TFRSAC Update November 2013

Thermal Mapping Airborne Simulator (TMAS)
Staring Wide Area Imager (StareWAI)
Wide Area Imager (WAI)
Three Band IR Detector (TBIRD)
Small Airborne Metric Camera System (SMC)

Xiomas Technologies, L.L.C.
Principle Investigator: John Green
johngreen@xiomas.com
734-646-6535

XIOMAS

TMAS
Thermal Mapping Airborne Simulator
for
Small Satellite Sensor
Phase II
July 2013 to July 2015
Technical Monitor James Brass

Xiomas Technologies, L.L.C.

Phase II Contract Number: NNX13CA58C

Principle Investigator: John Green
734-646-6535

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Background and Rationale –

ASTER has a smaller field of view than MODIS, viewing a swath width of 60km.

To scan any point on earth, tilt-able telescopes are employed for ASTER.

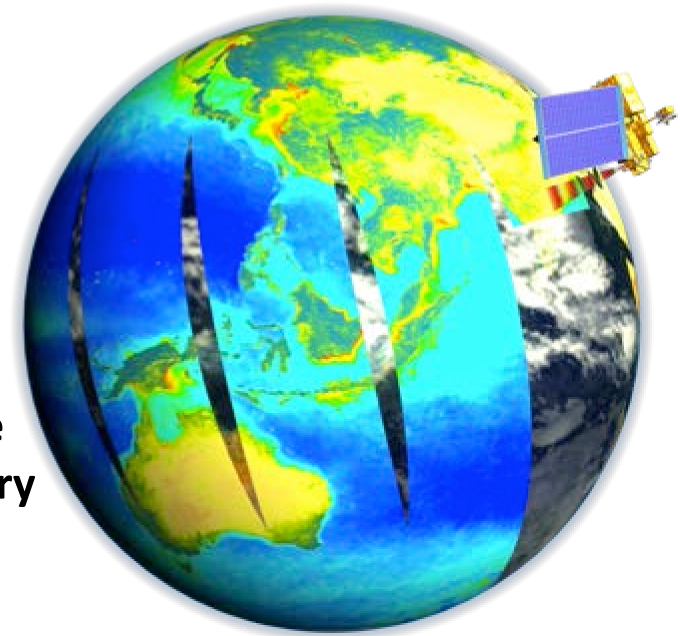
ASTER Spectral -- five spectral bands in the 8 to 12 um range.

ASTER Spatial -- The ASTER thermal infrared subsystem has a spatial resolution of 90m

The ASTER instrument operates for a limited time during the day and night portions of an orbit. The full configuration (all bands plus stereo) collects data for an average of 8 minutes per orbit. Reduced configurations (limited bands, different gains, etc.) can be implemented as requested by investigators.

TMAS
110 degree field of view (same as MODIS)
94 meter spatial resolution (similar to ASTER)
3 Spectral Bands (more can be added in Phase III)

Operating at the same altitude and velocity as MODIS the TMAS will have the same capability to map the globe every one to two days



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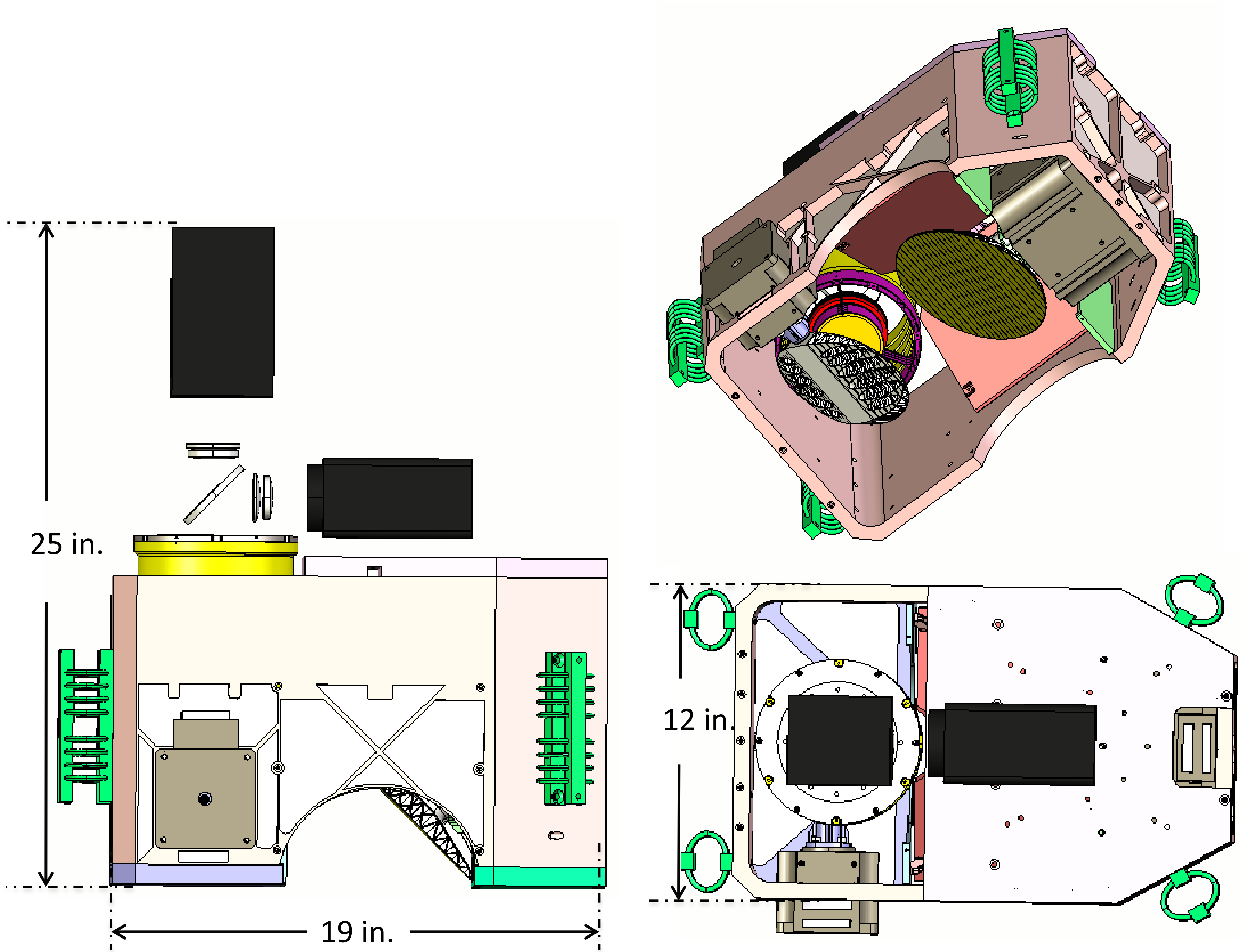
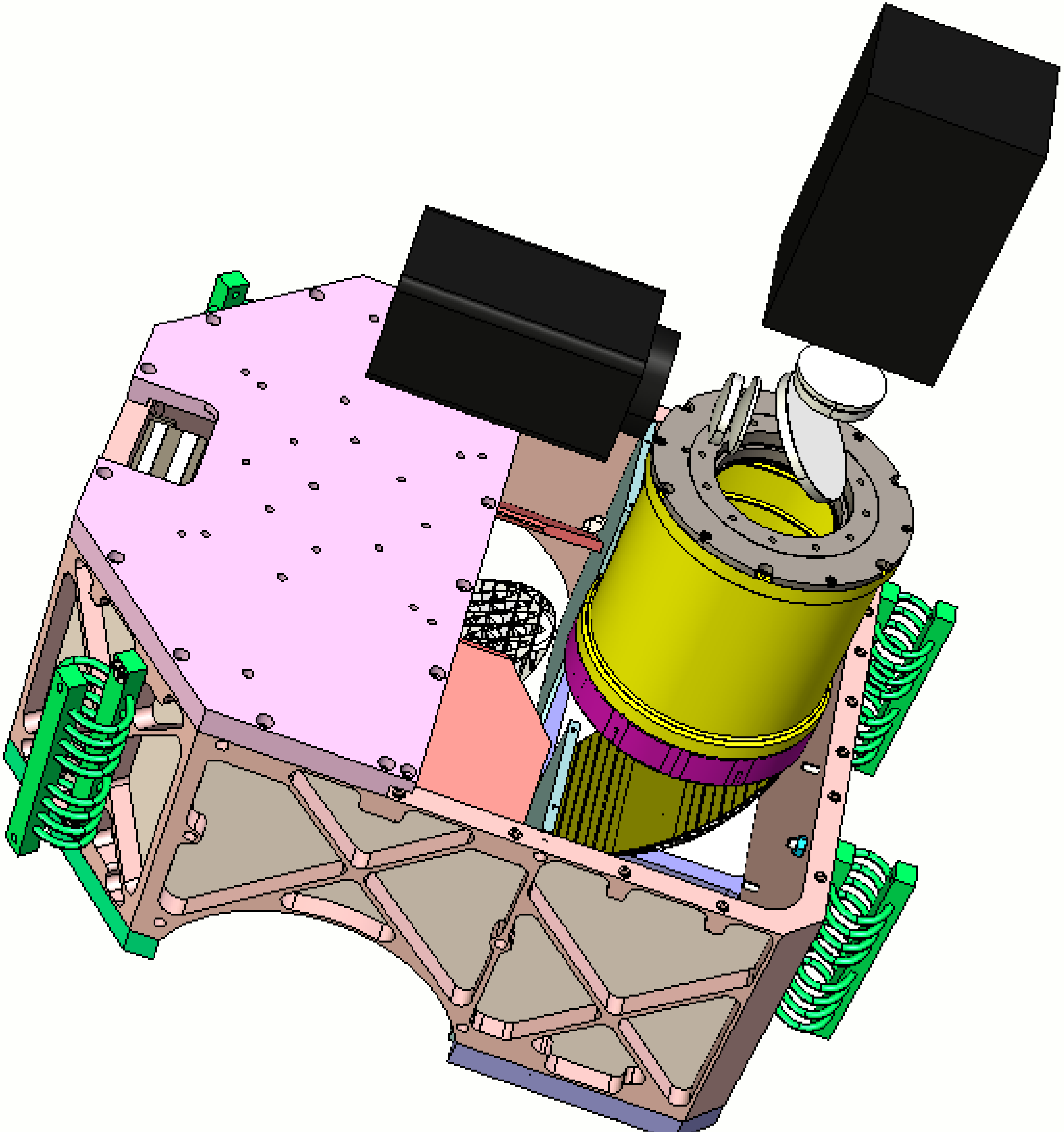
Phase I engineering prototype:

- XVME-6300 processor board with dual core i7 @ 2GHz, 8GB RAM
- Intel 64GB SSD with 3Gb/s SATA interface. Formatted as EXT4 file system
- WD 256GB SSD with 3Gb/s SATA interface. Formatted as EXT4 or JFS file systems.
- EDT PMC DV C-Link frame grabber
- Teli 640 x 480 camera

1. Simulate the data rates of the two cameras
2. Simulates a GigE QWIP, with the simulation running on another PC and connected over a 1000BaseT wire
3. Simulate SWIR sensor using CameraLink frame grabber and a 640 x 480 Vis Camera


25 in.
19 in.
12 in.

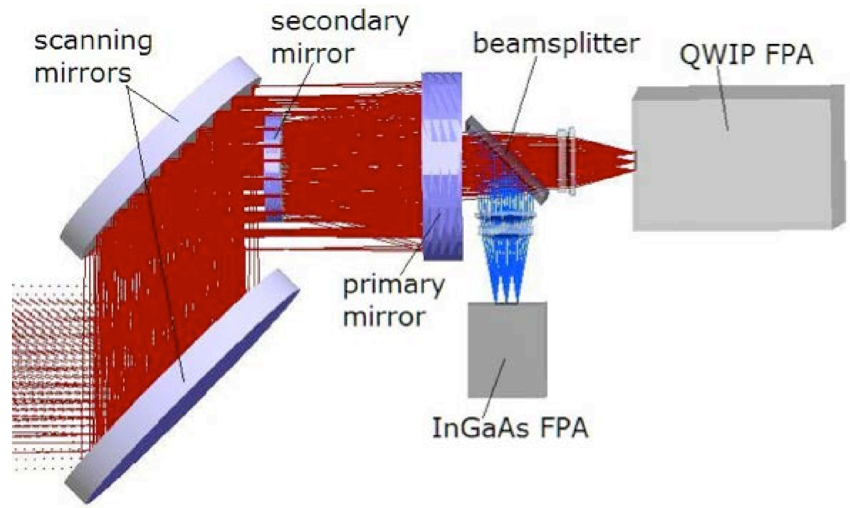


TMAS incorporates a step stare optical design which provides fundamental advantages over current imaging systems including:

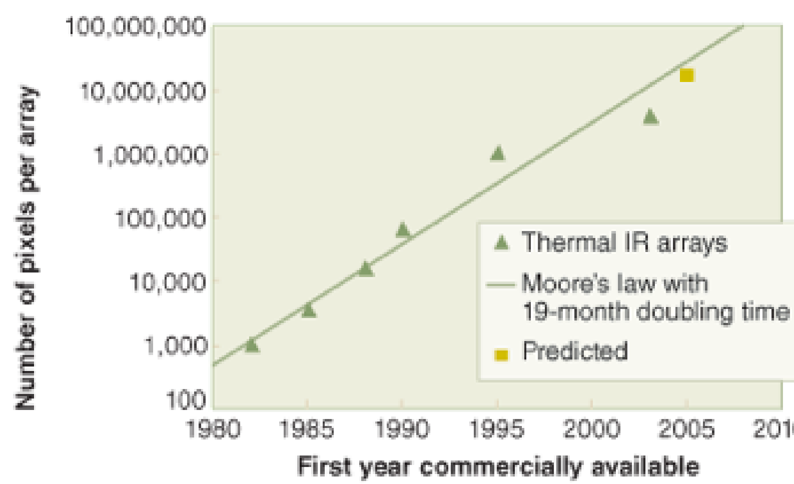
1) The combination of a step stare scanning mirror with a focal plane array offers fundamental improvements in spatial resolution

2) The high performance of the step stare scanning system combined with current state of the art detectors results in wide area coverage similar to MODIS and with the spatial resolution of ASTER

3) During the Phase I we have determined that advancements in detector technology can be easily incorporated, either in Phase II or in Phase III.

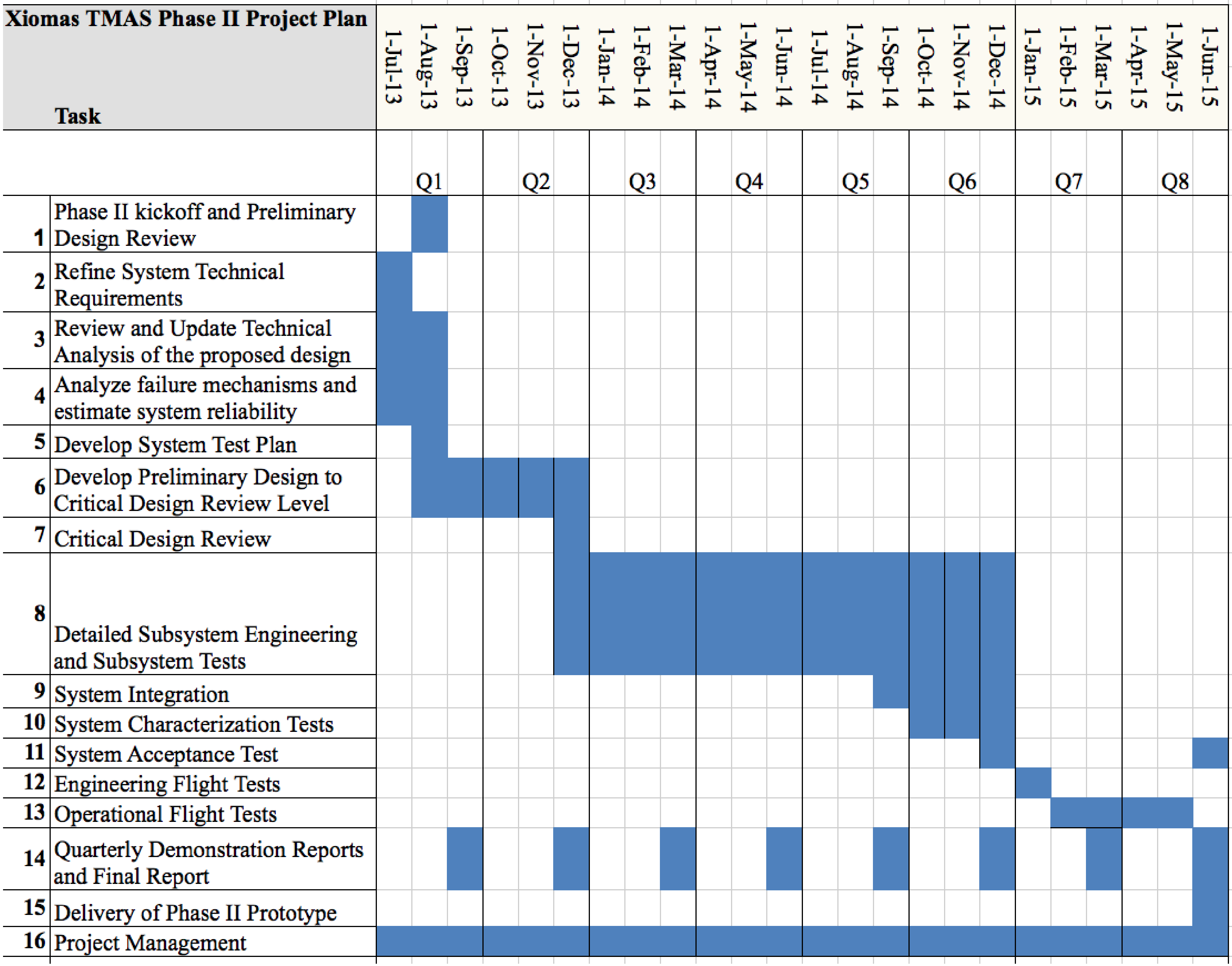


TMAS Optical System



The number of pixels on an infrared array has been growing exponentially
in accordance with Moore’s Law for 25 years with a doubling time of approximately 19 months

Phase II Project Plan and Schedule



TMAS Phase II Enhancement
The contract includes an optional $250K of additional SBIR funds.
The short story on the Phase II-E from the contract follows:

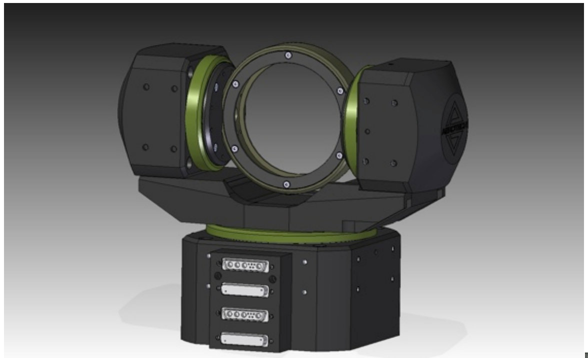
" Phase II-Enhancement (Phase II-E)
The purpose of the Phase II-E Option is to further encourage the advancement of innovations developed under Phase II contracts via an extension of R/R&D efforts to the current Phase II contract. Eligible firms must secure a third-party investor to partner and invest in enhancing their technology for further research, infusion, and commercialization. Under this option, the NASA SBIR Program will match, on a dollar-to-dollar basis, up to $250,000 of non-NASA-SBIR investments to extend an active contract up to a minimum of 4 months to perform additional R/R&D. These non-NASA-SBIR third party investments can come from a NASA project, NASA contractor, or any commercial investor. The total cumulative award for the Select Phase II contract plus the Phase II-E match is not expected to exceed $950,000.00 of SBIR funding. The non-SBIR contribution is not limited since it is regulated under the guidelines for Phase III awards."

Possible Phase II E candidates.
1)Commercial TMAS Sale to PhotoScience or other remote sensing company
2)TMAS Sale to the USFS
3)USFS funds conversion of the WAI to TMAS configuration
4)NASA funded transition (or partial/preliminary design effort) of TMAS to small satellite

Staring Wide Area Imager (STAREWAI)

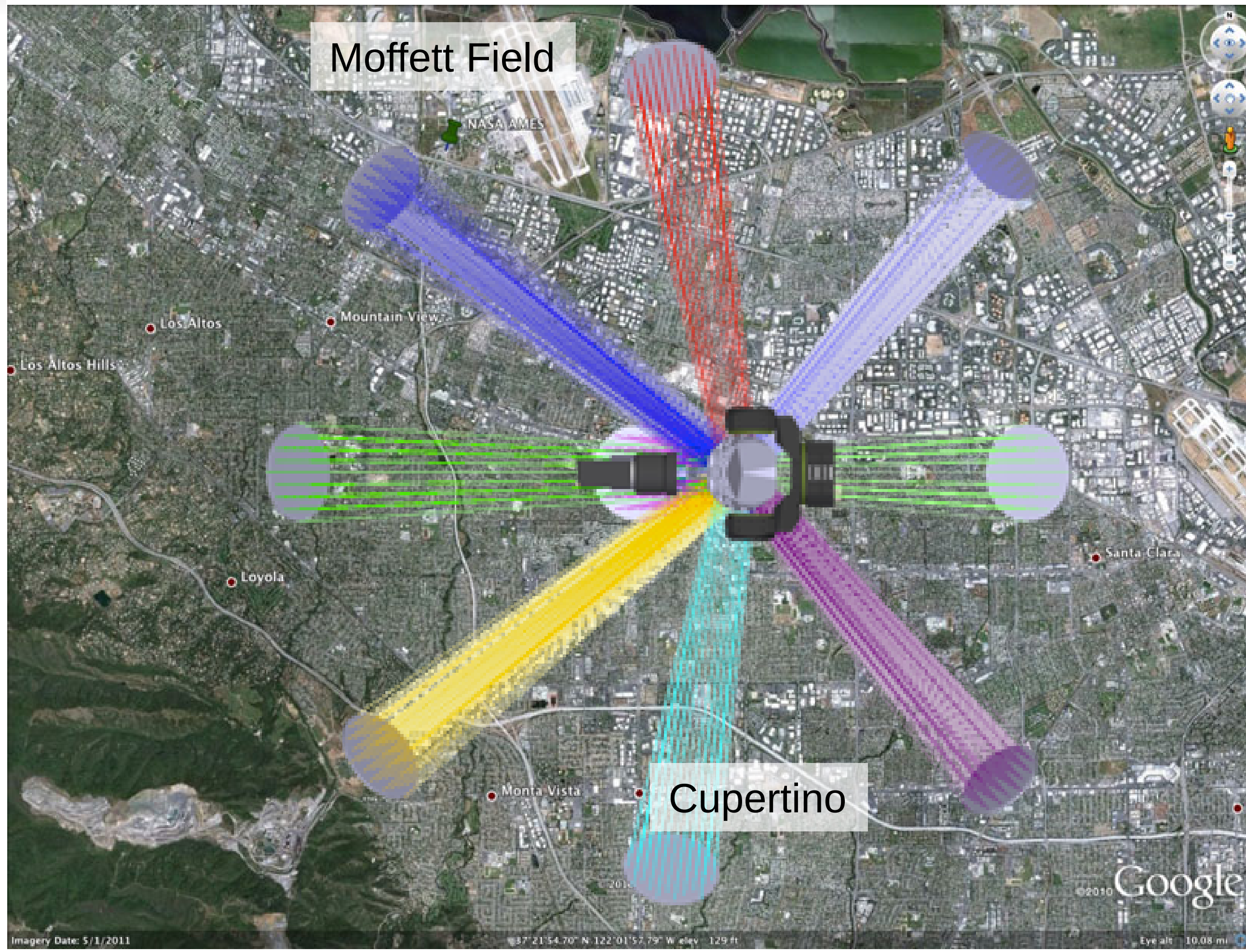
USDA Phase II SBIR
September 2013 to September 2015

Xiomas Technologies, L.L.C.

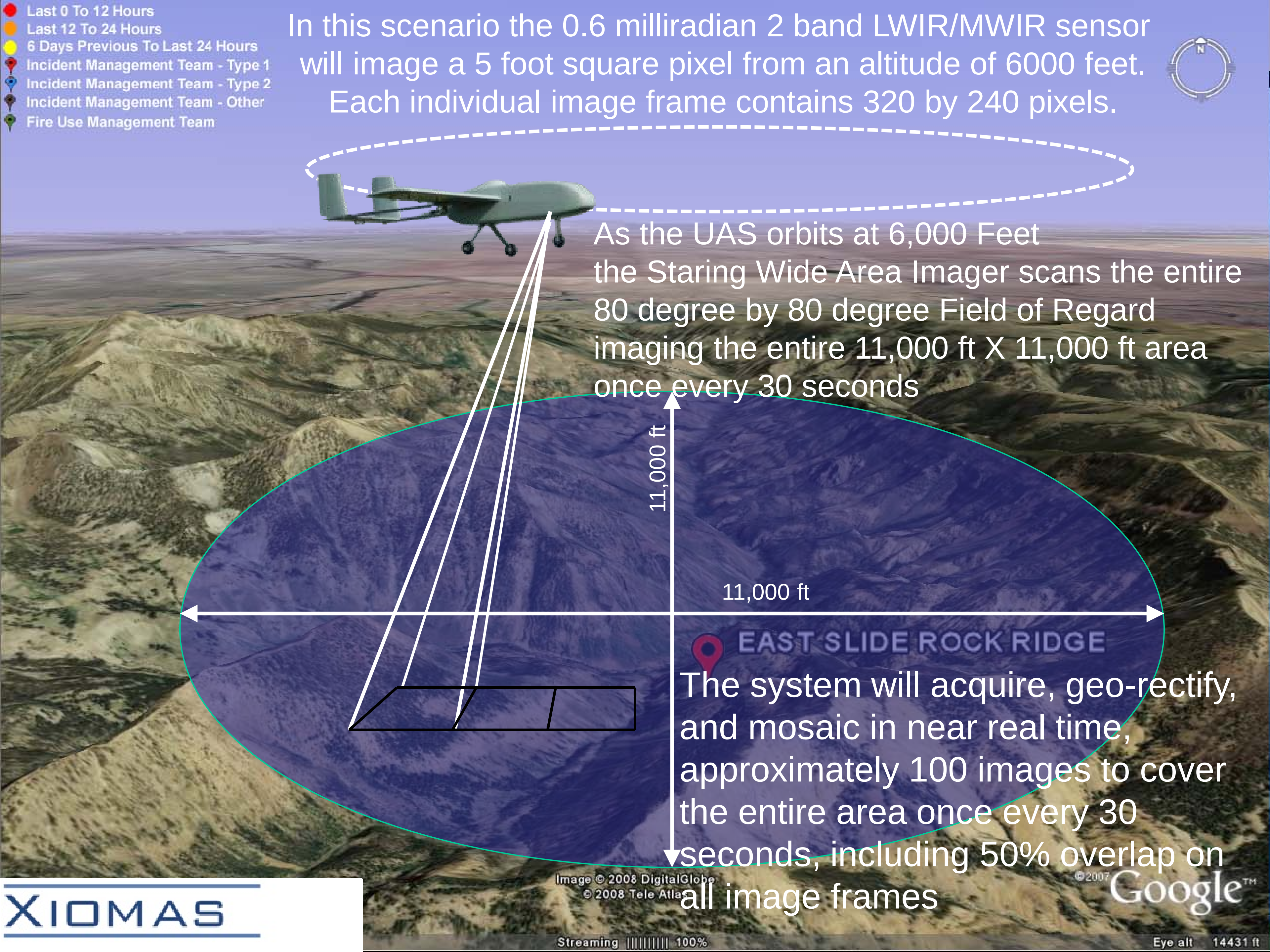


In this scenario the 0.6 milliradian 2 band LWIR/MWIR sensor will image a 14 foot square pixel from an altitude of 23,000 feet. As the aircraft orbits at 23,000 Feet the Staring Wide Area Imager scans the entire 80 degree by 80 degree Field of Regard, imaging the entire 9 mile diameter area once every 30 seconds -- acquiring, geo-rectifying, and mosaicking in near real time, approximately 100 images to cover the entire area once every 30 seconds. This calculation includes 50% overlap on all image frames

- LWIR (8 to 9 um)
- MWIR (4 – 5 um)
- SWIR 1.6 um (optional)
- 600 urad instantaneous field of view
- ground sample distance of approximately 14 feet from our notional operating altitude of 23,000 feet.
- At this altitude the system will be capable of detecting a 6 inch by 6 inch 600 degree C fire.
- 9 Mile Diameter Field of Regard



In this scenario the 0.6 milliradian 2 band LWIR/MWIR sensor will image a 5 foot square pixel from an altitude of 6000 feet. Each individual image frame contains 320 by 240 pixels.



As the UAS orbits at 6,000 Feet the Staring Wide Area Imager scans the entire 80 degree by 80 degree Field of Regard imaging the entire 11,000 ft X 11,000 ft area once every 30 seconds

The system will acquire, geo-rectify, and mosaic in near real time, approximately 100 images to cover the entire area once every 30 seconds, including 50% overlap on all image frames

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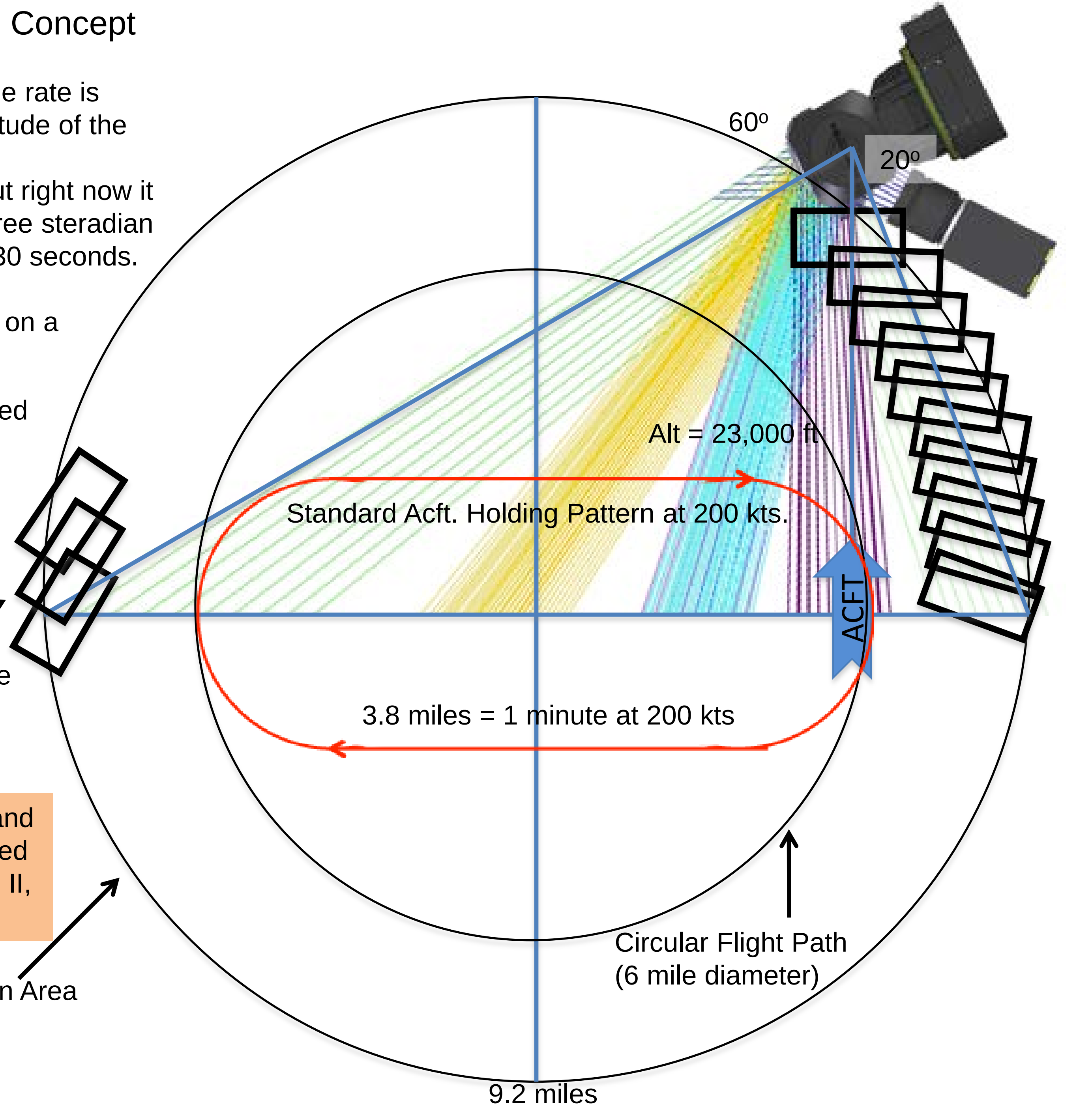
Flight Path and Operational Concept

In Persistent Stare Mode the frame rate is independent of the speed and altitude of the aircraft.
We're still analyzing the design but right now it looks like we can scan an 80 degree steradian using about 100 frames in about 30 seconds.

The proposed flight path is based on a standard aircraft holding pattern.

We think this works well for manned aircraft at higher altitudes

(or for a UAV at any altitude).

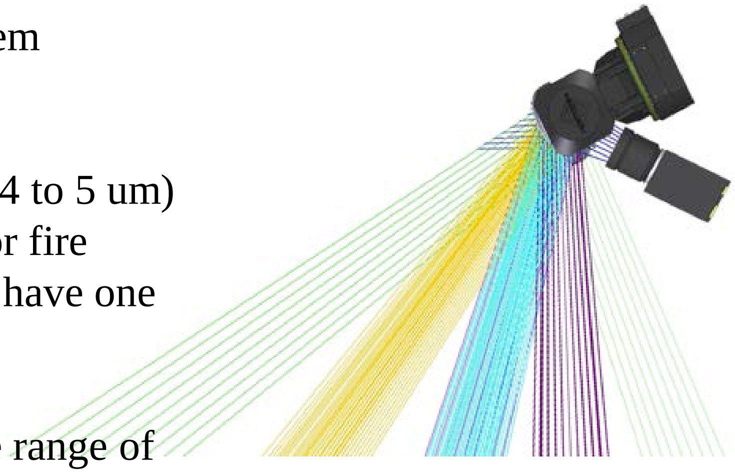


There's a good deal of flexibility and other flight patterns will be explored later in the Phase I, and in Phase II, and beyond …

A note about existing staring imagers ….

Existing staring systems rely on stabilized turrets or gimbals such as the Cloud Cap Tase systems or the FLIR systems.

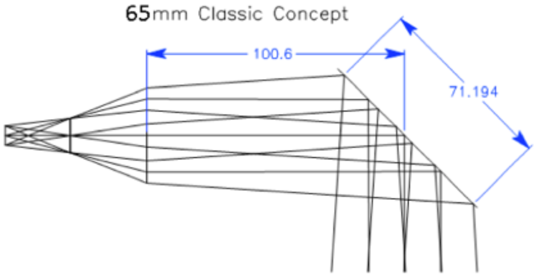
These stabilized mounts do a very good job of staring at a target but have a number of shortcomings compared the proposed StareWAI system including:



1.The StareWAI has two perfectly co-registered bands, MWIR (4 to 5 um) and LWIR (8 to 9 um), optimum for fire detection, and useful for fire science (and a third band is possible). The turret systems either have one band, or if they have multiple bands they are not co-registered.

2.The StareWAI system can both stare and scan allowing a wide range of mission scenarios. The turret systems are very good at staring and can be programmed to scan but at much lower speeds rendering them poor candidates for mapping larger areas.

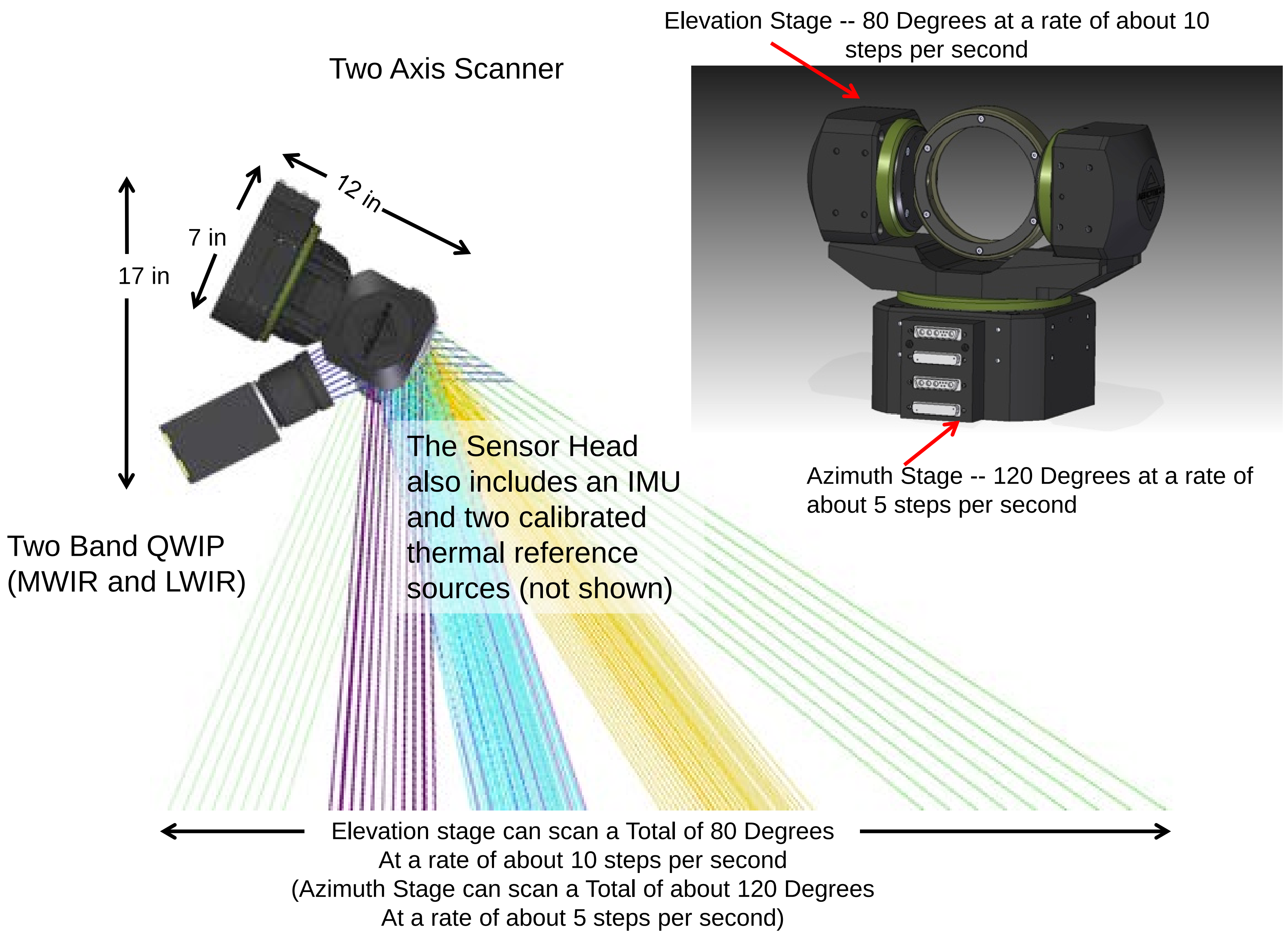
3.Reliability – simply put, moving the entire system (as with a stabilized turret) is much harder from an engineering standpoint than moving a mirror (steering the beam as in the StareWAI). As a result the StareWAI will require much less maintenance and be more reliable.



basic performance parameters for the

600 uRadian design

% of Pixel Filled with 600 Degree C which can be thresholded above 400 Degree C Field filling False Target (est from % pixel fill Chart)		0.40%				
GSD (m)		4.30	13.975	ft		
Focal Length Len (mm)		66.05				
Fire detection limit (m squared)		0.07	0.78	ft	9.4	in
Swath Width (m)	14,200		46150	ft		
operating Altitude (m)	7,100					
Operating Altitude (ft)	23,075					
Operating Speed (kts)	200					
Operating Speed (m/s)	103					
IFOV (mr)		0.606				
FOV per frame across track degrees		11.07				
FOV per frame Along Track degrees		8.31				
Percent Overlap Across Track		0.2				
Percent Overlap Along Track		0.4				
Step Stare Mirror Optical Scan Angle (degrees)		90.00				
Across Track Steps		11				
Frame Rate (Hz)		3				
Mapping Rate (square miles per hour)		2029				


Two Axis Scanner
Elevation Stage -- 80 Degrees at a rate of about 10 steps per second
12 in
7 in
17 in
Two Band QWIP (MWIR and LWIR)
The Sensor Head also includes an IMU and two calibrated thermal reference sources (not shown)
Azimuth Stage -- 120 Degrees at a rate of about 5 steps per second
Elevation stage can scan a Total of 80 Degrees
At a rate of about 10 steps per second
(Azimuth Stage can scan a Total of about 120 Degrees
At a rate of about 5 steps per second)

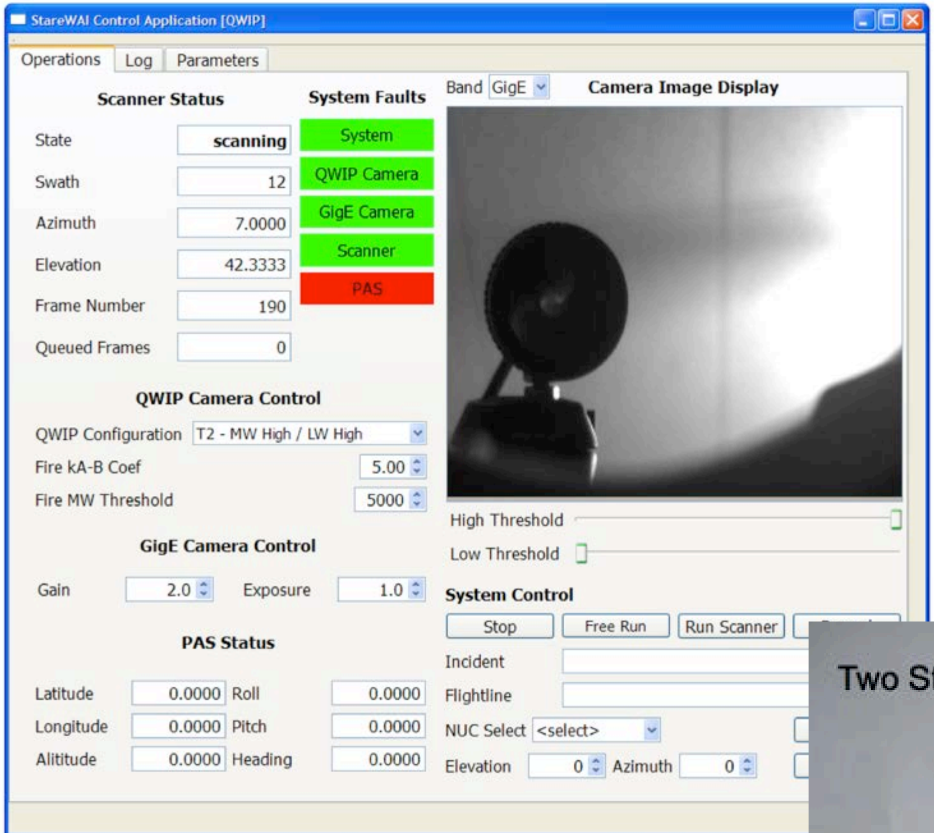
Flight Path and Operational Concept

Mapping Mode –

- In mapping mode the system will function as an across track scanner.
- In this mode, operating from the notional altitude of 23,000 feet the system will map over 2000 square miles per hour (assumes an aircraft speed of 200 knots).
- Please note that this is just an example and the other altitudes and speeds will also work.

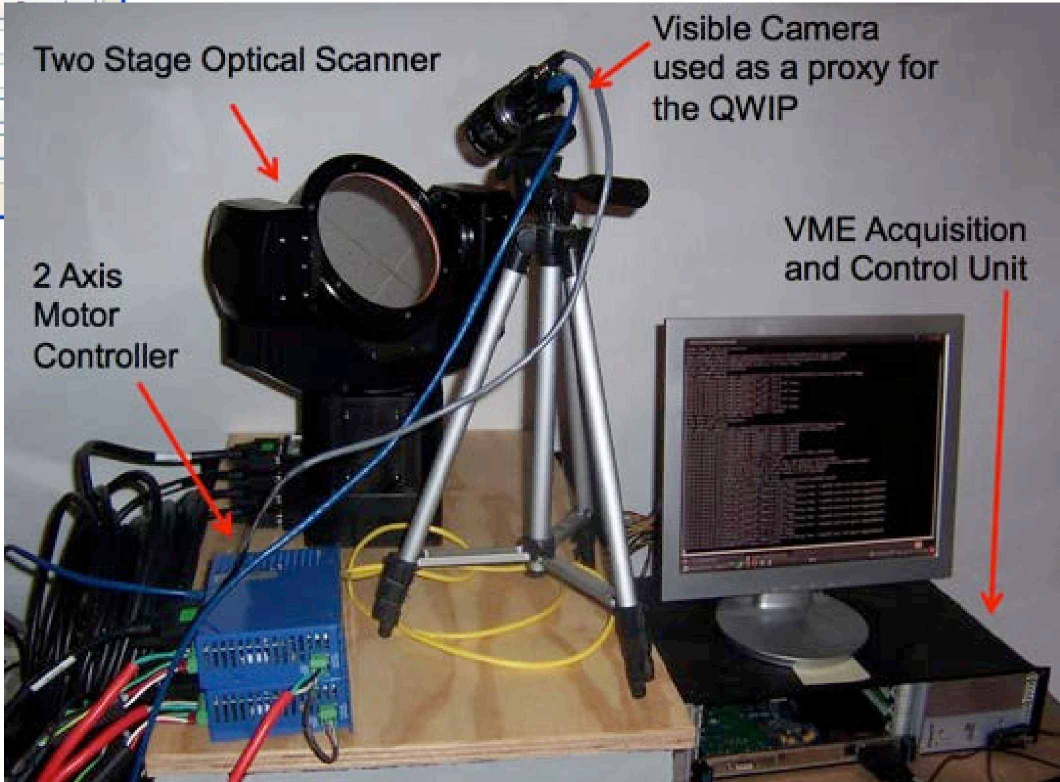
Combination Mapping and Staring Mode –

- Another interesting scenario combines mapping mode with the persistent stare mode.
- As the aircraft flies over an area of interest the system could be commanded to scan a circular pattern on the ground, constantly looking in front, under, behind, and to each side.
- This is the optimal pattern for a variety of scenarios such as search and rescue and looking for small cooking fires.
- The advantage is seeing the ground from multiple look angles, as targets hidden from one angle are likely to be visible from another.



Screenshot of GUI during scanner operation

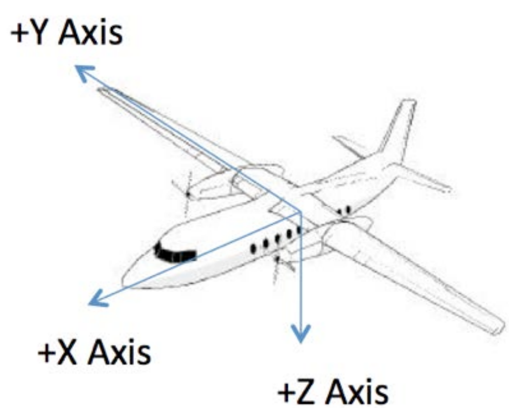
StareWAI Phase I Prototype

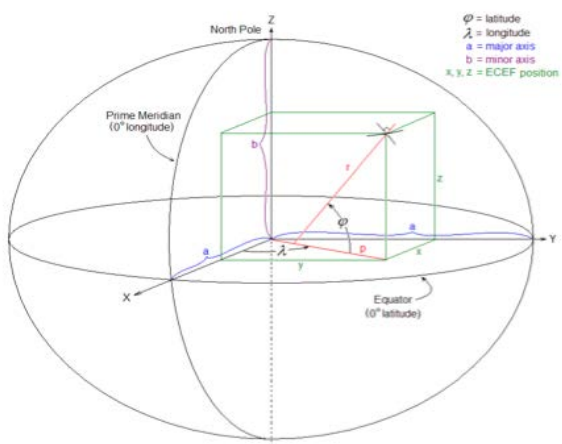


The StareWAI OPU is based on the ENVI Rigorous Orthorectification module.

This is a modification of the Orthorectification Processing Unit OPU) used in the Wide Area Imager

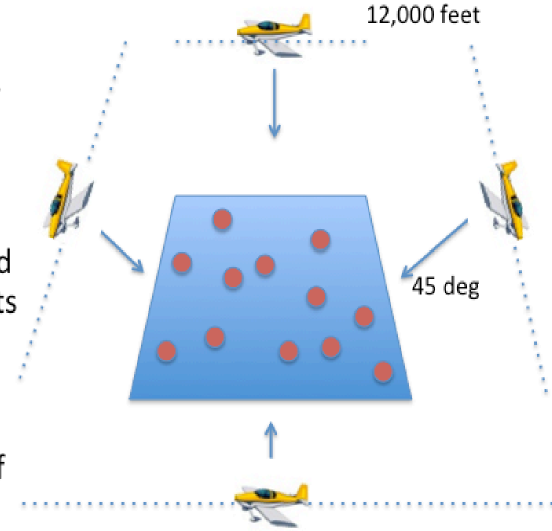
We have shown that the GPU based OPU can process 17 megapixels per second, providing a comfortable margin above the StareWAI data rates.





Calibration Flight Layout

- Take advantage of 55 degree max view angle for strong geometry
- Full intrinsic and extrinsic bundle adjustment will allow comparison of solved points with surveyed points (i.e. two independent calibration options)
- After the camera model is determined, a boresight of INS offsets is computed



We are proposing to perform the StareWAI boresight calibration by using a hybrid of the "well-known-scene" and *in situ* methods. The goal is to develop an easily repeatable and cost-efficient calibration procedure. We will fly StareWAI at night over a 1 sq. mile target area with a large number of ground-surveyed calibration targets (20 to 50). The targets will be plates of polished aluminum that will be easily identifiable as very dark spots due to their low emissivity at night in all bands (they will essentially reflect the cold night sky).

Summary of saturation issue over high temperature features

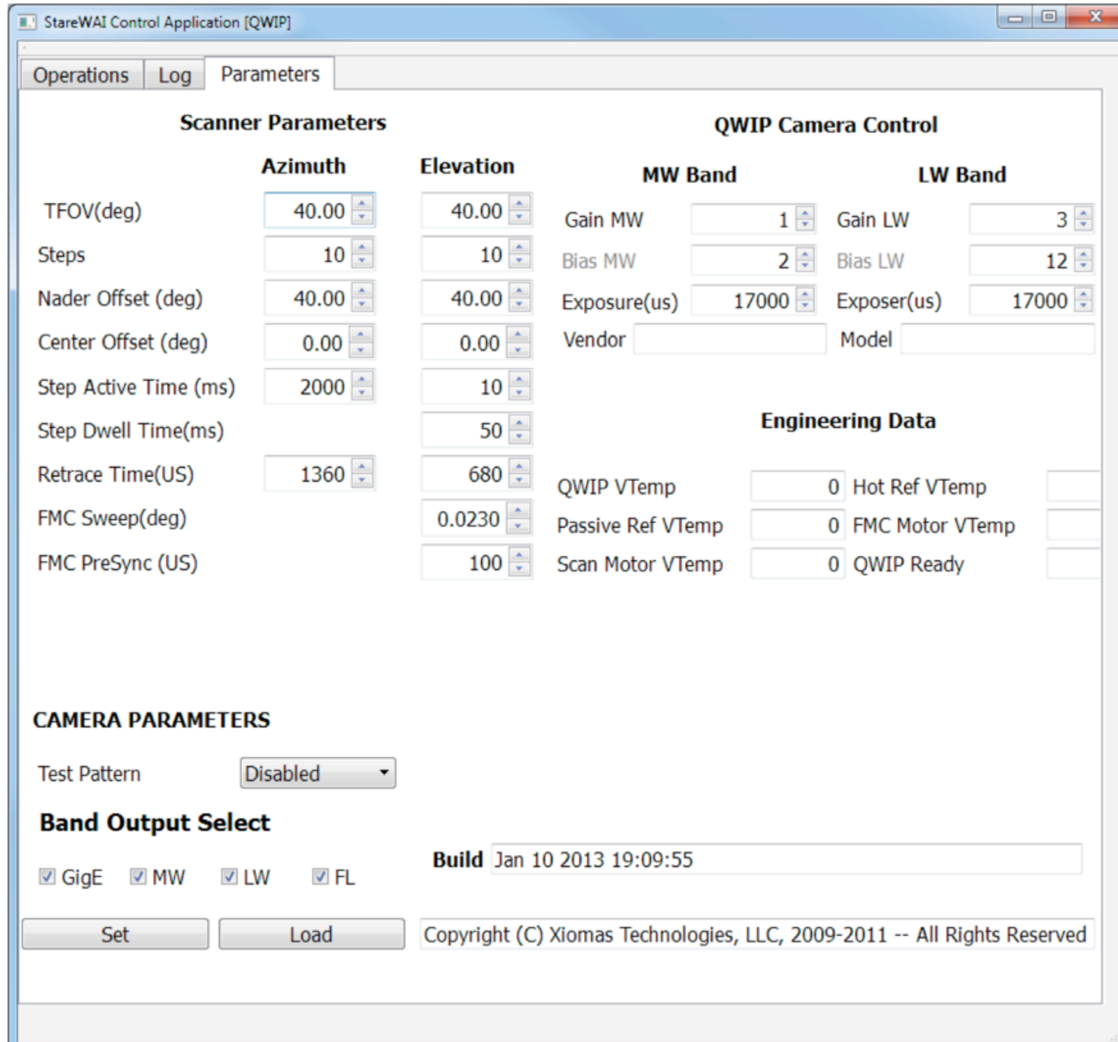
During the WAI Phase I we did a preliminary analysis of the energy on a pixel for various field filling sources at different integration times, along with the estimated saturation level of the detector and ROIC for the 2-Band QWIP detector.

Integration times below 1ms will be required to prevent saturation of 1200K sources in the MWIR band.

Integration times around 10 to 15 ms are required for terrestrial mapping and produce an NEDT around 200 mK.

The QWIP detector with standard ROIC provides a number of features which can be applied to solving this problem, such as, applying different integration times for each band and/or applying different gains to each band.

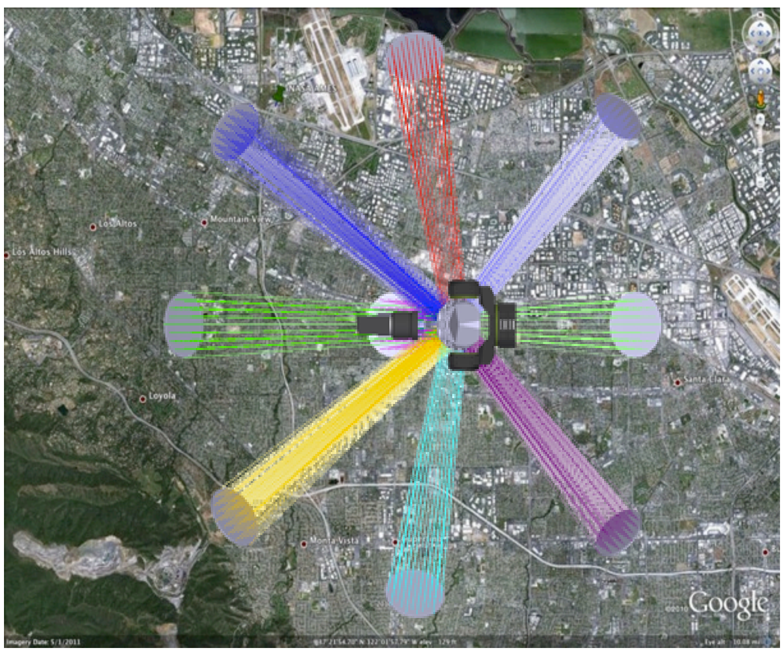
The StareWAI will include a "Dual Gain/Exposure" feature for each band



Xiomas StareWAI User Interface

Project Schedule

1. Phase I Kick-Off – September 10, 2012
2. Mid Project Review – Several discussions have been held to discuss details of the design and possible trade-offs in preparation for the Phase II proposal
3. Phase I Design Review – January 11, 2013 -- Discussion of Phase I results and last chance to discuss USFS requirements for Phase II
4. Phase I Preliminary Design Ends – January 14 2013
5. Phase II Begins – September 2013
6. Phase II Prototype Flight Tests – March 2015



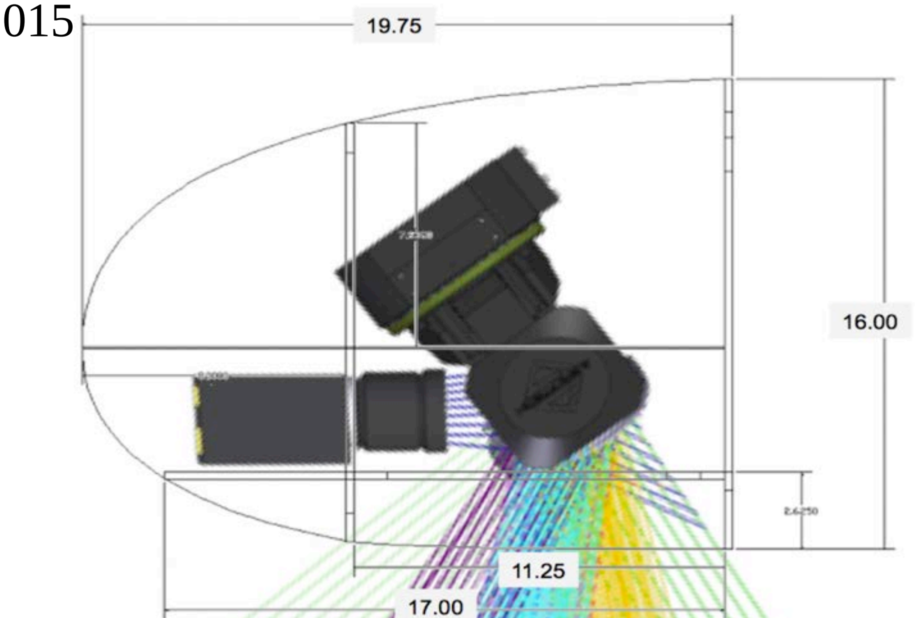


Figure 4.2B SIERRA Standard Payload Nose. This engineering drawing depicts the side view of he SIERRA standard payload nose.

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Airborne Wide Area Imager for Wildfire Mapping and Detection (WAI)
TFRSAC Update November 2013

NASA PHASE III SBIR

PHASE II CONTRACT NUMBER

NNX09CA09C

Technical Monitor: Steve Dunagan

Xiomas Technologies, L.L.C.
Principle Investigator: John Green
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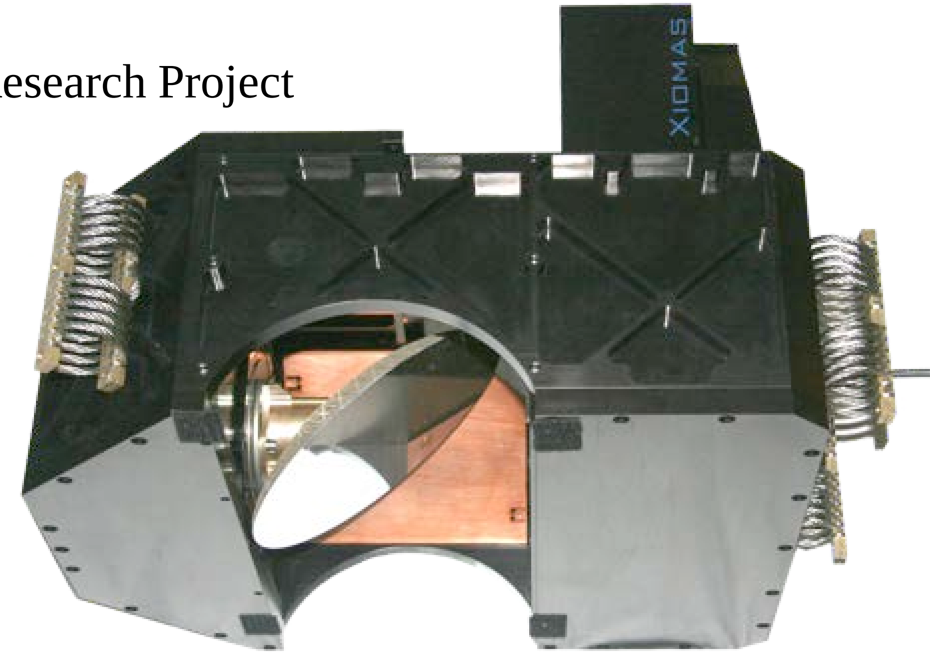
Wide Area Imager for Wildfire Mapping

- NASA Funded Small Business Innovative Research Project
- Multi-Band System – 2 to 5 Bands
  - 2 Band QWIP for Mid-Wave and Long Wave Infrared
  - 3 Band Color Infrared Sensor (Green Red NIR)
- "Step – Stare" Optical System Combines High Resolution -- 300 uRadian and Wide Field of View -- 90 Degrees



- Data System Generates Fire Layer and Terrain Layer
- Real Time Orthorectification Processing Unit (OPU) generates GIS compatible Files
- Image Classification and Compression
- Data Transmission via Ethernet -- Air to Ground or Satellite --

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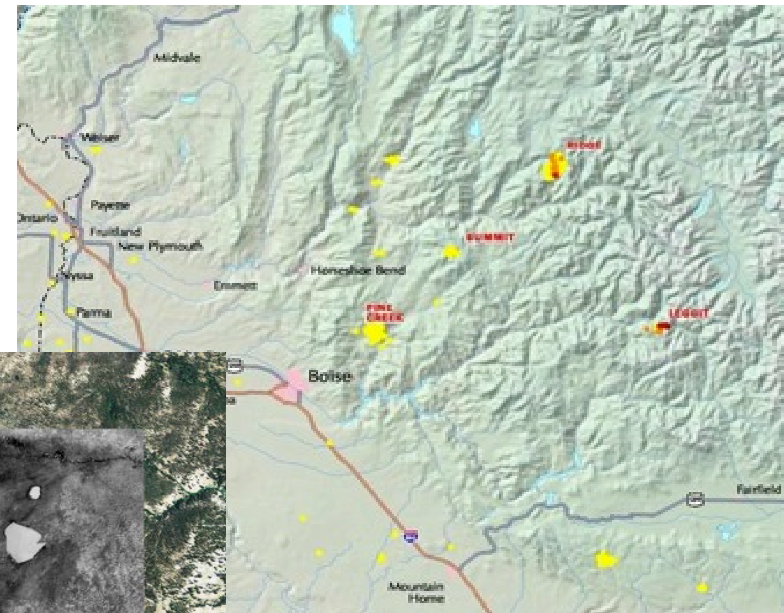
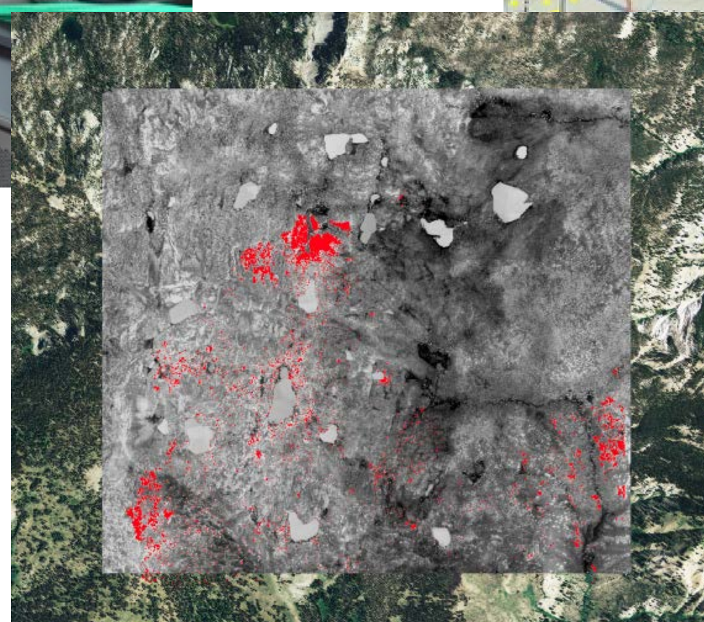
Wide Area Imager Update

As of this report the WAI has flown about 20 flights, including a number of engineering tests, calibration flights, several flights for a commercial imaging project, and the fire mapping flights

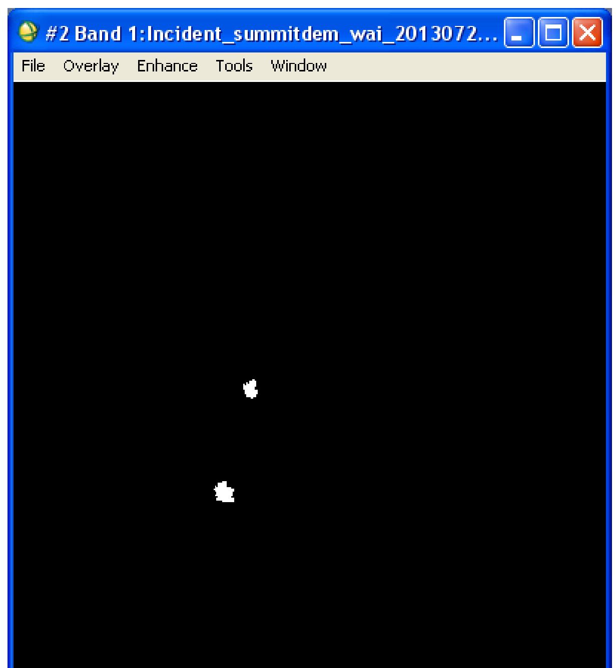
Wide Area Imager Fire Mapping Evaluation/Demonstration Mission --
Multi-day mission conducted July 23-26, 2013 over active fires near Boise Idaho

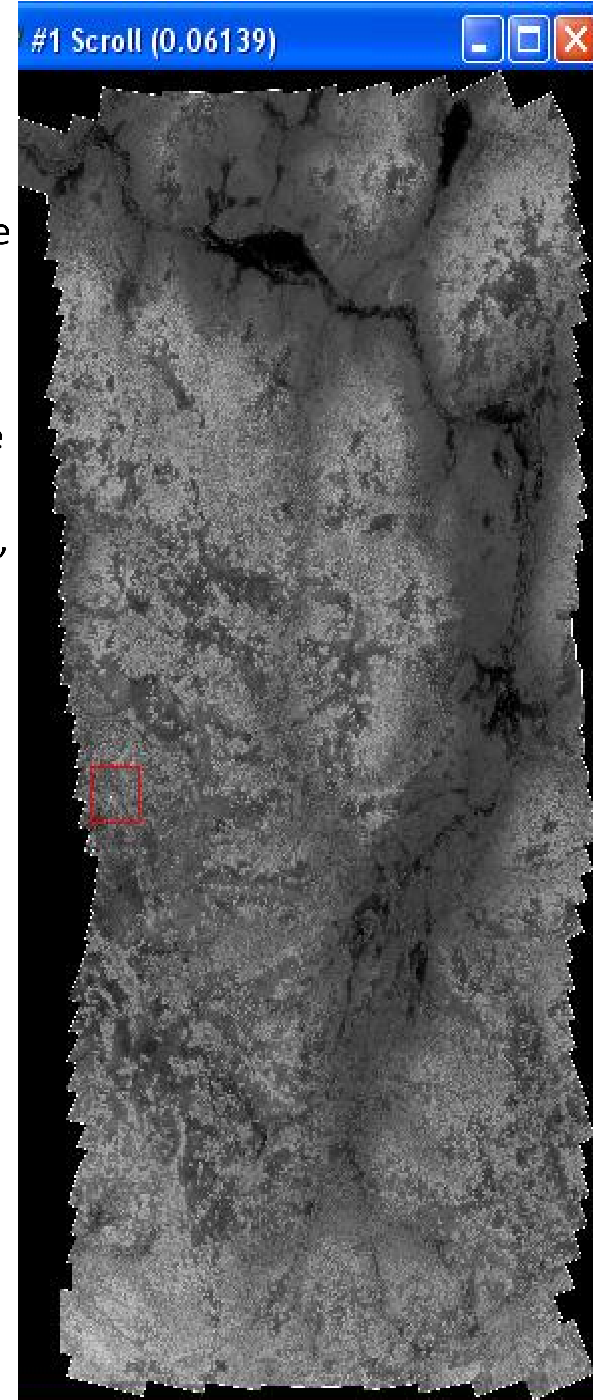


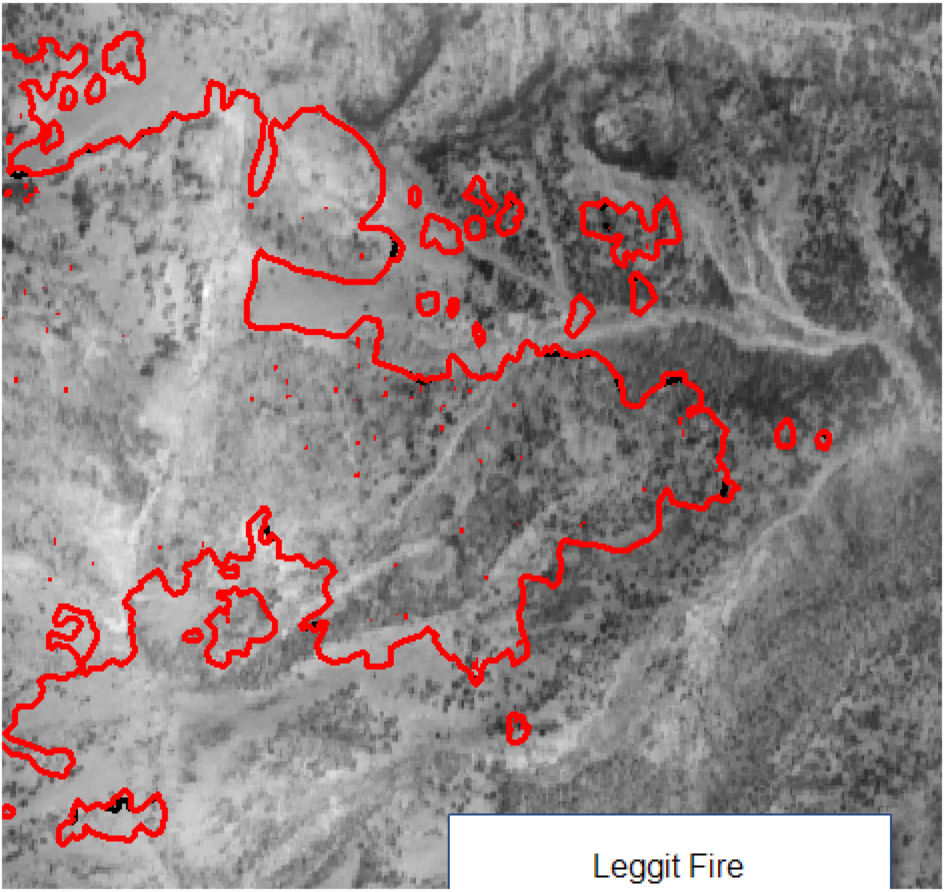


Flight operations generally occurred between 10:30 pm and 2:00 am. Immediately following the flight Xiomas delivered the orthorectified imagery to the USFS, briefed the USFS personnel on the flight and any items of interest in the imagery, and participated in the evaluation of the imagery by USFS personnel.

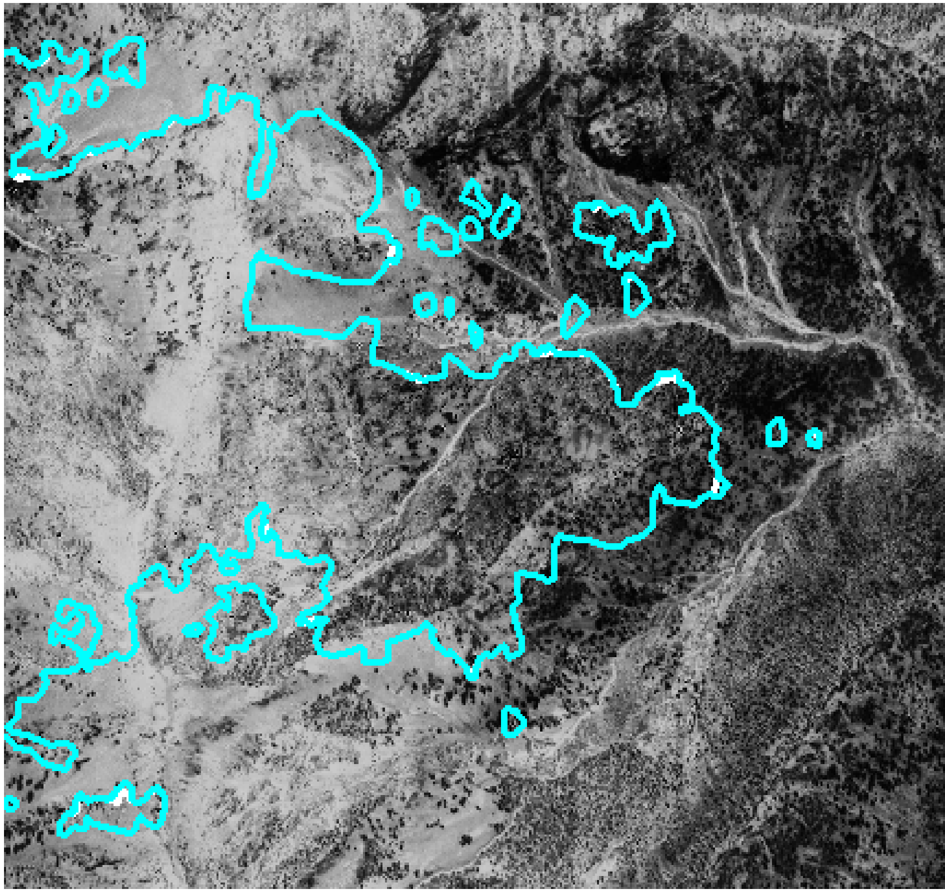
In general the USFS and Xiomas agreed that the registration of the WAI imagery to the reference base imagery (NAIP) was very good, with some occasional mis-registrations up to 10 meters, the detail in the LWIR WAI imagery was very good with small features such as drainages, structures, and roads, clearly visible, and the fire detection was very similar to the USFS Phoenix system.







Phoenix Imagery



WAI Imagery

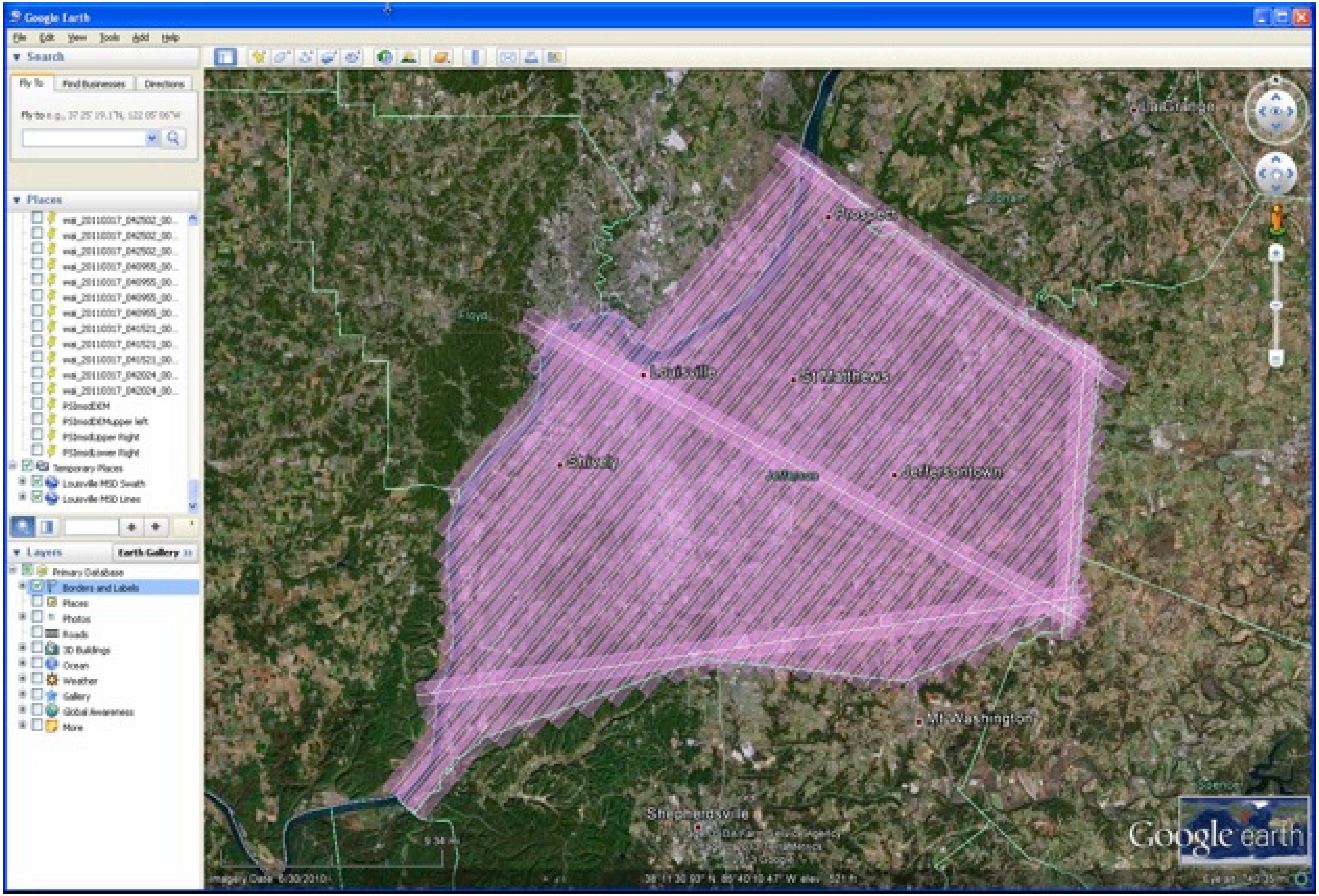
Both data sets are collected around the same time
and from around the same altitude (9,000 foot AGL)

Xiomas WAI Thermal Imaging project over Jefferson County KY for Photo Science

The project was flown over three nights, January 4, 7 and 8.

The WAI performed reasonably well, we had some system faults that caused us to repeat or partially repeat 10 flight lines over the three nights (10 out of 70 total flight lines).

WAI Long Wave IR Image after processing. This is typical of the image quality of the data set.



Screen Shot of Flight Plan
The longest line is about 32 miles
Total of about 650 flight line miles

Report on Xiomas WAI Thermal Imaging project for Photo Science

The following slides summarizes the Xiomas Wide Area Imager (WAI) thermal imaging flights and preliminary image processing.

The project was flown over three nights, January 4, 7 and 8. Note that the imagery from Jan. 4 was not usable due to a problem with the Applanix POS system.

The WAI performed reasonably well, we had some system faults that caused us to repeat or partially repeat 10 flight lines over the three nights.

In operation the system reliability is around 85% (10 faults out of 70 files) and we lose about 1 hour for every ten hours of mission time. In total the WAI has flown 15 flights, with no mission critical failures.

The boresight calibration has been performed and 6 flight lines have been orthorectified and converted to temperature.

The imagery was rectified using a pixel size of 70 cm, The average horizontal error after the boresight process was 3.2 pixels (2.4 meters) with a maximum horizontal error of 6.6 pixels (4.6 meters).

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Wide Area Imager samples
January 4 to 8
Altitude is approximately
6300 feet AGL
aircraft speed is 140 knots.

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Interesting LWIR image of Electrical Power Substation with two contrast stretches

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Pretty LWIR picture of the river

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Interesting warm water outflow into the river from a facility

XIOMAS

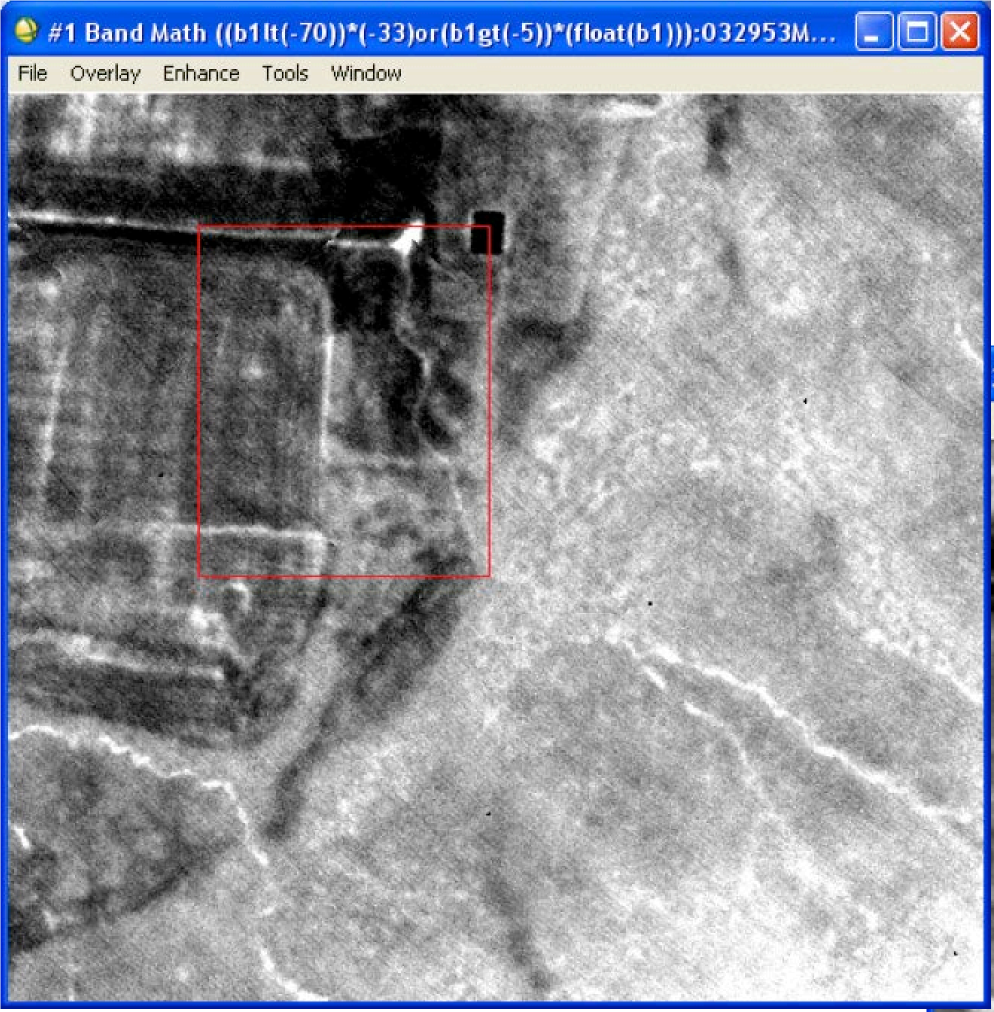
Interesting warm water outflow into the river from a facility

XIOMAS

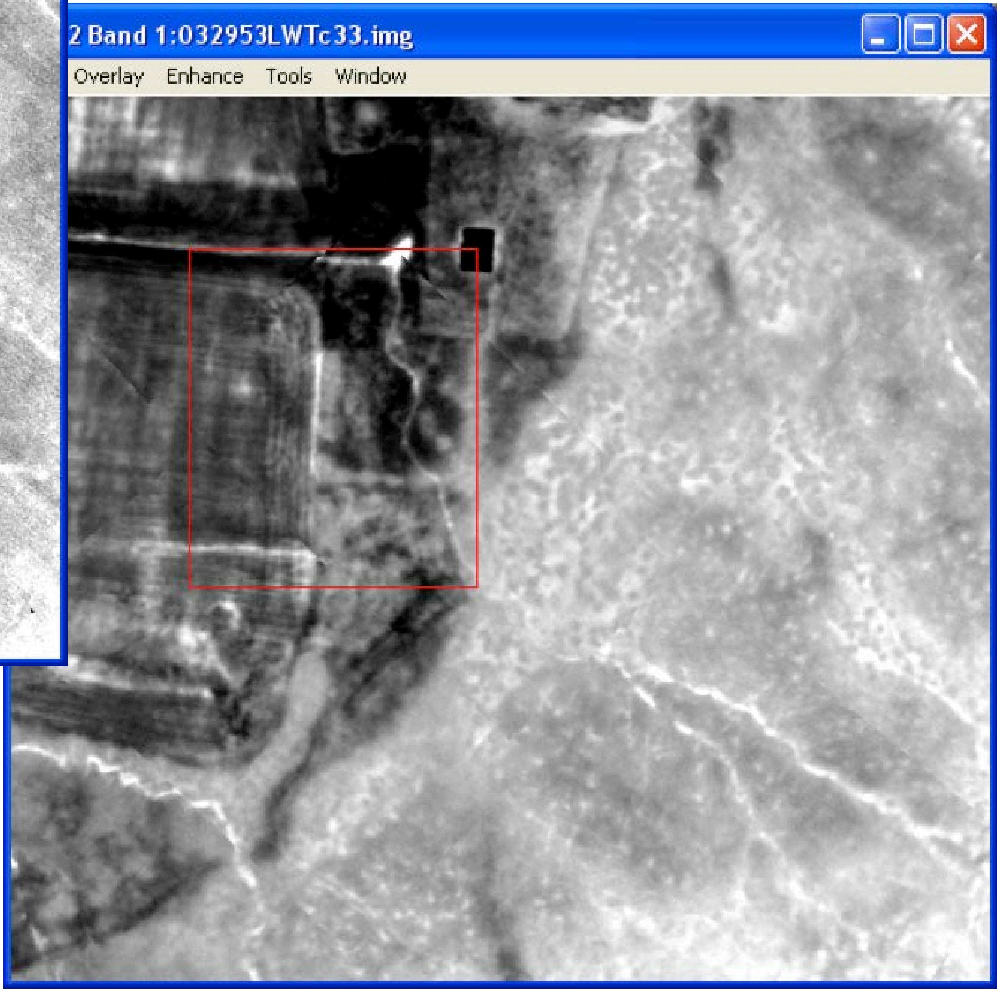
Interesting LWIR Image of water treatment plant

WAI Long Wave IR Image after processing. This is typical of the image quality of the data set

XIOMAS



MWIR Image



LWIR Image

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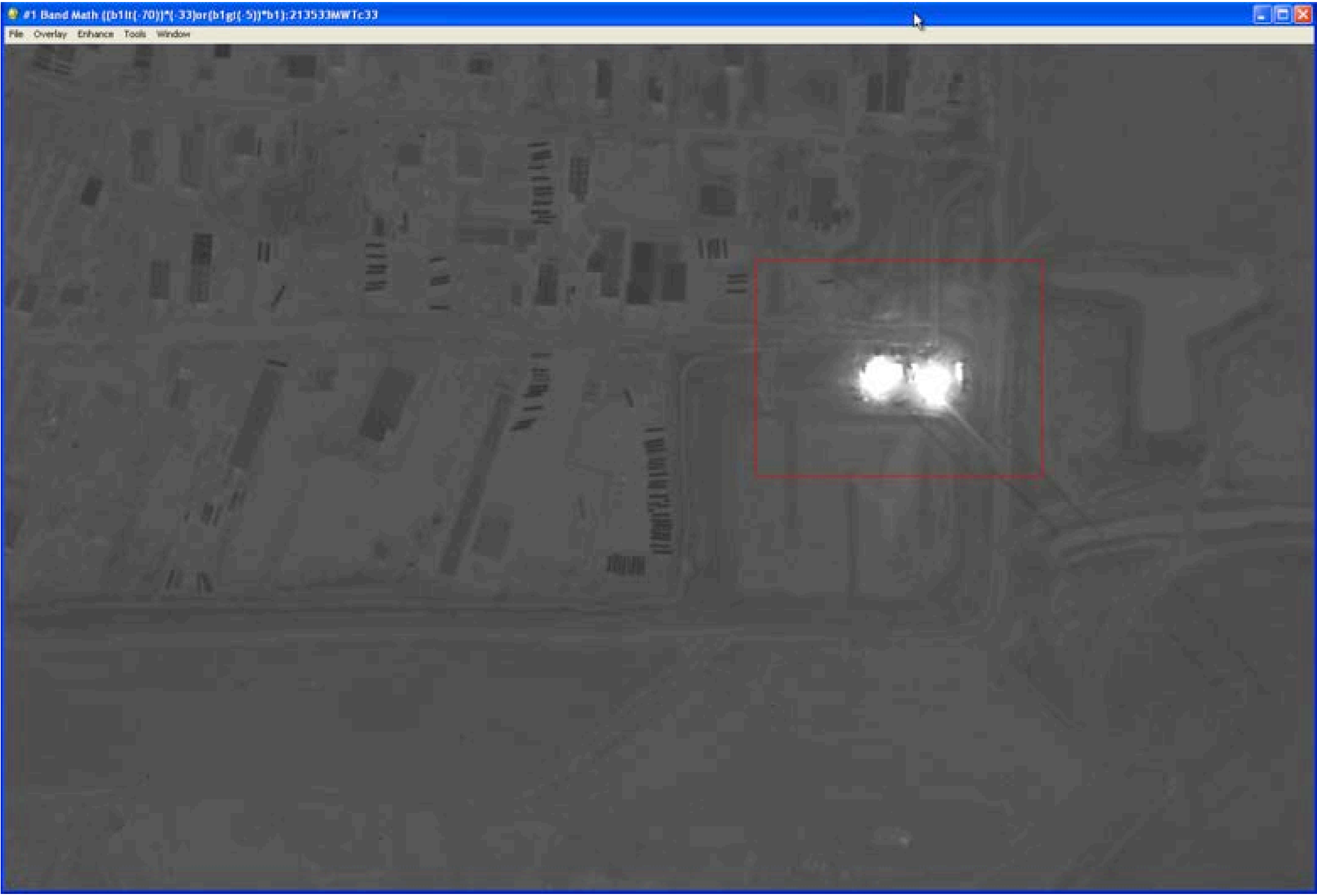

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MWIR Image with something hot

Wide Area Imager Color Infrared Update (repeated from last year)

The project to add a Color IR Sensor to the Xiomas Wide Area Imager is complete and the system is working well. The sensor integration went well, but took much longer than anticipated.

In summary the following was accomplished:

- Purchased the CIR camera
- Modified the WAI optical design to accommodate the new sensor
- Modified the WAI SW to accommodate the new sensor
- Modified the Orthorectification processing SW
- Modified the WAI Acquisition and Processing HW with the following components:
- OPU mother board upgraded to faster processors
- OPU memory increased
- Solid State disk drives upgraded to increase capacity
- Solid State disk drives upgraded to allow easy removal
- Flight tested the system
- Conducted D0160 vibration tests
- Performed Boresite calibration
- Integrated Boresite parameters with the WAI OPU

Update on the Wide Area Imager Phase III

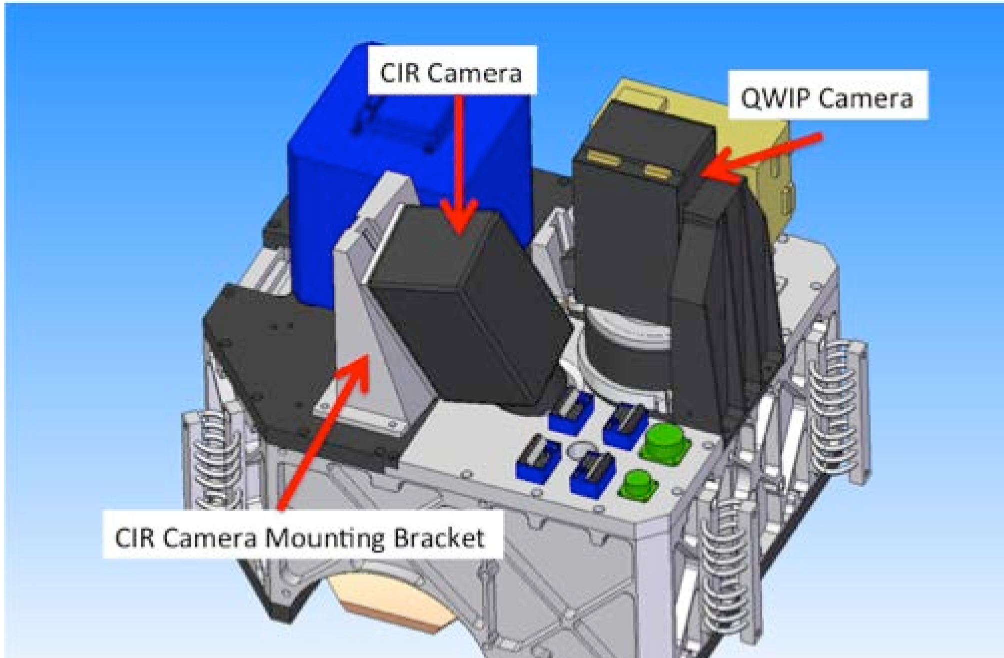
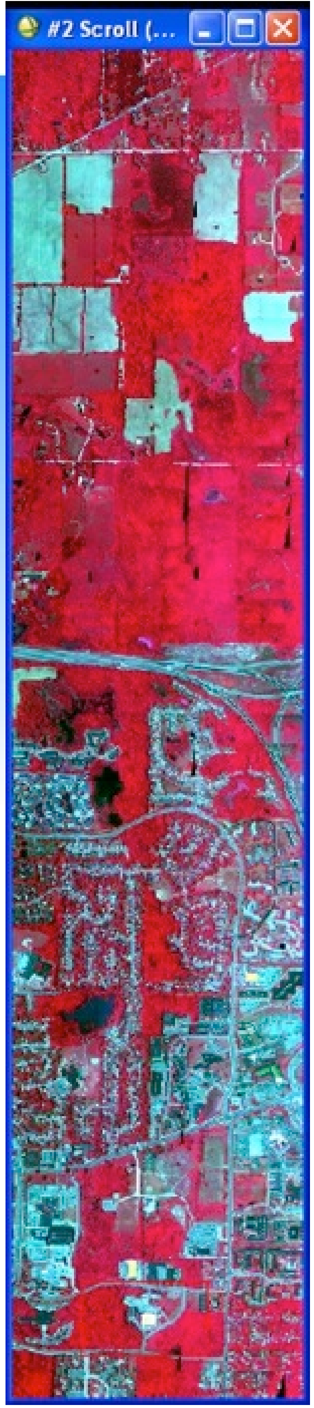
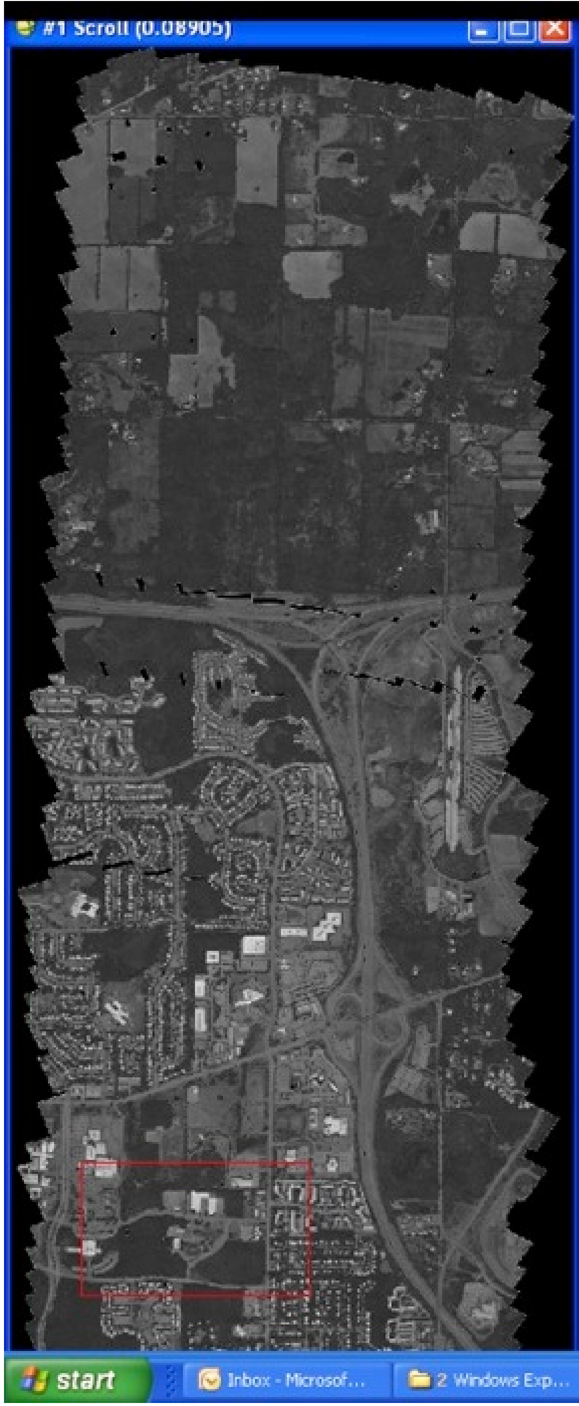
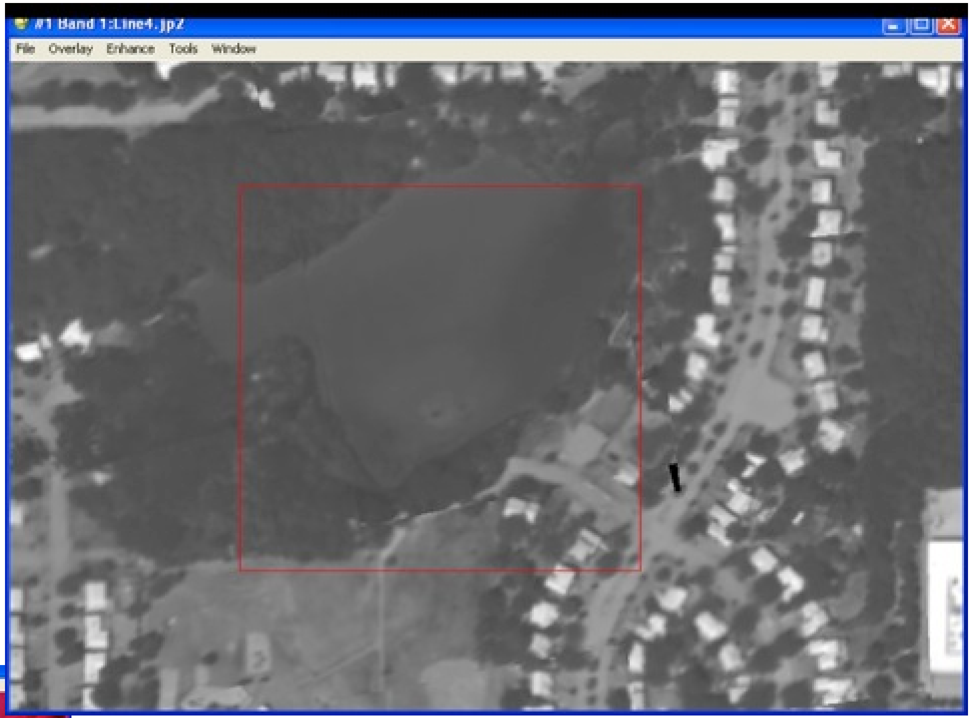


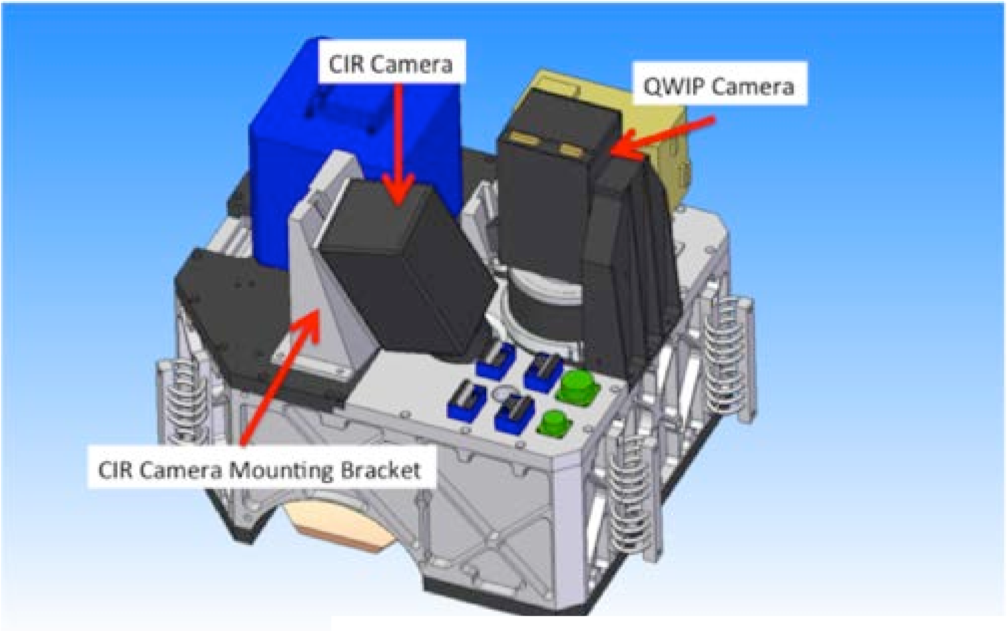
image above is composed of around 8 CIR frames





Update on the Wide Area Imager Phase III





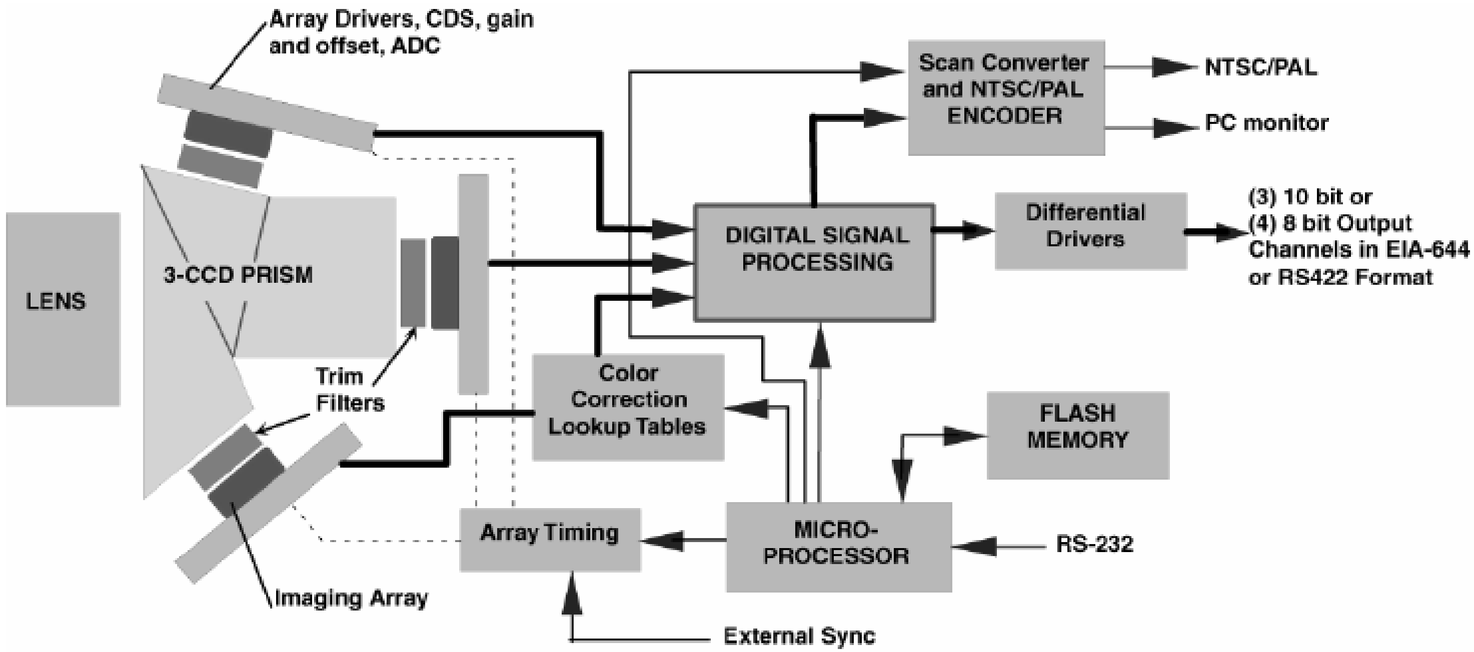


Figure 1. Functional diagram –MS4100 camera

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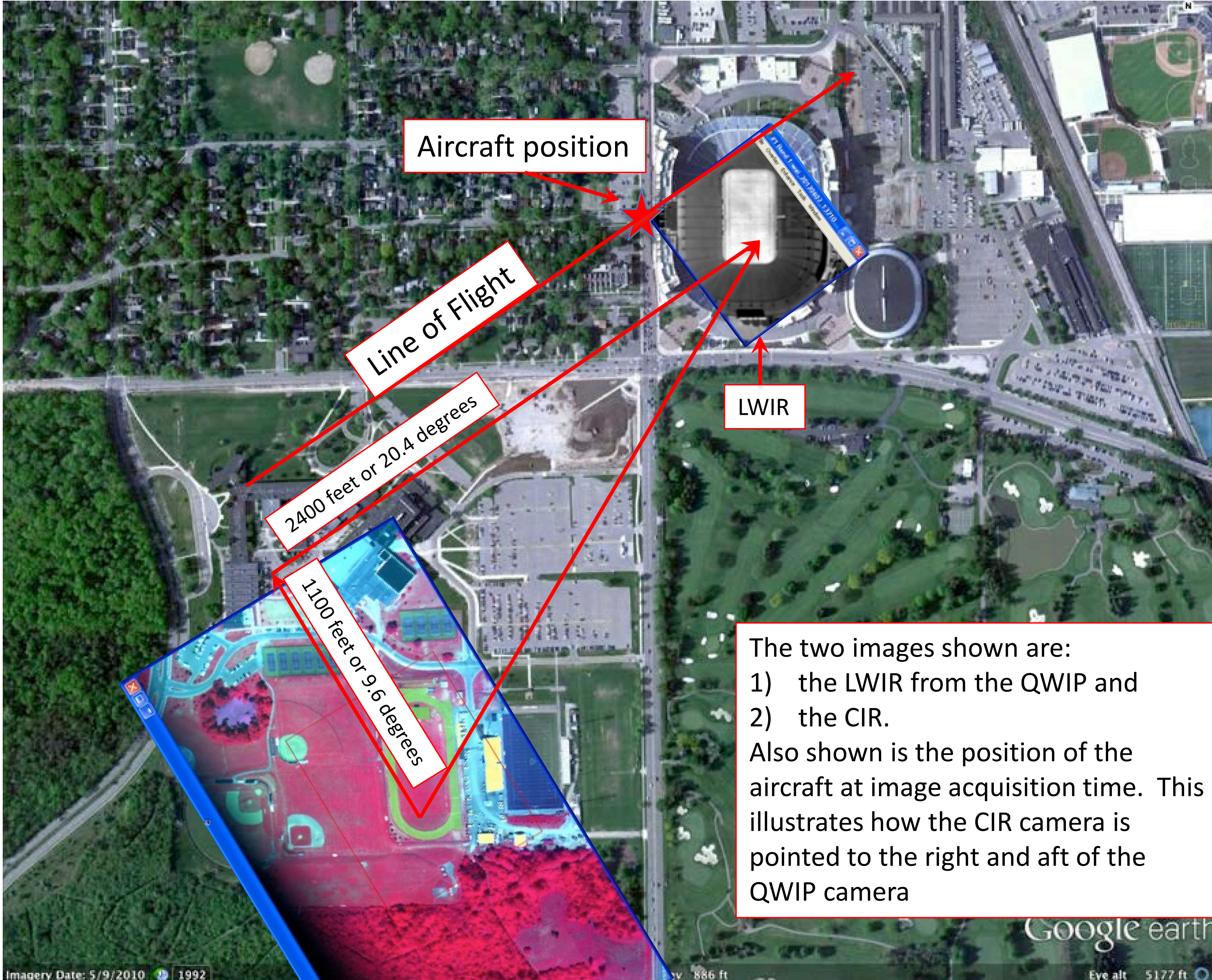
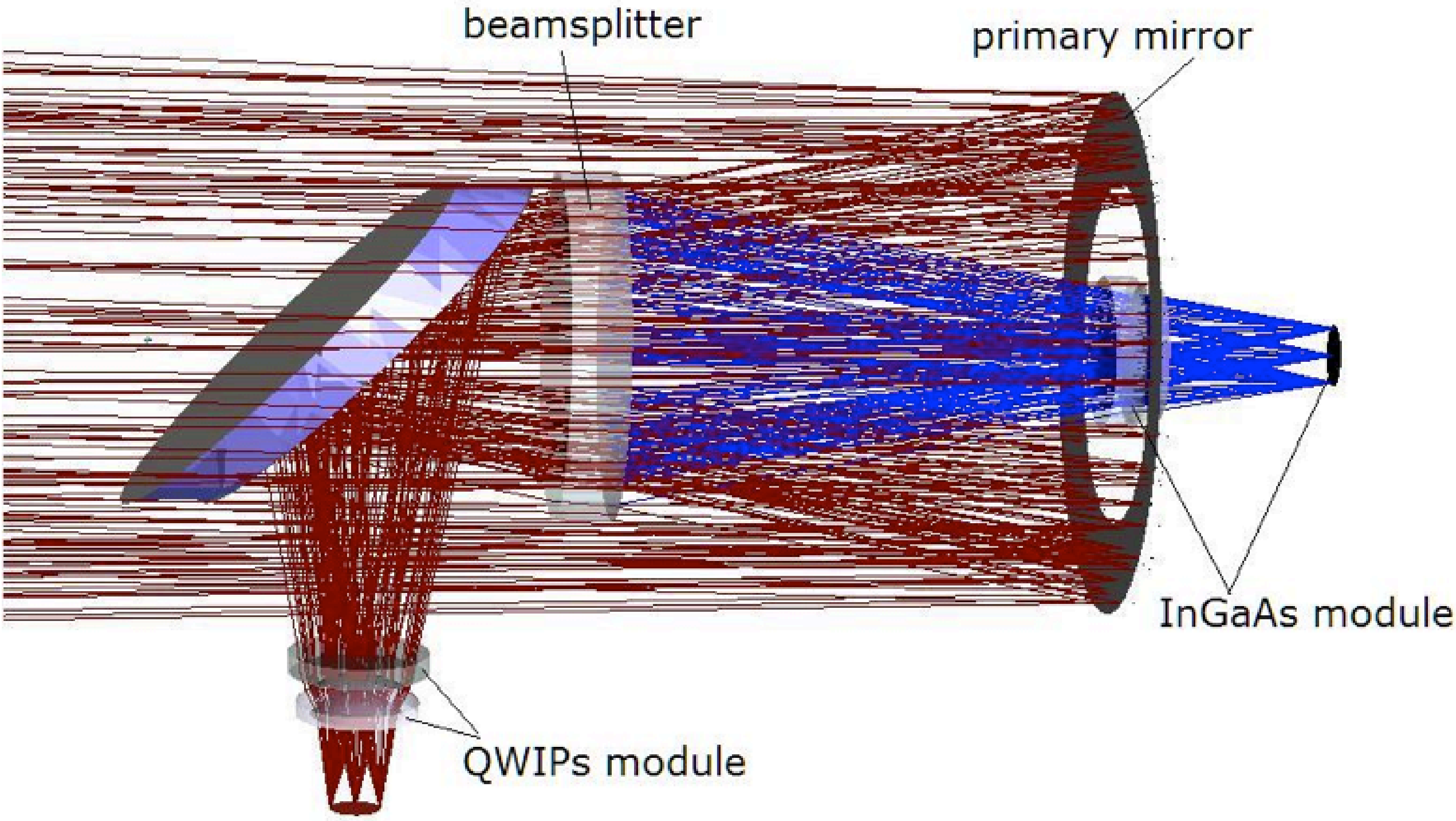


The two images shown are:
1) the LWIR from the QWIP and
2) the CIR.
Also shown is the position of the aircraft at image acquisition time. This illustrates how the CIR camera is pointed to the right and aft of the QWIP camera

We should also note that we are in the process of designing a co-axial multi-sensor optical system for the TMAS SBIR which can be adapted for the WAI.



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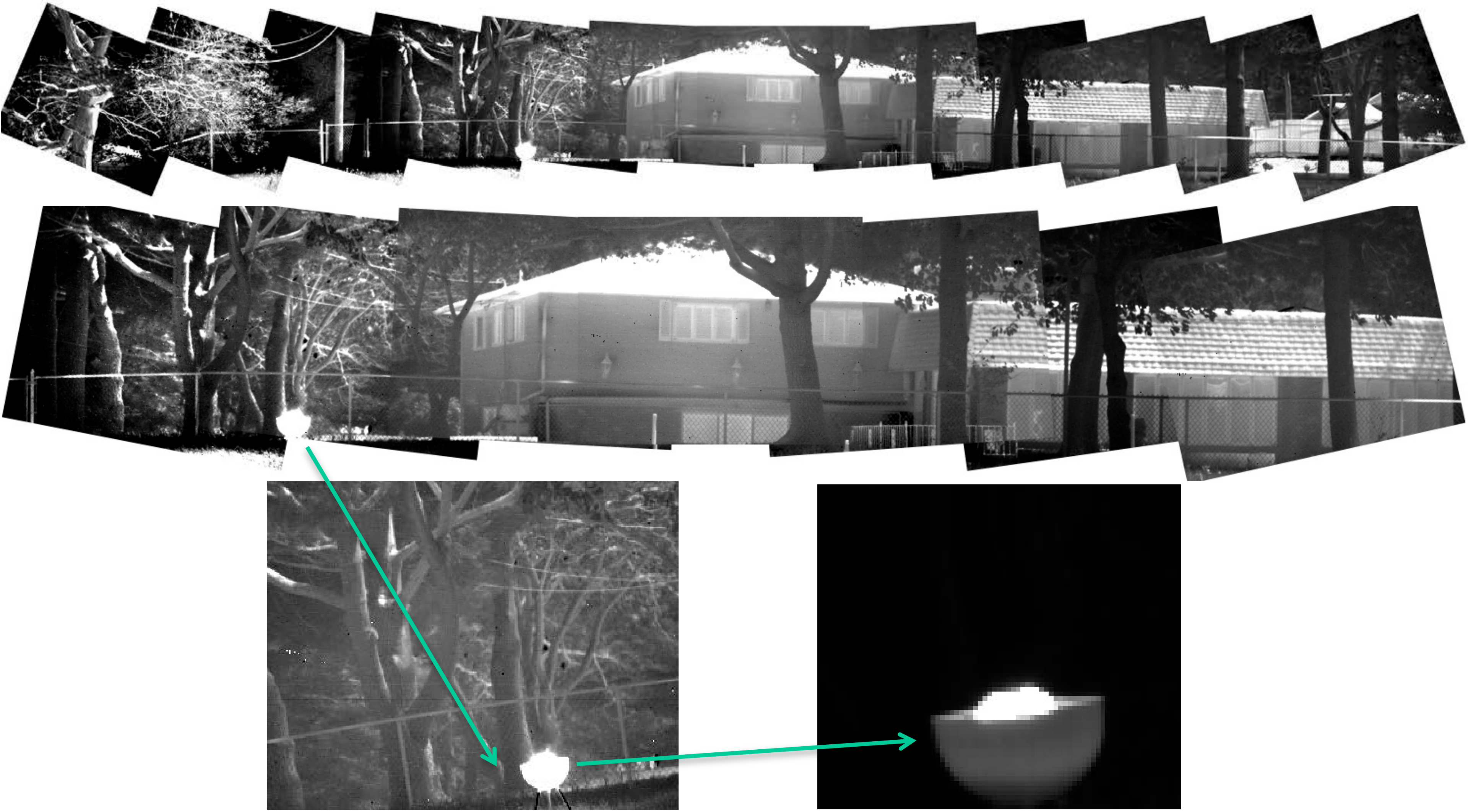
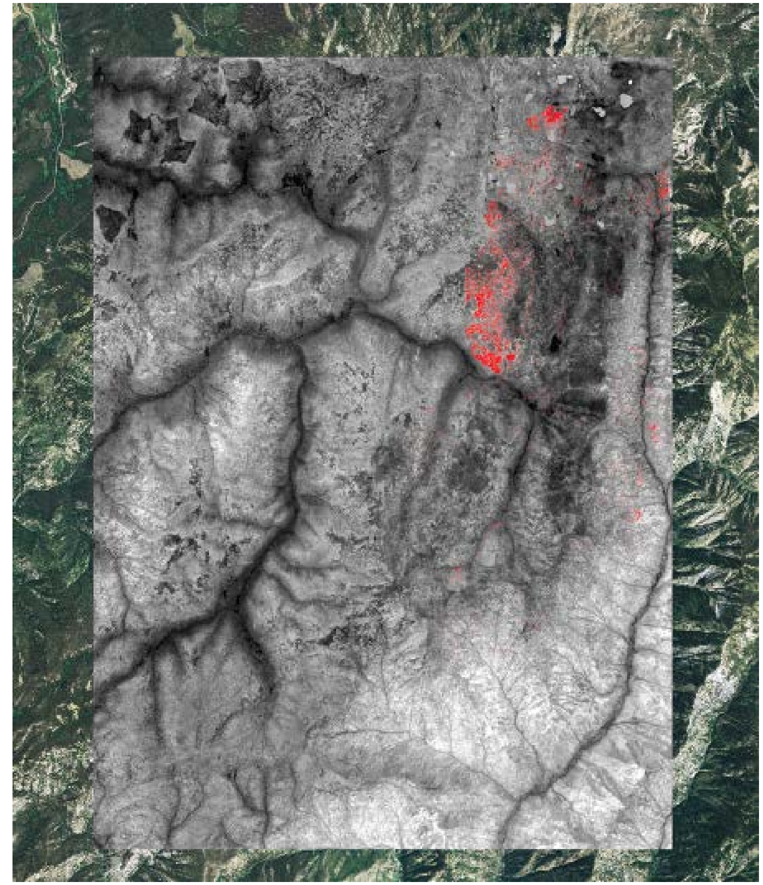
First imagery from the WAI



2 Point Non-Uniform Correction Applied, but
Bad Pixel Replacement has not been done

Next Steps and Recommendations

At this point it seems that the system is ready for Forest Service operational tactical fire mapping missions. Following are some thoughts on how to insure efficient and reliable operation:



1) Hardening the system -- In general the system has performed well. In the long term we would like to upgrade the WAI phase II prototype to the new TMAS data system architecture. TMAS uses a more reliable VME based architecture. In addition, if we upgrade the WAI to the TMAS architecture we will be able to run the scanner at a higher rate, improving our flight profile performance (fly faster, wider field of view, etc.)

2) Improve frame to frame registration – We see several examples where the imagery is shifted frame to frame. This mis-registration does not prevent the system from serving the fire mapping mission, but does raise some concerns as it is outside the expected performance.

3) Develop Boresight procedure we can run in the field – At present the boresight is processed by Fireball in Nevada (Ryan Dotson). The results are good, but it is time consuming transferring the data and it should be possible to perform the calibration in the field using standard image processing tools.

4) Improve documentation of operational procedures - In general the WAI is easy to operate; however the set up routines and processes are poorly documented.

5) Automation and Remote Control of the operation – There are a number of features and planned improvements that we believe will essentially eliminate the need for an airborne operator, further reducing the cost of operation.

Three Band IR Detector (TBIRD)

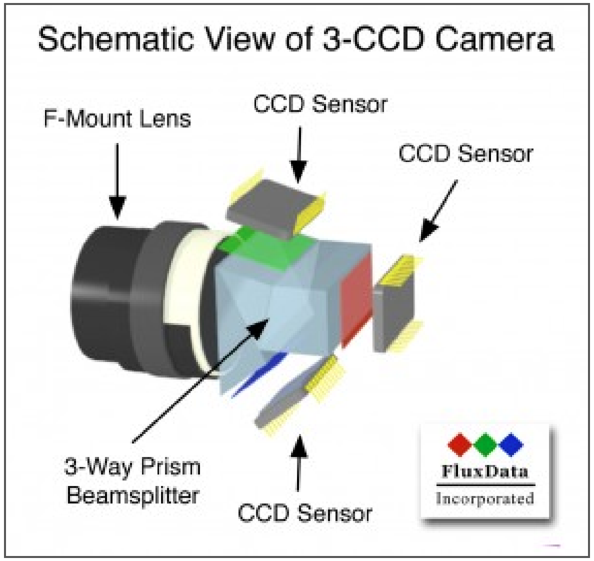
And we have an idea to develop a 3 FPA Design similar to the standard 3 CCD shown at the right.

Our concept uses 3 dichroic prisms and 3 microbolometer FPAs.

Resulting in 3 coregistered spectral bands

Patented Optical 3CCD Design

The FD-1665 has a patented prism corrective optical design that corrects for spherical and chromatic aberration caused by the prism. The versatile dichroic prism design allows for unique spectral configurations with unlimited options for wavelength cutoff between 400nm-1000nm for each sensor. The FD-1665 camera features standard Nikon F-mount lenses providing a wide range of lens flexibility.



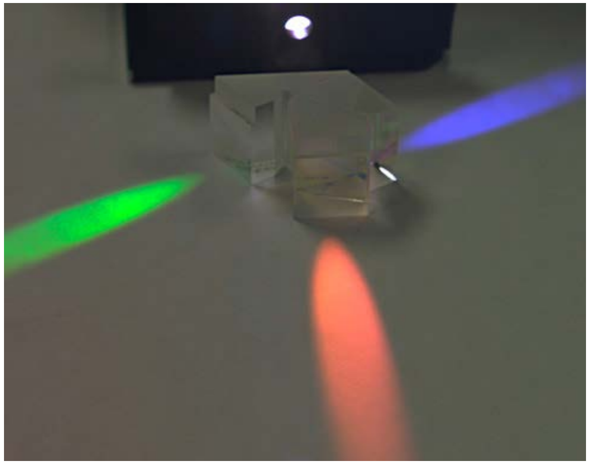
From http://www.fluxdata.com/products/fd-1665-ms3

This concept can be extended to use 5 dichroic prisms and 5 microbolometer FPAs, resulting in 5 coregistered spectral bands for wavelengths between 2um and 12um.

This has the advantage of:

1) High sensitivity
2) Precise narrow bands
3) Excellent registration between bands

The concept is based on a commonly used optical design, and we have researched the feasibility of developing dichroic prisms in the 2 um to 12 um spectral range, and we are quite certain it will work.



A bare color-separation beam-splitter prism assembly of the type used in some Three-CCD cameras, Dick Lyon, Nov. 2006, public domain

Small Airborne Metric Camera System

Significance of the innovation

•Quantitative radiometric data

•Metric Camera -- High Precision geometry for Orthorectification of imagery

What makes a camera a metric camera …

•High quality, high precision opto-mechanical design and components

•Calibration – things like lens distortions and radiometric sensitivity are measured in the lab. In addition we propose to include a field calibration kit.

•Stability – for example, lenses need to be athermalized, and the system needs to be mechanically stable.

Small Airborne Metric Camera System

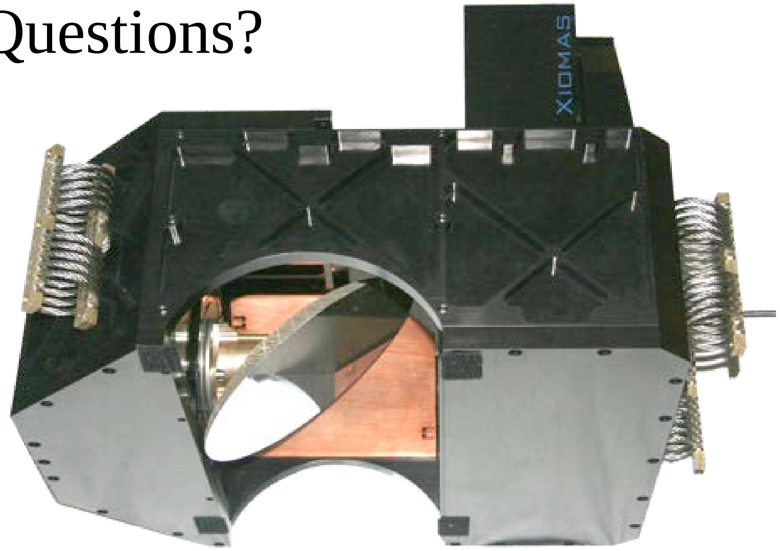
Key Problems to overcome and brief description of proposed solutions:

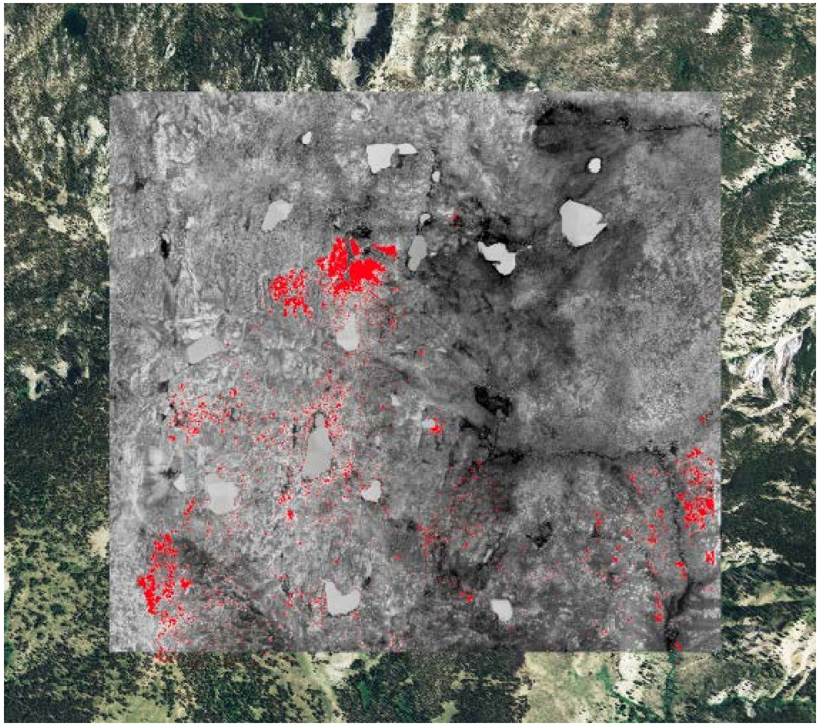
Saturation, blooming, and image smear – These are common problems which prevent quantitative measurement when imaging high temperature targets from an airborne platform.
We propose to solve these problems primarily by:
1. controlling the sensor parameters such as integration time, and gain
2. implementing optical filters (spectral band pass and neutral density)
3. In addition, we propose to integrate technology to minimize motion induced smear, such as mechanical shutters, or motion compensation.

Radiometric Accuracy – Generally speaking all sensors require some form of calibration if they are to deliver accurate measurements.
We propose to solve this problem by:
1. developing a field calibration kit which includes small calibrated thermal panels and calibration reflectance panels
2. incorporating on board calibration sources
3. laboratory calibration of the sensor suite

Image To Base Map Registration – Registering the image to a base map is critical to delivering actionable intelligence to the end user. The usual solution is a high performance position orientation system with high update rates, but these are very expensive, and too heavy for the small UAV. We propose to solve this problem through a combination of geometric calibration, mechanical stabilization, and ground base image processing.

Questions?





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