Trends, Needs and Dreams in Astro-Physics

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Talk Outline

- **Astro-Physics**
  - Cosmology
  - High-energy Particle Astro-physics
- **Experiments**
  - Ongoing
  - Future
- **Photo-detectors**
  - Demands
  - New Detectors on Horizon
  - Dream Detectors

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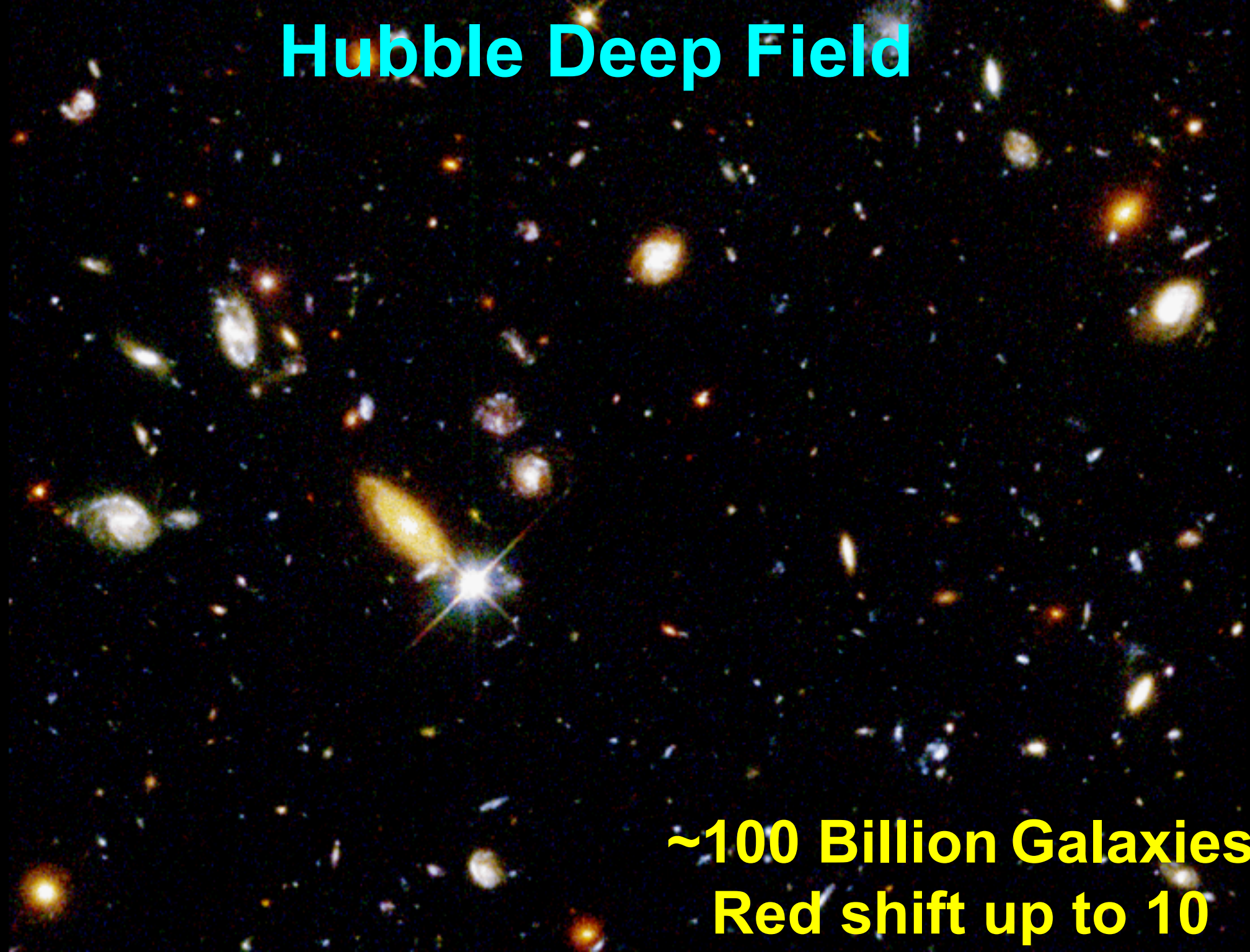
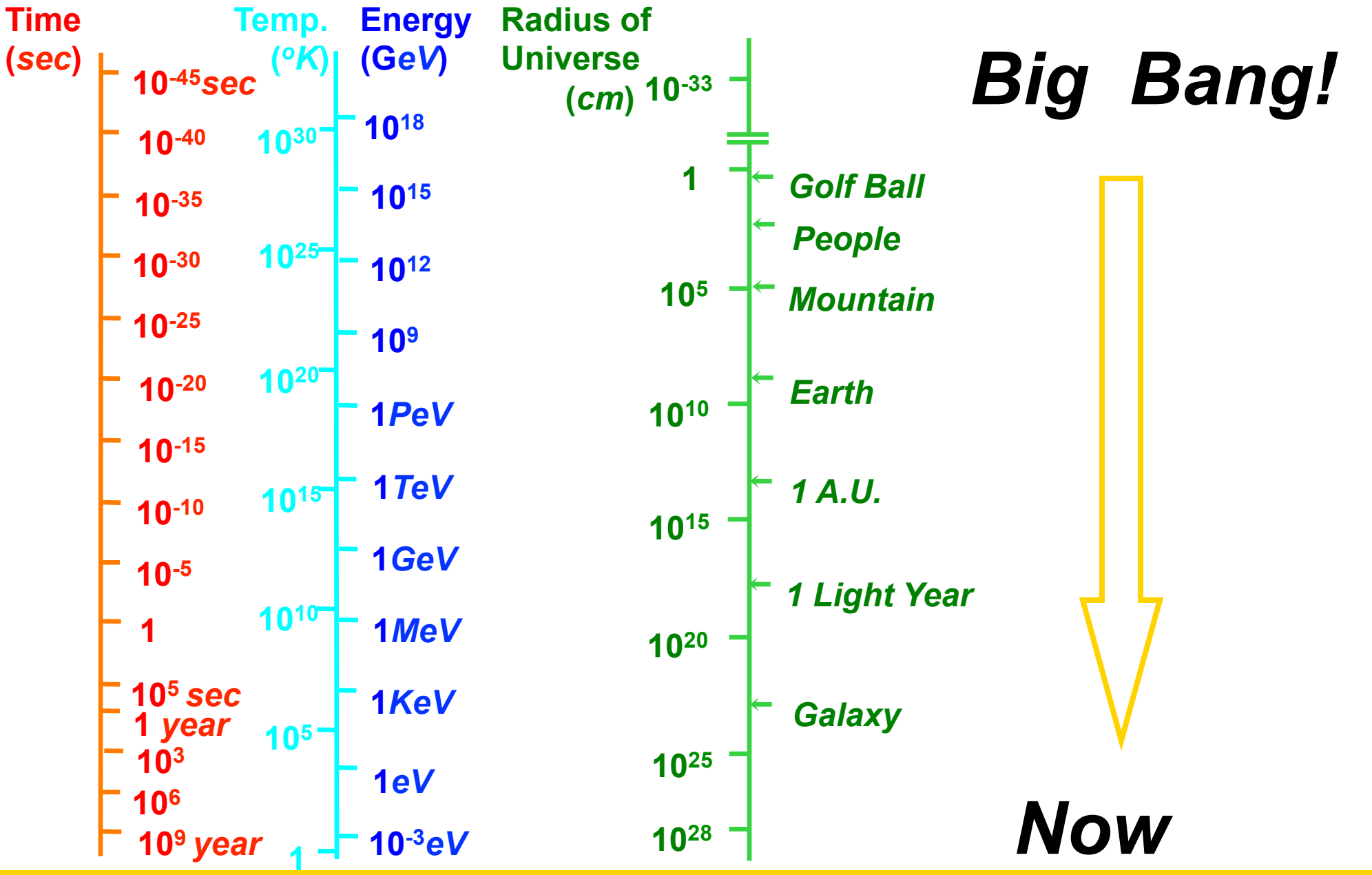
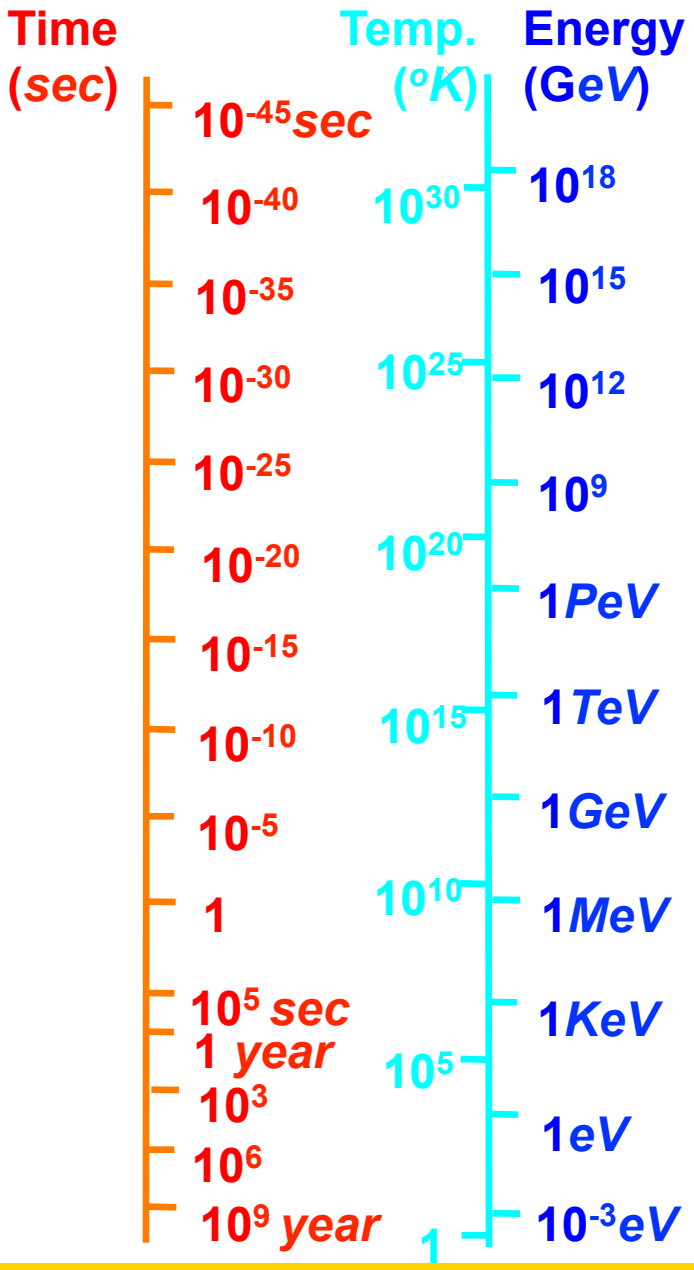
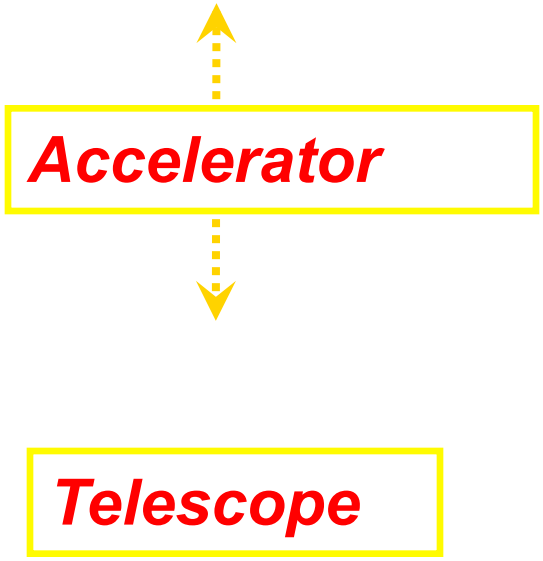

Hubble Deep Field
~100 Billion Galaxies
Red shift up to 10

Evolution of the Early Universe

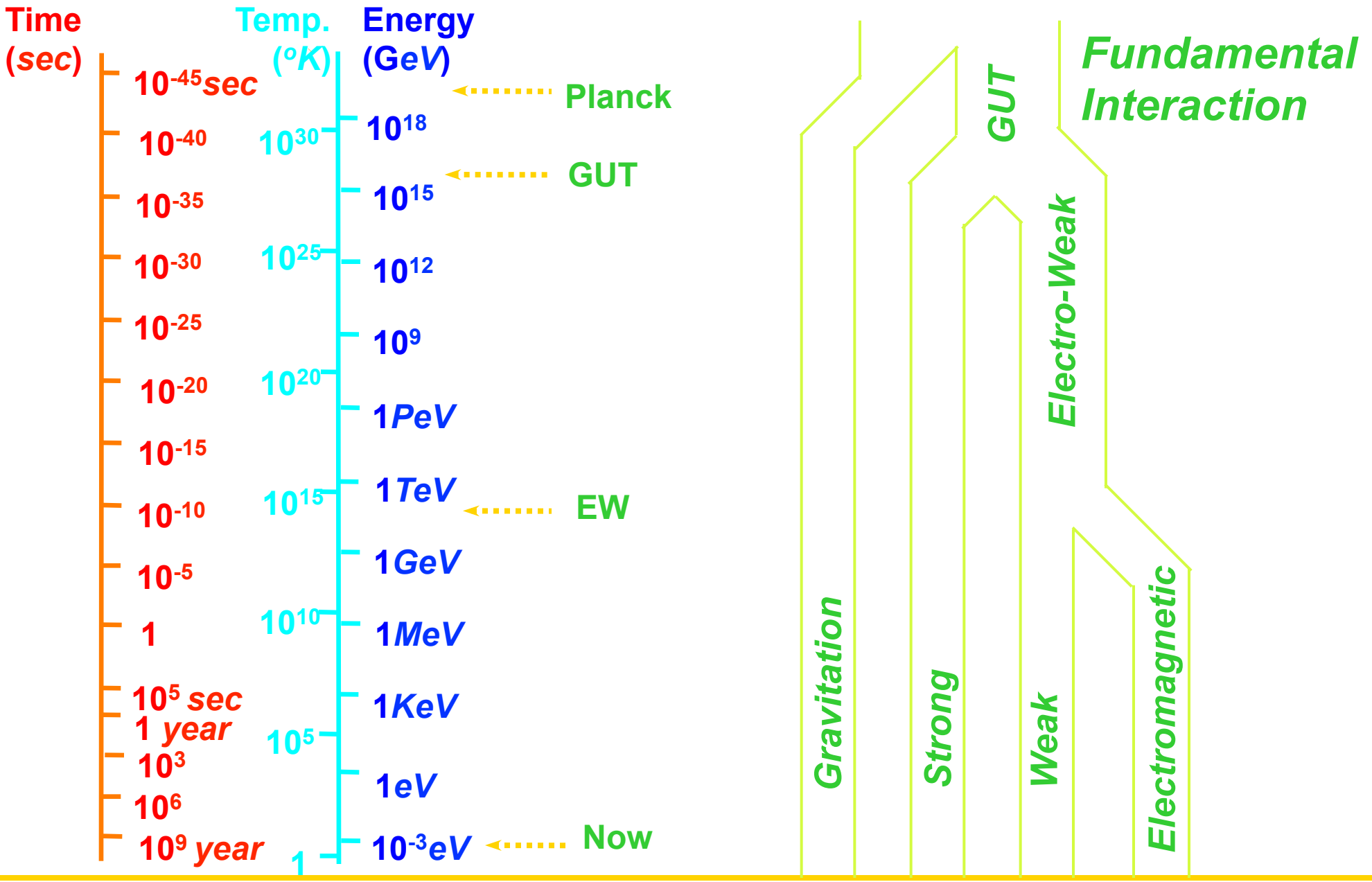


Tools to explore the Early Universe





Unification of Fundamental Forces



Physicists' View of Early Universe

Symmetry Breaking

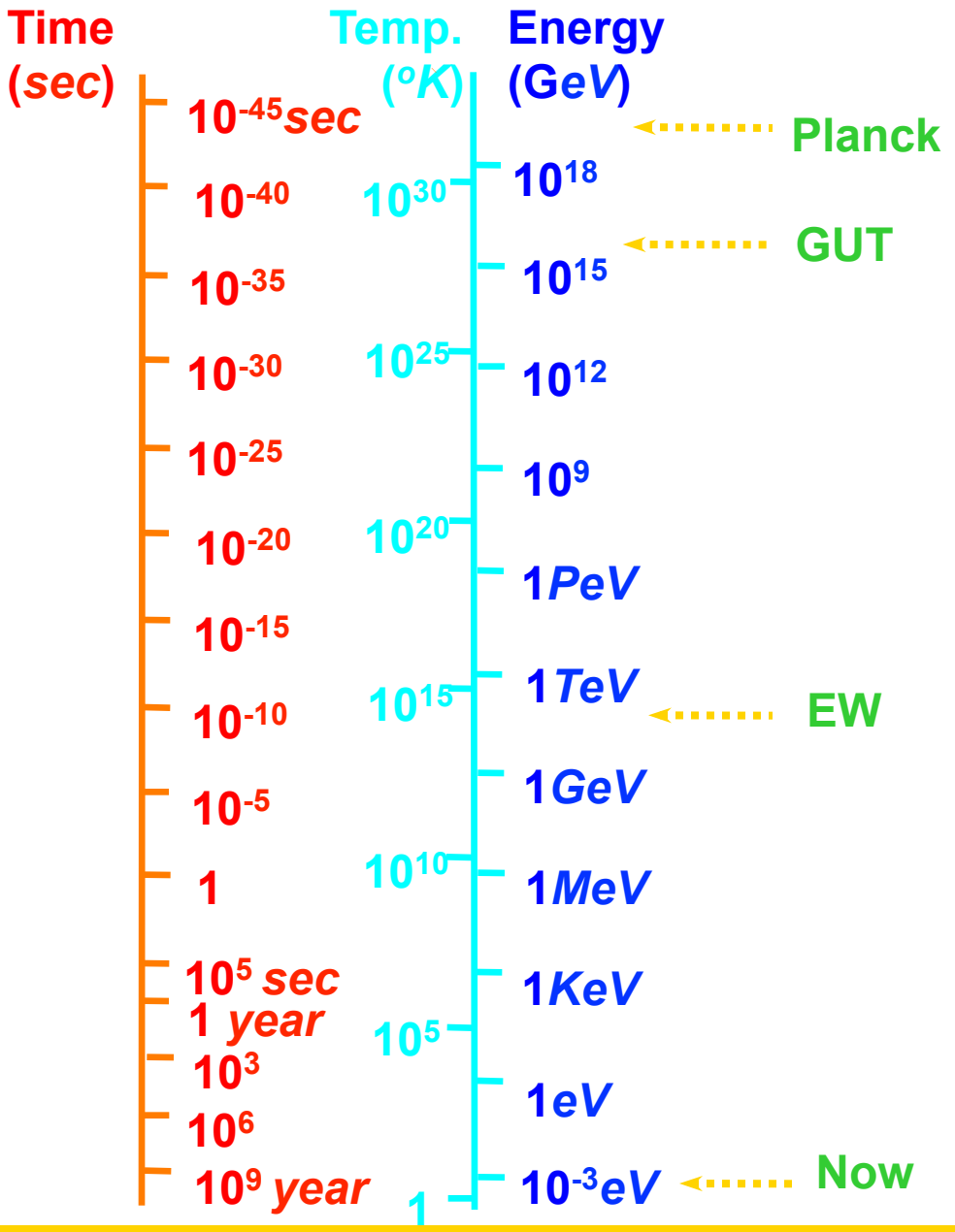
Time (*sec*)	Temp. (^oK)	Energy (*GeV*)
10^{-45} *sec*		
10^{-40}	10^{30}	10^{18}
10^{-35}		10^{15}
10^{-30}	10^{25}	10^{12}
10^{-25}		10^{9}
10^{-20}	10^{20}	1*PeV*
10^{-15}		
10^{-10}	10^{15}	1*TeV*
10^{-5}		1*GeV*
1	10^{10}	1*MeV*
10^{5} *sec* 1 *year*		1*KeV*
10^{3}	10^{5}	
10^{6}		1*eV*
10^{9} *year*	1	10^{-3}*eV*

Simple

Symmetry Break Down

Complex

Relics from the Earliest Universe



Big Bang

Gravitational Wave

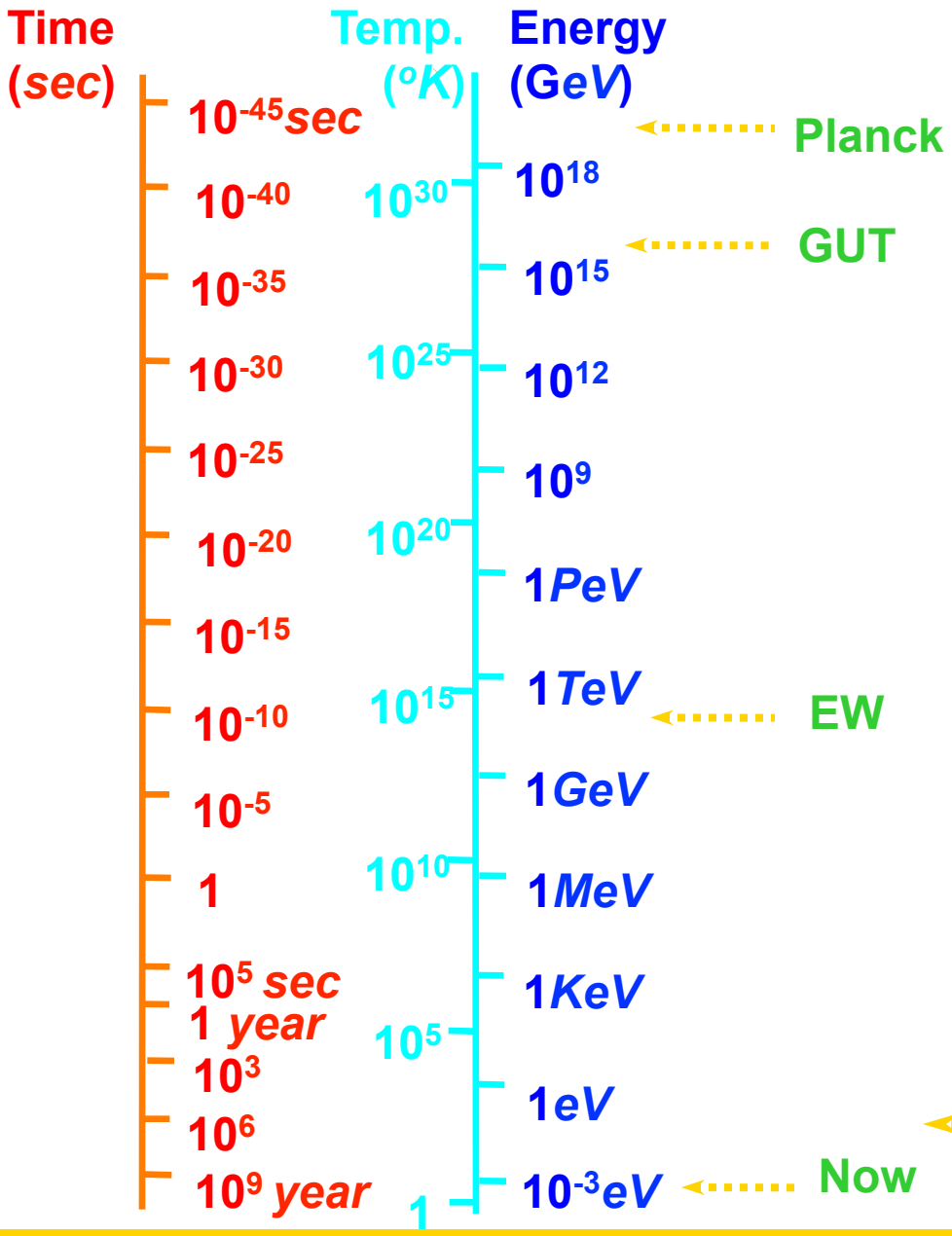
GUT Particle

Neutralino
(Cold Dark Matter)

Relic Neutrino
(Hot Dark Matter)

CMB

CMB : Matter-Radiation Decoupling



Time = 300,000 *years*

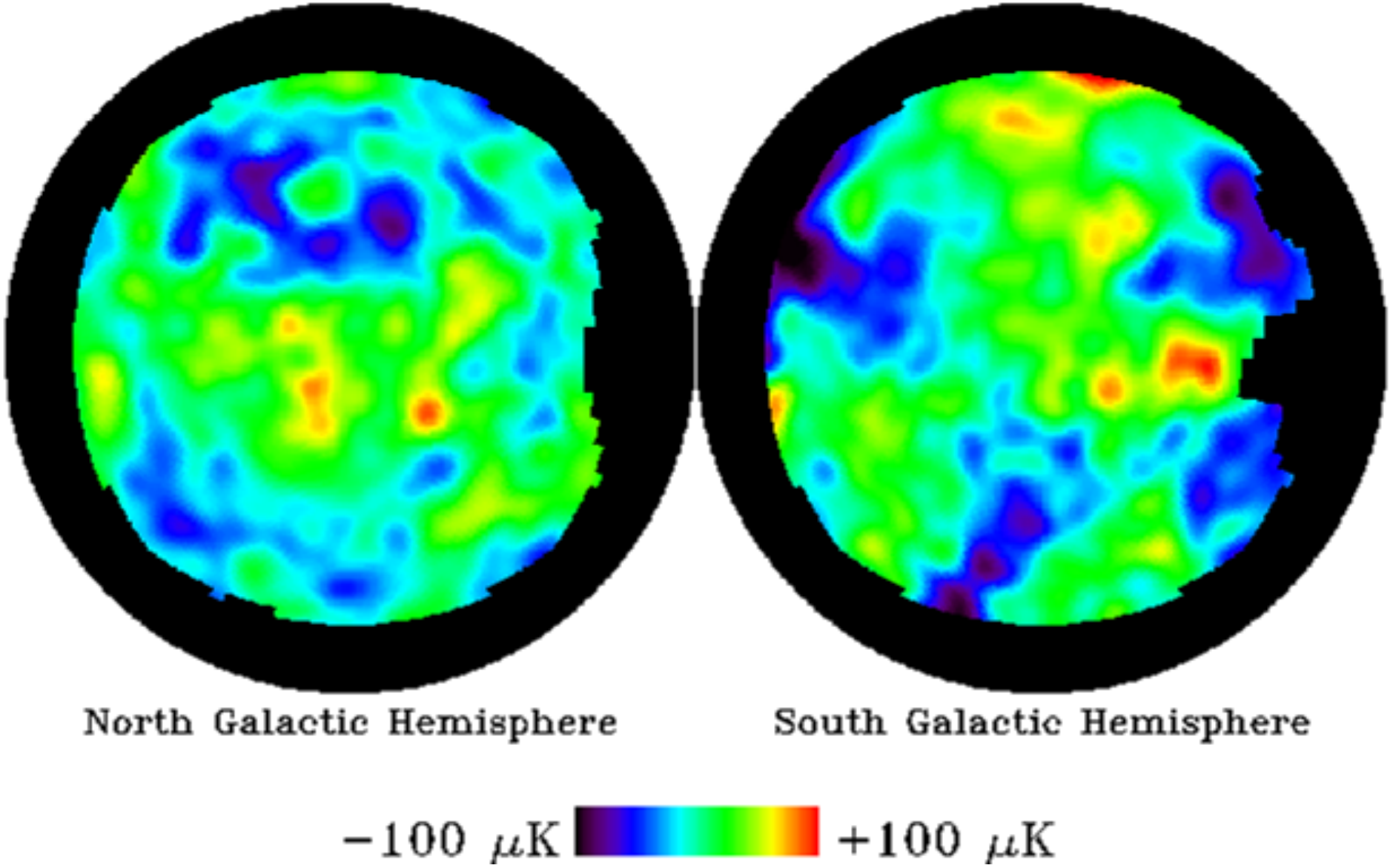
Temperature = 3,000 °*K*

Energy = 0.3 *eV*

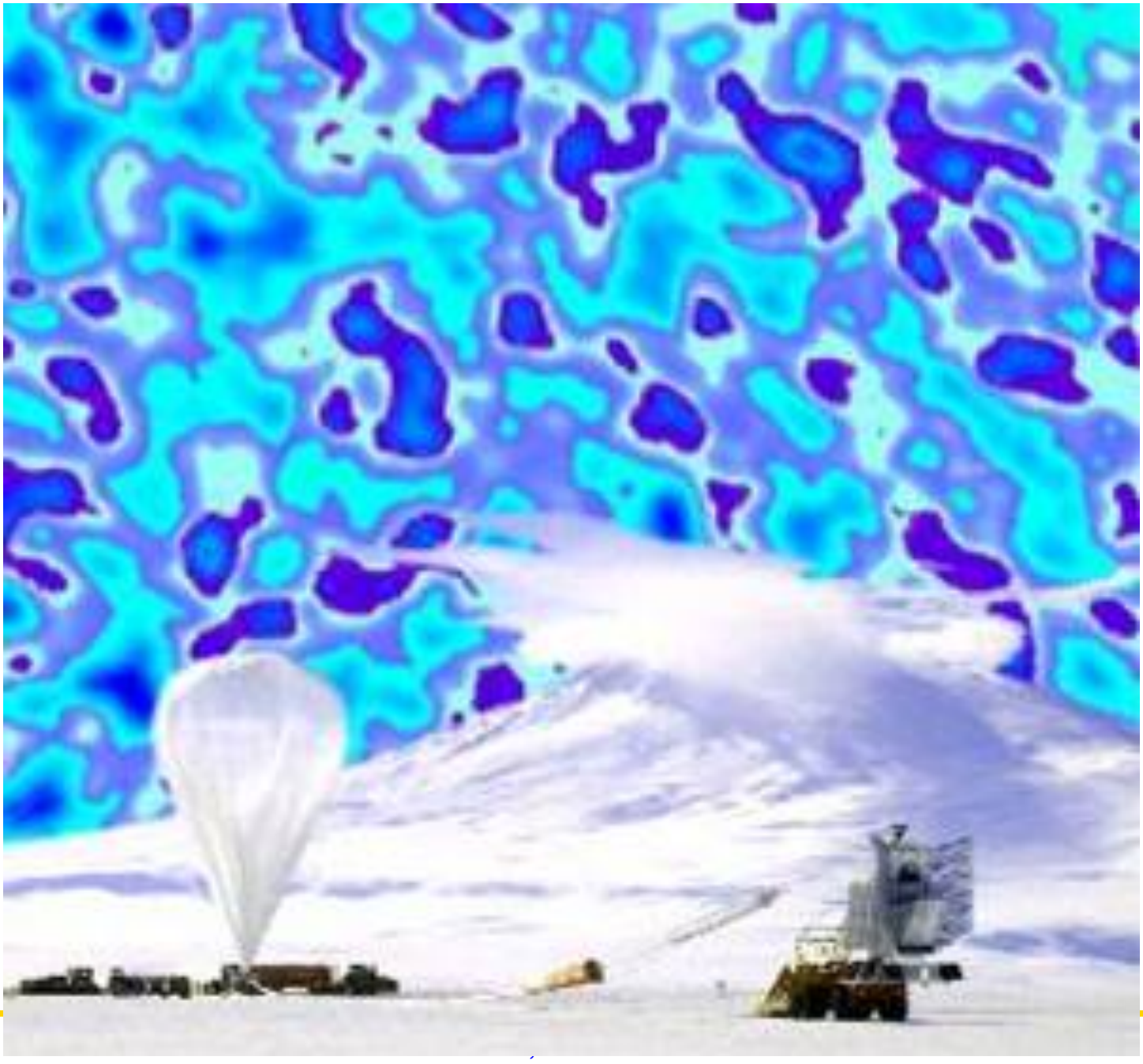
Z = 1,100

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

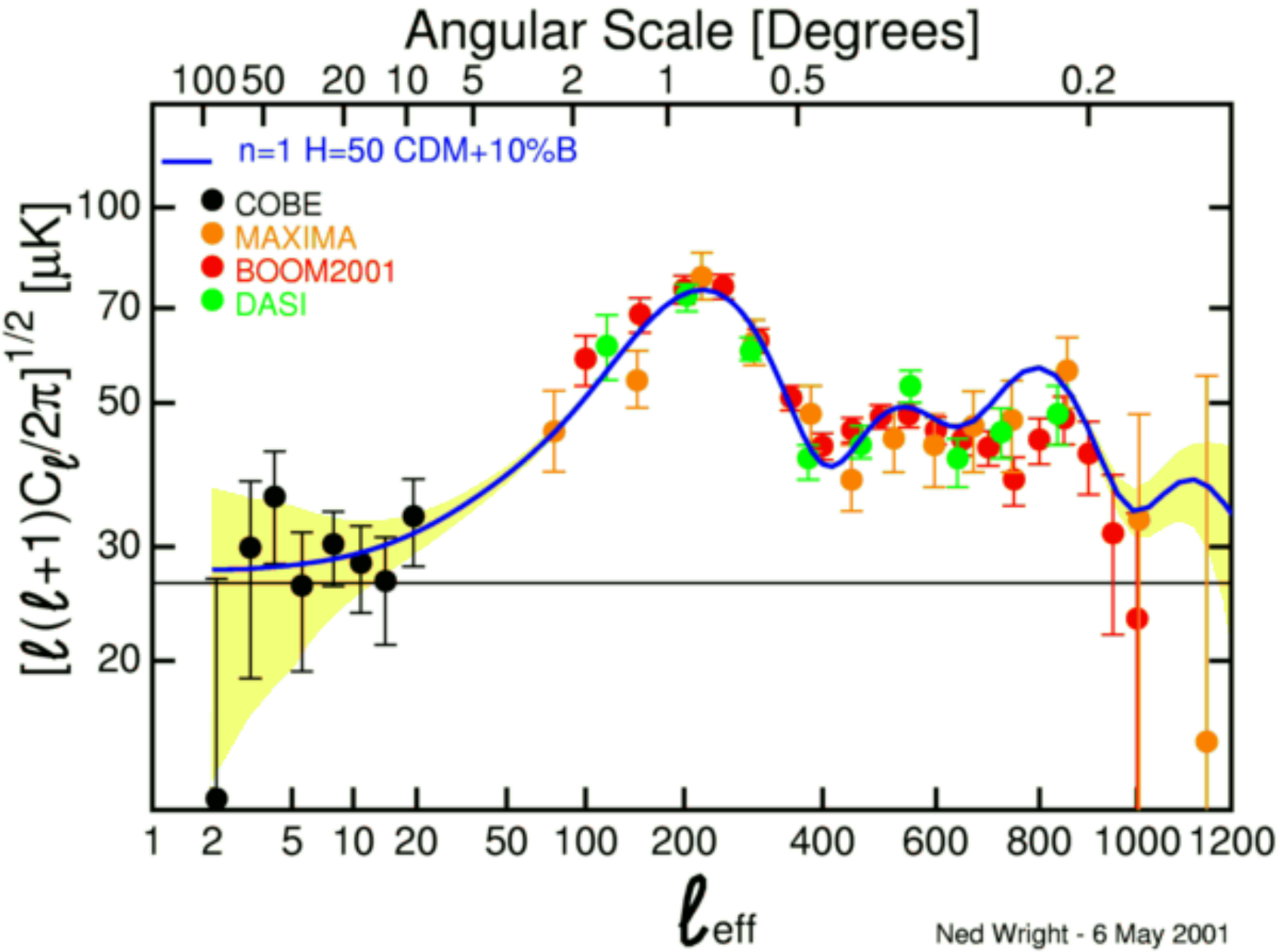
CMB Anisotropy by COBE DMR



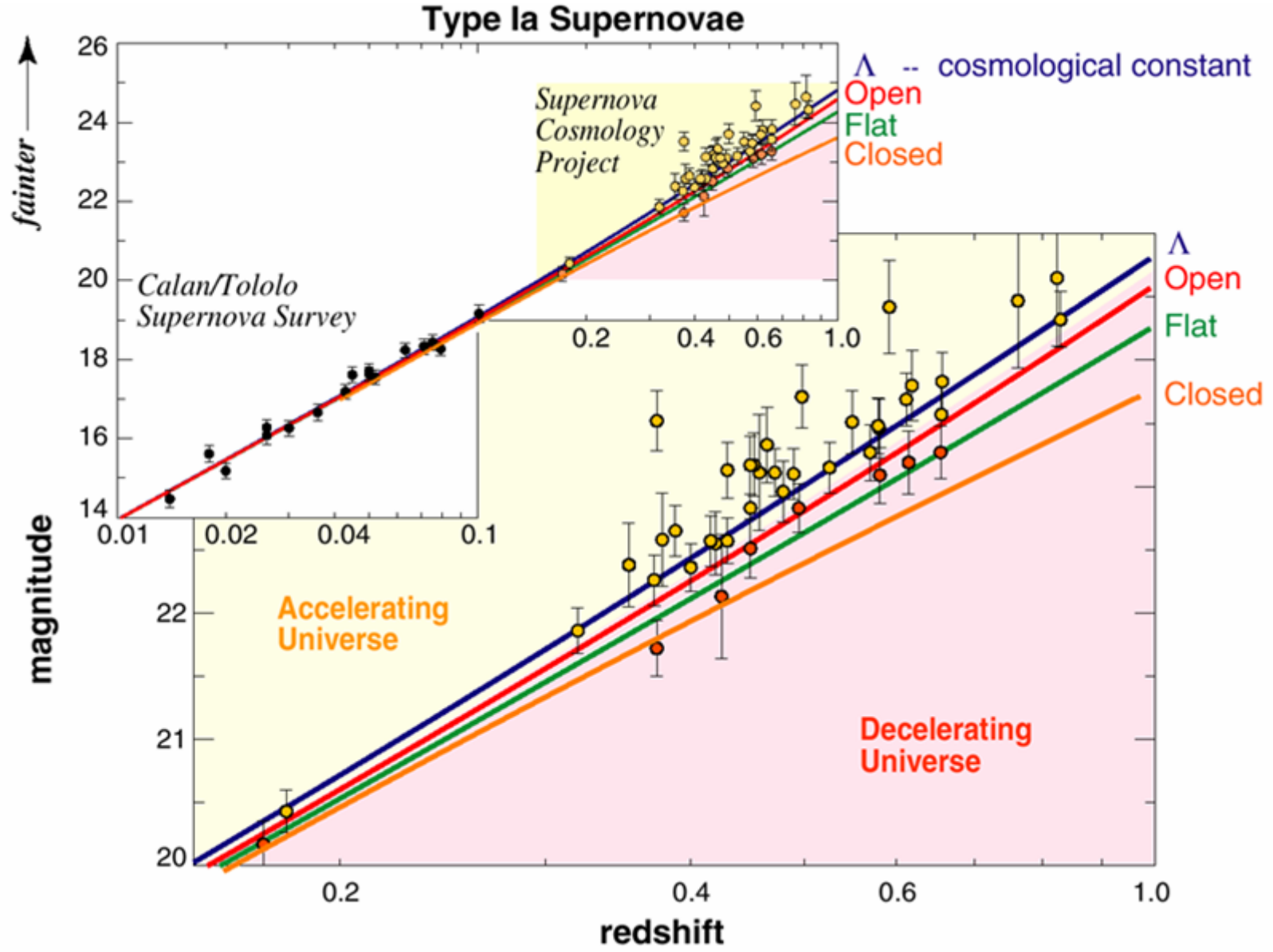
CMB Anisotropy by Boomerang



Recent Results of CMB Anisotropy

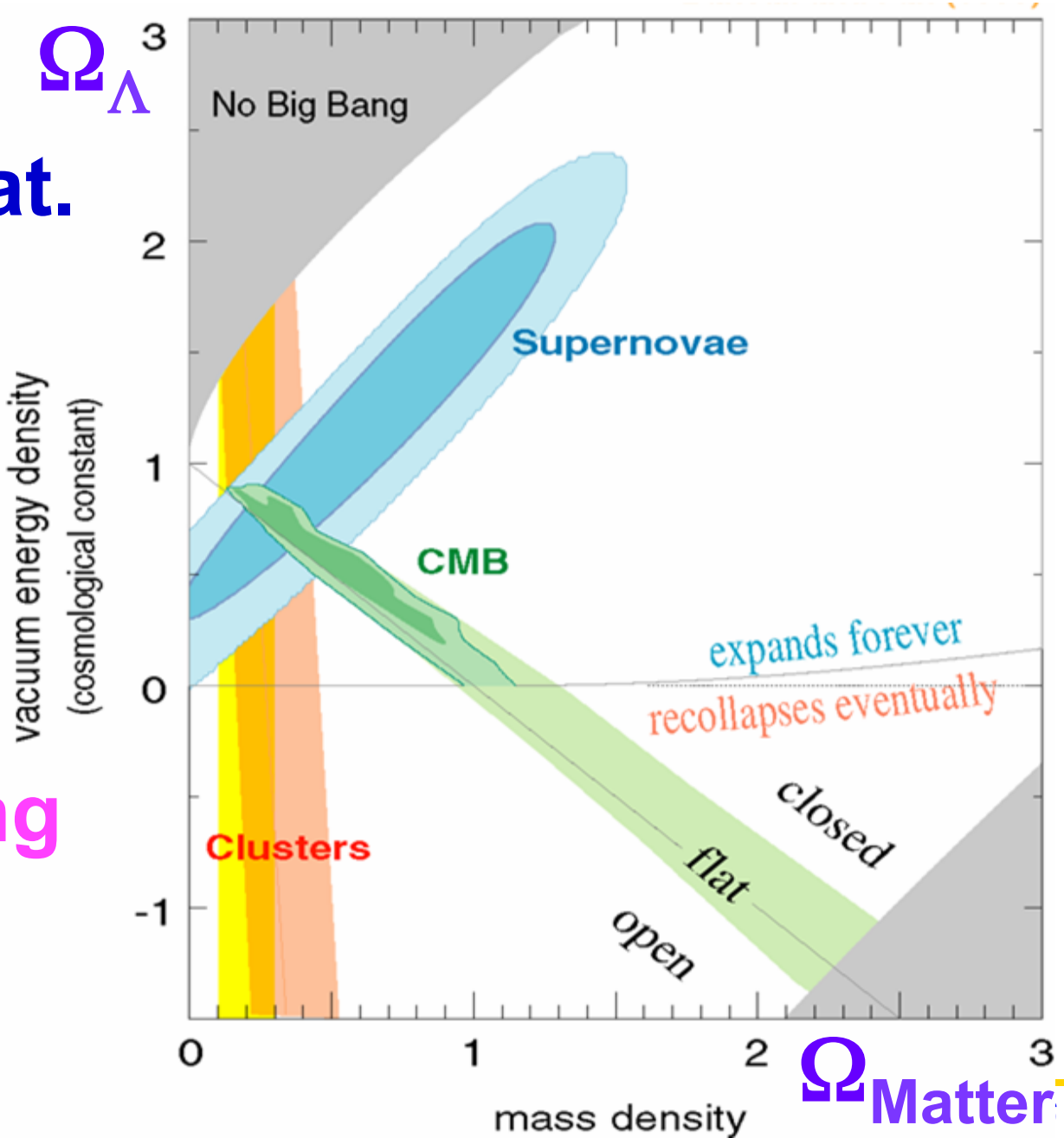


The Accelerating Universe



Density of Our Universe

- **Universe is Flat.**
  - ⇒ **Inflation**
- **70% is Dark Energy.**
  - ⇒ **Accelerating**



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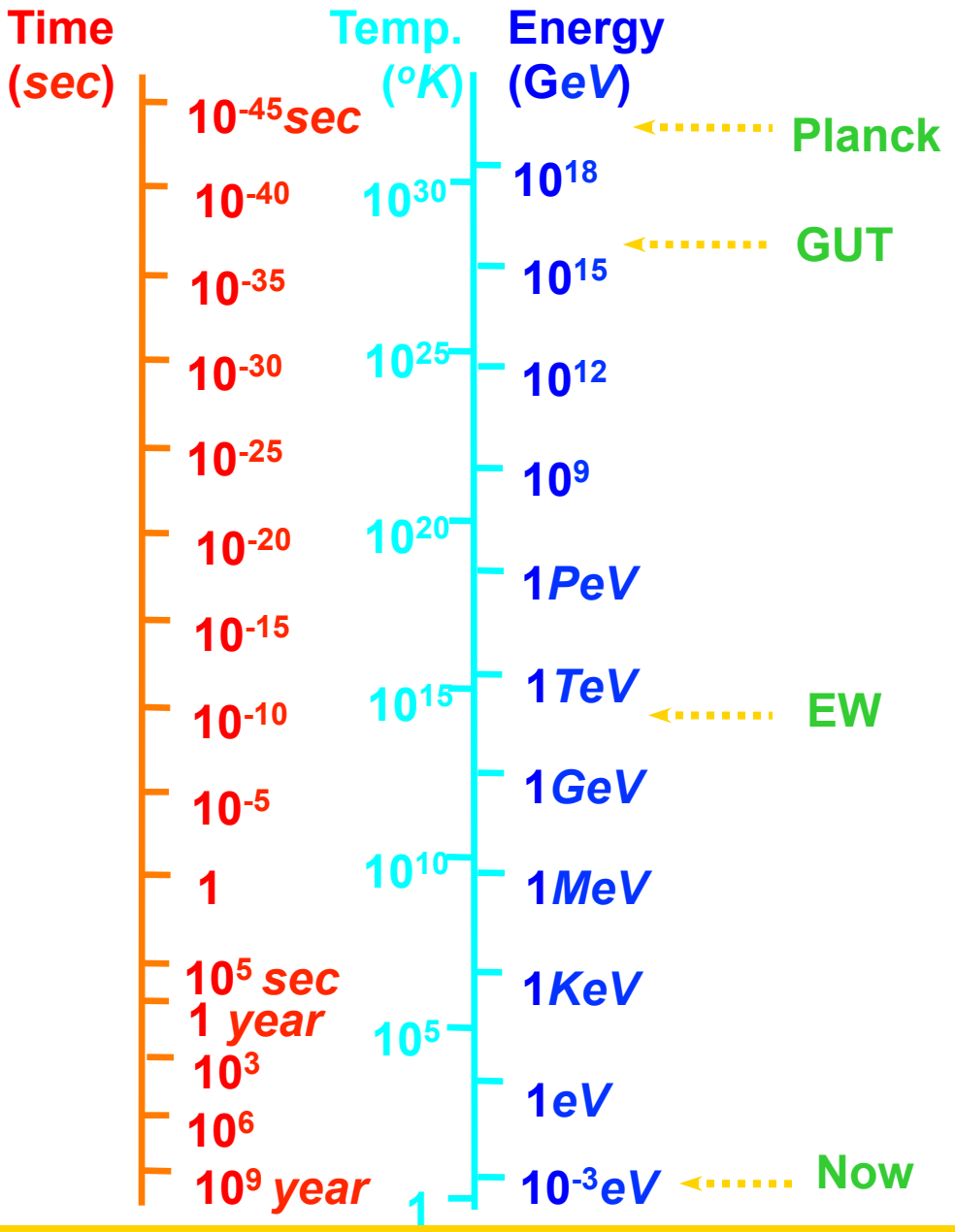

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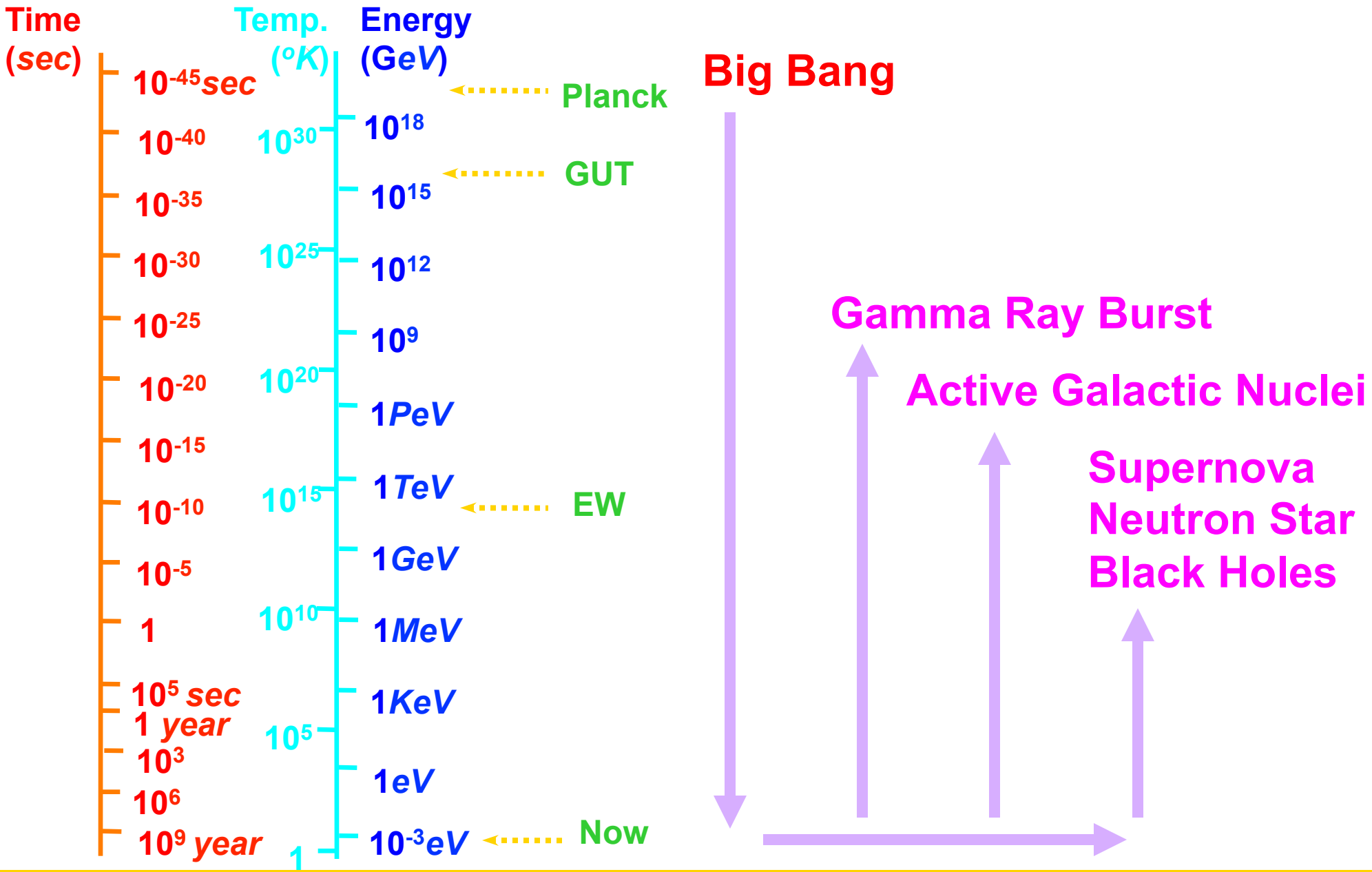
Dark Energy

The Extreme Universe



Messengers from the Universe

- **Photons**
  - Visible, ~~Infrared, UV~~
  - ~~X-rays,~~ Gamma-rays
  - ~~Micro-wave, Radio~~
- **Charged Particles**
  - Ultra High Energy Cosmic Rays
  - Anti-particles
- **Neutrinos**
  - Solar-neutrino, Supernova
  - Relic Neutrino
- ~~**Dark Matter**~~
- ~~**Gravitons**~~

~~_____~~ *not covered in this talk*

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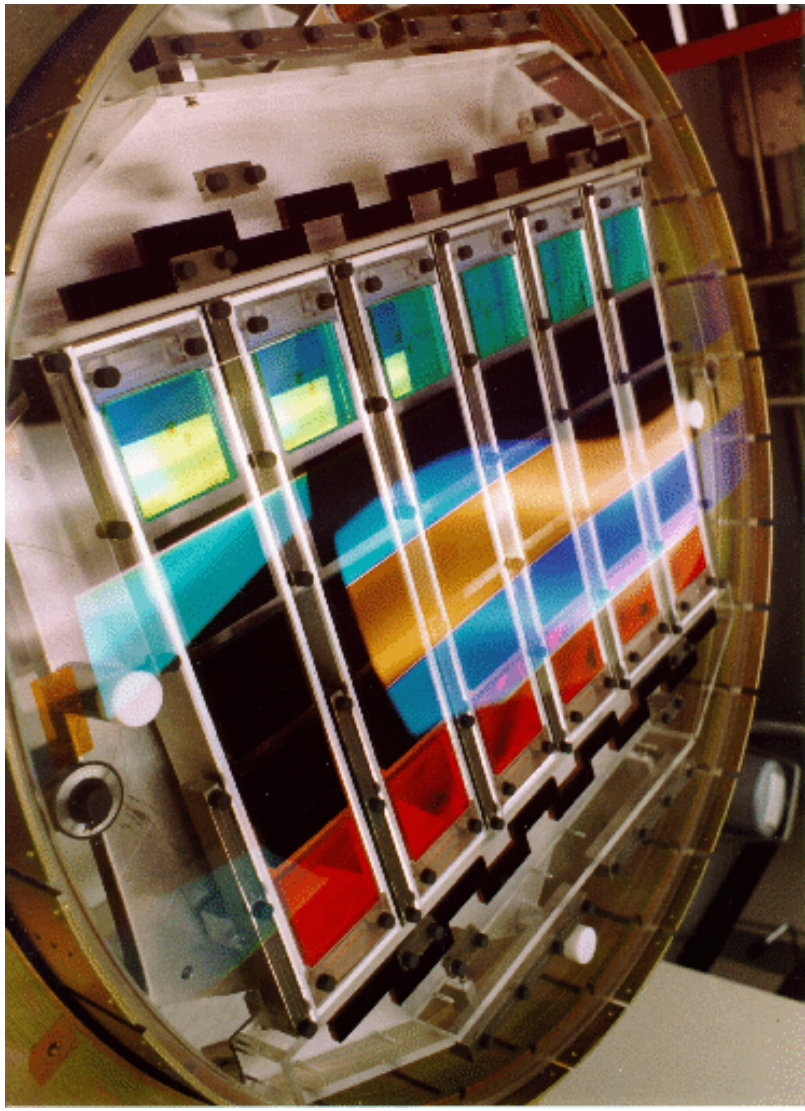
- **Gravitons**

SDSS (Sloan Digital Sky Survey)

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



Focal Plane

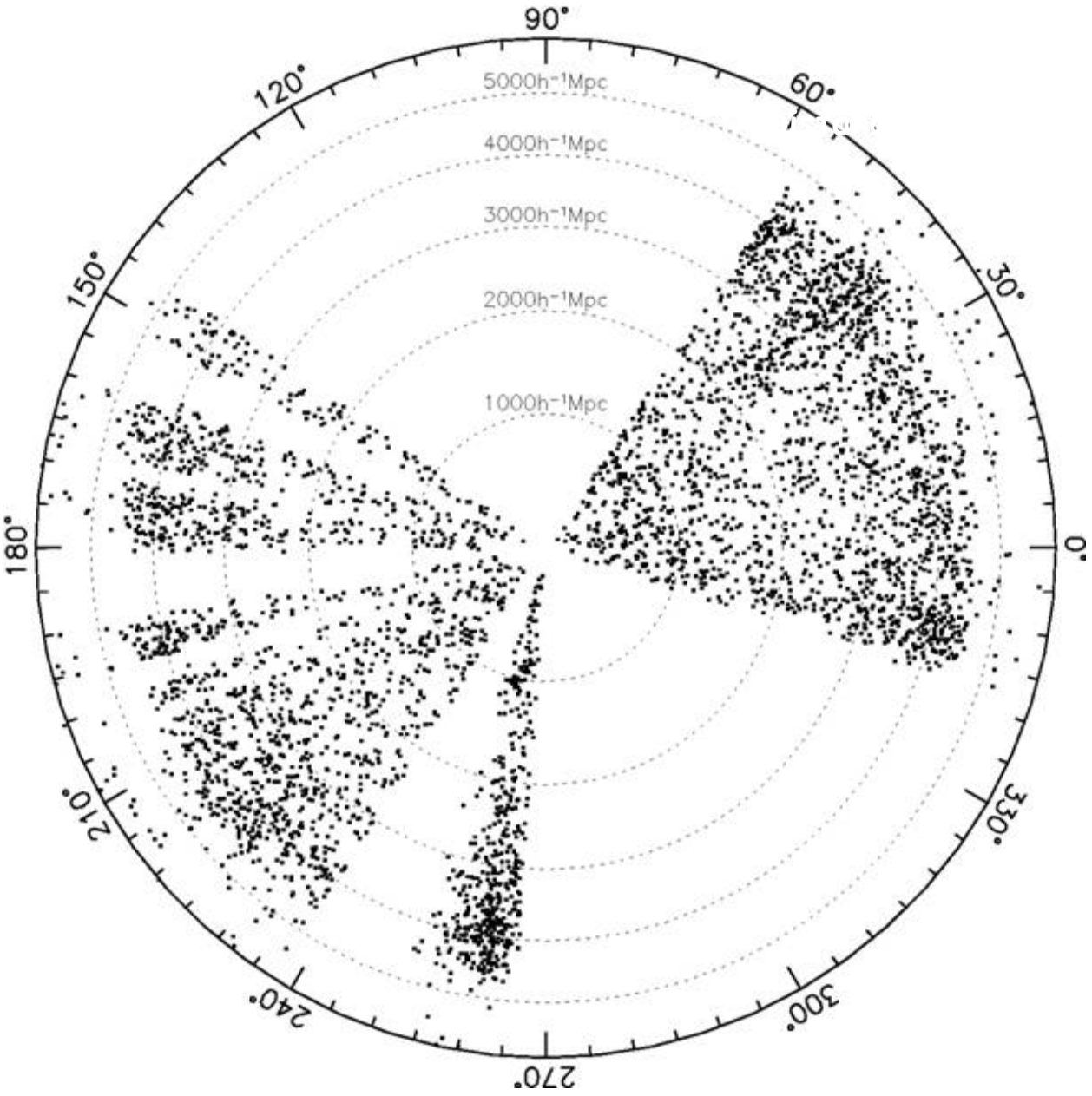
SDSS Early Data Release

Goal:

500 sq. degree of the sky.

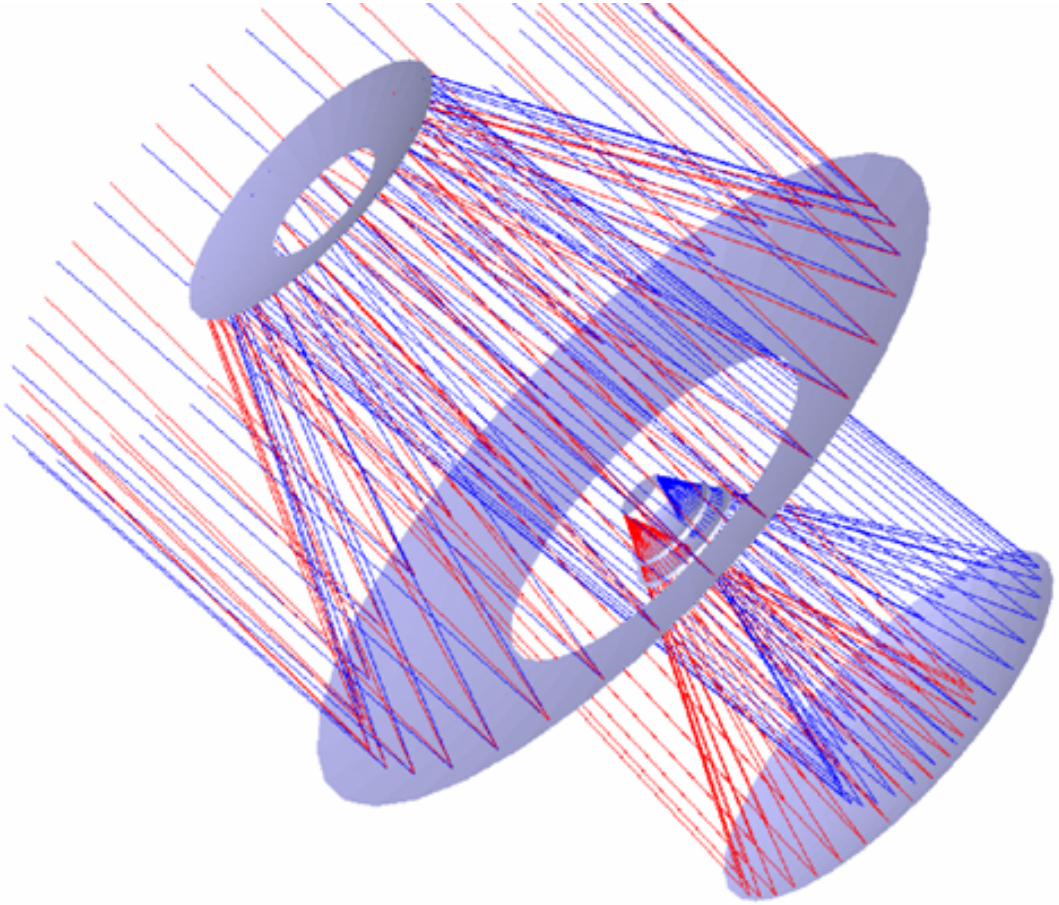
14 million objects.

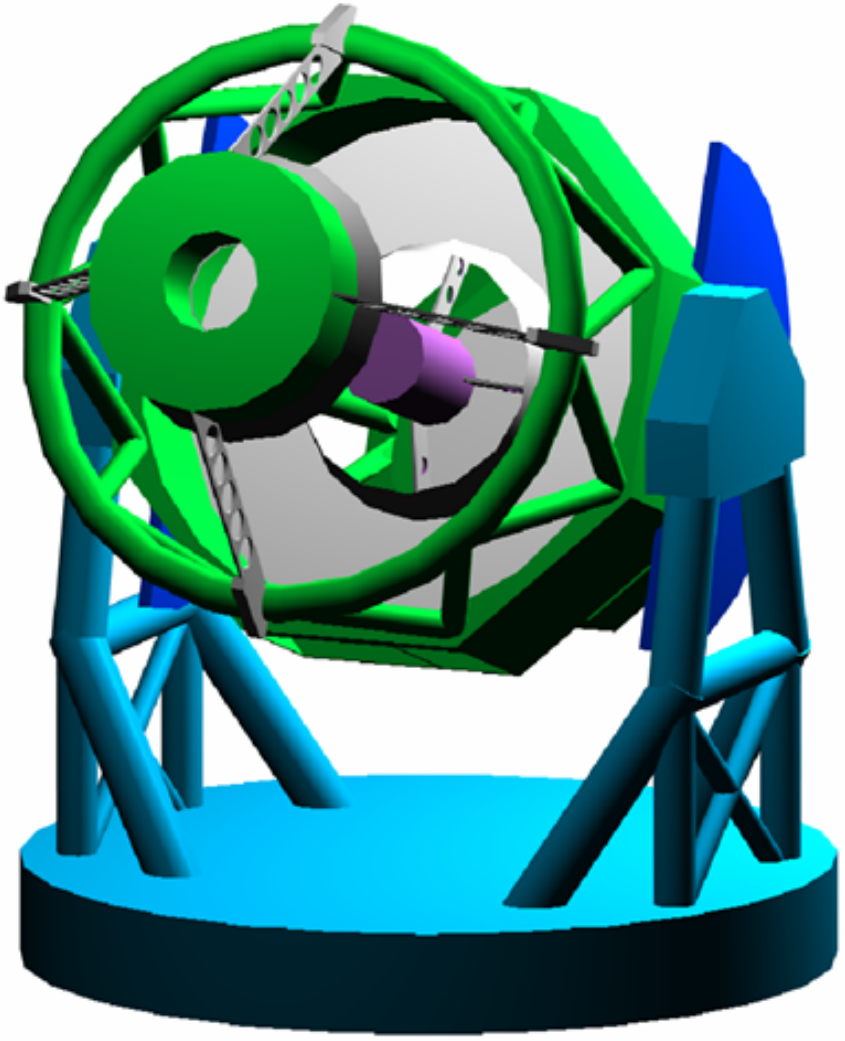
Spectra for 50,000 galaxies 5,000 quasars.



LSST (Large-aperture Synoptic Survey Telescope)

- 8m Diameter
- 3° x 3° FOV
- f/1.2, 50cm Focal plane
- 1.4Giga-pixel CCD





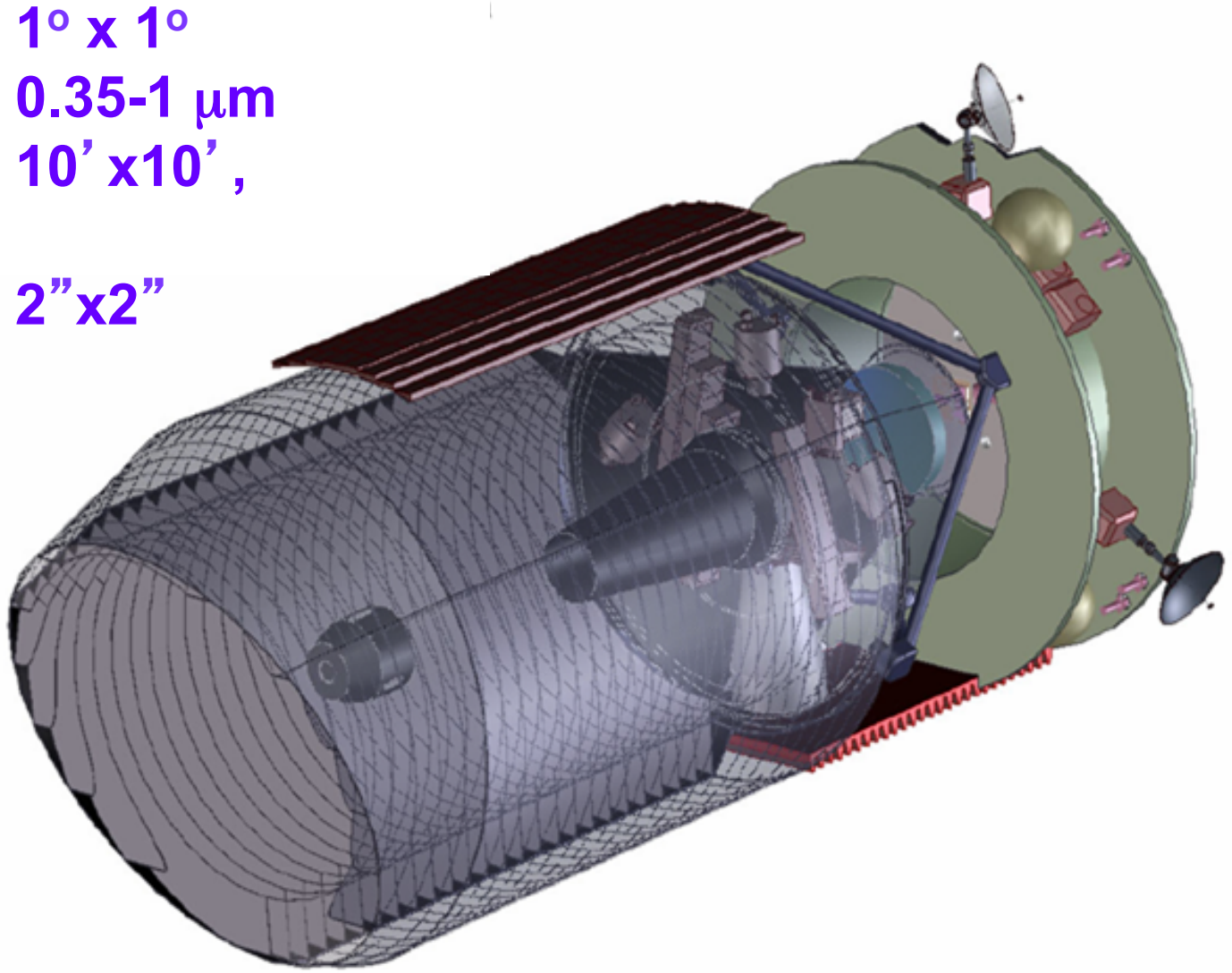
NGST (Next Generation Space Telescope)

- Mirror Diameter: ~6.5 m
- FOV: 4’ x 4’
- Wavelength: 0.6-28 μm
- Orbit: L2 point
- Payload mass: ~3000 kg
- Mission duration: 5-10 years

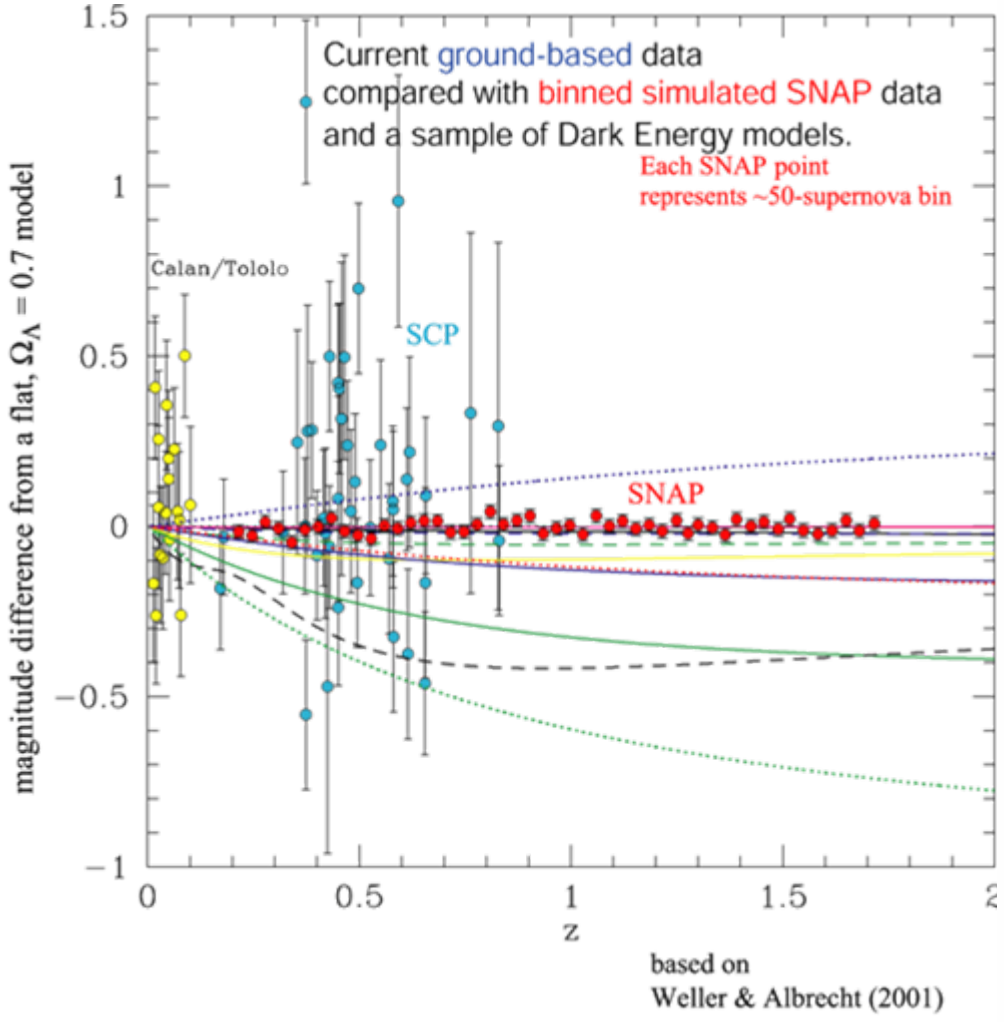
GSFC Design

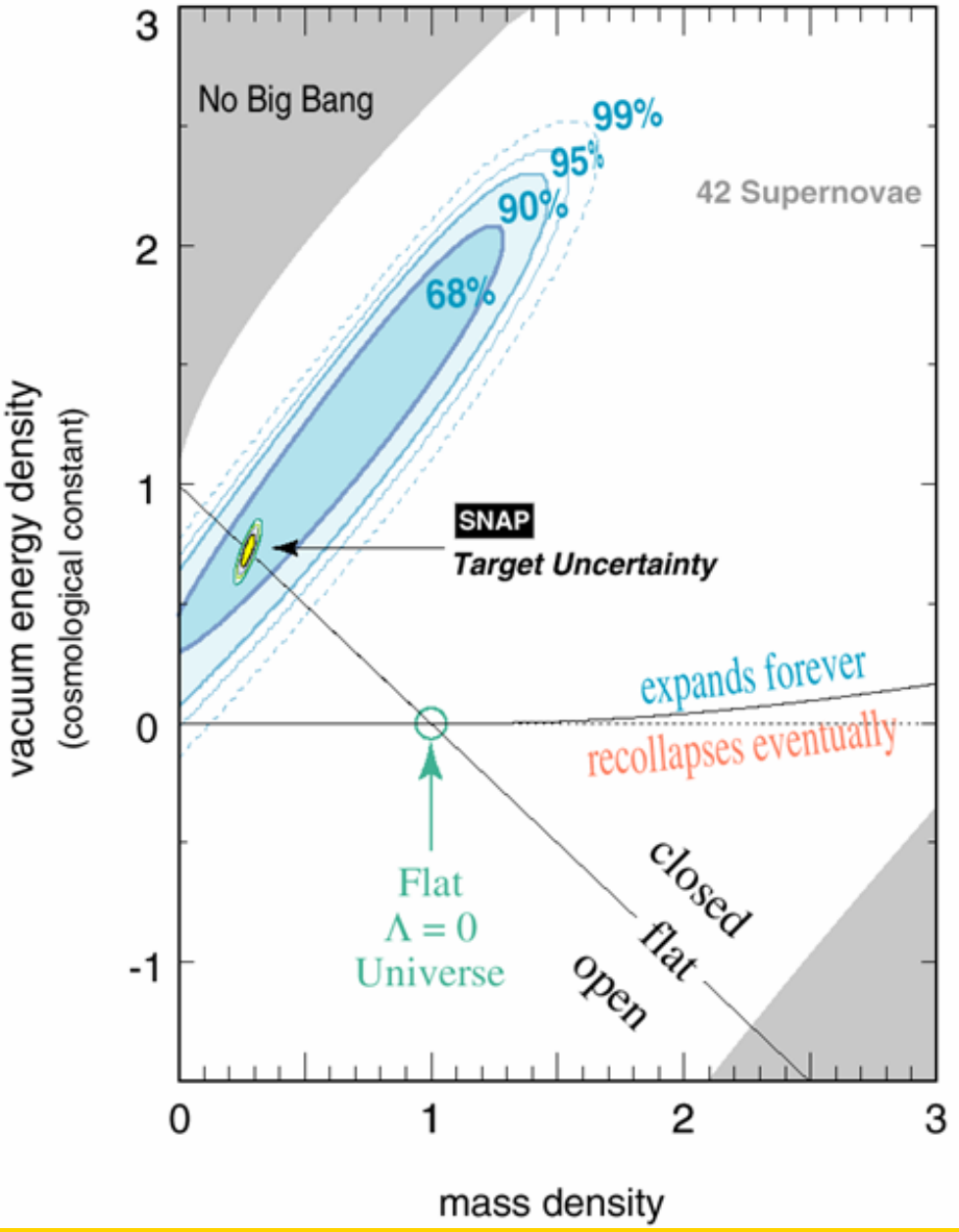
SNAP (SuperNova Acceleration Probe)

- **Mirror Diameter:** 2 m
- **FOV:** 1° x 1°
- **Wavelength:** 0.35-1 μm
- **IR Photometry:** 10' x10' , HgCdTd
- **IR Spectroscopy:** 2"x2"

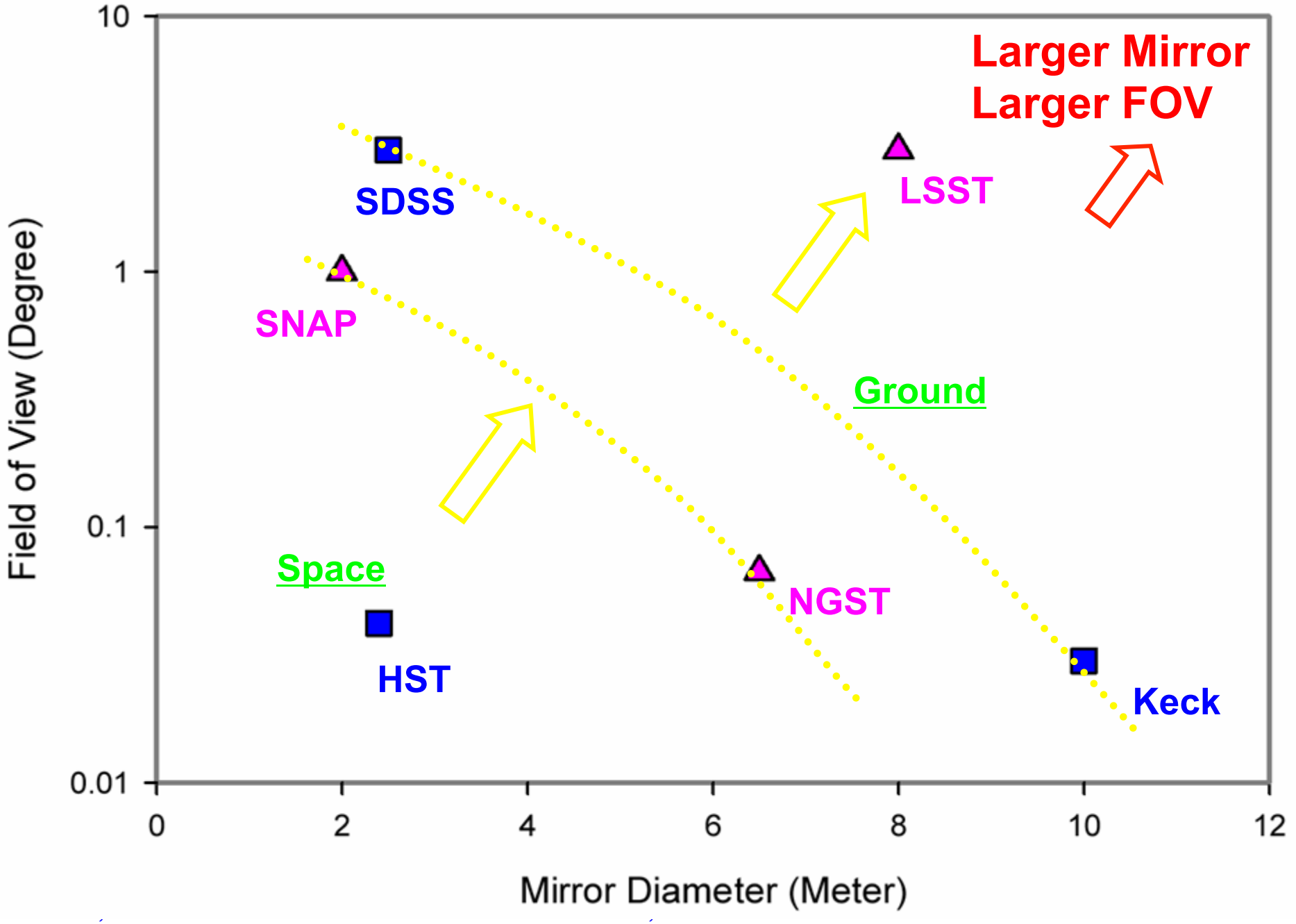


SNAP – Dark Energy Sensitivity



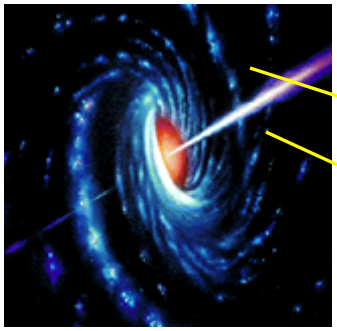


Deep Sky Survey by Telescopes

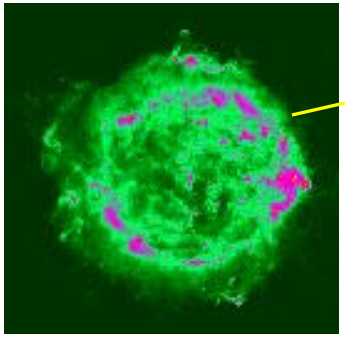


The Extreme Universe

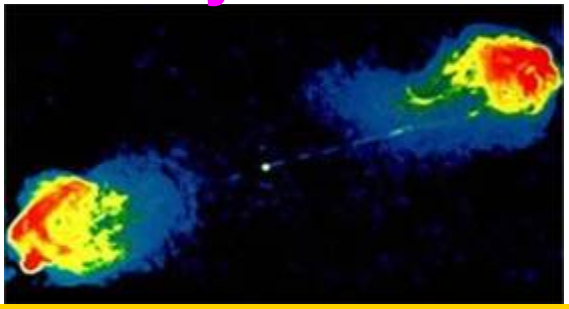
AGN

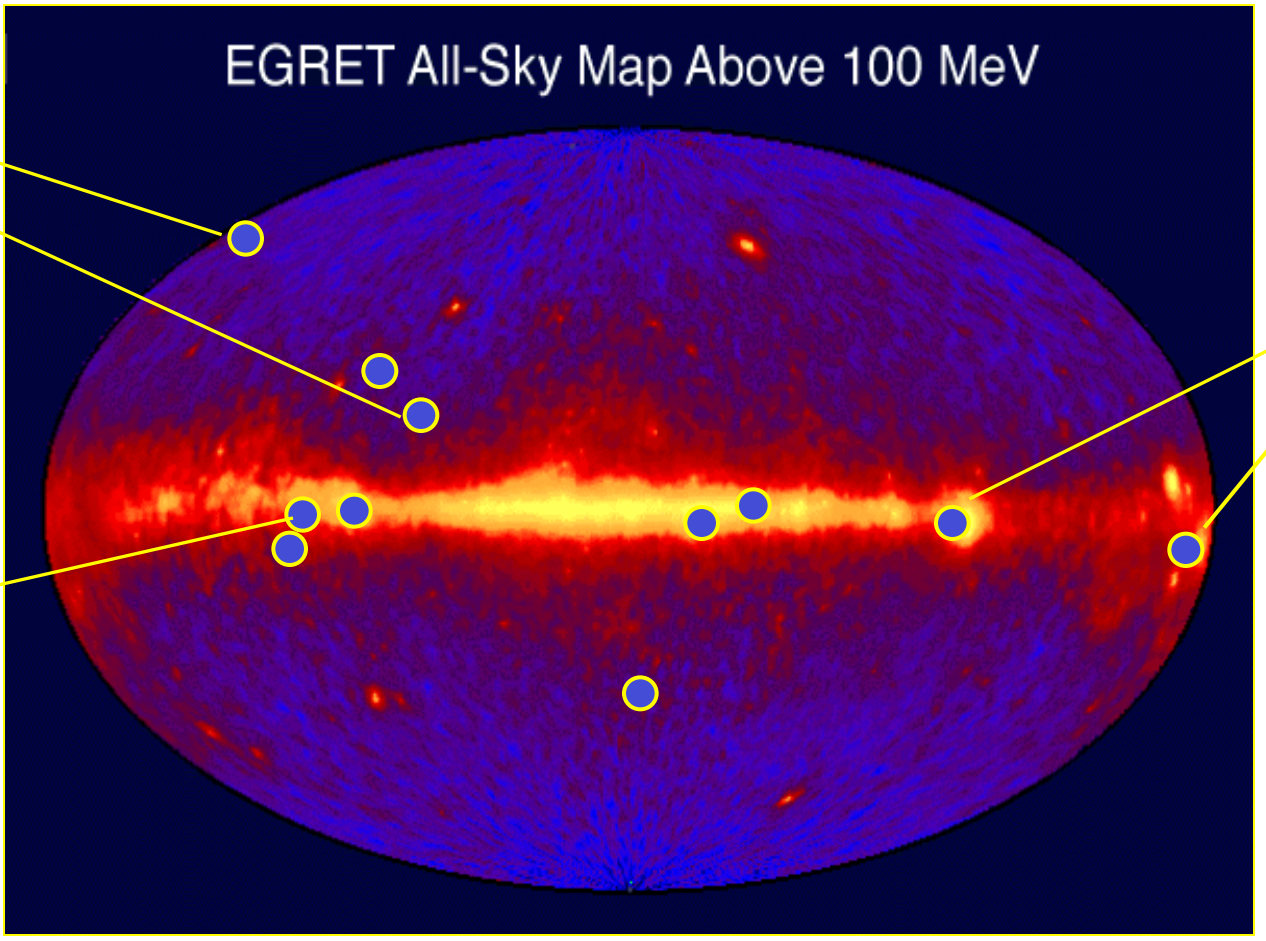


SNR

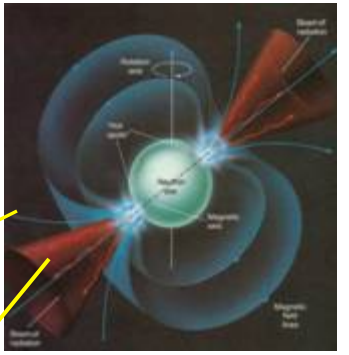


Radio Galaxy

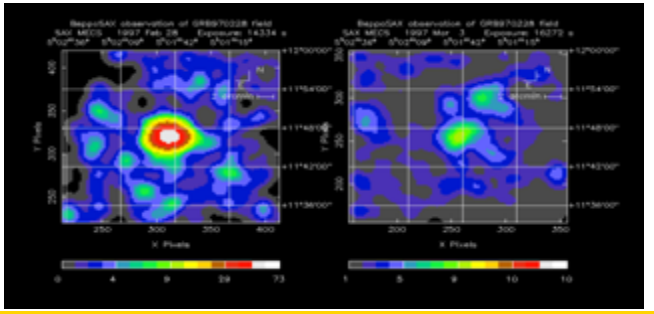




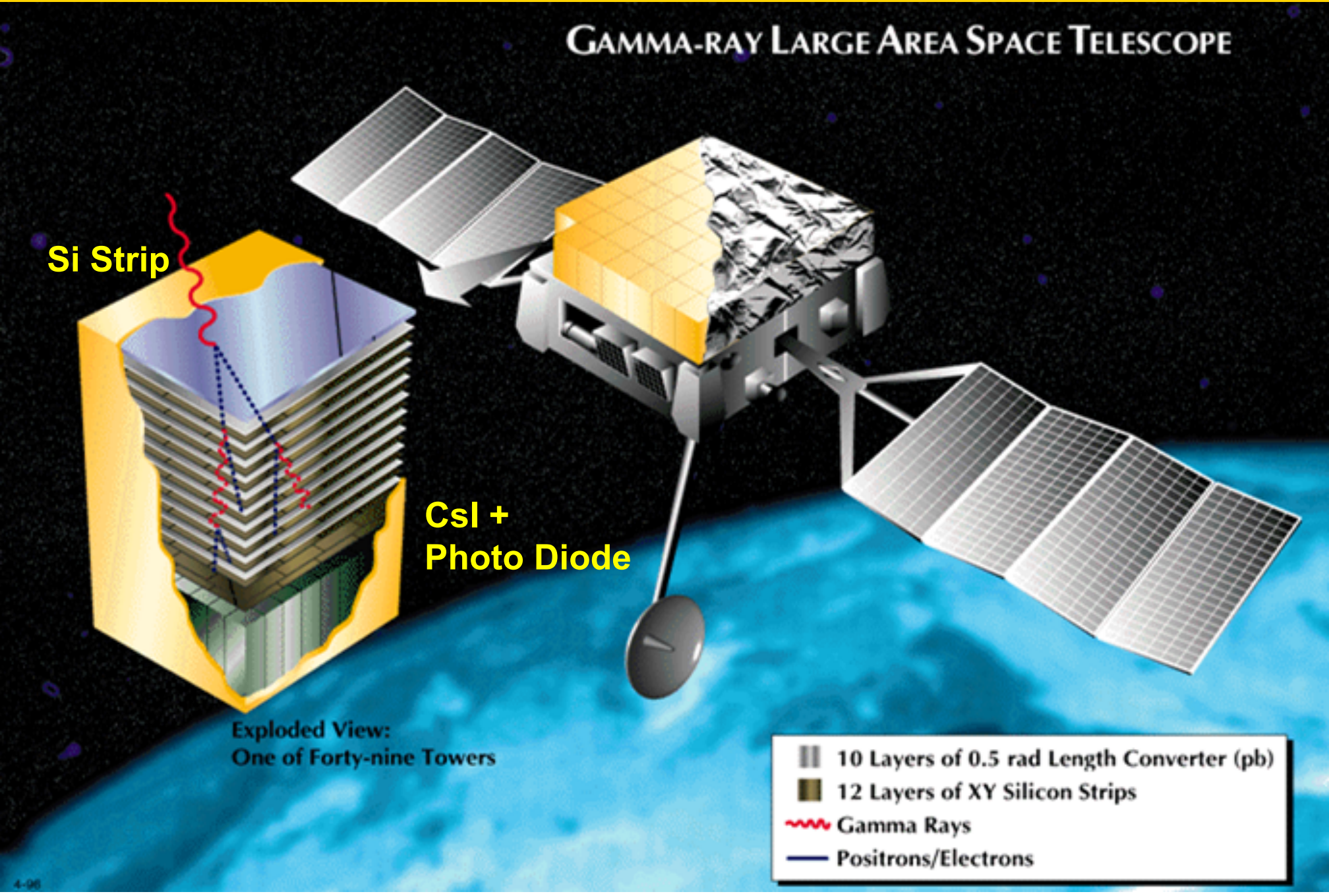
Pulsar



GRB

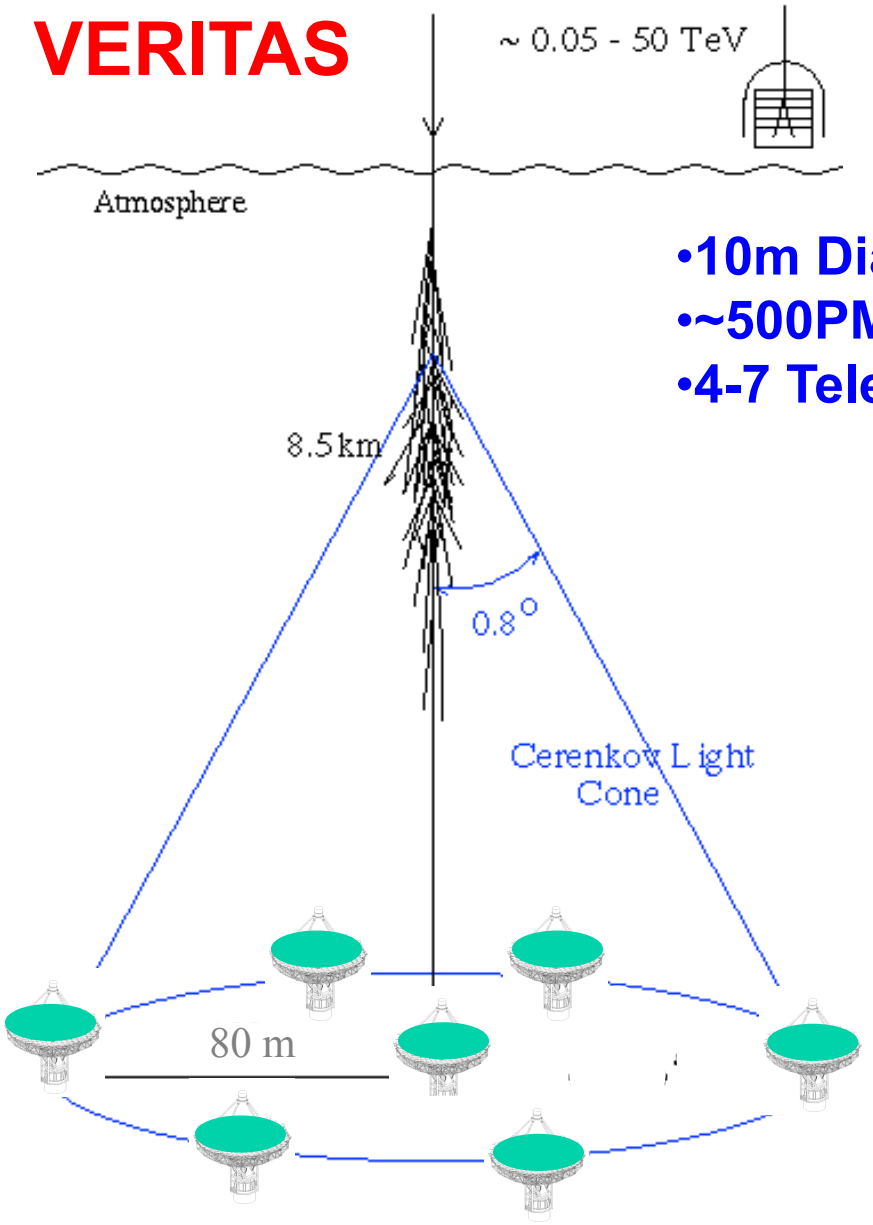


GLAST - Gamma Ray Sky Survey



Gamma ray Telescopes

VERITAS

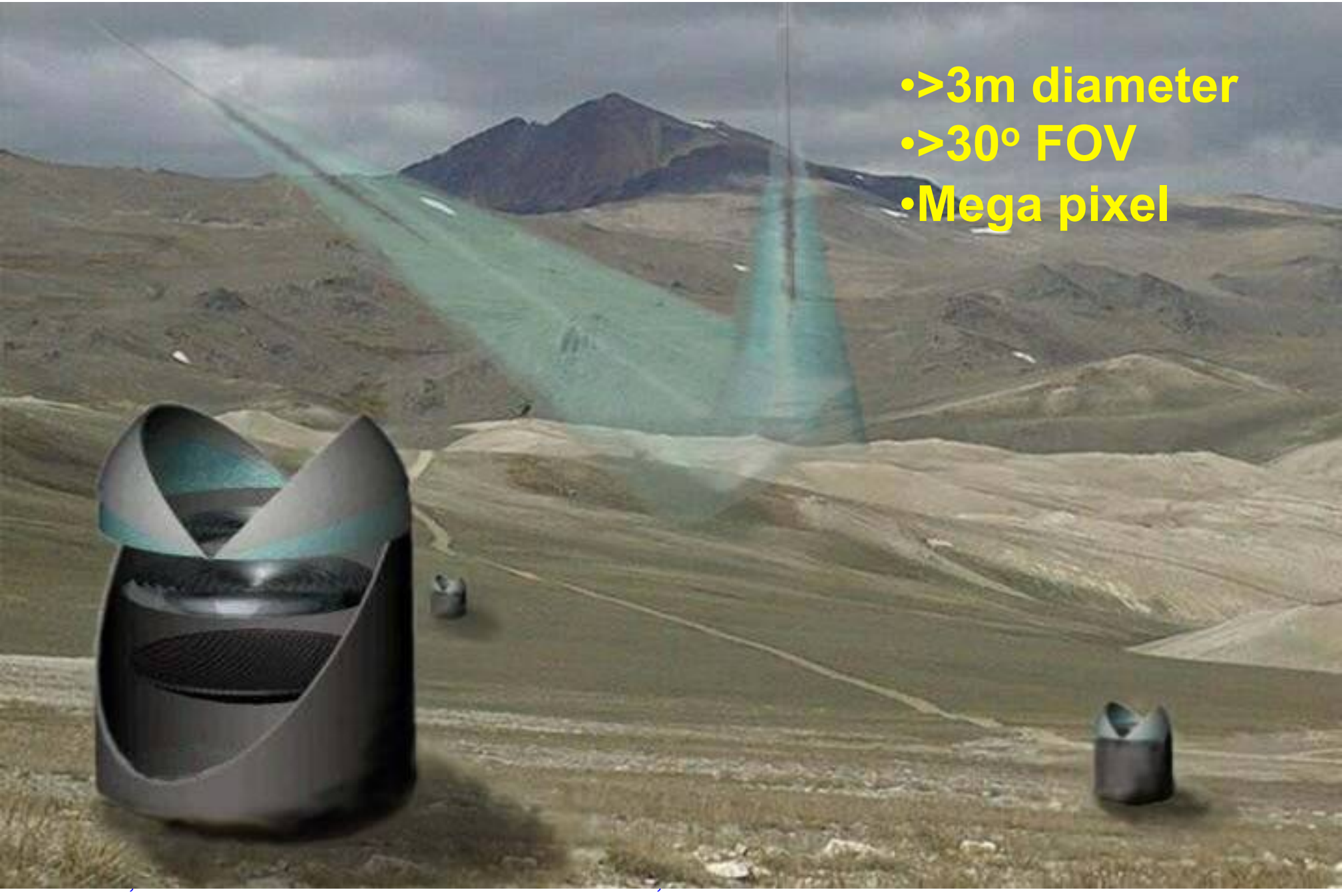


HESS

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

MAGIC under Construction

γ-ray Wide-FOV Telescope

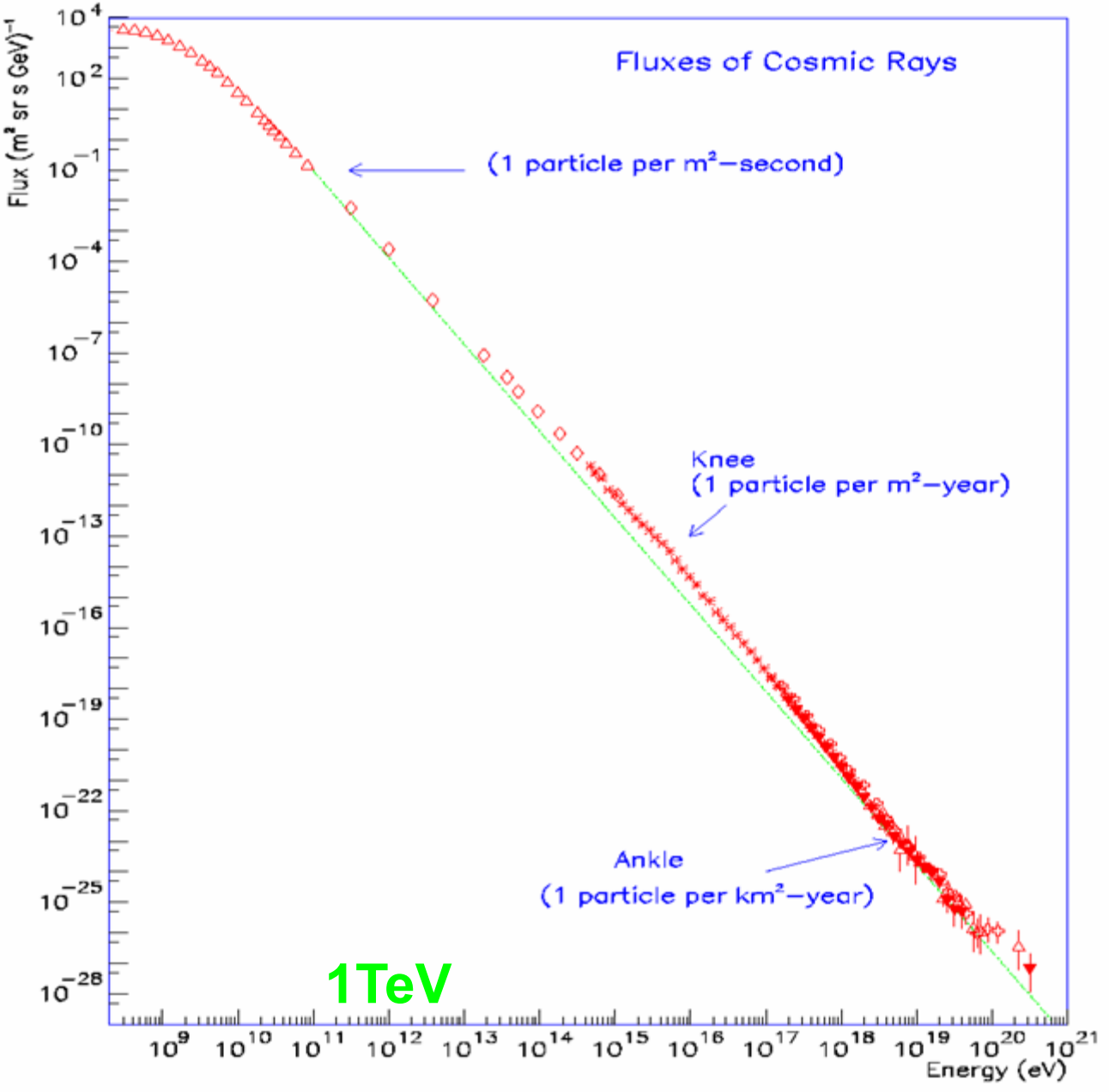


Messengers from the Universe

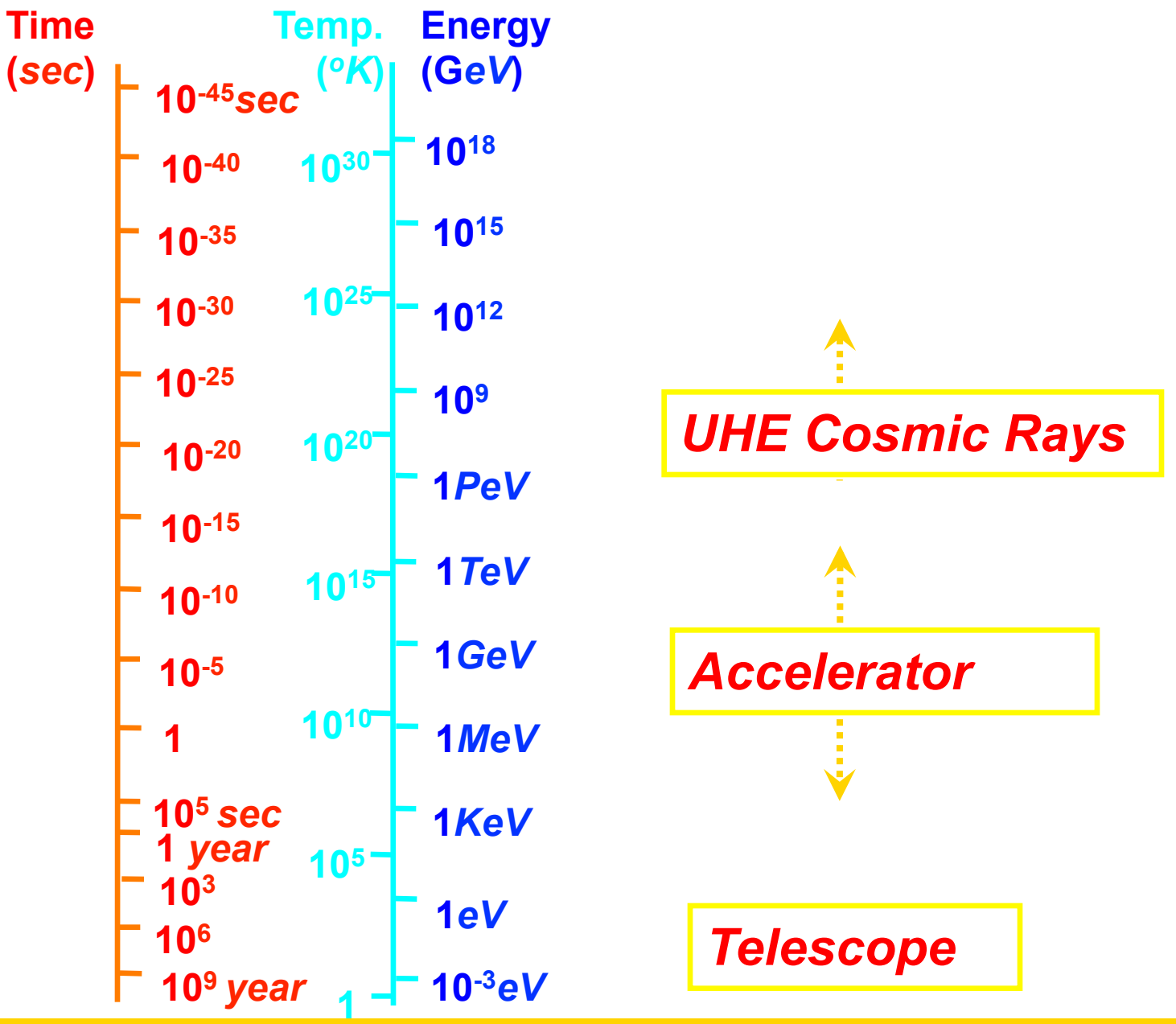
- Photons
  - Visible, Infrared, UV
  - X-rays, Gamma-rays
  - Micro-wave, Radio
- **Charged Particles**
  - **Ultra High Energy Cosmic Rays**
  - **Anti-particles**
- Neutrinos
  - Solar-neutrino, Supernova
  - Relic Neutrino
- Dark Matter
- Gravitons

Energy Spectrum of Cosmic Rays

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



Tools to explore the Early Universe



Why is 10^{20}eV so special?

- Nearly impossible to accelerate beyond 10^{20}eV by nature.

  → Top-down Mechanism?

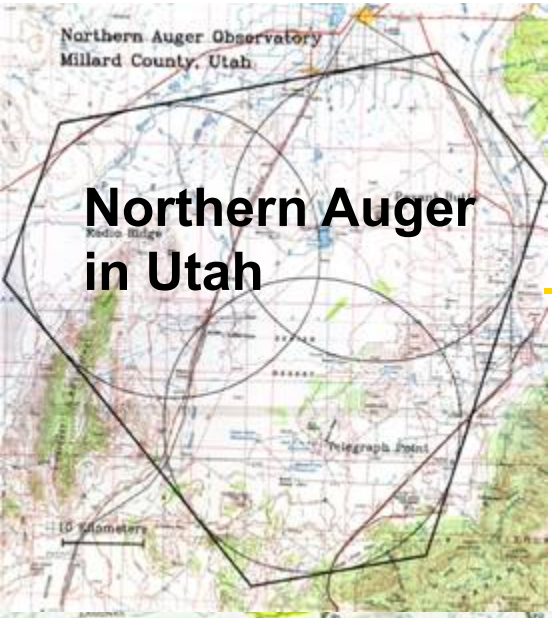
- Protons can travel straight at E>10^{20}eV.

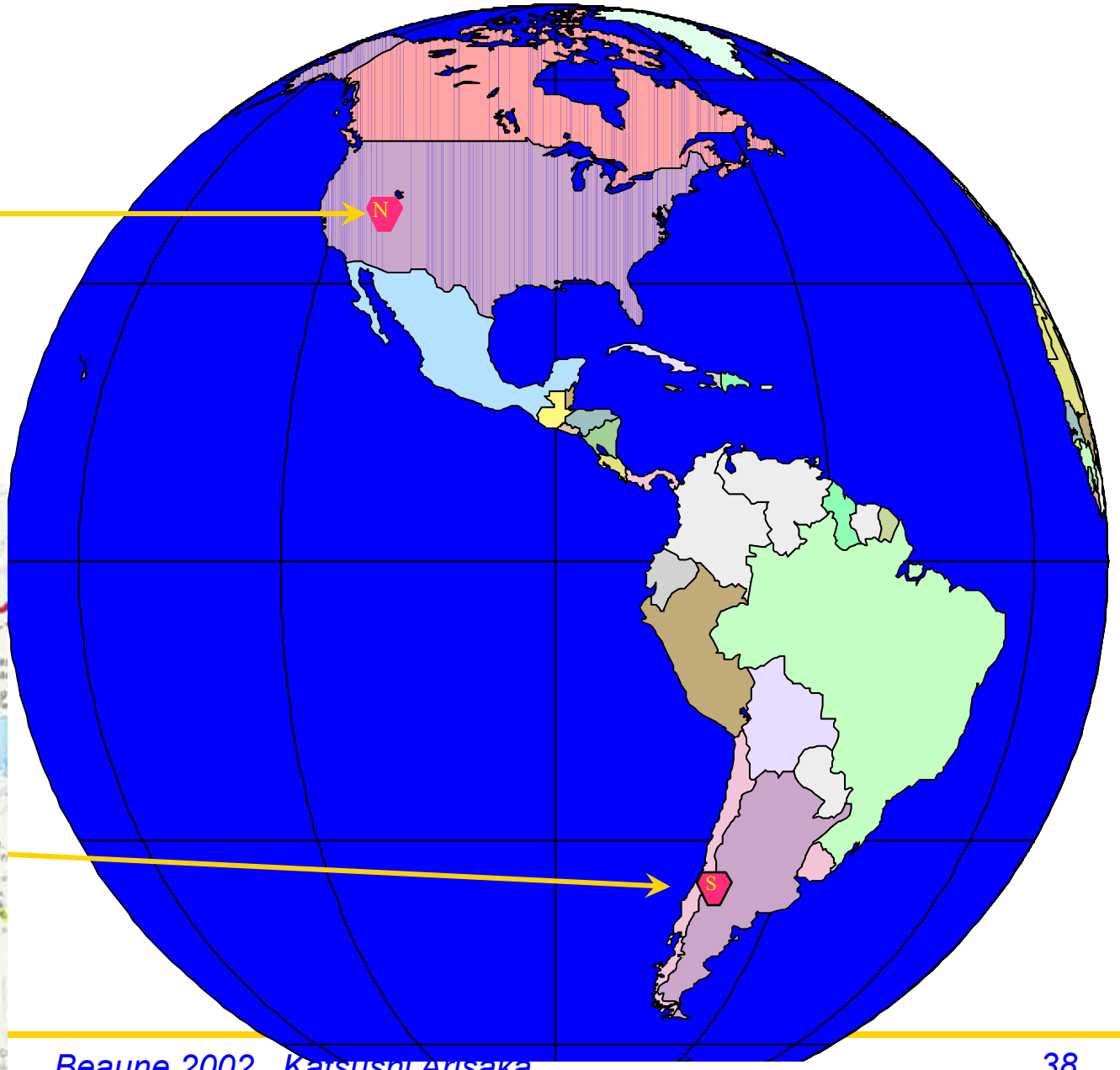
  → Charged-Particle Astronomy

- Protons can <u>not</u> travel beyond ~50Mpc at E> 5 x 10^{19}eV due to interaction with CMB.

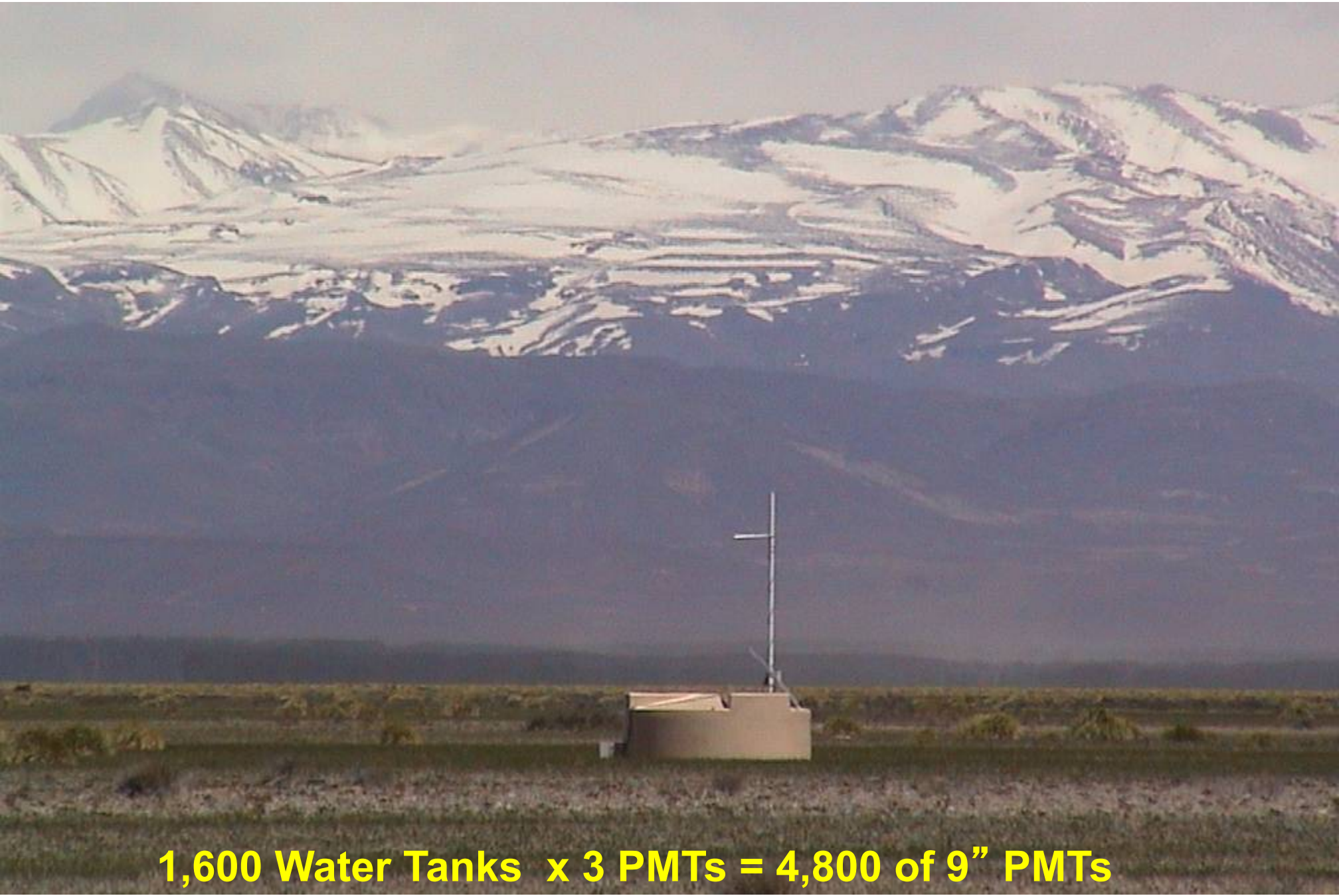
  ⇒ GZK Cut-off

Pierre-Auger Observatory





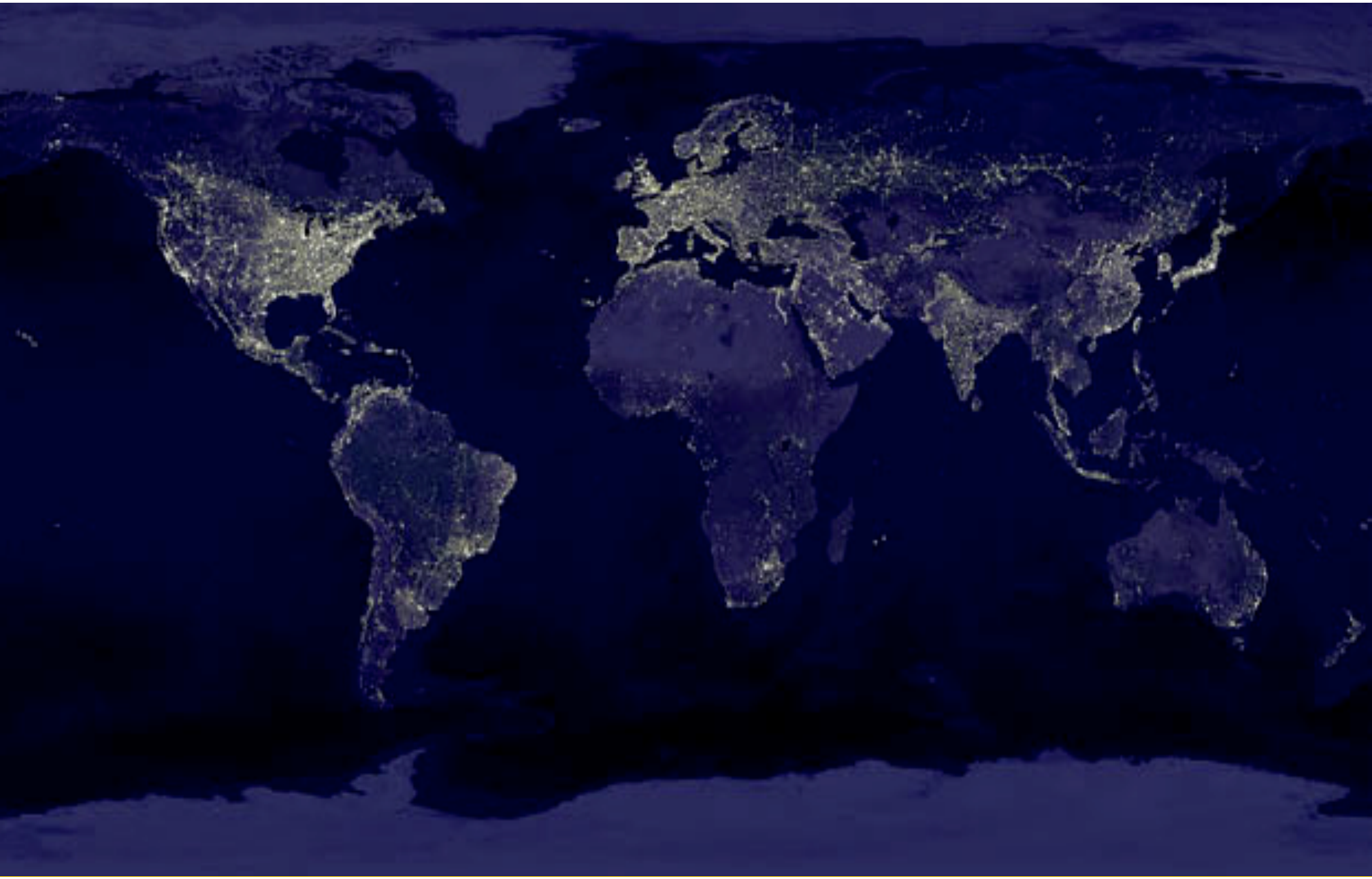
Surface Detector and the Andes



1,600 Water Tanks x 3 PMTs = 4,800 of 9” PMTs

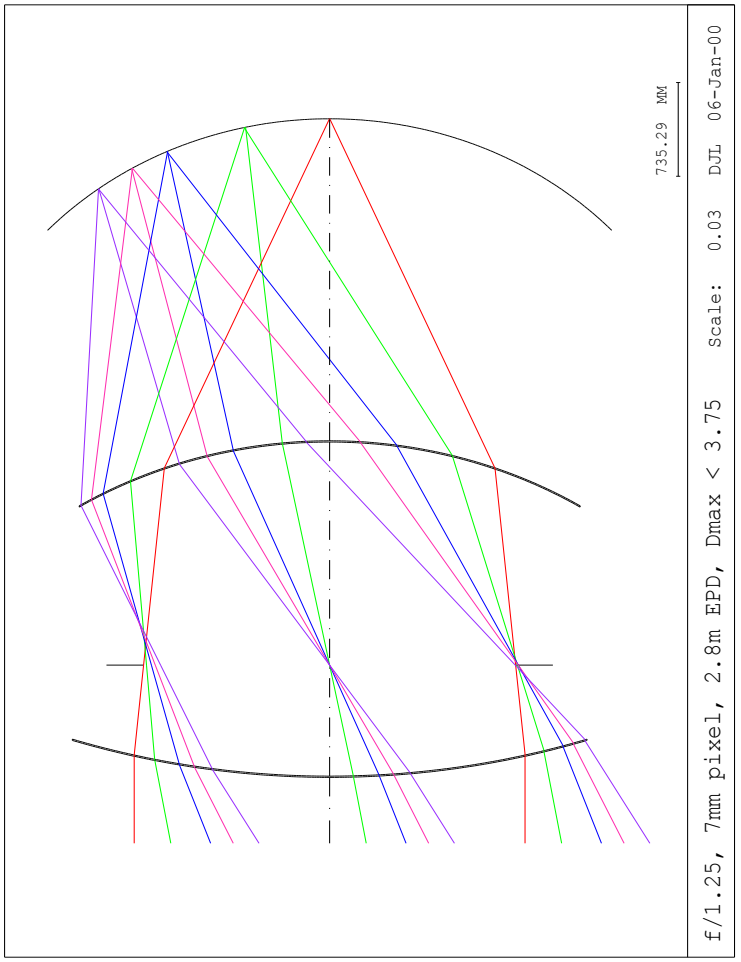
EUSO on International Space Station

Night Sky

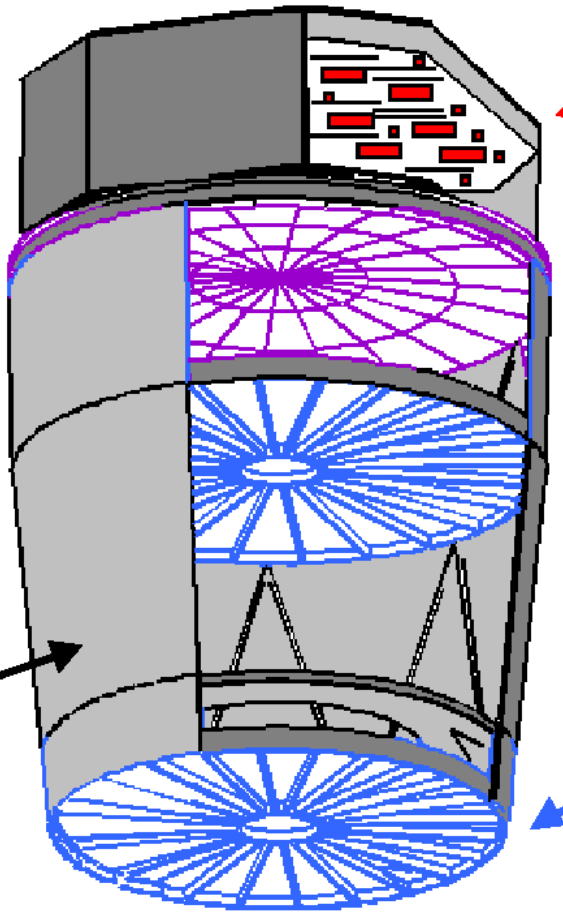


EUSO vs. Pierre-Auger

EUSO Detector



- 2.5m Diameter
- 60° FOV
- f/1.25



Electronic system

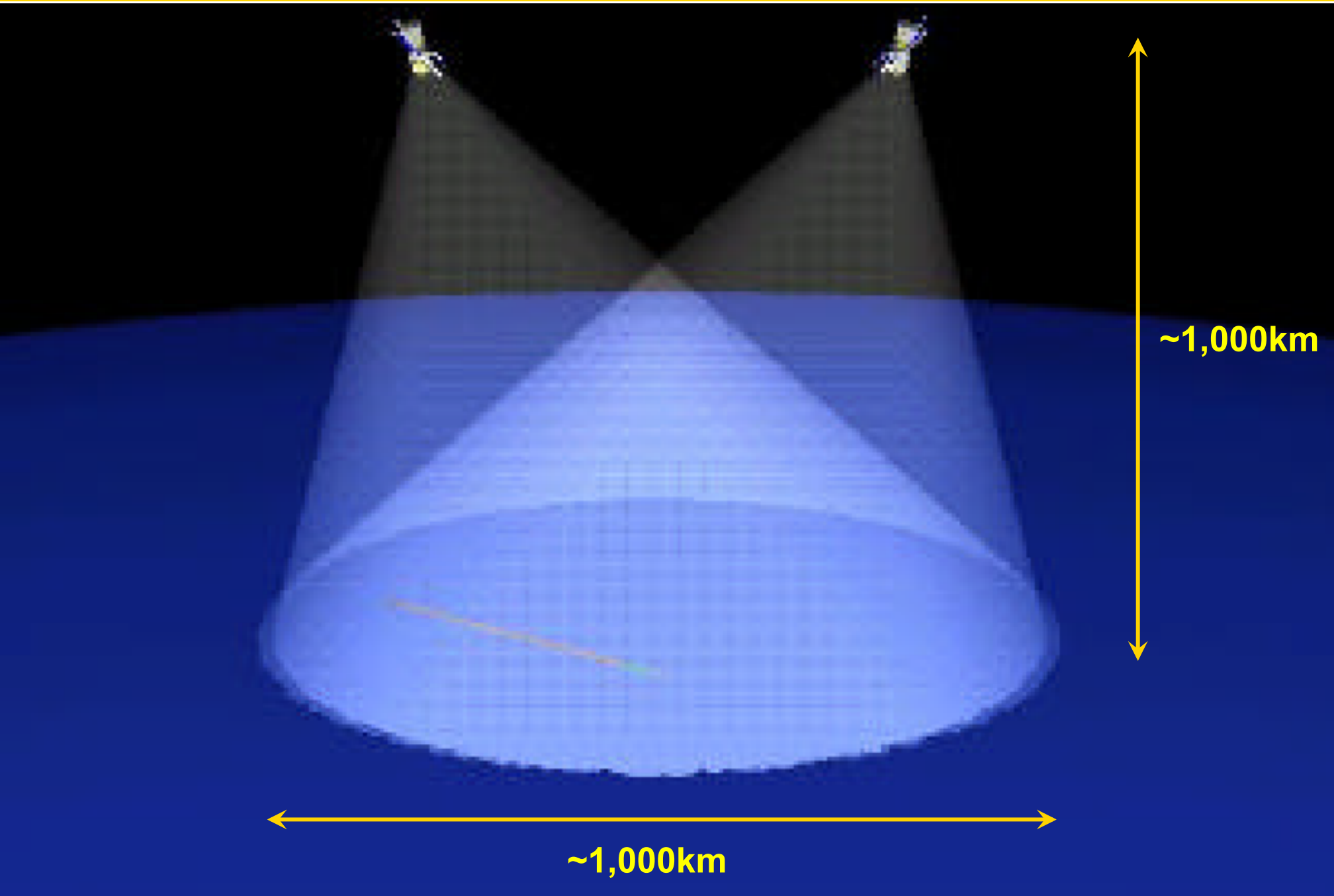
Focal surface detector

Hamamatsu R7600-M16/64 250k Pixel

Optics system

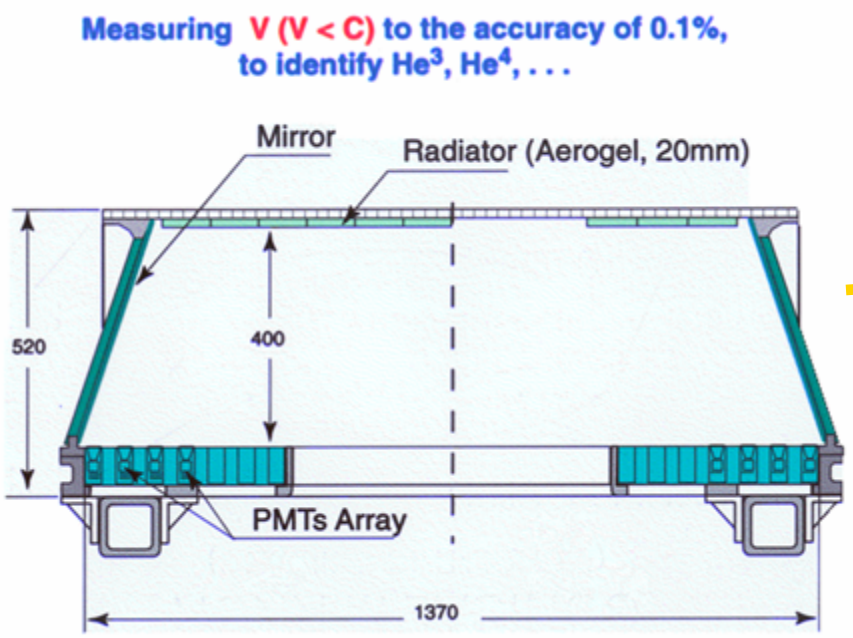
Support structure

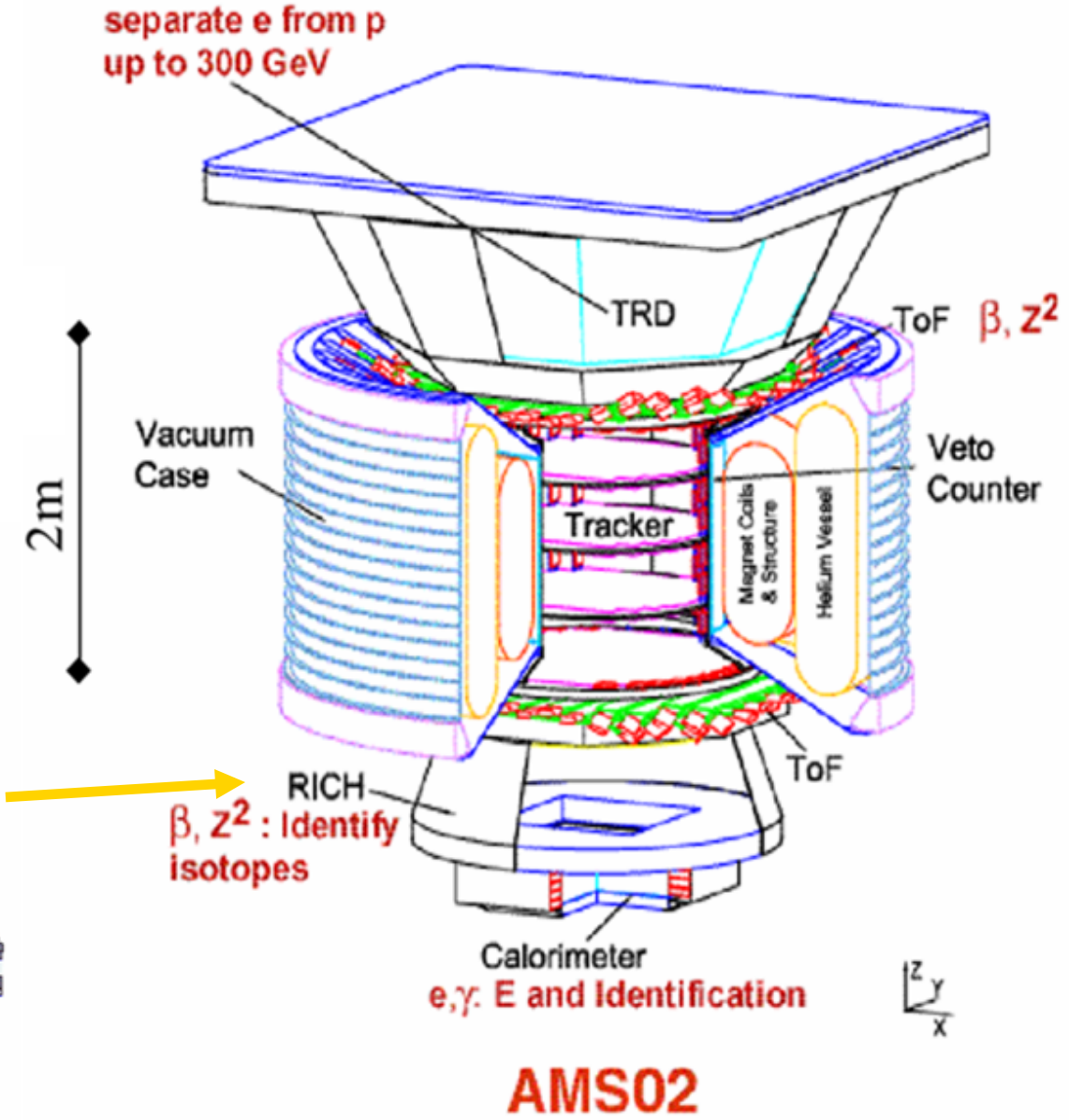
OWL Stereo View from Space



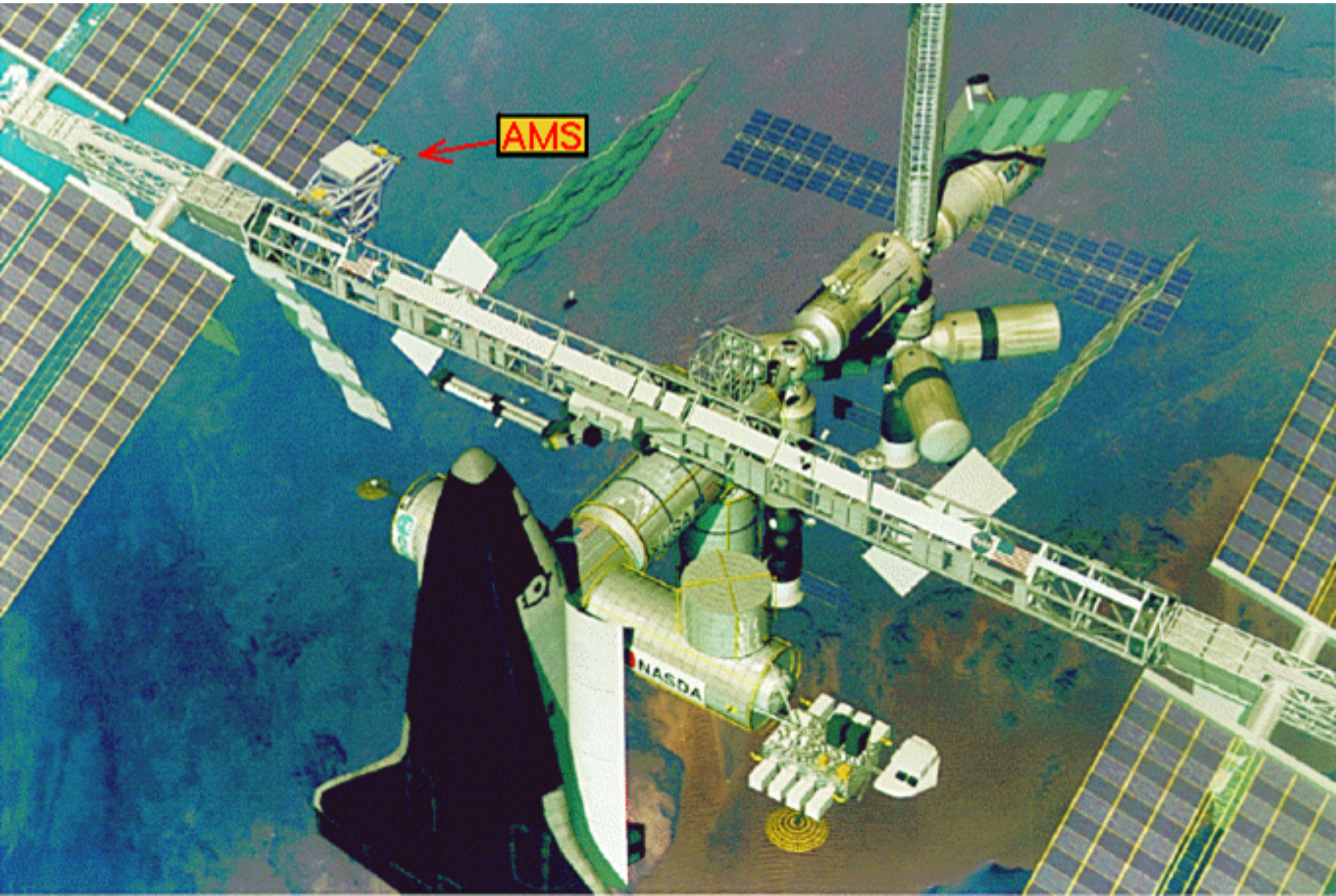
AMS - Anti-Matter Search

- RICH uses Multi-anode PMT
- Hamamatsu R7600-M16
- 14k Pixel





AMS on International Space Station



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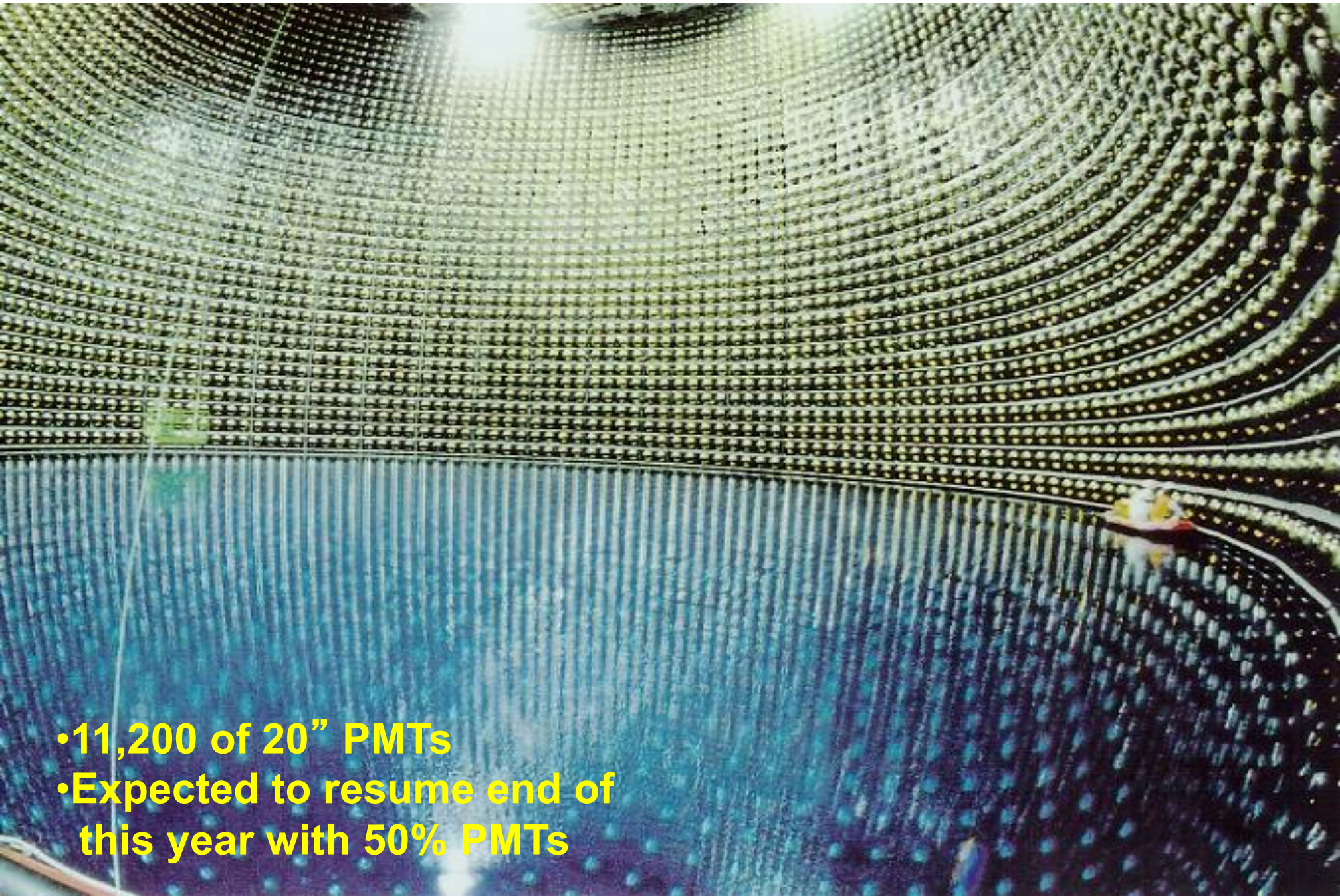
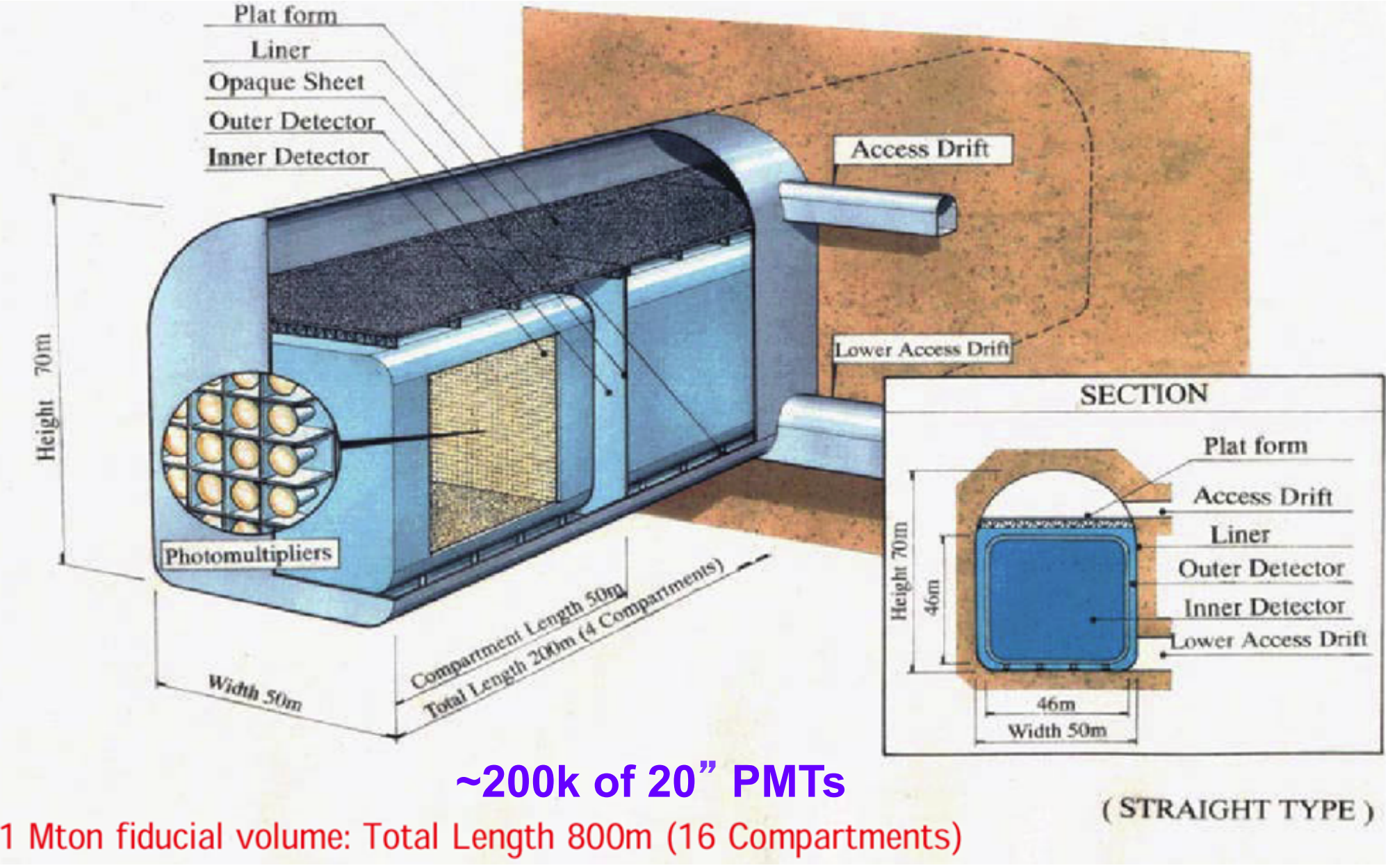
Super-Kamiokande



Future: Hyper-K/UNO



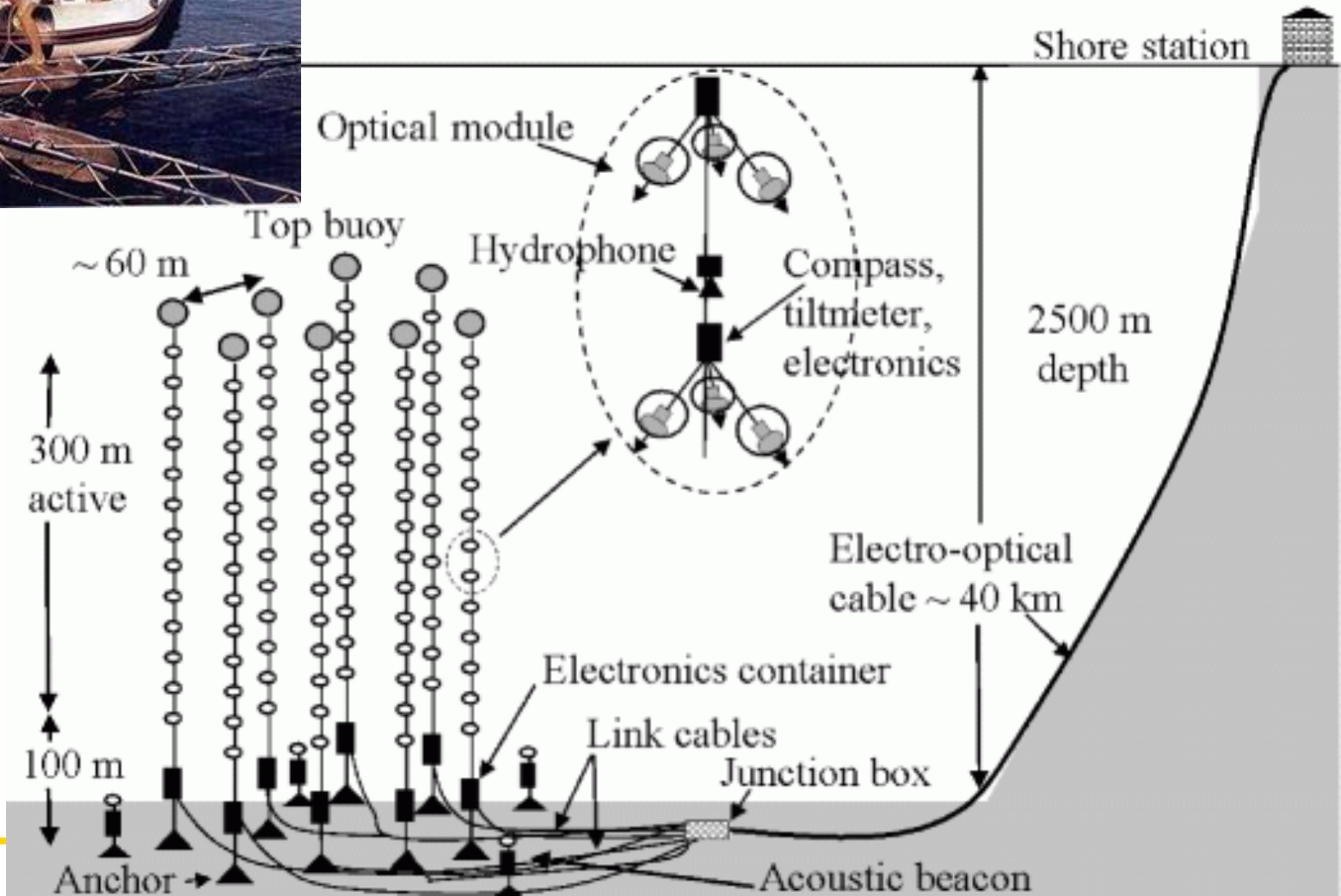
~200k of 20" PMTs

1 Mton fiducial volume: Total Length 800m (16 Compartments)

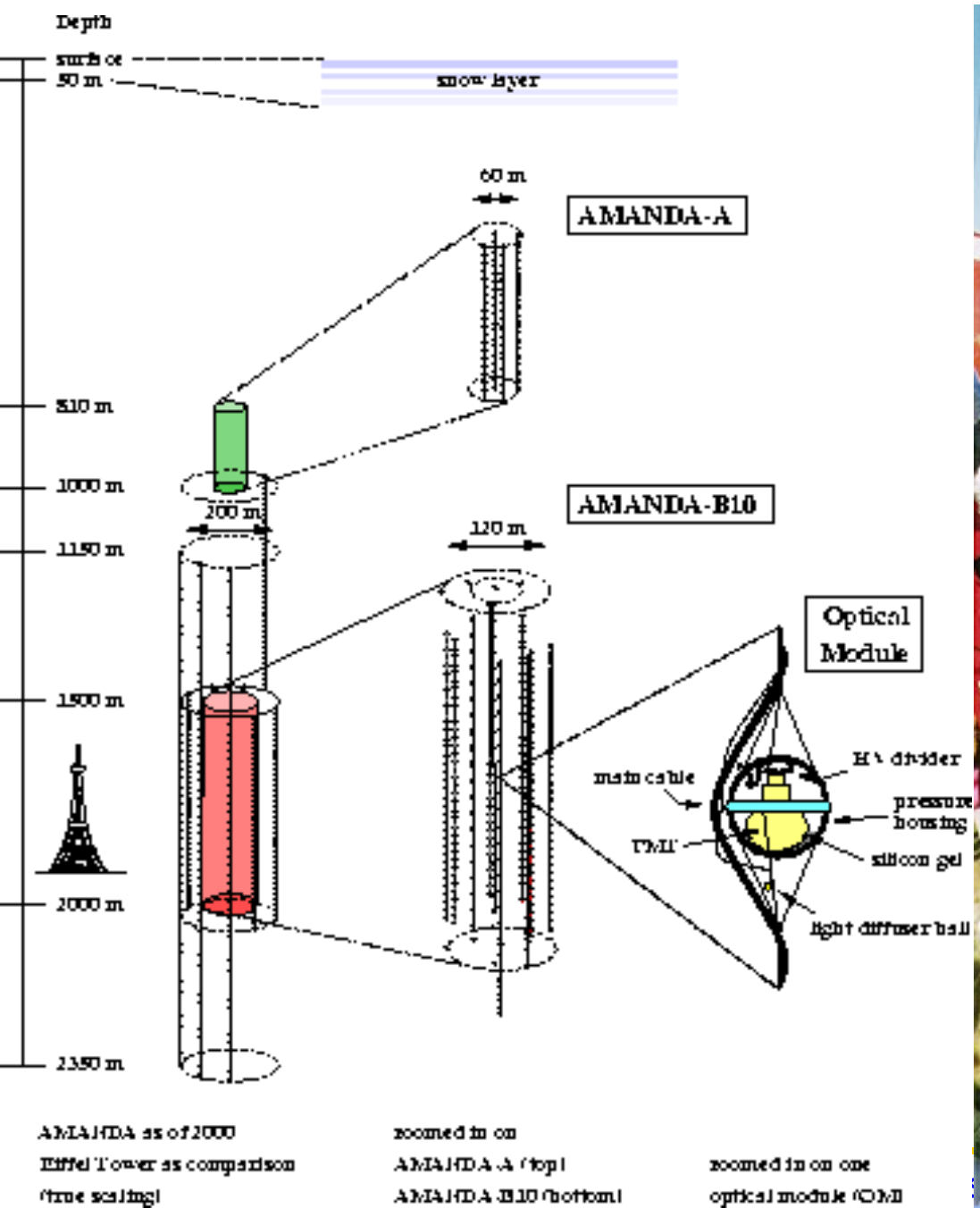
NESTOR and ANTARES

NESTOR

ANTARES

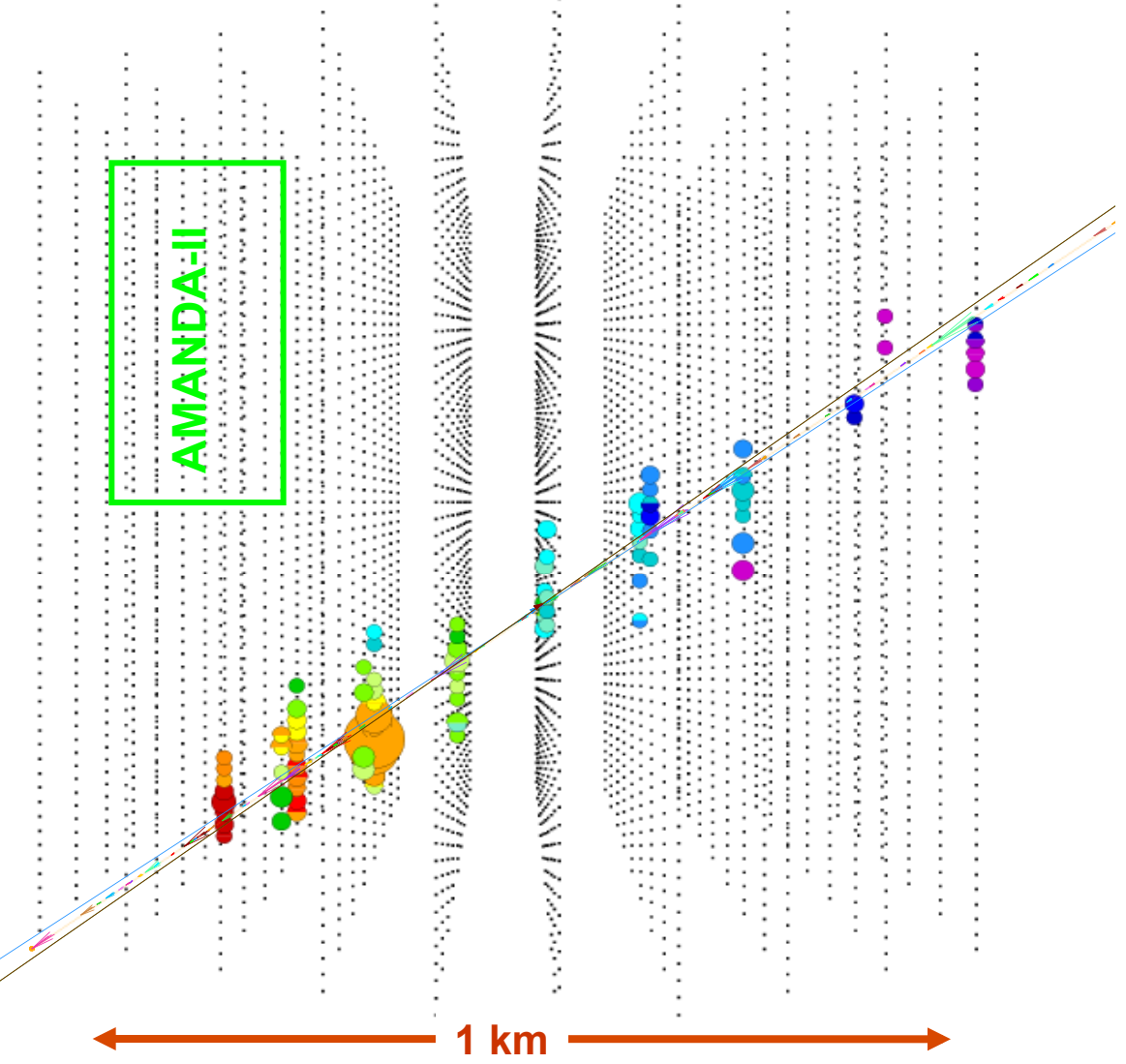


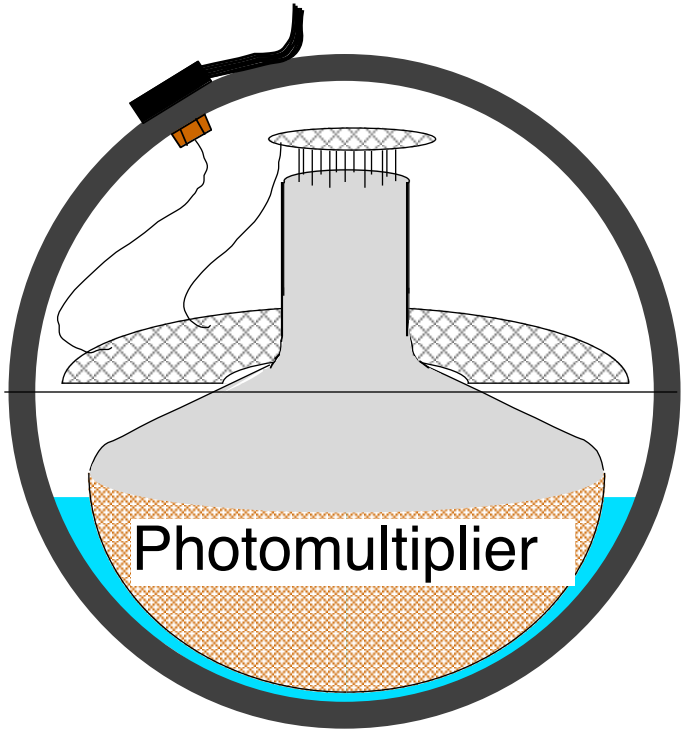
AMANDA


Depth
surface
50 m
snow layer
60 m
AMANDA-A
810 m
1000 m
200 m
AMANDA-B10
120 m
1150 m
Optical Module
1500 m
main cable
HV divider
pressure housing
DMI
silicon gel
light diffuser ball
2000 m
2350 m
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

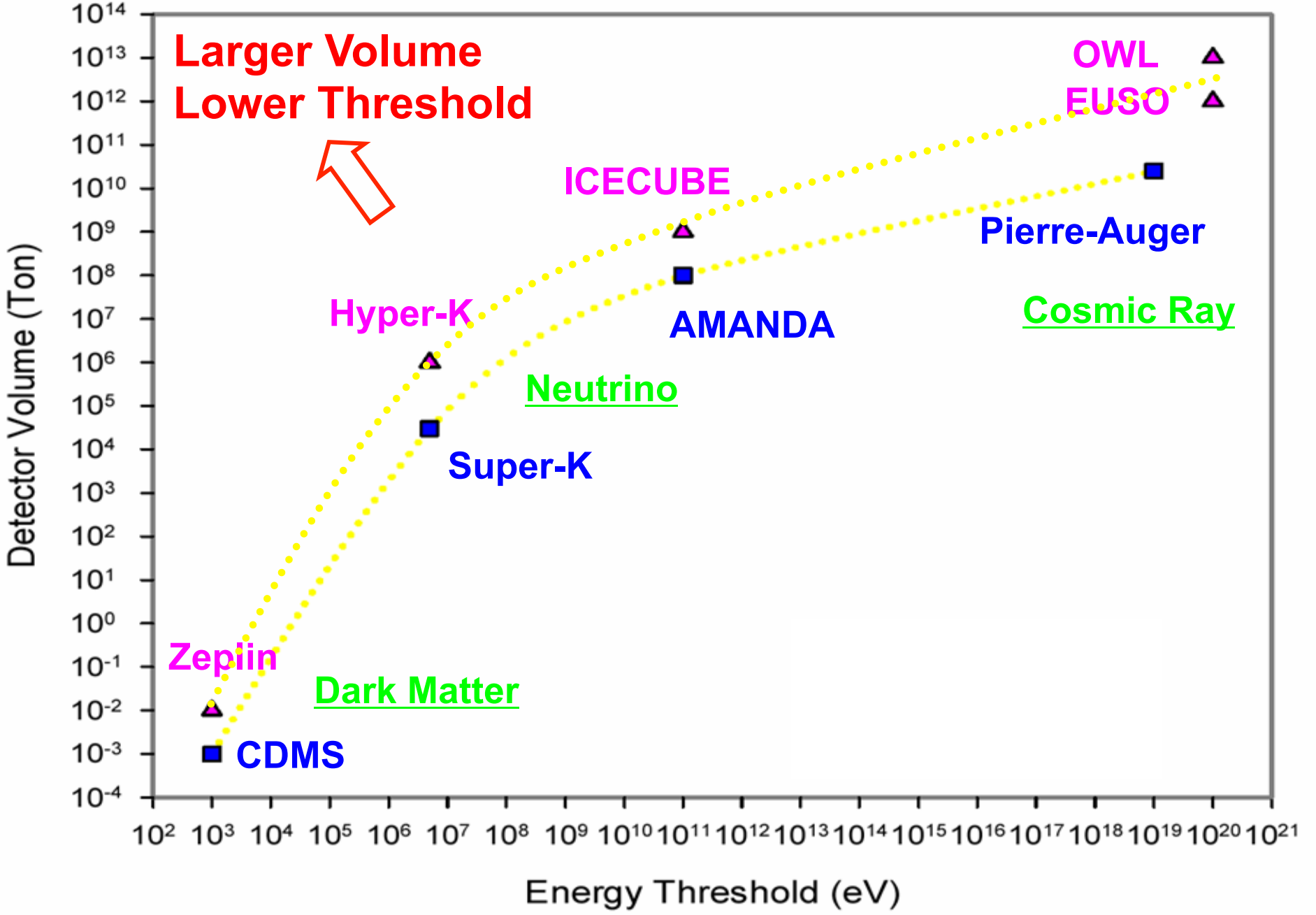
10 TeV Muon Event





60 PMTs/string x 80 strings
= 4,800PMTs

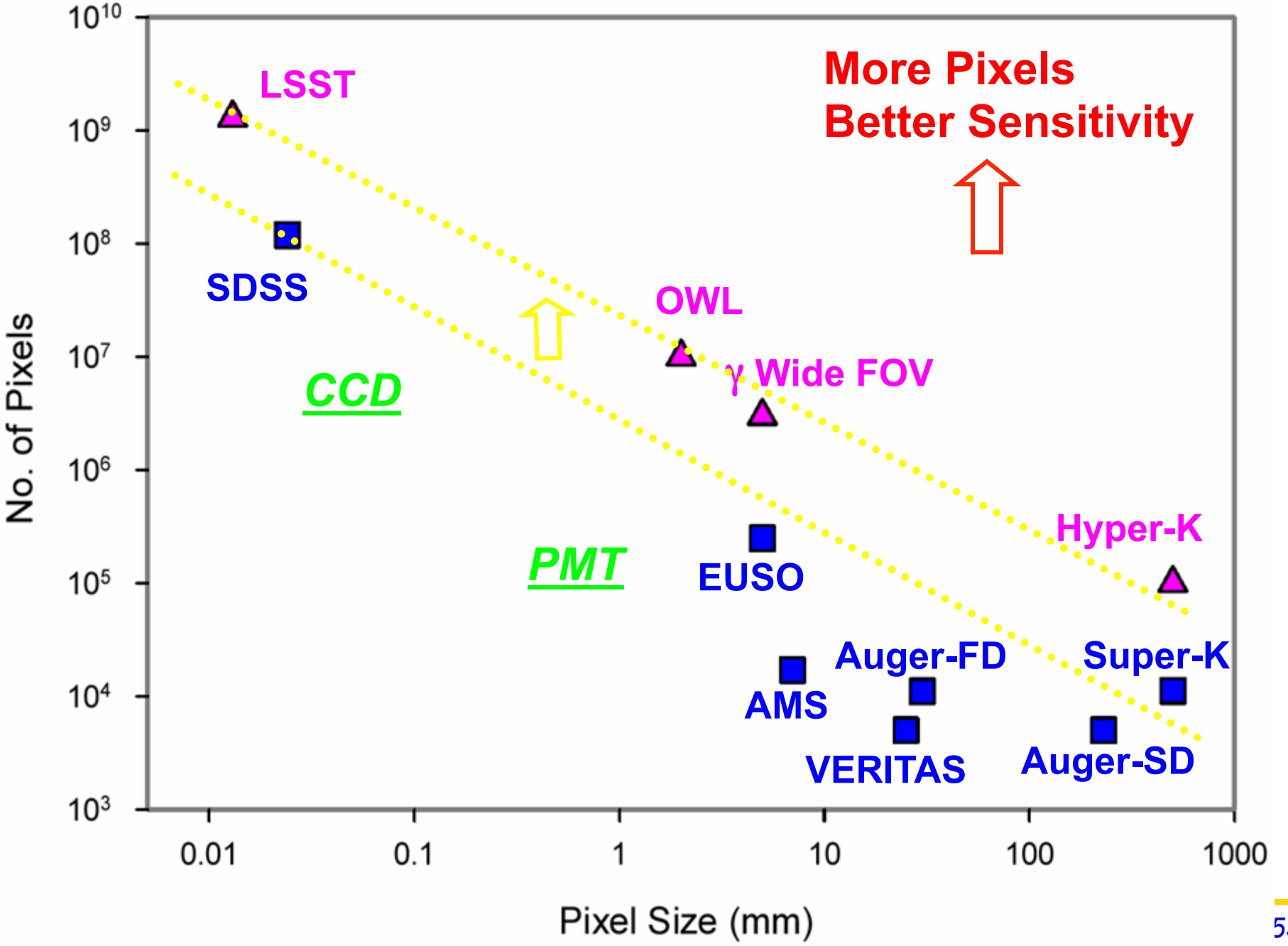
Detection of Cosmic Radiation



Talk Outline

- Astro-Physics
  - Cosmology
  - High-energy Particle Astro-physics
- Experiments
  - Ongoing
  - Future
- **Photo-detectors**
  - **Demands**
  - **New Detectors on Horizon**
  - **Dream Detectors**

Photon Detector



Demands on Photon Detectors

- **Giga-Pixel CCD**
  - Sky Survey
- **Mega-Pixel (1-5mm), Photon Counting**
  - EUSO/OWL, Wide-FOV γ-ray Telescope
- **Large Area (>50cm), Photon Counting**
  - Neutrino, Proton decay
- **Time-resolving Imaging**
  - Transient Phenomena
- **Low Costs!**

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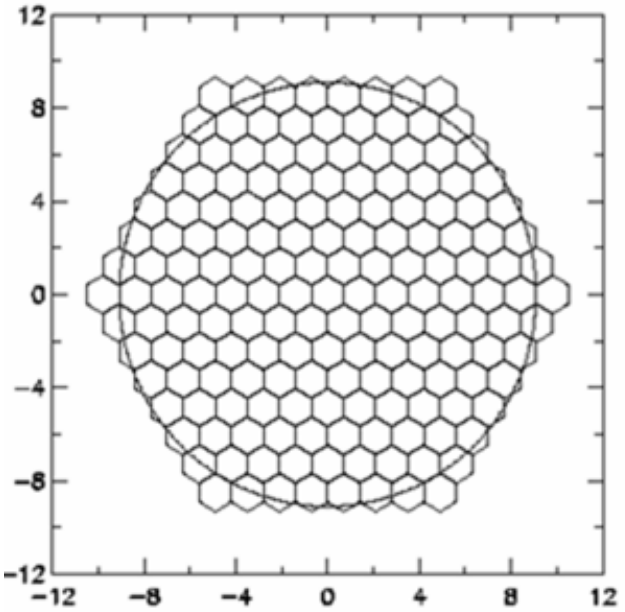
New Detectors on Horizon

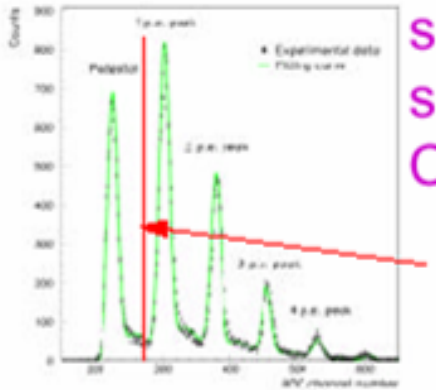
- **Vacuum**
  - Multi-Pixel HPD — DEP
  - Flat Panel PMT — Hamamatsu, Burle
  - Silicon MCP — Nano-science
  - New Photo Cathode
- **Solid State**
  - Silicon PMT — Russia
  - STJ — ESTEC
  - TES — Stanford

DEP Hybrid Photodiode (HPD)

- Baseline design for LHC-b RICH
- 8cm diameter
- 61 Pixel, (5mm view)

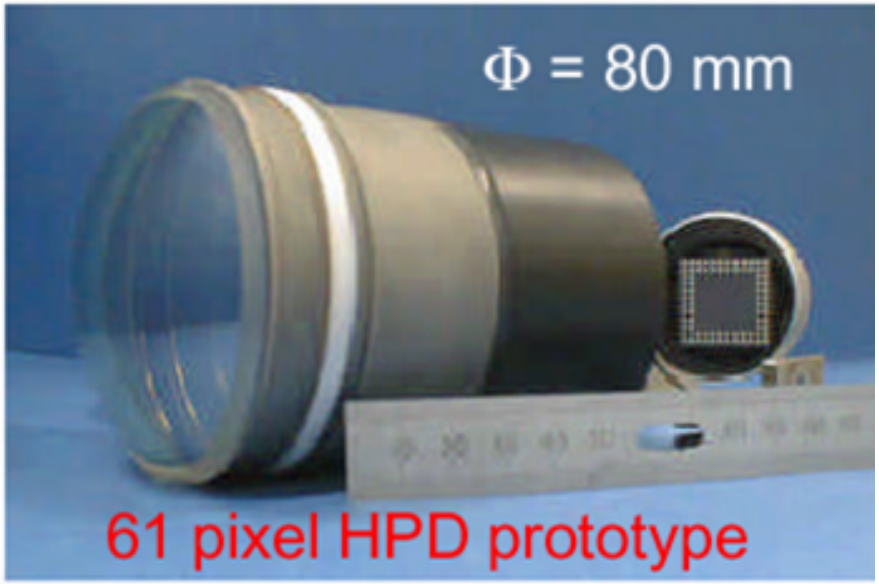


baseline: Hybrid Photo Diodes (HPD)



single pixel:
spectrum of
Cherenkov light

binary readout



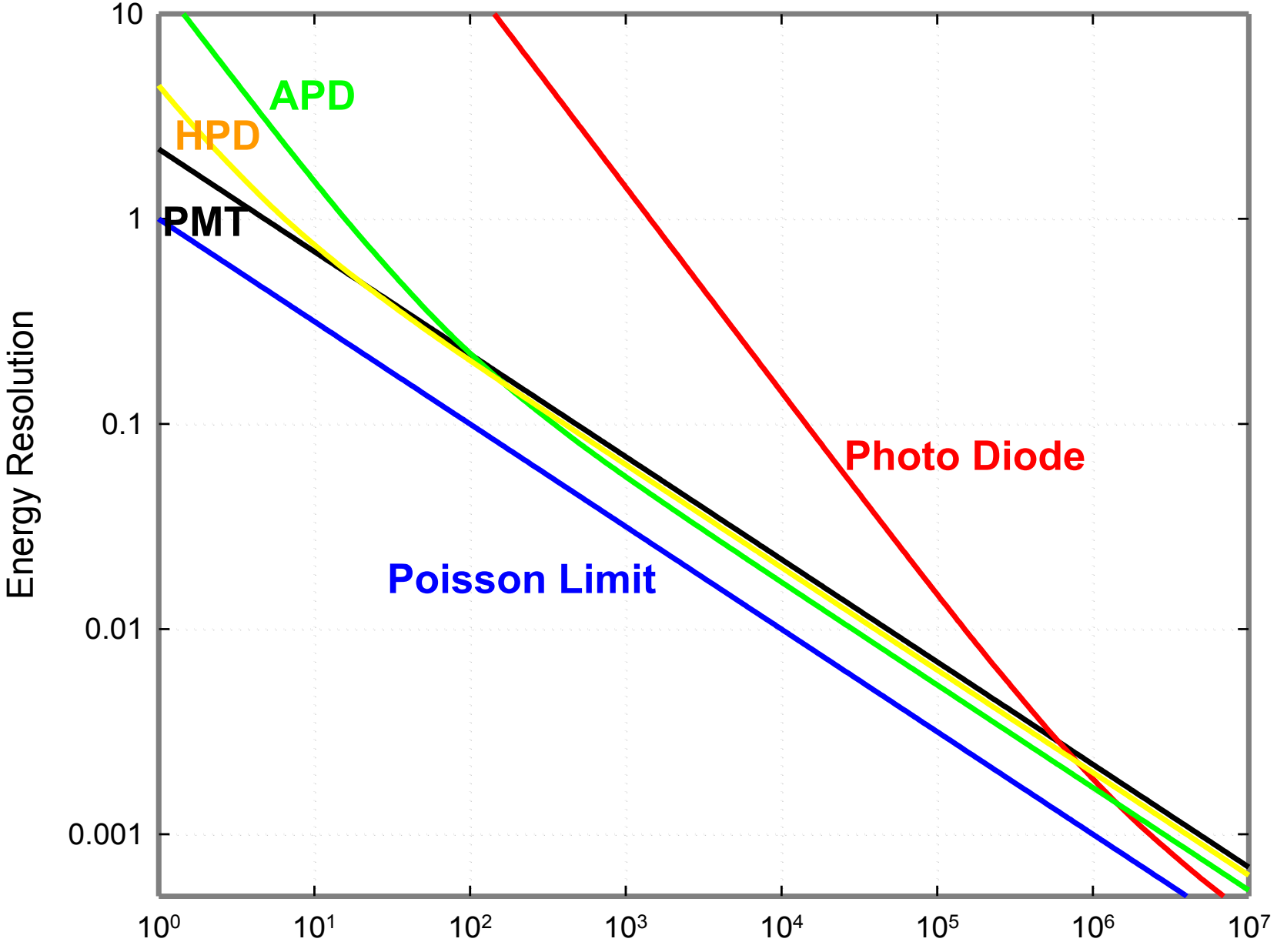
Energy Resolution

$$\frac{\sigma}{E} = \frac{\sqrt{ENF \cdot QE \cdot C_{ol}(N_\gamma + N_{BG}) + (ENC/G)^2}}{QE \cdot C_{ol} \cdot N_\gamma}$$

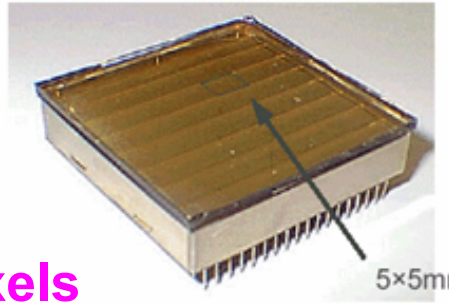
$$\approx \sqrt{\frac{ENF}{QE \cdot C_{ol} \cdot N_\gamma}}$$

- QE as high as possible. (> 30%)
- C_{ol} as close as 100% (> 0.9)
- ENF as close as 1.0 (< 1.2)
- G >> ENC (~1000e^-) (>> 10^4)
- N_{BG} << N_γ (<< 1)

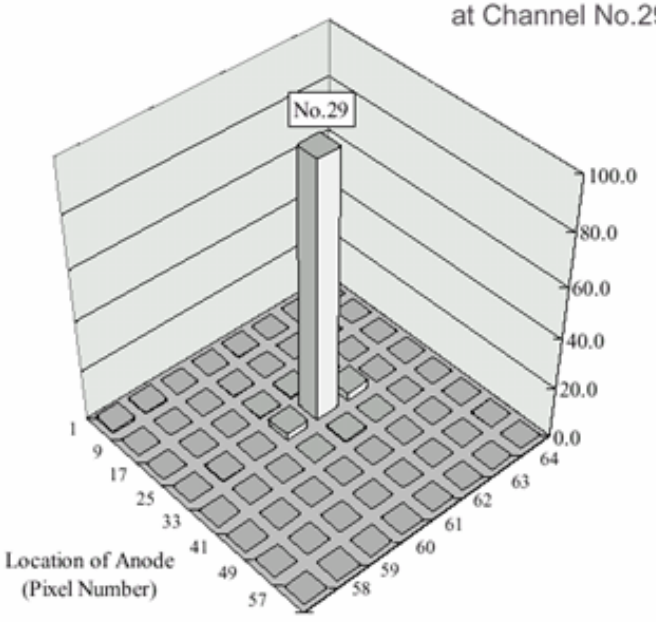
Energy Resolution



Hamamatsu Flat Panel PMT



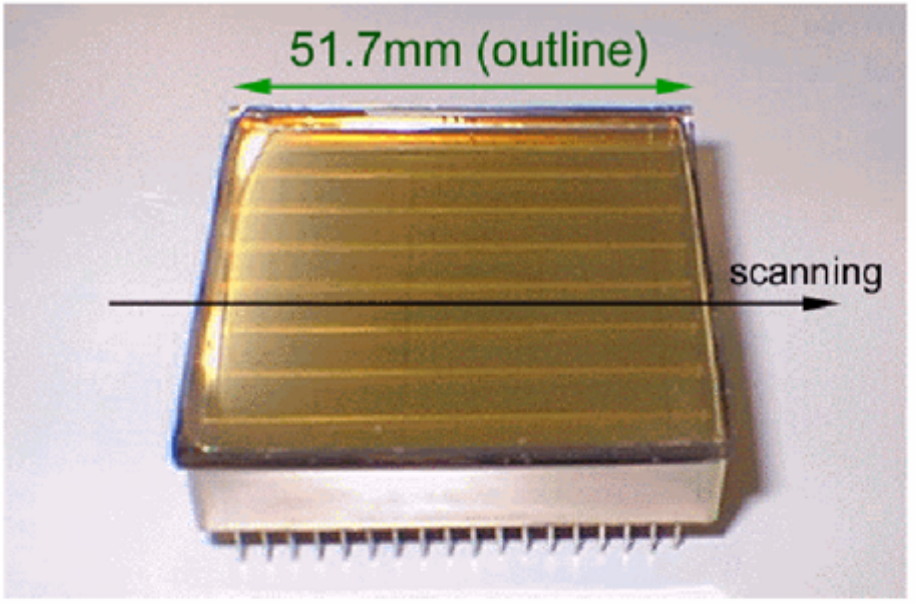
64 Pixels

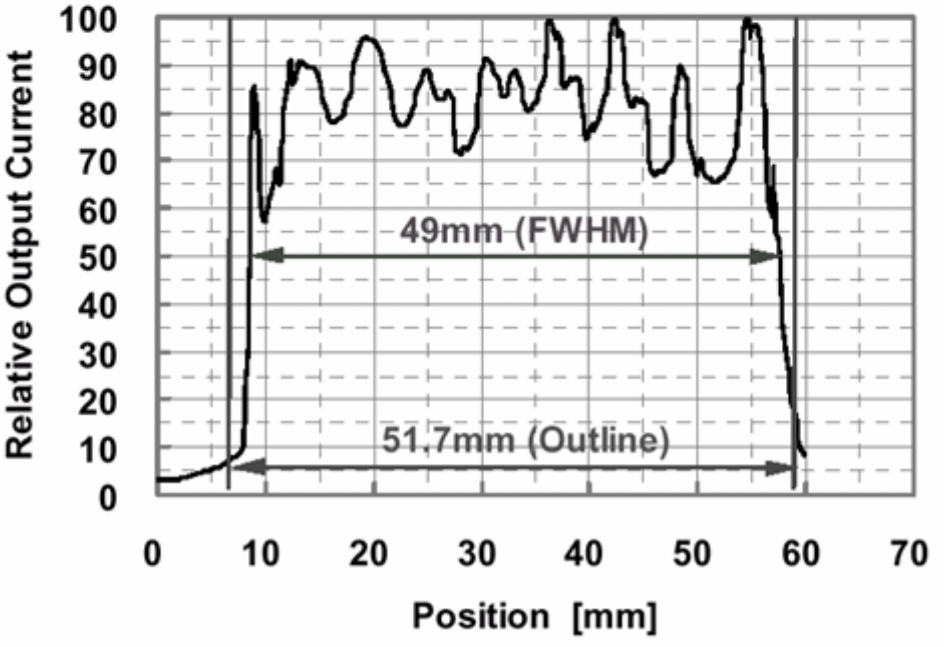


Light Source : W Lamp
Wavelength : 400nm
(5x5 mm Mask is used.)
Applied Voltage : 1000V

No.20 0.0	No.21 0.5	No.22 0.0
No.28 2.5	**No.29 100**	No.30 3.4
No.36 0.0	No.37 0.7	No.38 0.1

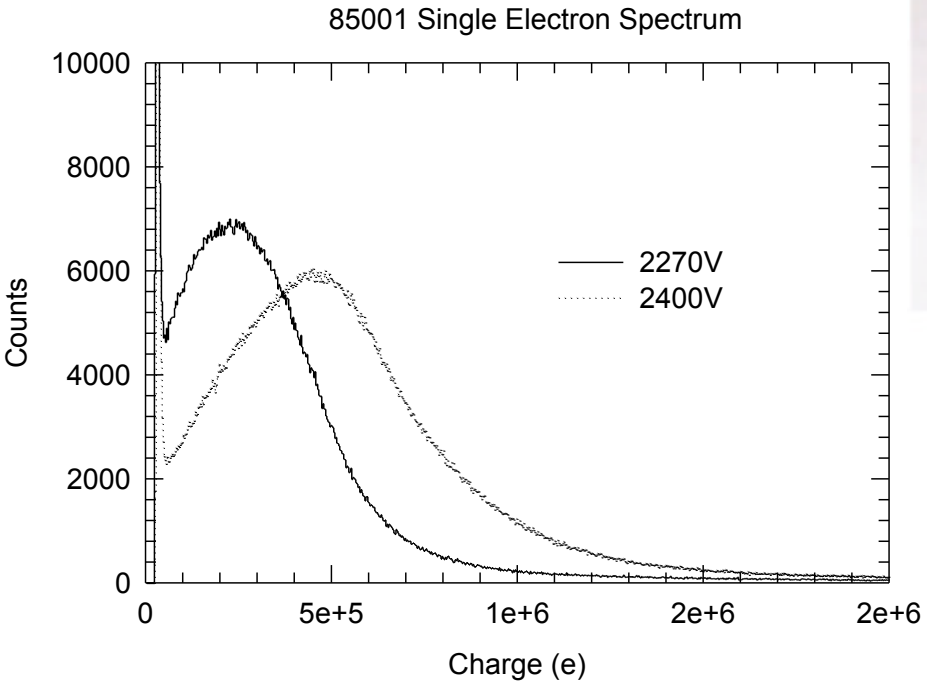
(unit:%)





Burle Flat PMT

- 2 inch Square
- Ceramic Case
- Dual MCP-PMT
- 4 anodes, uniformity < 2:1
- Maximum Gain ~ 1 x 10^6

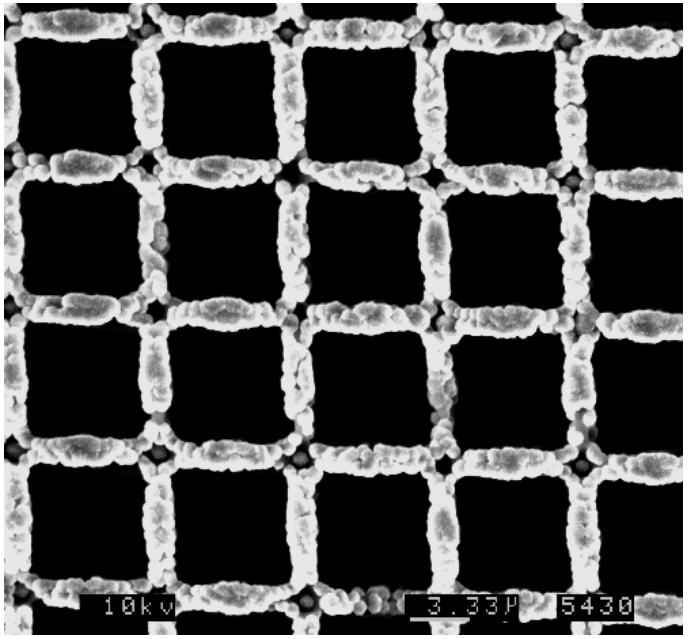


The BURLE 85001 Low Profile PMT is significantly shorter than a conventional glass envelope PMT

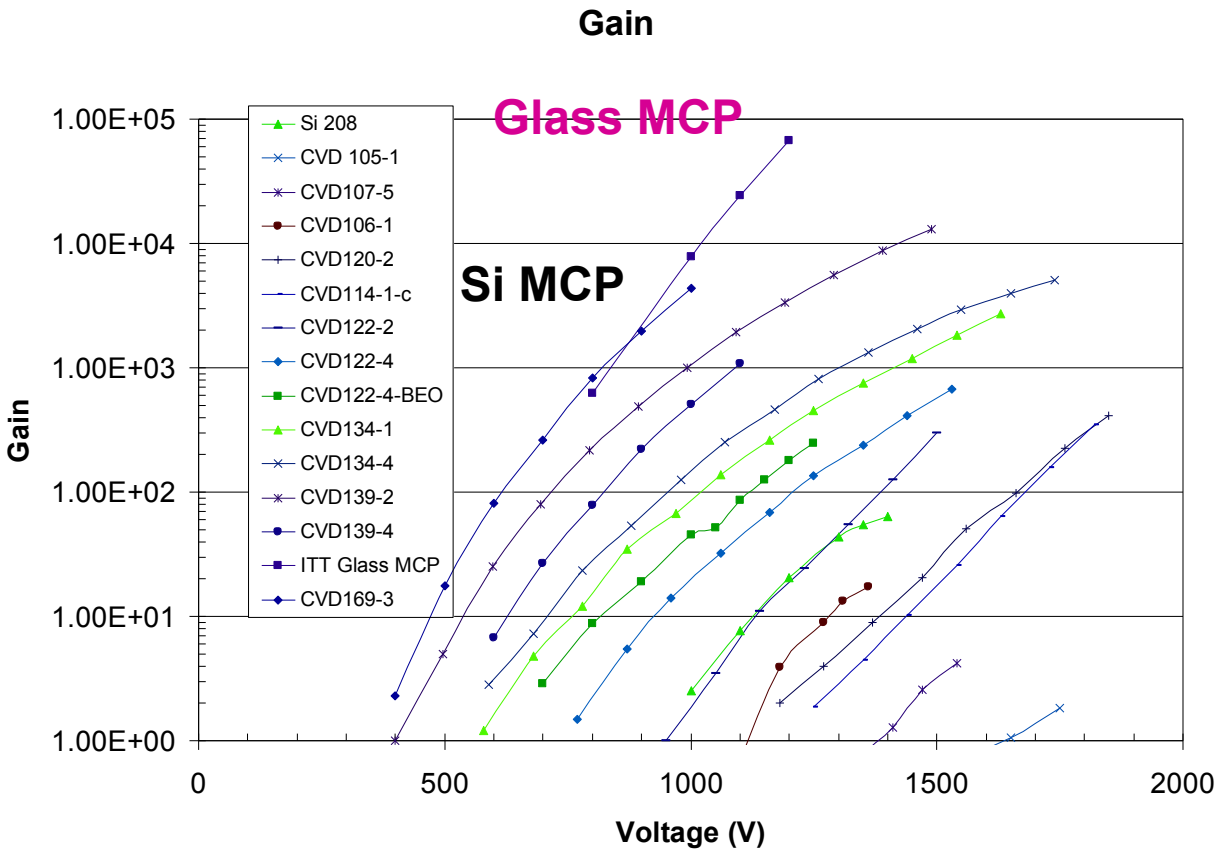
by Paul Hink

Silicon MCP

- ~7μm pores
- >75% open area
- Diamond coated

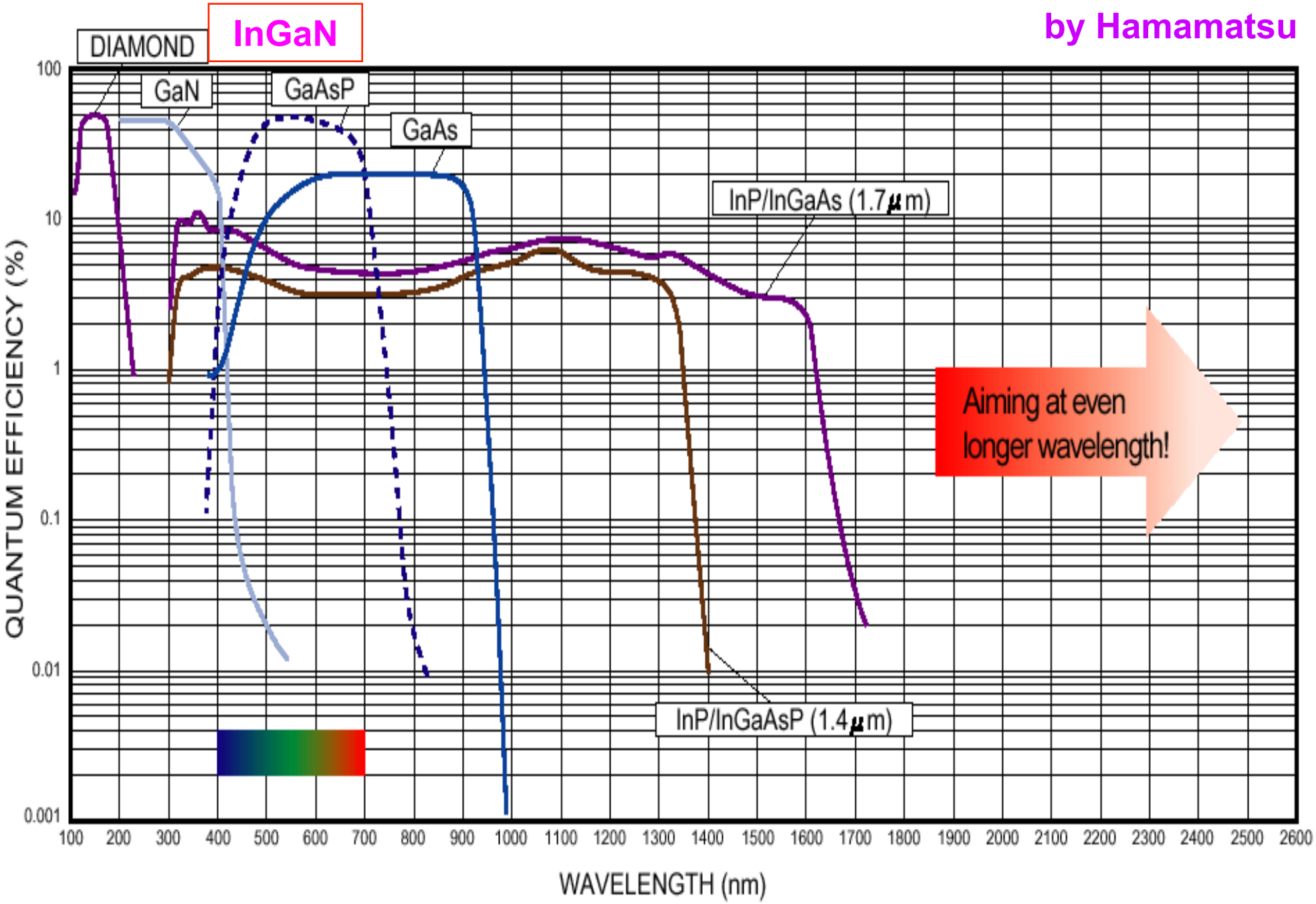


Gain > 1,000



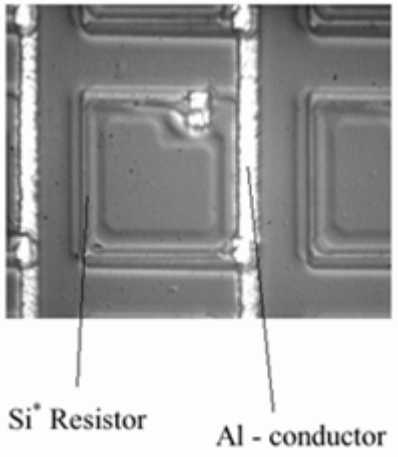
By O. Siegmund, U.C. Berkeley

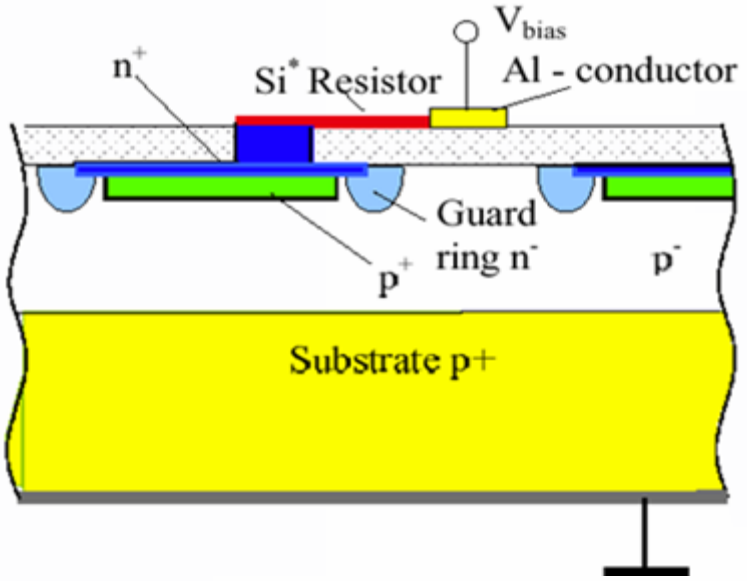
Semiconductor Photo-cathode

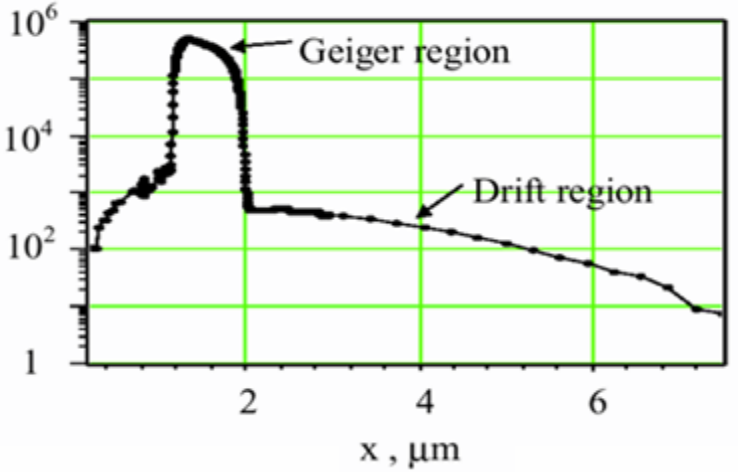


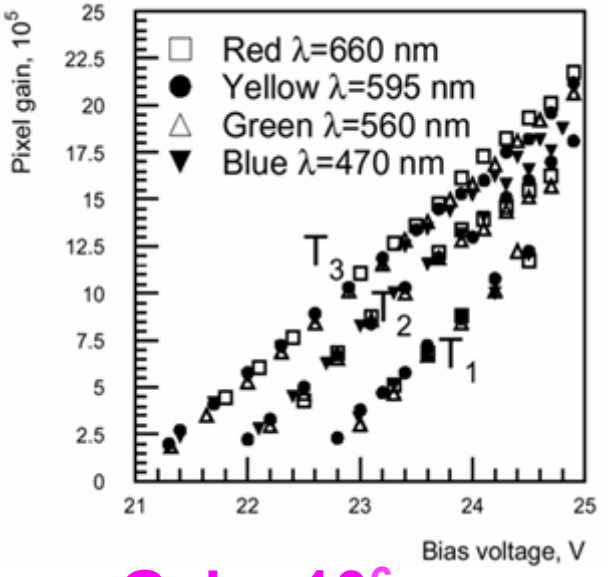
Silicon Photomultiplier

by P. Buzhan, B. Dolgoshein et. al.

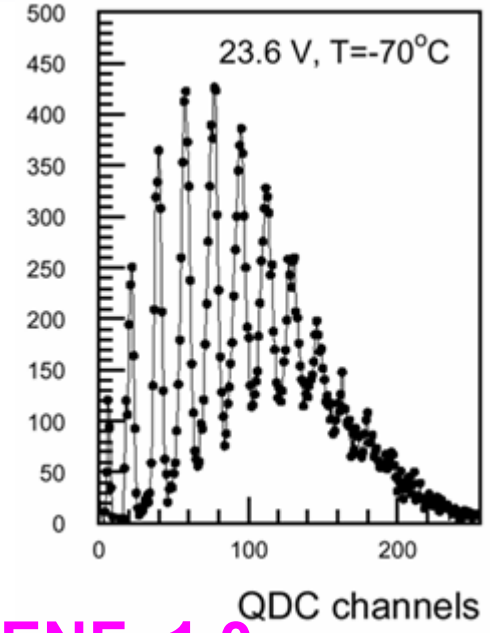




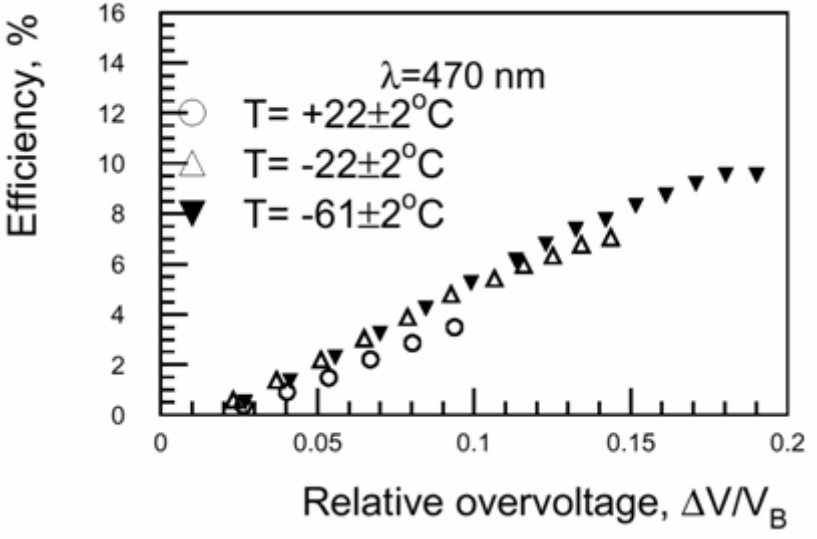




Gain~10^6



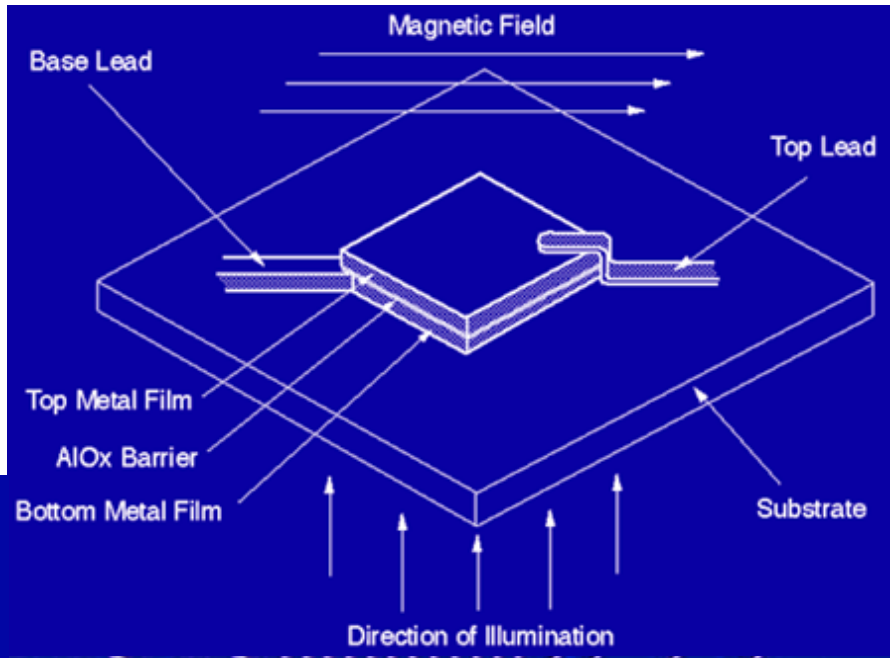
ENF=1.0

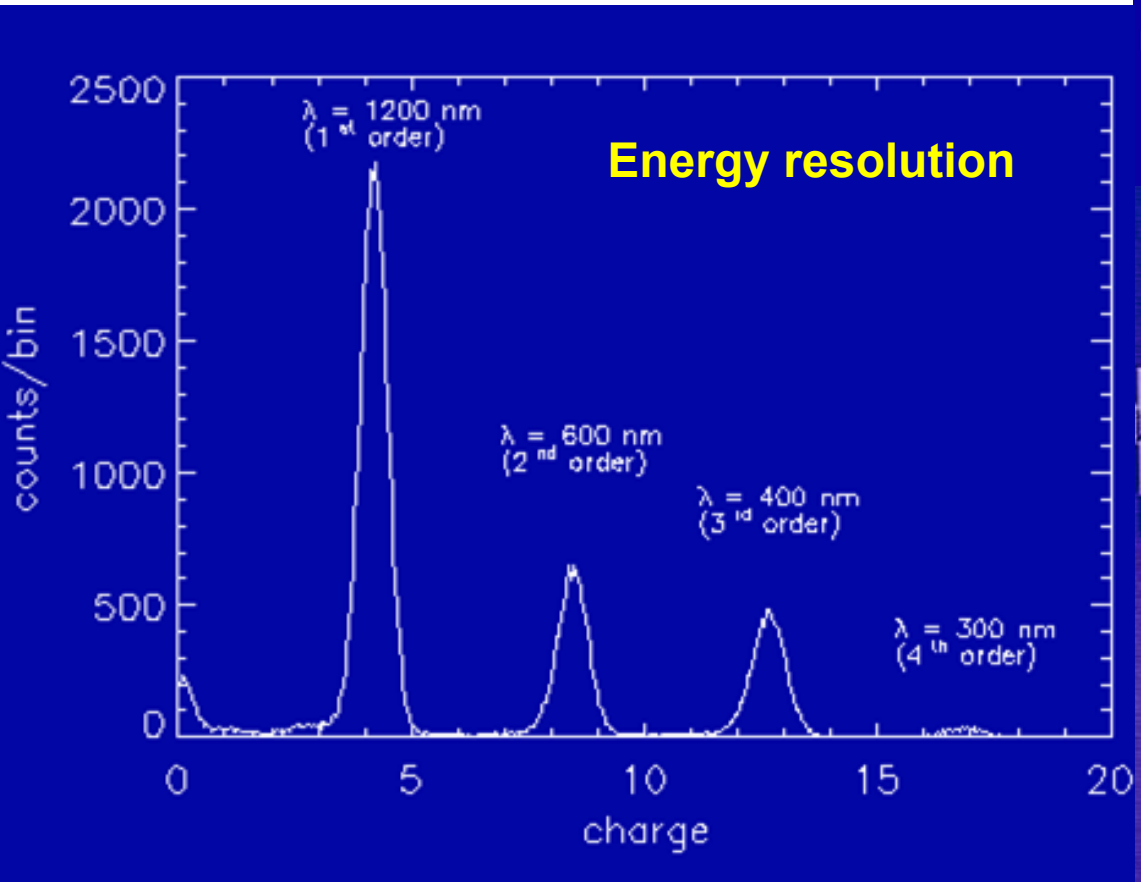


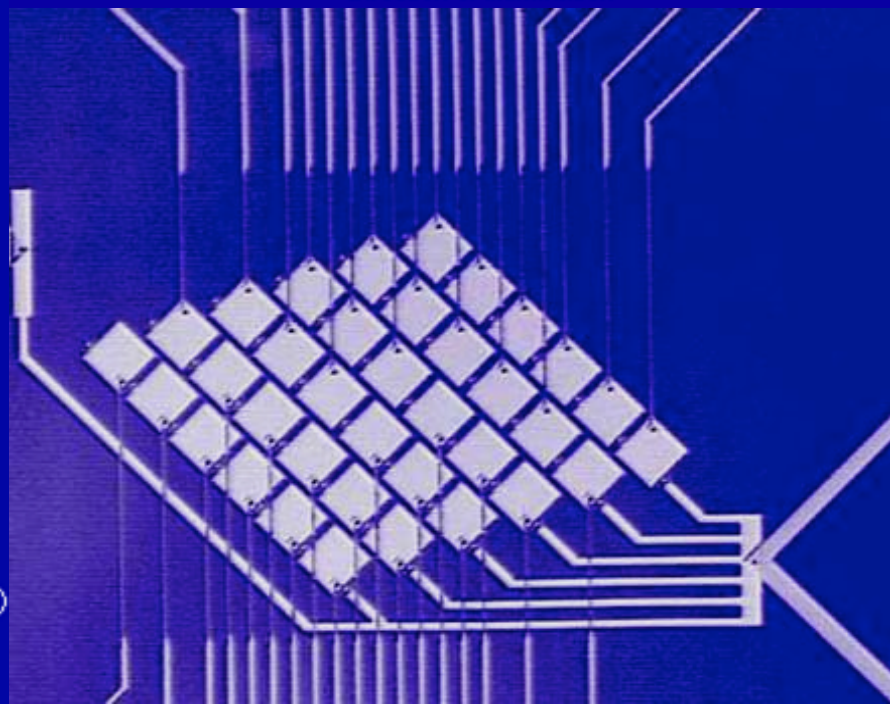
DQE~10%

Superconducting Tunneling Junctions (STJ)

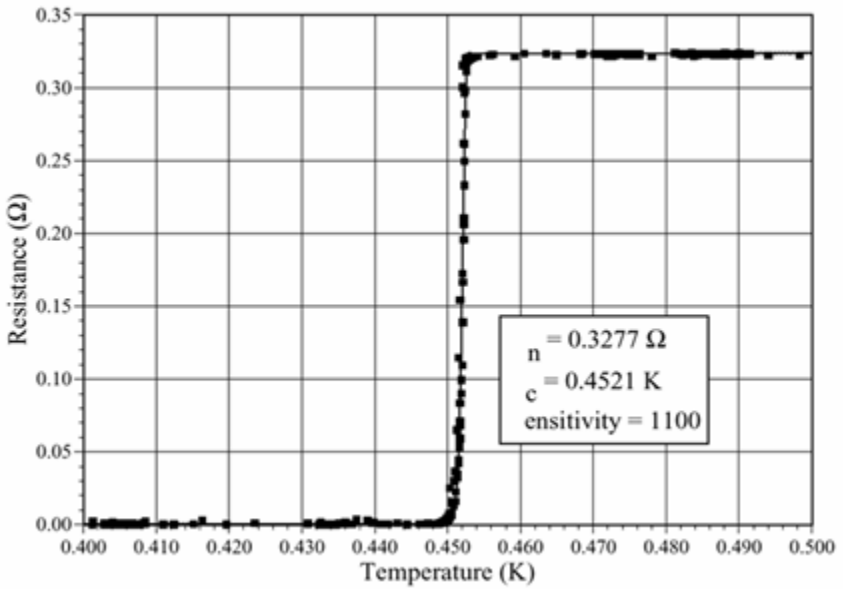
- Developed by ESTEC, ESA
- Detect Photon by Photon:
  - Energy < 0.1 eV
  - Time < 1 nsec
  - Position < 10 μm



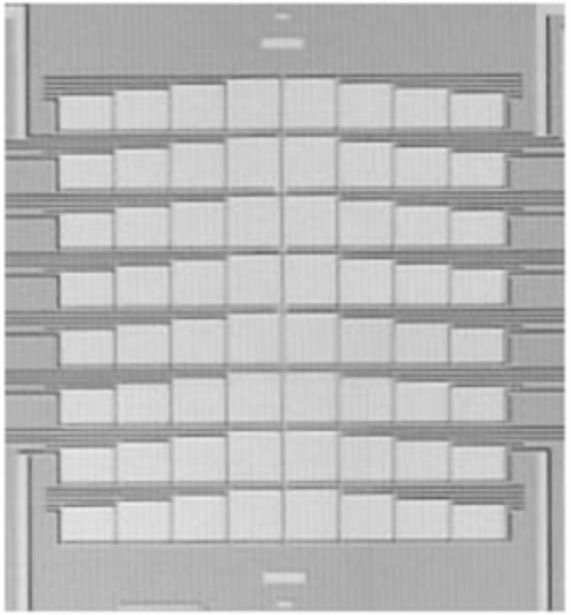




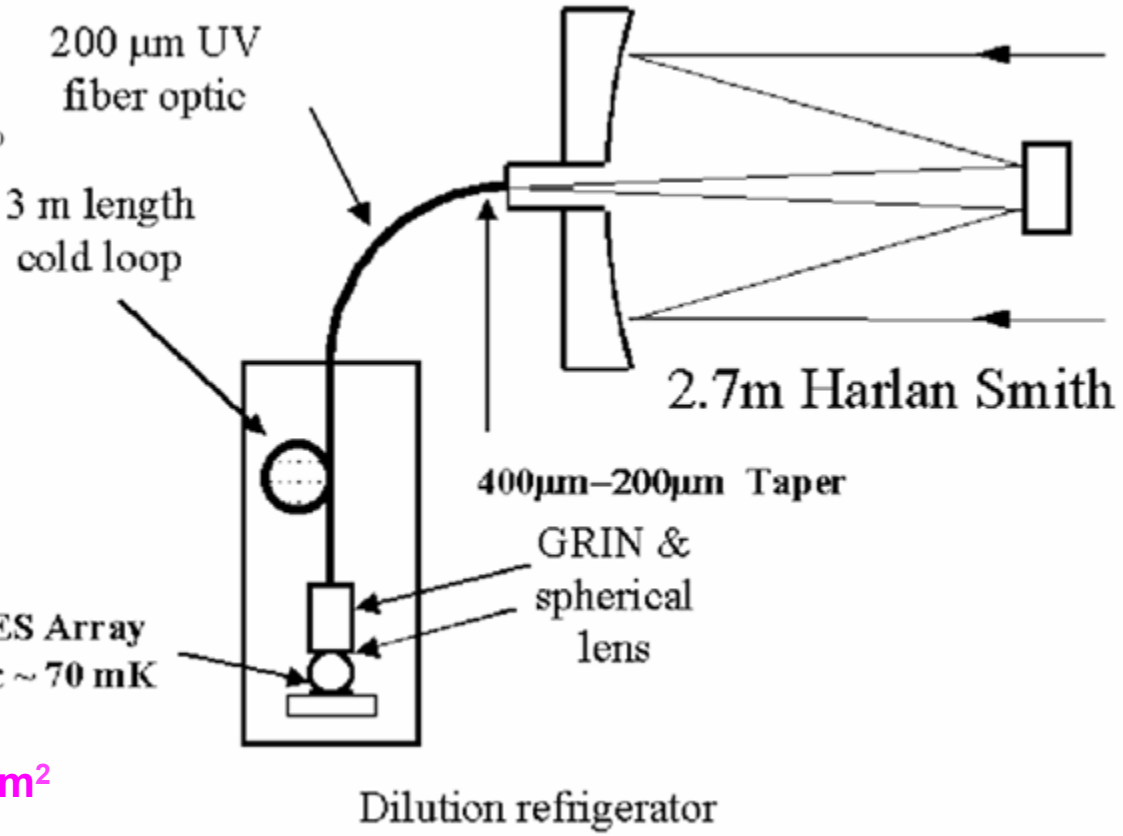
Transition Edge Sensor (TES)



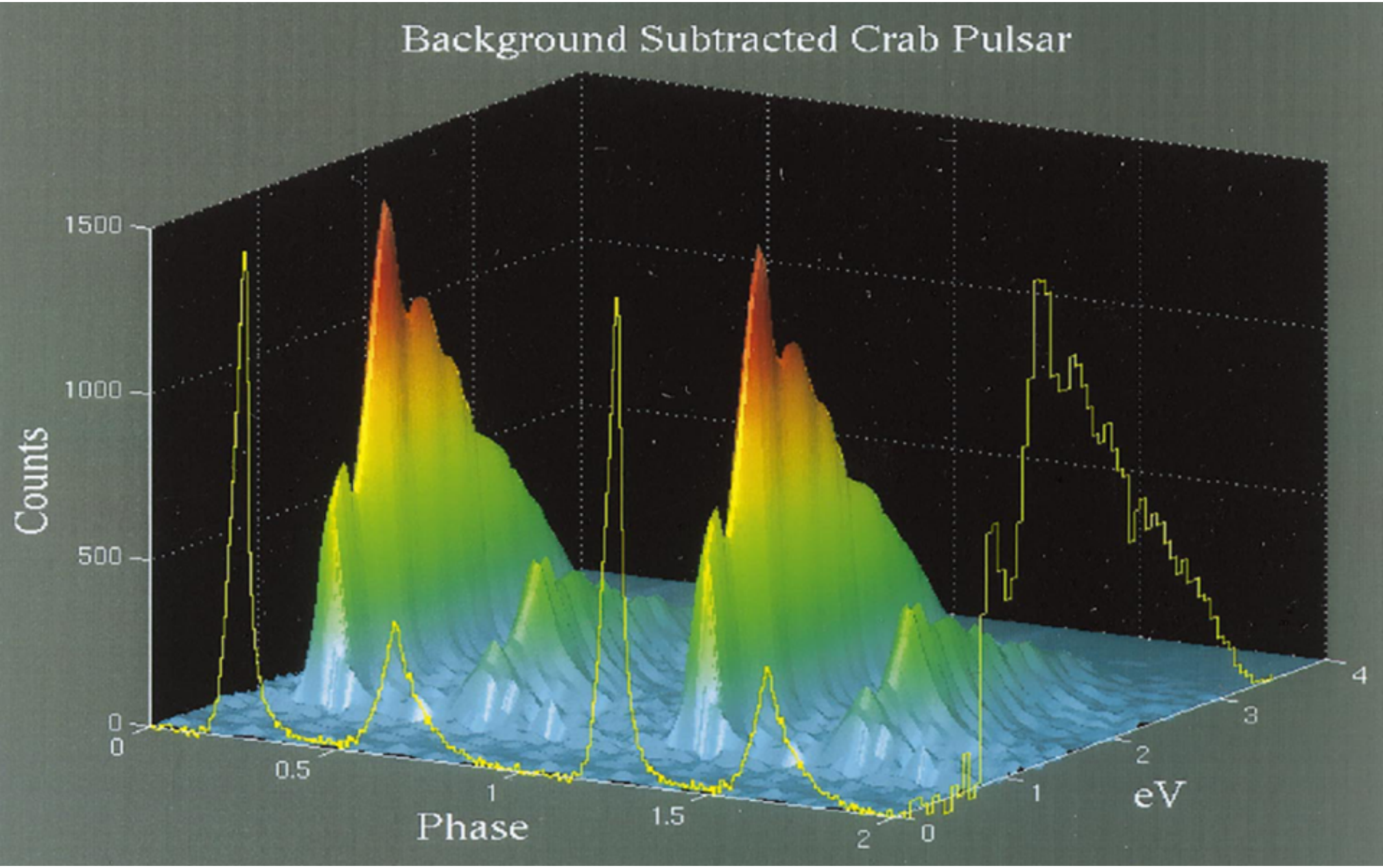
The Astrophysical Journal, 563: 221È228, 2001 December 10
R. Romani ,et al.



20 x 20 μm²



Crab Pulsar observed by TES



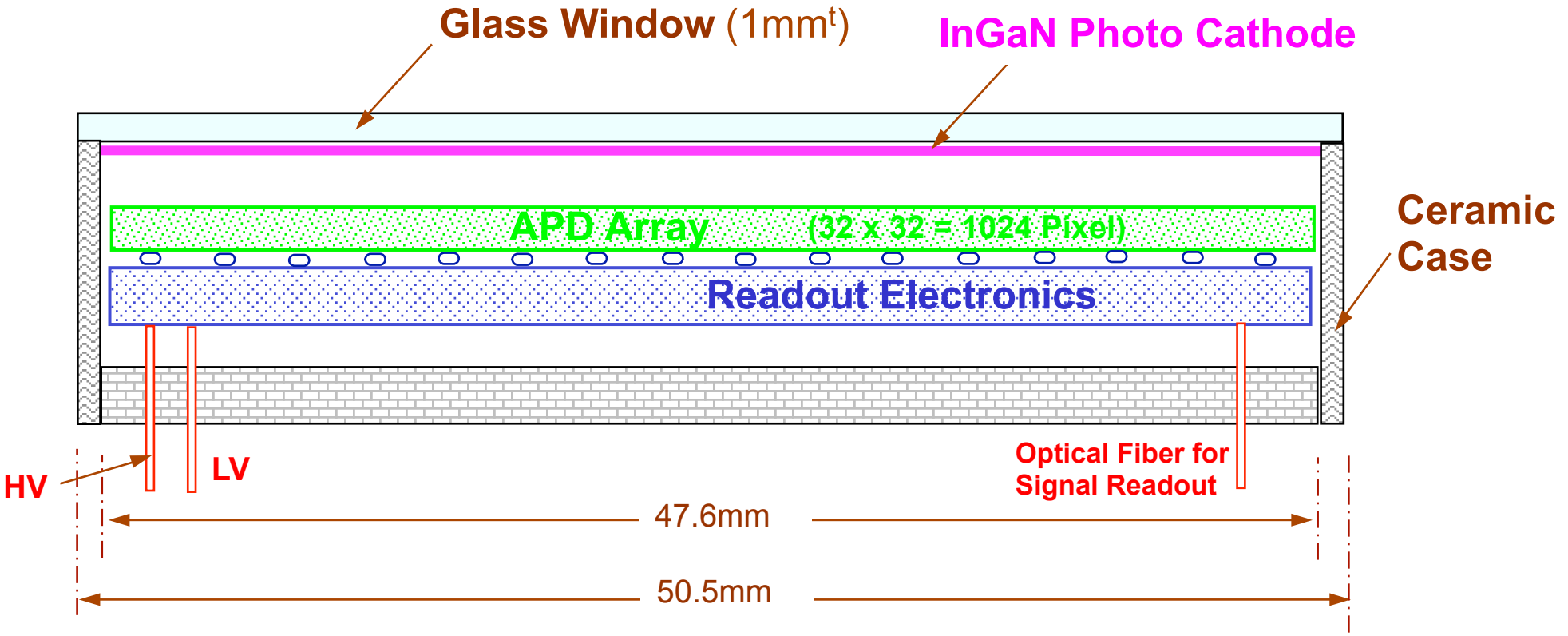
Mega-Pixel TES/STJ

- **Detect Photon by Photon:**
  - **Energy** **< 0.1 eV**
  - **Time** **< 1 nsec**
  - **Position** **< 10 μm**
- **Ultimate Photon Detector!**

Dream Team for Astro-Physics

- CCD: ~10μm 1G pixels
- STJ: ~20μm 1M pixels
- HAPD: ~1mm 1K pixels

Multi-pixel Hybrid APD



- 1.4mm Pixel Size, 1.5mm Pitch
- 32 x 32 = 1,024 Pixels
- QE ~ 50% at 350 ~ 400nm
- Gain ~10^5

Katsushi's Dream Telescope

- **Ground & Space-based 2π observatory:**
  - 20m diameter mirror
  - 30° FOV, f/0.8
  - 0.1arcsec pixel size
  - 1Tera pixels
  - Photon counting
  - 1nsec time resolution
  - 0.01eV energy resolution

Concluding Remarks

- **Where did we come from? Where are we going?**
- **The answer is still hidden in the dark side of the Universe which only more advanced photo-detectors can see.**
- **Time is now to develop dream detectors!**


Can “your photo-detector” see
the dark side of this picture?