Disruptive Innovation in Geoenvironmental Sensing:

Bringing Raman Spectroscopy to the Field

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Purdue University | April 18, 2008

Outline:

- A model to describe innovation
- Applicability of this model to research
- Example of disruptive innovation in geoenvironmental sensing

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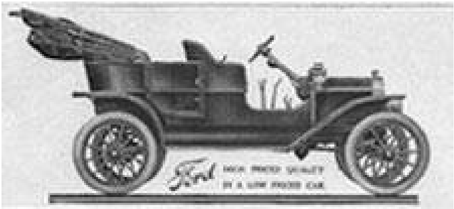
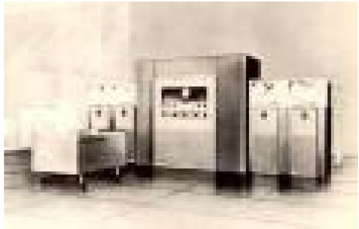
Innovation is often considered in the context of technological breakthrough





We use many terms to characterize innovation, but few convey its true essence

Discontinuous or radical vs. **Incremental**[1]

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Competence enhancing vs. **Competence destroying**[2]

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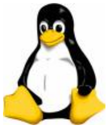
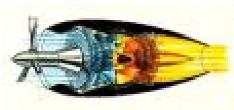
Architectural vs. **Generational**[3]

 → Microsoft Windows

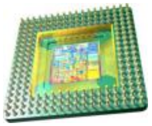
 → 

Core vs. **Peripheral**[4]

Modular vs. **Interdependent**[5]

 +  + 

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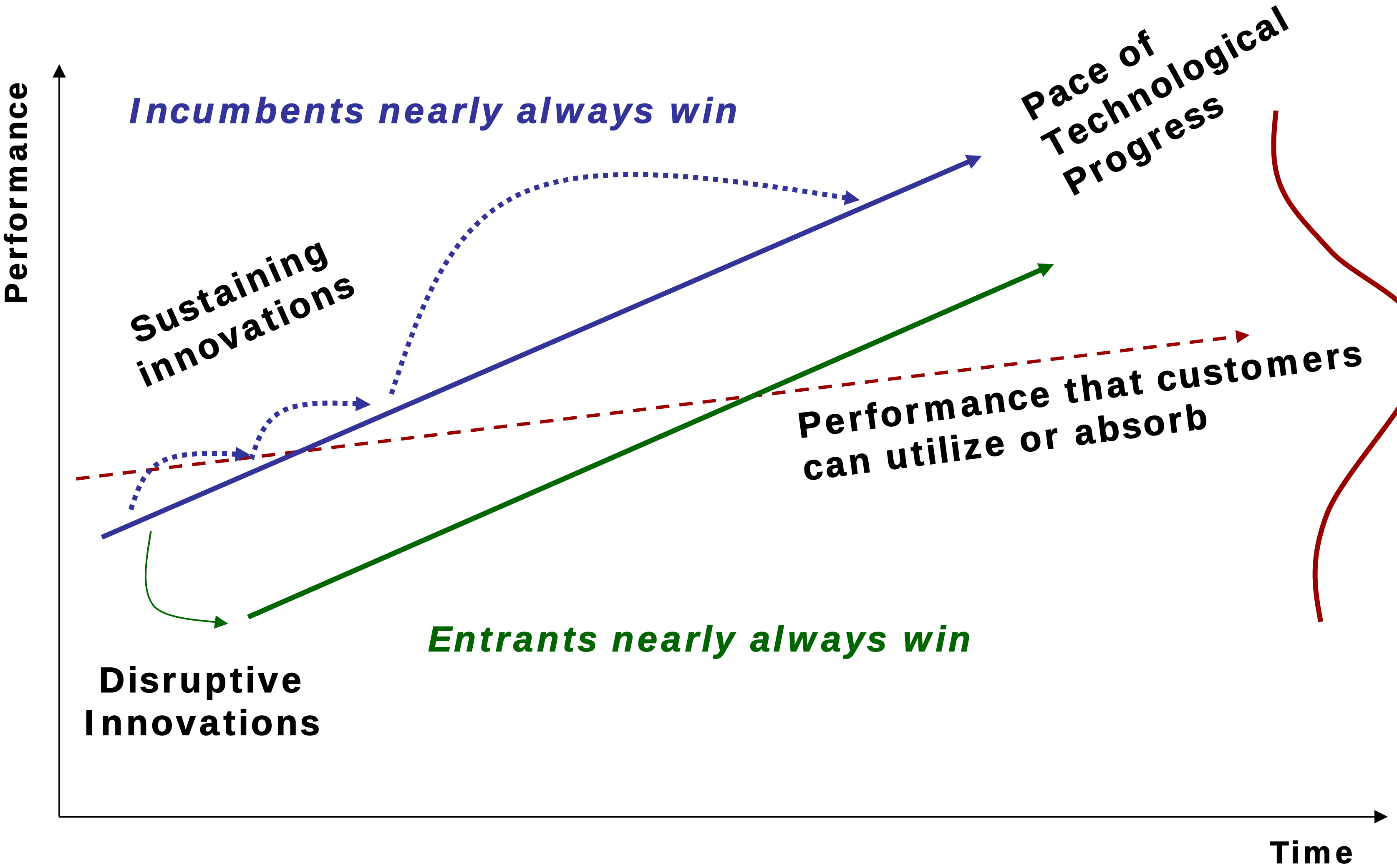
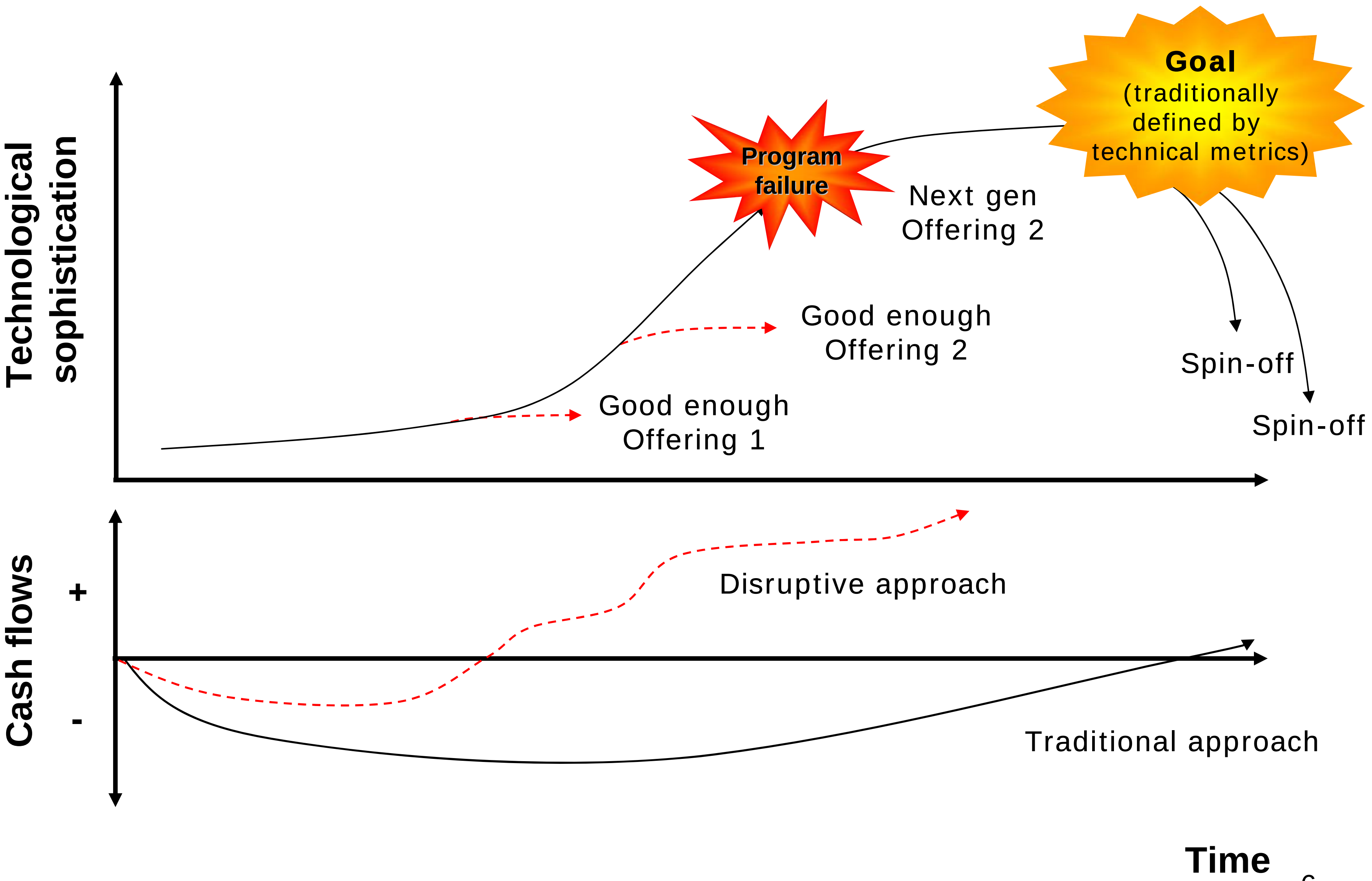
[1] Dewar and Dutton, 1986; Ettlie et. al., 1984; Damanpour, 1996; [2] Tushman and Anderson, 1986; Anderson and Tushman, 1990; [3] Henderson and Clark, 1990; [4] Clark, 1985; Tushman and Murmann, 1998; [5] Baldwin and Clark, 2000; Schilling 2000

One model synthesizes these perspectives



Source: Christensen and Raynor; *The Innovator's Solution*

Understanding this perspective highlights different paths to research success



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These principles have been demonstrated many times in industry: Adoption of the Transistor

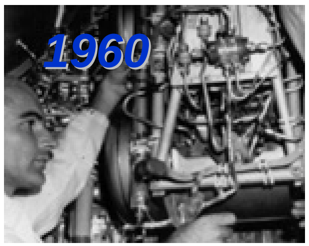
In academia we commonly drive toward radical sustaining innovation:

Special Notice SN08-19: Materials with Novel Transport Properties (MANTRA); Proposer's Day Workshop, DATE: March 20, 2008; Primary technical areas of interest include particle rejection and chemical separation. ***Only novel technologies that improve water permeability one hundred-fold over existing systems will be investigated.***

Source:Innosight, LLC; http://news.sel.sony.com; www.kirainet.com/english/history-of-sony/; http://www.dself.dsl.pipex.com/MUSEUM/COMMS/mechamp/mechamp.htm

What if we instead asked, “For what is our current capability ‘good enough’?”

What if fuel cells were used in power tools instead of automobiles?



Zara Solar Ltd

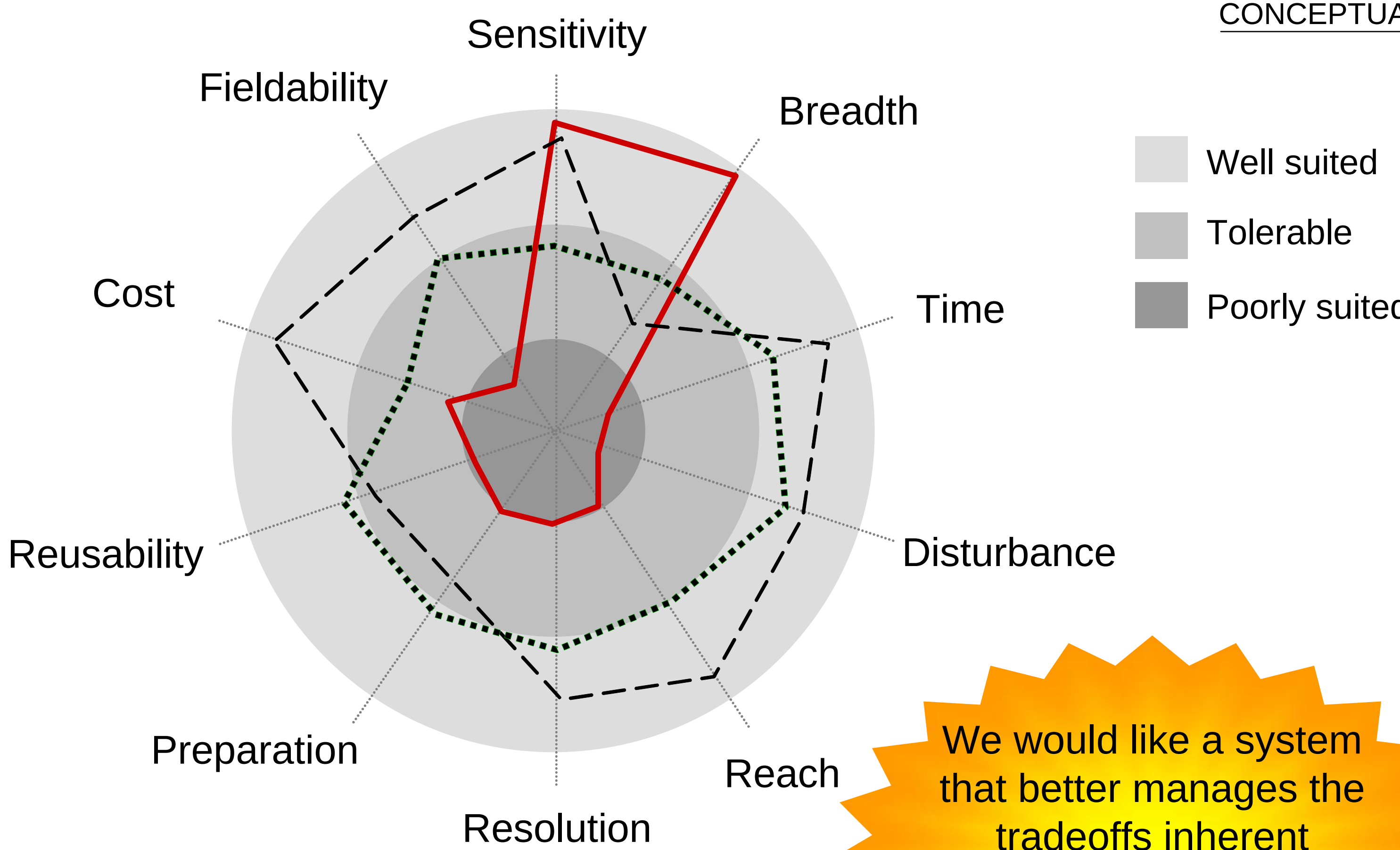
What if photovoltaics were used to periodically power small appliances in developing countries instead of western homes?

What if electric arc furnaces were used to melt down recycled ferrous scrap for re-bar instead of trying to make structural steel?

Source: http://americanhistory.si.edu/fuelcells/pem/pemmain.htm

We can apply these same concepts to geoenvironmental sensing

CONCEPTUAL



In-laboratory analyses

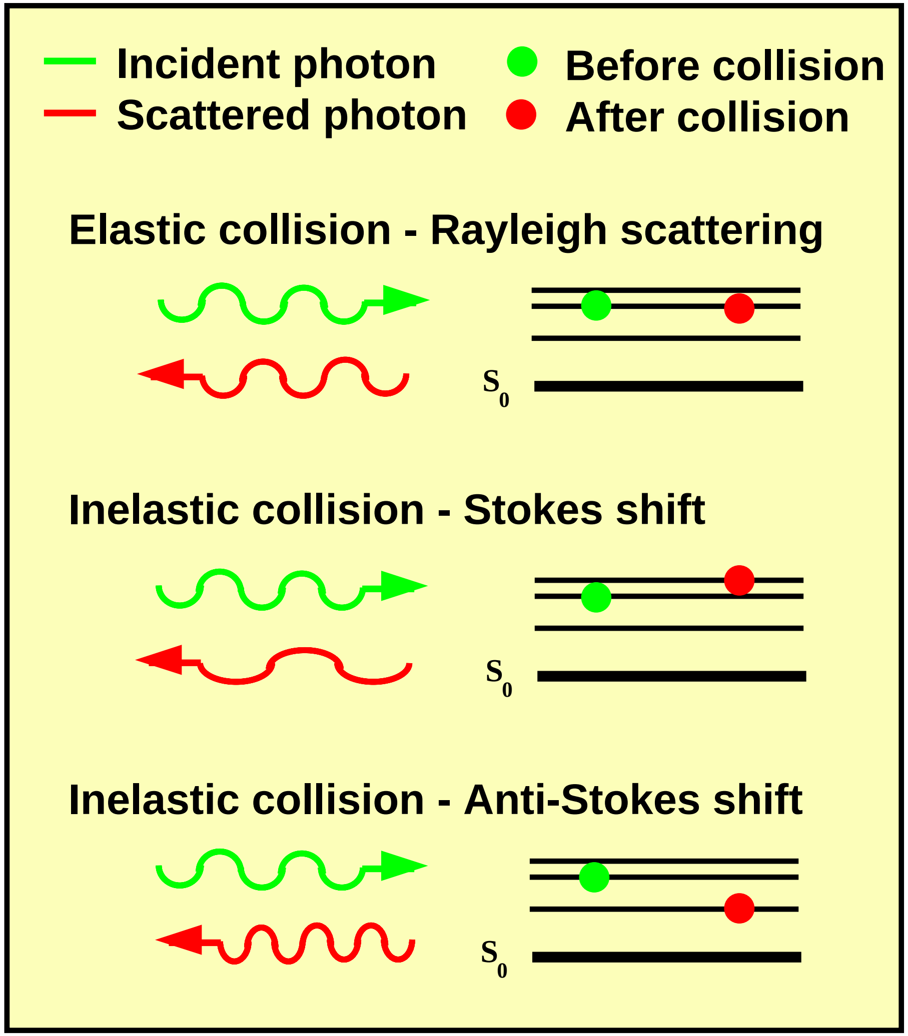
Probes/portable units

Point sensors

We would like a system that better manages the tradeoffs inherent to geoenvironmental sensing, particularly to target in-situ analysis

Conceptually, Raman spectroscopy offers the *potential* to better address the in-situ challenge

- Raman is an optical spectroscopic technique
- Physical mechanism entails observation of photon-molecule collisions
- Time scale of 10^{-12} seconds
- Raman shift provides indication of vibrational energy
- Raman cross-section is proportional to $1/\lambda^4$



The fundamental principles underlying the Raman technique point toward a capability that could be non-destructive, highly specific, very fast, and rich in breadth.

However, viewed through a sustaining lens, the technique is perceived to have weaknesses

Raman "weaknesses"

- The equipment used to perform Raman analysis is typically very expensive
- The Raman phenomenon is inherently weak
- **The usefulness of Raman is hindered by fluorescence**

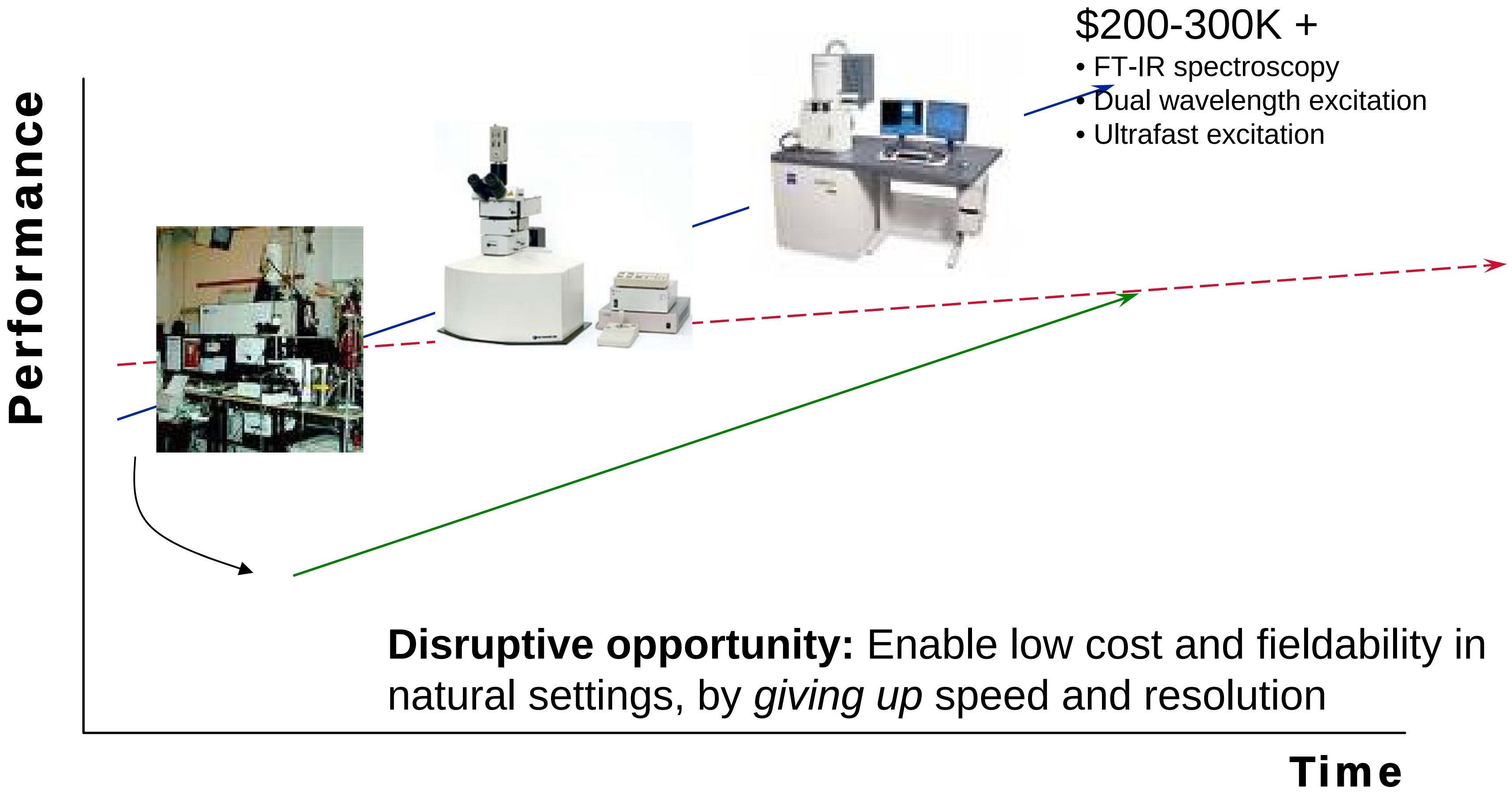
"Sustaining innovation rules"

- Better = More power, resolution, and speed
- It is better to avoid fluorescence than to manage it

Implication:
In fluorescence inhibited settings, Raman is the tool of the few vs. the many

Fluorescence limited Raman spectroscopy – sustaining vs. disruptive perspective

Sustaining trajectory: Avoid fluorescence or suppress its effects with costly cumbersome laboratory equipment



We can pursue this opportunity by taking advantage of recent technological advances

Compact spectrometers

- Fieldable configurations
- Low cost
- Compact

Miniature diode lasers

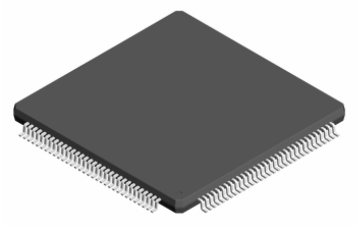
- Useful λ's
- Pulsed
- Small form factor
- No cooling
- Low cost

Telecom fiber and switching

- Fieldable configurations
- Low cost
- Compact

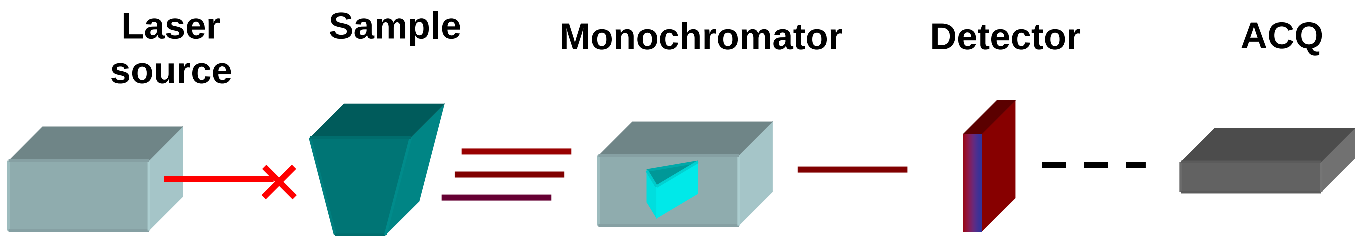
Low cost, high speed DAQ

- Fieldable configurations
- Low cost
- Compact



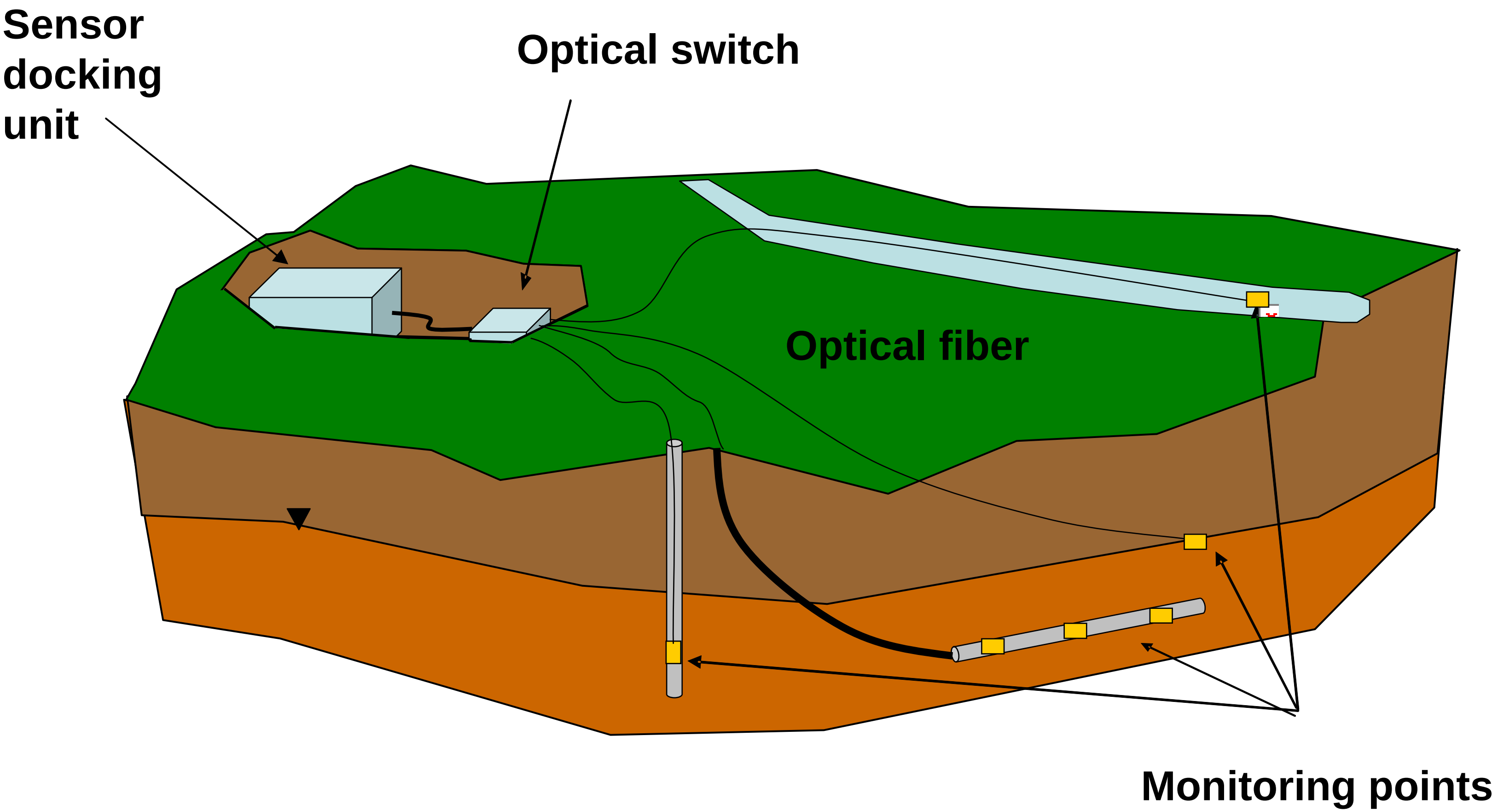
Employing some of these technologies, we can change the "rules"

Fundamental Raman system components

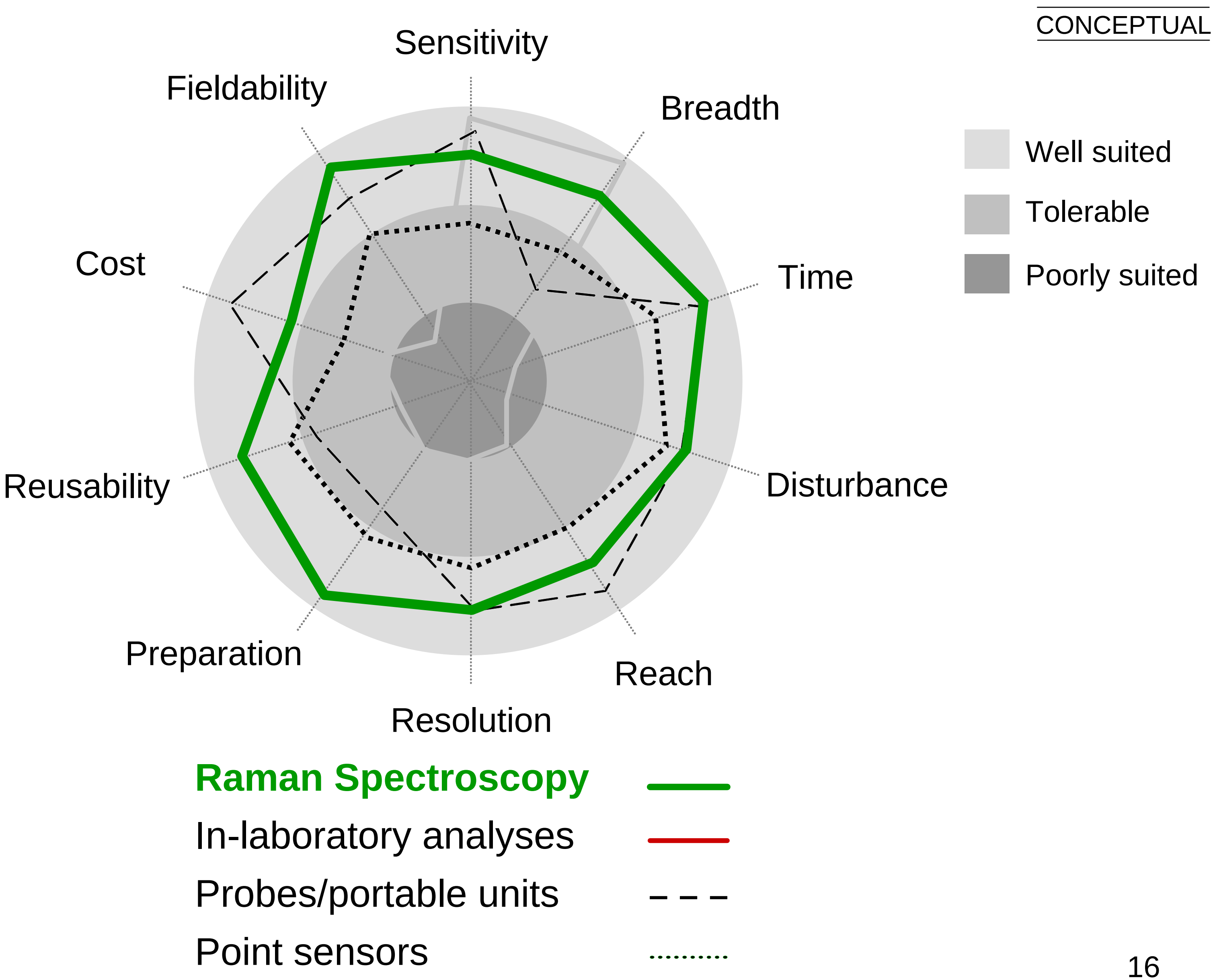


	Laser source	Sample	Monochromator	Detector	ACQ	Attributes
Sustaining	• High average power • CW • N/M IR	• Non-fluorescing media	• High resolution • FFT	• Rapid full spectrum detection (CCD) • LN cooled	• Continuously integrated voltage • FFT signal de-convolution	***Gives*** • Size • Cost • Media ***Gets*** • Resolution • Speed • Sensitivity
Disruptive	• Low average power • Pulsed • VIS	• Fluorescing samples	• "Low" resolution • Scanning spectral coverage	• Slow mono-chromatic detection (PMT) • TEC cooled	• Time-resolved photon counting	***Gives*** • Resolution • Speed ***Gets*** • Size/portability • Media • Affordability

On this basis, we can envision a highly flexible in-situ monitoring system

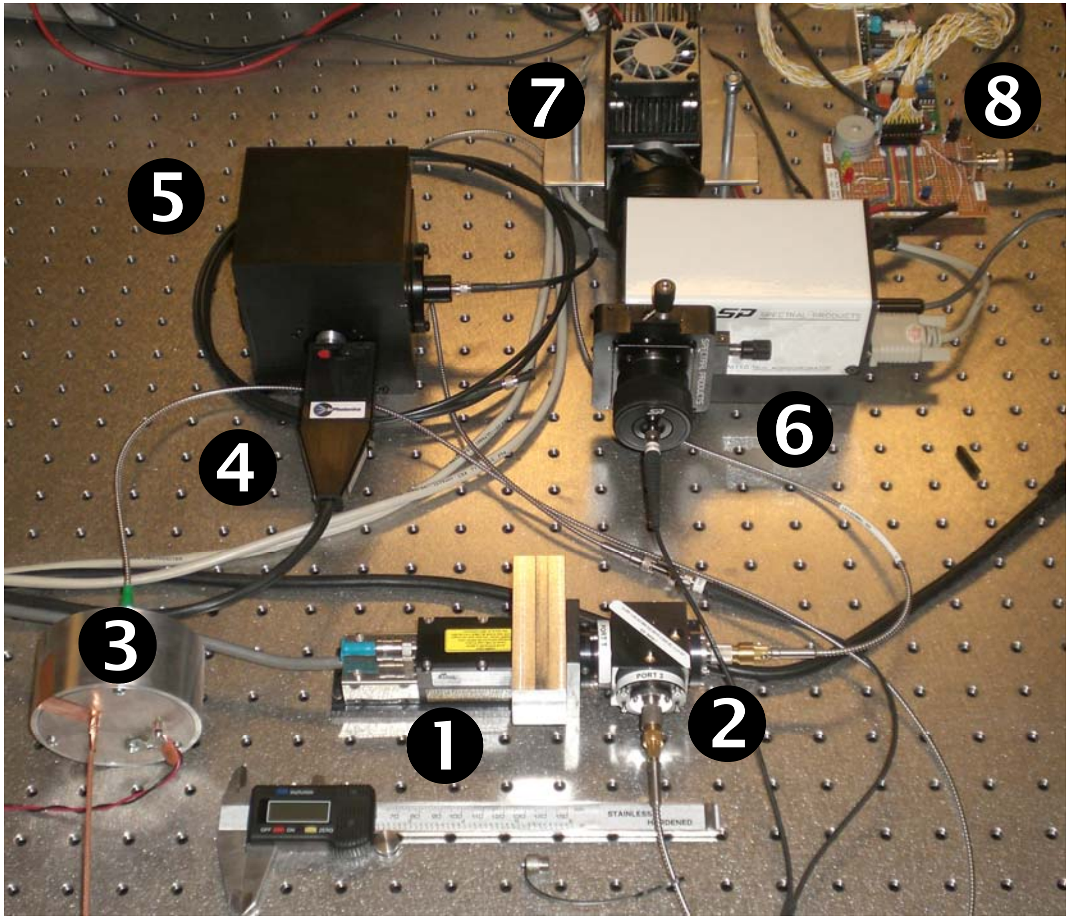


Ultimately, this type of system would satisfy many of the objectives of in-situ analysis



Following the disruptive pattern, we started with a “good enough” system

Prototype time-resolved visible Raman spectroscopy system



(1) 532 nm Q-switched microchip laser

(2) Trigger photodiode

(3) Beam splitter

(4) Co-linear focus/filter probe

(5) Sample chamber

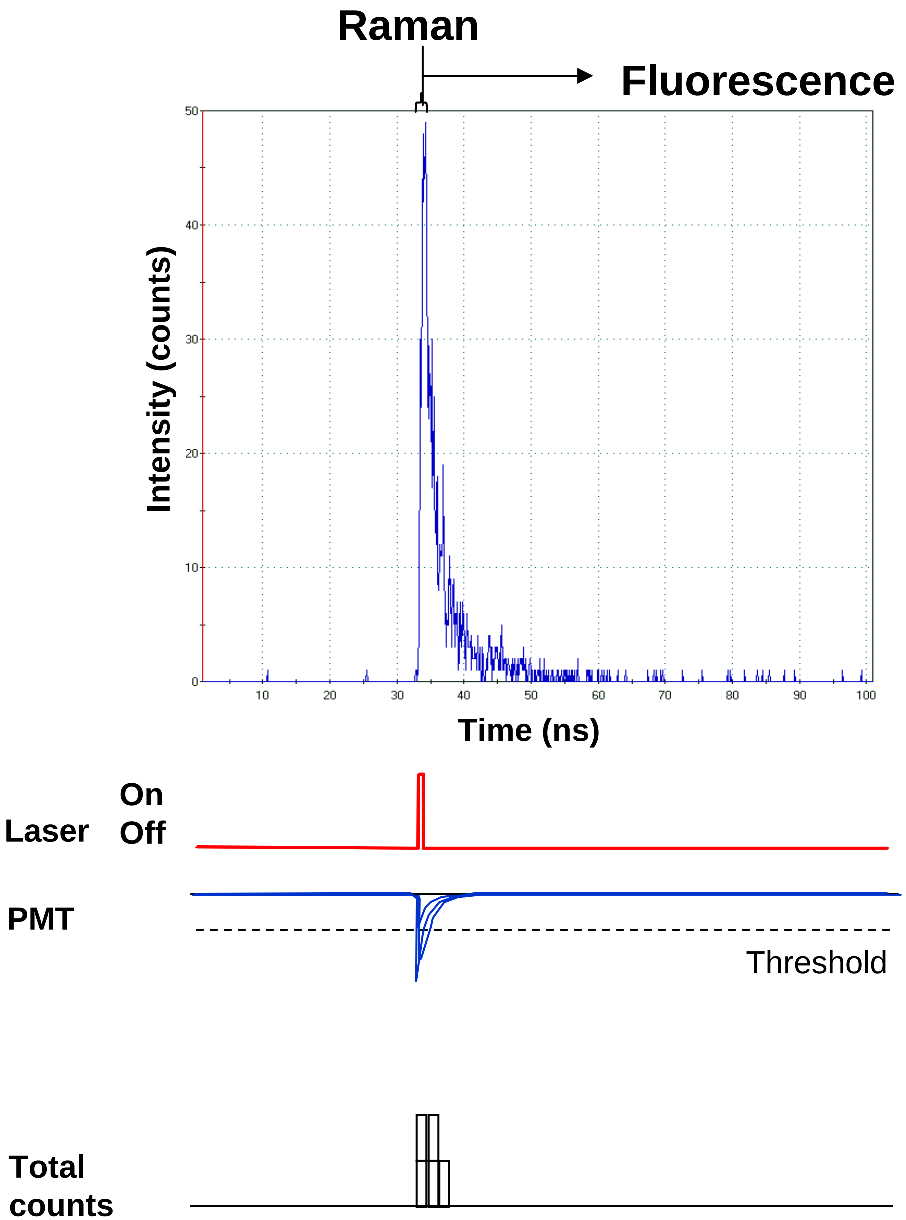
(6) Monochromator

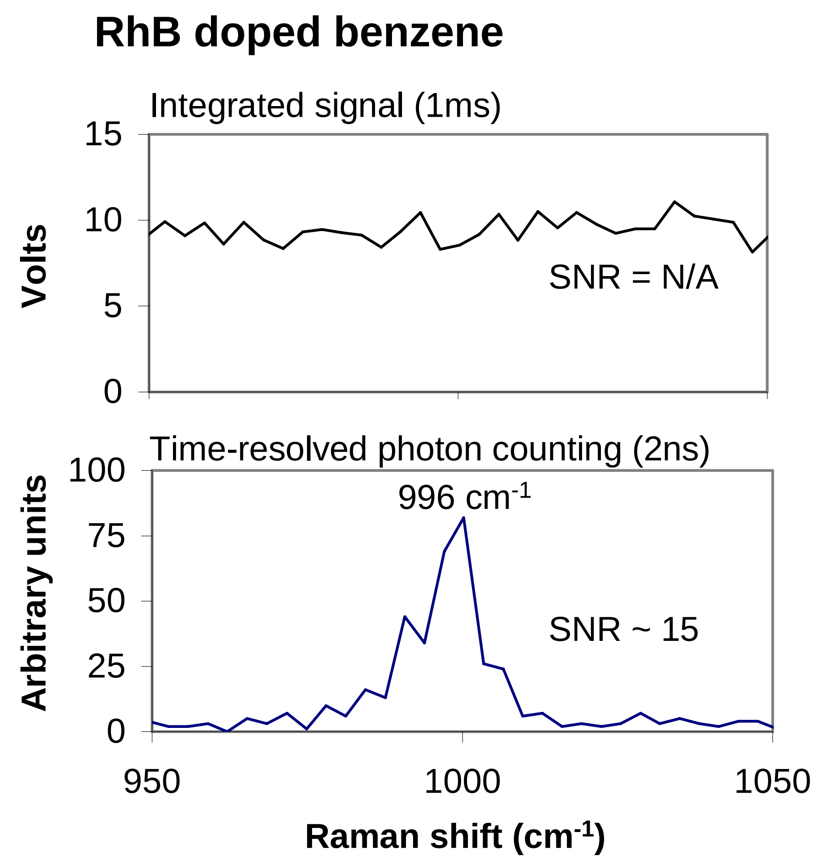
(7) Photomultiplier tube

(8) … izer

Total cost <$35,000

The system relies upon time-resolved photon counting to mitigate fluorescence effects



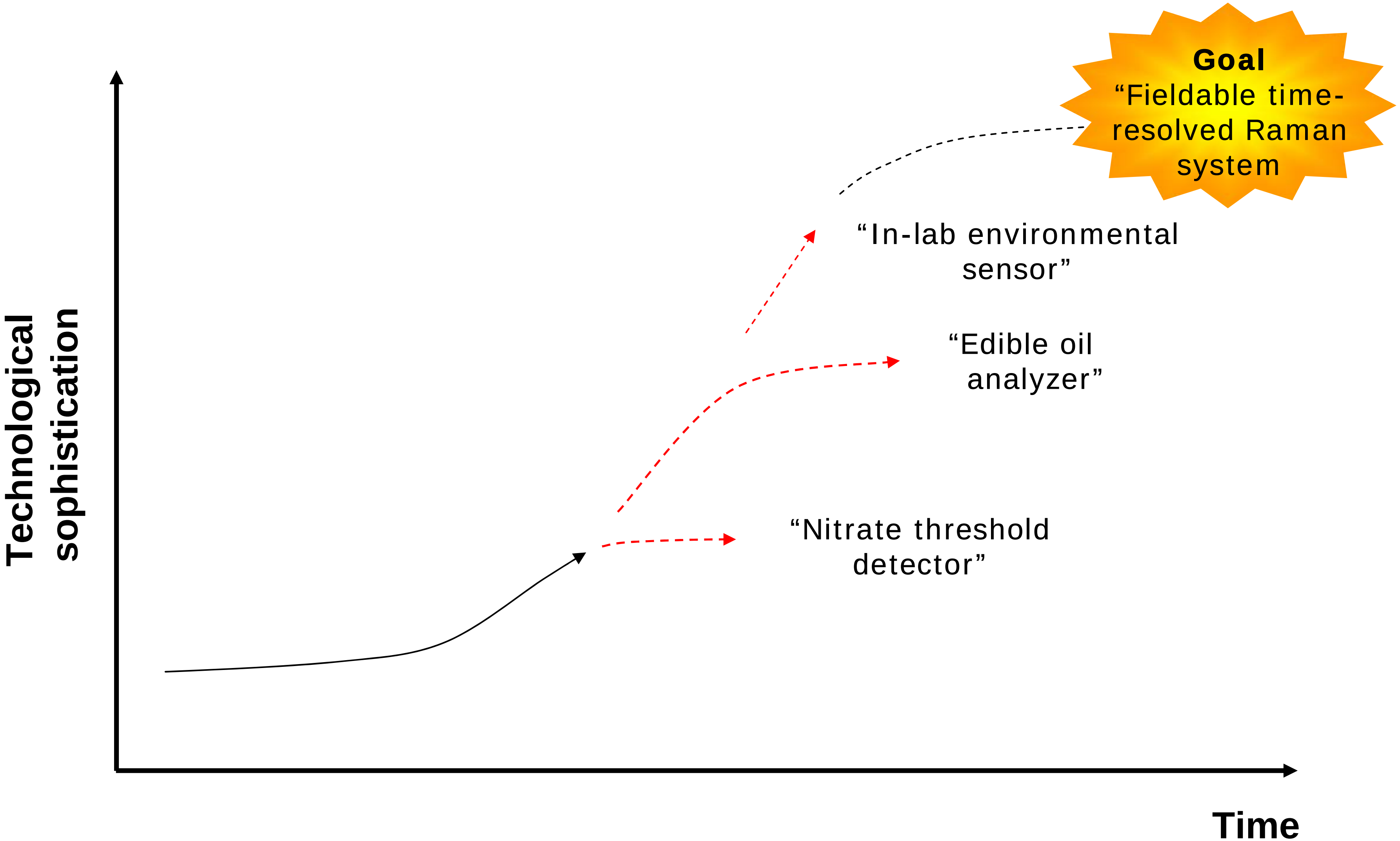


The system balances tradeoffs

“GIVES”	“GETS”
• Use of scanning monochromator slows spectrum acquisition • Low cost / low average power laser requires time to build SNR • Low cost spectrometer limits Raman line resolution	• Applicability to multiple compounds • Potential to assess multi-compound mixtures • Efficient signal averaging to enable low concentration tests • Ability to suppress fluorescence • Balance of sensitivity and resolution with VIS excitation • Fieldable versatility with fiber

Key question: For what application is the prototype technology likely to be “good enough”?

We looked for a market where the system's capability would be "good enough"



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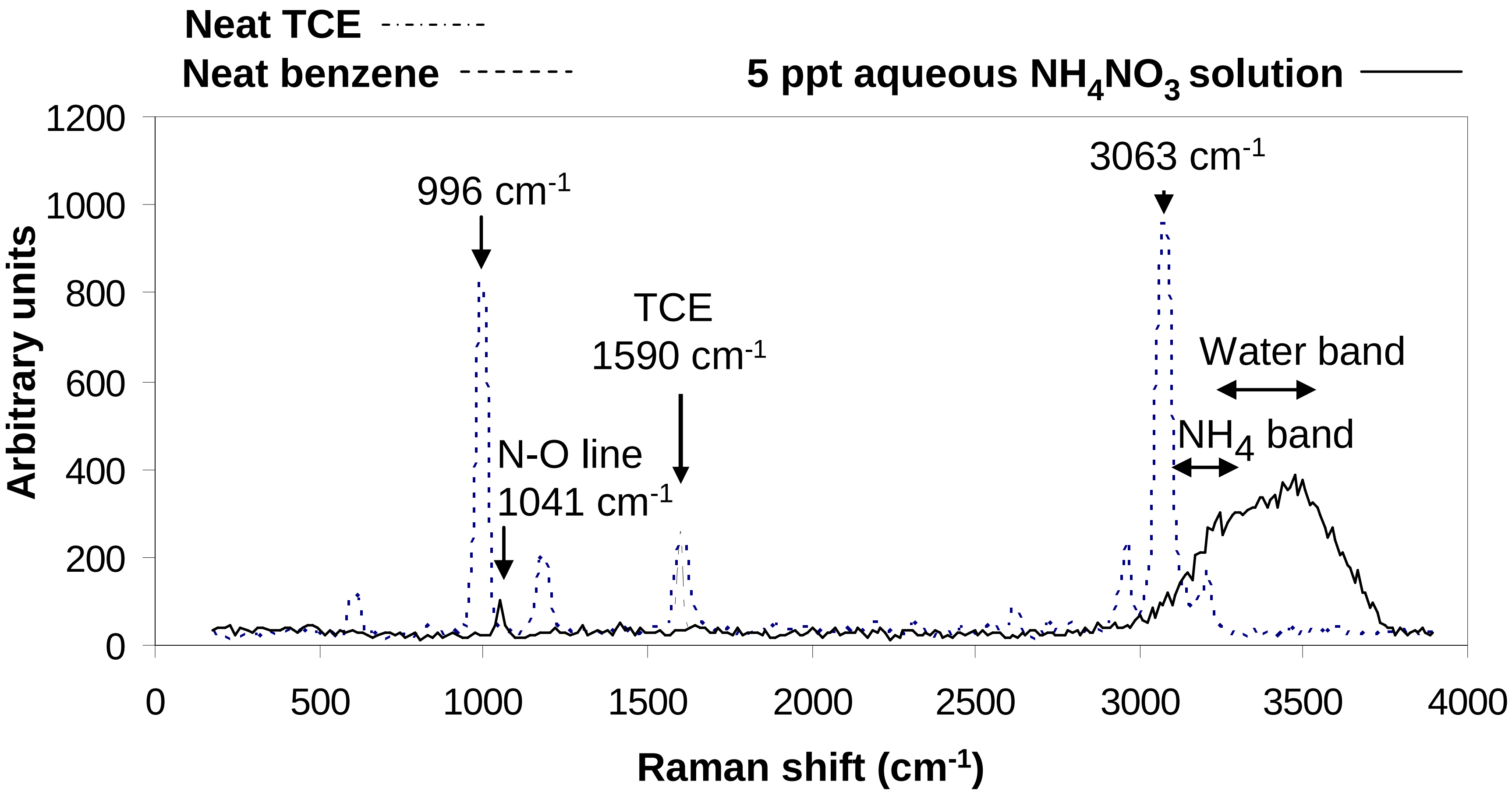
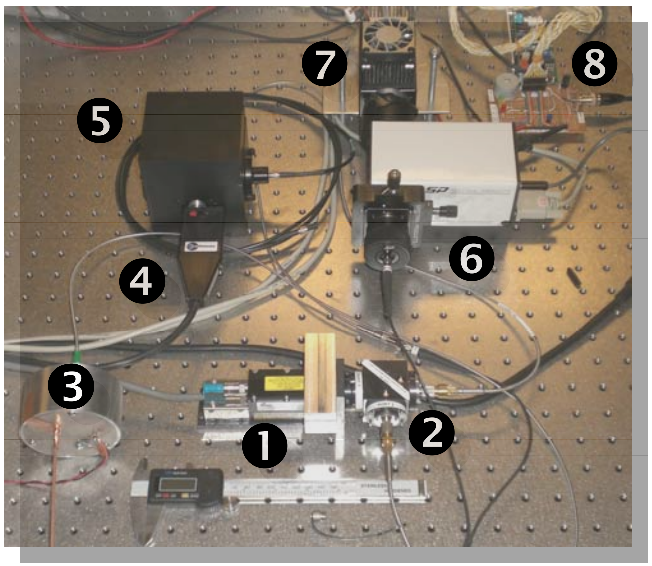
With improvements implemented through work on oils, system applicability has expanded



The system has evolved quickly and is now amenable to a range of possible applications

Low-cost, Time-resolved Raman System



Concluding thoughts

- There are benefits to addressing the needs of the overshot
- “Low end disruption” does not necessarily mean “low tech”
- Democratization can drive improvement and new research direction
- Technology (and science) can improve faster through trial
- Advances occur when you engage more minds outside your field

“Don’t let perfection be the enemy of the good enough”

- Meg Whitman
Former CEO, eBay