M4 Implementation Issues

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Outline

- We do not need to start over - M4/97 as a basis for M4/99
- M4/97 Implementation
  - Instrument
  - S/C
  - Operations
  - Data
- M4/97 Weaknesses
- Delta’s - M4/99 Improvements over M4/97
- Remaining “Tall Poles” & Risks
- Remaining Trades & TBDs
- Appendices -- Why things are the way they are in M4

Don’t start over - M4/97 as a basis for M4/99

- M4/1997 nearly made it into the “final dozen” of 50+ proposals
  - Highly rated science
  - Highly rated implementation
- M4/1997 proposal did a good job of “following the data”
  - from source flux
  - to detection
  - to observing modes
  - to data compression
  - to downlink
  - to data processing
  - to science analyses
- Let’s start with M4/97 and look for places to improve

M4/1997 Implementation

- Instrument
  - Telescope & Cryostat
  - Detectors
  - No-moving-parts imaging polarimeter
- Spacecraft
  - 3-axis stabilized SWAS-like
  - gyro-less
  - performance well-matched to instrument requirements
- Operations
  - satellite roll & orbit segments - polarimetry on the cheap
  - only 3 observing templates (AOTs) needed
- Data
  - detector readout
  - calibration issues
  - charged particles
  - uplink/downlink

Instrument

- Telescope
  - 20cm = largest telescope primary diameter to fit inside dewar
  - cooled to 5-6K with effluent He gas
  - 120 arcsec diffration limit at 95um
- Cryostat
  - "STD" - SIRTF Technology Demonstration dewar
  - never flown, but strong flight heritage
  - modern design
  - required significant redesign to contain M4 telescope
    - STD designed w/o telescope in mind
- Detectors
  - Ge:Ga photoconductors
  - SIRTF/MIPS instrument derived
  - good FIR performance
  - high pixel count - twin 32x32 arrays
  - modest temperature operation for background-limited performance
    - 2K (vs < 0.3K for bolometers)
  - multiplexed readouts for low focal plane heat load

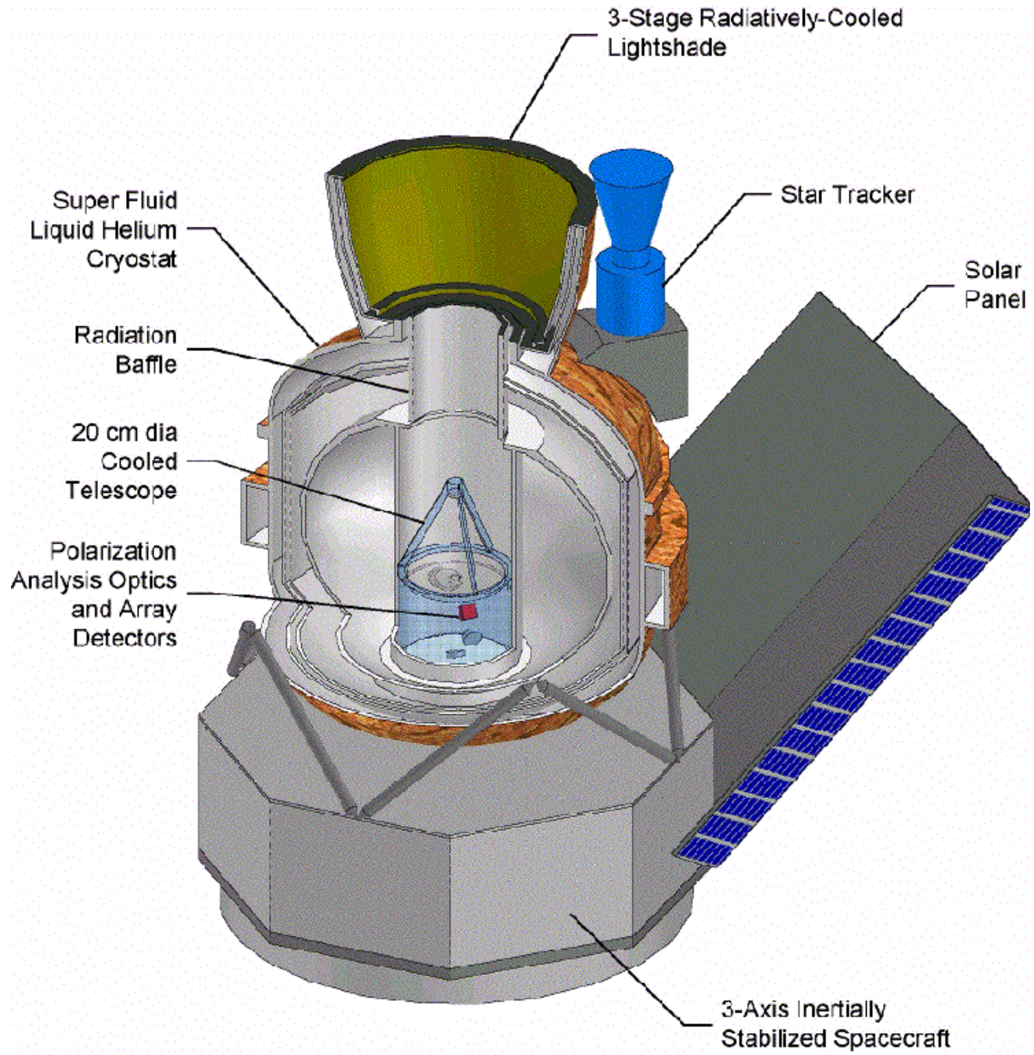
No-Moving-Parts Imaging Polarimeter

- Cassegrain telescope
- Wire-grid beam splitter
- Twin detector arrays - each sees opposite polarization sense
- Satellite roll about bore sight direction
  - fixed 45 degree orientations through one orbit “segment”
  - follow orbit around Earth as a series of segments & rolls
  - detectors for “ISS” = Instantaneous Single Stokes parameters at each orientation
  - 45 degree roll to another orientation turns “U” -> “Q”
  - more rolls turn “Q” -> “U*” and “U*” -> “Q*”
    - * values have detector number switched to remove systematics
- Full observation consists of four orbit segments

Spacecraft

- 3-axis stabilized (SWAS, WIRE like)
- Modest pointing, tracking, jitter requirements
  - beamsize is 120”, pixel size 48” so pointing, jitter less than 20” fine
  - don’t need most expensive star tracker
  - don’t need gyros!
    - big weight savings
    - Ball CT-631 star tracker can develop all finding, pointing information needed
- Must slew between pointings moderately quickly to make raster mapping efficient
  - 11 seconds
- Must develop good electrical power
  - 150-170 watts
- If orbit and launch date selected properly, won’t be eclipsed by Earth during Helium lifetime
  - batteries only needed through launch event
  - mass savings

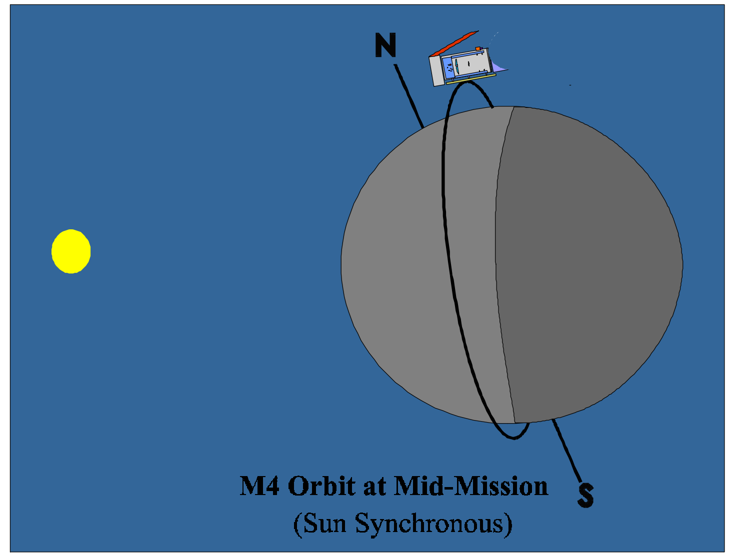
M4/1997 Satellite Configuration

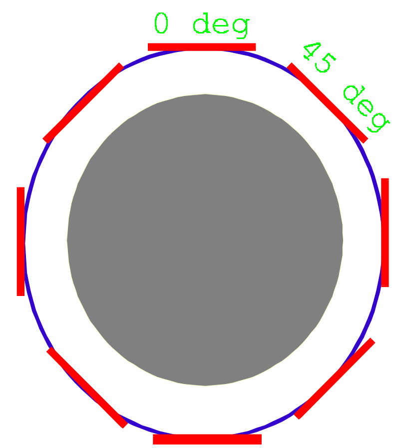


M4 Operations

- Sun-sync orbit
  - dawn-dusk
  - viewing “back” from the orbit
  - Sun avoidance 92deg
  - Earth avoidance 52 deg

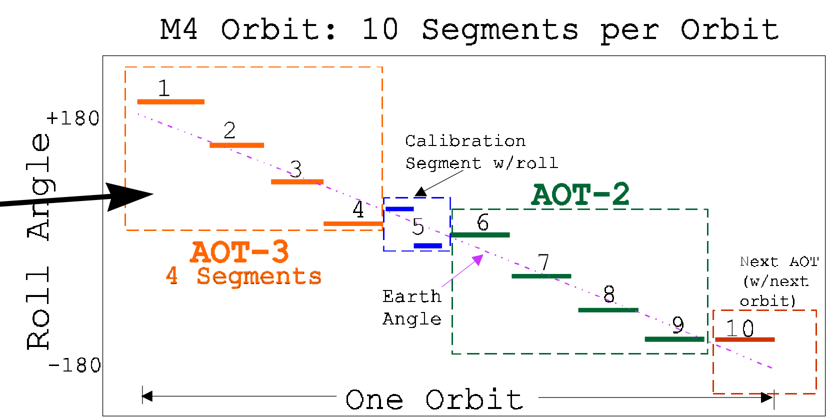
- Orbit Segments
  - 8-12 per orbit
  - 45 deg roll between
  - fixed orientations during each segment
  - 8-12 min segments



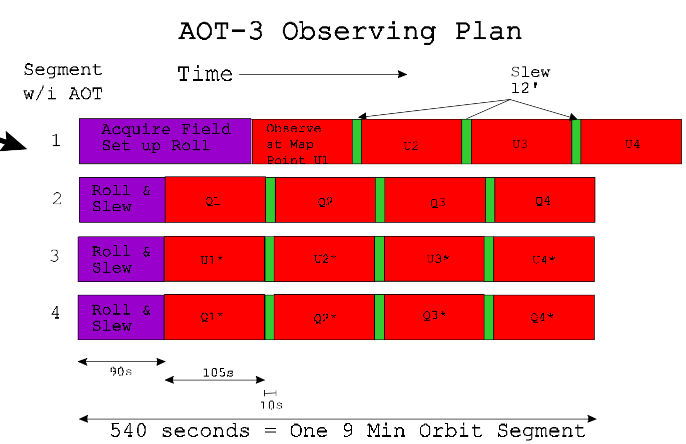


Observing Templates

- Only need 3 AOTs
- Hierarchical
  - 4 segments



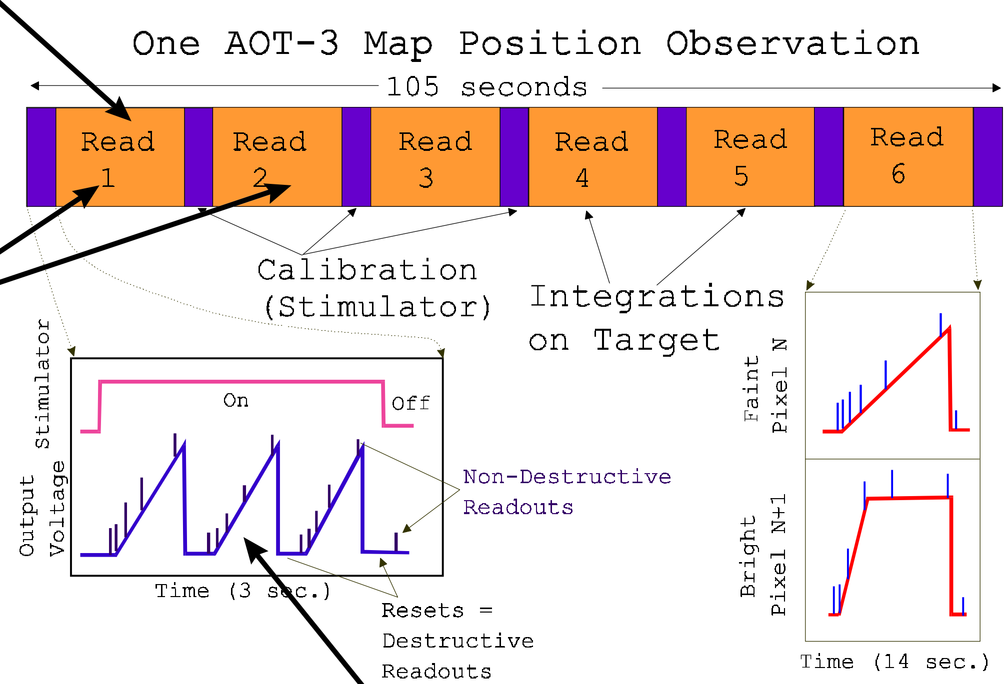
  - N x M raster pattern



Operations II

– Fixed integration times

– Multiple integrations per pointing



– Interspersed Stimulator flashes for Calibration

Data flow

- Preserve 600:1 S/N for all scene illumination levels
  - lowest level -> Cirrus = 1 MJy/sr target SB
  - highest level -> Galactic Center = 20,000 MJy/sr target SB
  - lowest NESB = 0.2 MJy/sr
  - maxium dynamic range = 600 * 20,000 / 0.2 = 60 million!
    - but don’t need all of this -> GC is target noise limited, not background
- Split up dynamic range across units
  - detector well depth
  - ADC conversion gain
  - AOT integration times
  - Raster map overlaps and resamples
  - Orbit segment redundancy
- Conversion gain to oversample noise in background limit
  - 0.02 MJy/sr/ADU

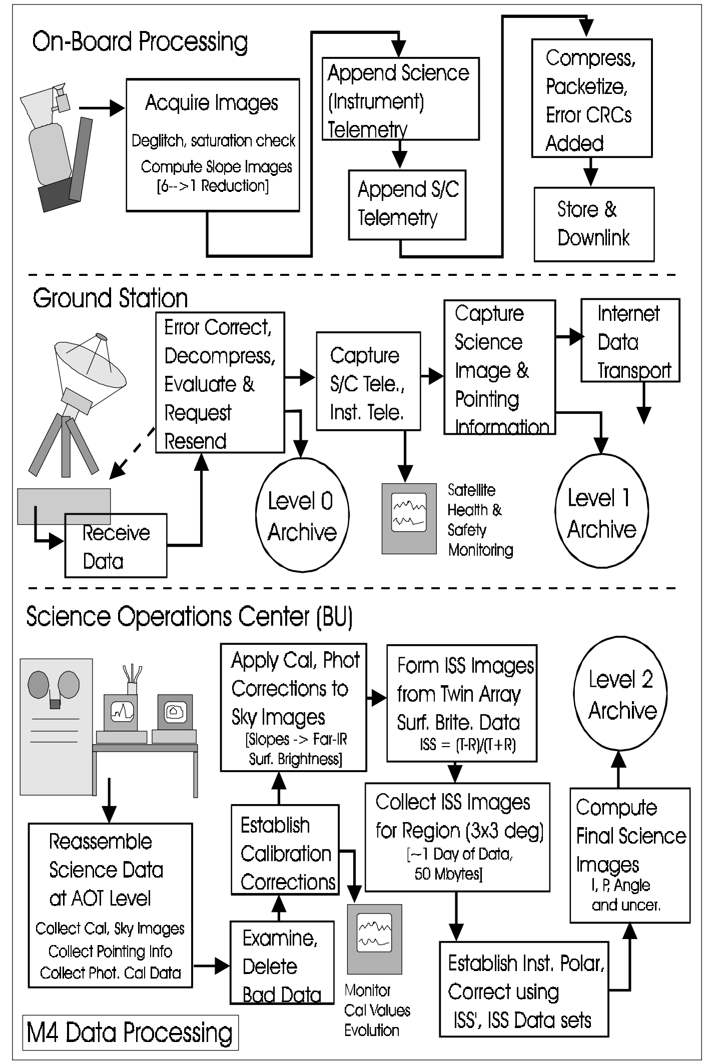
M4/1997 AOTs

- AOT Summary

	AOT-1	AOT-2	AOT-3
T(int.) [s]	0.15	1.5	14
Reads/map point	33	6	6
Cal Rate [1/s]	1/20	1/6.5	1/16
Map raster	5x5	4x4	2x2
Area/4 seg [sq.deg.]	1.13	0.73	0.18
Eff. ISS T(int) [s]	40	72	672
Data Vol./AOT [Mb]	6.1	1.7	0.8
Survey Application	G. Center, Plane	G. Plane, Dark Cl.	Cirrus, Galaxies

Data Flow

- Use "standard" NASA uplink and downlink services
  - No dedicated M4 ground station
    - reduced cost
  - Limited to <6min downlink per day
    - must compress data before downlink
    - must deglitch on-board
  - Must operate in robotic mode for 1-3 days w/o uplink
    - must store up to 3 days of data for all AOT mixes



Milky Way Magnetic Field Mapping Mission

M4/1997 Weaknesses

- Needed 4 consecutive “segments” to obtain full Stokes parameter set
  - U, Q, U’, Q’
- 92 deg Sun avoidance
- 52 deg Earth avoidance
- size of region which could be viewed by 4 segments --> 0
  - originally had 8 segments per orbit
  - even with 12 the 4-segment overlap was exceedingly small
- ISO PHT polarimetry experience
  - worked, but…
  - responsivity drifts on many time scales
  - need to cycle through polarization position angles many times
    - two cycles through 3 wire grids inadequate

Delta's - M4/99 Improvements over M4/97

- M4/1999 must have a "rapidly" rotating half-wave plate
- M4/1999 needs a larger instrument Field of View
  - Wider is generally better for mapping
    - Faster mapping
    - More sensitivity to faintest surface brightness levels
  - Wider is harder for telescope, collimator, halfwave plate, camera mirror designs
    - Makes mapping brightest scenes (Galactic Center) harder
      - must readout even faster to avoid saturation
  - 20 cm aperture, 95um PSF = 2 arcmin
  - 1997 - identified superresolution as a goal
    - PFOV 48 arcseconds
  - Optimum M4/1999 PFOV?
    - 75 arcseconds gives instrument FOV of 40x40 arcmin
    - ISO PHT at 160um was 92 arcseconds (and 3x3 arcmin)

Delta's II

- Wavelength Choice and Number
  - M4/1997 was 95um, twin detector arrays
    - redunancy and no light loss (looked at refl & trans beams from wire grid beamsplitter)
  - Longer wavelengths are better
    - more sensitivity to cooler dust
  - More wavebands is better
    - measure relative warm vs cool dust contribution to polarization
  - M4/1999 -> 2 wavelengths, still only two arrays
    - 90um 32x32 detector (refl beam)
    - 110um 32x32 detector (trans beam)

Remaining “Tall Poles” & Risk areas

- Ge Photoconductor Detector operations
  - Charged Particle Hit Rate & Responsivities
- Data collection issues
  - Photometric Data Collection - AC or DC?
  - Stimulators, Stability, and Polarimetry
  - Polarization Calibration
  - Stokes Mapping
- Cryogenic Issues
  - Thermal Management & Orbit Segments
  - Forward Light Shield
  - Cold Heat Loads
- Failure Modes
  - Gyro-less operation in the post-WIRE world
  - Batteries, solar panels, eclipse seasons
  - Aperture Cover Issues
  - Rotating Half-Wave Plate - Motors, gears, mechanisms

Remaining Trades & TBDs

- New M4 Orbit/operations model
- Detector operations model
- Data collection, compression, processing model
- Updated Thermal Model(s)
- Full Optical Design with half-wave plate
- Scheduling/observations planning tool

Appendices -- Why things are in M4

- Orbit & Lifetime
- Galactic Plane (& Center) Mapping Issues
- Telescope Aperture
- Instrument Temperature

Orbit & Lifetime Issues

- Cryo missions and equatorial NEOs don’t work
  - Sun, Earth avoidance “overconstrain” pointing
  - need dawn-dusk orbit
    - Sun-sync (evolving) - orbit “normal” to Earth-Sun line
    - Angular momentum conserving orbits hit Sun, Earth avoidance problems
    - both have Earth-eclipse “seasons”
- High orbits (>750km) can’t be reached with Pegasus & M4

Galactic Plane (& Center) Mapping Issues

- Galactic Plane is almost perpendicular to ecliptic
- Sun-sync orbit sweeps through Galactic Center quickly
- For limited lifetime mission (<6 months) not all parts of sky can be viewed
- Launch date important
- Inclination important
- Eclipse season avoidance important
  - allows reducing battery mass, increasing launch mass margin
- Need the GI program to fully utilize the “other” part of the orbit not spent looking at the inner Galaxy

Telescope Aperture

- Larger is better for science
  - better angular resolution
  - smaller physical sizes probed
  - trace star formation on smaller scales -> better “Origins” connection
- Limited to 20cm in SMEX config
  - Pegasus shroud limits dewar size
  - Dewar limits telescope size
- Unlikely to change for M4/1999 SMEX
  - need smaller cryogen volume to expand aperture
  - cryocooler!

Instrument Temperature

- Detectors need to operate at 2K to be background limited
- Telescope needs to operate below 10K to keep instrument background limited
  - related to observing wavelength
    - shorter wavelengths can allow warmer telescope (they just won't sense any cool dust polarization)
- Superfluid Liquid Helium is the only acceptable cryogen
  - solid hydrogen (7-10K; WIRE) isn't cold enough for our detectors
  - hybrid cryostat (He for detector, H_2 for telescope) is EVEN more costly
  - M4 mission lifetime determined by Helium volume (110 liters) and heat load to cryogen

Why Cryocoolers Won’t Work

- 2-K space qualified cryocoolers are not yet available
- 10-K space qualified cryocoolers are not quite ready (Ball)
- Hybrid (2K dewar for detector; 10K cryocooler for telescope) is beyond SMEX cost range
  - but might enable a long duration MIDEX mission...

Warm Launch Won't Work

- SIRTF-like configuration
  - detector cold at launch, telescope warm
  - on-orbit, telescope passively cools, then cryogen takes over
- M4 NEO won't let telescope passively cool enough
- M4 can't carry enough SFLHe to cool telescope and carry out mission