Atmospheric Imaging Assembly Investigation Overview

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Contents of This Presentation

- Quick Overview of the SDO Mission
- The AIA Program
- AIA within the Living With a Star program
- Science themes of the AIA investigation
- Implementing the science investigation
- Managing the science data
Objective: SDO spacecraft carries a suite of solar observing instruments that continuously downlinks real time data from the Sun. The SDO ground system distributes the data to PI run science operations and analysis centers.

Launch Date: April 2008
Mission Duration: 5 years, 10 years of expendables
 Orbit: 36,000km Circular, 28.5º Geo Synch Inclined
Launch Vehicle: Delta IV or Atlas V
Launch Site: KSC
GS Sites: SDO Dedicated
Supporting Sites: South Africa, Australia, Hawaii, Chile
Orbit Overview

• The SDO geosynchronous orbit will result in two eclipse seasons with a variable daily eclipse each day
  – The two eclipse seasons will occur twice a year due to the effects of the orbit geometry and the earth-sun position
  – During each eclipse season, SDO will move through the earth’s shadow - this shadow period will grow to a maximum of ~72 minutes per day, then subside accordingly as the earth-sun geometry moves out of the SDO eclipse season
  – Eclipse season effects:
    • Instrument
      o Interruption to SDO science collection
      o Thermal impacts to instrument optical system due to eclipse
    • Power
      o Temporary reduction or loss of power from solar arrays
      o Battery sizing includes eclipse impact
    • Thermal
      o S/C thermal design considerations due to bi-annual eclipses
Observatory Design

- Modular, distributed electrical architecture similar to MAP/EO-1
  - Uses Subsystem Services Nodes (SSN) as common-design building blocks to provide distributed processing, power regulation, & power switching functionality
  - Nodal architecture simplifies interfaces between subsystems and between spacecraft and instruments
- Five-year mission life suggests single-fault tolerant design will be used to the greatest extent possible, as limited by technical and programmatic resources

Instrument module constructed from Graphite composite to minimize thermal distortion, mounted to spacecraft using kinematic mounts

Spacecraft bus module (contains S/C & Instrument electronics boxes)

Propulsion module, allows for parallel integration & test flow. Includes orbit injection engine (not shown) located opposite end from instruments

Redundant HGAs at the end of rigid booms (must be rigid due to required waveguides). HGA FOV allows each antenna to be used continuously for ~6 months/year (scheduled antenna handovers twice/year)
AIA Program Overview & Future

• AIA Program began on 7 November 2003
  – Quickly confirmed original approaches: science, instrument, and organizations
  – Augmented HMI team to form LMSAL AIA & HMI & Joint teams
  – Got program off and rolling at SAO – major partner/subcontractor and time critical
• Interface Working Meetings with Project took place immediately
  – November, January, February
  – No problems with accommodating AIA onto the S/C; just needs routine work
• Conducted PDR-1 on 4 March
  – Requirements, early design, S/C interfaces and accommodations
• Participated in Mission PDR on 9-12 March
• PDR-2 on 14-15 April
  – Preliminary Design classical review
• Program moving rapidly and successfully
  – Enormous leverage from HMI
  – Extensive heritage from TRACE
  – Excellent established working relationships with SDO GSFC Project
AIA will be in-step by Confirmation Review
LMSAL SDO Organizational Features

• Single LMSAL SDO Program Manager
  – Co-ordinates efforts of AIA and HMI
  – Co-ordinates with Lead Engineers for common program elements
  – AIA builds on the HMI systems already in place
    • Electronics and software are the prime instrumental examples
    • Mission Assurance & Risk Management functions are the prime programmatic examples.

• Dedicated Deputy Program Managers for AIA and HMI
  – Strong advocates of their programs
  – Treat the common elements groups almost like vendors

• Dedicated Systems Engineers for AIA and HMI

• Much of the AIA efforts for mission operations, data analysis, and EPO will be conducted by Stanford University as an extension to those efforts already in place for HMI.

• The Smithsonian Astrophysical Observatory has a major role in the AIA program.
AIA is a key component to understanding the Sun and how it drives space weather

- AIA images the solar outer atmosphere: its science domain is shaded
- HMI measures the surface magnetic fields and the flows that distribute it
- EVE provides the variation of the spectral irradiance in the (E)UV
Themes of the AIA Investigation

1. **Energy input, storage, and release**: the 3-D dynamic coronal structure
   - 3D configuration of the solar corona; mapping magnetic free energy; evolution of the corona towards unstable configurations; the life-cycle of atmospheric field

2. **Coronal heating and irradiance**: thermal structure and emission
   - Contributions to solar (E)UV irradiance by types of features; physical properties of irradiance-modulating features; physical models of the irradiance-modulating features; physics-based predictive capability for the spectral irradiance

3. **Transients**: sources of radiation and energetic particles
   - Unstable field configurations and initiation of transients; evolution of transients; early evolution of CME’s; particle acceleration

4. **Connections to geospace**: material and magnetic field output of the Sun
   - Dynamic coupling of the corona and heliosphere; solar wind energetics; propagation of CME’s and related phenomena; vector field and velocity

5. **Coronal seismology**: a new diagnostic to access coronal physics
   - Evolution, propagation, and decay of transverse and longitudinal waves; probing coronal physics with waves; the role of magnetic topology in wave phenomena

*The needs of each of these themes determines the science requirements on the instrument and investigation.*
### Energy input, storage, and release

<table>
<thead>
<tr>
<th>Main tasks</th>
<th>Specific Goals</th>
<th>Technical approach</th>
<th>Science data requirements</th>
<th>Co-I team</th>
<th>Required resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Energy input, storage, and release</td>
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<tr>
<td>1A: 3D configurations of the solar corona</td>
<td>End-to-end connectivity; twist, writhes, and braids; field strength along field; global and local separators</td>
<td>Temperature Maps; stereoscopy, flow vectors</td>
<td>Full EUV sets, &lt; 1/min. cadence or better if fast flows are studied, continuous over up to 3 few days</td>
<td>Brozos, Demoulin, Keller, Metzolf, Priest, Title</td>
<td>Core: DEM inversions; global surface field model; field extrapolations; image-to-model fitting. External: loop modeling; topology models; stereoscopic techniques. Data: Hα images. Final: force-free field model; global surface field model; visualization tools. External: non-force-free field modeling, including MHD models.</td>
</tr>
<tr>
<td>1B: Mapping magnetic free energy</td>
<td>Free energy in active-region emergence; free energy build up by photospheric stressing motions; role of reconnection; scale couplings</td>
<td>Potential-field model, field-deformation model, MHD models</td>
<td>Sequences of vectormagnetograms and EUV and Hα images at ~ 1 hr cadence</td>
<td>Van Ballegooijen, Demoulin, Gary, Hurlburt, Keller, Kosovichev, Martens, Mikić, Metzolf</td>
<td></td>
</tr>
<tr>
<td>1C: Evolution of the corona towards unstable configurations</td>
<td>conditions for reconnection; dissipation of stresses and currents at a range of scales; balancing stress and relaxation; helicity evolution</td>
<td>connectivity studies; free-energy evolution</td>
<td>long-term continuous obs. at all coronal temperatures, &amp; surface flows and fields</td>
<td>van Ballegooijen, Hurlburt, Kosovichev, Martens, Mikić, Priest, Weiss</td>
<td></td>
</tr>
<tr>
<td>1D: The life-cycle of atmospheric field</td>
<td>Retraction and expulsion of flux from the corona; latitude-dependence of flux subduction</td>
<td>Field-connectivity evolution</td>
<td>10 s cadence at all coronal EUV wavelengths; HMI (vector)/magnetograms at least every few minutes; Hα observations</td>
<td>Hurlburt, Martens, Mikić, Title</td>
<td>As under 1B. Data: Hα</td>
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## Coronal heating and irradiance

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<tr>
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<tr>
<td><strong>2: Coronal heating and irradiance</strong></td>
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<tr>
<td>2A: Contributions to solar (E)UV irradiance by types of features</td>
<td>quantify contributions to spectral irradiance change from a variety of features (ARs, ephemeral regions, flares, quiet network, ...)</td>
<td>AIA/EVE comparisons; determine contributions for different solar regions and feature populations; isolate contributions by rotation tracking</td>
<td>calibrated EUV data (full-disk images and full-disk irradiance) at all coronal temperatures; 10 s cadence during flares, slower allowed otherwise</td>
<td>De Pontieu, Martens, Schrijver, Shine, Warren</td>
<td>Data: precise knowledge of AIA spectral response and other instrumental properties. Core: feature recognition and tracking</td>
</tr>
<tr>
<td>2B: Physical properties of irradiance-modulating features</td>
<td>thermal distribution of coronal plasma; properties of coronal heating, and dependence of field and its topology</td>
<td>Core: DEM analysis to estimate full spectral irradiance; detailed variability studies and distribution functions; coronal heating properties; loop and field modeling</td>
<td>full-resolution, full-disk EUV images and HMI vector-magnetograms at most 60 s cadence</td>
<td>Brosius, De Pontieu, Fludra, Golub, Gurman, Hassler, Lemen, Martens, Nordlund, Schrijver, Shine, Warren</td>
<td>DEM inversion code; loop identification; field modeling and visualization</td>
</tr>
<tr>
<td>2C: Physical models of the irradiance-modulating features</td>
<td>dynamics of loop atmospheres in response to heating changes</td>
<td>MHD modeling of loop atmospheres; comprehensive forward modeling of (sections of) solar corona</td>
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<tr>
<td>2D: Physics-based predictive capability for the spectral irradiance</td>
<td>predict spectral irradiance</td>
<td>forward model of full coronal emission, comparison with AIA and EVE data, iterative improvement by validation of results</td>
<td>see 2B,C</td>
<td>Brosius, De Pontieu, Fludra, Golub, Gurman, Hassler, Lemen, Martens, Nordlund, Schrijver, Shine, Warren</td>
<td>External: loop models, MHD and other field-modeling codes</td>
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</table>

- Core: coronal rendering, force-free field model.
- External: coronal heating model.
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<td>3: Transients</td>
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<tr>
<td>3A: Unstable field configurations and initiation of transients</td>
<td>identification of the instability that directly leads to transients; locating the instability; locating reconnection with respect to separatrices and separators; computation of helicity</td>
<td>Thermal maps; correlation tracking; field extrapolation; separator models; helicity localization and injection models; reconnection theory</td>
<td>Full EUV sets, full-disk vector magnetograms; high-cadence subregion image sequences.</td>
<td>Demoulin, Gary, Keller, Kosovichev, Metcalf, Priest, van Ballegooijen</td>
<td>External: techniques to compute helicity injection and field topology</td>
</tr>
<tr>
<td>3B: Evolution of transients</td>
<td>Rapid changes of field; dynamic connectivity; location and rate of reconnection; relation between impulsive and gradual phase energy release; high-energy activity in the post-eruption phase; implications of motions (e.g., down flows)</td>
<td>Thermal maps; connectivity studies; flare-ribbon tracing; field extrapolation</td>
<td>Full EUV sets; UV images at high cadence; high-cadence subregion image sequences</td>
<td>DeLuca, Hudson, McKenzie, Nitta, Tarbell, Warren</td>
<td>Data: radio observations for particle acceleration in the gradual phase</td>
</tr>
<tr>
<td>3C: Early evolution of CMEs</td>
<td>computation of Lorentz forces involved; characterization of adjacent and overlying field; CME speed profiles; fully open-up vs. closed ejecta; origin of ( H_\alpha )</td>
<td>Thermal maps, CME models, field extrapolation, tracing filaments</td>
<td>Magnetograms, Full EUV sets, high temporal and spatial ( H_\alpha ) images</td>
<td>Demoulin, Fuselier, Golub, Harrison, Martens, Metcalf, Mikio, Nitta</td>
<td>Data: coronagraph data (LASCO, STEREO, Mauna Loa). External: various CME models, different techniques for computing helicity injection</td>
</tr>
<tr>
<td>3D: Particle acceleration</td>
<td>relation between downward and upward moving particles; computation of electric field; identification of flare and CME shocks; geometrical relation between shock front and magnetic field; waves resonant with particular ions</td>
<td>Thermal maps; difference images, dispersion relation from in-situ SEP data, potential field model</td>
<td>Full EUV sets, fast cadence UV images (probes for precipitating electrons), high temporal and spatial ( H_\alpha ) images (both on- and off-band)</td>
<td>Harra, Keller, McKenzie, Metcalf, Nitta, Shine</td>
<td>Data: in-situ SEP data from ACE (UATIS/SIS) and STEREO (IMPACT), metric and DH dynamic spectra (ground-based and STEREO/SWAVES)</td>
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## Connection to geospace

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<tr>
<td>4: Connections to geospace</td>
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<tr>
<td>4A: Dynamic coupling of corona and heliosphere</td>
<td>interface between corona and heliosphere; geometry of open and closed fields, and its evolution</td>
<td>compare high S/N observations to force-free or PFSS models of the coronal field</td>
<td>observations at all AIA EUV wavelengths; coronagraphic image sequences</td>
<td>Fuselier, Hurlburt, Mikic, Scherrer, Schrijver</td>
<td>Core: force-free field models. External: MHD models of high corona &amp; heliosphere.</td>
</tr>
<tr>
<td>4B: Solar wind energetics</td>
<td>what determines the acceleration of the solar wind; why is field geometry apparently important</td>
<td>compare field models and observed coronal-hole boundaries with wind-propagation model to in-situ sensors in the solar wind</td>
<td>As 4A; in-situ wind measurements, preferably at multiple locations in the heliosphere</td>
<td>Fuselier, Hurlburt, Mikic, Scherrer, Schrijver</td>
<td>As in 4A, plus: External: propagation model for wind and field throughout the heliosphere out to available in-situ sensors.</td>
</tr>
<tr>
<td>4C: Propagation of CMEs and related phenomena</td>
<td>propagation of CMEs through background wind; determination of mass flows (outward and inward); energetics of field and plasma</td>
<td>model CME propagation using observed initial evolution</td>
<td>10 s cadence in all AIA EUV channels; coronagraphic observations</td>
<td>Fuselier, Mikic, Nitta, Scherrer</td>
<td>External: coronal MHD, and heliospheric MHD models.</td>
</tr>
<tr>
<td>4D: Vector field and velocity</td>
<td>initial evolution of the field associated with CMEs and filament eruptions</td>
<td>analyze high-cadence observations of field evolution during CMEs, combine with spectrometric observations whenever possible, combine with model computations</td>
<td>high-cadence observations of low corona, uninterrupted for hours at least to study the evolution of the writhing field; vector-field measurements</td>
<td>Fuselier, Mikic, Scherrer</td>
<td>External: MHD models of inner corona during eruptive processes.</td>
</tr>
</tbody>
</table>
Coronal seismology

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>5: Coronal seismology</td>
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</tr>
<tr>
<td>5A: Transverse waves: excitation, propagation and decay</td>
<td>wave excitation, propagation, decay</td>
<td>movie viewing to discover oscillations, measurement of properties, comparison to field and field topology and loop-atmosphere properties</td>
<td>10 s cadence full-disk movies at all coronal temperatures and UV/WL</td>
<td>De Pontieu, DeLuca, Priest, Hurford</td>
<td>Observer to inspect movies. Data: Solar-B/EIS coordination. Core: field models. External: coronal atmosphere models</td>
</tr>
<tr>
<td>5B: Longitudinal waves: excitation, propagation and decay</td>
<td>movie viewing to discover oscillations, measurement of properties, comparison to field and field topology and loop-atmosphere properties</td>
<td>wave excitation, propagation, decay</td>
<td>10 s cadence full-disk movies at all coronal temperatures and UV/WL</td>
<td>De Pontieu, DeLuca, Hassler, Kosovichev, Mikic, Metcalf, Tarbell</td>
<td>Observer to inspect movies. Data: Solar-B/EIS coordination. Core: field models. External: coronal atmosphere models</td>
</tr>
<tr>
<td>5C: Probing coronal physics with waves</td>
<td>use of dispersion relations, decay rates, etc., to quantify properties of coronal plasma and field</td>
<td>compare oscillation properties to field models and loop-atmosphere models</td>
<td>high-frequency, high S/N images at all temperatures</td>
<td>De Pontieu, DeLuca, Hassler, Priest</td>
<td>Core: field models, DEM profiles: along loops. External: MHD simulations</td>
</tr>
<tr>
<td>5D: The role of magnetic topology in wave phenomena</td>
<td>why are transverse oscillations seen only near magnetic separators, what is the imaged counterpart of high-temperature oscillations</td>
<td>field models and topology analysis</td>
<td>see 5A,B</td>
<td>De Pontieu, DeLuca, Hassler, Schrijver, Metcalf, Keller</td>
<td>External: advanced loop and field modeling based on HMI data and plasma-physical simulations</td>
</tr>
</tbody>
</table>
### Science Questions to Instrument Properties

The AIA instrument design and science investigation address all over-arching science questions (1...7) in the SDO Level-1 Requirements (August 2003)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Spatial</th>
<th>Temporal</th>
<th>Thermal</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science theme</td>
<td>Field of View</td>
<td>Continuity</td>
<td>$\Delta \log T$</td>
<td>T coverage</td>
</tr>
<tr>
<td><strong>1) Energy Input Storage &amp; Release</strong>&lt;br&gt;DYNAMIC CORONAL STRUCTURE</td>
<td>$\Delta x = 1 \text{ Mm}$</td>
<td>$\Delta t$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Full Corona &lt;br&gt;40'-46'</td>
<td>Full Disk passage</td>
<td>$\sim 0.3$</td>
<td>0.7-8 MK (full corona)</td>
</tr>
<tr>
<td>2</td>
<td>Active Regions</td>
<td>$&lt; 1$ min, a few sec in flares</td>
<td>Days</td>
<td>0.3 for DEM inv.</td>
</tr>
<tr>
<td>3</td>
<td>Majority of Disk</td>
<td>A few sec in flares</td>
<td>At least days for buildup</td>
<td>$\sim 0.3$ for T$\leq$5MK, $\sim 0.6$ for T$&gt;5$MK</td>
</tr>
<tr>
<td>4</td>
<td>Full Disk &lt;br&gt;+off-limb</td>
<td>Continuous observing</td>
<td>$\sim 0.3$</td>
<td>5000 K - 20 MK</td>
</tr>
<tr>
<td>5</td>
<td>Active Regions</td>
<td>As short as possible</td>
<td>Continuous for discovery</td>
<td>$\sim 0.5$ to limit LOS confusion</td>
</tr>
</tbody>
</table>
Thermal Coverage is Key to Coronal Physics

- 6 Fe-line EUV channels to recover the coronal thermal structure while avoiding the problem of different chemical compositions; 4 new channels to observe the warm and hot corona; all narrow band to optimize contrasts
- WL sharing low-T coronal optics for alignment with other instruments (HMI, …)
- UV to study waves and field going into the corona as well as particle beams and conducted thermal energy coming down; TRACE-like for continuity, with proven usefulness and technology
- He II 304Å to provide coverage of the chromosphere, to observe filaments, and as a key driver to chemistry of the Earth’s outermost atmospheric layers

### AIA wavelength bands

<table>
<thead>
<tr>
<th>Channel</th>
<th>$\Delta \lambda$(^\dagger\dagger)</th>
<th>Ion(s)</th>
<th>Region of Atmosphere*</th>
<th>Char. log($T$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible</td>
<td>-</td>
<td>Continuum</td>
<td>Photosphere</td>
<td>3.7</td>
</tr>
<tr>
<td>1700Å</td>
<td>-</td>
<td>Continuum</td>
<td>Temperature minimum, photosphere</td>
<td>3.7</td>
</tr>
<tr>
<td>304Å</td>
<td>12.7</td>
<td>He II</td>
<td>Chromosphere, transition region,</td>
<td>4.7</td>
</tr>
<tr>
<td>1600Å</td>
<td>-</td>
<td>C IV+cont.</td>
<td>Transition region + upper photosphere</td>
<td>5.0</td>
</tr>
<tr>
<td>171Å</td>
<td>4.7</td>
<td>Fe IX</td>
<td>Quiet corona, upper transition region</td>
<td>5.8</td>
</tr>
<tr>
<td>193Å</td>
<td>6.0</td>
<td>Fe XII, XXIV</td>
<td>Corona and hot flare plasma</td>
<td>6.1, 7.3</td>
</tr>
<tr>
<td>211Å</td>
<td>7.0</td>
<td>Fe XIV</td>
<td>Active-region corona</td>
<td>6.3</td>
</tr>
<tr>
<td>335Å</td>
<td>16.5</td>
<td>Fe XVI</td>
<td>Active-region corona</td>
<td>6.4</td>
</tr>
<tr>
<td>94Å</td>
<td>0.9</td>
<td>Fe XVIII</td>
<td>Flaring regions</td>
<td>6.8</td>
</tr>
<tr>
<td>133Å</td>
<td>4.4</td>
<td>Fe XX, XXIII</td>
<td>Flaring regions</td>
<td>7.0, 7.2</td>
</tr>
</tbody>
</table>

*Absorption allows imaging of chromospheric material within the corona;\(^\dagger\dagger\)FWHM, in Å
# AIA Design Characteristics

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<tr>
<th>Implementation Requirement</th>
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<tbody>
<tr>
<td>High Angular Resolution</td>
<td>~0.6 arc second pixels</td>
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<tr>
<td>Large Field of View (field &amp; irradiance)</td>
<td>full Sun + 2 pressure scale heights</td>
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<tr>
<td>Large Dynamic Range</td>
<td>&gt; 1,000</td>
</tr>
<tr>
<td>Complete Coronal Temperature Coverage</td>
<td>~10⁵–10⁷ K in 6 EUV Fe-line channels</td>
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<tr>
<td>Adequate photo-/chromospheric coverage</td>
<td>UV/WL and He II 304Å imaging</td>
</tr>
<tr>
<td>Time Resolution (dynamics &amp; irradiance)</td>
<td>~10 s baseline cadence, ~2 s fastest</td>
</tr>
<tr>
<td>Dynamic Exposure Control</td>
<td>brightness histogram feedback</td>
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<td>Long-Term Coverage</td>
<td>continuous observations up to many weeks, spanning half a cycle</td>
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<tr>
<td></td>
<td>Adequate aperture, filters, detector system</td>
</tr>
</tbody>
</table>

Exposure times below 3 s
Instrument Design Overview

- Four ST’s - 8 Science Channels
  - 7 EUV Channels in a sequence of Fe line and He 304Å
  - A UV Channel with CTN, 1600Å, 1700Å filters
- Active secondaries for image stabilization
- Four GT’s
- Four 4096 x 4096 thinned Back Illuminated CCD’s
- 2.5 Second readout of Full CCD
- One Second Reconfigure of all Mechanisms
  - Filter Wheels
  - Sector Shutter
  - Focal Plane Shutters
- On-Board Data Compression via several Lookup Tables
AIA Normal and Special Operations

- Regular cadence of 10 s for 8 wavelengths for full-CCD readouts allows observations of most phenomena, guaranteed coverage, ease of analysis (timing studies), and standardized software, compatible with HMI observations and EVE science needs.

<table>
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<tr>
<th>Baseline program</th>
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<tr>
<td>131 Fe XX/XXIII</td>
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<tr>
<td>0s</td>
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- But fast reconnection, flares, eruptions, and high-frequency waves require higher cadence. Within telemetry constraints, partial readouts in a limited set of wavelengths embedded in a slowed baseline program, infrequently implemented, broaden discovery potential without adverse effects to LWS goals.
Science Coordination

• The AIA team will stimulate joint observing and analysis.
  – Coordinated observing increases the coverage of the global Sun-Earth system (e.g., STEREO, coronagraph, wind monitors, …), provides complementary observations for the solar field (e.g., vector field, Hα filament data) and its atmosphere (Solar-B/EIS spectral information). And it increases interest in analysis of AIA data.
  – The AIA team includes PI’s and Co-I’s from several other space and ground based instruments committed to coordination (e.g., “whole fleet months”):
    - EVE and HMI needs have been carefully taken into account in setting plate scale, field of view, cadence, and channel selections, and in science themes.

• EVE and HMI needs have been carefully taken into account in setting plate scale, field of view, cadence, and channel selections, and in science themes.
AIA System Requirements

Science questions determine the top level system properties.

1. Field of View (FOV) and Pixel Size
2. Spatial Resolution
3. Temperature Coverage
4. Cadence
5. Dynamic Range
6. Guide Telescope

The system properties flow down to the component properties.

1. Filters, coatings, and detector
2. Mechanisms
3. Image Stabilization System
4. Electronics and Software
Field of View and Pixel Size

• AIA atmospheric images shall cover a field of view of 41 arcmin (along detector axes - 46 arcmin along detector diagonal) with a sampling of 0.6 arc seconds per pixel
• AIA science themes 1, 3, and 5 require whole Sun viewing

  – These requirements drive telescope prescription and detector size
  – These requirements drive the required focal length and the required resulting telescope envelop length
  – Sampling of 0.6 arcsec requires a 4096 x 4096 pixel detector
  – Derived requirements flow to telescope design (for PSF or RMS spot size) and the detector MTF
FOV Requirement

- Field of View: require observations to at least a pressure scale height (=0.1 \( R_{\text{solar}} \) at \( T_e=3 \) MK)

- AIA: 41 arcmin = 1.3 \( \tau_P \)
  46 arcmin = 2.0 \( \tau_P \)
  (see dashed lines)

- AIA will observe 96% of X-ray radiance (based on Yohkoh)

- AIA will observe nearly all (~98%) emission that will be in EVE’s FOV

Estimated X-ray radiance at 3 MK as observed by Yohkoh/SXT as function of limb height.
Implementation of AIA FOV

- AIA will have 41 arcmin FOV along detector axes
- AIA will have 46 arcmin FOV along diagonal of detector
- Corners of the FOV are vignetted by the filterwheel filters
Science questions determine the top level system properties.

1. Field of View (FOV) and Pixel Size
2. **Spatial Resolution**
3. Temperature Coverage
4. Cadence
5. Dynamic Range
6. Guide Telescope

The system properties flow down to the component properties.

1. Filters, coatings, and detector
2. Mechanisms
3. Image Stabilization System
4. Electronics and Software
Spatial Resolution

- Telescope response must be adequate over the entire FOV
- Criterion: spot size must fall within 1.2x1.2 arcsec\(^2\)
- e2v detector has 12 µm pixel size (=0.6 arcsec) \(\Rightarrow\) focal length (4.125 m)
- Two optical designs are being considered
  - Ritchey-Crétien: minimizes coma – results in symmetric PSF across Suncenter Solar Limb Edge of Field

Candidate Optical Prescription
Each channel (half telescope) fits within 2×2 pixels
Science questions determine the top level system properties.

1. Field of View (FOV) and Pixel Size
2. Spatial Resolution
3. **Temperature Coverage and Telescopes**
4. Cadence
5. Dynamic Range
6. Guide Telescope

The system properties flow down to the component properties.

1. Filters, coatings, and detector
2. Mechanisms
3. Image Stabilization System
4. Electronics and Software
Temperature Coverage Requirement

- The AIA instrument shall acquire solar images that cover a plasma temperature spanning from 5000K to 20MK with 8 wavebands
  - This requirement requires a broad range of wavelengths covering the optical, UV, EUV, and potentially X-rays

- AIA science themes 1, 2, 3, 4 require that the temperature resolution be $\Delta \log T \sim 0.3$
  - This requirement set limits on the bandpass of each channel.
  - Many science objectives will depend on the simultaneous multi-wavelength observations
  - One analysis technique we expect to use commonly is differential emission measure (DEM) modeling

$I_i = \int G_i(T_e) n_e^2(T_e) dT_e dl$
Selection of non coronal lines

- UV channel will have three filters: White light, C IV 1550, UV Continuum
  - White light used for ground calibration
  - White light used for co-alignment with HMI and other ground-based instruments
  - UV filters are similar to TRACE bandpasses
    - Study waves and field going into the corona as well as particle beams and conducted thermal energy coming down

- He II 304A
  - Observes the chromosphere
  - Monitor filaments
  - Key driver to chemistry of the Earth’s outermost atmospheric layers

Example of a prominence observed by SOHO/EIT. The upper chromosphere has a temperature of 60,000 K.

EIT 304A

14 Sept 1999
AIA temperature coverage

- EUV Wavelength selection meets AIA science objectives

Dots are SOHO/CDS + Yohkoh data. Black curve is the recovered DEM using simulated AIA responses. The responses of the AIA channels are shown normalized to recovered DEM.
DEM Reconstruction Tests

• Tests performed with simulated data – predicted AIA response functions show that multiple channels are necessary to constrain solution for DEM
  – Consistent with the fact that the solar atmosphere is emitting over a broad range of temperatures
  – With five channels, it is often possible to achieve solutions, but the quality of the recovered DEM improves with the number of temperature channels

From Deluca et al (AIA00407)
Looking at the AIA from the Sun

- 304 nm (Fe XVIII)
- 94 nm (He II)
- 171 nm (Fe IX)
- 1600 C IV
- UV
- 1700 UV Cont.
- 4500 White Light
- 211 nm (Fe XIV)
- 193 nm
- 335 nm (Fe XVI)
- 133 nm

Instrument Module / Optical Bench
Mesh Filter Mounts
AIA Telescope with Quad Selector

Cables route to primary end of telescope

Spider Assembly

Connector panel (protruding through cutout in graphite tube)
A GT is mounted to each Science Telescope

CCD Radiator

Guide Telescope (GT)

Camera Electronics Box (CEB)

Proposed Configuration

Aperture Door

Science Telescope (ST)
AIA Telescope Array Mounted on IM

- Four nearly identical science telescopes
- Each ST has a dedicated guide telescope for ISS
- CEB mounts separately to the IM
AIA Science Telescope Optical Layout
AIA System Requirements

Science questions determine the top level system properties.

1. Field of View (FOV) and Pixel Size
2. Spatial Resolution
3. Temperature Coverage
4. **Cadence**
5. Dynamic Range
6. Guide Telescope

The system properties flow down to the component properties.

1. Filters, coatings, detector performance
2. Mechanisms and their performance
3. Image Stabilization System
4. Electronics and Software
• The AIA shall have an observational cadence of one set of 8 wavelengths every 10s or shorter
• The AIA signal to noise of images shall be 8 in quiet sun, 20 in active sun
• AIA science themes: All (5) require high cadence of at least 10s. Science themes 3 and 5 would benefit from an even higher cadence
  – These requirements drive a multiple telescope approach in order to obtain necessary signal strength with corresponding simultaneity
  – Eight telescopes would meet the requirement, but requires greater resources
    • Chose an optimized approach in which each telescope observes two bandpasses
  – These requirements drive minimum telescope effective area, multilayer reflectivity requirements, CCD efficiencies, camera readout times, and mechanism set-up performance
Science questions determine the top level system properties.

1. Field of View (FOV) and Pixel Size
2. Spatial Resolution
3. Temperature Coverage
4. Cadence
5. **Dynamic Range**
6. Guide Telescope

The system properties flow down to the component properties.

1. Filters, coatings, detector performance
2. Mechanisms and their performance
3. Image Stabilization System
4. Electronics and Software
Dynamic Range Requirement

• The AIA signal to noise of images shall be 8 in quiet sun, 20 in active sun
  – Requires a dynamic range of at least 400 for photon statistics
• AIA instruments shall provide cameras with a dynamic range of at least 13 bits
• AIA Science Objectives 2 and 3 require a dynamic range of >1,000
  – Camera requirements clear from MRD 3.3.6
  – Detector must have adequate dynamic range
    • 335 A channel is the limiting case for EUV wavelengths:
      \[
      \frac{12.398}{335} \times \frac{3.65 \times 150,000}{3.65} = 1521
      \]
• AIA implementation: dynamic range between 1,500 and 4,000
  – e2v CCD: low noise, high efficiency, adequate well depth (>150,000 electrons)
  – Camera design has 14 bit A/D converter
AIA System Requirements

Science questions determine the top level system properties.

1. Field of View (FOV) and Pixel Size
2. Spatial Resolution
3. Temperature Coverage
4. Cadence
5. Dynamic Range
6. **Guide Telescope**

The system properties flow down to the component properties.

1. Filters, coatings, detector performance
2. Mechanisms and their performance
3. Image Stabilization System
4. Electronics and Software
Guide Telescope Requirements

- The AIA shall provide four identical guide telescopes each with a noise equivalent angle of 1 arcsec and update frequency to the spacecraft of at least 10 Hz
- The guide telescopes shall be designed such that the science sun acquisition can be performed given an initial pointing error of 120 arcsec (3 sigma) in the y and z axes
- The tracking signal has a linear range: ±95 arcsec

Derived requirements
- Used for AIA image stabilization system (ISS)
- Must have good mechanical coupling to science telescope (first mode must be >100 Hz)
Science Reference Boresight
• Each GT produces high bandwidth analog pointing error signals for image motion by rotations about the Y & Z axes (pitch and yaw)
• Analog signals are used by the image stabilization system (ISS) within the associated Science Telescope
• Digitized versions of the signals are used for S/C ACS pointing, housekeeping data on ISS health, high rate diagnostic data for ISS calibration
  – Signals from all GT’s sent to S/C
  – S/C points to null the primary GT signal plus bias (between SRB and GT)
  – Bias will be determined on ground and uplinked, after periodic (like monthly) GT & ST pointing calibrations

• GT Noise Level will be determined by electrical noise, not photon noise
  – 5 Volt analog signal corresponds to approx. +/-100 arcsec
  – Digitized to 12 bits ➔ LSB = 0.05 arcsec = 1.2 milli-volts, very small
  – TRACE & SECCHI GT have instantaneous 1-sigma noise ~10 mV = 0.4 arcsec
  – Noise will be reduced by averaging samples in AIA processor, as on TRACE
GT Design

- Mechanically similar to STEREO/SECCHI
- Same optical prescription as TRACE
- Linear range is ±95 arcsec
- Co-alignment to science telescope is <±20 arcsec
- One will be ACS prime and the others will be redundant
  - All four are available to the ACS
  - Photo diodes and preamp circuits are redundant
  - No cross-strapping for ISS
SECCHI Guide Telescopes

- AIA mechanical design is a copy of the STEREO/SECCHI design

- Optical prescription is same as TRACE

- Preamp electronics are identical to SECCHI
AIA System Requirements

Science questions determine the top level system properties.

1. Field of View (FOV) and Pixel Size
2. Spatial Resolution
3. Temperature Coverage
4. Cadence
5. Dynamic Range
6. Guide Telescope

The system properties flow down to the component properties.

1. **Filters, coatings, and detector performance**
2. Mechanisms and their performance
3. Image Stabilization System
4. Electronics and Software
Filter Requirements

• Entrance Filters
  – Must block $10^{-5}$ of out-of-bandwidth radiation
  – Used for wavelength selection (Al or Zr) in two telescopes (94/304; 133/335)
  – Flows down requirements to door, multifaceted frame mesh

• Filterwheel Filters
  – Must block $10^{-6}$ of out-of-bandwidth radiation
  – Wavelength selection (Al or Zr) in two telescopes (94/304; 133/335)
  – UV filters must have appropriate bandpasses for C IV, UV Cont, visible light

• Alignment requirement (for diffraction correction)
  – Support grids will create diffraction
  – Alignment will facilitate removal during ground analyses
  – Entrance filter support structure shall be aligned to 45 ±1 degrees (wrt CCD)
Zr & Al used to select wavelengths

- Properties of zirconium and aluminum are used to select the wavelengths in two of the telescopes: 94/304 and 133/335
- Al filters are similar to that used on TRACE and STEREO/SECCHI
- Zr has been developed by Luxel, but no flight experience
Coatings Requirements

- With filter transmissions must provide $\Delta \log T \sim 0.3$
- Must provide adequate reflectivity to meet cadence requirements (maximum of 2.7s exposures to meet 10s/2 cadence)
Summary of filters and coatings

- The choice of filters makes it possible to select wavelengths on each half of the telescope by choosing the appropriate filter except for the 193/211 telescope.
- Filter 2 represents a redundant filter.
- The Zr (3000 Å)/Poly filter in the 133/335 telescope could be used for additional attenuation during flares.

<table>
<thead>
<tr>
<th>Telescope</th>
<th>λ (Å)</th>
<th>Ion</th>
<th>Coating Materials</th>
<th>Entrance Filter</th>
<th>Filterwheel Filter 1</th>
<th>Filterwheel Filter 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1550</td>
<td>C IV</td>
<td>Al, Al, Mo/Si</td>
<td>Bandpass on MgF₂</td>
<td>Bandpass/MgF₂, MgF₂</td>
<td>Bandpass/MgF₂, MgF₂</td>
</tr>
<tr>
<td></td>
<td>1600</td>
<td>Continuum</td>
<td>Al, Al, Mo/Si</td>
<td></td>
<td>MgF₂, MgF₂</td>
<td>MgF₂, MgF₂</td>
</tr>
<tr>
<td></td>
<td>4500</td>
<td>White Light</td>
<td>Al, Al, Mo/Si</td>
<td></td>
<td>MgF₂, MgF₂</td>
<td>MgF₂, MgF₂</td>
</tr>
<tr>
<td></td>
<td>171</td>
<td>Fe IX</td>
<td>Al, Al, Mo/Si</td>
<td>Bandpass on MgF₂</td>
<td>MgF₂, MgF₂</td>
<td>MgF₂, MgF₂</td>
</tr>
<tr>
<td>2</td>
<td>94</td>
<td>Fe XVIII</td>
<td>Ru/Y, SiC/Si</td>
<td>Zr, 2000 Å</td>
<td>Zr, 2000 Å</td>
<td>Zr, 2000 Å</td>
</tr>
<tr>
<td></td>
<td>304</td>
<td>He II</td>
<td>SiC/Si</td>
<td>Al, 1500 Å</td>
<td>Al, 1500 Å</td>
<td>Al, 1500 Å</td>
</tr>
<tr>
<td>3</td>
<td>133</td>
<td>Fe XX/XXIII</td>
<td>Mo/Si, SiC/Si</td>
<td>Zr, 2000 Å</td>
<td>Zr, 2000 Å</td>
<td>Zr, 2000 Å</td>
</tr>
<tr>
<td></td>
<td>335</td>
<td>Fe XVI</td>
<td>SiC/Si</td>
<td>Al, 1500 Å</td>
<td>Al, 1500 Å</td>
<td>Al, 1500 Å</td>
</tr>
<tr>
<td>4</td>
<td>193</td>
<td>Fe XII/XXIV</td>
<td>Mo/Si, SiC/Si</td>
<td>Al, 1500 Å</td>
<td>Al, 1500 Å</td>
<td>Al, 1500 Å</td>
</tr>
<tr>
<td>Ap Select</td>
<td>211</td>
<td>Fe XIV</td>
<td>Mo/Si, SiC/Si</td>
<td>Al, 1500 Å</td>
<td>Al, 1500 Å</td>
<td>Al, 1500 Å</td>
</tr>
</tbody>
</table>
Detector Requirements

• Sensitivity (from cadence and minimum exposure time)
• Pixel size (from resolution, telescope design)
• Array size (from FOV requirement)
• Well depth (dynamic range)
• Cooling: Need to cool below –65C
  – Dark current performance
  – Mitigate loss of charge transfer efficiency due to radiation damage
CCD Camera Systems

- CCD Camera Systems are key elements of HMI & AIA
  - Were to be provided by UK Co-investigators
  - Now being procured from UK suppliers under subcontracts (same sources, however)
  - HMI and AIA use identical cameras and CCDs except AIA CCDs are back-side thinned
- CCD – 4096 x 4096, 12 micron pixels
  - Extension of devices that are being used on Solar-B FPP (2048 x 4096 pixels)
  - E2v has already produced non-flight functioning devices
- CEB – 8 Mpixels/sec via 2 Mpixels/sec from 4 ports simultaneously
  - Extension of SECCHI/STEREO cameras by RAL
  - Design modifications are quite mature with rescopes being imposed early to maintain schedule
CCDs and Cameras

Packaged thin gate CCD

**CCD Status:**

- Three batches of devices processed
- Third batch in probe testing and shows better yield
- Images from first packaged device
- Reviews in England
  - July 03 Peer Review
  - Feb 04 Demo Phase Review
- Deliver evaluation unit to RAL late-March
- Deliver 2 evaluation units to LMSAL April 04

**CEB Status:**

- Video board schematic is complete
- Characterized the ghosting affect
- CDS/ADC ASIC is being processed
- Existing wave form generator ASIC are being packaged
- Progress is being made on the mechanical interface
- Reviews in England
  - July 03 Requirements review
  - Sept 03 ICD discussions at RAL
  - Feb 04 Proposal and status discussions
CCD QE estimates based on SXI

- AIA detector quantum efficiency is based on GOES SXI measurements of back-illuminated e2v devices
- Experience with SXI and SECCHI programs indicate consistent QE performance within a wafer run
AIA response functions (1 of 2)

- Computed AIA response functions
AIA response functions (2 of 2)

- Computed AIA response functions
AIA observing times

• Provides for dynamic range of 8 (QS) and 20 (AR) [MRD 1.5.7]
• Provides 10s or better cadence with two wavelength channels per telescope

<table>
<thead>
<tr>
<th>Channel</th>
<th>Quiet Sun</th>
<th>Active Region</th>
<th>M flare</th>
<th>Microflare</th>
</tr>
</thead>
<tbody>
<tr>
<td>94 Å</td>
<td>35</td>
<td>&lt;0.1s&gt;</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>131 Å</td>
<td>22</td>
<td>240</td>
<td>&lt;2.8ms&gt;</td>
<td>3,400</td>
</tr>
<tr>
<td>171 Å</td>
<td>1,100</td>
<td>&lt;2.1s&gt;</td>
<td>&lt;57ms&gt;</td>
<td>&lt;0.19s&gt;</td>
</tr>
<tr>
<td>193 Å</td>
<td>810</td>
<td>&lt;1.6s&gt;</td>
<td>&lt;7.1ms&gt;</td>
<td>&lt;0.3s&gt;</td>
</tr>
<tr>
<td>211 Å</td>
<td>250</td>
<td>6,600</td>
<td>&lt;74ms&gt;</td>
<td>&lt;1.1s&gt;</td>
</tr>
<tr>
<td>304 Å</td>
<td>2,500</td>
<td>8,100</td>
<td>&lt;10ms&gt;</td>
<td></td>
</tr>
<tr>
<td>335 Å</td>
<td>61</td>
<td>2,700</td>
<td>&lt;97ms&gt;</td>
<td>5,200</td>
</tr>
</tbody>
</table>

Assumes thin filter wheel filters  From CSR, Appendix A
AIA System Requirements

Science questions determine the top level system properties.

1. Field of View (FOV) and Pixel Size
2. Spatial Resolution
3. Temperature Coverage
4. Cadence
5. Dynamic Range
6. Guide Telescope

The system properties flow down to the component properties.

1. Filters, coatings, and detector
2. **Mechanisms**
3. Image Stabilization System
4. Electronics and Software
Cross section: mechanism locations

- Requirements have been flowed down to all mechanisms
- Five mechanism types: all have design heritage
Mechanism Requirements (1 of 3)

• Aperture Door
  – Tight seal to protect entrance filters
  – Particle protection
  – Operates once on orbit
  – AIA design based on simplified TRACE design (no vacuum chamber)
  – Wax actuator controlled by AEB

• Focus Mechanism
  – Telescope tubes are made of carbon fiber with low CTE
  – Mechanism is required to have a ±100 \( \mu \text{m} \) range
  – AIA design has ±800 \( \mu \text{m} \) range
  – Moves the secondary mirror
  – Based on the TRACE design
    • Need to develop max ops spec
• Shutter Mechanism
  – Brushless DC motor
  – Based on EPIC and Solar-B/XRT
  – Blade diameter: 6.25 in
  – Beam diameter at shutter: 50.8 mm
  – Required life: 32 M operations
  – Repeatability/Uniformity: ±0.1ms/ ±0.5 ms
  – Minimum exposure: 5ms
  – Minimum cadence: 100 ms
    • For narrow slot or medium slot exposures
Mechanism Requirements (3 of 3)

- Filter wheel mechanism
  - Brushless DC motor with 5 positions
  - Based on SXI & Triana/EPIC filterwheel
  - Filter aperture diameter: 55 mm
  - Required life: 32 M operations
  - Max operational time: 1s between adjacent positions
  - Position accuracy: ±2 arcmin

- Aperture selector (in 193/211 channel)
  - Brushless DC motor/half shade
  - Move time: 1 s
  - Required life: 32 M operations
  - Position accuracy: ±15 arcmin
  - Blade diameter: 8.3 in
AIA System Requirements

Science questions determine the top level system properties.

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The system properties flow down to the component properties.

1. Filters, coatings, and detector
2. Mechanisms
3. **Image Stabilization System**
4. Electronics and Software
Image Stabilization System

- Requirements derived from
  - Exposure time
  - Angular resolution requirement
  - Spacecraft jitter performance

- Will control spacecraft jitter performance and ISS performance in MRD

- Design is based on TRACE (and STEREO/SECCHI)
  - Secondary is activated with three PZTs
  - Error signal provided by guide telescope
• The GT error signals are linear to high accuracy, as long as each diode has some sun and some dark sky on it
  – So sensor geometry (fixed) and solar diameter (varying) determine the linear range

• Linear operation for both S/C ACS control and image stabilization is possible out to offsets of ~ 95 arcseconds, with scale factor (arcsec / DN) somewhat dependent on offset
Measured TRACE GT Performance

- Special measurement over full range in one axis was done Feb 16, 2004
  - Non-linearity somewhat less in measurement than in model
- Diode intensity levels and scale factors have been measured throughout the five year mission: no long term trends seen, just small seasonal variations
Jitter Requirements

- The AIA Blur Jitter shall be less than 0.17 arcseconds (1-sigma in each axis)
  - This ensures the angular resolution of the telescope + detector is achieved in the AIA images
  - This requirement was derived from consideration of predicted resolution of the Science Telescope, CCD pixel size, charge spreading in CCD, and consistency with the HMI requirement

- “Blur jitter” is calculated using the following equation:

\[
\text{Blur (1-sigma)} = \left[ \int_{-\infty}^{\infty} PSD(\omega) \cdot |ATF(\omega)|^2 \cdot [1 - \sin^2(\omega \tau)] \, d\omega \right]^{1/2}
\]

ATF = Attenuation Transfer Function of ISS
PSD = Two-sided Power Spectral Density of the input jitter at the instrument mounting interface

\( \omega \) = Frequency in Hz
\( \tau \) = Exposure Time in seconds
\[ W_j = 1 - \text{sinc}^2(\omega \tau) \]

Weighting Function for RMS Blurring Formula

Use longest exposure time to include low frequency jitter

\[ \tau = 3 \text{ sec} \]
\[ 1/\tau = 0.33 \text{ Hz} \]

All frequencies above ~ 0.05 Hz contribute to blurring
Preliminary Jitter Attenuation

- The AIA ISS is open loop: the PZT tilt mirror does not move the image in the GT
- Therefore, the jitter attenuation depends critically on the calibration of PZT volts needed per volt of GT error signal
- The plot show results for various % errors in this calibration, for the TRACE transfer function
- Based on TRACE, -4% calibration error is a conservative value to use for jitter analysis
- MRD transfer function is slightly more conservative than this (.06 not .05 at DC)
AIA System Requirements

Science questions determine the top level system properties.

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The system properties flow down to the component properties.

1. Filters, coatings, and detector
2. Mechanisms
3. Image Stabilization System
4. **Electronics and Software**
Key Electronics and Software

- The AIA science data shall not exceed of maximum data rate allocation of 67 Mbps over the IEEE 1355 high rate science data bus
  - Requires the use of some data compression

- Electronics and software must provide observational sequence control
  - AIA science objectives require specific sequences (cadence, FOV, exposure time) to obtain appropriate observables

- Observing sequences must be configurable
  - To react to changing solar conditions
  - Expect weekly to daily operations
  - Automatic exposure control must be provided
Electronics and Software Design

• Data Compression
  – Will be provided using reconfigurable look-up tables
  – Square root binning (SRB) provides lossy compression
    • Amount of compression can be adjusted through updates to look-up tables
    • Multiple tables implemented to tune compression on a channel-by-channel basis
  – RICE (lossless) compression achieves 4.5 bits/pixel on 171Å TRACE images
  – SRB + RICE achieves 3.5 bits/pixel on 171Å TRACE images
  – Average SRB + RICE on all AIA images (including UV) is 3.7 bits/pixel
    • Provides a margin of 18% if telemetry allocation is limited to 58 Mbps
    • Increased allocation to 67 Mbps will improve data quality (requires less aggressive SRB algorithms)

• Automatic Exposure Control (AEC)
  – Based on TRACE design
  – Adjusts exposure time to account for changing solar intensity
  – In 133Å channel (Fe XX, XXIII) can control filterwheel for additional attenuation
AIA Electronics Boxes

AIA Electronics Box (AEB)
- Basic layout similar to HMI
- Connectors will be on the long side
- Connectors shown are notional

AIA Camera Electronics Box (CEB)
- Identical to HMI
- Mounts to IM behind science telescope focal plane assembly
AIA Block Diagram
Joint HMI/AIA SOC

• Common aspects
  – Commanding
  – data capture
  – Level-1
  – Export
  – Location

• Unique requirements
  – HMI Higher Level Helioseismology Data Products
  – AIA Visualization and Solar Event Catalog
Data Management Requirements

• HMI data volume and processing requirement
  – Raw data – One 4kx4k image each 2 seconds
  – Level-1 – set of 10 (V) or 20 (B) images to make observable
  – Higher Level Data Products – Projections, time-series, transforms, fits, and inversions to arrive at inferences of physical conditions in solar interior
  – Heritage - Similar to SOHO/MDI and NSO/GONG. All higher level products now exists as research tools. Complexity of data types very similar. Data organization the same. User community the same. Data export requirements expected to be similar in complexity and number but data volume will be larger.

• AIA data volume and processing requirement
  – Raw data volume – Eight 4kx4k images each 10 seconds
  – Level-1- Flat field and spike removal
  – Visualization – Long range coupling of active region scale processes
  – Solar Event Catalog – list of transients to enable “observing the archive”
  – Heritage– Similar to TRACE and SOHO/EIT. Complexity of data types very similar. Data organization the same. User community the same. Data export requirements expected to be similar in complexity and number but data volume will be larger.
Mission Data Flow Block Diagram

- Stanford/Lockheed
  - SOC
    - ops
  - Science
  - White Sands
    - DDS, etc
      - Ka Science
      - S-band Hk
      - S-band Hk
  - Users
  - Hk
  - Cmd
- GSFC
  - MOC
    - Hk
    - Cmd
  - Hk
  - Cmd
JSOC Data Flow

- DDS
- Redundant Data Capture System
- 30-Day Archive
- Offsite Archive
- Level-0
- Primary Archive
- Catalog
- Level-1
- HS & Mag Pipeline
- HS & Mag Pipeline
- HMI & AIA Operations
- House-keeping Database
- AIA Interactive Image Analysis
- Event Catalog
- Movie Tools
- Movie Archive
- Science Team Forecast Centers EPO Public
- MOC
- Offline Archive
- Data Export & Web Service
- High-Level Data Import
- Stanford
Components AIA Science Operations

- Health and Safety of AIA Instrument
  - Monitored via a pair of workstations

- Spacecraft Commanding for Normal Operations
  - Done only occasionally ~ weekly

- Production of Quick-Look Data
  - Web based survey page with movies and science data in near real time
  - Catalog data
    - Automatic recognition
    - Ancillary data from other sources e.g. GOES, ACE, STEREO, Solar B, GB Observatories
    - Visual event recognition by quick-look observers
    - Surveys from Visualization Center

- Production of Reference Data
  - DEM Maps
  - Potential Field Maps (from HMI)
  - Force Free Field Maps (from HMI)

- Support of Data Access
  - Web pages to access data and request specific processing
  - Maintenance of Data Archive Catalog
JSOC Implementation - AIA Component

• Instrument MOC (JMOC) - *Monitors Heath and Safety and Sends Instrument Commands*
  – Hardware and software developed by LMSAL as operational GSE for test and integration of HMI and AIA
  – Responsible for Instrument commanding, operations, health and safety monitoring
  – Development based on previous missions (SOHO, TRACE, SXI, FFP) GSE development
  – Minimal operations commands sent only for software uploads, calibration, and occasion operational mode selection

• Science Processing Center - *Provides Data for Scientific Analysis and Quick Look*
  – All computers, disk drives, and tape libraries in single computer system
  – AIA Quick look and calibration software developed by LMSAL based upon existing TRACE systems
  – Some software for special science products developed by Co-I’s and foreign collaborators.
  – Catalog uses formats developed for VSO and EGSO
  – AIA CPU Processing task approximately 160 times that required for TRACE
  – AIA On-line disk storage estimated 270 Terabytes.
  – On-line data available on Web in near real-time at two web sites
  – 2500 Terabyte Archive on robotic tape libraries for access to entire mission data base
  – Archive Data available via web request typically in less than 24 hours
AIA Data Flow

**Data Products**
- Low-Resolution (1024^2) Summary Movies
- Full-Resolution Event/Feature Movies
- Full-Resolution AR Extract Movies
- Irradiance Curves
- Reconstructed Temperature Maps
- Coronal Field-Line Models

**Level 1a**

**Level 2**

**On-Line Catalogs**
- Catalog of Events/Features
- Catalog of Descriptive Entries
- Catalog of Daily Summaries

**Web Services**
- “The Sun Today” Web Service
- User Requests
- Visualization Center

**Incoming AIA Data (from HMI pipeline)**

- Event Detection
- Feature Recognition
- Movie Maker
- Irradiance Monitoring
- DEM Inversion
- Loop Tracing

- Loop Outlines

- HMI Magnetograms (from HMI pipeline)

- Field Line Extrapolation

AIA Level 0 Archive
AIA Data Flow Block Diagram

Data from Stanford Pipeline
- Level 0 decompressed images
- Level 1a Selected Regions
- Level 1a Magnetograms

Level 0
1.1 Tb/Day

Total Cache 20 TB

AIA Science Data Production
- Quick Look Movies (Level 1a)
- Browser Catalog
- Index
- Calibrated Selected Regions (Level 1a)
- Calibrated Level 0 (Level 1)
- Temperature Maps (Level 2)
- Field Line Models (Level 2)

Quick Look Movies
Browser Catalog
Index
8 Gb/Day,

Total Disk 180 TB

Near Real time Tape
- Archive / Backup
- 1.4 Tb / Day, Life

Developed by Launch

Open Web Connection

On-Line
Survey Data for Public Outreach, Some Forecasting

Controlled Web Connection

100Gb / Day
Total Cache 70 TB

Developed by Launch, Upgraded software and hardware over mission life
Estimate of Quick-Look and Basic Science Data

- **FD Movies - 0.73 Mbits**
  - 10 frame/minute movies in all AIA wavelengths
  - 1 frame/minute of line of sight magnetograms
  - 1 frame/minute Loop Movie (overlay of AIA images)

- **Flat Field Corrected, Despiked, MTF corrected Data Sets of 8 5x5 arc minute Active Regions - 3.15 Mbits**
  - 12 bit Science Data
  - 8 5 x 5 arcminute regions on Sun
  - 8 images/sec for all regions from AIA
  - A loop composite from AIA
  - A line of sight magnetogram from HMI every minute

- **On-line Storage Requirements for Quick Look and Basic Science Data - 5.73 % Total Data**
  - Daily 42 Gigabytes
  - Yearly 15.3 Terabytes

- **One-line Storage for Level O data**
  - Daily 723.6 Gigabytes
  - Monthly 21.7 Terabytes
Quick-Look - What We are Doing NOW

• Quick-Look Page “The Sun Today”
  – Available at http://www.lmsal.com/solarsoft/last_events/

• Last Events Provides:
  – Single images in all available EIT, SXI, TRACE data
  – GOES X ray flux
  – GOES Proton flux
  – Bulk Solar Wind Speed
  – List of Events

• List of Events Provides:
  – Links to other data sets
  – Film strips and movie access

• Film Strips Provides:
  – Event Movies
  – Context Movies
  – GOES Flux
Forecasting System Exist

• Forecasts and Documentation Exists at http://www.lmsal.com/forecast/

• Magnetic Field Forecasts uses:
  – Current full disk MDI magnetograms
  – Acoustic maps of back side of Sun
  – Knowledge of magnetic spreading over solar surface

• Models Predictions based upon:
  – Potential field calculations of magnetic field
  – Gradients in field structure
  – Properties of Heliosphere