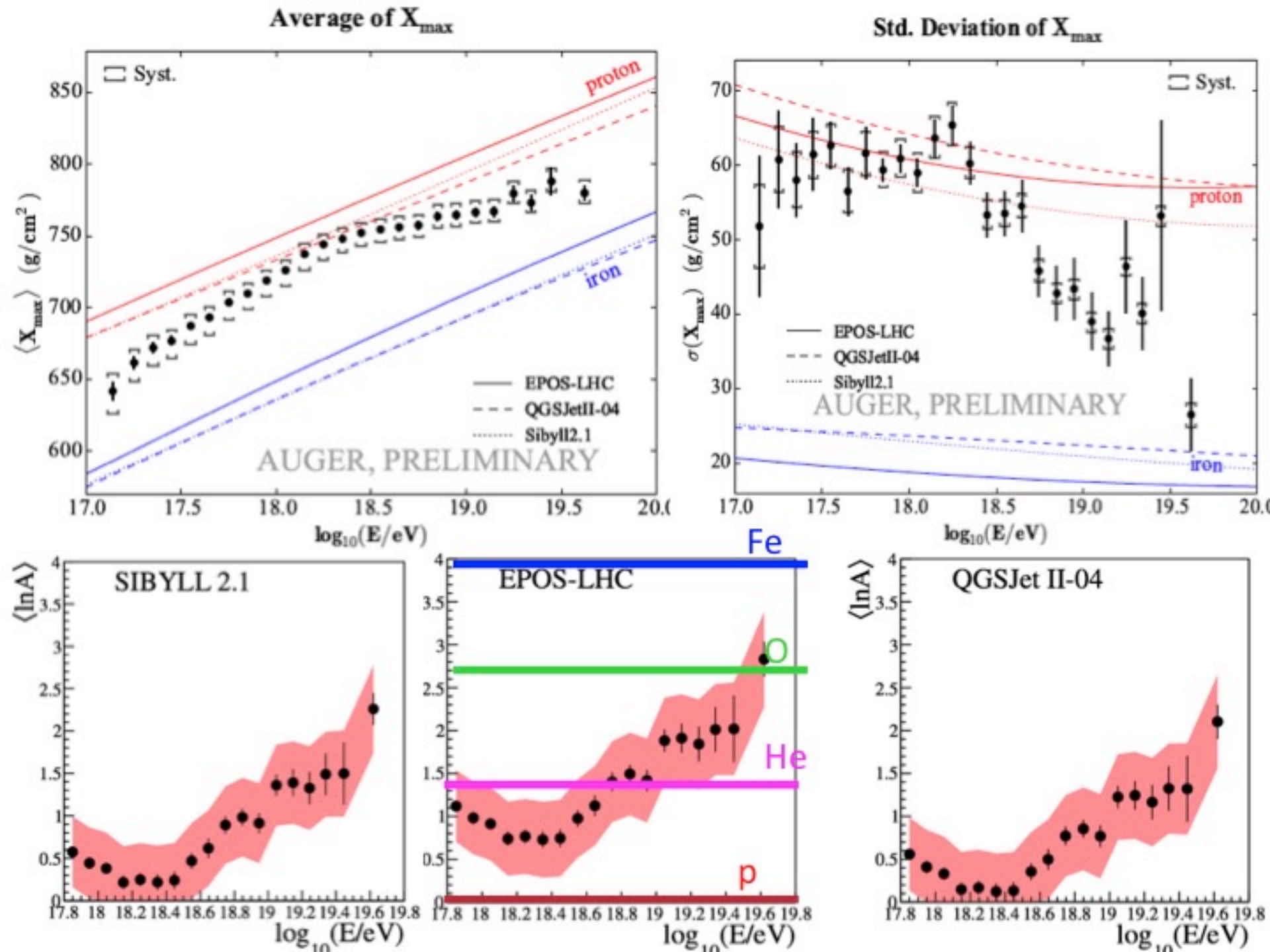
3,000 km^2 water cherenkov detectors array

4 fluorescence Telescopes, Malargue, Argentina

~ 500 Scientists, 19 Countries

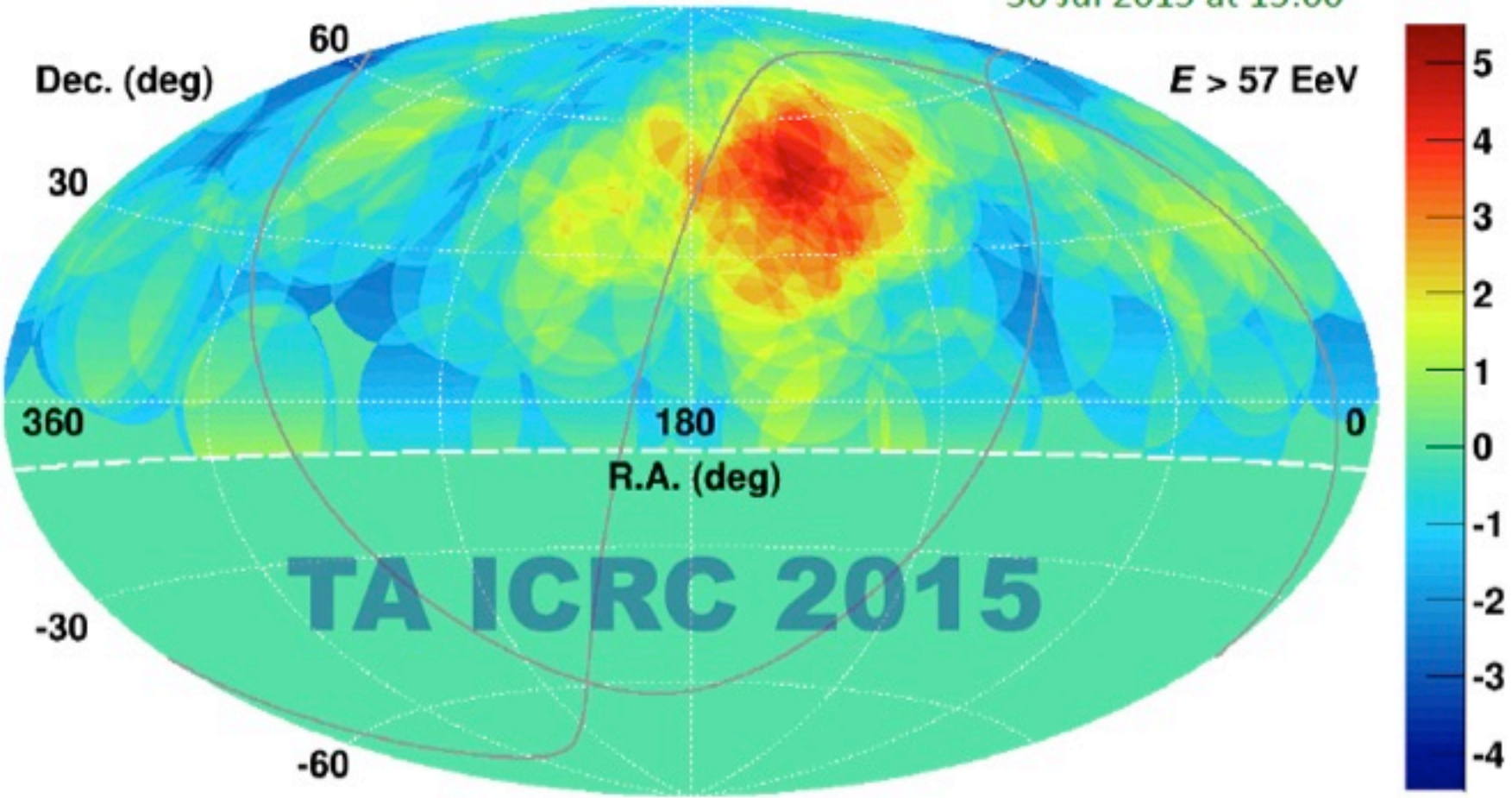



E[eV]
10^18
10^19
10^20
22217
13210
7774
4611
2639
3450
2629
2006
1344
60423
34861
26325
16317
10991
7585
5221
3491
2238
1405
888
569
267
130
54
10
4
1
~180,000 events
from 53,400 km² sr y
Auger (ICRC 2015 preliminary)
log10(E³ J /(m⁻² s⁻¹ sr⁻¹ eV²))
log10(E/eV)
24.5
24
23.5
23
22.5
17.5
18
18.5
19
19.5
20
20.5


Average of X_{max}
Syst.
proton
iron
EPOS-LHC
QGSJetII-04
Sibyll2.1
AUGER, PRELIMINARY
$\langle X_{max} \rangle$ (g/cm^2)
$\log_{10}$(E/eV)
Std. Deviation of X_{max}
$\sigma(X_{max})$ (g/cm^2)
SIBYLL 2.1
EPOS-LHC
QGSJet II-04
Fe
O
He
p
$\langle$lnA$\rangle$
$\log_{10}$(E/eV)

[414 - PoS 276] Parallel CR03
Aniso Track: CREX Presented
by Kazumasa KAWATA on
30 Jul 2015 at 15:00

7 Year Excess Map



Max significance **5.1σ** (N_{SIG} = 24, N_{BG}=6.88) for 7 years
Centered at R.A=148.4°, Dec.=44.5° (shifted from SGP by 17°)
Global Excess Chance Probability: 3.7×10^{-4} : 3.4σ (~ same as first 5 years)

TA×4 project

Quadruple TA SD (~3000 km^2)

- 500 scintillator SDs
- 2.08 km spacing

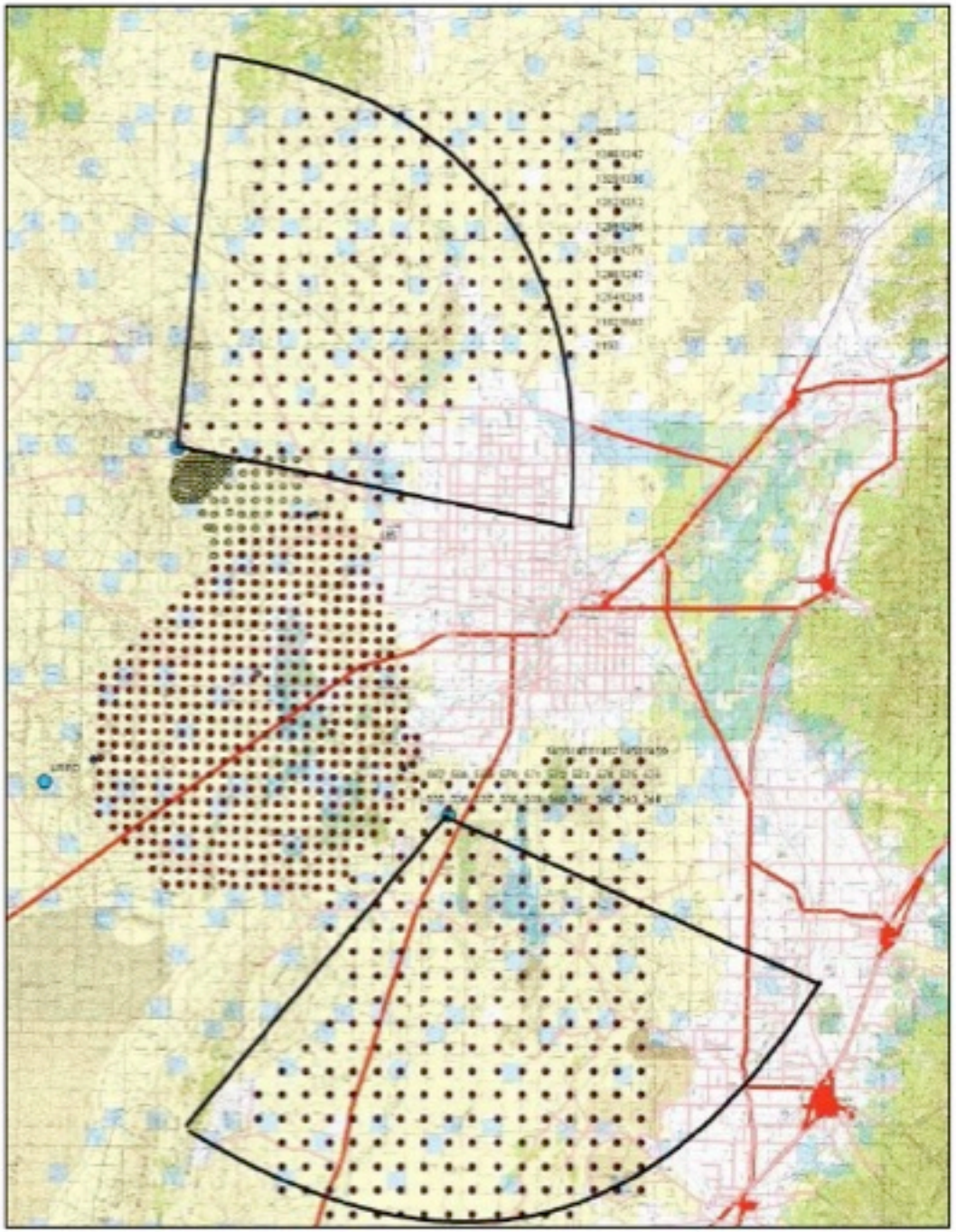
2 FD stations

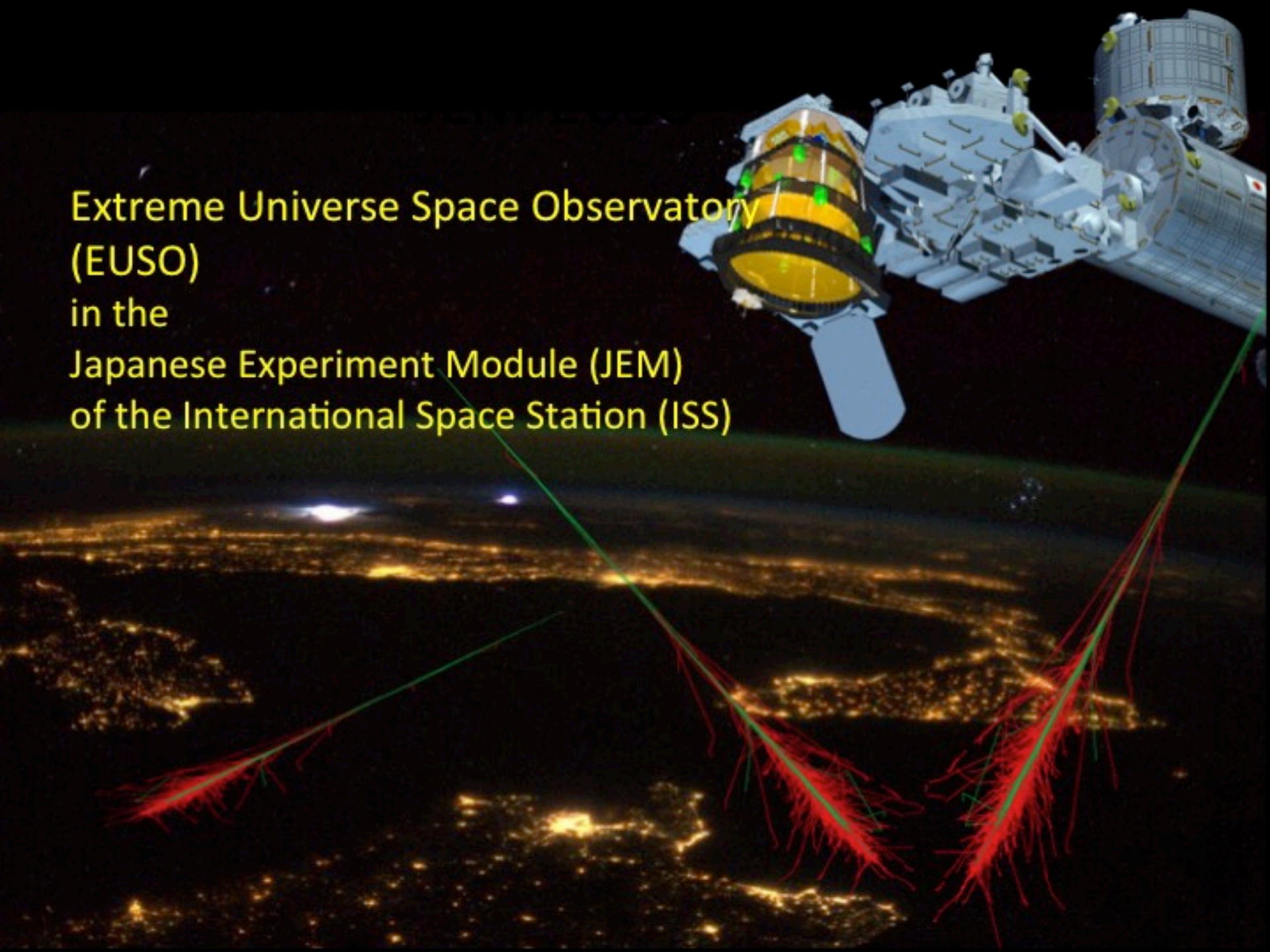
Proposals

- **SD: approved** in Japan in April 2015
- FD: submit in US in October 2015

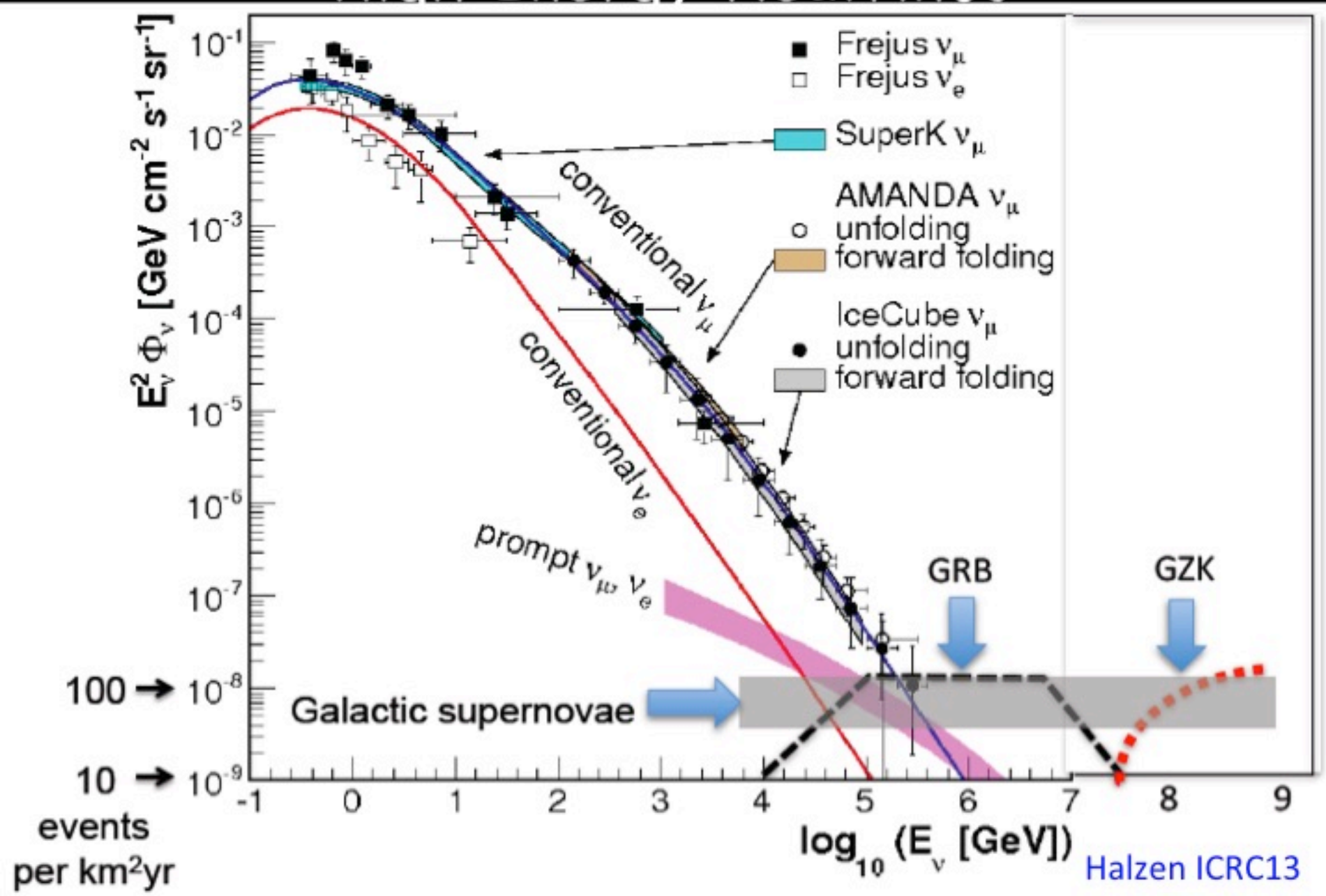
Get 19 TA years of SD data by 2020

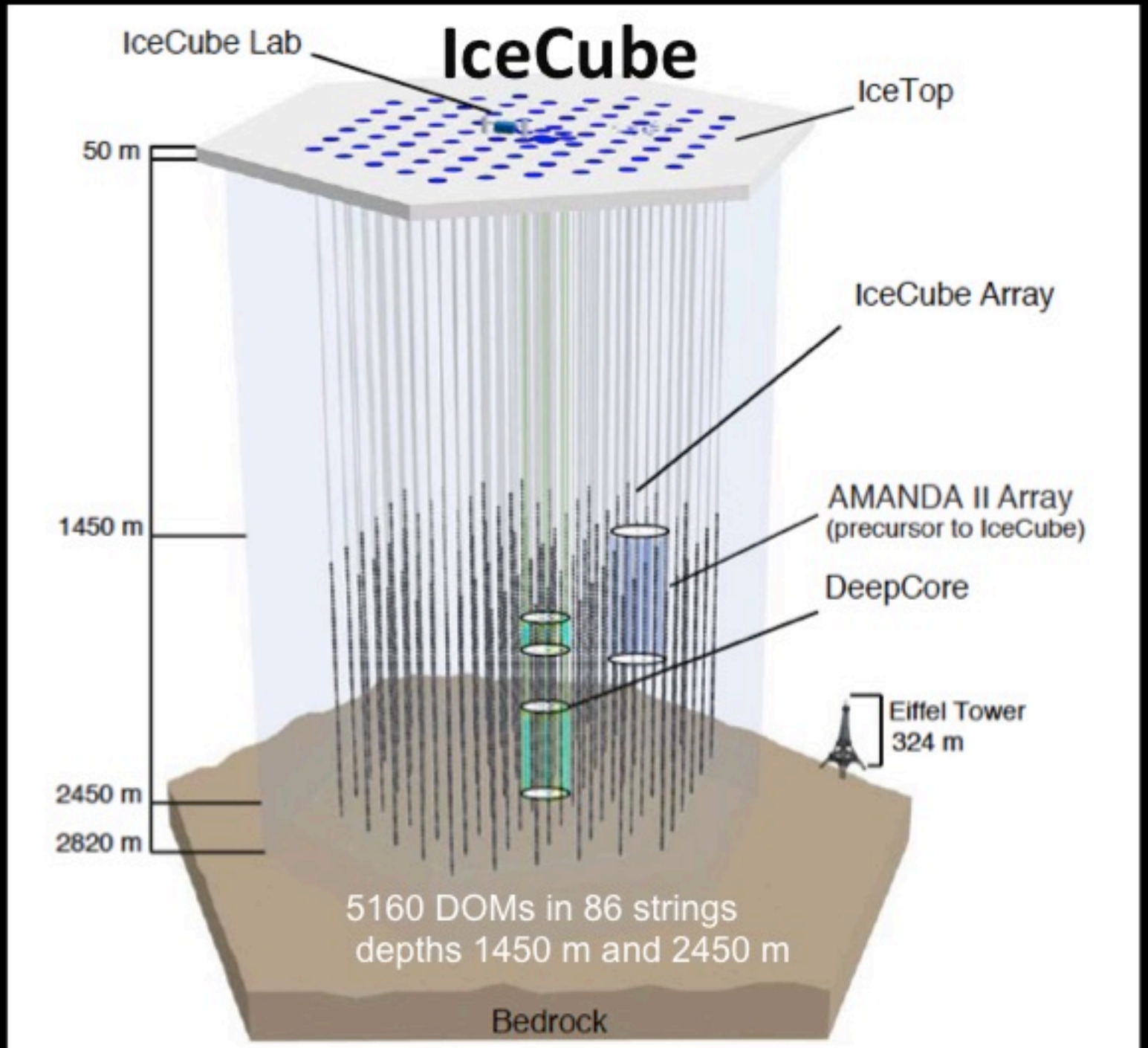
- Get 16.3 (current) TA years of hybrid data




Extreme Universe Space Observatory
(EUSO)
in the
Japanese Experiment Module (JEM)
of the International Space Station (ISS)

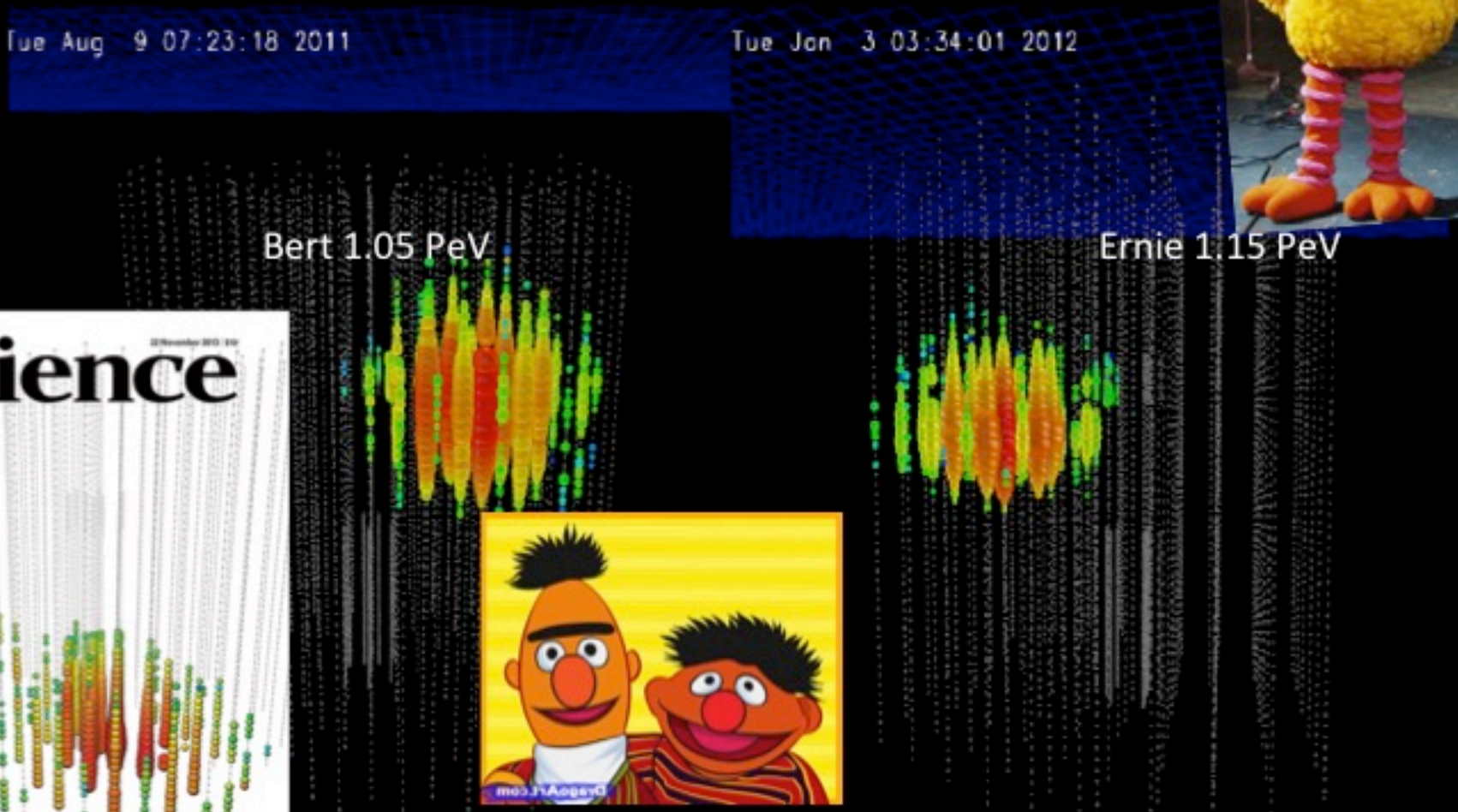
High Energy Neutrinos




IceCube
IceCube Lab
IceTop
50 m
IceCube Array
AMANDA II Array
(precursor to IceCube)
1450 m
DeepCore
Eiffel Tower
324 m
2450 m
2820 m
5160 DOMs in 86 strings
depths 1450 m and 2450 m
Bedrock

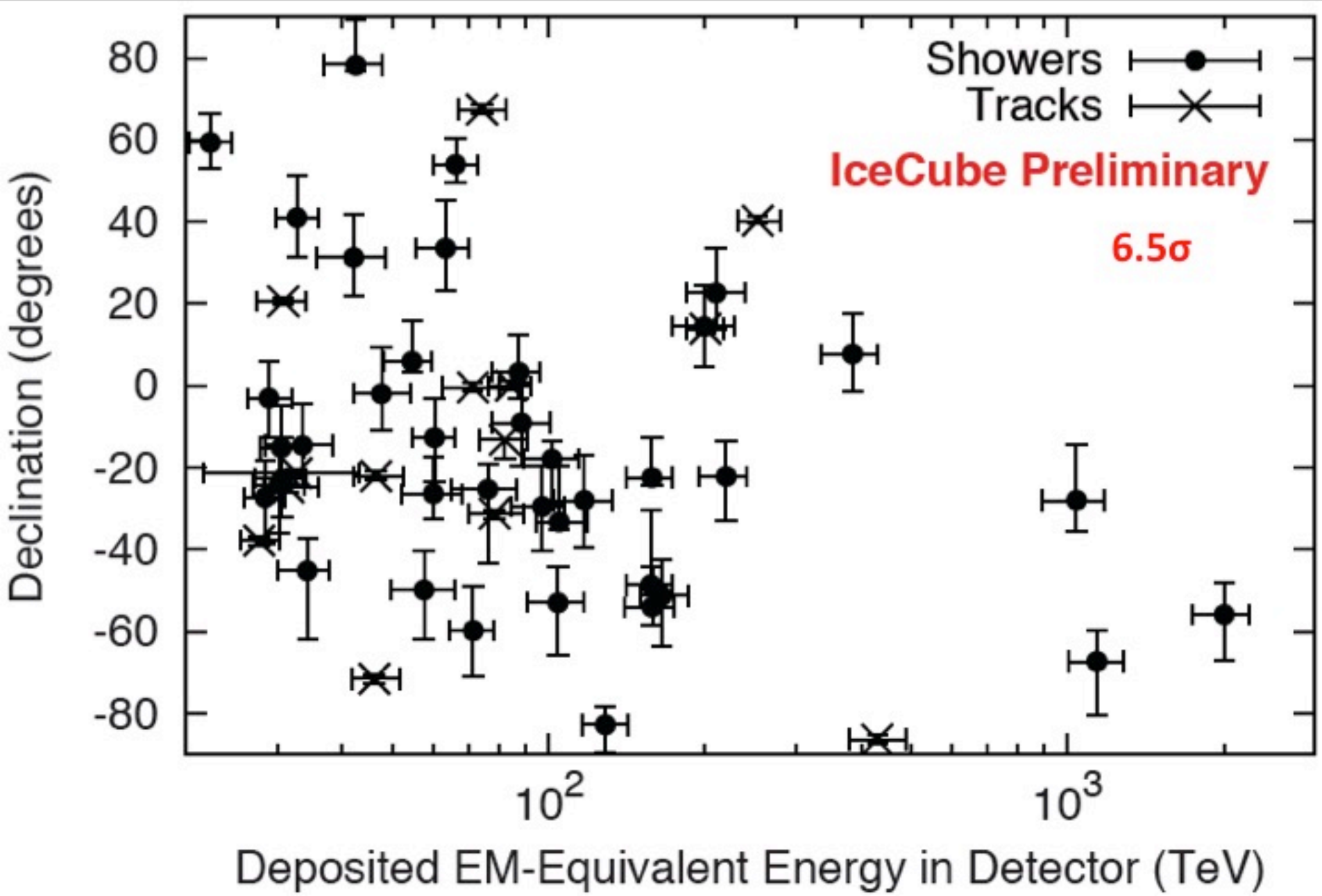
Neutrino Astronomy Begin

- PeV neutrinos first observed by **IceCube** (Apr'13)

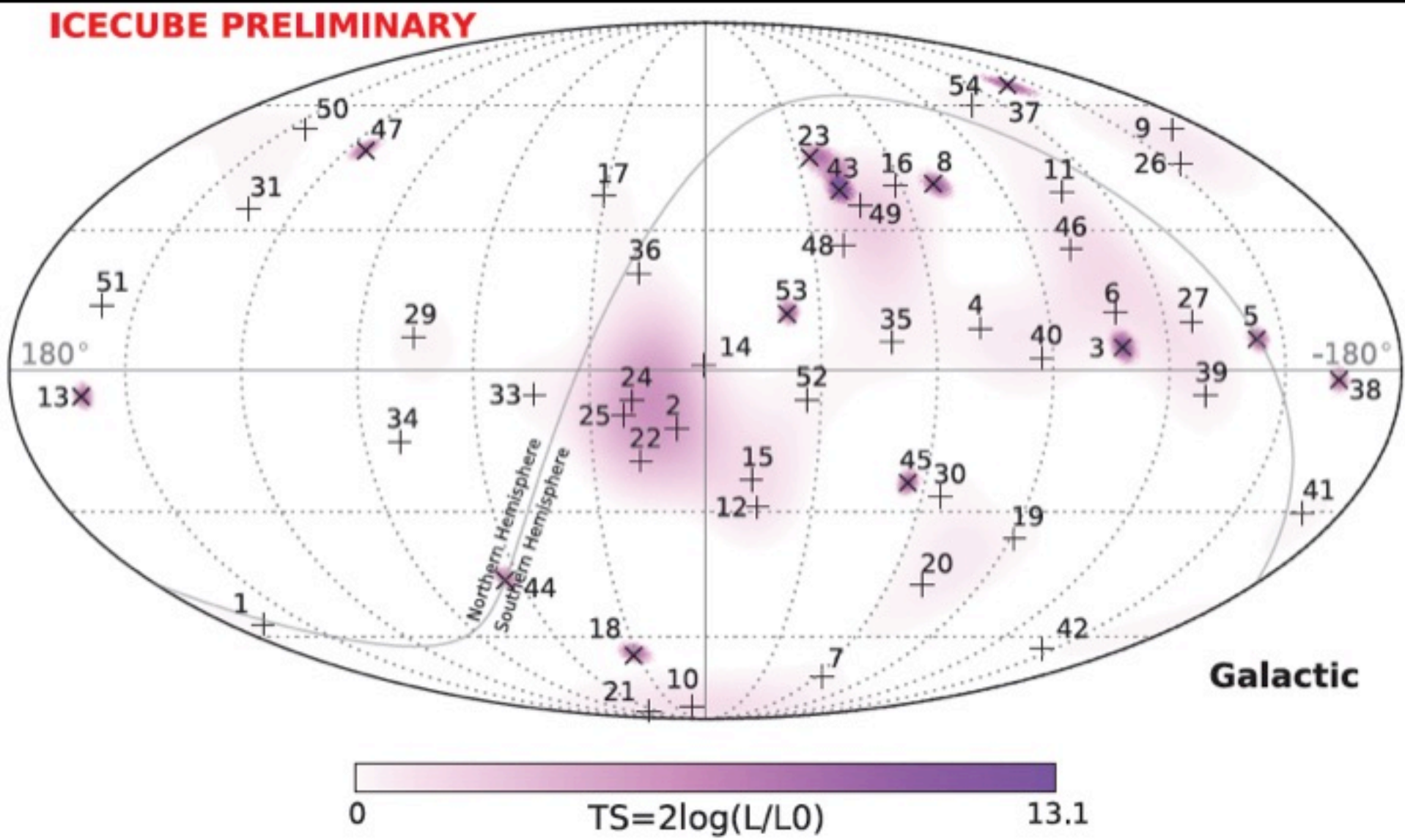


arXiv:1304.5356

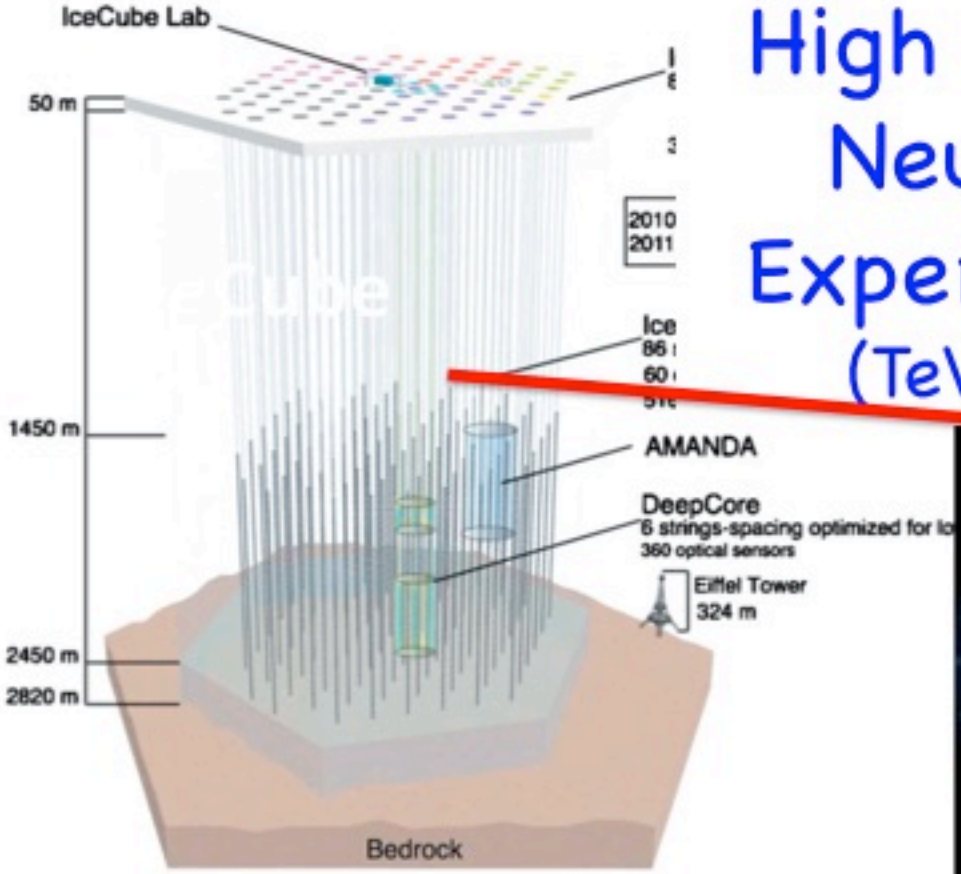
54 Events

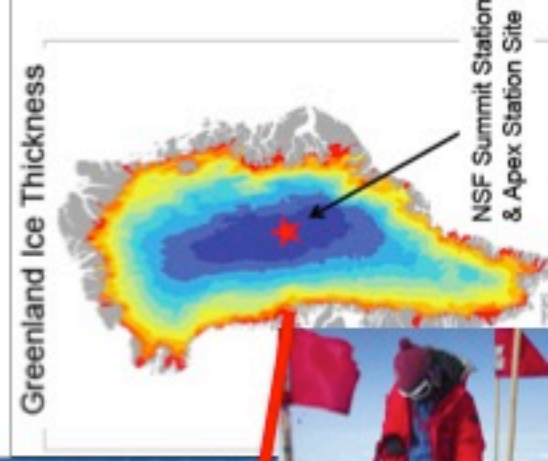

Showers
Tracks
IceCube Preliminary
6.5σ
Declination (degrees)
80
60
40
20
0
-20
-40
-60
-80
10^2
10^3
Deposited EM-Equivalent Energy in Detector (TeV)

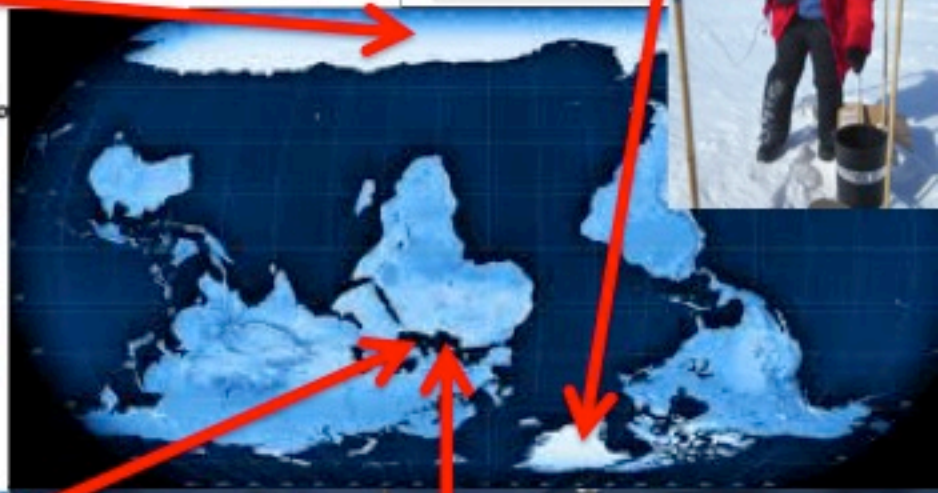
54 Events

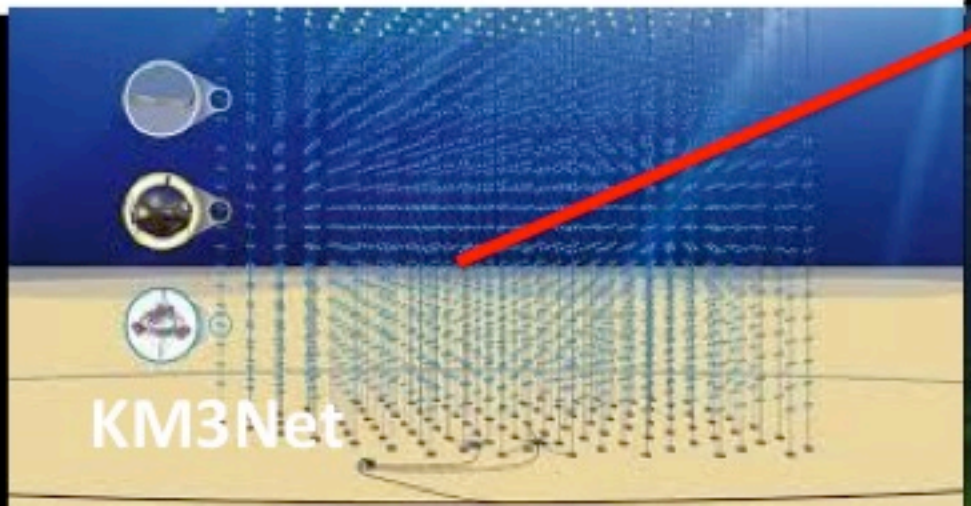

ICECUBE PRELIMINARY
180°
-180°
Northern Hemisphere
Southern Hemisphere
Galactic
0
TS=2log(L/L0)
13.1

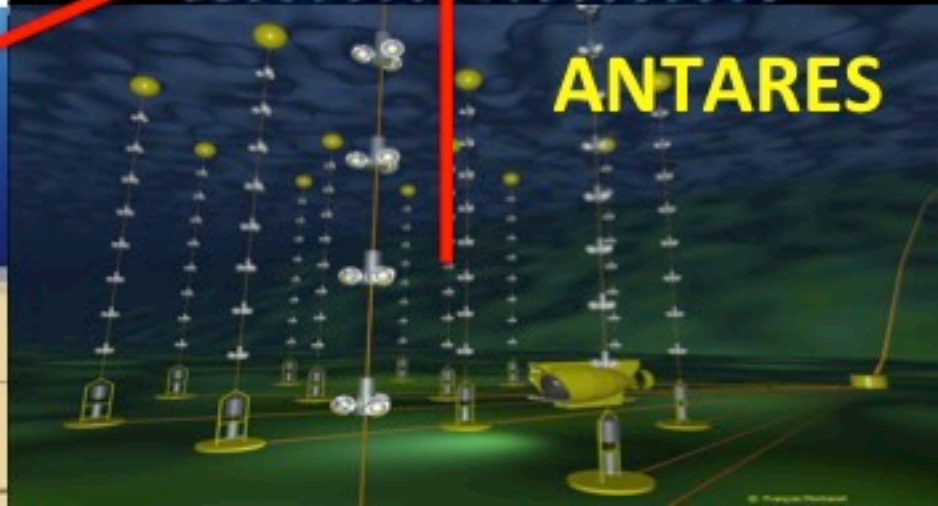
High Energy Neutrino Experiments (TeV-PeV)



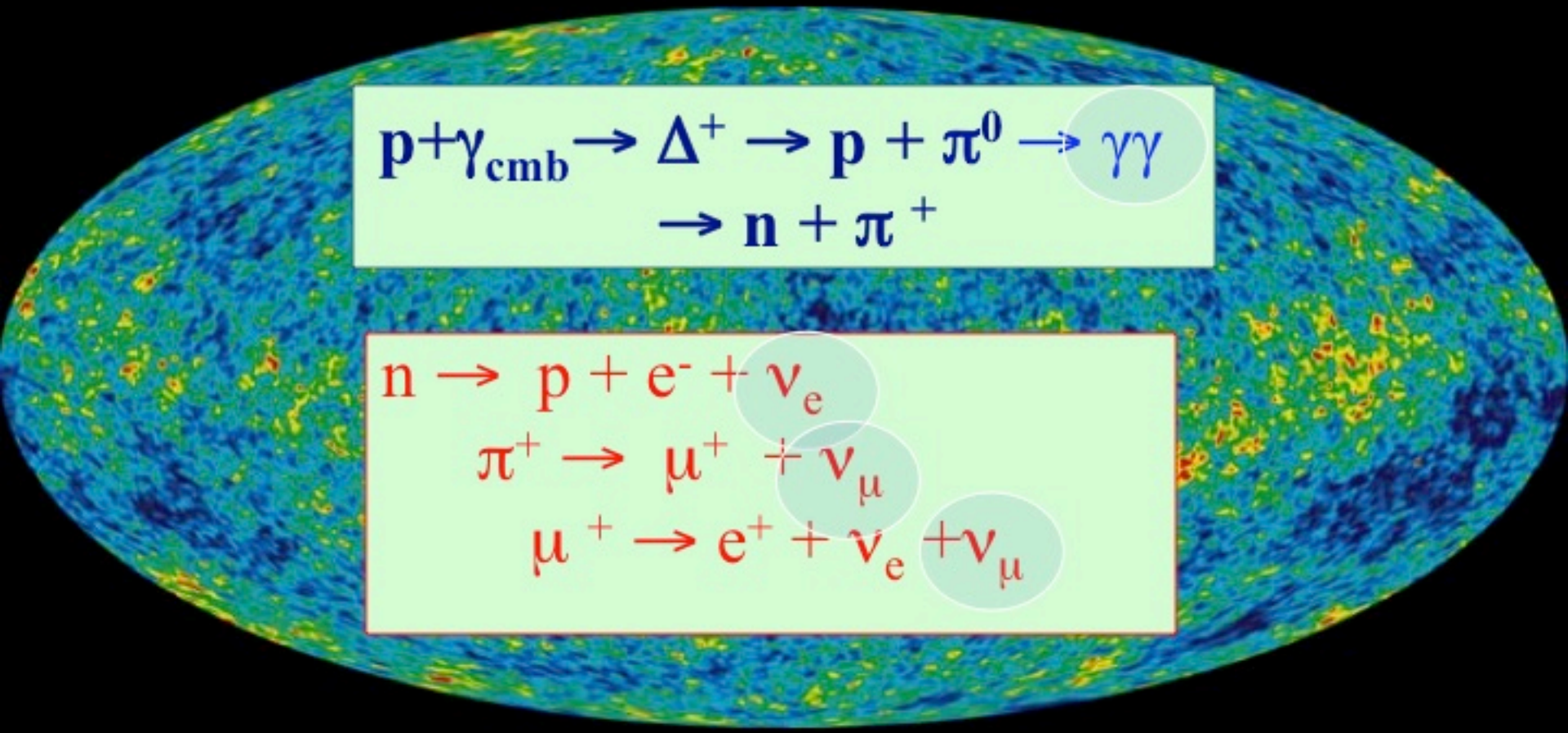








Cosmogenic (GZK, BZ*) Neutrinos & Photons

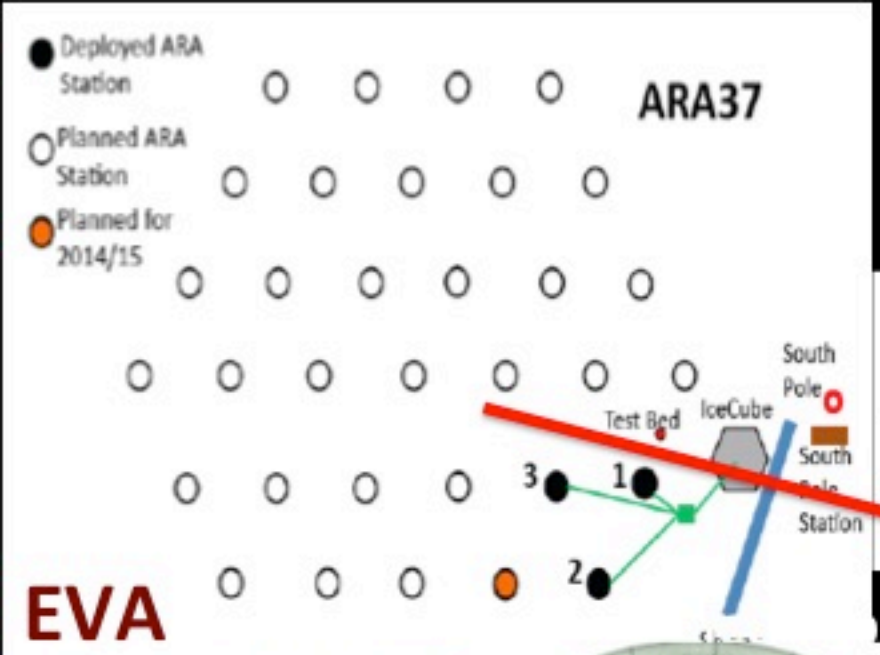


$$p + \gamma_{cmb} \rightarrow \Delta^{+} \rightarrow p + \pi^{0} \rightarrow \gamma\gamma$$
$$\rightarrow n + \pi^{+}$$

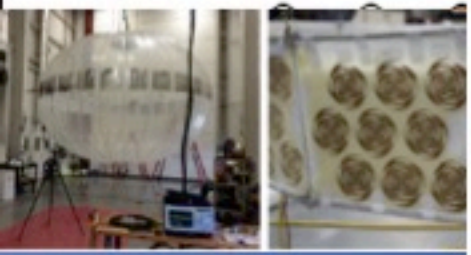
$$n \rightarrow p + e^{-} + \nu_{e}$$
$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu}$$
$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \nu_{\mu}$$

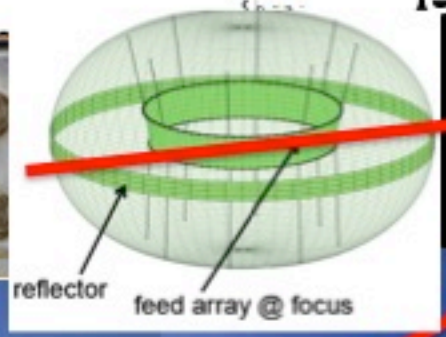
*Berezinsky & Zatsepin '69

UtraHigh Energy Neutrino Experiments (EeV-ZeV)

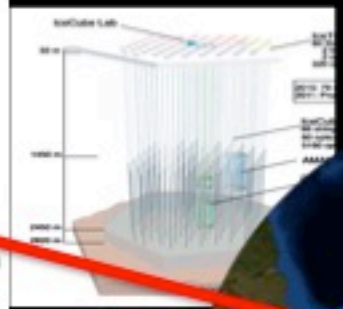


EVA

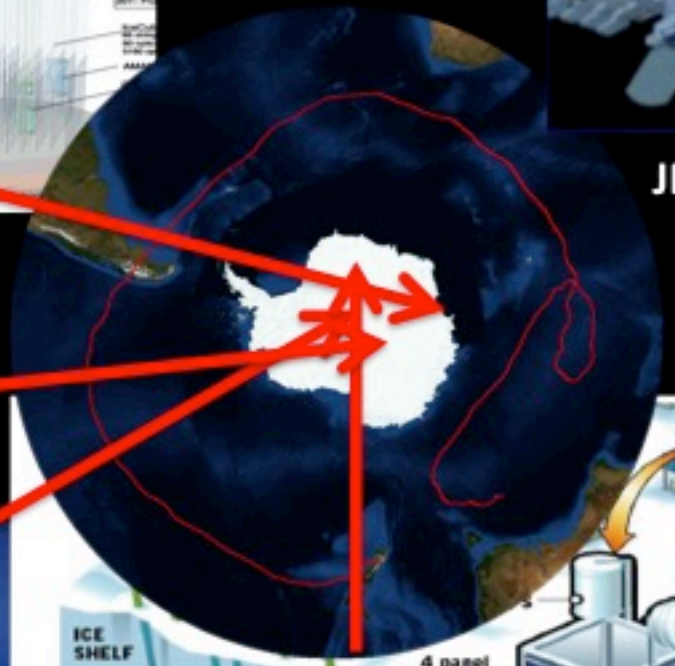


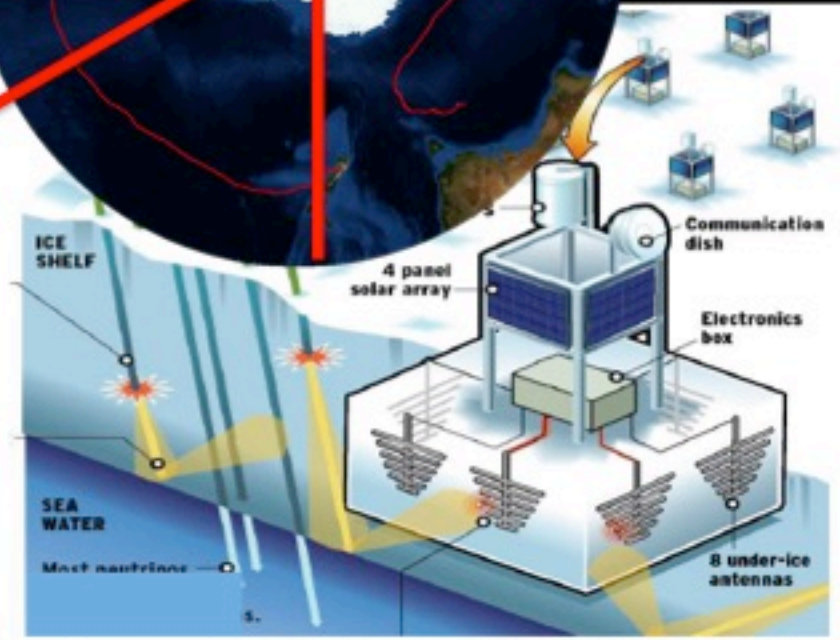


ANITA



JEM-EUSO





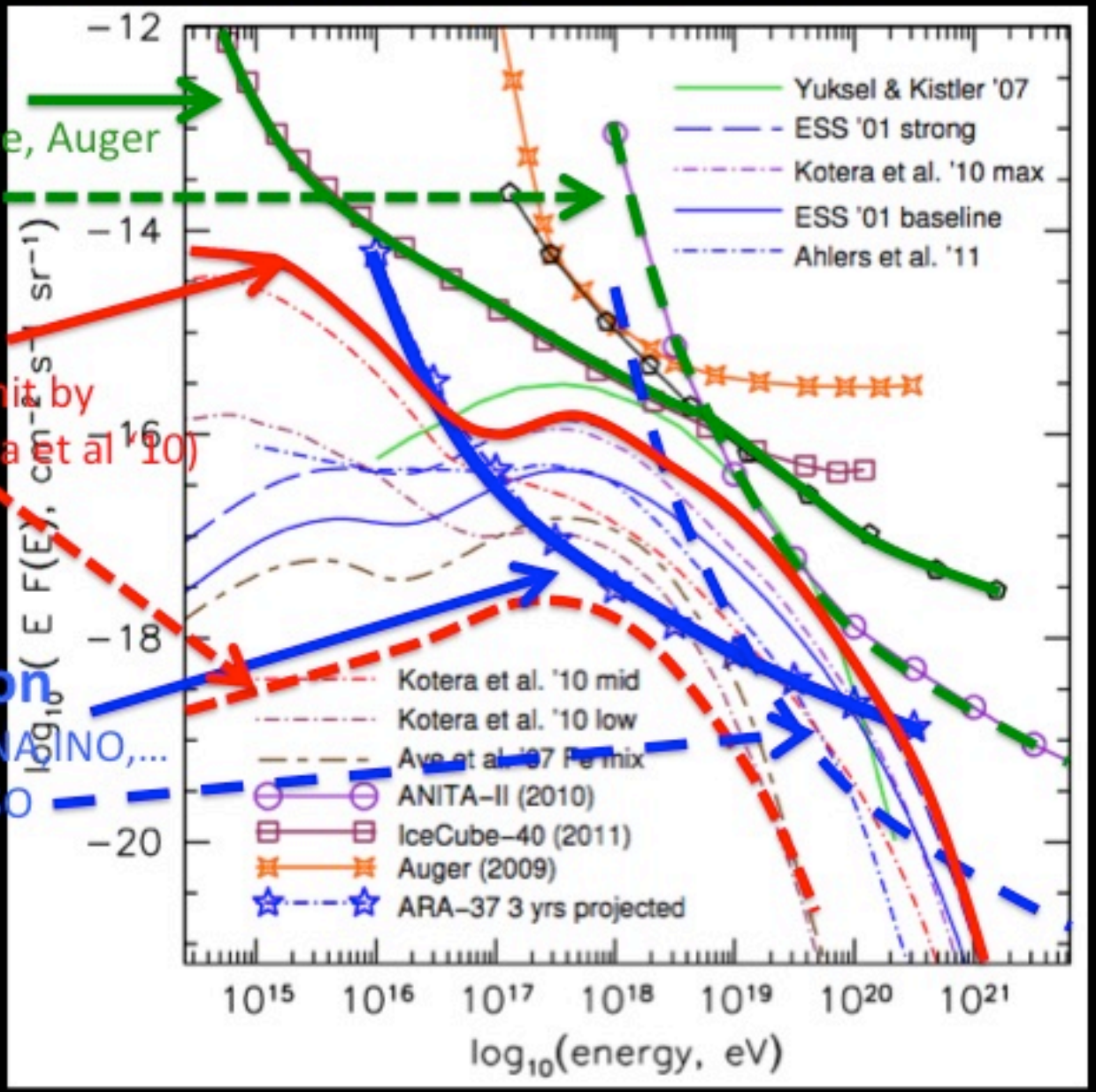
ARIANNA Coll. See arXiv:1207.3846

EeV Neutrino Detectors

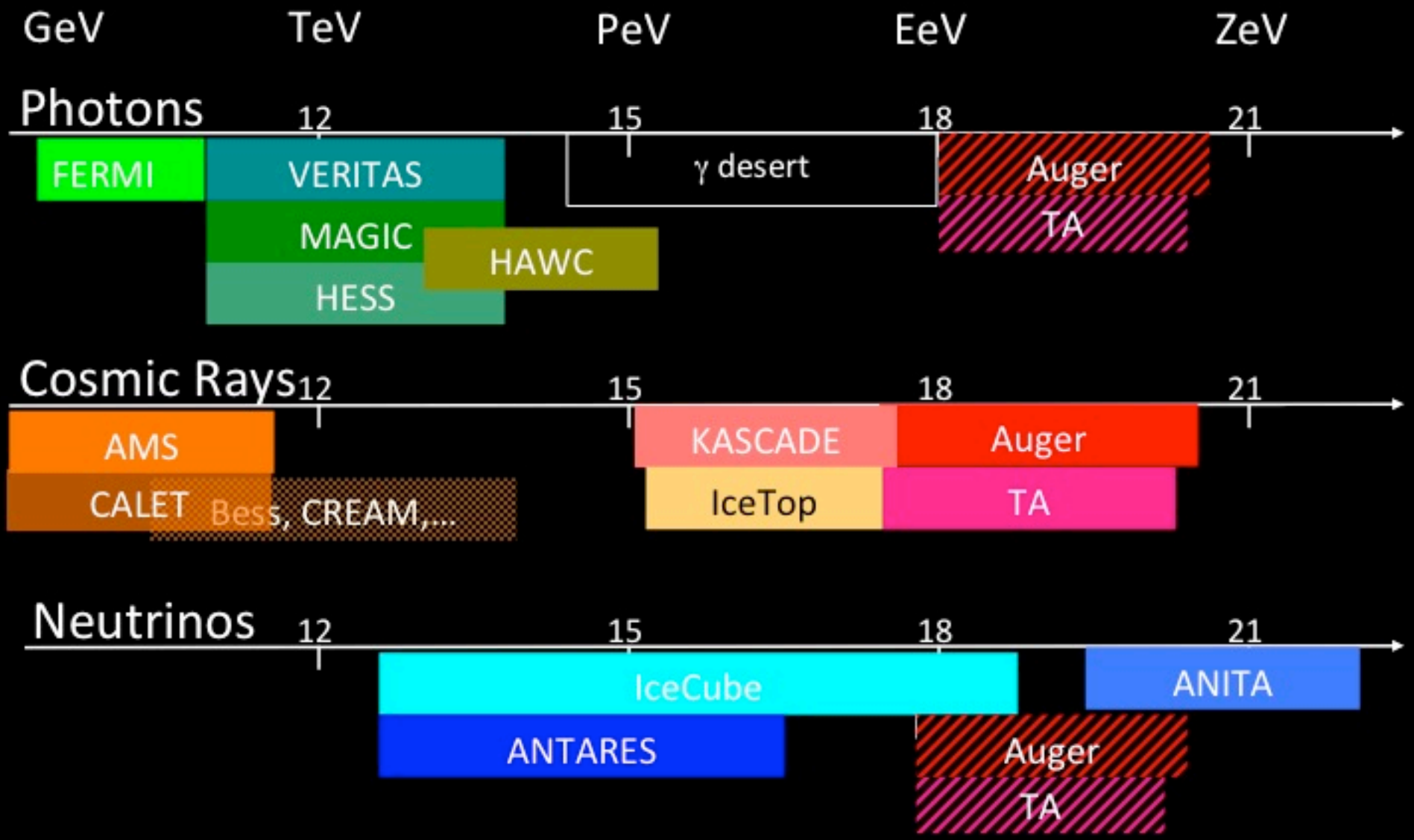
Current Limits
Ground: IceCube, Rice, Auger
Space: ANITA

Models range,
above flux Lower Limit by
UHECR comp. (Kotera et al '10)

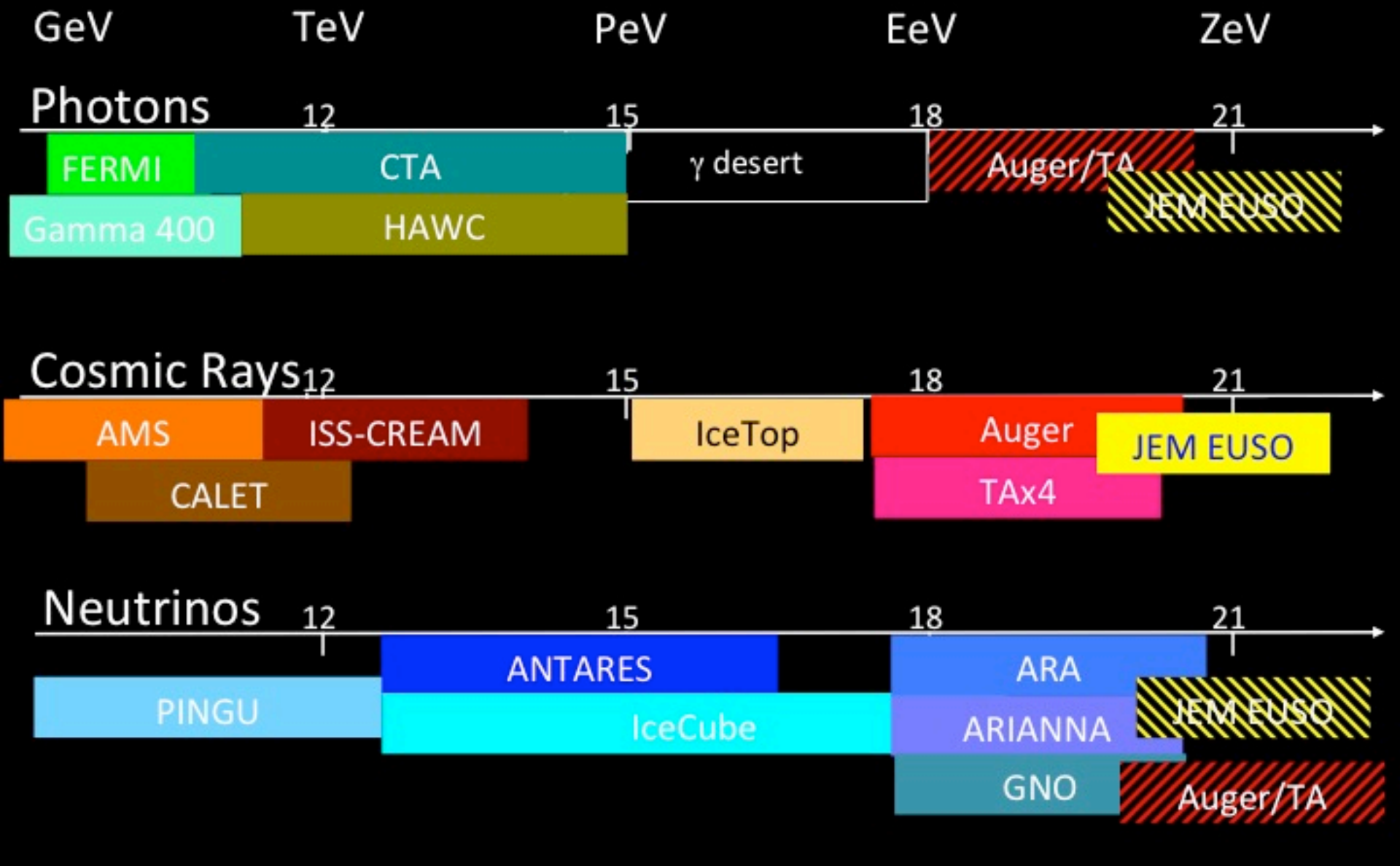
Next Generation
Ground:ARA, ARIANNA,ANITA-III,...
Space: EVA, JEM-EUSO



US Astroparticles 2015



US Astroparticles 2020+

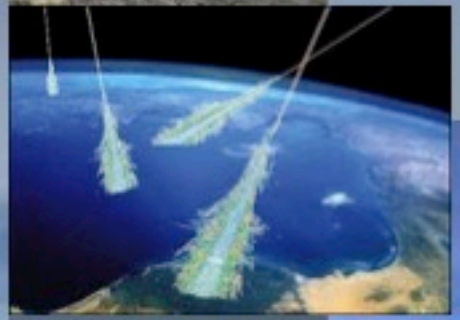


Busy HE Particles!!!










Busy HE Particles!!!
HERD
DAMPE
PANGU
GRAND


p $10^{15\text{-}18}$ eV
p 10^{20} eV
GZK
ν
γ
χ
The Best is
Yet to Come!

KIAA Workshop on *Astroparticle* Physics

KIAA@Peking University; Sept. 28-29, 2015 — http://kiaa.pku.edu.cn/aph2015/

TOPICS

COSMIC RAYS
DARK MATTER DETECTION
PARTICLE COSMOLOGY
PARTICLE PHYSICS IN STARS

The long-standing quest for understanding the fundamental laws of Nature has motivated the new field of **Astroparticle Physics** where observations of the Universe are used to probe particle interactions. This small workshop will bring together AstroParticle Physics experts to provoke discussion and foster collaboration especially between members of Kavli Institutes.

Organizers

Ke Fang (U Chicago)
Zhaosheng Li (PKU)
Angela V. Olinto (U Chicago)
Meng Su (MIT)
Renxin Xu (PKU)

KIAA – PKU

KICP
Kavli Institute for Cosmological Physics at The University of Chicago

謝謝

Xièxiè