

Title: The Nature and Origin of Cosmic Rays

Date: Oct 04, 2006 02:00 AM

URL: <http://pirsa.org/06100003>

Abstract: Conventional wisdom holds that the majority of high energy atomic nuclei ("cosmic rays") that continually rain upon the Earth originate in galactic supernova shock waves, although some different (likely extragalactic) origin must be invoked to explain the highest energy particles. Despite many decades of intensive research on the subject, only indirect clues to these ideas exist at present. Direct measurements of the spectrum and mass composition of high energy cosmic rays are needed to validate these notions, but are hampered by rapidly dwindling fluxes with energy. Indeed, there is an expectation that the cosmic nuclei should have progressively more charge (and therefore mass), on average, with increasing energy, up to the astrophysical "knee" (spectral break) in the spectrum at around  $3 \times 10^{15}$  eV. At energies beyond the knee, only indirect measurements are possible. The CREAM (Cosmic Ray Energetics And Mass) experiment is a complex particle detector flown by high altitude balloon to directly measure the charge and energy of the cosmic rays at energies near the spectral knee. It flew successfully in Antarctica in Dec 04 / Jan 05 for a record-breaking 42 days, and again in Dec 05 / Jan 06. We will review the science and performance of the instrument in flight, and present preliminary results and discuss prospects for additional CREAM missions. The Auger experiment is the largest cosmic ray detector ever built, currently nearing completion in Argentina, covering an area of  $3000 \text{ km}^2$ . Its aim is to resolve a number of mysteries surrounding the highest energy cosmic rays, beyond  $10^{18}$  eV, whose very existence and ability to reach the Earth are difficult to understand. The rarity of the highest energy particles has precluded definitive answers to the question of their nature and origin, and indeed some controversy surrounds the existing experimental evidence. The Auger experiment will afford an order of magnitude improvement in statistics over previous efforts, as well as much improved control of systematics. We will briefly review the science of the highest energy cosmic rays and present first results obtained with the growing Auger array, and discuss plans for the future of these efforts.

# The Nature and Origin of Cosmic Rays

Stéphane Coutu  
Penn State University

Perimeter Institute  
Colloquium  
4 October, 2006

## Outline

- Cosmic Rays
  - Origin and Propagation
  - Clues: Composition, Spectrum,  
Secondary-to-Primary Abundances

# The Nature and Origin of Cosmic Rays

Stéphane Coutu  
Penn State University

Perimeter Institute  
Colloquium  
4 October, 2006

## Outline

- Cosmic Rays
  - Origin and Propagation
  - Clues: Composition, Spectrum,  
Secondary-to-Primary Abundances

# The Nature and Origin of Cosmic Rays

Stéphane Coutu  
Penn State University

Perimeter Institute  
Colloquium  
4 October, 2006

## Outline

- Cosmic Rays
  - Origin and Propagation
  - Clues: Composition, Spectrum,  
Secondary-to-Primary Abundances
- The CREAM Experiment:  
High Energy Cosmic Rays
  - Instrument Layout, Performance
  - First Antarctic Campaigns 04/05, 05/06
  - Preliminary Results

# The Nature and Origin of Cosmic Rays

Stéphane Coutu  
Penn State University

Perimeter Institute  
Colloquium  
4 October, 2006

## Outline

- Cosmic Rays
  - Origin and Propagation
  - Clues: Composition, Spectrum,  
Secondary-to-Primary Abundances
- The CREAM Experiment:  
High Energy Cosmic Rays
  - Instrument Layout, Performance
  - First Antarctic Campaigns 04/05, 05/06
  - Preliminary Results



# The Nature and Origin of Cosmic Rays

Stéphane Coutu  
Penn State University

Perimeter Institute  
Colloquium  
4 October, 2006

## Outline

- **Cosmic Rays**
  - Origin and Propagation
  - Clues: Composition, Spectrum,  
Secondary-to-Primary Abundances
- **The CREAM Experiment:  
High Energy Cosmic Rays**
  - Instrument Layout, Performance
  - First Antarctic Campaigns 04/05, 05/06
  - Preliminary Results
- **The Pierre Auger Observatory:  
Highest Energy Cosmic Rays**
  - Instrument Design, Performance
  - Status
  - First Results



# The Nature and Origin of Cosmic Rays

Stéphane Coutu  
Penn State University

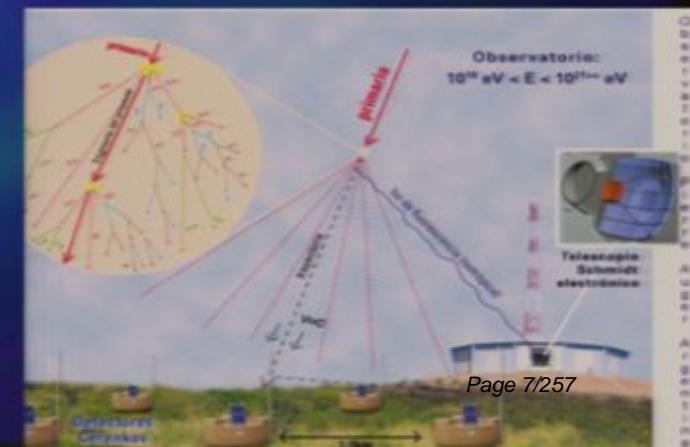
Perimeter Institute  
Colloquium  
4 October, 2006

## Outline

- Cosmic Rays
  - Origin and Propagation
  - Clues: Composition, Spectrum,  
Secondary-to-Primary Abundances
- The CREAM Experiment:  
High Energy Cosmic Rays
  - Instrument Layout, Performance
  - First Antarctic Campaigns 04/05, 05/06
  - Preliminary Results
- The Pierre Auger Observatory:  
Highest Energy Cosmic Rays
  - Instrument Design, Performance
  - Status
  - First Results



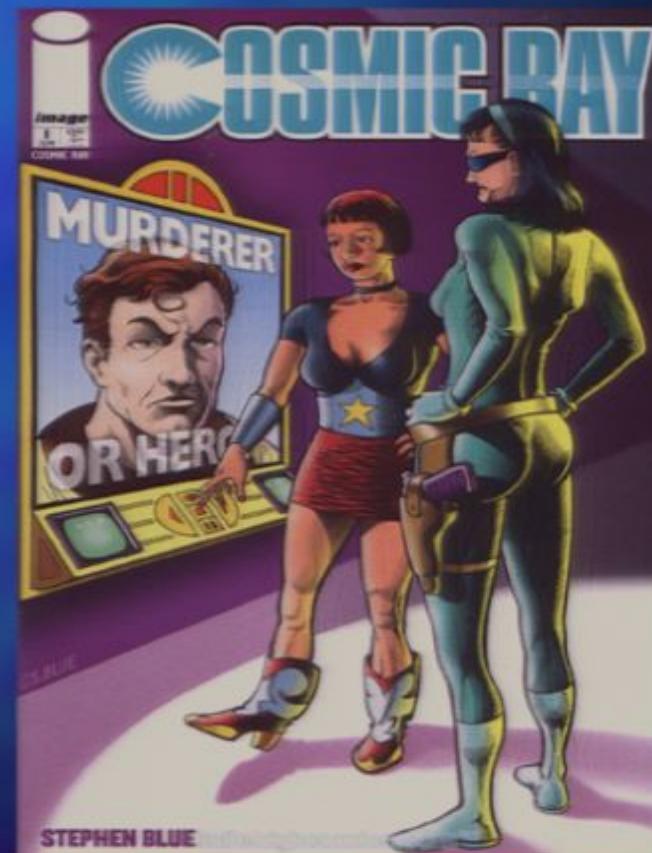
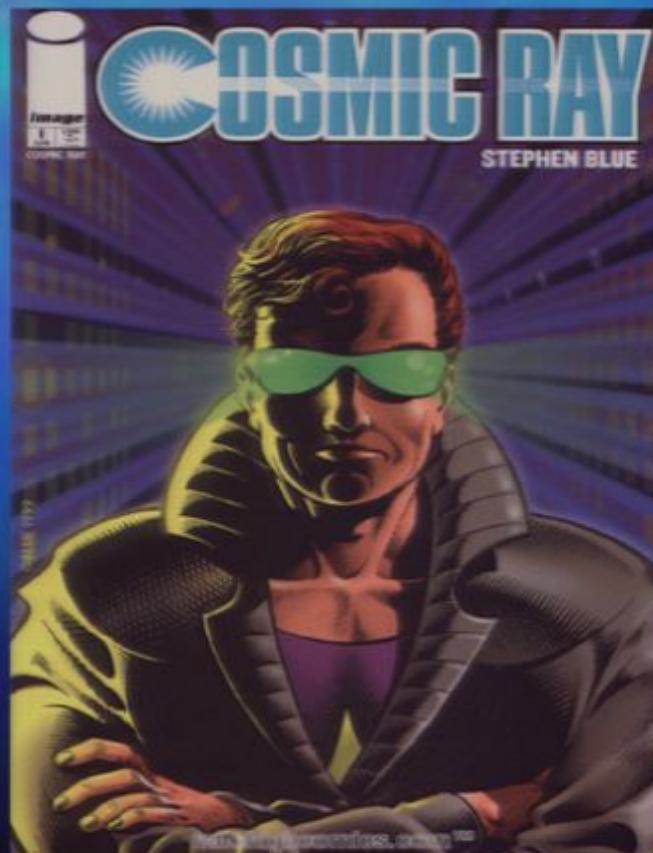
Pirsa: 06100003



Page 7/257

# Cosmic Rays on

# Cosmic Rays on ebay

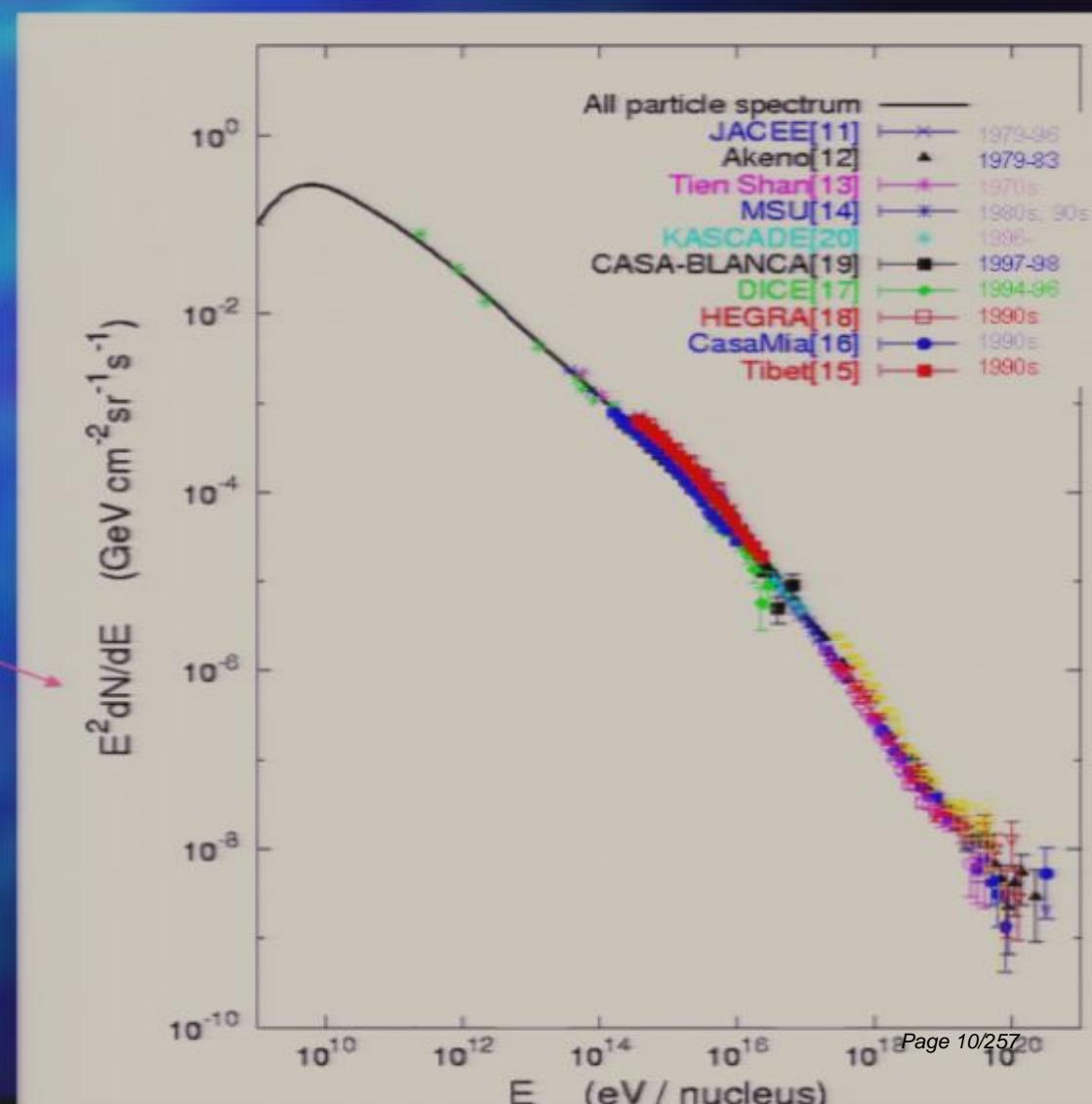


# The Cosmic Ray Spectrum

## Cosmic rays:

- high energy nuclei from H to Fe;
- $10^9$  eV to  $>10^{20}$  eV.

Fluxes rescaled by  $E^2$

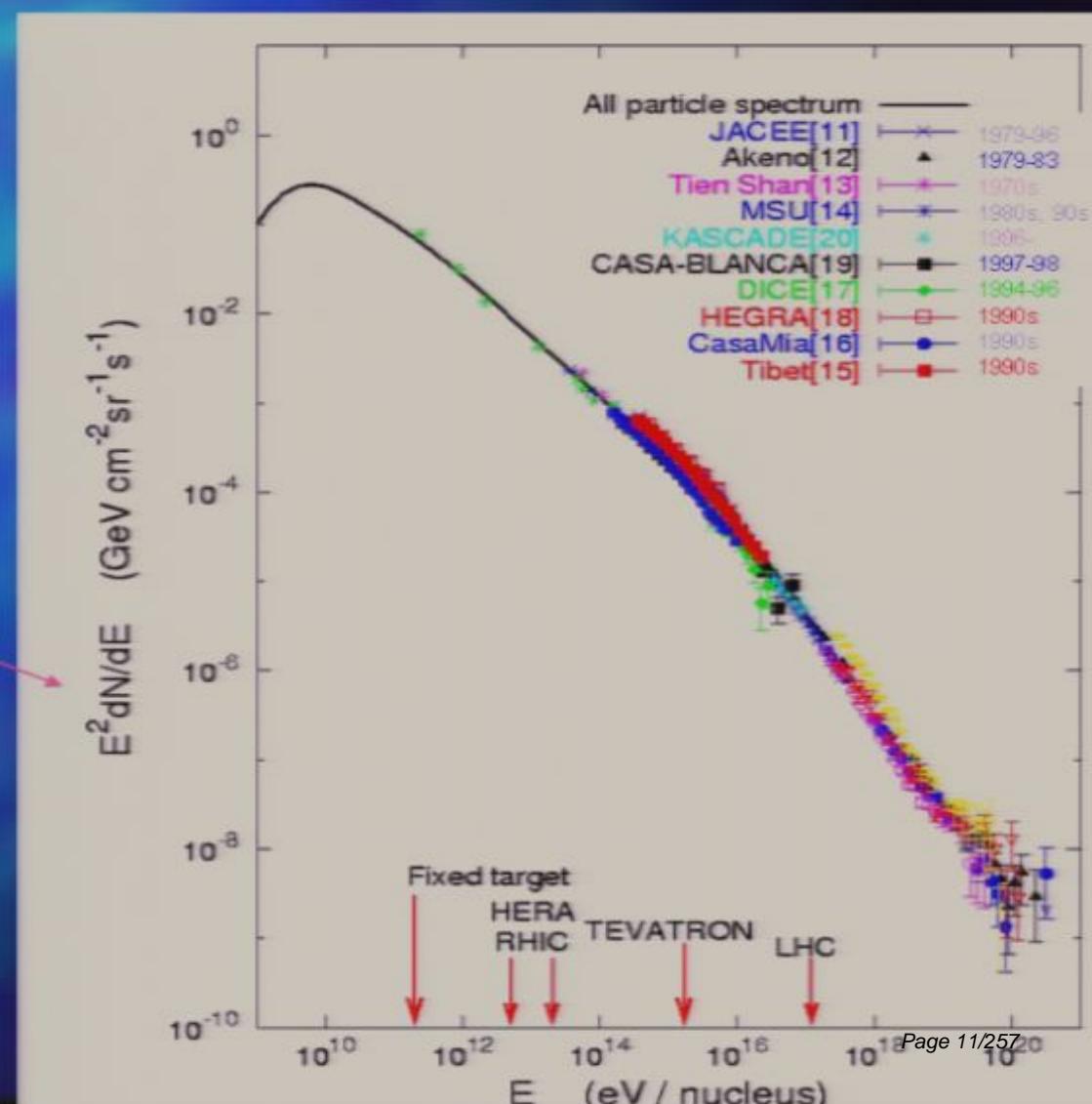


# The Cosmic Ray Spectrum

## Cosmic rays:

- high energy nuclei from H to Fe;
- $10^9$  eV to  $>10^{20}$  eV.

Fluxes rescaled by  $E^2$

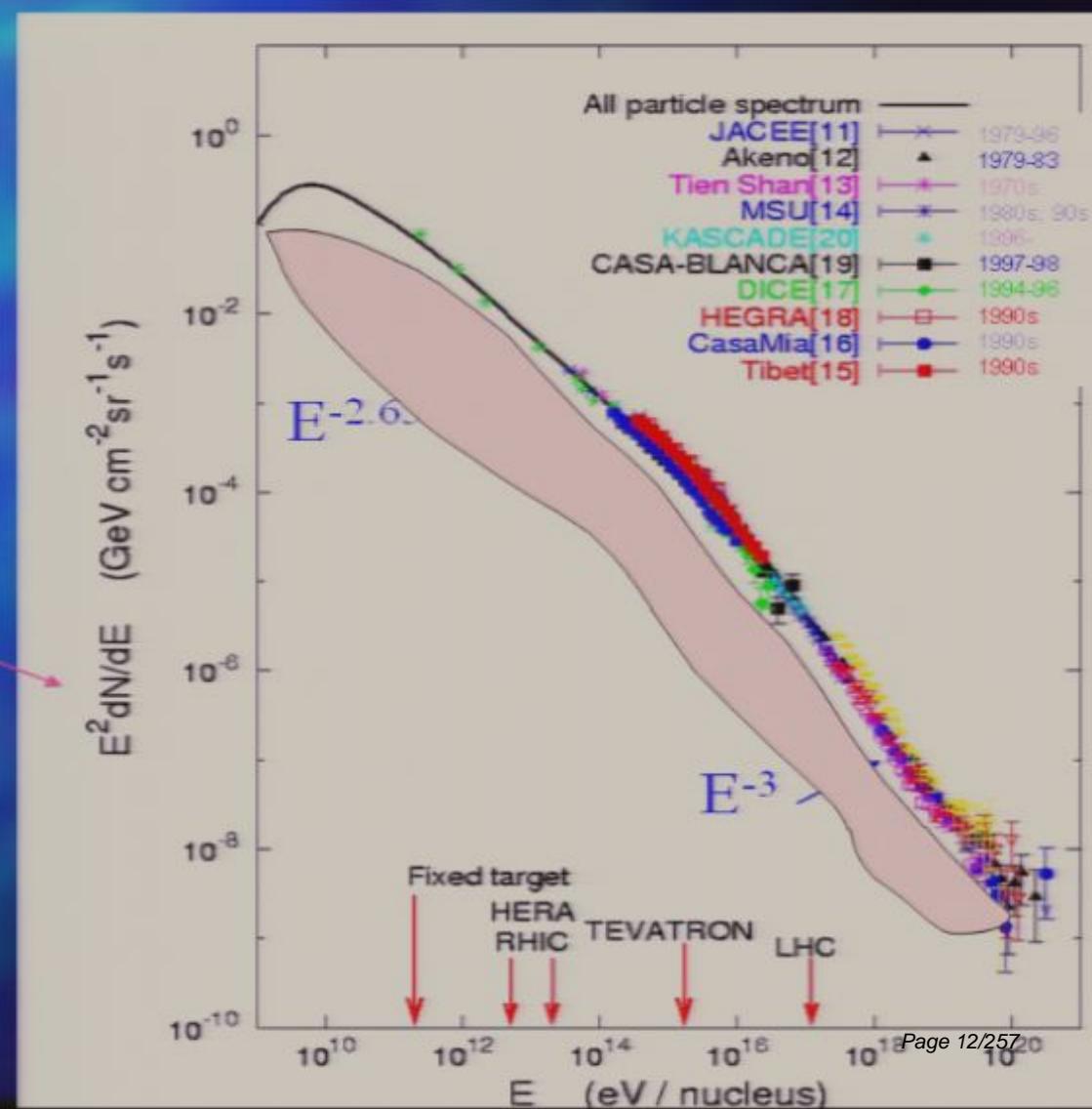


# The Cosmic Ray Spectrum

## Cosmic rays:

- high energy nuclei from H to Fe;
- $10^9$  eV to  $>10^{20}$  eV.

Fluxes rescaled by  $E^2$



# The Cosmic Ray Spectrum

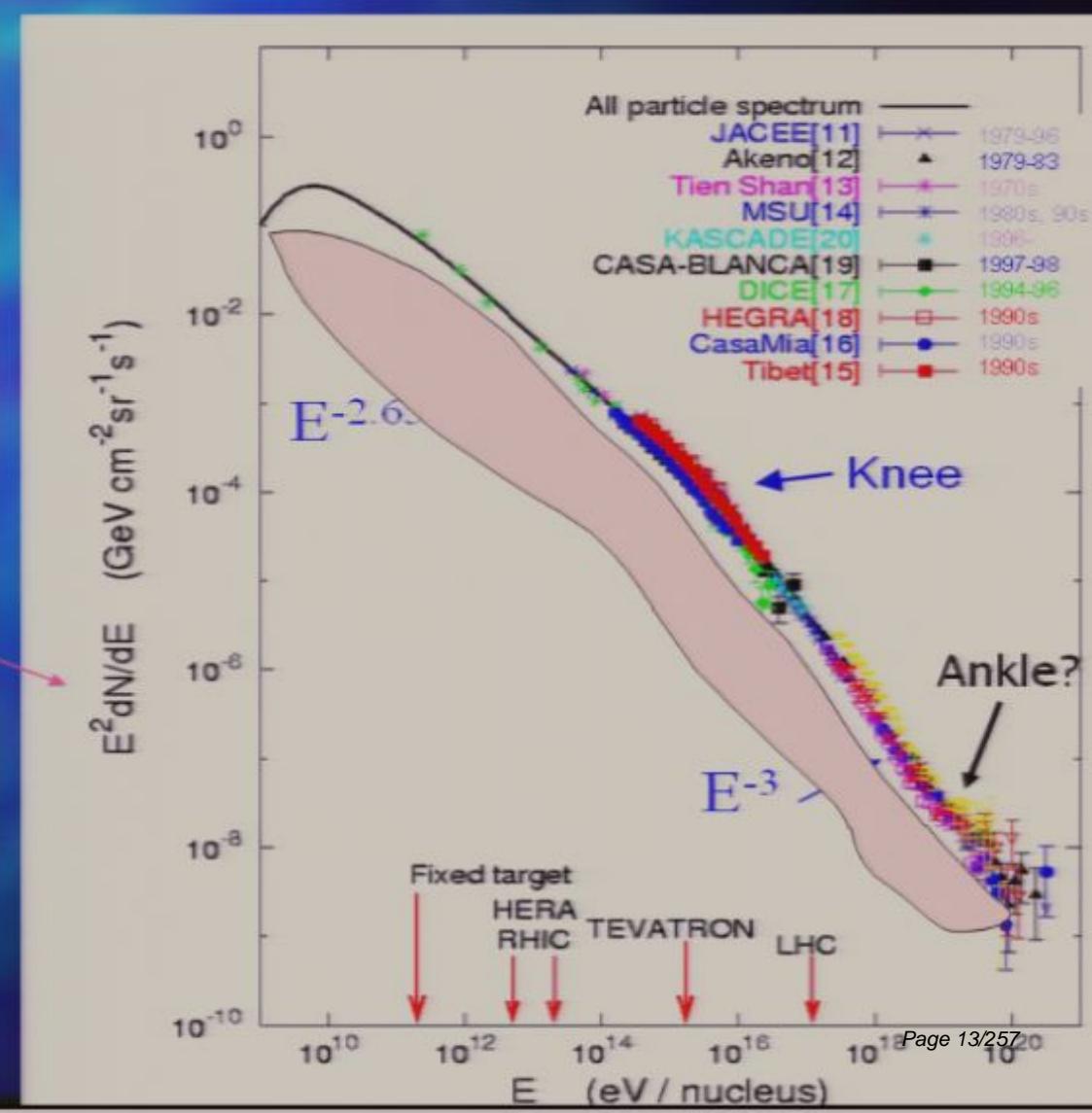
Cosmic rays:

- high energy nuclei from H to Fe;
- $10^9$  eV to  $>10^{20}$  eV.

The Knee:

Limit to shock acceleration?

Fluxes rescaled by  $E^2$



# The Cosmic Ray Spectrum

Cosmic rays:

- high energy nuclei from H to Fe;
- $10^9$  eV to  $>10^{20}$  eV.

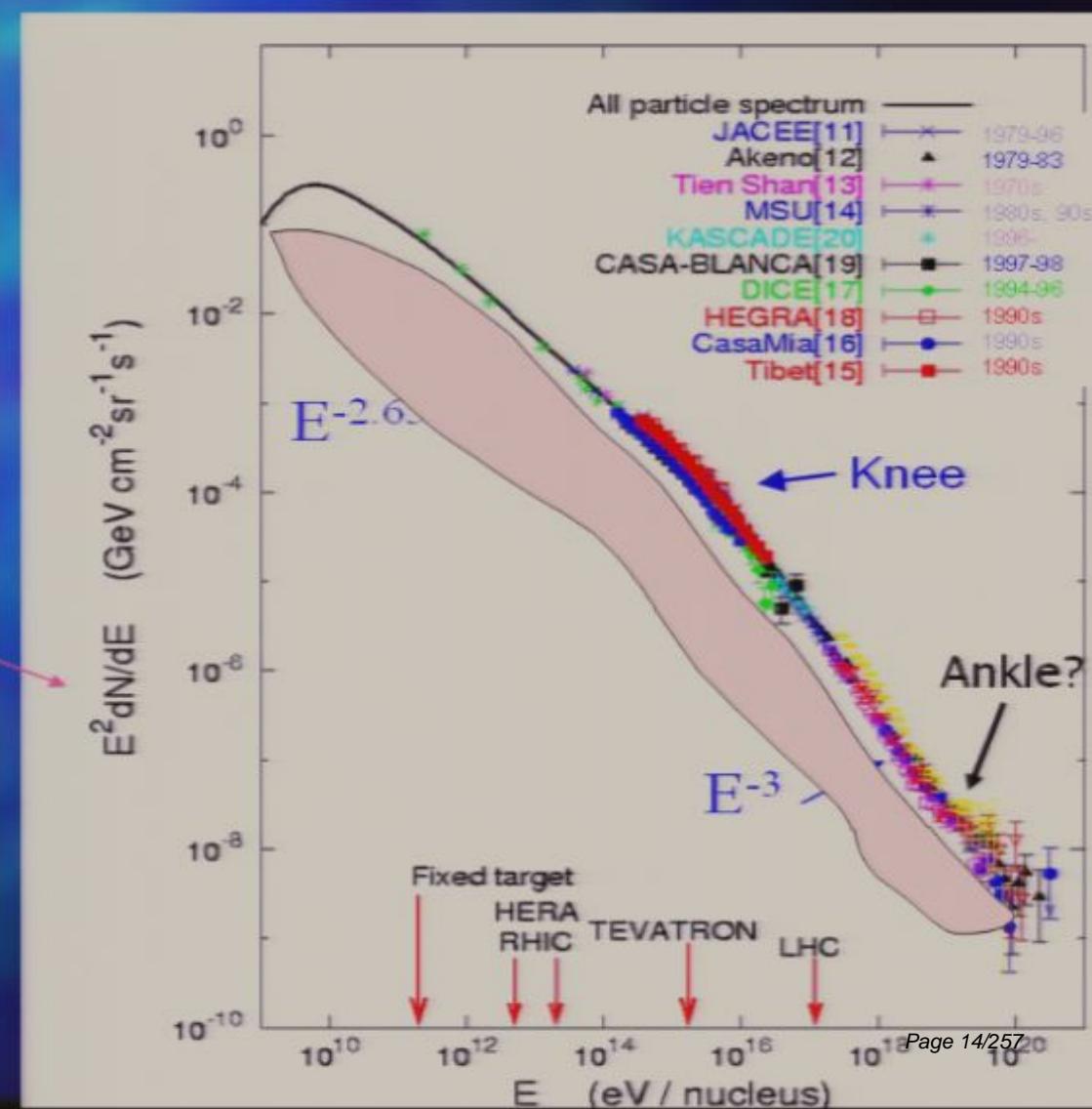
The Knee:

Limit to shock acceleration?

Clue: composition

Fluxes rescaled by  $E^2$

$>10^{12}$  eV: 1 per ( $\text{m}^2 \text{ second sr}$ )



# The Cosmic Ray Spectrum

Cosmic rays:

- high energy nuclei from H to Fe;
- $10^9$  eV to  $>10^{20}$  eV.

The Knee:

Limit to shock acceleration?

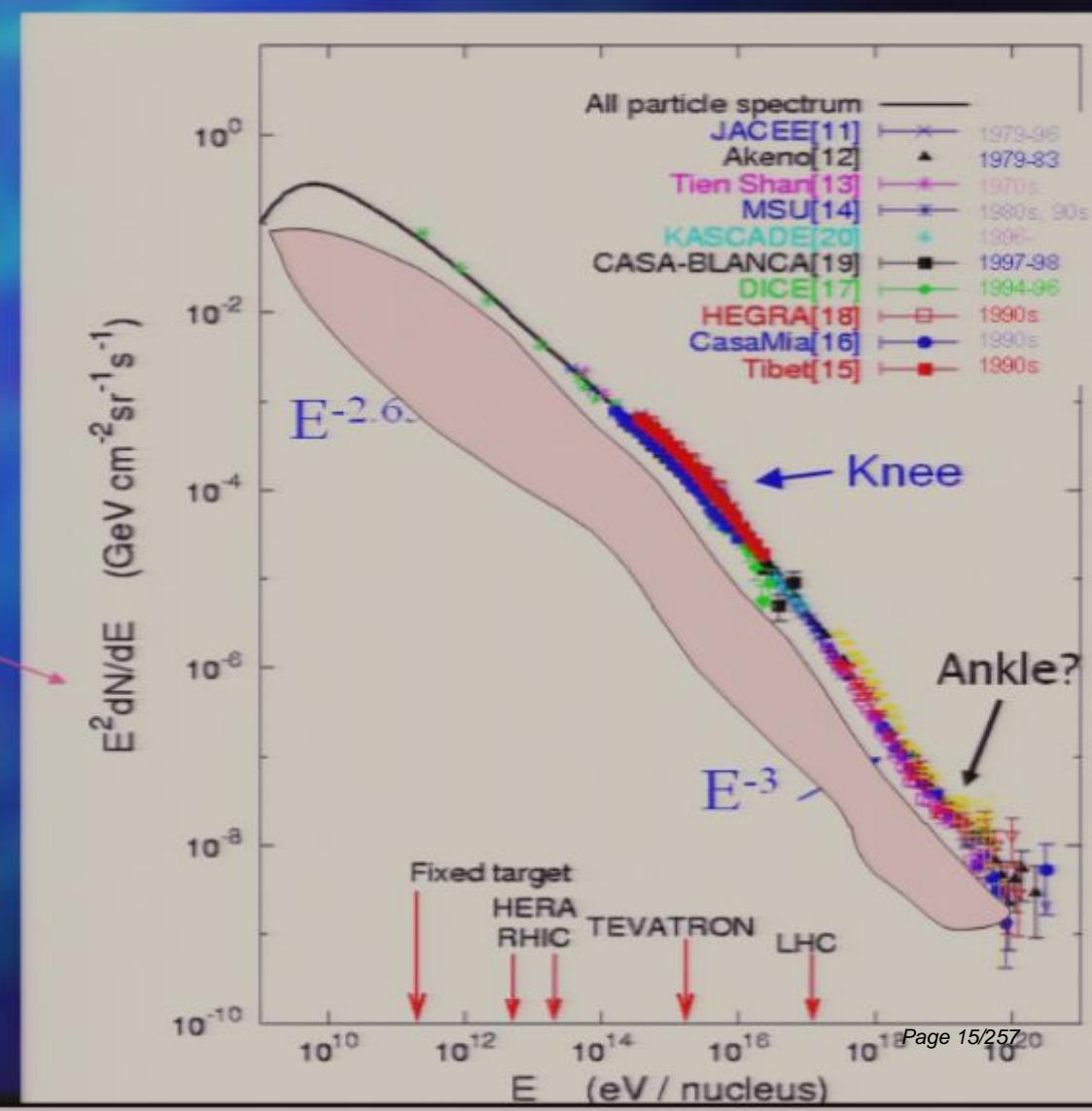
Clue: composition

Fluxes rescaled by  $E^2$

$>10^{12}$  eV: 1 per ( $\text{m}^2 \text{ second sr}$ )

$>10^{16}$  eV: 1 per ( $\text{m}^2 \text{ year sr}$ )

$>10^{20}$  eV: 1 per ( $\text{km}^2 \text{ century sr}$ )



# Cosmic Rays

---



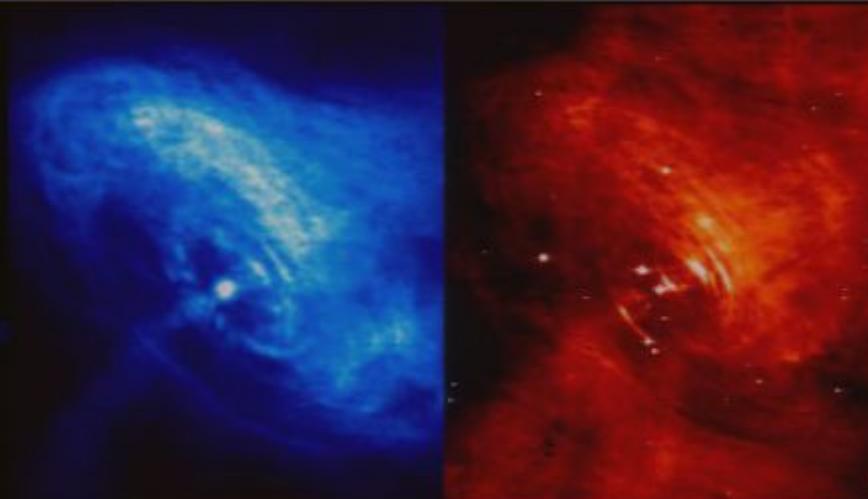
# Cosmic Rays



Production  
Acceleration  
**(Crab)**

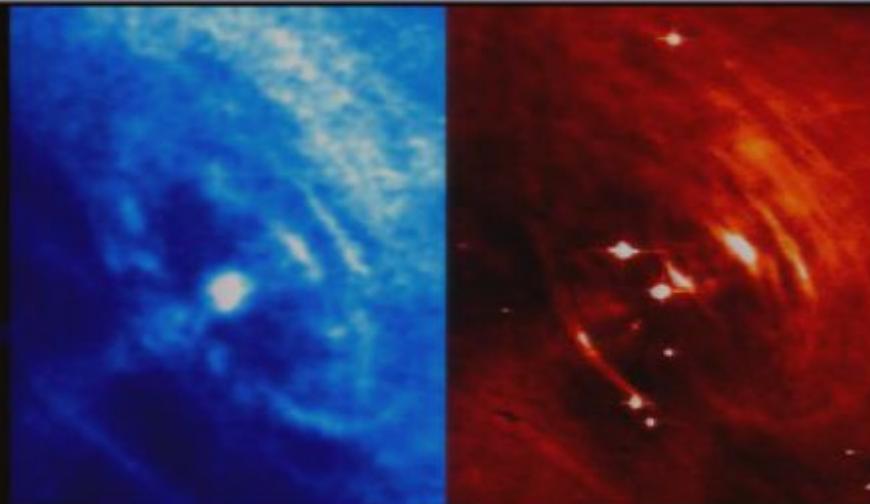


# Cosmic Rays



Production  
Acceleration  
**(Crab)**

# Cosmic Rays



Production  
Acceleration  
**(Crab)**



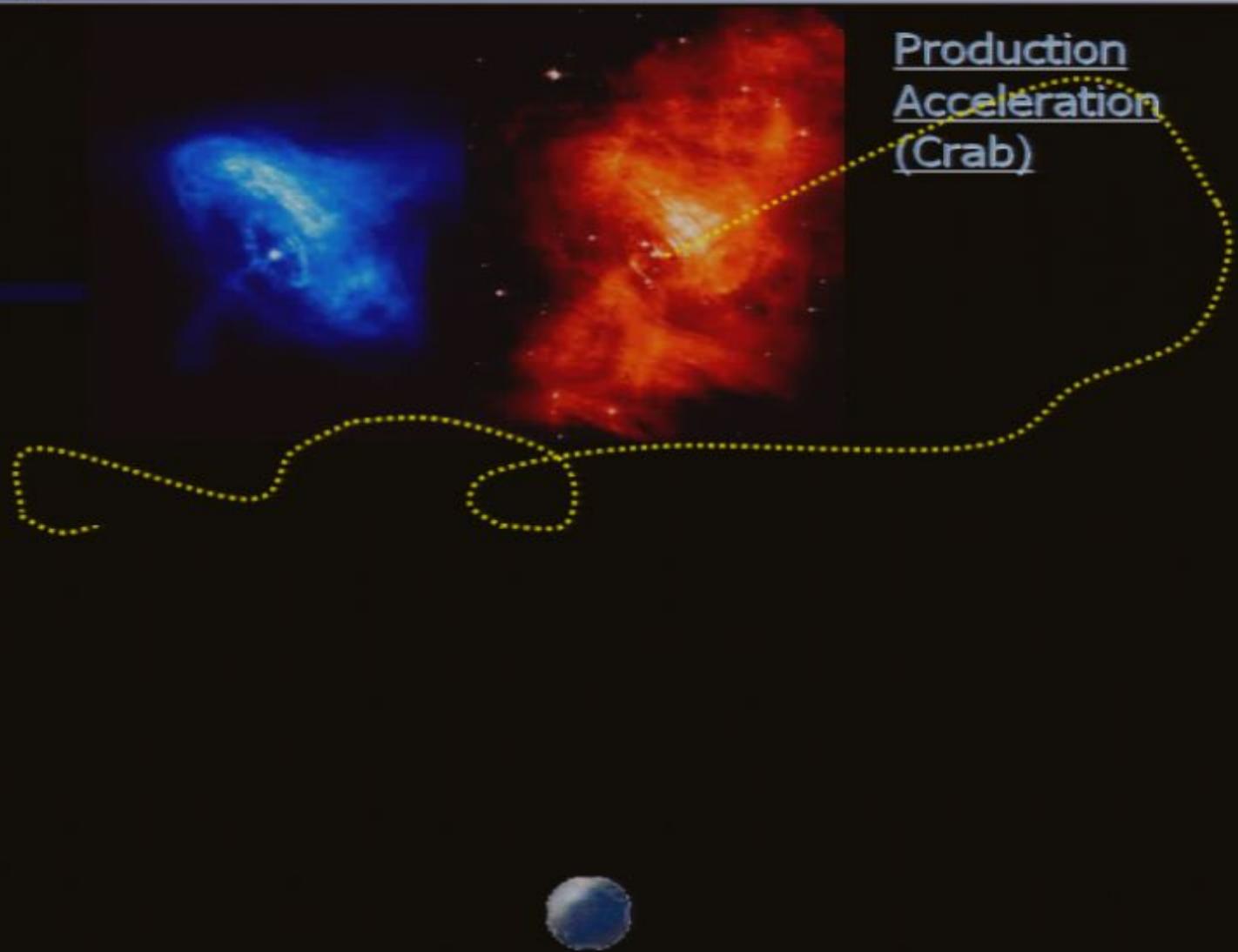
# Cosmic Rays



Production  
Acceleration  
**(Crab)**

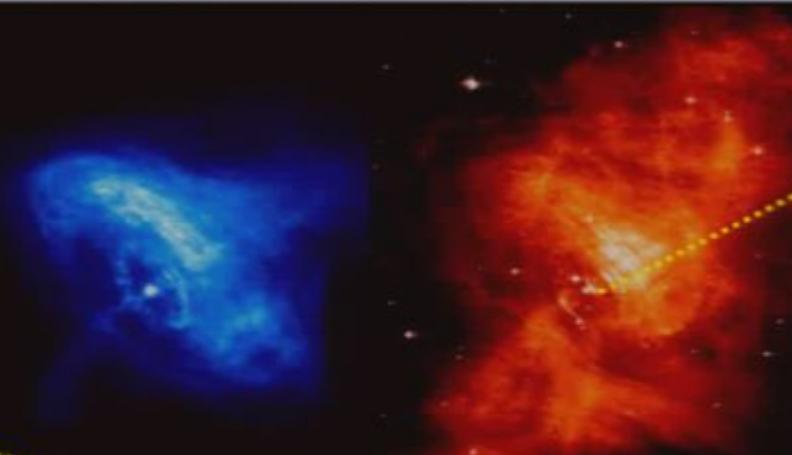


# Cosmic Rays



Production  
Acceleration  
**(Crab)**

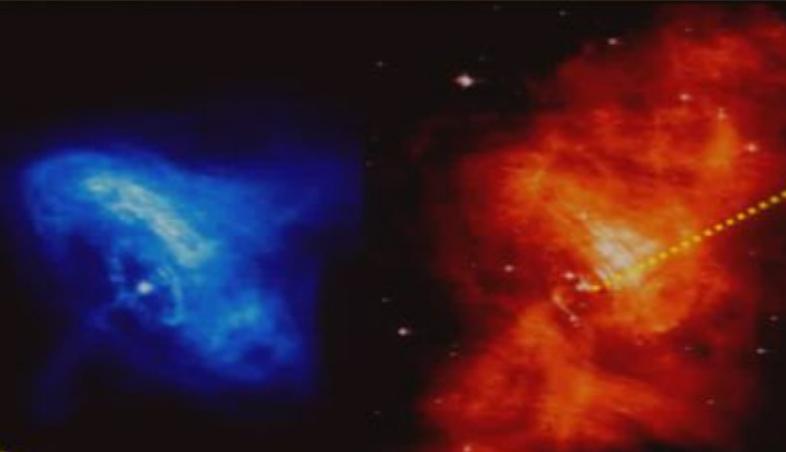
# Cosmic Rays



Production  
Acceleration  
(Crab)



# Cosmic Rays



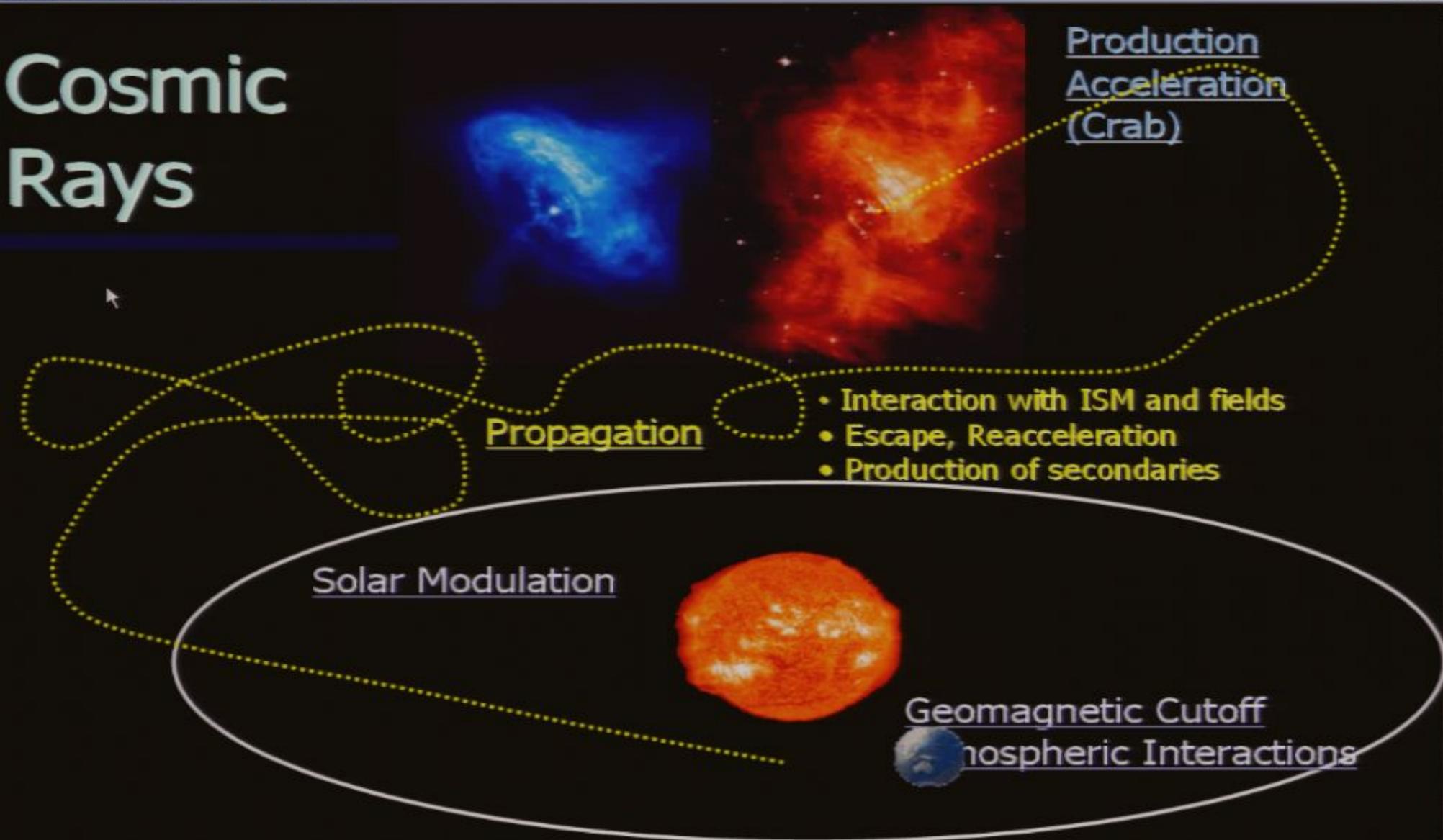
Production  
Acceleration  
(Crab)

Propagation

- Interaction with ISM and fields
- Escape, Reacceleration
- Production of secondaries

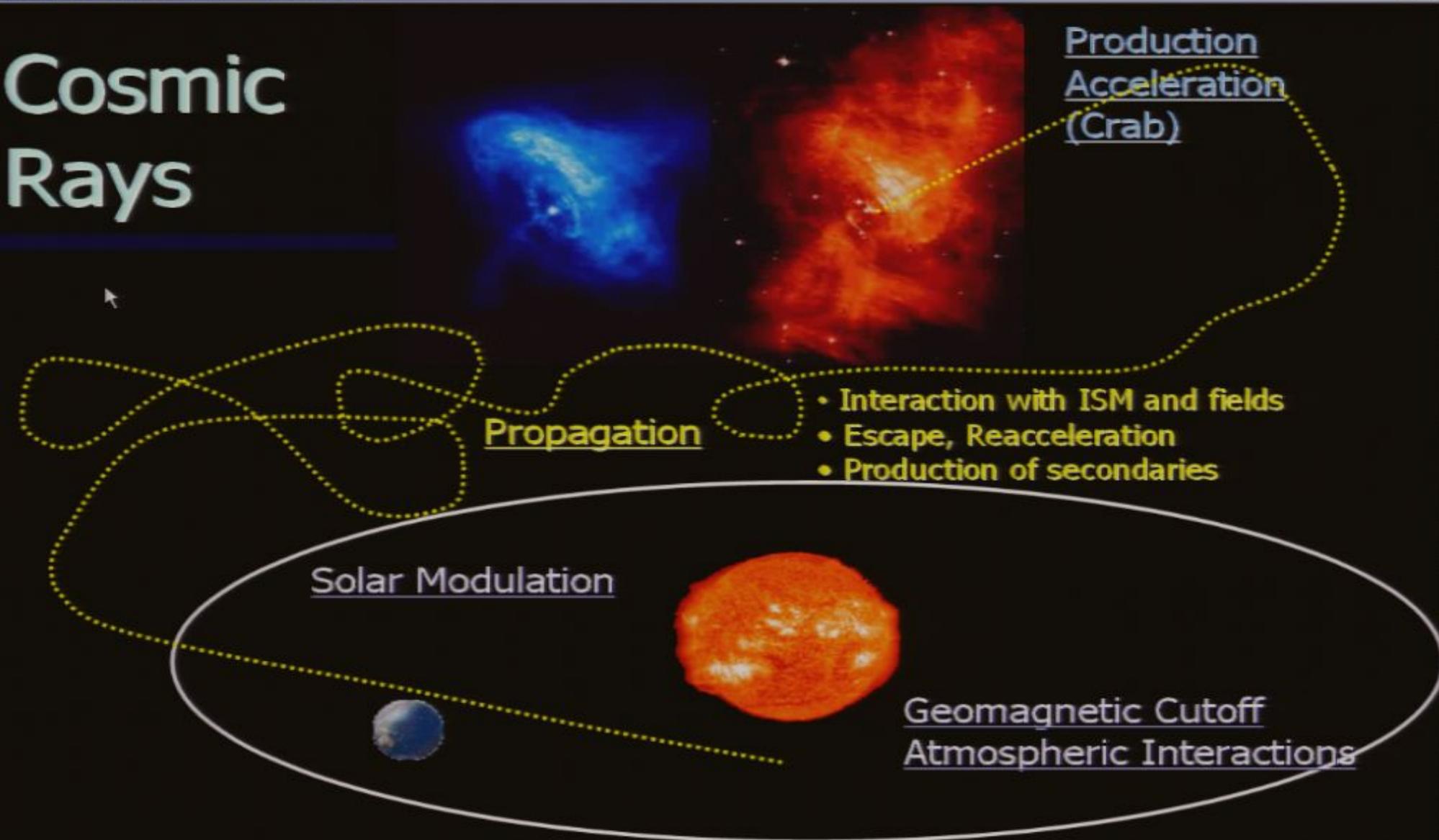


# Cosmic Rays



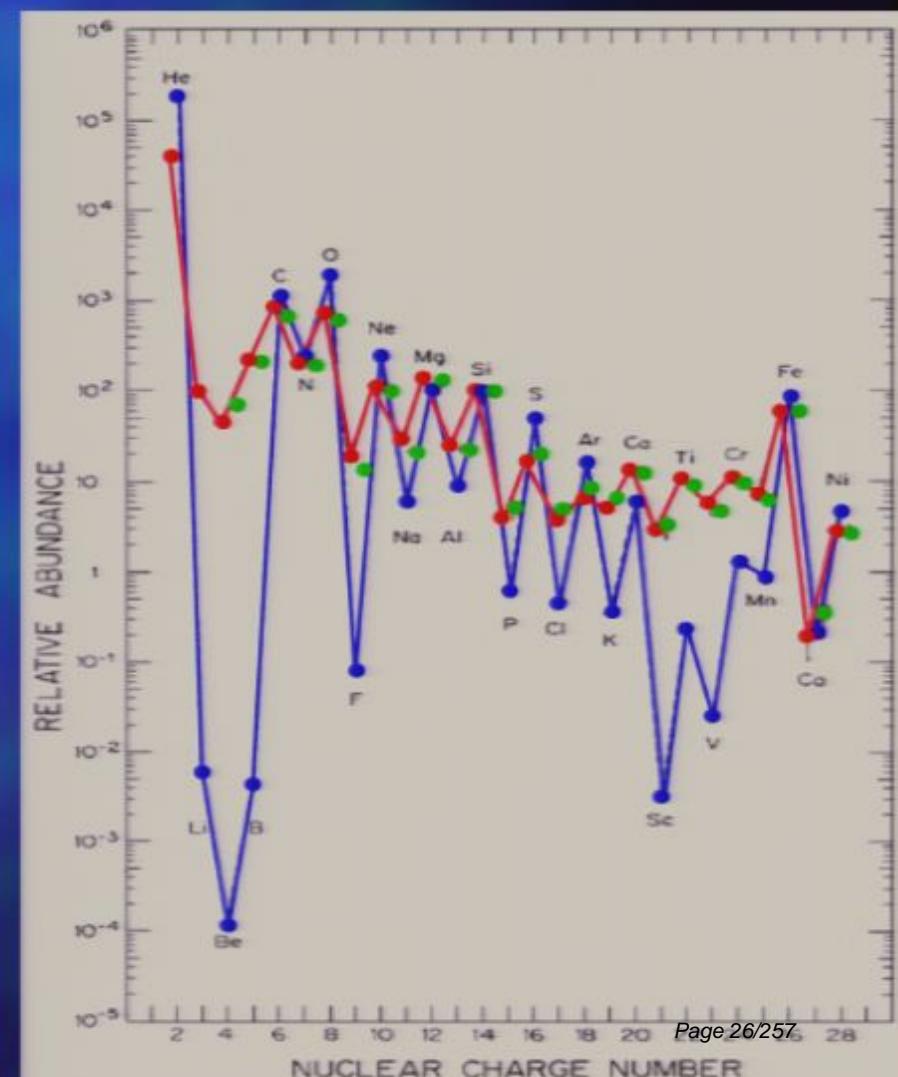
Fermi shock acceleration, naturally predicts  
 $J(E) \propto E^{\gamma}$ , with  $\gamma \sim 1 + 4/M^2$ , M Mach number

# Cosmic Rays



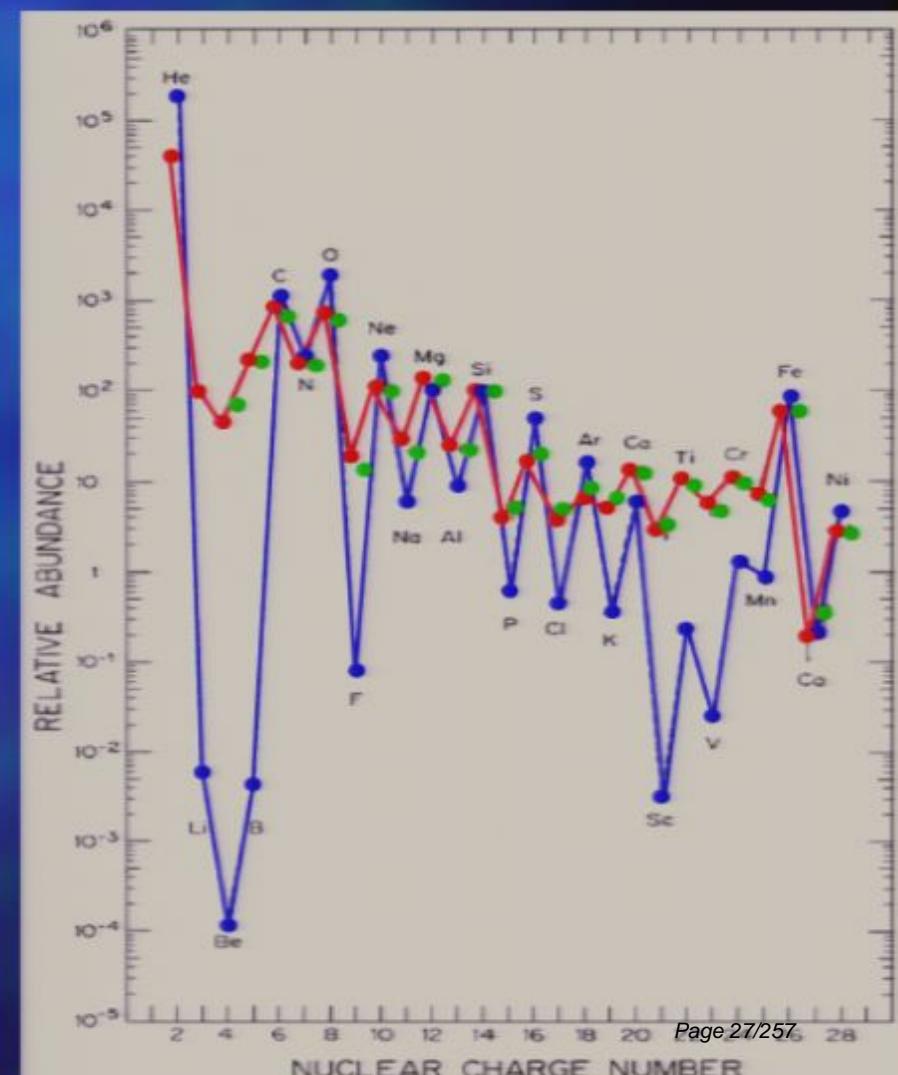
Fermi shock acceleration, naturally predicts  
 $J(E) \propto E^{-1}$ , with  $\gamma \sim 1 + 4/M^2$ , M Mach number

# Low Energy Cosmic Ray Abundances



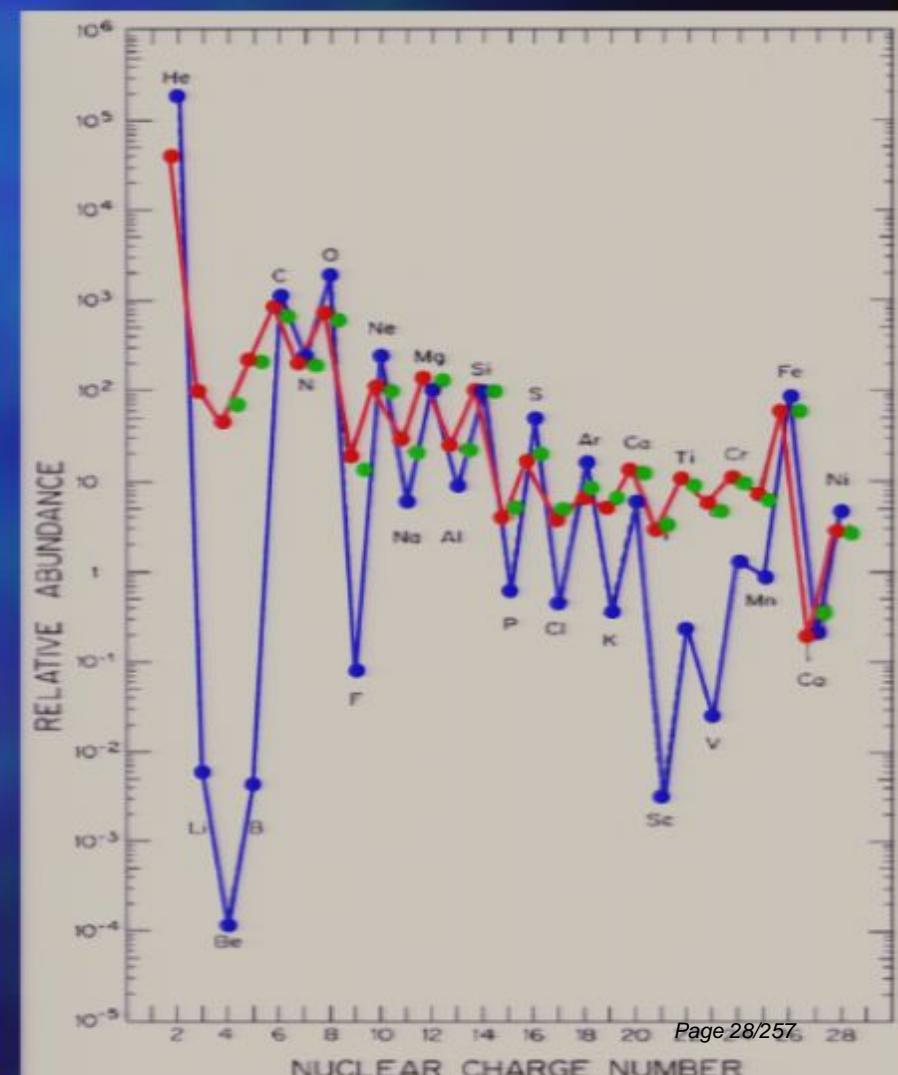
# Low Energy Cosmic Ray Abundances

- He and heavier, normalized to Si;
- CR 0.07 – 0.28 GeV/amu;
- CR 1 – 2 GeV/amu;



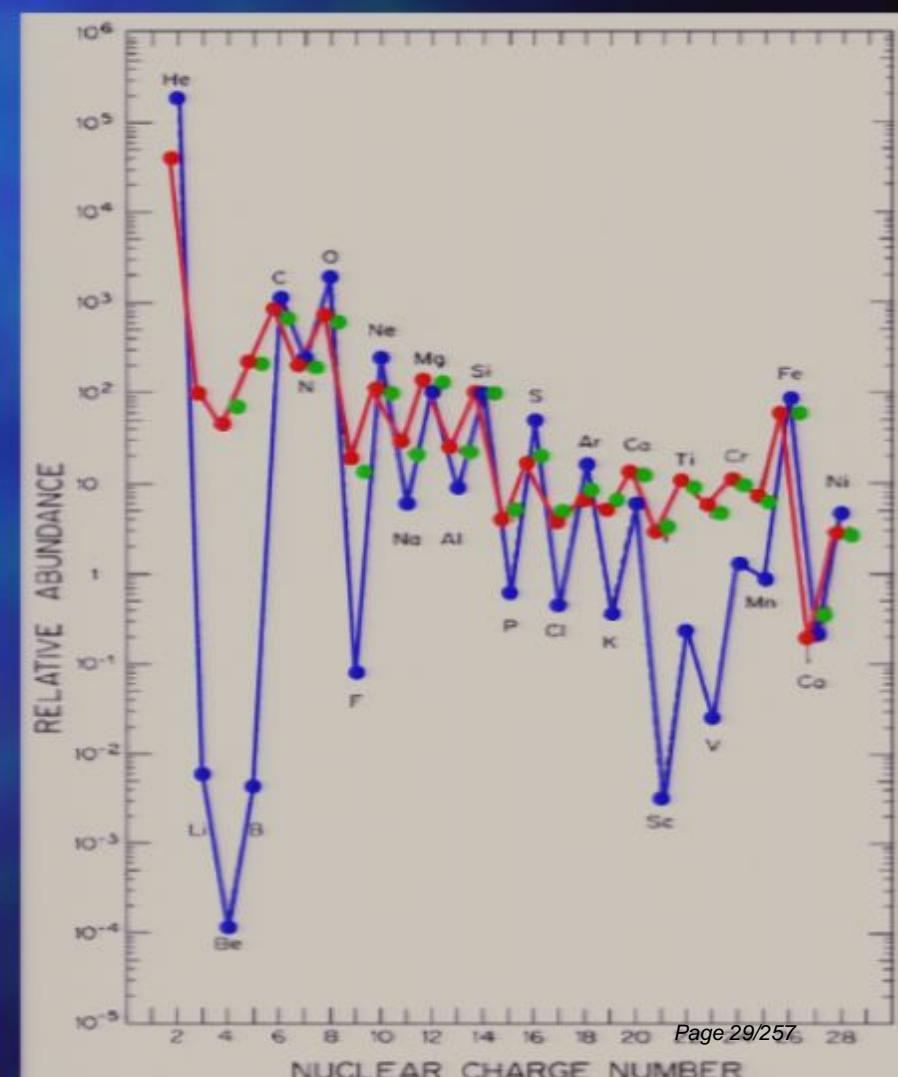
# Low Energy Cosmic Ray Abundances

- He and heavier, normalized to Si;
- CR 0.07 – 0.28 GeV/amu;
- CR 1 – 2 GeV/amu;



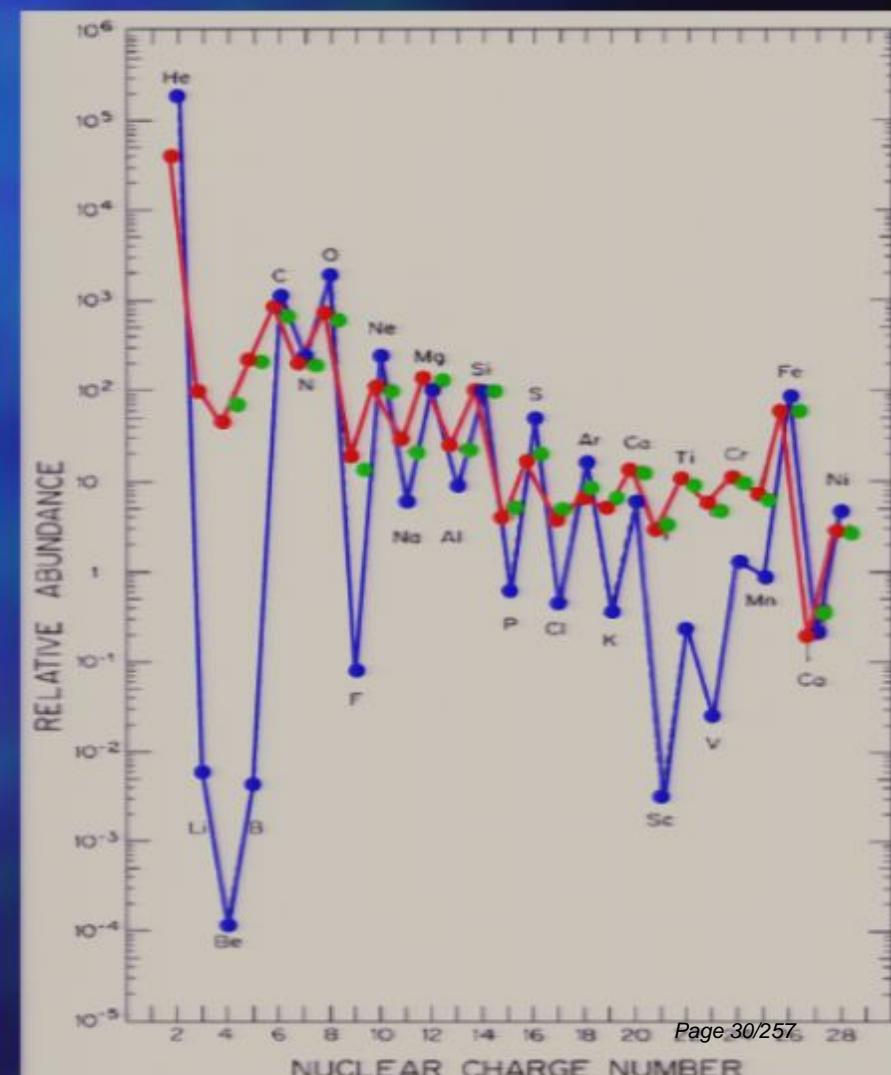
# Low Energy Cosmic Ray Abundances

- He and heavier, normalized to Si;
- CR 0.07 – 0.28 GeV/amu;
- CR 1 – 2 GeV/amu;



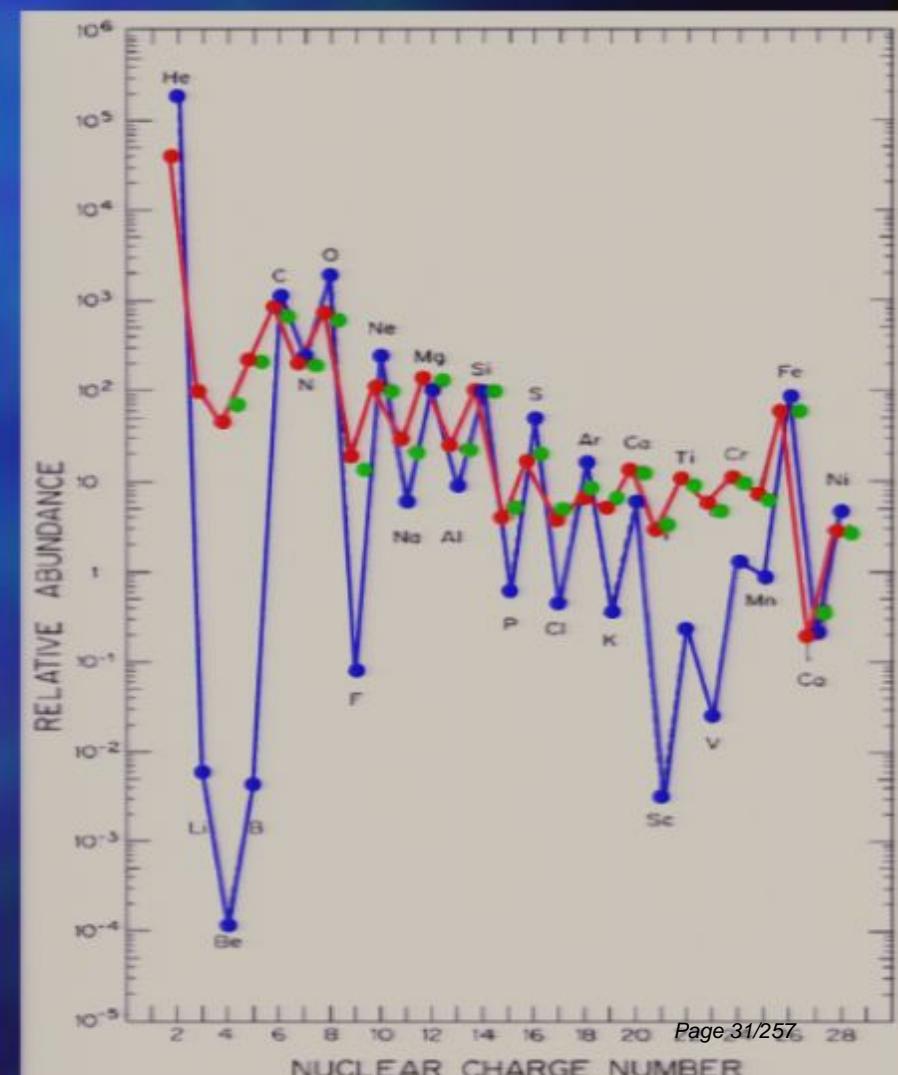
# Low Energy Cosmic Ray Abundances

- He and heavier, normalized to Si;
- CR 0.07 – 0.28 GeV/amu;
- CR 1 – 2 GeV/amu;
- Solar system abundances;



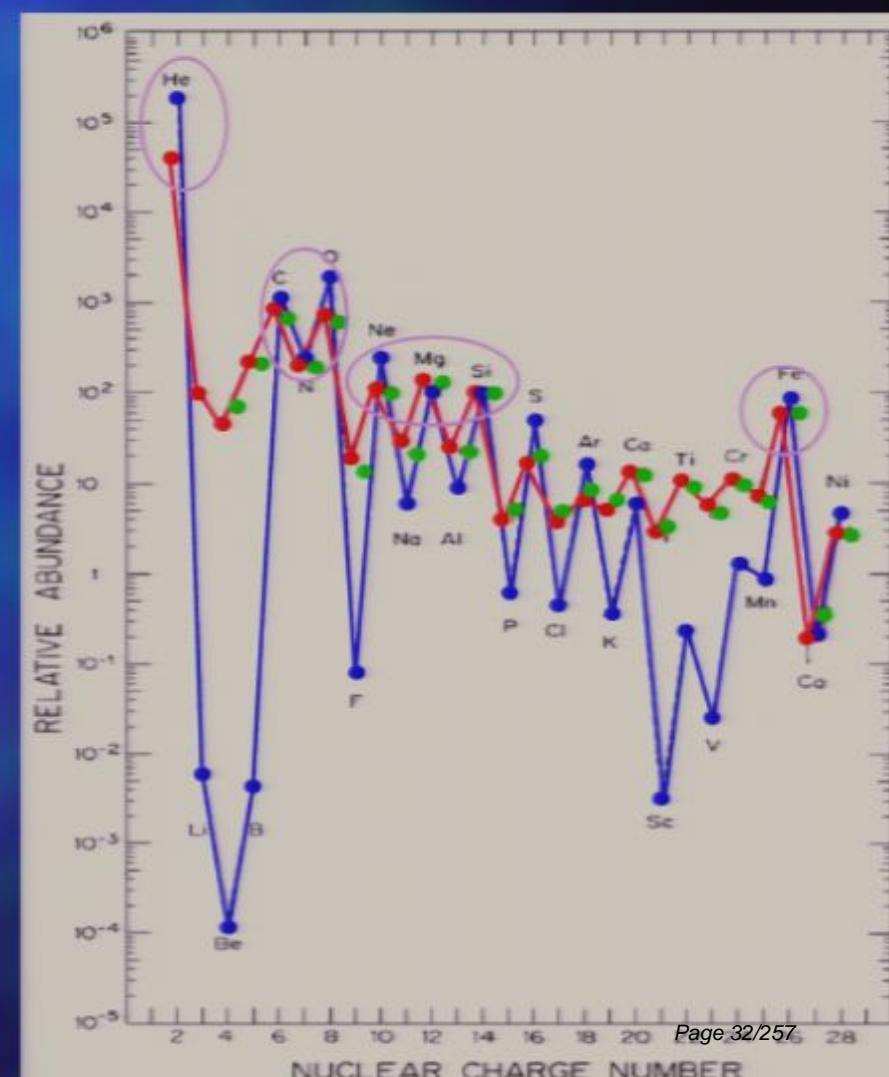
# Low Energy Cosmic Ray Abundances

- He and heavier, normalized to Si;
- CR 0.07 – 0.28 GeV/amu;
- CR 1 – 2 GeV/amu;
- Solar system abundances;
- Even-odd effect;



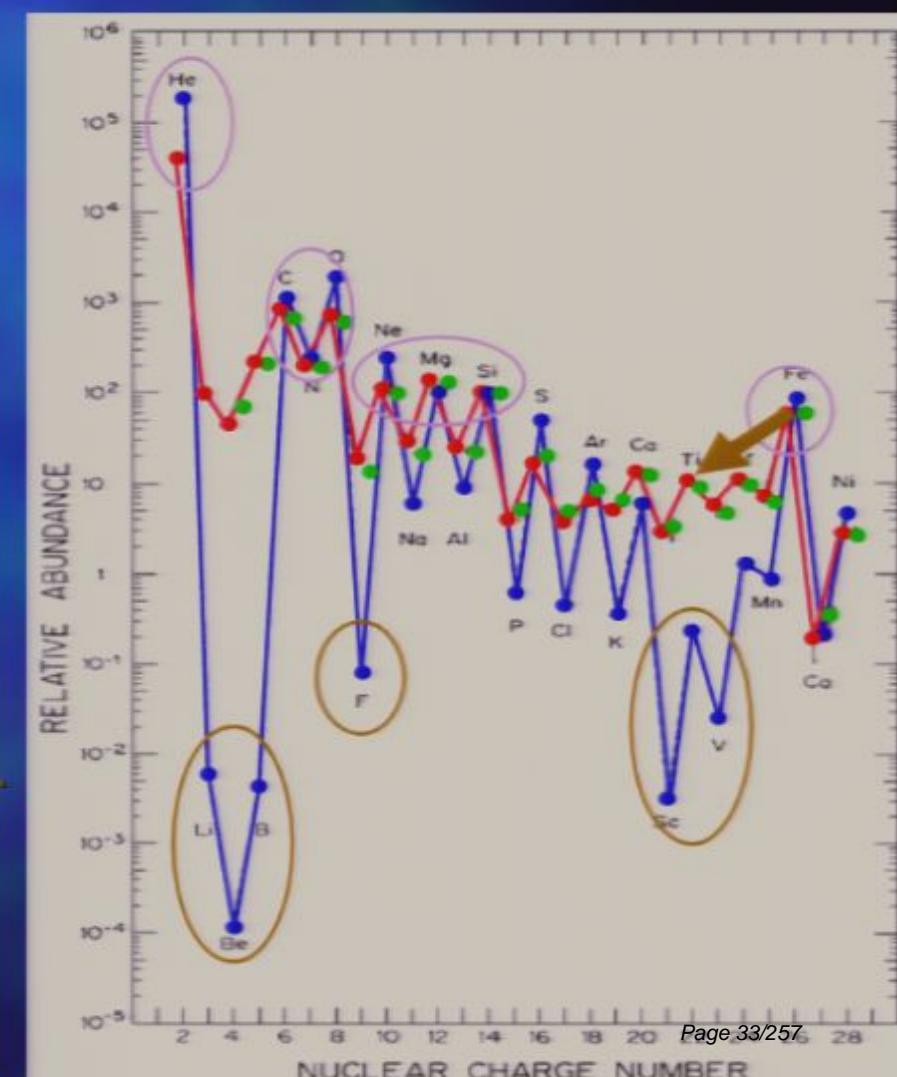
# Low Energy Cosmic Ray Abundances

- He and heavier, normalized to Si;
- CR 0.07 – 0.28 GeV/amu;
- CR 1 – 2 GeV/amu;
- Solar system abundances;
- Even-odd effect;
- He, CNO, NeMgSi, Fe abundant species.



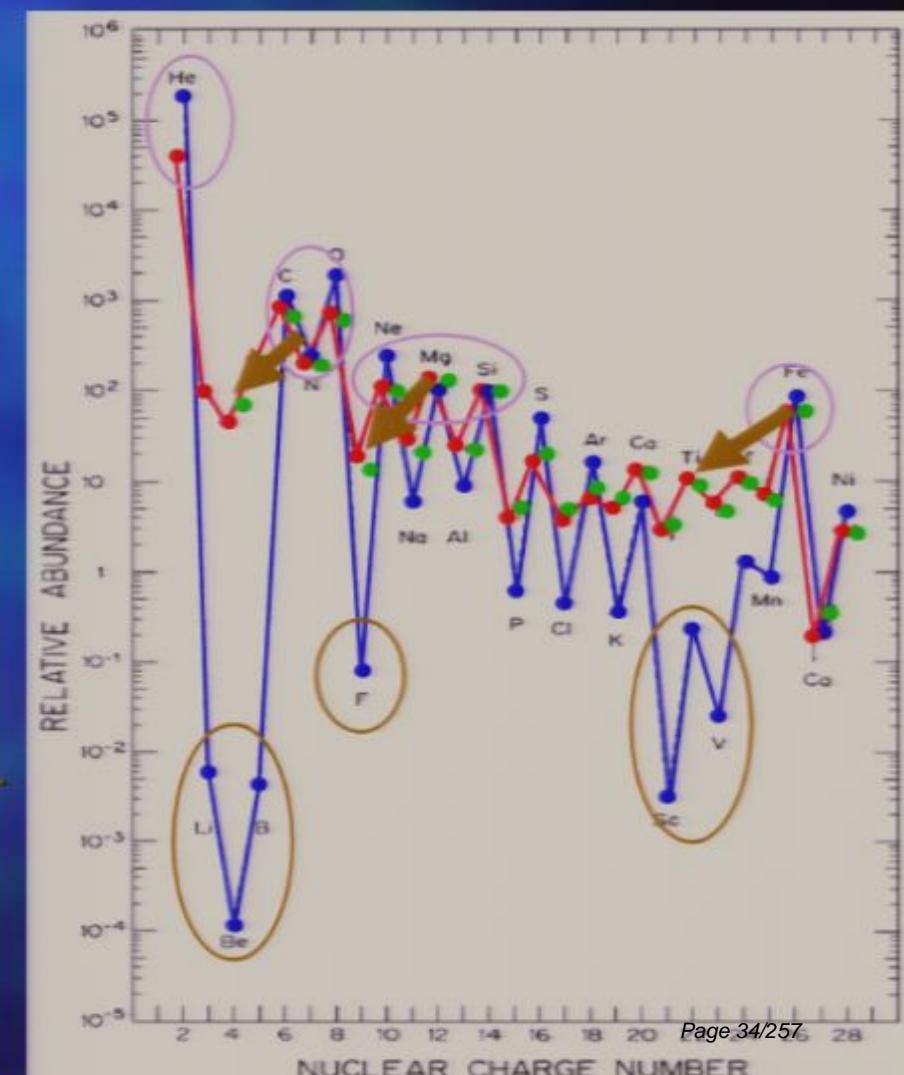
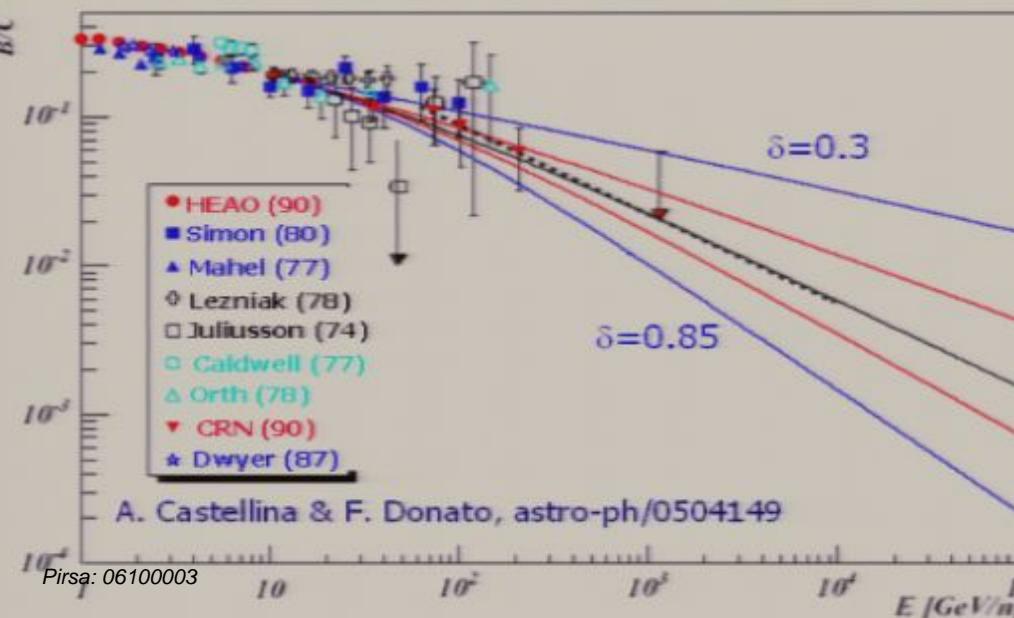
# Low Energy Cosmic Ray Abundances

- He and heavier, normalized to Si;
- CR 0.07 – 0.28 GeV/amu;
- CR 1 – 2 GeV/amu;
- Solar system abundances;
- Even-odd effect;
- He, CNO, NeMgSi, Fe abundant species.
- LiBeB, F, ScTiV not present as end products of stellar nucleosynthesis.
- Higher CR abundances, produced by spallation.



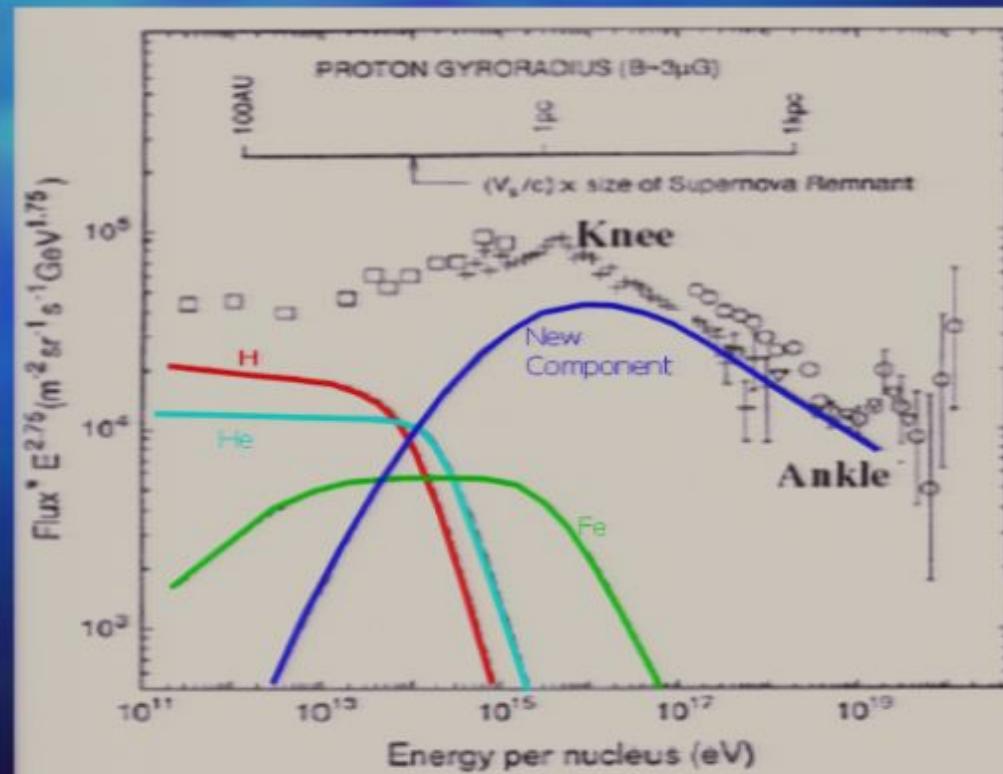
# Low Energy Cosmic Ray Abundances

- He and heavier, normalized to Si;
- CR 0.07 – 0.28 GeV/amu;
- CR 1 – 2 GeV/amu;
- Solar system abundances;



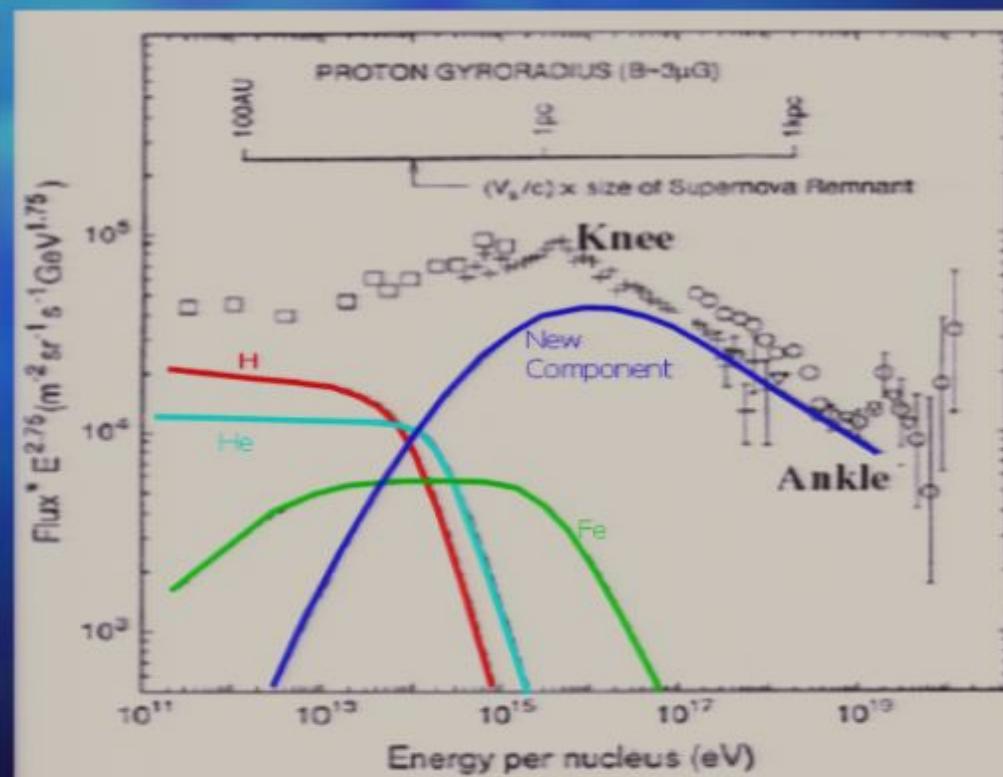
# Direct Composition: Expectations

- Under the SN shock acceleration scenario, expect charge-dependent knee, e.g., H spectrum knee at  $\sim 10^{14}$ eV.



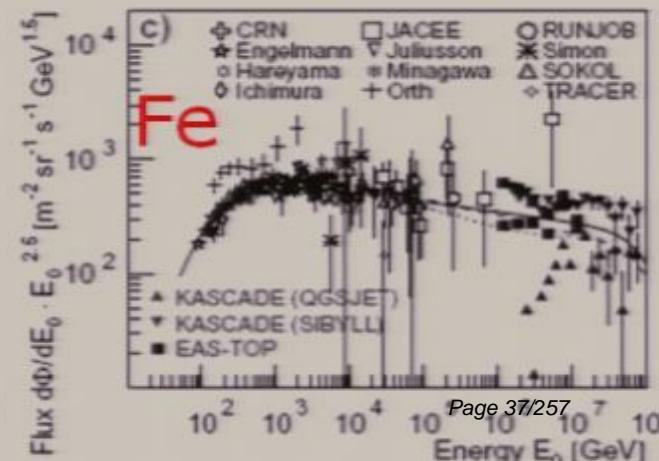
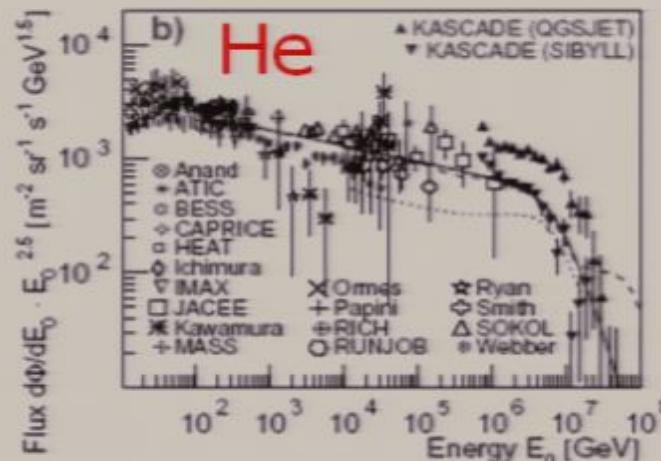
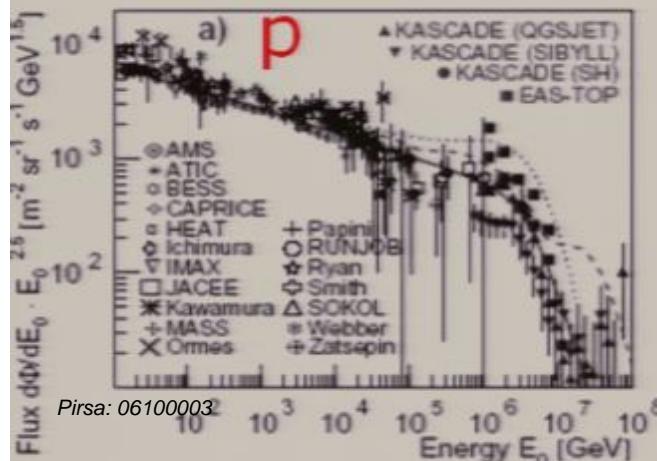
# Direct Composition: Expectations

- Under the SN shock acceleration scenario, expect charge-dependent knee, e.g., H spectrum knee at  $\sim 10^{14}$ eV.



# Cosmic Ray Mass Composition Status

Improved direct measurements can provide the foundation for studies at higher energies



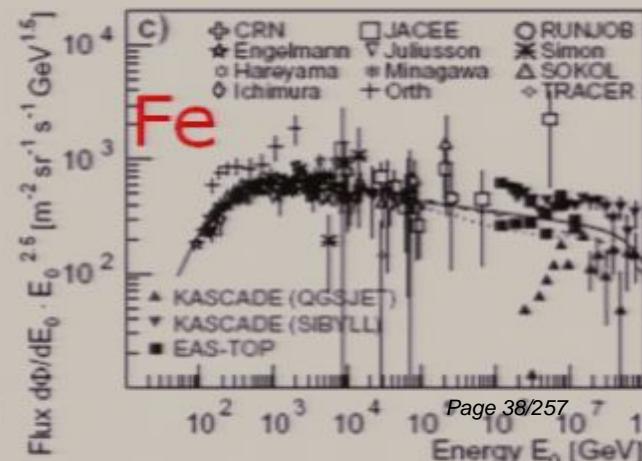
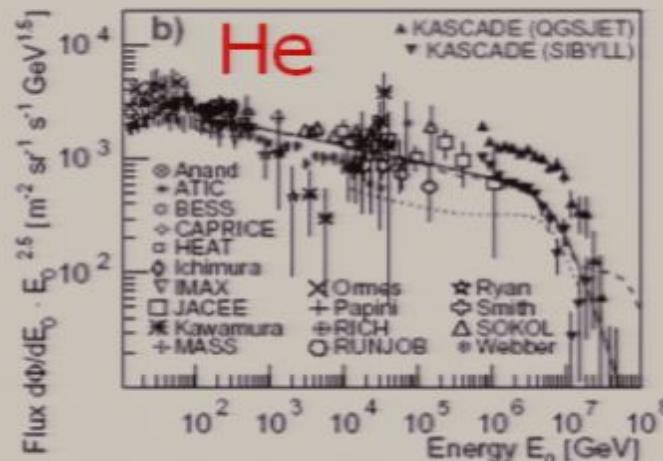
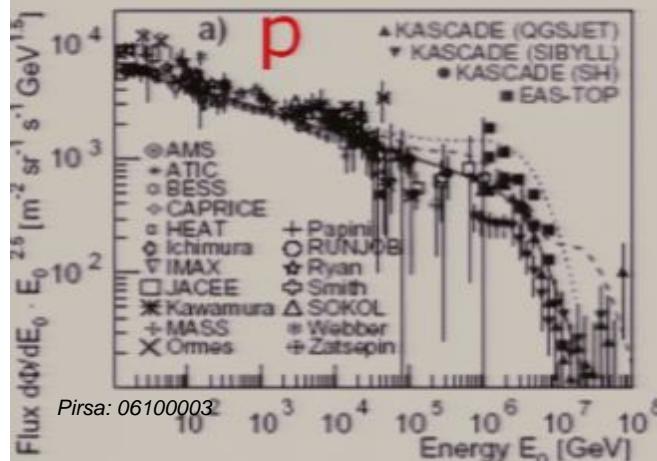
# Cosmic Ray Mass Composition Status

Improved direct measurements can provide the foundation for studies at higher energies

Direct  
measurements

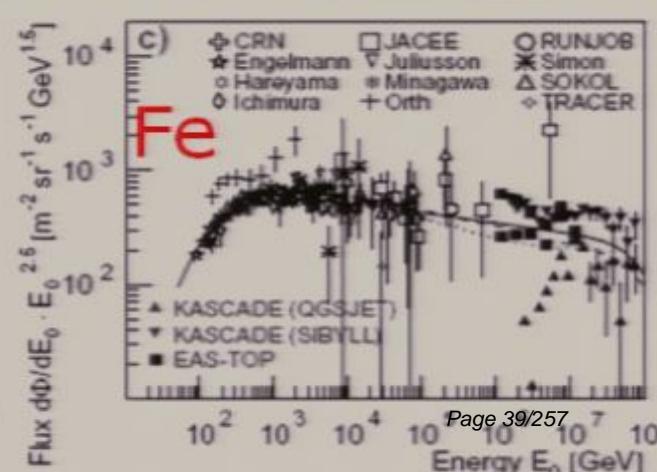
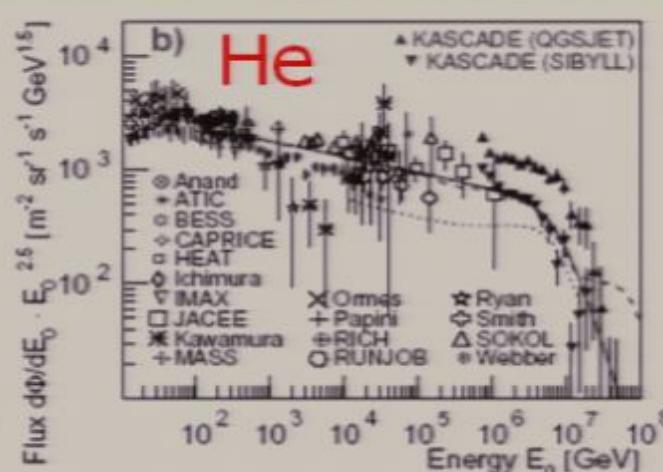
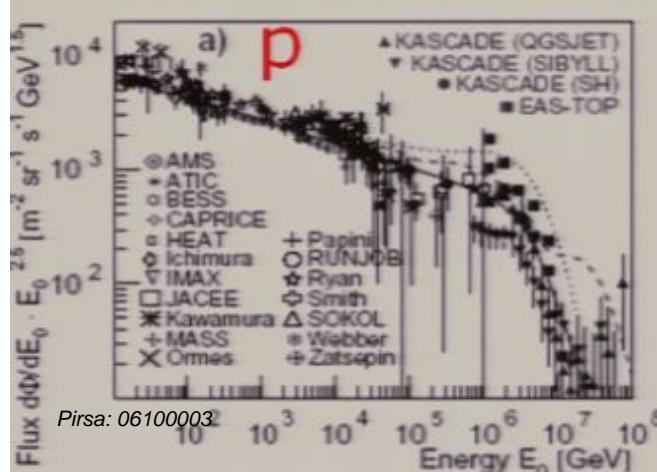
Direct  
measurements

Direct  
measurements



# Cosmic Ray Mass Composition Status

Improved direct measurements can provide the foundation for studies at higher energies

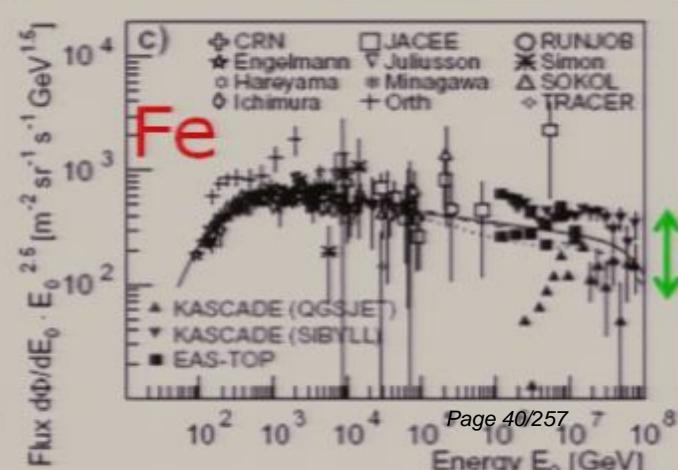
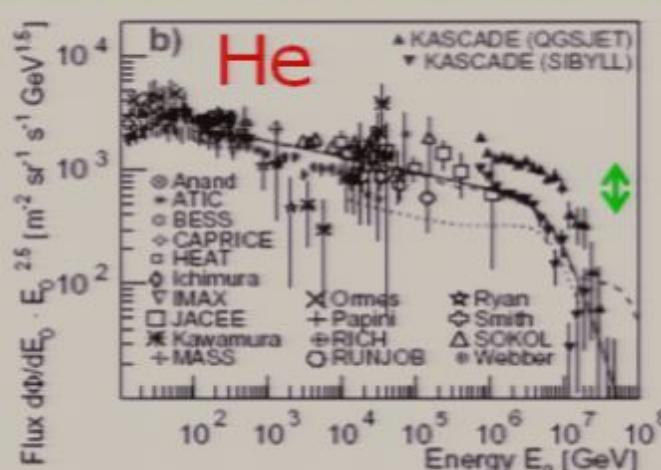
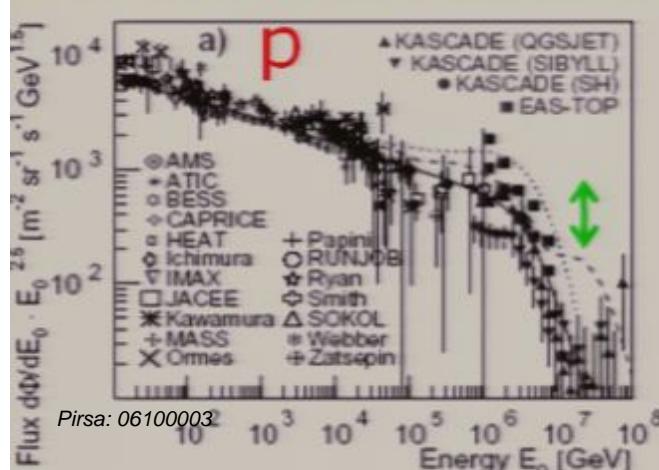


# Cosmic Ray Mass Composition Status

Improved direct measurements can provide the foundation for studies at higher energies

**Indirect evidence highly model dependent**

**Inferred fluxes can vary by factors of 2 or more**



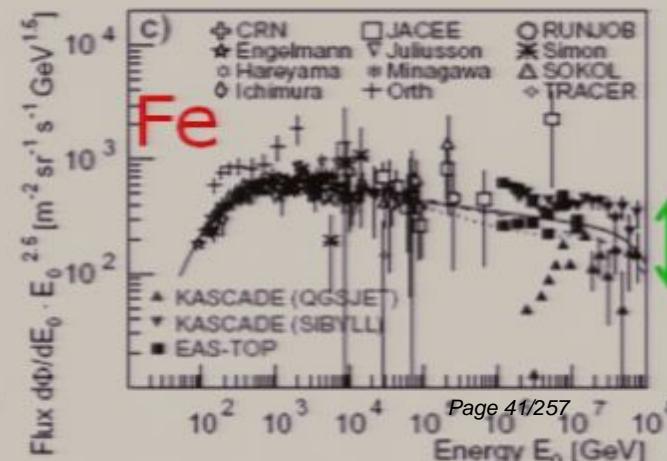
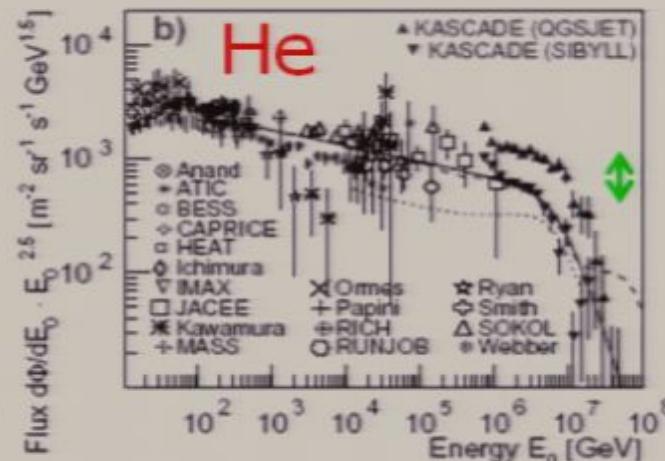
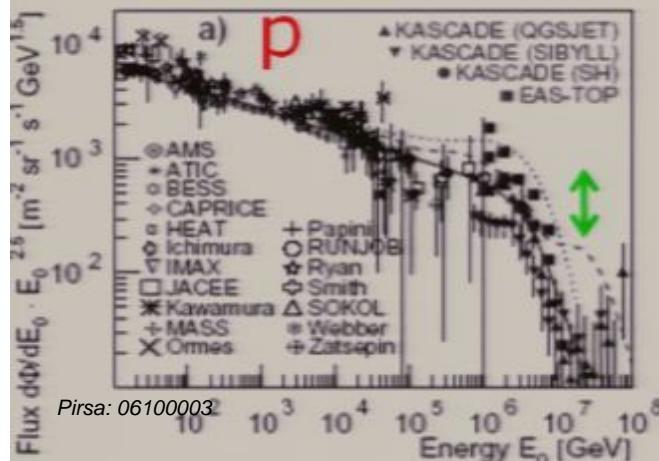
# Cosmic Ray Mass Composition Status

Improved direct measurements can provide the foundation for studies at higher energies

**Indirect evidence highly model dependent**

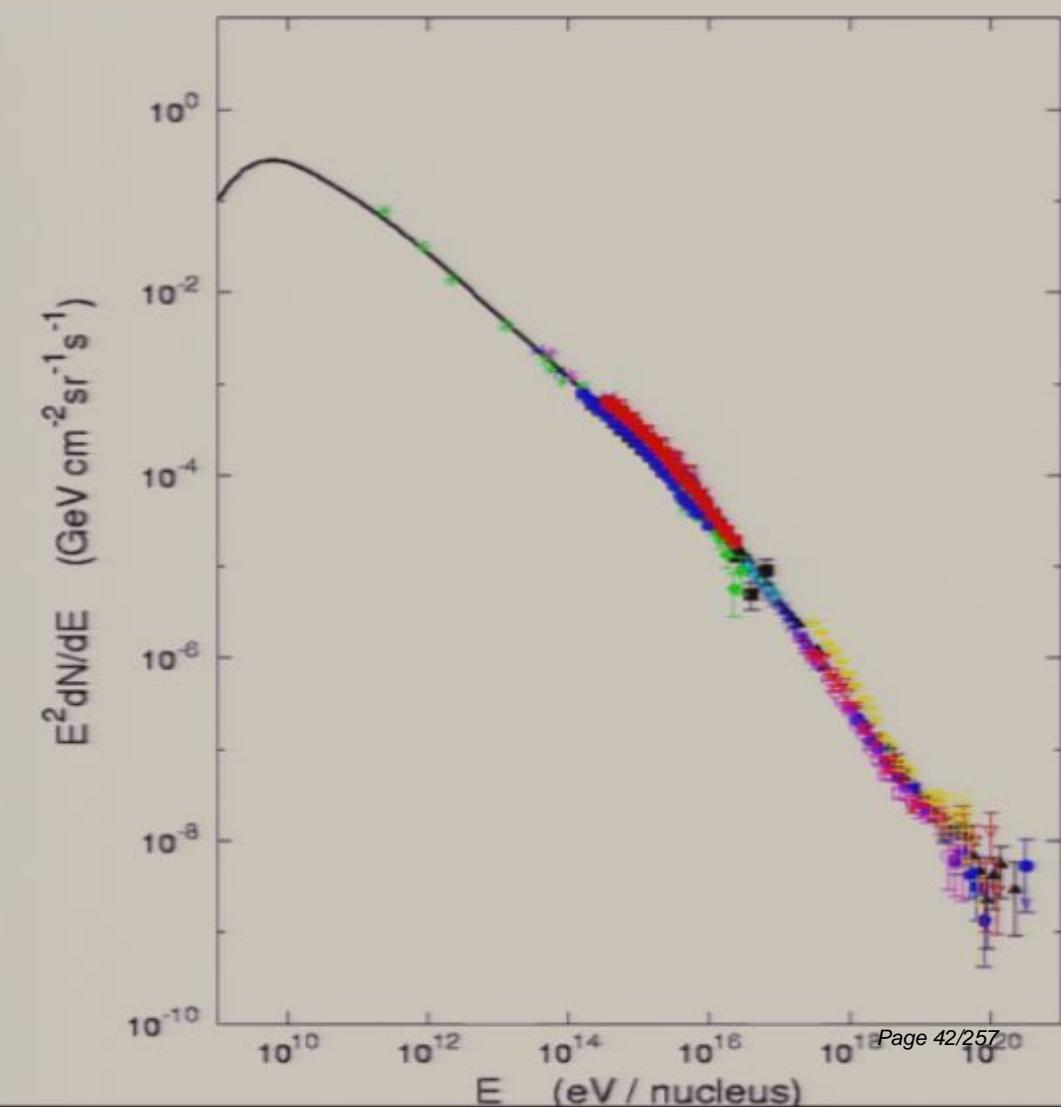
**Inferred fluxes can vary by factors of 2 or more**

**UHE cosmic rays (Auger) extend a further 3 orders of magnitude in energy**



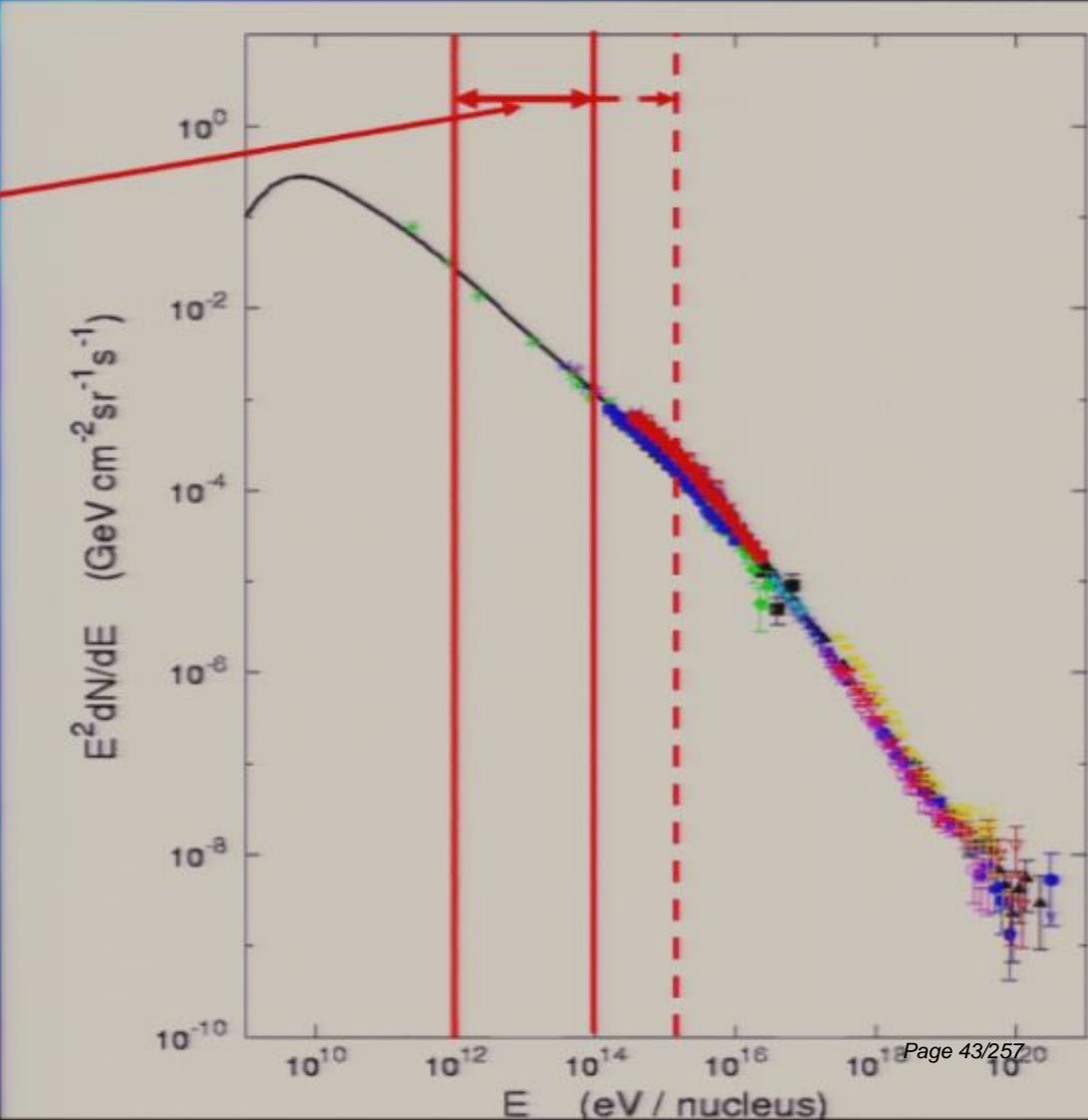
# Direct Composition Measurements

CREAM Missions (NASA)



# Direct Composition Measurements

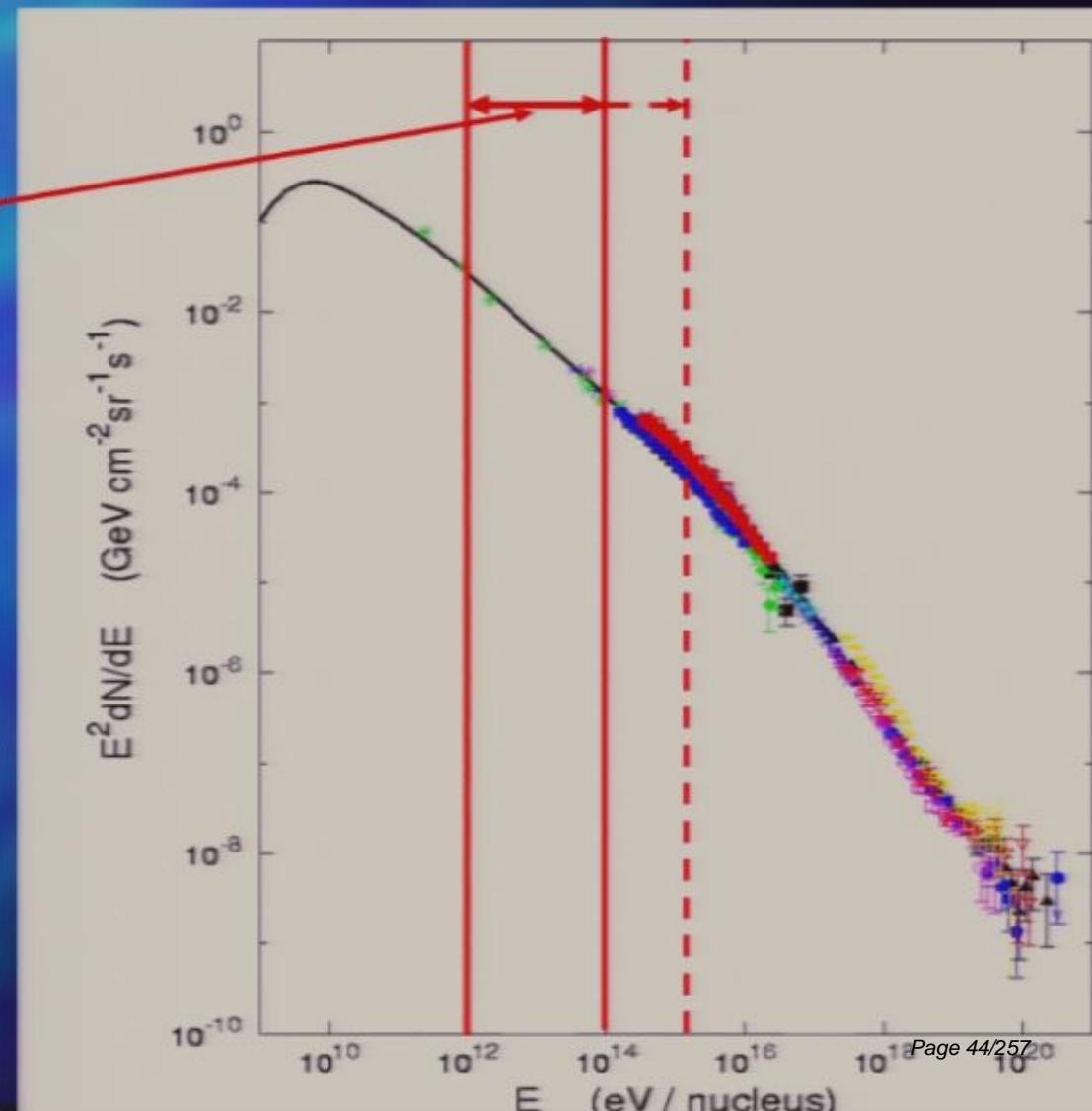
CREAM Missions (NASA)



# Direct Composition Measurements

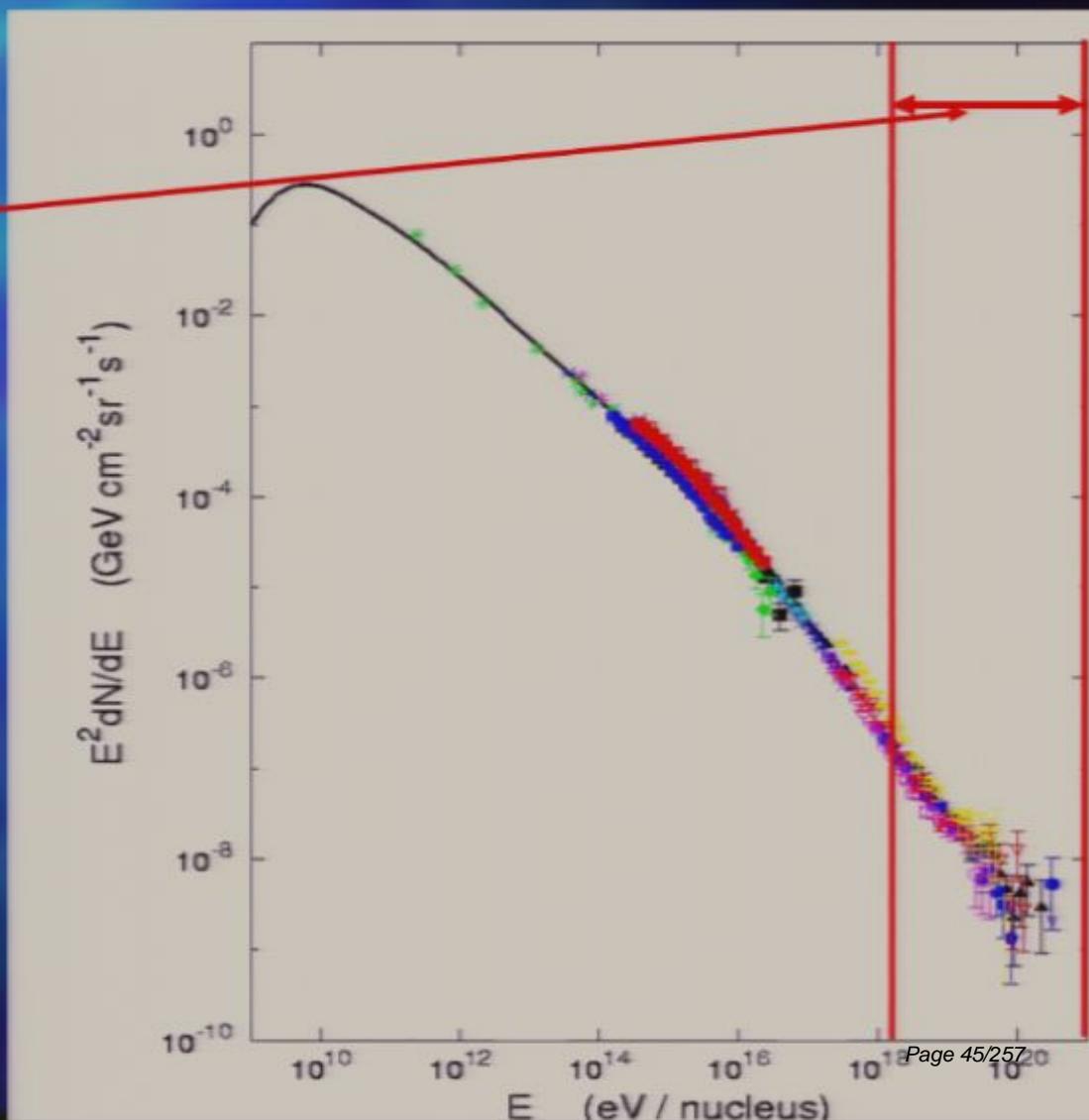
## CREAM Missions (NASA)

- Direct composition measurements;
- Spectrum measurement from  $10^{12} - 10^{15}$  eV;
- Elemental resolution;
- Antarctic Balloon missions;
- Redundant energy determination;
- Target: 200 days Antarctic exposure with a fully active instrument with geometric acceptance  $2.2 \text{ m}^2 \text{ sr}$ .



# The Highest Energies

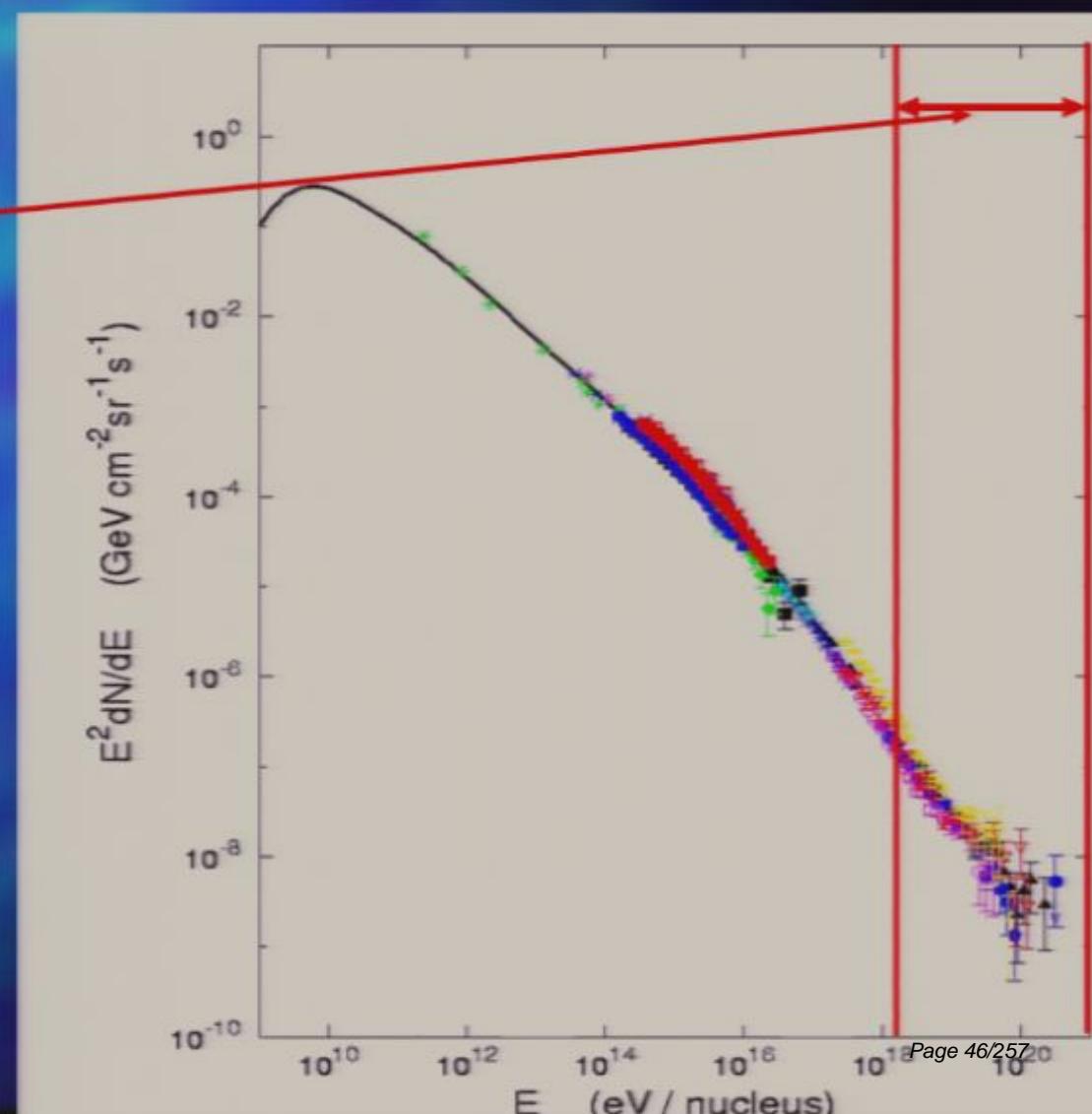
Pierre Auger Observatory  
(NSF/DoE)



# The Highest Energies

## Pierre Auger Observatory (NSF/DoE)

- Indirect, air shower measurements;
- Spectrum measurement from  $10^{18} - 10^{21}$  eV;
- Search for anisotropies, neutrinos;
- Some sensitivity to composition;
- Giant array under construction in Argentina;
- Hybrid energy determination.



# CREAM

## (Cosmic Ray Energetics And Mass)

Timing scintillators

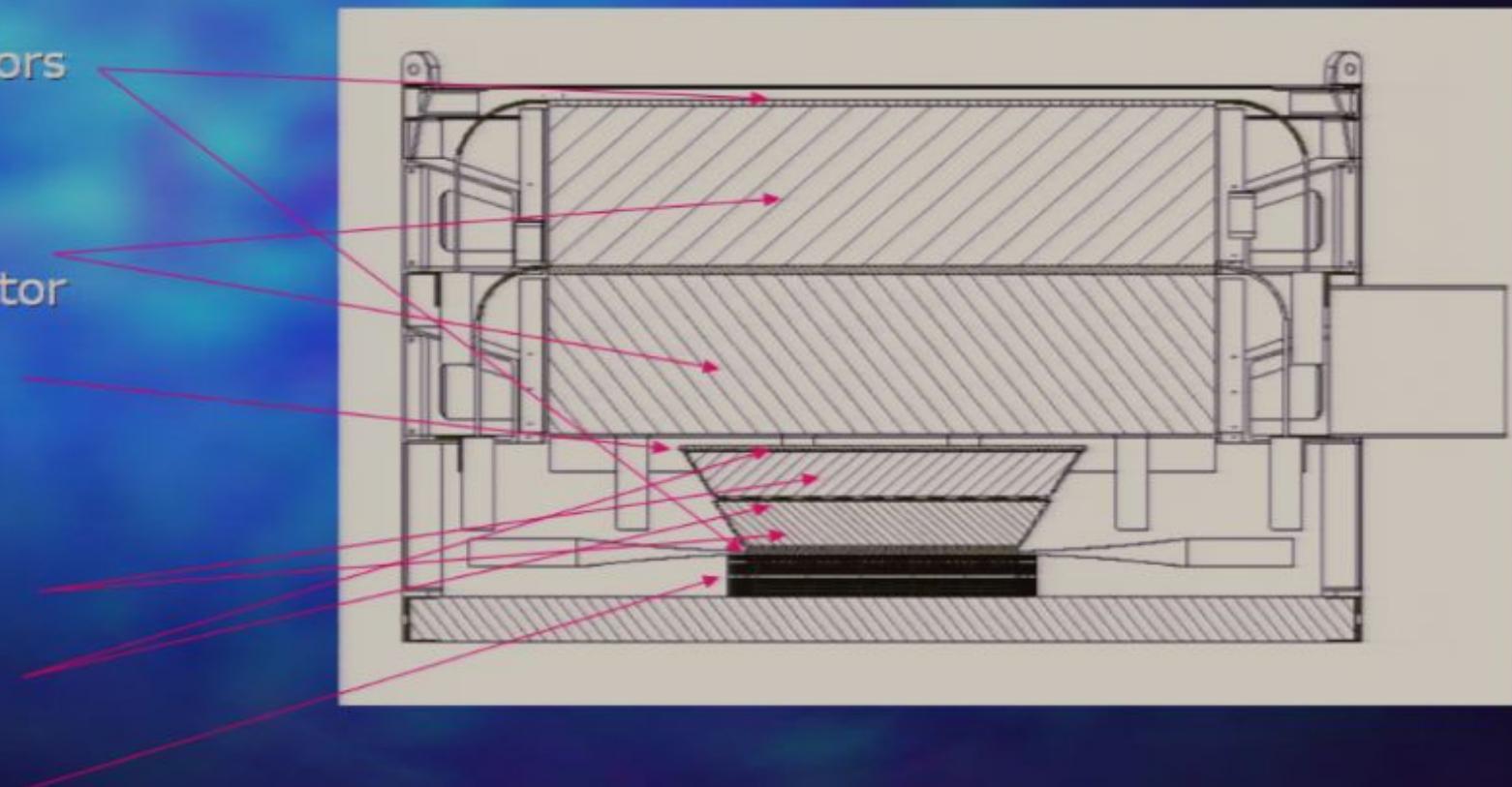
Transition  
Radiation Detector

Silicon Charge  
Detector

Target layers

Hodoscopes

Calorimeter



# CREAM (Cosmic Ray Energetics And Mass)

Timing scintillators

Transition  
Radiation Detector

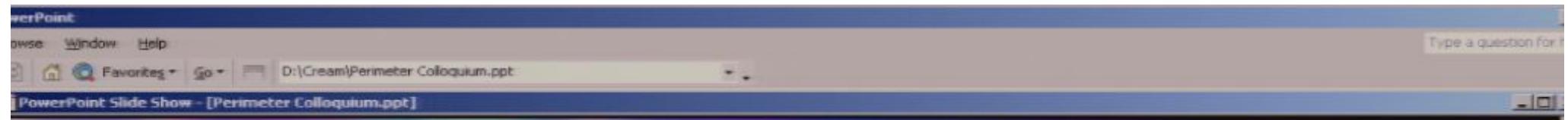
Silicon Charge  
Detector

Target layers

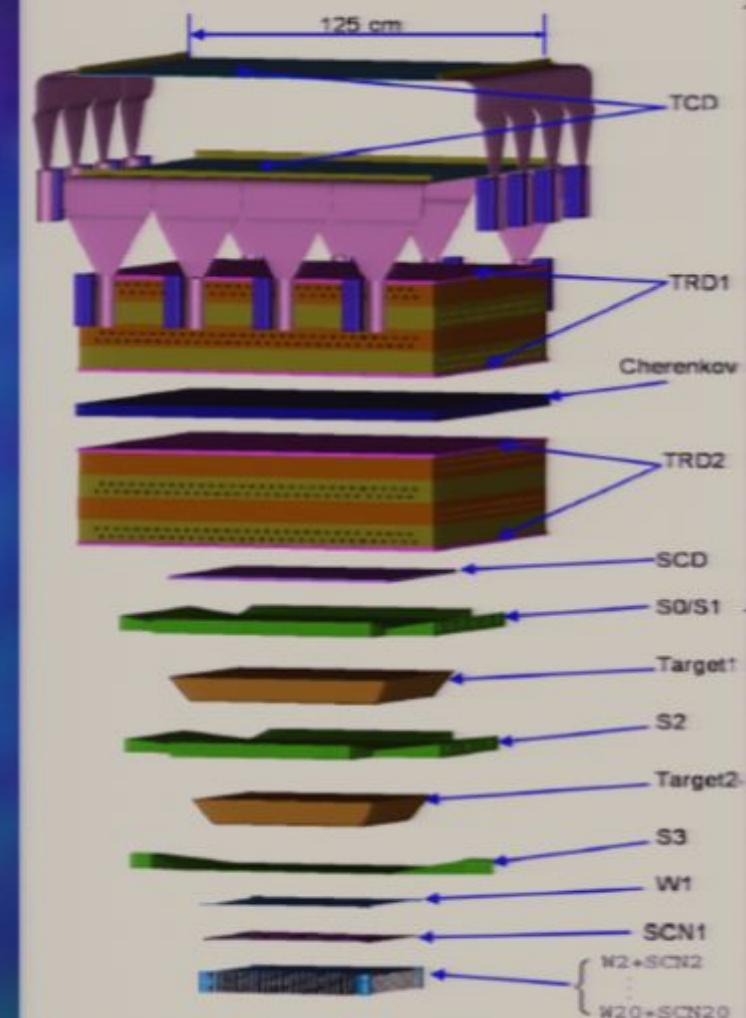
Hodoscopes

Calorimeter

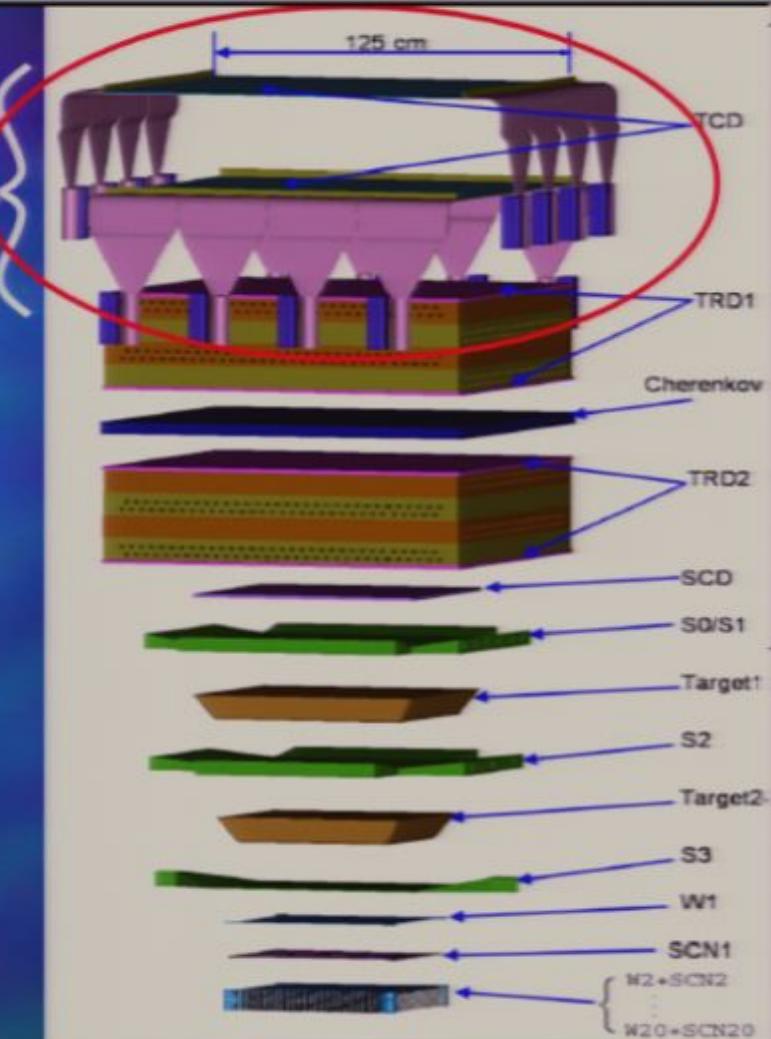




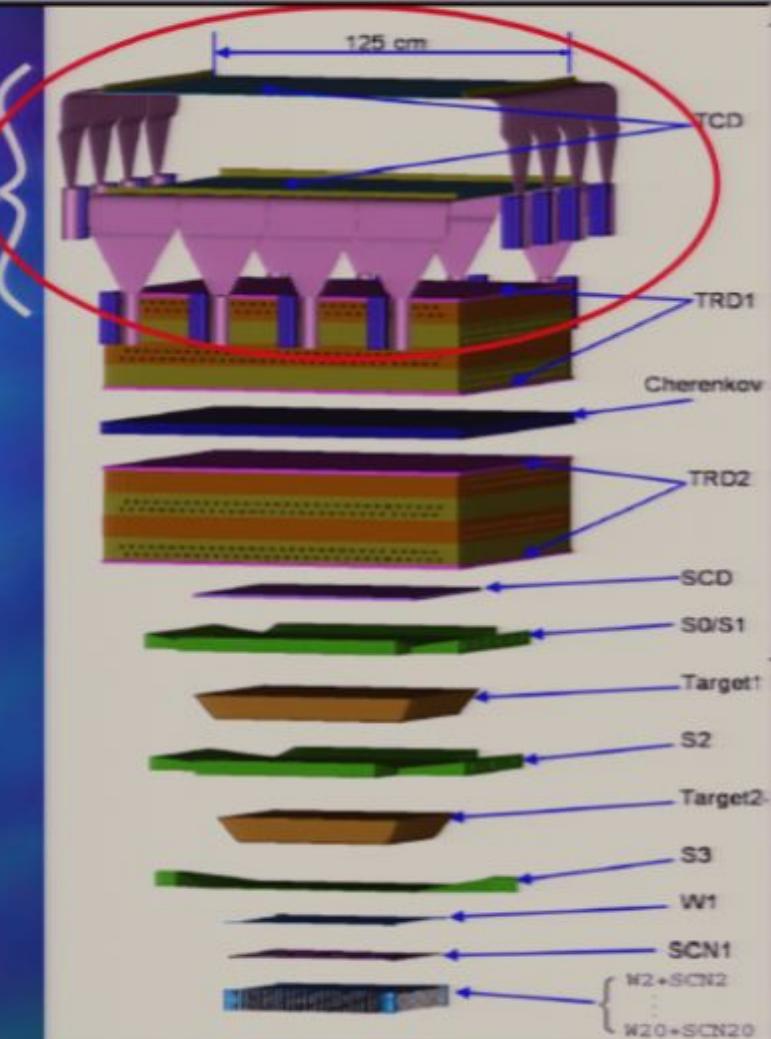
# TCD System



# TCD System



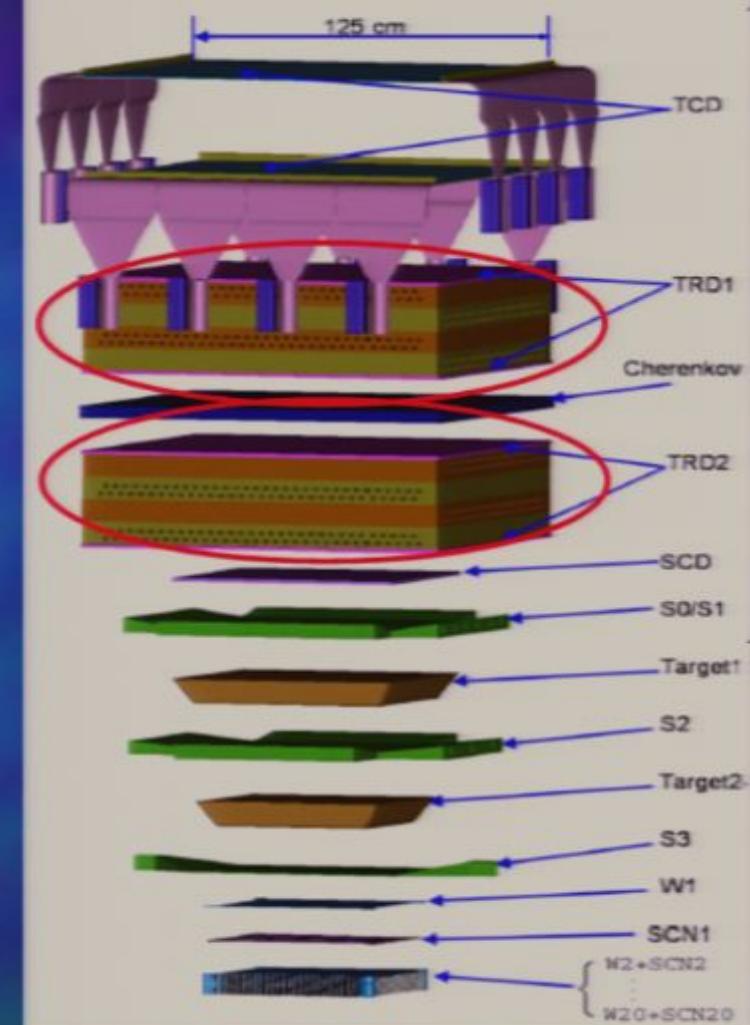
# TCD System



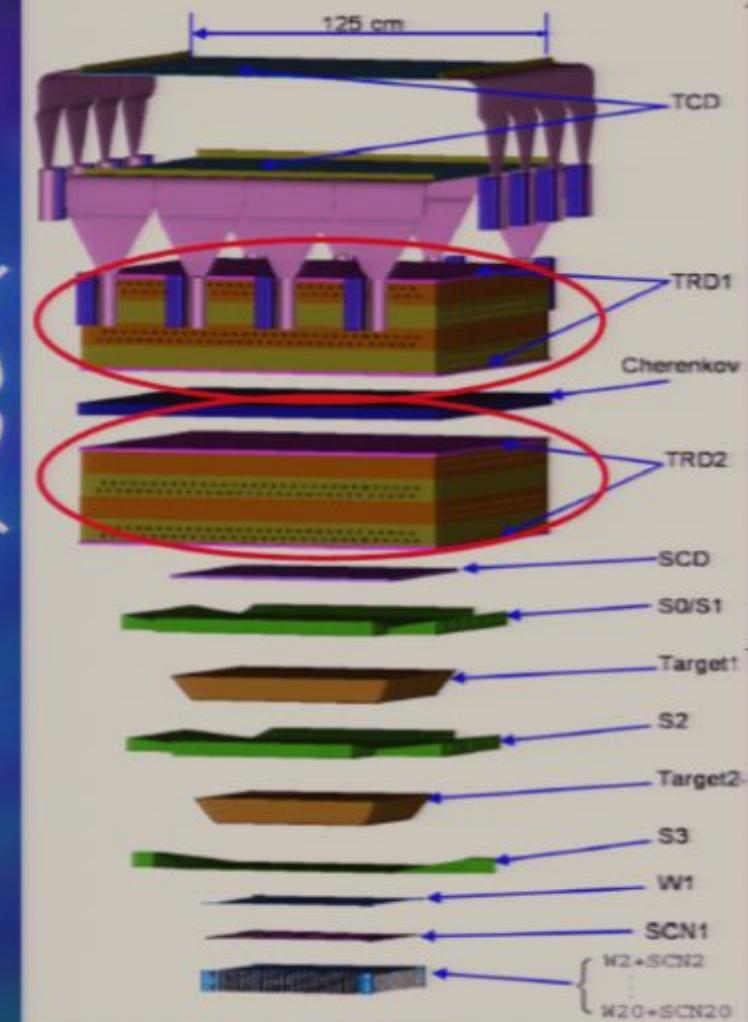
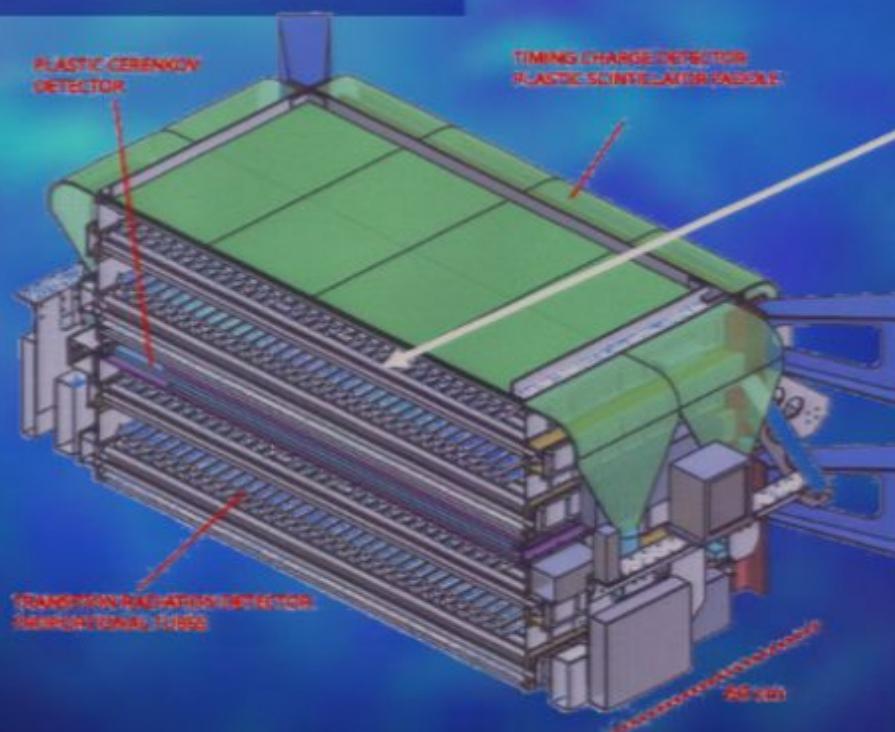
- **Timing Charge Detector (TCD):**

- 8 thin (5 mm) scintillators in 2 layers, 16 fast PMTs;
- Light pulse amplitude and time structure measured  $\Rightarrow$  Q measured before albedo from calorimeter, 3-8 ns after incident particle; provide Z>3 trigger;
- Charge accuracy  $\sim 0.2e$  for O,  $\sim 0.35e$  for Fe.

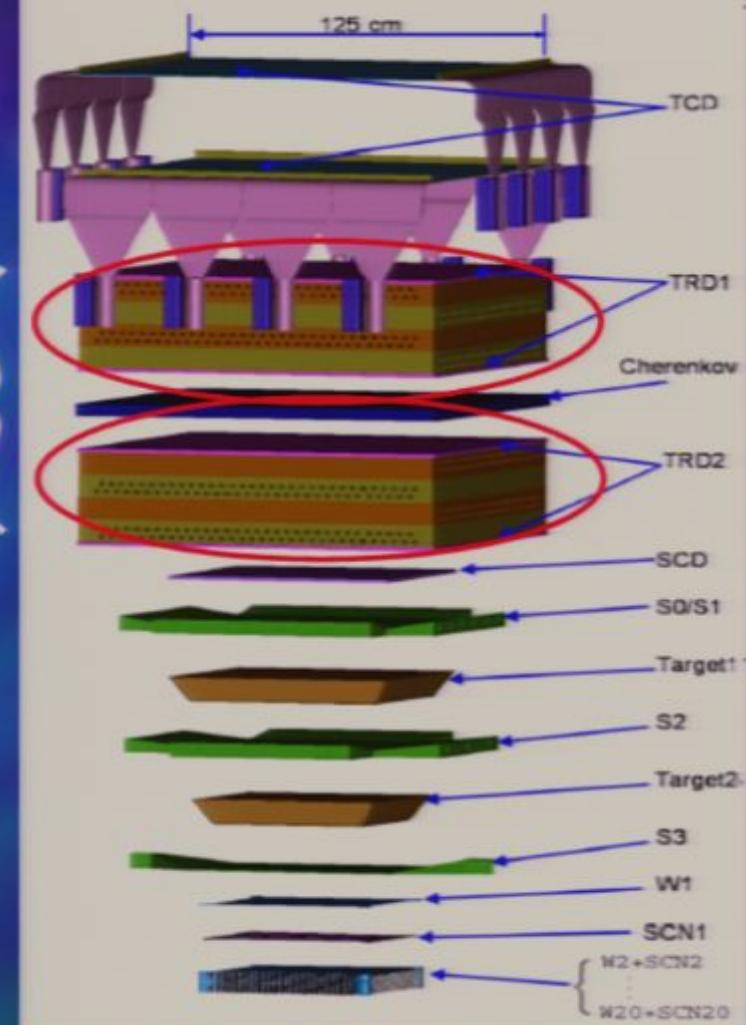
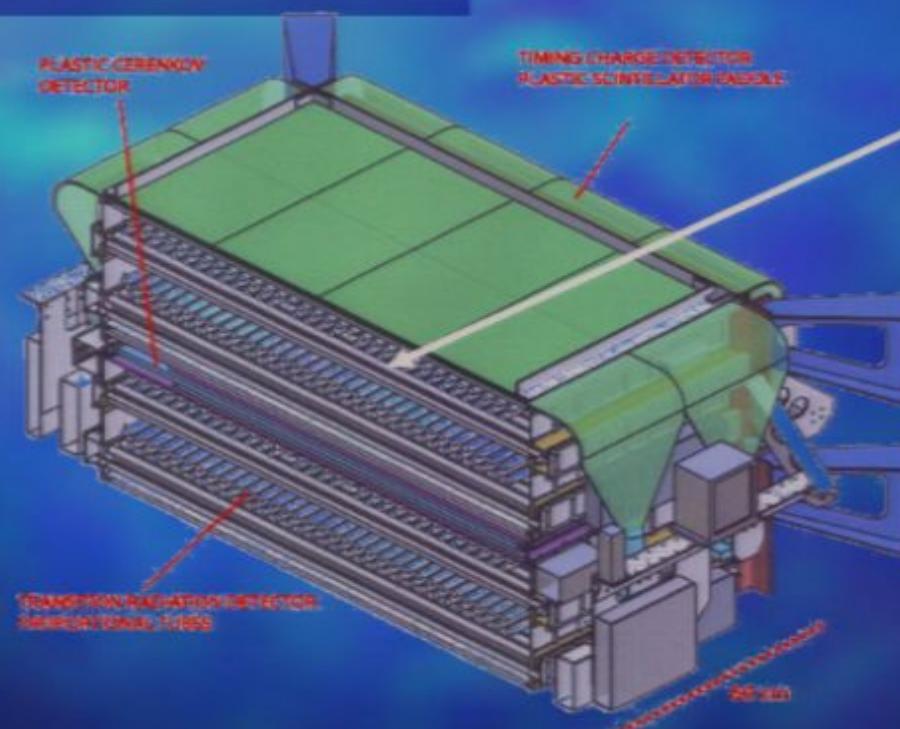
# TRD System



# TRD System



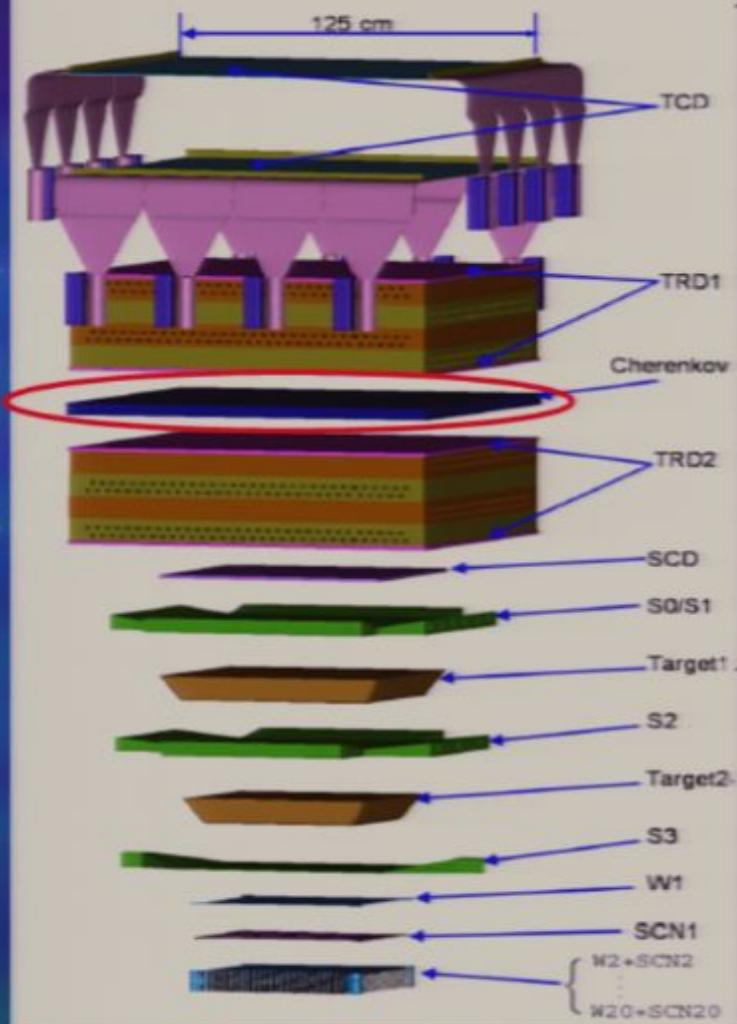
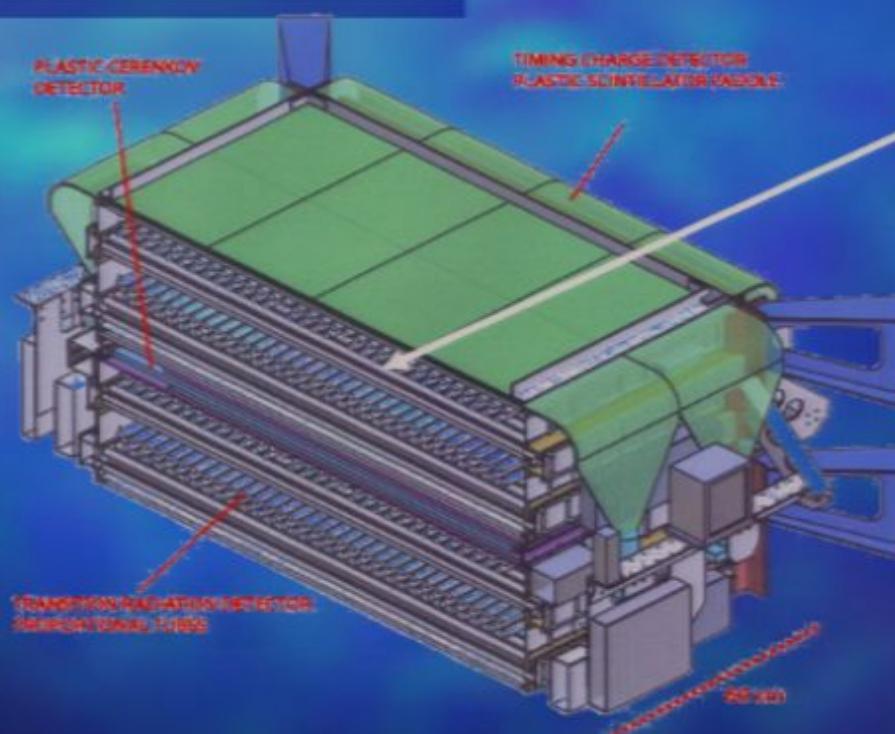
# TRD System



## Transition Radiation Detector (TRD):

- 512 thin-walled (100  $\mu\text{m}$ ) proportional tubes (2 cm diameter) in 16 layers in foam matrix;
- Filled with Xe(95%)-methane(5%);
- Hit pattern  $\Rightarrow$  3D track with  $\sigma_{\text{RMS}} \sim 5 \text{ mm}$  (ultimately 2 mm);
- $dE/dx$  (+TR @ >1 TeV/n) yields E until saturation at  $\gamma \sim 20,000$ ; sensitivity to Li and heavier.

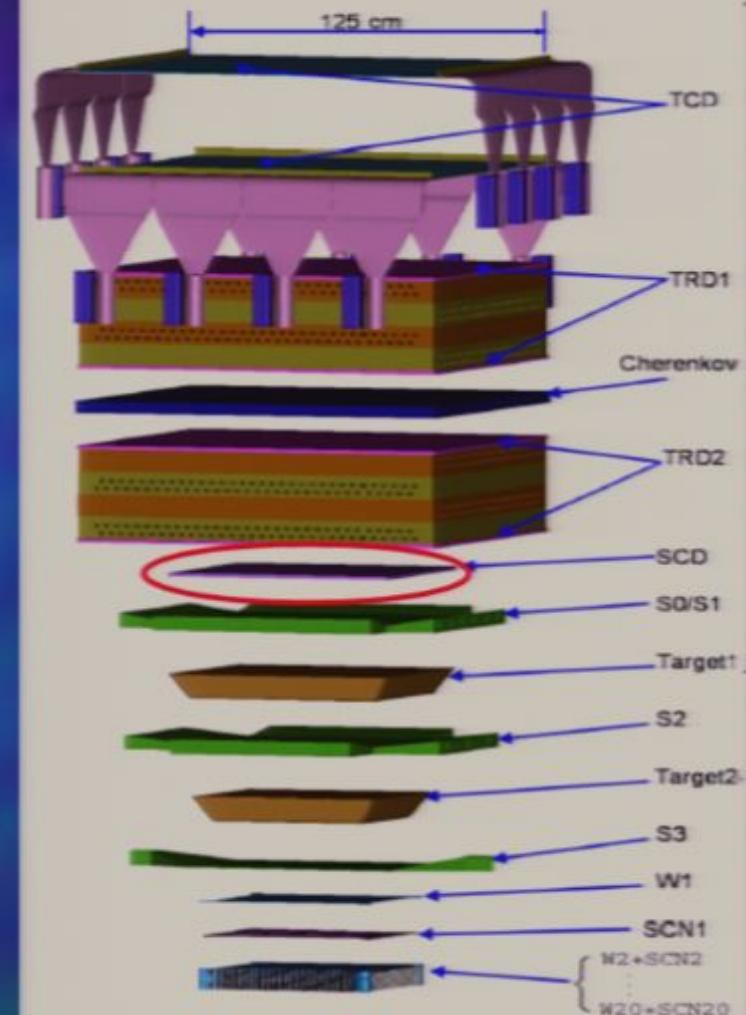
# TRD System Plus Cherenkov



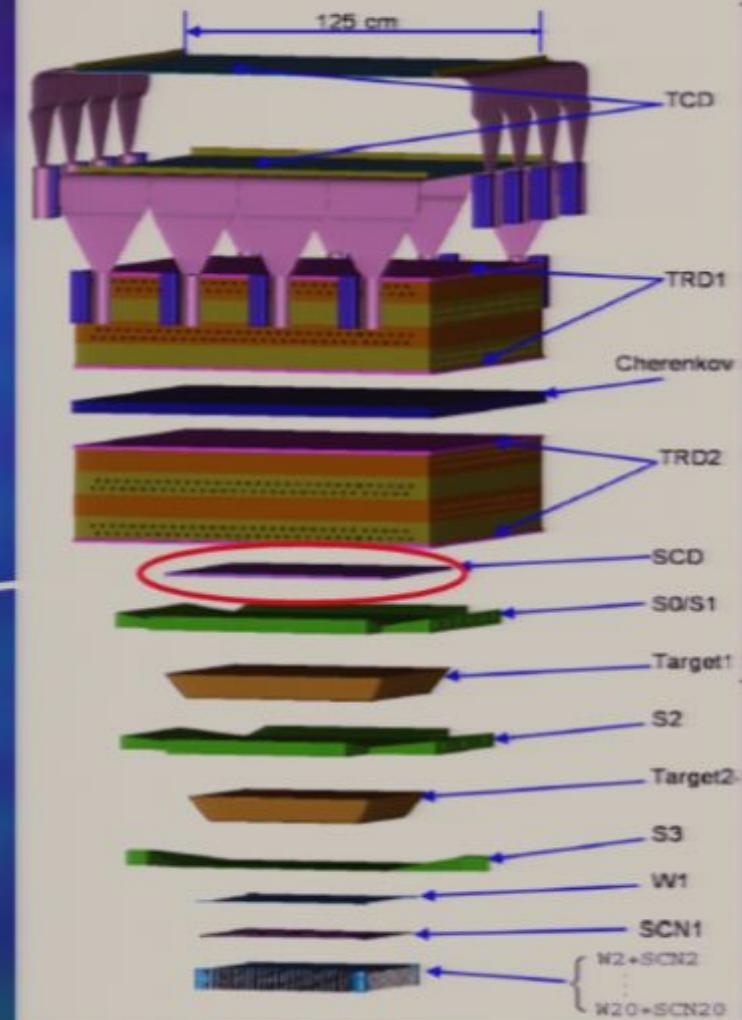
## Transition Radiation Detector (TRD):

- 512 thin-walled (100  $\mu\text{m}$ ) proportional tubes (2 cm diameter) in 16 layers in foam matrix;
- Filled with Xe(95%)-methane(5%);
- Hit pattern  $\Rightarrow$  3D track with  $\sigma_{\text{RMS}} \sim 5 \text{ mm}$  (ultimately 2 mm);
- $dE/dx$  (+TR @  $>1 \text{ TeV/n}$ ) yields E until saturation at  $\gamma \sim 20,000$ ; sensitivity to Li and heavier.

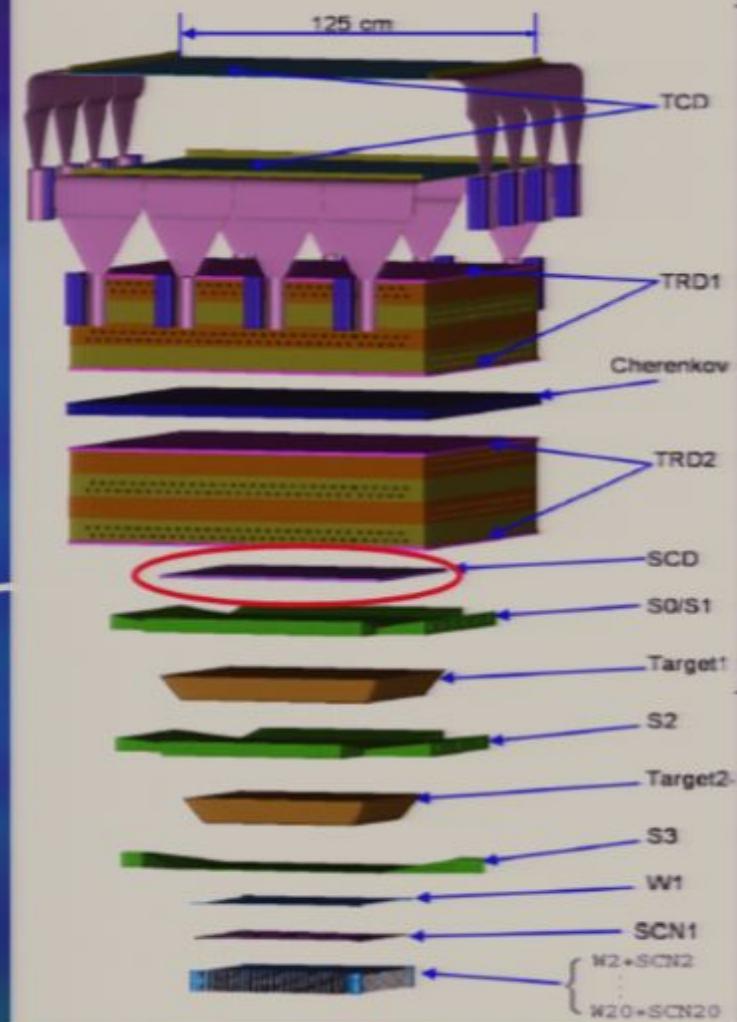
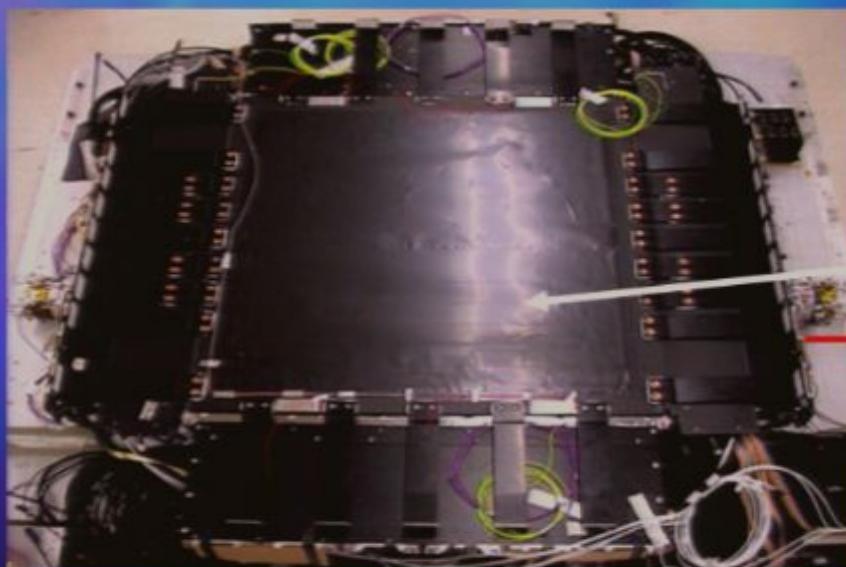
# SCD System



# SCD System



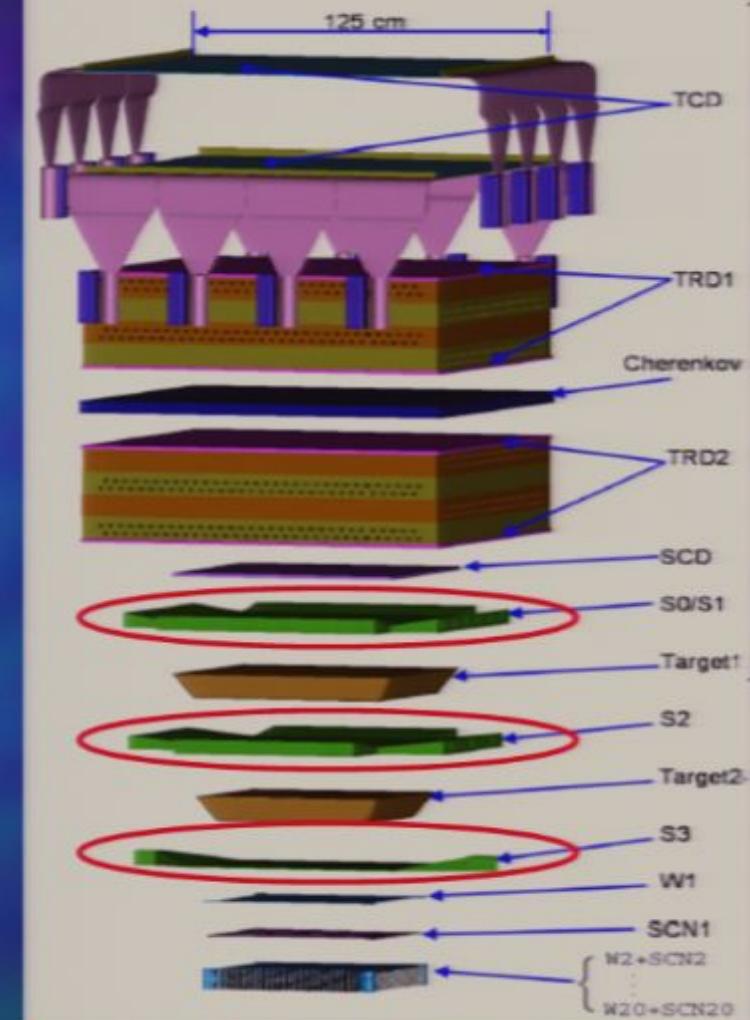
# SCD System



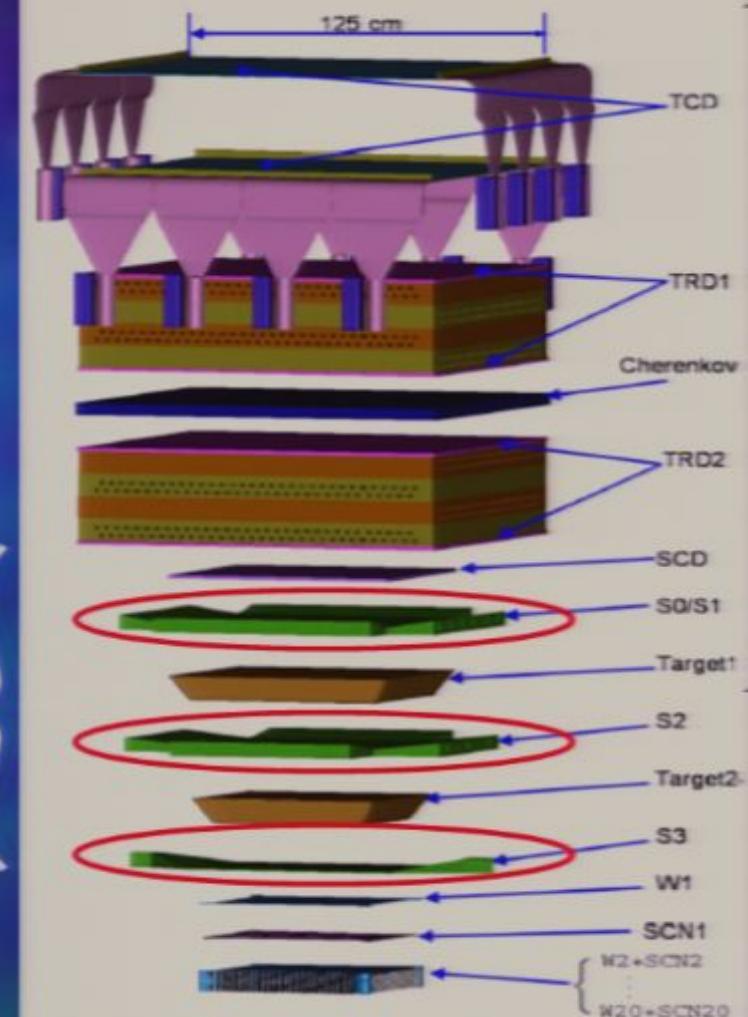
## c) Silicon Charge Detector

- 26 ladders, each with 7 silicon sensor modules, each with 16 cells  $2.12 \text{ cm}^2$ ;
- Charge measurement, resolution  $\sim 0.1e$ ;
- Segmentation reduces back-scatter impact.

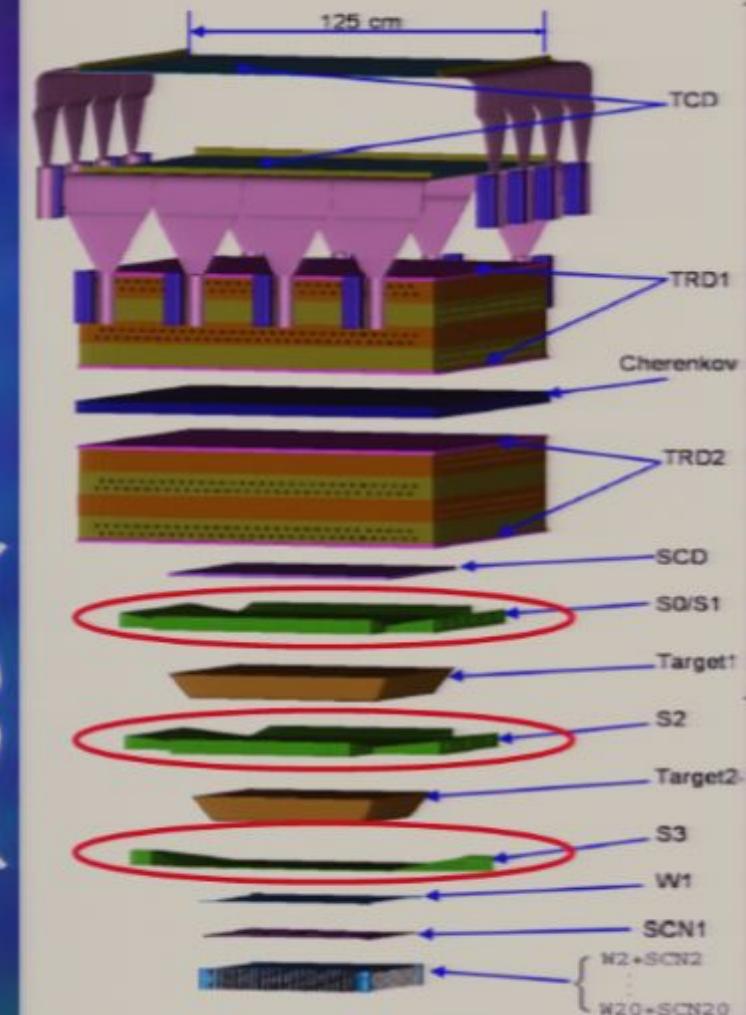
# Hodoscope System



# Hodoscope System



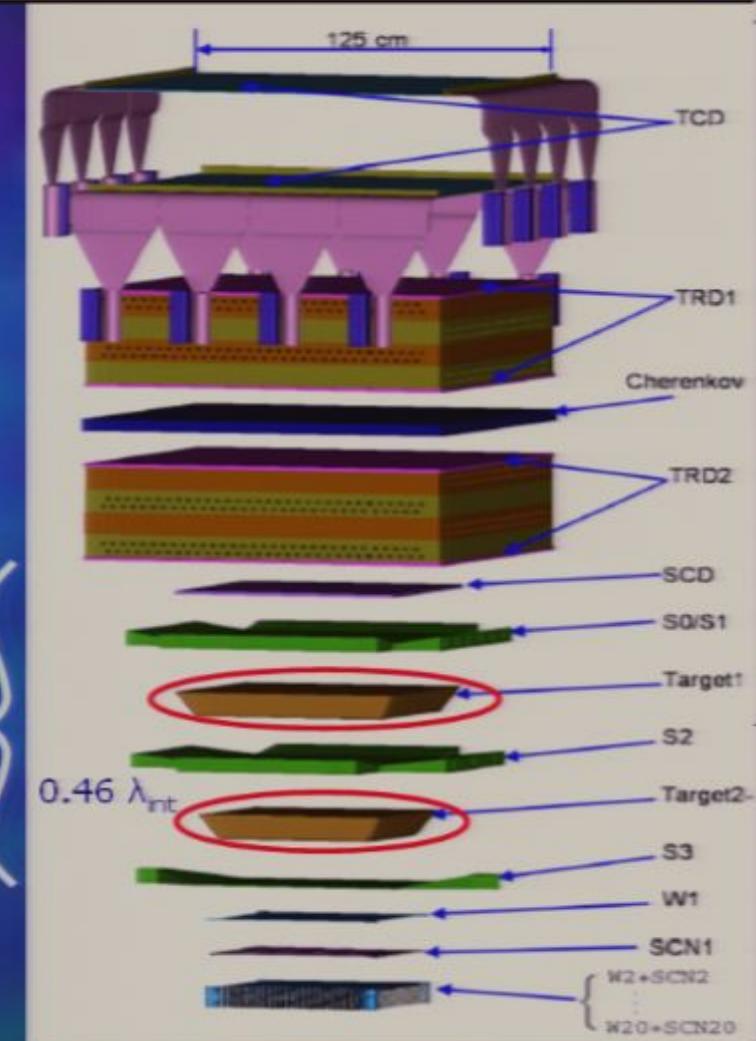
# Hodoscope System



## c) Hodoscopes

- 640  $2 \times 2 \text{ mm}^2$  scintillating fibers arranged in 2 orthogonal planes (exc. S3);
- HPD readout (bundles of 64 fibers), PMT readout for S3;
- Redundant charge measurement, plus trigger and tracking.

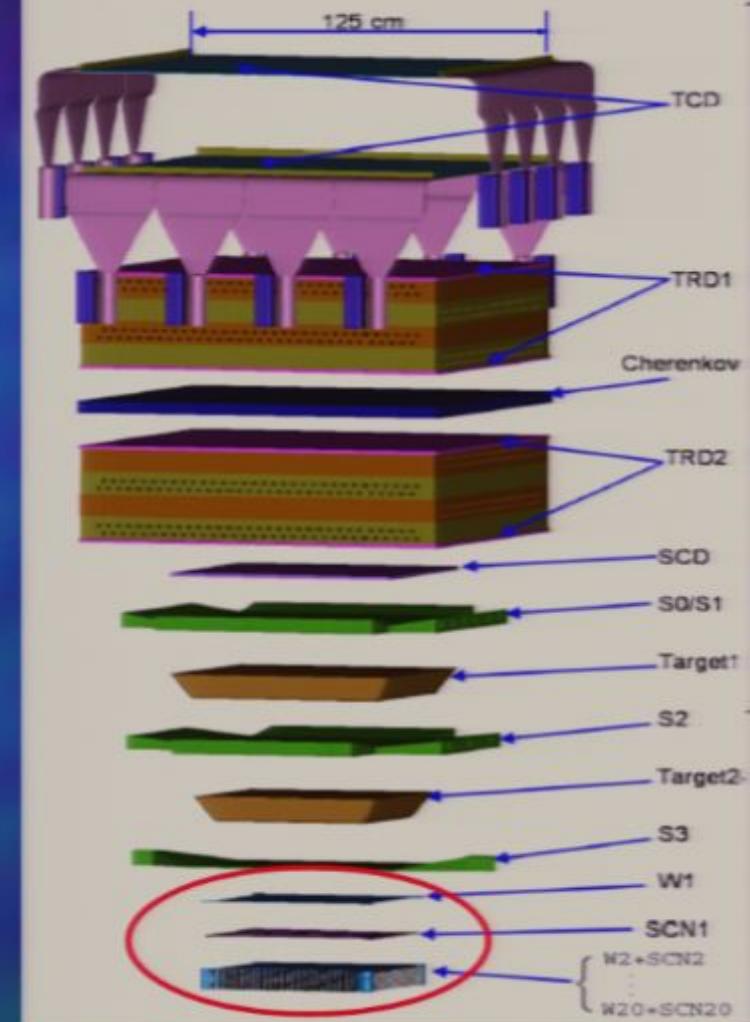
# Hodoscope System Plus Graphite Targets



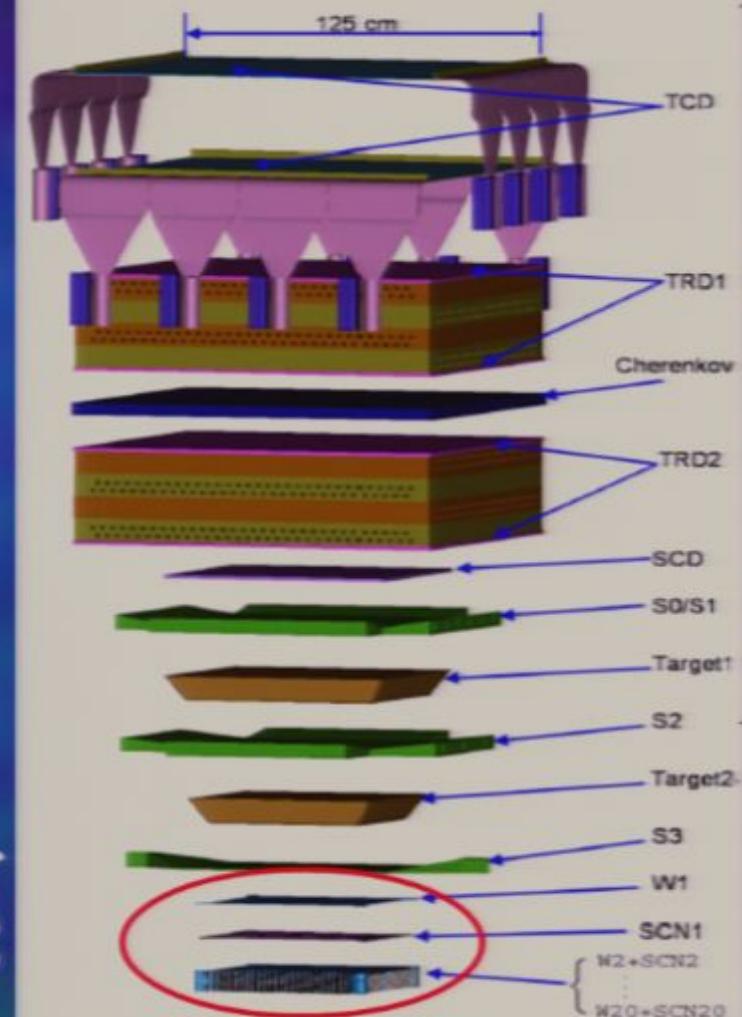
## c Hodoscopes

- 640  $2 \times 2 \text{ mm}^2$  scintillating fibers arranged in 2 orthogonal planes (exc. S3);
- HPD readout (bundles of 64 fibers), PMT readout for S3;
- Redundant charge measurement, plus trigger and tracking.

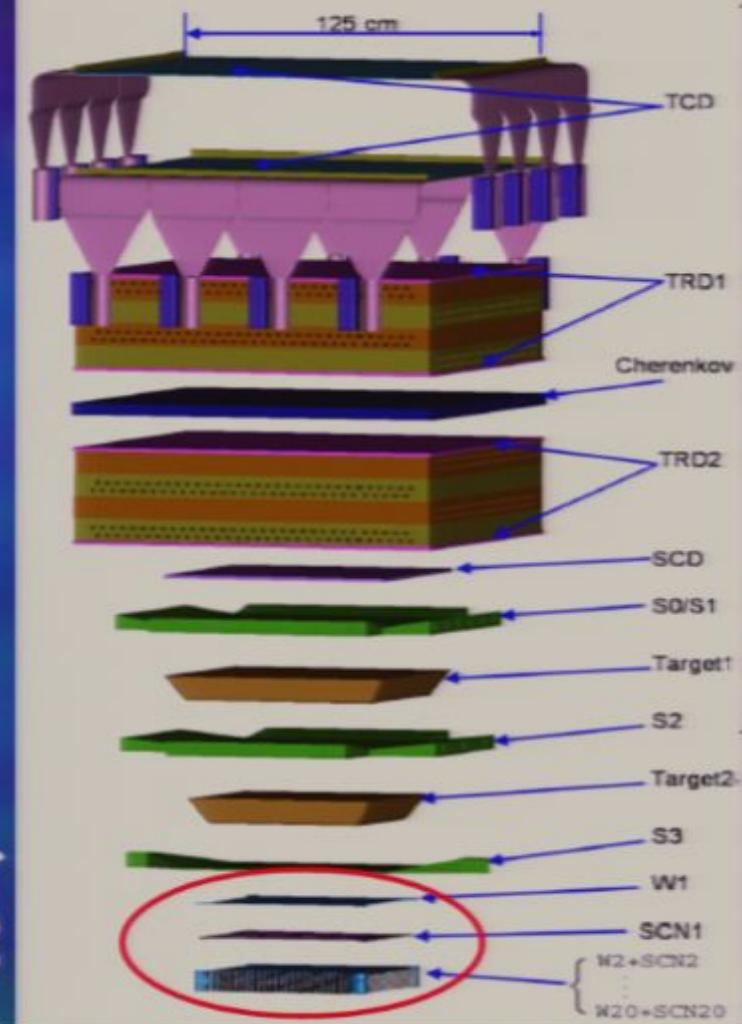
# Calorimeter System



# Calorimeter System



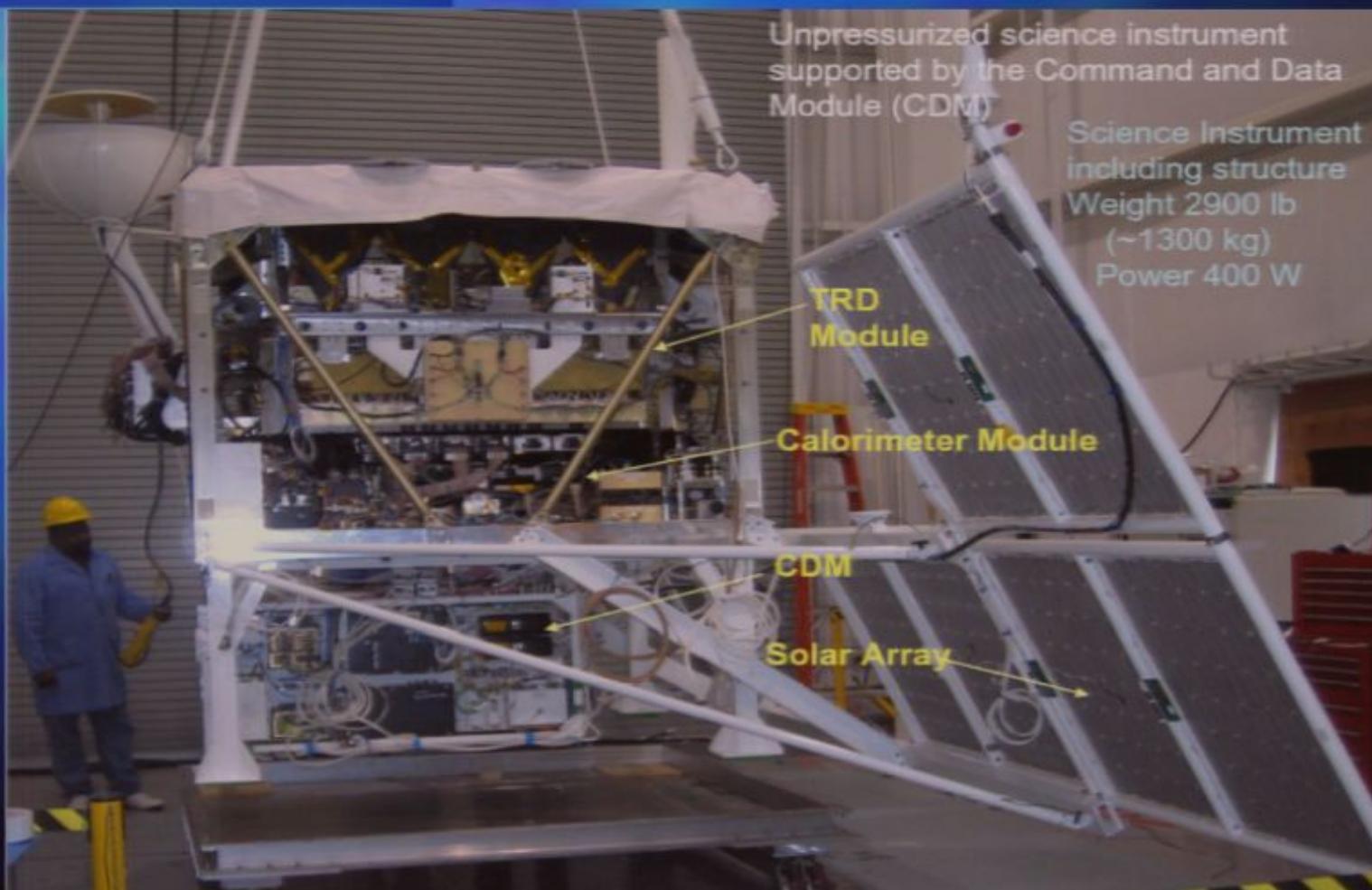
# Calorimeter System



## Calorimeter stack

- 20 W plates, 3.5 mm thick,  $1 X_0$  ;
- 20 scintillating fiber layers, 1 cm wide ribbons (Moliere radius 9 mm), 0.1 mm dia. fibers;
- HPD readout (40 HPDs, 2560 channels); fibers divided into low, mid, high energy readouts;
- Tracking, energy measurement  $Z=1-26$ ,  $E=\sim 200 \text{ GeV}-1000 \text{ TeV}$  (45% resolution).

# Overall Flight Configuration



# Getting to Antarctica

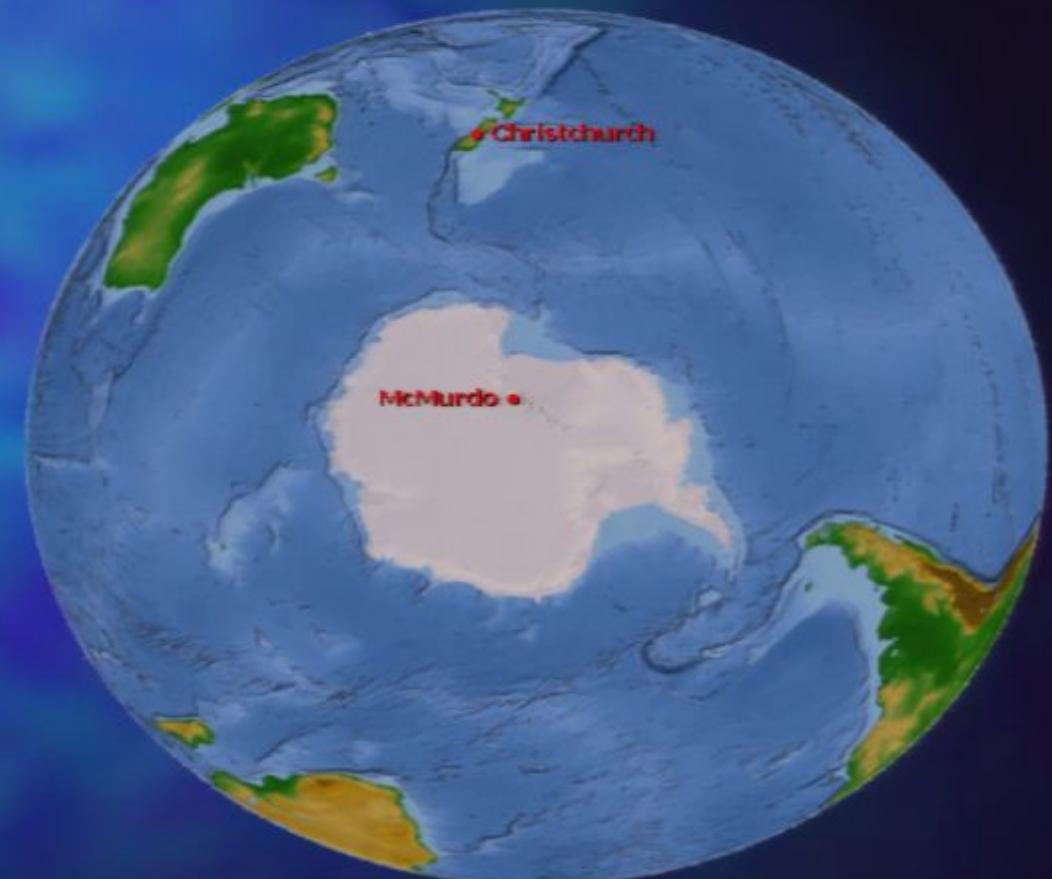
---

# Getting to Antarctica

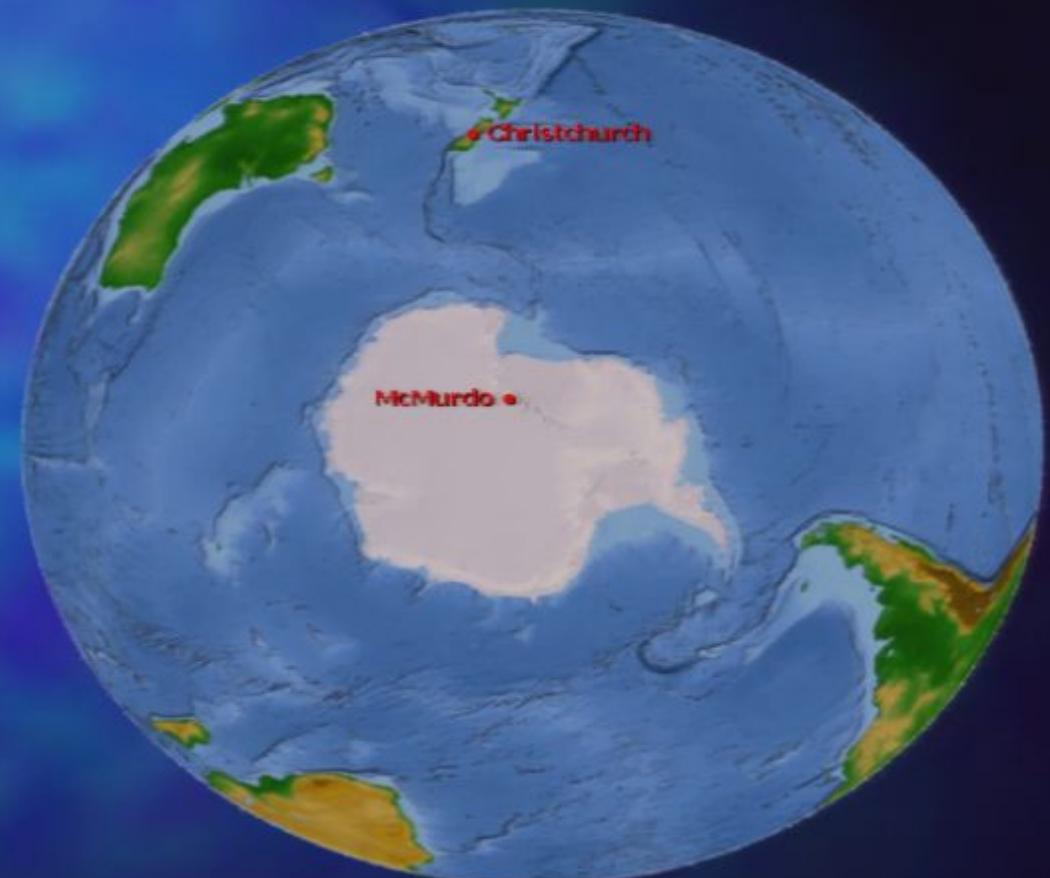




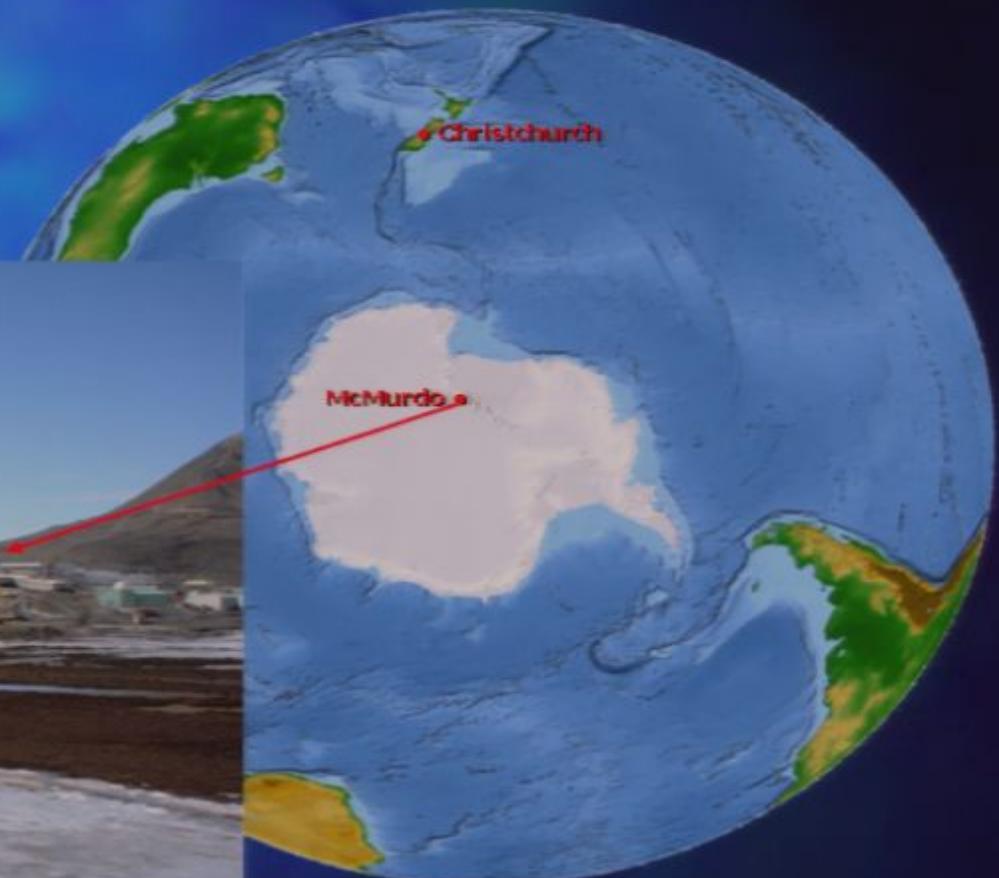
# Getting to Antarctica



# Getting to Antarctica



# Getting to Antarctica



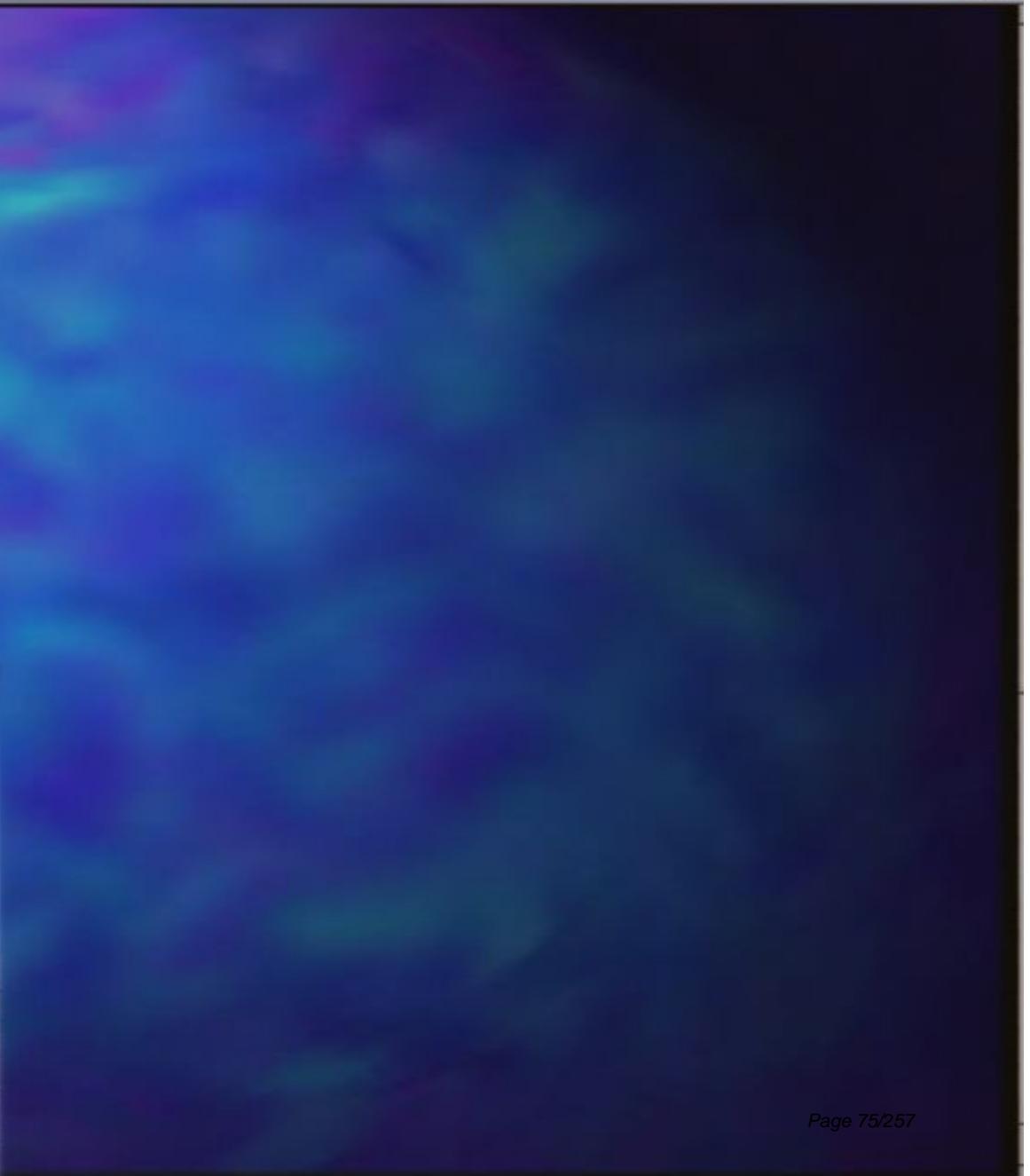
# Antarctica!

---

# Antarctica!



# Antarctica!

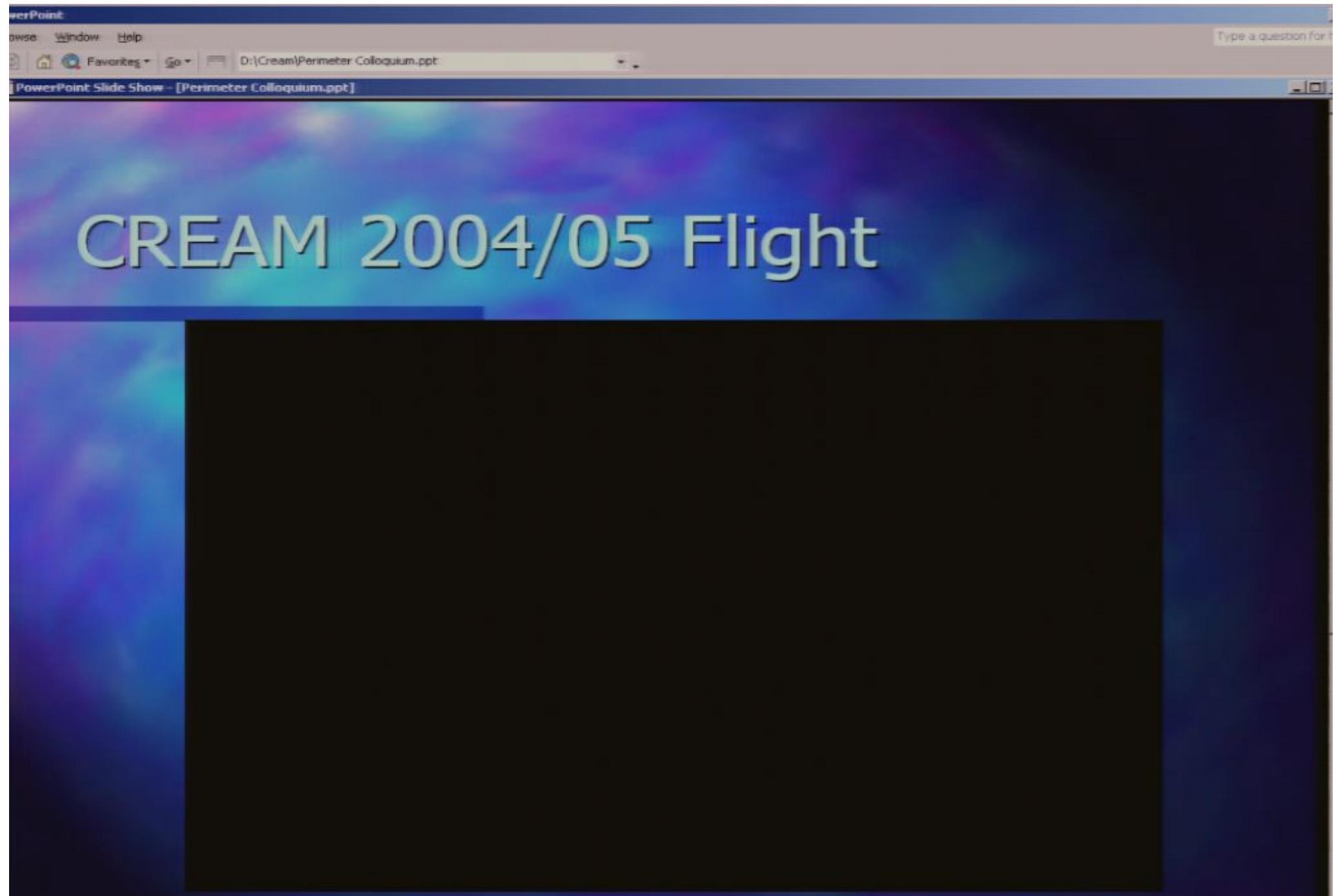


# Antarctica!



# Antarctica!





# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



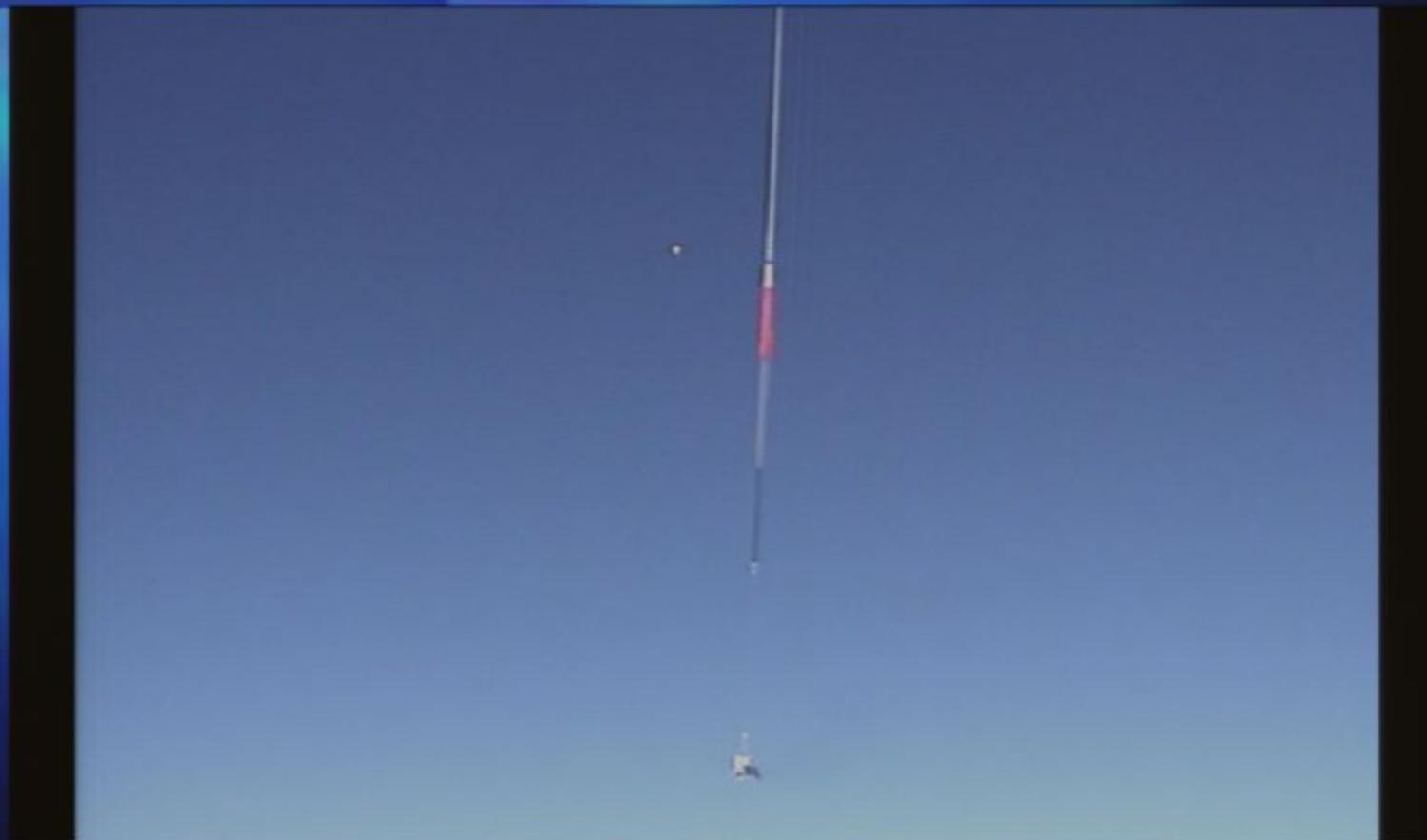
# CREAM 2004/05 Flight



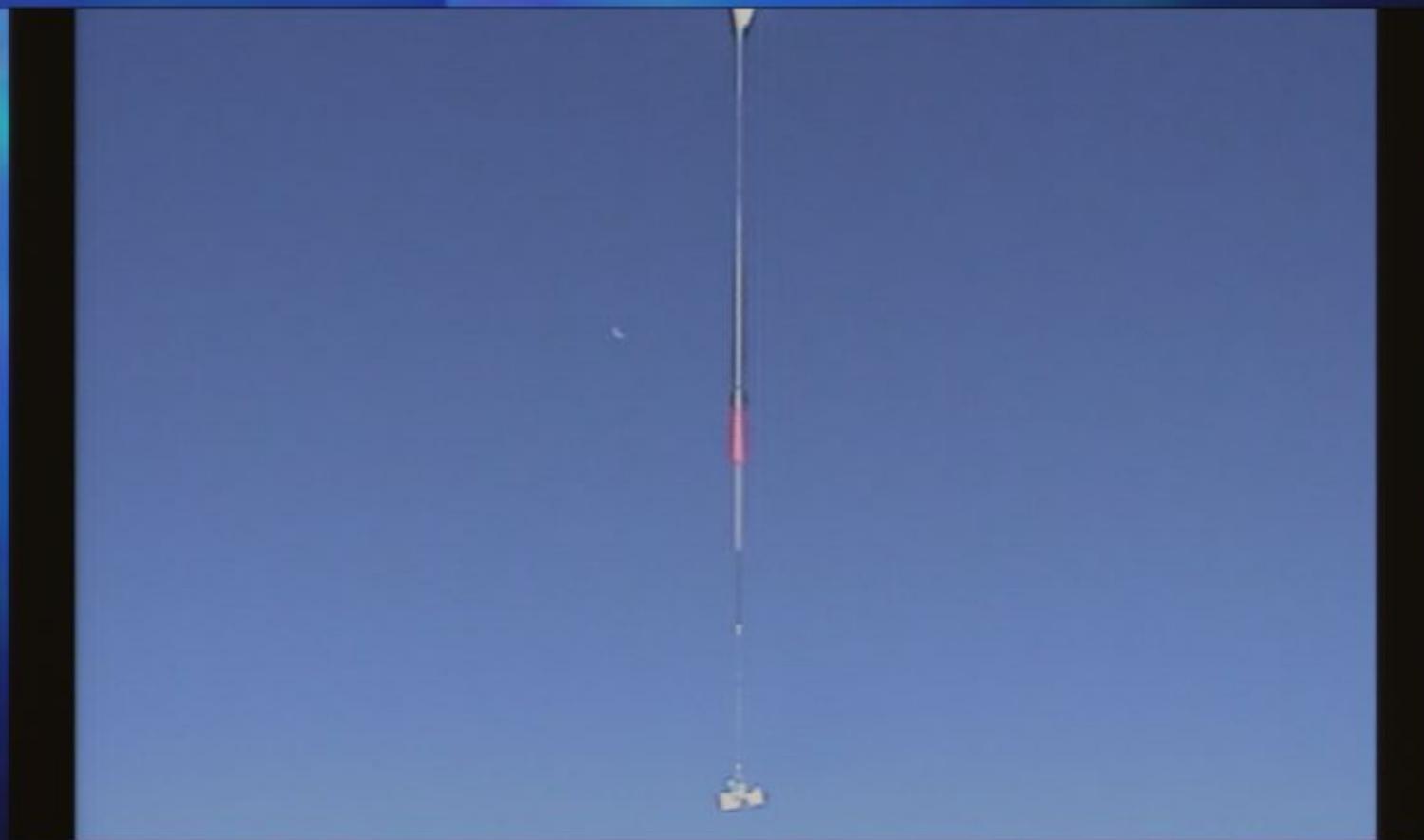
# CREAM 2004/05 Flight



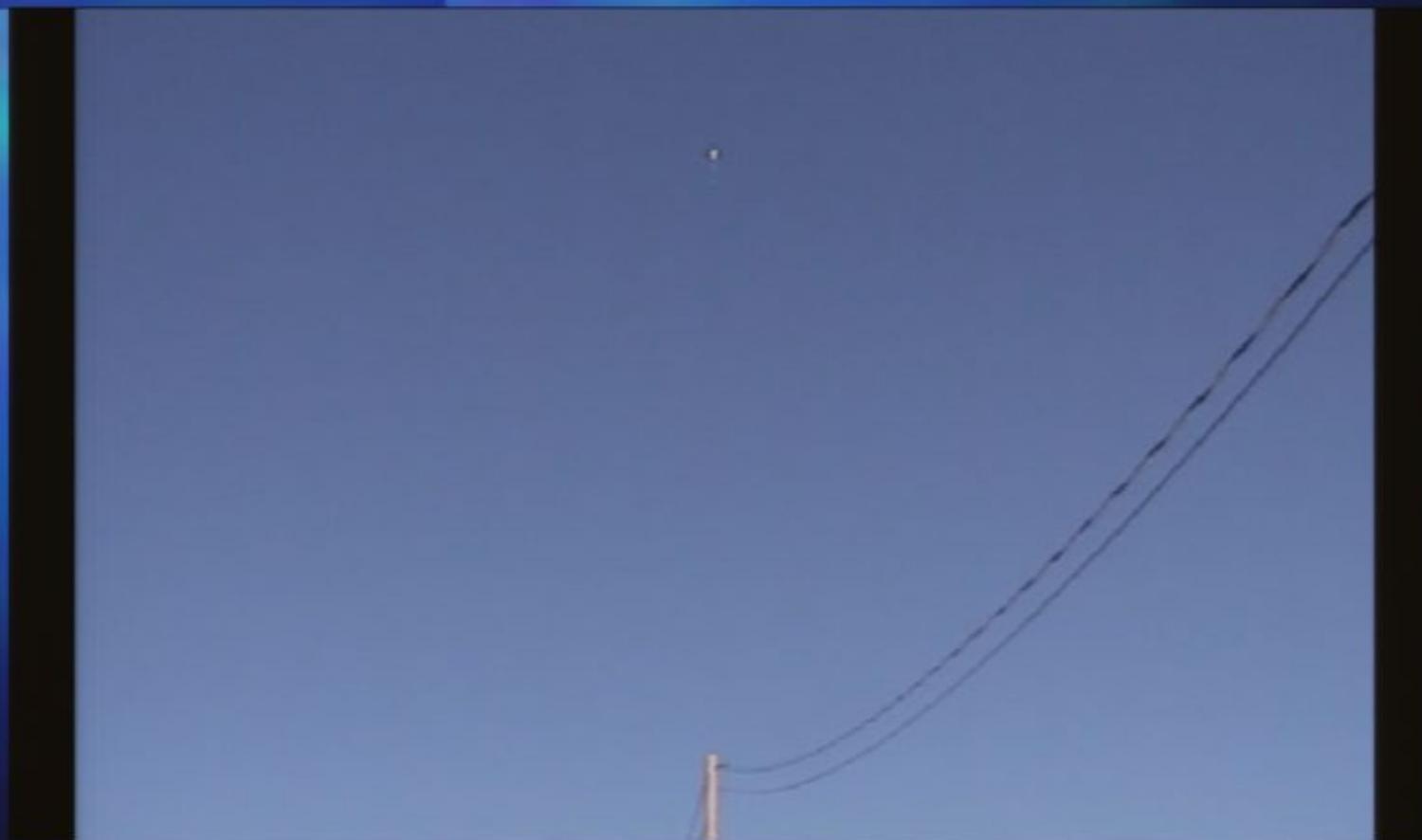
# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



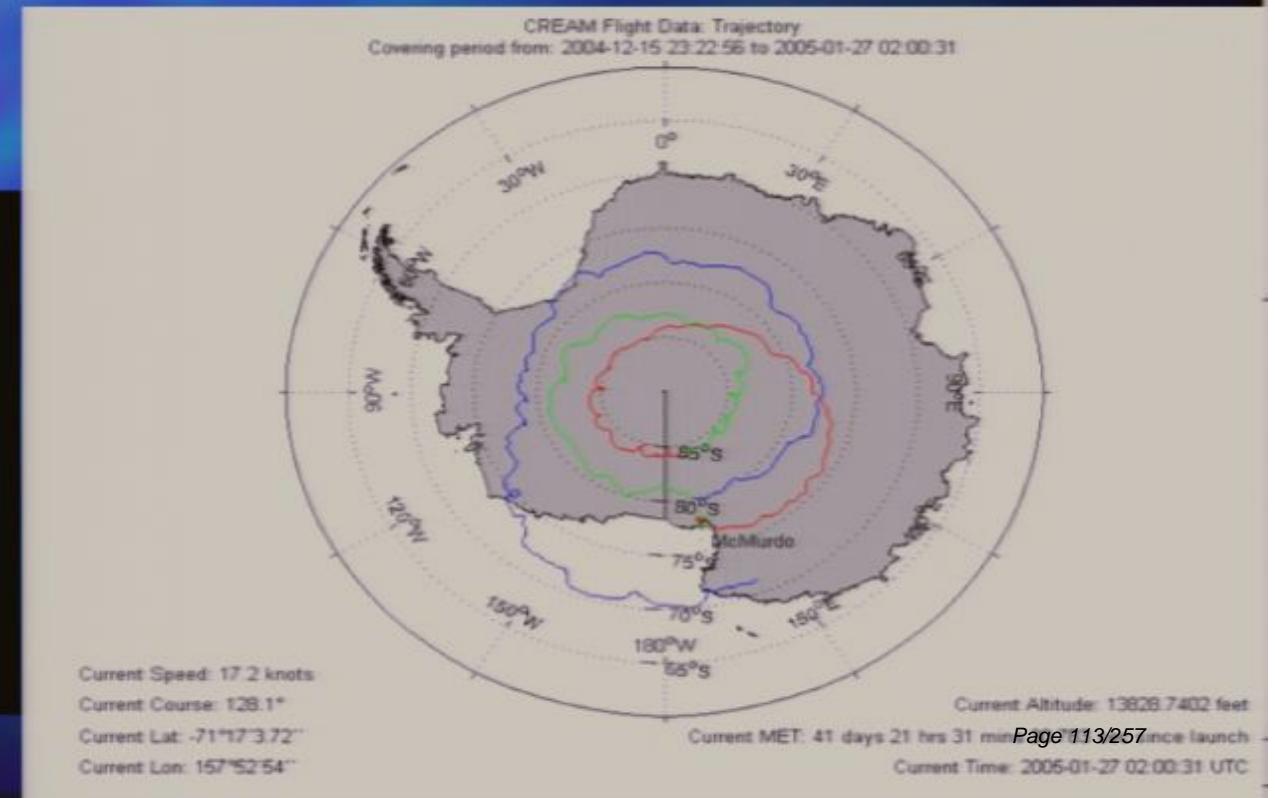
# CREAM 2004/05 Flight



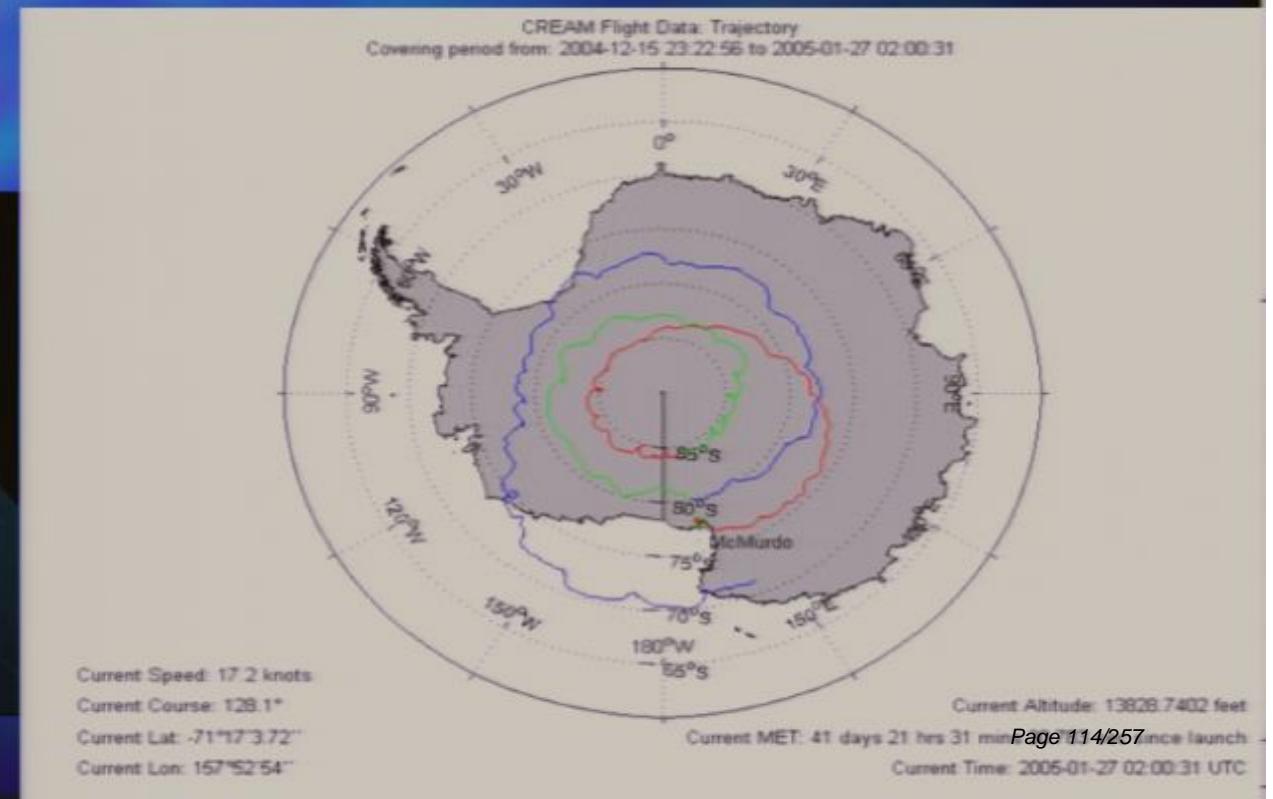
# CREAM 2004/05 Flight



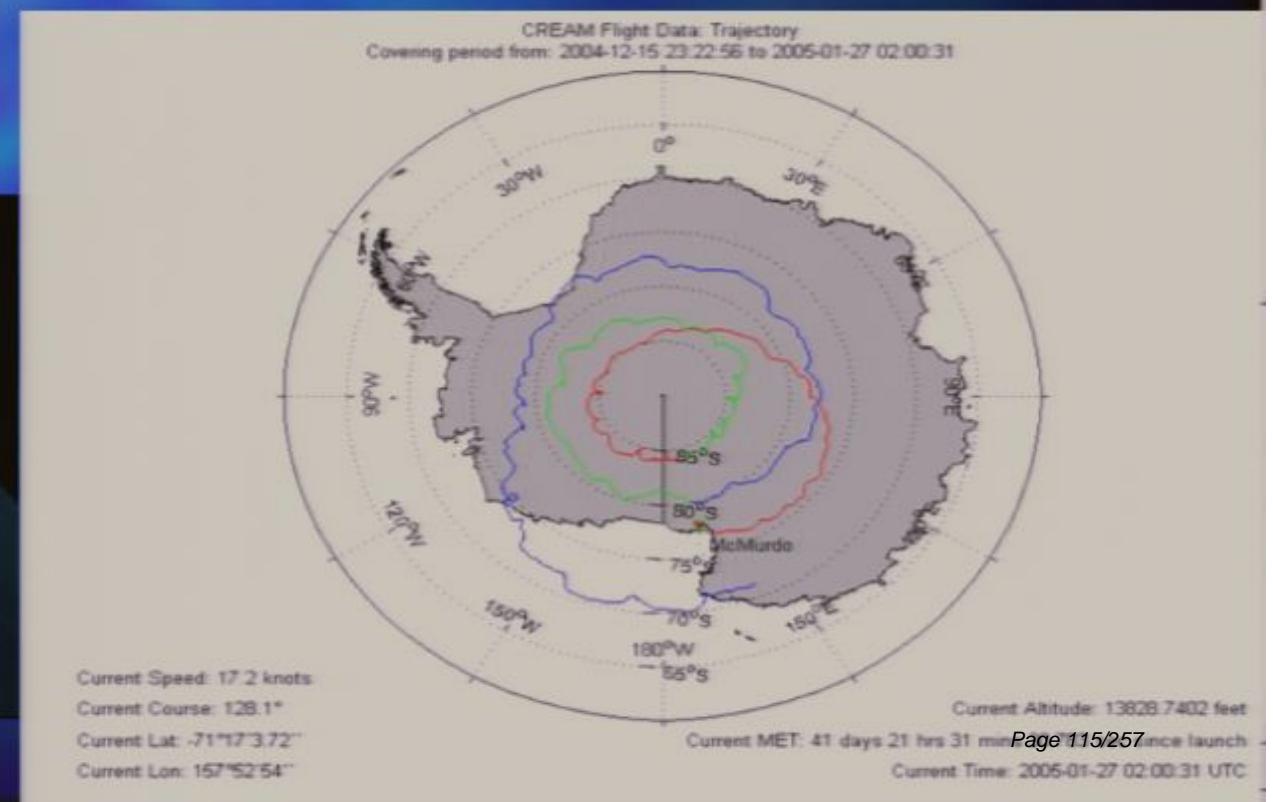
# CREAM 2004/05 Flight



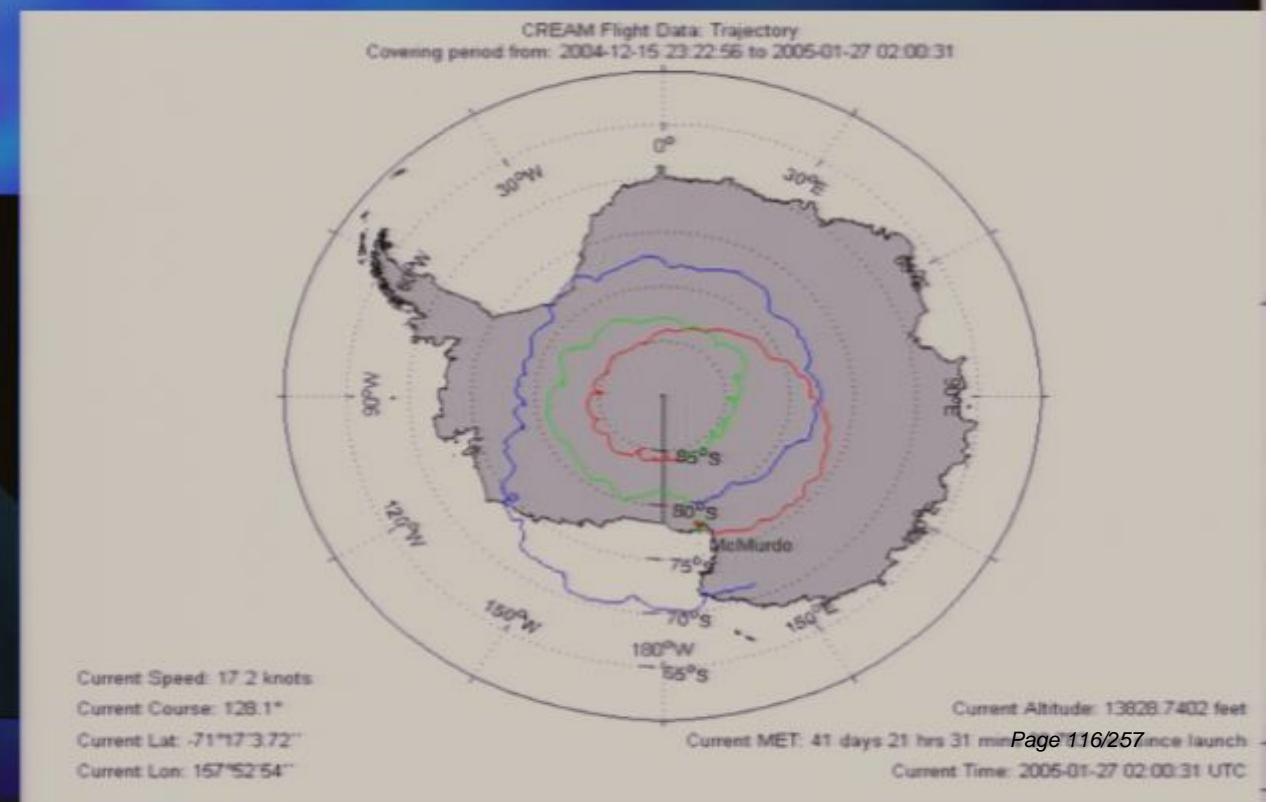
# CREAM 2004/05 Flight



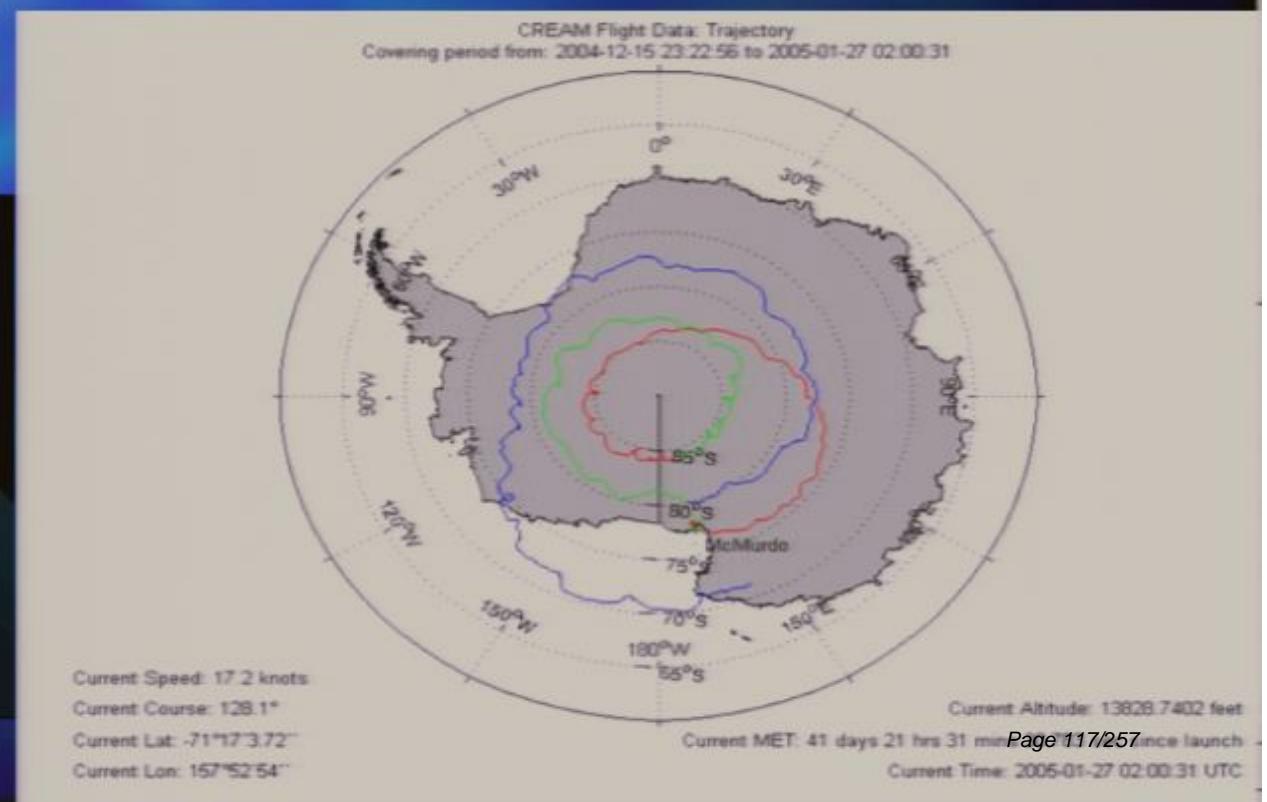
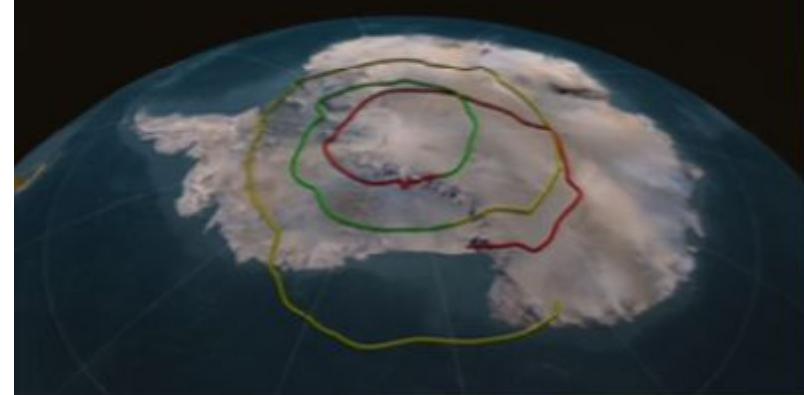
# CREAM 2004/05 Flight



# CREAM 2004/05 Flight

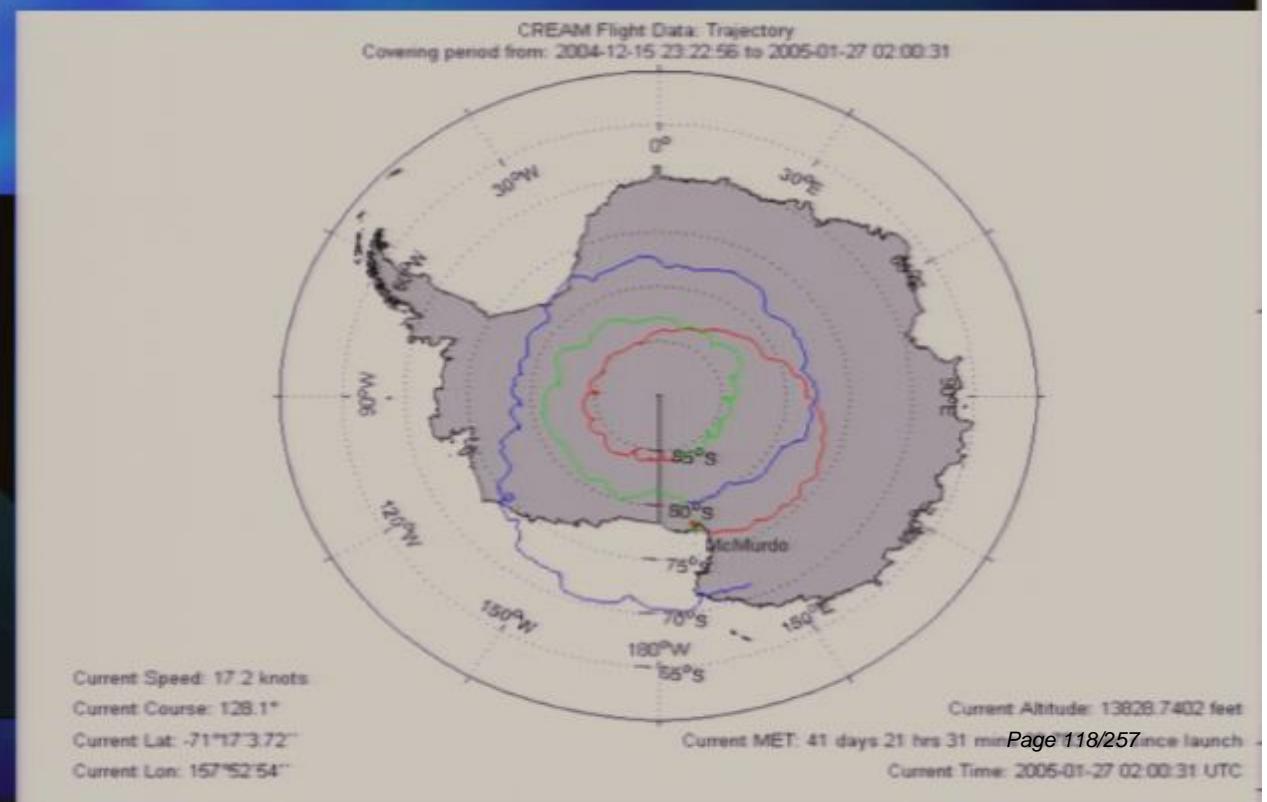
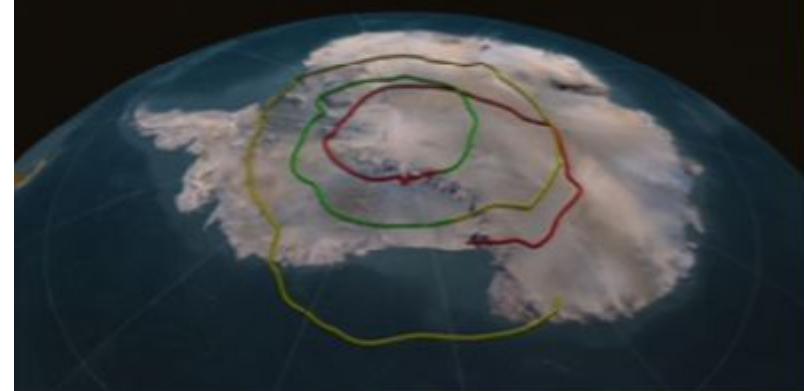


# CREAM 2004/05 Flight

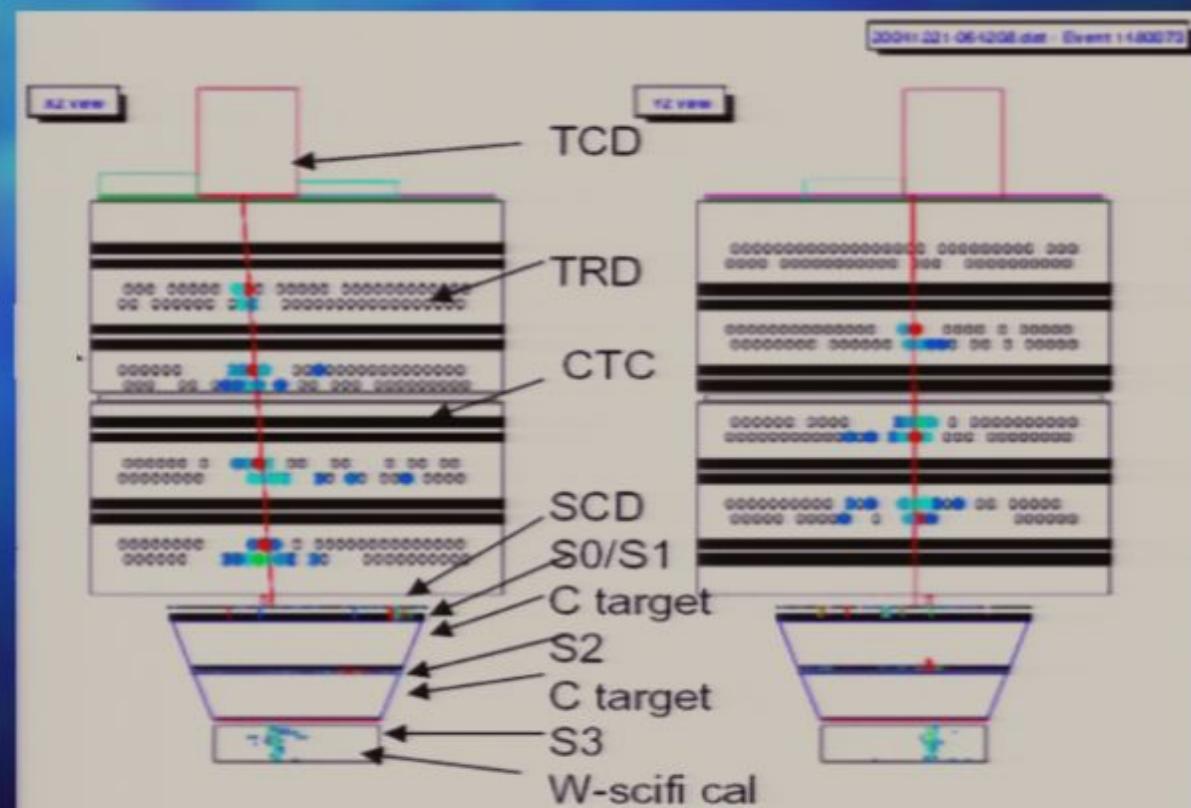


# CREAM 2004/05 Flight

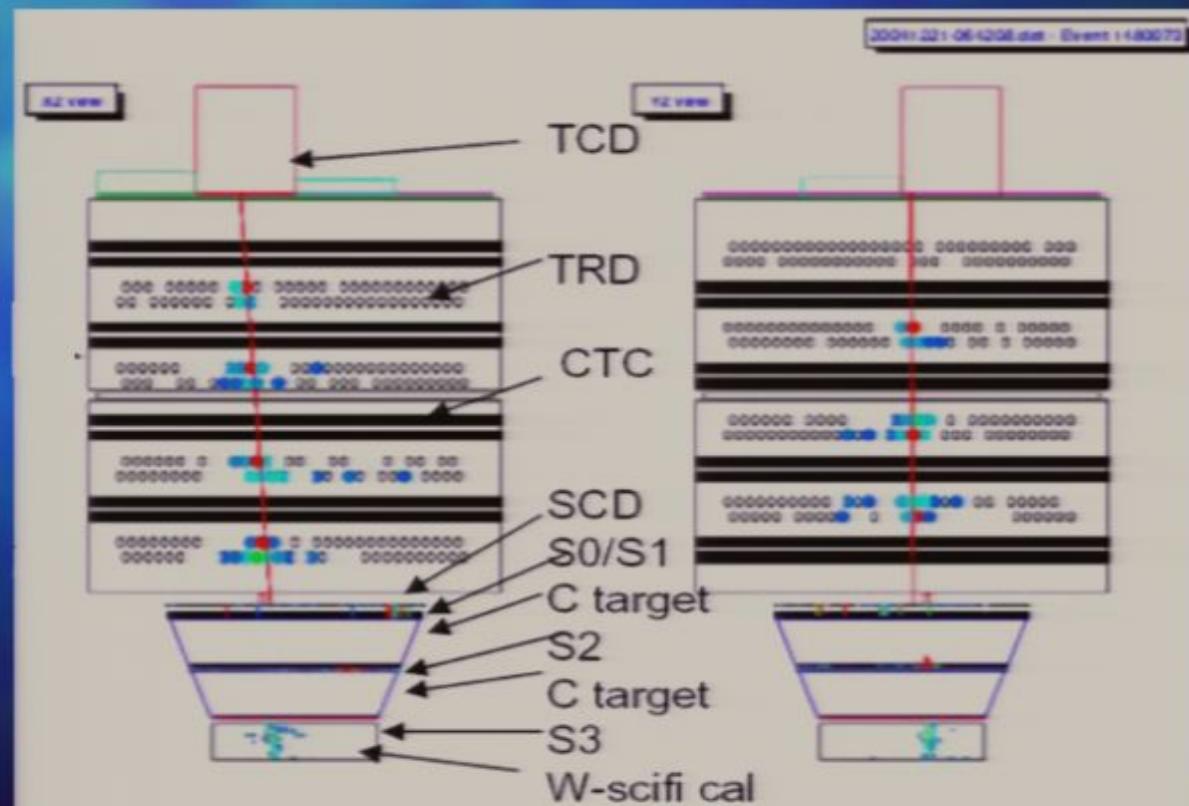
- First flight: Dec 15, 2004 → Jan 26, 2005
- 3 Antarctic orbits, 42 days! NASA LDB flight duration record (32 days previous)!



# Sample Event

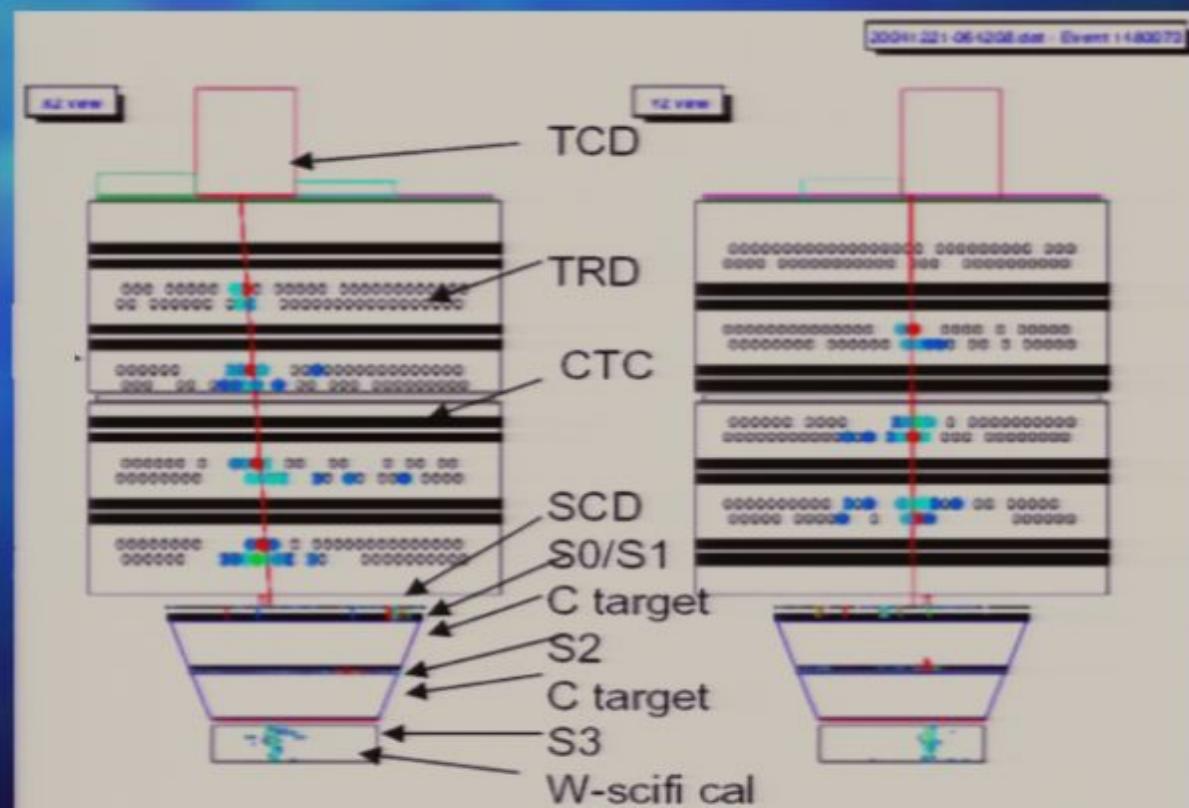


# Sample Event



# Sample Event

Estimated 10 TeV Fe nucleus





# CREAM 2004/05 Flight

# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# CREAM 2004/05 Flight



# TCD/Cherenkov Charge Sensitivity

- TCD mid-level gain signal *vs* Cherenkov;
- 1 day's data; geometry limited to well-understood central sections of the detectors.

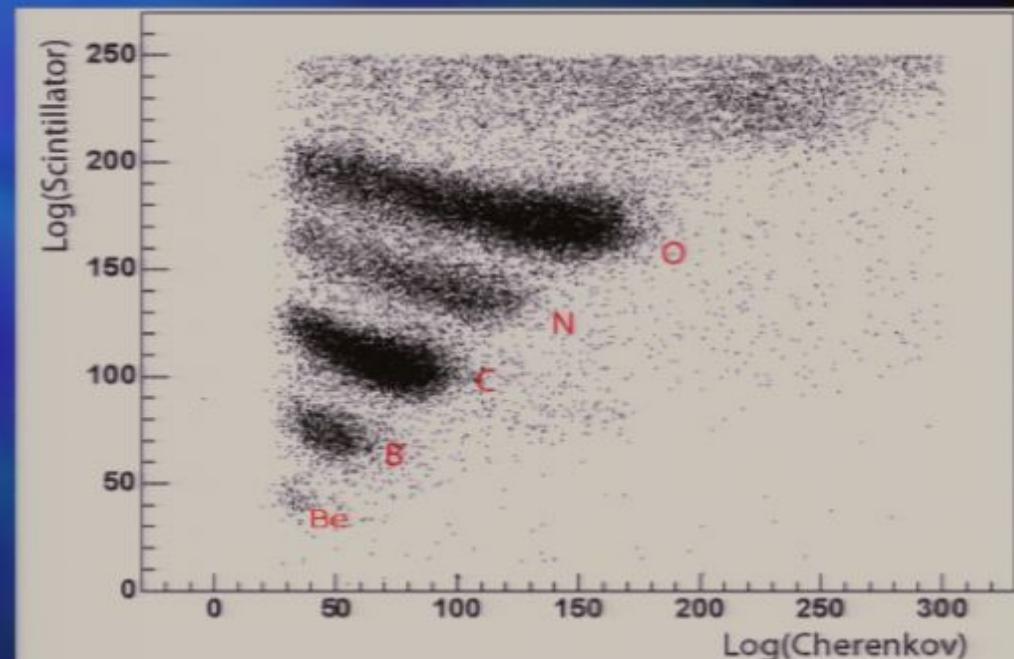


Figure 2. Measured energy losses in the TCD scintillator versus Cherenkov light signal for a short ( $\sim 1$  day) portion of the flight. B,C,N and O nuclei populations are clearly visible. Page 126/257

# TCD/Cherenkov Charge Sensitivity

- TCD mid-level gain signal *vs* Cherenkov;
- 1 day's data; geometry limited to well-understood central sections of the detectors.

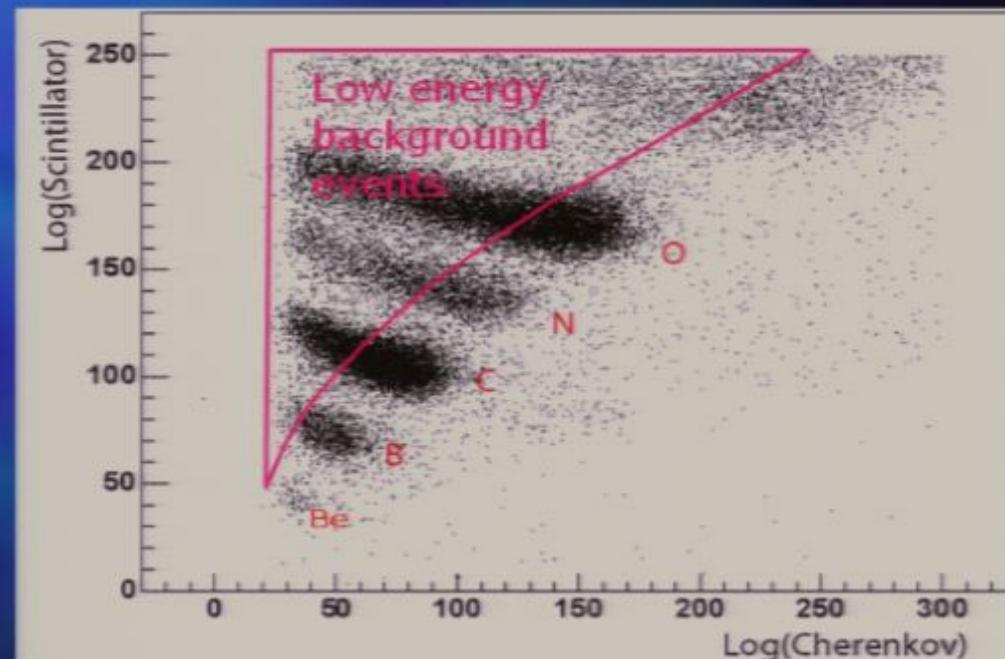


Figure 2. Measured energy losses in the TCD scintillator versus Cherenkov light signal for a short ( $\sim 1$  day) portion of the flight. B,C,N and O nuclei populations are clearly visible. Page 127/257

# TCD/Cherenkov Charge Sensitivity

- TCD mid-level gain signal *vs* Cherenkov;
- 1 day's data; geometry limited to well-understood central sections of the detectors.
- Good intrinsic charge resolution (especially for B, C);

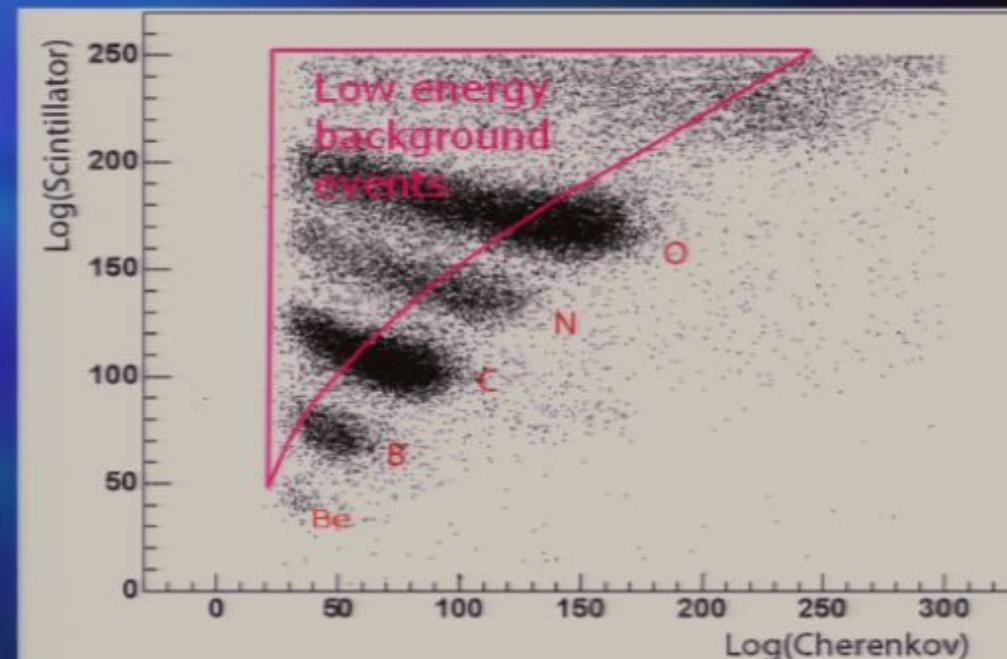


Figure 2. Measured energy losses in the TCD scintillator versus Cherenkov light signal for a short ( $\sim 1$  day) portion of the flight. B,C,N and O nuclei populations are clearly visible. Page 128/257

# TCD/Cherenkov Charge Sensitivity

- TCD mid-level gain signal *vs* Cherenkov;
- 1 day's data; geometry limited to well-understood central sections of the detectors.
- Good intrinsic charge resolution (especially for B, C);

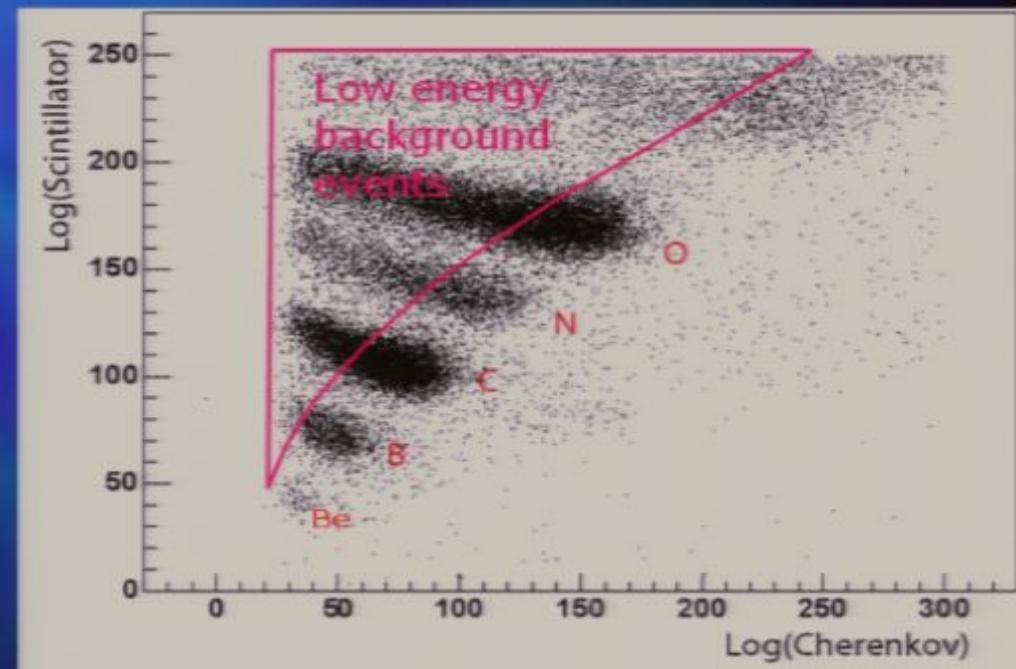


Figure 2. Measured energy losses in the TCD scintillator versus Cherenkov light signal for a short ( $\sim 1$  day) portion of the flight. B,C,N and O nuclei populations are clearly visible. Page 129/257

# TCD/Cherenkov Charge Sensitivity

- TCD mid-level gain signal *vs* Cherenkov;
- 1 day's data; geometry limited to well-understood central sections of the detectors.
- Good intrinsic charge resolution (especially for B, C);
- Low energy events must be eliminated;

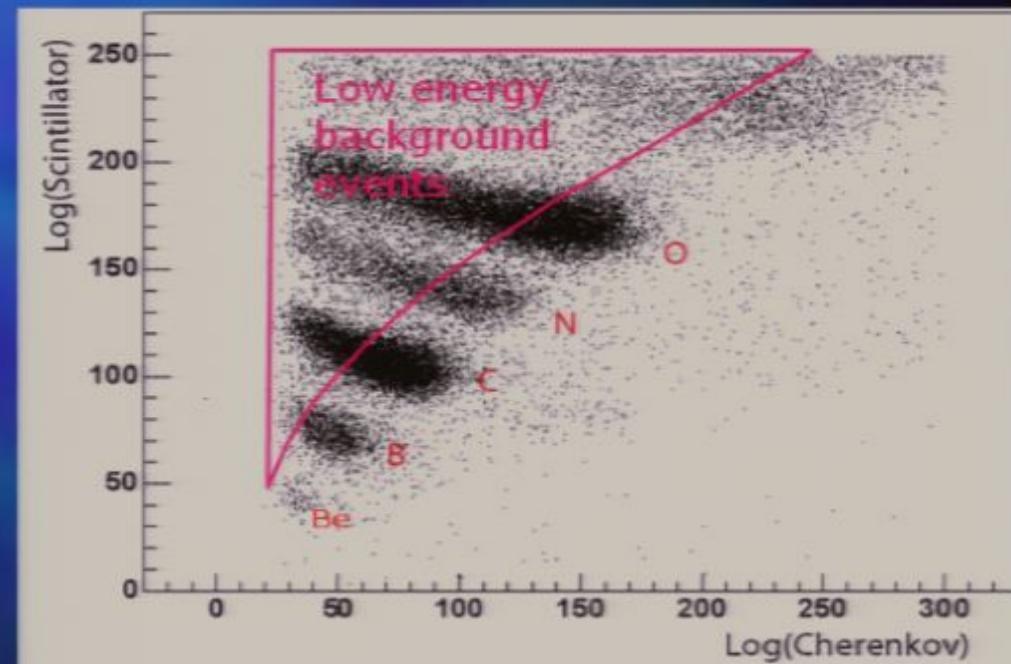
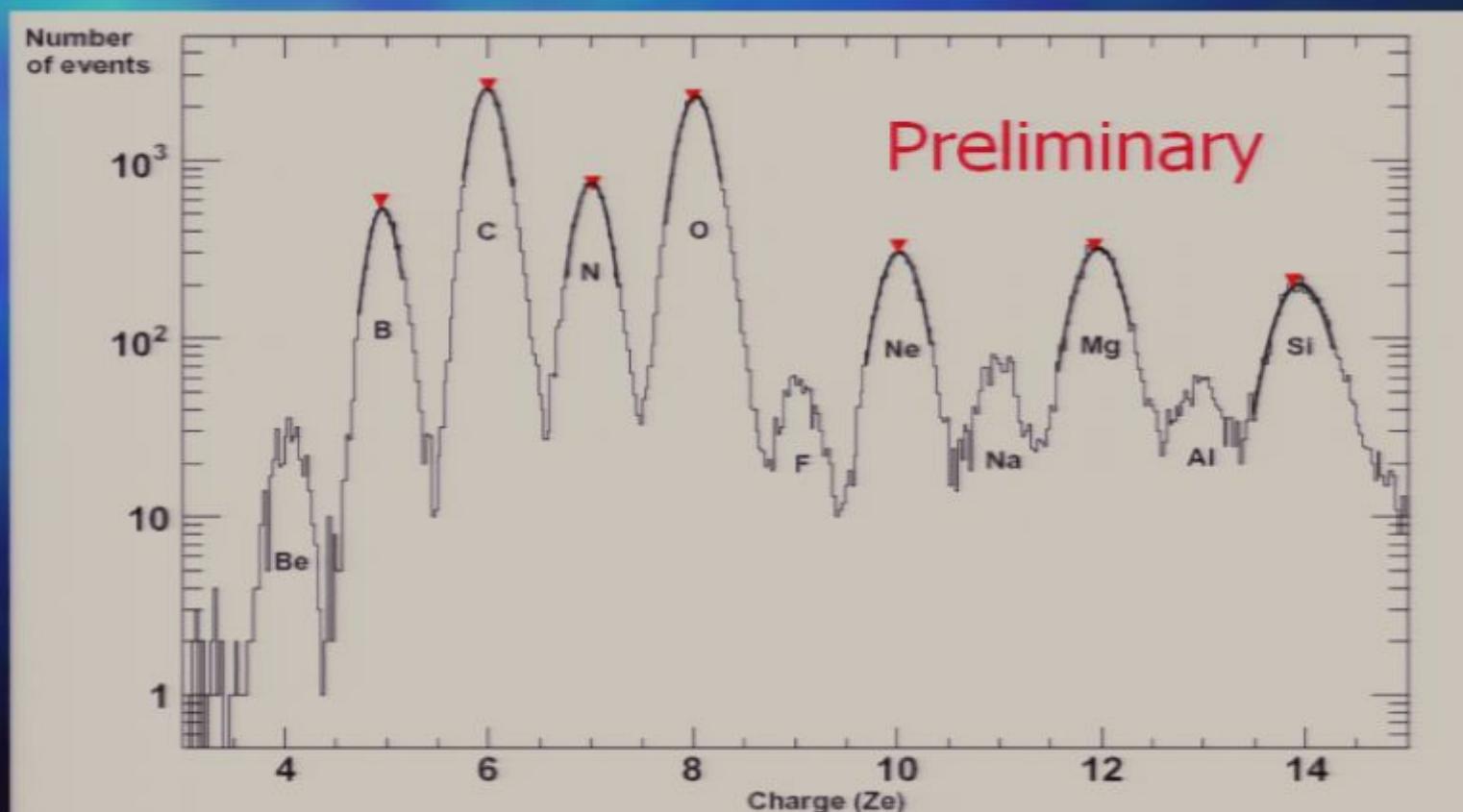


Figure 2. Measured energy losses in the TCD scintillator versus Cherenkov light signal for a short ( $\sim 1$  day) portion of the flight. B,C,N and O nuclei populations are clearly visible. Page 130/257

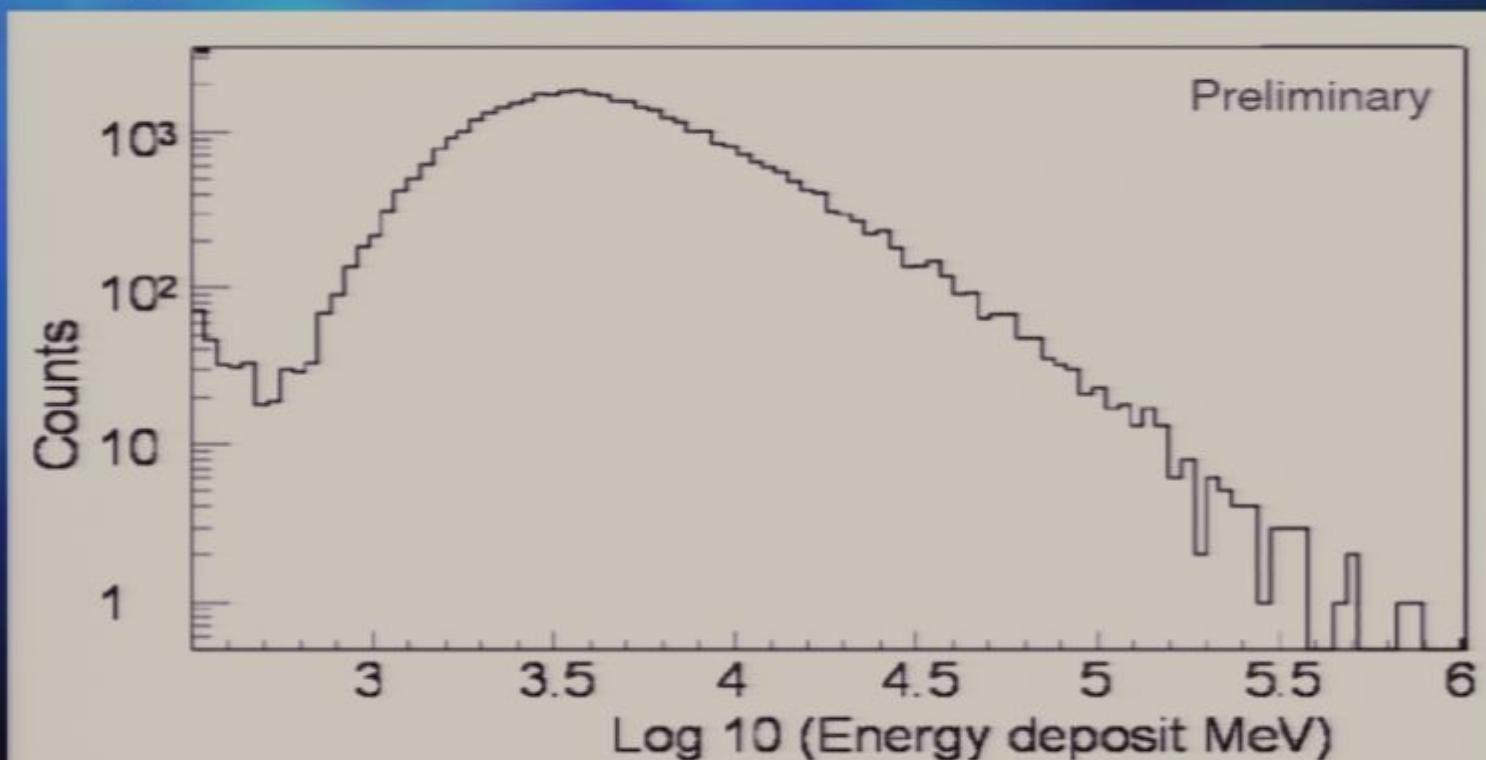
# TCD/TRD/Cherenkov Charge Distribution

- Not all corrections or event selection finalized!
- Only indicative of charge resolution; relative intensities not meaningful yet.



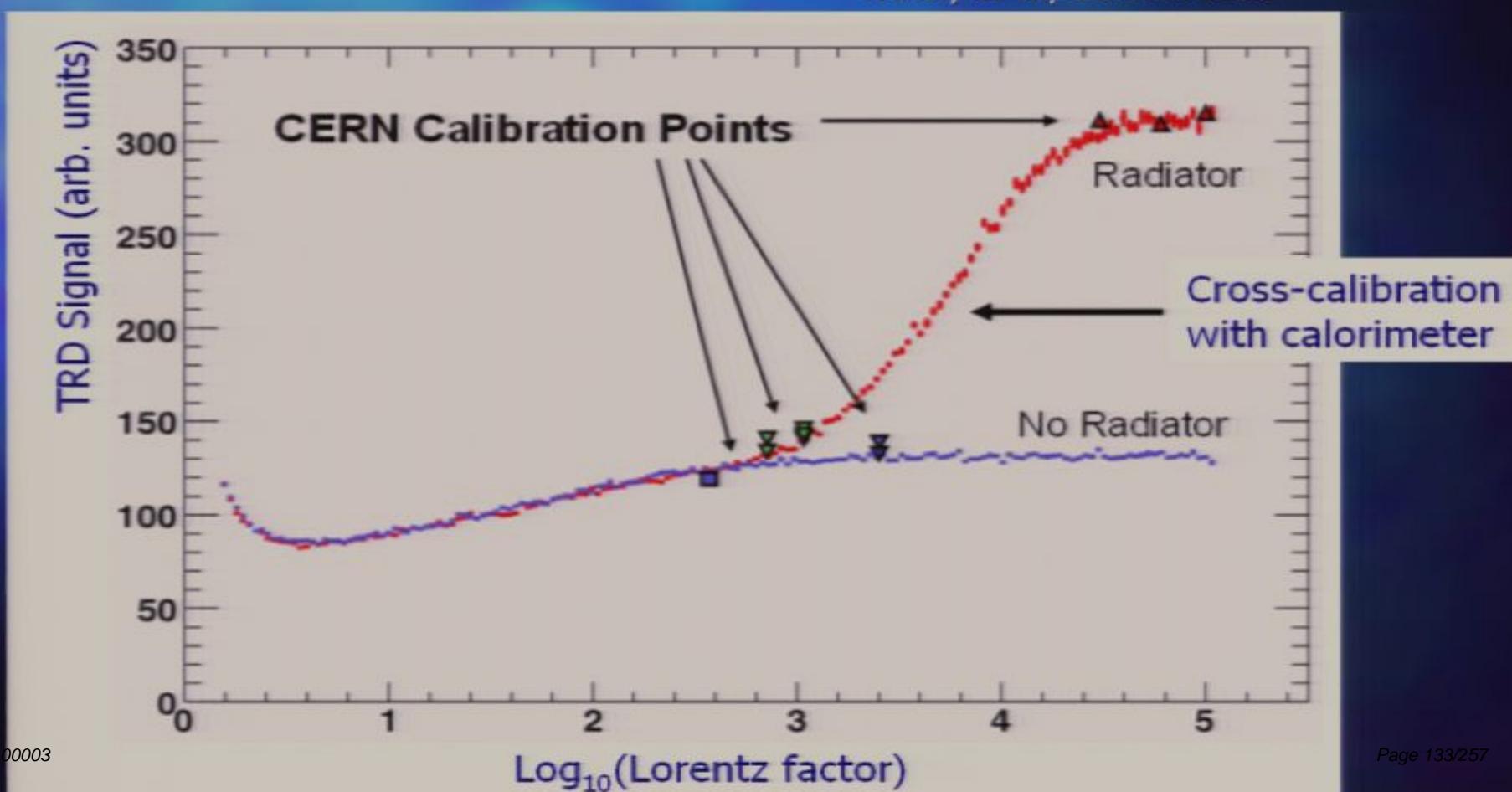
# Calorimeter Energy Distribution

- Not all corrections or event selection finalized!
- Only energy deposited, not yet converted to total energy;
- Power-law apparent.



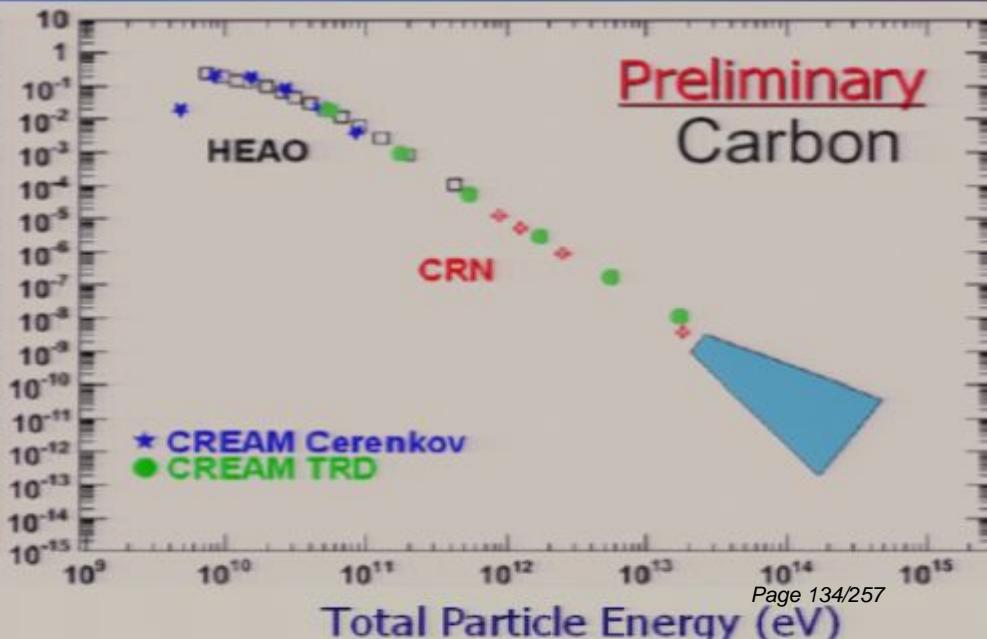
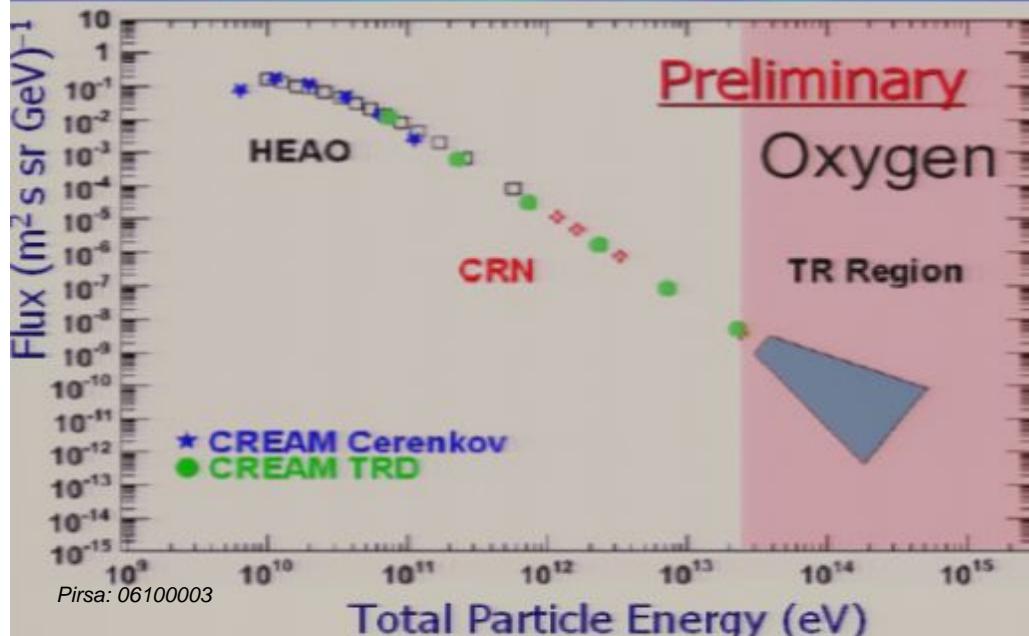
# TRD Energy Response

Wakely et al., COSPAR 2006



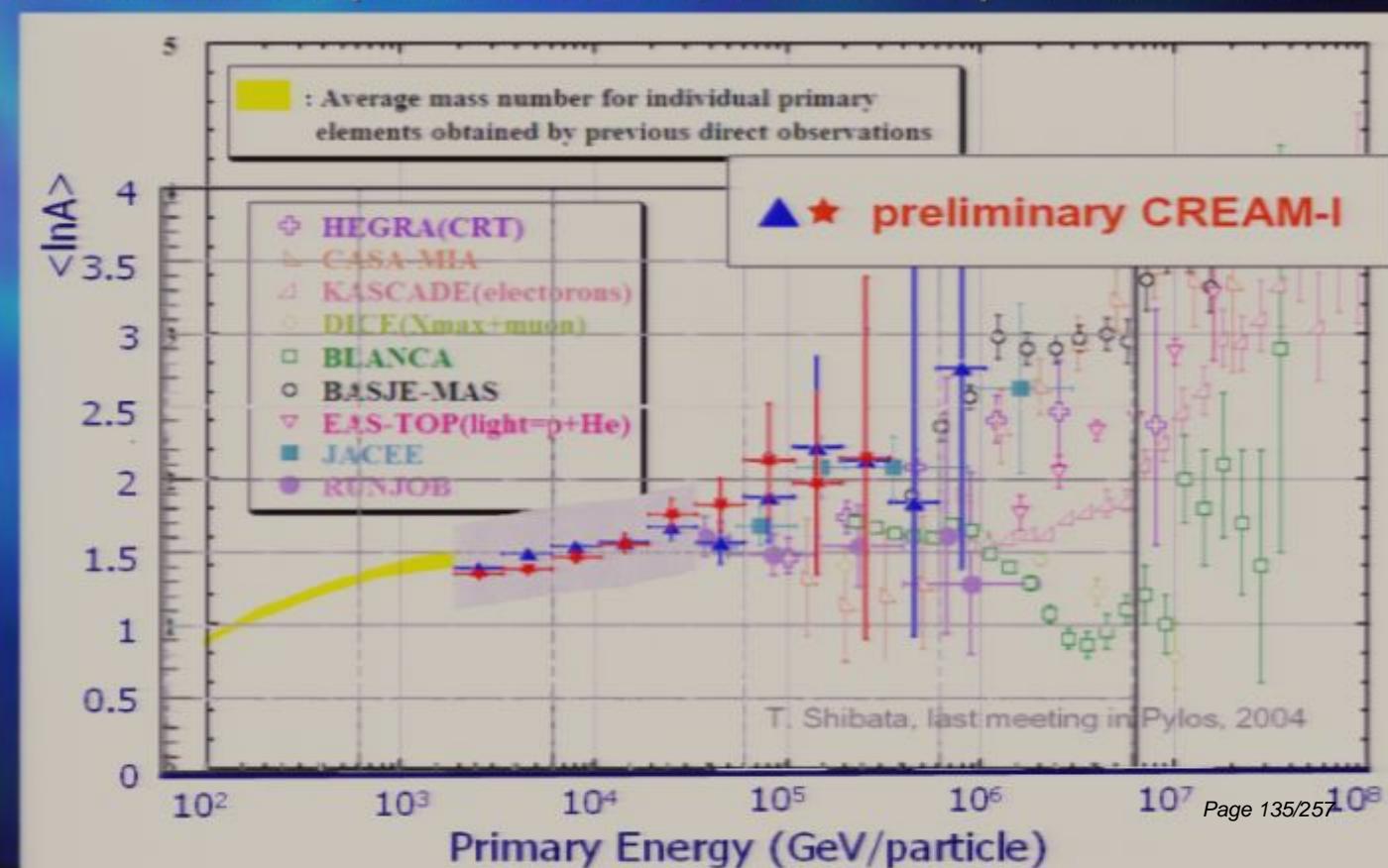
# First Spectra

- Preliminary!
- Arbitrary flux normalization for now;
- No atmospheric corrections yet;
- Spectral shapes agree with HEAO and CRN data at low energy;
- CREAM data extend up to  $\sim 100$  TeV.



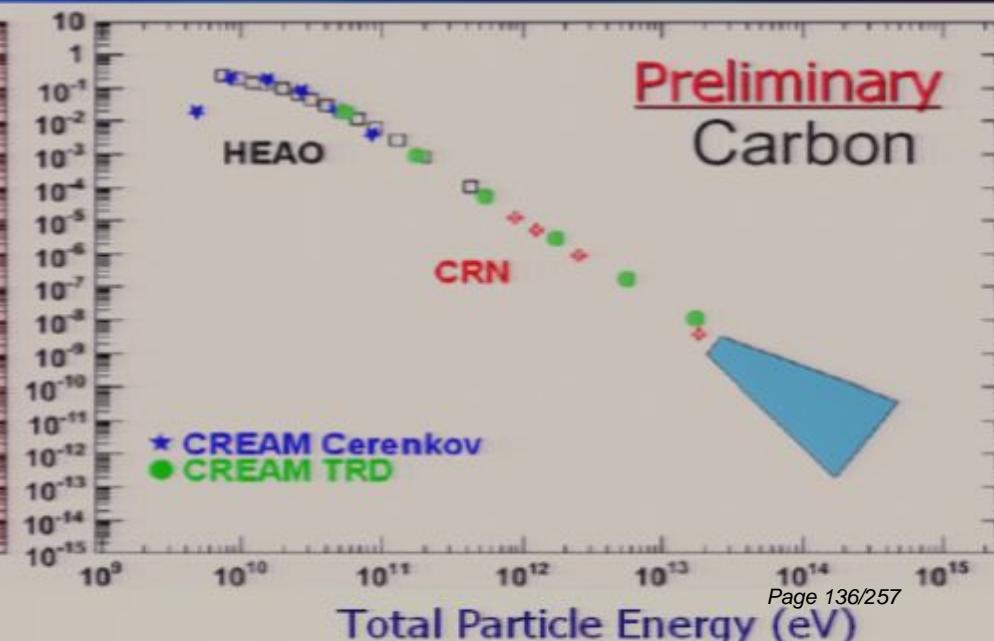
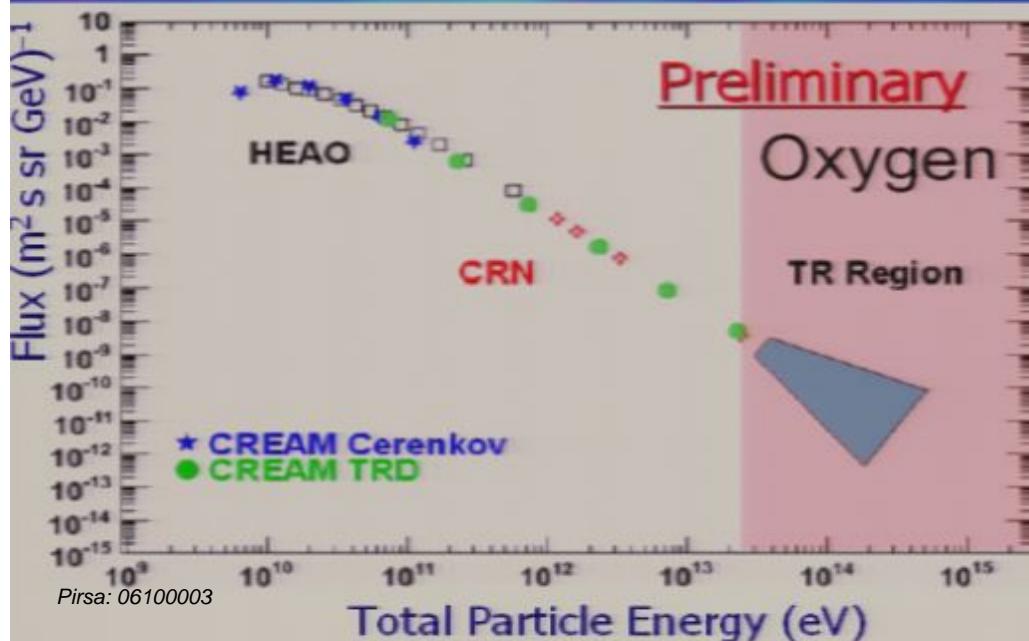
# Average Primary Mass

- Preliminary! Energies from the calorimeter.
- Provides anchor point for indirect composition studies, reduced dependence on MC.



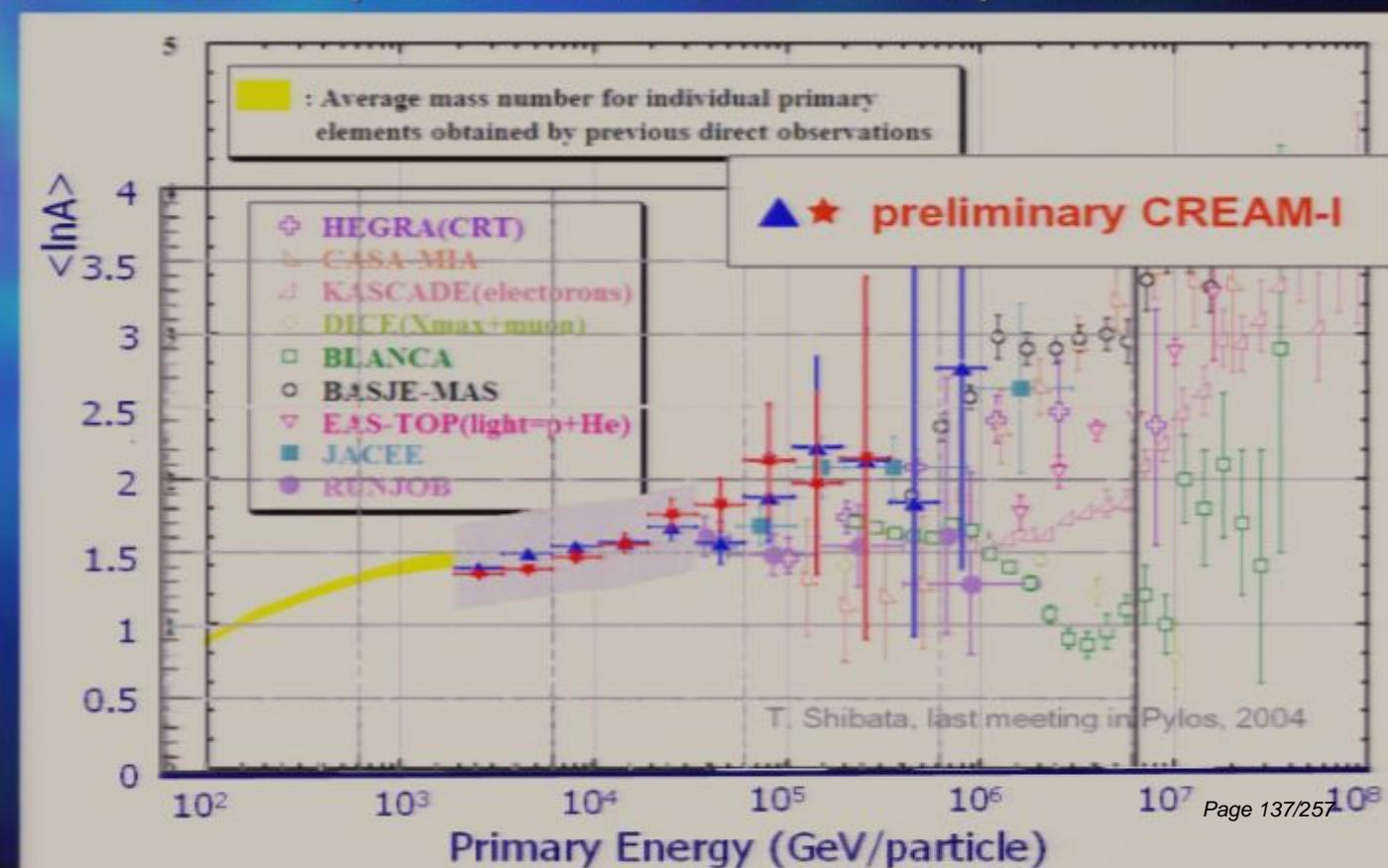
# First Spectra

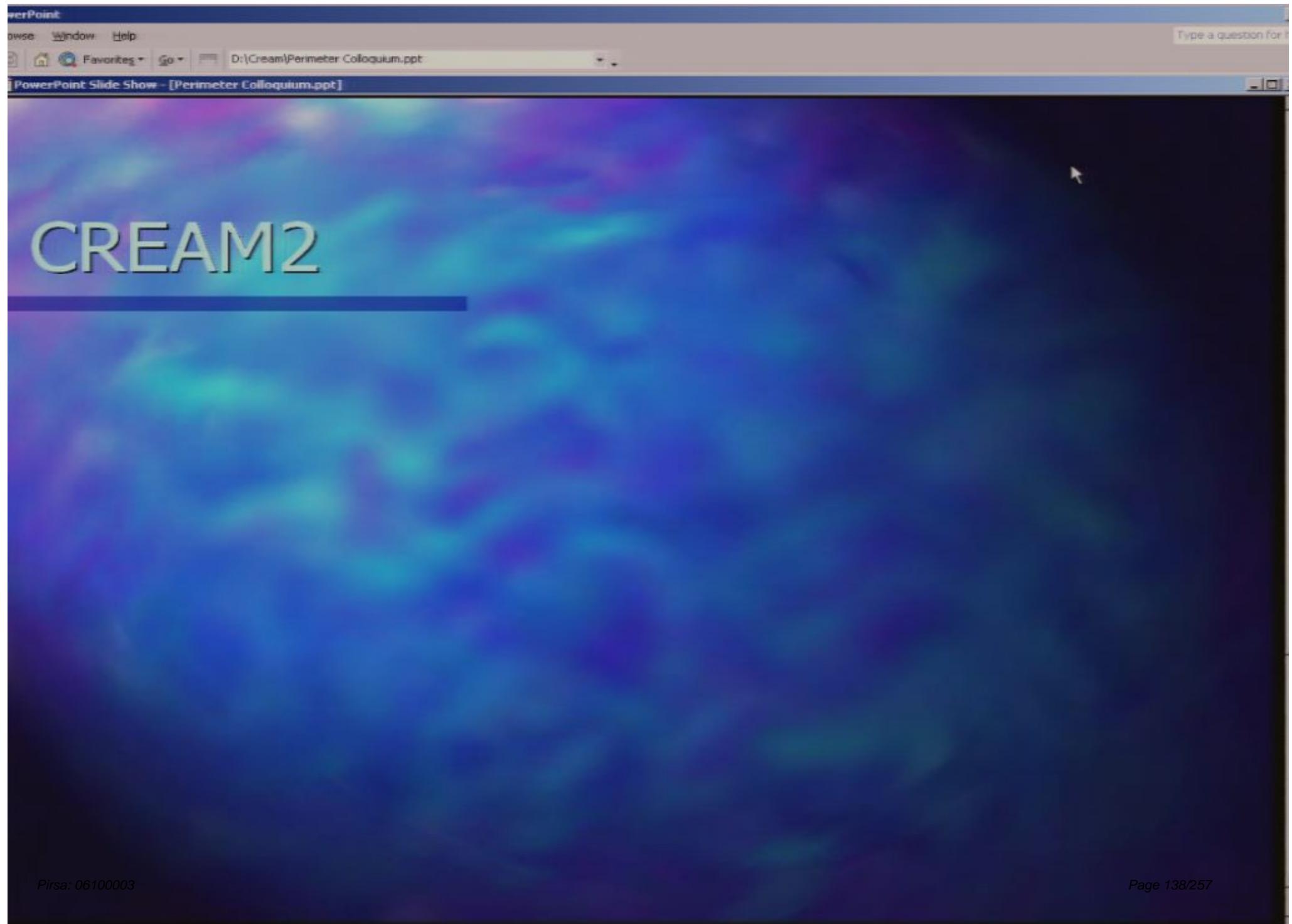
- Preliminary!
- Arbitrary flux normalization for now;
- No atmospheric corrections yet;
- Spectral shapes agree with HEAO and CRN data at low energy;
- CREAM data extend up to  $\sim 100$  TeV.



# Average Primary Mass

- Preliminary! Energies from the calorimeter.
- Provides anchor point for indirect composition studies, reduced dependence on MC.





# CREAM2





PowerPoint

File Edit View Insert Slide Show Window Help

Favorites Go D:\(Cream)Perimeter Colloquium.ppt

Type a question for me

PowerPoint Slide Show - [Perimeter Colloquium.ppt]

CREAM2

CREAM Flight Data: Trajectory  
Covering period from: 2005-12-13 20:51:10 to 2006-01-13 01:52:01

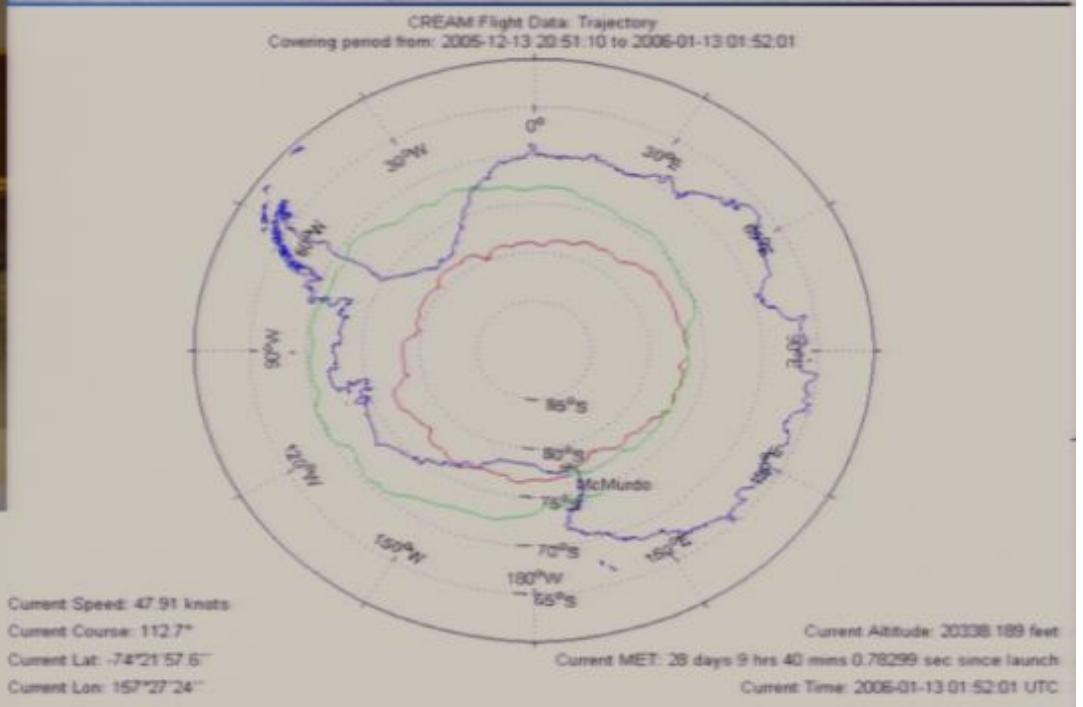
Current Speed: 47.91 knots  
Current Course: 112.7°  
Current Lat: -74°21'57.6"  
Current Lon: 157°27'24"

Current Altitude: 20338.189 feet  
Current MET: 28 days 9 hrs 40 mins 0.78299 sec since launch  
Current Time: 2006-01-13 01:52:01 UTC

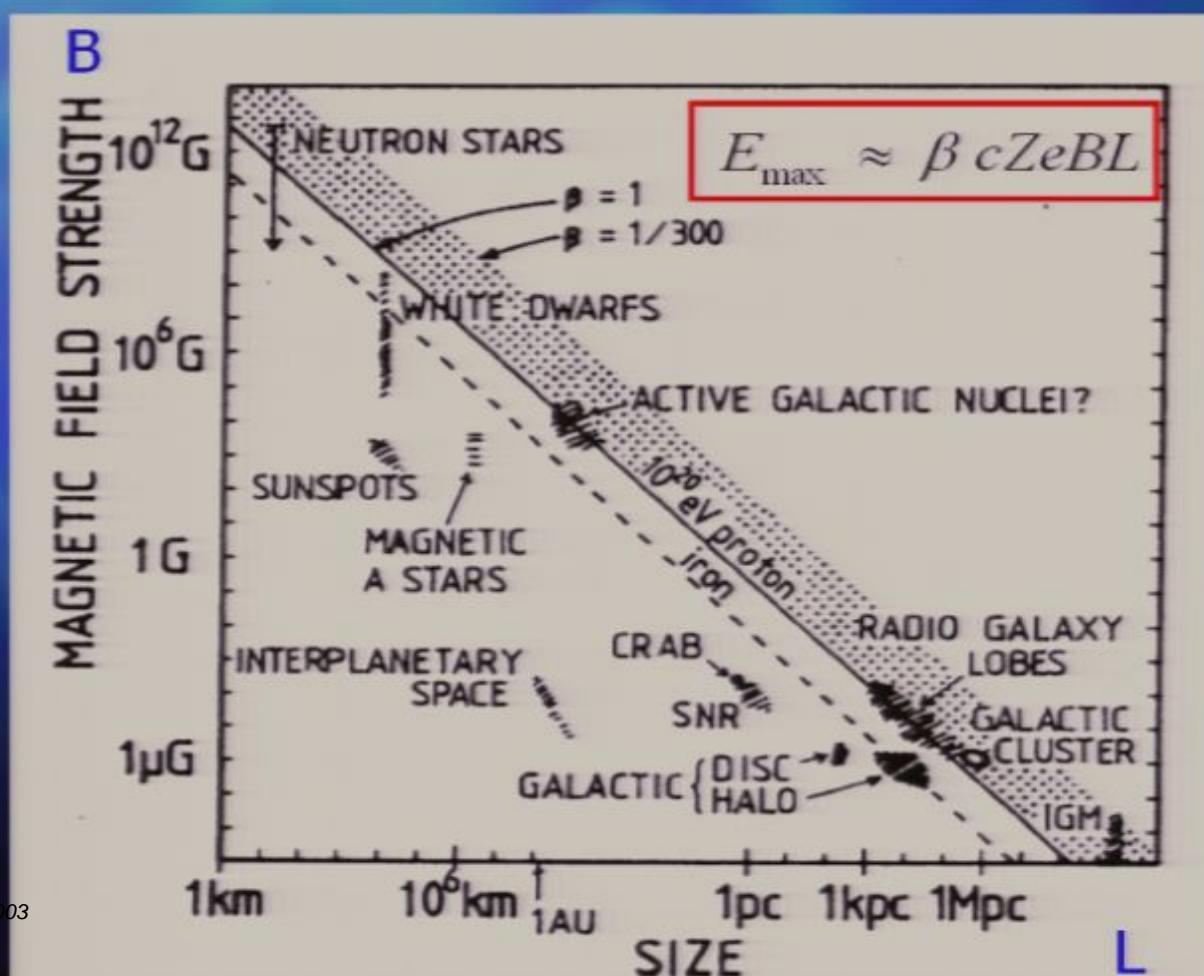
# CREAM2



CREAM2 flight: Dec 16 '05  
to Jan 13 '06 (28 days);  
• 70 days exposure so far!  
• CREAM2 already recovered.

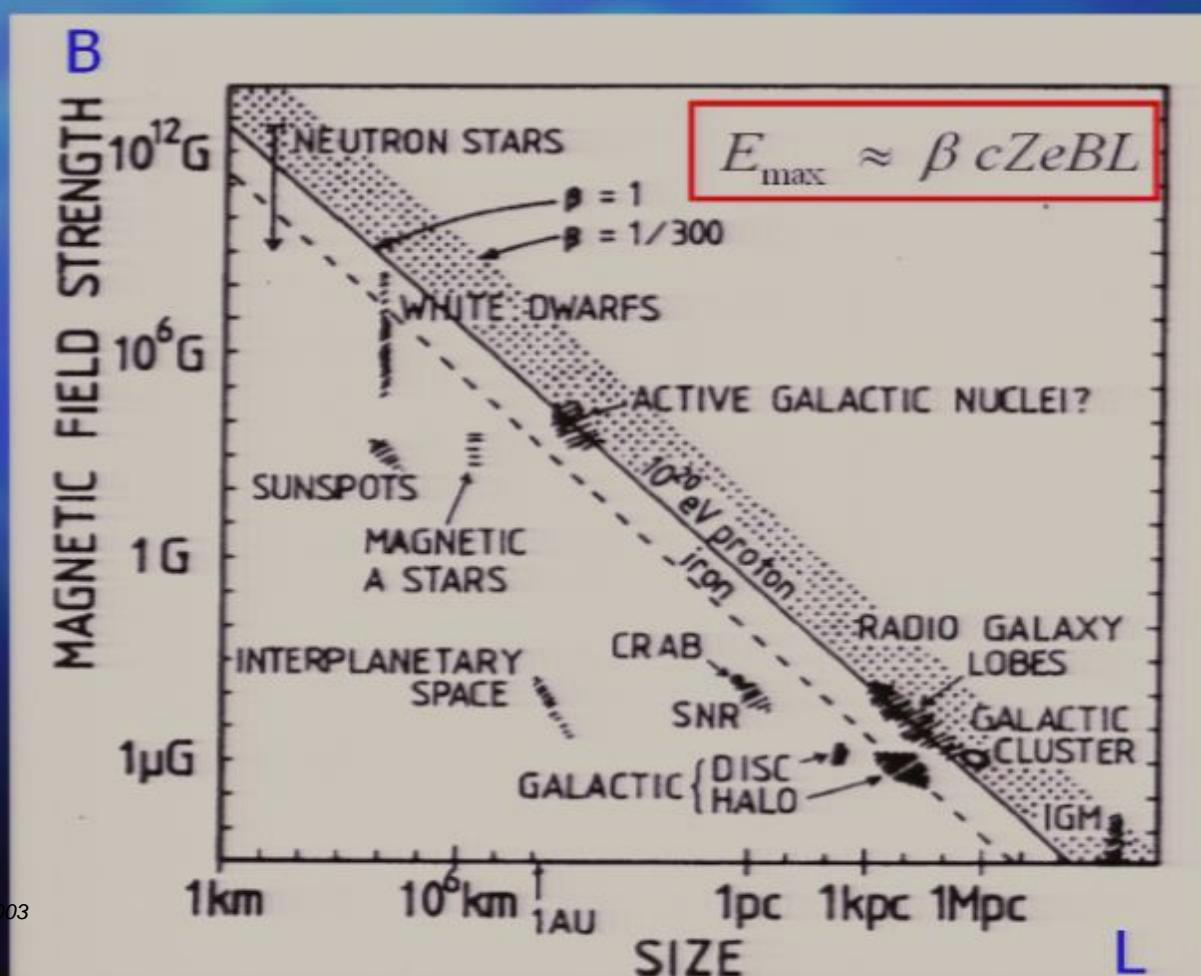


# Origin of UHE Cosmic Rays



Hillas, Ann. Rev.  
As. Ap. 1984

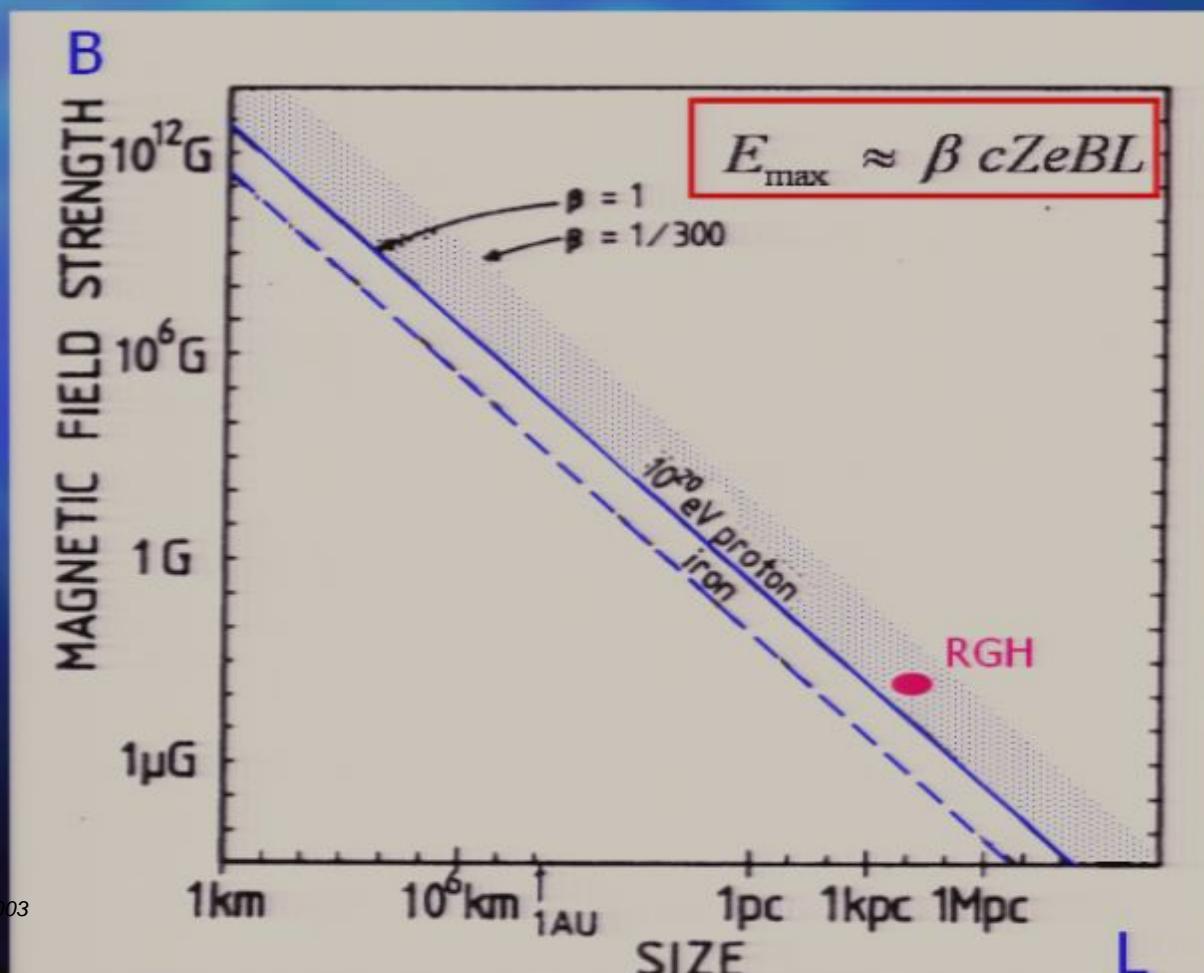
# Origin of UHE Cosmic Rays



Hillas, Ann. Rev.  
As. Ap. 1984

Account for radiative losses within the accelerating region (synchrotron losses, photoreactions)

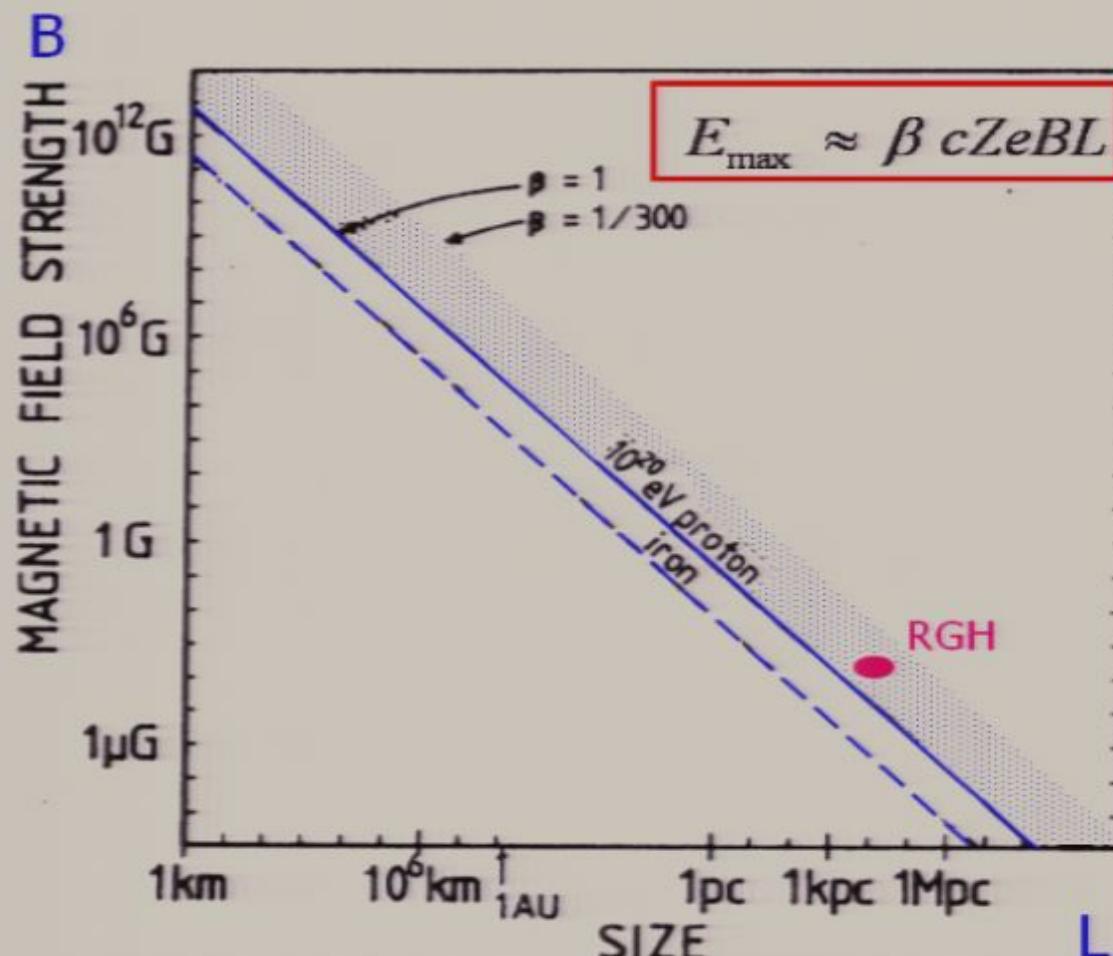
# Origin of UHE Cosmic Rays



Hillas, Ann. Rev.  
As. Ap. 1984

Account for radiative losses within the accelerating region (synchrotron losses, photoreactions)

# Origin of UHE Cosmic Rays

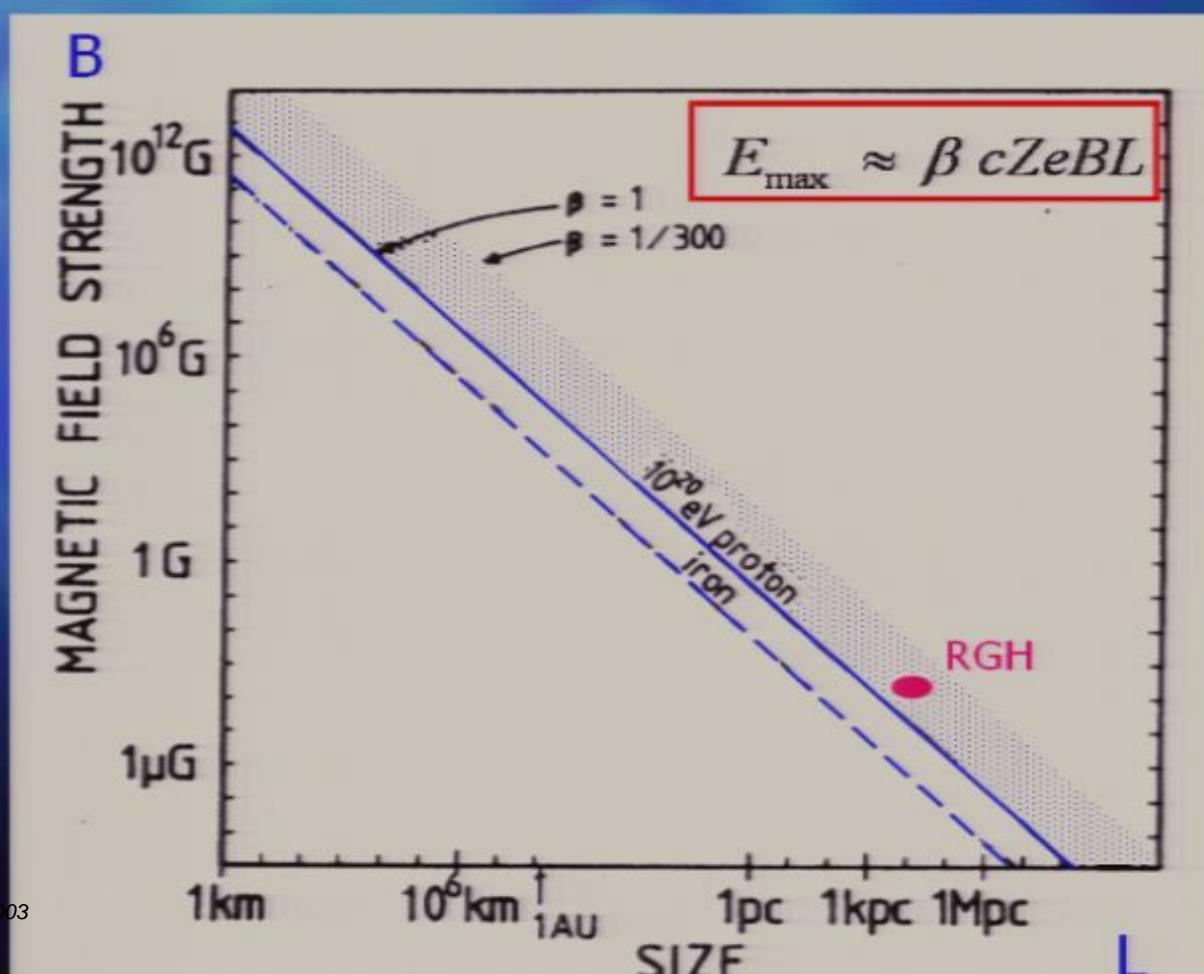


Hillas, Ann. Rev.  
As. Ap. 1984

Account for radiative losses within the accelerating region (synchrotron losses, photoreactions)

⇒ UHE cosmic rays likely extragalactic (also: Larmor radius, spectral structure near ankle)

# Origin of UHE Cosmic Rays



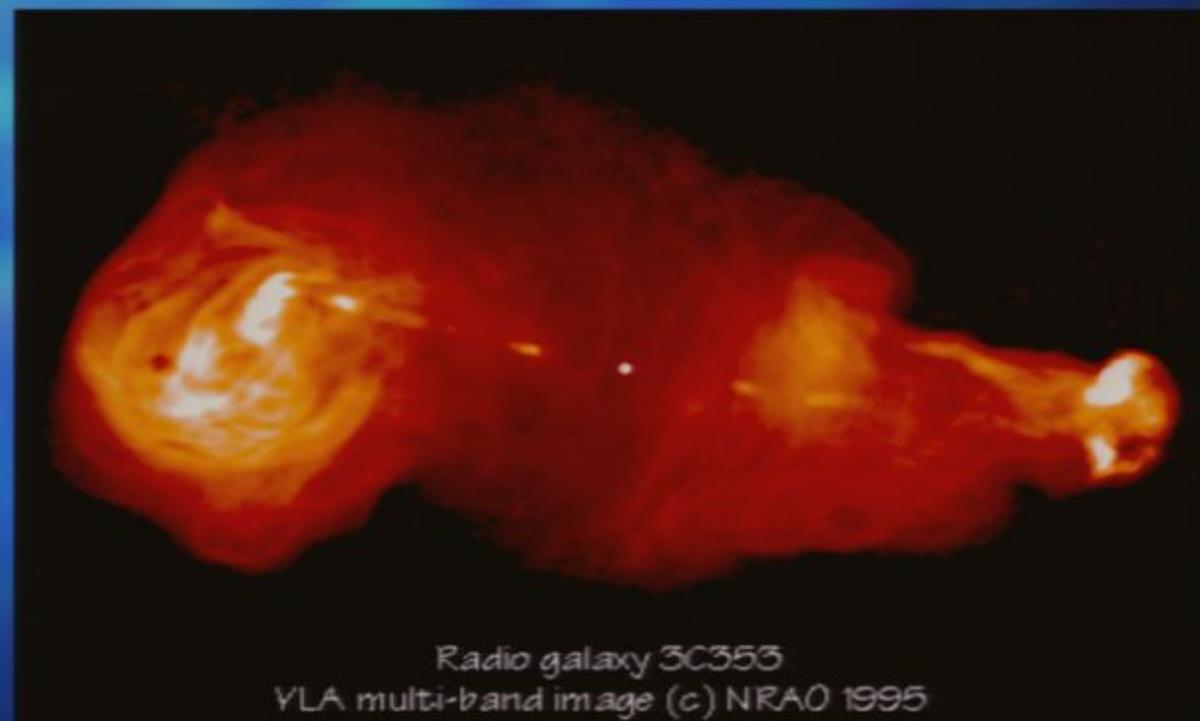
Hillas, Ann. Rev.  
As. Ap. 1984

Account for radiative losses within the accelerating region (synchrotron losses, photoreactions)

⇒ UHE cosmic rays likely extragalactic (also: Larmor radius, spectral structure near ankle)

These are bottom-up scenarios

# Radio Galaxy Hotspots



3C353: 130 Mpc away (420 Mly)

Jets ~ 28 kpc long (91 kly)



## Also Top-Down Scenarios

# Also Top-Down Scenarios

e.g. TD model:

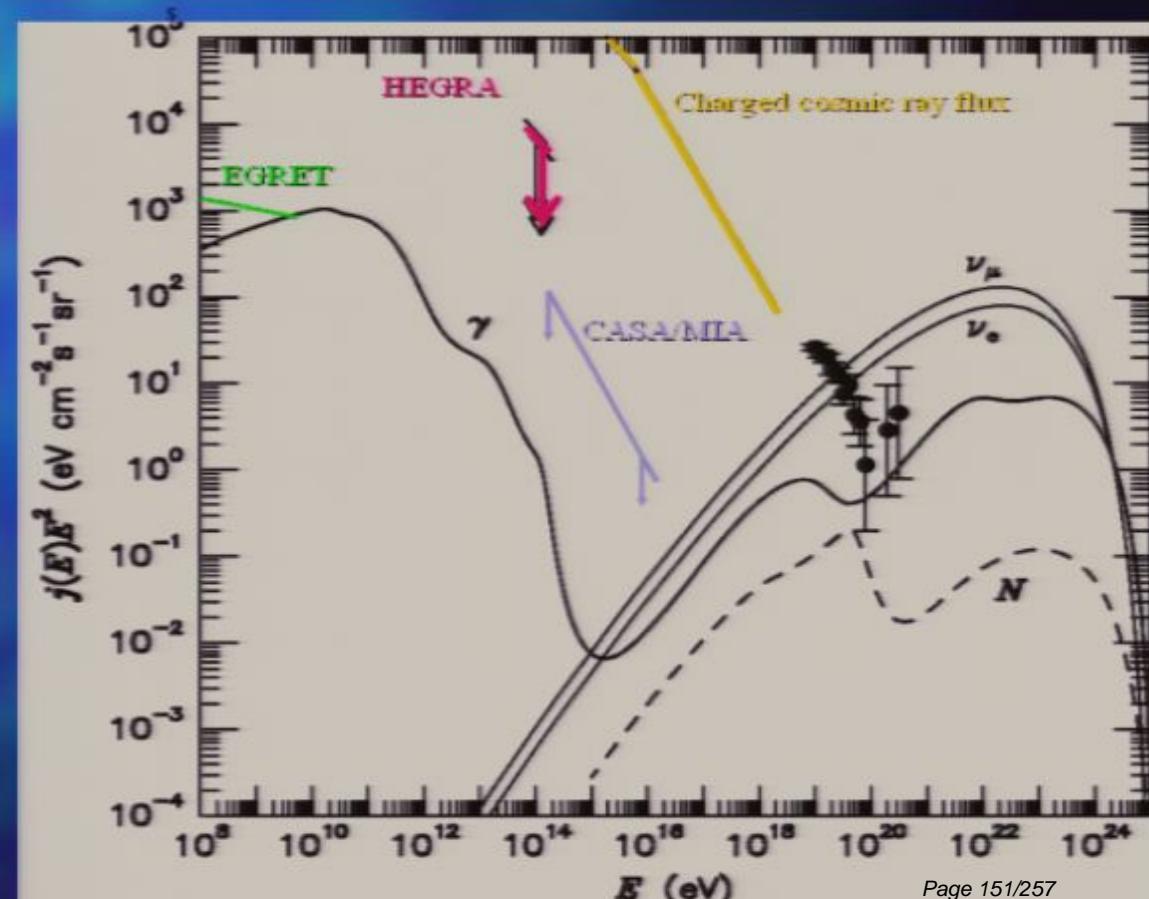
- UHE flux  $\nu$  dominated
- spectrum can extend beyond  $10^{20}$  eV
- possible constraints from  $\gamma$  flux

G. Sigl, S. Lee, D.N. Schramm &  
P. Coppi, Phys. Lett. B 392, 129 (1997)

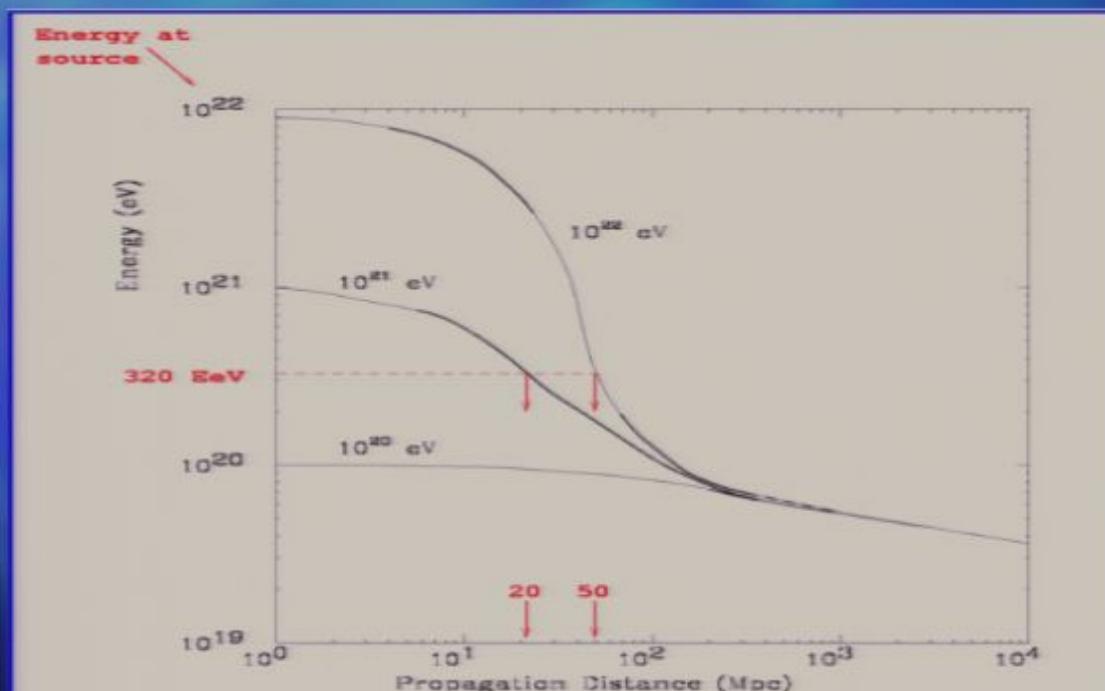
# Also Top-Down Scenarios

- e.g. TD model:
- UHE flux  $\nu$  dominated
  - spectrum can extend beyond  $10^{20}$  eV
  - possible constraints from  $\gamma$  flux

G. Sigl, S. Lee, D.N. Schramm & P. Coppi, Phys. Lett. B 392, 129 (1997)



# The GZK Cutoff



## Energy attenuation of protons

Protons: photopion threshold @ ~50 EeV

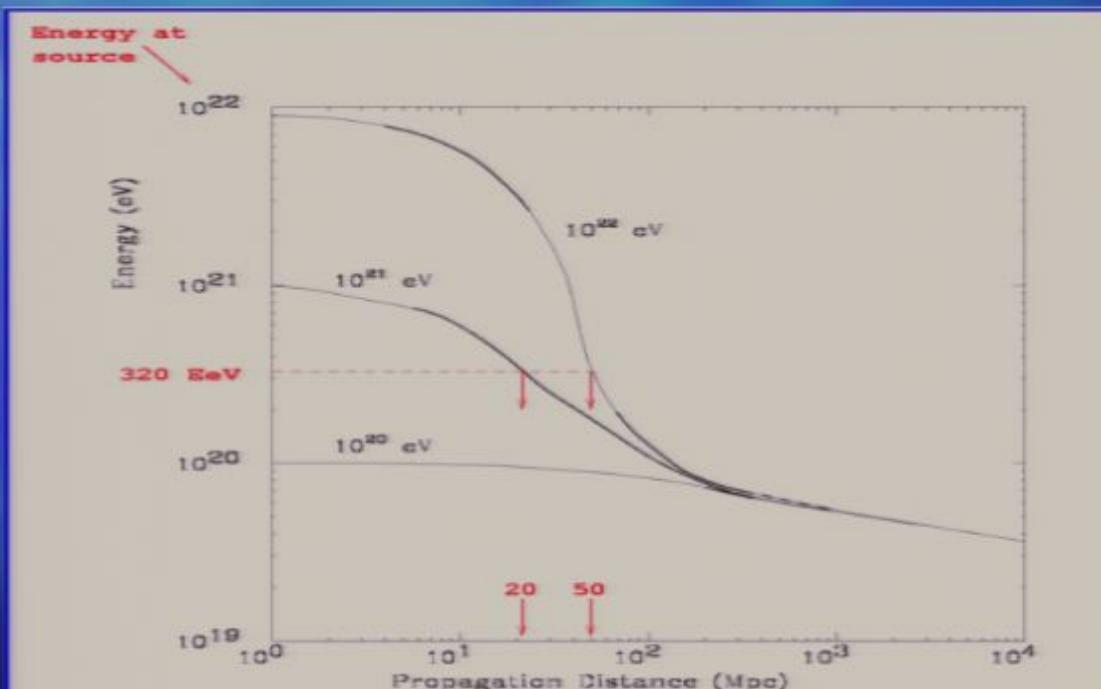
Photons: pair production threshold @ ~200 TeV

Nuclei: photodisintegration above 50 EeV

Neutrinos: no problem!

For E>100 EeV, the source must be within ~50 Mpc

# The GZK Cutoff



>  $4 \times 10^{19}$  eV:  
50% from within 130 Mpc

>  $10^{20}$  eV:  
50% from within 20 Mpc

## Energy attenuation of protons

Protons: photopion threshold @ ~50 EeV

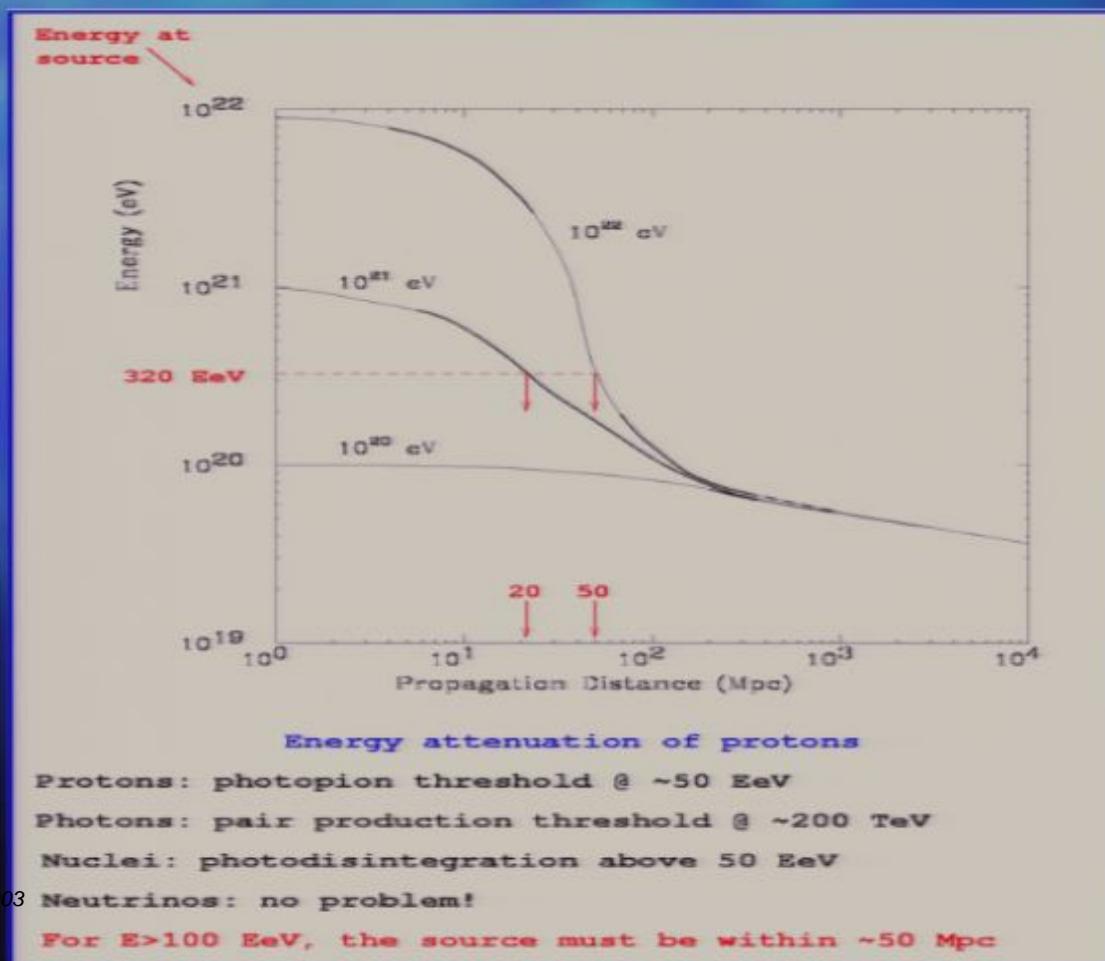
Photons: pair production threshold @ ~200 TeV

Nuclei: photodisintegration above 50 EeV

Neutrinos: no problem!

For  $E > 100$  EeV, the source must be within ~50 Mpc

# The GZK Cutoff

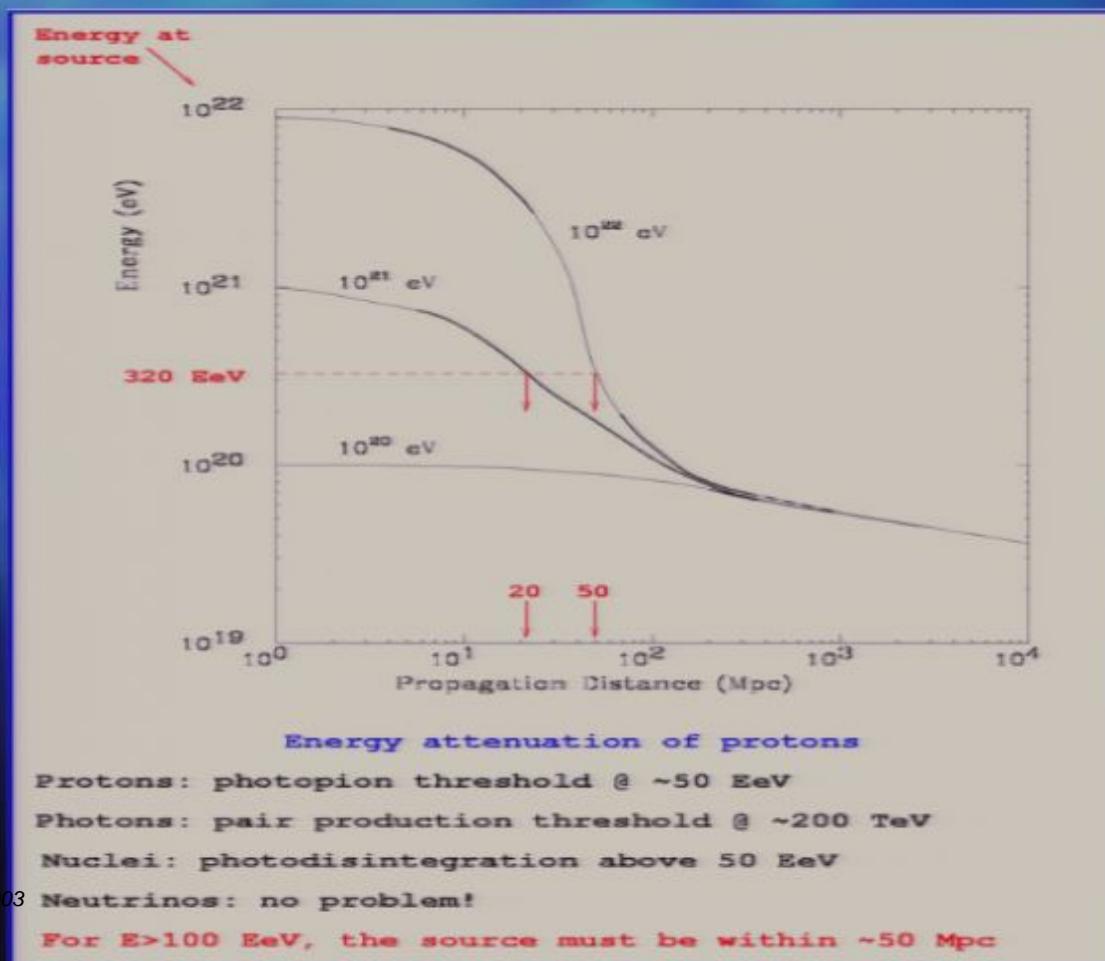


>  $4 \times 10^{19}$  eV:  
50% from within 130 Mpc

>  $10^{20}$  eV:  
50% from within 20 Mpc

**ANISOTROPIES** might be  
expected from  
nearby sources

# The GZK Cutoff



>  $4 \times 10^{19}$  eV:  
50% from within 130 Mpc

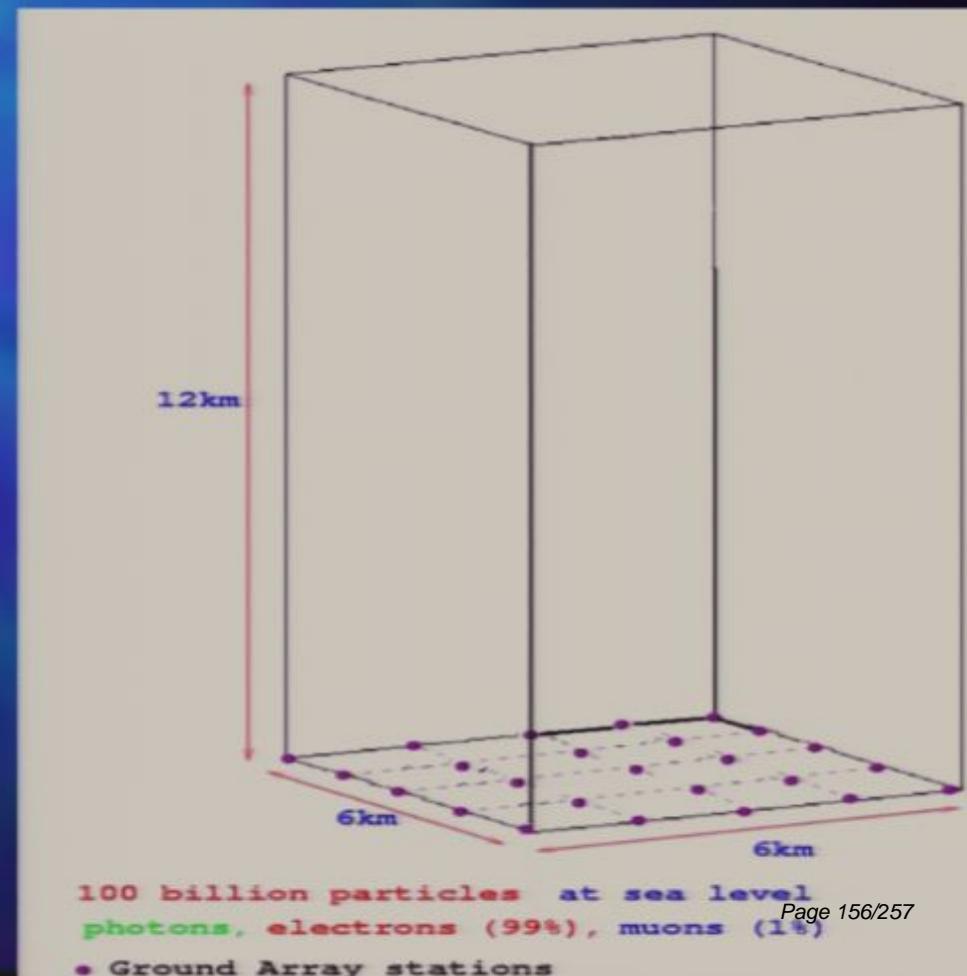
>  $10^{20}$  eV:  
50% from within 20 Mpc

**ANISOTROPIES** might be  
expected from  
nearby sources

} Expect GZK  
neutrino  
production

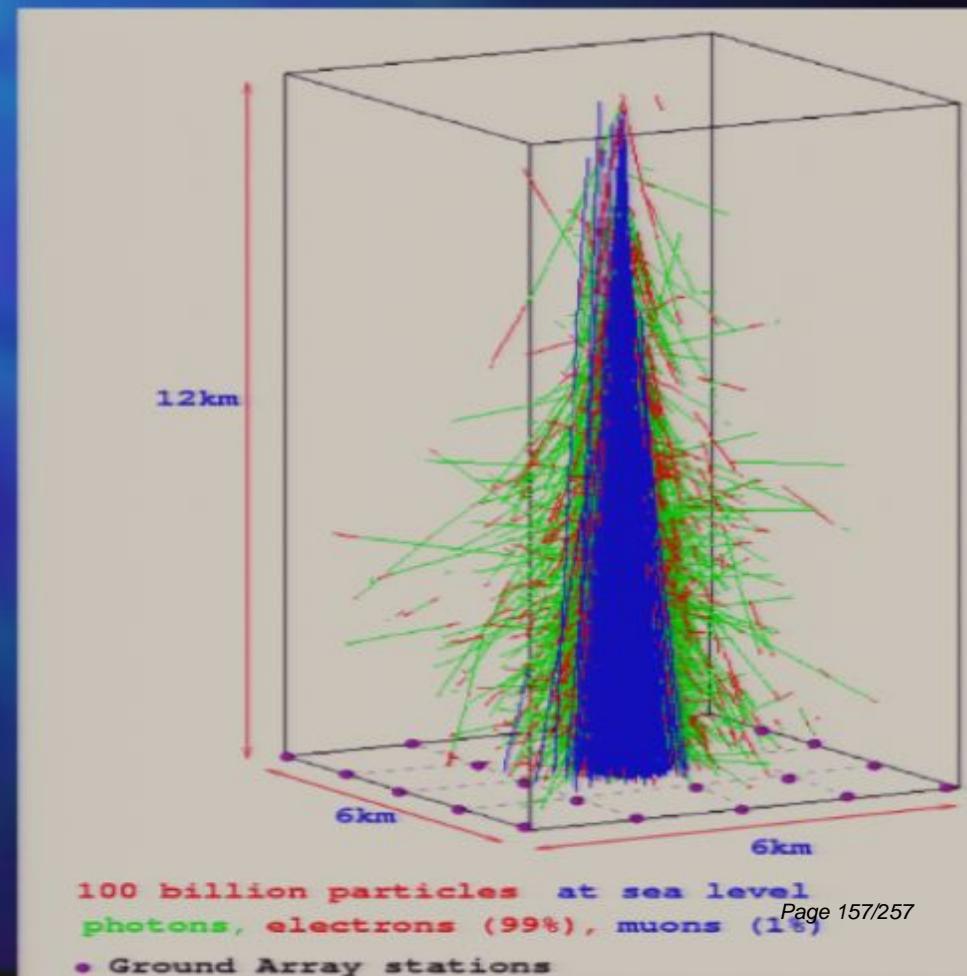
# Techniques for UHECR Detection

- UHECR generate cascades (showers) in the atmosphere
- $10^{20}$  eV yields  $10^{11}$  particles at maximum



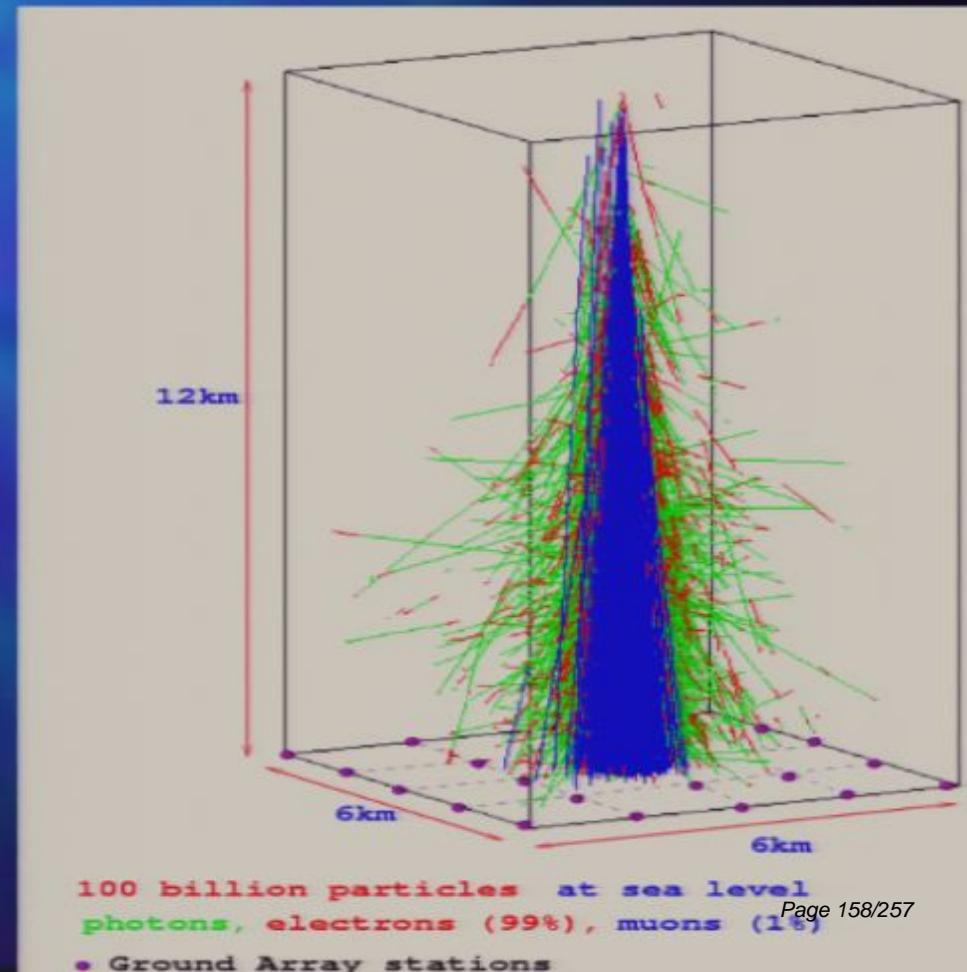
# Techniques for UHECR Detection

- UHECR generate cascades (showers) in the atmosphere
- $10^{20}$  eV yields  $10^{11}$  particles at maximum



# Techniques for UHECR Detection

- UHECR generate cascades (showers) in the atmosphere
- $10^{20}$  eV yields  $10^{11}$  particles at maximum
  - Shower front particles can be directly detected on the ground (e.g. AGASA  $2,000 \text{ km}^2\text{yr sr}$ )
  - Showers excite nitrogen fluorescence, detectable on dark nights (e.g. HiRes  $2,500 \text{ km}^2\text{yr sr stereo}$ )





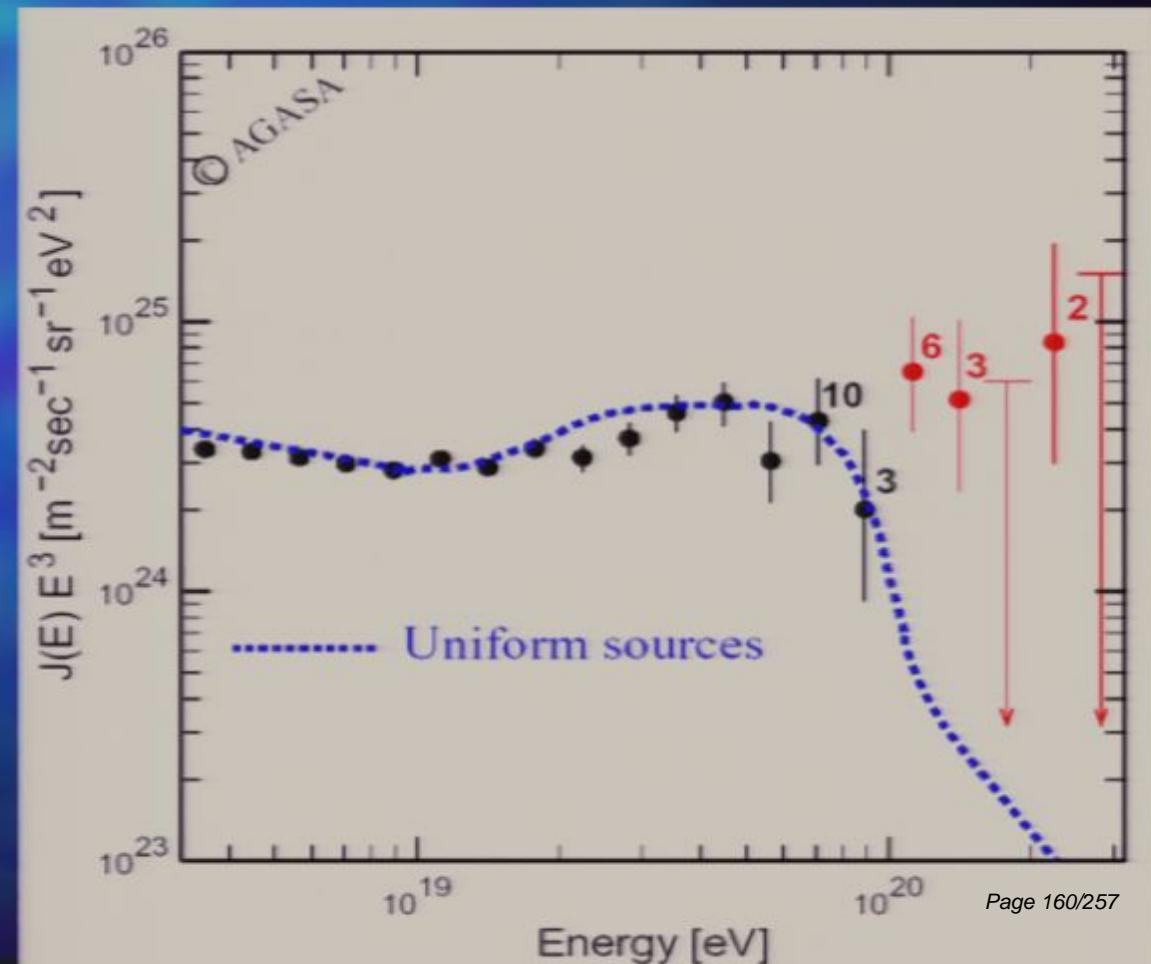
# AGASA Spectrum

**AGASA (Akeno, Japan)**  
100 km<sup>2</sup> ground array



# AGASA Spectrum

**AGASA** (Akeno, Japan)  
100 km<sup>2</sup> ground array



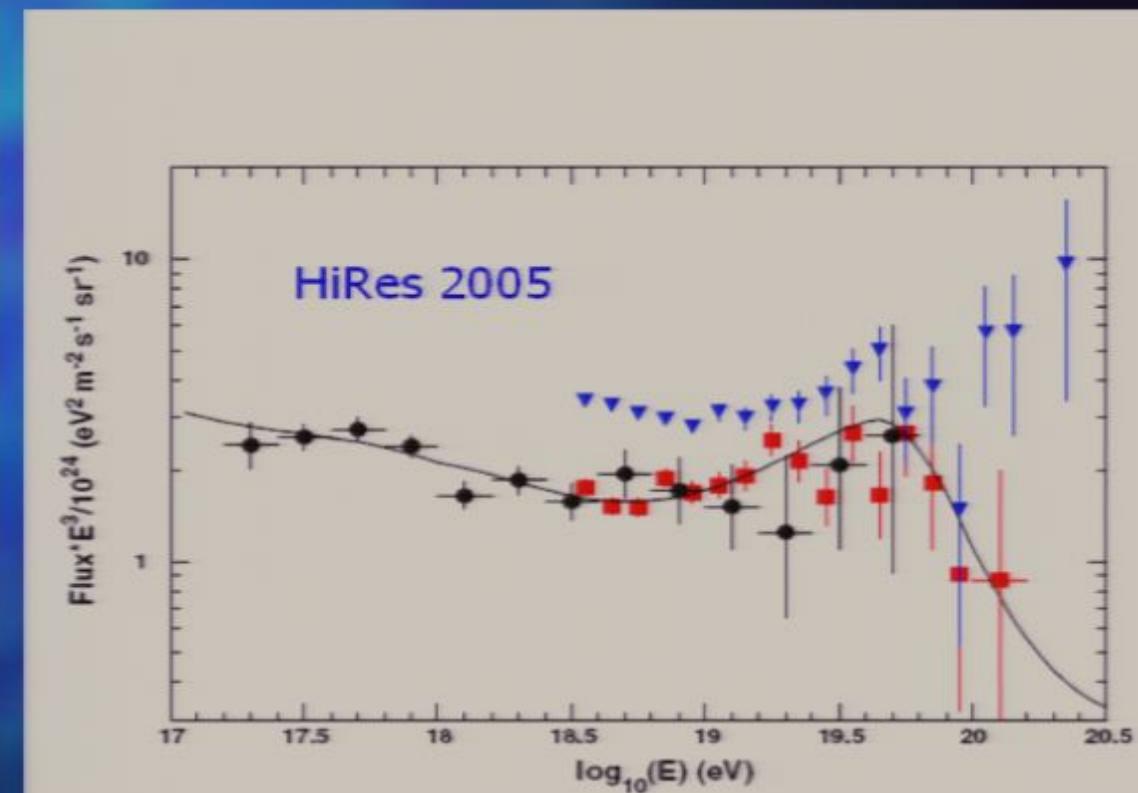
# HiRes Spectrum

**HiRes** (Dugway, Utah)  
2 N<sub>2</sub> fluorescence sites



# HiRes Spectrum

**HiRes** (Dugway, Utah)  
2 N<sub>2</sub> fluorescence sites



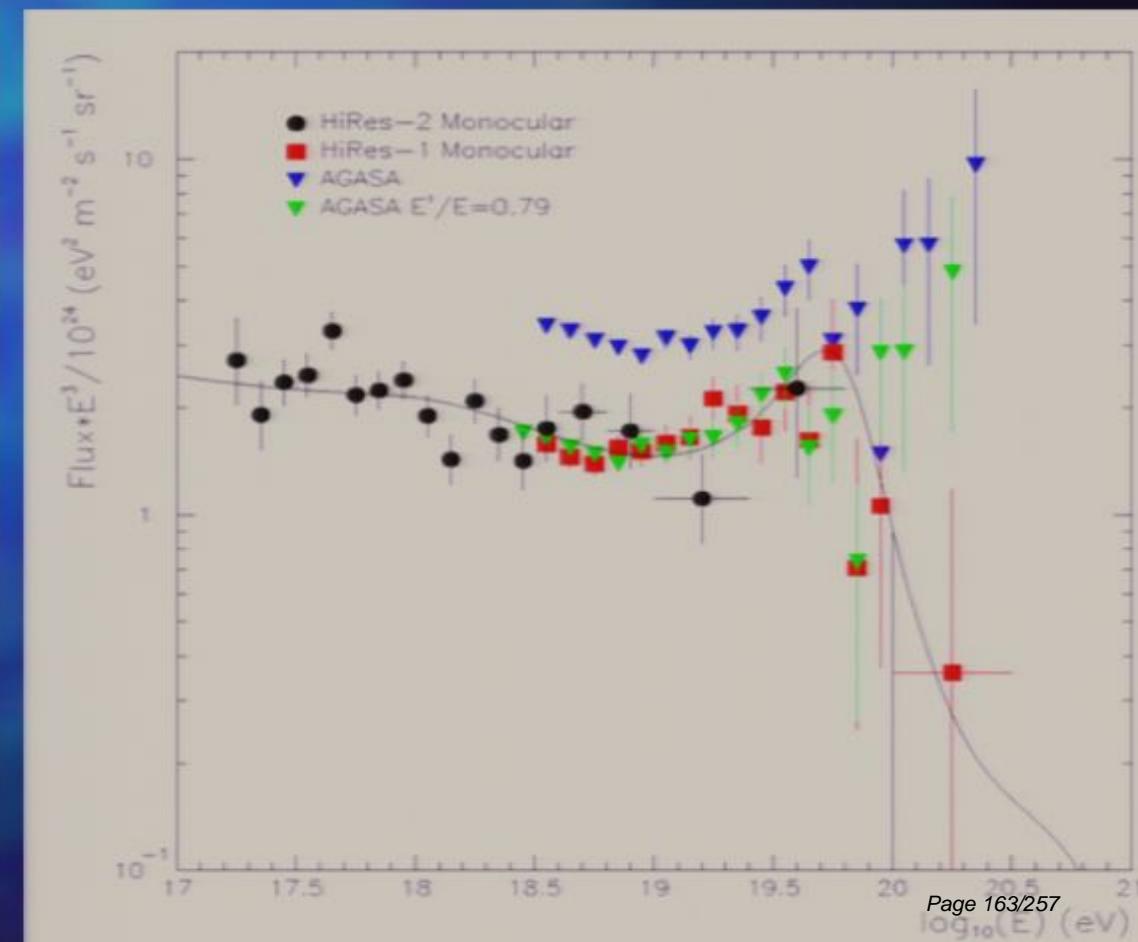
# HiRes Spectrum

**HiRes (Dugway, Utah)**  
2 N<sub>2</sub> fluorescence sites



GZK cutoff seen?

AGASA energies  
overestimated by 20%?



# HiRes Spectrum

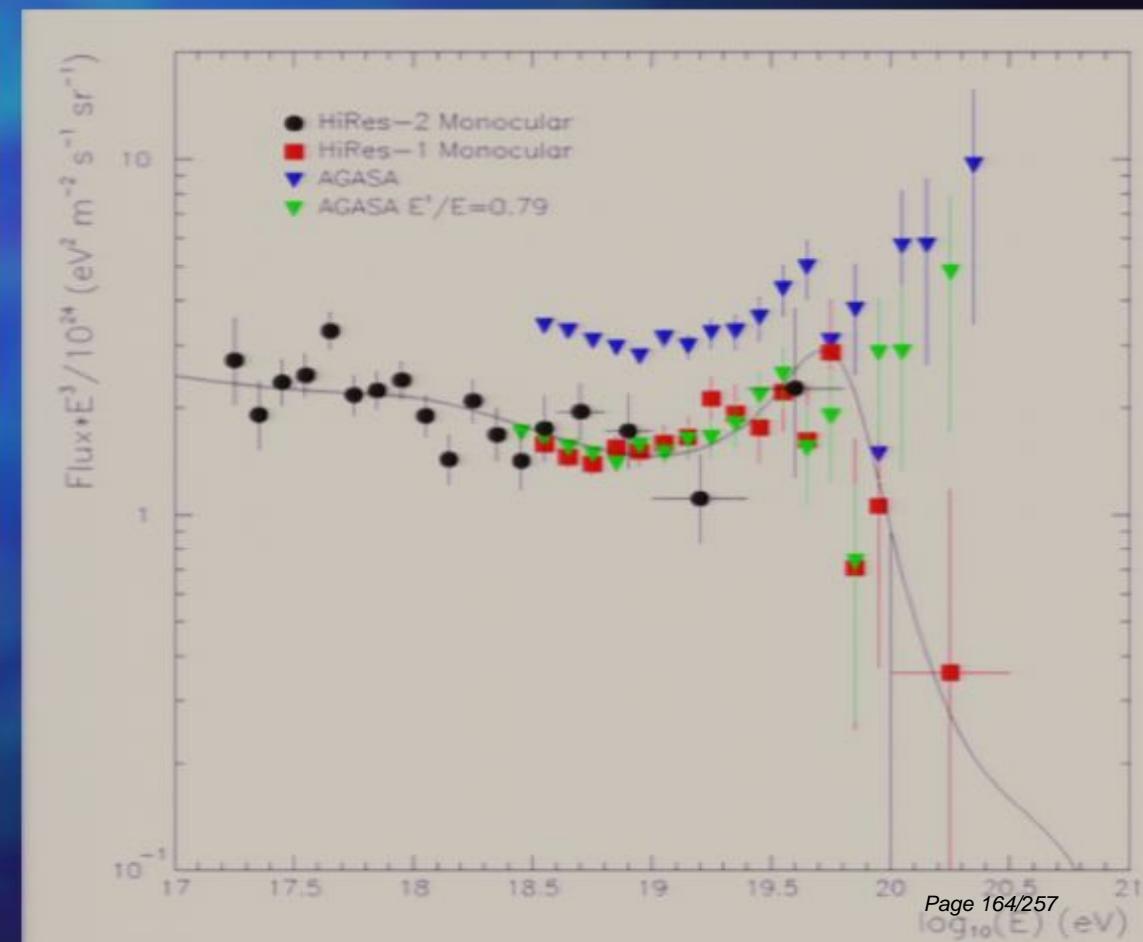
**HiRes** (Dugway, Utah)  
2 N<sub>2</sub> fluorescence sites



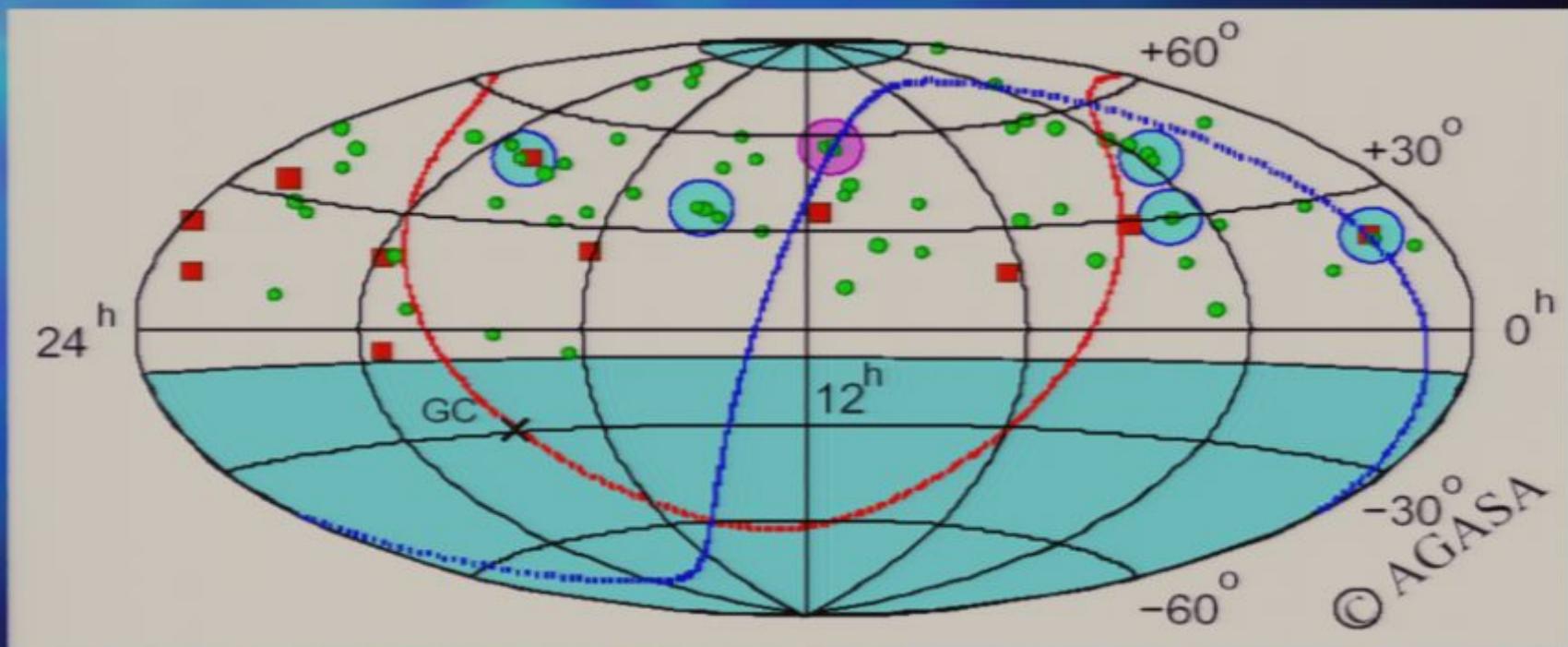
GZK cutoff seen?

AGASA energies  
overestimated by 20%?

But fluorescence yield poorly  
understood...



# AGASA UHECR Sky Map



■  $> 10^{20}$  eV

●  $4 - 10 \times 10^{19}$  eV

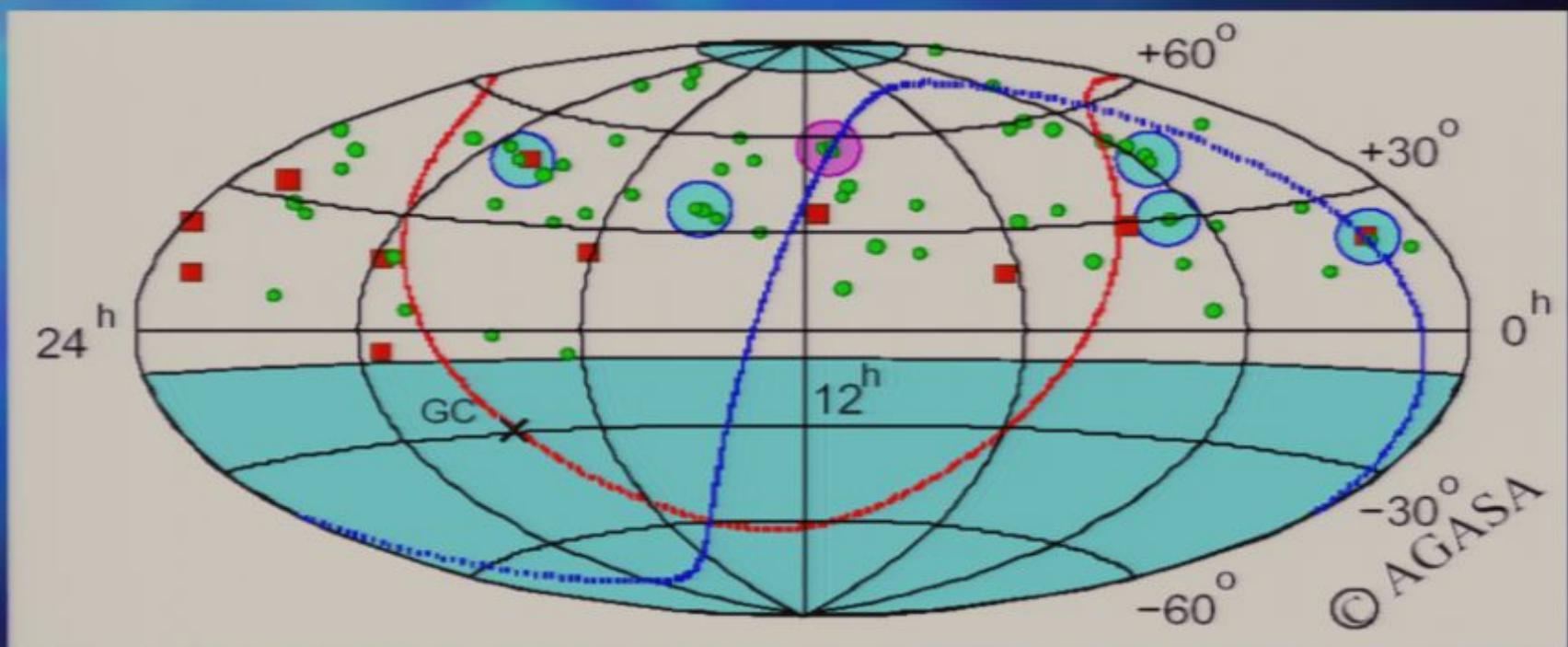
Galactic Plane

Supergalactic Plane

● Clustering within  $2.5^\circ$

● 0.9% probability

# AGASA UHECR Sky Map



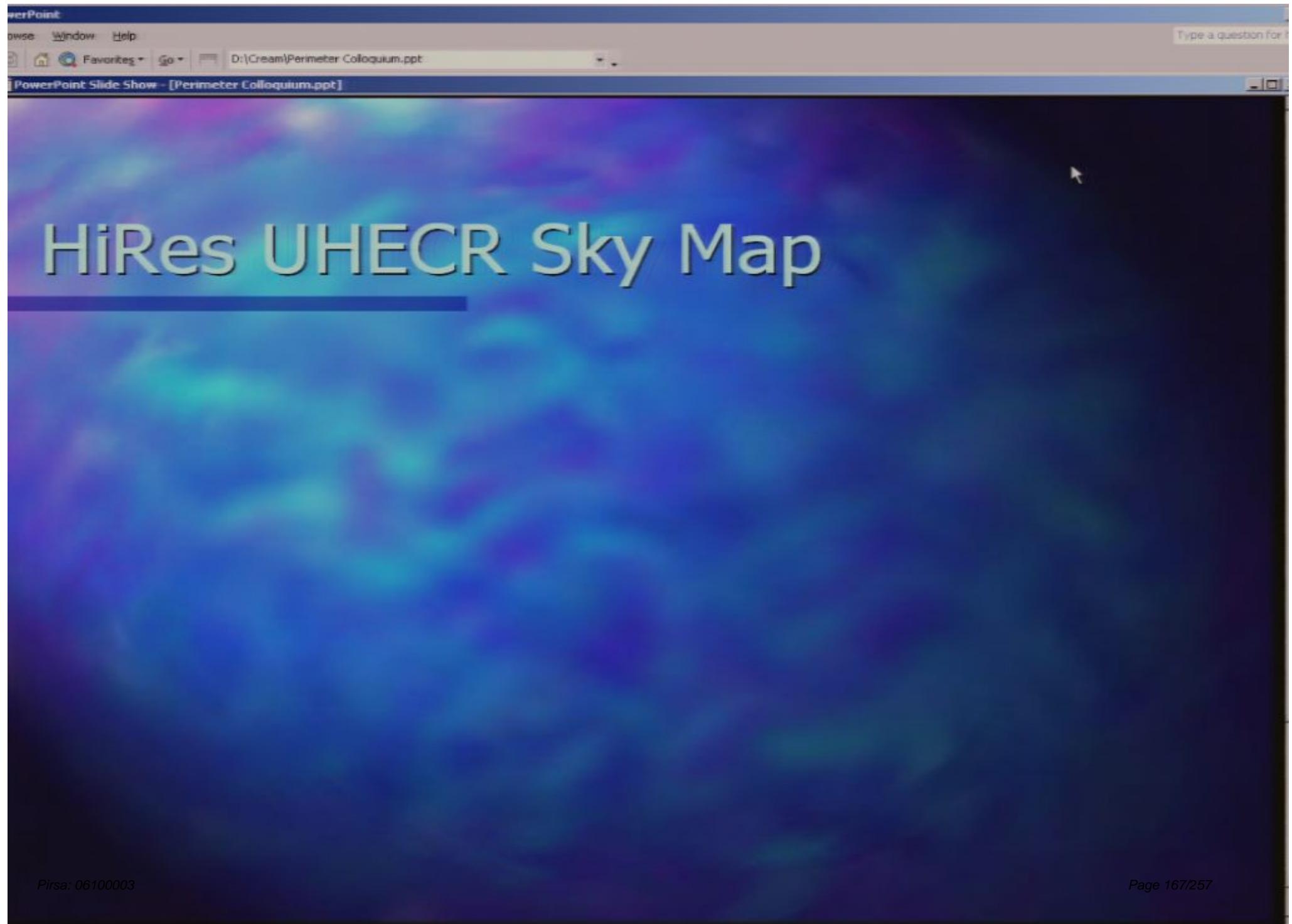
■  $> 10^{20}$  eV

●  $4 - 10 \times 10^{19}$  eV

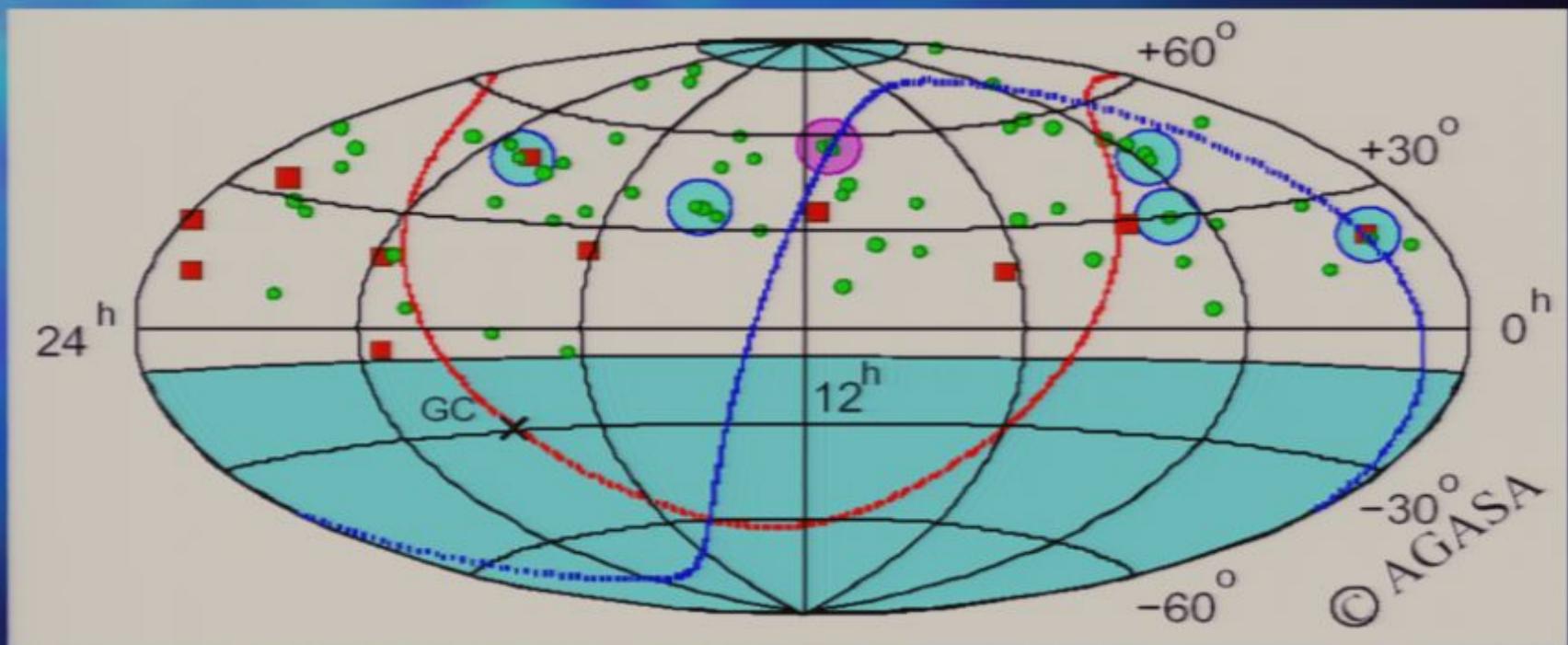
22% excess from GC at  $10^{18}$  eV

Galactic Plane

Supergalactic Plane



# AGASA UHECR Sky Map



■  $> 10^{20}$  eV

●  $4 - 10 \times 10^{19}$  eV

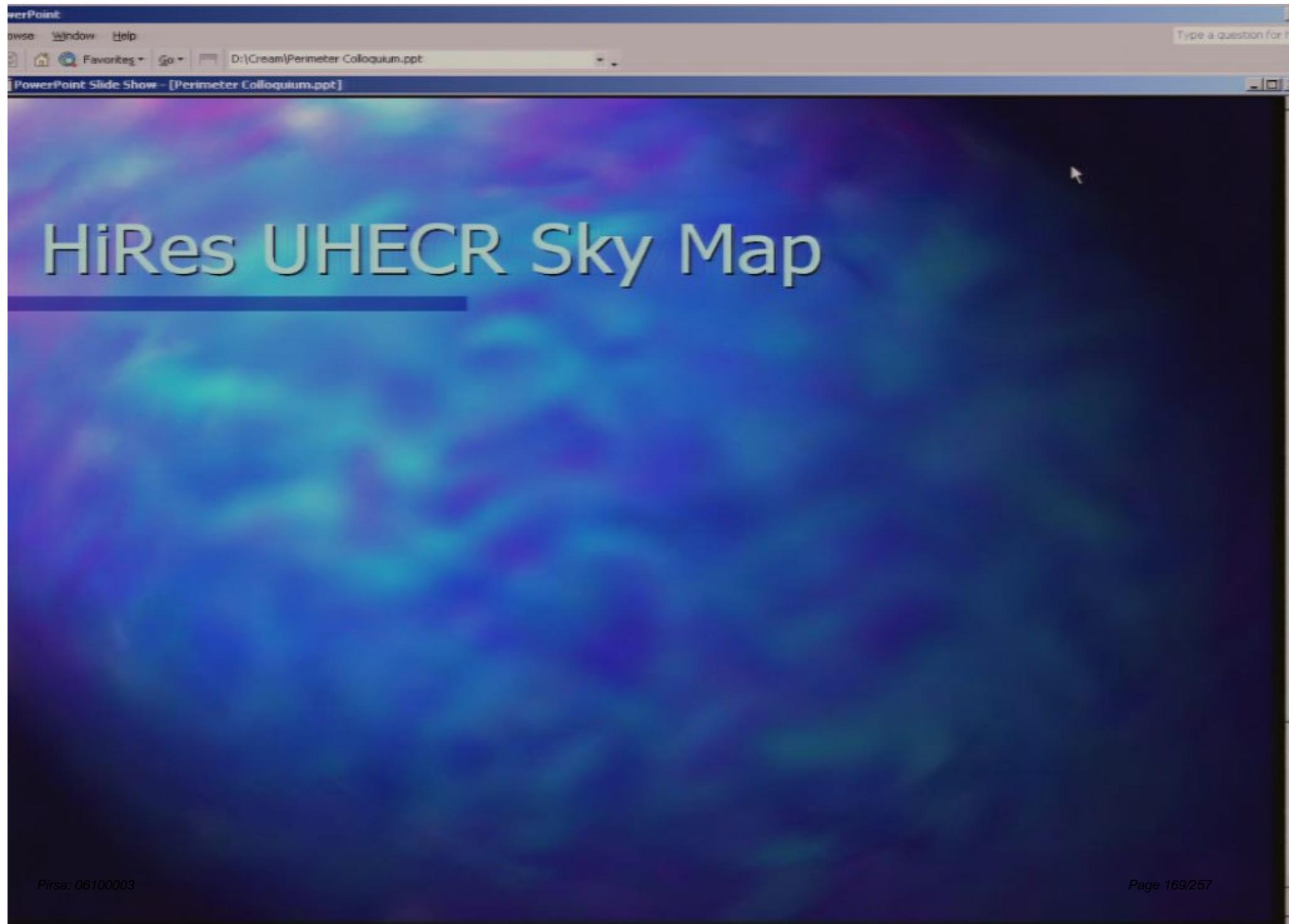
22% excess from GC at  $10^{18}$  eV

Galactic Plane

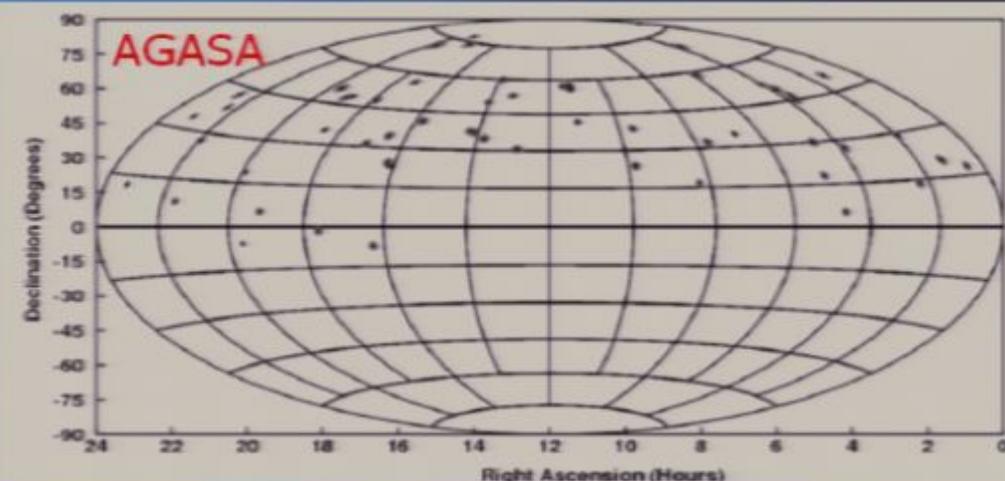
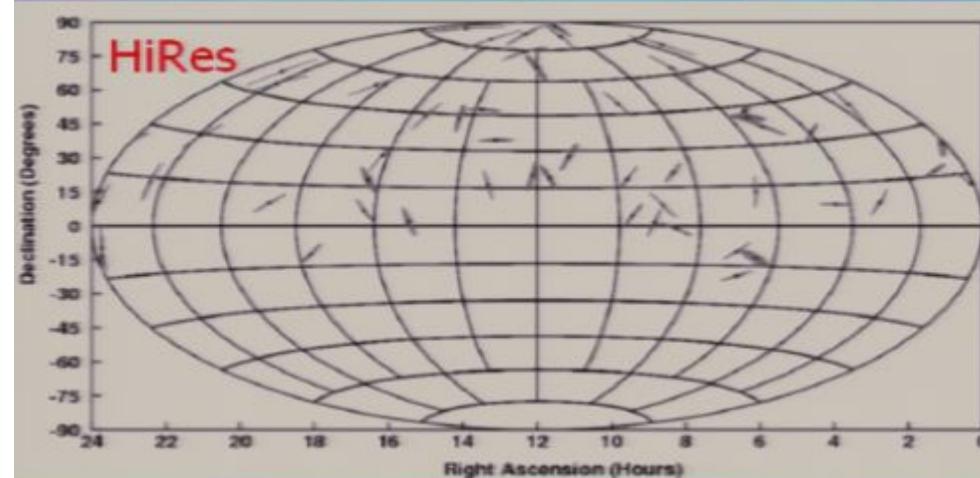
Supergalactic Plane

● Clustering within 2.5°

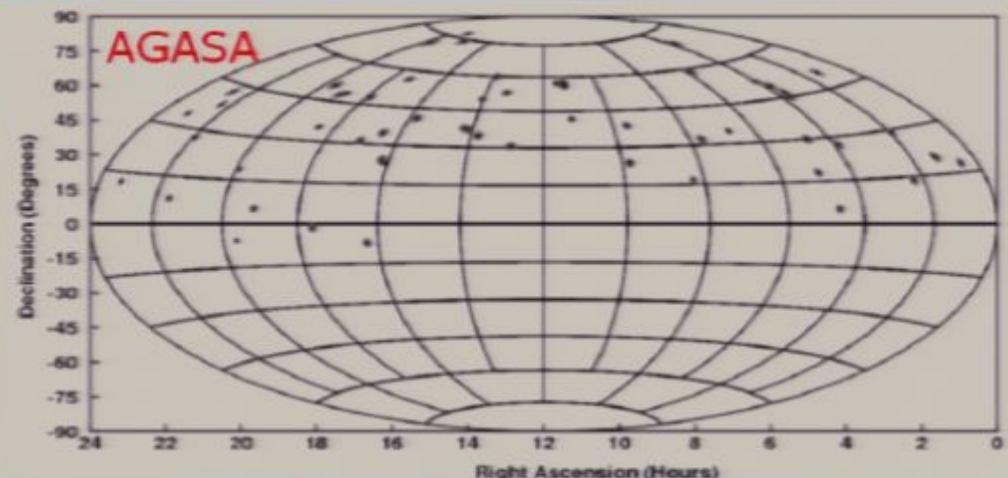
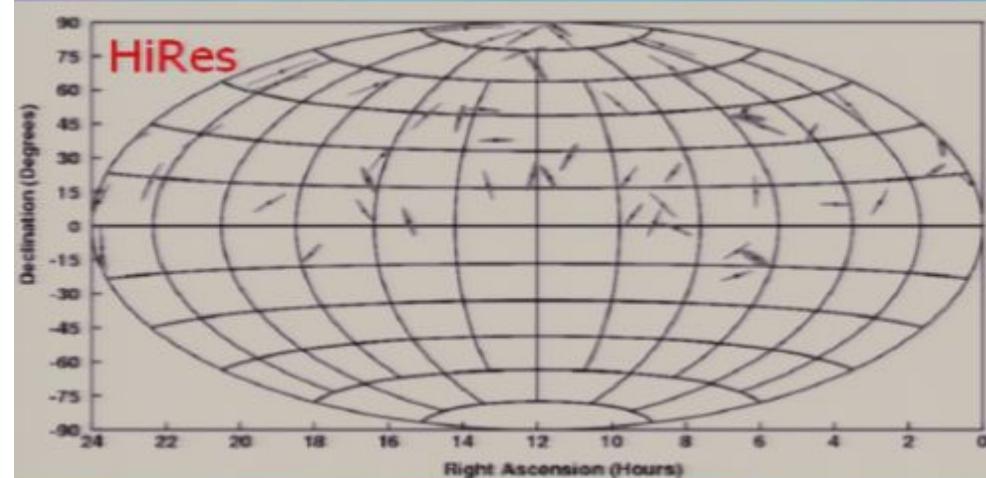
● 0.9% probability



# HiRes UHECR Sky Map

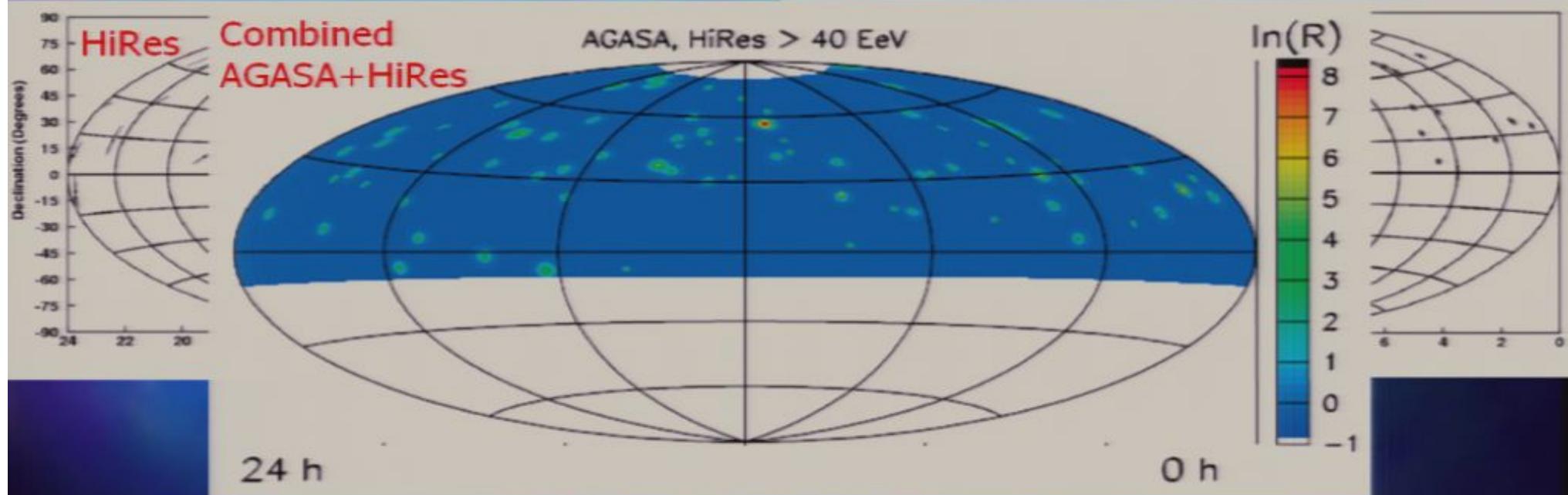


# HiRes UHECR Sky Map



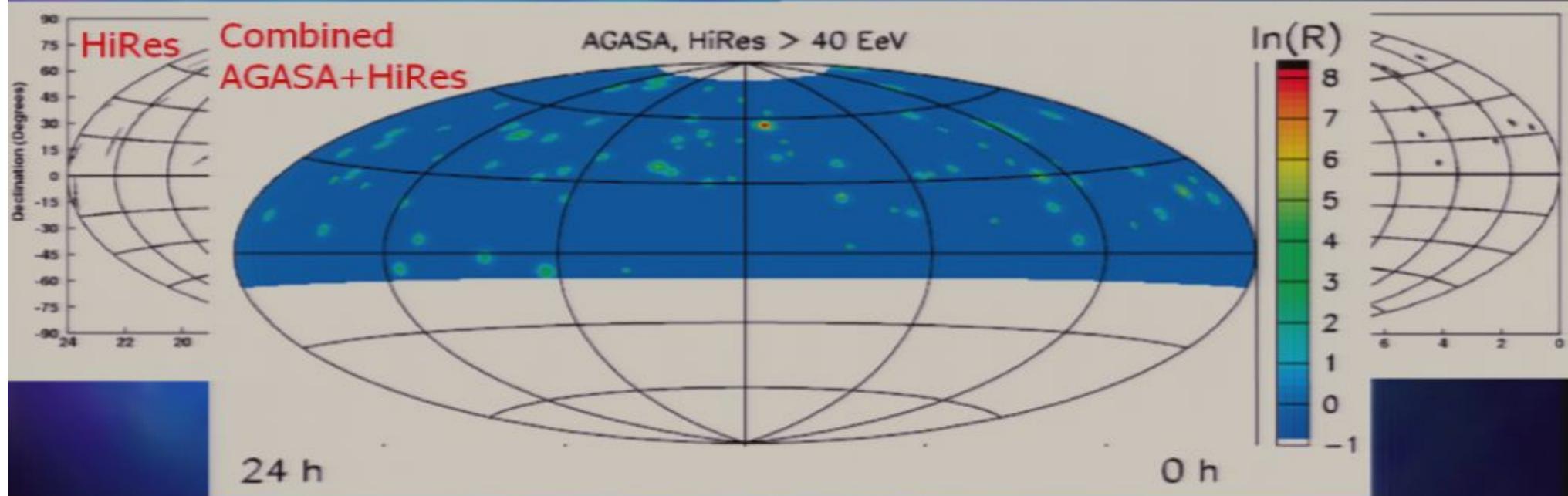
HiRes 2004: point sources ruled out above  $10^{19.5}$  eV in HiRes-I mono data

# HiRes UHECR Sky Map



HiRes 2004: point sources ruled out above  $10^{19.5}$  eV in HiRes-I mono data

# HiRes UHECR Sky Map



HiRes 2004: point sources ruled out above  $10^{19.5}$  eV in HiRes-I mono data

HiRes 2005: point sources ruled out above  $4 \times 10^{19}$  eV in an analysis of  
57 AGASA + 27 HiRes stereo events



Results so far suggest:



# Results so far suggest:

---

- There are events with energies beyond  $10^{20}$  eV; seen by AGASA, Fly's Eye and HiRes

# Results so far suggest:

---

- There are events with energies beyond  $10^{20}$  eV; seen by AGASA, Fly's Eye and HiRes
  - **BUT we are not sure of the fluxes**
- The arrival directions seem rather isotropic

# Results so far suggest:

---

- There are events with energies beyond  $10^{20}$  eV; seen by AGASA, Fly's Eye and HiRes
  - BUT we are not sure of the fluxes
- The arrival directions seem rather isotropic
  - BUT there may be clusters

Major problem is that flux above  $10^{20}$  eV

# Results so far suggest:

- There are events with energies beyond  $10^{20}$  eV; seen by AGASA, Fly's Eye and HiRes
  - BUT we are not sure of the fluxes
- The arrival directions seem rather isotropic
  - BUT there may be clusters

Major problem is that flux above  $10^{20}$  eV  
is  $\sim 1 \text{ km}^{-2} \text{ century}^{-1} \text{ sr}^{-1}$

Need much larger, *hybrid* detector

# Results so far suggest:

- There are events with energies beyond  $10^{20}$  eV; seen by AGASA, Fly's Eye and HiRes
  - BUT we are not sure of the fluxes
- The arrival directions seem rather isotropic
  - BUT there may be clusters

Major problem is that flux above  $10^{20}$  eV  
is  $\sim 1 \text{ km}^{-2} \text{ century}^{-1} \text{ sr}^{-1}$

Need much larger, *hybrid* detector

⇒ Auger!

Sources? Two Observatories necessary

# Results so far suggest:

- There are events with energies beyond  $10^{20}$  eV; seen by AGASA, Fly's Eye and HiRes
  - BUT we are not sure of the fluxes
- The arrival directions seem rather isotropic
  - BUT there may be clusters

Major problem is that flux above  $10^{20}$  eV  
is  $\sim 1 \text{ km}^{-2} \text{ century}^{-1} \text{ sr}^{-1}$

Need much larger, *hybrid* detector

⇒ Auger!

Sources? Two Observatories necessary



# Results so far suggest:

- There are events with energies beyond  $10^{20}$  eV; seen by AGASA, Fly's Eye and HiRes
  - BUT we are not sure of the fluxes
- The arrival directions seem rather isotropic
  - BUT there may be clusters

Major problem is that flux above  $10^{20}$  eV  
is  $\sim 1 \text{ km}^{-2} \text{ century}^{-1} \text{ sr}^{-1}$

Need much larger, *hybrid* detector

⇒ Auger!

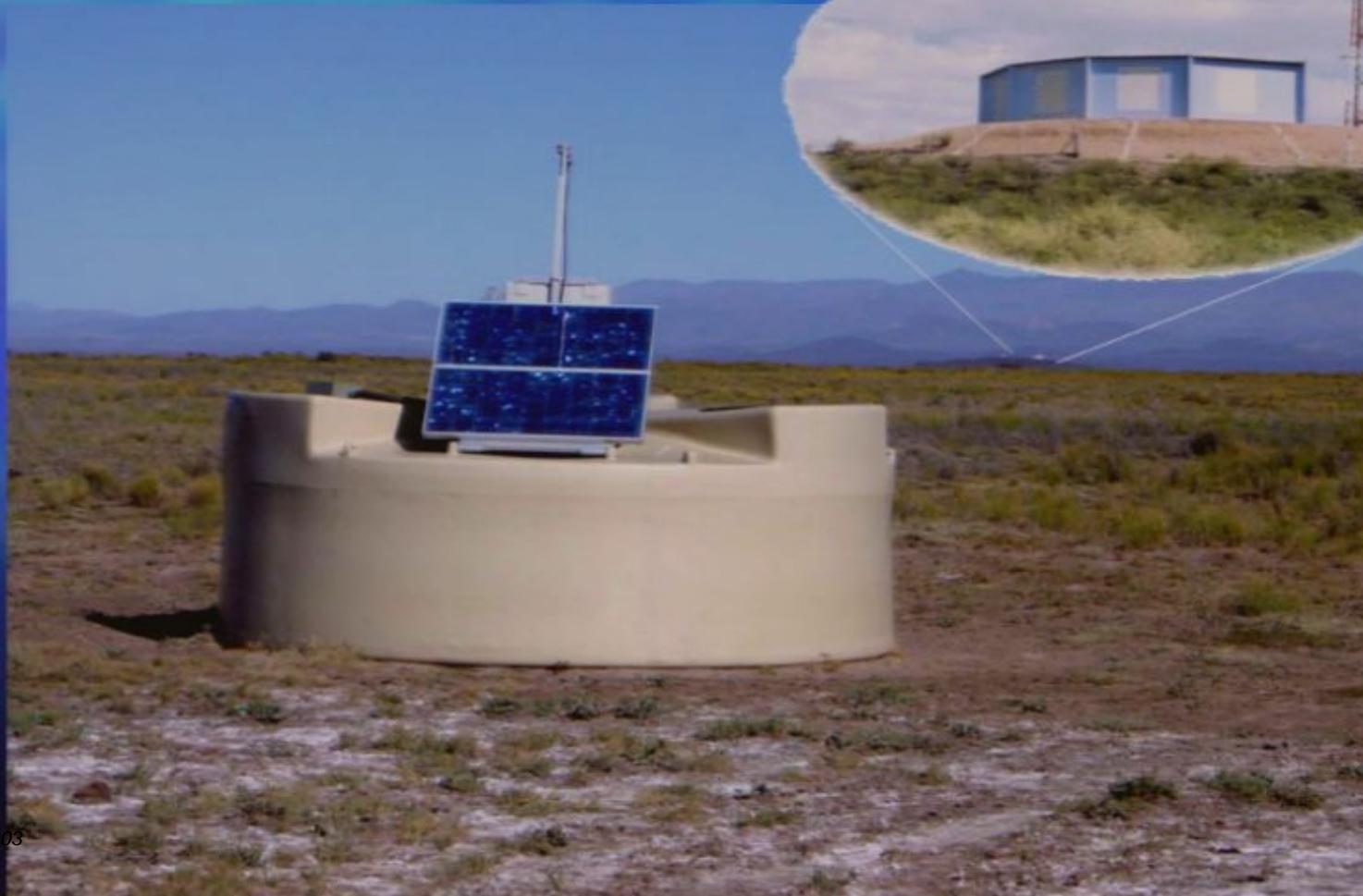
Sources? Two Observatories necessary



# Auger Hybrid Detector



# Auger Hybrid Detector



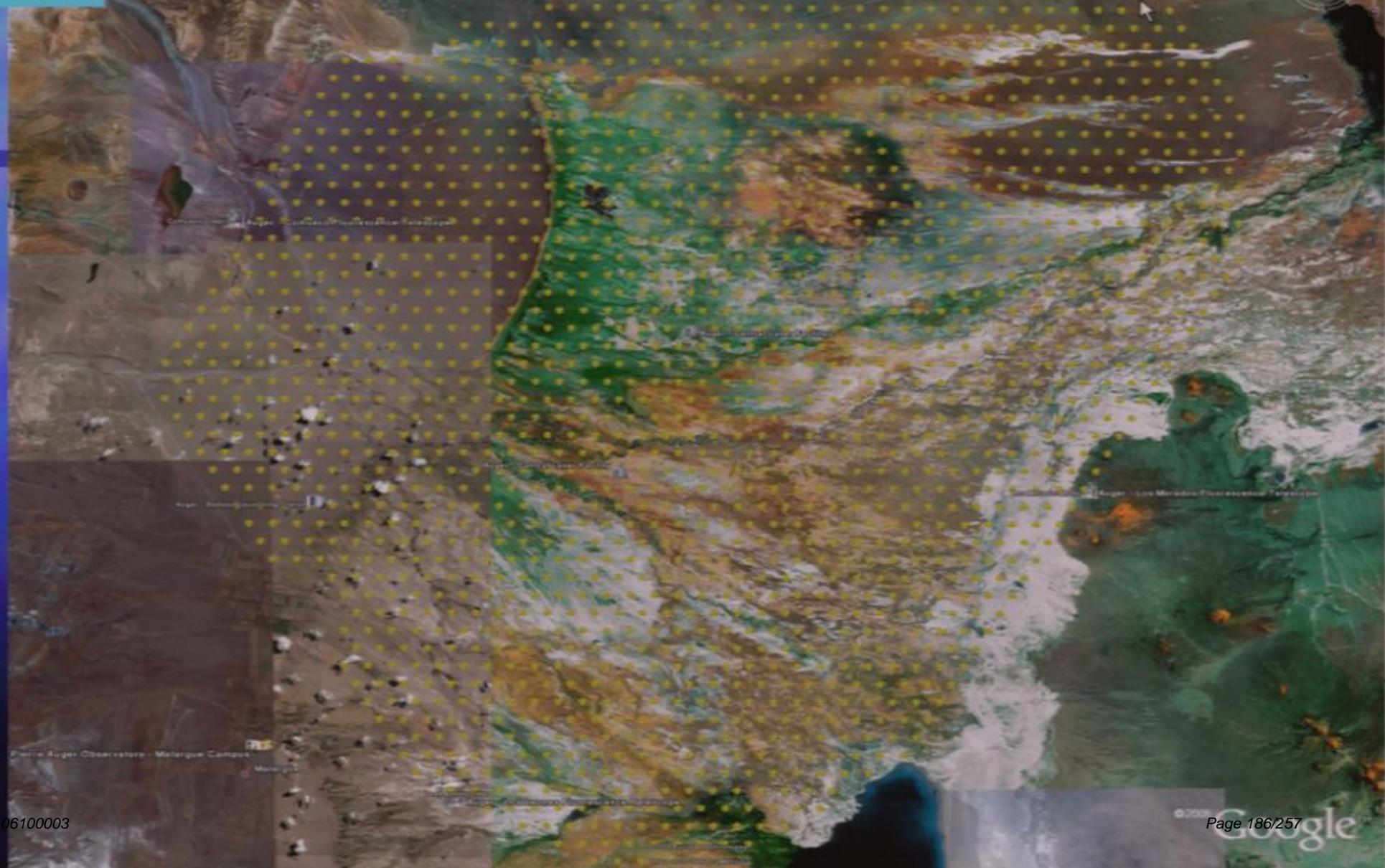
# Auger Surface Detectors



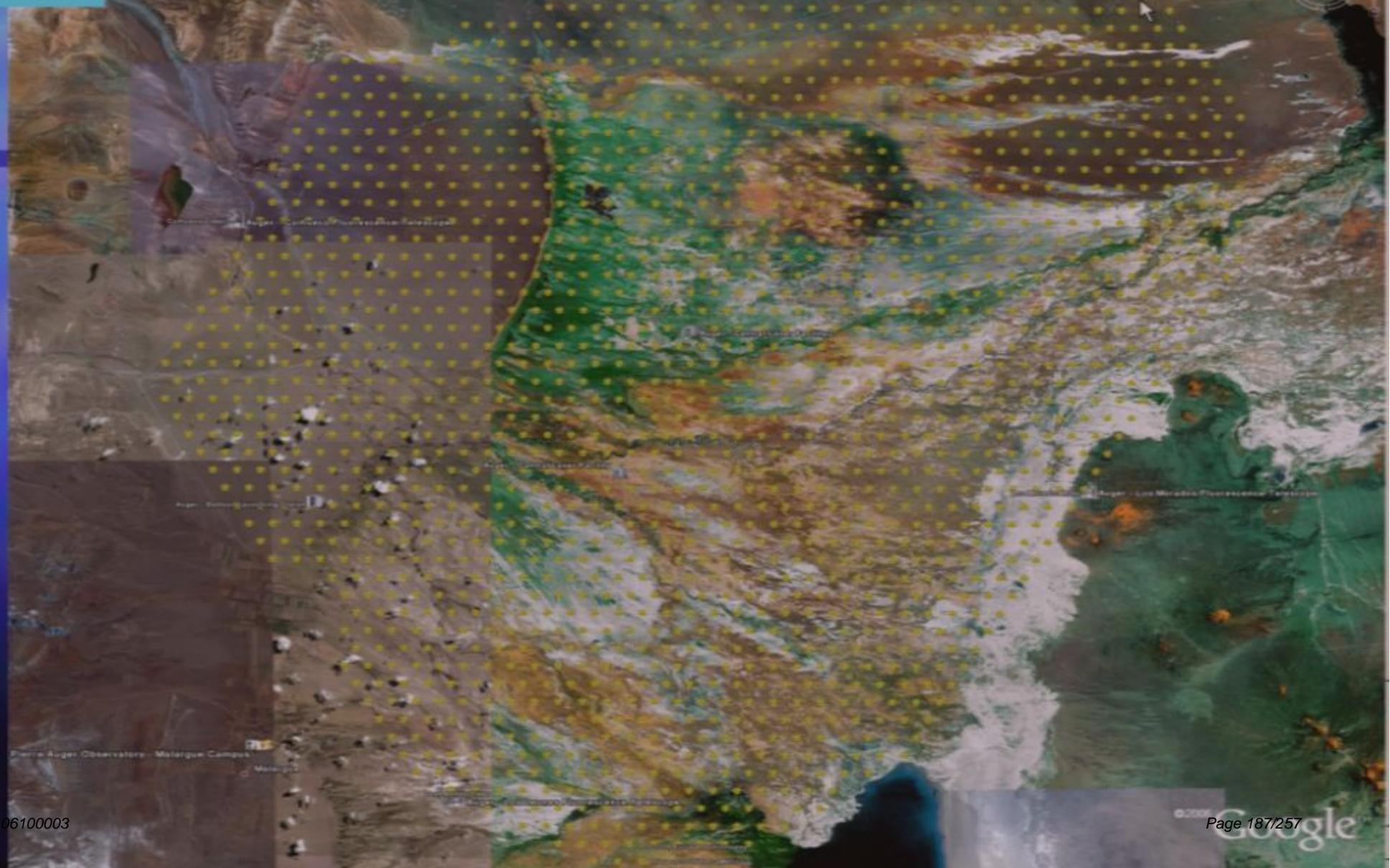
# Fluorescence Detector



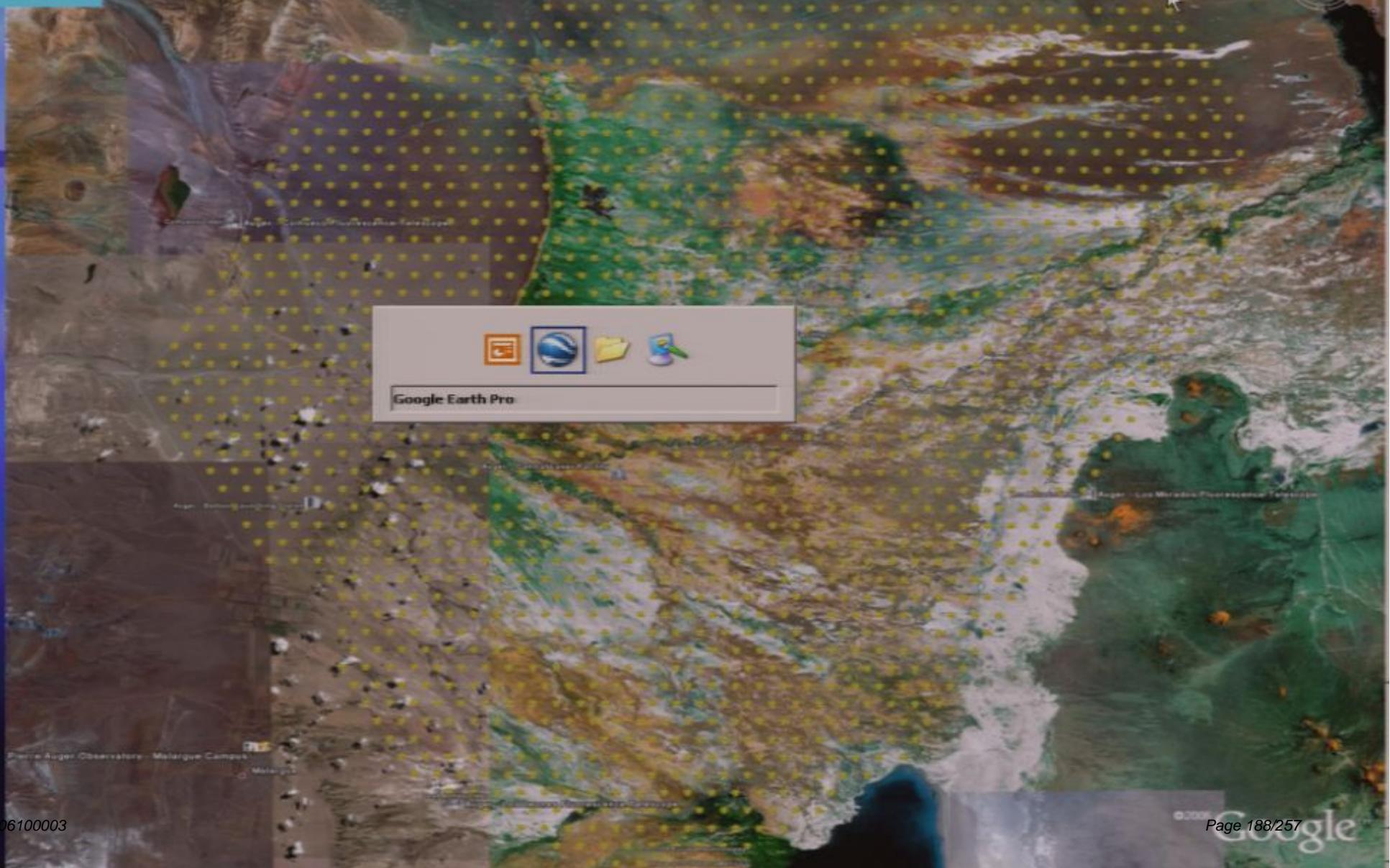
# Southern Hemisphere Site Argentina

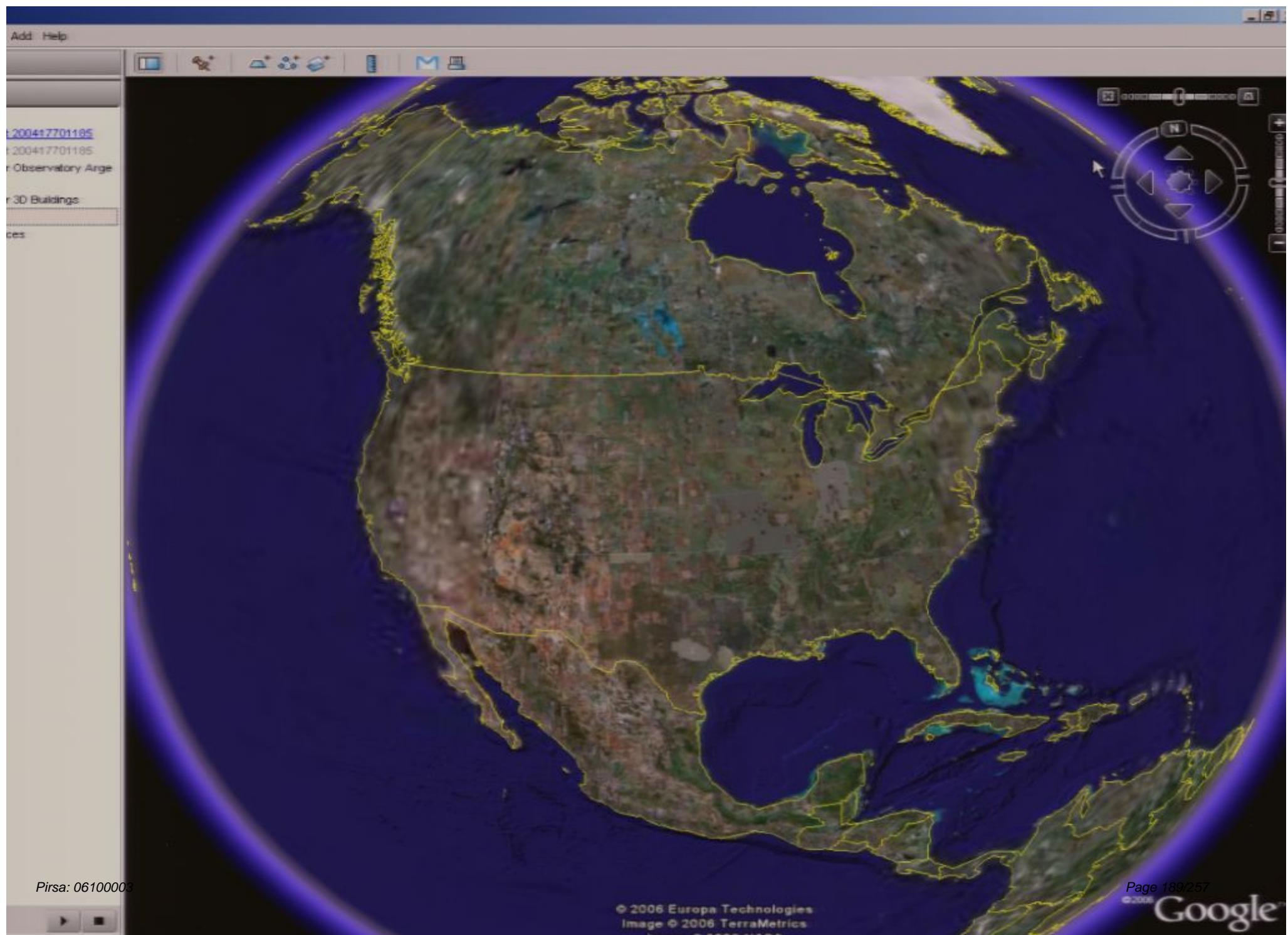


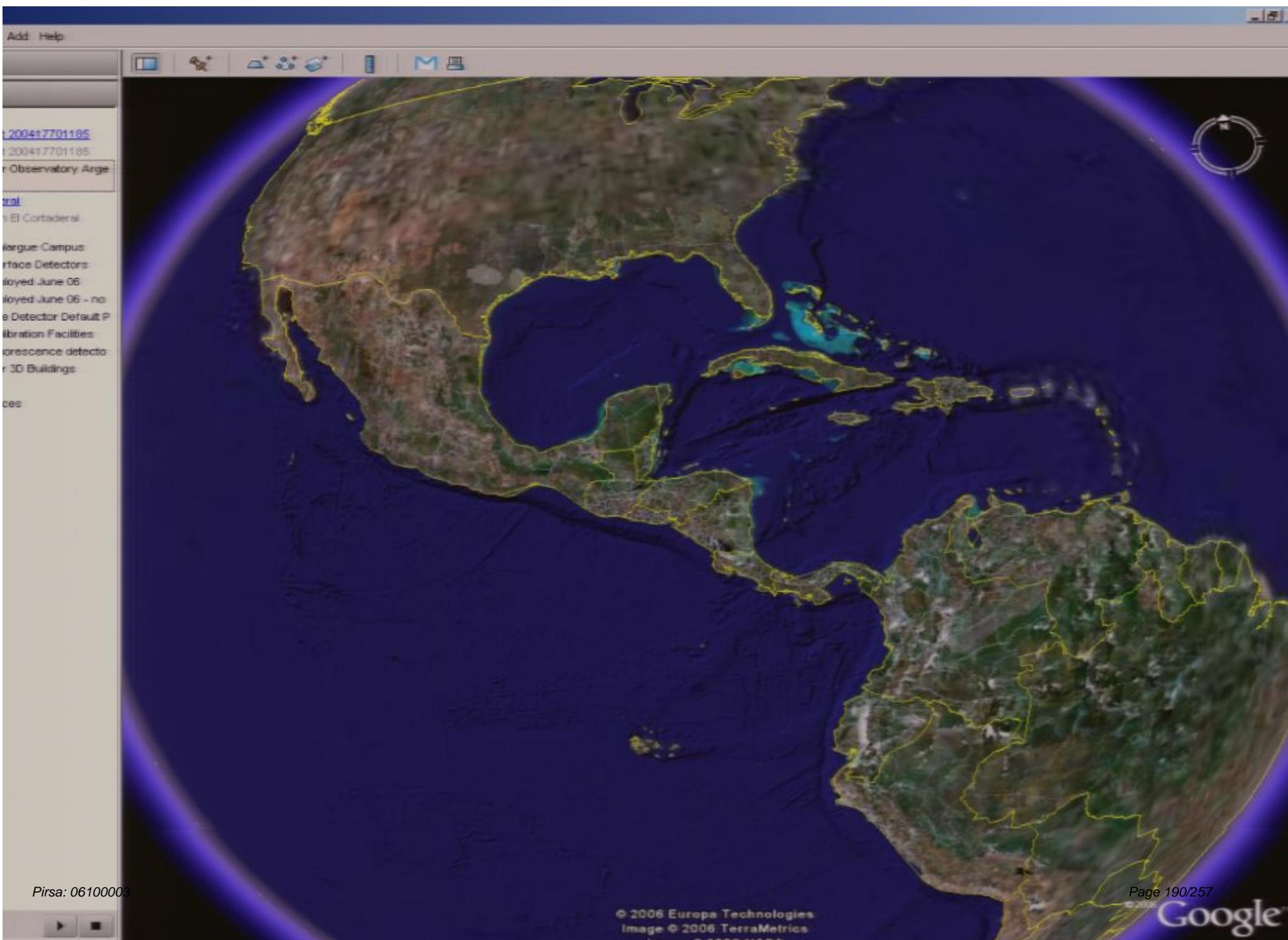
# Southern Hemisphere Site Argentina



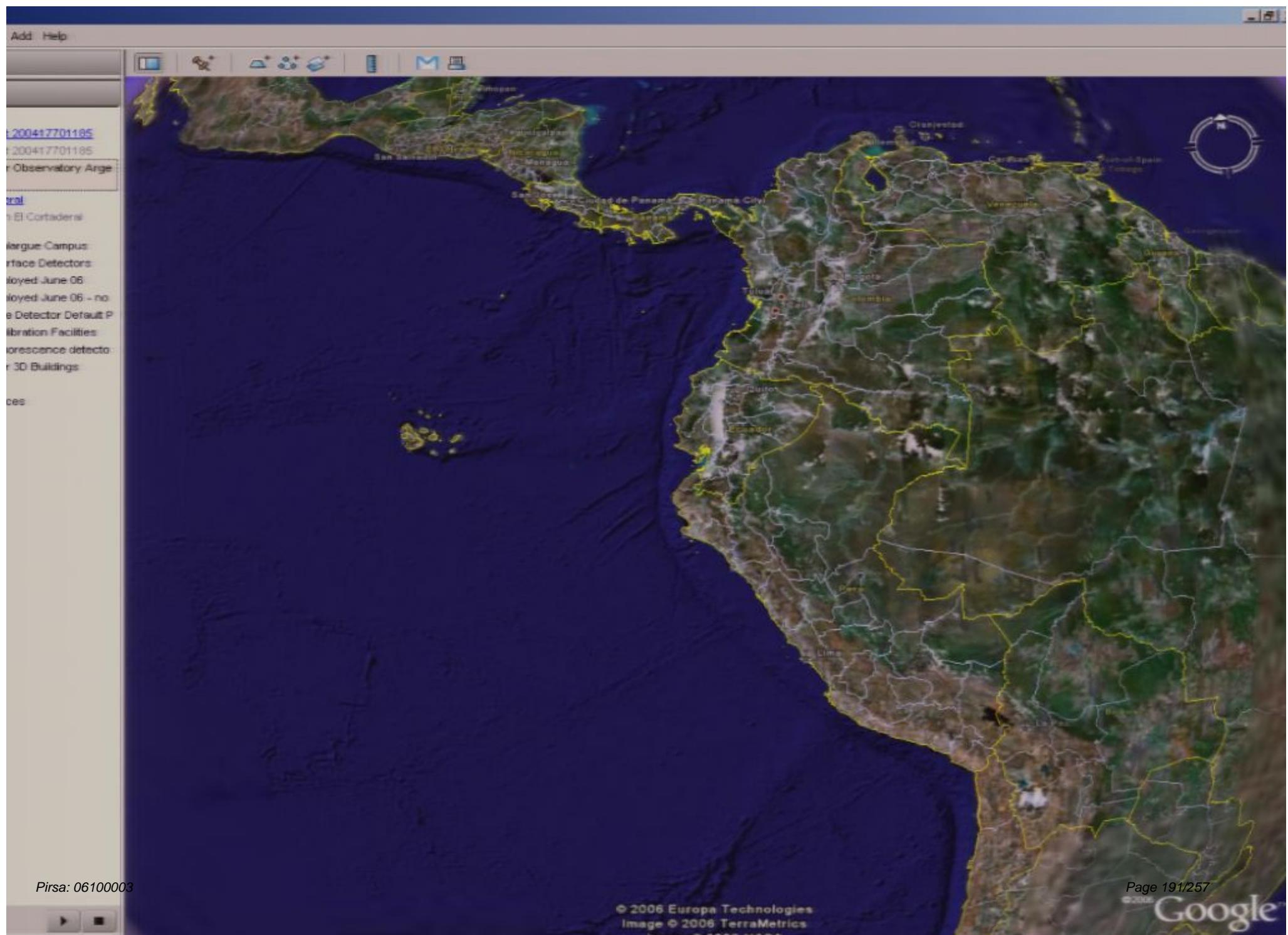
# Southern Hemisphere Site: Argentina

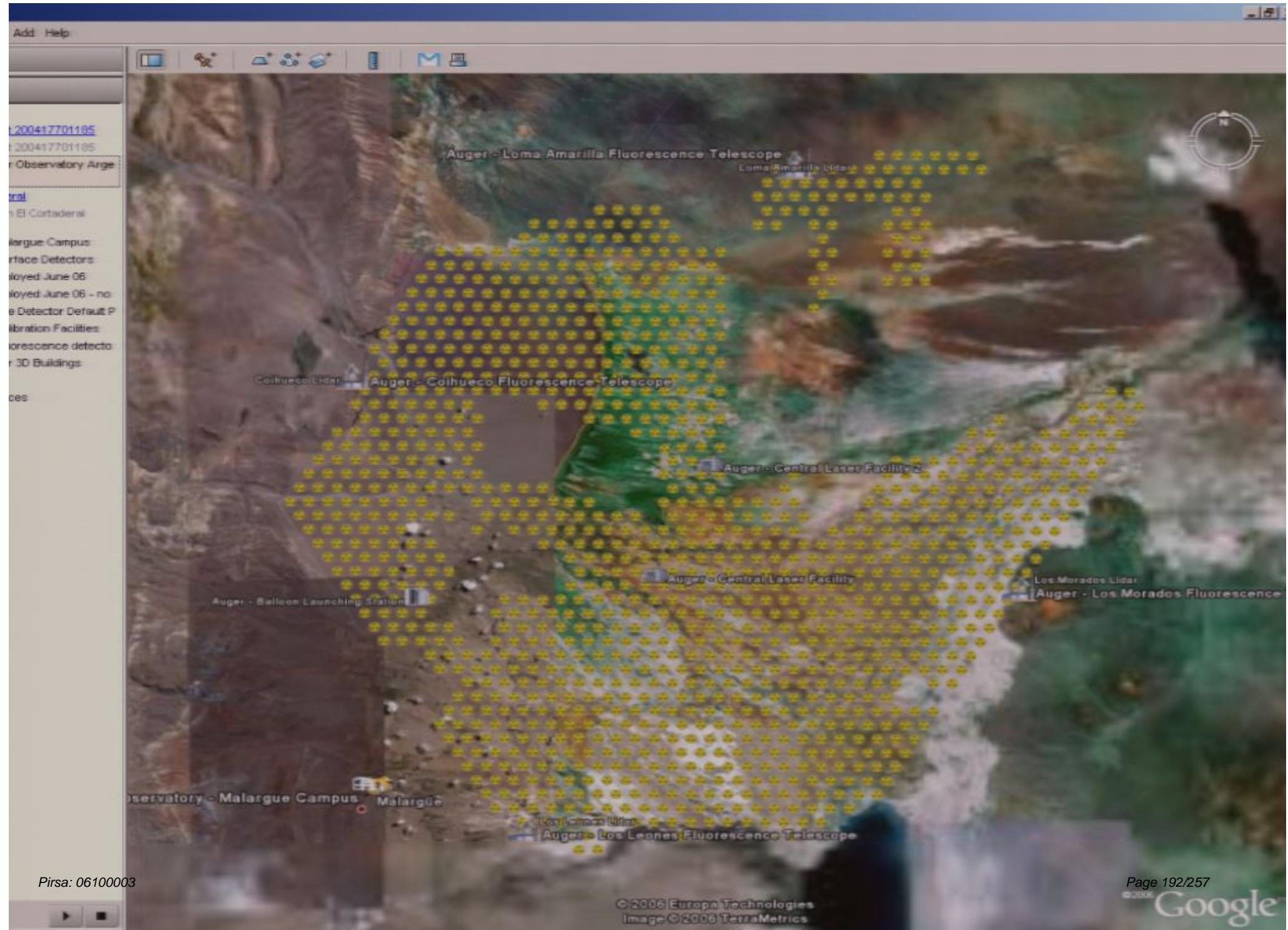






Pirsa: 06100003







200417701185

200417701185

Observatory Argentino

Central

El Cortadillo

Auger Campus

Surface Detectors:

Moved June 06

Moved June 06 - no

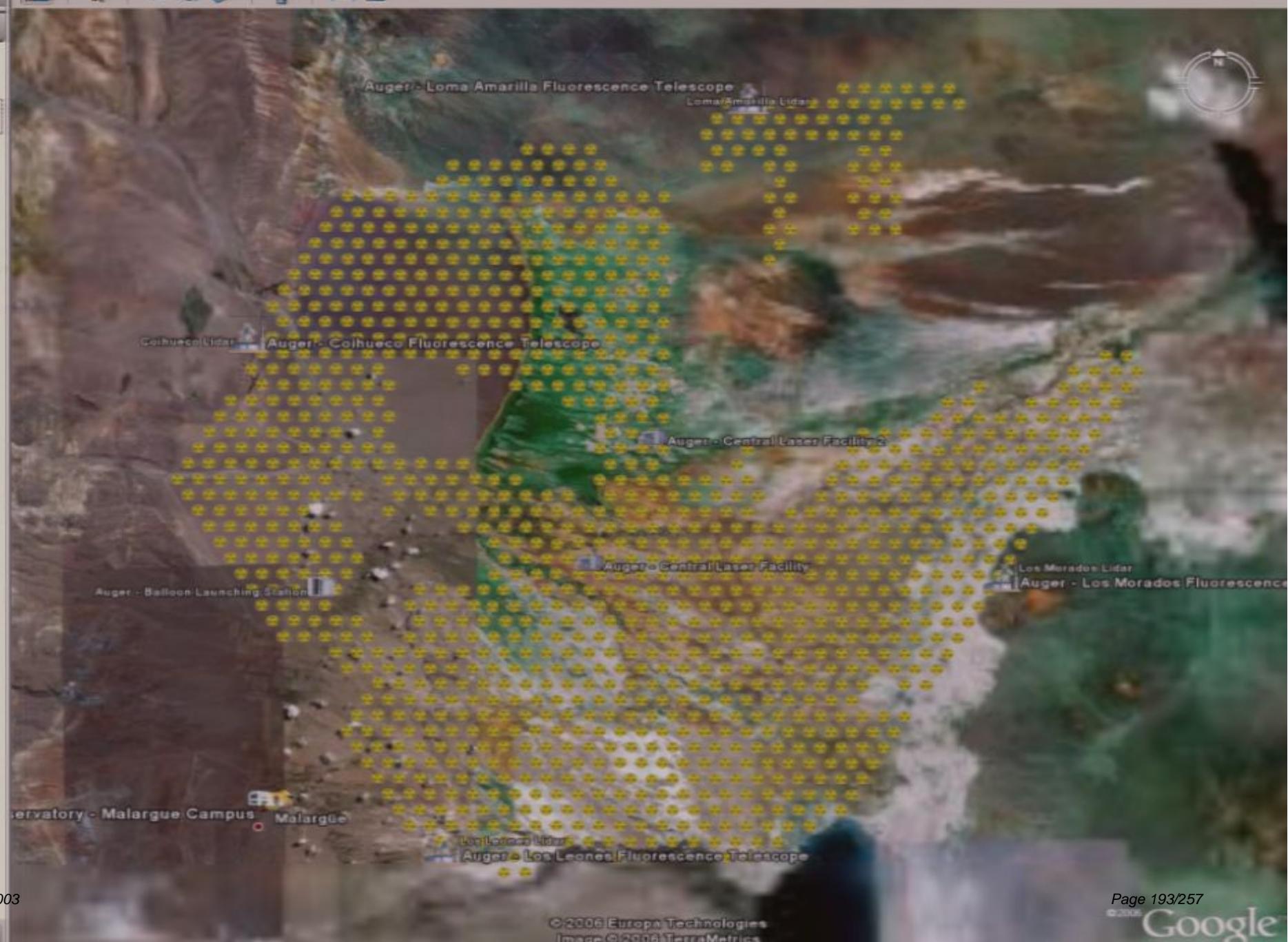
Detector Default P

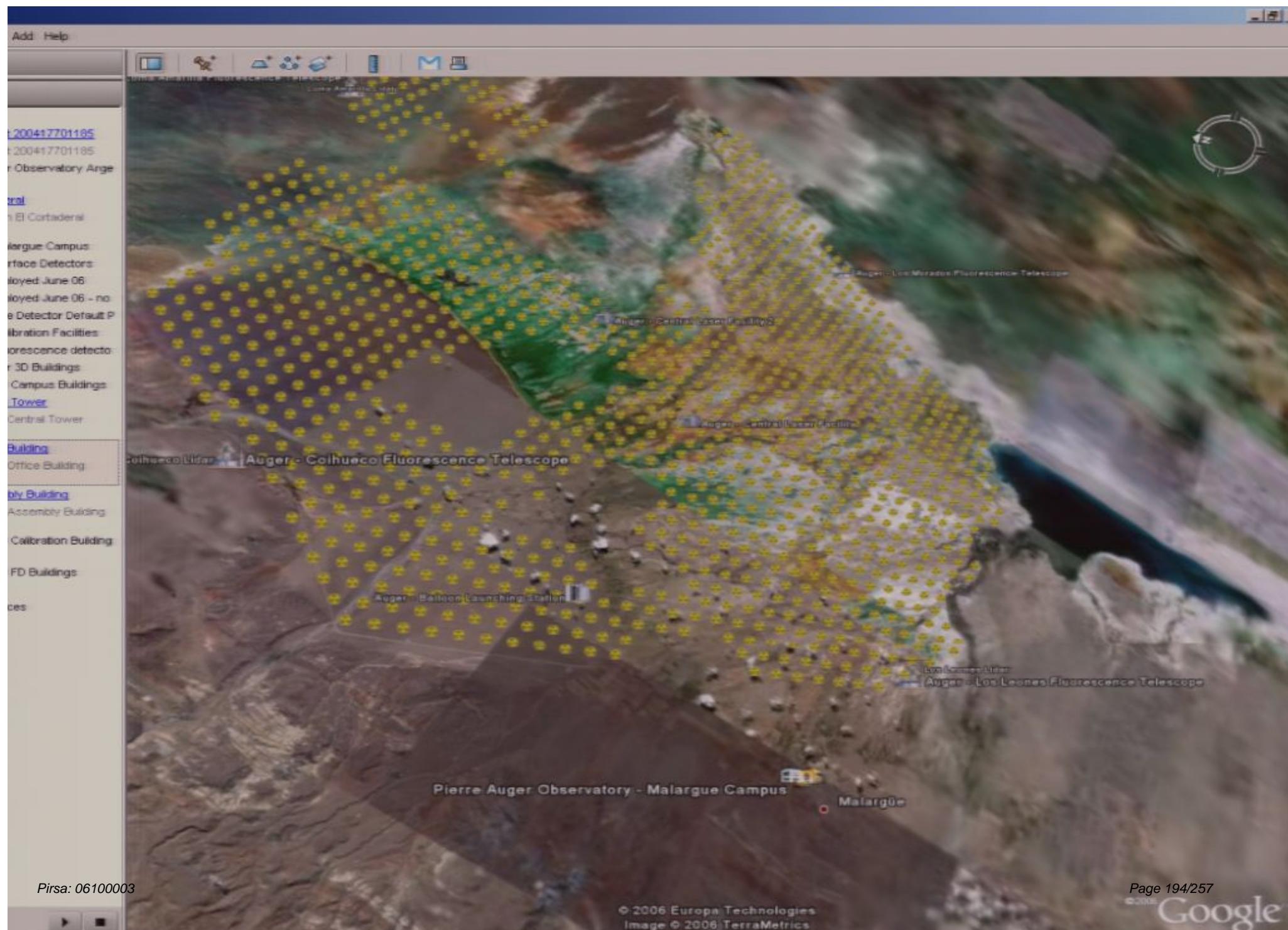
ibration Facilities

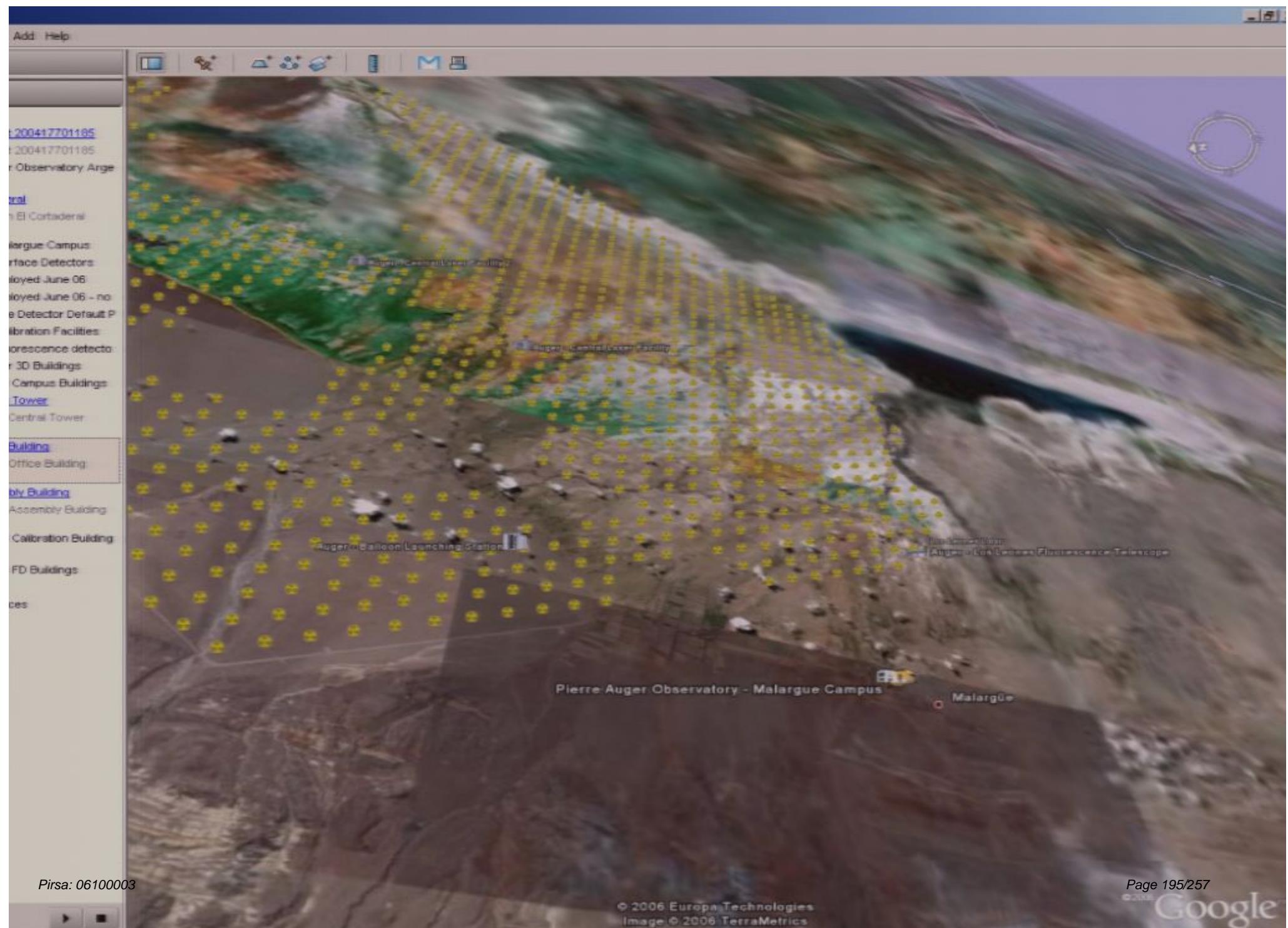
Fluorescence detecto

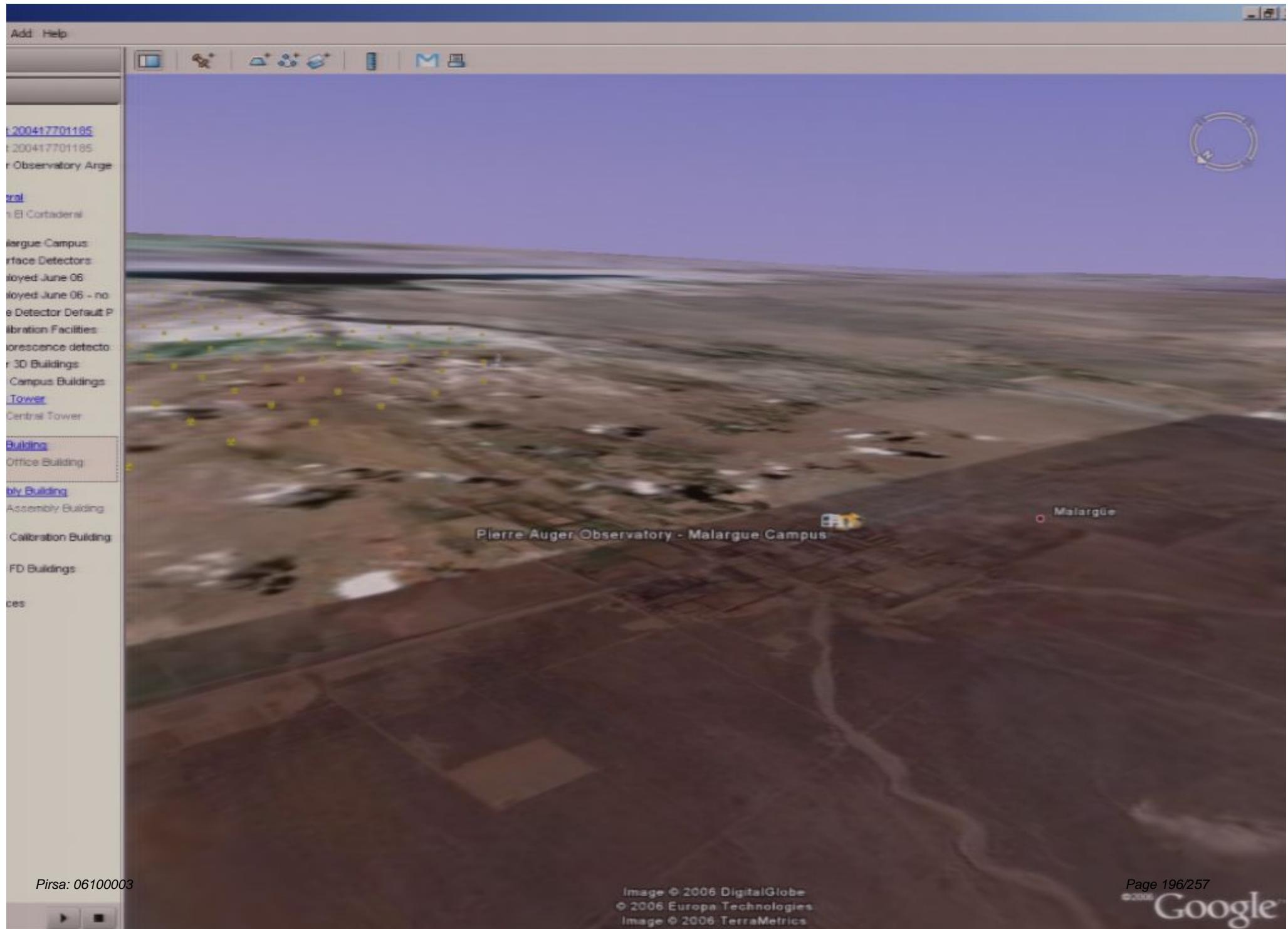
3D Buildings

ces









Add Help



[200417701185](#)

[200417701185](#)

[Observatory Argentino](#)

[Central](#)

[El Cortadillo](#)

[Mallargue Campus](#)

[Surface Detectors](#)

[Arrived June 06](#)

[Arrived June 06 - no](#)

[Detector Default P](#)

[ibration Facilities](#)

[Fluorescence detecto](#)

[r 3D Buildings](#)

[Campus Buildings](#)

[Tower](#)

[Central Tower](#)

[Building](#)

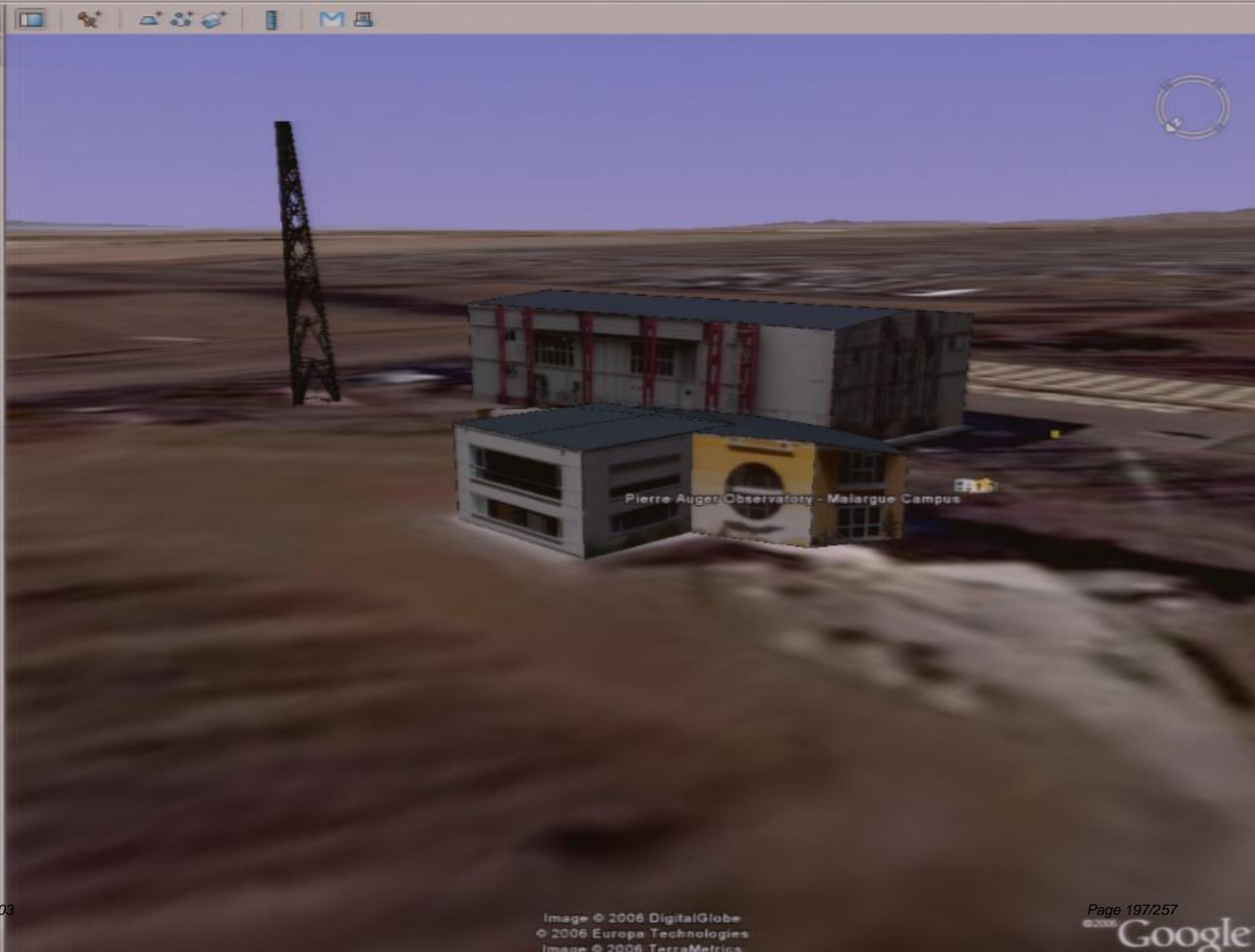
[Office Building](#)

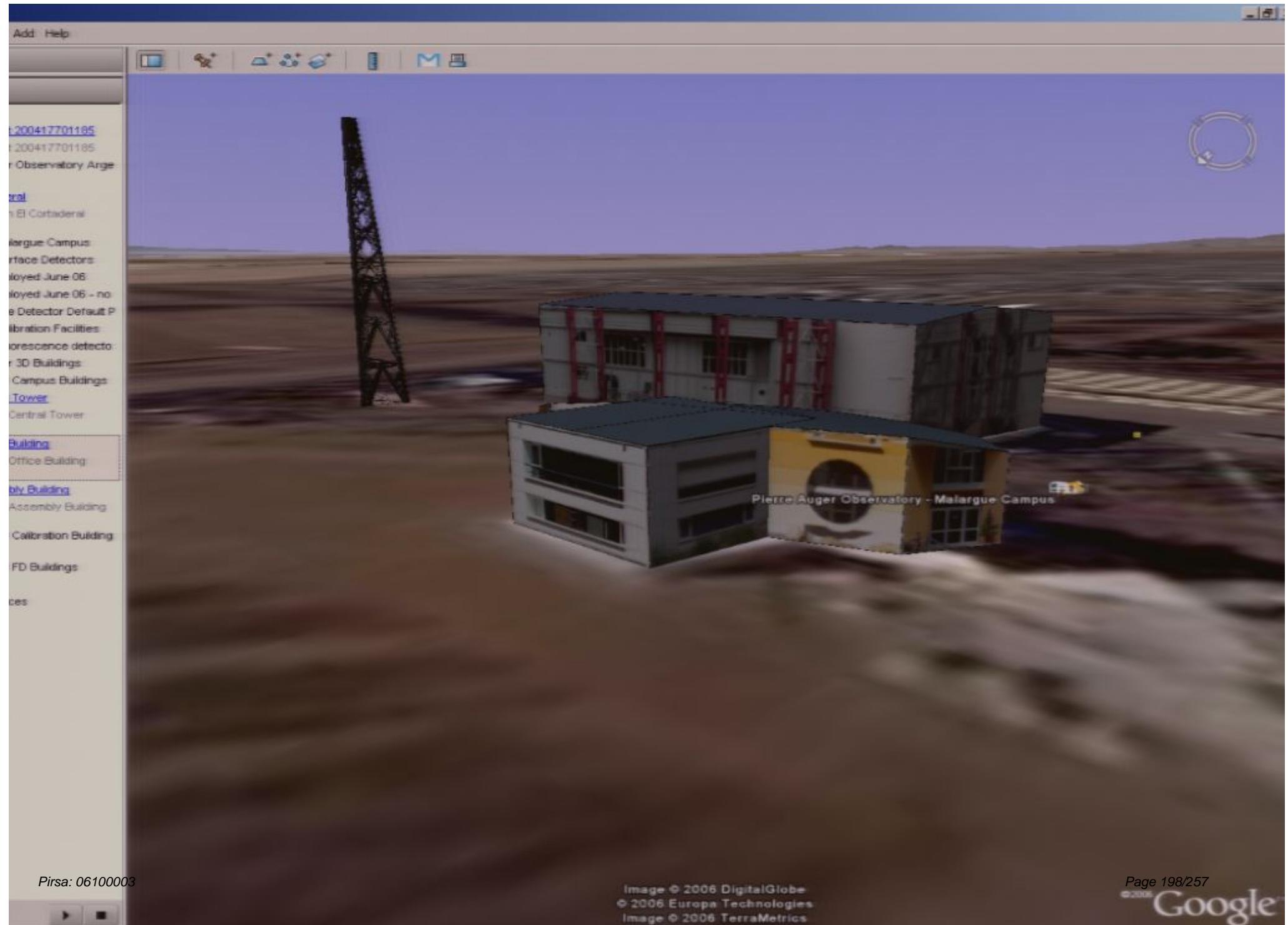
[Assembly Building](#)

[Calibration Building](#)

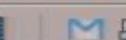
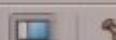
[FD Buildings](#)

[ces](#)





Add Help



20041770185

20041770185

Observatory Arge

ral

El Cortadero

Argue Campus

urface Detectors:

royed June 06

royed June 06 - no

e Detector Default P

ibration Facilities

orescence detecto

3D Buildings

Campus Buildings

Tower

Central Tower

Building

Office Building

bly Building

Assembly Building

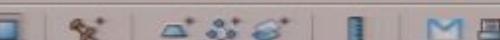
Calibration Building

FD Buildings

ces



Add Help



200417701185

200417701185

Observatory An-

tral

El Cortadero

Malargüe Campus

Surface Detectors:

Deployed June 06

Deployed June 06 - r

e Detector Default

Calibration Facilities

Fluorescence detec-

r 3D Buildings

Campus Building:

Tower

Central Tower

Building:

Office Building

Assembly Building

Calibration Buildi-

Laser Facility

CLF

Laser Facility 2

CLF2

Launching Statio-

BLS

Ones Lidar

Lidar

co Lidar

Lidar

rados Lidar

Lider

unilla Lidar

Lidar

Pirsa: 06100003

FD Buildings



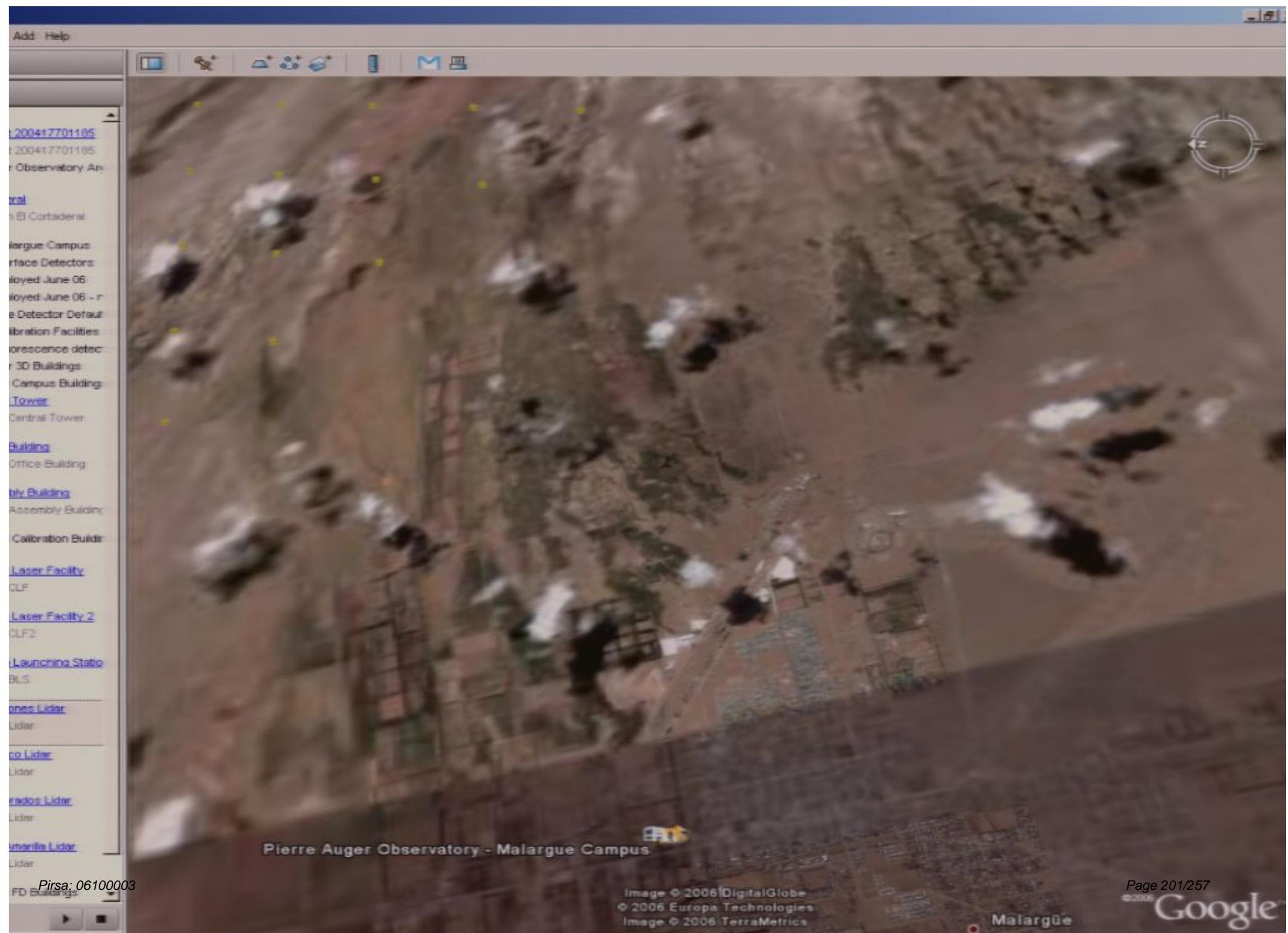
Image © 2006 DigitalGlobe

© 2006 Europa Technologies

Image © 2006 TerraMetrics

Page 200/257

Google



Add Help



...|<|>



200417701185

200417701185

Observatory An-

tral

El Cortadero

Malargüe Campus

Surface Detectors

Deployed June 06

Deployed June 06 - r

e Detector Default

Calibration Facilities

Fluorescence detec-

r 3D Buildings

Campus Building

Tower

Central Tower

Building

Office Building

Assembly Building

Calibration Buildi-

Laser Facility

CLF

Laser Facility 2

CLF2

Launching Statio-

BLS

Ones Lidar

Lidar

co Lidar

Lidar

rados Lidar

Lider

unilla Lidar

Lidar

FD Buildings

...

Pierre Auger Observatory - Malargüe Campus



Image © 2006 DigitalGlobe

© 2006 Europa Technologies

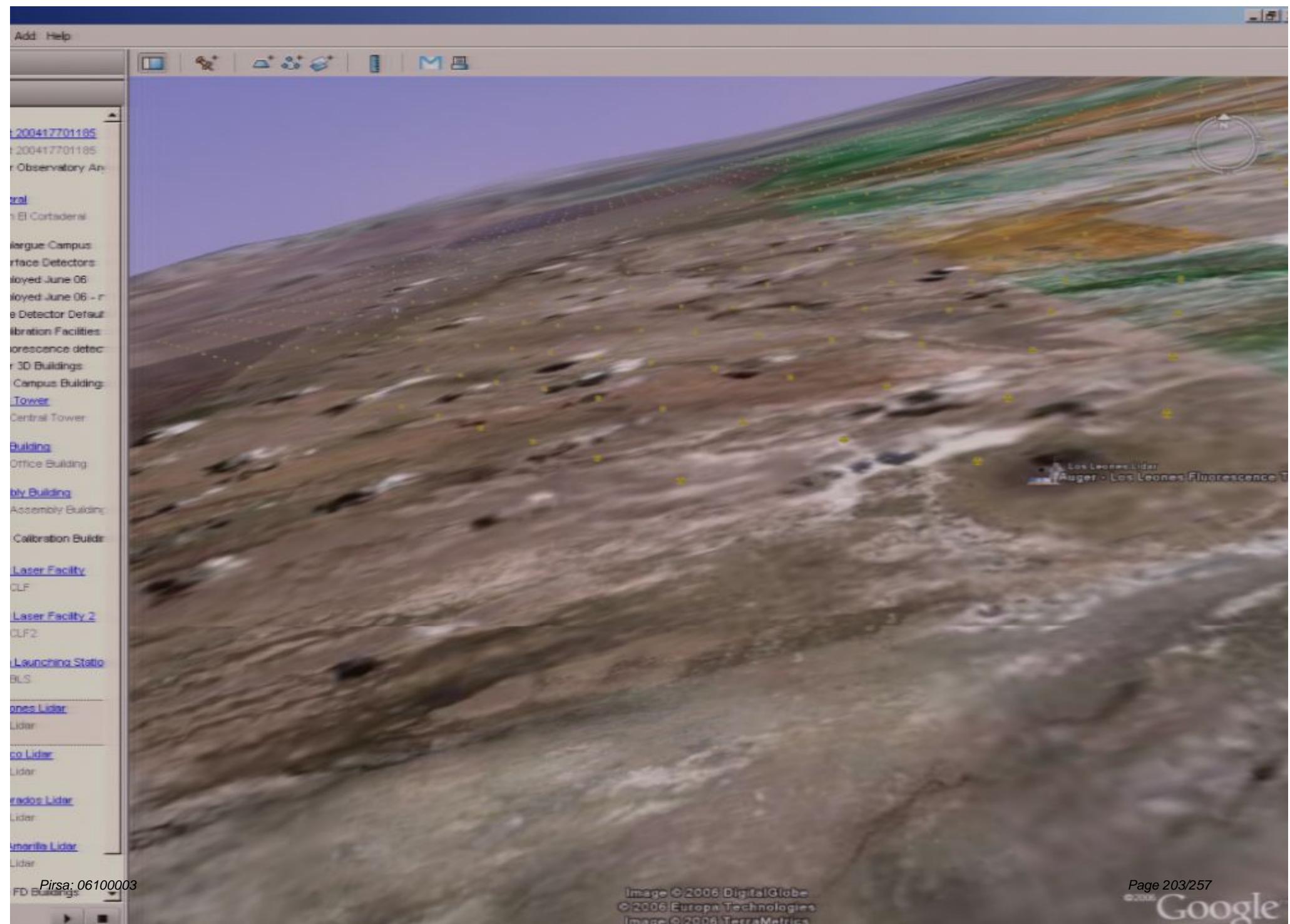
Image © 2006 TerraMetrics

Page 201/257

Google

Malargüe









Add Help



200417701185

200417701185

Observatory An-

eral

El Cortadillo

Kergue Campus

urface Detectors:

royed June 06

royed June 06 - r

e Detector Default

ibration Facilities

orescence detect

3D Buildings

Campus Building:

Tower

Central Tower:

Building:

Office Building:

Building:

Assembly Building:

Calibration Buildi

Laser Facility:

CLF

Laser Facility 2

CLF2

Launching Statio

BLS

ones Lidar:

Lidar

co Lidar:

Lidar

rados Lidar:

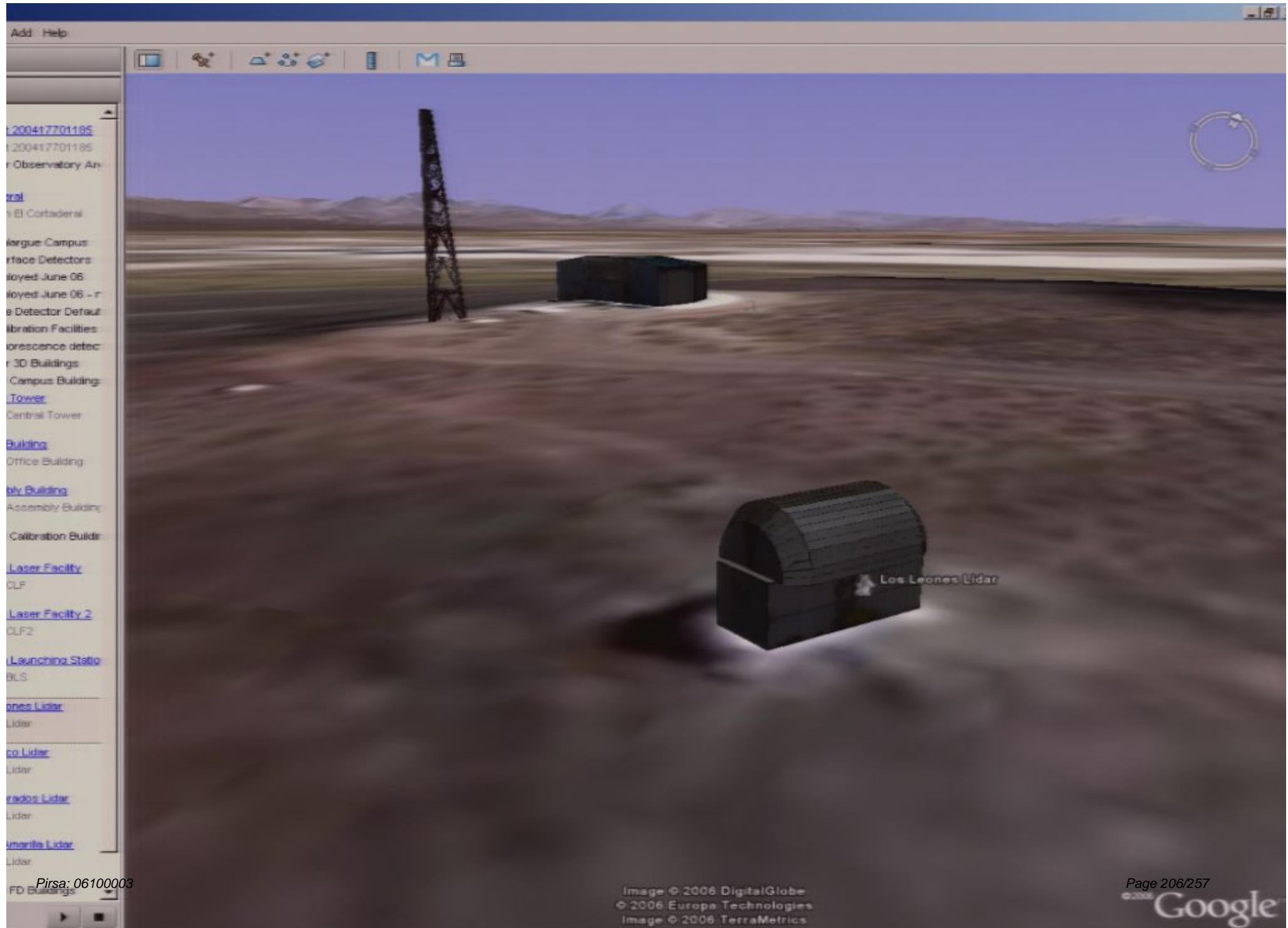
Lidar

charilla Lidar:

Lidar

Pirsa: 06100003





Add Help



200417701185

200417701185

Observatory An-

tral

El Cortadillo

Argue Campus

Surface Detectors:

Moved June 06

Moved June 06 - r

e Detector Default

libration Facilities

orescence detect

3D Buildings

Campus Building:

Tower

Central Tower

Building:

Office Building

gly Building

Assembly Building

Calibration Build

Laser Facility

CLF

Laser Facility 2

CLF2

Launching Statio

BLS

ones Lidar

Lidar

co Lidar

Lidar

rados Lidar

Lidar

unilla Lidar

Lidar

Pirsa: 0610003

FD Buildings

► ■

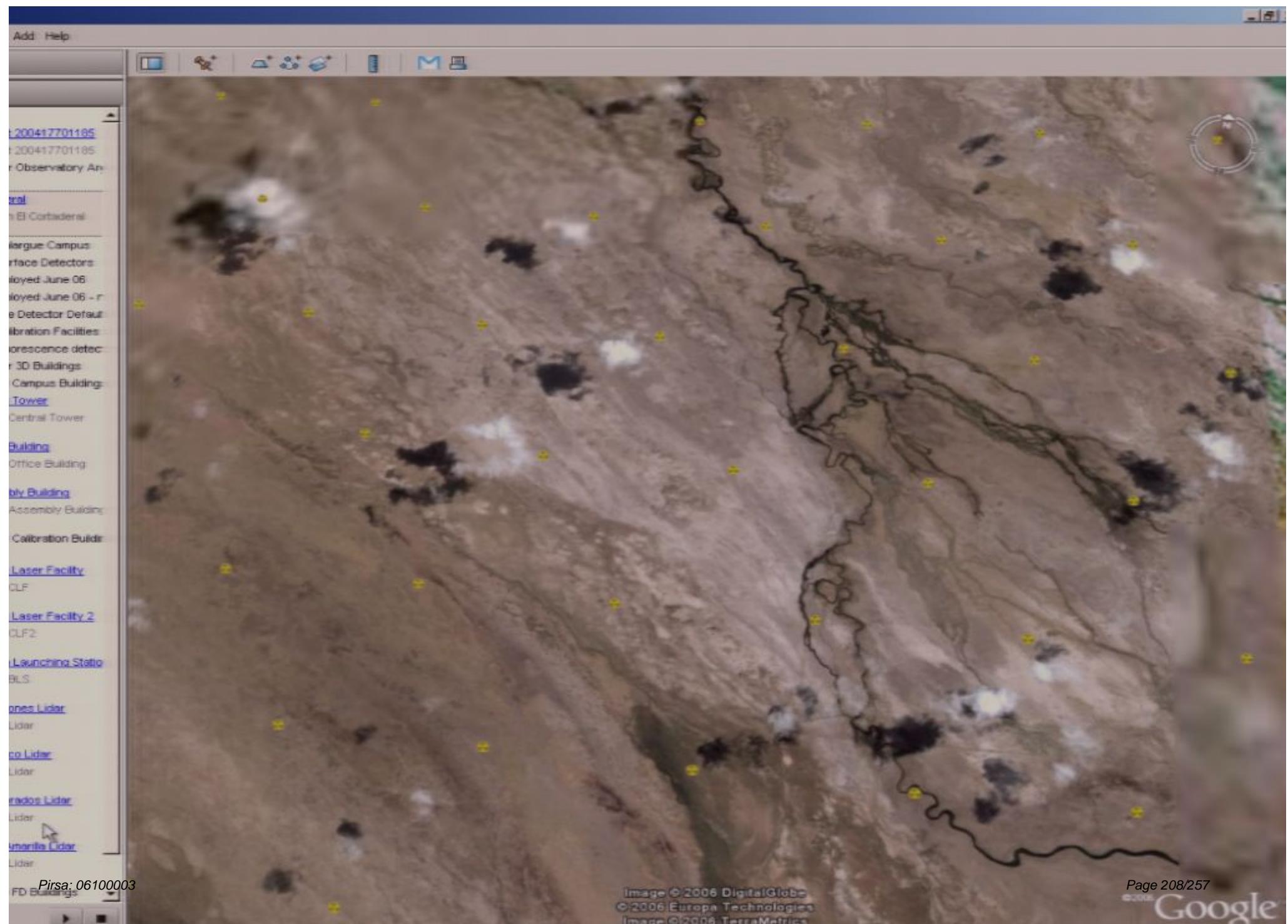
## Leones Fluorescence Telescope



Los Leones  
Image © 2006 DigitalGlobe  
© 2006 Europa Technologies  
Image © 2006 TerraMetrics

Page 207/257

Google



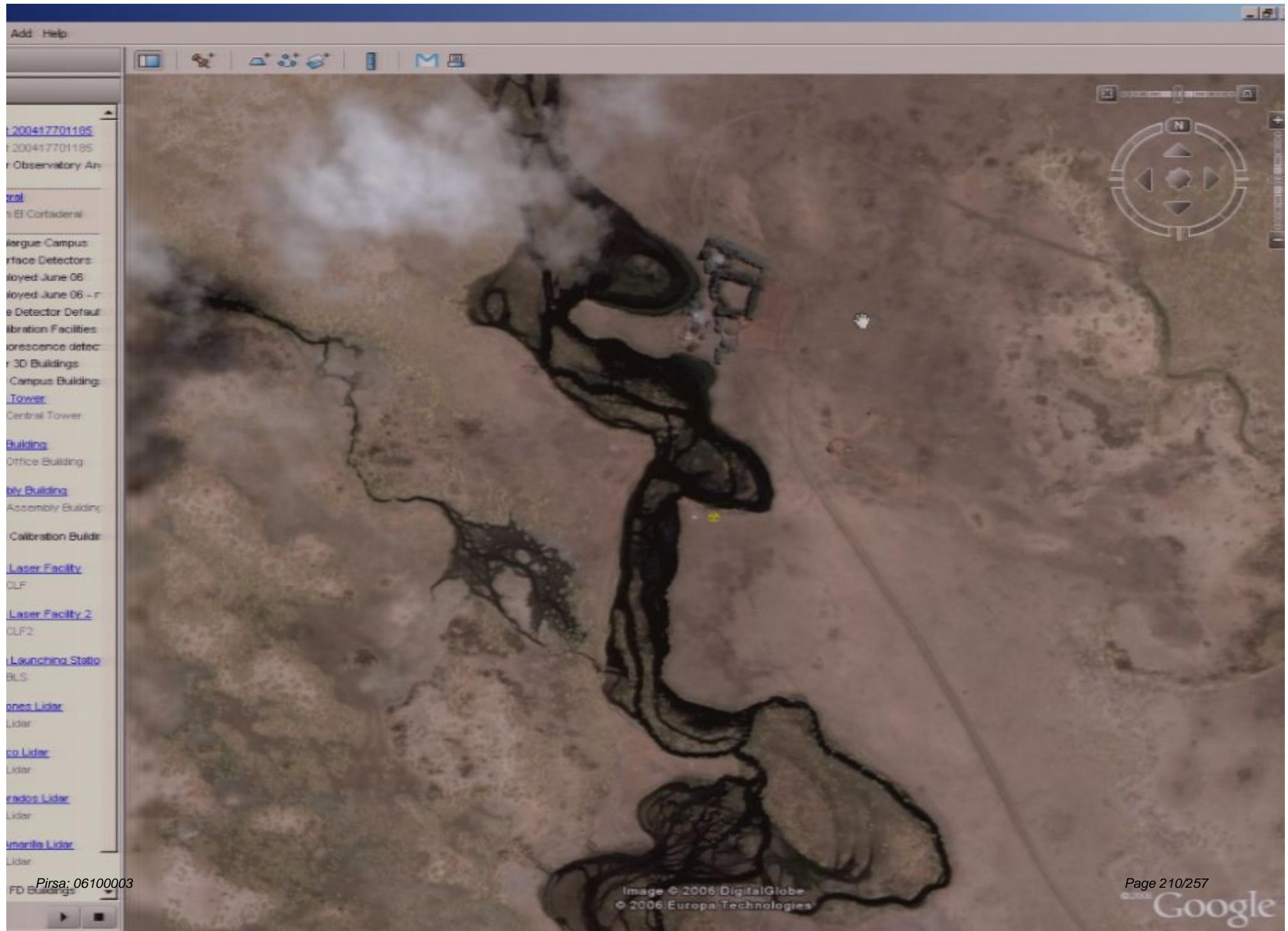


Pirsa: 06100003

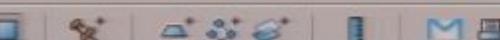
Image © 2006 DigitalGlobe  
© 2006 Europa Technologies

Page 209/257

Google



Add Help



20041770185

20041770185

Observatory An-

tral

El Cortadero

Argue Campus

Surface Detectors

ployed June 06

ployed June 06 - r

e Detector Default

ibration Facilities

orescence detect

3D Buildings

Campus Building

Tower

Central Tower

Building

Office Building

Building

Assembly Building

Calibration Build

Laser Facility

CLF

Laser Facility 2

CLF2

Launching Statio

BLS

ones Lidar

Lidar

co Lidar

Lidar

rados Lidar

Lidar

unilla Lidar

Lidar

Pirsa: 06100003

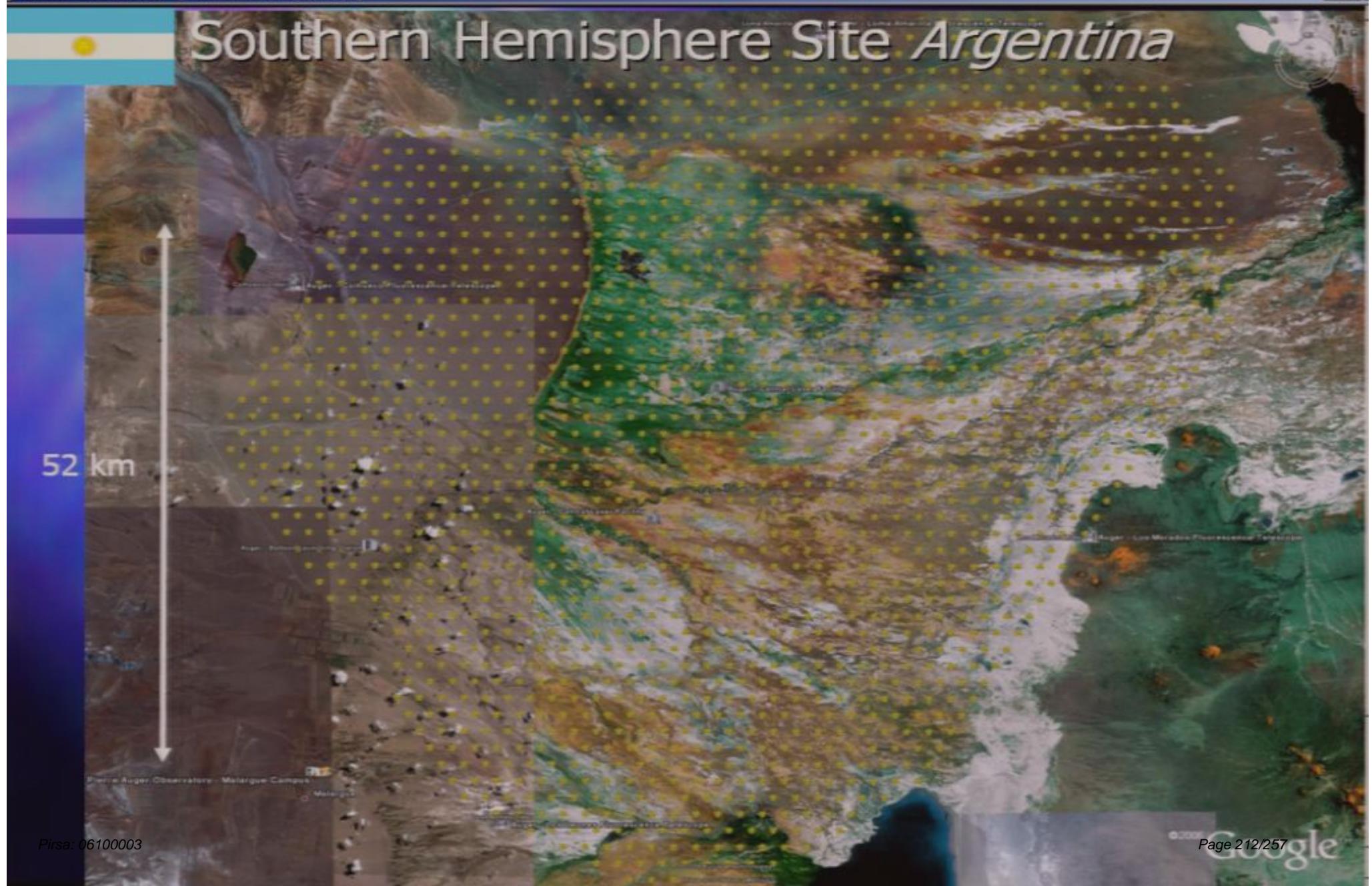


Image © 2006 DigitalGlobe  
© 2006 Europa Technologies

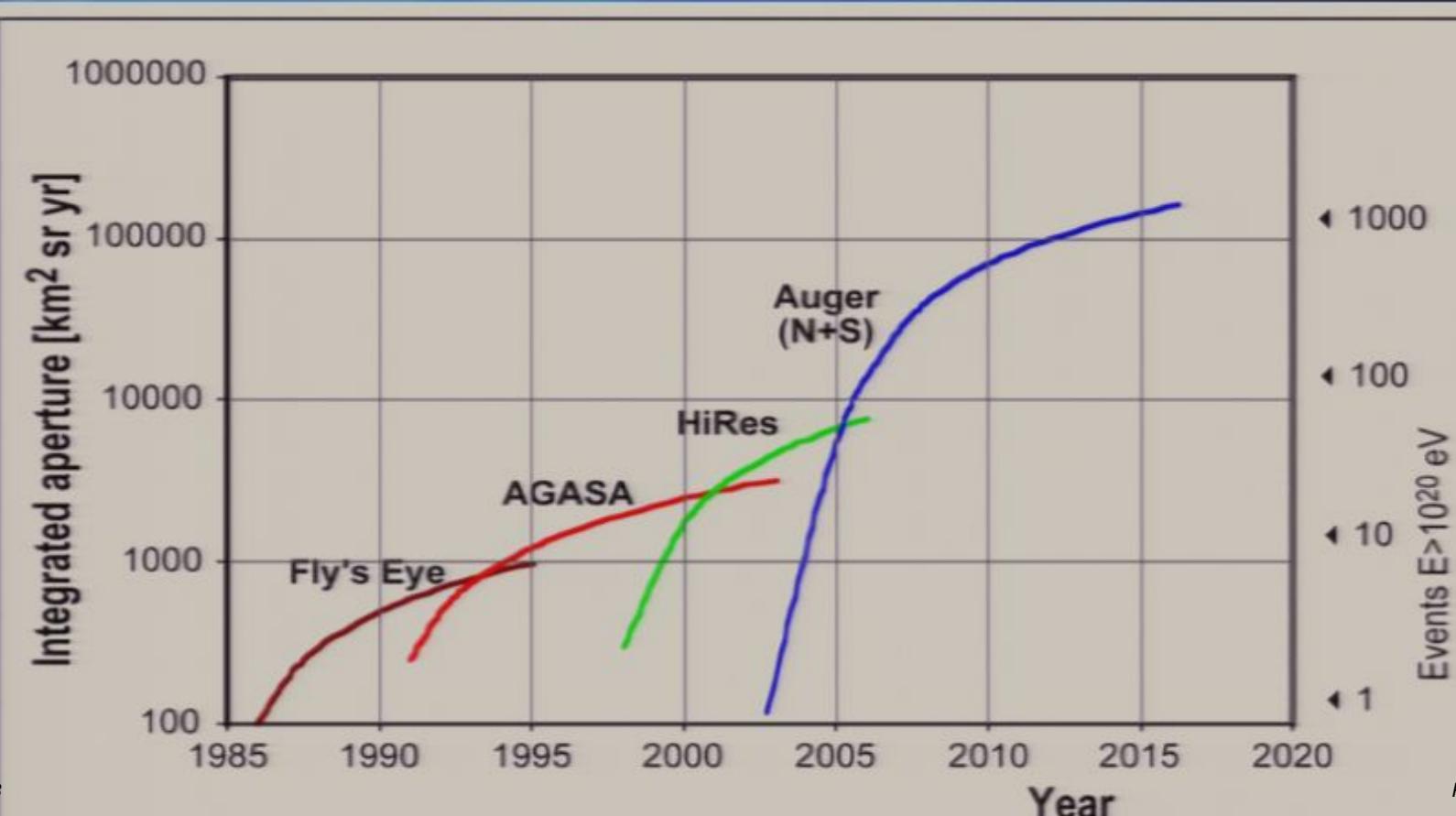
Page 210/257

Google

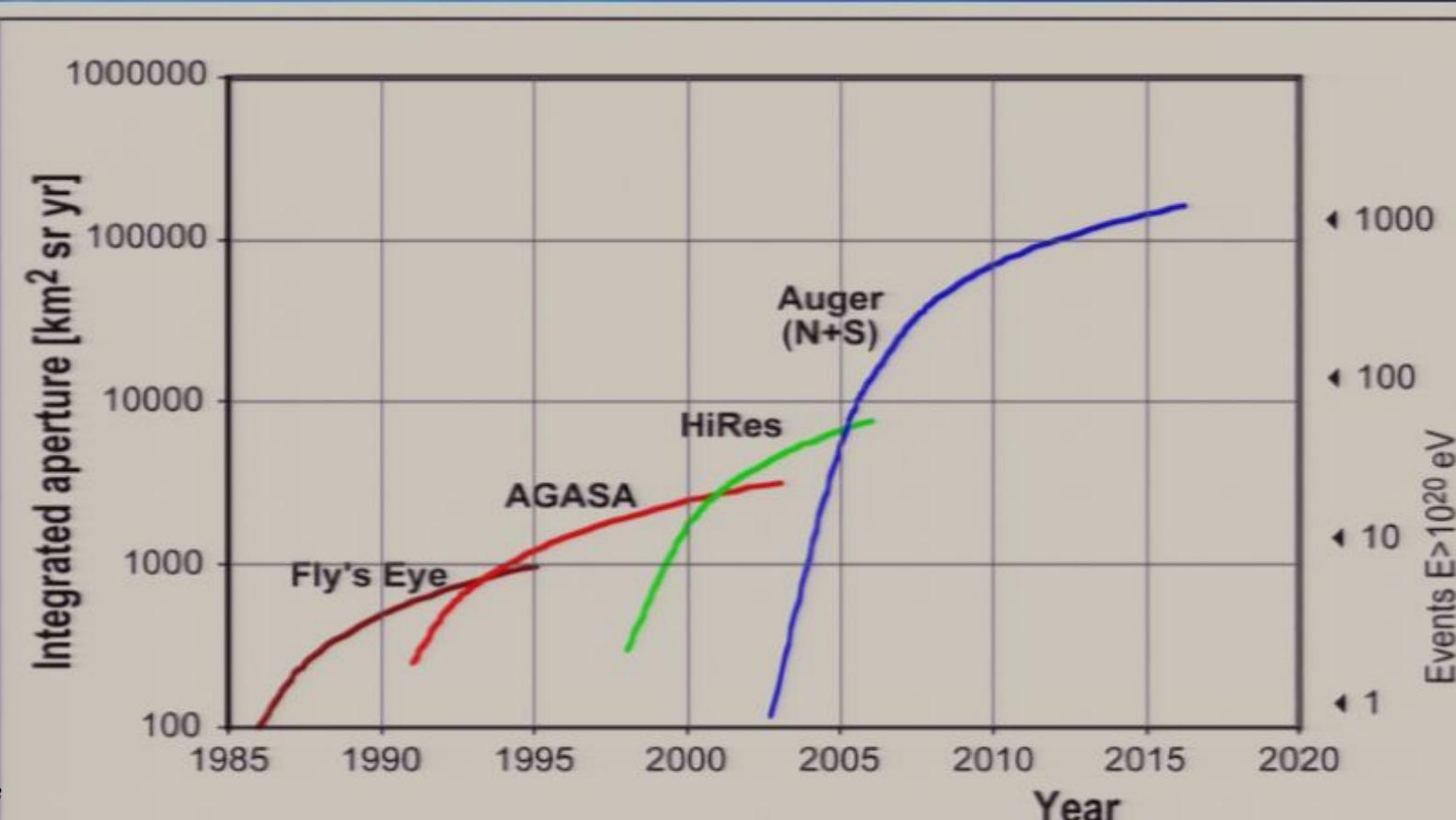




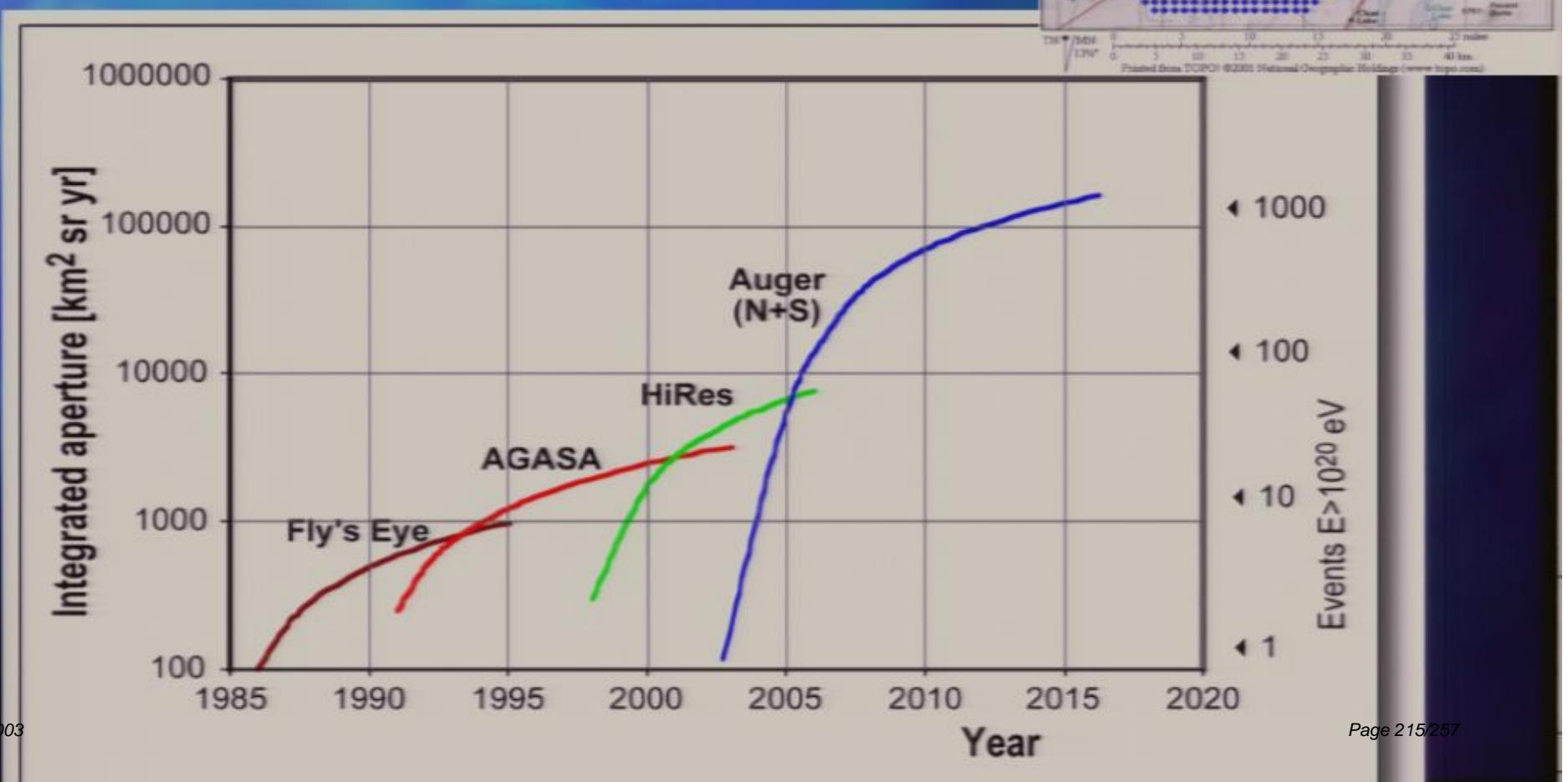
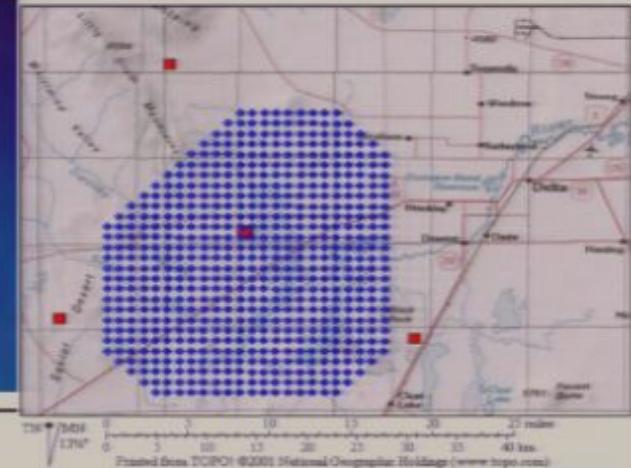
# UHE Exposures



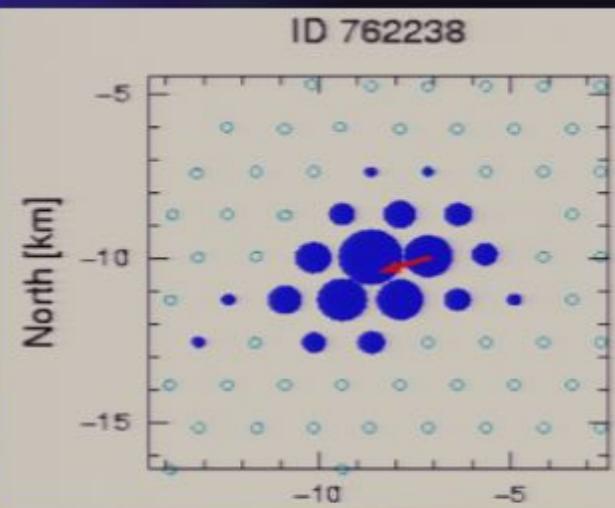
# UHE Exposures



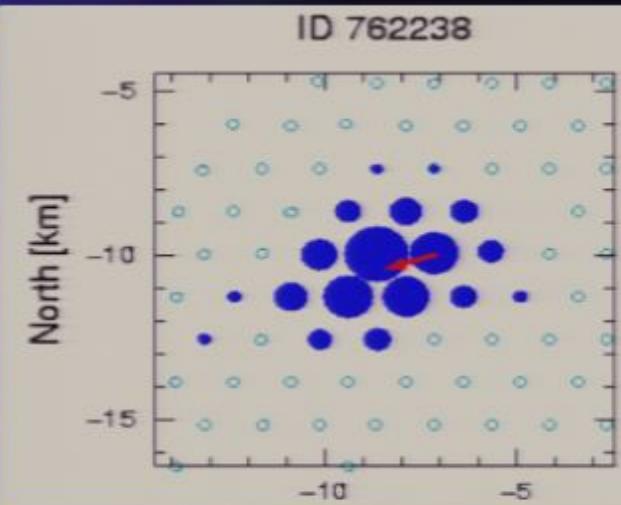
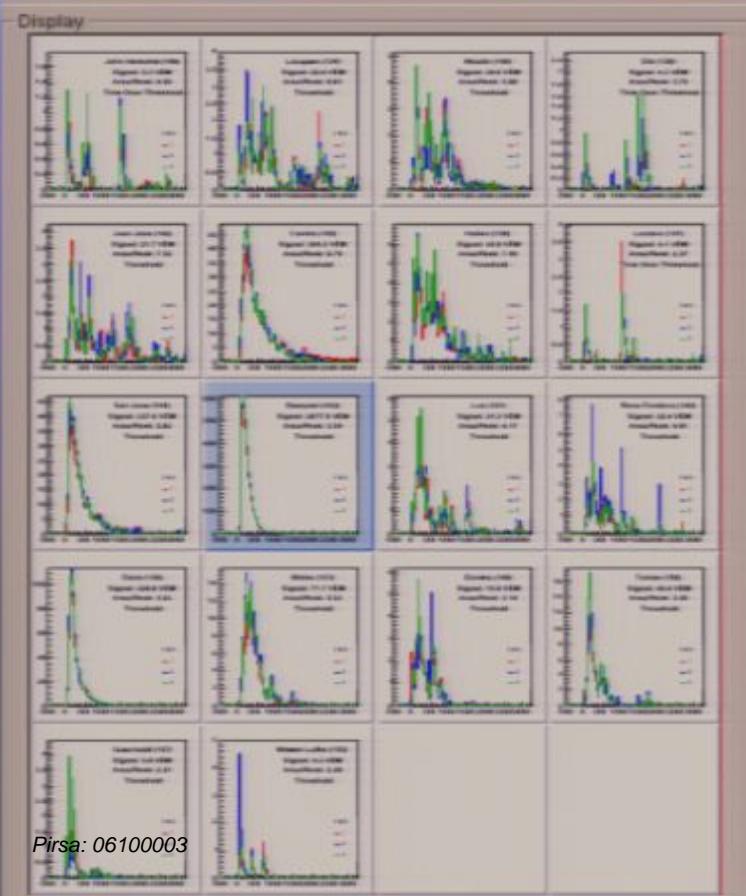
# UHE Exposures



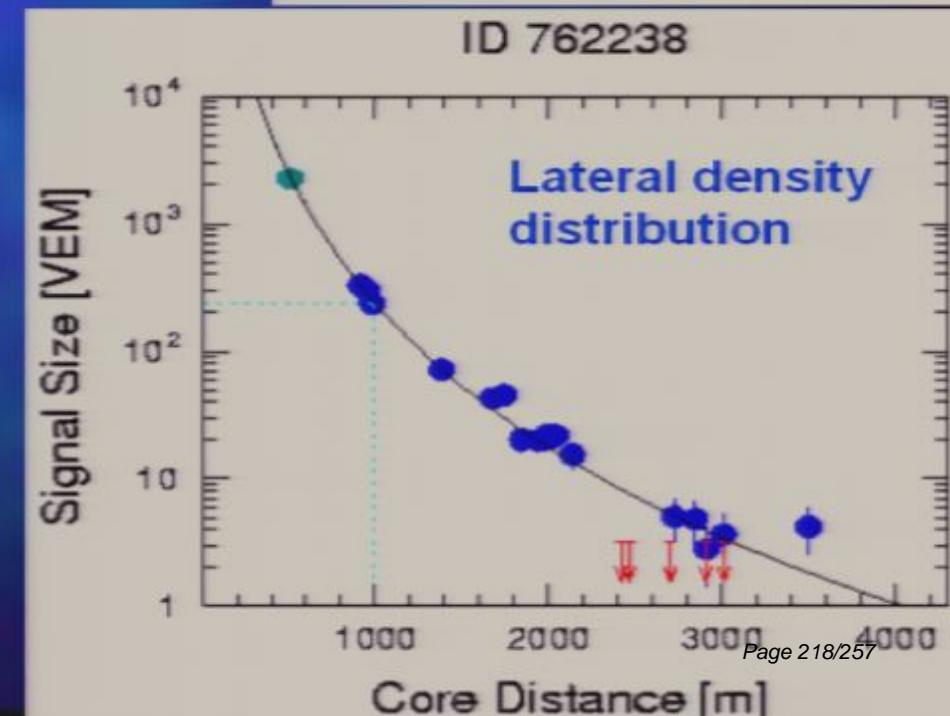
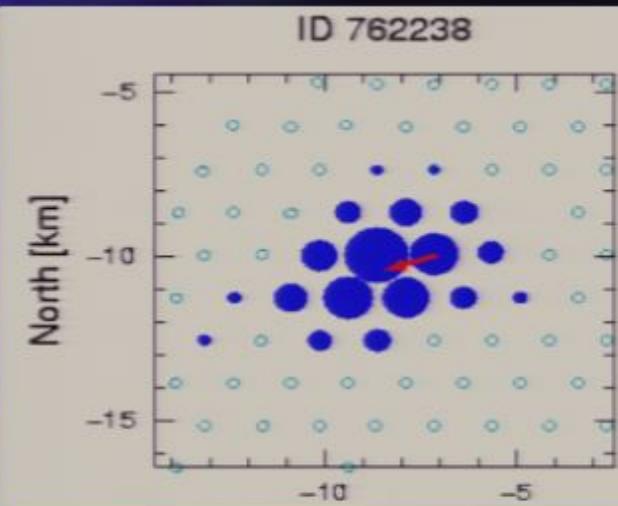
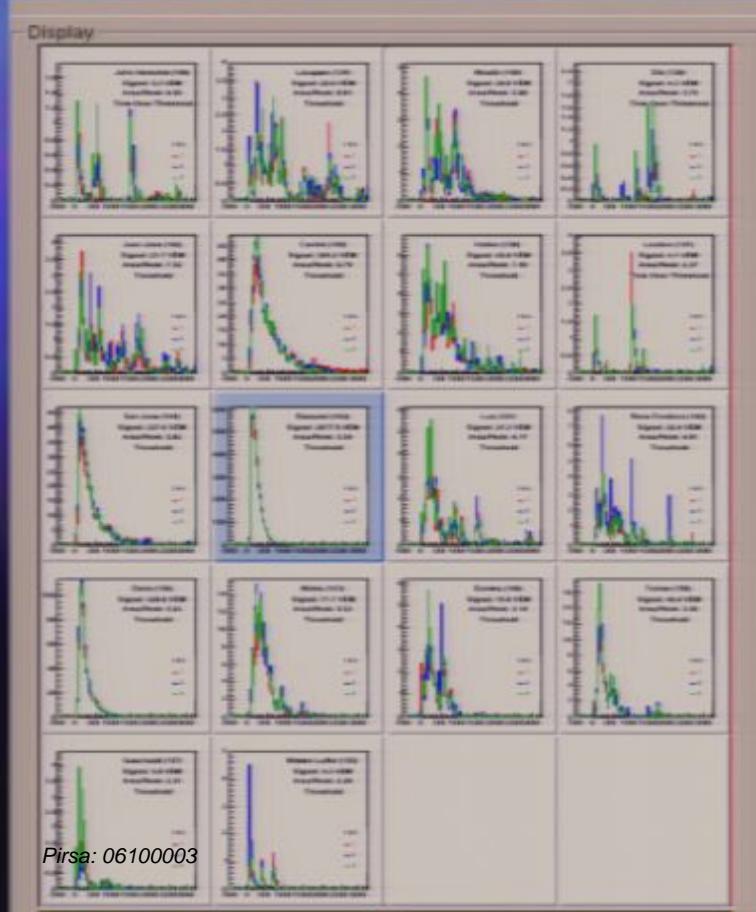
# Example Surface Array Event $\Theta \sim 48^\circ$ , $\sim 70$ EeV



# Example Surface Array Event $\Theta \sim 48^\circ$ , $\sim 70$ EeV

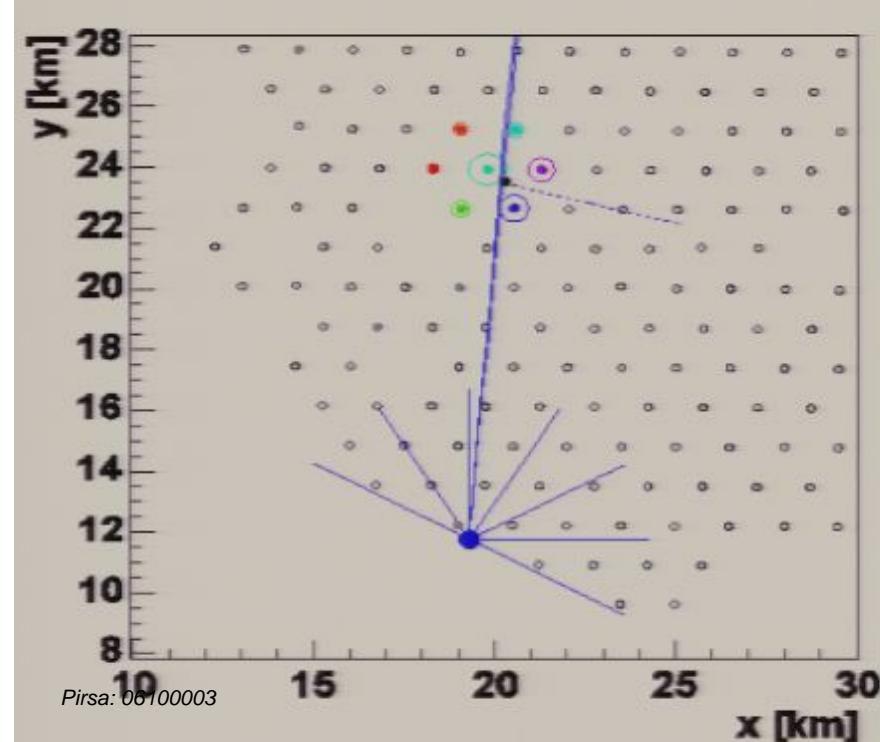


# Example Surface Array Event $\Theta \sim 48^\circ$ , $\sim 70$ EeV

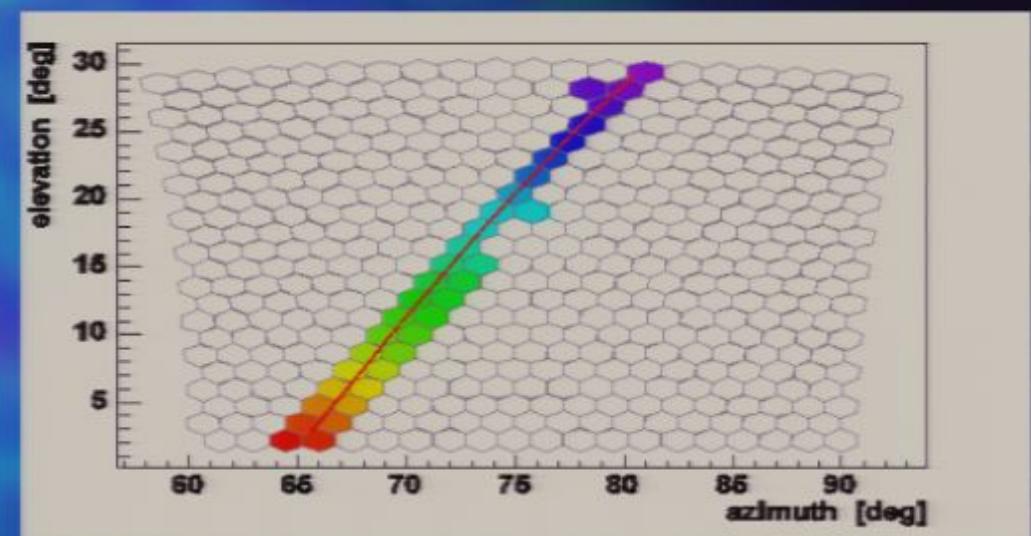
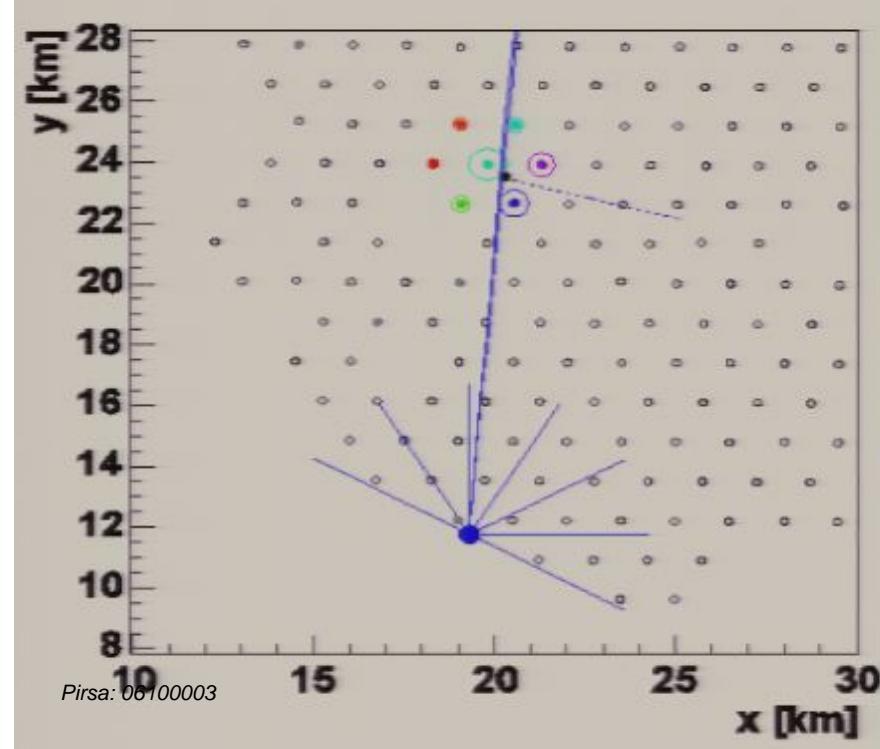


# Example Hybrid Event

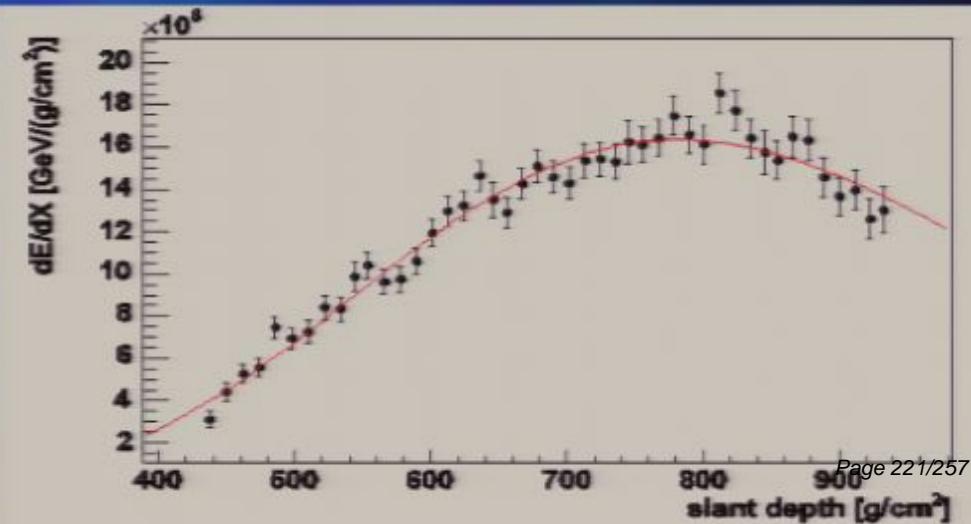
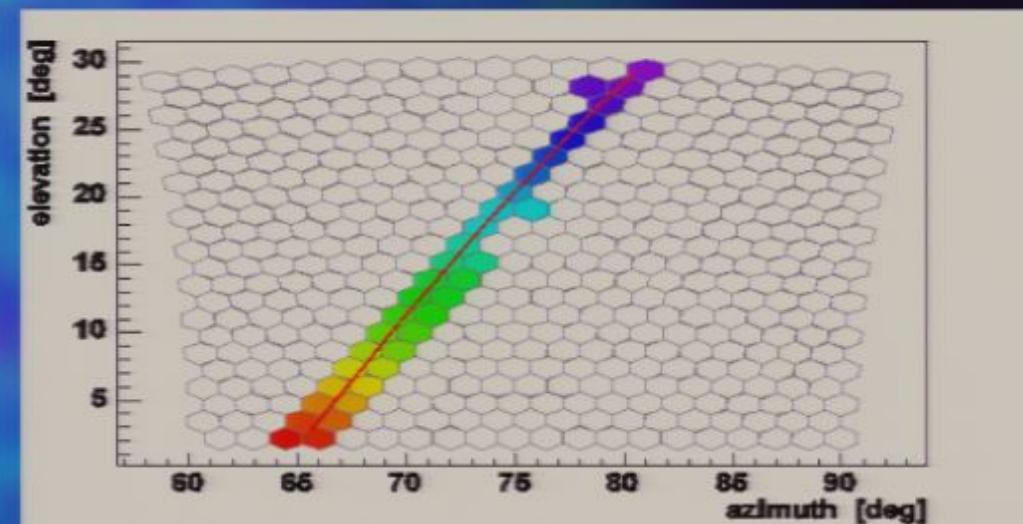
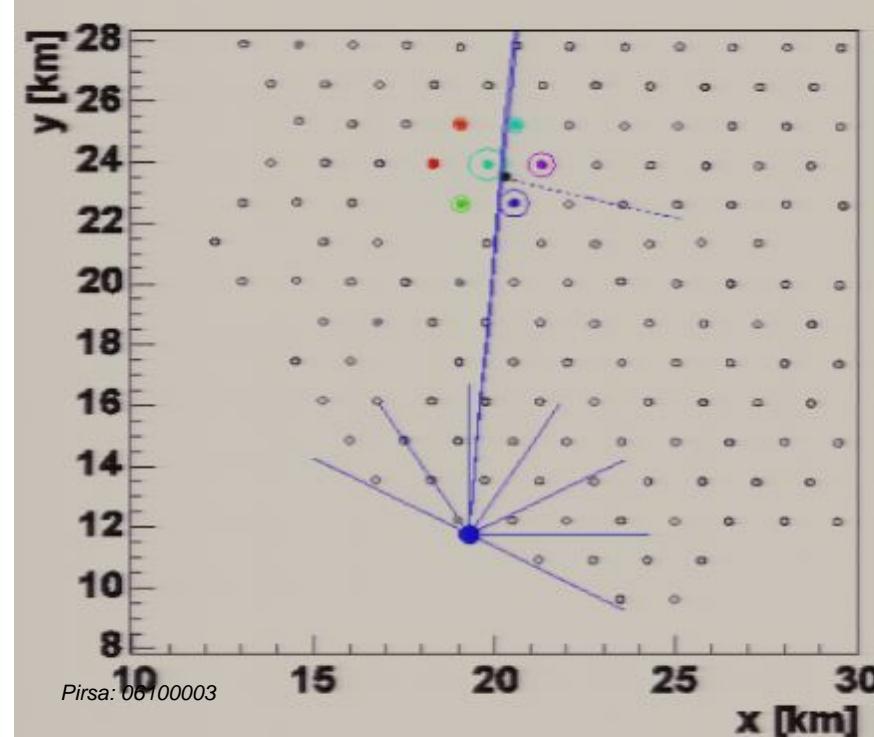
$\Theta \sim 30^\circ, \sim 8 \text{ EeV}$



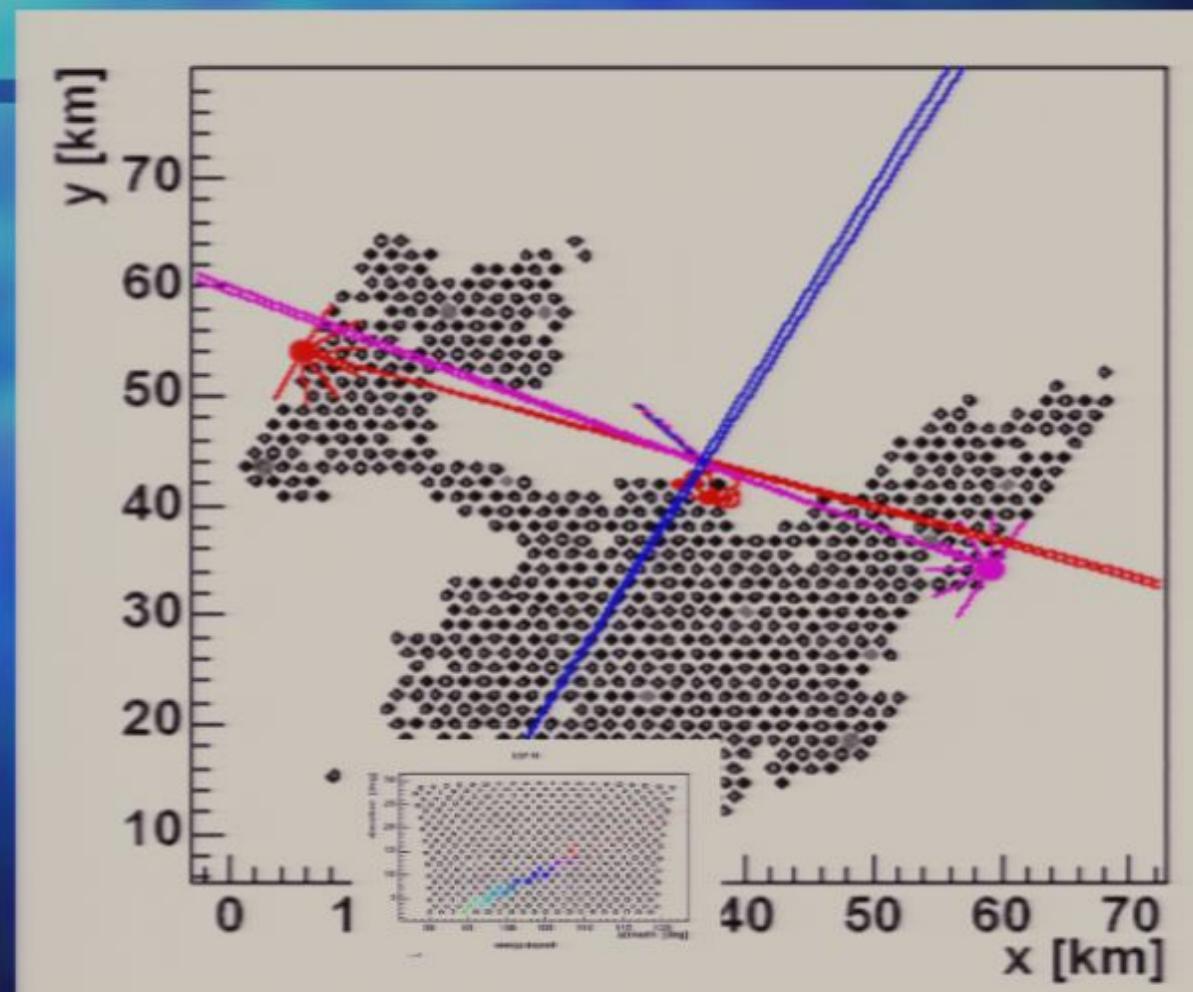
# Example Hybrid Event $\Theta \sim 30^\circ$ , $\sim 8$ EeV



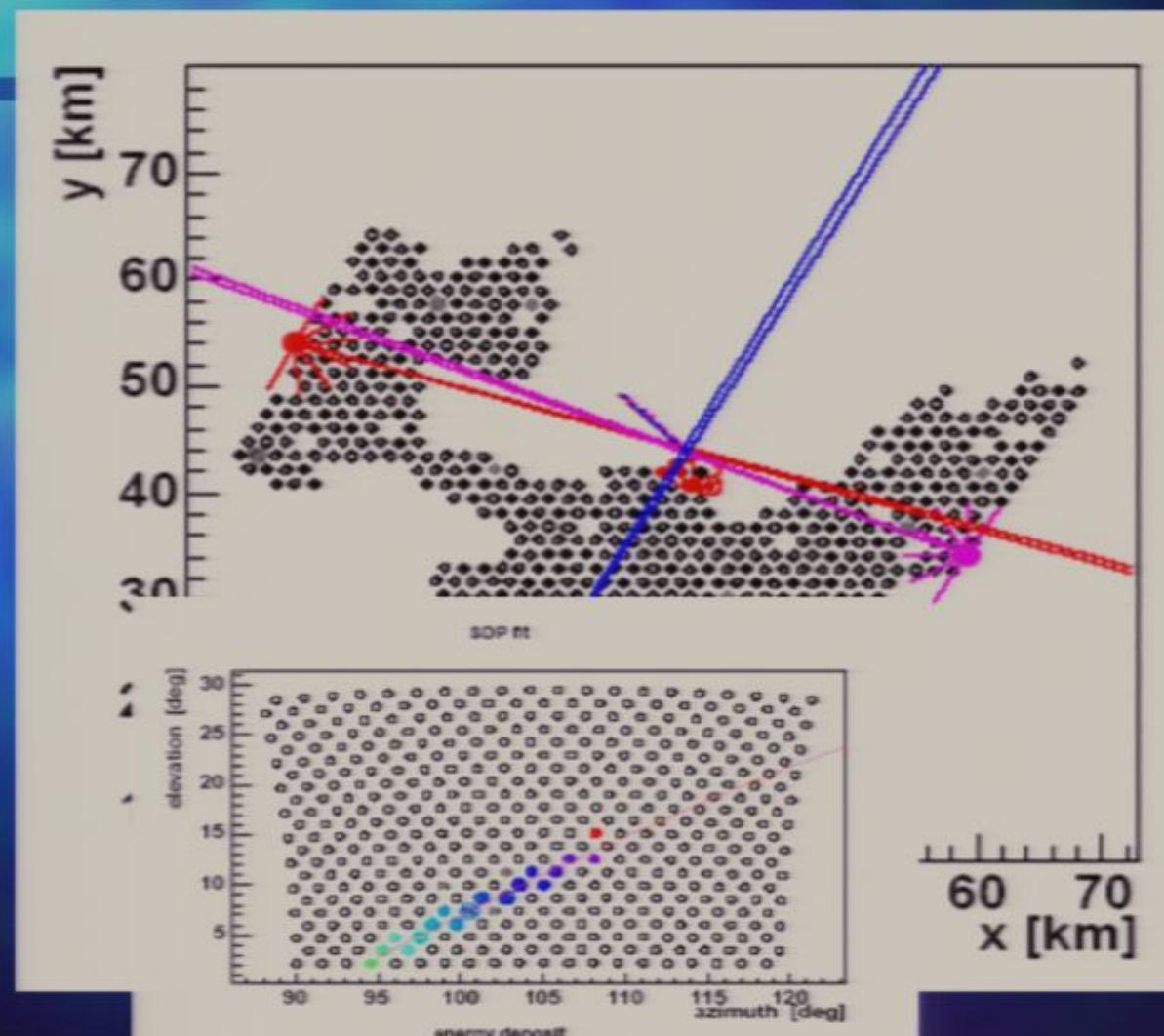
# Example Hybrid Event $\Theta \sim 30^\circ$ , $\sim 8$ EeV



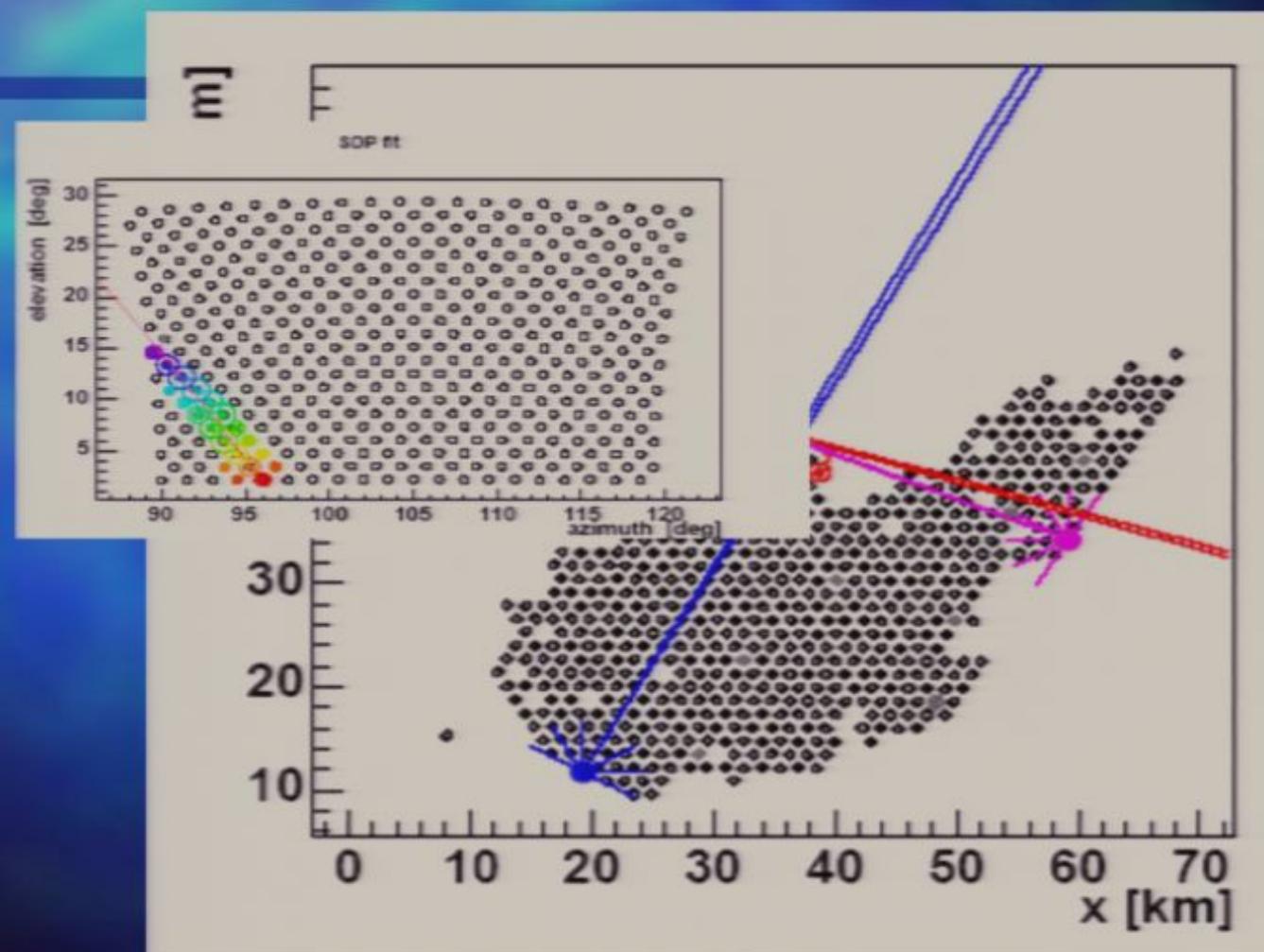
# A Tri-ocular Event! $\sim 20EeV$



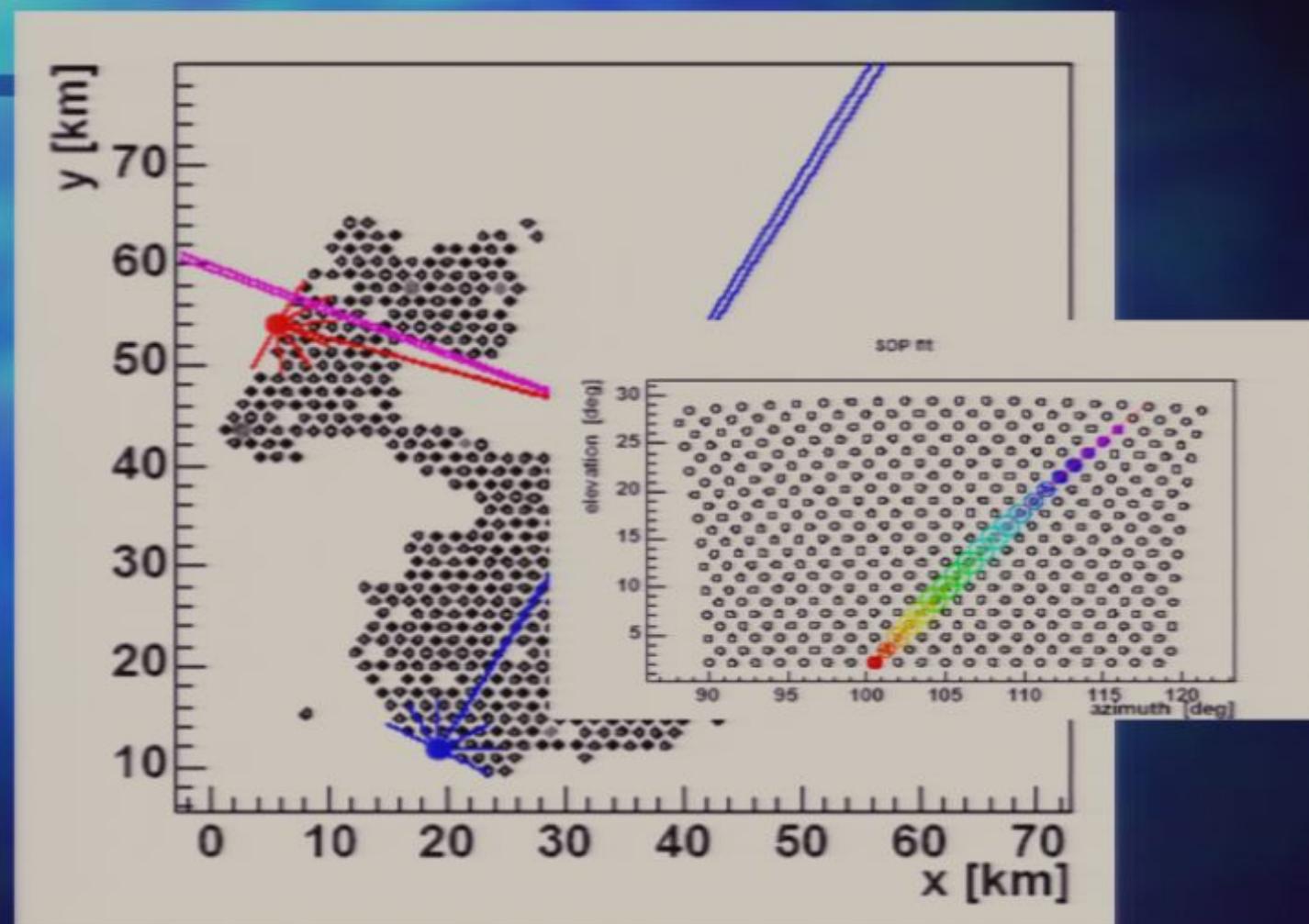
# A Tri-ocular Event! $\sim 20EeV$



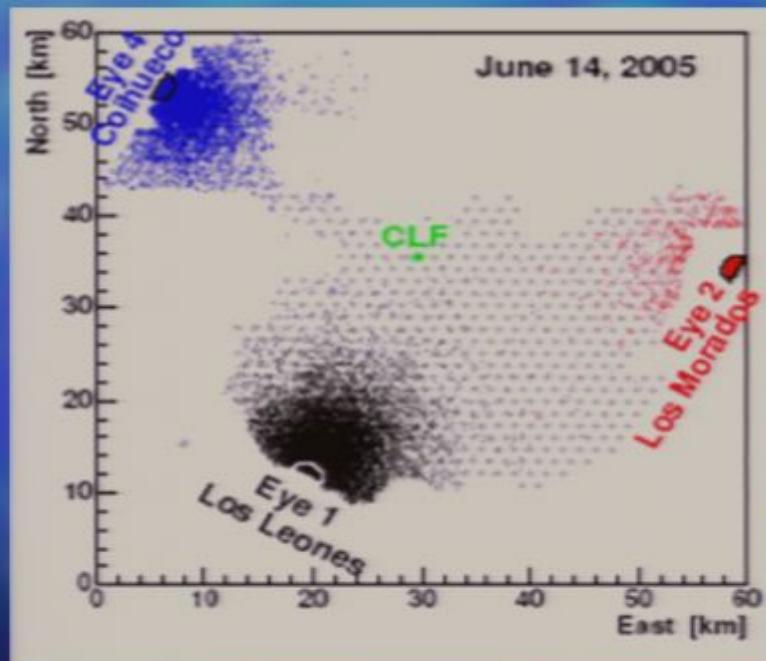
# A Tri-ocular Event! $\sim 20EeV$



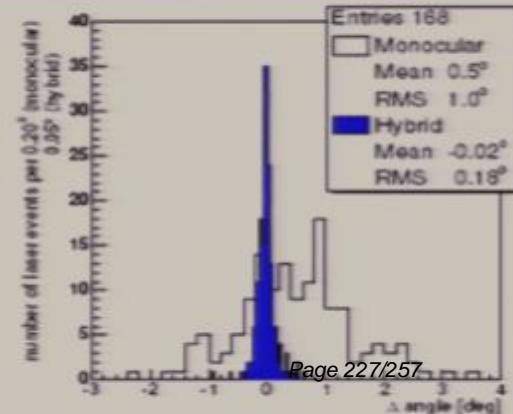
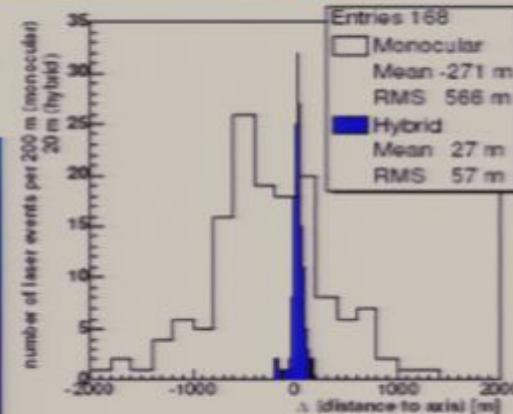
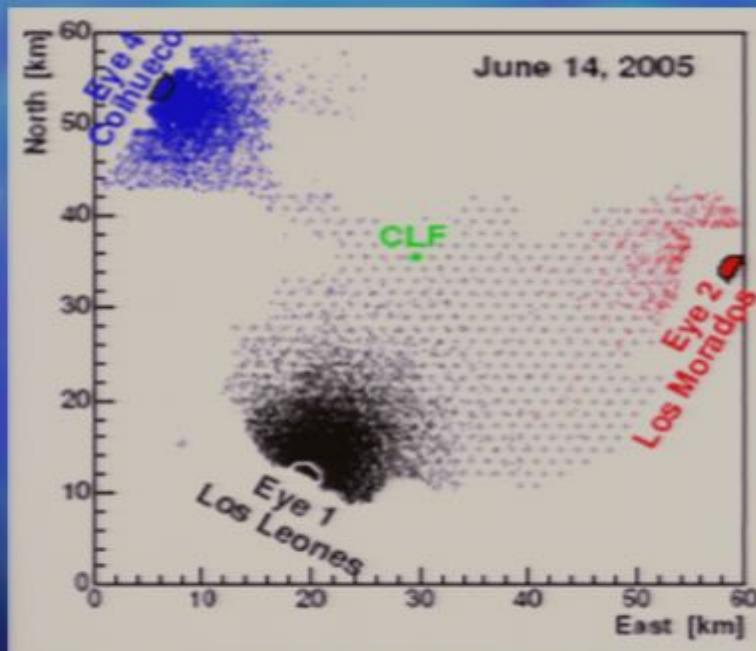
# A Tri-ocular Event! $\sim 20EeV$



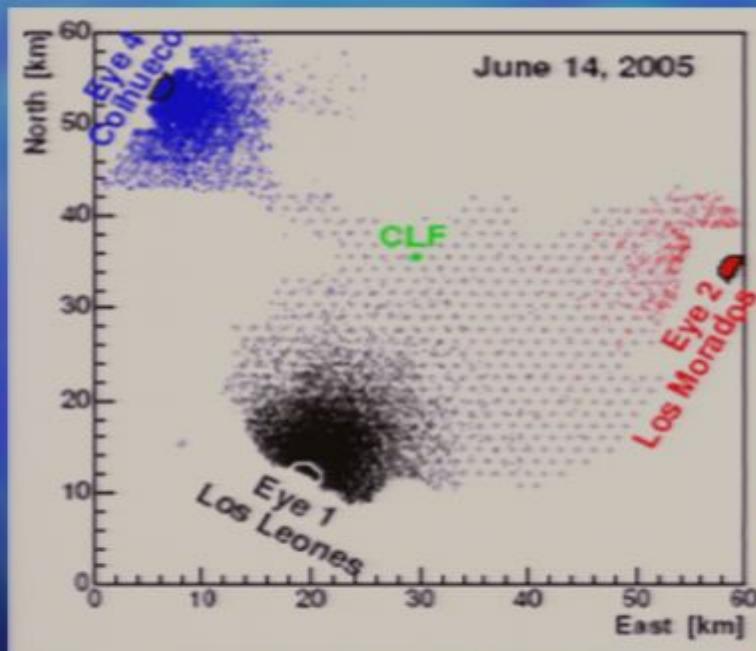
# Hybrid Reconstruction



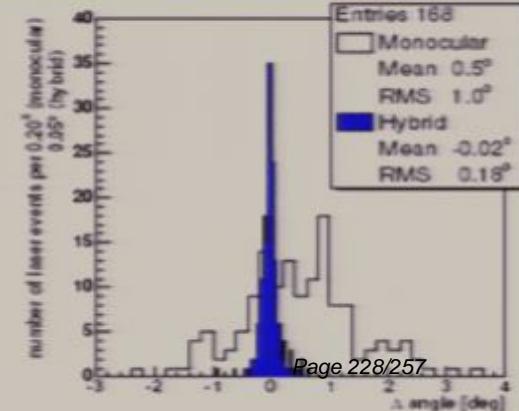
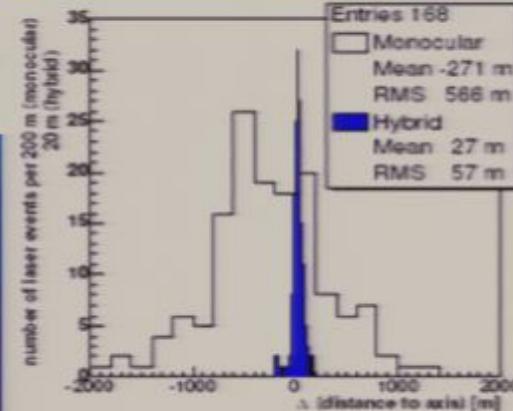
# Hybrid Reconstruction



# Hybrid Reconstruction



Uncertainty in the hybrid energy reconstruction increases from 15% at 3 EeV to 40% at 100 EeV





# First Auger Spectrum

---

# First Auger Spectrum

---

- January 1 2004 – June 5 2005
- Time averaged area =  $660 \text{ km}^2$   
(22% of final size)

# First Auger Spectrum

- January 1 2004 – June 5 2005
- Time averaged area =  $660 \text{ km}^2$   
(22% of final size)
- 0-60° zenith angle range
- Full efficiency above 3 EeV

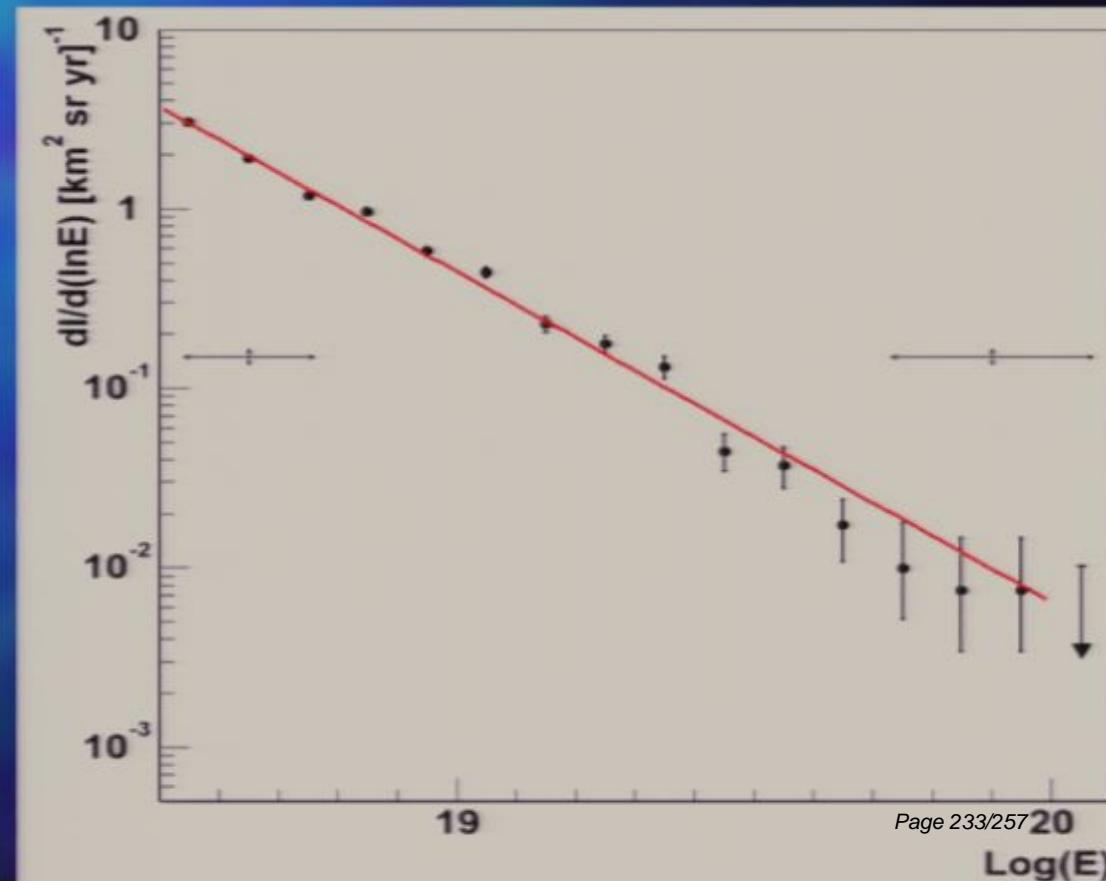


# First Auger Spectrum

- January 1 2004 – June 5 2005
- Time averaged area =  $660 \text{ km}^2$   
(22% of final size)
- 0-60° zenith angle range
- Full efficiency above 3 EeV
- Exposure =  $1750 \text{ km}^2 \text{ sr yr}$
- 3525 events above  $10^{18.5} \text{ eV}$

# First Auger Spectrum

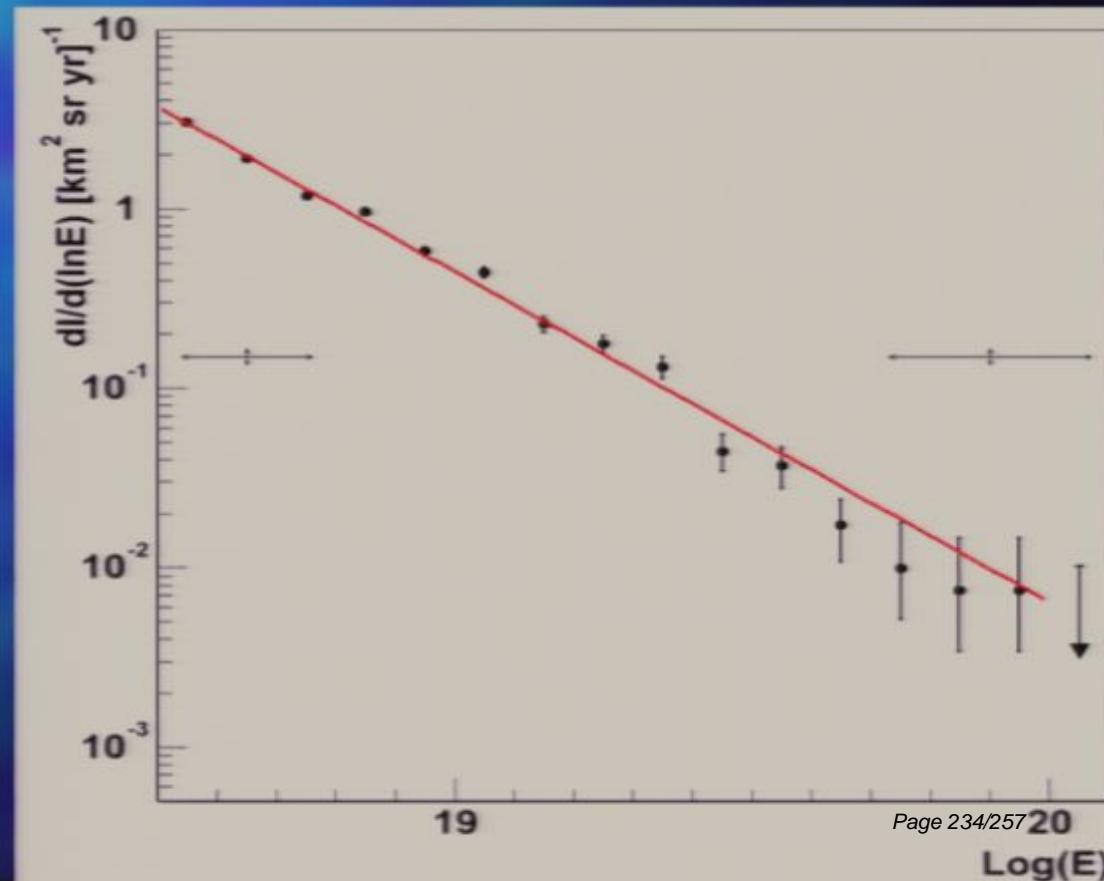
- January 1 2004 – June 5 2005
- Time averaged area = 660 km<sup>2</sup>  
(22% of final size)
- 0-60° zenith angle range
- Full efficiency above 3 EeV
- Exposure = 1750 km<sup>2</sup> sr yr
- 3525 events above  $10^{18.5}$  eV



# First Auger Spectrum

- January 1 2004 – June 5 2005
- Time averaged area = 660 km<sup>2</sup>  
(22% of final size)
- 0-60° zenith angle range
- Full efficiency above 3 EeV
- Exposure = 1750 km<sup>2</sup> sr yr
- 3525 events above  $10^{18.5}$  eV

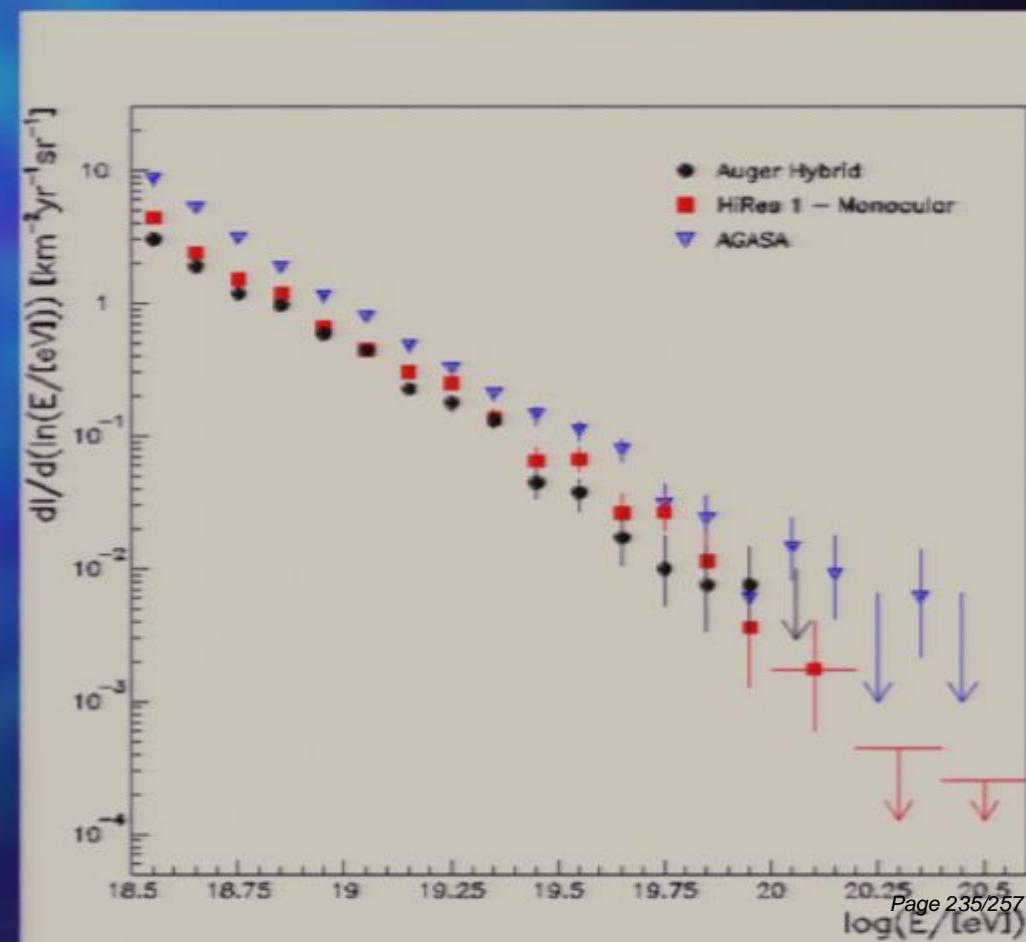
Uncertainties still large



# First Auger Spectrum

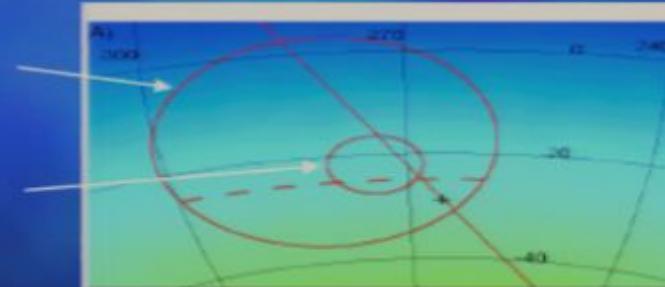
- January 1 2004 – June 5 2005
- Time averaged area = 660 km<sup>2</sup>  
(22% of final size)
- 0-60° zenith angle range
- Full efficiency above 3 EeV
- Exposure = 1750 km<sup>2</sup> sr yr
- 3525 events above  $10^{18.5}$  eV

Uncertainties still large

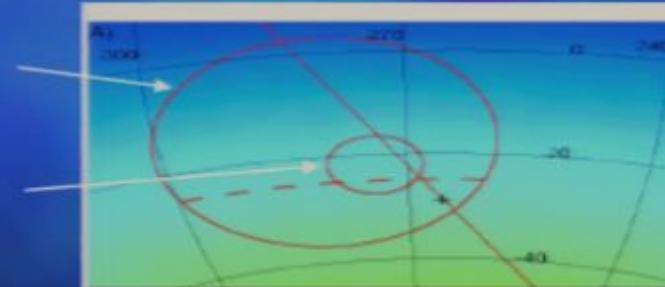


# First Auger Source Search

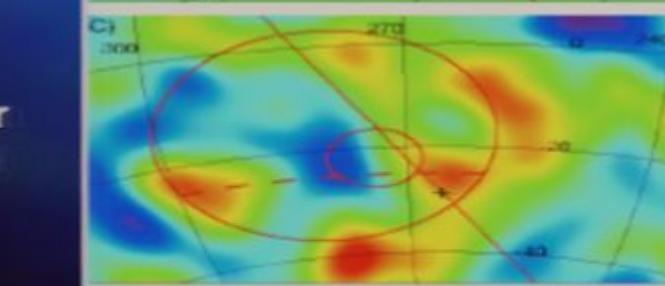
AGASA f.o.v



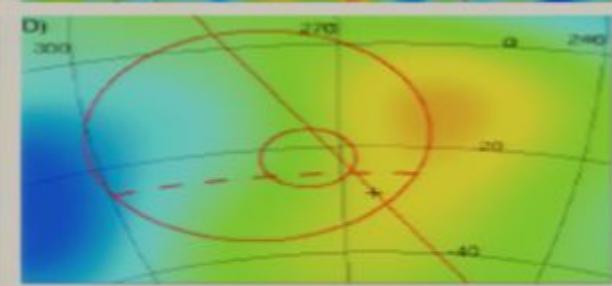
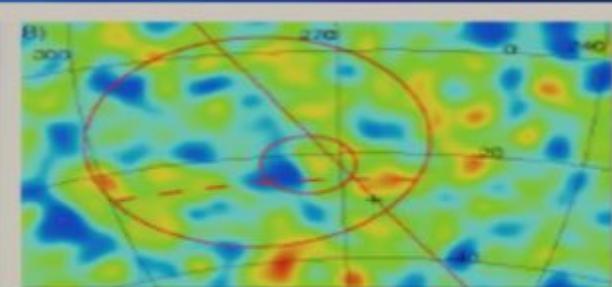
SUGAR f.o.v



3.7° filter  
(SUGAR)



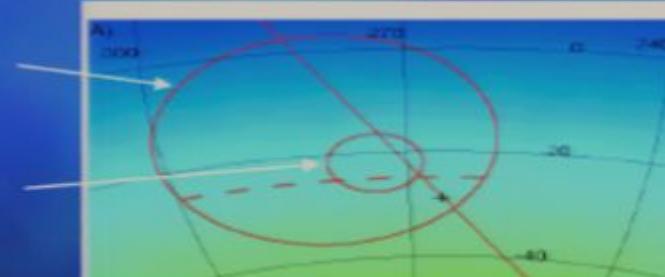
1.5° filter  
(Auger)



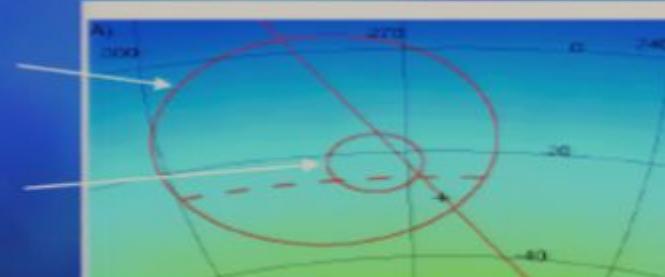
# First Auger Source Search

- No excess observed from near Galactic Center:

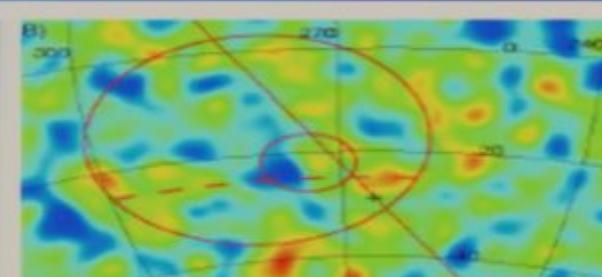
AGASA f.o.v



SUGAR f.o.v



3.7° filter  
(SUGAR)



1.5° filter  
(Auger)



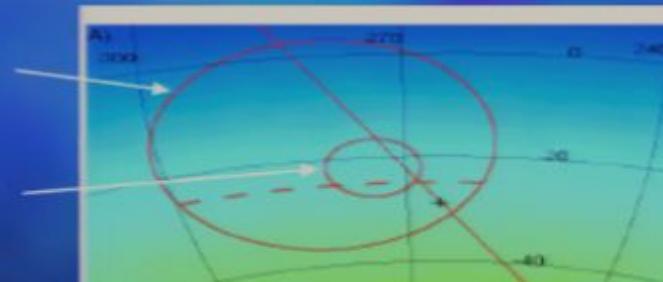
13.3° filter  
(AGASA)



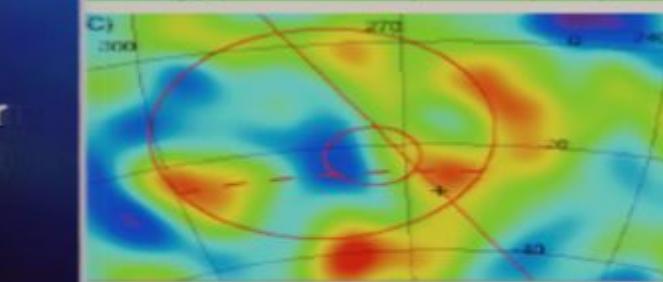
# First Auger Source Search

- No excess observed from near Galactic Center:
  - at [1.0-2.5] EeV:  $1155 \text{ observed} / 1160.7 \text{ expected} = (1.00 \pm 0.03)$

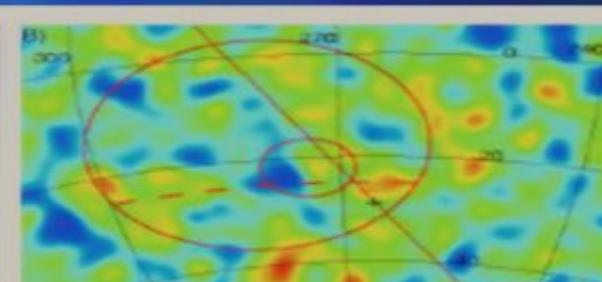
AGASA f.o.v



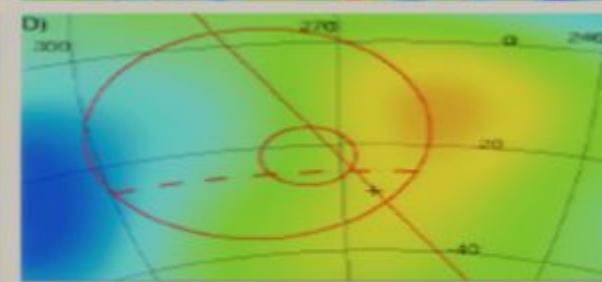
SUGAR f.o.v



3.7° filter  
(SUGAR)



1.5° filter  
(Auger)

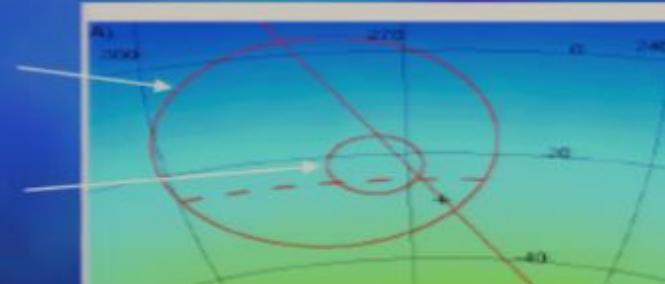


13.3° filter  
(AGASA)

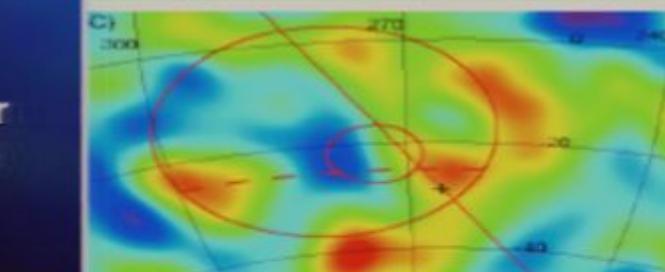
# First Auger Source Search

- No excess observed from near Galactic Center:
  - at [1.0-2.5] EeV:  $1155 \text{ observed} / 1160.7 \text{ expected} = (1.00 \pm 0.03)$   
AGASA excess (1/3 Auger statistics)  $\Rightarrow 7.5\sigma$  excess expected;

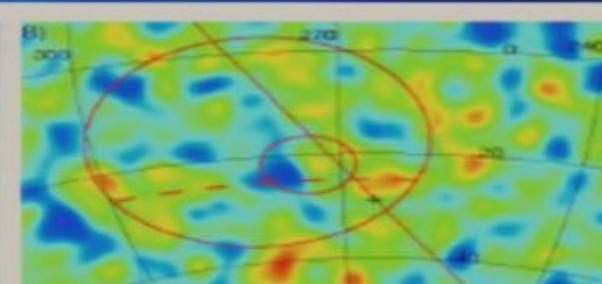
AGASA f.o.v



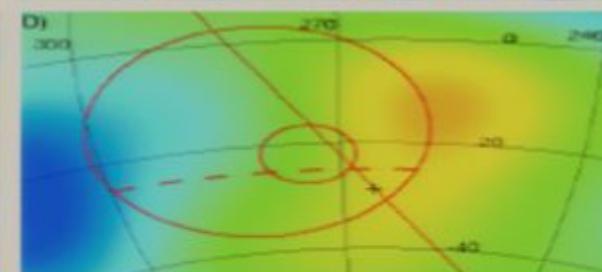
SUGAR f.o.v



3.7° filter  
(SUGAR)



1.5° filter  
(Auger)

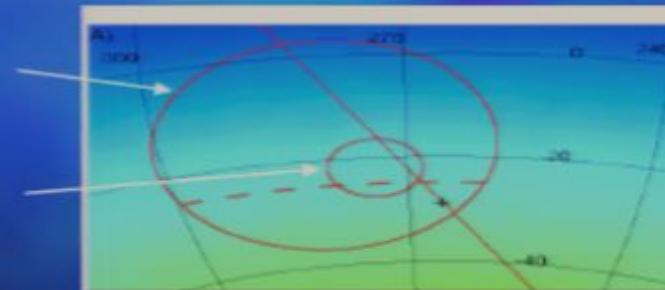


13.3° filter  
(AGASA)

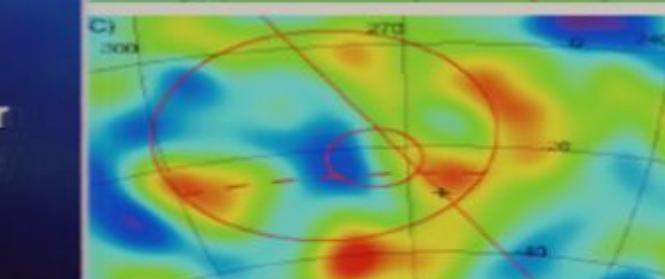
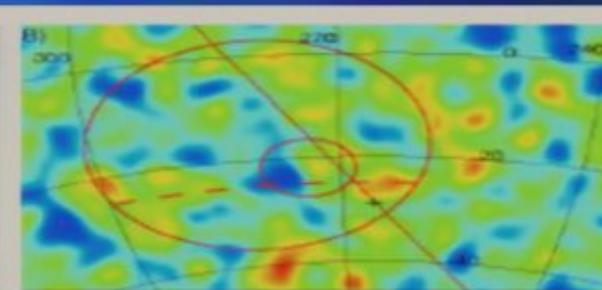
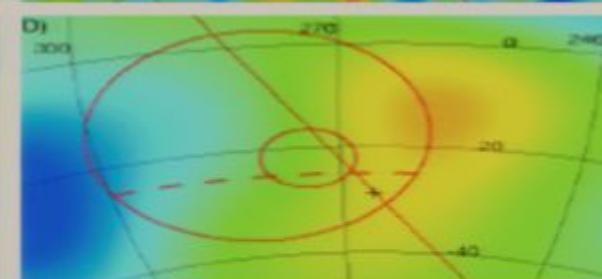
# First Auger Source Search

- No excess observed from near Galactic Center:
  - at [1.0-2.5] EeV:  $1155 \text{ observed} / 1160.7 \text{ expected} = (1.00 \pm 0.03)$   
AGASA excess (1/3 Auger statistics)  $\Rightarrow 7.5\sigma$  excess expected;
  - SUGAR-like search (1/10 Auger statistics  $\Rightarrow 2.9\sigma$  excess reported)

AGASA f.o.v



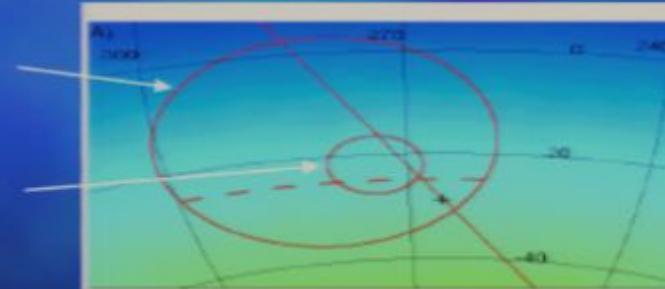
SUGAR f.o.v

3.7° filter  
(SUGAR)1.5° filter  
(Auger)13.3° filter  
(AGASA)

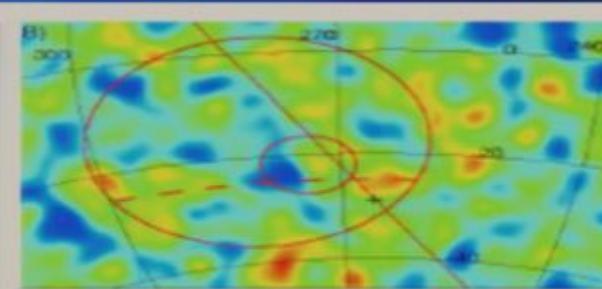
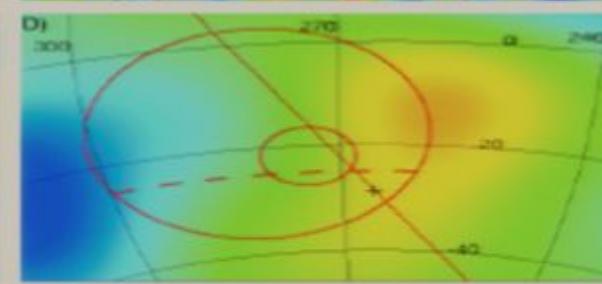
# First Auger Source Search

- No excess observed from near Galactic Center:
  - at [1.0-2.5] EeV:  $1155 \text{ observed} / 1160.7 \text{ expected} = (1.00 \pm 0.03)$   
AGASA excess (1/3 Auger statistics)  $\Rightarrow 7.5\sigma$  excess expected;
  - SUGAR-like search (1/10 Auger statistics  $\Rightarrow 2.9\sigma$  excess reported)  
 $144 \text{ observed} / 150.9 \text{ expected} = (0.95 \pm 0.08)$ ;
- No excess from GC, Galactic Plane, Super-Galactic Plane;

AGASA f.o.v



SUGAR f.o.v

3.7° filter  
(SUGAR)13.3° filter  
(AGASA)

# Conclusions

- Large, high-quality CREAM data set;



# Conclusions

- Large, high-quality CREAM data set;
- Expect  $\sim 200$  C nuclei above  $1 \text{ TeV/n}$  ( $10 \text{ TeV/particle}$ );
- Trigger aperture  $\sim 86 \text{ m}^2 \text{ sr days}$ ;

# Conclusions

- Large, high-quality CREAM data set;
- Expect  $\sim 200$  C nuclei above  $1 \text{ TeV/n}$  ( $10 \text{ TeV/particle}$ );
- Trigger aperture  $\sim 86 \text{ m}^2 \text{ sr days}$ ;



# Conclusions

- Large, high-quality CREAM data set;
- Expect  $\sim 200$  C nuclei above  $1 \text{ TeV/n}$  ( $10 \text{ TeV/particle}$ );
- Trigger aperture  $\sim 86 \text{ m}^2 \text{ sr days}$ ;
- Systems would have functioned well for  $> 100$  days (ULDB);



# Conclusions

- Large, high-quality CREAM data set;
- Expect  $\sim 200$  C nuclei above  $1 \text{ TeV/n}$  ( $10 \text{ TeV/particle}$ );
- Trigger aperture  $\sim 86 \text{ m}^2 \text{ sr days}$ ;
- Systems would have functioned well for  $> 100$  days (ULDB);



# Conclusions

- Large, high-quality CREAM data set;
- Expect  $\sim 200$  C nuclei above  $1 \text{ TeV/n}$  ( $10 \text{ TeV/particle}$ );
- Trigger aperture  $\sim 86 \text{ m}^2 \text{ sr days}$ ;
- Systems would have functioned well for  $> 100$  days (ULDB);
- Expect best B/C measurements up to  $\sim 500 \text{ GeV/n}$ ;





# Conclusions

- Large, high-quality CREAM data set;
- Expect  $\sim 200$  C nuclei above  $1 \text{ TeV/n}$  ( $10 \text{ TeV/particle}$ );
- Trigger aperture  $\sim 86 \text{ m}^2 \text{ sr days}$ ;
- Systems would have functioned well for  $>100$  days (ULDB);
- Expect best B/C measurements up to  $\sim 500 \text{ GeV/n}$ ;
- Expect best spectra up to  $900 \text{ TeV}$ ;



# Conclusions

- Large, high-quality CREAM data set;
- Expect  $\sim 200$  C nuclei above  $1 \text{ TeV/n}$  ( $10 \text{ TeV/particle}$ );
- Trigger aperture  $\sim 86 \text{ m}^2 \text{ sr days}$ ;
- Systems would have functioned well for  $> 100$  days (ULDB);
- Expect best B/C measurements up to  $\sim 500 \text{ GeV/n}$ ;
- Expect best spectra up to  $900 \text{ TeV}$ ;
- Best direct exploration of knee region;



# Conclusions

- Large, high-quality CREAM data set;
- Expect  $\sim 200$  C nuclei above  $1 \text{ TeV/n}$  ( $10 \text{ TeV/particle}$ );
- Trigger aperture  $\sim 86 \text{ m}^2 \text{ sr days}$ ;
- Systems would have functioned well for  $>100$  days (ULDB);
- Expect best B/C measurements up to  $\sim 500 \text{ GeV/n}$ ;
- Expect best spectra up to  $900 \text{ TeV}$ ;
- Best direct exploration of knee region;
- CREAM3 in the works, possibly ULDB.



# Conclusions

---

# Conclusions

- Highest energy cosmic rays: origin is still a complete mystery!

# Conclusions

- Highest energy cosmic rays: origin is still a complete mystery!
- Large increases in data, and fresh particle physics input, are needed;

# Conclusions

- ➊ Highest energy cosmic rays: origin is still a complete mystery!
- ➋ Large increases in data, and fresh particle physics input, are needed;
- ➌ Promising new experimental efforts;

# Conclusions

- Highest energy cosmic rays: origin is still a complete mystery!
- Large increases in data, and fresh particle physics input, are needed;
- Promising new experimental efforts;
- Auger Argentina site completion targeted for 2007; Northern site in CO under discussion;



# Conclusions

- Highest energy cosmic rays: origin is still a complete mystery!
- Large increases in data, and fresh particle physics input, are needed;
- Promising new experimental efforts;
- Auger Argentina site completion targeted for 2007; Northern site in CO under discussion;
- Expect definitive measurement of UHE spectrum, sensitivity to point sources, composition, potential for new neutrino frontier;

# Conclusions

- Highest energy cosmic rays: origin is still a complete mystery!
- Large increases in data, and fresh particle physics input, are needed;
- Promising new experimental efforts;
- Auger Argentina site completion targeted for 2007; Northern site in CO under discussion;
- Expect definitive measurement of UHE spectrum, sensitivity to point sources, composition, potential for new neutrino frontier;
- First Auger results!