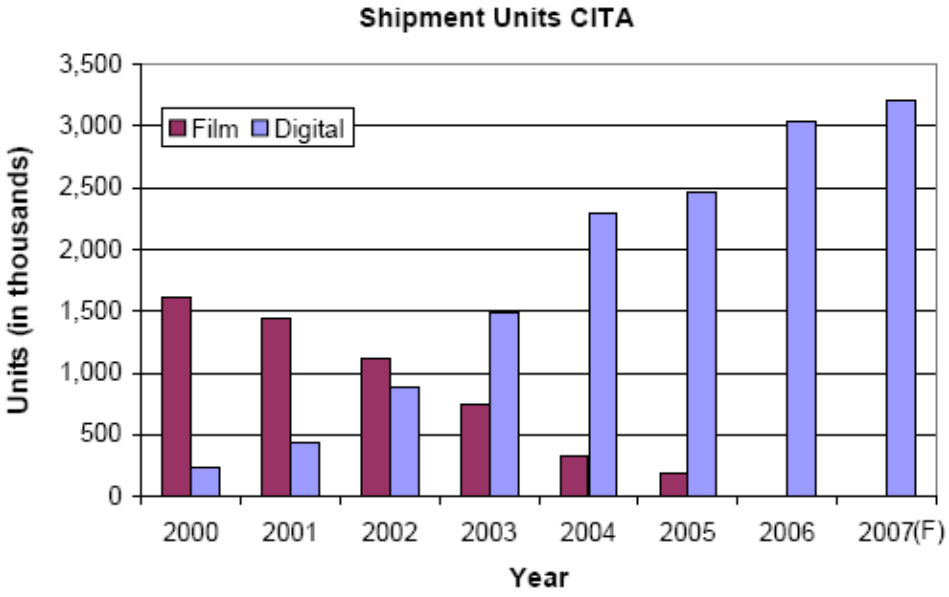
Digital Cameras vs Film: the Collapse of Film Photography

- Can Your Digital Camera reach Film Photography Performance?
- Film photography started in early 1800's – almost 200 years
- Commercial Digital Cameras started late 1995
- By 2000 digital "point & shoot" fell <$400
- Digital Single Lens Reflex Cameras (Nikon D1) appeared in 1999 at $10,000
- Cannon 10D in 2002 first semipro DSLR <$2000
- Digital Rebel in 2003 first <$1000
- By 2006 film camera almost stopped
- Kodak effectively destroyed by the move to digital
- Fujifilm, only major film manufacturers but Kodak is coming back
- But now many special producers eg Lomography



Why Digital Cameras Succeed

- Digital has clear advantages in many areas
- Immediate image view – can correct picture
- Film takes hours/days (or minutes with polaroids)
- Cost: Film >50¢ photo,
- Storage – film bulky,
- Digital 32GB cards now $22, <0.03¢/photo
- Largest cards now 1TB for video
- If use DVD 4GB disk cost 25¢, holds ~4000, 0.006¢/picture
- 2TB usb drives give 400 million photos at 2.5×10^{-5} ¢/picture
- Digital SLR's now near film in price

EOS Rebel K2 film ~$400

Digital Rebel X5Ti ~$900

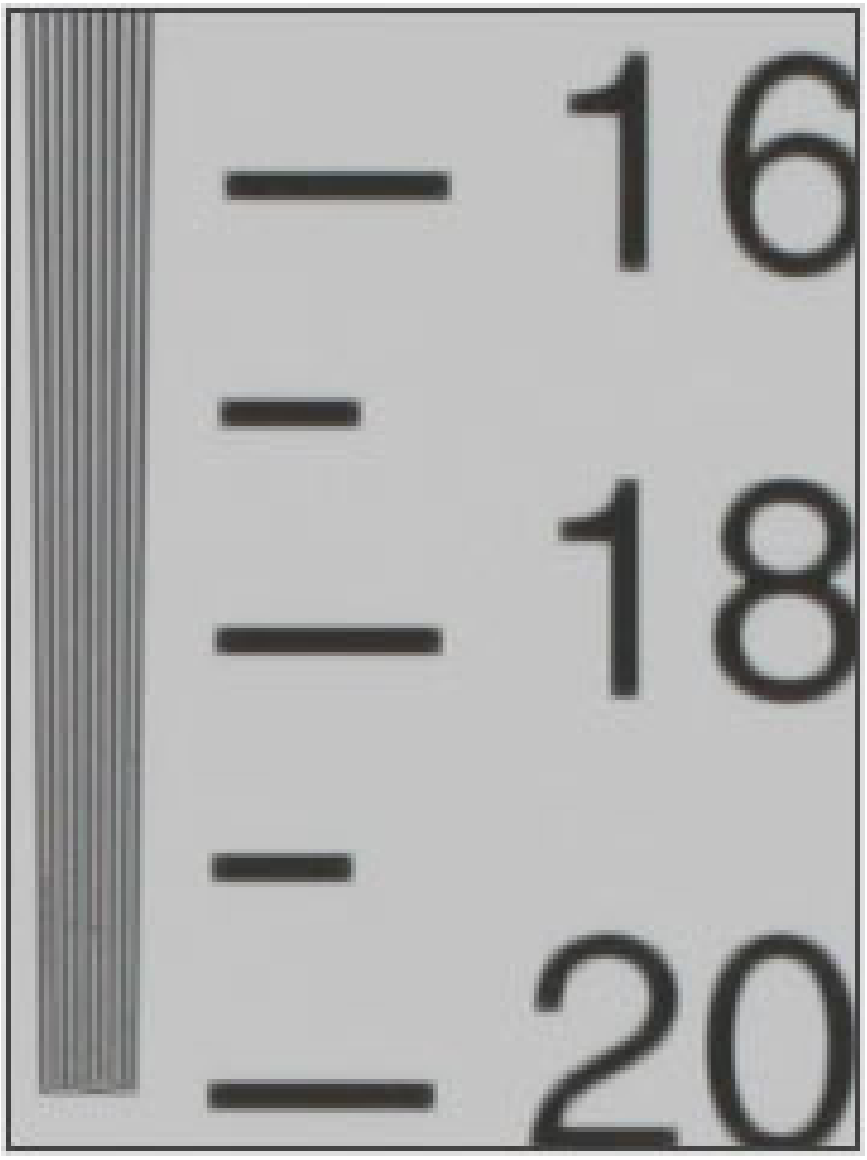
Canon 5DsR – pro end $4000

Why some Top Pro Photographers have not fully Converted

- Journalist & sports professionals photographers have converted
- Need rapid turnaround of pictures
- But high end Portrait, advertisement have not fully – Why
- Film still has advantages in several area:
- Resolution
- Colour accuracy
- Sensitivity
- Dynamic Range
- Special photographic conditions: cold climates & long exposure
- Let us look at why & where digital is responding

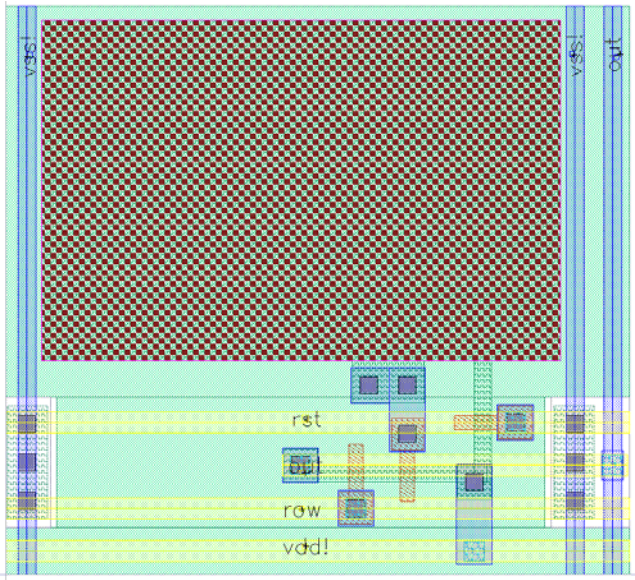
Resolution Measurements

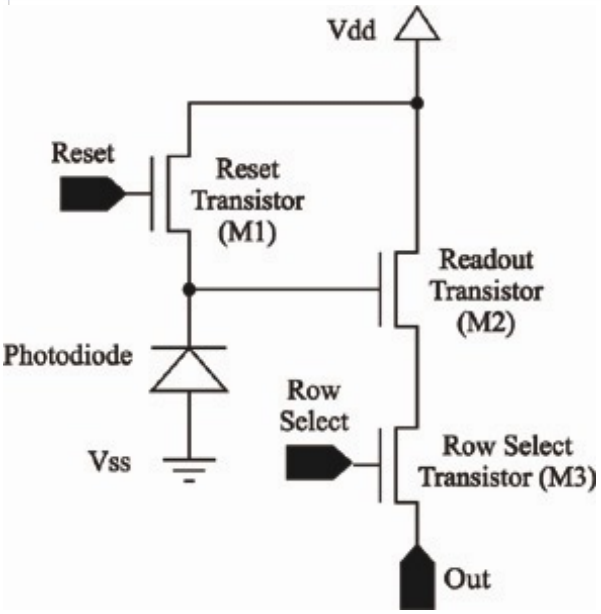
- Measure resolution in line pairs per millimeter (lp/mm)
- This is called MTF type measurement
- One line and space per line pair
- Nyquest theorem: need minimum of 2 pixels per line pair
- So size of pixel limits resolution

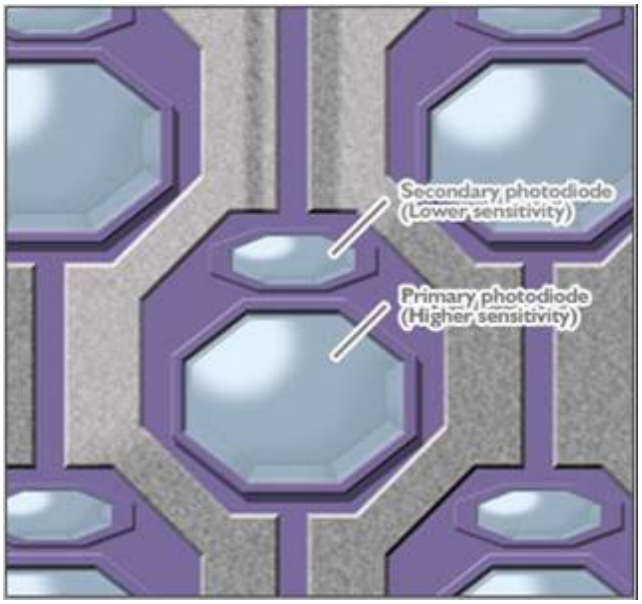


Digital Resolution

- Digital sensors of two types
- CCD: Charge Coupled Device
- Active Pixel Sensor (CMOS) resolution set by pixel size
- Typical size 4-8 microns – cell phones down to 1.5 microns
- Sensor area (fill factor) ~25%-50%
- Use microlenses to get collection near 95% of pixel area
- Best Digital resolution ~35 line pairs/mm
- Smaller pixels do not generate better resolution
- Digital noise/spread limits resolution

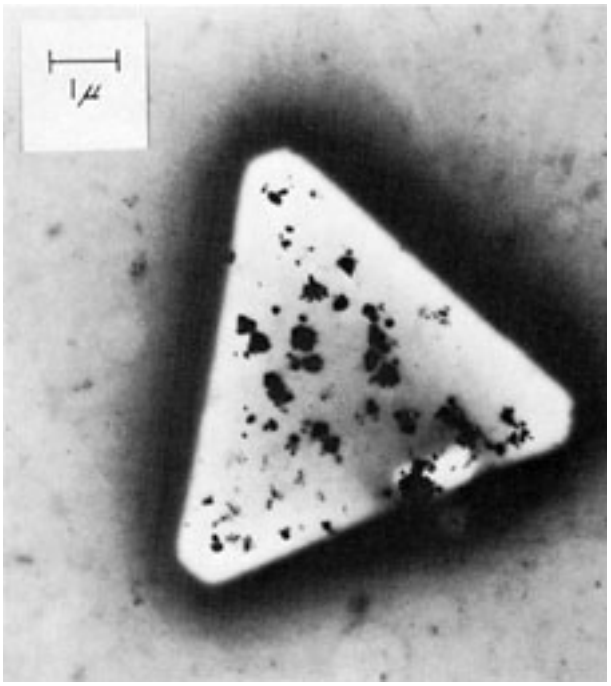


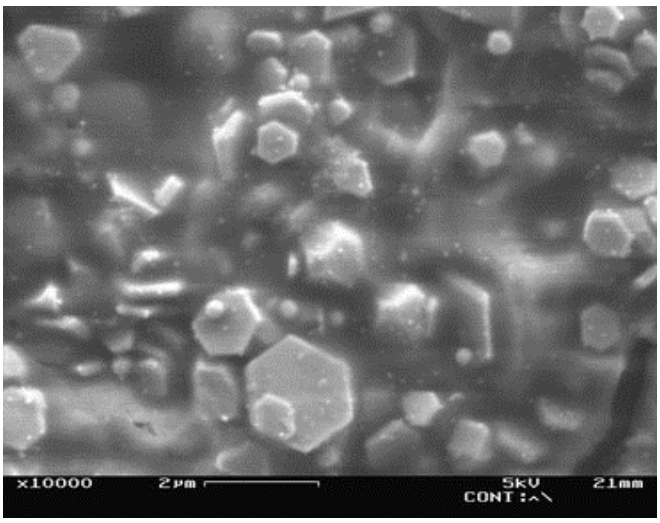


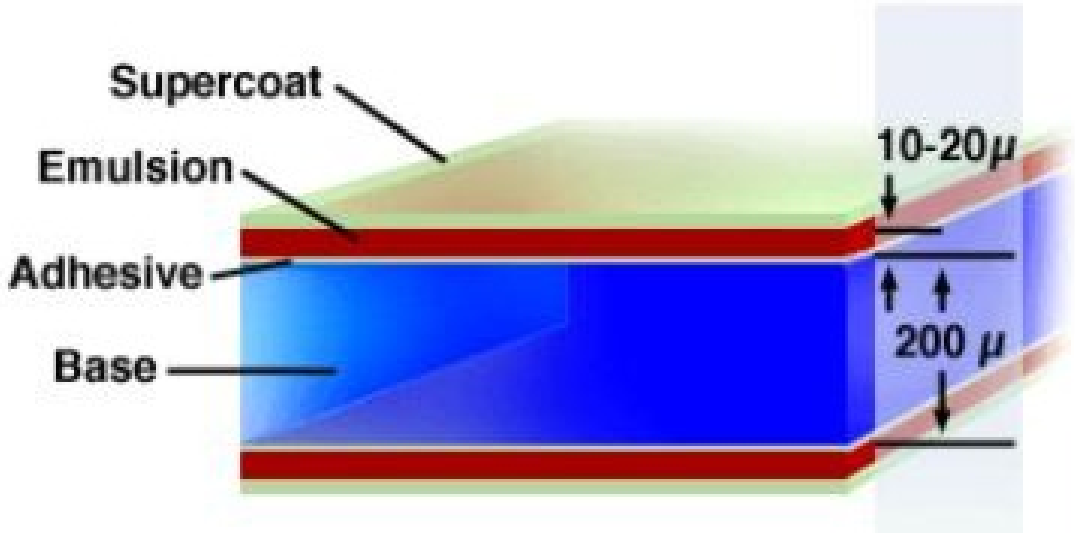


Film Resolution set by Grain size

- Film sensor is silver halide grains in emulsion 10-20 μm thick
- Resolution in film set by silver halide grain size
- Typical grain is ~1-2 um
- Large grain ~20 um
- Ultra fine grain 0.015 um (done in 1920's!)
- Single photon activates all the silver halide in a grain
- Thus larger grains more sensitive, smaller less sensitive
- Creates Latent Image – can be stored for years before fading

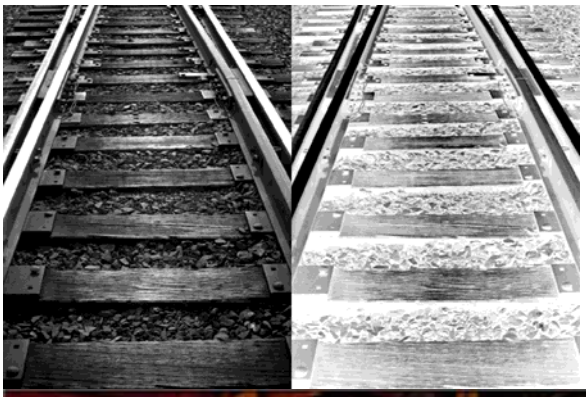


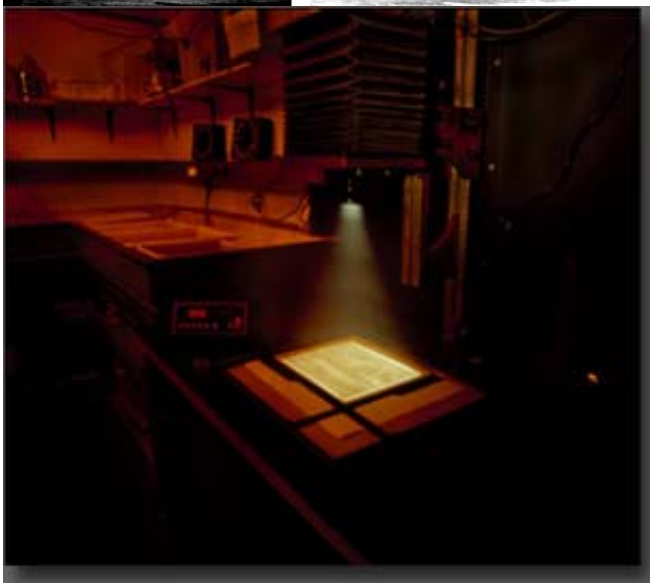




Photographic Process

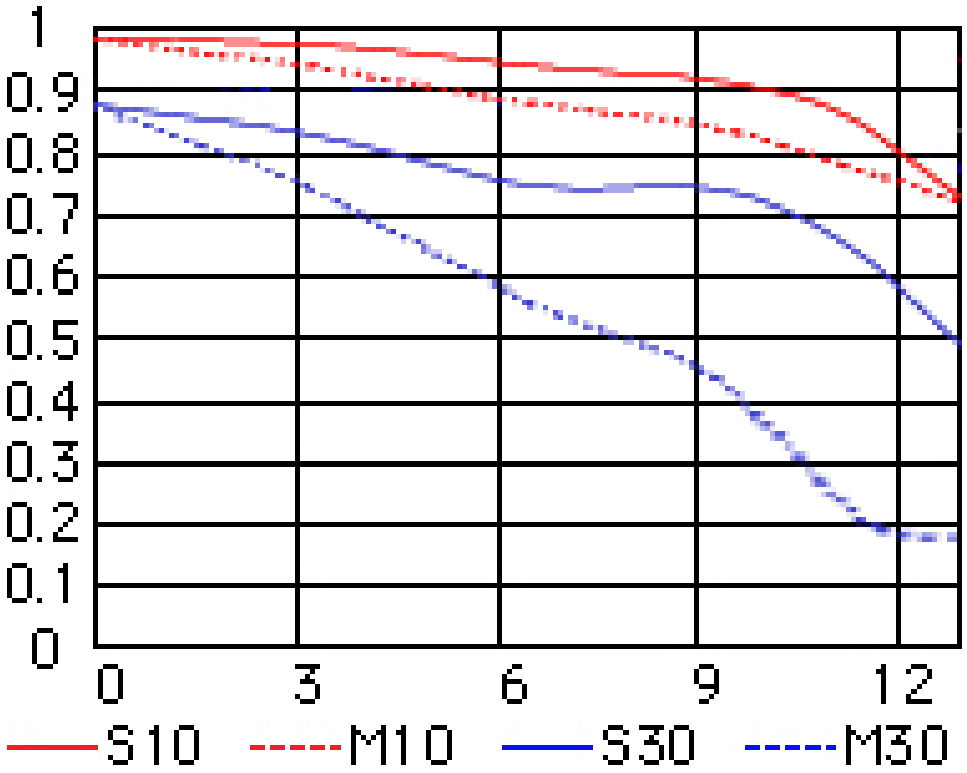
- Development process (done in dark or container)
- Film placed in developer solution
- Developer eg Metol and hydroquinone in high pH solution
- Put in developer for ~1-3 min: agitate to move solution over film
- Reduces the activated grains leaving metallic silver (black)
- Thus image is negative: exposed area black
- Then put in a “Stop Bath”, e.g. water: to stop the reaction (30 sec)
- Then in fixer: sodium thiosulfate (hypo) or ammonium thiosulfate
- After ~5 min removes unexposed silver halide: leaves black silver
- Removed grains leaves transparent film
- Then final wash in water to remove all chemicals ~ 10 min
- Print uses then uses paper covered with emulsion
- Project negative on paper & develop to get image





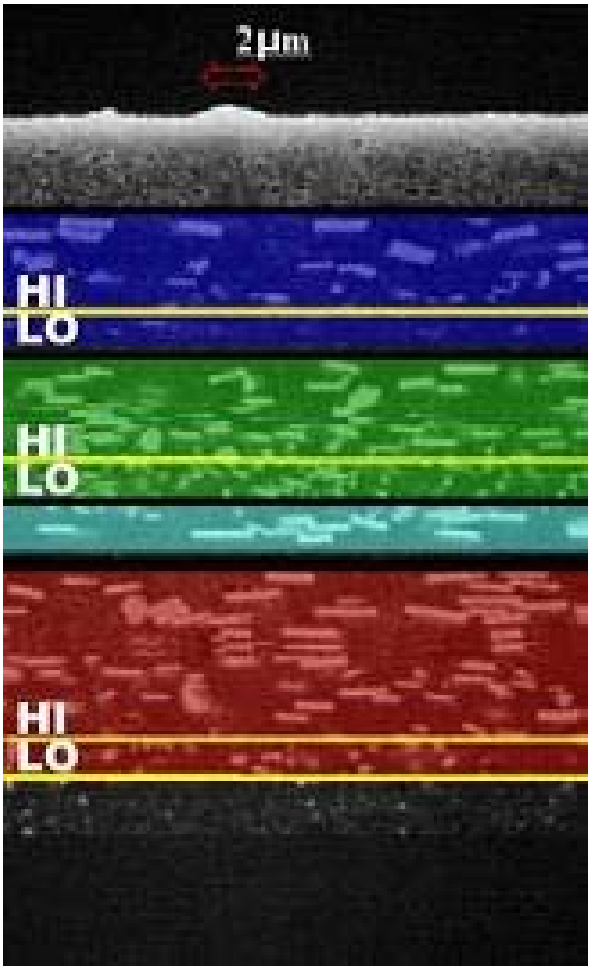
Resolution Limit by Lens

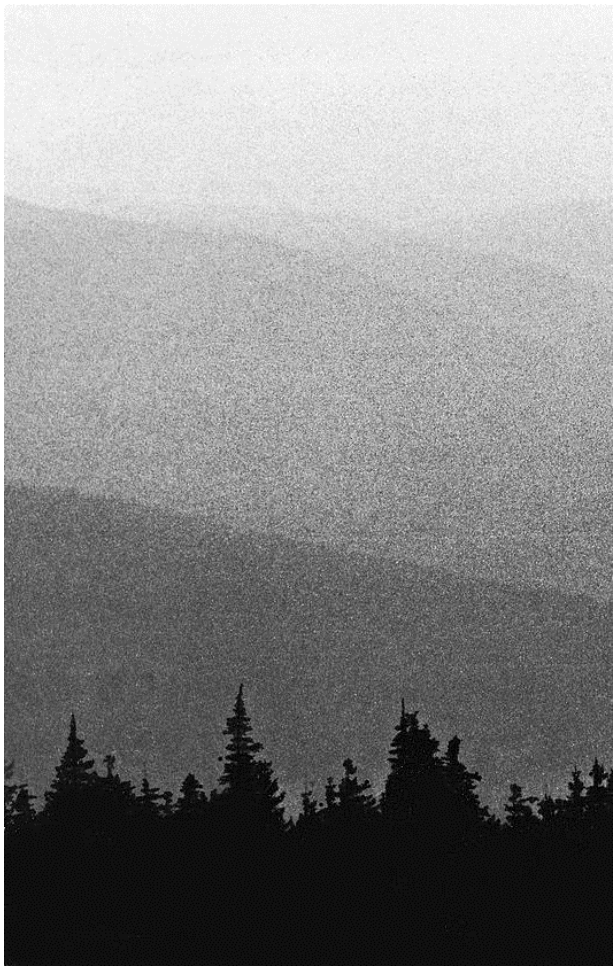
- Best resolution is usually limited by the lens
- For digital point and shoot lens and imager about same resolution
- But for DSLR lens still better than detector
- Resolution limit of DSLR fines lenses 200 lp/mm
- Requires at lest 1.2 um pixels
- Top Digital end 50 Mpix (~8700x5800 pix)
- Film limit on 35 mm ~29,000x19,000 pixels = 552Mpix
- In film days some large cameras had much bigger lenses
- Eg Medium format Hasselbald 6x 4.5 cm was portrait standard
- 4x5” (10x12.7cm) graphic, 8x10 (20x24 cm) sheet film cameras
- Even higher resolution Could make bill board sized photos.



Film Resolution

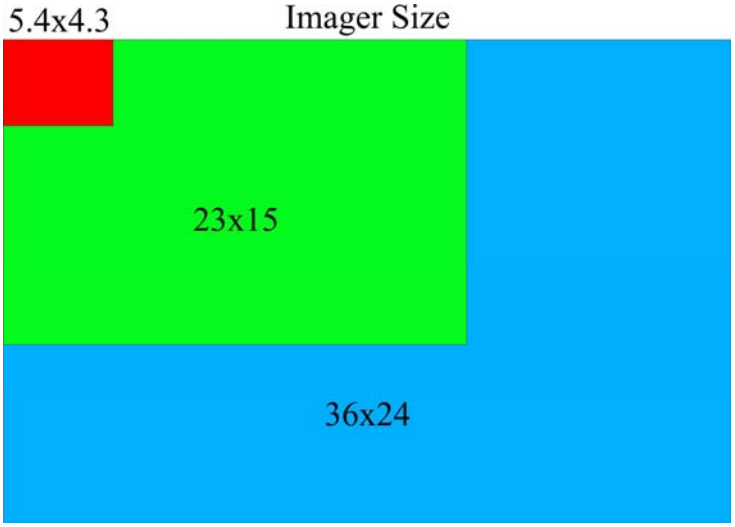
- Film has many layers of gain, with several sizes
- Often have course layer & fine grain layer
- Grain size also distributed in film
- Resolution also set by developer:
- fine grain developer better resolution for same film
- Typical film has 80-100 lp/mm
- Ultra fine grain films very high
- Panatomic Areographic
- Regular developer 120-200 lp/mm = 1.25 um pixels
- Fine grain developer 400-500 lp/mm=0.5 um pixels
- Best films 1000-2000 lp/mm =0.25-0.12 um pixels

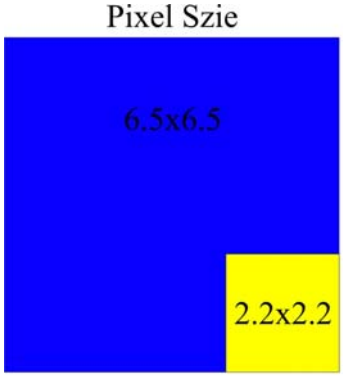




Sensor Size

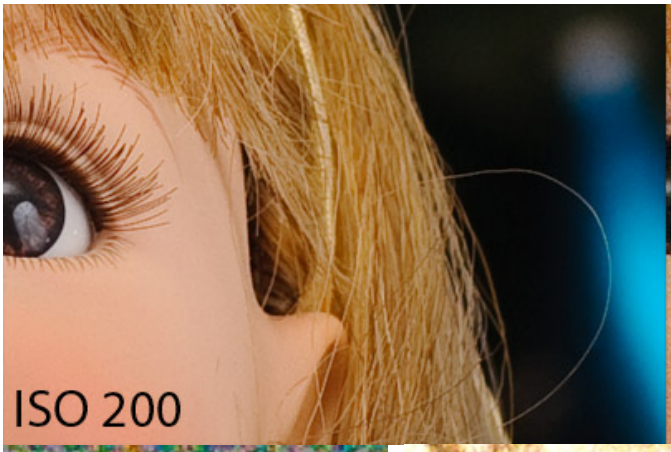
- Typical film 36x24 mm
- High end 57x57 and 100x127 mm but really no limit
- Some camera film 60x100 cm
- Digital point & shoot & cell phone about ~3-5 mm
- Semi pro 24x15 mm
- Full pro 36x24 mm (but ~$3K cost)
- Cost dropping – latest full frame is ~$2K
- Best Digital Hasselblad 40x54 mm (60 Mpix)
- Pixel Size: 5-7µm for high end, 2µm for lower price
- Smaller pixels have more noise lower sensitivity

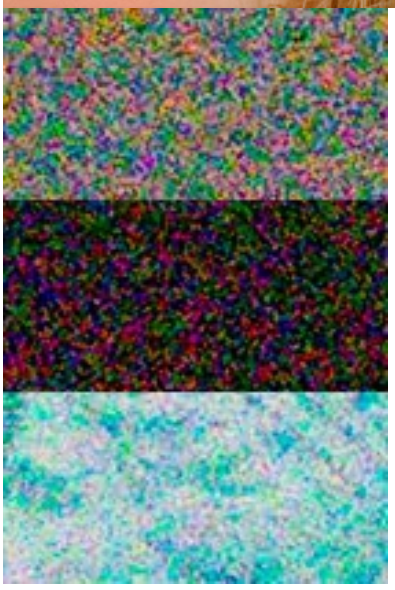




Film/Pixel Sensitivity

- Film or digital cameras measure sensitivity as ISO
- ISO=100 gives a picture in sunlight at ~F#16 and 1/60th sec
- Double ISO can cut exposure time in half or go up 1 F stop
- Film ranged from ISO 20 to ISO 1600: 100 was typical
- (1600 ISO is 4x more sensitive than 100 ISO)
- At high ISO films were very grainy
- Colour films much gainer than B&W
- DSLR's get 50-409,600 ISO these days
- But at highest ISO get digital noise
- Makes the pictures look grainy
- Gets colour (Chromenance) and signal (intensity level) shifts





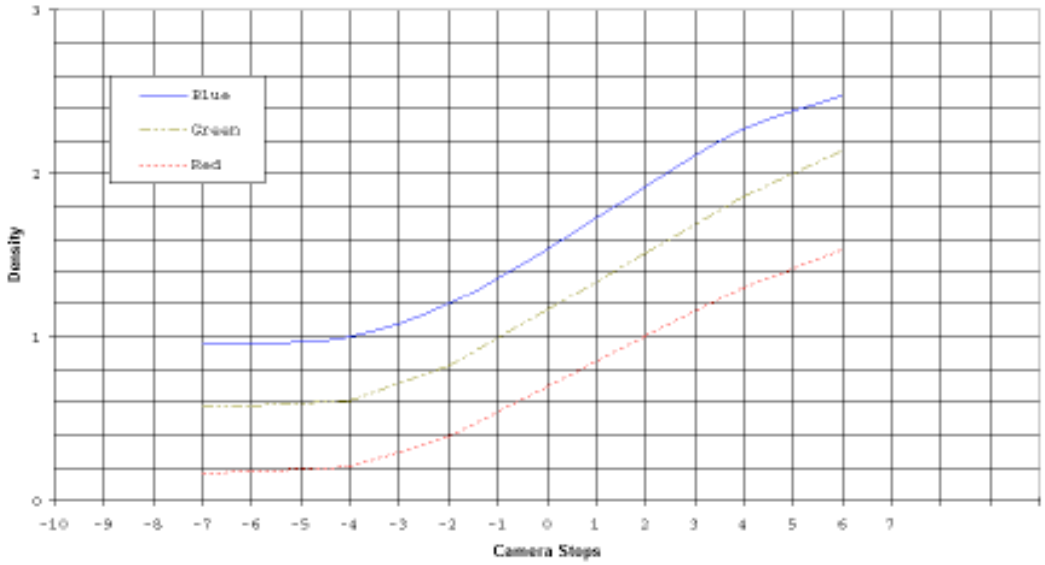
12,800 ISO

12,800 ISO

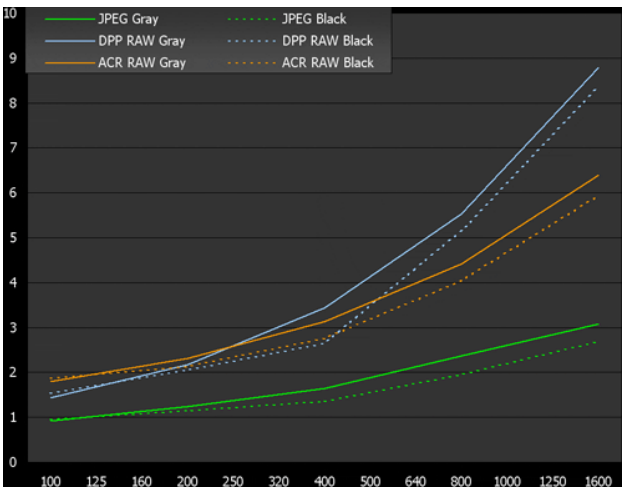
409,600 ISO

Dynamic Range

- Digital 8 bit (256 levels) is the standard
- High end Digital cameras do have 10-14 bit conversion
- But noise limit is about 8-10 bit at best ISO
- Film records a max dynamic range of 20,000:1 (~15 bit)
- Top and bottom saturation
- Comes from distribution of grains
- At most sensitive end film has some large grain halides
- This extends sensitivity at low exposure end
- Similarly distribution of small grains
- Hence extension of sensitivity at high exposure end
- Best film 3 layer XR from EGG 10^8:1 – better than the eye

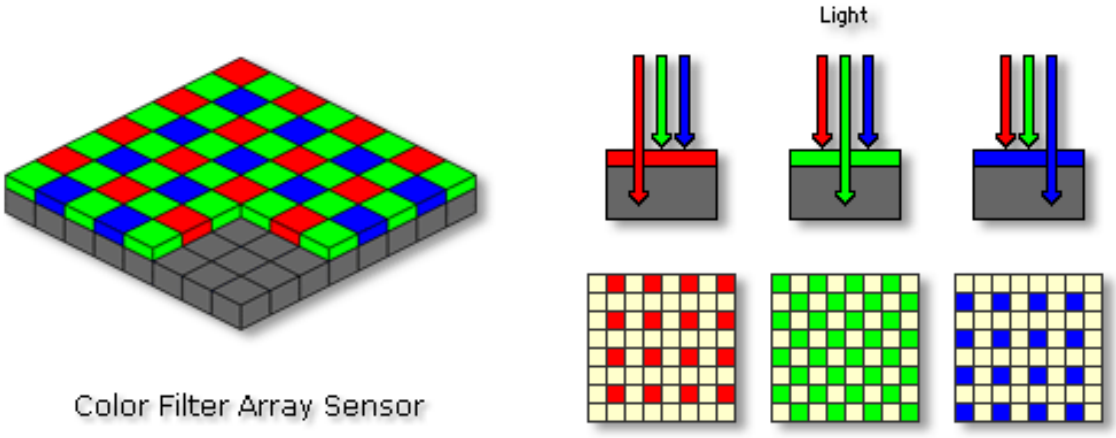


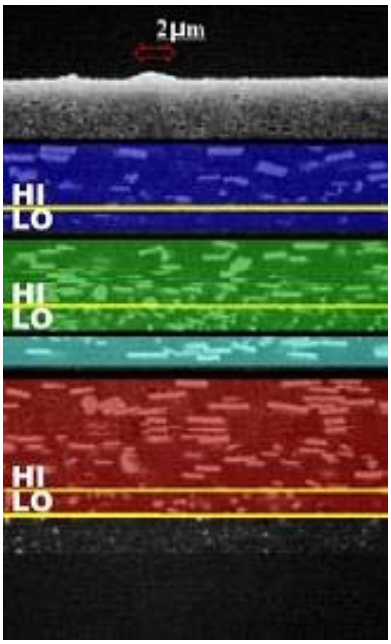
Notice: While the data presented are typical of production coatings, they do not represent standards which must be met by Eastman Kodak Company. Varying storage, exposure, and processing conditions will affect results. The company reserves the right to change and improve the product characteristics at any time.



Colour Limits

- Digital uses Bayer colour filter of Red, Green & Blue
- Algorithm interpolates colour between pixels called Demosaicing
- Eg for G pixel use neighboring R&B to estimate RGB values
- However if pattern changes rapidly produces colour error
- Film does all 3 colours at same spot- better colour resolution
- Also problem with colour balance: getting the whites correct
- In digital jpg colour balance calculated in camera but frozen in
- But may freeze in wrong balance and only 8 bits of colour
- Shoot Digital Raw (pure sensor data)
- Can do balance after for the light scene





Colour balance error

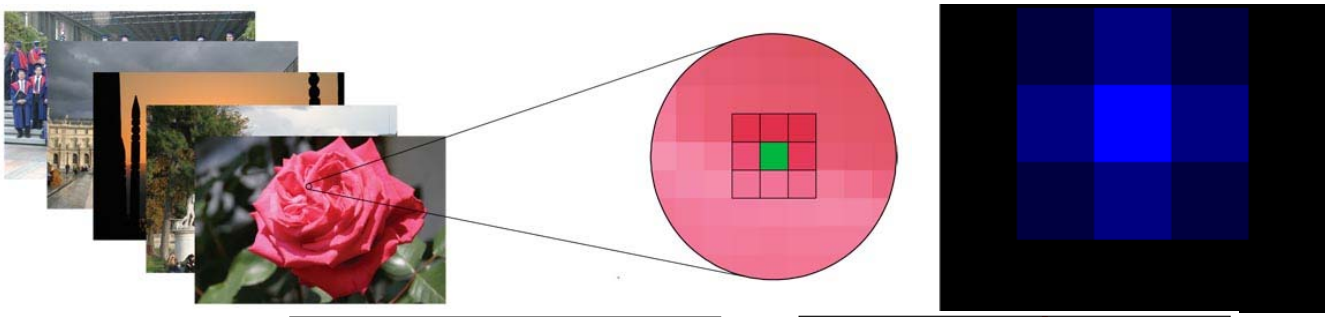
High Dynamic Range Photos

- Take several pictures: 3 spaced at -2, 0, +2 f stops
- Extends Dynamic range to about 1000
- Called High Dynamic Range or HDR
- Possible now automatically in photoshop CC
- Problem: pictures are typically 0.3 sec or more apart
- OK for still images, bad for scenes with movement
- Also HDR tone maps scene onto 8 bit (256 level) display
- Substitutes overexposed and underexposed areas to get best
- Tone map and alignment of images creates artifacts
- Wide Dynamic Range pixels that do this being researched

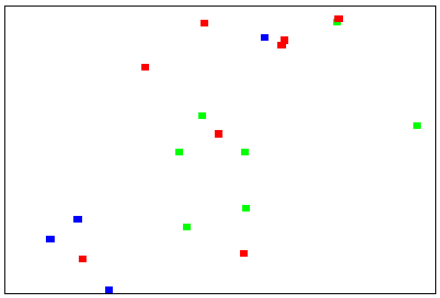
Tone map artificcts – halos and gosting

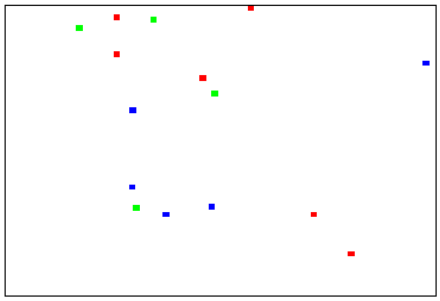
Defects and Film or Digital Imagers

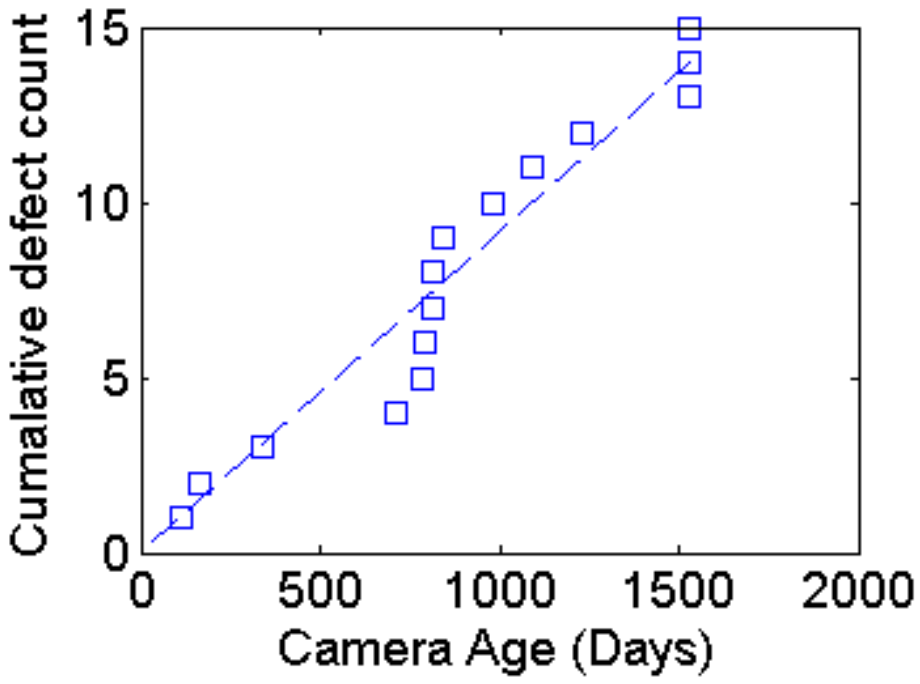
- Film is constantly changed: only slow deteriorates with time
- One frame or roll may have defect but others will not
- Defects accumulate in digital camera
- Demosaicing spreads defects from pixel point to nearby pixels
- Grow at about 3.5-6 defects per year in DSLR cameras (low ISO)
- CCD grow ~2x faster than CMOS
- Defects are randomly distributed spatially in sensor
- Probably cause – cosmic rays which damage photodiodes



Camera Fault Locations

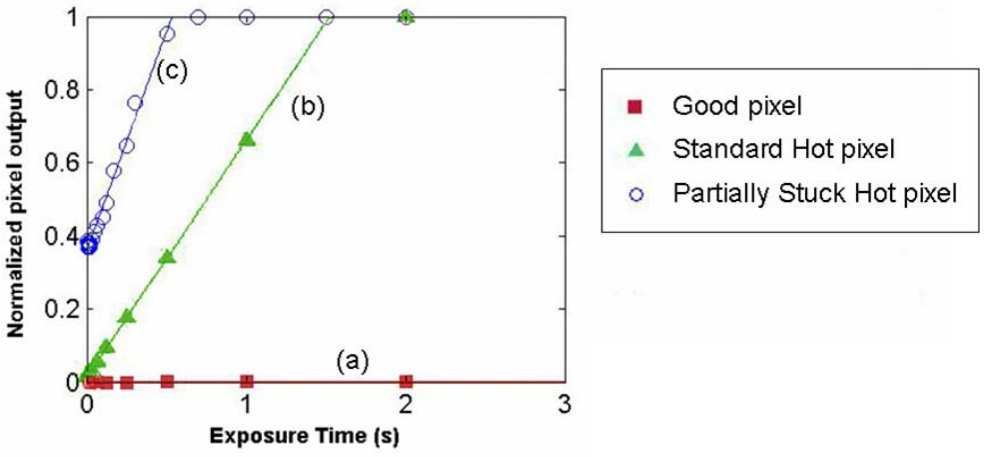




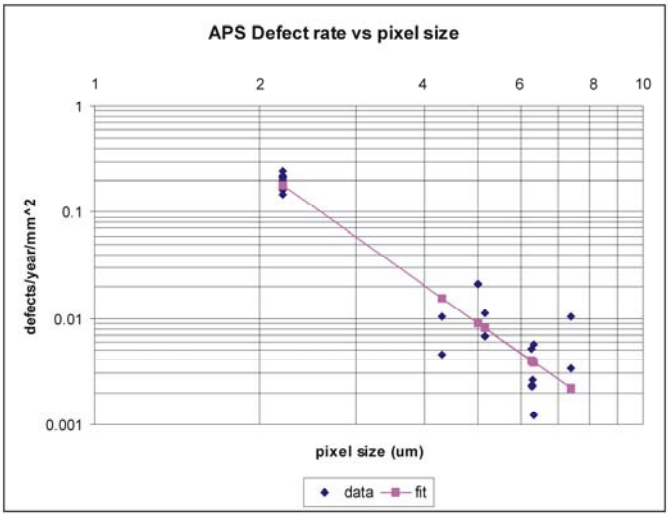


Defects in Digital Imagers: Hot Pixels

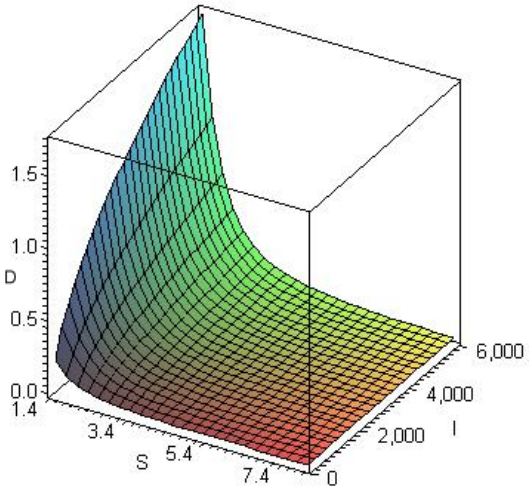
- Measurement of defect development in cameras at SFU
- 21 cameras developed significant faults after few years
- 3 – 26 faults per camera - All hot pixels - no stuck pixels
- Hot pixel – signal increase with time even when no exposure (b)
- 70% show an offset signal independent of exp. Time (c)
- Found partially-stuck hot pixels – have an offset
- Smaller pixels more defects – 2μm pixels 30x defects of 7μm
- Found defect rate increase with pixel size as $1/S^{3.5}$
- Defects increase with sensitivity as $ISO^{0.6}$
- Find defect rates per mm^2 scales with pixelsize $S^{-3.2}$
- Thus defects grow rapidly as pixel size shrinks very high at 2 um
- With 1um pixels DSLR's 17,000 defects/year at highest ISO



Hot Pixels



APS Defect rate/year/mm^2 vs pixel size



APS Defects rate/year/mm^2 vs pixel size and ISO