Extreme Universe Space Observatory on a Super Pressure Balloon II (EUSO-SPB2)

Lawrence Wiencke for the EUSO Collaboration
Cosmic Ray SIG Minisymposium

Lawrence Wiencke
Colorado School of Mines
(Virtual, w/ April APS meeting)
April 17 2021
NASA grant 80NSSC18K0477
Fluorescence: UHECRs EeV
First observation of UHECRs from near-orbit altitude with the fluorescence technique
Search for Upward Event Candidates

Cherenkov: PeV
Above Limb:
First Observation of Cosmic Rays from near-orbit altitude with the Direct Cherenkov Technique
Below Limb:
Search for tau neutrino ($\nu_\tau$)
Measure optical backgrounds for earth-skimming technique
<table>
<thead>
<tr>
<th>Country</th>
<th>Institution</th>
<th>EUSO-SPB2 Science Team</th>
<th>Work Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>Mines</td>
<td>L. Wiencke (Dep. PI), F. Sarazin, G. Filippatos, V. Kungel</td>
<td>Telescopes: (Mech, Testing, Integ, Calib, Field Testing) Optical Test Stand, Simulations</td>
</tr>
<tr>
<td>US</td>
<td>Iowa</td>
<td>Y. Onel, M. Reno</td>
<td>CT, FT LED systems, simulations</td>
</tr>
<tr>
<td>US</td>
<td>MSFC</td>
<td>M. Christl, R. Young</td>
<td>Gondola, SIP Interfacing</td>
</tr>
<tr>
<td>US</td>
<td>UAH</td>
<td>P. Reardon, J. Adams, E. Kuznetsov,</td>
<td>Optics Design, Solar Power, CT systems</td>
</tr>
<tr>
<td>US</td>
<td>Lehman U.</td>
<td>L. Anchordoqui</td>
<td>MAPMTs, Simulations</td>
</tr>
<tr>
<td>US</td>
<td>Ga Tech</td>
<td>N. Otte, E. Gazda, M. Bagheri, O. Romero</td>
<td>CT SiPM camera development</td>
</tr>
<tr>
<td>AL</td>
<td>CDTA, CRAAG</td>
<td>M. Traiche (CDTA), M. FOUKA (CRAAG)</td>
<td>Simulations</td>
</tr>
<tr>
<td>CZ</td>
<td></td>
<td>C Kerny, M. Pech, P. Schovanek</td>
<td>Mirror Segments for CT and FT</td>
</tr>
<tr>
<td>FR</td>
<td>APC</td>
<td>G. Prévôt, S. E. Parizot</td>
<td>FT camera Elementary Cells,</td>
</tr>
<tr>
<td>FR</td>
<td>OMEGA</td>
<td>S. Blin</td>
<td>Electronics - ASICS</td>
</tr>
<tr>
<td>IT</td>
<td>INFN &amp; U. Napoli</td>
<td>G. Osteria, V. Scotti, L. Valore, F. Guarino</td>
<td>CPU, Fluorescence Detector – DAQ,</td>
</tr>
<tr>
<td>IT</td>
<td>INFN &amp; U. Torino</td>
<td>M. Battisti, M. Bertaina F. Bisconti, F Fenu H. Miamoto K. Shinozaki</td>
<td>Simulations, lab testing, trigger algorithms</td>
</tr>
<tr>
<td>IT</td>
<td>INFN &amp; Univ. Bari</td>
<td>F. Cafagna</td>
<td>Flight (telescope) Software, FT Camera Housing</td>
</tr>
<tr>
<td>IT</td>
<td>UTIU</td>
<td>C. Fornaro</td>
<td>Fluorescence Telescope DAQ Software</td>
</tr>
<tr>
<td>IT</td>
<td>LNF-INFN, Frascati</td>
<td>M. Ricci</td>
<td>Italian coordinator</td>
</tr>
<tr>
<td>JA</td>
<td>RIKEN</td>
<td>M. Cassolino, T. Ebisuzaki, Y. Takizawa</td>
<td>Optics (ACP), PMT testing</td>
</tr>
<tr>
<td>Mx</td>
<td>U. Mexico</td>
<td>G. Medina-Tanco</td>
<td>Thermal Modeling</td>
</tr>
<tr>
<td>POL</td>
<td>NCBJ</td>
<td>J. Szabelski, L. Petrowski</td>
<td>FT HV system</td>
</tr>
<tr>
<td>RU</td>
<td>MSU</td>
<td>P. Klimov, A. Belov</td>
<td>FT Camera zynq boards</td>
</tr>
<tr>
<td>SE</td>
<td>KTH</td>
<td>C. Fuglesang</td>
<td>FT Camera structure (prototype)</td>
</tr>
<tr>
<td>SK</td>
<td>SAS</td>
<td>S. Mackovjak</td>
<td>UV/Vis Monitors</td>
</tr>
<tr>
<td>Country</td>
<td>Institution</td>
<td>EUSO-SPB2 Science Team</td>
<td>Work Packages</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------</td>
<td>---------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>US</td>
<td>Mines</td>
<td>L. Wiencke (Dep. PI), F. Sarazin, G. Filippatos, V. Kungel</td>
<td>Telescopes: (Mech, Testing, Integ, Calib, Field Testing) Optical Test Stand, Simulations</td>
</tr>
<tr>
<td>US</td>
<td>Iowa</td>
<td>Y. Onel, M. Reno</td>
<td>CT, FT LED systems, simulations</td>
</tr>
<tr>
<td>US</td>
<td>MSFC</td>
<td>M. Christl, R. Young</td>
<td>Gondola, SIP Interfacing</td>
</tr>
<tr>
<td>US</td>
<td>UAH</td>
<td>P. Reardon, J. Adams, E. Kuznetsov,</td>
<td>Optics Design, Solar Power, CT systems</td>
</tr>
<tr>
<td>US</td>
<td>Lehman U.</td>
<td>L. Anchordoqui</td>
<td>MAPMTs, Simulations</td>
</tr>
<tr>
<td>US</td>
<td>Ga Tech</td>
<td>N. Otte, E. Gazda, M. Bagheri, O. Romero</td>
<td>CT SiPM camera development</td>
</tr>
<tr>
<td>AL</td>
<td>CDTA, CRAAG</td>
<td>M. Traiche (CDTA), M. FOUKA (CRAAG)</td>
<td>Simulations</td>
</tr>
<tr>
<td>CZ</td>
<td>Kerny</td>
<td>C Kerny, M. Pech, P. Schovanek</td>
<td>Mirror Simulations</td>
</tr>
<tr>
<td>FR</td>
<td>APC</td>
<td>G. Prévôt, S. E. Parizot</td>
<td>FT Camera – DAQ,....</td>
</tr>
<tr>
<td>FR</td>
<td>OMEGA</td>
<td>S. Blin</td>
<td>FT Camera – Optics</td>
</tr>
<tr>
<td>IT</td>
<td>INFN &amp; U. Napoli</td>
<td>G. Osteria, V. Reva, F. Guarino</td>
<td>FT Camera Housing – Mirror Software</td>
</tr>
<tr>
<td>IT</td>
<td>INFN &amp; U. Torino</td>
<td>M. Balletti, E. Bisconti, F. Fenu, Miamoto K. Shinohara, F. Bisconti, F. E. S.</td>
<td>Simulations, lab testing, trigger algorithms</td>
</tr>
<tr>
<td>IT</td>
<td>INFN &amp; Univ. Bari</td>
<td>E. Fenu</td>
<td>Flight (telescope) Software</td>
</tr>
<tr>
<td>IT</td>
<td>UFIU</td>
<td>C. Fornaro</td>
<td>FT Camera Housing DAQ Software</td>
</tr>
<tr>
<td>IT</td>
<td>LNF-INFN, Frascati</td>
<td>M. Ricci</td>
<td>Italian coordinator</td>
</tr>
<tr>
<td>JA</td>
<td>RIKEN</td>
<td>M. Cassolino, T. Ebisuzaki, Y. Takizawa</td>
<td>Optics(ACP), PMT testing</td>
</tr>
<tr>
<td>Mx</td>
<td>U. Mexico</td>
<td>G. Medina-Tanco</td>
<td>Thermal Modeling</td>
</tr>
<tr>
<td>POL</td>
<td>NCBJ</td>
<td>J. Szabelski, L. Petrowski</td>
<td>FT Camera zynq boards</td>
</tr>
<tr>
<td>RU</td>
<td>MSU</td>
<td>P. Klimov, A. Belov</td>
<td>FT Camera structure (prototype)</td>
</tr>
<tr>
<td>SE</td>
<td>KTH</td>
<td>C. Fuglesang</td>
<td>UV/Vis Monitors</td>
</tr>
<tr>
<td>SK</td>
<td>SAS</td>
<td>S. Mackovjak</td>
<td></td>
</tr>
</tbody>
</table>
EUSO-SPB1

EUSO-Balloon

2014 Timmins

2017 Wanaka

EUSO-SPB2

(2023) Wanaka

Earth Orbit

POEMMA
EUSO-SPB2 Fluorescence Telescope
UHECR Simulation Event Rate

~ 1/hour of observation time

10% partially reconstructable

Few % with Xmax bracketed
Examples of Simulated EASs

EUSO-SPB2 Fluorescence Telescope UHECR Simulation
Example Air Shower 5 EeV, Zenith 34 deg

Fluorescence 3.9K
Chern (scatt) 1.1K
Chern (refl) 549

2021 CR-Sig (Apr APS)
EUSO-SPB2 Fluorescence telescope will also look for upward-going events

Anita event-like candidates

And

Macroscopic dark matter signatures
Fractionally Charged Particles
(5 MeV/c² – 100 TeV/c²) and velocities (βγ=0.1 – 10⁶)

see T. Paul, L. Anchordoqui, A. Olinto
Q10.00009
Model independent probes of macroscopic dark matter with EUSO-SPB2
Astroparticle Physics with the EUSO-SPB2 Cherenkov Telescope

First Observation of Cosmic Rays from near-orbit altitude with the Direct Cherenkov Technique

Predicted Event Rate above $10^{15}$ eV (1 PeV)

100/hr observing time

$\rightarrow$ In-situ test of the instrument

A. Cummings, PhD Thesis (GSI)
Astroparticle Physics with the EUSO-SPB2 Cherenkov Telescope

Earth Skimming Neutrinos
1. Optical Backgrounds: Fast flashes that mimic neutrino signatures?
2. Diffuse Neutrino Flux: Well below EUSO-SPB2 sensitivity
3. Target of Opportunity: Point the CT at a transient astrophysical object as it crosses the limb
   Tantalizing!

background discussion for ToO in Venters et al., Phys. Rev. D 102 (2020) 123013

Also see
nuSpaceSim (J. Krizmanic et al) https://pos.sissa.it/358/936/pdf
Astroparticle Physics with the EUSO-SPB2 Cherenkov Telescope

Earth Skimming Neutrinos
1. Optical Backgrounds: Fast flashes that mimic neutrino signatures?
2. Diffuse Neutrino Flux: Well below EUSO-SPB2 sensitivity
3. **Target of Opportunity**: Point the CT at a transient astrophysical object as it crosses the limb

_Tantalizing!

---

Sensitivity of EUSO-SPB2 to “Long Burst Transient” ie 30 Days
(case that the transient is active during the SPB2 mission)

Blue curves are the prediction of

Shaded region is EUSO-SPB2 sensitivity

Also, sensitivity to “Short Burst Transients”

---

Reno, Mary Hall S10.00005 Prospects for EUSO-SPB2 detection of transient astrophysical sources of neutrinos

Venters, Tonia S10.00007 Targets of Opportunity with POEMMA
POEMMA
Hybrid Focal Surface

FS filled with ECs

1.6 m

UHECR

2021 CR-Sig (Apr APS)
POEMMA
Hybrid Focal Surface

UV Fluorescence Detection with MAPMTs (1µs)

Cherenkov Detection with SiPMs (10 ns)

64 Photo Detector Modules (PDMs) = 147k pixels
1 PDM = 36 MAPMTs = 2,304 pixels
EUSO-SPB2
Two Telescopes

UV Fluorescence Detection with MAPMTs (1µs)

Cherenkov Detection with SiPMs (50 ns)

3 Photo Detector Modules (PDMs) = 6.9k pixels
3 x 11 deg x 11 deg FOV
0.2 deg/pixel w/ UV filter

512 pixels
6.4 deg x 12.8 deg FOV
0.6 deg/pixel
EUSO-SPB2
Two Telescopes

UV Fluorescence Detection with MAPMTs (1µs)

Cherenkov Detection with SiPMs (50 ns)

Also IR Camera System
For clouds UCIRC

Elementary Cell (EC)
SiPM (8x8)
PCB1
Si-Diode
PCB2
Interconnector

SiPM focal surface units

512 pixels
6.4 deg x 12.8 deg FOV
0.6 deg/pixel

2021 CR-Sig (Apr APS)
<table>
<thead>
<tr>
<th>Telescopes</th>
<th>2</th>
<th>1 Fluorescence (FT)</th>
<th>1 Cherenkov (CT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Threshold</td>
<td>~5 EeV</td>
<td>tbd (10’s of PeV)</td>
<td></td>
</tr>
<tr>
<td>Sensor Type</td>
<td>MAPMT (Hamamatsu)</td>
<td>SiPM Hamamatsu (S14521-6050CN)</td>
<td></td>
</tr>
<tr>
<td>Wavelength Sensitivity</td>
<td>UV 300-420 nm (BG3 filter x QE)</td>
<td>no filter (~300-~900 nm)</td>
<td></td>
</tr>
<tr>
<td>Time Bin</td>
<td>1000 ns/bin</td>
<td>10 ns x 512 bins 12 bit</td>
<td></td>
</tr>
<tr>
<td>Pointing (zenith angle)</td>
<td>nadir</td>
<td>Limb +/- 10</td>
<td></td>
</tr>
<tr>
<td>FOV (instrumented)</td>
<td>3x(11x11) deg</td>
<td>6.4x12.8 deg</td>
<td></td>
</tr>
<tr>
<td>Number of Pixels</td>
<td>3x2304=6912 (3 48x48 PDMs)</td>
<td>16x32=512 (16 Vert x 32 Horz)</td>
<td></td>
</tr>
<tr>
<td>Pixel FOV (&amp; size)</td>
<td>0.2x0.2 deg (2.8x2.8 mm)</td>
<td>0.4x0.4 deg (6.25 x 6.25mm)</td>
<td></td>
</tr>
<tr>
<td>Optics (modified Schmidt)</td>
<td>Spherical Mirror Glass, ROC 1659.8 mm</td>
<td>8 segments common focus + camera corrector/filter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 segments bifocal separation 2 pixels horizontal</td>
<td></td>
</tr>
<tr>
<td>Entrance Pupil</td>
<td>1 m diameter</td>
<td>PPMA corrector plate</td>
<td></td>
</tr>
<tr>
<td>Payload Mass (lbs)</td>
<td>3128/3533 (3000 max)</td>
<td>876 base 1050 w/ contingency</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>719 base 871 w/ contingency</td>
<td></td>
</tr>
<tr>
<td>Payload Power (24 V)</td>
<td>457/218/575 night day peak</td>
<td>142/49/181</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>197/53/241</td>
<td></td>
</tr>
<tr>
<td>Float Height</td>
<td>110,000 ft (33 km, 7 mbar)</td>
<td>Earth limb 5.8 deg below horz.</td>
<td></td>
</tr>
<tr>
<td>Launch Location</td>
<td>Wanaka NZ</td>
<td>2023 requested</td>
<td></td>
</tr>
<tr>
<td>Duration Target</td>
<td>100 days</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Telescope Opto-Mechanics
UAH (Huntsville), Olomouc (CZ), Mines (US)

Fluorescence Telescope

Not Shown: light shrouds, aperture doors

Cherenkov Telescope
EUSO-SPB2 Opto-Mechanical

Pat Reardon UAH

Y. Takizawa, RIKEN (Japan)

Petr Schovanek, Miroslav Pech (Olomouc Group CZ)

Kungel, Viktoria D10.00009 EUSO-SPB2 Telescope Optics and Testing

2021 CR-Sig (Apr APS)
The Fluorescence Camera
EUSO-SPB2 Fluorescence Telescope Camera Components

**Elementary Cell**

- 4 Multi-Anode PMTs
- 256 channels total
- Cockcroft-Walton High Voltage Circuit
- Digitization count single photoelectron pulses

Data Out:

# of PE / microsecond

Sylvie Blin (OMEGA, IN2P3), (France)
Guillaume Prévôt (APC, IN2P3) (France)
The Cherenkov Camera

Read-out Electronics

Trigger Board

Digitizer Board

Power Module

Camera

Camera Shelf

Gondola

Cherenkov Telescope

Corrector Lens

Mirrors

DAQ

CT-CPU

CoBo

The EUSO-SPB2 Cherenkov Telescope, Performance of Camera

24 APS April Meeting 2021 -- egazda6@gatech.edu
SiPM characterization

We have 35 SiPM arrays from Hamamatsu in the lab.

Measurements performed on SiPM array:
1. photon detection efficiency (PDE)
2. gain using a pulsed laser
3. breakdown voltage for each array and pixel
Bi-focus Mirror Segment Alignment: Cherenkov Telescope
(Background Reduction Technique)

Charged Particle Hits Camera: 1 spot 1 spot
Light Pulse from far-field outside the telescope: 1 spot 2 spots

2021 CR-Sig (Apr APS)
Planned Lab Test Configuration (CT, FT) using 1 meter diameter test beam system

Also, field tests with a laser and point light sources
Summary

**POEMMA** will open **two new Cosmic Windows**: neutrinos from transient astrophysical sources extreme energy cosmic ray (> 20 EeV)

**EUSO-SPB2**  Improved 2-Telescope Instrument, builds on SPB1 experience
Add unexplored areas
EAS observations from suborbital altitude
Search for upward candidate-events (beyond standard model)
Direct Cherenkov above the limb from suborbital altitude
Optical backgrounds for Earth-Skimming neutrino technique
Target of Opportunity Neutrino Search

**EUSO-SPB2**  on track for 2023 launch from Wanaka NZ  (also thinking about SPB3)
Scientific and Technical Pathway toward POEMMA or POEMMA-like instrument

2021 CR-Sig (Apr APS)