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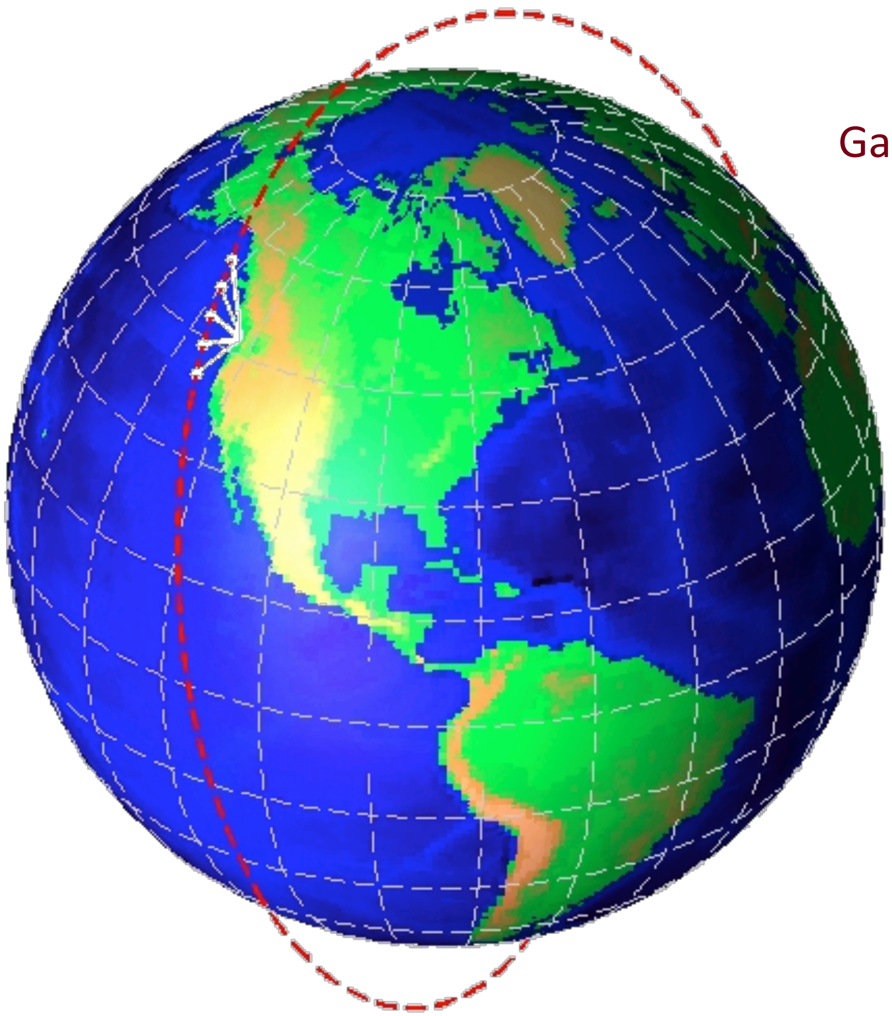

Staring Imaging Overview

Gazing at the Solar System: Capturing the Evolution of Dunes, Faults, Volcanoes and Ice from Space

KISS Workshop 2014

Joseph Green

Jet Propulsion Laboratory
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June 16, 2014

Canonical Remote Sensing Telescopes

- **Pushbroom Imagers**

  - Images scene with a linear array of pixels
    - Multiple rows operating in a TDI mode

  - Satellite ground track sweep forms 2nd dimension of image
    - Low Earth Orbit (400-1000 km)
    - Ground Track moves at 7 km/s

  - Implemented with Several Linear FPAs (panchromatic, mutltispectral)
    - MISR – 9 Different 4-band (VNIR) cameras at different viewing angles
    - LANDSAT – 7 Bands (VNIR, MWIR and TIR)
    - ASTER – 15 bands (VIS, SWIR and TIR)
    - WORLDVIEW 2 – 8 Bands (Pan + MSI: 400-1000nm)

Canonical Remote Sensing Telescopes

- **Design Space for Pushbroom Imagers**

  – *Very limited integration time* due to projected orbital velocity (7km/s)

  – *Systems are undersampled* to minimize line-of-sight blur and to benefit FOV
    - Q=1.00 for panchromatic imaging (1 sample per resolution element)
    - Q=0.25 for multispectral imaging (To maintain same integration time as Pan)
    - Q=2.00 would be critically sampled (2 samples per resolution element)

$$Q = \lambda * fn / Pixel\ Pitch$$

  – *Larger telescope diameter (and/or lower altitude)* is needed to make up resolution loss due to low-Q

  – Optimized for world mapping applications with area-rate-coverage being a driver
    - Tend to collect *single (to few) observations* of a target in a pass
    - May take many orbits for a subsequent revisit

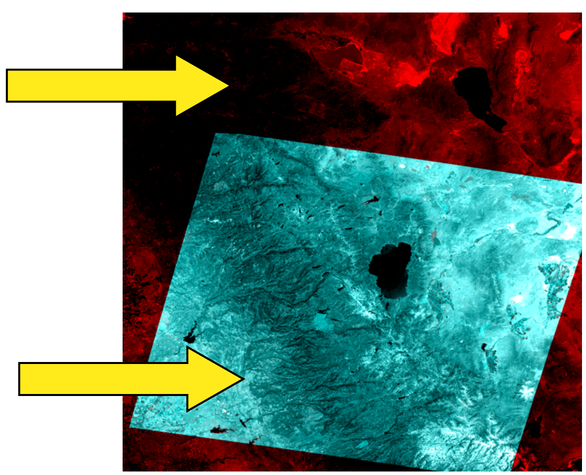
Key Problem in *Classic* Remote Sensing

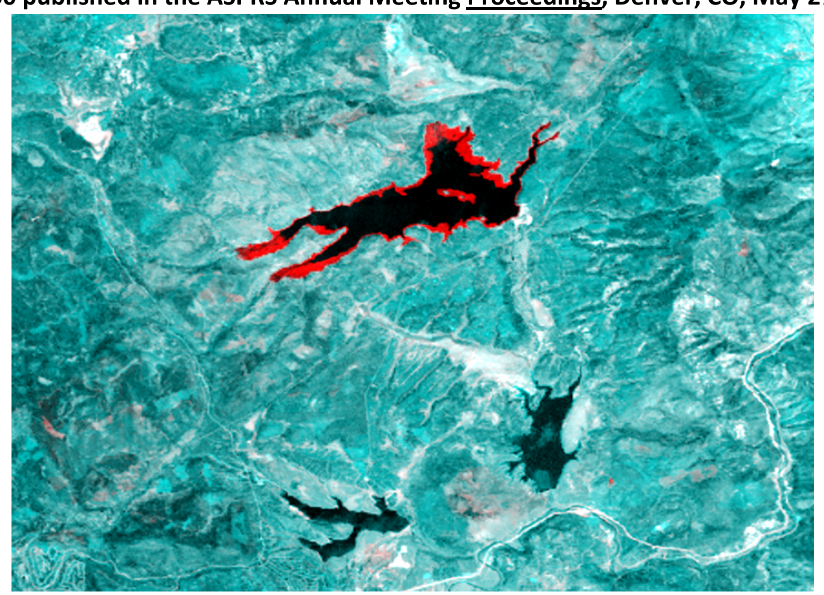
- **Orthorectification**
  - High Precision Orthorectification is required to related images between difference observation times and different sensors
  - Problem difficulty driven by disparity in viewing geometry against high relief targets
  - Further complexity from changes in scene contents between revisists
  - When done well, it enables mosaicing, change detection and data fusion processes

Example Courtesy of : Nevin Bryant, JPL

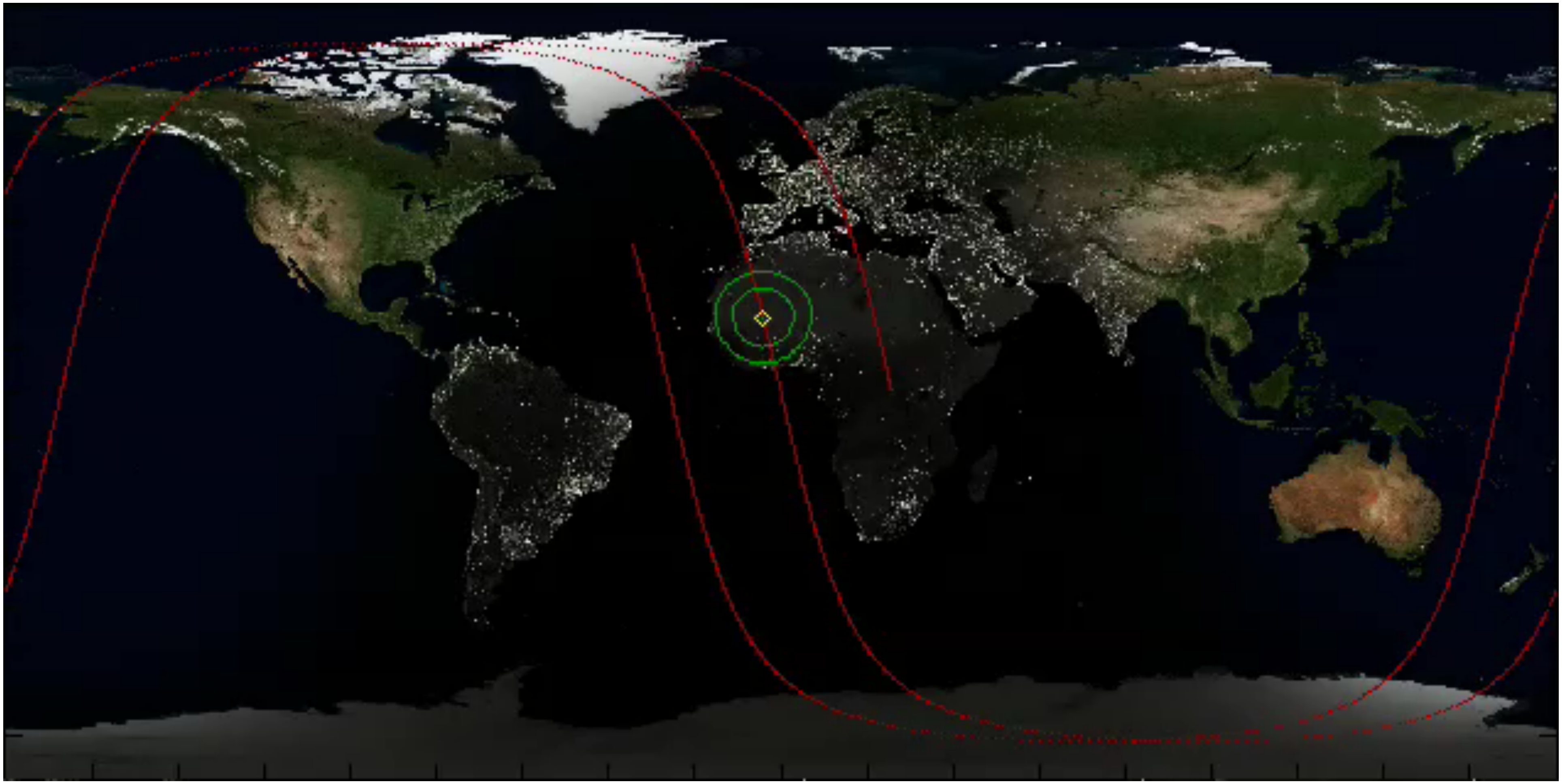
AFIDS (Automatic Fusion of Image Data System)

Nevin A. Bryant, Thomas L. Logan, Albert L. Zobrist, "Precision Automatic Co-Registration Procedures for Spacecraft Sensors", Paper 6550 published in the ASPRS Annual Meeting <u>Proceedings</u>, Denver, CO, May 27, 2004





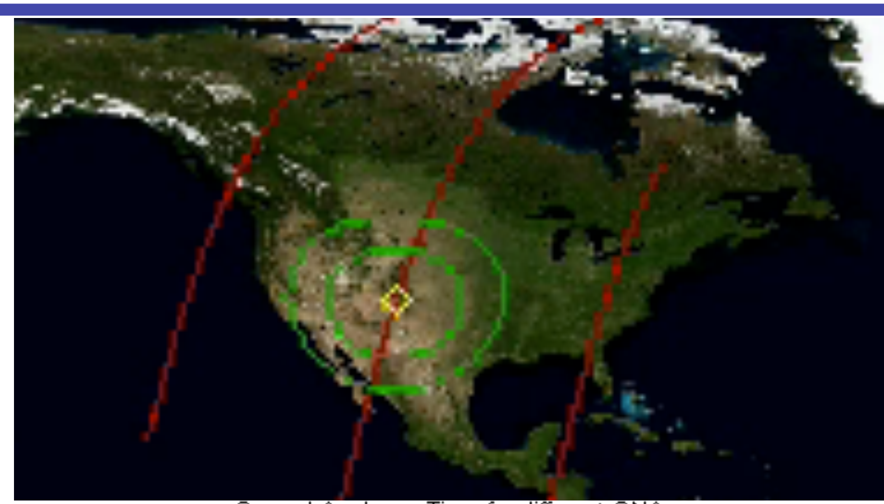
LEO Orbit Example

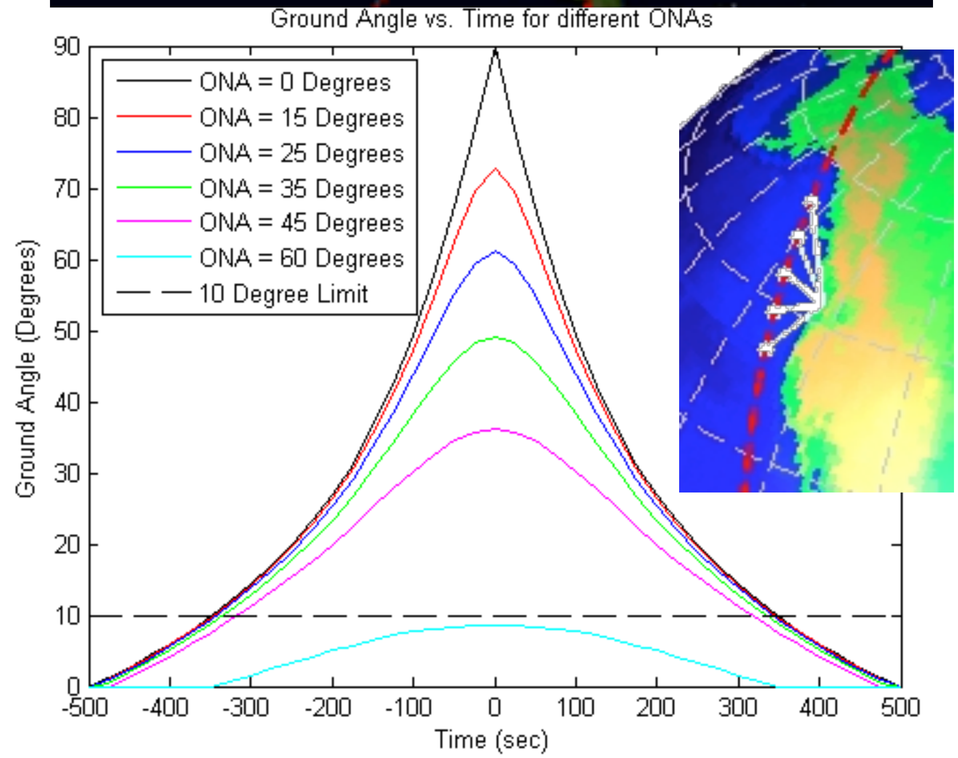


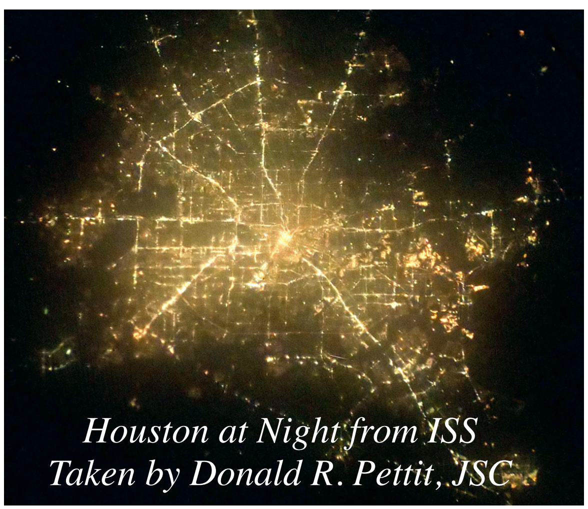
Contours shown for 30 and 45 degree Target Elevation Angles from 900km

Staring Imagers

- **Fixed-Point-Stare Imaging**
  - Vehicle rotates to maintain a fixed aim point to the ROI during pass
    - Cancels out principal ground motion
  - Images are acquired with a a 2-D Focal Plane Array
  - Examples
    - Skybox!!
    - Weather Satellites
    - Cameras on the ISS







Houston at Night from ISS
Taken by Donald R. Pettit, JSC

Staring Imagers

Design Space for Staring Imagers

- *Long Integration times* possible (up to 1000msec) before residual orbital blur is an issue
  - Primary ground track motion is canceled
  - Secondary dynamic effects of from scene scale and rotation are slow
- *System can be well-sampled* (Q = 1.5-2.0) while maintaining a good imaging SNR
  - *Both Pan and MSI modes can be well sampled*
  - *Integration time is free to be a variable*
  - *Not constrained to operate at high sun-elevation angles*
- *Telescope diameter (and altitude)* can be co-optimized with relaxed Q
  - Leads to smaller telescopes flying higher to achieve the same resolution
- Optimized for persistence and continuous angle diversity
  - Collections can have 100's to 1000's of frames

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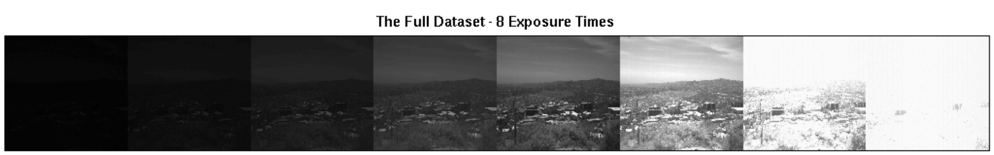
Fixed-Point-Staring Applications

- **Enables New Processing Capabilities**
  - Automatic change detection, tracking and flow-measurements
  - 3D Visualization (e.g. Anaglyphs – but with **highly tunable disparity**)
  - 3D Reconstruction
  - Sun/Viewing Angle induced effects (e.g. BRDF estimation)
  - Multiframe super-resolution
  - High Dynamic Range Imaging
    - Exploit range of integration times to overcome finite FPA Dynamic Range

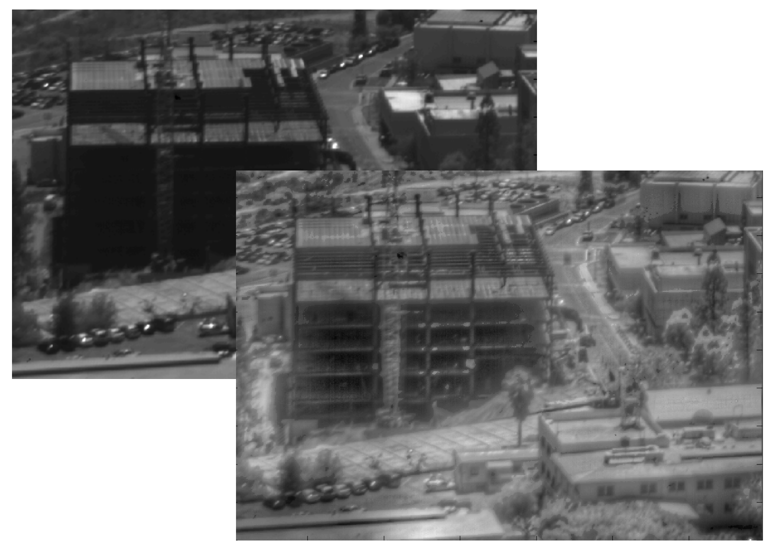
- Automation of pass-ensemble data is straight forward

Example: High Dynamic Range Imaging

HDRI Study Lead: Sidd Bikannavar, JPL



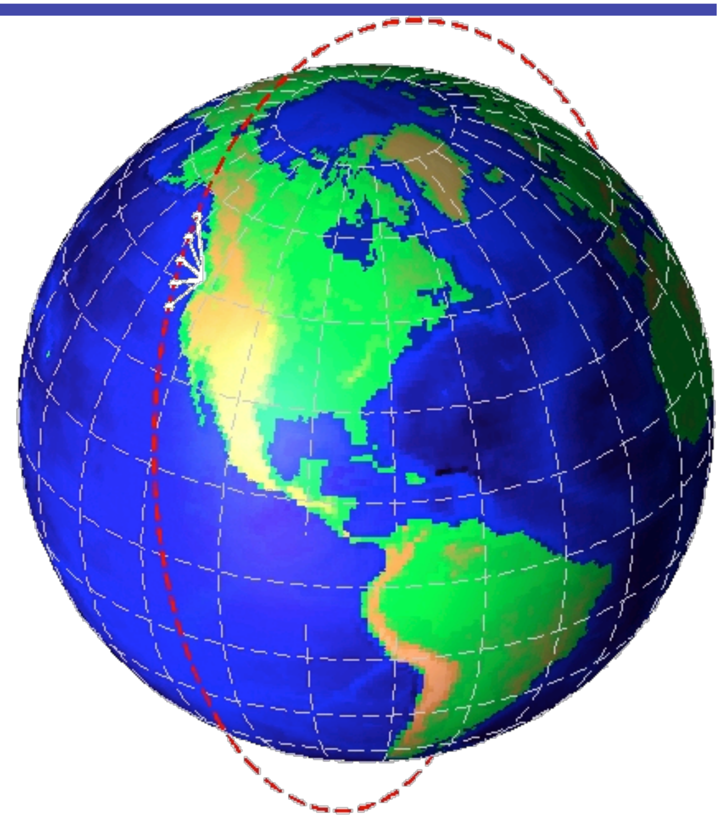
.94 ms	1.95 ms	3.97 ms	7.95 ms	15.97 ms	31.94 ms	63.89ms	127.3 ms



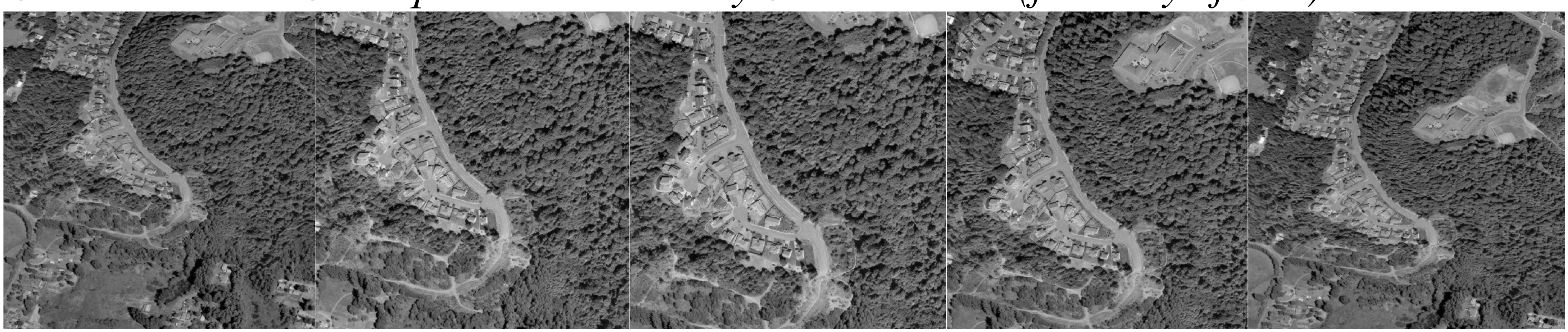
•Eight 12-bit exposures synthesize 21-bit image
•Gradient-domain tonal mapping methods used to display image

Example Scenario

- Simulation of starting imaging from low Earth orbit
  - Ground target (47.0132° N, 122.9241° W)
  - Satellite altitude = 900 km
- Imaging system
  - Panchromatic channel
  - Aperture diameter = 1 m
  - Ground sample distance = 0.5 m
  - Time between images = 1 min
  - Comparable to high-resolution commercial imager (WorldView-1)



Simulations and Subsequent 3D Results by Sam Thurman (formerly of JPL)



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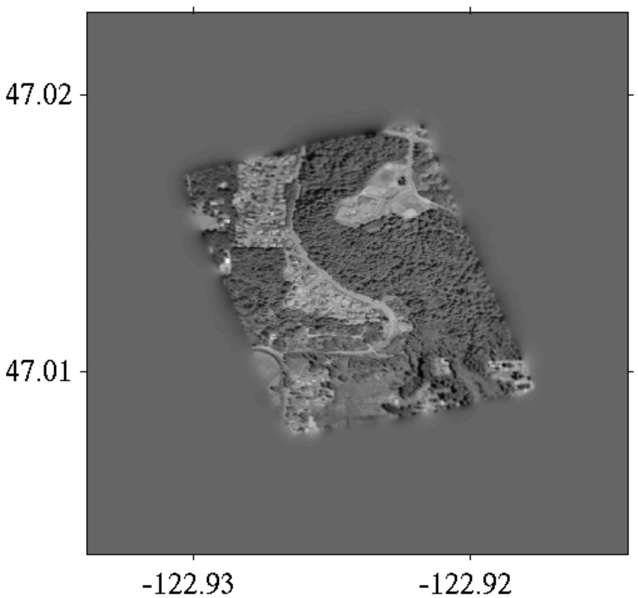
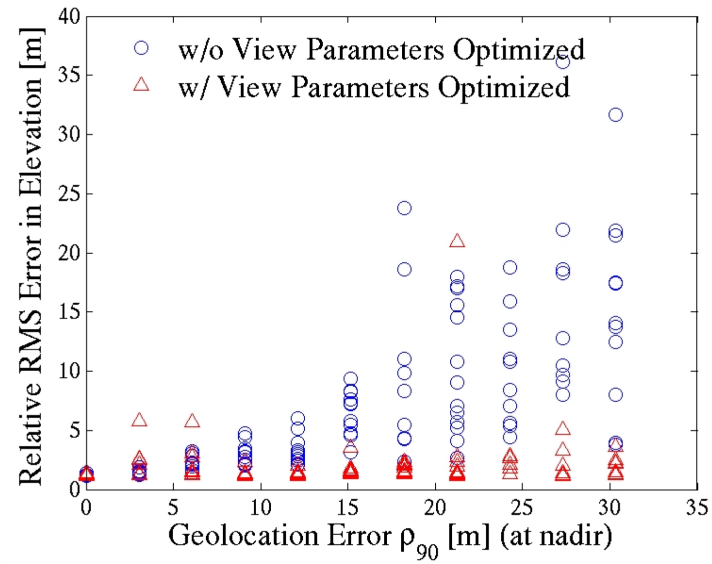
Joint Estimation of Scene and Pose

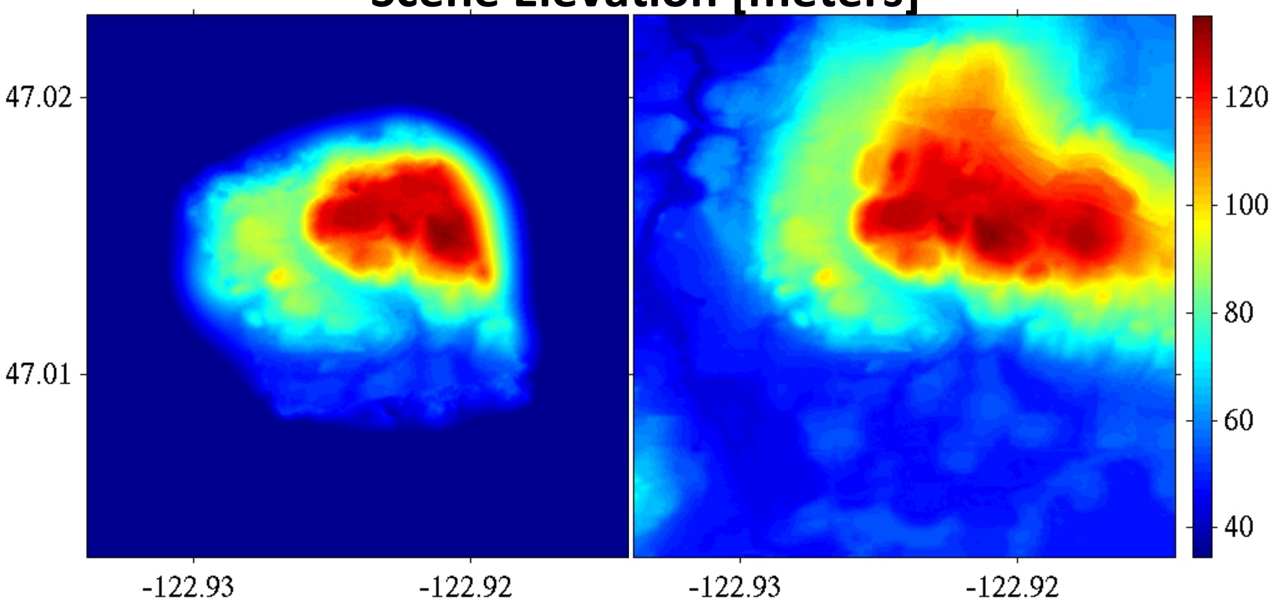


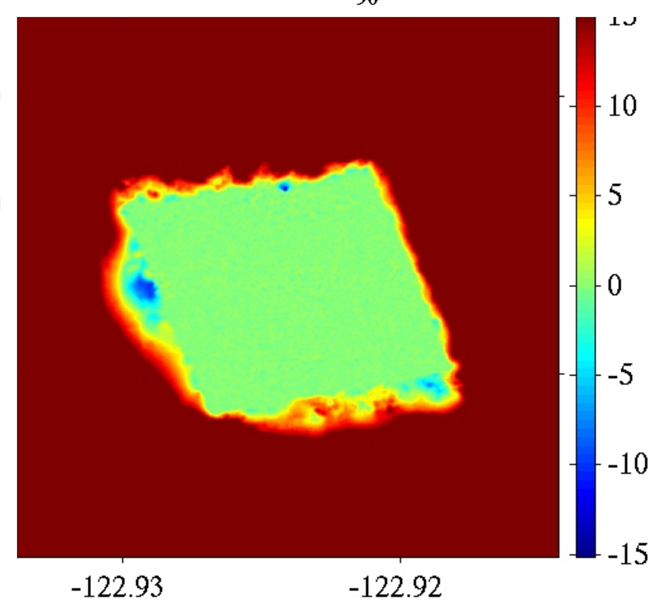
Scene Radiance

Satellite Ephemeris



Scene Elevation [meters]





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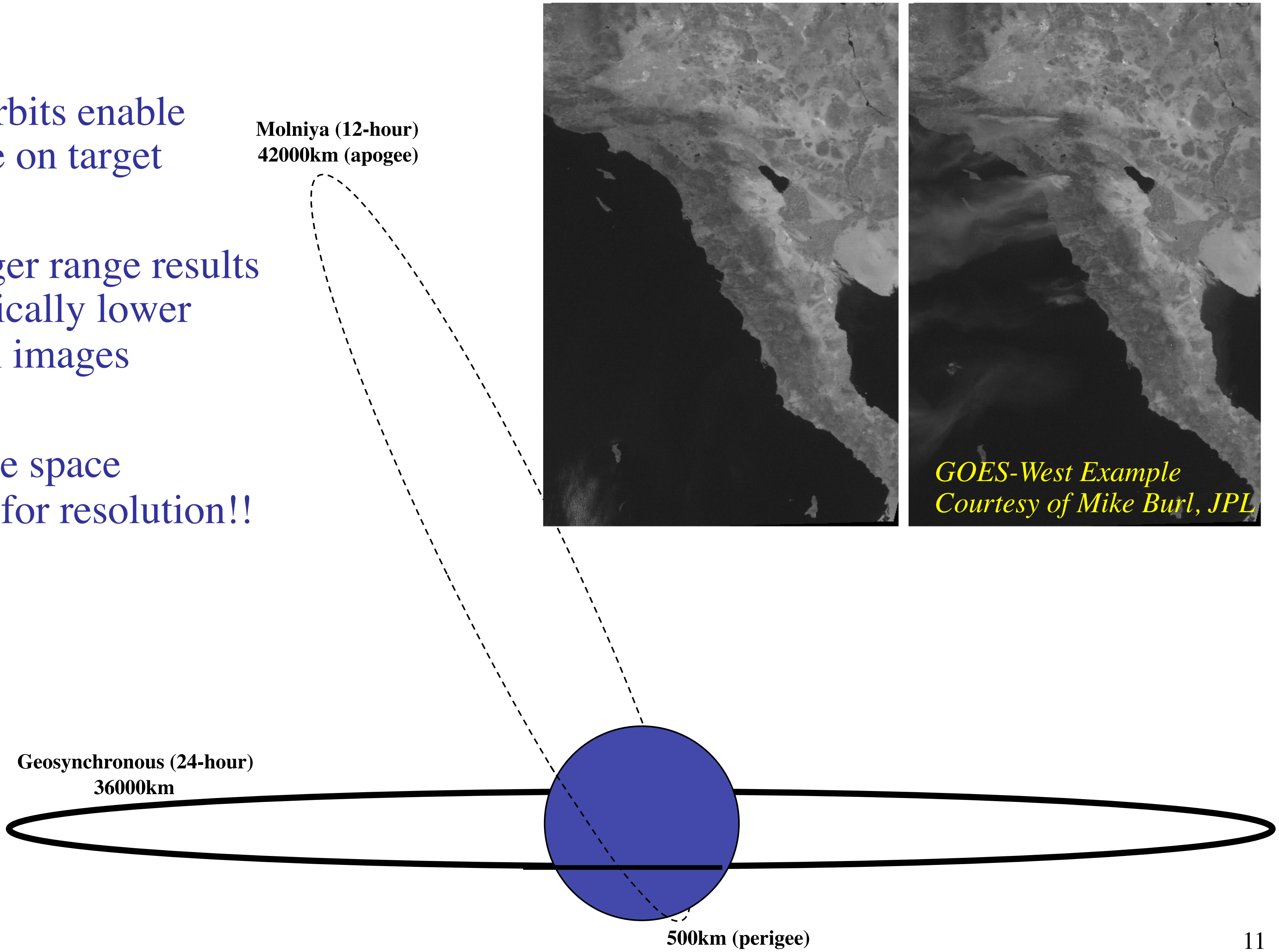
Non-LEO Orbits

- Higher Orbits enable more time on target
- ~50x longer range results in dramatically lower resolution images
- Need large space telescope for resolution!!



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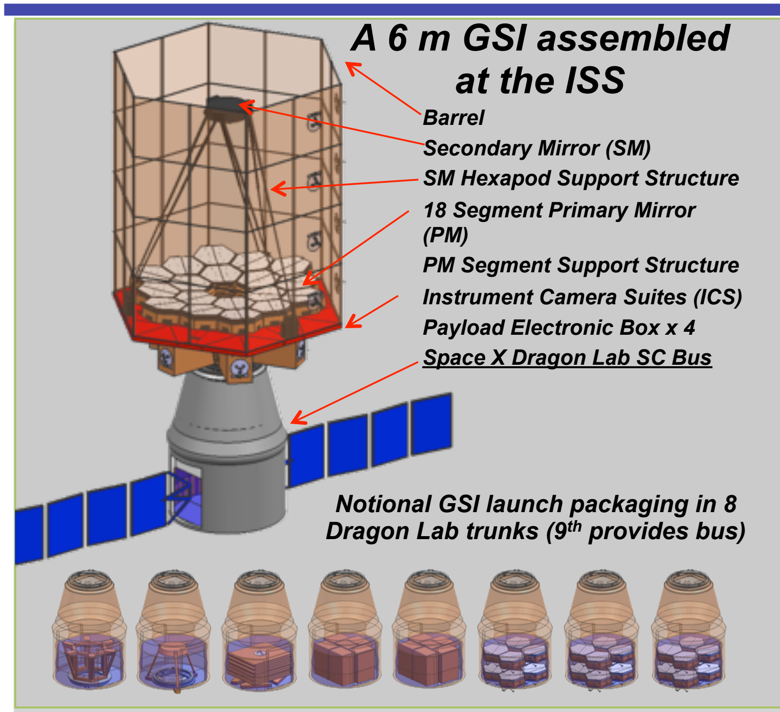
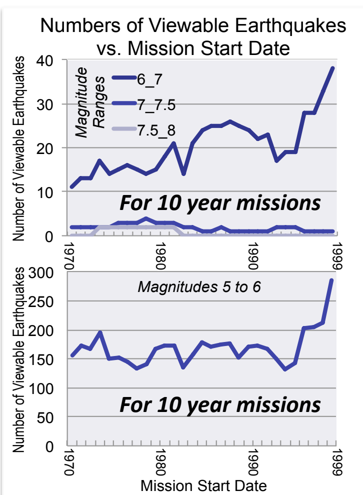
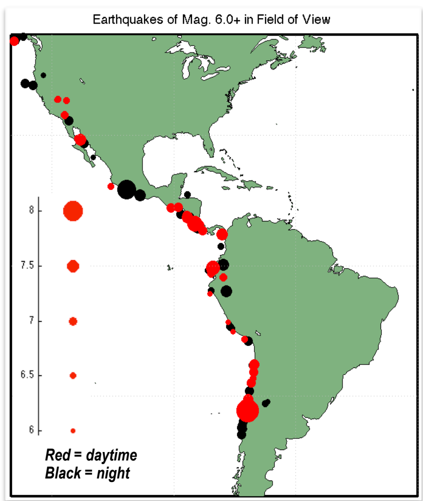
GEO Seismic Imager (Previous KISS Study)

PI: David Redding, JPL

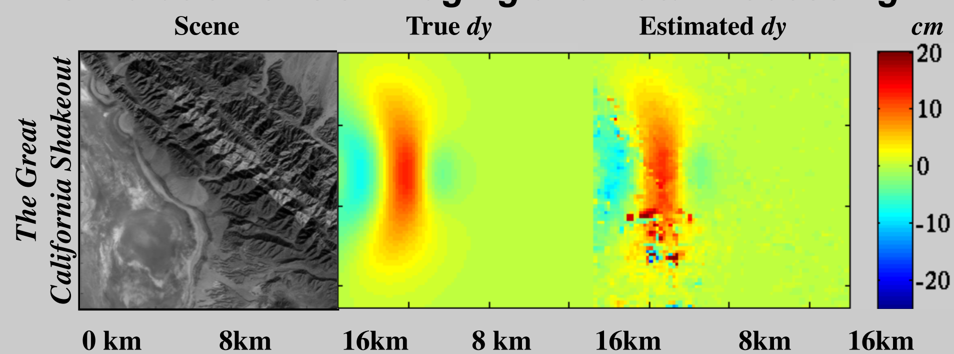


- An ISS-assembled 6m telescope for imaging large earthquakes
- Telescope is pointed in response to events detected on the ground
- Stationed in GEO over the Pacific coast of the Americas, GSI would be in position to observe 1 to 4 M_v > 6 earthquakes per year
- GSI data would revolutionize earthquake seismology





Simulation of GSI Imaging and Data Processing



- *Image frame rate is 2Hz, with 20 min of rolling data storage*
- *Resolution as good as 1 cm on a 200m grid, over a field of view up to 300 km by 300 km*
- *Surface deformation movies reveal rupture propagation, enabling correlation of ground motion to subsurface geology*
- *GSI data could ultimately lead to effective warning capabilities and to improved public management of earthquake risk*

Remarks

- **Staring Imagers provide a unique operational and design space for telescopes**
  - Long integration times
  - Large ensemble SNR per pass
  - High level of of continuous angular diversity
  - High-Q maximizes 'processibility' of data

- **Must be matched to the right science application**
  - Target focused (not world mapping centric)

Nothing in this world can take the place of persistence. Talent will not: nothing is more common than unsuccessful men with talent. Genius will not; unrewarded genius is almost a proverb. Education will not: the world is full of educated derelicts. Persistence and determination alone are omnipotent.

- Calvin Coolidge

Backup

Pushbroom vs Staring

	Pushbroom Imaging	Staring Imaging
Integration Time	0.1 - 3 msec (TDI)	Up to 1000 msecs
Orbital Constraints	Sun-synchronous (10AM-2PM)	Highly relaxed
Focal Plane Technology	1-D Linear Arrays (TDI)	2-D Focal Plane Arrays
Multispectral Implementation	Multiple Linear Arrays w/filters	Filter Wheel, Dichroics, Bayer-Filter…
Imaging Q	0.25 - 1.0+ (Optimized for Int Time)	Up to 2.0 (Optimized for Resolution)
Aperture Diameter	Large to overcome low-Q	Significantly Smaller (Matched to Q)
Frames per Pass	1 to 10's	100's to 1000's
Field of View	Large (Array + Sweep Limited)	Small (FPA limited)
Targets per Orbit	Many 10's	2 - 10
Persistence on Target	very limited	4-10 minutes
Data Quality Issues	2D image not rigid (sweep/LOS errors) Aliasing in Imagery from low-Q	Time-separation between bands 'Grain' in images from high-Q