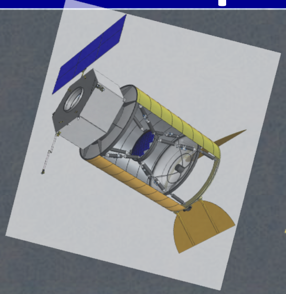
νSpaceSim: A Cosmic Neutrino Simulation Package for Space-based Experiments

NASA Partner

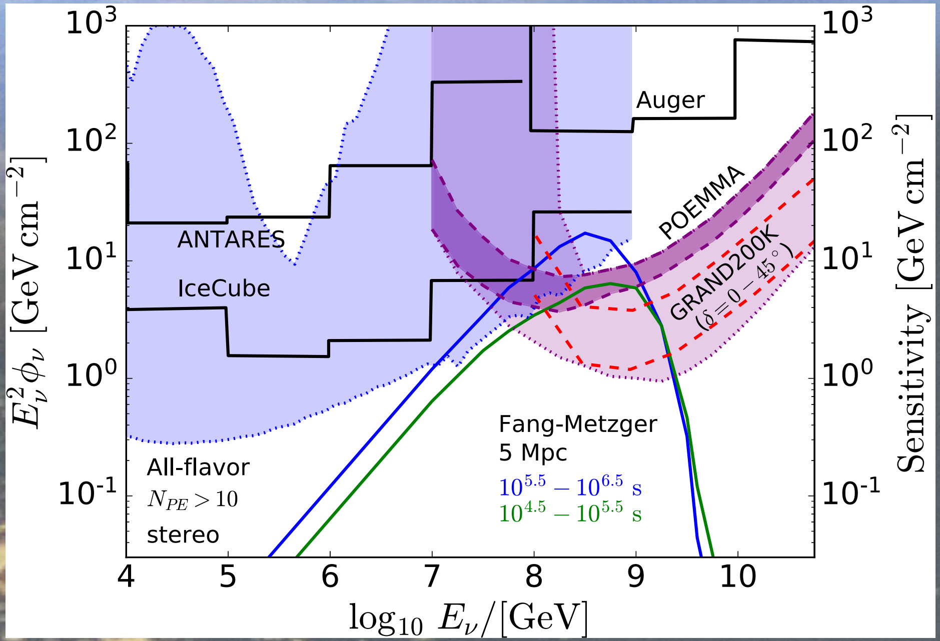
νSpaceSim

Your Detector Here!

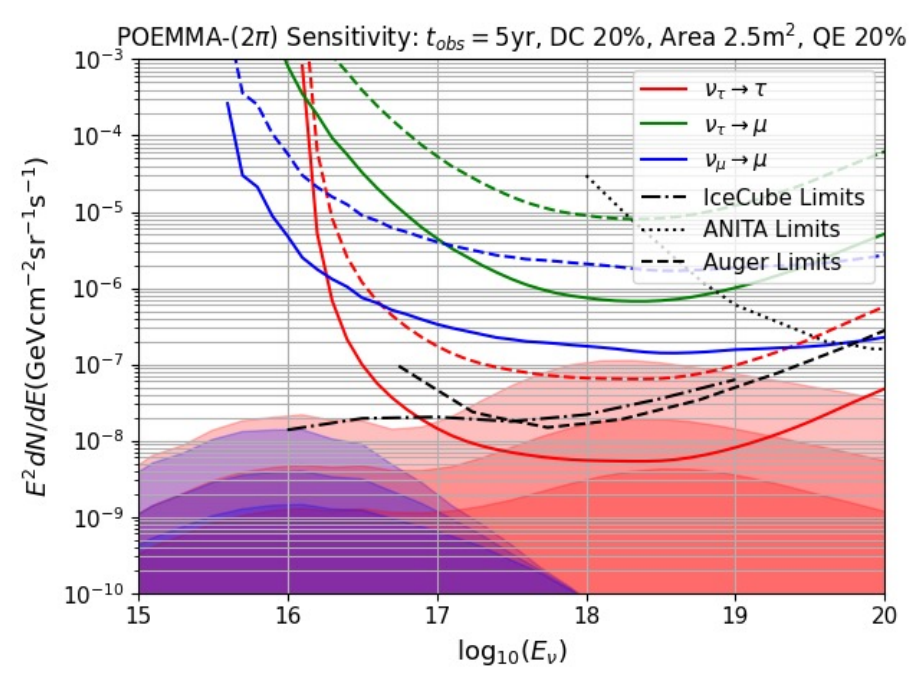


John Krizmanic (UMBC/CREASST/NASA/GSFC) for the νSpaceSim Collaboration

ν_τ – induced upward EAS generating optical Cherenkov and radio signals



Venters et al, *PhysRevD.102.123013*



Cummings et al, *PhysRevD.103.043017*

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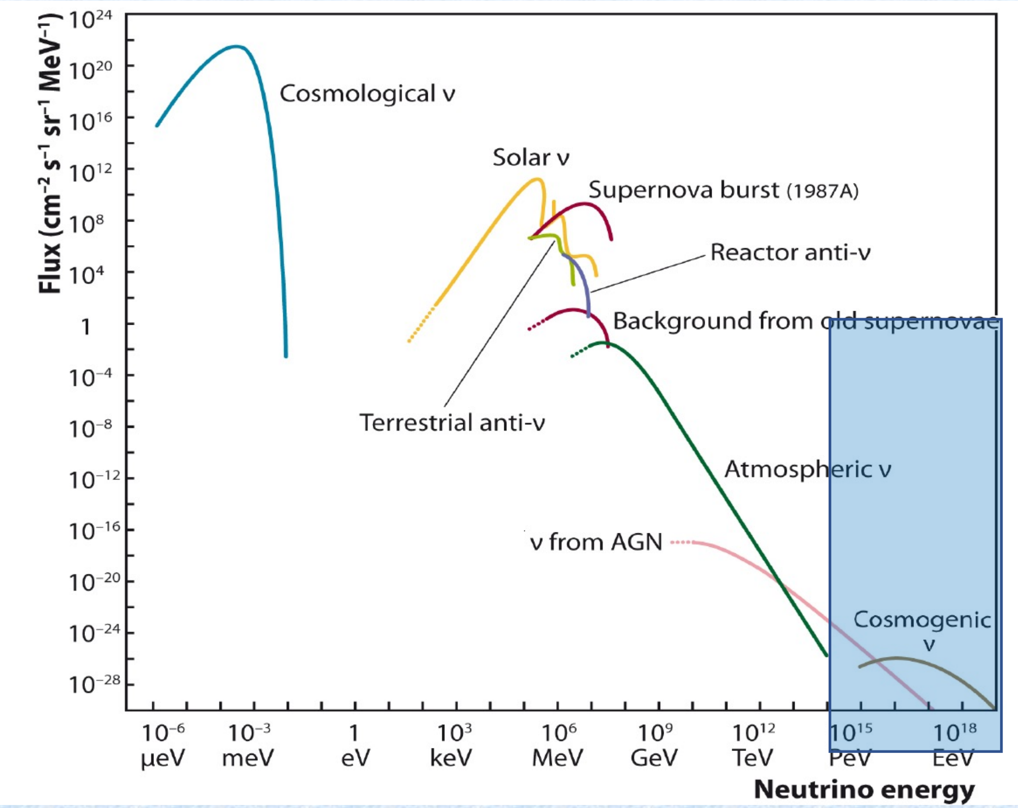
Space-based Neutrino Detection via EAS Optical Signals

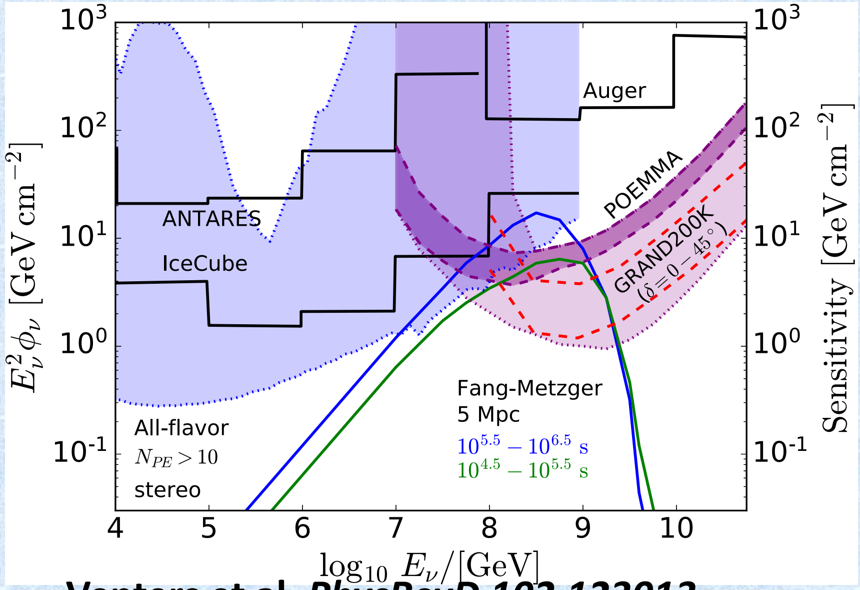


Spiering, C. 2012, The European Physical Journal H, 37, 515

See *High-energy Neutrinos from NGC 1068* MM ID#187
Luis Ancordoqui (Lehman), John Krizmanic (UMBC), & Floyd Stecker (GSFC)

Use the Earth and Atmosphere as large neutrino target & detector using extensive air showers (EAS)

- $\sigma_\nu \approx \sigma_{\nu bar}$ for $E_\nu \gtrsim$ PeV
  - y-dependence similar for charge-current (CC) and neutral-current (NC) interactions
- For meter^2-scale optical collecting area:
  - $E_\nu \gtrsim$ PeV for optical Cherenkov detection
  - $E_\nu \gtrsim$ 10 EeV for air fluorescence detection
  - Optical signals ~20% duty cycle (dark nights)



Venters et al, *PhysRevD.102.123013*

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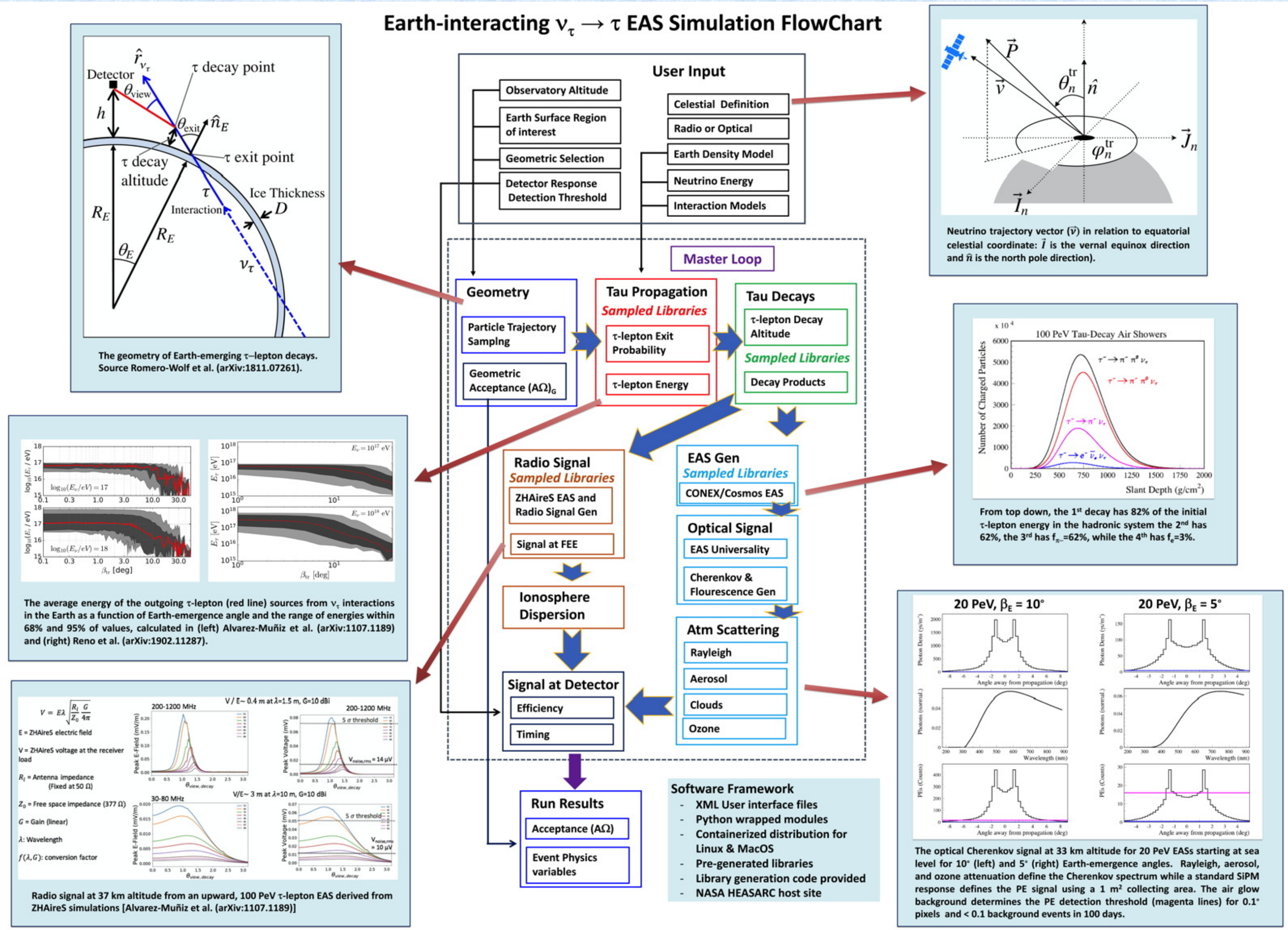
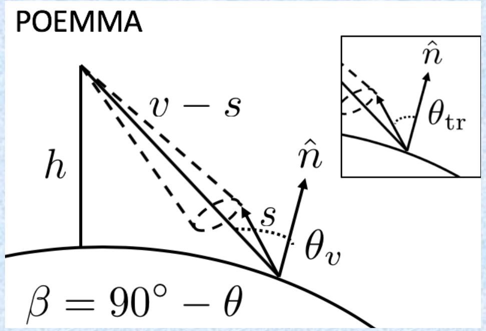
Simulation Architecture

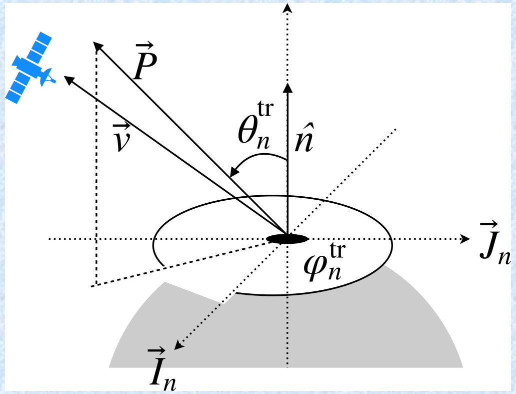
SpaceSim

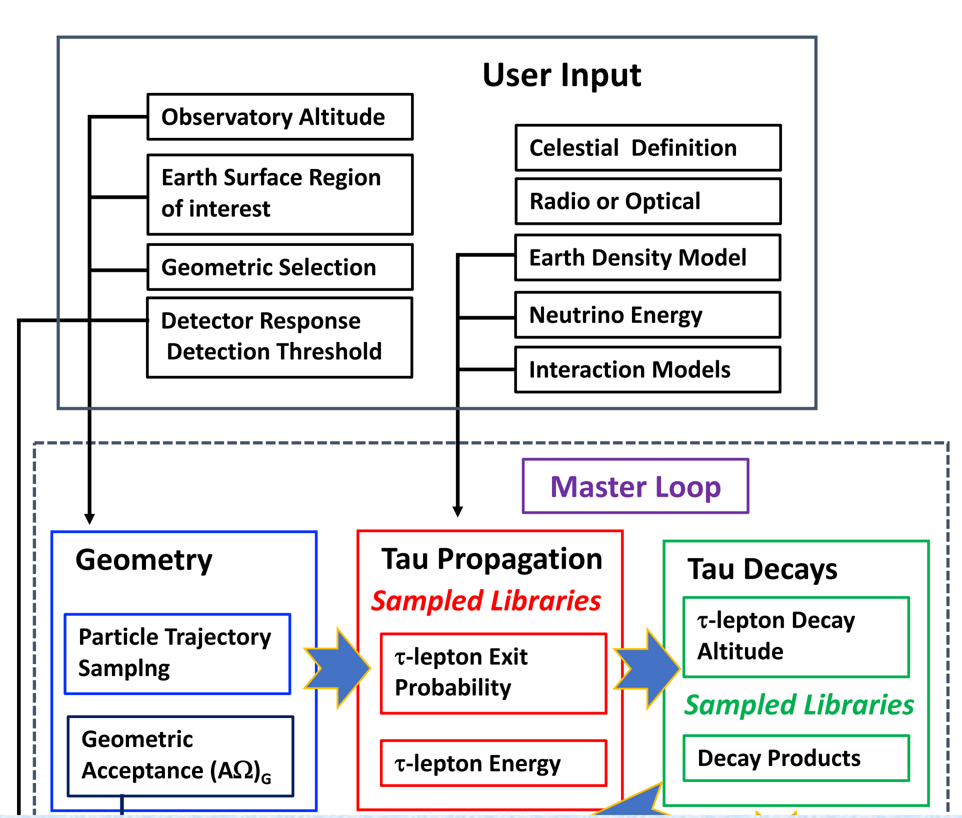
- **Vectorized Python wrapper than schedules modules written in higher-level languages, C, C++, Fortran.**
  - Inherent multi-core processing via *Dask*
  - XML input format and HDF5 library and output format
  - Led by Alex Reustle (GSC)
- **Libraries pre-generated, with code of user to re-generate:**
  - τ-lepton exit Probability (nuPyProp, nuTauSim)
  - τ-lepton decay tables (Pythia)
  - EAS longitudinal profiles (CONEX)
- **Optical:**
  - Optical Cherenkov properties via EAS age
  - Atmosphere definition:
    - Baseline for Rayleigh scattering, aerosol & ozone absorption
    - Cloud libraries from MERRA-2 database
  - Detailed Optical Detector modeling
- **Radio: based on ZHAireS simulated libraries**

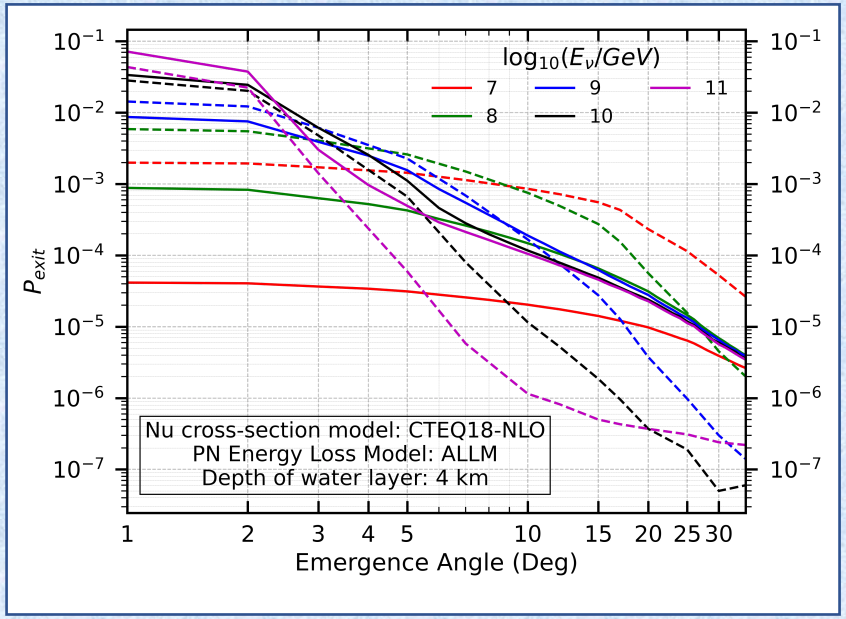


User Input, Geometry, Tau Yield, EAS Generation





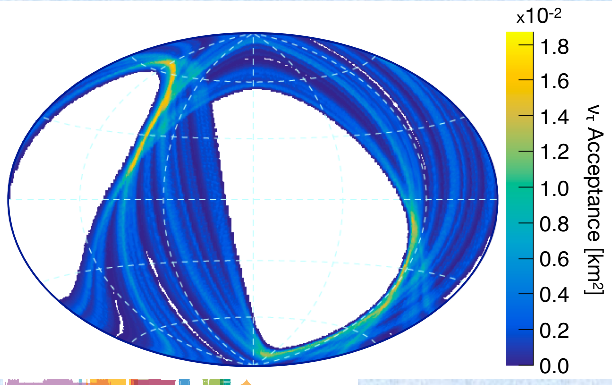


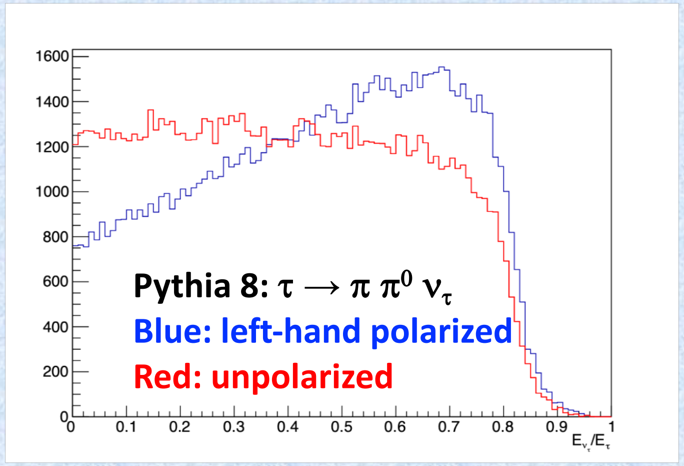


see nuPyProp : NU ID#482
Sameer Patel & Hallsie Reno (Iowa)

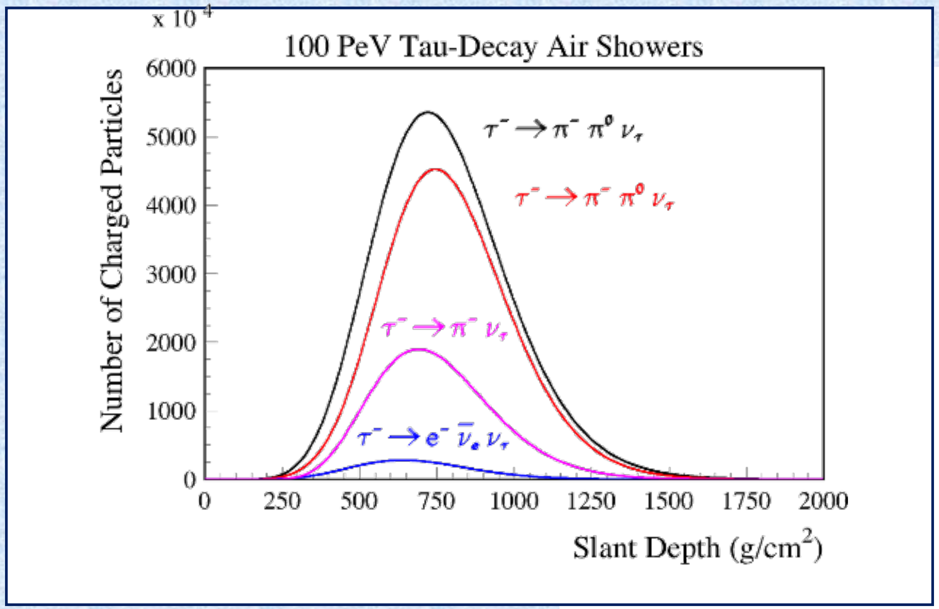
see ν Transient Detection : MM ID#1337
Toni Venters (GSFC)

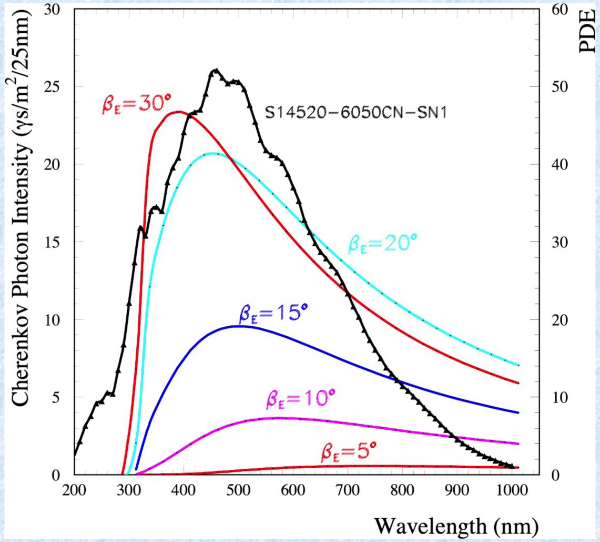
Sky map of the sensitivity to transient neutrino fluxes for the EUSO-SPB2 ULDB instrument assuming observations in astronomical night near new moon. ***implementation in progress.***





Optical Cherenkov Light Generation & Detection





EAS Gen

Sampled Libraries

CONEX/Cosmos EAS

Optical Signal

EAS Universality

Cherenkov & Flourescence Gen

Atm Scattering

Rayleigh

Aerosol

Clouds

Ozone

Signal at Detector

Efficiency

Timing

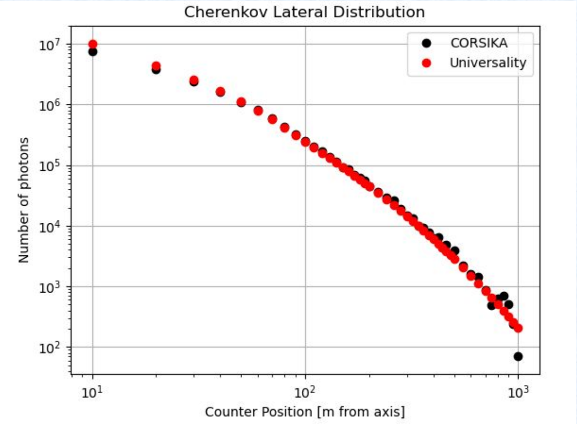
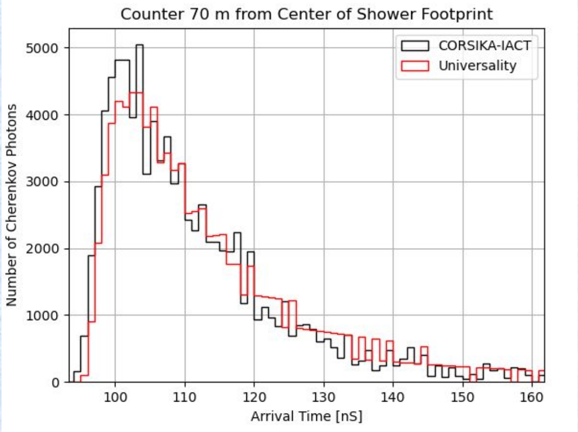


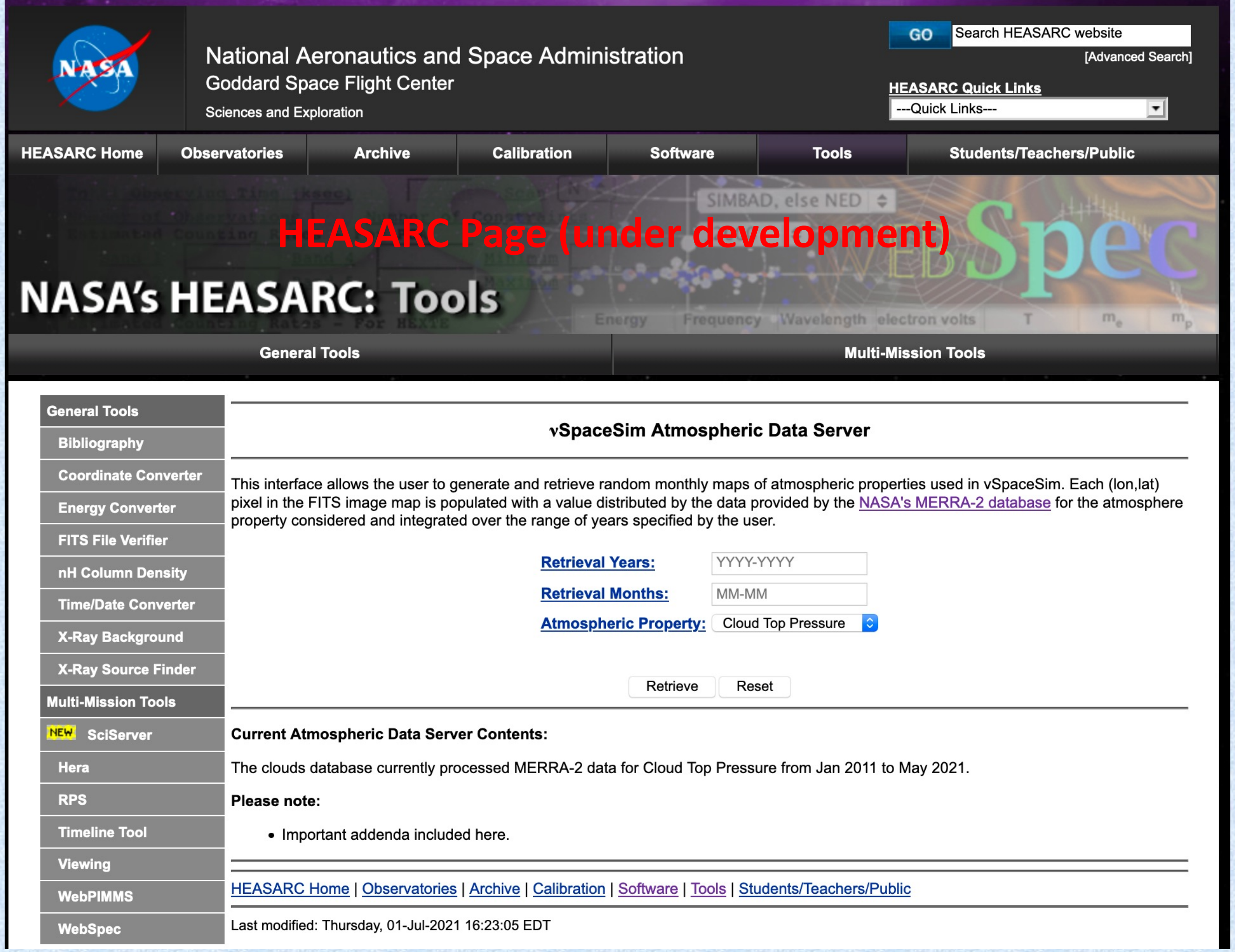
Figure 1: Comparison of Cherenkov lateral distribution from both CORSIKA and universality.



New Optical Cherenkov Calculation based on Shower Universality: Isaac Buckland & Doug Bergman (Utah)

Cloud Distribution Generation based on MERRA-2 Database

Partner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HEASARC Page (under development)

NASA's HEASARC: Tools

General Tools | Multi-Mission Tools

- General Tools
- Bibliography
- Coordinate Converter
- Energy Converter
- FITS File Verifier
- nH Column Density
- Time/Date Converter
- X-Ray Background
- X-Ray Source Finder
- Multi-Mission Tools
- NEW SciServer
- Hera
- RPS
- Timeline Tool
- Viewing
- WebPIMMS
- WebSpec

vSpaceSim Atmospheric Data Server

This interface allows the user to generate and retrieve random monthly maps of atmospheric properties used in vSpaceSim. Each (lon,lat) pixel in the FITS image map is populated with a value distributed by the data provided by the NASA's MERRA-2 database for the atmosphere property considered and integrated over the range of years specified by the user.

Retrieval Years: YYYY-YYYY
Retrieval Months: MM-MM
Atmospheric Property: Cloud Top Pressure

Retrieve | Reset

Current Atmospheric Data Server Contents:

The clouds database currently processed MERRA-2 data for Cloud Top Pressure from Jan 2011 to May 2021.

Please note:

- Important addenda included here.

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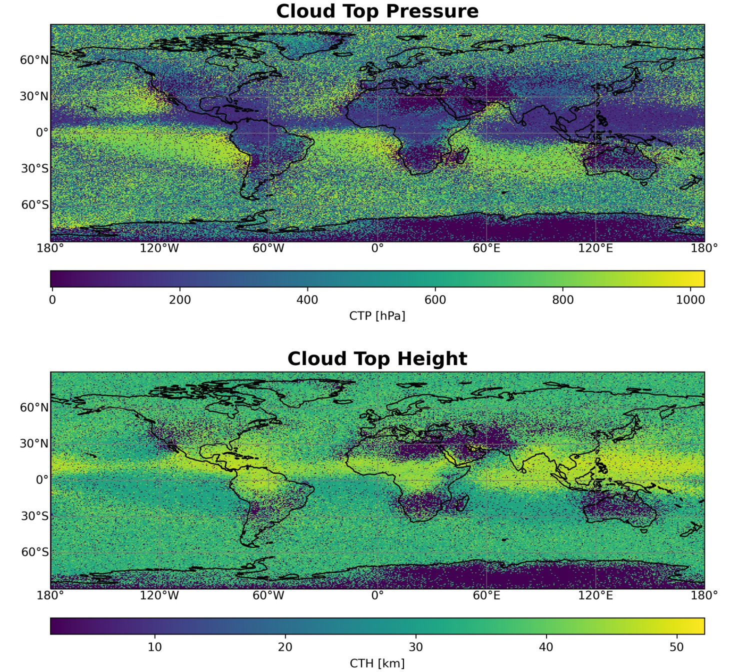
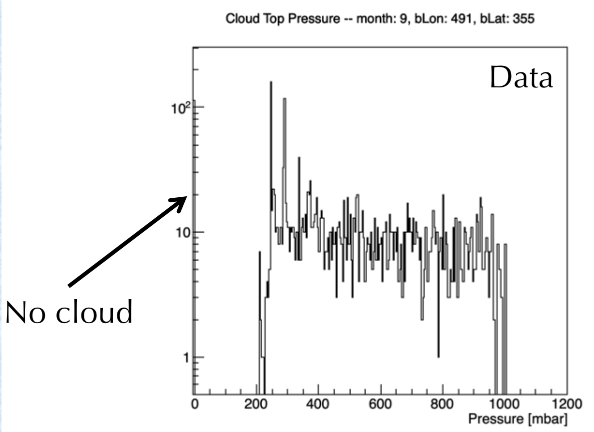
Sampled from MERRA-2 for specific time frame



Sampled from MERRA-2 for specific pixel (lat. Long: 0.5° × 0.625°)



Cloud top pressure shown: aerosol and ozone depth also available.

Alex Reustle (GSFC), Fred Sarazin (CSM) & Johannes Eser (Chicago)

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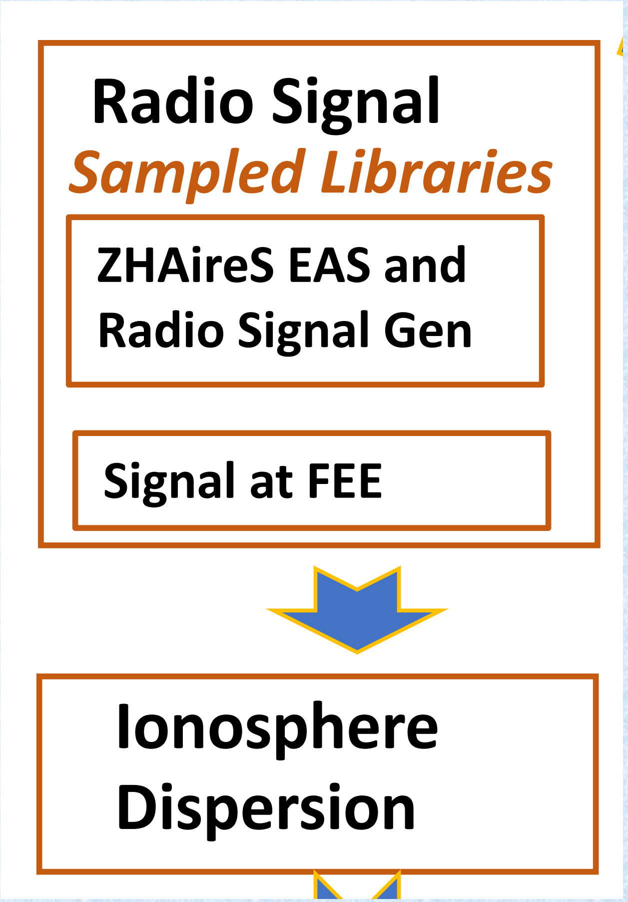
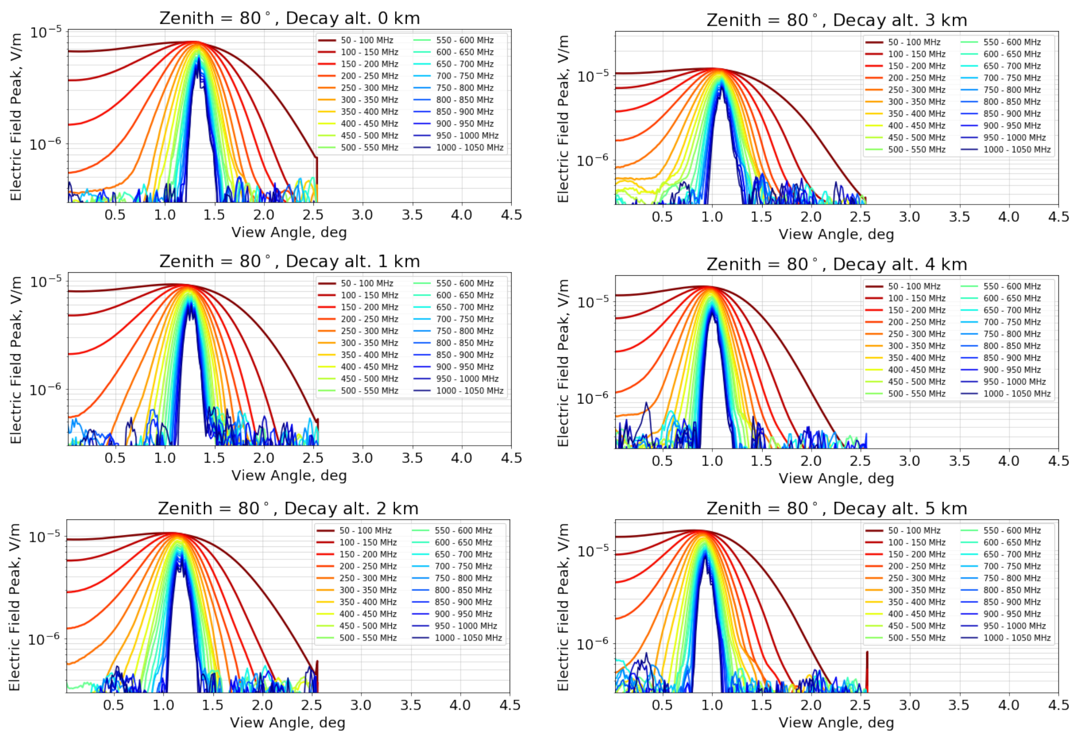
Radio Generation



Based on ZHAireS simulations of upward-moving EAS

See Upward EAS Radio Generation: NU ID#205
Andres Romero-Wolf (JPL)

Altitude dependence



Beta Version: Optical Cherenkov Results for POEMMA-like Configuration

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  <SimulationParameters DetectionMode="Diffuse">
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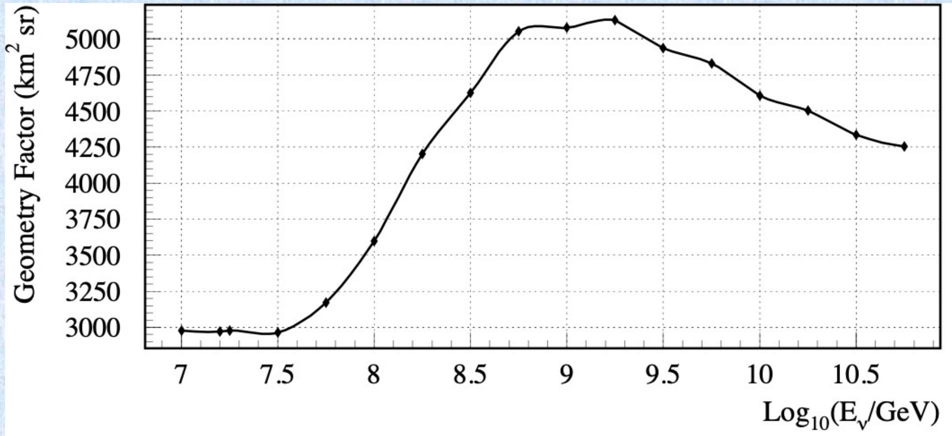
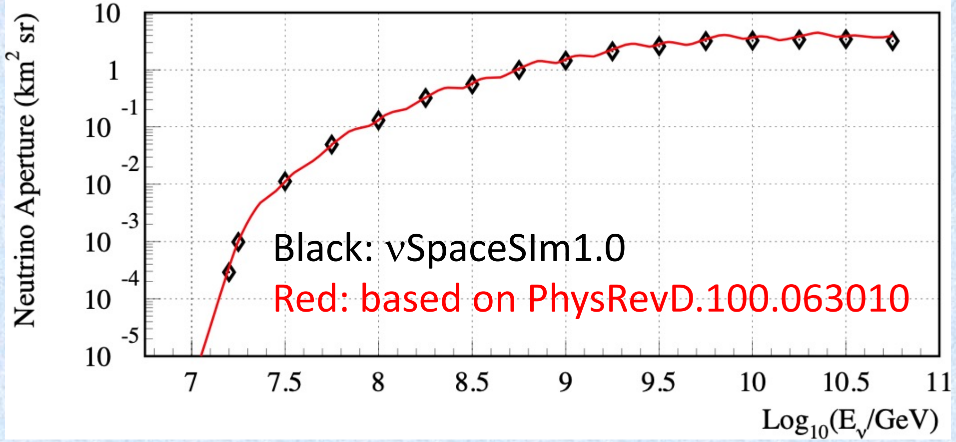
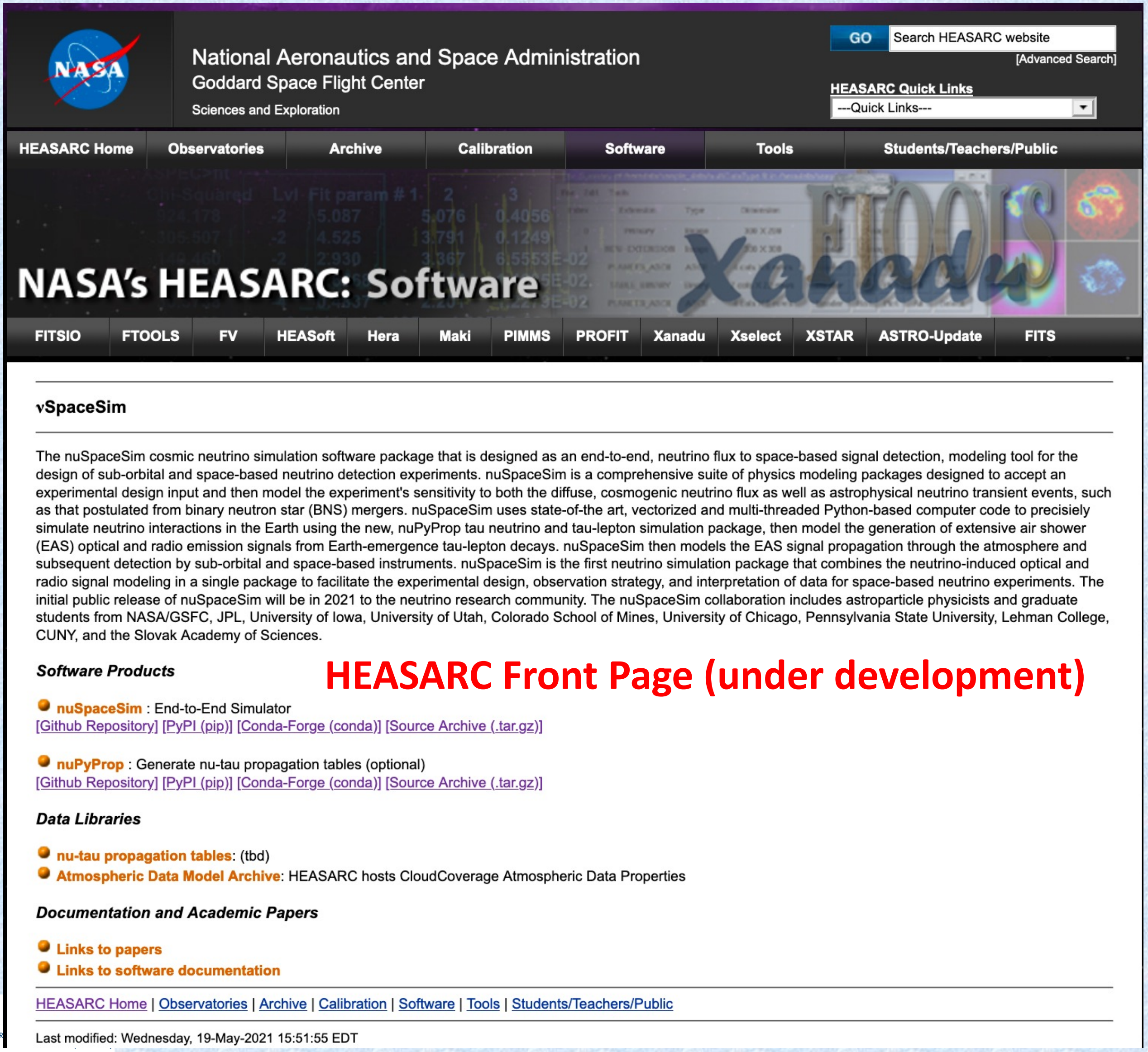




Vectorized Python wrapped higher-level language code with inherent multi-processing: takes ~ 5 hours to do this energy scan on my Mac

HEASARC Front Page (under development)

- νSpaceSim is designed to be a comprehensive, end-to-end simulation package for the development of space- and sub-orbital based experiments to detect the optical and radio EAS signals and interpret data:
  - Provides a quantification of modeling systematics by choice of different libraries by user
  - Development is in parallel with POEMMA, beyond POEMMA, EUSO-SPB2 modeling efforts.
- Initial public release by ICRC2021:
  - nuPyProp: τ-lepton P_{exit} and Energy Distributions
  - νSpaceSim1.0
  - Cloud & Aerosol Distribution Generation Tool using MERRA-2 Database
- **Related ICRC2021 Papers:**
  - **Sameer Patel: NU ID#482**
  - **Mary Hall Reno: NU ID#248**
  - **Toni Venters: MM ID#1337**
  - **Andres Romero-Wolf: NU ID#205**
  - **Austin Cummings: CRI ID#1002**
  - **Luis Anchordoqui: MM ID#187**



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νSpaceSim

The nuSpaceSim cosmic neutrino simulation software package that is designed as an end-to-end, neutrino flux to space-based signal detection, modeling tool for the design of sub-orbital and space-based neutrino detection experiments. nuSpaceSim is a comprehensive suite of physics modeling packages designed to accept an experimental design input and then model the experiment's sensitivity to both the diffuse, cosmogenic neutrino flux as well as astrophysical neutrino transient events, such as that postulated from binary neutron star (BNS) mergers. nuSpaceSim uses state-of-the art, vectorized and multi-threaded Python-based computer code to precisely simulate neutrino interactions in the Earth using the new, nuPyProp tau neutrino and tau-lepton simulation package, then model the generation of extensive air shower (EAS) optical and radio emission signals from Earth-emergence tau-lepton decays. nuSpaceSim then models the EAS signal propagation through the atmosphere and subsequent detection by sub-orbital and space-based instruments. nuSpaceSim is the first neutrino simulation package that combines the neutrino-induced optical and radio signal modeling in a single package to facilitate the experimental design, observation strategy, and interpretation of data for space-based neutrino experiments. The initial public release of nuSpaceSim will be in 2021 to the neutrino research community. The nuSpaceSim collaboration includes astroparticle physicists and graduate students from NASA/GSFC, JPL, University of Iowa, University of Utah, Colorado School of Mines, University of Chicago, Pennsylvania State University, Lehman College, CUNY, and the Slovak Academy of Sciences.

Software Products

- **nuSpaceSim** : End-to-End Simulator
  [Github Repository] [PyPI (pip)] [Conda-Forge (conda)] [Source Archive (.tar.gz)]
- **nuPyProp** : Generate nu-tau propagation tables (optional)
  [Github Repository] [PyPI (pip)] [Conda-Forge (conda)] [Source Archive (.tar.gz)]

Data Libraries

- **nu-tau propagation tables**: (tbd)
- **Atmospheric Data Model Archive**: HEASARC hosts CloudCoverage Atmospheric Data Properties

Documentation and Academic Papers

- **Links to papers**
- **Links to software documentation**

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HEASARC Front Page (under development)

νSpaceSim Collaboration

νSpaceSim Collaboration:

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8 Department of Astronomy and Astrophysics University of Chicago, Chicago, Illinois 60637 USA
9 Department of Astronomy, University of Maryland, College Park, College Park, Maryland 20742 USA
10 Institute of Experimental Physics, Slovak Academy of Sciences, Kosice, Slovakia
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12 Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, USA
13 Department of Physics, Colorado School of Mines, Golden, Colorado 80401 USA
14 Department of Physics, Pennsylvania State University, State College, Pennsylvania 16801 USA

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νSpaceSim NASA Summer Interns:

Julia Codera: 2020
- Project involved EAS modeling and interfacing to Cherenkov light Universality libraries
- Now 1st year graduate student at Stony Brook & working on DUNE!

Fred Garcia: 2021
- Project involves forming composite EAS from τ-lepton decay products interfacing to Cherenkov light Universality libraries

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EUSO-SPB2 ULBD Flight in Spring 2023