

## A Light for Science



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## Synchrotron Radiation Imaging: Palaeontology and Cultural Heritage Studies

Francesco Sette – ESRF BP 220 – 38043 Grenoble – France

- X-rays and Synchrotron Radiation
- X-ray Synchrotron Imaging: A Revolution for Paleontology
- Life at a Synchrotron Facility: the ESRF
- X-ray Synchrotron Imaging: ESRF & Cultural Heritage





#### European Synchrotron Radiation Facility





#### A closer look at a battery with Synchrotron X-ray tomography

#### charged



or empty?





#### charged

empty

M. Scheel, Max Planck Institute for Dynamics and Self-Organization, Göttingen

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#### Paleontology



Così l'anello del sincrotrone

dirà tutto dell'anello mancante

Nell'acceleratore di particelle di Grenoble si studia uno dei fossili più

antichi mai ritrovati. Viene dal Sudafrica, potrebbe essere il legame

tra australopitechi e «Homo», e conserva ancora tracce di cervello

Dete 73 Pagina Foglio 1

Settimanal

E TECNOLOGIA . PSICOLOGIA . MEA CINA **NATURA** 

> "Senza una legge sul testamento biologico ossiamo dire che c'è tolta la libertà di scegliere della nostra vita" forgherita Hack 
> ASTRONOMA

16-04-2010

#### ALEX SARAGOSA

A NOTIZIA ha fatto molto rumore: gli scheletri quasi completi di due australopitechi vissuti 1,9 milioni di anni fa, rinvenuti dal paleontologo sudafricano Lee Berger in una grotta vicino a Johannesburg, potrebbero essere l'anello mancante fra gli ancora scimmieschi australopitechi (quelli ai quali appartiene anche la famosa Lucy) e il genere Homo. Parte dell'esame delle ossa è avvenuto all'European synchrotron radiation facility (Esrf) di Grenoble, un centro di ricerca finanziato da enti scientifici di diciotto nazioni europee, fra i quali il Cnr è uno dei principali. All'Esrf le ossa dell'australopiteco più pic-

colo sono state esaminate con i raggi X prodotti dal velocissimo movimento circolare di elettroni nell'anello del sincrotrone (acceleratore di particelle). «I raggi X di sincrotrone» spiega il fisico Alberto Bravin, direttore del laboratorio di ricerche mediche dell'Esrf, «hanno una maggiore intensità, sono

INCONTRI RAVVICINATI Alberto Bravin direttore del laboratorio Esrl che ha eseguito le analisi

tutti paralleli fra loro e se ne può selezionare la frequenza più adatta al mate riale da esaminare. In questo modo si possono ottenere immagini con un dettaglio tra dieci e cento volte più fine di quello visibile nelle normali tac ospedaliere. La radiazione viene estratta in vari punti dell'anello e usata in diversi laboratori per analisi fisico-chimiche e per la cura di tumori». Così delle ossa fossili è stato evidenziato ogni dettaglio, senza estrarle completamente dalla roccia col rischio di romperle. L'esame ha già riservato una grossa sorpresa:nel cranio del giovane potrebbe ancora esserci una parte fossilizzata del cervello. Nelle prossime settimane, l'analisi delle linee di crescita microscopiche dei denti, una tecnica inventata proprio all'Esrf, ci farà anche conoscere con estrema precisione (dell'ordine di qualche giorno) l'età del piccolo, E che si ipotizza avesse otto-nove anni.



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ommon ie of wave	RADIO FREQUENCIES						INFR	INFRARED ULTRAVIOLET GAMMA RAYS								

*X-rays* – as electrons – are ideally suited to achieve *sub-nano-*metre spatial resolution:

No diffraction limit as for visible light
 X-ray Synchrotron nanoscopes achieved spatial resolution well below 10x10 nm<sup>2</sup>





Röntgen discovered X-rays in 1895 and received the FIRST NOBEL PRIZE in Physics in 1901.





#### X-rays

W. presidnich

bin dos criters Inderis and infraction 1912.

Laue and the Braggs discovered in 1912-13 that X-rays can be used to study atomic structures and properties of materials. They received Nobel Prizes in physics in 1914 and 1915, respectively.



**Max von Laue** 

#### W. Bragg father and son





#### X-rays: A new eye on Nature



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#### Relativistic electrons and light

#### Alfred-Marie LIENARD (1869-1958)



*"Champ électrique et magnétique produit par une charge électrique concentrée en un point et animée d'un mouvement quelconque" L'Éclairage Électrique, 16(27), pp. 5–14 (1898)* 



#### **First Observation of Synchrotron Radiation**



The General Electric team (Langmuir, Elder, Gurewitsch, Charlton and Pollock) looking at the vacuum chamber of the 70 MeV synchrotron (1947).



## Synchrotron Radiation from the Sky Crab Nebula Jupiter's radiation belts



Photo from Hale 5mTelescope plates by David Malin



Gas emission (reddish) and synchrotron radiation (bluish) generated by high energy electrons in the magnetic field of a neutron star. Radiation belts of Jupiter: high energy electrons in the magnetic field of the planet produce synchrotron light, which reproduces the field distribution.



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#### The European Synchrotron Radiation Facility: the 1<sup>st</sup> Third Generation Source





#### Major X-Ray sources in the world



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#### Investigating matter, materials and living matter Fields of application

# Understanding matter down to the single atom links many scientific disciplines at Synchrotrons:





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# X-ray Synchrotron Imaging: A Revolution for Palaeontology

# Paul Tafforeau (father and son)

4 cm

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2 cm

When looking at a fossil, palaeontologists want to study both external morphology and internal anatomy



But studying the internal anatomy leads to a serious problem: how to have access to it ?



The simplest and fastest way consists in breaking the fossil with a hammer

## Unfortunately, it generally leads to quite disappointing results

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A better way consists in sawing the fossil in order to precisely control the sample preparation

## This technique takes some more time, ...



# but the results are generally better !

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## It is different with rare and important specimens!



## In this case using a hammer is hazardous ....



Some fossils are extremely rare and precious, they represent the only trace of life history on our planet.

It is as important to study them as to preserve them, since they are an inestimable heritage that has to be respected and kept for future generations.

Nowadays, palaeontologists can be reassured!

A new powerful method indeed has been found:

This consists in the use of a third generation synchrotron to look inside the fossils without destroying them.

# Some basics about synchrotron imaging techniques used for paleontology

X-ray tomography is based on radiographies: the images are directly obtained by imaging the X-ray beam before and after going through a sample.

The ESRF synchrotron, thanks to tunable spectrum, brilliance, collimation and spatial coherence, allows several radiographic techniques, some of them being used to image fossils :

- Absorption (classical radiography)
- Propagation phase contrast (edge detection)
  Phase retrieval (quantitative phase imaging)

## Absorption mode (classical radiograph)



#### **Propagation phase contrast mode**

# Enhanced edges visibility

# Absorption on opaque amber



# Propagation phase contrast

# Some applications of Synchrotron imaging in paleontology





### The Malapa Synchrotron Project and Sediba

New hominid species (age 1.9 million years) have been discovered in August 2008 in South Africa by Pr. Lee Berger and colleagues.

Species showing intermediate character between *Australopithecus* and *Homo-Genus*.



*9 April 2010* : Four papers describe the discovery of a new hominid species



## CT with a Hospital Machine





## CT with Synchrotron Light on the ID17 Line at ESRF











#### April 11, 2010 - CBS - 60 Minutes:

#### Fossil Find New Branch in Human Family Tree?

Correspondent Bob Simon accompanies paleoanthropologist Lee Berger to the ESRF in France where they use 21<sup>st</sup> century technology to look at a 1.9 million year old skull.



<u>http://www.cbsnews.com/video/watch/?id=6386131n&tag=contentBody;housing</u> http://www.esrf.eu/news/general-old/general-2010/first-studies-of-fossil-of-new-human-ancestor-take-place-atthe-esrf/

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http://www.esrf.eu/UsersAndScience/P ublications/Highlights/2011/imaging/i

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#### Australopitecus Sediba at the ESRF



9 September 2011



*"The many very advanced features found in the brain and body ...make it possibly the best candidate ancestor for our genus, the genus Homo."* Lee Berger, Wits U, Johannesburg



## Amber... and others! Carmen Soriano, ESRF





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#### What is Amber?

**Resin produced by trees deposited in deltaic deposits produces** copal (sub-fossil) and then amber





# "San Just", 100 million years, Spain

#### Paleobiology

- Taxonomy and systematics
- Behaviour (etology): Relationship between organisms
  - of the same species
  - of other species
- Evolution and phylogeny



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ne coordinate system



From a series of tomography 2–D slices to 3–D reconstruction

#### sub-micron resolution possible!



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http://www.esrf.eu/news/media/ Spanish-Amber-Pollen

#### First ever Record of Insect Pollination from 100 Million-years ago.



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July 2011 Residency of four young artists at the ESRF



#### Paleontologist Carmen Soriano presents her work to the artists



#### Nina Grunova creates an oil painting inspired by insects in amber

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#### http://www.esrf.eu/news/general/ISWA-Berlin/ European Synchrotron Radiation Facility

Traveling exhibition: Berlin – Prague Vienna – Grenoble





## Franco Rusticcheli

7

**Geneviève Fioraso** 

5 prix d'une valeur de 1000 euros sont a gagner Exposition des gagnants à Orenoble Câture des insernieurs - 30 him Dépôt des seuvres - 197 Octobre Four participer il te atifit d'avoir entre Internet des 19 ans tu atmes la danse moderne la lititicature la internetoria



Tu aimes l'art, la science, et tu es lycéen !

Inscription et information (en anglais) sur le site : www.iswaproject.eu

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Imaging of fossil embryos *in ovo*: Small eggs from Cretaceous of Thailand thought, based on the shell structure, to belong either to a small theropod dinosaur or to a bird

> PhD thesis of Vincent Fernandez, with E. Buffetaut, V. Suteethorn, M. Kundrat, E. Maire, J. Adrien and P. Tafforeau





#### Absorption synchrotron microtomography







#### Phase contrast microtomography









# Conclusion

After the first scan of a fossil performed in 2000 at the ESRF on ID19, palaeontology is living a small revolution. Synchrotron imaging of fossils illustrates in a way the palaeontology of the 21<sup>st</sup> century.

Third generation synchrotrons are currently the most powerful machines for non-destructive investigations of fossils. Imaging possibilities are already impressive, but the ongoing upgrade projects at the ESRF will push far further the possibilities.



## Thank you for your attention!

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