

Canada's National Laboratory for Particle and Nuclear Physics Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

#### Highlights and Status from TRIUMF: ISAC & ARIEL

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TRIUMF/University of British Columbia Vancouver, Canada

NUSTAR week 2015











## TRIUMF



#### **Members**

University of Alberta University of BC Carleton University University of Guelph Queen's University Simon Fraser University of Toronto University of Victoria York University

#### Associate Members

University of Calgary McMaster University University of Northern BC University of Regina University of Manitoba Saint Mary's University Université de Montréal University of Winnipeg McGill University Western University

**Canada's National Laboratory for Particle and Nuclear Physics** 

**TRIUMF** is owned & operated by a consortium of 19 universities Founded 45 years ago in Vancouver



## **TRIUMF's accelerator complex**



Highest Power ISOL RIB

- Nuclear Structure
- **Nuclear Astrophysics**
- Fund. Symmetries CMMS (βNMR)

#### Nordion

commercial medical isotope production 3 cyclotrons

Centre for Molecular and Material Science (µSR)



### ISAC rare isotope facility





#### ISAC rare isotope facility



# Experimental facilities and programs @ ISAC



#### &TRIUMF





#### TRIUMF/ISAC: ARIEL

- expand RIB program with:
  - 3 simultaneous beams
  - increased number of hours delivered per year
  - new beam species
  - enable long beam times (nucl. astro, fund. symm.)
  - increased beam development capabilities
- New electron linac driver for photo-fission
- New proton beamline
- New target stations and front end
- staged installation

## ARIEL: A two-stage project

### • **ARIEL-I** (2010-2014):

RIUMF

- Civil construction to encompass objectives of both ARIEL-I & II
- Electron linac up to 25 MeV, 100 kW

#### • ARIEL-II (2015-2020):

- Completion and scientific utilization of the ARIEL facility
- Phased approach to bring science online





## ARIEL: e-Linac completion



## ARIEL e-Linac: on-time, on budget



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## **ARIEL: MW-class e-linac**





Photo-fission products using 50 MeV 10 mA electrons on Hg convertor &  $UC_x$  target.

#### TIMELINE:

- 2014 first beam, target R&D
- 2017 new front end (phase II)
- 2017 physics production <sup>8</sup>Li
- 2018 photo fission
- 2020 proton beam (3 beams)





## Science highlights from ISAC



### Low energy examples:

- Ion trap program
- TRINAT electro weak
- Francium APV
- Post accelerated:
  - Sr with TIGRESS
- Be-spectroscopy

Experiment developments:

- GRIFFIN
- TITAN MR-TOF

#### Ion Trap experiments with TITAN: PHYSIC MOTIVATION

Tests of Isobaric Mass Multiplet Equation (IMME)

Quadratic form predicted by Wigner based on Isospin symmetry

IS NC

 $M(A,T,T_z) = a(A,T) + b(A,T) T_z + c(A,T) T_z^2$ 

- Mass measurements of Mg masses Technical difficulty: ISOL production is not selective:
- isobars are co-produced with the isotopes of interest!
- Na, closer to stability, and longer-lived
- much more Na extracted and delivered to experiment (1.000.000-1 ratio)
- cleaning system required!

**FRIUMF** 

- <sup>21</sup>Mg a challenge for Penning traps
- LIST-type laser ion source: S. Raeder et al., Rev. Sci. Instrum. 85, 033309 (2014)





## Triumf's Ion Trap for Atomic and Nuclear science

TITAN





#### Penning trap mass measurements Excellent performance.





## Isospin-symmetry IMME in *A* = 20,21

 $M(A,T,T_z) = a(A,T) + b(A,T) T_z + c(A,T) T_z^2 + d(A,T) T_z^3 + e(A,T) T_z^4$ 



A.T. Gallant et al., PRL 113, 82501 (2014)

IMME:

- d (and e) term required to agree with new experimental data
  - non-zero *d* coefficients in all three multiplets: A=20,0+, A=21,1/2+, 5/2+
  - $d_{exp}$  cannot be explained by standard shell model
  - higher orders needed when:
    - Higher order perturbation
    - 3-body interaction

#### •Why still test 'old symmetries?

- First time technically possible
- Developed the necessary tools in theory

### TITAN PHYSICS MOTIVATION: Decay spectroscopy of highly charged ions

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#### TRINAT: atom trap for weak interaction PHYSICS MOTIVATION



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## Beta-neutrino correlation measurement of trapped atoms in a laser trap (MOT):

- provide backing free 'clean' sample <sup>38m</sup>K
- polarized sample <sup>37</sup>K
- measure correlation parameters
- sensitive tests of SM





## **βv**-correlation measurements of <sup>37</sup>K and <sup>38m</sup>K



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#### Fr-TRAP: atom trap for weak interaction PHYSICS MOTIVATION

Heavy nucleus and simple atomic structure  $\Rightarrow$  excellent candidate atom for low-energy fundamental symmetry tests BUT: no stable isotopes!!!

- Long-term program at TRIUMF:
- Atomic parity-violation measurements
- •Nucl. spin dep. (anapole moment)
- Hadronic weak interaction inside nuclei







#### **RTRIUMF**



#### **Towards atomic PV in Francium**

- Parity violating nucleon-nucleon interaction, enhanced in heavy atoms: Flambaum & Khriplovich 1980
- will try new approach: measure PV in hyperfine transitions (microwave)
- Effect 18x-stronger than in Cs and can use multiple isotopes







Dec. 2014: First transfer of ultra-cold francium atoms from the capture trap to the science chamber trap.





Zhang et al. submitted to PRL

Hyperfine anomalies in Fr: boundaries of the spherical single particle model

#### PHYSICS Motivation: Transfer program at ISAC-II



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#### **FRIUMF**

#### ISAC II program with <sup>10</sup>Be, <sup>11</sup>Be confronting theory with high quality experimental data

PLB 2014

- <sup>11</sup>Be: enhanced E1 strength in halo
  - polarizability not reproduced by no-core shell model
  - coupling to continuum states?

<sup>10</sup>Be: intrinsic deformation of first excited state in question Coulomb excitation + lifetime measurement role of 3-body forces unclear









### Technical developments: GRIFFIN installation





## Technical development: GRIFFIN is operational



New array for decay spec.
All 16 clovers accepted
Custom designed and built digital DAQ
New beam-line commissioned

First RIB delivered
300fold more sensitive than 8π

26Na in beta-gamma coincidence with beam on



![](_page_25_Picture_7.jpeg)

![](_page_26_Picture_0.jpeg)

## MR-TOF isobar separator for TITAN

Ch. Jesch et al, submitted

TCP proceedings 2015

![](_page_26_Figure_2.jpeg)

 Off-line tests show R~50.000 in ~20µs in timewidth resolution, about 250 turns.

- R~13,000 for recapture mode, 130 turns
- Developed and built in Giessen, Sept 2014 at TRIUMF. Commissioning plan:
  - R>40.000 at 100Hz operation
  - Contamination ratio 1: 10<sup>5</sup>
  - Integration into TITAN beam line and control system

**THANKS** to the Giessen Team!

![](_page_26_Picture_10.jpeg)

#### Mass Selective Retrapping

![](_page_26_Figure_12.jpeg)

![](_page_27_Picture_0.jpeg)

- ISAC is performing well, and produces a lot of science
  - Improved range of targets and isotopes
  - 18 state of the art experimental installations on the floor
  - Program: Nuclear Structure, Fun.-Symmetries, Nuclear Astro (Solid State & Material Science, Nuclear Medicine)
  - Post acceleration program underway, higher energies possible
- ISAC science program complementary and cutting edge
- ARIEL demonstrated electron beam at spec. energy, starting phase II (after funding approval April 2015)
- Excellent science potential and open for new opportunities and users.

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![](_page_28_Picture_9.jpeg)

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