Solar Physics with IceTop

(How I Learned to Stop Worrying and Love the South Pole)

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ThaisCube

Chiang Mai

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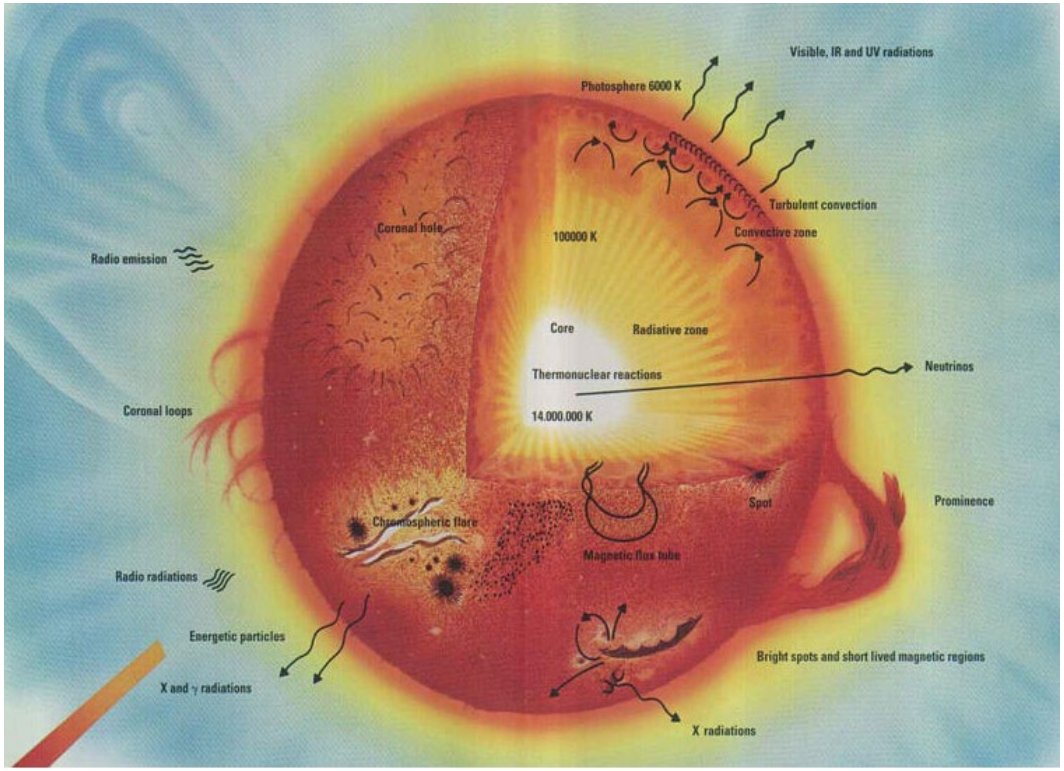
The Sun is a Giant Heat Engine

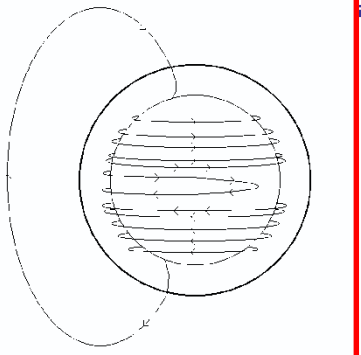


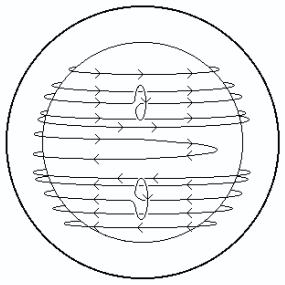
It takes approximately one million years for the energy to be conducted (by radiation) to the outer part of the sun.

Near the surface, convective motion sets in

Approximately 100,000 years of sunlight is stored in the convection zone

The Heat Engine Powers a Magnetic Dynamo

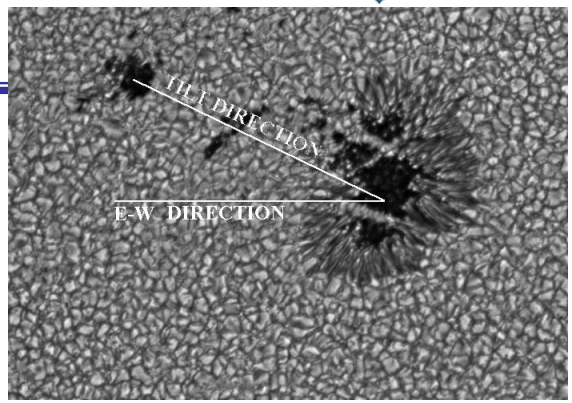




Magnetic fields within the Sun are stretched out and wound around the Sun by differential rotation

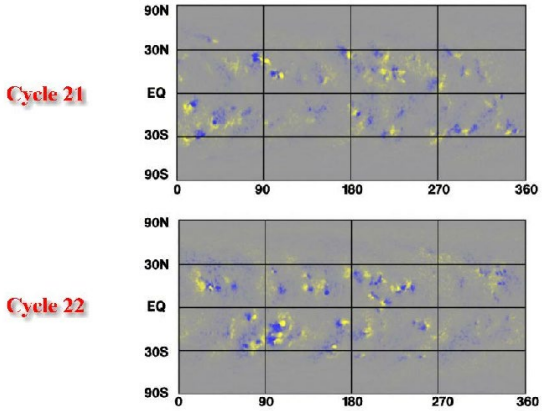
This is called the *omega-effect* after the Greek letter used to represent rotation.

The Sun's differential rotation with latitude can take a north-south oriented magnetic field line and wrap it once around the Sun in about 8 months.



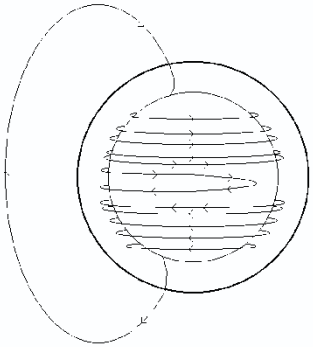
Hale's Polarity Law:

The polarity of the leading spots in one hemisphere is opposite that of the leading spots in the other hemisphere and the polarities reverse from one cycle to the next.

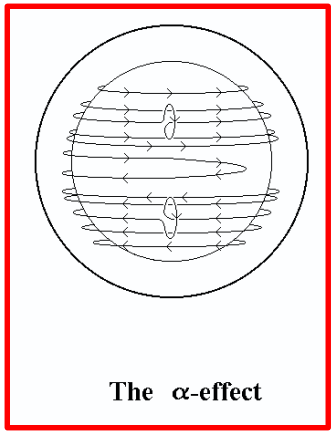


- http://solarscience.msfc.nasa.gov/dynamo.shtml

The Heat Engine Powers a Magnetic Dynamo



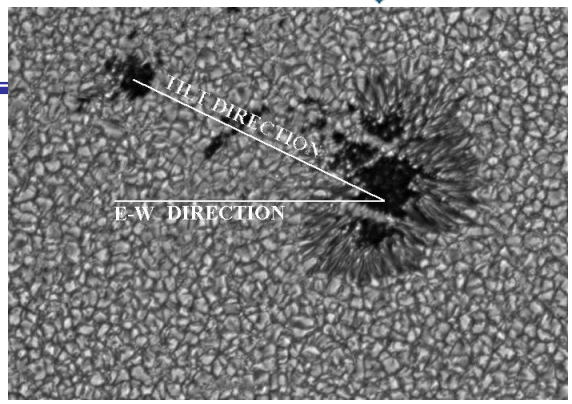
The ω-effect



The α-effect

Twisting of the magnetic field lines is called the *alpha-effect* after the Greek letter that looks like a twisted loop.

Early models of the Sun's dynamo assumed that the twisting is produced by the effects of the Sun's rotation on very large convective flows that carry heat to the Sun's surface.



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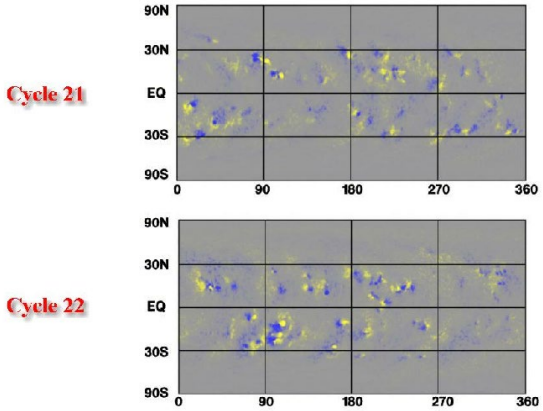

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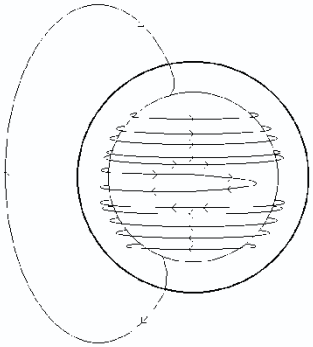
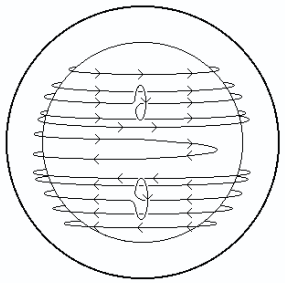
The Heat Engine Powers a Magnetic Dynamo



The ω-effect

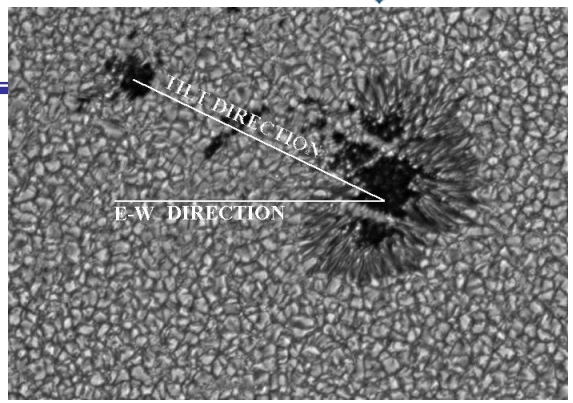


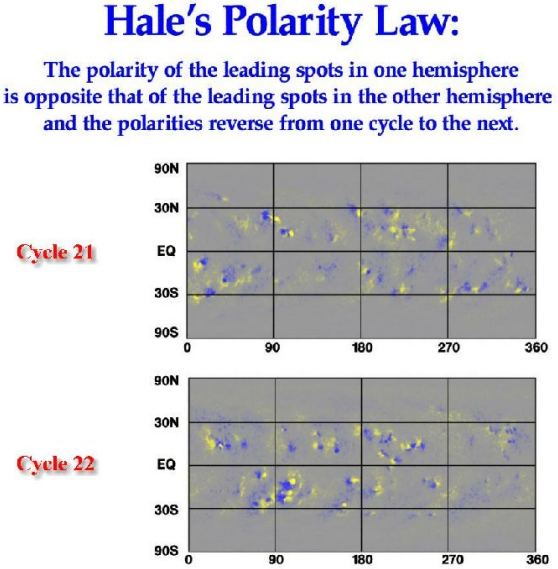
The α-effect

More recent dynamo models assume that the twisting is due to the effect of the Sun's rotation on the rising "tubes" of magnetic field from deep within the Sun.

The twist produced by the alpha effect makes sunspot groups that obey “Joy’s law” – the relation of the angle between sunspots in a group to location on the sun.

It also makes the magnetic field reverse from one sunspot cycle to the next (Hale’s Law).





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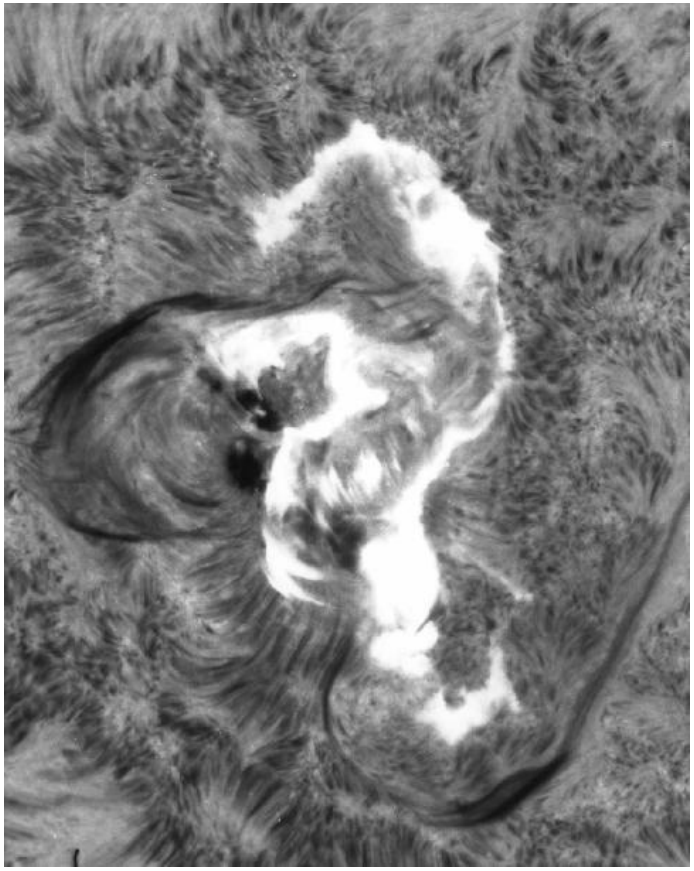
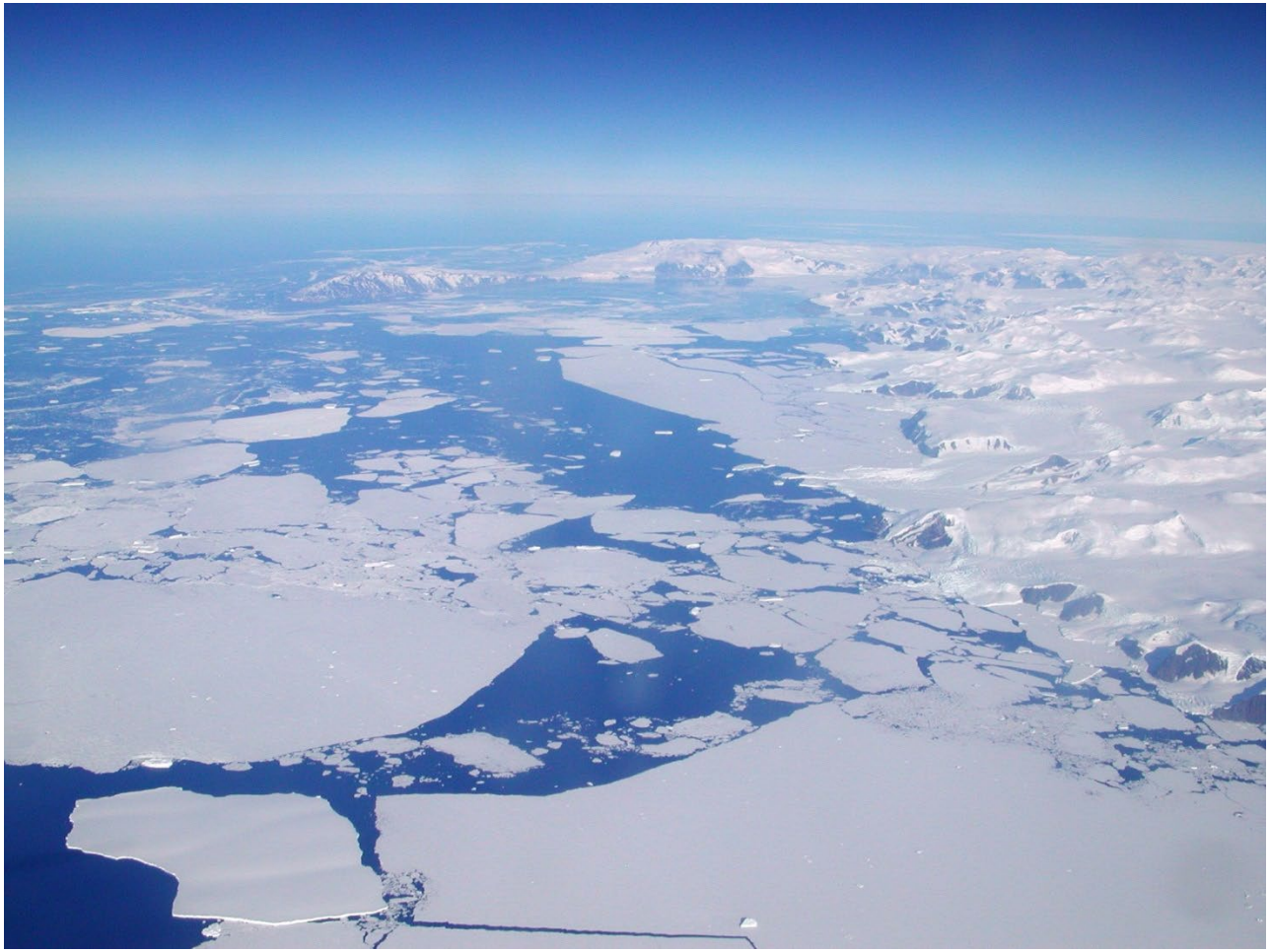
Magnetic Energy Powers Flares



- Somewhere in this picture, particles are being accelerated to GeV energy.
- Can you tell where?
- I certainly cannot!
- Possibly different mechanisms are even operating at the same time.

What Does This Have to do with Antarctica?



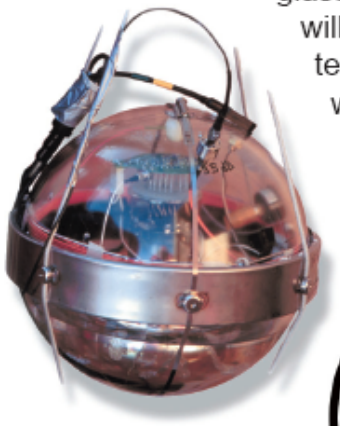
The IceCube Project: A New View of the Universe from the South Pole

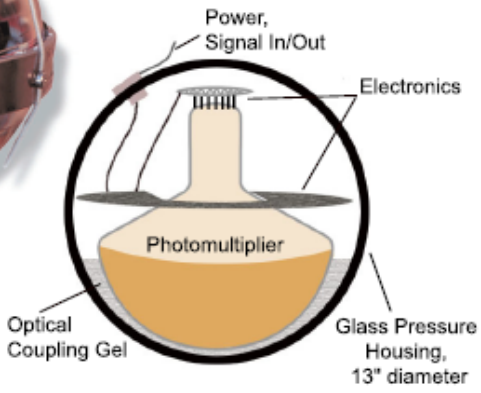
Ice Cube Collaboration

Ice Cube Operation

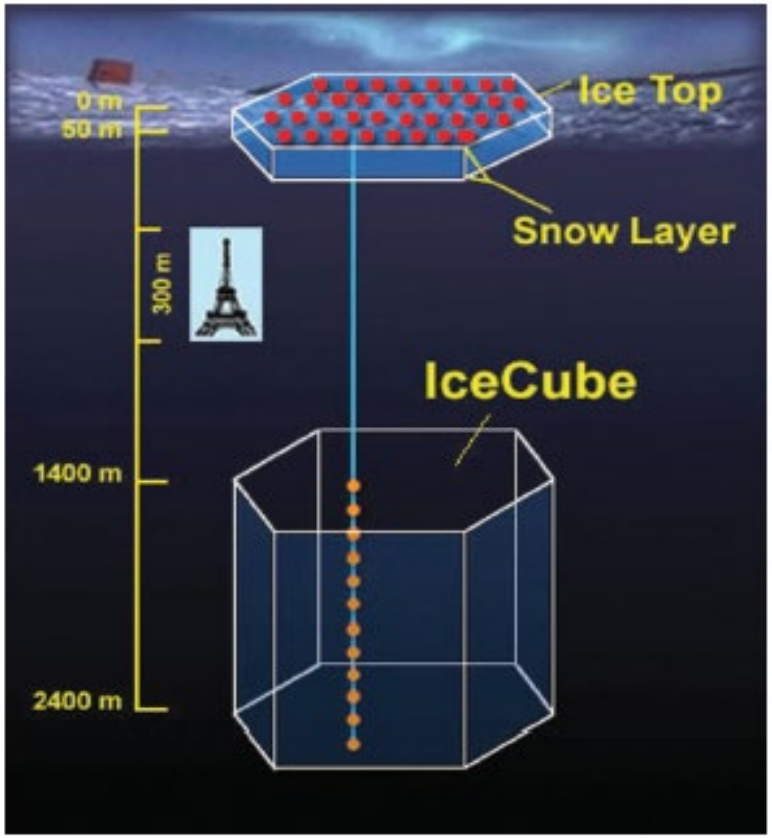
How does IceCube "see" a neutrino?

Like its predecessor, AMANDA, the basic component of IceCube is the sensor that transforms light into electrical signals. A sensor is a photomultiplier tube housed in a glass pressure vessel; IceCube will boast nearly 5000. The technology used in IceCube will be more advanced than that of AMANDA. IceCube will have "smart"





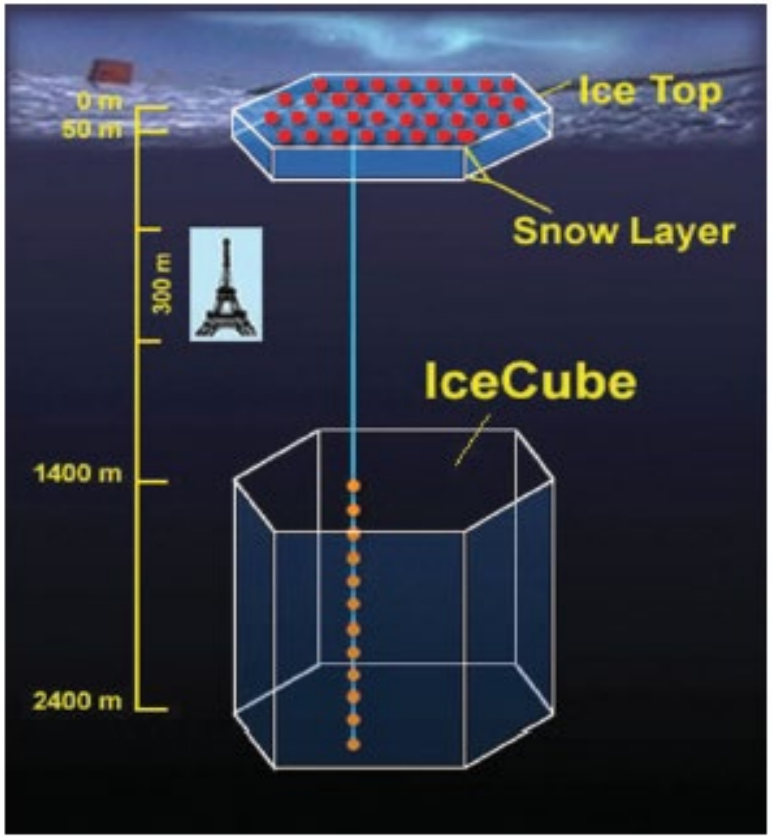
sensors, meaning that each sensor will contain a computer chip connected through the internet to computers in scientists' offices! It is not too fanciful to think of the device as a cubic-kilometer, continuously sensing computer.

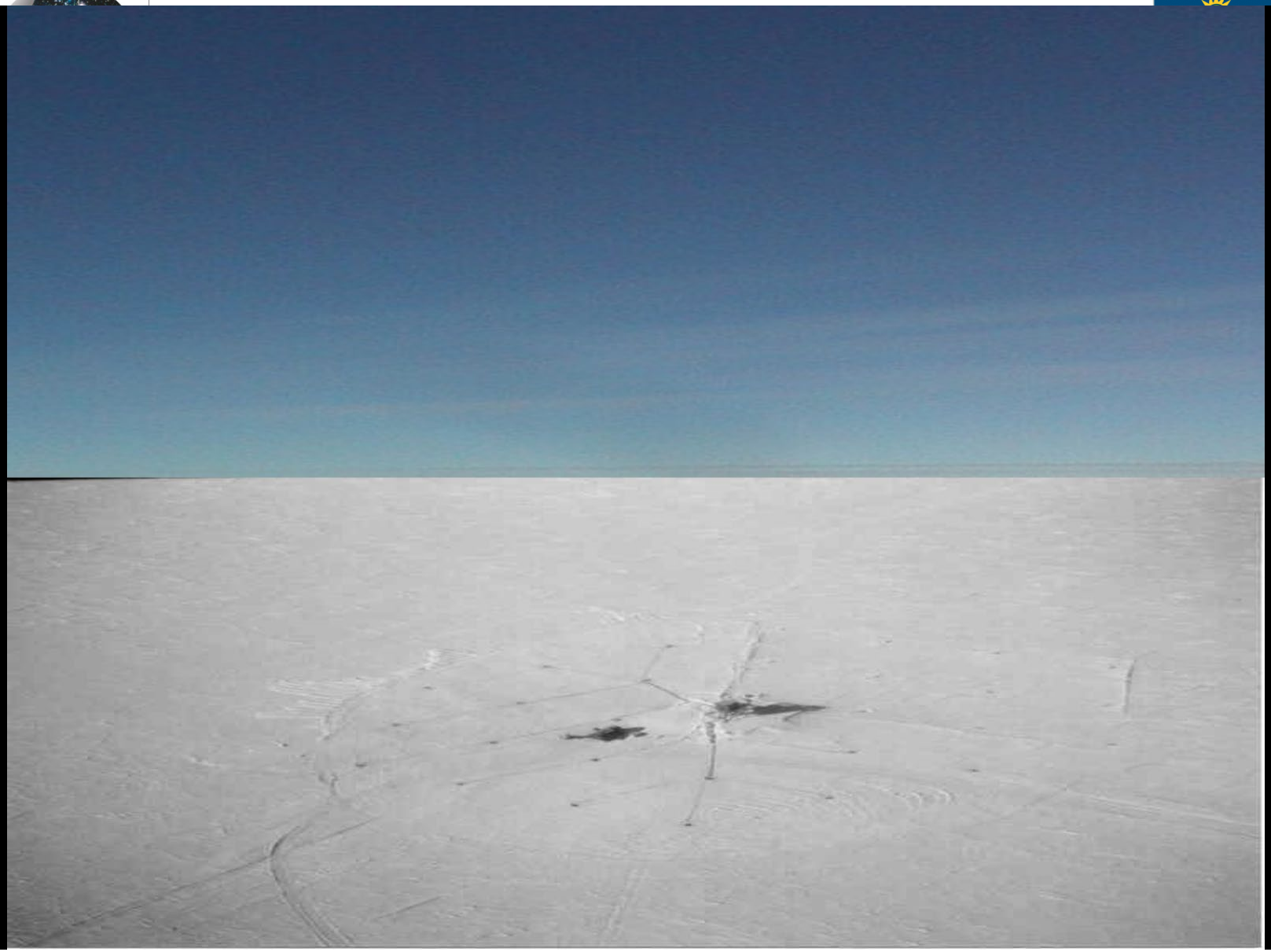


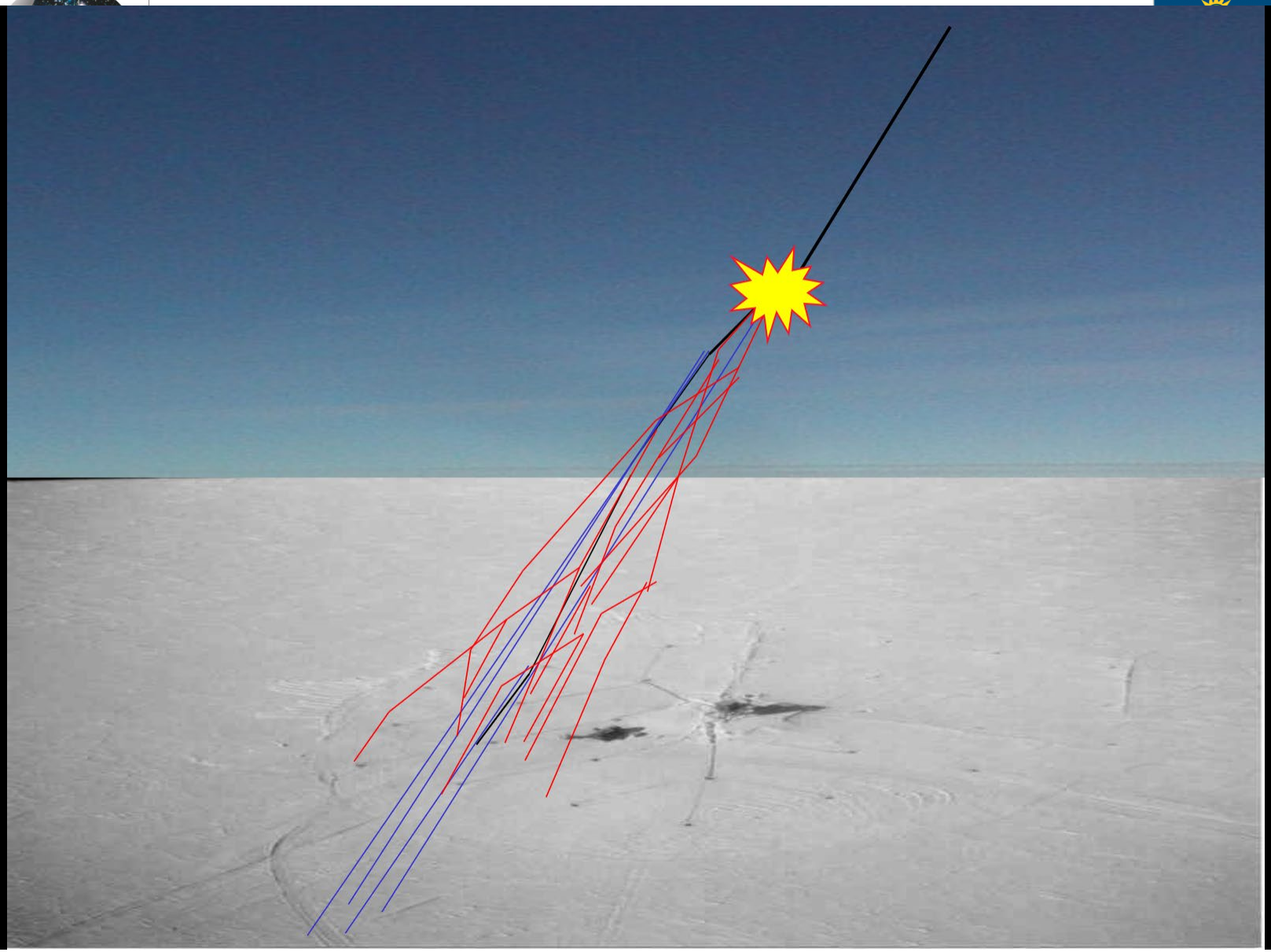
The Surface Air Shower Array (IceTop)

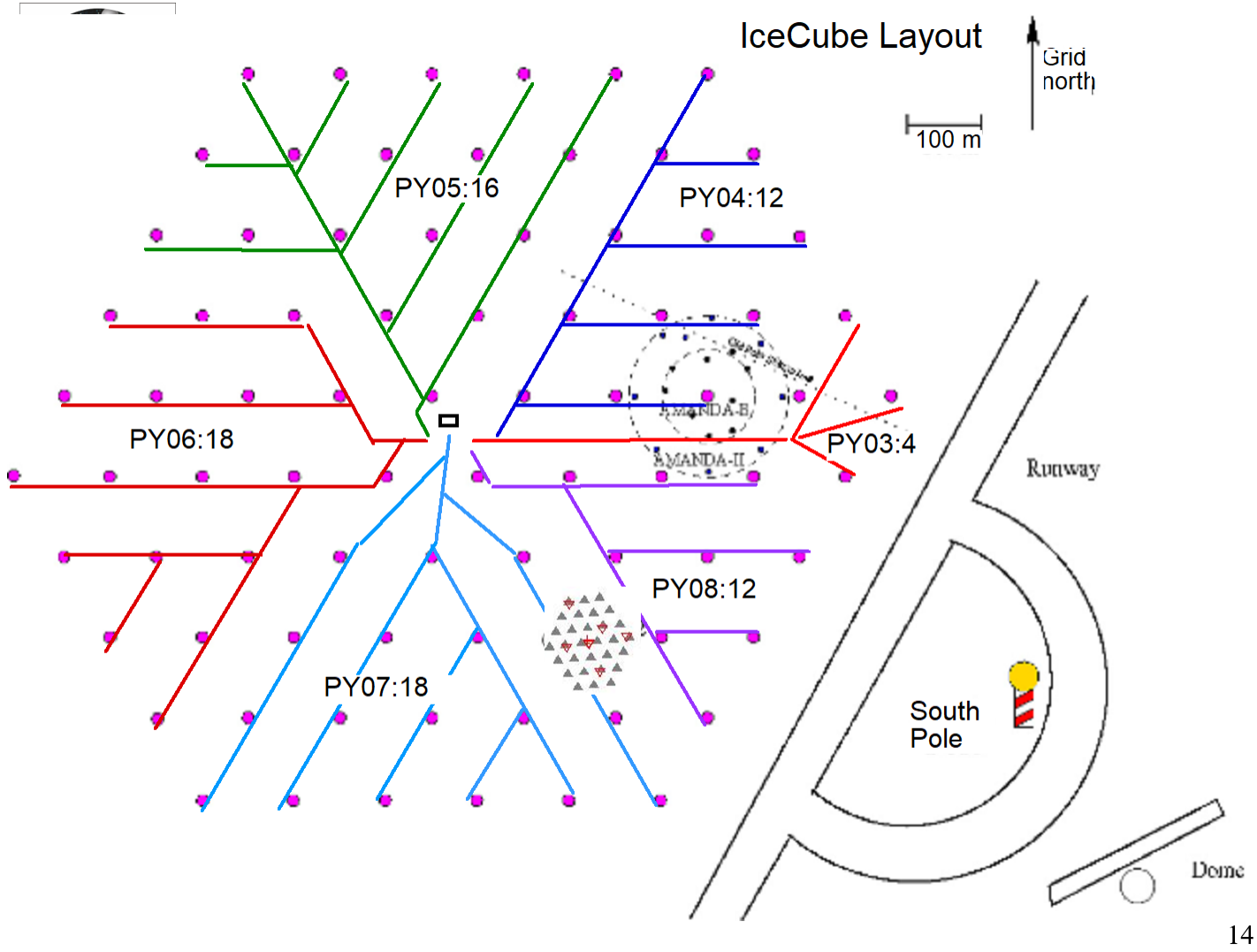
Developing and deploying the surface air shower detector is where I spent most of my time, so I focus on the unexpected results from that part of the detector.

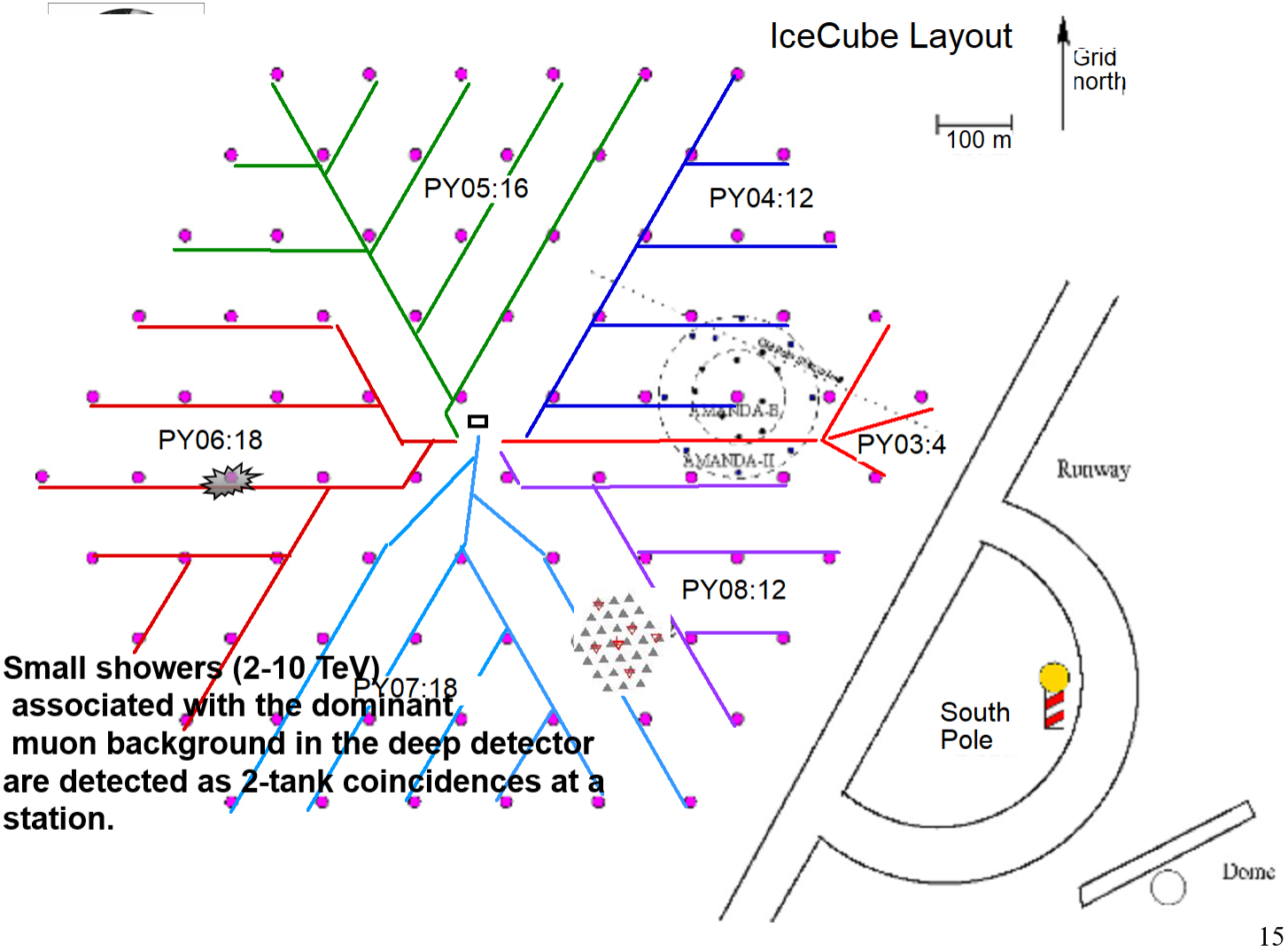
It is also an important part of the collaboration with Mahidol and Chiang Mai.



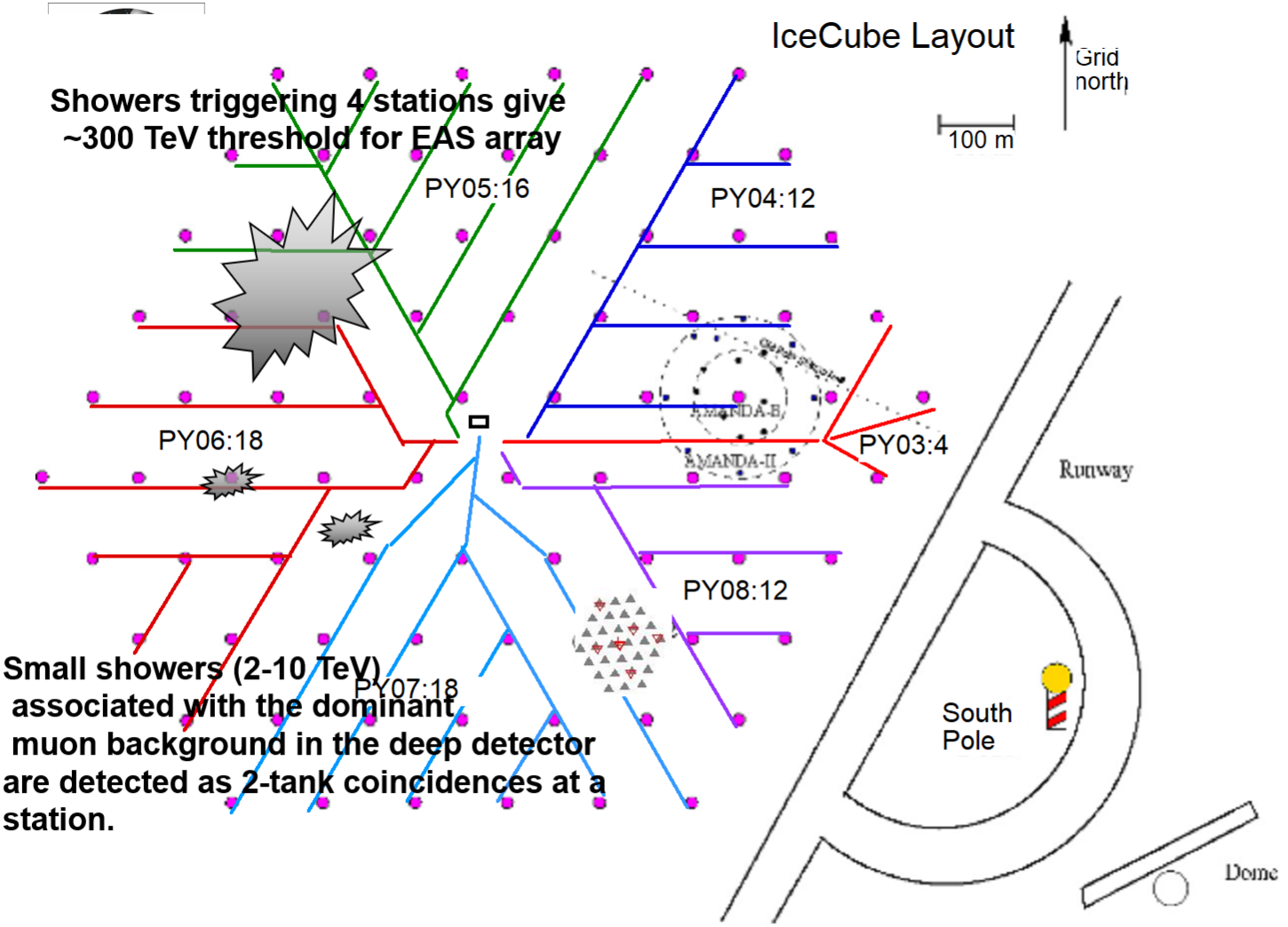





IceCube Layout
Grid north
100 m
PY05:16
PY04:12
PY06:18
PY03:4
AMANDA-B
AMANDA-II
PY08:12
PY07:18
Runway
South Pole
Dome
14



Small showers (2-10 TeV) associated with the dominant muon background in the deep detector are detected as 2-tank coincidences at a station.


IceCube Layout
Grid north
100 m
Showers triggering 4 stations give ~300 TeV threshold for EAS array
PY05:16
PY04:12
PY06:18
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AMANDA-B
AMANDA-II
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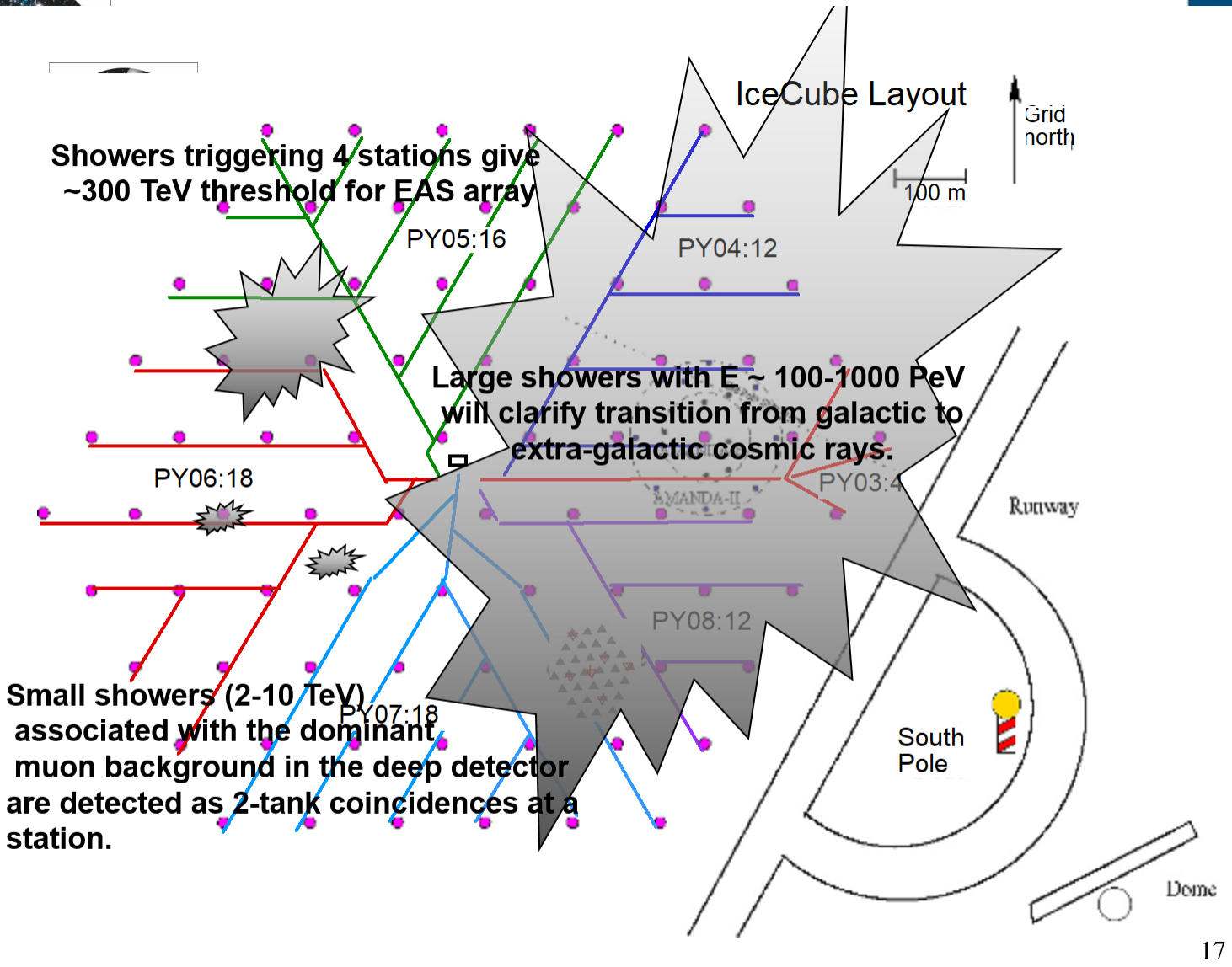
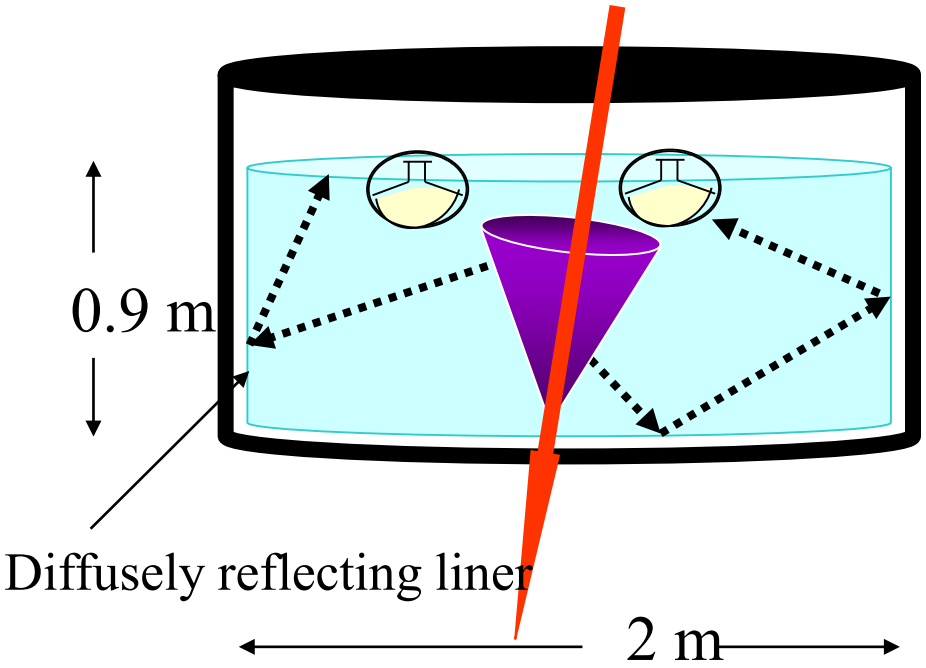
Runway
South Pole
Dome

16


IceCube Layout
Grid north
100 m
Showers triggering 4 stations give ~300 TeV threshold for EAS array
PY05:16
PY04:12
Large showers with E ~ 100-1000 PeV will clarify transition from galactic to extra-galactic cosmic rays.
PY06:18
PY03:4
AMANDA-II
Runway
PY08:12
Small showers (2-10 TeV) associated with the dominant muon background in the deep detector are detected as 2-tank coincidences at a station.
PY07:18
South Pole
Dome
17

IceTop Detectors

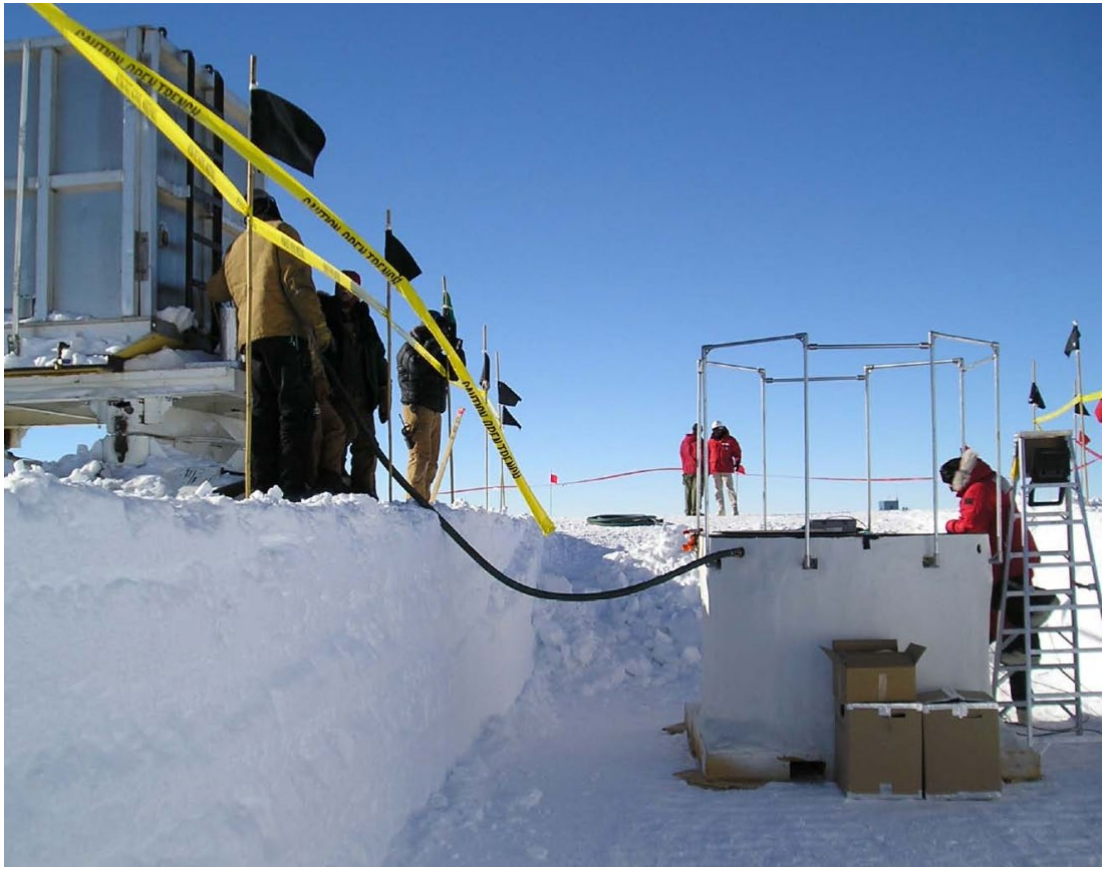


- Blocks of clear ice produced in tanks at the Pole
- Cherenkov radiation measured by standard IceCube photon detectors
- Two tanks separated by 10 meters form a station

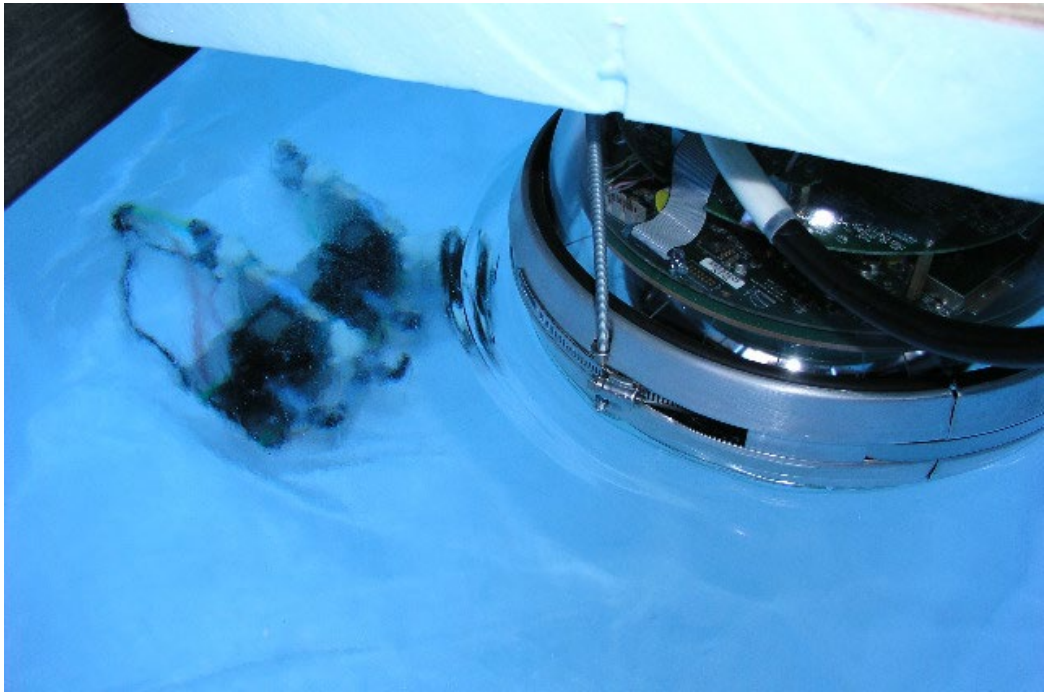
Getting to Antarctica: Christchurch, NZ

Installing the Detector "Tanks"

Fill Tanks with Water then Just Let Them Freeze



Removing Dissolved Air Produces Perfectly Clear Ice

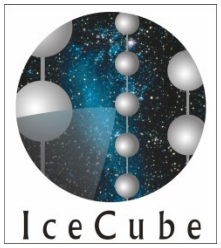


Dual degassing units are seen under 75 cm of ice

DOMs are frozen into the ice

Finishing the Detector

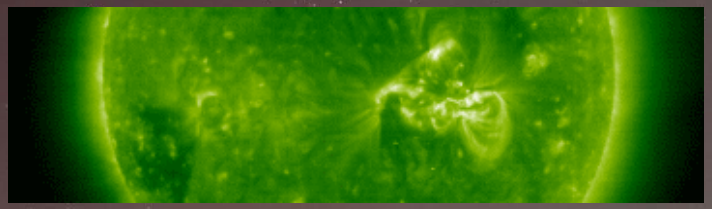
- After filling the void at the top with perlite the lid is screwed down on the tank.
- In about 100,000 years these will fall off the coast of Antarctica, to the great surprise of some fish or another.



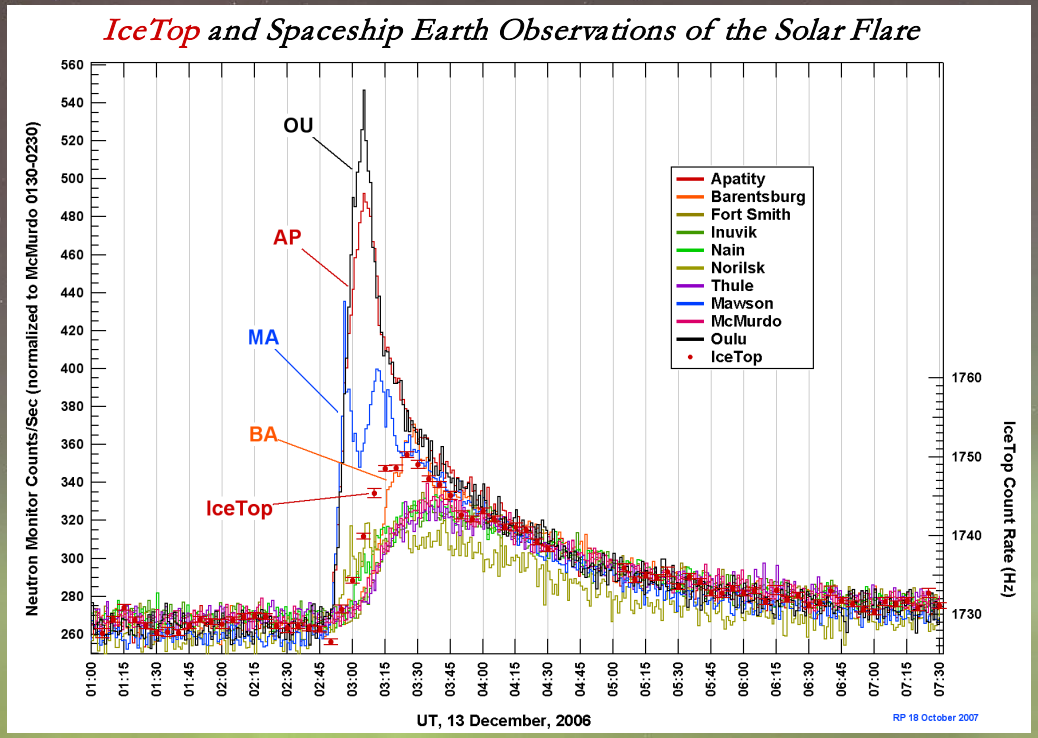
Solar Particles in IceTop

- It never occurred to us originally that IceTop could be used as a complement to the neutron monitor network.
- This realization has developed over time, and has been a significant part of my research for several years.
- As part of a huge collaboration, one has to find a niche in keeping with personal interest and expertise.

The First Extraterrestrial Event Detected by IceCube

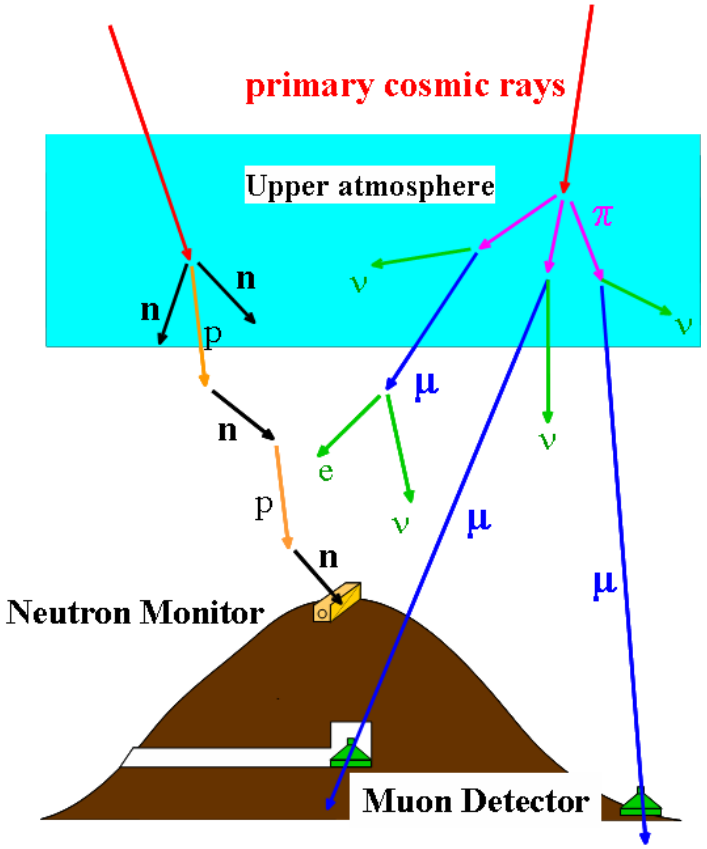


Dec 13, 2006 X3-Class Solar Flare (SOHO)

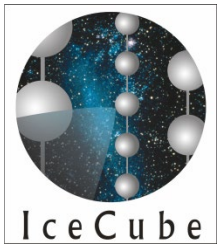


Dec 14, 2006 photograph of auroras near Madison, WI

"Showers" from Low Energy (1 - 10 GeV) Primary Particles



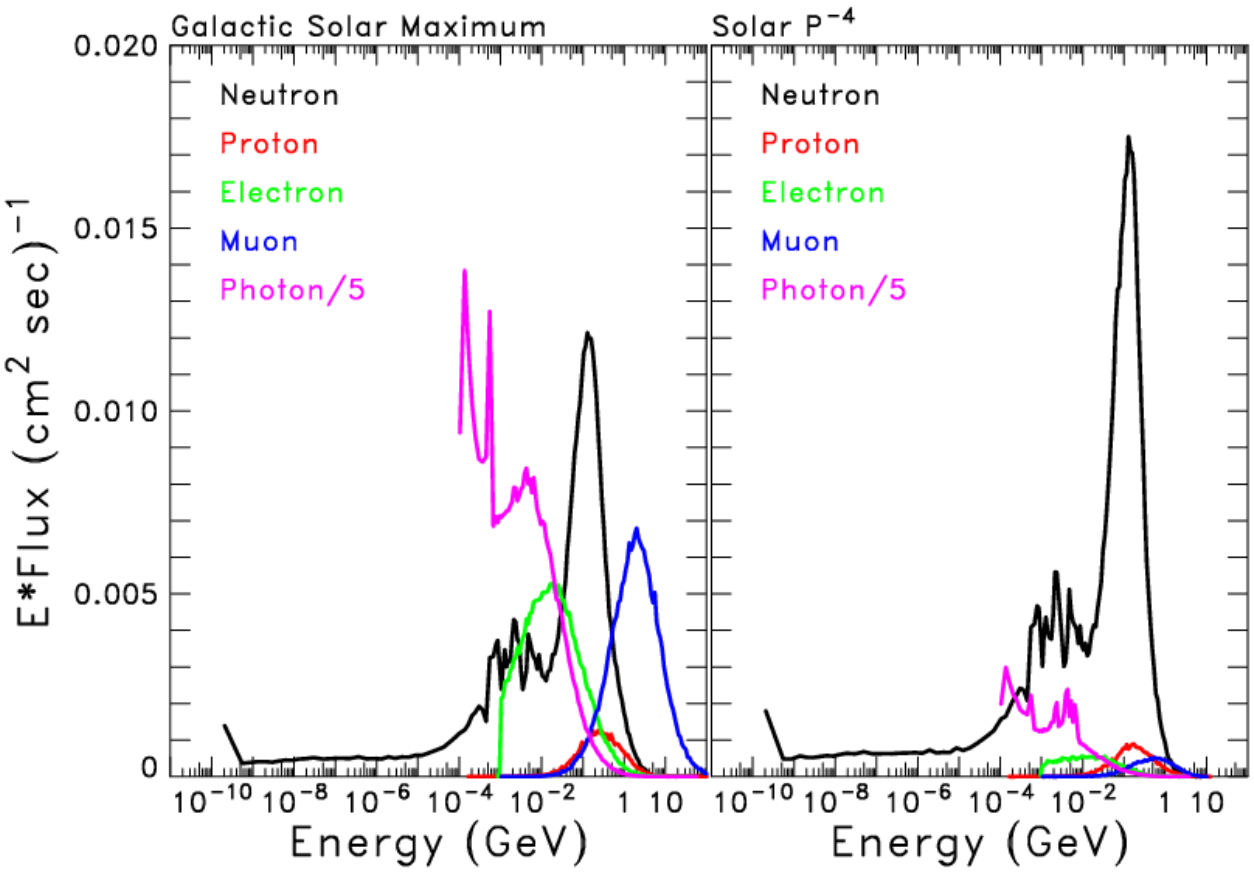
- Particles with energy as low as 1 GeV produce secondaries that survive to the surface
- Rarely does a single detector see more than one secondary from a primary
- Large detectors can have high enough counting rates to make statistically significant measurements of the primary flux
- Conventional detectors count muons or neutrons



Why IceTop Works as a GeV Particle Spectrometer

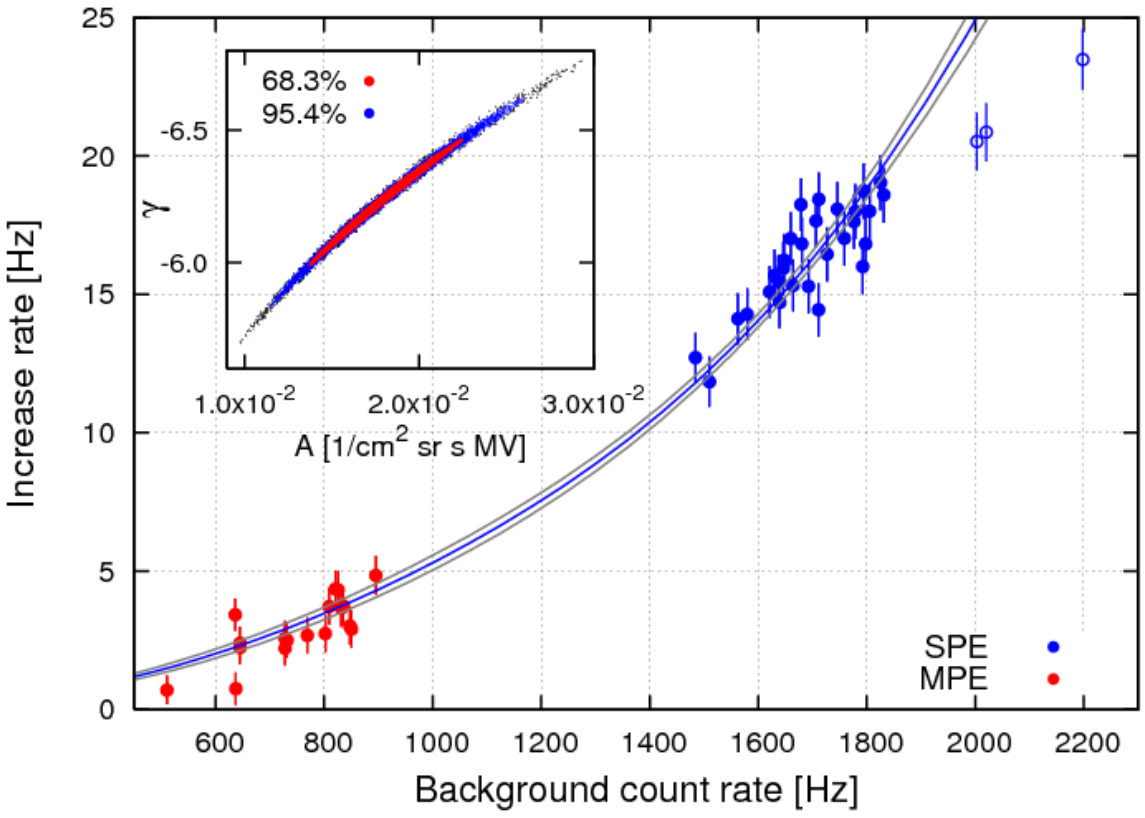
- Neutron monitors are comparatively insensitive to the particle spectrum
- IceTop detectors are thick (90 g/cm^2) so the Cherenkov light output is a function of both the species and energy of incoming particles
- Individual waveform recording, and extensive onboard processing, allow the return of pulse height spectra with ten second time resolution even at the kilohertz counting rate inherent to the detector

Secondary Particle Spectra



- At the South Pole, spectra of secondary particles "remember" a lot of information about the primary spectrum.

Solar Particle Spectrum Published in Ap J Letters



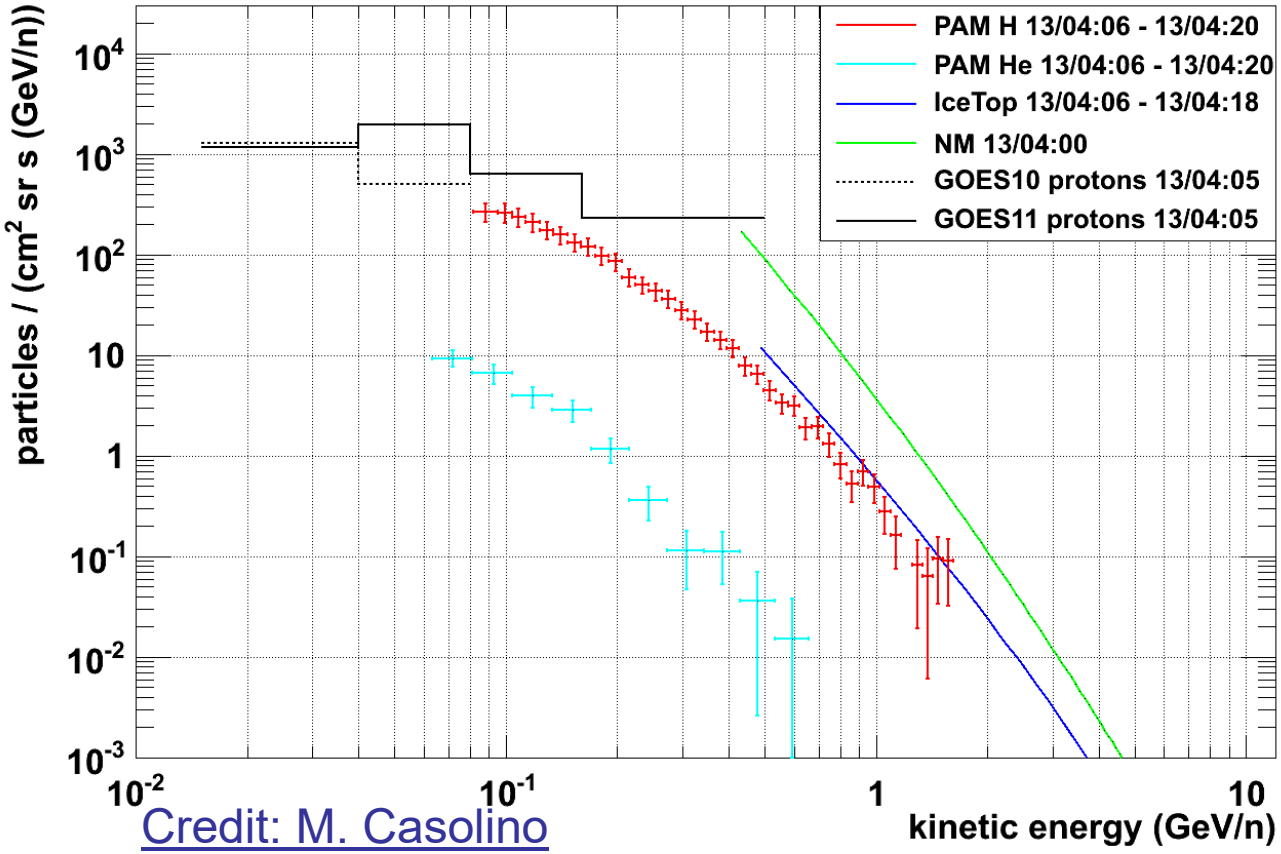
Excess count rate (averaged over approximately one hour near the peak of the event) as a function of pre-event counting rate.

Each point represents one discriminator in one DOM.

By using the response function for each DOM we fit a power law (in momentum) to the data assuming that the composition is the same as galactic cosmic rays

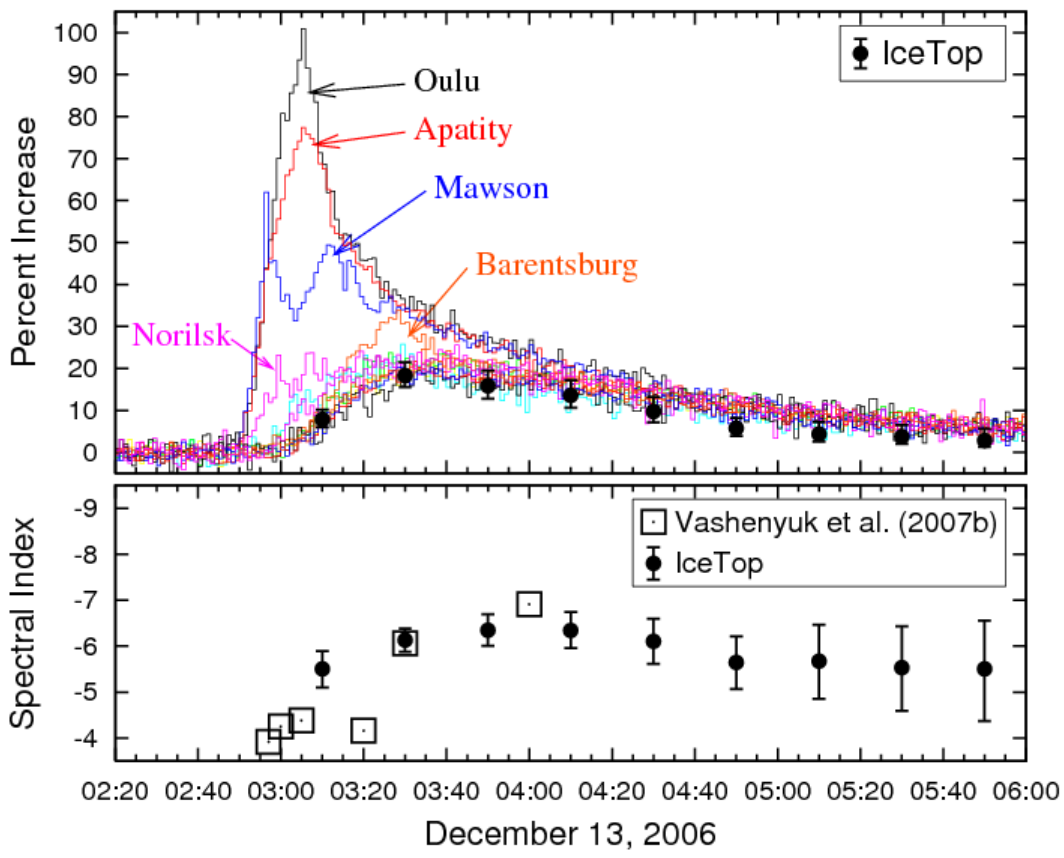
The lines show this fit and the one sigma (systematic) errors

IceTop and PAMELA

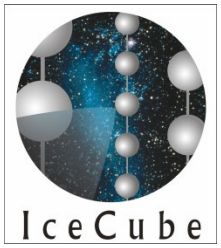


Credit: M. Casolino

Neutron Monitors and IceTop



- Good agreement (with understanding of viewing direction)
- Continuous determination of precise spectrum
- All information on anisotropy comes from the monitor network
- Here we see the failure of the “separability” assumption in neutron monitor network analysis



Conclusions

- IceTop is a powerful new tool in the study of energetic solar particles
- I did not understand this when I agreed to work on it as “a favor to a friend”
- Moral: Keep your eyes open – in physics an opportunity is always there, one just has to recognize it!
- Now we just hope that the sun has not gone to sleep