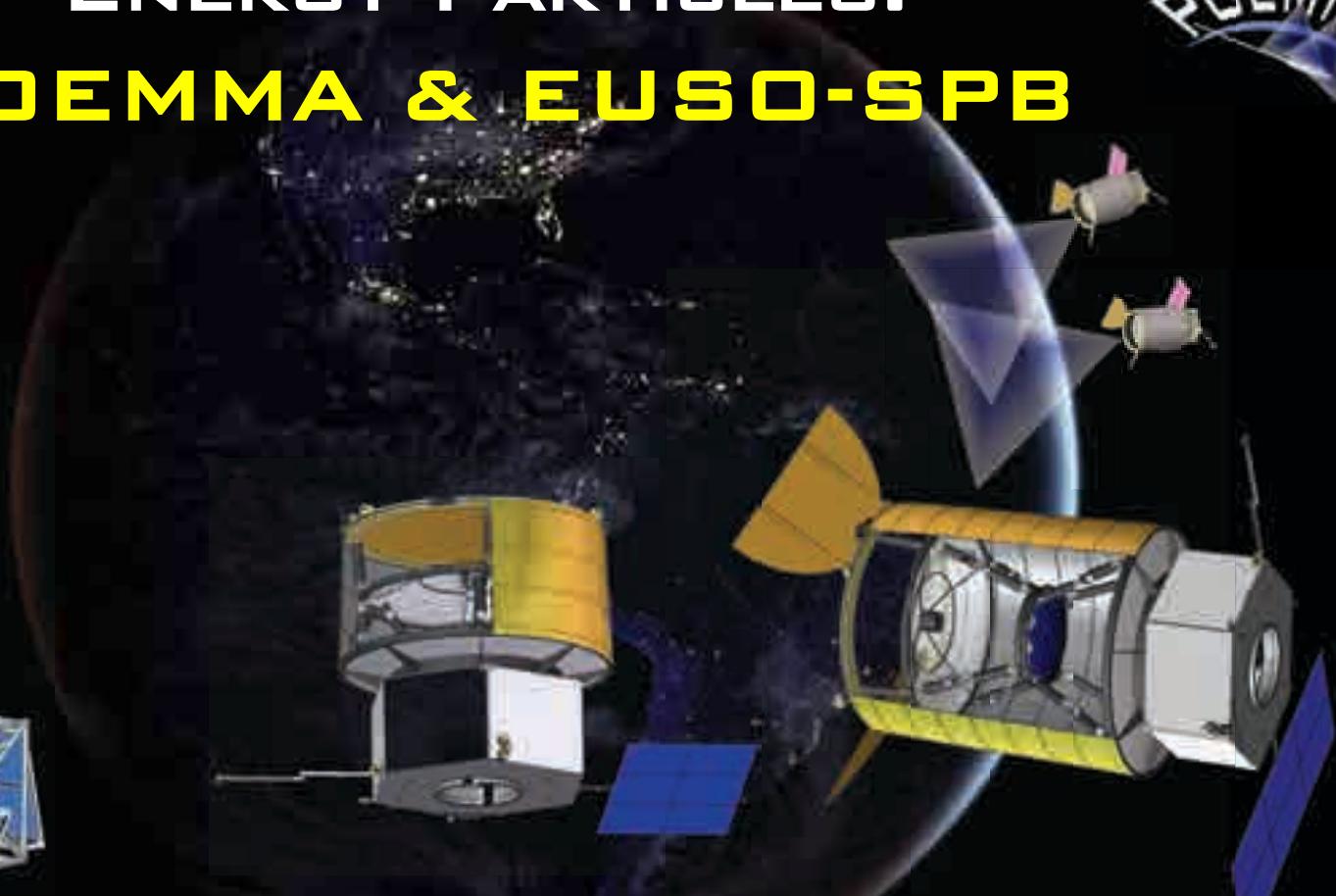


# SPACE PROBES OF THE HIGHEST ENERGY PARTICLES: **POEMMA & EUSO-SPB**

POEMMA

**EUSO-SPB2**



ANGELA V. OLINTO



THE UNIVERSITY OF  
**CHICAGO**



THE UNIVERSITY OF  
CHICAGO

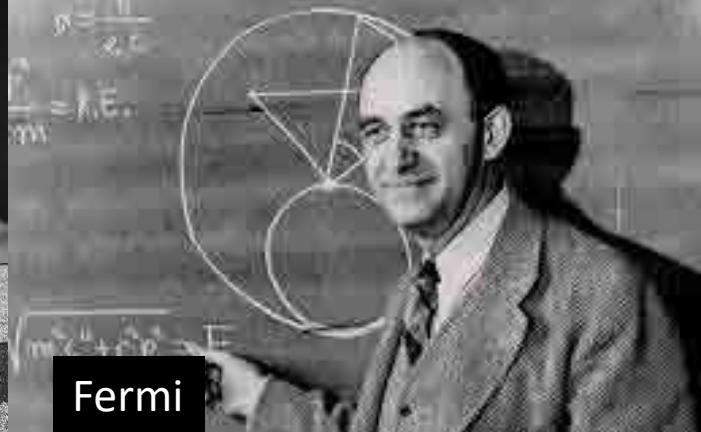


Millikan

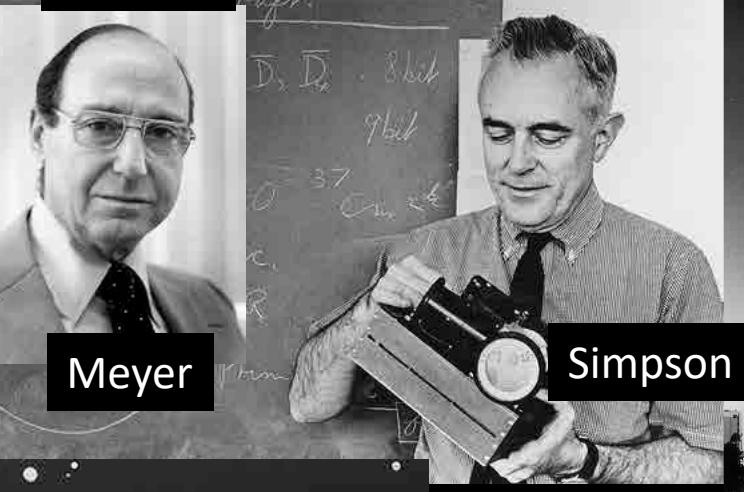
Compton



Schein

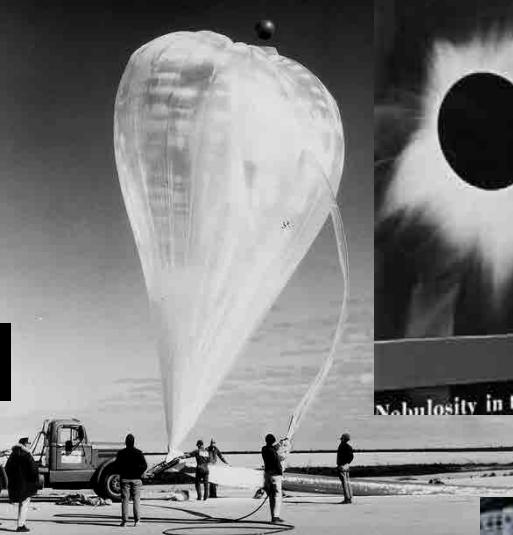


Fermi

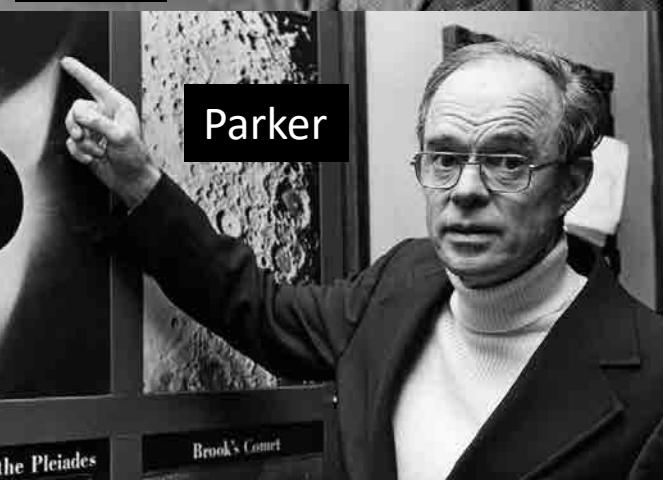


Meyer

Simpson



Nebulosity in the Pleiades



Parker

TRACER

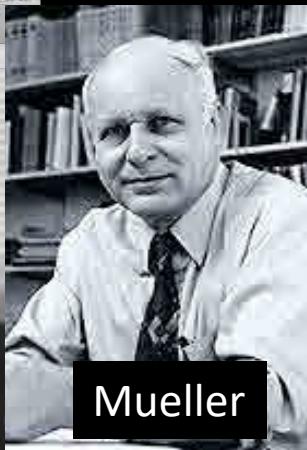


Cronin

VERITAS



Swordy



Mueller



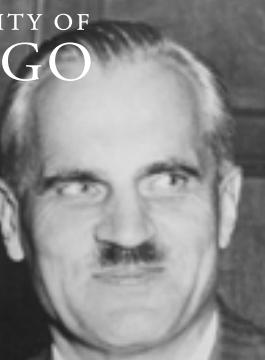
Auger Obs



THE UNIVERSITY OF  
CHICAGO



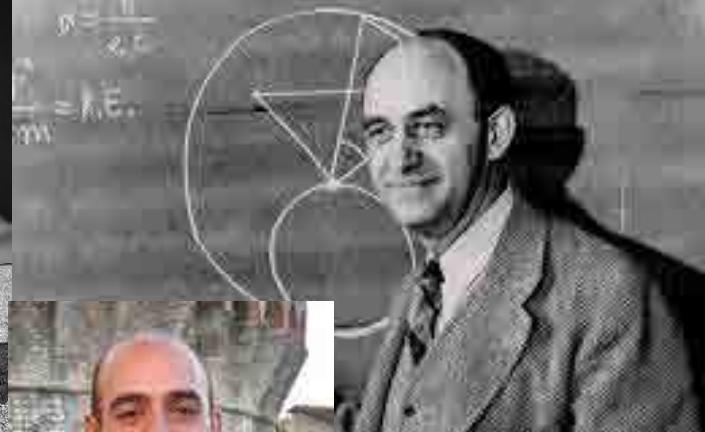
Millikan



Compton



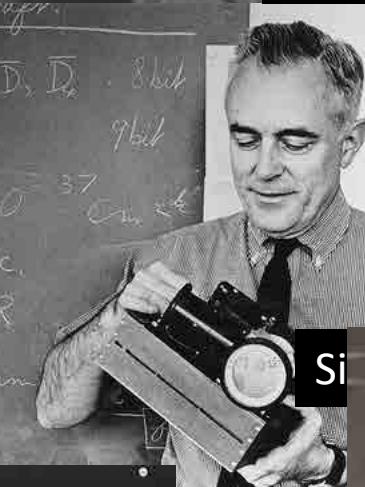
Scheir



Caprioli



Meyer



Si



Viereg



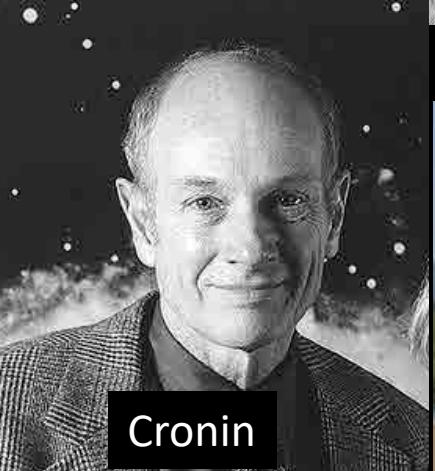
Olinto



Caprioli



Privitera



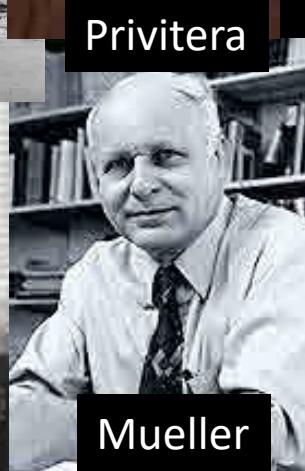
Cronin



VERITAS



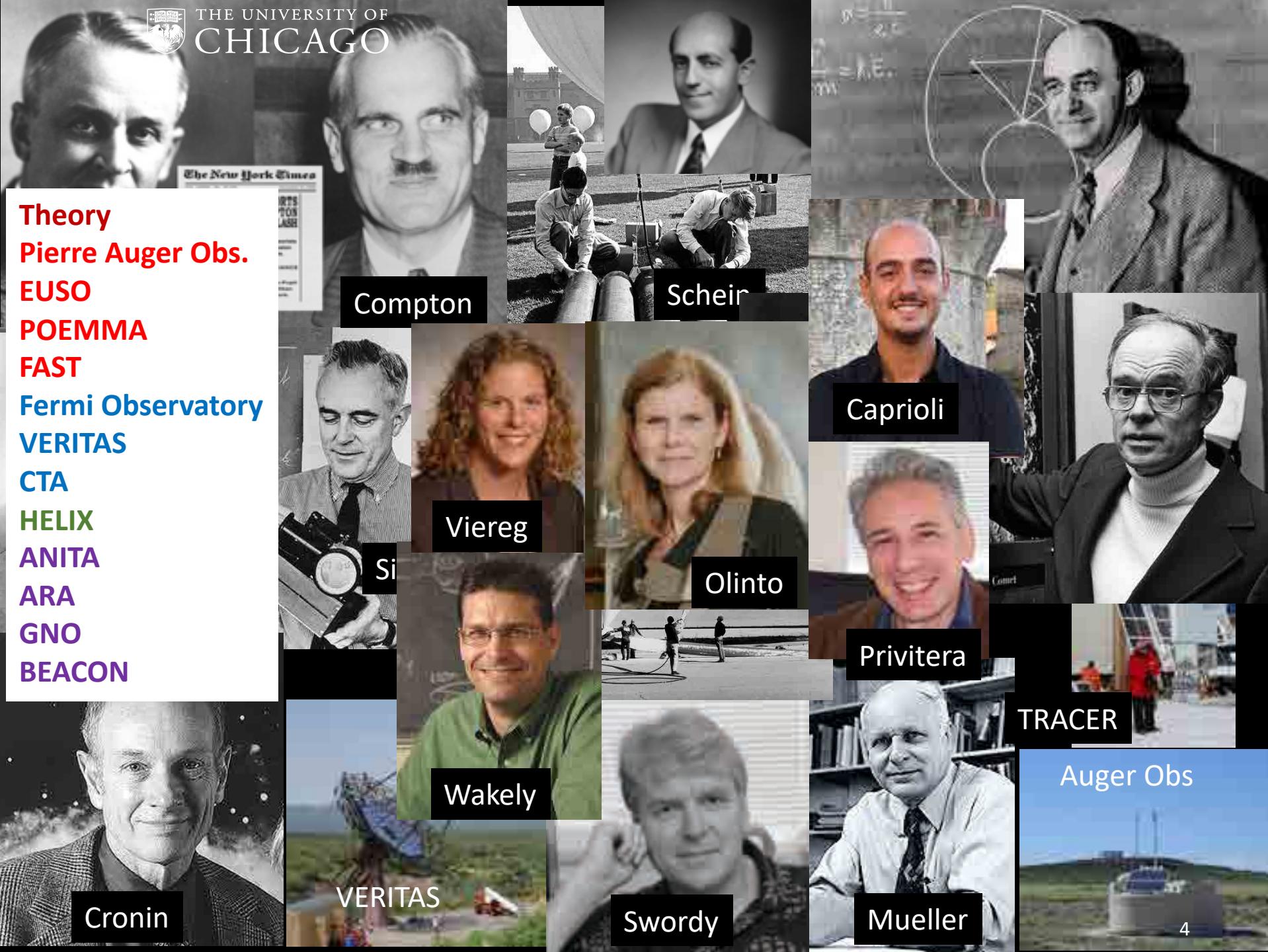
Wakely



Mueller



Auger Obs



**Theory**

**Pierre Auger Obs.**

**EUSO**

**POEMMA**

**FAST**

**Fermi Observatory**

**VERITAS**

**CTA**

**HELIX**

**ANITA**

**ARA**

**GNO**

**BEACON**

2010s

WHAT ARE THE SOURCES OF THE  
ULTRAHIGH ENERGY COSMIC RAYS (UHECRs)?

WHAT IS THE COSMOGENIC NEUTRINO FLUX?

WHAT ARE THE SOURCES OF ICECUBE NEUTRINOS?

2020s

WHAT ARE THE SOURCES OF THE  
EXTRAGALACTIC UHECRs?

WHAT IS THE COSMOGENIC NEUTRINO FLUX?

WHAT ARE ALL\* SOURCES OF ICECUBE NEUTRINOS?

2020s

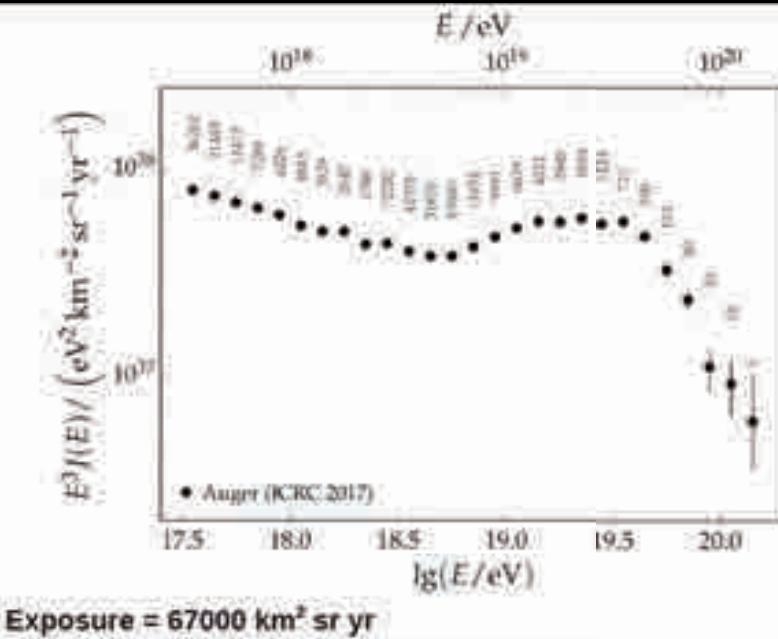
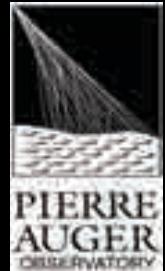
WHAT ARE THE SOURCES OF THE  
EXTRAGALACTIC UHECRs?

WHAT IS THE COSMOGENIC NEUTRINO FLUX?

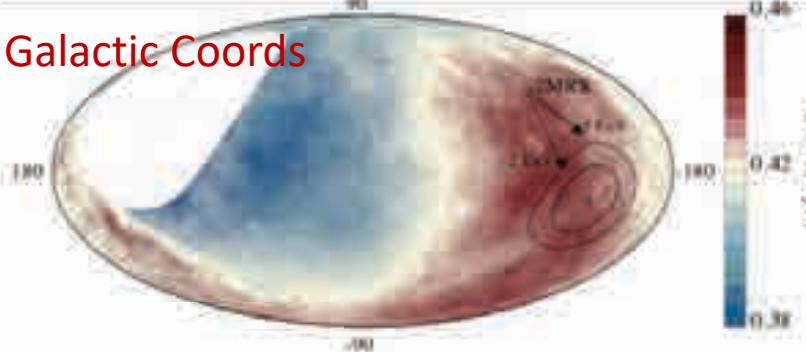
WHAT ARE ALL SOURCES OF ICECUBE NEUTRINOS?

- SPECTRUM  $E >> 50 \text{ EeV}$
- COMPOSITION  $E >> 50 \text{ EeV}$
- ANISOTROPIES → POINTING
- MULTI-MESSENGER COINCIDENCE

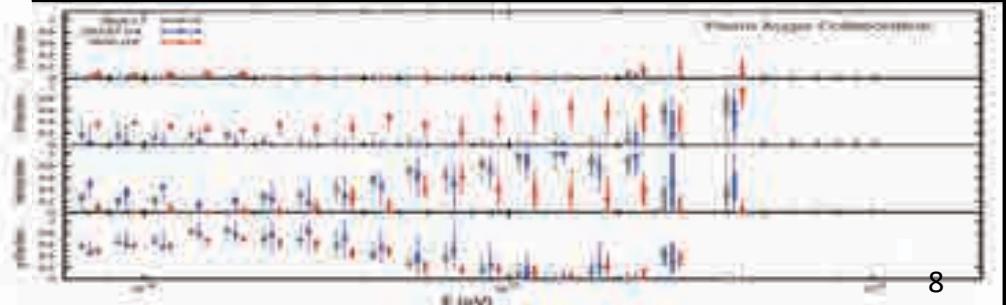
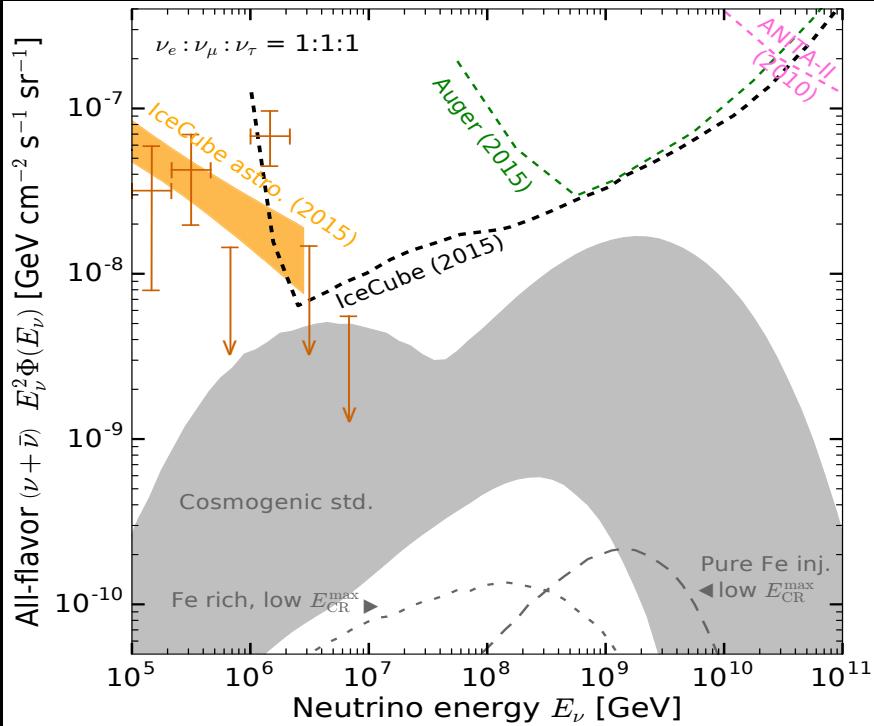
# UHECRs



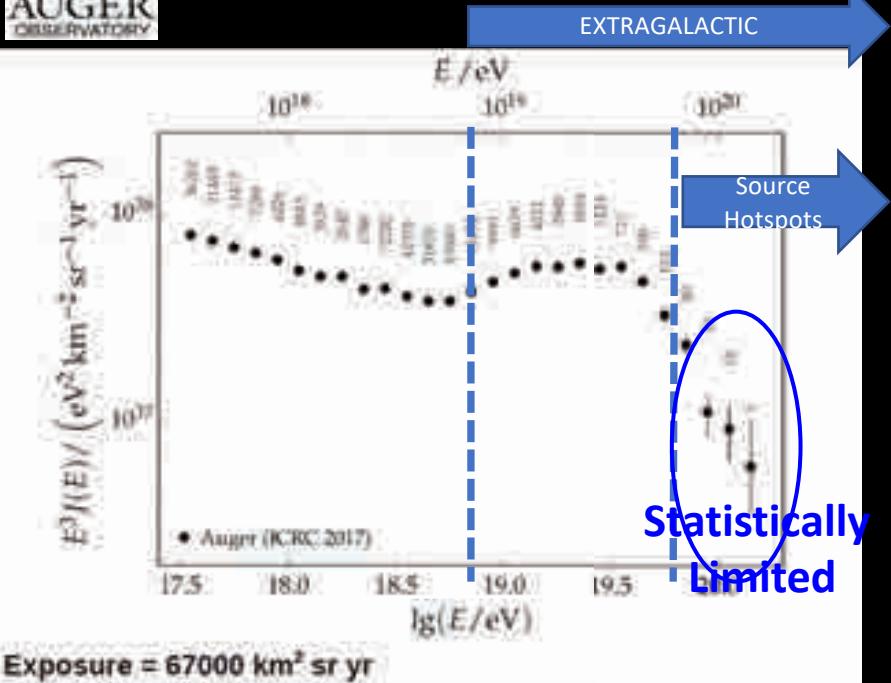
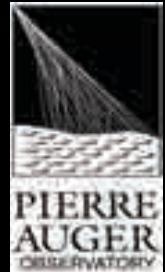
Galactic Coords



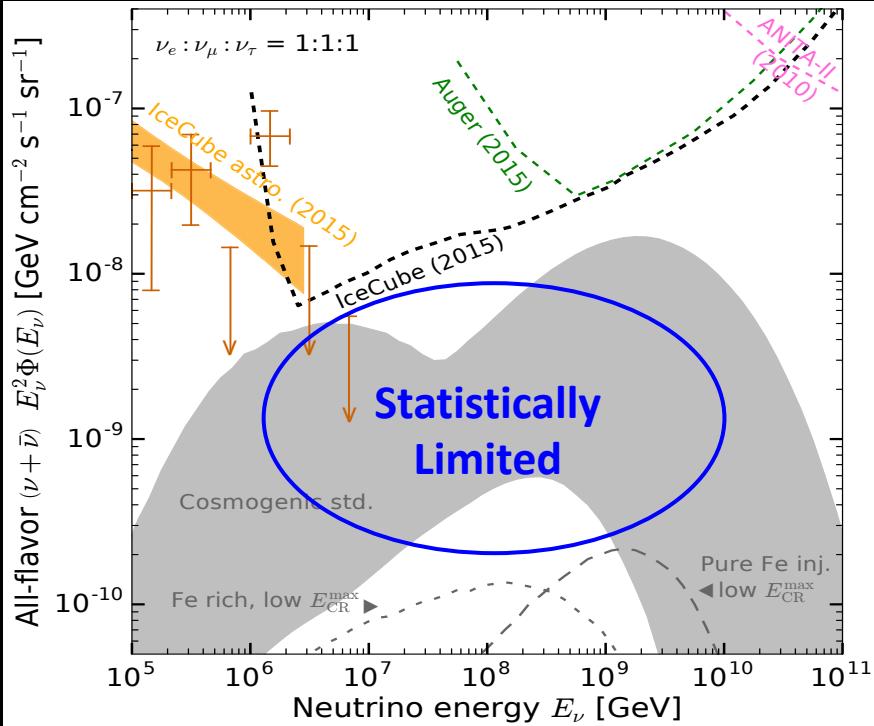
# UHE NEUTRINOS



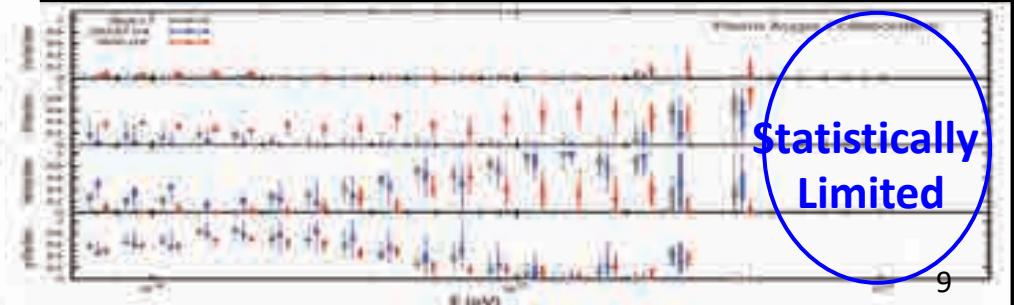
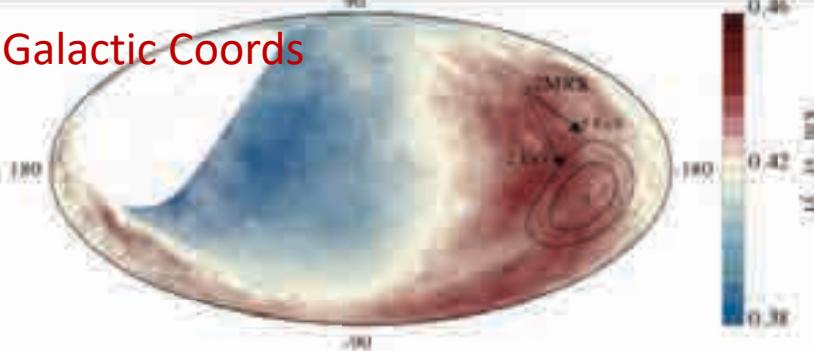
# UHECRs



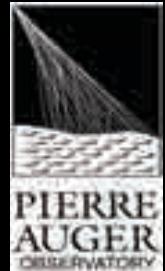
# UHE NEUTRINOS



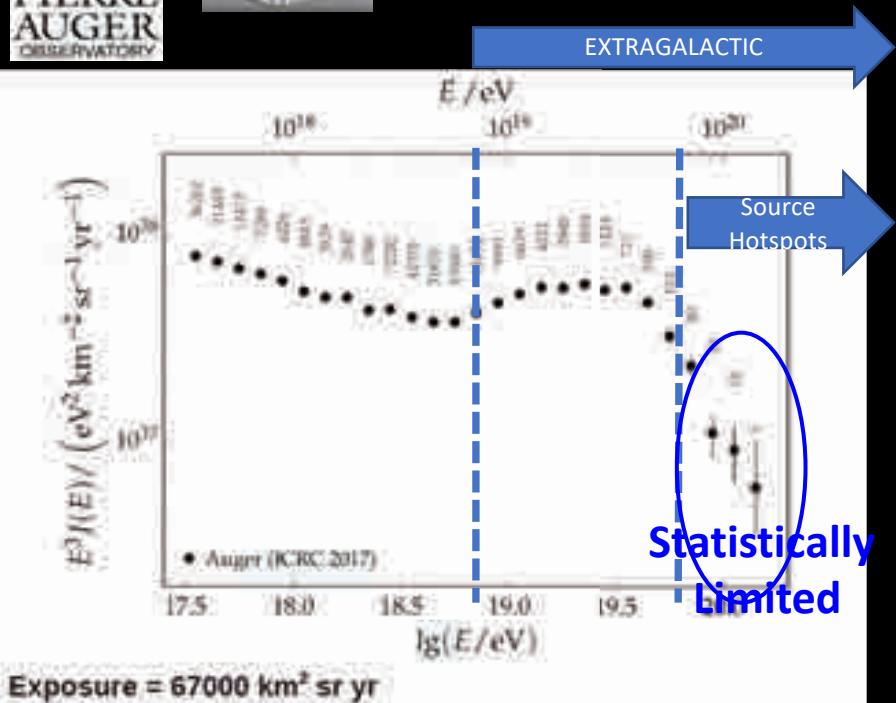
Galactic Coords



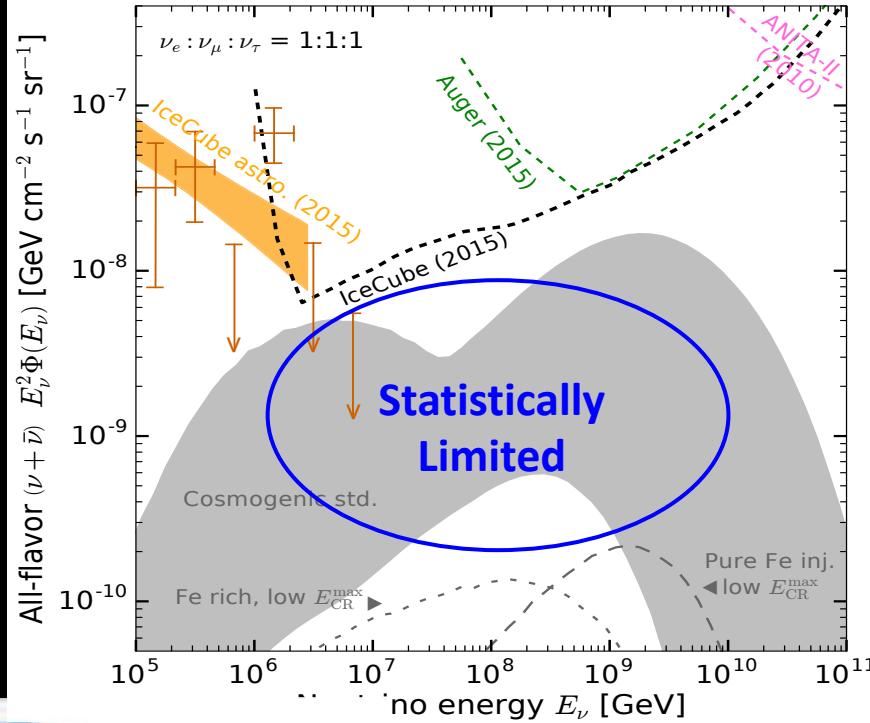
# UHECRs



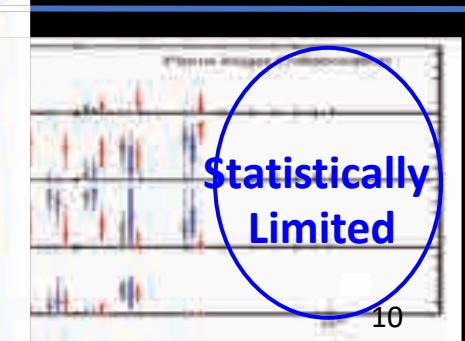
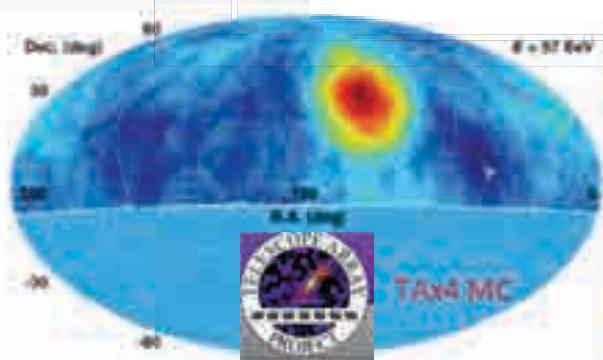
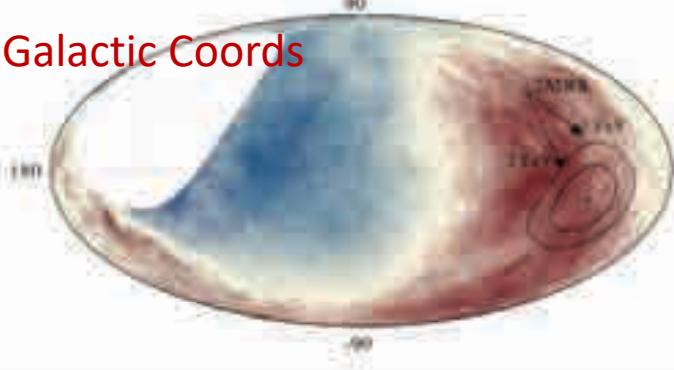
PIERRE AUGER  
OBSERVATORY



# UHE NEUTRINOS



Galactic Coords



# SPACE PROBES OF THE HIGHEST ENERGY PARTICLES: **POEMMA & EUSO-SPB**



EUSO-SPB2

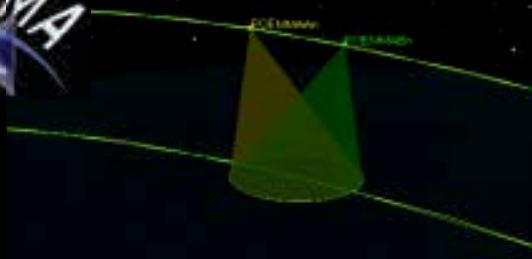


EUSO-SPB1

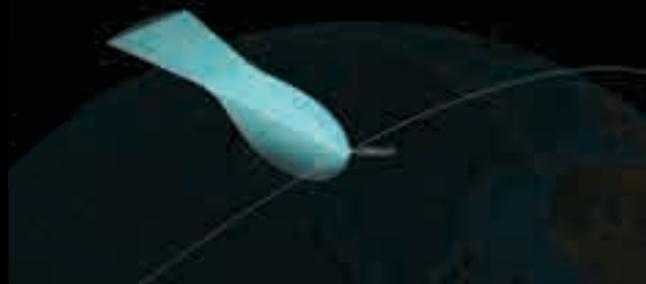


THE EARTH'S ATMOSPHERE  
AS AN EXTREME ENERGY  
PARTICLE OBSERVATORY

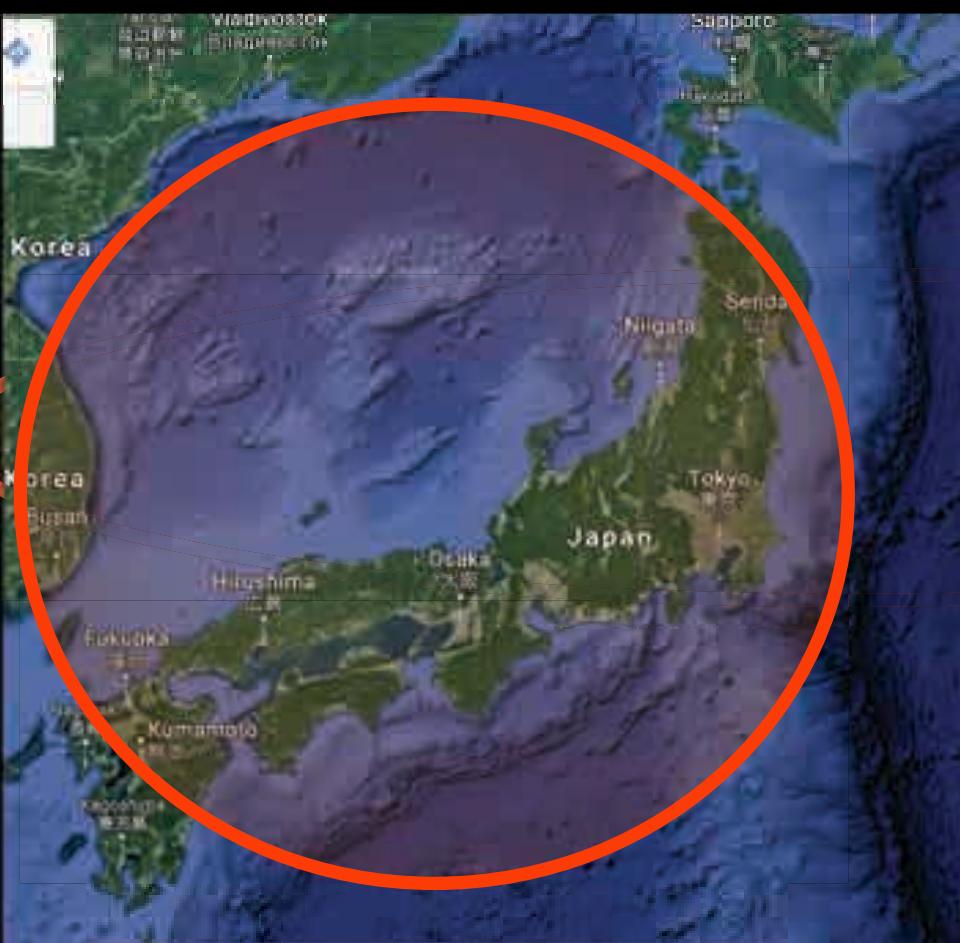
POEMMA



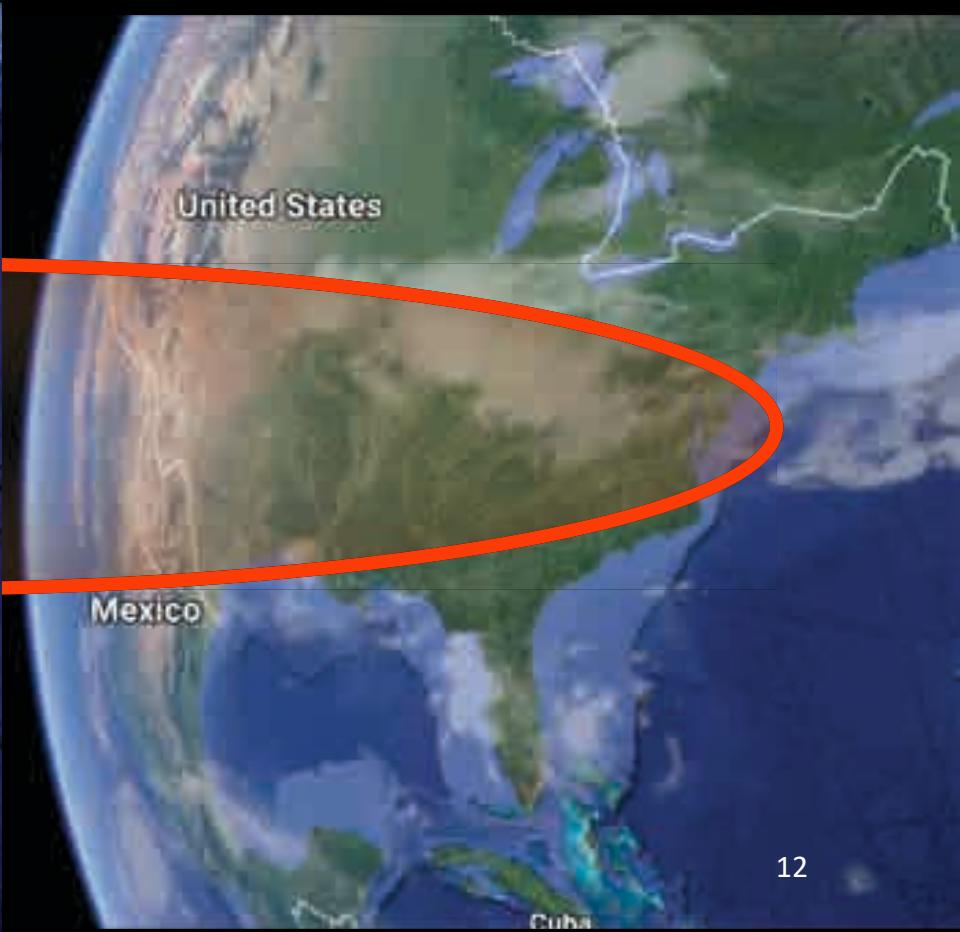
POEMMA



NADIR FOR UHECR:  
RADIUS 200-400 KM



LIMB FOR NEUTRINOS:  
RADIUS  $2.6-3.7 \cdot 10^3$  KM





# POEMMA: PROBE OF EXTREME MULTI-MESSENGER ASTROPHYSICS

BASED ON OWL 2002 STUDY, JEM-EUSO, EUSO  
BALLOON & SPB EXPERIENCE, AND CHANT PROPOSAL



OWL  
2002  
DESIGN



TUS, KLYPVE-EUSO



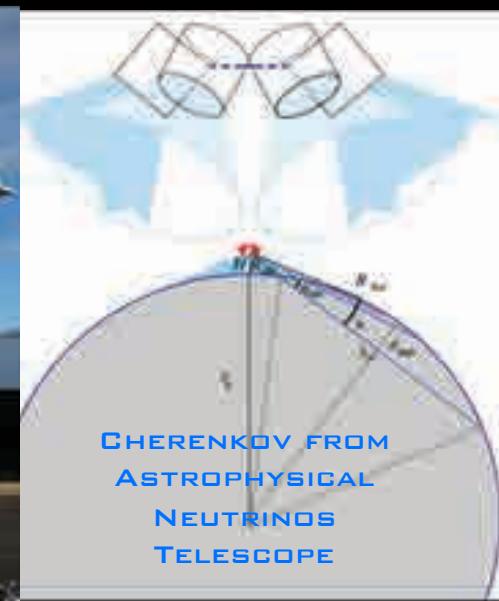
JEM-EUSO:  
EXTREME  
UNIVERSE  
SPACE  
OBSERVATORY



EUSO-SPB1



CHANT



EUSO-Balloon  
EUSO@TA  
Mini-EUSO

EUSO-SPB2



# POEMMA: STUDY COLLABORATION

University of Chicago: *Angela V. Olinto (PI)*

NASA/MSFC: Mark J. Christl (deputy PI), Roy M. Young, Peter Bertone, Jeff Apple, Gary Thornton, Brent Knight, Kurt Dietz, Mohammad Sabra

University of Alabama, Huntsville: James Adams, Patrick Reardon, Evgeny Kuznetsov, J. Watts Jr., J. Tubbs, M. Mastafa

NASA/GSFC: John W. Mitchell, John Krizmanic, Jeremy S Perkins, Julie McEnery, Elizabeth Hays, Floyd Stecker, Stan Hunter, Jonathan Ormes, Tonia Venters

University of Utah: Doug Bergman, John Matthews

Colorado School of Mines: Lawrence Wiencke, Frederic Sarazin

City University of New York, Lehman College: Luis Anchordoqui, Thomas C. Paul

Georgia Institute of Technology: A. Nepomuk Otte

Space Sciences Laboratory, University of California, Berkeley: Eleanor Judd

University of Iowa: Mary Hall Reno

Jet Propulsion Laboratory: Insoo Jun, L. M. Martinez-Sierra

Vanderbilt University: Steven E Csorna

APC Université de Paris 7: Etienne Parizot, Guillaume Prevot

Universita di Torino: Mario Edoardo Bertaina, Francesco Fenu, Kenji Shinozaki

University of Geneva: Andrii Neronov

**RIKEN, Japan: Yoshiyuki TAKIZAWA**

Gran Sasso Science Institute: Roberto Aloisio

**SCIENTISTS FROM 16+ INSTITUTIONS FROM  
OWL, JEM-EUSO, AUGER, TA, VERITAS, CTA, FERMI, THEORY**



## POEMMA INSTRUMENT

Two 4 meter F/0.64 Schmidt telescopes; 45 deg FoV

Hybrid focal surface (MAPMTs and SiPM)

Instrument Mass: 1,547 kg

Primary Mirror: 4 meter

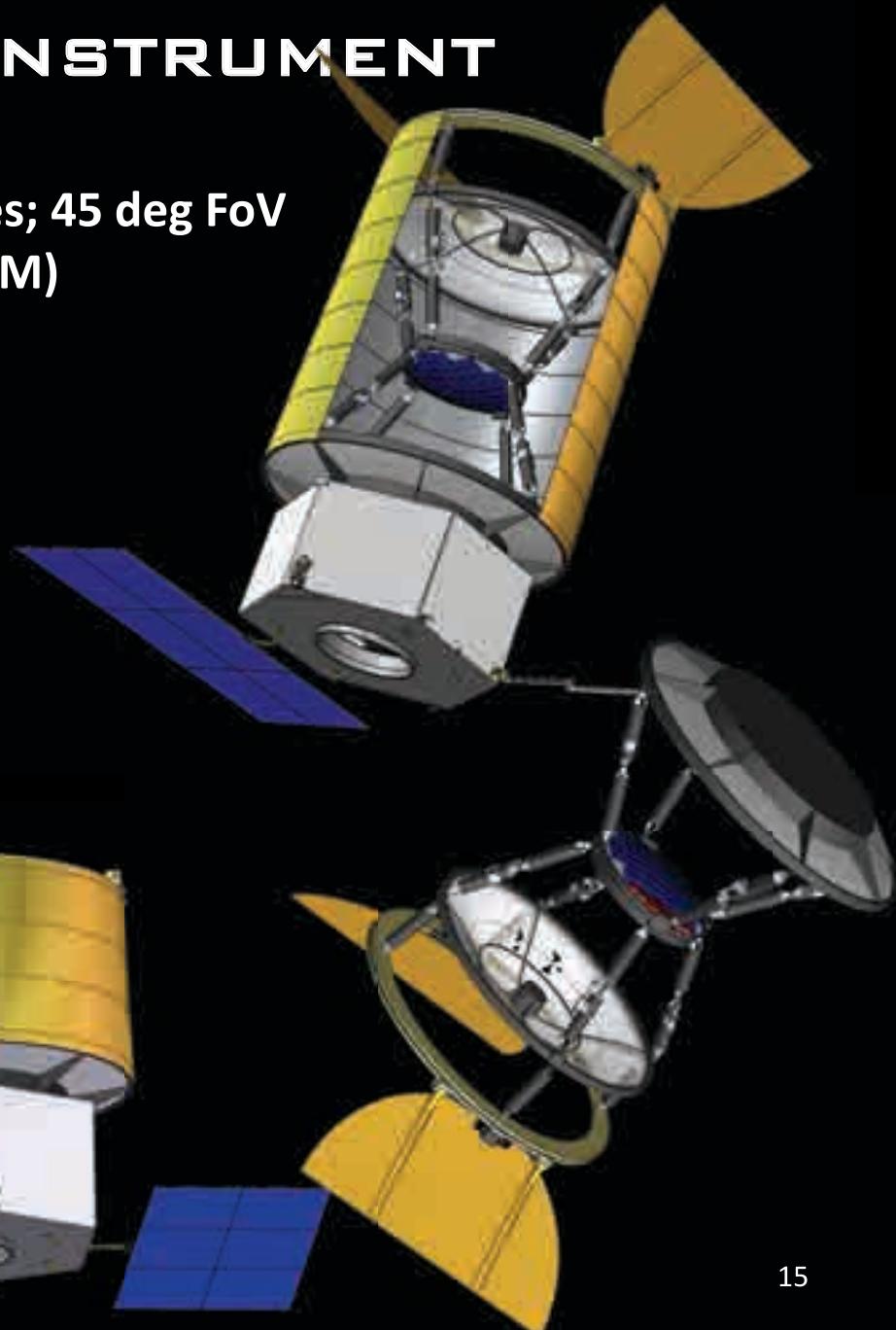
Corrector Lens: 3.3 meter

Focal Surface: 1.6 meter

Aperture: 6 to 2 m<sup>2</sup>

Power: 550 W

Data: 1 GB/day



Stowed Configuration Launch

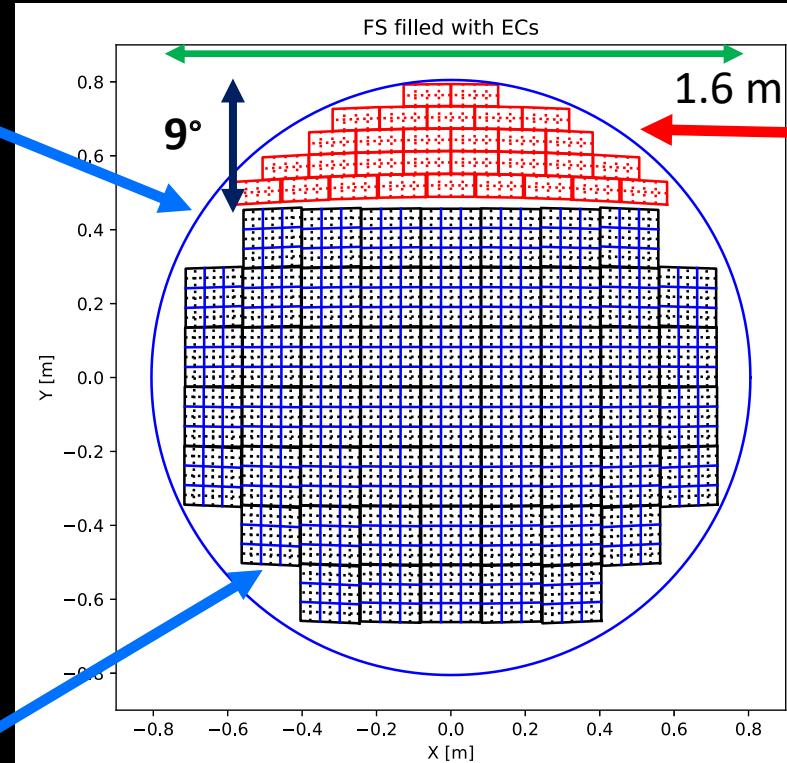
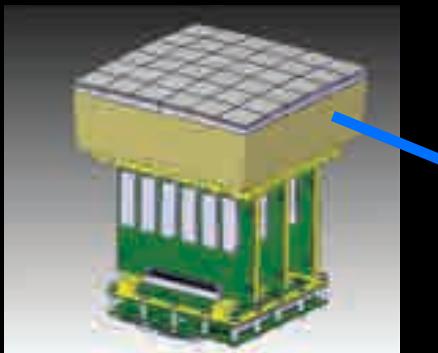




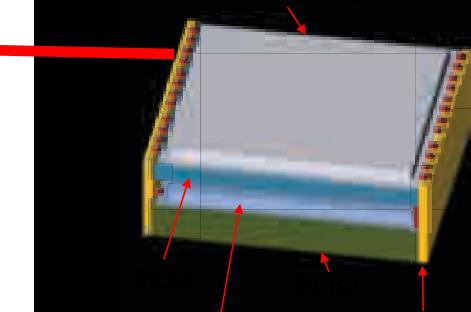
# POEMMA

## HYBRID MM FOCAL SURFACE

UV FLUORESCENCE  
MAPMTs WITH BG3 FILTER:  
JEM-EUSO: 1 USEC SAMPLING

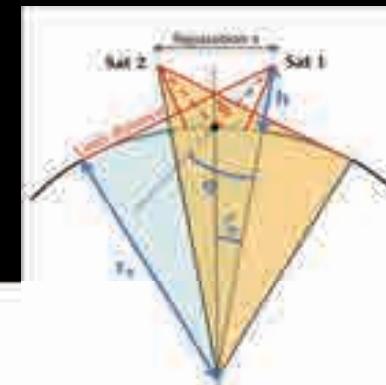


CHERENKOV DETECTION  
WITH SiPMs:  
20 NSEC SAMPLING



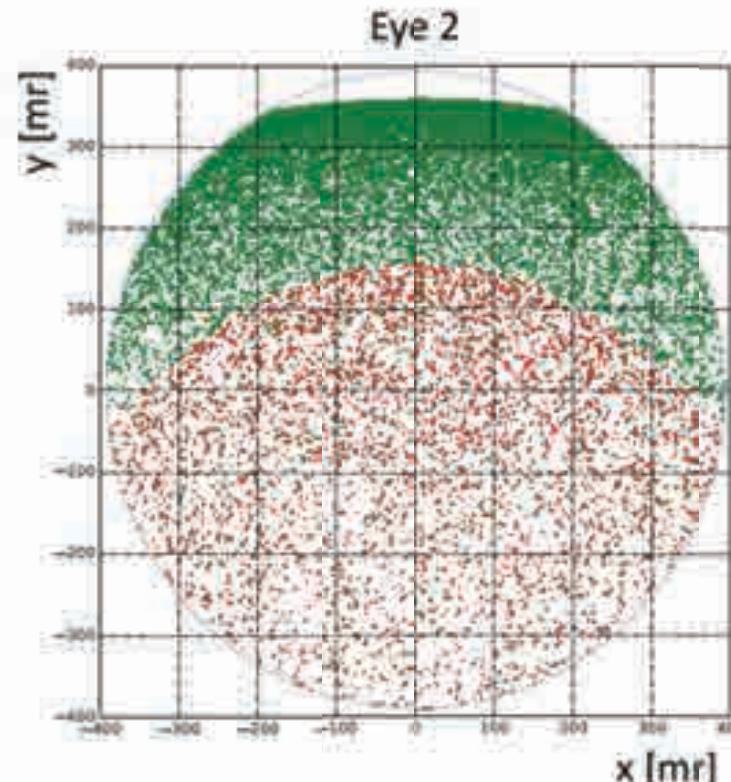
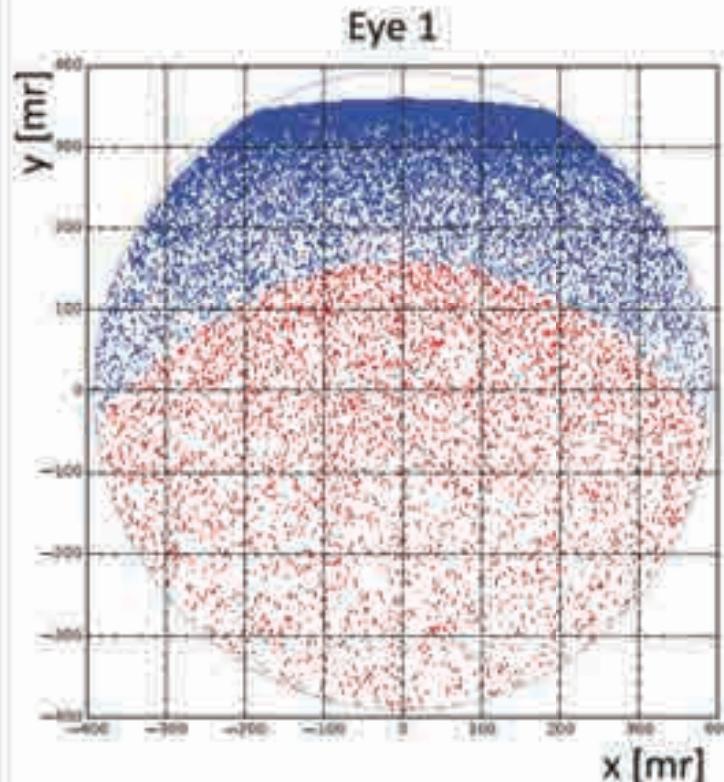
3D SiPM FOCAL  
SURFACE UNITS  
TOTAL 15,360 PIXELS  
512 PIXELS PER FSU  
(64x4x2)  
Si-DIODE FOR LEO  
RADIATION  
BACKGROUNDS  
REJECTION

55 PHOTO DETECTOR MODULES (PDMs)=  
126,720 PIXELS  
1 PDM = 36 MAPMTs = 2,304 PIXELS



# FOV 2° above limb

Focal surface coordinates





# POEMMA MISSION

Mission Lifetime: 3 years (5 year goal)

Orbits: 525 km, 28.5° Inc

Orbit Period: 95 min

Satellite Separation: ~25 km – 1000+ km

Satellite Position: 1 m (knowledge)

Pointing Resolution: 0.1°

Pointing Knowledge: 0.01°

Slew Rate: 8 min for 90 °

Satellite Wet Mass: 3860 kg

Power: 2030 W

Data: 1 GB/day

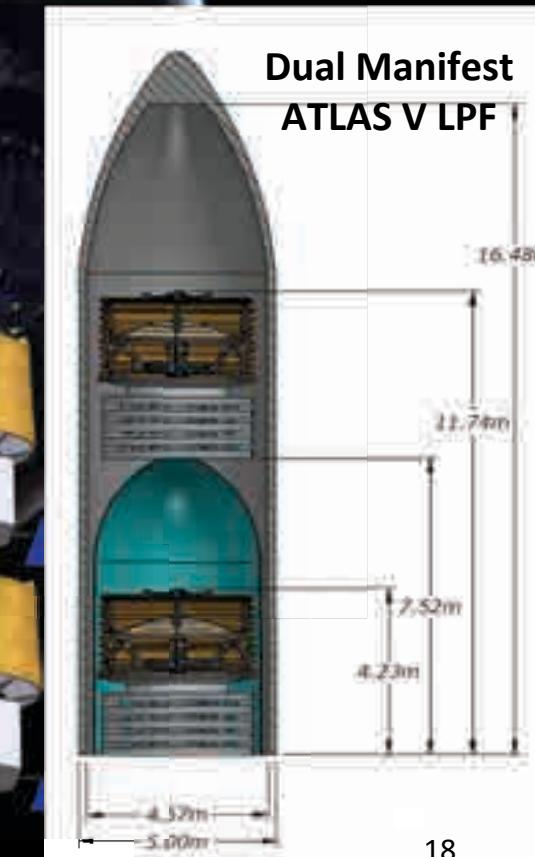
Data Storage: 7 days

Communication: S-band (X-band if needed)

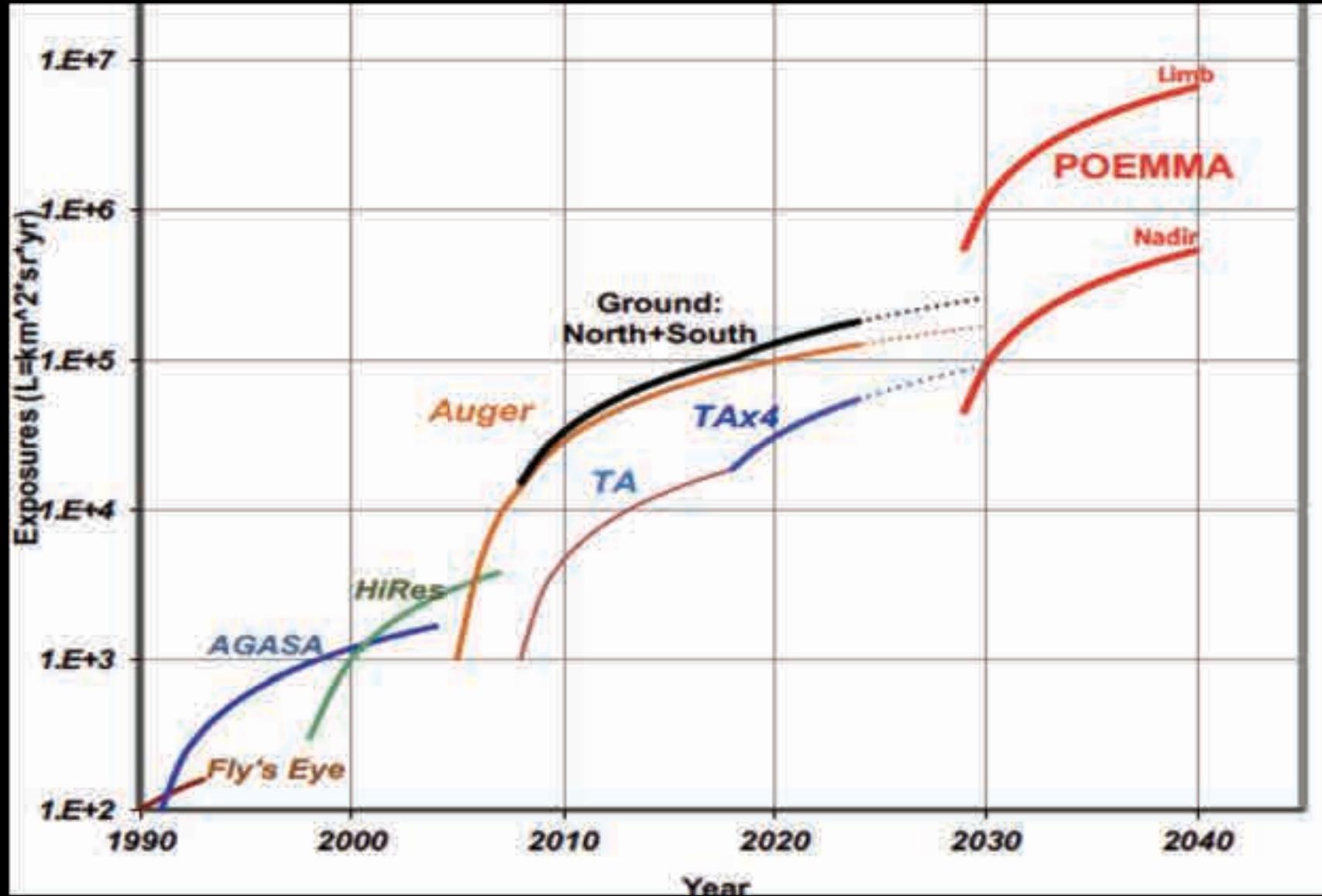
Clock synch (timing): 10 nsec

## Operations:

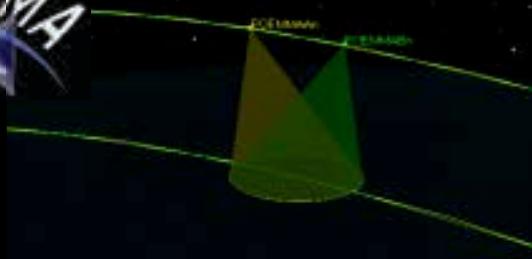
- Each satellite collects data autonomously
- Coincidences analyzed on the ground
- View the Earth at near-moonless nights, charge in day and telemeter data to ground
- ToO Mode: dedicated com uplink to re-orient satellites if desired



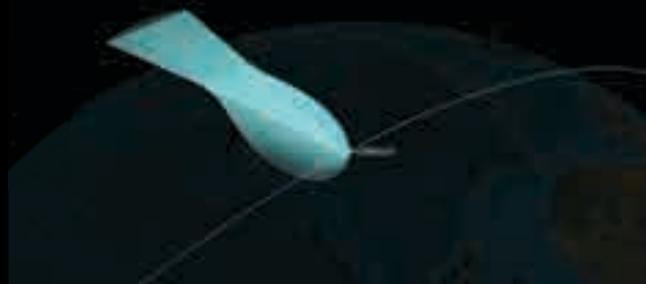
## POEMMA: Exposure History



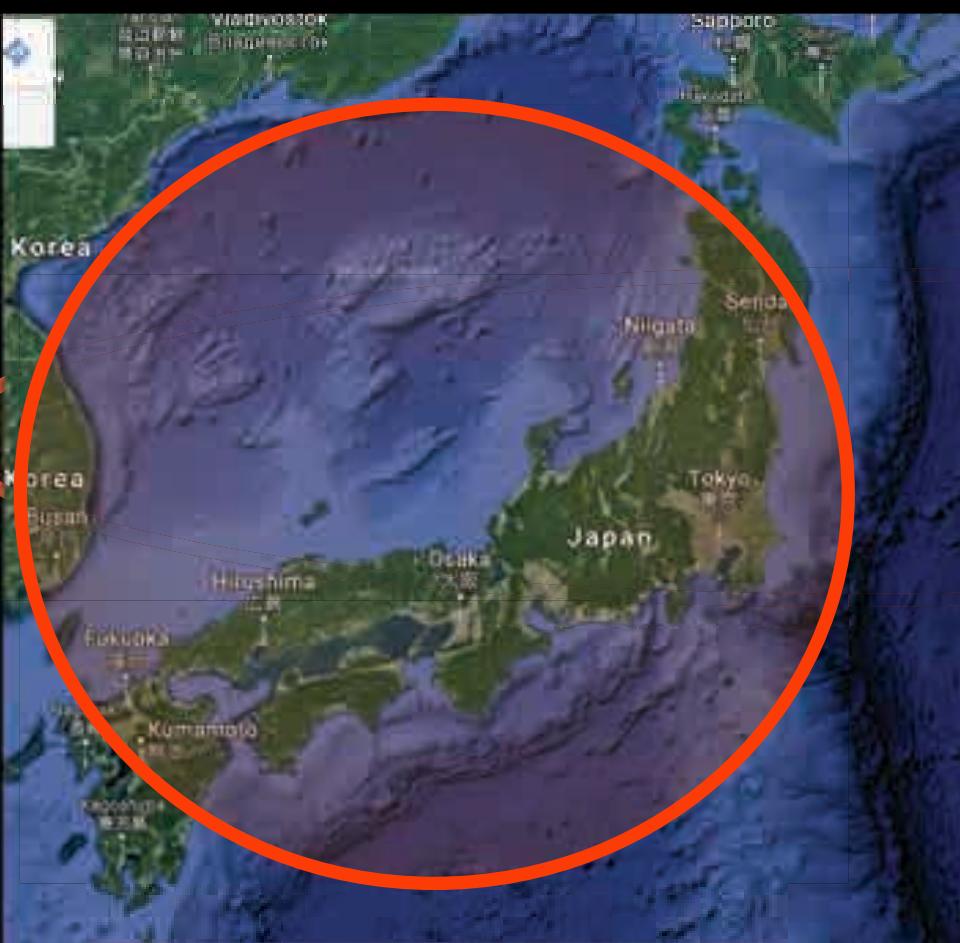
POEMMA



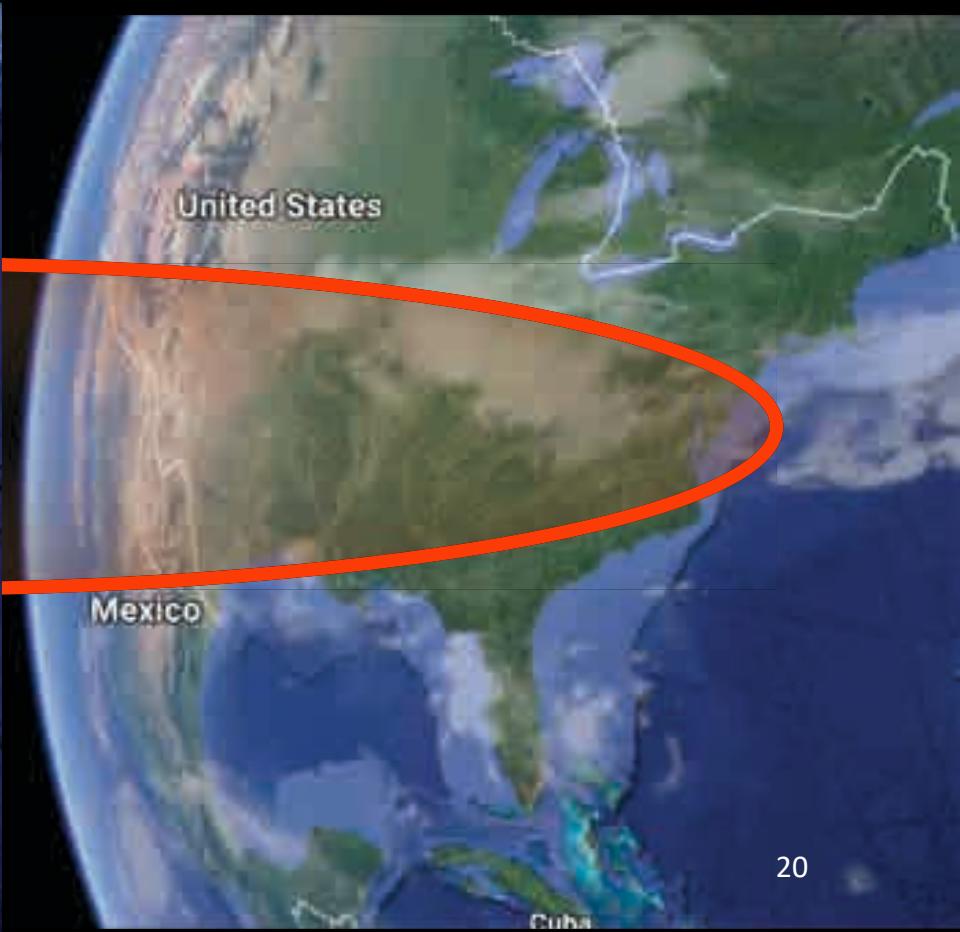
POEMMA



NADIR FOR UHECR:  
RADIUS 200-400 KM

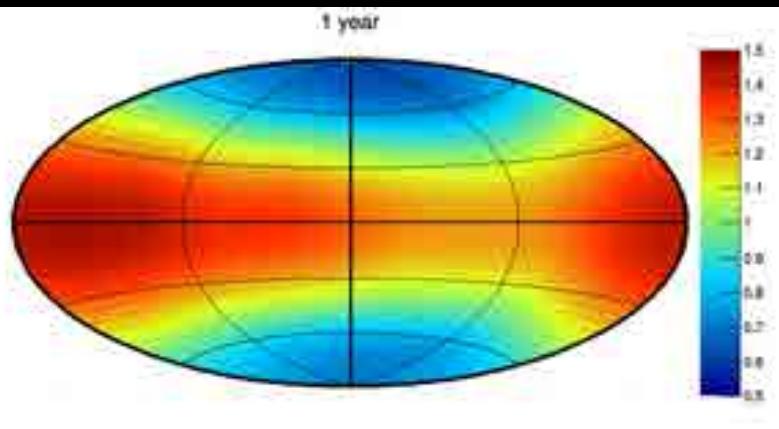


LIMB FOR NEUTRINOS:  
RADIUS  $2.6-3.7 \times 10^3$  KM

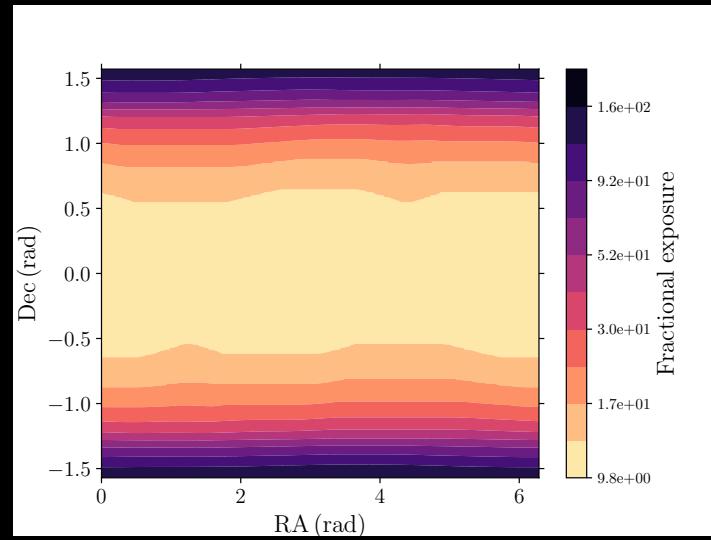
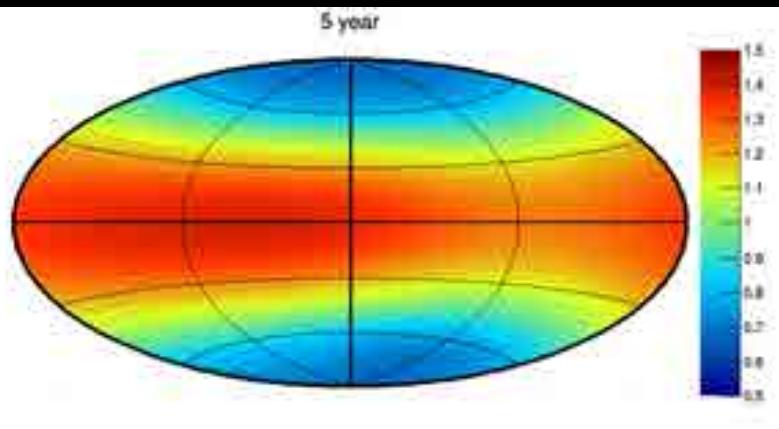
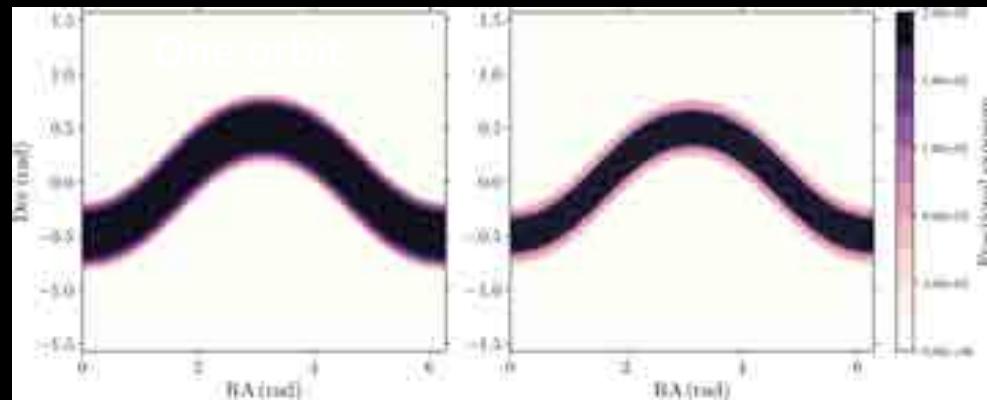


# POEMMA: UHECR and Neutrino Sky Coverage

UHECR Stereo Mode



Neutrino Mode: SiPM part of focal plane



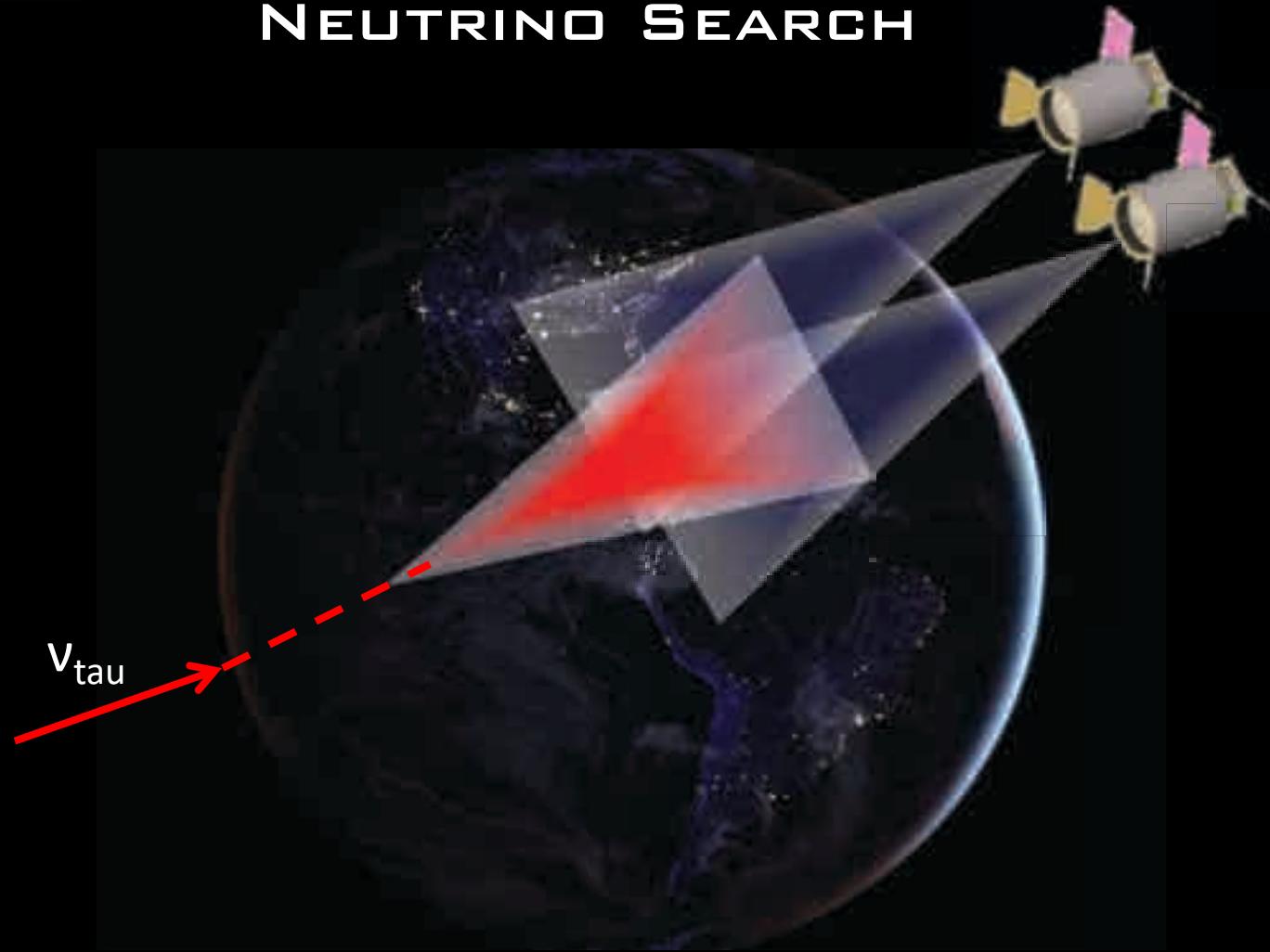
Calcs & plots by K. Shinozaki

Calcs & plots by C. Guépin & F. Sarazin

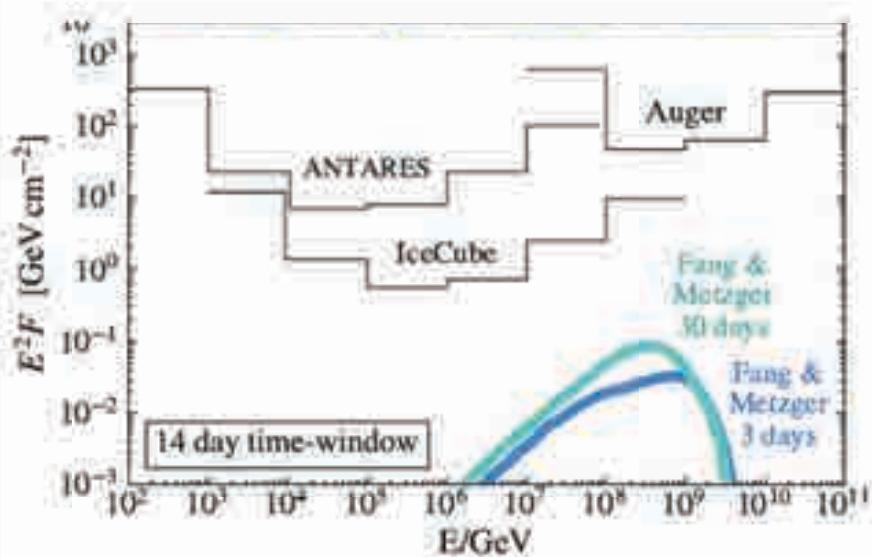
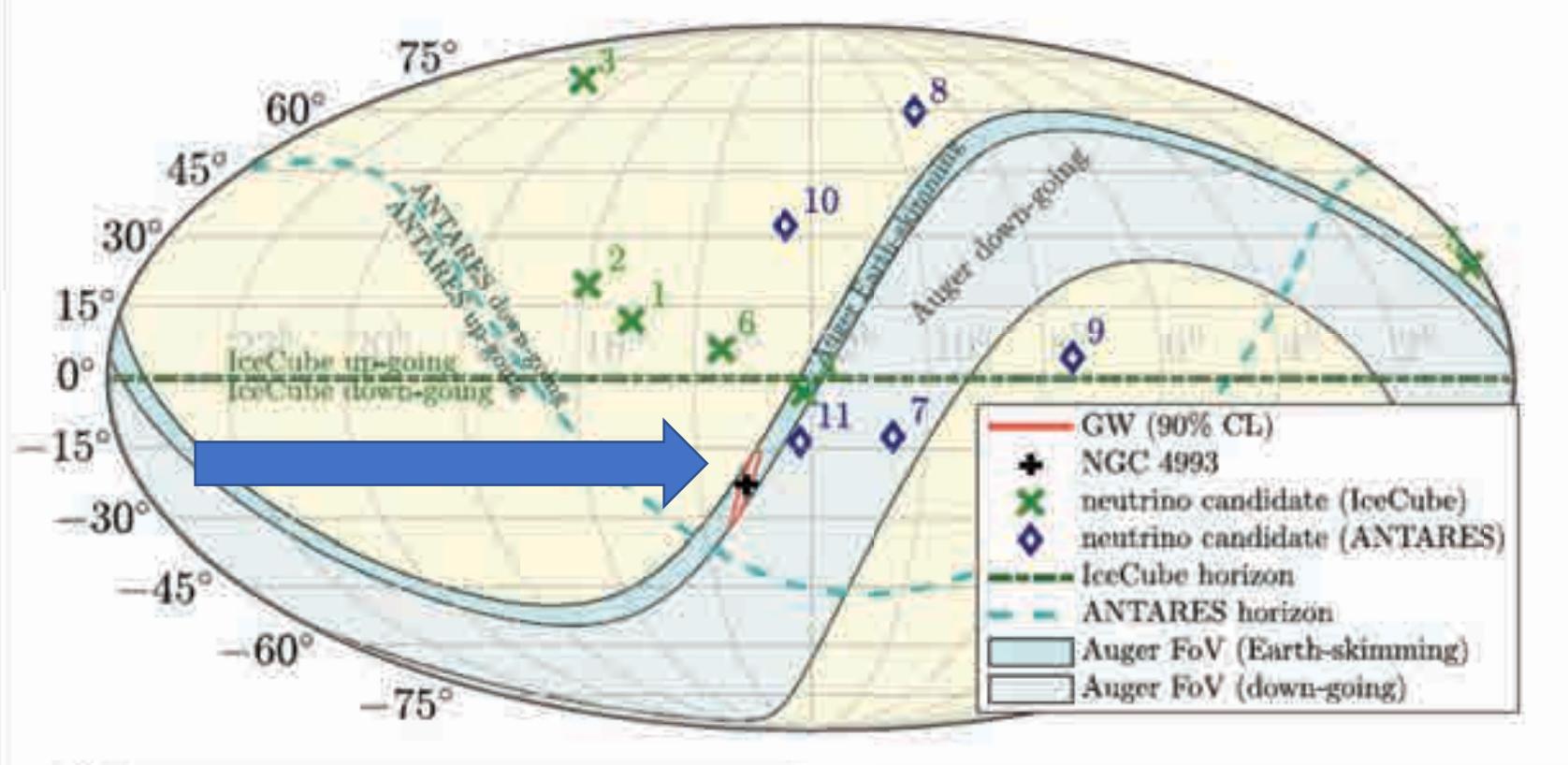
POEMMA

POEMMA

NEUTRINO SEARCH



OPTICAL CHERENKOV SIGNAL FROM TAU NEUTRINOS  
PEV → HIGHEST ENERGIES



arXiv:1710.05839

## GW170817 follow up w ANTARES, ICECUBE, AUGER



# POEMMA

## UHECR AND NEUTRINO OBSERVATIONS



# JEM-EUSO PROGRAM

EUSO-TA (2013- )

EUSO-Balloon (2014)

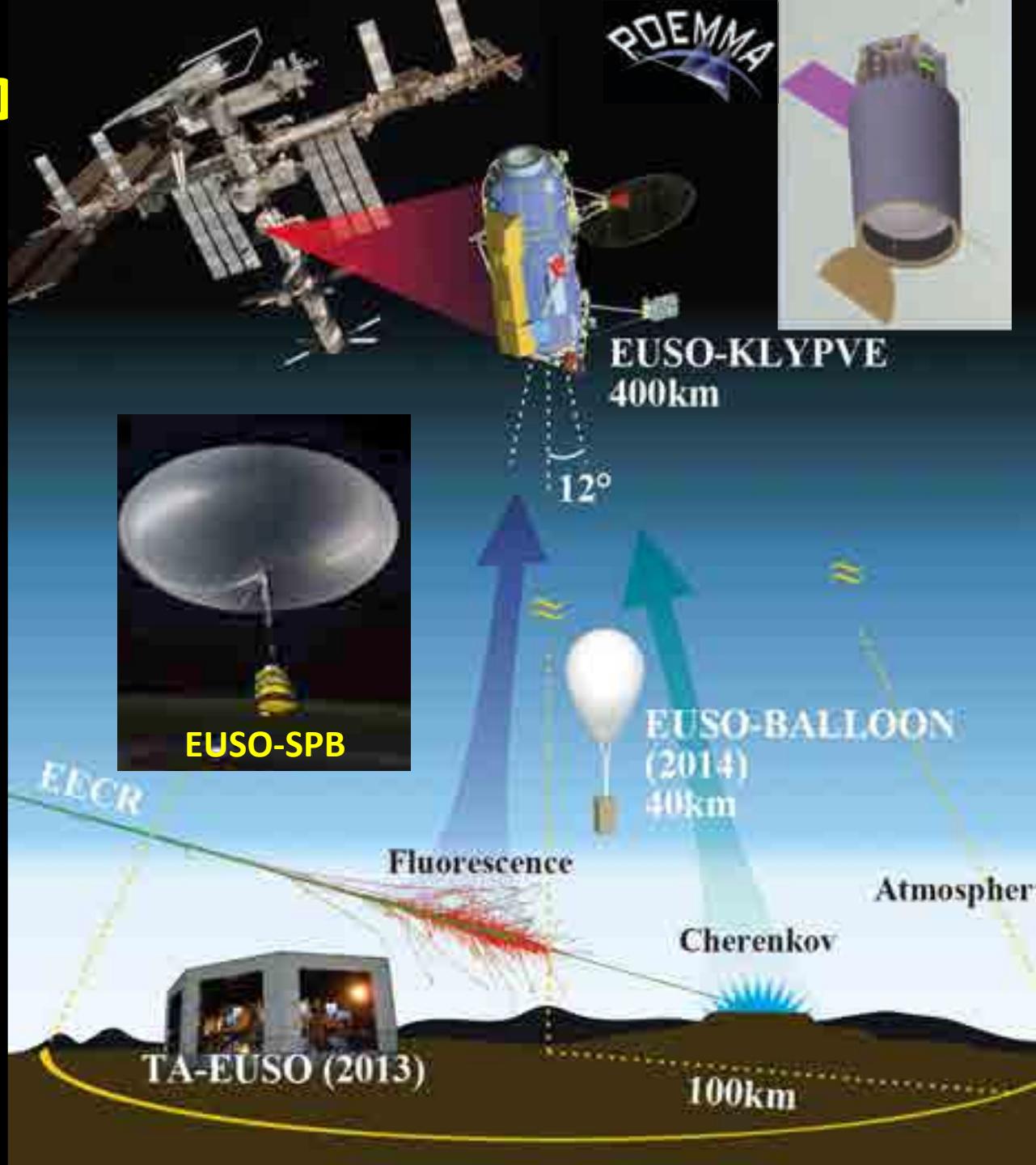
EUSO-SPB1 (2017)

Mini-EUSO (2018-19)

**EUSO-SPB2 (2020-22)**

K-EUSO (2023+)

POEMMA (2028+)



EUSO Balloon:

1<sup>st</sup> flight and first light on 24-25.8.2014

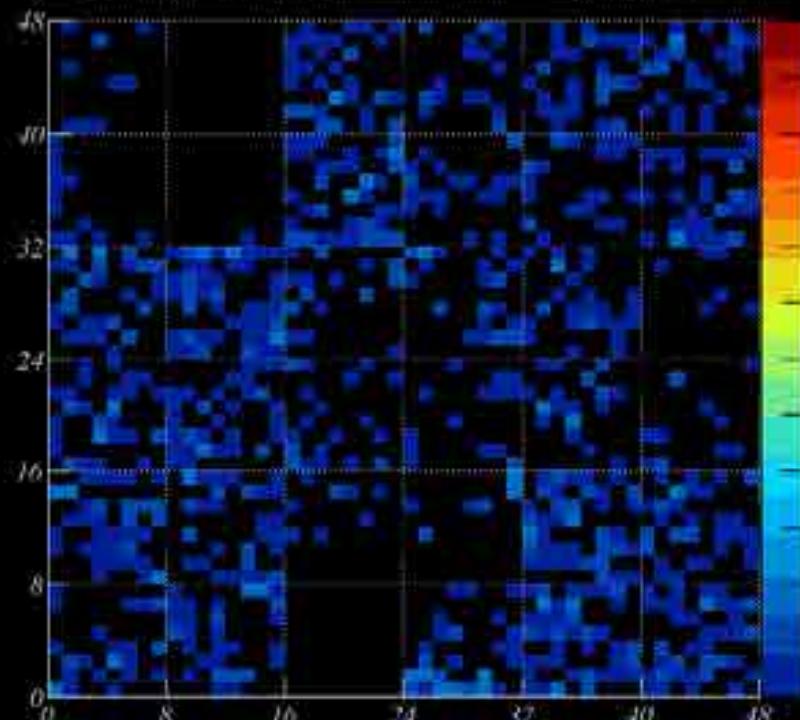


# EUSO-BALLOON 2014

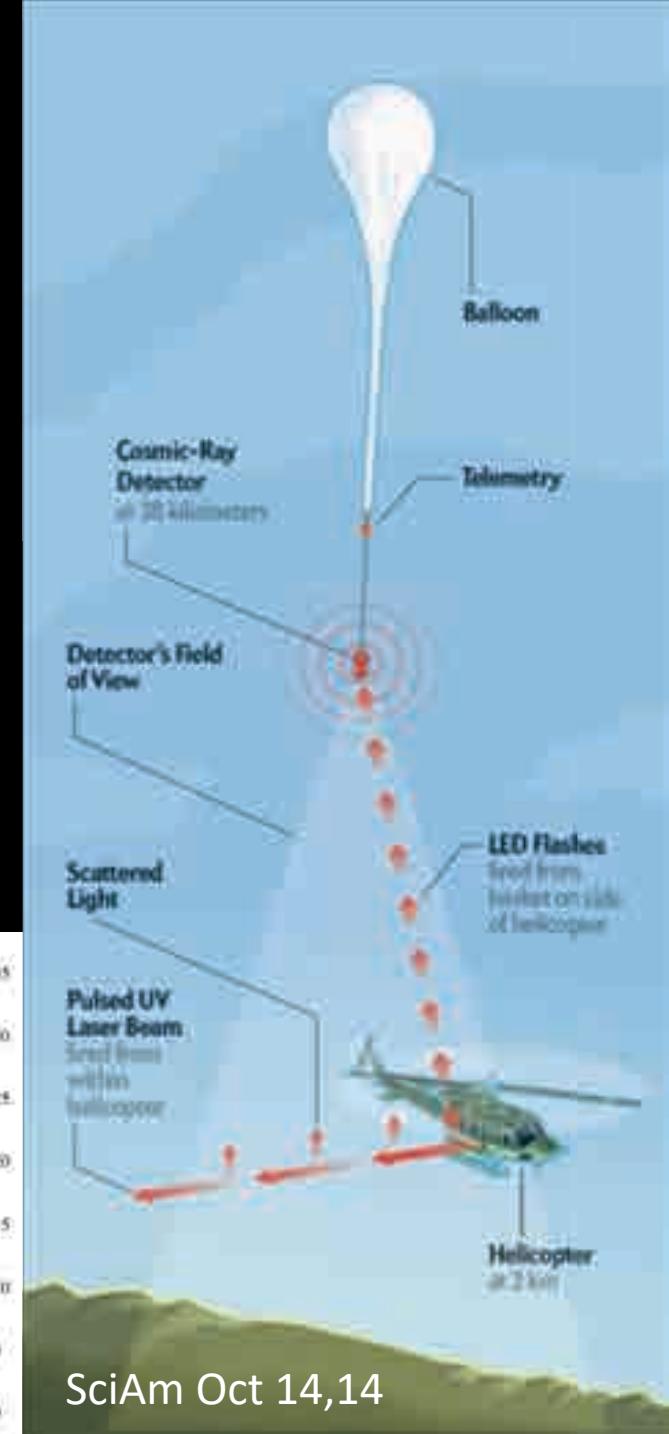
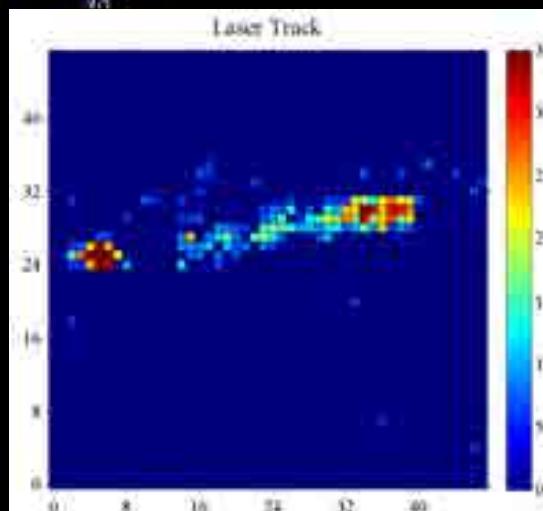
## FLASHER & LASER EVENTS

Aver. Count: 0.442

GTU: 0



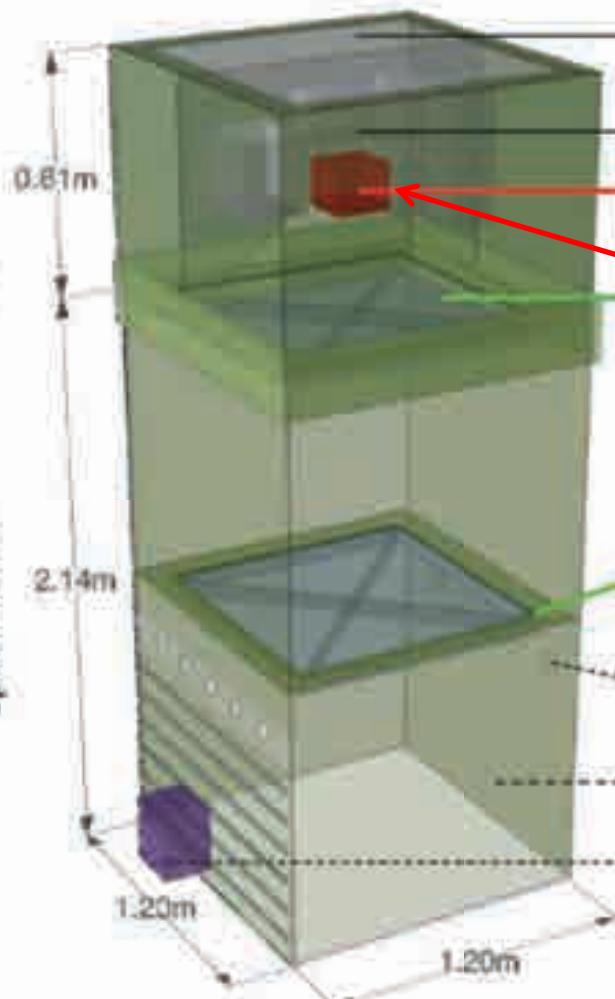
355nm Laser:  
~ $10^{20}$  eV equivalent brightness



SciAm Oct 14,14

# EUSO-SPB Extreme Universe Space Observatory on a Super Pressure Balloon

Instrument booth



radiator

electronics subsystems  
on "dry shelf"

PDM

Fresnel  
fixed/tig



Fresnel lens L1  
adjustable

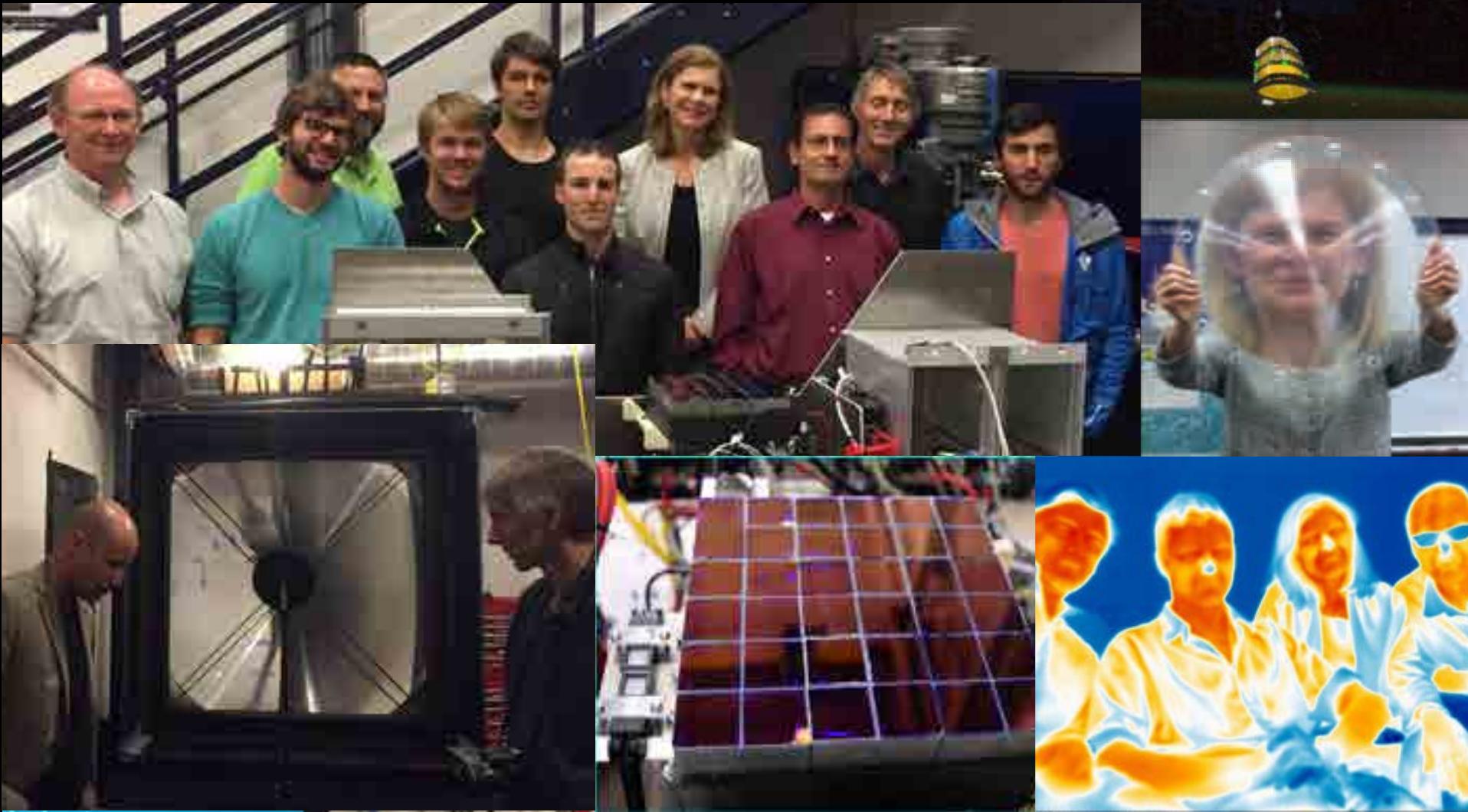
evacuation  
holes  
Baffle &  
"deceleration cylinder"

IR Camera



# EUSO-SPB Extreme Universe Space Observatory on a Super Pressure Balloon

Ultrafast Camera: Photo-Detector Module (PDM)  
(3x3 ECs = 36 MAPMTS ; 2,304 pixels)



# EUSO-SPB Extreme Universe Space Observatory on a Super Pressure Balloon



**EUSO-SPB**  
**LAUNCH,**  
**APRIL 24,**  
**2017**  
**23:51 UTC**



# WANAKA 2017 Campaign

## Super Pressure Balloon (SPB) EUSO mission



2015

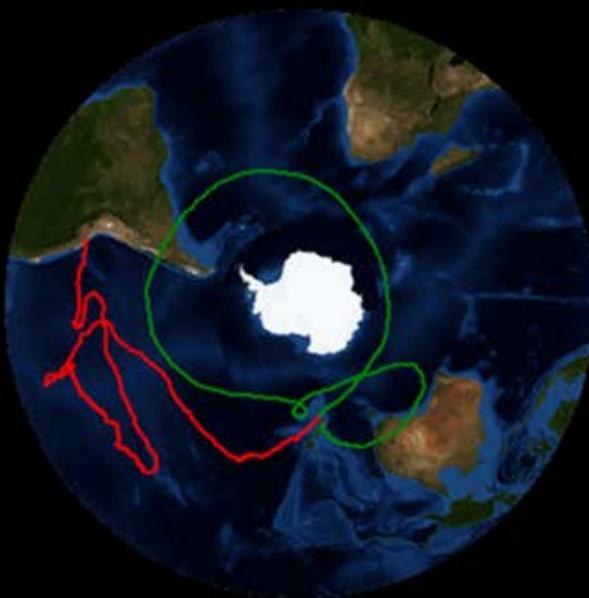
NASA Engineering Flight



32 d 5 h

2016

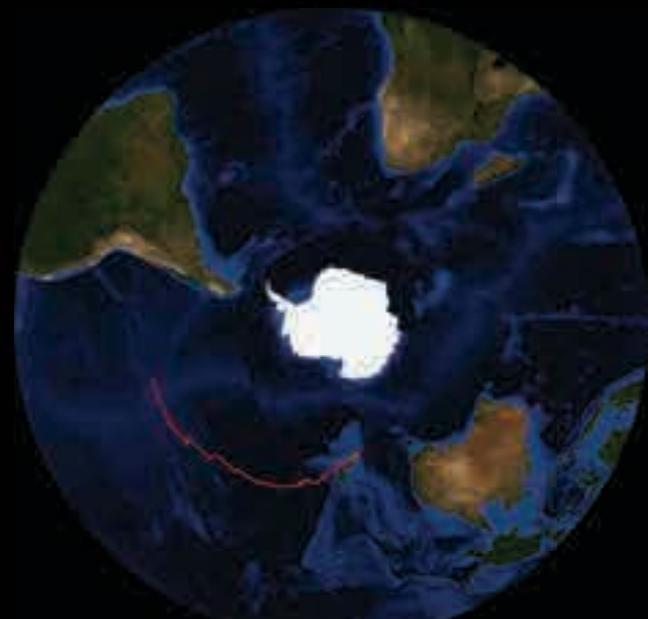
COSI



46 d 20 h

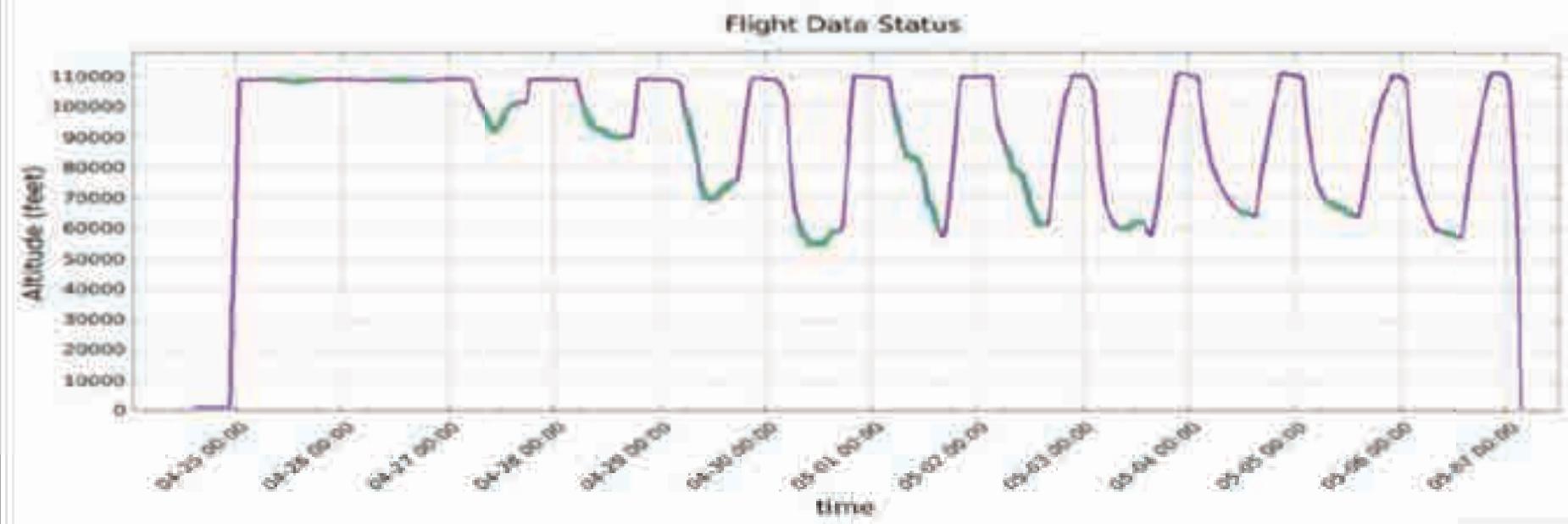
2017

EUSO-SPB

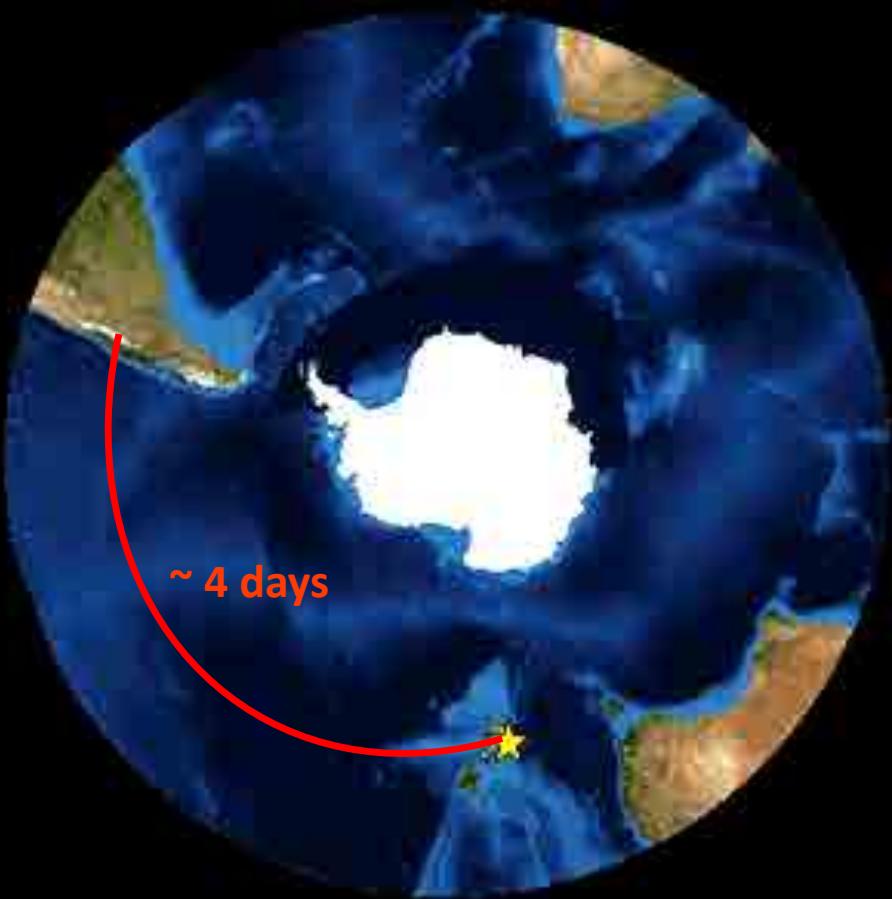


12 d 4 h

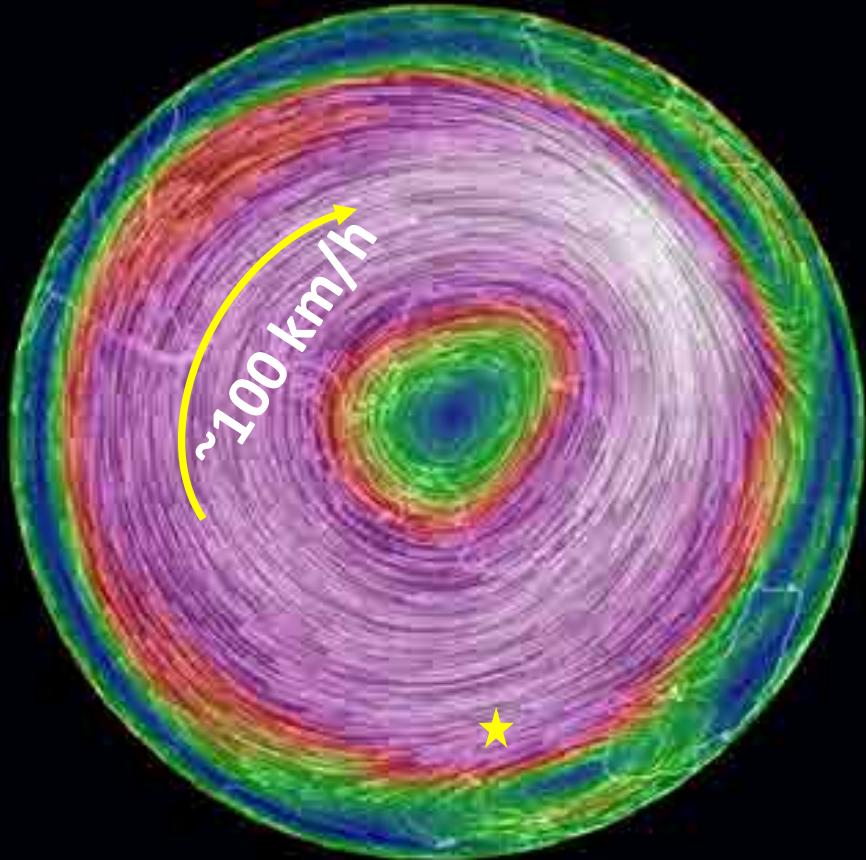
NASA completed its third mid-latitude Super Pressure Balloon (SPB) flight at May 7 3:40 UTC, after 12 days, 4 hours and 34 minutes aloft.



# Why New Zealand?



Wanaka  
South Island  
New Zealand

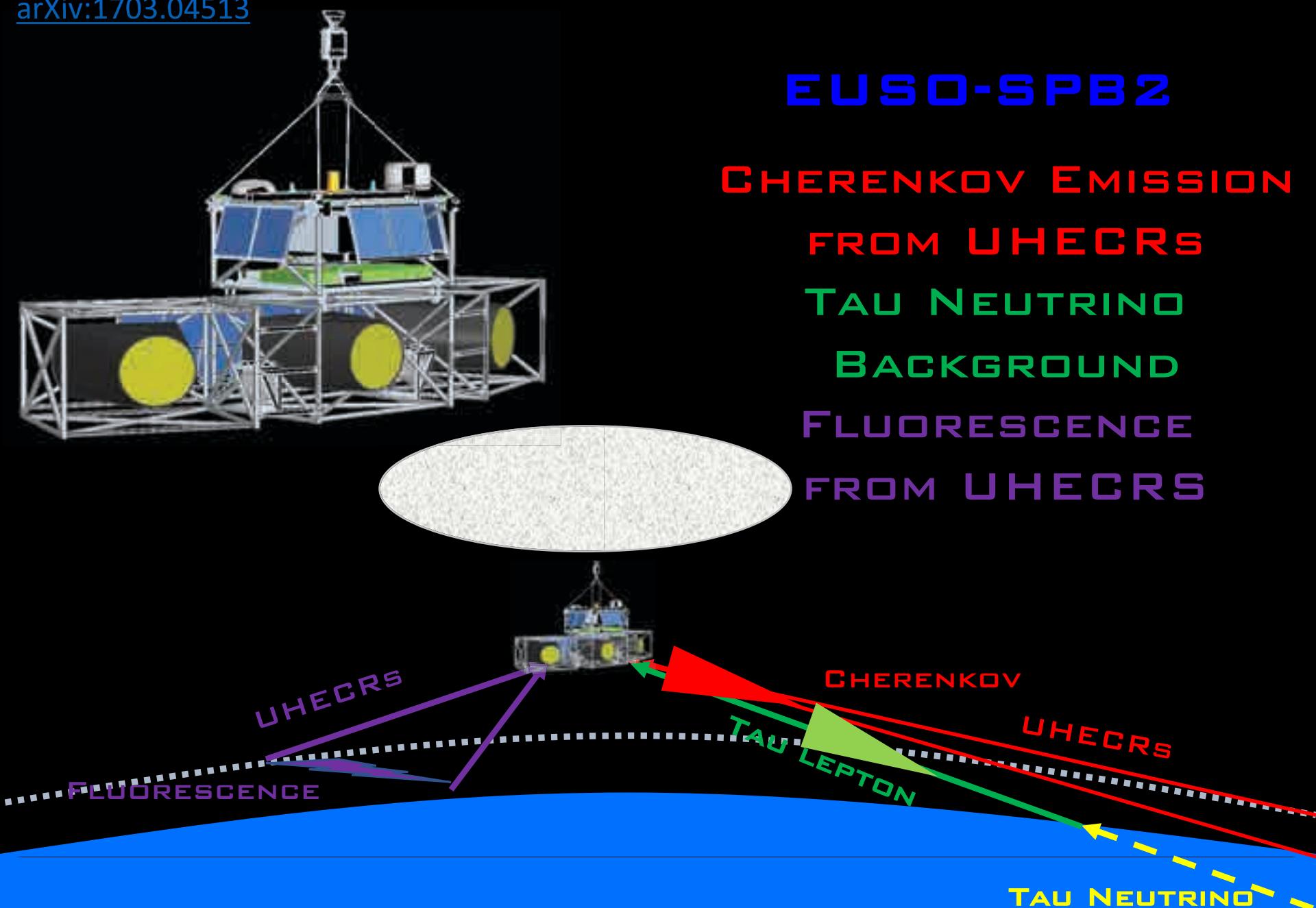


air flow at ~30 km June 9<sup>th</sup> 2017

<https://earth.nullschool.net/#current/wind/isobaric/10hPa/orthographic=180,-90,300>

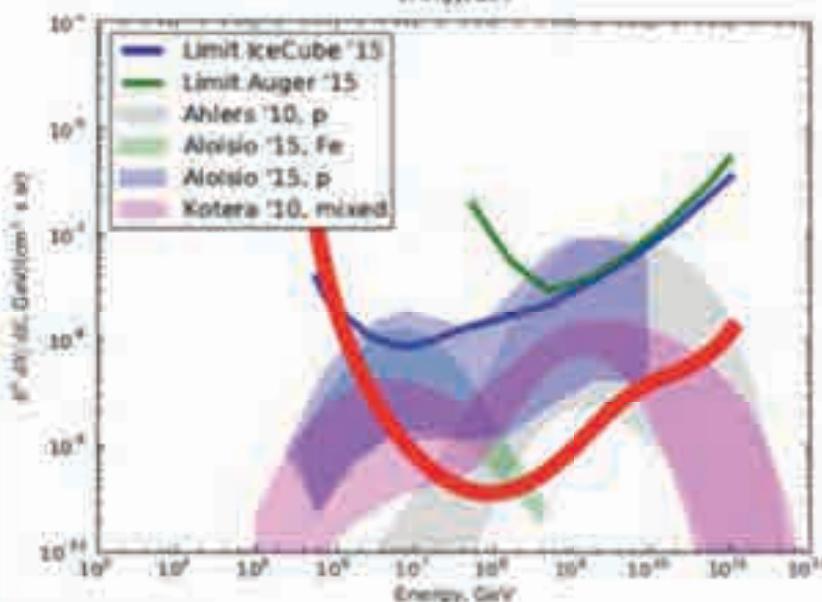
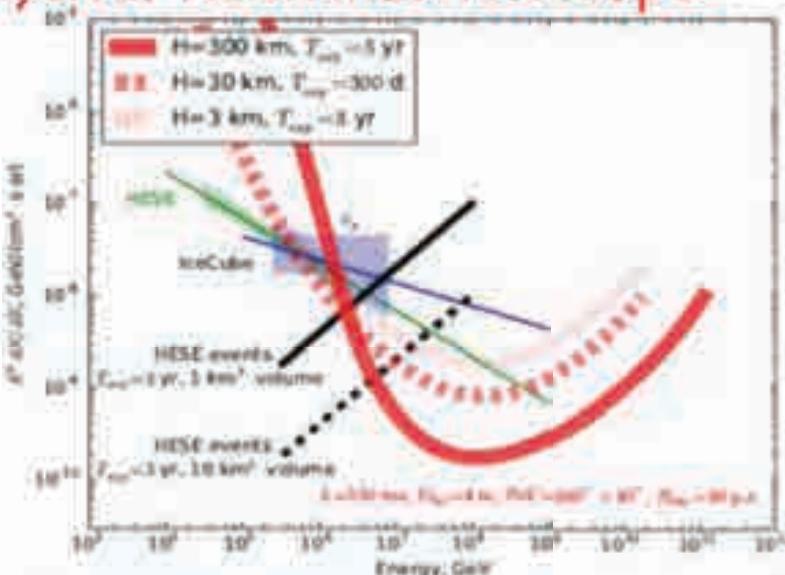
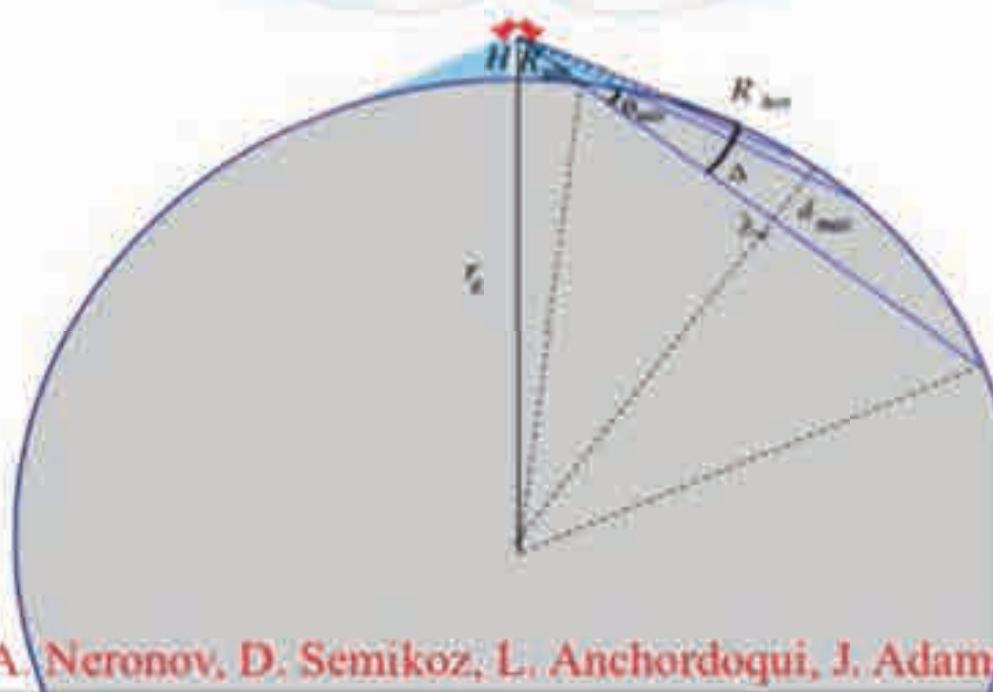
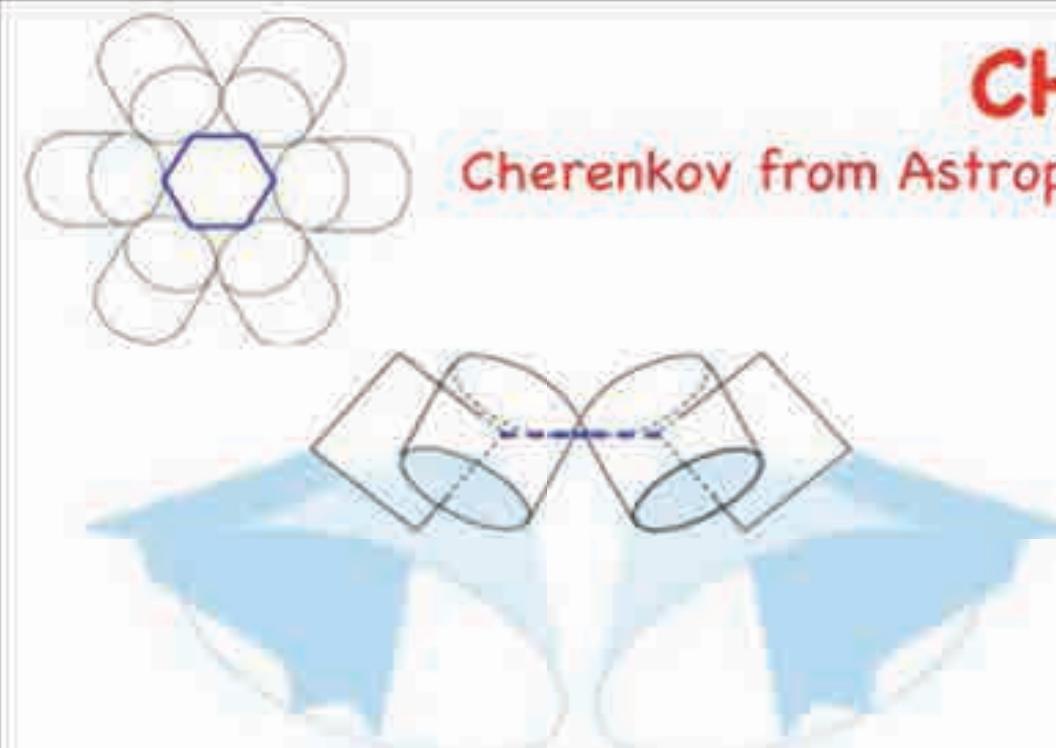
**EUSO-SPB2**

**CHERENKOV EMISSION  
FROM UHECRs  
TAU NEUTRINO  
BACKGROUND  
FLUORESCENCE  
FROM UHECRs**



# CHANT

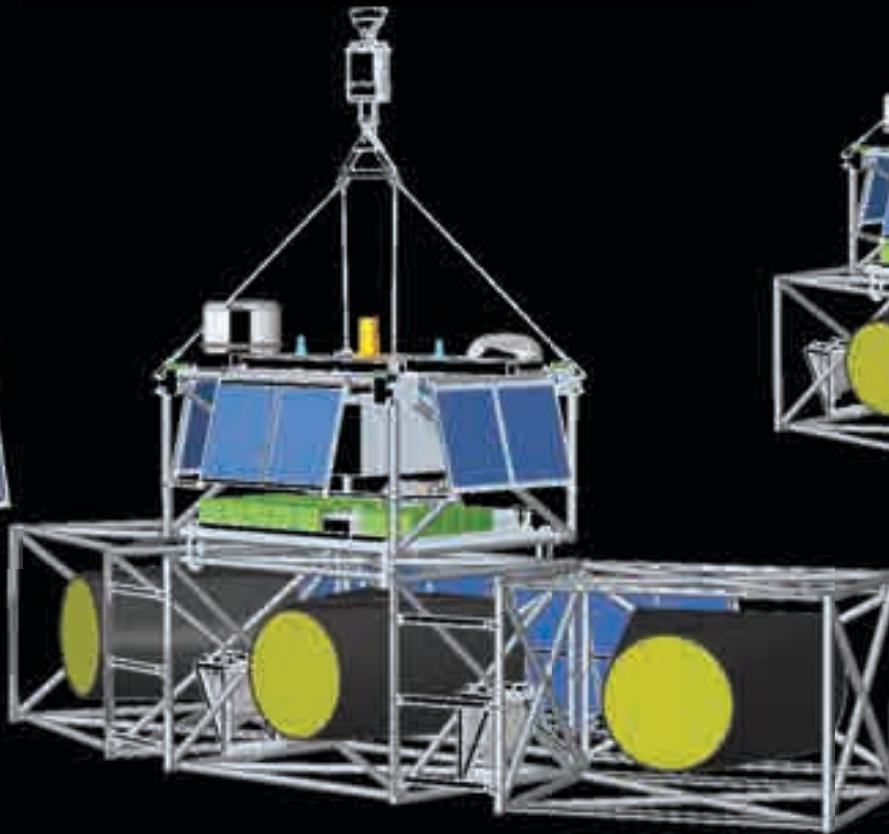
## Cherenkov from Astrophysical Neutrinos Telescope



# EUSO-SPB 2



Telescope



Fluorescence Camera  
MAPMTs  
3 x EUSO-SPB1

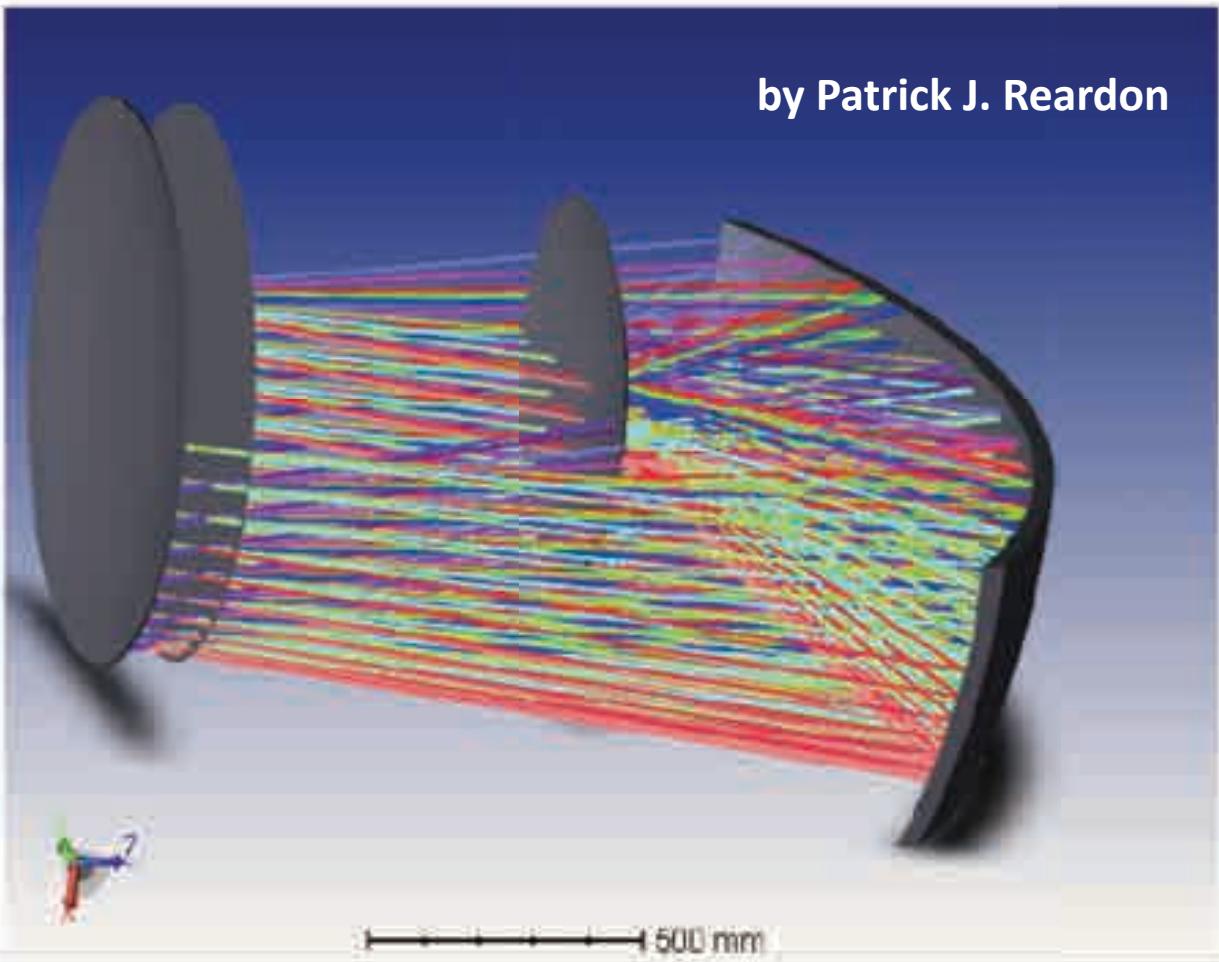


Cherenkov camera  
SiPMs



# Bifocal Design

by Patrick J. Reardon



## Cherenkov Telescopes

FoV  $5^\circ \times 45^\circ$  bi-focal mirror

FoV  $5^\circ \times 45^\circ$  normal mirror

## Focal Surface

7cm x 70cm

## Fluorescence Telescope

FoV  $15^\circ \times 45^\circ$  normal mirror

Corrector Plate:  $1m^2$

Image resolution: ~ few mm

Pixel size: ~3mm square

## Challenges/Opportunities:

Space qualified SiPMs, ultra-fast ASICs, corrector lens development, bifocal mirror  
SPB stability

# SPACE PROBES OF THE HIGHEST ENERGY PARTICLES: **POEMMA & EUSO-SPB**

POEMMA

EUSO-SPB2



THE EARTH'S ATMOSPHERE  
AS AN EXTREME ENERGY  
PARTICLE OBSERVATORY

EUSO-SPB1 LAUNCH FROM WANAKA, NZ

APRIL 24, 2017



ありがとう



# POEMMA

## UHECR AND NEUTRINO OBSERVATIONS



ありがとう