LECTURE 15

POSITRON EMISSION TOMOGRAPHY (PET)

PHYSICAL MODEL
FILTERED BACKPROJECTION) TODAY

ITERATIVE RECONSTRUCTION
3D PET) NEXT TIME

READ

"POSITRON-EMISSION TOMOGRAPHY" OLLINGER FESSLER

POSITRON EMISSION TOMOGRAPHY

INJECT A TRACER WITH A RADIOACTIVE ISOTOPE

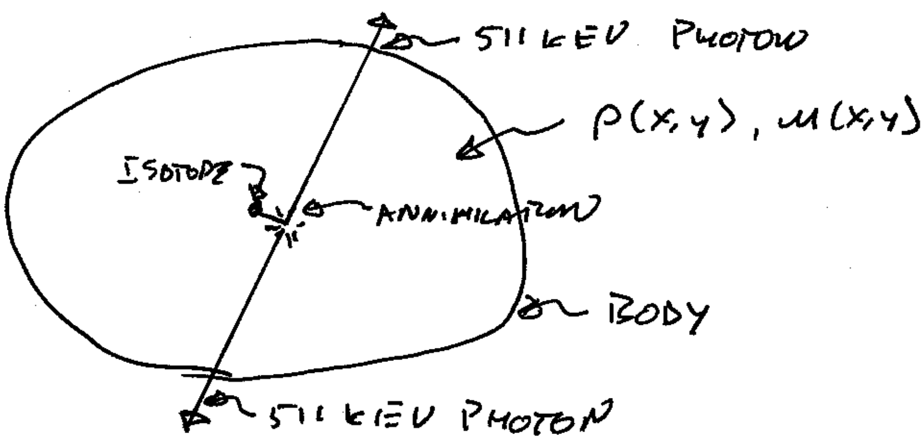
FDG (FLUORODEOXYGLUCOSE) MOST COMMON

ISOTOPE DECAYS PRODUCING POSITRON

POSITRON ANNIHILATES WITH ELECTRON PRODUCING TWO 511 KEV PHOTONS AT ± 180°

$\rho(x,y)$ - TRACER DENSITY

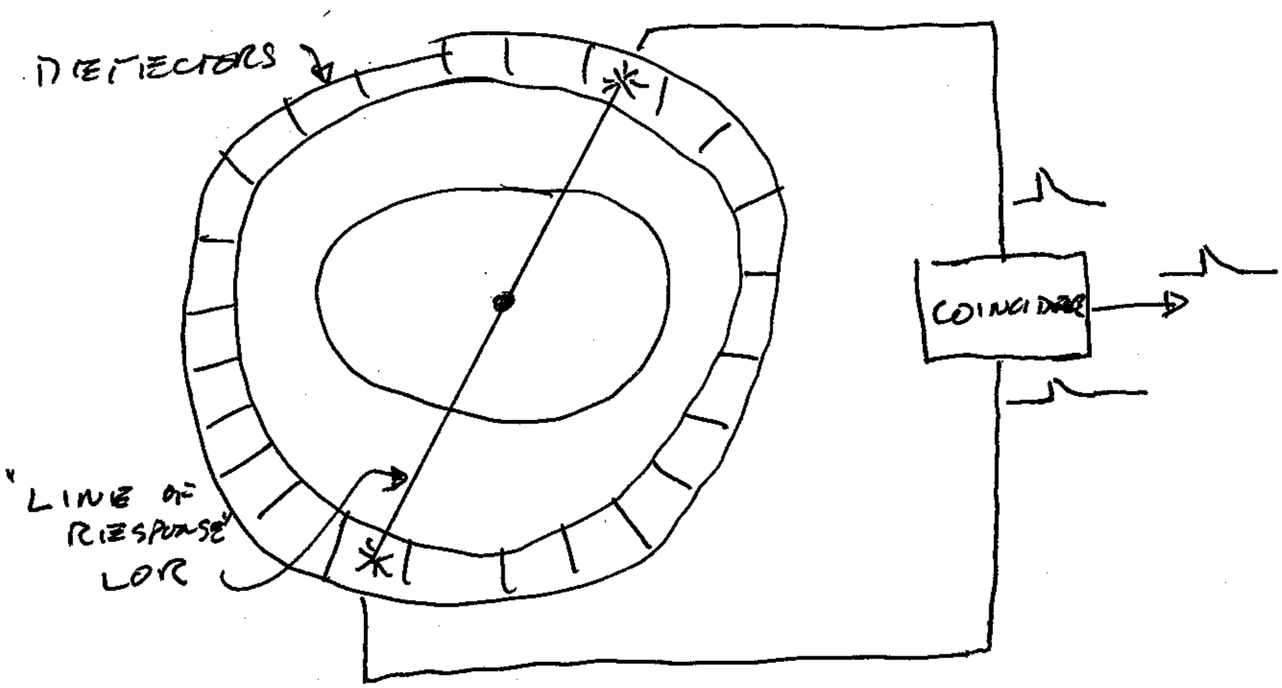
$\mu(x,y)$ - ATTENUATION



HOW DO YOU MAKE AN IMAGE OF $\rho(x,y)$?

CONVERT THE PROBLEM INTO A PROJECTION RECONSTRUCTION PROBLEM.

SURROUND BODY WITH RING OF DETECTORS

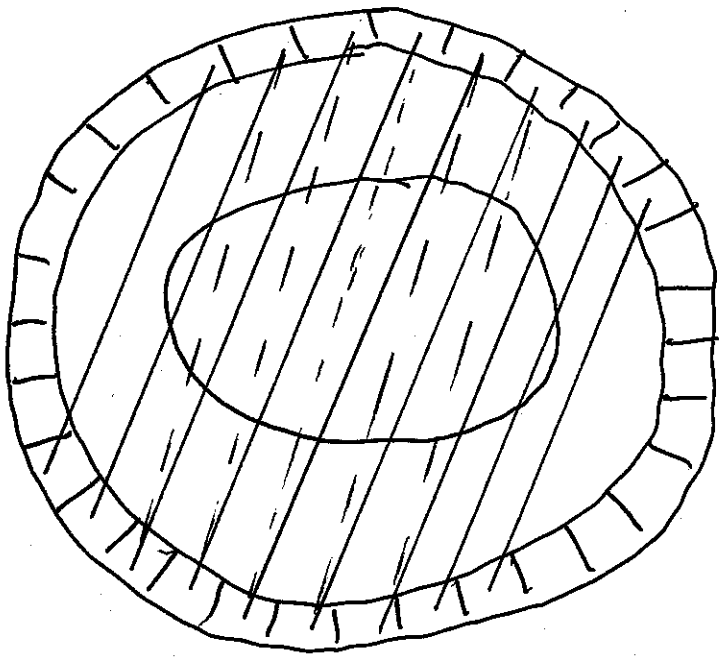


IF TWO EVENTS ARE DETECTED IN A 5-15 ns WINDOW, WE KNOW THERE WAS AN EVENT ALONG THE LINE CONNECTING THEM

THIS IS THE "LINE OF RESPONSE", OR LOR

MANY POSSIBLE LOR'S!

WE CAN GROUP LOR'S TO FORM PROJECTIONS



- COLLECT EVENTS
- SORT INTO PARALLEL PROJECTIONS
- BACKPROJECT

COLLECT TWO SETS

OPPOSING DETECTORS

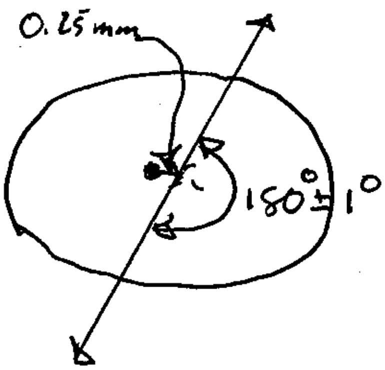
OPPOSING BUT 1 DETECTORS

INTERLACING DOUBLES LOR SPACING

DETECTOR SPACING IS ~3mm

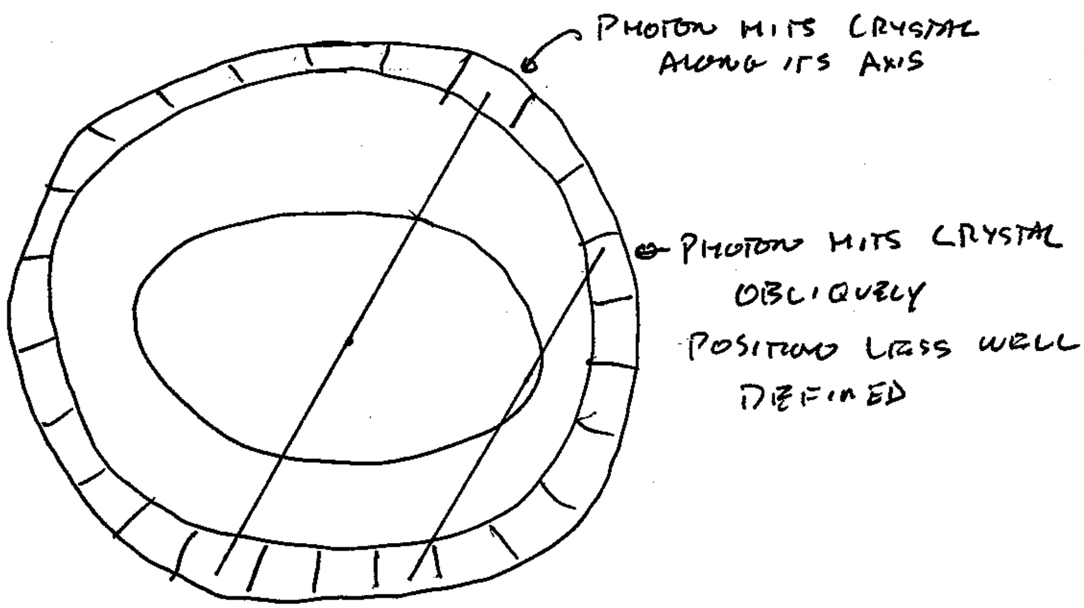
WITH INTERLACING IS ~1.5mm

RESOLUTION



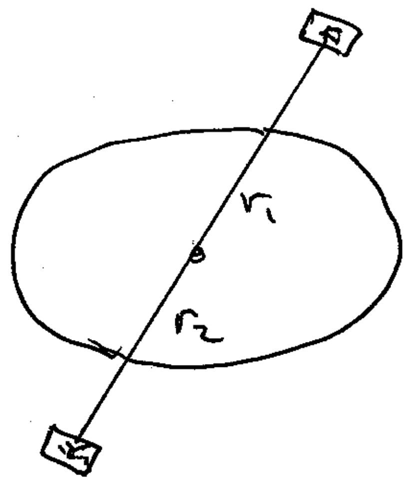
LIMITS ARE

POSITRON RANGE	~ 0.25 mm	
POSITRON MOMENTUM	~ 180° ± 1°	
LOR SPACING	~ 1.5 mm	
DETECTOR FWHM	~ 3 mm	CENTER OF FOV
	~ 5 mm	EDGE OF FOV



ATTENUATION

WE WANT TO RECONSTRUCT $\rho(x,y)$, BUT ATTENUATION WILL CAUSE EVENTS TO BE LOST



WE LOSE EVENT IF EITHER PHOTON IS ATTENUATED.

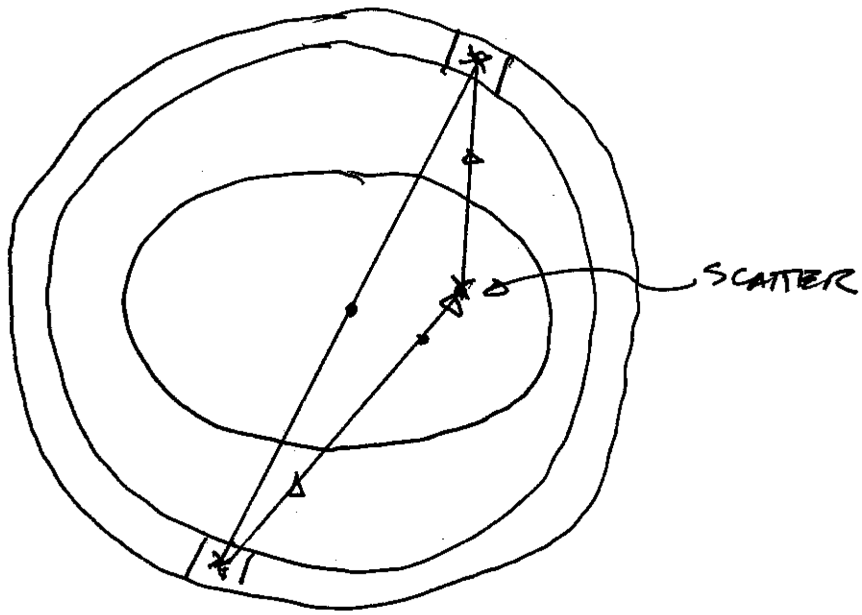
THE PROBABILITY BOTH PHOTONS SURVIVE IS

$$P(\text{PHOTON } 1) \cdot P(\text{PHOTON } 2)$$

$$= \left[e^{-\int_{r_1} \mu(x,y)\,ds} \right] \left[e^{-\int_{r_2} \mu(x,y)\,ds} \right] = e^{-\int_{r_1+r_2} \mu(x,y)\,ds}$$

ONLY A FUNCTION OF TOTAL PATH LENGTH, NOT SOURCE LOCATION.

SCATTERING

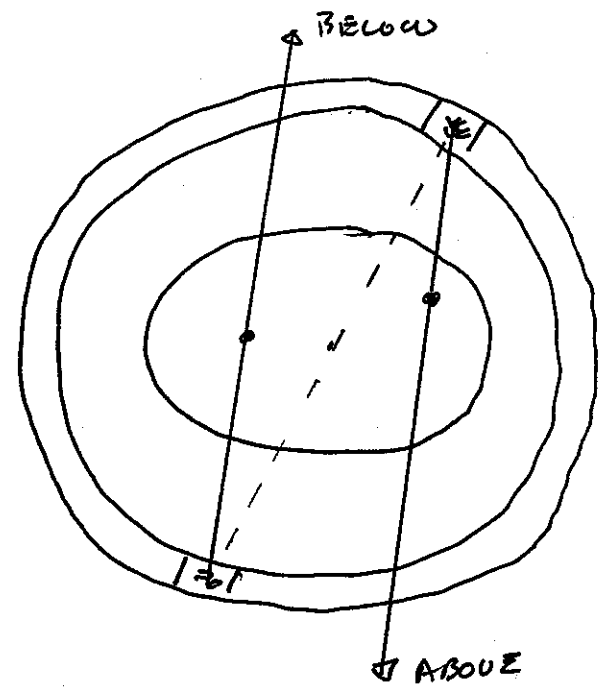


SCATTERED PHOTONS ALSO PRODUCE COINCIDENCE

ENERGY SENSITIVE DETECTION (±10%) REDUCE
LARGE ANGLE EVENTS

FUNCTION OF SUBJECT.

ACCIDENTALS (RANDOMS)



TWO COINCIDENT EVENTS LOOK LIKE A SINGLE EVENT.

RATE AT DETECTOR i IS R_i

GIVEN AN EVENT AT i, THERE ARE

$$\tau R_j$$

AT DETECTOR j, WHERE τ IS COINCIDENCE WINDOW (5-15 ns)

TOTAL RATE IS

$$R_r = 2\tau R_i R_j$$

WHERE THE FACTOR OF 2 IS BECAUSE EITHER DETECTOR COULD BE FIRST

QUADRATIC IN DOSE!

15% IN 2D

30-50% IN 3D

DEAD TIME / DETECTOR EFFICIENCY

AFTER EVENT THERE IS A RECOVERY TIME
1 – 10's OF nS

IF THE RATE IS HIGH ENOUGH, DEAD MOST OF THE TIME
SATURATED

LIMITS DOSE

PET IMAGE RECONSTRUCTION

SYSTEM MODEL

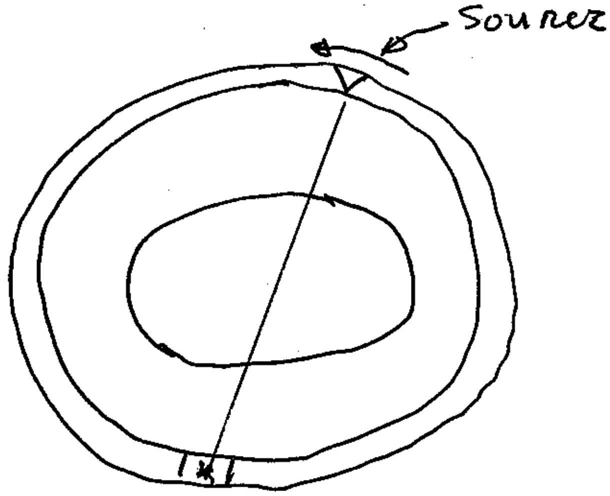
DETECTED EVENTS ALONG r, θ

$$\underbrace{Y_{r,\theta}}_{\text{MEASURED}} = \gamma\left[\eta^t P_{r\theta} \underbrace{m}_{\text{DESIRED}} + \eta^r r + \eta^s s\right]$$

WHERE

- m – NUMBER OF SOURCE EVENTS
- P – SOURCE ATTENUATION $e^{-\int \mu(x,y)ds}$
- r – NUMBER OF RANDOM EVENTS
- s – NUMBER OF SCATTERED EVENTS
- η^t, η^r, η^s – DETECTOR EFFICIENCIES FOR TRUE, RANDOM AND SCATTERED EVENTS
- γ – DEAD TIME LOSS

ATTENUATION ESTIMATE



MEASURE USING:

BLANK SCAN $B_{r,\theta}$ DETECTOR SENSITIVITIES (ONCE / DAY)

TRANSMISSION SCAN $T_{r,\theta}$ ATTENUATION OF SUBJECT (ONCE / STUDY)

THEN

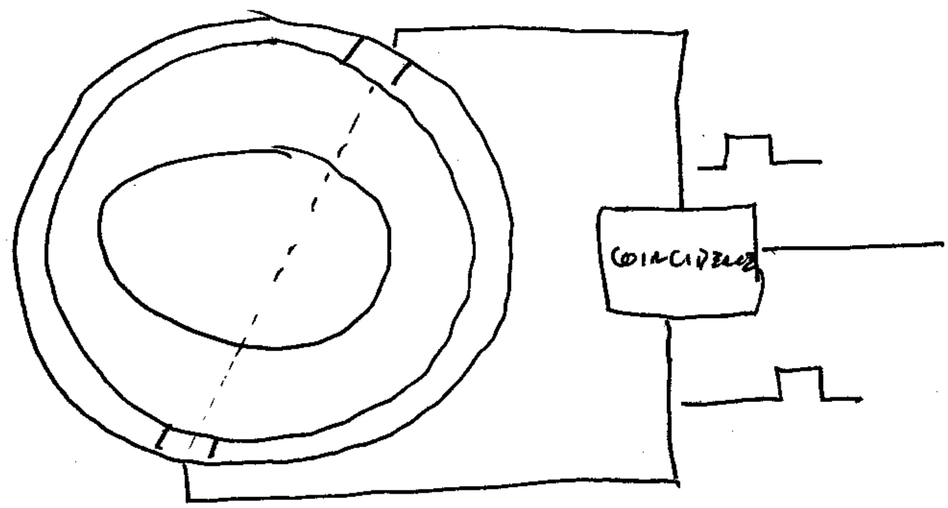
$$P_{r,\theta} = \frac{T_{r,\theta}}{B_{r,\theta}}$$

INCLUDES γ, η^t

ESTIMATE USING

CT SCAN (PET / CT SCANNER)

ACCIDENTAL ESTIMATE



USE NON-OVERLAPPING COINCIDENCE WINDOWS

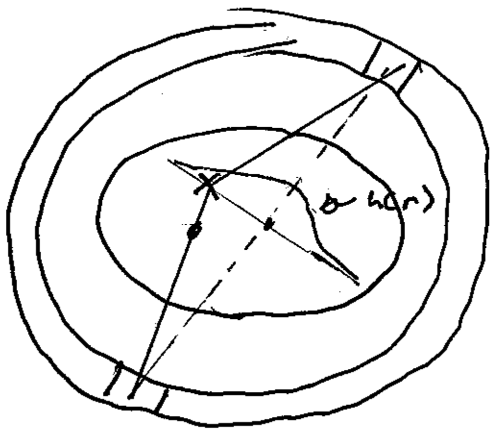
ACCIDENTALS ARE SAME!

NO TRUE EVENTS

MEASURES $\gamma u' r$

NOISY, SNR SIMILAR TO DATA

SCATTER ESTIMATE



PROBABILITY OF SCATTER IS DETERMINED BY PROBABILITY
OF SOMETHING TO SCATTER OFF OF

ENERGY SELECTIVITY LIMITS ANGLE

ESTIMATE BY CONVOLVING PROJECTION DATA WITH
KERNEL h(r) IN 2D

INCORPORATE INTO SYSTEM MODEL IN 3D

CORRECTED BACKPROJECTION DATA

SYSTEM MODEL

$$\underbrace{Y_{r,\theta}}_{\text{MEASURED}} = \underbrace{\gamma \eta^t P_{r,\theta}}_{\text{MEASURED}} \underbrace{m}_{\text{DESIRED}} + \gamma \eta^r \underbrace{r} + \gamma \eta^s \underbrace{s}$$

RANDOM, ESTIMATED

CORRECTED DATA

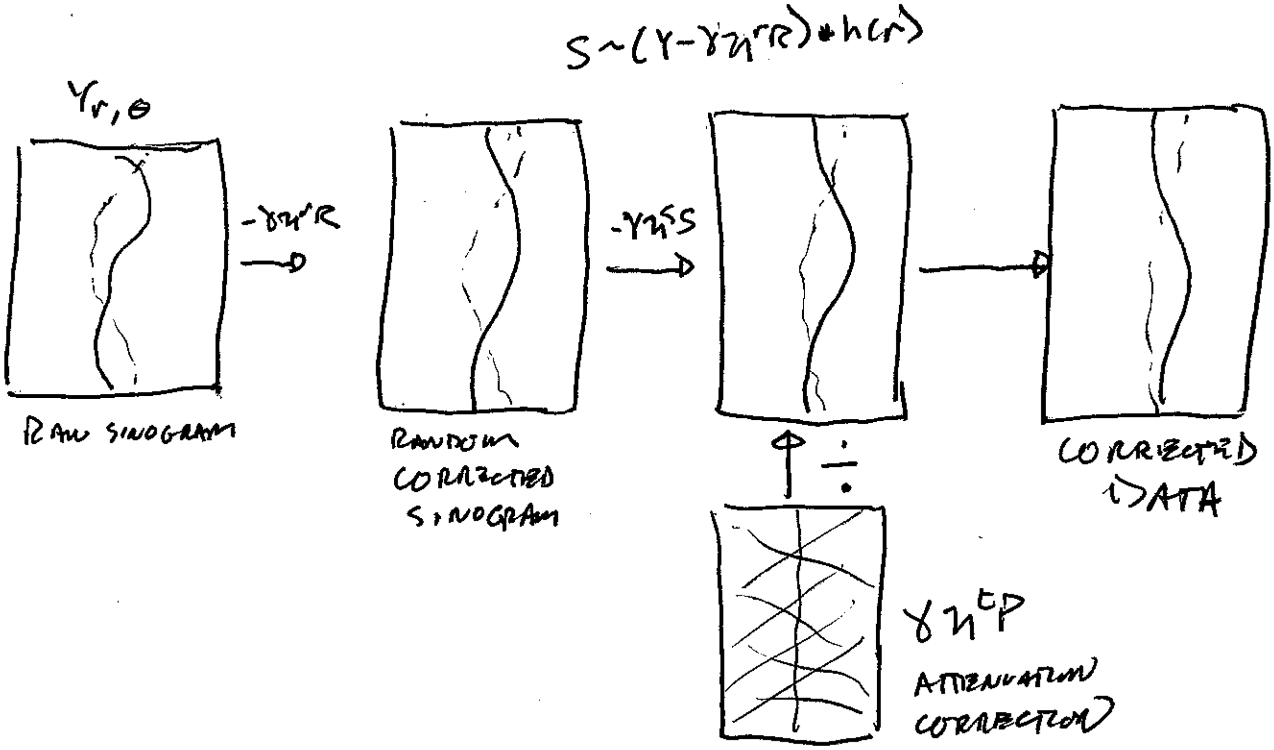
$$\hat{m}_{r,\theta} = \frac{1}{\gamma \eta^t P_{r,\theta}} \left[Y_{r,\theta} - \gamma \eta^r R - \gamma \eta^s S \right]$$

WHERE

$$R = E[r]$$
$$S = E[s]$$

$\hat{m}_{r,\theta}$ CAN BE BACKPROJECTED

Block Diagram



Problems

CORRECTIONS ARE RANDOM, ADD NOISE

DOESN'T EXPLOIT KNOWLEDGE OF SYSTEM

- IMAGE IS POSITIVE
- STATISTICS ARE POISSON
- PARTS OF IMAGE ARE ZERO

NEXT TIME, HOW CAN WE EXPLOIT THESE CHARACTERISTICS TO PRODUCE BETTER RECONSTRUCTIONS