Simposio di Biomedicina spaziale

ASI, Roma , 15-16 Marzo 2023

ASTRO-QCT: un apparato CT ad imaging spettrale per lo studio in tempo reale della perdita di densità ossea negli astronauti durante il volo spaziale

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SSM Scuola Superiore Meridionale

PhD SPACE Cosmology, Space Science & Space Technology

5 Hazards of Human Spaceflight

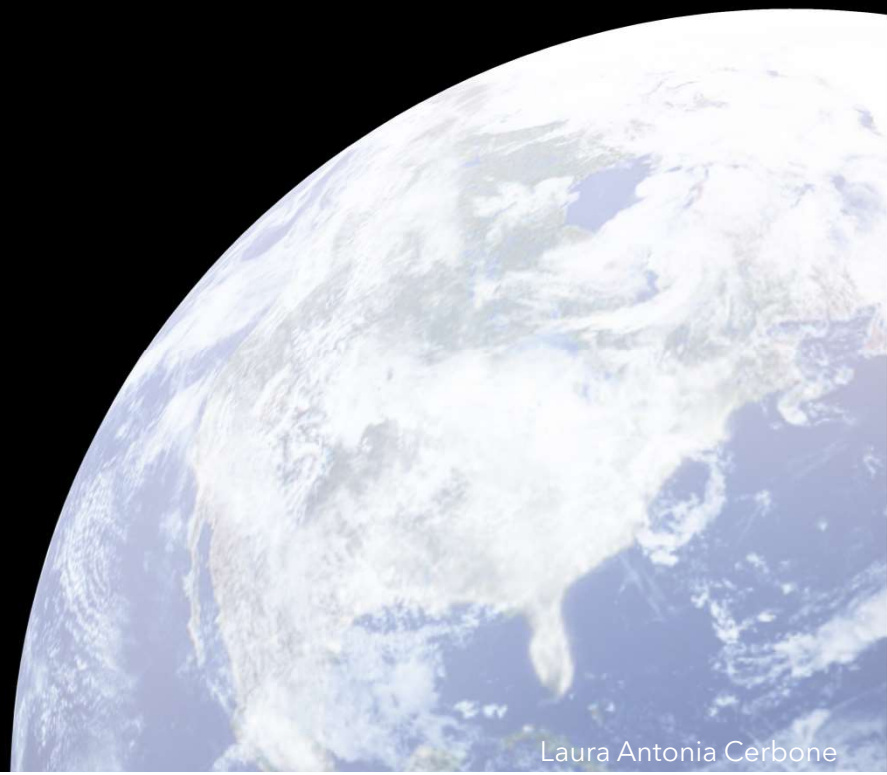
- Radiation
- Isolation and confinement
- Distance from Earth
- **Gravity (or lack thereof)**
- Hostile/closed environments

Microgravity leads to skeletal deconditioning; thus, **bone mass is reduced,** especially at weight-bearing sites.

Average bone loss is 0.1 % per month for upper limbs and 0.8 % per month for lower limbs relative to pre-flight values.

Bone Mass Density (BMD) is a biophysical parameter to assess bone quality.

From this parameter, the diagnosis of osteoporosis is made.



Lifetime Surveillance of Astronaut Health (LSAH)

1. Dual X-Ray Absorptiometry (DXA)
   Before and after the flight and every 3 years after the mission
2. Biochemical analyses of blood and urine to
   Look for bone formation/resorption markers.
3. Advanced Resistive Excercise Device (ARED)
4. Balanced Diet, vitamin D supplements,
   bisphosphonate (to restore the calcium balance)

Dual X-Ray Absorptiometry (DXA)

Golden standard for measuring the bone mineral density (BMD) in **osteoporosis** patients.

By performing two acquisitions at different energies, the attenuation coefficient and, thus, the material density can be derived.

Analyzed anatomical compartments:
- Hip
- Lumbar spine
- Femoral neck

High-Resolution peripheral quantitative CT (HR-pQCT)

Capable of resolving the micrometric trabecular structure of bones (≈50 μm). It measures the bone density and quantifies the 3D microarchitecture of the bone at the distal tibia and radius.

Commercially available HR-pQCT

- Isotropic spatial resolution ≈ 60 μm
- Cone beam (scan time 2-4 minutes)
- Dual Energy
- **4 μSv effective dose** to the patient per scan (9 mm scan length, 12 cm FOV)
- Weight ≈ 600 kg
- Footprint 1 m^3

ESA used this scanner within the Early Detection of Osteoporosis is Space (EDOS) program; it allows one to observe bones' microarchitecture and characterizes its changes due to microgravity.

**Image credits: SCANCO medical (https://www.scanco.ch/xtremectii.html)

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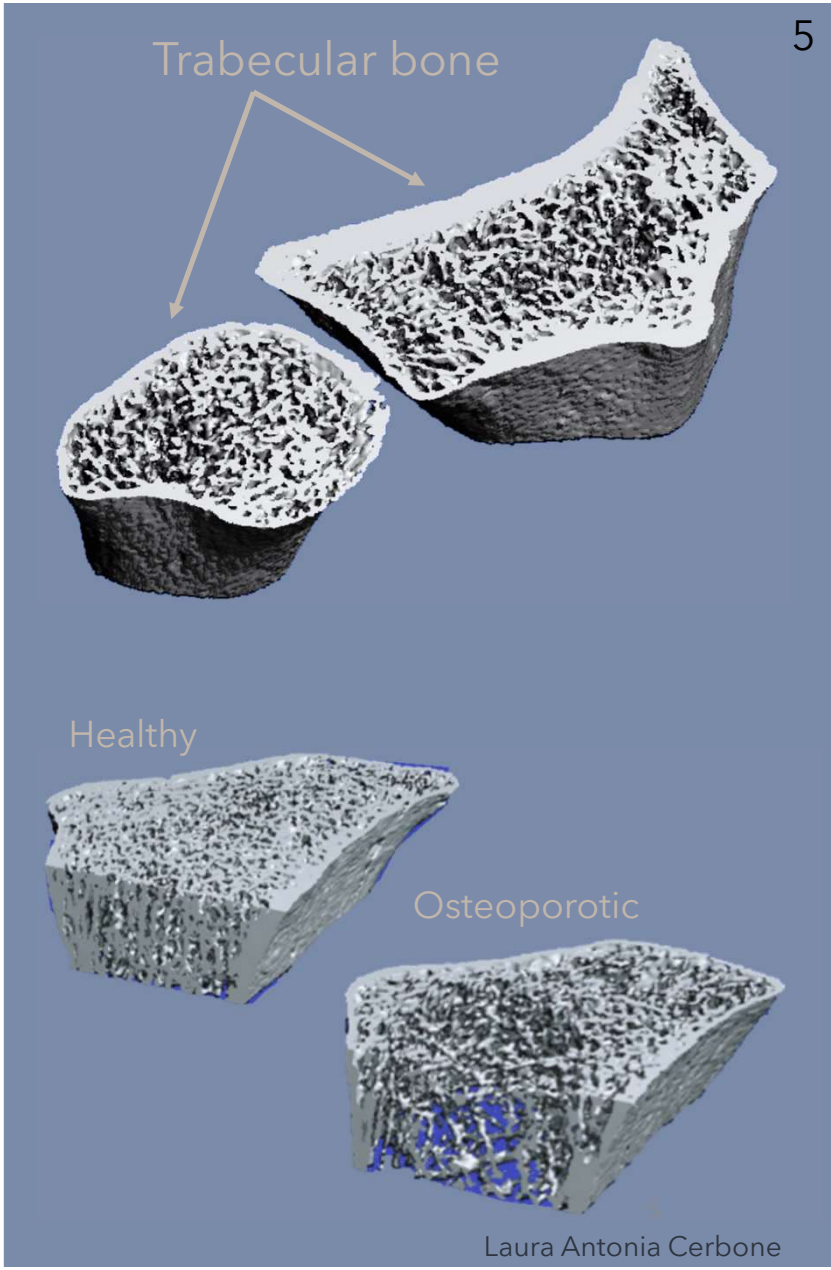

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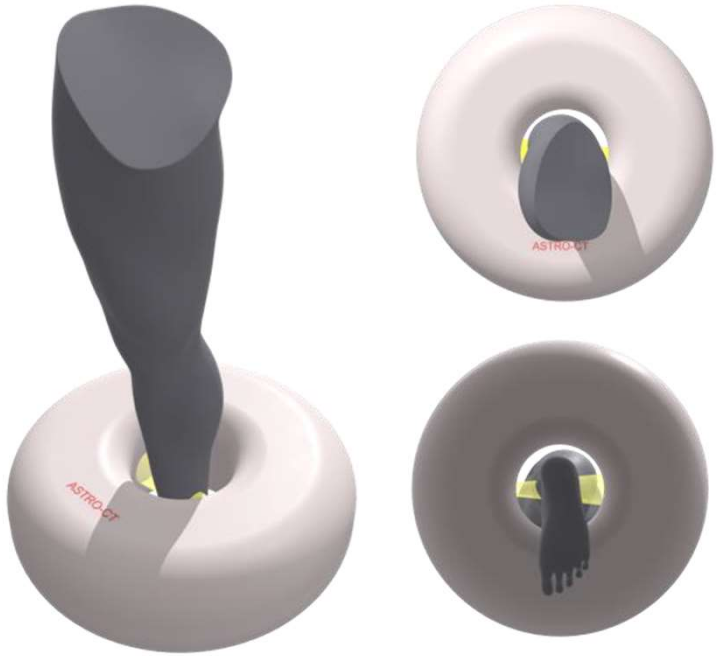
ASTRO-QCT

A compact micro-CT system with spectral capabilities (Timepix4 hybrid pixel detectors) for assessing bone density loss in astronauts while onboard the International Space Station.

This device could be used within the **LSAH program (NASA) to perform monthly scans** during flights, assess bone density loss in real-time, and better comprehend this phenomenon.

Photon counting detectors (Timepix4)	• High granularity (55 μm x 55 μm pixels) • Spectral imaging (distinguish bone from soft tissue) • **Lower dose** than energy integrating CT (30% - 60% reduction)
High spatial resolution	• A spatial resolution below 40 μm • A **3D-printed personalized** holder should be used to avoid body movements.
Peripheral anatomical compartments	• Compact device • **Lower dose**
Cone beam	• Short acquisition time • **Lower dose**



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Timepix4 ASIC Hybrid pixel detector readout ASIC

Timepix4 ASIC (448 x 512 square pixels, 0.055 mm pitch).

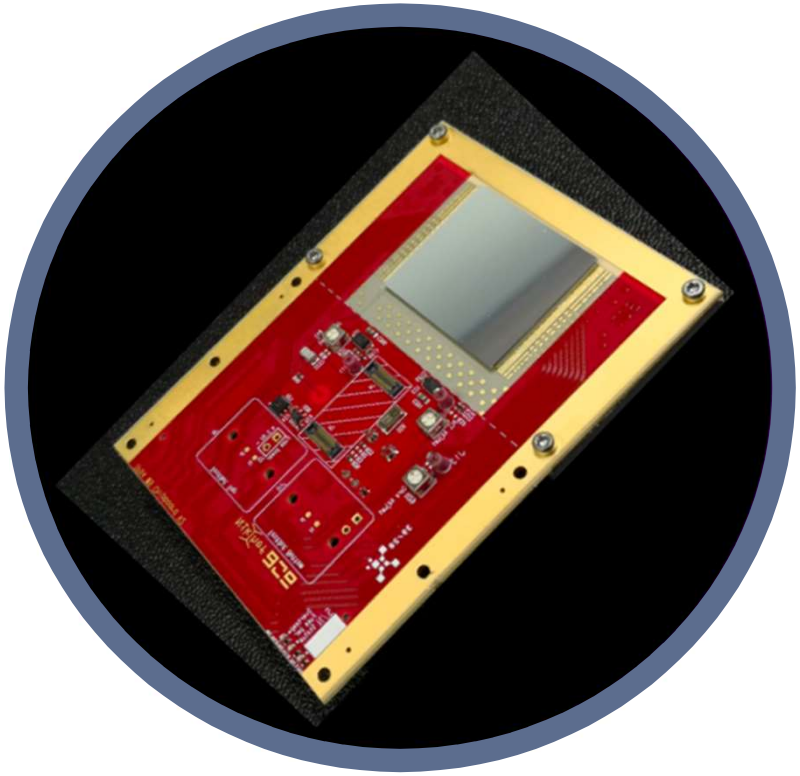
1 mm or 2 mm thick CdTe sensor (sensitive area of **6.93 cm²**).

4 side buttable (TSV connections)

Spectral imaging and particle tracking

Time Resolution ≈ 200 ps

Energy resolution < 1 keV



INFN Istituto Nazionale di Fisica Nucleare

medipix collaboration

CERN

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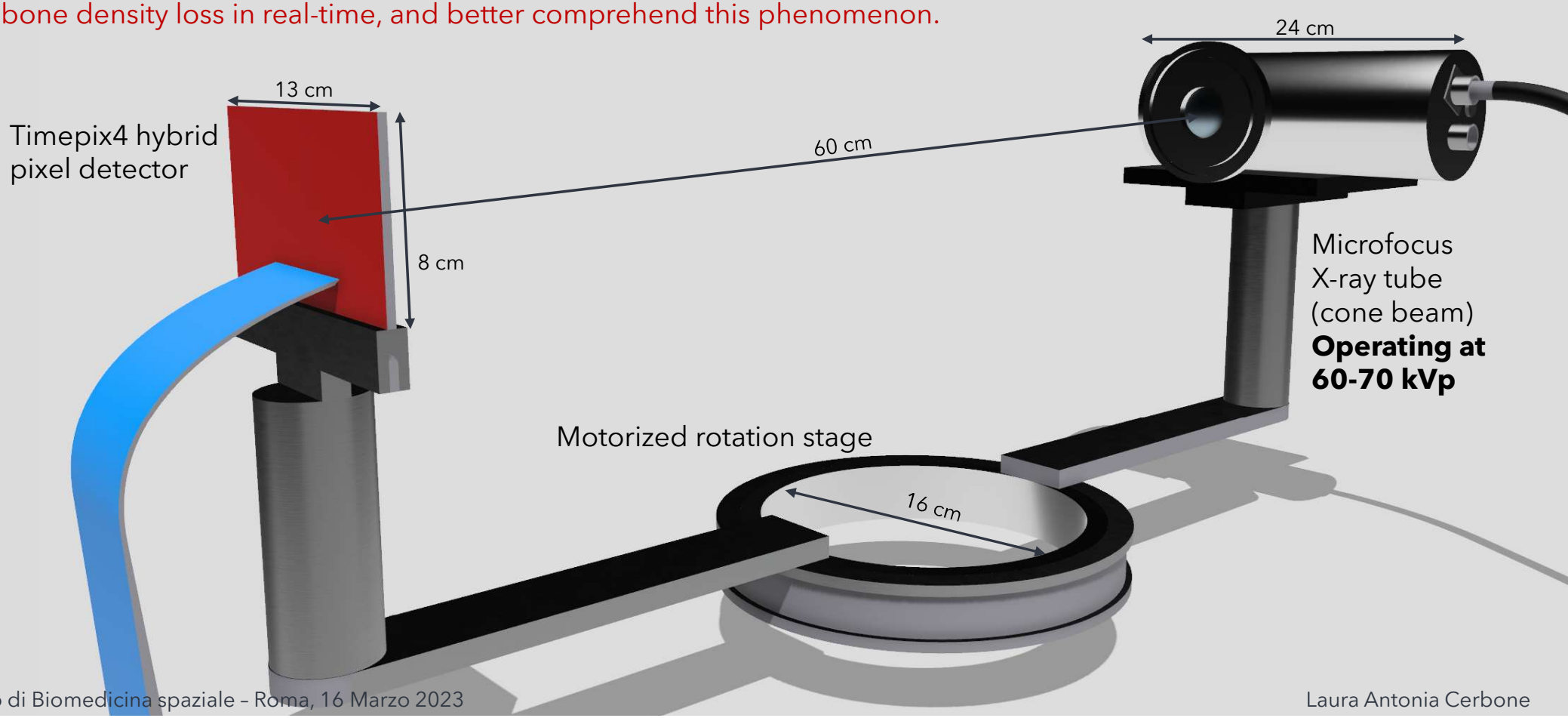


ASTRO-QCT

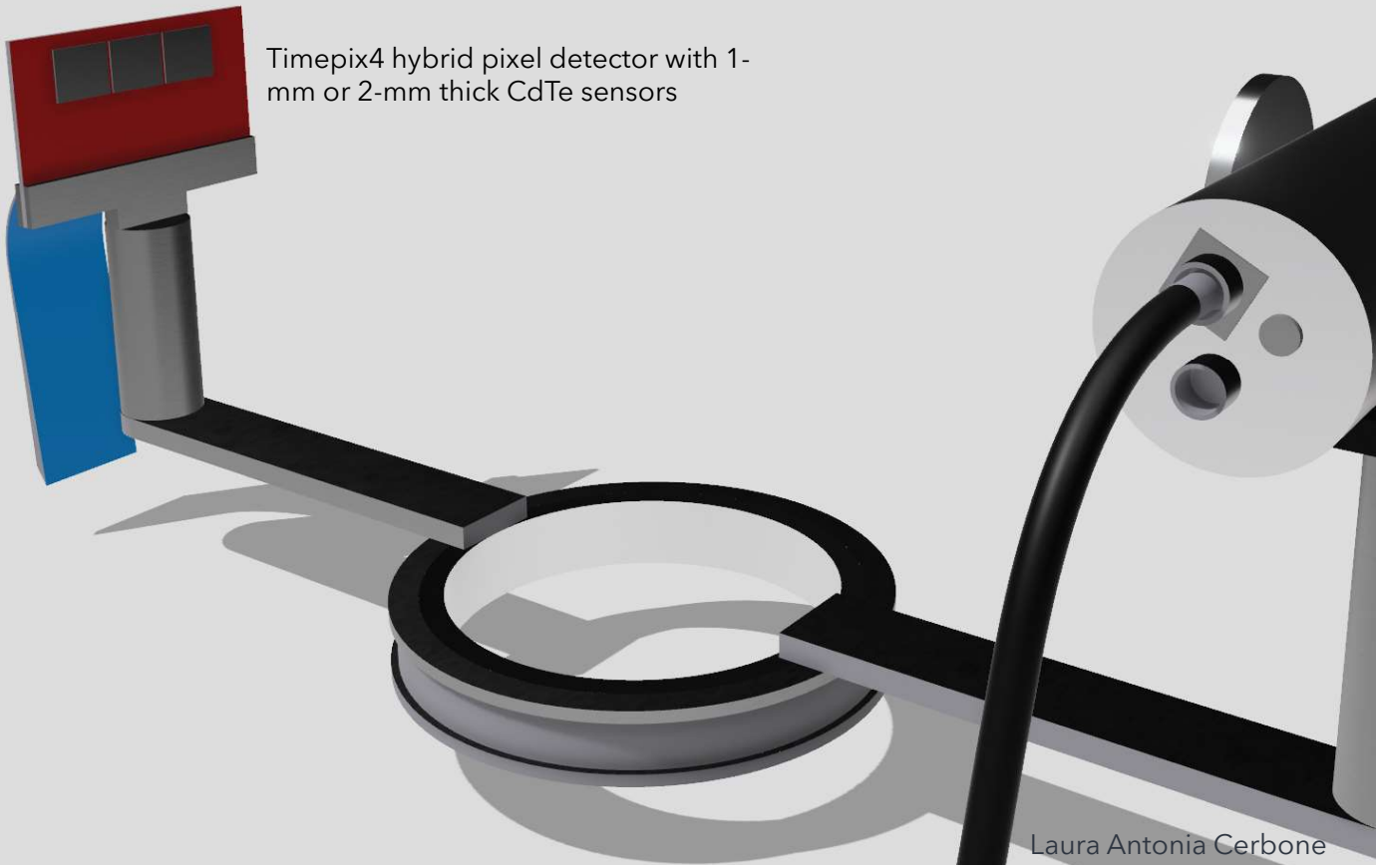
The device's overall weight is expected to be under 40 kg.

A footprint of 0,11 m^3 should be considered for the device itself, with an additional 0.04 m^3 for the electronics, the power supply, and the controllers.

Acquisition time should be **3-5 mins.**

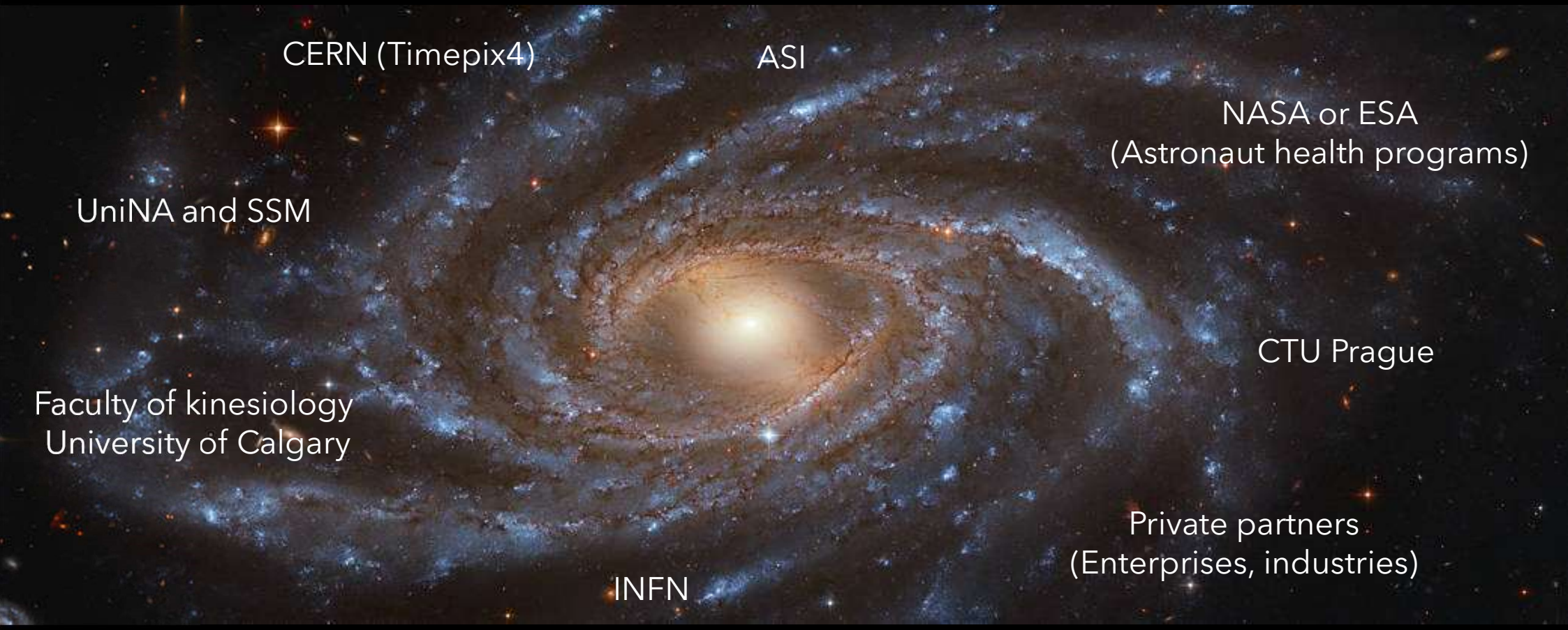
Depending on the magnification factor, it could potentially reach a **spatial resolution** below **40 µm.**

Depending on the imaging task, the **effective dose** is expected to be Of the order of **10 µSv** (under assessment via Monte Carlo simulations)



Timepix4 hybrid pixel detector with 1-mm or 2-mm thick CdTe sensors

Potential partners



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Thank you for your attention

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