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STATUS OF CHIPS: A NASA UNIVERSITY EXPLORER ASTRONOMY MISSION

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Abstract. In the age of "Faster, Better, Cheaper", NASA's Goddard Space Flight Center has been looking for a way to implement university based world class science missions for significantly less money. The University Explorer (UNEX) program is the result. UNEX missions are designed for rapid turnaround with fixed budgets in the \$10 million US dollar range. The CHIPS project was selected in 1998. The CHIPS mission has passed the Concept Study and will be having the Confirmation Review in August 2000. Many lessons have already been learned from the CHIPS UNEX project. This paper will discuss the early issues surrounding the use of commercial satellite constellations as the bus and the politics of small satellites using foreign launchers. The difficulties of finding a spacecraft in the UNEX price range will be highlighted. The advantages of utilizing Internet technologies from the earliest phases of the project through to communications with the spacecraft on orbit will be discussed. The current state of the program will be summarized and the project's plans for the future will be charted.

What Is UNEX

The University-Class Explorer (UNEX) program is funded by NASA with the goal of demonstrating that significant science and/or technology experiments can be performed with small satellites and in constrained budgets. UNEX requires a development time of approximately two years and a mission budget on the order of \$10-\$15M inclusive of the launch vehicle and mission operations.

CHIPS Winning Proposal

The proposed Cosmic Hot Interstellar Plasma Spectrometer (CHIPS) mission, designed within

the constraints UNEX program, will provide spectral sky maps of the scientifically critical but virtually unexplored extreme ultraviolet (EUV) band between 90 and 260 Å. The CHIPS full-sky survey will help determine the electron temperature, ionization conditions, and cooling mechanisms of the million-degree plasma believed to fill the local interstellar bubble. Although the diffuse million-degree plasma is ubiquitous in the Universe, the EUV band where the majority of its thermal emission is expected to emerge remains poorly explored. As a result, there is significant uncertainty in the mechanisms by which hot interstellar plasma sheds its reservoir of thermal energy. Therefore, key plasma diagnostics from CHIPS high-resolution data will help to constrain

theoretical models of heating and cooling in the interstellar medium and galactic structure.

CHIPS exploits flight-proven optical, detector, and electronic components to achieve an unparalleled combination of sensitivity and spectral resolution in the grazing incidence EUV band. The instrument, a multi-channel spectrograph, consists of an array of entrance slits and cylindrical diffraction gratings that disperse and focus diffuse extreme ultraviolet radiation onto a photon-counting microchannel plate detector. A dedicated electronics unit provides all instrument specific functions, including power distribution and control, photon data processing and instrument safing.

The CHIPS mission was initially proposed as part of the 'Secondary Payload Program' aboard a FAISAT commercial communications satellite. The satellite was scheduled for launch on a Cosmos rocket in mid-2001. The partnership with Final Analysis Inc., providers of FAISAT, represented an innovative approach to achieve a long duration mission at an extraordinarily low cost. However, because of complications described further in this paper, the CHIPS instrument will instead be carried aboard a dedicated small satellite developed by SpaceDev and launched as a secondary payload aboard a Delta II booster. Although this configuration differs from the flight implementation envisioned in the original proposal, the scientific goals are unchanged and the data products are actually improved. The flexible and capable SpaceDev configuration not only provides the ability to accomplish a full sky survey of the entire celestial sphere, but also allows very deep observations of regions of particular interest.

Politics Intervene

The proposed match between Final Analysis, Inc (FAI) and the CHIPS payload was a good one. While FAI did have to make some changes to their bus design (because CHIPS was an astronomical, not Earth observation payload) the ability to utilize their attitude, power, and data systems was very convenient. From a cost perspective, the fact that CHIPS was merely buying space aboard an

existing satellite rather than purchasing a dedicated bus offered obvious savings.

FAI chose a Russian company for the launch of the FAISAT constellation, exercising their right as a commercial company to have non-USA rocket companies bid for launch services. Payload contracts with FAI are not related to the launch costs: payloads essentially pay for time on orbit and their power, storage, and other operational needs. This was key in that a 1994 government rule forbade the launch of government payloads on foreign boosters.¹ The plans for launch of the CHIPS spectrograph aboard the FAISAT, including the use of the Russian booster, were explained in the initial proposal to NASA. At the time of approval, the agency foresaw little difficulty with the aforementioned regulations because the project was small in scope, bore no direct launch costs, and the government-supported hardware was merely an instrument, not a "payload."

In October of 1998, the project became aware of the requirement for an Office of Science and Technology Policy (OSTP) review for the launch of the CHIPS instrument on the Russian rockets. The precise origin of this requirement, and the procedure by which it could be met, remained uncertain through most of early 1999.

In April of 1999, the CHIPS team proposed a initial review that would cover just the payload and not the spacecraft bus or launch, potentially affording time for the Russian issue to be resolved while enabling the Berkeley team to begin hardware work. NASA was justifiably skeptical of this approach and reiterated their desire to have a review that covered the payload, satellite, and launcher. Within the fixed price structure of the UNEX programs, initial funding was planned to cover a study period of only a few months duration. Eight months later, with no resolution in sight, a decision had to be made.

In May, NASA graciously granted an extension of the review schedule until July, the CHIPS team regretfully parted ways with FAI, and started the search for a new ride into space.

The Hunt

The CHIPS team now had several months to find either a new host spacecraft, and fly as a secondary payload, or a free flying spacecraft and launch that would fit within the UNEX cost caps.

The search team talked to a number of primary spacecraft missions. The issues of schedule and accommodations on a primary spacecraft seemed insurmountable. Missions large enough to accommodate the CHIPS instrument as a potential secondary payload were generally so large that the few million dollars budgeted was of little interest. Combined with the natural reluctance of project managers to complicate their own lives, the situation for finding accommodations for CHIPS as a secondary payload looked bleak. A standalone spacecraft now seemed like the best option.

Most primary spacecraft already had launches. The CHIPS team had to identify not only a spacecraft bus but also a means to get into orbit. NASA tentatively offered a launch as an ejectable from the shuttle. This initially seemed to be the only viable option and was therefore baselined despite the difficulty that most shuttle missions fly at altitudes too low for a small spacecraft to remain in orbit for a full year without a propulsion system.

With this option in hand, a number of spacecraft vendors were solicited for proposals for a dedicated CHIPS spacecraft. After receiving a half dozen good proposals for standalone spacecraft, the CHIPS team, with the help of outside reviewers, finally selected the one from SpaceDev.²

The New Partnership

The initial SpaceDev proposal included a cold gas propulsion system because of the low space shuttle release orbit. It was also a moderately sophisticated three-axis stabilized spacecraft, which would allow an enhanced science mission.

Early on in the preparations for the oft-delayed initial review, SpaceDev identified a launch

opportunity on a GPS refurbishment mission aboard a Delta II launch vehicle. This option could leave a CHIPSat sized spacecraft in a respectable 600 km circular orbit, eliminating the need for a propulsion system.

The SpaceDev/UCB team hosted a highly successful initial review (Concept Review) in July 1999.

Redesign Woes

From the initial review, the CHIPS team proceeded towards a Confirmation Review scheduled for early Spring 2000. However, as the design matured, it became clear that CHIPS spacecraft would not meet the center of gravity requirements published in the Delta II Secondary Payload User's Guide. Although the Delta II launch opportunity offered significant advantages, a major disadvantage was that communication with Boeing, the Delta II provider, was difficult before the CHIPS mission was officially confirmed by NASA. However, for a successful Confirmation Review, NASA required a viable instrument/spacecraft design, one that would meet all launch vehicle constraints. Faced with this Catch 22, the CHIPS team decided a redesign to fit within the published guidelines would be the best course.

Most significantly, the instrument was scaled down from the initially proposed nine channels to six channels so it could fit within the mass and volume constraints of the launch vehicle. The reduction in instrument throughput by 50% was deemed acceptable, primarily because by this time in the project the efficiency or throughput of most of the individual components in the science instrument were fairly well characterized and therefore there was less need for margin. The descoped instrument should achieve at least the "minimum" science performance criteria established for the initial instrument, and may approach the nominal or "baseline" criteria.

Current Design

The CHIPS instrument, as currently baselined, consists of six independent channels. The entrance apertures are narrow slits, covered by simple once-open covers to protect the CHIPS interior from contamination during integration and launch. Light passing through the entrance slits illuminates individual, identical cylindrical diffraction gratings. The gratings disperse and focus the diffuse extreme ultraviolet radiation onto a single detector through a filter assembly.

The instrument detector is a planar, photon-counting microchannel plate system with a crossed delay line anode. In-band photon locations are determined from the anode, which converts the light into analog electronic pulses. RF amps amplify the anode signal and the pulses are converted into digitized coordinates by the Time to Digital Converter (TDC) in the CHIPS Instrument Electronics Box (EBOX). The digitized events are then transmitted to the instrument computer for processing.

The CHIPS spectrograph is illustrated in Figure 1.

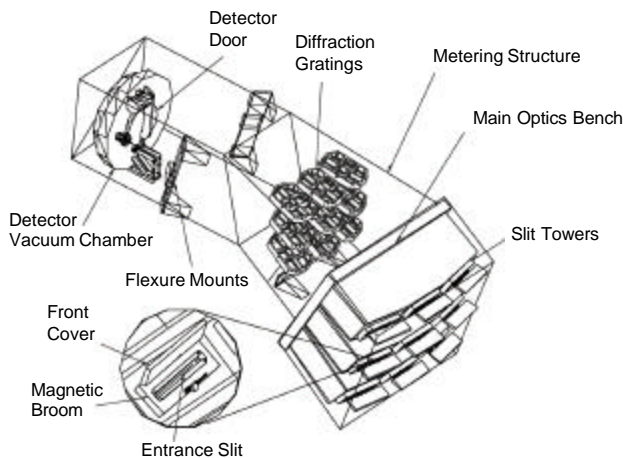


Figure 1: CHIPS Spectrograph

Low-current power to the CHIPS Low Voltage Power Supply (LVPS) and high-current power to the instrument door and cover actuators and to heaters is supplied directly from the spacecraft 14V batteries (through the spacecraft unregulated power supply). The instrument incorporates its own converters to generate required secondary

voltages. The CHIPS Data Processing Unit (DPU) controls all instrument power distribution control through the LVPS, from opening the detector door and covers to autonomous thermal control and count rate shutdown of the instrument HV power supplies.

The DPU also packages and formats all instrument data for transmission to the spacecraft Single Board Computer (SBC) via redundant asynchronous RS-422 links. Scientific and instrument housekeeping data is stored within spacecraft memory, combined with orientation data, and downlinked several times daily to S-band ground stations. Data is received, archived, and monitored at the Mission Control Center (MCC) and then sent to the CHIPS Science Operation Center (SOC).

If necessary, the spacecraft provides thermostatically controlled heaters to keep the instrument within its survival temperature range while the instrument is not powered.

The current baseline design of the CHIPS spacecraft (CHIPSat) meets the requirements imposed by the UNEX program, as well as the requirements imposed by the science objectives, instrument and launch vehicle.

CHIPSat is a 3-axis stabilized spacecraft using 4 momentum wheels, 3 torque coils, a sun sensor, magnetometer, and rate sensors to provide ~2 degrees attitude accuracy and control. The spacecraft is nominally sun pointing with complete freedom to yaw about the solar array normal vector allowing the CHIPS instrument to obtain a full sky survey within a year while avoiding pointing the instrument at sun, earth, moon and orbital Ram direction. This flexible and highly capable design provides access to all points on the celestial sphere within the one-year mission lifetime.

The CHIPSat structure uses a milled aluminum transition adapter and aluminum honeycomb panels with facesheets to provide the structural integrity required to survive launch conditions as well as a stable platform for the CHIPS instrument and other spacecraft components. The component configuration supports all subsystem thermal,

volume and field of view needs, while minimizing wire lengths and losses. The calculated mass for the entire satellite is less than 70 kg.

Dual-junction GaAs/InP/Ge solar arrays with Nickel Cadmium batteries provide the necessary peak and average power during all mission phases. The primary solar arrays are body mounted on three sides of the spacecraft and sized to provide energy margin for all nominal mission phases at end-of-life. In addition, small keep-alive arrays are positioned on the other sides of the spacecraft and will provide enough power to run critical subsystems regardless of the spacecraft's attitude. A peak power setting system provides CHIPSat with an efficient means of supplying required power throughout the spacecraft's lifetime.

Signals from the instrument and spacecraft subsystems are acquired, formatted and stored by the spacecraft's communication and data handling system prior to downlink transmissions. This system incorporates a single-board flight computer consisting of a Motorola Power PC 750 CPU, memory, and I/O for interfacing to distributed processors. CHIPSat will use an S-band transceiver for the RF communications. A pair of quadrifilar antennas mounted on opposite sides of the spacecraft provides an omnidirectional beam pattern.

The spacecraft thermal subsystem relies primarily on the passive techniques of conduction and radiative heat transfer to provide the necessary thermal control at a low cost and with minimum power consumption. Surface coverings, component placement and limited heater use are the foundation of the thermal design. Figure 2 shows the CHIPSat configuration.

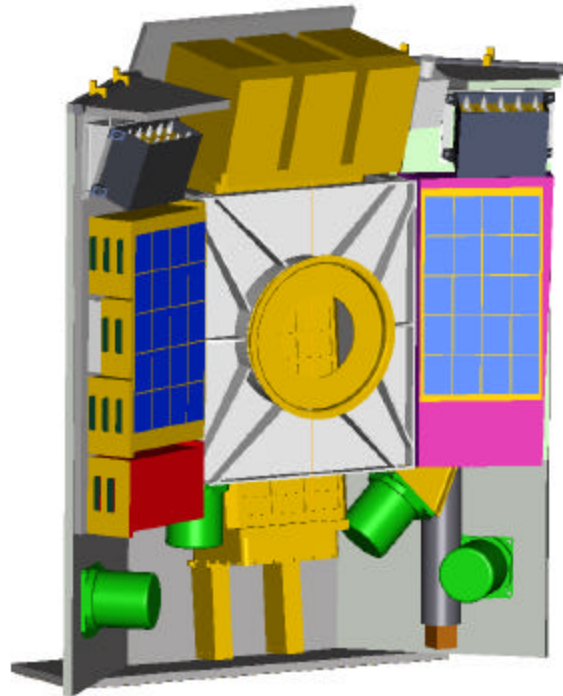


Figure 2: CHIPSat

The Internet

Controlling costs are critical to a small project like CHIPS. Every effort must be made to assure that team members work effectively and that communications are clear. Duplication of effort must be avoided and all available tools must be exploited as much as possible.

The Internet has proved to be a boon for distributed projects such as CHIPS. A document archive has been established using commonly available web tools. This archive is being used to provide a ready reference between engineers and scientists at the many locations involved in the CHIPS project.

UCB has been a strong proponent of Internet tools since the mid-1980s when Internet protocols were used to connect flight hardware prototypes and various ground systems together.³

Determined to take the next step and utilize Internet protocols all the way from the scientists to the payload interfaces on board the spacecraft, CHIPSat has teamed with the OMNI project at GSFC in this venture.⁴ The TCP/IP stack and

existing utilities (such as FTP) built into the WindRiver VX Works RTOS in the spacecraft provide an essentially “Free” infrastructure for moving data between the spacecraft and the ground systems. This system is ideal in that it is essentially transparent: it works as well in the lab when the spacecraft is on the bench as it does on orbit.

The Internet is also being used to support early “virtual integration” of components. We have already started to use virtual terminal routers to move serial data between the payload computer, the Mission Control Center (MCC) at SpaceDev, and the initial version of our Science Operations Center (SOC). We expect to have worked out the vast majority of interface problems well before the expensive on site integration begins.

The Future

The CHIPS program is now back on track for an April 2002 launch. The team is working towards a Confirmation Review in August 2000 with a Design Verification Review soon after. Delivery of the Instrument to SpaceDev is expected in April 2001 for a full year of integration and testing prior to launch.

References

¹ Science, *Red Tape Entangles Small Satellite*, Volume 283, 1999-02-12.

² Space News, *SpaceDev Shifts Focus to Low-Cost Missions*, 1999-11-15.

³ W. Marchant, C. Dobson, S. Chakrabarti, R. Malina, Telescience-Concepts and Contributions to the Extreme Ultraviolet Explorer Mission, Proc. SPIE, 851,1987.

⁴ <http://ipinspace.gsfc.nasa.gov/>