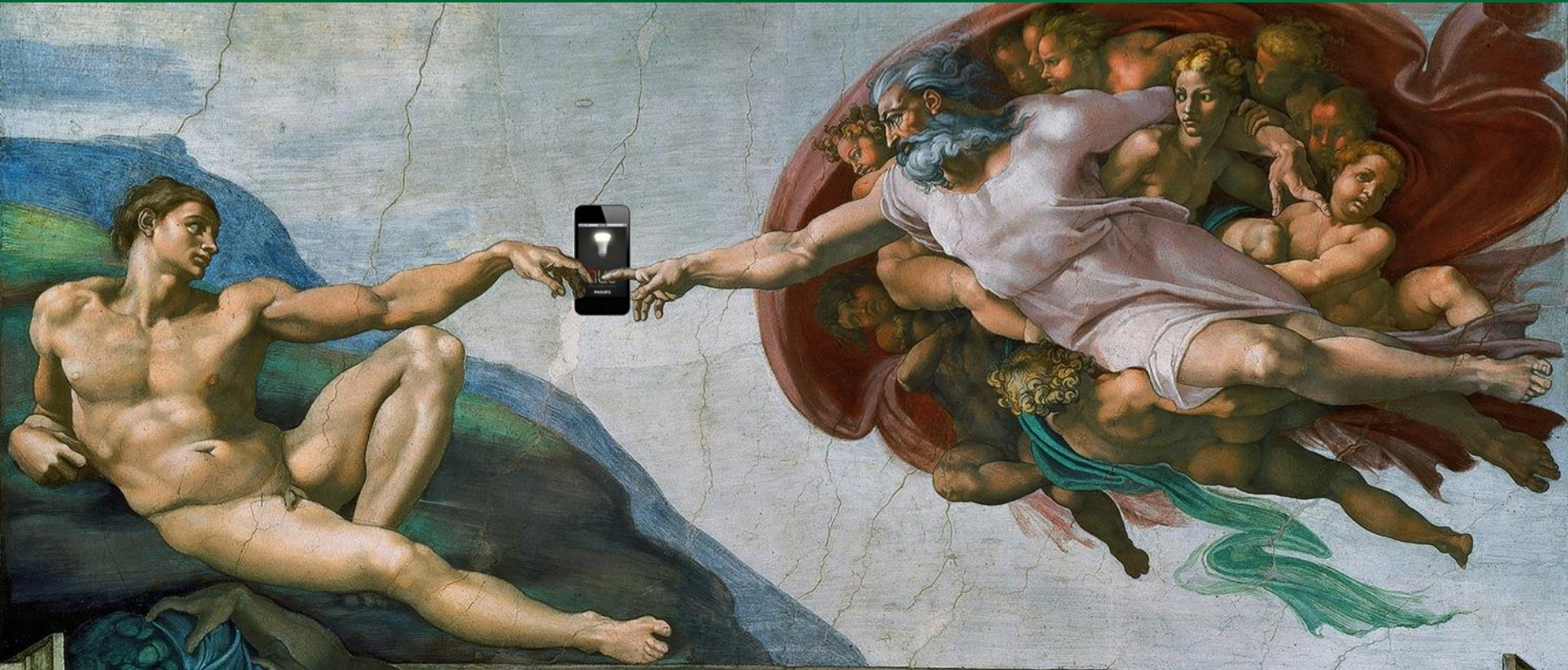


# Intelligent and Adaptive Lighting Systems of the Future



**LIGHTFAIR International**

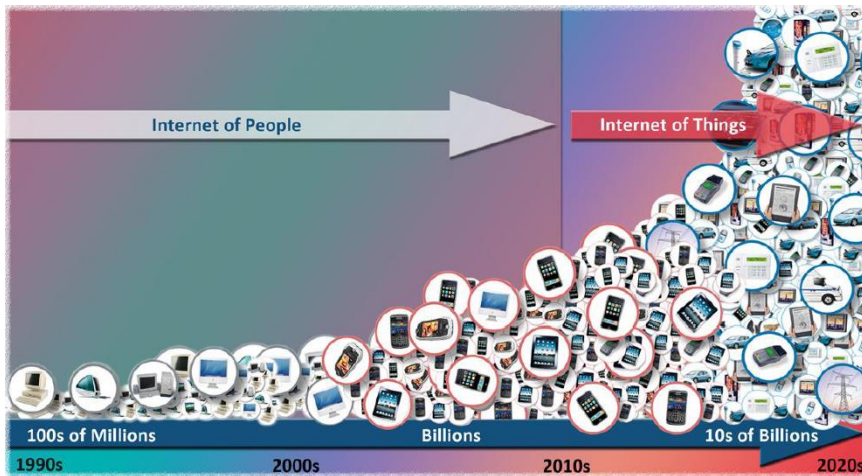
May 5-7, 2015

**Tess Perrin – Lighting Scientist**

**Michael Poplawski – Senior Engineer**

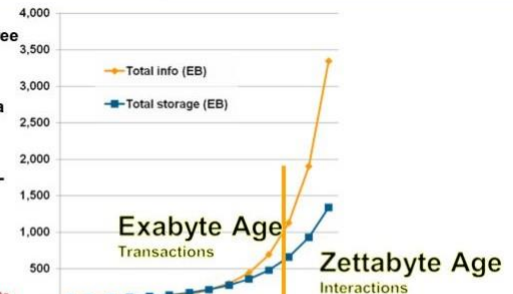
**Pacific Northwest National Laboratory**

# What is the Internet-of-Things, and who cares?



- More data has been created in the last three years than in all past 40,000 years.
- Almost all of this data has a location
- Business and government decision-makers must have a strategy for dealing with location based data

**Technology Trend:** (1) Sensor data and mobility apps are creating more data tagged with location. (2) Increasing number of apps are location-aware, so queries involve spatial dimension. High confidence that analytic apps will include who-what-when-where dimensions.



One Zettabyte (ZB) = 1,000,000,000,000,000,000 bytes =  $10^{21}$  bytes.  
Based on IDC and UC Berkeley data growth estimates.

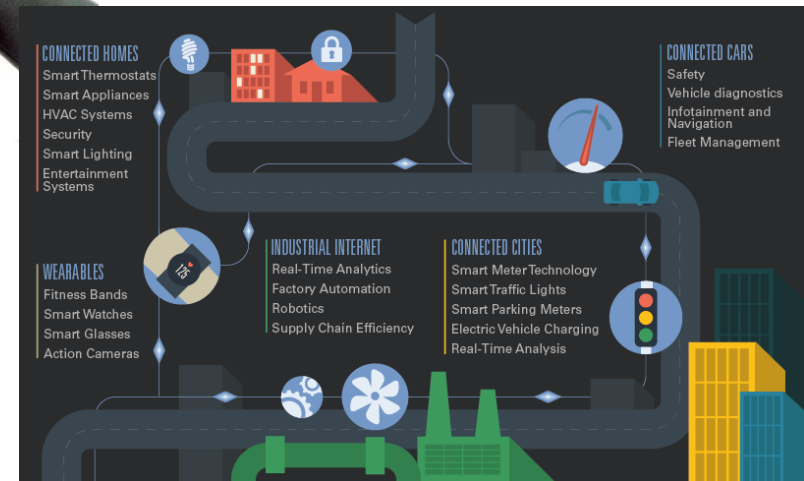
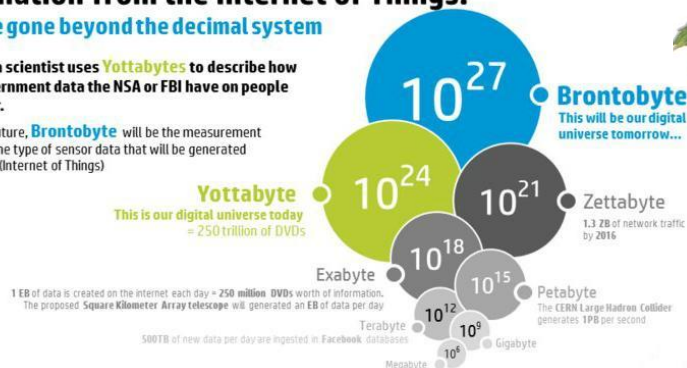
TERADATA  
Enabling Intelligence

## Information from the Internet of Things:

We have gone beyond the decimal system

Today data scientist uses **Yottabytes** to describe how much government data the NSA or FBI have on people altogether.

In the near future, **Brontobyte** will be the measurement to describe the type of sensor data that will be generated from the IoT (Internet of Things)



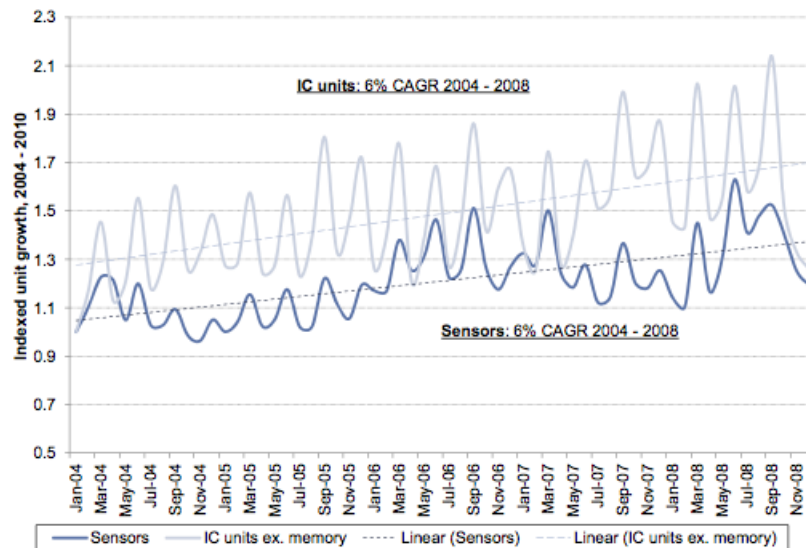


# What technologies are enabling the IoT?

- Cheap sensors
- Cheap intelligence
- Cheap data transport
- Cloud Computing?
- Smart Phones?
- **Lighting?**

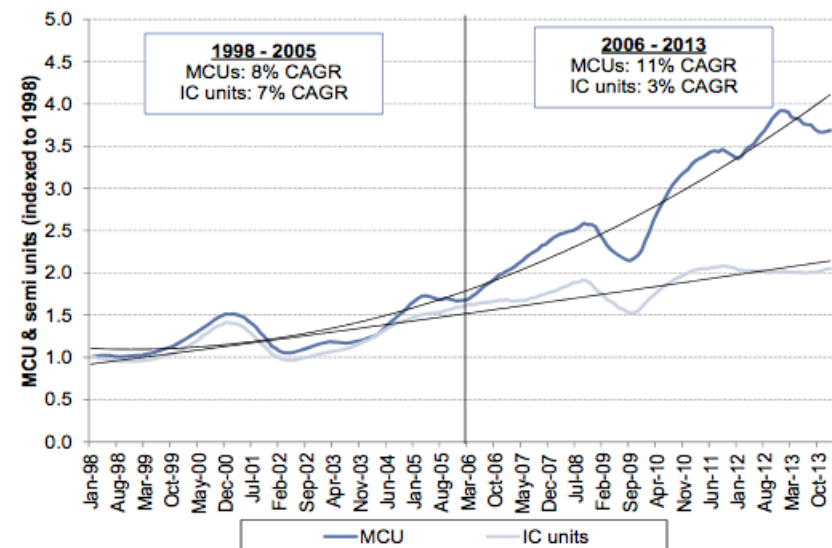


**Exhibit 3: Sensor growth outstripped the overall semiconductor market from 2011-2013 (5% CAGR vs. semis at 0%)**  
Indexed IC units and sensor units to January 2011



Source: SIA, Goldman Sachs Global Investment Research.

**Exhibit 4: Microcontroller growth has significantly outpaced the semiconductor market**  
Market size and unit CAGR



Source: SIA, Goldman Sachs Global Investment Research.

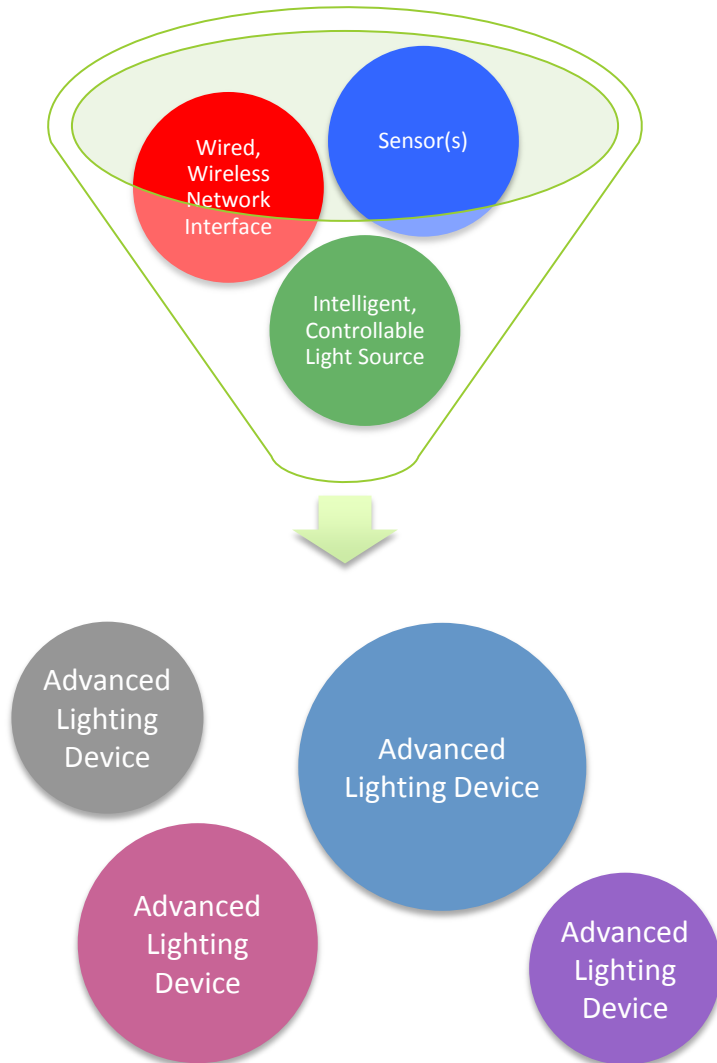
# Why lighting? SSL is the catalyst...

- Solid-State Lighting (SSL) is the most energy efficient, flexible, controllable lighting technology in history
  - Spectral power distribution (color characteristics, e.g. CCT, CRI, Duv), light output (e.g. luminous flux, intensity, distribution)
  - System architecture, partitioning, and power conversion
- SSL is blurring the traditional lines between lighting system devices (e.g. lamps and ballasts/drivers, luminaires, and lighting controls)
- SSL is poised to catalyze the deployment of intelligent, networked lighting devices that collect and exchange data
  - Embedded intelligence (e.g. for managing power conversion) can be leveraged for other purposes (e.g. output control, network interface)
  - Microelectronic platform facilitates the cost-effective integration of additional functionality (e.g. network interfaces, sensors)

# How can the IoT benefit lighting and buildings?

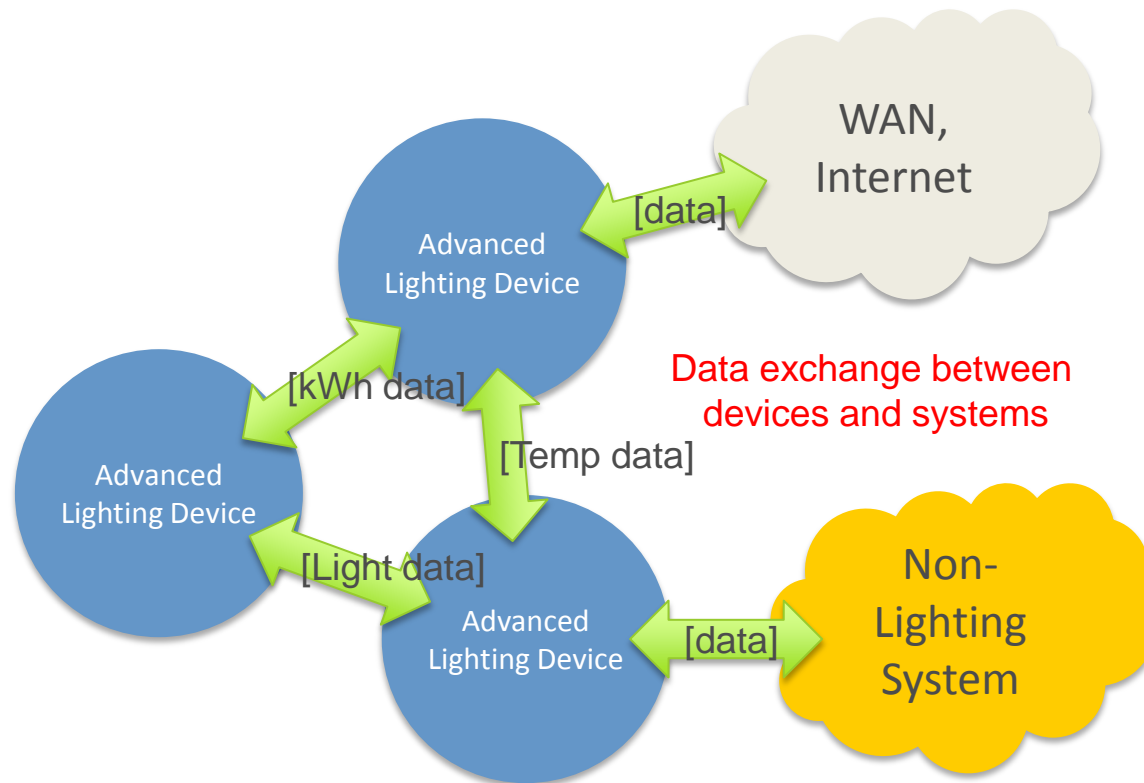
- Enabling intelligent lighting systems with data can result in reduced energy consumption and improved lighting performance
- The data collected (via sensors) by advanced lighting devices and exchanged (via network interfaces and interoperability protocols) with other lighting and non-lighting devices can facilitate reduced energy consumption and improved performance of those devices, as well as a growing number of non-lighting and non-energy related benefits
  - Lighting is pervasive (in all buildings and spaces), well-distributed, and AC powered
  - Leverage SSL transition driven by energy and maintenance savings

# Lighting is poised to dramatically change in the future



- Many integration possibilities
  - Single-function (e.g. sensor-only) devices
  - Multi-function devices (e.g. controllable light source and sensor(s) and network interface)
- Not clear that any particular device integration or system architecture will dominate
  - Many will be likely be able to succeed in the market
  - Solutions for retrofits and new install

# Future advanced lighting systems



# Aren't there already technologies for controlling lighting?

- Lighting control is a function that requires the integration of devices; while a controlled lighting system can far out-perform a static system, performance depends on much more than device capabilities
- Lighting control strategies have been overly focused on devices that are tightly coupled to installed luminaires, with not enough consideration given to system issues and intangibles such as owner organizational maturity
- Lighting control energy savings have been widely varying and unpredictable, and limited by the number of installations, failure to adopt performance monitoring and continuous optimization, and lack of interaction with non-lighting systems
- Complex configuration requirements, high total cost of deployment, poor user satisfaction, and difficult to predict performance have been and remain significant barriers to adoption (estimated as < 1%) and energy savings



# DOE Museum Resources



Home > GATEWAY DEMONSTRATION MUSEUM REPORTS

## GATEWAY DEMONSTRATION MUSEUM REPORTS

[Home](#)  
[About the Solid-State Lighting Program](#)  
[R&D Program](#)  
[Market-Based Program](#)  
[SSL Basics](#)  
[Using LEDs](#)  
[Information Resources](#)  
[Financial Opportunities](#)

It's hard to find a lighting application with aesthetic standards higher than those of museums, where success depends upon showing the artifacts and works of art in the best possible light—literally speaking. DOE has conducted several demonstrations of LED lighting in museums, providing valuable data and experience on product performance in this highly demanding environment. In addition, DOE conducted a survey regarding LED lighting conversions in museums, and published a summary of the results in a report.

### MUSEUM SURVEY REPORT




**SSL Adoption by Museums: Survey Results, Analysis, and Recommendations**  
Summary of results of a survey regarding LED lighting conversions in museums (November 2014)  
[Report](#)  
[Brief](#)  
[Posting: LED Adoption by Museums](#)


### RELATED RESOURCES

[The Getty Conservation Institute: Guidelines for Selecting Solid-State Lighting for Museums](#)  
[Color Maintenance of LEDs in Laboratory and Field Applications](#)  
[CALIPER Application Reports: LED MR16 Lamps](#)  
[CALIPER Application Reports: LED PAR38 Lamps](#)  
[Foot Sheet: LED Color Stability](#)  
[Foot Sheet: Lifetime and Reliability](#)  
[Foot Sheet: Understanding LM-79 Reports](#)


### MUSEUM DEMONSTRATION REPORTS




**Burden Museum in Troy, New York**  
Evaluation of the dimming performance of LED track lighting, A19 screwbase lamps in chandeliers, and linear cove lighting. (October 2013—Updated August 2014)  
[Report](#)  
[Posting: Maximizing Dimming Success at the Burden Museum](#)




**Smithsonian American Art Museum in Washington, DC**  
Evaluation of LED PAR30, PAR38, and MR16 lamps in several galleries (June 2012)  
[Report](#)  
[Video](#)  
[Posting: GATEWAY Demonstration at the Smithsonian American Art Museum](#)



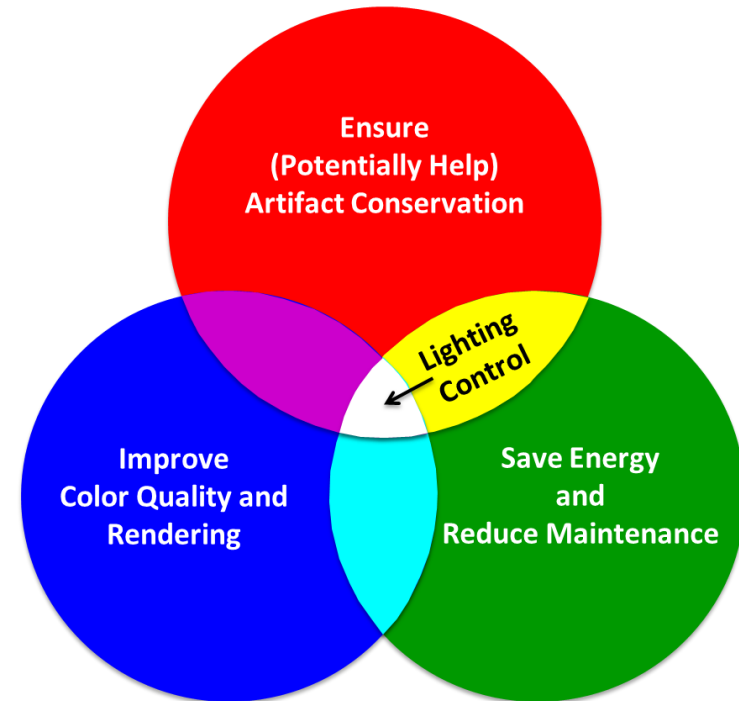
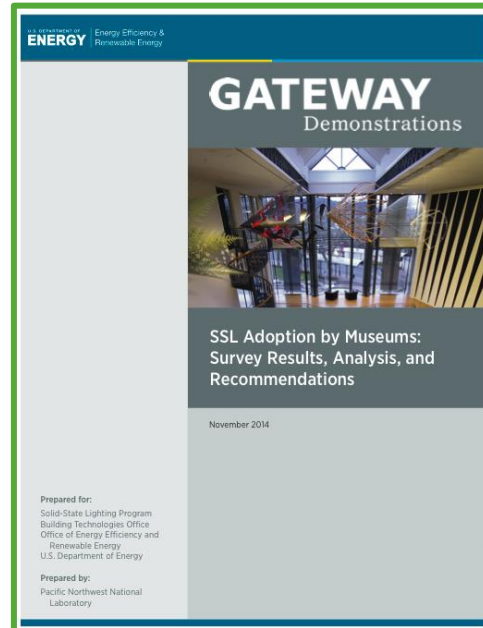
**J. Paul Getty Museum in Malibu, California**  
Evaluation of LED PAR38 lamps in a special photography exhibition (March 2012)  
[Report](#)  
[Posting: GATEWAY demonstration at the J. Paul Getty Museum](#)



**Jordan Schnitzer Museum of Art in Eugene, Oregon**  
Evaluation of LED PAR38 lamps in a special exhibition, plus side-by-side comparisons of three different LED PAR38 lamps (September 2011)  
[Report](#)



**Field Museum of Natural History in Chicago, Illinois**  
Evaluation of LED track lighting system in an enclosed gallery exhibit (November 2010)  
[Report](#)

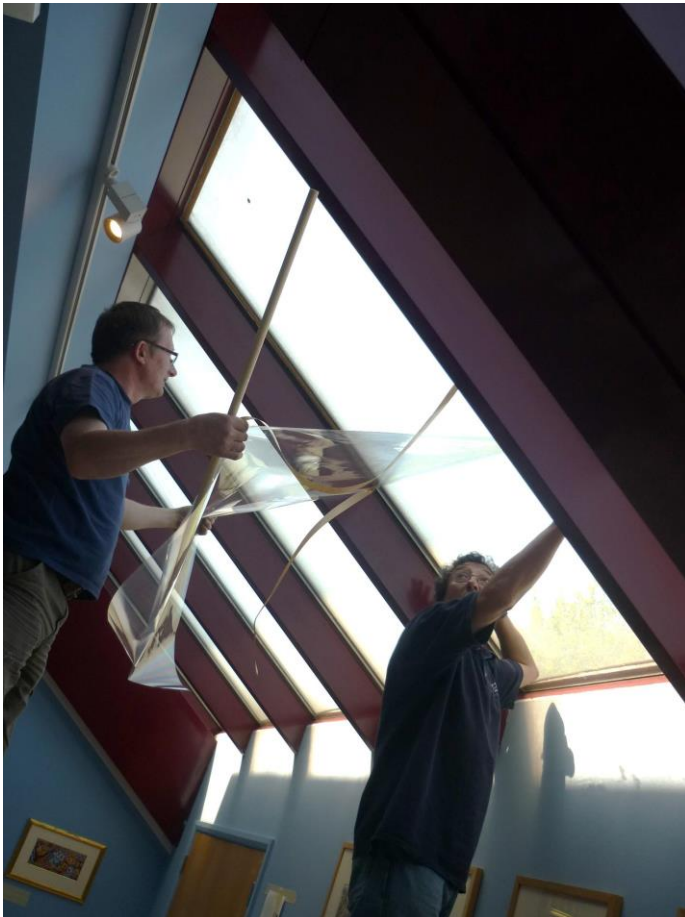


**Survey responders:**  
39% incandescent dimming  
42% 0-10V/DALI/DMX  
12% combination  
**33% no controls**

# Control of Lighting in Museums

## MECHANICAL METHODS

are the dominant approach for limiting exposure



## INTEREST IN AUTOMATIC CONTROL

65% would use lighting controls if they worked with existing infrastructure and afford lamp-by-lamp control

*"It is hard to imagine having the money for replacing existing equipment with these options when what we have [filters, screens] works fine with manual installation."*

Flicker?

Additional wiring?

Dim down to 50 lux?

# Why does DOE work with museums?

LEDs have the potential to save **80% or more** in energy, with further savings from controls.

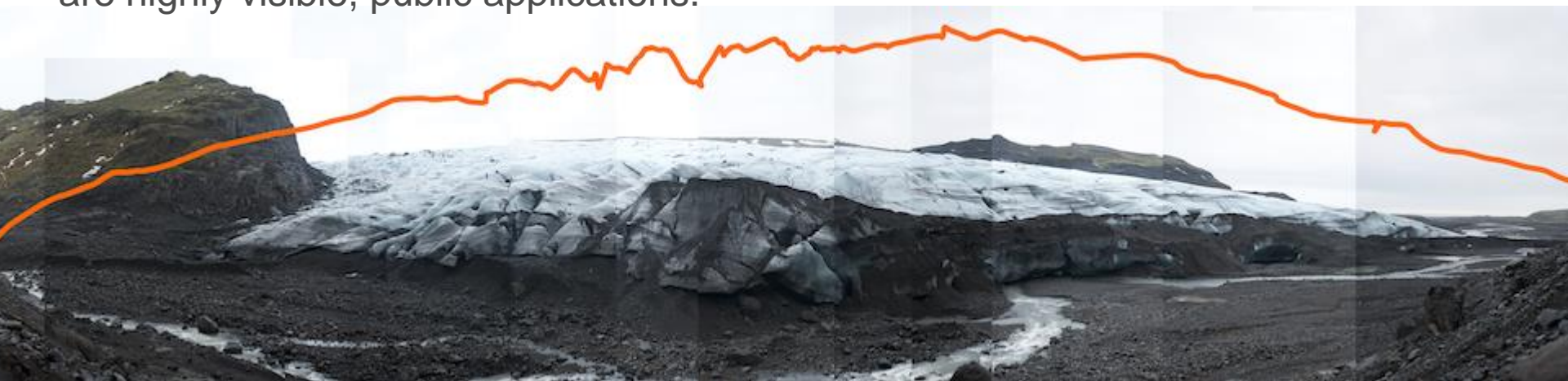
Museums use approximately **twice** the electricity compared to other commercial buildings due to the increased HVAC used to regulate the relative humidity.

Museums require optimal lighting conditions, need to control exposure, and are highly visible, public applications.

**Common goals:**  
sustainability and energy savings



National Museum, Stockholm  
*Intelligent combination of daylight with SSL*

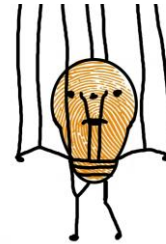




# Museum Interest in Advanced Lighting Systems

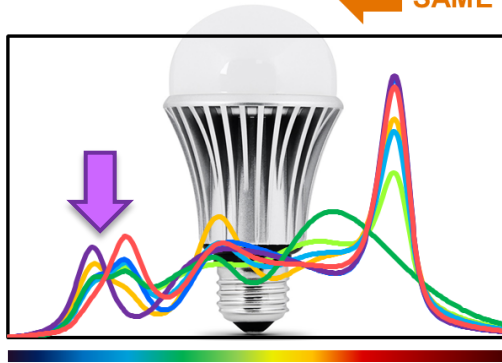
## Control of more than just light intensity

- Specification of lighting exposure (illuminance, spectrum, time) in order to
  - Minimize damage
  - Optimize viewing conditions
  - Maintain color performance
- Integration with sensors that monitor
  - Ambient light (e.g. daylight)
  - Physical environment (RH, T)
  - Use of space
- Adaptive exposure control
- Network interfaces to enable
  - Reporting of logged data
  - Central management

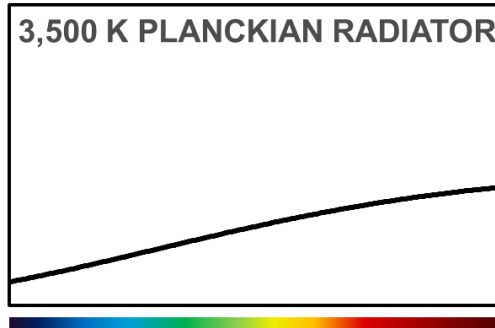


# How adaptive exposure control helps conservators

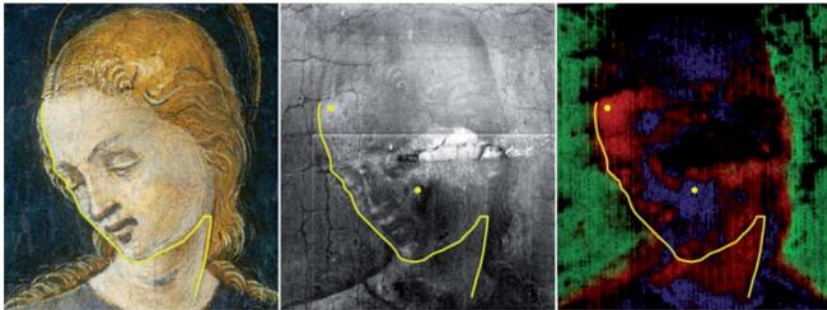
← SAME CHROMATICITY →



3,500 K PLANCKIAN RADIATOR



Enable more accurate evaluation of potential damage for the selected spectrum, intensity, and material



Complement more nuanced tracking of condition over time

Blue Wool Standards



Eliminate the subjectivity of using the ISO Blue Wools



Minimize the labor involved in precision measurements

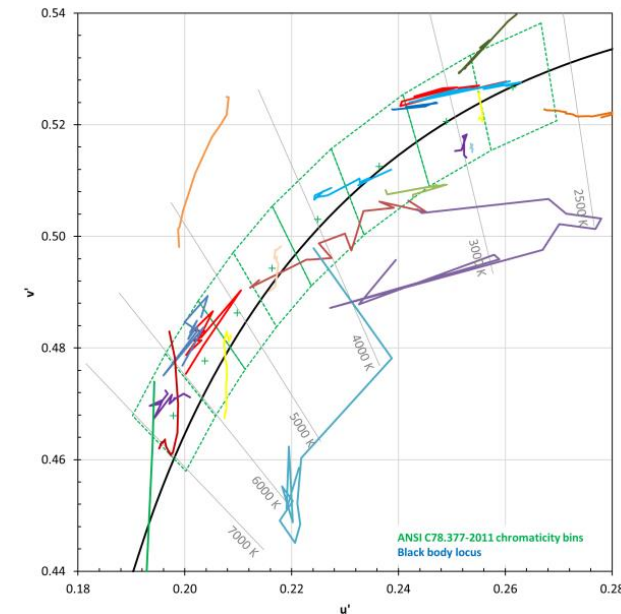
Reduce the burden of frequent hand-held monitoring





# How adaptive exposure control helps industry

## Log measurements



## User-driven database on performance

Benefit Manufacturers  
Improved products and  
innovation

Benefit Primary Institution  
Long-term performance  
supports warranty claims

Benefit Other Institutions  
Long-term performance  
helps decision making

# How adaptive exposure control helps visual performance

Norman Brommelle, Color and conservation, Studies in Conservation, **1955**



*free range*

**Canadian Conservation Institute**  
Benchmark value

**50 lux**

For dark surfaces

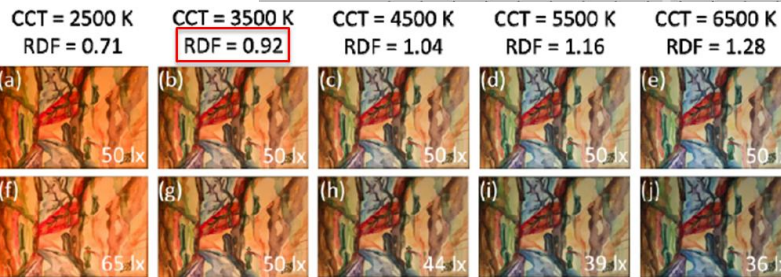
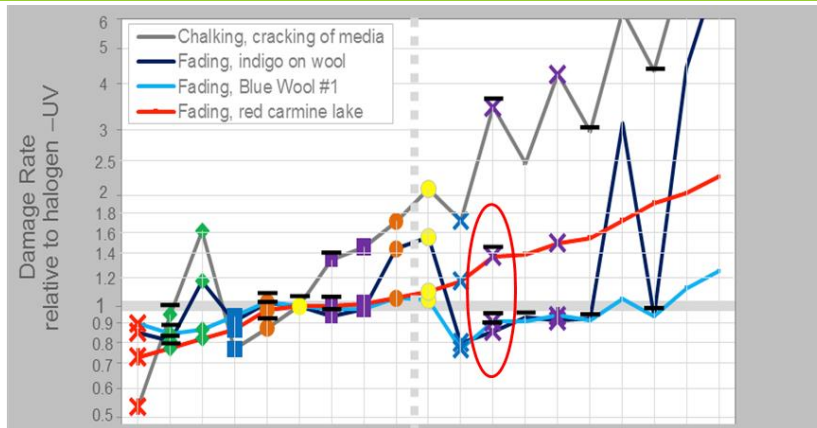
For low contrast detail

For fine detail or complex tasks

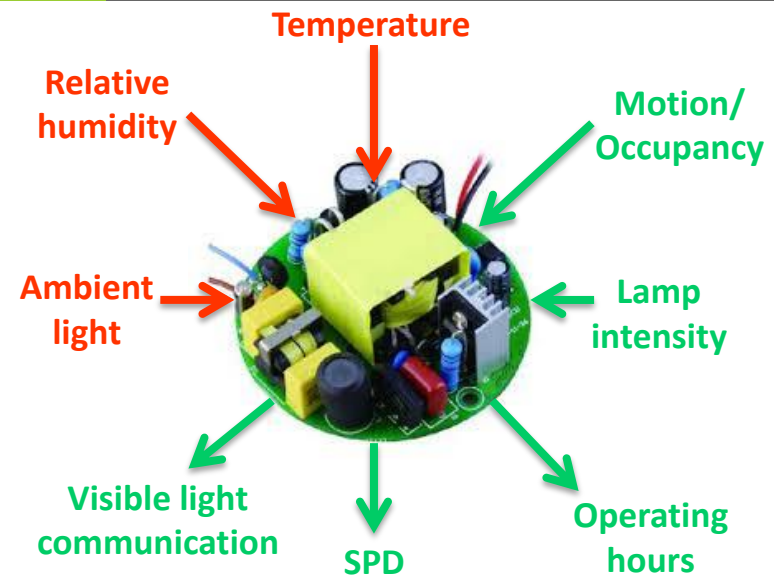
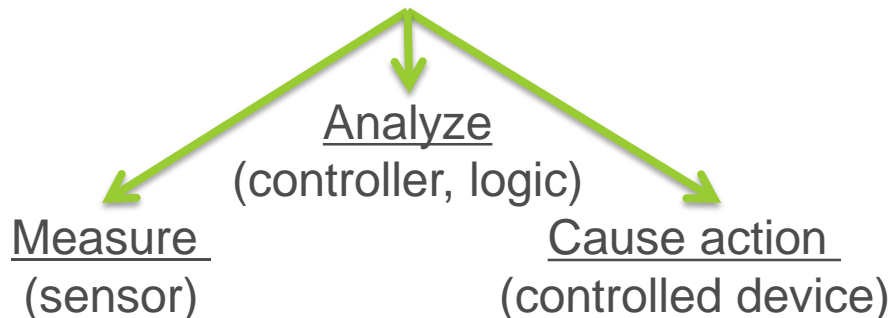
For older viewers



# Potential application of adaptive exposure control



Integrate with other environmental monitoring strategies → combining three major agents of deterioration (light, RH, T) to:







# QUESTIONS?

Photograph by Sisse Brimberg

