#### WORKSHOP ON NUCLEAR ASTROPHYSICS OPPORTUNITIES AT ATLAS 2019



# RESEARCH OPPORTUNITIES WITH CARIBU



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2019/Jul/12



#### My goal for this talk:

Show you the capabilities and limitations of CARIBU and associated devices so you get a better idea as to what type of experiments can be proposed



# **RESEARCH OPPORTUNITIES WITH CARIBU**

## Outline

- CARIBU overview
  - Available beams
  - Key beam line elements
  - Time structure of CARIBU beams
  - Beam purity
- Target areas
- Detector systems
  - CARIBU area
  - Area 1
  - Reaccelerated beams
- Planned modifications/upgrades





# AVAILABLE BEAMS

#### **Fission fragments from <sup>252</sup>Cf source**

- CARIBU provides beams of <sup>252</sup>Cf fission fragments
- Neutron-rich isotopes far from stability
- Nuclei of interest for r-process





# **AVAILABLE BEAMS**

### **Fission fragments from <sup>252</sup>Cf source**

- CARIBU provides beams of <sup>252</sup>Cf fission fragments
- Neutron-rich isotopes far from stability
- Nuclei of interest for r-process
- Basic beam info tabulated in our website (for most intense beams)
  - Expected beam intensities on target
  - Half lives
- Beams from weaker fission branches can be developed

#### https://www.anl.gov/atlas/caribu-beams

#### A searchable table of CARIBU beams

Nuclide	+	1 - 25 / 321			< >
Nuclide		Nuclide	t1/2	Low Energy [ions/sec]	Re-Accelerated [ions/sec]
		83As	13.4 s	6.30E+02	9.30E+01
٨		83Se	22.3 m	2.40E+02	3.80E+01
A		84As	5.5 s	5.90E+02	8.30E+01
		84Se	3.3 m	6.90E+02	1.10E+02
Z		85As	2.03 s	7.00E+02	8.30E+01
		85Se-m	19 s	1.00E+03	1.50E+02
		85Se	39 s	1.00E+03	1.60E+02
N		85Br	2.87 m	5.20E+02	8.10E+01
Low From Par	(a.a.l	86As	0.9 s	2.50E+02	2.10E+01
Low Energy [lons/sec]		86Se	15 s	1.80E+03	2.70E+02
220	120000	86Br-m	4.5 s	5.70E+02	7.80E+01
Re-Accelerated [ions/sec]		86Br	55.5 s	5.70E+02	8.70E+01
4.3	18000	87Se	5.6 s	1.90E+03	2.70E+02
4.0	10000	87Br	55.9 s	3.00E+03	4.60E+02
More actions	~	87Kr	1.27 h	6.00E+02	9.40E+01
wore actions	÷	88Se	1.5 s	1.20E+03	1.30E+02
		88Br	16.4 s	4.60E+03	6.90E+02
		88Kr	2.84 h	2.40E+03	3.70E+02
		89Se	0.41 s	4.10E+02	1.70E+01
		89Br	4.37 s	4.10E+03	5.50E+02
		89Kr	3.15 m	4.70E+03	7.30E+02
		88Se         1.5 s         1.20E+03           88Br         16.4 s         4.60E+03           88Kr         2.84 h         2.40E+03           89Se         0.41 s         4.10E+03           89Br         4.37 s         4.10E+03           89Kr         3.15 m         4.70E+03           89Rb         15.4 m         5.40E+02	8.40E+01		
		90Br	1.9 s	2.90E+03	3.40E+02
		90Kr	32.3 s	9.00E+03	1.40E+03
		90Rb-m	4.3 m	2.00E+03	3.10E+02
		1 - 25 / 321			< >



# **KEY BEAM LINE ELEMENTS**

#### **Capabilities and limitations**







# TIME STRUCTURE OF CARIBU BEAMS

#### **Reaccelerated beams (EBIS)**

- Beam pulse period 100 ms
- Beam pulse width 0.1-10 ms
- Figure shows example for ~1 ms pulse
- Larger pulse width → less instantaneous rate on target detector (deadtime)
- Currently ion distribution with 10-ms pulse is not homogeneous (work in progress)

### Low-energy beams

- Beam pulse period 50-100 ms (variable)
- Beam pulse width ~100 ns





# **BEAM PURITY**

### **Reaccelerated beams (EBIS)**

- Recently delivered radioactive ion beams (RIB) and purities
  - A/Q=106/20: 94% RIB (<sup>106</sup>Mo and <sup>106</sup>Tc)
  - A/Q=134/28: 99% RIB (<sup>134</sup>Te and <sup>134</sup>I) -
  - A/Q=138/25: 96% RIB (<sup>138</sup>I and <sup>138</sup>Xe)
  - A/Q=143/28: 96% RIB (<sup>143</sup>Ba and <sup>143</sup>La)
  - A/Q=145/28: 83% RIB (<sup>145</sup>Ba and <sup>145</sup>La)
  - A/Q=146/27: 99% RIB (<sup>143</sup>Ba and <sup>143</sup>La)

#### Low-energy beams

- Using MRTOF: single isotope purity is possible (depends on isotopic mass differences)
- Fast HV switches (BNG, ~200-ns wide) remove contaminants
- Example: A/Q=150/2 (mixture of Ce,Pr,La)
- MRTOF → higher purity, less intensity (consider trade-offs)





# DETECTOR SYSTEMS CARIBU Area

- Beam specifications
  - Pulsed beam (period 50 ms, pulse width ~100 ns)
  - Beam E ~ 2-4 keV
- Two beam lines
  - 0-degree: Canadian Penning Trap (CPT, see talk by R. Orford) used for mass measurements
  - General purpose: typically used by Yang group (UIUC), beam implantation CARIBU
- High background from <sup>252</sup>Cf
- source in same room







### DETECTOR SYSTEMS Area 1

- Beam specifications:
  - Pulsed beam (period 50 ms, pulse width ~100 ns)
  - Beam E ~ 25 keV (variable)
- Currently two end stations
  - X-array+SATURN (tape station, gamma+beta coinc., see talk by F. Kondev)
  - Modular Total Absorption Spectrometer (MTAS, see talk by C. Rasco)







## DETECTOR SYSTEMS Area 1

- Beam specifications:
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- Currently two end stations
  - X-array+SATURN (tape station, gamma+beta coinc., see talk by F. Kondev)
  - Modular Total Absorption Spectrometer (MTAS, see talk by C. Rasco)
- More end stations to come, including CARIBU
  - Summing Nal detector+Tape station (SuNTAN, see talk by A. Spyrou)
  - Laser spectroscopy
  - Trap to study beta-delayed neutron emissions (see talk by S. Marley)

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- Low background from <sup>252</sup>Cf source
- First CARIBU beam sent May/2019
- First experiment performed Jun/2019 (X-array)
   Contraction of the array by the array of the array



# **DETECTOR SYSTEMS**

### **Reaccelerated beams (EBIS)**

- Pulsed beam (period 100 ms, pulse width 0.1-10 ms)
- Beam E = 3-10 MeV/u
- RIB purity > 80% (typically RIB contains 2 or more isobars)
- Max. intensity <2x10<sup>4</sup> pps (limits reaction studies)
- ATLAS end stations (contact)
  - AGFA (D. Seweryniak)
  - ATSCAT (D. Santiago)
  - FMA (D. Seweryniak)
  - Gammasphere (M. Carpenter)
  - HELIOS (B. Kay)
  - MUSIC+SPS (M. Avila)
  - Trap area (J. Clark)





# PLANNED MODIFICATIONS/UPGRADES

### • CARIBU beam yields:

- Additional attempts at HFIR to produce thin, strong <sup>252</sup>Cf sources (short term)
- Looking for alternatives that would replace <sup>252</sup>Cf source (long term) and provide:
  - Higher feeding in <sup>132</sup>Sn region
  - Larger portfolio of available beams at higher intensities than at present
- Low-energy experimental areas:
  - Complete installation of MTAS and SuN in Area 1
  - Carry out PAC-approved experiments with CPT, X-array, MTAS, SuN(TAN)
  - Expand beam lines in Area 1 (for Laser Spec, beta-delayed neutron, etc.)





# THANK YOU FOR YOUR ATTENTION

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under contract number DE-AC02-06CH11357





# EBIS BEAM PURITY ON TARGET

- Had performed a <sup>106</sup>Mo experiment with ECR-CB in 2015, 10 days
- Repeated the same experiment with EBIS-CB in 2018, 6 days
- Improved signal-to-noise ratio



Argonne 🕰

#### **BEAM CONTAMINATION – 106Mo** ANL ECR vs. ANL EBIS



Beam from ECR charge breeder

<sup>106</sup>Mo<sup>21+</sup>: 6000 pps (beta) Stable background rate: 25 Hz RIB: <0.01% of total beam current

IT #: 1577-3	SILIC	ON BARRL DETECTOR ENERGY	18-SEP	-2018 14:22:01
Clear: 300494 M3	DIA	AGNOSTIC AREA: PII		
MIC MASS	106	CENTROID AT CHANNEL	1913.4	
MIC NUMBER	42	ENERGY	151.03	MEV
ARGE STATE 1	20	FWHM	2.163	MEV
ARGE STATE 2	20	AREA	1335	
ARGE STATE 3	20	WINDOW RANGE: From	1865 to	1961
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500 1	000 1500	2000 2500	3000	3500 400
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Beam from EBIS charge breeder

<sup>106</sup>Mo<sup>20+</sup>: 5500 pps (beta)
Stable background rate: 0.3 Hz
RIB: 94% of total beam current



#### BEAM CONTAMINATION EBIS only

Instruction         DOMENSITY DATE         POINT           ATTORK MARKER         52         EVENDO AT GHANNER         3246.1           ATORK MARKER         52         EVENDO AT GHANNER         3246.1           O'MANGE STATE 1         28         PANHA         2.825         MEV           O-MANGE STATE 2         28         AVIKA         106         2016           O-MANGE STATE 2         28         AVIKA         106         2016           O-MANGE STATE 3         28         WINCOW/MARKER, Preim 2027         10         2016	DAVANGET APRIL P0 // 21526 MEV ATTOR/CMARS 134 CONTROL 21526 MEV OWING STATE 2 BENERY 21526 MEV OWING STATE 2 B PARK 1252 AV OWING STATE 2 B PARK 125 OWING STATE 2 B PARK 155 OWING STATE 2 B PARK	XPERIMENT #: 1484b	SILICON B/	ENELSY Y	22-MAR	2019 20:08:02
ATOMESMAS 134 CONTROL AT CHANGE 2265 MEY ATOME MARKIN 52 EXERCISE CHANGE STATE 1 28 PAN4 2405 MEY CHANGE STATE 1 29 AVAI 2405 MEY CHANGE STATE 2 29 AVAI 2405 MEY CHANGE STATE 2 29 AVAI 2405 MEY CHANGE STATE 2 29 MEY CHANGE STATE 2 20 MEY CHAN	ATTORNETMOS         134         CENTING AT GRAVE         22461           ATTORNETMOS         2250         MeV         2250           CHARGE STATE 2         30         MeVA         2250           CHARGE STATE 2         30         MeVA         2250           CHARGE STATE 2         30         MeVA         2250           CHARGE STATE 3         30         MeVA         2250           CHARGE STATE 3         30         MeVA         2250           CHARGE STATE 3         30         MeVORATION MADE         MeV           CHARGE STATE 3         30         MEVORATION MADE         MeV           CHARGE STATE 3         30         MEVORATION MADE         MeV         3287	THE DIFICE LESS CIERT: 300048 MS	DIAGNOS	TIC AREA: PIL		
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OWARDE STATE 1 28 PANEAL 2205 MEV OWARDE STATE 2 28 AREA OWARDE STATE 2 28 WECOW/RARDE, Pain 2007 M 2007	Orandos ITATE 1 28 PARAE 2805 MEV Orandos ITATE 1 28 ARIA Orandos ITATE 2 28 ARIA Orandos ITATE 2 28 ARIA VIECON/MARK / 100 2007 MB 2007 MB 2007	ATCMIC NUMBER	52	ENERGY	219.06	MEV
OWING STATE 2 20 AREA 105 OWING STATE 2 20 WECOVITANCE: Frem 3207 to 3238	OWARD STATE 2 20 AREA OWARD STATE 3 20 WHOOM MADE: Pres 3257 W 3258	CHARGE STATE 1	28	FWHM	2.825	MEV
CAMIGE STATE 3 28 WROOWTANDE from 3007 to 3238		CHARGE STATE 2	20	AREA	195	
		CHARGE STATE 3	28	WINDOW RANGE: From 3	1207 to	3298
a 568 1888 1568 2660 2668 266 266 266 266 266 266 266 266 26		mment: 134Te from CARIBU. N	No tuning.			

<sup>134</sup>Te<sup>28+</sup>: 300 pps (beta) Stable background rate: 0.0 Hz RIB: 99% of total beam current



<sup>138</sup>|<sup>25+</sup>: 1300 pps (beta) Stable background rate: 0.2 Hz -RIB: 96% of total beam current\_



<sup>145</sup>Ba<sup>28+</sup>: 7000 pps (beta) CHICAGO (Senergy Stable background rate: 0.7 Hz RIB: 83% of total beam current <sup>143</sup>Ba<sup>28+</sup>: 6800 pps (beta) Stable background rate: 0.1 Hz RIB: 96% of total beam current

SILICON BARRIER DETECTOR

STIC AREA: PIL

ENERGY

FWHM

AREA

CENTROID AT CHANNEL

WINDOW RANGE

21-DEC-2018 13:54:12 XPERIMENT #: 1726c SILICON BARR! DETECTOR ENERGY Time Since Last Clear: 120351 MS DIAGNOSTIC AREA: ATLAS 900.2 Beam On MEY ATOMIC NUMBER ENERGY 215.44 5.814 MEV CHARGE STATE 1 FWHM CHARGE STATE 2 AREA HARGE STATE 2000 ADC Channel Comment: detector position 8.10 ENT

EXPERIMENT #: 1746

Time Since Last Clear: 300400 MS

ATOMIC NUMBER

CHARGE STATE 1

CHARGE STATE 2

HARGE STATE 3

<sup>146</sup>La<sup>27+</sup>: 2500 pps (beta)Stable background rate: 0.0 Hz*RIB*: 100% of total beam current



29-AUG-2018 08:53:22

111

203.02 MEV

4.303 MEV

625