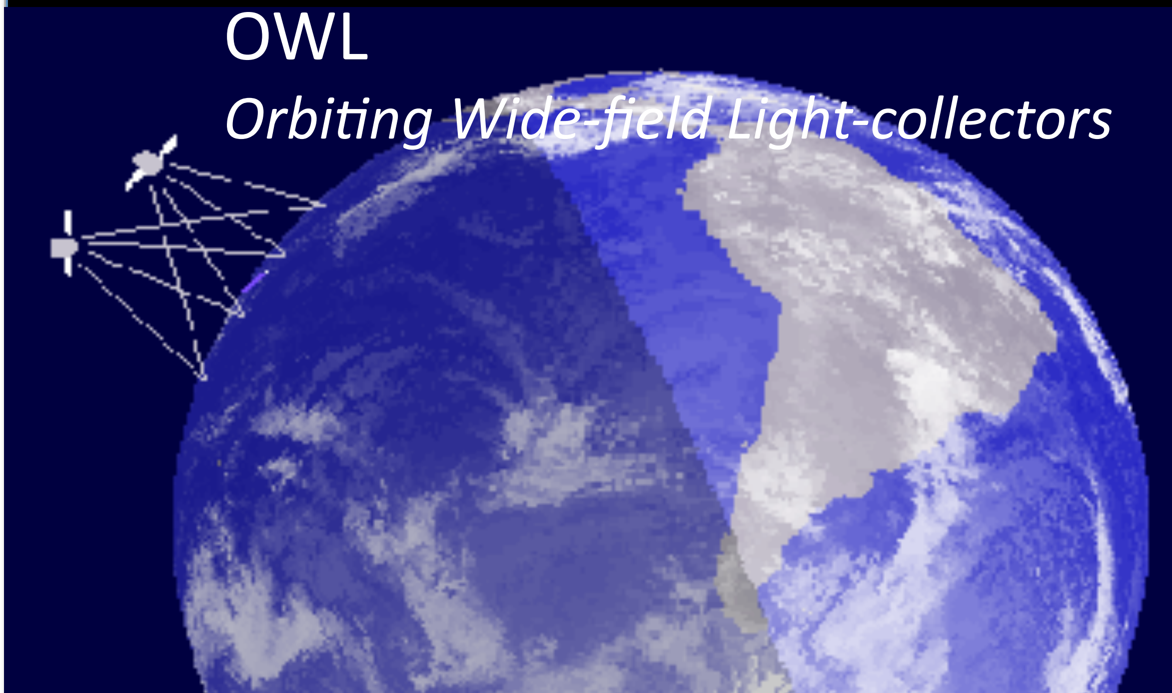
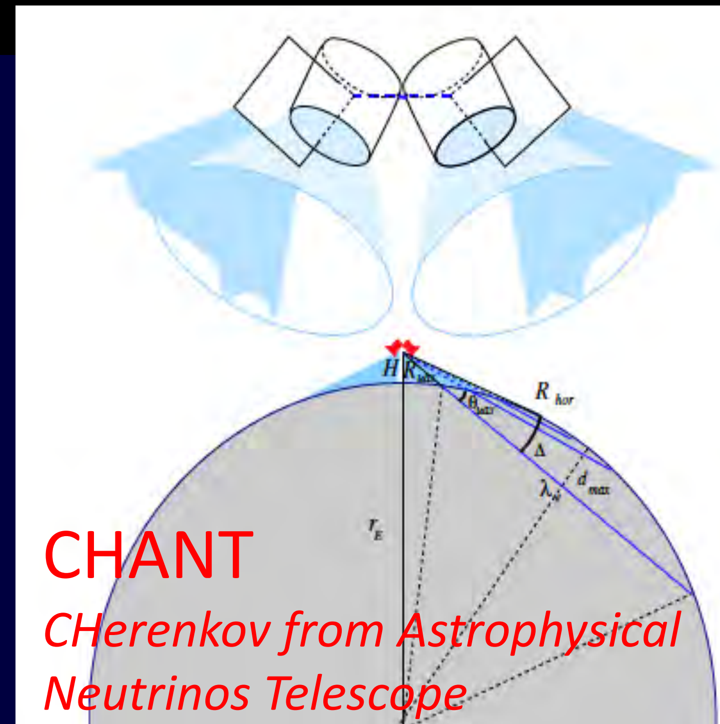
# POEMMA:

## Probe of Extreme Multi-Messenger Astrophysics



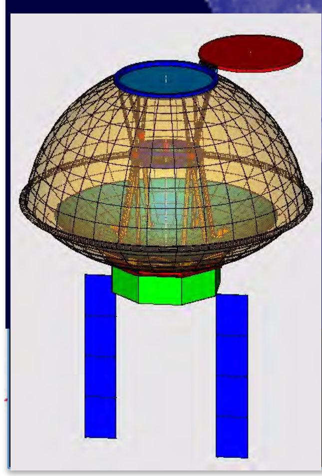
OWL

*Orbiting Wide-field Light-collectors*



CHANT

*CHerenkov from Astrophysical Neutrinos Telescope*




**John Krizmanic**

**(NASA/GSFC/CRESSTII/UMBC)**

**for the POEMMA study team**


**IPA2017 09-May-17**

# NASA Astrophysics Probe Mission Concept Studies POEMMA

***NASA Solicitation NNH16ZDA001N-APROBES* (Scope of Program):**

***Announced: 19-Feb-16 Due Date: 15-Nov-16 Selection: 17-Mar-17***

***NASA has started preparations for the 2020 Astronomy and Astrophysics Decadal Survey (http://science.nasa.gov/astrophysics/2020-decadal-survey-planning/). One of the tasks of the 2020 Decadal Survey Committee will be to recommend a portfolio of astrophysics missions. The Decadal Survey Committee may choose to recommend a portfolio of missions containing a mix of prioritized large- and medium-size mission concepts, or even a program of competed medium-size missions. NASA and the community are interested in providing appropriate input to the 2020 Decadal Survey regarding medium-size mission concepts, also referred to as Astrophysics Probe concepts.***

***To this end, NASA is soliciting proposals to conduct mission concept studies for Astrophysics Probe missions. Following peer review of the proposed mission concept studies, NASA will select a small number of proposals for 1.5 year (18 month) funded studies. Results of the selected studies will be provided by NASA as input to the 2020 Decadal Survey.***

***Astrophysics Probes are envisioned to have a total lifecycle (NASA Phases A through E) cost between that of a MIDEX mission (~$400M) and ~$1B. Proposals for concept studies may envision missions that include contributions from other agencies (national or international), industry, and universities.***

***Should NASA choose to develop a mission that flows from any selected mission concept study, the responsibility for that mission will be assigned by NASA; there is no expectation that the mission concept study team or participating organization***

**FINAL REPORTS DUE SEPTEMBER 2018**

# POEMMA Study Collaboration

POEMMA

**University of Chicago:** *Angela V. Olinto (PI),* Edivaldo Moura Santos, Jason Wei Jie Poh,Mikhail Rezazadeh

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

**NASA/MSFC:** Mark J. Christl, Roy M. Young, Peter Bertone

**University of Utah:** Doug Bergman, John Matthews

**University of Alabama, Huntsville:** James Adams, Patrick Reardon, Evgeny Kuznetsov, Malek Mastafa

**Colorado School of Mines:** Lawrence Wiencke, Frederic Sarazin

**City University of New York, Lehman College:** Luis Anchordoqu, 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

**Penn State University:** Foteini Oikonomou

**Vanderbilt University:** Steven E Csorna

**APC Univerite de Paris 7:** Etienne Parizot, Guillaume Prevot

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

**University of Geneva**: Andrii Neronov

# POEMMA Study Teams

POEMMA

**Principle Investigator**: Angela Olinto

**Overall Coordination:** Angela Olinto, Mark Christl

**Science Case:** Angela Olinto, Luis Anchordoqui, Andrii Neronov, Etienne Parizot, Foteini Oikonomou, Hallsie Reno, Ina Sarcevic, Floyd Stecker

**Simulations:** John Krizmanic, Tom Paul, Kenji Shinozaki, Malek Mastafa, Francesco Fenu, Doug Bergman, Hallsie Reno, Mario Bertaina

**Optical Design & Deployment:** Roy Young, Mark Christl, Pat Readon, Stan Hunter, John Mitchell

**Focal Plane & Electronics:** Doug Bergman, Nepomuk Otte, Mark Christl, Fred Sarazin, Elenor Judd, Guillaume Prevot, John Mitchell, Jeremy Perkins, Liz Hays, Evgeny Kuznetsov, Mario Bertaina, Jim Adams

**Mission & Spacecraft Integration**: Jim Adams, John Mitchell, Insoo Jun, Julie McEnery, Lawrence Wiencke, Jeremy Perkins

**Observers**: Jonathan Ormes, Robert Streitmatter



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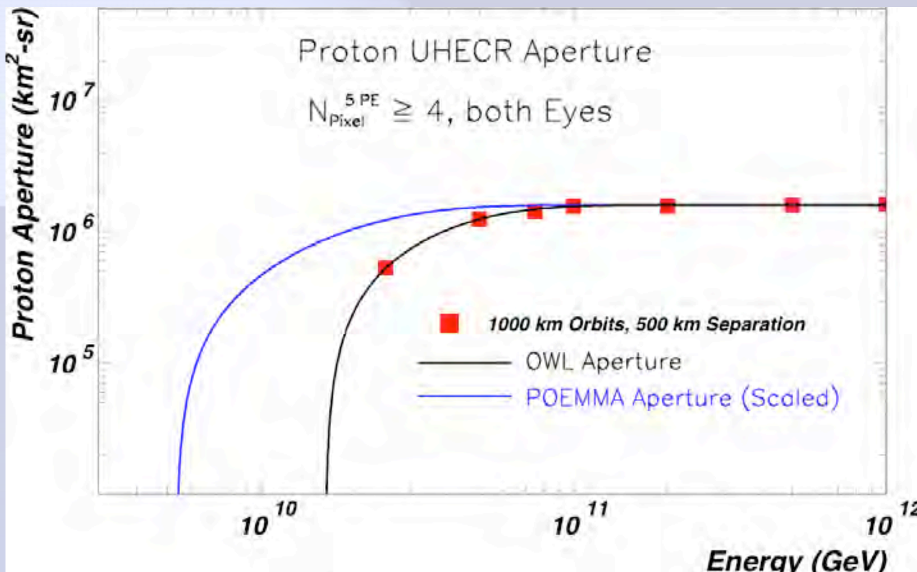
# POEMMA UHECR Performance

POEMMA

**Building upon OWL, CHANT, JEM-EUSO, Auger, TA, … create a space-based UHECR and VHE neutrino mission with the needed performance ➔ POEMMA**

Large exposure for UHECR for both Northern and Southern Hemispheres

- OWL study showed 5 year mission should achieve $7 \times 10^5$ $km^2$-sr-yr for OWL eyes in 1000 km orbits and 500 km satellite separation (assuming 10% Duty Cycle)
- OWL Studies showed ~1° angular resolution and ~15% energy resolution around $10^{20}$ eV.
- POEMMA was proposed for ×2 improvement in light collection vs OWL, and higher QE of current focal plane detector technology leads to an additional 30% increase.
- Improved response yields higher PE statistics in the air shower profile measurement to get better $X_{MAX}$ resolution➔ better composition determination.
- Atmospheric neutrino fluorescence air shower detection similar to UHECR detection, except deep in the atmosphere (using the $10^{13}$ ton interaction volume).



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# OWL Mission Design Summary

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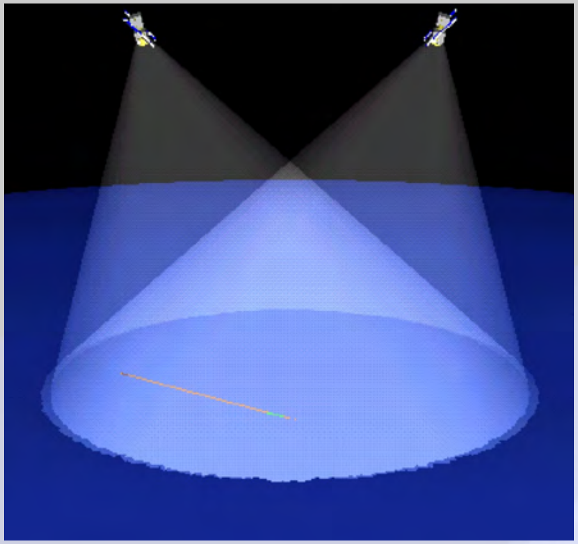


Use the stereo air fluorescence technique to image 325 → 425 nm photons in ~ 0.06$^{O}$ pixels (~1 km$^2$ projected on the ground) using 100 ns readout, from low Earth, equatorial (5 - 10$^{O}$ inc.) orbit, induced by airshowers: Original OWL Concept: **$E_{th}$ ≈ 3 × $10^{19}$** eV

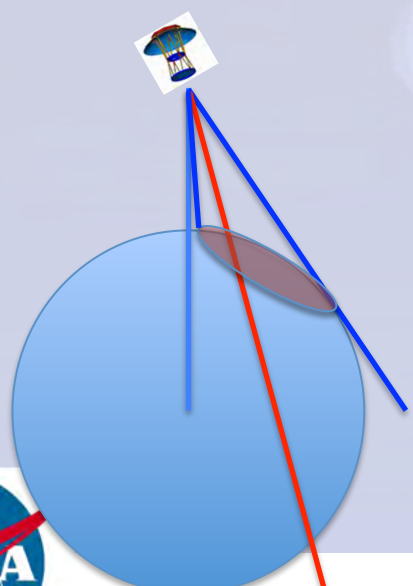
Each Eye: Wide angle (45$^{O}$ full, FOV) Schmidt optical camera at a 1000 km orbit in a stereo configuration (aids event reconstruction and provides consistency check via two air shower profile measurements)

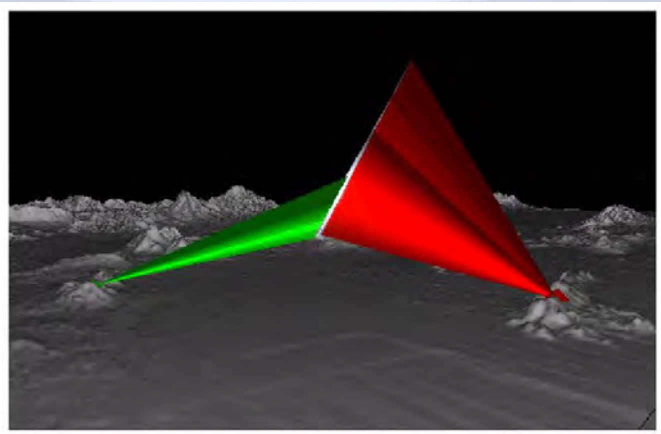
→ an asymptotic, *instantaneous* aperture 1.6 × $10^6$ km$^2$-sr

~10% duty cycle, reconstruction & 5 year mission

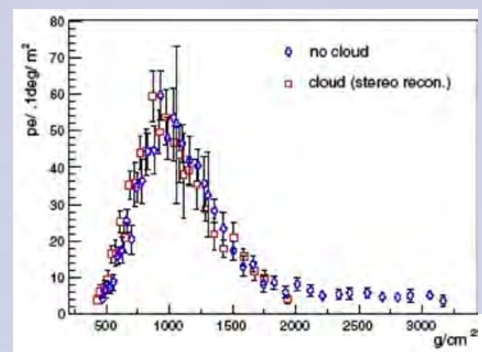
→ *effective* proton exposure **8 × $10^5$ km$^2$-sr-yr**

End of mission 550 km orbits → energy threshold to < $10^{19}$ eV albeit with reduced aperture and to look for upward Neutrino-induced air showers via Chrerenkov signal





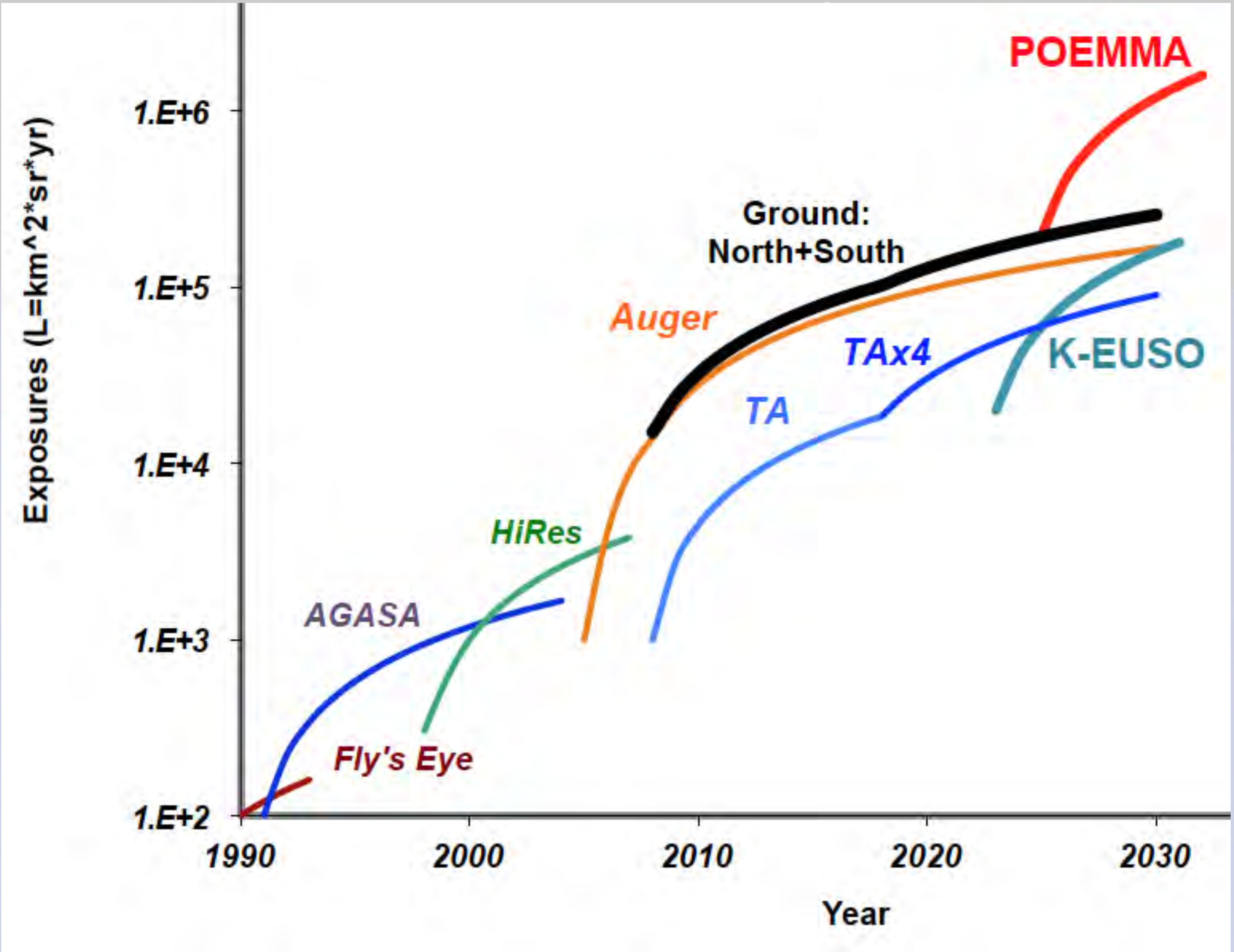
HiRes Stereo Observation (P. Sokolsky)




T. Abu-Zayyad et al.

# UHECR Exposure History

POEMMA



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# UHECR Source Location

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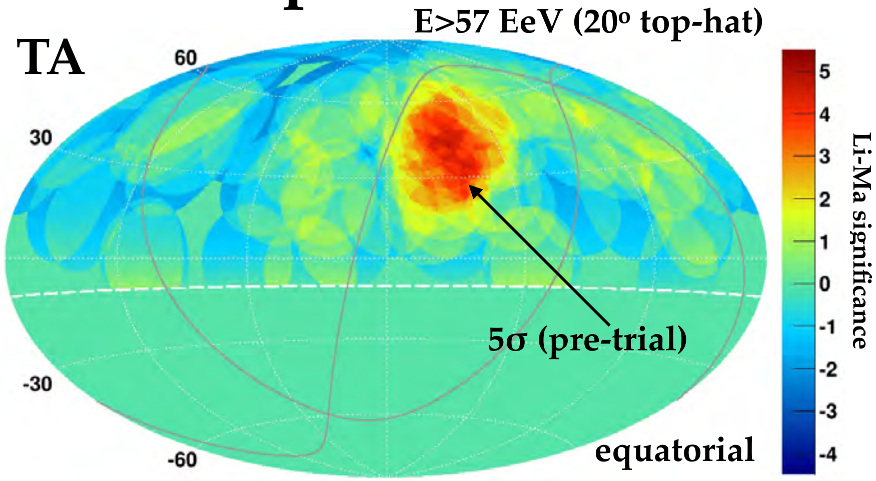
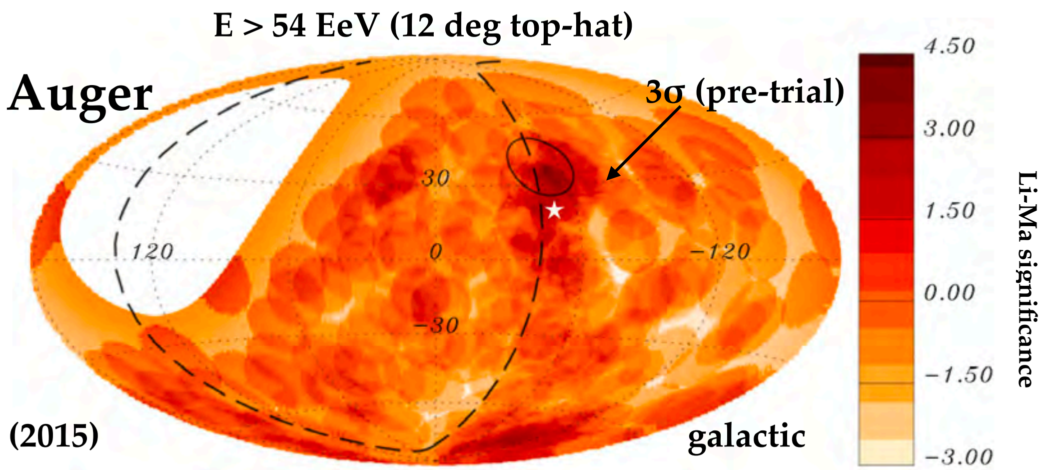
## Anisotropies at intermediate angular scales




ApJ 790, L21 (2014)

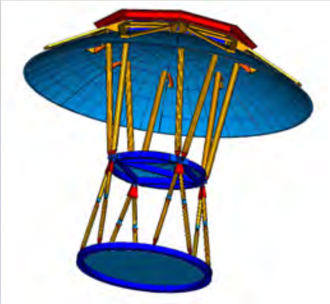



ApJ 804, 15 (2015)

# Funding includes IDL and MDL Support **POEMMA**

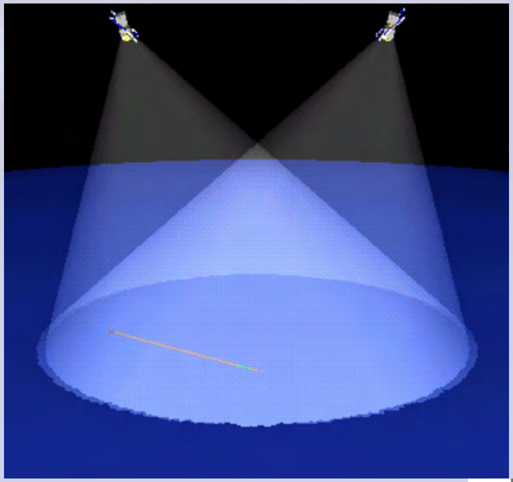
**Example: OWL studies … POEMMA builds on this development.**
**IDL: Instrument Design Lab (GSFC)  MDL: Mission Design Lab (GSFC)**

Jan 7 - 18, 2002 : Complete/Review detailed instrument design at GSFC in the Instrument Synthesis and Analysis Laboratory (ISAL) now IDL:



- Finalized optical design
- Developed mechanical and deployment designs
- Developed focal plane and electronics design
- Determined Mass and power specifications

Jan 22 - 25, 2002: Completed detailed mission study at GSFC in the Integrated Mission Design Center (IMDC) now MDL.



- Develop mission profile using pointing and formation flying requirements
- Specified spacecraft and systems to provide necessary performance

**POEMMA IDL/MDL studies will start with OWL design refining to increase performance using current technologies while considering potential future technology development, eg inflatable structures, SiPMs, etc.**

# POEMMA Baseline Schmidt Optics

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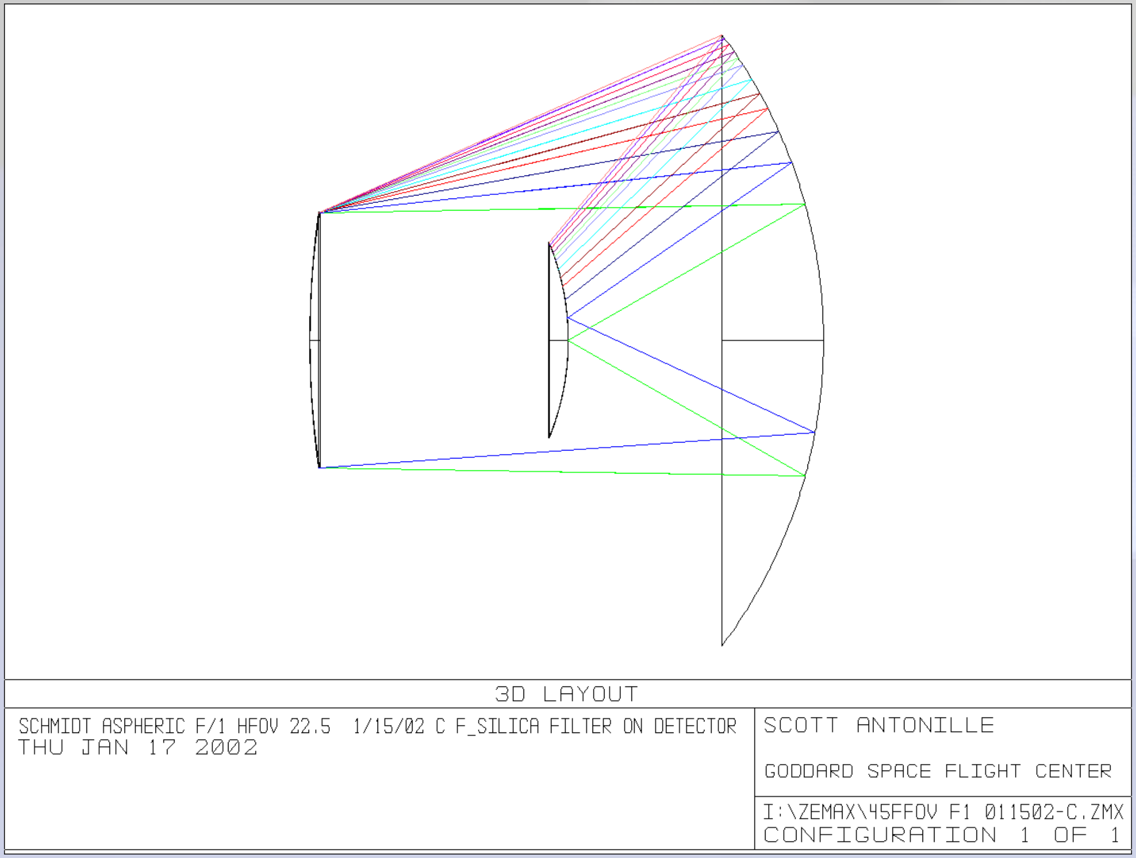
**0.06° Pixel Angular Resolution**

Scale OWL Optical Parameters by 10/7.1 = 1.41




- F/1 System
- 4.23 m Diameter Optical Aperture formed by Single Corrector Plate
- 10 m Diameter Aspherical Mirror
- 3.24 m Diameter Focal Plane
- Full FOV 45°
- **4.23 mm Focal Plane Pixel Diameter**
- **~500,000 pixels**
- ~ 1 mm, 0.1° Alignment

**14.05 $m^2$ Optical Aperture (×2 that for OWL)**

# OWL Opto-Mechanical Design

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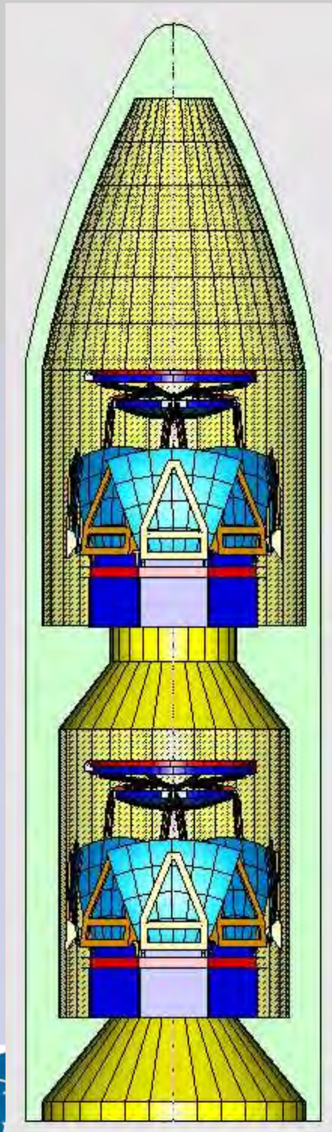
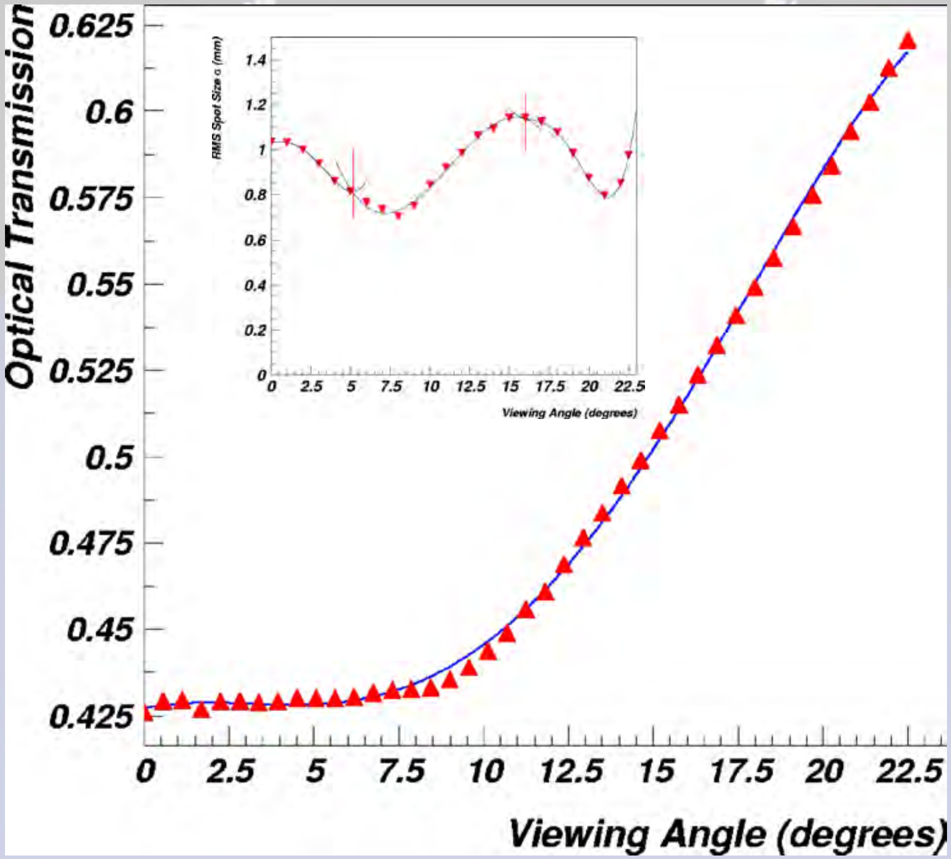
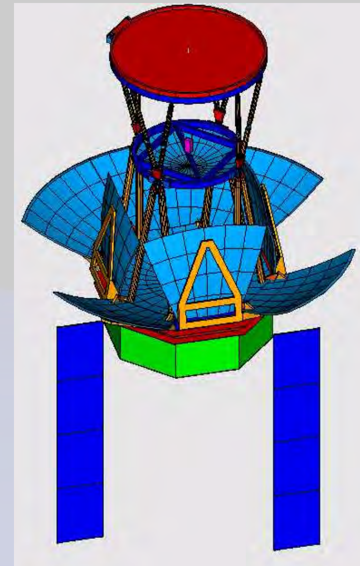
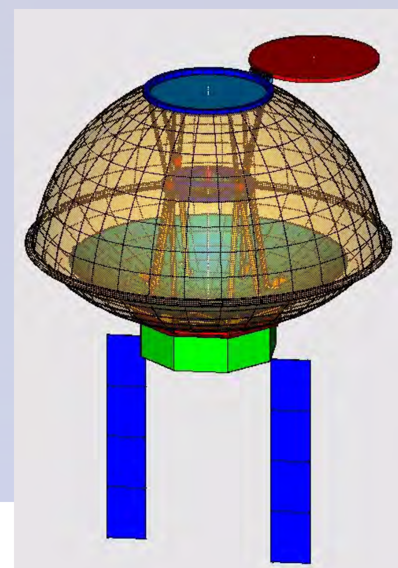






Satellite Mass: 2360 kg
Satellite Power: 1200 watts

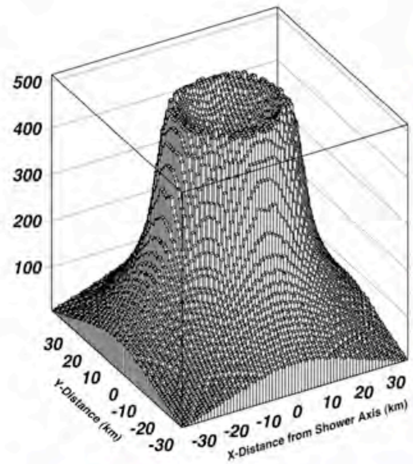
Rodger Farley et al., NASA GSFC

# Upward Tau Neutrino Cherenkov Detection

POEMMA

## 100 PeV Air Shower Cherenkov Simulation Results

Simulation based on **Hillas (JPhysG 8)**




**Nadir Pointed Instrument**

Vertical Airshower ($\theta_V$=0°)

**Signal: 400 photons/m²**

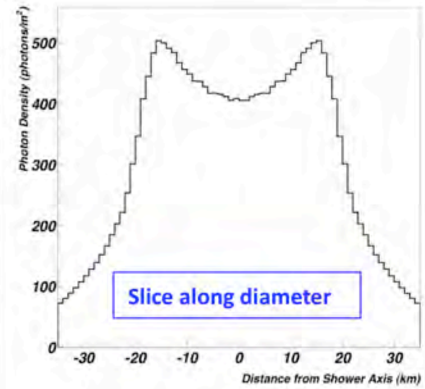
**7 m² collection for OWL**

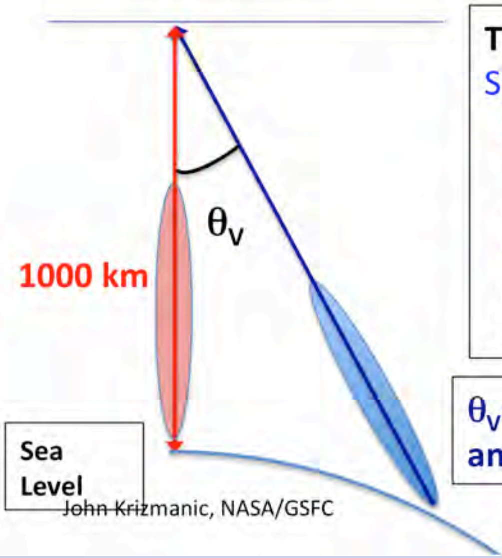
Lateral Size: ≈ 40 km at 1000 km

**Solid Angle: 1.3 × 10⁻³ steradians**

Distance from $S_{Max}$: 990 km

**Photon density and Δω agree to ~30% to D. Kieda (27th ICRC, Hamburg), with proper scaling.**




John Krizmanic, NASA/GSFC

**Tilted Instrument**

Slanted Airshower ($\theta_V$=55°)

**Signal: 35 photons/m²**

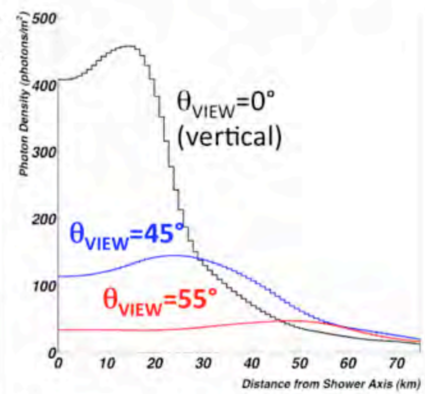
**14 m² collection for POEMMA**

Lateral Size: ≈ 110 km at 1000 km

**Solid Angle: 1.9 × 10⁻³ steradians**

Distance from $S_{Max}$: 2187 km

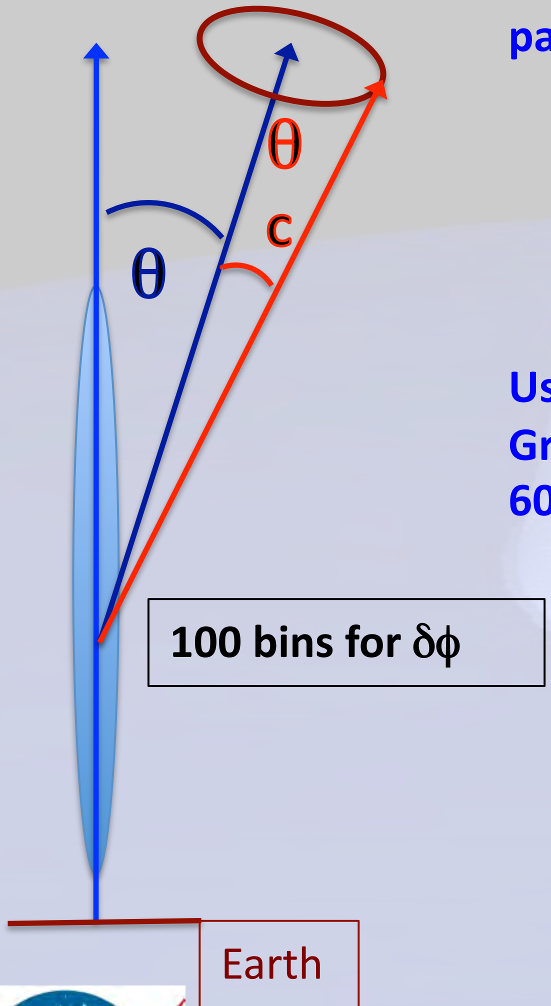
55° at z=1000 km -> 71 deg at z=0




**$\theta_V$=55° signal reduction: factor of 4 due to larger distance (1/r²) and 60% additional reduction due to atmospheric scattering.**

# Upward Air Shower Simulation

POEMMA




**Model of Upward-going (relative to Earth) created based upon parameterizations given by Hillas (JPhysG 8)**

- Index of Refraction of Air vs altitude (used up to 65 km)
- Track length fraction vs shower age and energy
  - Allows enactment of $E_{CHER}$ & sampling in decades for $E \geq E_{CHER}$
- Angular distribution of particles vs angle, energy, and age

**Use to build Cherenkov light generation model based upon Greisen shower parameterization in 100 m steps (200 nm $\leq \lambda \leq$ 600 nm)**

- Model atmospheric attenuation
  - Shibata atmospheric model (see Gaisser's book)
  - Rayleigh scattering (see Sokolsky's book)
  - Ozone absorption (Krizmanic 26$^{th}$ ICRC, Salt Lake City)
  - Aerosols not modeled (estimate of signal reduction at large angles ≈ 25% for 1.2 km scale height and $\lambda_A$=14 km )
- **Effects of Earth's curvature modeled**

# Tau Neutrino Terrestrial Target

POEMMA

**Consider $\nu_\tau$ Interactions:** {Gandhi et al., PRD 58}

- $\sigma_{cc}(\nu N) = \sigma_{cc}(\nu bar N) = 5.5 \times 10^{-36} (E_\nu / 1 \text{ GeV})^{0.363}$, $E_\nu > 10^{16}$ eV
- $<E_\lambda> \approx 0.75 \times E_\nu$ at $E_\nu = 10^{15}$ eV, rising to $\approx 0.8 \times E_\nu$ at $E_\nu = 10^{20}$ eV

**Depth of neutrino target given by the minimum of:**

- **$\gamma c\tau$ for the produced taon**
- **$\lambda_{Loss}$ due to taon catastrophic energy losses at higher energies:**
  **$\lambda_{Loss} = (\beta\, \rho_{AVE})^{-1}$; where $\rho_{AVE}$ is the average density and**
  **$\beta[E] = \beta_{19}[\rho_{AVE}](E_\tau/10^{19} \text{ eV})^{0.2}$ {Palomares-Ruiz et al., PRD73}**

| $E_\tau$ (eV) | Depth ($\rho_{AVE}$ =1 g/cm$^3$) | Depth ($\rho_{AVE}$ =2.65 g/cm$^3$) |
|---|---|---|
| $10^{15}$ | 0.05 km | 0.05 km |
| $10^{16}$ | 0.5 km | 0.5 km |
| $10^{17}$ | 5 km | 5 km |
| $10^{18}$ | **29 km** | **16 km** |
| $10^{19}$ | **18 km** | **10 km** |



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# CHANT & Tau Neutrino Detection

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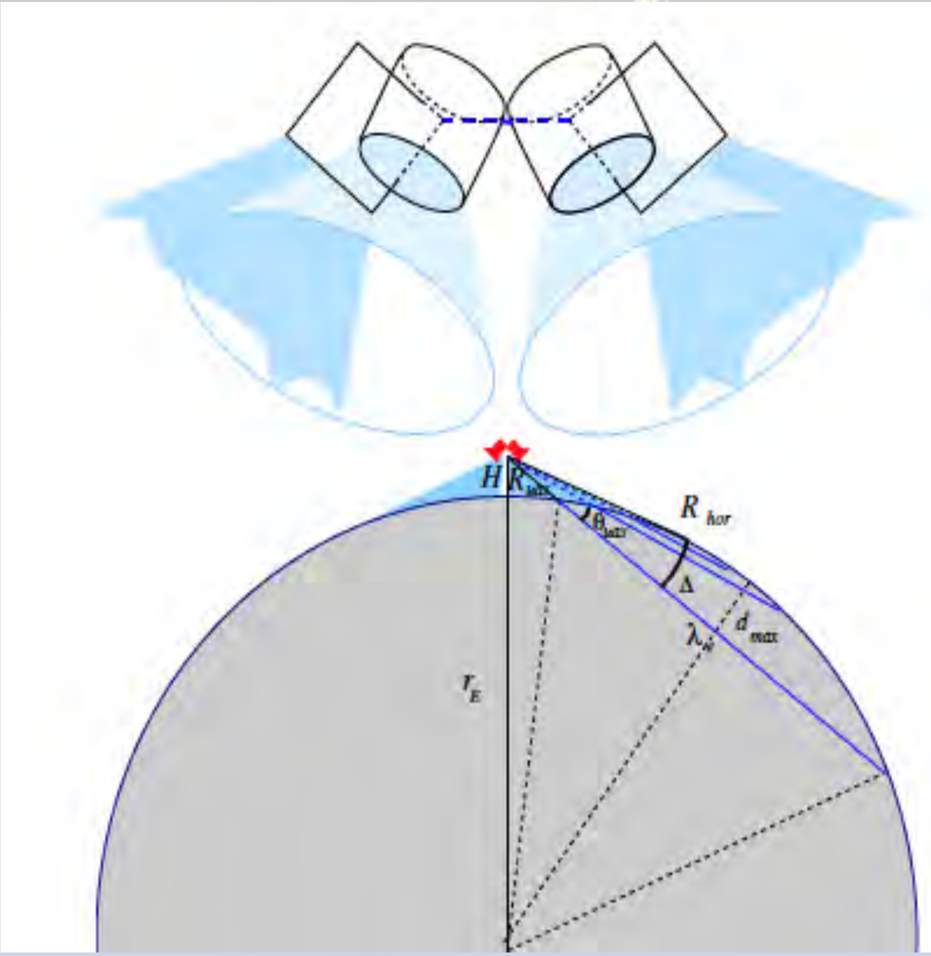
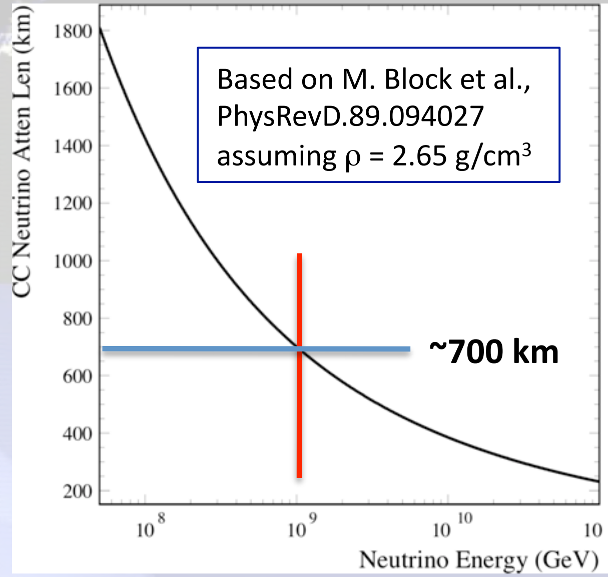
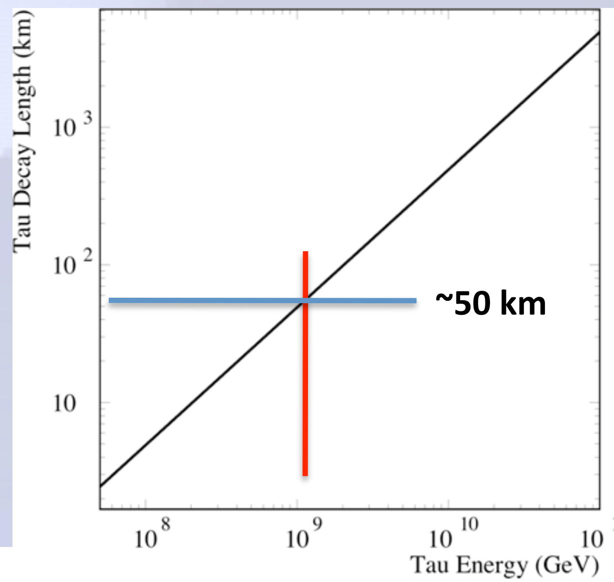
Physical Review D, Volume 95, Issue 2, id.023004




**Need also to consider tau energy losses in the Earth, which limits target depth.**

**Initial simulation work is focused on upward tau neutrino detection.**



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# CHANT Neutrino Sensitivity

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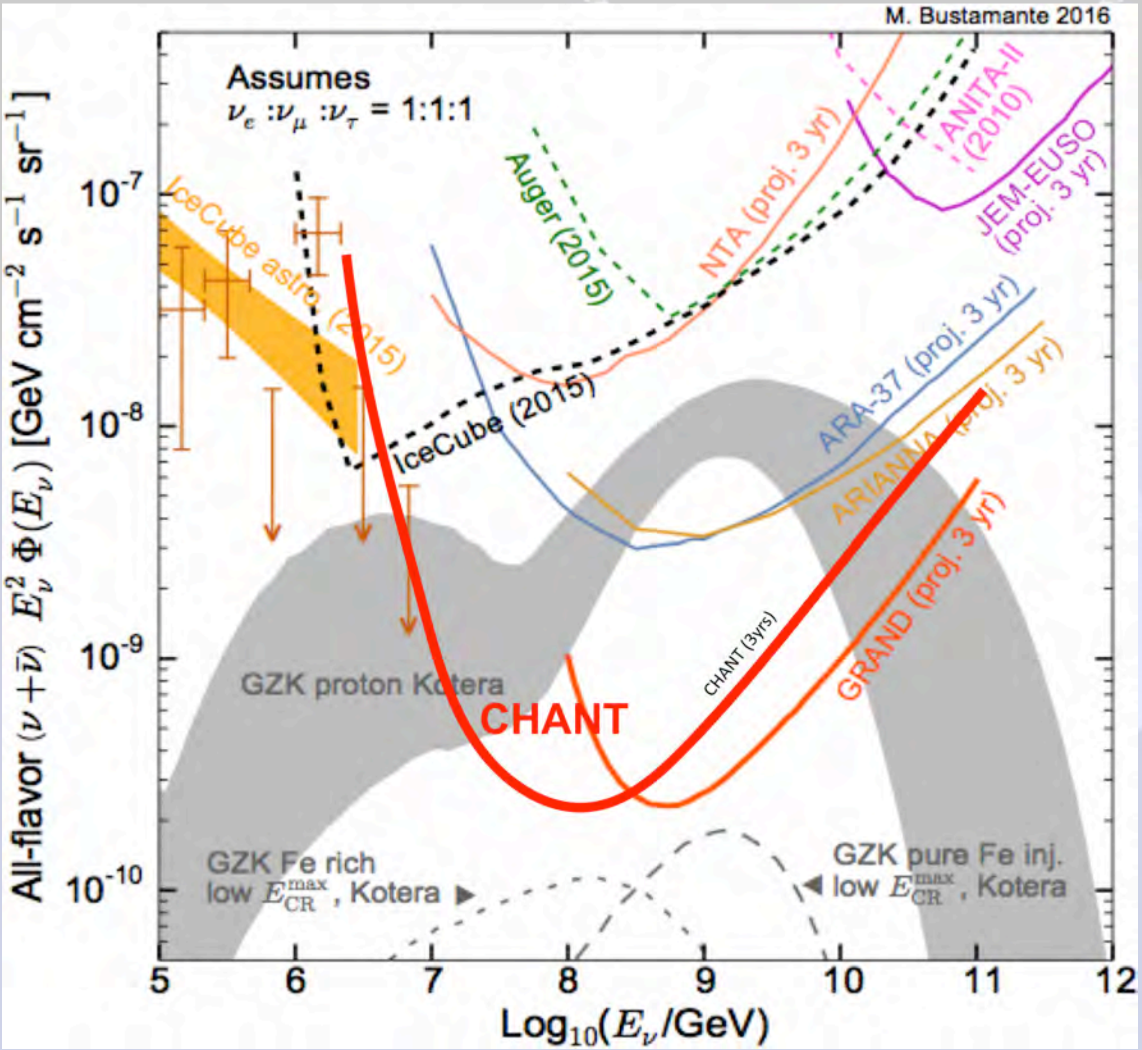



**Assumptions:**

- Based on Physical Review D, Volume 95, Issue 2, id. 023004
- 360° viewing of Earth's limb using 6 telescopes (60° FOV for each)
- 4 m diameter optical aperture for each telescope
- Altitude 300 km
- Model for estimated energy in air shower (ν interaction, energy loss in Earth, tau decay energy)
- Model for atmospheric scattering (including aerosols)
- CHANT limits are for 3 years with 20% duty cycle

# Summary

POEMMA

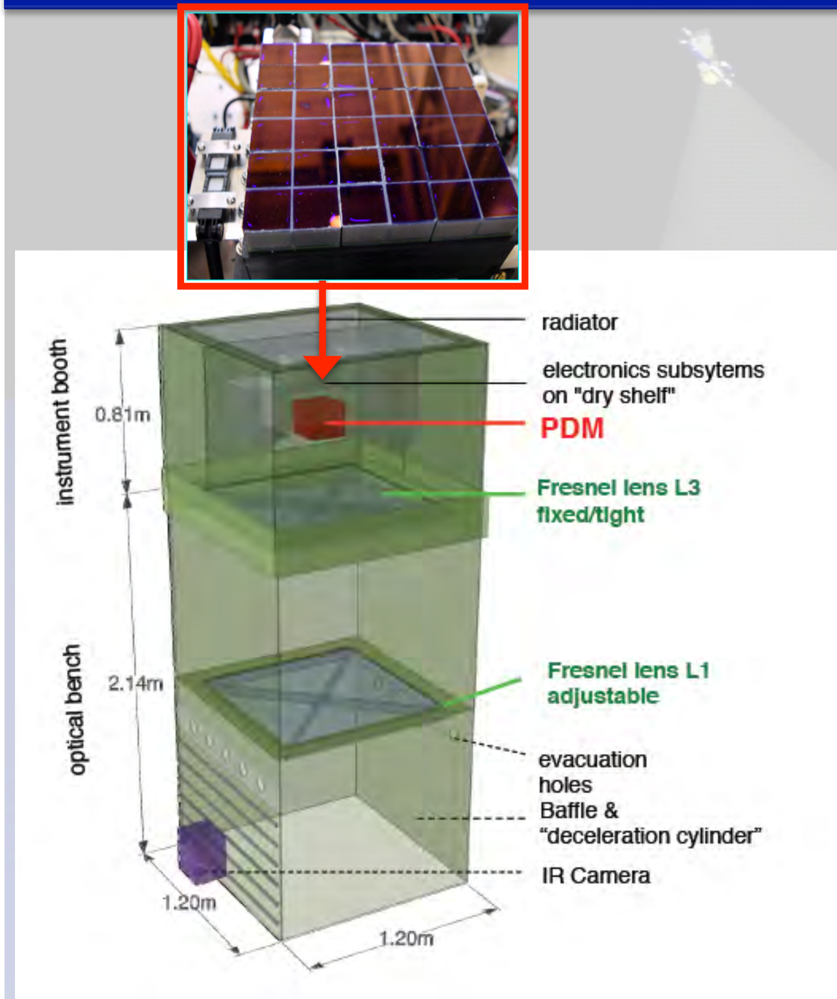
POEMMA has been selected for a NASA Astrophysics Probe Mission Study

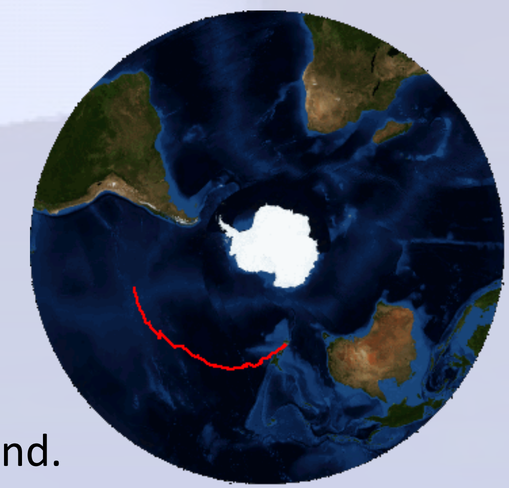
The goal of the study is to build upon the well-developed OWL design & CHANT studies and other experiments to design the instruments and mission to perform space-based cosmic ray measurements:

- UHECR Capability: ~$10^6$ km$^2$ sr yr exposure in 5 years with good angular and resolution, push for capability to perform UHECR composition measurements in $10^{19}$ eV decade.
- VHE Neutrino Capability: Working to optimize the design to maximize sensitivity to Cherenkov signal in upward air showers from 'Earth skimming' tau neutrinos in the Cosmic Radiation.
    - Study team is currently working on quantifying the Cherenkov signal intensity, wavelength spectrum, and timing profile at the instrument as well as tau lepton energy spectrum versus tau neutrino flux models to define the instrument design for these signals.

# EUSO-SPB launched Apr24 from Wanaka NZ

POEMMA



Flight terminated after 12.1 days.
Final location ~200 miles south of Easter Island.