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CONNECTING MINDS. ADVANCING LIGHT.

Integrated Spectropolarimetric Imagers for the Multi-Angle Imager for Aerosol (MAIA) Project

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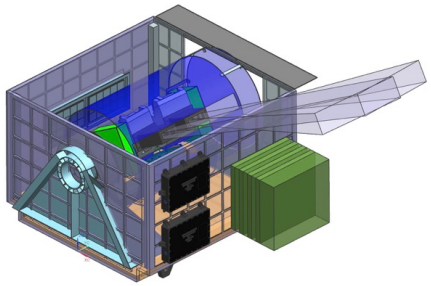

NASA Jet Propulsion LaboratoryCalifornia Institute of Technology

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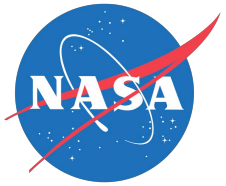
Introduction



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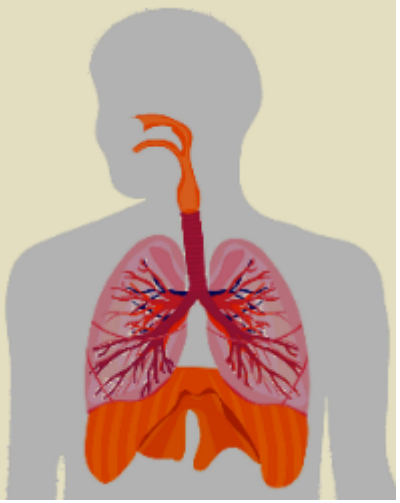
Agenda

- Particulate matter and health
- Spectropolarimetric imager description
- Observing modalities
- Camera architecture
- Focal Plane Module
- Packaging
- Spectropolarimetric filters
- Conclusions

Particulate matter (PM) impacts on human health

Science framework



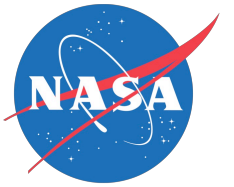
Airborne PM is a well-known cause of cardiovascular and respiratory diseases.

Coarse particles (PM_{10}-$PM_{2.5}$) irritate our respiratory systems.

Fine particles ($PM_{2.5}$) penetrate deep into our lungs. Toxins can migrate to other organs.

- Heart attacks
- Stroke
- Lung disease, lung cancer
- Aggravated asthma
- Low birth weight and preterm delivery

Importance of particle type



3 Value of observing from space

	UV	Visible							Near-IR		Shortwave IR			
Band (nm)	367	389	415	445	551	645	749	762.5	864	943	1039	1607	1880	2126

polarimetric absorbing particles fine particles coarse particles

Although PM is implicated in many adverse health impacts, the relative toxicity of specific **PM types** is not well understood

PM "type" refers to the fractional proportions of PM_{10}, $PM_{2.5}$, and $PM_{2.5}$ components (sulfate, nitrate, organic carbon, black carbon, dust)

According to the US EPA (2013)

> *The use of central fixed-site monitors to represent population exposure is a key factor limiting our knowledge as to which PM types pose the greatest health risks*

.Satellite remote sensing offers a practical way of mapping PM type over large areas with moderately high spatial resolution (~1 km)

The value of multiple observing modalities

Observing modalities

Multi-angle imaging

Enhances the aerosol signal relative to surface reflection

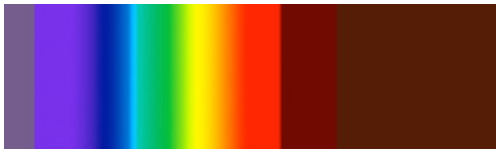
Sensitive to aerosol particle size and shape

Broad spectral coverage

UV: aerosol absorption and height

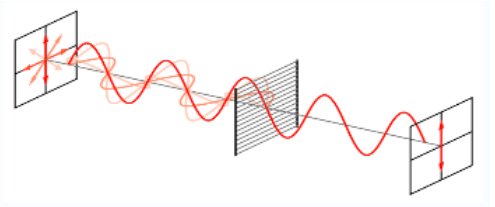
VNIR: Fine mode aerosols

SWIR: Coarse mode aerosols



Multi-angle polarimetry

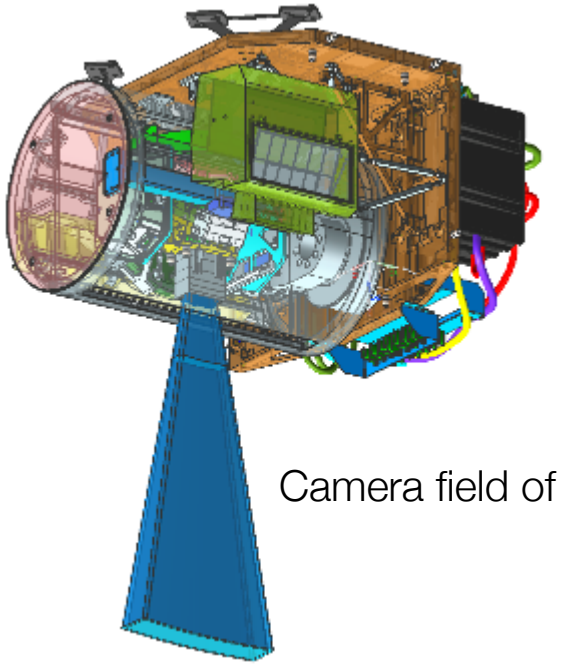
Sensitive to particle size and compositional proxies such as refractive index



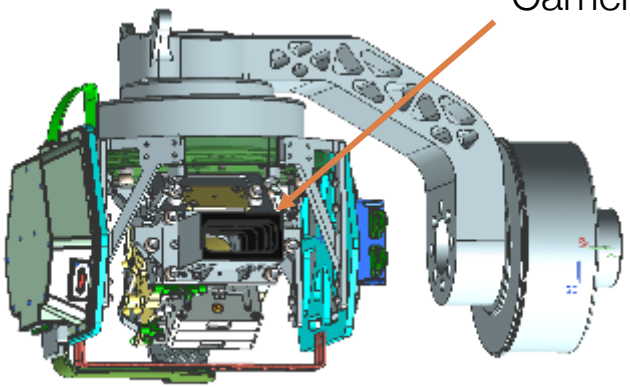
MAIA instrument

Technical capabilities

- UV-VNIR-SWIR spectropolarimetric camera on a 2-axis gimbal
- Launch ~2021 on a commercial spacecraft (3 yr nominal mission)



Camera field of view



Along-track gimbal (±60° range) for multiangle viewing of Earth targets

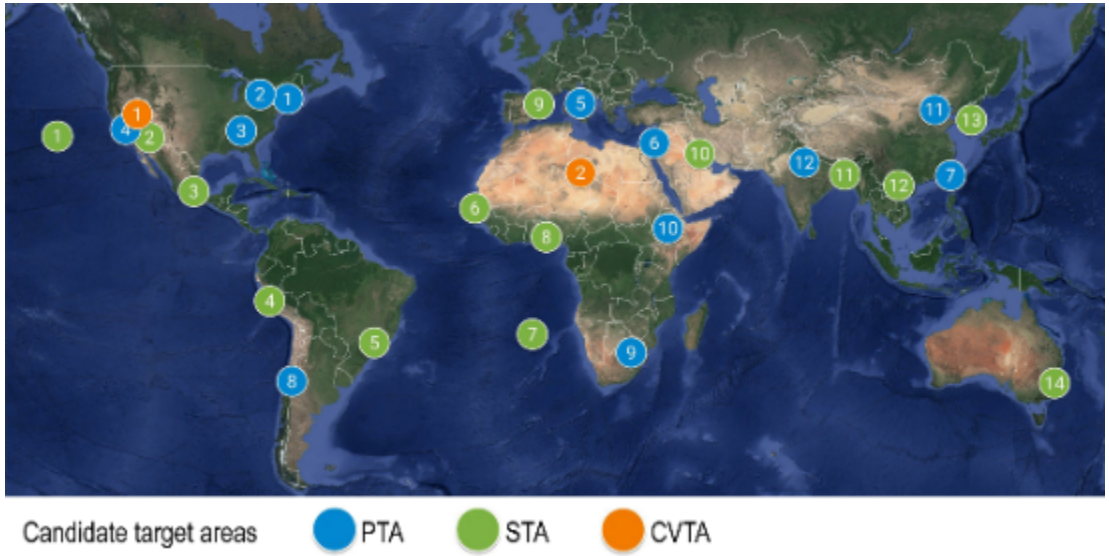
Cross-track gimbal (±39° range) for observation of targets off the sub-satellite track

MAIA investigation is target based

Primary Target Areas (PTAs): for epidemiological studies

Secondary Target Areas (STAs): secondary studies (e.g., climate)

Calibration/Validation Target Areas (CVTAs): instrument calibration, product validation



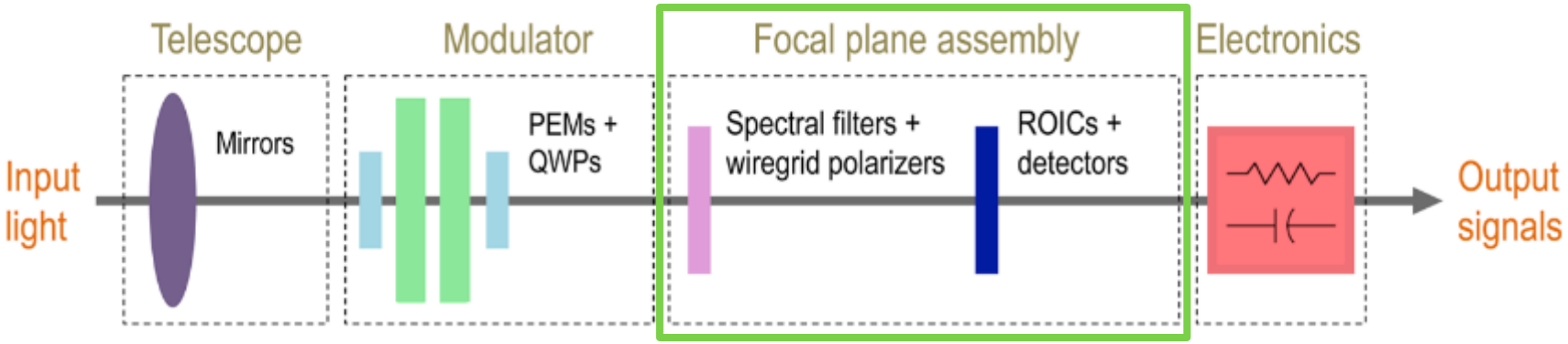
1. NE US
2. NE Canada
3. SE US
4. SW US
5. Italy
6. Israel
7. Taiwan
8. Chile
9. South Africa
10. Ethiopia
11. China
12. India

1. Cloud field
2. Arizona (Phoenix)
3. Mexico (Mexico City)
4. Peru (Lima)
5. Brazil (São Paulo)
6. Senegal (Dakar)
7. Cloud field
8. Nigeria (Lagos)
9. Spain (Barcelona)
10. Kuwait (Kuwait City)
11. Bangladesh (Dhaka)
12. Vietnam (Hanoi)
13. South Korea (Seoul)
14. Australia (Sydney)

1. Nevada (Railroad Valley)
2. Libya-4 desert site

Camera Architecture

Instrument definition and block diagram



The instrument is a gimbaled pushbroom camera system

The camera architecture uses the spectropolarimetric imager approach developed for AirMSPI and AirMSPI-2

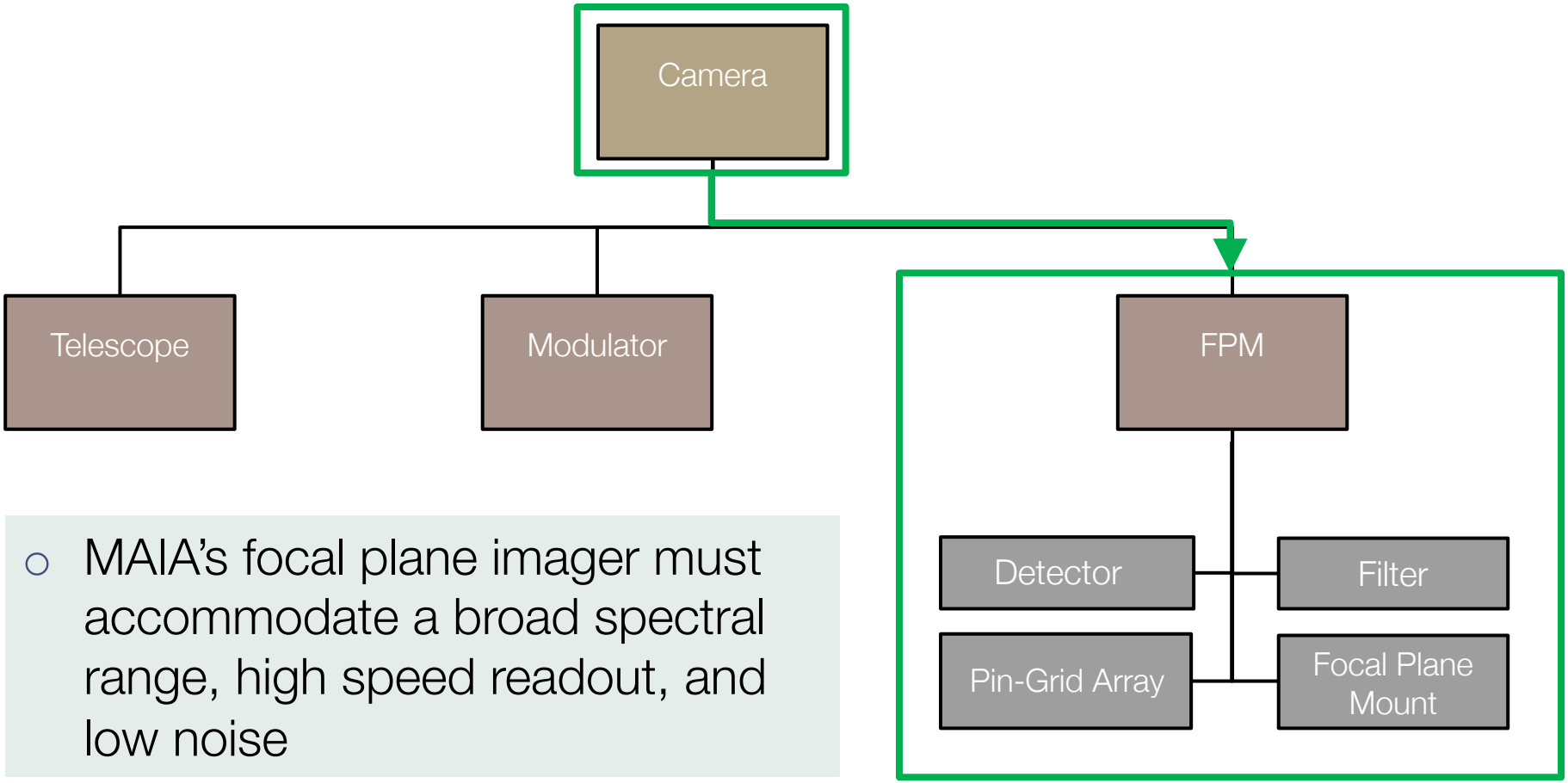
Detector rows are overlaying with stripe spectral filters and patterned wiregrid polarizers

Polarization signals are modulated using photoelastic modulators (PEMs) and achromatic quarter-wave plates (QWPs)

- Modulation provides significantly greater accuracy than static polarimetry

Focal plane module subsystem

Focal Plane Module (FPM)



- MAIA's focal plane imager must accommodate a broad spectral range, high speed readout, and low noise

FPM Design Requirements

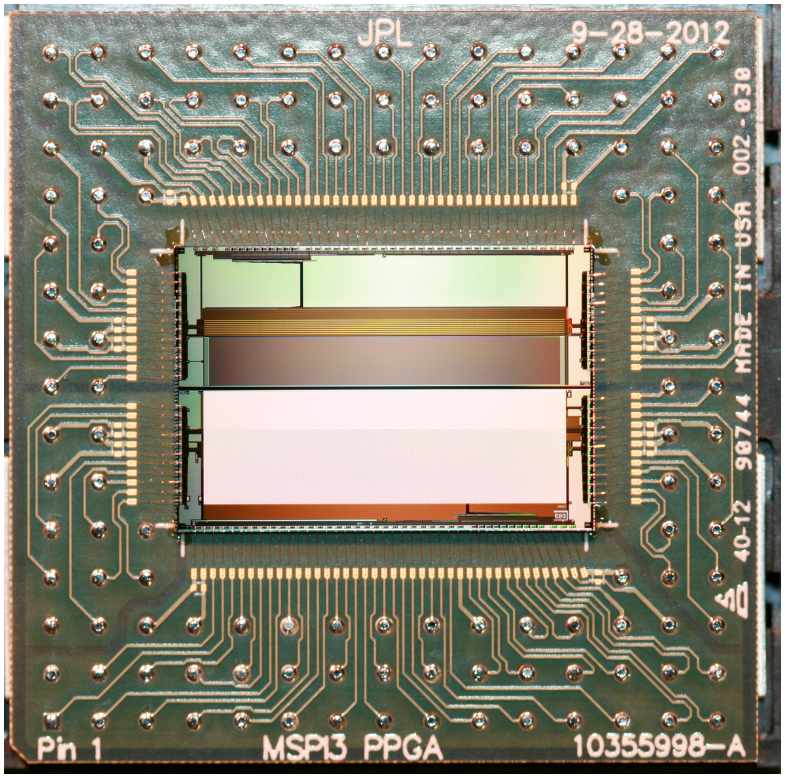
Focal Plane Module

Several requirements are imposed on the FPM design, including:

1. Electronic Interface – Power, housekeeping, and data rates
2. Filter smoothness and cleanliness – minimize stray light
3. Dark current levels – ensure adequate SNR for science req's
4. Pixel arrangement – dictated by design at the ROIC level
5. Spectral quantum efficiency – UV/Vis silicon photodiodes, IR HdCdTe detector
6. Full well 140,000e- SWIR, 180,000e- UV/NIR
7. Dynamic Range ≥ 5,000
8. High speed readout (1 kHz) to sample the modulated polarization signals and avoid full well saturation

Focal Plane Detector

Focal Plane Module



ROIC detector array mounted on a test board showing 130 wire bonds

The UV/VNIR and SWIR ROICs share the same reticle and have the same number of pixels (1280 pixels × 128 rows) and pixel size (15 μm × 15 μm)

SWIR row pitch is 15 μm and the UV/VNIR row pitch is 20 μm

UV/VNIR array uses integrated (on-chip) photodiodes, and the SWIR array uses hybridized HgCdTe p+/n photodiodes (Teledyne)

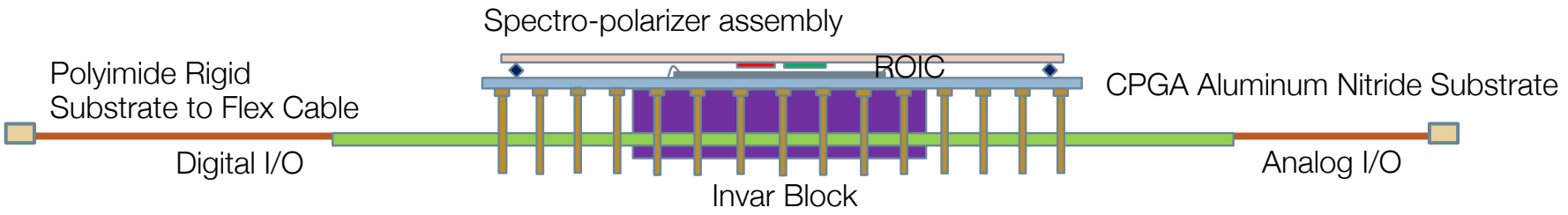
UV/VNIR and SWIR arrays are separated by a gap

The two designs are electrically isolated, except for the common substrate

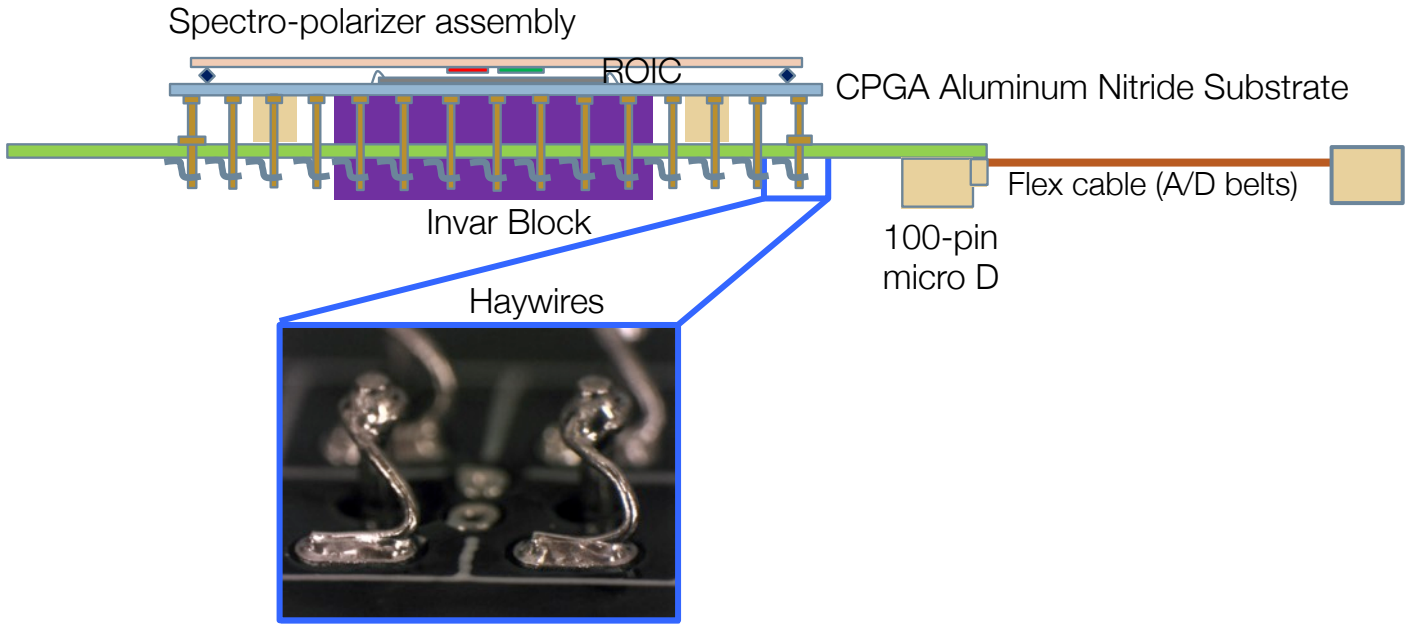
Packaging approaches for FPM imagers

Focal Plane Module

Heritage



Current



Proposed jumper-wired connections

Solid core technology demonstrated

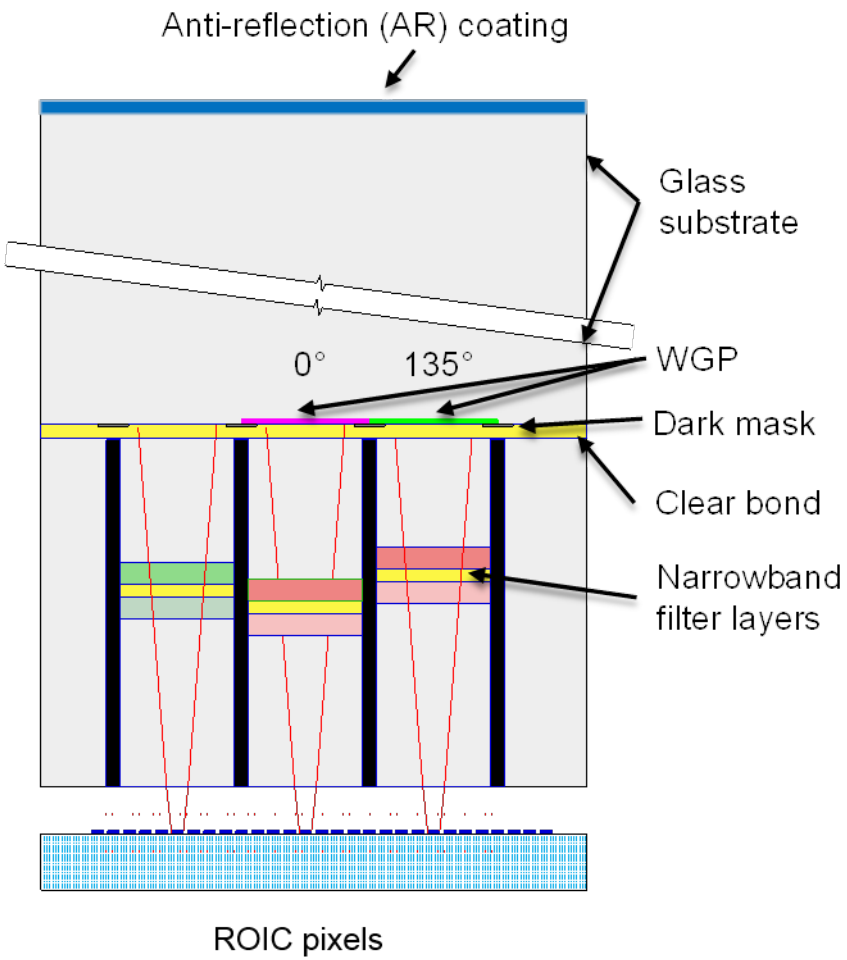
Focal Plane Module

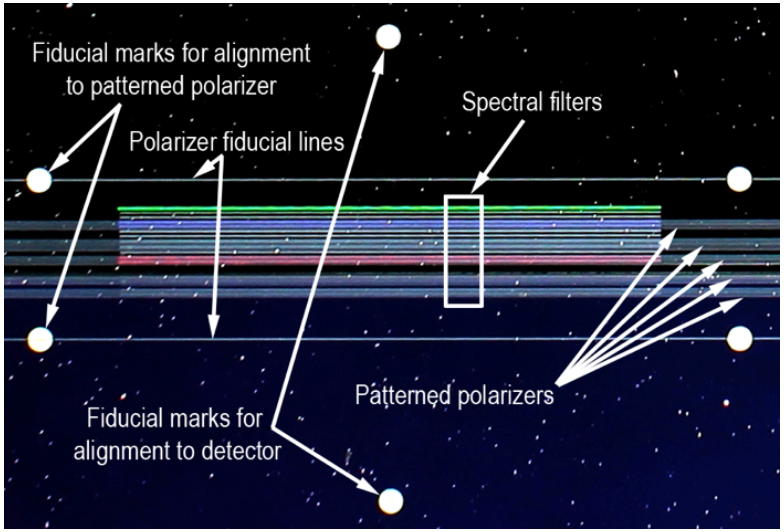
	Heritage (AirMSPI-2)	Current design	Implementation
Packaging	CPGA/rigid-flex	CPGA/board	Standard engineering practice
	Soldered CPGA	Jumpered wires	Tested for stress relief
Electronics Interface	Connectors on flex	Connectors on board	Streamlined mate/demate
ROIC design	Minor fixes post-fab	Peer-reviewed fixes incorporated	ROIC fabrication

- ROIC is fabricated and wafer probed
- All functionalities from design baseline are implemented in the current instrument
- Testing units being built at JPL while hybridized units are built by Teledyne (Camarillo, CA)
- Polarizers are complete and filters are being assembled

Spectropolarimetric filter assembl

Focal Plane Module





Simultaneously front- and back-lit photograph of the AirMSPI-2 spectropolarimetric filter

- Shows the stripe spectral filters and patterned polarizers

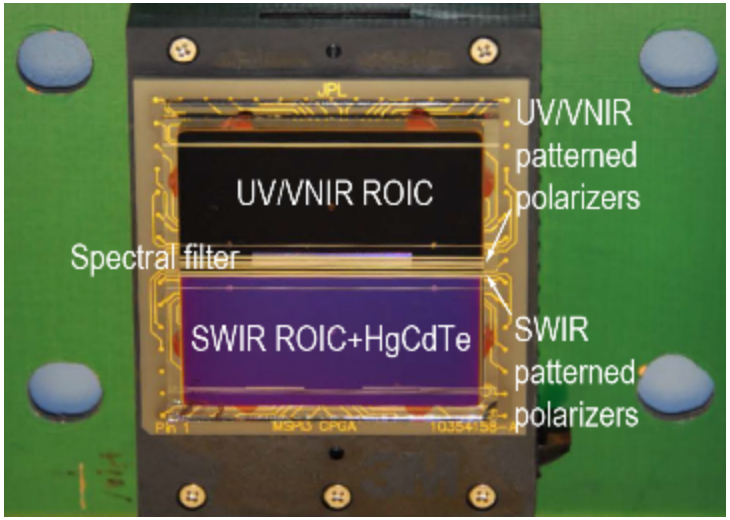
Unique integrated assembly which starts from a wiregrid polarizer substrate

Butcher-block type filter assembly is aligned and built directly onto polarizer substrate

Integrated Detector and Filter

Focal Plane Module

Band	Center wavelength (nm)	QE (%)*	Active detector rows
1	365	4	1
2	385	8	1
3	415	20	1
4	445	27	2 (polarimetric)
5	550	50	1
6	645	52	2 (polarimetric)
7	749	33	1
8	762	33	2
9	867	17	2
10	945	6	2
11	1035	72	4 (polarimetric)
12	1610	75	1
13	1880	80	1
14	2125	82	1



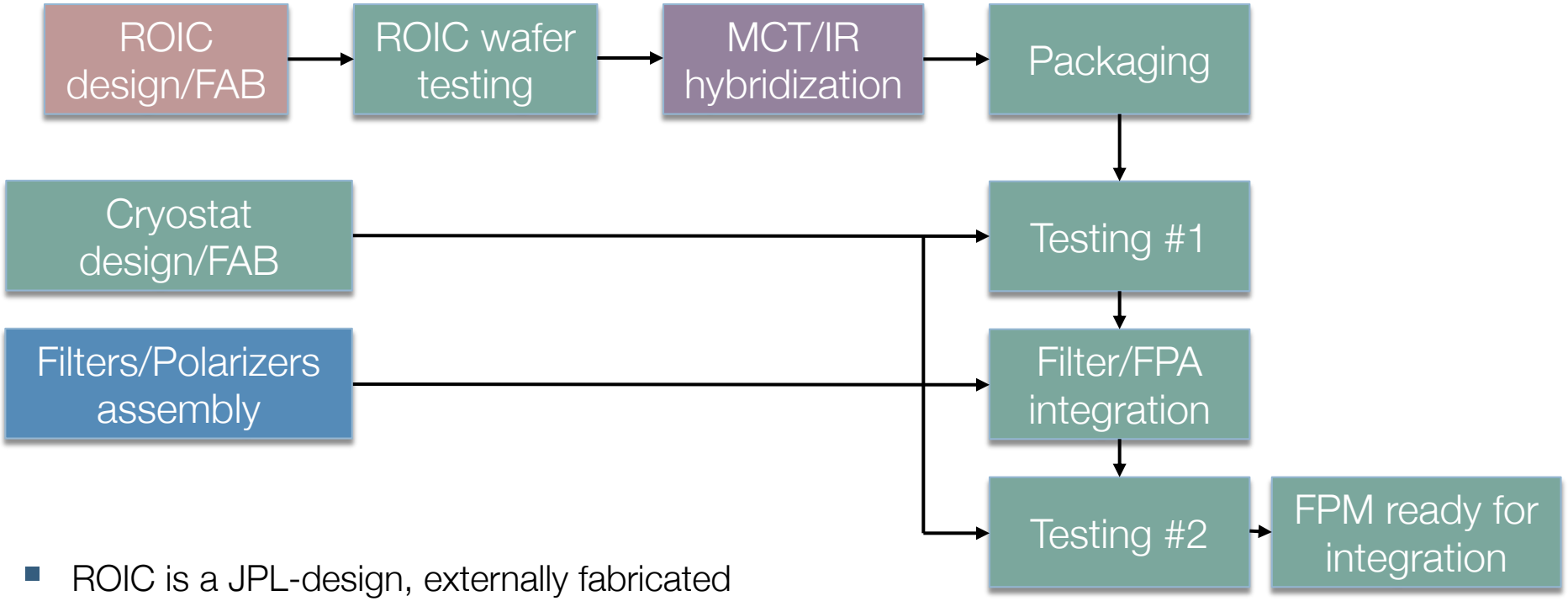
Filter aligned to the detector array and bonded to the custom ceramic pin grid array

UV/VNIR array | SWIR array

*Quantum efficiency based on previous detector performance

Assembly/testing flowchart

Focal Plane Module



- ROIC is a JPL-design, externally fabricated
- Wafer screening occur before hybridization of MCT detector
- Testing #1 will verify most of the electrical functionalities of the ROIC/detector
- Testing #2 will verify all the opto-electrical functionalities of the FPM

Conclusions

- MAIA uses integrated capabilities of multi-angle radiometry, broad spectral coverage, and multi-angle polarimetry to conduct epidemiological investigations of health impacts of particulate pollution
- MAIA provides pushbroom spectropolarimetric imaging from a gimbaled platform
- JPL-designed ROIC is a key component of the MAIA camera and allows for UV/VNIR and SWIR sensing on the same chip, with high-speed readout to enable modulated polarimetric imaging
- ROIC + spectropolarimetric filters constitute the focal plane modules to be integrated at the MAIA camera level