Historical development of CR/DR and new detector technologies

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J. Anthony Seibert, Ph.D.
Professor of Radiology
University of California Davis Health System
Sacramento, California USA

UCDAVIS
University of California, Davis

Learning Objectives

- Explain technology of available and future digital radiography technology
- Understand underlying system operation and characteristics
- Compare CR – DR - Novel image acquisition advantages and disadvantages

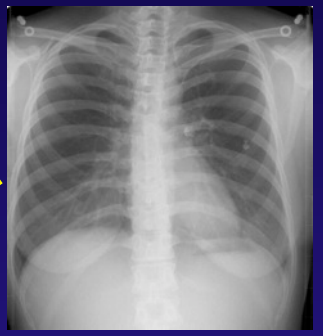
DIGITAL IMAGING IN RADIOLOGY

- *Digital* imaging is an *essential* component of Electronic Imaging, Telemedicine and Remote Diagnosis

- Steps for digital imaging
  - Acquisition
  - Display
  - Diagnosis
  - Distribution
  - Archive

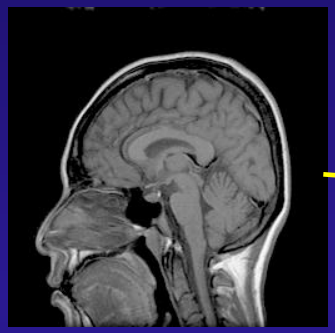
The “Big” Picture

- “Digital” Radiology



Digital Radiography

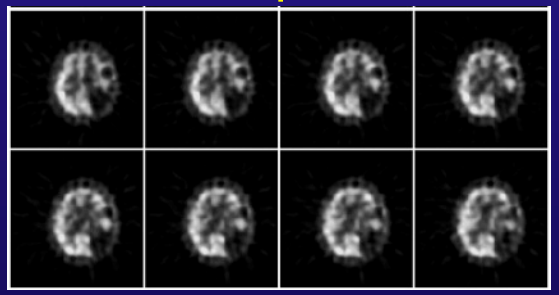
PACS



MRI

Interventional Angio

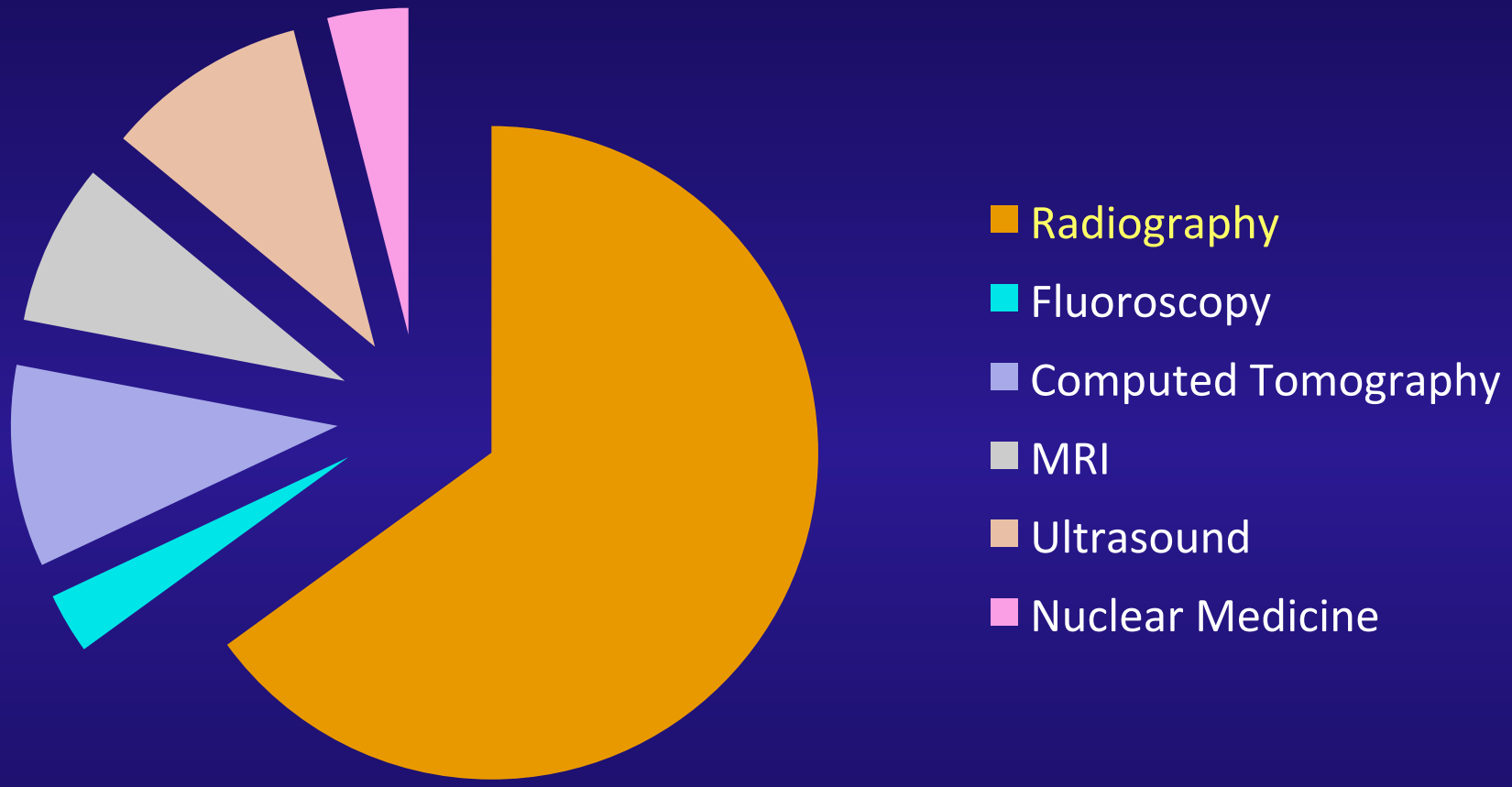
CT



Nuclear Medicine

Ultrasound

Imaging Volume



Projection imaging: 60% - 70% of medical imaging

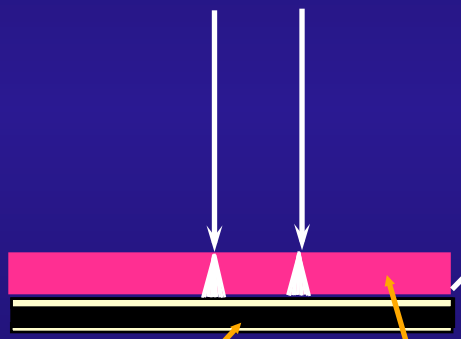
But First…… CR & DR

- An intrinsic part of the PACS
- Historically, the last electronically integrated
- Lots of changes in the past decade…..

Digital x-ray detector

1. Acquisition

Transmitted x-rays through patient

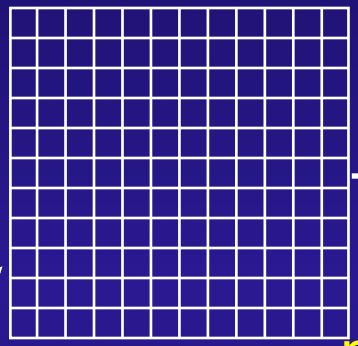


Charge collection device

X-ray converter
x-rays → electrons

Analog to Digital Conversion

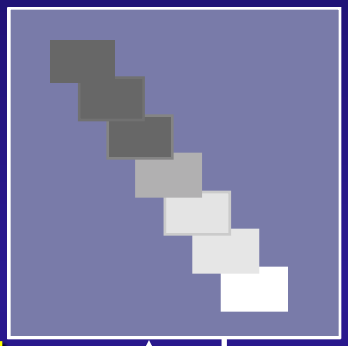
Digital Pixel Matrix



Digital processing

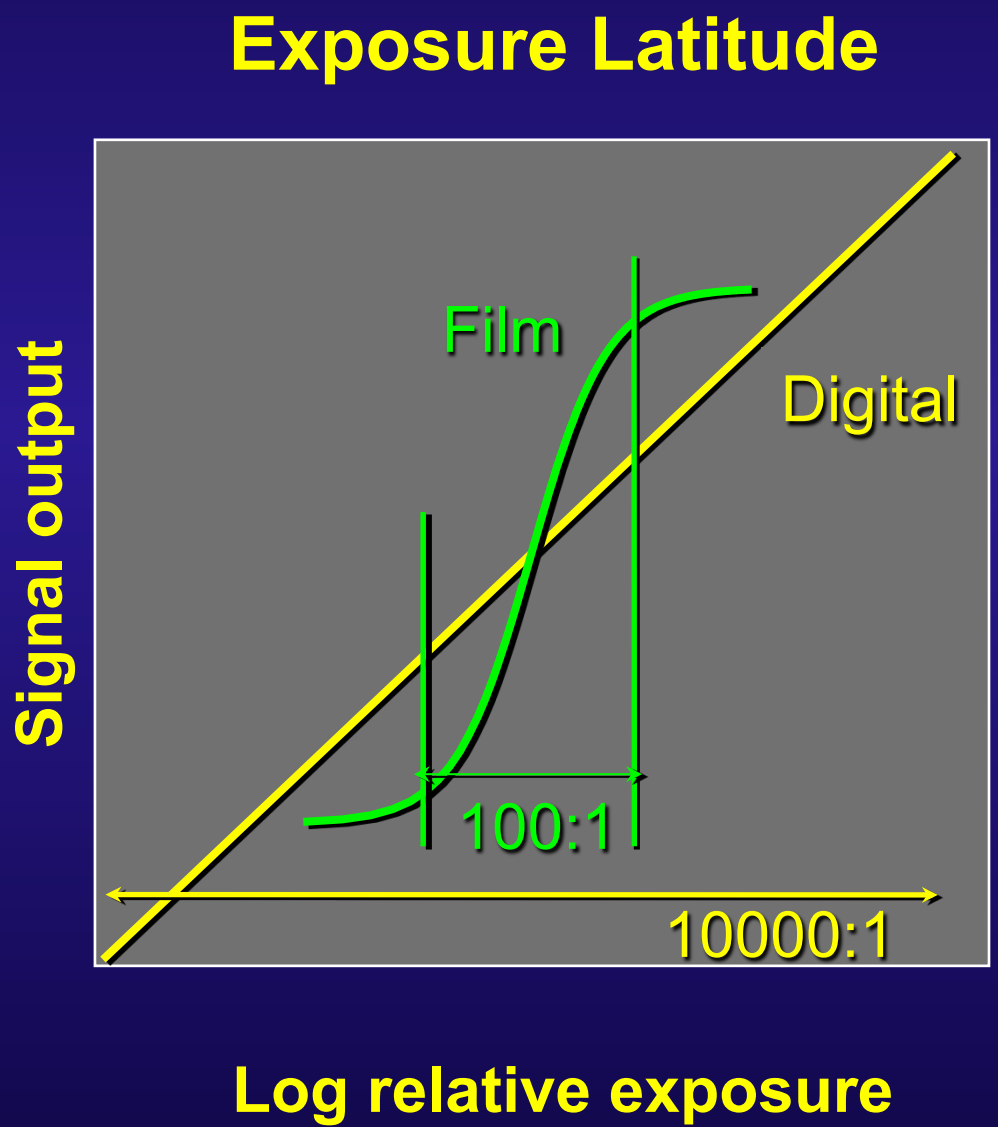
2. Display

Digital to Analog Conversion



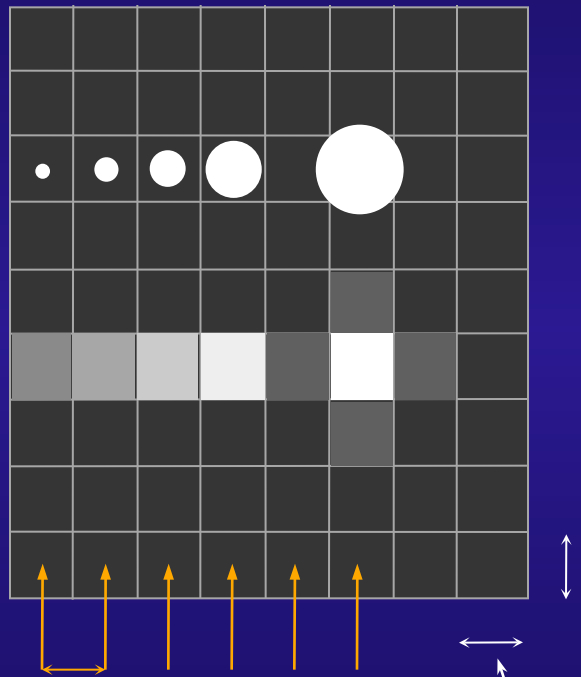
3. Archiving

Analog versus Digital



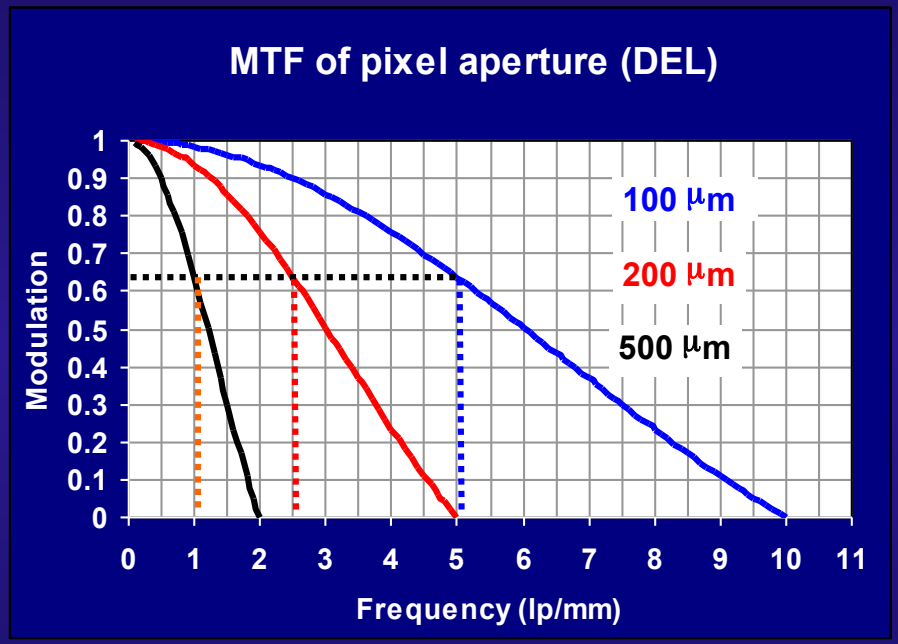
Digital sampling

Spatial Resolution



Sampling Pitch

Detector Element, "DEL"



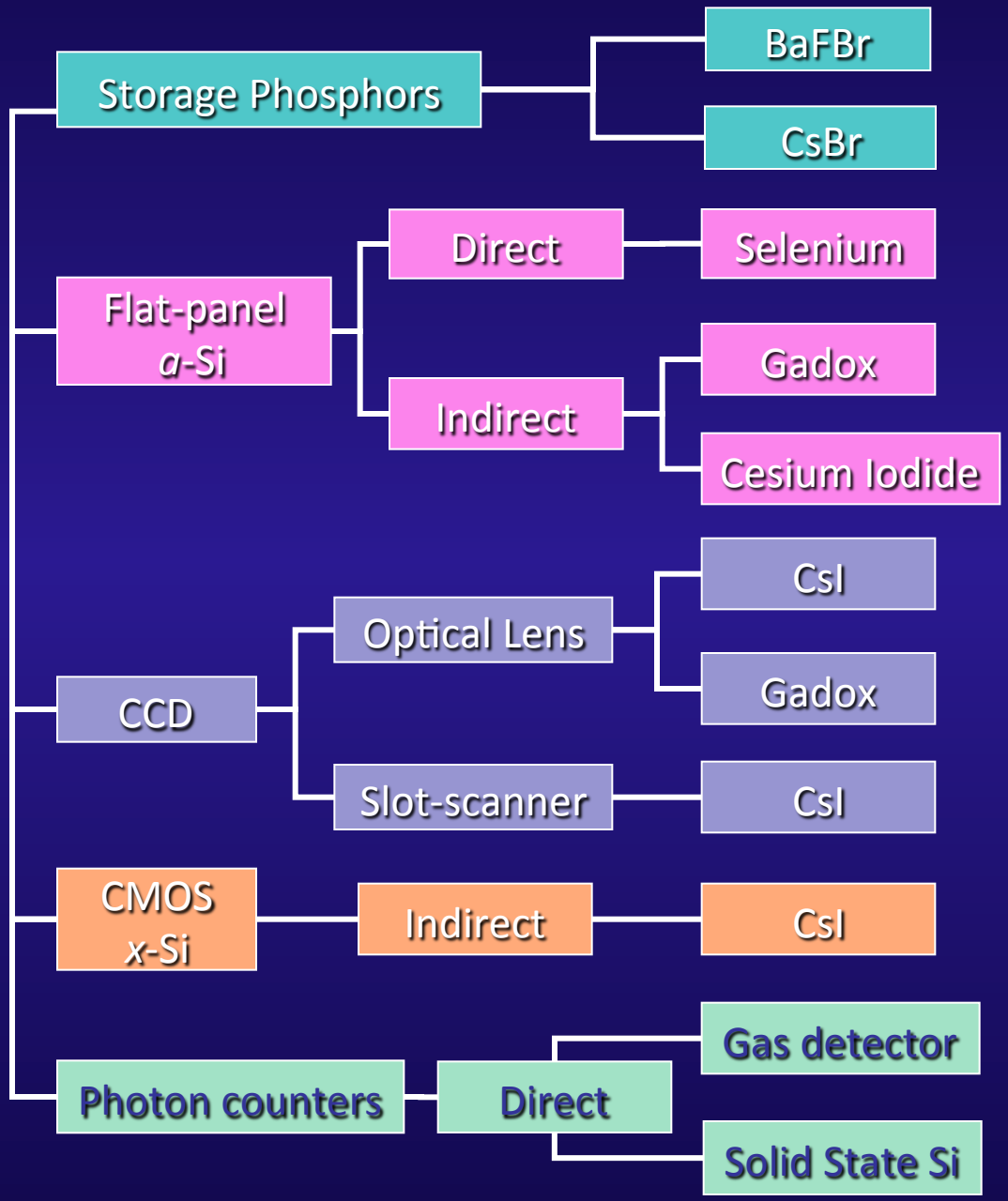
Fourier transform of Rect (Dx) = sinc(Dx)

Cutoff frequency $f_C = (Dx)^{-1}$

With sampling pitch = sampling aperture, Dx

Nyquist Frequency $f_N = (2\ Dx)^{-1}$

Digital Radiography 2013: detectors and manufacturers



Fuji, Agfa, Kodak, Konica….

Hologic, Toshiba, Shimadzu…

Canon, Carestream

GE, Trixell, (Philips, Siemens..)
Varian, others….

Imaging Dynamics, Imix,
Swissray, Wuestec

Delft Dx Imaging, LoDox

Bioptics, Dexela

X-Counter

Sectra, Philips

Digital Radiography common themes

- Separation of Acquisition, Display, and Archive
- Wide dynamic range
  - ~0.01 to 100 mR (~0.1 to 1000 mGy) incident exposure
- Variable detector exposure operation
  - 20 to 2000 “speed class”
- Appropriate SNR & image processing are *crucial* for image optimization

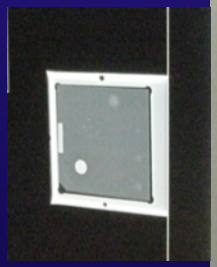
Categorization of digital radiography detectors

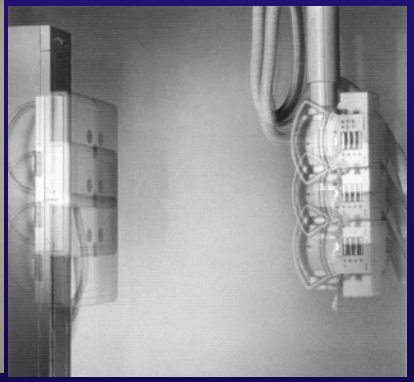
- Detector form factor
  - Cassette versus cassette-less

Line-scan PSP detector system

Slot-scan CXR system

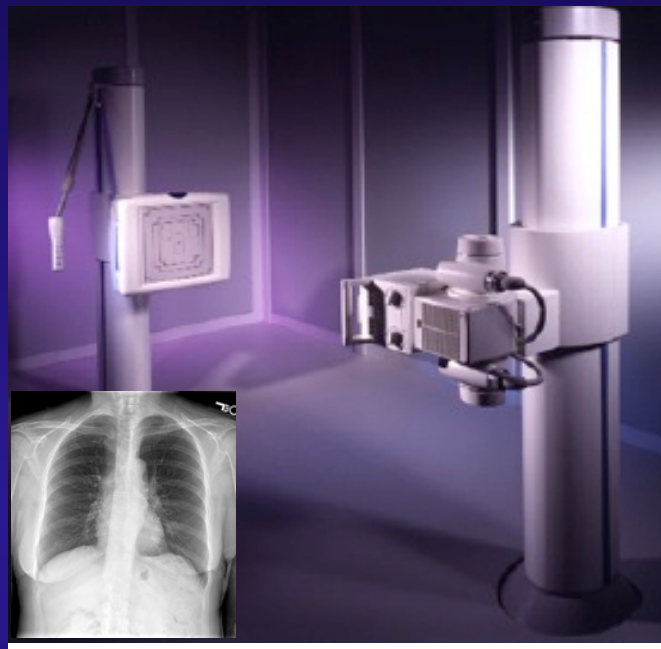
  - Passive versus active x-ray detection





Categorization of digital radiography detectors

- Image acquisition geometry
  - Large FOV (milliseconds)
    - Reduced patient motion
    - Real-time operation possibilities
    - Anti-scatter grid necessary
  - Slot-scan (seconds)
    - Reduced scatter
    - Lower patient dose
    - Possible motion problems



Available digital radiography technology 2013

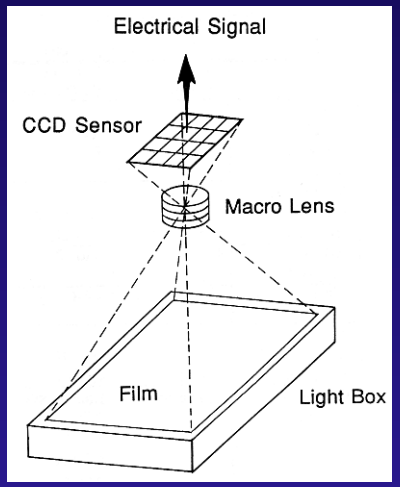
- CR: Photostimulable Storage Phosphor (PSP)
  - Cassette-based detectors/readers
  - Flying spot mechanical changers
  - Line scan integrated detectors
- CCD: Charge-Coupled Device
  - 2-D lens coupled systems
  - 1-D slot-scan systems
- Thin-Film-Transistor (TFT) flat panel
  - Indirect detection (scintillator)
  - Direct detection (semi-conductor)
  - Portable wireless implementations
- Photon Counting slot-scan systems

“In-progress” technologies

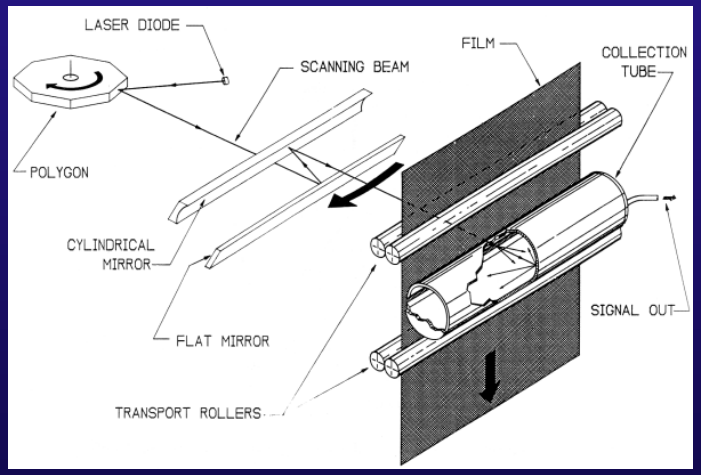
- X-ray energy sensitive counters: gas or silicon strip detectors
- Complementary Metal Oxide Semiconductor (CMOS)
- Hybrid direct / indirect flat panel TFT with variable gain
- X-ray “light valve” Liquid Crystal / scanner detector system

Starting point: Analog film digitization

- Video of trans-illuminated radiographs
  - "Camera on a stick"
  - Low cost, low quality



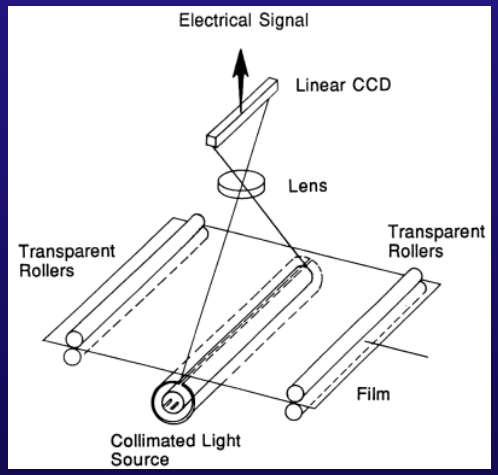
- Film digitizers
  - LASER
    - Better quality
    - Not reliable



CCD Array

Limited dynamic range

Very reliable

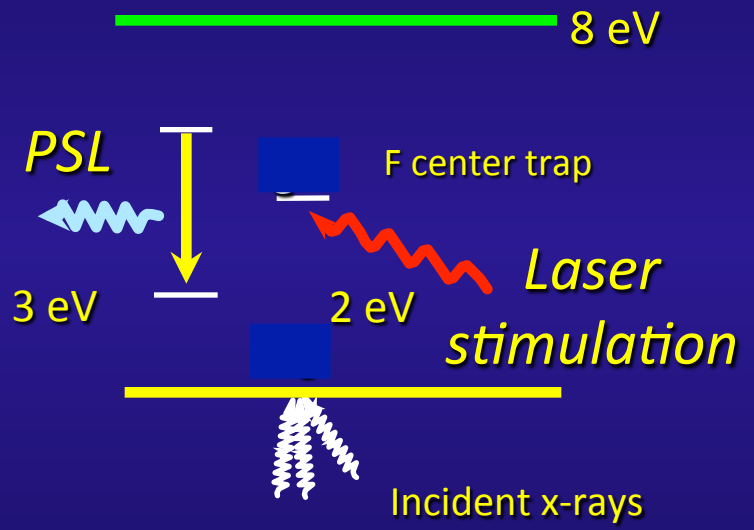


Computed Radiography (CR)

- *The* first clinically useful technology available for large field-of-view digital imaging
- Based upon the principles of photostimulated luminescence; 30+ years of experience
- Operation emulates the screen-film paradigm in use and handling.. (flexible, but labor intensive)
- Manufacturing trends:
  - Smaller, faster, less expensive

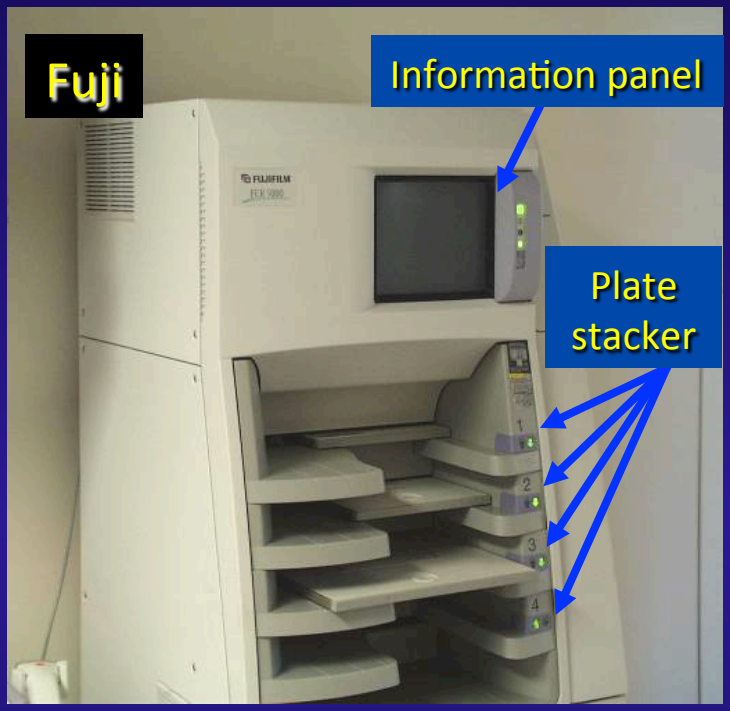
PSP Detector

- Photostimulable Storage Phosphor (PSP)

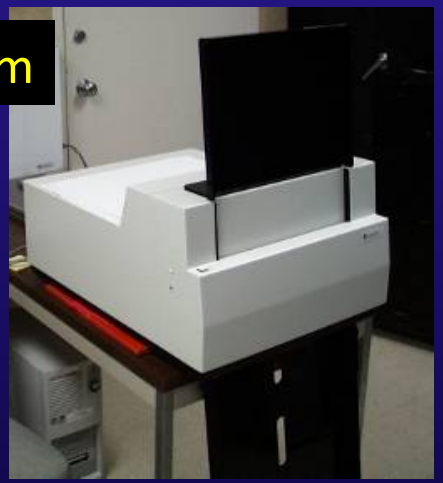


  - Coating thickness:
    - Standard resolution: ~100 mm BaFBr
    - High resolution: ~50-70 mm BaFBr
  - Enhancements: Dual-side read; structured phosphor – CsBr

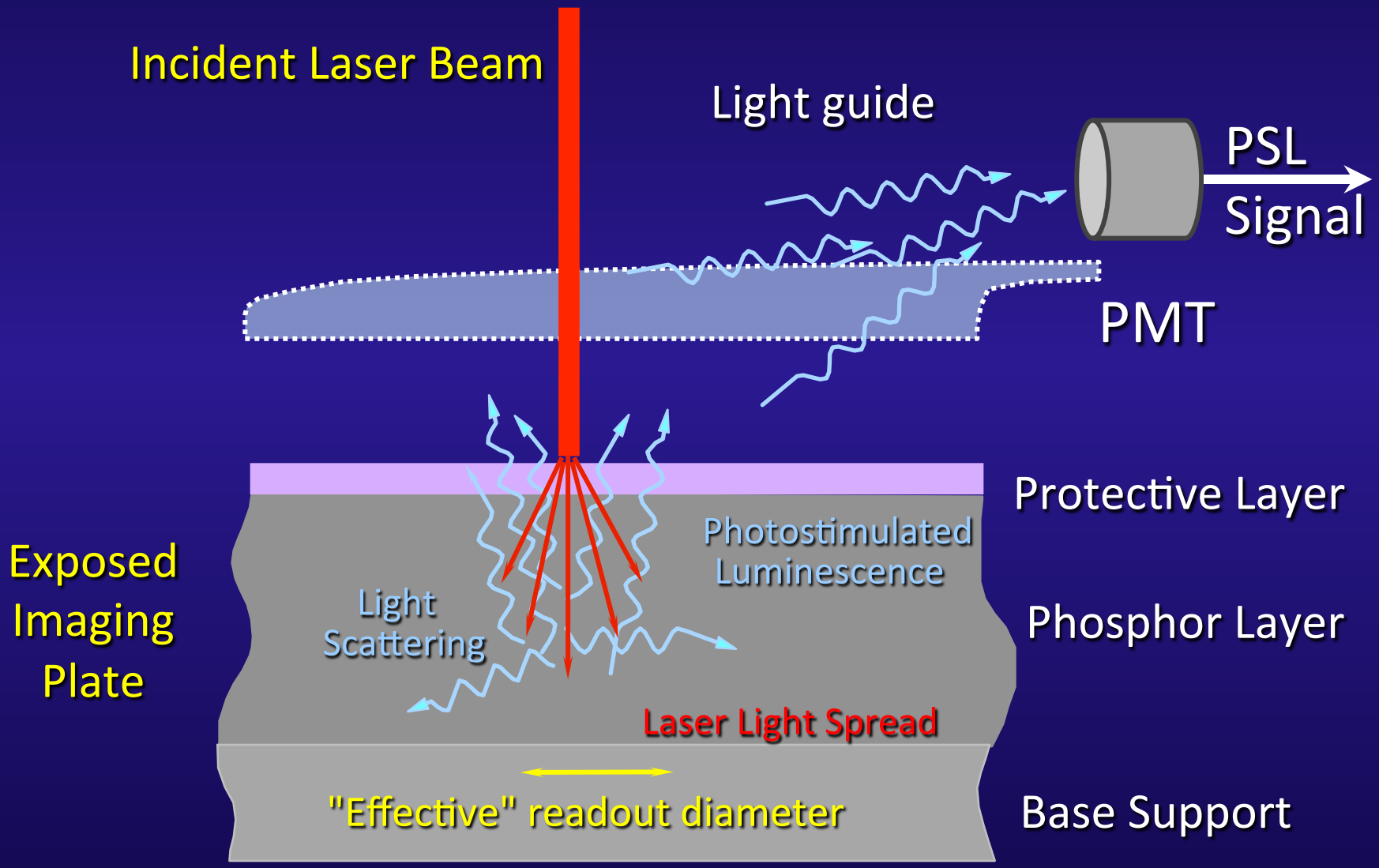
Computed Radiography "reader"



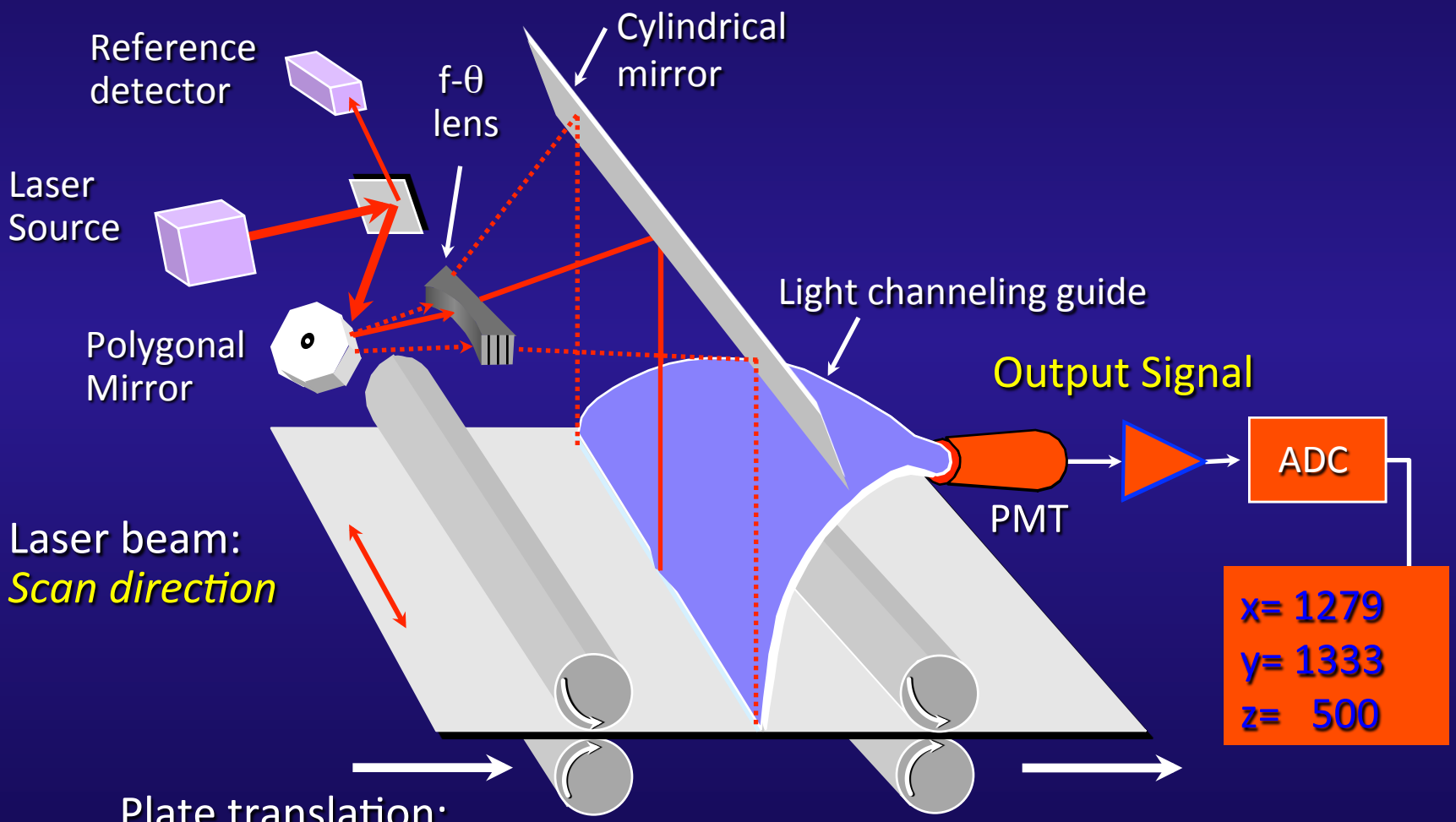
Various capabilities, sizes, throughput

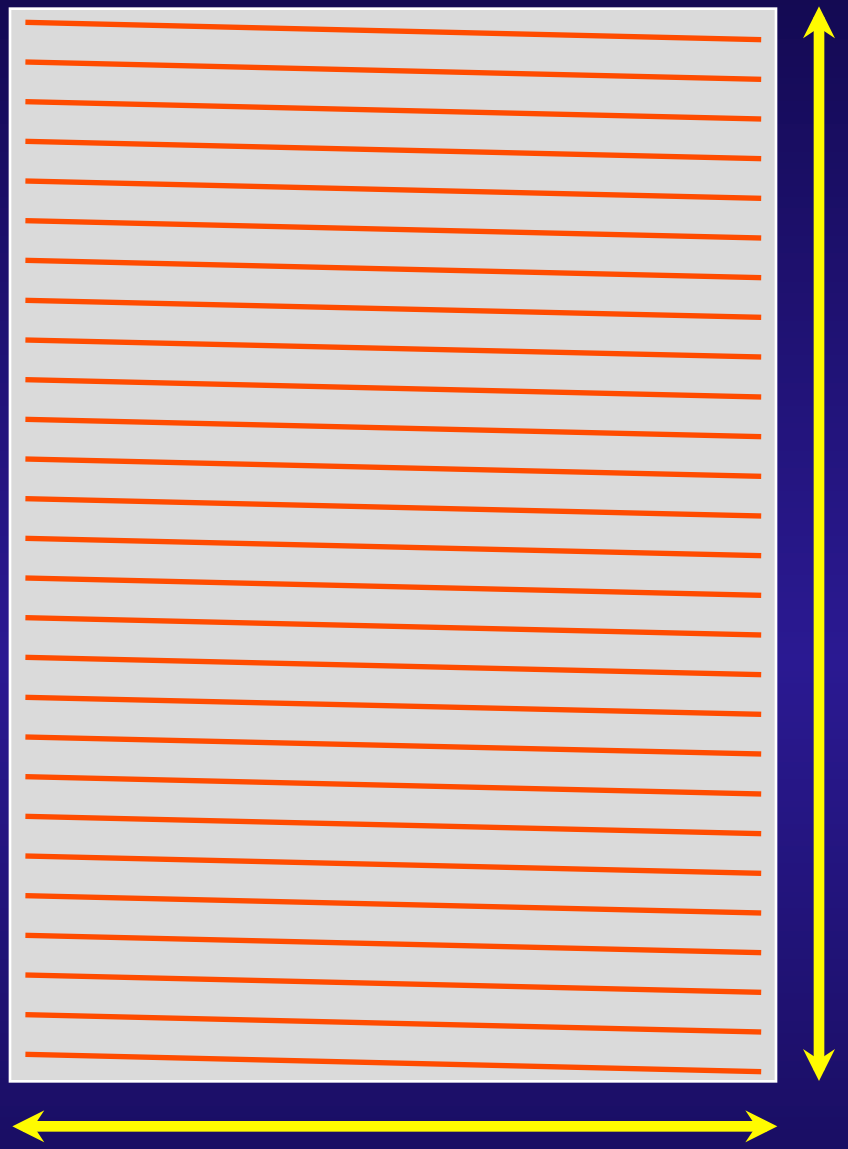


Photostimulated Luminescence



CR Point-scan readout





Scan Direction
Laser beam deflection

Sub-scan Direction
Plate translation

Typical CR resolution:
35 x 43 cm -- 2.5 lp/mm (200 μm)
24 x 30 cm -- 3.3 lp/mm (150 μm)
18 x 24 cm -- 5.0 lp/mm (100 μm)

Screen/film resolution:
7-10 lp/mm (80 μm - 25 μm)

Phosphor Plate Cycle

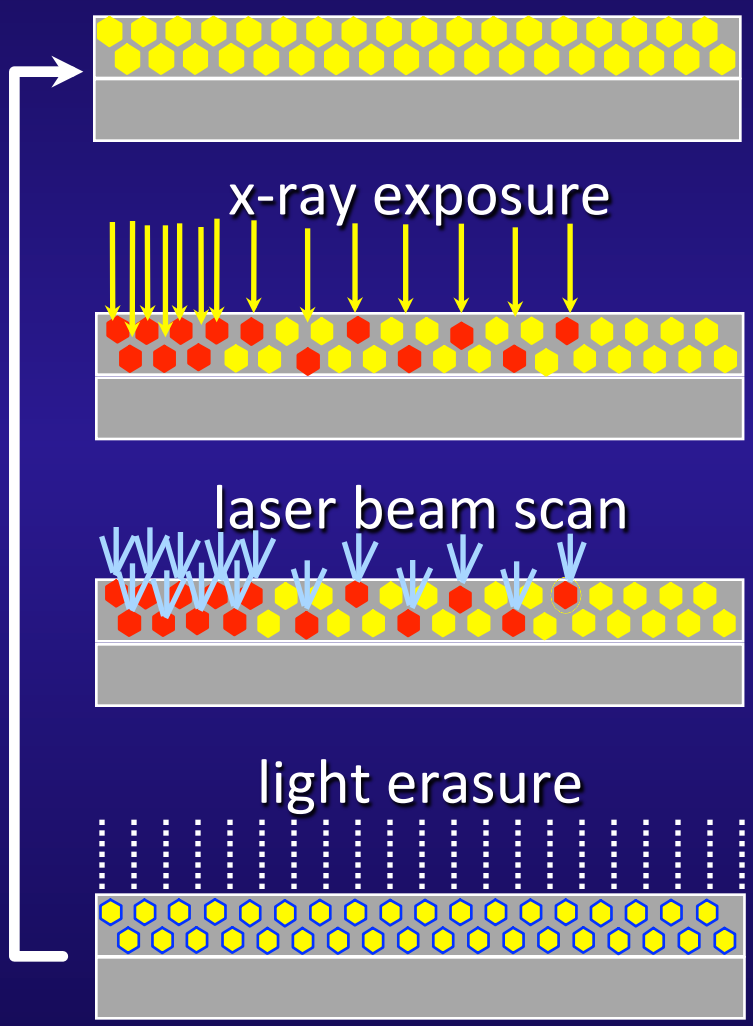
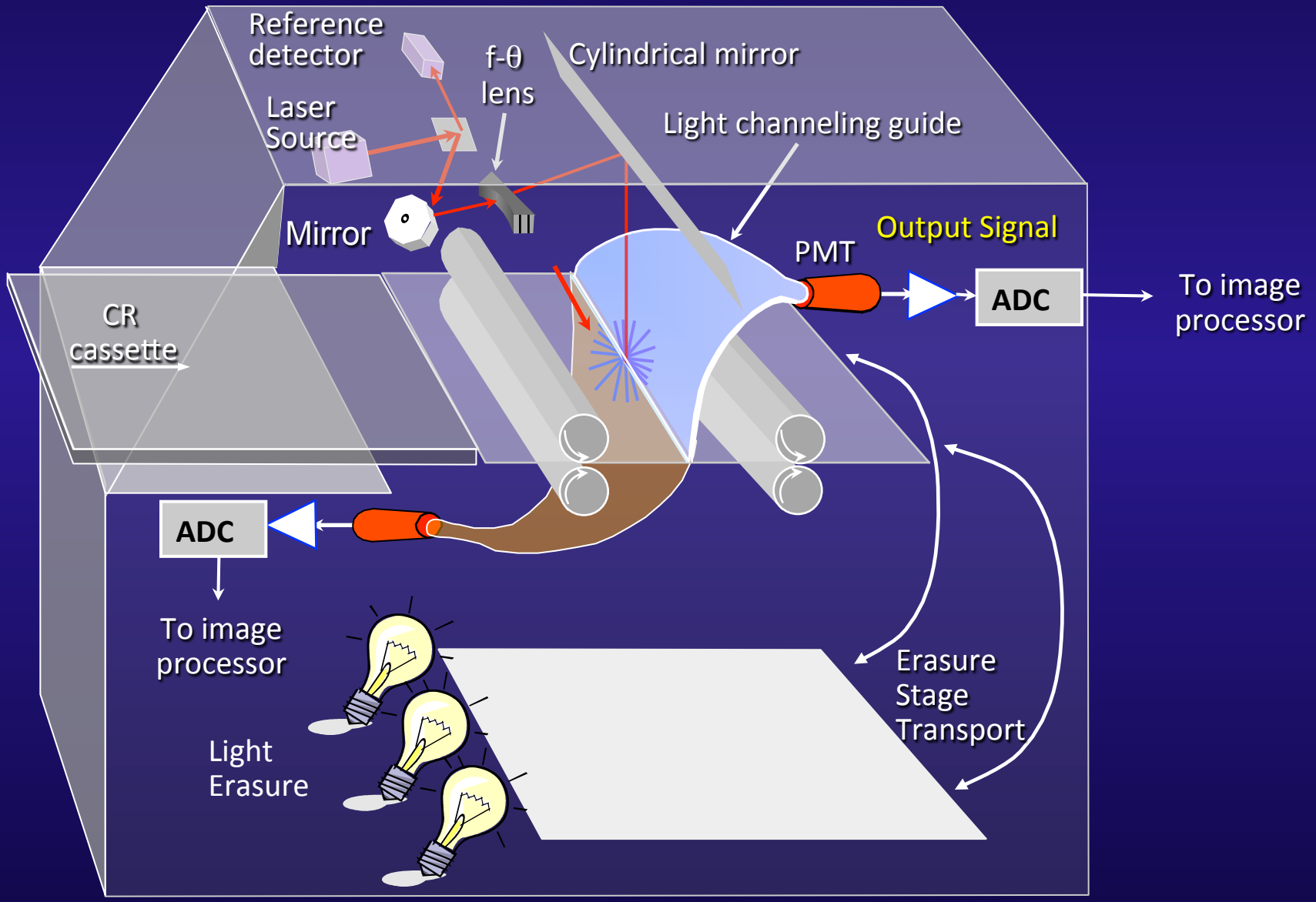


plate exposure:
create latent image

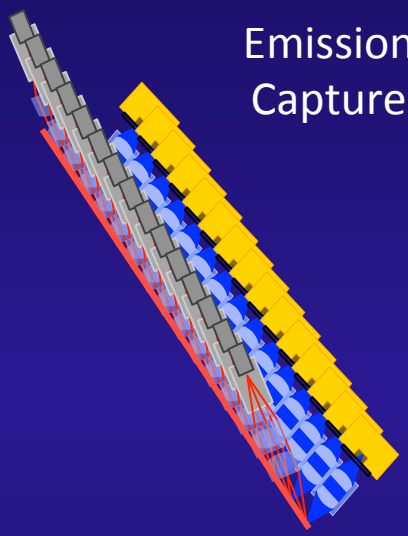
plate readout:
extract latent image

plate erasure:
remove residual signal

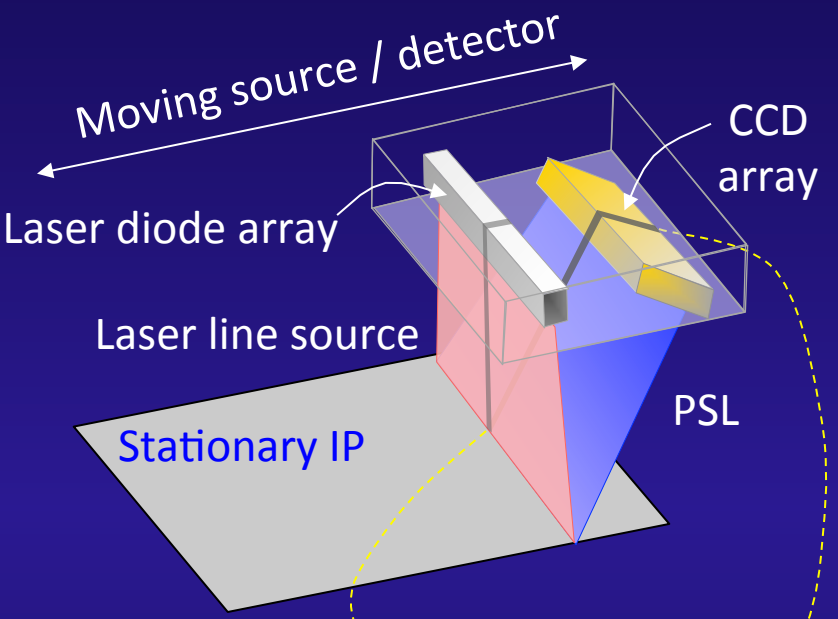
Dual-side CR readout with transparent substrate



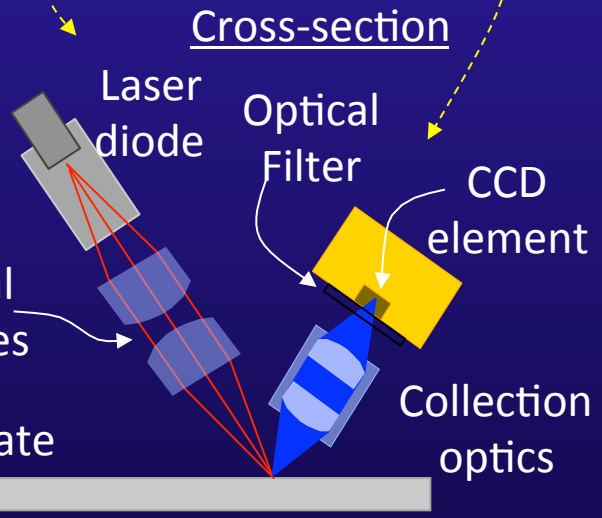
Parallel excitation *line-scan* PSP readout



Linear array:
Excitation
Emission
Capture



5 sec scan



“Direct” Radiography (DR)

....refers to the acquisition and capture of the x-ray image *without user intervention* (automatic electronic processing and display)

– “Indirect” detector: a conversion of x-rays into light by a scintillator, *and* light into electrons for signal capture

– “Direct” detector: a conversion of x-rays to electron-hole pairs with direct signal capture

X-ray scintillator conversion
(Gd_2O_2S, CsI compounds)

Unstructured (turbid) phosphor

Thick Screen:

- Good Absorption
- Poor Resolution

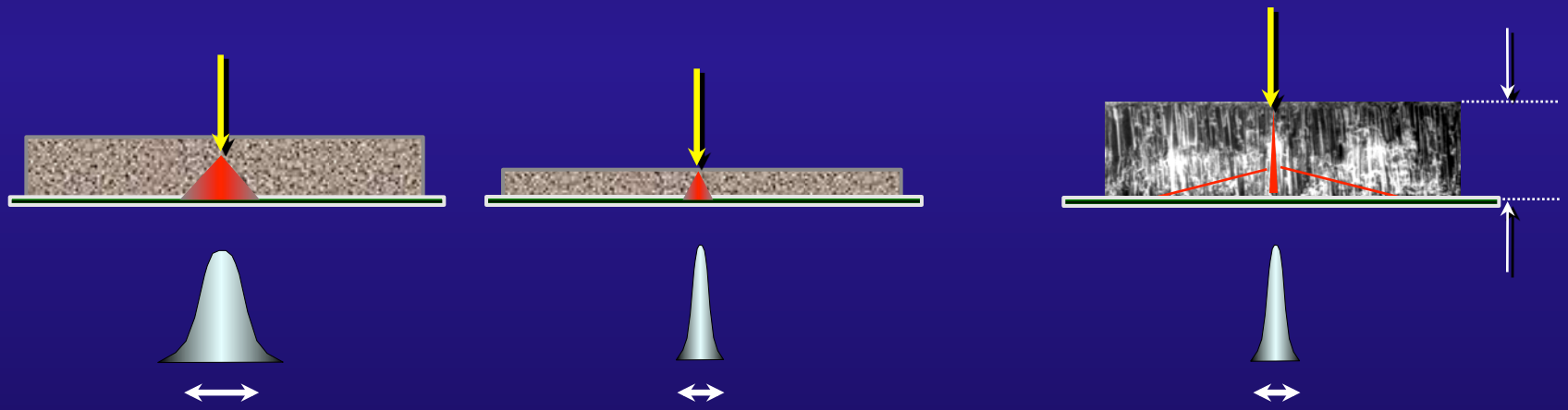
Thin Screen:

- Poor Absorption
- Good Resolution

Structured phosphor

Thick Screen:

- Good Absorption
- Good Resolution

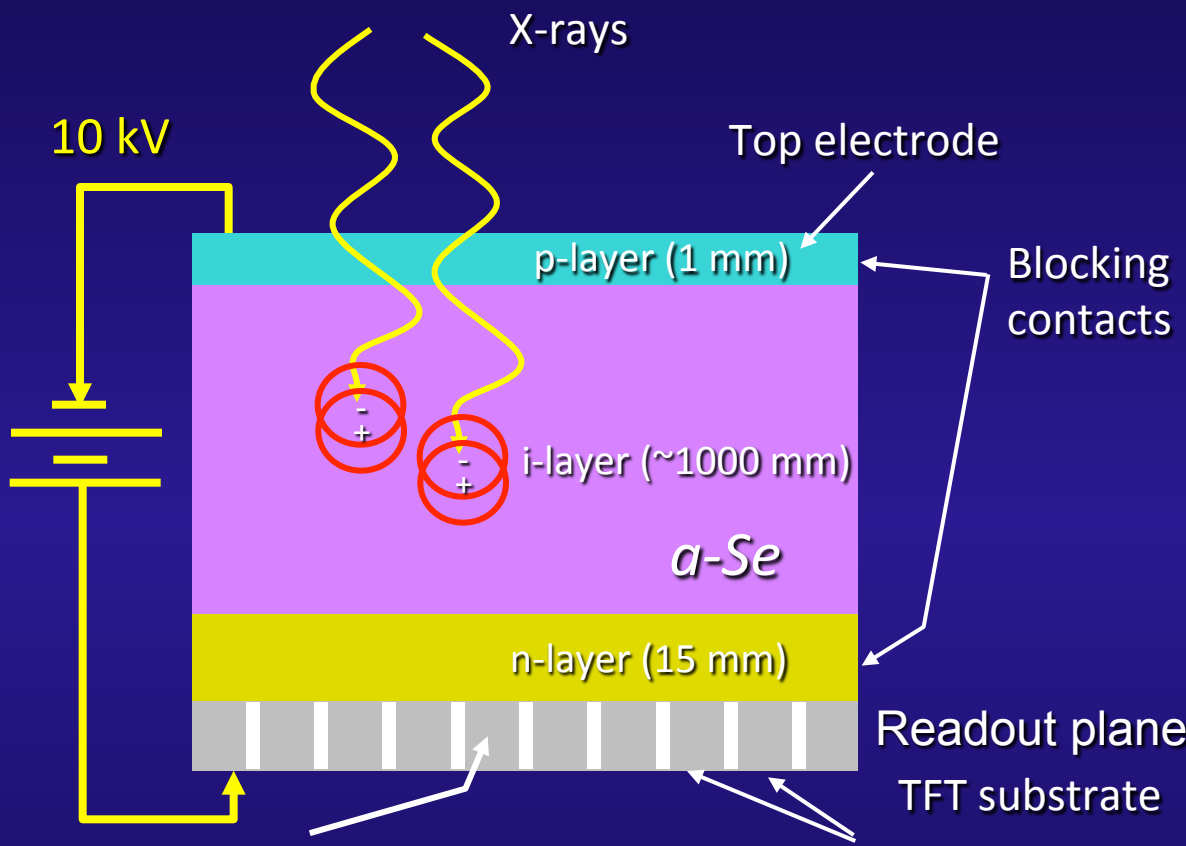


LSF

Resolution limit

Light Pipe
(Optical Fiber)

Direct *semi-conductor* conversion



FUTURE:

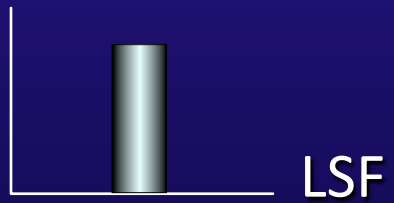
PbI_2

PbO

HgI_2

CdZnTe

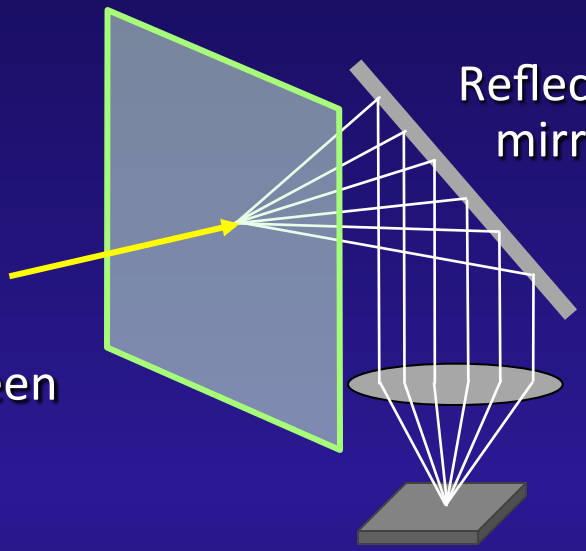
Little or no horizontal spread of signal



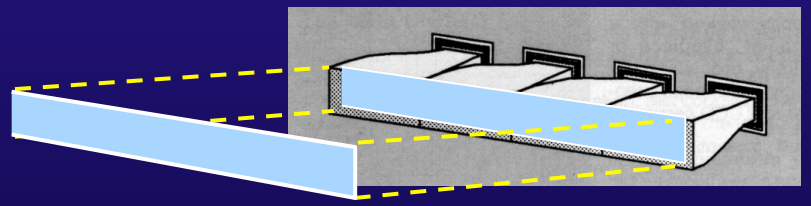
Spread is ~ independent of detector thickness

CCD-based DR systems

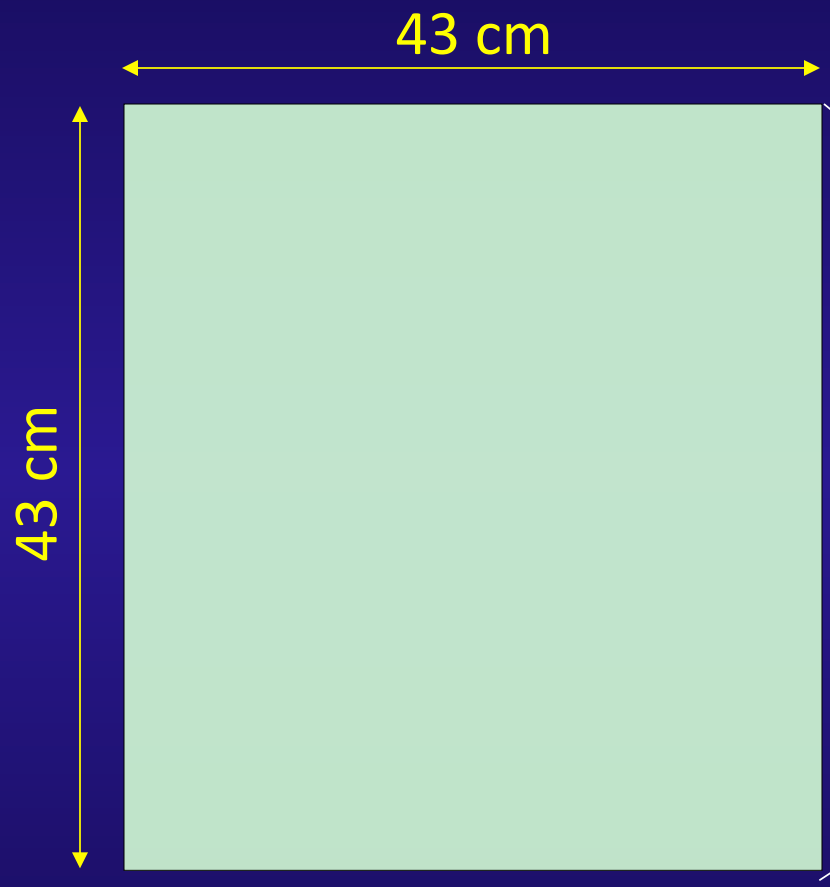
- Area Scintillator / lens coupling



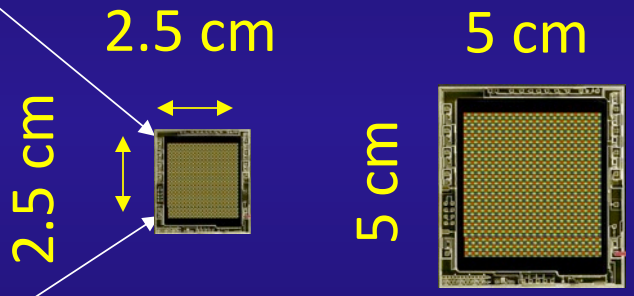
- Slot scintillator / fiberoptical coupling



CCD area detector

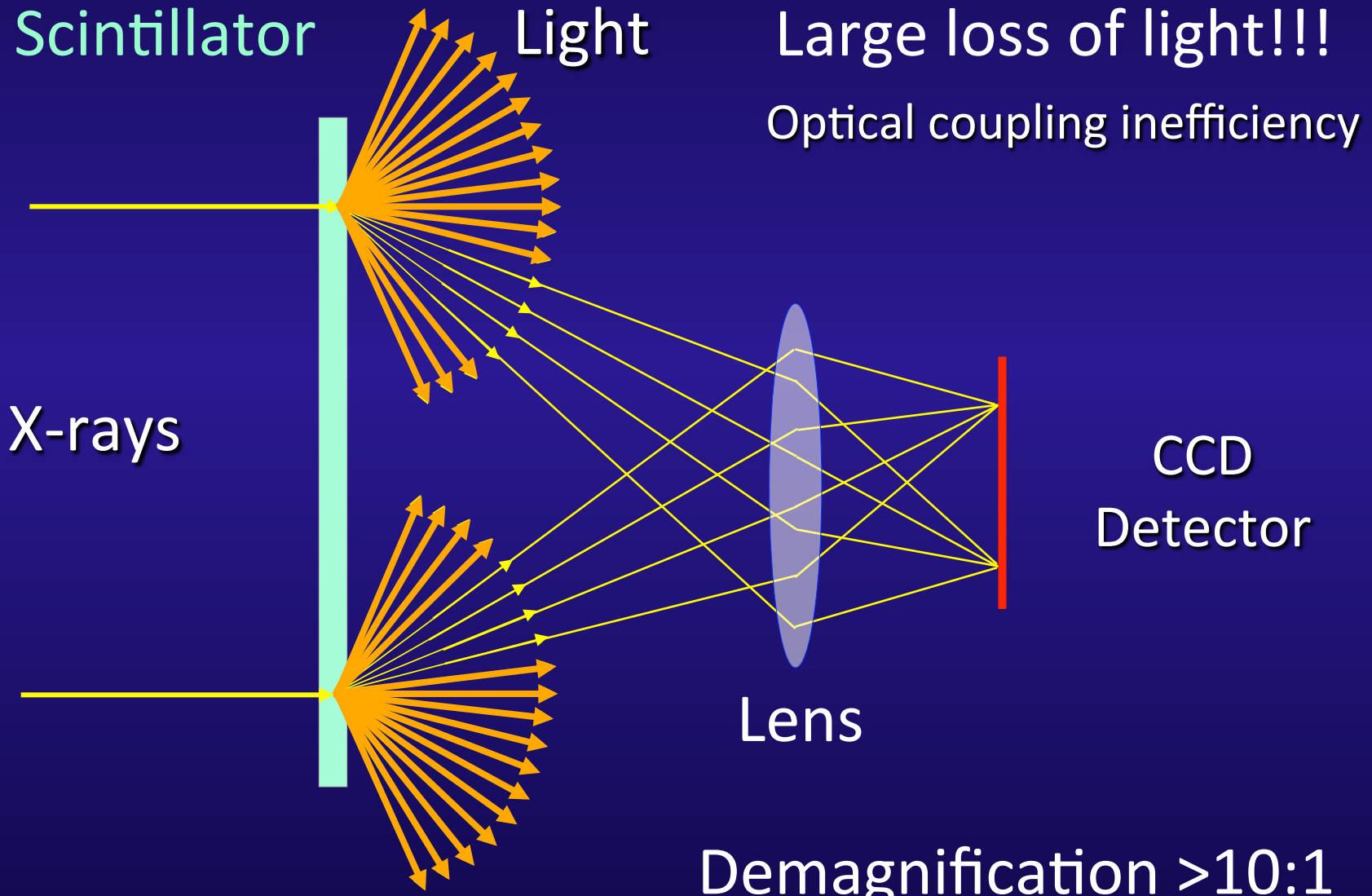


High fill factor ~ 100 %
Good *light conversion* efficiency (~85%)



4 to 16 megapixels
Optical de-magnification
Lens efficiency?
Secondary Quantum Sink

Light emission & Optical coupling



Optically coupled CCD systems

- Technology improvements have overcome quantum sink issues (lens / CsI phosphor)
- Relatively low cost (for integrated DR unit)
- Capable, OK image quality, higher dose

CCD slot-scan imaging

- “One dimensional” scanning acquisition
- Efficient scatter rejection
- Best dose efficiency
- Time-Delay-Integrate (TDI mode)
- “Effective DQE” in absence of scatter is comparable to CsI area detectors

Slot Scan CCD systems

No grid; Reduced scatter; Low dose

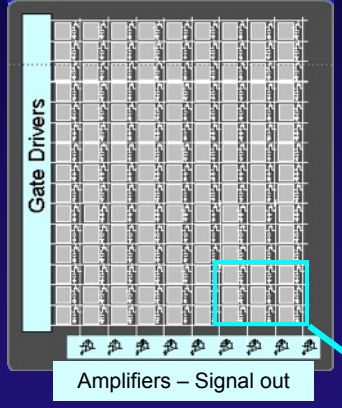
???

- Exposure time
- Patient motion
- Tube loading
- DQE

Flat Panel Detector:

TFT *active matrix* array

(Amorphous Silicon)



Gate switches

G1

G2

Active Area

Dead Zone

Thin-Film Transistor

Storage Capacitor

Fill Factor = Active area ÷ (Active area + Dead Zone)

Large pixels: ~ 70% 120 – 200 mm

Small pixels: ~ 30 % 70 - 100 mm

Charge Collector Electrode

D1 D2 D3

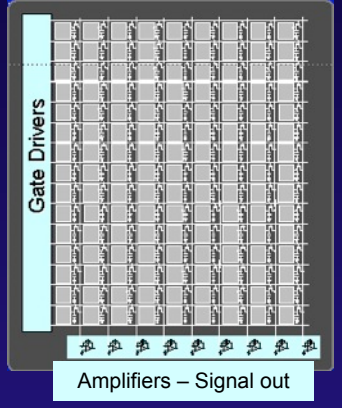
CR1 CR2 CR3

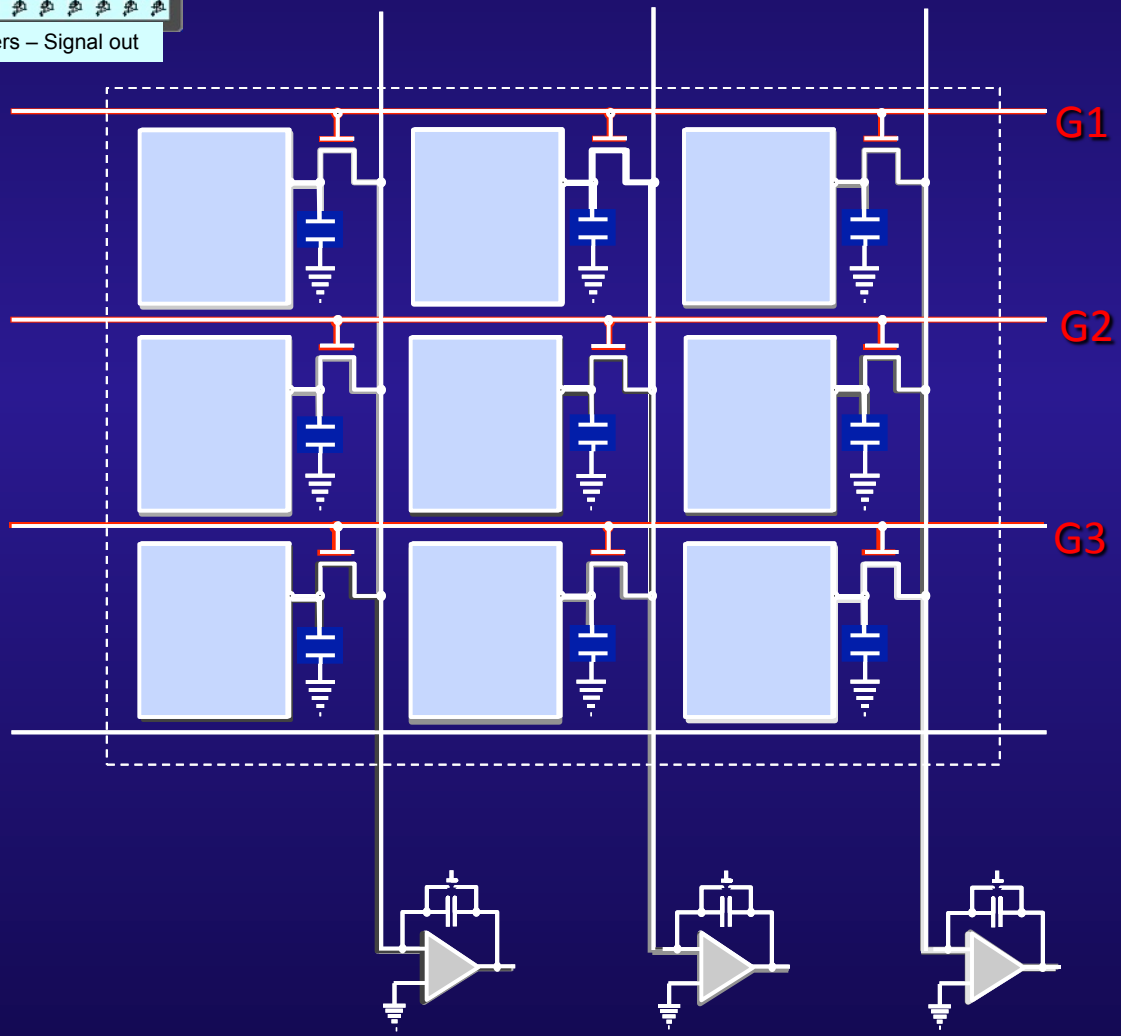
Data lines

Charge Amplifiers → Analog to Digital Converters

TFT *active matrix* array

Functional Illustration





Expose to x-rays

Store the charge

Active Readout

Activate gates

Amplify charge

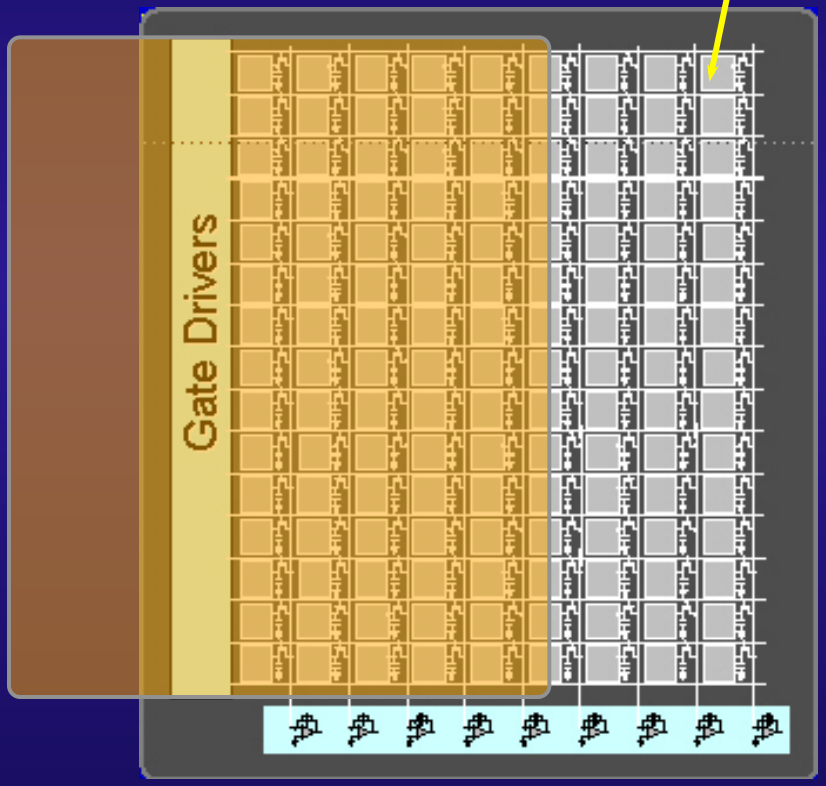
Convert to Digital

X-ray Indirect Detection

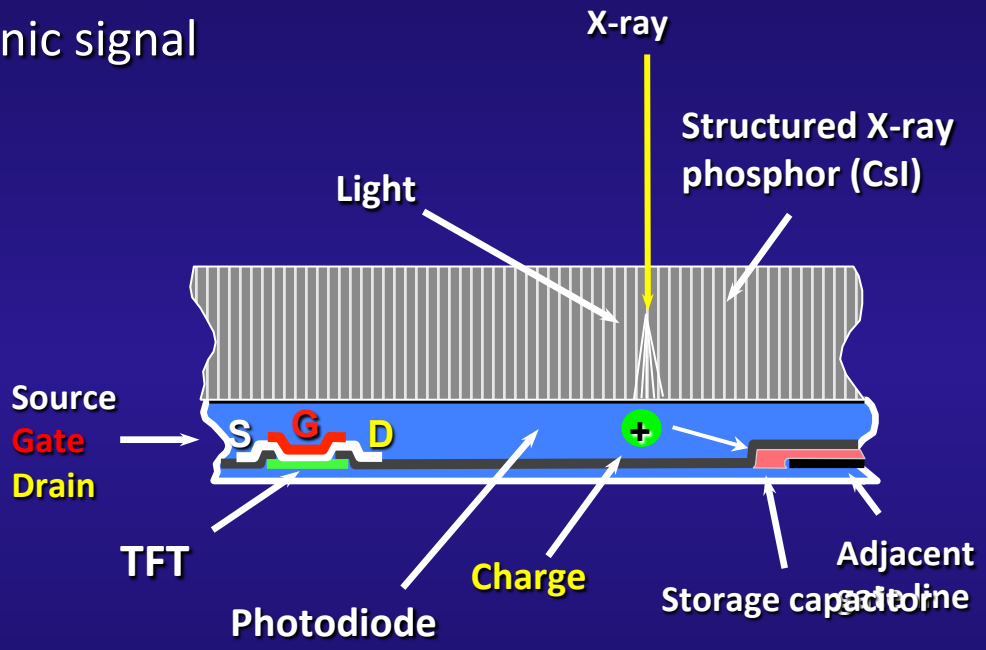
CsI phosphor / a-Si TFT

Scintillator:
X-rays to light

Photodiode:
Light to electronic signal



Amplifiers – Signal out



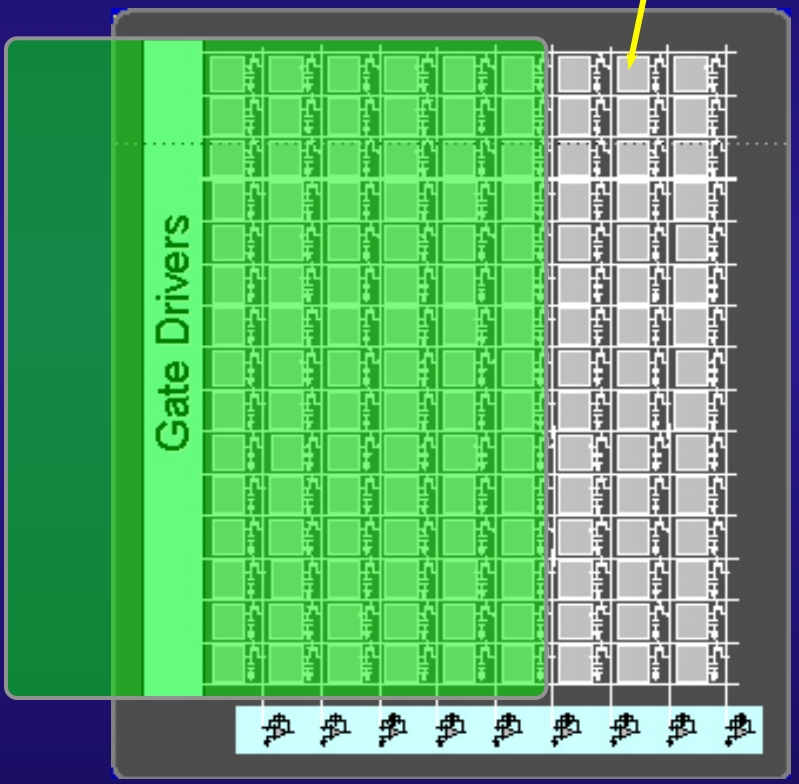
TFT array: Storage and readout

X-ray Direct Detection

a-Se layer / a-Si TFT array

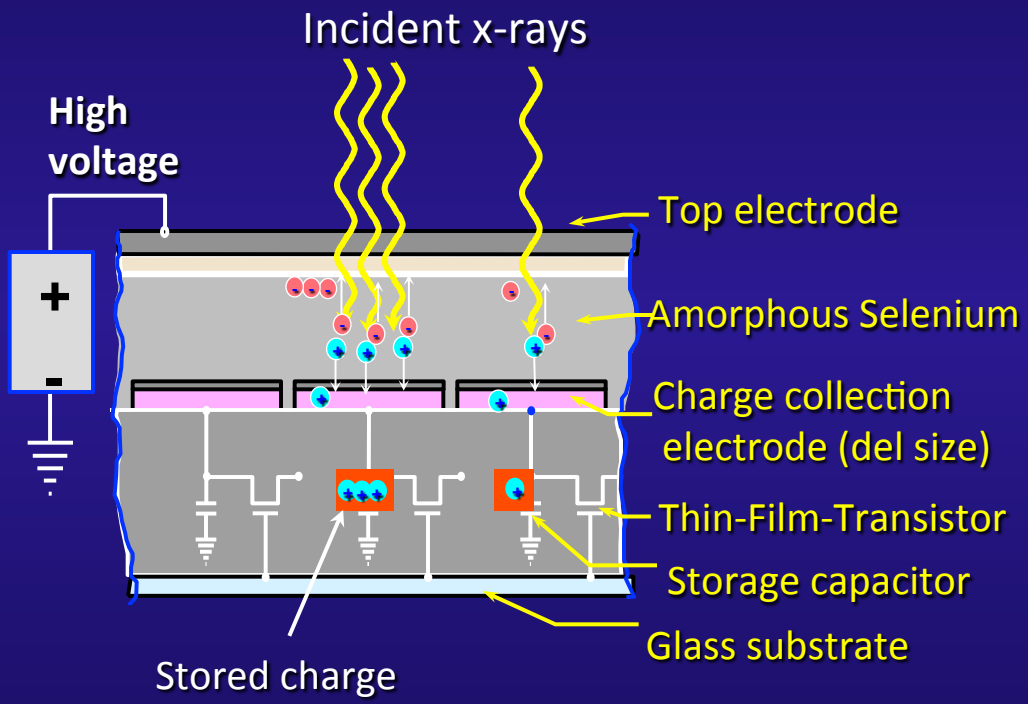
Semiconductor:
X-rays to charge

Charge collection
electrode



Amplifiers – Signal out

TFT array: Storage and readout

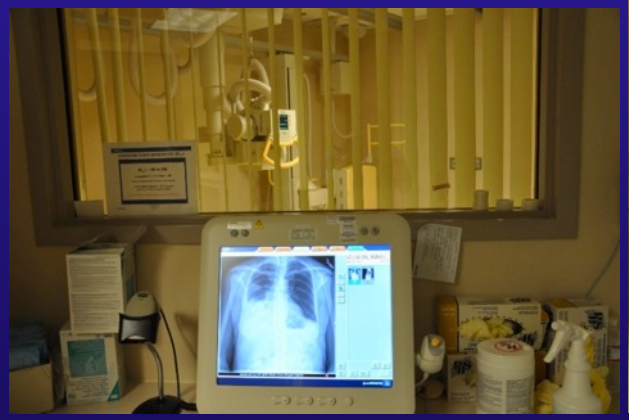


Alternate materials: PbI_2, Hg_2

DR flat panel systems

Indirect

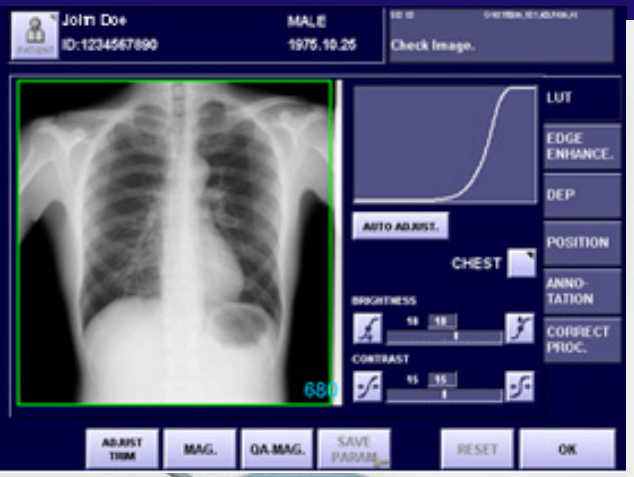
Direct



Flat panel portability

- Initial products introduced by Canon
  - Tethered, thick profile
- Wireless products now on the market
  - Trixell, Carestream, Canon, Source one …

CR and DR mobile radiography



Tethered cassette

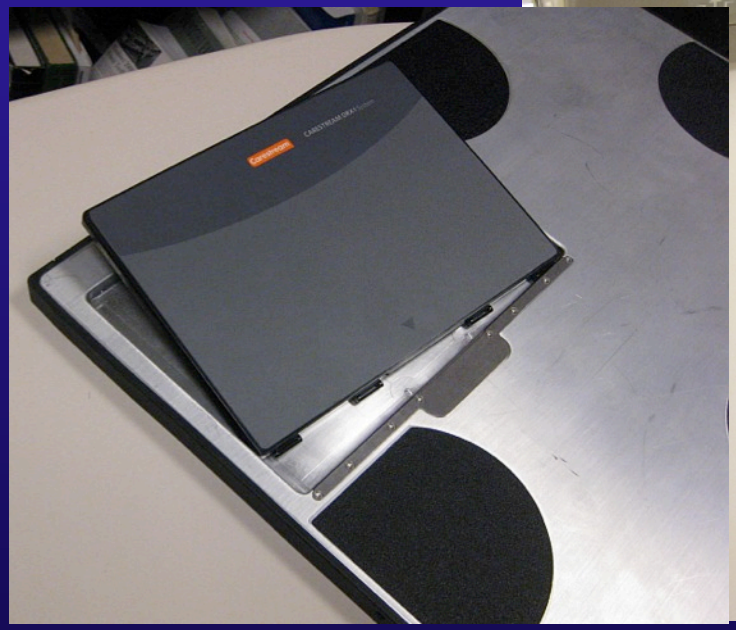
CR reader / processor

Wireless DR cassette

- Integrated
- Battery powered
- On-board computer and processing

Point of service direct imaging

- 14x17inch cassette…



Point of service direct imaging

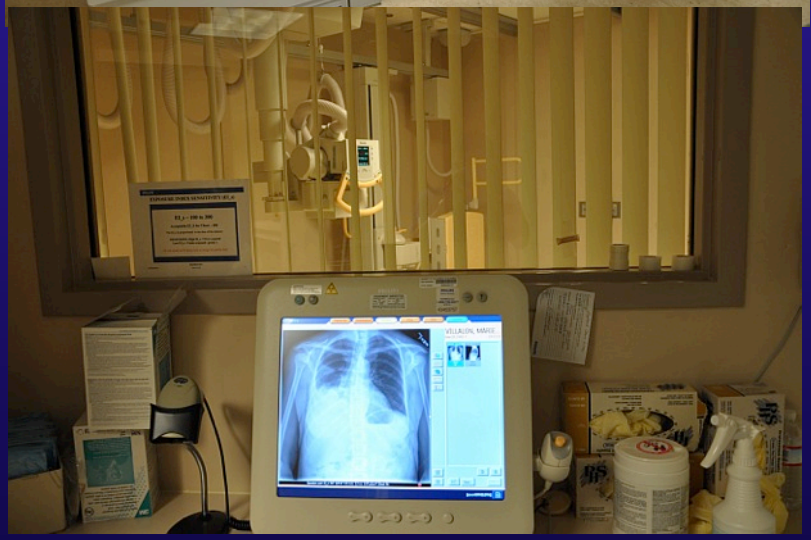
- Preview image in 2-3 s

Point of service direct imaging

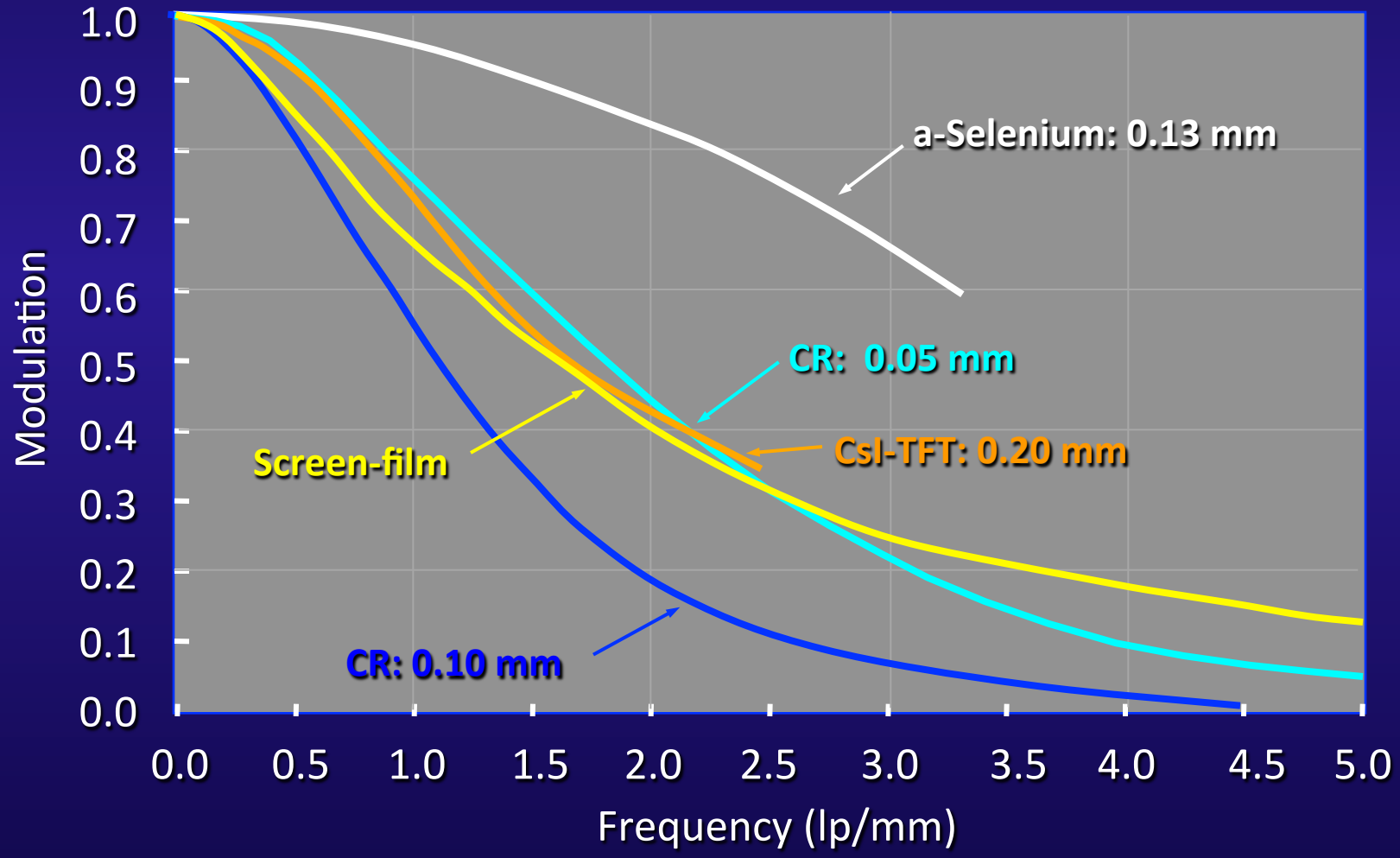
- For Processing image…. 15 s
- QC
- Annotation
- Send

DR replacement trends

- Passive for active detector technology



Spatial Resolution – MTF

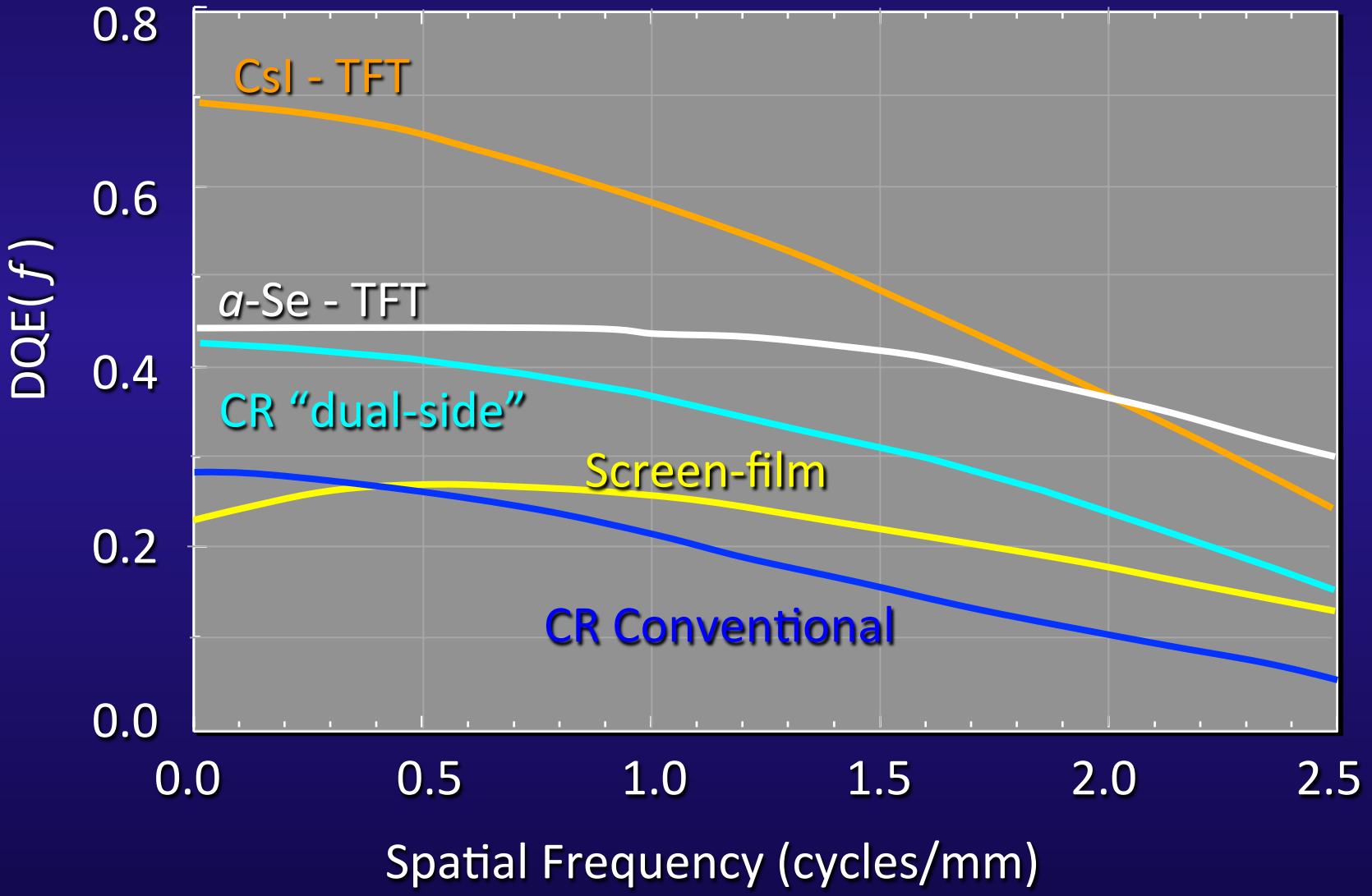


Detective Quantum Efficiency (DQE)

$$\mathrm{DQE}(f) = \frac{\mathrm{SNR}_{\mathrm{out}}^2}{\mathrm{SNR}_{\mathrm{in}}^2} = \frac{\mathrm{MTF}(f)^2}{\mathrm{NPS}_{\mathrm{N}}(f) \times q}$$

- A measure of the *information transfer efficiency* of a detector system
- Dependent on:
  - Absorption & conversion efficiency
  - Spatial resolution (MTF)
  - Conversion noise & electronic noise
  - Detector non-uniformities / pattern noise
  - **Not necessarily indicative of clinical performance**

Detective Quantum Efficiency
Radiography



High DQE does not "guarantee" good image quality

- There is no substitute for appropriate radiographic technique
- Optimization of acquisition technique
  - kV, mAs, SID, filtration, anti-scatter grid
- For similar acquisition techniques and grid use, similar SNR requires dose proportional to DQE^{-1}
- "Effective DQE" concept takes into account clinical situations (magnification, grid)

Attribute	CR	DR	CCD
Positioning flexibility	****	**	**
Replacement for screen/film	****	**	**
DQE / dose efficiency	**	***	**
Patient throughput	*	***	**
X-ray system integration	**	****	****
Access to advanced technology applications	**	****	***
Cost for comparable image throughput	***	**	***
Radiographer ease of use (manufacturer dependent)	*	***	**

SUMMARY

Enterprise distribution of images is crucial for implementation and application of technology

- *Cassetteless, active detector* radiography devices are becoming the detectors of choice
- Proliferation of web-based PACS and unified patient database (instead of Radiology centric orientation) is coming
- New opportunities
  - Image acquisition and image processing tools
  - Imaging technology innovation for diagnosis and intervention