



# POEMMA and the road to a multi messenger space observatory

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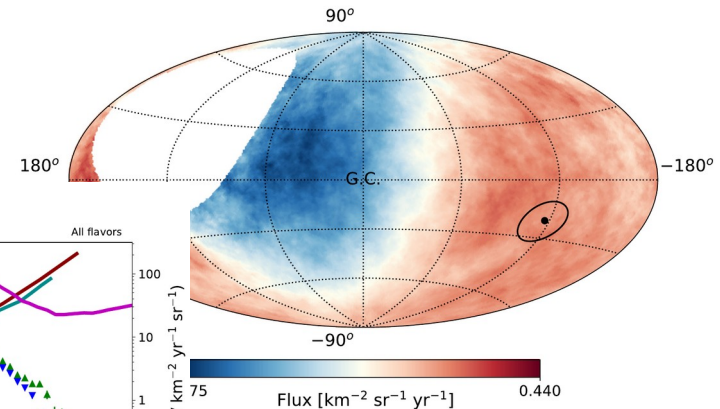
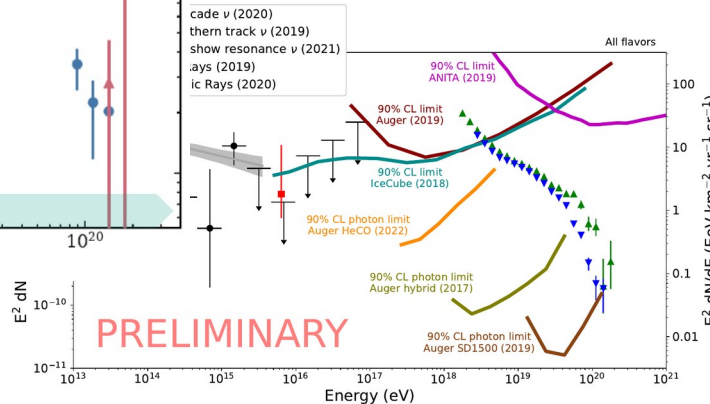
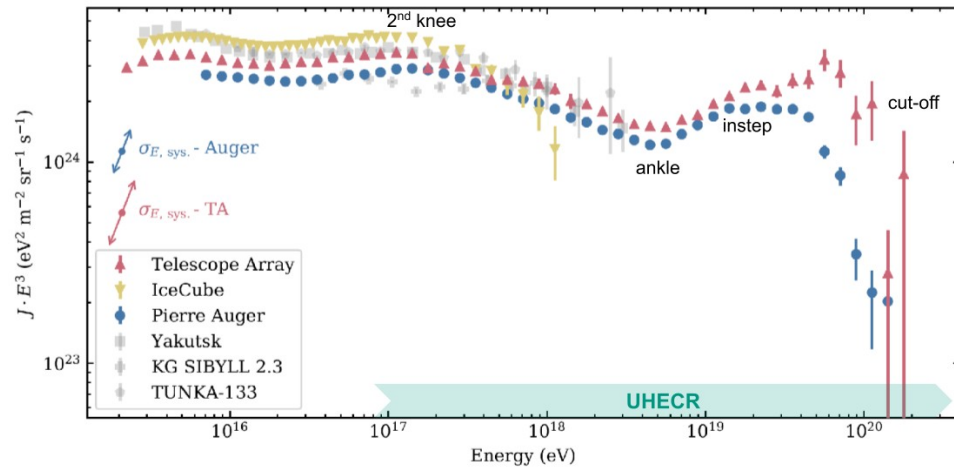
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# What we know so far

- Well measured energy spectrum
- Measured mass composition of CR primaries
- First indication of anisotropy found (Auger and TA hotspots)
- UHECR Observatories are Multi-Messenger observatories

**Driven by ground arrays  
Auger & TA**





# Remaining Open Questions



- What is the nature and origin(s) of UHECRs?
- What are the sources and acceleration mechanism of UHECRs?
- What is the nature of the flux suppression at the highest energies?
- To what degree will charged-particle astronomy, the ability to study individual (classes of) sources with cosmic rays, be possible?
- Are there new interactions and phenomena waiting to be discovered at energies past those achievable at the LHC?

**Attempt to answer these question is going to Space**

**➡ POEMMA**

Cumminuty Road-map outlined in AstroPart Vol. 149





# POEMMA collaboration



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(US + 10+)**

**OWL, JEM-EUSO, Auger, TA, Veritas,  
CTA, Fermi, Theory**

JCAP 2021, id.007

[10.1088/1475-7516/2021/06/007](https://doi.org/10.1088/1475-7516/2021/06/007)

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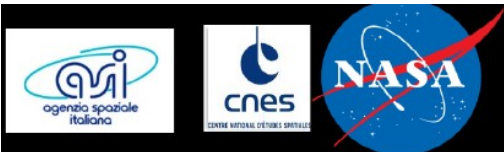
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# Past - Present - Future



**EUSO-Balloon**



**2014**

**EUSO-SPB1**



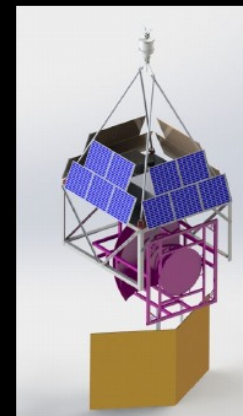
**2017**

**EUSO-SPB2**

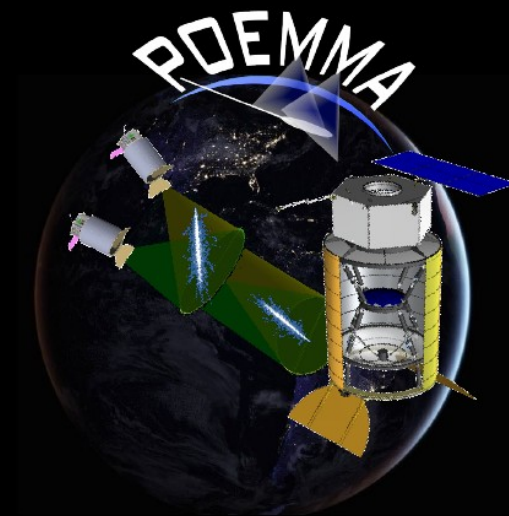


**2023**

**PBR**



**2027**





# Future



## EUSO-Balloon



2014

## EUSO

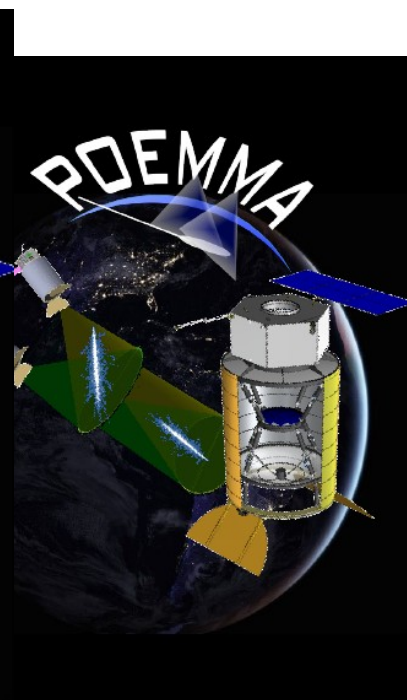
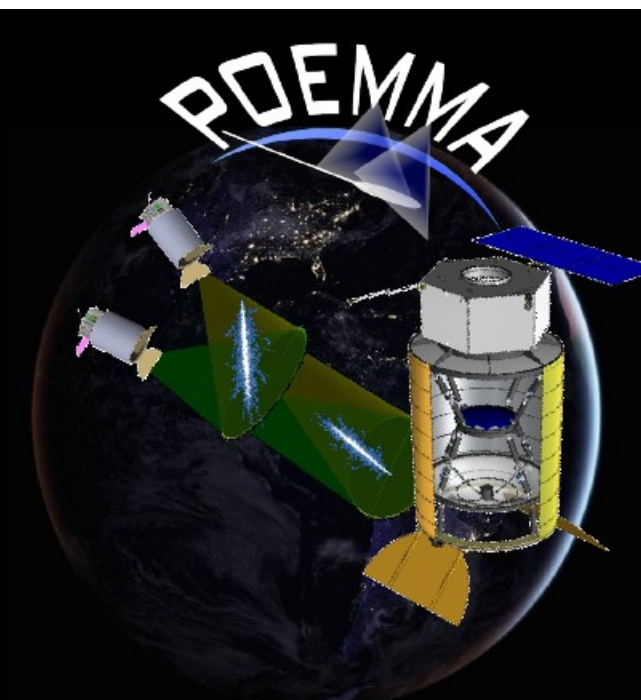


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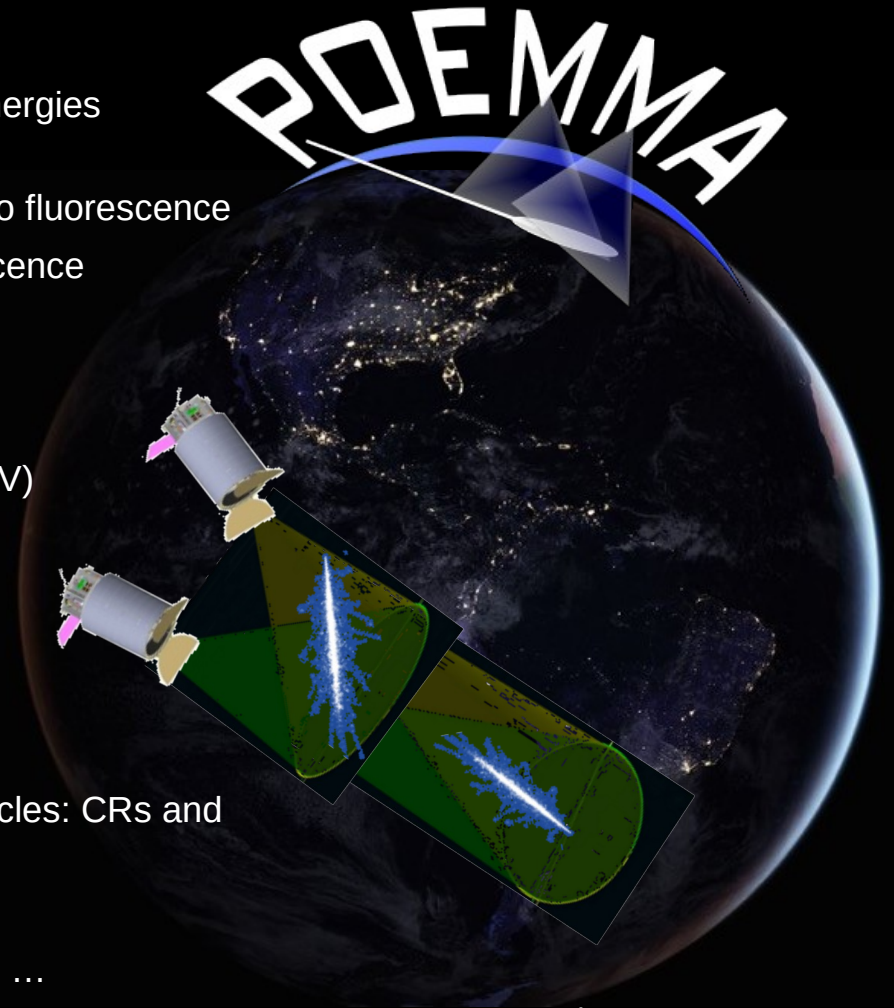
## PBR



2027



- Discover the origin of Ultra-High Energy Cosmic Rays
  - Measure Spectrum, composition, Sky Distribution at Highest Energies ( $E_{\text{CR}} > 20 \text{ EeV}$ )
  - Requires very good angular, energy, and  $X_{\text{max}}$  resolutions: stereo fluorescence
  - High sensitivity UHE neutrino measurements via stereo fluorescence measurements
- Observe Neutrinos from Transient Astrophysical Events
  - Measure beamed Cherenkov light from upward-moving EAS from  $\tau$ -leptons source by  $\nu_\tau$  interactions in the Earth ( $E_\nu > 20 \text{ PeV}$ )
  - Requires tilted-mode of operation to view limb of the Earth &  $\sim 10\text{ns}$  timing
  - Allows for tilted UHECR air fluorescence operation, higher GF but degraded resolutions
- Secondary goals
  - study fundamental physics with the most energetic cosmic particles: CRs and Neutrinos
  - search for super-Heavy Dark Matter: photons and neutrinos
  - study Atmospheric Transient Events, survey Meteor Population, ...



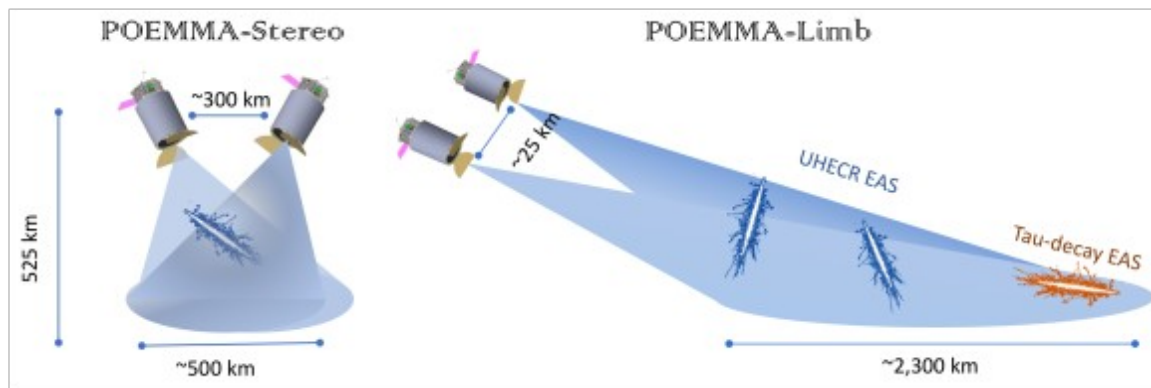
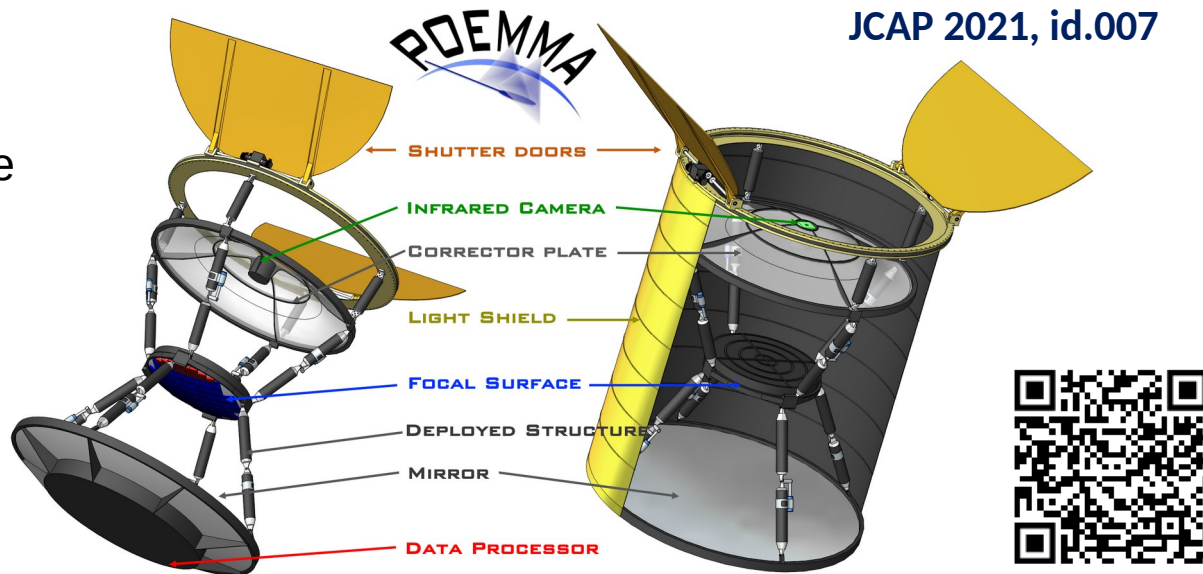


# The Telescope & Operation Mode



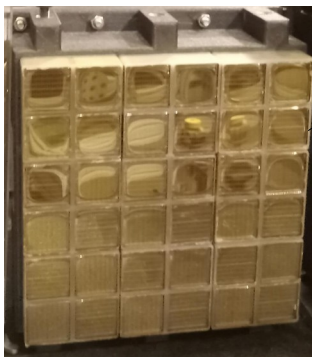
JCAP 2021, id.007

- 3-5 year dual satellite mission
- Orbit: **525km**,  $28.5^\circ$  inc,  $\Delta t$ :95min
- 3.3m diameter Schmidt optics telescope
  - FoV:  **$45 \times 45^\circ$**
  - Pixel FoV:  $0.084^\circ$
- **Hybrid** focal surface
  - 126720 MAPMT px ( $1\mu s$ )
  - 15360 SiPM px (10ns)
- Slew rate: **8min/90deg**
- **Two** observation modes
  - **Stereo** for UHECR, separation 300km
  - **Limb** for ToO, separation 25km
  - 300 km  $\rightarrow$  25 km Satellite Separation
    - Puts both into Cherenkov Light Pool
    - $\Delta t$ : 3h
    - 8-15 times during mission

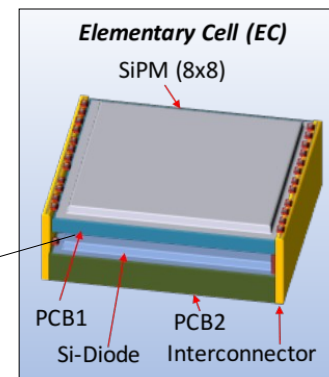
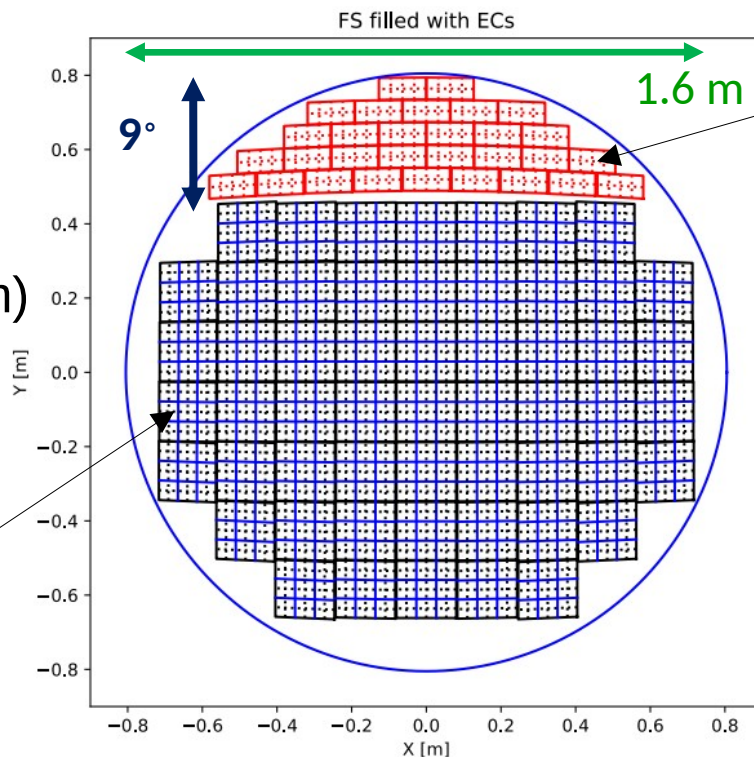


- Fluorescence  
Optimized Detection

- 55 PDMs = 126,720 pixels (JEM-EUSO design)
- 2304 MAPMT px/PDM
- BG3 filter (300-500 nm)
- $1\mu\text{s}$  sampling



## Hybrid Focal Surface 100,000+ channels



- Cherenkov Optimized Detection

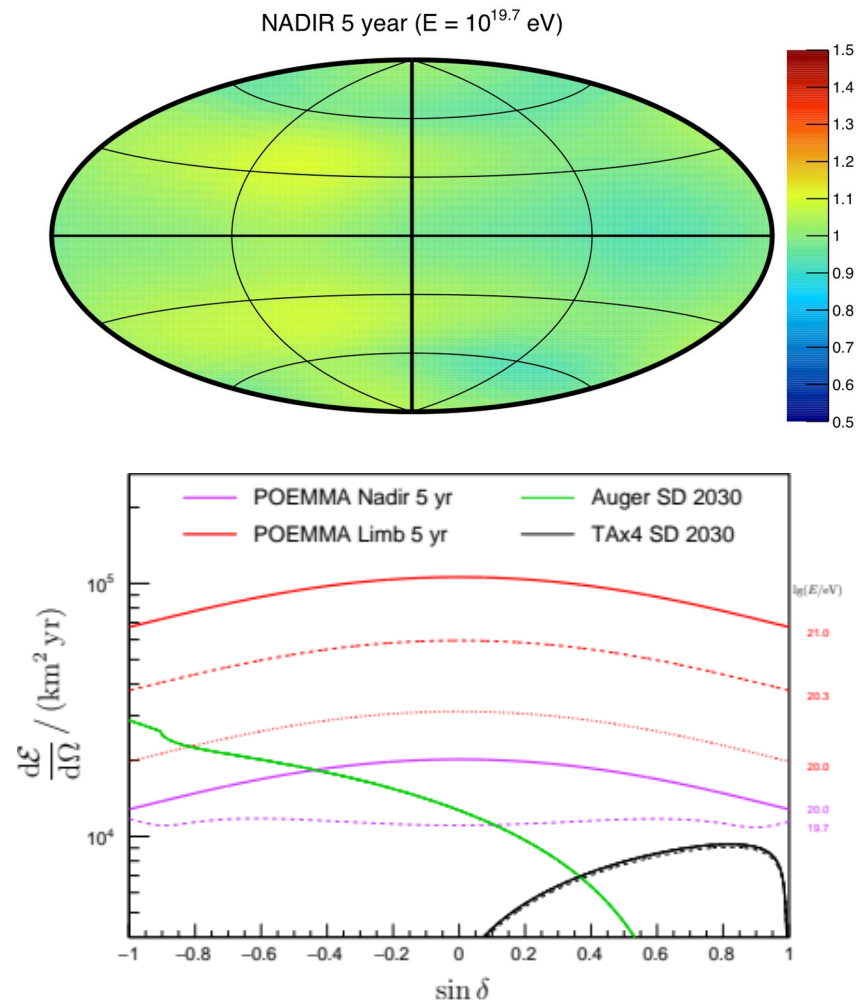
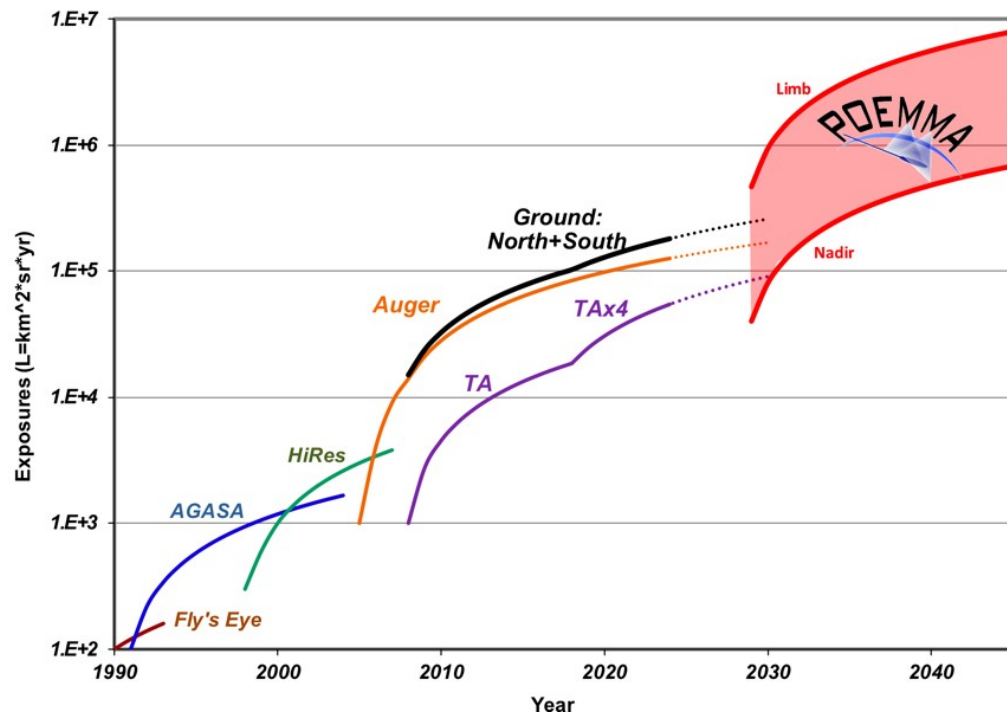
- 30 SiPM FSU = 15360 pixels
- 512 pixels/FSU (64x4x2); 300-1000nm
- 10ns sampling
- **Updated design based on PBR development**



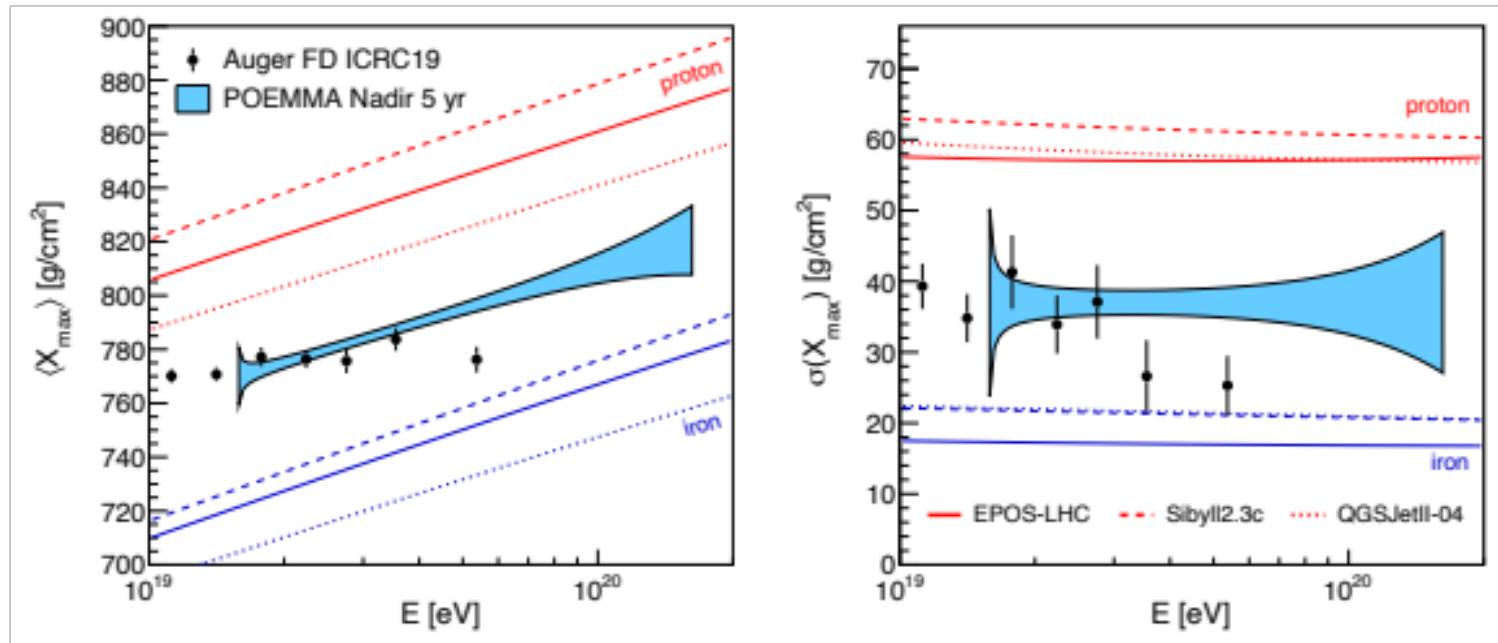
# UHECR Observation Performance



- Significant increase in exposure with full sky coverage (by 1 detector)



- Spectrum, Composition, Anisotropy:  $E_{\text{CR}} > 20 \text{ EeV}$ 
  - Very good energy ( $<20\%$ ) angular ( $<1.2^\circ$ ), composition ( $\sigma_{\text{Xmax}} < 30 \text{ g/cm}^2$ ) resolutions

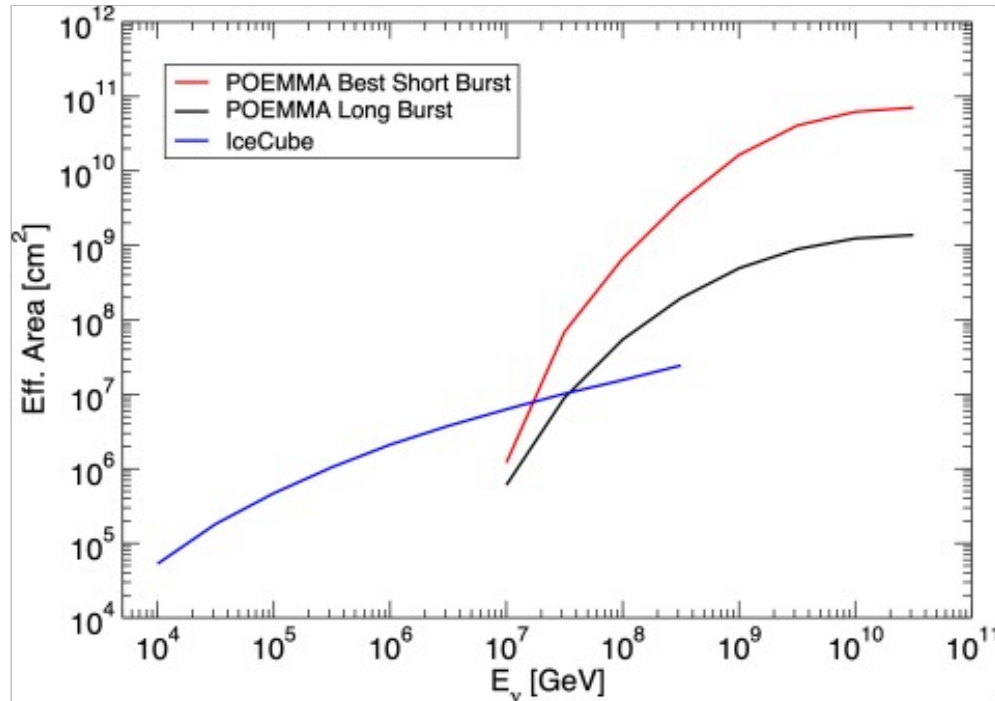




# ToO Observation Performance



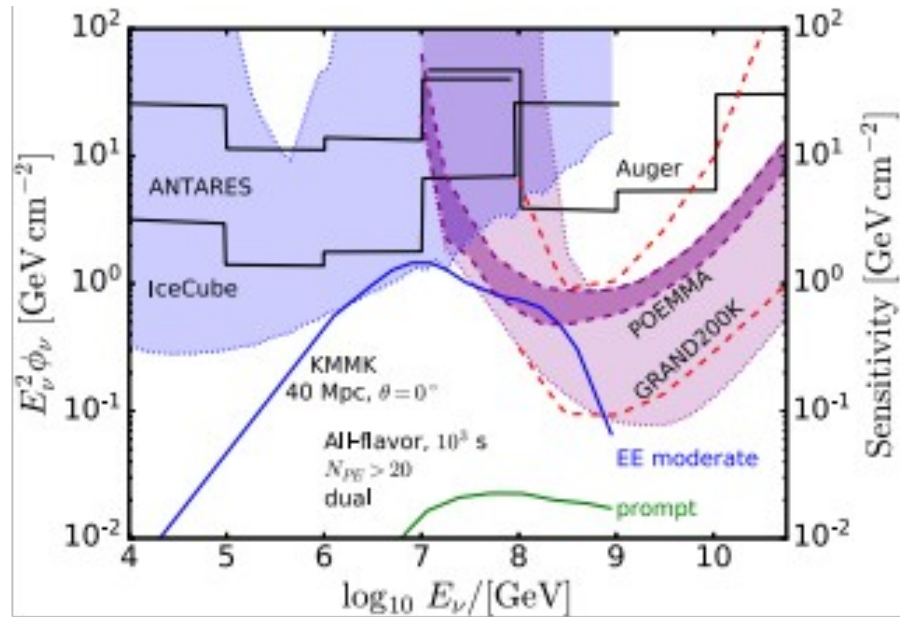
- No competitive sensitivity to diffuse  $\nu$ -flux
- Observe Neutrinos from Transient Astrophysical Events
  - $\tau$ -lepton EAS from  $\nu_\tau$  interactions in the Earth ( $E_\nu > 20$  PeV)



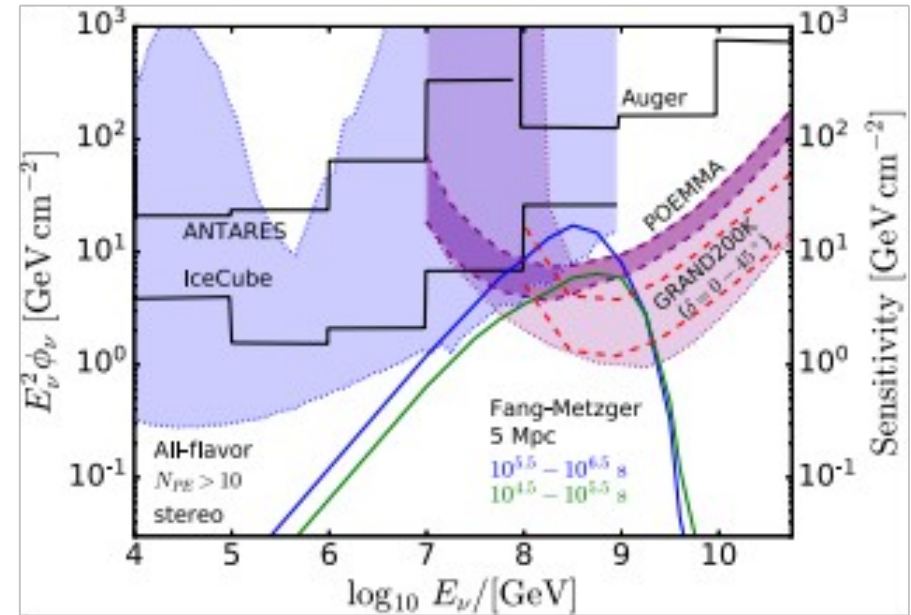
# ToO Observation Performance



## Short Burst (1000 s)



## Long Burst (>10<sup>5</sup>s)



- Ideal source location (500s to slew after alert)
- Two independent Cherenkov measurements

➡ 20 PE threshold:

- AirGlowBack < 10<sup>-3</sup>/year

- 3 to 24+hr to move Satellite Sep to 50 km
- Simultaneous Cherenkov measurements

➡ 10 PE threshold (time coincidence):

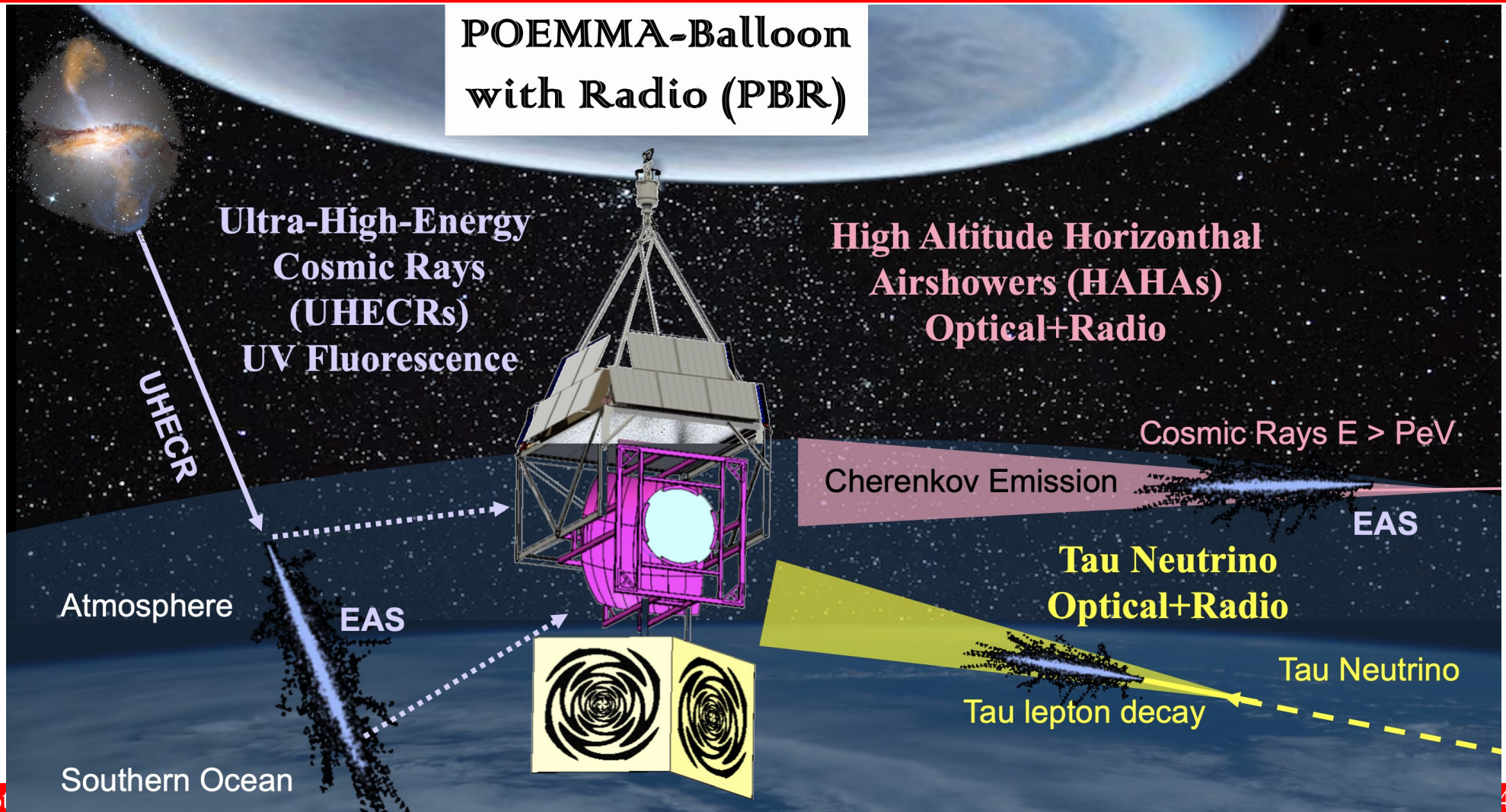
- AirGlowBack < 10<sup>-3</sup>/year



# Near Future: PBR

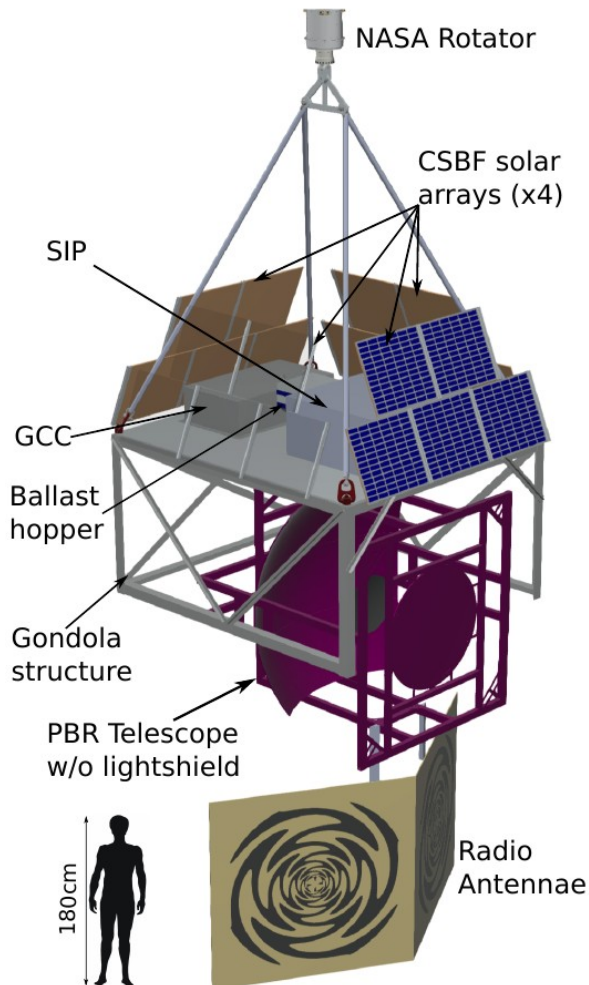


## POEMMA-Balloon with Radio (PBR)





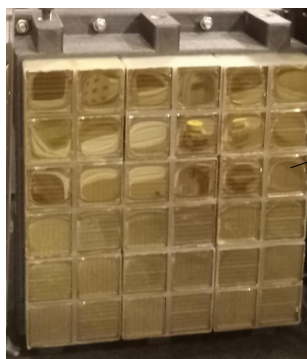
# PBR Instrument & Mission



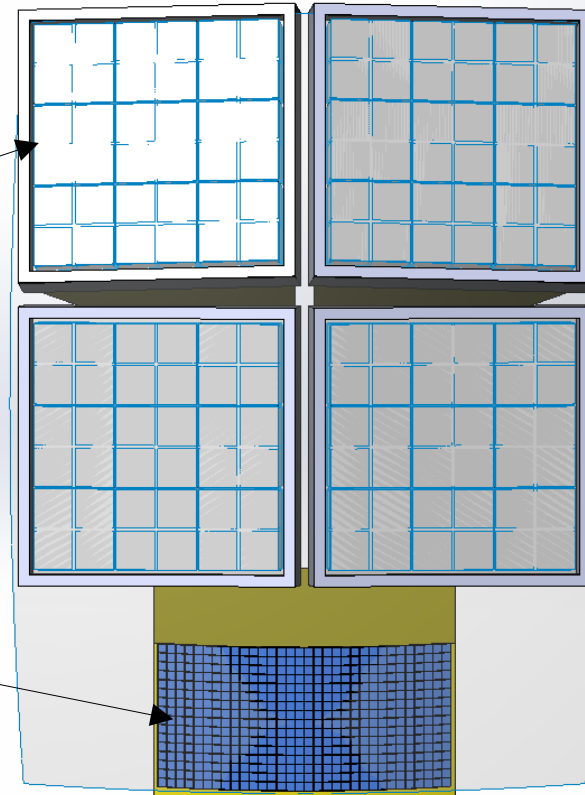
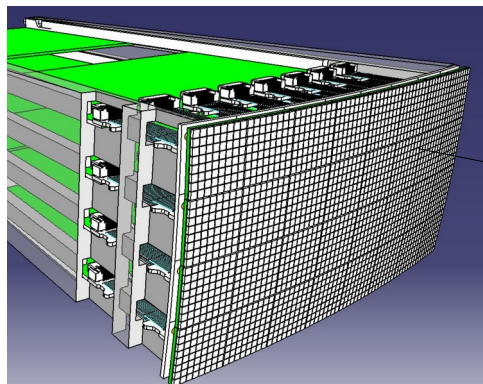
- Payload of NASA **SPB** with launch from Wanaka, NZ
- Target date: Spring, **2027**
- Flight duration: up to **100 days**
- 3000lbs of science
  - 1.1m diameter Schmidt Optic Telescope
  - 2 radio antennas
  - 1 IR Camera
- Pointing:
  - 360° in azimuth via NASA provided rotator
  - Nadir to 10° above horizon in zenith

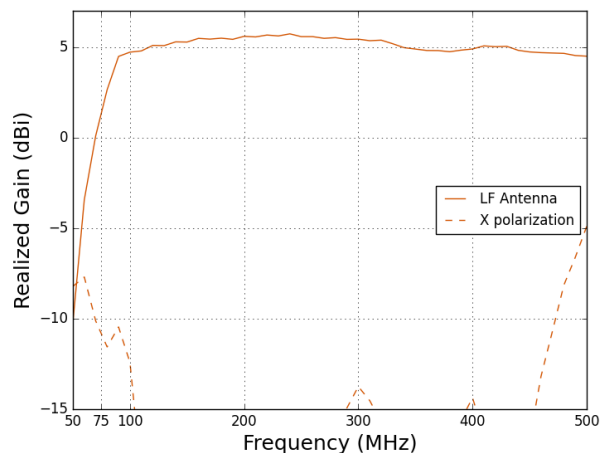
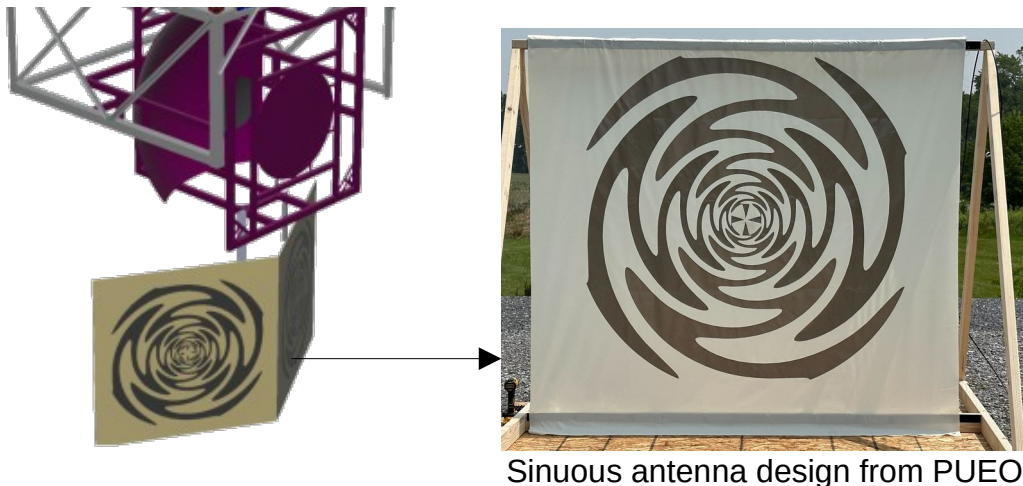
- Down scale design of POEMMA's FS
- Fluorescence Camera (FC)
  - Optimized for EAS detection via fluorescence (UHECR)
  - 4 Photo Detection Modules with 2304px each (MAPMTs): **9216px**
  - 24x24deg FoV
  - 290-430nm detection window (BG3 filter)
  - Integration time of **1 $\mu$ s**
- Cherenkov Camera (CC)
  - Optimized for EAS detection via cherenkov (VHEN and CR)
  - 4 rows of SiPM matrices: **2048px**
  - 12x6deg FoV
  - Bi-focal for event selection
  - 320-900 nm detection window
  - Integration time of **10ns**

EUSO-SPB2 PDM

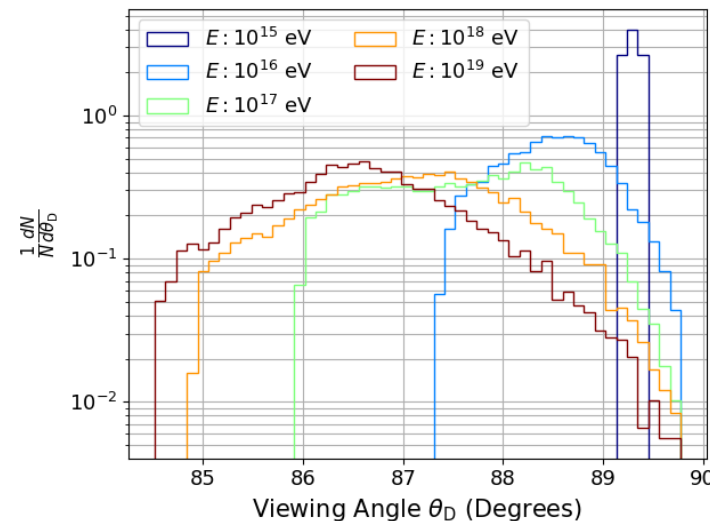
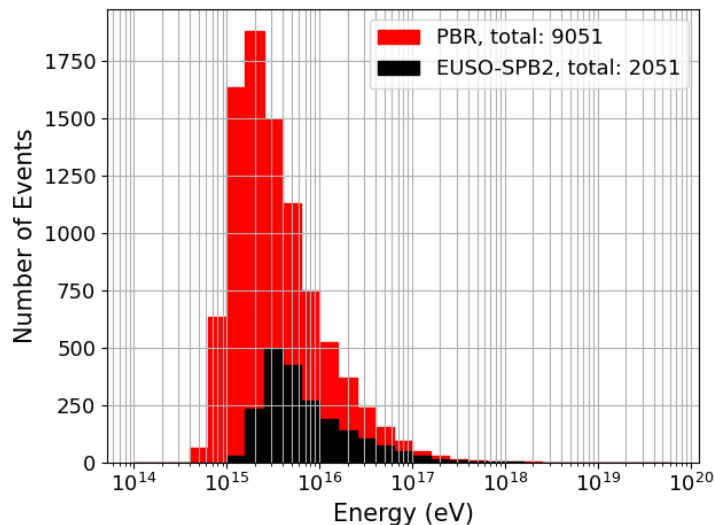
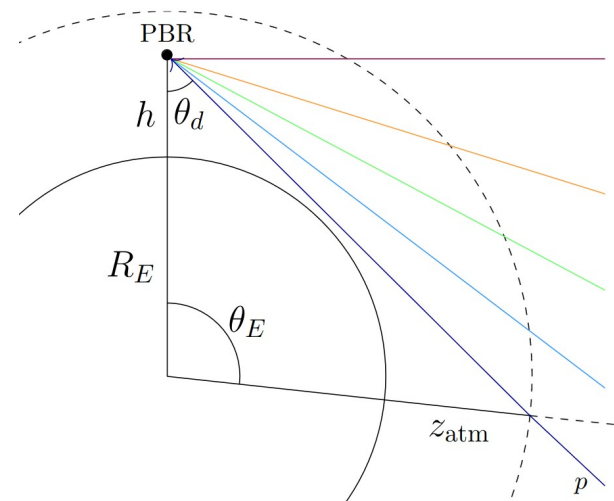


PBR CC Design



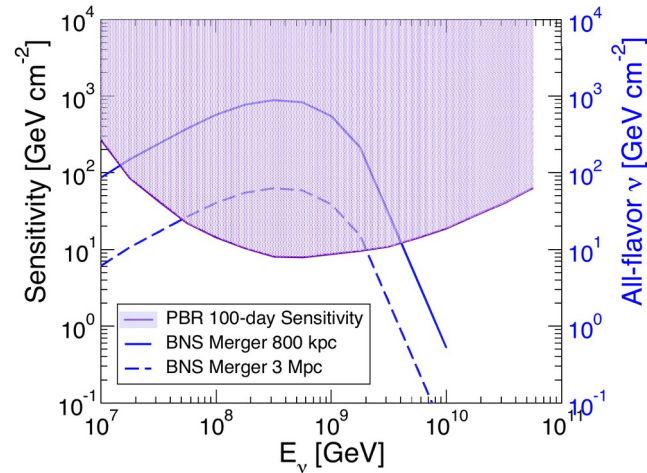


- Two 2 by 2m dual-polarize Sinuous antennas
- Based on PUEO-LF instrument
- Frequency range: 50-500MHz
- 60 x 60deg field of view
- Overlapping with CC
- Canted at 120deg from one another
- Expected energy threshold  $E > 10^{18}$  eV
  - Forced trigger same threshold as CC

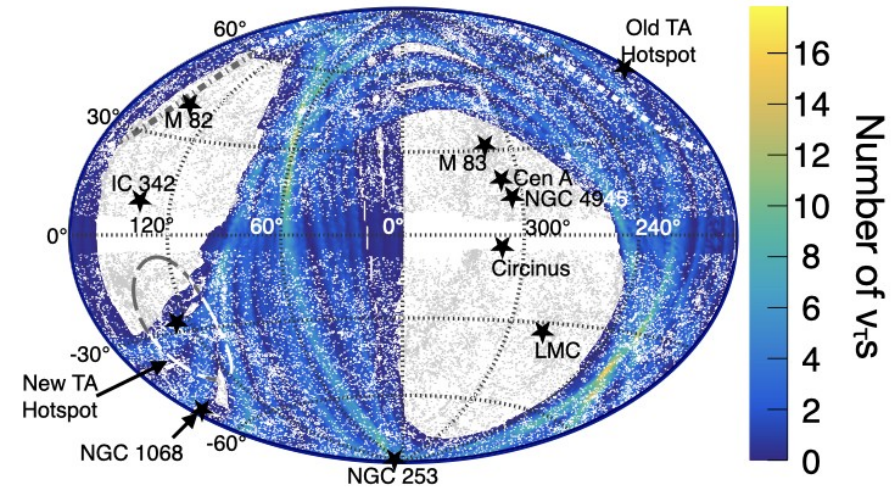
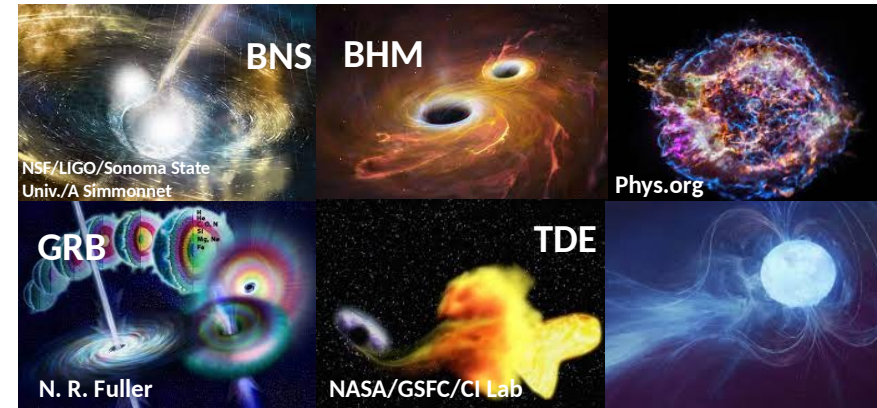


- Guaranteed signal with significant statistics (similar signature to neutrino event)
- Simulation study using EASCherSim\*
- Energy threshold of 0.4 PeV (max sensitivity 2PeV) **➡ ~60+ events/h**
- Angular acceptance is energy dependent
  - Geometric energy filter

- PBR has very limited sensitivity to diffuse neutrino flux, but can observe transients by pointing (similar to POEMMA and EUSO-SPB2)



- Models are fluences (integrated over time)
- Accounting for Sun/Mond effect but no balloon motion currently
- Flight date of Apr 6 2027 (realistic launch date)





# Summary & Conclusion



- POEMMA Balloon (PBR) is the **successor** of the **EUSO-SPB2** mission and an advanced **precursor** of the dual satellite mission POEMMA
- Preparation have started for a launch from Wanaka, NZ **2027**
- First combined measurement of Cherenkov and Radio (from above)
- POEMMA will make **high-statistics UHECRs above 20 EeV** with the goal of **discovering** the source(s) of **UHECRs**
  - stereo fluorescence measurements provides excellent reconstruction of direction, energy and mass composition (via  $X_{\max}$ )
  - full sky coverage with one instrument
- POEMMA will have **unique VHE tau-neutrino sensitivity** above 20 PeV to **transient neutrino sources** using EAS optical Cherenkov



# Summary & Conclusion



- POEMMA Balloon (PBR) is the **successor** of the **USO-SPB2** mission and an advanced **precursor** of the dual balloon mission POEMMA
- Preparation have started for a launch in Spring of **2027** as an SPB2 payload
- POEMMA will have a goal of **improving the sensitivity of UHECR experiments above 20 EeV** with the **development of POEMMA as one of the next generation UHECR experiments (along with GCOS and GRAND)**
  - Community Road-map (arXiv:2205.05845) recommends **proceeding** with the development of POEMMA as one of the next generation UHECR experiments
  - provides excellent reconstruction of position (via  $X_{\max}$ )
  - full sky instrument
- POEMMA will have **unique VHE tau-neutrino sensitivity** above 20 PeV to **transient neutrino sources** using EAS optical Cherenkov