Far Ultraviolet SpectroPolarimeter (FUSP)

Target:

Beta and Zeta Tau

Experimenter's Data Package

Vehicle
36.173UG

Revision F
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Prepared for:

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Change History

Rev	Date	Description
A	28 Aug, 1997	Original. For PIC
B	20 Mar, 1999	Preliminary Design Review
C	2 Nov, 1999	Design Review; update success criteria, mass properties, event list, interface; include test startracker (ST3)
D	14 Jan, 2000	Changes from Design Review: door hinge; ST3 connector
E	2 June, 2006	Update to use MkIID ST5000 for main startracker (ST1) and for ZOD (ST2). Delete ST3. Add uplink requirements
F	5 May, 2008	Reorganize for re-MIC

1. Description of Experiment

FUSP is a sounding rocket payload that will obtain the first high-precision spectropolarimetry from 1050 - 1500 Å, and the first astronomical polarimetry of any kind below 1300 Å. It will provide measurements of polarization produced by electron scattering, resonance line scattering, and hydrogen Rayleigh scattering in the inner circumstellar environment of hot stellar systems, and thereby quantitatively constrain the geometry and dynamics of the system. In addition, the strength and geometry of the magnetic field will be determined from two new diagnostic tools, the Hanle Effect and Magnetic Realignment. A variety of specific scientific questions relating to inflows and outflows from stars will be addressed by FUSP:

- Measuring the effects of rotation in the envelopes of OB stars: These observations are designed to allow us to go beyond the simplest ideas of spherical winds to build a much more realistic understanding of stellar mass loss.
- Exploring the role of magnetic fields in hot stellar winds from OB stars and binary stars by means of the Hanle Effect and Magnetic Realignment: Can magnetic fields confine or significantly modify OB stellar winds, and what is the geometry of the magnetic field in the diffuse interstellar medium around them?
- Investigating the possible sign change of the interstellar polarization in the Far UV predicted by many interstellar dust models.

Table 1 lists some candidate targets for calibration targets, Oe/Be stars, Wolf-Rayet stars, supergiants, interacting binaries, and the interstellar medium. "V" is the visual magnitude, and "m_{133}" is the Far UV magnitude. The experiment is intended for multiple reflights on different targets. For the first flight, 36.173UG, we will target β Tau, an unpolarized calibration star, and ζ Tau, a known highly polarized Be star with numerous FUV emission and absorption lines which are expected to show a variety of polarimetric effects.

Prog	Target	V	m_{133}	Comment
Unpol	β Tau	1.7	-0.5	
Be	γ Cas	2.5	-1.6	No shell lines
	ζ Tau	3.0	-0.3	Shell, WUPPE obs
Oe	ξ Per	4.0	1.0	O7e rapid rotator
	HD93521	7.1	2.8	O9e rapid rotator
WR	EZCMa	6.9	2.5	WN5, WUPPE obs
SG	β Ori	0.1	-0.8	
	ζ Ori	2.1	-2.5	Magnetic Field Probe
Bin	β Lyr	3.5	2.0	FUV all scattered?
ISM	σ Sco	2.9	-0.5	λ_m=560 nm
	ρ Oph	5.0	2.1	λ_m=680 nm

Table 1. Candidate FUSP Targets

Figure 1 illustrates the FUSP optical design. The telescope is F/2.5 prime-focus with a 50-cm primary. The spectrometer uses an aberration-corrected spherical holographic grating with a radius of curvature 35 cm, a diameter of 12 cm and a groove density 1500 gr/mm, for a dispersion of 18.3 Å/mm. The spectrum from 1050 -1500 Å is then 25 mm long. A typical image has an rms width of 25 μ in the direction of the dispersion and 100 - 900 μ perpendicular to the dispersion. With a ±2 arcsec pointing deadband, the rms width due to pointing is 11μ, and the net spectral resolution is then 27μ (0.39 Å, R=3000, 1.0 25μ pixels, 4.5 arcsec), and the net spatial resolution is about one arcmin perpendicular to the dispersion. The primary mirror and spectrometer coatings will be LiF overcoated Aluminum. On the ground, the entire telescope is evacuated, with the aperture sealed by a vacuum door.

The polarimetric modulator is a 12.7 mm square, 1.5 mm thick stressed-LiF waveplate, mounted just before the telescope focus. The waveplate is made to be halfwave at 1240 Å by applying approximately 15 pounds pressure to one edge of the plate; polarimetric modulation is performed by rotating the plate 45°, which rotates the plane of polarization by 90°. The LiF plate is the only transmissive element in the instrument, and results in a short wavelength limit of 1050 Å. The pressure on the LiF plate is applied by a spring; this pressure will be monitored by a strain gauge. The polarization analyzer is a diamond mirror mounted at the telescope prime focus at an angle of 72.5° (the Brewster angle). The diamond mirror will be mated to a substrate which is reflective in the visible, so that a pointing monitor at the zero order of the spectrometer may aid in acquiring the target. The detector is a thinned 1024×1024 SITe CCD with 25µ pixels, overcoated with a UV down-convertor. The CCD will be operated shutterless, by using frame transfer readout: one half of the CCD will be masked so that the 12×25 mm spectrum image may be rapidly shifted onto the non-imaging half and then read out slowly without smearing. The CCD is cooled to -60°C by a Thermo-Electric Cooler (TEC), which discharges its heat into a copper heat sink on the rear of the spectrograph housing. The heat sink is cooled to about -40°C by a thermal link to a 0.5 liter capacity LN_2 storage bottle, which is mounted in the optical section near the spectrometer. The bottle is filled and vents boil-off gas via an LN_2 coolant port block integral to the optical section skin.

An ST5000 MkIID star tracker sensor head ("ST1"), boresighted with the telescope, is mounted to the top of the spectrometer housing. The sensor head interfaces directly to its control electronics located in the ACS section. ST1 will be used to acquire and stabilize the science targets.

For target centering, the experiment optical train will provide a narrow-field sensor at the zero order of the grating. The ZOD (Zero-Order Detector) sensor is coupled to control electronics in the experiment electronics section. This system (ST2) is also an ST5000 MkIID star tracker. RS-170 video from ST2 will be downlinked via the TM and provide the optical information for fine pointing corrections via the standard ACS command uplink system. In addition, ST2 will provide detailed tracking telemetry and compressed images over a 56 kBaud serial line in the engineering telemetry.

In operation, the FUSP experiment timeline will consist of fairly short exposures, approximately 3-10 sec, on each waveplate position. The CCD readouts will be binned to reduce the readout time to less than one second. Eight images with waveplate angles 11.25° apart will complete a polarimetric measurement. Eight waveplate angles provides an overdetermination of the two linear Stokes parameters, so that the systematic error in each pixel may be accurately evaluated. We anticipate two science targets per flight.

Other than redundant batteries on the experiment system timer board, there are no redundant hardware systems. There are fallback software routines within the experiment processor that will be used in the event of certain hardware failures. For instance, in case the processor is reset by a power glitch, the processor will check the experiment system timer and resume the observing program from the pre-programmed time table stored in ROM.

2. Experiment History

This payload has not flown before. The electronics section is largely a copy of the WISP experiment electronics, which has flown successfully five times (36.050UG, 36.128UG, 36.157UL, 36.162UG, and 36.188UL). The skins have been fabricated and delivered.

3. Outline Diagram

A conceptual drawing of the payload stack is shown in Figure 2. Estimated weights and center of gravity positions for the experiment sections are shown in Table 2 (gray cells).

An outline of the experiment section, with electronic and umbilical interfaces, is shown in Figure 3. The experiment coordinate system used in Table 2 and Figure 3 is shown in Table 3.

ITEM	C.G. Positions (in) Z	X	Y	Wt in lbs Subassy	Assy	Source
ORSA					80	NASA
Chute					32.7	NASA
Adapter Ring					15	NASA
Upper Balance Wt					10	NASA
ACS					116.5	NASA
S-19					78.35	NASA
TM					108.82	NASA
Electronic bulkhead	0.337	0.032	1.25	12		UW
DC/DC Convertors	0	0	2.94	10		UW
Vertical supports	0	0	10.94	4		UW
Electronics crate	0	0	11.38	12		UW
CCD Cntrlr	0	-5	11.38	4		UW
Satellite boards	0	5	11.38	3		UW
Electronic access port	-1.773	7.65	11.3	2		UW
Electronic skin	-0.228	0.975	15.975	19.1		NASA
Exp Electronics Total	-0.06	0.44	9.56		66.1	
Bulkhead					22.7	NASA
Mirror cell/ Support ring	0	0	26	14.4		UW
Primary mirror	0	0	26.125	20		UW
Payload wiring	0	0	45	20		UW
Support ring	0	0	51.5	6		UW
Rod supports 4@9lbs	0	0	59	36		UW
Cooling port assembly	10	1.654	62.584	15		NASA
Vacuum port assembly	-10	0	62.718	10		NASA
Spider ring	0	0	73	13		UW
Spectrometer assembly	3	-0.025	79.455	30		UW
Spider ring	0	0	92.25	13		UW
Star tracker assembly	6.666	0	97.625	8		UW
Optics skin	0	0	61	89.1		NASA
Exp Optical Total	0.70	0.09	60.27		274.5	
Shutter door assembly					41.6	NASA
HVSS/Transition					80	NASA
Lower Balance Wt					0	NASA
Ignitor Housing					45	NASA
TTS motor components					13.8	NASA
Total					985.07	

Table 2. Payload Weight and CG

Exp	ACS	Direction	On Pad	Zero
X	-Yaw	Perpendicular to the spin axis, though electronics access panel	West	Spin Axis
Y	-Roll	Along spin axis, along LOS of Ball startracker	Down	Exp/TLM I/F
Z	-Pitch	Perpendicular to the spin axis; along ACS 0; though spectrometer and rail	South	Spin Axis

Table 3. Coordinate System Definition

4. Structure and Mechanisms

The electronics section is packaged in a 17.25/22.0 inch transition section, and the optical section is contained in a 22.0 inch section (Figure 3). The vacuum door is a standard 22.0 inch NASA shutter door.

The optics section is vacuum-sealed; vacuum doublers for the LN_2 cooling flyaway and for the vacuum/ purge ports are shown in the optics skin. The standard 22-inch vacuum door provides the seal for the experiment aperture and protection for the startracker.

5. Outgassing and RFI

The optics section contains FUV optical coatings which are susceptible to humidity and hydrocarbon contaminants. WFF-supplied subsystems exposed to the optics (door, startracker) should consist of low-outgassing materials. The front-end CCD electronics is susceptible to RFI during readouts in flight, so should not be in the transmitter beam.

6. Experiment Events

The science experiment is controlled entirely by preplanned sequences, one uplink signal, and one timer-based signal. The ZOD will be controlled by uplink commands. The experiment requirements for these are as follows:

Event	Origin	Destination	Requirement
ACS Settled	Timer	Science Experiment	"Timer A" Remove on slew
On Target	Uplink	Science Experiment	
Gain Low/ High	Uplink	ZOD	
Integration Low/ High	Uplink	ZOD	
Acquire Enable	Uplink	ZOD	
Downlink PIT Image	Uplink	ZOD	
Exp Power Off	Timer	Experiment	Parachute deploy - 20 seconds

In Table 4 we show a nominal experiment sequence. We assume a nominal apogee altitude of 315 km at 288 seconds and an ACS arrival at β Tau at T+90 seconds. The experiment timeline starts at t-60 secs. The low voltage logic power will be on at lift-off and telemetry will be continuous. CCD dark frames will commence on despin. When the ACS has settled upon

Event	Time	Src	Nom Altitude	2-sig low Altitude	Dur	Comment
Clock Start	-60	Exp			1	
CCD Bias/ Dark	-59	Exp			54	
Safe	-5	Exp				Safe for powered flight
BB Burnout	44.42	Veh	46.7	17.9		
CCD Bias/ Dark	48	Exp	54.7	26.5	57	
P/L Sep	64	Veh	88.5	63.1		
Open Door	75	Veh	110.4	86.8	15	
Arrive Beta Tau	90	ACS	138.4	116.9	15	"ACS Settled" signal
On Target Beta Tau	105	Upl	164.2	144.8	3	Center by uplink cmd
8 Exposures	108	Exp	169.2	150.0	100	ACS hold on target
Slew to Zeta Tau	208	Exp	285.9	273.6	10	
Arrive Zeta Tau	218	ACS	292.6	280.5	10	"ACS Settled" signal
On Target Zeta Tau	228	Upl	298.4	286.3	3	Center by uplink cmd
24 Exposures	231	Exp	300.0	287.9	259	ACS hold on target
Close Door	490	Veh	131.1	84.7	5	
Door Closed	495	Veh	121.8	74.0		
CCD Bias/ Dark	495	Exp	121.8	74.0	109	
Exp Power Off	604	Veh				
Chute Deploy	624	Veh				

Table 4. Experiment Events

arrival at β Tau the “ACS Settled” signal will be sent to the experiment. The experiment CPU will begin Science exposures on β Tau on receipt of the uplinked "On Target" signal, after the target is centered by uplink command. After 100 sec the ACS will slew to the second science target, ζ Tau. The “ACS Settled” signal will be turned off until lock onto ζ Tau, when it will be issued again. The target will be centered by uplink command, and the “On Target” command uplinked again. ζ Tau exposures will be adjusted to fill the time until a nominal altitude of 130 km at 490 secs. If the "On Target" is not received, the CPU will begin science exposures at “ACS Settled” + TBD seconds. Starting at door close, CCD dark frames will continue until experiment power off.

7. Instrumentation - Telemetry

Electrical interfaces to the TM section are similar to those of the WISP (36.172 UG) experiment. An experiment overall block diagram is shown in Figure 4. All major experiment electronics are located in a separate electronics section of the experiment. This system is a copy of the electronics section of the Wide-Field Imaging Survey Polarimeter (“WISP”) payload. The CPU controls the waveplate rotator and the CCD detector based on internally stored sequences and one uplink-generated signal, an "on target" signal. The CPU also controls the CCD temperature by controlling the TEC voltage. All experiment system power is regulated from the vehicle 22 - 36V bus. Experiment outputs include a dedicated digital telemetry stream at 2 Mbit/s; the CPU will multiplex this data into a serial data channel complete with the required synch words. In addition, a number of analog monitors will be fed to the vehicle multiplexer to provide system status independent of the CPU. Also, the 56 kBaud serial telemetry from the zero order sensor is to be downlinked through this channel. The vacuum door will be controlled directly by the payload timer. Electrical interface details are given in the Telemetry, Commands, and Electrical Specification, FP1100-S-0010 Rev H, Attached.

8. Vehicle

A nominal peak altitude of 315 km is desired.

During science exposures the experiment line-of-sight will be pointed at two celestial targets (Table 5). Slew accuracy requirements are

Pitch/Yaw	$< 0.1°$
Roll	$< 0.1°$

Target	RA (2000)	Dec (2000)	Roll
β Tau	$5^h\ 26^m\ 17.4^s$	28° 36' 35"	TBD (to be optimized by ACS program)
ζ Tau	$5^h\ 37^m\ 38.6^s$	21° 08' 34"	TBD (to be optimized by ACS program)

Table 5. Science Target Coordinates

After fine mode lock on each target, uplink commands based on the ZOD image will center the target to better than one arcmin. Jitter/ drift requirements during science observations are

Pitch/Yaw	±2 arcsec deadband
Roll	< 0.5'/min drift

9. Flight Qualification Status

Not yet tested.

10. Testing Restrictions

None yet identified.

11. Range Support

1) Purge gas: A continuous low pressure (2-3 psig) flow of dry N_2 is to be maintained into the experiment optical section whenever it is not under vacuum, venting from the experiment electronics section access panel. We estimate a maximum consumption of one high pressure bottle every two days when the experiment is integrated into the payload.

2) Detector coldsink coolant: A 35-liter liquid nitrogen dewar located at the base of the launcher or mounted to the rail, provides refill capability for the internal 0.5 liter storage tank. The experimenter will provide the dewar, transfer line, and pullaway connector for the fill port. The 35 liter dewar should be topped off each night a launch is attempted. In addition, one standard high pressure gaseous nitrogen bottle will be required underneath the launcher to back pressurize the LN_2 dewar if necessary. The experimenter will provide a regulator to drop the gaseous nitrogen to low pressure (10 psig).

3) Access to experiment prior to launch: While the experiment is horizontal the experimenter requires access via the electronics section access door, and via the optics section cooling panel. The optical section will remain under vacuum while on the rail, and the vacuum pump must remain on as late as possible in the launch countdown in order to minimize contaminant condensation on the cooled detector.

4) Recovery is required.

12. Launch Conditions

Launch criteria are based entirely on the preplanned launch window requirements and on experiment health. All experiment health measurements are available to the experiment processor, so that experiment health will be judged based on performance of an experiment self-test during the launch countdown.

Launch window criteria depend entirely on minimization of celestial and terrestrial backgrounds at the time of flight. The following graphic illustrates the window for β/ζ Tau from WSMR:

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FUSP Launch Window for WSMR

Target  RA=  5 37 38   Dec=  21  8 34
  Zenith Distance constraints
  "s": Sun    <  120
  "t": Target >  65

Local Time:
yyyymmdd 18    19    20    21    22    23    0     1     2     3     4     5     6
         |     |     |     |     |     |     |     |     |     |     |     |     |
20090901 sssssssssssssssssssssssstttttttttttttttttttttttttttttt       ssssssssss
20090915 sssssssssssssssssssssstttttttttttttttttttttttttttt             sssssssss
20091001 sssssssssssssssssssttttttttttttttttttttttt                      sssssss
20091015 sssssssssssssssssstttttttttttttttttttt                            ssssss
20091101 ssssssssssttttttttttttttt                                    sssssssssss
20091115 sssssssssttttttttttt                                          ssssssssss
20091201 sssssssssstttt                                                  sssssssss
20091215 sssssssss                                                        ssssssss
20100101 ssssssssss                                                  tttttsssssss
20100115 sssssssssss                                           tttttttttttsssssss
20100201 sssssssssssss                                  ttttttttttttttttsssssssss
20100215 ssssssssssssss                            ttttttttttttttttttttssssssssss
20100301 sssssssssssssss                     ttttttttttttttttttttttttssssssssssss
20100315 ssssssssssssssss               tttttttttttttttttttttttttttttssssssssssss
20100401 ssssssssssssssssssssssss      tttttttttttttttttttttttttttttttttsssssssss
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13. Special Range Requirements
None.

14. Radioactive Sources
None.

15. Mission Success Criteria
Comprehensive
1) Vehicle: 1000 lb to 300 km apogee minimum
2) ACS: experiment LOS pointing error < 0.1°, updated to < 1 arcmin; stability ±2 arcsec.
3) Experiment: data on both targets obtained.
4) Payload recovered in good shape.

Minimum
1) Vehicle: 1000 lb to 290 km apogee minimum
2) Experiment: data on one target obtained.

16. List of Contacts

Name	Title	Address	Phone (608)-	email @astro.wisc.edu
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Michael Westphall	Instrument Scientist	"	263-4683	mswestph
Kurt Jaehnig	Instrumentation	"	263-4688	kurt
Jeff Percival	Software	"	262-8686	jwp

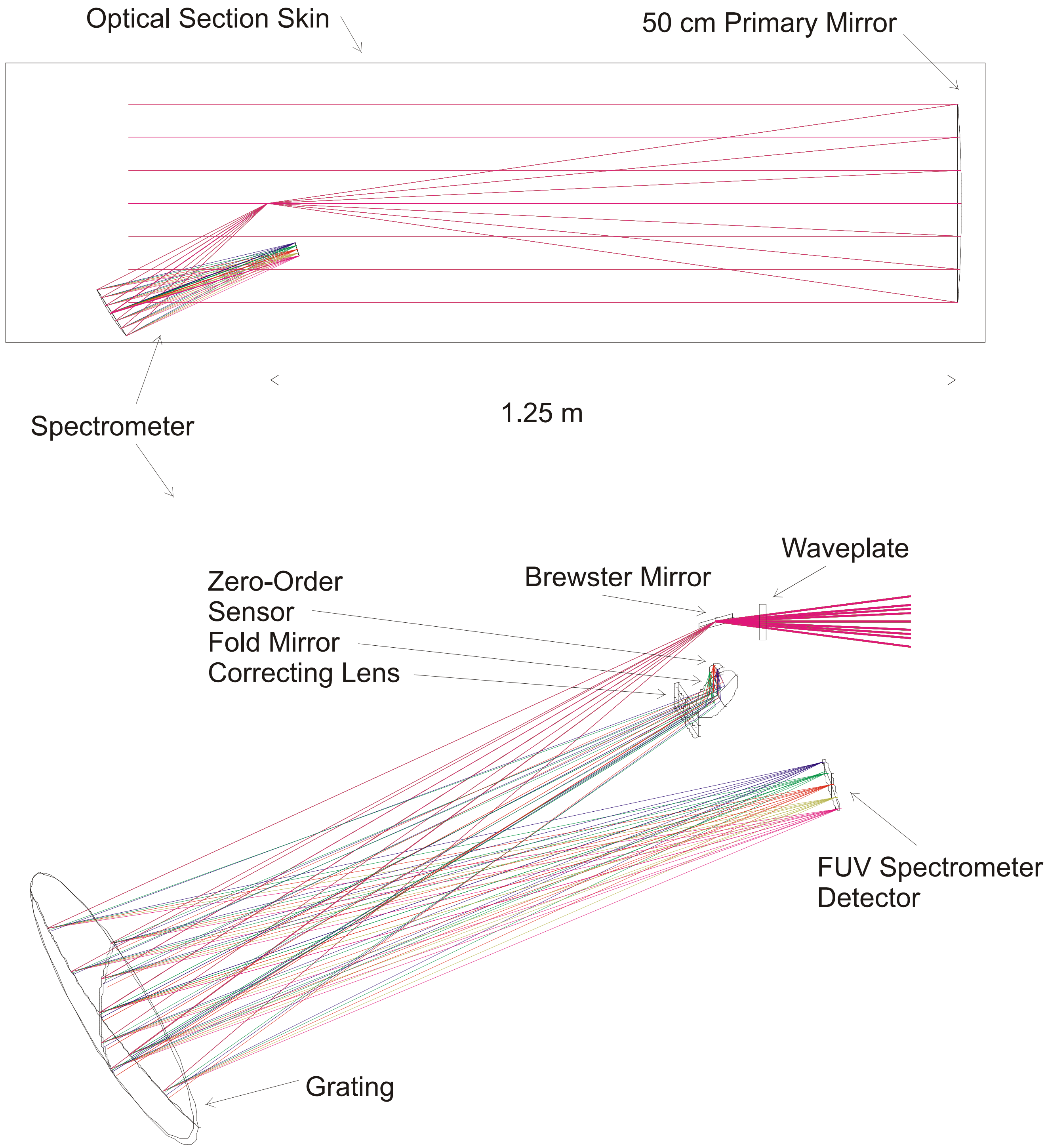

Figure 1. FUSP Optical Design

Figure 2. Payload Stack

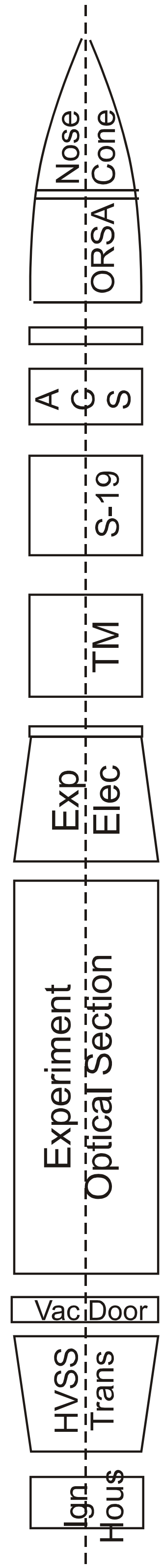

Figure 3. Experiment Structure Outline and Interfaces

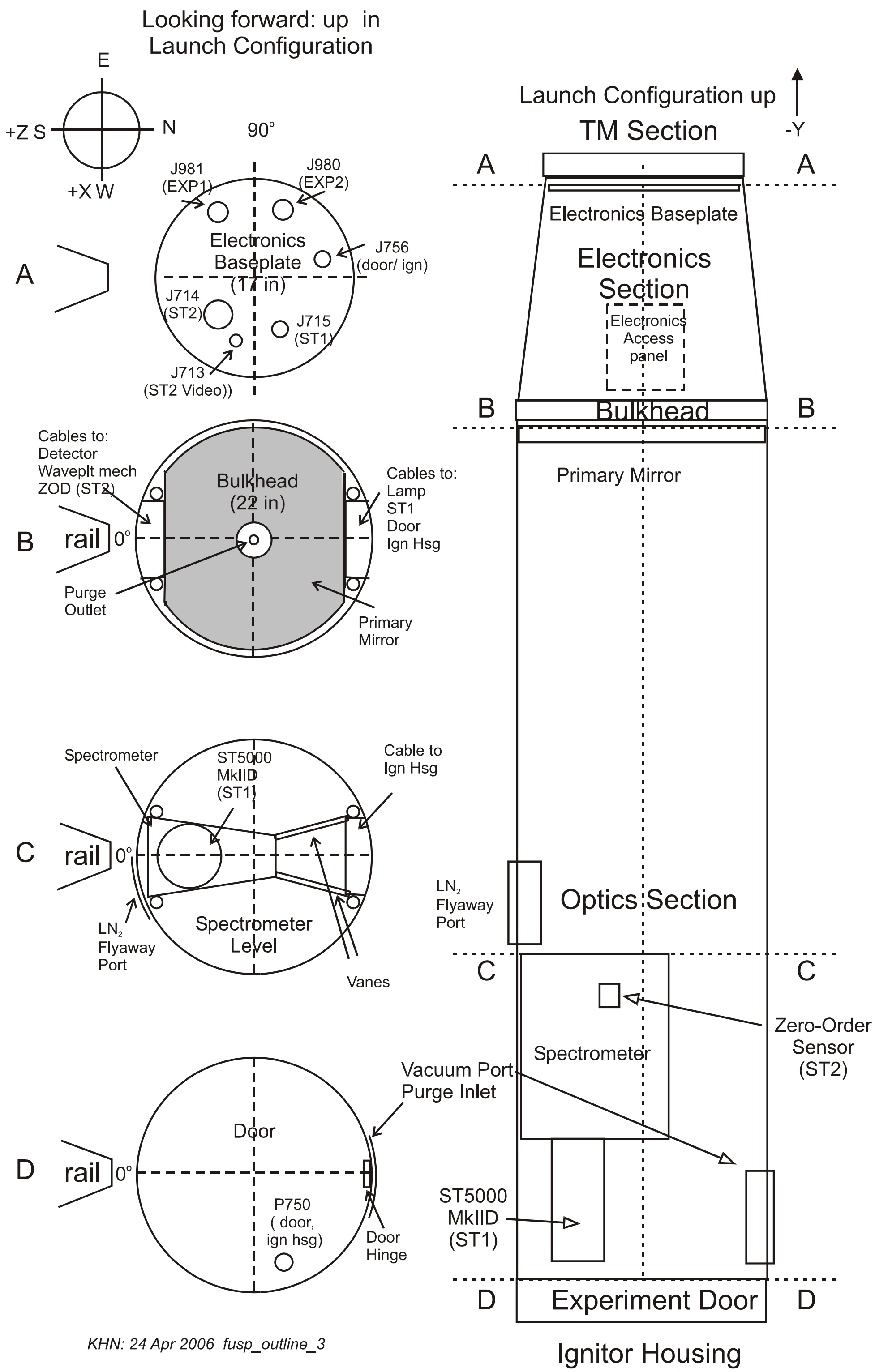

Figure 4. FUSP Electronic System