Polarization Ray Trace, Radiometric Analysis, and Calibration

Jesper Schou
Instrument Scientist
Stanford University
jschou@solar.stanford.edu
650-725-9826
Polarization Ray Trace – Purpose and Implementation

• **Purpose**
  – Allows for modeling of various types of imperfections and enables trade-off studies
    • Coating properties versus angle
    • Finite thickness of birefringent elements
    • Etc.

• **Standard ray trace including polarization effects**
  – Allows for birefringence
  – Models multilayer coatings
  – Can use tables of measured reflectance and transmission instead
    • But phase changes can’t be included in tables - Possible solution exists

• **Based on existing Zemax model**
  – Easy to keep things consistent

• **Interference implemented by making 4 vacuum/solid leg configurations**
  – Add electrical field vectors at the detector using Zemax macro
  – Tune in wavelength and select polarization from macro
  – Plots done externally
Polarization Ray Trace - Status and Plans

• Currently have “ideal” model
  – Mostly using ideal coatings and waveplates
  – Needs some refinement and crosscheck with final layout

• Need to turn ideal model into “as designed” model
  – Add coatings in various places
  – Model actual waveplate thicknesses
  – Etc.

• Make “as built” model as instrument is built

• Use various models to check for sensitivity to imperfections
Radiometric Analysis – Photon Counts

- **Purpose:** Determine that exposure time is acceptable for 4 sec cadence
- **Number of photons per pixel in the passband outside instrument**
  - Photons per wavelength from Planck function: $7.56 \times 10^{31} \text{photons/sr/m}^2/\text{s/m}$
  - Area of pixel $0.5'' \times 0.5''$: $5.88 \times 10^{-12} \text{sr}$
  - Area of front window (14 cm diameter): $0.0154 \text{m}^2$
  - Filter width (0.0086 nm): $8.6 \times 10^{-12} \text{m}$
  - Total: $5.89 \times 10^7 \text{photons/s}$
- **Efficiency (spec. numbers)**
  - Front window and Blocker: $0.8 \times 0.65 = 0.52$
  - 5 Lyot polarizers: $0.9^5 = 0.59$
  - 2 Michelsons and polarizer: $0.8 \times 0.8 \times 0.9 = 0.58$
  - ISS and BDS beamsplitters: $0.5 \times 0.5 = 0.25$
  - 3 fold mirrors: $0.9^3 = 0.73$
  - CCD QE: 0.4
  - 40 glass/vacuum surfaces: $0.9975^{40} = 0.90$
  - Total efficiency: 0.0116
- **Total photons:** $680000 \text{e}^-/\text{s}$
Radiometric Analysis – Exposure Time

- Science plan assumes 125 ke⁻ exposure level including margins
- Expected exposure time: $125 \text{ ke}^- / (680000 \text{ e}^-/\text{s}) = 183 \text{ ms at BOL}$
- Assume factor 2 loss to EOL: 366 ms
  - MDI had 30% loss in 8 years
- 700+ms exposures acceptable, so margin is 91% - More than adequate
Radiometric Analysis – MDI Comparison

- Rough PDR estimate based on MDI used as check
- BOL exposure time 150 ms
- Several differences (MDI versus HMI)
  - Aperture: \((125 \text{ mm}/140 \text{ mm})^2 = 0.8\)
  - Filter width: \(0.0129 \text{ nm}/0.0086 \text{ nm} = 1.51\)
  - Planck function correction (676.8 nm vs. 617.3 nm): 0.99
  - BDS beamsplitter (most light to HR path in MDI): 0.105/0.5 = 0.21
  - Pixel size: \((2''/0.5'')^2 = 16\)
  - Full well: 125 ke\(^{-}/400\) ke\(^{-} = 0.31\)
  - Final estimate: 150 ms*0.8*1.51*0.99*0.21*16*0.31 = 187 ms
- Within a few percent, but several minor differences not modeled
- Gives additional confidence that we have adequate margin
Calibration - Overview

- Purpose
- Levels of testing
- Parts level tests
- Assembly level tests – Covered in other presentations
- Integrated instrument tests
  - Polarization
    - Polarization GSE setup
  - Analysis
- Test equipment – Covered under I&T
- Status and future work
Purpose

• Acquire measurements needed to enable calibration of data taken on orbit
  – Needed to meet even the minimum science requirements
  – Maximize science return

• Determine optimal observing sequences
  – Actual performance determines optimal framelist
  – Better utilization of instrument

• Quantify instrument performance versus requirements derived in Instrument Performance Document (IPD)

• Predict observables performance based on IPD derivations
Testing at Various Levels

• **Some properties can only be measured before final integration**
  – Detailed filter transmission profiles
  – Waveplate and polarizer properties
  – Angular dependencies

• **Test at different levels of assemblies as appropriate**
  – Individual optical elements, e.g.
    • Waveplates
    • Beamsplitters
    • Polarizers
    • Powered optics
  – Filter sub elements
    • Lyot elements – See filter presentation
  – Entire filters or other subsystems
    • Assembled Lyot filter – See filter presentation
    • Each Michelson – See Michelson presentation
  – Integrated Instrument

• **Similar sets of calibrations were performed on MDI and Solar-B FPP**
  – Procedures already developed
Part Level Tests

- **Front window and blocker**
  - Angular and spatial variations
    - Temperature dependency
    - Discussed in optics and filters presentations

- **Powered optics**

- **Beam splitters**
  - Polarization properties as a function of position, angle and wavelength

- **Waveplates**
  - Retardence values and uniformity
  - Tests performed at HAO with system used for Solar-B FPP

- **CCDs and cameras**
  - Gain, linearity and full well
  - Flat fields
  - Noise level

- **Hollow core motor wobble and distortion**

- **Shutter**
Integrated Instrument Tests

- Sunlight and test sources
- Essential for instrument characterization
- Understand instrument before launch
  - Make efficient use of commissioning time
  - Develop analysis algorithms
- Baseline for trending
  - Little change expected during I&T - Functional testing done regularly.
  - See on orbit calibrations in operations presentation
- Sunlight tests in normal observing mode possible on the ground
  - Significant science analysis possible using ground data

Sunlight tests of the integrated instrument are essential to meet even the minimum science requirements on orbit.
Integrated Instrument Tests

• Filter performance
  – Transmission as a function of wavelength for different tunings
    • Laser and sunlight
  – Temperature sensitivity

• Imaging optics
  – Optical distortion and image quality
  – Flatfields
  – CCD coalignment, relative flatfields and image quality
  – Absolute focus and temperature stability

• ISS
  – Range, performance vs. frequency

• Cameras and CCDs
  – Gain, linearity, …

• Mechanisms
  – Wobble, uniformity, repeatability
Integrated Instrument Tests- Polarization

- Use HAO supplied GSE to make well defined input polarizations
- Determine transmission for different settings of HCMs
- Derive polarization calibration matrix
Integrated Instrument Tests - Analysis

• Significant analysis of calibration data required
  – Adjust instrument if necessary
  – Determine optimal framelist
  – Derive actual observables performance based on IPD derivations
  – Design calibration routines for various observables
  – Determine calibration parameters and tables

• Analysis procedures developed early
  – Use canned procedures to the extent possible
  – Enables efficient use of calibration time
  – Ensures that needed measurements are taken
  – Allows for problems to be caught and corrected early
Status and Future Work

- **Update calibration plan throughout mission**
  - Draft plan available

- **Peer review action items**
  - None received

- **Perform sunlight tests at times with reliable weather**
  - Integrated instrument tests currently scheduled for summer 2006
    - Minimum number of days to be defined
  - Other shorter tests also require sunlight