Possible Future Cosmic Ray Experiments in Space

Robert E. Streitmatter

CR Measurements in Space

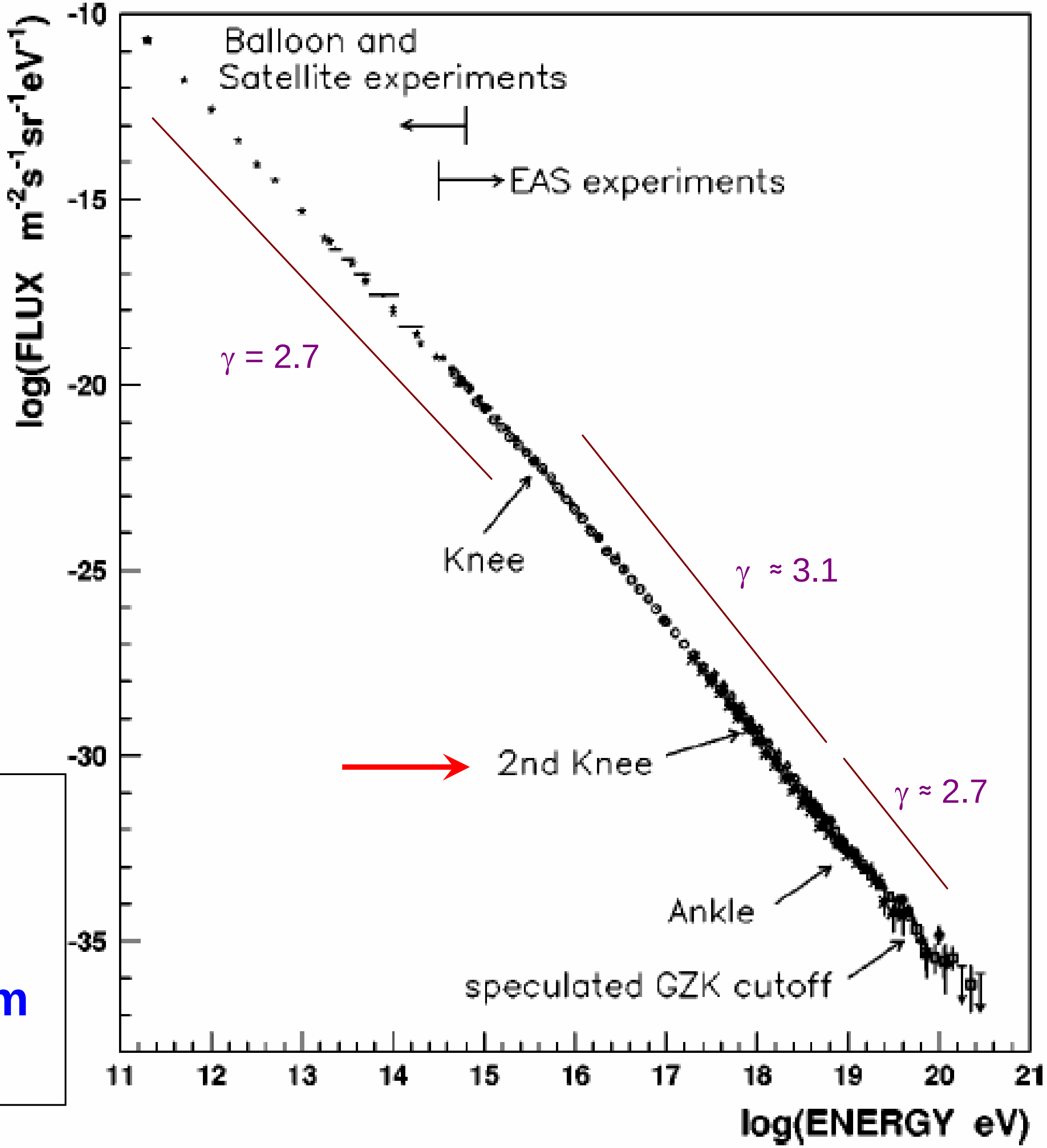
- **VIRTUE**
  - ☺ No atmosphere
  - ☺ Long operation time / large exposure

- **VICE**
  - ☺ Cost, scale of activity
  - ☺ Many year project / typically
  - ☺ You get one try

Conventional Wisdom:

SN accelerate CR to an energy $\approx 10^{14} * Z$ eV

But ……..



Other Features

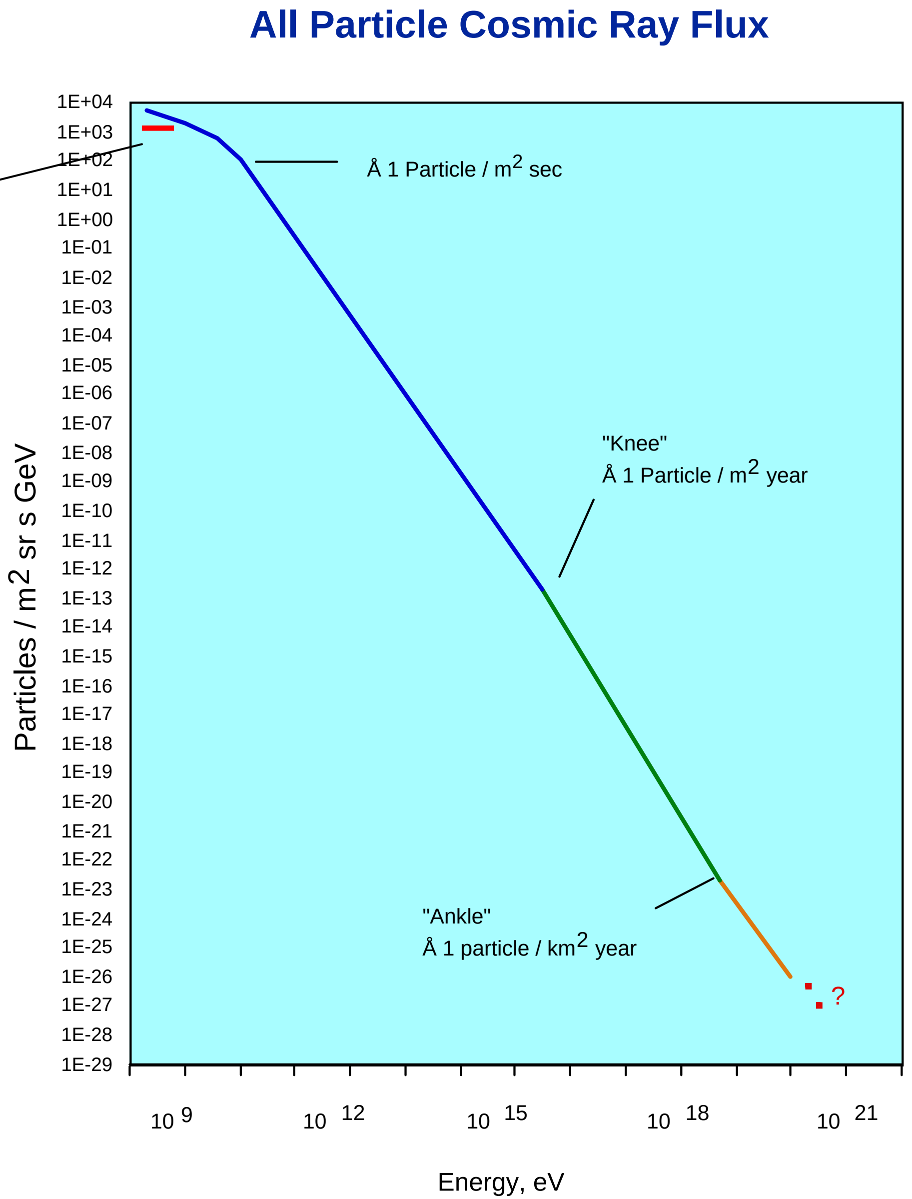
- 2nd knee $\approx 10^{17}$ eV
- Ankle $\approx 3 \times 10^{18}$ eV
- End (?) of Spectrum

ENergetic Trans-Iron Composition Explorer

- ENTICE will measure all the cosmic-ray nuclei from ~Ne (Z=10) through the actinides (Z>90)

- ENTICE will measure the composition of the most recently synthesized material that we have access to, the heavy CR

- ENTICE is a free-flyer

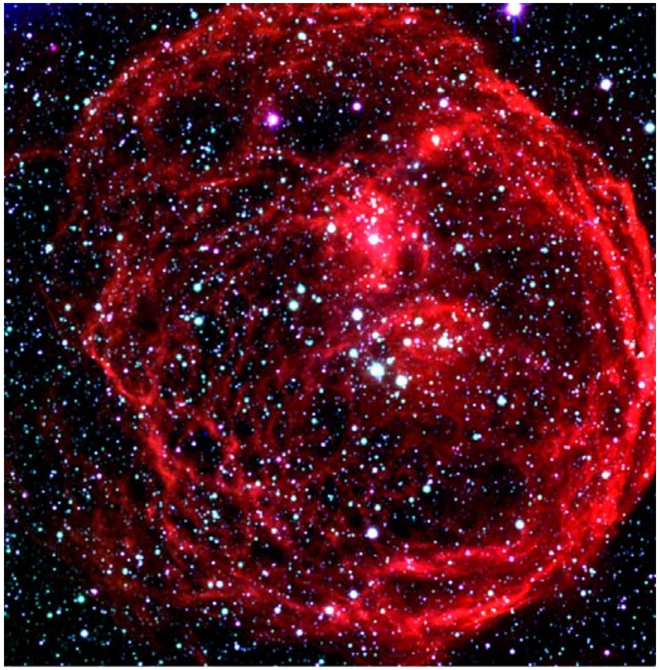


ENTICE Science Objectives

- **Sample matter from the birthplace of heavy nuclei**

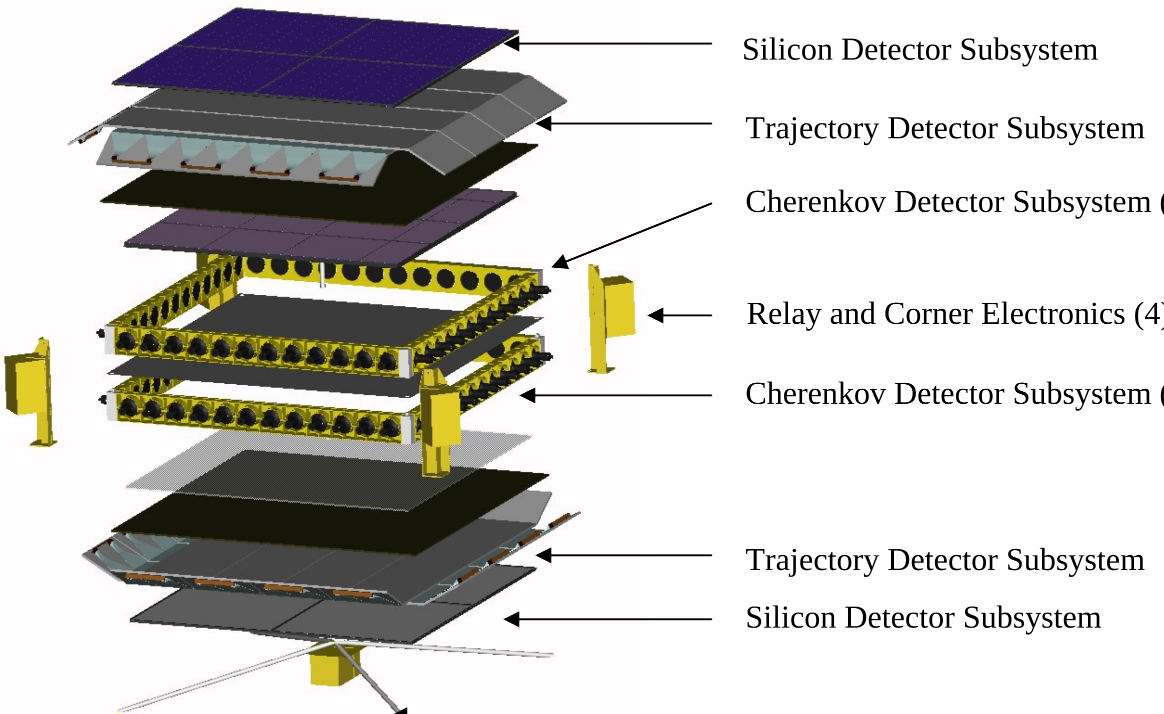
- SN shocks in superbubbles formed by OB associations accelerate material from recent SN and stellar winds.
- ENTICE samples nuclei that almost certainly contain recently synthesized material from OB associations.
- This is a young sample (<10 Myr since acceleration); It can tell us the production ratios of heavy nuclei.
- The presence of fresh material in the heaviest cosmic rays strongly suggests supernova acceleration.
- Pattern of element abundances carries the signature of the site of injection into the accelerator.
  - OB associations?
  - Warm stellar atmospheres?
  - Cold ISM (dust and gas)?

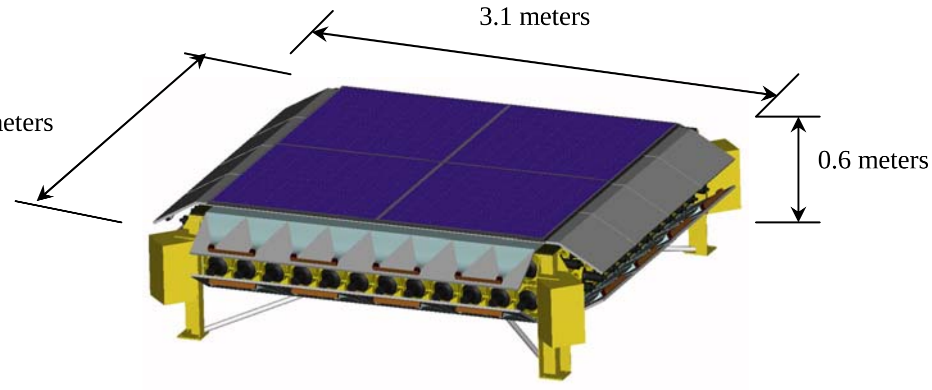
100 pc



Superbubble (N 70) in the Large Magellanic Cloud
(ESO Very Large Telescope Image)

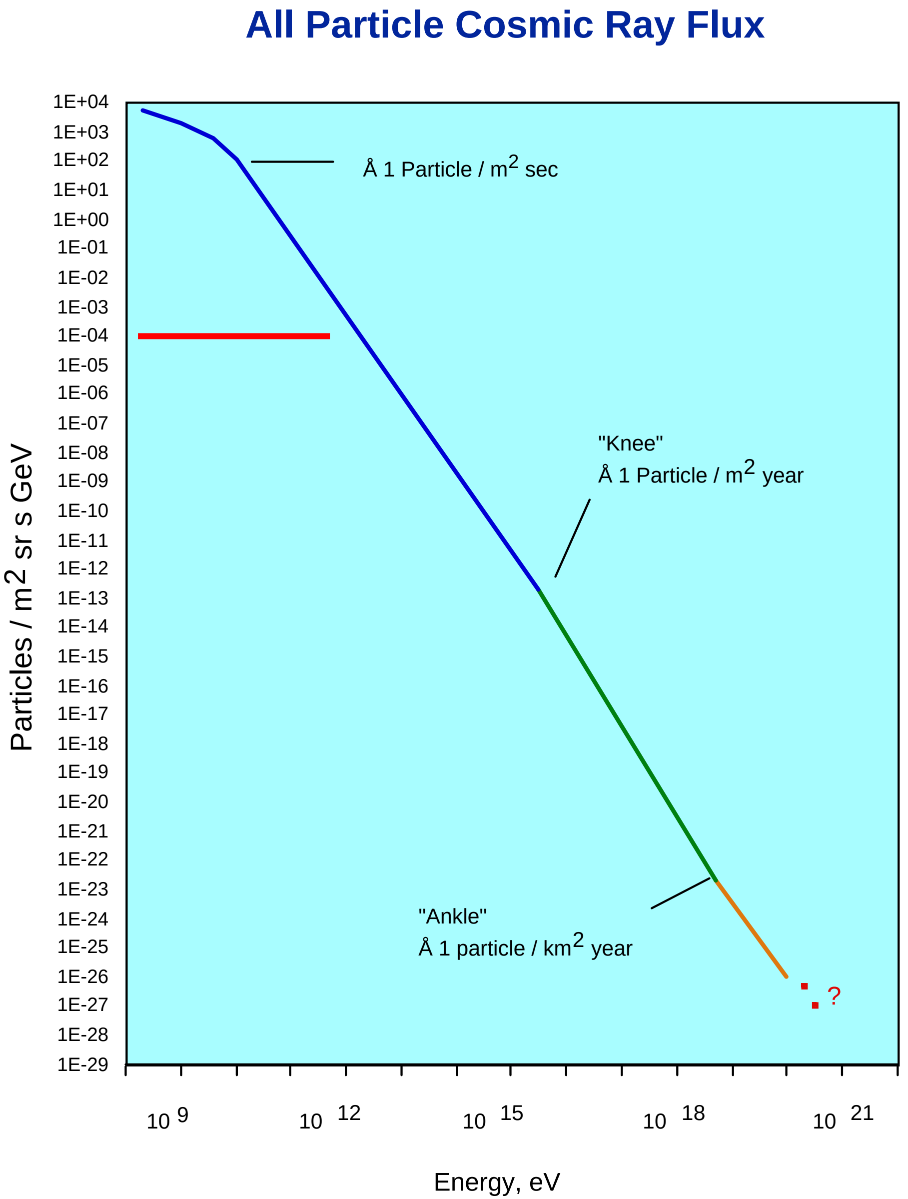
ENergetic Trans-Iron Composition Explorer, ENTICE



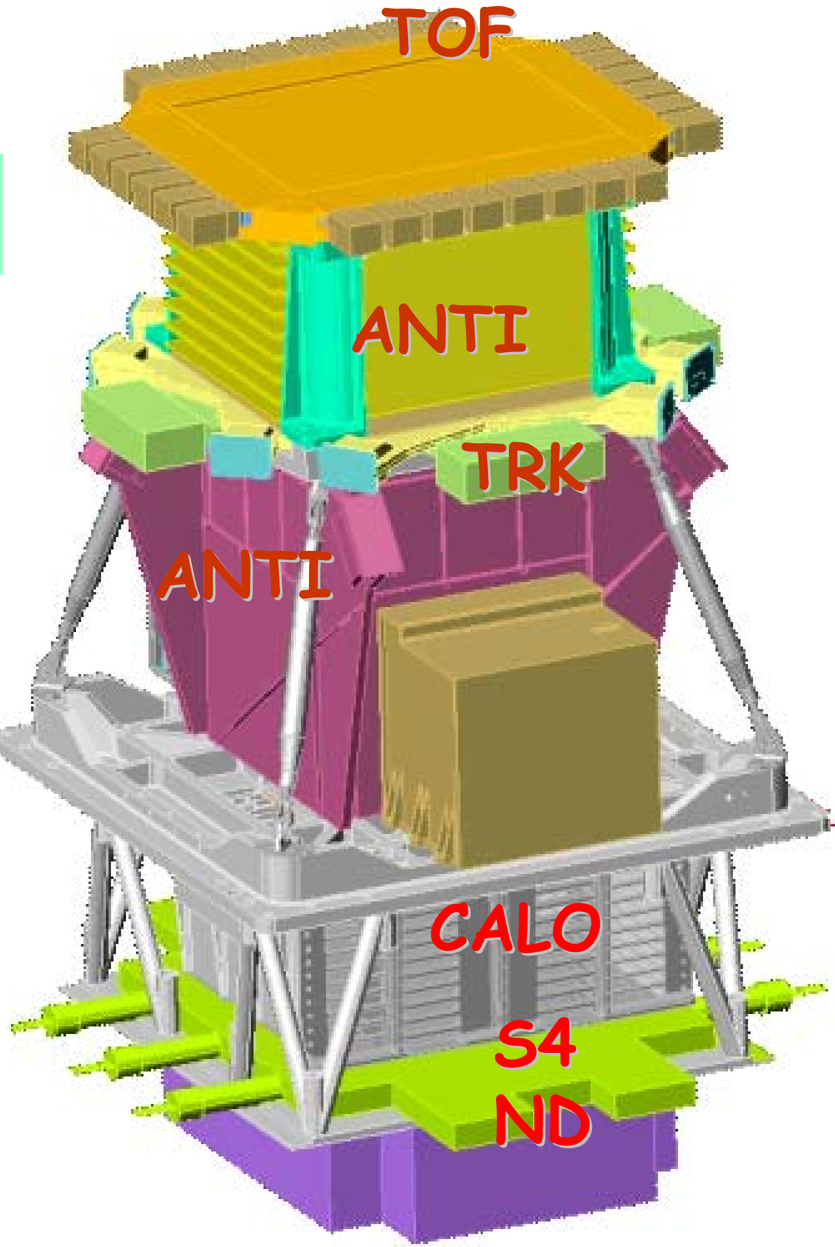


Payload for **A**ntimatter **M**atter **E**xploration and **L**ight Nuclei **A**strophysics. PAMELA

- Orbiting space experiment
- Magnet spectrometer
- Wide-ranging measurements
  - Antiprotons
  - Anti-nuclear search
  - Electrons
  - Positrons
  - Protons
  - Nucleons



PAMELA DETECTOR



Anticoncidence system

Multiple particles rejection

Anticoincidence system

Defines tracker acceptance

Plastic scintillator + PMT

Si-W Calorimeter

Imaging Calorimeter : reconstructs shower profile discriminating e^+/p and $\bar{p}/e^-$ at level of $10^{-4} \sim 10^{-5}$

Energy Resolution for $e^{\pm}$ $\Delta E/E = 15\% / E^{1/2}$.

Si-X / W / Si-Y structure

22 W planes

$16.3\ X_0 / 0.6\ l_0$

Time-of-flight

Level 1 trigger

particle identification (up to 1GeV/c)

dE/dx

Plastic scintillator + PMT

Time Resolution ~ 70 ps

Si Tracker + magnet

Permanent magnet B=0.4T

6 planes double sided Si strips 300 μm thick

Spatial risolution ~3μm

MDR = 740 GV/c

S4 and Neutron detectors

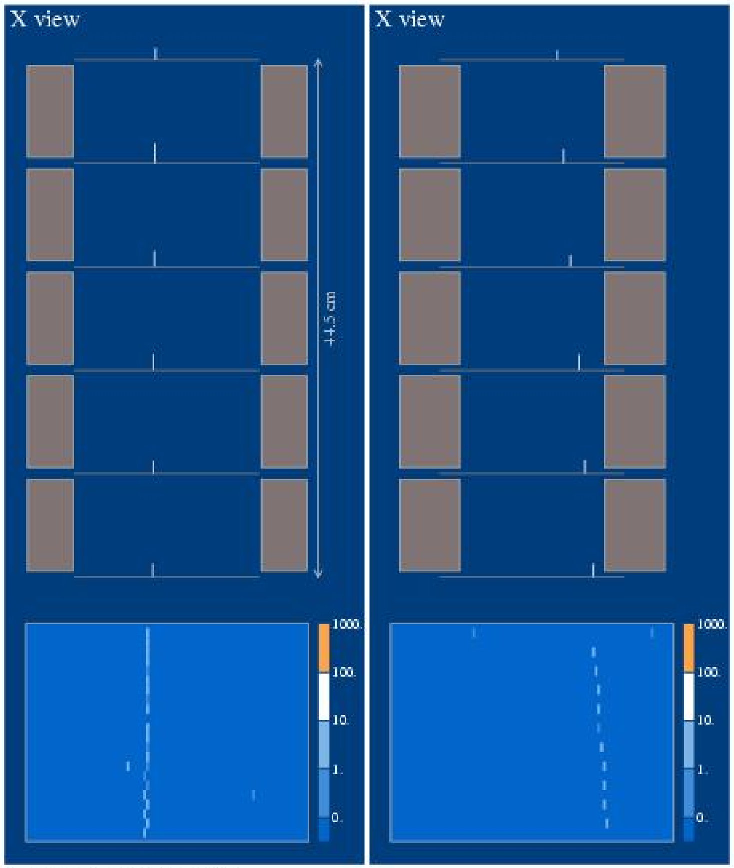
Identify hadron interactions

Plastic Scintillator

36 ^3He counters in a polyetilen moderator

Tracker+Calorimeter Performance

SPS Test Beam Data: p
50 GeV/c



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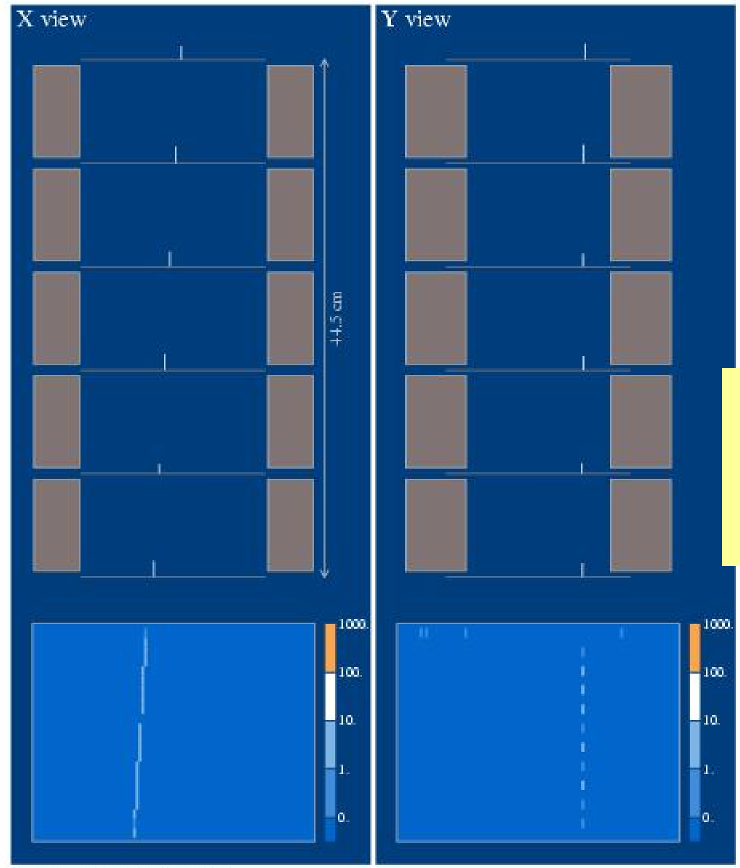

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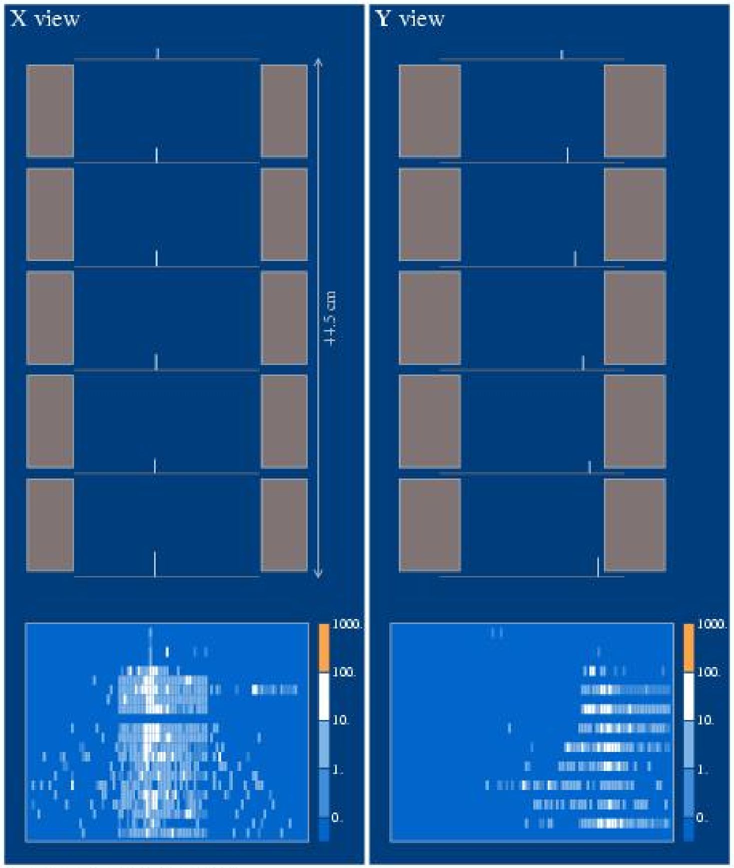
SPS Test Beam Data:
p
100 GeV/c

Tracker+Calorimeter Performance

SPS Test Beam Data: p 50 GeV/c



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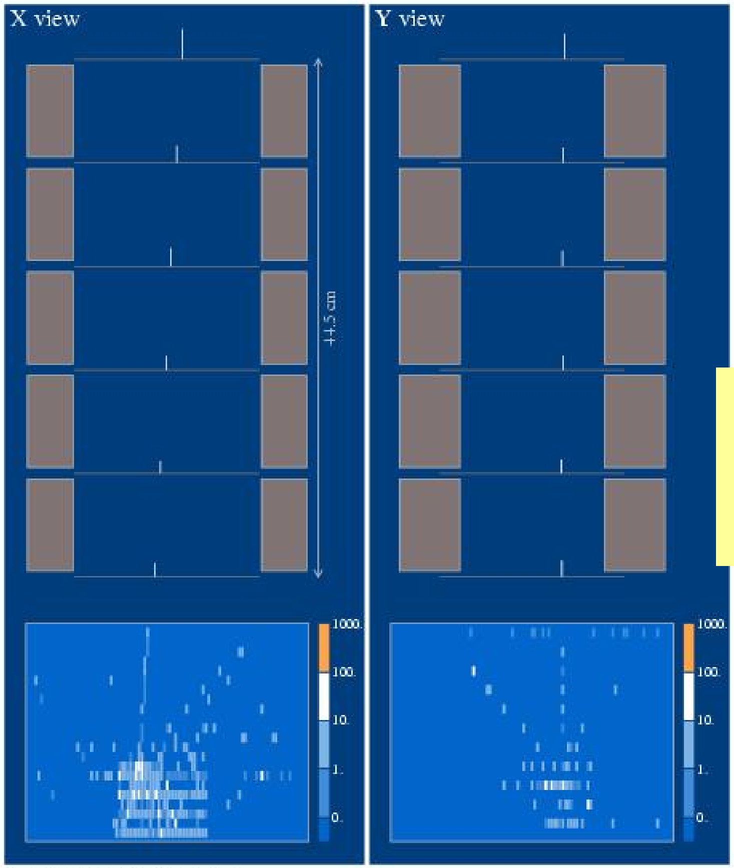
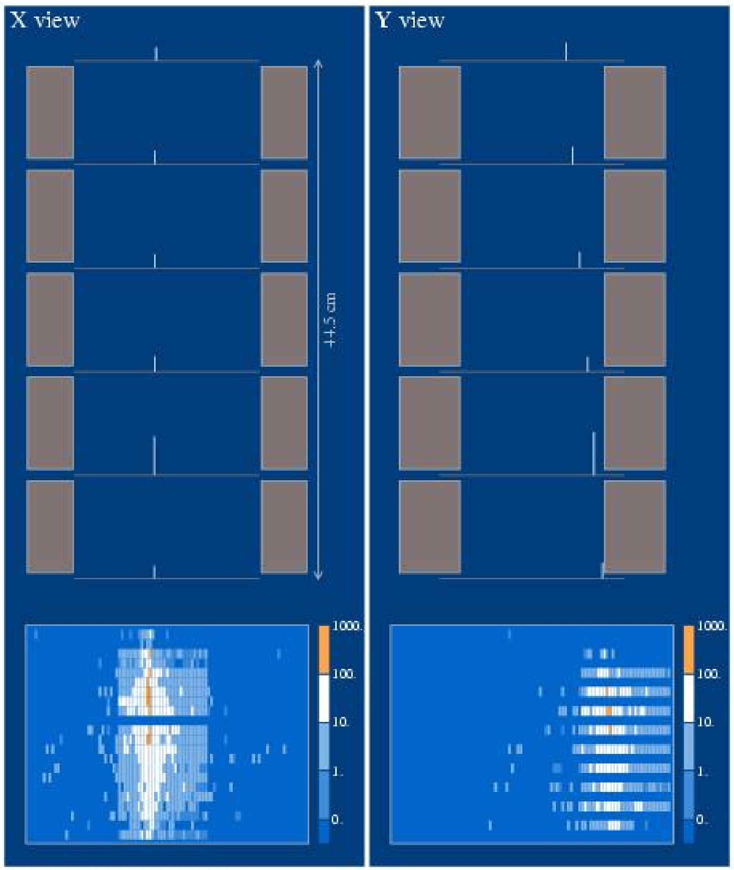


Date 030920 File 169 Event 1023

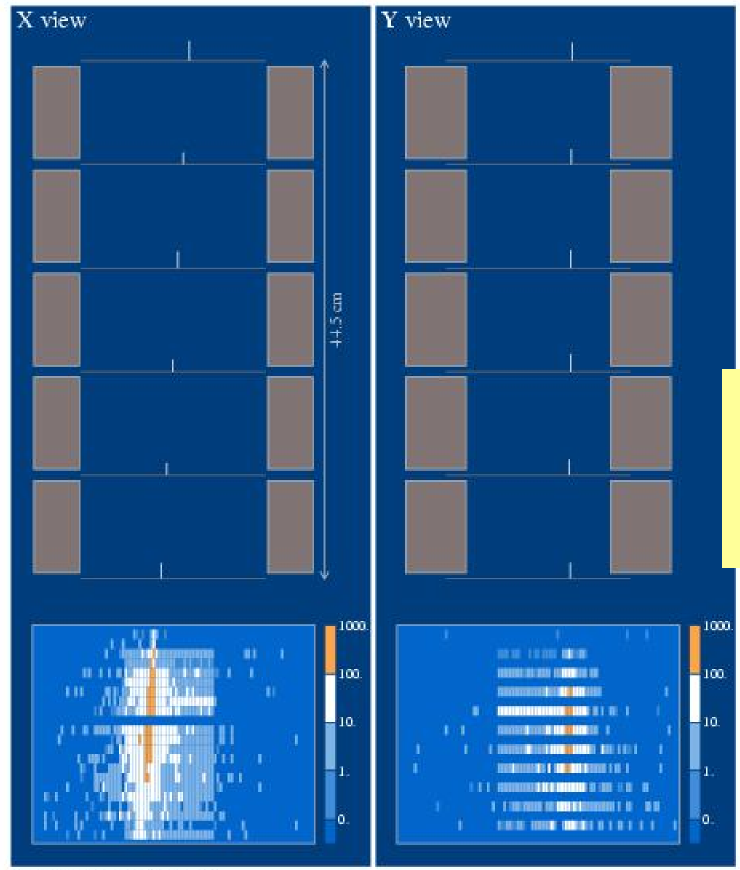
SPS Test Beam Data: p 100 GeV/c

Tracker+Calorimeter Performance

SPS Test Beam Data: e^- 50 GeV/c



Date 030921 File 323 Event 35



Date 030920 File 245 Event 6

SPS Test Beam Data: e^- 100 GeV/c

PAMELA MISSION

Particle	Number (3 yrs)	Energy Range
Protons	3.10^{8}	80 MeV - 700 GeV
Antiprotons	**$>3.10^{4}$**	**80 MeV - 190 GeV**
Electrons	6.10^{6}	50 MeV - 2 TeV
Positrons	**$>3.10^{5}$**	**50 MeV - 270 GeV**
He	4.10^{7}	80 MeV/n - 700 GeV/n
Be	4.10^{4}	80 MeV/n - 700 GeV/n
C	4.10^{5}	80 MeV/n - 700 GeV/n
Antihelium Limit (90% C.L.)	**7.10^{-8}**	**80 MeV/n - 30 GeV/n**

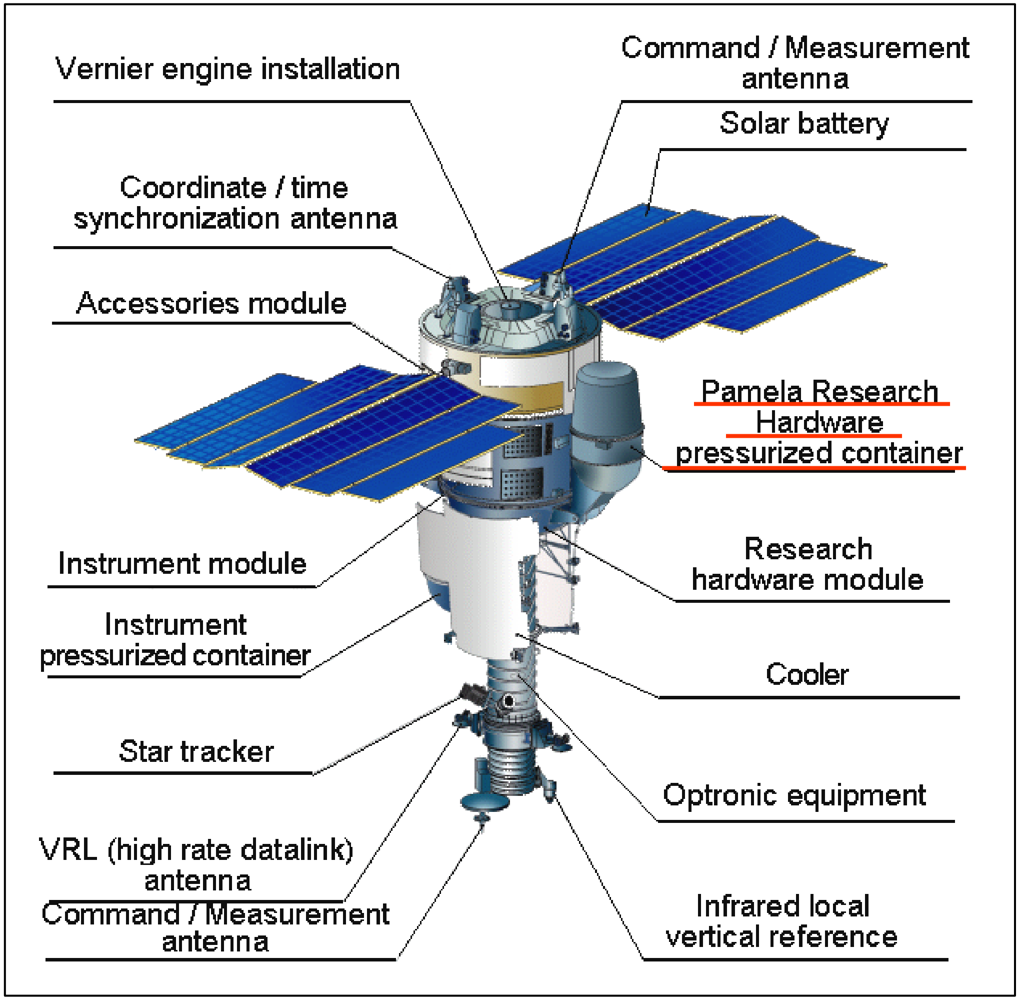
- Semi-polar orbit (70.4°) $\Rightarrow$ access to low energy regime
- 3 year mission $\Rightarrow$ large data sets

PAMELA

Flight model before delivery to Samara, March 2005

Launch Oct. 2005

PAMELA Rides Upon ---> Resurs-DK1:



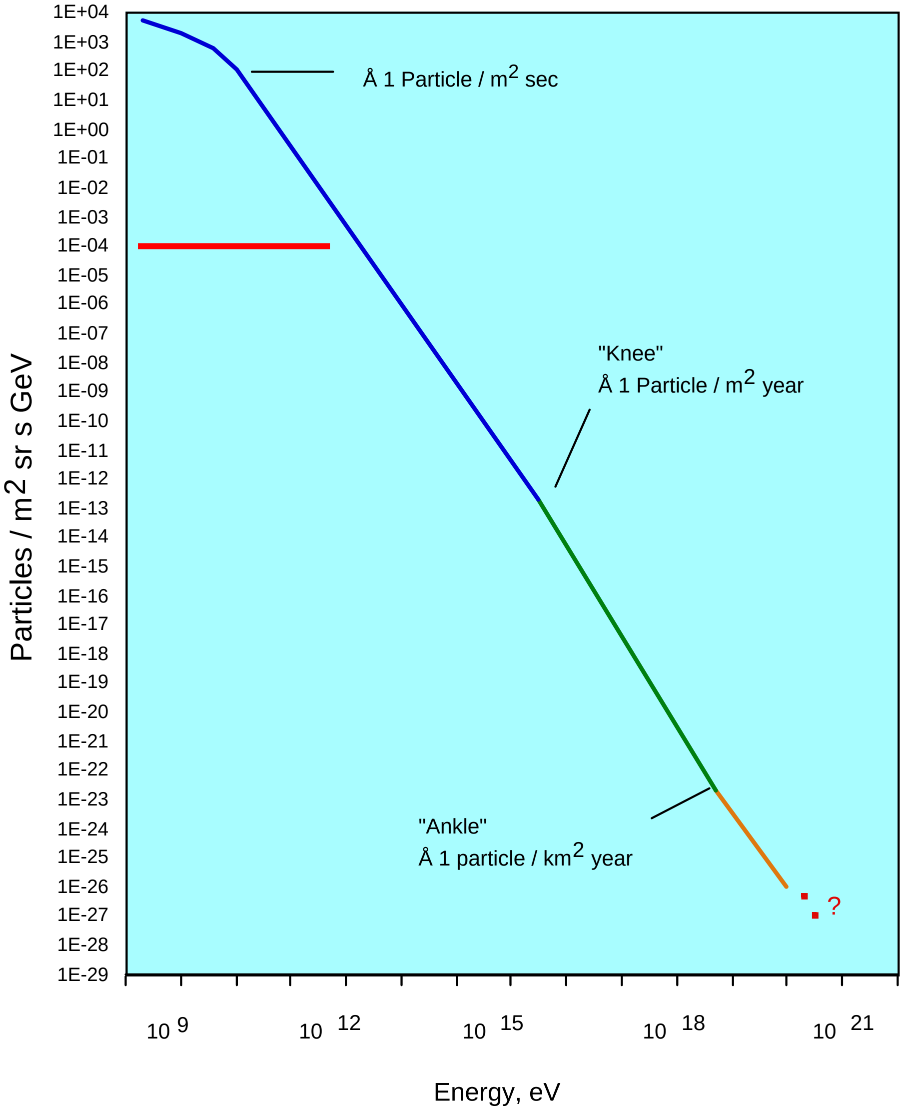
TsSKB-Progress
Samara Russia

Mass: 6.7 tons (satellite)
Orbit: Elliptic
Altitude: 300 - 600 Km
Inclination: 70.4°
Life Time: > 3 years
Launch foreseen October 2005 from Baikonur with Soyuz TM rocket
2 downlink stations: Moscow and Khanty-Mansiysk West Siberia

Alpha Magnet Spectrometer 2

- ISS-based experiment
- Magnet spectrometer
- Wide-ranging measurements
    - Antiprotons
    - Anti-nuclear search
    - Electrons
    - Positrons
    - Protons
    - Nucleons
    - Light isotopes

All Particle Cosmic Ray Flux

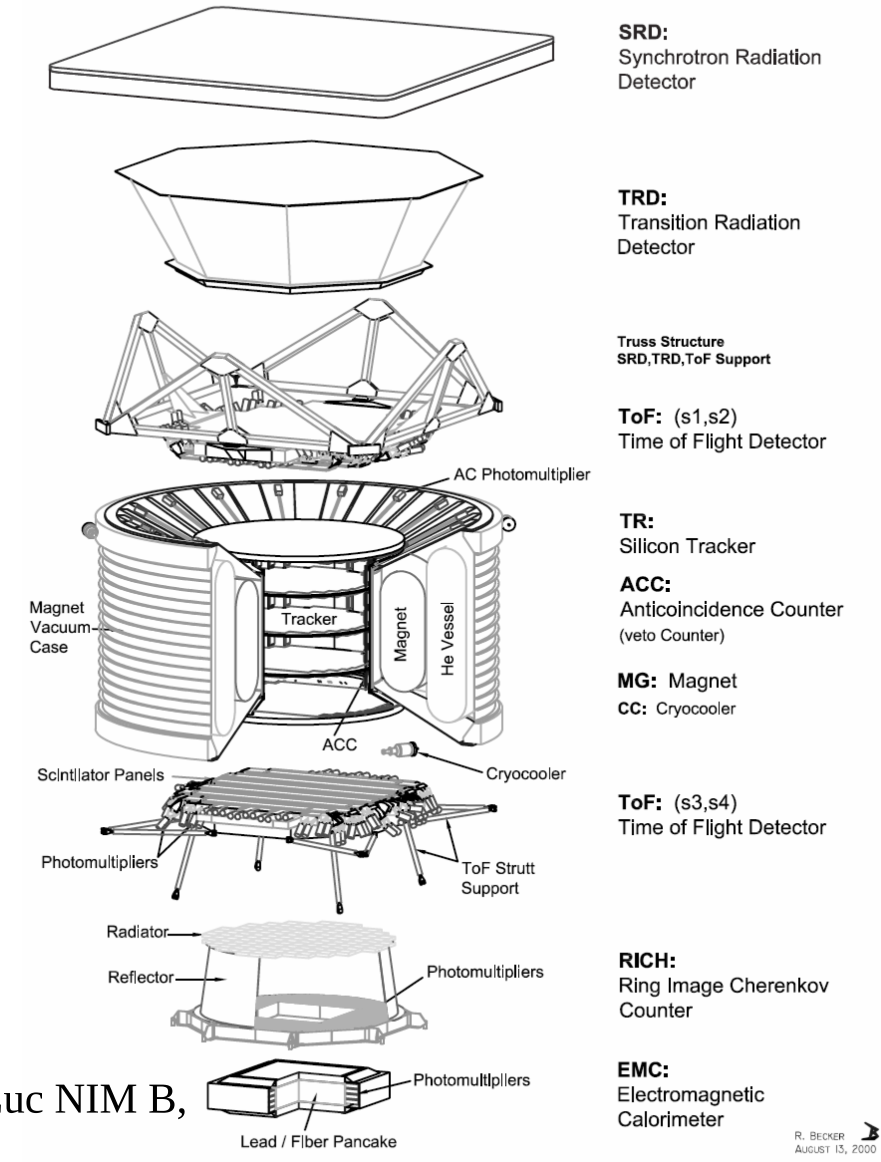


Alpha Magnet Spectrometer 2

Scheduled for ISS, 2008

Geometry factor ≈ 0.3 m^2 sr

Superconducting magnet, lifetime 3 years



Lechanoine-LeLuc NIM B, 214 (2004) 103

Advanced Cosmic-ray Composition Experiment for Space Science, ACCESS

- **High Energy**
- **High Statistics**

Measure ~ 30 times more p, He events than Japanese American Cooperative Emulsion Experiment (JACEE) balloon fights (1979 - 1995)

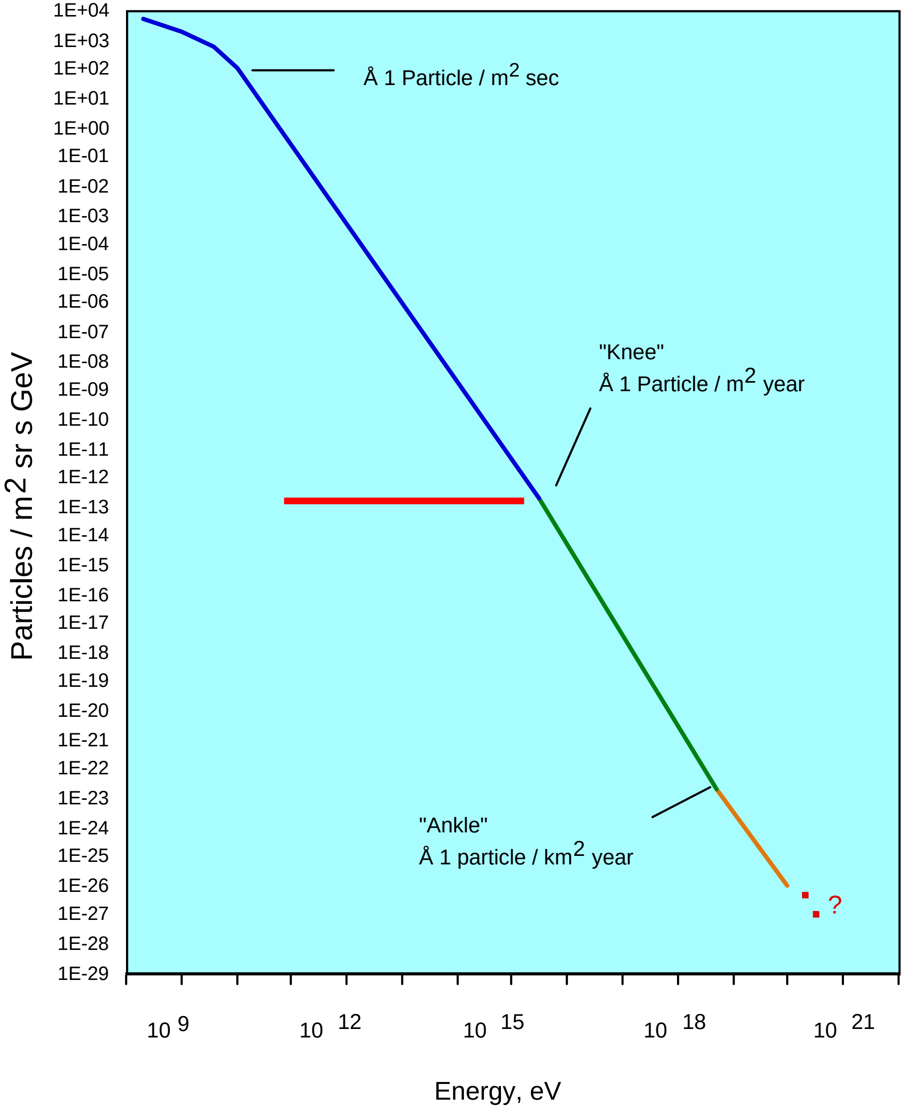
-Extend p and He spectra from to 1000 TeV

Measure ~ 3000 times more Z > 4 events than CRN Shuttle flight of 1985.

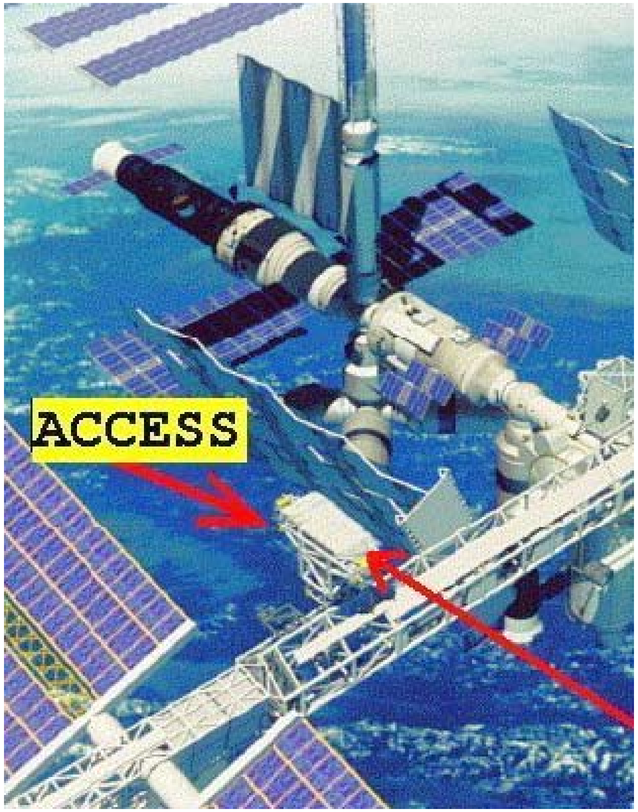
-Extend carbon spectrum from 20 TeV to 1000 TeV

-Extend iron spectrum from 80 TeV to 5000 TeV

All Particle Cosmic Ray Flux



HISTORY: ACCESS Studied for Space Station



Astroparticle Experiment, “tolerant” pointing, i.e. Up

Addresses questions of
- **Origin**
- **Acceleration**
- **Galactic history**
  of the Cosmic Radiation

Launch on STS
4 years on-orbit to achieve 1000 days operating time

ACCESS Instrument Complement (ISS Study)

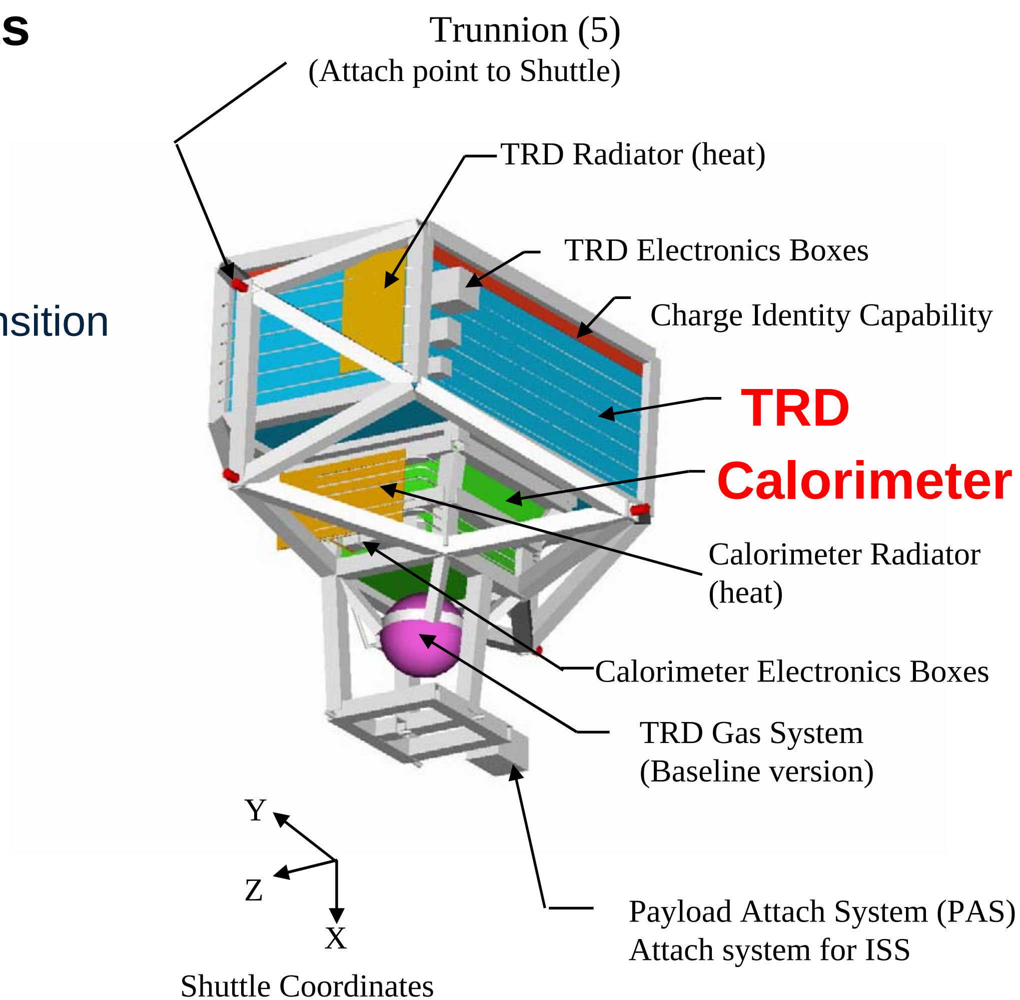
Two Baseline Instruments

Transition Radiation Detector (TRD)

• Measures Lorentz factor via transition radiation to $\gamma \approx 10^5$

Hadron Calorimeter

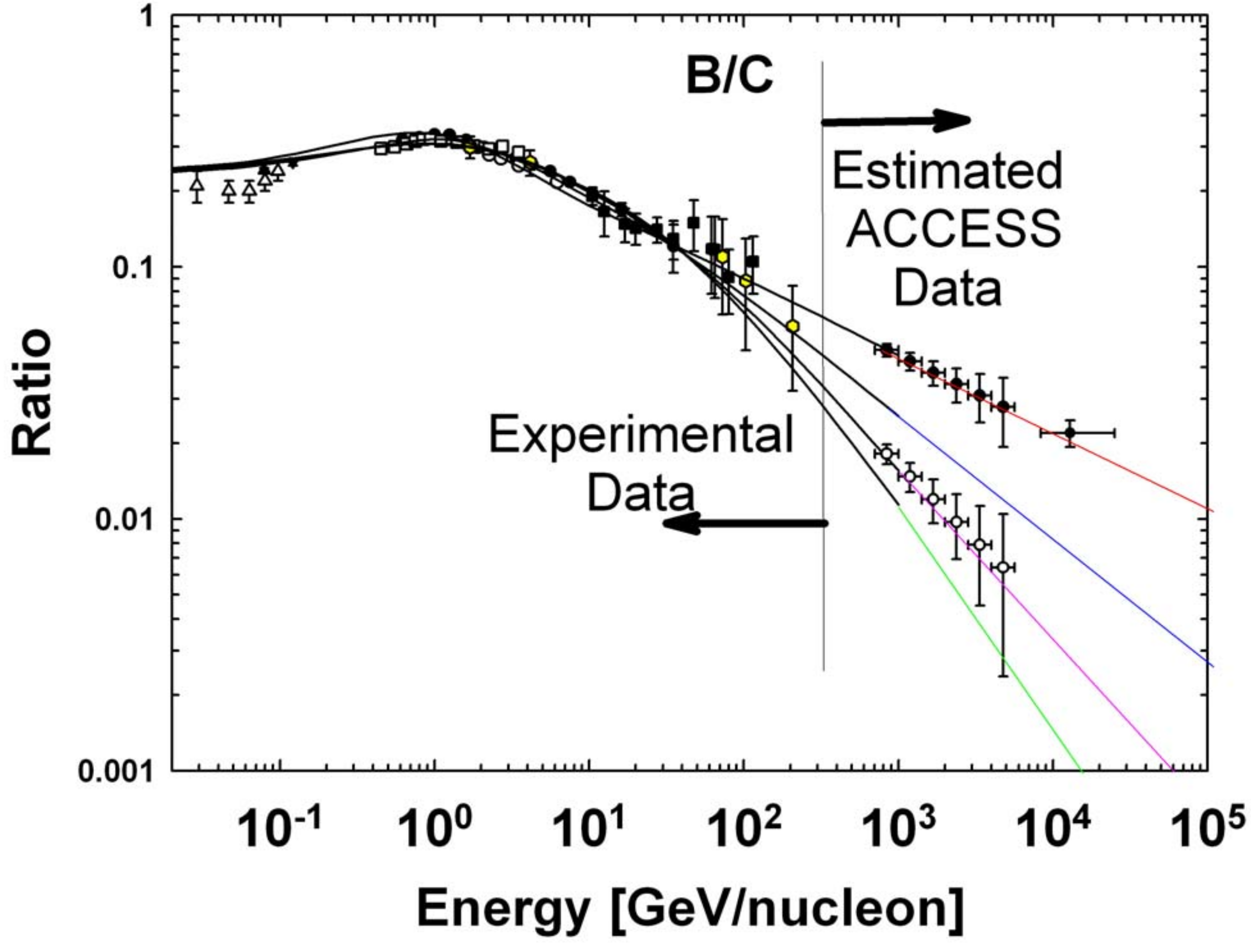
• Measures energy deposition of interaction cascade



ACCESS: GENERIC Capability

	Experiment	Species	Technique	Energy/nucleus (eV)	Instr. Effective Geometry Factor (m^2sr)	Exposure Factor (m^2sr-days)
Space Expt.	SEZ - Proton	All particle	Calorimeter	10^{11} - 5 x 10^{15}	0.3	500
	HEAO-3 - French-Danish	4 • Z < 28	Cherenkov	3 x 10^{10} - 2 x 10^{12}	0.14	33
	HEAO-3-HNE	16 • Z • 28	Ioniz.-Cherenkov	3 x 10^{10} - 10^{13}	1.2	370
	CRN	5 • Z < 26	TRD	7 x 10^{11} - 3 x 10^{13}	0.1- 0.5 (low Z) 0.5- 0.9 (high Z)	0.3 to 3
	SOKOL	1 • Z • 26 (element groups)	Calorimeter	3 x 10^{12} - 10^{14}	0.04	1.2
	ACCESS	**4 • Z • 28** **1 • Z • 8**	**TRD** **Calorimeter**	**10^{14} - 5 x 10^{15}** **10^{11} - 10^{15}**	**5 - 10** **0.9**	**5000-10,000** **900**
	JACEE	1 • Z • 26 (element groups)	Emulsion chamber	10^{13} - 5 x 10^{14}	2 - 5	80
	RUNJOB	1 • Z • 26 (element groups)	Emulsion chamber	10^{13} - 5 x 10^{14}	1.6	70
	ATIC	1 • Z • 28	Calorimeter	10^{10} – 10^{14}	0.23	7
	CREAM	4 • Z • 28 1 • Z • 28	TRD Calorimeter	10^{11} – 10^{14} 10^{10} – 10^{14}	1.3 0.3	50 12
	TRACER	5 • Z • 28	TRD	10^{11} – 10^{14}	5	50

GENERIC Prospective ACCESS B/C Measurement



ACCESS: GENERIC Expectation

E (TeV)	H	He	B	C	Fe
1 - 3	3.8×10^{6}	3.1×10^{6}	3.0×10^{4}	4.5×10^{5}	9.5×10^{5}
> 100	1400	1800	61	3900	8100
> 300	210	300	8	630	1300
> 1000	25	40	1	90	180

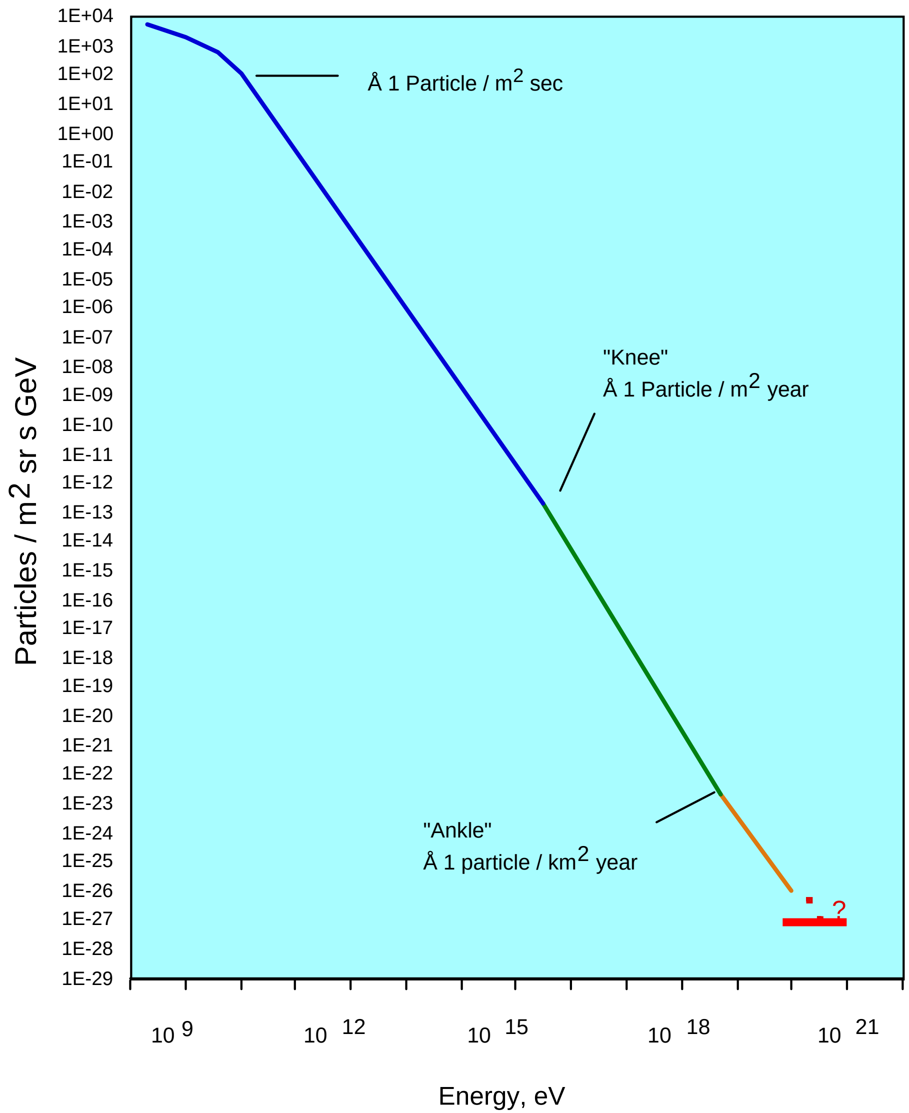
Electron Measurement to ≈ 10^{13} eV

Orbiting **W**ide-angle **L**ight-collector

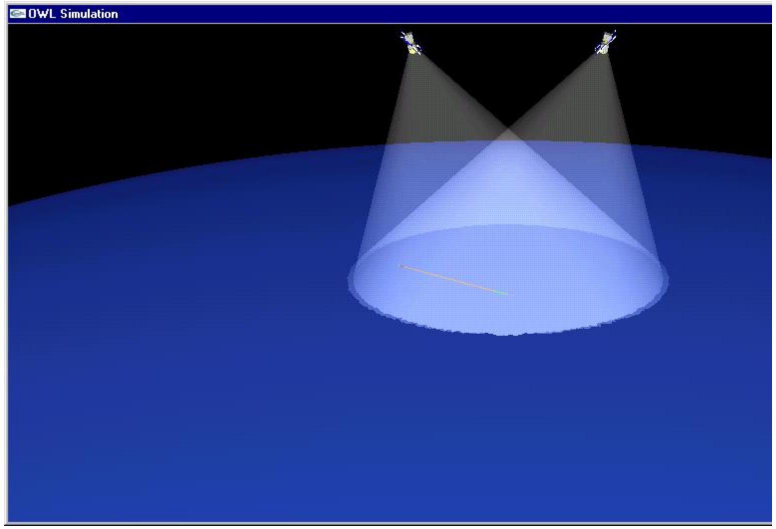
Concept

- **Air fluorescence imagery**, night atmosphere
- Builds on success of ground-based Flys Eye and HiRes fluorescence detectors
- 300-400 nm photons induced by atmospheric cascade from E~10^{20} eV cosmic rays
- **Stereo viewing** unambiguously determines shower height and isolates external influences (e.g., cloud effects, surface light sources)

All Particle Cosmic Ray Flux



OWL Mission Specs



J. F. Krizmanic Simulations Inc.

Variable satellite separation and **halving the orbit altitude** in last phases of the OWL mission:

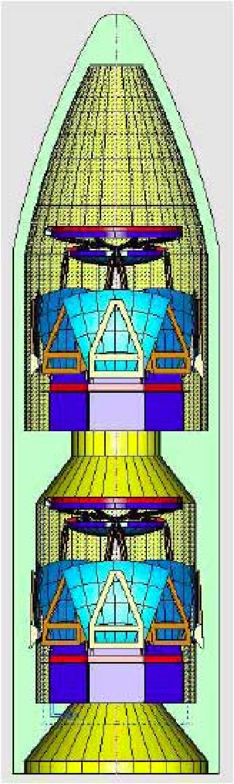
- **Extends energy coverage**
- **Allows signature for upward tau-neutrino-induced showers**

Mission Specs

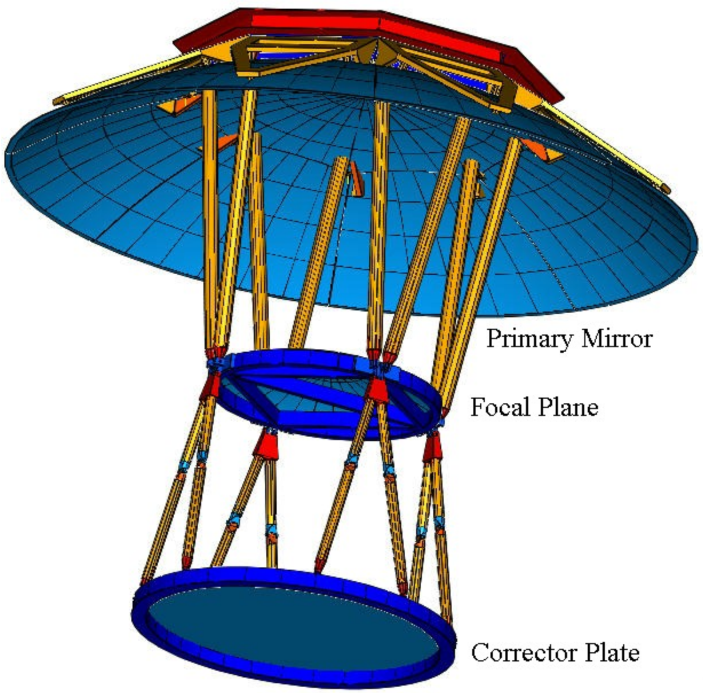
Mission:
* Launch vehicle: Delta IV
* Two formation-flying satellites
* (600 km Nominal satellite separation is variable)
* Near-equatorial orbit (5 - 10° inclination)
* 1,000 km altitude (550 km at end-of-mission)
* 3-year mission lifetime
* 2×10^6 km^2-sr instantaneous aperture

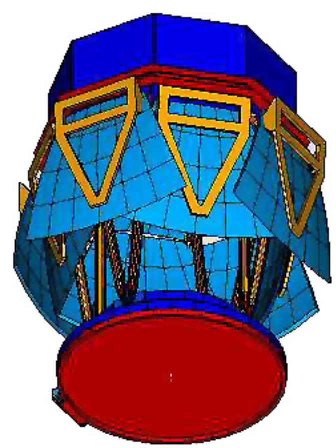
Focal Plane:
* 2.3 meter diameter focal plane
* Formed by mosaic of multi-channel elements
* Commercial technology (flat panel photomultiplier)
* ~ 539,000 total channels
* Switched capacitor array ring buffer/readout
* 1 - 10 msec readout time
* 10^{-3} - 10^{-2} dead time fraction
* Focal plane detector and electronics power < 1000 W

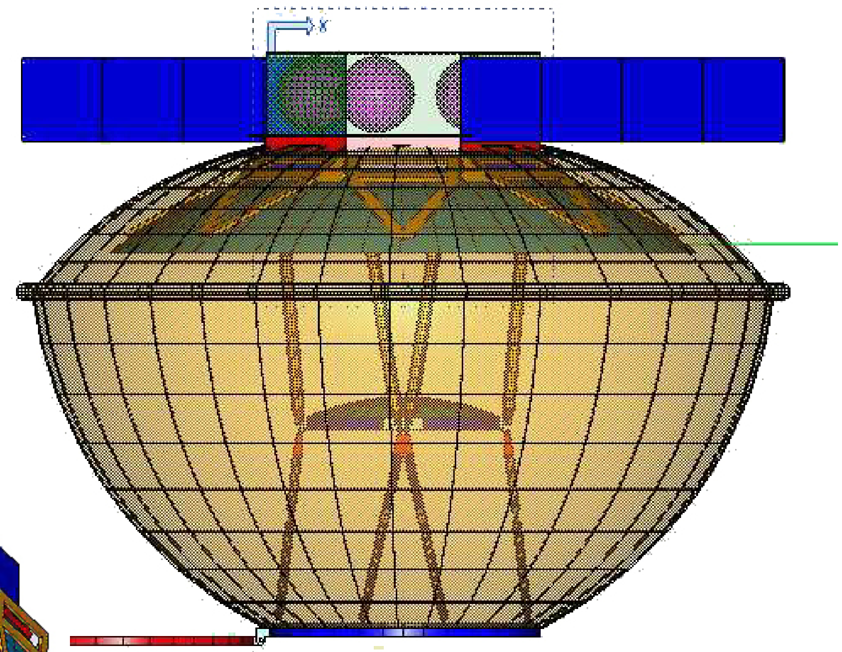
Optics:
* f/1 System
* 300 - 400 nm Wavelength range
* Transmission: 43% (on-axis, 0°) - 62% (off-axis, 22.5°)
* Spot-size (RMS): 1.03 mm (on-axis, 0°) -0.98 mm (off-axis, 22.5°)
* 3.0 meter diameter optical aperture
* 7.1 meter diameter aspherical mirror
* 2.3 meter diameter focal plane\
* Full FOV 45°
* 3 mm focal plane pixel diameter
* ~ 1 mm, 0.1° alignment tolerance



OWL-eye Configuration







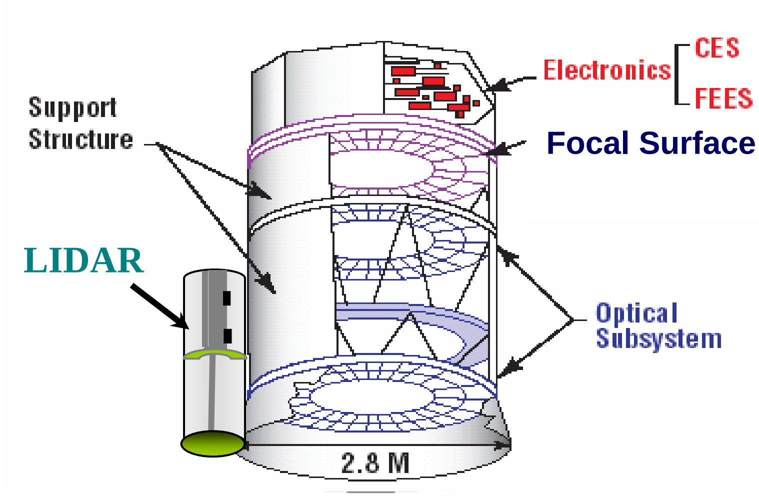
Optics Layout

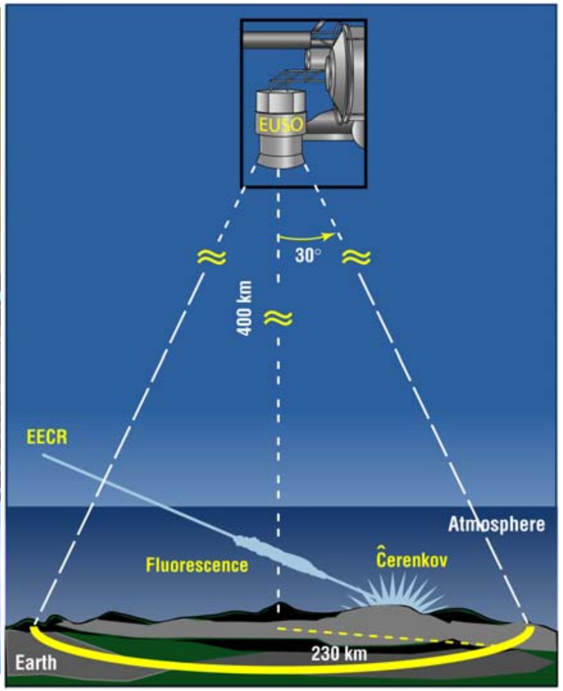
Mechanical Configuration

Jiffy-Pop Solution

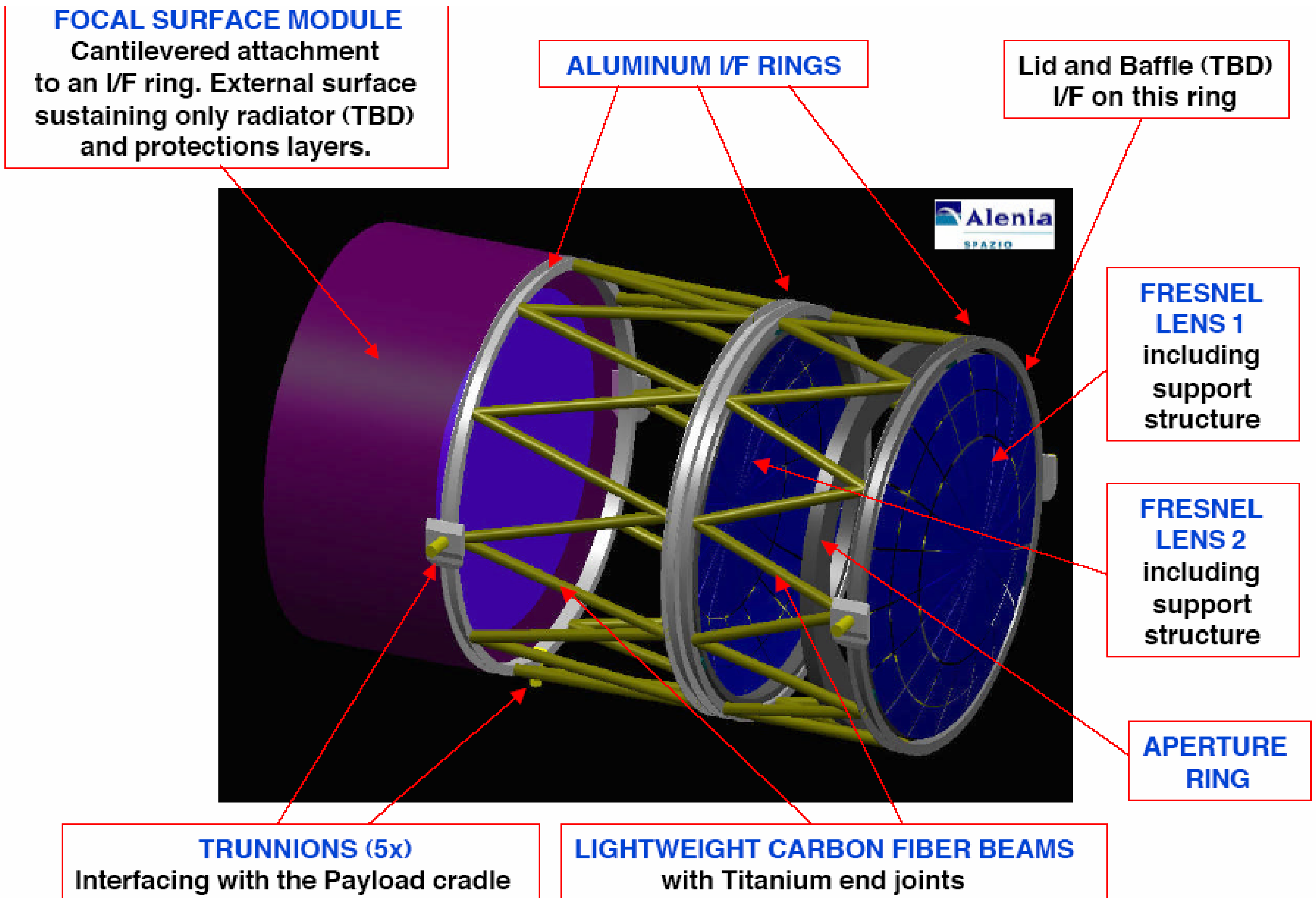
Extreme Universe Space Observatory, EUSO

- Monocular fluorescence imaging detector
- Observes atmosphere from ISS
- Optical system uses Fresnel lenses
- Completed "Phase A" study; waiting approval of Phase B





Extreme Universe Space Observatory, EUSO



GENERIC COMPARISONS: Don't Quote, Ask or Tell

	HiRes	Auger Ground (Hybrid)	EUSO 1 ISS Instrument	OWL 2 Satellites
Status	Running	Under Construction	Waiting approval	Hibernating
Energy [(1)] Range (eV)	10^{17} - 4 x 10^{20}	10^{19} - 10^{21}	Few x 10^{19} – 3 x 10^{21}	Few x 10^{19} – 10^{22}
Incident θ Resolution	0.6^{O} (E = 10^{18} eV)	1.3^{O} (0.3^{O}) (E = 10^{20} eV)	0.2^{O} - 3^{O}	0.2^{O} - 1^{O}
Energy Resolution	< 20% (E = 10^{18} eV)	25% (10%) (E = 10^{19} eV)	< 20% (E = 10^{20} eV)	15% (E = 10^{20} eV)
***Instantaneous* Aperture (km^2-ster)**	10^4	7000 /site	4 x 10^5	4 x 10^6
Duty Cycle	10%	100% (Hybrid 10%)	10%	10%
***Effective* Aperture (km^2-ster)**	1000	7000 /site (700 /site (hybrid))	40,000	400,000

(1) The upper limit is defined as the energy where 1 event/year is observed as determined by the experiment's aperture and assuming a differential spectral index of -2.75

NASA GSFC

SUMMARY OVERVIEW

ENTICE

PAMELA

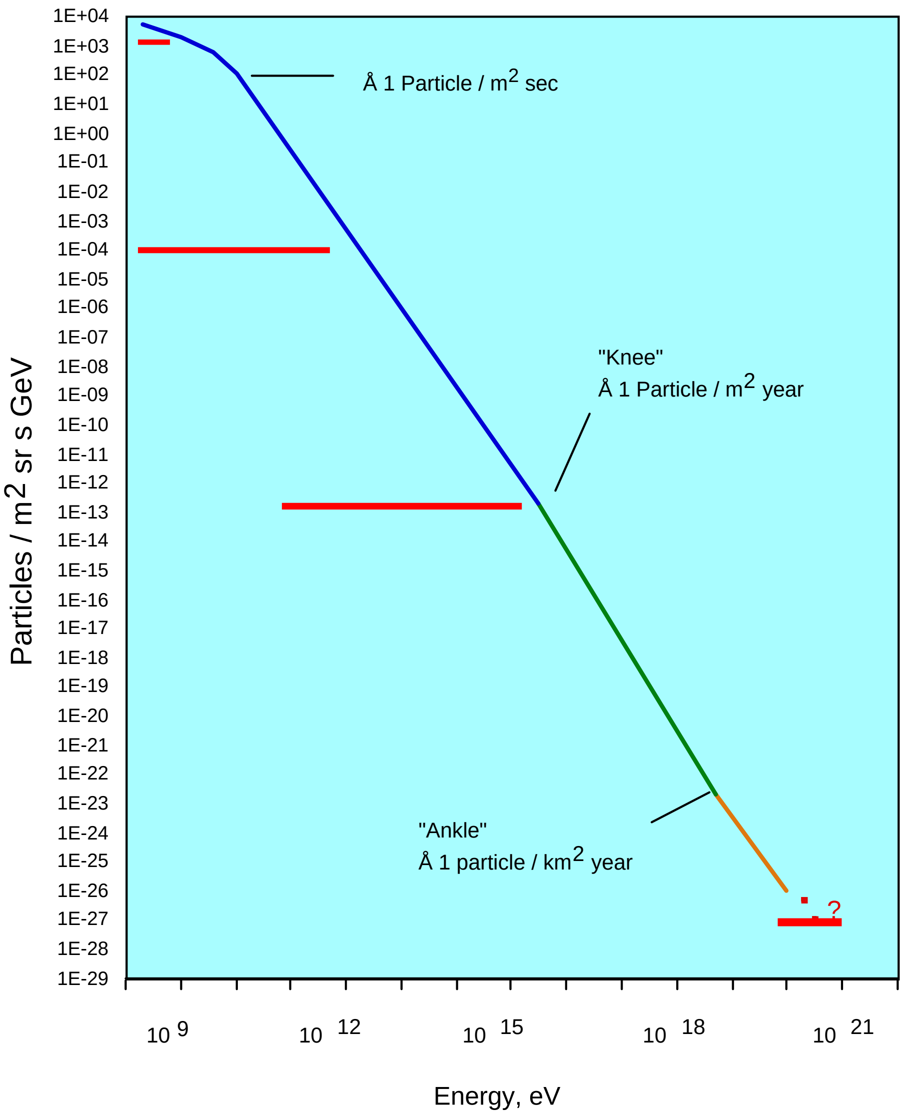
AMS-02

ACCESS

OWL

EUSO

All Particle Cosmic Ray Flux



The ISS “Problem”

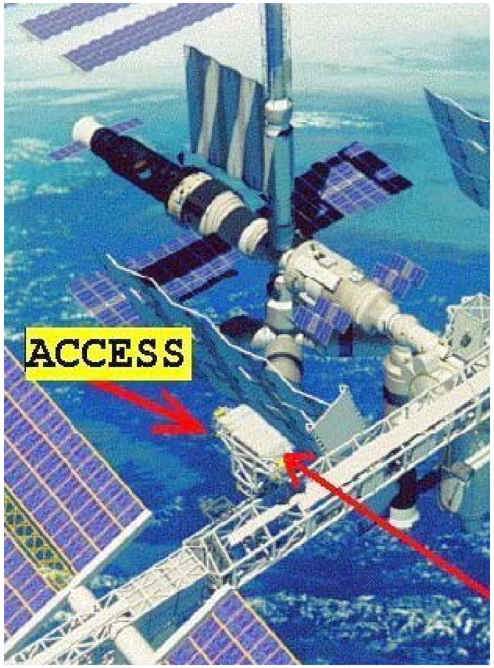
HNX (ENTICE)

AstroMag

ACCESS

AMS-02

EUSO



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