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# The Union for Compact Accelerator-driven Neutron Sources: Past, Present, and Prospects

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*The 5<sup>th</sup> Meeting of the Union for Compact Accelerator-driven Neutron Sources,  
May 12-15, 2015 • INFN, Legnaro (Padova), Italy*

# *Günter S. Bauer (1941-2013)*



*photo courtesy of Jack Carpenter*

# Overview given by Jack Carpenter

# Low-Energy Nuclear Reactions to be Optimized for CANS

Table 1 Neutron production from low-energy nuclear reactions

Reaction types	Examples	Neutron yield per event	Heat Deposit (MeV)	Residual Products & radiation
(p/d, xn)	$^7\text{Li}(\text{p},\text{n})^7\text{Be}$ $^9\text{Be}(\text{p},\text{n})^9\text{B}$ $^9\text{Be}(\text{d},\text{n})^{10}\text{B}$	$\sim 10^{-3}$ - $10^{-2}$ n/p or n/d	$\sim 2000$	Mostly $\gamma$ , possibly t and accumulation of hydrogen
Fusion	$^2\text{H}(\text{d},\text{n})^3\text{He}$ $^3\text{H}(\text{d},\text{n})^4\text{He}$	$\sim 10^{-5}$ n/d	>3000	Mainly $\gamma$
Photonuclear	35 MeV $e^-$ on a W target	$\sim 10^{-2}$ n/e	$\sim 2000$	Mainly $\gamma$

Table 2 The neutron producing reactions considered by Drosd *et al.* [2002] as candidates for monoenergetic neutron sources.

Reaction types	Examples
(p,n)	$^3\text{H}(\text{p},\text{n})^3\text{He}$ , $^6\text{Li}(\text{p},\text{n})^6\text{Be}$ , $^7\text{Li}(\text{p},\text{n})^7\text{Be}$ , $^9\text{Be}(\text{p},\text{n})^9\text{B}$ , $^{10}\text{Be}(\text{p},\text{n})^{10}\text{B}$ , $^{10}\text{B}(\text{p},\text{n})^{10}\text{C}$ , $^{11}\text{B}(\text{p},\text{n})^{11}\text{C}$ , $^{12}\text{C}(\text{p},\text{n})^{12}\text{N}$ , $^{13}\text{C}(\text{p},\text{n})^{13}\text{N}$ , $^{14}\text{C}(\text{p},\text{n})^{14}\text{N}$ , $^{15}\text{N}(\text{p},\text{n})^{15}\text{O}$ , $^{18}\text{O}(\text{p},\text{n})^{18}\text{F}$ , $^{36}\text{Cl}(\text{p},\text{n})^{36}\text{Ar}$ , $^{39}\text{Ar}(\text{p},\text{n})^{39}\text{K}$ , $^{59}\text{Co}(\text{p},\text{n})^{59}\text{Ni}$
(d,n)	$^2\text{H}(\text{d},\text{n})^3\text{He}$ , $^3\text{H}(\text{d},\text{n})^4\text{He}$ , $^7\text{Li}(\text{d},\text{n})^8\text{Be}$ , $^9\text{Be}(\text{d},\text{n})^{10}\text{B}$ , $^{11}\text{B}(\text{d},\text{n})^{12}\text{C}$ , $^{13}\text{C}(\text{d},\text{n})^{14}\text{N}$ , $^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$ , $^{15}\text{N}(\text{d},\text{n})^{16}\text{O}$ , $^{18}\text{O}(\text{d},\text{n})^{19}\text{F}$ , $^{20}\text{Ne}(\text{d},\text{n})^{21}\text{Na}$ , $^{24}\text{Mg}(\text{d},\text{n})^{25}\text{Al}$ , $^{28}\text{Si}(\text{d},\text{n})^{29}\text{P}$ , $^{32}\text{S}(\text{d},\text{n})^{33}\text{Cl}$
(t,n)	$^1\text{H}(\text{t},\text{n})^3\text{He}$
( $\alpha$ ,n)	$^3\text{H}(\alpha,\text{n})^6\text{Li}$ , $^7\text{Li}(\alpha,\text{n})^{10}\text{B}$ , $^{11}\text{B}(\alpha,\text{n})^{14}\text{N}$ , $^{13}\text{C}(\alpha,\text{n})^{16}\text{O}$ , $^{22}\text{Ne}(\alpha,\text{n})^{25}\text{Mg}$

# Cross-disciplinary applications each requires tailored configuration

Table 3. Preferred characteristics of CANS applications. The underlined items represent the preferred configurations.

Applications	Neutron-matter reactions	Accelerator systems	Neutronics & energies	Remarks
Interrogation of materials/structures  $(n,\gamma)$	PGNAA	P, CW	cold, thermal	Compact, rugged, transportable (portable for landmine detection & well logging), minimal innate $\gamma$ background & large, scannable beams
	DGNAA	P, CW	cold, thermal	
	NRCA	P, CW	epithermal	
	FNAA	P, CW	fast	
	APT	P (ns)	$D(T,\alpha)n$ , $E_n=14\text{MeV}$	
Radiography & imaging  $(n,\gamma)$	+ PGNAA	P, CW	cold, thermal	Combined tomographic and activation analysis techniques, neutron polarization analysis of magnetic materials
	+ NRCA	P, CW	epithermal	
	+ FNAA	P, CW	fast	
	RITS	P	thermal	
	polarization	P, CW	cold, polarized	
Irradiation effects on electronics	Neutron-induced soft errors (SEU)	P, CW	fast, selective	High flux to speed up testing/certifying processes, matching test and environmental spectra
Neutron capture therapy	BNCT	P, CW	epithermal	Compact and suitable for operation in hospitals, good flux and clean beam, development of boron-bearing pharmaceuticals
Isotope production	$^N\text{X}(n,\gamma)\text{X}^{N+1*}$	CW	selective	Compact, prevalently located near isotope processing and generation facilities
Nuclear data & cross section measurements	reaction & scattering	P, CW	all	Flexible and multi-purpose beamline and endstations
Nuclear astrophysics	n-capture, $\beta$ -decay, $(n,\gamma)$ decay rate, calorimetry	P, CW	fast	High-intensity beams needed for microgram samples
ADS science & technology	subcritical fission, transmutation	P	thermal to epithermal (?)	Intense beams & reliable operation

Andreani et al. (2015)

# Collaboration: UCANS' Endeavoring Roles

UCANS-V  
2015

→JCANS - 2014

UCANS-IV  
2013

UCANS-III  
2012

UCANS-II  
2011

UCANS-I  
2010

Source  
neutronics & instrumentation  
extant members (8)

3

8

existing & prospective sources

4 +

(8)

polarization  
irradiation, imaging  
interaction w/ big sources  
members (10)

8

2 +

existing & prospective sources  
irradiation, imaging, detectors  
medical. neutron interrogation  
interaction w/ big sources  
members (11)

8

2 +

existing & prospective sources + science  
irradiation, imaging, detectors  
medical. neutron interrogation  
interaction w/ big sources  
members (12)

8

2 +

sources + science  
irradiation, imaging, detectors  
medical. neutron interrogation  
laser-driven sources  
cultural heritage

8

2 +

sources + science  
irradiation, imaging, detectors  
medical. neutron interrogation  
laser-driven sources  
cultural heritage

8

2 +

sources + science  
irradiation, imaging, detectors  
medical. neutron interrogation  
laser-driven sources  
cultural heritage

8

2 +

interaction w/ big sources  
nuclear astrophysics, nuclear data  
members (14)

8

2 +

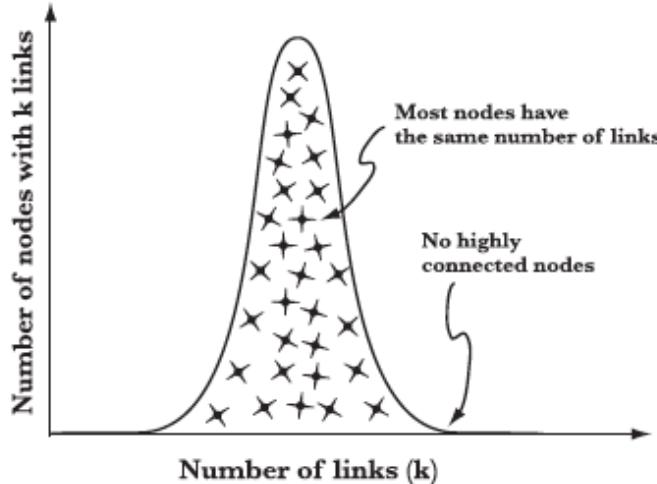
This slide needs to be checked and brought up to date

## A. Maintain connectivity & momentum between meetings

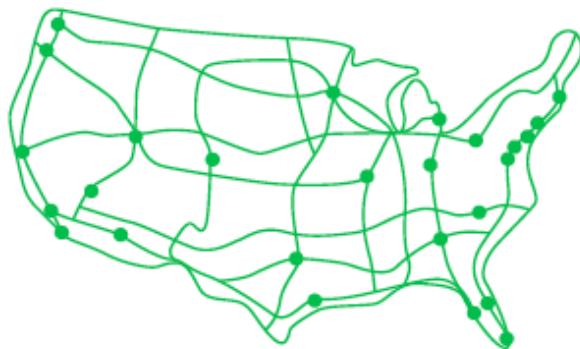
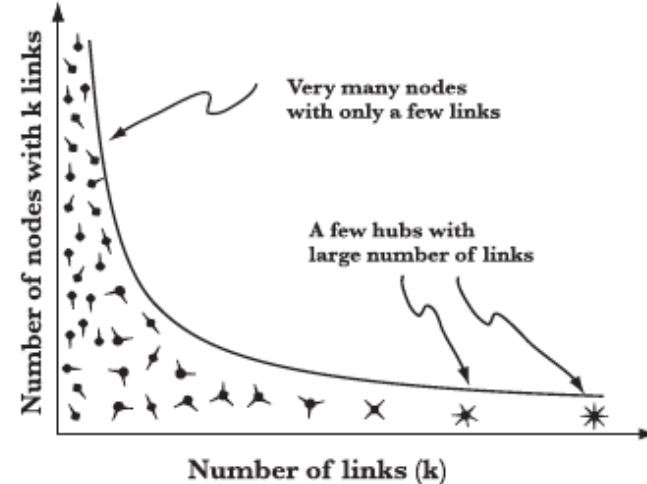
1. Upkeep of a master mailing list
2. Tending an attractive & informative website  
<http://ucans.org/> by Hiro Shimizu (Nagoya U.)
3. Posting all the presentations for download
4. Expedite proceedings publication  
Gianfranco Prete (INFN), editor
5. Report of UCANS progress (a set of thematic papers)  
in The European Physical Journal EJP Plus  
1<sup>st</sup> session: Carla Andreani (U Rome), G. Prete, C. Loong, guest editors
6. ...

## B. Networking

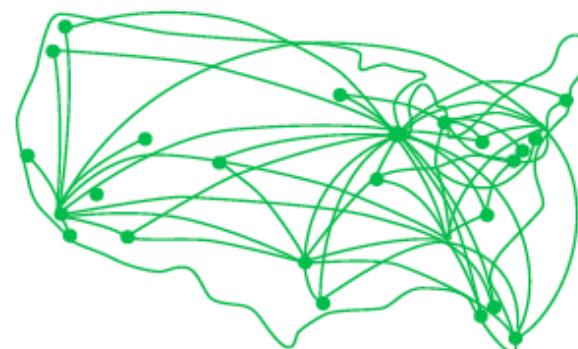
**Bell Curve**



**Power Law Distribution**

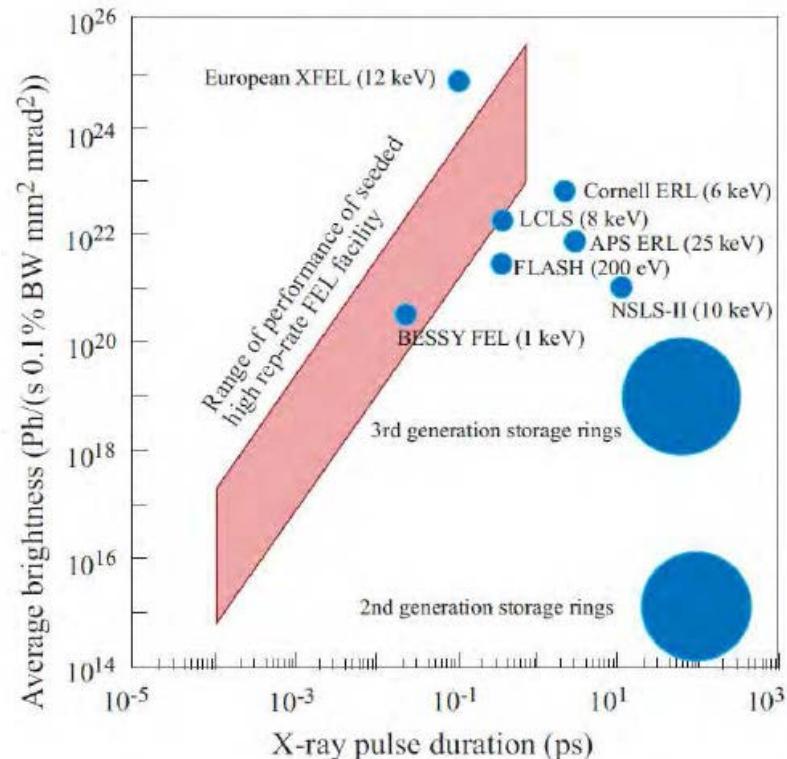
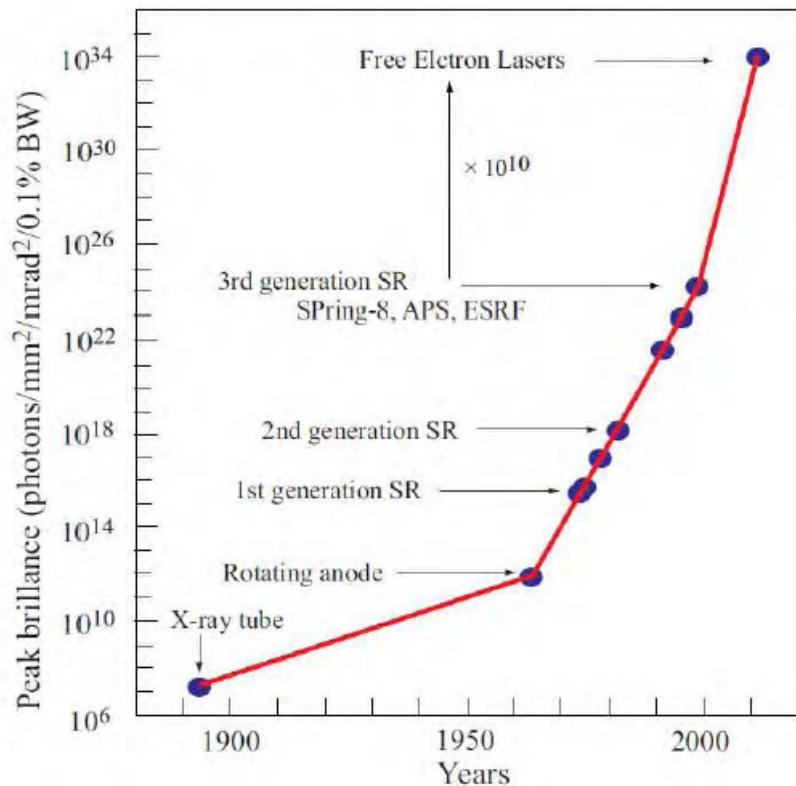


After A.-L. Barabási, *Linked*



Each UCANS member acts as a hub in a CANS Network; elects a correspondent to communicate highlights.

## C. Challenges & Competitions



To inspire young talents, helping them to realize the unique advantage of neutrons and to empower the complementarity between neutrons and photons for the best science.

**XIII School of Neutron Scattering (SoNS)  
“Francesco Paolo Ricci”**

**“International School of Neutron Science and  
Instrumentation”**

**28<sup>th</sup> July – 4<sup>th</sup> August 2015**

A Course within the **School of Neutron Science and Instrumentation**

### 3 Books about CANS:

**ETTORE MAJORANA FOUNDATION AND CENTRE FOR  
SCIENTIFIC CULTURE, Erice (IT)**

*Neutron Scattering Applications and Techniques* (Springer)

Series Editors: Ian Anderson, Alan Hurd, & Robert McGreevy



Upcoming volumes:

*Compact Accelerator Driven Neutron Sources: Physics,  
Technology and Applications*

Editors: David V. Baxter (Indiana U), Michihiro Furusaka (Hokkaido U),  
& Chun Loong

*Neutron Experimental Methods in Cultural Research*

Editors: Nikolay Kardjilov (Helmholtz-Zentrum Berlin) and

Giulia Festa (U Rome)

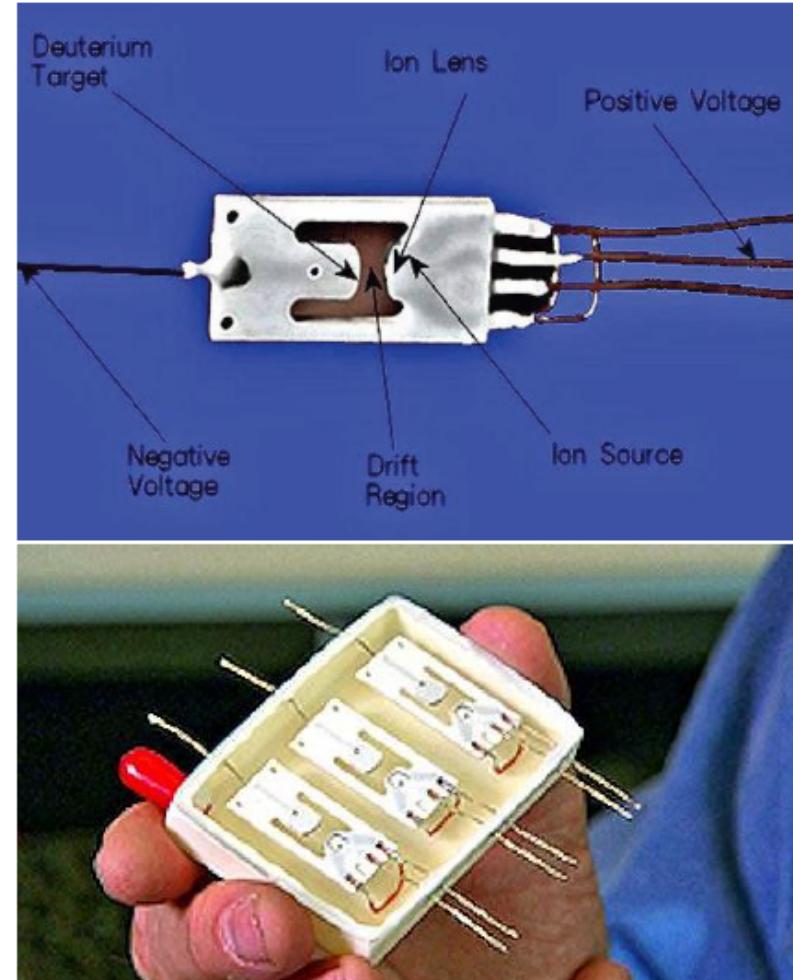
**Application is now open** for the XIII School of Neutron Scattering (SoNS) “Francesco Paolo Ricci”: International School of Neutron Science and Instrumentation as a specialized course within the School of Neutron Science and Instrumentation (Directors: Ian S Anderson and Carla Andreani). The school will be held at the ETTORE MAJORANA FOUNDATION AND CENTRE FOR SCIENTIFIC CULTURE, Erice (Sicily, IT) between the 28<sup>th</sup> July and the 4<sup>th</sup> of August 2015

## E. Novel ultra-compact ‘neutristor’

### Novel Surface Mounted Neutron Generator (Neutristor)

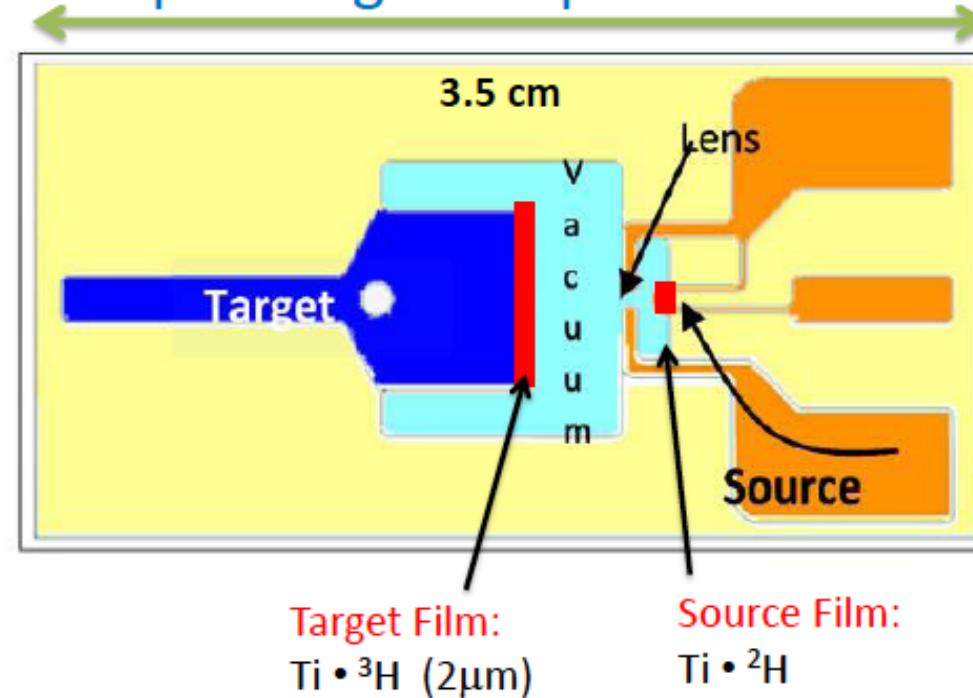
- J. Elizondo-Decanini at Sandia National Laboratories in the U.S. has been developing a compact neutron source based on surface deposition and lithography
- Original development motivation is for cancer therapy
  - Introduce  $^{10}\text{B}$  into cancer cell
  - $\text{n} + ^{10}\text{B} \rightarrow ^4\text{He} + ^7\text{Li} + \gamma$ 
    - $\alpha$  and  $^7\text{Li}$  cause local cell damage
- To prevent damage to healthy cells put the source as close as possible to target
- Goals:
  - Small
  - Inexpensive

IEEE TRANSACTIONS ON PLASMA SCIENCE,  
VOL. 40, NO. 9, SEPTEMBER 2012



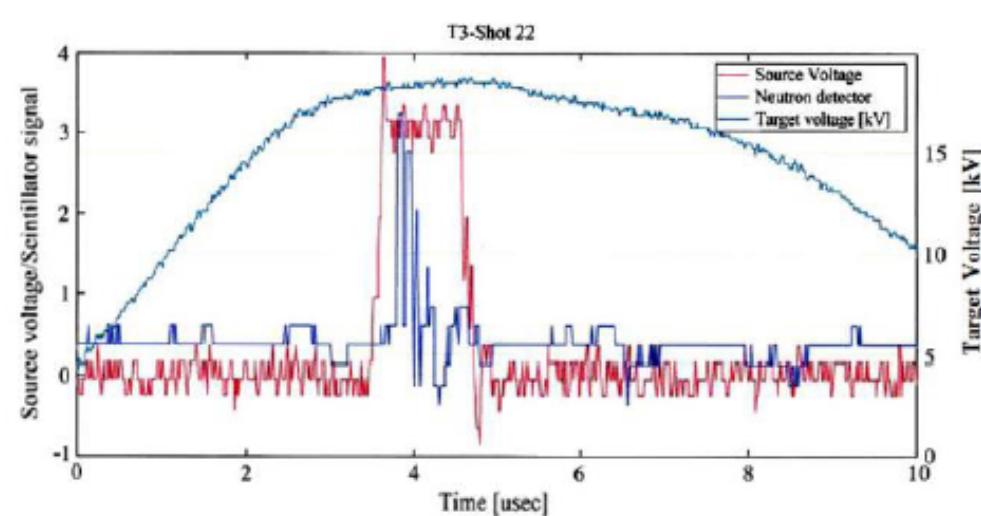
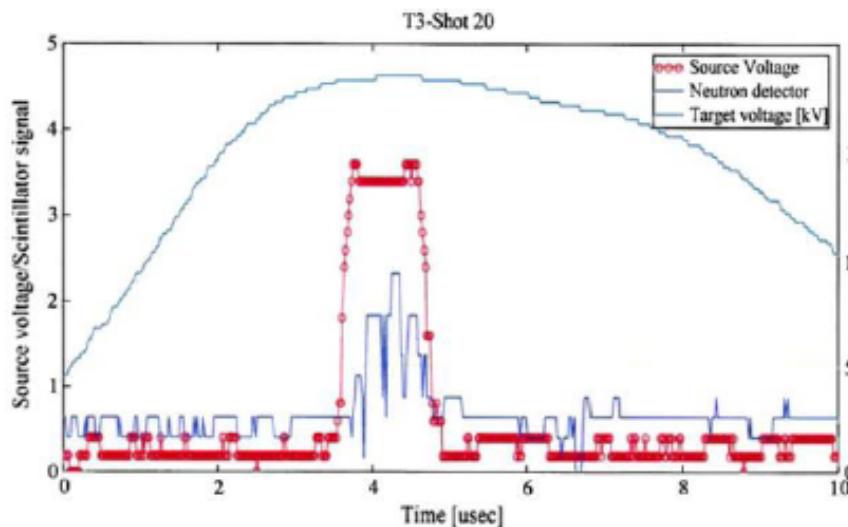
Roger Wendell, 2014

# Neutristor : The Operating Principal



- Deuterium and Tritium thin films are deposited onto the ion source and target elements
- Applying  $O(300)V$  at the source gap causes breakdown and the formation of an arc. The arc heats the source film releasing deuterium into the vacuum and ionizing it at the same time
- An accelerating voltage  $O(15)\text{kV}$  across the target is used to accelerate  $^2\text{H}^+$  (etc.) ions onto the target film to induce D-T fusion
- An electrostatic lens is used to focus the ion flow to the target

# Neutristor : Performance



- Several prototype devices have been built and operated successfully
- Source voltage 600 V ( $>150$  kV/cm at ion source gap)
- Target (accelerating voltage) 20 kV trapezoid,  $10\mu\text{s}$  in duration
- Produces  $\sim 2000$  n per pulse ( $10^9$  n/s)
- Long rep time  $O(60)$  s to allow the device to cool
- Principal of operation is proven

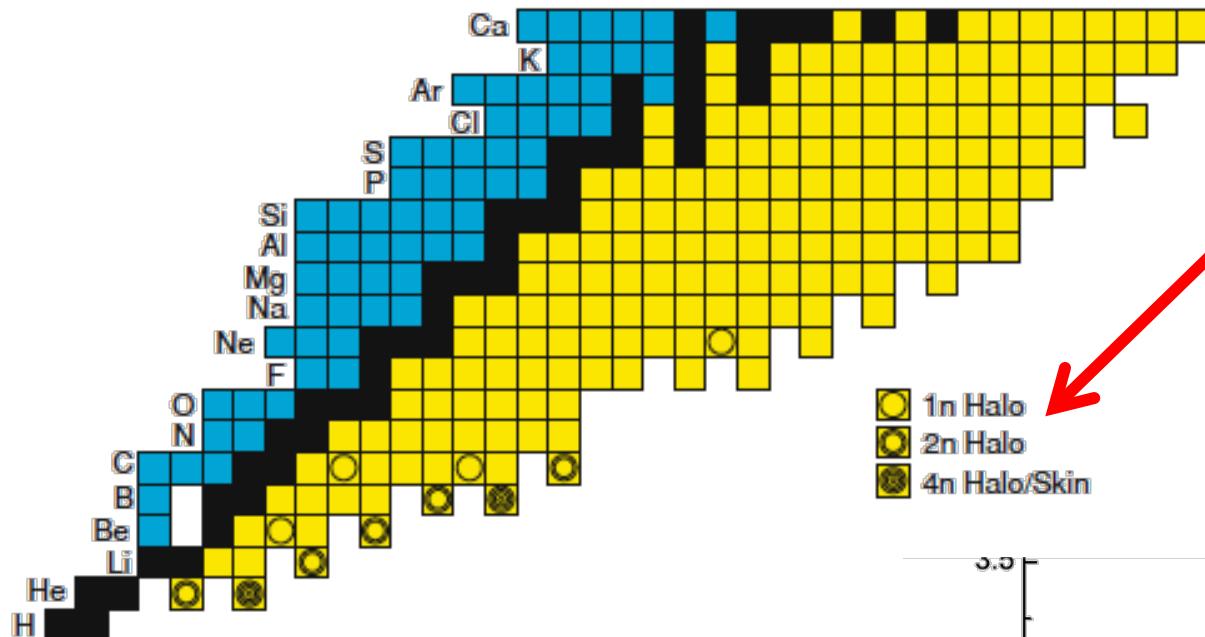
## F. Halo Nuclei



Borromean Rings – A coat of arms and symbol of the Renaissance Borromeo Family in north Italy. If one ring is removed, all rings fall apart.

## The Future: pie-in-the-sky ideas

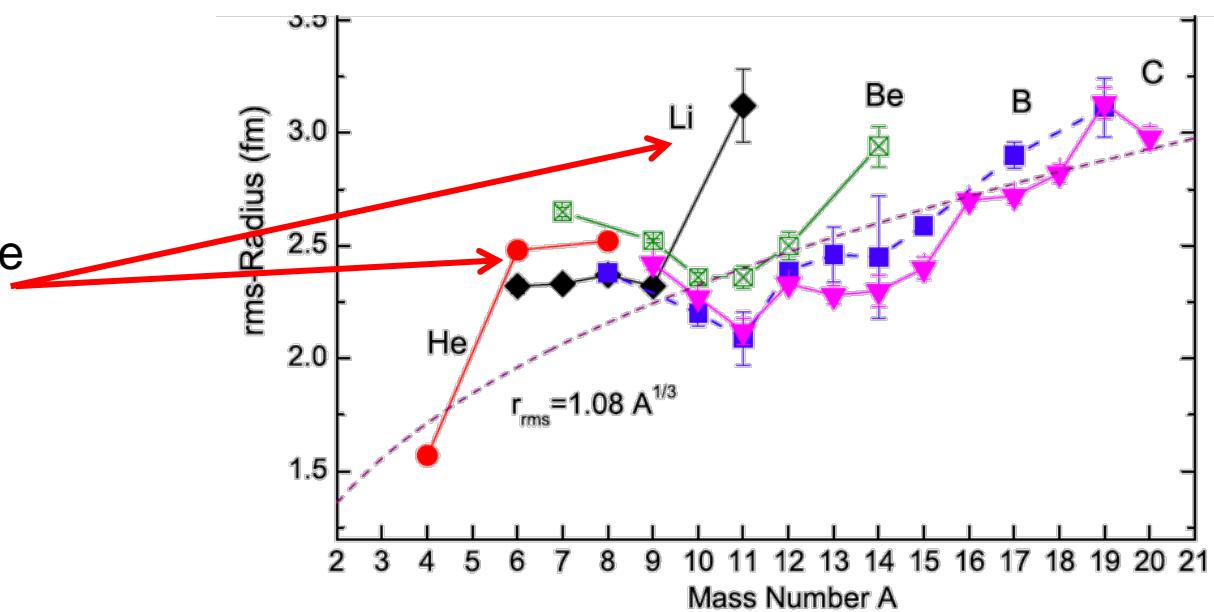
### F. Halo Nuclei



*Borromean nuclei* – they appear to have halos of weakly bound neutrons that surround a more strongly bound core.

Nakamura et al. (2009)

The binding energy of these halo neutrons approach zero, making the nuclei nearly unbound which results in large radii.



## G. Compactness: Portable Devices



**DECO student summer internship opportunity**

**JOIN THE WIPAC TEAM** and participate in the development of the DECO project.

DECO is a citizen science project that enables users around the world to detect cosmic rays and other energetic particles with their cell phones and tablets.

WIPAC is a UW–Madison research center located in Madison, WI, that focuses on astrophysics projects.

**OUR IDEAL STUDENTS ARE** entering 11<sup>th</sup> and 12<sup>th</sup> grade in the fall. They have enrolled (or are planning to enroll) in subjects such as physics, astronomy, computer science

**APPLY by April 7**

A large red diagonal slash is drawn across the top right portion of the advertisement, starting from the top edge and ending near the middle of the page.

We welcome your ideas and comments,...and sincerely solicit your help.

***Let's Discuss &...  
To Achieve a List of Action Items***