Andromède

De la nucléosynthèse à la chimie prébiotique
Andromede is an interdisciplinary platform of the IJCLAB (UMR 9012) which contribute to the scientific and technical skills development of Paris Saclay University.

It is open to the academic and industrial world in the fields of nuclear physics; biology, biochemistry; astrophysics and astro-chemistry; molecular chemistry; and chemistry and physics of materials.

https://andromede.in2p3.fr
// Accelerator and ion source

The ion beams are accelerated at high energy by a 4MV NEC Pelletron® accelerator. The voltage can be adjusted from 500 kV to 4 MV. The terminal of this accelerator is designed to receive two kinds of ion sources, an electron cyclotron resonance (ECR) source and a liquid metal ion source (LMIS). The accelerator delivered proton to nanoparticle beams.
SERGE DELLA NEGRA
CNRS Research Director, Scientific Manager of the Andromede platform
Expertise: Nuclear physics, particle-matter interaction, surface analysis, mass spectrometry, ion sources, applications in chemistry, biology and astrochemistry.

ISABELLE RIBAUD
CNRS Engineer of the Research Division of IPNO, Specialties: Experimental Biology and Quality Control, Development of Multi-Technical Surface Analysis Experiments with Andromede.
Interim Operational Manager!

FRANCOIS DAUBISSE
University Paris-Saclay Assistant Engineer. Accelerator’s operator, set up of experiments, source tests for new beams, maintenance

Andromede gathers a team of 20 researchers on its site of the Faculty of Orsay.

DOMINIQUE JACQUET
MARIN CHABOT
CNRS Research Directors, Physicists
Three operational experiments
Two new experiments 2019

nucleosynthesis
Carbon burning
3-4 MV, C^{1,2,3,4+}

Molecular Fragmentation
Atomic molecules collision
3-4 MV, CH_{1,2,3,4}^{+}, C_2H_{1-6}^{+}

Ionic Imaging
Biology, Health, Exobiology
4 MV, SF_5^{+}, C_{60}^{3+}, Au_n^{+}, Au_{400}^{4+}

November 2016

AGAT April 2017

June 2017
Fundamental Research

the wide range of ions, delivered by Andromede, permits to address many fields of fundamental researches: very low energy nuclear physics, astrochemistry molecule-gas interaction, nanoparticle-solid interaction
MULTIDISCIPLINARY RESEARCH/APPLICATIONS

In the field of nanotechnologies and surfaces, Andromede responds to the great need of very high resolution surface analysis tools both in mass spectrometry and in ion imaging. Access to the chemical characterization of a nanometric volume is envisaged.
The use of nanoparticle beam (Nanoparticle Probe in Biology (NPB)) as a probe in biology is the results of research on particle-matter-secondary emission interaction conducted at IPNO in the last few decades. The offer of analysis was then opened to bio-organic surfaces with the emergence of metallic cluster beam and molecular beams.

The availability of cluster beams and high energy nanoparticles make it possible to simultaneously determine the elemental and molecular composition of a complex surface such as meteorites. These analyses of cosmo-materials by mass spectrometry and ion imaging can be supplemented by simulation to obtain analogs in the laboratory.
Andromede provides the scientific community molecular beams of methane, fullerenes and metal clusters for studying the behavior of materials under irradiation. The scientific fields studied are the modification of materials under irradiation or implantation, the aging of materials, study of solid physics, microelectronics, cosmo-materials and earth sciences.

The Andromeda platform has two sets of ion source development. A filtered NAPIS ionic column dedicated to R & D around LMIS, LICIS and vacuum electro-spray type sources for the production of cluster beams or molecular beams with great brightness. TANCREDE beam line for ion beam developments with ECR type sources. These two systems are available for all new developments with our support and the contribution of our expertise on these kinds of source.
Nuclear astrophysics experiments at Andromede
Fusion cross sections

D. Curien, IPHC, Strasbourg
for the STELLA collaboration

Contact: Sandrine.Courtin@iphc.cnrs.fr
STEEL (Stellar Laboratory)

A toolbox for the measurement of fusion reactions of astrophysics interest

- Si detectors
- LaBr₃ detectors
- Rotating target system
- Andromede facility, University of Paris-Sud - Orsay
- ¹²C up to 10 μA

M. Heine et al., NiM. A 903 (2018) 1-7

Contact: Sandrine.Courtin@iphc.cnrs.fr
Results of the first run

_runs on $^{12}$C+$^{12}$C (206-2017, 2019), 1 under analysis:_ Fusion measured down to astro. energies, down to $\sigma \sim 100$ pb (important result for nuclear astrophysics)

- 4 articles (refereed journals)
- 6 proceedings
- 2 'brèves' IN2P3
- 24 invited talks at international conferences such as INPC, Nucleus-Nucleus, Fusion, Nuclear Physics in Astrophysics, HIAS, Cluster ...
- 1 series of courses. The technique used for STELLA at Andromede is now the standard for direct measurements of fusion X sections for astrophysics
- 1 PhD (G. Fruet, sept. 2018)

Contact: Sandrine.Courtin@iphe.cnrs.fr
Nanoparticle-Solid Interaction

EVE
Nanoscale ion imaging

Electron or Proton Emission Microscope

TOF Mass spectrometer

Primary Ions

Secondary Ions
What is the volume of emission?

Controlled parameters:
- Incident ions number
- Material thickness
- Sputtered Volume

3D Confocal microscopy image
PMMA irradiation by Au$_{400}^{4+}$, 400 eV, 2.10$^{10}$ ions/cm$^{2}$

PMMA irradiated by Au$_{400}^{4+}$, 400 eV, 2.10$^{10}$ ions/cm$^{2}$

Au$_{400}^{4+}$, 12 MeV irradiation

Volume of emission (voxel)

Si clusters m/z = 26, 28

Si$_{29}$ + SiH$_{28}$

10$^{13}$ ions/cm$^{2}$

1000 times less than the commercial probes
The sputtered Volume has been measured with Dextrat XT A from Brucker Nanosurface division.

The total ejected volume is: 11200 µm³ of PMMA for 1.2 \(10^{10}\) Au\(_{400}^{4+}\) ions.

Max. ejection voxel \(\sim 10^6\) nm³

Typical size (R,h)\(\sim 100\) nm, 30nm

Profile measurement is possible with the EPEM localisation >>> 3D ion imaging
What is the track diameter?

Graphene 6 ML

| region | Diameter 1 (nm) | Diameter 2 (nm) |
|--------|----------------|----------------|
| 1      | 80.2           | 88.2           |
| 2      | 74.5           | 93.5           |
| 3      | 70.2           | 93.1           |

Nion UltraSTEM 200 operated at 60 keV, Beam settings: 30 pA current, 34 mrad half angle convergence, 350 meV energy spread In coll. With Luiz Galvao-Tisei and Fuhui Shao from LPS, Orsay
Secondary Ion Emission

Thick deposit

5 intact molecules /impact

\( \text{Au}_{400}^{4+} \) 12 MeV : Emission efficiency 1000 times higher than commercial probes
Secondary Ion Emission

Thin deposit ~10 nm

3 intact molecules / impact
Characteristics of the Secondary Ion Emission

- \( \text{H}^- \)
- \( \text{Au}_3^- , \text{low energy} \)
- \( \text{Au}_3^- , \text{High energy} \)
- Bradykinin (M-H)^-
Characteristics of the Secondary Ion Emission

Probing ground zero
In April, scientists will drill into Chicxulub crater, where an asteroid impact 66 million years ago led to one of Earth’s biggest mass extinctions. They hope to reach a buried peak ring, Earth’s only preserved example.

Making the mounds
Impact shocks could make rocks behave like fluids, piling deep crustal rocks on top of rocks of shallower origin.

1. Post-impact excavation and beginning of uplift

2. Central uplift becomes unstable

3. Uplift collapses to form peak ring

Buried treasure
Offshore from Progreso, Mexico, scientists will drill into the crater’s peak ring, partially seen in geophysical remote sensing data (below). Onshore wells have been drilled into the crater before, but few were cored and none reached the peak ring.
Andromede is crucial for achieving a major objective, nanoscale co-localization of tagged proteins in cell membranes. Is it possible?

Comparison with other techniques:
keV Bismuth clusters IONTOF V
Pegase 500 keV Nanoparticles beams
Eosin Antiody Conjugated

12 MeV Au$^{4+}_{400}$ projectile

520 keV Au$^{4+}_{400}$ projectile

IonToF (LAMS) Bi$_3^+$, 25 keV : Y(Br) = 0.003 ions/impact
Colocalization - Coemission

Br and I peaks in coincidence with F
A mean value of 3 F emitted per impact

Evidence for colocalization of the 3 tagged antibodies within the voxel
(thousands proteins of 150 000 Daltons)

F and I peaks in coincidence with 79Br
A mean value of 4 79Br emitted per impact.
Lipopolysaccharides analysis

**Feasibility study**

Emission yield: $Y$ (lipid A) $\sim 30\%$

Now, it is possible to develop a method combining both mass spectrometry and microscopy to localize in tissue and cell endotoxins-receptors interactions and to study these interactions driving the host physiological responses.
Large Hadron Collider (LHC) - the world's largest and most powerful particle collider

https://fr.wikipedia.org/wiki/Grand_collisionneur_de_hadrons
The beam emittance increases, the luminosity deteriorates and the beam becomes instable.

Surface conditioning by the electron flux decreases the emission of secondary electrons.
Deposit similar to "hydrogenated" graphene

Graphene (6 monolayers, 2 nm)

Analysis of copper from CERN chambers conditioned by electrons irradiation

CₙHₘ increase → Organic deposit

Copper after conditioning

Copper before conditioning

Surface analysis-Collaboration IJCLAB
Surface analysis Collaboration IJCLAB

Before e- irradiation

After e- irradiation

A deposit is accumulated on the surface

$C_nH_m$ peaks increase
Cu speed and intensity decrease

$\text{CuO}^-, \text{CuOH}^-, \text{CuO}_2^-, \text{CuO}_2H^-$ disappear

$C_6^-$

$m/q$ 60 61 62 63 64 65
Andromede set-up is unique world-wide, with its capability to perform molecular analysis at the nanoscale with detection limits that are near a single molecule (for MW below 1,500 Da). Yet to be implemented is a molecular imaging capability which promises again to be unequalled.

https://andromede.in2p3.fr
Andromede team
Acknowledgments

Thank you for your attention!
**STRENGTHS**

- New Platform/low maintenance machine for 5 next years
- Strong multidisciplinary expertises: nuclear physics, vacuum and surfaces, materials science, physics and astro-chemistry, biology
- Originality of beams (atomic, aggregates, nanoparticles)
- Unique performance of nanoparticle beams: ion emission efficiency/impact analysis (chemical environment, co-localization, 3D ion imaging, etc.)
- Complementarity of our platform with local, national and international ones

**WEAKNESSES**

- Strategic Human Resources Plan
  - thesis and post-doc supervision
  - strategy for future project submission
- Operating and maintenance funding
- Chronic dwindling of human and financial resources
- recognition for multidisciplinary Platforms

**OPPORTUNITIES**

- Unique international research infrastructure
- Local, national and international partnerships
- Lab unification/Technical support IJCLab
- University Paris-Saclay/interdisciplinary programs focus on training/Meet My Platform
- SATT/ R&D and technology transfer
- Openness of the EMIR federation to the scope of analysis IBA

**THREATS**

- Sustainability of the platform due to mainly unpaid collaborations
- Change of ASN rules
- Barriers to delivering programs that would no longer be free in the academic community
Back up
Publications related to Andromède, Nanoparticles beams and feasibility studies

Andromede : 1
*Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 51 (décembre 2015) Volume 365, Part A, Pages 367-370*

Stella : 4
*Nucl.Instrum.Meth.A, 2018, 903, pp.1-7.*

Agat : 2
*A&A 628, A75 (2019)1-14*

Instrumentation : 3
*Rev. Sci. Instrum. 84, 103706 (2013)*

Ion-Solid Interaction : 4
*The Journal of Chemical Physics 146, 054305 (2017); doi: [http://dx.doi.org/10.1063/1.4975171](http://dx.doi.org/10.1063/1.4975171)*

Biological surface Analysis: 6 publications
*Scientific Reports volume 9, Article number: 1928 (2019)*

Astrochemistry : 3
*Life 2019, 9, 44; doi:10.3390/life9020044*
Oral Presentation:
Permanents, Postdocs, doctorants
2019 : SMAP 2019 keynote (T.L. Lai), IBA2019 (T.L. Lai- I. Ribaud), SIMS22(S. Della Negra)
2018: SNEAP2018 invited talk (S. Della Negra)
2017 : SIMS21 (S. Della Negra), (T.Fu), Pittcon 2017 (T. Fu)
2016 : SIMSEUROPE2016 (T. Fu)
2015 : SIMS20 invited talk (S. Della Negra)
2015 : 16th International Conference on Ion Sources (O. De Castro)
2014 : 9\textsuperscript{TH} INTERNATIONAL CONFERENCE ON CHARGED PARTICLE OPTICS (O. De Castro)
   (M.S. Verruno), Desorption 2014 (M. Eller) (M. Noun)
2013 : PASI2013 (M.Eller), 61 ASMS (M. Noun)
Internship and practical work in the Master2 large instruments (S. Kazamias)  
2017 2018  
4 practical work, 1 intern.  
1 BTS Biology Intern in 2017  

Theses 7 including 1 in progress within the framework of the PHENIICS doctoral school 
international co-supervision or joint supervision  

IN2P3 Bio Network I. Ribaud  
GDR I. Ribaud
Estimated ANDROMEDE service costs

Particle beam production: **1280 h/year**

### Personal costs

| Nom         | Prénom | ETP (%) | Grade | Coût exploitation |
|-------------|--------|---------|-------|-------------------|
| Ribaud      | Isabelle | 30      | IR    | 23 472,00 €       |
| Daubisse    | François | 100     | AI    | 63 257,00 €       |
| Maintenance |        | 30      | IR    | 3 912,00 €        |
|             |        | 70      | AI    | 7 379,98 €        |

Sub-total: **98 020,98 €**

| Personal environment | Sub-total: **78 416,79 €** |
|----------------------|----------------------------|

Total: **176 437,77 €**

### Operating costs:
- 40 000 € + 20 000 € (estimates of fluid and electricity costs)

### Accelerator depreciation: (3 M€ / 120 months)
- 250 000 € (8 months of operation + 2 months of maintenance)
## Estimated costs of ANDROMEDE services

| Types of services          | Actual Costs | Prices¹                       |
|---------------------------|--------------|-------------------------------|
|                           |              | Internal (excluding HR)       |
| Irradiation               | 380 €/h      | 300 €/h                       |
|                           |              | 475 €/h                       |
| Irradiation + Analyses²   |              | Irradiation prices + scientific expertise |

¹ + 20% margin in the case of laboratory direct debit (under discussion)

² The fees for scientific expertise (ion beam analyses + analysis report) will be calculated later and will be subject to a quote

**Note:** An inventory of the different calculation and deduction policies on the services of the old laboratories is in progress. Once the rate and the sampling base will be fixed by the management of the IJCLab, the file for the validation of the rates will be sent to the DR4.
// R&D ion sources

In addition to the accelerator platform, ionic columns equipped with the ECR source and the NAPIS source are available to test source developments and to produce new beams. These devices are also available for analysis and material modifications in the low energy range (a few keV)

Promotion: DR4 - University of Paris Sud and SATT
Patent under evaluation and Polyions maturation project with SATT in collaboration with ICMMO
// Ion beams and characteristics - Source ECR Microgan

The ions produced by this source are selected at the accelerator terminal by a Wien filter.

Ions multichargés d’Argon

Ions moléculaires
// Ion beams and characteristics

--- Sources LMIS NAPIS ---

The NAPIS column is equipped with a LMIS (Liquid Metal Ion Source) providing beams of metallic atomic ions, clusters and nanoparticles.
| Ions          | Energy (MeV) | Intensity (nA) at the exit of the acc. | beam size (µm) & Intensity (pA) in the centre of MSI EVE chamber |
|--------------|--------------|----------------------------------------|---------------------------------------------------------------|
| Ar\(^{q+}\), q=1-8 | 1-32         | 100-1000                               |                                                               |
| SF\(_5\)\(^{+}\) | 1, 2, 3, 3.65 | 150 (1000)                            | 50                        300                                    |
| Au\(^{2+}\) | 1, 2, 3      | 6 (10)                                | 10                        1000                                  |
| Au\(^{+}\) | "             | 20(40)                                | 10                        1000                                  |
| Au\(_2\)\(^{+}\) | "             | 2(4)                                  | 150 (3nA)                     |                                           |
| Au\(_3\)\(^{+}\) | "             | 1.5 (3)                              | 10 (200)                     | 150 (3nA)                                  |
| Au\(_5\)\(^{+}\) | "             | 0.2                                   | 20                       20                                     |
| Au\(_{400}\)\(^{4+}\) | 4-16MeV      | 0.4 (.5-1)                            | 100 (400-800)            < 10                                     |
| Au\(_n\)\(^{q+}\), n = 120, 1600 atoms | "             | 0.1-1-0.4                            | 400 (800)                     | 10                                     |

Future beams for MSI Experiment

C\(_{60}\)\(^{q+}\), q= 1-3  | 10-100
Positive ions

Bradykinin

Negative ions

Au₅
Very high mass resolution and determination of the molecular structure

Orbitrap Thermo Résolution > 240 000
Précision 0.3 ppm

Or
Spectro Brucker Ion mobility+ trap+ OToF
Résolution > 30 000, MS/MS & Software
What is Orbitrap?

The Orbitrap is an ion trap mass analyzer that consists of two outer electrodes and a central electrode, which enable it to act as both an analyzer and detector. Ions entering the Orbitrap are captured through "electrodynamic squeezing," after which they oscillate around the central electrode and in between the two outer electrodes. Different ions oscillate at different frequencies, resulting in their separation. By measuring the oscillation frequencies induced by ions on the outer electrodes, the mass spectra of the ions are acquired using image current detection. Due to its setup, the Orbitrap mass analyzer is actually a Fourier Transform mass analyzer analog of FT-ion cyclotron resonance (ICR) technology, yet with smaller instrument size and easier instrument operation.
ATLANTA, Georgia – May 31, 2019: At the 67th American Society for Mass Spectrometry Conference (ASMS) being held June 2-6 in Atlanta, Bruker is announcing highly innovative new mass spectrometry products and workflows:
Réhabilitation Igloo pour ThomX et Andromède : **2,1 + 0,3 M€** : terminé
11 lots, 15 entreprises,
non réalisés, : tests en charge 11 k€, faux plancher ThomX 30 k€
pris sur projet : chemin câbles, contrôle accès

Marché PSS+radioprotection : **272 619,86 + 381 728 €**

Projet Fresque : ravalement façade igloo + peinture : **500k€?** : 2019-2020
projet fresque abouti (Beton Puzzle)

Déménagement Andromède : 80 k€ (NEC) + 5 k€ (BOVIS) : 2020 (prix 2016)
