Our Environment of Light

An Interdisciplinary Survey Course

The nature of light and its sources, its interaction with the materials on which it falls, its effects on Earth's climate, and the subtle ways that living organisms respond to its presence and absence

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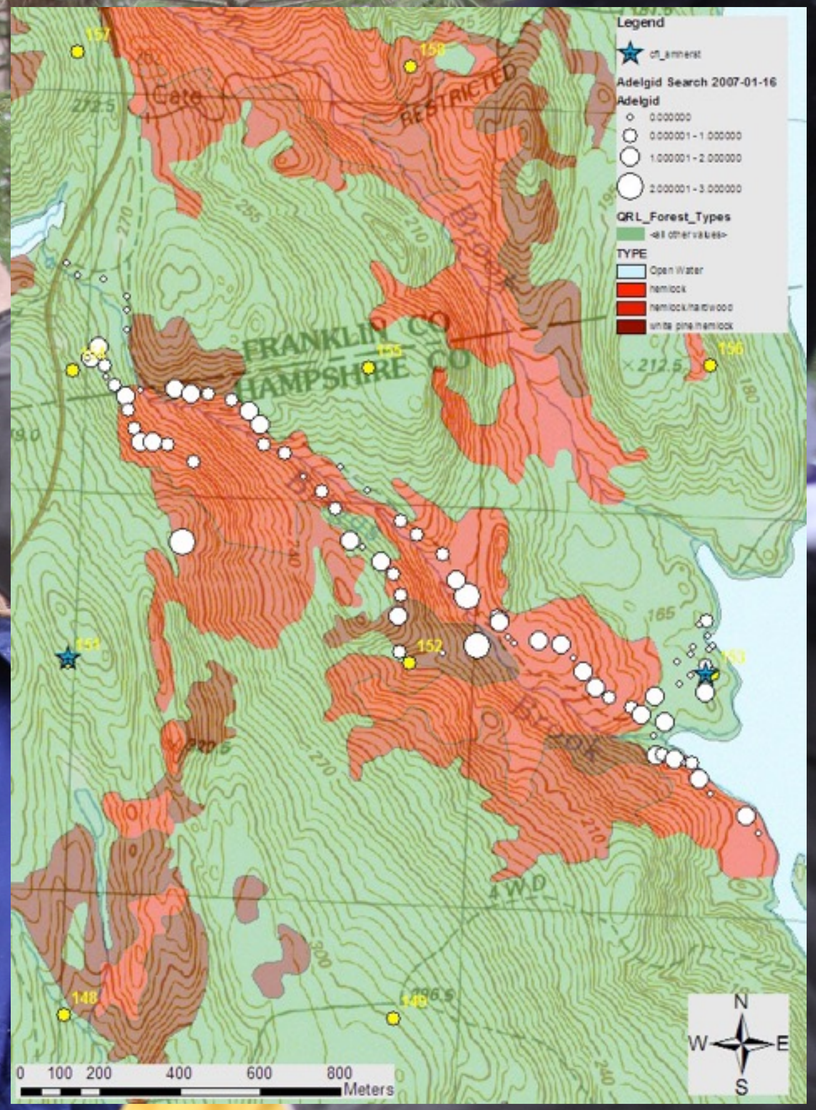
My Background

- Adjunct Assistant Professor in Environmental Conservation at UMass Amherst
- Academic Technology Specialist for Data Science and Spatial Analysis at Amherst College
- Teaching and research with geographic information science & technologies, also history
- Ph.D. in nanospatial statistical physics
- Previously taught physics & astronomy
- Member, International Dark-Sky Association



Characterizing the spread of the hemlock woolly adelgid

Survey Course Organization

- **Opportunity:** Design and teach a course in UMass' Commonwealth Honors College
- **Goal:** Provide an overview of light's many characteristics, and relate them to a multitude of environmental issues, and tools of the trade
- **Format:** 1 hour per week, at most 15 students, no background expected, primarily sophomores & juniors
- **Assignments:** ~30 pp readings (open educational materials, scientific & news articles), online responses, in-class discussion, short experiments
- **Final:** research proposal & presentation on a relevant topic; basics exam

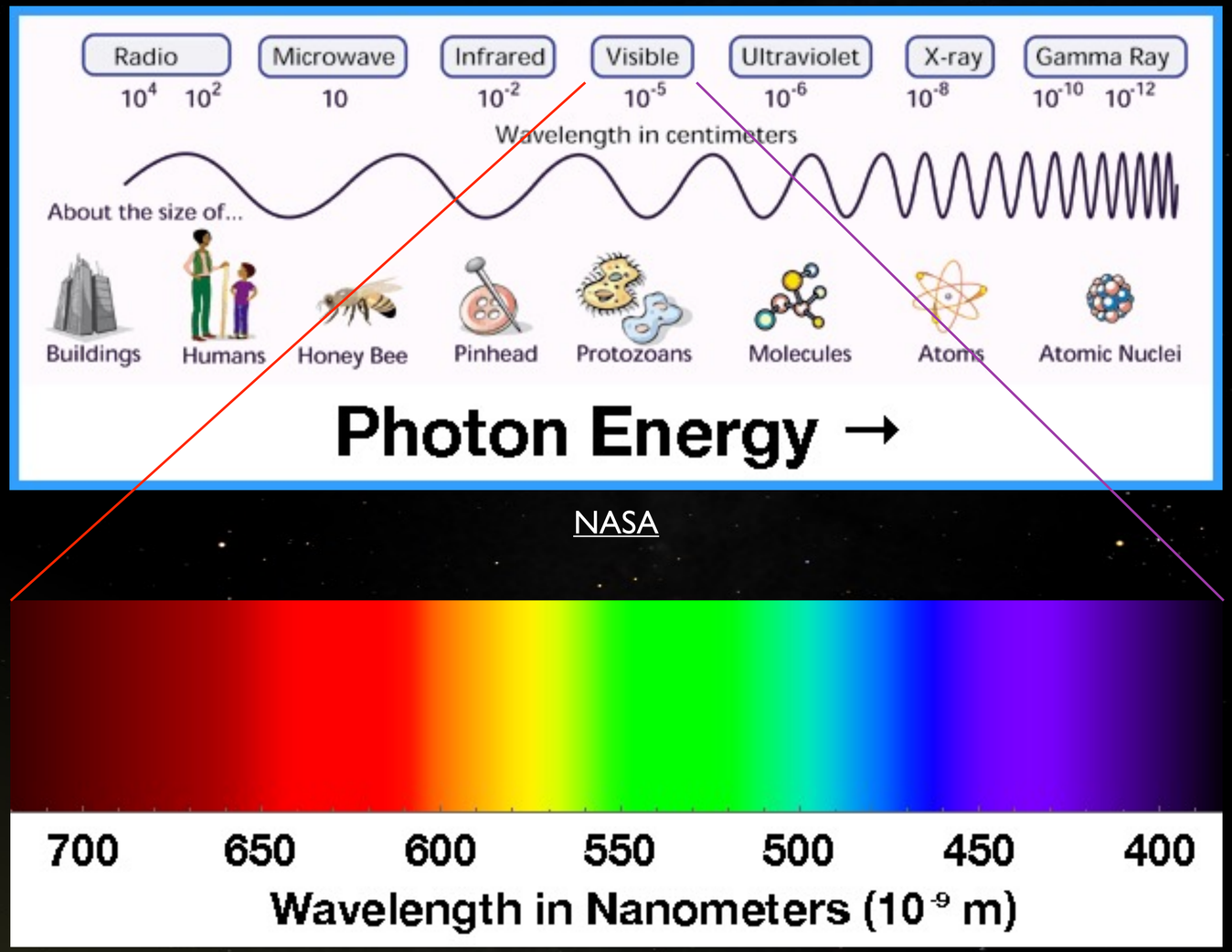
Class photo (Polaroid camera with focusing issues!)

Survey Course Syllabus

- Week 1: The Nature and Origin of Light, Heat, Blackbodies, and Daylight
- Week 2: Combustion — Firelight, Candlelight, and Gaslight
- Week 3: Electricity — Aurorae, Lightning, Incandescence, and Fluorescence
- Week 4: Light-Emitting Diodes (LEDs) and Lasers
- Week 5: Reflection, Refraction, Scattering, Absorption, and Pigmentation
- Week 6: The Greenhouse Effect and Climate Change
- Week 7: Painting, Photography, Photocells, and Digital Images
- Week 8: Lenses, Eyes, Cameras, 'Scopes, and Remote Sensing
- Week 9: Eyesight, Night Vision, and Circadian Rhythms
- Week 10: Nocturnal Impacts — Birds and Bees, Bats and Bugs, Frogs and Turtles, and Trees
- Week 11: Light Pollution — Outdoor Lighting, Skyglow, Glare, and Legislation

Week 1.1: The Nature of Light

- *Visible light* is one portion of the *electromagnetic spectrum*
- The colors of visible light are how our brains perceive different wavelengths
- The near infrared and near ultraviolet are similar to visible
- Blue wavelengths are shorter but more energetic than red wavelengths



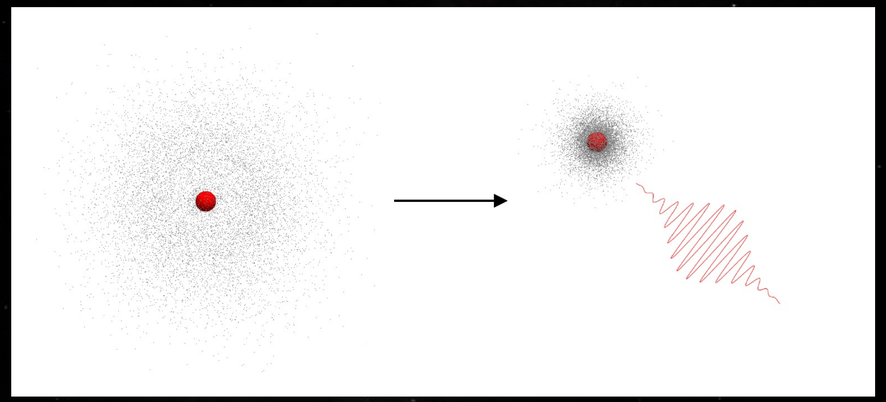
NASA

Week 1.2: The Origins of Light

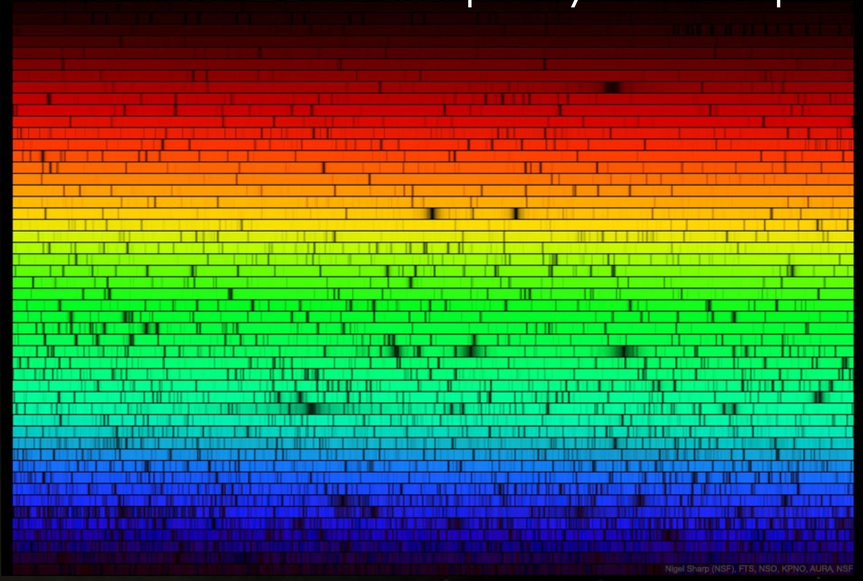
- EM radiation is produced by the *acceleration* of electric charge
- Visible and near-visible light comes from *quantum transitions* of electrons near the surface of atoms, from higher to lower energy, releasing "wave packets" called *photons*
- The elements have distinct *emission spectra*
- Electrons can be excited to release light by:

Heat (atomic/molecular collisions) ✷ Electric fields

✷ Chemical reactions ✷ Photon absorption



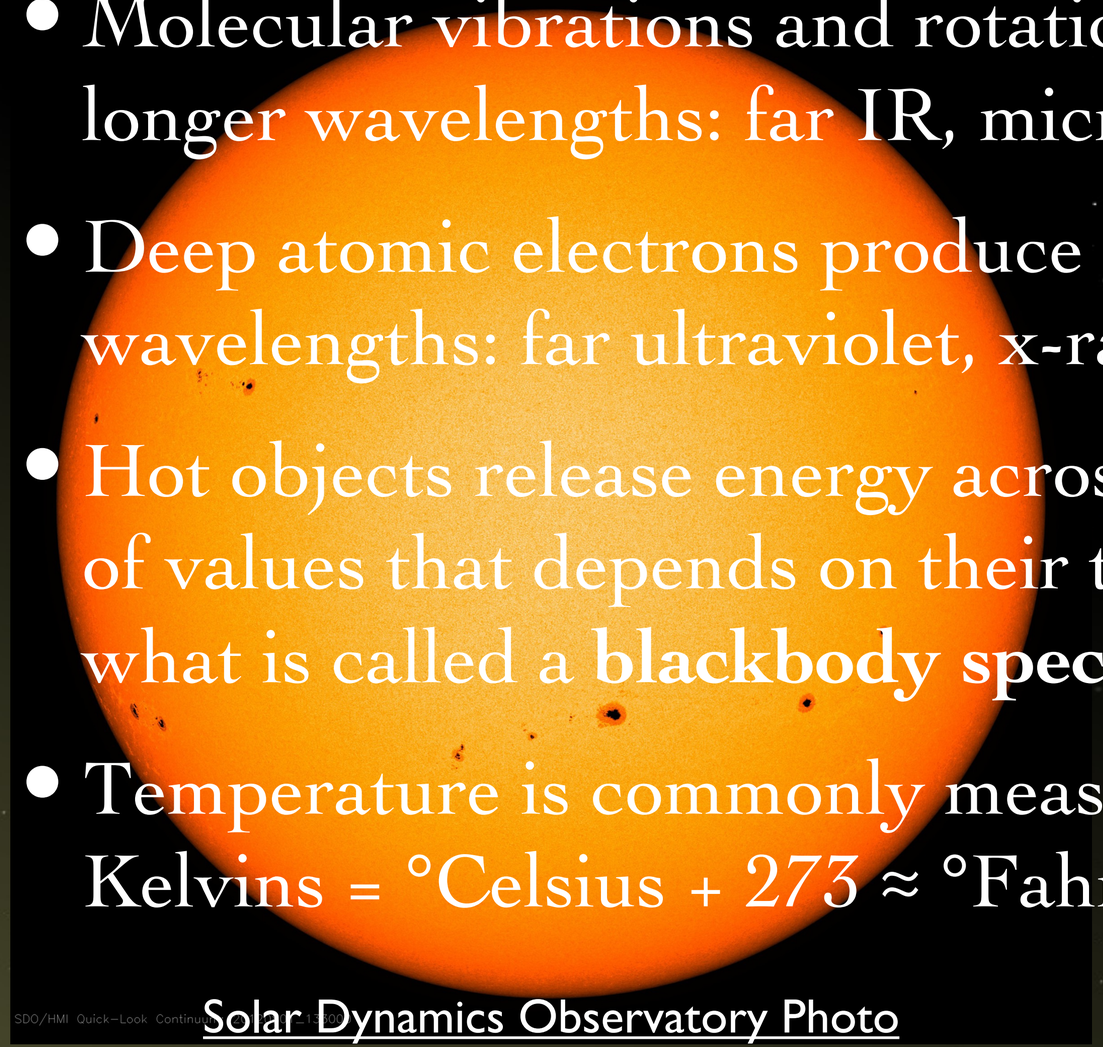
Above: Emission Below: Absorption by Solar Atmosphere



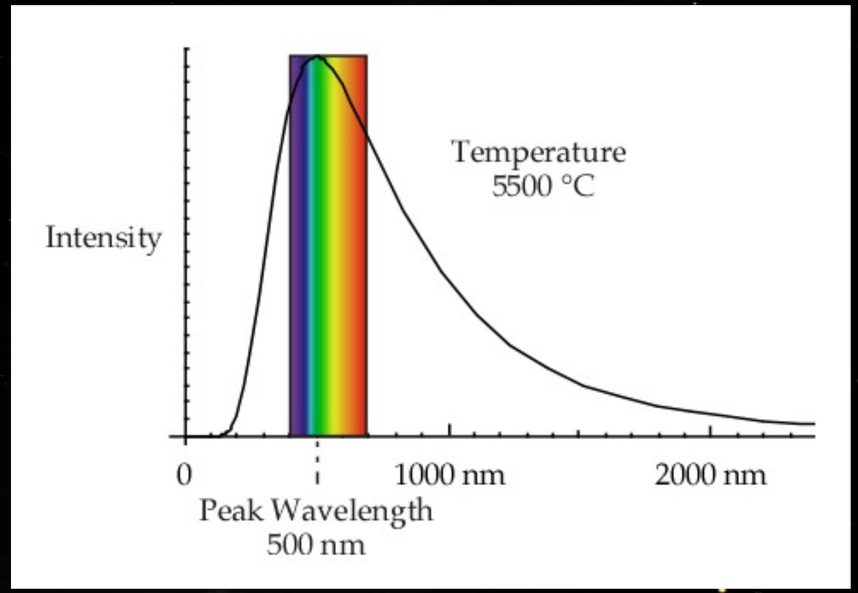
Nigel Sharp (NSF), FTS, NSO, KPNO, AURA, NSF

Week 1.3: Heat, Blackbody Radiation, Daylight

- Molecular vibrations and rotations produce longer wavelengths: far IR, microwave
- Deep atomic electrons produce shorter wavelengths: far ultraviolet, x-ray
- Hot objects release energy across a wide range of values that depends on their temperature, in what is called a **blackbody spectrum**
- Temperature is commonly measured in Kelvins = °Celsius + 273 ≈ °Fahrenheit / 2 + 257



Solar Dynamics Observatory Photo



Solar Spectrum: T = 5800 K

- Hotter objects appear bluer, cooler objects appear redder

Week 2: Combustion, Firelight, Candlelight, & Gaslight

- Organic materials: wood, fat, etc.

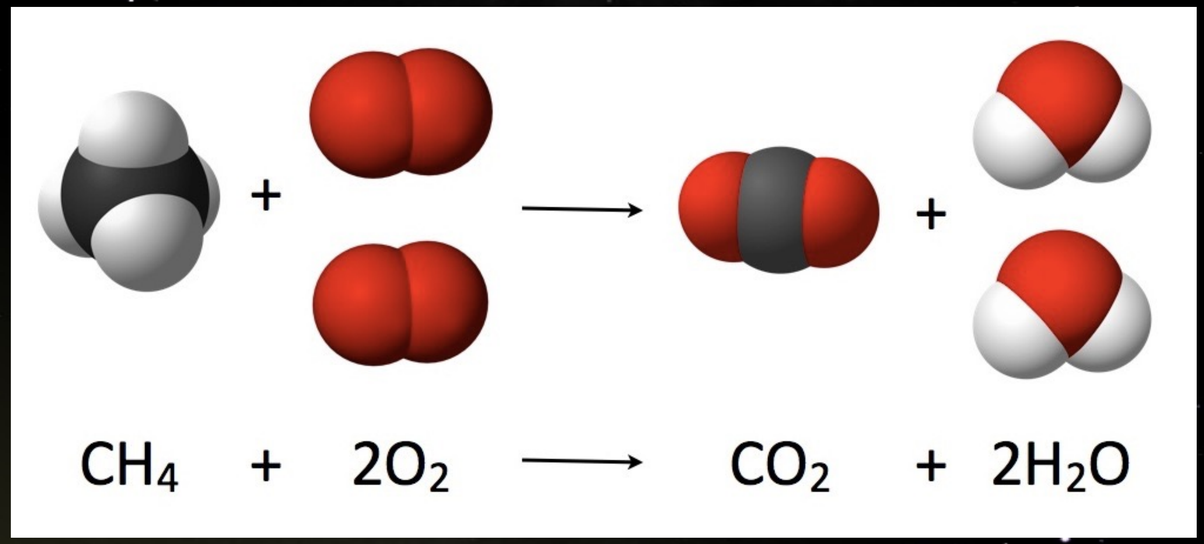
  Specific example of methane

- History of different sources:

  Article: Toward a Long Prehistory of Fire, discussing human evolution and the “cooking hypothesis”.

  Article: They Used to Say Whale Oil Was Indispensable, Too

  Article: The Gas Industry In Great Britain, a history of town gas in the 19th century



Week 3.1: Electricity, Aurorae, and Lightning

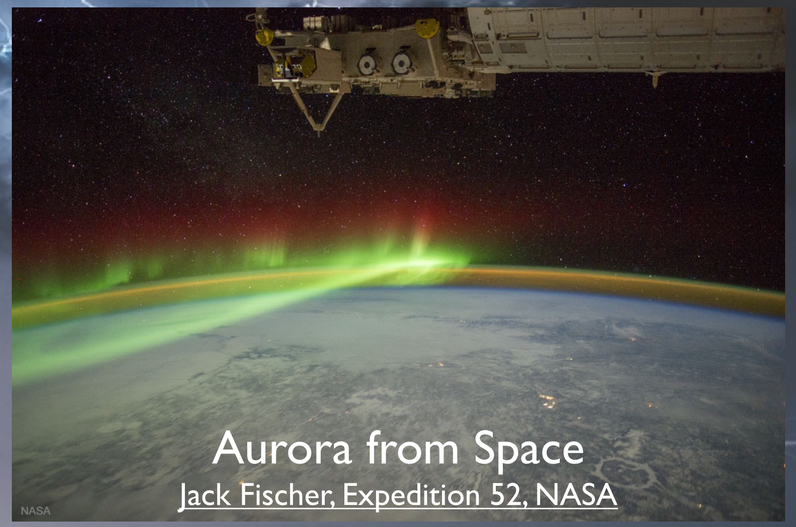
- Aurorae: Strong magnetic fields smashing solar particles into the air

  Article: What are the Northern Lights?

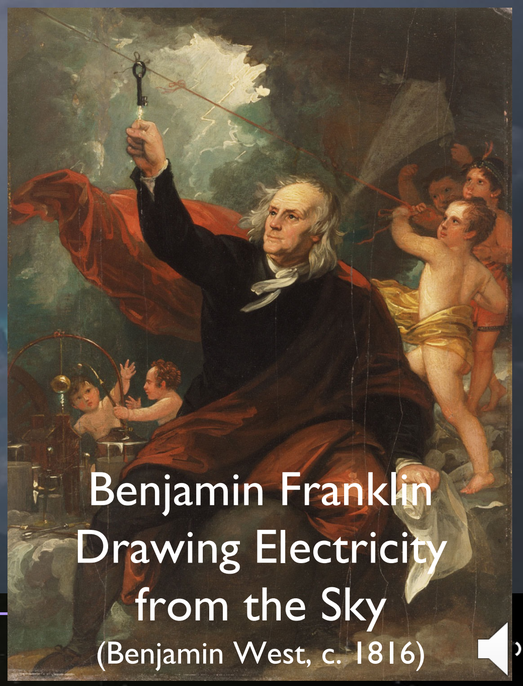
  Article: The History of Auroras

- Lightning: Strong electric fields ionizing and heating air

  Article: Lightning and the Space Program, notes it could be responsible for > 50% of nitrogen in the soil, essential for plant life.



Aurora from Space
Jack Fischer, Expedition 52, NASA



Benjamin Franklin Drawing Electricity from the Sky
(Benjamin West, c. 1816)

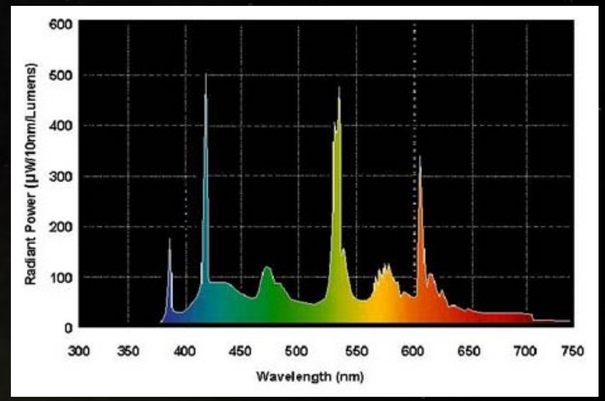
Week 3.2: Electricity, Incandescence & Fluorescence

- Arc lamps: the first artificial electric light, two carbon rods passing ionized C between them
  - Article: Moonlight Towers: Light Pollution in the 1800s
- Incandescent lamps: heating a carbon filament — 10% efficient, most of the energy into the IR
  - Article: Edison's Electric Lamp
- Fluorescent lamps: ionized mercury producing UV and blue light, and a fluorescent coating to convert UV to red and green, resulting in white — 40% efficient; neon lights similar

BIRDS KILLED BY ELECTRIC LIGHT TOWERS AT DECATUR, ILL.—I enclose a slip cut from the Decatur Republican of last evening; also a list of birds brought to me yesterday by boys from different parts of the city, as determined by Professor J. H. Coonradt of our High school. Some of them are seldom seen in this neighborhood, so far as my observation goes. Indeed, most of them are rarely noticed in the city this time of the year. I think none were found under the lamps this morning. From the numbers I saw and heard of yesterday I should think it probable that a thousand birds were killed around the electric light towers which light our town. I suppose this is not an unusual occurrence, but as the numbers were so great I thought possibly you would like to make a note of it.

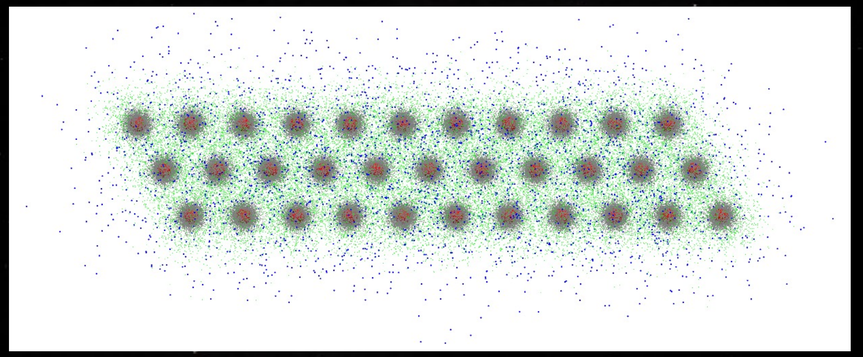
Following is the list of the birds killed by the electric light towers: Redstart (*Setophaga ruticilla*), red-breasted grosbeak (*Goniaphea ludoviciana*), indigo bird (*Cyanospiza cyanea*), black and yellow warbler (*Dendræca maculosa*), house-wren (*Troglodytes ædon*), Maryland yellow-throat (*Geothlypis trichas*), Acadian fly-catcher (*Empidonax acadicus*), scarlet tanager (*Pyranga rubra*) cat-bird (*Galeoscoptes carolinensis*). olive-backed thrush (*Turdus swainsoni*).—*E. A. Gastman, Decatur, Ill., Sept. 29, 1886.*

The American Naturalist, v. 20 p. 981



Week 4.1: Light-Emitting Diodes (LEDs)

- Conductors, insulators, and semiconductors
- Semiconductors can produce specific wavelengths with electronic stimulation: LEDs



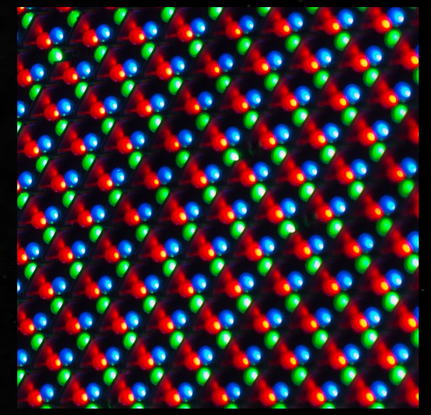
  Television remotes, digital displays, computer and TV screens (RGB)

  Nobel Prize Article: Blue LEDs – Filling the World with New Light

- Eventually LED lamps: high-blue were the first to market, using fluorescent coating to produce very white light (5000K)

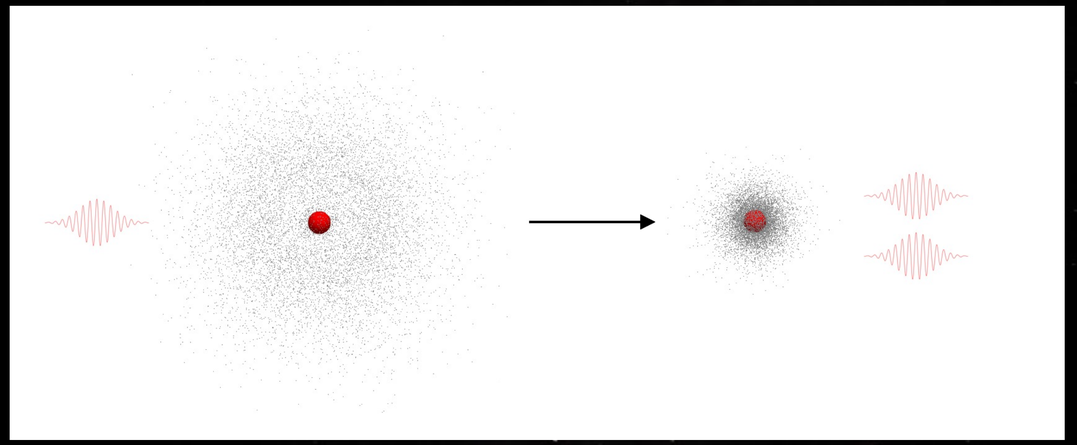
  50% efficient, long life, no mercury, but expensive up front

  Article: Disparities in Energy-efficient Lighting Availability and Prices



Martin Kraft
(photo.martinkraft.com)

Week 4.2: Lasers



- Certain materials can be “pumped” into a metastable electronic state, ready to emit photons of a particular wavelength, and stimulated to emit them by photons of the same wavelength, doubling output with each pass to produce high intensity, monochromatic light.
- Light Amplification by Stimulated Emission of Radiation (LASER)

  Compact discs, DVDs, blue-ray discs, laser cutting, microsurgery
- Light Detection and Ranging (LIDAR) to measure distance to objects

  Article: LIDAR Forest Inventory with Single-Tree, Double- and Single-Phase Procedures

Class Experiments

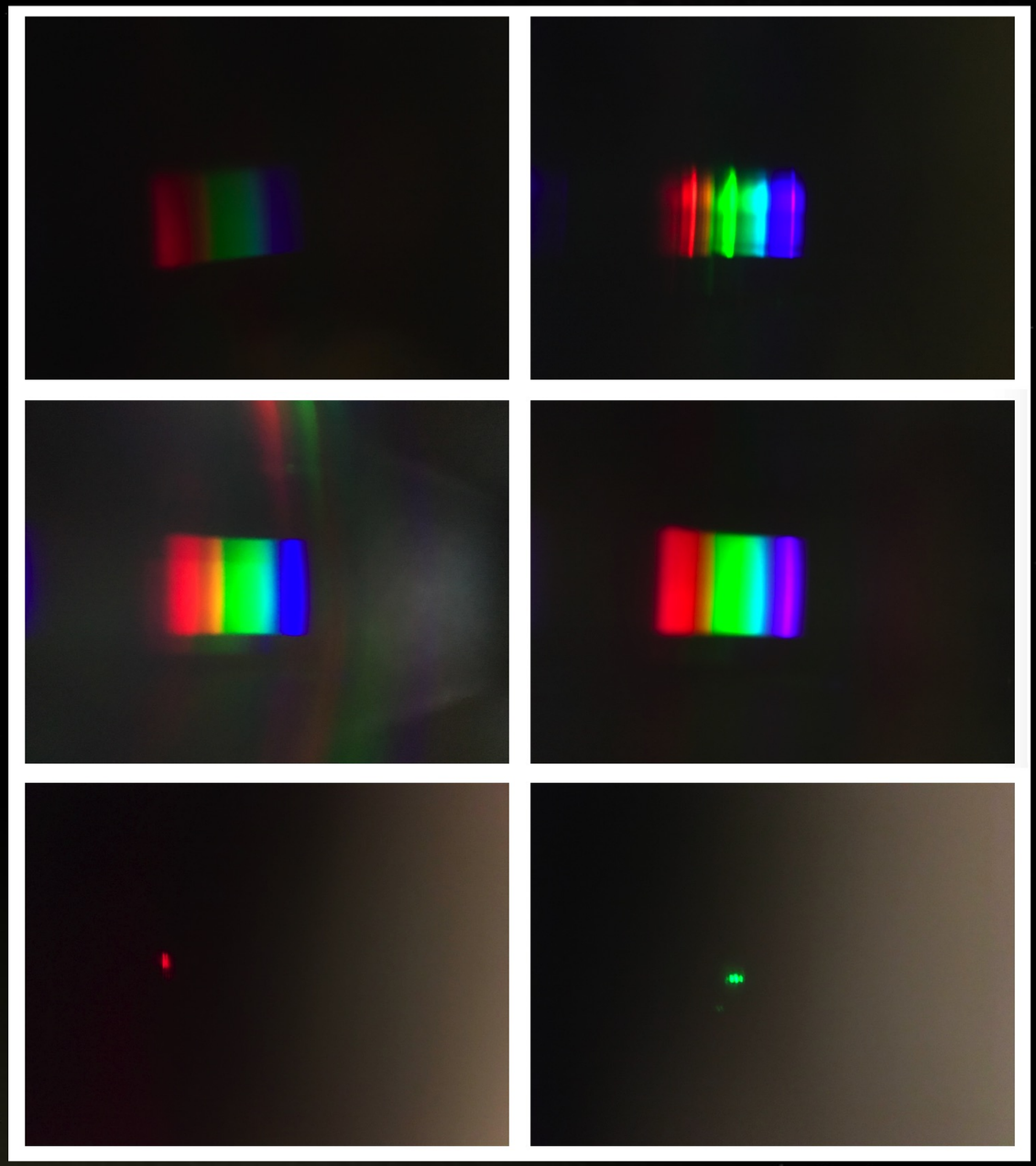
- A sequence of spectra from different sources of light:

  incandescent, fluorescent;

  2700-K LED, 5000-K LED;

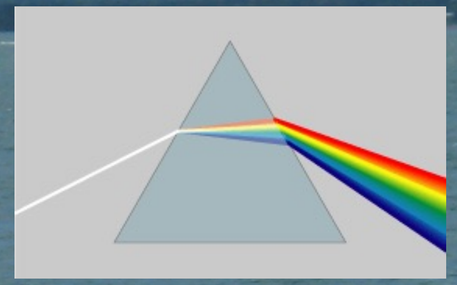
  red laser, green laser

- Produced with the simple Papercraft Spectrometer from Public Labs



Week 5.1: Reflection, Refraction, and Scattering

- *Reflection* due to electrons in materials that can freely respond
  - Clouds; water; ice; fiber optics
- *Refraction* as light travels from one material into another, due to different speeds, the result of molecular polarization
- *Dispersion*: also different speeds for different colors: prisms
  - Article: About Rainbows
- *Scattering* due to small particles that absorb and re-emit in all directions, more strongly for shorter wavelengths
  - Article: Why is the Sky Blue? (including why are sunsets red?)

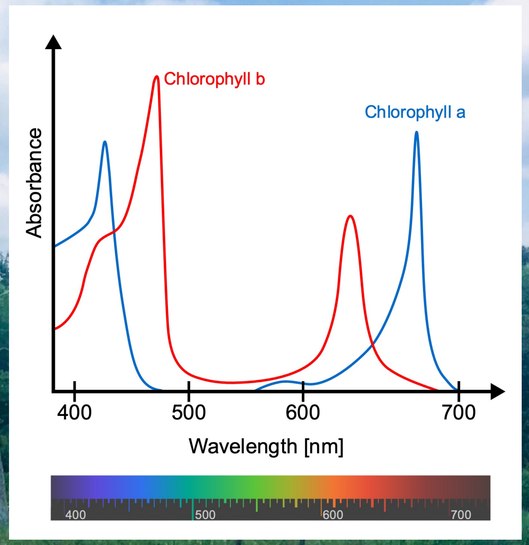


Dispersion in a Prism
JoanJoc

Week 5.2: Absorption, Pigmentation

- Materials preferentially absorb specific wavelengths, generally warming as a result
- Transparent materials still absorb light outside of the visible range
- Generally some combination of reflection, refraction, and absorption: water
- Plants are generally green because the chlorophyll used for photosynthesis absorbs in the blue and the red, reflecting green

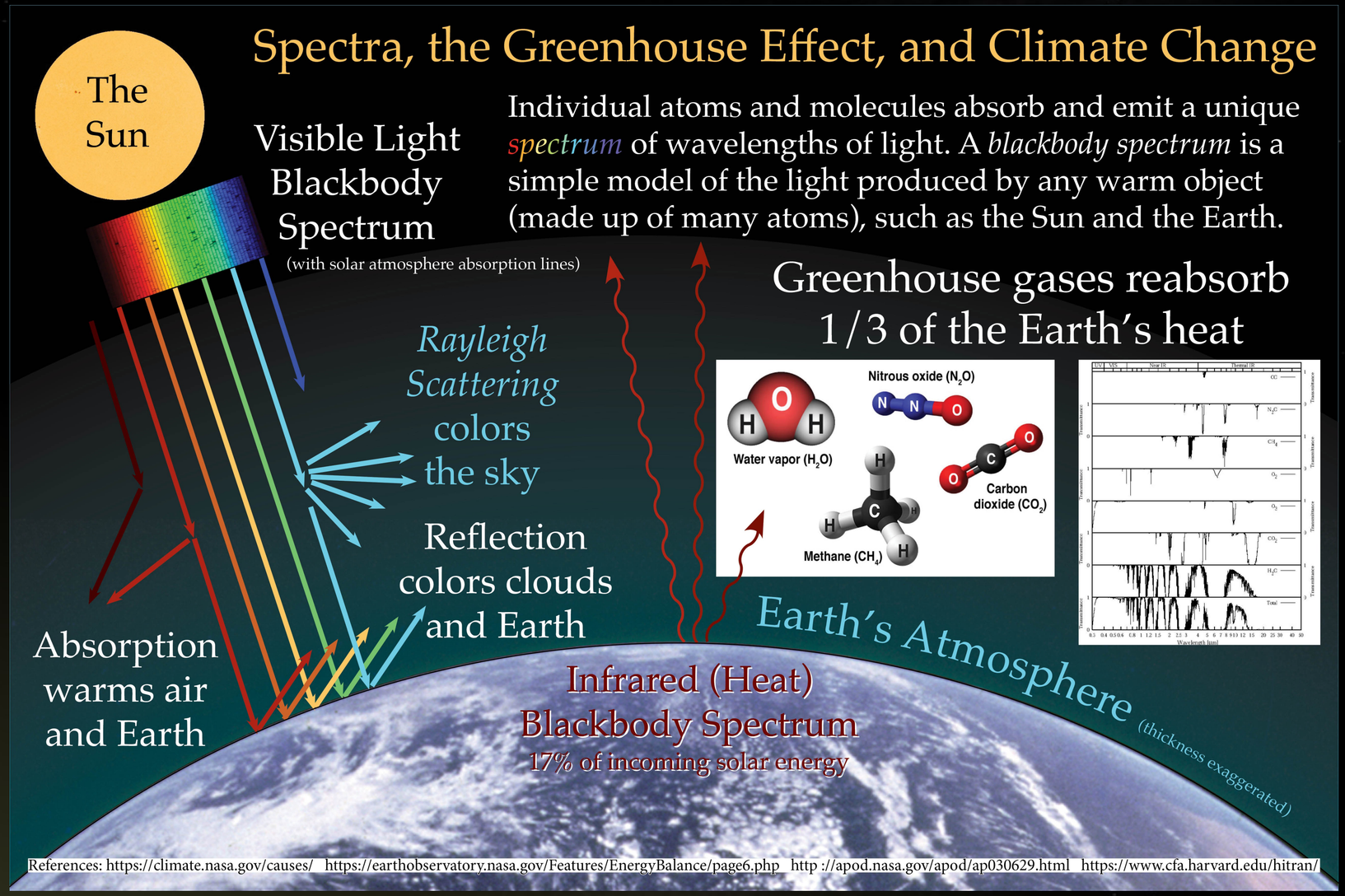
Article: Melanin and Human Evolution



Chlorophyll ab Spectra
Daniele Pugliesi, M0tty

Week 6: The Greenhouse Effect and Climate Change

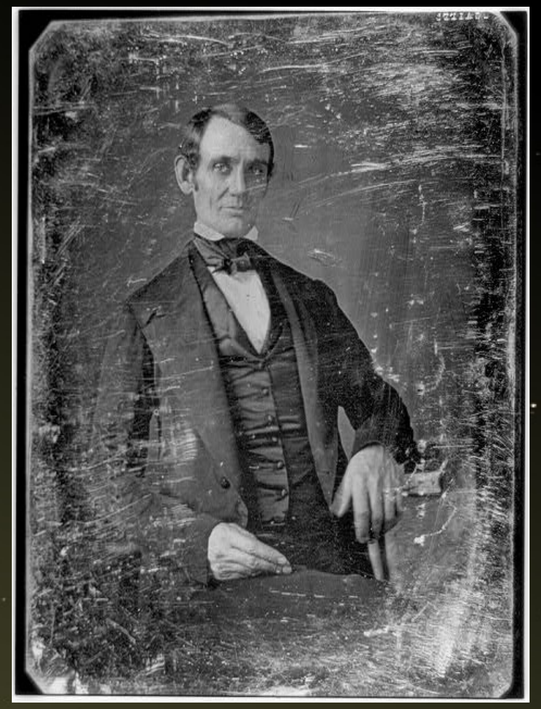
- All of the pieces now:
  - Article: The Causes of Climate Change
  - Article: Climate Change 2013: The Physical Science Basis, Fifth Assessment Report of the Intergovernmental Panel on Climate Change
  - Article: The Discovery of Global Warming, 19th c.



Week 7.1: Painting and Photography

- Artists have worked with pigmentation for millennia.

  Article: The History of Painting

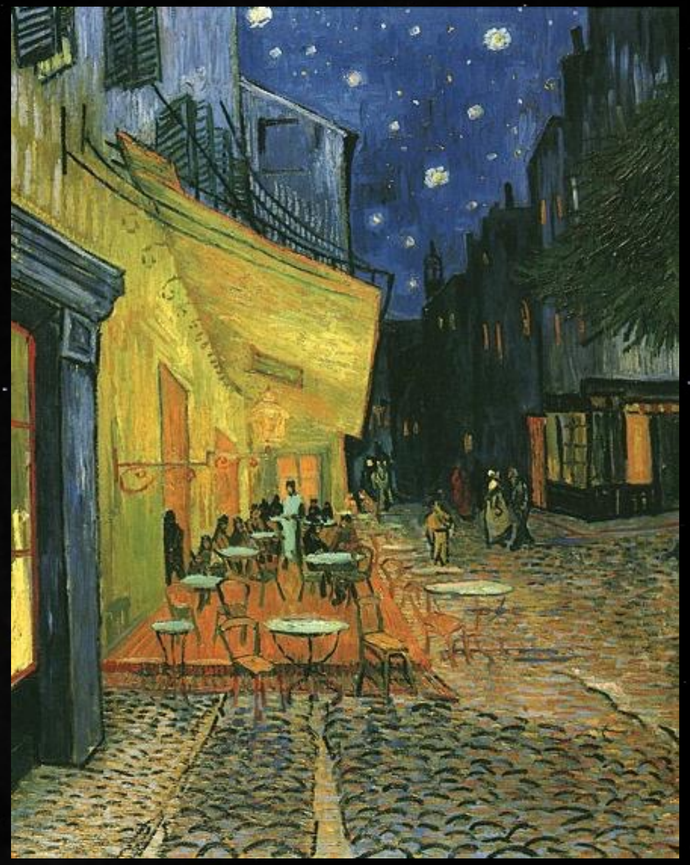


Abraham Lincoln, 1846-7
Library of Congress

- Photography: film coatings respond to light intensity

  Video: Early Photography: Making Daguerreotypes

- Color film has multiple layers that capture different parts of the visible spectrum; others just pass through!

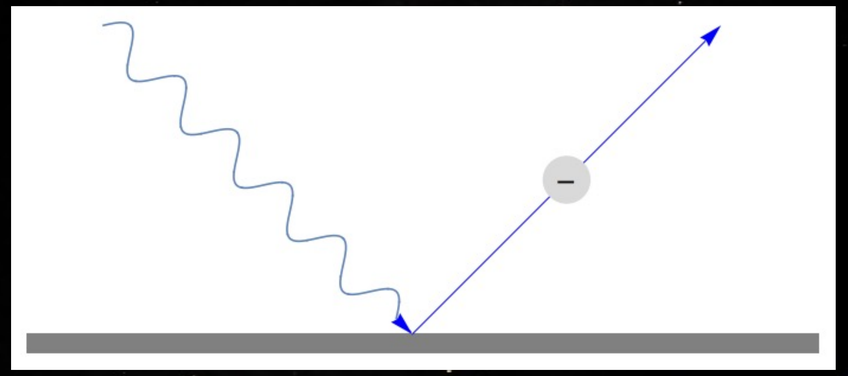


Cafe Terrace on the Place du Forum at Night
Vincent Van Gogh (Arles, France, 1888)

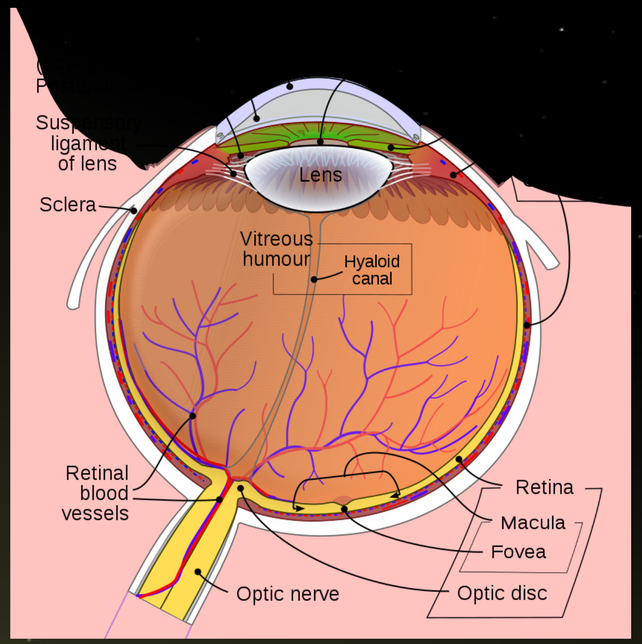
Week 7.2: Photoelectric Effect, Photocells, Digital Images

- *Photoelectric Effect*: light impinging on certain materials can eject electrons, which can be captured to produce an electric current
- *Photovoltaic Effect*: electrons not ejected, but produce a current in the material
- *Photocells*: collects current to send a signal, e.g. for motion detection (wildlife cameras), energy collection (solar cells), and digital images (most cameras now)

Article: The Siting and Impact of Photovoltaic Systems



Week 8.1: Lenses, Eyes, Cameras, and 'Scopes



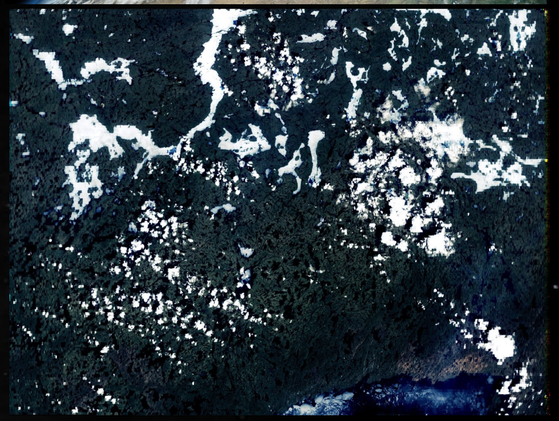
Cross-section of the Eye
Rhcastilhos and Jmarchn

- Eyes collect light, as do many of the instruments in use for environmental studies, so a basic understanding of geometric optics is important.
  - Articles: Lenses and Image Formation
  - Articles: The Human Eye, Cameras, and Accomodation
  - Articles: Common Vision Defects, Presbyopia, and Cataracts
  - Articles: Magnification and Microscopes
  - Articles: Mirrors and Telescopes: Refracting and Reflecting

Week 8.2: Remote Sensing

- Satellite imagery is becoming an increasingly important source of environmental information.

  Article: Landsat 8

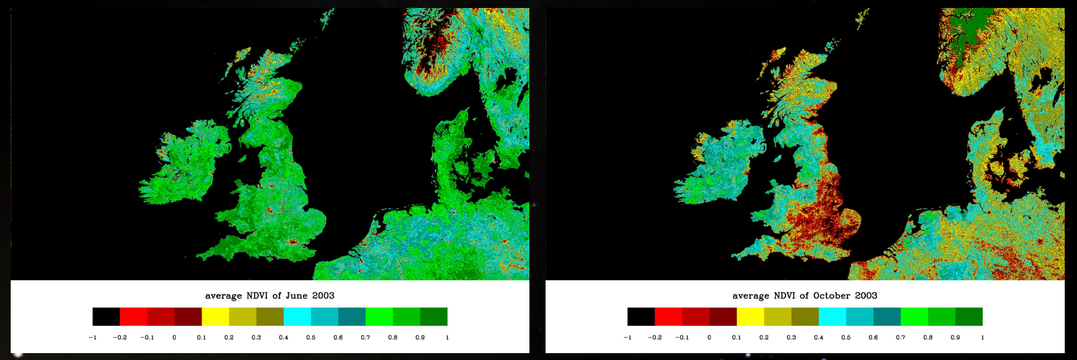


LANDSAT 8 Image

- Because leafy plants absorb red but reflect near-infrared, a standard way to study vegetation is using the normalized difference vegetation index:

  $$NDVI = (NIR - R)/(NIR + R)$$

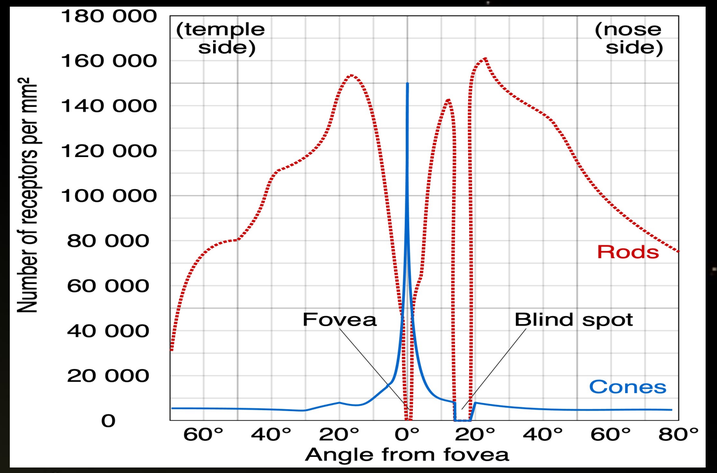
- NDVI will be close to 1 during green times, and less than 0 at other times, as brown dominates.



NDVI in June and October

Gennaro Cappelluti

Week 9.1: Eyesight and Night Vision



Human photoreceptors

Frog and Parietal Eye

- How *photopigments* in the *retina* in the back of the eye pass signals to the nervous system is important to understanding the light response of many species

  Article: Visual Processing: Eye and Retina

- The eye functions differently in low-light situations: *photopic* (cone) vs. *scotopic* (rod) vision

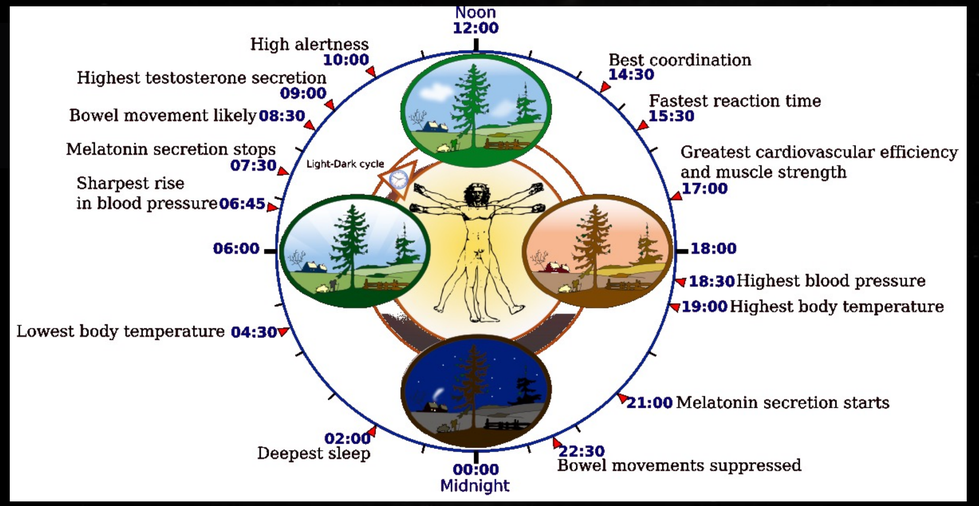
  Article: How Eyes See at Night

- But there's also a special blue light detector, *melanopsin*, communicating with the pineal gland:

  Article: Intrinsically Photosensitive Retinal Ganglion Cells

Week 9.2: Circadian Rhythms

- Circadian rhythms are the body's biological clock, turning on and off certain metabolic functions between day and night, via the hormone *melatonin* from the *pineal gland*



The Human Circadian Cycle
Yassine Mrabet

Article: Nobel Prizes 2017: Everything You Need to Know about Circadian Rhythms

- Our bodies respond to light in our environment to prepare us. And blue light can disrupt sleep and contribute to health problems such as cancer:

Article: Blue Light Has a Dark Side

Article: Irregular Sleep/Wake Patterns Are Associated with Poorer Academic Performance and Delayed Circadian and Sleep/Wake Timing

Week 10.1: Nocturnal Impacts – Birds & Bees, Bats & Bugs

World Trade Center

- Most migratory songbirds are nocturnal migrants; lighthouses, lit towers, and searchlights can disorient them:

  Video: World Trade Center Tribute-in-Light Traps Birds

  Article: Project Safe Flight

- Bat foraging is disrupted by artificial light:

  Article: Artificial Light Puts Frugivorous Bats at Risk

- Pollination is extensive at night:

  Article: Artificial Light at Night as a New Threat to Pollination

  Article: Light Pollution Is a Driver of Insect Declines

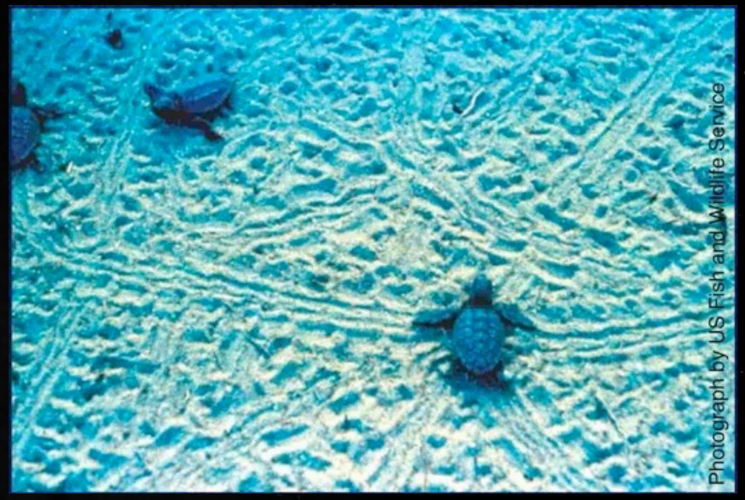
Week 10.2: Nocturnal Impacts - Frogs & Turtles, & Trees

- Frogs and tadpoles in excess lighting deal less successfully with stressors:

  Article: The Effect of Intensified Illuminance and Artificial Light at Night on Fitness and Susceptibility [of Frogs] to Abiotic and Biotic Stressors

- Newly hatched turtles should be attracted to the low glow of the sea horizon, but instead can be attracted to street and house lights

  Article: Understanding, Assessing, and Resolving Light-Pollution Problems on Sea Turtle Nesting Beaches



Baby Sea Turtles

- Many trees detect day length, *photoperiodism*, to determine dormancy:

  Article: Does Night Lighting Harm Trees?

The Milky Way, from Cerro Tololo, Chile

K. Don and NOAO/AURA/NSF


Los Angeles, United States
© 2008 Dave Jurasevich (Mt. Wilson Observatory)

Week 11.1: Light Pollution

- *Light pollution* is artificial light that is unnecessary, misdirected, inefficient, distracting, or dangerous.
- 80% of Americans & Europeans lack "real night"
- 2/3 of the world's population affected

Week 11.2: Outdoor Lighting, Skyglow, and Glare

- The International Dark-Sky Association works "to preserve and protect the night-time environment and our heritage of dark skies through quality outdoor lighting"
  - ⋆ *Skyglow*: Light shining upward, reflecting off the air
  - ⋆ *Glare*: Light shining sideways, trespassing, blinding

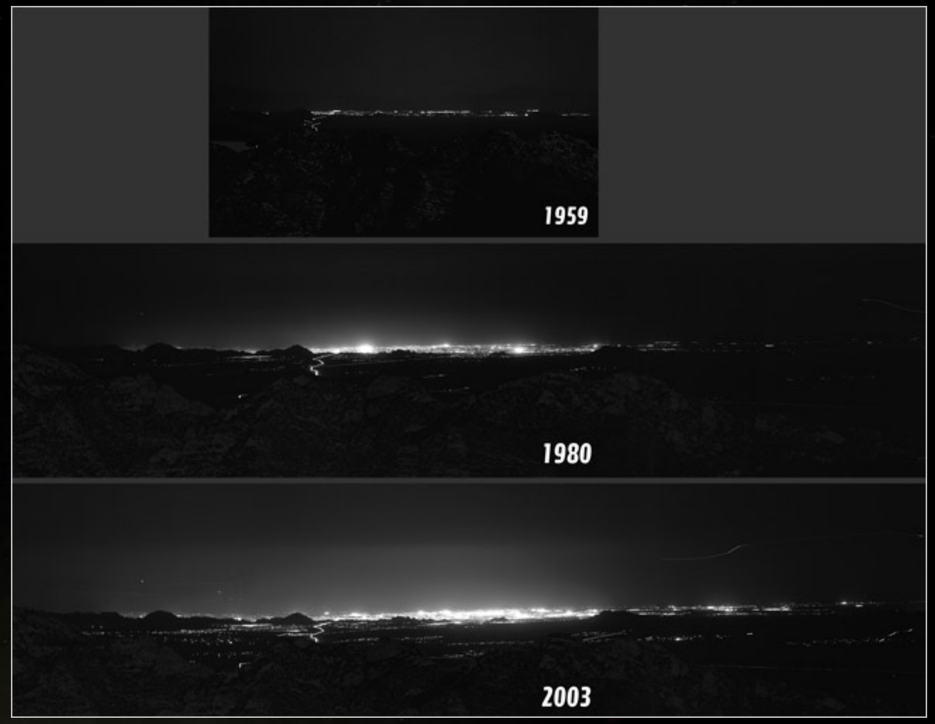
Article: Light Pollution

Article: Outdoor Lighting Basics

Article: Light Pollution Wastes Energy and Money

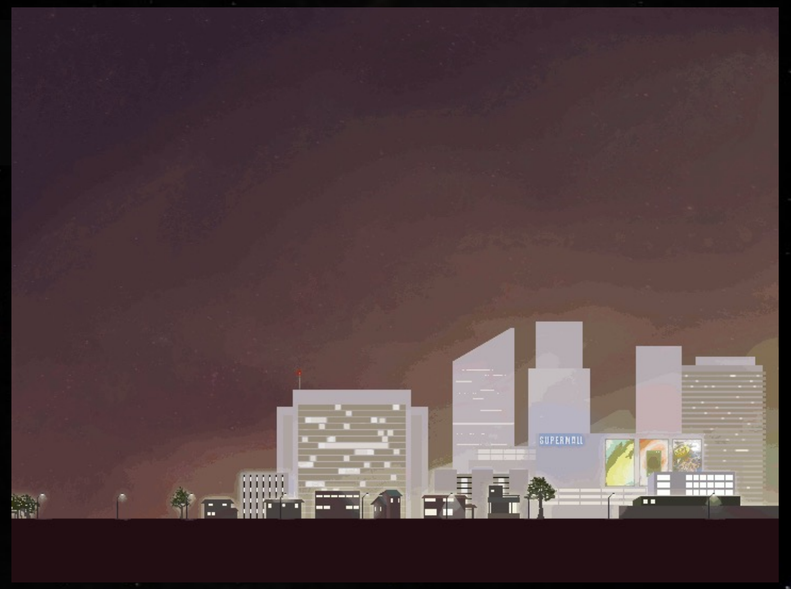
Article: Lighting, Crime and Safety

Article: Night Sky Heritage



Tucson, AZ from Kitt Peak Observatory

Week 11.3: Light on Legislation



Norman Mazga

- Action on Light Pollution:

  Article: Danish Night Shift Workers with Breast Cancer Awarded Compensation

  Article: The Laws that Saved Florida's Sea Turtles

  Article: AMA adopts guidance to reduce harm from high intensity street lights

- Improved Lighting Requirements:

  Article: Joint IDA-IES Model Lighting Ordinance
  (IES is the Illuminating Engineering Society of North America)

  Article: LEED Certification for Light Pollution
  (LEED is Leadership in Energy and Environmental Design)

Conclusions

- Successes:
  - Organized development of the theme to raise many environmental issues
  - Students appreciated the diverse topics and activities
  - Attracted students with many majors, Astronomy to Nursing
- Failures:
  - Some students' first contact with an article-based course, requiring some adjustment
  - Some of the activities took more time to work through than expected
  - No one changed their major to Environmental Conservation ☹
- Future: Could be scaled up to a 3-credit course with more details & labs