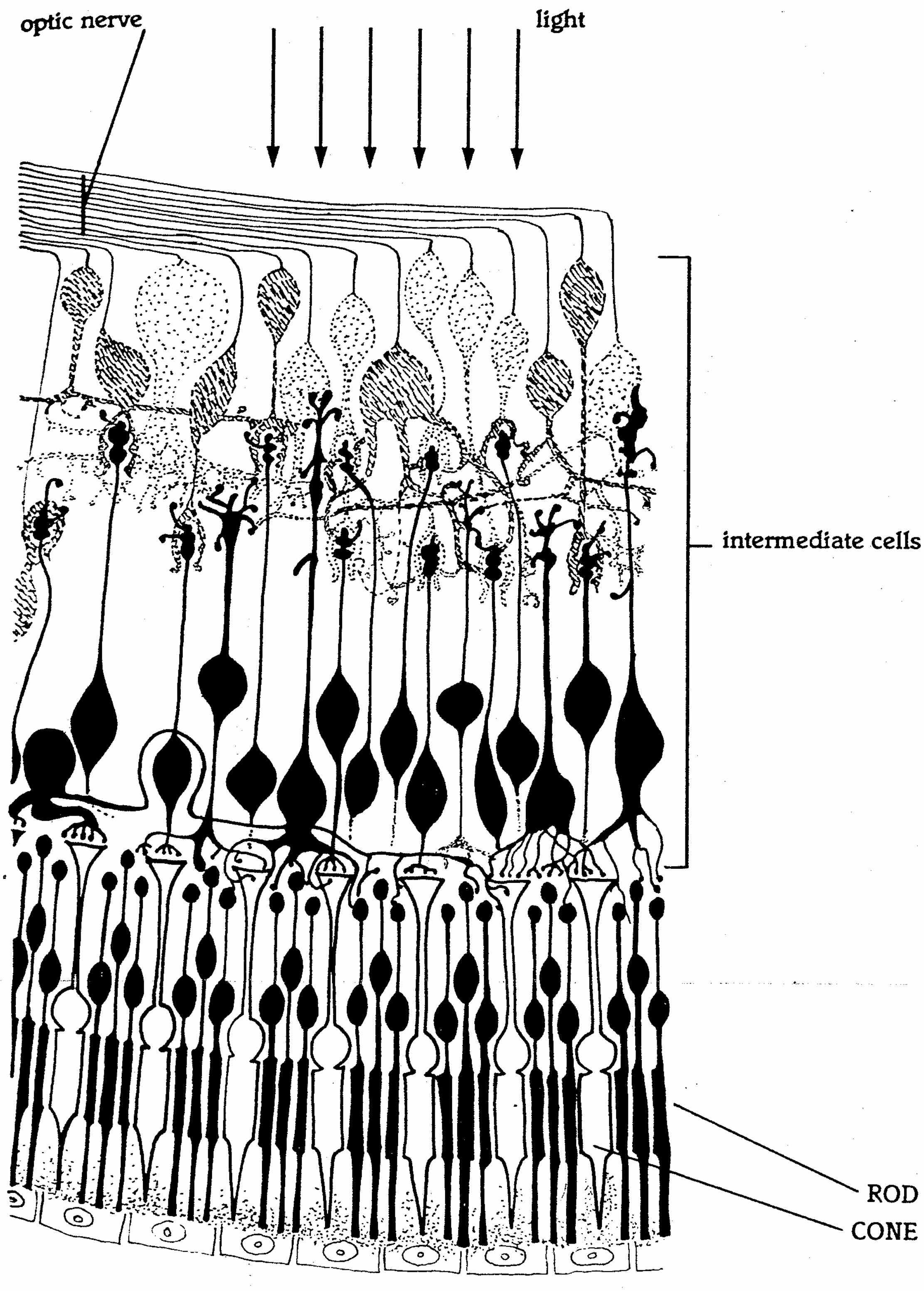
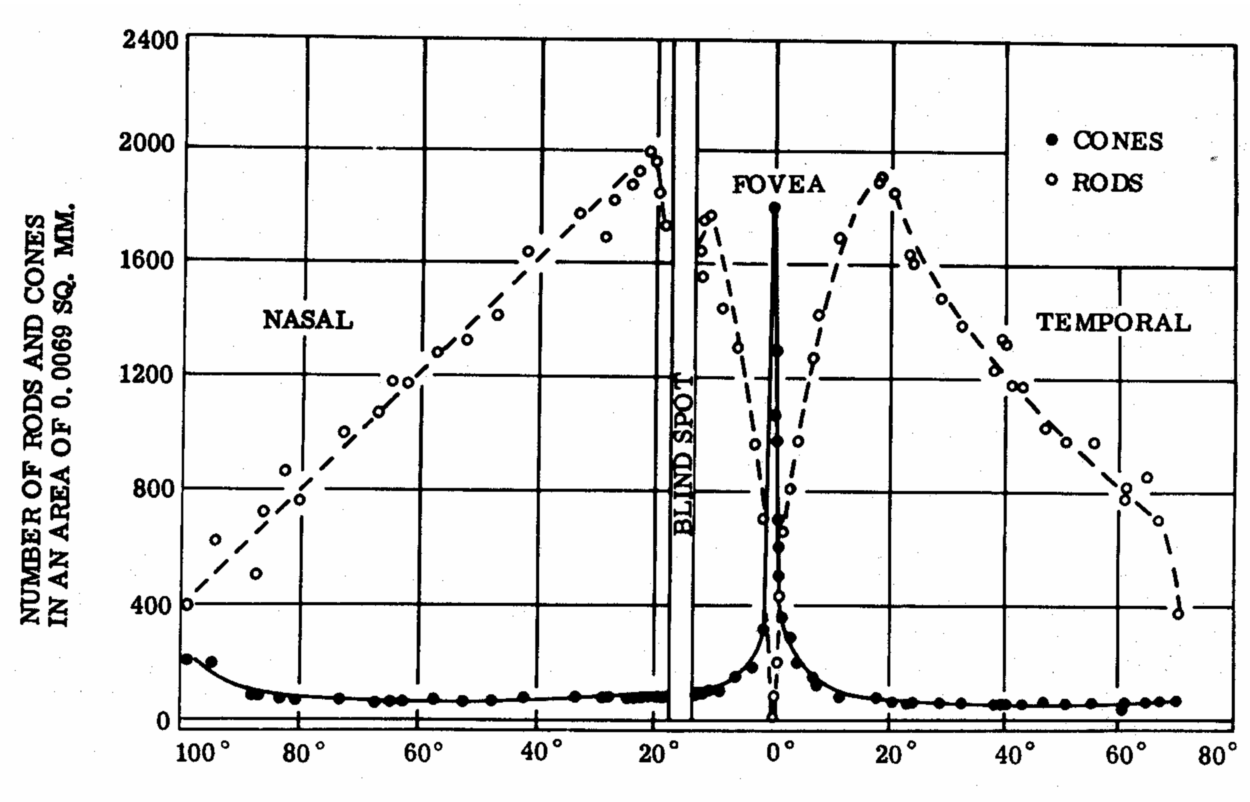
STRUCTURE OF THE RETINA



Total area of retina ~1100 mm^2, covers 72% of inner surface of eye

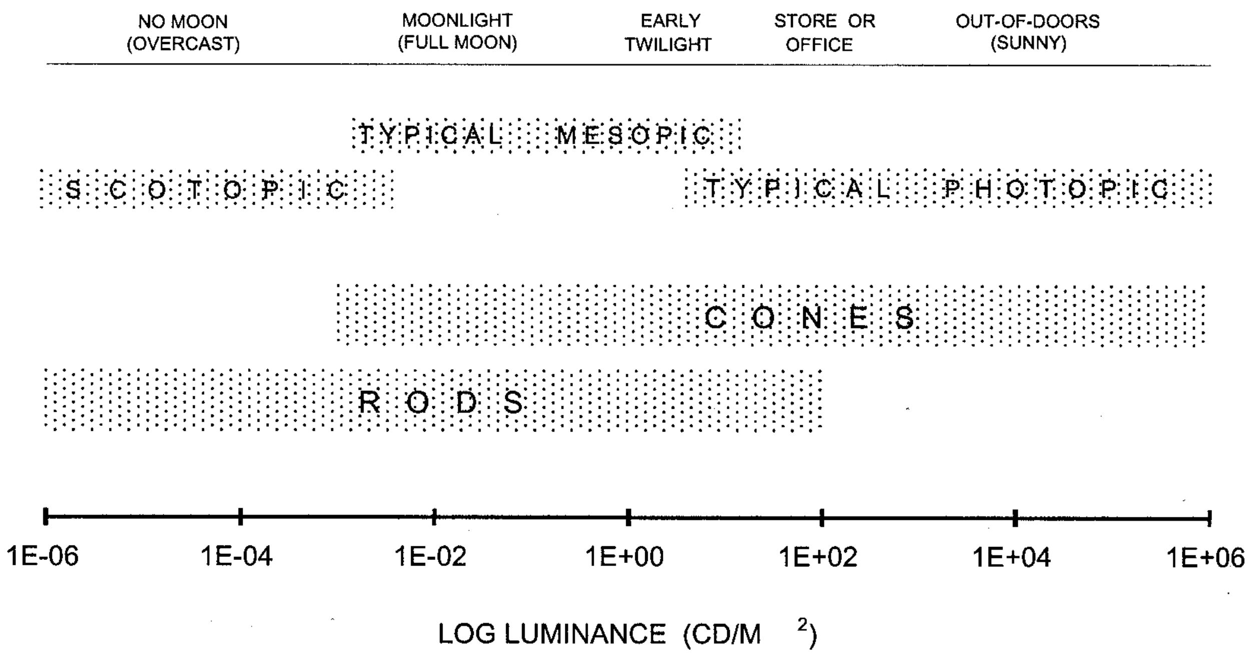


CONES - high resolution, color sensitive [3 different response curves from erytholabe (red), chlorolabe (green) and cyanolabe (blue)], Used for daylight-adapted (photopic) vision, good from 0.01 to 10^4 ft-lamberts, total number of cones ~5×10^6.

RODS - use rhodopsin, low resolution, no color, ultra-sensitive, used for night vision, good up to 0.01 ft-lambert; total number of rods ~10^8.

FOVEA has 10^4 cones which are 1-4 μm in diameter, no rods, size of fovea ~0.5 mm, subtends FOV of ~2°

RANGE OF VISION



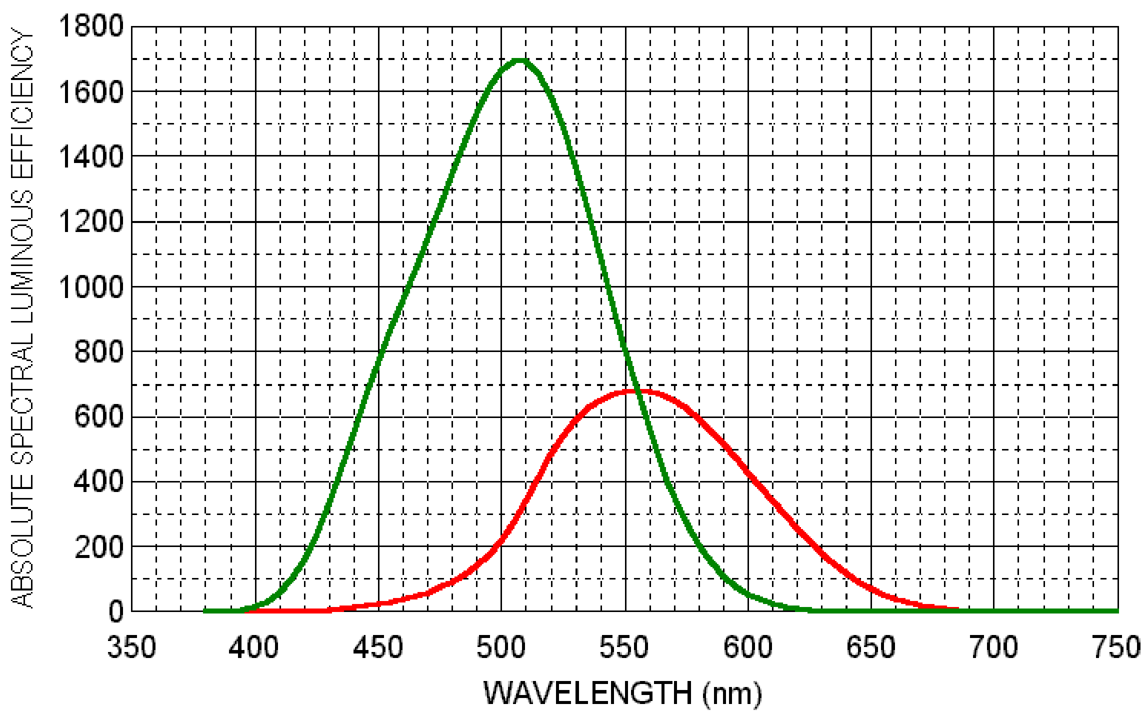
Photopic (cones, color vision, high acuity) at high lighting levels

Scotopic (rods, monochromatic, low acuity) at low lighting levels

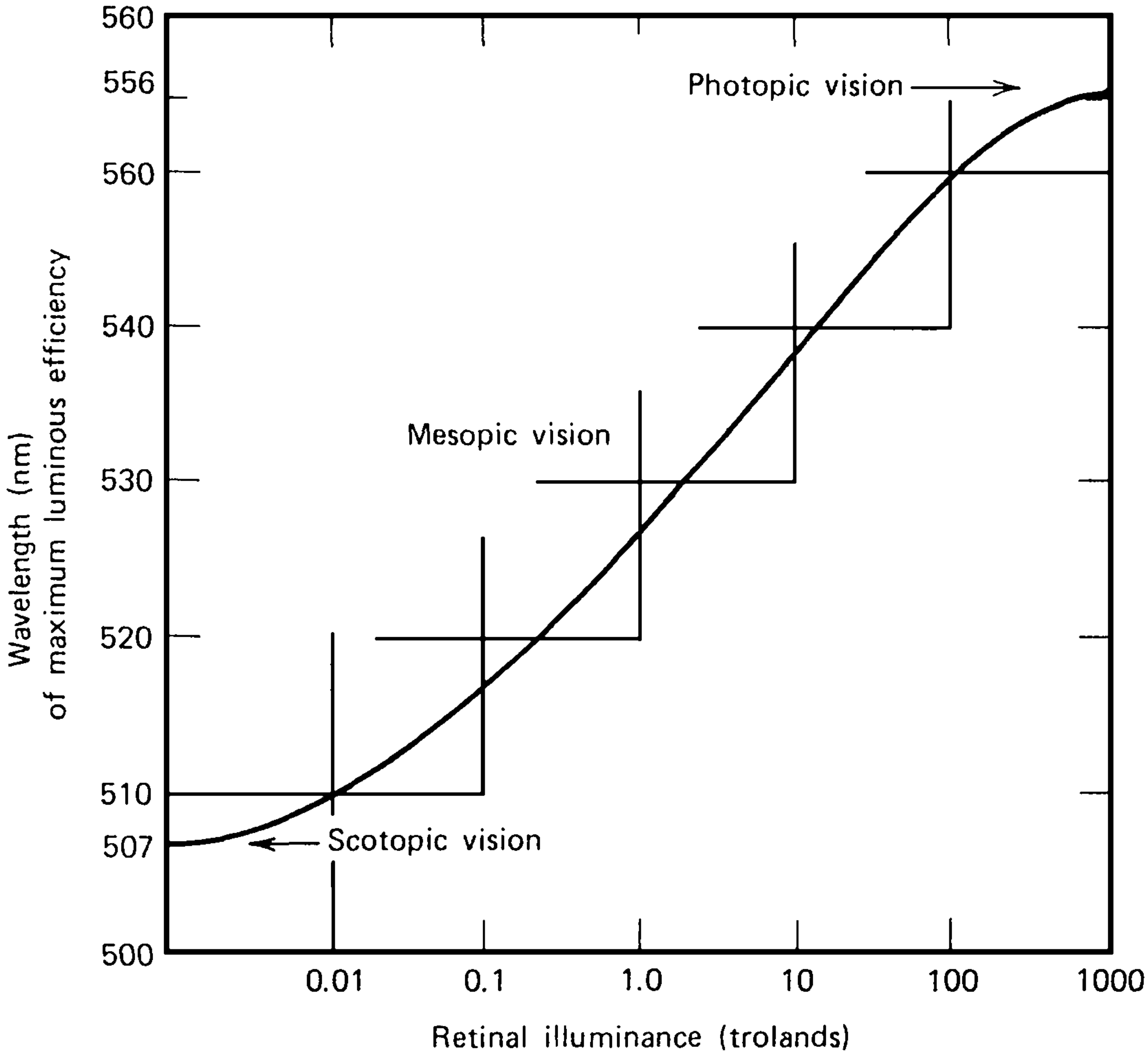
Mesopic (combining cones and rods) at intermediate levels. Complex problem still under study. For example, do new blue HID headlamps do a better job?

SPECTRAL RESPONSIVITY OF THE EYE

CONES (photopic) peak at 555 nm (K_m = 683 lm/W)
RODS (scotopic) peak at 507 nm (K'_m = 1700 lm/W)
Purkinje shift through mesopic range

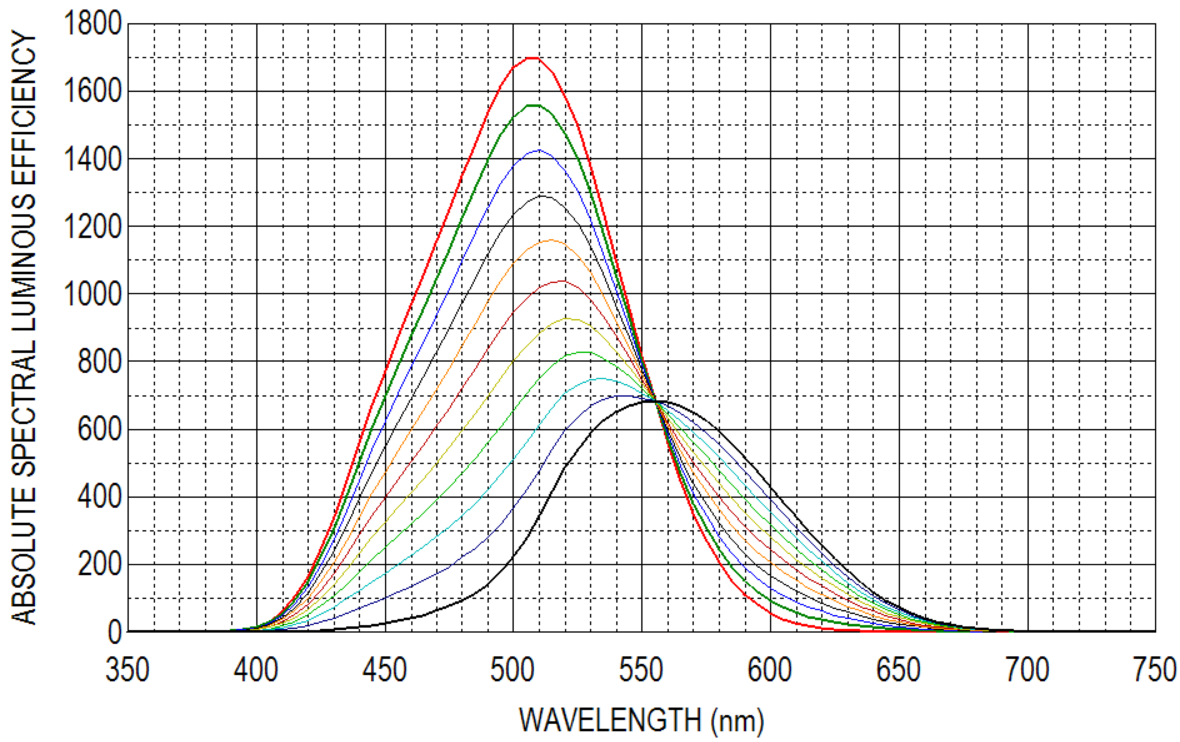


PEAK WAVELENGTH vs. LUMINANCE



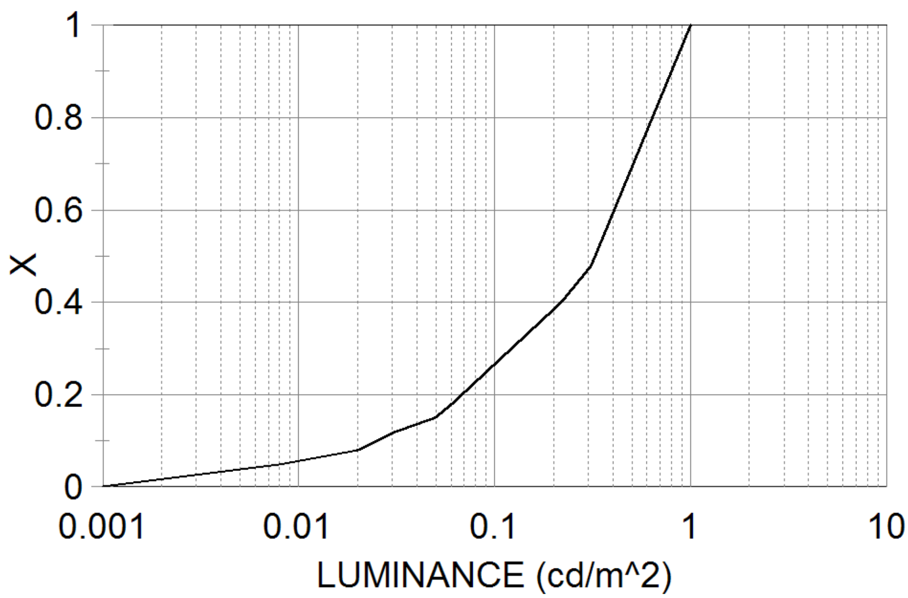
This is the **Purkinje shift**. Objects that look blue in daytime are brighter at night than objects that look red in daytime.

TRANSITION THROUGH MESOPIC RANGE



$$V(\lambda)_{mes} = X\,V(\lambda) + (1-X)\,V'(\lambda)$$

X varies from 0 (red curve, scotopic) to 1 black curve (photopic)

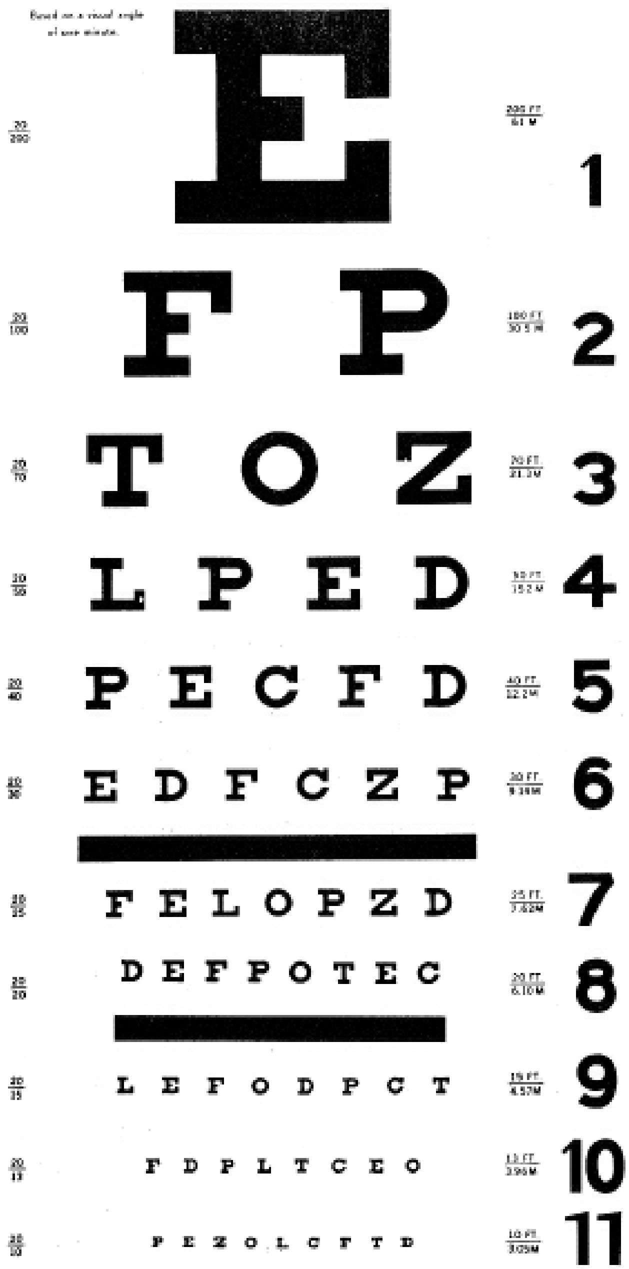


THRESHOLD OF VISION

- Monochrome, we need 5×10^{-7} cd/m^2 to detect light
- Order of magnitude more to detect an image
- Colored images detected at $3\text{x}10^{-3}$ cd/m^2
- Ultimate sensitivity at 505 nm (scotopic vision), about 10 photons entering a single rod or group of multiplexed rods within 100 ms
- Because of losses, need externally about 100 photons within 100 milliseconds in cross-section of pupil area
- Individual rod therefore responds to a single photon
- Synapse pulses to brain much larger, the biological gain is $>10^6$

MORE ON VISUAL ACUITY TESTING

The classic visual acuity test is the Snellen test.



which is a high-contrast test. But real life is not always at high contrast

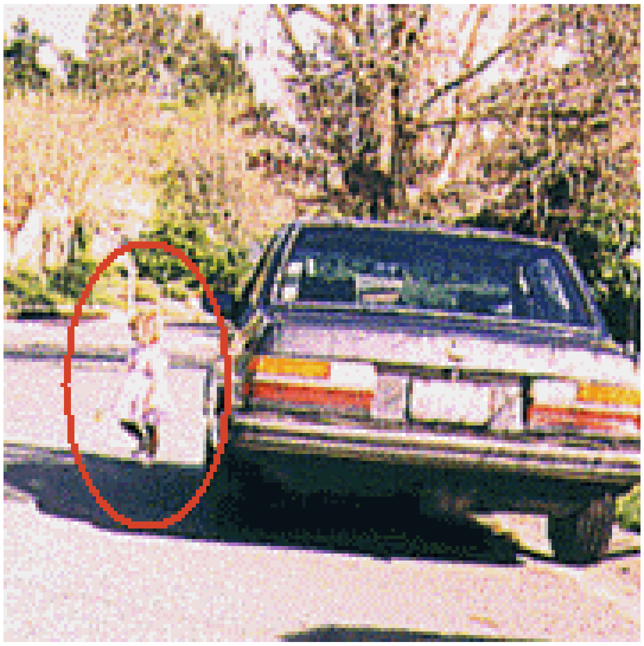
LOW VISION SIMULATIONS

Normal Vision

A cataract is a clouding of the lens of the eye and light that passes through the lens to the retina is scattered. The scattered light causes images to be blurred and visual acuity is reduced.

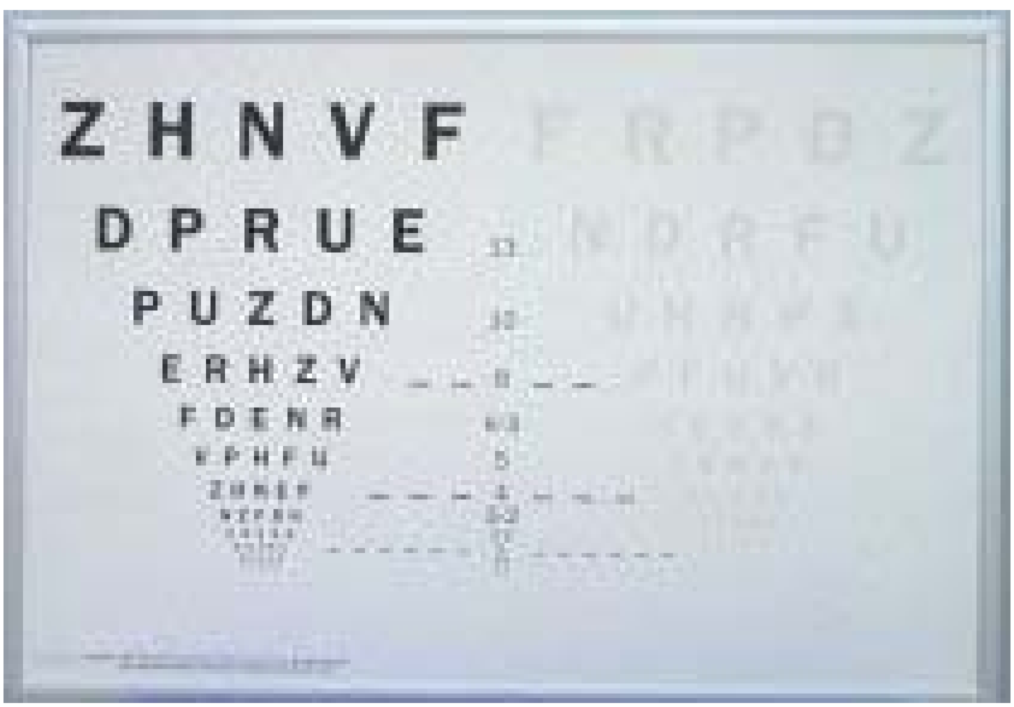
As we age, the lens of the eye yellows and becomes fixed and unable to focus, the pupil does not dilate very well to changes in illumination, and the retina and cortex become less able to process visual information. Contrast sensitivity decreases, visual acuity drops somewhat, and vision in low light levels suffers.

LOW CONTRAST VISUAL ACUITY



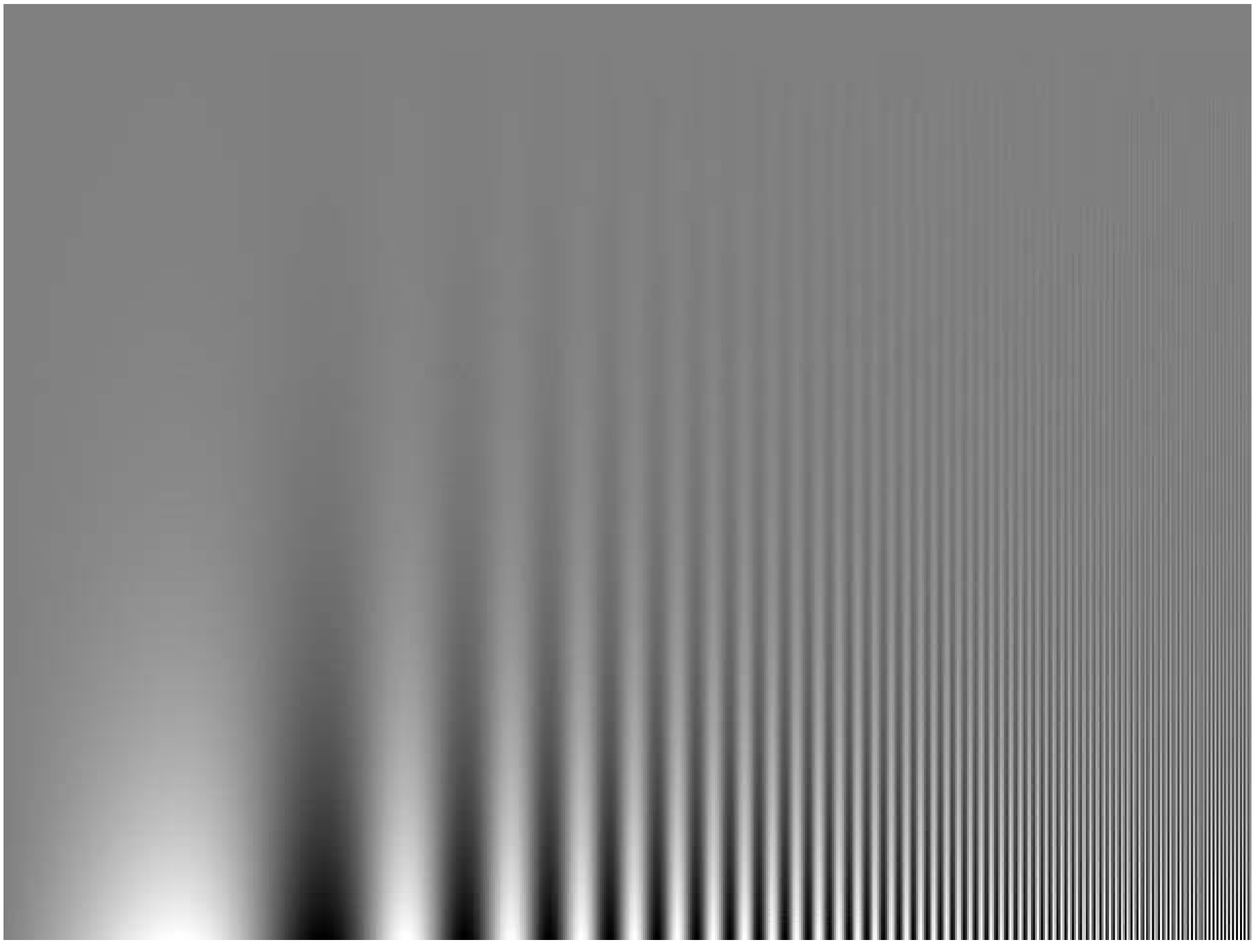
Good Contrast Sensitivity

Poor Contrast Sensitivity

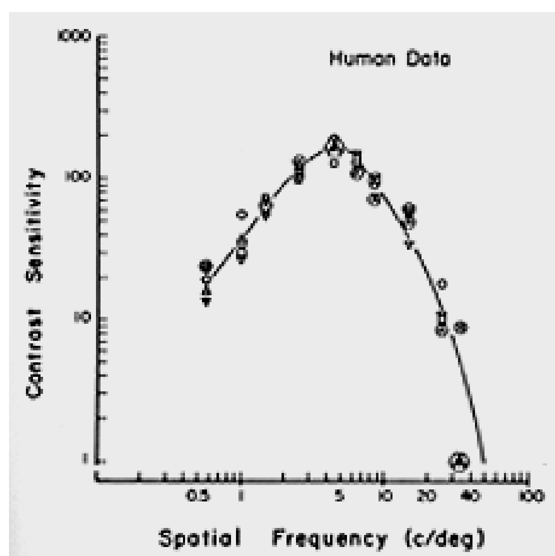


PELLI-ROBSON CHART

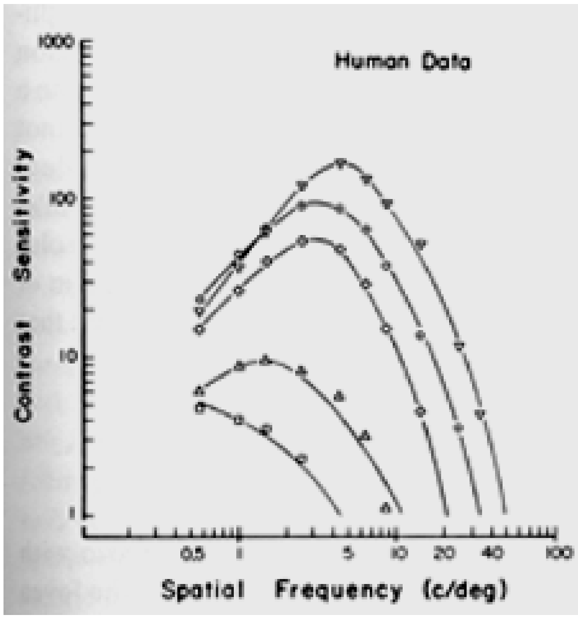
CAMPBELL-ROBSON CONTRAST SENSITIVITY

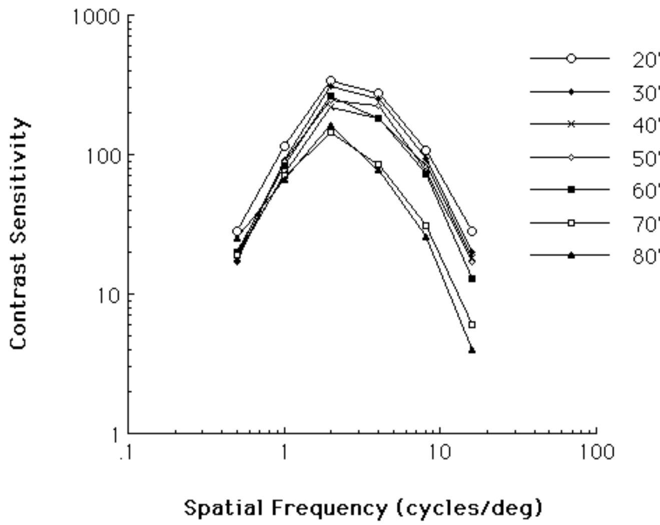


Contrast is on the vertical (Y) axis and spatial frequency (SF) is on the horizontal (X) axis. Note the characteristic shape, peaking in the middle of the graph and diminishing towards lower (coarser) and higher (finer) spatial frequencies.



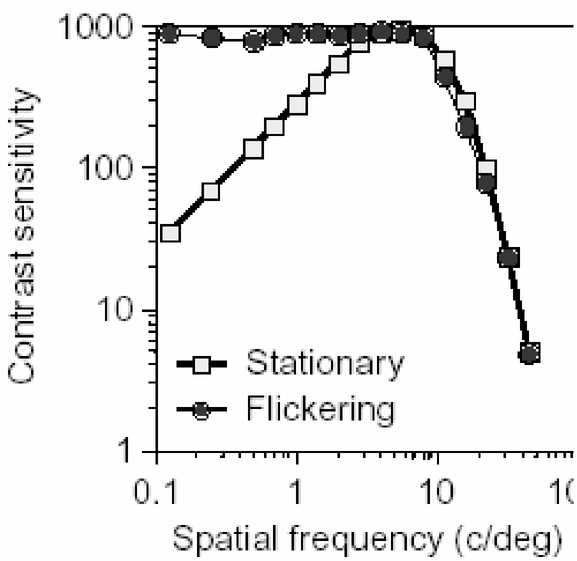
MORE CONTRAST SENSITIVITY FUNCTION

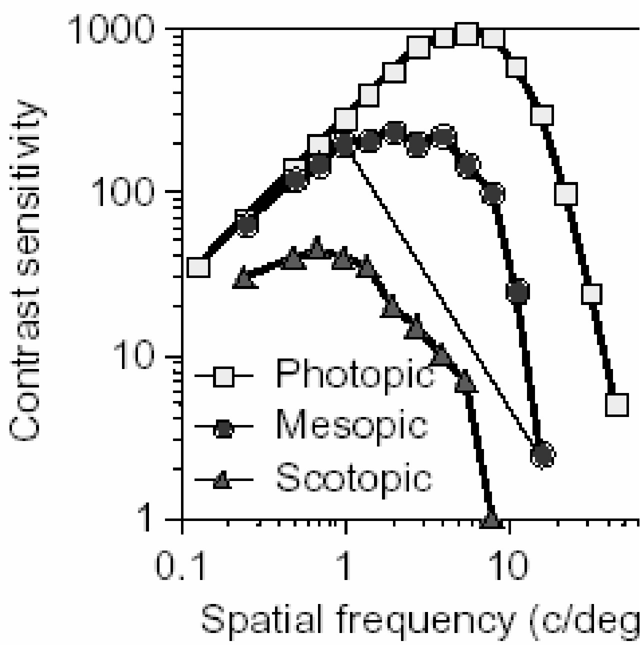




WITH LUMINANCE

WITH AGE

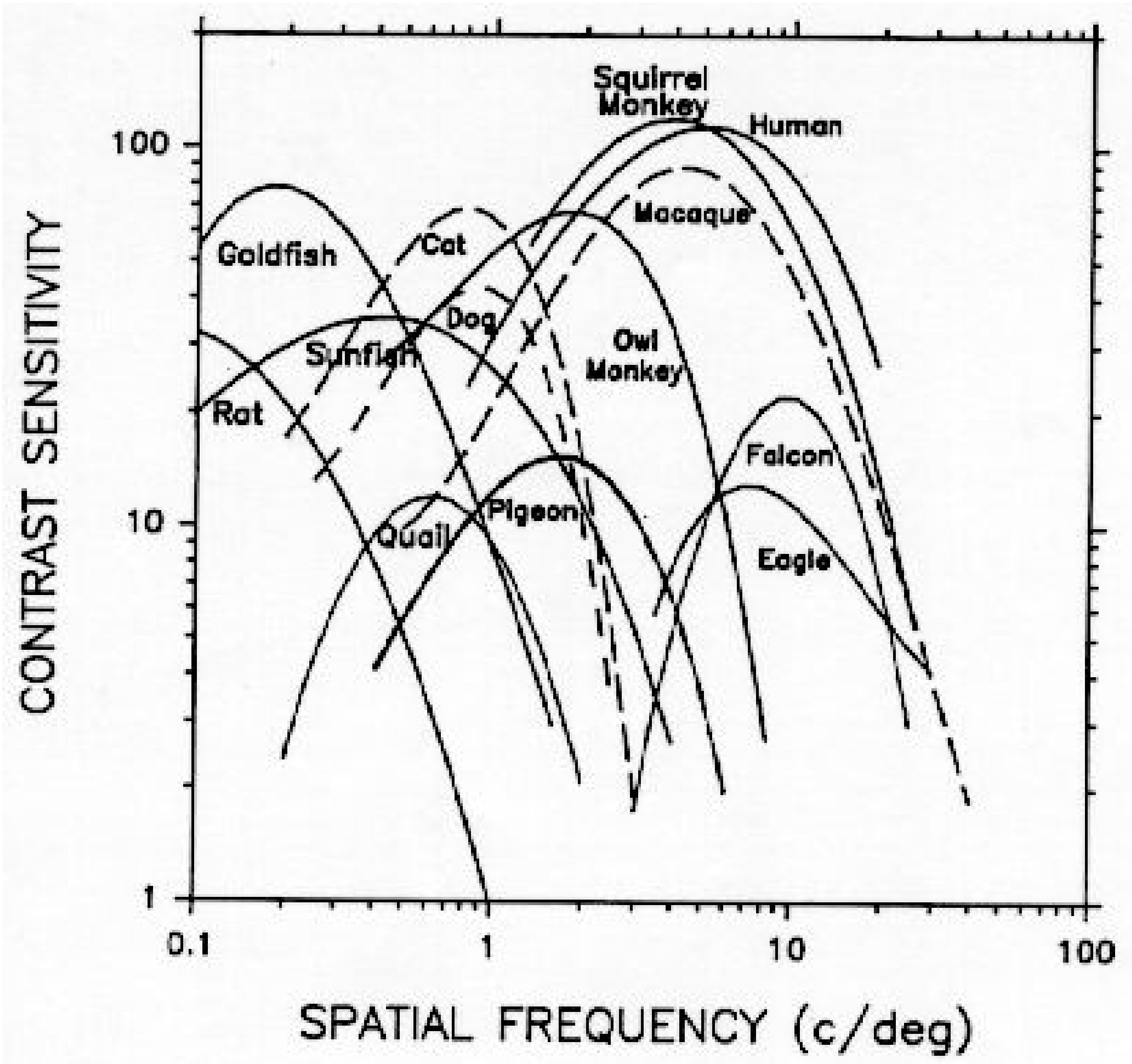




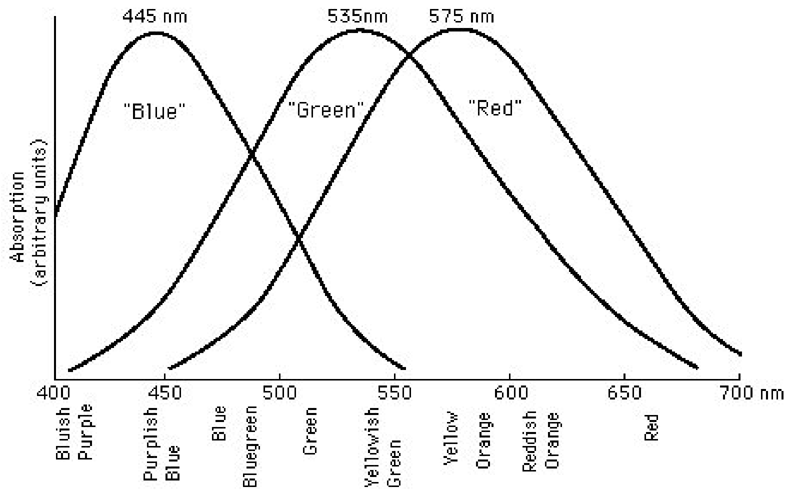
WITH FLICKER

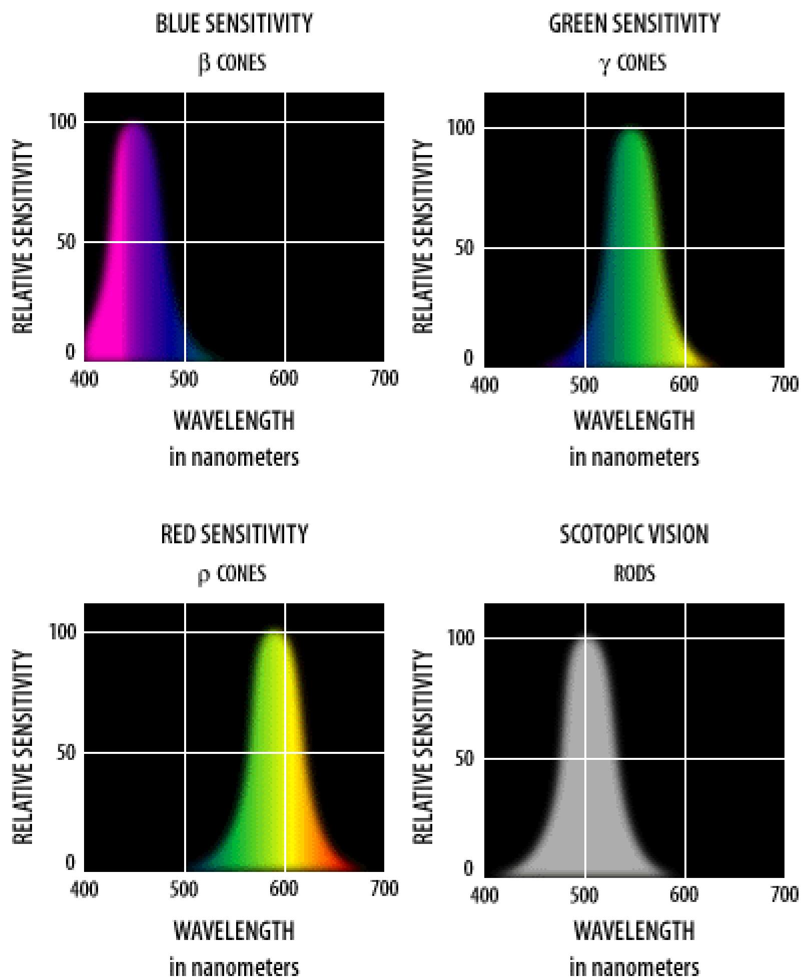
WITH SENSOR

CONTRAST SENSITIVITY IN ANIMALS

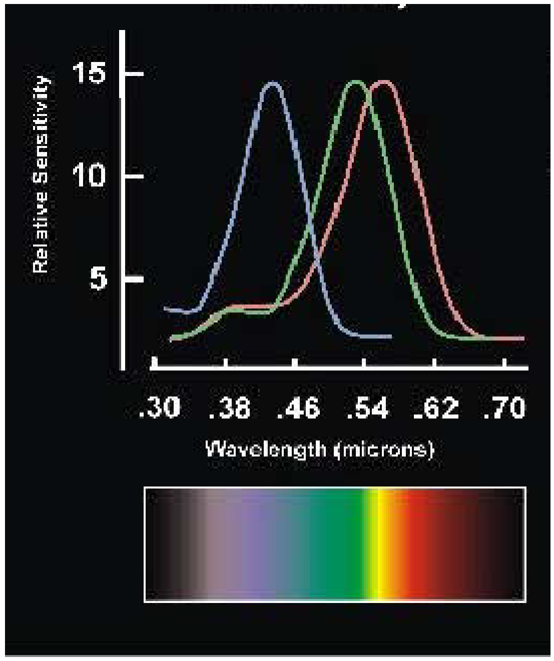


SPECTRAL RESPONSE OF INDIVIDUAL CONES

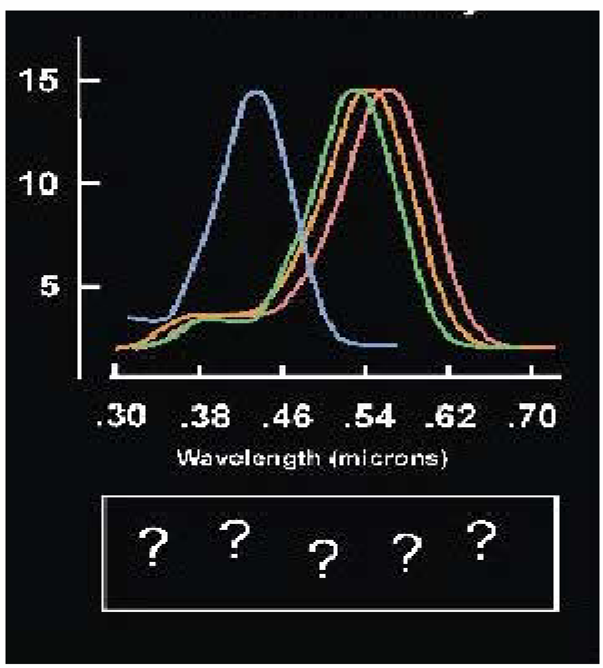




HUMAN TETRACHROMATIC VISION



TRICHROMAT (NORMAL)



TETRACHROMAT

PROBLEMS OF VISION - COLOR

- Most defects in color vision are X-linked recessive (means females are the carriers and males are the victims). Rarely seen in females.
- **Monochromats** (rare)
  blue cones & rods - see in gray scale .001%
  rods only - poor acuity, always saturated .01%
- **Dichromats** (one cone type absent)

  Protanope - no red cones, 1% of population, see blue, yellow, gray

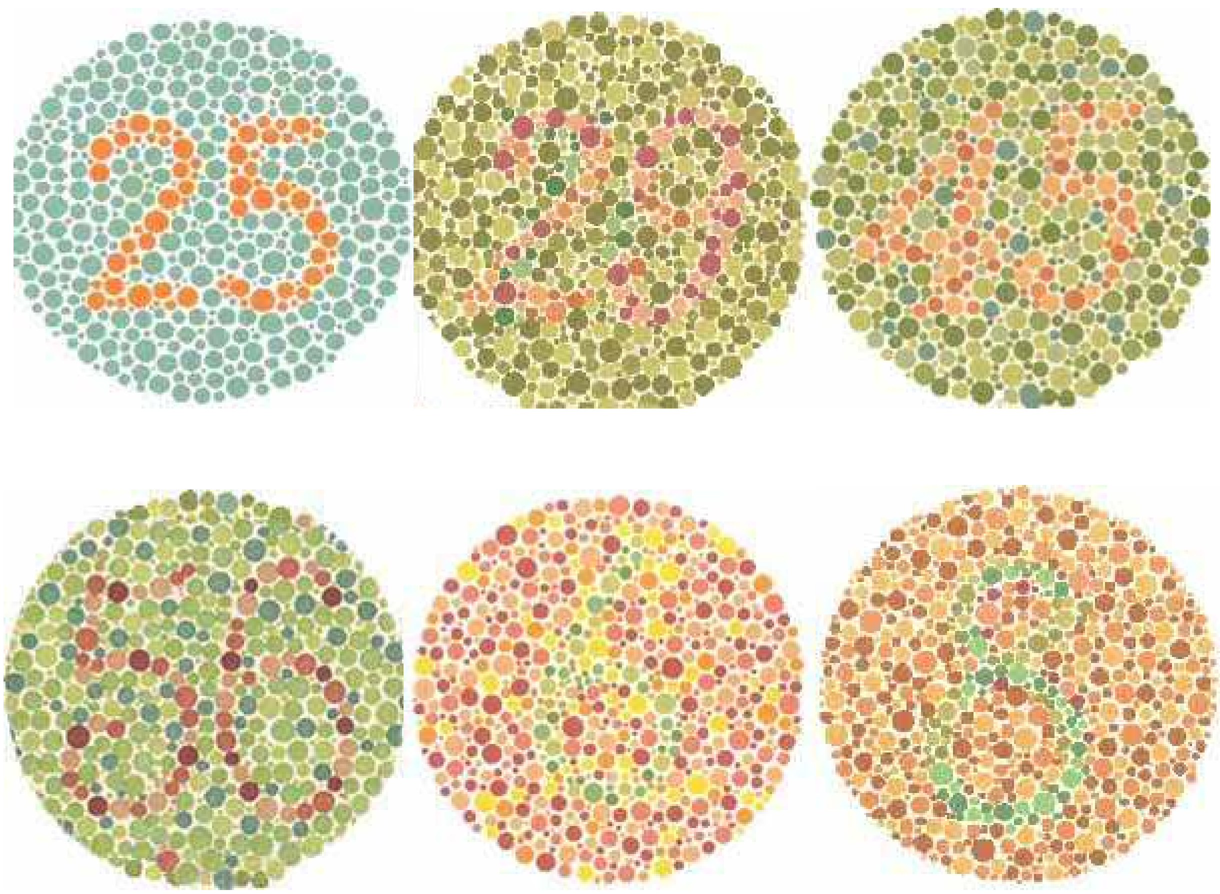
  Deuteranope - no green cones, 1% of population, see blue & yellow

  Tritanope - no blue cones, .01% of population, see red and green

- **Anomalous trichromats** - unbalanced chemistry, about 6-8% of population. Red-green vision whacked

ISHIHARA TEST FOR COLOR DEFICIENCY

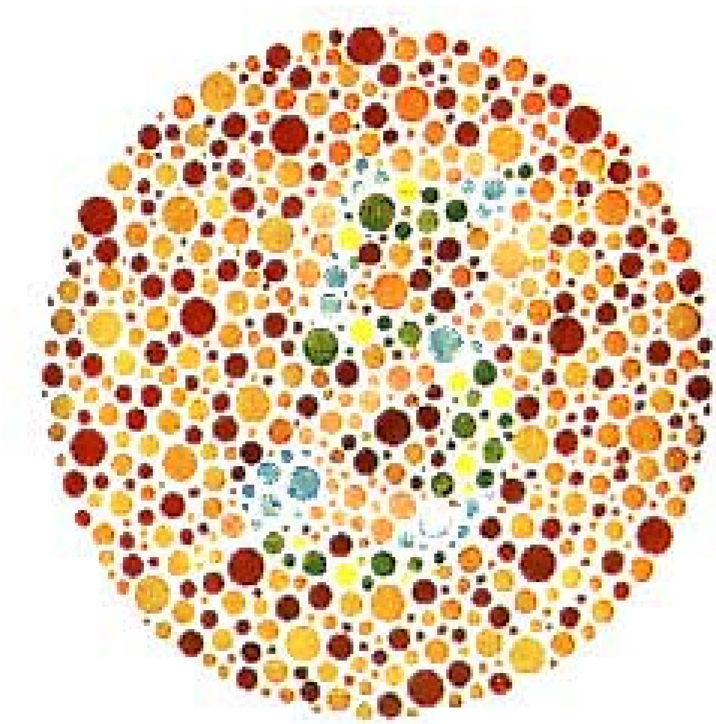
What numbers do you see revealed in the patterns of dots below?



NORMAL Color Vision	**25** **56**	**29** **6**	**45** **8**
Red-Green Color Blind	**25** **56**	**spots** **spots**	**spots** **spots**

MORE ISHIHARA

Here is another interesting Ishihara pattern:



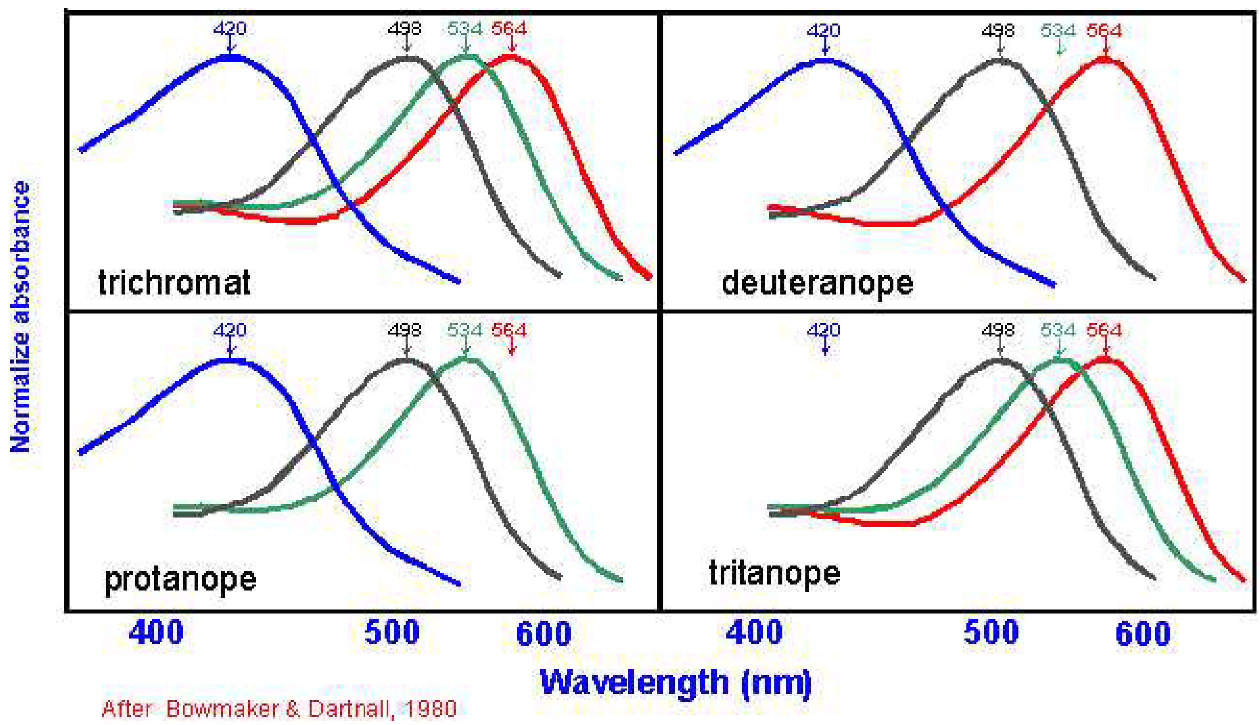
Those with normal color vision see a 5.

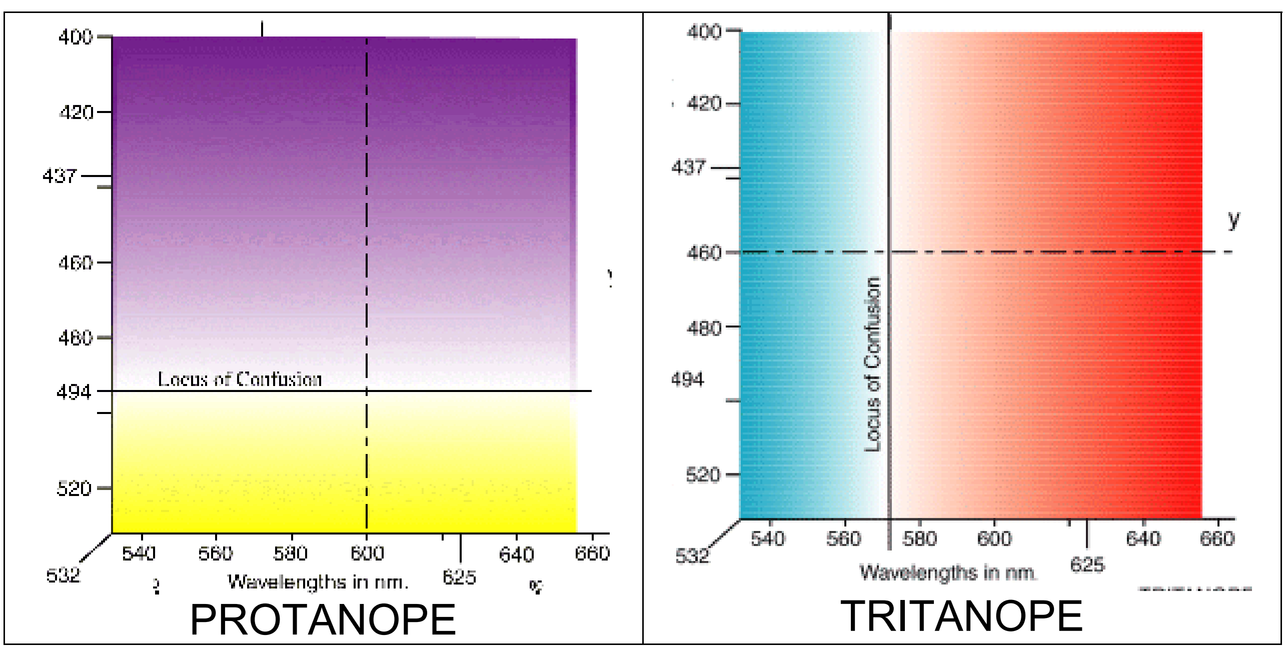
Those with Red/Green color blindness see a 2.

BLUE-GREEN

NORMAL

SPECTRAL SENSITIVITY FOR COLOR DEFICIENTS





HOW ABOUT FIDO?

NIGHT VISION

Dogs have better night vision for 2 reasons:

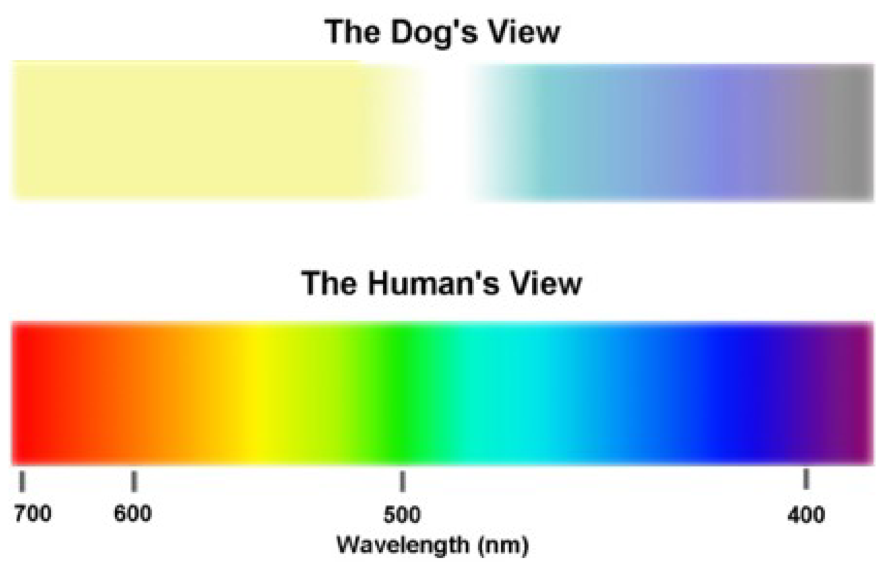
(1) They have more rods (night vision).

(2) They have Tapetum Lucidum, the reflective surface behind the retina that reflects light back through it.

SENSITIVITY TO MOVEMENT

Dogs are better able to detect movement.

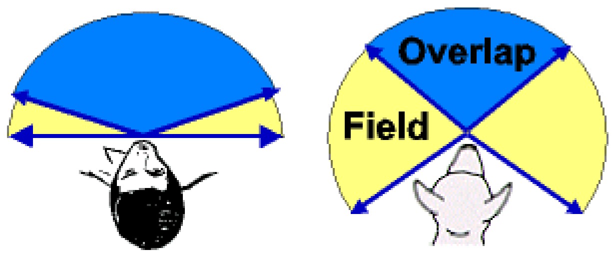
COLOR



Dogs see similar to a human deuteranope (red-green), they have only two types of cones.

DEPTH & FIELD

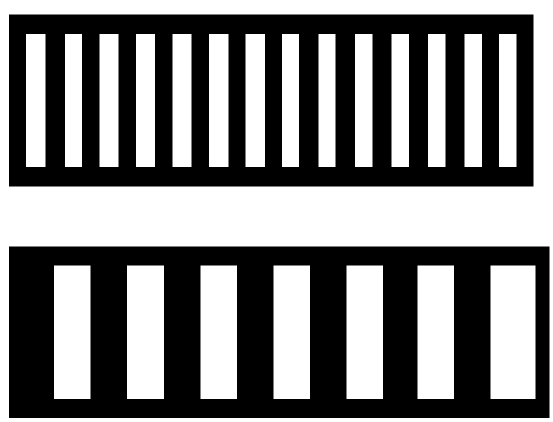
The cartoon compares angular fields of view of humans and dogs. Due to the placement of the eyes, humans have an overlap of the field of each eye of 140; in dogs, it is about 100.



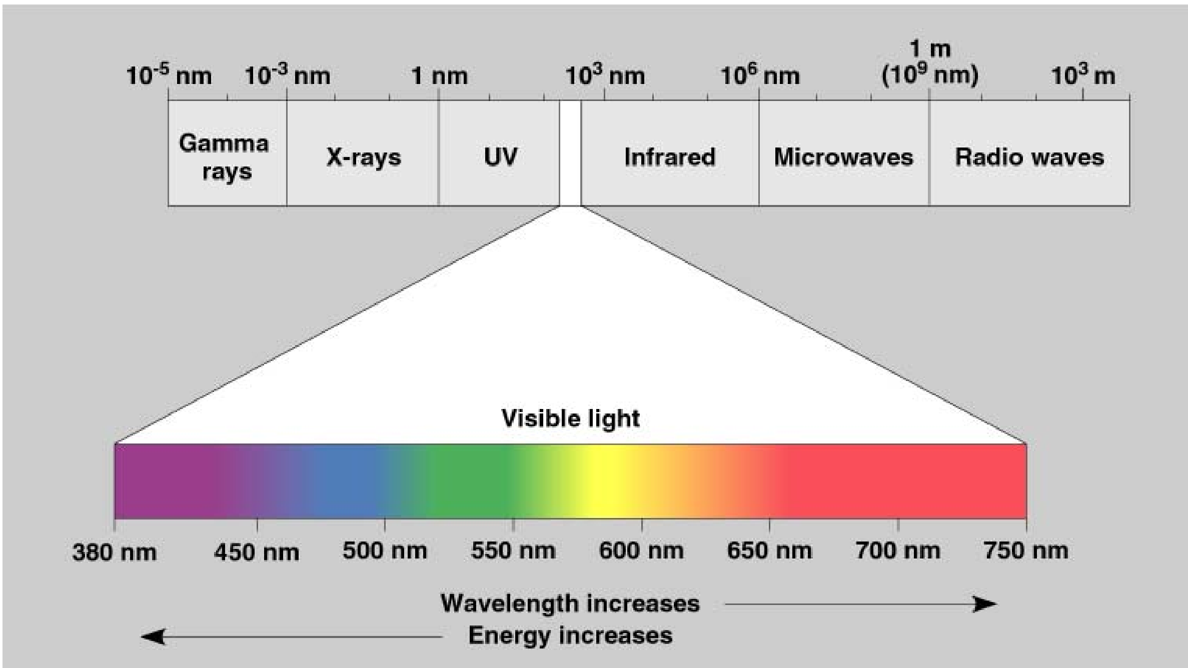
ACUITY

The central retina of the canine eye contains about 20% cones, while humans have an area of 100% cones called the fovea. Since dogs have no fovea, their estimated acuity is about six times worse than 20/20 humans. We can see about 30 cycles per degree while dogs can see about 6 to12.

HUMAN	**20/20**
DOG	**20/50 to 20/100**
HORSE	**20/33**
CAT	**20/100**



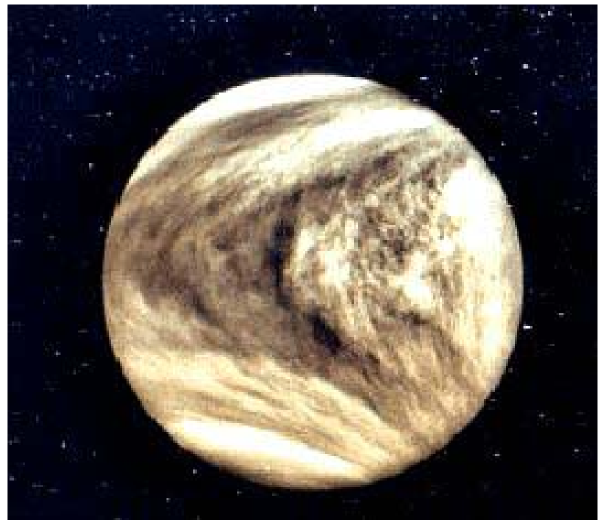
IN WHAT PART OF THE ELECTROMAGNETIC SPECTRUM DO WE SEE?



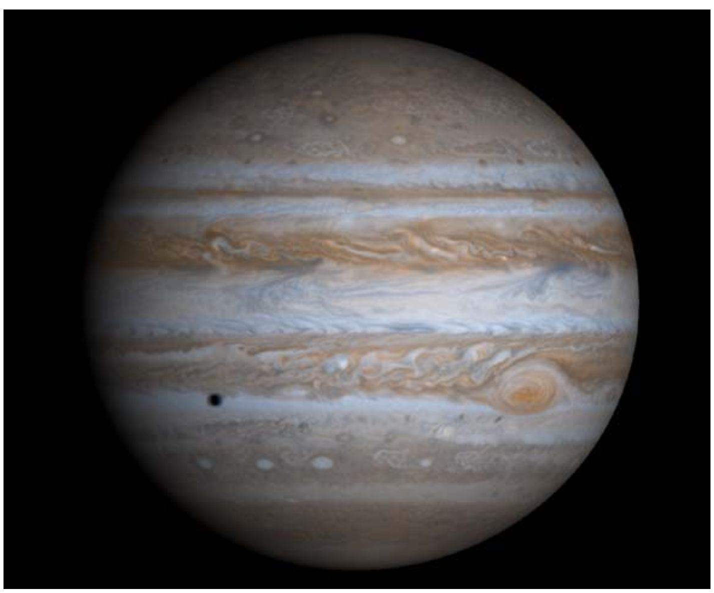
Our lone octave doesn't cover much. But we can devise instruments and techniques for looking in other wavelength regions.

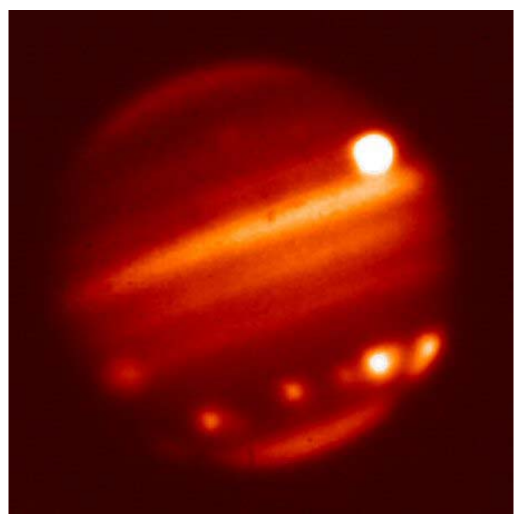
A grayscale represents some other quantity, and any color seen is "false color" where colors are used to distinguish features. In the infrared region, we are generally looking at a representation of temperature.

PLANETS REVEAL SOME STRANGE STUFF



VENUS (UV)



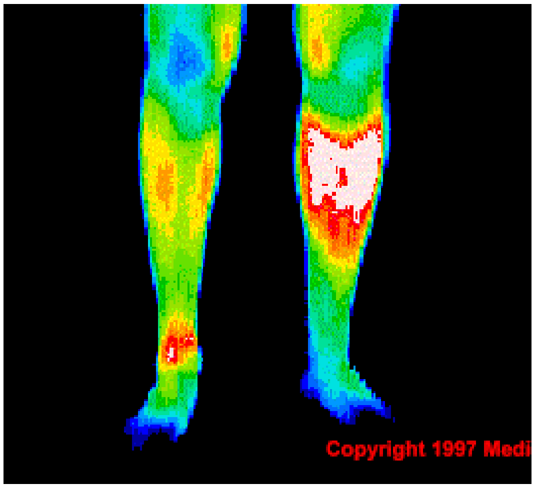


JUPITER (IR)

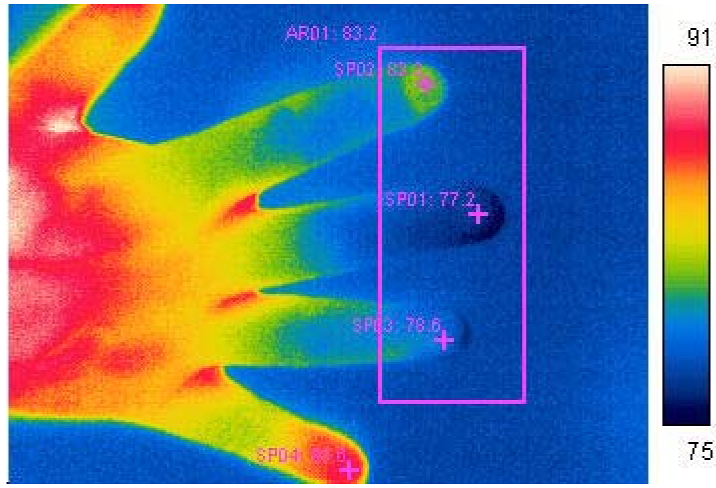
JUPITER (VISIBLE)

SHOEMAKER-LEVY

INFRARED IS USEFUL MEDICALLY

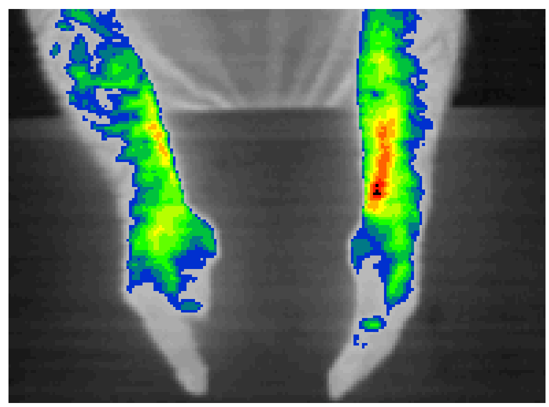


BAD LEGS

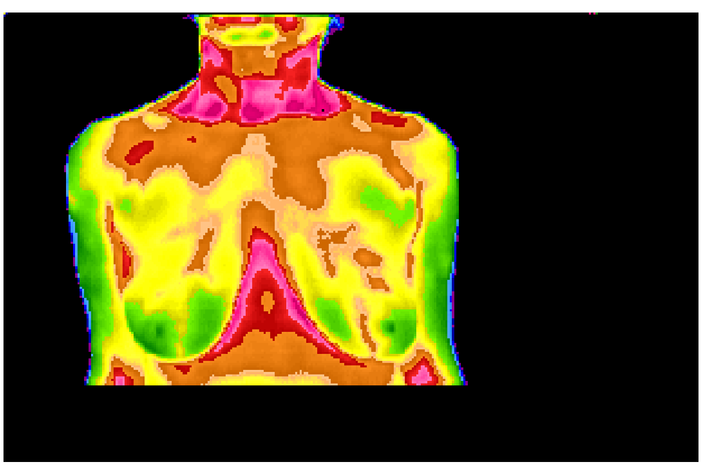


REYNAUDS

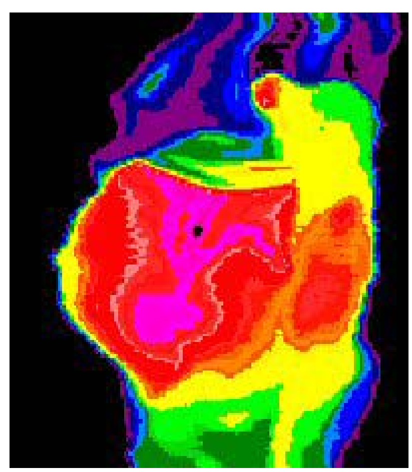
BAD BRAIN



TUNNEL CARPAL



BREAST CANCER

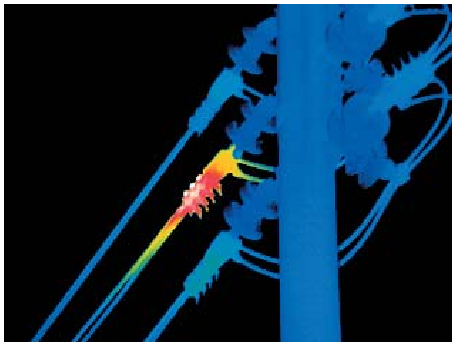


VERY PREGNANT

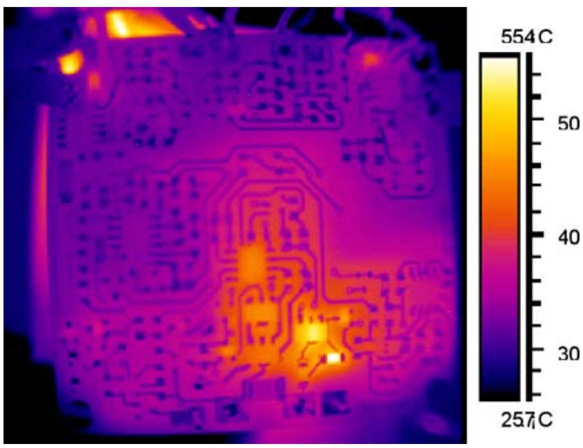
INFRARED IS USEFUL IN MANY WAYS

CADILLAC NIGHT VISION SYSTEM

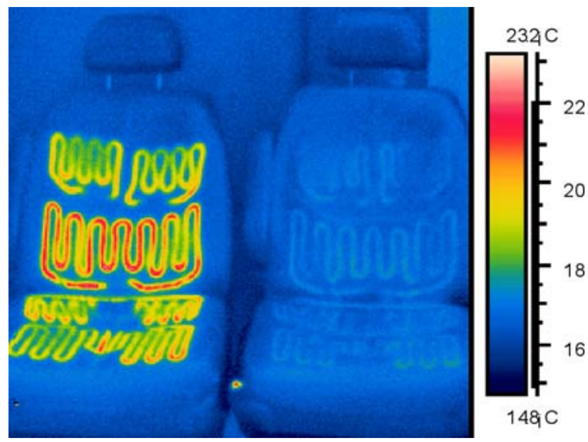
YOU CAN RUN BUT YOU CAN"T HIDE!



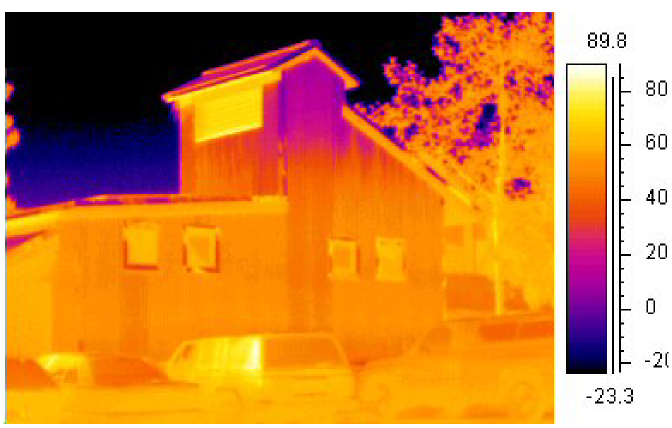
THERMAL ANOMALY AT BOLTED CONNECTION



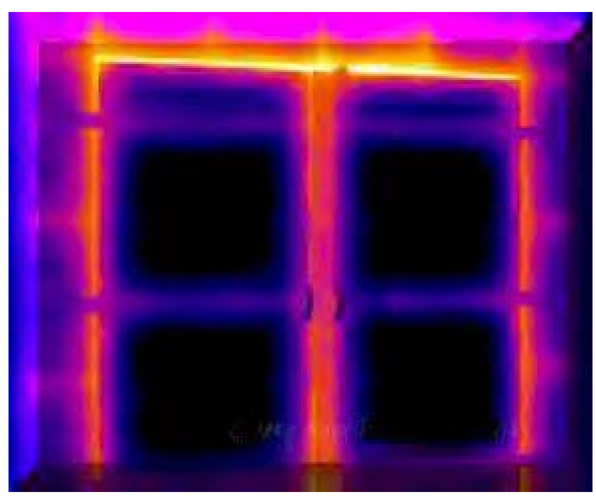
HOT CHIP ON PC BOARD



HEATED SEATS



ENERGY LOSS



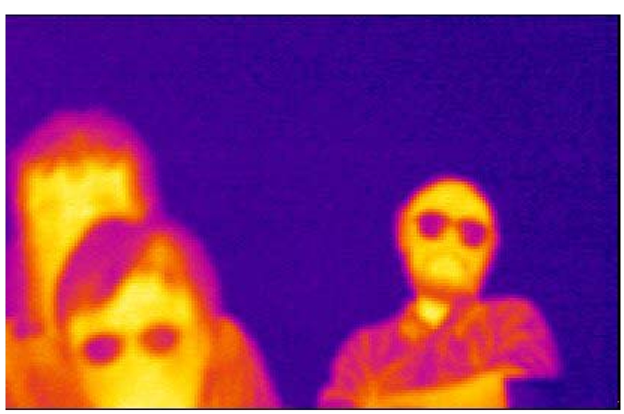
ENERGY LOSS

INFRARED IS ALSO FUN

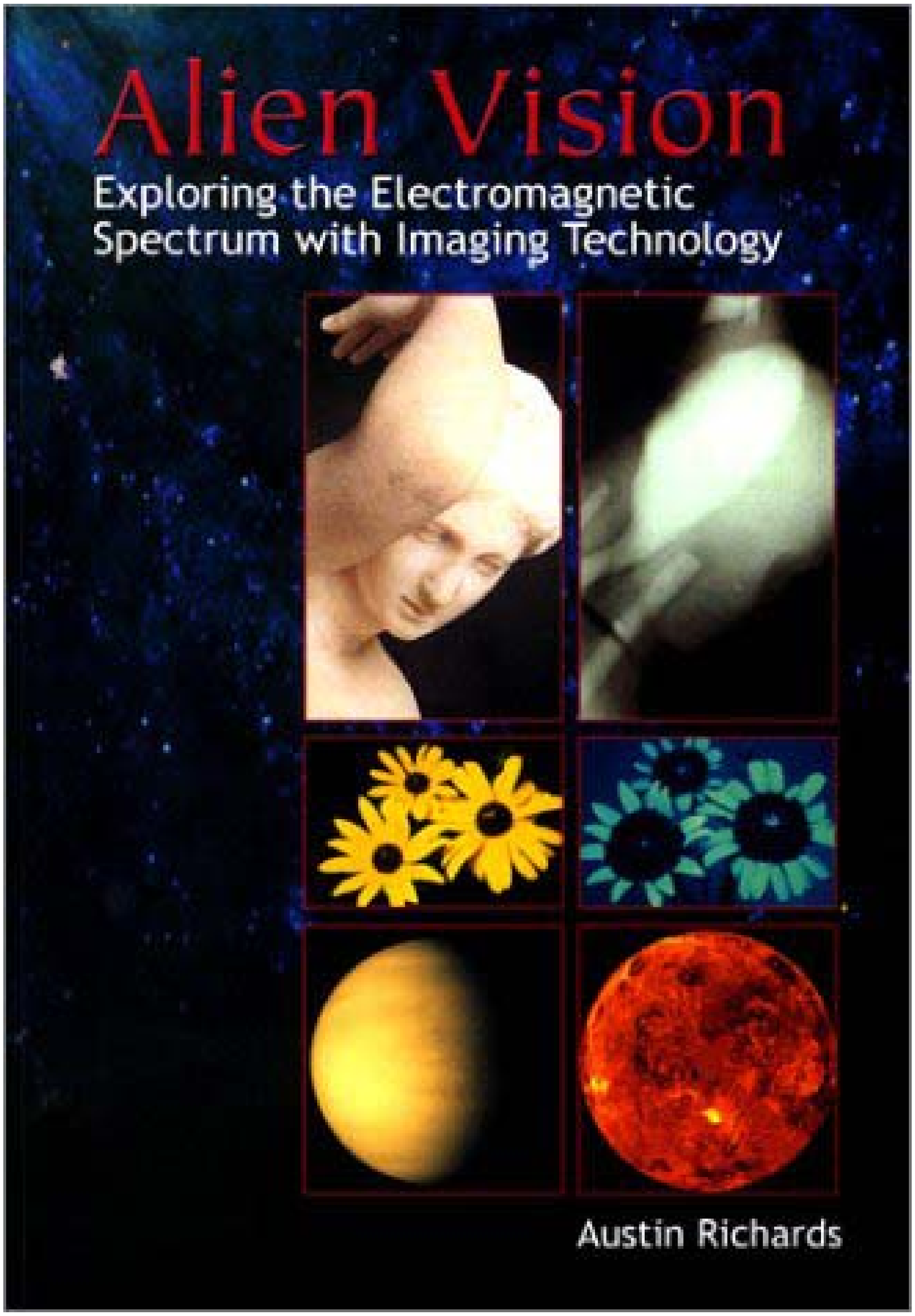
VISIBLE

NEAR-INFRARED

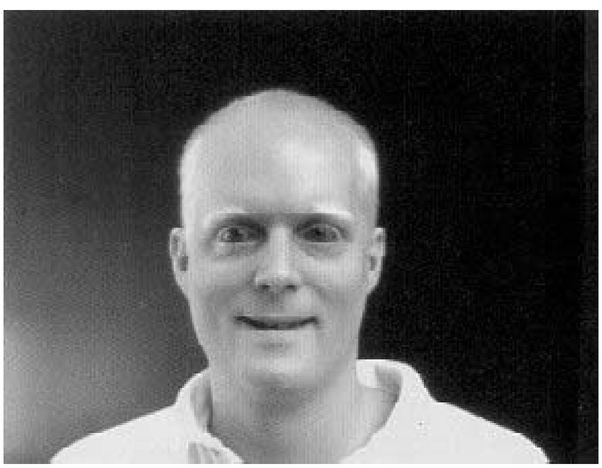
THERMAL INFRARED



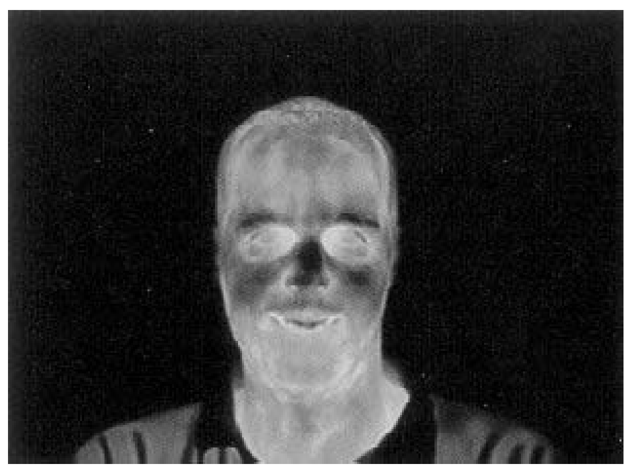
ALIEN VISION



THE AUTHOR IN MANY GUISES

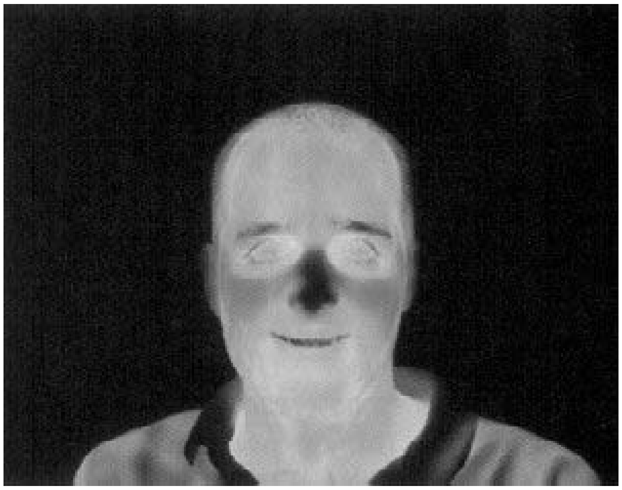


SWIR

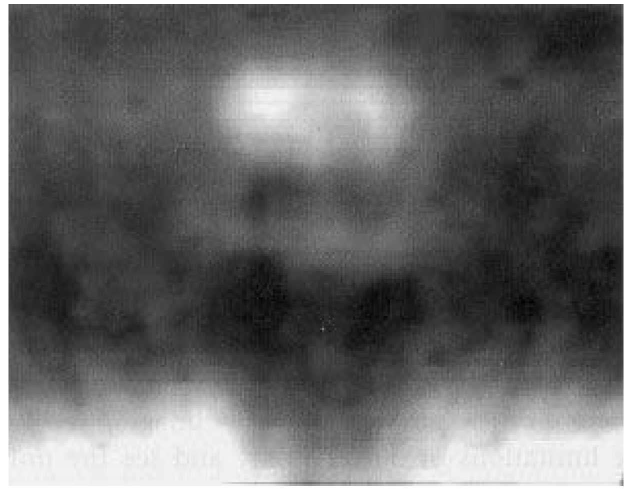


MWIR

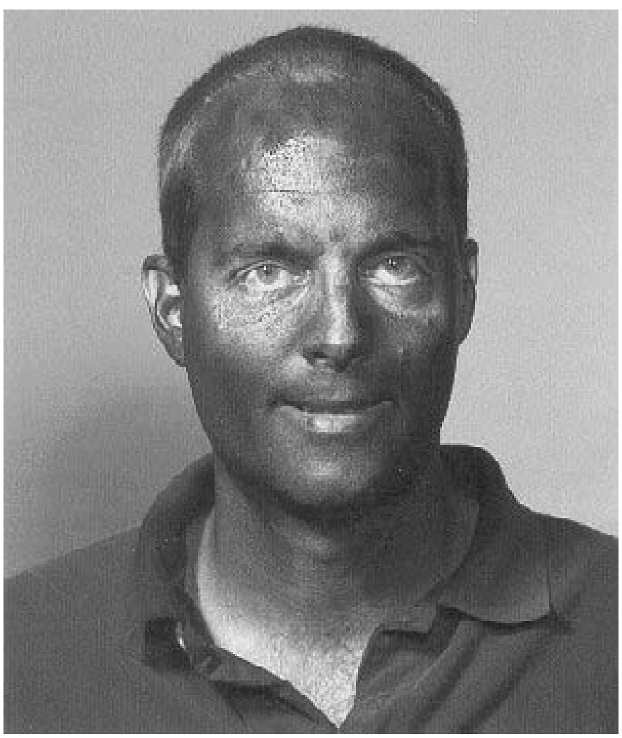
FURTHER AFIELD



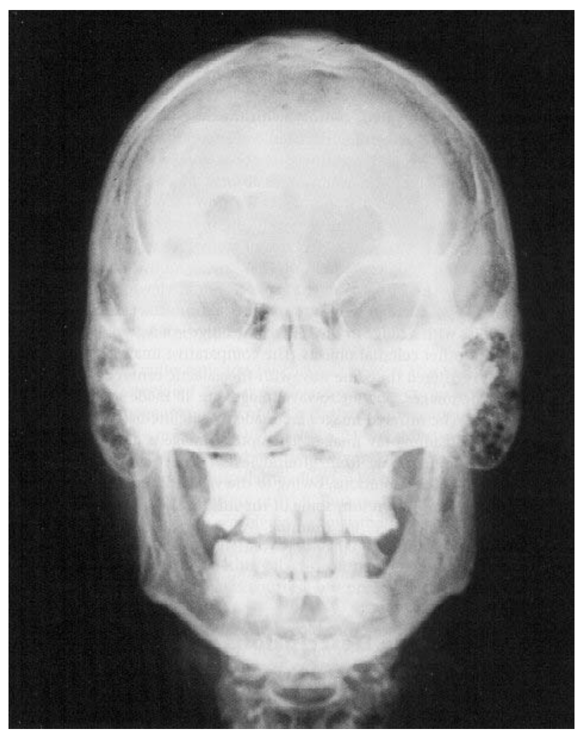
LWIR



THz



ULTRAVIOLET



XRAY