Where do we go from here?

The Big Problems in sensor networks

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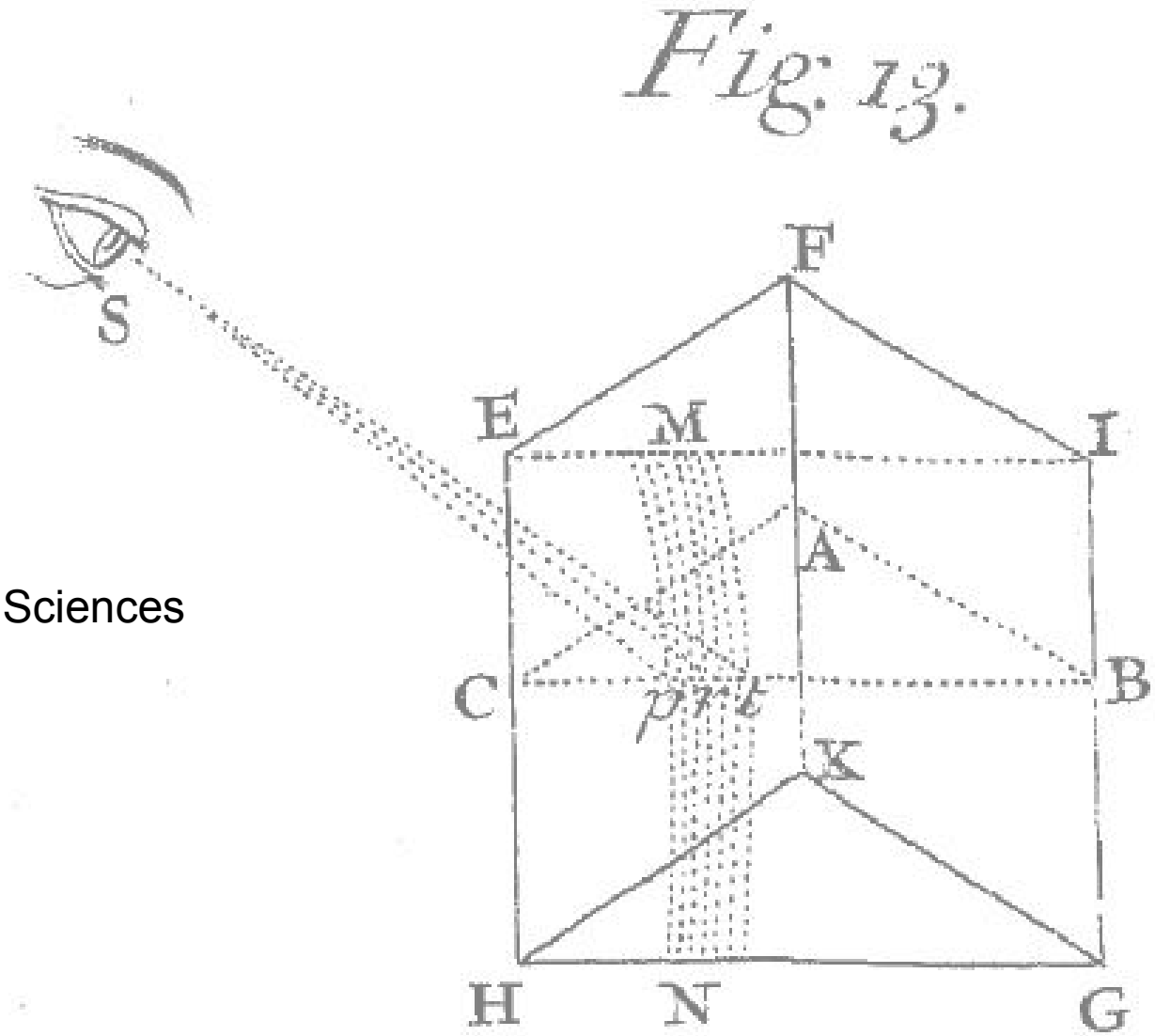
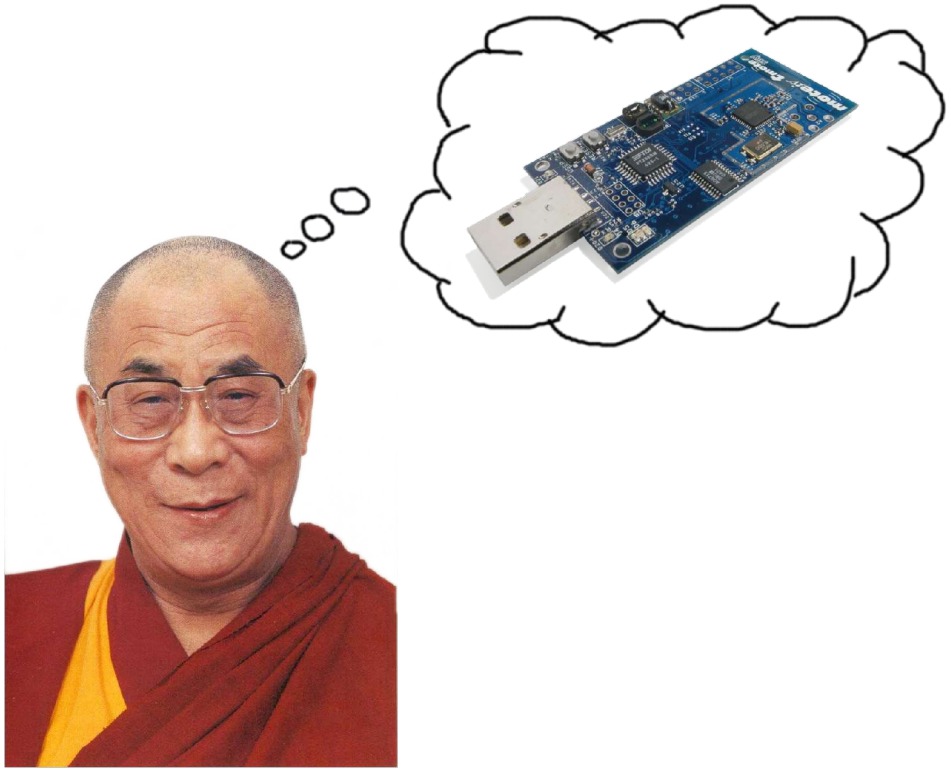


Introduction

I want to ask the question:

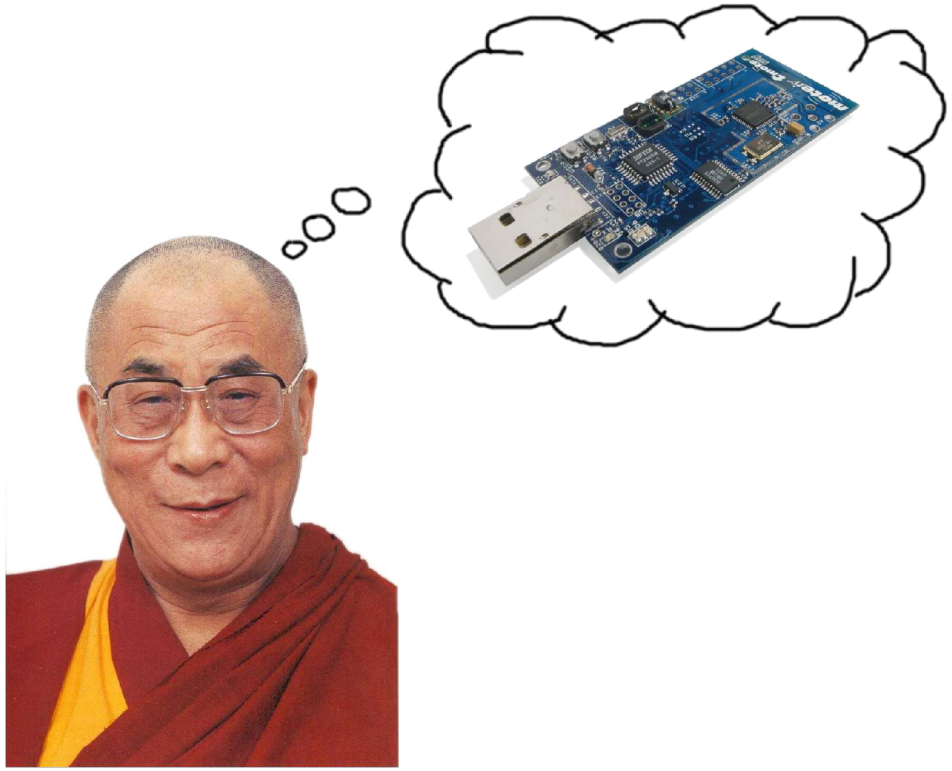
How can sensor networks *really* change the world?



Introduction

I want to ask the question:

And what do we need to do to get there from here?



Basic outline

Where can sensor networks *deeply* impact science and medicine?

Some examples from my own research:

- Monitoring volcanic eruptions in Ecuador
- Wireless sensors for medical care

Some examples from other research groups.

What are the big problems that we now face?

- 1) Programming the network as a whole.
- 2) Tools for managing limited resources.
- 3) Connecting sensor networks to the rest of the Internet.

The Macroscope

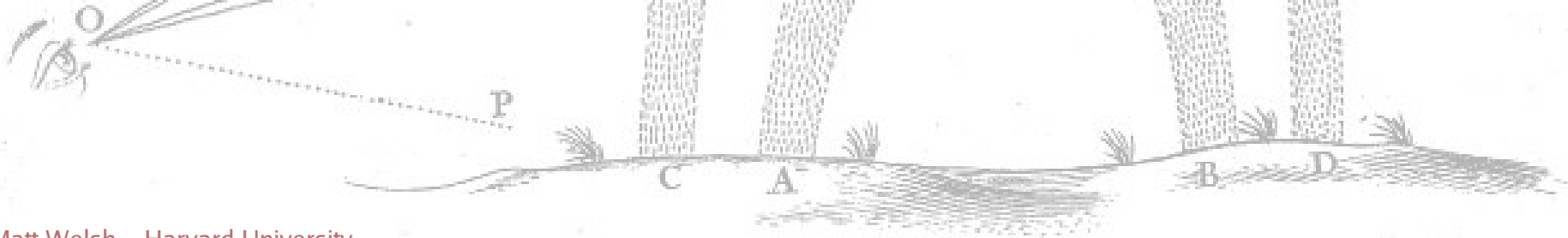
For the first time, sensor networks allow us to:

1) Observe the world (environment, buildings, people, etc.) at very *high spatial resolutions*;

2) Make these observations *continuously*; and

3) Collect the observations in *digital form*.

Some have referred to this concept as a "macroscope" -- a scientific instrument that observes entire systems.



Intelligent Instrumentation

Sensor networks are not just passive instruments!

We can push processing and “intelligence” into the network.

Processing can happen at many levels:

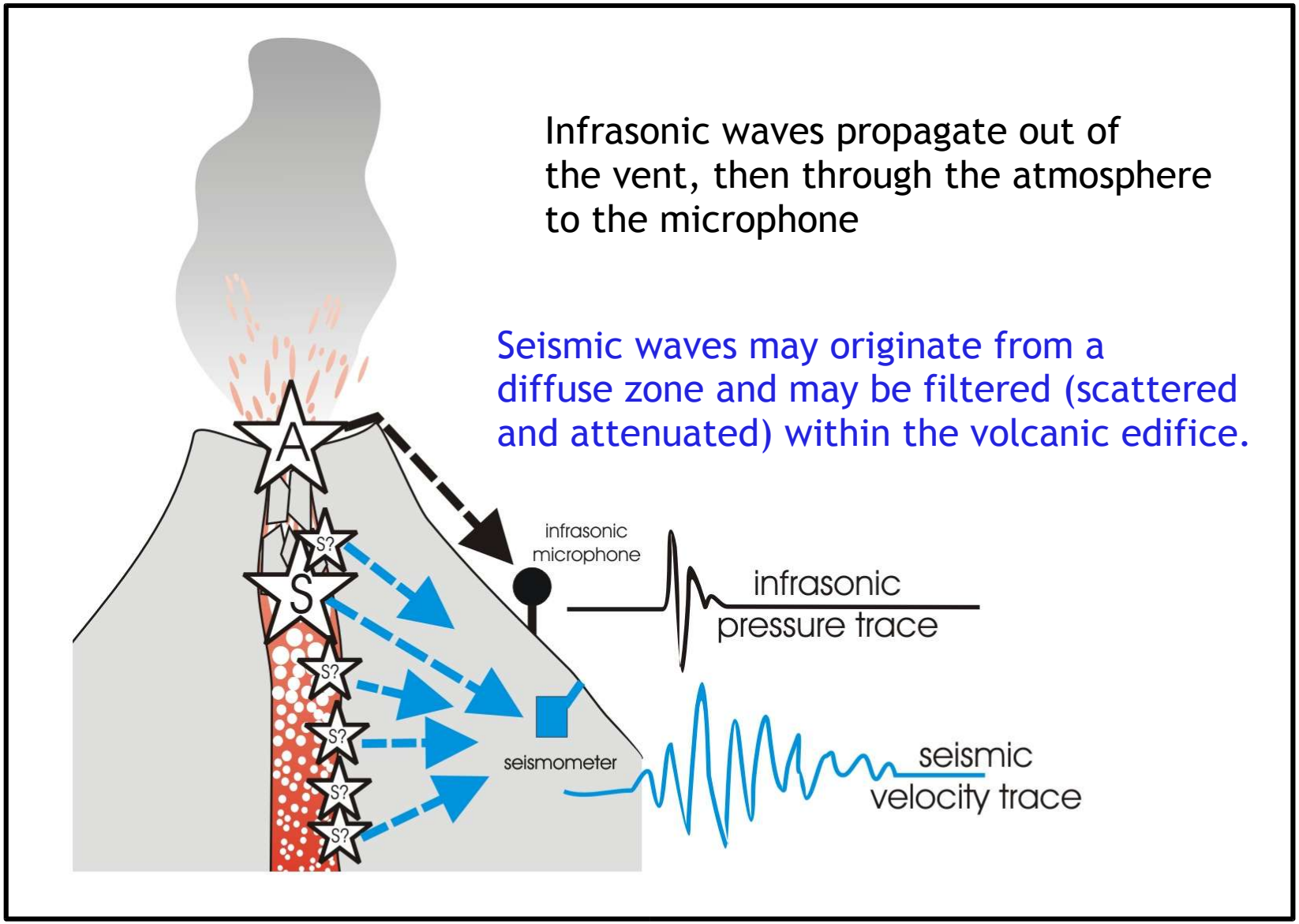
- On individual sensor nodes.
- At aggregation points within the network.
- At the base station or gateway.

Sensor networks fundamentally change the notion of “scientific observation” from a *passive* process to an *active* one.

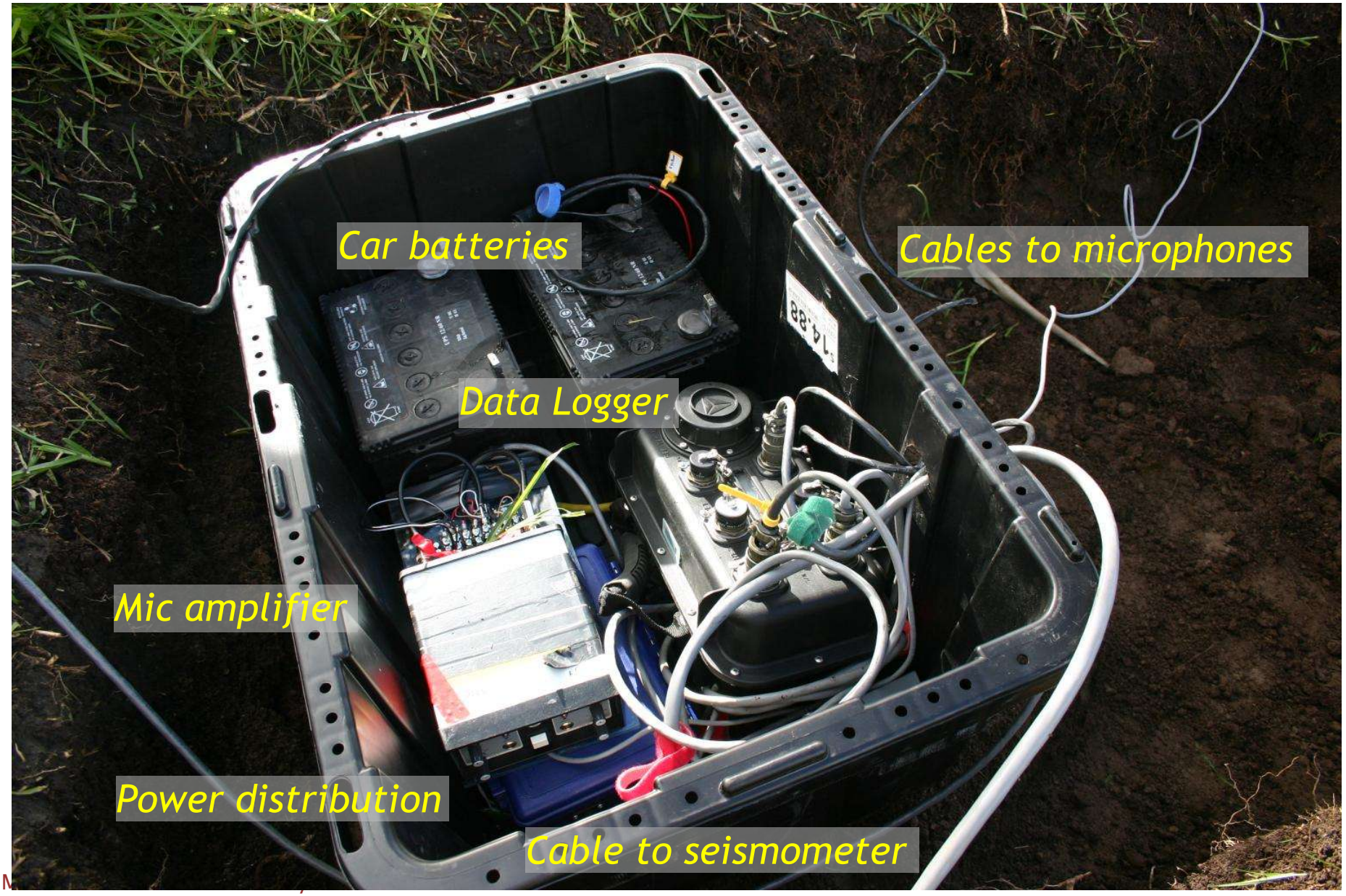
- This has a deep impact on many aspects of science.

Example: Monitoring Volcanic Eruptions

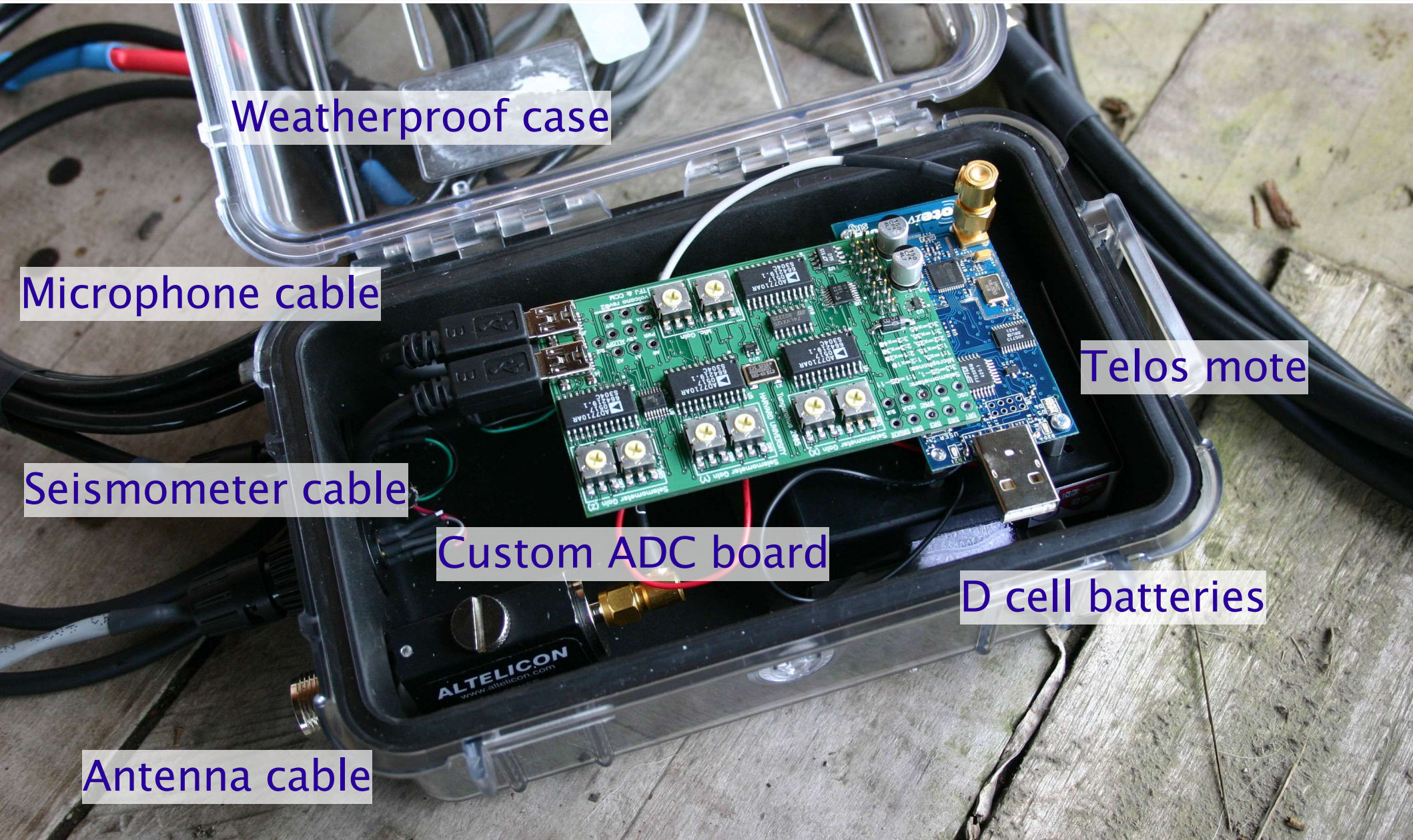
joint work with UNH, UNC, Instituto Geofisico Ecuador



Typical Volcanic Sensor Station

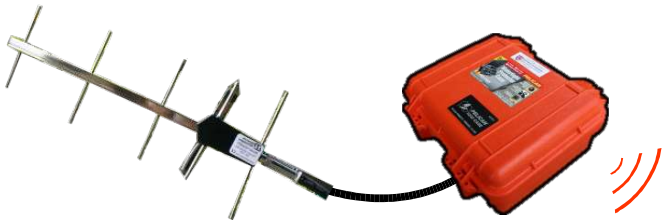


Our Wireless Volcano Monitoring Sensor Node



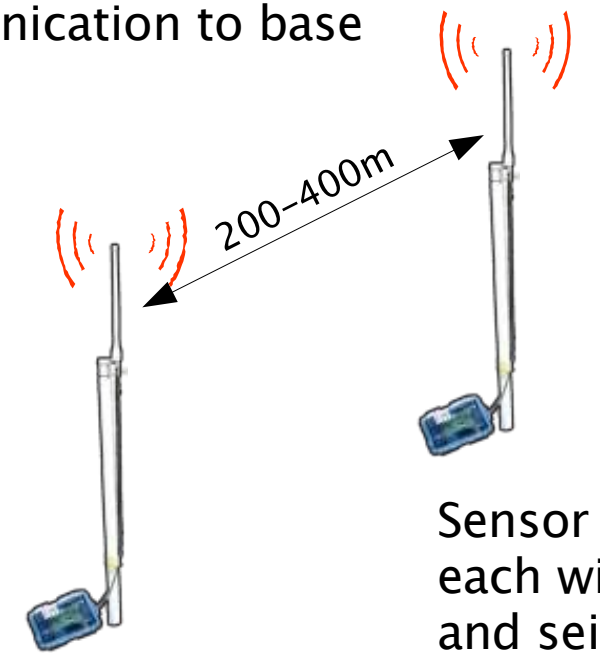
The Volcano Monitoring Macroscope

Yagi to repeater

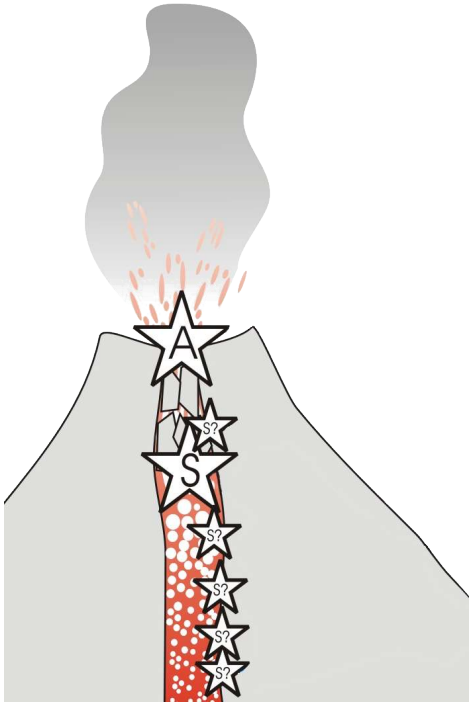


FreeWave radio modem for long-distance communication to base

GPS receiver for time sync

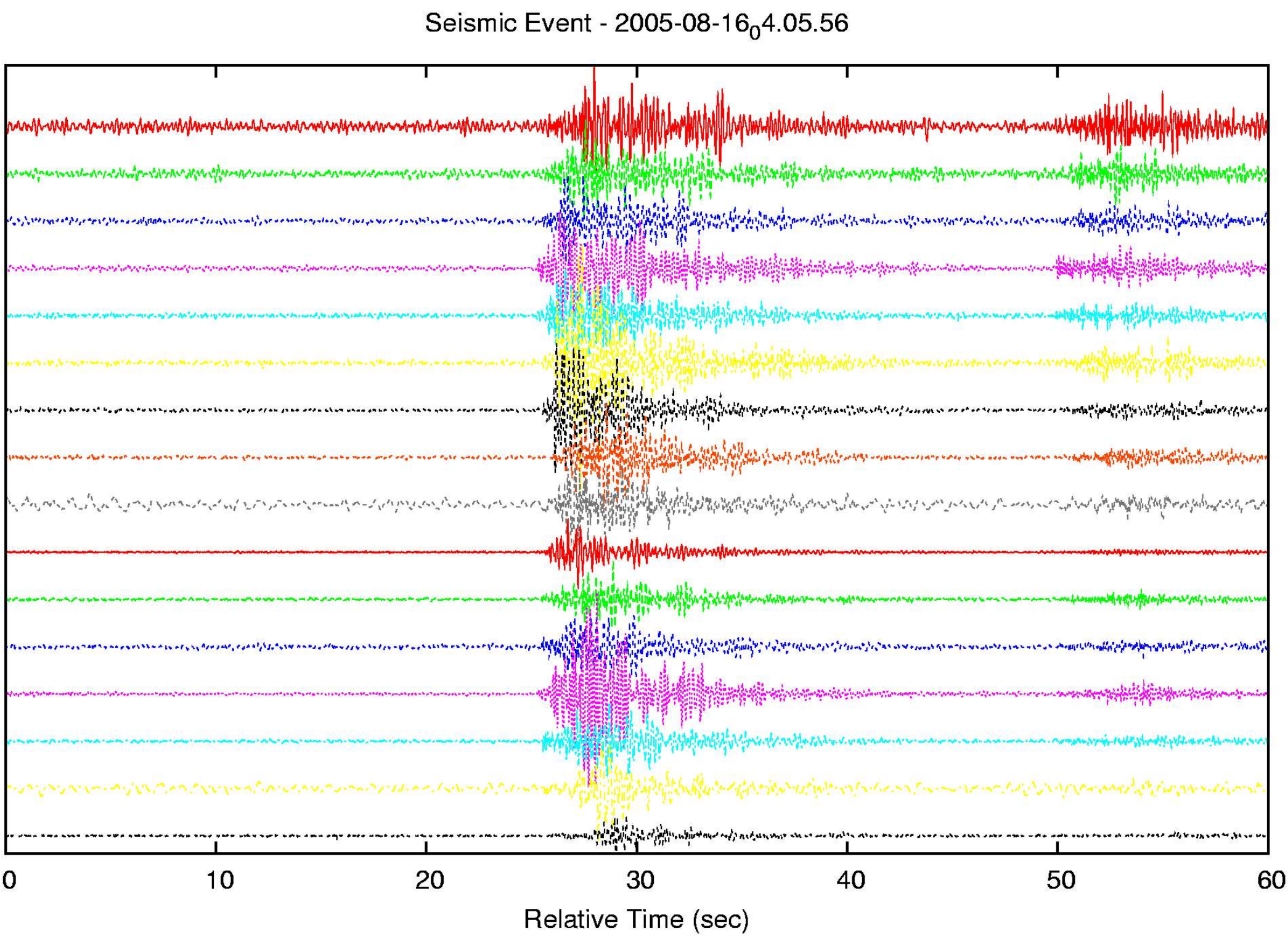


Sensor nodes each with mic and seismometer



Volcán Reventador, Ecuador

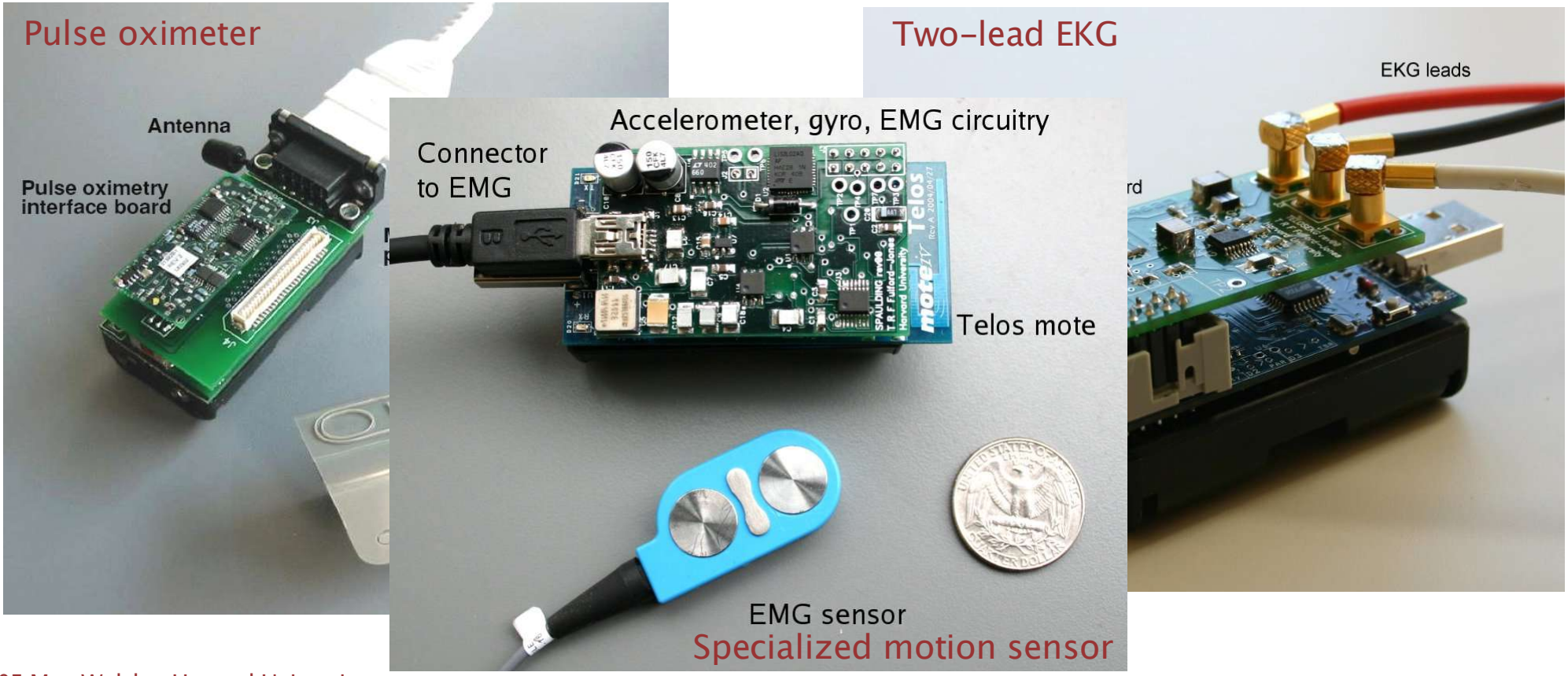
July/August 2005



Another Frontier: Medical Care
The Harvard CodeBlue Project

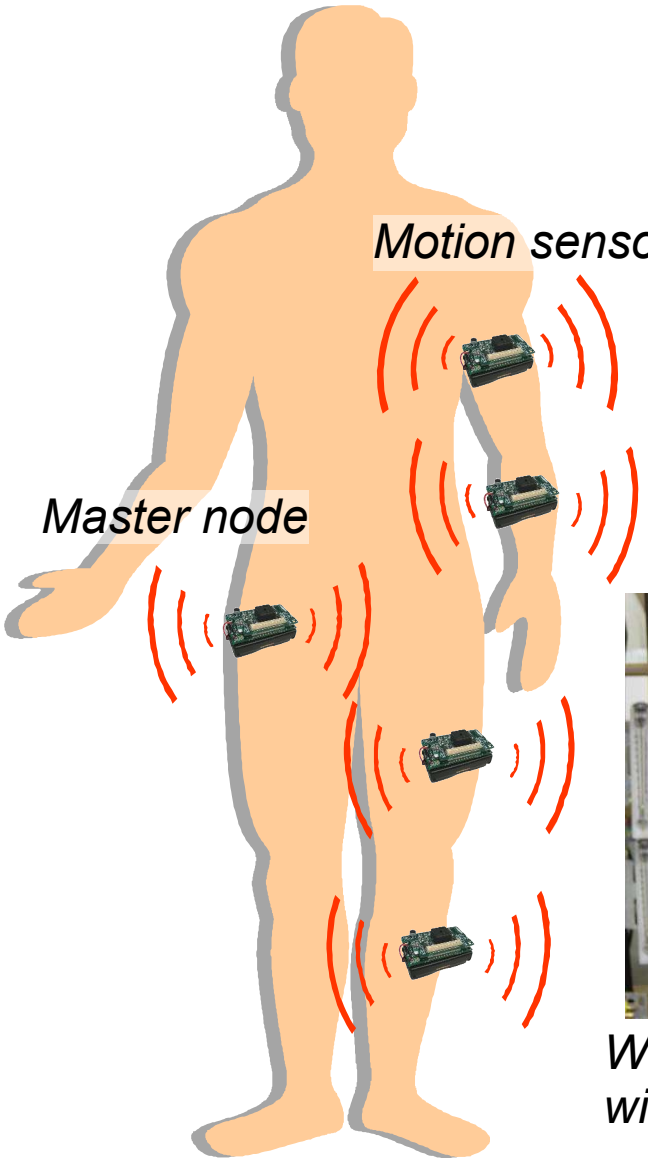
Sensor networks have enormous potential in medicine:

- Pre-hospital, in-hospital, and ambulatory monitoring
- Tracking many patients in a disaster or mass casualty event
- Monitoring entire populations (e.g., chronic or elderly patients at home)



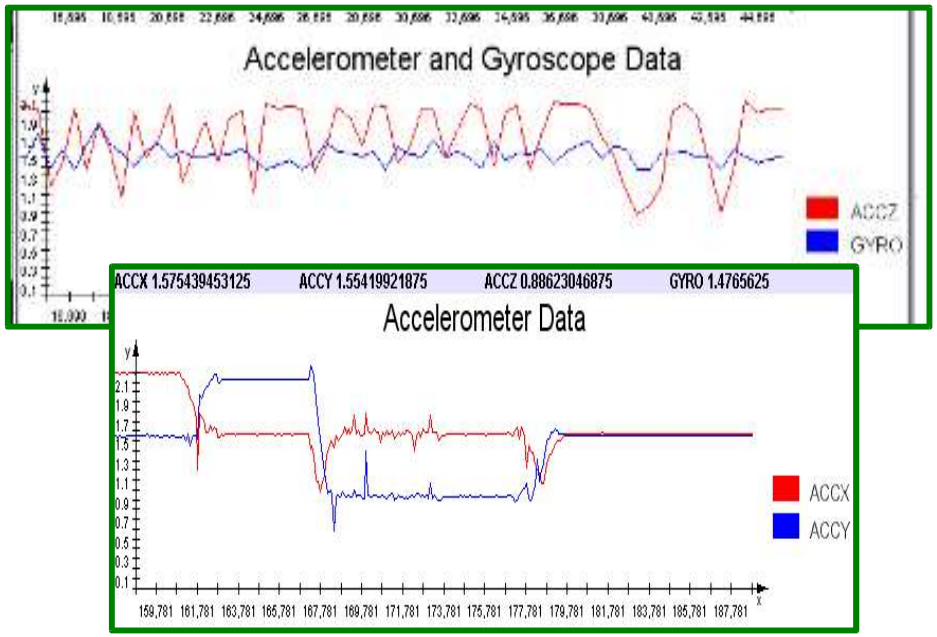
Stroke rehabilitation and Parkinson's Disease monitoring

with Spaulding Rehabilitation Hospital, Boston



Data acquisition controlled by laptop

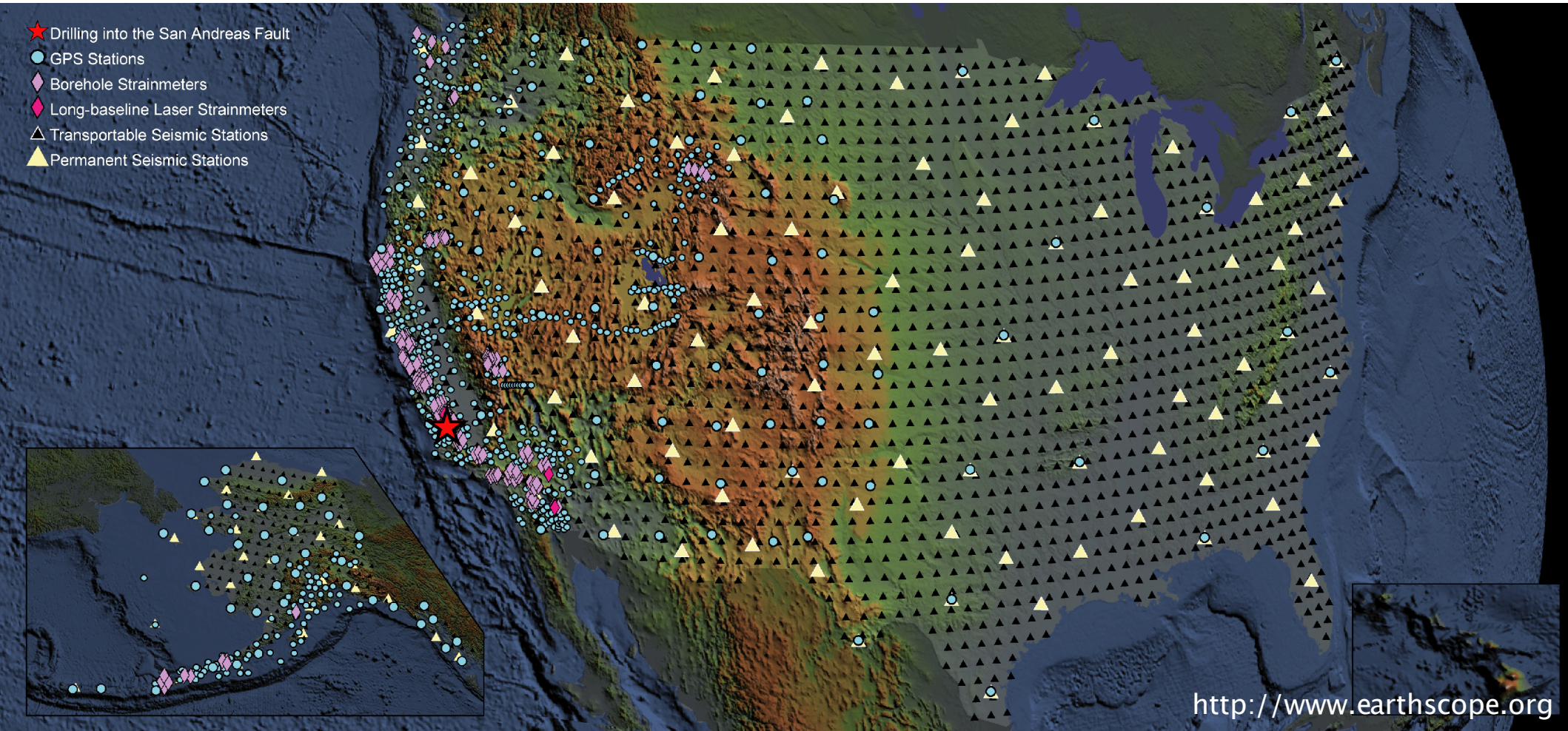
Wearable mote with armband



Global Scale Sensor Networks

We often think of sensor networks as relatively small, and local.

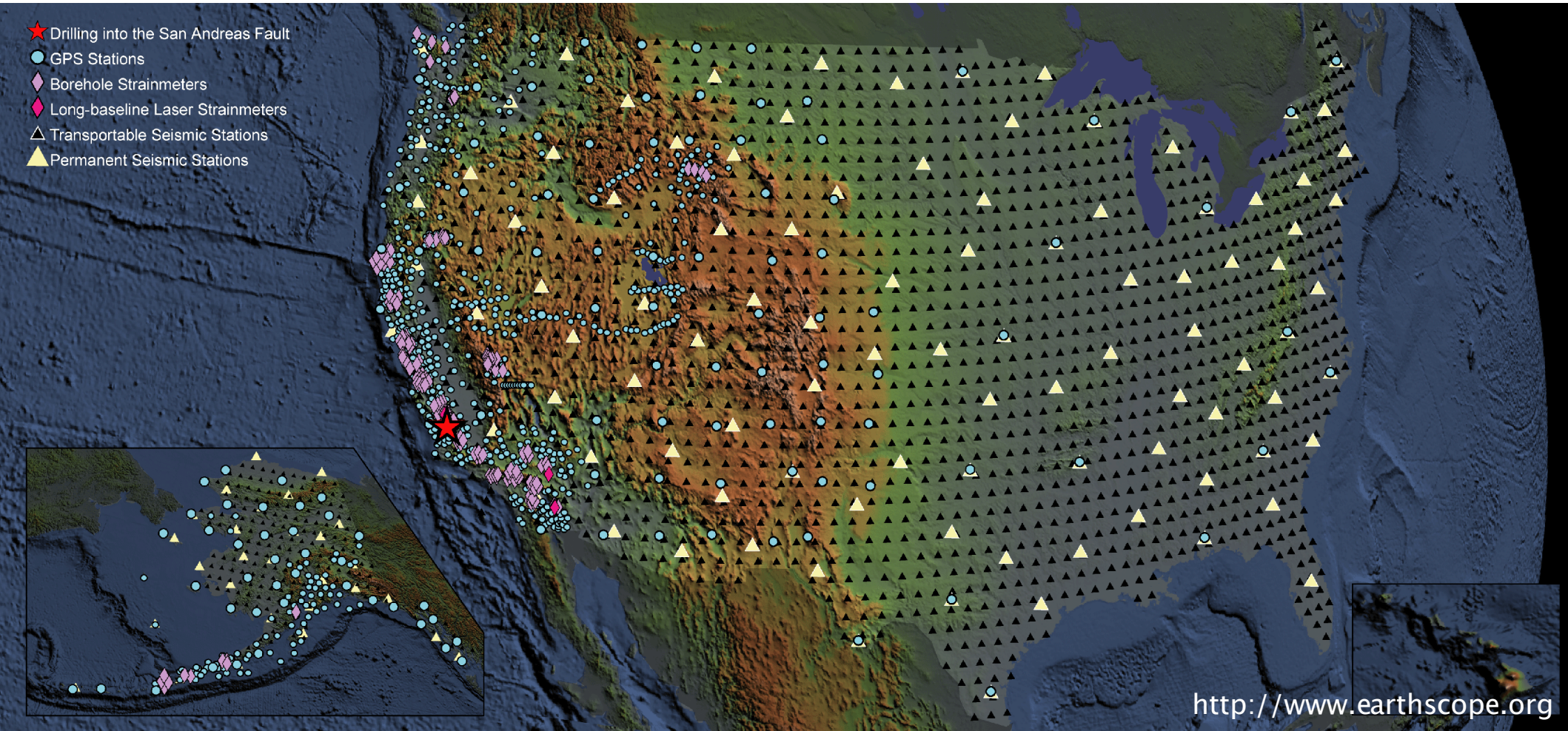
- What about connecting thousands of sensors all over the planet?



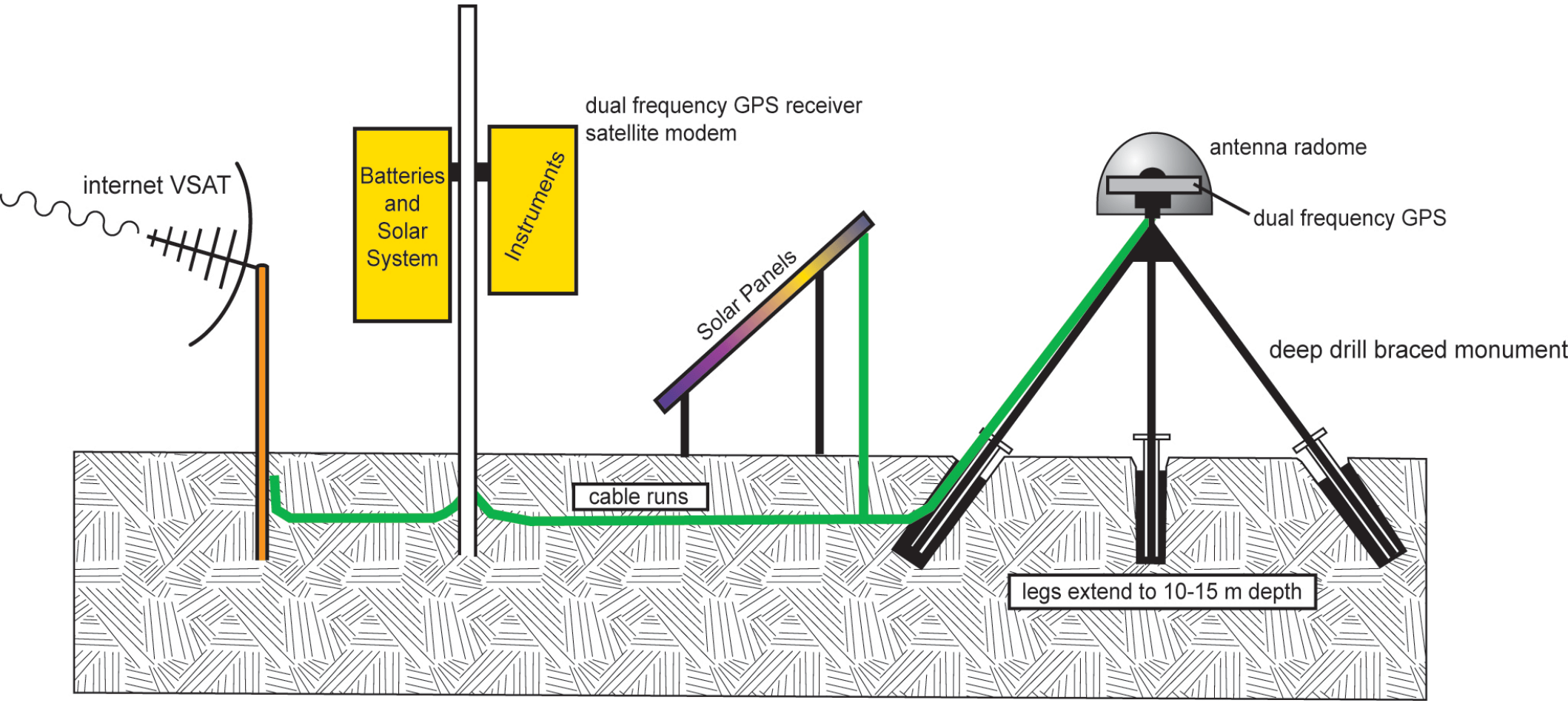
EarthScope (NSF)

15-year effort to understand earthquakes, volcanism, and plate movements in N. America

- 400 seismometers, 1000 GPS stations, 180 strainmeters



Earthscope GPS Station

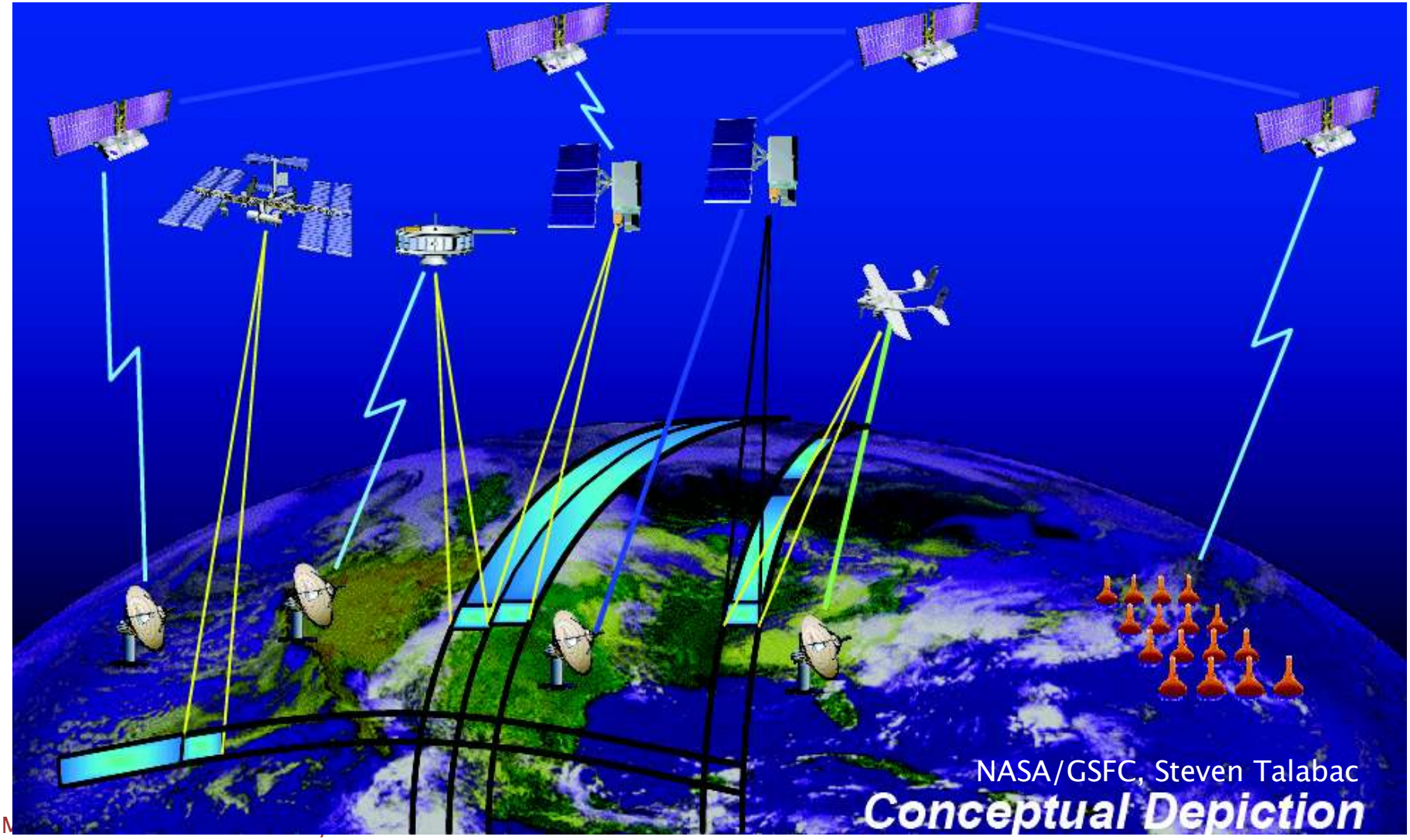


http://www.earthscope.org

SensorWebs

NASA Goddard Space Flight Center

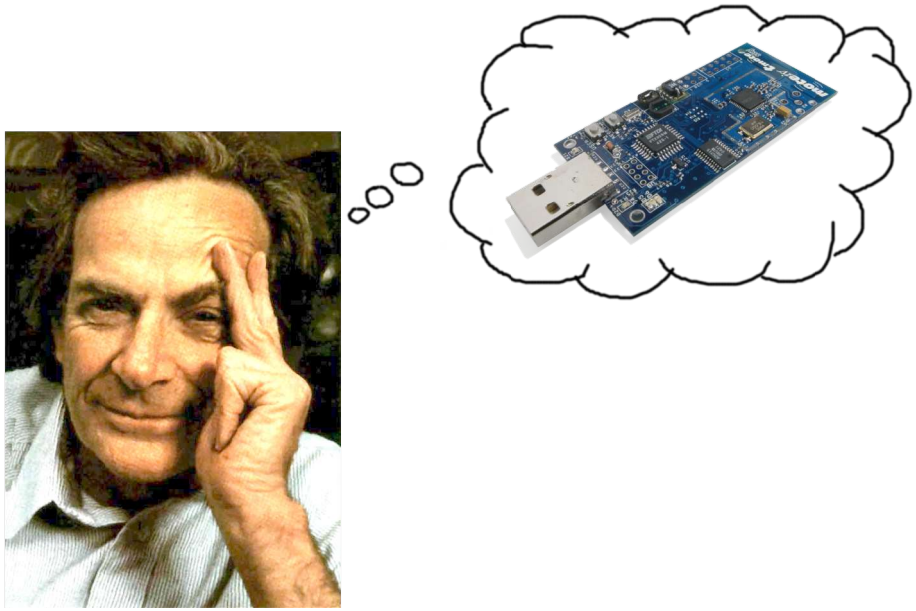
Adaptive, model-based sensing with ground and space-based sensors



Where do we go from here?

OK, we all agree that sensor networks have huge potential.

Now I want to ask: What are the Big Problems that we now face?



Three Big Questions

1) How do we program the sensor network as a whole?
   - That is, rather than programming the sensor nodes as individuals?

2) How do we manage limited energy, bandwidth, and memory?
   - Especially under highly dynamic conditions?

3) How do we interconnect sensor networks with the rest of the world?
   - The problem doesn't end at the base station!

Big Question #1: Programming the Network

Domain scientists and engineers need much better tools for programming sensor networks.

- Requiring geophysicists to grok TinyOS is not going to work...

Macroprogramming: Program the sensor network as a whole, compile down to node-level code

- Greatly simplify the process of developing sensor net applications
- Automate the process of distributing computation in the network

Many possible programming models:

- Many scientists would probably like something like MATLAB!
- Others would like to think in terms of SQL queries, or RDF queries, etc.

TinyDB
(Sam Madden, MIT)

Declarative SQL-like query interface

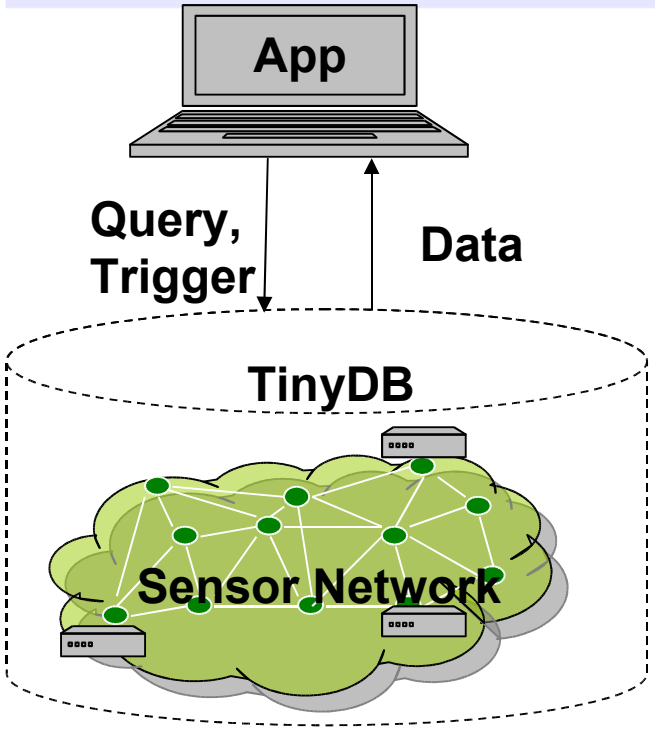
- Treat entire sensor network as a “table”
- Columns correspond to sensor attributes: sensor values, ID, location, etc.
- Each tuple represents a reading from one sensor

In-network aggregation

- Aggregates such as average, max, min, etc. computed within the network
- Nodes push data up a spanning tree to the base station, aggregation performed at intermediate hops

Extremely powerful, yet simple, abstraction

```
SELECT MAX(mag)
FROM sensors
WHERE mag > thresh
SAMPLE PERIOD 64ms
```



Regiment

with G. Morrisett (Harvard) and R. Newton (MIT)

Sensor language based on functional reactive programming

- View sensor network as a set of data streams
- Primitives for naming, grouping, and combining stream data
- Can group sensors into “regions” based on location, data type, other attributes

```
let aboveThresh(p,x) = p > THRESHOLD
    read node = (read_sensor node,
                 get_location node)
in compute_centroid
      (rfilter aboveThresh (smap read world))
```

Vehicle tracking program implemented in a few lines of code

- Compiles down to simple, intermediate language that runs on sensor nodes

Big Question #2: Adaptive Resource Management

Existing approaches to sensor resource management are very simple

- Main focus on *duty cycling:* Periodic wake/sleep scheduling
- Coordinate schedules in the network to reduce latency and energy use

Given complex network dynamics, need better techniques.

- This is a very difficult problem.
- Encompasses broad range of limited resources: CPU, energy, radio, memory.
- Complex tradeoffs between bandwidth, latency, data fidelity, and lifetime.

Sensor networks may be shared by multiple users or applications

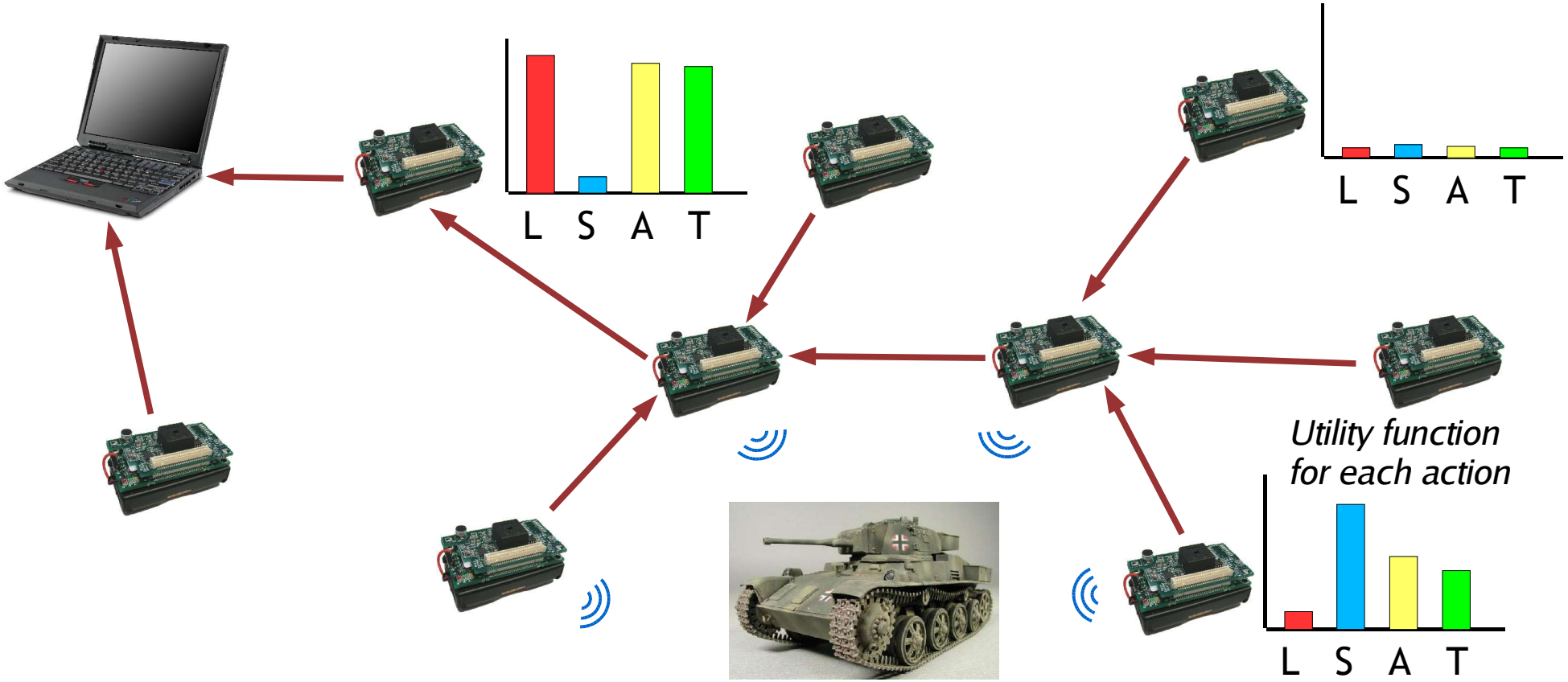
- How to balance resource use across multiple queries?

Self-Organizing Resource Allocation (SORA)

with G. Mainland and D. Parkes (Harvard)

Idea: Use economic principles to control sensor resource use!

- Nodes attempt to maximize their "profit" for taking certain actions
  - *e.g., Sensing, listening for radio messages, transmitting data*
- Each action has an associated energy/bandwidth cost and a reward if successful



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SORA allows nodes to tune resource use over time

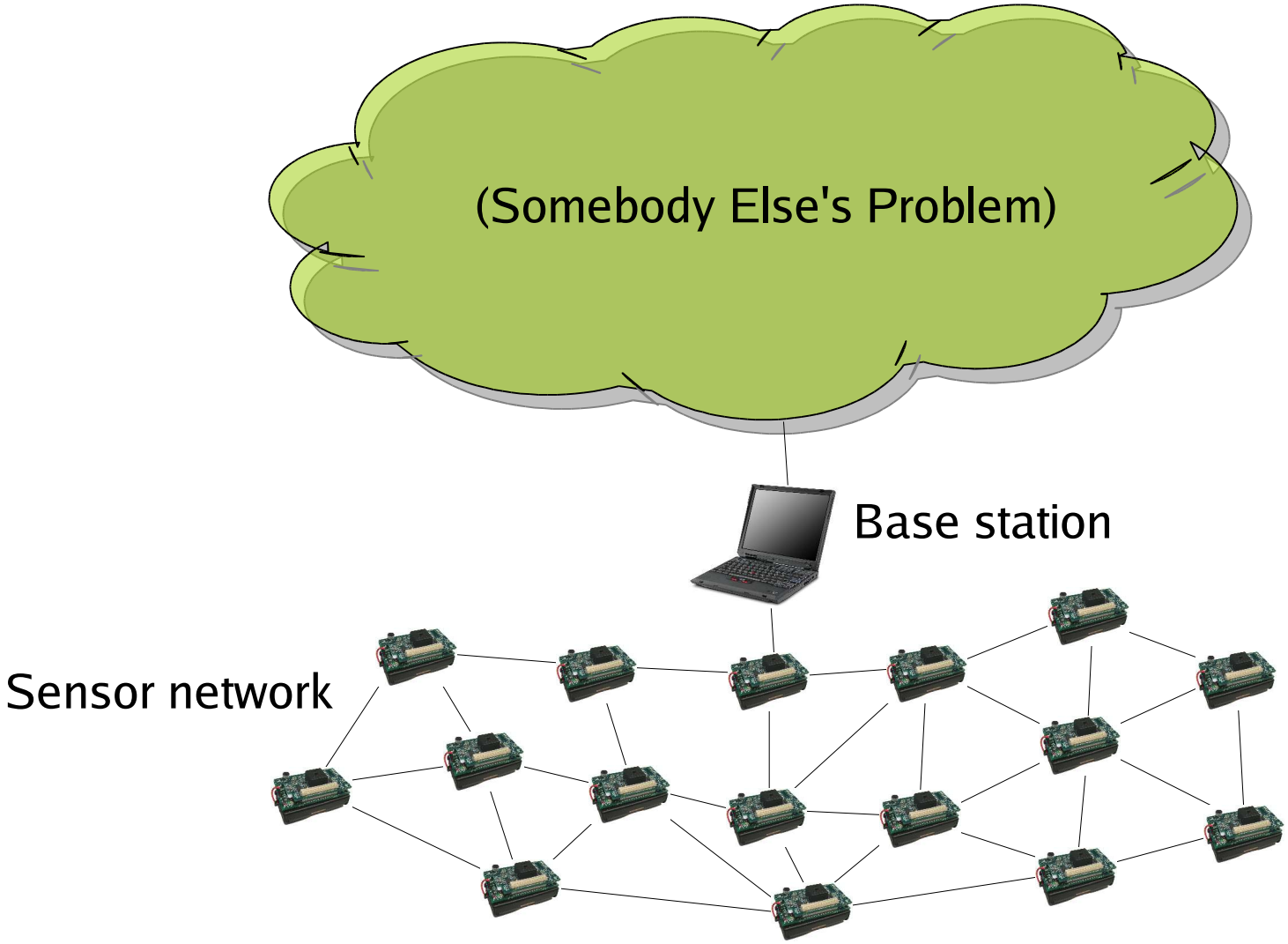
- Nodes use reinforcement learning to adapt to changing conditions

SORA achieves very high *energy efficiency*

- Percentage of energy use that results in data arriving at the base station
- Tracking system: SORA yields 60% efficiency, compared to 20% for duty cycling

Big Question #3: Interfacing with the Rest of the World

Traditional view of sensor networks:



Big Question #3: Interfacing with the Rest of the World

Many questions arise here:

How do we expose sensor data to the Internet?

- HTTP? SOAP? RDF? Raw bytestreams?

How do we open up sensor networks for queries or reprogramming?

- Need mechanisms to manage access, protect privacy, support multiple applications

How do we discover and harness data from multiple sensor networks?

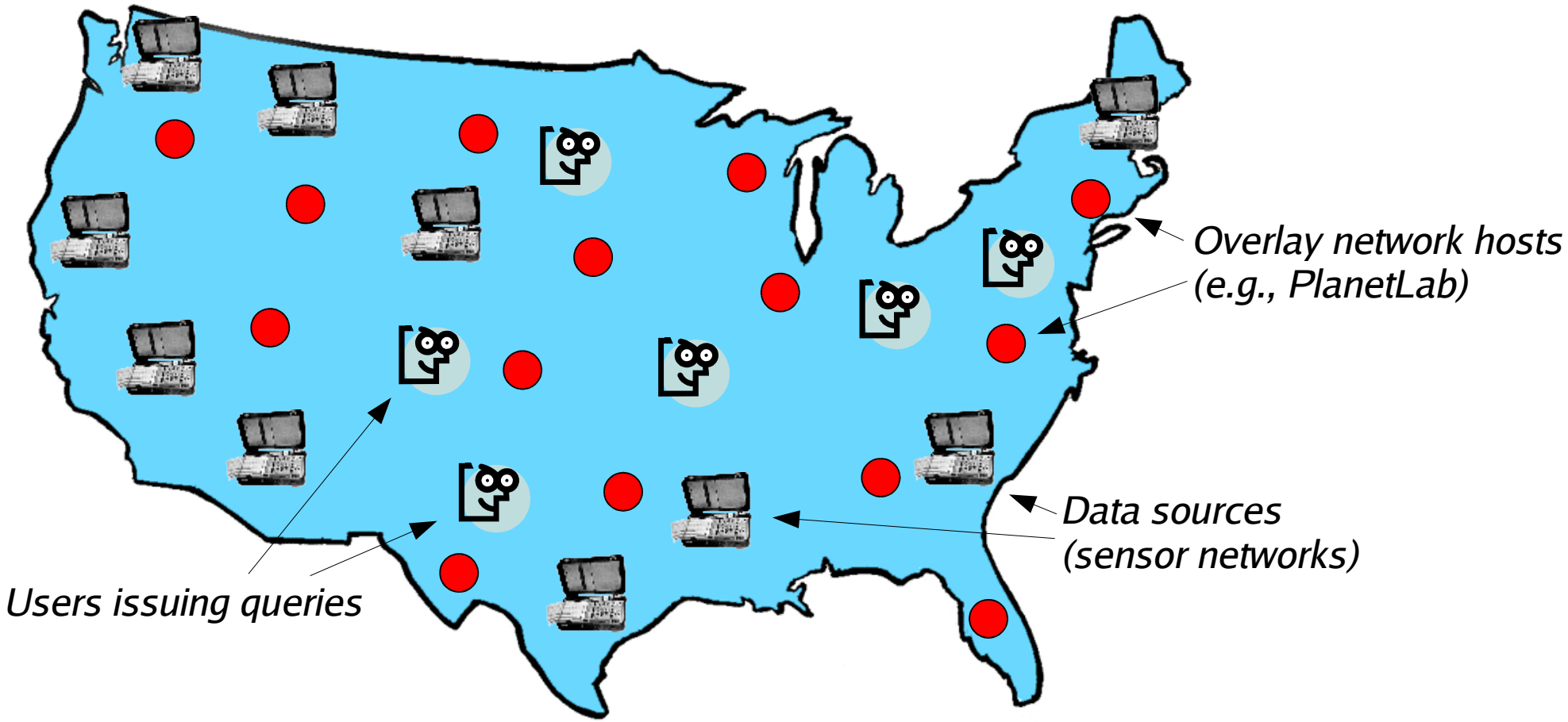
- "sensor.google.com" -- Now searching 8,162,375,201,799 motes!

How do we distribute query processing across the Internet?

- Must handle vast numbers of data sources and simultaneous queries.

Hourglass and SBONs

Hourglass: Set of services to harness real-time sensor data across many geographically-distributed sources



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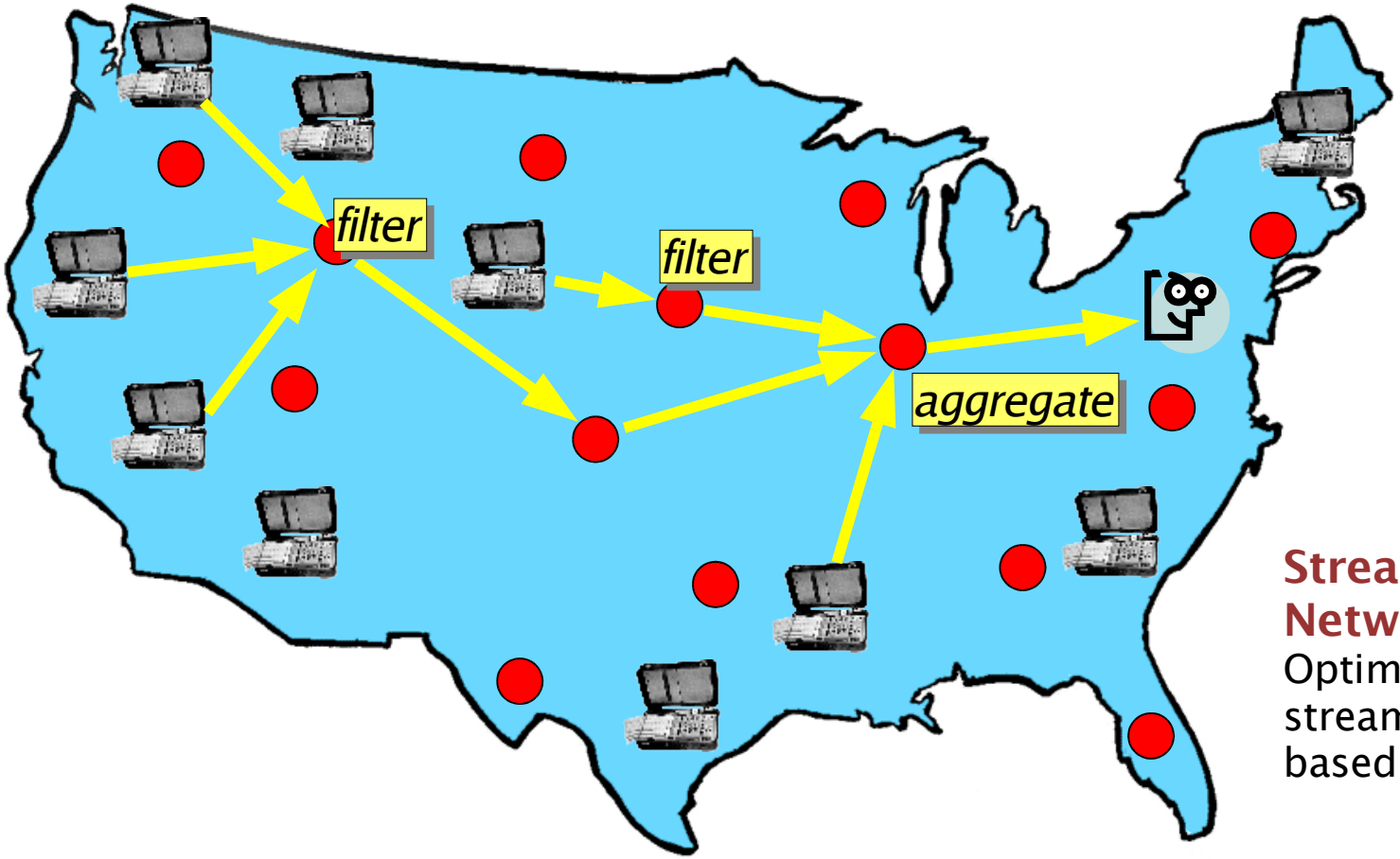
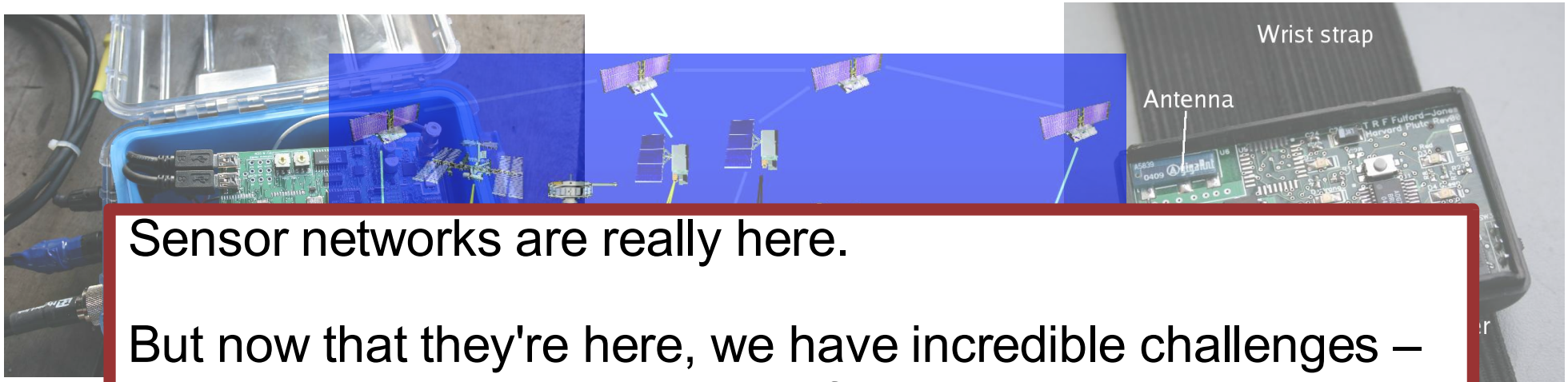


Stream-Based Overlay Network (SBON):
Optimize placement of stream-processing services based on network conditions

Take Away Points...

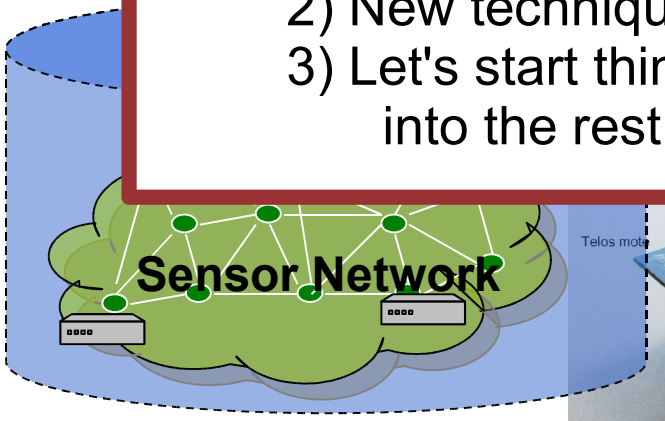


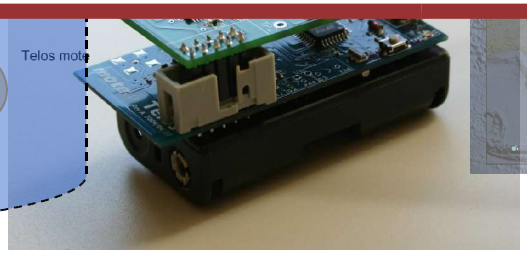
Sensor networks are really here.

But now that they're here, we have incredible challenges – and responsibilities – ahead of us.

So, where do we go from here? Some thoughts:

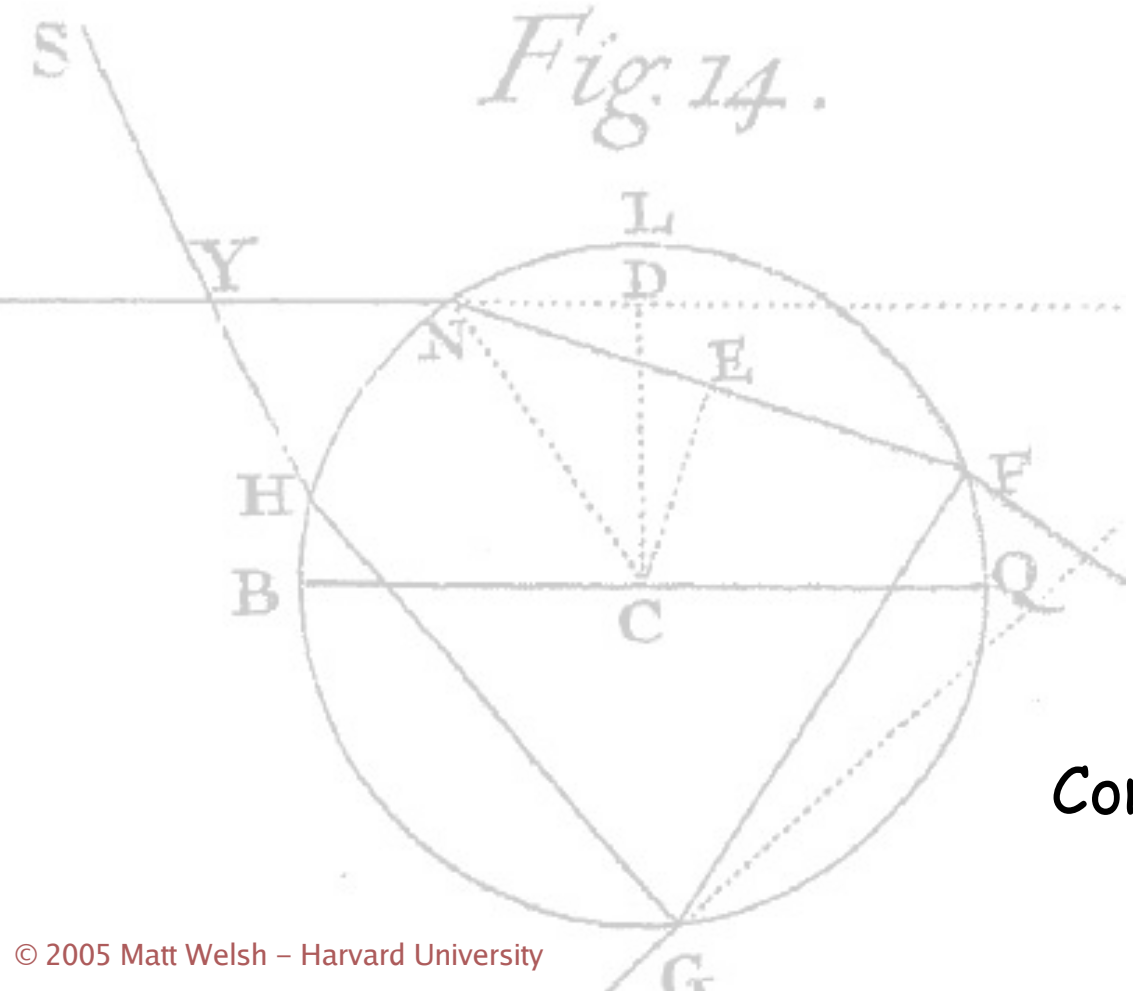
1) Better tools for programming...
2) New techniques for resource management and sharing...
3) Let's start thinking now about how to tie all of these sensors into the rest of the world!





Thank You!

*"If anything I've said seems useful to you, I'm glad.
If not, don't worry. Just forget all about it."*
-- HH The Dalai Lama



Comments and questions welcome!

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