Proposal Summary

This is a proposal to support The United States (U.S.) participation in the European-lead Extreme Universe Space Observatory (EUSO) mission.

EUSO will investigate the highest energy processes in the universe by measuring extensive air showers from space. Based on existing measurements, EUSO is expected to observe thousands of events at energies where the Universe is predicted to be opaque to cosmic rays. The results obtained will address and perhaps resolve the mystery of these extreme-energy events. Also, EUSO may be the first instrument with sufficient collecting power to detect extreme-energy neutrinos, ushering in the era of neutrino astronomy. This gives EUSO the potential to make important discoveries in astrophysics, high-energy physics, cosmology, and/or fundamental physics.

The optical system is the proposed U.S. hardware contribution to EUSO. The Space Optics Manufacturing Technology Center (SOMTC) at Marshall Space Flight Center is the only source with expertise in large space optics. This contribution will enable the EUSO mission. U.S. scientists will participate in all aspect of EUSO.

EUSO is the pathfinder for a future U.S.-led Orbiting Wide-Angle Light collector (OWL) mission. EUSO will determine the effectiveness of space-based measurements and provide the experience NASA needs to confidently invest in the OWL mission.

1. Fact Sheet

Our Proposal: This is a proposal to participate in a European-led investigation of the most extremely energetic processes in the accessible universe using Extreme Universe Space Observatory (EUSO). EUSO is planned as a collaborative effort of research groups from Europe, Japan and the United States (U.S.). The European Space Agency (ESA) has approved a 1 year Phase A Study of EUSO to begin in December 2001.

Science Objectives: The objectives of EUSO are to investigate extreme energy cosmic rays (EECRs), those with energies $>3\times10^{19}$ eV and very-high-energy cosmic neutrinos. The primary objective is to investigate the source(s) of events observed with energies exceeding the Greisen-Zatsepin-Kuzmin (GZK) cutoff[1]. Proposed explanations for these events include:

1) Powerful comic ray (CR) sources within the Virgo cluster
2) Decay of super-heavy relic particles[9] in our galactic halo
3) Violation of Lorentz invariance[2]
4) Neutrinos from distant sources that either interact with relic neutrinos[3] in our super cluster or interact strongly with nuclei above a TeV scale[4] to produce EECRs.

Because of its huge target volume, EUSO will measure thousands of events beyond the GZK cutoff. These measurements will allow us to discriminate between these and other proposed explanations and perhaps discover the source of these extreme energy events.

The second objective of EUSO is to search for high-energy cosmic neutrinos. The proposed sources include the GZK effect; super-heavy relic particles[9]; and topological defects[5] left from the formation of the universe. If the predicted GZK neutrino fluxes are correct, EUSO will have sufficient collecting power to detect a few of them. If some other predictions[11] are correct, EUSO may discover the first cosmic neutrino sources, ushering in the era of neutrino astronomy.

EUSO will survey the whole sky with the potential to make major discoveries in astrophysics, high-energy physics, cosmology, and/or fundamental physics and this proposal offers NASA the opportunity to participate at a modest cost.

Importance to NASA: The Space Sciences Board has recommended the scientific objectives addressed by EUSO. Their 1997 NRC report stated, "These particles, with energies in excess of some 10^{19} eV, open a promising window onto astrophysical processes, cosmology, and fundamental physics. Because their deflection and containment by galactic-magnetic fields are negligible, particles with such energies must be extragalactic, and yet they are so energetic that they are blocked by interactions with the photons composing the CMBR within a few hundred megaparsecs, a distance that is small compared to the size of the universe. Their existence could signal new physics associated with grand unified theories (GUT) of particle physics."

One of the research focus areas of the NASA's Office of Space Science (OSS) Strategic Plan is to identify the sources of gamma-ray bursts (GRBs) and cosmic rays. EUSO's objectives support the first two objectives of the flight program in the strategic plan, i.e., the midterm Orbiting Wide-angle Light-collector (OWL) mission to investigate these extremely high-energy cosmic rays. For NASA, EUSO will be a pathfinder for OWL. EUSO will determine the effectiveness of space-based measurements and provide the experience NASA needs to confidently proceed with the OWL mission.

Mission Overview: ESA's plans are to launch EUSO on the Space Shuttle in 2007 and attach it to the Columbus Module of the *International Space Station* (*ISS*) for a 3-year mission. The basic facts of the EUSO mission are given in table 1:

Table 1: Basic EUSO mission characteristics.

Orbital Parameters	Height/Inclination	500 km nominal/51.3°
Mass	Payload Module	1050 kg
Power	Payload Module	400 Watt
Telemetry	Rate	100 KBit/s though the *ISS*
Attitude and Pointing	3 Axis Stabilized	±2°, knowledge to ±0.1°

Science Payload: EUSO will detect EECRs by measuring the fluorescence light from extensive air showers. EUSO will observe this fluorescence signal with a collecting power that exceeds what is possible from the ground as it looks downward on the dark sky with a 60° field-of-view (FoV) from its berth on the *ISS*. The fluorescence light will be imaged onto a finely segmented focal plane detector using two large Fresnel lenses. The segmentation and the time resolution will enable reconstruction of the arrival direction and shower energy with high precision. EUSO will detect about 10^3 extreme energy events per year. Table 2 gives EUSO's characteristics.

Table 2: Basic EUSO payload characteristics.

FoV	60°
Entrance pupil diameter	2.0 m
Operating wavelengths	330–400 nm
Angular resolution	~0.1°
Pixel diameter (and spot size)	~6 mm
Number of pixels	$\sim 2.5\times10^5$
Pixel size on ground	1 km
Duty Cycle	0.1

Management, Schedule, and Cost: EUSO will be managed by ESA. ESA will be responsible for the qualification testing, transportation, launch, deployment, retrieval, and data acquisition. Alenia Aerospazio will manage the instrument. Alenia will also build the instrument bus and provide instrument integration. The instrument subsystems will be developed by the collaborating institutions, supported by the national research programs of Italy, France, Switzerland, Japan, The U.S. and delivered to Alenia.

The NASA Contribution: Marshall Space Flight Center (MSFC) will manage the proposed U.S. contribution. The hardware will be two Fresnel lenses integrated into a metering structure and the ultraviolet (UV) optical filters. All will be from the Space Optics Manufacturing Technology Center (SOMTC) at MSFC. The U.S. team will deliver this hardware to Italy and Japan on a no-exchange-of-funds basis for integration into EUSO. Afterwards the optics engineering and technical team will disband. If EUSO is delayed, the U.S. program will be mothballed so the OSS cost will not grow. The total cost for U.S. participation will be $24M.

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2. Science Investigation

2.1 Introduction

EUSO is an ESA mission[1] to explore the most powerful energy sources in the universe. The mission objectives of EUSO are to investigate EECRs, those with energies $>3\times10^{19}$ eV, and very high-energy cosmic neutrinos. These objectives are directly related to extreme conditions in the physical world and possibly involve the early history of the big bang and the framework of GUTs. EUSO tackles the basic problem posed by the existence of these extreme-energy events. The solution may have a unique impact on fundamental physics, cosmology, and/or astrophysics. At these energies, magnetic deflection is so small that the EECR component serves as the particle channel for astronomy. EUSO's objectives support the Structure and Evolution of the Universe (SEUS) theme and the first two objectives of NASA's OSS Strategic Plan for 2003 and beyond[2]. These objectives are as follows:

- Objective one: Understand the structure of the universe from its earliest beginnings to its ultimate fate.
- Objective two: Explore the ultimate limits of gravity and energy in the universe.

EUSO will make the first measurements of EAS from space by observing atmospheric fluorescence in the Earth's night sky. Earth's atmosphere serves as the huge target and transparent detector for remotely sensing EECRs from space. Through measurements of the air shower track, EUSO will determine the energy and arrival direction of these extreme-energy events[3]. EUSO will make high statistics observations of CRs beyond the predicted GZK cutoff energy[4] at $E>10^{20}$ eV and widen the channel for high-energy neutrino astronomy. The energy spectra, arrival directions, and shower profiles will be analysed to distinguish the nature of these events and search for their sources. With EUSO data, we will have the possibility to discover a local EECR source, test Z-burst scenarios[5] and other theories, and look for evidence of the breakdown of the relativity principle at extreme[6] Lorentz factors (γs).

Prof. Roger Blanford of Caltech and Prof. George W. Clark of MIT have endorsed this proposal for the U.S. to participate in EUSO. This endorsement letters are included in section I.1.

The European phase-A study, beginning in December 2001, is to develop the concepts for the accommodation of EUSO on the Columbus module and the instrument. ESA will depend on the U.S. phase-A study to develop the concept for the optical system. Our help will also be needed in the phase-A study of other subsystems, as described in this proposal.

Raw data (level 0) from EUSO will be processed at the Science Data Center (SDC) in Europe to create a level 1 data product. Both levels of data will be archived and distributed to the entire EUSO collaboration. All the EUSO data and a database of results will be available to the international scientific community in accord with ESA rules and directives.

2.2 Science Goals and Objectives

2.2.1 Specific Astrophysics, Cosmology, and Fundamental Physics Quests

Investigation of the highest energy events in nature involves more than traditional astrophysics. It has a strong and direct relevance to the following questions:

- Astrophysics: What processes and what astronomical objects are generating such high energies? Are there particular point sources responsible for the spatially correlated multiple events[7]?
- Astroparticle Physics: How far does the CR energy spectrum extend? What is the ultimate energy (E_{MAX}), if there is any limit below the theoretical Planck mass scale 10^{28}eV or the grand unification energy scale $10^{24\sim25}$ eV?
- Cosmology: How many neutrinos are there above 10^{20} eV? Do topological defects[8] and/or super-massive relic particles[9] exist and do they decay copiously producing neutrinos that appear in CRs?
- Neutrino Astrophysics: Do cosmic neutrinos really oscillate[10] in the universe? Can we detect them coming from active galactic nuclei (AGN) and other suspected acceleration sites?
- Fundamental Science: Does the relativity principle still hold at extreme velocities? Observation of a pileup of EECRs[11] near 5×10^{19}eV due to the GZK effect[4] is in itself a crucial test for the LI at extreme γs(for protons) where $\gamma\sim10^{11}$ and greater.

These quests contribute directly to achieving the objectives of the SEUS theme.

The observed existence of CRs with $E>10^{20}$ eV has been itself enigmatic. In this energy range, the generation mechanisms and propagation of primaries involve processes that are experimentally poorly confirmed. Known sources have difficulty accelerating particles to these energies[12]. Energy loss of known extreme-energy particles in the universe is (with the exception of neutrinos) so severe that we cannot expect to observe these events from distant sources. EUSO will address the questions listed above. It seems likely that the high statistics investigation of these events proposed here will lead to some important discoveries.

Past Investigations: Six ground-based experiments have detected a total of 15 events above 10^{20} eV during the last 40 years (1 event from Volcano Ranch[13], 4 events from Haverah Park[14], 1 event from Yakutsk[15], 1 event from Fly's Eye[16], and 8 events from the Akeno Giant Air Shower Array (AGASA)[17]). This corresponds to a flux of about 1 event per km^{2}per century. An additional seven events were reported in 1999 by the High Resolution Fly's Eye (HiRes) experiment[18,19]. At the August 2001 International Cosmic-Ray Conference (ICRC)[20], HiRes reported revised results of two events $>10^{20}$eV with a larger aperture and Haverah Park revised their results downward to zero events. AGASA, with its new extended aperture, increased their statistics to 17 events[21]. While these latest results are discordant, they continue to indicate the existence of these particles (hereafter called Super-GZK events). The number of events is too low to allow a quantitative investigation about their origin.

At present, the two highest energy CRs measured have the energy of $\sim3.2\times10^{20}$ eV (Fly's Eye[16]) and $\sim3.4\times10^{20}$ eV (AGASA[21]), respectively. The origin of these highest energies is mysterious, for there are no visible source candidates within the GZK horizon except possibly M87, a radio-loud AGN about 20 Mpc away from us, and Cen–A (NGC5128), a radio galaxy at 3.4 Mpc. Neither of these is in the direction of any of the observed events[22]. The large-scale isotropy of observed events[23] suggests that many sources rather than one source is required. Figure D 2-3 in foldout 1 shows a recent compilation of the data published[22,24] from AGASA, Fly's Eye, and HiRes, clearly extending the spectrum beyond the GZK cutoff energy (E_{GZK}). The overall E^3 dependence seen in Figure D2-2 is removed in the figure to see the detail. The dashed line shows the effect of the GZK cutoff, assuming that a homogeneous source population evolved and is filling the present universe. The numbers given are the actual numbers of events in each bin. Because the universe is transparent only to neutrinos at these energies, much speculation has arisen about the nature of primary particles.

CRs with lower energies of ~10^{18} eV are found to arrive preferentially from the galactic center[7]. Higher energy events should show much stronger anisotropy due to their increasing rigidity, so long as they have the same galactic origin. However, AGASA[23] and a world data summary[22,24] of CRs above ~E_{GZK} (4×10^{19} eV) show an isotropic distribution in the sky (see figure D 2-4 in foldout1), clearly suggesting an extra-galactic origin. Among them, 6 pairs and 1 triplet, of spatially correlated events have been recognized, by AGASA alone, from 58 events within 2 years. Meanwhile, the world data shows nine pairs and two triplets. The chance coincidence probability for these clusters arising from an isotropic distribution is less than 0.04 percent[23,24], suggesting that particles in these clusters may have the same sources.

Present and Planned Ground-Based Observations compared with EUSO: The largest planned ground-base experiment is the Pierre Auger Observatory[25], presently under construction in Argentina. This will consist of an array of 1,600 particle detectors, and 4 fluorescence light detectors similar to the ones used in the HiRes experiment[18,19]. This hybrid detector allows cross calibration and a check of the systematic uncertainties inherent in each of the techniques. The construction is expected to be completed in 2004. The Auger observatory will have an aperture of 3,500 km^2 sr, leading to about 15 events per year with energies $>10^{20}$ eV. It will produce, in only 8 months, a number of events comparable to all previously observed events above 10^{20} eV. A second Auger observatory is proposed for the northern sky.

A rate of 30 events per year, with most above 10^{20} eV, may still be too limited to follow the CR spectrum to much higher energies, or to obtain the detailed form of the spectrum with small statistical errors. Above one ZeV (10^{21} eV), only about 5 events are expected in 10 years of operation. At least an order of magnitude more statistics is desirable. By the year 2006, provided Auger is completed on schedule, the world data set will comprise about 100 events above 10^{20} eV and perhaps one or two events above 10^{21} eV, if the spectrum continues without a GZK cutoff. The existence or nonexistence of the proton GZK cutoff will most likely be established by then. However, should iron nuclei dominate, the GZK cutoff is 3×10^{20} eV and its profile might remain out of reach.

An effective geometrical factor of 5×10^{5} km^2sr combined with an efficiency of 0.1 gives EUSO an expected event rate of >1,700/yr above its energy threshold ($E_{th}=3\times10^{19}$) and ~500/yr with $E \geq 10^{20}$ eV. This will be sufficient to detect a GZK cutoff even at 3×10^{20} eV. The expected rates for neutrinos interacting in the atmosphere vary from a few per year (GZK processes[26], AGN[27], GRB sources[28], etc) to ~150 per year if top-down processes or Z-bursts[5] dominate. In the tilted mode, EUSO has a geometrical factor of 4-million km^2sr, nine times larger than in the non-tilted mode. The number of trans-ZeV events expected in the tilted mode reaches 100 events/yr. Table 2.7 shows how EUSO compares with the present and future ground experiments.

Future Space-Based Observations: The night-sky Earth atmosphere, viewed from space, constitutes an ideal calorimeter for remotely observing EECRs. The area of the night sky of the whole Earth, 4×10^8 km^{2}sr, is the ultimate size limit for space observatories to be compared to ground-based observatories that are reaching a practical limit at ~10^4 km^{2}sr. The next generation of EECR detectors must be space based. EUSO will be the first of this new generation.

A single mission rarely answers all the outstanding scientific questions and the discoveries that are made usually raise even more interesting questions. The EUSO mission will be followed by the U.S. OWL mission[29] that is in the OSS midterm strategic plan[2]. OWL is a much more ambitious project. It uses two satellites, with much larger pupils, in higher orbits. These two satellites are tilted to allow stereo imaging of the same volume in the atmosphere. This strategy will provide redundant measurements of each EAS. EUSO is an outgrowth of OWL planning and will become the pathfinder mission for EAS measurements from space. The data and on-orbit experience gained with EUSO will be of immense value to OWL. EUSO's last year on orbit will be devoted to tilted observations, acquiring data that will be useful for planning OWL. EUSO will provide the experience needed to confidently proceed with the OWL mission.

2.2.2 The Need for This Investigation

The present data suggest intriguing new science horizons. Origin, propagation, and the fundamental science considerations point to the discovery potential of EECR investigations that make systematic high-quality measurements with sufficient statistics. The very low event rate of EECRs requires extremely large detectors that cannot be achieved with ground-based methods. The following paragraphs explain the need for EUSO.

The present data confront us with the existence of super-GZK events[22,24,30] for which we have no explanation[22,30] and intrigue us with possible coincidences of two or three events arriving from nearly the same direction[7]. These data contain events at energies so high that no known source seems capable of producing them.

The GZK Cutoff: Soon after Penzias and Wilson discovered the cosmic-microwave background radiation (CMB), Greisen[4] and independently Zatsepin and Kuzmin[4] pointed out that this radiation would make the universe opaque to CRs of sufficiently high energy. For protons, this occurs when the pion production threshold is reached (~$5 \mathrm{X} 10^{19}$ eV). The reaction $p+\gamma \rightarrow \Delta^+ \rightarrow \mathrm{p}+\pi^0$ or $n+\pi^+$ gives an effective attenuation length of ~50 Mpc for a proton of 10^{20} eV. This is just a small fraction of the size of the universe. If EECR sources exist throughout the universe, super GZK protons from distant sources will loose energy and pile up at sub-GZK energies. The GZK effect predicts a complicated shape for the observed EECR energy spectrum. This shape is a function of the assumed distribution of the extra-galactic sources in the universe (see figure. D2-6 of foldout 1). However, the measured spectrum shows none of these features and is well described by a power law.

The predicted cutoff of the energy spectrum above 5×10^{19} eV may not be observable if a high abundance of cosmological neutrino events, or EECRs from nearby sources, are dominant. Details of the energy spectrum in the trans-GZK energy regime (10^{19} ~3×10^{20} eV) reflect the evolution of the universe (see figure D2-6 in foldout 1). The additional data acquired by the present and planned experiments may permit us to discern a GZK pileup[11]. EUSO's high statistics will make possible a much more sensitive search for evidence of this pileup.

Super GZK Particles: The existing data already show an access of super-GZK particles. The conundrum posed by these events has lead many to suggest explanations employing extreme values of the key parameters of known astrophysical objects or invoking new physics and/or particles that avoid the GZK cutoff. Several explanations of super-GZK events are presented in the following paragraphs.

In the first class of explanations suggest that particles are accelerated to super-GZK energies. A search for suitable acceleration sites[12] reveals that no known astrophysical object is easily able to accelerate particles to 10^{20}eV. This is illustrated in figure D2-5 of foldout 1, where objects below the diagonal line cannot accelerate particles to 10^{20} eV by shock acceleration. The solid line indicates the limit for protons, the dashed line is the limit for iron nuclei, both with extreme shock speeds of $\beta=1$. The upper end of the shaded area corresponds to more realistic shock speeds of $\beta=1/300$. Even if 10^{20} eV could be achieved, it is unclear how the particles can leave the dense radiation fields near the acceleration region[31]. A predominance of local sources are needed to explain the data but most of the radio galaxies and AGN are at distances >>100 Mpc from Earth. The losses during propagation mean that acceleration, even to 10^{21} eV, would not be sufficient to explain the observed events (see figure 2.1). These results only deepen the mystery surrounding the nature of Super-GZK particles, for they appear to come from numerous nearby sources of an unknown kind. Other explanations, dead pulsars[32], long-lived shocks due to galaxy collisions[33] or the formation of galaxy clusters[34], and even GRBs[35] have been proposed as possible bottom-up sources of EECRs but these too have their difficulties.

The second group of explanations attempts to use neutrinos to overcome the distance restrictions. From distant acceleration sites, only neutrinos, among the known particles obeying known physics, can propagate unimpeded to Earth. Exploiting this fact are the Z-burst model[5,36] and the strongly interacting neutrino model[37]. A neutrino-primary hypothesis of Z-burst is generally supported by the observed large-scale isotropy and small-scale clustering of events on the celestial sky. The cosmic neutrino background (CNB) is theoretically firmly established by Lee and Weinberg[38] in the big-bang model and has the present-day temperature 1.95K. The extreme-energy (EE) primary particles that propagate across cosmic distances are neutrinos, which then annihilate with these CNB within the Virgo cluster to create a local flux of nucleons and photons above EGZK (see figure D2-7 in foldout1). From big-bang cosmology, and on the established standard model (SM) of particle physics, the probability for a neutrino with resonant energy to annihilate to a Z-burst within the distance across the local cluster of galaxies[39] is more than about 3×10^{-4}. This local annihilation rate is much larger (>1 percent) if our matter-rich portion of the universe clusters relic neutrinos as well[5]. Each resonantly annihilated neutrino pair produces a Z boson with a 70 percent branching ratio into hadrons. For a neutrino mass in the range 0.1–2.0 eV, as inferred by oscillation studies, the Z-burst energy is fortuitously situated at $E_\nu^R=\mathrm{M}_Z^2/2m_\nu=4(\mathrm{eV}/m_\nu)\times10^{21}$ eV so as to produce on average of 2 baryons and 20 photons with energies exceeding E_{GZK}.

If the Z-burst occurs in the Virgo cluster, then one or more of the photons and nucleons in the burst may initiate a Super-GZK air-shower at Earth[5]. For a sufficient cosmic neutrino flux, the hypothesis successfully explains the observed air showers above E_{GZK}[36]. While certainly large, the neutrino flux required at ~10^{22} eV violates no existing limits and is directly measurable in a detector, like EUSO. In addition, this resonant neutrino annihilation (Z-burst) provides the best hope to actually measure, for the first time, the relic neutrino density liberated only a second after the big bang (see figure D2-1 in foldout 1).

Using neutrinos to explain the existence of super-GZK events shifts the problem to production of these neutrinos. Where would the even more energetic particles that produce the neutrinos be accelerated? Other explanations postulate ultra-high-energy cosmic particles (X-particles), exotic strongly interacting massive particles with a longer range in the CMB than nucleons. Such particles are predicted in certain super-symmetric models. The decay of X-particles is thought to produce copious amounts of photons, neutrinos, and leptons, and a smaller fraction of protons and neutrons that may be detected. The X-particles themselves may be produced by the decay of topological defects or super-massive relic particles produced after the inflationary stage of the universe (see figure D2-1 in foldout 1). From the cosmology and particle physics point of view, the EECRs have energies only a few decades below the grand unification energy (10^{24}–10^{25} eV), therefore, varieties of new phenomena are expected.

Finally, the other way of solving the puzzle is to posit the breakdown of the Lorentz invariance (LI). Implicit in the principle of relativity is a smoothness assumption for space and time. On the other hand, it is expected that a final theory of quantum gravity will include space-time fluctuations and granularity at small distances (and equivalently, high energies). Therefore, it is possible that the first indication of the failure of relativity may occur in EECR physics. A breakdown of the relativity at extreme γs has been proposed in several theoretical works[6]. In a simple but explicit model, Coleman and Glashow[40] parameterised the breaking of the LI by giving the vacuum a preferred (four-vector) direction (similar in spirit to Einstein's endowing the vacuum with energy via the cosmological constant, L). In this class of theories, there may be a maximum γ. In addition, the maximum velocities of massive particles(c*) may be species-dependent and different from the ordinary light velocity (c)[40] (Coleman, 1997). Notable signatures are an absence of photopion production above E_{GZK}, the consequent absence of a proton pileup below E_{GZK}, and possible a suppression of neutron decay leading to undeflected pointing of the primary neutrons back to their sources. The experimental reach is different for each particle species.

With a sample of proton events at 10^{21} eV, EUSO's reach extends to $\gamma_p \sim 10^{12}$. At this extreme energy, the proton velocity differs from c at less than one part in 10^{24}, if relativity remains valid. Relativity at $\gamma_p \sim 5\times10^{10}$ is tested by the existence or absence of the GZK cutoff and pileup.

Neutrinos can provide far more robust tests, because their γs are the largest in the universe, reaching beyond 10^{20} for a 1 eV mass neutrino. We note that in the rest frame of a 10^{20} eV neutrino, the target protons in the $n_\nu p$ interaction have a de Broglie wavelength of 1.3×10^{-35} cm, smaller than the Planck length ($l_P=(Gh/c^3)^{1/2}=4\times10^{33}$ cm) and placing them in the quantum gravity domain. Cosmological neutrino annihilation on a dark-matter neutrino (i.e., a Z-burst) at its resonant energy of 10^{21} eV/$m_n c^2$ implies extreme γs$\sim10^{21}$ and neutrino velocities to within one part in 10^{-42}. Thus, the measurement of Z-burst events or extreme-energy n_ν-induced air showers a test of the relativity principle at the point where quantum effects should become important.

Historically, space-borne detectors discovered unexpected phenomena when they first went onto orbit with new capabilities. EUSO will measure thousands of events with <1-degree angular resolution. EUSO should at least provide ample opportunities to discriminate among the postulated models.

Neutrino Astronomy: Astronomy at the highest energies must ultimately be performed by neutrinos because the universe is transparent to no other form of radiation. The effects of the CMB on potential astronomical channels are summarized in table 2.1. As shown in the table, space is so opaque to photons at extreme energies that they are of little use for probing the universe. Only neutrinos have a mean free path that is large enough to make the universe transparent. However, astrophysical neutrinos demand an extraordinarily large detector for observation. EUSO can greatly increase the target size enabling exploration of the neutrino universe. In the standard electroweak and quantum chromodynamics (QCD) theory the neutrino-nucleon (νN) cross-section continues to increase above the center of mass energy due to the increase of partons with energy. This cross section has been established at energy $E_{eP(LAB)}$~10 TeV by the Deutches Electron-Synchrotron (DESY) and the QCD theory predicts[55] $\sigma_{\nu N} \propto E_{LAB}^{0.4\pm 0.1}$. It is 0.1 microbarn at 10^{20} eV, sufficiently high for cosmic neutrinos to produce observable numbers of showers in the atmosphere. EUSO, with its large sensitive area and target of the order of 10^{13} tons of atmosphere, will be sensitive to this class of events. If the predicted flux of GZK neutrinos[10] is present, EUSO is expected to observe a few events from interaction of neutrinos in the earth's atmosphere. If other predictions[8,9,36] are correct, even more will be observed. The observation of an EECR neutrino ($E \geq 10^{19}$ eV) with a coincidence of a GRB or AGN flare would provide a crucial test of these sources, in spite of their location at distances far beyond the GZK limit.

In addition to observing neutrinos interacting in the atmosphere, EUSO has the possibility to detect tau neutrinos even at much lower energies by the upward showers they produce after penetrating the whole Earth (see figures D2-8 and 2-9 in foldout1). While electron neutrinos (ν_e) and mu neutrinos (ν_μ) are fully absorbed by the Earth at energies $>10^{14}$ eV, a ν_τ, will regenerate through the Earth, undergoing several interactions but always producing ν_τs from tau decays[41]. This results in an emerging upward shower of energy 10^{14} – 10^{18} eV. Above the energy threshold (~3×10^{14} eV) EUSO can detect a collimated beam of Cherenkov light emitted in a narrow cone. The case is even more favorable for anti-$\nu_\tau$since the total cross section is half as big and the kinematics transfer more energy into the tau lepton. The highly collimated light beam from upward going showers is well adapted to the search for point sources of neutrinos (e.g., from the galactic center or AGN)[27,42]. Observing a point source would prove that protons are accelerated to energies above 10^{15} eV in AGN, and that ν_τs result from the cosmological $\nu_\mu \leftrightarrow \nu_\tau$ oscillations. If upward tau neutrinos (ν_τ) can be observed, they, together with the EECR neutrinos, offer the promise of opening a window to the high-energy neutrino universe.

High –Energy Gamma Rays: Gamma rays in the high-energy range, 10^{13}–10^{20} eV, should be attenuated by e+e- pair production on CMB and infrared (IR) photons so no gammas from distant AGN or GRBs are expected. However, it is conjectured that alterations in the energy-momentum relation of relativity, due to the effects of quantum gravity on the vacuum, may allow EECR gamma rays to survive over path lengths exceeding the size of the visible universe[44] universe[44] (see figure 2.3). Thus, an observation of EECR gamma rays originating from AGN and GRBs could be evidence for quantum gravity. Such an observation would also extend the reach of gamma-ray astronomy to the whole universe.

Some quantum gravity theory[45] suggests that c is reduced for very high energy gamma rays according to the formula $v/c=1-E/E_{QG}+O(E^2/E_{QG}^2)$, where E_{QG} is the fundamental scale of quantum gravity[45]. The linear term in the dispersion relations predicts a 1-yr delay of the arrival time of EE gamma rays from GRBs if E_{QG} is comparable to the Planck energy, $E_P=10^{28}$ eV. The time delay is ~10 s if only the quadratic term $(E/E_P)^2$ is valid. EUSO can also observe and distinguish EASs from gamma rays. EUSO's 1-s to 1-yr temporal sensitivity allows determination of the reduced light velocities relative to *c* to one part in 10^{17} and 10^{7}, respectively. This is shown in figure D2-10 in foldout 1.

Need for High Quality Calorimetric Measurements: The quality of ground-based data is probably the underlying cause of the inconsistent results reported at the 2001 ICRC. Improved calorimetric energy measurements of EECRs are critically needed to settle the issues of the highest energy observations. The present and planned ground-based measurements will be greatly aided by stereo viewing of the shower[19] (HiRES) or by co-locating the fluorescence detector with a ground EAS array[25] (Auger). Ground-based fluorescence detectors must view the EAS horizontally through the lower thick atmosphere, therefore, corrections for absorption and aerosol scattering are quite important. Here, stereo imaging offers a second confirming estimate of the shower's intrinsic luminosity.

Viewing from 400 km above, EUSO can determine the range of showers accurately. Atmospheric attenuation and aerosol scattering is less important for EUSO because it views showers looking down through the thin upper atmosphere. The downward-looking ultraviolet (UV) night background has been measured to be ~250 photons/m^2 sr ns (see figure D3.6 on foldout 2). This is significantly lower than the background looking up, due to the lack of zodiac and starlight. For these reasons, the data quality from EUSO is expected to be superior to ground-based experiments.

2.2.3 Mission Overview:

The EUSO instrument is a large high-resolution digital camera (~2.5×10^5 pixels) with a 60-degree field of view that records nitrogen fluorescence from EAS events. It will be deployed on the Columbus External Payload Facility (CEPF) looking down from ~380 km on a 1.7×10^5 km^2 field of view divided into 0.8×0.8 km pixels (see figures D 3.4 and D.3-7 in foldout 2). Taking into account the effective acceptance of the fiducial volume, the aperture is 5.3×10^5 km^2 sr. The *ISS* is stabilized to ±2 degrees with knowledge to ±0.1 degree. EAS images will be recognized by the trigger electronics, and the luminosity along the EAS track will be recorded. Within the first second following the EAS, the atmosphere along the EAS track will be sounded with EUSO's lidar to determine the atmospheric corrections. EUSO must have a reliable absolute calibration. During phase A, we will investigate the possibility of using a calibrated light source on the ground such as a xenon flash lamp to help calibrate EUSO during its flight. The lidar will also systematically sample EUSO's FOV to correct the instantaneous aperture for clouds.

With it's 51-degree orbit and with good sensitivity for large zenith angle showers, EUSO provides full sky coverage, allowing a sensitive search for anisotropy over the whole sky with a single instrument.

The EUSO will observe EAS events only in the night sky over the dark earth under low moonlight conditions (see Figs D3-5a,b. in Foldout 2). The useful observing duty cycle is estimated taking into account the *ISS* orbit, natural and man-made background light(Fig D3-6 in Foldout 2), the lunar cycle, cloud cover, and interfering *ISS* activities. The likely duty cycle will be 0.1–0.15. We will use 0.1 to estimate event rates in this proposal.

EUSO data will be recorded on the *ISS,* transmitted to the ground, and provided to the EUSO SDC on a TREK workstation via the Internet. The SDC will process the raw data (level 0), producing a level 1 data product. Both level-0 and level-1 data will be archived at the SDC and made available to the entire collaboration for analysis and interpretation as soon as they are available via the Internet.

For the last year of its mission, EUSO will be repositioned on CEPF tilted at ~40 degrees to the nadir. The oblique view in this mode covers the area:

$$S = \pi\left(H\tan\theta_0\right)\times\left\{R\times\left(\frac{\pi}{2}-\arcsin\left(\frac{R}{R+H}\right)\right)\right\}-H\tan(\theta-\theta_0)=1.55\times10^6\,km^2$$

where θ and θ_0 are the angles to the horizon(≤70 degrees) and the instrument FOV (60 degrees), respectively. R and H denote the Earth's radius of 6,400 km and the orbital height of ~400 km, respectively. The viewed area in the tilted mode is up to 9.2 times larger for a total effective aperture is 4.9×10^6 km^{2}sr. The energy threshold will be much higher with the instrument tilted, and the spatial resolution degrades the far end of the FOV. We plan to simulate the tilted mode to understand these effects. Experience with tilted mode operation will benefit the future OWL mission, which also plans to tilt.

At the end of its mission, EUSO will be retrieved by the shuttle and returned to Earth. All EUSO data will be made available to the general scientific community in accordance with ESA rules and directives. At the end of the investigation, the data will be transferred to a publicly available archive.

2.2.4 Experimental Approach:

Primary CRs and neutrinos interacting with atmospheric nuclei produce a propagating cascade (see figure D3.5b in foldout 2) of secondary particles, an EAS. These relativistic particles excite atmospheric nitrogen atoms producing a fluorescence signal that develops in the lowest 25 km of the atmosphere. Nitrogen fluorescence has a broad spectrum, but the signal-to-noise ratio is most favorable in the 300-nm–400-nm band(see Fig. D3.5d in Foldout2). The fluorescence yield for this band is 4.2 photons per electron per meter in air and it is practically independent of altitude.

The most numerous particles in the EAS are electrons. Their fluorescence at the maximum of the shower's development and the total fluorescence of the EAS are proportional to the energy of the primary. Practically all the particles in the EAS are relativistic and their fluorescence is isotropic. Because the nitrogen atoms fluoresce a few ns after excitation, the EAS is observed as a luminous disk a few meters thick and ~100 m in diameter, streaking though the atmosphere at *c*. In addition, forward-collimated Cherenkov light scatters from the Earth, giving a flash that indicates the precise EAS landing point and timing.

The fundamental formulae for the observable signal strength are well known as a function of energy, calorimetric material depth, and radius. They are summarized in figures D3-10 and D3-11 of foldout 2. Taking the fluorescence yield from these figures and the background from figure D3.6 We can see that the EUSO is signal-limited to a detection threshold of energy of ~3×10^{19} eV. Events with energies above this threshold will be analysed to obtain their energy, arrival direction and shower profile (which will be useful in identifying the particle).

EUSO will also detect upward-directed showers by tau neutrinos at energies $>3\times10^{14}$ eV because the cherenkov light intensity in the wavelength range 330–400 nm is very high, ~ 40 pe ($E/10^{15}$ eV)/pixel. This low threshold is extremely useful for the observation of tau neutrinos. The directional Cherenkov signal of these upward showers is collimated within 1.3 degrees. Such a signal generally forms a short track, as seen by the gamma Cherenkov observatories (Whipple[47] and Cangaroo[48]). These events will be used for neutrino astronomy and to investigate neutrino oscillations.

2.2.5 Data Expected from EUSO:

The slope of the CR energy spectrum in the region of the GZK limit and beyond is poorly known because of the reduced statistics available (see figure D2-3, in foldout 1). Therefore, the expected counting rates for energies that are above 10^{20} eV are difficult to define and are strongly dependent from the assumed extrapolation for the energy spectrum. As an example, for the integral spectrum given for indices of –2.7 (no pileup or cutoff) and –2.3 (AGASA data[49]) respectively, EUSO's nadir-pointing count rate above 10^{20} eV varies from 500/yr to 1,300/yr. In the following discussion, a conservative index of –2.7 is assumed. Figures 2.5 and 2.6 show the predicted number of EECR and neutrino events per year as a function of energy detected by EUSO in the *ISS* nadir-pointing mode. Note that higher statistics at higher energies (~× 9 times higher) in the tilt mode (for 1 yr) are shown in figure. 2.6 compared with expected integral spectrum in the nadir mode (for 3 yrs). The energy spectra for neutrinos from various sources are also shown in table 2.5 for the nadir mode. An observing efficiency of 0.1 is assumed. A calculation of the expected number of upward tau-shower events shows that EUSO would observe a few hundred events per year above 3×10^{14} eV. EUSO may observe some nearby AGN sources with statistics greater than 10 events for each.

Data Quality: The reconstructed angular resolution of inclined showers simulated for EUSO is shown in figure 2.4. It ranges from 0.1 degrees to a few degrees, depending on the incident zenith angle and energy. These simulations used only the fluorescence data. Figure D3.12 in foldout 2 shows some typical results. It is expected to improve further when the Cherenkov landing-point flash data are added (see Fig. D3-5b,c). Such directional resolution enables astronomical investigations. It's accuracy is comparable to the expected bending of protons in an extragalactic magnetic field. The accuracies of these measurements have been evaluated from preliminary Monte Carlo simulations, incorporating the experiment geometry, instrumental efficiencies, nightglow backgrounds, duty cycle, existence of clouds, and trigger efficiencies[50,51] (see Fig. D3-12 in Foldout 2). Table 2.2 summarizes the results.

Monte Carlo simulations estimate the energy resolution , incorporating the atmospheric transmittance, optics transmittance, quantum efficiency of photon detectors, and trigger algorithm. It ranges from 10–25 percent, depending on the angle of incidence and particle species of EECRs. The accuracy of the measured energy of neutrinos is expected to have larger variance (~21%) due to larger fluctuations in energy transfer into the electromagnetic component in neutrino-air interactions(see Fig.3-12 right-hand-side in Foldout 2). The detailed study has been initiated and will be continued during phase A.

By selecting events with large zenith angles that initiate deep in the atmosphere (see figure 2.7). It may also be possible to distinguish some nearly horizontal $\nu_\tau$events by their unique double-bang shower structure. The first bang comes from the shower caused by the $\nu_\tau\rightarrow\tau$ interaction. The second bang is caused by the τ decay. The bangs will typically be separated by ~1,000km (at E ~10^{20} eV). It is possible that both bangs could be observed from space.

EUSO can observe neutrinos interacting in three possible targets: The atmosphere using the fluorescence method; the Earth's crust can be the target for near-horizontal neutrinos, with the showers emerging into the lower atmosphere; and the solid Earth for upward ν_τ showers. Table 2.4 summarizes these cases. For comparison, the largest planned ground experiment (ICECUBE) has a target mass of 10^9 tons.

Upward showers from ν_τs are also distinct from those of other events but may prove difficult to recognize. The main signal is the cherenkov flash that lasts only a few ns and appears within the optics spot size (mostly one pixel). This alone is not a distinguishing signature. It may be difficult to recognize in the presence of the background. Some of the upward electromagnetic showers are likely to extend into the upper atmosphere where the electrons will have a long enough mean free paths to gyrate in the Earth's magnetic field. The Cherenkov radiation from these electrons will last ~1 μs. If the event is sufficiently energetic, there will be an observable level of fluorescence as well. Both the fluorescence and Cherenkov light from gyrating electrons will extend the duration of the signal beyond the ~1 ns scale. This will give time for the image to spread into adjacent pixels giving these events some discernable character that will help to distinguish them from the background.

Discrimination between the other particle types is not highly reliable. Heavy nuclei should show earlier shower maxima than protons or gamma rays. Gamma rays penetrate deeper in the atmosphere at such energies due to the suppression of electron-pair production and Bremsstrahlung processes by the Landau-Migdal-Pomeranchuk effect[52]. The depth of the shower maximum in the atmosphere, while dependent on particle type, is not as sufficient to discriminate on an event-by-event basis. Statistical separation is feasible, and this will be attempted in the EUSO analysis. Furthermore, high statistics around 3×10^{20} eV permits the distinctive observation of iron abundance, using the GZK pile-up and cutoff for them. Gamma rays may also be separated from nuclei on a statistical basis, due to the North–South asymmetry in the depth of their shower maxima. This transition into early cascading will be important for gamma ray incident from the north at energies above 3×10^{19} eV, reflecting their electron-pair production with earth's magnetic field[53].

2.2.6 Planned Investigations:

The GZK Cutoff: EUSO is expected to collect ~10,000 CR events (~5,000 from the nadir mode and ~5,000 form the tilt mode). These will be used to construct a much more precise energy spectrum. If there is a GZK pileup and cutoff in any of its predicted forms, it should be easily detected with these statistics. If the EECR spectrum continues as a power law, EUSO should be able to follow it to about 5×10^{21}eV.

Super GZK particles: Figure D2-11 on foldout 1 shows a flow chart we will follow to discriminate among the proposed models. Following this chart, we can see that all the decision points at the top except the question of E_{max} >10^{22}eV can be decided with EUSO data. Nuclei can be distinguished from other particles only on a statistical basis. If Nuclei dominate some energy range, we should be able to recognize them from their shower profile. The same method will be used to recognize gamma rays if they are the dominant source. The arrival direction distribution will be used to search for anisotropies that will suggest where the sources are located. Up to now, no such anisotropy has been established, possibly just due to the small number of events. Nearby sources, including secondaries from Z-bursts, are expected to induce anisotropy in the arrival direction distribution that should be more distinct at higher energies. A ~2 percent level anisotropy can be measured with EUSO so we should be able to decide if events are isotropic or coming from the galactic center or halo. These data will also be searched for point sources of EECRs that will appear as multiple events arriving from nearly the same direction. Attempting to identify these events with nearly simulataneous GRBs could tell us that GRBs are sources of EECRs. Finally, if nuclei are the dominant source, we can use multiple events to recognize point sources and search for counterparts. The excellent sensitivity to anisotropy will allow us to recognize an anisotropy favoring the super-galactic plane. The data provided by EUSO will also let us make (or at least attempt) most of the decisions needed to discern the source of the super GZK particles.

Astronomy: EUSO will measure the arrival directions of all events. These measurements will be used to search for point sources indicated by spatially correlated multiple events that are statistically significant. Using charged particles and gamma rays we may be able to identify EECR sources with our local cluster of galaxies and search for counterparts.

Neutrinos offer the chance to observe extreme energy sources anywhere in the universe. Neutrinos can be recognized among horizontal EASs and as upward showers from ν_τ events.
The spectra from proposed sources of high-energy neutrinos are shown in figure 2.8. The differences of the predicted spectral indices could make it possible to discriminate between these sources in the energy regime 10^{19}–10^{21} eV. The neutrino events will also be searched for spatially correlated multiple events that are statistically significant to identify sources. If sources are found, counterpart searches will be made in other astronomical channels and searches will be made for temporally correlated GRBs and AGN flares.

EUSO has the possibility to detect tau neutrinos above ~3×10^{14} eV as previously noted. If we are successful in detecting upward showers from ν_τs, the events will be searched for spatially correlated multiple events that are statistically significant to identify sources and a search will be made for counterparts. AGNs, in particular Blazars, are theoretically capable of producing ν_μs and ν_es. If neutrino oscillations occur, we can expect that one third of these will become ν_τs before they reach earth. This makes AGNs candidate sources, so the error boxes surrounding the galactic center and AGNs will be searched for statistically significant correlations with neutrino events. A positive detection would prove that protons are accelerated to very high energies in AGNs.

If the speculations discussed earlier prove correct, extreme energy gamma rays may reach earth from throughout the universe. EUSO can distinguish gamma ray initiated EASs from the others on a statistical basis by taking advantage of the depth of the shower and the north-south asymmetry if gamma rays dominate in some energy range. If gamma ray showers can be recognized among the recorded events, smaller error boxes can be assigned for the analyses mentioned above knowing that the gamma rays are not subject to deflection in the galactic and intergalactic magnetic fields. A search will be made for temporal and spatial correlations between identified gamma ray events and GRBs. If correlations are found, the time delay can be used to measure the reduced speed of light for extreme energy gamma rays.

2.3 Science Implementation

2.3.1 Instrumentation: A scientific description of the instrumentation was given in section 2.2.3. EUSO will be calibrated before flight to determine the spot size of a point source on the image plane as a function of angle to the optical axis. This will be used to optimize onboard pattern recognition for maximum efficiency and in data analysis. During the flight, the onboard pattern recognition software can be further adjusted for optimization. The lidar system software can also be revised in flight. This will allow optimization of the procedure for sounding the EAS tracks and sampling the aperture. If the phase A study identifies a concept for in-flight calibration of EUSO from sources on the ground, these will be used to calibrate the absolute luminosity measurements during the mission.

2.3.2 Data Analysis, Track Reconstruction, and Archiving

The production data analysis will be designed to produce a Level 1 data product consisting of event records in which the events are identified by pattern recognition and the data for each event is calibrated. This data product will also contain correlated data for each event such as the GPS time, the ISS ephemeris and knowledge of the instantaneous pointing of EUSO.

Shower track reconstruction software will be developed for production data analysis, starting with those used for ground-based experiments[54]. It will be designed to recognize events against various natural and man-made backgrounds. The interfering backgrounds will include red sprites[55] from upward lightening, flashing aircraft beacons, etc. Fortunately, the instrument is signal-limited so the typical background is quite low. We will also take advantage of the fast (~ 800 ns) pixel crossing time. Most track-like backgrounds are much slower. This software will also be used to reconstruct the event topology and shower profiles so that showers from different kinds of events can be separated. Event recognition will rely on simulations to develop the pattern recognition software needed to separate events.

In essence, the atmosphere is used as a calorimeter. The fluorescence signal must be integrated over the spot size of the optics, corrected for light collection efficiency and the attenuation within EUSO, and the range and atmospheric absorption and scattering to obtain the intrinsic luminosity of the EAS. The range is found using the angular displacement of the EAS from the nadir and the orbital altitude. The measured fluorescence yield[56] is used to find the energy deposition rate. We must integrate along the trajectory to find the deposited energy. Finally, the hadronic shower theory and shower simulations must be used to convert the deposited energy into event energy.

The analyzed data will be used to conduct the investigations described in section 2.2.6. The interpretation of the results of those investigations will also be a significant effort because it involves testing theoretical models. An in-depth understanding of these models and a careful investigation of their prediction and implications will be required to decide if they are supported by the data.

Archiving Data in the National Space Science Data Center: The format of the level 0 data will be as received on the TREK workstation. The level 1 data will be organized into event records containing all the data on each event. Both levels of data will be available for archiving. These products will be made available for archiving by C. Espirito Santo from the Science Data Center in Lisbon, Portugal. In accordance with ESA rules and directives, these data will be released to the general scientific community and archived at publicly available sites. One of these sites will be the

National Space Science Data Center (NSSDC) in Greenbelt, MD.

2.3.3 Science Team Description

The science team will make unique contributions to enable EUSO. These contributions include the optics and expertise on theory, simulations, track reconstruction, electronics, photon detectors, and Education and Public Outreach (EPO). The team members were chosen by the process described in appendix I.6 for their expertise in these areas as described below and in I.3. Each member will participate in analysis, interpretation, and publication of the results. NASA will support the efforts of all team members.

James H. Adams, Jr. leads two research teams at Marshall Space Flight Center (MSFC). He will serve as PI and will be responsible for leading the U.S. EUSO team. Dr. Adams is an experimental CR physicist who has experience with six satellite experiments, three that were launched on the Space Shuttle. He has participated in, or lead, five international collaborations, three involving satellite launches.

Katsushi Arisaka is a high-energy physicist and an expert on vacuum photon detectors on the faculty of UCLA. He will advise on the design of the EUSO focal plane.

Mark Christl is a CR physicist at MSFC. He will do radiation testing of the optical components and oversee the design, procurement, and testing of the optical filters.

Henry Crawford is an experimental physicist and instrumentation expert at the University of California at Berkeley (UCB) Space Sciences Laboratory (SSL). He will work on shower development and signal simulations and provide advice on the electronics and trigger system.

Steven Csorna is an experimental physicist on the faculty of Vanderbilt University (VU) with extensive experience in Cherenkov detectors and simulating high-energy physics experiments. He is spokesman for OWL simulations. He leads the U.S. contribution to the EUSO simulation work.

David Cline is an experimental physicist on the faculty of UCLA. His major focus is on astroparticle physics. He will be responsible for leading the U.S. effort to develop track reconstruction software for the production data analysis code.

Lloyd Hilman is an optics physicist on the faculty of the University of Alabama at Huntsville (UAH). He directed the wide-angle optics development. He will participate in the design and testing of the optics and the data analysis.

Carl Pennypacker is an astrophysicist and supernova expert at the SSL. He is the founder of the Hands-On Universe (HOU) project. He will lead our EPO effort.

Toshiki Tajima is a plasma physicist on the faculty of the University of Texas (UT) at Austin and an expert in particle acceleration in plasmas. He will help to interpret of the data.

Yoshiyuki Takahashi is an experimental CR physicist on the faculty of UAH. He conceived the OWL and the optics for OWL and EUSO. He will serve as instrument scientist for the optical system and filters.

Tom Weiler is a theoretical physicist on the faculty of VU. He has developed models for EECR sources. He will lead the theoretical effort to interpret the data.

John Watts is a CR physicist at MSFC with years of experience in simulations. He will contribute to the EUSO simulation effort.

2.4 Proposed Contributions

An integrated international research team will conduct the EUSO investigation. EUSO planning has assumed that the U.S. will provide the optical components of the instrument because only the U.S. has experience with large space optics. In addition, we propose to play a role in the other major aspects of the investigation. Not only will this make U.S. expertise available on these aspects, it will also allow the U.S. team to gain an indepth understanding of the instrument and the whole investigation. This deep understanding will be useful in analyzing and interpreting the data. It will also equip the U.S. team to apply the lessons learned from EUSO to the U.S. OWL mission. In this section we describe the scientifically relevant aspects of the U.S. contributions in more detail. Section E describes the technical and managerial aspects of these contributions.

2.4.1 Optics

The science requirements for EUSO that drive the optical system are as follows:

- View the largest possible area in the lower atmosphere to maximize the data sample
- Obtain the largest collection aperture possible to minimize the energy threshold
- Obtain an angular resolution of 0.8×0.8 km^2 pixels on the ground
- Obtain a good signal-to-noise ratio for the nitrogen fluorescence signal.

The design of optics to meet these requirements is described in section E.

2.4.2 Other Contributions

Theory—Origins Acceleration Mechanisms, and Sites: EUSO will use measurements of EECR particles to test principles, theories, and models in astrophysics, cosmology, and fundamental physics, including the LI[6],the quantum-gravity effects[7], and the Z-burst mechanism in the halo of our galaxy or in the local cluster[5]. The EUSO investigation will probe these theoretical issues and, if necessary to interpret the data, embark on constructing a new theoretical framework for extreme-energy particle generation or acceleration in the universe. One direction for this investigation is to develop a top-down type phenomenology, using cutting-edge particle physics tools developed at VU and UCLA. Another direction of inquiry is an in depth analysis of various collective processes in astrophysics plasmas; this promising but difficult topic has been mainly neglected in work up to now. The traditional main-line mechanism in astrophysics has been the diffusive first order Fermi acceleration[57] or its variations. It is based on the cumulative effect of stochastically moving magnetic fields in galaxies that deflect and energize particles.

To understand extreme high-energy acceleration, a number of issues need to be resolved. The mechanism of the magnetic induction dynamo and electromagnetic plasma waves of various kinds will be investigated for pulsars and AGN. Mode-converted electromagnetic waves and associated wake fields from Alfven shocks will be examined in GRBs and other potential sites. Theoretical analyses and computer simulations of the acceleration processes in the astronomical sites are planned in EUSO for maximizing the science return of the proposed mission. UT at Austin, UAH, and UCLA participants will undertake this task. When large-scale computation is needed, our team, lead by UT, will collaborate with computational members of the new National Science Foundation (NSF) Physics Frontier Center (FOCUS) awarded to UT and the University of Michigan.

Simulations: The EUSO simulations will be a international team effort. U.S. team members from VU, MSFC, UCLA, and UAH will contribute to the following tasks:

- Provide the ability to accurately simulate air showers. Historically, a variety of interaction and air shower simulations, such as MOCCA, SIBYLLized MOCCA, CORSIKA, and AIRES, have demonstrated disagreements in the comparison of their results[22]. We need to reconcile these disagreements and identify or construct a code that accurately simulates at the EUSO energy scale, 10^{19}–10^{22} eV.

- Provide the coding of the theoretical models that seek to explain the EECRs in order to calculate the fluxes of protons, nuclei, gamma rays, neutrinos, etc.

- Modeling the generation of fluorescence light, including the pressure, temperature, and wavelength dependence. The effects of varying conditions as a function of altitude and atmospheric conditions (i.e. Rayleigh and Mie scattering due to aerosol attenuation and clouds). Meteorological data from weather satellites and the onboard lidar will be used to drive the model.

- The available angular FOV and spot size are largely determined by the optical design constraints. The results of ray tracing will be parameterized for incorporation into the simulation code to account for viewing angle and other instrumental effects.

- The modeling of the electronic readout, electronic noise, event trigger, and the study of radiation damage to the electronics have to be accomplished by our European collaborators. The development of optimal algorithms for use in event reconstruction and analysis are still needed.

Data Analysis: The UCLA team at CERN and MSFC will work closely with the European EUSO team to develop the production data analysis system. We expect to use methods developed in high-energy physics to help with the reconstruction program. The U.S. group will work closely with the Univ. of Palermo (UP) and CERN teams to develop this program.

During turn on and initial payload checkout, the EUSO instrument will be controlled and the quick-look data will be analyzed in the Space Station Operations Center at MSFC. MSFC collaborators will host the European ground segment team and work with them during this crucial initial period.

Electronics Consultations: The scientific output of EUSO depends explicitly on the quality and robustness of the front-end and trigger electronics. The strawman EUSO-electronics concept has been well developed by our European collaborators using an ingenious process for generating a fast trigger and recording the data. The U.S. team will consult with our European collaborators to search for an improved scheme that makes more complete use of the information This should result in better data capture and a robust ability to reprogram the trigger in flight. These consultations will be lead by our team members from the Space Science Laboratory at the UCB who have immense experience in the development of state-of-the-art trigger systems.

Focal Plane Consultations: The proposed U.S. contribution includes consultations on the EUSO focal plane array led by our photon detector experts at UCLA. The strawman concept for the focal plane is based on Hamamatsu multianode PMT 7600-16M. The U.S. team will consult on the following:

- The optical coupler design and mechanical testing
- The mounting of the optical filters provided by the U.S. team on the PMT UV-glass window
- The testing of flat panel and multianode, microchannel plate tube alternatives
- Thermal, vacuum, and temporal testing of the photon detectors.

3. EUSO Mission Implementation

3.1 Mission Description

The ESA plans to launch EUSO in a cross-bay carrier on the Space Shuttle (see figure D3.1 in foldout 2). The launch opportunity will be provided by ESA as part of an agreement in which ESA is allocated an 8.3 percent share of unpressurized payload transportation to *ISS* or as the result of a barter arrangement with NASA. Once at the *ISS*, EUSO will be attached robotically to the external CEPF site. Following an instrument check out period, EUSO will begin collecting scientific data. Observations will be made quasi-continuously for 3 years, as required, to meet the science objectives. The three conditions that may interrupt continuous observations are sunlit periods, reduced electrical power availability intervals, and nonquiescent *ISS* operational events. EUSO science data will be transferred to the *ISS* in the burst mode at regularly scheduled intervals. The data will then be down linked by the *ISS* to the U.S. Payload Operations Center at MSFC and transferred to the Mission Operation Center (MOC) in Italy and the Science Operations Center (SOC) in Portugal. EUSO will be monitored and controlled from the MOC. The SOC will do the production data analysis and distribute the data products to the EUSO science support team at their home institutions. Table E.1-1 summarizes the EUSO mission requirements. The U.S. role in the EUSO mission is to provide the optics, expert advice on the focal plane and electronics design, and to participate in simulations for instrument definition and the development of production data analysis software.

The objectives of the EUSO science mission were described in the previous section. The U.S. Co-investigators will be part of the integrated science team that will analyze and interpret the data. Our team will contribute to the simulations needed to understand the data and to the theoretical interpretation of the results.

3.2 EUSO Instrument

EAS measurements from space call for an approach that is different from that of the conventional ground-based fluorescence experiments. For space applications, the instrument has to be as compact as possible and highly efficient (see figure D3-9 in foldout 2). It must have a highly reliable design that will withstand launch and the space environment. For the detection method, a single photon-counting technique is preferred because the faint UV fluorescence signals collected on orbit will produce a small number of photoelectrons.

The EUSO instrument conceptual design is shown figure E2-1 in foldout 4. The instrument consists of seven main parts: The OS, the filter subsystem (FS), the focal surface detector subsystem (FSDS), the front-end electronics subsystem (FEES), the trigger and onboard data-handling subsystem (T&ODHS), the control electronics subsystem (CES), and the support structure subsystem (SSS).

3.2.1 Optical Subsystem

The main function of the optical subsystem is to focus fluorescent light generated by EAS onto the focal plane. To accomplish this, EUSO will make use of wide-angle optics in the form of Fresnel lenses supported and held in alignment by a metering structure (see figure E1-12 on foldout 3). The two-Fresnel lens system has been designed to meet the EUSO requirements (see figure D3-2 in foldout 2). Each lens is cut on a spherical substrate and has grooves in both sides.

3.2.2 Filter Subsystem

An FS will be needed to limit the band-pass of the optics in the 330–400 nm band. This band has the best signal-to-noise ratio for the N_2 fluorescence lines and Cherenkov radiation. We have chosen a bulk absorption for this task.

3.2.3 Focal Surface Detector Subsystem

Due to the large FOV and the large collecting area of the optics, the focal surface detector requires approximately 2×10^5 pixels. The demanding detector requirements of low power consumption and weight, small dimensions, fast response time, high detection efficiency in the near UV, and single photoelectron sensitivity, limit the possible choices to a few devices.

A suitable off-the-shelf device is the Hamamatsu R7600 series multianode photomultiplier tube (MAPMT) with 64 anodes. The pixel size, gain, fast response time, low weight, small dimensions, and single photoelectron (pe) resolution of this MAPMT are well suited to the EUSO focal-surface detector application. The MAPMTs that form the focal plane are organized into macrocells consisting of 36 MAPMTs. Each macrocell consists of 2,304 pixels. This system is described in more detail in foldout 4.

3.2.4 Front-End and Trigger Electronics Subsystem

This system pipeline processes the signals from each macrocell in the focal plane, using online pattern recognition to identify events of interest. The intensity of each event and its track across the focal plane are captured for transmission to the ground. The functions of the front-end electronics (FEE) subsystem are as follows:

- To convert the analog pulses from single pe's in each pixel into a logic pulses
- To count the logic pulses in each pixel and fire the trigger at a programmable threshold
- To OR the pixels along rows and columns in each macrocell that fired within the same gate timing unit (GTU), the time required for image to cross a pixel.
- To record the number of pe's detected in the macrocell in each GTU.

The row and column ORs counts and the pe counts during each GTU are recorded in a pipeline memory. The trigger module processes this memory to recognize events of interest. When a pattern is recognized, the data from the pipeline memory covering a programmable number of GTUs is recorded for transmission to the ground. The trigger module has been designed to provide different levels of triggering such that fast, normal, and slow time-scale events can be detected. Custom very large scale integration (VLSI) chips are being developed for the FEE and the trigger module. This sysem is described in more detail in foldout 4.

3.2.6 Control Electronics Subsystem

The Control Electronics (CE) manages the operation of the entire instrument. The main functions of the CE are as follows:

- The collection of scientific data coming from the focal-plane array
- The collection of housekeeping data
- The preparation of telemetry source packets, their storage and their transmission to the *ISS*
- The reception, validation, and distribution of instrument commands
- The control of instrument operating modes
- The management of time information
- The conversion of the primary electrical bus power provided by the *ISS* into secondary regulated voltages needed for instrument operation.

This unit will be a standard electronics box based on microprocessor architecture with an internal standard bus.

3.2.7 Support Structure Subsystem

The EUSO Support Structure (SS) will provide a mounting interface for all of the above subsystems. The structure will also be equipped with components for the thermal control of the instrument. An optical baffle, to limit the effects of stray light, and a lens cover mechanism to protect the focal surface from reflected sunlight will be included as part of the SS.

3.3 EUSO Instrument Interface with *ISS*

As stated earlier the EUSO interface with the *ISS* is through the CEPF. Figure D3-4 on foldout 2 shows the CEPF attach sites on the *ISS* Columbus Module. The CEPF provides the mechanical, electrical, and data interfaces between the Columbus Module and the EUSO instrument. ESA concluded in their "Report on the accommodation of the EUSO on the Columbus Exposed Payload Facility" that "…with regard to resource utilization, overall compatibility with the CEPF and Columbus is apparent". Table E.3.2 compares the EUSO requirements to the *ISS*/CEPF capabilities. The concepts for accommodating EUSO on CEPF are to be worked out during the ESA Phase A study.

3.4 EUSO Instrument Development Approach

The instrument will consist of subsystems designed and built by EUSO collaborators in several countries. Table E.4-1 lists the subsystems and the countries contributing them.

The overall management of the instrument development will be the responsibility of the PI and his Italian team. Payload qualification testing, transportation, launch, deployment on the *ISS*, data recovery and instrument retrieval at the end of the mission will be the responsibility of ESA.

3.5 Proposed Hardware Contribution

As listed in Table E.4-1, we are proposing to provide the OS and FS. A detailed discussion of these contributions follows. Flight and protoflight units will be provided to ESA. Filters, prepared to be applied to the focal-plane array. will be provided to our Japanese collaborators who will install them.

3.5.1 Optical Subsystem

The U.S. contribution of the OS is a critical element for the EUSO mission because it enables observation of EAS fluorescence from space within a large FOV. Section E.5.1.2.1 below describes why and how double Fresnel lenses are used to achieve this wide FOV. The double Fresnel lens concept was developed in the U.S. with support from NASA's Cross-Enterprise Technology Development Program.

Optical Subsystem Requirements: From the science requirements presented in section D.4.1 we have determined the detailed instrument requirements as follows:

- A 2-meter entrance pupil: This is the size needed to detect faint fluorescence signals from the air showers described in section D.
- A 60-degree full-angle FOV*:* This is required to collect sufficient samples of events during the mission.
- A 6-arcmin resolution*:* This resolution matches the desired pixel size and is quite easy to achieve (The Fresnel lens in an overhead transparency projector is more precise.).
- A 330-400 nm bandwidth: This bandwidth is sufficient to contain the prominent nitrogen fluorescence lines at 337 nm–391 nm and narrow enough to minimize the signal-to-noise ratio.
- Fast optics range with f-number of~1.2: This is required to minimize the size and weight of the focal plane.

The most challenging requirement is to achieve a wide FOV with a small f-number.

The engineering requirements for the design include: 1) lowest resonant frequency >40 Hz; 2) operation over a temperature range that is to be determined from the ESA Phase A Study; 3) mounting interface within EUSO that avoids stresses on the metering structure from differential thermal expansion.

Fresnel Lenses: A Fresnel lens (see figure E1-1 in foldout-3) is a lens in which the surface curvature of one or both of its surfaces has been collapsed into annular zones to form a thin plate. If both surfaces of the lens are Fresnel surfaces, then the lens is said to be a double-sided Fresnel lens. The thin plate that consists of the Fresnel lens may also be allowed to take on a curvature. This base curvature acts as an additional degree of freedom in the design and can be used to further enhance the system's performance. Fresnel lenses provide large-aperture, wide-field systems, and much higher imaging stability against deformation than mirrors, with drastically reduced mass and absorption. The use of lightweight polymers allows for further reduction in the overall weight. A two-Fresnel lens system with parameters described in table E.5.1.2-1 has been designed to meet the EUSO specifications. Each lens is a double-sided Fresnel lens cut on a spherical base substrate.

Rational for Selecting Fresnel Lenses: The size of the telescope with a diameter exceeding 1 meter normally calls for a reflective system that provides a superior on axis achromatic imaging with a limited weight. However, reflective systems have a limited effective FOV of only a few degrees due to a large spherical aberration for the majority of the off axis FOV. Catadioptric systems (Schmidt or Maksutov) improve the off axis imaging up to a 40 degree FOV using a corrector plate (4th order aspheric lens). They have a small f-number, allowing the focal plane to be smaller than the entrance pupil. This focal plane, however, masks the FOV requiring the mirror to be larger. This results in a large heavy mirror that would need to be folded for launch in the accommodations provided EUSO. Normal refractive optics are capable of extending the FOV to 60 degrees but are too heavy and have a high chromatic dispersion.

EUSO’s 6-arcmin resolution requirement allows the simple incoherent light collection and the 330–400 nm bandwidth requirement allows the use of refractive devices. This suggests the use of an unconventional solution, the Fresnel lens technology (see fig. E1-3 in foldout 3). Fresnel lenses provide a large aperture and a wide field with drastically reduced mass and absorption. Chromatic aberration for a limited bandwidth is not serious and multiple Fresnel lenses have some potential for chromatic corrections. The use of lightweight polymers reduces the overall weight.

Baseline Design: The Fresnel lens system has been designed to meet the EUSO specifications (the baseline design, figure E1-3 in foldout 3, and table E.5.1.2-1). The system optics has initially been optimized for λ=391 nm. Chromatic aberration of the refractive system limits the performance, but more than 85 percent of the energy in the 337 nm and 391 nm bands is contained within a single pixel on either side of the central pixel. This allows sufficient image quality to yield a reliable trigger. Spot sizes are shown in figure E1-3 in foldout 3. The drawback deriving from the faceted nature of the Fresnel surface causes a portion of the incident light to deviate from its intended imaging path. This reduces the signal available to the photon detector and results in scattered light and a reduction in image contrast. These effects have been analyzed via computer modeling and fabrication and testing of prototype optics. Undesirable light scattered at the backcut edges can be absorbed by a dark pigment coating on the backcut surfaces and by an absorptive outer screen at the entrance pupil. The results of this analysis (figure E1-10 in foldout 3) indicate that the signal losses are acceptable. The design of the Fresnel system conceptual design will be finalized in phase A.

To survive launch, the optics system must have a first resonant frequency >40 Hz. While the curvature of the lenses helps to raise the fundamental frequency, it will be necessary to construct these large lenses from segments that are contained in a structural frame in order to raise the resonant frequency.

Production of Double-Sided, Curved Fresnel Lenses: The EUSO optics, as shown in figure E1-12 in foldout 3, must be segmented. The current design includes a central section that consists of pie-shaped wedges with a series of concentric rings that will bring the diameter up to the full 2.5 m. Direct turning can produce these lenses but it will be less expensive to mold them. Pressure or injection molding will require the diamond turning of mandrels with inverse groove patterns to replicate the lenses. These mandrel techniques have the advantage of producing many lens copies from a single machined master, but there are many issues to be investigated including invisible fracture formation, and curing shrinkage. In addition, the diamond turned metal mold will have an inherently smoother surface than a turned polymer and can easily be polished by conventional optical shop methods.
The loss due to the total integrated scatter (*TIS*) is a general concern for any short-wavelength optics: ($TIS=\Delta n^2\times(2\pi/\lambda)^2\langle\Delta h\rangle^2 A(x)B(y)$; $AB=\pi(\sigma_x/\lambda)(\sigma_y/\lambda)\ll 1$ for a refractive surface, while $AB=1$ for a reflective surface). However, *TIS* arising from the roughness in a refractive surface ($\Delta n\sim 0.5$) is at most 16 times less than that of a reflective surface ($\Delta n=2$), and negligible.

During phase A, we will complete our investigation of molding to decide the best method for manufacturing the lenses.

Test Results: Prototype 20-cm Fresnel lenses were manufactured at UAH by directly diamond turning acrylic blanks with no postpolishing; see figures E1-4 and E1-5 in foldout-3. In addition, the UAH team fabricated a 40-cm model (figures E1-6 in foldout 3) using the facility at the Institute for Chemical and Physical Research (RIKEN) in Japan. Testing of the optical systems has been accomplished at UAH and figure E1-10 in foldout 3, shows the actual two-spot image versus predicted images measured for the 20-cm UAH prototype. These prototype optics are approximately 1/12th and 1/6th the *ISS* version of the EUSO. A mold fabrication test is in progress. The first mold is shown in figure E1-9 in foldout 3) and the product shows a satisfactory surface quality for replication of pie-slice lens segments. NASA MSFC has a current Space Act Agreement with Reflexite, Inc. to diamond turn Fresnel lens mandrels up to 1.5 m in diameter for the replication of large Fresnel lenses for use in large screen televisions, see Figure E1-8 in foldout 3.

Optical Materials Resources: The lens material must be selected for the best transmittance and longevity in a space environment. Candidate materials for the EUSO Fresnel optics are pure UV-grade polymethyl methacrylate (PMMA), polymethyl pentene (TPX), amorphous cyclo-olefin (ZEONEX), amorphous perfluoro alkenylvinylether (CYTOP), and optical-grade PMMA. Pure UV-grade PMMA, Zeonex and TPX are known to have appropriate properties for use in space. These candidate materials have efficient transmission of 86–93 percent in the near-UV spectrum for thicknesses of several mm to several cm. Surface reflection for all materials can be reduced to 4 percent (transmissivity, 90~96 percent) by antireflection coating on most of the candidates (CYTOP reduces the surface reflection further). The candidate materials were chosen to be resistant to solarization, and UV photochemistry. They were also chosen for their molecular-structural and radiation hardness. Formation of crystalline or broken chain-links due to water loss, radiation, and solarization can cause scattering loss for the lens materials by inducing a local change of refractive index and other effects. The amorphous nature of the materials is desirable to make the EUSO optics immune to these effects. The selection criteria for lens materials includes resistivity to the photochemical damage by the solar UV light and orbital atomic oxygen although the EUSO optics will be protected against daylight and direct atomic-oxygen flux in the *ISS* environment by the lens cover and the walls of the instrument. The presence of phenyl rings and oxygen radicals that undergo photochemistry in the space-UV environment should be minimized in the selected materials. Hardness against the photolysis and chemical reactions is excellent for the selected candidate materials. TPX, ZEONEX, and CYTOP polymers are highly resistant to chemical reactions. Their immunity to the dust resins and gasses in the *ISS* environment is superior. Loss of transmission due to long-term water ejection in a vacuum is less than 3 percent for the TPX due to low water-absorption characteristics.
Candidates that were already tested and qualified at MSFC for EUSO are TPX and UV PMMA. Transmittance data are shown in figure E1-2 of foldout 3. The radiation effects on the pure UV-grade PMMA and TPX are less than 3- percent and 1- percent loss, respectively, after a radiation exposure equivalent to 3 years on orbit.

Mechanical strength and flexibility of the candidate materials are considered to be acceptable for the launch vibrations and thermal excursions on orbit if we choose support structure materials having similar thermal coefficients, and Young’s moduli. These structural materials must also have high limits of elasticity, and little moisture content.

Weight of Lens Materials: The most light-weight Fresnel optical-lens configuration design consists of two plastic Fresnel lenses manufactured from TPX, with diameters of 2.5 m and thickness of 1 cm, weigh 46 kg each. Lens designs utilizing other materials weigh about 50 percent more than the TPX case; e.g., 200 kg total.

Metering Structure: The OS metering structure holds the two Fresnel lenses in alignment and allows the integration of the OS, as a unit, into the cylindrical EUSO instrument structure that will be built in Italy. The EUSO instrument structure will hold the OS in alignment with the focal plane. The OS metering structure will consist of a series of concentric rings and ribs that support and align the segments that make up each Fresnel lens and a set of struts and cross braces to maintain proper spacing between the two lenses. The metering structure will maintain the alignment and focus of the lenses during thermal fluctuations. The concentric rings will also provide the stiffness required so that the lenses can survive launch loads. Analysis by software and evaluation of the prototype hardware models indicate that the alignment tolerances for spacing between the lenses are very forgiving and that an active metering system will not be required. They also show that the required alignment accuracy of the OS within the instrument structure is only ±1 cm. The metering structure will be manufactured from graphite epoxy and the total mass is calculated to be less than 200 kg.

3.5.2 Filter Subsystem: As stated earlier, an optical filter will be needed to limit the band pass of the optics in the 330–400 nm band where the strongest N_2 fluorescence lines and Cherenkov radiation are emitted. Bulk absorption filters, dielectric coatings, or combinations can be used for this purpose. The preferred solution is related to the overall optical design. An interference filter has been designed transmitting 90 percent of the desired flux over a large range of incidence angles. It also blocks more than 80 percent of the flux in the ranges 200–300 nm and 425–800 nm. This interference filter outperforms absorption filters for narrow lines due to its decreased and centered pass band and its increased stop band. The most attractive feature of the absorption filter is that it is readily available, and manufacturing issues do not come into play. Table E.5.2-1 summarizes the performance of BG3, the most suitable absorption filter that was identified for use with the EUSO system. The filter can be mounted on the top of the glass window of the photomultipliers. The bonding materials identified as space qualified and UV transmitting (>96 percent; 300 – 400 nm) is EPO–TEK 301–2, having a high transmittance for the near UV (96 percent). Our design studies have lead us to the conclusion that an absorption filter rather than an interference filter should be used for the EUSO optical system.

3.5.3 Heritage and Maturity: Cosmic ray fluorescence experiments began with Fresnel lenses in the 1960's. Historically, Greisen, Bunner, Tanahashi, et al. initiated the first ground-based fluorescence exploration at Cornell University[56] using 40-cm single-sided Fresnel lenses mounted to form a structure like a fly's eye to cover a wide angle. Later, the first fluorescence signal of the air shower was successfully discovered by Tanahashi, et al. with a 2-m Fresnel lens (Tokyo-2) in 1968[57], which made possible the subsequent development of ground-based fluorescence observatories, Fly's Eye, and HiRes. Later, a 4-m diameter Fresnel lens was successfully manufactured by the Tokyo group, but this technology has not been used much after the initial discovery of the air shower by this technique. Spherical mirrors (similar to a search light) have been used instead, largely due to the manufacturing difficulty of Fresnel lenses and the large number of units required for a ground-based observatory (Fly's Eye needed ~100 telescopes to cover the whole sky.).

The NASA/MSFC and UAH optics team have made a systematic study of wide-angle optics since 1995, beginning with a modified Maksutov type[58], and discovered the capability of double-Fresnel lenses[59]. In recent years, the team has further developed the study of Fresnel multiple-lens designing reducing the f-number from the initial 2.5 down to 1.15. This has enabled the reduction of the focal plane to a realistic size. One-tenth (and one-fifth) size OS prototypes were manufactured (see figs. E1-4,5, and 6 in foldout 3), and tested. The results showed satisfactory performance of the design (see fig. E1-10 in foldout 3). The 40-cm prototype was also tested (see figure E1-11 on Foldout 3) with the AGASA air shower array, successfully detecting Cherenkov light from air showers.(Kawasaki, 2001)

Material compatibility tests have been performed at NASA/MSFC for space-borne refractive devices. Present plans for phases A and B are to focus on the manufacturing and testing a large (2.5-m) baseline model.

E.5.4 Assembly Integration and Test

The Fresnel lenses for the OS will be made in segments. Once each segment has been manufactured the groove geometry, mechanical and optical properties will be assessed. Upon completion of the replication process the segments will be joined and aligned utilizing the ribs and concentric rings of the metering structure to form a lens element. After both lens elements have been assembled the metering structure struts and cross braces will be attached thus completing the OS integration.

Optics Test Plan: Techniques for evaluating the performance of the large Fresnel lenses proposed here have not been addressed in industry. Development of evaluation techniques as part of quality control within the manufacturing process can greatly improve manufacturing efficiencies and reduce mission costs. Use of laser interferometry techniques, originally developed for measuring weld seam cracks on the Space Transportation System (STS) External Tank, has been identified as a potential method of accomplishing this. This technique requires some modification for measuring highly reflective surfaces, but may be extremely efficient in measuring mandrel groove geometry while the mandrel is still under production. After each lens is produced, the optical performance will be evaluated for consistency with design specifications. Current industry standard Fresnel lens characterization is a visual inspection of groove geometry (sometimes using a high powered microscope) followed by an optical performance test. Optical testing will be accomplished by using a laser to scan across the lens system to build up a spot image at the focal plane that can be evaluated. The Stray Light Facility (SLF) at MSFC (see figureE.5.4.2-1) has been identified as the location for testing the optical system. It is an extremely-clean, dynamically-stable, high-vacuum, optical-test facility. The SLF consists of a 3×12-m polished stainless steel chamber capable of achieving a vacuum of 10^{-7} Torr. The vacuum chamber is connected to class 10 k and 100 k clean areas for hardware unpacking and assembly

Environmental Testing: The environmental testing philosophy adopted by our team is to develop both a protoflight unit and a flight unit for hardware to be provided for EUSO. The protoflight unit will be certified at qualification levels and the flight unit at acceptance levels. The testing will provide confidence that the designs will perform as expected in the prescribed environments. Sufficient margin will be included in the tests to satisfy both NASA and ESA requirements for manned space flight. The level of testing for U.S.-provided hardware is necessarily limited to the component level. Our test program will be active throughout the design and development phases of the optical system and our team will support the EUSO instrument integration of the optics and instrument level testing.

The test requirements, procedures and the detailed test plans will be developed for the Concept Study Report during phase A. These tests will cover mechanical structure, thermal and material properties and space environmental effects. Specifically the tests will include acoustic-vibration environments relevant to the STS, thermal-vacuum compatibility and compliance with both STS and *ISS* environments. The test plans include development of models, analyses, and functional tests to verify the system will meet requirements.

Testing during phase B will support the preliminary design phase of the optical system. Candidate lens materials and optical filters will be tested to evaluate compatibility with the space environment. The total mass loss, out-gassing, collected volatiles and condensable materials will be evaluated to determine their compliance with STS and *ISS* requirements (ref.). Standardized durations for these compliance tests will be used for this preliminary screening of candidate materials. The principal functional test for the materials will be optical transmission measurements over a wide bandwidth that will indicate any change in the desired optical properties.

Exposures to radiation and atomic oxygen will be made to test material compatibility with the LEO environment. The dose-depth profile and atmosphere at the *ISS* orbit will be used to calculate the total dose and fluence for a 3-year mission. The test exposures will be carried out at MSFC/Space Environmental Effects Facility and possibly Los Alamos National Laboratory. Lens material samples are baked in a vacuum for 1 week prior to each exposure. Optical transmission measurements are performed before and after each such exposure to document any change in the optical properties. Compliance and compatibility tests have been done for two candidate lens materials and one UV-band-pass filter with positive results (ref.).

The testing during phase C and D will concentrate on the certification of the proto-flight and flight hardware. The qualification of the proto-flight optical hardware is performed in accordance with the General Environmental and Verification Specification (GEVS)–SE, Rev A, June 1996. Test durations and margins for qualification and acceptance are given in table E.5.4.3-1 (from table 2.2-2. from GEVS-SE, Rev A, June 1996). An optical/mechanical functional test shall be performed before, during, and after environmental tests, as appropriate, in order to demonstrate that capability has not been degraded by the tests. In the event that mechanical- and thermal- load requirements are not available for the optical system, the tests will use generalized limits for the STS payloads (ref GEVS). The verification of the flight unit will be to the acceptance level as listed in the table. In the case of significant modifications from the protoflight design are included in the flight unit, the flight unit would then be certified at the qualification test levels.

3.5.5 Product Assurance Plan

EUSO will be managed in accordance with the ANSI/ASQC Q-9001-9004 (ISO-9001-9004) certification awarded to MSFC on October 15, 1999. All U.S. institutions participating in EUSO will comply with this policy. A preliminary Product Assurance Plan detailing the roles and responsibilities of each institution will be developed as part of the phase A study.

3.5.6 Systems Engineering and Trade Studies

Our team will implement a systems engineering approach in the development of the OS using SP–6105, NASA Systems Engineering Handbook, and Marshall Procedures and Guidelines (MPG) 8060.1, Flight Systems Design Control. The process will be tailored to fit the size and complexity of the OS development effort.

Overall OS requirements will flow from the EUSO Science Requirements Document (ESRD) and the EUSO Instrument Requirement Specification (EIRS) to the OS Requirements, Verification, and Compliance (RVC) document, then to the OS to EUSO Interface Control Document (ICD). Figure E.5.6-1 depicts the flow down of OS requirements.

The University of Palermo (UP) is responsible for the development of the ESRD and the EIRS. We will develop preliminary versions of the OS RVC and OS to EUSO ICD during phase A. The UP will concur on the baseline of the OS RVC and will approve the OS to EUSO ICD. Our lead systems engineer is responsible for ensuring that the OS requirements are complete, accurately defined, documented, unambiguous, and appropriately allocated to all OS elements. All requirements will be rigidly controlled using configuration management techniques in accordance with MPG 8040.1, Configuration Management MSFC Programs/Projects. All requirements will be thoroughly verified by test, analysis, or inspection.

System analyses will be performed to support requirement development and system integration. Key Technical Performance Measurements (TPMs) will be identified during phase A. TPMs and TPM trend data will be used by the project as indicators of potential sources of risk. Trade studies will be conducted on the OS to support the objective selection of solutions to engineering problems. The trade studies planned for phase A are to: 1) investigate calibrating EUSO using a calibrated light source on the ground; 2) finalize the of the fresnel lens system concept; and 3) decide the best method for manufacturing the lenses.
include the structural design of the Fresnel lens mounting hardware that will allow the large optic to survive ascent loading and the mechanical/thermal design of the OS that will prevent degradation of it's performance.

3.5.7 Potential Risks and Mitigation Plans

The items in table E.5.7-1 have been identified as potential risks to the proposed investigation**.** The planned mitigation for each of these risks is also listed in the table. Section F.2 discusses the project's risk assessment and management approach.

3.5.8 Technology Development Plans and Backup Plans

Under an on-going Cross Enterprise Technology Development Program (CETDP) large Fresnel lens design tools were developed. These design tools have been used to produce 20 and 40 cm monolithic lens models and the image resolution of these lenses has been investigated. Lens materials for space-based, lightweight optics have also been investigated.

The EUSO lens segments can be manufactured using the ELID or conventional grinding processes however we anticipate that significant cost savings can be realized if replication techniques can be used. The CETDP has also supported investigations of manufacturing techniques for large lenses that include segmented lenses produced by pressure- and injection-molding replication techniques. These techniques are currently used in industry to produce thin, single-sided Fresnel lenses for large screen video display units These units are produced commercially by Reflexite, Inc., Fresnel Technologies, Inc., and 3M Company.

Results from our studies to date indicate that the replication of double-sided, curved Fresnel lens segments will be achievable using either the pressure or injection-molding method. During Phase A we will concentrate on the manufacture and metrology of replicated segments utilizing molds provided by RIKEN. Results from the Phase A study will provide us with the data required to determine if the EUSO optics can be manufactured utilizing a replication process.

4. Management and Schedule

4.1 Management Approach

The MSFC/National Space Science and Technology Center (NSSTC) and the science community have formed a strong science, management, and development team to provide science consultation, data analysis, interpretation, and development of the optical subsystem for the EUSO investigation. The PI, Jim Adams, who has overall responsibility for all aspects of the U.S. portion of the mission, will lead the EUSO team. This team will be managed in accordance with NASA Procedures and Guidelines (NPG) 7120.5A – NASA Program and Project Management Processes and Requirements. MSFC is an ISO 9001 certified Center and all applicable ISO procedures will be followed by the EUSO project.

4.1.1 Organization Structure

The U.S. EUSO organizational structure is shown in Figure F.1. The core management comes from within the MSFC/NSSTC creating a centralized management team. These functions include the PI, project manager (PM), instrument scientist, and lead systems engineer (LSE). A centralized management team, within the same institution and location, will facilitate program oversight and management of all program aspects including scientific, design, schedules, and resources. Oversight and management is of utmost importance in this scientific endeavor and will take place on a continuous day-to-day basis. The PM’s support staff is drawn from within MSFC directorates. This organization is selected to provide the PI with effective control of the project, permit the delegation of authority and responsibility, ensure short lines of communication and reporting, and permit corrective action to be invoked at the proper level of responsibility. A science team, consisting of personnel from various universities, who are experts in their respective fields, will make unique contributions to instrument development and will support data analysis and interpretation. A detailed description of the science team is provided in section D.3.4.

4.1.2 Decision-Making Process

The organization structure defines the limits of individual authority and responsibility relative to cost, schedule, and technical requirements. At the top level the PI establishes overall project goals. The PM, and LSE, in consultation with the PI, establish budget allocations, project master schedules, and top-level technical requirements. The PI is the final authority on all matters affecting project. He will delegate to the PM authority on the allocation of overall resources, schedules, and requirements. Subsystem managers have the authority to establish and maintain cost, schedule, and requirements flow downs within their subsystem. As long as changes are within a particular subsystem manager's scope of responsibility and do not impact externally imposed constraints (requirements, interfaces, schedule milestones, costs, or critical path), no approval is required of any higher authority. Crosscutting decisions involving interorganizational conflicts are evaluated by the LSE with the final decision being made by the PI or the PM in those matters where he has been delegated the authority by the PI.

4.1.3 EUSO Teaming Arrangements and Acquisition Strategy

The team involves seven primary institutions: NASA MSFC/NSSTC, the UAH Center for Applied Optics, UCB, UCLA, VU, and UT Austin. UAH is currently under a cross-enterprise technology program (CETP) contract with NASA for concept development of the Fresnel lens. If this proposal is selected, a new fixed priced contract will be negotiated for the Phase A study. NASA will also negotiate fixed priced contracts with the other institutions to support the CR research.

4.1.4 Roles and Responsibilities

Team institutions have critical roles in science, hardware, outreach, and/or data analysis. The institutions' roles and responsibilities are identified in table F.1. Each institution has submitted a letter of commitment to the PI for EUSO. These letters are included in Appendix I.1. The MSFC has indicated its commitment through signature on this proposal.

5.1.5 Experience and Capabilities of Team Member Organizations

MSFC/NSSTC: NSSTC, a joint effort between the NASA MSFC, the State of Alabama/Space Science and Technology Alliance (SSTA), and industry, is headquartered in Huntsville, AL, and provides an environment focused on research and education in selected key scientific disciplines. MSFC/NSSTC personnel have significant experience in the areas of space science research, program and project management, systems engineering, engineering design, and space optics manufacturing and technology.

MSFC scientists at NSSTC have a proven history of successful scientific investigations dating back 40 years to the start of the U.S. space program on Explorer 1. They have made major contributions to the success of NASA's three great observatories, the Hubble Space Telescope, the Compton Gamma-Ray Observatory (GRO) and the Chandra X-Ray Observatory (CXO) as both project scientists and PIs. Recent successes include PI investigations for the POLAR and IMAGE spacecraft (TIDE and WIC), the enormously successful BATSE instrument on GRO and the Solar X-Ray Imager that recently saw first light on GOES 12. They are currently developing the Burst Monitor for the Gamma ray Large Area Space Telescope (GLAST), and a plasma diagnostic package (DIPFM) for the ProSEDS Space Shuttle deployed tether mission. They have provided project scientists for CXO and for NASA contributions to two Japanese solar observatories, Yohkoh (Solar-A), which is still operating and Solar-B, which is currently under development.

Project management personnel have an extensive knowledge of program management/PM and systems engineering, having led a team to define MSFC's implementation of NPG 7120.5A. Past and ongoing flight project activities include the following:

- Optical Transient Detector (OTD)
- Lightning Imaging Sensor (LIS) flying on the The Tropical Rainfall Measuring Mission (TRMM) mission
- Instrument development for the Japanese Solar-B Mission
- GammaRay Large Area Space Telescope (GLAST) Burst Monitor (GBM) for the GLAST mission
- Solar X-Ray Imager (SXI) for the Geostationary Operational Environmental Satellite (GOES–M) mission
- Microgravity Crystal Growth Demonstration Project for the Future-X Program.

These projects are currently on schedule and within costs or were, completed on schedule and within costs.

The MSFC/NSSTC SOMTC capability includes optical fabrication technology, accurate surface measurements, and optical testing. Mission heritage for large space optics includes the High Energy Astrophysical Observatory (HEAO) series -1977 to1979, the Apollo Telescope Mount (ATM) – 1973, the Hubble Space Telescope (HST) 1992, Chandra X-ray telescope–1998, and the manufacture of a number of flight mirrors including Solar X-ray Imager (SXI), Ultra-Violet Imager, and CASSINI. In addition, the MSFC/SOMTC is the Agency lead in developing and evaluating mirror manufacturing technologies for the Next Generation Space Telescope, including testing candidate mirrors down to a temperature of 20 degrees K.

UAH CAO: Scientists of the University of Alabama in Huntsville (UAH) Department of Physics and the Center for Applied Optics (CAO) have extensive experiences and a proven history of successful scientific investigations on numerous space flight missions using rockets, satellites and Space Shuttle. Recent examples of achievements include

- Aspheric Mirrors for the Ultra-Violet Imager (UVI) on POLAR Spacecraft
- Total Integrated Scatter Instrument (TISI) for the Space Station MIR
- Burst and Transient Spectroscopy Experiment (BATSE) of the Compton Gamma Ray Observatory (GRO)
- direct observation of high-energy cosmic-rays with 16 successful JACEE balloon flight experiments during 1979 – 1994
- developed unique light-weight, large-area technology of emulsion calorimeters for balloons including four circumpolar flights from Antarctica (1989; ‘92, ‘93, ‘94) and one space flight on Emulsion Chamber Technology (ECT) (STS62)

The Department of Physics and the Center for Applied Optics (CAO) of the UAH has a 110,000 sq. ft. vibrationally-isolated facility and advanced design tools and diamond-turn facilities for state-of-the-art optics research. The UAH Co-Investigators have extensive experiences in the development and integration for space optical systems and instruments and are currently the Lead Optics Design Team for NASA’s Next Genereation Space Telescope (NGST) and the Orbiting Wide-angle Light-collector (OWL).

UCB: The UCB Space Sciences Laboratory has extensive experience in trigger schemes and electronics and in EPO. They have designed, built, and operated very large arrays of photomultipiers in numerous accelerator-based experiments, and have constructed position-sensitive detectors based on the multianode PMTs selected for use in EUSO. Their expertise in the hardware and software of multilevel triggers is ideally suited to the pattern recognition problem at the heart of the EUSO trigger and data acquisition system. Their experience includes the following:

- Building a research prototype for ATLAS Level II, a premier particle-physics detector in the world at the CERN Large Hadronic Collider in Geneva
- Designing and partially building the DAQ for NESTOR
- Designing the DAQ for GRETA
- The lead institution in design and implementation of the fully pipelined trigger for the STARexperiment at the Relativistic Heavy Ion Collider (RHIC).

UC Berkeley has forefront experience in EPO, particularly with moving real data into students' hands. They have spent 10 years developing a system for undertaking real research in astronomy with secondary school students and teachers, using images from small telescopes.

UCLA: UCLA has a long history of activity involving basic research in various areas of physics and astronomy. It has an active high-energy astroparticle physics program, with a prime interest on detecting ultra-high-energy cosmic rays (UHECRs) and neutrinos. As part of this program, it is one of the leading groups of the Pierre-Auger Project (the largest ground-based CR experiment), and is currently in charge of testing, assembling, and final installation of the 5,000 large photomultipliers used in the project. In the past, the physics program has been involved in the development of several photon detectors, such as the following:

- Position sensitive PMT for FNAL–E799 and FNAL–CDF
- Position sensitive PMT for Scintillating-Fiber readout for SSC–SDC shower-max detector
- Linear/low-gain PMT for FNAL.

The UCLA team also has strong experience in the area of event simulation, event reconstruction, and data analysis. This team was partially responsible for the muon events reconstruction in the famous UA1 experiment at CERN, where the W and Z intermediate Vector Bosons were discovered and studied during 1983-1987. From this, the observation of the mixing of B mesons resulted. In the current generation of Time Projection Chambers for the ICARUS detector, the UCLA team has a similar role. This detector provides 3D reconstruction of events using time as a coordinate. There are similarities between this event structure and EUSO events, especially neutrino events, as well as the database.

UT Austin: The UT Austin is a strong research university that is active in high-energy physics, plasma physics, computational physics, relativity, cosmology, astrophysics, and optics research. UT facilities and capabilities include the following:

- A theoretical plasma physics center
- The Institute for Fusion Studies
- The Center for Relativity
- The MacDonald Observatory, one of the largest optical telescopes in this continent
- A supercomputer center that houses CRAY and other supercomputers and a computation center that serves large-scale computation.

In addition, NSF has recently designated the UT Frontier Optical Coherent Ultrafast Center (FOCUS) as a center of excellence for optical science.

Vanderbilt University: Vanderbilt University is a Class I Research Institution that consists, in part, of scientific institutes and centers such as the Institute for Software Integrated Systems and the Measurement and Computing Systems Laboratory. The Department of Physics and Astronomy has hosted a number of major projects in the area of detector research, development, and construction. Projects from the area of nuclear and particle physics include the following:

- DE/DX system for the CLEO detector at the Cornell Electron Storage Ring (CESR)
- Robot design and construction for stringing the CLEO III detector
- Muon identification system for the FOCUS and BTeV detectors
- Proportional Chamber System for the Phenix Experiment at RHIC.

Institution	**Role**
NASA/Marshall Space Flight Center National Space Science and Technology Center (MSFC/NSSTC)	PI institution including project management and systems engineering; provide optics and structure manufacturing; support data analysis, simulations, consultation, and E&PO
University of Alabama, Huntsville (UAH)	Instrument Scientist institution; lead for optical design
University of California, Berkeley (UCB)	Lead for E&PO; provide design consultation for the electronics and trigger system
University of California, Los Angeles (UCLA)	Image plane lead to evaluate new photon detector technologies; lead for software and interpretation support; lead for data analysis and theory
Vanderbuilt University (VU)	Lead for simulations related to interpretation of data
University of Texas (UT)	Support data analysis and theory

Table F.1 Institution Roles and Responsibilities

4.2 Project Risk Assessment and Management Plan

4.2.1 Risk Management Approach

The proposed mission has been designed to mitigate the effects of risks on the successful outcome of the investigation. It is possible, however, that unanticipated events may occur that will introduce risk areas during project implementation. The PM will implement an ongoing process that will allow, in fact encourage, each individual on the project team to bring any perceived or actual risks to management's attention at their first occurrence. The project will use a hierarchical approach to manage risk and will use a descending order decision path for mitigating risk. The first step is to identify project risks including technical, cost, and schedule. Risks will be analyzed to determine the risk exposure by defining the probability of an unsatisfactory outcome and degree of loss or impact. Risks will be prioritized based on decreasing risk exposure and mitigation plans developed for significant risks. The first level to resolve risks is by the allocation of technical resources and margins. If that is an insufficient or inappropriate solution, then cost and schedule reserves will be used. Finally, descoping is a last resort and, if used, will be coordinated with the Explorer Program Office and the EUSO Steering Committee.

A detailed risk management plan will be developed for this project as part of the Phase A concept study.

4.2.2 Risk Assessment

A preliminary risk assessment has been completed that identifies the top risks and developed mitigation plans. This preliminary assessment is summarized in table E5.7-1. Significant risk mitigation for EUSO has already been accomplished. Under the CETP contract with NASA, UAH completed a demonstration of the direct cut manufacturing technique for the center segment of the Fresnel lens.

It should be noted that the successful demonstration of this technique substantially reduces the technical risks to the program for which we are currently proposing.

In essence, we already possess the capability to manufacture the center segment of the Fresnel lens of the size required of the EUSO Project. Other planned mitigation includes development of prototype hardware and development of a metering system to address thermal perturbations. A comprehensive risk assessment, using the method described above, will be conducted as part of our Phase A concept study.

In our judgement, the biggest risk facing this project is the cost impact of delays in ISS or the Shuttle schedule. To mitigate these costs, we have asked the EUSO PI, Prof. Livio Scarsi, to agree to the following plan. We will deliver the U.S. provided hardware on an agreed schedule. ESA and our European collaborators will absorb the integration costs of the OS into EUSO should their instrument development is delayed and the costs of storage should deployment on the ISS is delayed. They understand that after delivering the OS, we intend to re-assign the members of the SOMTC team. After reviewing our plan with ESA and obtaining their concurrence, he has agreed to this plan. The letters exchanged are in Appendix I.1.

4.2.3 Descoping Strategies

The EUSO team has proposed a protoflight development approach to minimize hardware and development costs. Should the planned margins prove insufficient, our descope strategy, in priority order, would be to:

- Eliminate funding for consulting on the focal plane and electronics
- Eliminate U.S. contributions to simulations and production data analysis software development for EUSO
- Use alternate cheaper materials for lenses accepting some science degradation

4.3 Sponsoring Organization Commitment and Relationship

ESA is the sponsoring organization for the EUSO mission. The ESA Science Program Committee and Manned Space Program Board have approved EUSO for a 12-month Phase A study to begin December 2001. They are counting on NASA to support U.S. participation in the Phase A study to make it a success. A letter from ESA requesting a U.S. commitment for Phases B, C, D, and E by December, 2002 is provided in Appendix I.1.

The U.S. team will have one or more representatives on each of the three standing committees that govern EUSO. Figure F.2 illustrates the ESA EUSO governing committee organization and how the U.S. team participates in it. The PI and PM will serve as the U.S. representatives on the International EUSO Steering Committee that will be charged with ensuring the timely delivery of all non-ESA provided components. Dr. David Cline/UCLA and the PI will serve on the EUSO Science Working Team, which will act as an executive body for the EUSO and advise ESA's project scientist. The instrument scientist and Mr. Roy Young will serve as the U.S. representatives on the EUSO Instrument Working Group that will oversee the technical aspects of the mission.

The U.S. team will be fully integrated into the international EUSO team. U.S. team members will participate in the design working groups for the focal plane array, the front-end electronics, and the trigger system, contributing to these designs. U.S. science team members will participate in the multinational teams on simulations, data analysis, and theory. The US science team will have full access to all the EUSO data; and will participate in all aspects of data analysis and interpretation.

4.4 Master Schedule

The EUSO Work Breakdown Structure (WBS), figure F.3, has been used to develop a Master Schedule shown in Figure F.4. Based on the preliminary risk assessment described in section E.5.7, a schedule reserve of 6 months has been allocated for the EUSO development.

5. Cost and Estimating Methodology

This proposal is submitted by the Space Science Research Center of the NSSTC, a partnership between NASA and the State of Alabama. The State of Alabama is represented by the Space Science & Technology Alliance (SSTA), which is comprised of six Alabama Universities. As an NSSTC participant, research scientists have the advantage of leveraging the resources of NSSTC partners through existing formal alliances and thereby, maximizing potential research awards.

5.1 Cost and Estimating Methodology

5.1.1 Cost Estimating Methodology

Cost estimates for this proposal were developed using a bottoms-up approach, drawing on our long history of successful project and hardware development experiences. A WBS has been developed and is the basis for cost identification. The WBS is shown in figure F.3. Lens development efforts, accomplished thru the CETP contract with UAH, provide confidence that the manufacturing techniques and the cost associated with them are well understood. In addition, parametric cost modeling was used to verify the bottoms-up cost estimate. Models used include the CERV model and a DOD model consisting of 14 cost estimating relationships (CERs) that estimate the development manufacturing costs of infrared sensor assemblies (i.e., optics, focal plane assemblies, cryogenics, etc.)

5.1.2 Budget Reserve Strategy

The risks in development of the Fresnel lens for EUSO has been reduced with the successful demonstration of the direct cut manufacturing technique. A reserve of 30 percent of the total Phase A-D budget has been added. Based on the preliminary risk assessment described in section E.5.7, twenty-five percent of this reserve is allocated to Phase B, 40 percent of this reserve is allocated to phase C, and 35 percent of this reserve is allocated to phase D. The EUSO Phase E effort is limited to data analysis only therefore no reserves have been added to Phase E. The project manager, with concurrence of the PI, will manage reserves. The total budget reserve is $XXX.

5.1.3 Costing Assumptions

Key ground rules and assumptions in developing the cost estimates are as follows:

- All costs are reflected in real year dollars
- Inflation rates of X% for all years have been used
- Civil service costs are reflected as a contribution to the project.

5.1.4 Cost Summary

Table B-2
Table B-3

6. Education and Public Outreach, New/Advanced Technology, Small Disadvantaged Businesses

6.1 Education and Public Outreach

Our team understands the NASA/OSS requirements for EPO and is committed to carrying out a program that meets the goals listed in section 3.7 of the Announcement of Opportunity (AO). Dr. Carl Pennypacker of the University of California at Berkley is our E/PO Lead. Dr. Pennypacker will develop a detailed EPO implementation plan during Phase A. Details of the plan will be included in the Phase A concept study report. The following is a short discussion of our current thoughts and ideas for EPO.

The EUSO mission has tremendous potential for EPO and embodies powerful education and outreach possibilities for several reasons:

- The data from EUSO are intrinsically simple and understandable by a broad range of people.
- EUSO measures the most energetic particles in the universe, from either the most powerful accelerators in the universe (AGN, etc.) or from the most bizarre objects (topological defects, etc.) ever conceived. Powerful things fascinate people. This will stimulate the curiosity of both the keenest and the more typical student.
- From its berth on the *ISS*, EUSO will observe the Earth and beam down events after each orbit, thereby giving an immediacy to its data.
- EUSO is one of the few cosmologically interesting and accessible uses of the *ISS*. The *ISS* is the largest technical project of modern times. Results from experiments on it will attract public interest.

The EPO goal is to capture the power of EUSO for building a greater understanding of the universe and appreciation of space science, the NASA EUSO EPO team will work with the ESA team to produce a number of activities and events that hold the potential for reaching thousands of schools and many museums, Web sites, and other venues. We do this in the following ways:

- We will engage an expert team of educators, scientists, and students experienced in EPO to create a scalable and useful program. The HOU –(see http://hou/lbl/gov) teacher training system and Web-based education system will create modules, simulations, and interactive Web-based learning system to train new teachers and students in EUSO science. It will genuinely enable them to become part of the EUSO team, experiencing the science and the excitement of discovery. Such a system will become part of Earth science, astronomy, and physics classrooms, pegged to the U.S. and the Third International Mathematics and Science Study (TIMSS) international science standards. HOU Teachers will be trained on the EUSO system and develop EUSO curricula and activities that the EUSO E/PO team will bring to the Web.

- EUSO/HOU will monitor AGN and development of a ground-based follow-up system to search for optical afterglow from the area of a EUSO event. This monitoring system would initially be searching known nearby AGN within EUSO event error boxes (1to 2 degrees), but could eventually search more distant AGN or other sources within the error boxes. We will remind readers that many of the advances in the understanding of radio, x ray, gamma ray, and GRBs came when optical counterparts were identified. The monitoring program will be done in collaboration with an existing framework of telescopes, educators, and scientists. Teachers, students, and researchers will undertake the monitoring effort.

- EUSO will be responsible for Construction of a Data Center Video Library and Web-casting: As the Web is evolving to handle video with more and more ease, at time of launch, we anticipate we can disseminate archival video of all aspects of EUSO construction, testing, launch, and on-orbit deployment. We also intend to Web-cast data analysis sessions, modified lecture/demonstrations, and many other activities of the EUSO system to all schools in the EUSO team members.

6.2 New/Advanced Technology

Our team understands the NASA/OSS goals for new/advanced technology transfer and intends to address these goals. A detailed advanced technology infusion and transfer implementation plan will be developed by our team as part of the Phase-A concept study. Details of the plan will be included in the Phase-A concept study report.

6.3 Small Disadvantaged Businesses

Our team understands the NASA/OSS requirements for participation of small disadvantaged businesses (SDBs) and minority institutions (MIs) and intends to comply with these requirements. A detailed implementation plan for the participation of SDBs and MIs in our project will be developed as part of the Phase-A concept study. Details of the plan will be included in the Phase-A concept study report.

7. Appendices

7.1 Letters of Endorsement

7.2 Statement of Work

2.0 Statement of Work (SOW) and Funding Information

2.1 EUSO U.S. Contribution SOW

2.1.1 Phase A Tasks

2.1.1.1 MSFC shall:

2.1.1.1.1 Develop and submit a Concept Study Report (CSR) that complies with the ***Medium-Class Explorer Program Guidelines and Criteria for the Phase A Concept Study*** document. The CSR will be delivered four months after project initiation.

2.1.1.1.2 Develop a detailed education and public outreach implementation plan

2.1.1.1.3 Develop a detailed small disadvantaged business and minority institutions participation plan

2.1.1.1.4 Develop a detailed technology infusion and transfer implementation plan

- 2.1.1.1.5 Perform trade studies of the following
  - 2.1.1.1.5.1 Lens materials
  - 2.1.1.1.5.2 Lens designs
  - 2.1.1.1.5.3 Lens manufacturing techniques
  - 2.1.1.1.5.4 Tilt mode (and parameters)
  - 2.1.1.1.5.5 Ground light source for calibration
- 2.1.1.1.6 Develop full scale optic and test to validate planned manufacturing and assembly techniques
- 2.1.1.1.7 Develop a preliminary project plan
- 2.1.1.1.8 Develop a detailed EUSO Work Breakdown Structure (WBS)
- 2.1.1.1.9 Develop a detailed EUSO project schedule
- 2.1.1.1.10 Perform a detailed EUSO life cycle cost analysis
- 2.1.1.1.11 Develop a detailed risk management plan
- 2.1.1.1.12 Develop a preliminary configuration management plan
- 2.1.1.1.13 Finalize OS Ground Support Equipment (GSE) conceptual design
- 2.1.1.1.14 Perform OS preliminary structural analysis
- 2.1.1.1.15 Perform OS preliminary thermal analysis
- 2.1.1.1.16 Perform polymer shrinkage testing
- 2.1.1.1.17 Develop a preliminary product assurance plan detailing the roles and responsibilities of each institution
- 2.1.1.1.18 Develop preliminary versions of OS RVC and OS to EUSO ICD
- 2.1.1.1.19 Perform system analysis to support requirements development, system integration, and key Technical Performance Measurement (TPM) definition
- 2.1.1.1.20 Develop agreement with ESA for delivery date of the OS

2.1.1.2 UAH shall:

- 2.1.1.2.1 Develop Optical Subsystem (OS) Specification
- 2.1.1.2.2 Finalize OS conceptual design
  - 2.1.1.2.2.1 Develop OS sketches
  - 2.1.1.2.2.2 Develop OS mass and volume estimates
- 2.1.1.2.3 Support OS risk identification and documentation
- 2.1.1.2.4 Support development of WBS, Schedule, and Budget Estimates
- 2.1.1.2.5 Support development of CSR

2.1.1.3 UCB shall:

- 2.1.1.3.1 Develop EUSO E&PO Plan
- 2.1.1.3.2 Support development of WBS, Schedule, and Budget Estimates
- 2.1.1.3.3 Support development of CSR

2.1.1.4 UCLA shall:

- 2.1.1.4.1 Support development of WBS, Schedule, and Budget Estimates
- 2.1.1.4.2 Support development of CSR

2.1.1.5 UT shall:

- 2.1.1.5.1 Support development of WBS, Schedule, and Budget Estimates
- 2.1.1.5.2 Support development of CSR

2.1.1.6 VU shall:

- 2.1.1.6.1 Continue the detailed study of neutrino energy measurement accuracy
- 2.1.1.6.2 Support development of WBS, Schedule, and Budget Estimates
- 2.1.1.6.3 Support development of CSR

2.1.2 **Phase B Tasks**

- 2.1.2.1 Finalize project plan
- 2.1.2.2 Finalize risk management plan
- 2.1.2.3 Finalize safety and mission assurance plan
- 2.1.2.4 Finalize configuration management plan
- 2.1.2.5 Finalize WBS
- 2.1.2.6 Finalize project schedule
- 2.1.2.7 Finalize project life cycle cost estimate
- 2.1.2.8 Finalize OS requirements
- 2.1.2.9 Finalize OS to EUSO ICD (get ESA approval)
- 2.1.2.10 Perform preliminary design of the OS and GSE
- 2.1.2.11 Mitigate programmatic and technical risk
- 2.1.2.12 Develop verification plan
- 2.1.2.13 Develop Integration and test plans
- 2.1.2.14 Develop manufacturing plan
- 2.1.2.15 Develop and test a prototype lens
- 2.1.2.16 Continue polymer shrinkage testing
- 2.1.2.17 Conduct an OS Requirements Review (RR)
- 2.1.2.18 Conduct an OS Preliminary Design Review (PDR)
- 2.1.2.19 Conduct a project Confirmation Review (CR)
- 2.1.2.20 Perform science simulations
- 2.1.2.21 Provide focal plane and electronics consultation to EUSO design teams
- 2.1.2.22 Provide science support to EUSO science team

2.1.3 Phase C Tasks

- 2.1.3.1 Perform final design of the OS and GSE
- 2.1.3.2 Conduct an OS Critical Design Review (CDR)
- 2.1.3.3 Begin the verification of the OS
- 2.1.3.4 Perform science simulations
- 2.1.3.5 Provide focal plane and electronics consultation to EUSO design teams
- 2.1.3.6 Provide science support to EUSO science team

2.1.4 Phase D Tasks

- 2.1.4.1 Fabricate and assemble the OS and GSE
- 2.1.4.2 Test the OS
  - 2.1.4.2.1 Functional testing
  - 2.1.4.2.2 Performance testing
  - 2.1.4.2.3 Environmental testing
- 2.1.4.3 Complete the verification of the OS

    2.1.4.4 Produce science data analysis software
    2.1.4.5 Perform science simulations
    2.1.4.6 Provide focal plane and electronics consultation to EUSO design team
    2.1.4.7 Provide science support to EUSO science team

2.1.5 Phase E Tasks

    2.1.5.1 Provide science support to EUSO mission operations team
    2.1.5.2 Provide EUSO science data analysis

2.2 Funding Information

Only one contractual arrangement is required between NASA and the EUSO team for Phase A. Therefore, no additional funding information is included other than that provided in section XX of the proposal

7.3 Resumes

7.4 International Participation Plan

The U.S. EUSO team will provide optical system components to the European Space Agency in support of the Extreme Universe Space Observatory (EUSO). This requires that the U.S. team comply fully with U.S. Export Laws and Regulations. U.S. team will develop appropriate agreements (Technical Assistance Agreement (TAA), Interim Agreement (IA), or other as required) through NASA Headquarters and the Department of State with all non-U.S. entities. These agreements will spell out the technical responsibilities between the U.S. and any International Partners.

All Export/Import paperwork will cite the appropriate agreement and address the International Traffic in Arms Regulations (ITAR). All exports will be documented utilizing MSFC Form 4312 – Export Clearance Information Sheet (ECIS). The U.S. EUSO Project Office Center Export Representative (CER) will generate ECIS's and any licenses required by the Exports. The CER will consult with the MSFC Export Control Officer as necessary to meet the regulations and associated required documentation.

It should be noted that SD20 has extensive experience with International Partnering (Japan and U.K.) on the Solar-B Project. SD20 has knowledge with the processes involved with the Export/Import of Science Payloads and Equipment.

7.5 Outline of Assignment of Technical Responsibilities Between U.S. and International Partners

I.6 Orbital Debris Generation Acknowledgement

The EUSO is launched on the Space Shuttle, attached to the ISS for the duration of its science operations, and then returned to earth on the Space Shuttle. Therefore, on-orbit spacecraft/payload disposal is not anticipated. The European led EUSO project office is responsible for any required formal assessments of orbital debris generation for the EUSO payload.

7.7 NASA Principal Investigator Proposing Team

7.8 List of Abbreviations and Acronyms

Acronym List

AGASA	Akeno Giant Air Shower Array
AGN	Active Galactic Nucleus
ASIC	application specific integrated circuit
ATM	Apollo Telescope Mount
Auger	The Pierre Auger Experiment
c	speed of light
c'	asymptotic velocity of massive particle
CE	control electronics
CEPF	Columbus External Payload Facility
CER	cost estimating relationship
CERN	
CES	control electronics system
CESR	Cornell Electron Storage Ring
CETP	
cm	centimeter
CMB	Cosmic Microwave Background
CORSIKA	tbd
CR	Cosmic Ray
CXO	Chandra X-Ray Observatory
CYTOP	amorphous perfluoro alkanyl vinyl ether
DAQ	
DIPFM	
E	
EAS	Extended Air Showers
EE	extreme energy
EECR	Extreme Energy Cosmic Ray
E_{GZK}	The GZK cutoff energy
EIRS	EUSO Istrument Requirement Specificaiton
ELID	electrolytic in-process dressing
E_{MAX}	high-energy end of the cosmic spectrum
EPO	Education and Public Outreach
ESA	European Space Agency
ESRD	EUSO Science Requirements Document
EUSO	Extreme Universe Space Observatory
eV	
FEES	front end electronic systems
FIRE	flourescence image readout electronics

Fly’s Eye	The Fly's Eye Experiment
FOCUS	Frontier Optical Coherent Ultrafast Center
FOV	Field of View
FS	filter system
FSDS	focal surface detector system
γ	Lorentz factor
GBM	GLAST Burst Monitor
GEVS	General Environmental and Verification Specification
GLAST	Gamma-Ray Long-Range Space Telescope
GOES–M	geostationary operational environmental satellite
GRB	Gamma-Ray Burst
GRO	Gamma-Ray Observatory
GTU	gate timing unit
GUT	Grand Unified Theory
GZK	Greisen-Zatsepin-Kuzmin
HEAO	High-Energy Astrpphysical Observatory
HiRes	Hgh Resolution Fly's Eye experiment
HOU	hands-on universe
HsST	Hubble Space Telescope
ICD	Interface Control Document
ICRC	International Cosmic-Ray conference
ISS	International Space Station
km	kilometer
Level 0	unprocessed raw data
Level 1	processed datas to the first level of analysis
LI	Lorentz invariance
LIDAR	laser radar
LMS	lightning mapper sensor
LSE	lead systems engineer
LSP	
MAPMT	miltianode photomotiplier tube
MI	minority institutions
MOC	Mission Opportunity Center
Mpc	
MSFC	Marshall Space Flight Center
NPG	NASA Procedures and Guidelines
ns	nano second
NSF	
NSSDC	National Space Science Data Center
OS	optical subsystem
OSS	Office of Space Science
OTD	optical transient detector

OWL	Orbiter Wide-angle Light-collector
pe	photoelectron
PI	principal investigator
PM	project manager
PMMA	polymethal methacrylate
PMT	
QGSJET	tbd
RHIC	
RIKEN	Institue for Chemical and Physical Research
RVC	requirements, verification, and compliance
SDB	small disadvantaged business
SDC	Science Data Çenter
SEUS	Structure and Evolution of the Universe
SIBYLL	tbd
SLF	stray light facility
SM	**standard model of high energy physics**
SOC	**Science Operations Center**
SOMTC	Space Optics Manufacturing and technology Center
sr	
SS	support structure
SSDD	Science Systems Development Department
SSL	Space Science Laboratory at UCB
SSRC	Space Science Research Center
SSS	superstructure support system
SSTA	Space Science & Technology Alliance
STS	space transport system
SXI	solar x-ray imager
T&ODHS	trigger and onboard data handling subsystem
TIMSS	
TPM	technical performance measurement
TPX	polymethyl-pentene
TREK	
TRMM	
UAH	University of Alabama in Huntsville
UCB	University of California at Berkeley
UCLA	University of California at Los Angeles
UHECR	High Energy Cosmic Ray
UHECRons	ultrahigh-energy cosmic particles
UP	University of Polermo
UT	University of Texas
UV	UltraViolet radiation
VLSE	very large scale integration

VU	Vanderbuilt University
WBS	work breakdown structure
Z-burst	resonant neutrino annihilation
ZEONEX	amorphous cuclo-olefin
ZeV	10^{21} eV

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