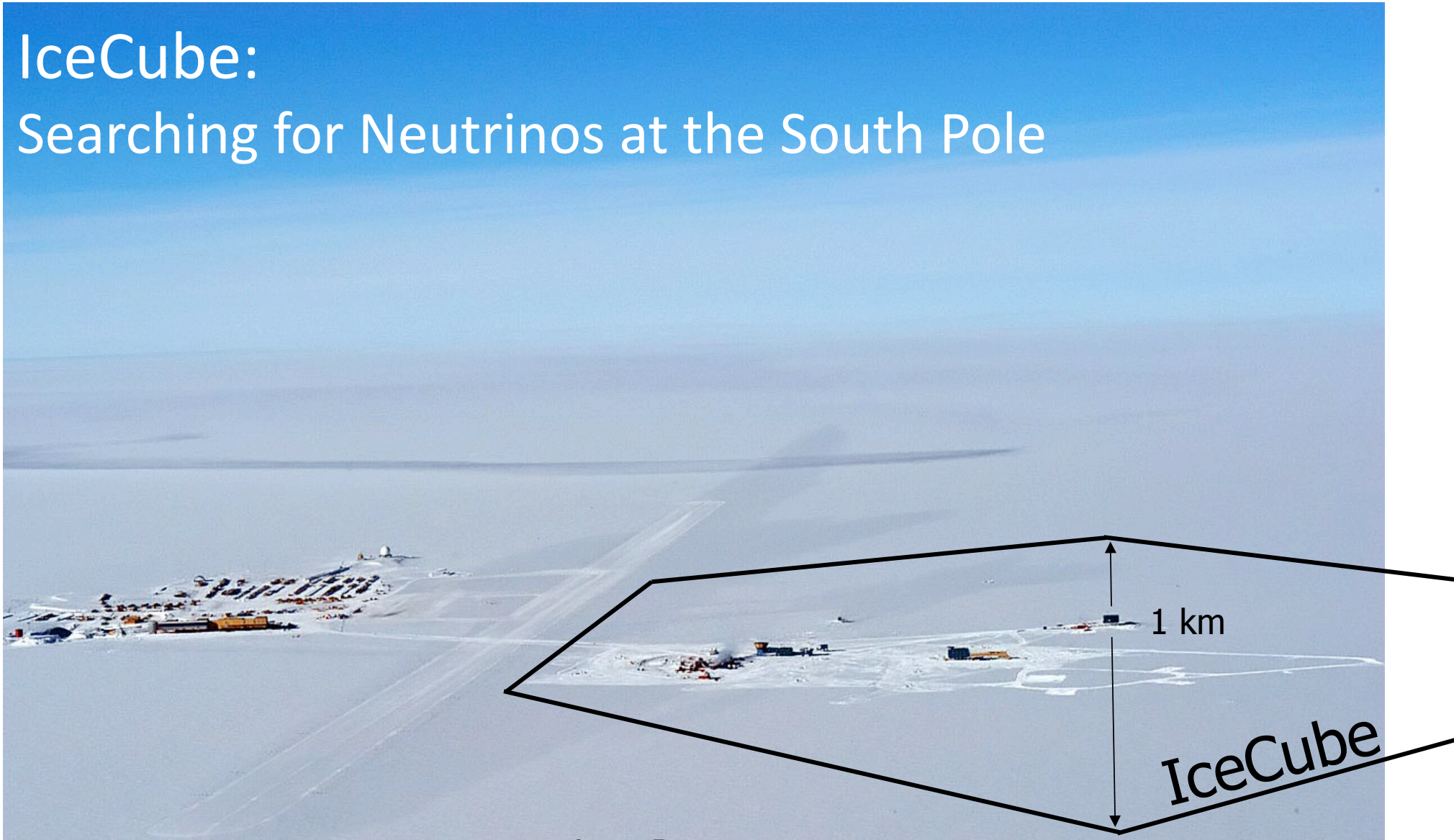
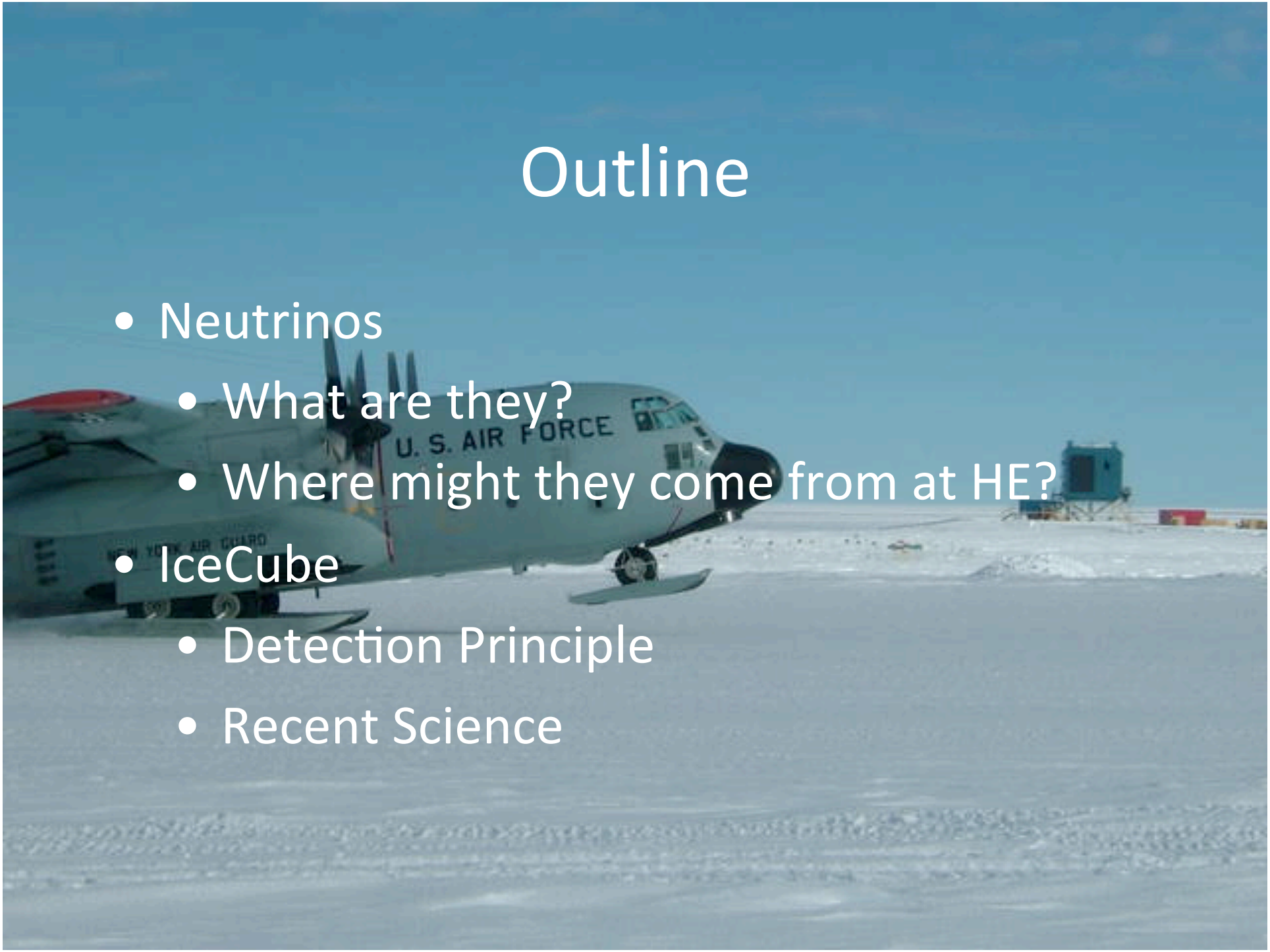
IceCube:
Searching for Neutrinos at the South Pole



Jon Dumm

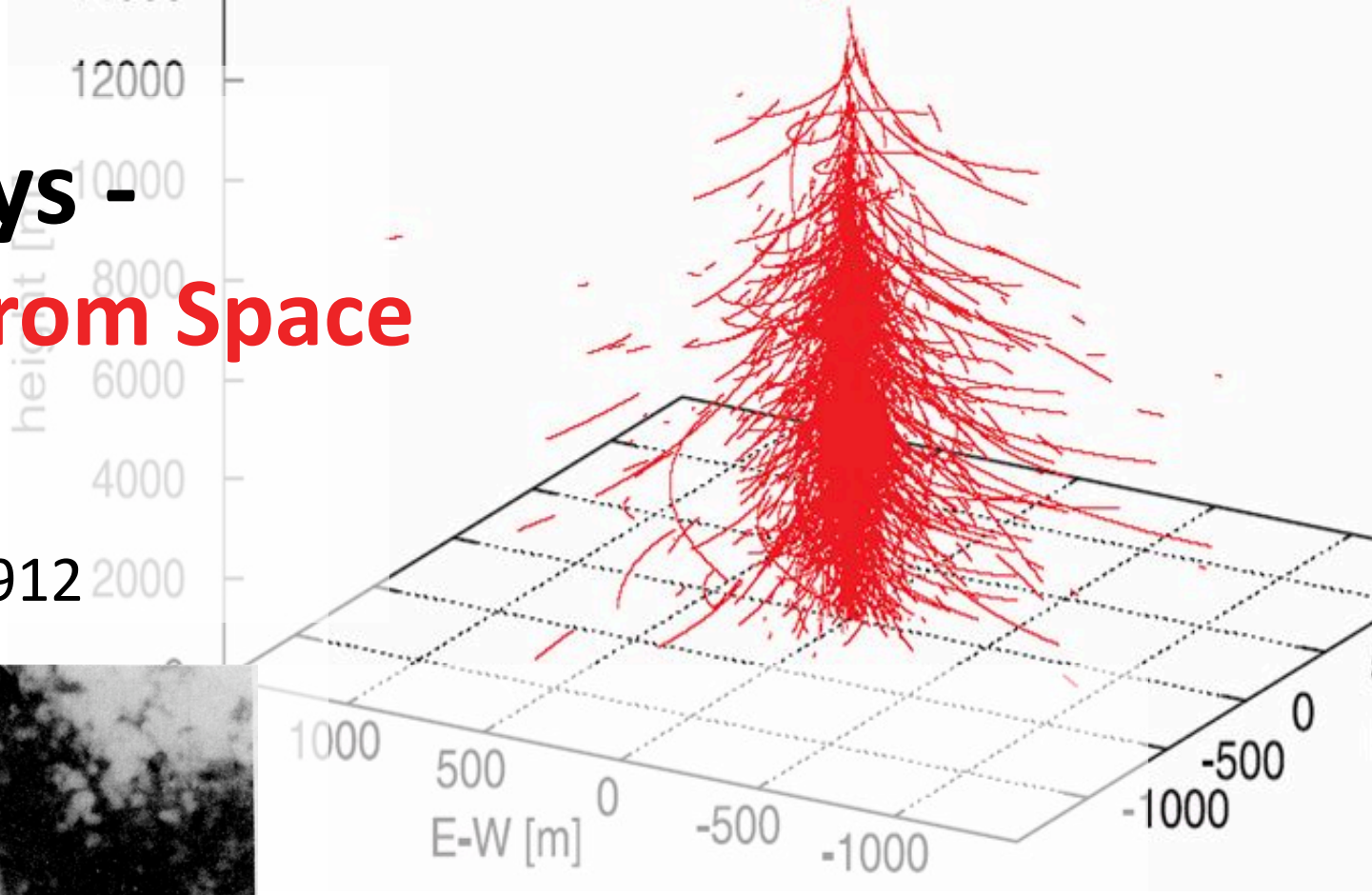
March 12, 2010



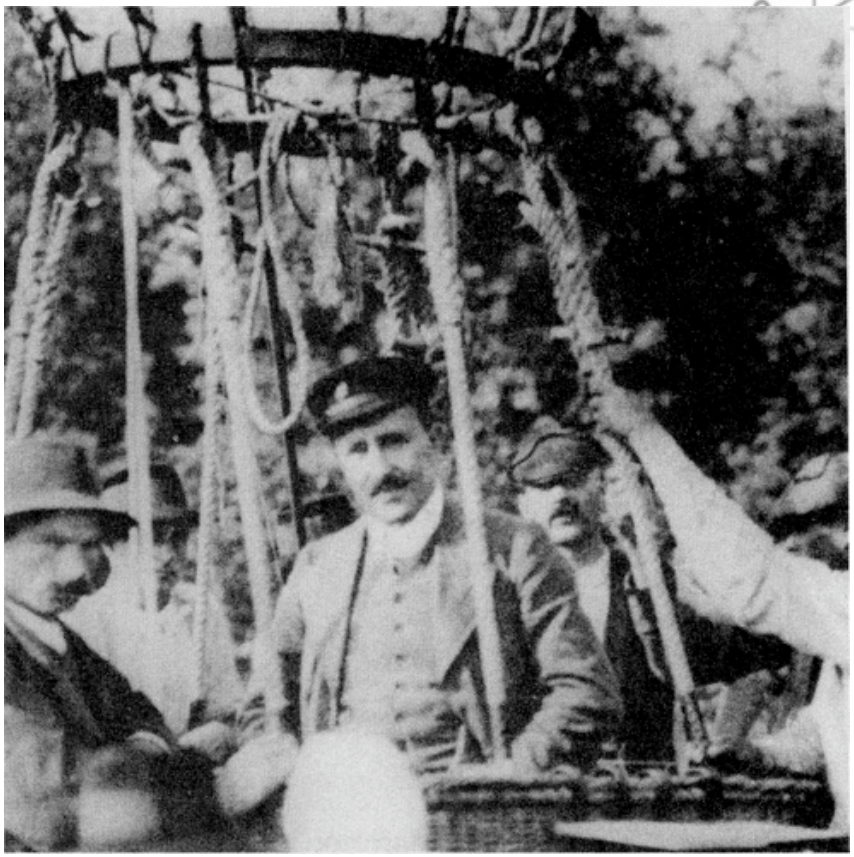
Outline

- Neutrinos
  - What are they?
  - Where might they come from at HE?
- IceCube
  - Detection Principle
  - Recent Science

Cosmic Rays -
A Mystery from Space

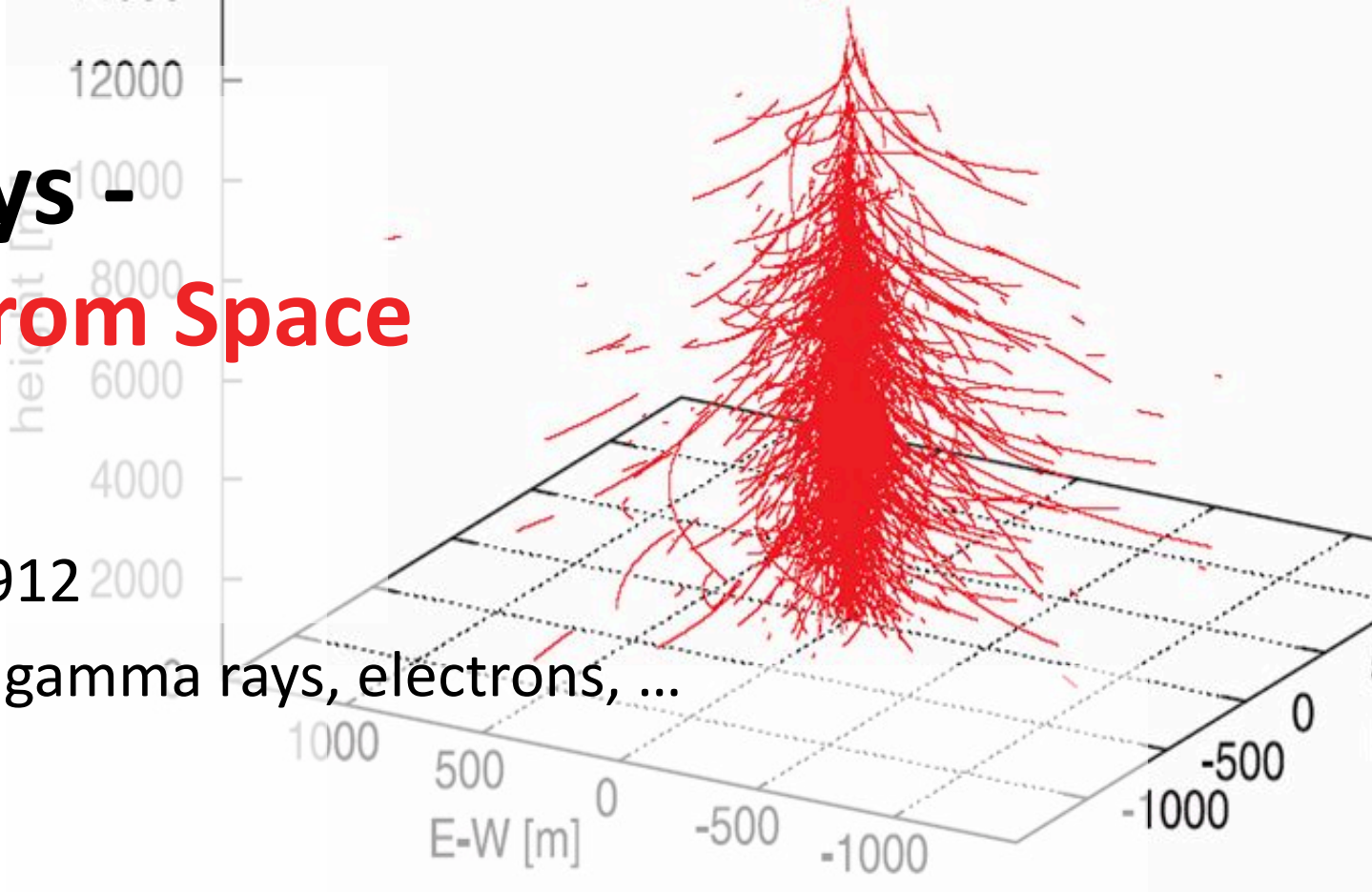


- Discovered in 1912



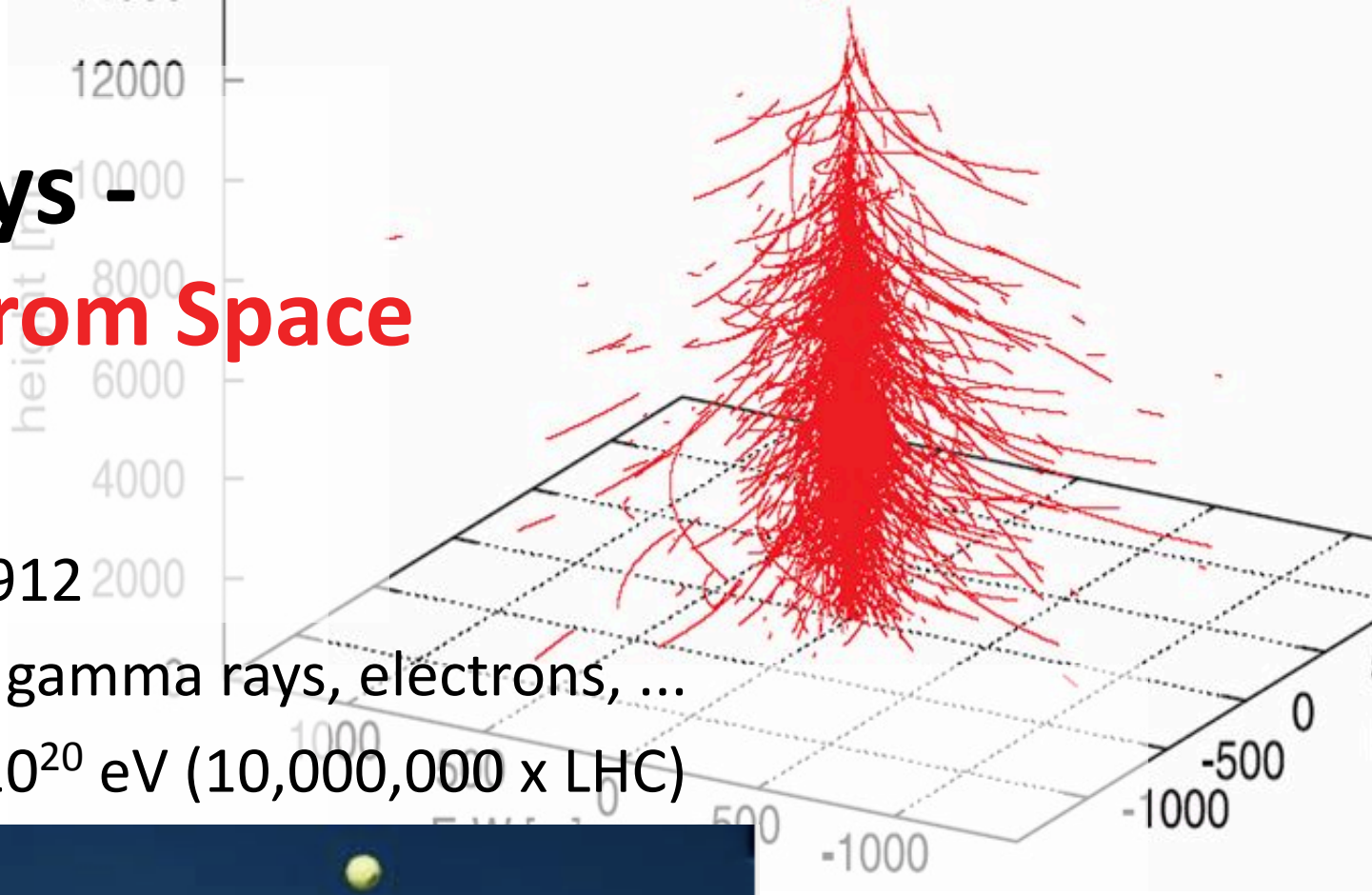
Victor Hess

Cosmic Rays -
A Mystery from Space



- Discovered in 1912
- Protons, nuclei, gamma rays, electrons, …

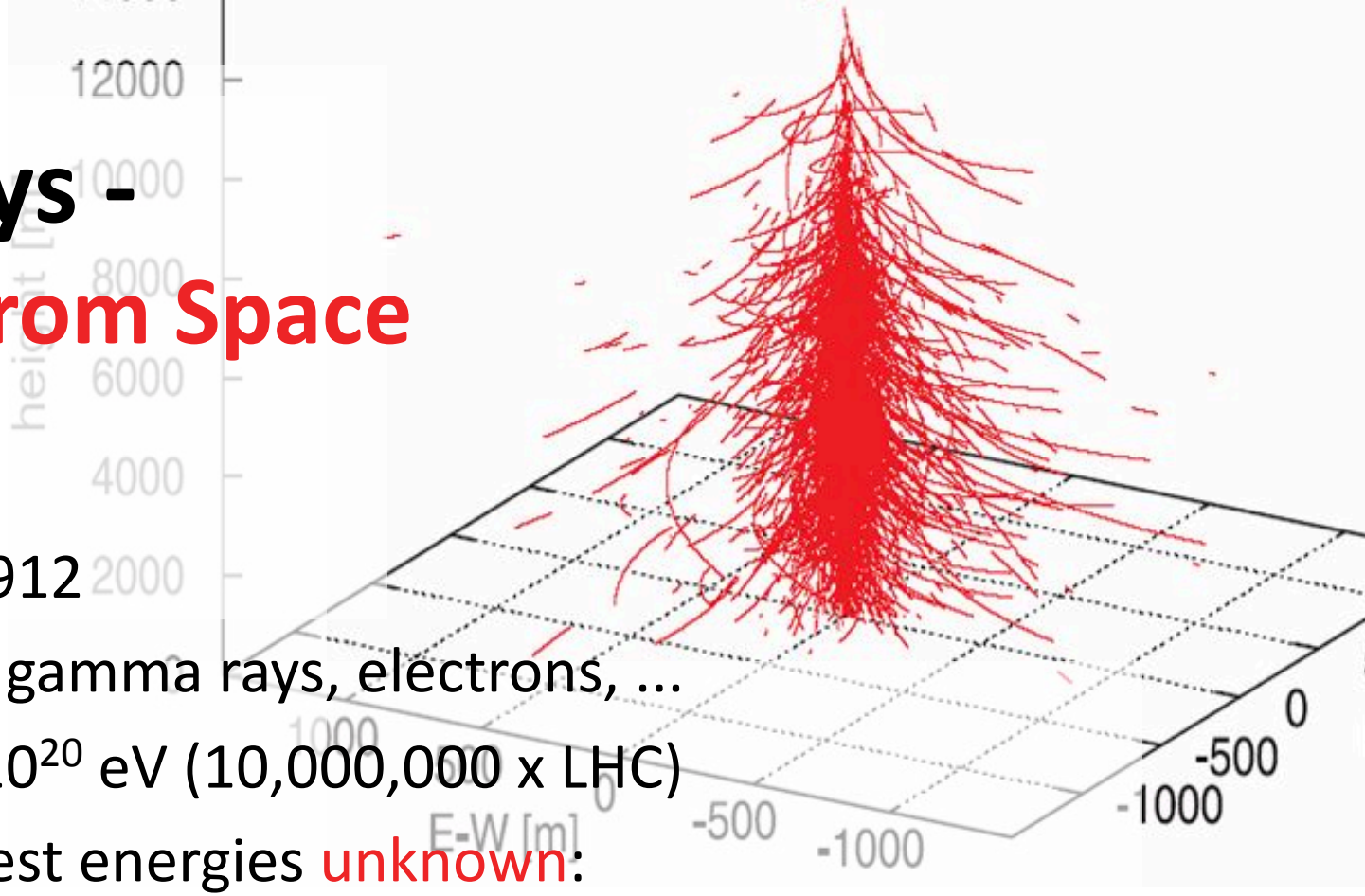
Cosmic Rays -
A Mystery from Space



- Discovered in 1912
- Protons, nuclei, gamma rays, electrons, ...
- Energies up to 10^{20} eV (10,000,000 x LHC)



Cosmic Rays -
A Mystery from Space



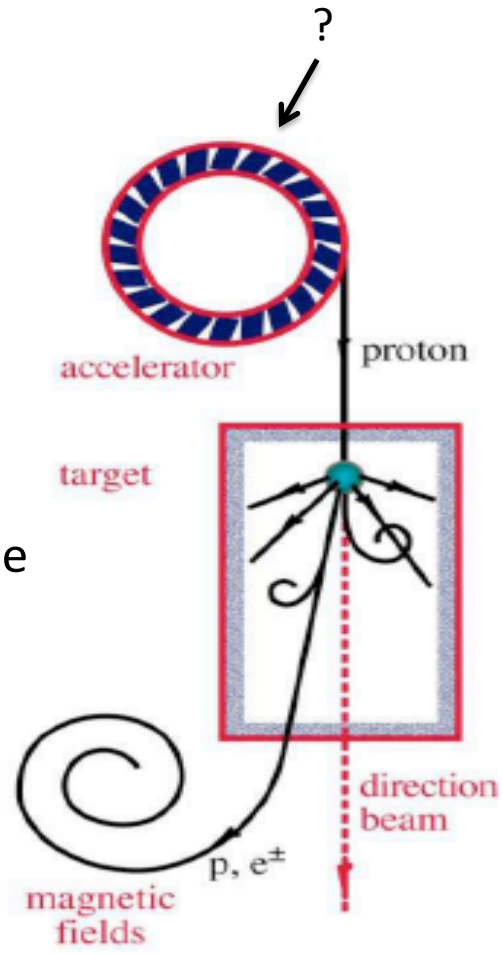
- Discovered in 1912
- Protons, nuclei, gamma rays, electrons, ...
- Energies up to 10^{20} eV (10,000,000 x LHC)
- Sources of highest energies unknown:
  - Charged particles bent by magnetic fields
  - Energetic particles absorbed by intervening material

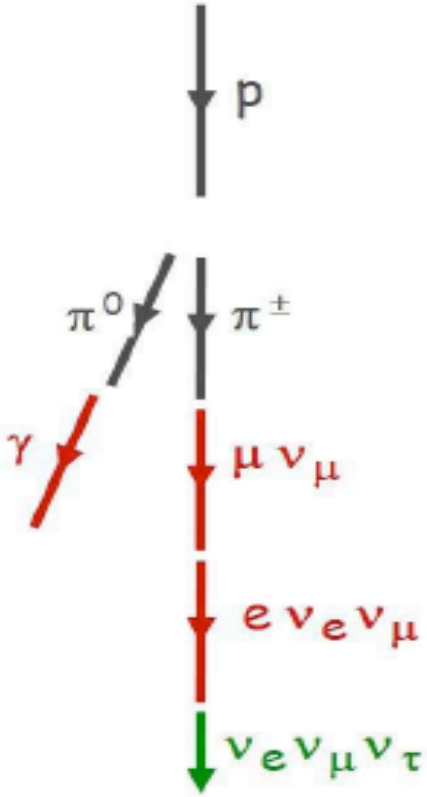
–> Enter a new astronomical messenger: the neutrino...

Cosmic Rays => Neutrinos

Some accelerator produces high energy CRs:
Beam at LCH = $6B
Beam from Universe = Free

When CRs interact they will produce neutrinos and gamma rays





An introduction to neutrinos and their properties…

The Neutrino



"I have done a terrible thing - I have invented a particle that cannot be detected"

-- Wolfgang Pauli, 1930

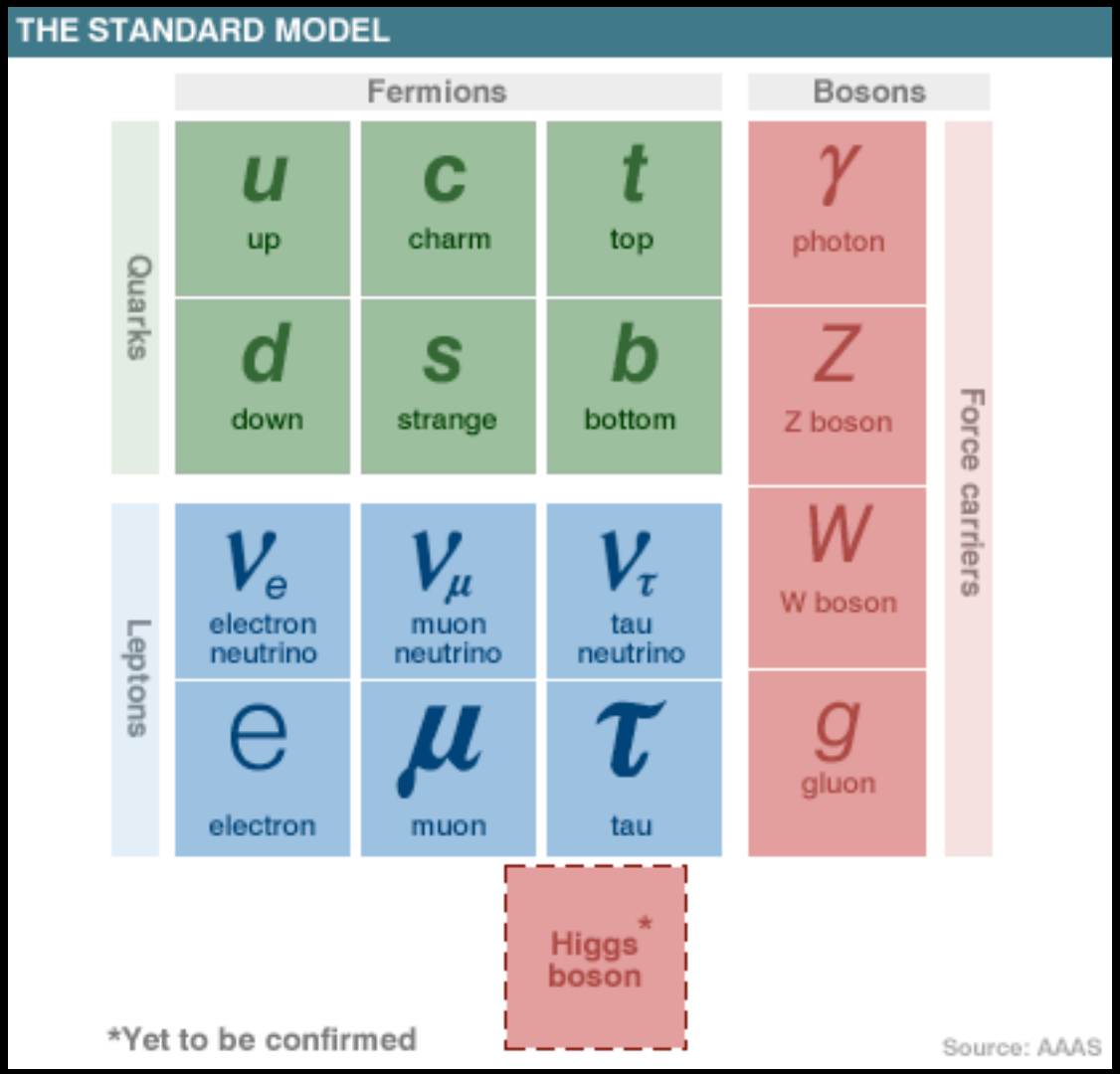
n –> p + e^- + __? (conserve momentum in beta decay)

Tiny bits of almost nothing:

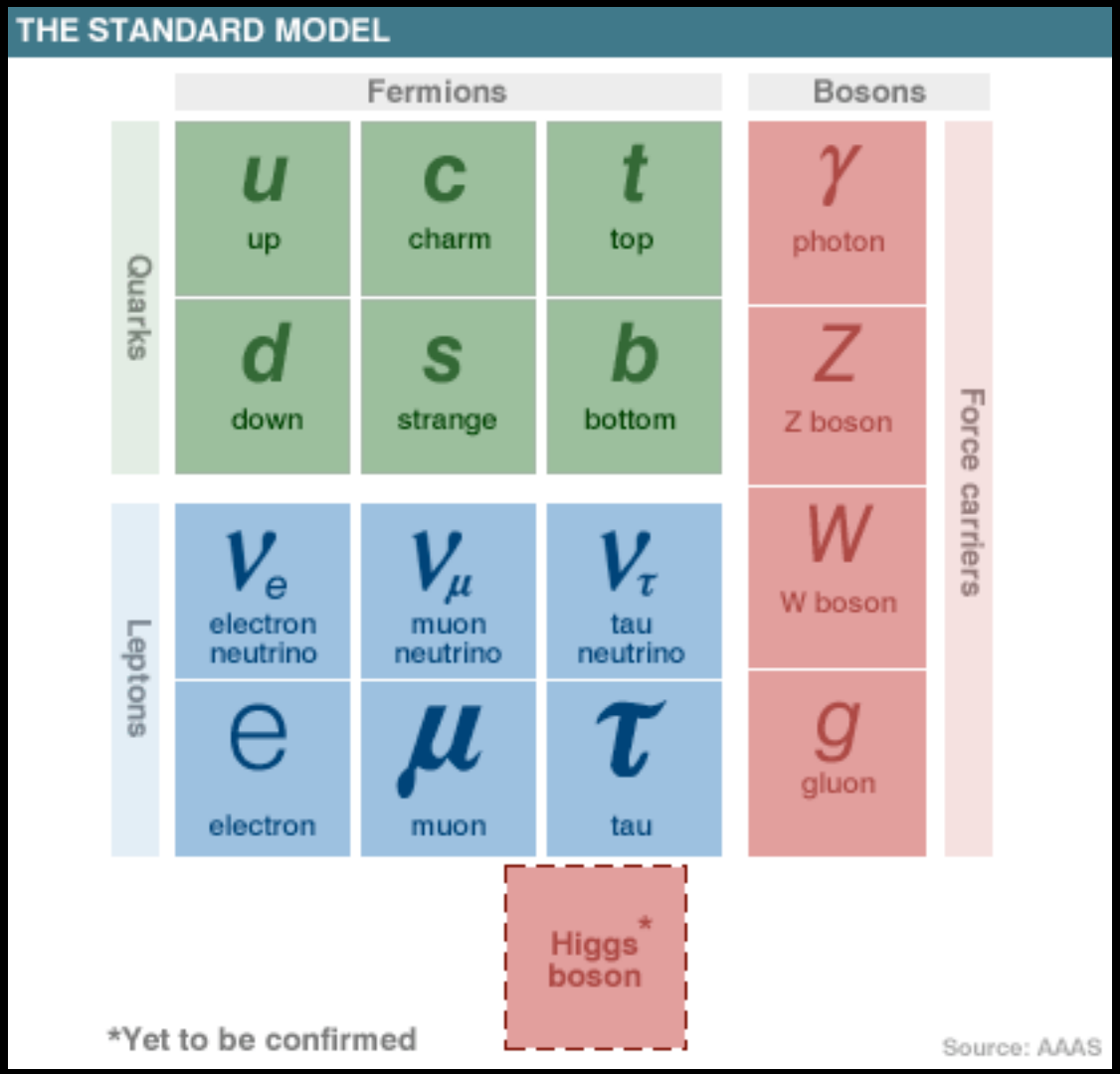
- Stable, no charge, very little mass
- Produced in violent/energetic processes
- Incredibly numerous
  - Billions passing through you every second
- Rarely interact
  - Maybe one in your life will interact with your body
- First detected in 1956, coming from nuclear reactors

$$\bar{\nu}_e + p \rightarrow n + e^+$$

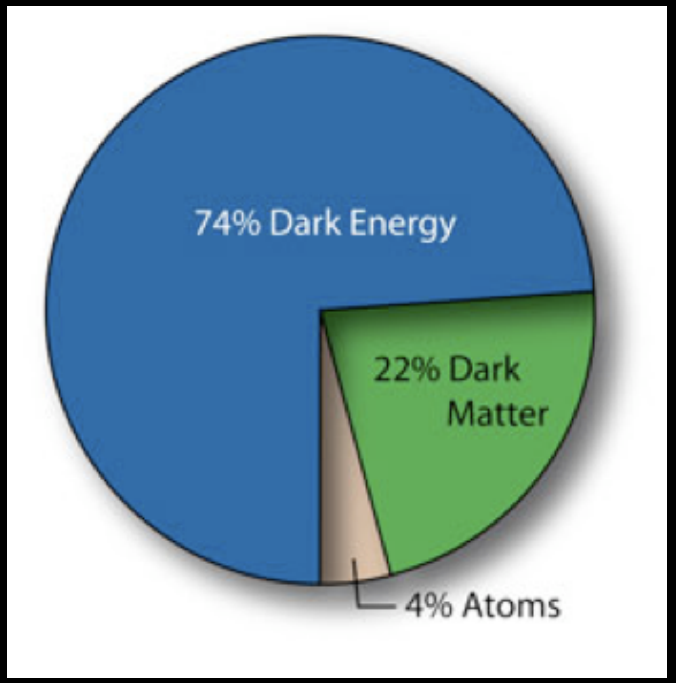
The Neutrino –
Where does it fit in?



The Neutrino –
Where does it fit in?



- No Gravity?
- No Dark Matter/Energy?



First Astrophysical Neutrinos –
The Sun

- Combined effect of many known processes

$$4p \rightarrow {}^{4}\mathrm{He} + 2e^{+} + 2\nu_e$$

- Number of neutrinos predicted to within ~0.1%
  - "Standard Solar Model" by John Bahcall

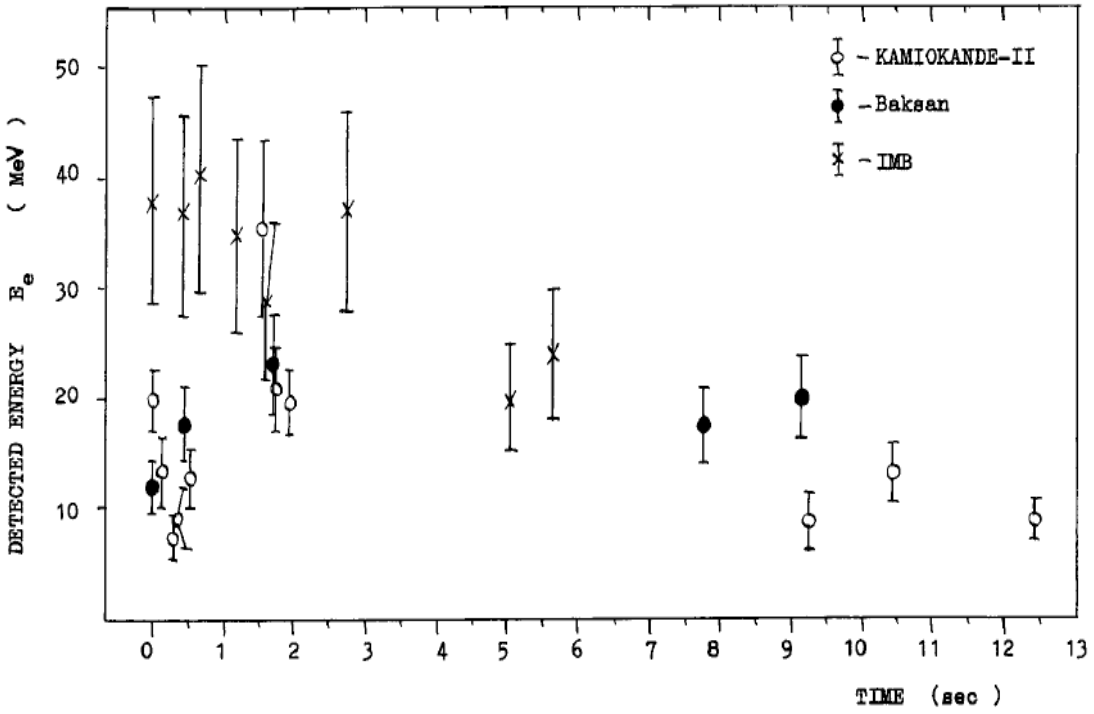
- 1966: Experiment detects 1/3 expected # of neutrinos!
  - Homestake Mine Experiment by Ray Davis

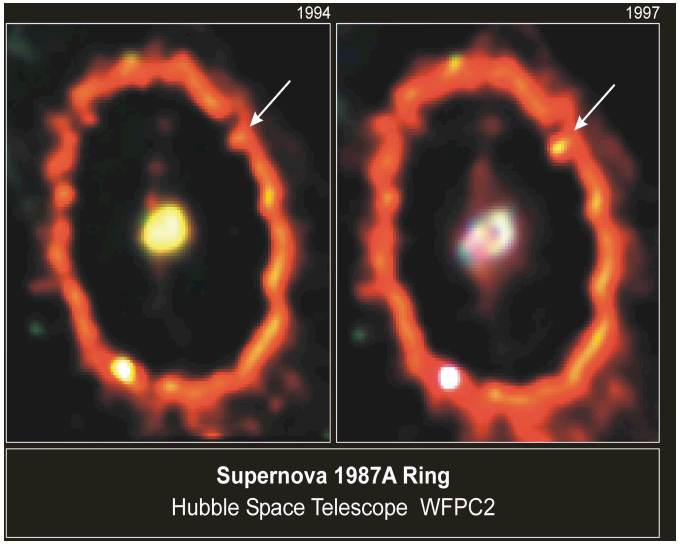
- 30-year controversy between theory and experiment resolved by "neutrino oscillations"

Astrophysics 1st major contribution to particle physics

Second Astrophysical Neutrinos – Supernova 1987a (in satellite galaxy of M.W.)

- Core collapse S.N. releases ~99% of energy in neutrinos

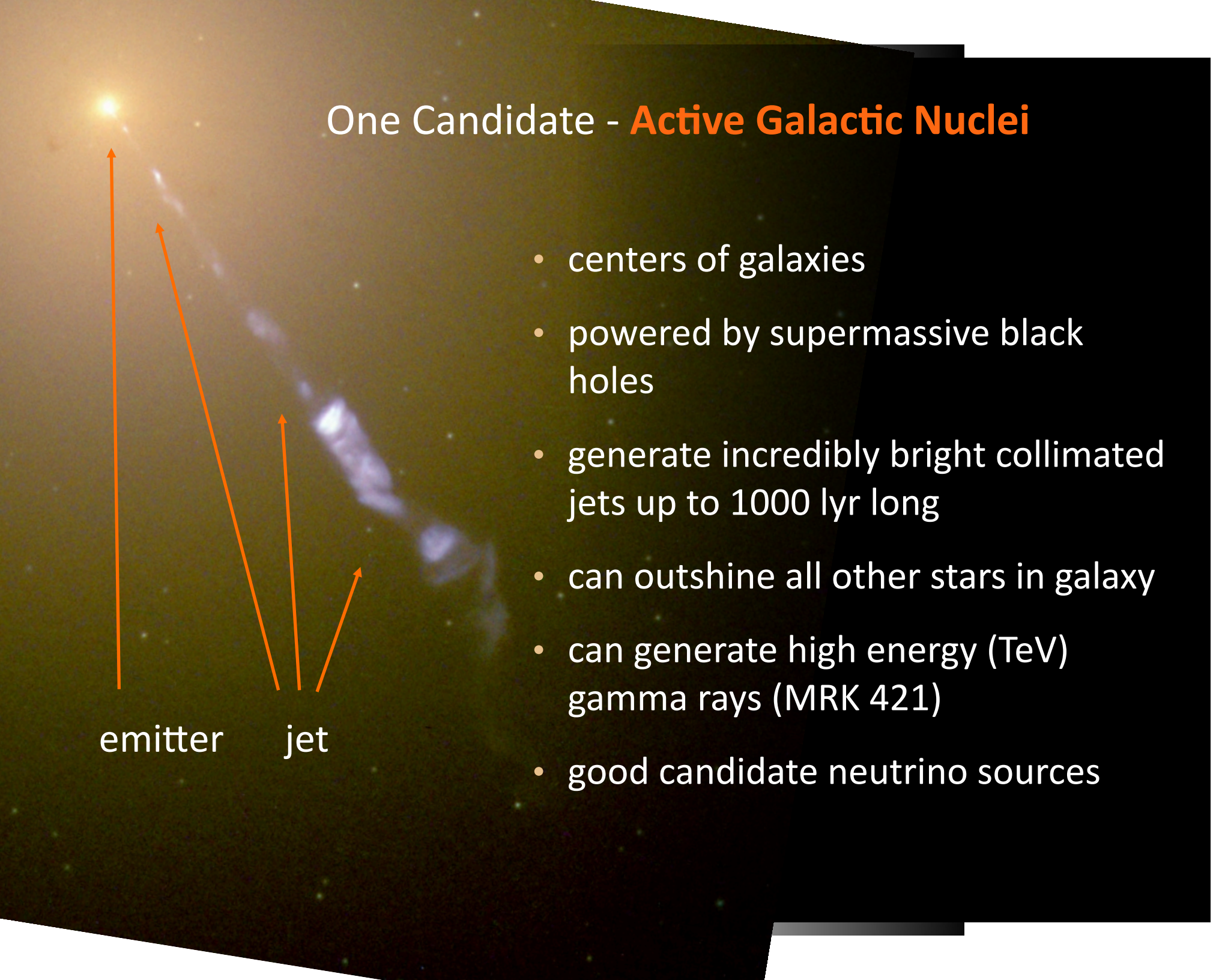




This rare event provided a plethora of knowledge on neutrinos (mass) and S.N. dynamics

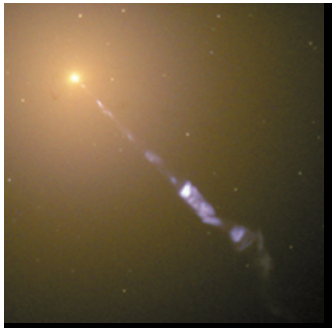
Even higher energies?

One Candidate - **Active Galactic Nuclei**



- centers of galaxies
- powered by supermassive black holes
- generate incredibly bright collimated jets up to 1000 lyr long
- can outshine all other stars in galaxy
- can generate high energy (TeV) gamma rays (MRK 421)
- good candidate neutrino sources

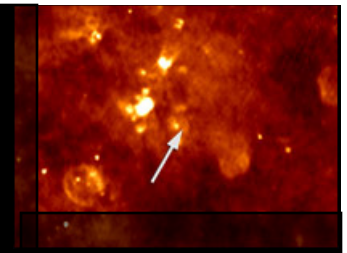
Potential Neutrino Sources



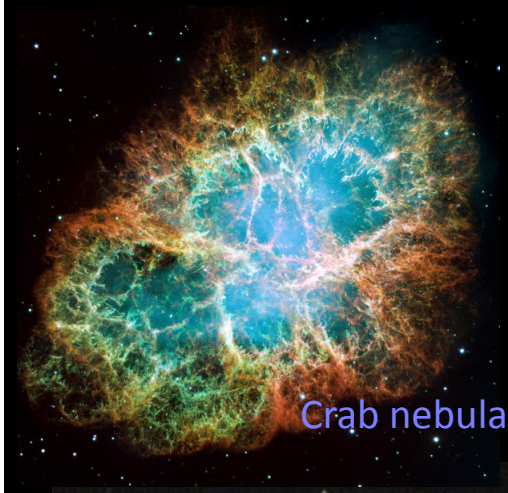
nearby AGN M87 (HST)



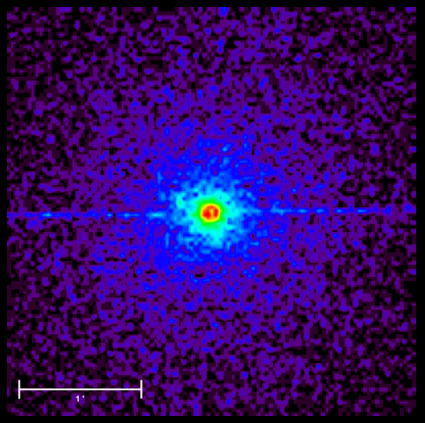
Quasar 3C273 Kitt Peak



Magnetar SGR 1806-20



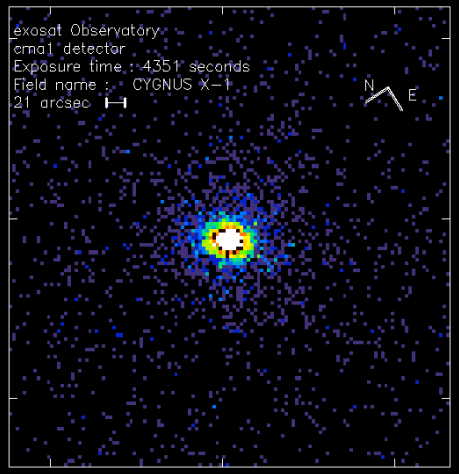
Crab nebula SNR



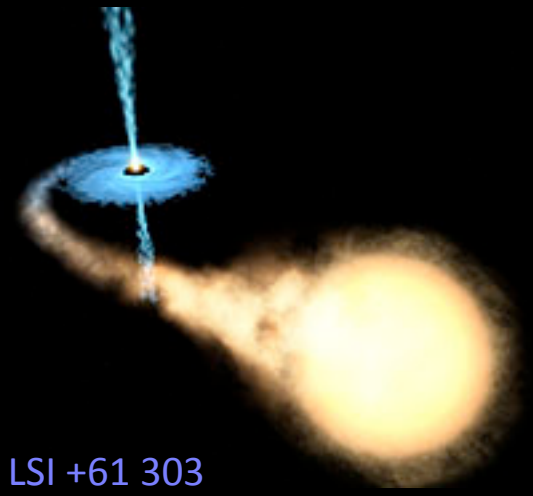
Cygnus X-3 x-ray (Chandra)



BL Lac Markarian 421



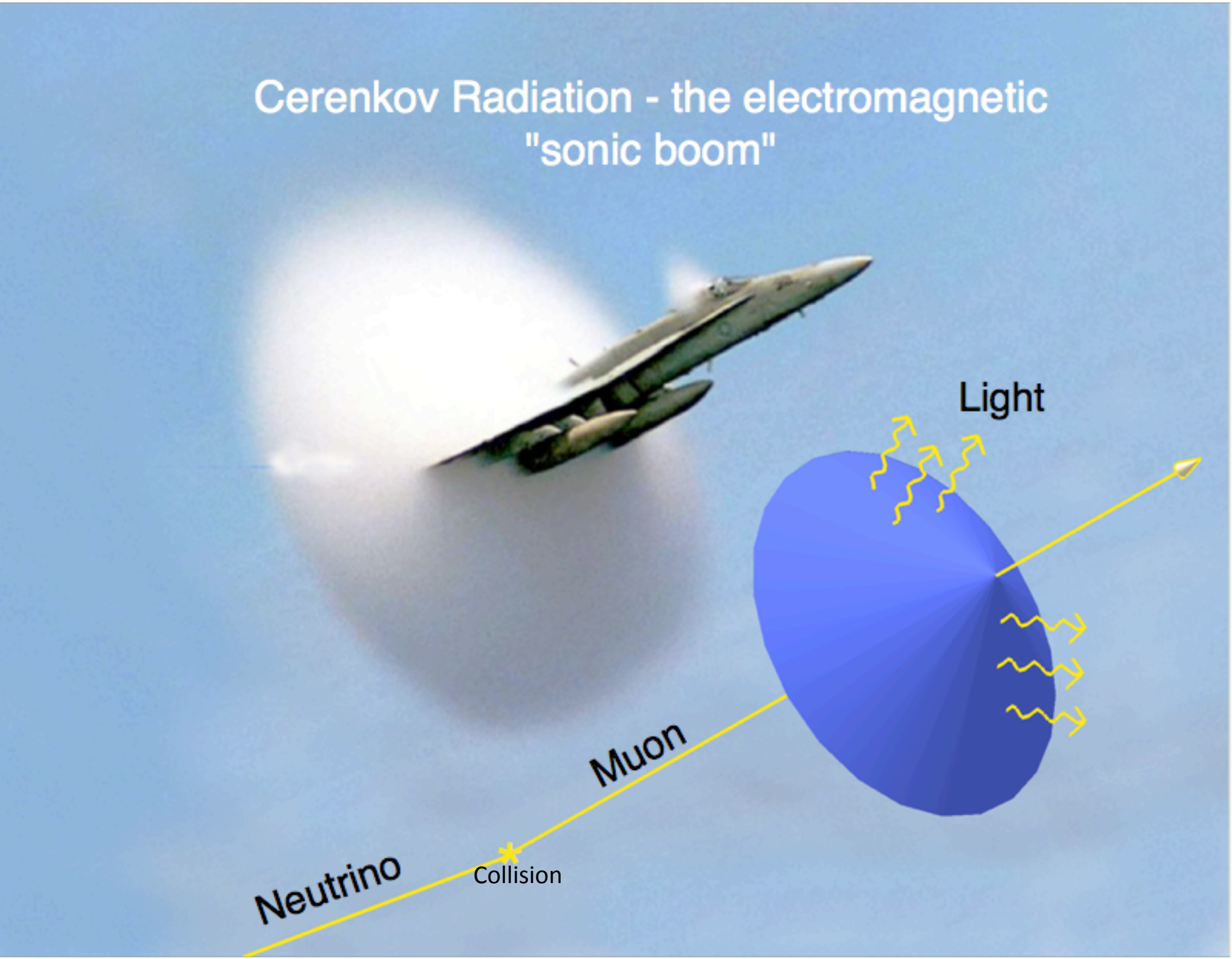
Cygnus X-1



LSI +61 303

Telescope	User	Date	Intended Use	Discovery
Optical	Galileo	1608	Navigation	Moons of Jupiter
Optical	Hubble	1929	Nebulae	Expanding Universe
Radio	Jansky	1932	Noise	Radio Galaxies
Microwave	Penzias & Wilson	1965	Radio astronomy, communications	3K cosmic background
X-ray	Gicacconi et. al.	1965	Sun, moon	Neutron Stars, accreting binaries
Radio	Hewish, Bell	1967	Ionosphere	Pulsars
Gamma rays	Military	1960(?)	Thermonuclear explosions	Gamma Ray Bursts

Moral of the story: **expect the unexpected . . .**

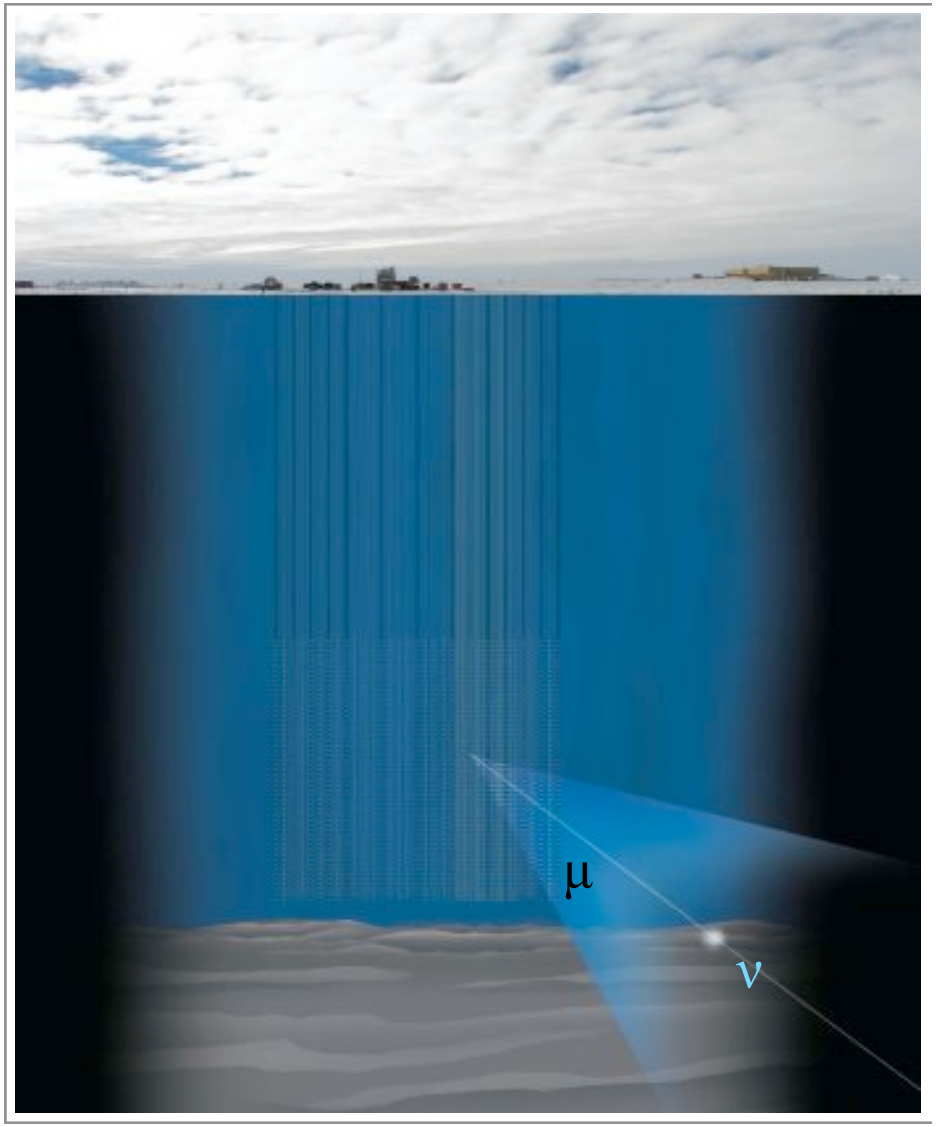

Cerenkov Radiation - the electromagnetic "sonic boom"
Light
Muon
Neutrino
Collision

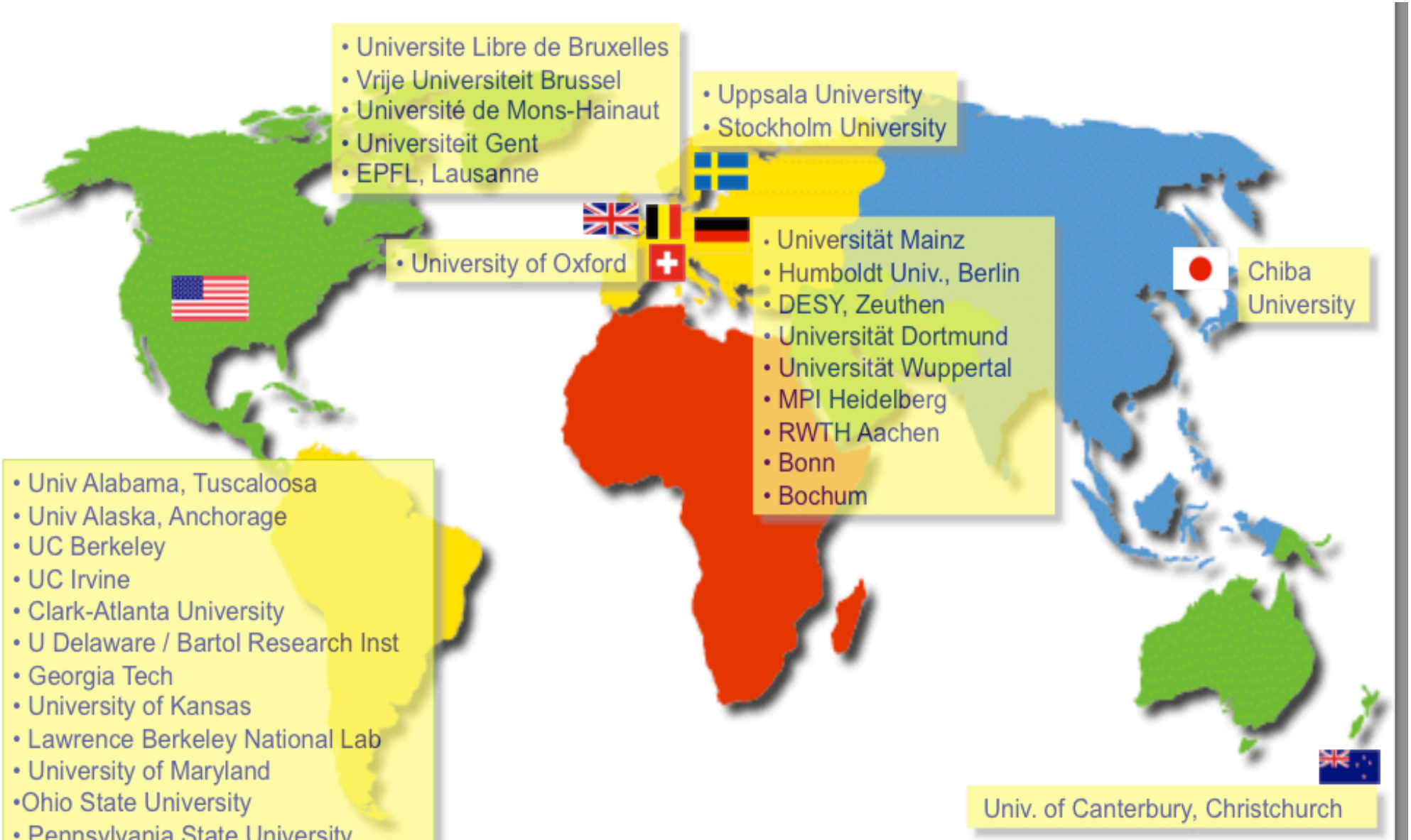
Detection Technique - Cherenkov Radiation

- A large 3D array of optical sensors can be used to reconstruct neutrino arrival direction

- Problems to overcome:
  - Size: must rely on nature (sea or ice or salt dome)
  - Backgrounds: must be shielded (deep)

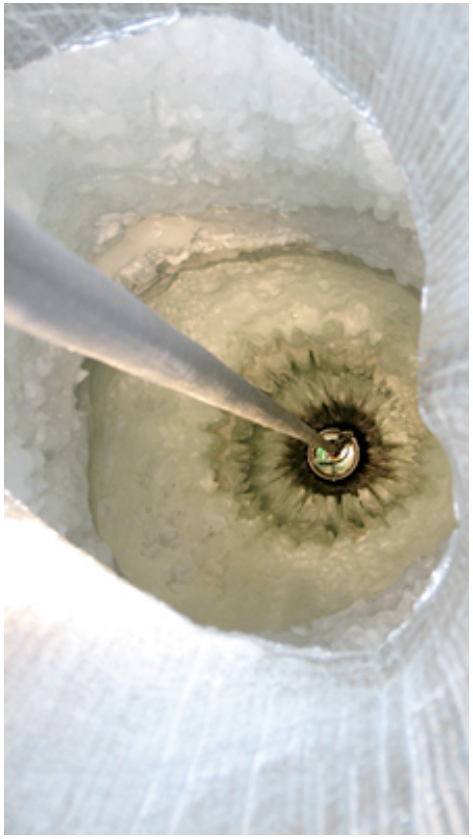
- South Pole ice is ideal choice
  => IceCube

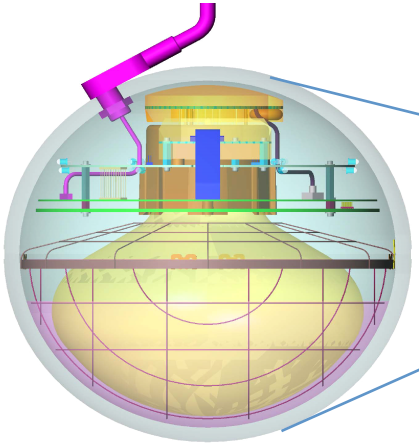




the IceCube Collaboration

34 institutions in 4 continents





Digital Optical Module (DOM)

IceCube Lab

IceTop
80 Strings each with
2 IceTop Cherenkov Detector Tanks
2 Optical Sensors per tank
320 Optical Sensors

50 m

2010: 79 strings in operation
2011: Project complettion, 86 strings

IceCube In-Ice Array
86 Strings, 60 Sensors each
5160 Optical Sensors

1450 m

AMANDA-II Array
Precursor to IceCube

Deep Core
6 Strings - Optimized for lower energies
360 Optical Sensors

Eiffel Tower
324 m

2450 m

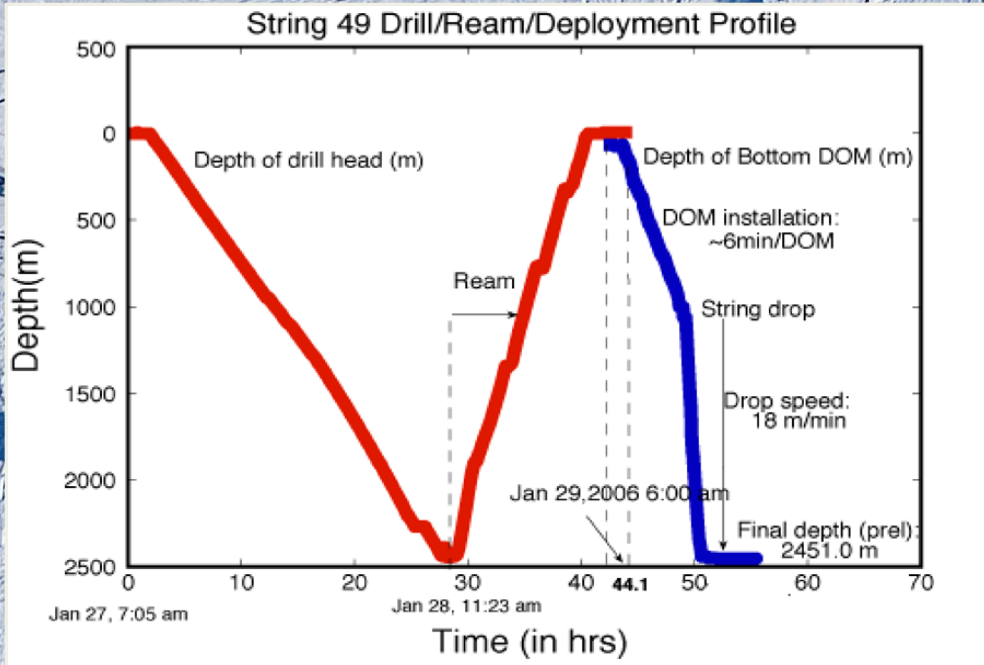
2820 m

Bedrock



IceCube Installation





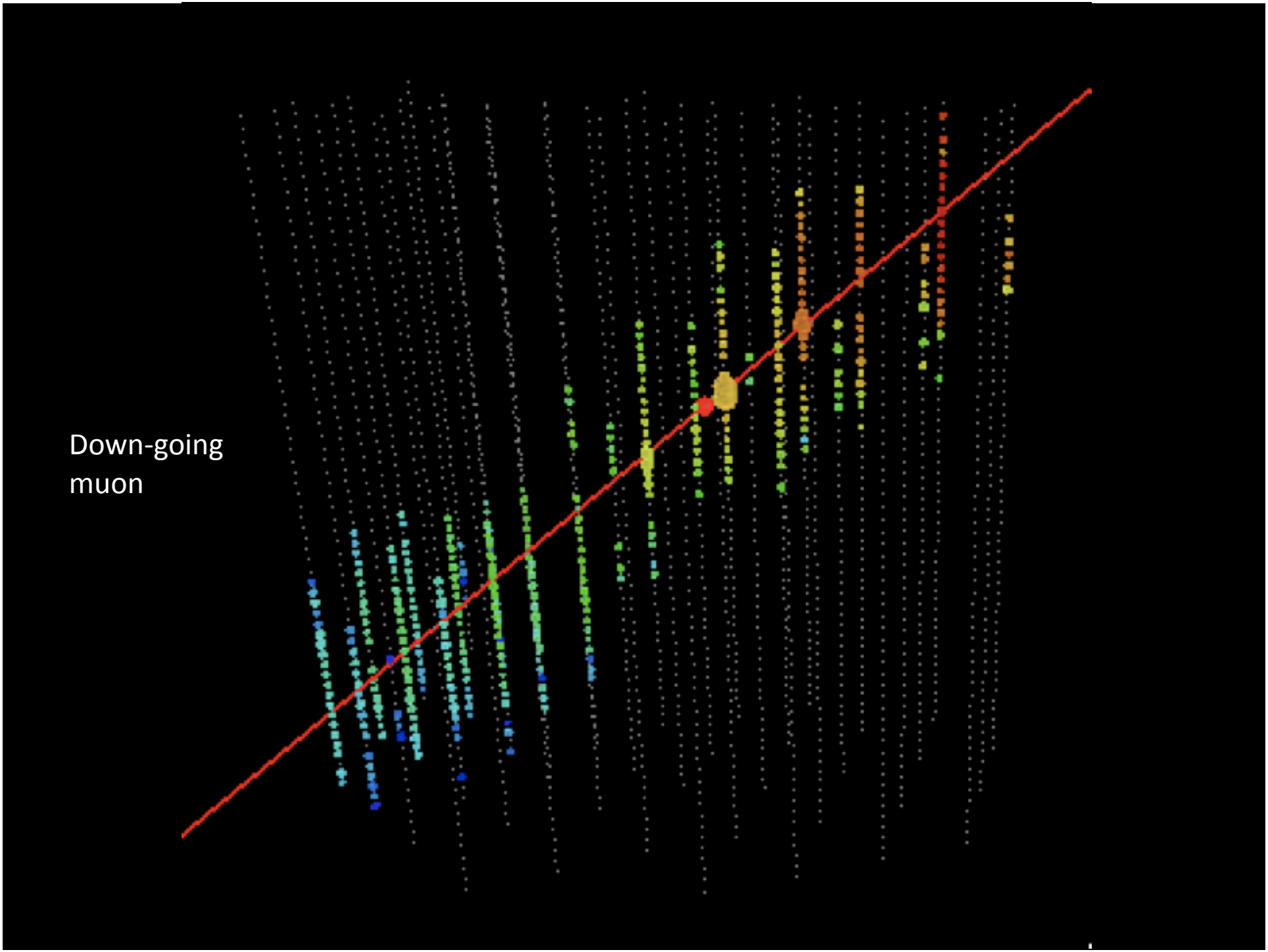
IceCube Installation

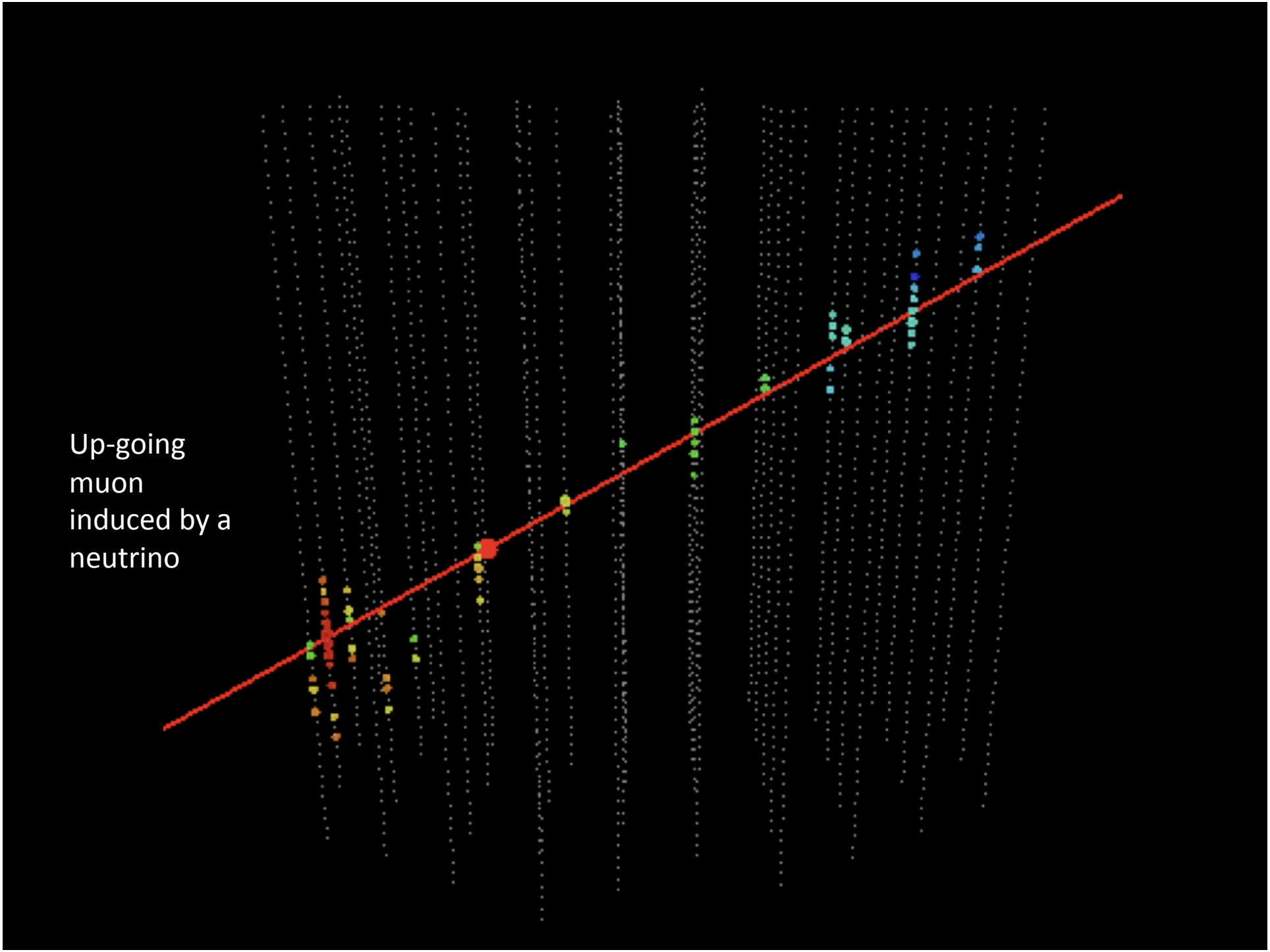


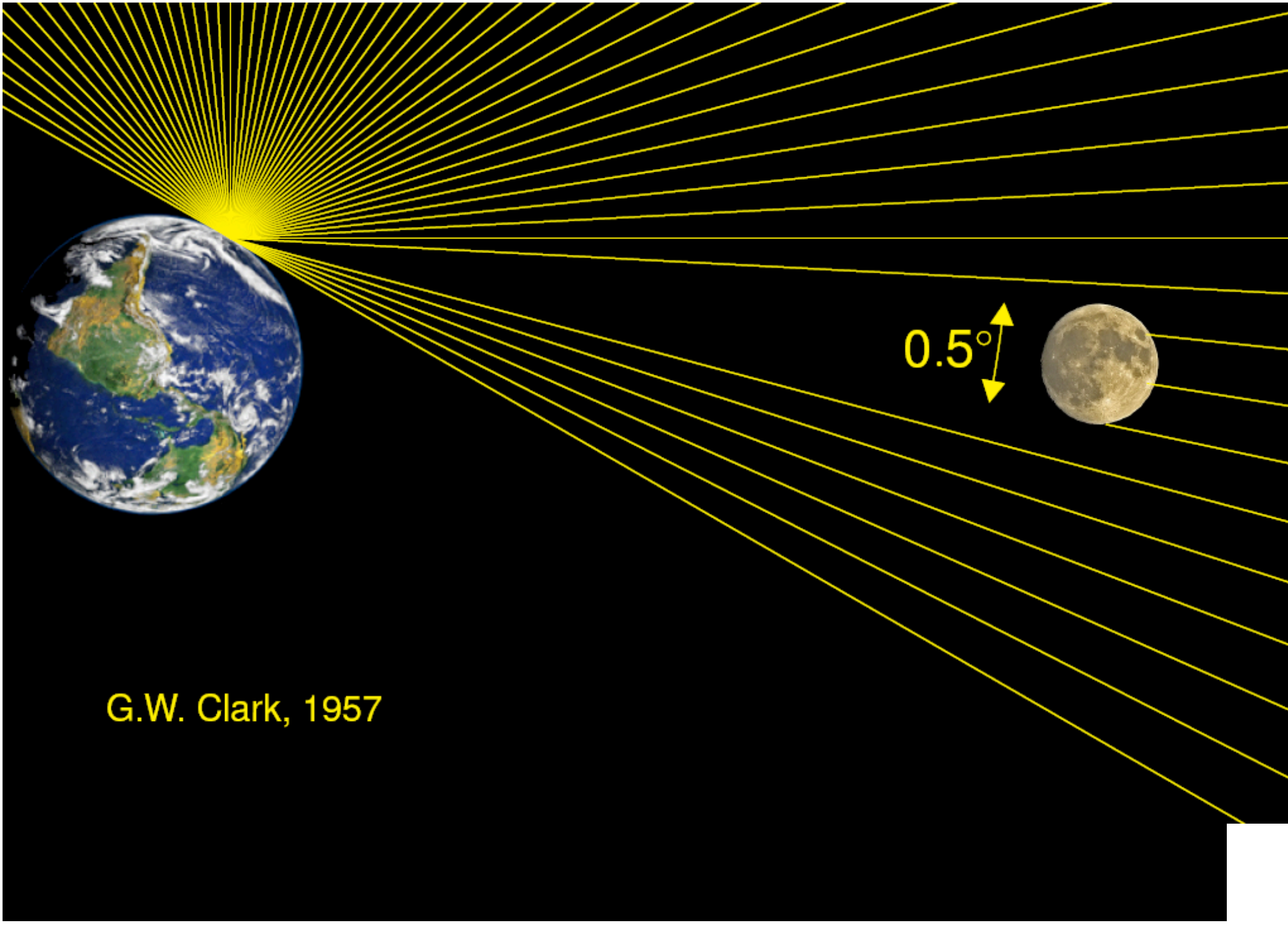





HOLE "L"

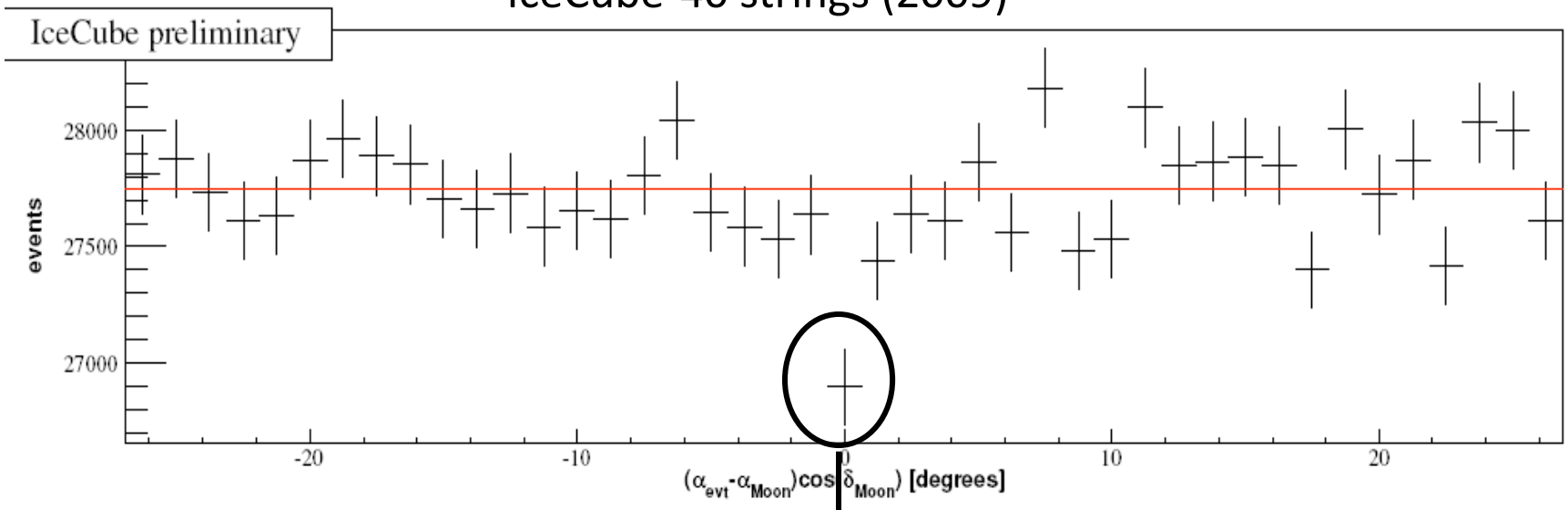

Down-going
muon


Up-going
muon
induced by a
neutrino


0.5°
G.W. Clark, 1957

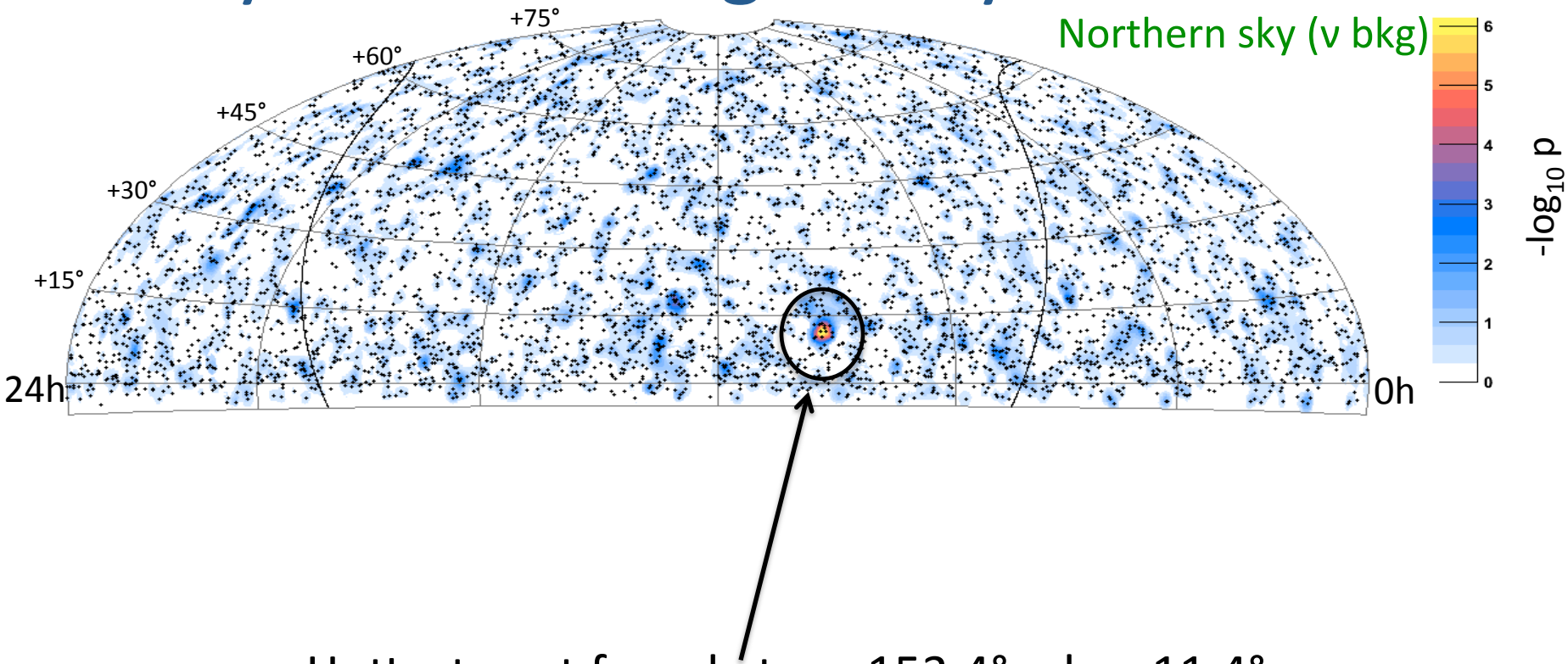
Pointing Verification with the Moon -
The Standard Anti-Candle

IceCube-40 strings (2009)



Observation of moon shadow: 5.04 sigma
~ 1 degree angular resolution

Last year: 22-string all-sky results



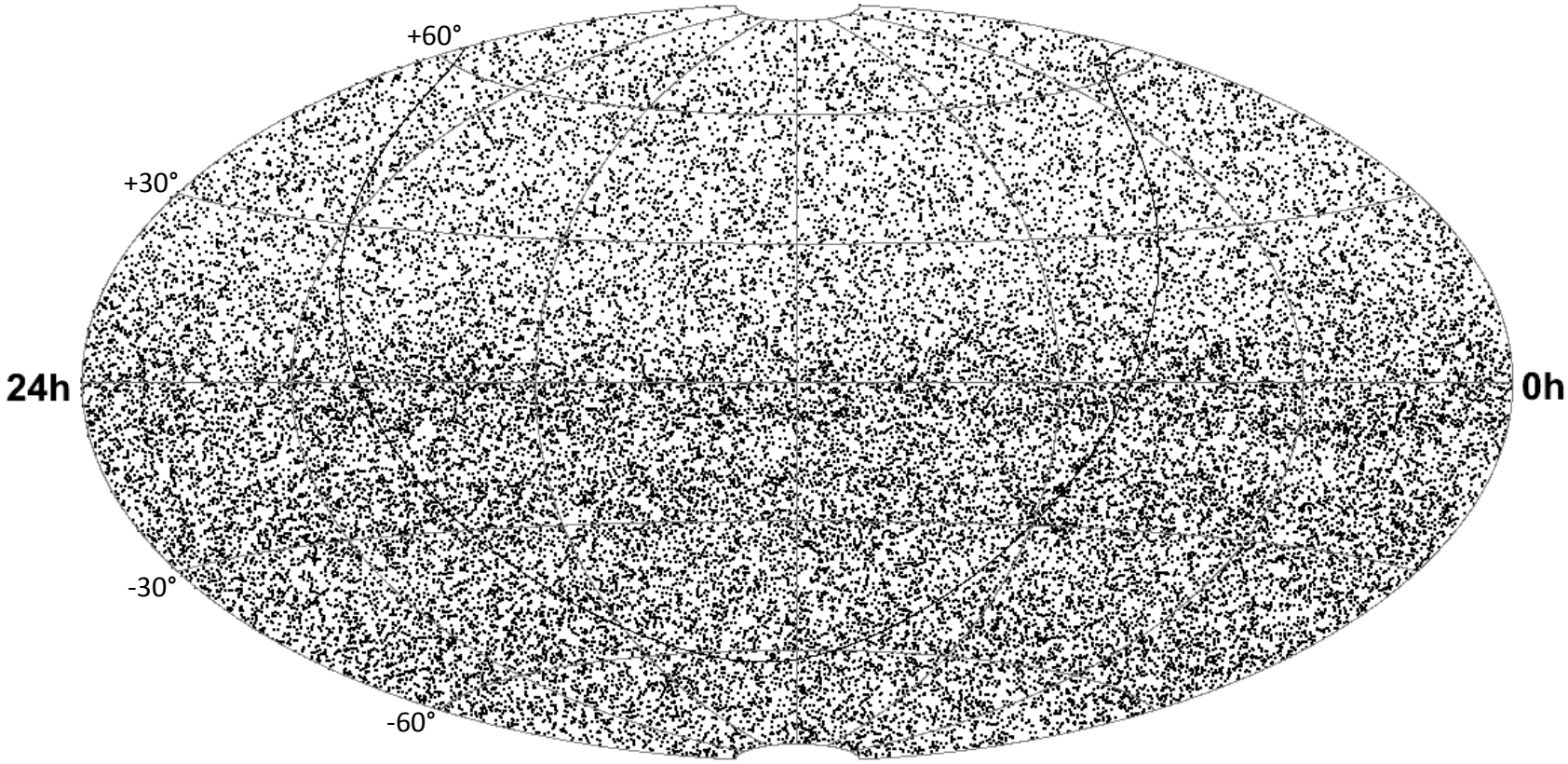
Hottest spot found at r.a. 153.4° , dec. 11.4°

Final Significance = 2.2 sigma

I.e. ~1% chance of occurring due to background alone

ApJL 70, 47 (2009)

40-string all-sky results

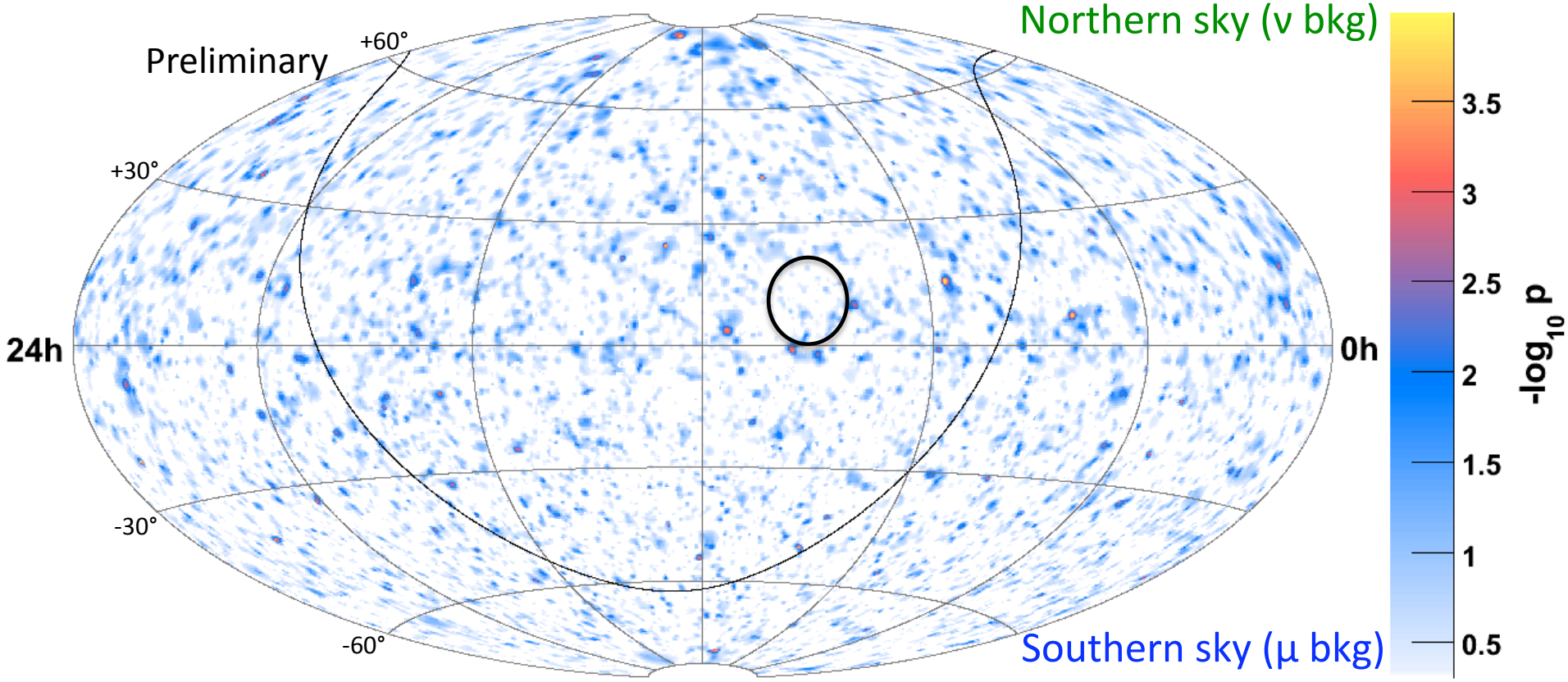


Livetime = 375.5 days

Events = 37290
(14139 up-going,
23151 down-going)

- Do you see any hotspots?
- Statistical methods developed for the search

40-string all-sky results

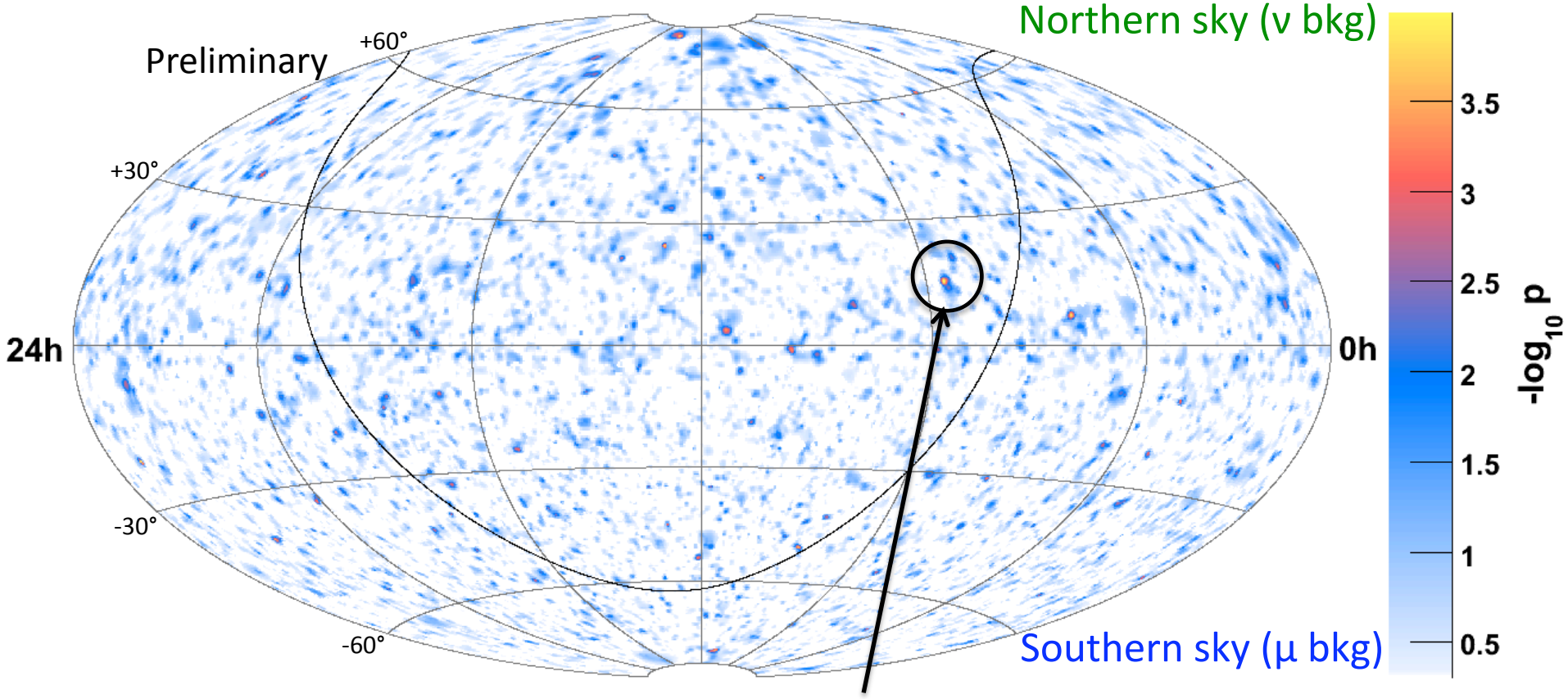


Livetime = 375.5 days

Events = 37290
(14139 up-going,
23151 down-going)

Hottest location in the all-sky search is:
Ra=115.05°, Dec=15.05°

40-string all-sky results



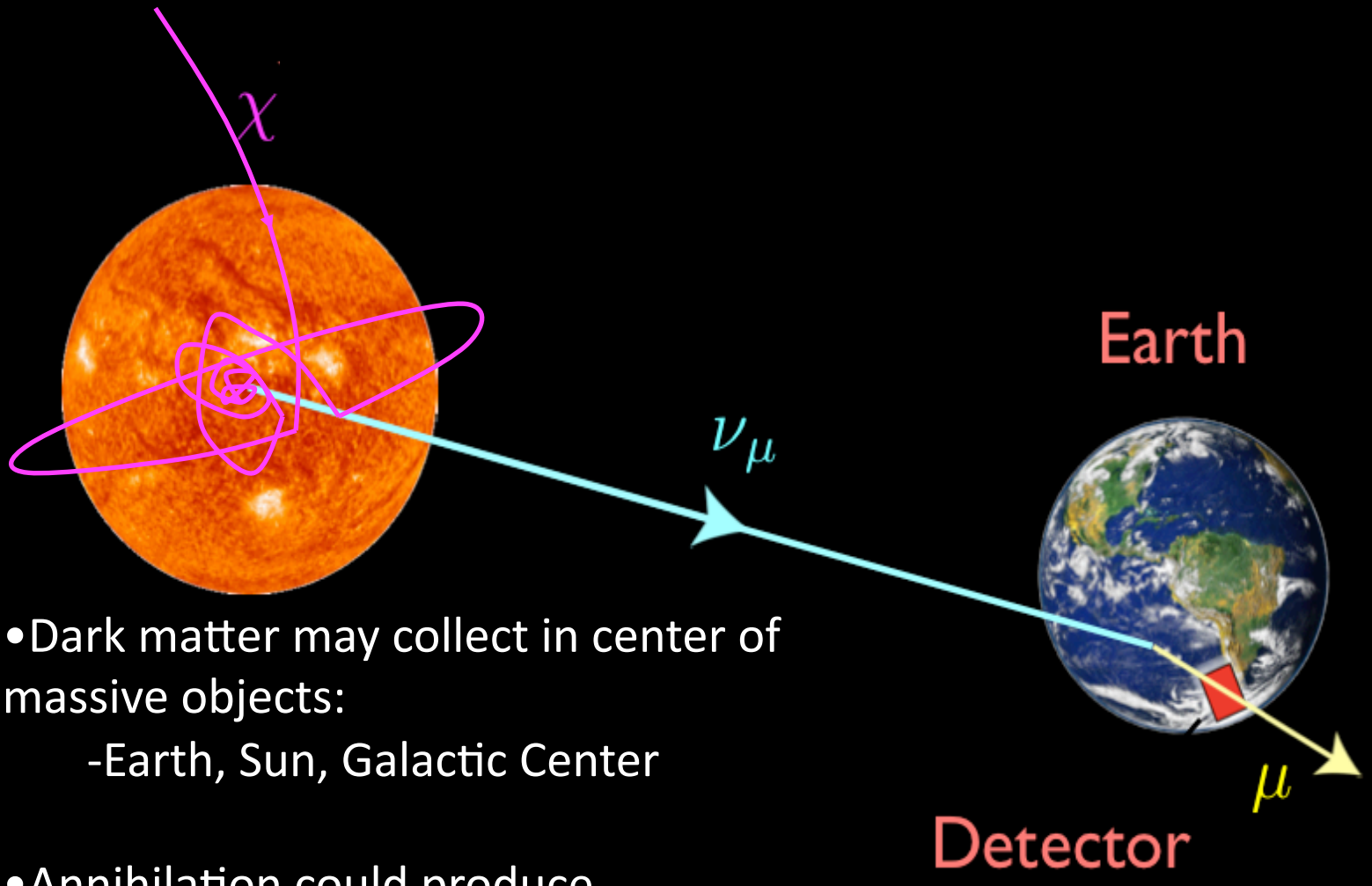
Hottest location in the all-sky search is:
Ra=115.05°, Dec=15.05°

Livetime = 375.5 days

Events = 37290
(14139 up-going,
23151 down-going)

In background simulated trials (scrambling data in r.a.), an equal or greater excess occurs by chance 9588/10000 times.
=> **all-sky final p-value is 96%, not significant**

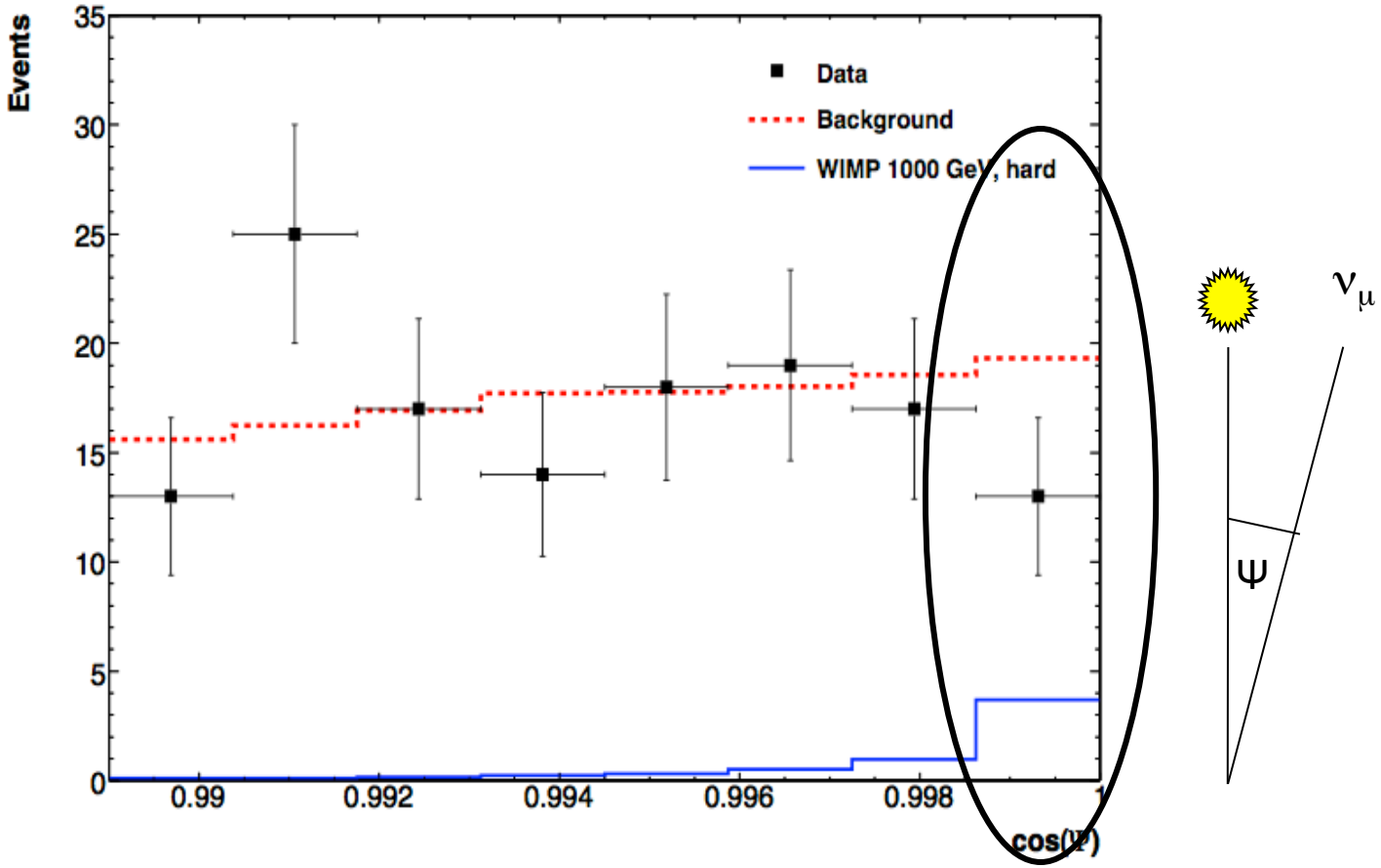
Indirect Detection of Dark Matter:
HE Neutrinos from the sun



- Dark matter may collect in center of massive objects:
  - -Earth, Sun, Galactic Center

- Annihilation could produce neutrinos, observable by IceCube

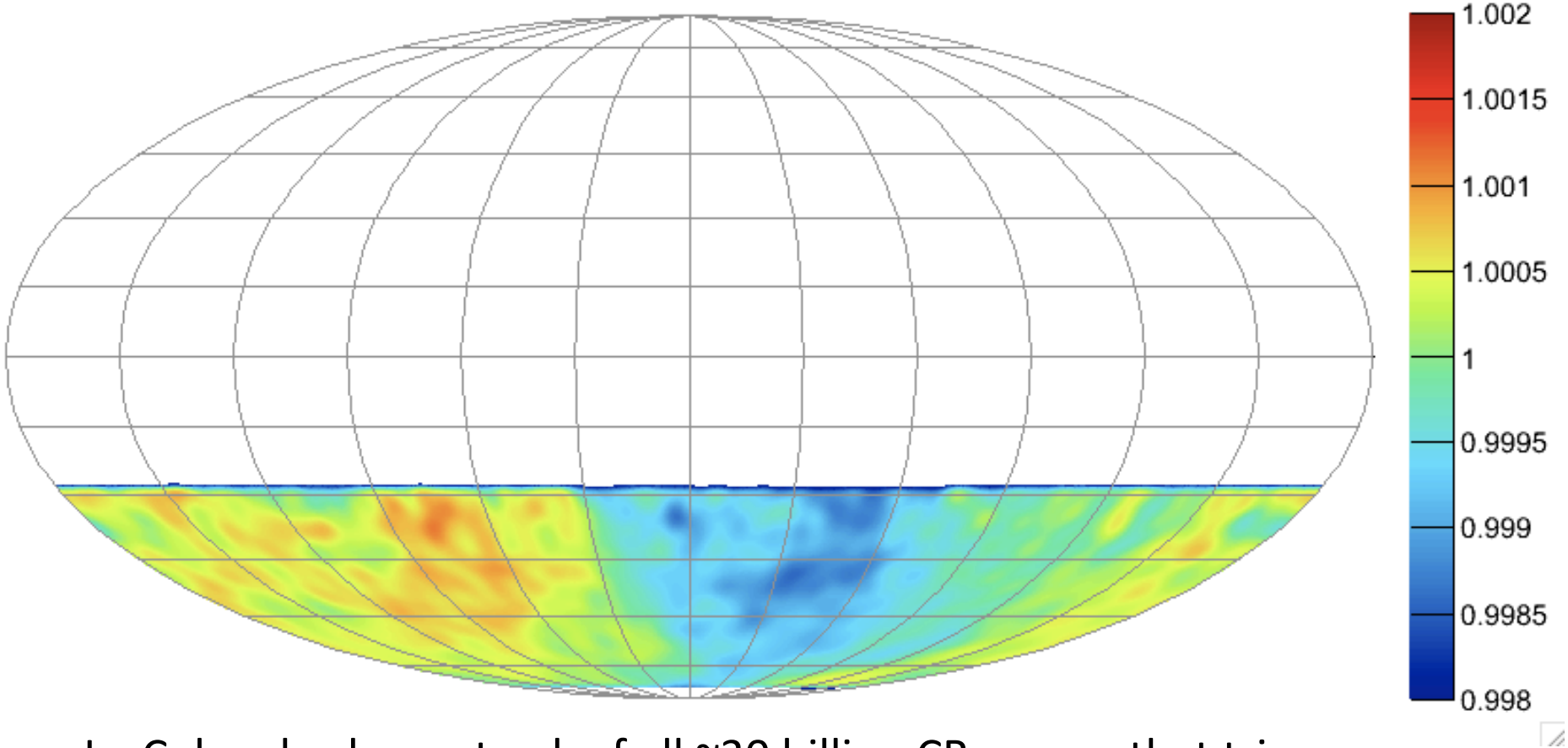
Indirect Detection of Dark Matter:
HE Neutrinos from the sun



Observation consistent with expectation
from atmospheric neutrinos⇒upper limit

Abbasi et al., PRL, 2009

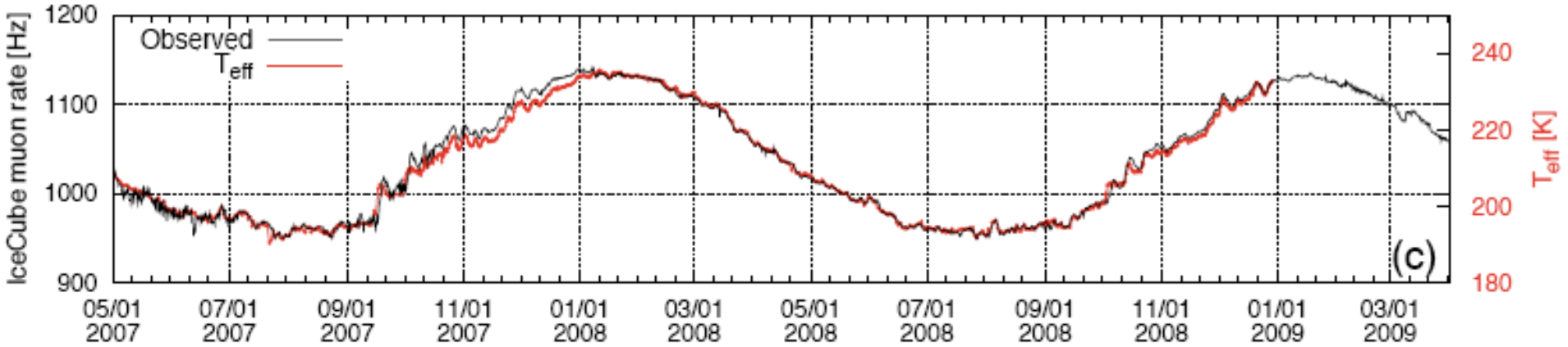
Cosmic Ray Anisotropy:
Science hidden in the “background”



- IceCube also keeps track of all ~30 billion CR muons that trigger

- 1 part in 1000 deviations from uniformity hint at local (~1000 lyr) magnetic field structure or possible nearby source of CRs!

Atmospheric Science -
Correlations with Temperature

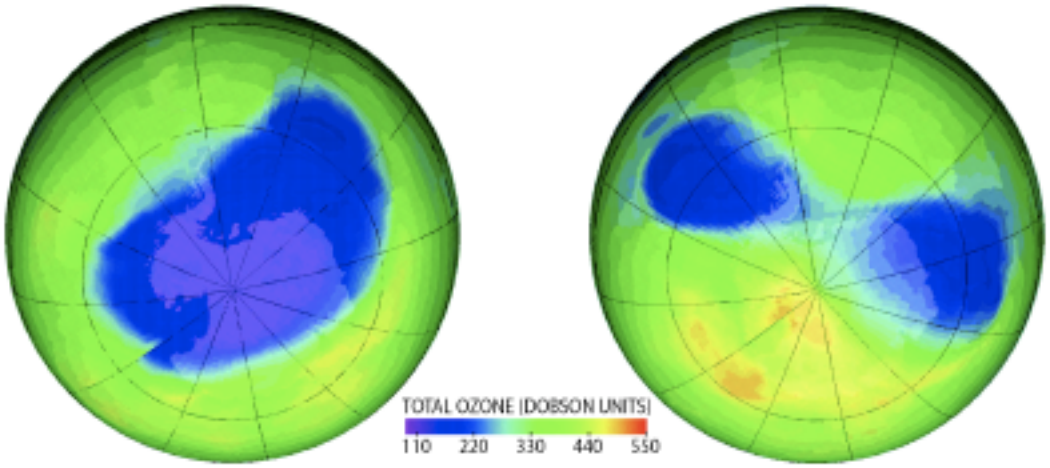


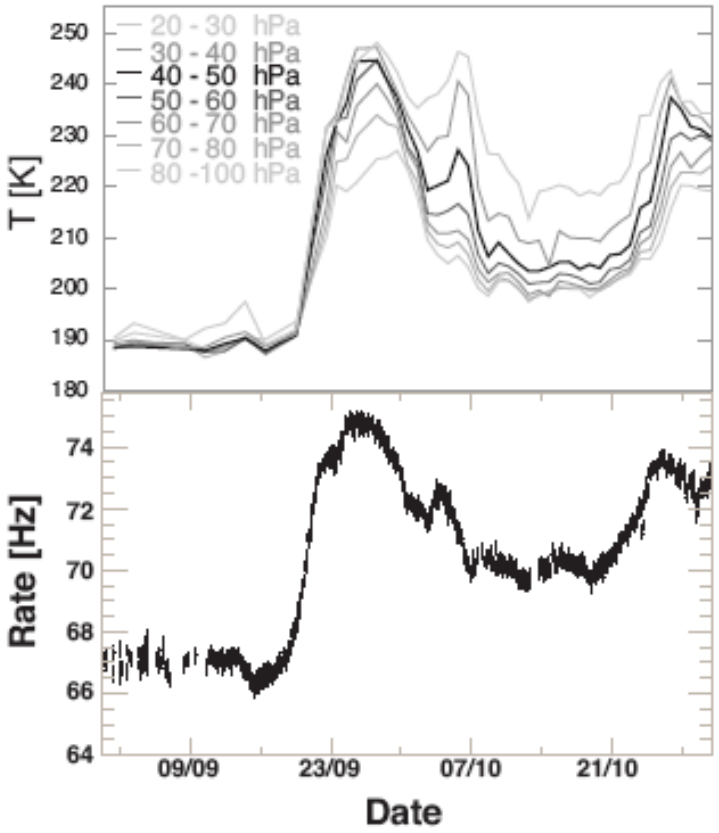
- The correlation between IceCube's event rate and atmospheric temperature variation is quite striking

Atmospheric Science - Split in Ozone Hole

Sept 20

Sept 25





- Sudden Stratospheric Warming event

- IceCube monitors atmospheric changes – mostly for improved understanding of atmospheric CR shower development

Wrap Up

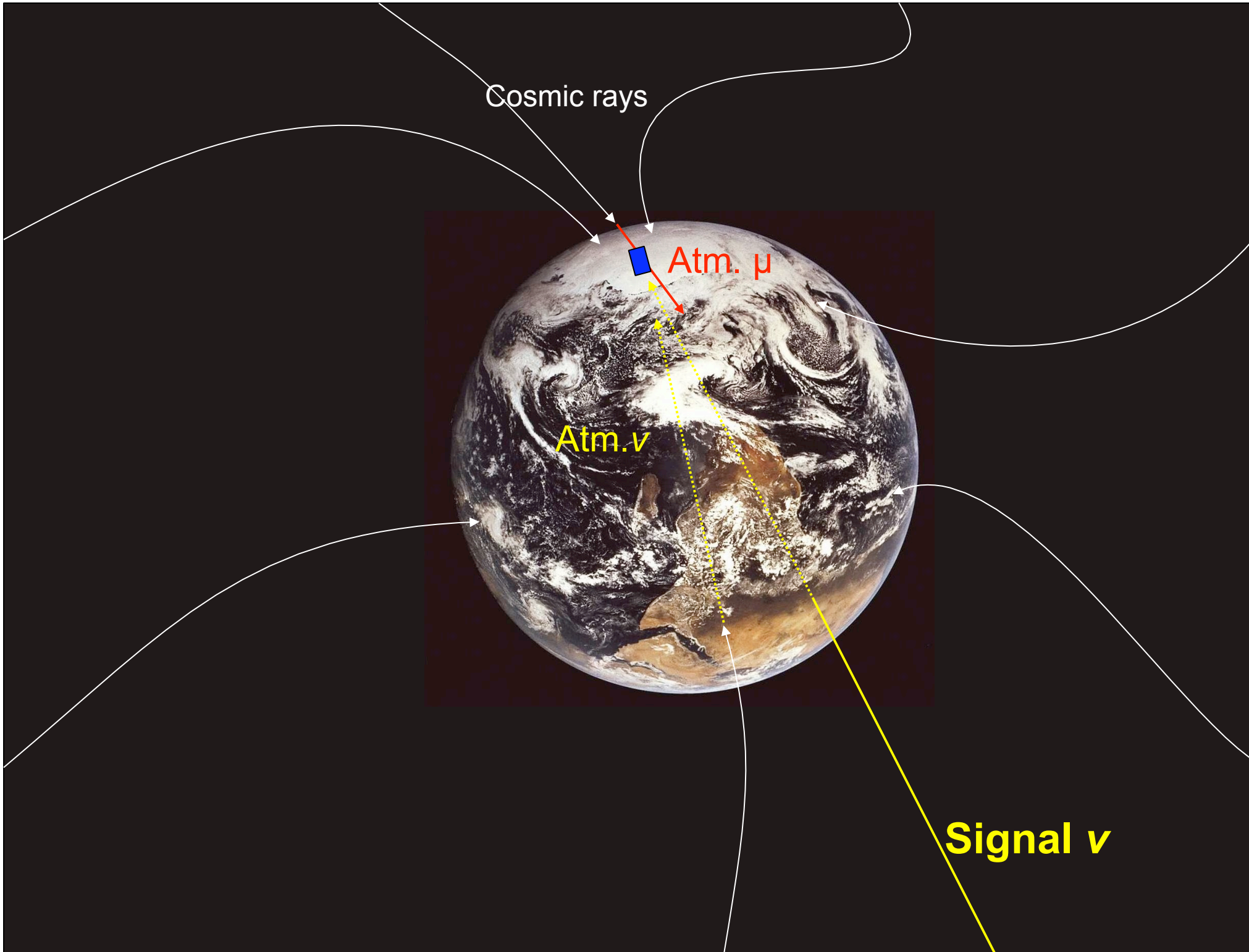
- High energy astronomy is in need of a new messenger
  - Cosmic Rays deflected by magnetic fields
  - High energy light is absorbed over long distance

  ⇒Neutrinos

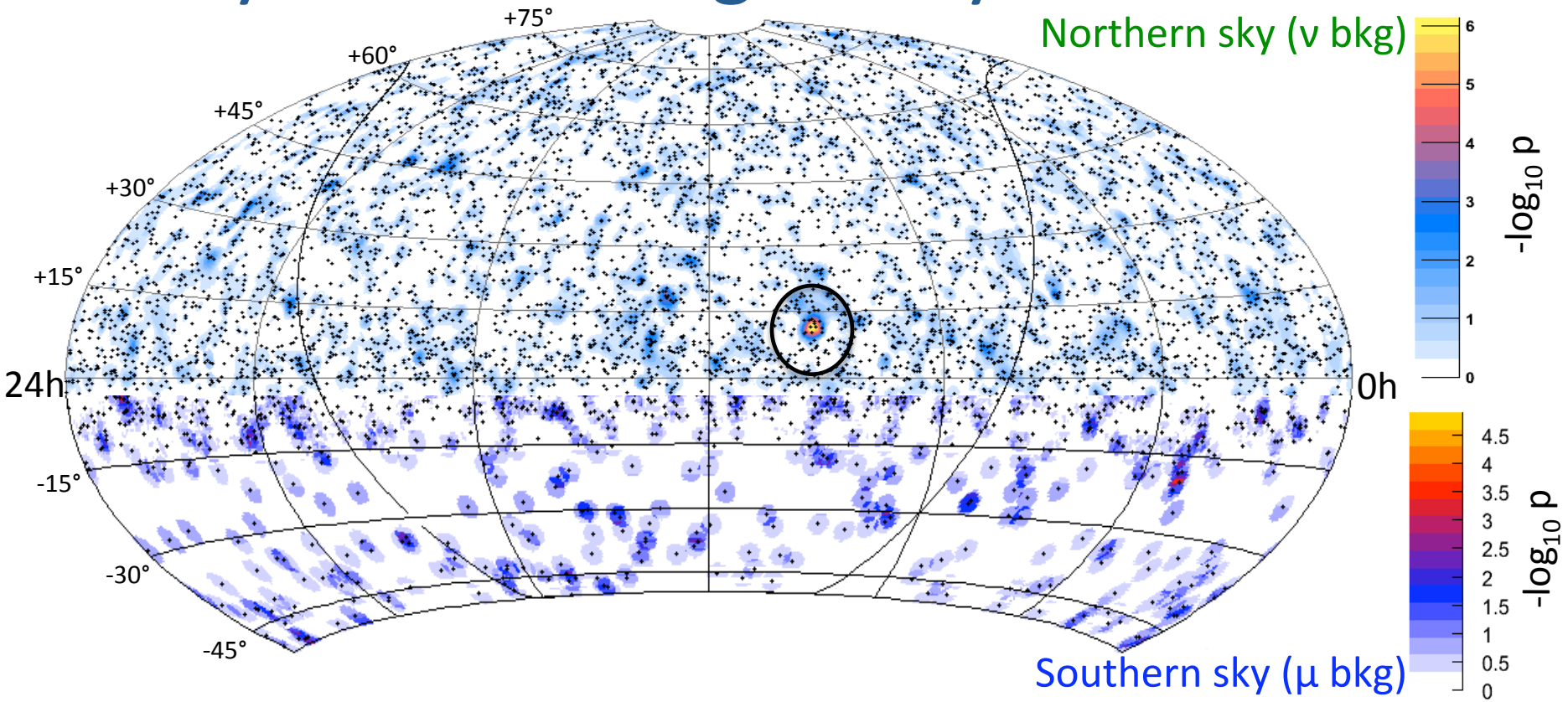
- IceCube is the first 1 km^3 neutrino observatory
  - Construction at the South Pole is nearly complete (79/86)
  - Analysis is proceeding as detector is being built

- IceCube addresses a wide range of science topics (no signal yet!)
  - Point-like sources
  - Indirect dark matter searches
  - Cosmic ray physics, atmospheric science
  - (exotic particle physics, glaciology, paleo-climatology)

  ⇒Expect sources within 2-3 yrs of full operation or we begin the long process of ruling out CR sources


Cosmic rays
Atm. μ
Atm.ν
Signal ν

Last year: 22-string all-sky results



First IceCube analysis extended to -50° dec

PRL 103, 221102 (2009)