GANIL/SPIRAL facility
- Recent highlights
- Future SPIRAL 2 facility
- Layout of the facility
- Scientific opportunities
- Letters of Intent for SPIRAL 2

See also talks of: Y. Blumenfeld, G. Georgiev and J.M. Daugas
STABLE BEAMS
• from C to U
• energies up to 95 A.MeV
• intensities up to $2 \times 10^{13}$ pps (6 kW)

RIB production schemes
• in-flight method: SISSI, LISE
• ISOL method: SPIRAL (SIRA)
  • Use of this two techniques in the same lab is a unique feature

Up to 10000 hours of stable and radioactive beams per year
Available and possible RIBs at SPIRAL

7 elements, about 40 isotopes

- Available
- Available, to be controlled
- Possible, to be controlled
- R&D possible
- Seen with the Shypie source

Used for experiments

<table>
<thead>
<tr>
<th>Ion</th>
<th>I (pps) and E</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^6\text{He}^{1+}$</td>
<td>$3 \times 10^7$</td>
</tr>
<tr>
<td></td>
<td>5 AMeV</td>
</tr>
<tr>
<td>$^8\text{He}^{1+}, ^8\text{He}^{2+}$</td>
<td>$6 \times 10^5, 3 \times 10^4$</td>
</tr>
<tr>
<td></td>
<td>3.4, 15.4 AMeV</td>
</tr>
<tr>
<td>$^{18}\text{Ne}^{4+}$</td>
<td>$2 \times 10^6$</td>
</tr>
<tr>
<td></td>
<td>7 AMeV</td>
</tr>
<tr>
<td>$^{76}\text{Kr}^{11+}, ^{74}\text{Kr}^{11}$</td>
<td>$5 \times 10^5, 1 \times 10^4$</td>
</tr>
<tr>
<td></td>
<td>4.3 AMeV</td>
</tr>
</tbody>
</table>

...and recently $^{15}\text{O}, ^{24,26}\text{Ne}, ^{44,46}\text{Ar}$

About 17 different RIB used in exp.

200 RIB shifts/year

PURE RI BEAMS!
Experimental study of $^{16}$F

Elastic scattering

$E_x, \Gamma_x, J^\pi$

$H(^{15}\text{O}, p)^{15}\text{O}$

$^{16}$F

Polypropylene target ($H_6C_3$)
thickness 2.7 mg/cm$^2$

$^{15}$O Spiral beam
2 $10^7$ pps
1.2 MeV/A

$^{14}$N detector

16F structure
(Ex, $J^\pi$, $\Gamma$)

$H(^{14}\text{N}, p)^{14}\text{N}$

$H(^{15}\text{N}, p)^{15}\text{N}$

Si detector

FWHM=13.4 keV for
5.486 MeV $\alpha$

protons scattered from the target

Best resolution at 0°

Experimental study of $^{16}$F

14/06/06

L. Stefan
Measured excitation functions

\[ H(14N, p)14N \]

\[ 15O \]

\[ E_x, \Gamma, J^\pi \]

R-matrix

\[ S_p = 7.297 \text{ MeV} \]

\[ H(15N, p)15N \]

\[ 16O \]

\[ E_x, \Gamma, J^\pi \]

R-matrix

\[ S_p = 12.127 \text{ MeV} \]

\[ H(15O, p)15O \]

\[ 16F \]

\[ E_x, \Gamma, J^\pi \]

R-matrix

\[ S_p = -0.536 \text{ MeV} \]
What about the $^{15}\text{O}(p,\gamma)^{16}\text{F}_\text{gs}(\beta^+)$?

$1/2^- + p \rightarrow ^{15}\text{O}$

$E_1 = 0.734 \text{ MeV}$  
$E_0 = 0.536 \text{ MeV}$

$15\text{O} + p$  
$16\text{F}$  
$\beta^+$

$Q_\beta = 13.3 \text{ MeV}$

$1\text{ps}$

$M1$  
$\gamma$

$E_0 = 0.536 \text{ MeV}$

$E_1 = 0.734 \text{ MeV}$

$^{15}\text{O} + p \rightarrow ^{16}\text{F}$  
$\beta^+$


$^{15}\text{O}(p,\gamma)^{16}\text{F}$

$E_\text{CM} (\text{keV})$  
$E_x (\text{keV})$  
$E_x (\text{keV})^a$  
$J^\pi$  
$\Gamma_p (\text{keV})^b$  
$\Gamma_p (\text{keV})$

$534 \pm 5$  
$0$  
$0$  
$40 \pm 20$  
$25 \pm 5$

$732 \pm 10$  
$193 \pm 6$  
$198 \pm 16$  
$< 40$  
$70 \pm 5$

$958 \pm 2$  
$424 \pm 5$  
$495 \pm 2$  
$< 40$  
$6 \pm 3$

$^a$Recommended values  
$^b$This work.

$E_0 = 0.536 \text{ MeV}$

$E_1 = 0.734 \text{ MeV}$

$1/2^- \rightarrow 1^- \rightarrow 0^-$

$\gamma$

$M1$  
$\tau_\gamma = 1 \text{ ps}$

$\beta^+$

$Q_\beta = 13.3 \text{ MeV}$

$\text{MeV}$

$\log_{10} N_{(\alpha,\gamma)}$

$\log_{10} N_{(p,\gamma)(\beta^+)}$

$\log_{10} N_{(p,\beta^+)}$

$T (\text{K})$  
$10^0$  
$10^9$  
$10^7$

$10^0$  
$10^9$  
$10^7$

$14/06/06$

I. Stefan
Collapse of the N=28 shell closure in $^{42}$Si

**Experimental set-up**

- In-beam $\gamma$ Spectroscopy:
  - GANIL-Caen
  - SISSI+ALPHA
  - SPEG

![Diagram showing the experimental setup with isotopes and labels](image)

**PRELIMINARY**

Collapse of the N=28 shell closure in $^{42}$Si - Beyhan Bastin
Collapse of the N=28 shell closure in $^{42}$Si

Results: $^{38}$Si

$2^+ \rightarrow 0^+ : 1081 \pm 8 \text{ keV}$

ref: $1084 \pm 20 \text{ keV}$

$1185 \pm 10 \text{ keV}$ [NEW]

Z=14

$^{37}$Si $^{38}$Si $^{39}$Si $^{40}$Si $^{41}$Si $^{42}$Si

N=28
Collapse of the N=28 shell closure in $^{42}$Si

### Results: $^{40}$Si

- $E(2^+ - 0^+) = 624 \pm 10$ keV
- Ref: $990 \pm 20$ keV
- $E(2^+ - 0^+) = 991 \pm 10$ keV

| $^{37}$Si, $^{38}$Si, $^{39}$Si, $^{40}$Si, $^{41}$Si, $^{42}$Si |  |
|---|---|---|---|---|---|
| $Z=14$ | $N=28$ |  |  |  |  |
Collapse of the $N=28$ shell closure in $^{42}\text{Si}$

**Results:** $^{42}\text{Si}$

$2^+ \rightarrow 0^+ : 770 \pm 15$ keV

NEW

To be published

PRELIMINARY
Collapse of the N=28 shell closure in $^{42}\text{Si}$

- LOW energy observed for the first $2^+$ state in $^{42}\text{Si}$

$^{42}\text{Si} = \text{deformed nucleus}$

Loss of magicity at N=28 for Si isotopes

In contradiction with J. Fridmann et al. [Nature vol.435(2005)03619]
Shapes of atomic nuclei

- Oblate ground states predicted for $A \sim 70$ near $N=Z$
- Prolate and oblate states within small energy range
  \[ \Rightarrow \text{shape coexistence} \]
Systematics of the light krypton isotopes

- Inversion of ground state shape for $^{72}$Kr
- Coulomb excitation to determine the nuclear shapes directly
- Energy of excited $0^+$
- $E0$ strengths $\rho^2(E0)$
- Configuration mixing

$\rho^2(E0)$:
- $^{72}$Kr: $72 \cdot 10^{-3}$
- $^{74}$Kr: $85 \cdot 10^{-3}$
- $^{76}$Kr: $79 \cdot 10^{-3}$
- $^{78}$Kr: $47 \cdot 10^{-3}$

Coulomb excitation of $^{74}$Kr and $^{76}$Kr

SPIRAL beams
$^{76}$Kr $5 \times 10^5$ pps
$^{74}$Kr $10^4$ pps

4.7 MeV/u

Quadrupole moments $Q_0$ in $^{74}\text{Kr}$ and $^{76}\text{Kr}$

- Direct confirmation of the prolate–oblate shape coexistence
- First reorientation measurement with radioactive beam

E. Clément et al., to be published
Study of the N=28 shell closure in Ar chain through (d,p) reaction

First experiment with radioactive beam of $^{46}$Ar @ 10 MeV.A

SPIRAL/GANIL

MUST array

Transfer reaction (d,p)

$d + p \rightarrow ^{28}f_{7/2} + ^{29}p_{1/2}$

$^{46}$Ar $\rightarrow ^{47}$Ar


See talk of Y. Blumenfeld tomorrow

Count / 100 MeV

GS

FWHM : 175 keV

1.13 3.33 5.50
GANIL discoveries

Exotic nuclei

- Proton drip-line
- Light nuclei

Results at GANIL
- new nuclei
- mass measurements
- half-life measurements
- $\Sigma R$ measurements
CIME Cyclotron
Acceleration of RI Beams
E < 25 AMeV,
1 - 8 AMeV for FF

Production Cave
C converter+UC_\text{x} target
\leq 10^{14} fissions/s

CIME Cyclotron
Acceleration of RI Beams
E < 25 AMeV,
1 - 8 AMeV for FF

Production Cave
C converter+UC_\text{x} target
\leq 10^{14} fissions/s

Low energy RNB
(DESIR)

Stable Heavy-Ion Exp.
Hall

Superconducting LINAC
E \leq 14.5 AMeV for heavy Ions A/q=3
E \leq 20 A MeV for deuterons (A/q=2 ions)
E \leq 33 MeV for protons

Heavy-Ion ECR
source (A/q=3), 1mA

Deuteron source
5mA

Existing GANIL Accelerators

Existing GANIL Exp. Area

Direct beam line CIME-G1/G2 caves

RFQ

Spiral2
E ≤ 20 A MeV, 5mA, deuterons (A/q=2 ions)
E ≤ 33 MeV 5mA, protons
E ≤ 14.5 AMeV , 1mA, heavy Ions A/q=3
(extension possible for A/q=6)

MOU with SARAF
LINAG Heavy-Ion Beam Challenge

Choice of the HI source:

• Phoenix V2 - competitive for A<50
• A-Phoenix - competitive for A<70 (but not included in the construction budget)
• A/Q=6 extension (4 times more expensive than A-Phoenix)
Fast neutron induced fission

Goal: Up to $10^{14}$ fissions/s

- 5 mA
- Deuterons 40 MeV
- UCx 2000°C diffusion/effusion
- Source
- Neutrons
- 1+ n+ C
- Neutrons
- Fast neutron induced fission
SPIRAL 2 yields of fission fragment after acceleration compared to other RNB facilities (best numbers for all)
**Light and N=Z RIB at SPIRAL 2**

**Rough Estimation of Yields (Examples)**

<table>
<thead>
<tr>
<th>RI Beam</th>
<th>Reaction</th>
<th>Production method</th>
<th>Yield (min. - max.) in pps</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^6\text{He}$</td>
<td>$^9\text{Be} (n,\alpha)^6\text{He}$</td>
<td>ISOL</td>
<td>$5 \times 10^7 - 10^{12}$</td>
</tr>
<tr>
<td>$^{11}\text{C}$</td>
<td>$^{14}\text{N} (p,\alpha)^{11}\text{C}$</td>
<td>ISOL</td>
<td>$10^7 - 3 \times 10^{11}$</td>
</tr>
<tr>
<td>$^{15}\text{O}$</td>
<td>$^{15}\text{N} (d,2n)^{15}\text{O}$</td>
<td>ISOL</td>
<td>$3 \times 10^7 - 10^{10}$</td>
</tr>
<tr>
<td>$^{18}\text{Ne}$</td>
<td>$^{19}f (p,2n)^{18}\text{Ne}$</td>
<td>ISOL</td>
<td>$6 \times 10^6 - 7 \times 10^9$</td>
</tr>
<tr>
<td>$^{34}\text{Ar}$</td>
<td>$^{35}\text{Cl} (p,2n)^{34}\text{Ar}$</td>
<td>ISOL</td>
<td>$2 \times 10^6 - 2 \times 10^8$</td>
</tr>
<tr>
<td>$^{56}\text{Ni}$</td>
<td>$^{58}\text{Ni} (p,p2n)^{56}\text{Ni}$</td>
<td>Batch mode</td>
<td>$2 \times 10^4 - 10^8$</td>
</tr>
<tr>
<td>$^{58}\text{Cu}$</td>
<td>$^{58}\text{Ni} (p,n)^{58}\text{Cu}$</td>
<td>Batch mode</td>
<td>$10^4 - 10^8$</td>
</tr>
<tr>
<td>$^{80}\text{Zn}$</td>
<td>$^{24}\text{Mg} + ^{58}\text{Ni}$</td>
<td>In-flight</td>
<td>$&lt; 3 \times 10^4$</td>
</tr>
</tbody>
</table>

Reactions to be used: transfer, fusion-evaporation, deep-inelastic
Regions of the Chart of Nuclei Accessible with SPIRAL 2 Beams

- Light beams
- Heavy ions
- RIB induced reactions

Production of radioactive beams/targets: (n,α), (p,n) etc.

N=Z Isol+In-flight

Transfermium A
Fission products (with converter)

Fission products (without converter)

Fusion reaction with n-rich beams

Deep Inelastic Reactions with RIB

High Intensity Light RIB

SHE
Operation of the accelerators:
66 weeks today (3 beams)
120 weeks with SPIRAL 2
(5 simultaneous beams)

Marek Lewitowicz, GANIL
14/06/06
Stable ion beams from LINAG

RIB from non-fissile targets
RIB of fission fragments > 10^{12} fiss./s

Phase 1
>10^{12} fiss./s

Phase 2
Goal: 10^{14} fiss./s
RIB of fission fragments 10^{14} fiss./s

Reference planning and phases


Reference Planning

Cost of the facility: 130M€

Reference Project Def.

Safety authorisation

Buildings construction

Construction of LINAG

Possible scenario

Cost of the facility: 130M€
SPIRAL2 « Scientific Objectives »

- Final Version on Web
  www.ganil.fr
- to be printed soon

Thanks to all (>110) contributors
The scientific case of SPIRAL 2

- **Position of drip-lines**
- **N=Z**
- **rp-process**
- **Spins & Shapes**
- **Heavy and Super Heavy Elements**
- **Equation of State**
- **Role of Isospin**
- **Haloes & Structures in the Continuum**
- **r-process path**
- **Shell structure far from stability**
- **Neutrons for science**
- **Atomic & solid state physics**
- **Isotope production**

**Neutrons for science**

**Equation of State**

**Role of Isospin**

**Haloes & Structures in the Continuum**

**Spins & Shapes**

**r-process path**

**N=Z**

**rp-process**

**Position of drip-lines**

**Heavy and Super Heavy Elements**
Neutrons For Science at SPIRAL 2: "nTOF - like" facility

- Fission
  - Minor actinides, main isotopes
  - Cross section
  - Neutron spectrum, multiplicity
  - Prompt fission gammas
  - Detailed A and Z distributions
  - Delayed neutron yields and precursor characteristics

- Scattering
  - Secondary neutron energy and angle differential cross sections
  - Inelastic scattering

- Fusion reactors
- Astrophysics
SPIRAL 2 - Letters of intent

Goals:

- Assess the technical feasibility, space, infrastructure requirements and cost for experiments
- Identify new equipment to be constructed
- Formalise collaborations of the SPIRAL 2 users
- Form a basis allowing to define priorities for the scientific programme of SPIRAL 2

Procedure and schedule:

1. Call for LoI - May 26\textsuperscript{th} 2006 - \textbf{Dead-line for LoI: October 2\textsuperscript{nd} 2006}
2. Evaluation of LoI by SAC + additional experts (if necessary) - \textbf{October 19 & 20\textsuperscript{th} 2006} will include oral presentations of all LoI
3. Call for proposals aiming in construction of new detectors - 2007
4. Signature of MoU by collaborations constructing detectors in 2007-2008