# C. FACTSHEET

## IRIS – Interface Region Imaging Spectrograph

- All but a few percent of the non-radiative energy leaving the Sun is converted into heat and radiation within the chromosphere and transition region (TR). Here, magnetic field and plasma exert comparable forces, resulting in a complex, dynamic interface region between photosphere and corona whose understanding remains a challenge.
- IRIS fills a crucial gap in our ability to advance Sun-Earth connection studies by tracing the flow of energy and plasma through this foundation of the corona and heliosphere for which no suitable observations exist.
- The IRIS investigation combines advanced numerical modeling with a uniquely capable observatory: IRIS obtains UV spectra and images with high resolution in space (1/3 arcsec) and time (1s) focused on the chromosphere and TR.
- An ideal opportunity: scientific need; near sunspot maximum; complementing observatories; powerful numerical tools.

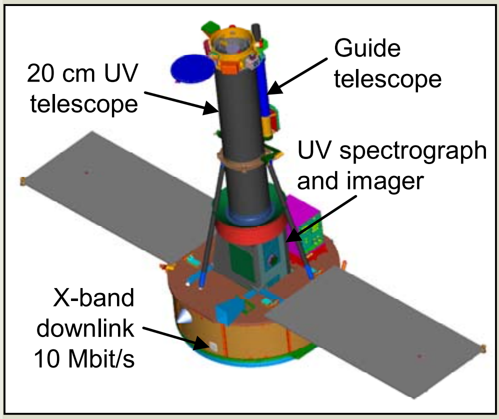
## 1. Science and Mission Objectives

The IRIS science investigation is centered on three themes of broad significance to solar and plasma physics, space weather, and astrophysics, aiming to understand how internal convective flows power atmospheric activity:

**1. Which types of non-thermal energy dominate in the chromosphere and beyond?**
**2. How does the chromosphere regulate mass and energy supply to corona and heliosphere?**
**3. How do magnetic flux and matter rise through the lower atmosphere, and what role does flux emergence play in flares and mass ejections?**

The complex processes and enormous contrasts of density, temperature and magnetic field within this interface region require instrument and modeling capabilities that are only now within reach. The IRIS team will use advances in instrumental and computational technology, its extensive experience, and its broad technological heritage to build a state-of-the-art instrument to provide unprecedented access to the plasma-physical processes in the interface region.

## 2. Science Payload



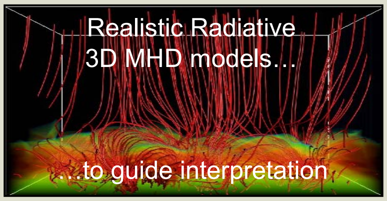
**20 cm UV telescope:**
1/6 arcsec pixels

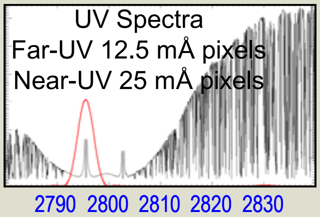
***multi-channel spectrograph***
*far-UV*: 1332-1358 Å, 1390-1406 Å,
40 mÅ resolution, effective area 2.8 cm$^2$
*near-UV*: 2785-2835 Å,
80 mÅ resolution, effective area 0.3 cm$^2$

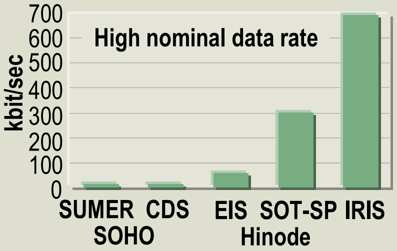
***slit-jaw imaging***
1335 Å & 1400 Å with 40 Å bandpass each;
2796 Å & 2831 Å with 4 Å bandpass each.

## 3. Mission Overview

1. Sun-synchronous, polar orbit for continuous observations
2. One command load per day from Svalbard GS (NASA GN)
3. Coordination w/ Hinode, SDO, STEREO, and ground-based obs.
4. Baseline: 5s cadence for UV slit-jaw images, 1s for 6 spectral windows, rastering to map solar regions; 2-year mission
5. Average data rate: 0.7 Mbit/s, 13 X-band passes/day
6. Spectra covering temperatures from 4,500K to $10^7$K, and images covering temperatures from 4,500–65,000K
7. With strong components in theory and numerical modeling in radiative MHD; involvement of laboratory plasma physicists
8. Significant flight heritage (and therefore low cost/schedule risk)







## 4. Key Spacecraft Characteristics

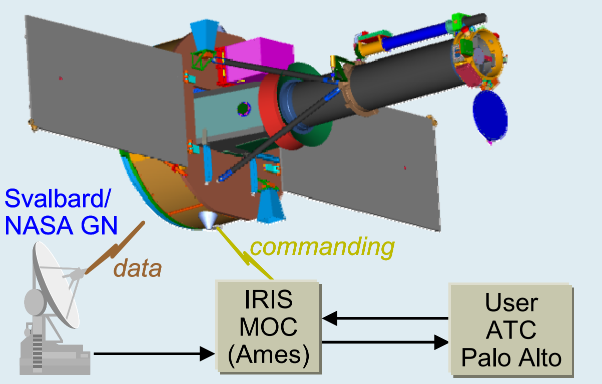
### Spacecraft: LMS&ES

- Instrument 90 kg
- S/C Bus 77 kg
- Total 167 kg w/ 41% launch margin
- RAD 750 CPU
- Deployable solar arrays, 28V, 294W at EOL, w/ 30% margin
- 3-axis stabilized, fine pointing from guide telescope
- Pointing anywhere within 1.2 $R_\odot$ from disk center
- X-band 10 Mbit/s
- 48 Gbit solid state memory

## 5. Anticipated Launch Vehicle

**Pegasus XL**

- Launch from Vandenberg AFB
- Launch capacity 236 kg
- Sun-synchronous orbit Altitude 596x666 km
  Inclination 97.9°

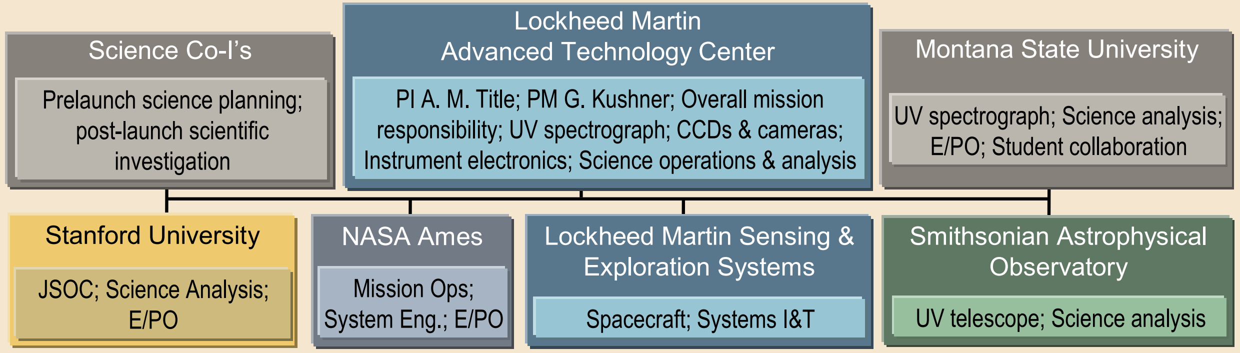


IRIS with deployed solar arrays

## 6. Cost Estimate

| FY08 M$ | A | B | C/D | E/F | Total |
|---|---|---|---|---|---|
| Satellite | 0.7 | 19.1 | 57.8 | | 77.6 |
| Science, E/PO | | 0.3 | 4.7 | 10.7 | 15.7 |
| Mission Ops | 0.05 | 1.1 | 7.3 | 2.8 | 11.3 |
| **Total** | 0.75 | 20.5 | 69.8 | 13.5 | 104.6 |

## 7. Mission Management



**Science Co-I's**
Prelaunch science planning; post-launch scientific investigation

**Lockheed Martin Advanced Technology Center**
PI A. M. Title; PM G. Kushner; Overall mission responsibility; UV spectrograph; CCDs & cameras; Instrument electronics; Science operations & analysis

**Montana State University**
UV spectrograph; Science analysis; E/PO; Student collaboration

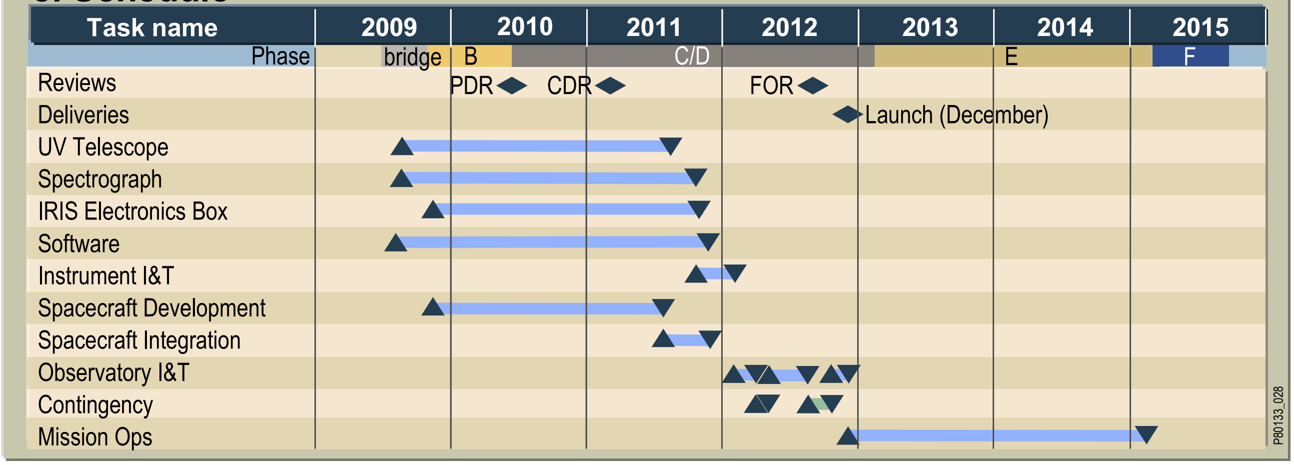
**Stanford University**
JSOC; Science Analysis; E/PO

**NASA Ames**
Mission Ops; System Eng.; E/PO

**Lockheed Martin Sensing & Exploration Systems**
Spacecraft; Systems I&T

**Smithsonian Astrophysical Observatory**
UV telescope; Science analysis

## 8. Schedule



# D. EXECUTIVE SUMMARY

The Interface Region Imaging Spectrograph (IRIS) opens a window of discovery onto a crucial gap in our current observational capabilities: IRIS is designed to measure the flow of energy and plasma through the foundation of the Sun's atmosphere and heliosphere formed by the solar chromosphere and transition region. In this interface region, all but a few percent of the Sun's non-radiative energy flux is converted into heat and radiation, with a little leaking through to power the corona and solar wind. To understand how this domain powers mass and energy flows into the heliosphere, IRIS combines high-throughput spectroscopy and high-resolution imaging in ultraviolet windows around 1400Å and 2800Å, with advanced modeling and with supplemental information from close collaborations with other space- and ground-based observatories.

IRIS will contribute to our fundamental understanding of the solar energy transport, will increase our ability to forecast space weather, and will deepen our understanding of distant astrophysical phenomena. The ~10x smaller resolution elements and the increase in effective area and spectral resolution relative to SOHO's SUMER and Hinode's EIS enable IRIS to reveal significantly more of the small-scale dynamics of the chromosphere and transition region that is currently veiled within poorer point spread functions and line broadenings.

A launch in 2012 places IRIS near solar maximum in a unique configuration of supporting instruments like SDO, Hinode, SOLIS, SST, and IBIS that observe from the solar surface to the global corona. This advantageous constellation and the significant heritage in hardware and software, both in the satellite and ground system, allow us to effectively address a major scientific problem with a low-risk, cost-effective approach compatible with the modest SMEX budget.

The IRIS mission design has been developed during the Concept Study phase to a stage close to a Preliminary Design Review (PDR), with all risk factors identified, investigated, and addressed in the design. Lab demonstrations have proven the performance of critical instrument designs.

Although recent discoveries with Hinode (briefly discussed in the next section) make the scientific case for IRIS even more compelling, the fundamental science and mission requirements (Tables D-1 and D-2) are unchanged from the proposal. We chose to leave §E Science Investigation of this concept study report unchanged, except to address the minor weaknesses identified by the proposal reviewers (marked with light grey background shading) and update Figs. FO1, FO2, and FO3. ***If anything in §E conflicts with §F regarding technical details of the implementation, §F takes precedence.***

***Table D-1 Science Requirements are unchanged from the original proposal.***

| # | Requirement |
|---|---|
| 1 | IRIS shall obtain images and spectra covering the solar chromosphere and transition region up to the low corona (i.e., plasma at temperatures through the range of 5,000K to 1,500,000K) for 8 months per year over a period of 2 years. |
| 2 | IRIS shall obtain images over a field of view of 120 arcseconds, and obtain spectra with a slit of matching length, both with an angular resolution of 0.4 arcsec. |
| 3 | IRIS shall obtain images with a 10s cadence, and spectra with a 1s cadence and the spectrograph shall raster 3.3 arcseconds on the Sun (10 steps at 0.33 arcseconds per step) in 10 seconds. High-cadence observing shall be sustainable for 8 hours per day. Exposure times should be of order 1s or less in active regions. |
| 4 | The IRIS spectrograph shall have a spectral dispersion with pixels equivalent to 3 km/s, compatible with spectral pixels of 12.5 mÅ around 1400Å, and 25 mÅ near 2800Å. The achievable post-observation velocity calibration shall be 0.5 km/s for spectral lines with more than 800 photons per exposure. |
| 5 | The IRIS design shall enable rolls of the spectrograph slit by up to 90 degrees for observing periods of up to 5 hours. |
| 6 | IRIS mission operations shall be coordinated with other space-based solar missions and ground observatories that provide photospheric and/or chromospheric magnetograms, as well as coronal images in EUV and/or X-ray wavelengths. |
| 7 | The IRIS scientific investigation shall support an extensive numerical radiative MHD and plasma-physics component to enable full-forward modeling of IRIS measurements in the domain from the top of the convective envelope to the low corona. |

## D.1 SCIENTIFIC OBJECTIVES

The central IRIS science objective is to understand the flow of energy and mass through the Sun's chromosphere and transition region (TR) in which the magnetic field, density, and temperature exhibit dramatic gradients—a critical interface through which all non-thermal energy that drives space weather is transported. This objective is captured in three crucial questions:

- Which types of non-thermal energy dominate in the chromosphere and beyond?
- How does the chromosphere regulate mass and energy supply to the corona and heliosphere?
- How do magnetic flux and matter rise through the lower atmosphere, and what role does flux emergence play in flares and mass ejections?

Hinode observations show a highly dynamic and finely structured chromosphere that is intimately connected to coronal dynamics. High-resolution spectroscopic observations with high spatial and temporal resolutions are required to address these questions. For example, comparison between SOT chromospheric images and EIS coronal spectra show correlations between short-lived jet-like brightenings in the chromosphere and rapidly upflowing but faint coronal plasma. The data suggest that upper chromospheric dynamics and heating routinely cause evaporative upflows at coronal temperatures, hinting at the long-sought direct connection between chromospheric and coronal heating mechanisms. The process is much more dynamic (~10s) than the raster exposure times (~1 min) and cadence (~5 min) of current instruments. It occurs everywhere on small scales (<1 arcsec), and involves rapid (~100 km/s) apparent motions of plasma that swiftly disappears from the limited passbands now available.

With current instruments, we cannot trace the spatio-temporal and thermal evolution of the plasma during the dominant heating modes of the solar atmosphere. This leaves many crucial issues that are at the forefront of heliospheric physics unresolved. What is the mechanism that drives the chromospheric jets, and subsequently coronal heating: currents, reconnection from braiding, waves, electron beams? What fraction of the chromospheric jets are heated to TR and coronal temperatures? Is the coronal counterpart directly heated at low heights, or caused by subsequent heating of a fraction of the chromospheric jets? Do these events carry enough mass into the corona to dominate the coronal mass balance?

The Hinode results show that IRIS' powerful combination of co-temporal and co-spatial spectra and images of lines formed in the chromosphere, transition region and corona at cadences as fast as 1 s and spatial scales below 0.5 arcsec are critical. The combination of IRIS, Hinode, SDO, and ground-based observations, along with the planned numerical MHD and multi-fluid plasma simulations, will deliver a breakthrough in our understanding of the energization and dynamics of the solar atmosphere.

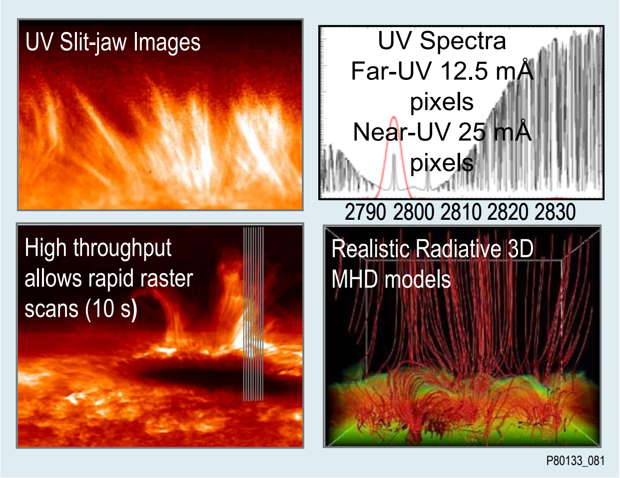


***Fig. D-1 IRIS provides simultaneous images and spectra in the near- and far-UV.*** *The design provides rapid cadence, high spectral and spatial resolution observing to compare with detailed MHD and multi-fluid models.*

## D.2 TECHNICAL APPROACH

The IRIS mission science objectives require a high resolution imaging spectrometer observing in the UV and Near-UV to observe the chromosphere and transition region between 5,000K and $1.5\times10^6$K. The required spectral resolution of calibrated spectra must provide 0.5 km/s velocity resolution in bright lines with spatial resolution of 0.4 arcsec and a field-of-view of 120 arcsec. The throughput of the instrument must enable a 10s observing cadence. The solar event and evolution timescales require eight-hour observing periods.

IRIS achieves these requirements with a 20-cm UV telescope that is based on the SDO AIA design, but with a longer focal length to provide the required spatial resolution. This is a low cost, low risk approach as only incremental changes to the mirror specification and mounting are needed from the AIA design to meet the IRIS requirements. The AIA front door design is reused and the secondary spider and mirror mount designs are used with minimal changes.

The telescope feeds a stigmatic UV spectrograph and a slit-jaw imager that provide simultaneous intensity and velocity maps in multiple UV emission lines emitted by chromospheric and transition region plasma. The spectrograph has a Czerny-Turner design using two plane reflection gratings and spherical collimator and camera mirrors, which simplifies fabrication and assembly. The spectrograph mechanical design uses techniques employed on Hinode FPP and SDO HMI.

The instrument electronics reuses SDO AIA and HMI flight designs. Except for the backplane in the instrument electronics boxes and reprogrammed FPGAs for the mechanisms, all electronic board designs are reused from SDO unchanged. IRIS utilizes two flight-spare SDO camera electronic boxes. The optical design of the Guide Telescope (GT), which provides jitter signals for image stabilization by the active secondary telescope mirror and for the spacecraft attitude control system (ACS), is the same as TRACE and very similar to SECCHI and to AIA.

The design, integration, and testing of the IRIS instrument leverages previous flight program experience, including that from GOES SXI, STEREO/SECCHI, SDO/AIA and HMI, and Hinode/FPP. As a result, no new technologies are required and cost risk remains low.

The instrument integrates to a compact spacecraft that is based on Lunar Prospector, Spitzer, IMAGE, and XSS-11. The spacecraft has no consumables and carries X-band and S-band transceivers for commanding and telemetry downlink. It provides a stable platform from which to make high-resolution observations. Inputs from the star trackers and GT are used by the ACS for fine sun pointing which meets all requirements with margin. The RAD750 control computer, ACS, and communication system are in an integrated avionics unit that is at PDR level now, and all but two boards are at CDR level, greatly reducing cost and schedule risk. Selected hardware redundancy is implemented, including star trackers, reaction wheels, solar cells, ACS and other electronics. All spacecraft hardware is at TRL 7 or better, so new technology is not required.

A Pegasus will launch IRIS into a 596×666 km Sun-synchronous orbit, giving it an 8-month season of uninterrupted observing each year. Data are downlinked 10 to 13 times a day to the Svalbard Ground Station in Norway. Operations will be conducted from the Ames Research Center (ARC) during working hours, five days a week, with science planning at Lockheed Martin Advanced Technology Center (LMATC). Data from IRIS is transferred on the Internet to the SDO Joint Science Operations Center (JSOC) located at Stanford University and LMATC. The JSOC will archive 60 Gbits/day of IRIS data. The IRIS data volume over the whole mission is less than the equivalent of three days observing with SDO AIA and HMI, and therefore is readily accommodated within and served from the JSOC system.

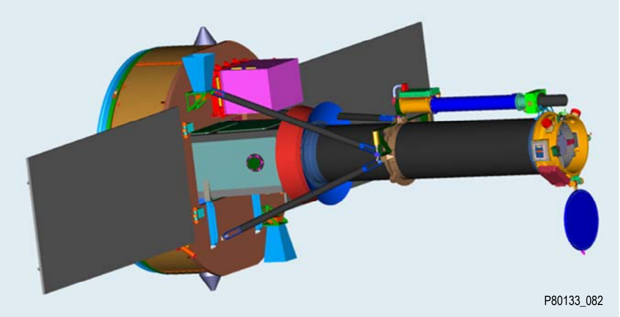


***Fig. D-2 The IRIS design is derived from several previous instruments built by LMSAL and spacecraft produced by LM to reduce technical, schedule, and cost risks.***

Members of the IRIS team are developing the most advanced radiative MHD codes available for the solar atmosphere, and the program will support enhancements, e.g., for speed and more accurate physics of the interface region. Comparisons of IRIS data with numerical simulations will enable interpretation in terms of the fundamental plasma-physical processes.

## D.3 MANAGEMENT PLAN

IRIS will be managed from within Principal Investigator Dr. Alan Title’s home organization, the Lockheed Martin Solar and Astrophysics Laboratory (LMSAL), which is part of LMATC. Figure D-3 shows the IRIS management structure. Dr. Title has ultimate responsibility for the IRIS program and is the formal interface with NASA. Dr. Title has been the principal investigator for several NASA flight programs including the TRACE SMEX and is currently the PI of the SDO AIA investigation, from which IRIS derives a significant portion of its technical approach.

The IRIS management structure, shown in Fig. D-3, establishes clear boundaries for program responsibilities and assigns those responsibilities to experienced team members best equipped to accomplish the work. LMATC manages all aspects of the IRIS program and is responsible for the overall development of the IRIS instrument and Guide Telescope.

Our science instrument team partnership is well established, and all team members are present AIA co-investigators. The Smithsonian Astrophysical Observatory (SAO) will have chief responsibility for the development of the telescope that feeds the spectrograph. SAO had this

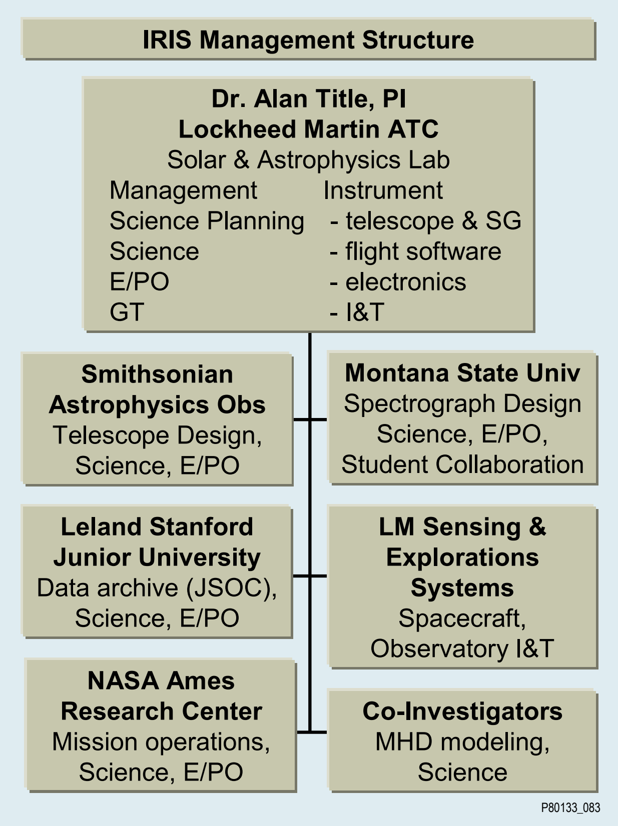


***Fig. D-3 IRIS management structure provides clear interface responsibilities of tasks that are assigned to experienced team members.***

responsibility on the AIA program. Montana State University (MSU) leads the spectrograph design activity. MSU is well-qualified to lead this effort, having successfully flown the MOSES suborbital rocket payload consisting of a wide field-of-view, high spatial resolution EUV spectrograph. Stanford University is responsible for the IRIS data archive and distribution, using the facilities and expertise developed for the SDO JSOC.

The spacecraft is provided by an organization within Lockheed Martin Sensing & Exploration Systems of Sunnyvale, California. This organizational proximity permits early integration of science payload and spacecraft flight hardware and software and enables risks to be retired early in the program. The spacecraft team members have worked “cradle to grave” on Lunar Prospector, IMAGE, GP-B and Spitzer.

NASA Ames Research Center will have chief responsibility for IRIS missions operations and will provide management and technical engineering support to the instrument and spacecraft development teams.

The modeling component of IRIS will be managed via dedicated working groups, each with the goal of delivering mature numerical codes. This management approach is based on that used by LMATC for a very successful group effort to advance nonlinear force-free field modeling.

A substantial benefit is expected from the fact that the ATC, S&ES, ARC, and LSJU teams are neighbors, all within a few miles of each other. Integration of the science payload and spacecraft to form the IRIS observatory occurs in a building in Palo Alto and during a substantial portion of Phase C and D the ATC, S&ES, and ARC personnel will work side-by-side in the same facility.

The program management tools used for AIA and HMI are in place and available to manage the IRIS program. Risk management is a central element of our approach to successful program implementation. The program is planned with four months of funded schedule reserve, slightly more than one month per year. The schedule reserve will be preserved for use during integration and test periods. Our management model makes use of cost contingency sparingly in Phase C (less than 10% of total) to mitigate and retire technical and schedule risks.

Finally, there are well-defined de-scope options (see §G.1.16) and clear minimum science requirements (see Table D-2). The Principal Investigator and his management team will use these options if necessary to manage the program to the SMEX-defined cost cap and schedule.

***Table D-2 Minimum Science Requirements are unchanged from the original proposal.***

| # | Requirement |
|---|---|
| 1 | IRIS shall obtain images with an angular resolution no coarser than 0.5 arcseconds. IRIS shall obtain spectra that have a resolution along the slit that is no coarser than 0.5 arcseconds. IRIS images shall cover a field of view of at least 40 by 70 arcseconds. The IRIS spectra shall cover at least 70 arcseconds along the slit. |
| 2 | IRIS shall execute 50 observational sequences with a minimum duration of 30 minutes. A sequence will include images and a spectral raster of at least 3 arcsec wide, repeated at least every 30 s. The images and spectra shall include thermal coverage of the chromosphere and TR. |
| 3 | IRIS spectra shall have a spectral resolution of 80 mÅ in FUV and 160 mÅ in NUV. |
| 4 | IRIS shall obtain images from at least one of the two wavelength bandpasses (FUV/NUV). IRIS shall obtain spectra from at least one of the two wavelength bandpasses (FUV/NUV). |

## D.4 COST ESTIMATE

Estimates for the costs of Phases B through F are derived from assessments of similar activities on prior programs. In the case of the instrument costs, the estimates rely heavily on the SDO AIA and HMI programs. The reuse of the AIA telescope design, AIA and HMI mechanism and electronics, and a substantial reuse of flight software contribute to a well-understood cost profile for the instrument. IRIS will fly the spare SDO flight cameras. For the spacecraft, the costs are based on previous experience on the Spitzer and IMAGE programs. These were checked against cost models, but the cost models were not the basis for the provided estimates.

A summary of the IRIS cost of the Phases B through F is shown in Table D-3, including NASA Ames Research Center costs. We maintain a 30% contingency for all phases including the two-year Phase E mission operations. In addition to the explicit contingency is a further four months of funded schedule reserve, on which contingency is also held. Thus, our cost estimate is robust and low risk.

The costs for obtaining telemetry via the Svalbard Ground Station are included in the mission operations and ground data systems cost estimates. Our European co-investigators successfully applied for ESA-funded Svalbard operations for the IRIS mission during Phase A. If, as we fully expect, a memorandum of understanding is signed during Phase B, we will reprogram the funds allocated for Svalbard operations to additional mission science and program reserves.

## D.5 EDUCATION AND PUBLIC OUTREACH PLANS

The IRIS team understands and is committed to the NASA SMD requirements for E/PO. The IRIS mission holds tremendous opportunity to interest young people in the science and engineering disciplines that define NASA's mission and will help recruit the next generation workforce.

Our E/PO program is led by LMSAL and includes contributions by Montana State University, NASA Ames Research Center, and Stanford University. The E/PO program is concentrated in three areas. First, we will formulate an undergraduate-level National Solar Spectrograph Student Competition. The competition requires students to design, fabricate, and operate a solar spectrograph. The competition will judge the quality of the (1) engineering, (2) science observations made, and (3) presentation of results.

The second major E/PO effort is the distribution of activity-based education materials, such as posters that can be made into models of the IRIS spacecraft and paper spectrograph kits. These will serve as both formal education for K-12 students and informal education for the general public.

Finally, providing undergraduates with research opportunities is a proven means for attracting students to the field of science and engineering. We will model our program on Stanford University's highly-successful Summer Research College whereby students will work alongside groups at LMATC, Stanford, and ARC for a 10-week summer period. The students will work with researchers on a specific topic and at the end of the program will make a final presentation.

***The student collaboration***, described in §H.3, proposes to fly an anti-Sun-looking imager to study the gegenschein light without the complicating effects of the Earth's atmosphere. The Gegenschein Imager (GI) will be built by students at Montana State University, provided that funds are identified. The science goals of the GI do not directly support IRIS, and so its inclusion is not essential to the mission. But this novel investigation will provide new scientific observations and will provide flight hardware experience for a new generation of scientists and engineers.

In the current cost estimate, there is no funding for the MSU efforts to develop the GI. Mechanical, thermal, and electrical accommodations for the GI, however, are included in the cost estimates in Table D-3. Thus, if the funding becomes available by IRIS PDR, the GI may be turned on with no impact on the spacecraft development schedule.

***Table D-3 Summary of IRIS Costs.***

| | $M | % |
|---|---|---|
| Phase A | 0.75 | |
| Program management/system engineering/mission assurance | 15.1 | 19 |
| Instrument development | 20.4 | 25 |
| Spacecraft development | 26.1 | 33 |
| Mission operations/ground data system | 6.9 | 9 |
| Science (pre- and post-launch) | 10.2 | 13 |
| Education and Public Outreach (E/PO) | 1.0 | 1 |
| Subtotal | 80.4 | 100 |
| Contingency (30% of subtotal) | 24.1 | |
| **Total** | **104.6** | |