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In-Flight Performance Assessment Of Imaging Systems Using The Specular Array Radiometric Calibration (SPARC) Method

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Unclassified

Introduction

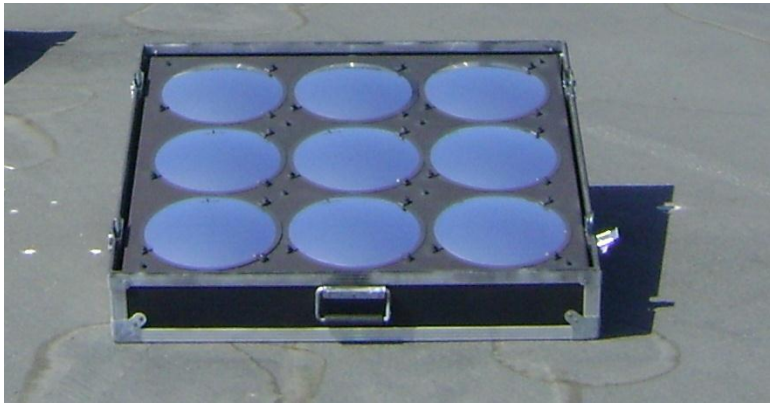
- Temporal image assessment (IA) is essential for maintaining accurate spatial, radiometric, spectral and geometric characterization of sensor data products and monitor compliance with data quality requirements.
- The Specular Array Radiometric Calibration (SPARC) target set provides a means to enhance IA through the life of a mission.
- SPARC target systems are low cost, portable and easy to deploy. They can be used for radiometric IA in much the same way as psuedoinvariant sites but with much better reproducibility. (reduced atmospheric effects and improved reflectance and BRDF stability over the full dynamic range)
- They can also address spatial, spectral and geometric issues in the same overpass

Presentation Overview

- This presentation looks at the SPARC method as an IA tool with the emphasis on image quality.
- The analysis utilizes imagery recorded by GeoEye's IKONOS satellite in 2009 and 2011.
- Please note that the results are not unique to IKONOS. The effects reported occur to a greater or less degree with all commercial and civil MSI pushbroom systems.
- The analysis not only considers temporal data but also the evolution of product quality at different tap points along the image chain. Specifically Level 0 (radiometric cal only), Level 1 (synthetic array registered and resampled) , and Level 1 + MTFC restoration.

SPARC Target Arrays

Radiometric Panel



- The SPARC vicarious calibration approach uses radiometric panels containing multiple convex spherical mirrors and spatial point source targets based on single mirrors.

- Individual mirrors produce a virtual image of the sun with an upwelling intensity determined by the incident solar irradiance and the mirrors reflectance and radius of curvature.
- Spatial knowledge of the sensor point spread function (PSF) profile supports the calculation of ensquared energy essential for accurate radiometry of small targets.
- Imaging an array of point targets provides the data needed to generate a full system 2-D PSF.

Point Source Array

How Image Blurring & Detector Sampling Affects The Image Quality Of Small Targets

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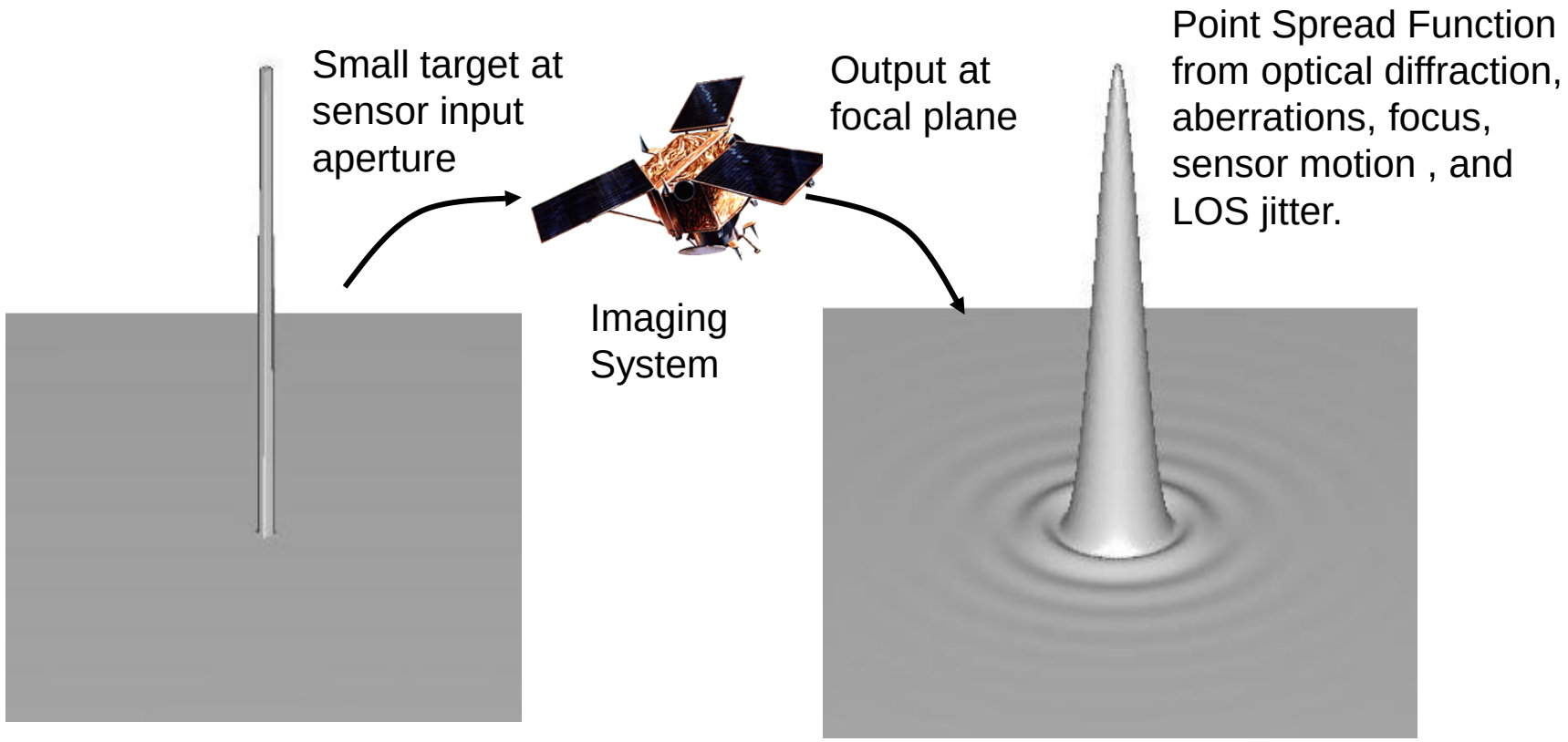
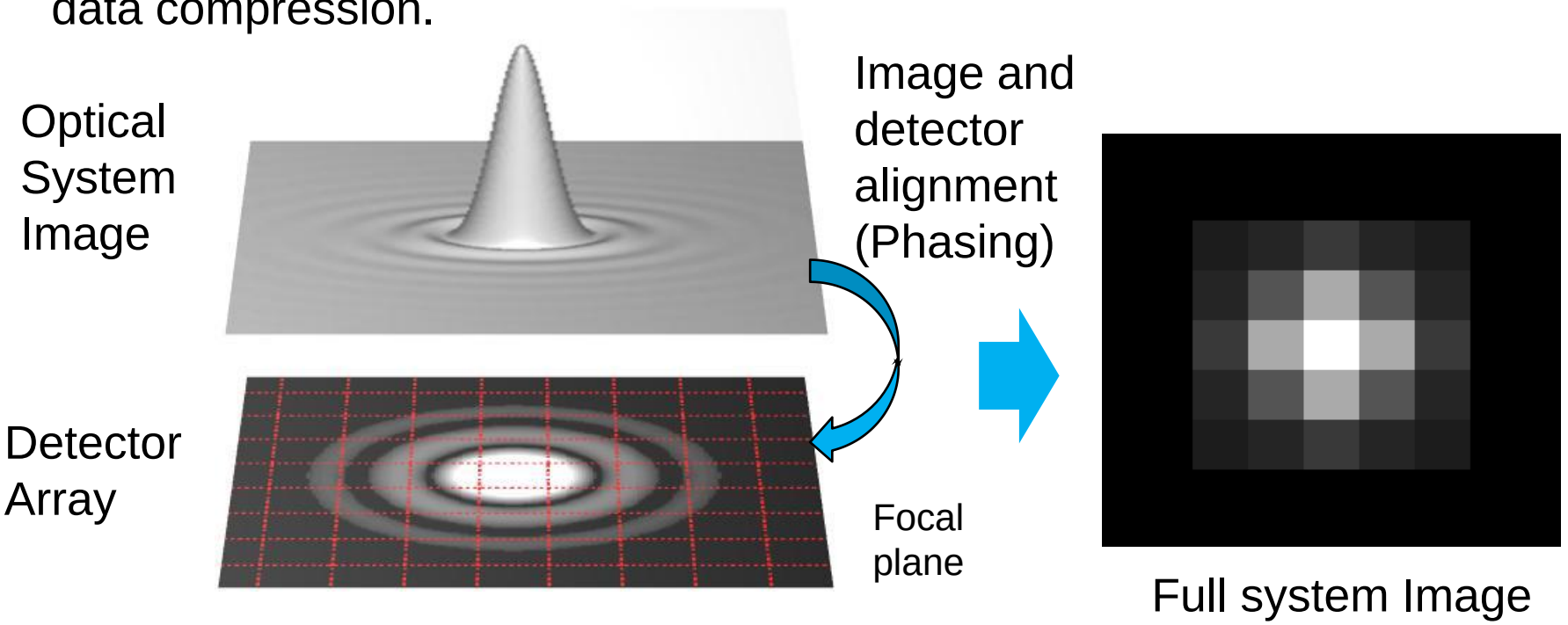
- Blurring from the optical system and platform motion creates the Point Spread Function of the imaging system



Detector Sampling Quality And Phasing Effects Determine Final Image Appearance

- Focal plane detector system effects – detector aperture size, detector and electronic noise, integration time, TDI, target/detector phasing and data compression.



Full system image construction is affected by a dynamic dance at the focal plane between the optical image and the sensor readout that depends on size of the optical PSF, detector pitch and target /detector phasing.

The Resolution Of The Full System PSF Profile Depends On Detector Spatial Sampling

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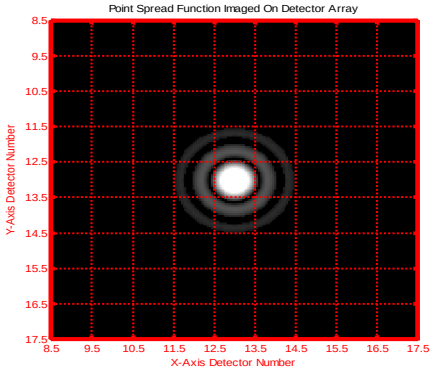
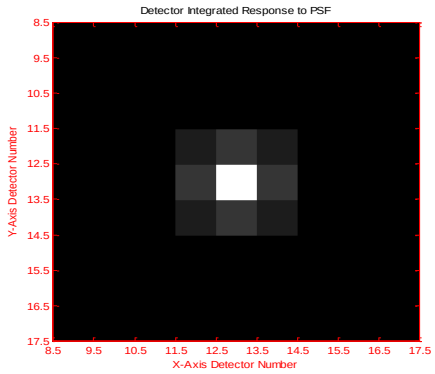
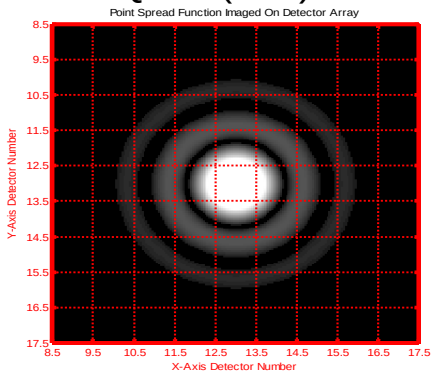
For a diffraction limited system, image resolution of small targets depends on sensor quality sampling ratio Q (detector size relative to size of the Airy disk)

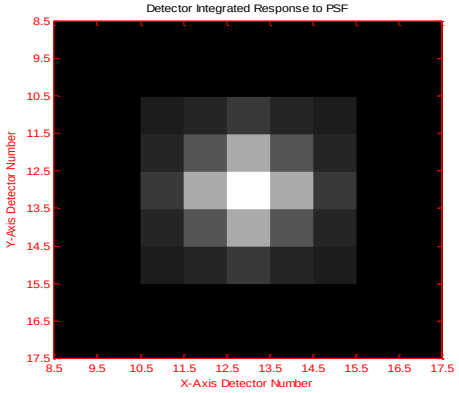
Q = 0.5 (Multispectral/Hyperspectral)



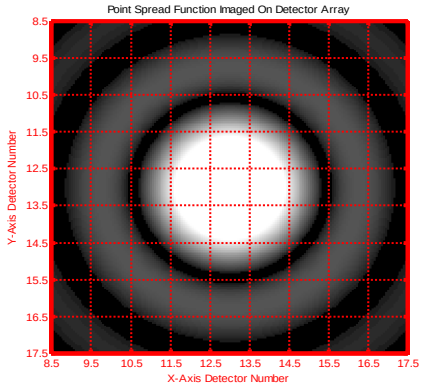


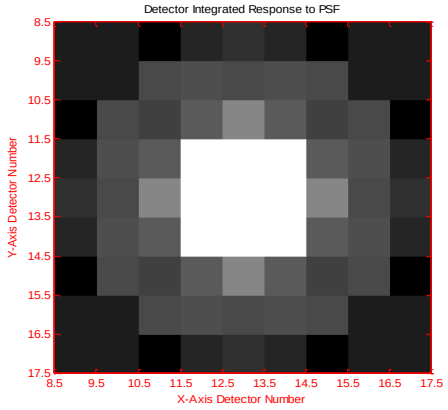
Q = 1 (Pan)





Q = 2 (Nyquist)





Because spatial knowledge is limited by the Nyquist frequency, a snapshot of a single point target will always undersample the PSF in any imaging system.

Responsivity Depends On The Point Target Spatial Phasing Relative To Pixel Center

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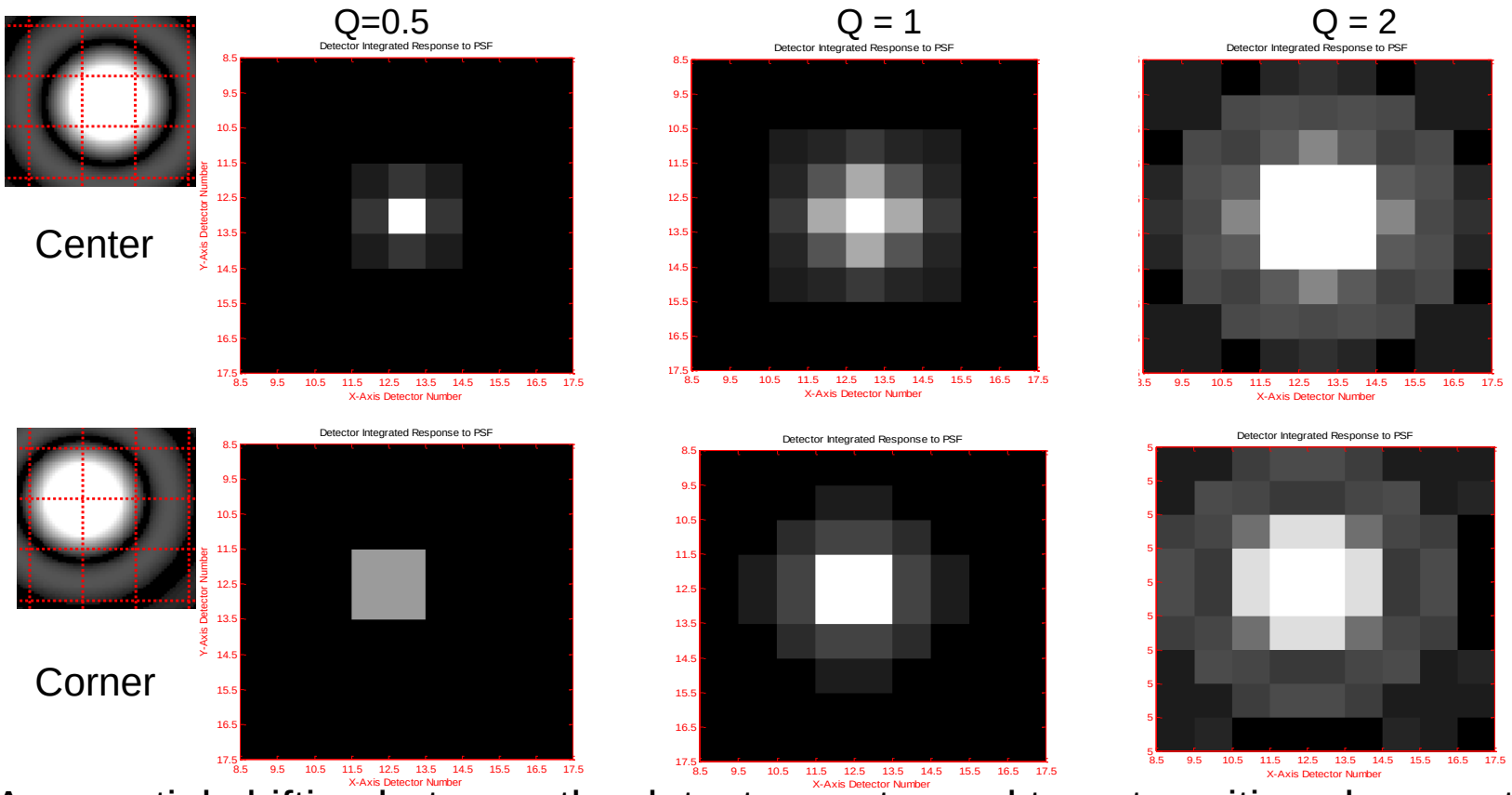

- Any spatial shifting between the detector center and target position changes the full system appearance of a single small target because the detectors see different parts of the PSF.

- Imaging an array of point targets creates multiple images each a snapshot of the PSF at different pixel phasing allowing one to build an oversampled full system PSF.

Spatial Characterization: Oversampling The Full System Point Spread Function

- SPARC uses a grid of spherical reflectors to create points source images at different pixel phasing.
- As a result, the oversampled PSF can be generated from a single image of a mirror array (an instantaneous PSF) or from multiple images of the array for better sampling statistics (a time averaged PSF).

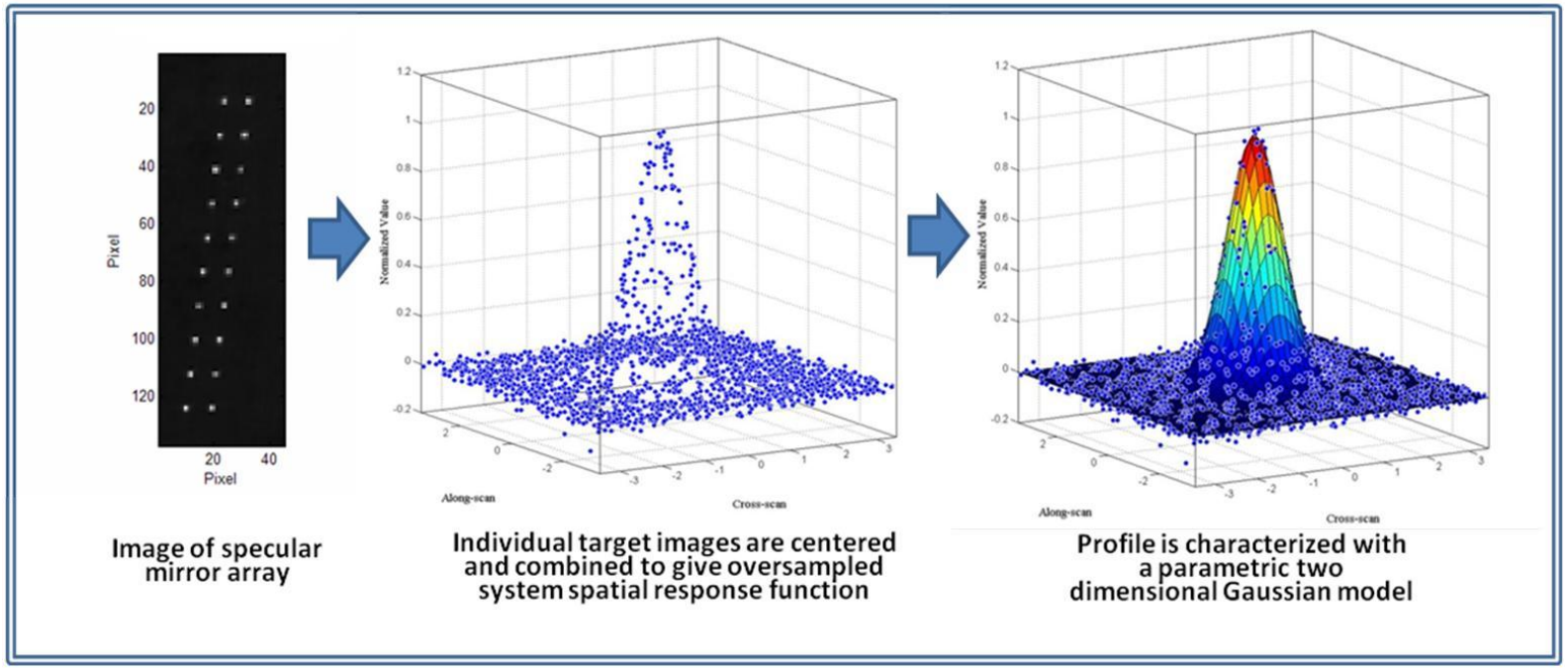

Image of specular mirror array

Individual target images are centered and combined to give oversampled system spatial response function

Profile is characterized with a parametric two dimensional Gaussian model

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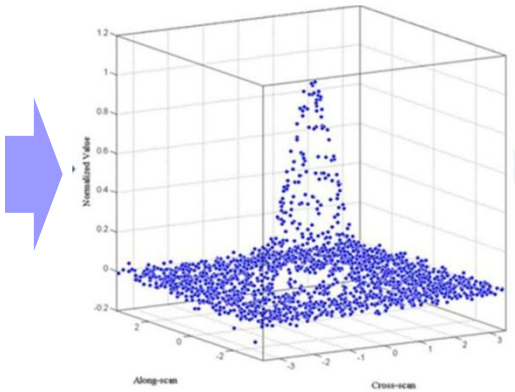
Modeling The Full System PSF for IA

- Each target profile is modeled with a 2-D Gaussian function, invoking a central limit theorem that each blurring process is independent resulting in a shape that converges statistically to a Gaussian profile.

- **The semiparametric oversampled profile**
  - Each point source is best fit (in least squares sense) with a Gaussian function finding the **centroid** for each target. It iterates to a common cross-scan and along-scan FWHM for all targets while minimizing the RMS Errors in the residuals of the normalized pixel values.

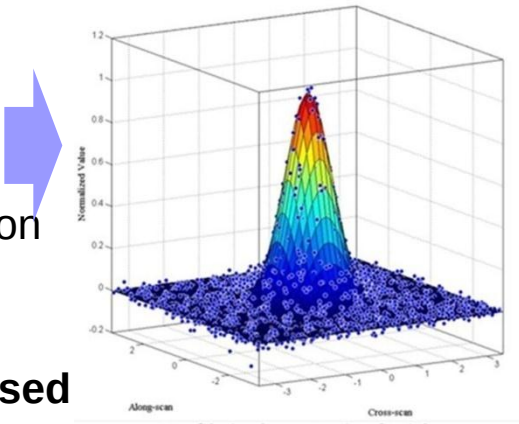
  -The resulting **centroids** are aligned combining the pixel values for all targets in a single profile revealing the actual overall shape of the system PSF. (semiparametric –Gaussian model is only used for finding the centroids. The shape is defined by the actual pixel values)



- **The 2-D Gaussian parametric model**

  - Gaussian parameters are derived by finding a best fit function for all the points in the final oversampled profile.

  - **The cross-scan and along-scan FWHM from the final Gaussian fit to the combined oversample 2-D profile is used as the metric for image quality assessment and trending.**



Data Sets And Analysis Footnote

- In 2009 and 2011 3 to 5 IKONOS images were collected of SPARC spatial and radiometric reflectors from each of a total of 8 overpasses.
- Site: Parking lot of Raytheon SAS Facility in El Segundo, CA.
- Two miles south of the LAX airport
- Elevation 35 m

- Image quality trending of the data proceeds assuming a Gaussian profile
- The reality is when the FWHM ~1 pixel or less (which will be the case for the MSI bands), the square detector aperture profile dominates and the Gaussian assumption starts to break down (square detector aperture dominates).
- However, for this analysis, the Gaussian FWHM will continue to be used as a relative image quality metric even when FWHM ~1 or less.

Measuring And Tracking The PSF Profile: Example For The IKONOS Pan Band Level 0 Data

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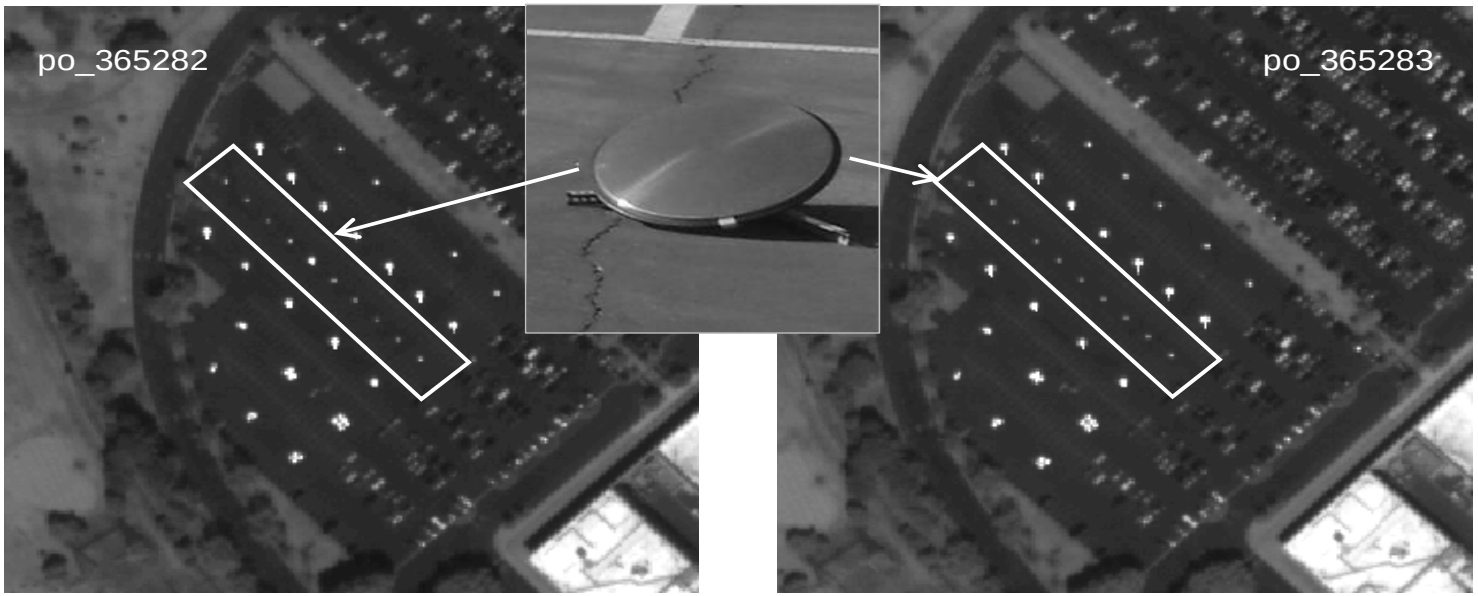
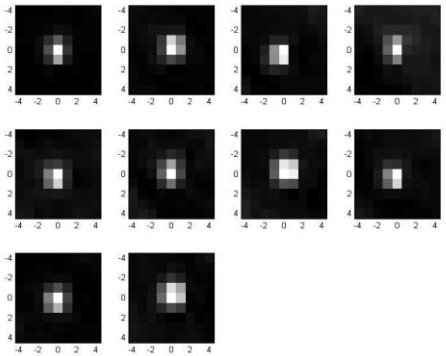
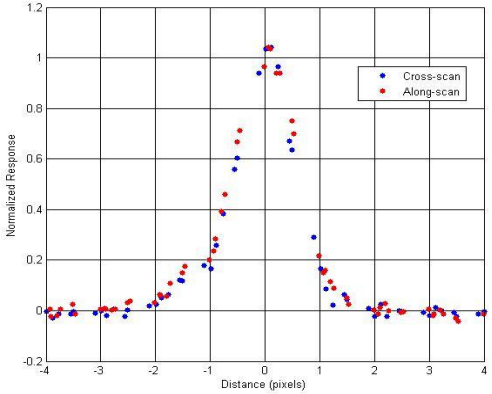


IKONOS images of SPARC Targets

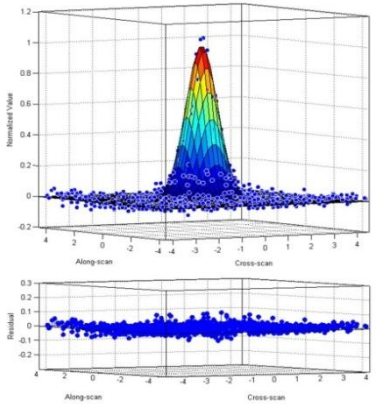
Sept 10, 2009



Point target images extracted (po_365283)



Semiparametric profile in the cross-scan and along-scan directions



Targets centroided and oversampled PSF built – fitted with 2-D Gaussian model

Tracking Of IKONOS Image Quality FWHM Metric In 2009 And 2011 For level 0 Processing

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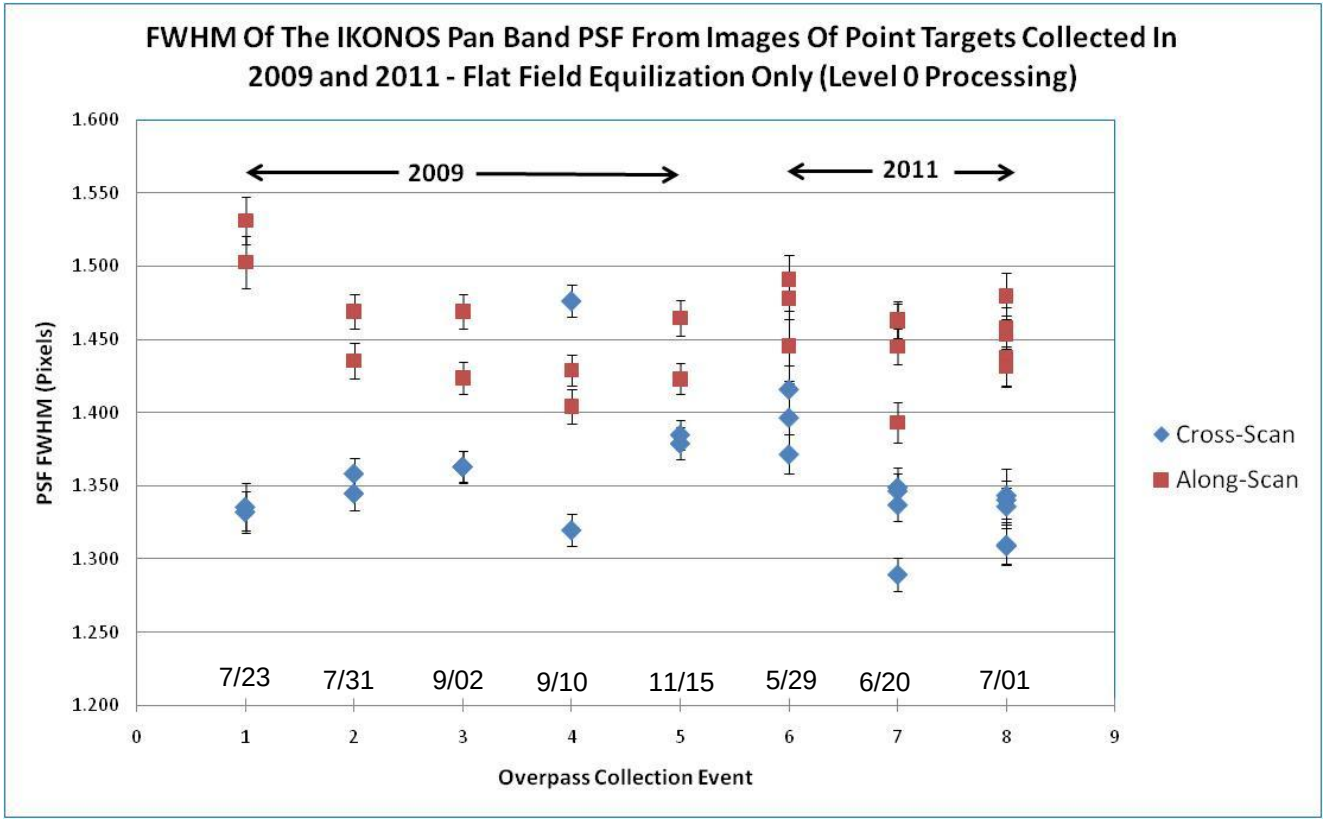

- Error bars indicate measurement precision of FWHM (~ +/-0.012 pixels) for a single image.
- Spread in values for multiple collects in a single overpass indicates repeatability of FWHM for IKONOS (~+/- 0.03 pixels).

Precision of technique indicates that the FWHM of the PSF for the IKONOS pan band actually varies slightly from image to image, even on the same overpass (terrestrial scintillation?, LOS jitter?)

Semiparametric Profile of IKONOS 2-D PSF (Seasonal Average)

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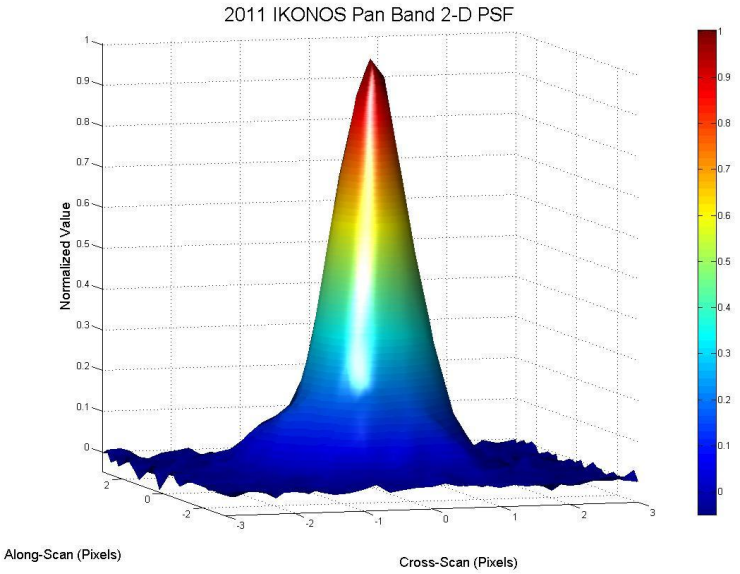

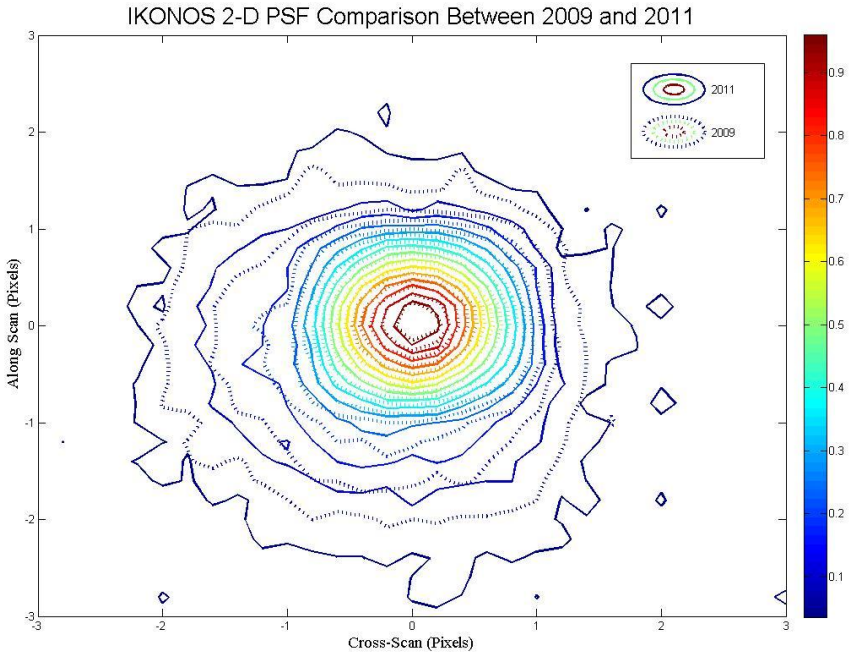

- Composite 2-D PSF for IKONOS Pan band from all images collected in 2011 – Reveals asymmetry in sensor PSF.
- Contour plot of PSF comparison between 2009 and 2011 shows accuracy in SPARC technique – possible broadening in the wings of the PSF indicating slight performance degradation over this period.
- Such detailed knowledge of the full system PSF can be used to establish better Resampling and restoration kernels for improved product generation and exploitation.

Change In Spatial Resolution Along Image Chain: Level 0 to Level 1

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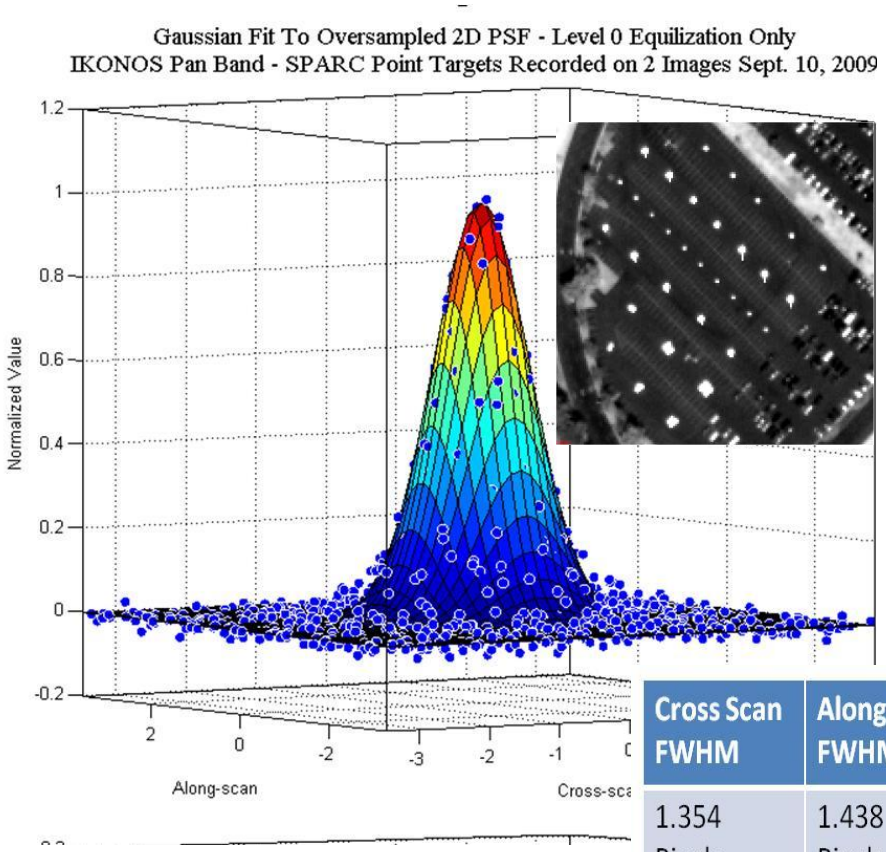
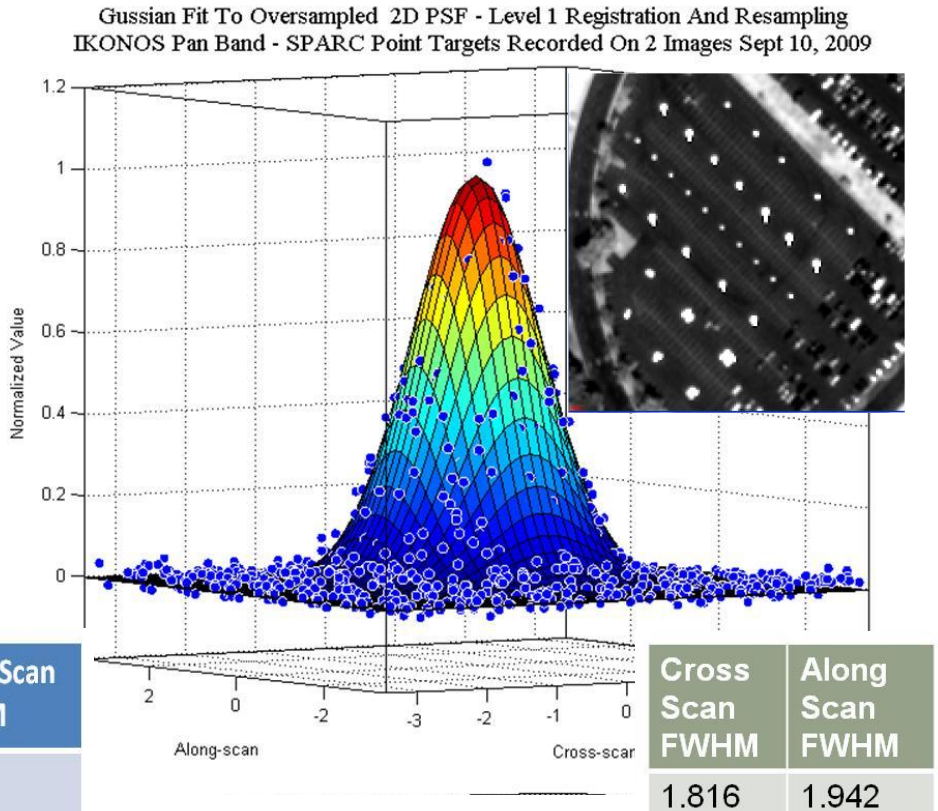
- Results show significant reduction in spatial resolution between Level 0 (raw data with flat field correction only) and the Level 1 product (synthetic array generation using cubic convolution resampling).



Cross Scan FWHM	Along Scan FWHM
1.354 Pixels	1.438 Pixels



Cross Scan FWHM	Along Scan FWHM
1.816 Pixels	1.942 Pixels

Tracking Of IKONOS Spatial Resolution In 2009 For level 1 processing

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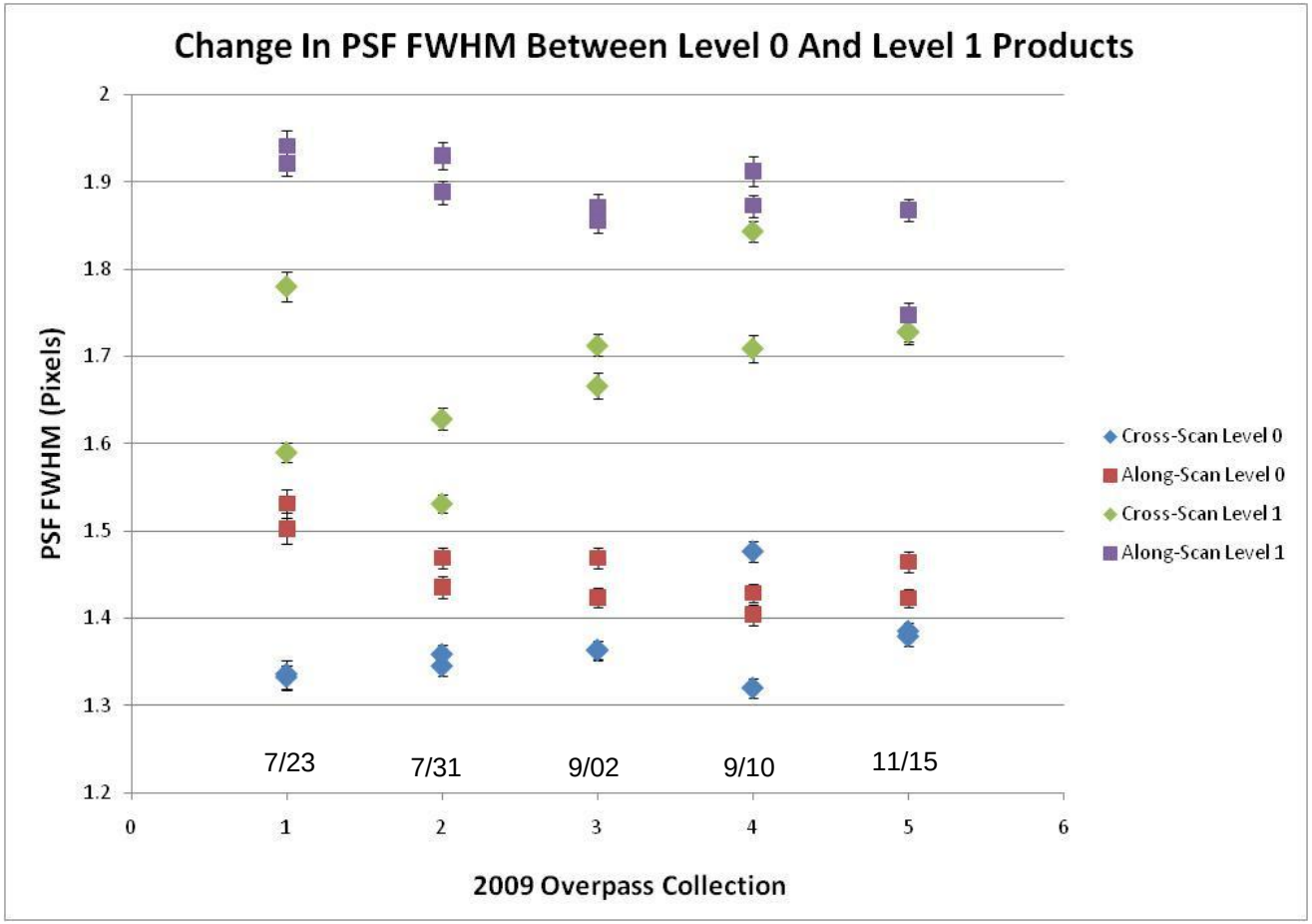

- Typical broadening is 0.3 to 0.4 pixels in the PSF FWHM
- Except for a couple outliers, the trends are similar between level 0 and level 1 as expected

Change In Spatial Resolution Along Image Chain: Level 0 to Level 1 + MTFC

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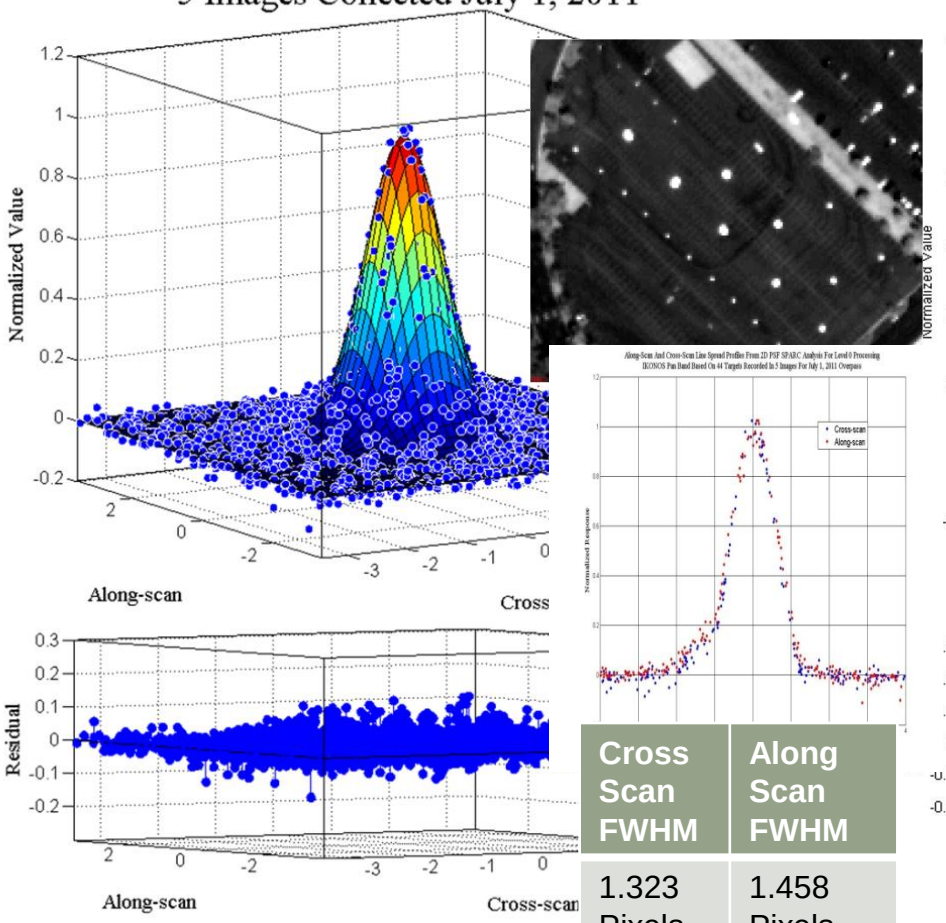
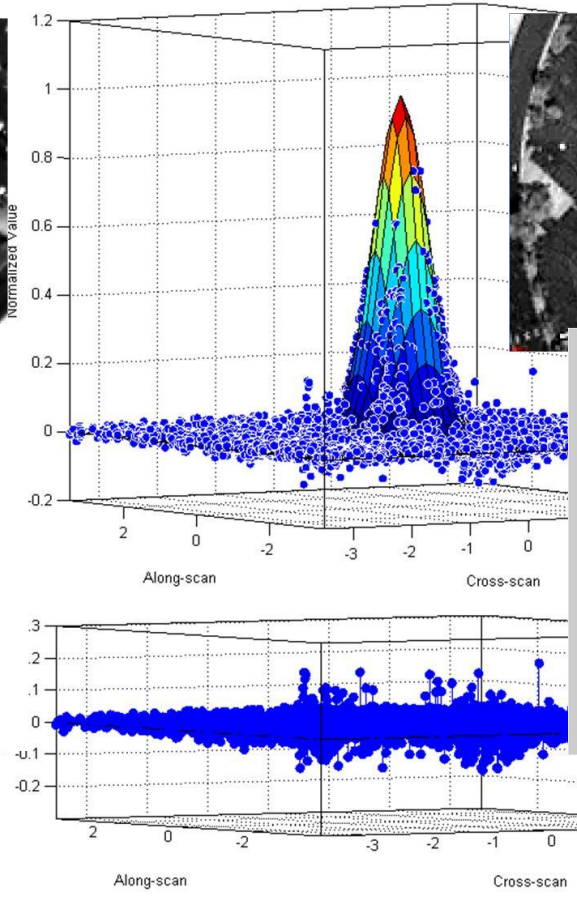
MTFC successfully improves resolution but the shape of small targets take on the shape of the restoration kernel used. Noise is increased (ringing) and radiometric content is compromised.

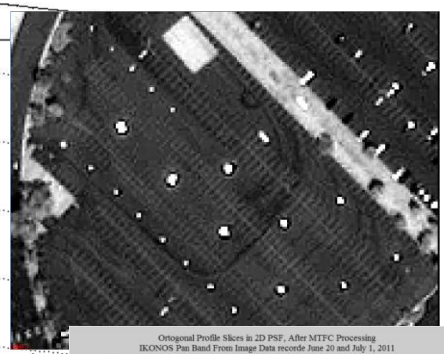
Gaussian Fit to Oversampled 2D PSF from 5 Images Collected July 1, 2011

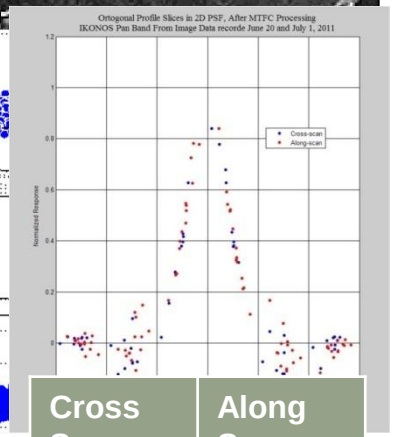


Cross Scan FWHM	Along Scan FWHM
1.323 Pixels	1.458 Pixels

IKONOS PSF Profile After MTFC Restoration
June 20 & July 1, 2011 Image Data







Cross Scan FWHM	Along Scan FWHM
0.947 Pixels	0.962 Pixels

Image Chain Processing May Influence Geometric Performance At Sub-Pixel Scale

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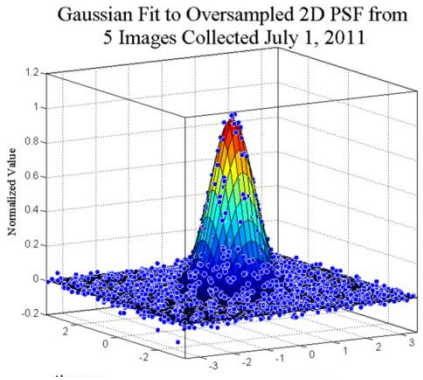
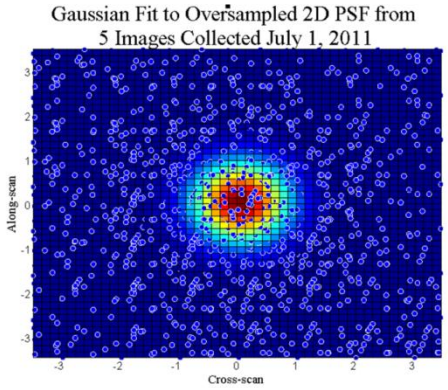
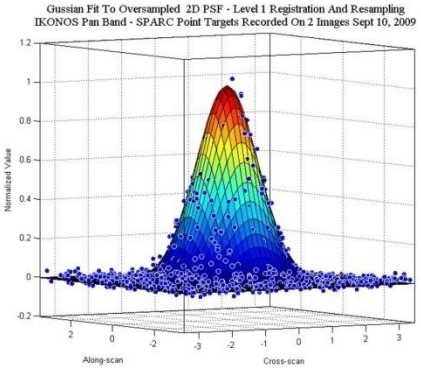
Level 0

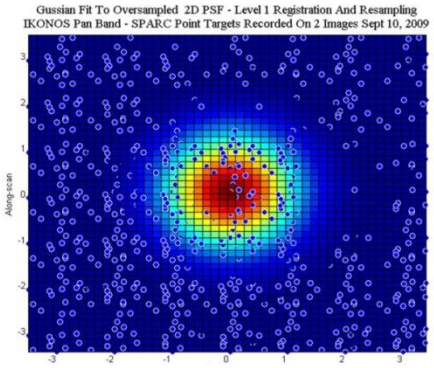


Rotate to top view

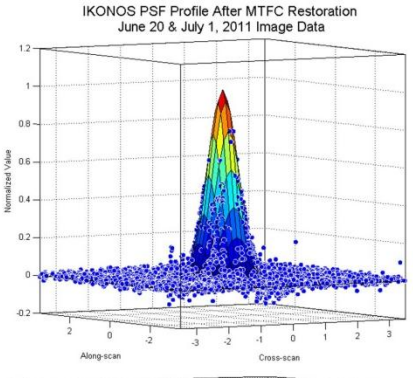


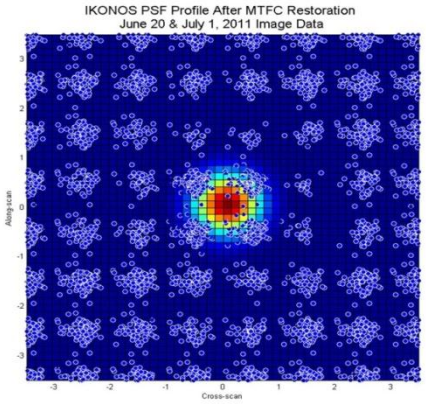
Level 1





Level 1 + MTFC





- Pixel centers (blue dots) relative to target centriods starts out as random in phasing but becomes less as processing proceeds in image chain
- It appears that resampling and restoration pushes target centers around (for MTFC, prominently to pixel corners.)
- Ground control points for geometric calibration are small targets and processing may decrease absolute geometric knowledge of higher level products (1/4 of a pixel?)
- SPARC targets supports quantitative assessment of such effects important to geometric error analysis

IKONOS MSI Analysis

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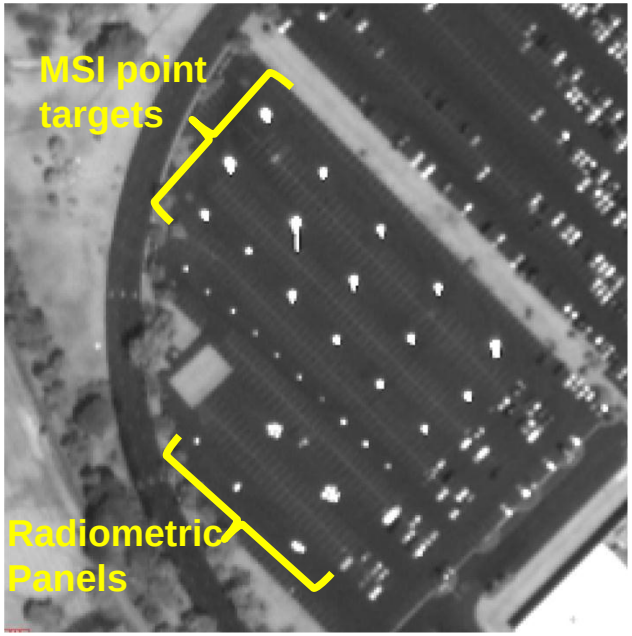
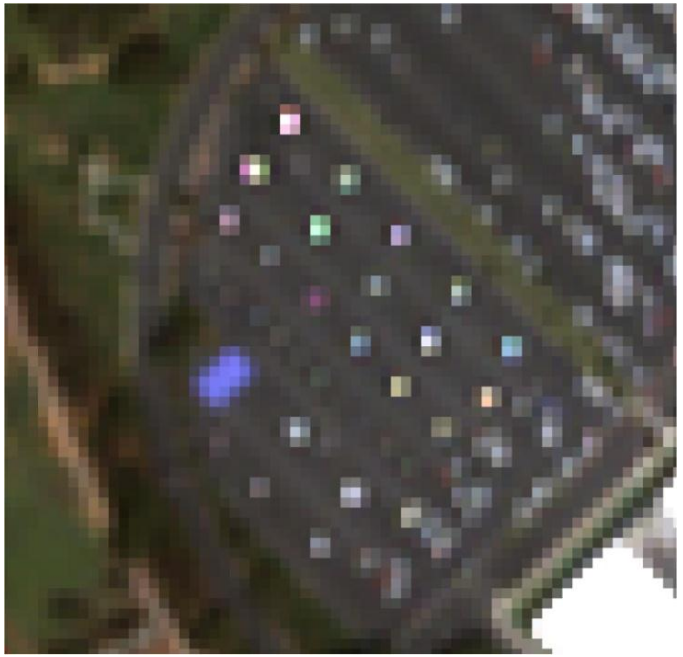
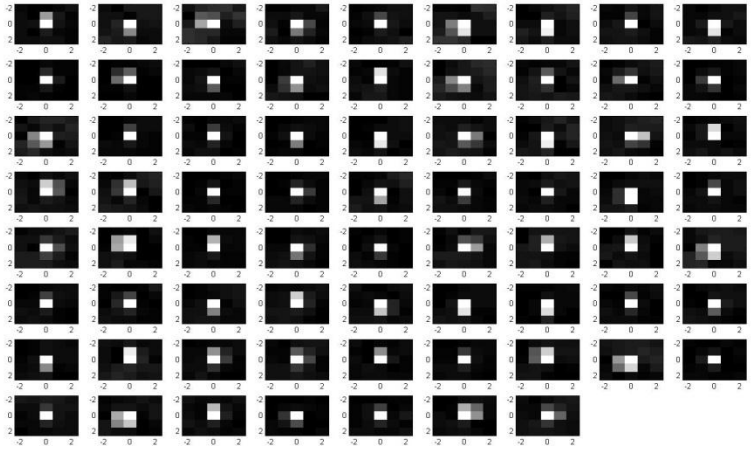


po_353731
Pan image



"true color" RGB Image po_353731 recorded July 31, 2009

In the pan image, MSI point targets are saturated



IKONOS red band SPARC point target sample for generating oversampled PSF (70 point targets selected from ten 2009 images)

IKONOS MSI Point Target Profiles Form All 2009 Level 0 Image Data

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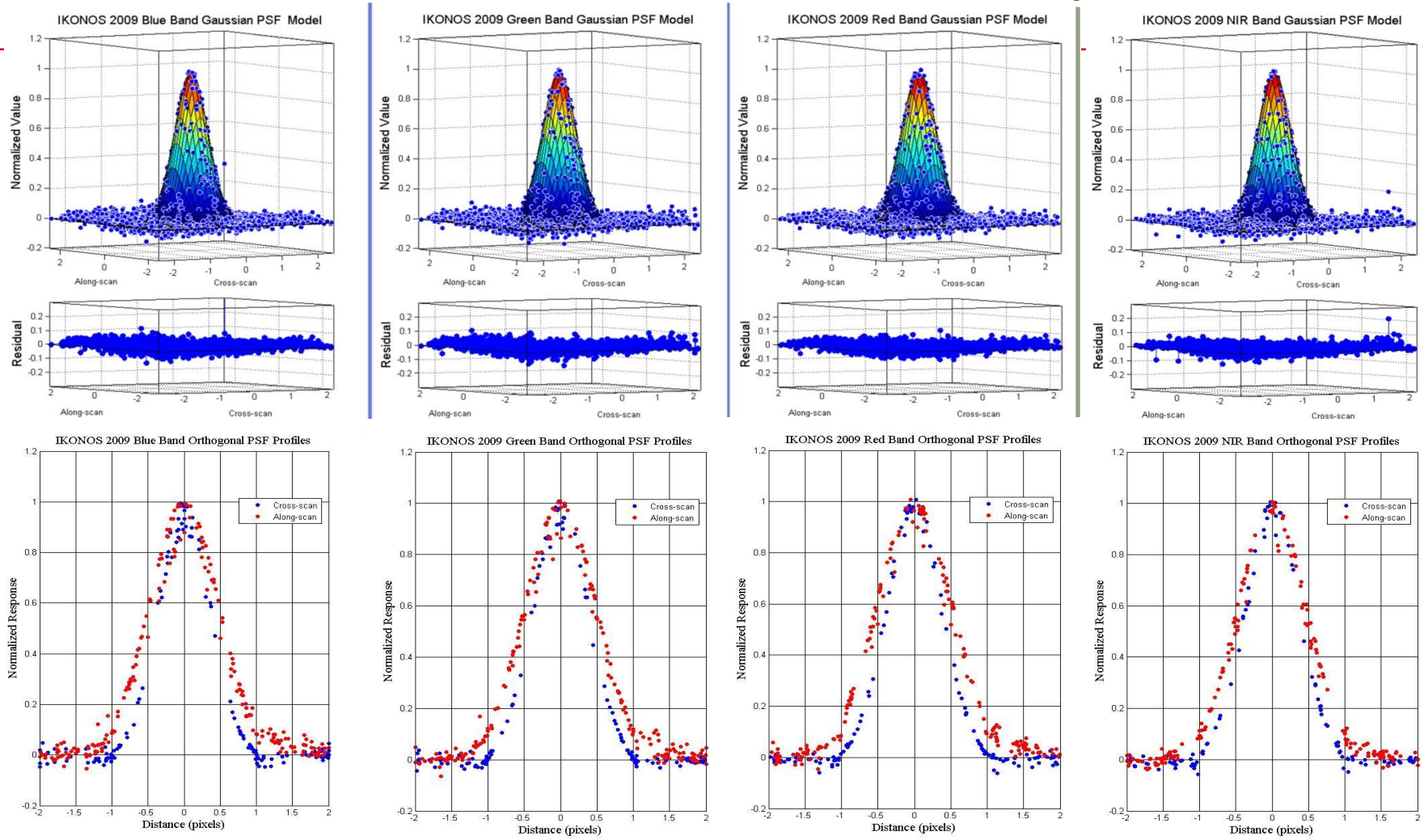

- MSI PSF profiles are very consistent between bands based on semiparametric Gaussian 2-D analysis.

System PSF Effects From Level 0 To Level 1 Processing (Resampling For Band-to-Band Registration)

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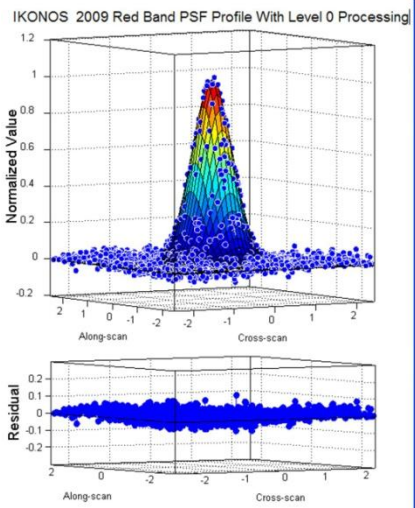
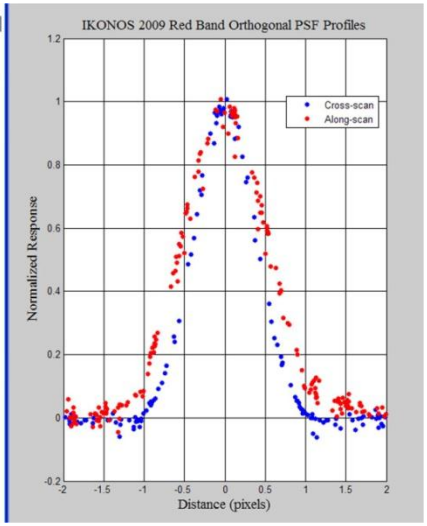
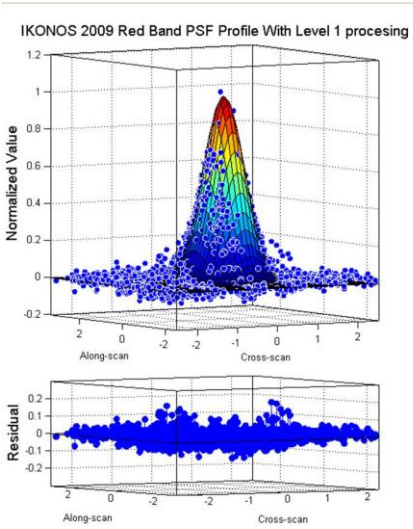
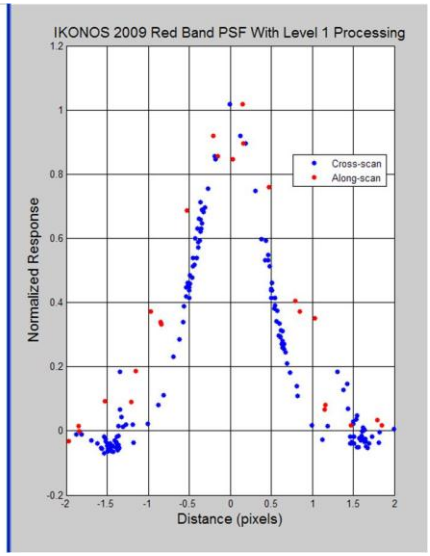
Level 0 Processing





Level 1 Processing





FWHM Metric Comparison

MSI Band	Level 0 FWHM (Pixels)	Level 1 FWHM (Pixels)
Blue Cross-S Along-S	 0.837 1.135	 0.898 1.341
Green Cross-S Along-S	 0.890 1.161	 0.893 1.401
Red Cross-S Along-S	 0.889 1.115	 0.943 1.494
NIR Cross-S Along-S	 0.894 1.215	 0.952 1.496
FWHM Precision Cross-S Along-S	 0.004 0.005	 0.004 0.009

Results:

Processing from level 0 to level 1 increases FWHM in MSI bands.

Increase is asymmetric.

Cross-scan ~6%

Along-scan ~20%

Noise is increased in the wings and some ringing is introduced

The loss of definition in the along-scan direction is the result of changes in relative pixel phasing (next slide).

FWHM is based on 2-D fit thus utilizing points along PSF diagonals.

Potential Movement Of Target Image Centriods By Resampling Process

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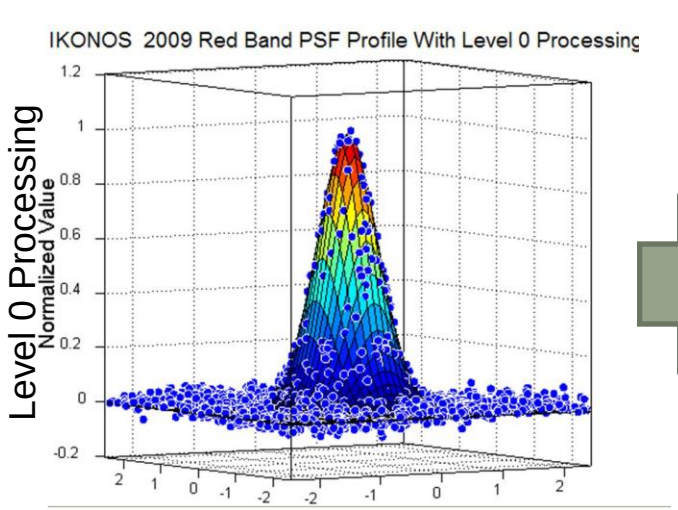

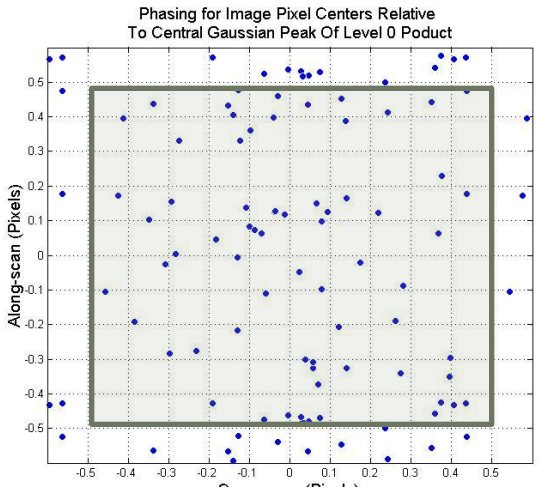

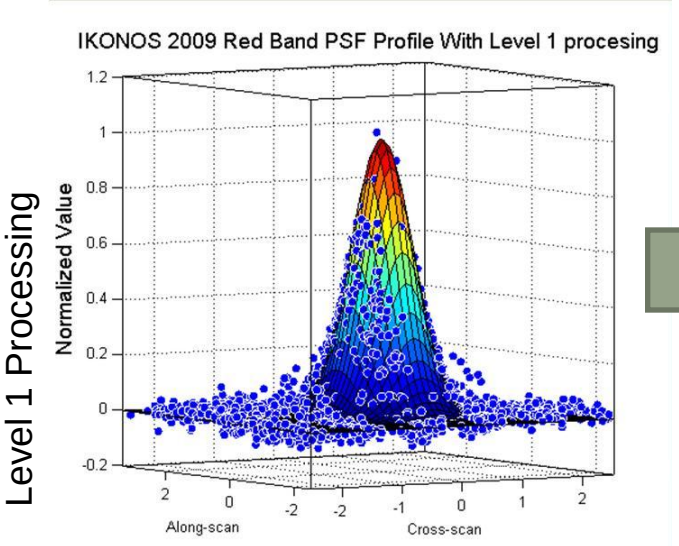

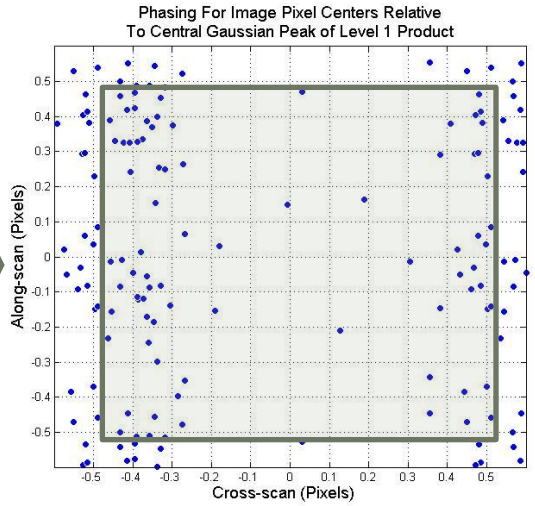

Shaded area is the central image pixel on the x,y plane of the oversample profile.

Pixel phasing of individual target images (blue dots) relative to the target centroid are random as expected in level 0 image.

After resampling to Level 1 (cubic convolution), nominal phasing appears to be bunched at edges in cross - scan direction indicating that individual point targets centroids may be moved at the subpixel level within the pixel grid by the resampling process.

PSF Effects From Level 0 To Level 1 + MTFC Processing

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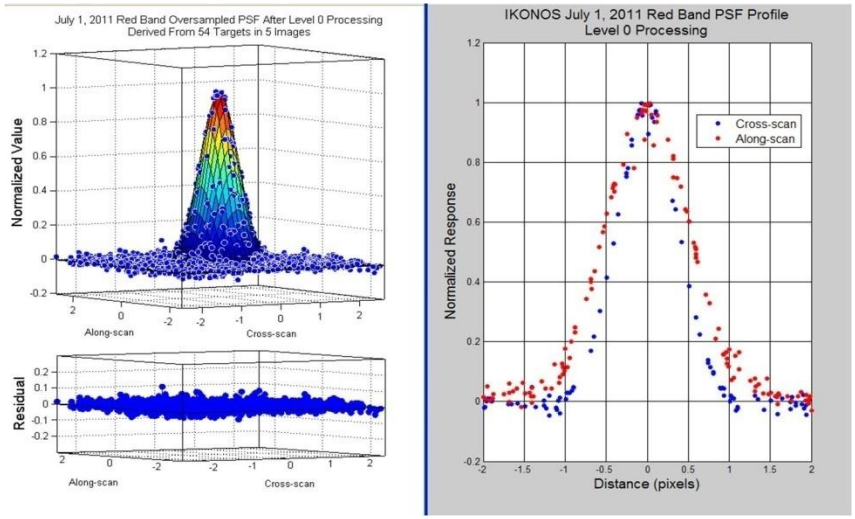
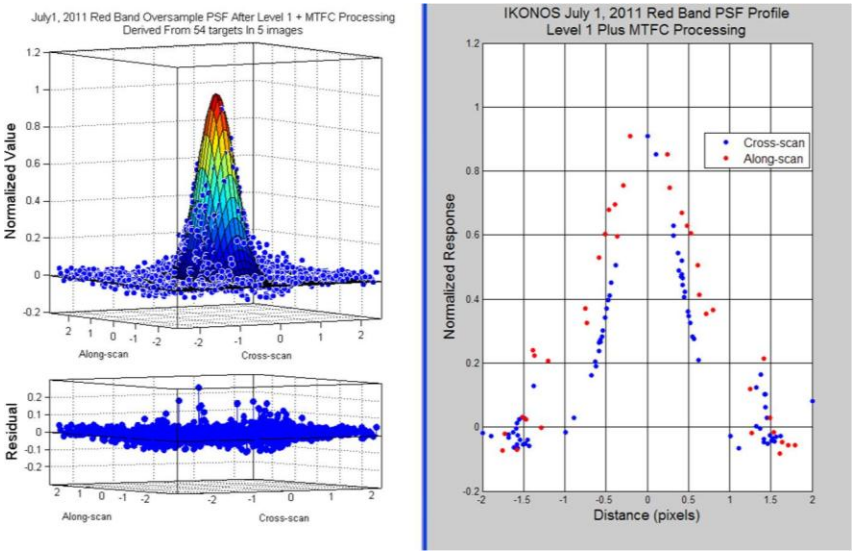
2011 IKONOS data was processed with MTFC on.

Level 0 Processing



Level 1 + MTFC Processing



IKONOS MSI Band	Level 0 FWHM (Pixels) 2009	Level 1 FWHM (Pixels)	Level 0 FWHM (Pixels) 2011	Level 1 + MTFC FWHM (Pixels) 2011
Blue Cross-S Along-S	0.837 1.135	0.898 1.341	0.878 1.177	0.867 1.336
Green Cross-S Along-S	0.890 1.161	0.893 1.401	0.848 1.155	0.879 1.332
Red Cross-S Along-S	0.889 1.115	0.943 1.494	0.883 1.113	0.855 1.200
NIR Cross-S Along-S	0.894 1.215	0.952 1.496	0.872 1.203	0.828 1.309
FWHM Precision Cross-S Along-S	0.004 0.005	0.004 0.009	0.004 0.005	0.006 0.012

- Results show no significant change in FWHM For IKONOS Level 0 data between 2009 and 2011 (gray columns).
- MTF Compensation shows improved sharpness in level 1 images (yellow columns). However, it does not restore along-scan blur back to level 0 sharpness.

MSI Point Source Rainbow Effect May Make Spectral Signatures Indeterminable For Sub-Pixel Targets

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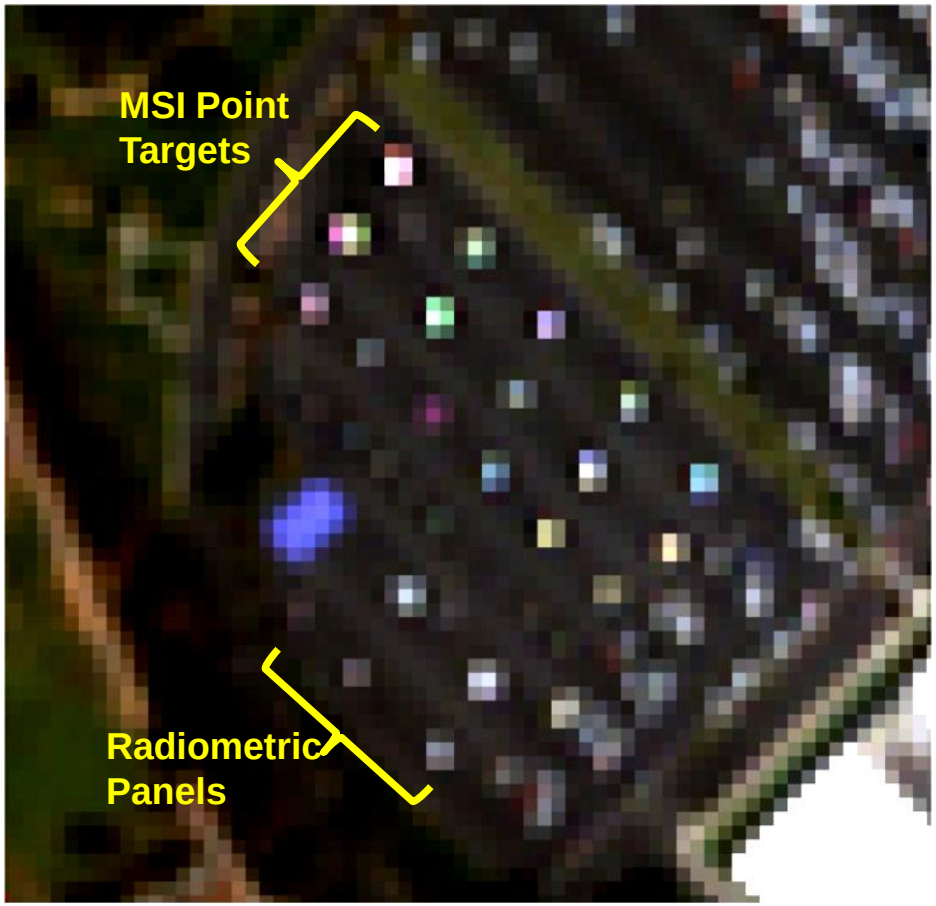

"true color" RGB Image po_353731 of SPARC targets recorded July 31, 2009

Mirror sources have a reflectance that are spectrally flat, so all should appear white.

Point targets, however, appear as a rainbow of colors! From purple, to red, to green, to blue.

In contrast, the radiometric mirror panels (~ 1 pixel or larger across) all appear white as expected.

Implies there is a sub-pixel target size at which the spectral signature may become indeterminable For MSI sensors **no mater how bright the target is!**

A rainbow effect is not seen in hyperspectral image data (all point targets appear white) indicating that source of the effect is in the time delay between bands in imaging the same ground point creating misregistration.

In a hyperspectral system there is not a time delay. A point on the ground is recorded in all bands simultaneously.

SPARC Temporal Radiometric Assessment For IKONOS 2009 Collections

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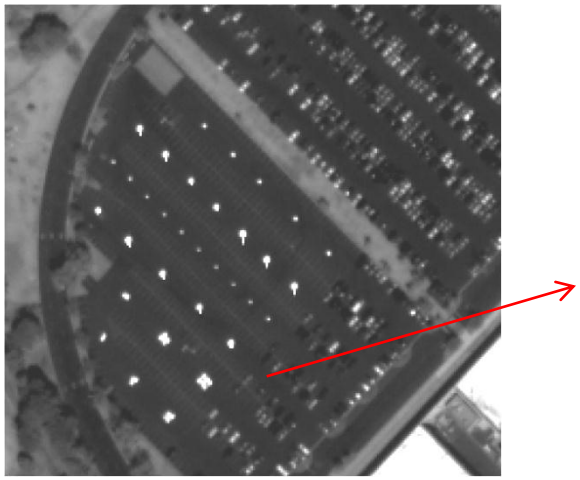
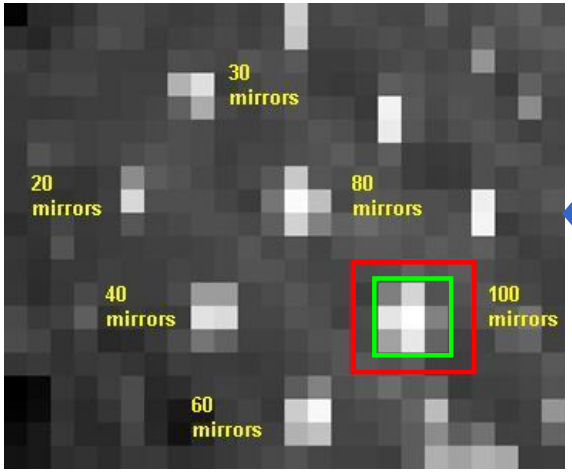
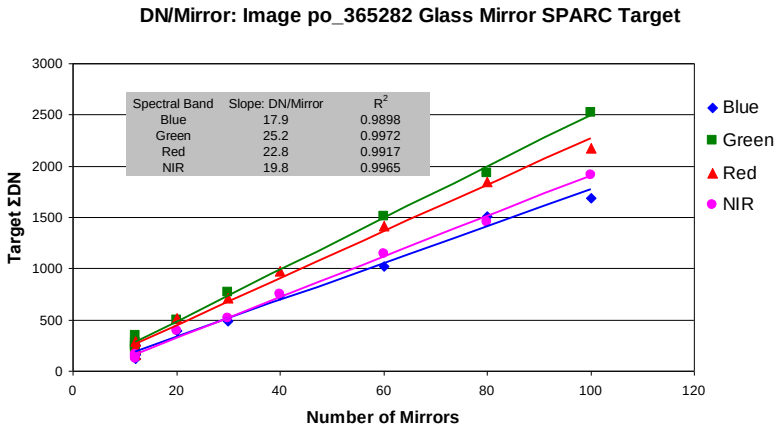
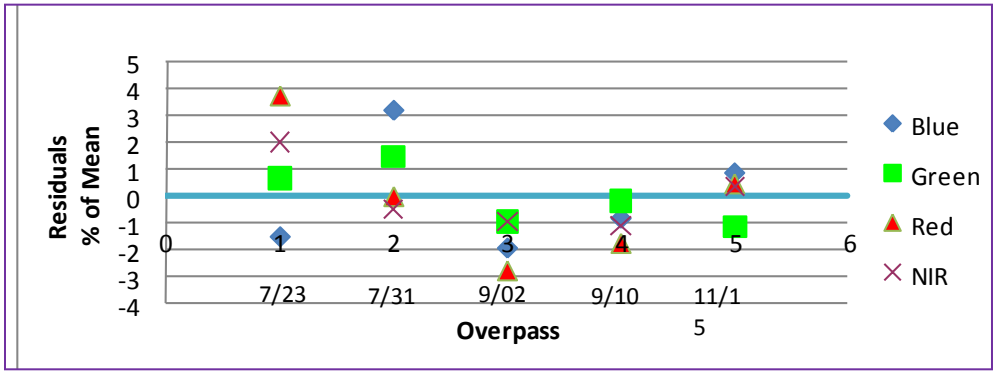




SPARC radiometric assessment is based on the integrated DN response to mirror panel targets where the radiance from target to target is determined by the number of mirrors in the target



The slope of the line of integrated DN/mirror results in the measure of the sensor gain.



Monitoring the radiometric gain over 5 months in 2009 showed a reproducibility in gain measurements of <2.5% and the Pan band to <3%

Summary

- Results demonstrate that the SPARC vicarious method is very effective in supporting spatial, spectral, radiometric and geometric performance assessments of imaging systems all from a single image collect. It applies from visible to MWIR imaging sensors.
- Imbedding SPARC point targets in image data provides the capability to generate a system PSF quantifying the FWHM, as an image quality metric, to better than +/-0.03 pixels.
- The stability and repeatability of the SPARC method can enhance the analysis of temporal variations, spatial shift variations, and variations along the processing chain of many sensor performance parameters if included as part of an Image Assessment System.