Introduction.

Energetic particles and plasma measurements are fundamental for space plasma physics and for space weather, and they are needed for virtually all future space (including planetary) missions. In particular, to separate spatial and temporal effects for magnetospheric and space physics multi-point measurements are required – e.g., the currently operating 4-spacecraft Cluster and 5-spacecraft THEMIS missions. In general, resources for scientific payloads are tightly constrained, even more so for future missions – e.g., Magnetospheric Constellation – that depend on tens (or more) nanosatellites (of cubesat scale). Consequently, the development of miniature, lightweight, low-power instruments is essential.

At UCB/SSL we have developed silicon semiconductor detectors (SSD) with thin windows and unusually low energy electronic thresholds, ~1-2 keV rather than the usual ~20-30 keV, for suprathermal particle measurements. These SSDs can provide much higher sensitivity and lower background than the electrostatic analyzers usually used in the ~2-30 keV energy range, while requiring about an order of magnitude less resources - few cm size, ~100 grams mass, ~100s milliwatts power. With modest pre-acceleration, these SSDs could measure down to thermal energies, thus providing a miniature sensor for plasmas as well as energetic particles. The first such detectors, the Suprathermal Electron (STE) sensors (Lin et al 2008) on the STEREO spacecraft (launched Oct '06), are measuring ~2-100 keV suprathermal electrons in the interplanetary medium with uniquely high sensitivity and resolution (~1 keV FWHM).

On November 6, 2006, during STEREO A and B's perigee passes at ~500-800 km altitude on the Earth's nightside near the equator, STE unexpectedly detected enhanced fluxes of ~4-100 keV particles (Fig. 1a bottom), with those heading toward the Earth a factor of ~2-20 higher in flux than those heading away. These particle fluxes are not organized by the local magnetic field or by pitch-angle, indicating they are due to Energetic Neutral Atoms (ENAs) from the Earth's ring current protons that had charge-exchanged with neutral hydrogen of the Earth's exosphere (Wang et al, 2009, in preparation) . This is the first ENA imaging of the ring current at energies below 26 keV from low Earth orbit (LEO), and the first during quiet time (Dst ~ +- 2 nT). As discussed below, this ~10 minutes of observation provides significant new science, and it shows the potential of this type of detector.

Thus, STE can remotely sense (and image) suprathermal ion populations through ENAs they produce as well as directly measure ions and electrons *in situ*. For CINEMA (Cubesat for Ion, Neutral, Electron, MAgnetic fields), a simple electrostatic deflection system would be added to STE to obtain STEIN (Suprathermal Electron, Ion, Neutral), an instrument that can separate ions from electrons from neutral particles. Starting a year ago, UCB/SSL funded grad students with NASA technology development grant, competitive student summer fellowships, and internal seed money, to develop a prototype STEIN (now undergoing laboratory tests) and an attitude control system for spinning cubesat. NASA Ames Research Center, with their extensive experience with cubesats (including Genesat, one of the first successful scientific missions) provided spacecraft expertise. Over the past two years Imperial College London (ICL) in the UK has been developing small, low mass magnetoresistive (MR) sensor magnetometers for cubesats with UK funding, while UCB/SSL has previously developed a lightweight (~120g) extendable 1m boom that enables high quality magnetic field measurements in low earth orbit.

Last fall, Kyung Hee University (KHU) proposed a research program (Professor Dong-Hun Lee, PI) with UCB/SSL collaboration, to the World Class University (WCU) competition of the Korean government, that included KHU developing a second identical CINEMA spacecraft to provide stereo ENA imaging and multi-point *in situ* measurements, This was the only WCU proposal funded in the area of space research, providing KHU with >US$2 million per year for 5 years (renewable for another 5 years) for collaborative research and for enhancing graduate student training in this field.

UCB/SSL, NASA Ames, and unfunded co-I's at ICL and KHU, propose here to develop CINEMA, a spinning cubesat with the STEIN instrument and a dual MAG (provided by ICL). KHU will provide a second identical CINEMA with WCU funding; both will be launched into high inclination low Earth orbit in 2011 for a one- year nominal science mission. In addition, underrepresented

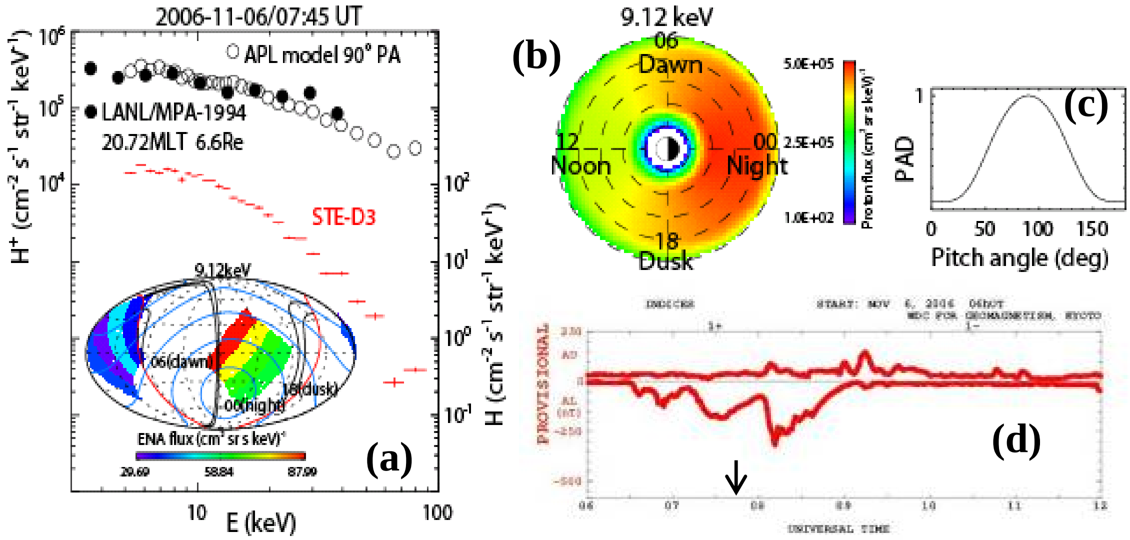

Figure 1. (a): The color-coded flux image shows the observed STE 9.12 keV angular distribution at 0745UT on Nov. 6, 2006, in a Hammer-Aitoff projection centered at local midnight. The maximum fluxes (red) are coming from the magnetotail towards the Earth (the Earth's horizon is indicated by red curve). The red crosses show the spectrum of the hydrogen ENA measured by STE-D3 sensor for the red region in the image. The solid circles (top) show the proton measurements (same energy range as ENA emissions) by LANL1994-084/MPA at 20.7MLT and 6.6Re, which agree well with the modeled proton fluxes (open circles) from STE ENA measurements. (b): The modeled equatorial proton distribution shows a strong day-night asymmetry peaking at midnight. (c): the modeled proton pitch angle distribution shows a "pancake" peaking at 90° PA. (d) The provisional AU and AL indices recorded between 06-12 UT; the arrow shows the STE measurement time.

minority students Inter American University of Puerto Rico (IAUPR) will participate fulltime in the summers at UCB/SSL to help develop and operate CINEMA and gain hands-on experience.

CINEMA will provide cutting-edge magnetospheric science and critical space weather measurements, including unique, high sensitivity ENA mapping and high cadence movies of ring current ENAs in stereo from LEO. It will also make 2-point direct suprathermal electron and ion measurements in the auroral and ring current precipitation regions and elsewhere in the magnetosphere, with a single high resolution (~1 keV FWHM) detector with uniform response from ~2 to ~100 keV; and high cadence 3-axis magnetic field measurements. Furthermore, CINEMA's development of miniature particle and magnetic field sensors, as well as cubesat-size spinning spacecraft will be important for future space missions.

1. Science Objectives and Planned Measurements

Magnetic Storms and Storm-Time Ring Current. Understanding magnetic storms is fundamentally important for space physics. Magnetic storms occur when the ring current is intensified in the inner Van Allen radiation belt. Imaging ring-current particles by means of charge-exchanged ENAs [Roelof, 1987] can provide a quantitative global view of the ring current evolution in space and time. ENA imaging on IMAGE showed that the ring current is formed only by injected particles that follow closed trapped orbits while the particles on orbits that intersect the magnetopause are lost into space [Mitchell et al., 2001]. A transforming scientific result from IMAGE was that ion injections from the near-Earth plasma sheet often built up ring current pressures to levels where the plasma beta exceeded unity on the night side between $3<L<8$. The storm-time ring current was shown to be fundamentally an *asymmetric* ring current exhibiting strong *azimuthal* gradients in the pre- and post-midnight sector. These night-side azimuthal gradients then drive strong electrical currents into the ionosphere, *i.e.*, the storm-time region 2 current system [Roelof, 1989]. Thus, to understand how the storm-time magnetospheric current system is generated and coupled through the ionosphere (M-I coupling), it is important to *image* the global distribution of non-thermal ion pressure, in particular, the *azimuthal pressure gradient*.

Mathematical techniques have been developed that successfully extract the ion pressure distribution from high-altitude ENA images [DeMajistre *et al.*,2005]. LEO measurements were shown to be complementary to high-altitude images by Roelof [1997], and recently, DeMajistre *et al.* [2008] demonstrated that images from the LEO vantage point are extremely advantageous for extracting the *longitude* (MLT) dependence of the ring current pressure, since the imager looks outward through the magnetosphere, and there are lines of sight (LOS) that lie nearly in the meridional planes (constant MLT) of the (dipole) magnetic field. To illustrate, the STEREO B ENA observations (Fig 1a.) were fit to a model of the ring current ion intensities (Roelof and Skinner, 2000) to obtain the parent ring current proton distribution. The inferred energy spectrum agrees well with *in situ* proton measurements near local midnight by the Los Alamos Magnetospheric Plasma Analyzer (Fig.1a top, M. Thomsen, private communication). The best model fit to the ENA angular distribution (Fig 1a bottom) indicates a day-night asymmetry in the ring current peaking at midnight (Fig. 1b) and a pancake (peaked ~90º) pitch angle distribution for the parent ring current protons (Fig. 1c). The Auroral Electrojet (AE) index (Fig. 1d) shows that a small substorm (~50-100 nT) was in progress, suggesting the ENAs came from charge exchange of protons injected into the ring current. These measurements indicate that STE-based instrument can easily detect ~4-100 kev ENAs at quiet times and in small substorms on short time scales.

Multi-Spacecraft Observations As part of our collaboration, KHU will develop and fly a second identical CINEMA cubesat to provide stereo ENA imaging of the ring current. Since ENA images represent line of sight (LOS) integrations of the parent ion distribution and the geocoronal H-atom density, multiple vantage points greatly (and non-linearly, see Roelof [1997]) enhance the information obtainable on the parent ring current ion distributions.

The ENA cameras on the two TWINS (Two Wide-angle Imaging Neutral atom Spectrometers) spacecraft cover the energy range ~2-40 keV/nuc (thus overlapping CINEMA for protons) and have total instrument geometry factors of 0.0087 and 0.0056 cm^2sr, about a factor of 3 smaller than CINEMA. The TWINS spacecraft are in two modified Molniya orbits with apogees ~7R_E (geocentric) and inclinations of ~63° (viewing from the north), enabling the extraction of the L-dependence of the pressure distribution to complement CINEMA's determination of the azimuthal distribution. Since ENAs are emitted anisotropically according to the local pitch angle distribution (PAD), the CINEMA orbit allows for observation of approximately equatorial ring current fluxes, while TWINS is biased towards more field-aligned fluxes, so together they can provide unprecedented observation of the evolution of ring current phase space distributions.

• ***CINEMA's STEIN instrument will image ring current and substorm injected particles in local time at a cadence as fast as 30 s (spin period), through 4-20 keV (energy range of most ring current ions) ENA measurements with much improved sensitivity (see Table 1) and energy resolution (~1 keV FWHM). The spin axis and imaging plane of STEIN (Fig. 2) have been specifically chosen to rapidly image the storm-time asymmetric ring-current pressure distribution that drives the Region 2 currents into the ionosphere (the fundamental M-I coupling mechanism). CINEMA and TWINS observations together (if TWINS is still operating) provide complementary pieces of the ring current pitch angle distribution, allowing for unprecedented observation of the evolution of ring current phase space distributions.***

Charged-particle precipitation in the high latitude atmosphere occurs in many forms and is intimately tied to injection of particles and magnetic storms. **Precipitation of ring current ions** by wave-particle interactions accounts for some of the recovery from magnetic storms [e.g. Jordanova et al., 2001]. Although precipitating ion fluxes are lower than those in the equatorial ring current, the rapidly increasing atmospheric column depth (especially for O and N_2 whose charge exchange cross-sections are larger than that of H) produces intense fluxes of ENA at ~400km altitude (much brighter than those directly from the

Scientific Observation	Geometric Factor (cm² sr)	Expected flux @ ~10keV (cm² s sr keV)$^{-1}$	Average Count Rate: #/s 4keV-20keV	Frequency of Observations	Duty Cycle	Orbit Averaged Data Rate (kbps)
Ring Current ENAs	0.02	10^3	300	Large part of the orbit Background lowest on night side near equator Storms occur ~ monthly	70%	3.5
Low atitude ENAs	0.02	$\sim 10^4$	$3x10^3$	High latitude passes during storms and substorms for nighttime observations	5%	2.5
Auroral protons	$3x10^{-5}$ (w/attenuator)	$\sim 10^5$	30	High latitude passes during storms and substorms	5%	0.5*
MicroBurst electrons	0.003	$\sim 10^6$	300	Most common during storms, but occur at all activity levels	5%	0.4
Auroral Electrons	$3x10^{-5}$ (w/attenuator)	$\sim 10^8$	$\sim 3x10^4$	High latitude passes during storms and substorms	5%	0.5*

Table 1. Expected count rates for the STEIN instrument.
*Average data rate includes decimation in auroral zone.

ring current). Astrid-1 demonstrated ENA imaging of these precipitating ring current 26-37 keV protons at LEO [Brandt et al, 1999] during storm times (STEREO A & B were at latitudes too low to see them).

CINEMA imaging of ENAs in an inclined orbit can thus map ring current precipitation losses while imaging the trapped ring current as well, in the energy range covering of the bulk of ring current ions. In addition, CINEMA will also make direct in situ *measurements of the precipitating ions while traversing the footpoints of ring-current field lines. This combination enables quantitative evaluation of ring-current precipitation losses, and measurement of the scale size of the wave-particle interaction regions. In addition, the two CINEMAs will provide multi-point in situ ion and magnetic field measurements to separate space and time effects and provide stereo mapping of the ENAs.*

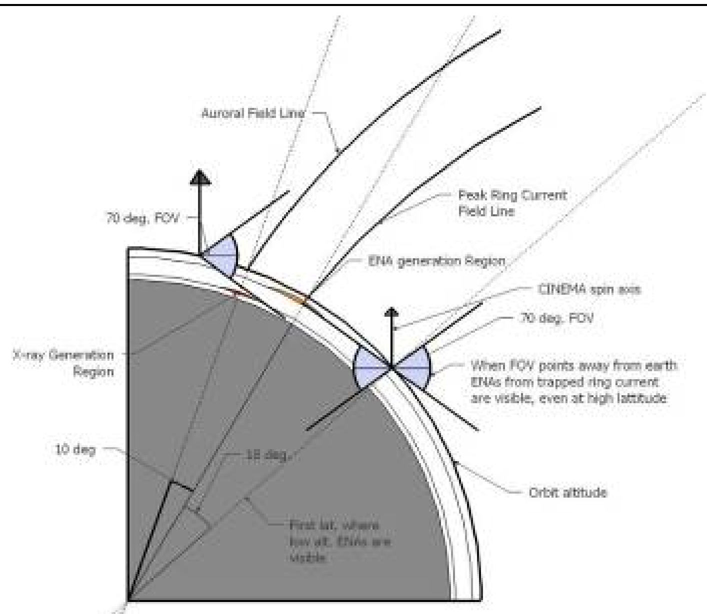

Fig. 2 The geometry of STEIN viewing angles. When looking away from the earth, STEIN will view ENAs from the trapped ring current. At high latitudes STEIN will image the longitudinal distribution of ENAs from precipitating ions as it spins. When FOV points towards the auroral zone, ENAs from precipitating ions and X-rays from precipitating electrons are imaged.

Electron microbursts are short (~0.25s) bursts of precipitating electrons that have been detected from tens of keV to >MeV. STSAT-1 observations [Lee, 2005] found microburst precipitation contains only electrons with energies >20 keV (the solid state telescope threshold) with no bursts detected at lower energies by their electrostatic analyzer. Similar results showing a low energy cutoff near 20keV were obtained by rocket experiments [Datta, 1996; Lampton [1967], although electrostatic analyzers on the FAST mission have detected microburst-like precipitation (C. Carlson, private communication) down to energies of a few keV and below. Thus far, there has not been a single instrument that covered energies from well below to well above the purported cutoff. Microbursts are thought to occur due to rapid pitch angle diffusion by wave particle interactions, but the rapid filling of the loss cone has yet to be explained [Lee, 2005]. Accurate measurement of the cutoff energy in microburst energy spectra is important for determining the physics that precipitates these electrons. The precipitating microburst electrons also produce bremsstrahlung X-ray emission (Parks et al, 1965) at altitudes of < ~100 km.

• *CINEMA will measure precipitated microburst electrons with a single detector continuously across the electron energy cutoff energies around tens of keV, with energy resolution of ~1keV. These measurements will be made with sufficient time resolution to observe microburst shape and any dispersive effects. CINEMA will also detect 2-15 keV* bremsstrahlung *X-rays from the microburst precipitation region at <~100 km altitude. The two CINEMA spacecraft observations will allow space-time separation.*

Auroral ion and electron precipitation has been studied in detail by FAST electrostatic analyzers from plasma energies to ~30 keV. Inside the precipitation regions, STEIN extends the energy range of *in situ* electron and ion measurements to ~100 keV with a single detector that has uniform response from ~2-4 keV. When the CINEMA spacecraft are outside the precipitation regions, STEIN will map the precipitation of ~4-20 keV ions at ~400km altitude through ENA measurements, and of ~2-15 keV electrons at <~100 km altitude through X-ray measurements (Fig. 2).

CINEMA will provide in situ electron and ion measurements extending from ~2-4 keV to ~100 keV from a single detector. The two CINEMA spacecraft observations will allow space-time separation and stereo viewing of auroral precipitation. This combination enables quantitative evaluation of the precipitation mechanism, and measurement of the scale size of the interaction regions.

Magnetic Fields. The magnetometer (MAG) will provide the complementary measurements of magnetic fields, waves, and currents required for interpreting the *in situ* STEIN electron and ion measurements. In addition, the CINEMA measurements of the magnetic fields in low Earth orbit, combined with ground-based magnetometer data and data from upstream spacecraft such as Cluster, THEMIS, Wind, and ACE, will allow the tracking of the phase fronts of ULF waves and flux transfer events (FTEs), quasi-periodic reconnection events at the Earth's magnetopause, into near-Earth space. The Earth's bowshock reflects a small fraction of incoming solar wind particles, which can generate large-amplitude ULF waves in the upstream, "foreshock" region. These waves can significantly affect the shock, magnetosheath and magnetopause; the interaction is strongly controlled by the orientation of the solar wind magnetic field.. Recent measurements of the flow-perpendicular scale of foreshock ULF waves (Archer et al, 2005) suggested the possibility that the recurrence rate of FTEs could be controlled in some circumstances by the arrival of the edges of ULF waves at the shock. We will compare observations against predictions of their orientation and tracking speed based on the upstream solar wind conditions to test this hypothesis for the first time. Since the bursty reconnection process injects energy into near-Earth space, ultimately energizing the radiation belts and generating the aurora, this is a potentially important causal link.

2. Relevance to Space Weather Research Goals

Understanding magnetic storms, substorms and particle precipitation are fundamentally important space weather research goals. CINEMA will provide a powerful new capability for high sensitivity and energy resolution ~4-20 keV ENA imaging from LEO, especially of the azimuthal dependence of the ring current; as well as high energy resolution, measurements of precipitation of ions and electrons by a single detector with uniform response from a few to ~100 keV. Ions of these energies are hypothesized to drive the generation of EMIC waves that precipitate MeV-energy “killer” electrons. In addition, the development of the miniature STEIN sensor and magnetometer is important for future space weather research conducted by constellations of multiple, tens or more, small (cubesat-sized) spacecraft.

3. Orbital Requirements

CINEMA is designed for a high inclination, low Earth orbit, such as the 72° inclination, 650 km altitude orbit planned for the first NSF Cubesat mission. Any such orbit (~500-800 km altitude) will allow measurements over nearly all geomagnetic latitudes. CINEMA could operate well in low Earth orbits at other inclinations without modification, while other orbits may require modifications.

4. Technical Approach

a. Instrumentation. The advantages of a silicon semiconductor detector (SSD) based sensor (e.g., STE) versus the conventional electrostatic analyzers (ESAs) used for low energy (few to ~30 keV) electron and ion detection can be illustrated by comparison with the Wind Electron Electrostatic Analyzer (EESA-H) instrument (Lin et al, 1995). EESA-H, which discovered the electron superhalo, is a very large geometric factor top-hat electrostatic analyzer (~20 cm diam, ~3 kg, ~3 W), with anticoincidence rejection of penetrating high energy particle background. EESA-H, like most ESAs, measures only one energy band at a time. With $\Delta E/E$= ~0.2 it took ~14 energy steps to cover 2-20 keV, a duty cycle of ~7% for each energy. The STE instrument, meanwhile, measures electrons from 2 to 100 keV, using thin-window SSD arrays with four pixels in a row, each ~0.1 cm^2 area and 300 micron thick, surrounded by a guard ring (Fig. 3). The SSDs are made from high-resistivity silicon, featuring especially thin n-type contacts (Tindall et al., 2008), with a backside contact consisting of a 100 Å thick polysilicon layer plus a 100 Å aluminum layer. By utilizing state-of-the-art electronics, STE is able to detect electrons down to 2 keV with better than ~1keV FWHM resolution. The four SSD pixels look through a rectangular opening that provides a ~20 x ~80 FWHM FOV per pixel, for a total FOV of ~80x80 degrees and geometric factor of ~0.2 cm^2 ster (four times larger than EESA-H). STE has a 100% duty cycle, which together with the higher sensitivity provides a factor of >50 in effective signal as compared to EESA-H, with a background of ~1 c/s vs EESA-H's ~20c/s; thus signal to noise for STE is >1000 times greater than an ESA.

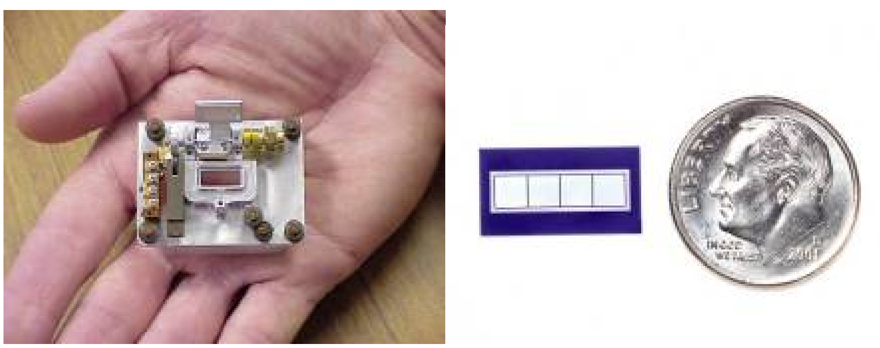

Figure 3. *Left.* SupraThermal Electron (STE) sensor (engineering model) for NASA's STEREO mission. *Right* The four pixel (each 0.1 cm^2) SSDs with guard rings used in STE.

STE also detects protons and ENAs (converted to ions in the window), down to ~4 keV for hydrogen (more energy loss in the window than electrons). SSDs have a huge advantage for ENA measurements in that they are insensitive to the EUV emission at geocoronal levels that comprises a major source of background for windowless detectors such as the channeltrons and microchannel plates used in previous low energy ENA sensors. EUV/UV/visible light is absorbed in the SSD window leading to increased leakage current, but at the level of geocoronal emissions the SSD performance is unaffected.

The **STEIN (Suprathermal Electrons, Ions, & Neutrals)** sensor for CINEMA adds a simple parallel plate electrostatic deflection system in front of the STEREO STE sensor to separate electrons from ions from neutrals. Electrons and ions are swept to opposite sides, where they are measured by the two edge pixels, while neutrals (un-deflected) and higher energy (less deflected) ions and electrons strike the center pixels (Fig. 4 left). When CINEMA is at low magnetic latitudes (outside the particle precipitation regions) the deflection voltage will be kept at its maximum so ions and electrons up to ~20 keV are completely swept away from the center pixels (Fig. 4 right) for clean measurements of ~4 - 20 keV ENAs. Meanwhile, the edge pixels measure charged particles. At high latitudes the deflection voltage can be swept to cover a wide range of ion and electron energies and angles. By measuring the energy spectra from the edge pixels for each deflection voltage step and exploiting the convolved energy-angle response, we can obtain both energy and angular information for electrons and ions. The STEIN edge pixels and center pixels have total sweep-averaged geometric factors of .002 and .02 cm^2 sr respectively, ensuring reasonable count rates for charged particles in the edge pixels, and ENAs in the central pixels. When the particle fluxes become extremely high (e.g., electron fluxes in the auroral zone) a 100-fold attenuator (based on the STEREO and THEMIS SST design, see Fig. 6) is automatically rotated in front of the SSDs to keep them from saturating. As CINEMA spins with spin axis orientation perpendicular to the ecliptic, the STEIN field of view (20ºx70º for neutrals, 40ºx70º for charged particles) sweeps out ~80% of the sky.

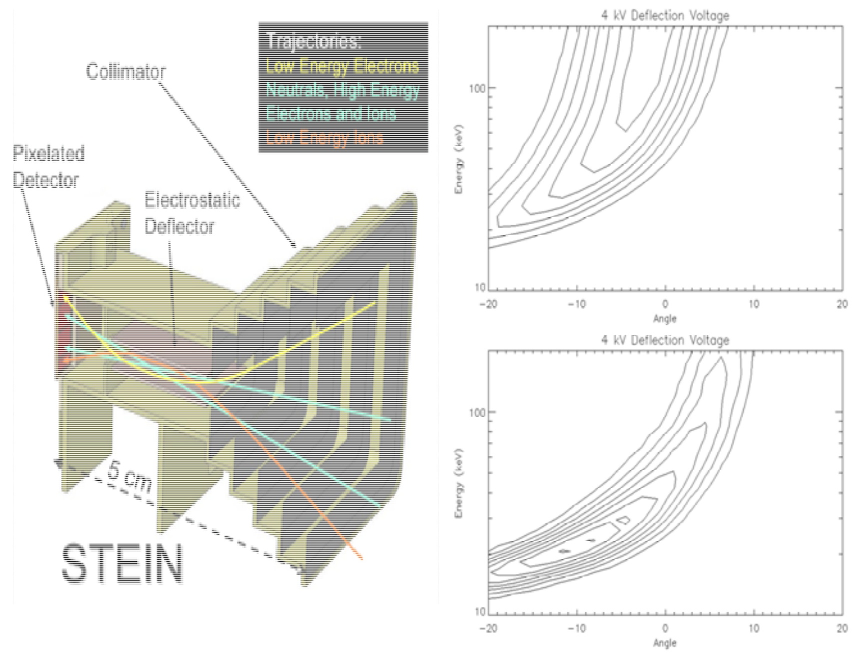

Figure 4: *Left*: schematic of electron, ion, and neutral trajectories in detector (see Fig. 6 for detailed mechanical design). *Right*: Energy-angle response for charged particles at maximum deflection voltage in center (top) and edge (bottom) pixels.

Direct sunlight and Earth-shine can produce leakage currents sufficient to blind the SSDs, so the STEIN electronics are designed to recover rapidly, ensuring good data for ~80-90% of each spin, even in sunlight. In addition, we plan to coat one of the two center pixels with ~500Å of Al to eliminate Earthshine. This will raise the threshold for detecting oxygen from ~20 to 45 keV in the coated pixel, so 20-45 keV oxygen will only be detected in the uncoated pixel, while 20-45 keV hydrogen will be detected in both pixels.

The **STEIN Electronics** (Fig. 5) are based on those for STEREO STE, simplified to minimize mass and power. The signal from each SSD pixel goes to a conventional charge sensitive amplifier with dual gate input FETs to achieve low noise performance. The output goes to a 5 pole unipolar shaping amplifier with a 2 usec shaping time - the same low power design as STEREO. This circuit includes comparators to provide LLDs (low level discriminators) and ULDs (upper level discriminators) and a peak detector to indicate when the A/D conversion should

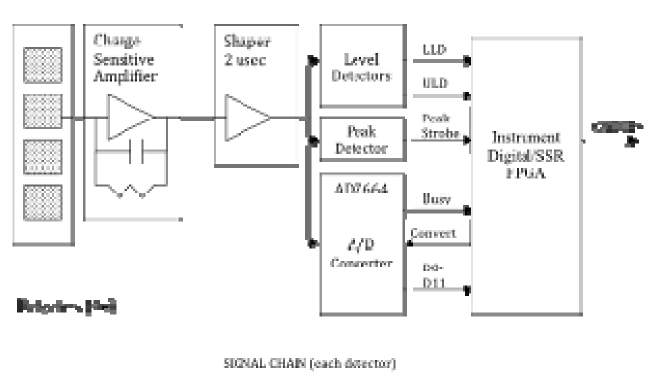

Figure 5: STEIN Analog Front End Electronics

take place. The output of the peak detector and discriminators go to an ACTEL FPGA that controls the A/D converters, acquires the data and then passes it to the IDPU. This is essentially the same design used in STEREO STE, and it will use the same parts that are already known to function successfully in this environment. With UCB/SSL internal technology development funds, we have already prototyped this exact design for another instrument that uses STE detectors.

The energy (to ~0.4 keV, 8 bits), pixel ID (2 bits) and time (to ~15ms, 6 bits) of every particle detected by STEIN is normally stored in the memory. When STEIN counts at very high rates (i.e., during auroral precipitation), decimation – taking only 1/N of the events where N = 4, 16, 64, etc. – is applied. This scheme is used very successfully on RHESSI to deal with intense solar flares. Table 1 gives the resulting orbit-average data rates. Except during intense auroral precipitation, information on every particle is downlinked to the ground providing complete flexibility in the data analysis.

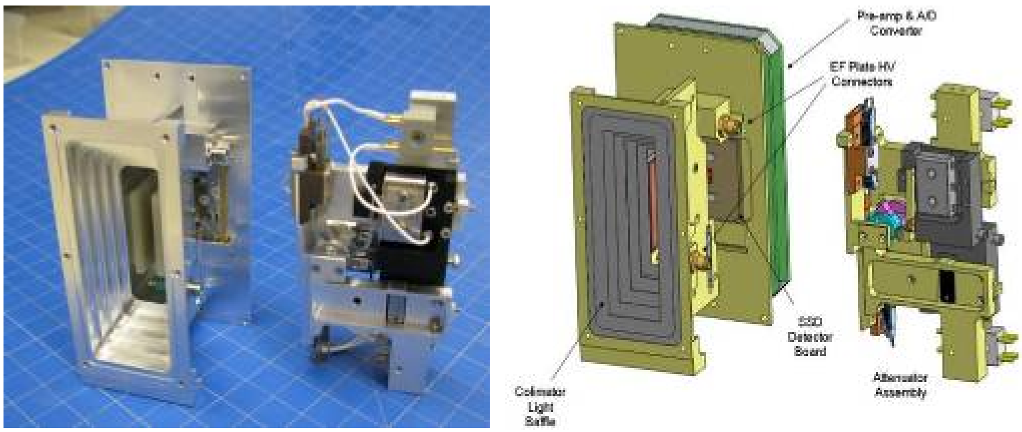

Figure 6: Photograph of STEIN ETU and CAD Model

A **STEIN Engineering Test Unit** (Fig. 6) has been assembled and is currently undergoing testing. The STEIN detector, preamps and A/D boards are mounted to the rear of the STEIN collimator, beneath a light-tight cover. Instrument electronics boards are stacked with inter-board connectors and standoffs, and mounted to the box sides on brackets. The STEIN HV and instrument LV power supplies are mounted between chassis sides. The STEIN attenuator mechanism (Fig. 7) consists of a BeCu foil with photoetched holes that will permit one percent of the impinging particles to reach the detector. The foil is mounted on a paddle that swings in front of the detector. The position of the paddle is controlled via a bi-stable mechanism with two nanomuscle actuators and two end-of-travel (EOT) switches. When the attenuator paddle lies in the closed position, only the opening actuator can be powered (and vice versa). This mechanism is based on a similar one that is being used successfully on NASA's THEMIS mission.

Magnetometer (MAG). Anisotropic Magnetoresistive (MR) sensors are solid state devices that can measure the absolute value of the local magnetic field. The sensors - 1,2, or 3 axis devices - come in plastic or ceramic chip packages (see Fig. 7), weigh a few grams, and are optimized for the Earth's field with typical sensitivities of 10 nT. To reduce noise and improve sensitivity, MR sensors include two coil metallizations. A set/reset coil is used periodically to align the internal magnetic anisotropy direction of the domains together with an offset coil. These coils enable the MR sensors to be run in feedback, or null, mode, like a normal fluxgate core, resulting in dramatic

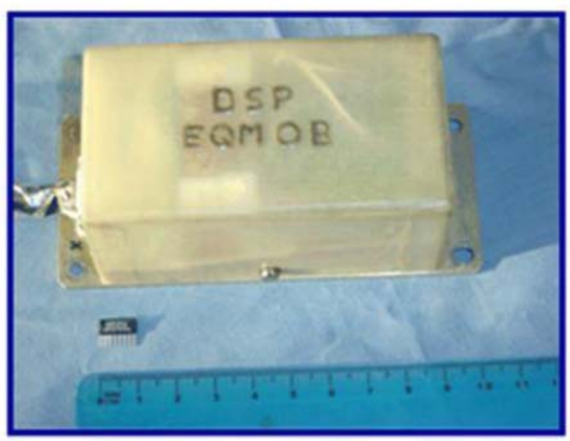

Figure 7. Comparison of a conventional fluxgate magnetometer sensor (back) with a MR sensor (front). Ruler numbers are in centimeters

improvements in sensitivity, linearity, and precision, but with additional power and mass. ICL has developed the necessary circuitry, adapted from fluxgate designs, and is continuing to improve sensitivity and lowering power requirements.

CINEMA will have a MR MAG sensor at the end of the 1m extendable boom and an inboard MR MAG sensor, allowing operation in a gradiometer mode to identify and remove changes in spacecraft-induce fields, improve final calibrated data, and add redundancy. There will be two operating modes - an attitude mode with 1 vector/s cadence and ~25nT precision for power of ~0.1 W; and a science mode using nulling, with better than 10 nT precision and ~>10 vectors/s for power of ~0.4 W.

b) CINEMA Spacecraft System Design. The CINEMA system consists of bus avionics which provides power, communications, and a Command and Data Handling System (C&DHS); plus two instruments; the magnetometer (MAG) and the STEIN electron/ion/neutral detector. The system is based on existing bus and instrument designs (see Figure 8). Off-the-shelf cubesat avionics are used (Fig.8, blue blocks, including solar arrays) although if ITAR issues can be resolved these may be supplied by NASA Ames. The MAG electronics and sensors are provided by ICL based on existing Cubesat magnetometer designs (Fig. 8, pink blocks). The remainder of the system is provided by UCB (Fig. 8, yellow blocks).

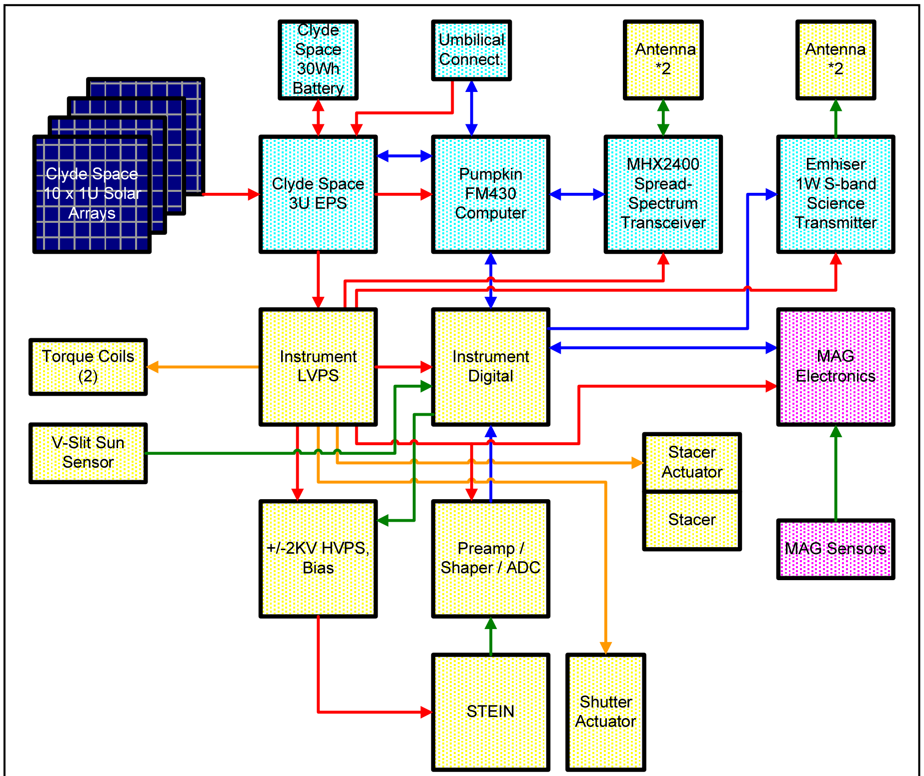

Figure 8. CINEMA Block Diagram

COMMAND and DATA HANDLING SYSTEM (C&DHS) The off-the-shelf Pumpkin Cubesat FM430 processor board controls CINEMA data collection, power modes, and ACS. It includes a solid state memory recorder (up to 2Gbytes) to collect telemetry between ground passes. Ground communications for commands and real-time housekeeping will use the MHX2400 transceiver, which can be interfaced directly to the FM430. The C&DHS interfaces to the instruments, ACS components, and S-band transmitter via a high speed SPI serial interface to the Instrument Digital electronics. C&DHS Software will be developed at UCB.

POWER SYSTEM The Power system includes Triple Junction GaAs solar cells, Li-Ion batteries, battery charging and power conditioning/switching/monitoring circuitry (subsystem power switching is provided by the Instrument LVPS). There are a total of 10 1U-sized solar array panels spread over all 6 faces of CINEMA to provide power in any orientation). Each array consists of 2 large-format EMCORE cells in series. The Clyde Space EPS system includes peak power tracking electronics to optimize the power collected from the arrays to the battery and bus. The 30Wh battery pack is sized to power the spacecraft during eclipses and to accumulate energy to power the transmitters during ground station passes. The power budget is discussed later.

COMMUNICATIONS For commanding and engineering telemetry, the bus communications system includes a uHard 2.4 GHz WiFi transceiver (MHX2400), a 3-dB power splitter and two circular polarized patch antennas mounted on opposite sides of the spacecraft body. The combined antenna radiation pattern provides nearly omni-directional coverage. The receiver will always be turned on in SAFE mode, while the transmitter will be powered on in burst mode in response to commands received from the ground during a pass. The uHard system can communicate with the already existing 11-m Berkeley Ground Station (BGS) at low bit rates (typically 80 kbps) to control and monitor CINEMA. BGS will be outfitted with a secondary feed containing a short helix antenna and a uHard WiFi transceiver that is identical to the unit on the spacecraft. One pass per day of housekeeping downlink provides 14 Mbits of data, corresponding to an average rate of 160 bps, more than adequate for CINEMA. For science telemetry downlink, the spacecraft will be equipped with a dedicated Emhiser 1 W S-band transmitter, another 3-dB power splitter and two additional circular polarized patch antennas that are mounted side-by-side with the WiFi patch antennas. This high-bandwidth transmitter will also communicate with the BGS ground antenna to downlink science data in a store-and-dump mode. For normal science operations, the transmitter will be powered on by time-tagged commands during passes over the ground station. Science telemetry data will be transmitted at 1 Mbps, and are formatted in CCSDS packets and frames, using Reed-Solomon coding for error correction. Figure 9 shows the link margin calculation, showing a solid 7.5 dB margin at an elevation of 5 deg. With this system, the data volume to the ground is calculated to be 760 Mbits/day, corresponding to an average of 8.8 kbps of continuous science data acquisition. The CINEMA communications paths are shown in Figure 10. Data distribution will use the RHESSI and THEMIS approach that provides rapid (~1 day) online open access to both the data and analysis software.

DOWNLINK ANALYSIS

Frequency [MHz]	2282.500
Wavelength [m]	0.131
Sat Transmit Power [W]	1.000
Sat Component Loss [dB]	4.000
Sat Antenna Size [m]	0.021
Sat Antenna Efficiency [%]	100.000
Sat Antenna Gain [dBi]	-6.000
Sat EIRP [dBW]	-10.000
Range [km]	2700.000
Free Space Loss [dB]	168.243
Atmospheric Loss [dB]	0.000
Rain Loss [dB]	0.000
Radome Loss [dB]	0.000
Polarization Loss [dB]	0.500
Pointing Loss [dB]	0.500
Gnd Antenna Size [m]	11.000
Gnd Antenna Efficiency [%]	64.000
Gnd Antenna Gain [dBi]	46.464
Gnd Component Loss [dB]	0.500
Gnd Rcvr Input Power [dBm]	-103.279
Gnd Rcvr Noise Figure [dB]	0.400
Gnd Antenna Temperature [K]	28.000
Gnd System Temperature [K]	94.778
Gnd Receiver G/T [dB/K]	26.697
Modulation Type	BPSK
Modulation Function	SQUARE WAVE
Modulation Deviation [rad]	1.570
Modulation Loss [dB]	0.000
Bit Error Rate	1.0E-06
Coding Type	RS
Coding Gain [dB]	4.300
Data Rate [kbps]	1000.000
Bandwidth [kHz]	1000.000
Required Eb/No [dB]	6.200
Predicted C/No [dB-Hz]	76.053
Predicted Eb/No [dB]	16.053
Implementation Loss [dB]	2.300
Predicted Link Margin [dB]	7.553

Figure 9. CINEMA Link Margin Analysis

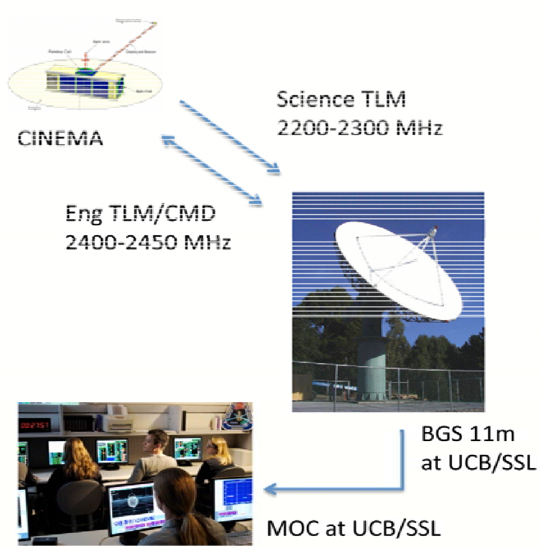

Fig. 10 CINEMA ground system.

Spectrum licensing will be coordinated with NASA/GSFC. The low-rate command and engineering telemetry link at 2400-2450 MHz will operate on one of the lowest six channels of the WiFi band, which also coincides with the amateur radio S-band section, so spectrum licensing will be covered by an amateur radio license. The high-rate science telemetry downlink operates in the 2200-2300 MHz section of the S-band, and therefore requires a NTIA license. We propose to operate the high-rate telemetry link co-channel with the five THEMIS spacecraft that are also controlled from the existing Multi-mission

Operations Center (MOC) at UCB/SSL and also use BGS as their primary ground station. It is anticipated that this approach will minimize the impact to other spectrum users and will also accelerate the license application process.

All aspects of CINEMA mission and science operations will be conducted from the MOC that already supports eight other spacecraft simultaneously. Operations of CINEMA will be integrated seamlessly, taking advantage of the existing infrastructure and software systems. A high degree of automation in the existing operational systems allows saving costs at a low risk. All mission planning products and ground station acquisition data will be based on two-line element (TLE) sets downloaded from USSTRATCOM. The existing Flight Operations Team (FOT) will be augmented with students to operate CINEMA under the supervision of the Operations Manager.

INSTRUMENT ELECTRONICLS The Instruments and ACS system are integrated to the C&DHS via the Instrument Digital Electronics. This is an FPGA-based system which controls instrument operations and collects instrument telemetry under the control of the C&DHS. It provides Magnetometer and sun sensor data to the C&DHS which runs the ACS software. It also provides a stream of high bandwidth science data to the C&DHS when in Normal mode. The instrument electronics also includes the Instrument Low Voltage Power Supply (LVPS) which converts, conditions, and switches bus voltage to the various subsystems under control of the C&DHS, including the ACS Torque coils.

MECHANICLAL The CINEMA bus chassis (Figure 11) consists of a .050" aluminum sheet metal box with hard-anodized edges for anti-galling with the P-POD rails. Corner bumpers are equipped with kickoff springs and a release switch per the P-POD requirements. The avionics module mounts between the chassis walls and the S-band transmitter is attached to one of the end plates. The four patch antennas are located on the top and bottom of the satellite (top shown in Figure 11). A prototype of the antenna has been fabricated and is currently undergoing testing.

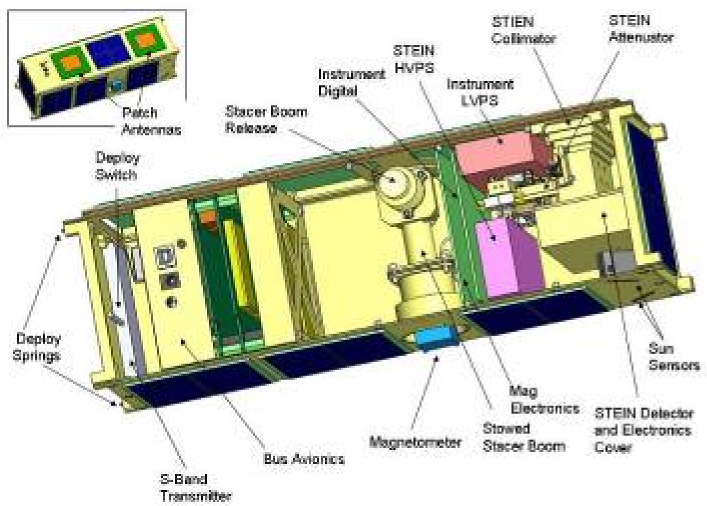

Figure 11 CINEMA Mechanical Configuration – An identical pair of patch antennas is located on the underside of the satellite (not visible)

The STEIN detector, preamps and A/D boards are mounted to the rear of the STEIN collimator, beneath a light-tight cover. Instrument electronics boards are stacked with inter-board connectors and standoffs, and mounted to the box sides on brackets. The STEIN HV and instrument LV power supplies are mounted between chassis sides.

A magnetometer and boom assembly (Figure 12) has been designed and fabricated. The magnetometer is deployed on the end of a 1m Stacer boom (shown deployed in Figure 13). A Stacer is a self-deploying spring element that stows into a 50mm long canister, and deploys into a ~7mm diameter rigid tube. The stacer release is controlled by a TiNi Aerospace pinpuller. The orientation of the magnetometer about the stacer axis after deployment is not controlled. The final mag position will be determined after deployment by pulsing the pointing torque coil and observing the mag response to this field. The

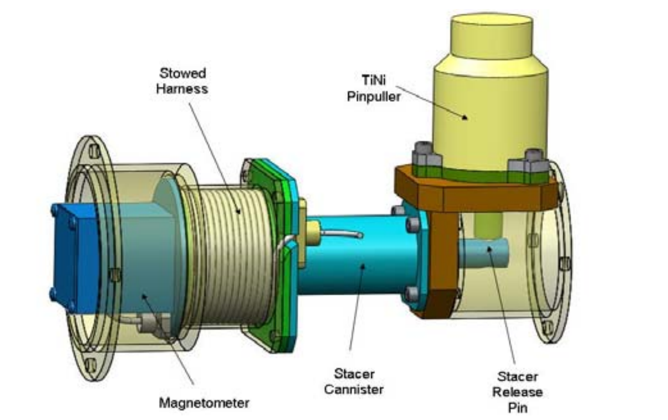

Figure 12. The stowed magnetometer boom.

Figure 13. The magnetometer boom after deployment.

mag harness is stowed in an annular space surrounding the stowed stacer, and deploys in a loose helix around the stacer (Figure 13). The harness consists of sixteen strands of insulated 36 AWG magnet wires twisted together and protected by a woven Aracon sheath. A prototype harness has been assembled and found to have an acceptable bending radius and sufficient durability to withstand stowage and deployment. An identical harness was also evaluated for electrical and magnetic properties by the MAGICL team and found to be acceptable .

Pending detailed thermal analysis, bus temperatures will be controlled passively through careful selection of thermal finishes. Area is available for radiators if needed for bus heat balance or for spot cooling on the transmitter. Sufficient power is available for survival heaters if needed.

Figure 14 shows the mass breakdown for CINEMA. Given a nominal 3kg launch capability we have 9% mass margin; increasing the launch mass slightly will reduce risk in the development effort.

Figure 14 Mass Budget

Subsystem	**Mass, g**
Chassis	463
Solar Arrays	375
MAG Boom system	160
Sun Sensors	10
Antennas	140
Avionics	500
Transmitter	57
Torque Coils	85
STEIN Detector Head	261
STEIN Electronics	90
STEIN HVPS	150
MAG electronics	45
Instrument Digital	90
Instrument LVPS	150
Harnessing	100
Thermal	50
TOTAL	**2726**

ATTITUDE CONTROL SYSTEM (ACS) The ACS system (Fig. 15) consists of two torque coils, one v-slit Sun sensor, and the 3-axis science MAG. Additionally, solar array currents provide an extra coarse attitude sensor for initial attitude determination and the in-board calibration MAG is used for initial de-tumble activities. The ACS system is primarily used to take the spacecraft from its initial attitude and precess it to an ecliptic normal spinner. Once in that configuration, controls commands are required once per day to maintain the spin axis within a 10° cone, and the sensor data is sent to the ground for science attitude determination. The v-slit Sun sensor contains two collimated photodiode devices with 4° x 90° fan-shaped fields of view (FOV). This design has heritage from the UCB Rocket program. The devices are oriented looking in the spin plane, tilted 45° above and below, forming a V. Each device provides an event pulse whenever the FOV crosses the Sun. Therefore, the average of the pulse timing gives the Sun azimuth and the time between pulses gives the Sun elevation. A prototype of this sensor was assembled and tested at SSL (Figure 16). The three axis magnetometer (MAG) will provide the vector direction of the local earth's magnetic field (B). The combination of the MAG and Sun Sensor data is adequate to determine CINEMA's attitude.

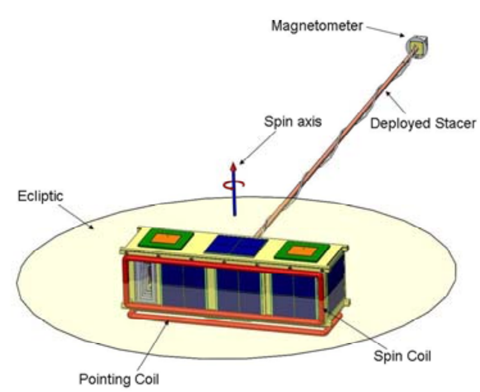

Figure 15. CINEMA ACS
(Torque coils are shown schematically)

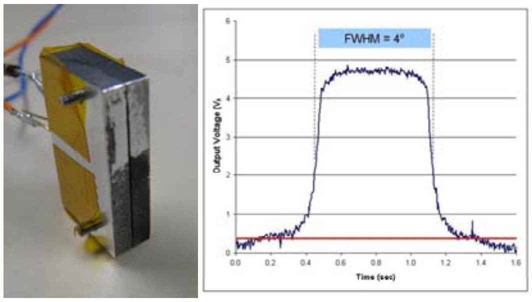

Figure 16 Prototype Sun Sensor (left), showing entrance slit for light. Plot of sensor output (left) when panned across the Sun at 1 RPM.

Two magnetic torque coils will be used to maneuver CINEMA, one is for spin rate control and the other for spin vector precession (pointing), as was done on UCB's FAST satellite (1996). These consist of magnet wire wound on an aluminum frame and screwed to the chassis walls, one mounted perpendicular to the mag boom and one perpendicular to the spin axis as shown in fig. 15. The CINEMA torque coils have a capacity of 1.16 A-m^2 at 5.3W. These torque coils are significantly larger than those typically used on CubeSats. Each coil will be operated at a ten percent duty cycle for the duration of ACS operations, according to the spacecraft power budget. These torque coils correspond to a torque in the order of 5.3e-5 N-m at 650 km orbit altitude, which will precess the spin vector several degrees/day

The automated on-board ACS algorithm will provide three functions. Initially, the de-tumble mode will reduce CINEMA's angular velocities due to the separation from the launch vehicle. This will be accomplished using a "B-Dot" controller, which is based on the measurement of the rate of change of the body-fixed in-board magnetometer data (Flatley, et al, 1997). With the use of only the spin coil and the in-board magnetometer, the controller will de-tumble the spacecraft relative to the Earth's magnetic field vector. Once the B-dot rates are reduced, a small torque will be generated with the spin coil to activate the v-slit Sun sensor. The spin control loop will maintain a spin rate of 2 RPM using the sun sensor & FGM inputs to commute the spin coil. This will be achieved using a control law based on the difference between the desired angular momentum vector and the present state of the spacecraft (Shigehara 1972). The pointing control loop uses these same inputs and similar control law to maneuver the CINEMA to a Sun vector normal spinning attitude using the pointing coil. When viewed from the spinning cube, the pointing loop would torque the cube so as to move the sun into its spin plane. Both the spin and pointing control loops determine the satellite attitude by using the simultaneous line-of-sight sightings algorithm (Grubin, 1977). Under selected initial conditions, the ACS is capable of achieving sun normal orientation in approximately ten orbits, provided that all the instruments are powered on continuously and running under ideal conditions. The final step is to move the spin vector to the desired ecliptic normal attitude, which will be achieved by ground generated and uploaded "bias" commands to the on-board pointing control loop. Solar Array currents will be monitored to determine the post launch attitude for the initial ACS de-tumble activities. The ACS will sequence into a hold state in orbit shadows. CINEMA is planned to be a major axis spinner ($I_1 > I_2 > I_3$) which means that its spin will be passively stable. The ecliptic normal spinning attitude is also a stable attitude, when the spin period is much greater than the orbit period. These stable environments are consistent with very low bandwidth control techniques, and the limited torque authority of the on-board coils. A paper describing the design and modeling of the CINEMA ACS in detail has been submitted to the 2009 AIAA Modeling and Simulation Technologies Conference. Additionally, a presentation with a brief overview of the subsystem has also been submitted for the April 2009 CubeSat Developer's workshop. Prof. D.M. Auslander from UCB's Mechanical Engineering Dept. is overseeing these student based ACS efforts.

LAUNCH AND EARLY ORBIT OPERATIONS CINEMA will be launched in a passive mode. Shortly after separation from the P-POD, the MAG boom will be deployed. Then the system will enter SAFE mode and wait for commands from the ground. SAFE mode has all loads powered off except for the receiver, which is turned on continuously. The spacecraft is power positive in any attitude in SAFE mode. All telecommunications between the spacecraft and the MOC will take place via the BGS 11-m antenna. Initialization, commanded from the ground, will include placing the spacecraft into ACS mode, system checkout and MAG calibration using the torque coils. The resulting MAG calibration coefficients will be uploaded into the ACS software which will be programmed to (1) de-tumble the spacecraft, (2) spin up the spacecraft to 2 RPM, and (3) orient the spin vector to ecliptic normal as described in the ACS section of this proposal. In ACS mode, the MAG is operated in Low Rate (LR) mode and the STEIN

High Voltage is turned off to conserve power. Once normal attitude is reached, the instrument is changed to NORMAL mode, the STEIN instrument can be powered up and MAG and STEIN can start collecting data in High Rate (HR) mode to be transmitted via the high-bandwidth system.

NORMAL OPERATIONS Once configured and oriented, the system will enter normal operations. The spacecraft will be contacted at least once per day to monitor status and upload the time-tagged command sequences to operate the spacecraft. The MOC will schedule passes for both commanding and engineering telemetry reception as well as for high-bandwidth science data recovery using time-tagged sequences that are based on ground station coverage. The MOC will also coordinate MAG and STEIN instrument operations based on predicted orbit location, again using time-tagged onboard command sequences. Spacecraft status monitoring is also automated, with operators being called in when limit checking indicates an anomaly. Otherwise operators monitor activities periodically during normal working hours.

POWER BUDGET CINEMA has solar arrays on all faces so that it is power-positive in any attitude. The CINEMA solar arrays produce an orbit-average power of 3.78W worst case (during the orbits with longest shadows) in Normal operations (ecliptic normal spinning). Prior to achieving ecliptic normal spin, the worst case power configuration is if the small face of the bus is pointed continuously at the Sun, combined with the orbits with the longest shadows, resulting in an orbit-average power of 2.51W. This is adequate to power the bus in SAFE mode. Figure 17 shows the spacecraft power budget in all modes. The bus has adequate power margins in all modes. Should the bus ever become low on power (low battery state of charge), it will automatically go to SAFE mode. If it is still low on power it will load shed while in the dark, powering the receiver back on only when the battery has recharged. Note that in ACS mode power consumption is dominated by ACS torque coil operation, and in a low power condition, torque coil power can be further restricted to save power, but at the cost of a longer time to achieve ecliptic normal orientation. In Normal mode, power can be saved by power-cycling the instruments and reducing downlink times.

Modes:		**SAFE MODE**		**ACS Mode**		**Normal Mode**	
	Base, mW	**Duty**	**Power, mW**	**Duty**	**Power, mW**	**Duty**	**Power, mW**
SAFE							
Bus	120	100.0%	120	100.0%	120	100.0%	120
COM Rx	1,167	100.0%	1167	3.4%	40	3.4%	40
COM Tx	1,889	0.0%	0	0.6%	12	0.6%	12
Science Tx	9,750	0.0%	0	0.0%	0	2.8%	273
Instrument, LR	796	0.0%	0	100.0%	796	0.0%	0
Instrument, HR	1,653	0.0%	0	0.0%	0	100.0%	1,653
ACS	8,000	0.0%	0	10.0%	800	0.0%	0
		Total:	**1,287**		**1,768**		**2,097**
		Margin	49%		30%		44%
		Available	2,513		2,513		3,776

Figure 17. CINEMA Power Budget

The Battery is used for operations in shadow and also to store energy to be used during downlink. The worst case battery Depth Of Discharge (DOD) will occur during Normal operations due to the large transmitter loads, at 25%. An option for a second battery pack to reduce this DOD is under consideration.

5. Technical Readiness & Heritage

UCB/SSL has developed about 100 space instruments/missions, with over ~20 instruments currently operating in space, all competitively selected for scientific excellence. Most recently, we developed the IMPACT instrument suite (including the STE sensors) for the two-spacecraft STEREO mission and led the development of the entire 5- small (~100kg) spacecraft THEMIS MIDEX mission. In addition, UCB/SSL has had an long and extensive history of suborbital projects – balloon and rocket –that have been extremely successful in training students, many of whom have gone on to faculty positions. Thus, we are very experienced in both highly risk-averse NASA missions and small spacecraft, with the very tight QA/reliability specifications, and the nearly completely unconstrained suborbital projects. We believe this heritage is ideal for successful implementation of a scientifically highly rewarding and successful CINEMA space mission; using our experienced space scientists, engineers, technical staff, and managers to mentor and oversee physics grad students and engineering graduate students, enabling them to gain the hands-on training of a suborbital project but with the scientific return of a long-lived space mission.

NASA Ames has developed a number of cubsesat missions, including the successful Genesat mission, and they will provide mentoring and practical experience in cubesat development including avionics, ground systems, launch, and operations. If ITAR regulations can be waived, we will explore the possibility that Genesat avionics could be used for CINEMA.

Our STEIN sensor uses spare STE detectors and electronics left over from the STEREO program. The addition of a sweep electric field in front to convert STE to STEIN is a standard technique using standard sweeping HVPS, and has already been implemented under internal funding for future space missions. Similarly, the magnetometer is already being developed (by our Imperial College collaborators under UK funding) while the boom makes use of stacers that were flight spares for the Polar mission. The CINEMA avionics design utilizes off-the-shelf systems designed for Cubesats with flight heritage. UCB/SSL's uniquely experienced engineering and technical staff that developed the IMPACT suite (including STE) for the two-spacecraft STEREO mission and the 5-spacecraft THEMIS mission will oversee and mentor the UCB engineering students in the development, fabrication, integration and test of the CINEMA spacecraft.

Extensive development work has been going on for a year at UCB/SSL. Engineering grad students mentored by UCB faculty and SSL senior engineers, have developed and prototyped the STEIN sensor (currently being tested), and developed the ACS algorithms and hardware. ICL (with current UK funding) and UCB/SSL have developed the magnetometer/boom system.

6. Deviations from Cubesat Standards

There are no deviations from Cubesat Standard.

7. Student Training

Most of the work on CINEMA will be done by two physics and three engineering grad students, as well as several UCB undergrads (partly supported by other funds), under the mentorship of one of the most experienced senior research and technical staff in space physics. Three physics (J. Sample, L. Wang, A. Shih) and two engineering students (K. Vega on ACS; D. Glaser, M.S, thesis on STEIN) are working on CINEMA now. An important part of CINEMA is the training of ___under-represented minority students per year from the IAUPR in aerospace engineeringby hands-on participation in CINEMA development and operation, funded by external matching funds from IUAPR and local government Our collaboration with KHU involves teaching a CINEMA-based course in space research and engineering for both Korean and US grad students; and ICL magnetometer effort also is student-based. Our group at UCB/SSL has a long history of training students to become outstanding experimental solar and space physicists through the suborbital and space experimental programs, including Professors M. Kelley (Cornell), R.Torbert (UNH), J. Wygant and C. Cattell (Minnesota), G. Parks and R. Holzworth (U. Washington), D. Smith (UCSC), R. Ergun (U. Colorado), R. Millan (Dartmouth), etc., as well as distinguished researchers – 2008 Hale prize winner H. Hudson, 2007 Alfven Medalist C. Carlson, etc. In addition, we have trained over 30 engineering students who have gone on to productive careers in aerospace, including STEREO and CINEMA project manager D. Curtis and mechanical lead P. Turin.

CINEMA Management Plan

Management

UCB shall employ its extensive experience with satellite, balloon, and sounding rocket projects to develop a project management structure which is efficient and cost effective, concentrating effort on the significant technical, cost, and schedule risks. The CINEMA Principal Investigator (PI), Dr. Robert Lin, and Project Manager (PM), Mr. David Curtis, shall work together to manage costs, schedule, technical, and programmatic issues. They will coordinate a tightly coordinated and highly experienced team (Figure 1) to develop the space and ground systems and quickly respond to issues as they come up. Student work will be closely monitored by highly experienced engineers. Regular team meetings will be held to coordinate activities and flush out issues. The PM will support regular telecons with the NSF Program Office to provide project status information and work programmatic issues. Spending will be tracked and resource margins controlled (cost, schedule, and technical) by the PM. Backup and descope options shall be proposed to the NSF Program Office if the PI/PM find the project has inadequate reserves remaining.

Figure 1. CINEMA Key Personnel

Name	Org.	Role	Experience
Dr. Robert Lin	UCB	Principal Investigator	40 years experience as PI including spacecraft, and balloon missions
David Curtis	UCB	Project Manager / Systems Engineer	25 years experience as PM/SE, mostly for NASA missions
Paul Turin	UCB	Lead Mechanical Engineer	20 years experience in developing instrument & spacecraft mechanical systems
Dr. David Pankow	UCB	Analyst	40 years experience developing rocket, balloon, and spacecraft systems
Dr. David Auslander	UCB	ACS Lead	Professor of Mechanical Engineering with expertise in control system engineering
Steve McBride	UCB	STEIN Electrical Lead	30 years experience developing instrument electronics; STEREO STE electrical lead
Chris Smith	UCB	Thermal Engineer	Lead thermal engineer for THEMIS spacecraft mission
Dr. Manfred Bester	UCB	Ground Systems & Telecom	Director of Operations, recently led the on-orbit commissioning, navigation, and science operations of the 5-spacecraft THEMIS mission
John Hines	ARC	Bus Avionics Advisor	Led the development of Genesat, etc.
Timothy Horbury	Imp. College	Magnetometer	This group is PI for Ulysses, Cassini, Cluster, Doublestar, & Solar Orbiter magnetometers
Craig Tindall	LBNL	STEIN Detectors	Fabricated the identical STEREO STE Detectors

Korean CINEMA Kyung Hee University (KHU) will separately manage, fabricate, test, launch, and track a second identical CINEMA spacecraft using their World Class

University (WCU) funding from the Korean government. UCB and KHU will work closely together to provide an academic small satellite design course as a means to bring UCB and KHU students into the process of devloping the CINEMA design. Students from the Inter American University of Puerto Rico (IAUPR) will participate in these classes and in the development and operation of CINEMA to gain hands-on space research experience .

Figure 2, Key Personnel (Korea)

Name	**Org.**	**Role**	**Experience**
Dr. Lee, Dong-Hun	KHU	Principal Investigator	Plasma and MHD waves in space. WCU program PI.
Dr. Seon, Jongho	KHU	Project Manager	15 years experience as PM/SE for Space missions
Dr. Jang, Minnhwan	KHU	Lead Mechanical	10 years experience in developing instrument & space mission
Dr. Park, Soojong	KHU	Software	Infared space Astronomical Instrumentation, Control software
Dr. Kim, Kap-Sung	KHU	Science	Modeling of Solar atmosphere. Non LTE radiation transfer. Analysis Solar data.
Dr. Kim, Khan-Hyuk	KHU	Science	Magnetospheric responses to solar wind changes, Magnetospheric MHD waves .
Dr. Jin, Ho	KHU	System & Electrical Lead	15 years experience developing Astronomical Instrumentation, and space mission
Dr. Lee, Jaejin	KASI	Science & Detector	15 years for Space physics mission development

Risk Management

UCB has a Risk Management system in place with personnel trained and experienced in Continuous Risk Management. The PM will accumulate and classify by likelihood and impact a list of significant risks. He will periodically review them with the PI to determine what mitigations might need to be funded. Any significant risk will be brought to the attention of the NSF Program Office.

Reviews

Internal design reviews will be held to ensure that the design and plans are at the appropriate level of maturity, and that the team is all on the same page and ready to proceed to the next level. NSF Program Office personnel are welcome at these reviews. The combined System Requirements Review and Preliminary Design Review was held in August 2008 (SRR/PDR). This review is targeted at being sure the system requirements are correctly flowed down and the preliminary system design meets those requirements, and served as a gate for the fabrication of prototype instruments. The next review is the Critical Design Review (CDR), which is the final review before starting flight fabrication (in most cases), and will show readiness to proceed with fabrication. The CDR will also cover the ground system design. A Pre Environmental Review (PER) will be held before starting environments to review integration and test results to verify we are ready to proceed to environments, and to review detailed environmental test plans. CINEMA will also participate as needed in the Launch Readiness Reviews (LRR) and any other required mission reviews.

Schedule

The top level schedule is shown in Figure 2. The critical path is shown in red, and follows the S-band transmitter, due to licensing issues and frequency selection (as discussed in the Communications section). Instrument and ACS design and prototype work has already started, funded by UCB. The schedule shows 2 months of schedule reserve prior to delivery. The PM will monitor progress against this schedule and use schedule reserve sparingly, maintaining a reserve of at least 10% of the remaining time to complete. Some of the later qualification activities are considered descope options to maintain the delivery date, such as the full magnetic characterization. The KHU CINEMA spacecraft will follow a similar schedule, depending on their launch opportunity.

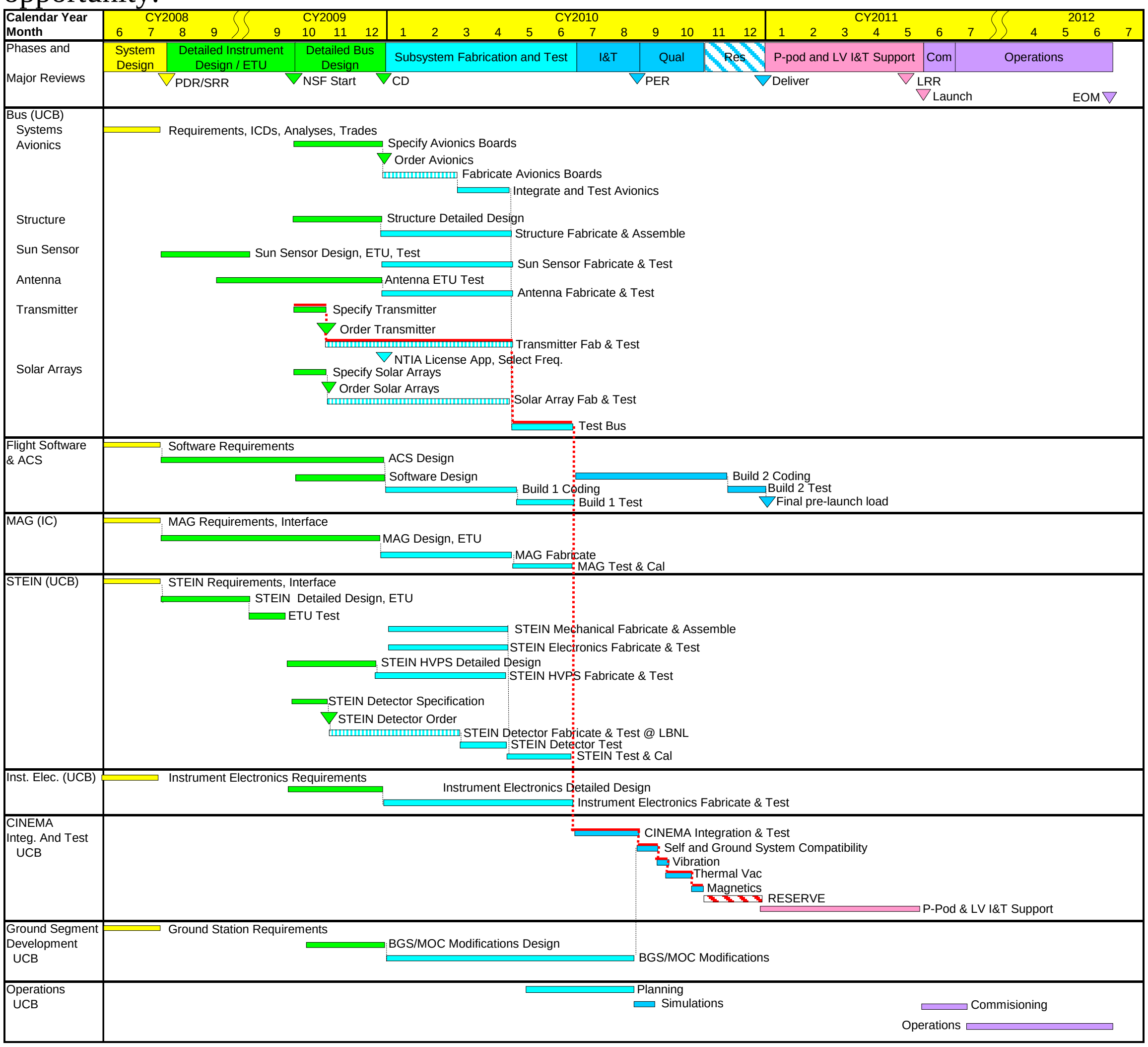

Figure 2 CINEMA Schedule

Quality Assurance and Reliability

CINEMA will be developed with off-the-shelf commercial hardware and parts. Radiation dose will be low so that radiation tolerance is not a primary concern in parts selection. CINEMA will use high reliability parts where cost effective, and follow existing in-house high reliability fabrication procedures, but we plan on achieving most of our reliability by test. We have left significant time at the end of our development for qualification testing to completely check out and burn in the full system with end-to-end and environmental tests. AMES will provide experience with cubesat launch site safety issues.

Environmental Test Plan

Environmental tests include the Cubesat standards (Random Vibration, Thermal Vacuum Bakeout), plus Thermal Vacuum cycling, Magnetics Characterization, Self and Ground Station compatibility and Operational Simulations. Any additional testing required by the launch vehicle provider can be added. Vibration takes place at a local test house we have used frequently. The vibration environment can be tailored to the launch vehicle requirements. Thermal Vacuum / Bakeout will take place at UCB in existing facilities. Self compatibility and Ground station compatibility can take place at UCB, facilitated by the fact that the Berkeley Ground Station and MOC are close by (and in the line of sight to) the UCB I&T facilities. Magnetics characterization can best be carried out at the facilities at Imperial College, but if schedule or other issues make that difficult we can do a simplified magnetics test at UCB.

Budget

The Magnetometer shall be provided at no cost to NSF by Imperial College. The avionics are low-cost off-the-shelf systems from experienced cubesat subsystem manufacturers (Pumpkin, Clyde Space), to be purchased by UCB . Other than a small fund to ARC for consulting with UCB, all NSF funding will be spent by UCB. The CINEMA budget (excluding donations) is shown in figure 3. It is based on a grass-roots estimate, drawing from previous experience with balloon and rocket programs.