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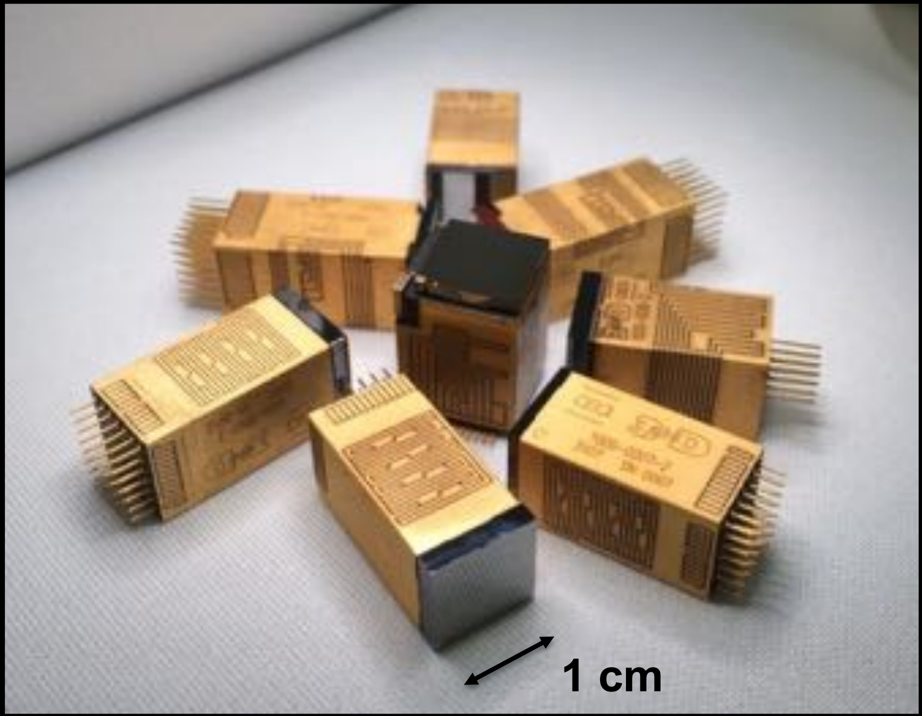
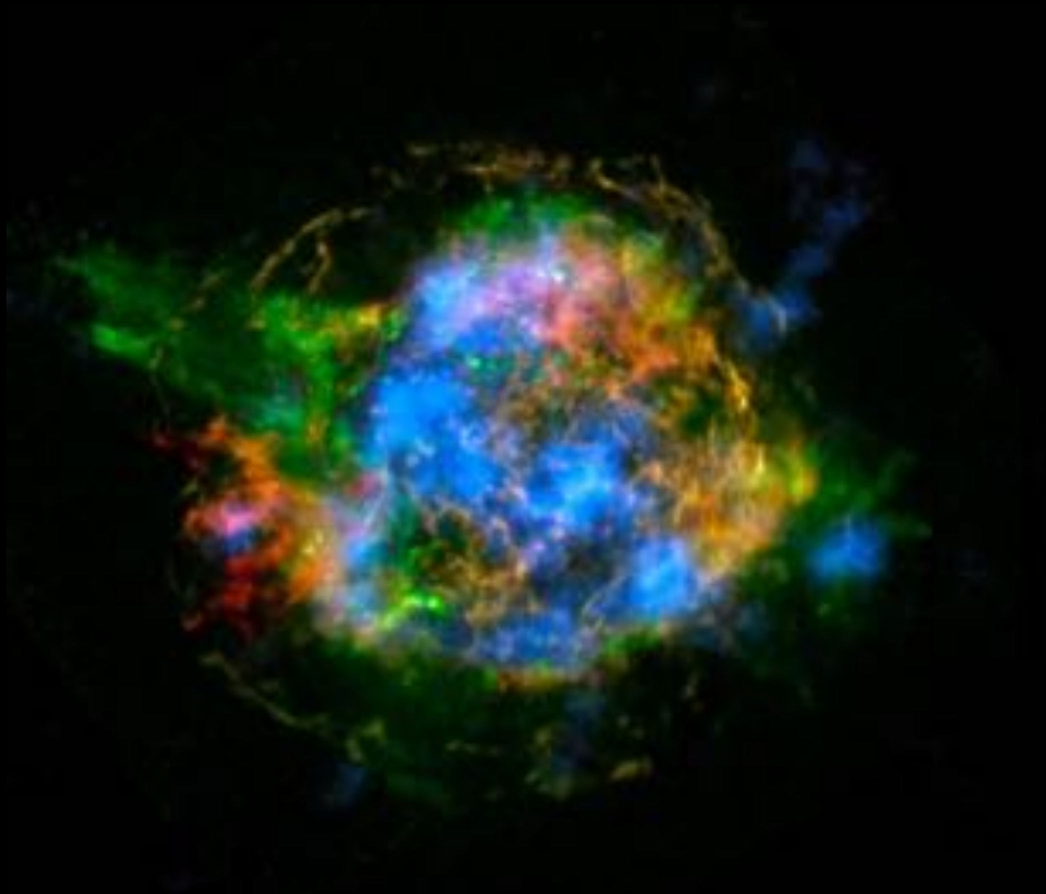
Spectro-imageur Caliste: De l'astronomie à la mesure de dose en radiothérapie



Olivier Limousin, CEA-Saclay

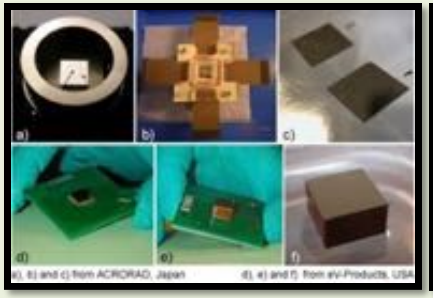
CAS A VIEW WITH NUSTAR

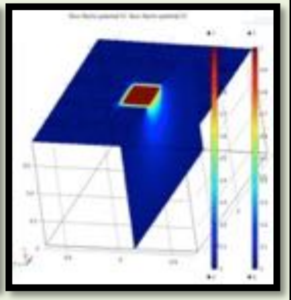


NASA / Composite image Chandra & NuStar, 2014
http://www.nustar.caltech.edu/
Nature, 2014

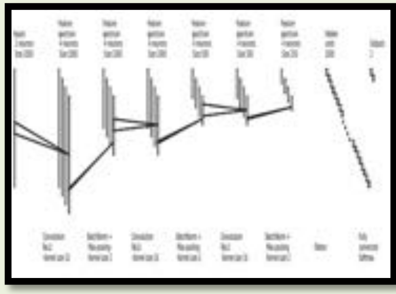
R&D PROCESS FOR HXR DETECTORS

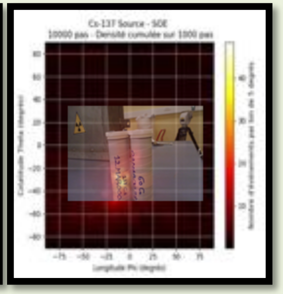
CdTe detectors design, modelisation and simulations



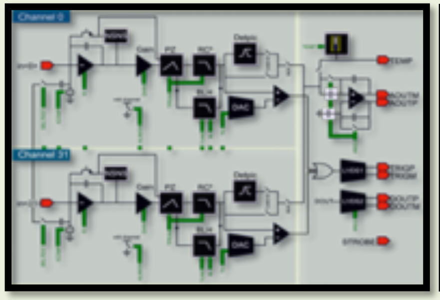


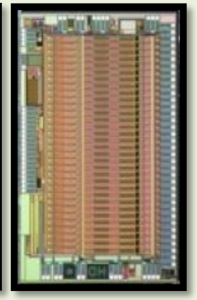
Data Analysis methods And reconstruction





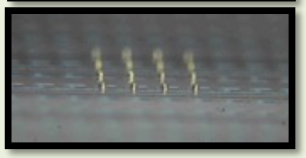
ASIC, Design, tests

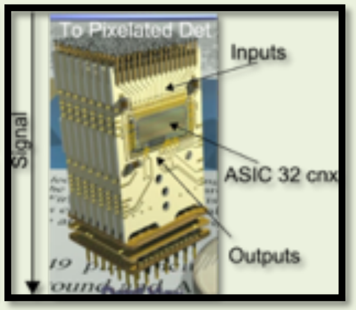




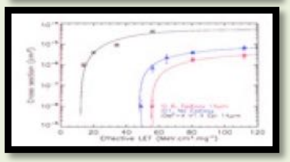
Performances, TRL

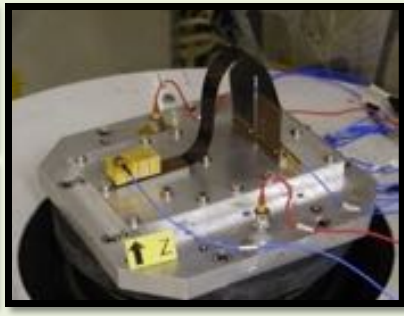
Hybridization





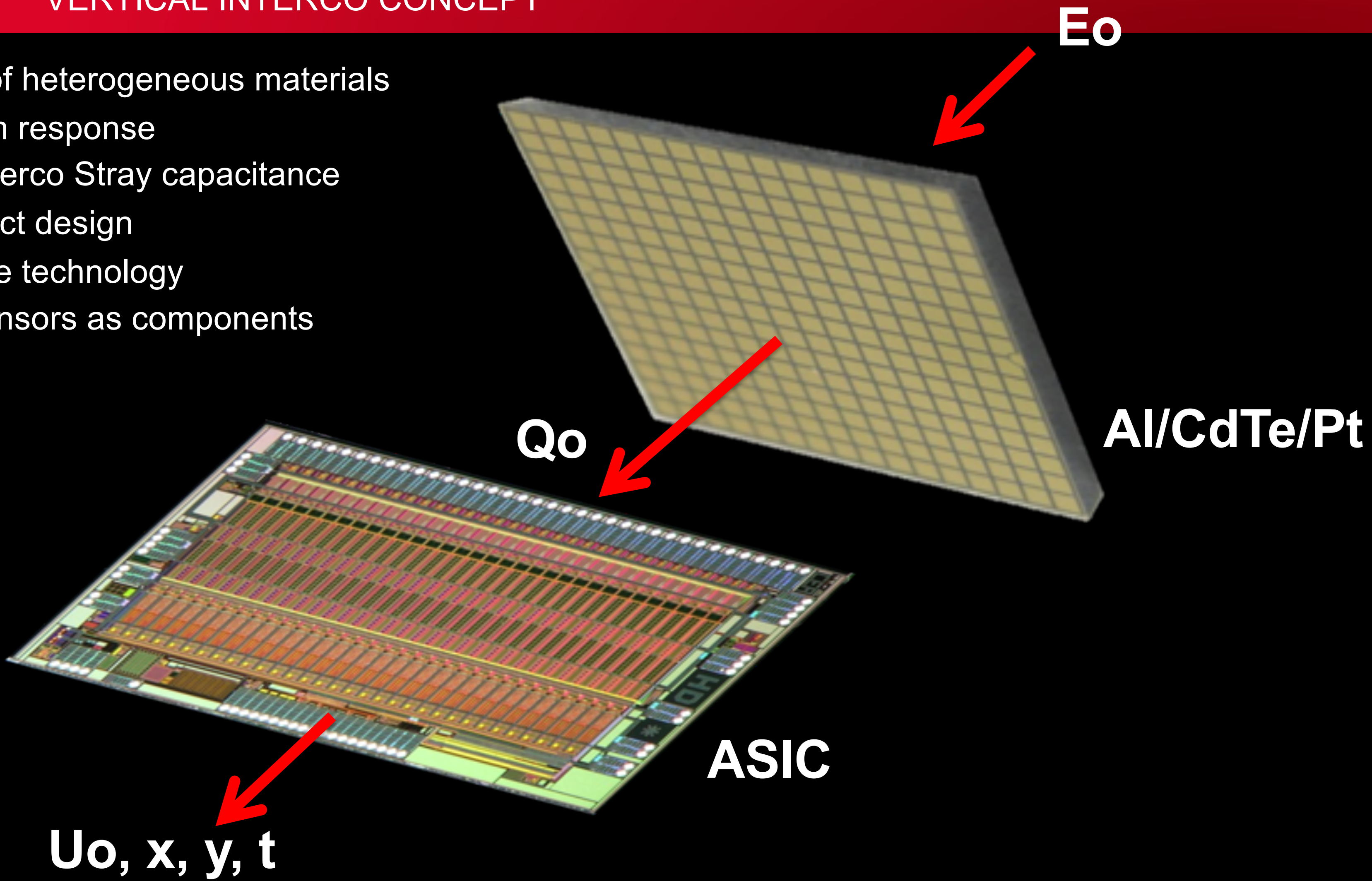
Space Qualification



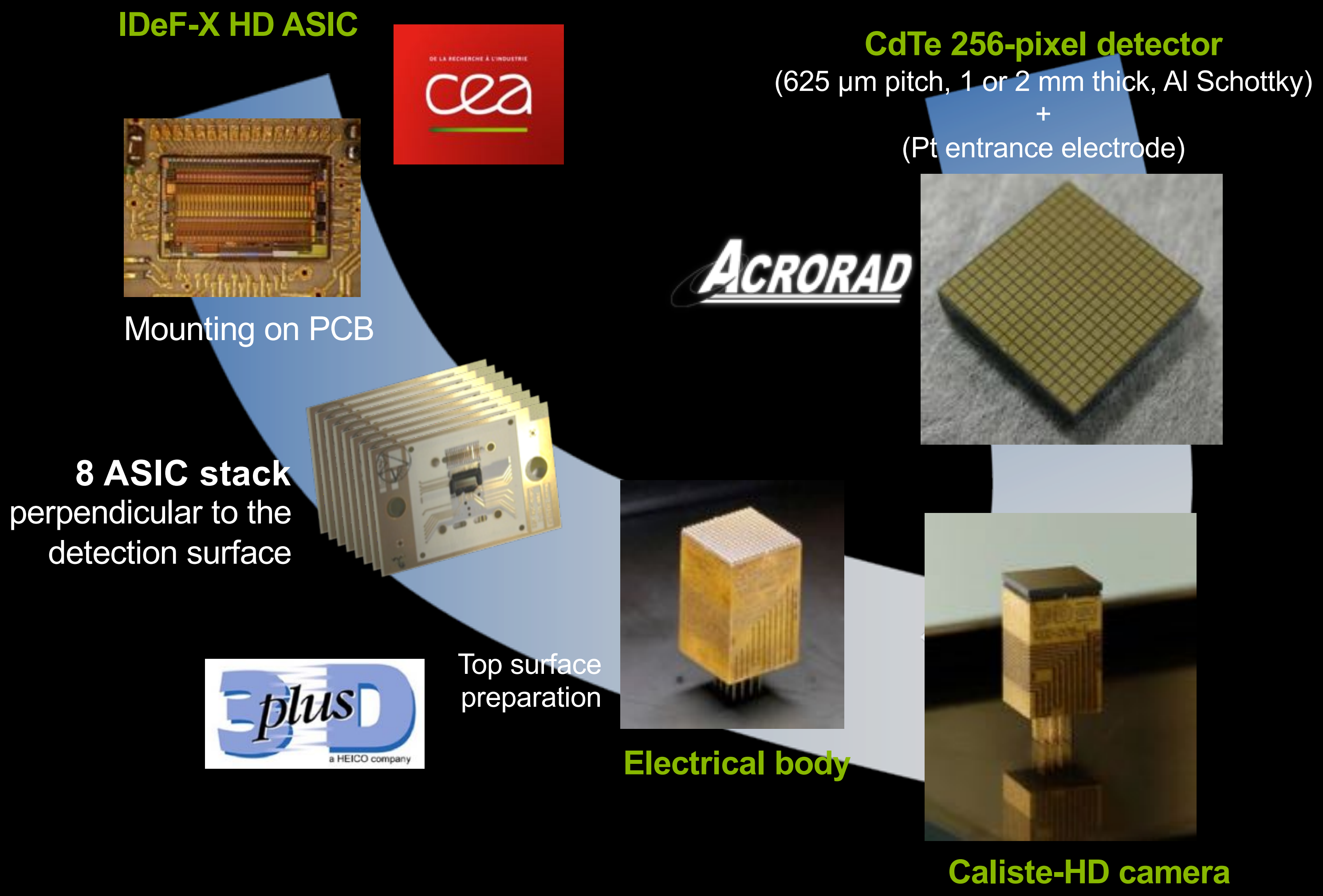


VERTICAL INTERCO CONCEPT

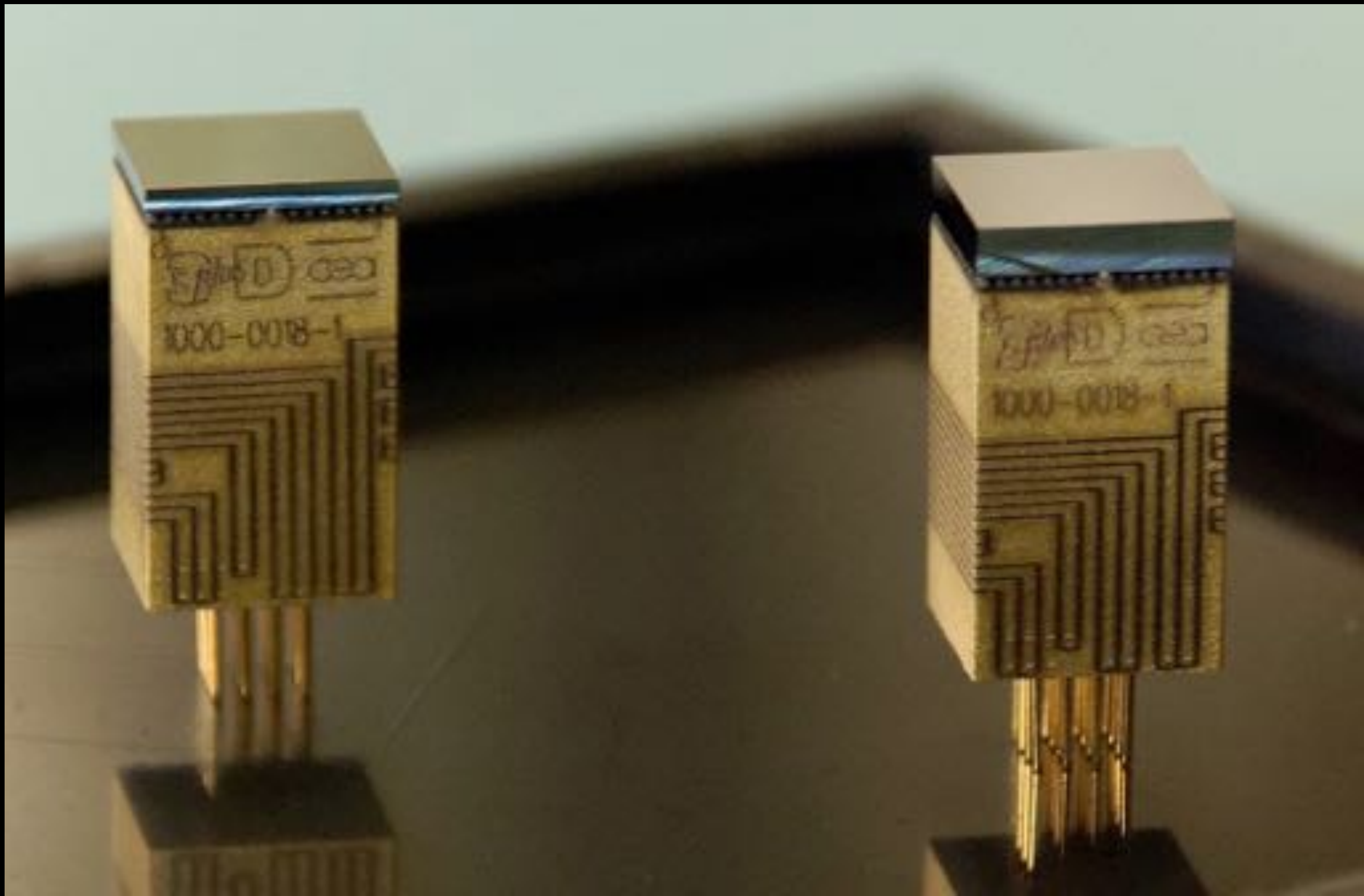
- Stack of heterogeneous materials
- Uniform response
- Low Interco Stray capacitance
- Compact design
- Reliable technology
- Use sensors as components



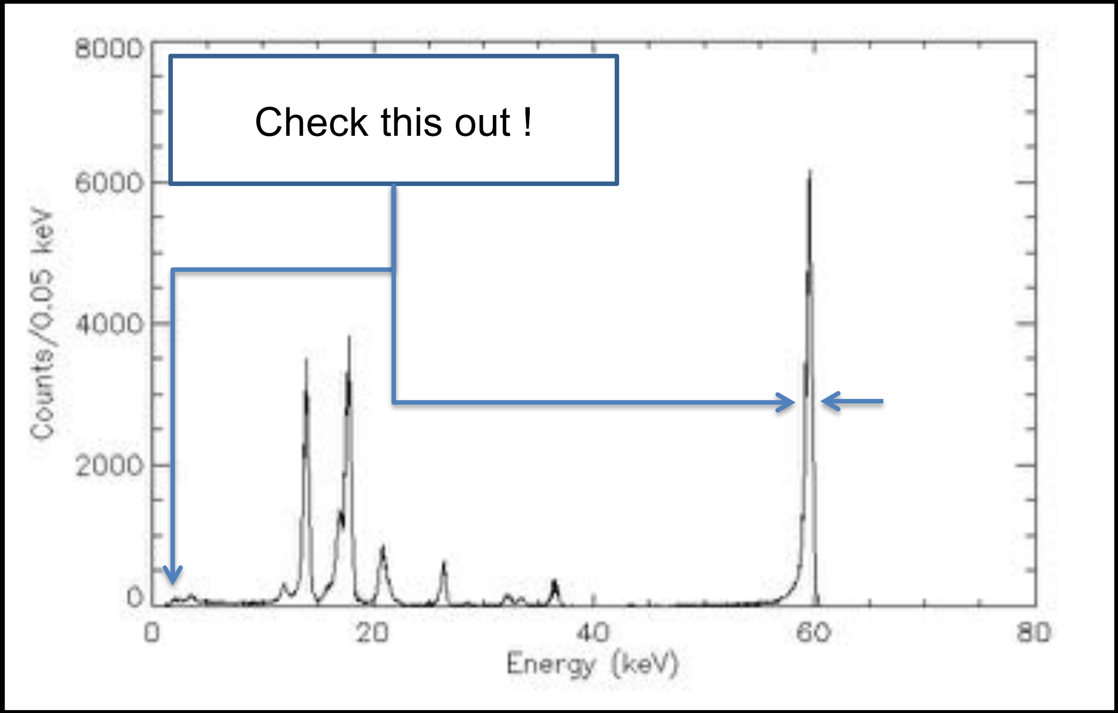
HYBRIDIZATION TECHNOLOGY



CALISTE CONCEPT



CALISTE HD SPECTRAL RESPONSE



- -4°C / 400V
- **256 pixels (Sum of 256 calibrated spectra)**
- 562 eV FWHM at 13.9 keV
- **666 eV FWHM at 59.5 keV**
- **1.2 keV low threshold**

SOLAR ORBITER

10 instruments for remote sensing and in-situ measurements

Launch date: 2020 + 2-year cruise

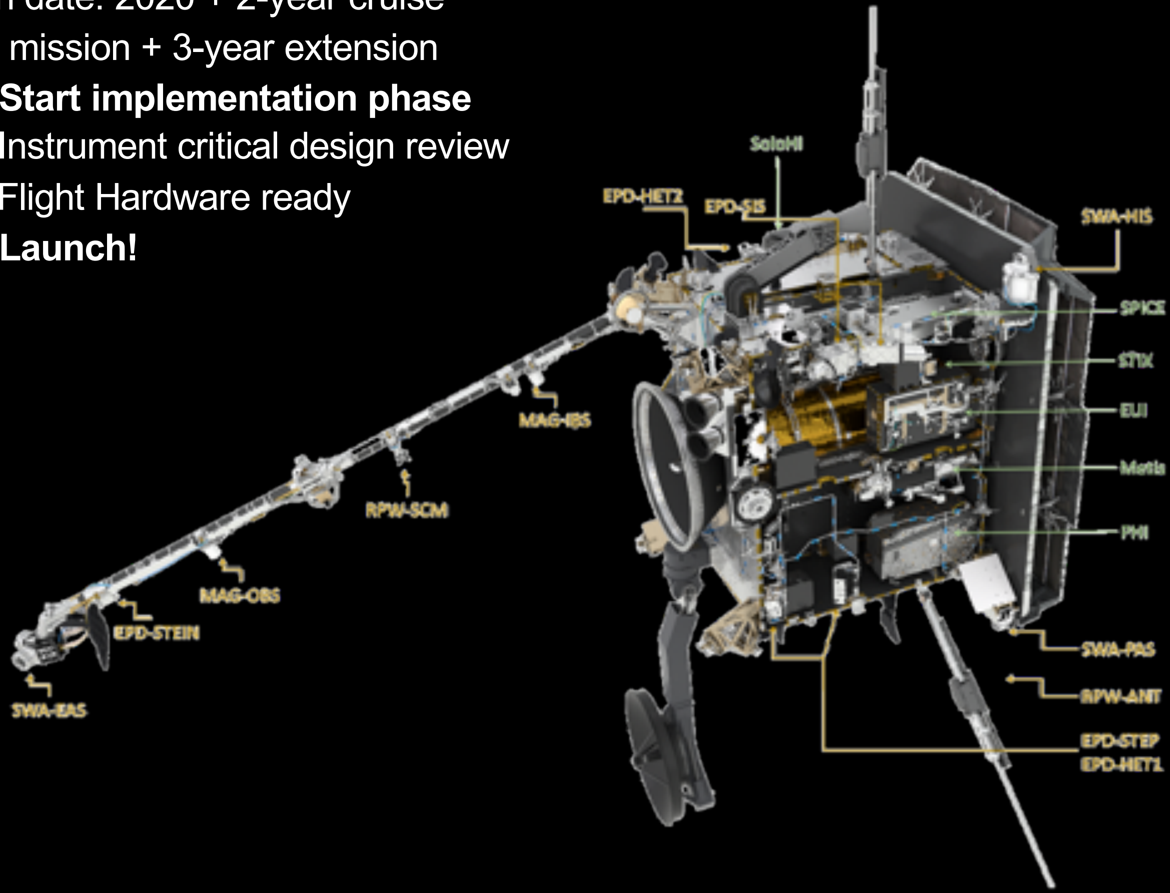
4-year mission + 3-year extension

2012: Start implementation phase

2014: Instrument critical design review

2016: Flight Hardware ready

2020: Launch!

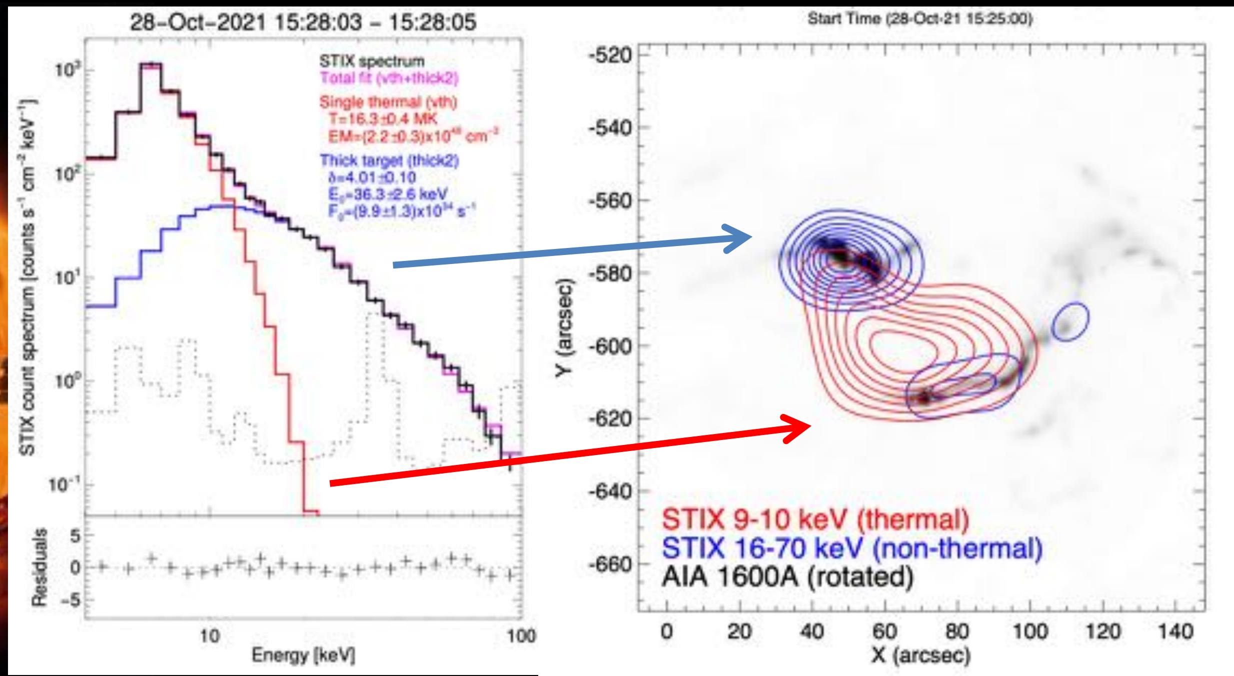


SCIENCE GOAL

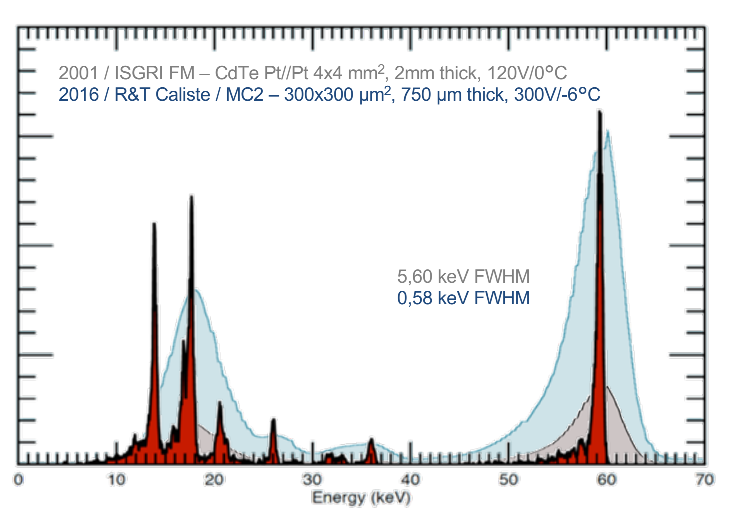
STIX: Spectrometer Telescope Imaging X-rays

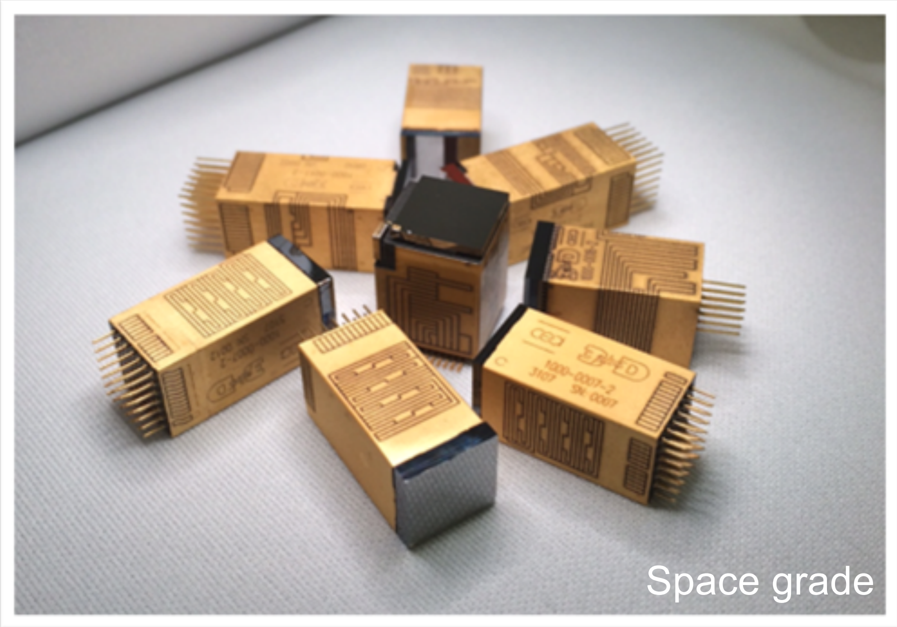
By detecting X-rays from **4 to 150 keV**, STIX determines the intensity, the location, the timing, the spectra of accelerated electrons near the Sun.

Hard X-ray Spectrum and Image from STIX



CALSITE FAMILY





CEA

ORIGAMIX

Scale 5cm

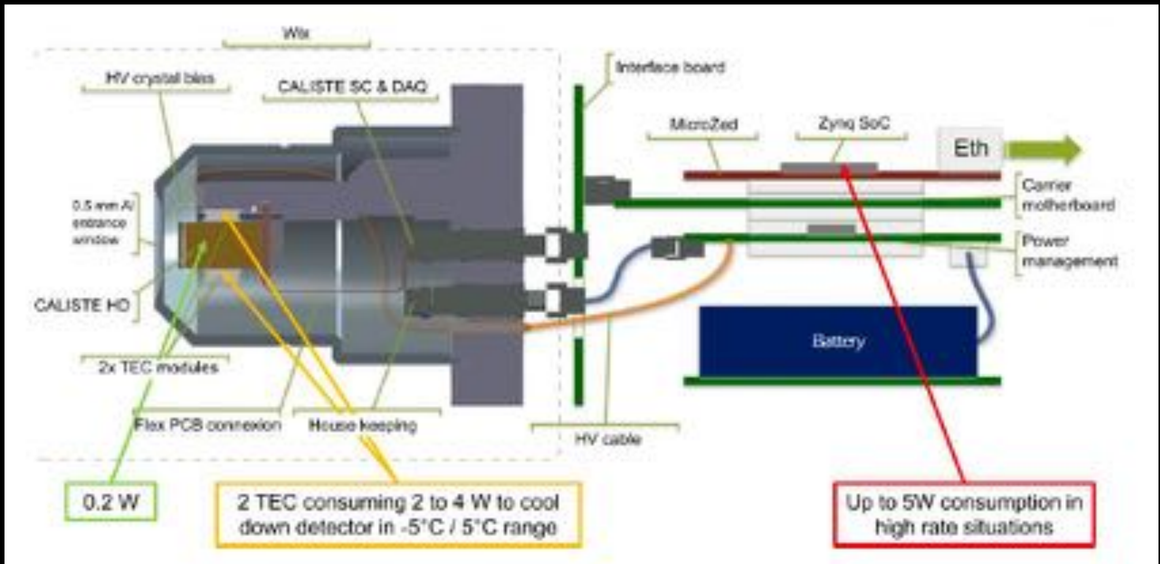
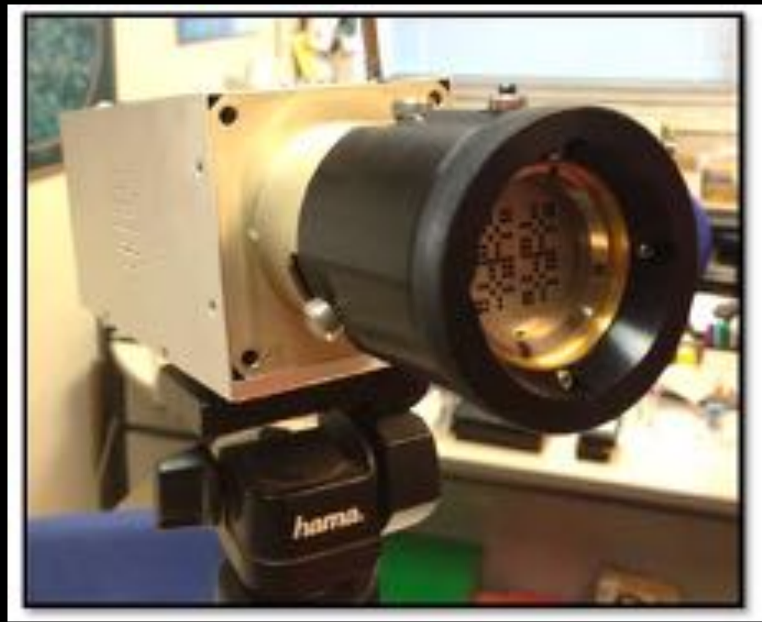


Figure 1 – Schematical drawing of the WIX camera head and its associated electronics.



- Low weight portable camera
- Compact design
- Flexible detector setup, with different versions of Caliste
- Industrial grade Caliste version

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Spectro-imageurs d'Assistance à la radioThérapie roBOTisée

SATBOT

DRF-IMPULSION

DRF Impulsion

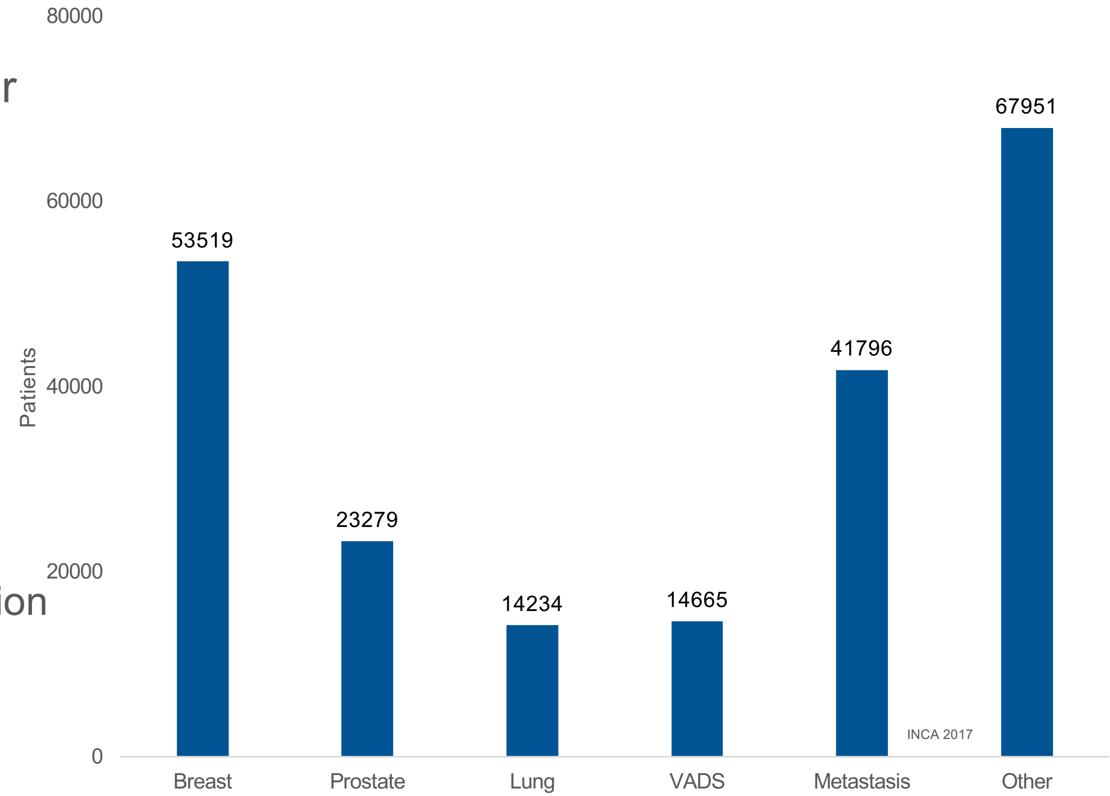
FRANCE – INCA 2017

Radiotherapy (RT) a major treatment of cancer

- 215 444 patients received radiotherapy
- 2 023 591 sessions of RT
- 25% of them for breast cancer

But:

- **20% of radioresistant cancers**
- Efficacy limitation: Toxicity
  - Use of new sources (hadron therapy)
  - **RT enhancement (nanoparticles)**
- **No in situ dosimetry (simulation)**
- Limited physiology and morphology integration
  - Diminution of tumor volume
  - Inflammation
  - Patient loss of weight

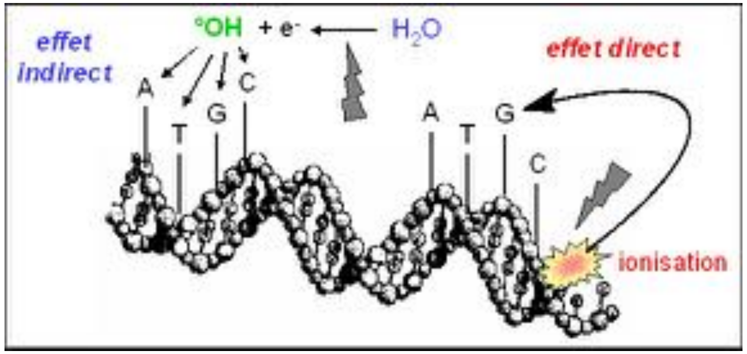


Two biological challenges to tackle for Radiotherapy Optimization: treatment efficacy and dosimetry

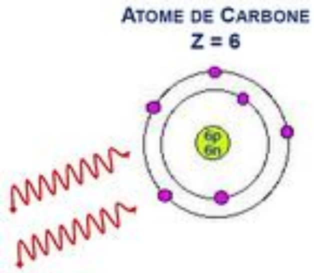
Irridiation Enhancement with nanoparticles

Excitation directe, ionisation de la matière

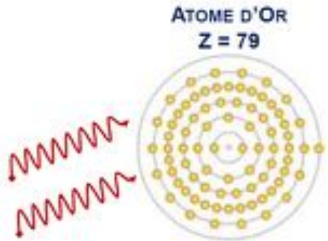
Excitation indirecte, ionisation H_2O

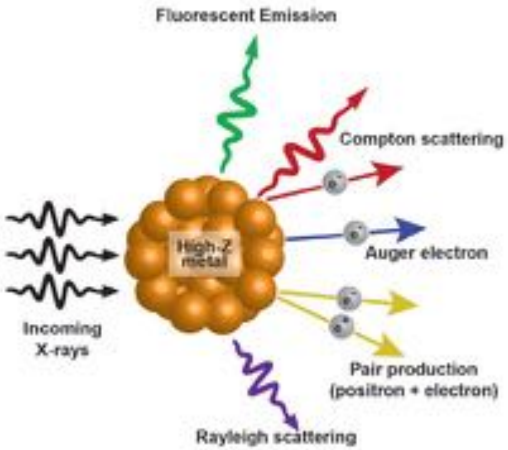


Focaliser et concentrer les interactions rayonnements / matière

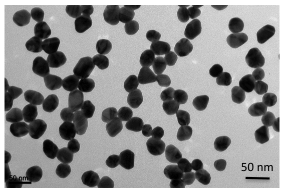


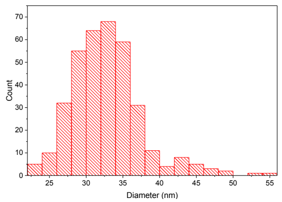
Augmenter :
- densité du tissu cible
- ROS





AuNPs 32nm
PEG1000 NH_2





LES SATBOTIENS

4 laboratoires - 21 personnes impliquées

52% < 35 ans

- DRF/IRFU: Détecteurs, Filtrages X et analyses des données spectro

  Olivier Limousin (CdTe, coord.), Diana Renaud (campagnes essais), Daniel Maier (analyse données), François Visticot (Caméra X), Pierre-Anne Bausson (DAQ), Jérôme Martignac (mécanique frontale)

- DRF/iRCM : Cellules, effet des radiations sur les cellules

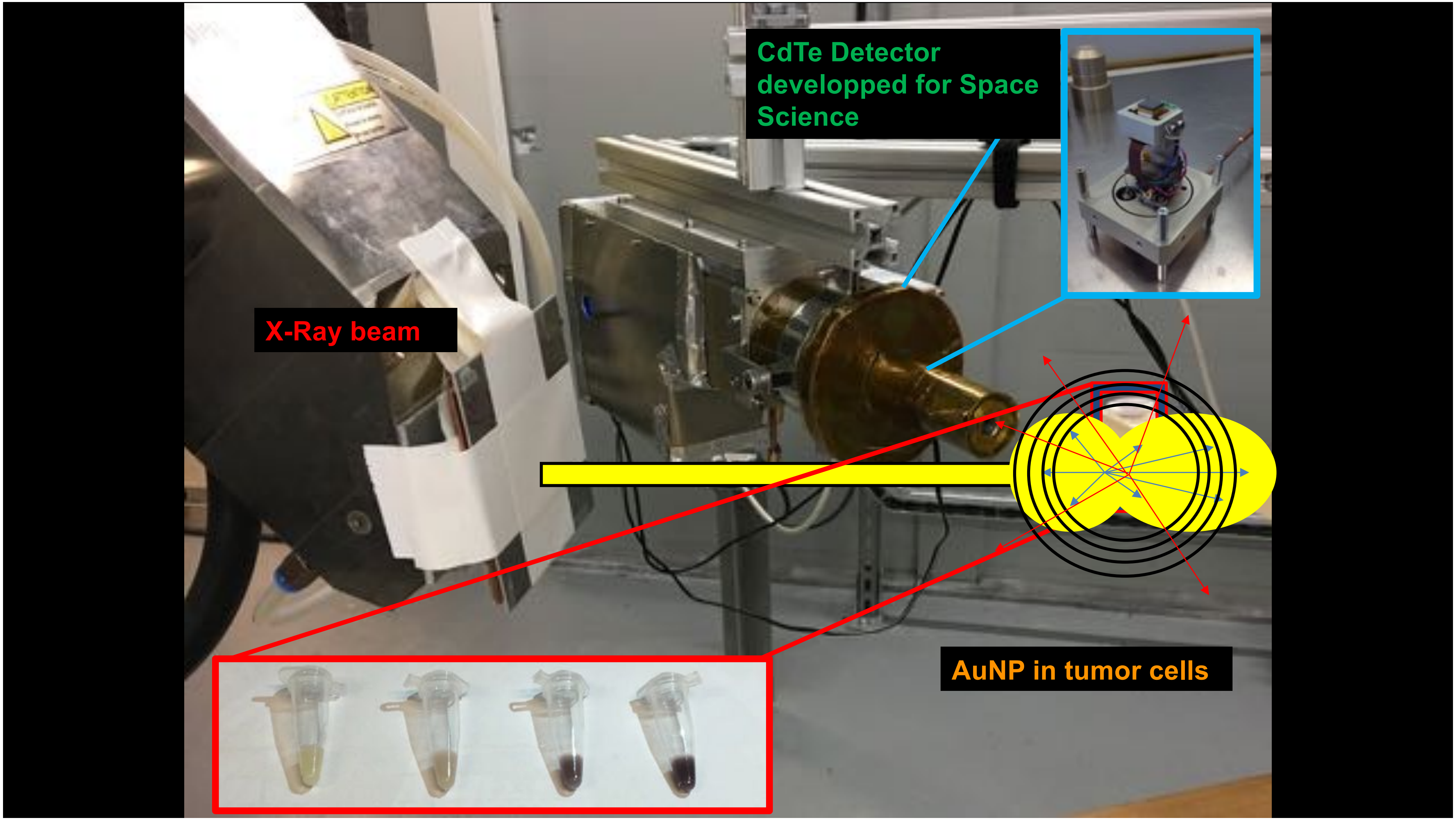
  Sylvie Chevillard (bio et coord.), Romain Grall (bio), Jérôme Lebeau (bio), Jozo Delic (bio), Pauline Castelneau (étudiante M2), Céline Lacrouts (technique), François Leteurtre (bio), Benoît Faye (Postdoc)

- DRT/LIST : Tomographie robotisée et source de rayons X

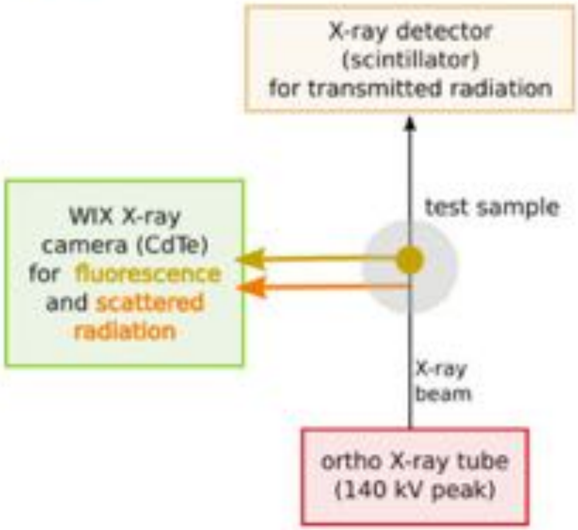
  Hermine Lemaire (imagerie X), Caroline Vienne (Robots et Tomo), Adrien Stolidi (Tomo)

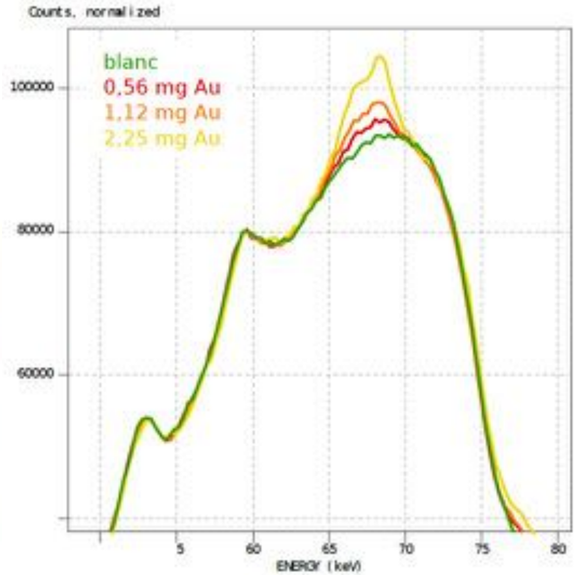
- Univ. Paris Sud / LCP : synthèse et caractérisation des NPO

  Cécile Sicard (Nanos), Emilie Brun (nanos), Stéphanie Droniou (Technique) et Alexandre Niedergang-Ribolzi (étudiant M1)


CdTe Detector
developped for Space
Science
X-Ray beam
AuNP in tumor cells

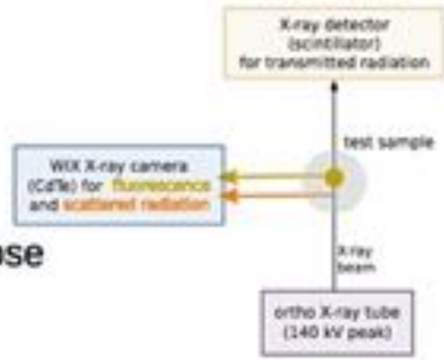
- industrial robots for
  - alignment of X-ray tube
  - alignment of detector





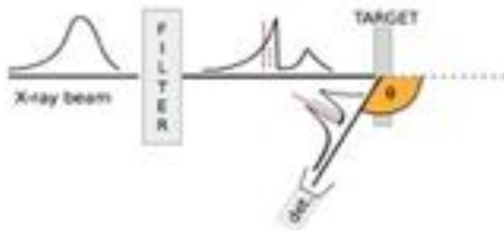
SOPHISTICATED FILTER NEEDED …

- E_{XRF} < K-edge
  - only E > K-edge causes XRF
  - background photons $E_{XRF} < E <$ K-edge → noise
  - unnecessary photons $E < E_{XRF}$ → unnecessary dose



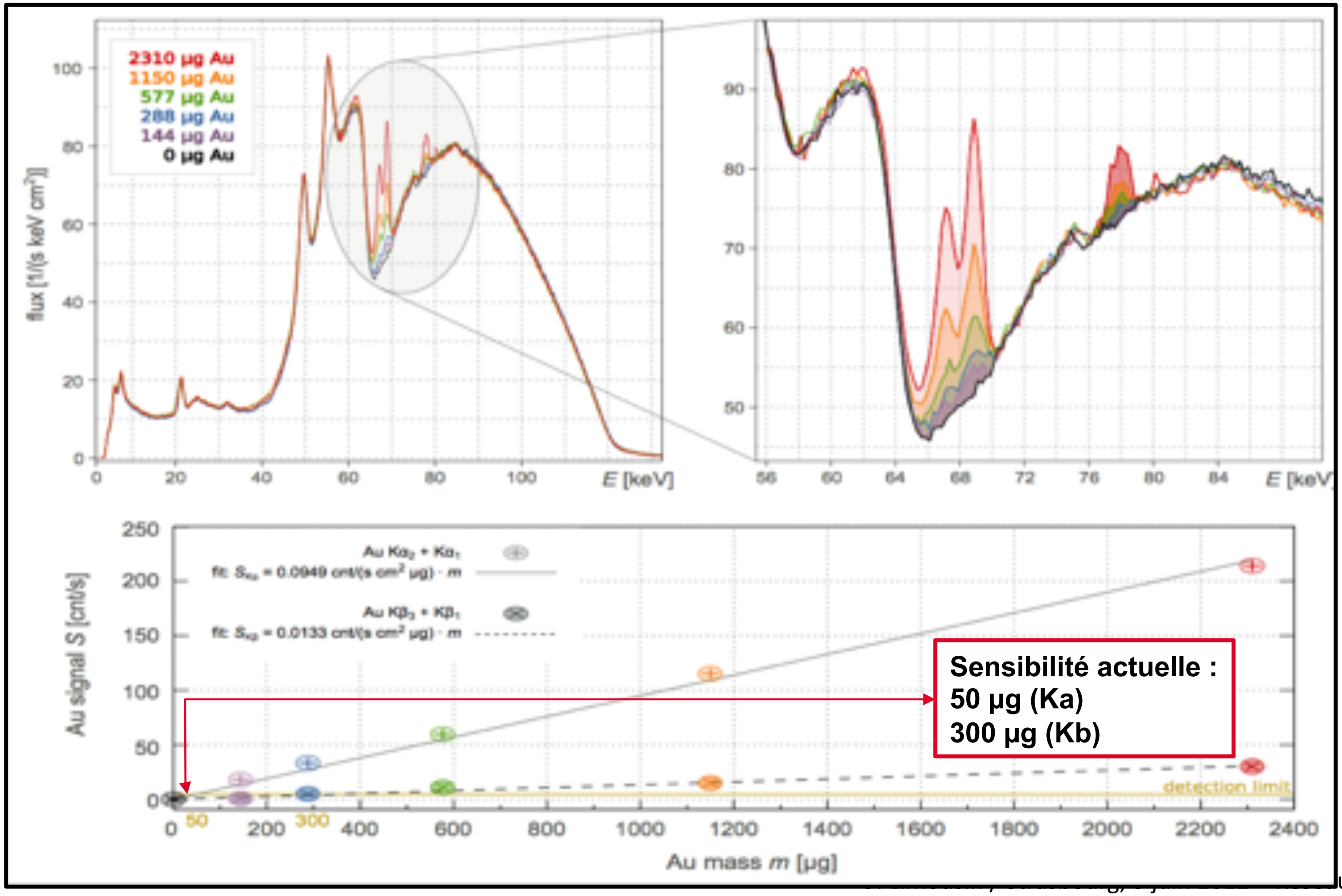
- Combine filter with incoherent scattering
  - scattered radiation loses energy

$$E^{sc} = \frac{E}{1+\frac{E}{511\,\mathrm{keV}}\left(1-\cos(\theta)\right)}$$



$Z_{filter} = Z_{target} + n$

MUCH BETTER …


2310 µg Au
1150 µg Au
577 µg Au
288 µg Au
144 µg Au
0 µg Au
flux [1/(s keV cm²)]
E [keV]
E [keV]
Au Kα₂ + Kα₁
fit: S_Kα = 0.0949 cnt/(s cm² µg) · m
Au Kβ₃ + Kβ₁
fit: S_Kβ = 0.0133 cnt/(s cm² µg) · m
Au signal S [cnt/s]
Au mass m [µg]
detection limit
50
300
Sensibilité actuelle :
50 µg (Ka)
300 µg (Kb)

TECHNIQUE: how to measure ~µg of gold in situ during radiotherapy?

- The task:
  „conclude on the absorbed dose and the quantity of gold in an irradiated volume"

- What we use: fluorescence radiation
  - Characteristic Au fluorescence
  - K-edge ≈ 81 keV
  - Ka ≈ 69 keV
  - Kb ≈ 78 keV

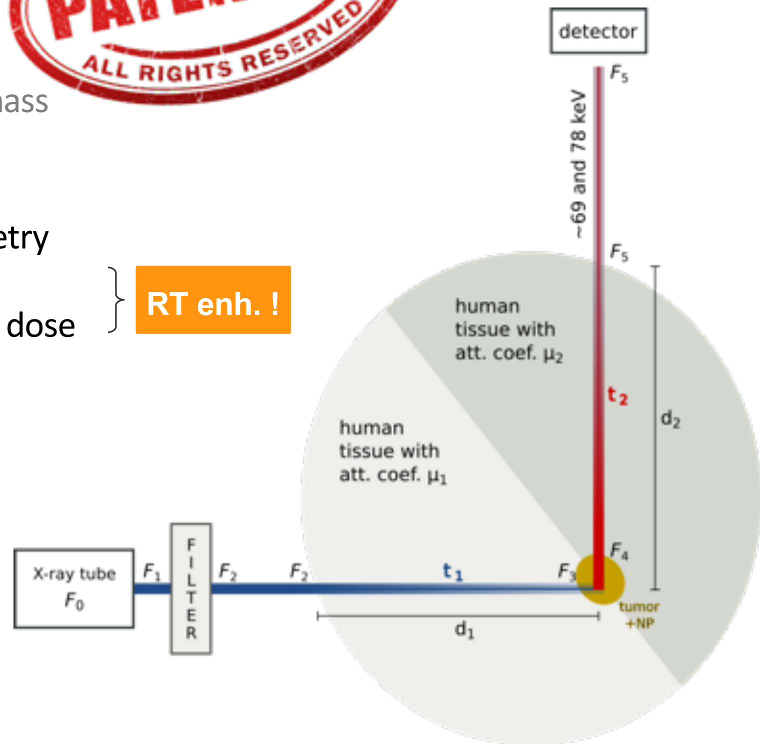
- What we need:
  - precise knowledge of the incoming flux F2
  - precise measurement of the outgoing flux F5

- What we **DO NOT** need:
  any prior knowledge of the constitution of the body (we get the product d1 *µ1 and d2 *µ2 by our measurement)

- How we do it:
  - Ka/Kb → t2
  - reverse config.: X-ray tube ⇔ detector
  - Ka/Kb → t1
  - F2 → F3 → Dose
  - F5 → F4 → Au mass

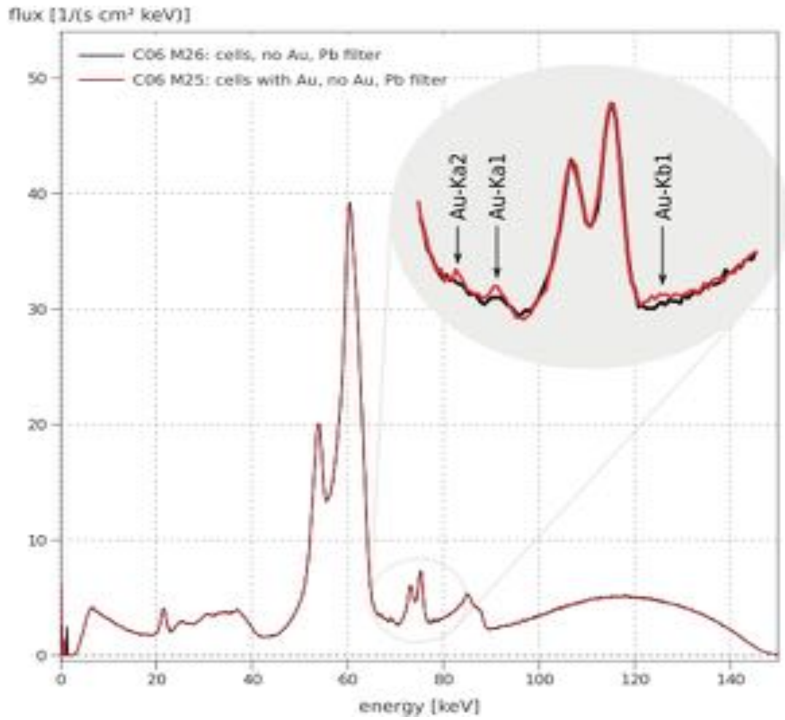
- Use:
  - real-time dosimetry
  - Au distribution
  - info: spectrum > dose

} **RT enh. !**



RESULTS: Au NP in cells

- SATBOT measurement with Au loaded cells



result: m_{Au} = 54 ± ? µg

- Mass spectrometry analysis of the same sample

result: m_{Au} = 33 ± 3 µg

XRF CT – FIRST TRY, SAMPLES

- 2 mm de diamètre, anneau cylindrique, 6 mm de haut

- 3 mm de diemètre, anneau cylindrique, 1.2 mm de haut

- Petits objets de 1à 2 mm séparés de 3 à 4 mm de distance dans de la mousse

XRF CT – LES ROBOTS EN ACTION …

- Tube à rayons X micro-foyer - 200kV 1600 µA 320 W
  Filtration : Au 0,150 mm Cu 2mm Al 1,5 mm
- Sténopé - Pb diamètre 1 mm épaisseur 5 mm
- Distance échantillon-sténopé - 90 mm
- Distance sténopé-détecteur - 110 mm
- 26 vues, pas de 10°, course de 250°

*Data fusion a posteriori


MERCI DE VOTRE ATTENTION
SATBOT
DRF-IMPULSION
Olivier
Sylvie
Diana
Adrien
Cécile
Jérôme
Hermine
Caroline
Daniel
Pierre-Anne
François
Romain
Emilie
Benoit
Jérôme
François
Jozo
Bénédicte
Mathieu