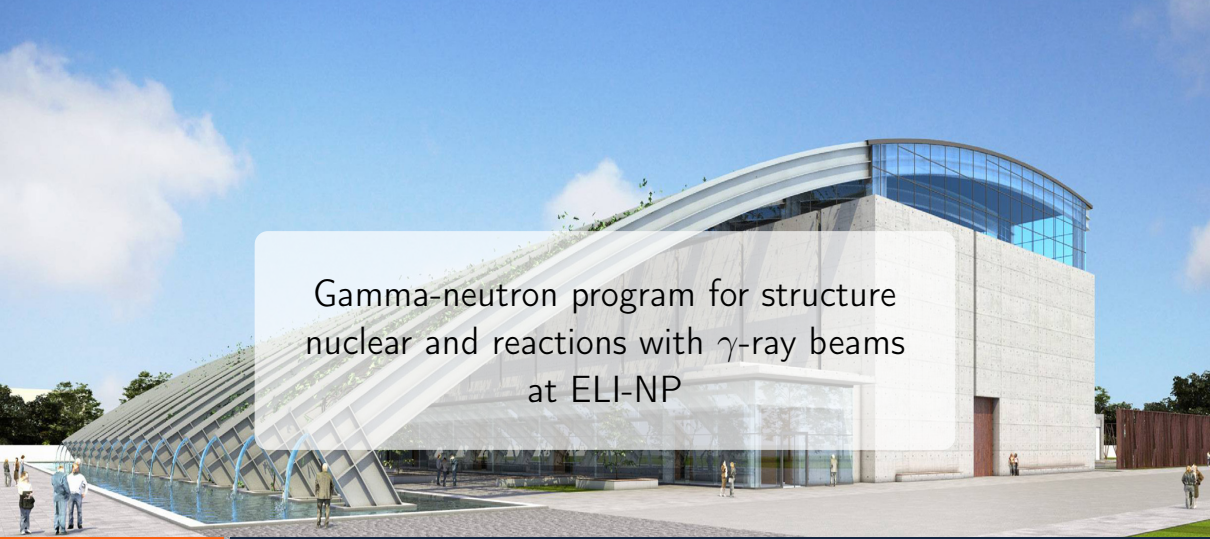
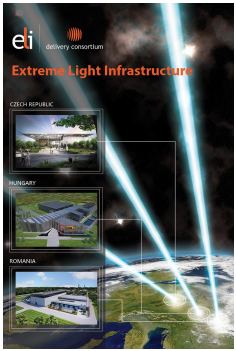


Gamma-neutron program for structure nuclear and reactions with γ-ray beams at ELI-NP

Pär-Anders Söderström
par.anders@eli-np.ro

15th Nordic Meeting on Nuclear Physics

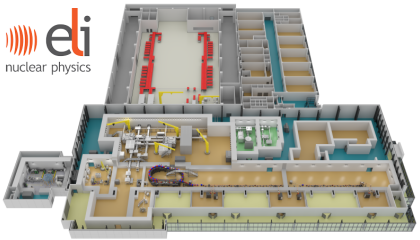
The Extreme Light Infrastructure



- ELI Beamlines, Prague
- ELI ALPS, Szeged
- ELI Nuclear Physics, Măgurele

- ELI-NP is based on two main components
- High-power lasers (HPLS) 100 TW, 1 PW, 10 PW, Thales Romania
- High-brilliance gamma-beam (ELI-GBS)

The ELI-NP GBS



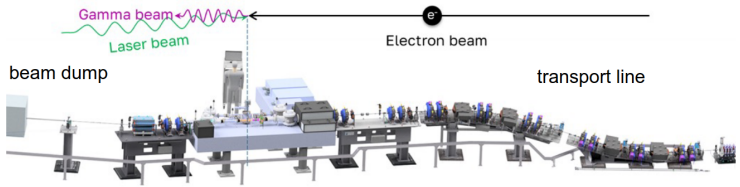
- ELI-NP is based on two main components
- High-power lasers (HPLS) 100 TW, 1 PW, 10 PW, Thales Romania
- High-brilliance gamma-beam (ELI-GBS)

`https://www.eli-np.ro/gsd_second.php`

Parameter	**Specification**
Maximum Photon Energy	19.5 MeV
Tunability of the Photon Energy	Steplessly variable
Linear Polarization of Gamma-Ray Beam	> 95 %
Average Relative Bandwidth of Gamma-Ray Beam (FWHM)	$\leq 5.0 \times 10^{-3}$
Total Photon Flux	$\geq 1.0 \times 10^{11}$ 1/s
Time-Average Spectral Density at Peak Energy	$\geq 5.0 \times 10^{3}$ 1/(s eV)

Gamma Production System – contract with RI for:

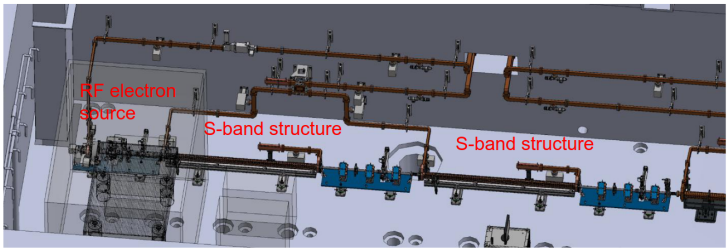
transport line + interaction chamber & optical cavity – finalized by 11/26



	Conservative	Technical limit
Flux (photons/sec)	**2.4×10^5**	**4.3×10^7**

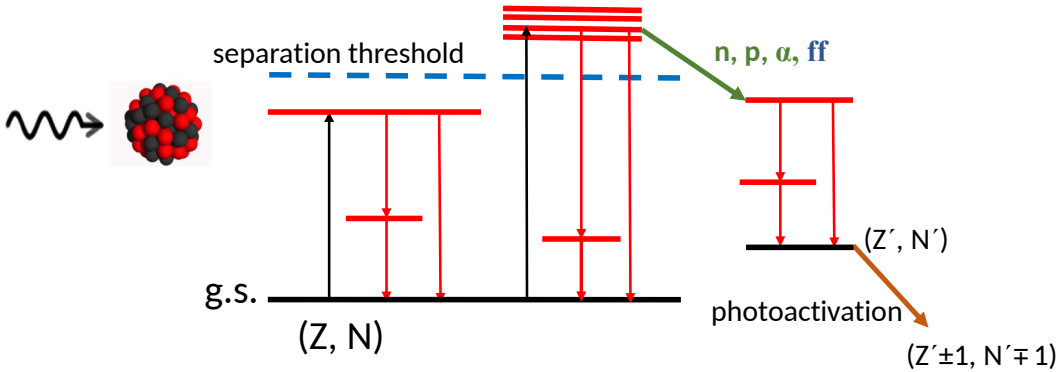
C. Matei: private communication

Components for the Upgrade for existing ELI-NP LINAC – contract with RI for: multi-bunch electron source (50 Hz x 200 micro pulses) + x2 accelerator structures, more modulators + klystrons – to be delivered by 11/2026 (installation 2027+)



	Conservative	Technical limit	Development potential
Flux (photons/sec)	**2.5×10^7**	**1.8×10^9**	**4×10^{11}**

C. Matei: private communication

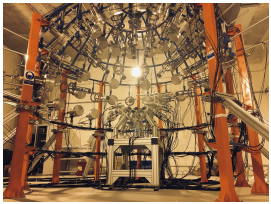


- Incoming γ ray can select individual states to excite
- Above particle separation threshold, particle decay to neighbouring nucleus, fission, etc.
- ... or γ-decay. This type of branching probabilities will be one key topic for measurements

Physics with the gamma beam system

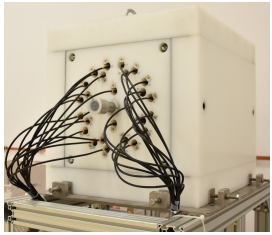
- Nuclear Resonance Fluourescence spectroscopy using (γ, γ') reactions and the HPGe array ELIADE
- Pygmy- and giant resonances, level population following neutron emission, and neutron resonances, using (γ, n) reactions in ELIGANT
- Photo-induced fission cross-sections, fragment distributions, and fission isomers with the ELI-BIC and ELITHGEM instruments
- Production of exotic isotopes using through a γ-induced ISOL facility
- Properties of key astrophysics (γ, p) and (γ, α) reactions using ELISSA Si array and ELI-eTPC time-projection chamber
- High-intensity positron beamline for material research and characterization
- Applications of Nuclear Resonance Fluourescence for non-proliferation, waste-management and cultural heritage with ELIADE

ELIGANT - ELI Gamma Above Neutron Threshold



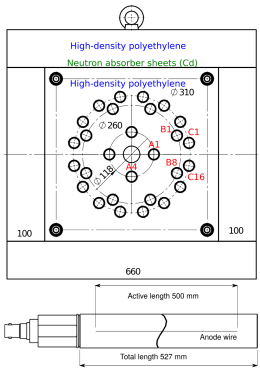
- An array of CeBr and LaBr for γ-rays, liquid scintillators and Li-glass detectors for neutrons
- Tested in-beam (2022-2025 campaigns at ROSPHERE, IFIN 9MV)

P.-A. Söderström, et al.: Nucl. Instrum. Methods Phys. Res. A 1027 (2022) 166171

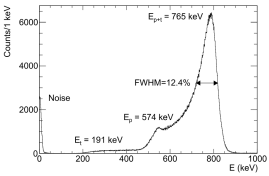


- ^{3}He tube array contained in a polyethylene moderator for neutron counting
- Detector is operational
- Tested in-beam

P.-A. Söderström, et al.: Nucl. Instrum. Meth. A 1084 (2026) 171229

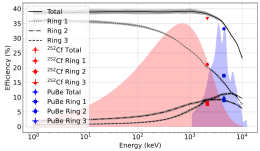


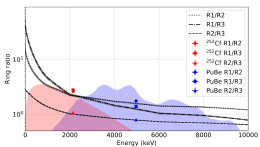
P.-A. Söderström, et al.: Nucl. Instrum. Meth. A 1084 (2026) 171229

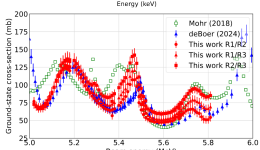


- Thermal neutron capture on ^{3}He gas
- Low γ-ray sensitivity
- Integrate total counts

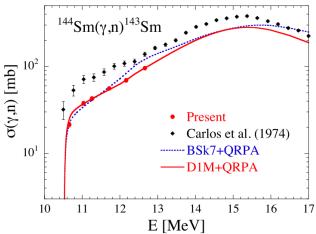
- 28 ^{3} He neutron counters
- 12 bar gas pressure
- Arranged in three rings for neutron energy sensitivity via ring ratio method
- Flat efficiency for minimizing systematic uncertainties

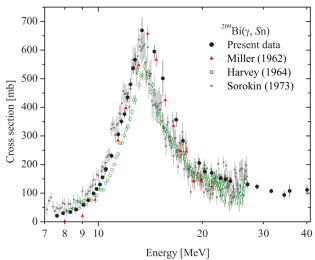






Preparatory GANT experiments at NewSUBARU





- First campaign of (γ, xn) experiments performed at NewSUBARU LCS beamline, D. M. Filipescu and I. Gheorghe
- Part of the *Coordinated Research Project on Photonuclear Data and Photon Strength Functions* (IAEA CRP F41032)
- Wealth of experimental data, continued measurements possible at ELI-NP
- *T. Kawano, et al., IAEA Photonuclear Data Library 2019, Nucl. Data Sheets, 163 (2020) 109*
- *S. Goriely, et al., Reference database for photon strength functions, Eur. Phys. J. A55 (2019) 172*

D. M. Filipescu, et al., Phys. Rev. C 90 (2014) 064616

I. Gheorghe, et al., Phys. Rev. C 96 (2017) 044604

ELIGANT-TN (α, n) cross-sections for applications

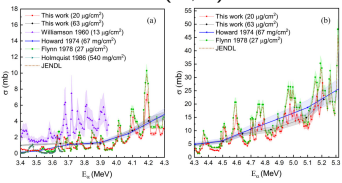
- ELI-NP; Nuclear Physics Department; Applied Nuclear Physics Department at IFIN-HH
- National Physical Laboratory (NPL), UK
- Indian institute of Technology Ropar, India
- UK Atomic Energy Authority (UKAEA), UK

- Complementary program to measure (α, n) cross-sections in the energy range of the α decay from actinides
- Mainly energy range of interest $3 - 6$ MeV, but other ranges for specific applications
- 3 MV and 9 MV Tandetron accelerators at IFIN-HH
- Example 1: ^{19}F (α, n) induced neutron background from ^{234}U in UF_6
- Example 2: ^{27}Al (α, n) induced neutron background in low-background experimental constructions

R. Roy: Ph.D. Thesis, Indian Institute of Technology Ropar (2025)

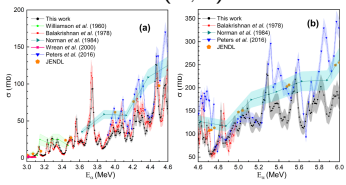
ELIGANT-TN (α, n) cross-sections for applications

$^{27}\mathrm{Al}(\alpha, n)$

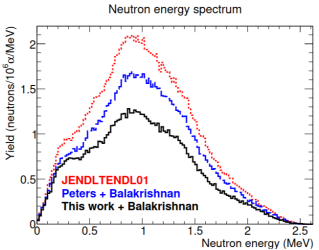


R. Roy, et al.: Phys. Rev. C, 112 (2025) 044613

$^{19}\mathrm{F}(\alpha, n)$



R. Roy, et al.: in manuscript



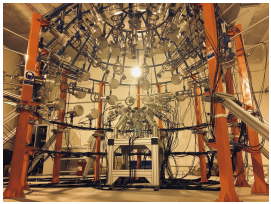
Example of the impact of the $^{19}\mathrm{F}(\alpha, n)$ cross-sections using three different data sets

- The cross-sections were included in the Geant4 based (α, n) source simulation code SaG4n

  E. Mendoza, et al.: Nucl. Instrum. Meth. Phy. Res. A 960, 163659 (2020)

- $^{234}\mathrm{U}$ α source isotropically distributed in a UF_6 cylinder of 76 cm diameter and 206 cm length

ELIGANT - ELI Gamma Above Neutron Threshold



- An array of CeBr and LaBr for γ-rays, liquid scintillators and Li-glass detectors for neutrons
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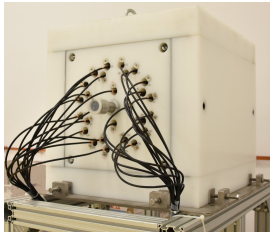
P.-A. Söderström, et al.: Nucl. Instrum. Methods Phys. Res. A 1027 (2022) 166171



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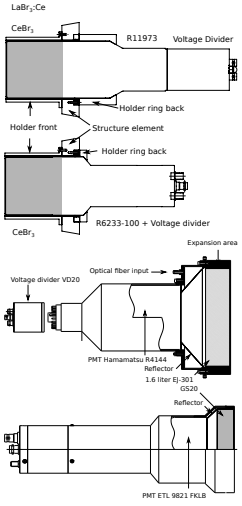
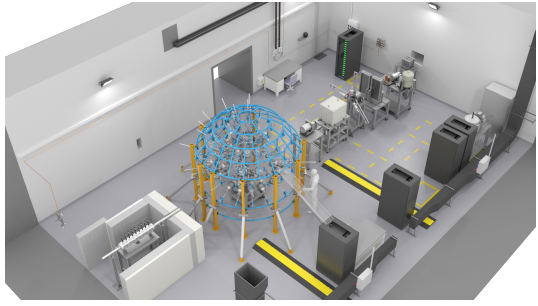
- Detector is operational
- Tested in-beam

P.-A. Söderström, et al.: Nucl. Instrum. Meth. A 1084 (2026) 171229

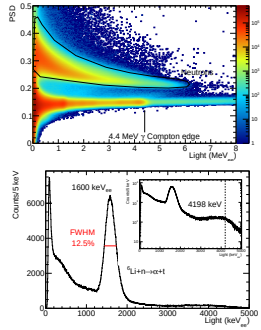
ELIGANT-GN





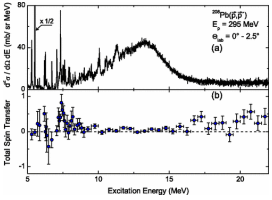
- 34 $LaBr_3$:Ce and $CeBr_3$ detectors
- 36 EJ-301 liquid scintillator detectors
- 25 GS-20 lithium glass detectors

P.-A. Söderström, et al.: Nucl. Instrum. Meth. A 1027 (2022) 166171

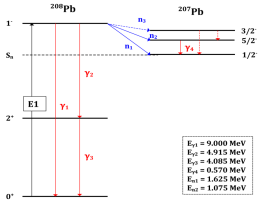


Typical ELIGANT-GN physics case

- Excitation cross section measured with polarized protons at RCNP – Good case for commissioning
- No information on the GDR decay to ground or high lying states through gamma or neutron emission – Good case for day-1
- Clean measurement of the absolute value of GDR ground state γ-decay
- Measure the energy dependence of the GDR $B(\mathrm{E1})$
- Simultaneous $\sigma(\gamma,\gamma)$ and $\sigma(\gamma,n)$ to exctract details of the wave function
- Finer structure from higher-order (3p-3h,...) coupling?
- What is the nature of the PDR?

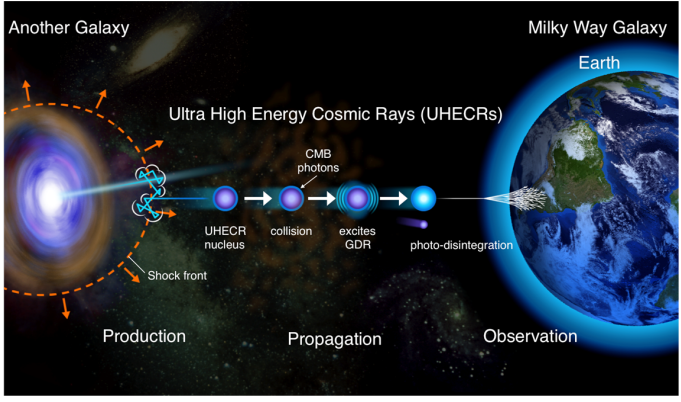


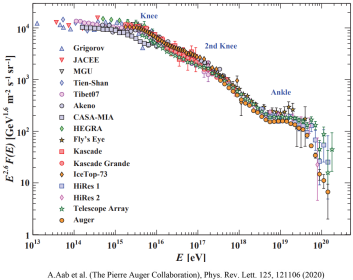
A. Tamii, et al.: Phys. Rev. C 107, 062502 (2011)



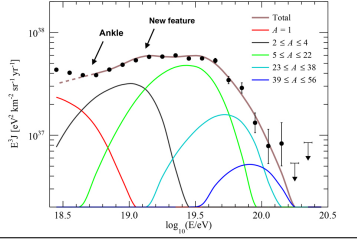
F. Camera, et al., Rom. Rep. Phys. 68 (2016) S539 M. Krzysiek, et al., Nucl. Instrum. Meth. A916 (2019) 257 P.-A. Söderström, et al., Nucl. Instrum. Meth. A 1027 (2022) 166171

Nuclear data for Ultra High-Energy Cosmic Rays

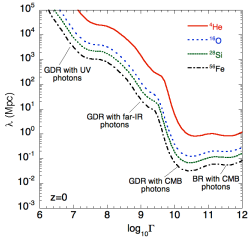


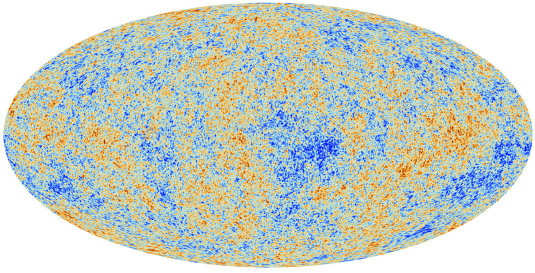


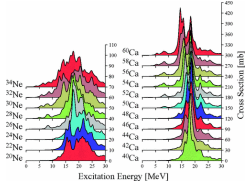
A.Aab et al. (The Pierre Auger Collaboration), Phys. Rev. Lett. 125, 121106 (2020)



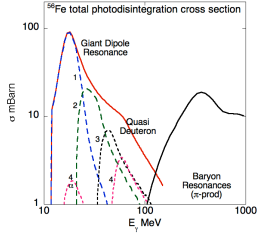
Extragalactic UHECRs fly through empty space... almost





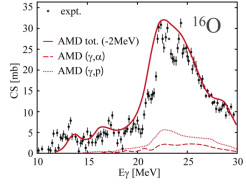


T. Inakura, et al.: Phys. Rev. C 84, 021302(R) (2011)



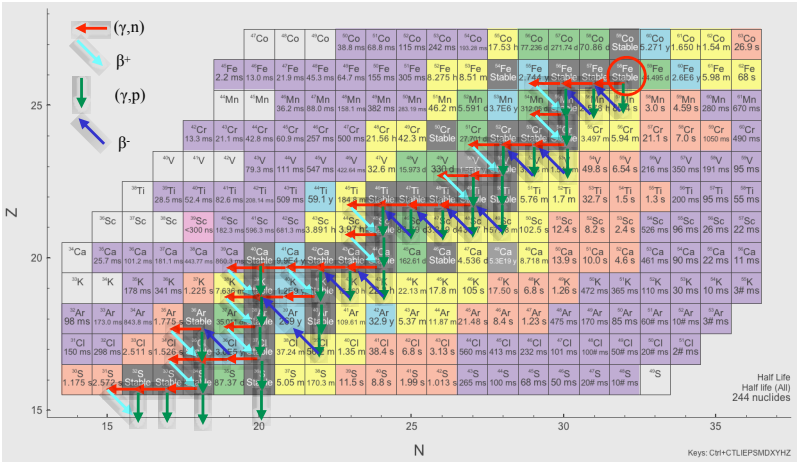
D. Allard: Astropart. Phys. 39-40, 33 (2013)

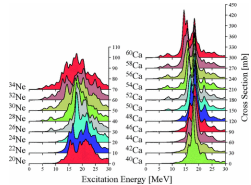
- Very low density in extracalactic space
- Except for Cosmic Microwave Background!
- Extremely high energy, extreme Doppler shifts
- Enough for nuclear excitations to reduce the mean-free path!



M. Kimura, Y. Taniguchi: Private communication

Nuclear data for Ultra High-Energy Cosmic Rays





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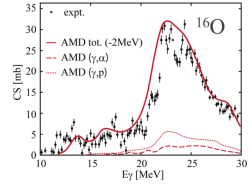

M. Kimura, Y. Taniguchi: Private communication

Nuclear data for Ultra High-Energy Cosmic Rays


Japan


Romania


South Africa

Astroparticle physics

Nuclear physics

Theory

- Propagation Calculations
- Galactic magnetic field
- Acceleration mechanisms

Experiment

- Pierre Auger
- Telescope Array
- Source direction
- Composition

Theory

- Reaction theory
- Structure theory
- Shell model, mean-field models, ab-initio models...

Experiment

- $(p, p'x)$
  - RCNP, Japan
  - iThemba LABS, South Africa
- $(\gamma, \gamma'x)$, ELI-NP

- Oct 2023, RCNP: ^{10}B, ^{11}B, ^{12}C, ^{13}C, ^{27}Al
- Oct 2025, RCNP: ^{12}C, ^{27}Al, ^{24}Mg, ^{56}Fe
- High-priority to-do: ^{6}Li, ^{7}Li, ^{9}Be (Lightest IVGDR), ^{24}Mg, ^{28}Si, ^{32}S, ^{40}Ca (α-clustering), ^{26}Mg, ^{48}Ca ($N > Z$), ^{14}N, ^{51}V (odd-even and odd-odd effects)

A. Tamii, et al.: Eur. Phys. J. A, 59 (2023) 208

Conclusions

- ELI-NP instruments ready for nuclear data on electric dipole strengths; cross sections for astrophysics, astroparticle physics, energy applications; and much more
- Broad collaborations with scientists in related fields in Europe and worldwide

Acknowledgements: Various topics in this research has been funded by the ELI-RO program by the Institute of Atomic Physics, Măgurele, Romania, contract number ELI-RO/RDI/2024-002 and ELI-RO/RDI/2024-007, the Romanian Ministry of Research, Innovation and Digitization, research contract PN 23 21 01 06.

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Aslı KUŞOĞLU, Andreea GHITIU (GAVRILESCU), Sohichiroh AOGAKI, Dimiter BALABANSKI, and everyone else that helped