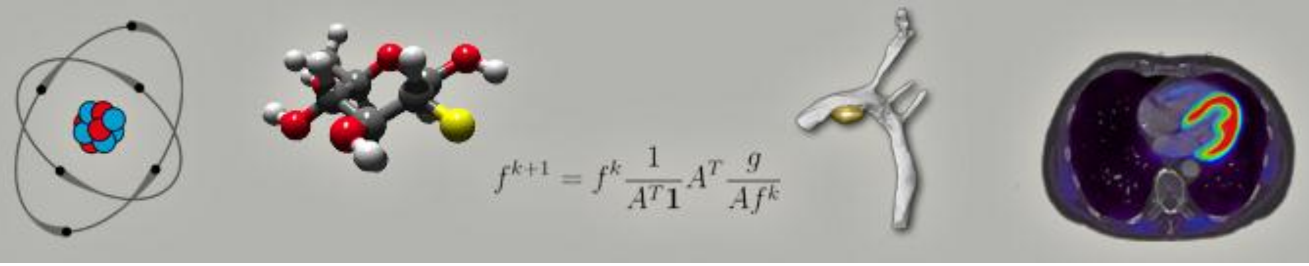


CiM Cells in Motion

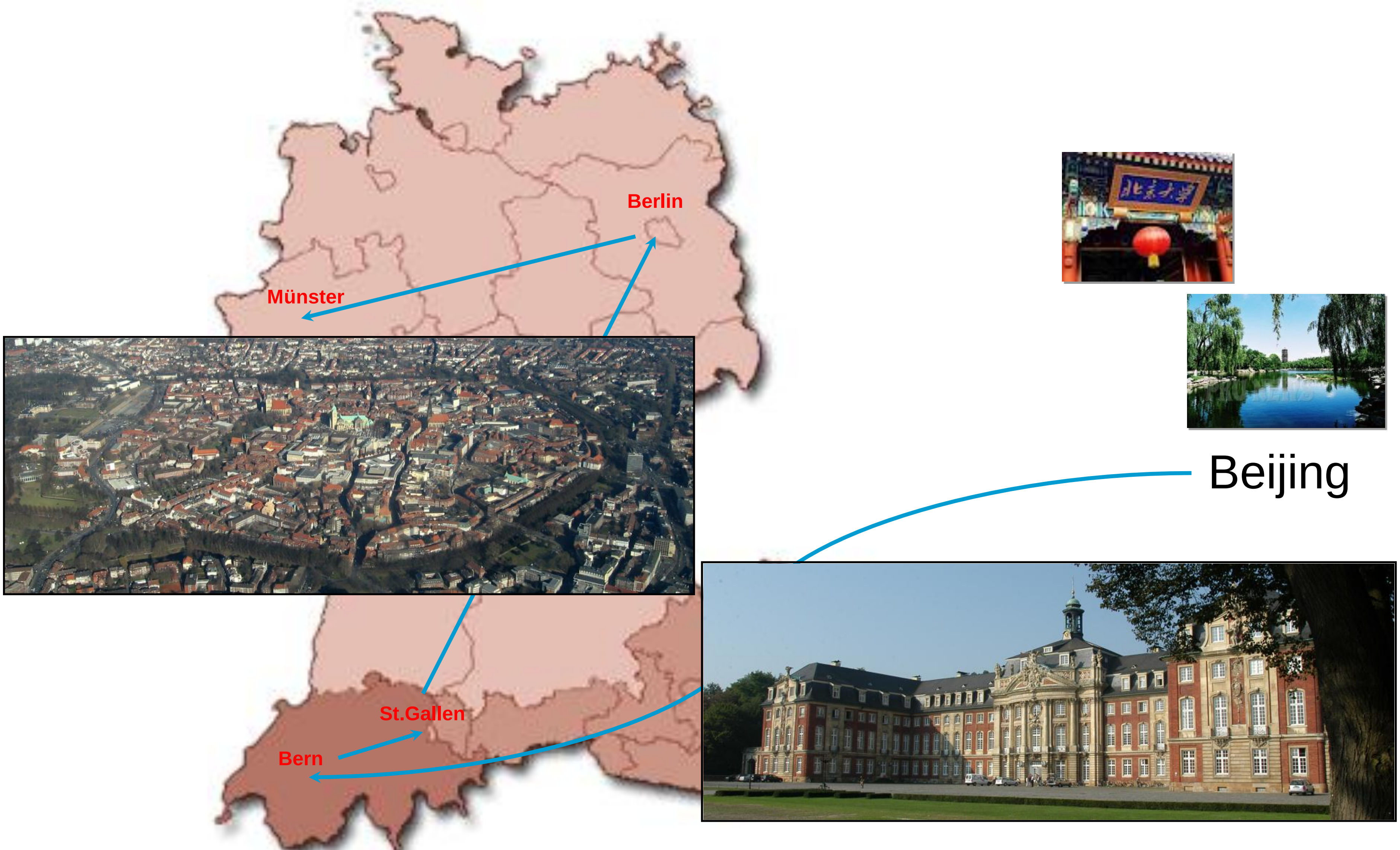
Motion Analysis in Medical Imaging
- Some Münster Perspective -

Xiaoyi Jiang
Department of Mathematics and Computer Science
University of Münster
Germany

Westfälische Wilhelms-Universität Münster

European Institute for Molecular Imaging

All roads lead to Münster



Outline

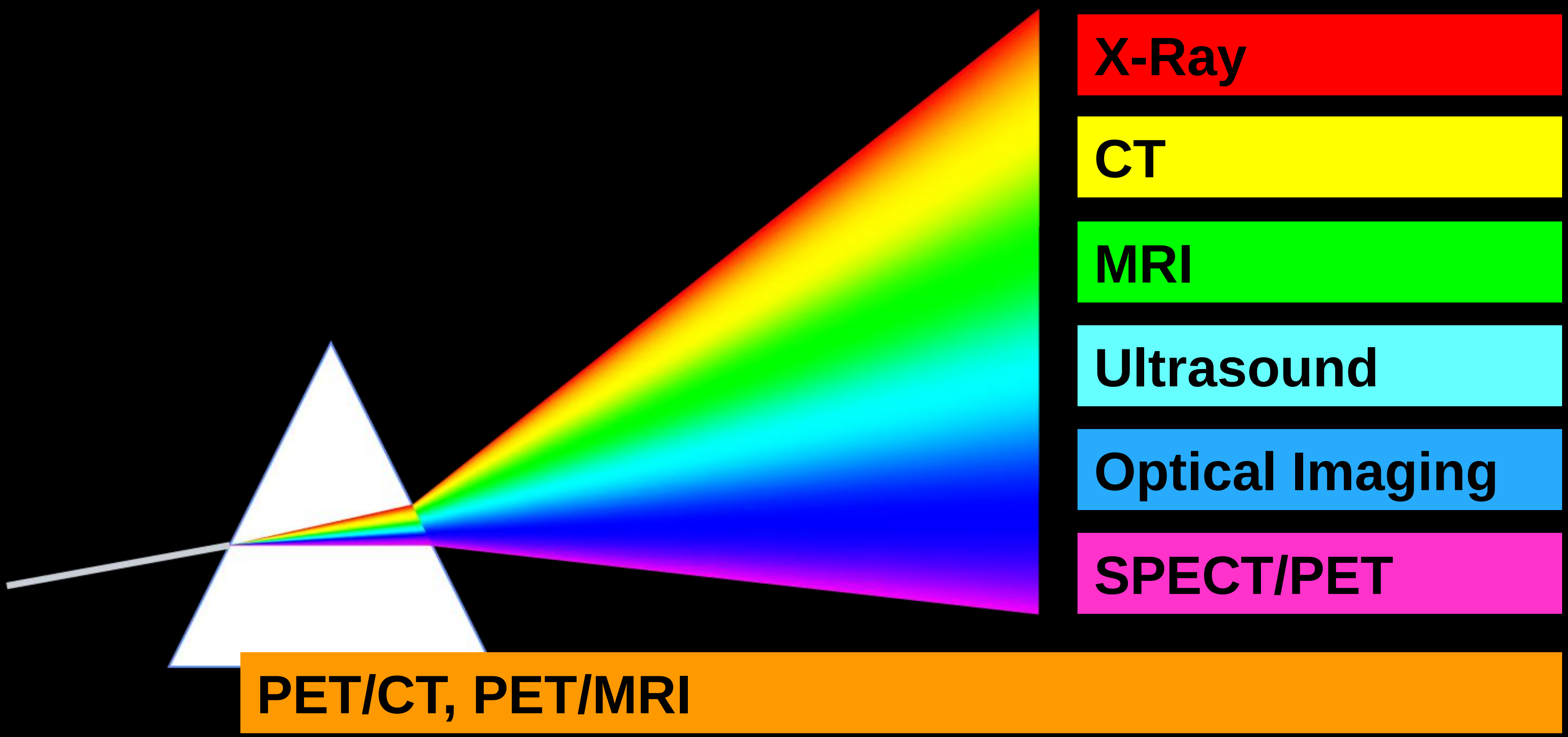
- Medical imaging, in particular gated PET imaging
- Motion detection and correction in gated PET
- Motion estimation in ultrasound imaging

- Freely moving animal PET imaging

Medical imaging modalities

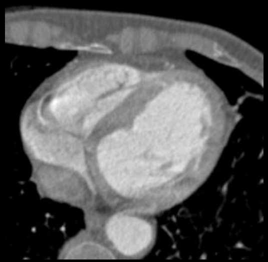
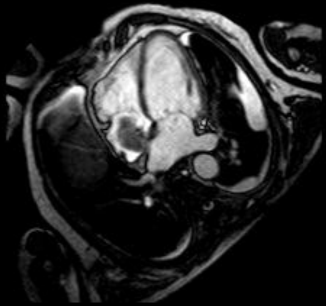
Question ▶ Diagnostics ▶ Modalities

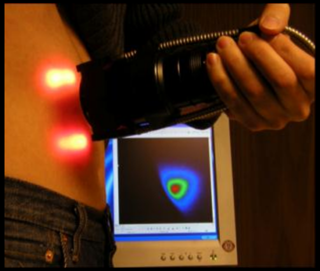
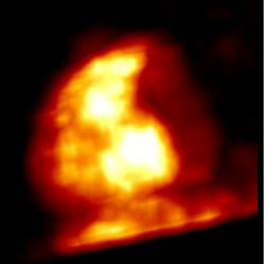
Morphology ▶ Function ▶ Molecules



Medical imaging modalities

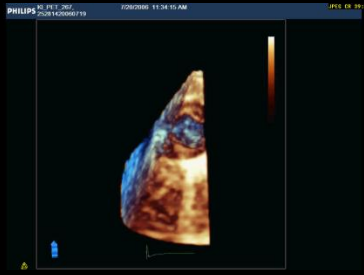
CT	MRI	Ultrasound	Optical	PET

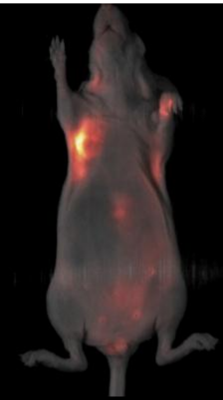
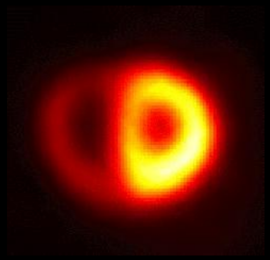



Men





Mice

PET imaging

PET (Positron Emission Tomography) / CT:

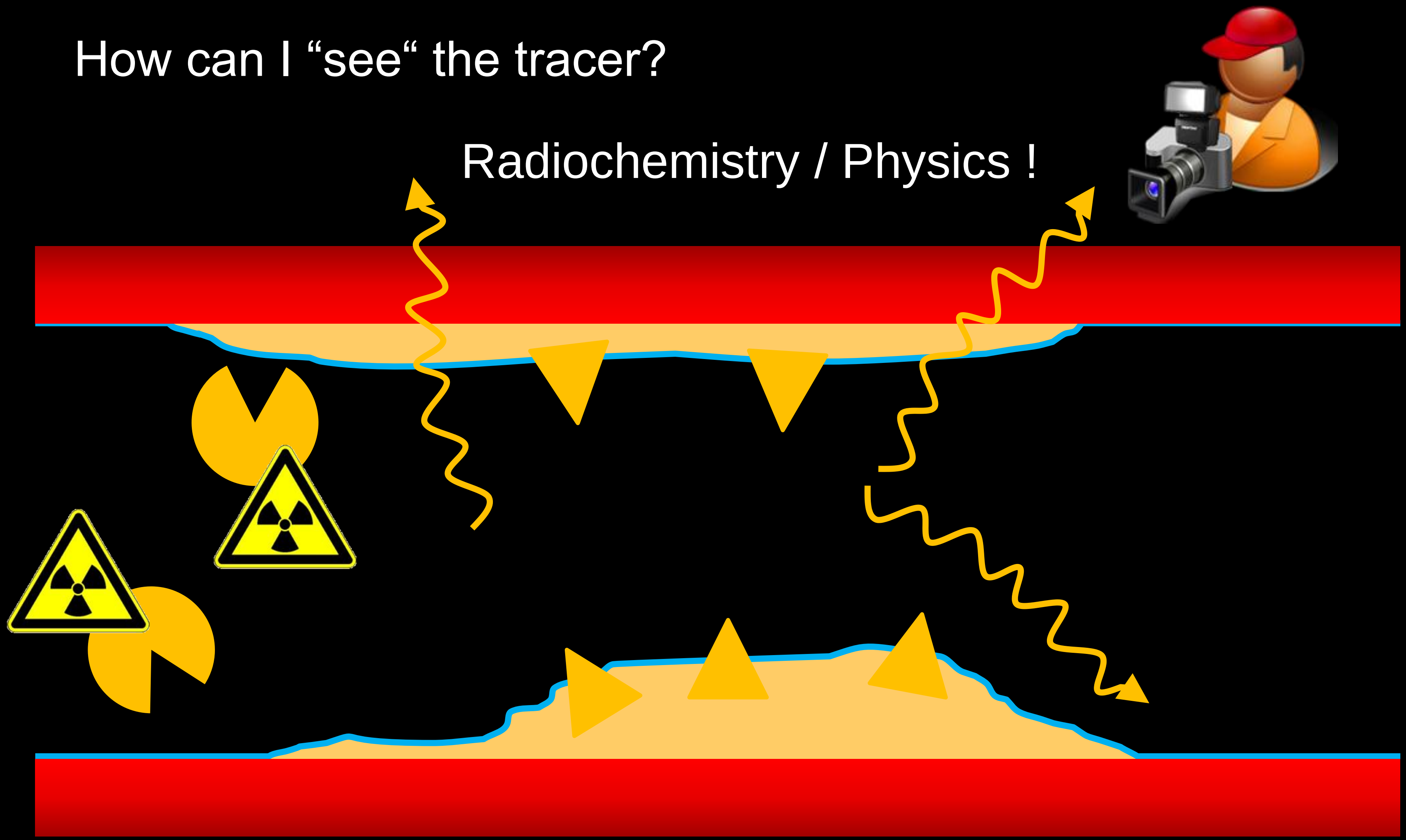
Achieve functional (metabolic) and anatomic images of patients simultaneously

Siemens Biograph Sensation 16 PET/CT scanner in our study:
384 detectors, 24 rings/slices and 16.2cm length per bed position

PET imaging

How can I “see“ the tracer?

Radiochemistry / Physics !

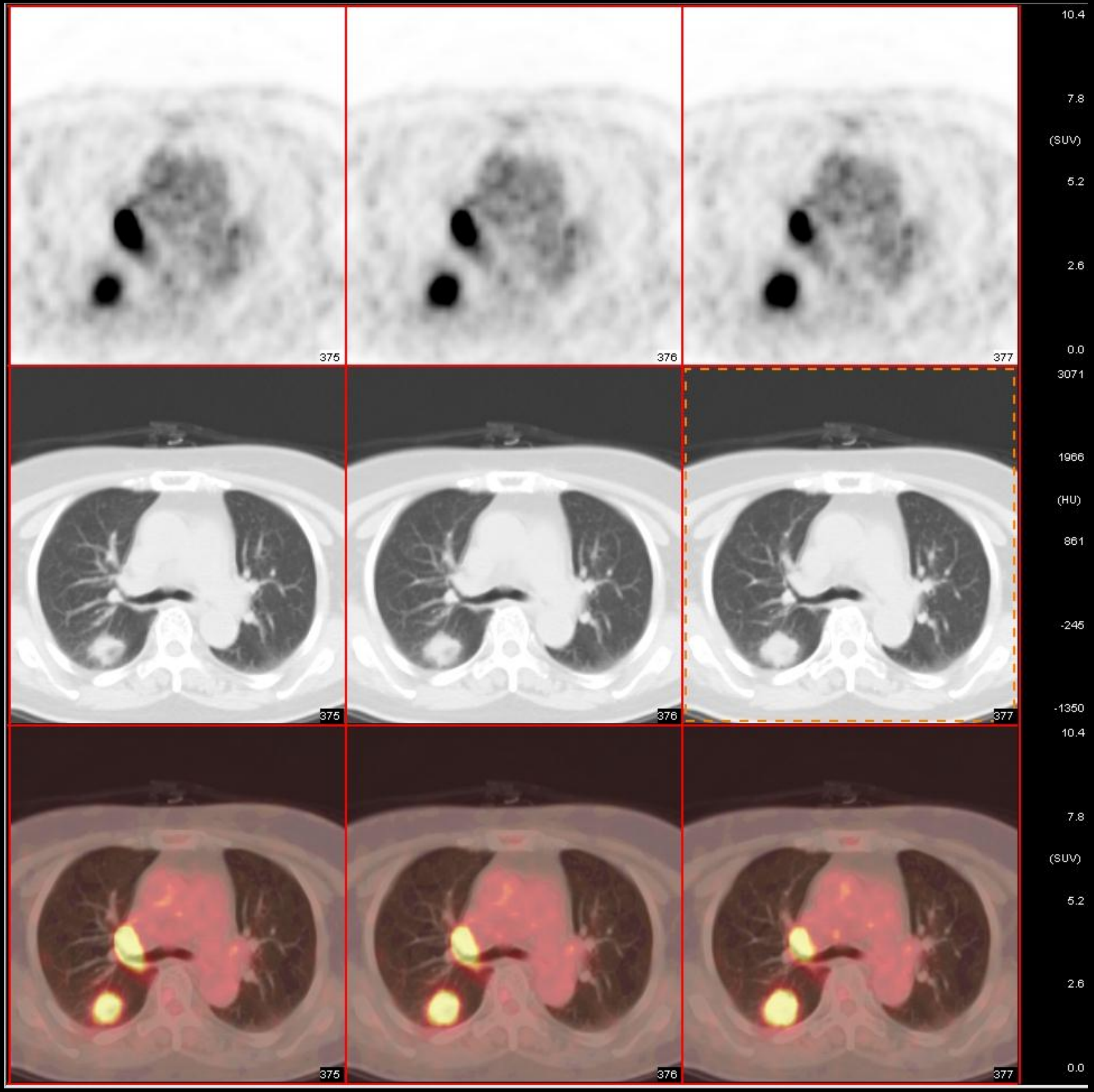


PET imaging

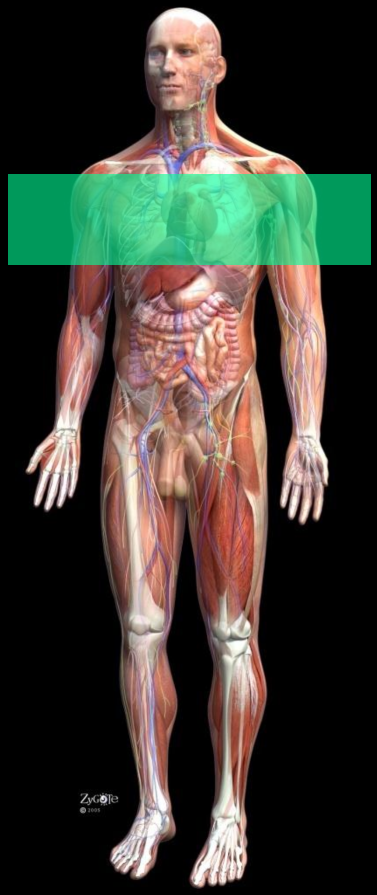
PET (functional)

CT (anatomic)

PET/CT



PET imaging



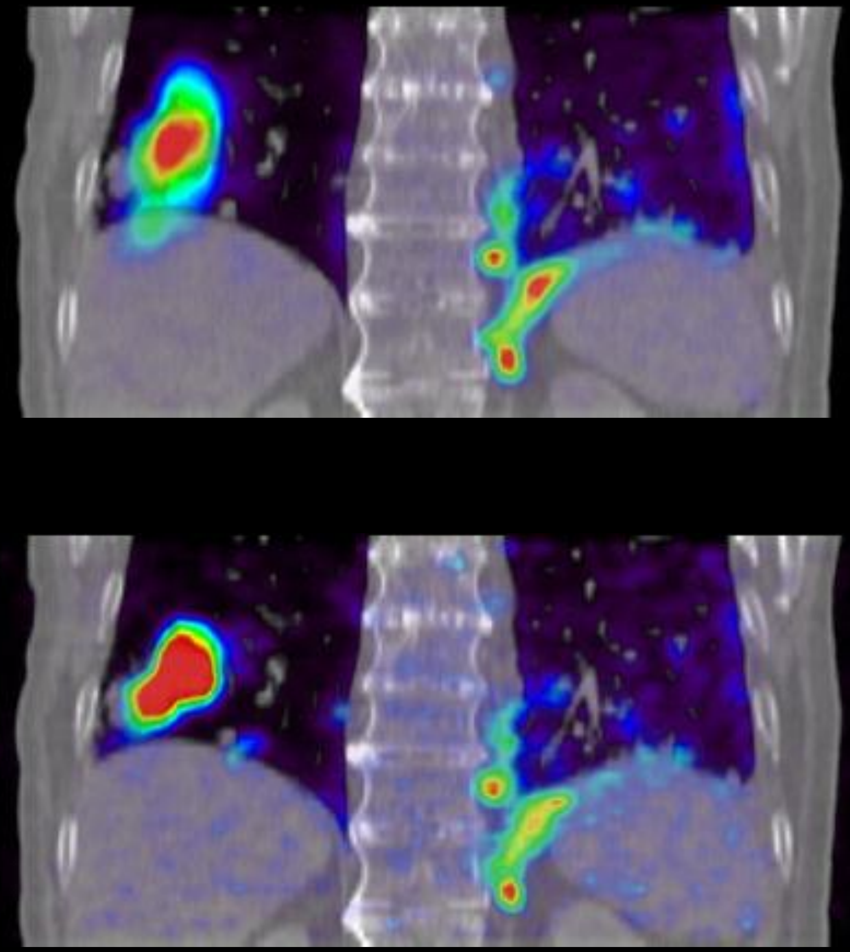
PET: minutes while breathing

CT: seconds while breath hold

PET imaging: Respiratory gating

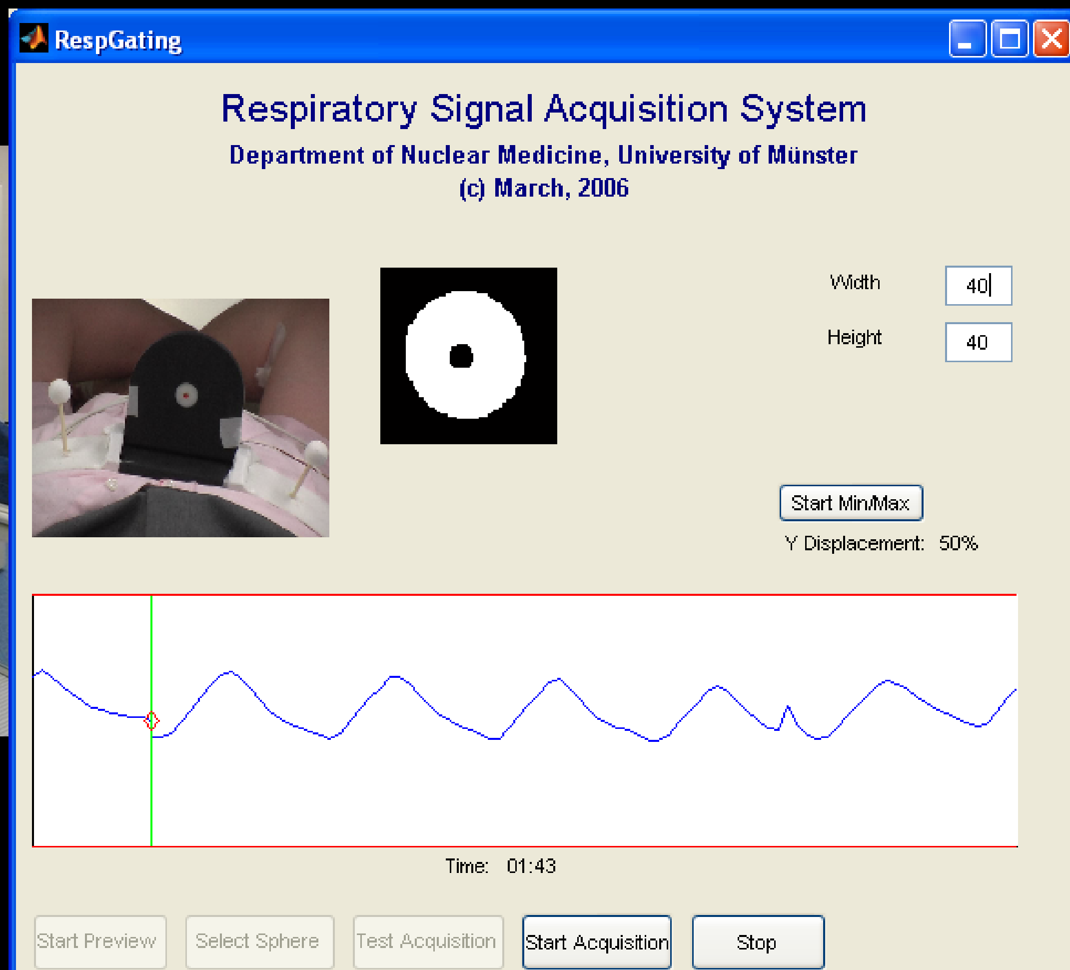
[^{18}F]-FDG-PET/CT

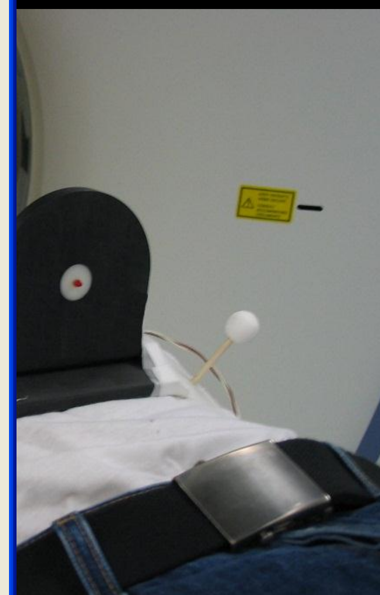
1 h p.i. 5 MBq/kg FDG i.v.
3D-CT
Listmode-PET (10 min)



PET: without attenuation correction

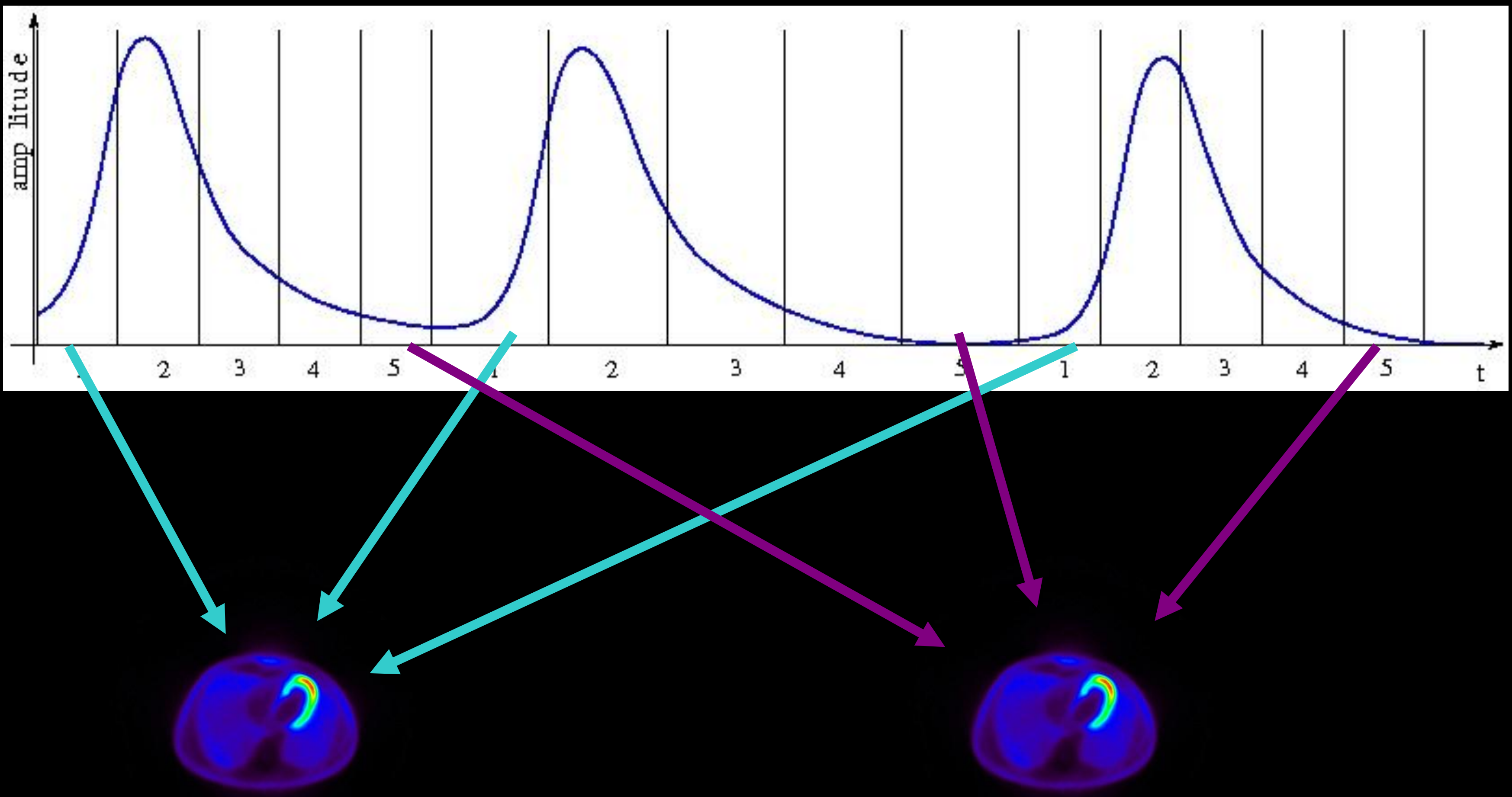
Method: Respiratory signal acquisition





PET imaging: Respiratory gating

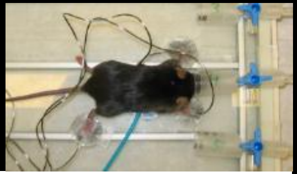
Gating: List-mode PET data are resorted

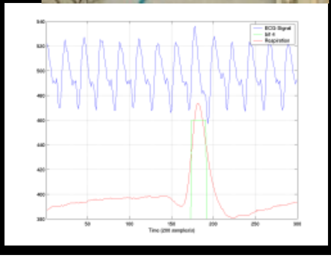


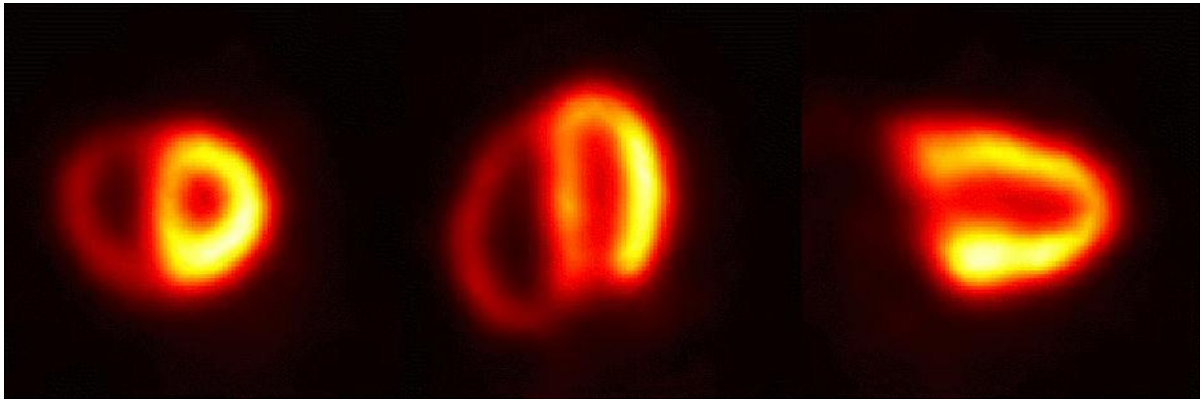
PET imaging: Mouse heart

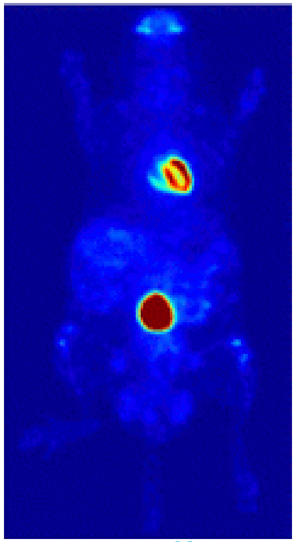
Listmode Acquisition (ECG gating)

Mouse:	27 g, heart rate 500 bpm
Acquisition:	30 min, 1h p.i., 12 MBq FDG
Reconstructed gates:	8

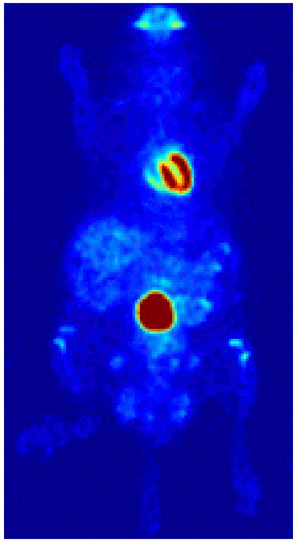








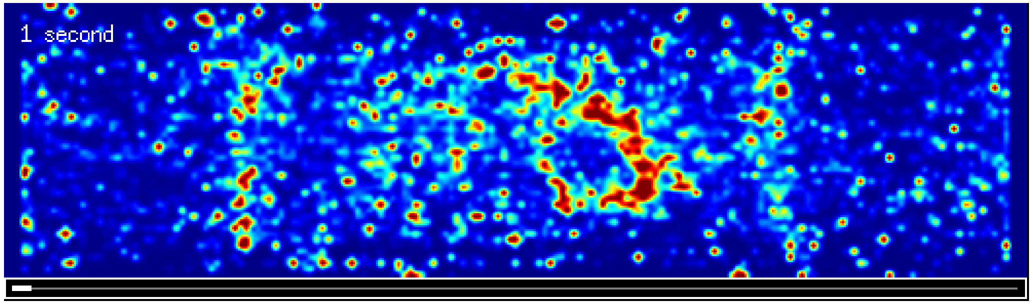
cardic



resp.

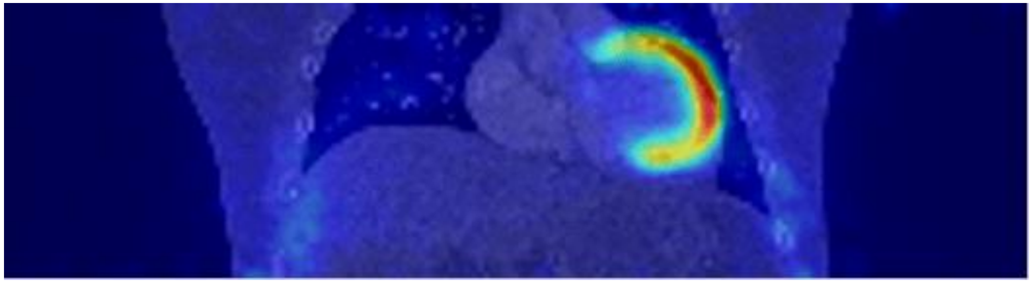
Motion correction in gated PET

Noise:
(static, no motion)

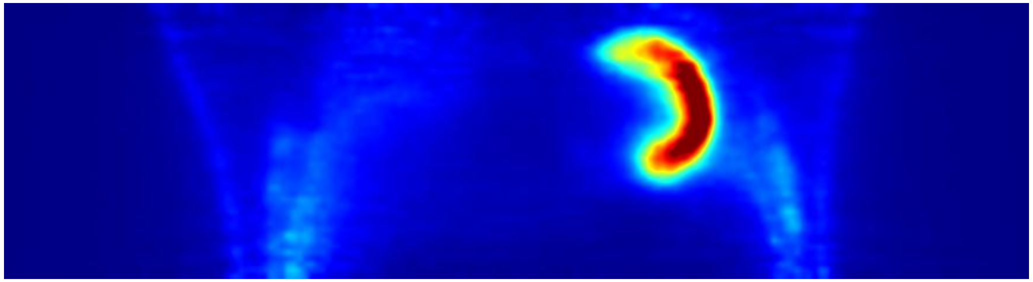


(GATE simulation of the XCAT phantom; data from Michael Fieseler)

Motion:
(20 min patient scan,
dual gating)



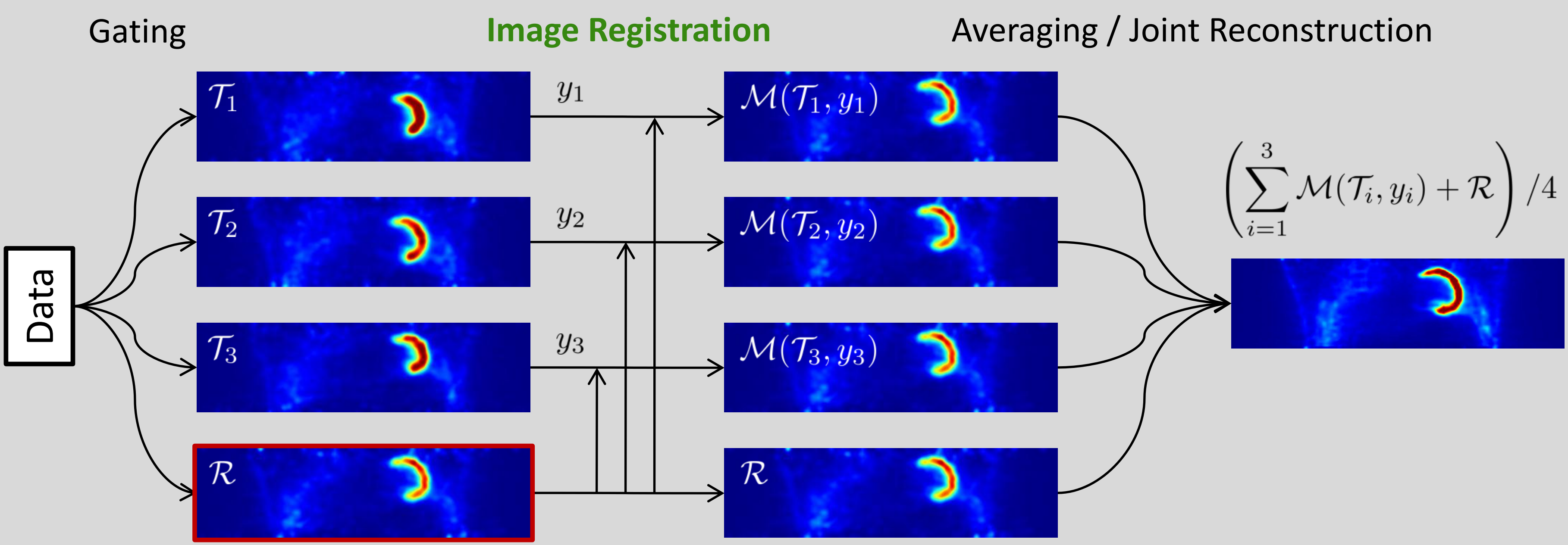
Reconstruction:
(20 min patient scan,
no gating)



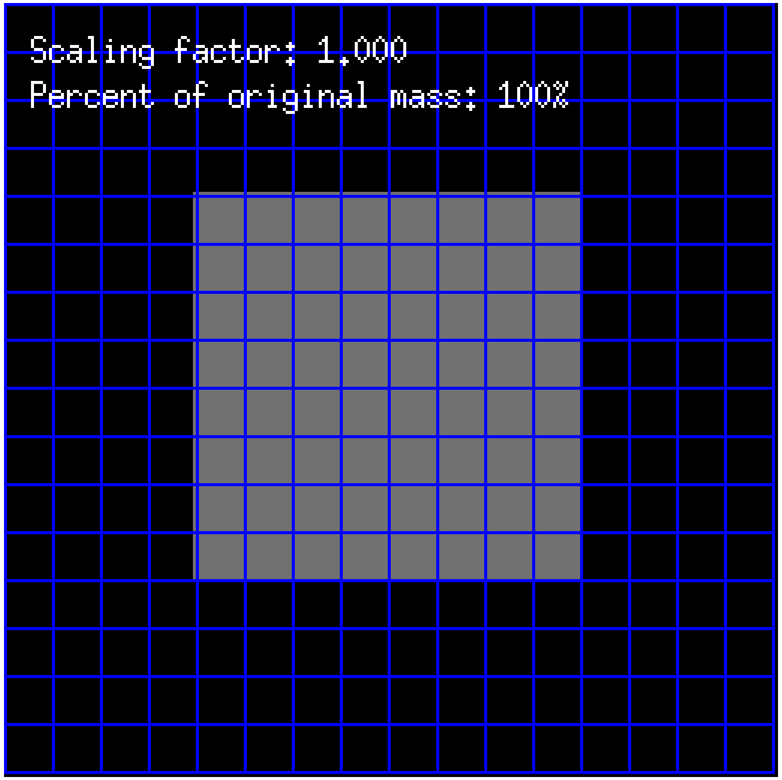
Motion correction in gated PET

Without motion correction:

With motion correction:

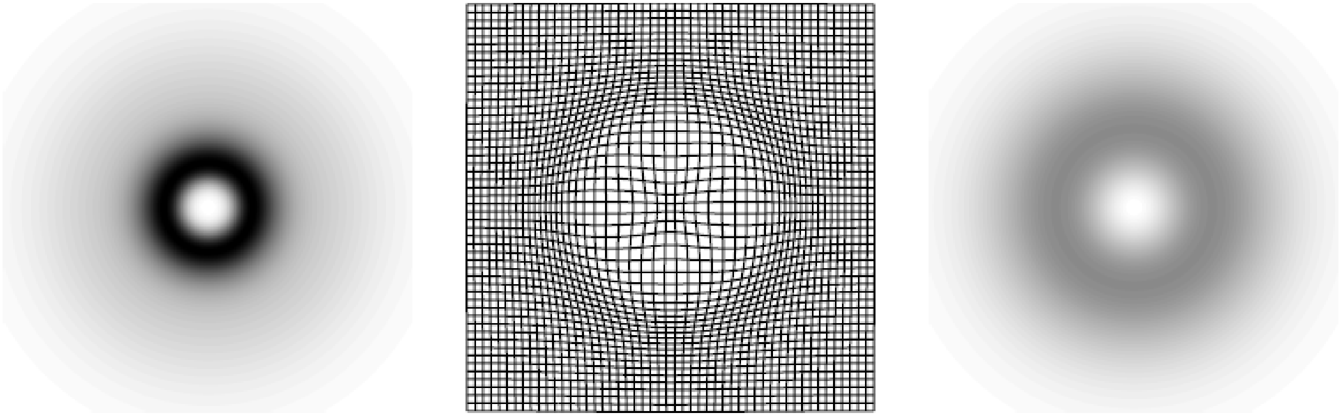


without mass-preservation



Motion estimation:
first idea

Motion correction: Mass-preserving



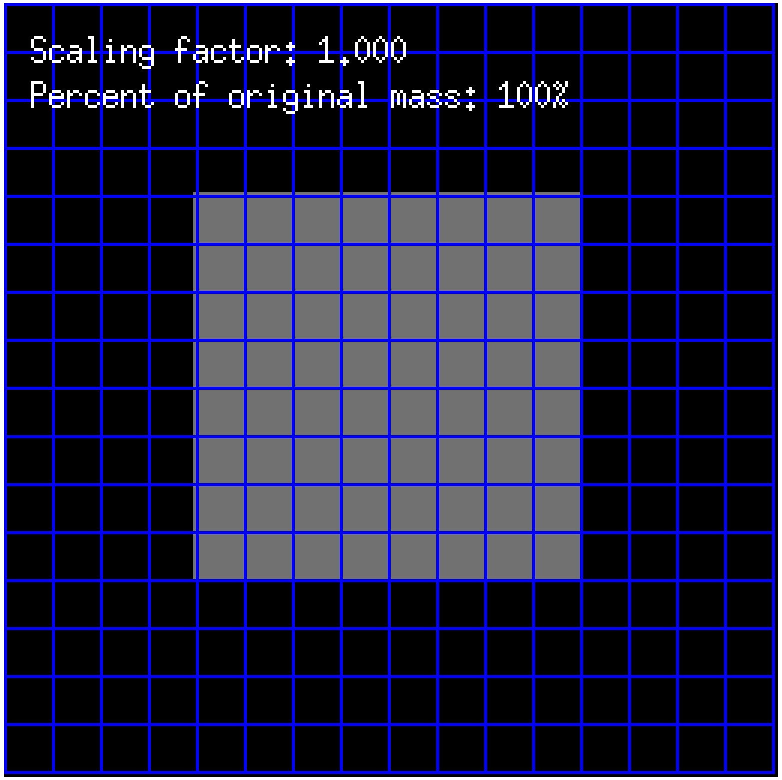
(a) $\mathcal{R}$ (b) Original grid (c) $\mathcal{T}$

Reference image *R* created from analytically defined template image *T*; original grid

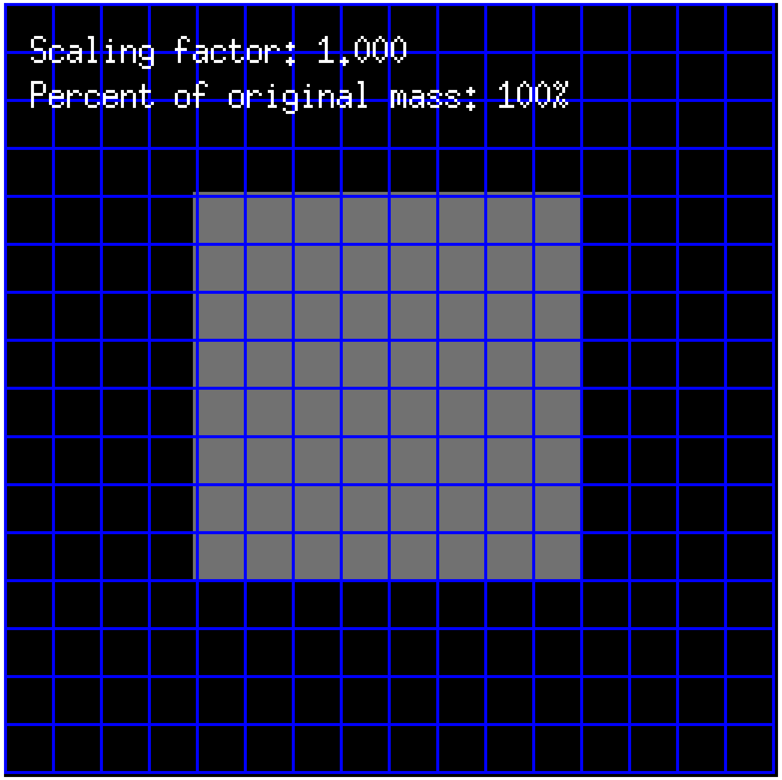
- We need a process, which not only spatially transforms the pixels, but also redistributes the intensity values (intensity modulation)
- ~ same amount of radioactivity of each gate

Motion correction: Mass-preserving

without mass-preservation



with mass-preservation



Motion correction: Mass-preserving

CiM
Cells in Motion

$\mathcal{T} : \Omega \subset \mathbb{R}^d \to \mathbb{R}$, template image

$\mathcal{R} : \Omega \subset \mathbb{R}^d \to \mathbb{R}$, reference image

$y : \mathbb{R}^d \to \mathbb{R}^d$, transformation

$\mathcal{D}$ = distance measure (SSD)

$\mathcal{S}$ = regularization term

α = weighting factor

Mass-preserving image registration:

“Standard” image registration:

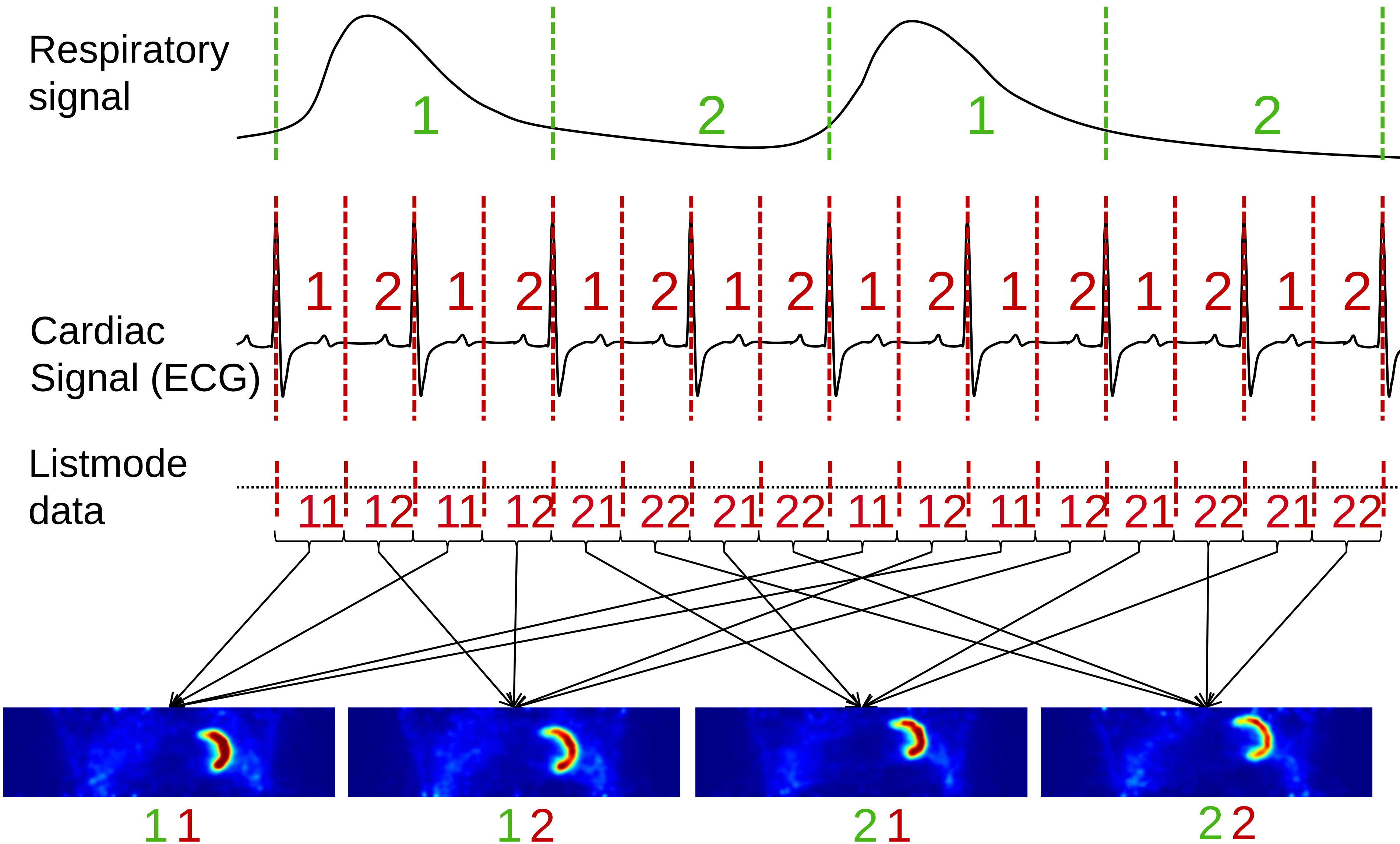
$$\mathcal{J}(y) = \mathcal{D}[(\mathcal{T} \circ y) \cdot \det(\nabla y),\ \mathcal{R}] + \alpha \cdot \mathcal{S}[y] \xrightarrow{y} \min$$

Idea:

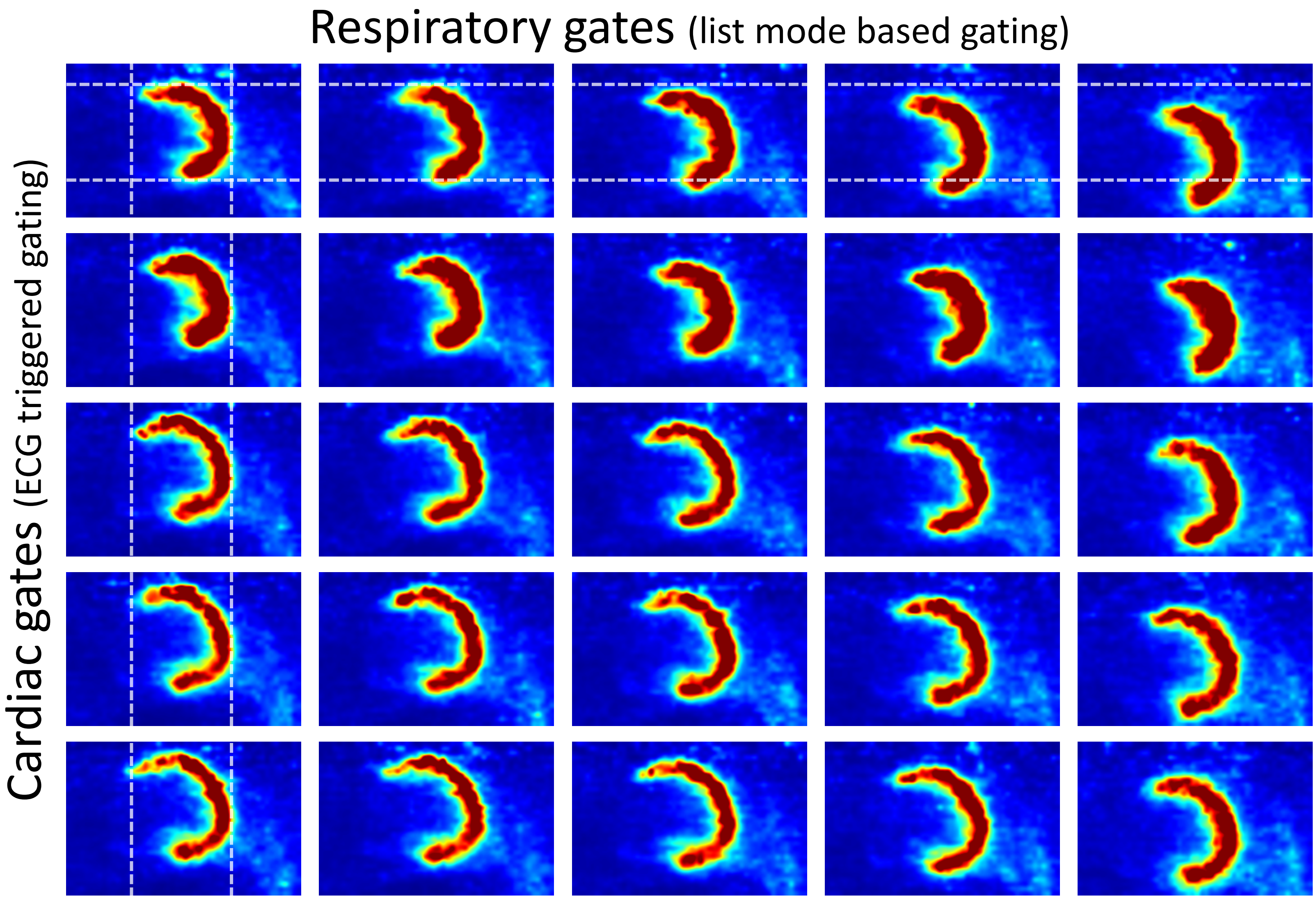
- Include the volumetric change $\det(\nabla y)$ (Jacobian determinant) due to the transformation into the transformation model

  → intensity modulation

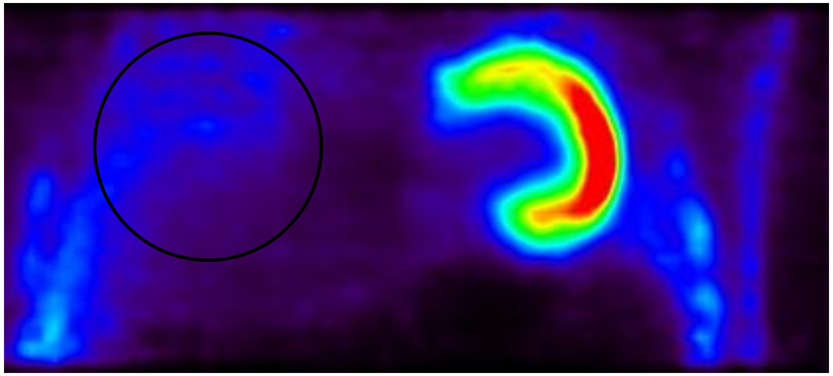
Motion correction: Mass-preserving



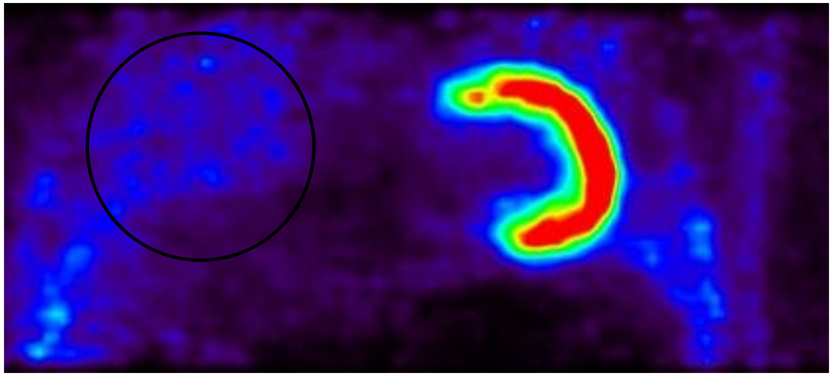
Motion correction: Mass-preserving



Motion correction: Mass-preserving

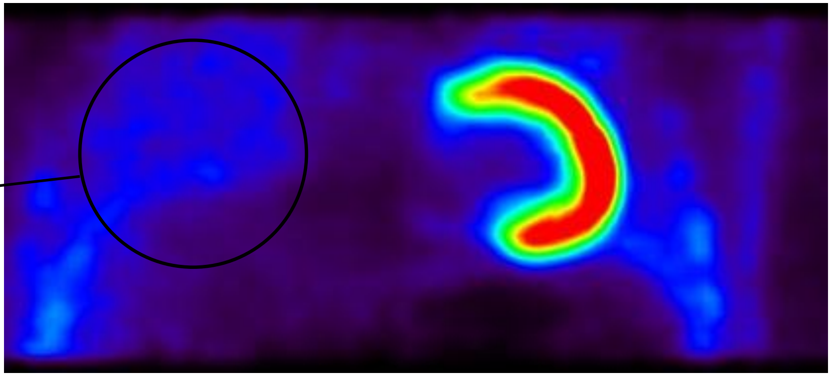


non gated PET
good SNR; motion contaminated



respiratory gated PET
bad SNR; few motion

fully motion corrected PET
all coincidence information



good SNR
few motion

Gigengack et al. IEEE-TMI 2012

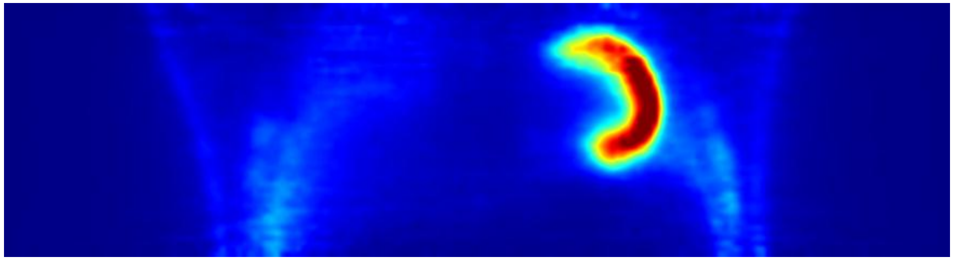
Motion correction: Mass-preserving

Patient: 20 min

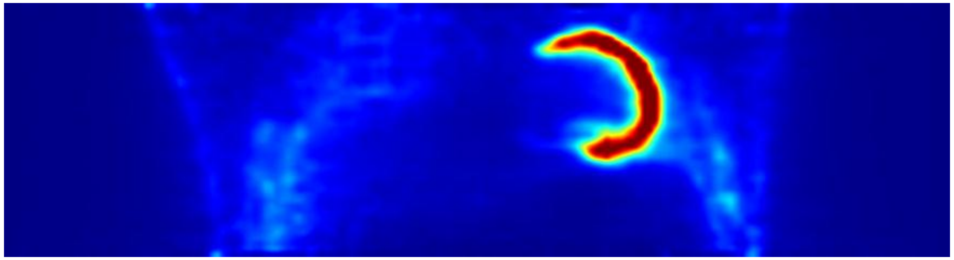
Dual gating:
- 5 respiratory gates
- 5 cardiac gates

Settings:
- linear interpolation
- Gauss-Newton
- CG-solver

Image without gating

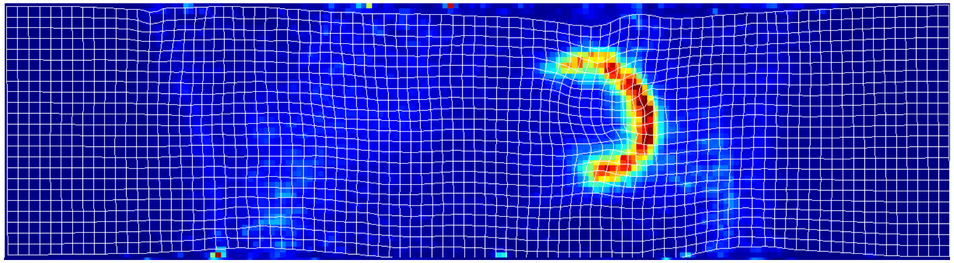


After motion correction



Reference image (48 sec)

Template image + grid (48 sec)



Motion correction: Mass-preserving

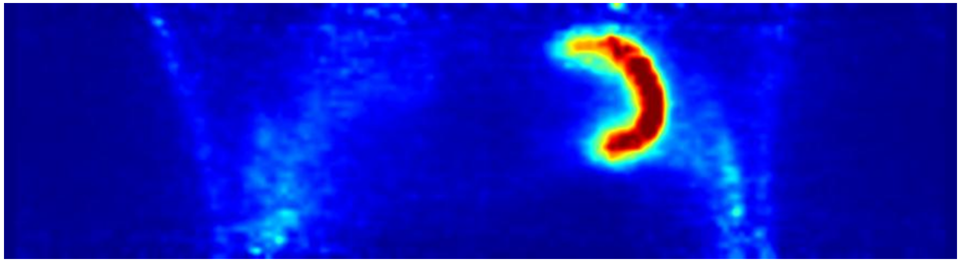
CiM
Cells in Motion

Patient: 3 min

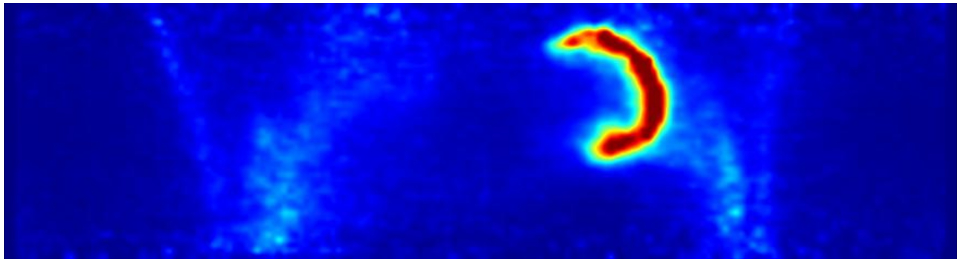
Dual gating:
- 5 respiratory gates
- 5 cardiac gates

Settings:
- linear interpolation
- Gauss-Newton
- CG-solver

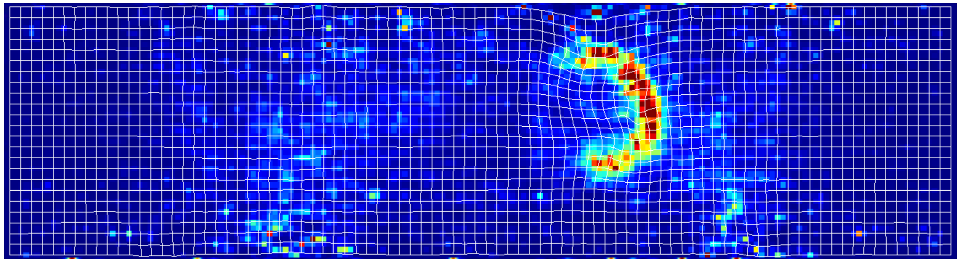
Image without gating



After motion correction



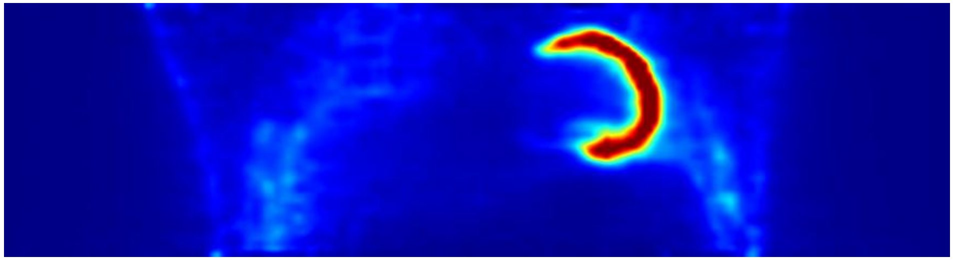
Reference image (7,2 sec)
Template image + grid (7,2 sec)



Motion correction: Mass-preserving

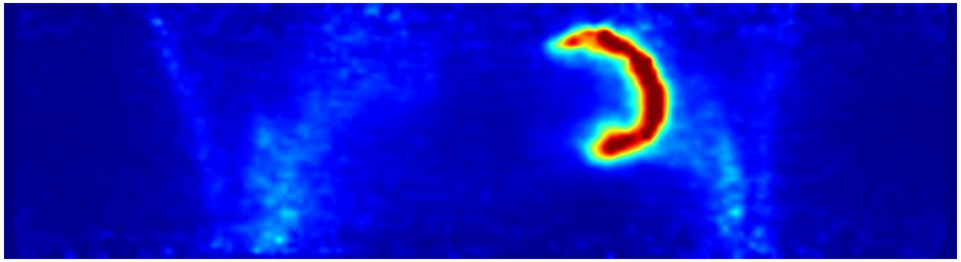
Patient: 20 min

After motion correction



Patient: 3 min

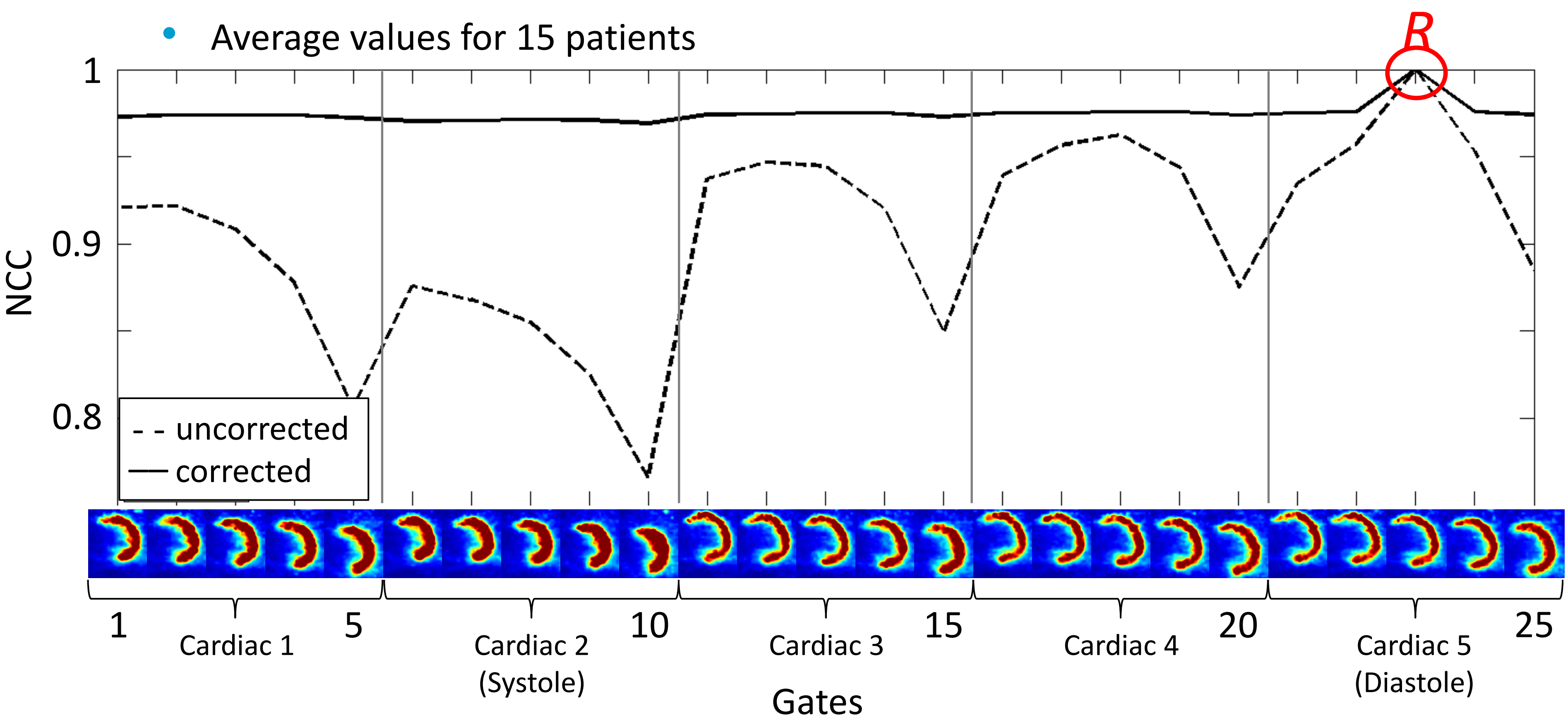
After motion correction



Motion correction: accuracy study

Patient study (n= 15)

- Normalized Cross Correlation (NCC)
- Average values for 15 patients



Gigengack et al. IEEE-TMI 2012

Alternative: Mass-preserving optical flow

$$\underbrace{f \cdot \nabla I + I_t}_{\text{brightness constancy}} + \underbrace{I \cdot div(f)}_{\text{redistribution}} = div(I \cdot f) + I_t = 0$$

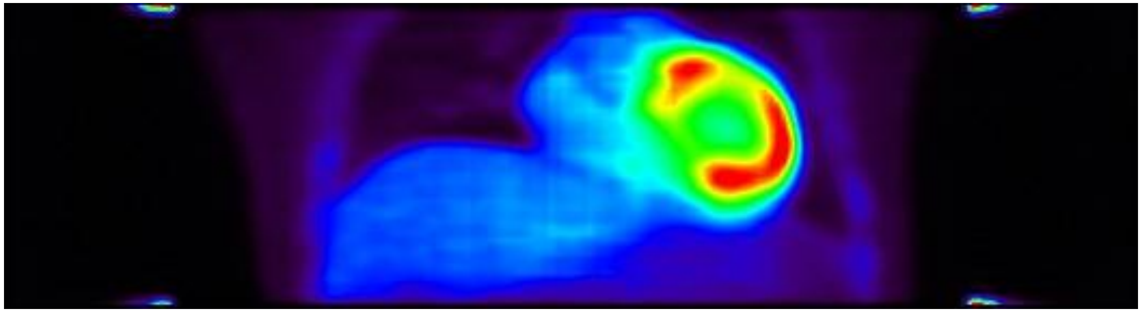
$$\downarrow$$

$$E = \iint_{\Omega} (div(I \cdot f) + I_t)^2 + \alpha(|\nabla u|^2 + |\nabla v|^2)\ dxdy$$

M.Dawood, F.Gigengack, X.Jiang, K.Schäfers: *A mass conservation-based optical flow method for cardiac motion correction in 3D-PET*. Medical Physics (under revision).

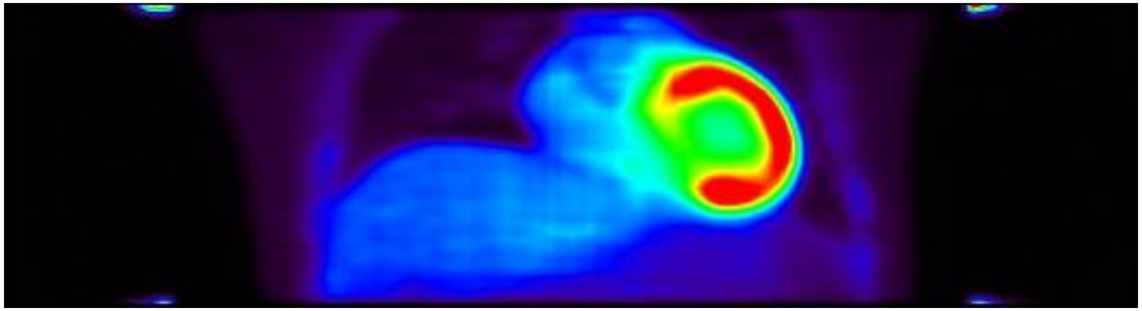
Motion detection and correction in PET

without motion correction (indication of infarction)

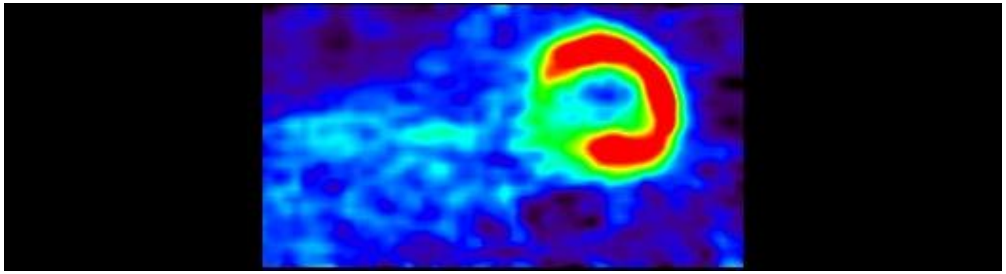


with motion correction

PET data after attenuation correction with CT based mu-map



PET data with Ge based attenuation (validation data)



Histogram-based optical flow in ultrasound

D.Tenbrinck, S.Schmid, X.Jiang, J.Stypmann, K.Schäfers: *Histogram-based optical flow for motion estimation in ultrasound imaging*. Journal of Mathematical Imaging and Vision (under revision).

Histogram-based optical flow in ultrasound

Based on the multiplcative noise model (speckle noise):

$$\tilde{I}(\boldsymbol{x}) = I(\boldsymbol{x}) + s_\sigma(\boldsymbol{x}) \cdot \sqrt{I(\boldsymbol{x})}$$

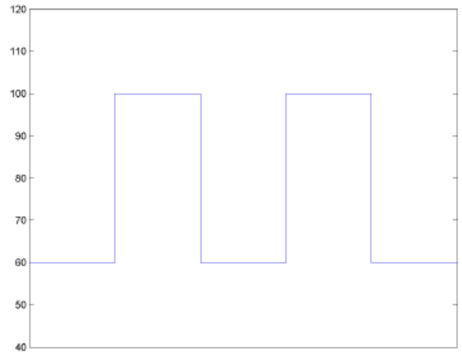
the histogram consistency (instead of intensity consistency) is proposed:

$$H(x, y, t) = H(x + u, y + v, t + 1)$$

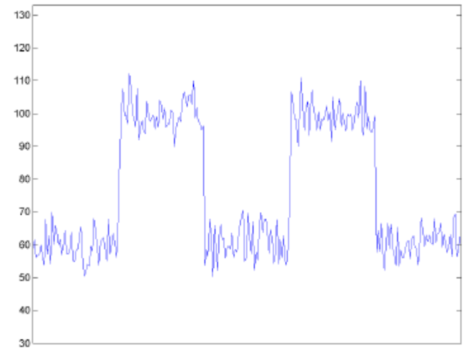
which leads to the optical flow problem:

$$\underset{u,v}{\operatorname{argmin}} \iint \|H(x+u, y+v, t+1) - H(x, y, t)\|^2 + \alpha \left(|\nabla u|^2 + |\nabla v|^2\right) dx dy$$

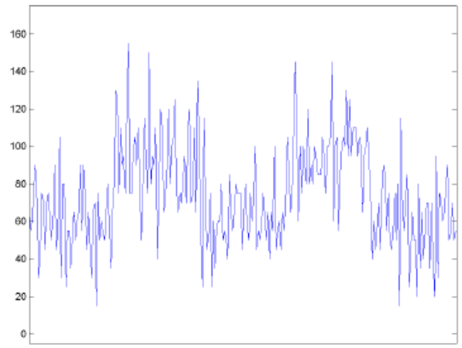
Noise modelling: 3 models in comparison



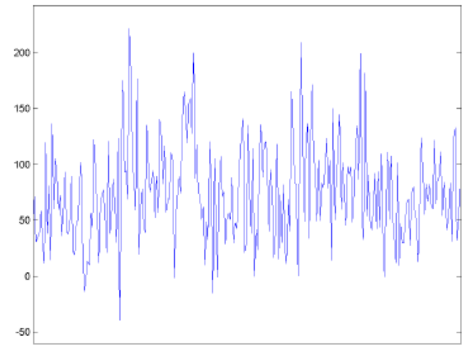
(a) Original 1D signal without noise



(b) Signal biased by Gaussian noise (SNR = 15.4)



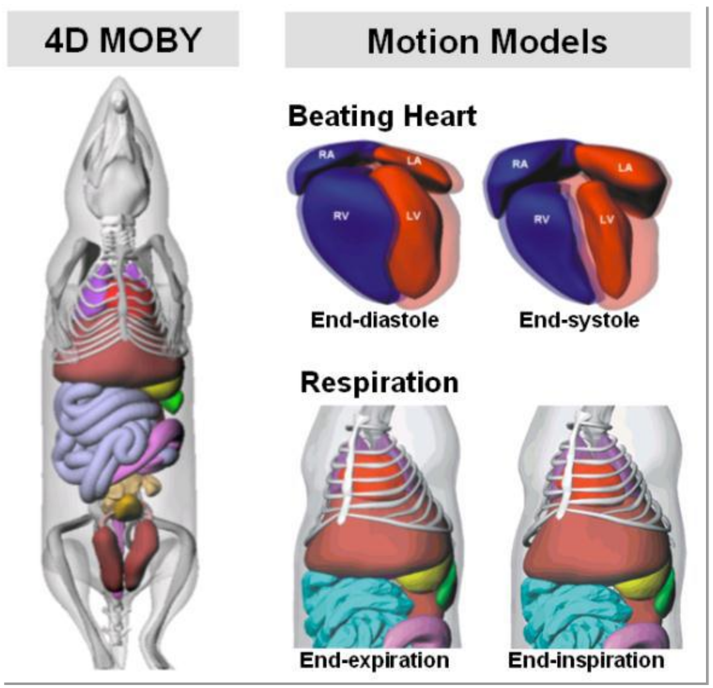
(c) Signal biased by Poisson noise (SNR = 4.2)

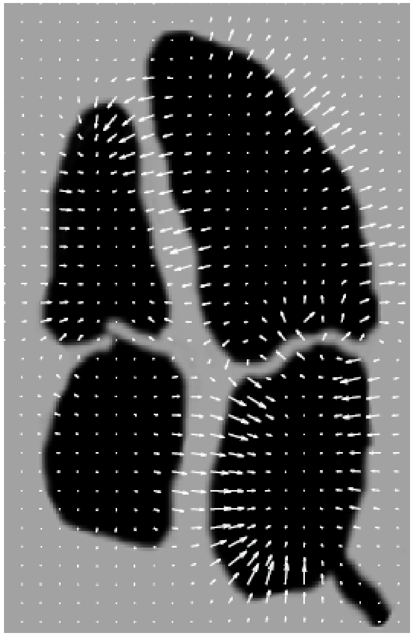


(d) Signal biased by speckle noise (SNR = 2.1)

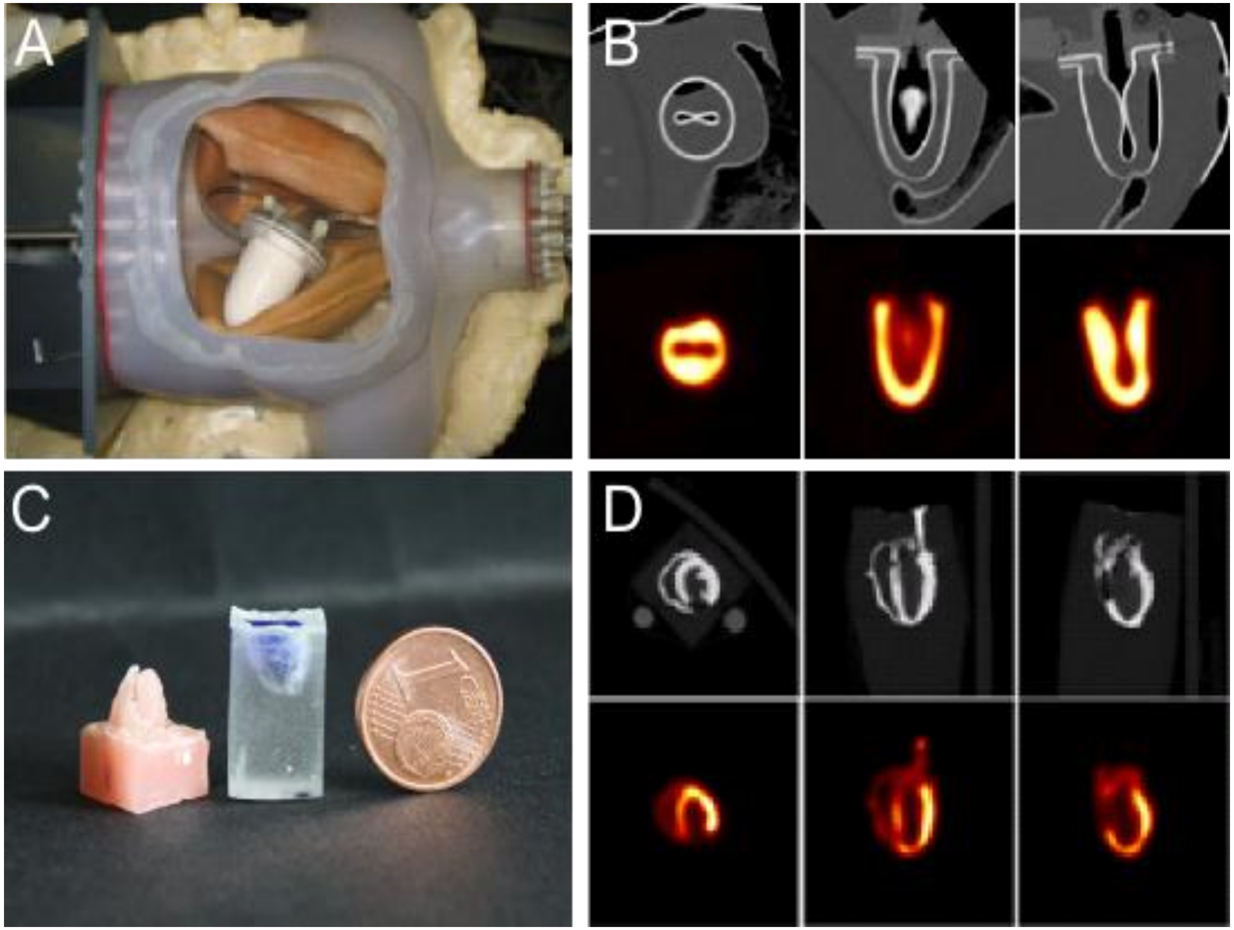
Validation

- manually specified ground truth
- mathematical phantom

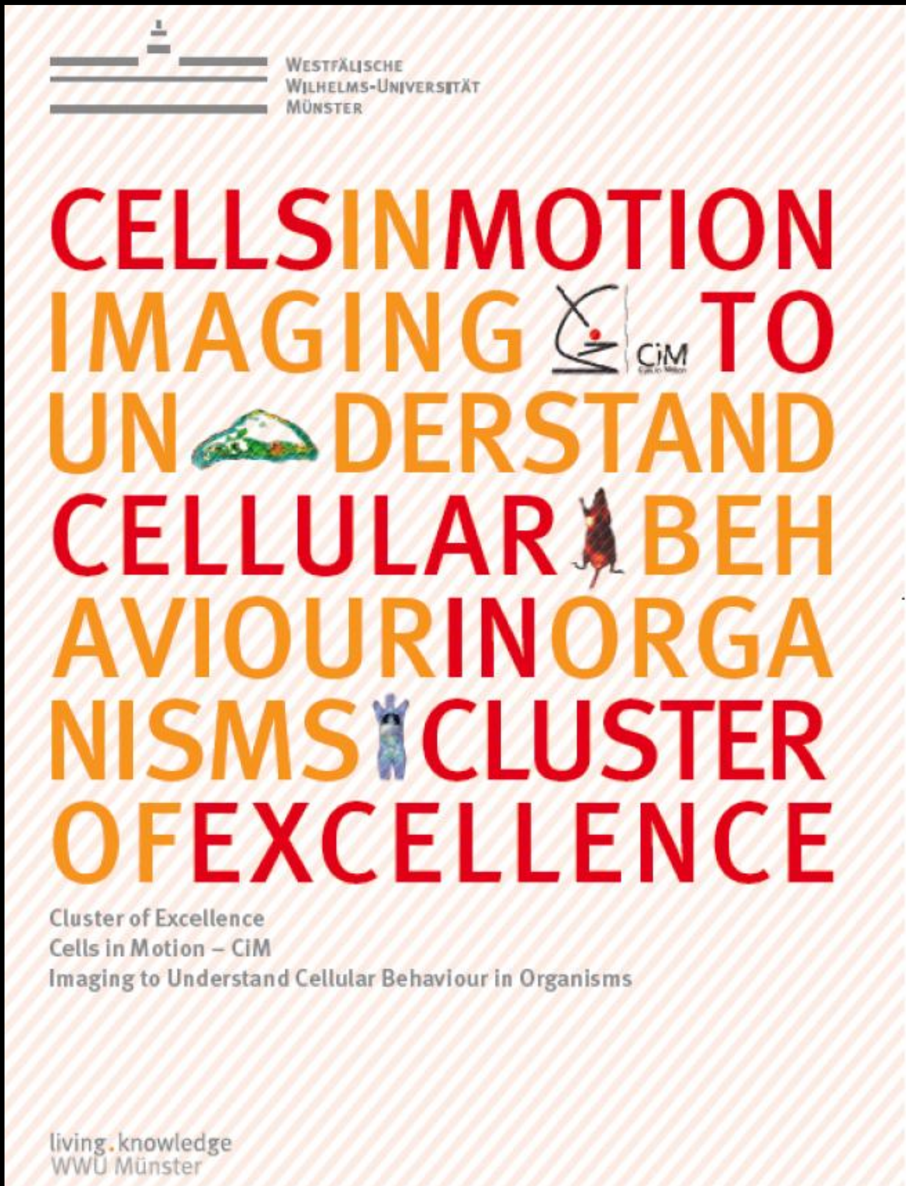




- physical phantom



Cells in Motion (CiM)

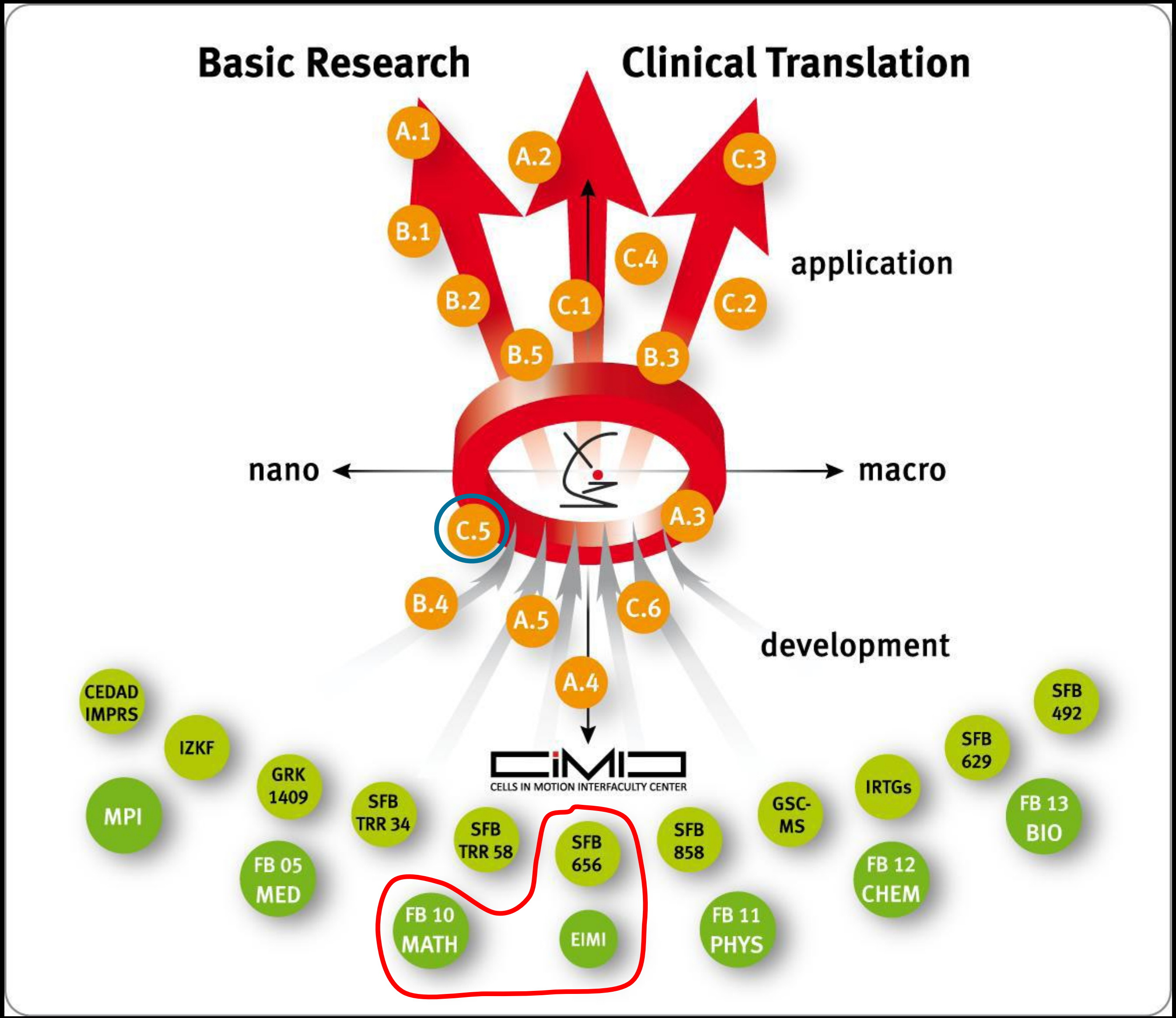


Imaging to Understand Cellular Behaviour in Organisms:

A total of 107 proposals were submitted. CiM was selected as one of ~10 clusters of excellence.

2012-2017, ~40M €.

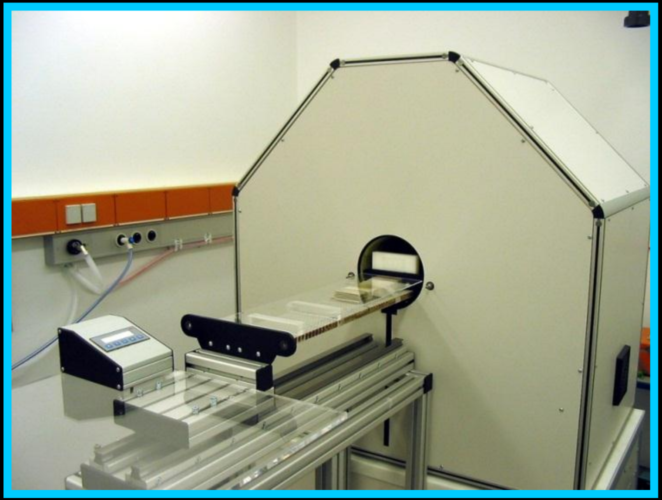
Cells in Motion (CiM)



Why imaging conscious animals?

Today's reality:

- Organisms (mouse, zebrafish, etc.) are studied using whole-body functional molecular imaging techniques
- There is no "instant" imaging technique; popular imaging techniques require minutes or more for measurement
- Animals are anesthesized to obtain "motion-free" imaging



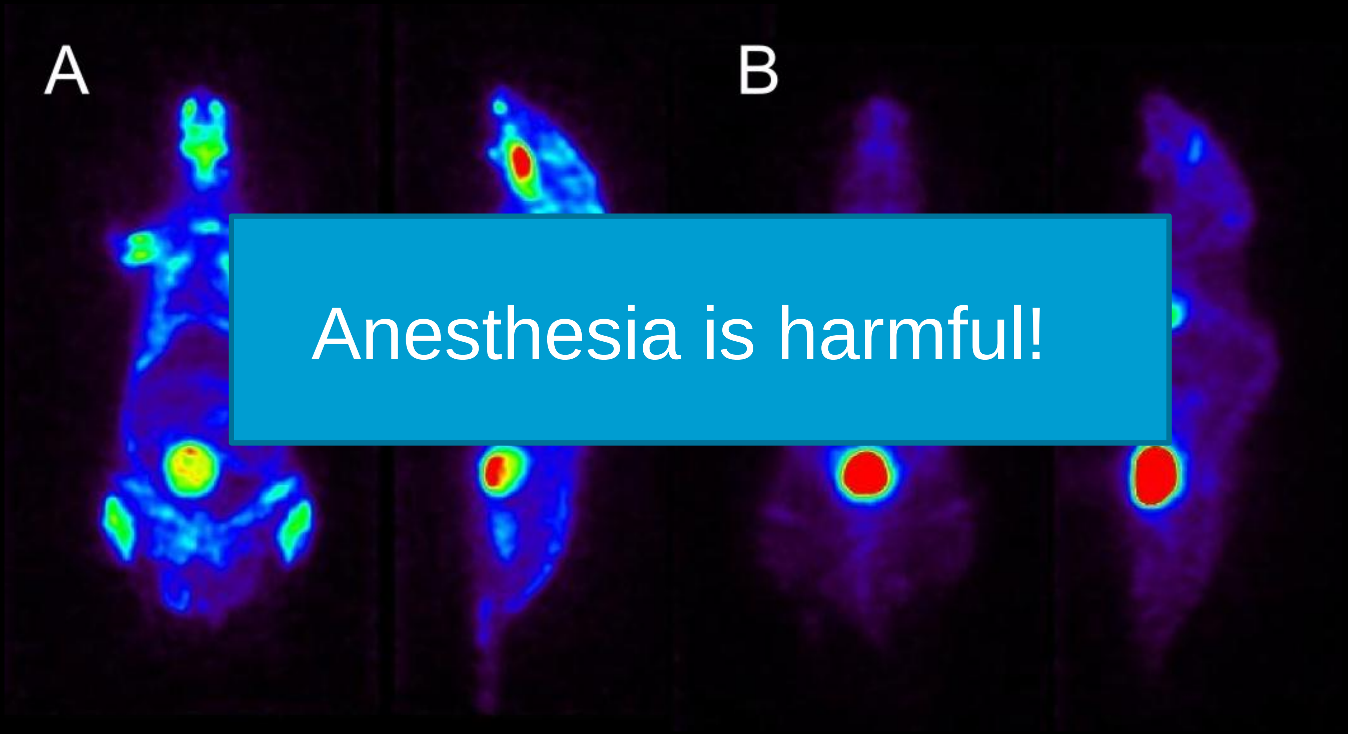
Why imaging conscious animals?

While anesthetics are required to achieve artifact-free images by eliminating the possibility of animal motion in an ethical way, they may profoundly disturb the neurological systems under study.

Vaska, et al.

Why imaging conscious animals?

Current: anesthesia in small animal studies to avoid motion → impact of anesthesia on organ function (such as brain function, heart function, etc.)



F^{18}-FDG, 1 h post injection into the
awake mouse anesthetized mouse

State of the art

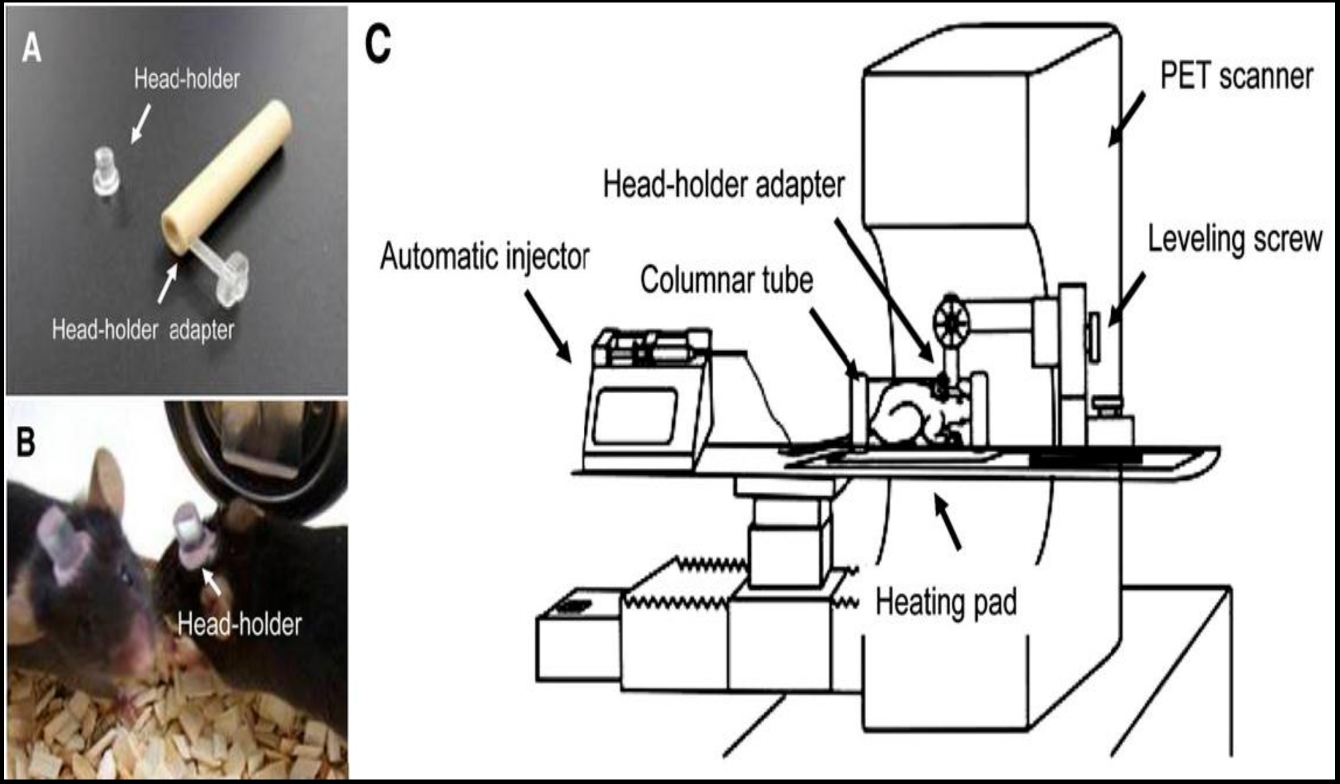
Conscious animal PET imaging is still in the infancy:

- The Kobe group
- The Brookhaven group
- University of Sydney (2 systems)

State of the art: The Kobe group

Avoidance of motion:

- Special head-holder surgically attached to the skull
- The rat is kept in a fixed position in the PET scanner using the head holder



State of the art: The Kobe group

How to avoid stress for the animals?

- They are allowed to recover from the surgery for one week.
- During this time they are trained to remain in a small cage for two hours at a time on at least three alternate days and thus become acclimated to this environment

Do you want to measure *many animals* this way?

State of the art: The Brookhaven group

Moving miniaturized scanner:

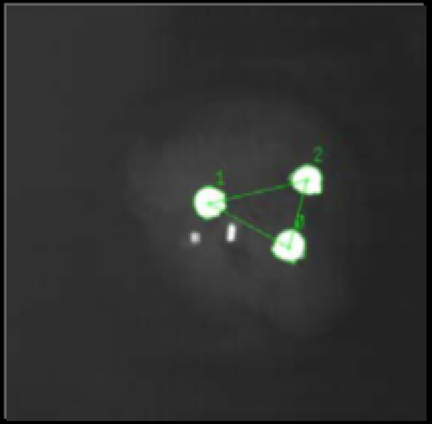
Miniaturized full-ring PET scanner attached directly to the animal head

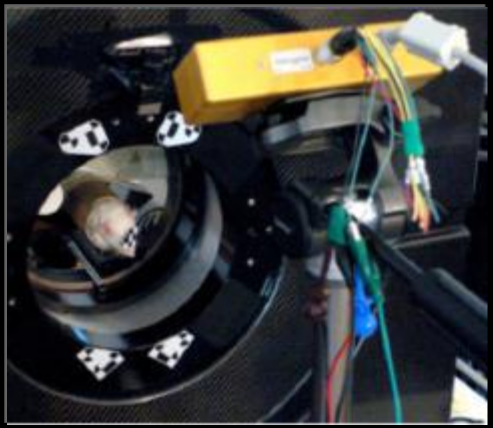
- Motion and behavior of animals affected by the system
- Use of smaller crystals for miniaturization leads to reduced sensitivity of the scanner

Allow and compensate minimal motion:

- The animals are constrained within a small (glass-) tube with only the possibility to turn the head
- kers
-

- Very limited motion allowed only
- Stress for animals?

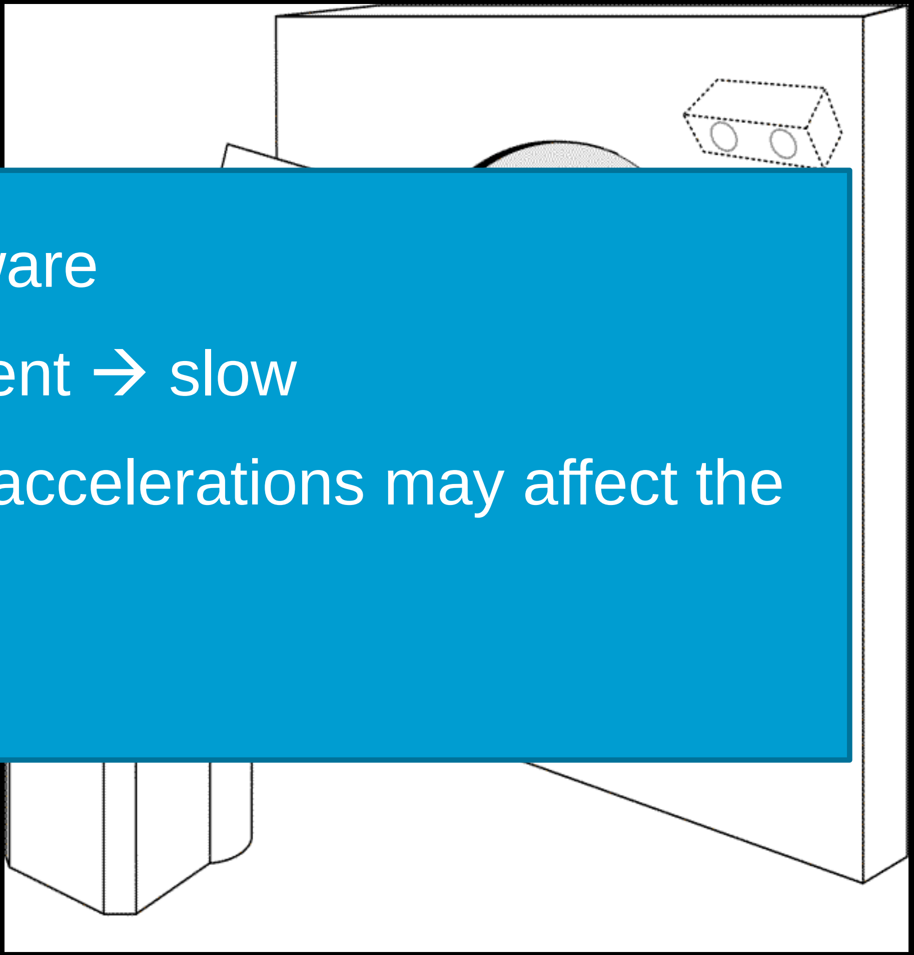




State of the art: University of Sydney (2)

No motion restriction, mechanical motion compensation:

- The animals move freely in a chamber
-
-
the direction opposite to the animal motion.



- Sophisticated hardware
- Mechanical movement → slow
- Even the moderate accelerations may affect the behavior of animals
- Small field of view

State of the art

Conscious animal PET imaging is still in the infancy:

- The Kobe group
- The Brookhaven group
- University of Sydney (2 systems)

Drawbacks:

- No or very limited animal motion allowed → stress
- Behavior of animals affected
- Long training time (making animals acclimated)
- Mechanical movement
- Small field of view

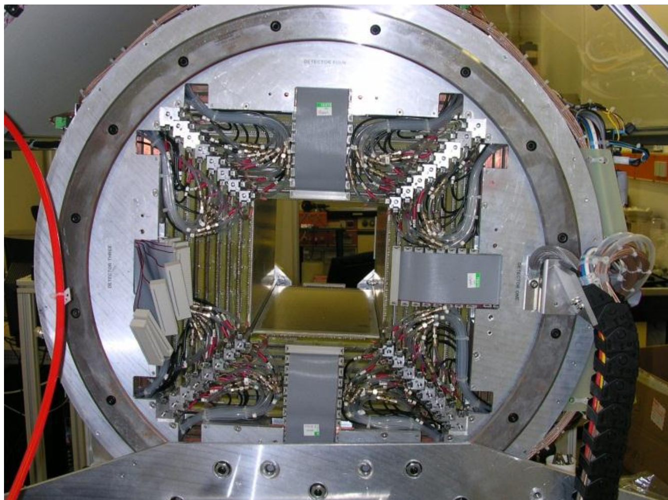
Our dream: genuine animal imaging

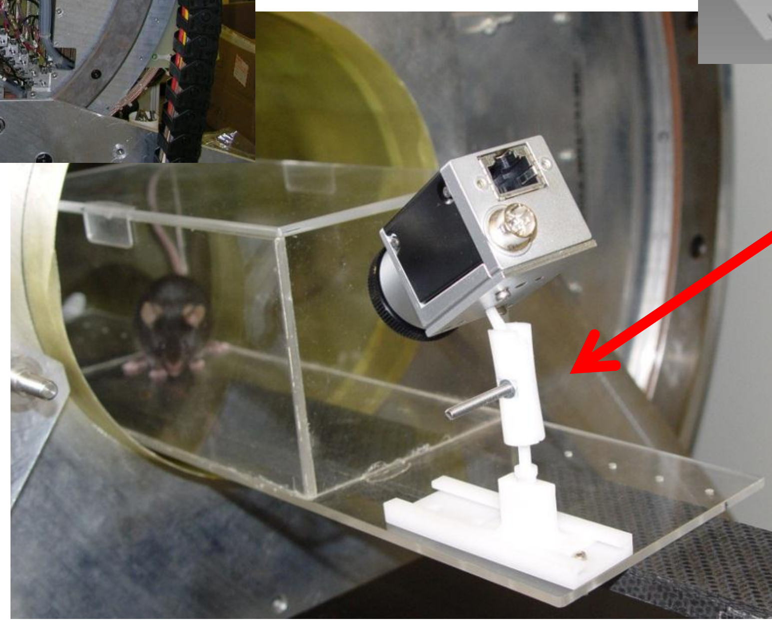
I Have a Dream.

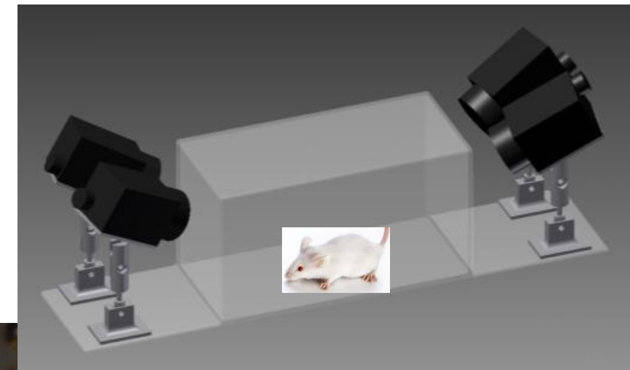
Martin Luther King

Our dream: genuine animal imaging

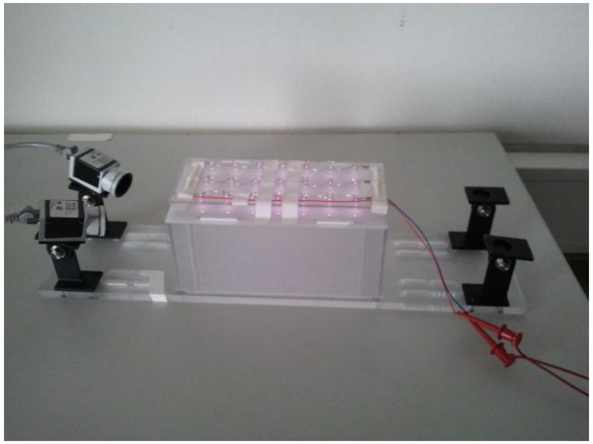
Our dream: freely moving animals without anesthesia

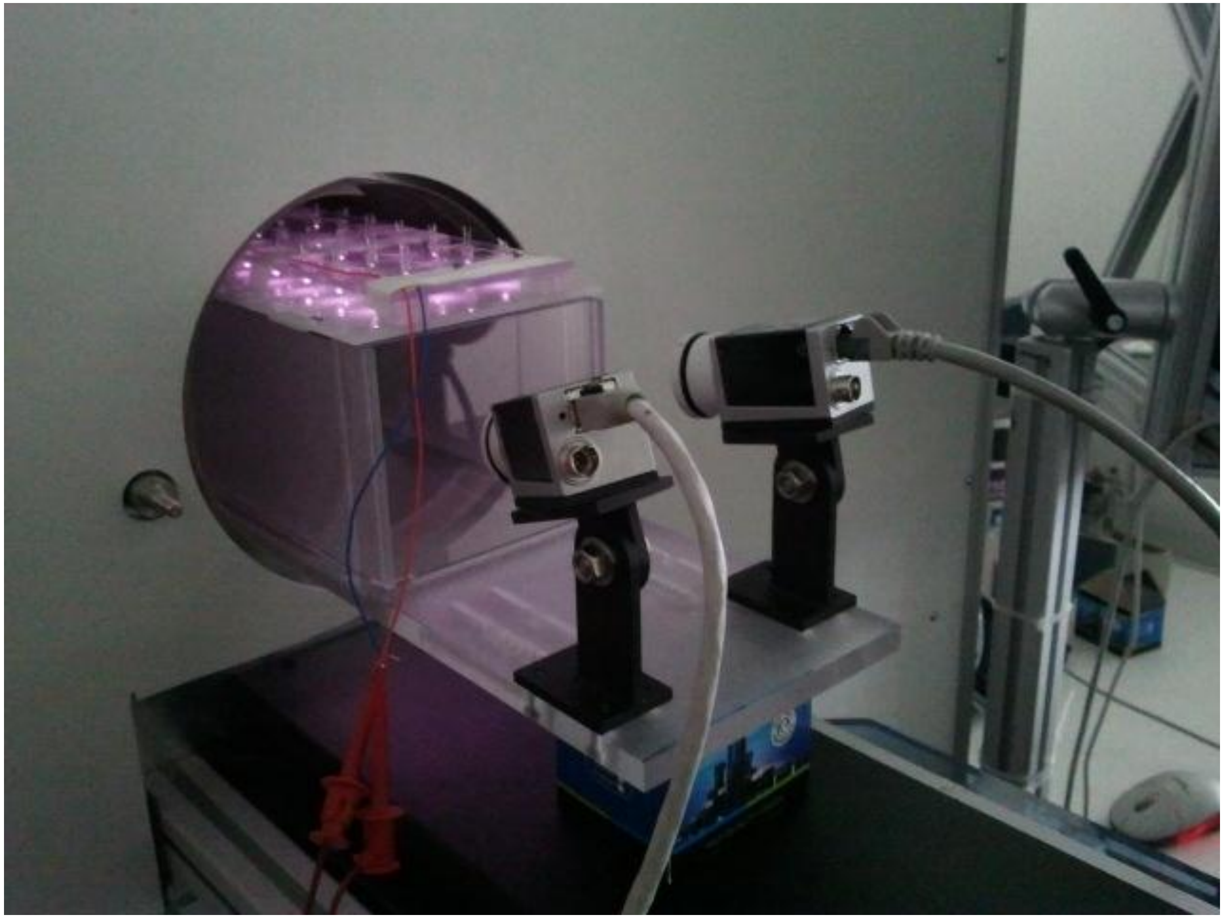




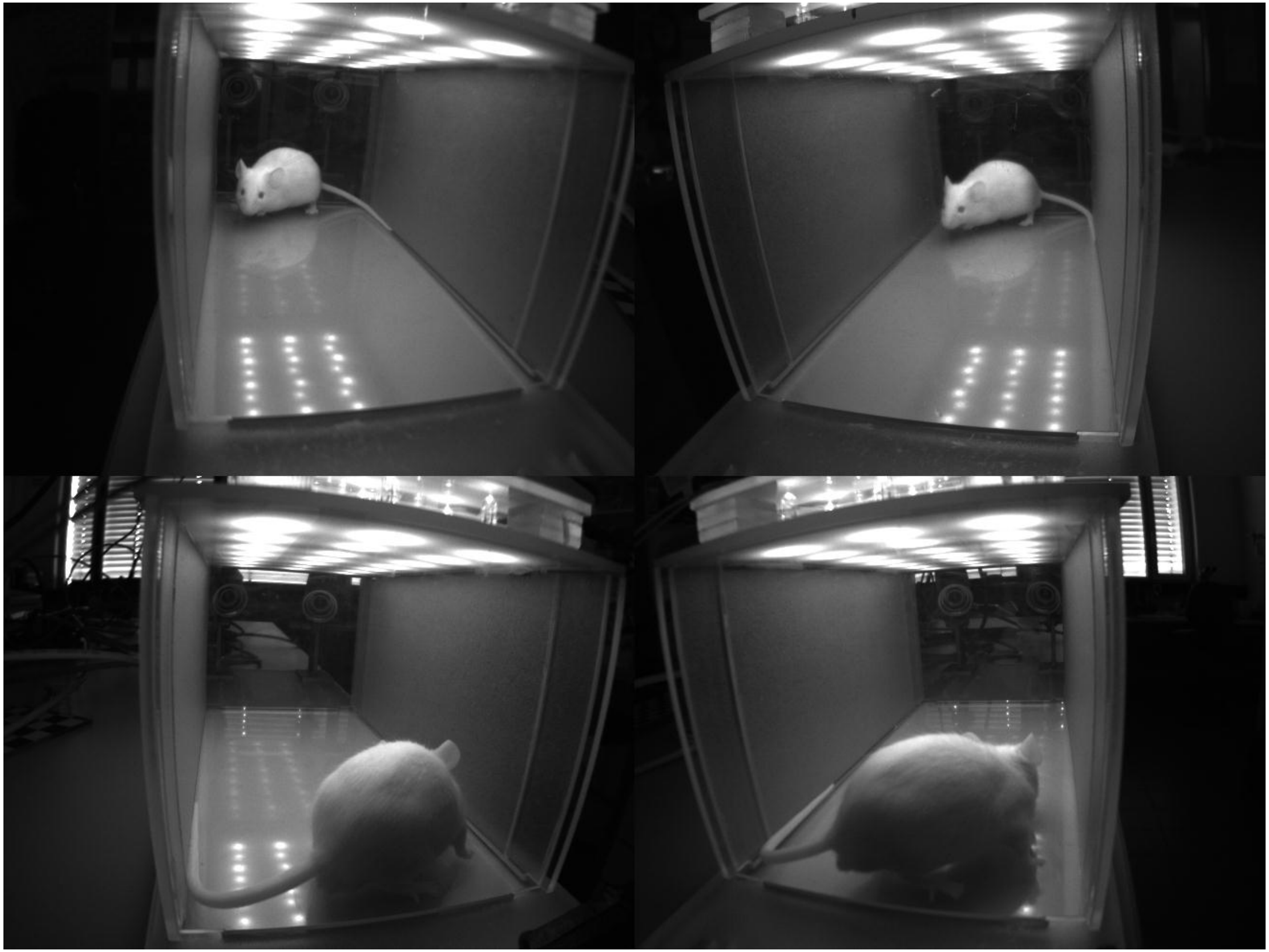


Our dream: genuine animal imaging





Our dream: genuine animal imaging



Our dream: genuine animal imaging

CiM
Cells in Motion

Our dream: genuine animal imaging

informatics

mathematics

Look forward to
being PETed

physics

medicine

biology

Summary

- Medical imaging, in particular gated PET imaging
- Motion detection and correction in gated PET
- Motion estimation in ultrasound imaging
- Freely moving animal PET imaging
- Improved (more accurate) radiotherapy

Vielen Dank!

谢谢！