The Earth's Many Voices:
Learning to Decipher Pre-Earthquake Signals

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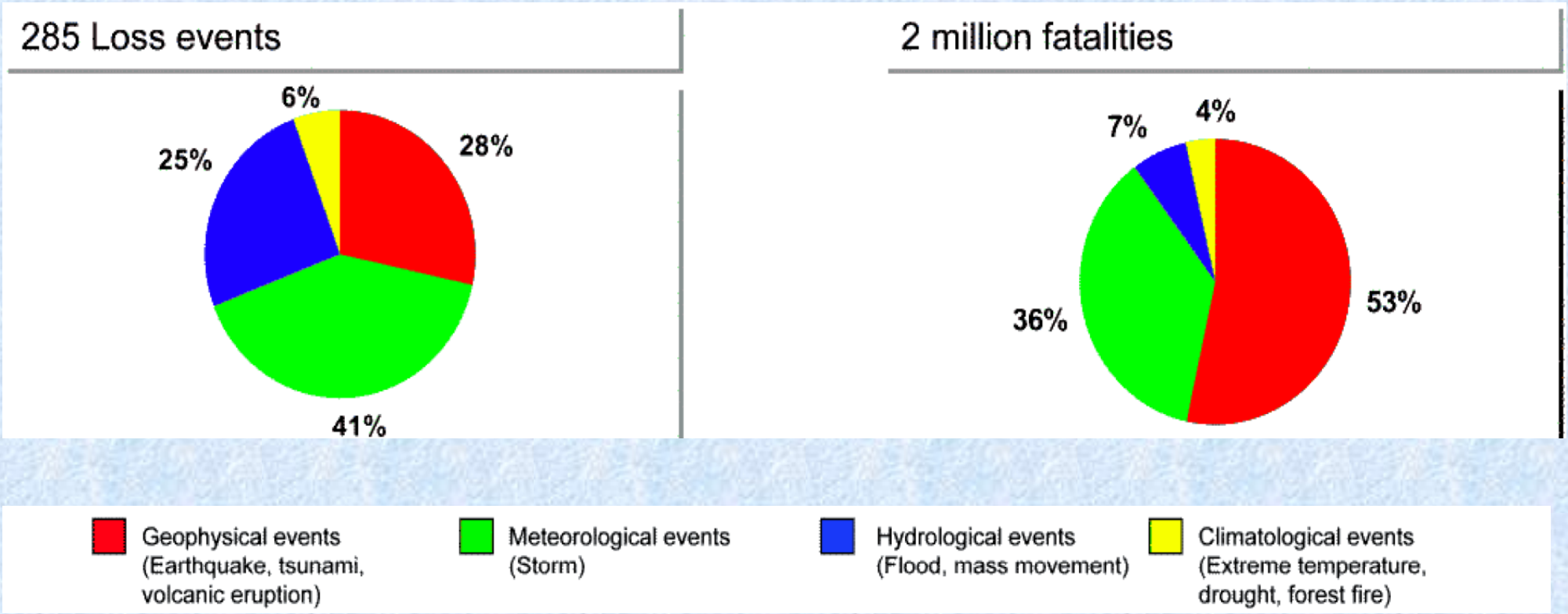
Natural Disasters 1950-2009



If earthquakes are the deadliest of all natural disasters,

what can we do about it?

Prominent seismologists have proclaimed

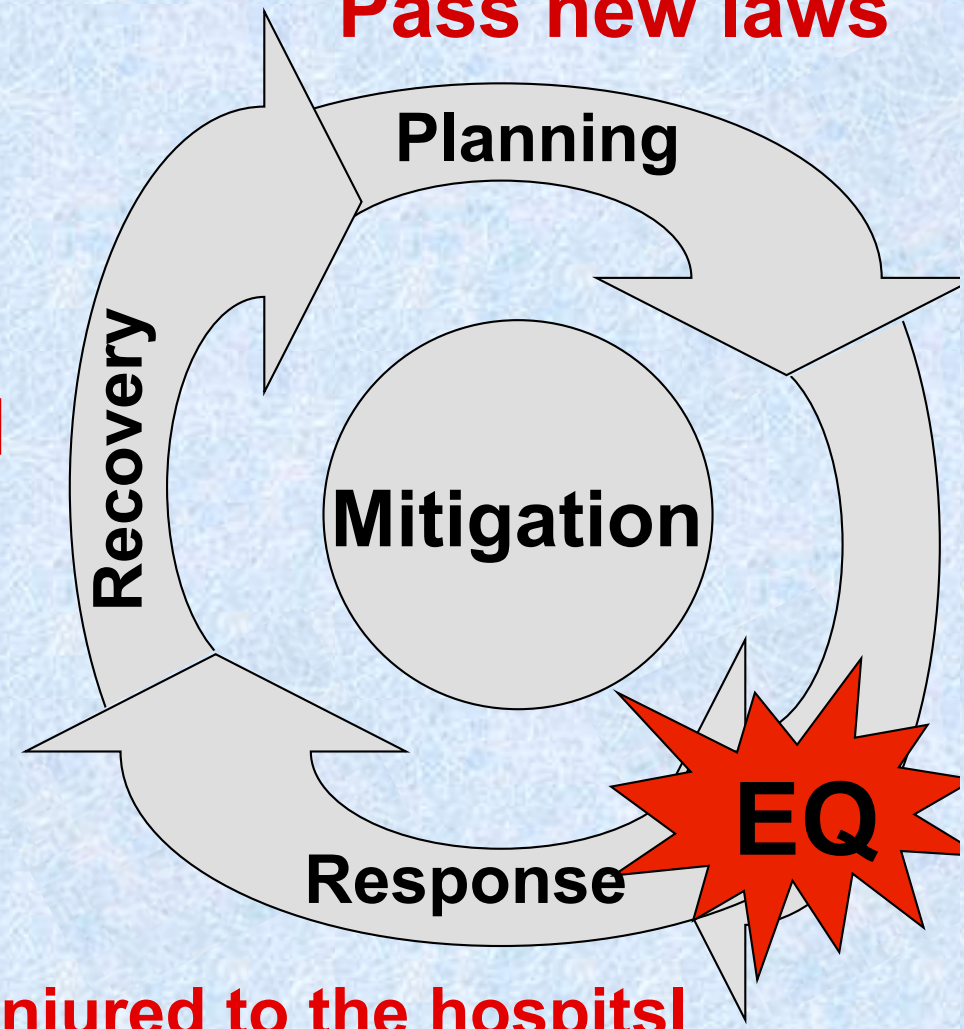
"Earthquakes cannot be predicted"

Robert Geller, 1997

…and (almost) everybody believes them.

Disaster Management Cycle

Pass new laws

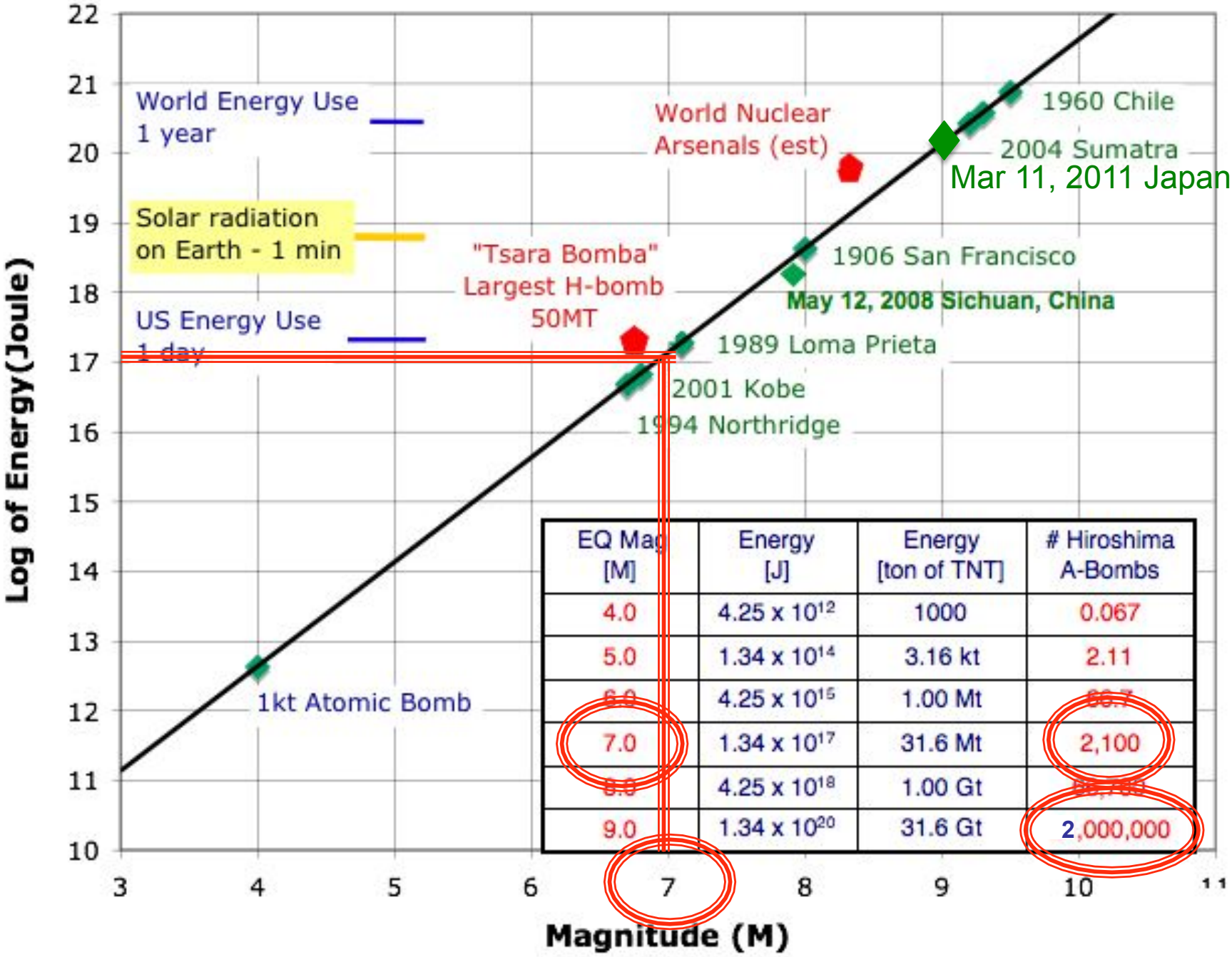


Rebuild

Sit and wait
and wait
and wait
until the
next one
hits

Take the injured to the hospitsl
and the dead to the morgue

Comparing EQ's with other known events and energy scales



EQ Mag [M]	Energy [J]	Energy [ton of TNT]	# Hiroshima A-Bombs
4.0	4.25×10^{12}	1000	0.067
5.0	1.34×10^{14}	3.16 kt	2.11
6.0	4.25×10^{15}	1.00 Mt	66.7
7.0	1.34×10^{17}	31.6 Mt	2,100
8.0	4.25×10^{18}	1.00 Gt	66,700
9.0	1.34×10^{20}	31.6 Gt	2,000,000

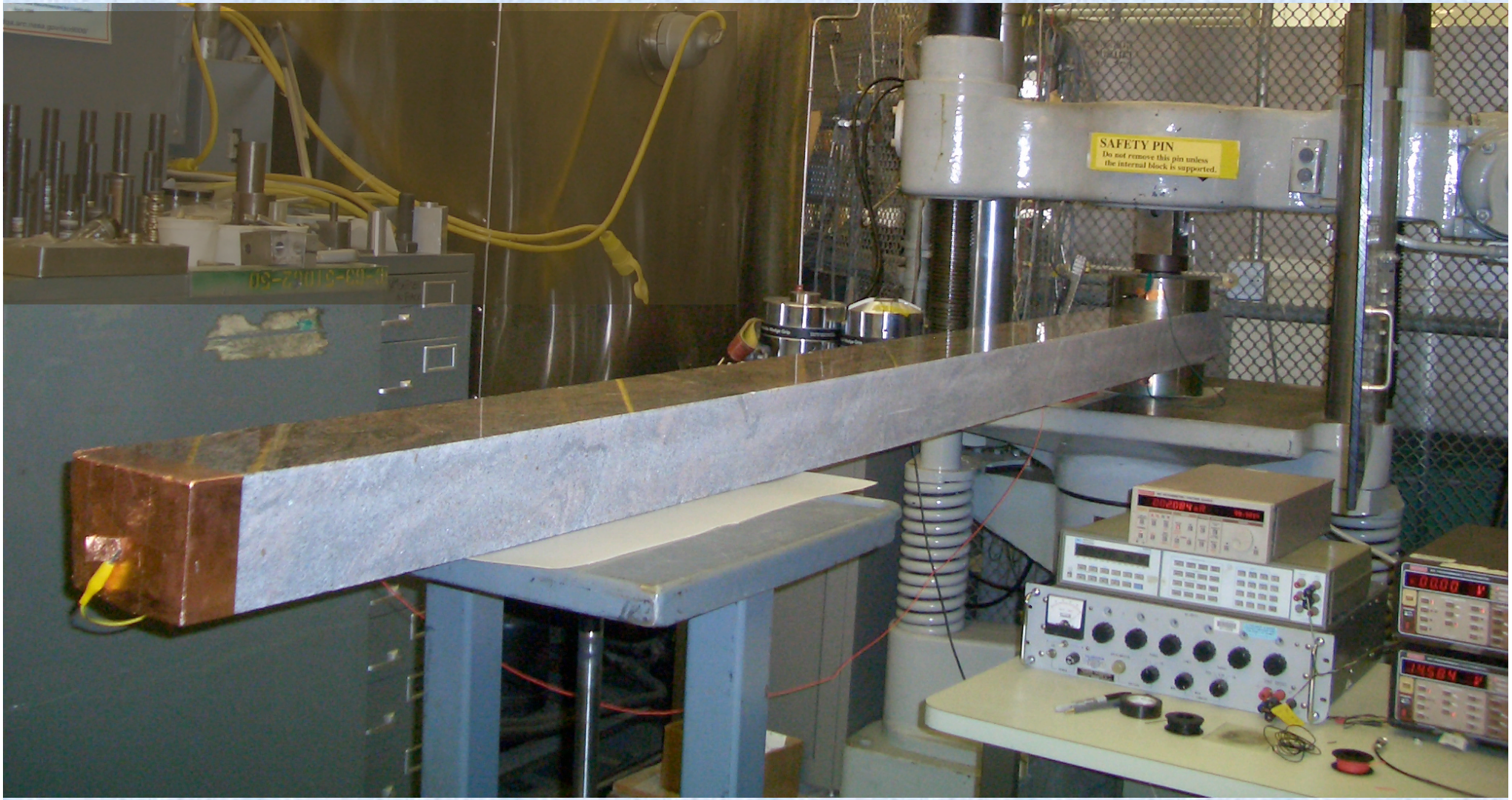
If an M 9 earthquake releases
energy equivalent to
more than 2,000,000 Hiroshima A-bombs,
it's even more inconceivable

Surely seismologists
didn't look at the right place

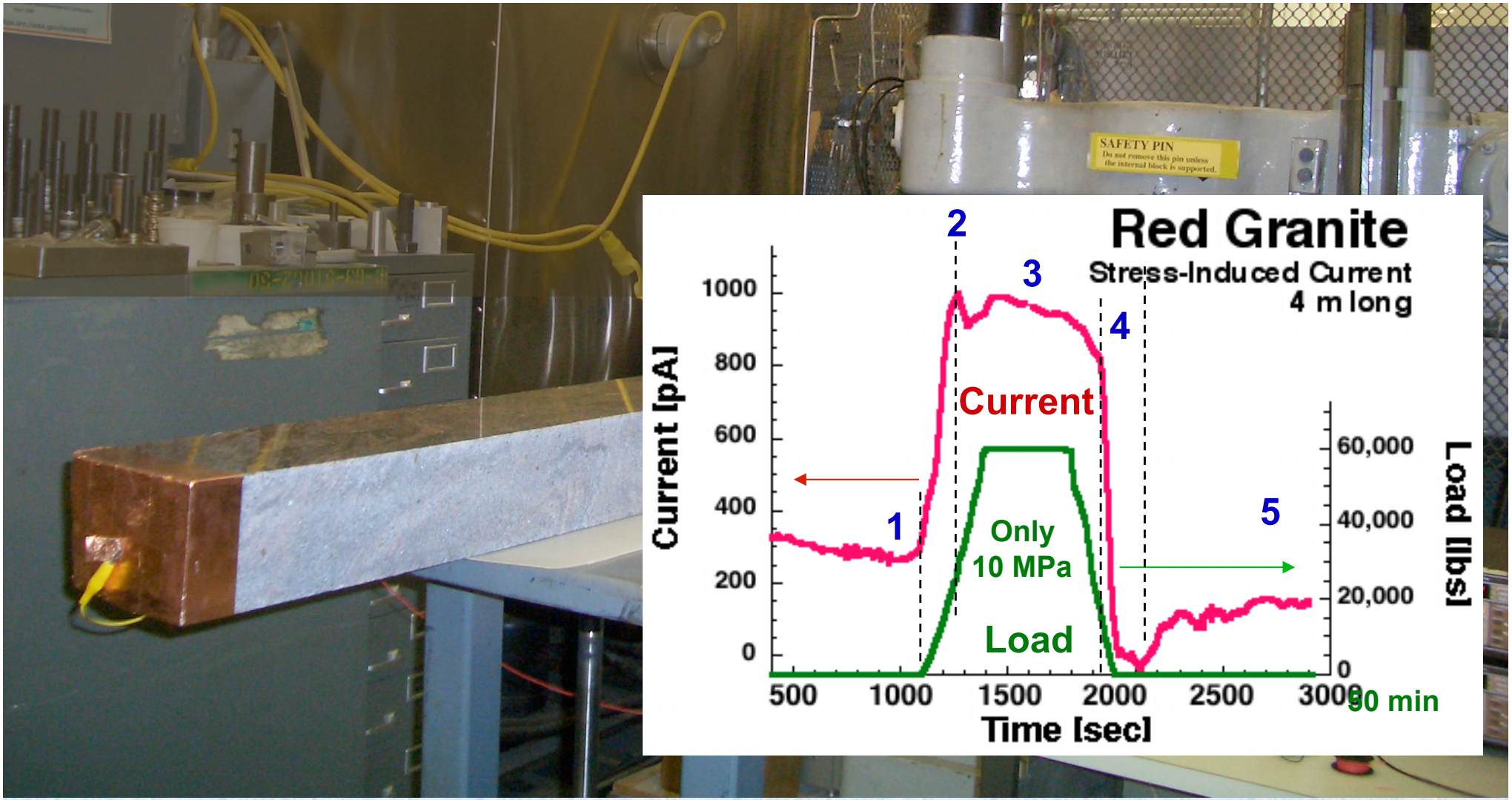
Let's do a simple laboratory experiment that nobody has ever done before:

Take a rock and squeeze it at one end…

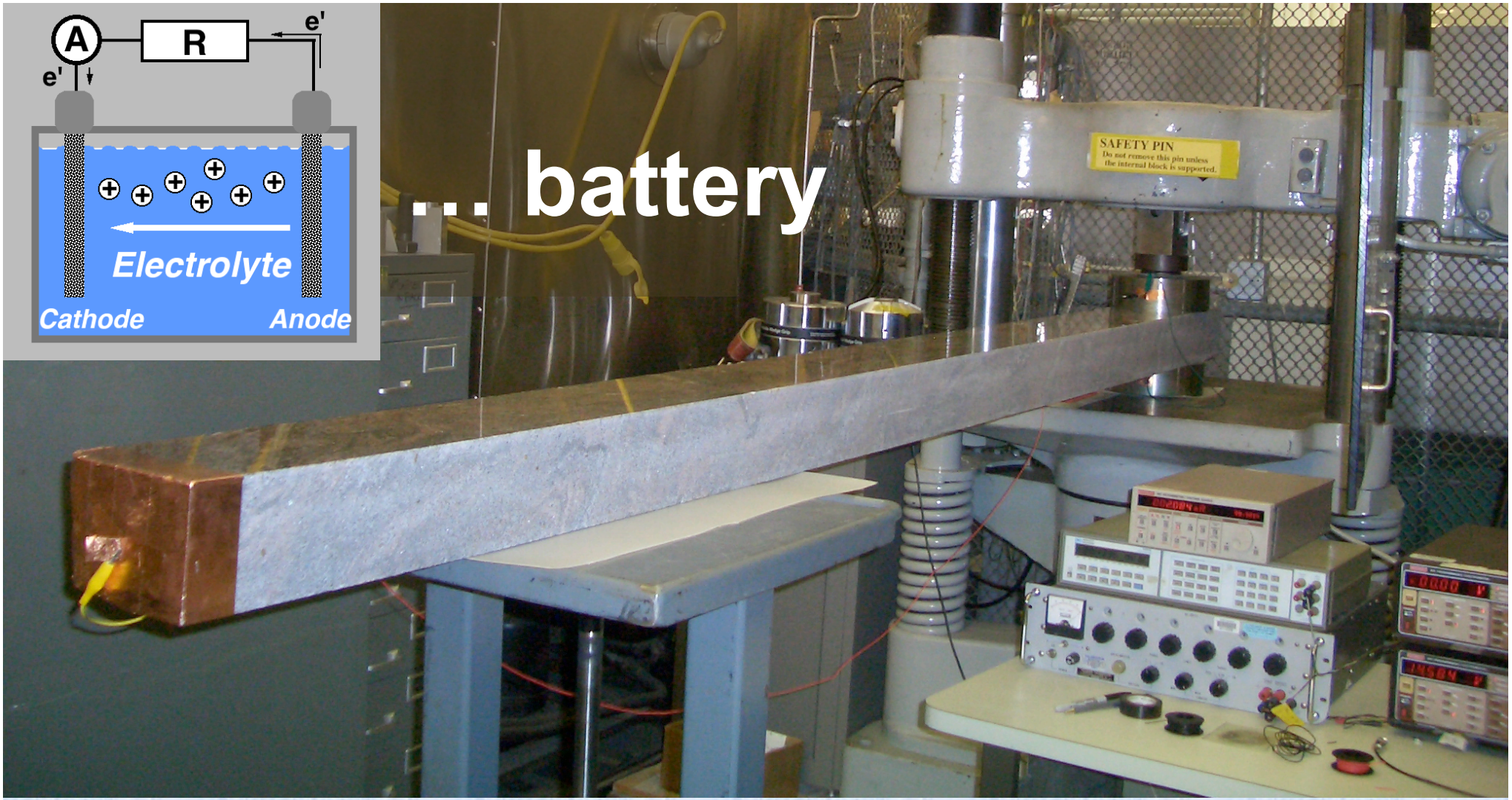
What do you expect?



4 m long slab of granite squeezed at the far end



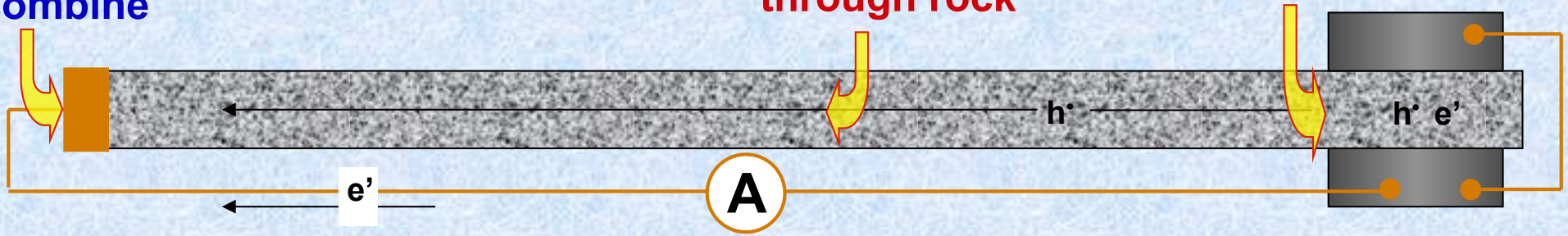
1. Electric current instantly starts to flow
2. Current saturates
3. Continues to flow at constant load
4. Current stops when unloaded
5. Can be repeated infinite number of times



Electrons and holes recombine

Holes flow through rock

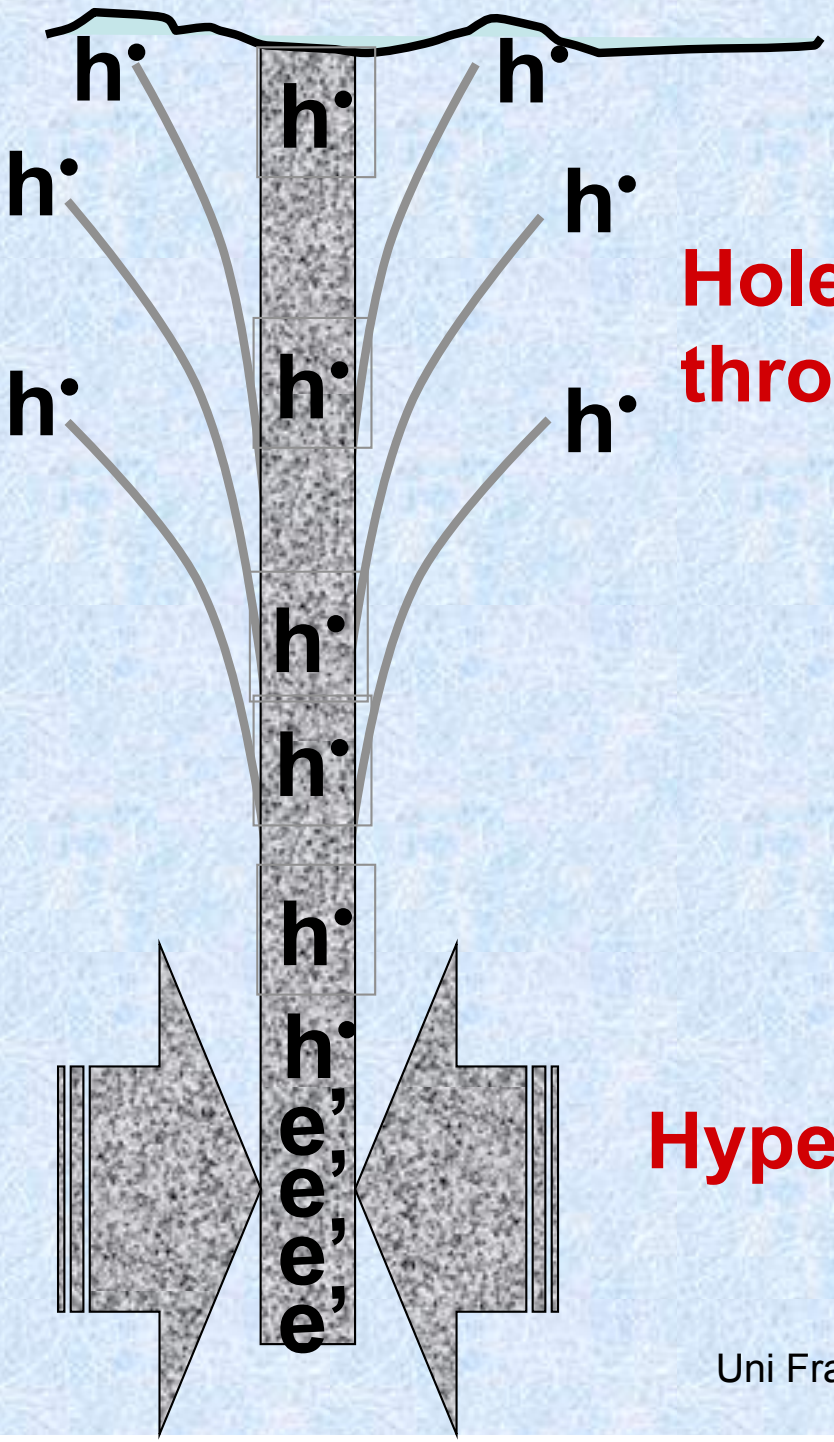
Activation volume: electrons and holes



Question:

Is there anything in Nature that produces electric signals before major earthquakes?

Answer: Plenty.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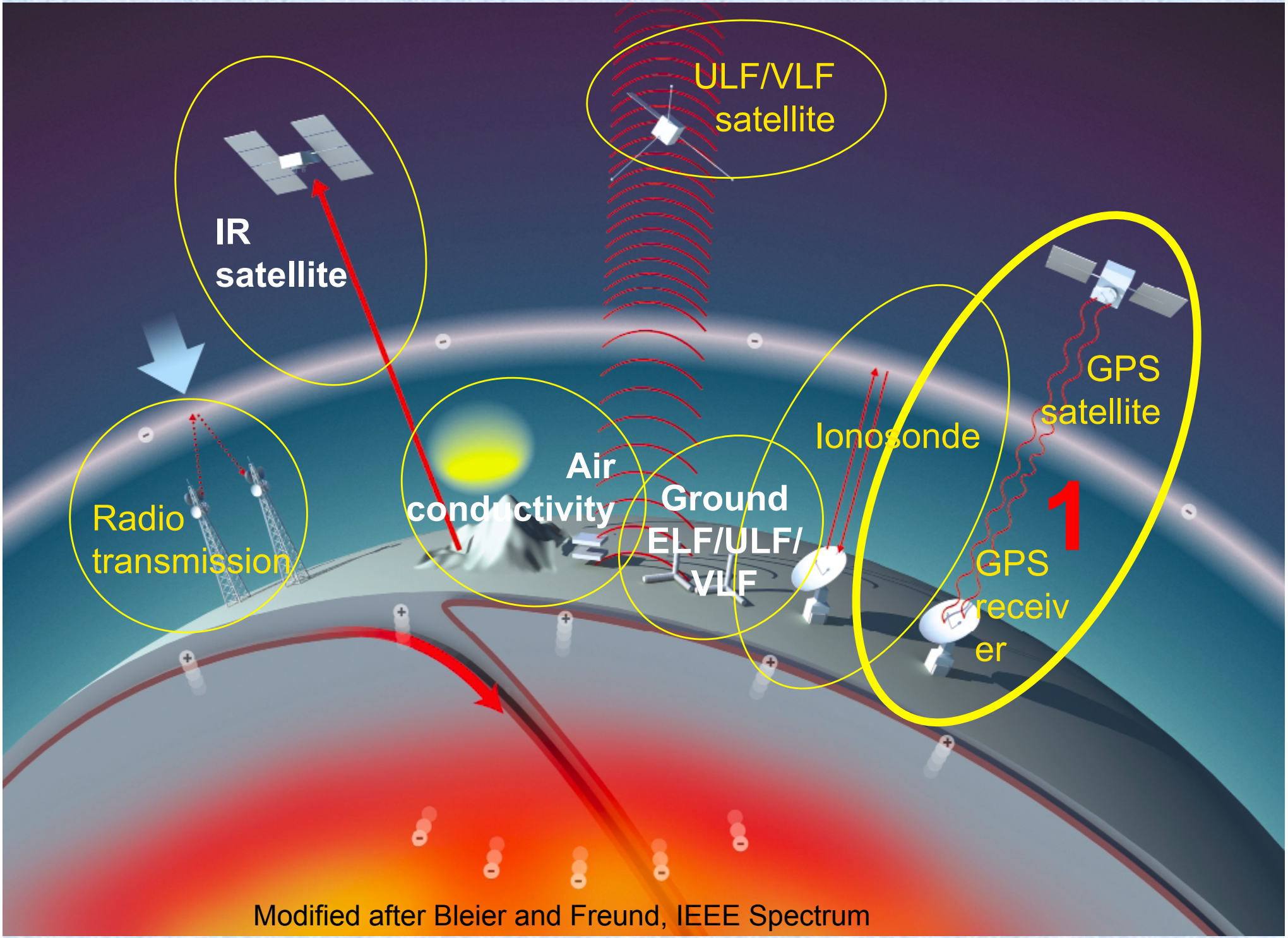


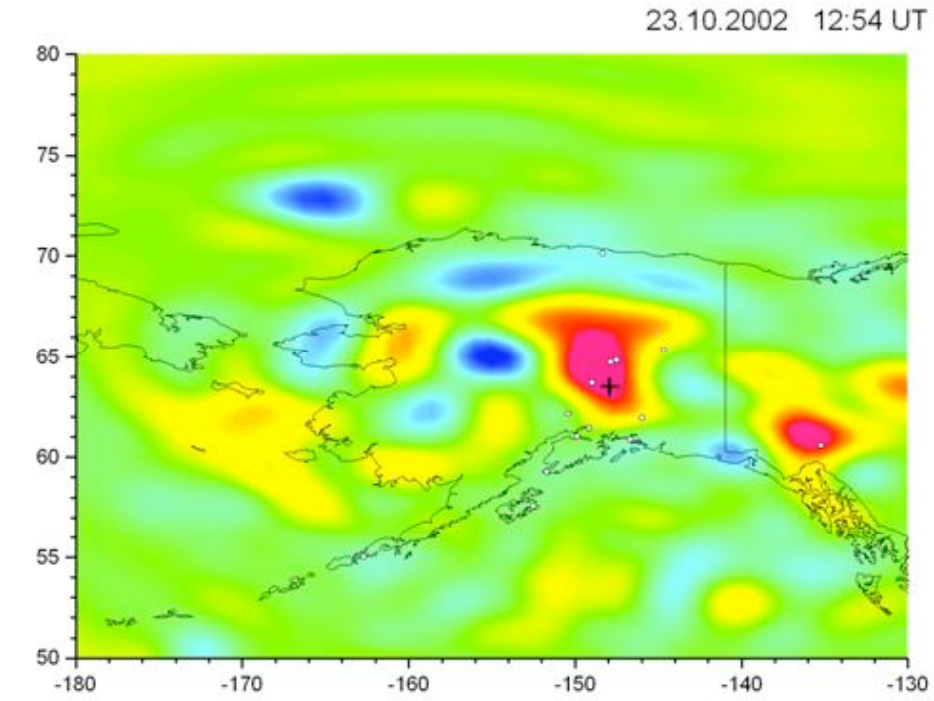
Modified after Bleier and Freund, IEEE Spectrum 2005

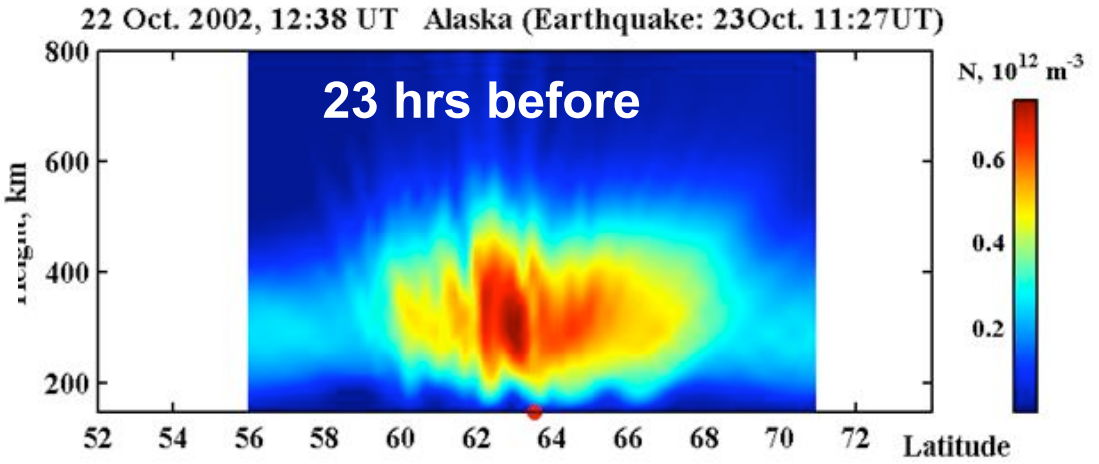
Selected Pre-Earthquake Signals

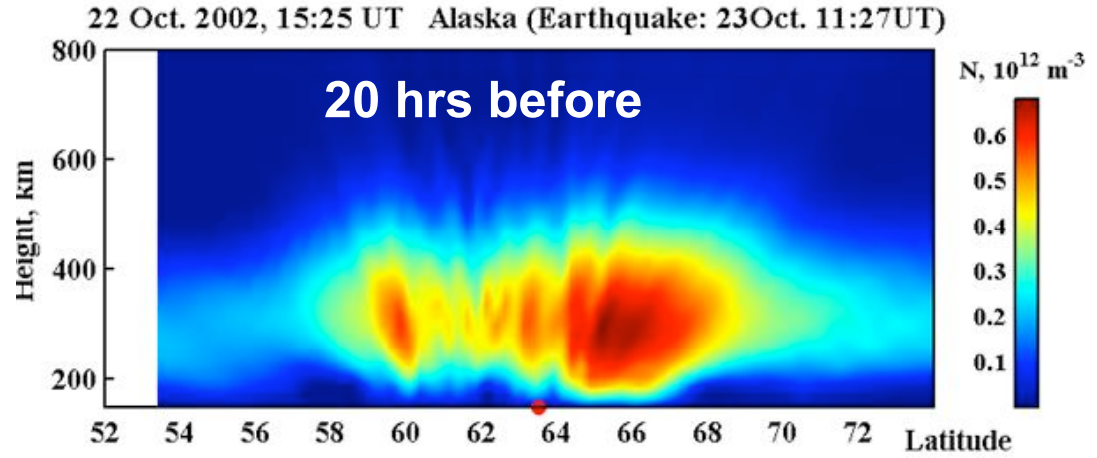
Ionospheric perturbations

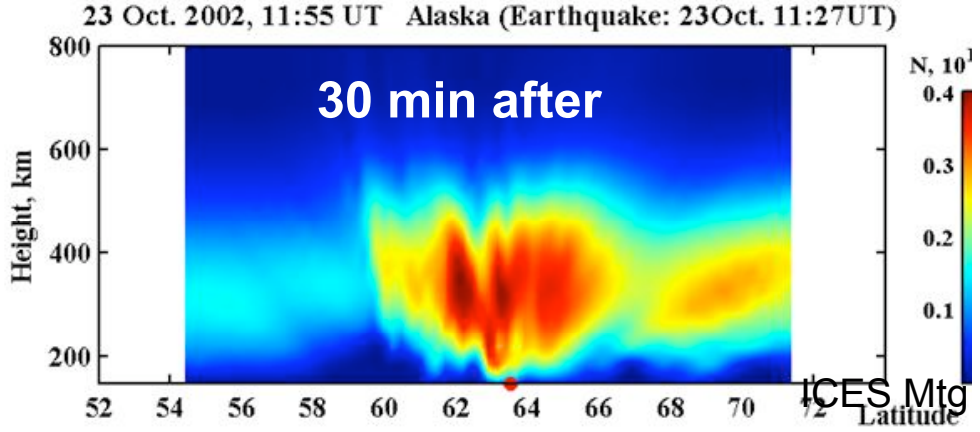
Representative Ionospheric Perturbation
M=6.4 EQ Alaska
23. Oct. 2002 at 11:27 UT

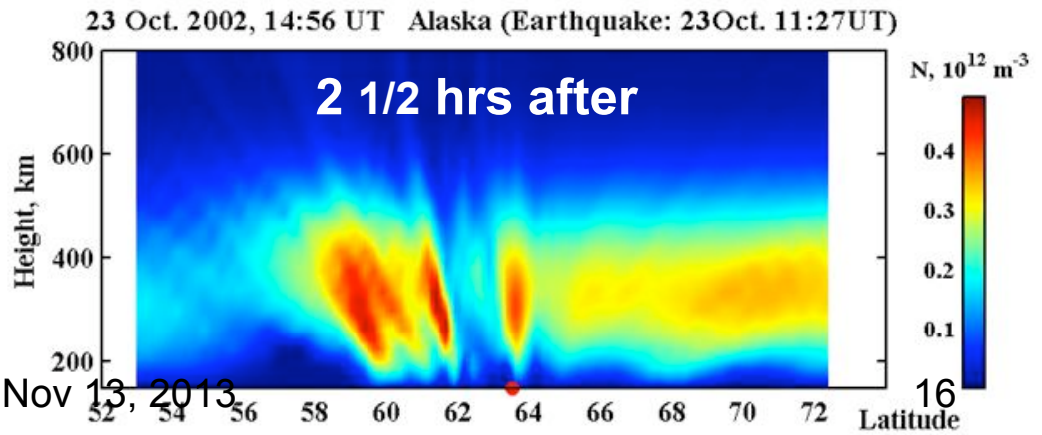
(courtesy D. Rekenthaler 2008)





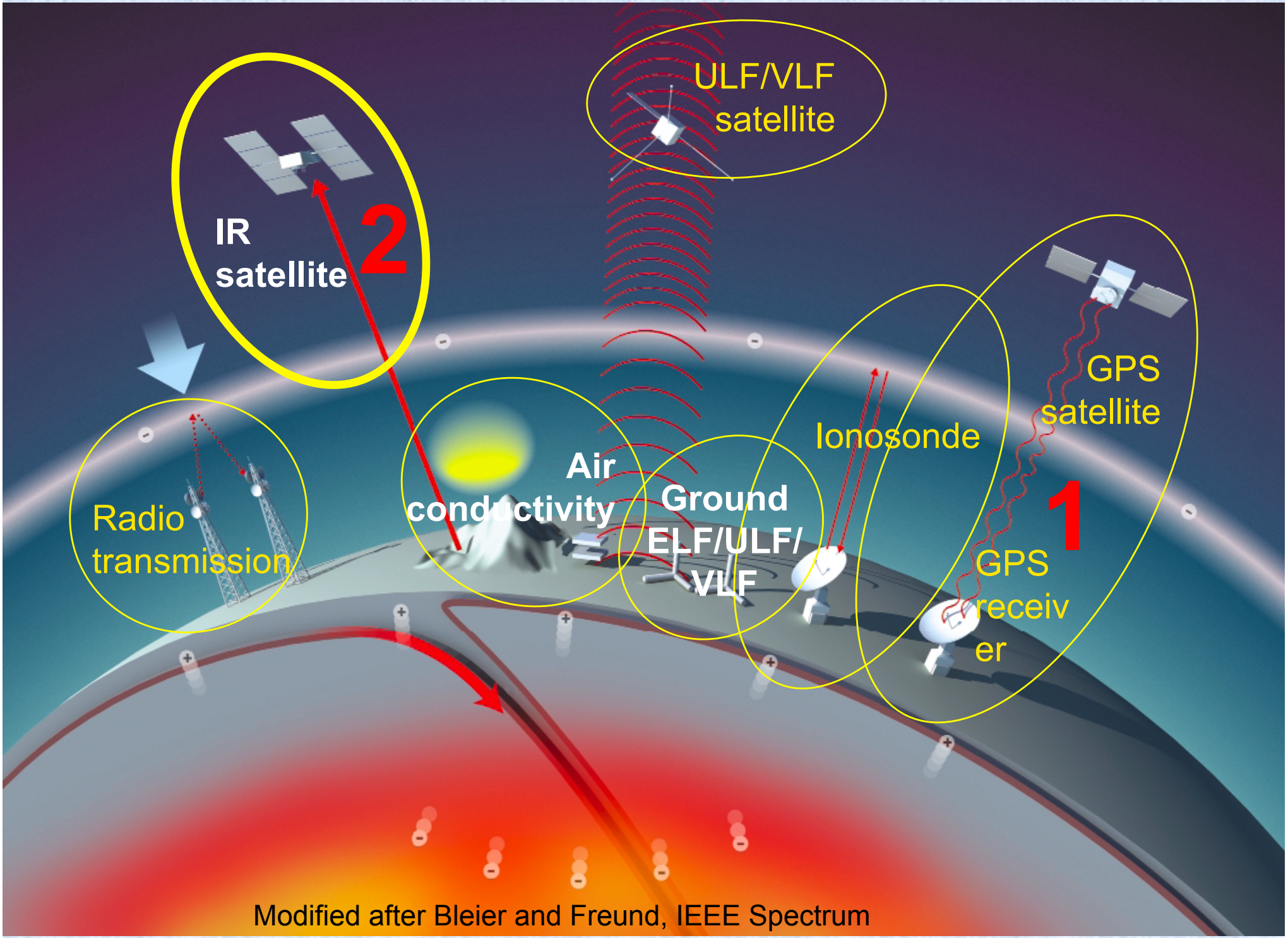






Ionospheric Perturbations

- **Operational 2012 from Vancouver to San Diego**
- **Planned: from Turkey to India, possibly all the way to Malaysia and Indonesia.**
- **Planned: from Ecuador through Peru to Chile.**



Modified after Bleier and Freund, IEEE Spectrum 2005

If positive holes accumulate at Earth surface, what else can they do?

…they can ionize the air

massive positive air ionization

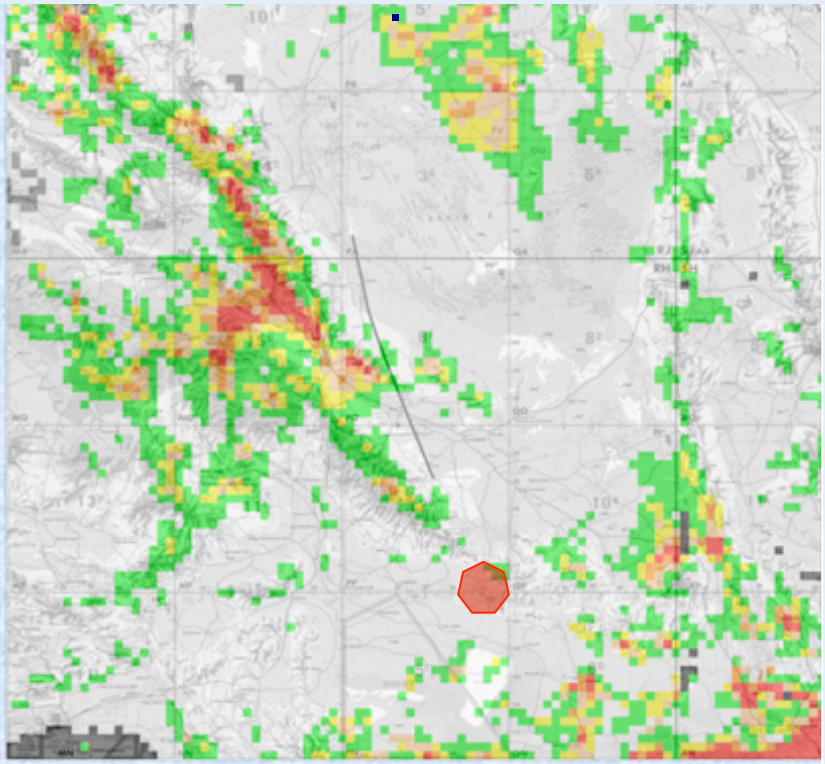
If positive holes accumulate at Earth surface, what else can they do?

…they can recombine, returning to the peroxy state:

Infrared emission

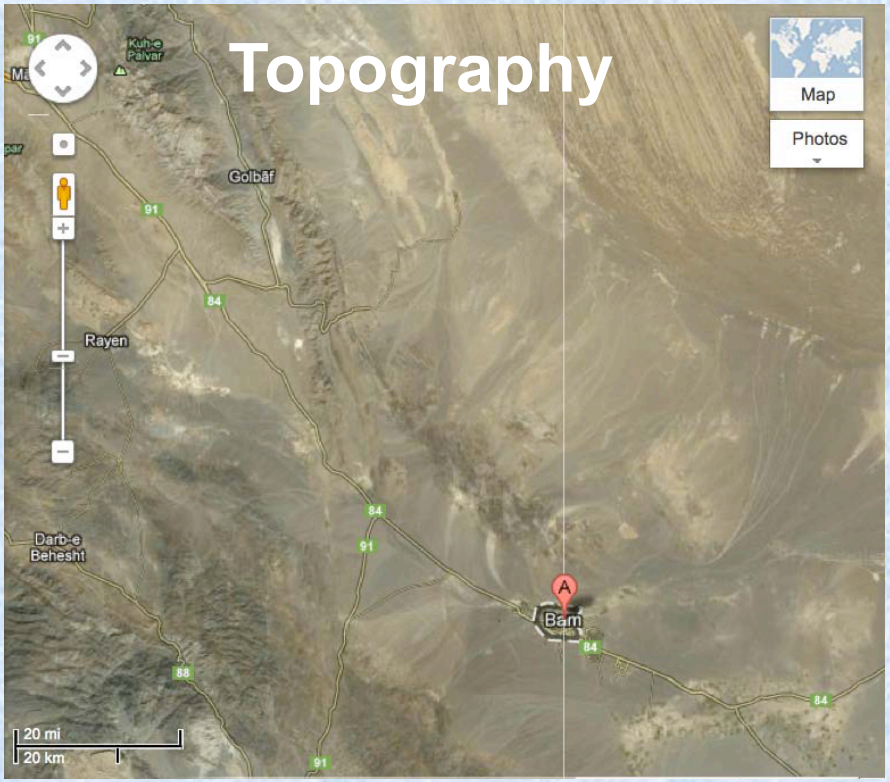
INFRARED EMISSION IN ACTION IN THE FIELD

Night Thermal Gradient map
2 nights before earthquake



Courtesy Nevin Bryant
and Ray Bambery, JPL

Bam earthquake, Iran



Google map of Bam region, SE Iran

Warning Signs for City of Bam

- Strange infrared glow from the mountains
- Strange cloud rising from a point
- Nobody took note and over 20,000 died

IRAN KERMAN

Before Earthquake

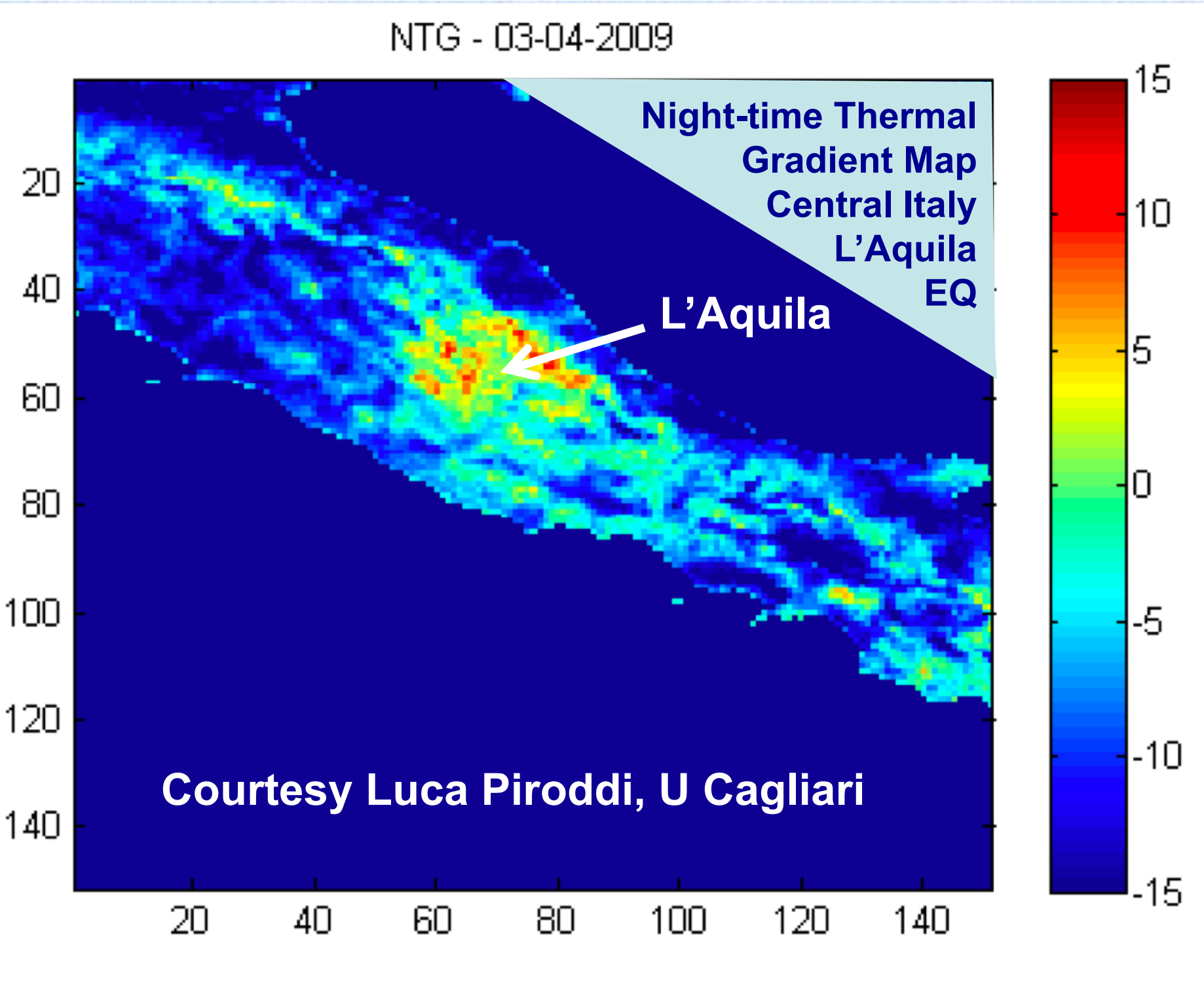
ارگ بم قبل از زلزله

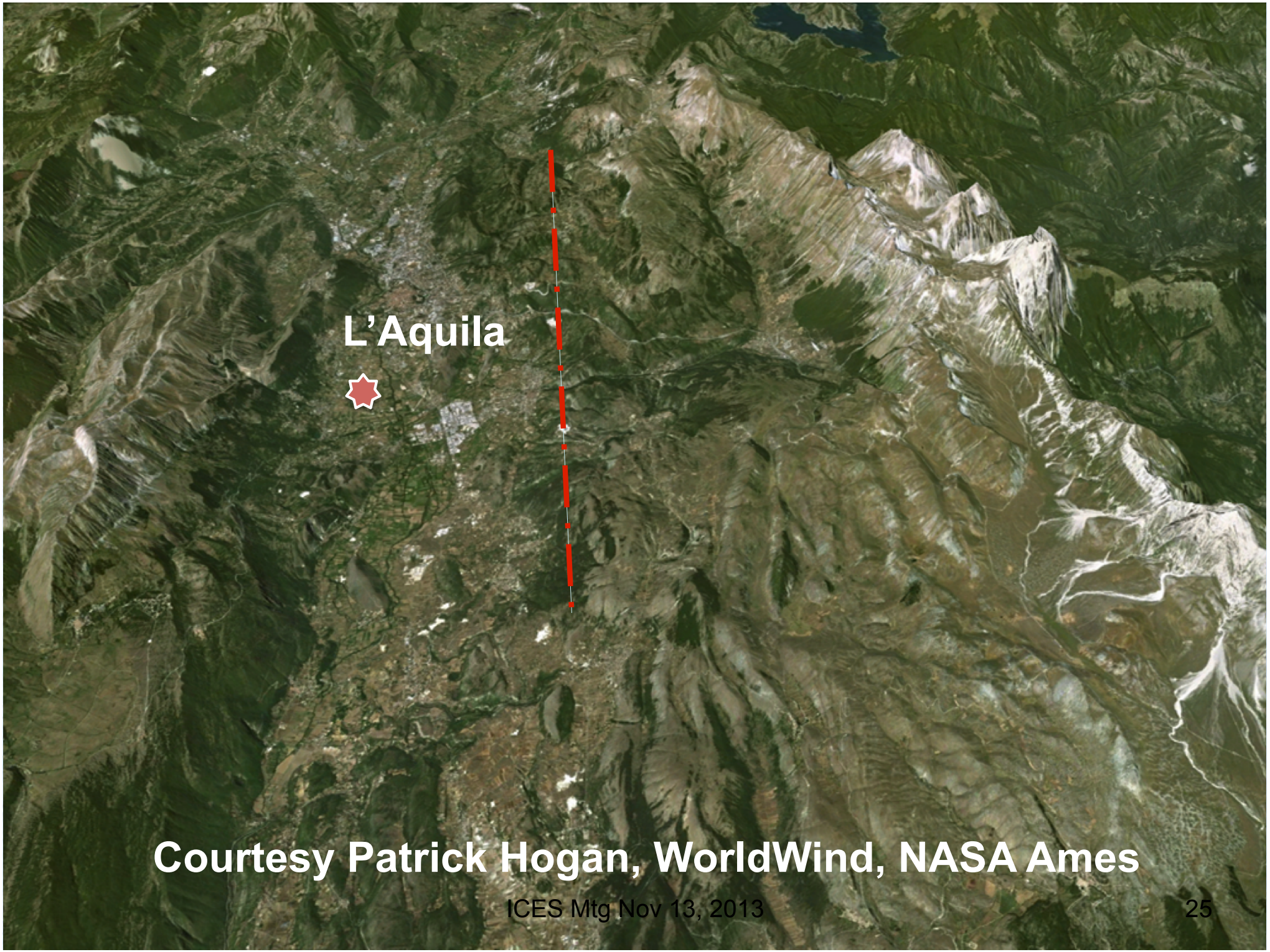
After Earthquake

ارگ بم بعد از زلزله

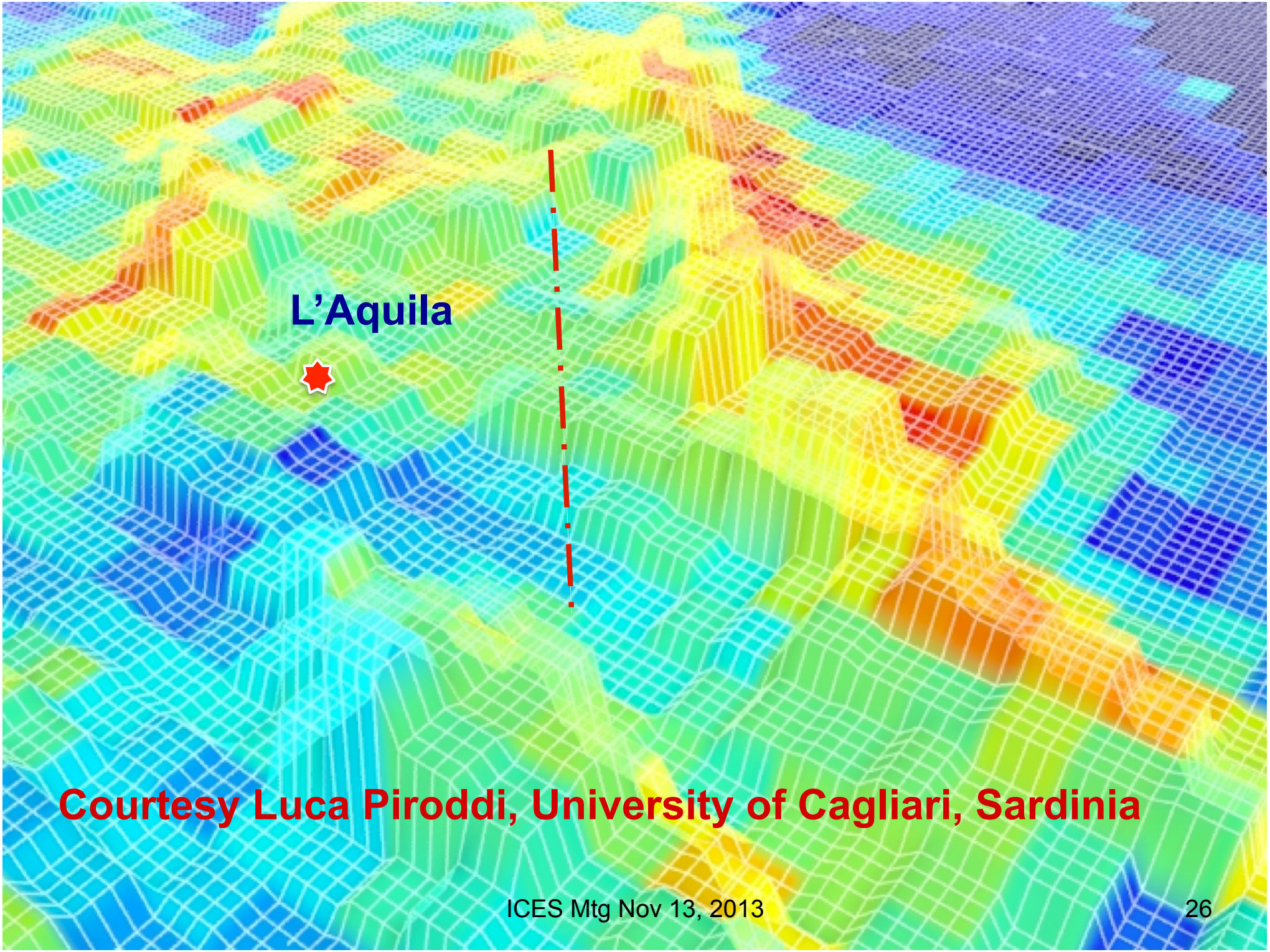
سازمان ایرانگردی و جهانگردی استان کرمان
IRAN TOURING AND TOURISM ORGANIZATION
KERMAN PROVINCE
www.kermantourism.ir

WWW.PEZHMAN.COM


NTG - 03-04-2009
Night-time Thermal
Gradient Map
Central Italy
L'Aquila
EQ
L'Aquila
Courtesy Luca Piroddi, U Cagliari
20
40
60
80
100
120
140
15
10
5
0
-5
-10
-15

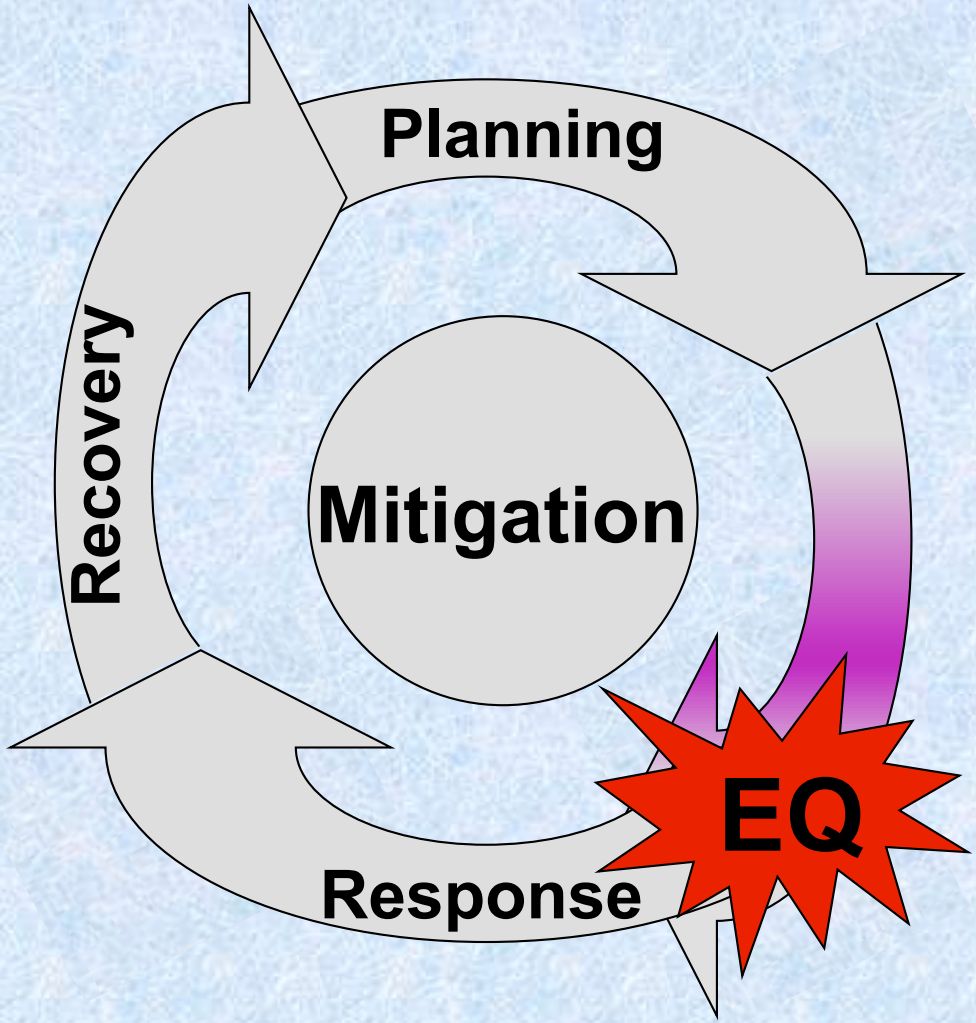


Courtesy Patrick Hogan, WorldWind, NASA Ames



Courtesy Luca Piroddi, University of Cagliari, Sardinia

a final thought…
Future Disaster Management Cycle



Monitor pre-EQ signals

The basic physics that controls the generation of pre-EQ signals has been solved,

(at least in its most important aspects)

We are ready to begin implementing Global Earthquake Forecasting System

Actionable EQ Forecasting System

- is possible
- lies within technical reach
- will combine many more pre-EQ signals
- will provide 24-48 hrs warning
- is financially attractive
- would be politically smart
- economically, it's a no-brainer

Conclusions

- Positive hole charge carriers exist in Earth's crust
- Positive holes are activated by stress
- Positive holes have lifetimes from subsecs to hrs
- Positive holes hold the key to understand a wide range of pre-earthquake processes
  - inside the crust
  - at the ground-to-water interface
  - at the ground-to-air interface
  - all the way up to the ionosphere

SETI Institute
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NASA Ames Research Center

San José State University
Physics Department

Hyperspectral 7-14 μm Imager

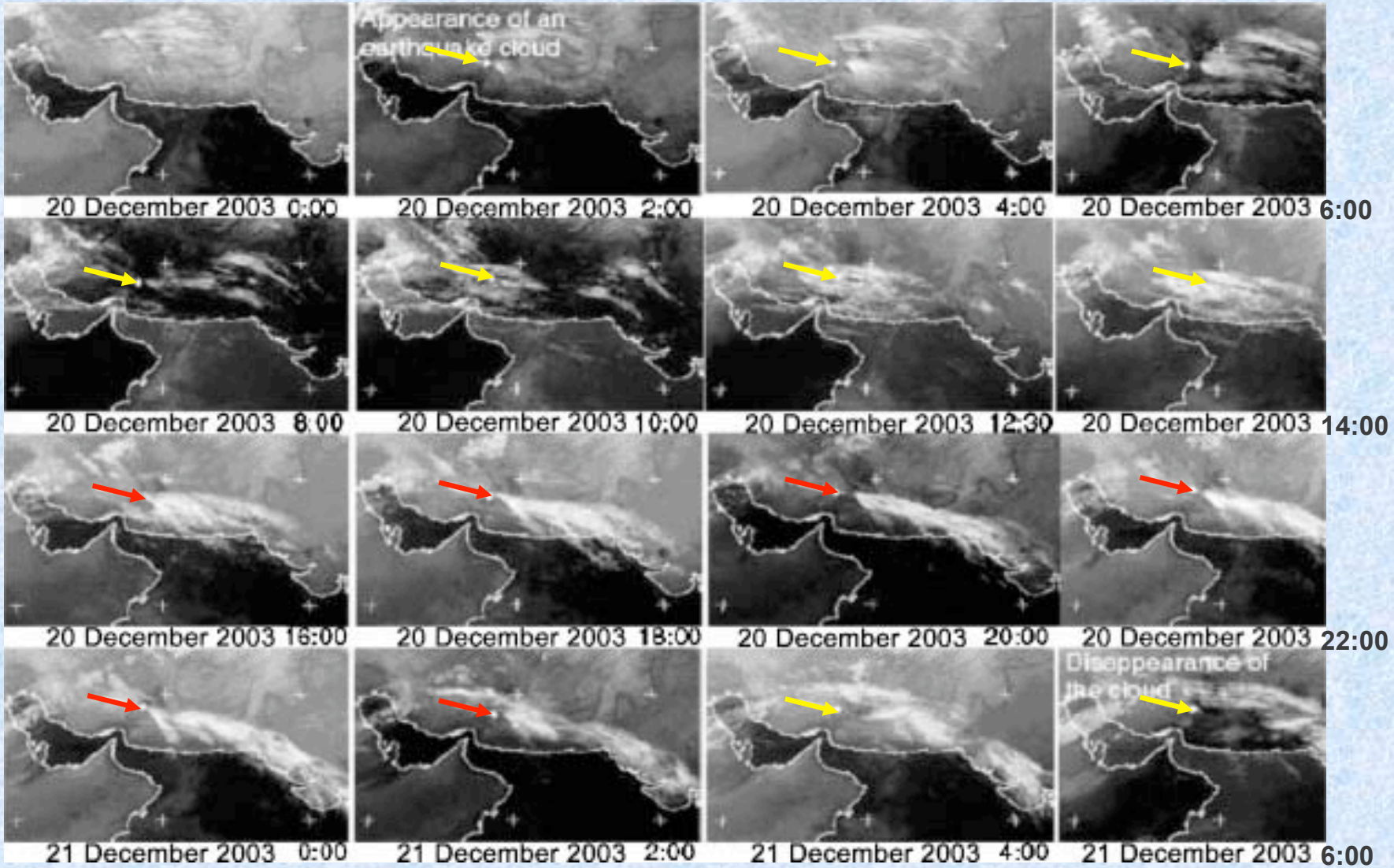
- **Proposal by Aerospace Corp (13-IIP13-0066)**
  P.I. David Tratt, Sci-P.I. Friedemann Freund
- **Cost: $4M over 3 yrs**

- **In the meantime we can do Night-time Thermal Gradient Maps with existing weather satellites**
- **Cost: $0.8 to 1.2M/yr**

1. **Ionosphere anomalies** ~~These~~ are detectable typically 3-5 days before major earthquakes. The anomalies in the ionosphere consist of increases in the Total Electron Concentration (TEC) at the lower edge of the ionosphere, best measured during night-time when the effects of the solar radiation on the ionosphere are fading away. They can be recorded by at least three techniques (i) using existing GPS technology to reconstruct a tomographic images of the ionosphere over seismically active regions; (ii) using "over-the-horizon" FM radio wave transmission to detect changes in the morning or evening terminator times; and (iii) using long-distance AM radio waves reflected off the ionosphere over the seismically active region.
2. **Thermal Infrared (TIR) anomalies** ~~TIR anomalies~~ consist of increases to (i) the radiative temperature of the ground and (ii) the radiative temperature at the top of the clouds, also known as Long Wavelength Infrared anomalies. TIR anomalies mark the impending earthquake's epicentral region and become detectable typically 3-5 days before major earthquakes. They can be detected by various satellite-borne infrared cameras or by hyperspectral infrared imagers. Medium resolution detection is currently possible using MODIS data on the NASA satellites TERRA and AQUA, providing one data point during the day and one during the night per each 24-hour period. Even low resolution detection is possible using geostationary weather satellite data by determining the slope of the night-time cooling curves from IR images every 15-30 min. Satellite with hyperspectral capabilities are not yet available but AeroSpace Corp is interested in developing such an imager for geostationary deployment.
3. **Anomalous CO** release from the ground is currently retrievable from the MOPPIT sensor onboard the NASA satellites TERRA and AQUA providing one daytime data set per 24 hours.
4. **Increase in positive and negative air ion concentrations** using networks of ground stations typically 100-200 km apart.
5. **Changes in the total magnetic field intensity**, x, y, z-components to be measured by ground stations less than 100 km apart.
6. **Emission of ultralow frequency (ULF) electromagnetic (EM) waves** from the ground. Both of these unipolar pulses typically last 100 msec to 1-2 sec.~~,~~ Continuous ULF wave trains last minutes to hours, and their x, y, z-components can be measured by ground stations typically less than 100 km apart.
7. **Regional changes in radio frequency noise** at different frequencies from very low to medium low (VLF-LF).
8. **Soil resistivity changes** can be detected 1-2 m deep as measured by 4-point ground electrode systems, less than 100 km apart.
9. **Radon emanation** from the ground by stations, typically less than 100 km apart.
10. **Changes in water chemistry** at commercial natural spring water bottling companies or from ground water wells, typically less than 100 km apart.
11. **Noticeable changes to the circadian rhythm studies** being carried out 24/7 at universities, hospitals and zoos, using well-kept laboratory animals.
12. **Hospital records** with emphasis on increasing numbers of Emergency Room calls related to central nervous system disorders.

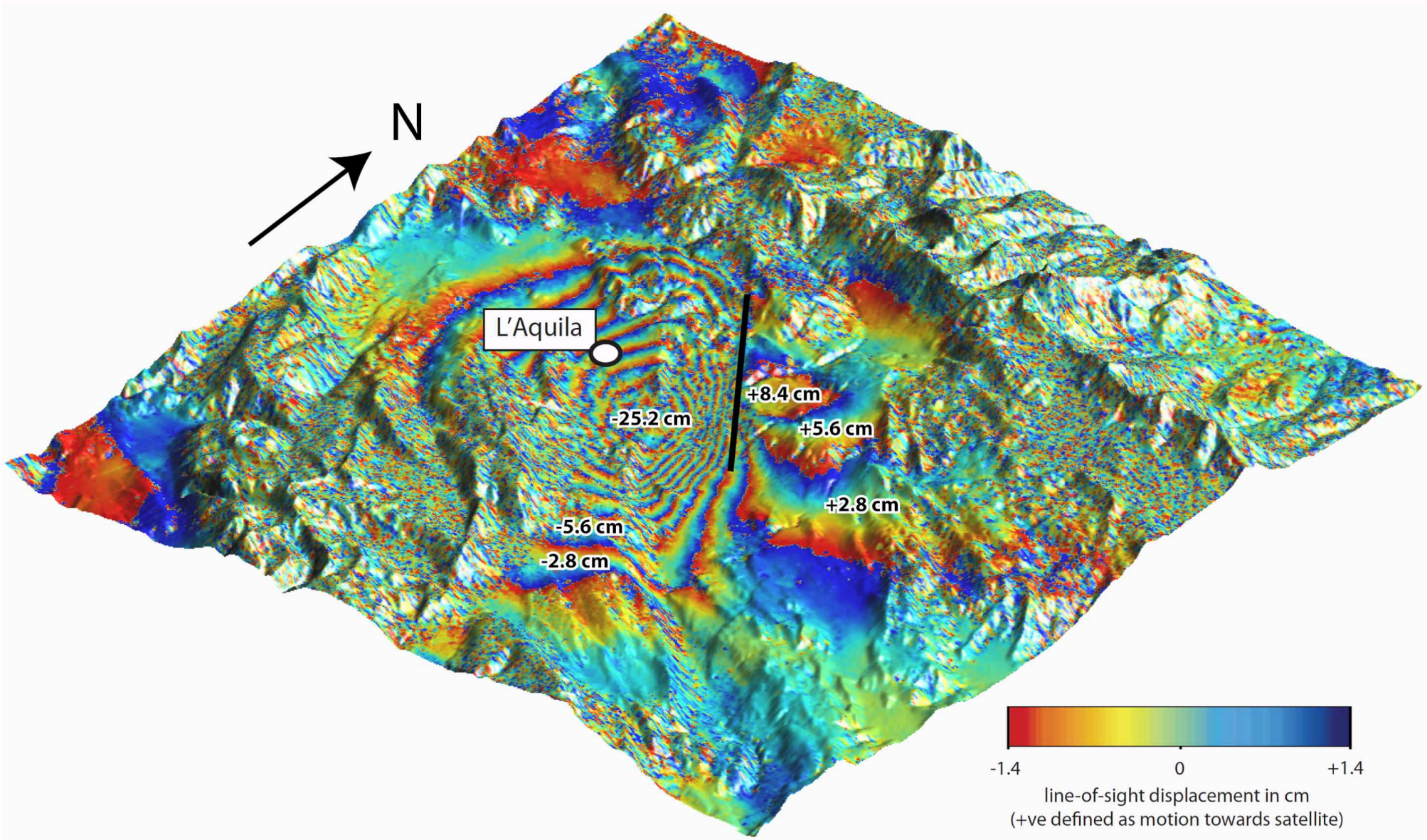
Back-up Slides

Strange cloud over Bam, Iran: MeteoSat

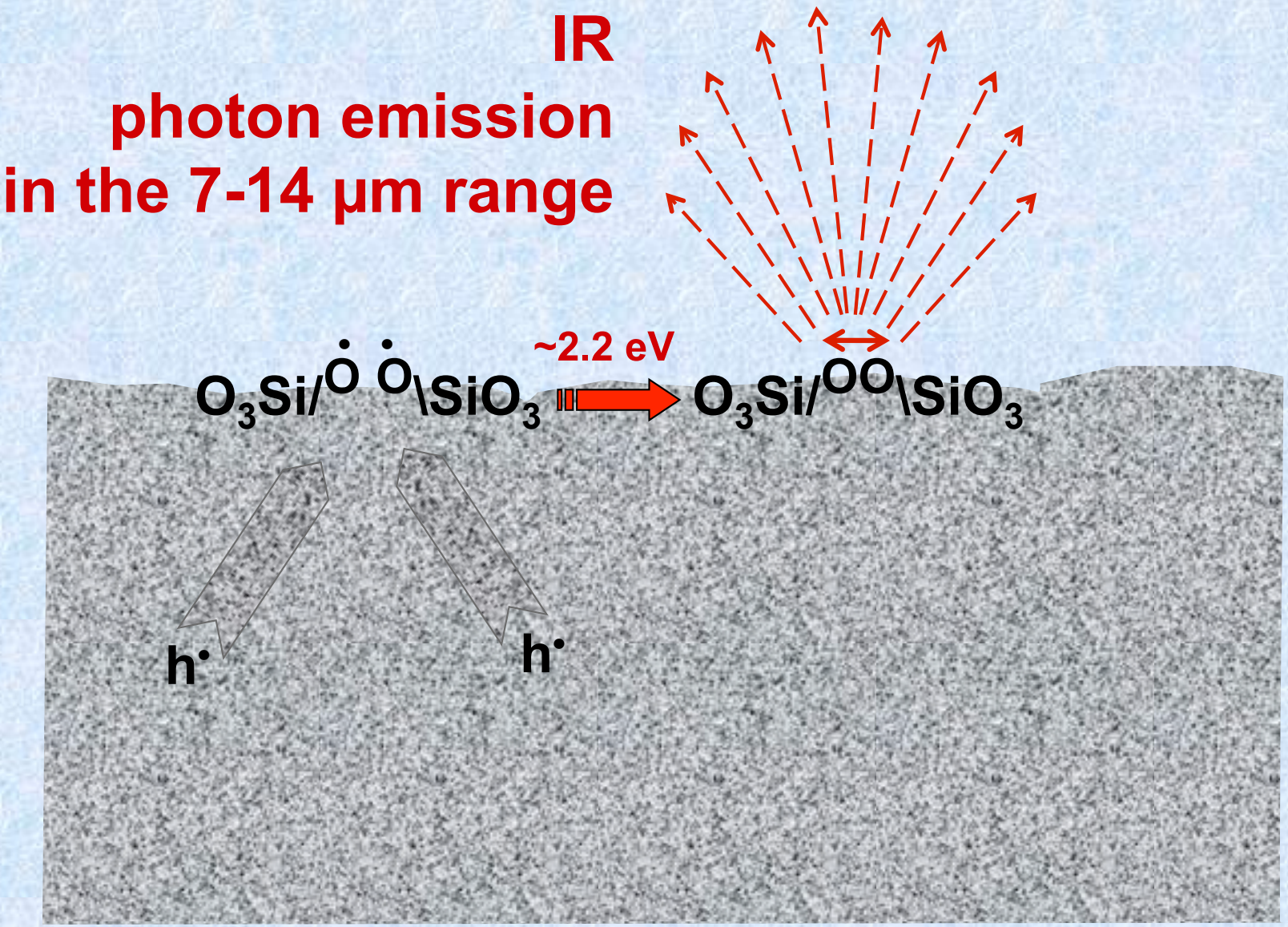


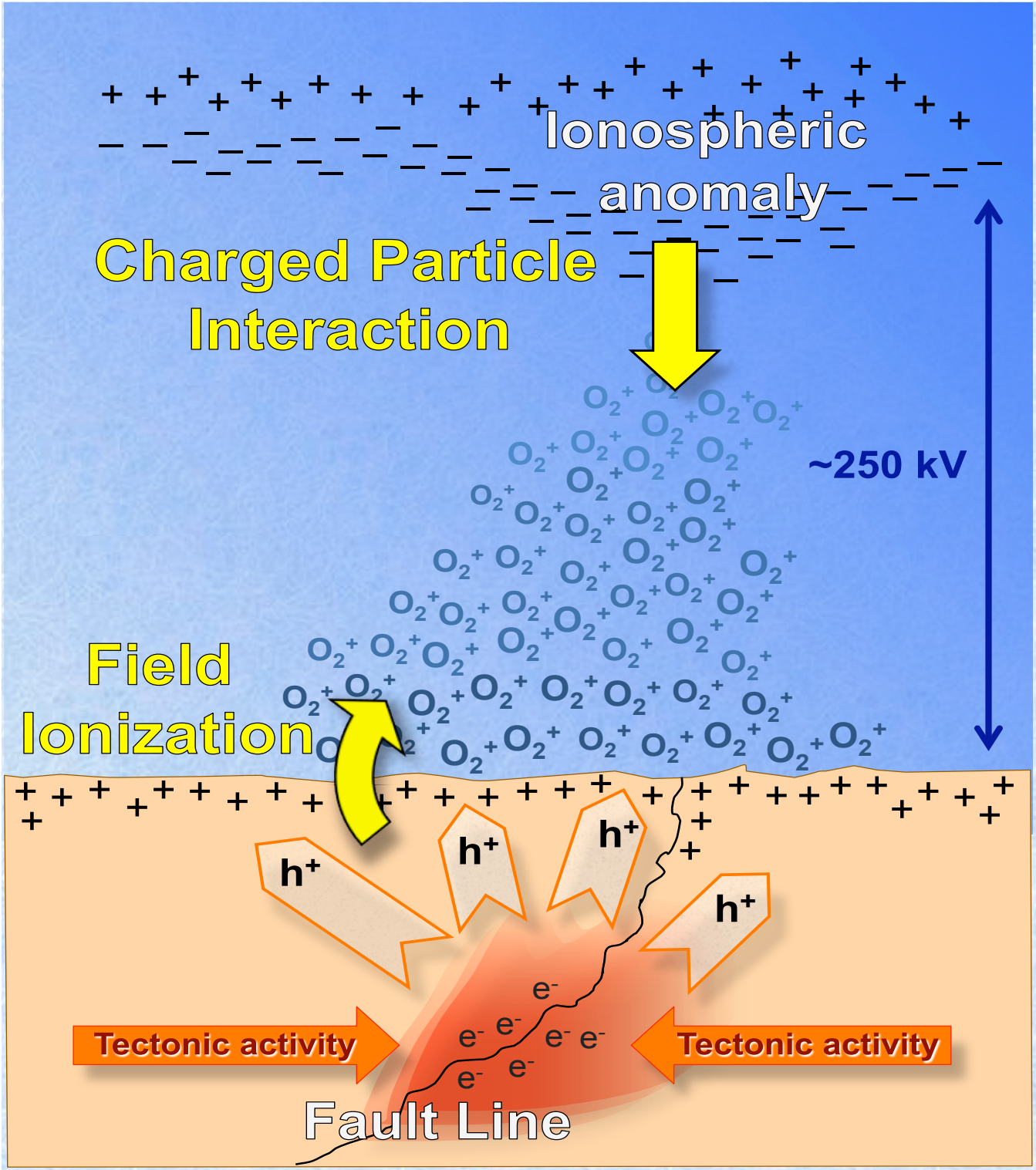
Courtesy Shou Zhonghao after Guangmeng Guo & Bin Wan 2008

Bam Earthquake M=6.8, Iran, Dec. 26, 2003


N
L'Aquila
-25.2 cm
+8.4 cm
+5.6 cm
+2.8 cm
-5.6 cm
-2.8 cm
-1.4
0
+1.4
line-of-sight displacement in cm
(+ve defined as motion towards satellite)

Pairwise Surface Recombination of h•





Stresses deep below activate electronic charge carriers.

Positive.

Flow to the surface.

Ionize the air.

Positive air ions.

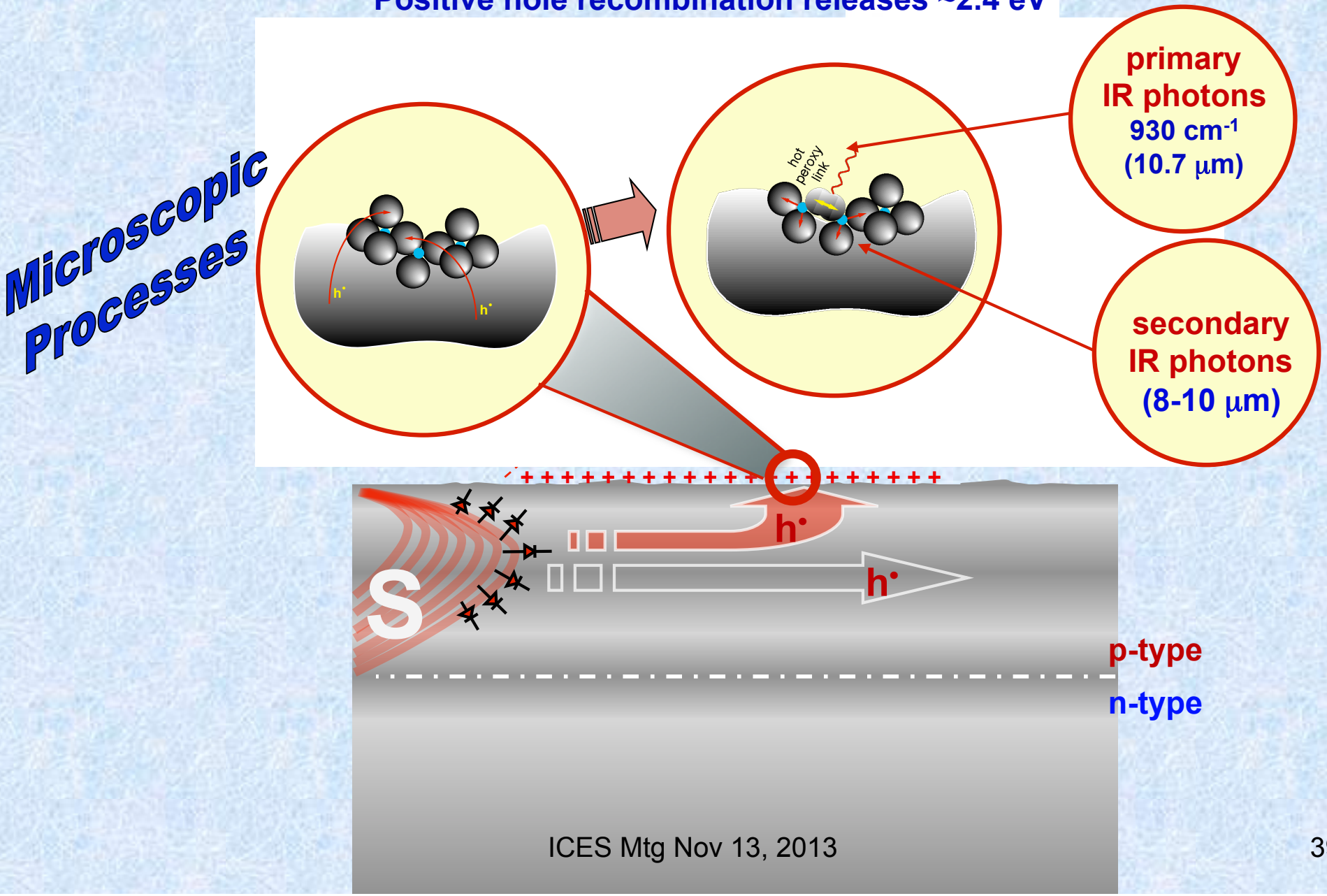
Air bubble rises.

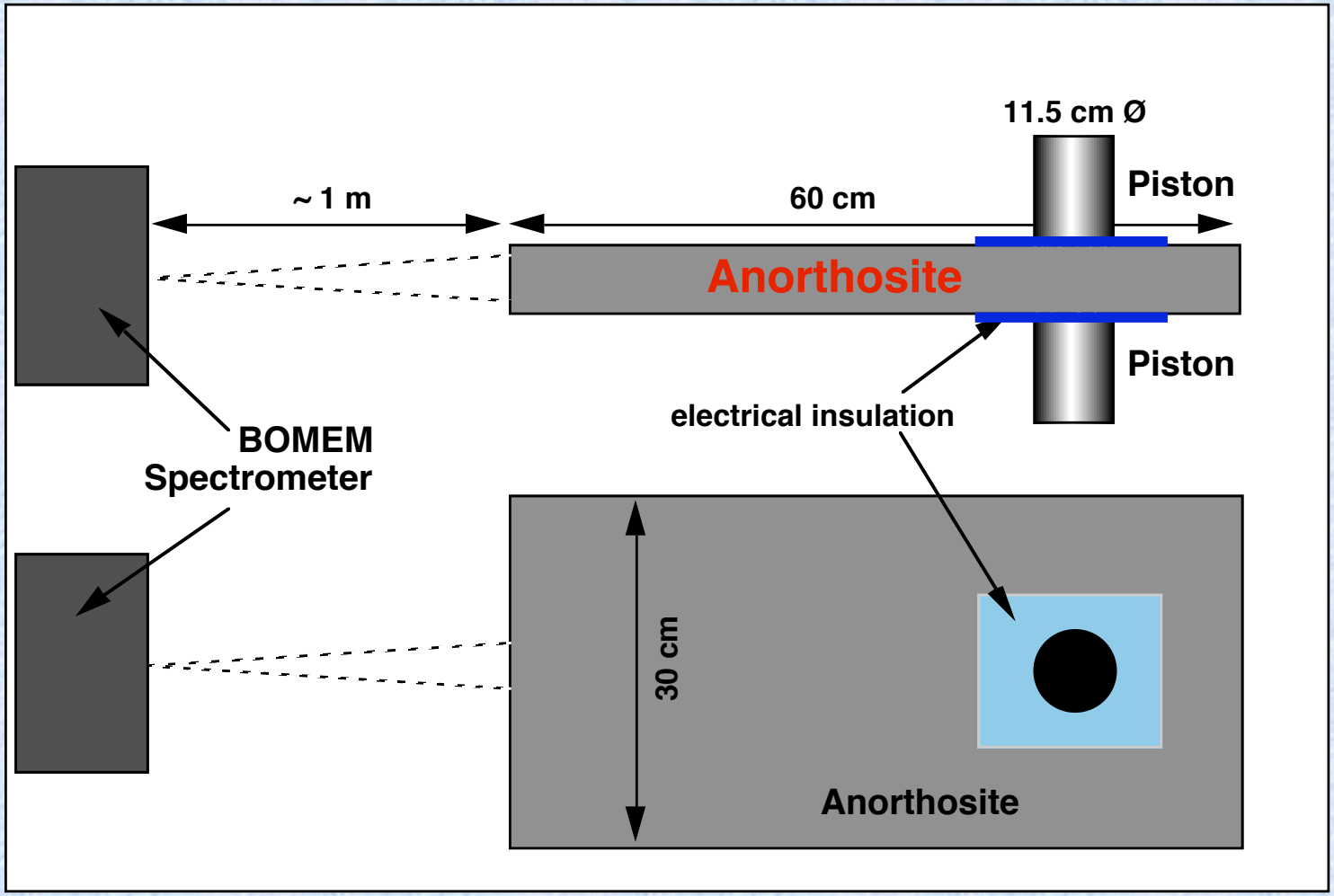
Electrons in the ionosphere come down.

If an M 7 earthquake releases
energy equivalent to
more than 2,000 Hiroshima A-bombs,
it is inconceivable
that it will not produce
some detectable precursory signals

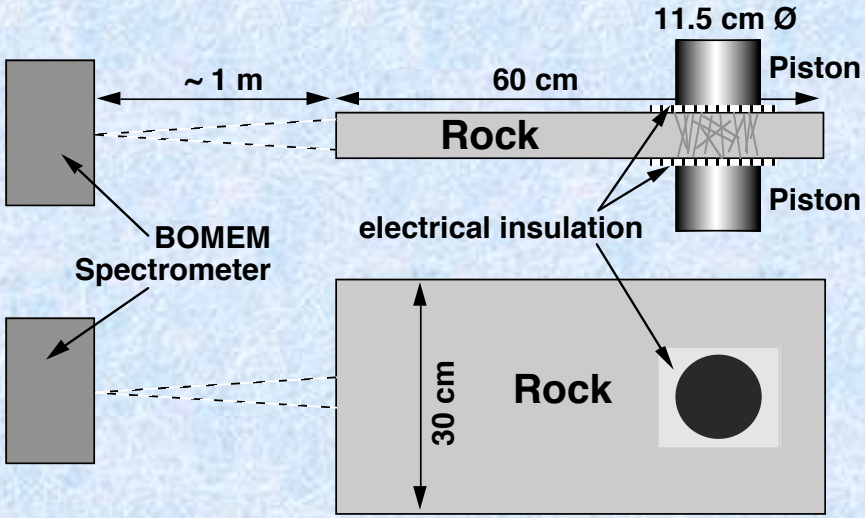
Microscopic Processes

Positive hole recombination releases ~2.4 eV



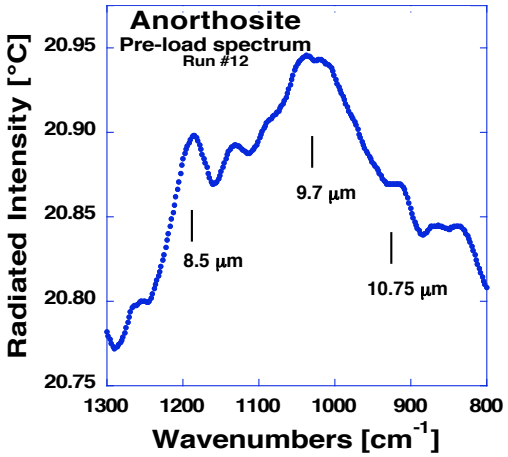

11.5 cm Ø
Piston
~ 1 m
60 cm
Anorthosite
Piston
electrical insulation
BOMEM
Spectrometer
30 cm
Anorthosite

Stimulated IR emission due to h• recombination

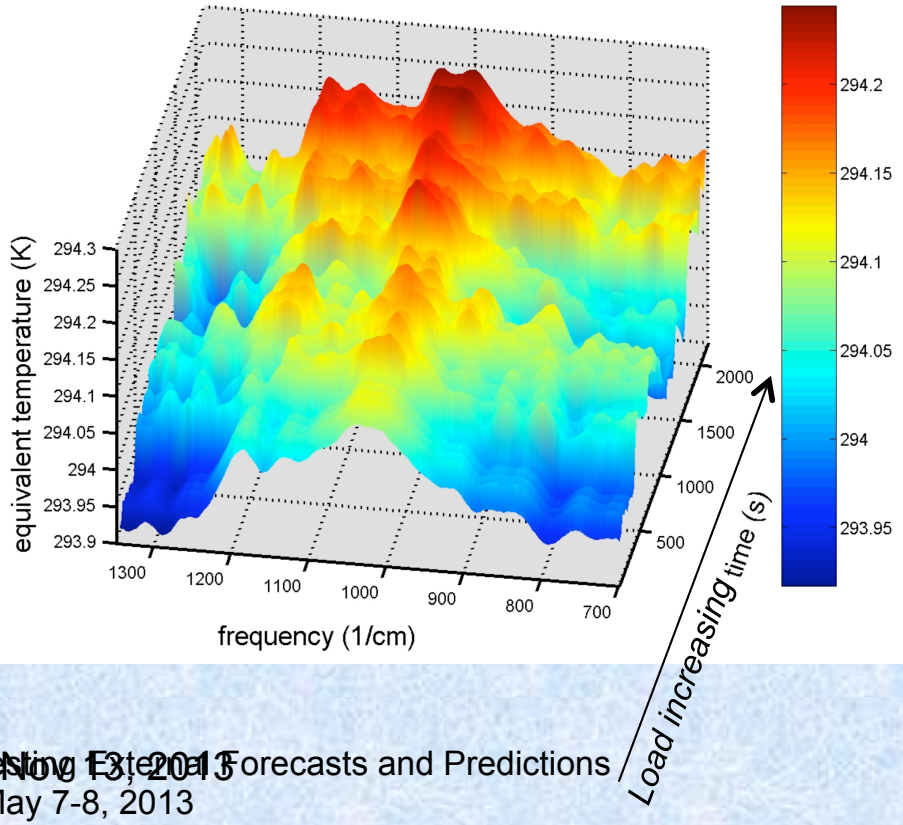


Anorthosite rock stressed at one end

300K IR emission spectrum

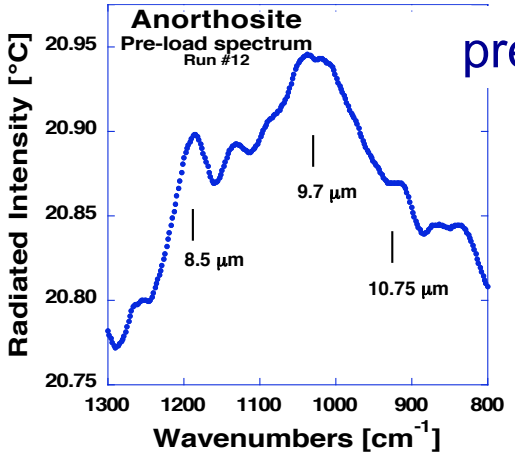


Stimulated IR emission during loading up to failure within 30 min

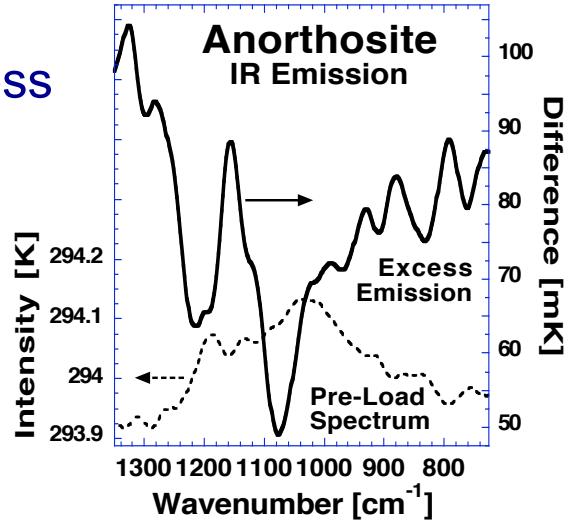


Stimulated IR emission due to h• recombination

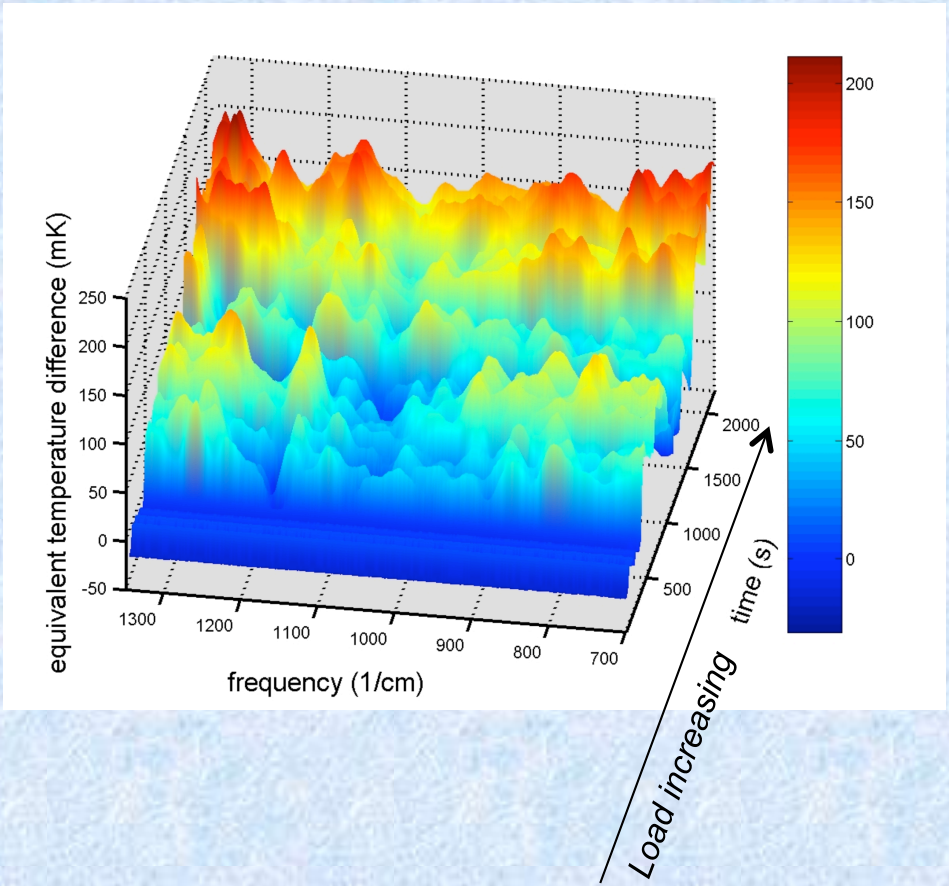
pre-load



excess

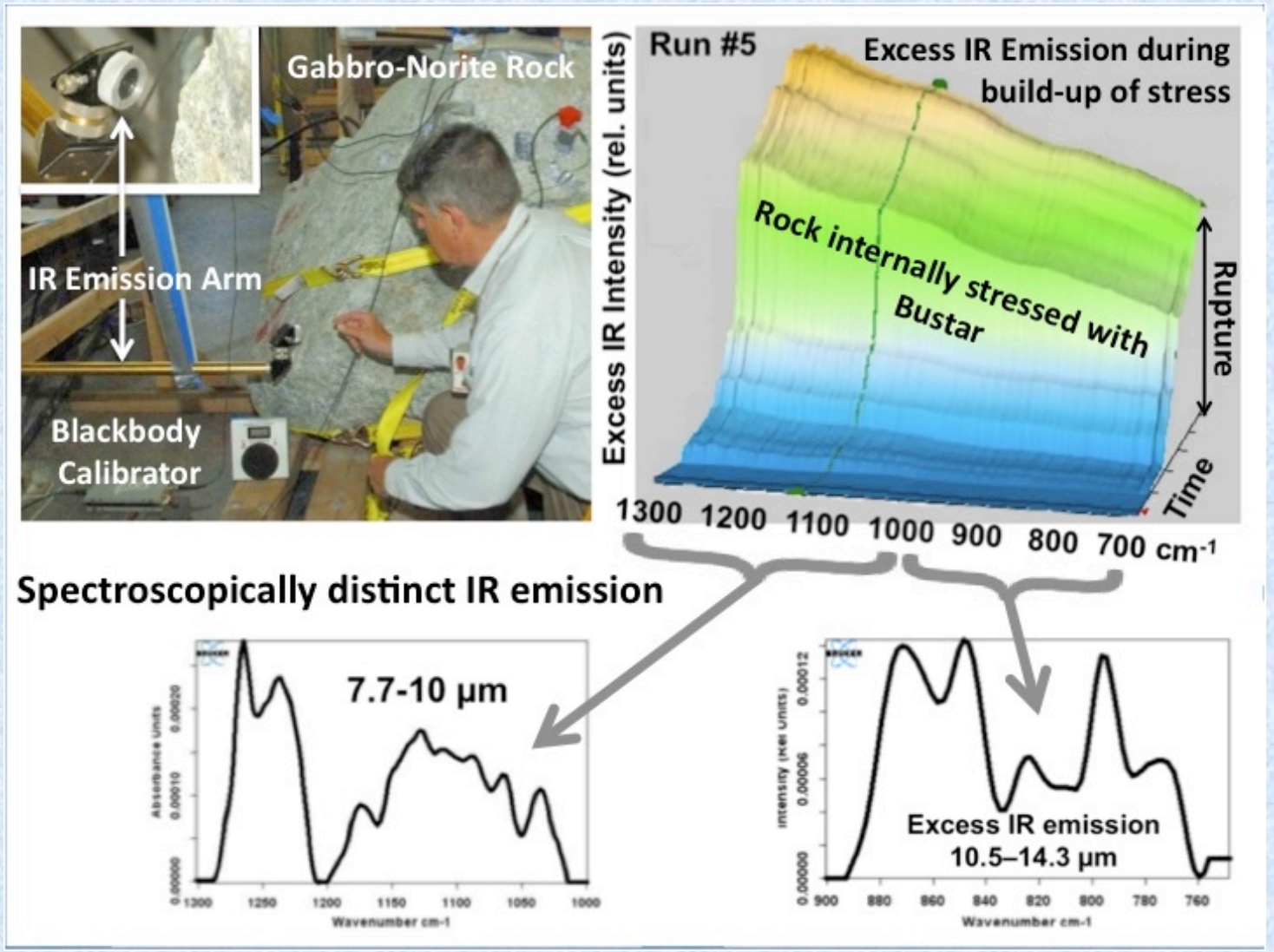


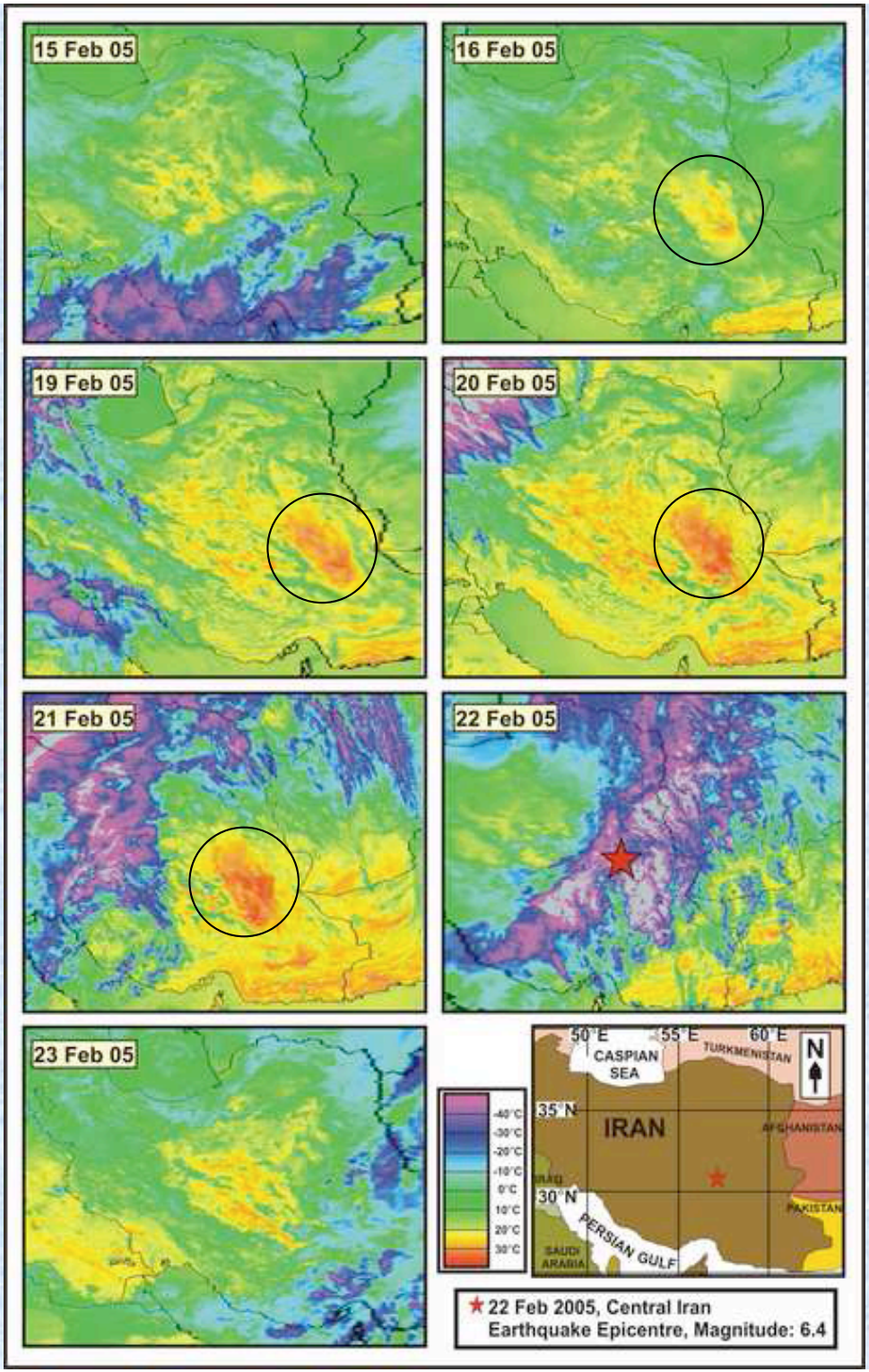
Excess spectroscopically distinct IR emission during loading up to failure within 30 min



INFRARED EMISSION IN ACTION IN THE LAB

4 ton boulder, stressed on far end by BUSTAR, begins to shine in the mid-IR



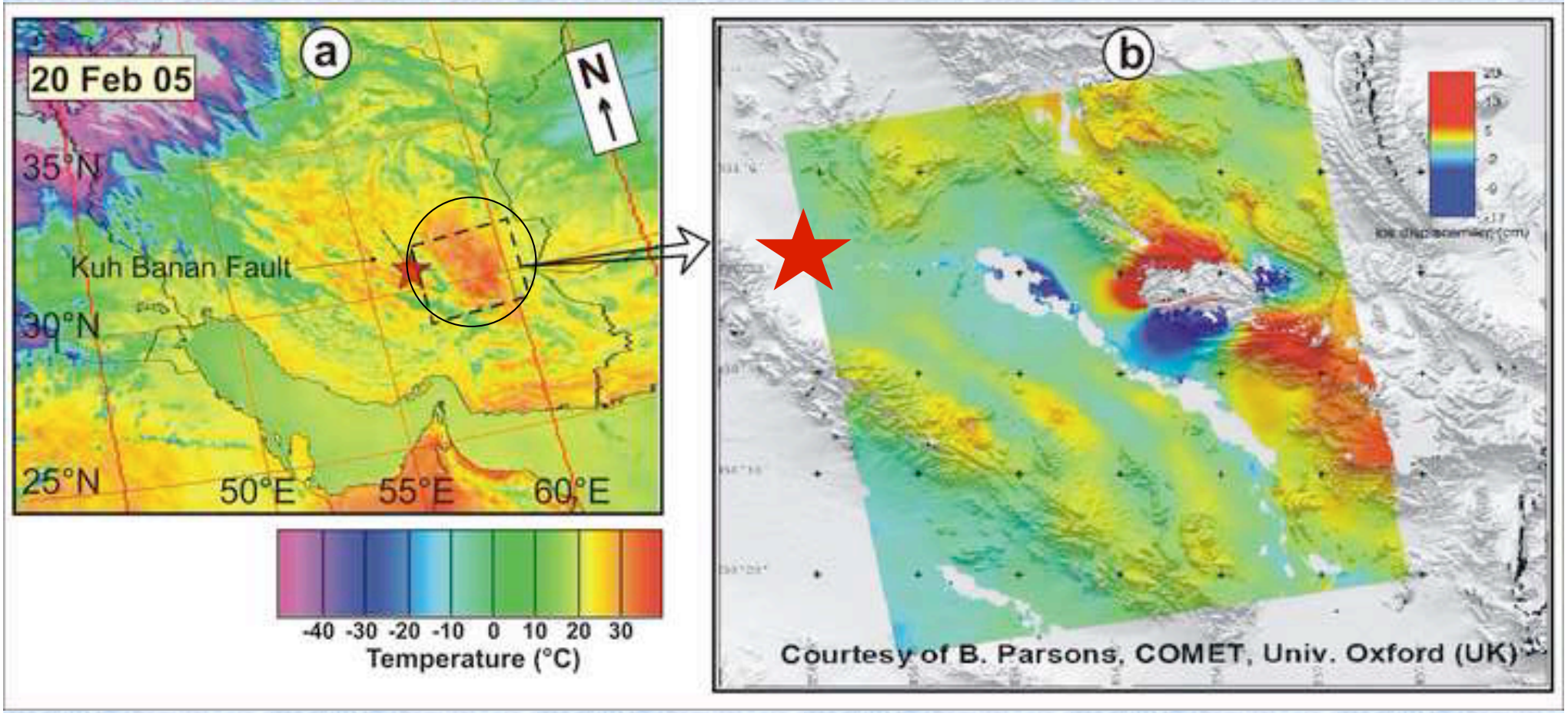


Magnitude 5.4 event in SW Iran

22 Feb. 2005

Desert
Ideal viewing conditions (similar to Southern CA)

NOAA AVHRR satellite



Temperature map from pre-EQ NOAA AVHRR Satellite Data

Vertical ground elevation change from post-EQ minus pre-EQ InSAR data

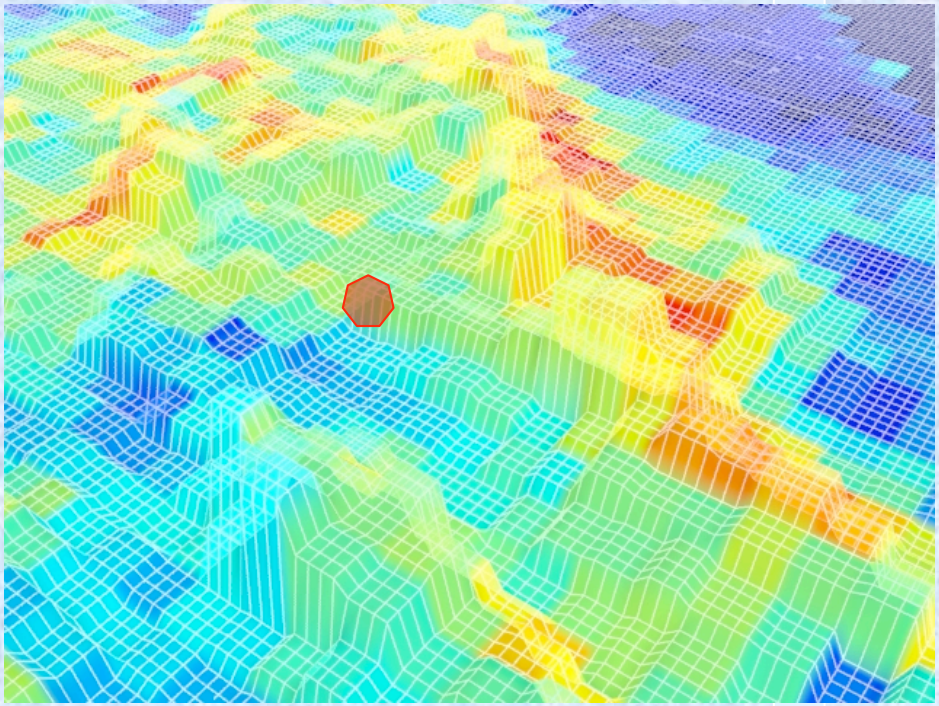
The Earth is stranger than we give it credit for

John Derr

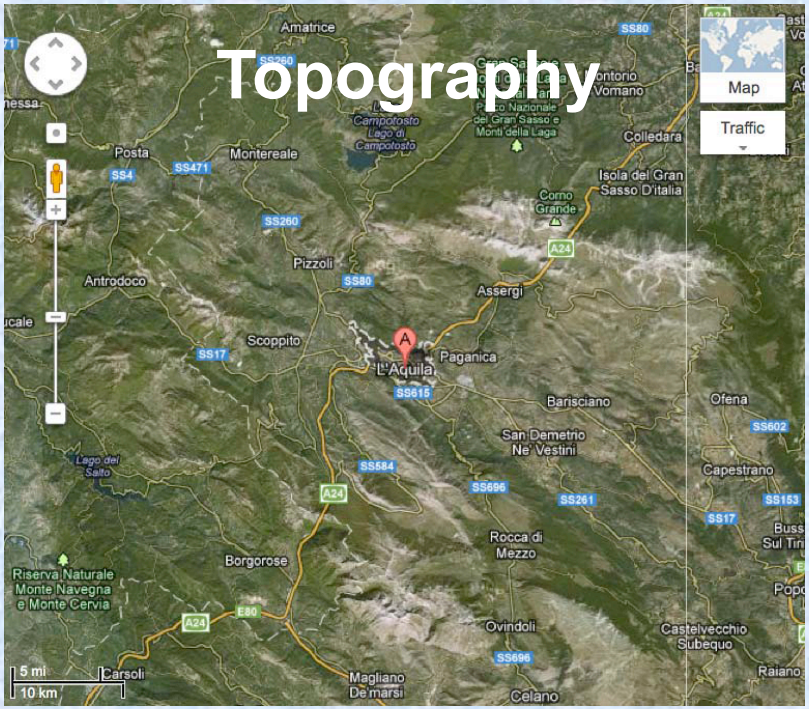
former Head of the USGS Global Seismographic Network

Example 2: L'Aquila earthquake, Italy

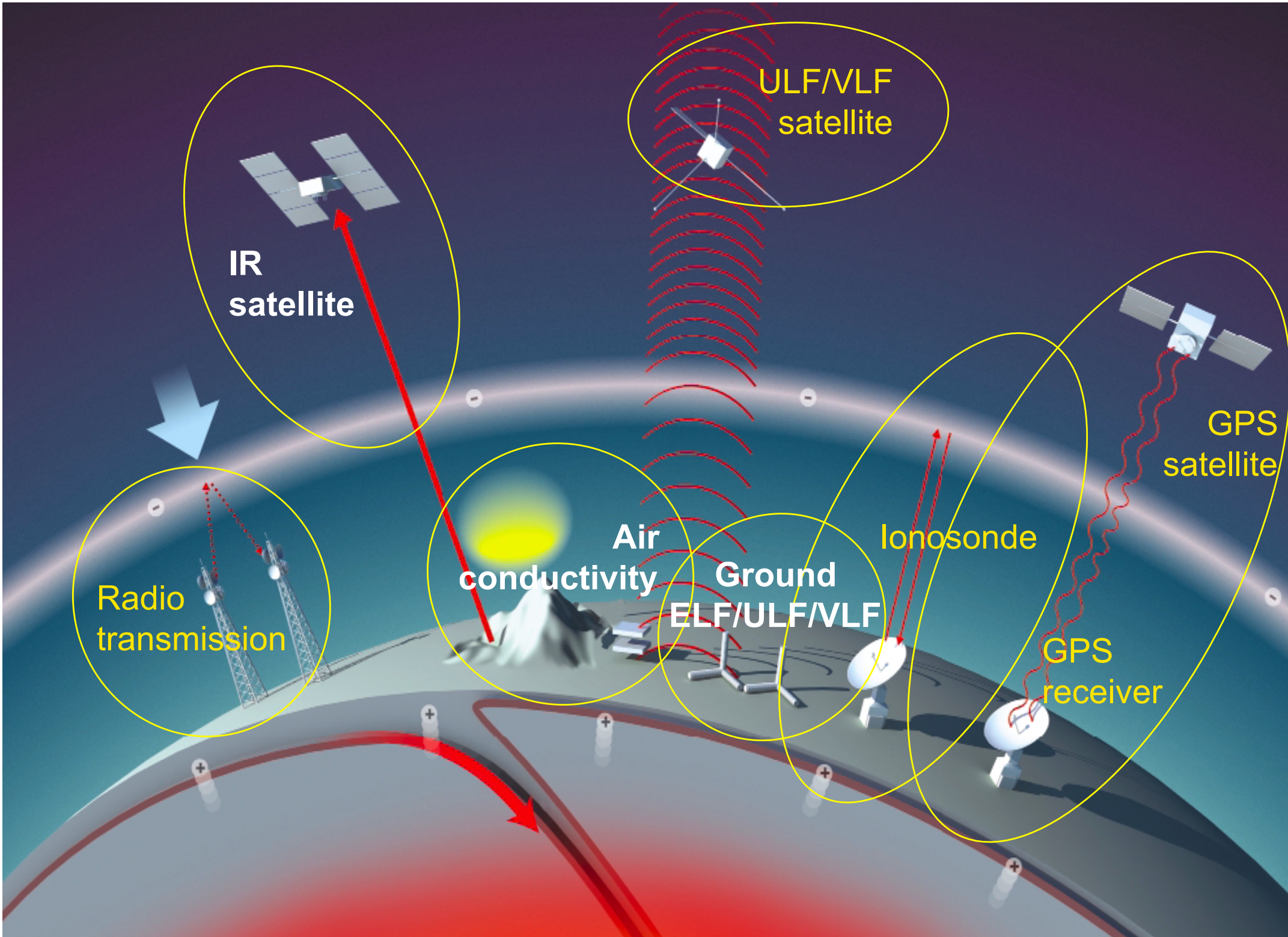
Night Thermal Gradient map
2 nights before the earthquake



USGS Digital Elevation Map projected onto Meteosat cells
by Eumetsat LSASAF with NTG coloring (IEEE JSTARS 2011)
Courtesy: Luca Piroddi & Gaetano Ranieri U of Cagliari, Italy



Google map of L'Aquila region, Italy


ULF/VLF
satellite
IR
satellite
GPS
satellite
Radio
transmission
Air
conductivity
Ground
ELF/ULF/VLF
Ionosonde
GPS
receiver