Total-Body Positron Emission Tomography

State-of-the-Art in Scanner Design and Technology

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Disclosures

Research Agreements

Canon Medical Research Unit

United Imaging Healthcare

UC Davis has a revenue sharing agreement with

United Imaging Healthcare

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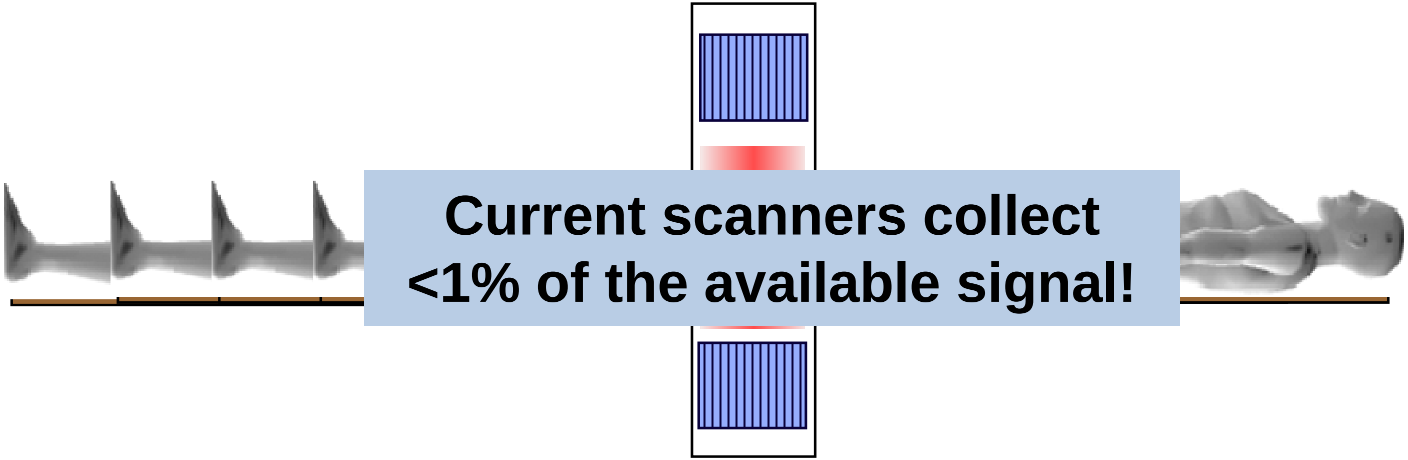
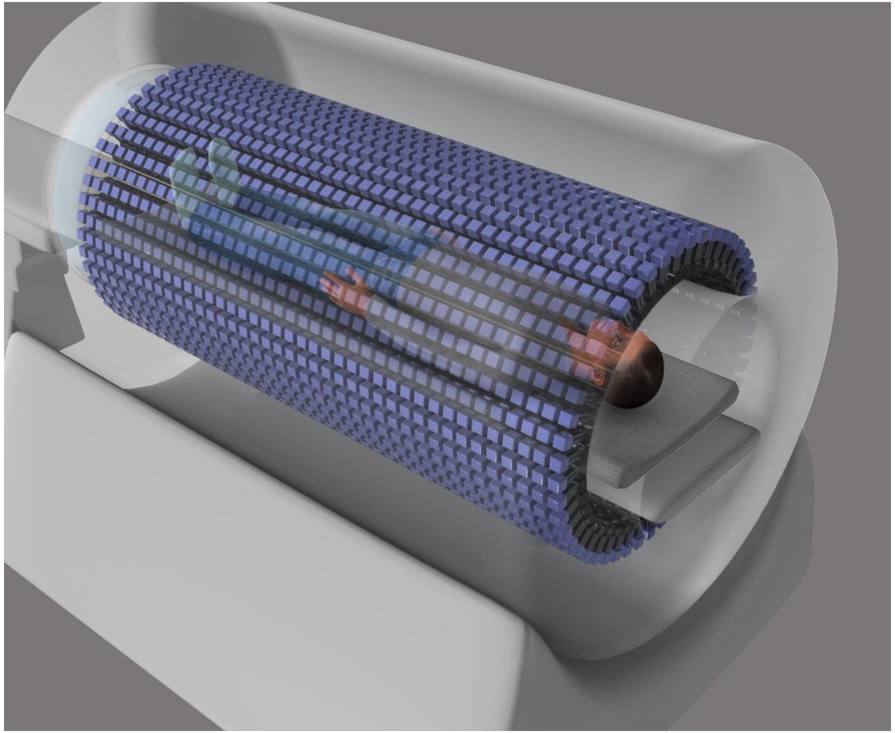
Signal Collection in PET

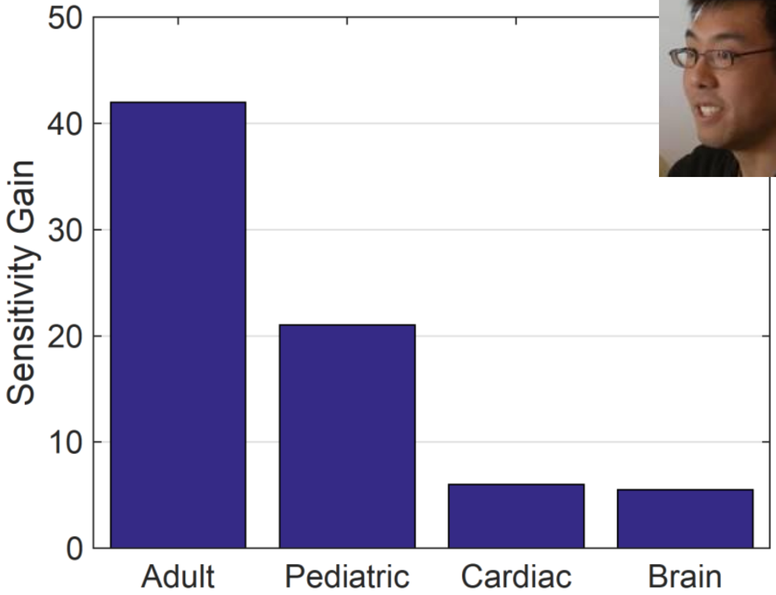


Current scanners collect <1% of the available signal!

- PET provides the most sensitive non-invasive molecular assay of the human body
- All PET studies are limited by low signal, radiation dose, or both

Predictions





Poon *et al*, *Phys Med Biol*, 57: 4077-4094, 2012
Poon, *Ph.D. Thesis*, University of California, 2013

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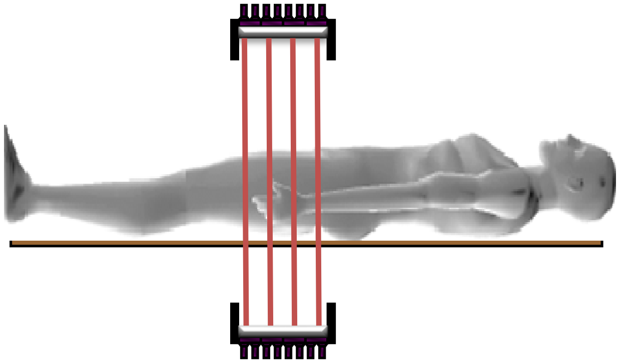
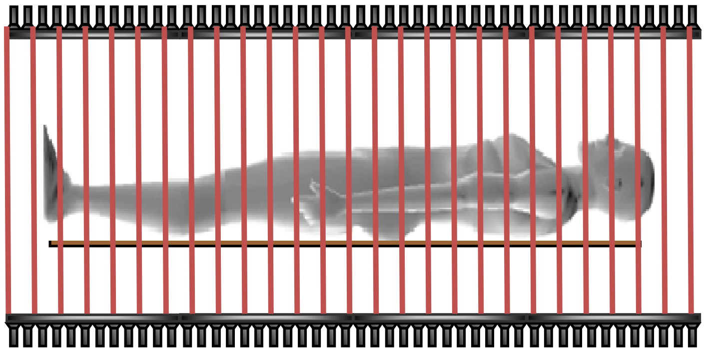
Total-Body PET: Maximizing Sensitivity

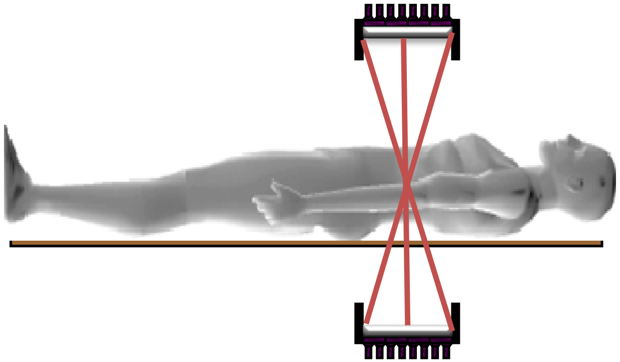


CONVENTIONAL PET

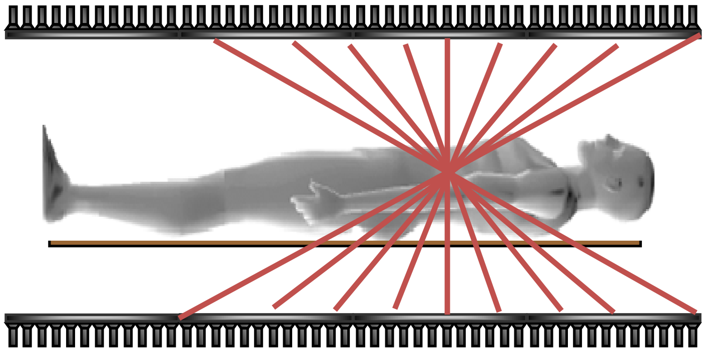


TOTAL-BODY PET

Total-Body PET: Maximizing Sensitivity



CONVENTIONAL PET

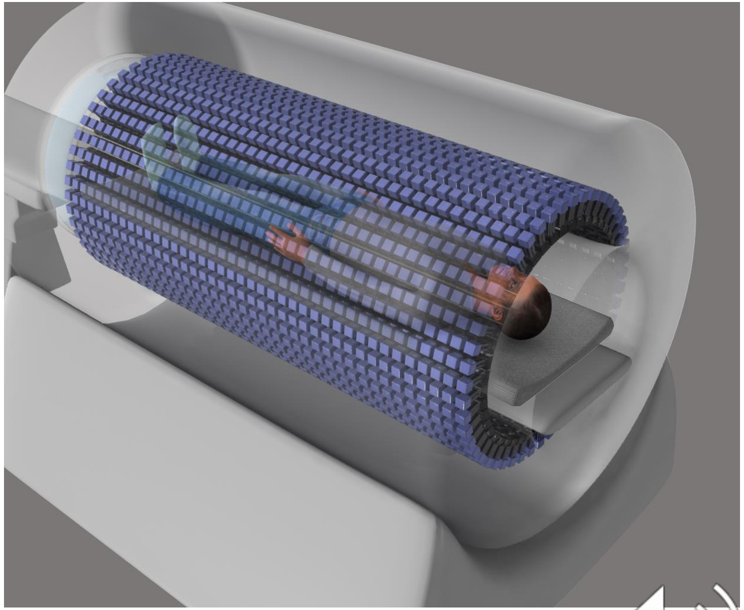


TOTAL-BODY PET

Claims

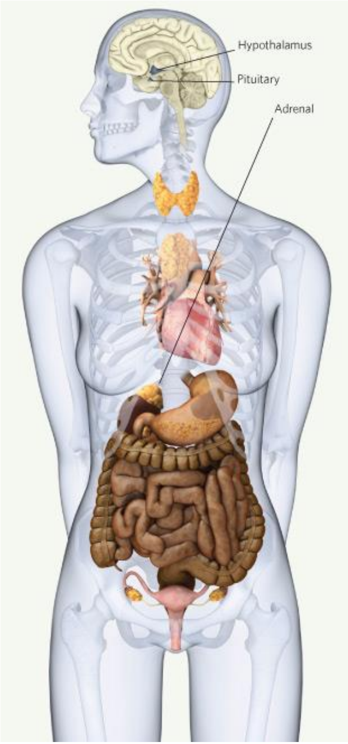
What can we do with 40 times more signal?

- **Improve Signal-to-Noise Ratio by ~6.5**
  - Better quality images
  - Detect smaller lesions
  - Detect lower grade disease
  - Fast dynamic imaging
- **Increase dynamic range**
  - Acquire images for 5 more half-lives
- **Acquire total-body PET scans in 30 seconds**
  - Less motion
  - Single breath-hold PET?
- **Acquire total-body PET scans at 0.15 mSv**
  - Equivalent radiation dose to roundtrip transatlantic flight
  - 40 scans in an individual for same dose as 1 current scan



Applications

- **Systemic disease and therapies:**
  - Cancer: Ultra-staging and micrometastasis
  - Inflammation
  - Infection
  - Cellular therapy and trafficking
  - Mind-body interactions
- **Total body pharmacokinetics**
  - Drug development
  - Toxicology
  - Biomarker discovery
- **Low dose opens up new populations:**
  - Expanded use in pediatrics
  - Use in chronic disease
  - Studies of normal biology



Cherry *et al.*, *Science Trans Med* 9; eaaf6169 (2017)

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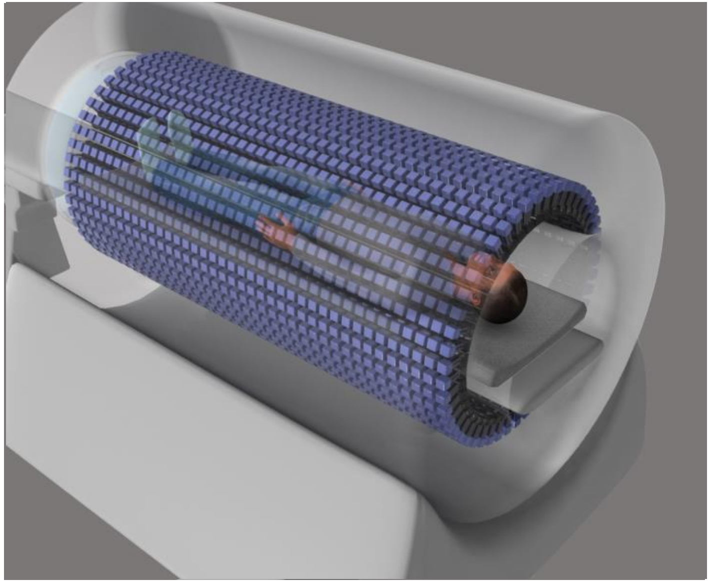
Total-Body PET



Goal of EXPLORER Consortium: Build the world's first total-body imaging system

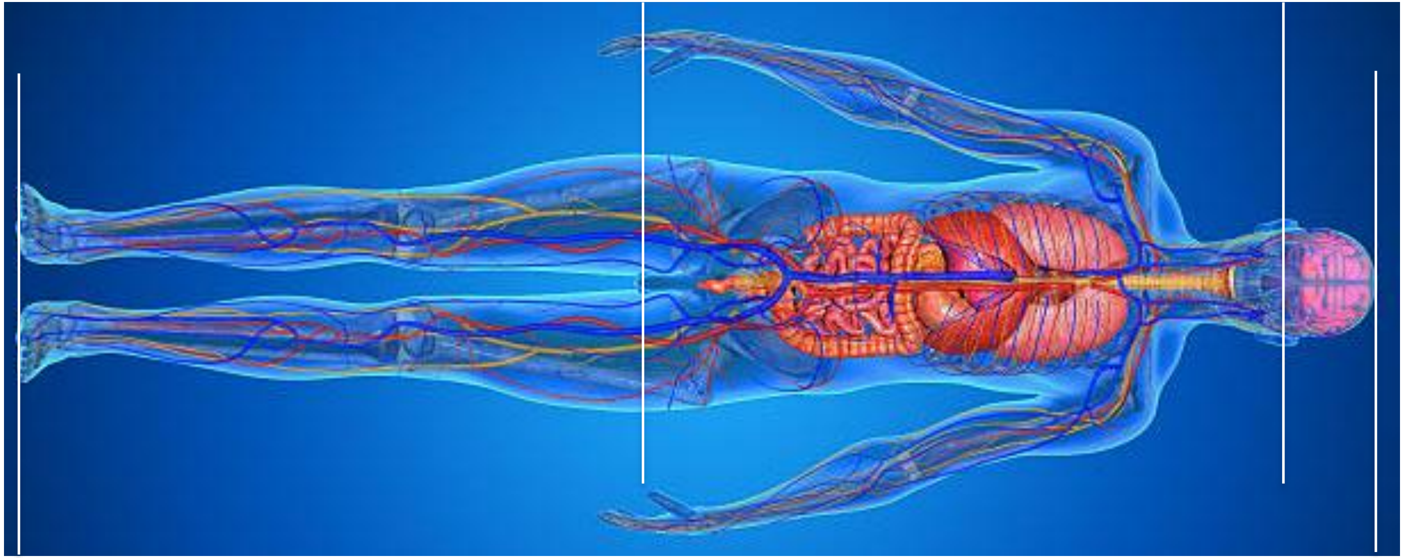
Conventional PET/CT scanner

Challenges:

- **Scale of system**
  – >500,000 detectors
  – >50,000 channels of electronics
- **Big data**
  – ~100 GB for 5 min static scan
  – ~1-2 TB for 60 min dynamic scan
- **Cost**

How Long Should the Scanner Be?

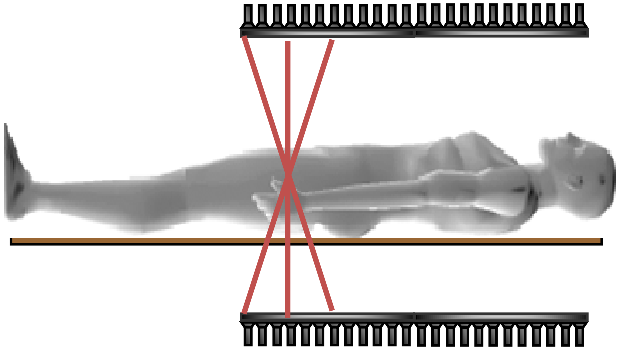
103.8 mm (99%)



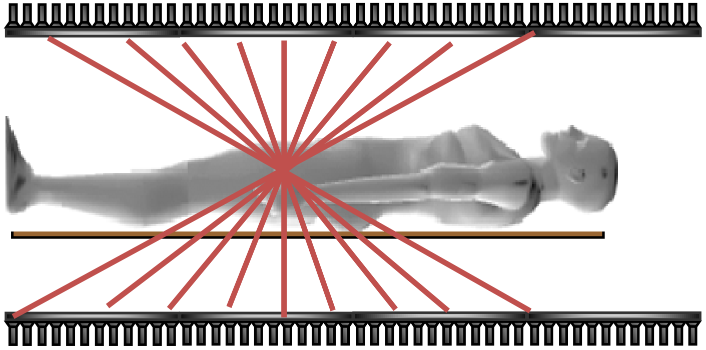
192.5 cm (99%)

DINBelg.be

Scanner Length Considerations



LARGE AXIAL FOV PET
(~ 1 meter)



TOTAL-BODY PET
(~ 2 meters)

EXPLORER Consortium

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EXPLORER

NIH R01 CA206187

UC DAVIS
UNIVERSITY OF CALIFORNIA

Penn

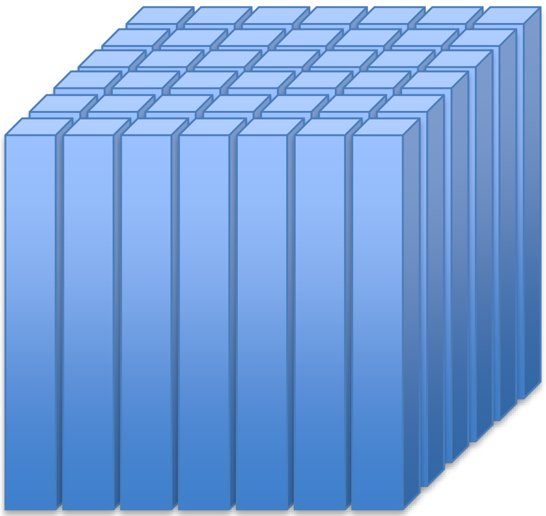
uEXPLORER

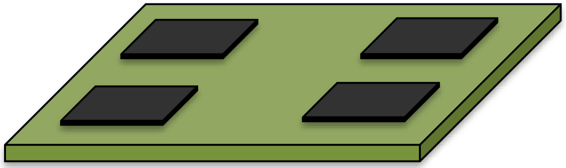
- High spatial resolution
- Total-body imager (~ 2m)
- UIH technology platform

PennPET EXPLORER

- High TOF resolution
- Torso imager (~1.4m)
- Philips technology platform

EXPLORER Technology





Detector Module:

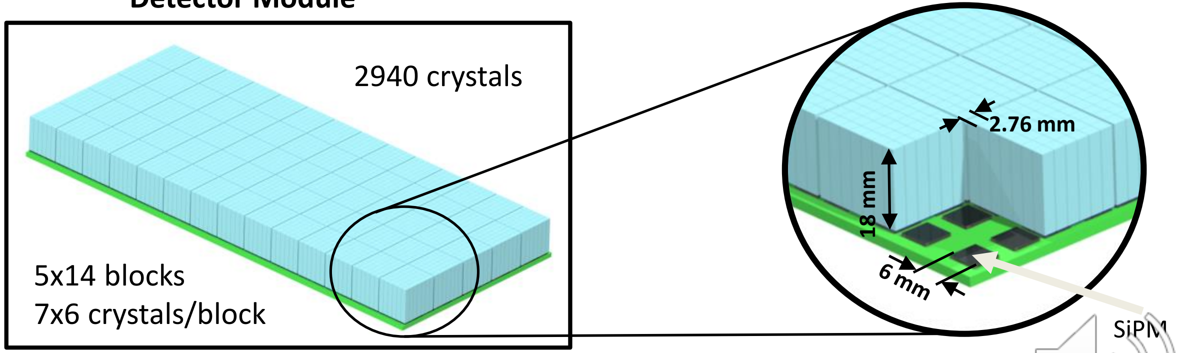
Crystals: 2.76 x 2.76 x 18.1 mm LYSO

Array: 7 (transaxial) x 6 (axial)

SiPMs: 4 - Sensl 6 mm J-series

Scintillator arrays and photodetectors

Detector Module



uEXPLORER Scanner

# of crystals: 564,480
crystal blocks: 13,440
of SiPMs: 53,760
# of LORs: 92 x 10^9

Ring diameter: 78.6 cm
Transaxial FOV: 68.6 cm
Axial FOV: 194.8 cm
80-row CT

Performance:
174 kcps/MBq sensitivity*
(<20 kcps/MBq industry standard)
2.9 mm spatial resolution*
505 psecs time of flight*
11.7% energy resolution

*NEMA NU 2-2018 protocol

Claims

Collect 40 times more signal

- **Improve Signal-to-Noise Ratio by ~6.5**
  - Better quality images
  - Detect smaller lesions
  - Detect lower grade disease
  - Fast dynamic imaging
- **Increased dynamic range**
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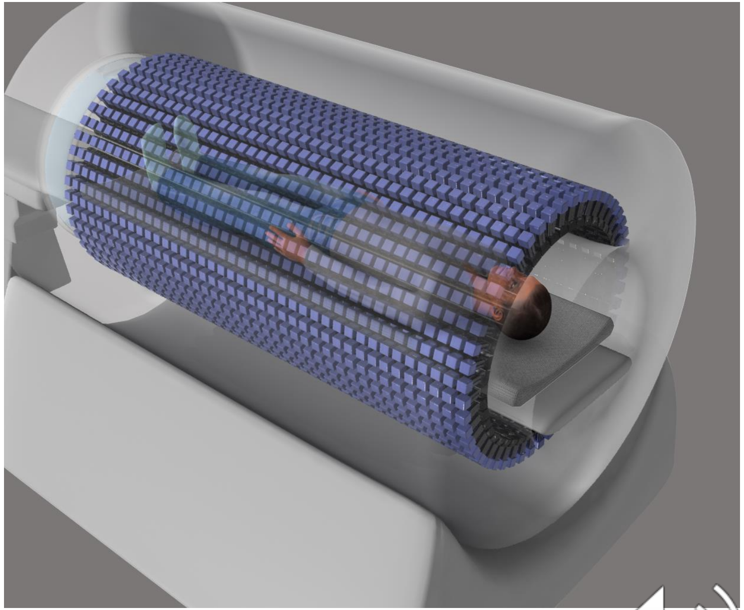


EXPLORER Capabilities:

Higher Quality

Less Time

Lower Dose

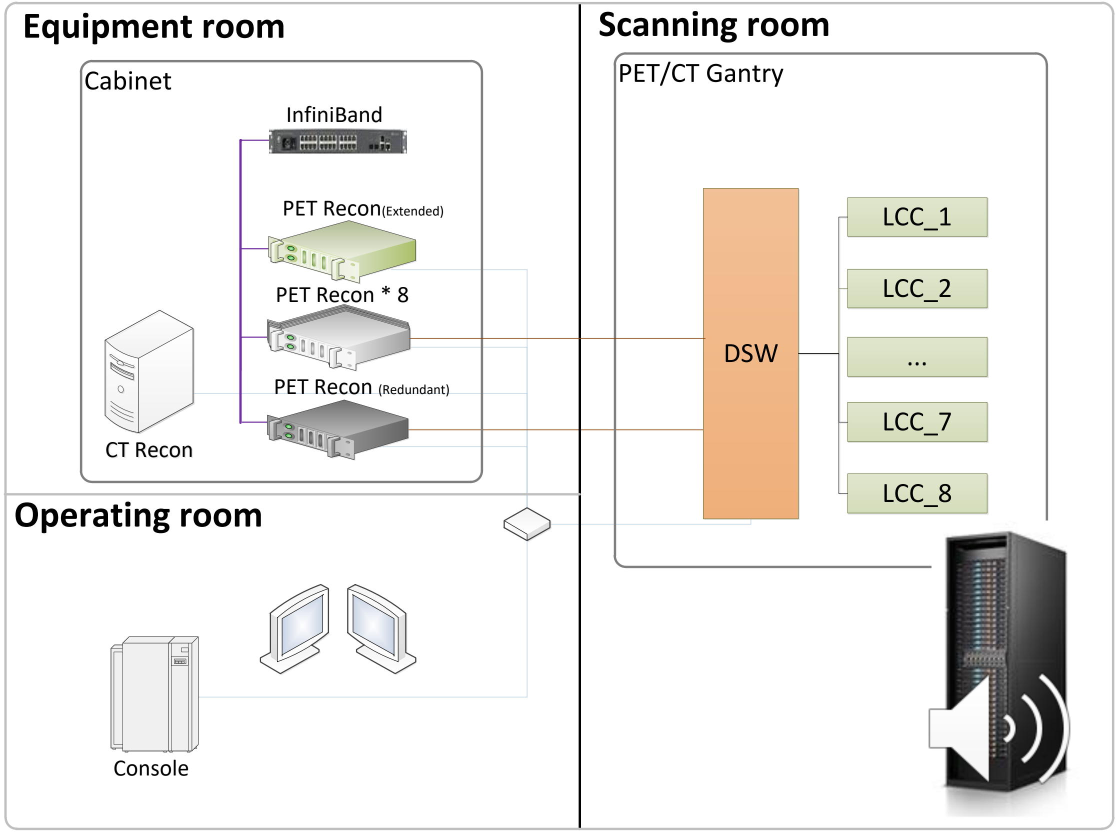
20 mins
High-Quality
Imaging

30 secs
Fast
Imaging

5% Dose
Low Radiation
Dose Imaging

Data Handling

- 1 host computer + 8 node server for acquisition and reconstruction
  - one redundant node
  - scalable for reconstruction
- Node configuration:
  - Dual Intel Xeon 6126 CPU
  - 96 GB memory
  - 2 Tesla V100 GPUs
- Data volume and recon times:
  - 10 min clinical scan, 5 mCi injection ~100 GB, 10-15 minutes
  - 60 min dynamic scan,10 mCi injection ~1.5-2 TB, several hrs



^{89}Zr-Antibody Imaging

HIV Infection imaging with immunoPET (^{89}Zr-VRC01)

- 0.9 mCi of ^{89}Zr-VRC01
- Imaged 2 days after injection, ~ <0.6 mCi
- Only ~23% positron fraction from ^{89}Zr

Equivalent to < 1/100th of the normal dose of FDG!

Tim Henrich, UCSF

Henry VanBrocklin, UCSF

EXPLORER
20 min scan

Conventional PET
GE PET/MR; 48 min scan

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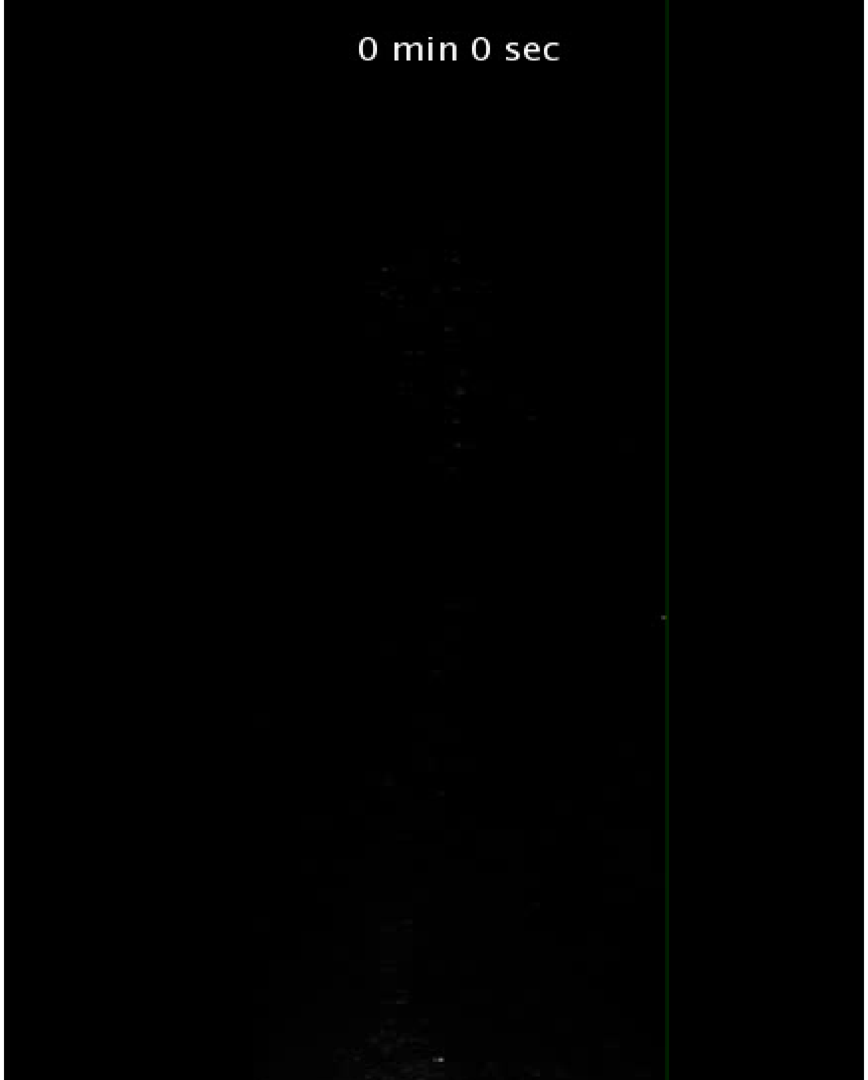
Dynamic FDG Movie

Age: 61
Gender: Female
Height: 156 cm
Weight: 56 kg

Tracer: FDG
Dose: 255 MBq (6.9 mCi)
60 min dynamic scan

in collaboration with Zhongshan Hospital



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Total-Body Dynamic Imaging

Gender: Male
Weight: 87 kg

Tracer: FDG
Dose: 388 MBq (10.5 mCi)
60 min. dynamic scan

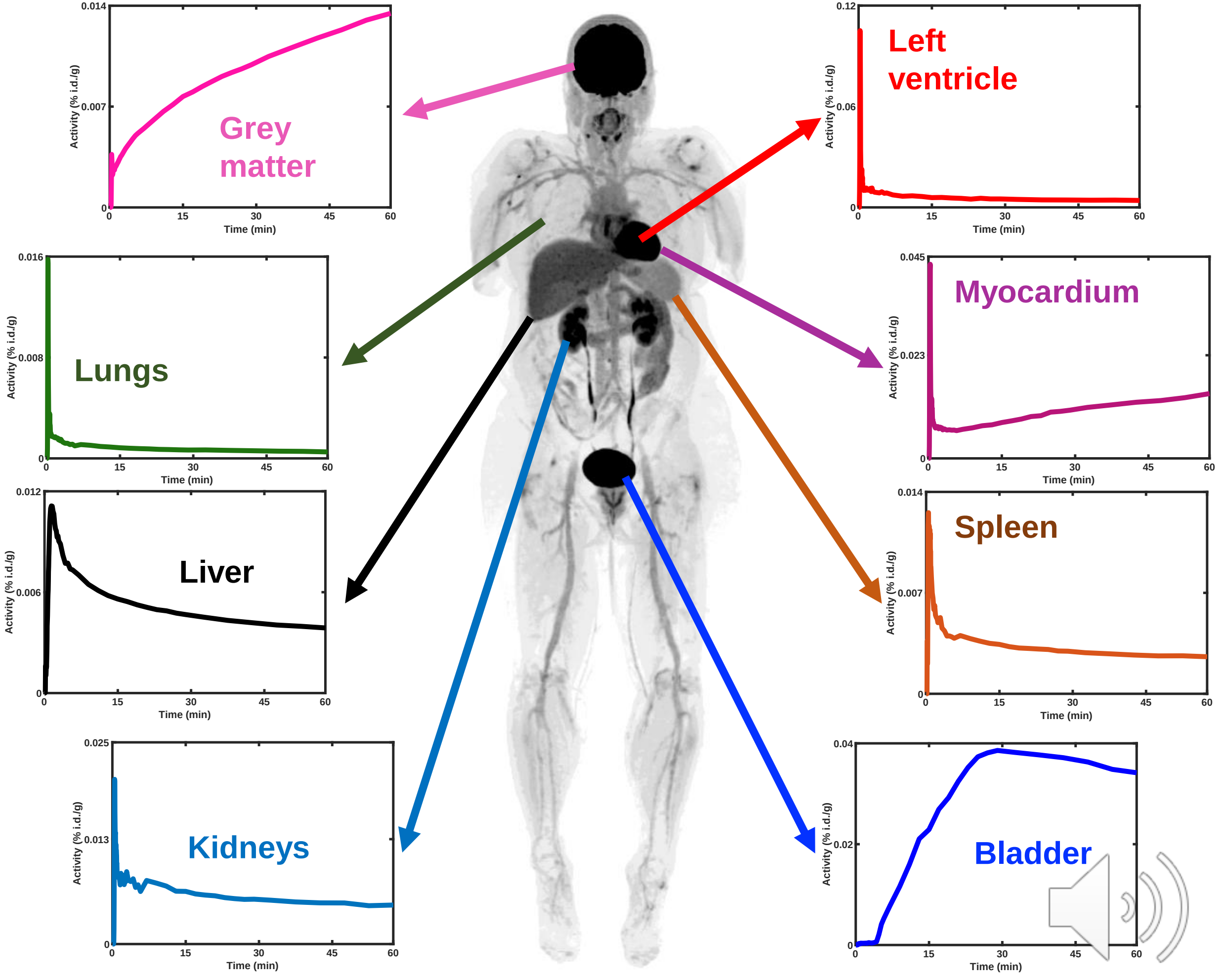
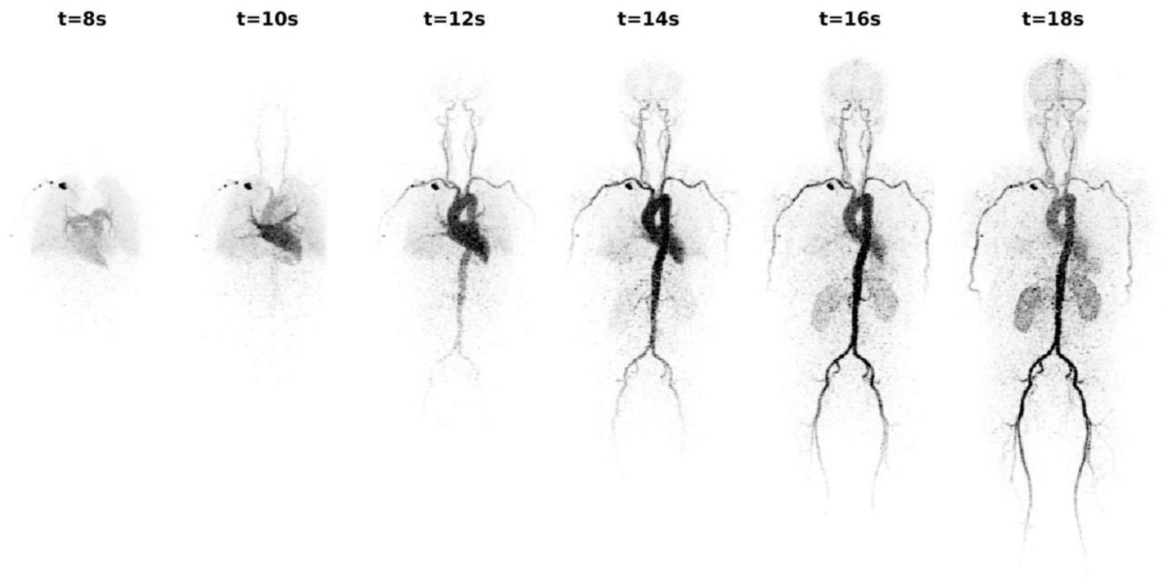
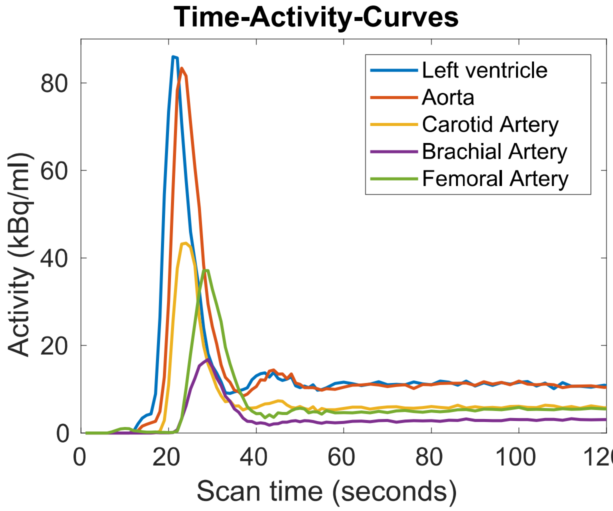


Image-Derived Arterial Input Function





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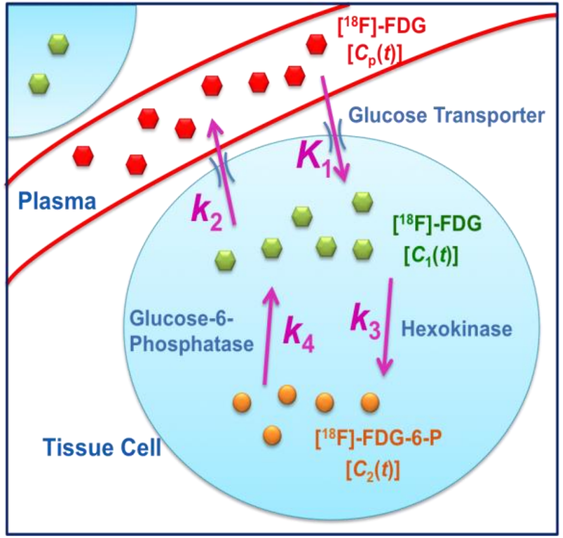
Total-Body Parametric Imaging

Age: 79
Gender: Male
Height: 170 cm
Weight: 71 kg

Tracer: FDG
Dose: 348 MBq (9.4 mCi)
Last 30 mins used

FDG Tracer Kinetic Modeling

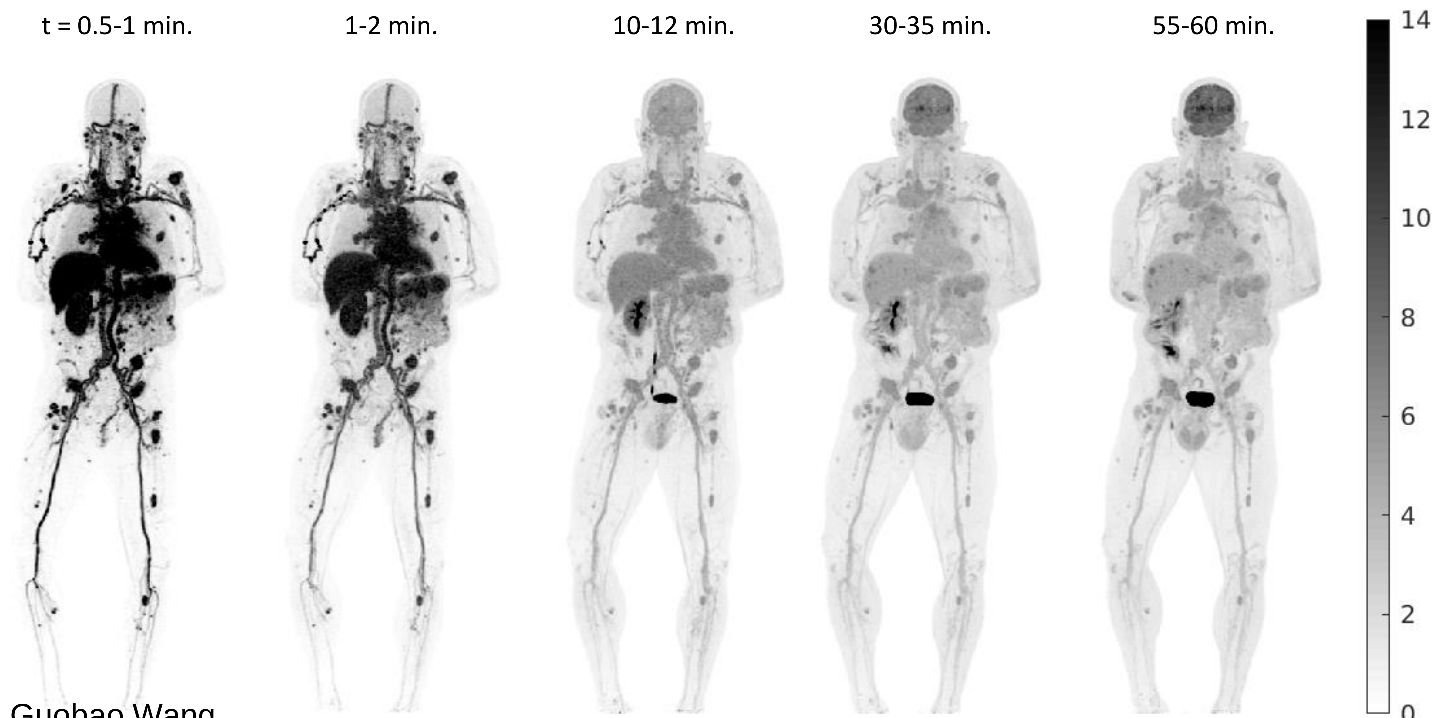


$$K_i = \frac{K_1 k_3}{k_2 + k_3}$$

FDG Influx Rate Constant, K_i *(ml/min/g)*

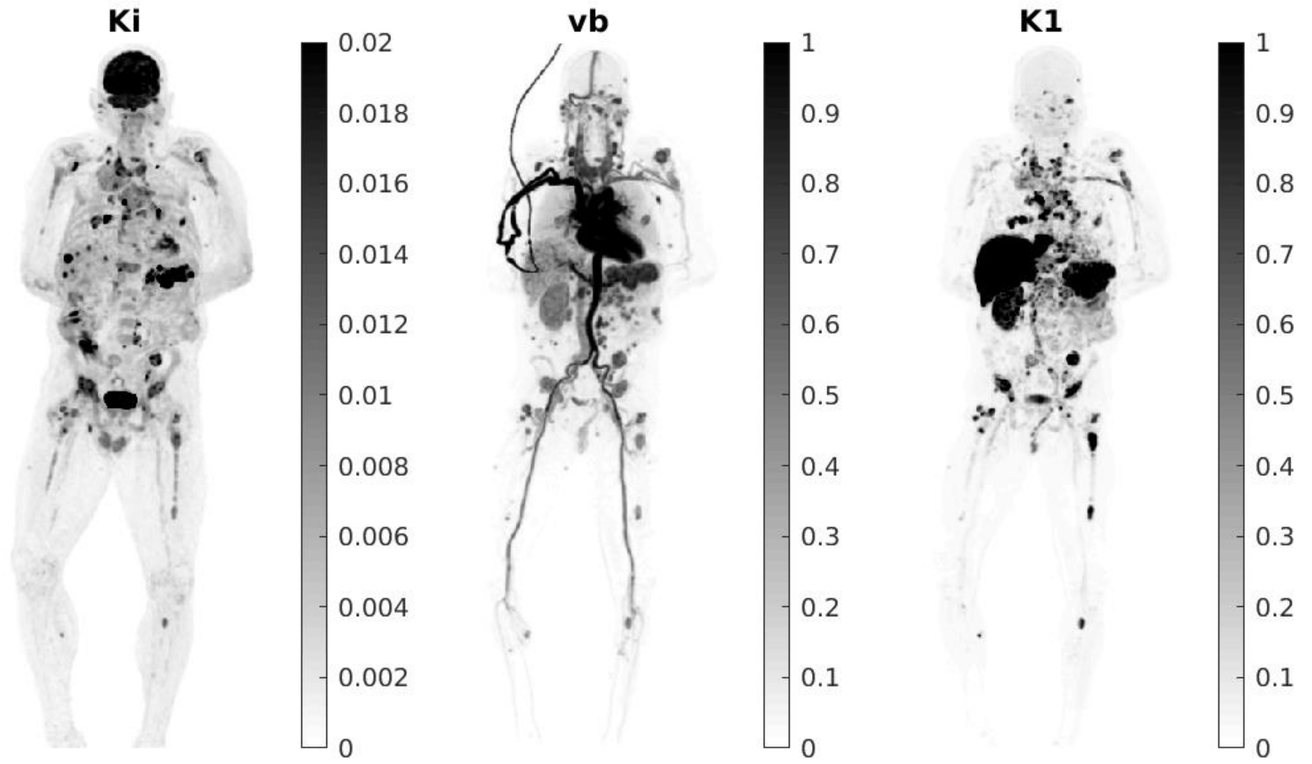
Total-Body Dynamic PET of Metastatic Cancer

^{18}F-FDG PET images of a patient with metastatic kidney cancer scanned on uEXPLORER (10 mCi injection; Patient weight: 76 kg; one-hour dynamic scan)



Courtesy of Dr. Guobao Wang

Multi-Parametric Imaging of Metastases and Organs



K_i: Overall FDG influx rate (ml/g/min)

v_b: fractional blood volume

K_1: glucose transport rate (ml/g/min)

Courtesy of Dr. Guobao Wang

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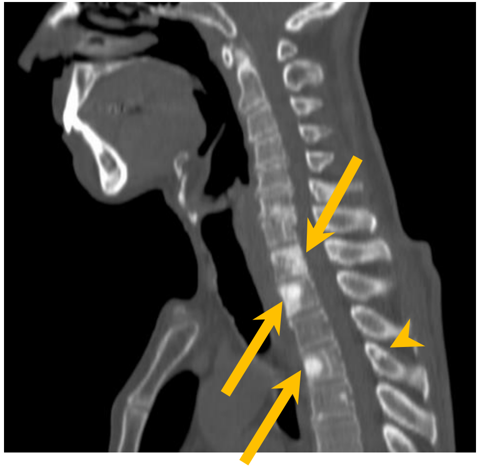
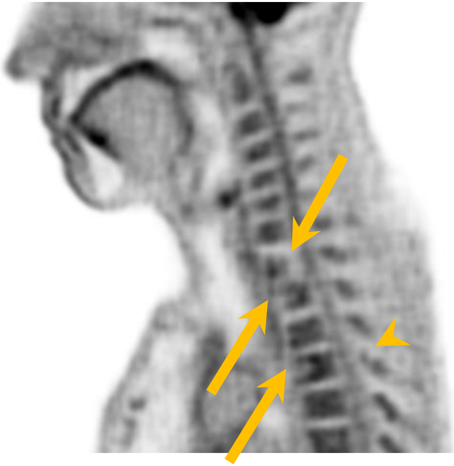
Clinical Case

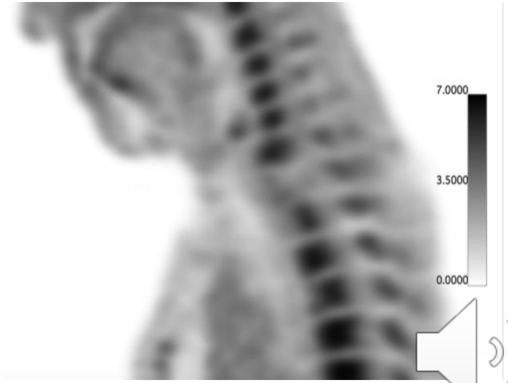
^{18}F-FDG

Protocol:
5 mCi (187 MBq) dose
20 min scan
Imaging at 120 mins p.i.

1.17 mm isotropic voxels







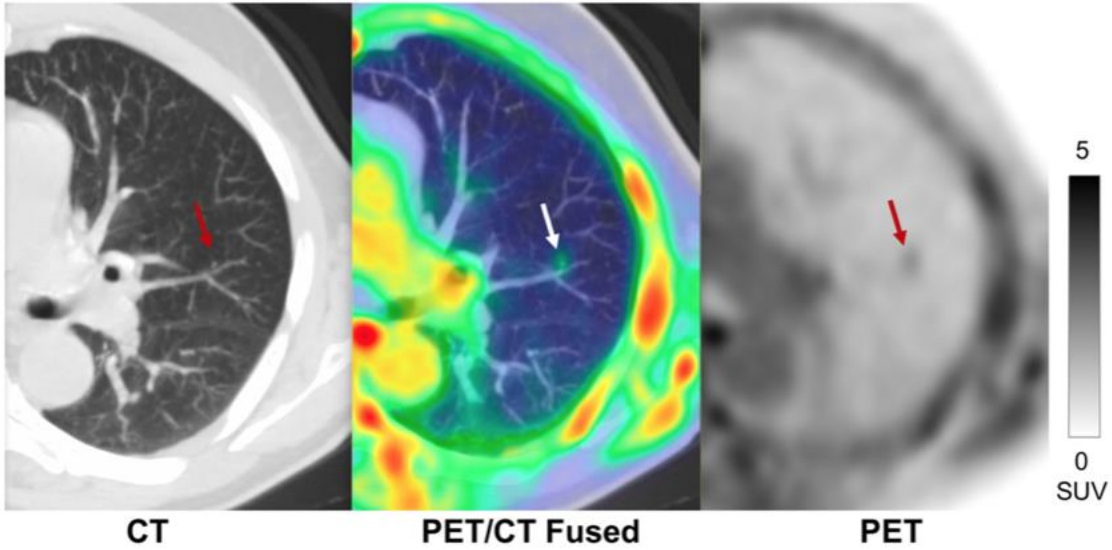
Clinical Case

^{18}F-flucyclovine

68-yr old male

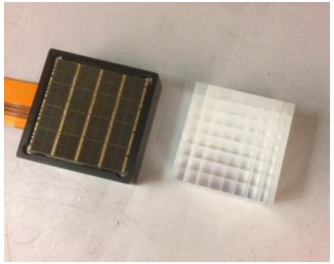
Castration-resistant metastatic prostate cancer

2.5 mm pulmonary nodule



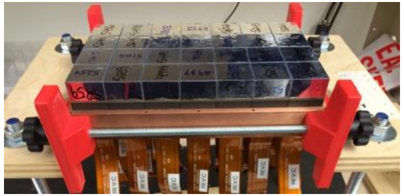
Technology for PennPET Explorer

Imaging chain components



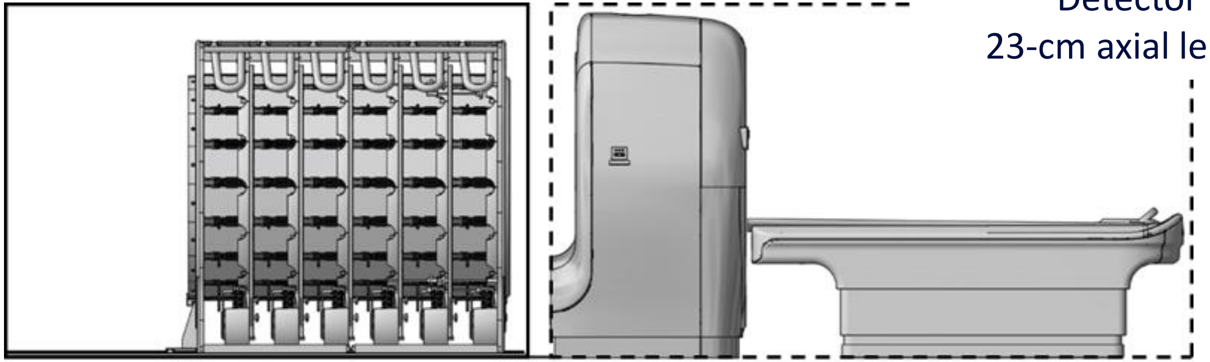
3.86 x 3.86 x 19 mm^3 LYSO
PDPC digital SiPM
64-channel array
1:1 coupling

Tile Stack

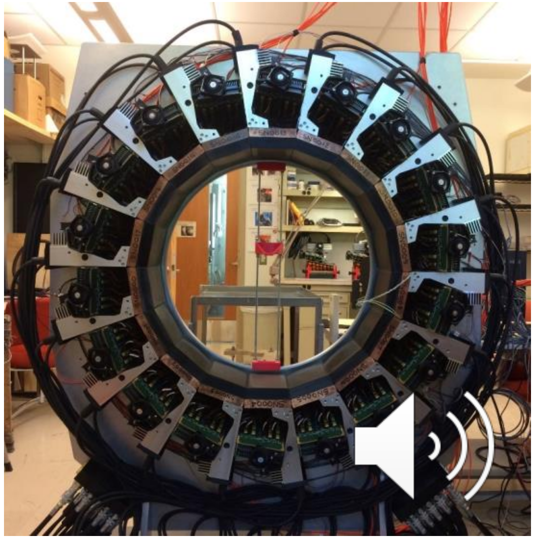


Detector module

Per ring



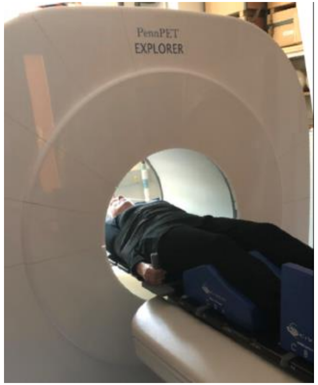
Detector ring:
23-cm axial length



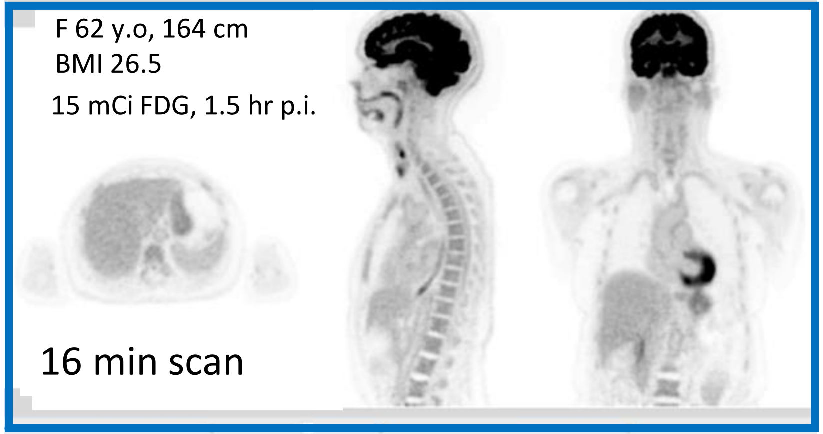
PennPET Explorer: FDG studies

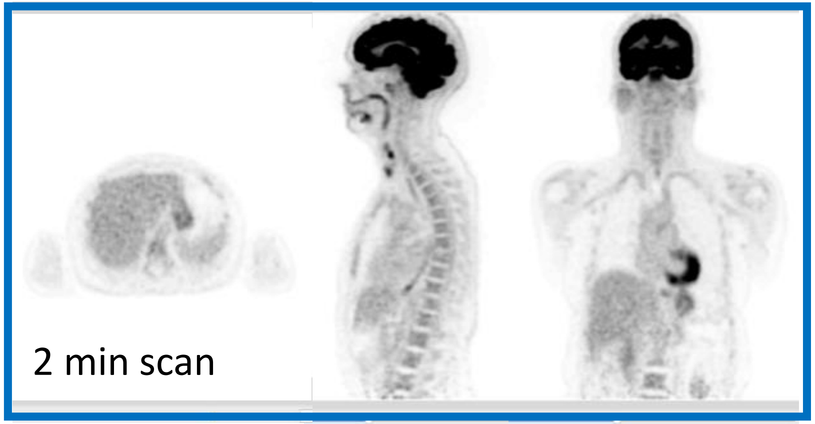
Prototype Configuration: 3 rings

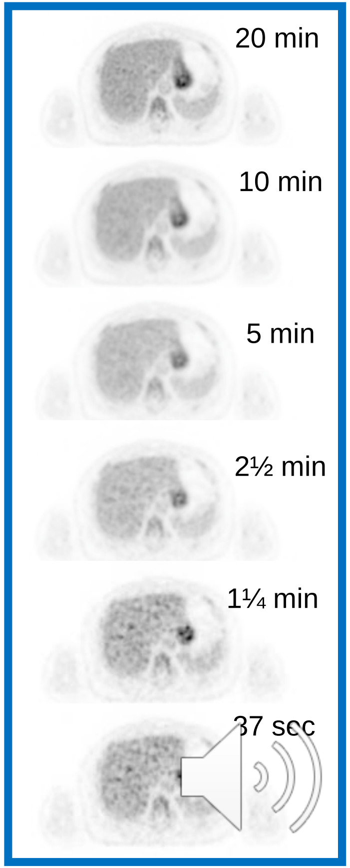
Expansion to 6 rings summer 2020



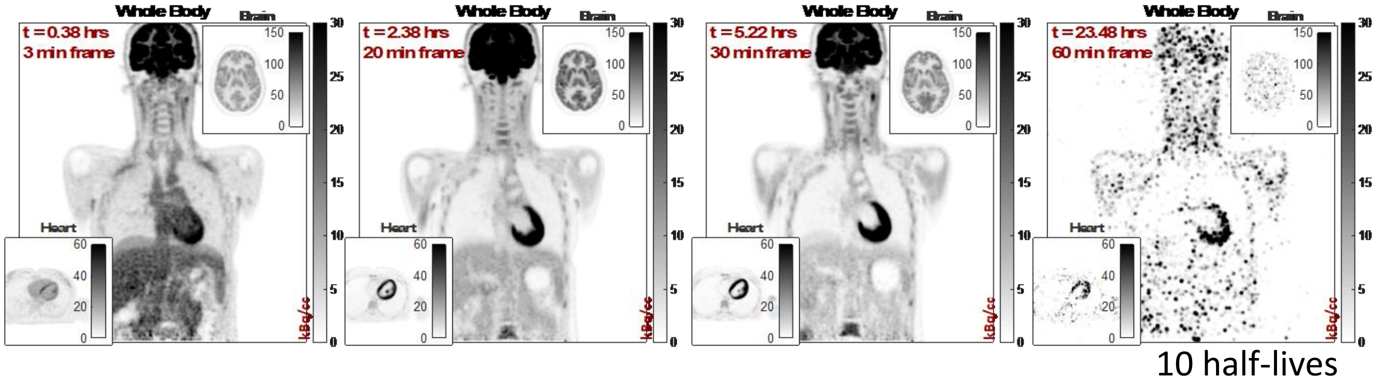
- NEMA performance measures
  - Spatial resolution: 4 mm
  - **TOF resolution: 250 ps**
  - Sensitivity: 55 kcps/MBq



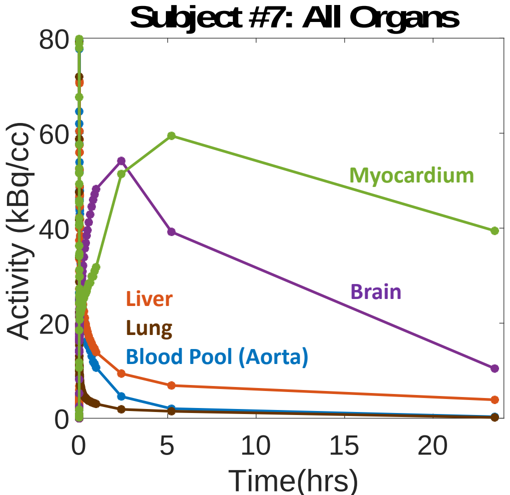


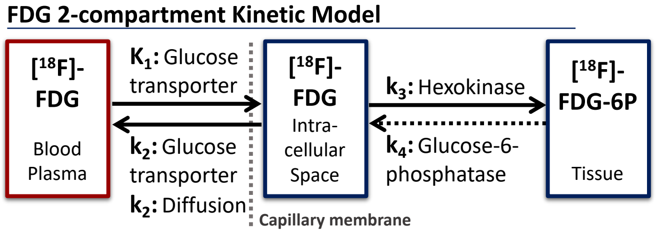


Delayed Imaging: capture slower biology



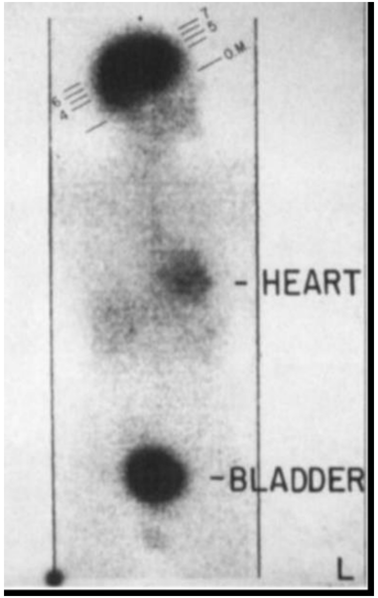
Comparison of brain to heart activity at 24 hrs (10 half-lives) better defines kinetic model





- Activity in the brain decreases over time implying that k_4 is non-zero and that G6Pase is activated to break down [^{18}F]FDG-6P
- Activity in the myocardium decreases more slowly over time implying t[illegible] k_4 is near zero and that G6Pase is not active in the myocardium

We have come a long way…



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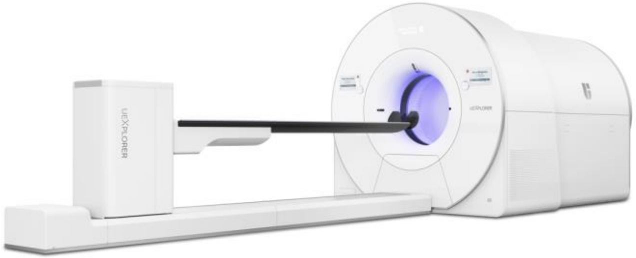
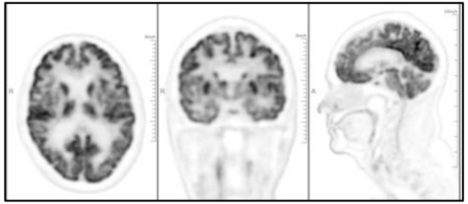
Courtesy Abass Alavi



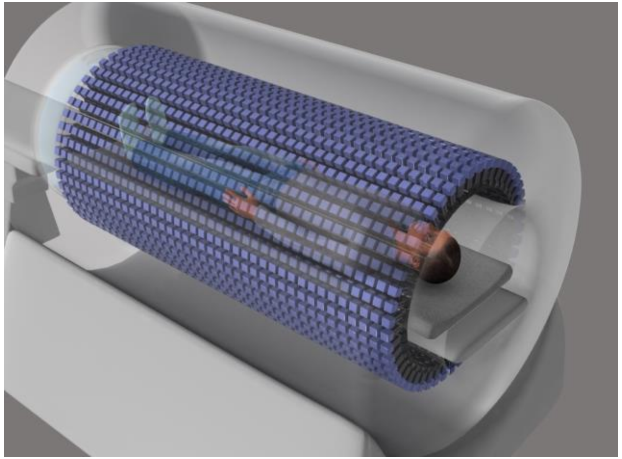


2019

Summary

First total-body and long axial FOV PET/CT scanners have been built.

Early clinical and research results are very promising.



Future areas for focus:

- Handling big data
- Cost
- Motion correction
- Total-body modeling

- Developing impactful research and clinical applications

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Acknowledgements

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PennPET EXPLORER Team

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Xinyu Lv	Shaohui An	Shaoping [illegible]u
Yu Ding	Debin Hu	Ping Zhou
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