Strain Seismometers
and
Radar

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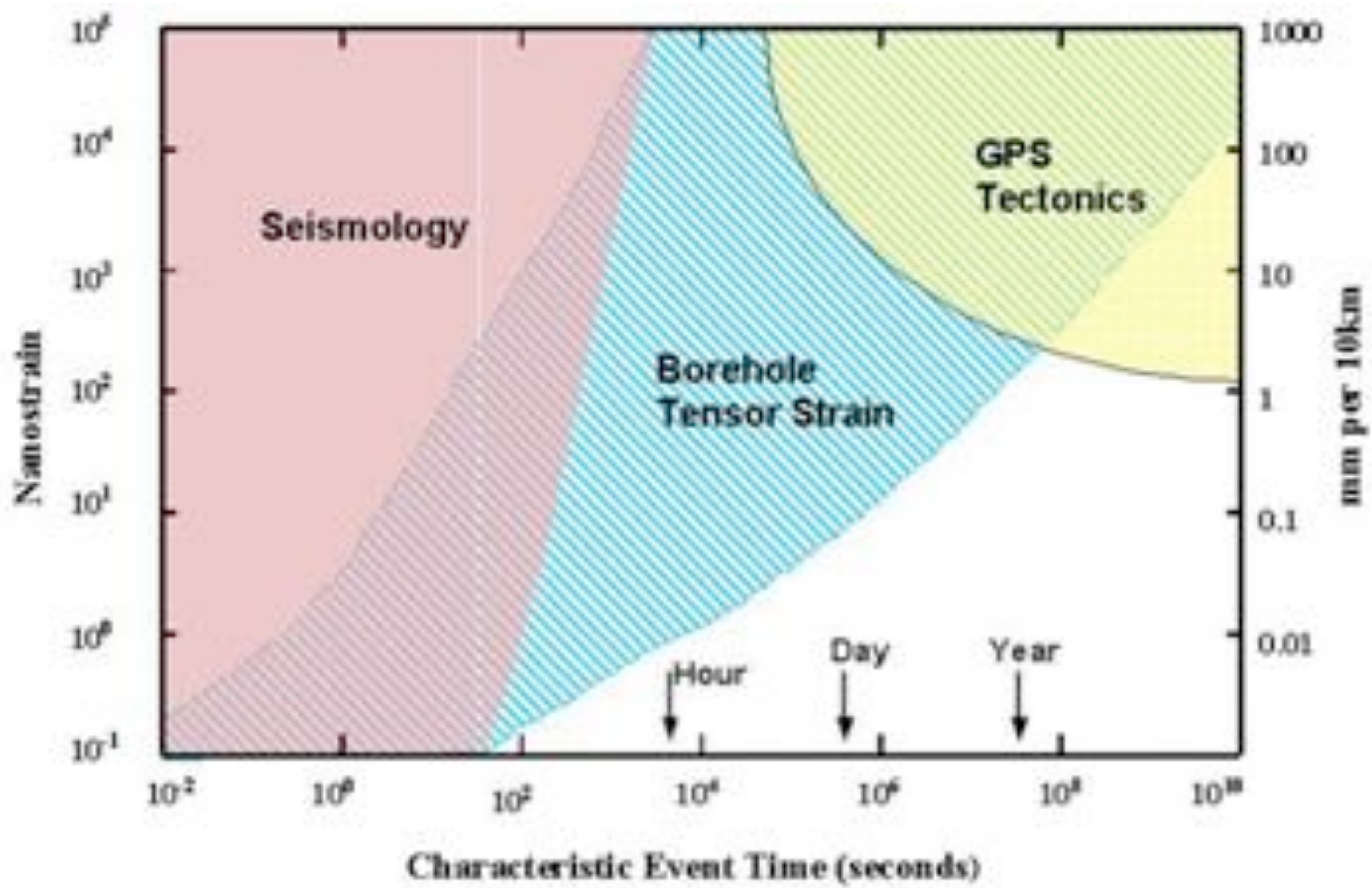
Strain Seismometer

- Strain seismology is not new
- Strain seismometer uses a different principle
  - Inertial seismometer – suspended mass measures acceleration or displacement or velocity of a point
  - Strain seismometer – use length standard to measure strain between 2 points in medium.

Caltech Strainmeter Model

Properties of Strain Seismometers

- Response all the way out to DC
  - Limited by stability of electronics and installation
  - Normal modes of Earth were first discovered with a strain seismometer [Benioff 1962]
- 3 horizontal components gets full 9 component strain tensor (assume nearby free surface)



Gladwin: http://gtsmtechnologies.com/index_files/history.htm

Combine Strain and Inertial

- Strain (spatial derivative) and Inertial (temporal derivative) yields phase velocity
  - Use phase velocity to help identify arrivals (P, S, PP, PS, SP, SS, L, R etc) [Benioff 1962, 1935]
- Fix & Sherwin [1970] demonstrated ability to determine the back azimuth of Rayleigh waves independent of frequency
  - An array of inertial instruments gradually loses its ability to determine the back-azimuth of Rayleigh waves as the frequency of the waves decreases

Low Frequency

$$x(t) = A\cos(\omega t + f)$$

$$a(t) = \frac{\partial^2}{\partial t^2}x(t) = -A\omega^2\cos(\omega t + f)$$

Inertial

$$x(y) = A\cos\left(\frac{\omega y}{v} + f\right)$$

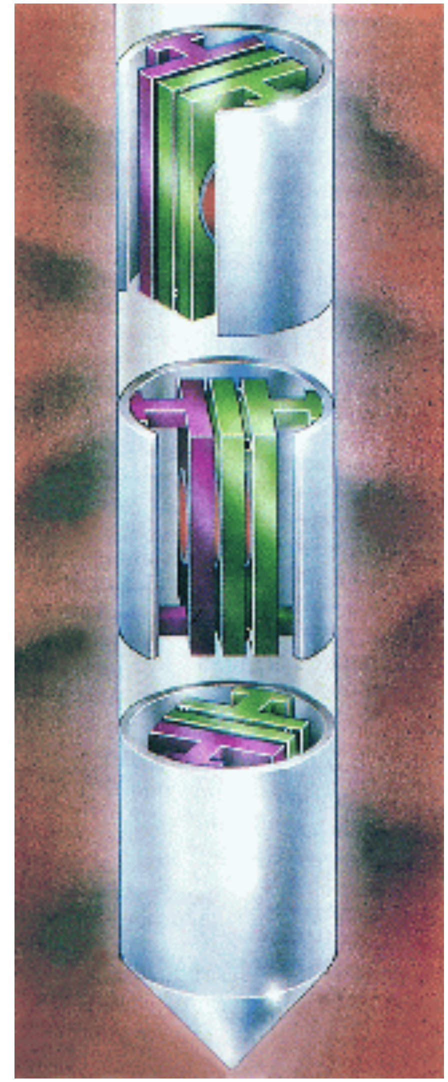
$$strain = \frac{\partial}{\partial y}x(y) = -A\frac{\omega}{v}\sin\left(\frac{\omega y}{v} + f\right)$$

Strain

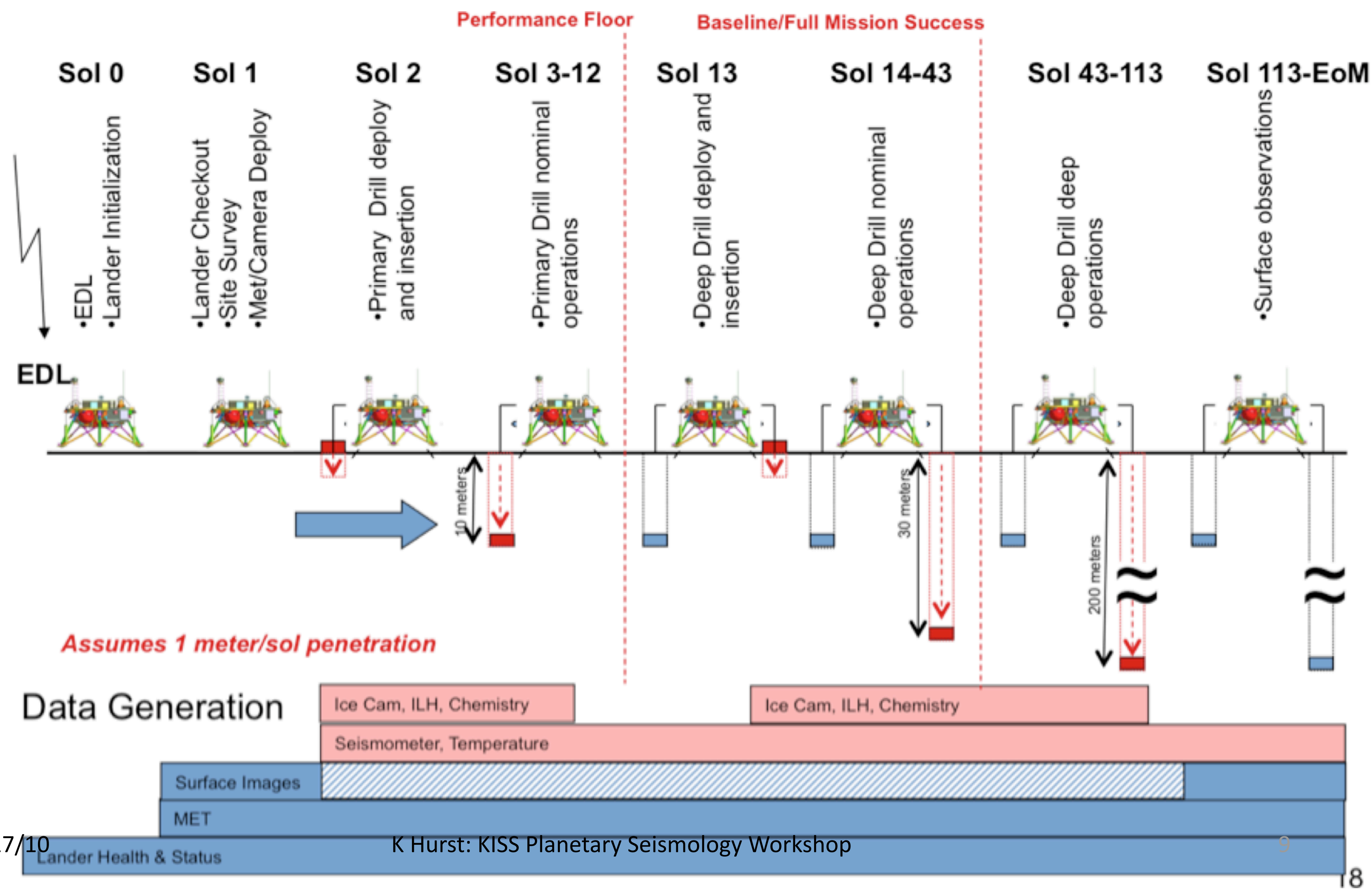
Borehole Tensor Strainmeter

- Measures strain in 3 directions in a borehole at up to ~200 m depth.

Development work done by Michael Gladwin. Hundreds of them have been deployed world wide.



Strain Seismometer in Ice on Mars



Advantages of Installation in Ice

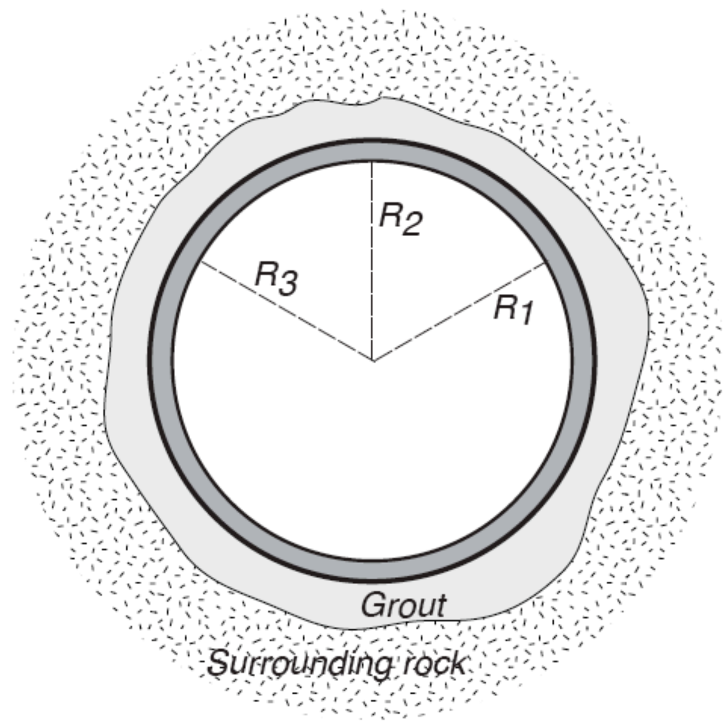
$$strain = \frac{\partial}{\partial y} x(y) = -A \ \frac{\omega}{v} \ \sin\left(\frac{\omega y}{v} + f\right)$$

1/v term implies greater signal for slower velocity

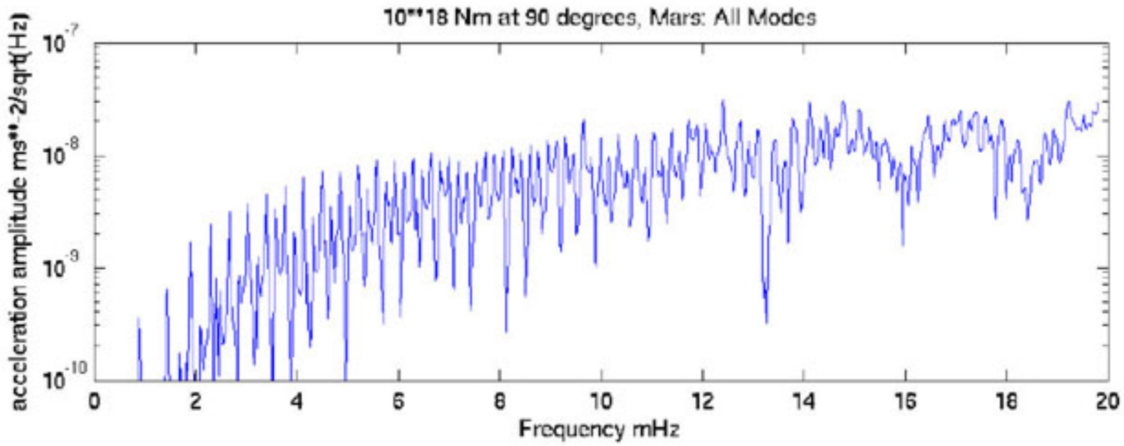
	V_p (km/sec)	V_s (km/sec)
Basalt	5.6	3.1
Ice	3.5	2.0

Advantages of Installation in Ice

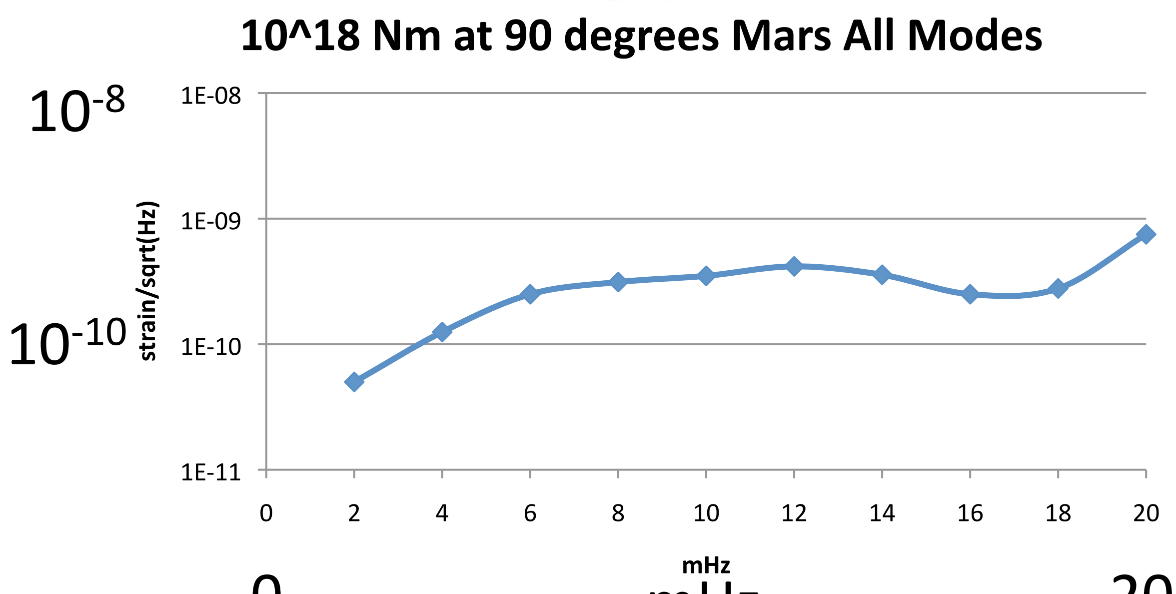
- Relatively simple to drill
- Freezing in ice eliminates "Grout" annulus, improving coupling to medium



10^{18} Nm Quake at 90° Mars All modes



From Bruce Banerdt



Divide above curve by (frequency*velocity)

Mars Tides

Mars radius	3396.2	km	
	Period (hr)	Displacement at the surface (mm)	Strain (Disp/Rad)
Sun	24.6	~30	9e-9
Phobos	7.7	~10	3e-9
Deimos	30.3	<1	3e-10
Solid-body tidal displacement response from W Banerdt			

RADAR

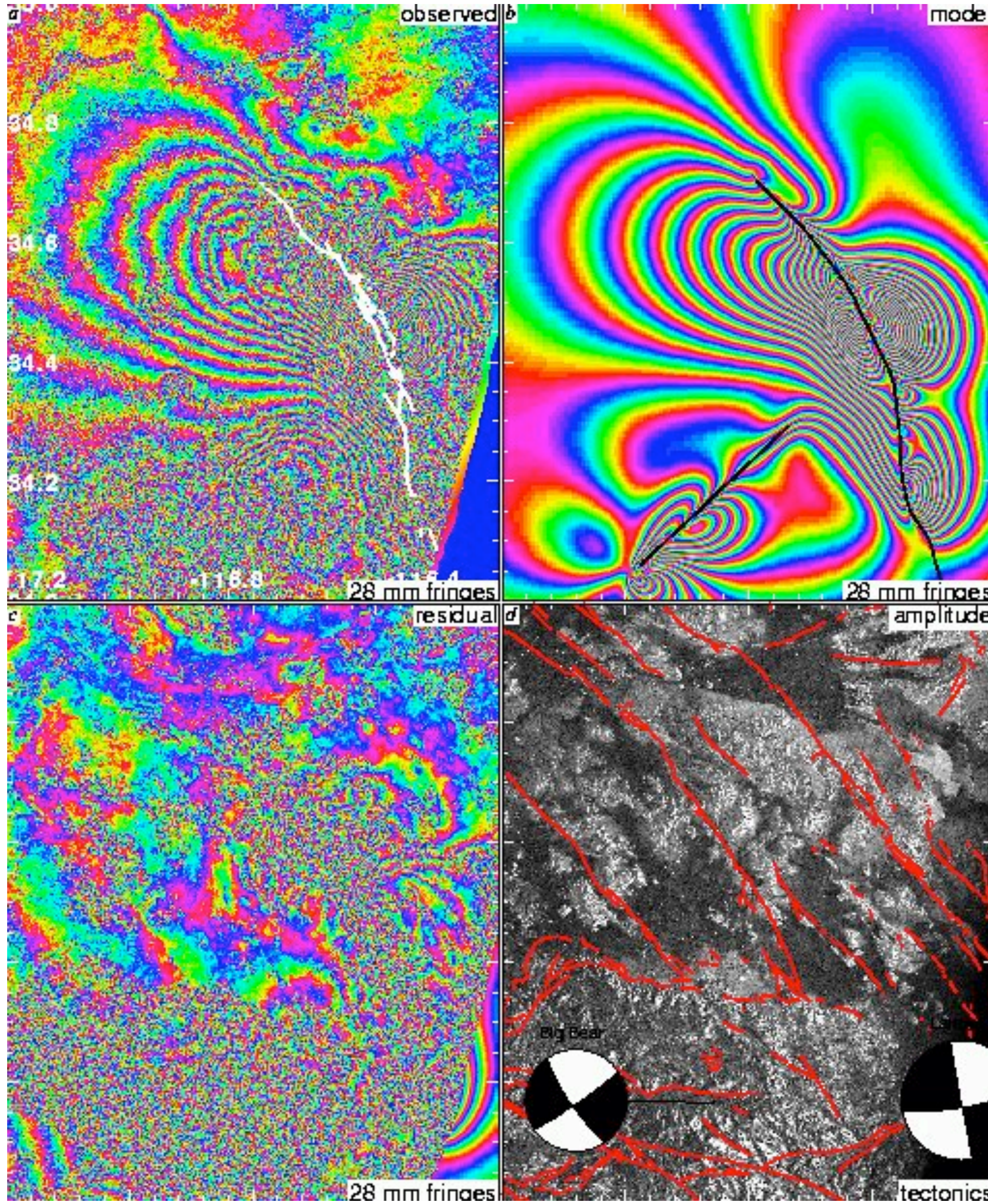
1992 Landers Earthquake SAR Image

Top Left: SAR image

Top Right: Model

Botom Left: Residual

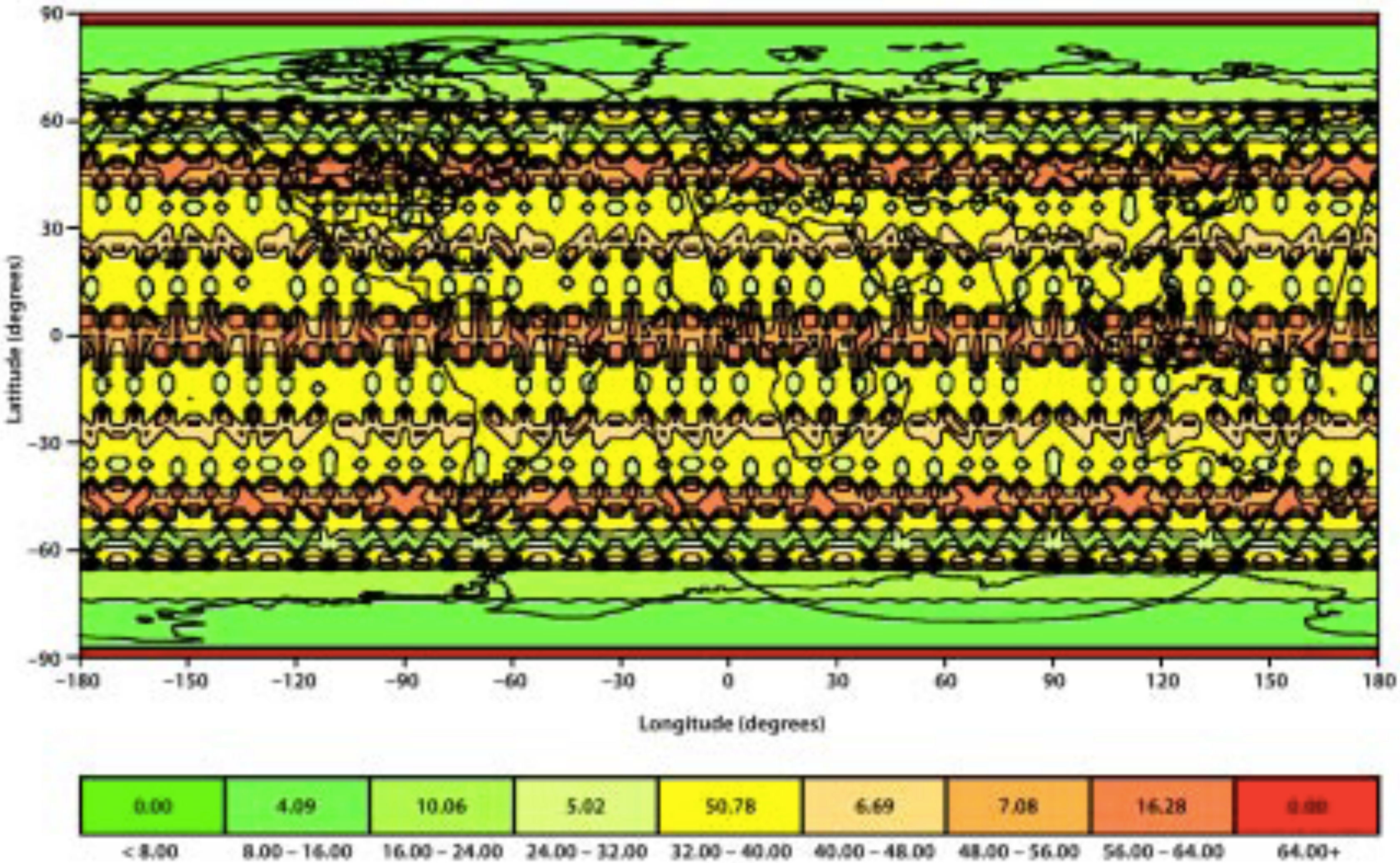
Bottom Right: Radar brightness (amplitude) image



From rrsg.uct.ac.za/applications/applications.html

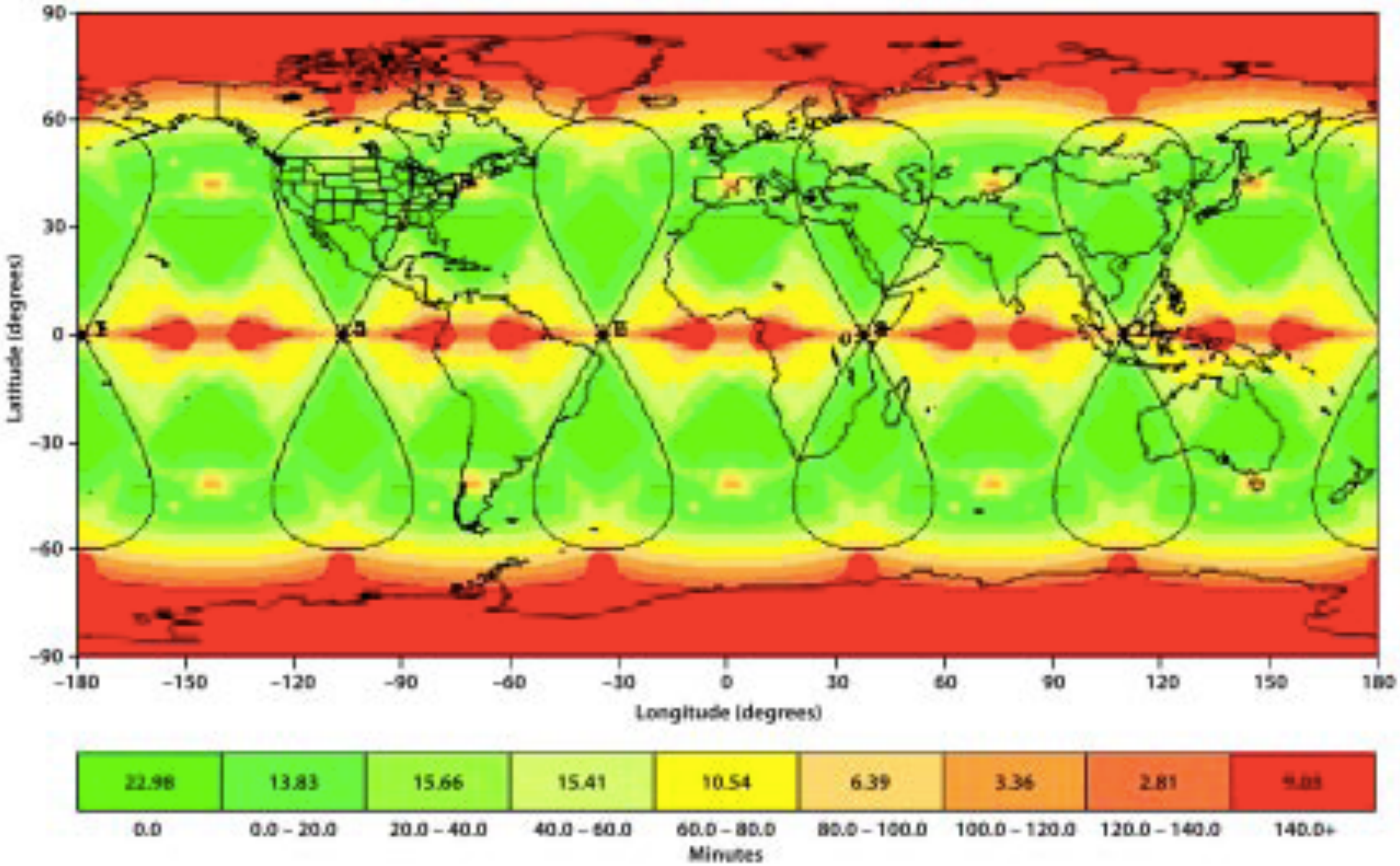
LEO SAR for deformation

1 Satellite in 1325 km orbit with 100 degree inclination



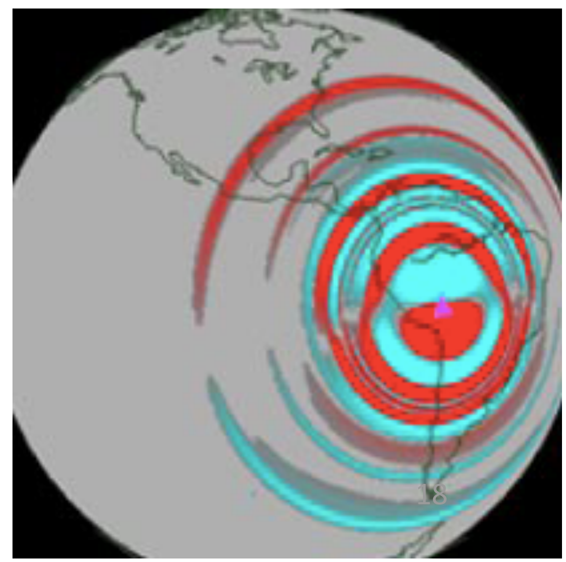
Geosynchronous SAR for deformation

10 Satellites in 5 orbits



Imaging Seismic Waves with Radar

- To measure propagating seismic waves need
  - Real-aperture Radar in geostationary orbit.
    - Ka band (λ=8.6 mm, 35 GHz)
    - 100 m aperture for Earth (smaller for Mars)
    - 50 kW radiated power
  - Difficulties
    - Station keeping
      - solar radiation pressure
    - Atmosphere



From “Global Earthquake Satellite System” Study