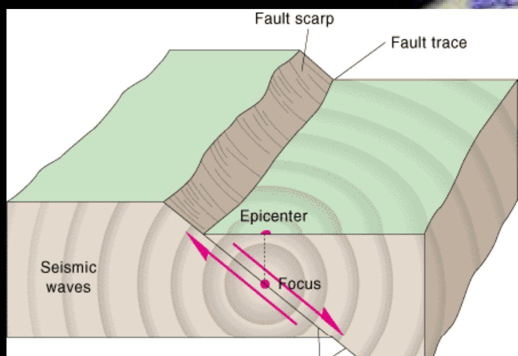
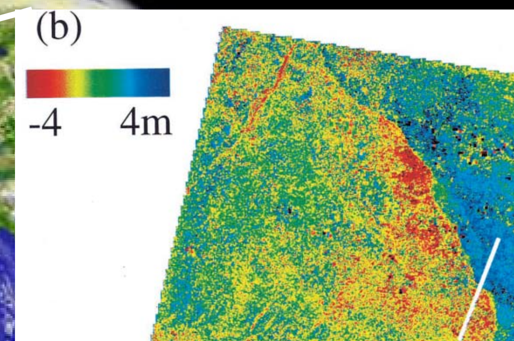
Geostationary Optics of Geophysical Deformations



Surface Waves
Within 10 years?



Landers image
10 years old

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Tectonics Observatory, Wednesday, March 29, 2010

The Study Benefited from Inputs and Fruitful Discussions with

J.-P. Ampuero (Caltech)

J.-P. Avouac (Caltech)

S. Leprince (Caltech)

S.Nadh Somala (Caltech)

N. Lapusta (Caltech)

A. Rosakis (Caltech)

P. Wennberg (Caltech)

.

Rodolphe Marion (CEA-France, radiative transfert)

Serge Primet (REOSC-France, space telescope)

E.W. Bogaard (DALSA, CCD)

Coherent inc. (Laser)

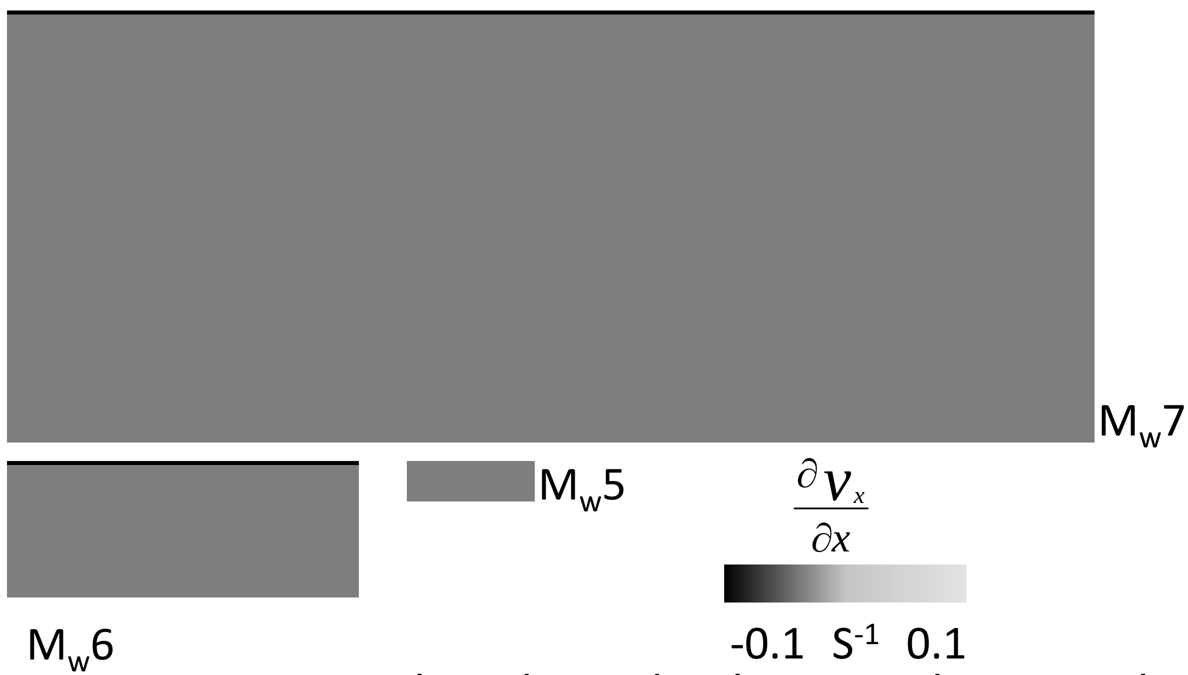
Routes AstroEngineering inc.(Data Storage Units)

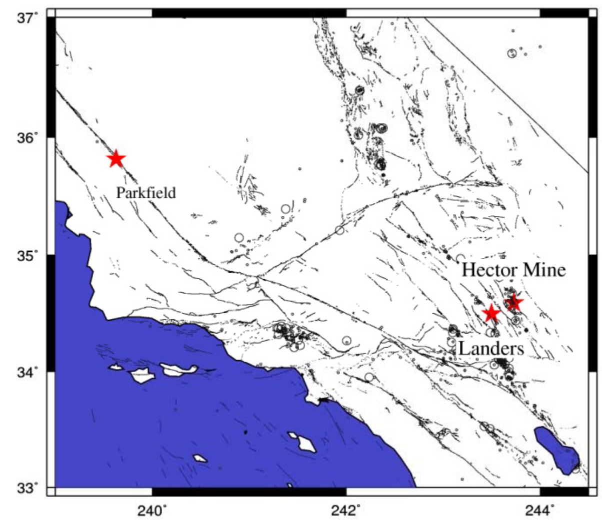
Steven Hosford (Cnes)

Preliminary Requirements

Monitoring Glacier, Landslide, Seism in the range]1Hz-1 day[

Topic		Requirements	Comments
Field of view		# 550X250 km	Main Shocks, California
Sampling	Spatial	# 100 m	Ok for Mw > 5.5 Poor for Mw < 5.5 ?
	Temporal	# 1 Hz	
Accuracy		# 1cm.s^{-1}	That of sparse seismometers





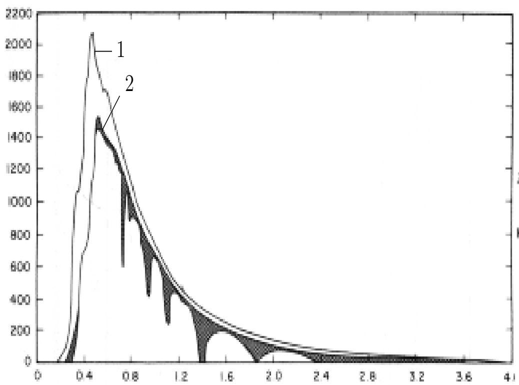
Requirements may be adjusted to limits and potential of dense video-imagery

Optical systems

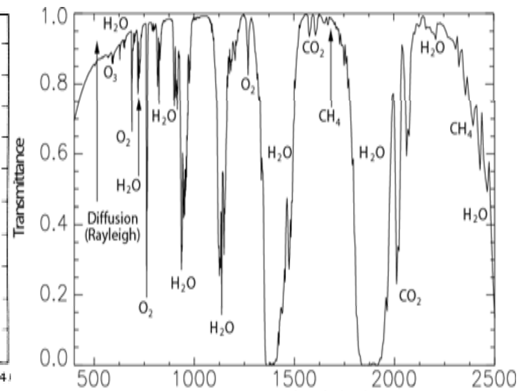
Instrument	Comments	"TRL"
Drones	**Field Of View**	
Airplanes	**FOV, temporal sampling**	?
Balloons	**Stability, FOV**	
Earth Orbiter *Low, Medium*	**Temporal Sampling** **FOV # 1000km : Huge Constellations**	
Geostationary	Instrumentation?	
➢ *{Radar*	**Paul Rosen's talk about GESS Geosynch Radar Study***}*	
➢ *Optics*	Passive Imagery Limited to Clear Sky, Daylight	**?**

A Large Opportunist Geostationary Optical Seismometer?
Interesting Risk=breakthrough(Societal, Science, Industry)

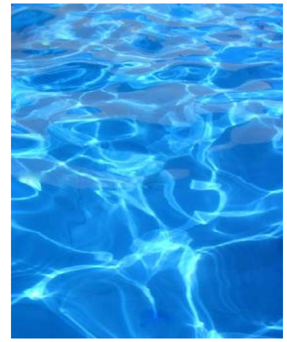
Photometry Essentials



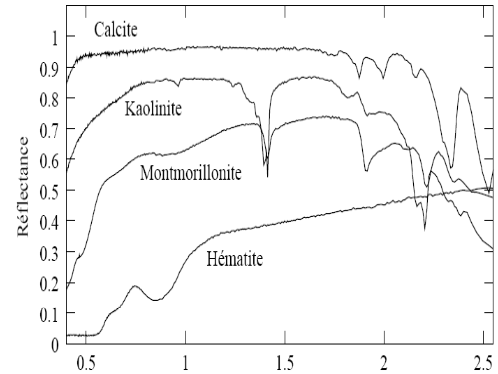
Wavelength (µm)
Sun Radiance



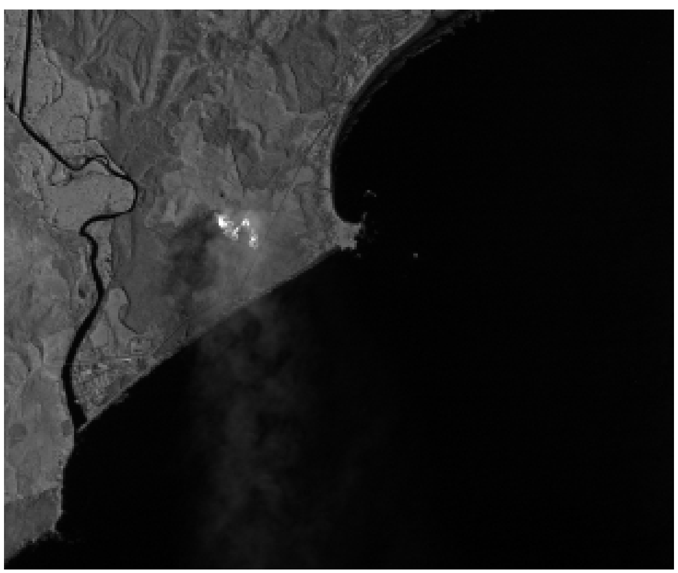
Wavelength (µm)
Atmosphere Transmittance



Atmospheric Turbulence



Wavelength (µm)
Ground Reflectance

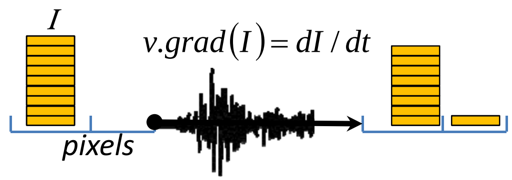
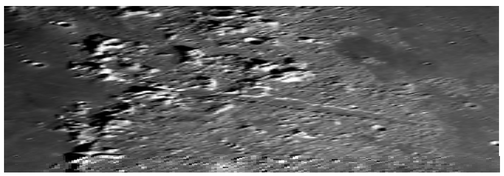
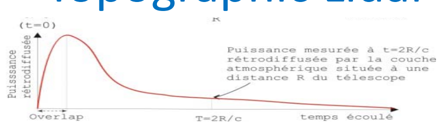
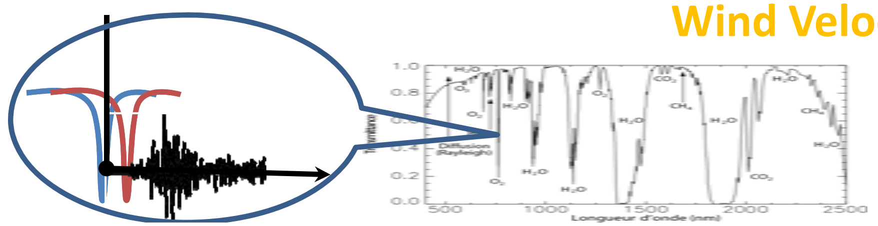


$$I = \frac{\pi L_{sun}\cos(\theta_{sun})}{2\left(\frac{focal}{\emptyset_{telescope}}\right)^{2}} . T_{optics} T_{atm}^{2} . \frac{\rho}{1 - S\rho} . \Delta t . S_{detector} . \rho_{quantic}$$

L:radiance, ρ : reflectance, S : atmosphere spherical reflectance

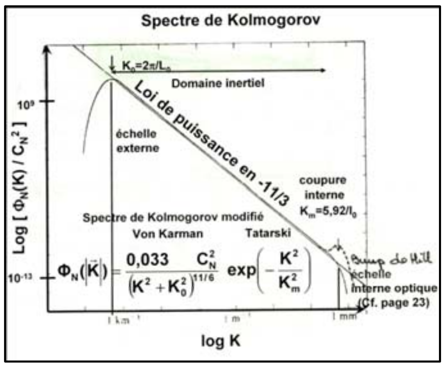
Movie [0.4-2.5µm]

Optical Consequences of Earthquakes

	Signals	Keywords	Geostationary Issues
Passive	Horizontal Deformation 	Optical flow, Correlation, sub-pixel	➢Telescope size (Resolution) ➢Detection ➢Data flow ➢1/100 pixel
Passive	Radiance, Slope Variation  $\Delta z \approx \frac{\Delta I . pixel}{I . \tan\theta}$	Photoclinometry	➢Telescope size (Photometry) ➢$\Delta I/I = 2.10^{-5}$(1cm) ➢Detection ➢Stability
Active	Topographic Lidar 	Differential topography	➢Laser Energy! ➢#100 photons=5cm
Active	Doppler Shift (atmosphere) 	**Rayleigh=>Acoustic Wind Velocimeters**	➢Small Doppler ➢10 $cm.s^{-1}$ ➢Complex Signal

Natural Light Fluctuations [10Hz-1Hz]

Sun		Poisson	$\frac{\sigma_I}{I} = \frac{1}{\sqrt{I}}$
		Incidence	$\frac{dI}{I} \leq 10^{-5}.s^{-1}$
Atmosphere	Steering (geometry)	*Kolmogorov*	Shift < few centimeters<6cm
	Dancing (geometry)	*Kolmogorov*	Blur < few centimeters<6cm
	Scintillation (photometry)	*Rytov*	$\frac{\sigma_I}{I} = \frac{[2-3]}{\sqrt{I}}$
Ground	Bidirectional Reflectance Distribution Function	*Natural, 1-100m*	$\frac{dI}{I} \approx 10^{-6}$
		Urban	TBD (high level), lightening, damages, etc.
		Vegetation	TBD
		Shacken ground	TBD



Measurements by Correlation & Optical Flow

Telescope	Nb_pixels (diffraction)	Data rate (read out)	Data Memory (100s)	Accuracy (rms)
4m	10 billions	Several 10Gbs	7 Terabits	6cm
10m	40 billions		42Terabits	2cm
JWST (6.5m) Herschel (3.5m)	*LSST (4x3.2 Gpix)*	*0.5Gbs (single DSU)*	*15 Terabits*	

1/100 of the pixel size.
SNR 1000 (reflectance 0.15, back-illuminated CCD) : 0.03 s per frame for ϕ 4m.
Stability is an issue for data management and not for accuracy.

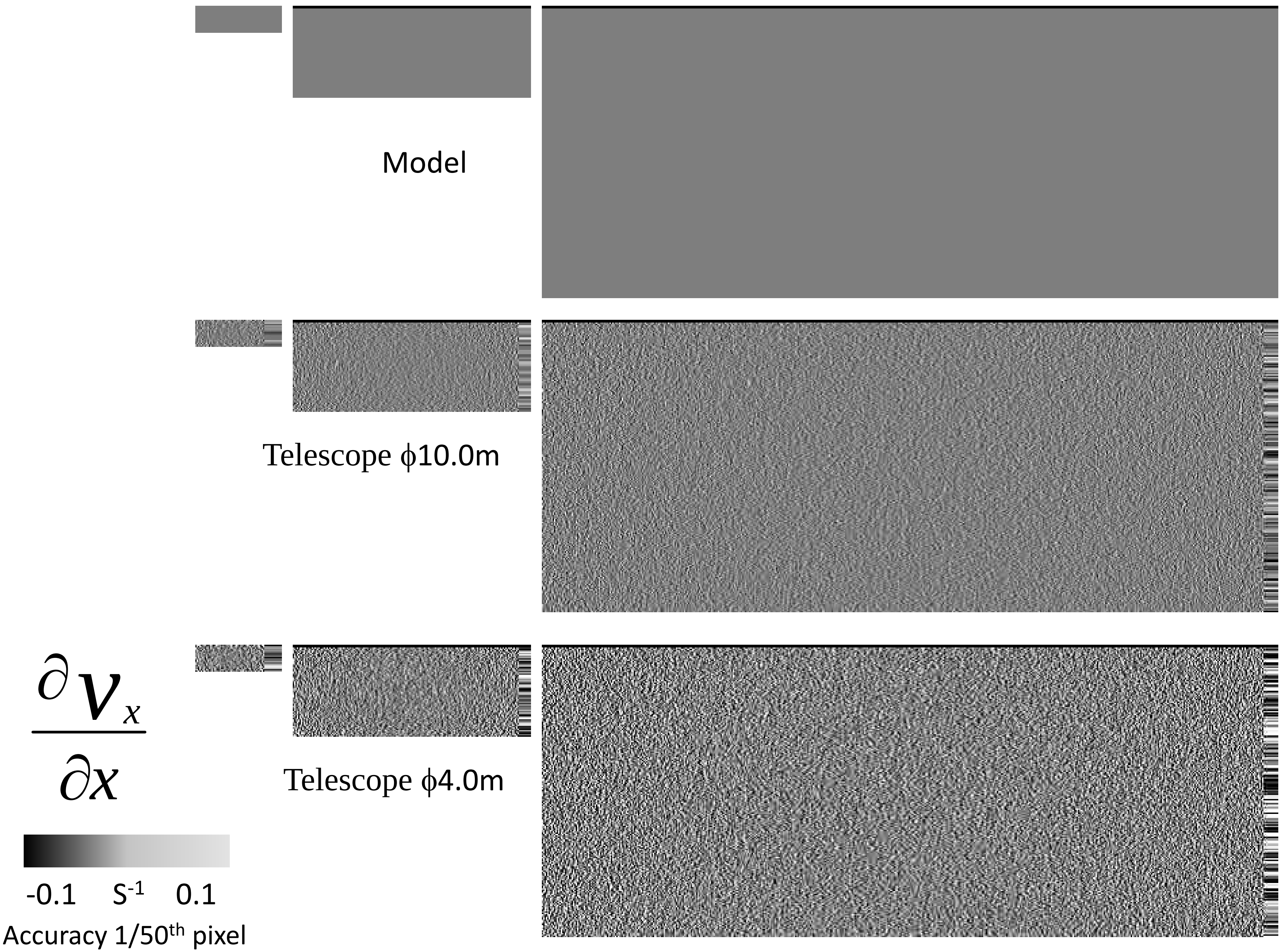
The "Vertical" Component

- Photoclinometry $\partial I / I \approx \tan(\theta).d\theta$

- Accuracy possible up to [10^{-4}-10^{-5}] (number of detected photons [10^{10} – 10^{11}])

- ρ=0.15, pixel size : 100m, integration time 0.03s, most unfavorable incidence angle # 11 degrees

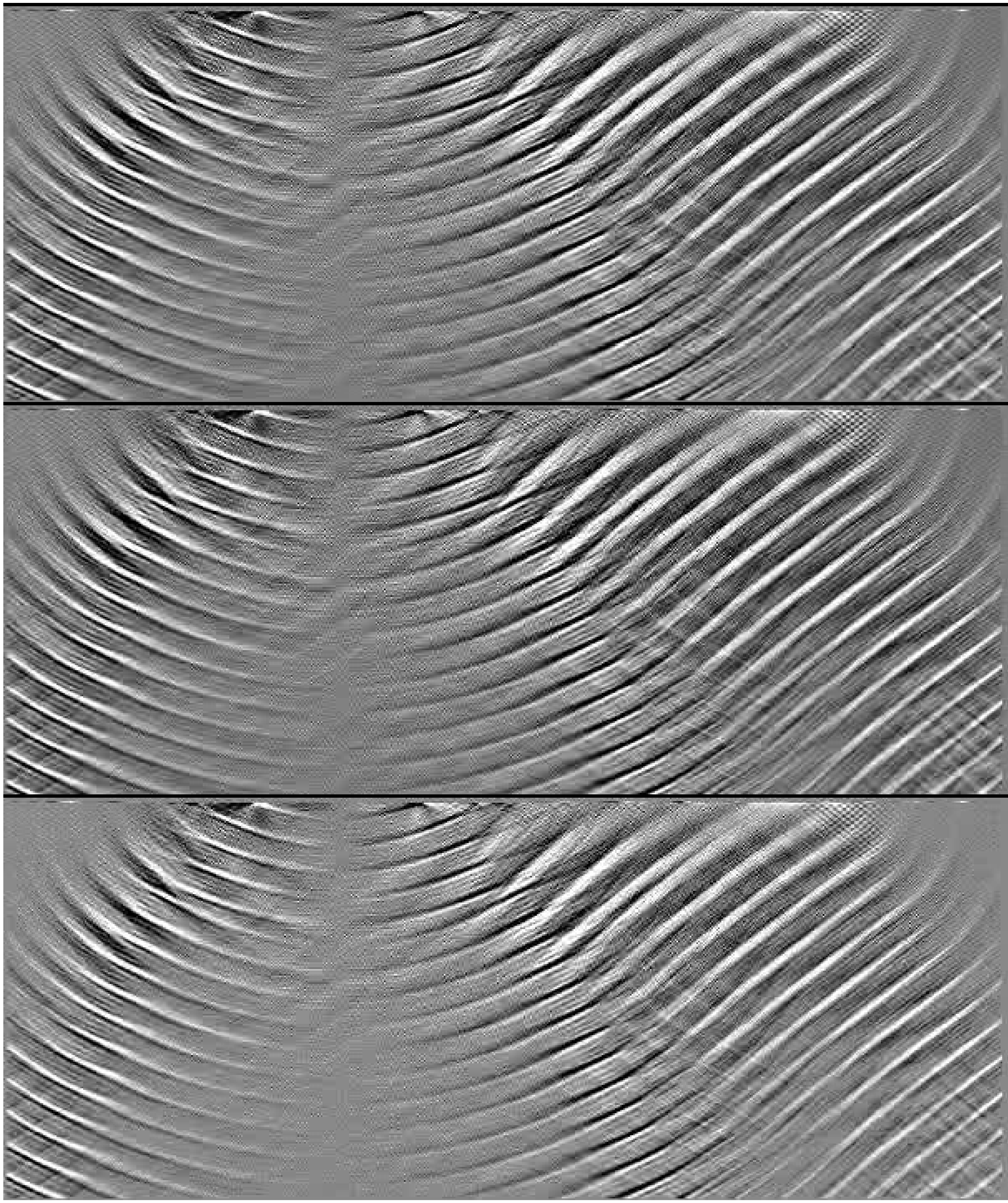
Telescope	Stability	Data rate (read out)	Accuracy (rms)
4m 10m	Few milliarcs/Hz	0.5Gbs	8 cm 6 cm
JWST (6.5m) *Herschel (3.5m)*	*JWST* *(1-3milliarcs/Hz)*	*0.5Gbs* *(single DSU)*	



Model
Telescope ϕ10.0m
Telescope ϕ4.0m
$\frac{\partial v_x}{\partial x}$
-0.1
S^{-1}
0.1
Accuracy 1/50th pixel

Simulations-
Vertical Component (slope)
(Mw7.1, supershear)

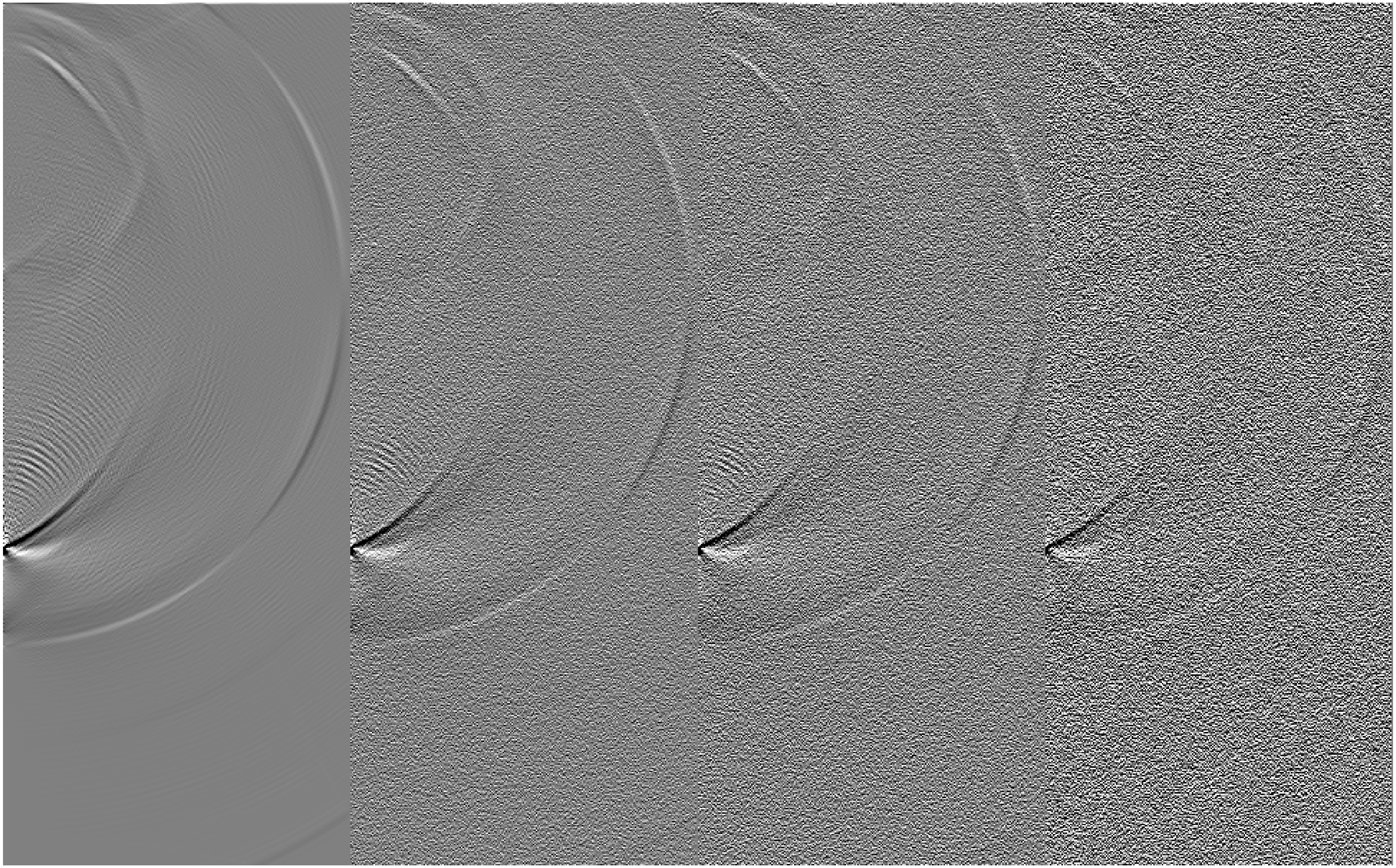
0.004 rad.s^{-1}



Model

Simulation (nominal)

Simulation (conservative, noisex10)



Modele

ϕ10.0m

ϕ7.0m

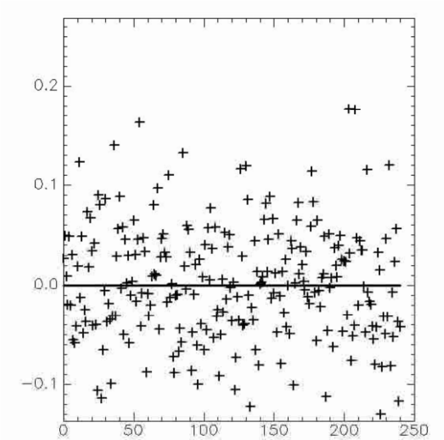
ϕ4.0m

$$\frac{\partial v_x}{\partial x}(15s)$$

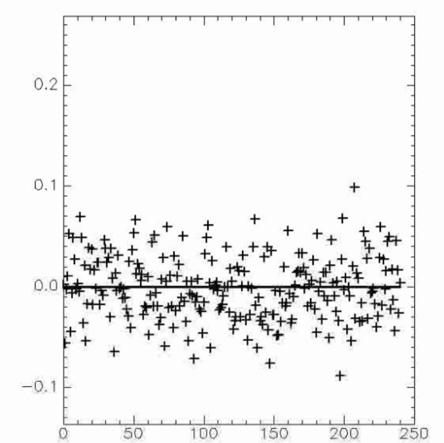
A’ Transept A

Accuracy of Optical Correlation = f(ϕ telescope, geostationary)

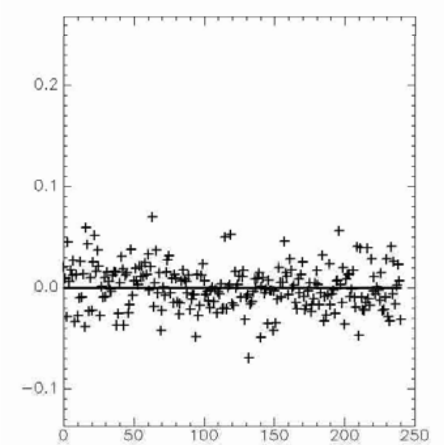
- Model of strike slip fault (Mw 7.1), Field of view 60*24km, 1Hz, ground resolution 100m



ϕ4.0m
Ariane V Compatible



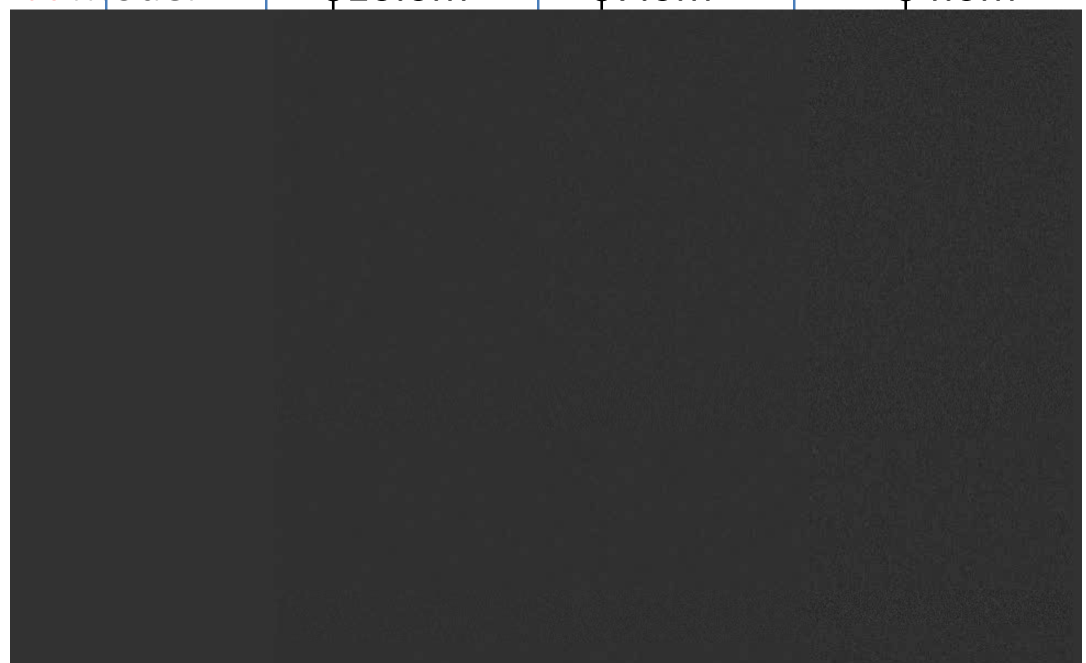
ϕ7.0m
Challenging



ϕ10.0m
Challenging

Horizontal Velocities [-0.4,+1.9] (m.s-1)

A Model | ϕ10.0m | ϕ7.0m | ϕ4.0m



A’

Concept Analysis. Conclusions

- Optics-Geostationary : a solution to seismic waves and other rapid phenomena
  - Take benefit from Very Large Space Telescopes for Astronomy
- 40% of Earthquakes in North California, #1.2 per year with Mw 5.5 and above
  - Most slip distribution and post-seismic deformation within few hours
- Telescope size is critical (monolithic, assembled)
  - Large field of view (up to 4degrees?)
- Horizontal and Vertical Components : 6cm-100m-1Hz-300km. Better?
  - Stability
- Less than 10% light budget, more applications possible
  - Larger areas, vegetation, atmospheric optics, urban, etc.
- Payload sub-critical
  - Data management
- Further investigations required
  - Atmosphere, aliasing, moonlight, weather, wide field up to 4 degrees telescope design, geostationary environment, laser, etc.
- Assessments and feedback by seismologists needed.

Thank you