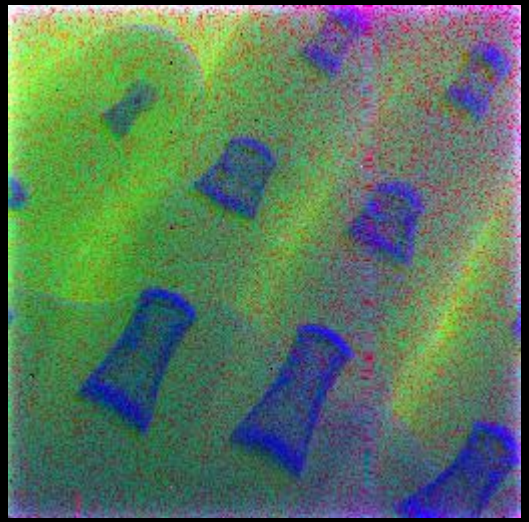
Spectral x-ray imaging in medicine

Anthony Butler,
On behalf of the MARS Collaboration

Black and white, to colour

Wilhelm Röntgen, 1895

Photographic plate



MARS Team, 2006

Medipix2

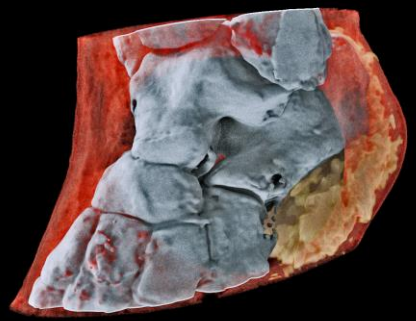
Motivation

300,000,000 Medical x-ray CT scans per year

Global imaging devices market: 47B USD by 2025

Healthcare applications

- Joint, bone, and implant imaging
- Cancer diagnosis and management
- Cardiovascular disease *(stroke and heart attacks)*
- Infectious diseases



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The Team

NZ university team

- Canterbury, Otago, Lincoln, Auckland

International Partners

- Incl. CERN, Notre Dame, RPI, LLNL, OHSU, JINR
  plus many others

The Team

2018 workshop hosted by Uni. of Canterbury,
sponsored by NZ MedTech CoRE

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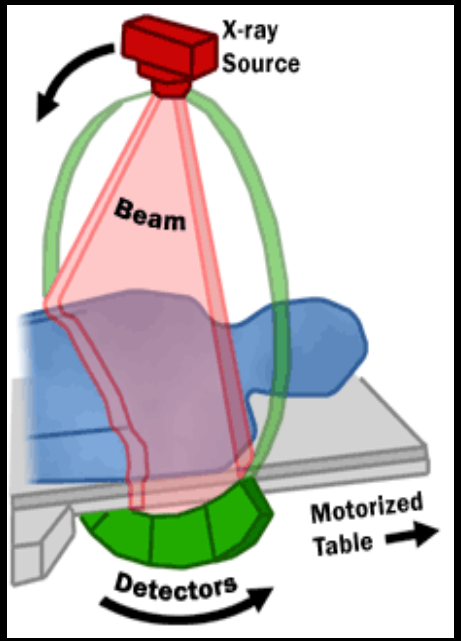
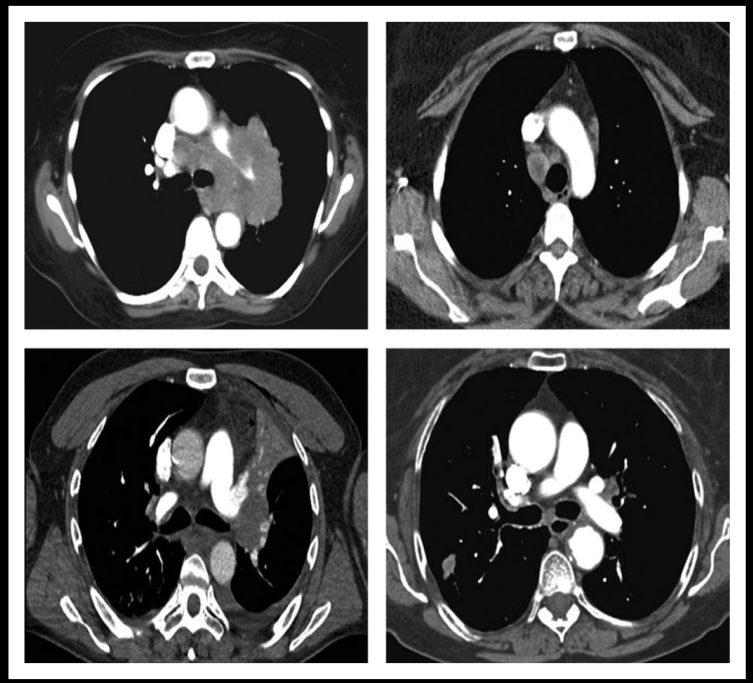
CT – Computed Tomography

Making 3D pictures with x-rays





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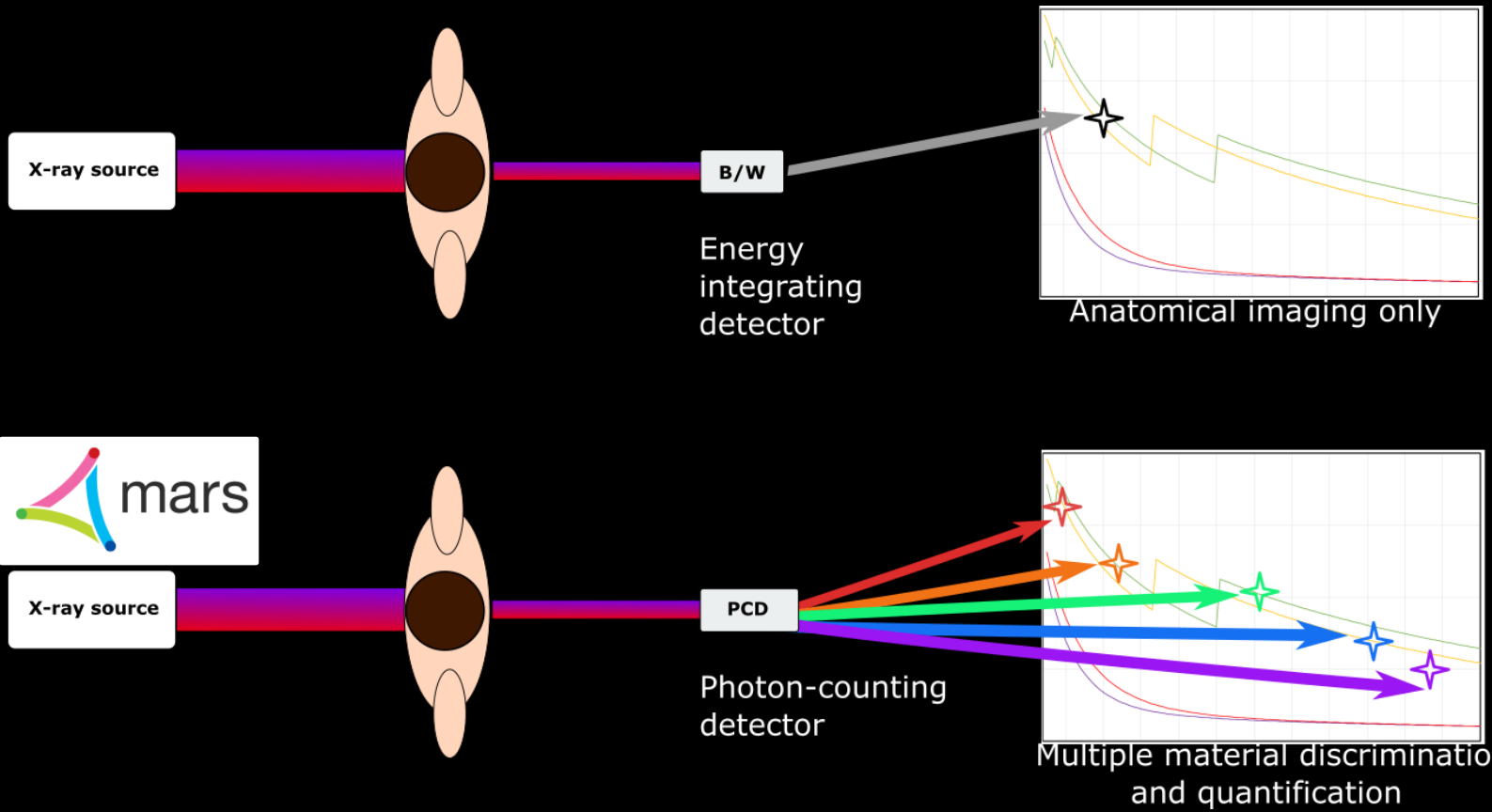
Spectral CT


X-ray source
B/W
Energy integrating detector
Anatomical imaging only
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X-ray source
PCD
Photon-counting detector
Multiple material discrimination and quantification

strategy

1) v3/4 small animal scanner

2) v5 *human translatable* small bore scanner

3) Large bore human scanner

4) Point-of-care scanners

5) Full human scanners

strategy

1) v3/4 small animal scanner

2) v5 *human translatable* small bore scanner

3) Large bore human scanner

4) Point-of-care scanners

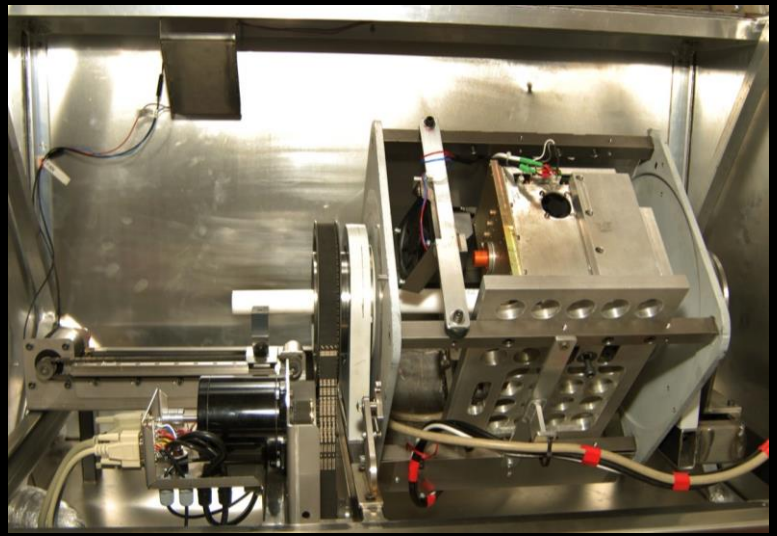
We are here

5) Full human scanners

MARS small animal scanners

MARS small animal scanners

- 5-35 keV energy range (Si sensor)
- Medipix2, then Medipix3.0



- Start/stop motion
- No slip rings
- Small detector array (translated)
- Non-scalable data handling

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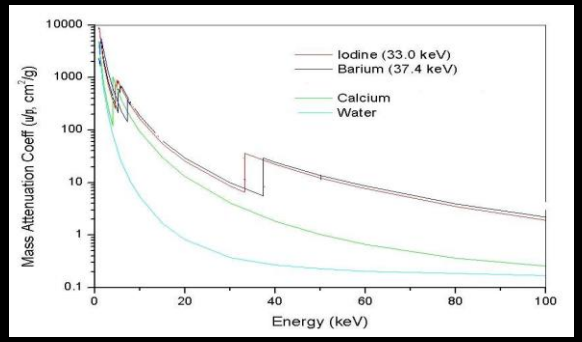
4 Material Decomposition
- Iodine
- Barium
- Calcium
- Water

Eur Radiol (2010) 20: 2126. https://doi.org/10.1007/s00330-010-1768-9



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MARS *Human Translatable*
small bore scanners

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MARS Human Translatable scanners

We work with dozens of partners worldwide

Photo at the Notre Dame imaging lab

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Scanner features

Human ready system

- X-ray energy is 30-120 kVp
- High efficiency CZT
- Continuous motion spiral scans
- Modular readout for scalability

Designed for biomedical users

- Automated detector set-up
- Green-button acquisition
- Automated recon and MD
- Visualisation and analysis tools

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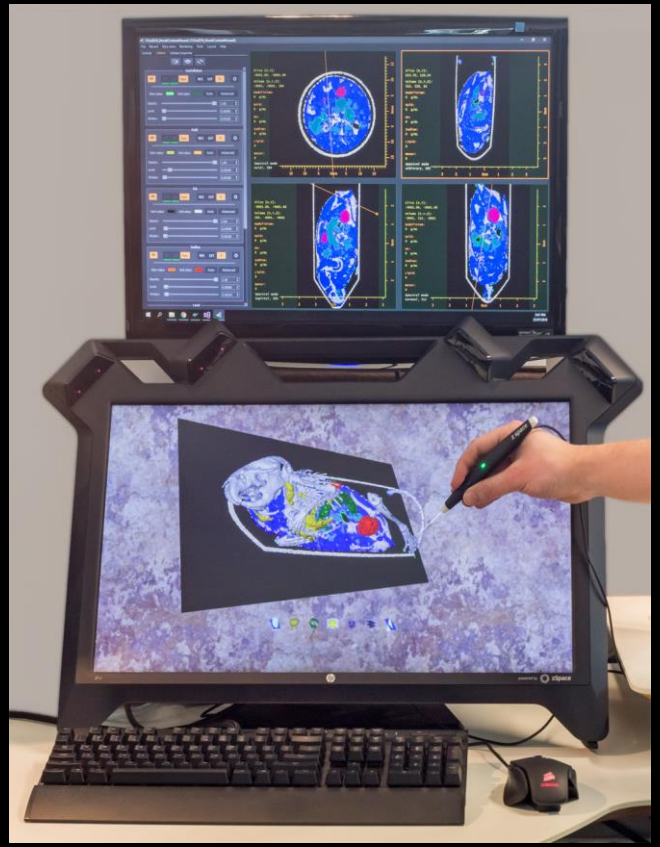
New Data



Hybrid 2D/3D viewer

- stereoscopic 3D for orientation
- 2D for detail

Tools

- Quantification (ROI, data export)
- Surface rendering
- Volume rendering
- Custom transfer functions

We provide

- raw data
- energy CT volumes (HU)
- material volumes (mg/mL)
- DICOM & OBJ support

2017, J Digit Imaging, DOI 10.1007/s10278-017-0002-6

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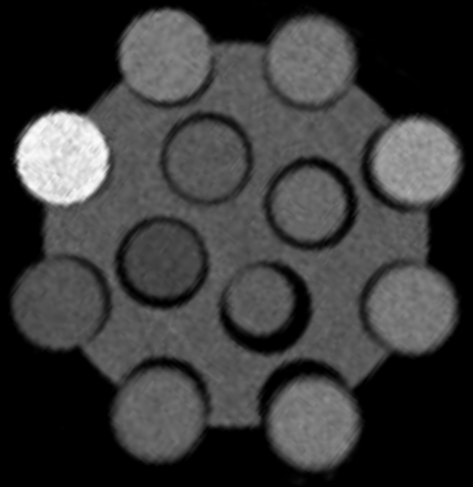
What do we want to translate?

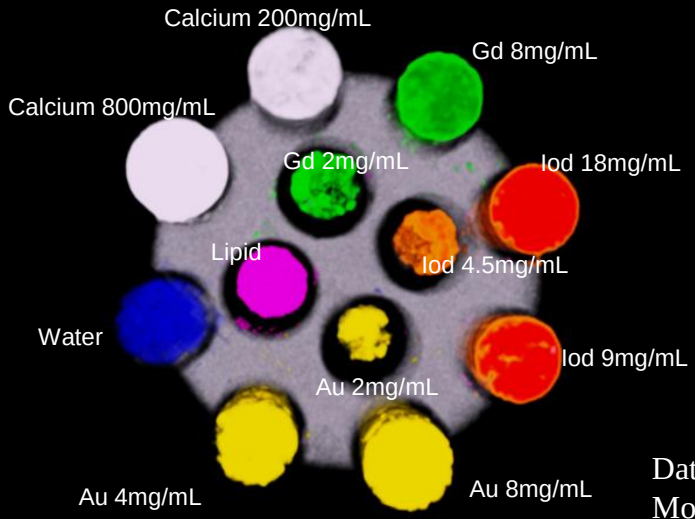
Greyscale to Material Imaging

Spectral imaging allows you to identify and quantify different materials

- a separate map (data channel) is made for each material
- each map gives the partial density (g/cm^3) for the material
- each material is then assigned a colour for easy visualisation

Single energy





MARS Spectral

A phantom containing Au, Gd, iodine, lipid, water and hydroxyapatite

Data available in:
Moghiseh et al, JSM Biomed Imaging Data Pap 3(1): 1007. (2016)

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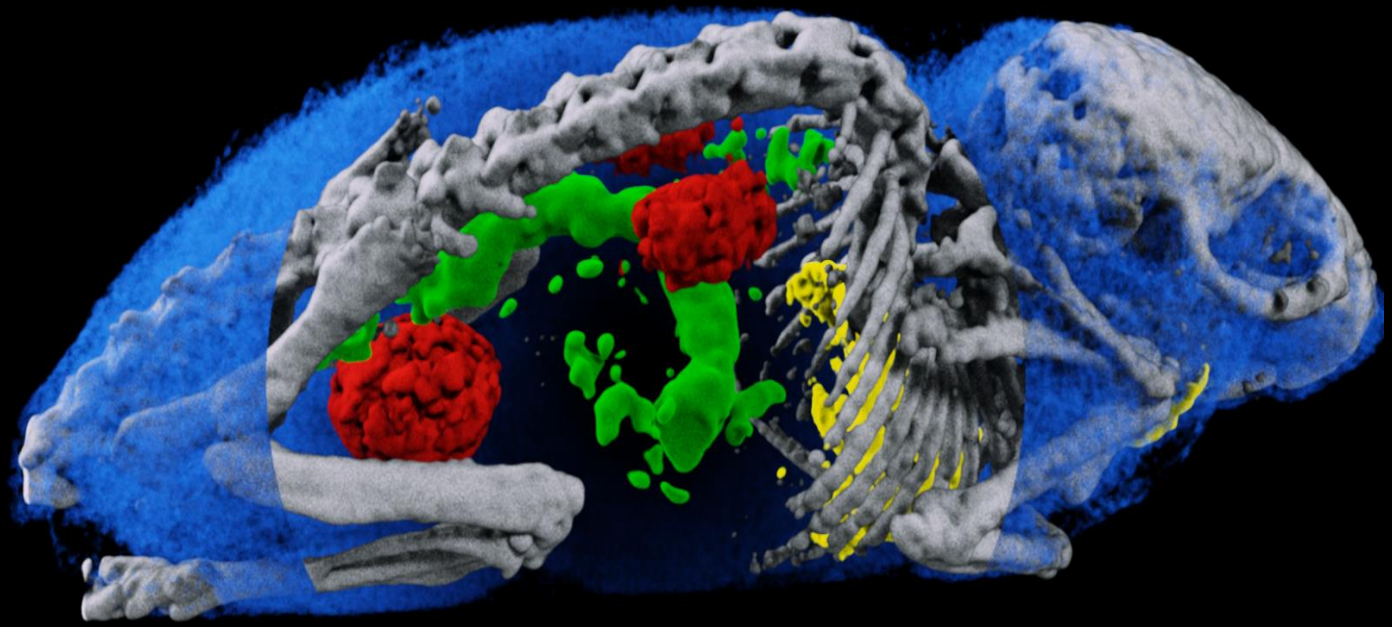
Greyscale to Material Imaging

A mouse containing, gold, gadolinium, and iodine



Images presented at the European Congress of Radiology, Vienna, March 2017.

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Atheroma Imaging

The cause of heart disease and stroke

Traditional CT

2012, Zainon et al, European Radiology 22 (12), 2581-2588

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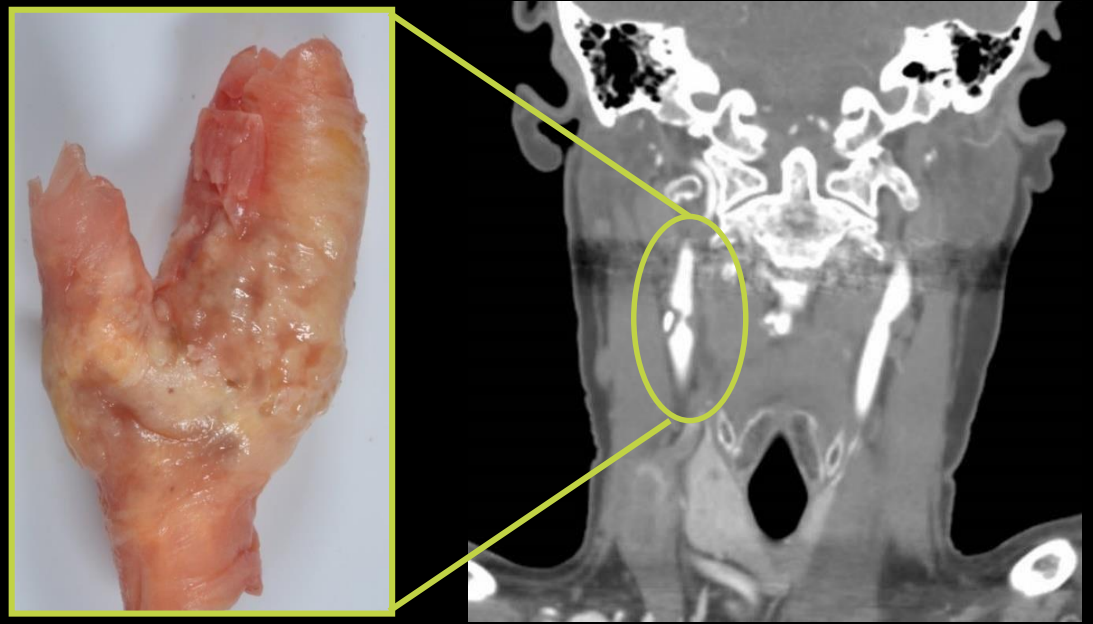
Atheroma Imaging

The cause of heart disease and stroke



Surgical Specimen

Traditional CT

2012, Zainon et al, European Radiology 22 (12), 2581-2588

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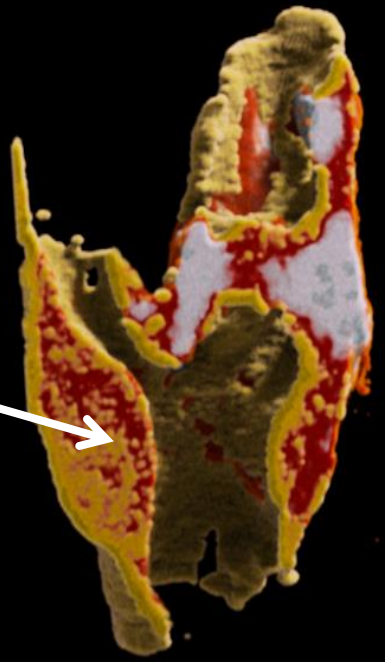
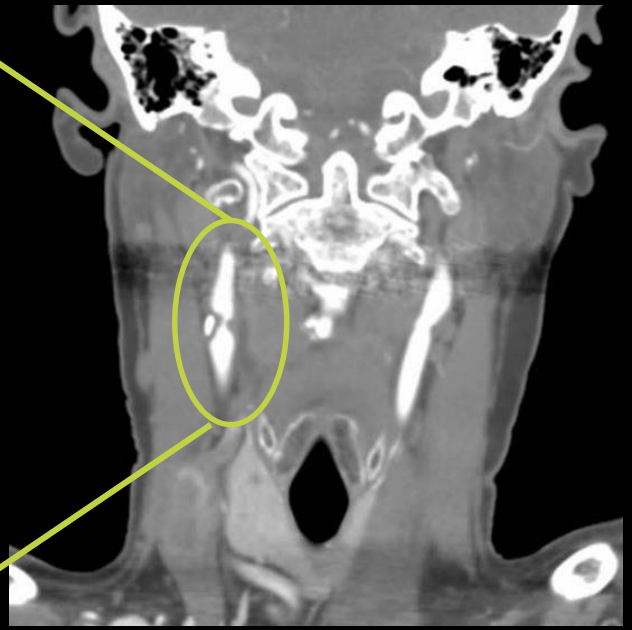
Atheroma Imaging

The cause of heart disease and stroke

Key
lipid
water
calcium



Necrotic
lipid core



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Surgical Specimen

Traditional CT

2012, Zainon et al, European Radiology 22 (12), 2581-2588

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Atheroma imaging

The cause of heart disease and stroke

Intra-plaque bleed
(thought to be very high risk)

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Bone Health

Bone structure and composition can be measured simultaneously

Bone structure

Human femoral neck

Composition

No colour information

Colour information

Presented at SPIE Medical Imaging, January 2017.

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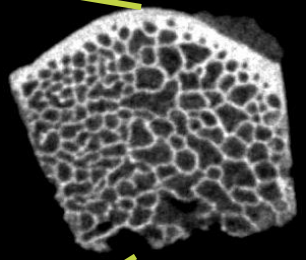
Bone Health

Bone structure and composition can be measured simultaneously

Bone structure

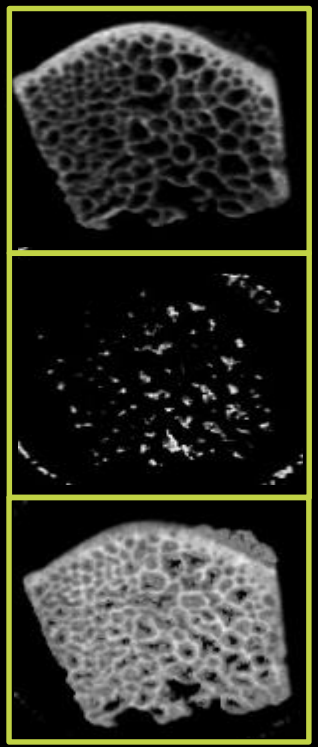
Cortical bone

Trabecular bone



Human femoral neck

Composition



Calcium

Lipid

Water

Presented at SPIE Medical Imaging, January 2017.

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Reducing metal artefacts in bone

Sheep clavicle with plate and screw

Plate is 10mm width

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Joints – crystal arthritis

Identification of CPPD vs. Gout

Finger Image

DECT

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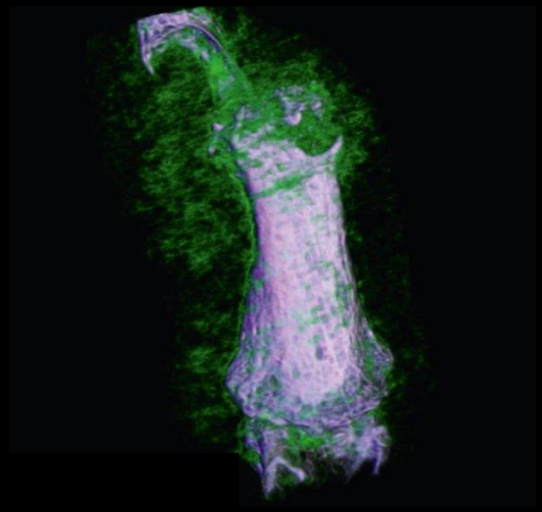

Stamp LK et al., Clinical utility of multi-energy spectral photon-counting CT in crystal arthritis. Arthritis Rheumatol. 2019 Feb 4. doi: 10.1002/art.40848.

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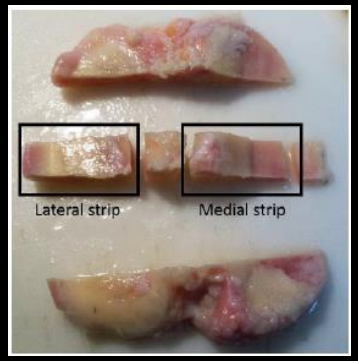
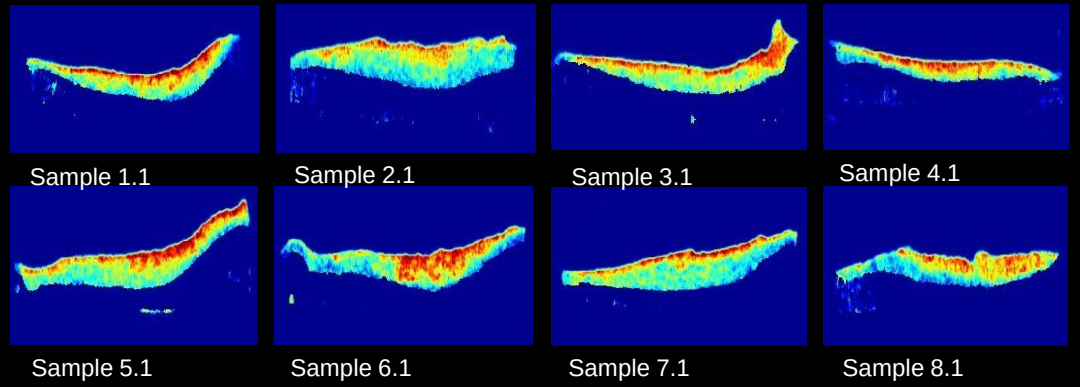
Joints – osteoarthritis

Measure cartilage glycosaminoglycans using Gd



Healthy Knee

Osteoarthritic Knee



Healthy cartilage

Narrowed joint space

Gadolinium concentration (g/cm^3)

K. Rajendran et al., 2016, Quantitative imaging of excised osteoarthritic cartilage using spectral CT. European Radiology, 1-9.

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MARS Human Scanners

CDTIw = 5 mGy (less than Australia/NZ reference dose)

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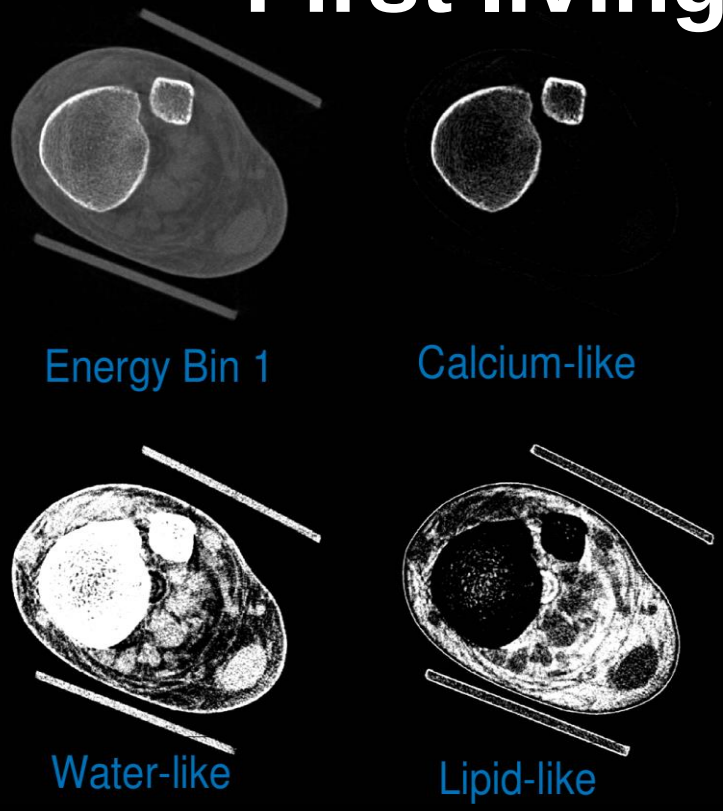
First living human images -



Leg at level of inferior 1/3 of tibia

Radiological assessment:

Bone micro-structure

- Cortex & Trabecular visible
- 80um voxel size

Bone mineralisation

- Calcium maps available
- Quantitative in mg/mL

Soft tissues

- Visualisation of tendons & ligaments

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Comparison with other modalities

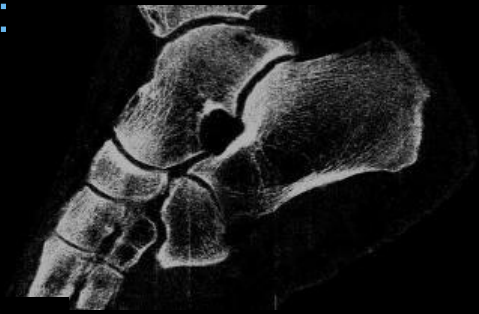
Library images:

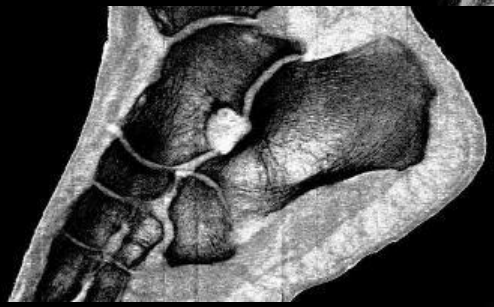
CT

MRI

MARS of my father:

Calcium,
colour it white





Fat,
colour it yellow

Water,
colour it red and
semi-transparent red

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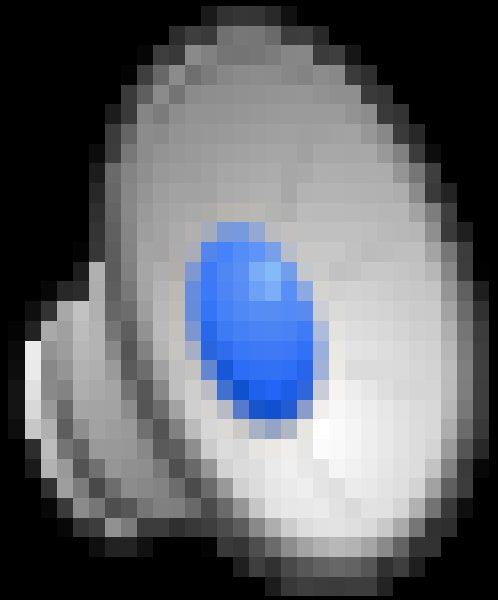
Each element is 1 nano-litre



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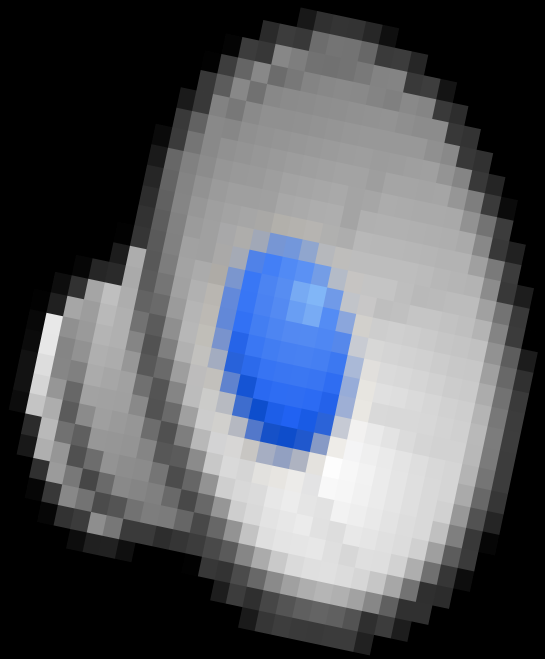

1.5 litre volume
15 Gb of raw data

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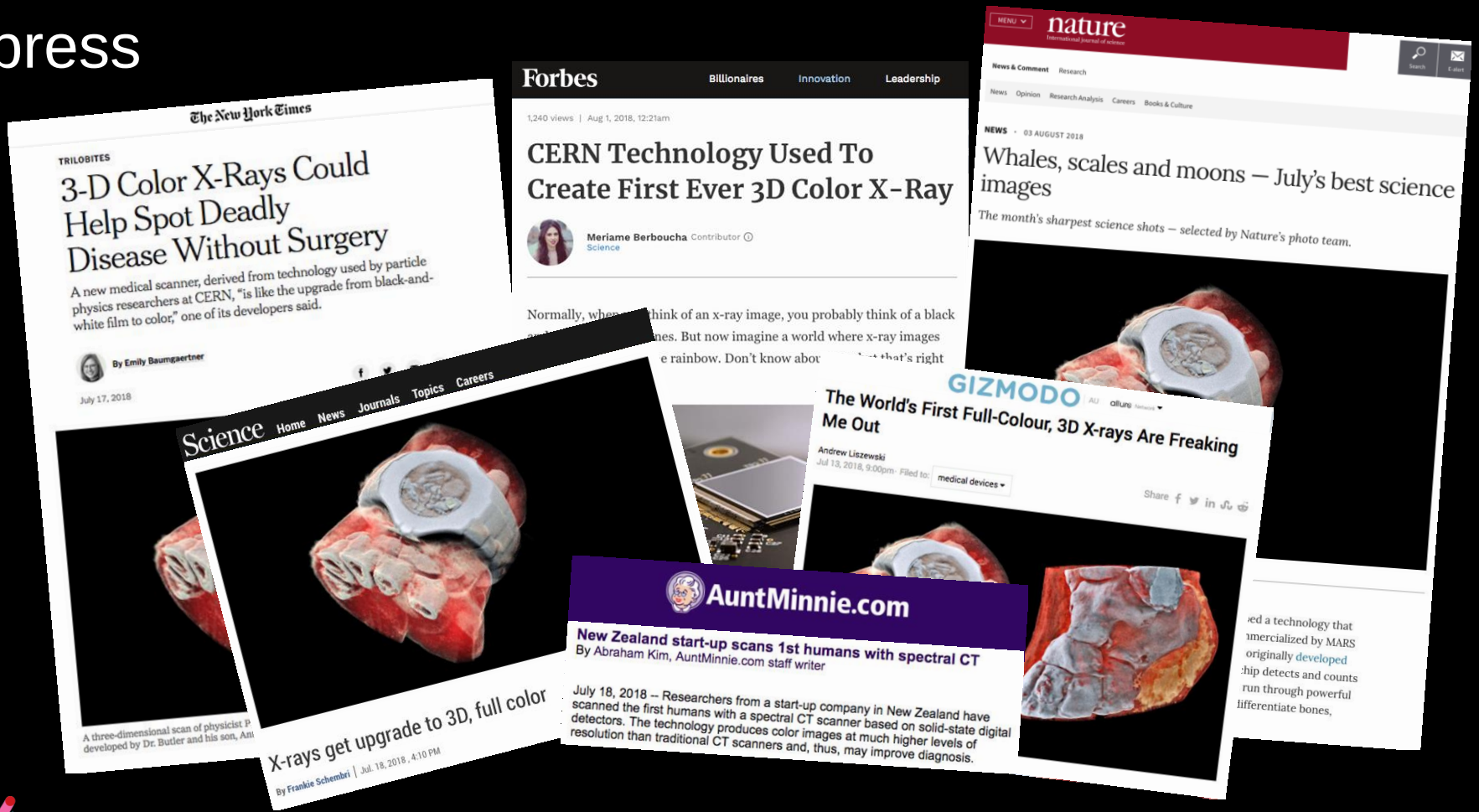
press


The New York Times
TRILOBITES
3-D Color X-Rays Could Help Spot Deadly Disease Without Surgery
A new medical scanner, derived from technology used by particle physics researchers at CERN, "is like the upgrade from black-and-white film to color," one of its developers said.
By Emily Baumgaertner
July 17, 2018
Forbes
Billionaires
Innovation
Leadership
1,240 views | Aug 1, 2018, 12:21am
CERN Technology Used To Create First Ever 3D Color X-Ray
Meriame Berboucha Contributor
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NEWS · 03 AUGUST 2018
Whales, scales and moons — July's best science images
The month's sharpest science shots — selected by Nature's photo team.
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X-rays get upgrade to 3D, full color
By Frankie Schembri | Jul. 18, 2018 , 4:10 PM
GIZMODO
The World's First Full-Colour, 3D X-rays Are Freaking Me Out
Andrew Liszewski
Jul 13, 2018, 9:00pm · Filed to: medical devices
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AuntMinnie.com
New Zealand start-up scans 1st humans with spectral CT
By Abraham Kim, AuntMinnie.com staff writer
July 18, 2018 -- Researchers from a start-up company in New Zealand have scanned the first humans with a spectral CT scanner based on solid-state digital detectors. The technology produces color images at much higher levels of resolution than traditional CT scanners and, thus, may improve diagnosis.

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Comparison with other modalities

Imaging of excised sheep joints

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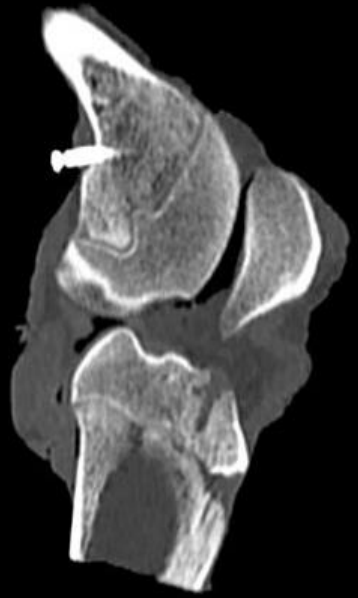
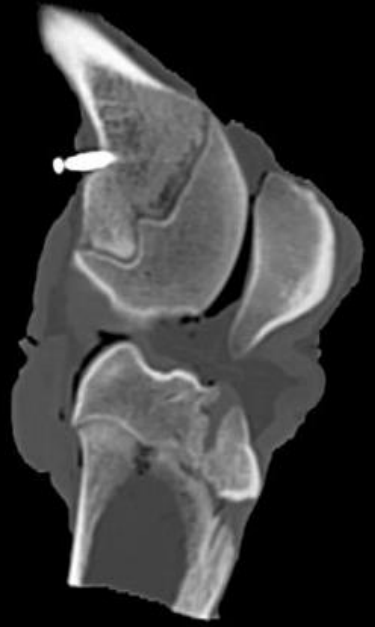
Conventional CT



Dual energy CT



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Comparison with other modalities

Imaging of excised sheep joints

Conventional CT

Comparison with other modalities

Imaging of excised sheep joints

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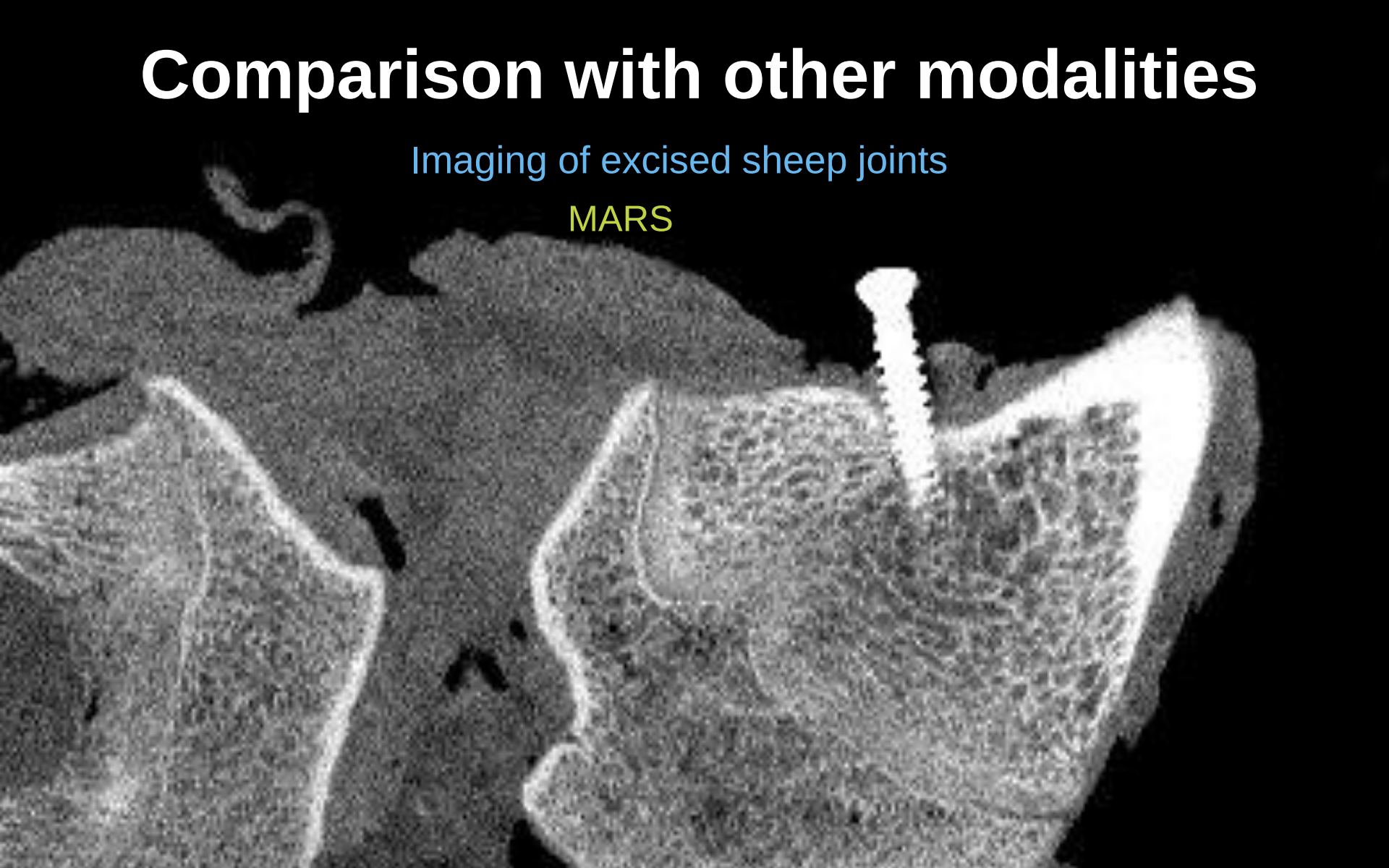

Conclusion

- Reproduced small animal image quality in living humans

- All components of scanner have been scaled

- Starting clinical trials of a range of diseases

Future: Taking MARS to the community

Point-of-care scanners

- Body parts and portable scanners: arms, legs, head, neck, hips

- MARS technology well suited to these applications

Cloud based image interpretation

- Radiologists across the internet

- Machine learning (AI) to improve accuracy and efficiency

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