The Global Light System (GLS) for JEM-EUSO

Fred Sarazin (fsarazin@mines.edu)
Colorado School of Mines

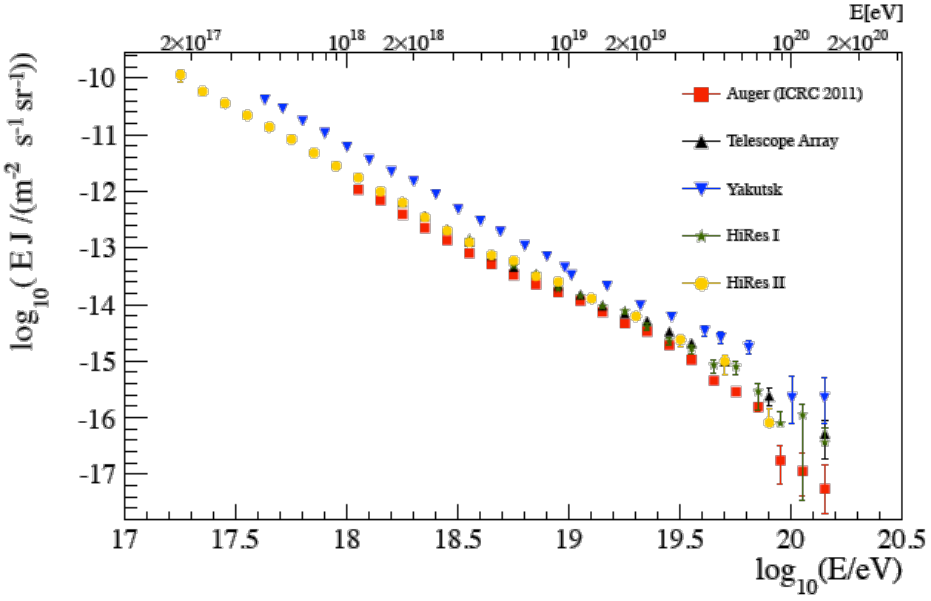
OUTLINE

- Ultra High Energy Cosmic Rays (UHECR)
- The Extreme Universe Space Observatory mission
- The Global Light System (GLS)
- Summary

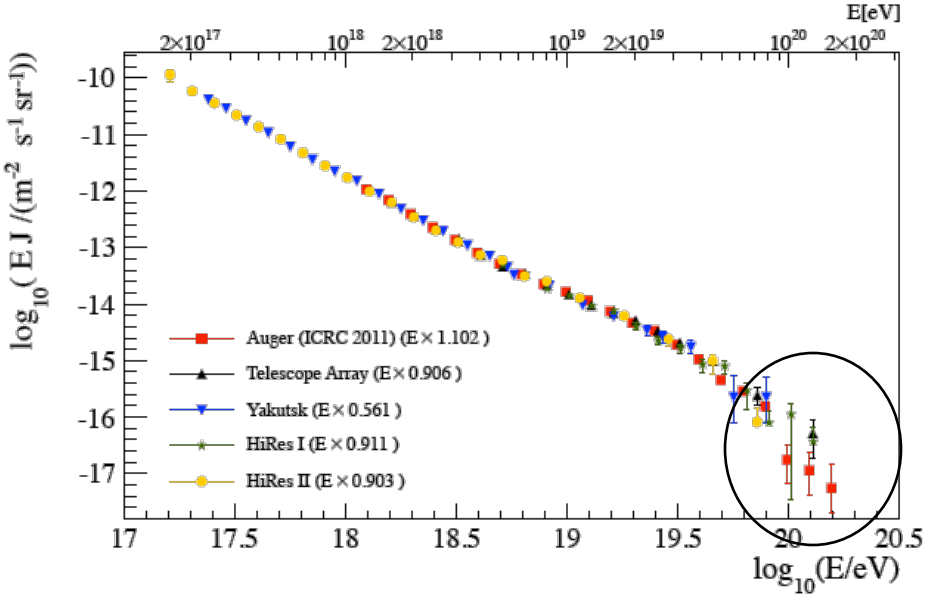
Suppression of the CR flux

"The energy spectrum of cosmic-rays at the highest energies", working group report UHECR 2012

No energy scaling



With energy scaling



GZK cut-off or sources running out of steam?

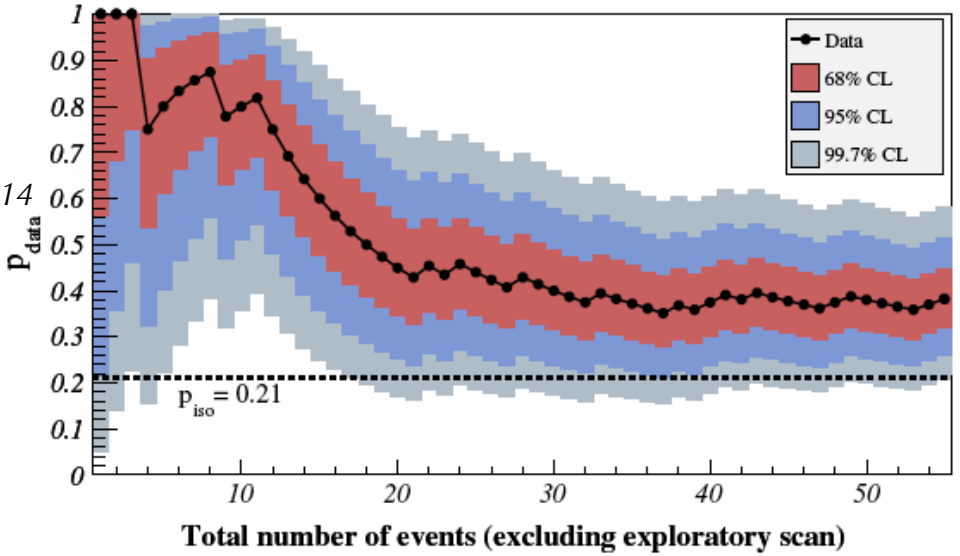
Anisotropy and Composition

- Composition
  - Auger: transition from light to heavy composition at the highest energy
  - HiRES / TA: light composition throughout UHECR energy range

- Anisotropy
  - Auger: evidence for anisotropy correlated with AGN / matter distribution across the super-galactic plane
  - HiRES / TA: no significant anisotropy observed

Fraction of events correlating with nearby VCV AGNs

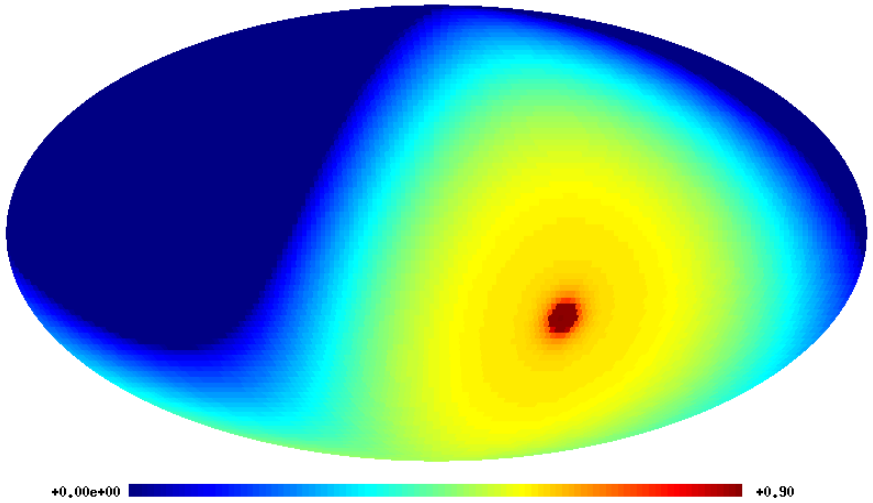
Pierre Auger Collaboration, Astropart. Phys. 34 (2010) 314



In the UHECR business, exposure is key

HOW MANY EVENTS ABOVE >55EeV?

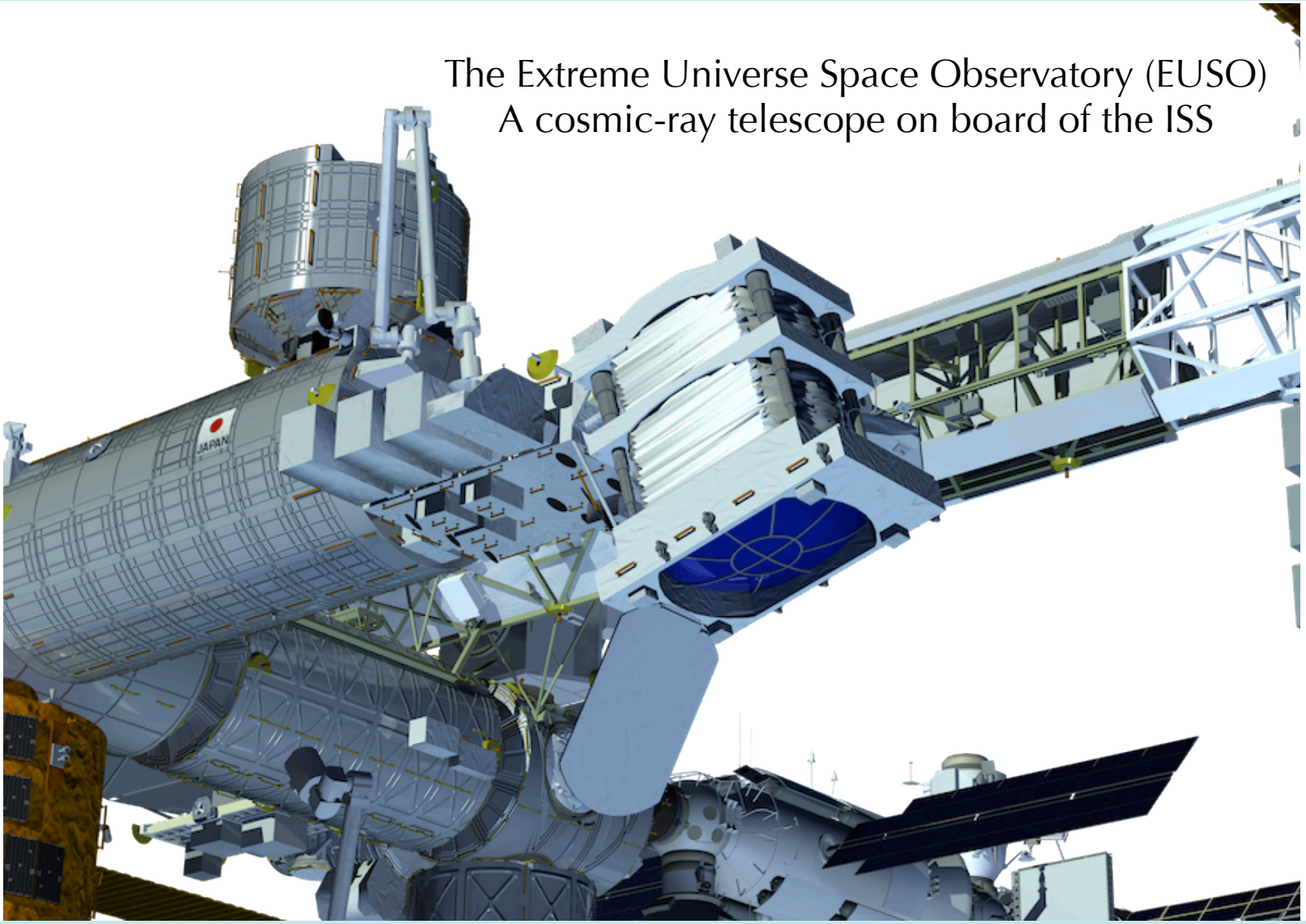
- Auger w/ 3,000 km^2 (Annual Exposure = 6,000 km^2 sr yr)
  - ~20 events > 55 EeV/ yr
  - ~ 1 events > 100 EeV/ yr
- Telescope Array w/ 700 km^2 (Annual Exposure ~ 1,400 km^2 sr yr)
  - ~5 events > 55 EeV/ yr



No UHECR single experiment has achieved full sky coverage

Space… the final frontier

The Extreme Universe Space Observatory (EUSO)
A cosmic-ray telescope on board of the ISS

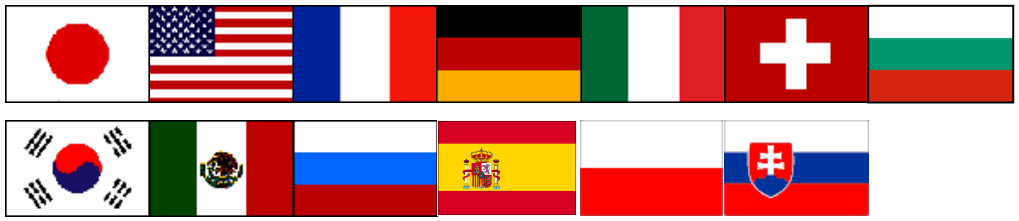


Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

The JEM EUSO Collaboration

13 Countries, 77 Institutions, more than 280 researchers

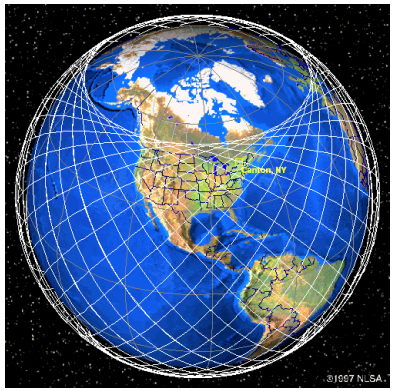
Asia:	Japan, Korea, Russia
America:	USA, Mexico
Europe:	Bulgaria, France, Germany, Italy, Poland, Slovakia, Spain, Switzerland



RIKEN (Japan): Leading institution

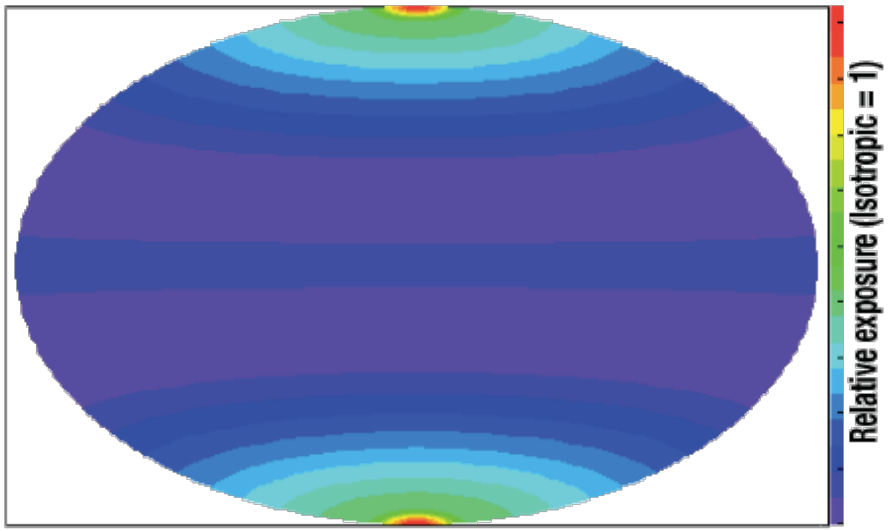
Full Sky Coverage

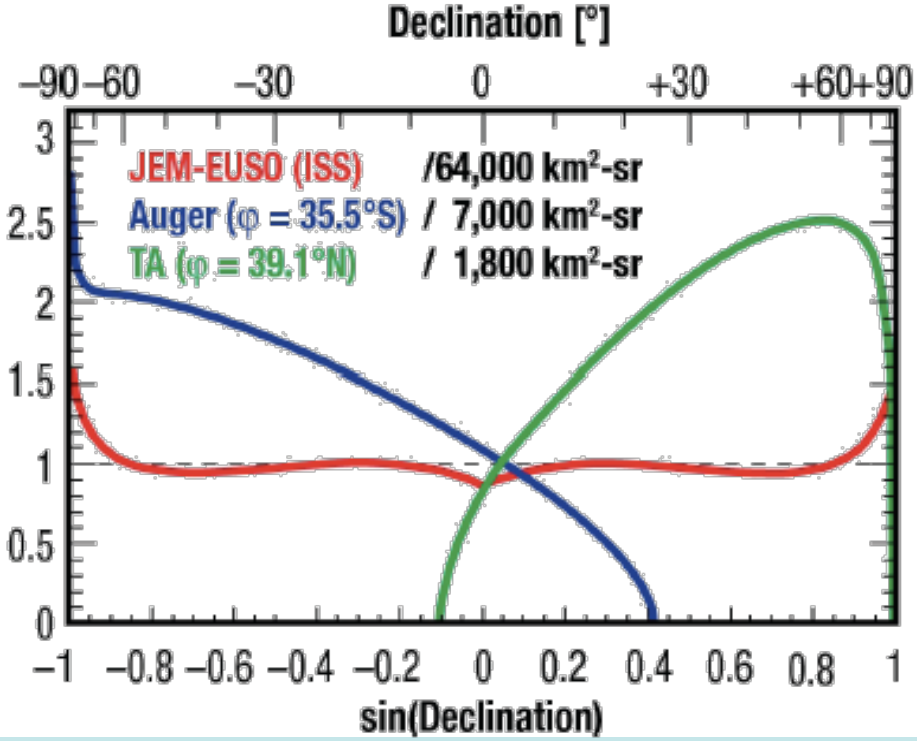
ISS trajectory
Inclination: 51.6°
Altitude: 350-400km



Near uniform exposure with a single detector

JEM-EUSO exposure
ε=100% at 100 EeV and 80% at 55 EeV
~160 events > 55 EeV/ yr
~ 10 events > 100 EeV/ yr





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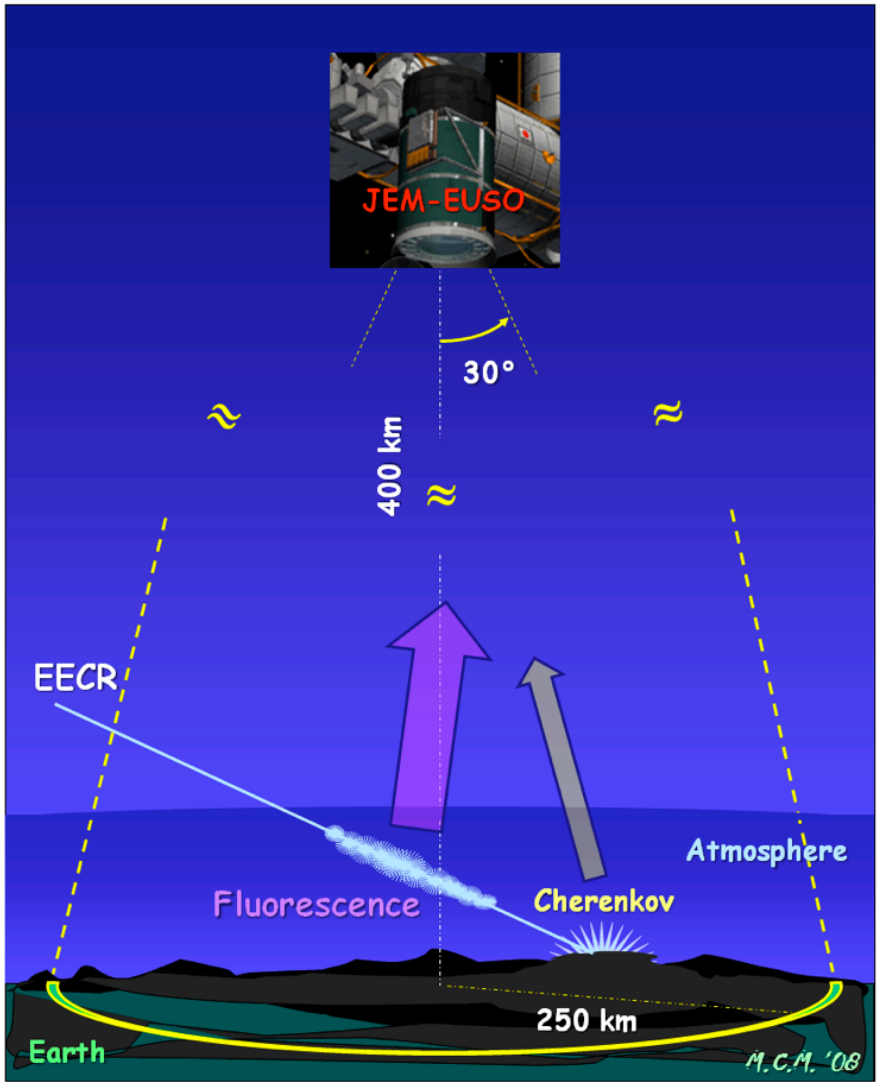
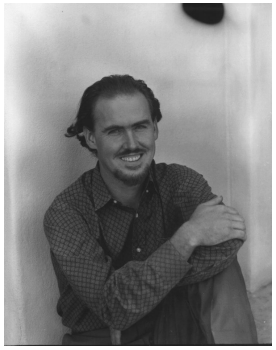
Physics Department, Colorado School of Mines

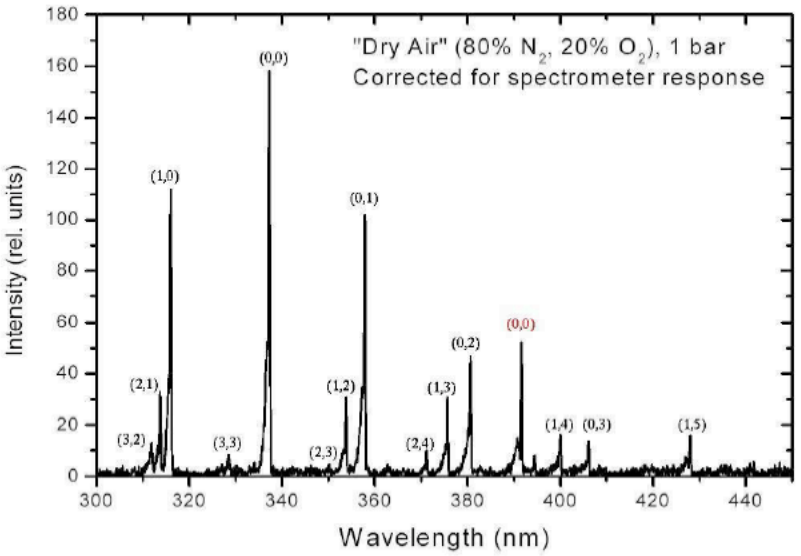
Observational technique: fluorescence from space





J. Linsley

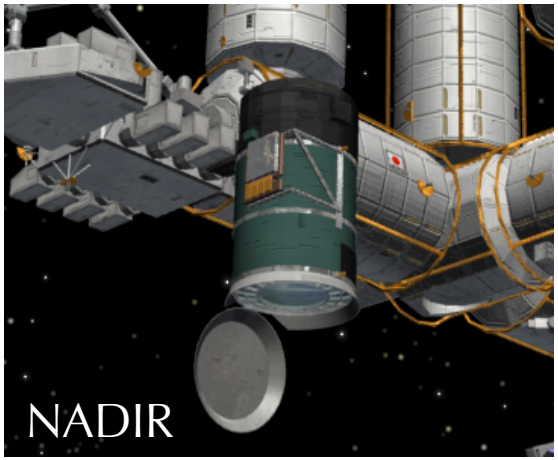
Y. Takahashi

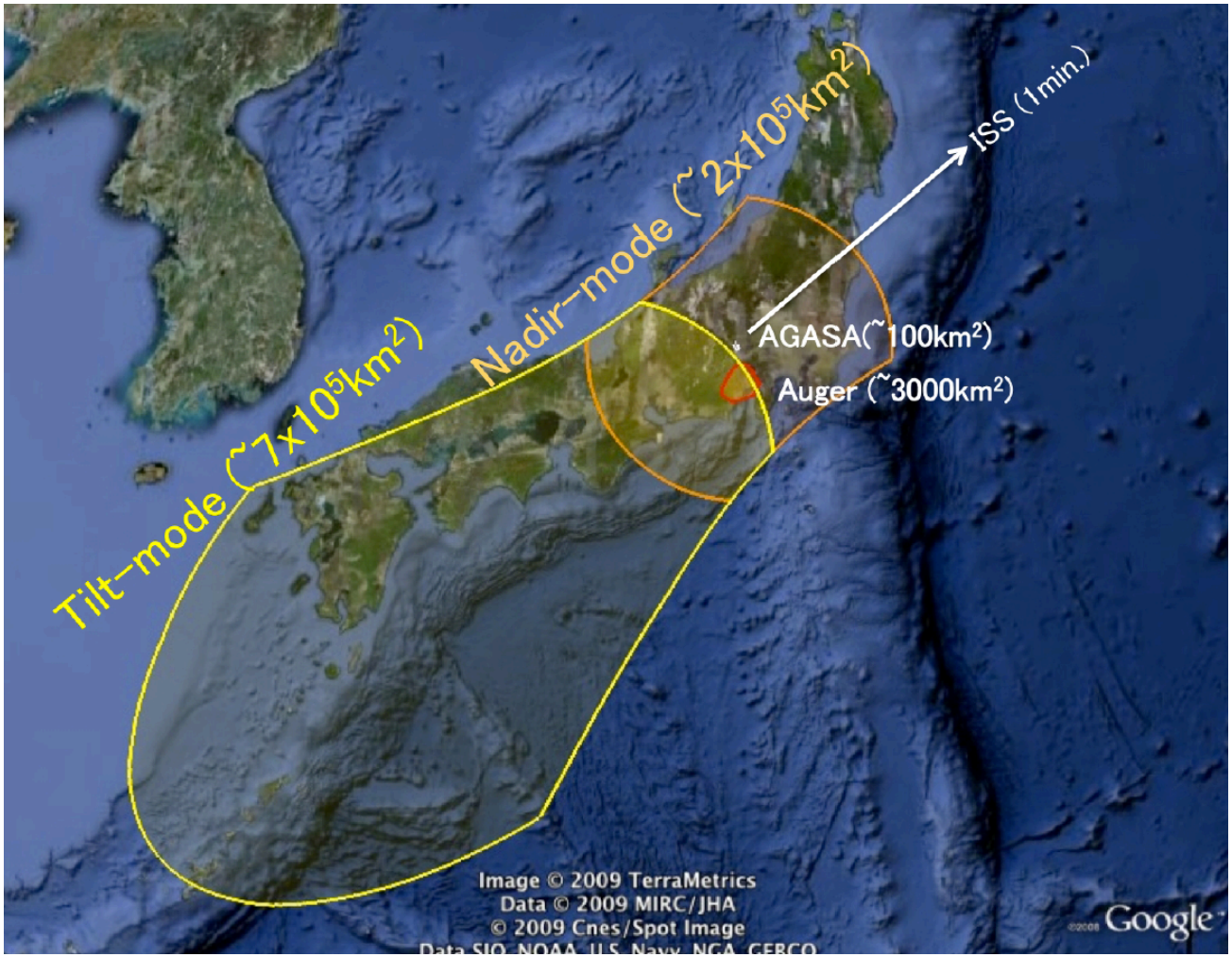


330-400 nm, UV

Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

Coverage

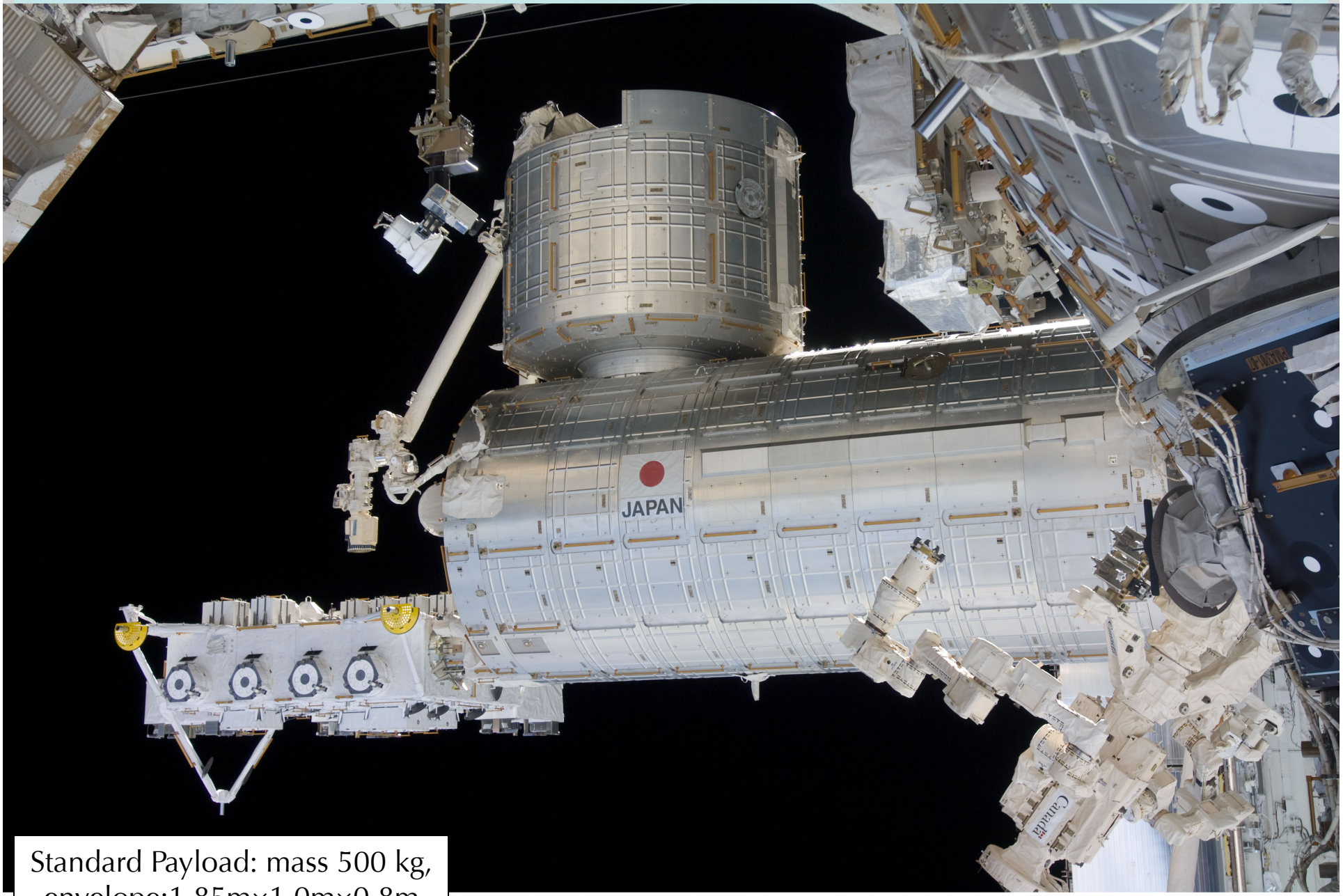




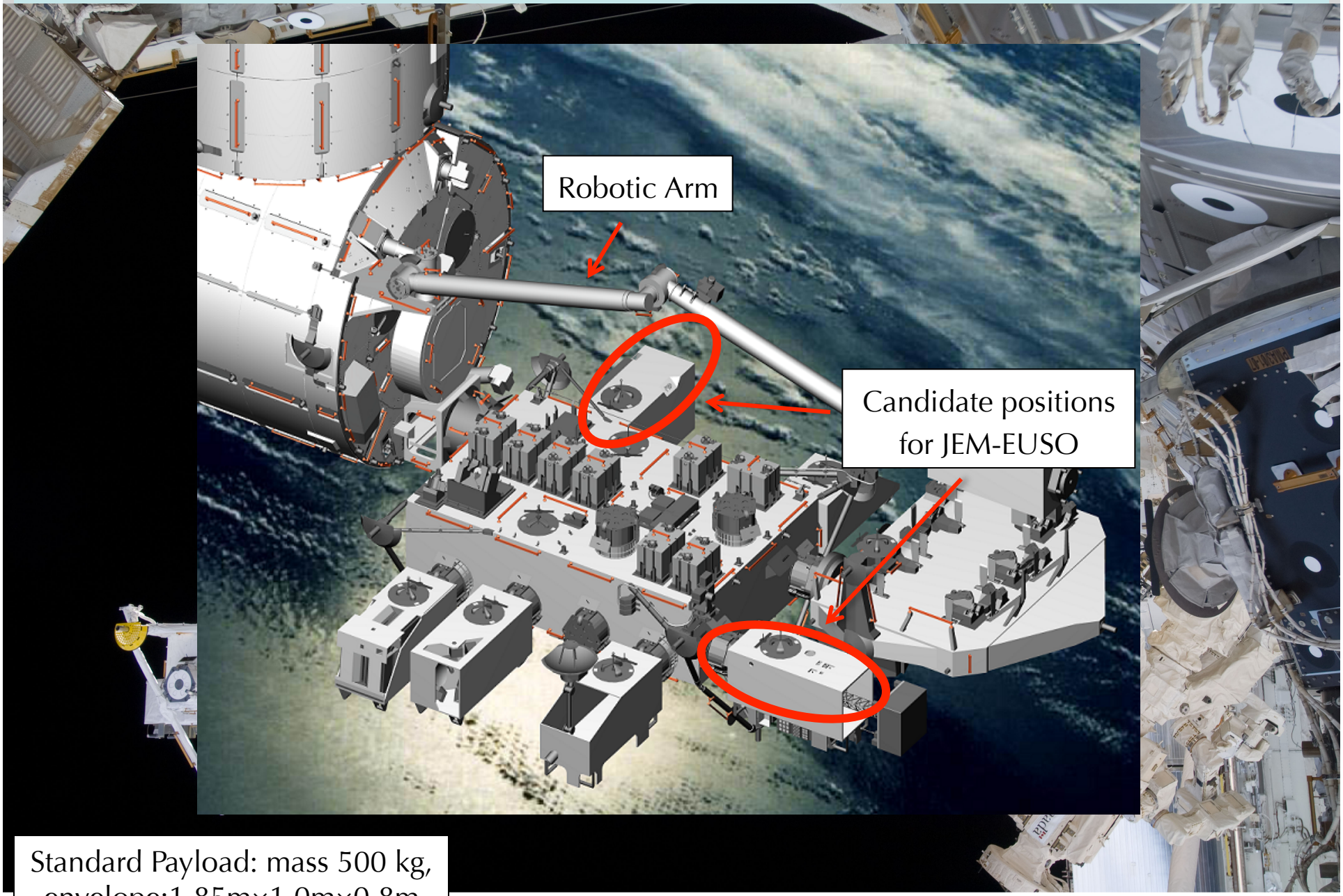
Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

きぼう, Hope

Japanese Experiment Module
"Kibo" July 2009

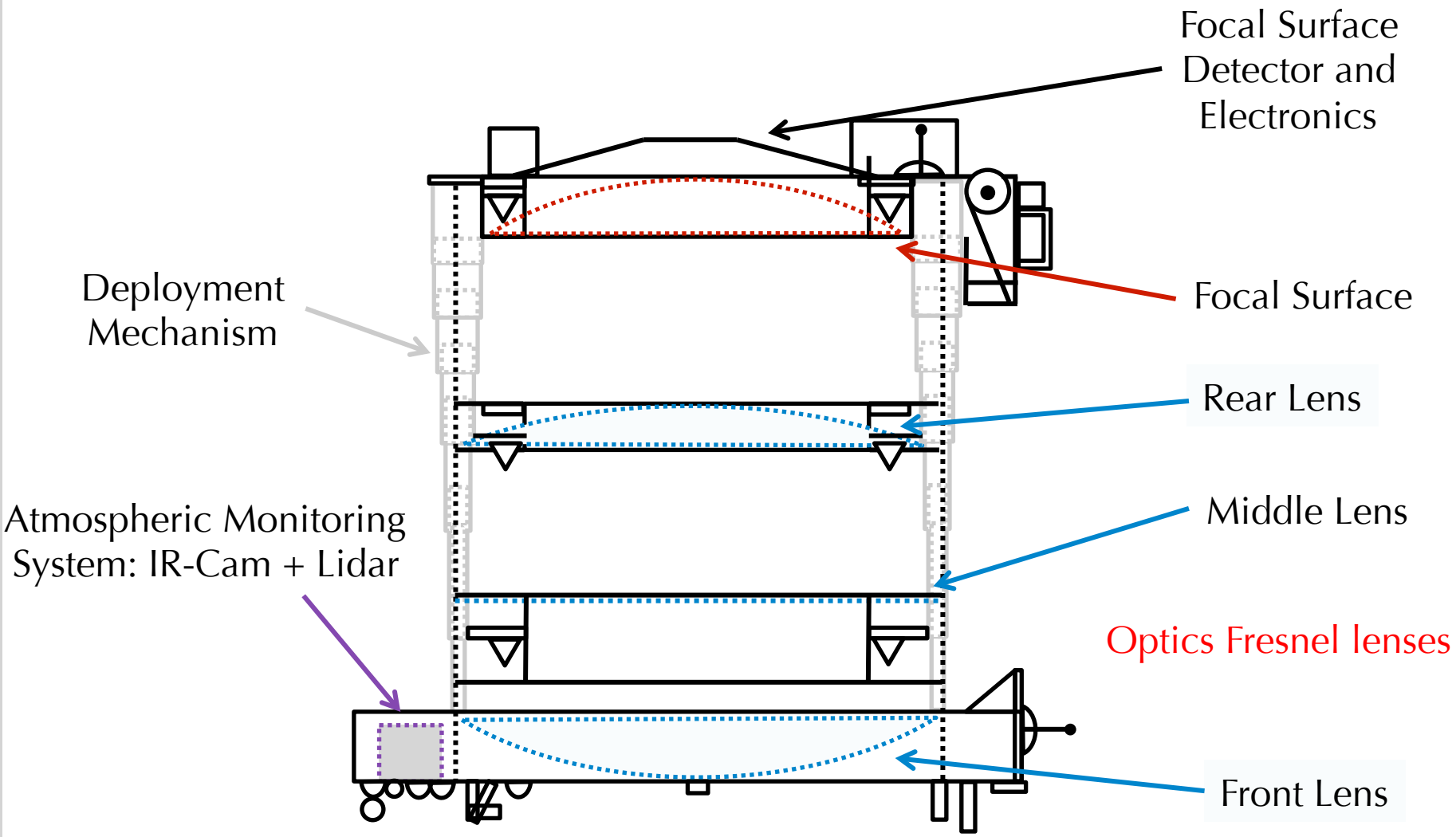


Standard Payload: mass 500 kg,
envelope:1.85m×1.0m×0.8m



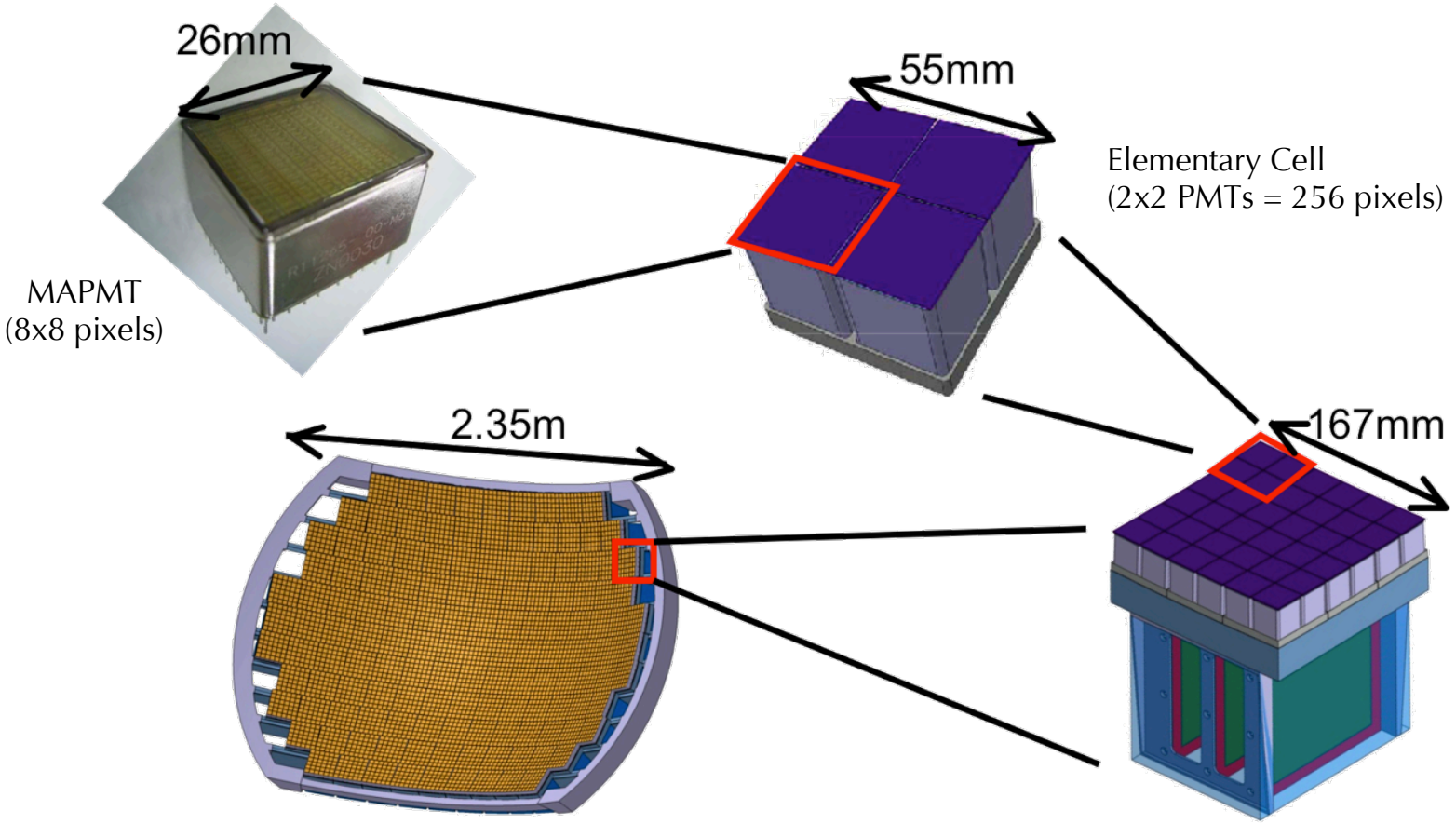
Standard Payload: mass 500 kg,
envelope:1.85m×1.0m×0.8m

Schematic of the telescope



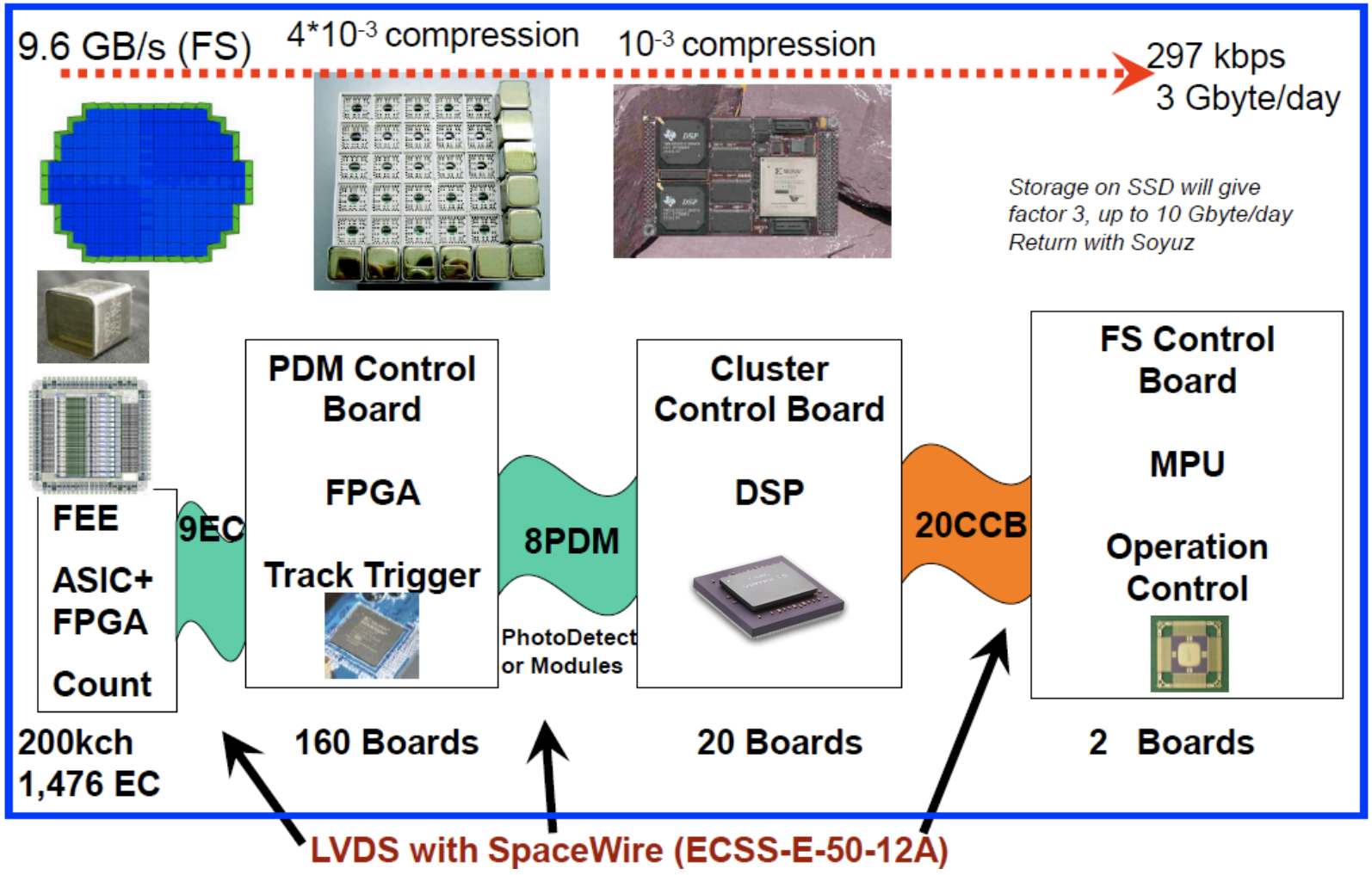
Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

The focal surface detector



Serious challenges: trigger & data compression

JEM-EUSO DAQ – Data reduction block scheme



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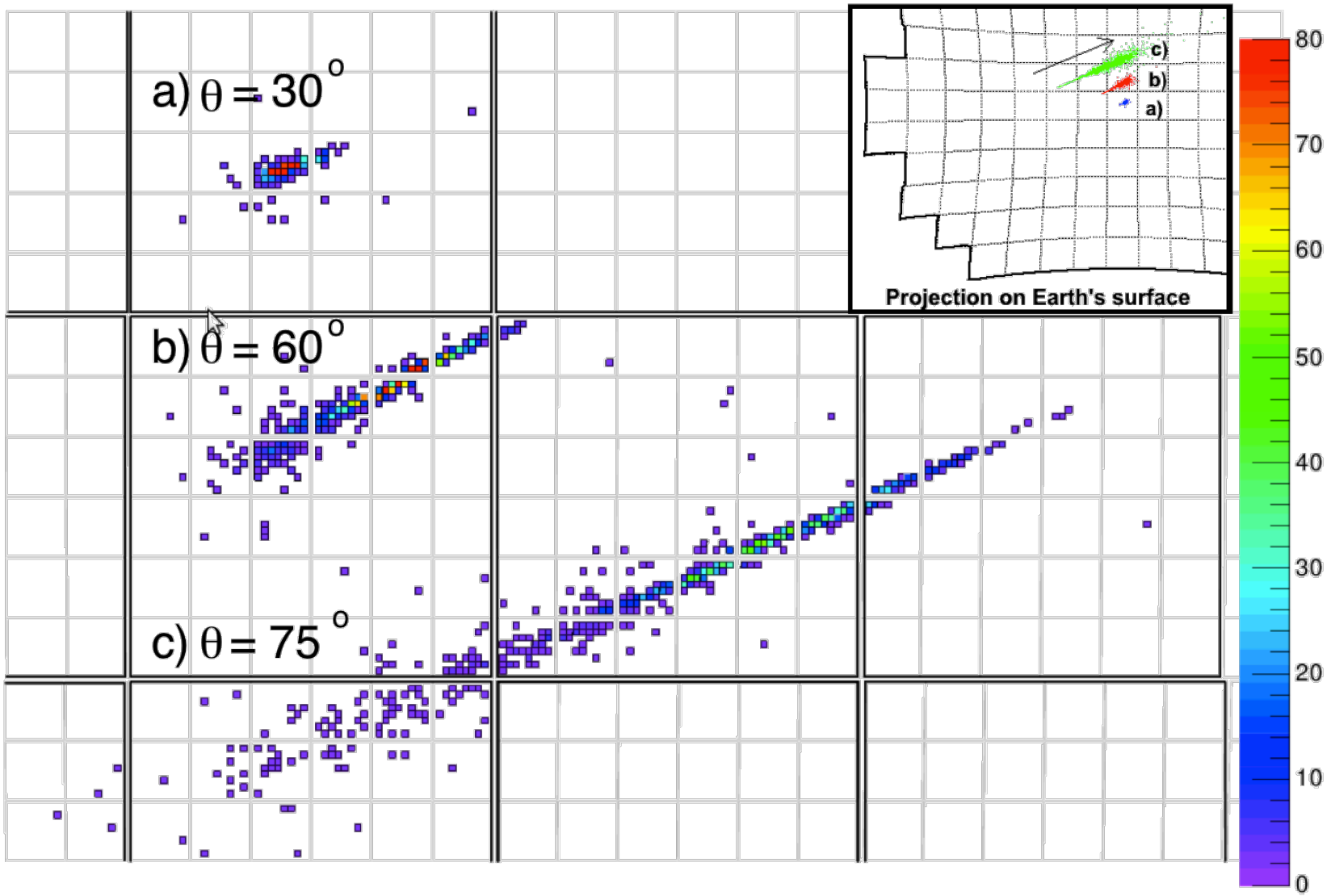
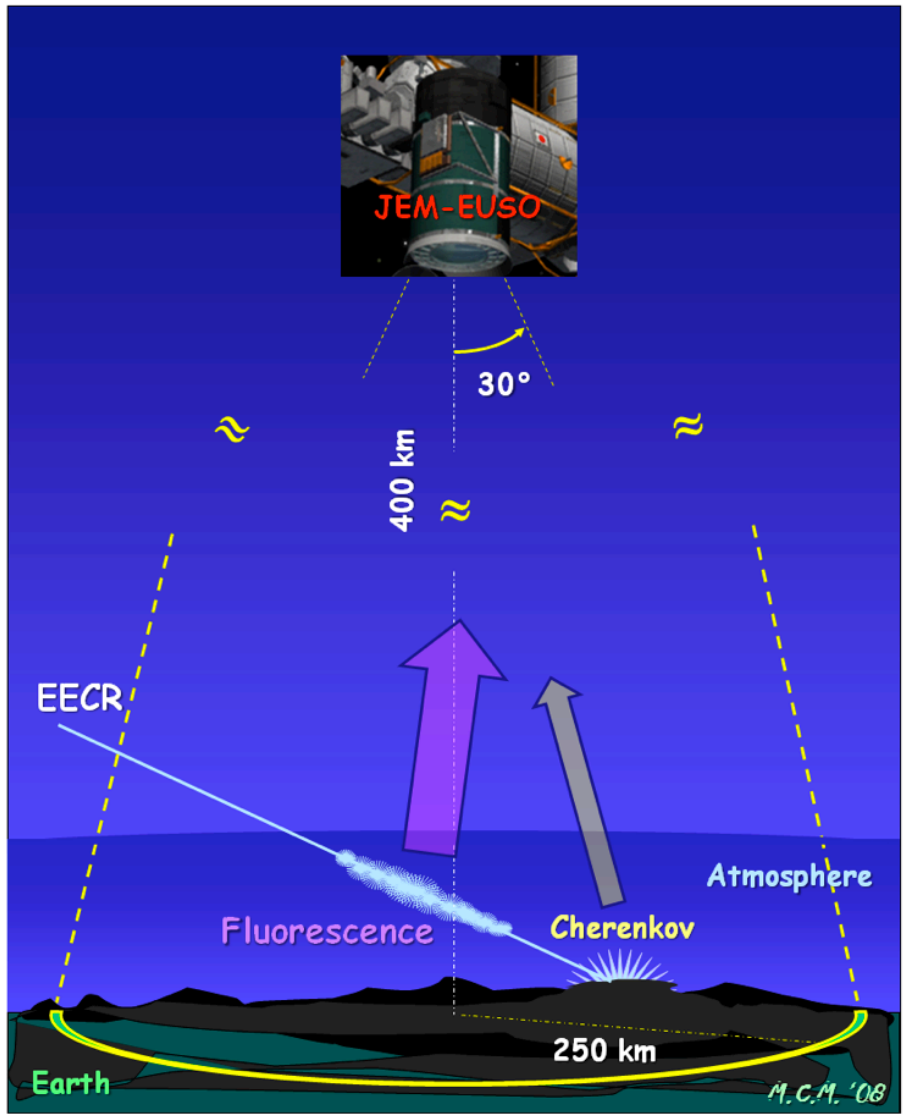
Physics Department, Colorado School of Mines

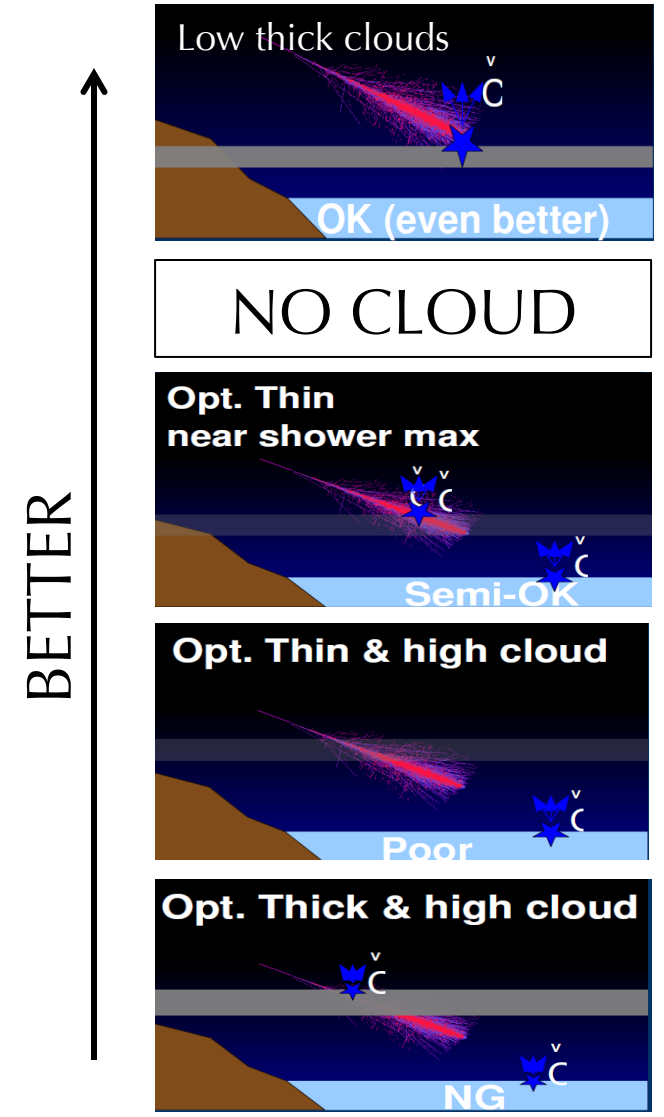
Cosmic-ray showers seen from space (end-to-end simulation)



Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

EECR detection and atmospheric conditions

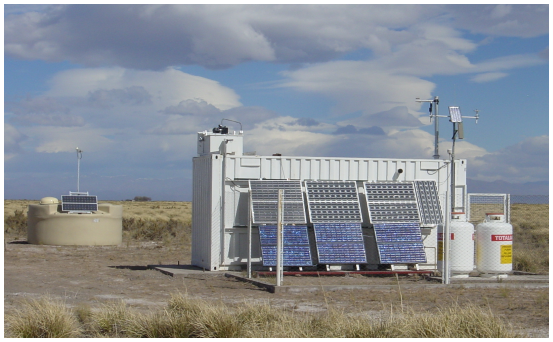




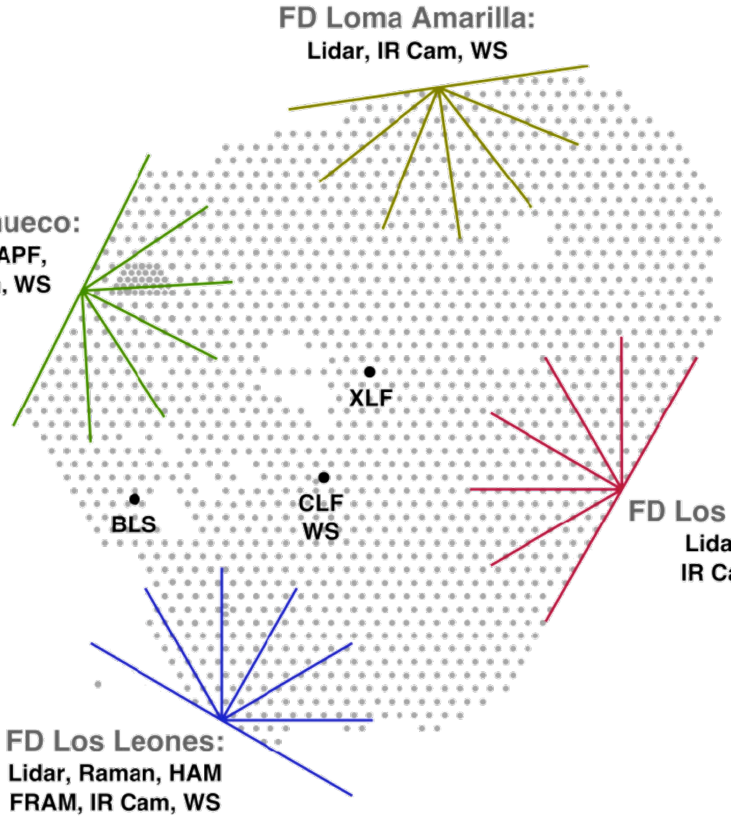
Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

"Know your detector": Atmospheric monitoring!

LIDAR

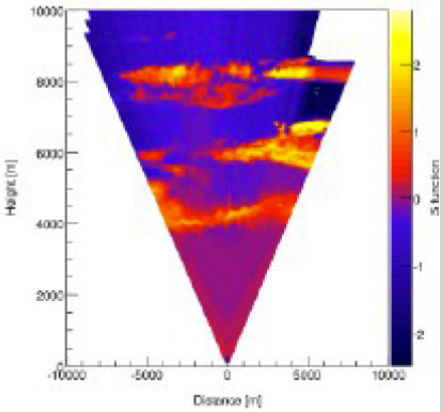


Central Laser Facility (CLF)
eXtreme Laser Facility (XLF)



Weather balloon

Cloud camera



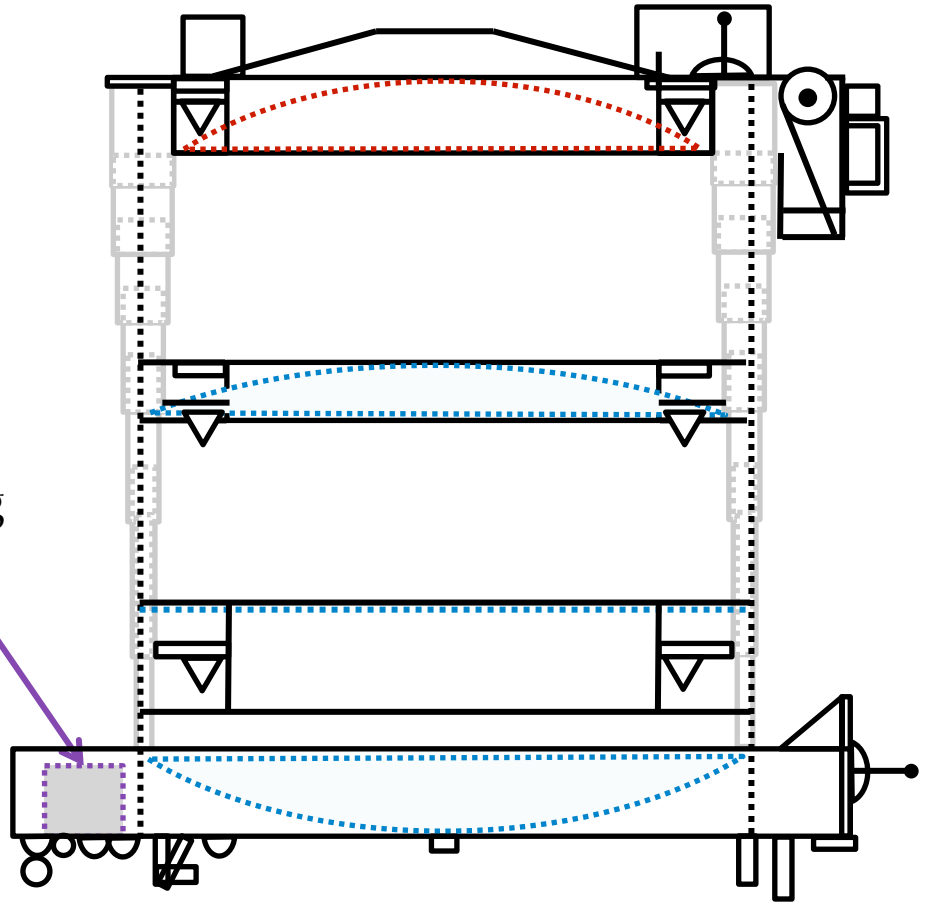
+ GDAS and satellite-based information

Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

On-board atmospheric monitoring

See: S.Toscano talk, "The atmospheric monitoring system of the JEM-EUSO telescope"

Atmospheric Monitoring System: IR-Cam + Lidar



The Global Light System (GLS) for JEM-EUSO

A global ground network of calibrated light sources

Objective: Benchmark JEM-EUSO throughout its mission.

Triggering: How efficiently JEM-EUSO triggers on the optical signatures of EAS and discriminates against background signals.

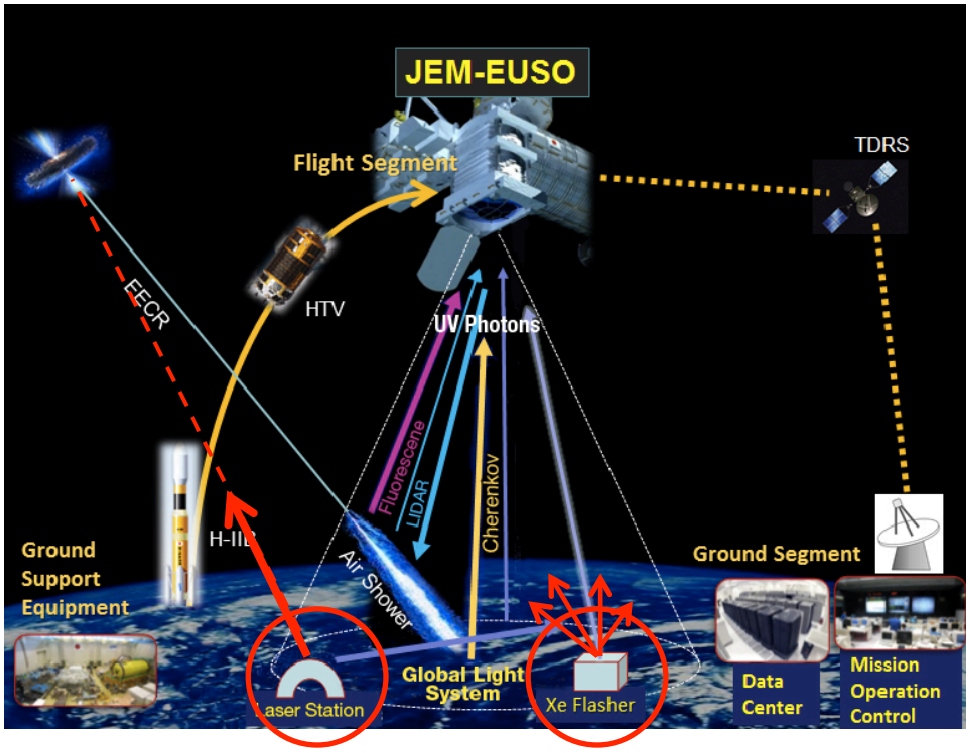
Intrinsic luminosity: How accurately JEM-EUSO measures the intrinsic luminosity of the EAS. Intrinsic luminosity is determined by applying properly the corrections for geometric, optical, timing, and atmospheric effects.

Pointing Accuracy: How accurately JEM-EUSO measures the arrival direction of the EAS over the entire sky

→ Not really atmospheric monitoring issues… but the GLS principles borrow very heavily on establish monitoring techniques, i.e. laser and flashers.

The Global Light System (GLS) for JEM-EUSO

- Calibration of JEM-EUSO by injecting a similar amount of UV light into the atmosphere to mimic EASs
  - Ground stations: CLF / XLF-like laser stations and Xenon flashers



12 GLS Ground stations
6 Laser + Flashlamps
6 Flashlamps only

1 Airborne system
A few flights per year(?)

NASA grant: GLS funded!

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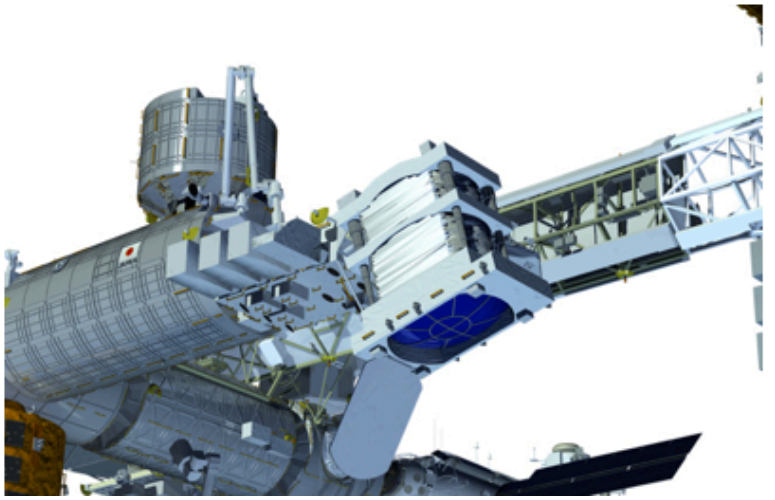
Mines part of $4.4M NASA grant to detect cosmic rays

GOLDEN, Colo., March 6, 2013 – Colorado School of Mines will participate in a $4.4 million NASA grant that will help researchers develop a telescope to be deployed on the International Space Station to detect extreme energy cosmic rays.

The Extreme Universe Space Observatory on board the Japanese Experiment Module (JEM-EUSO) is the first mission devoted to detect extreme energy cosmic rays – particles whose origin remain unknown – from space. The telescope, which is expected to be deployed in 2017, will measure the properties of these cosmic rays by recording the UV light produced by the air showers they produce in the Earth's atmosphere.

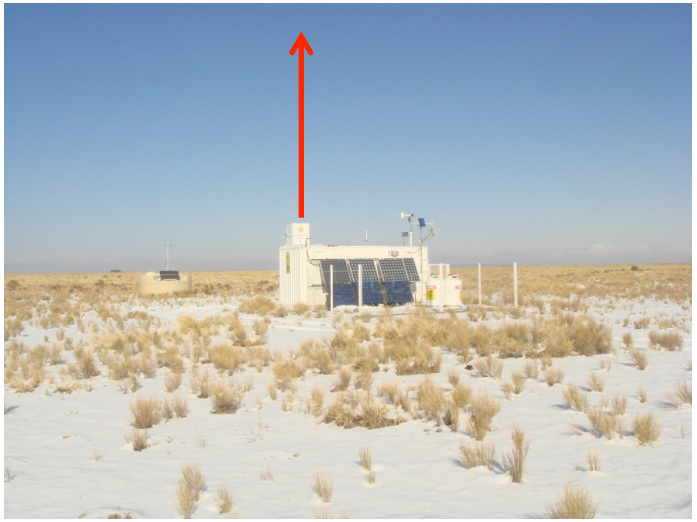
NASA selected Mines, along with partners at NASA's Marshal Space Flight Center and the University of Alabama, Huntsville, to design and develop a global network of light flashers and lasers These ground based light sources will be used to benchmark and monitor the observatory as it orbits the earth.

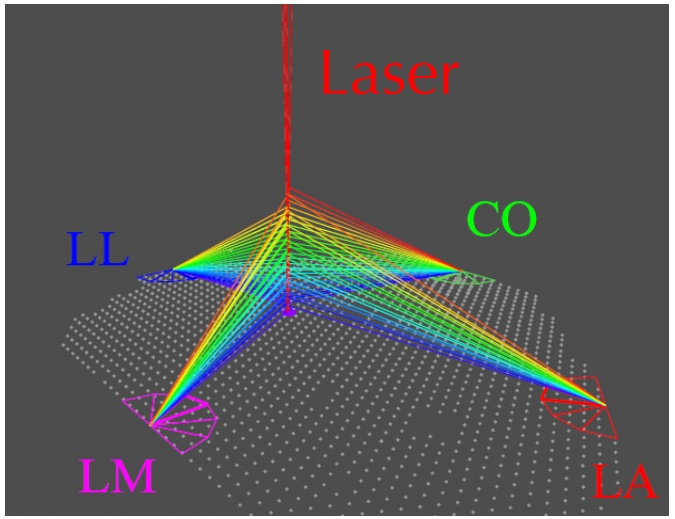
The Mines group, led by Physics Associate Professors Lawrence Wiencke (principal investigator) and Fred Sarazin, will help select suitable locations around the world and develop, install and maintain the laser stations of the Global Light System (GLS) array.

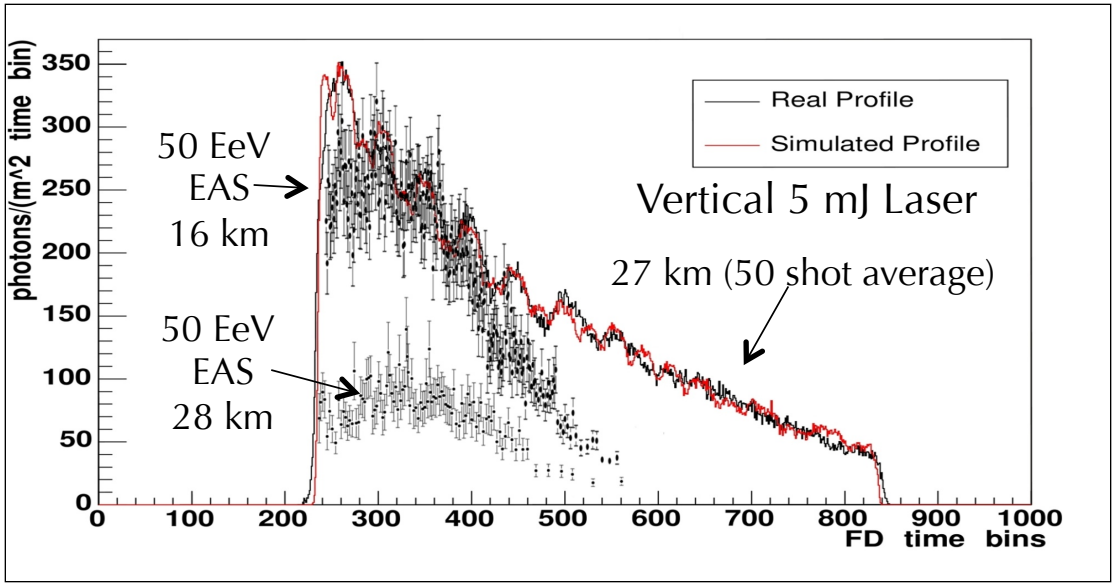


Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

The CLF / XLF at the Pierre Auger Observatory







Optical Equivalence:
5 mJ Laser Track~100 EeV EAS track
λ=357nm

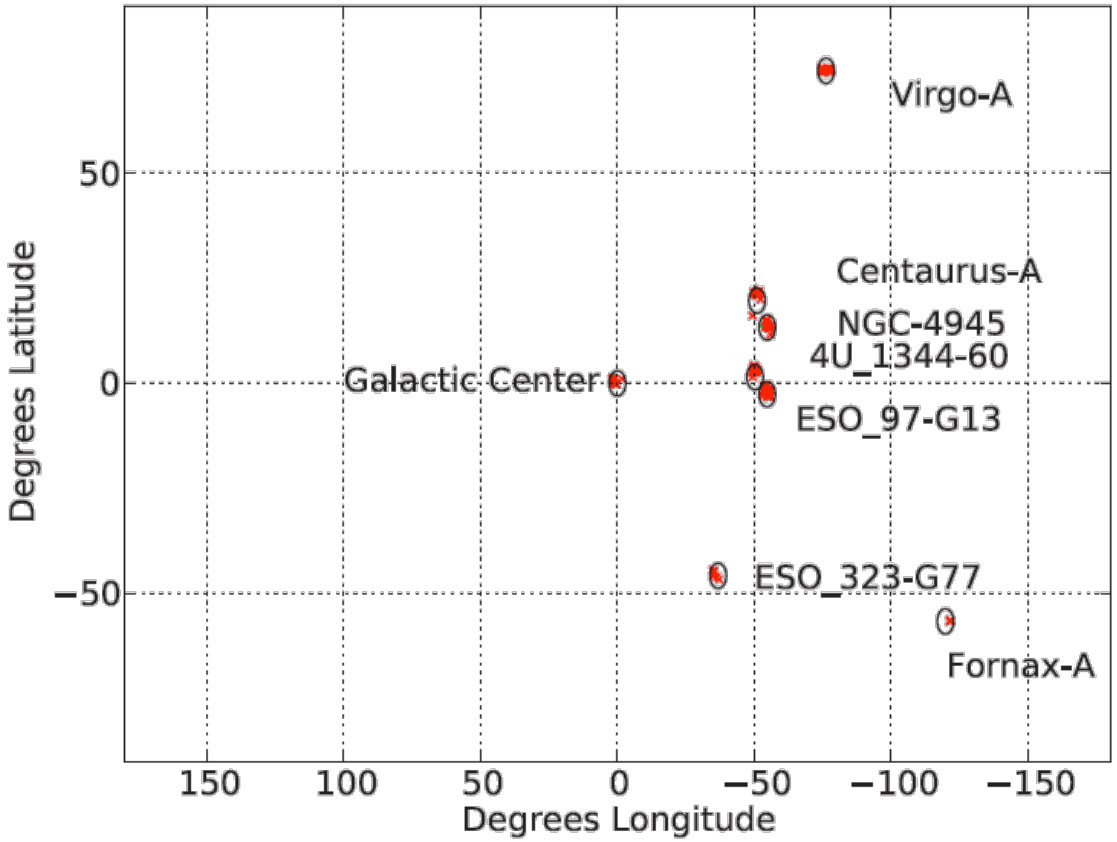
FD records ~ 500 laser tracks/hour

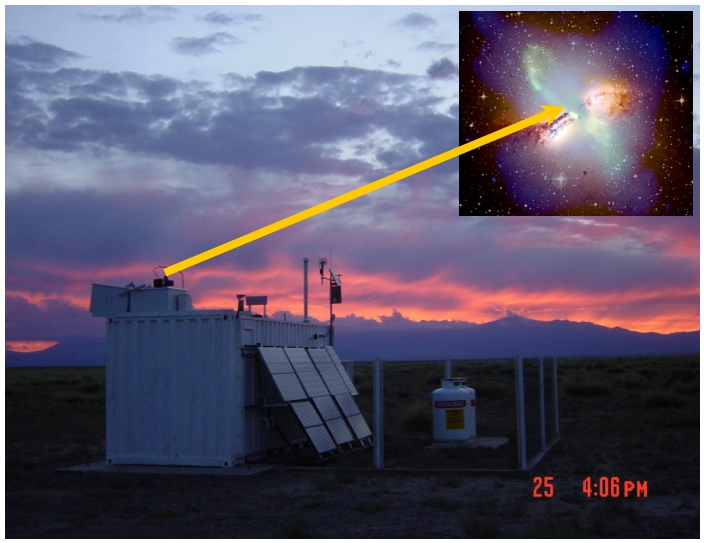
Applications:
Photometric Calibration
Timing, Pointing, Triggering,
Atmospherics

Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

Shoot-the-Sources

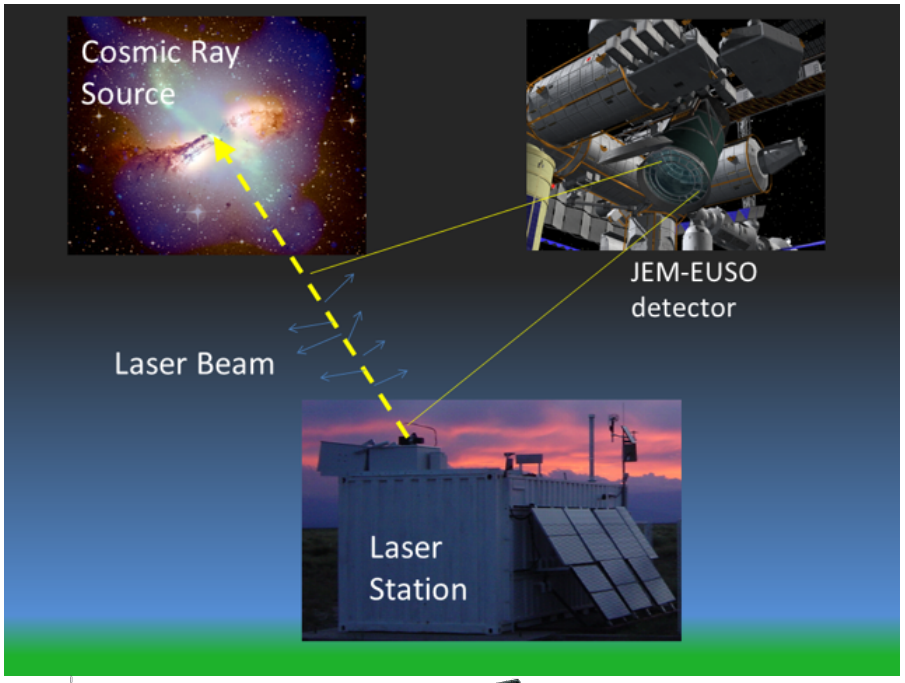
Using the laser as an optical test beam

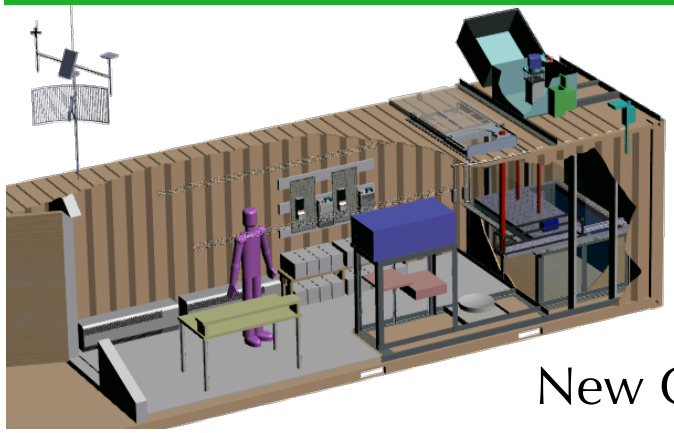




Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

Ground light system (GLS)





New CLF @ Auger

LASER & XENON FLASHERS

- Calibrated
- Remotely operated
- Programmable
- Reliable

LASER:

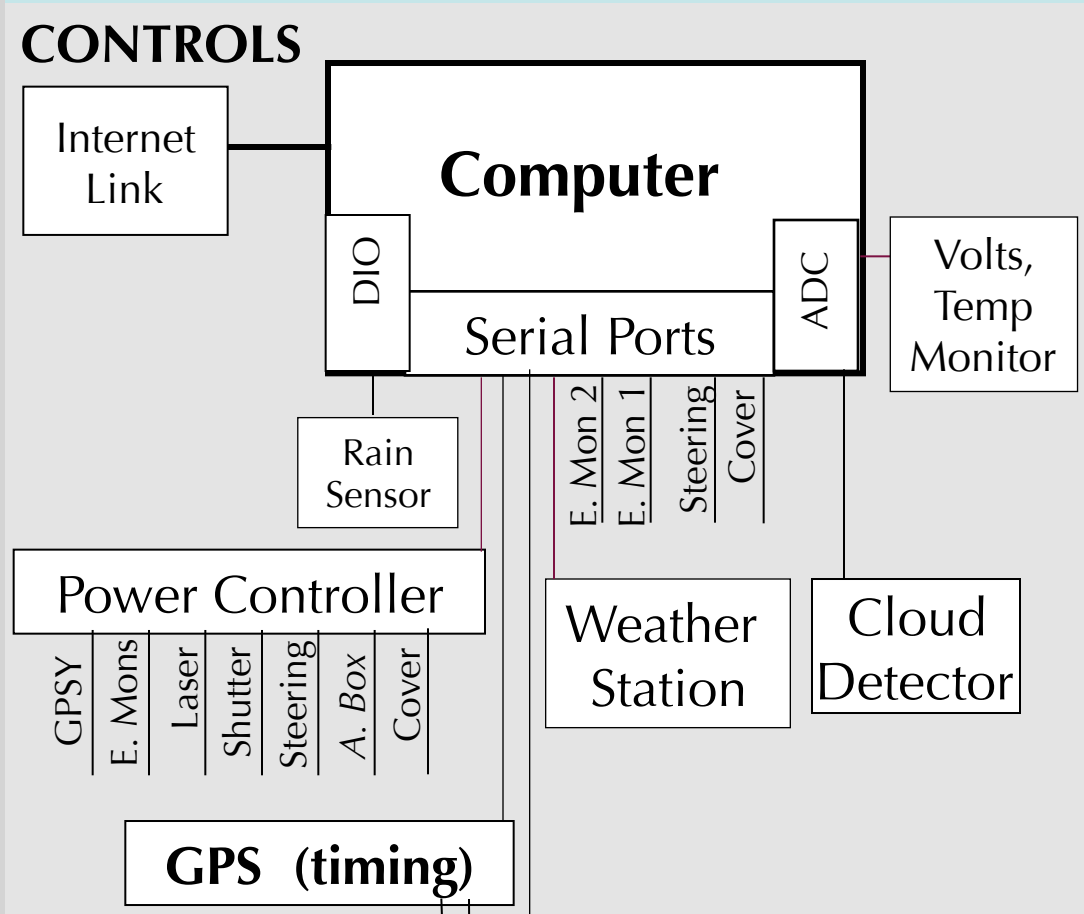
- Steerable

ADD-ON POSSIBLE:

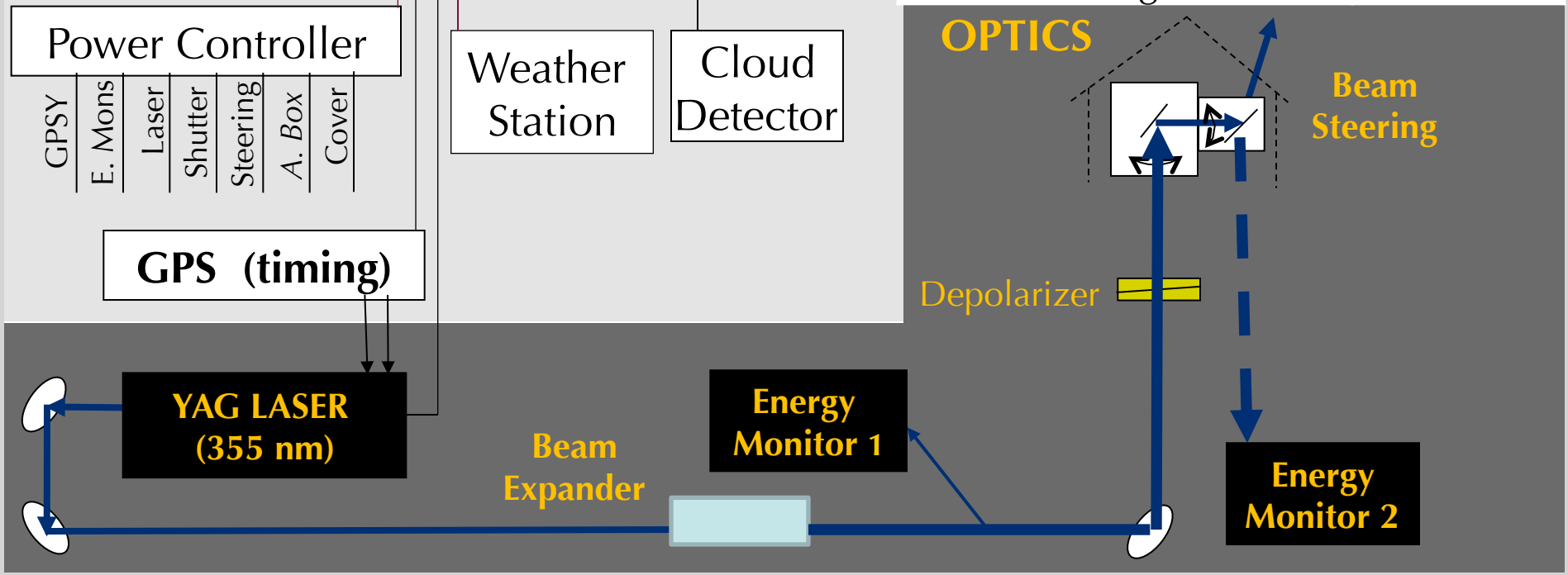
- Atmospheric monitoring!

Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

JEM-EUSO GLS Laser System

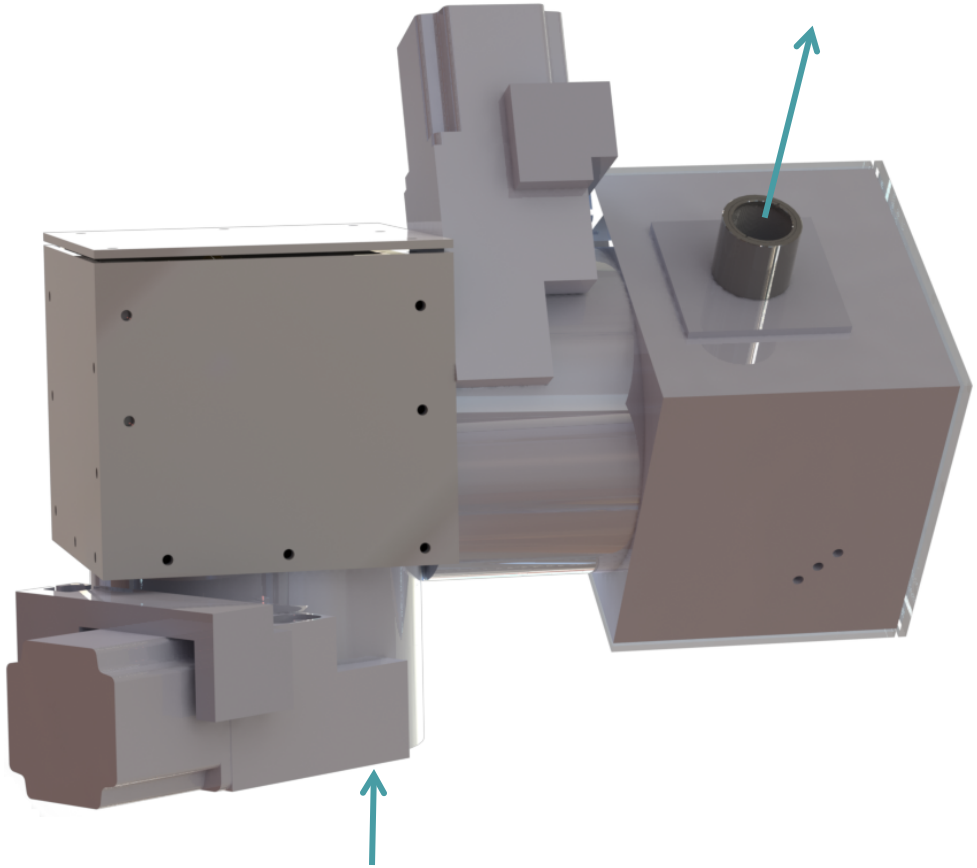


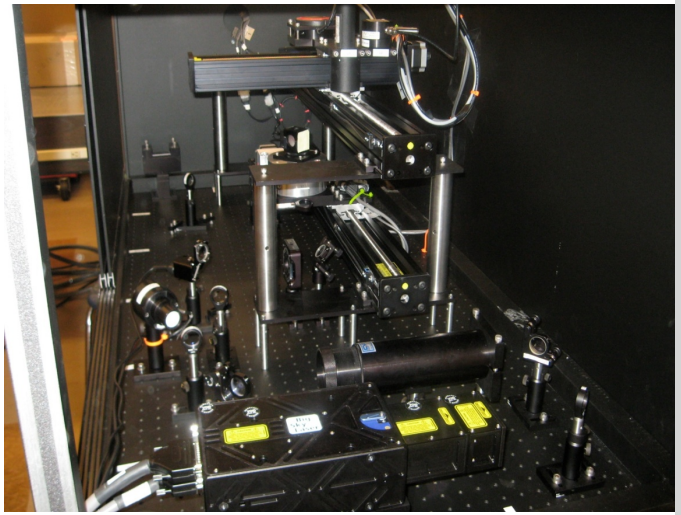
Parameter	Specs
Wavelength	355 nm
Energy/pulse	1-10 mJ
Pulse Width	10 ns
Energy Calib. (relative)	3%
Energy Calib. (absolute)	5-10%
Pointing (relative)	0.02 deg.
Pointing (absolute)	0.2 deg
Timing (Absolute)	50 ns

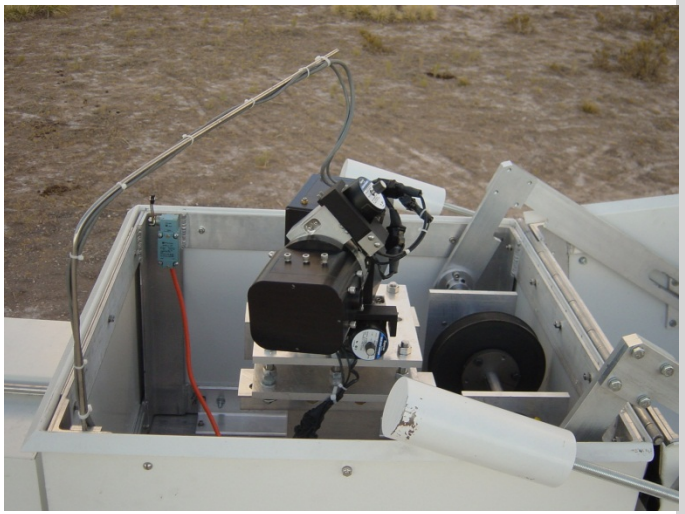


GLS Beam steering mechanism redesign

Jeremy Bogulski and Tyler Horvath
Senior Design Project, Colorado School of Mines
Sept 2012-April 2013



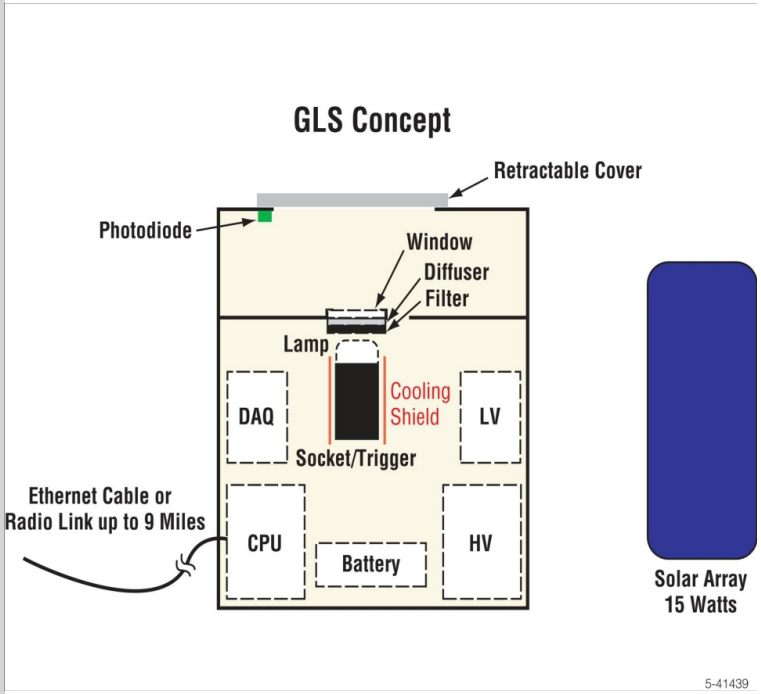


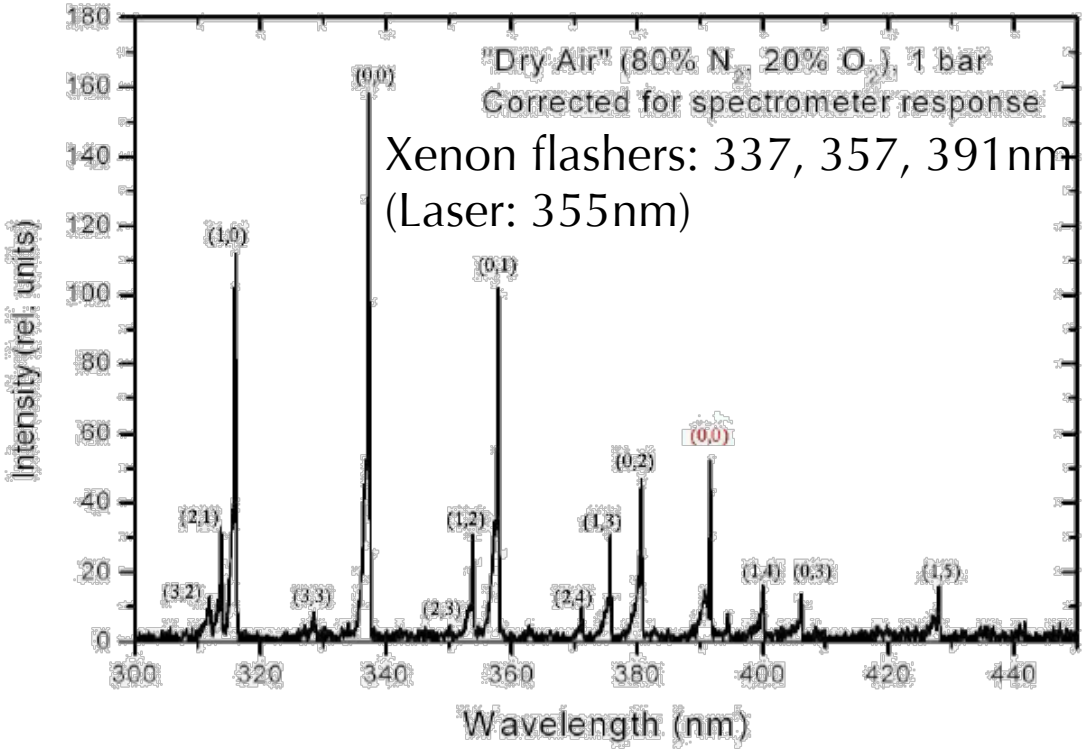


Pierre Auger System

Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

Xenon Flashers



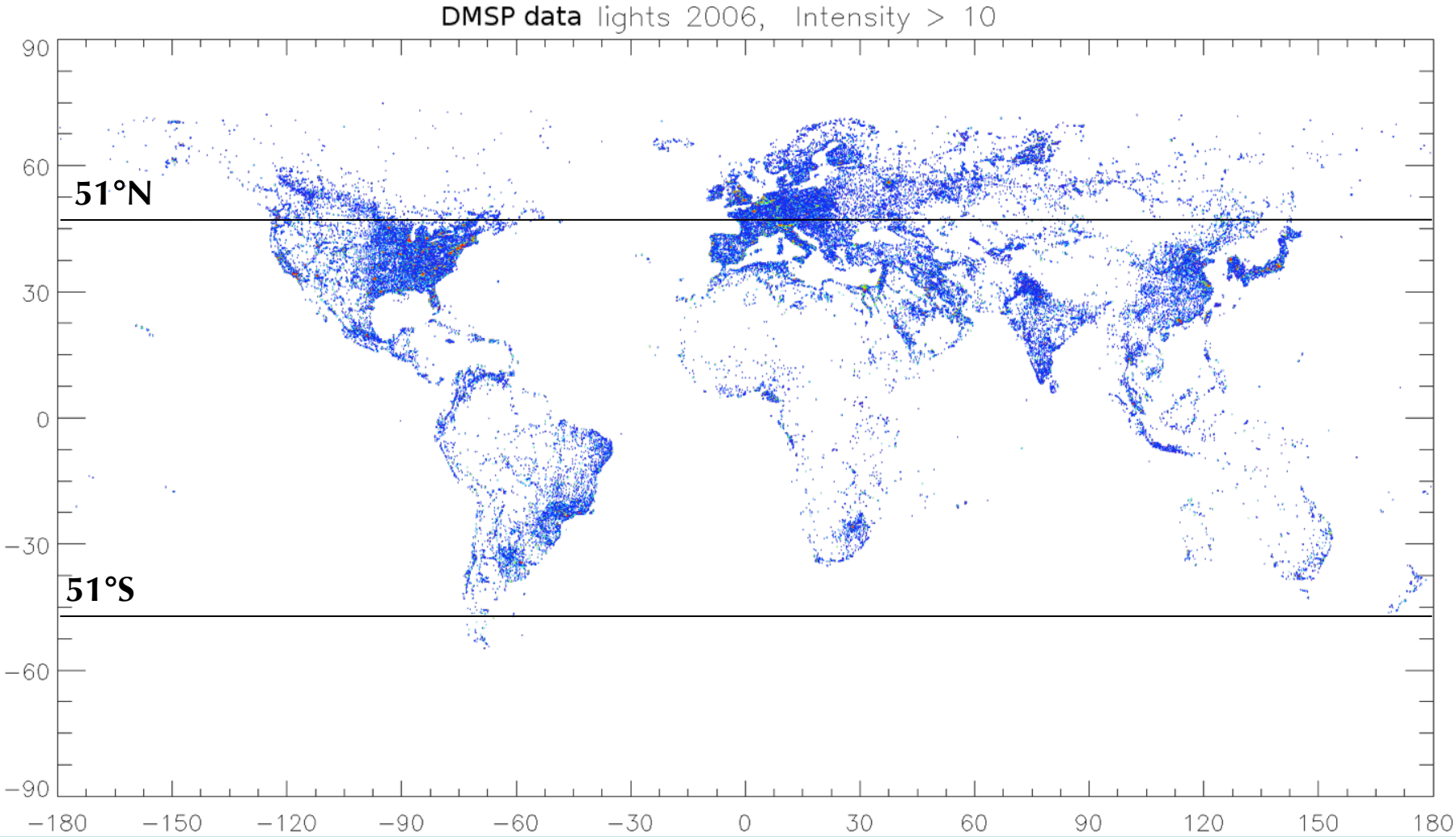


- The flashers will test:
  - Measurement of EAS luminosity
  - Focal spot size
- Design in progress…

Xenon flashers
Hamamatsu L6604
240-2000nm

Site selection / City light

Intensity > 2000 ph/m^2/ns/sr (9% of FoV)



Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

Average cloud coverage

Cloud top

Optical Depth	<3 km	3-7 km	7-10 km	>10 km
OD>2	17.2	5.2	6.4	6.1
OD:1-2	5.9	2.9	3.5	3.1
OD:0.1-1	6.4	2.4	3.7	6.8
OD<0.1	29.2	<0.1	<0.1	1.2

Occurence of clouds (in %) between 50° N and 50° S on TOVS database.

→ GLS locations: above 3000m better, but compromise likely needed

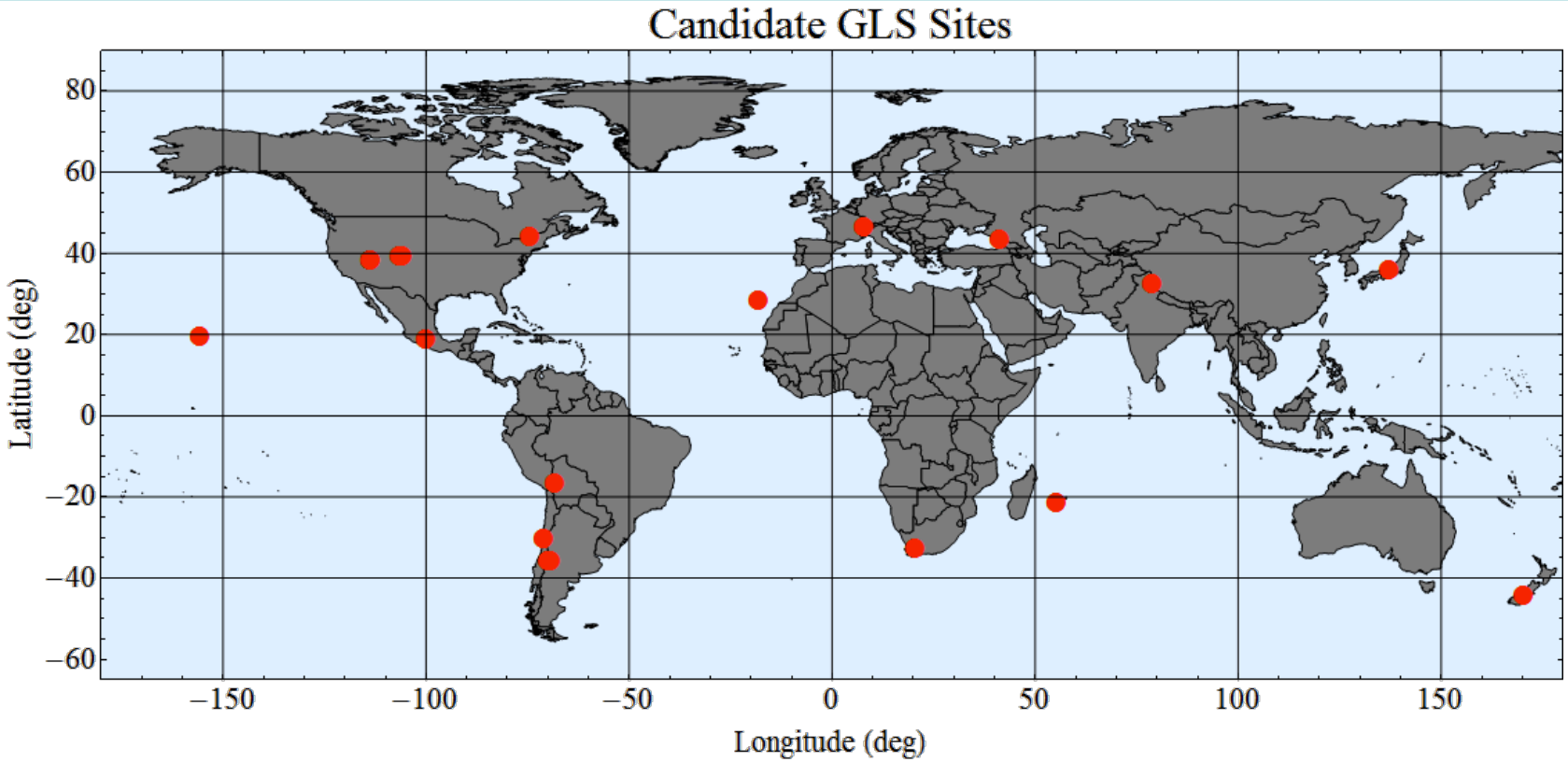
Site suitability

- Location properties:
  - Ambient light must be minimized
  - High altitude (above planetary boundary layer if possible), the higher the better
  - Should represent different climates and cover the Earth homogenously
  - Existing infrastructure (preferably scientific!)
  - And ideally: existing atmospheric monitoring program / data available!

- Some compromise will be necessary:
  - Remote operation, reliability, accessibility, cost of operation…

MAGIC (La Palma, 2200m)

Ground light system (GLS)



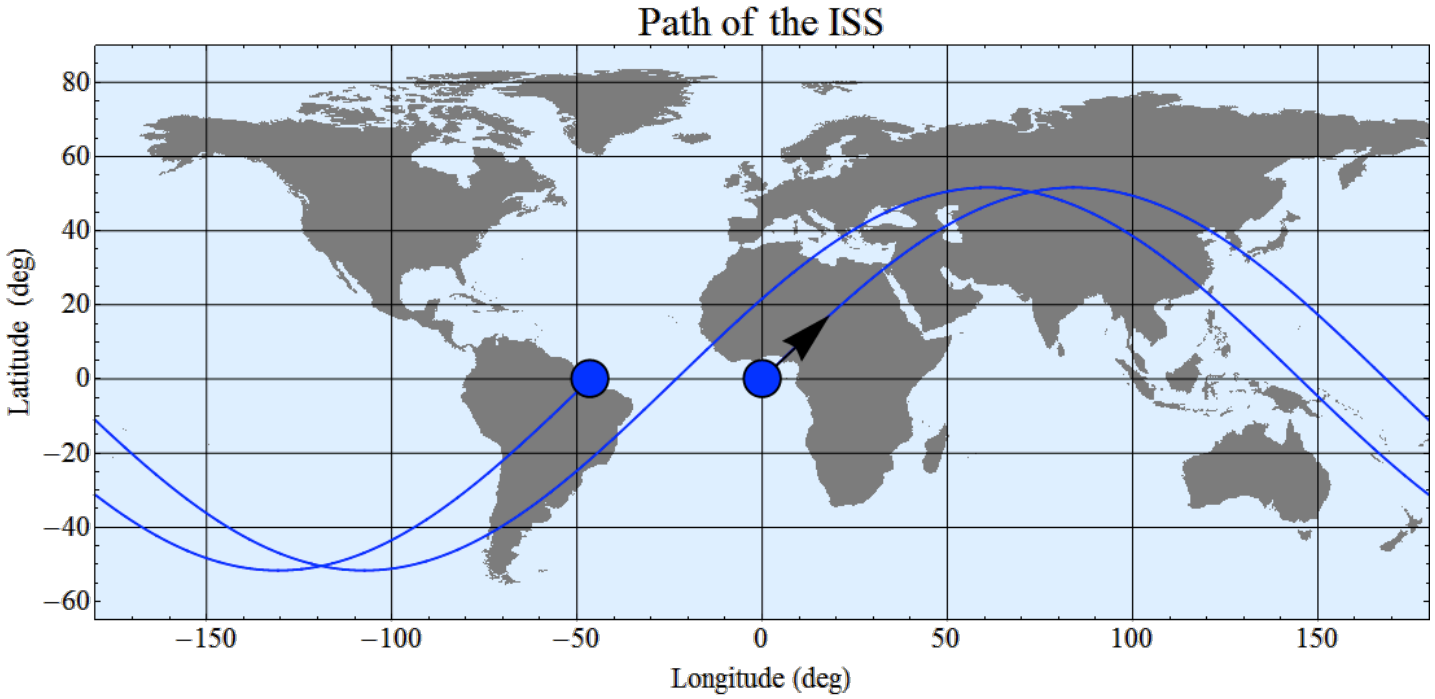
Location	Lat (deg)	Lon (deg)	Elevation(m)
Mt. Washington (NH, USA)	44.2706	-74.3033	1917.
Climax (CO, USA)	39.3658	-106.186	3463.
Frisco Peak (UT, USA)	38.5202	-113.288	2931.87
Mt. Norikura (Japan)	36.1064	137.554	3025.64
Nevado de Toluca (Mexico)	19.1017	-99.7675	4680.
Chacaltaya Obs. (Bolivia)	-16.3533	-68.1314	5230.
Cerro Tololo Obs. (Chile)	-30.1697	-70.8065	2207.
Sutherland (South Africa)	-32.3936	20.6614	1450.
Pampa Amarilla (Auger)	-35.4667	-69.0164	1400.

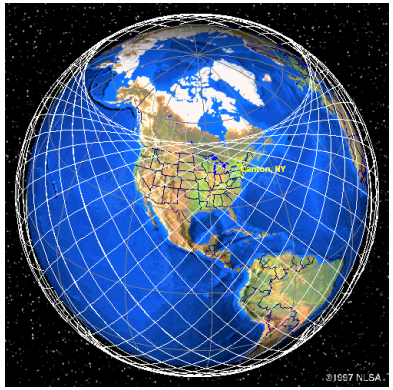
Location	Lat (deg)	Lon (deg)	Elevation(m)
India Astronomical Observatory (India)	32.7794	78.9642	4500.
La Palma (Canary islands)	28.7667	-17.8833	2396.
Mt. John Observatory (New Zealand)	-43.9867	170.465	1029.
Meyer-Womble Observatory (CO,USA)	39.5886	-105.643	4312.
Sphinx Observatory (Switzerland)	46.5475	7.985	3571.
Mt. Pastukhov (Russia)	43.6469	41.4406	2070.
Mauna Kea Obs. (HI,USA)	19.8167	-155.467	4190.
La Reunion	-21.1833	55.4167	1000

Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

Siting the GLS Stations

- In order to have a calibration opportunity for a given GLS station, several parameters considered
  - The GLS station must be within the FOV of JEM-EUSO
  - The Sun must be 18 degrees below the horizon (to ensure darkness)
  - The illumination of the Moon must be less than a given threshold (to ensure darkness)
  - The sky must be clear with little to no clouds (simplified condition used in this work)

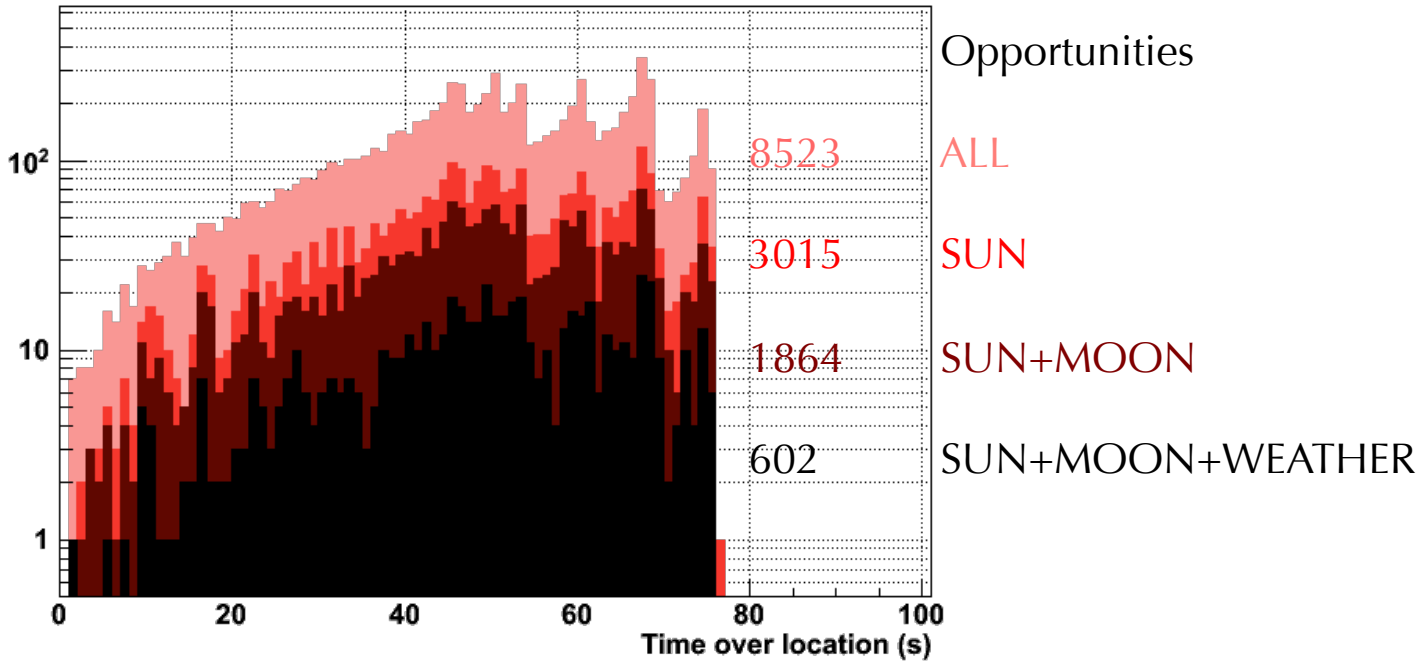




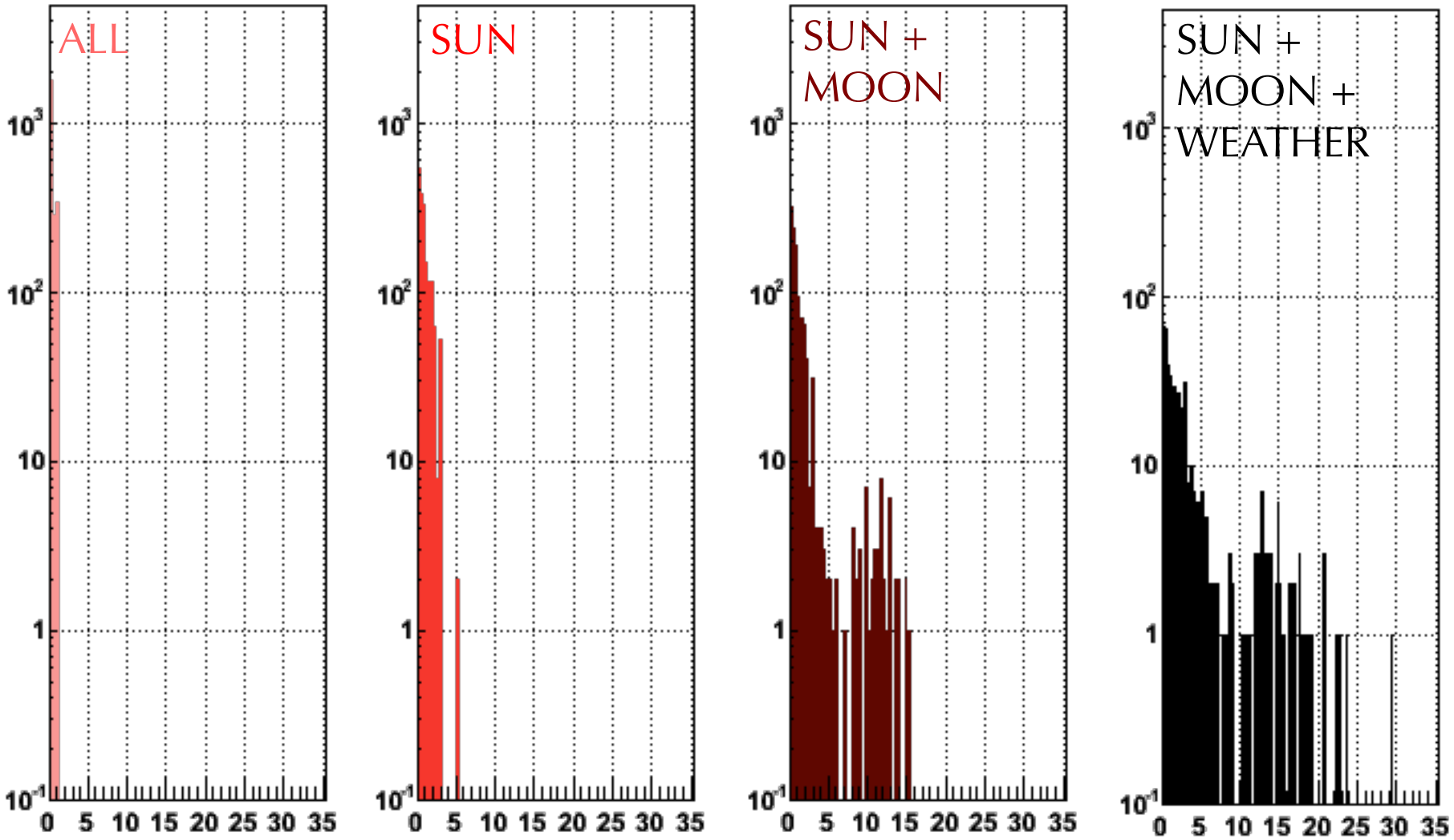
Zach Norman, Senior design project, Colorado School of Mines (Aug 2012 – April 2013)

7 Semi-randomly chosen locations

- Model Parameters:
  - Start date of 1/6/2017, 5 year run time, time step of 1 second, 350 km elevation of ISS, 18 degrees of twilight, critical illumination of the Moon at 50%, considered cloudy over GLS station 66% of the time
- Analysis:
  - How many opportunities for calibration are there? How much time between opportunities? What is the average time over each location?

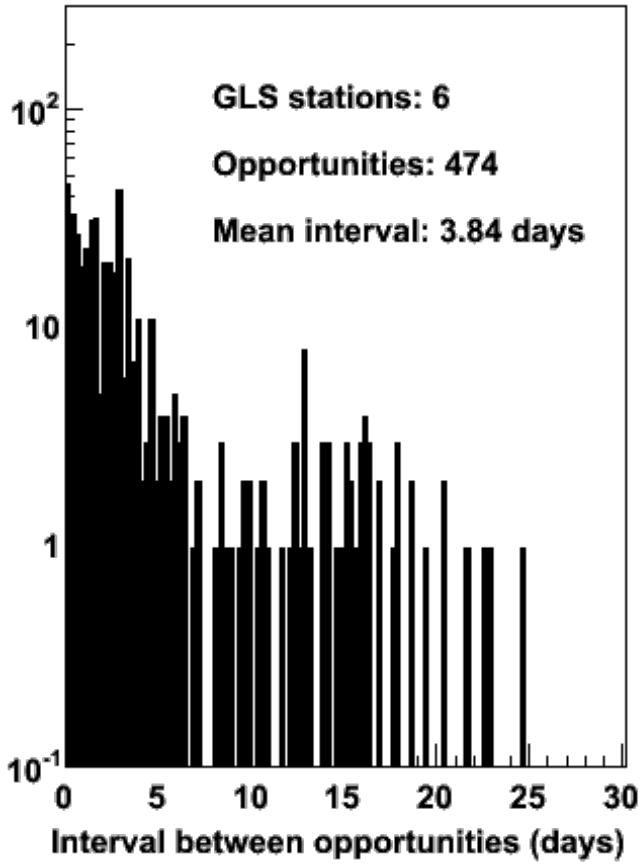


Interval Between ISS Visits (7 stations)

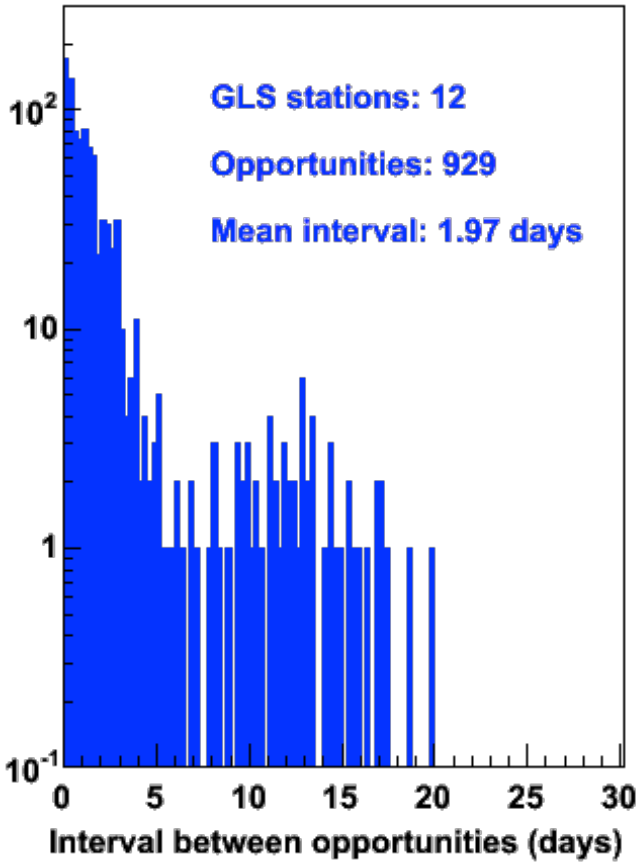


Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

6- vs 12-location GLS array



LASER stations only



All GLS stations

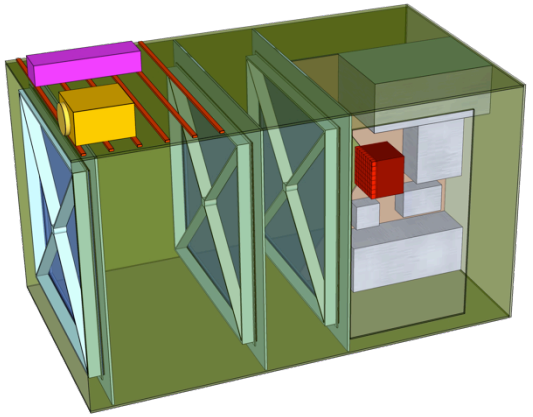
Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

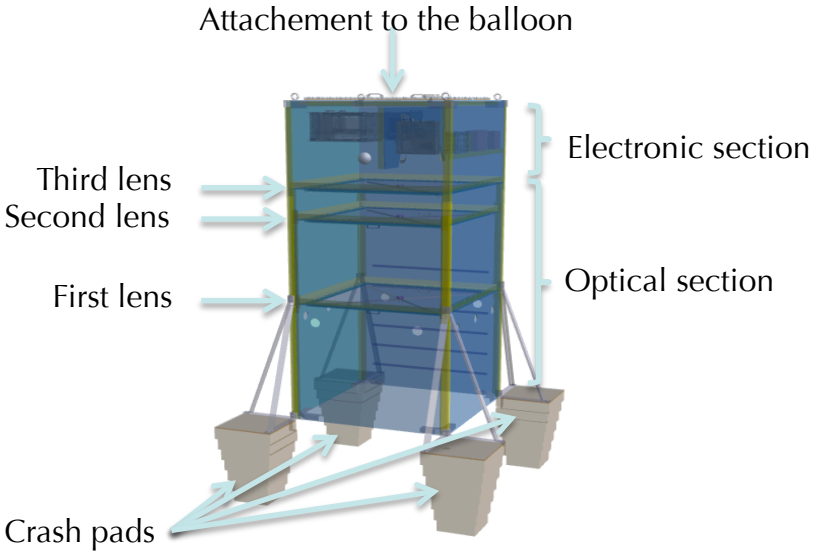
Planned improvements

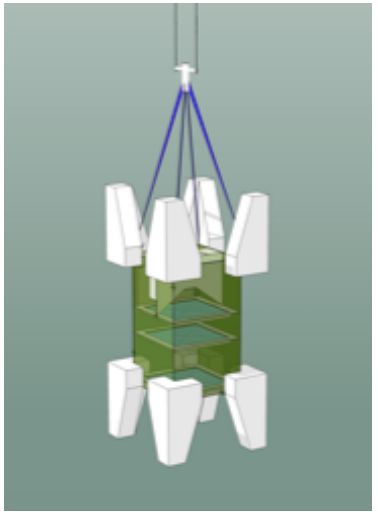
- Add a location-specific cloud cover (based on existing data)
- Preferred direction for laser shots
  - Maximize laser tracks in the FOV of JEM-EUSO
- Is it possible to optimize the combination of preferred sites?

EUSO-Balloon

- Goal: look down from the balloon with an UV telescope (PDM EM + 3 lenses system)
  - Engineering test
  - Background test
  - Airshower from 40 km altitude

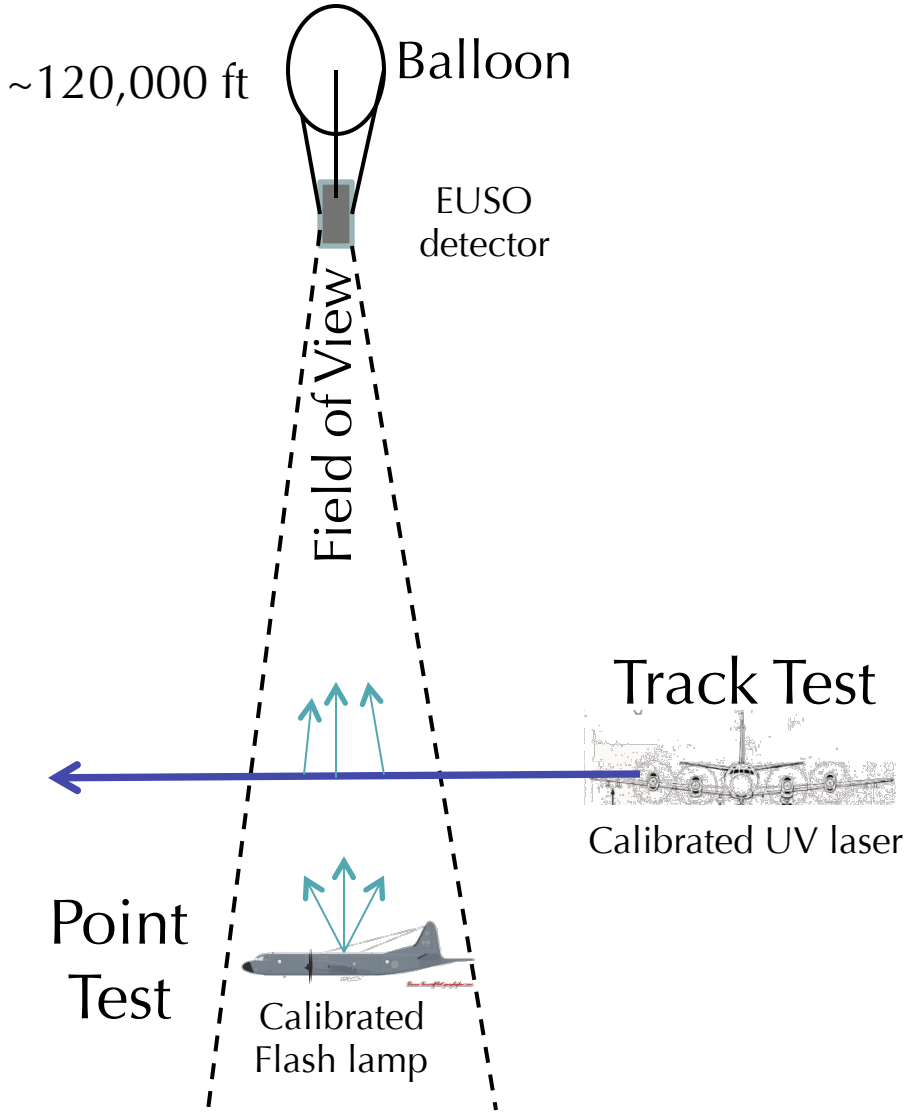






EUSO-Balloon: launch planned in Spring 2014 from Timmins (Canada)

EUSO-Balloon



Testing EUSO-Balloon: Fly one aircraft equipped with two types of calibrated pulsed UV light sources.

Point Test: Fly airplane in field of view and fire flash lamp. Light travels directly from lamp to detector

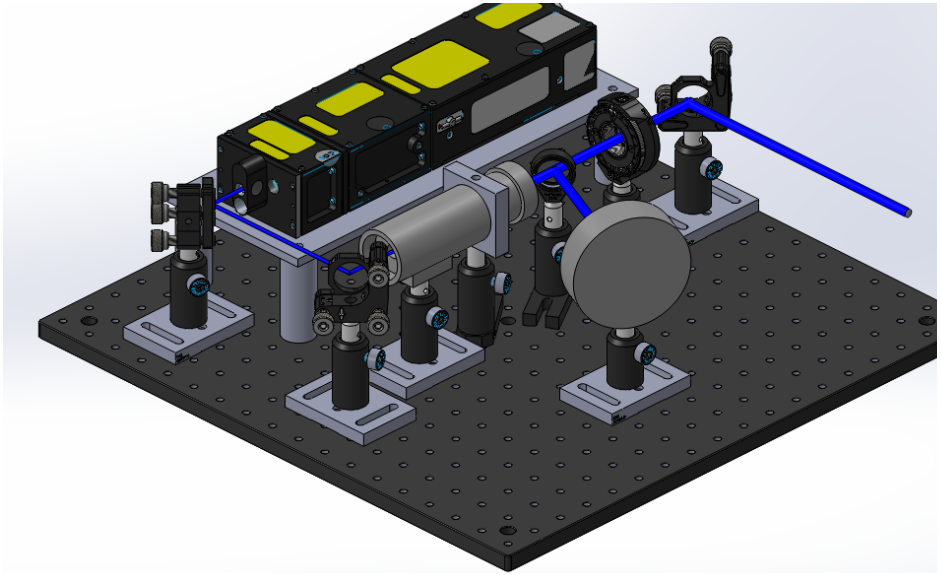
Track Test: Fly airplane outside field of view and shoot a UV pulsed laser across field of view. Light scatters out of the beam to the detector.

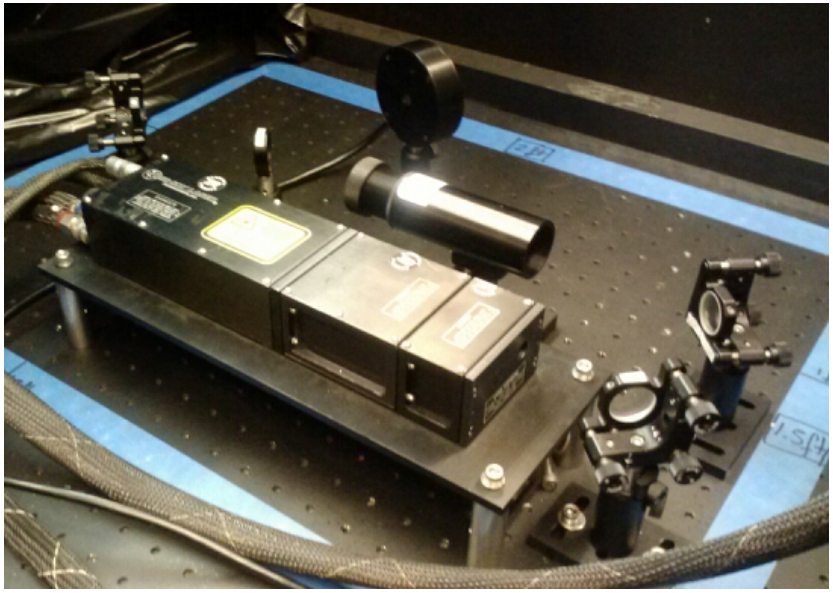
Fly aircraft at altitudes between 2,000 and 20,000 feet.

Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

Airplane-based Laser System

Ryan Larson, Wesley Naslund and Giuseppe Pasqualino.
Senior Design Project, Colorado School of Mines
Fall 2012-Spring 2013



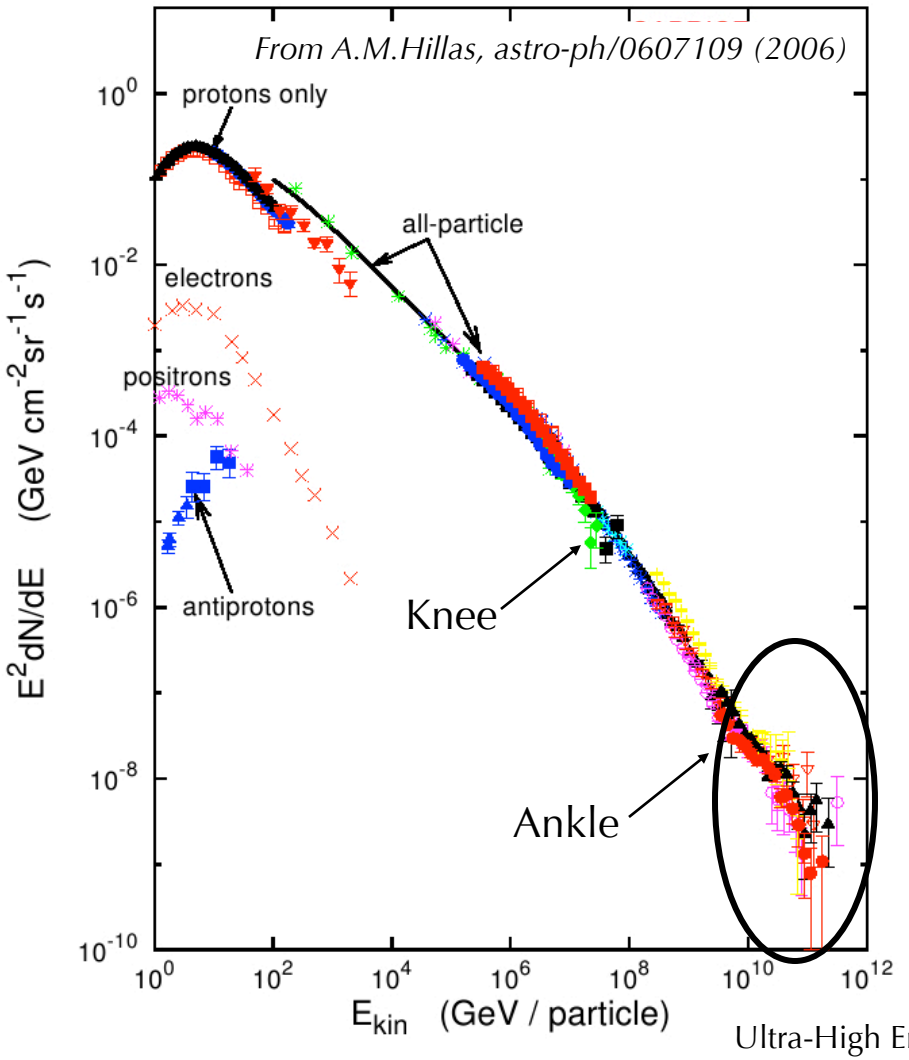


Summary

- The development of the JEM-EUSO mission is well underway
- The Global Light System (GLS) will play an important role to monitor the instrument and test many aspects of its operation (triggering, pointing accuracy, energy calibration).
  - Development of prototypes under way (lasers / flash lamps)
  - Preliminary selection of suitable sites
  - Atmospheric monitoring devices would be very useful (collaborators welcome!)
- Proof-of-principle (and basic concepts) will be tested at the EUSO-Balloon test to happen next year.
- JEM-EUSO (2017+), GLS array needs to be in place before launch!

Backup slides

The cosmic-ray energy spectrum

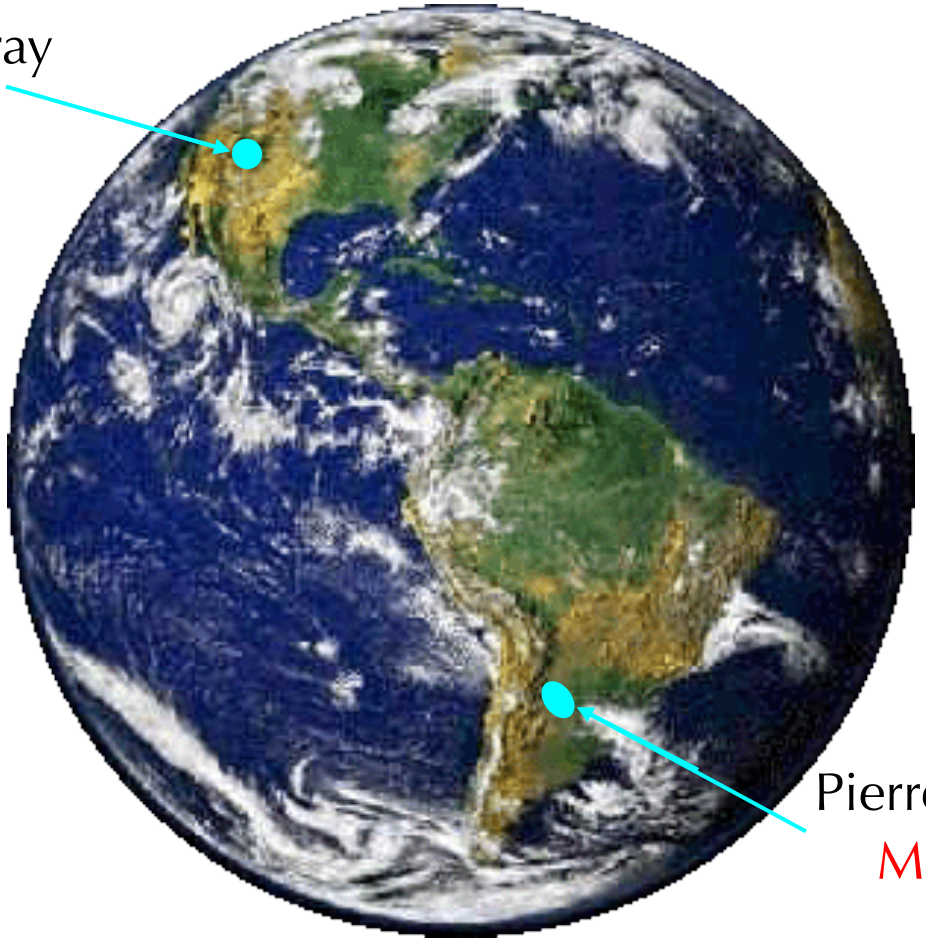


- Power-law flux over many orders of magnitude
- Direct measurements only below 10^{15}eV (10^6GeV)
- Features: knee, ankle
- End of the spectrum?
  - Flux at 10^{20}eV (10^{11}GeV): 1particle/km^2/century

Ultra-High Energy Cosmic-Rays (UHECRs) - E>10^{18}eV

Current UHECR Observatories

Telescope Array
Utah, USA

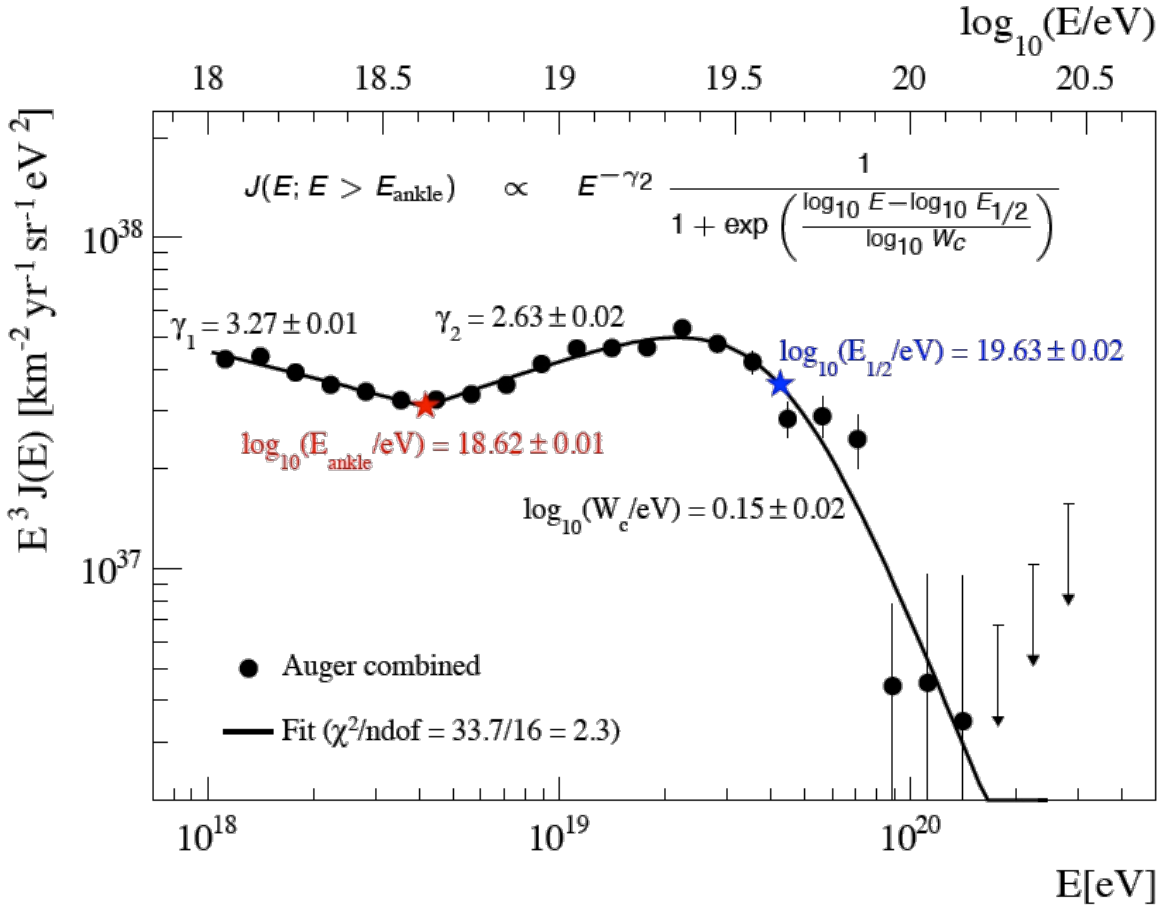


Pierre Auger Observatory
Mendoza, Argentina

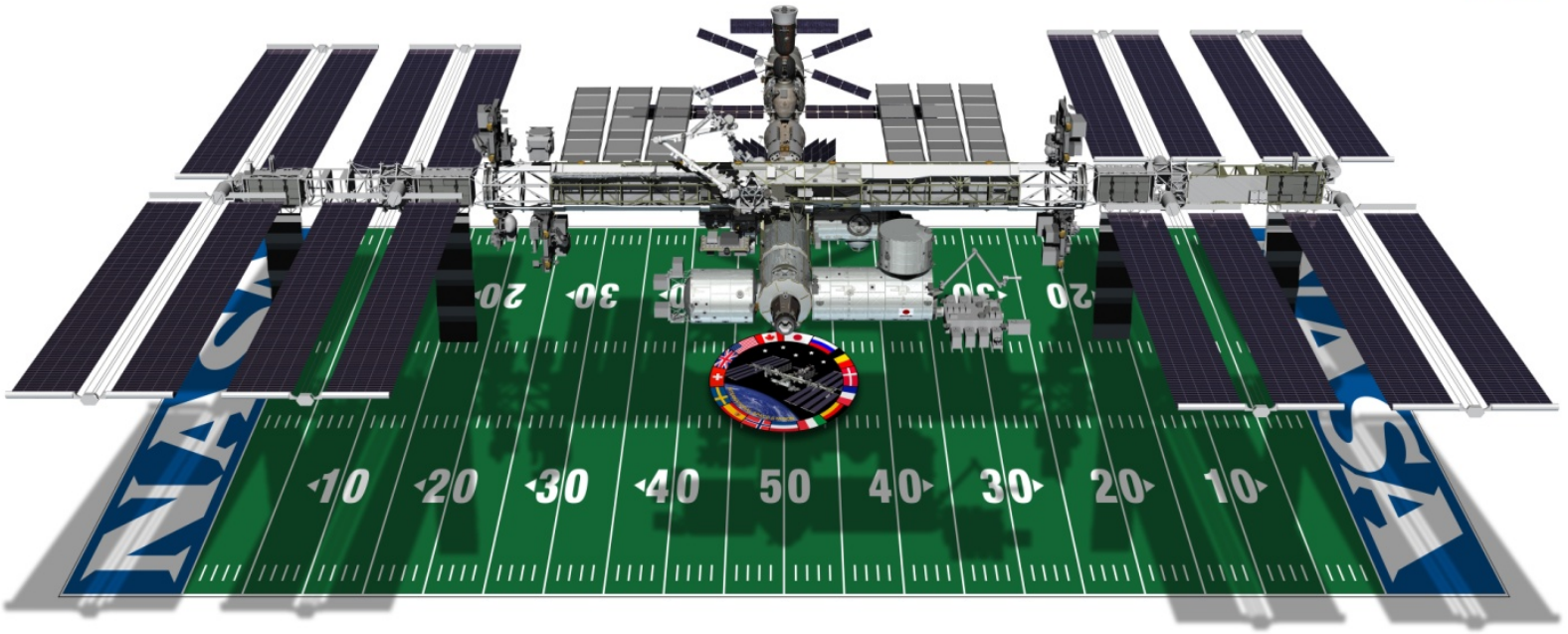
Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

Suppression of the CR flux

F.Salamida for the Pierre Auger Collaboration, ICRC 2011



The International Space Station



International Space Station Size & Mass:

Module Length: 167.3 feet (51 meters)
Truss Length: 357.5 feet (109 meters)
Solar Array Length: 239.4 feet (73 meters)
Mass: 924,739 pounds (419,455 kilograms)
Habitable Volume: 13,696 cubic feet (388 cubic meters)
Pressurized Volume: 32,333 cubic feet (916 cubic meters)
Power Generation: 8 solar arrays = 84 kilowatts

Exposure

Observatory	Aperture km^2 sr	Status	Start	Lifetime	Duty cycle	Annual Exposure km^2 sr yr	Relative to Auger
Auger	7,000	Operations	2006	4 (16)	1	7000	1
TA	1,200	Operations	2008	2 (14)	1	1,200	0.2
TUS	30,000	Developed	2012	5	0.14	4,200	0.6
JEM-EUSO ($E \approx 10^{20}$ eV)	430,000	Design	2017	5	0.14	70,000	10
JEM-EUSO (highest energies) Tilted mode 35°	1,500,000	Design	2017	5	0.14	200,000	28

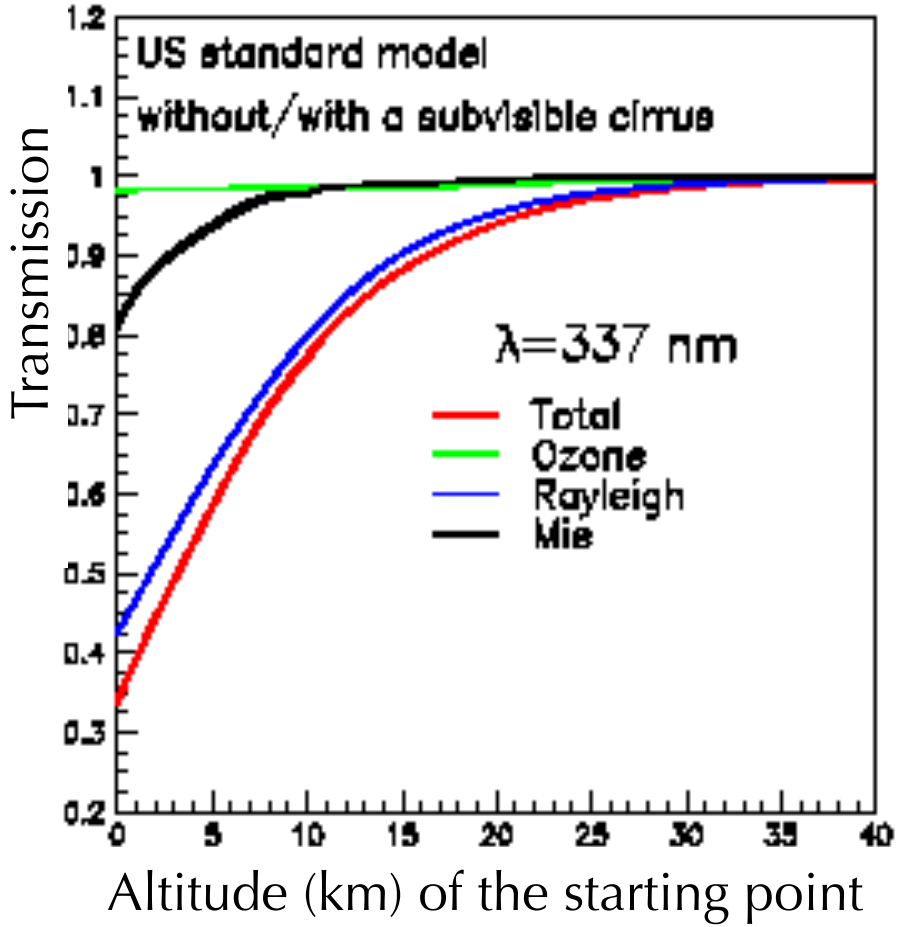
The (current) UV Telescope Parameters

Parameter	Value
Field of View	±30°
Monitored Area	$>1.3\times10^5 km^2$
Telescope aperture	≥2.5 m
Operational wavelength	300-400 nm
Resolution in angle	0.075°
Focal Plane Area	4.5 m^2
Pixel Size	<3 mm
Number of Pixels	$\approx3\times10^5$
Pixel size on ground	≈560 m
Time Resolution	2.5 μs
Dead Time	<3%
Detection Efficiency	≥20%

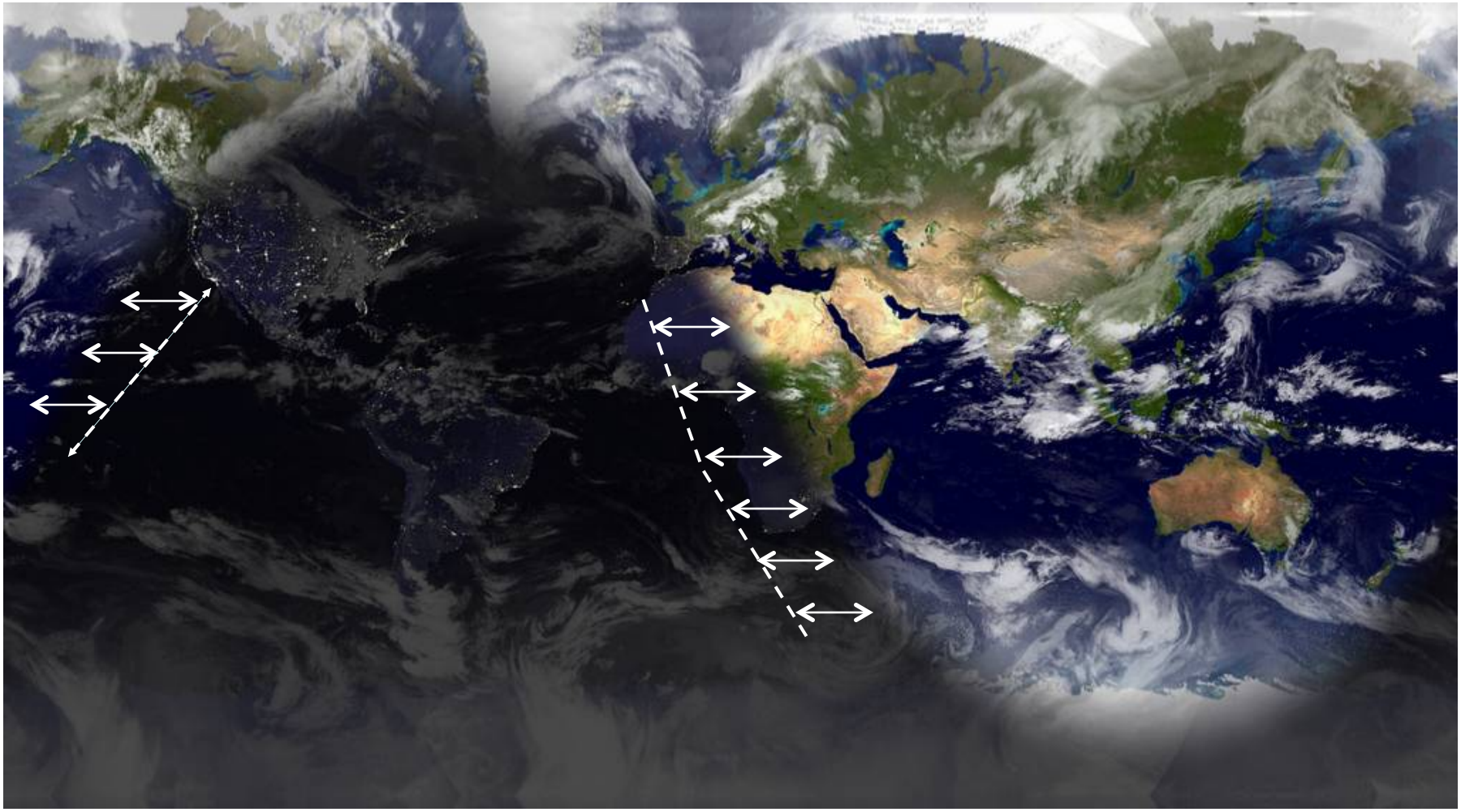
Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

Atmospheric Transparency

- Stratosphere and above
  - > 10-15 km
  - Essentially transparent
  - Only Rayleigh scattering
  - Occasional Nacreous or volcanic ash clouds
- Troposphere
  - < 10-15 km
  - Rayleigh Scattering
  - Clouds
  - Occasionally aerosol
- Planetary Boundary Layer
  - <2 km
  - Rayleigh Scattering
  - Clouds and aerosol

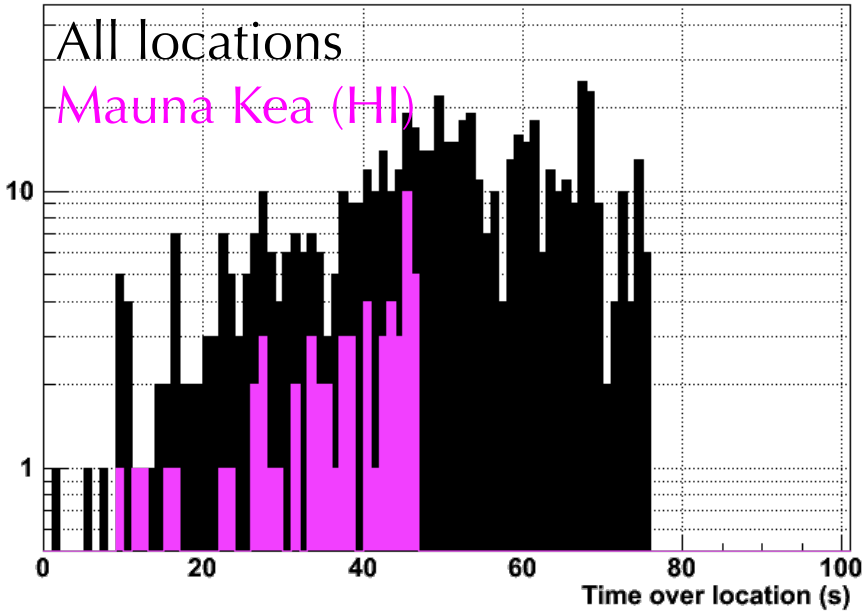


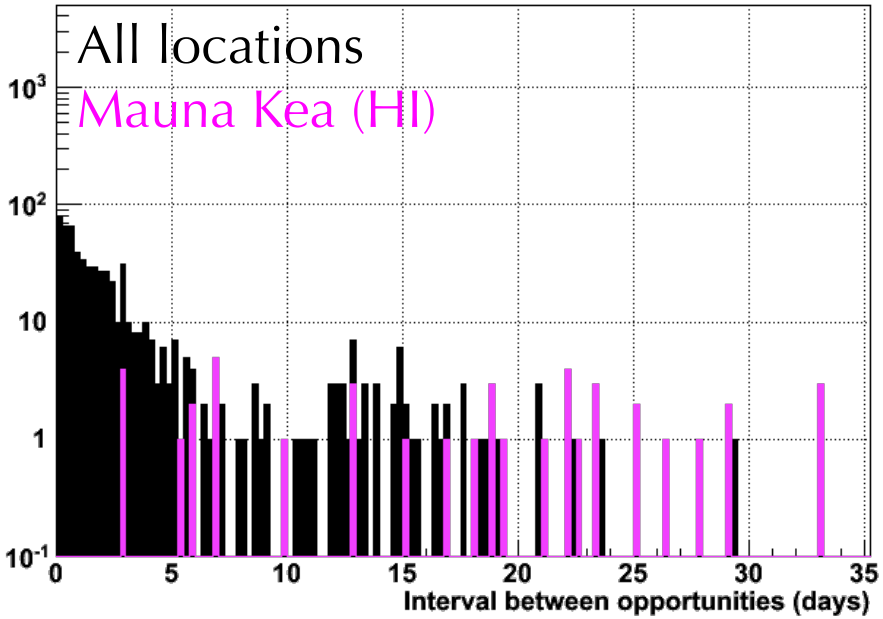
Twilight



Fred Sarazin (fsarazin@mines.edu)
Physics Department, Colorado School of Mines

Comparison to Specific Location

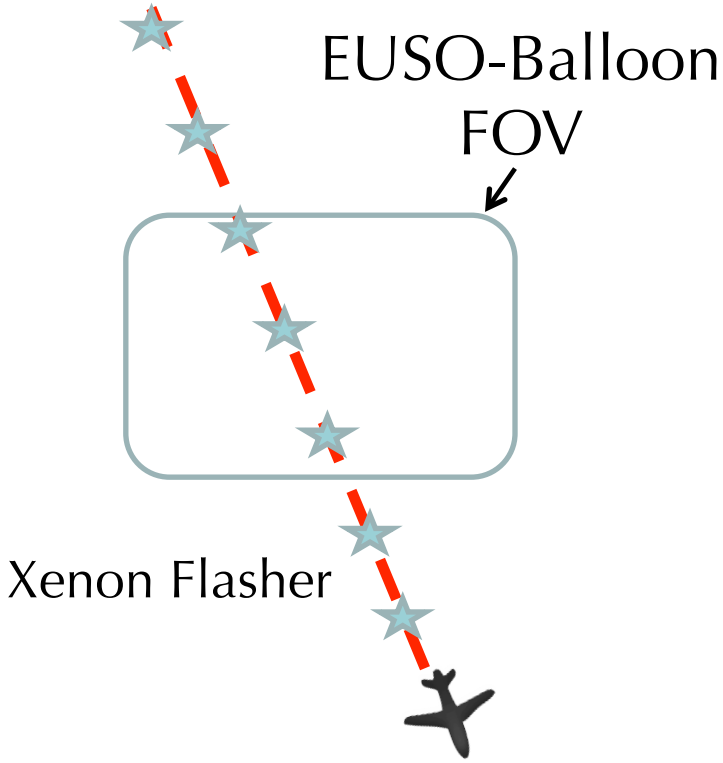


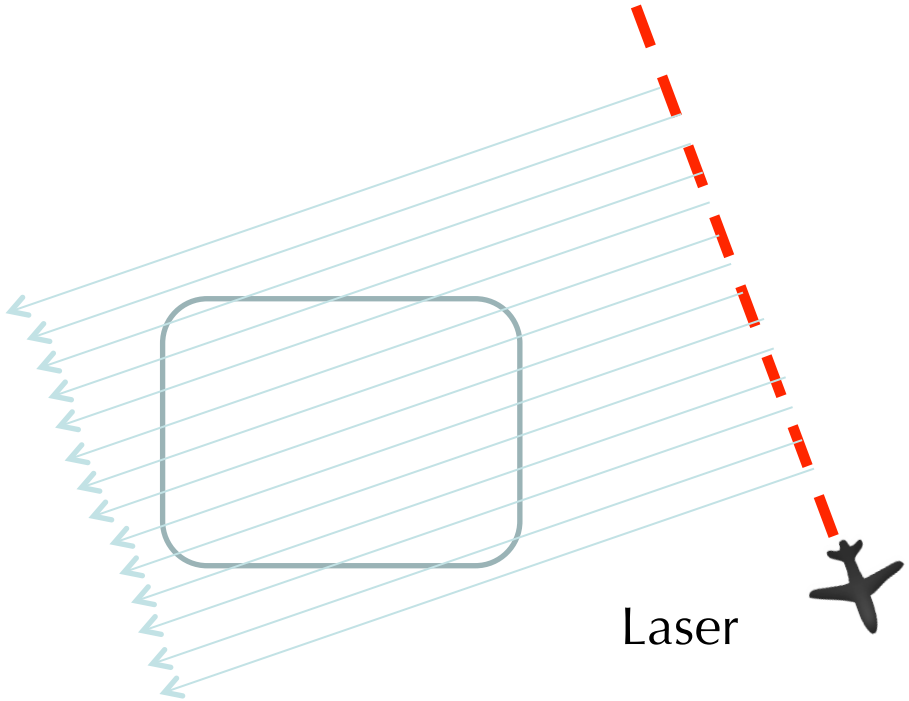


- The mean time over each location is a function of the location's latitude
- Interval between visits at individual location not representative of the whole GLS array

GLS and EUSO-Balloon

Objective:
show that EUSO-Balloon can record EAS-like triggers in flight from benchmarked sources





Simple tests: Vary parameters of the GLS (energy, distance/altitude)
Estimate sensitivity to Air Shower triggers