Nuclear

Structure, Reaction and Dynamics

GANIL / SPIRAL1 / SPIRAL2
A huge discovery potential

Exotic Nuclei

- Which force?
  3-body, tensor, spin-orbit, Isospin dependence, Continuum coupling

- Leading to which structure?
  Haloes, neutron skins, molecular states, new shells and magic numbers, super-heavies.

- Playing which role in the Universe?
  Nucleosynthesis, supernovae, Neutron stars.
GANIL’s cyclotrons
Multi-beam operating mode
From Carbon to Uranium
Up to 95 MeV/u and 24 MeV/u
$2.10^{13}$ pps $^{12}$C @ 95 MeV/u

SPIRAL2’s LINAG
33 MeV p, 40 MeV d, 14.5 AMeV HI
A/Q=2 (5 mA) ; A/Q=3 (1 mA) ; A/Q=6
Fusion evaporation reactions


\[ ^{58}\text{Ni}(^{36}\text{Ar},2n)^{92}\text{Pd} \quad E=3 \text{ AMeV} \]

\[ N=Z=46 \]

\[ T=1, J=0 \quad \text{(n,n)} \quad \text{Isoscalar n-p pairing} \]

\[ T=0, J>0 \quad \text{(p,p)} \]

58Ni(36Ar,2n)92Pd  E=3 AMeV

N=Z=46

Neutron wall

EXOGAM  NEDA
Spectroscopy of Super Heavy Elements

Production:
- On LISE with FULIS Mode
- On S3

Example: performed recently at GANIL
J. Piot, M. Vostinar et al.

\[ ^{209}\text{Bi}(^{50}\text{Ti},2n)^{257}\text{Db (z=105)} \] 2.4 nb

Example: A. Chatillon, Ch. Theisen et al.

\[ ^{209}\text{Bi}(^{48}\text{Ca},2n)^{255}\text{Lr (z=103)} \]
- gs \[ ^{255}\text{Lr J}=1/2^- \]
- Isomeric state Ex=37 keV \( 7/2^- \)
- Spectroscopy of daughter nuclei obtained
- All HFB theories fail to reproduce \[ ^{255}\text{Lr} \]
- Suggests a slightly underestimated \( 2f5/2 \)
Deep-inelastic reactions

Example: S. Bhattacharyya, M. Rejmund, A. Navin et al. PRL 101 (2008) 032501

$^{238}\text{U} \ (5.5 \text{ MeV/u})$ on $^{48}\text{Ca}$ target

First indication of Triaxiality in $^{48}\text{Ar}$ at low spin. p oblate shape n prolate shape
Physics cases for the AGATA campaign in GANIL

≈ 50 Lol submitted
4 main setups:
- Vamos in magnetic spectrometer
- Vamos in gas-filled
- Nwall + Diamant
- DSSSD (SPIRAL1)
Dynamics, Thermodynamics, Hot Nuclei

- Can we obtain a phenomenological equation of state for isospin asymmetric nuclear matter?
- The density dependence of the symmetry energy?
- Phase transition mechanism?


Simulation: largest cluster size distribution evolves with time

In data, largest fragment charge distribution evolves with beam energy

Similarity between model and data indicates time-scale decreases with increasing bombarding energy
Radioactive Beams

Fragmentation beams

LISE

**SPIRAL1**

gas ions up to Xe ( < 25 MeV/u)
+ Febiad source \( (^{33}\text{Cl}, ^{23}\text{Mg}, ^{29}\text{P}, ^{26}\text{Al}, ^{38}\text{K}...) \)

**SPIRAL2**

Low energy beams S3 - DESIR
Fission fragments (phase 2)
Other Beams Other Targets (phase 2)
1-15 AMeV
Beta Decay Studies / DESIR

Example: A. Lepailleur, O. Sorlin et al., PRL110 (2013) 082502

$^{36}\text{S}$

77 AMeV

$^{26}\text{F}$ 6 pps with a purity of 22%

Proton-neutron 0d5/2 – 0d3/2 effective force used in shell-model calculations should be reduced
Transfer Reactions with post-accelerated beams

Example: F. Flavigny, A. Gillibert et al. PRL 110, 122503 (2013)

$^{14}\text{O}(d,t)^{13}\text{O} ; ^{14}\text{O}(d,^3\text{He})^{13}\text{N}$

SPIRAL1 @ 18MeV/n

$\Delta L = 1$
Resonant Elastic Scattering

Example: M. Assié et al., PLB 2012, 198

Intermediate nucleus in $^{19}$Mg(2p)

SPIRAL Beam: $^{17}$Ne @ 4 A.MeV, $10^4$ pps
Beam purity $\sim 100$

$\Gamma = 5$ keV

$H^{(17}\text{Ne},p)^{17}\text{Ne}$

$^{18}$Na:
The only intermediate nucleus known

$^{17}$Ne

$^{18}$Na

this work

$^{19}$Mg

MAYA / ACTAR TPC
SPIRAL2 area of excellence

82 Letters of Intent (>1000 authors) for the Day 1 experiments at SPIRAL2

With the fusion-evaporation of medium mass nuclei proton-rich nuclei like $^{100}$Sn will be accessible

The primary beam intensities of the LINAC open new opportunity in the race for super-heavy nuclei

With the stable light ions induced reactions: light exotic nuclei will be produced with intensities comparable to current stable beam

High intense neutron rich beams, in the intermediate masses, will be available for the first time

High intense neutron source covering the 1–40 MeV energy range will be available
Thank you