Smart Lighting: Beyond Ordinary Illumination

Better Buildings By Design Efficiency Vermont Conference

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Robert Karlicek

Director,
Smart Lighting Engineering Research Center,

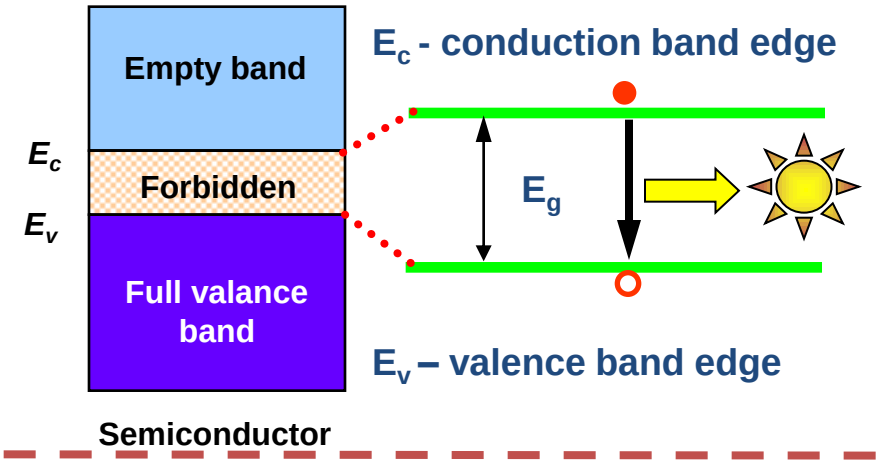
Professor, Electrical, Computer and Systems Engineering

Rensselaer Polytechnic Institute

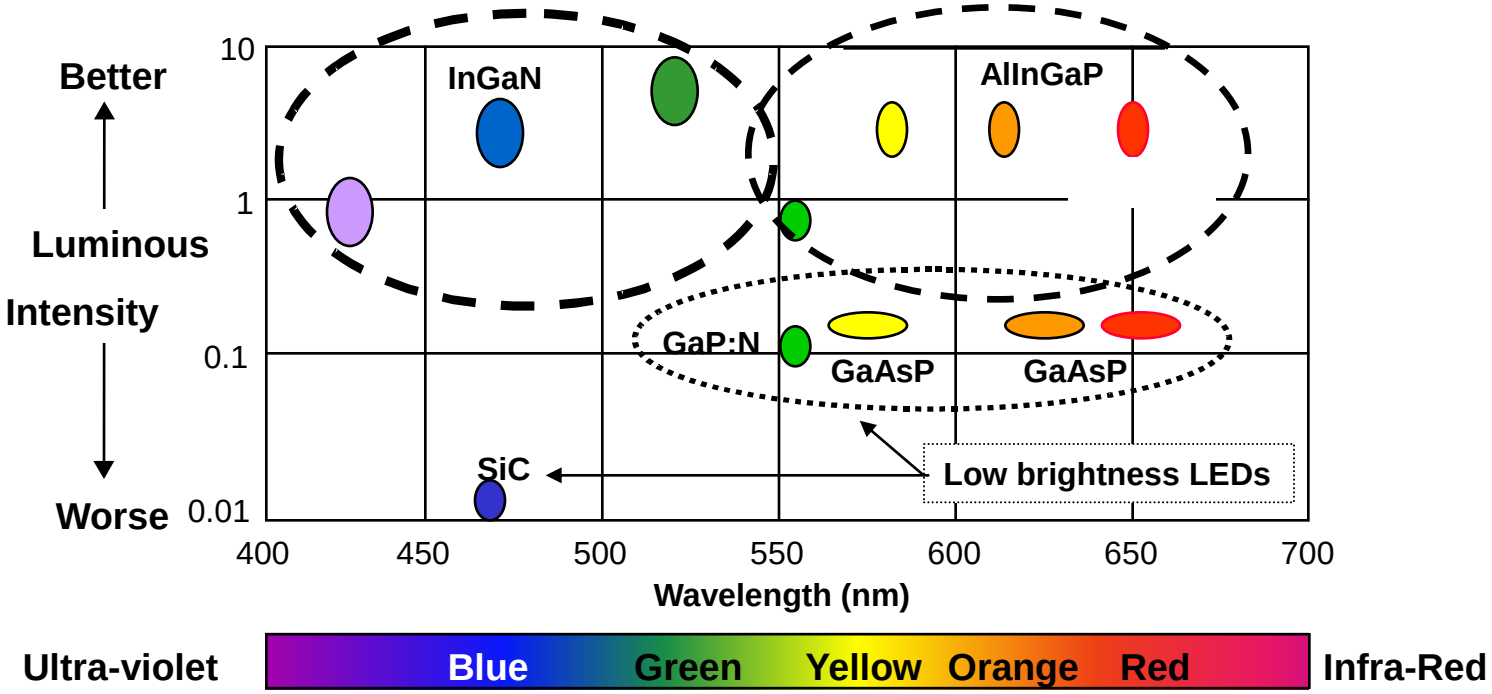
OUTLINE

- Some LED Basics
- Solid State Lighting, Status and Challenges
- Smart Lighting – what is it ???
- Summary

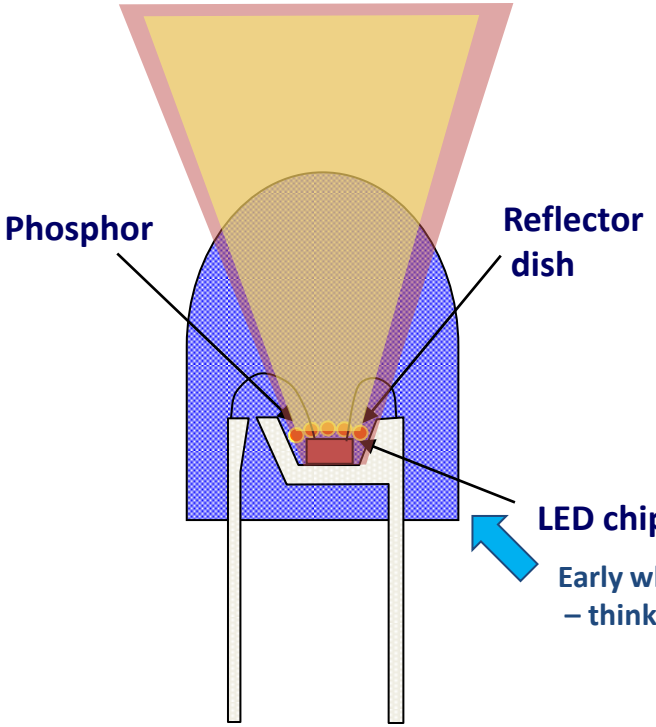
LED BASICS – ANY COLOR POSSIBLE

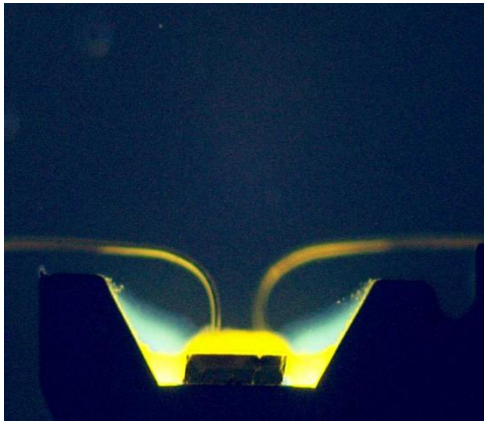


- Engineered, multilayered crystal structure efficiently converts current to light
- Semiconductor composition determines color
- Crystal quality determines efficiency



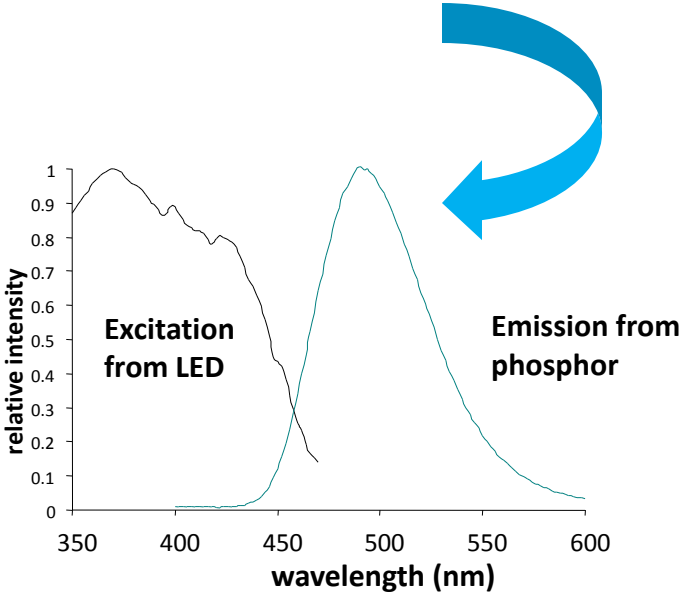
SSL – USE PHOSPHORS TO MAKE WHITE





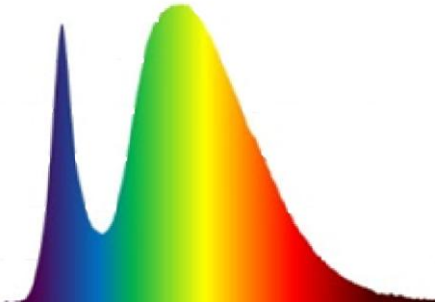
Early white LED Technology – think key chain lights

- The phosphor over the blue chip converts blue emission to yellow.
- Combined blue and yellow light appears white (or white-ish)
- Energy is lost in the process

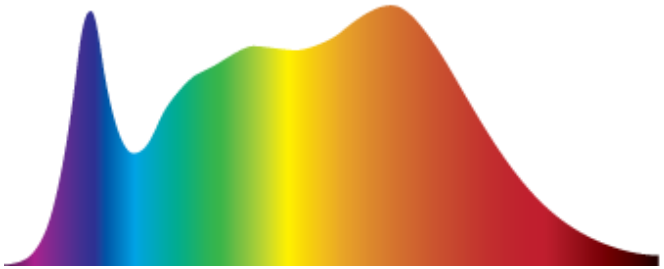


- Multiple phosphors can be combined with UV or Blue LEDs
- Sometimes a red LED can be included to get a warmer white

Phosphors – any color quality possible…



CCT: 6500 K



CCT: 4000 K

CCT: 2800 K

- Lots of phosphor compositions – **any spectrum possible**
- Can be optimized for specific needs and applications
- Key Issues – Color Uniformity, Color stability (getting better)
- Lots of ways to integrate phosphors and LEDs

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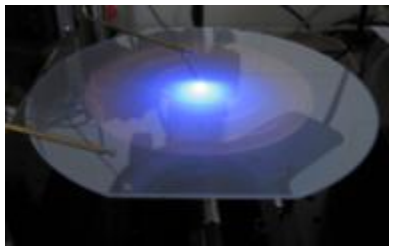
LED SUPPLY CHAIN – CHANGING RAPIDLY

SMART LIGHTING

Materials Processes Devices



Substrates/Epitaxy

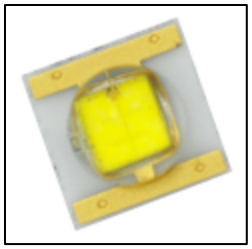
- Sapphire, SiC
- Silicon
- GaN
- Other

Materials & Subsystems

LED Device Designs

- Lateral
- Vertical
- Flipped (Lateral)
  - Sapphire off
  - PSS Sapphire on

Materials & Subsystems Integration



Packaging

- Single/multi-die
- Size (Etendue)
- Efficiency
- Thermals
- Cost

Full Systems Integration

Integration:

- Module
- Driver
- Fixture
- System

- **Upstream design selections impact down stream design options**
- **Rapid disruptive innovation across entire supply chain**
- **Short product lifetimes due to rapid innovation & platform change**

LED BULB EFFICIENCY IS MAXING OUT

Cree R&D Results, Summer 2012

- **Technology hitting Lm/W limits**
  - *Blue LEDs approaching* ***Efficiency Limits***
- **Reliability getting better (system)**
  - ***Socket Saturation*** *is a concern*
- **Solid State Lighting Markets changing**
  - ***Lm/$*** *is more important than Lm/W*
  - ***Integrated Control*** *becoming important*
- **Strategy for Future Growth?**
  - ***System features driving future revenue***

CONSIDER WHAT THE TRANSISTOR DID…

First Wave

The transistor replaced tubes – first wave

(it also killed RCA, Westinghouse, Magnavox, many others)

CONSIDER WHAT THE TRANSISTOR DID…

Second Wave

What will be possible with Smart Solid State Lighting???
(and who will be the victims in this next transition?)

SMART LIGHTING - ASSUMPTIONS

SSL Lighting System Lifetimes will approach Design Space Lifetimes (~10 years)

- Gradual Death of Bulb/Socket model
- Installed SSL fixtures must adapt to changing requirements

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Dynamic color will become increasingly important (Not just CCT – but full gamut capability)

- Spectral Content increasingly tied to Human Health
- Dynamic Lighting increasingly tied to Productivity, Learning

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"Internet of Things" will embrace Lighting

- Networked, embedded controls will "Google-ize" lighting
- Functional Integration will significantly reduce costs
- System in fixture (LEDs, controls, adaptive optics, sensors)

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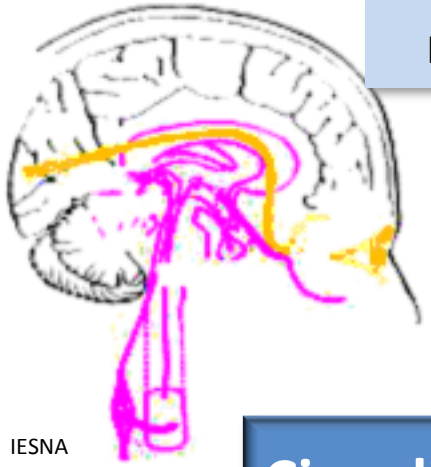
LIGHTING IMPACTS HEALTH – SPECTRUM IS IMPORTANT

SMART LIGHTING



IESNA

Intensity | Spectrum | Distribution | Timing | Duration

Visual System

Circadian Disruption:
- Cancer
- Heart Disease
- Diabetes
- Obesity

Performance, Well-being, Satisfaction, and HEALTH

Other Impacts
- Cognition
- Memory
- Recovery

Circadian System

Intensity | Spectrum | Distribution | Timing | Duration

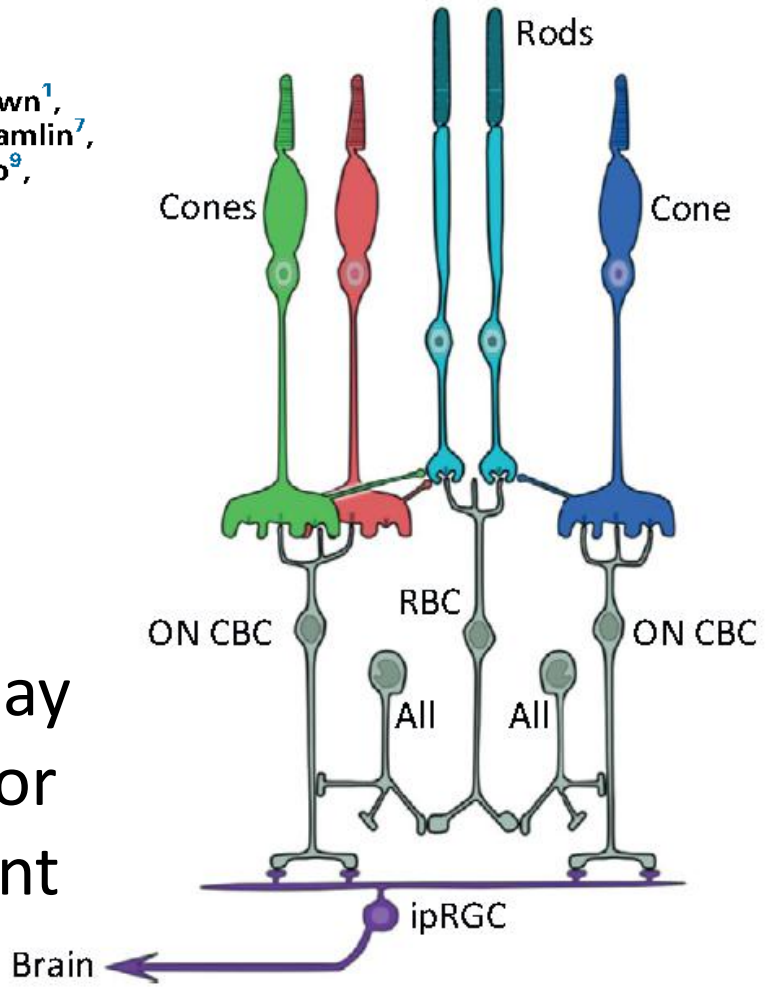
(After Figueiro & Rea, Lighting Research Center, RPI)

IT'S COMPLICATED…

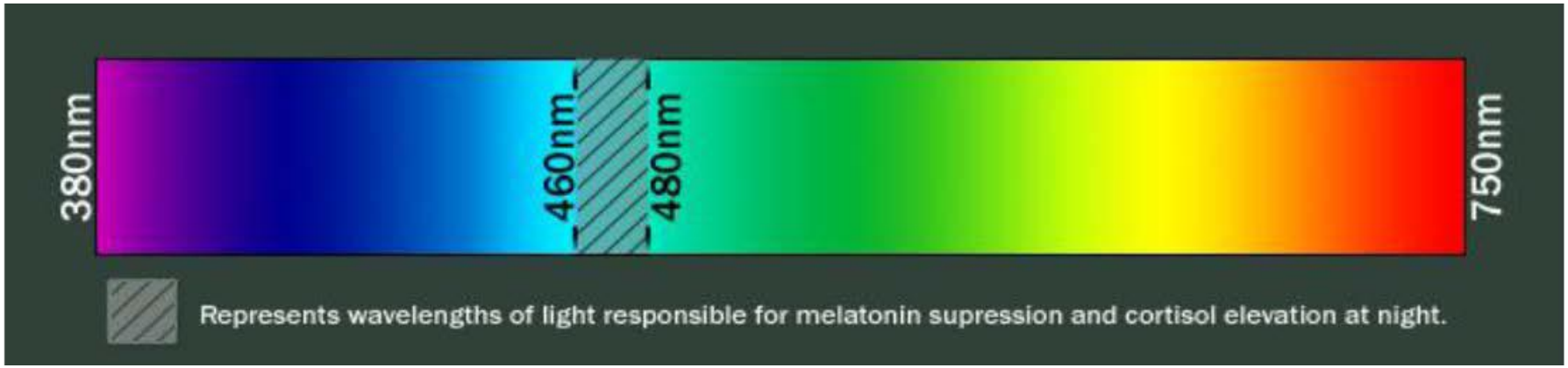
Measuring and using light in the melanopsin age

Robert J. Lucas[1*], Stuart N. Peirson[2*], David M. Berson[3], Timothy M. Brown[1], Howard M. Cooper[4], Charles A. Czeisler[5], Mariana G. Figueiro[6], Paul D. Gamlin[7], Steven W. Lockley[5], John B. O'Hagan[8], Luke L.A. Price[8], Ignacio Provencio[9], Debra J. Skene[10], and George C. Brainard[11]

- Light detection and circadian signaling is complex
- No single lighting metric used today is adequate to set specifications for light related circadian management



BUT IT IS MORE COMPLICATED THAN BLUE LIGHT



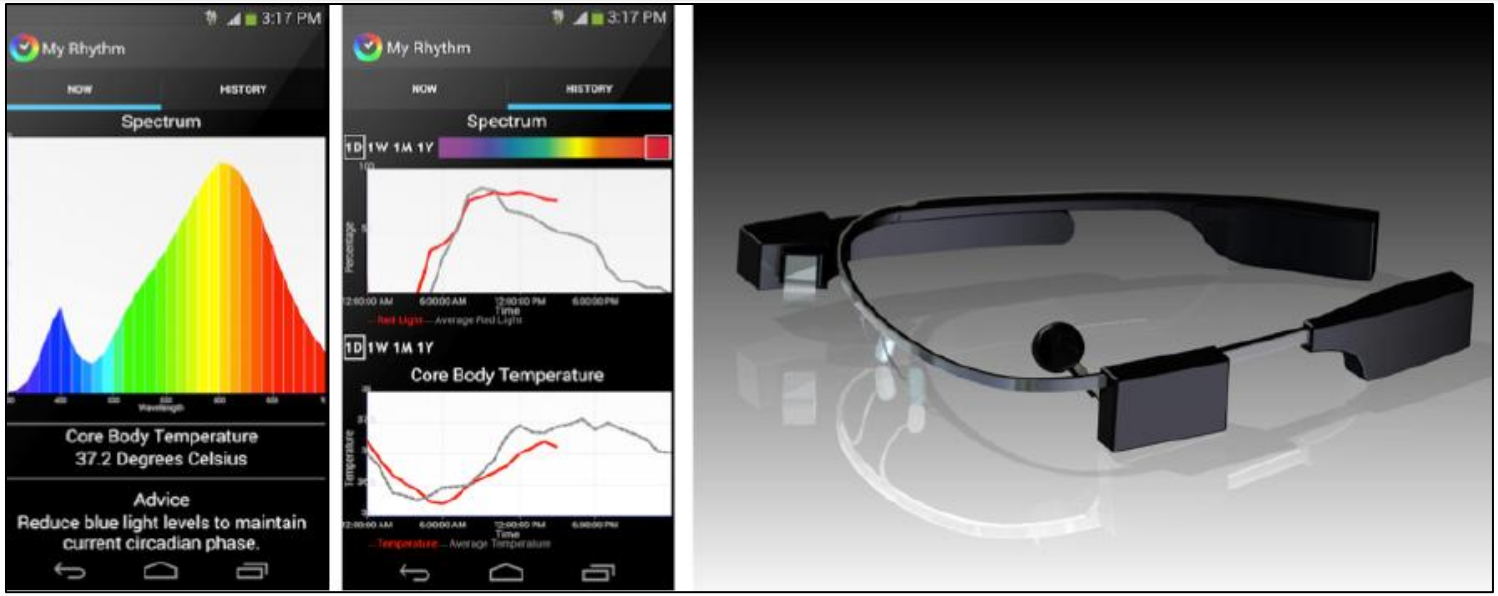
Removing a 20 to 40 nm notch of blue spectrum at night

- Melatonin suppression by light at night prevented
- Night shift cortisol elevation prevented
- Improved sleep duration and quality
- Shift-worker alertness improved

Spectral modulation attenuates molecular, endocrine, and neurobehavioral disruption induced by nocturnal light exposure
Rahman SA, Marcu S, Shapiro CM, Brown TJ, **Casper R**F
American Journal of Physiology - Endocrinology and Metabolism 3/1/2011

HEALTHY LIGHTING – HOW TO GET NEEDED DATA?

CES 2013



- Expanded measurement tools under development
- Use to get relevant data in in real world conditions
- Tool for critical studies?

HOW IMPORTANT IS LIGHTING CONTROL?

SMART LIGHTING

Breast Cancer and Circadian Disruption From Electric Lighting in the Modern World

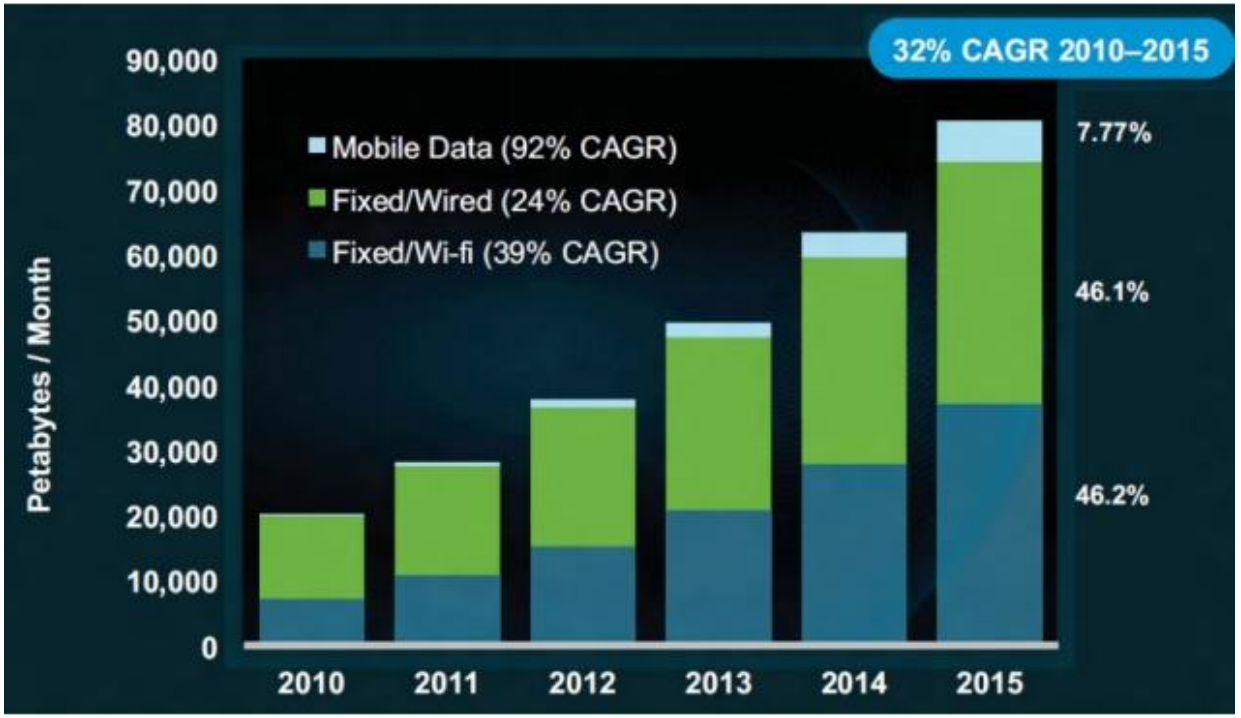
Richard G. Stevens, PhD[1]*; George C. Brainard, PhD[2]; David E. Blask, PhD, MD[3]; Steven W. Lockley, PhD[4]; Mario E. Motta, MD[5]

Breast cancer is the leading cause of cancer death among women worldwide, and there is only a limited explanation of why. Risk is highest in the most industrialized countries but also is rising rapidly in the developing world. Known risk factors account for only a portion of the incidence in the high-risk populations, and there has been considerable speculation and many false leads on other possibly major determinants of risk, such as dietary fat. A hallmark of industrialization is the increasing use of electricity to light the night, both within the home and without. It has only recently become clear that this evolutionarily new and, thereby, unnatural exposure can disrupt human circadian rhythmicity, of which three salient features are melatonin production, sleep, and the circadian clock. A convergence of research in cells, rodents, and humans suggests that the health consequences of circadian disruption may be substantial. An innovative experimental model has shown that light at night markedly increases the growth of human breast cancer xenografts in rats. In humans, the theory that light exposure at night increases breast cancer risk leads to specific predictions that are being tested epidemiologically: evidence has accumulated on risk in shift workers, risk in blind women, and the impact of sleep duration on risk. If electric light at night does explain a portion of the breast cancer burden, then there are practical interventions that can be implemented, including more selective use of light and the adoption of recent advances in lighting technology and application. **CA Cancer J Clin 2013;000:000-000.** © **2013 American Cancer Society.**

Keywords: breast neoplasms, circadian clock, melatonin production, shift work, sleep duration

WIRELESS COMMUNICATIONS WITH LIGHT

- **Huge Demand exceeding RF capacity**
- **New Interest in using Light for Datacomm**
- **Visible Light Communications standards emerging**
- **Light and RF based solutions will work together**

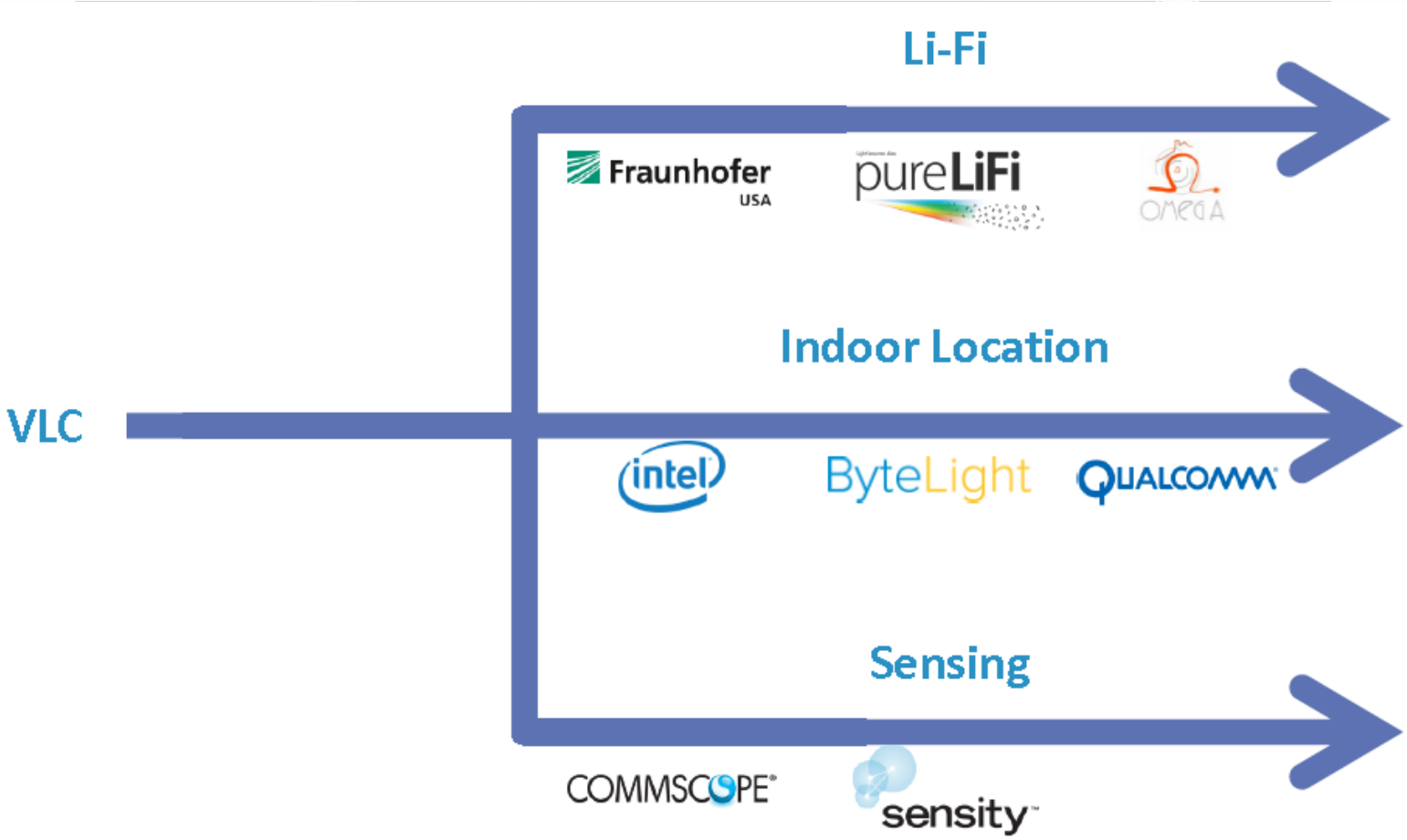


VISIBLE LIGHT COMMUNICATIONS – MORE THAN DATA

- Unregulated spectrum, secure communications
- Light or RF based uplink
- Luminaires sense commands from other lights
- Indoor GPS functions

LIGHTING SYSTEMS THAT USE DIGITAL CONTENT TO SEE, COMMUNICATE AND CONTROL

VISIBLE LIGHT COMMUNICATIONS – MORE THAN DATA



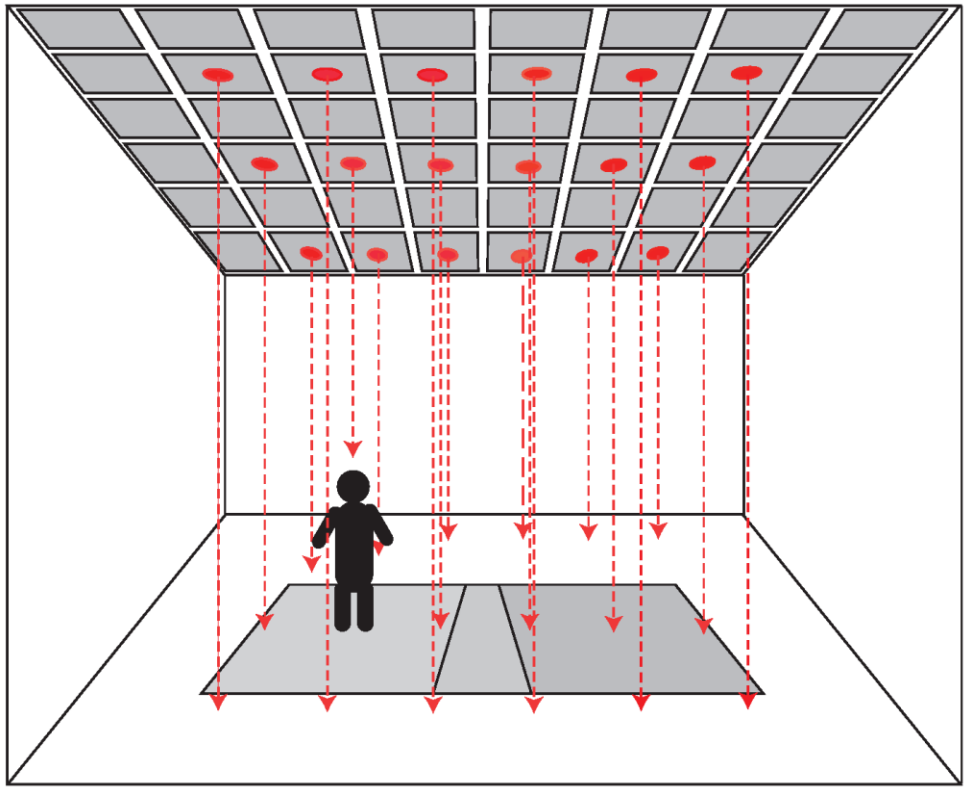
NEAR TERM APPLICATION – INDOOR GPS AND DATA

- PERSONALIZED SHOPPING
- MEASURE EFFECTIVENESS OF RETAIL EXPERIENCE

ADVANCED LIGHT SENSING

Color selective time of flight

- Modulated Light (MHz)
- Time-of-flight Sensors in fixtures like RADAR with light
- Generates low resolution map
  - Detects all objects
  - Senses change in position

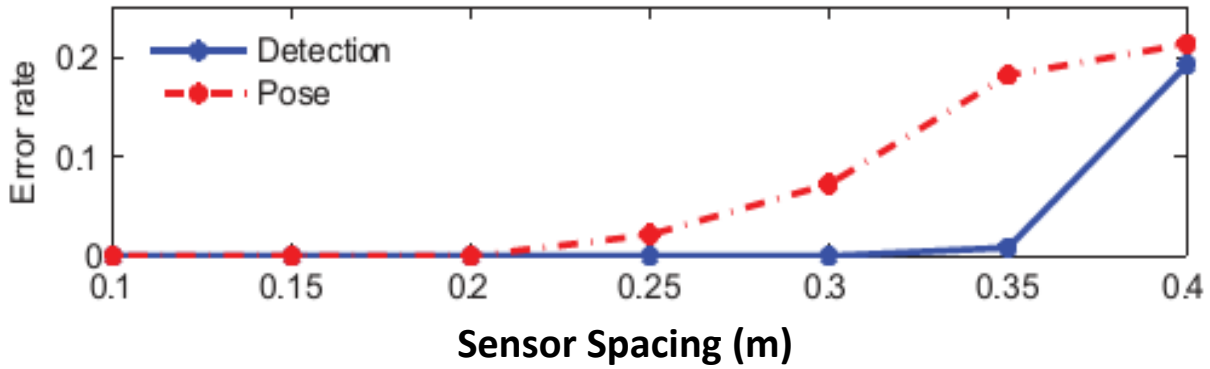


(Li and Radke, Smart Lighting ERC)

Optimized lighting control

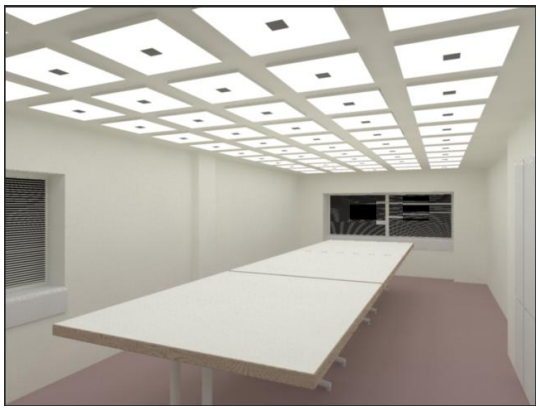
(illuminance, spectral content, local dimming, daylighting…)

EXTENDING TO LARGER ENVIRONMENTS



L. Jia and R.J. Radke, Using Time-of-Flight Measurements for Privacy-Preserving Tracking in a Smart Room. *IEEE Transactions on Industrial Informatics (2013)* http://dx.doi.org/10.1109/TII.2013.2251892

CONFERENCE ROOM SIMULATION



Lights on at night

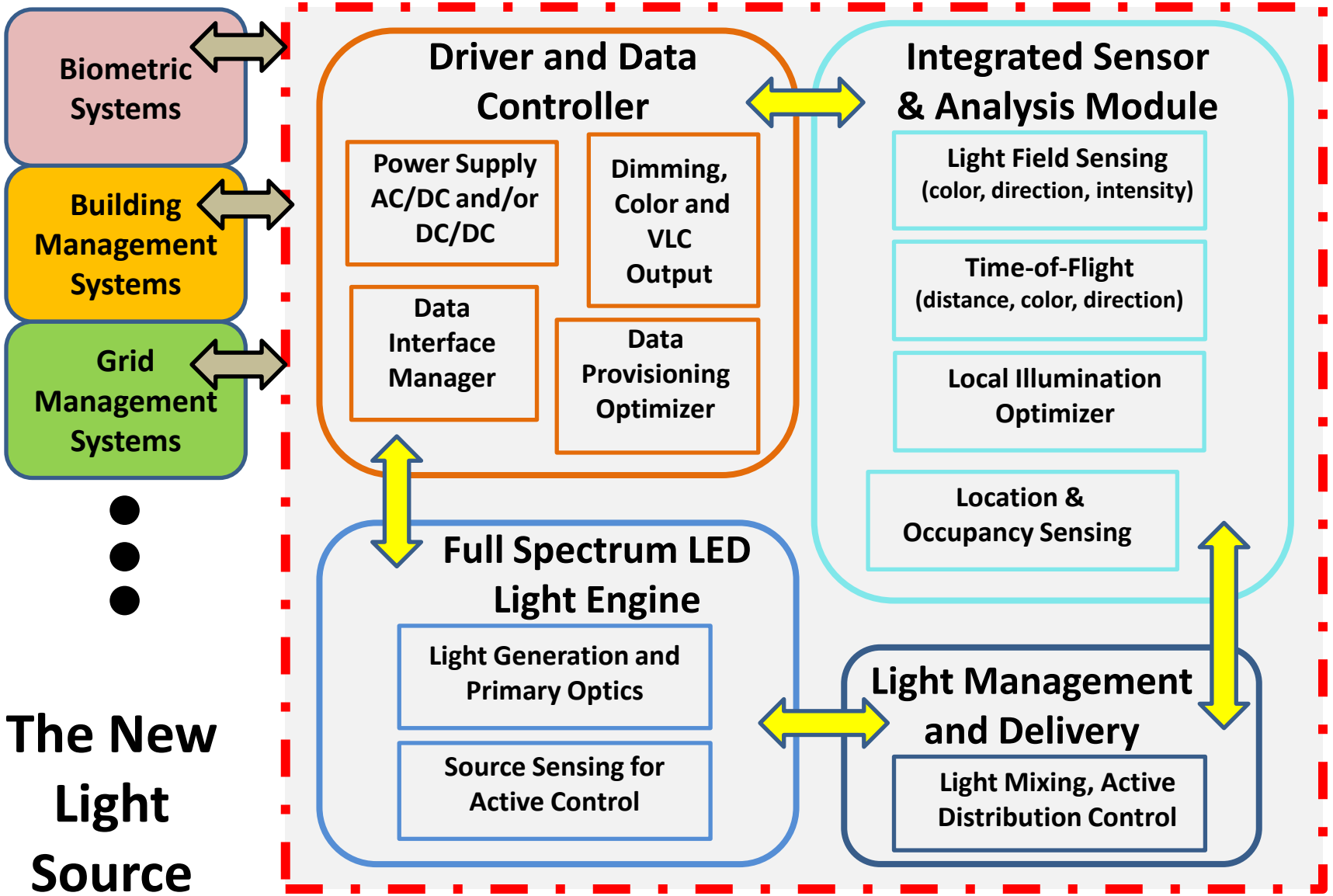
Lights on in daytime

Lights off in daytime

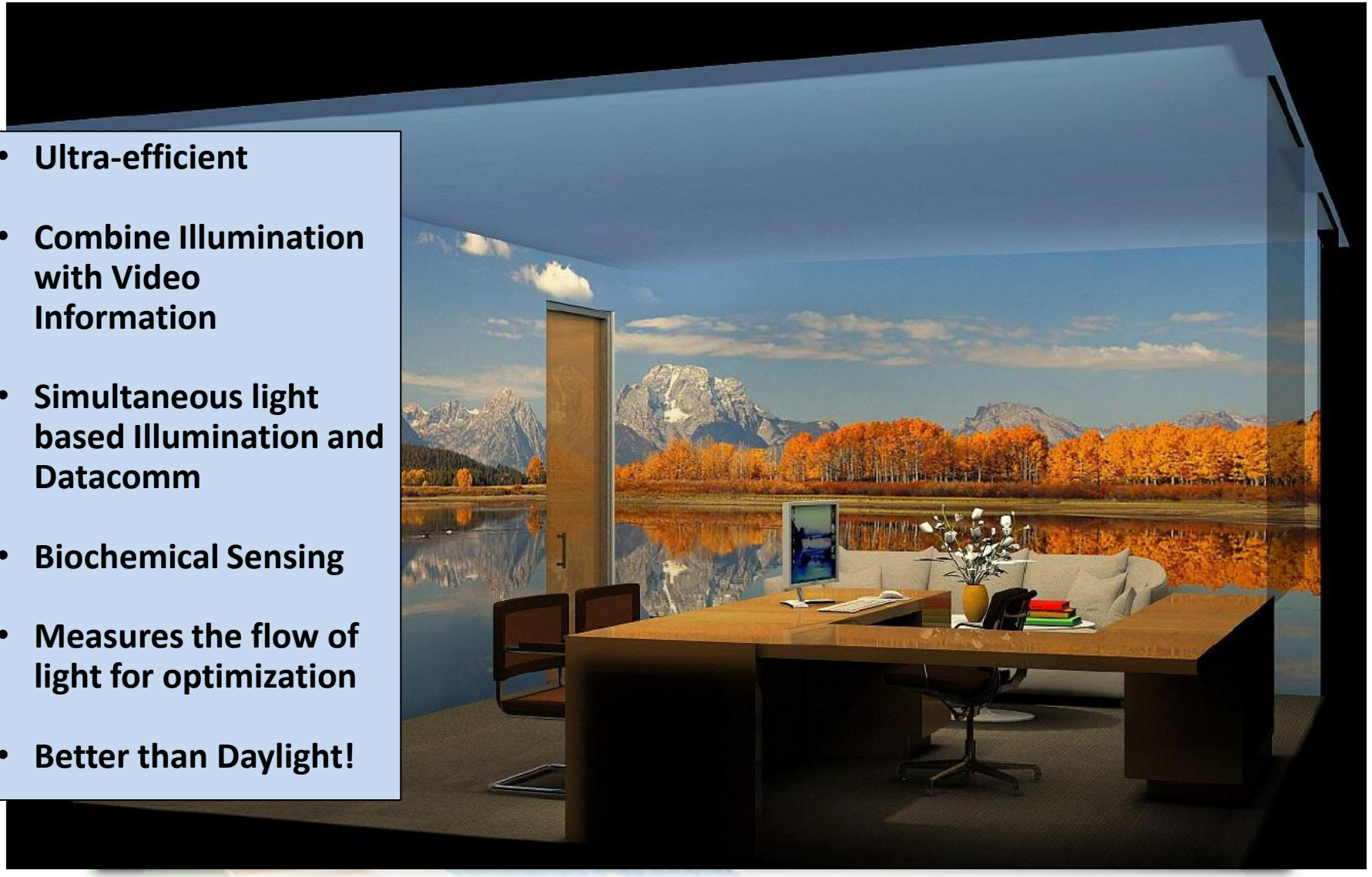
Per-fixture light field
Slow motion (10^5)

- Lighting system very quickly self – calibrates
- Changes in light response function tells lighting system about room changes
- Lighting systems automatically adapts

FUNCTIONAL INTEGRATION (WILL REDUCE COST)



SMART LIGHTING SYSTEMS: ILLUMINATION VIDEO FUSION



- **Ultra-efficient**
- **Combine Illumination with Video Information**
- **Simultaneous light based Illumination and Datacomm**
- **Biochemical Sensing**
- **Measures the flow of light for optimization**
- **Better than Daylight!**

BARRIERS TO SMART LIGHTING?

- Much more efficient green and yellow LEDs

Needed for full gamut control

- Radically different packaging and integration technologies

Addresses costs, integrated services

- Highly customized, networked light sensors integrated into fixtures

Biggest area of development need

From Consumer Electronics Show (CES) 2012

Sony Crystal-LED prototype

Sony's Crystal LED technology is self-emitting, uses ultra-fine LEDs

No LCD, No OLED:
Bright and efficient enough for synthetic windows?

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SUMMARY

- **Solid State Lighting is only just beginning**

  Rapid Technological Evolution will drive change for decades

- **Lighting will use light to see, control and communicate**

  Advanced light field mapping needed to use light to its fullest advantage – sparseness conserves privacy

- **Illumination will join "Internet of Things"**

  "apps" will customize illumination and lighting systems sense and learn best lighting practices autonomously

ACKNOWLEDGEMENTS

- **Funding from the NSF**

- **Colleagues at…**

  Rensselaer (lead)

  Boston University

  University of New Mexico

- The Smart Lighting ERC Industrial Members
  (26 Companies across the world supporting the Smart Lighting Vision)

Thank You!