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LUNANOVA synergy grant application

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State of the art, 2024 – given by Solar Fusion III paper (1)

Solar Fusion Cross Sections III – workshop in Berkeley, July 2022

Summary to be published in Rev. Mod. Phys., available at arXiv:2405.06470

State of the art, 2024 – given by Solar Fusion III paper (2)

TABLE I List of nuclear reactions reviewed in SF-III. Denoting the astrophysical S factor by S is given along with, where applicable, derivatives parameterized in Eq. (4). See the correspo higher precision values, and detailed discussion.

Reaction	S_{ij}	$S(0)$ (MeV b)	$S'(0)$ (b)	$S''(0)$ (MeV^{-1} b)
$^{1}H(p,e^{+}\nu)^{2}H$	S_{11}	4.09×10^{-25}	4.5×10^{-24}	9.9×10^{-22}
$^{2}H(p,\gamma)^{3}He$	S_{12}	2.03×10^{-7}	see text	
$^{3}He(^{3}He,2p)^{4}He$	S_{33}	5.21	−4.90	22.42
$^{3}He(\alpha,\gamma)^{7}Be$	S_{34}	5.61×10^{-4}	-3.03×10^{-4}	–
$^{3}He(p,e^{+}\nu)^{4}He$	S_{hep}	8.6×10^{-23}	–	–
$^{7}Be(p,\gamma)^{8}B$	S_{17}	2.05×10^{-5}	–	–
$^{14}N(p,\gamma)^{15}O$	$S_{1\,14}$	1.68×10^{-3}	–	–
$^{12}C(p,\gamma)^{13}N$	$S_{1\,12}$	1.44×10^{-3}	2.71×10^{-3}	3.74×10^{-2}
$^{13}C(p,\gamma)^{14}N$	$S_{1\,13}$	6.1×10^{-3}	1.04×10^{-2}	9.20×10^{-2}
$^{15}N(p,\gamma)^{16}O$	$S^{\gamma}_{1\,15}$	4.0×10^{-2}	1.07×10^{-1}	1.84
$^{15}N(p,\alpha)^{12}C$	$S^{\alpha}_{1\,15}$	73	3.37×10^{2}	1.32×10^{4}
$^{16}O(p,\gamma)^{17}F$	$S_{1\,16}$	1.09×10^{-2}	-4.9×10^{-2}	3.11×10^{-1}
$^{17}O(p,\gamma)^{18}F$	$S_{1\,17}$	4.7×10^{-3}	–	–
$^{18}O(p,\gamma)^{19}F$	$S_{1\,18}$	2.30×10^{-2}	–	–
$^{20}Ne(p,\gamma)^{21}Na$	$S_{1\,20}$	6.78	–	–
$^{21}Ne(p,\gamma)^{22}Na$	$S_{1\,21}$	$\approx 2.0 \times 10^{-2}$	–	–
$^{22}Ne(p,\gamma)^{23}Na$	$S_{1\,22}$	0.415	–	–
$^{23}Na(p,\gamma)^{24}Mg$	$S_{1\,23}$	1.80×10^{-2}	0	0

1. pp chain
2. CNO cycle
3. Higher hydrogen burning

State of the art, 2024 – given by Solar Fusion III paper (3)

1. pp chain: $^{3}He(\alpha,\gamma)^{7}Be$

   Solar Fusion II 2011 S(0) = 0.56 * (1 ± 5.0%)
   Solar Fusion III 2024 S(0) = 0.561 * (1 ± 5.1%)

2. CNO cycle: $^{14}N(p,\gamma)^{15}O$

   Solar Fusion II 2011 S(0) = 1.66 * (1 ± 7.2%)
   Solar Fusion III 2024 S(0) = 1.68 * (1 ± 8.4%)

Similar picture for other reactions reviewed, and also beyond SF III:

- No improvement in the uncertainty in the last decade.
- We are still not in the 3% precision realm given by astrophysics and neutrino physics!

What can be done?

NuPECC 2024 Long Range Plan for Nuclear Physics in Europe, 13.06.2024

“Soon, the 400-kV accelerator will also become part of the Bellotti facility by putting the two accelerators physically close together to fully exploit the capabilities. This creates the opportunity to upgrade the 400-kV accelerator, including the capability to produce doubly-charged ^{4}He beams. The two accelerators will form an ion-beam facility allowing the study of several reactions over a broader energy range and reducing systematic uncertainties arising from normalisation between different data sets. For these reasons, the relocation and upgrade of the 400 kV accelerator inside the Bellotti Ion Beam Facility is of strategic importance.

The successful exploitation of the new facility requires the development of cutting-edge
detectors and instrumentation. For example, total absorption spectroscopy would allow for total γ-ray energy measurements providing direct information on the total cross section with high efficiency. ”

NuPECC

CHETEC INFRA TECHNISCHE UNIVERSITÄT DRESDEN DRESDEN concept SCIENCE AND INNOVATION CAMPUS HZDR

ESFRI Landscape Analysis 2024

The Gran Sasso National Laboratory (LNGS), the largest underground laboratory in the world devoted to neutrino and astroparticle physics, is also of particular importance for nuclear astrophysics. It offers the most advanced underground infrastructure in terms of dimensions, complexity and completeness. For the last 30 years, research in nuclear astrophysics has been carried out by the LUNA Collaboration at LNGS. The collaboration plans to install a new LUNA 400-kV accelerator at LNGS.

Our approach - LUNANOVA

What we propose to do

- Buy a brand new 500 kV accelerator with ion source for $^{1}H^{+}$, $^{4}He^{++}$ beams,
  and place it on top of Bellotti Ion Beam Facility - total investment budget for this effort is up to 3.2 M€
- Use this brand new 500 kV accelerator for experiments to address the solar fusion precision problem.
- Hire technical / technological staff to operate the new 500 kV accelerator
- Make ancillary experiments elsewhere (e.g. HZDR, Caserta, Bellotti, …)
- Develop new experimental data also for a few (not all!) other science cases related to solar fusion.
- Develop new solar models taking into account up to date physics information.

What we cannot do

- We cannot make the new 500 kV accelerator into a facility before our project is over
  (it will be a facility, but only after our project has completed)
- We cannot address the status of the present 400 kV accelerator (this is the duty of the Gran Sasso lab)
- We cannot buy major equipment for LUNA-MV

ERC Synergy Grant, the framework (1)

Who can apply:

A group of **two to maximum four Principal Investigators (PIs)** working together and bringing different skills and resources to tackle ambitious research problems. One will be designated as the corresponding PI (cPI).

PIs must present an early achievement track-record or a ten-year track-record, whichever is most appropriate.

Proposals are evaluated on the **sole criterion of scientific excellence** which takes on the additional meaning of outstanding intrinsic synergetic effect.

Host Institution (HI)

PIs can apply within the **same HI or through different HIs**. Where the different PIs may be hosted by more than one HI, each of these HIs shall offer their support to the PI(s) hosted by them for the duration of the grant.

At submission stage, all Host Institutions must provide the host support letter for their Principal Investigator(s).

The ERC Synergy Grant is awarded to the cHI that engages and hosts the cPI for at least the duration of the grant, and to any other HI that engages and hosts other PIs participating in the project. The host institutions must engage the PIs for at least the duration of the grant and must offer appropriate conditions for PIs supported to independently direct the proposed research and manage the project's funding for its duration.

ERC Synergy Grant, the framework (2)

Team

ERC Synergy grants support projects carried out by **a group of two to four individual researchers** who can **employ researchers of any nationality** as team members. It is also possible to have one or more team members located in a third country.

Amount

Synergy Grants can be up to a maximum of € 10 million for a period of 6 years.

An additional € 4 million can be requested in the proposal in total to cover the purchase of major equipment and/or access to large facilities.

An ERC grant can cover up to 100% of the total eligible direct costs of the research plus a contribution of 25% of the total eligible costs towards indirect costs.

Total = 10 M€ + 4 M€ = 14 M€

- 80% = direct costs (for research)
- 20% = indirect costs (overhead „tax“, usually goes to the lab director – 25% of the direct costs)

ERC Synergy Grant, LUNANOVA approach

Startup fund 4 M€ (3.2 M€ research, 0.8 M€ overhead) - INFN

Purchase and installation of a new ~500 kV accelerator „LUNANOVA“ on the roof of the Bellotti facility in Gran Sasso.

No (positive or negative) interference with Marialuisa‘s Advanced Grant which uses 400 kV LUNA II accelerator.

Research fund 10 M€ (8 M€ research, 2 M€ overhead)

1. INFN (Alba Formicola) - Accelerator operation budget, research associate, travel
2. Naples University (Gianluca Imbriani) - research associate, scientific equipment (pro rata!!), travel
3. HZDR (Daniel Bemmerer) – research associate, beam time for ancillary experiments, travel
4. CSIC Barcelona (Aldo Serenelli) - research associate, travel

ERC Synergy Grant, science case and team on one slide

Science case

Owing in large part to underground nuclear astrophysics experiments, Big Bang nucleosynthesis has recently entered the 1% precision domain. However, for our Sun, which has an equal if not greater importance for nuclear astrophysics, this breakthrough is still missing. A combined great effort from nuclear and astrophysical theory and experiment is needed to transform the understanding of **hydrogen burning**, in our Sun but also in other stars, from the 10% to the 1% precision level.

Here, it is proposed to install and operate a new underground ion accelerator, LUNANOVA, complementary in capabilities to LUNA-MV that was inaugurated in 2023, at the **INFN** Gran Sasso lab. Ancillary experiments will be performed at the **HZDR** labs in Germany. The University of **Napoli** will bring in academic background and physics expertise, and **CSIC Barcelona** its competency as the maintainer of the Standard Solar Model.

PI, Host Institution, core competency

1.	Alba Formicola	INFN	Buy and operate LUNA-NOVA apparatus at INFN Gran Sasso lab
2.	Daniel Bemmerer	HZDR	Ancillary experiments at HZDR labs (Felsenkeller, IBC, ELBE, etc.)
3.	Gianluca Imbriani	Uni Napoli	Experimental and theoretical nuclear astrophysics
4.	Aldo Serenelli	CSIC Barcelona	Astrophysical theory, solar model