Current Status of the Cosmic Hot Interstellar Plasma Spectrometer (CHIPS) University-Class Explorer Mission

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ABSTRACT

We present a status report on CHIPS, the Cosmic Hot Interstellar Plasma Spectrometer. CHIPS is the first NASA University-Class Explorer (UNEX) project, and was launched on January 13, 2003. The grazing incidence CHIPS spectrograph is surveying selected regions of the sky for diffuse emission in the comparatively unexplored wavelength band between 90 and 260 Å. These data are providing important new constraints on the temperature, ionization state, and emission measure of hot plasma in the "local bubble" of the interstellar medium.

Keywords: CHIPS, spectrometer, spectrograph, extreme ultraviolet, EUV, interstellar, UNEX

1. INTRODUCTION

At 10^6 K, equilibrium models with solar abundances predict that more than half of the power radiated by an optically thin plasma emerges between 90 and 260 Å. Particularly prominent is a cluster of emission lines of highly ionized iron around 180 Å (Fe X 174.6 Å, Fe IX 171.1 Å, Fe XI 180.4 Å, and Fe XII 186.9 Å). Although some prior observations had suggested that the intensity of these lines was below the strength predicted by collisional ionization equilibrium models[1] for the emission measure expected for the from local diffuse hot plasma,[2] identifying the true background or zero point in these early observations was difficult, and the results correspondingly subject to systematic effects. More recently, McCammon *et al.*[3] reported a detection of the lines, with a combined strength of about 50 photons / (cm^2 s ster). The resolution of McCammon *et al.* was insufficient to distinguish the features.

The CHIPS mission was designed to record spectra of diffuse emission in the comparatively unexplored wavelength band between 90 and 260 Å. The peak spectral resolution is 1.4 Å. The instantaneous field of view is about 6° x 26°. In an integration time of 150,000 sec, any of the iron lines described previously, at a strength of 30 photons / (cm^2 s ster), would be expected to produce a 3σ or 99.7% confidence detection. For comparison, the three brightest lines, in the most favorable directions, were expected to combine to a strength of about 400 photons / (cm^2 s ster) if the equilibrium models were correct. CHIPS data are providing provide important new constraints on the temperature, ionization state, and emission measure of hot plasma in the "local bubble" of the interstellar medium.

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2. THE CHIPS SPECTROGRAPH

Figure 1: Light path of the six channels of the CHIPS spectrograph.

Figure 1 shows a representation of most of the components of the CHIPS spectrograph. Light enters the instrument through an array of six entrance slits, each 7 cm in length, and with width selectable to 0.025 or 0.1 cm. Three of the light paths, or channels, each contain a small flat pick-off mirror interior to the entrance slit to coalign its field of view with that of its nonmirrored counterpart. Each channel is otherwise optically identical. An array of thin-film filters immediately in front of the detector attenuate scattered light. The detector records a single spectrum from the entire field of view. These components are discussed more fully in Hurwitz et al. 2002.[4] Additional papers in this Proceedings describe the low-cost innovative spacecraft developed for the mission by SpaceDev, Inc. (Janicik *et al.*), the detector (Marckwordt *et al.*), the optical train (Sholl *et al.*), and the calibration and data analysis effort (Sirk *et al.*).

3. LAUNCH AND EARLY OPERATIONS

CHIPS was launched at 16:45 PST on January 12, 2003, aboard a Delta-II rocket with the primary payload ICESat. The orbit is close to circular at 586 km with an inclination of about 94°. The spacecraft was detumbled on January 20. Checkout and commissioning of the attitude control system and spectrograph occurred over the following weeks. The detector door was opened on January 26. By February 2, all six of the entrance slit covers had been opened to their 1mm or "wide" positions (the first detente following the closed positions employed during launch). Astrophysical observations ramped up in early February as commissioning activities wound down.

During orbital day, the main spacecraft solar panels must be pointed at or near the sun (both to achieve an overall power sufficiency and to place the sun within the field of view of the "medium sun sensor" or MSS). During orbital night, this constraint can in principle be relaxed. From mid February through March 17, however, we maintained the constraint even during orbital night as a method of risk reduction. Only during the brief slew periods were the main solar panels pointed far from the sun vector, reducing the risk that an anomaly would leave the spacecraft fixed in an undesirable attitude. Because the boresight of the spectrograph and the long axis of the field of view are about 90° from the MSS boresight, the observable sky was limited to approximately a great circle, extending to only moderate galactic latitudes at that time of year.

By mid-March, the spacecraft systems and operational procedures were deemed sufficiently robust that the sun constraint was relaxed during orbital night, opening up much more of the celestial sphere. Selected pointings at high galactic latitude fields provided hints of the extreme ultraviolet emission features that CHIPS was designed to resolve. At about the same time, the first lunar pointings in which the instrument moon sensor provided active feedback to the control loop were performed. The good agreement between the predicted and measured lunar flux confirmed that the faintness of the astrophysical emission was real, and not instrumental.

Although leaving the slit covers in the wide position offered the greatest sensitivity if only shot noise was considered, spectra taken through the wide slits were less ideal when systematic effects were considered. The wavelength scale with wide slits is such that the comparatively bright geocoronal He II feature at 256 Angstroms is shifted to the very edge of the detector, making it difficult to use that line to set the overall wavelength scale or as a flux calibrator. Furthermore, at the center of the band the resolution with wide slits is about a factor of 2.7x poorer compared to the narrow slits. Thus with the wide slits it was correspondingly more difficult to distinguish low S/N putative detections of astrophysical emission from coincidental artifacts either in the detector response to charged particles (which dominate the total background) or in the stray light (which is 4x brighter with wide than with narrow slits). From its earliest proposal stage, CHIPS was advertised as being comparatively free of the systematic effects that were so prominent in earlier observations, and the wide slits simply did not provide a sufficient number of independent resolution elements at wavelengths *outside* of the regions where astrophysical emission might plausibly occur. Finally, with the wide slits, CHIPS did not achieve the spectral resolution called for in the "Level 1" science criteria (a controlled document between U.C. Berkeley and NASA capturing, among other things, the minimum performance goals). Accordingly, by April 7, 2003, all six channels were switched to narrow-slit mode.

Throughout the early period, mission operations were conducted from the mission operations center at SpaceDev Inc., with only instrument commands originated at Berkeley. Operation of the satellite from the SpaceDev facility was crucial, as it enabled the most experienced and knowledgeable spacecraft engineers to participate in the day-to-day (sometimes moment-to-moment) decision making. As operations as a whole became routine, however, it became advantageous to rely on the mission operations personnel and infrastructure developed primarily for the HESSI and FAST missions already in place at Berkeley. Operations were transitioned to Berkeley in late May 2003, with SpaceDev continuing to participate in periodic meetings and as required to resolve anomalies.

Planning of the observing time-line is initiated by the science team, utilizing elements of the software originally developed for the Hopkins Ultraviolet Telescope (HUT) project and later adapted for the Orbiting Retrievable Far and Extreme Ultraviolet Spectrometer (ORFEUS) project. An independent code developed by SpaceDev confirms that the time-line satisfies those constraints related to spacecraft health and safety before the time-line is uploaded to the spacecraft. From about April 7 to mid-July, CHIPS averaged an observing efficiency of about 42%, inclusive of all deadtime effects.

4. LUNAR CALIBRATION

Like many small instruments, CHIPS achieves a comparatively high sensitivity to diffuse emission through its large field of view, not its collecting area. As a result, the only "point source" that it can detect in a reasonable period (other than the sun, which is far too bright) is the full moon, reflecting a faint solar spectrum. Because the full moon is always about 180° from the sun, the spectrograph cannot observe the moon while the sun is in the field of view of the MSS. In such a configuration, the attitude control system must rely on its magnetometer, and the integrated signal from its rate sensors, to achieve inertial pointing. In that configuration the pointing error can accumulate to ~4° during an orbital night, potentially moving the moon outside the field of view of the spectrograph. For this reason, the spectrograph was equipped with a dedicated moon sensor coaligned with the spectrograph boresight.

Signals from the moon sensor's quadrant cell not only provide *post facto* knowledge of the moon's position but are provided to the spacecraft attitude control system and can participate in the active control of the spacecraft.

The first observations of the moon under the control of the moon sensor were carried out on April 17, 2003. The moon was placed generally near the boresight of the spectrograph, and was observed again around May 15-16, 2003. In Figure 2 we show the resulting lunar spectrum histogrammed over the half of the detector covered by the polyamide and aluminum filters. We also show the scaled charged particle background (determined from periods when particles fully saturate the telemetry stream), and a model consisting of a reference solar spectrum (EUV97 model) scattered by the moon and folded through the instrument response curve scaled to the actual observing time. We assume that the first surface of the moon scatters with an albedo calculated for polished SiO_2 using the optical constants available at the web site of the Center for X-Ray Optics at the Lawrence Berkeley National Laboratory. We assume that the EUV scattering is isotropic over 4π steradians (*i.e.*, that half of the "reflected" EUV light is forward-scattered into the lunar surface). There are otherwise no free parameters in the model. Clearly, there are systematic uncertainties in these assumptions that are difficult to quantify, but the overall agreement between the model and the observed spectrum is excellent, and supports a finding that the instrument response is nominal. This result is further supported by the measured brightness of the geocoronal He II feature at 256.3 Å (which, for long-duration inertially fixed pointings sampling a range of coronal sight-lines, ranges from about 125 to 4600 photons / (cm^2 s ster)) and the instrument response to scattered He I 584 Å emission (which agrees well with the preflight prediction).

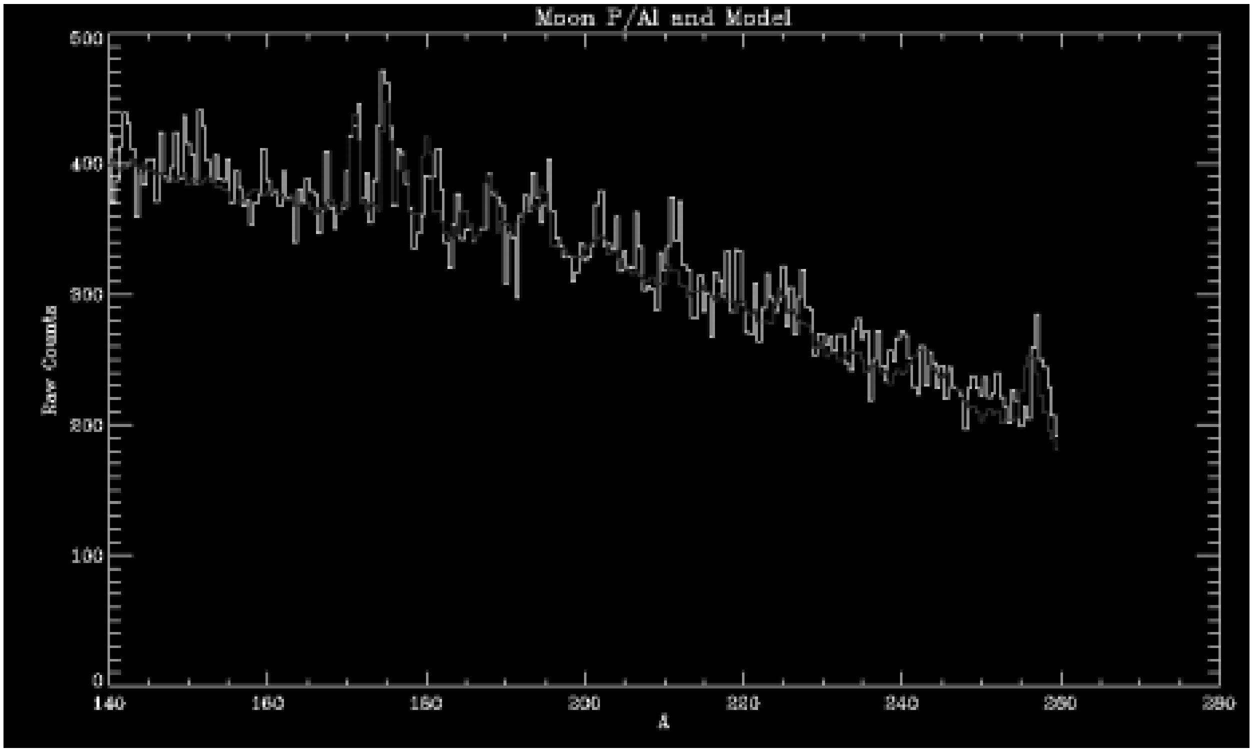

Figure 2: Observed and modeled lunar spectrum. White histogram: observed counts per 0.5 Å in Poly/Aluminum panels. Red histogram: Model described in text.

5. OBSERVATIONAL RESULTS

In Figure 3 we show spectra from the Poly/Al detector half, for three broad regions of sky: high and low galactic latitude, and near the plane (b>+45°, b<-45°, and -45°<b<+45°, resp.). For the b>+45° (highest curve), the values are the raw counts per 0.5 Angstrom bin. For the other two curves, the counts are scaled somewhat arbitrarily and offset to enable the curves to be distinguished. The data near the plane are shown in red. The data are extracted as described in Sirk et al. (this proceedings). Where detector "hot spots" are excluded (always representing a very small fraction of the total counts at a given wavelength), the remaining counts are scaled upward to account for the "missing" events. Otherwise, the data are completely raw; no smoothing has been applied. The observation time at b>+45°is about 2.5 million seconds; b<-45 and the galactic plane each represent about 0.5 million seconds.

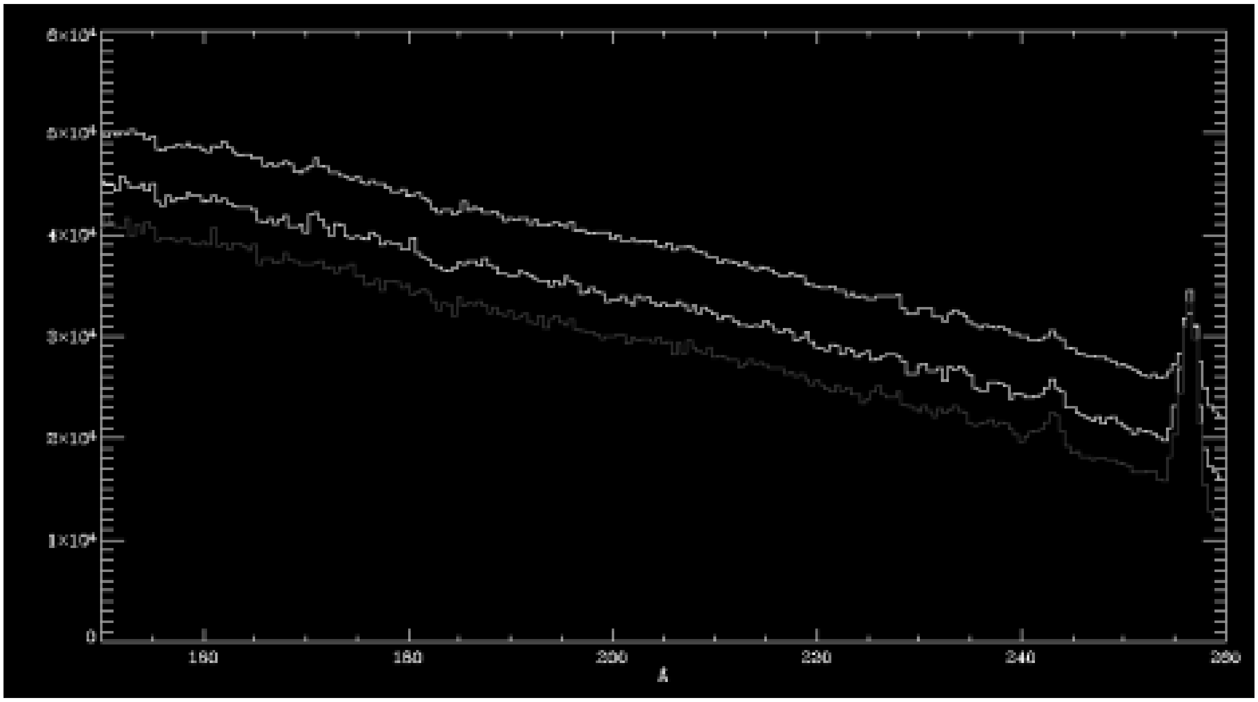

Figure 3: Poly/Al spectra; see text for details. The He II Lyman series (geocoronal) is detected at least through Ly δ.

The feature at 256.3 Å is of course the Lyman β line of He II, primarily geocoronal in origin. Additional He II Lyman lines are also clearly visible between the Ly β line and the ionization threshold near 228 Å. Near 171 Å, there may be a spectral feature visible in the high and low latitude data that is not seen closer to the galactic plane. If real, this would indicate that the emission line complex is dominated by Fe IX, a surprising result and indicative of temperatures closer to $10^{5.8}$ to $10^{5.9}$ rather than the $10^{6.0}$ to $10^{6.1}$ inferred from the X-rays. However, the feature is not confirmed in the spectra from the Zr/Al detector half, as shown below in Figure 4.

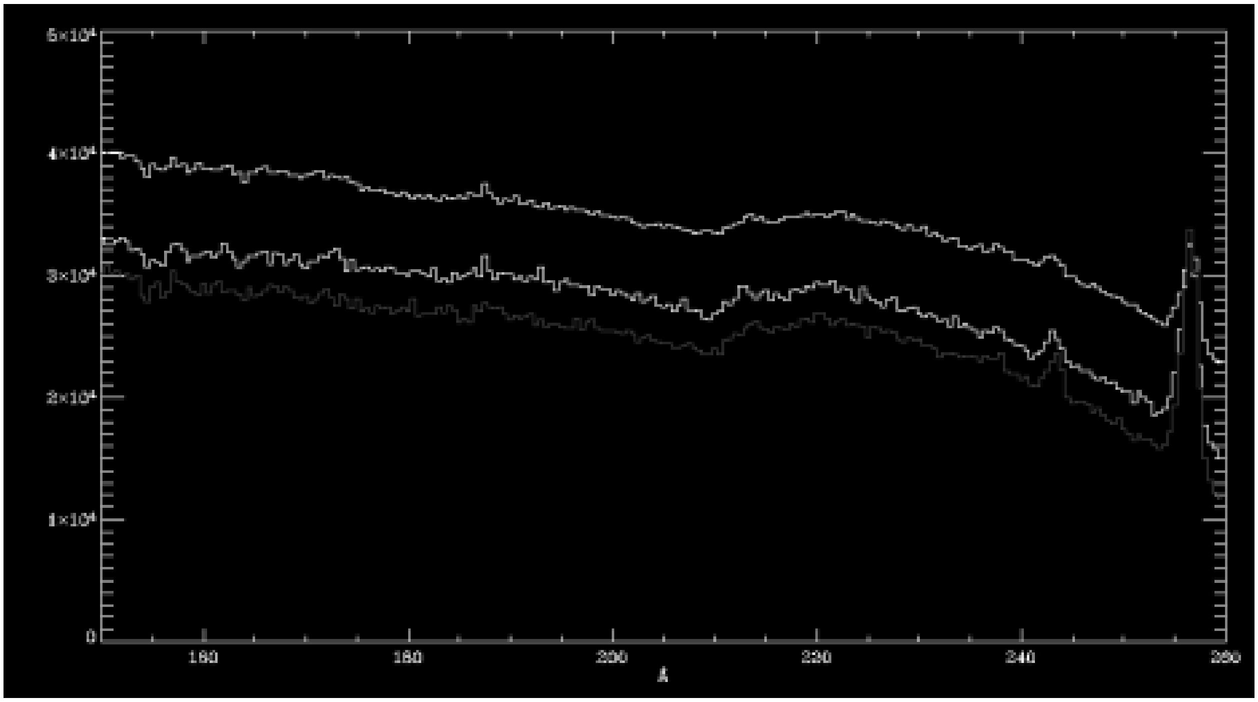

Figure 4: Zr/Al spectra; same presentation as Figure 3. The Fe XII feature at 187 Å is contaminated by a transient "hot spot," which appears as a narrow bump or blip in the high and low latitude spectra.

Combining the Poly/Al and Zr/Al spectra results in a tentative detection of the Fe IX feature at 171 Å, with an intensity of 10 ± 5 photons cm^{-2} sec^{-1} $ster^{-1}$. In addition to the low statistical significance, the detection cannot be considered secure until other excursions in the spectrum of comparable (or greater) magnitude, and the discrepancy between the Poly/Al and Zr/Al spectra are fully accounted for. Excluding the Fe XII feature at 187 Å, which is contaminated by a transient "hot spot," the remaining three Fe features have a combined strength of 2 ± 9 photons cm^{-2} sec^{-1} $ster^{-1}$. The CHIPS observations to date are strongly weighted toward regions where the emission is expected to be bright (based on soft X-ray flux, low foreground absorption, etc.). The high latitude emission measure of Kuntz and Snowden, if collisional ionization, solar abundances, and only moderate foreground absorption (typ. 4×10^{18} cm^{-2}) are assumed, predicts several hundred photons / (cm^2 s ster). Clearly, the CHIPS data are inconsistent with one or more of these assumptions.

Some individual CHIPS spectra show individual iron features as bright as 30 photons / (cm^2 s ster). However, to confirm that these are valid detections, and not merely the combined result of detector artifacts and/or ordinary excursions arising from sampling many individual spectra at 4 to 5 wavelengths of interest, will require further analysis. In the meanwhile, observations are ongoing.

6. CONCLUSION

Despite the comparatively low cost for which it was developed, the spectrograph and spacecraft of CHIPS are operating well on orbit, with throughput comparable to the prelaunch calibration. Initial results show that the diffuse EUV astrophysical emission is much fainter than predicted, challenging models of the local hot plasma believed to produce the soft X-ray background.

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