GIANTS

(Gruppi **I**taliani **di A**strofisica **Nucleare T**eorica **e S**perimentale**)**

Audizione CSN2 del 20 Maggio 2021

Understanding the synthesis of the elements in the Universe

Nuclear fusion reactions are at the heart of nuclear astrophysics as they control the energy production in stars and determine the synthesis of the elements in our Universe.

Unfortunately, most of the cross sections are too small to be directly measured in a laboratory at the stellar energies, and, instead, they are extrapolated by means of phenomenological nuclear models anchored to the existing high energy data.

Cosmic rays, environmental radioactivity and beam/target impurity induced reactions are the major limitations to the measurement of thermonuclear cross sections at stellar energies.

We must fight the background to understand the physical processes that control the chemical evolution of the Universe

4 international collaborations (and facilities):

- **LUNA 400 kV + LUNA MV (INFN-LNGS):** measurements (underground) of nuclear cross sections for astrophysics (Stellar energy sources and nucleosinthesys, BBN).

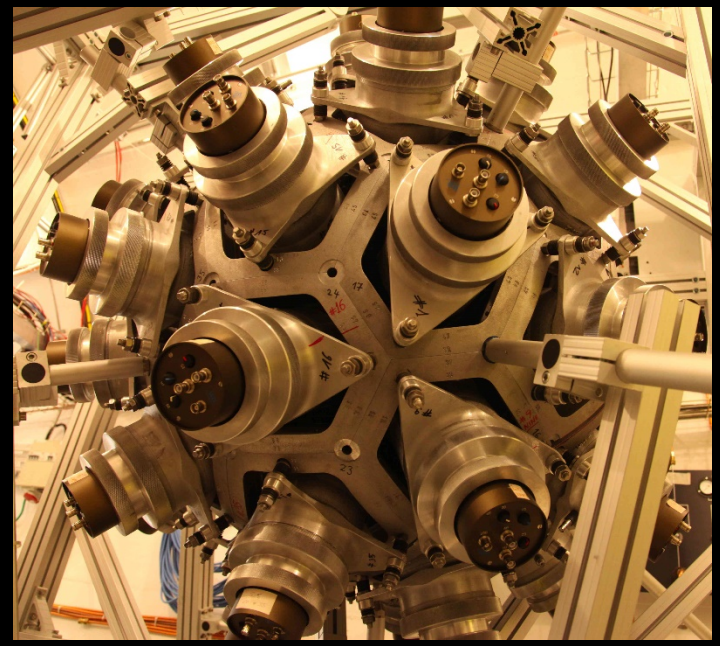
- **ERNA (UniCampania-CIRCE)**: measurements of nuclear cross sections for astrophysics (Stellar energy sources and nucleosinthesys).

- **nTOF (CERN):** measurements of Maxwelian-Average cross section of neutron capture (s and r process, BBN).

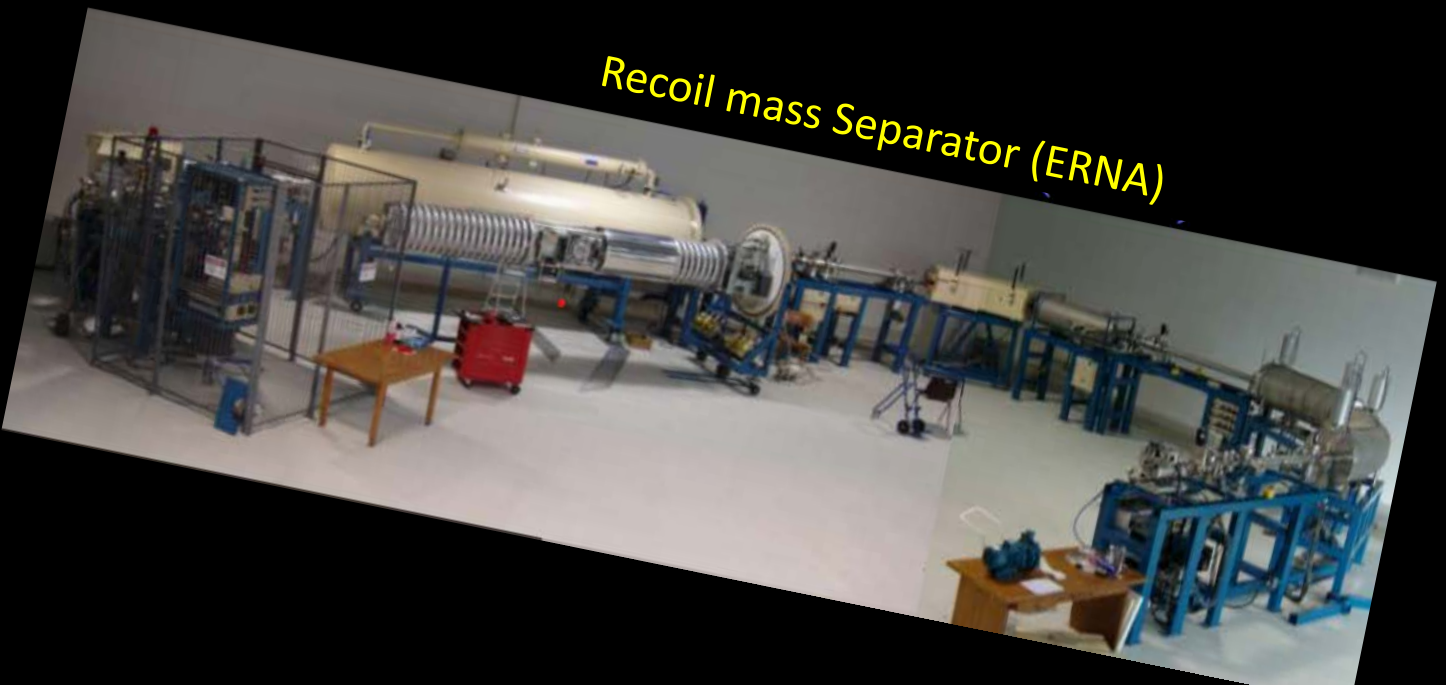
- **PANDORA (INFN-LNS):** astrophysics plasma physics, electron screening, radiative opacity.

Accelerator maintenance (LUNA 400 kV)

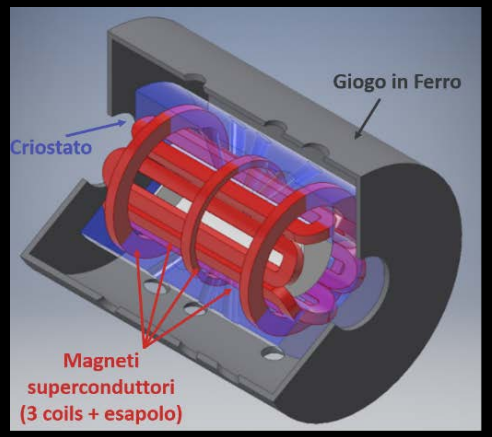
Calorimeter, (nTOF)

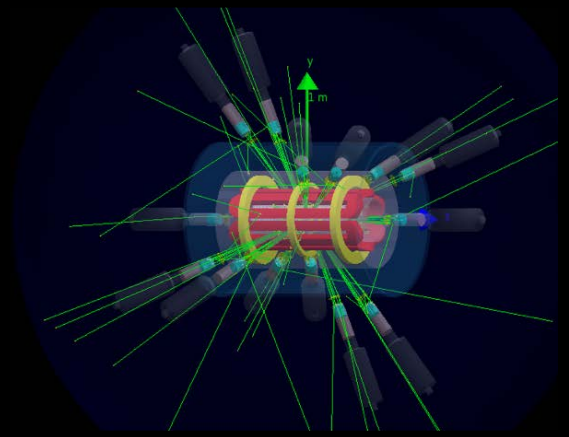


Recoil mass Separator (ERNA)



Superconductive-magnetic trap (PANDORA)





MULTIDISCIPLINARY

- Low-energy measurements of nuclear-reaction cross-sections (Nuclear Physics)
- Calculation of reaction rates in an astrophysical plasma (Nuclear Physics + Astrophysics)
- Stellar Models (Astrophysics)
- Cosmological model (Cosmology)
- Nucleosynthesis models, from BBN to stars (Astrophysics)
- Abundance measurements in stars and interstellar matter (Astrophysics)
- Abundance measurements in meteorites and pre-solar grains (Astrophysics + Geophysics)

Associated (INAF) projects that take advantage of GIANTS results.

- **HEN (S. Cristallo).** Heavy Element Nucleosynthesis, s and r process, AGB, core-collapse SNe and NS+NS mergers.

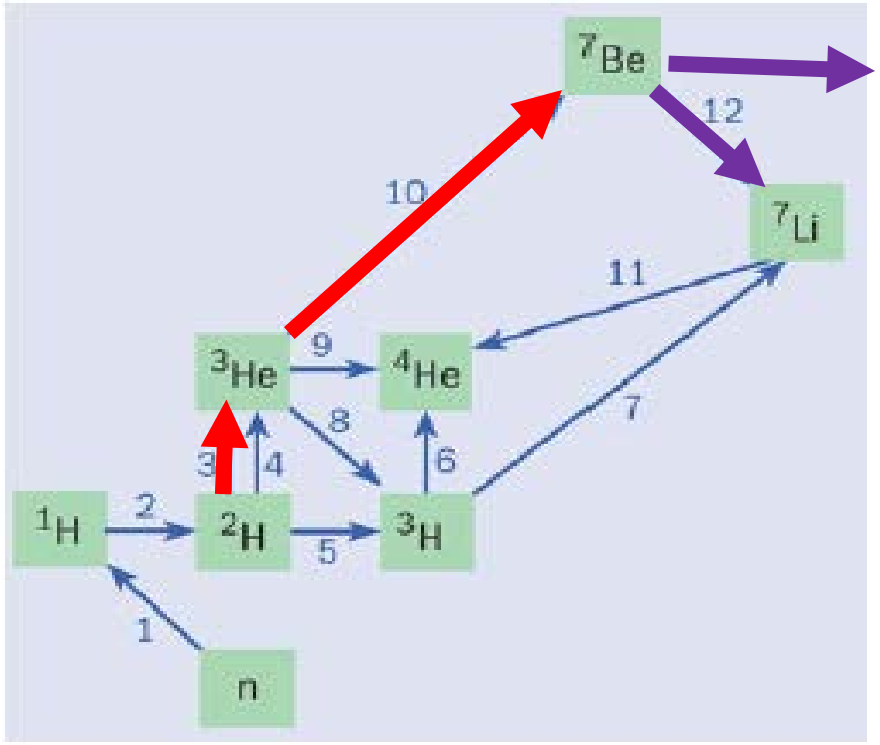
- **APES (L. Piersanti).** Advanced Phases of Evolving Stars, models of AGB stars, Supernovae Ia, their progenitors and nucleosynthesis.

- **STARDUST (P. Ventura).** Dust from AGB stars, formation, composition and ISM pollution.

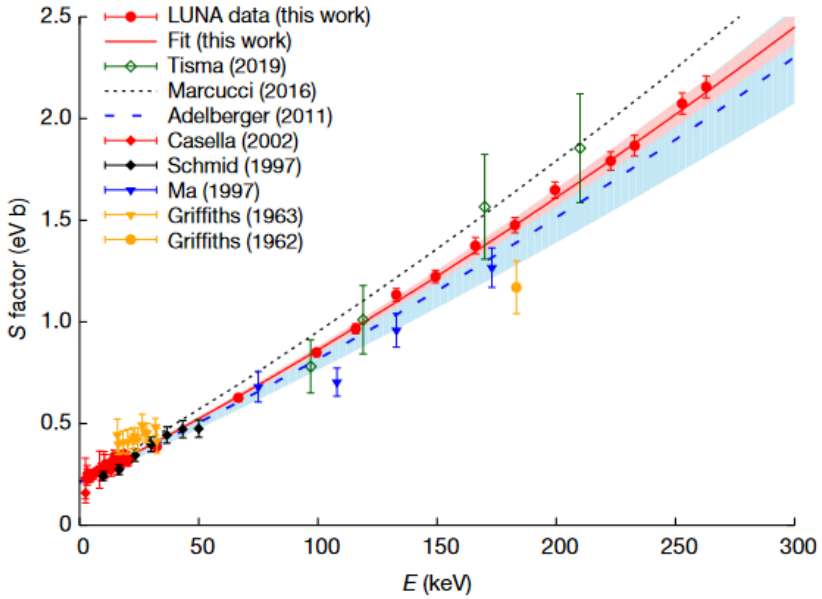
…. much more, see, e.g., the G. Cescutti and A. Chieffi presentations

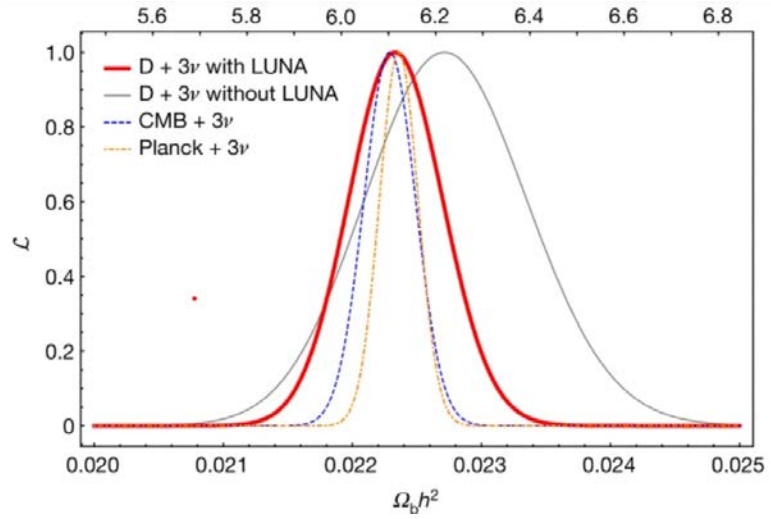
Scientific cases and results
A few examples

BBN Network



BBN reaction studied at LUNA (red arrows) and at nToF (violet arrows)





The baryon density of the Universe from an improved rate of deuterium burning (Nature 2020, LUNA collab.)

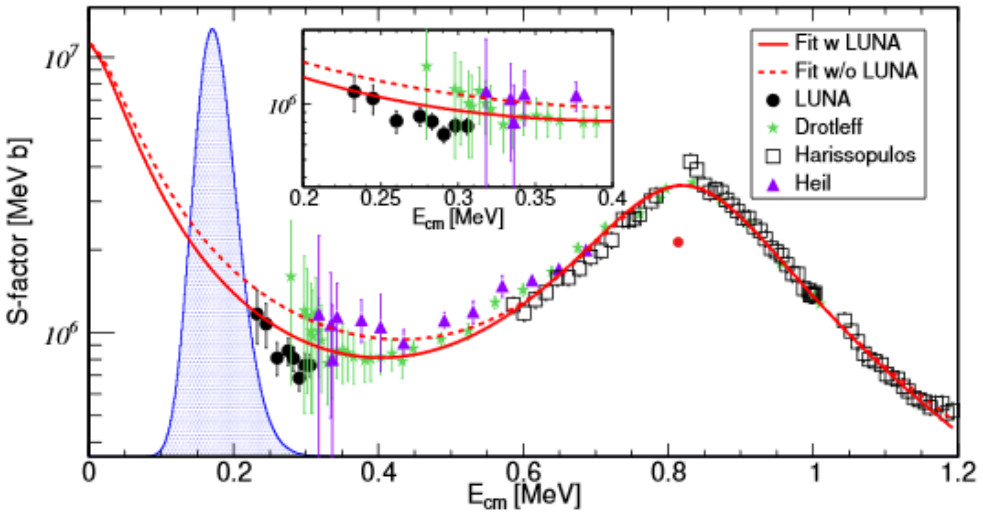
^{7}Be(n,p)^{7}Li Reaction and the Cosmological Lithium Problem (Phys.Rev.Lett. 2018, nTOF collab.)

Heavy Elements: s-process from AGB stars

Link to HEN project (Sergio Cristallo)

Neutron captures → **Measurement of the ^{154}Gd(n,γ) cross section and its astrophysical implications.**
Phys. Lett. B, 2020, nTOF collaboration

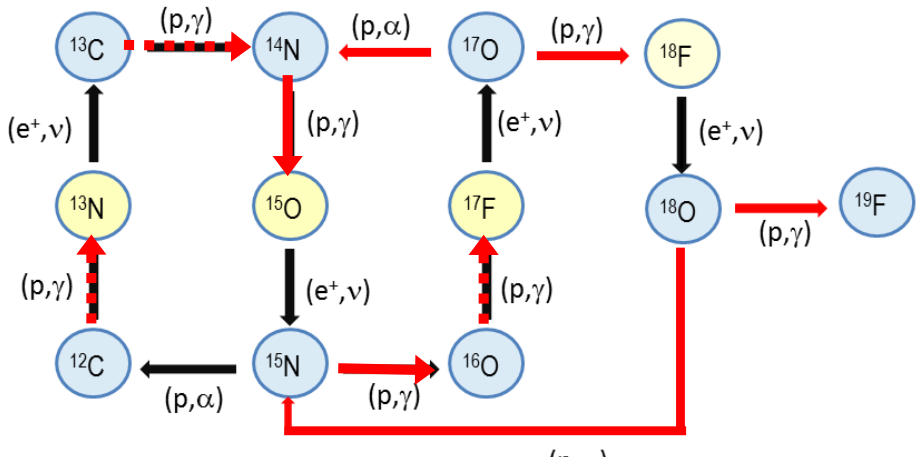
Neutron sources → **Direct measurement of the ^{13}C(α,n)^{16}O cross section into the s-process Gamow peak.**
Phys. Rev. Lett. , 2021, LUNA collaboration

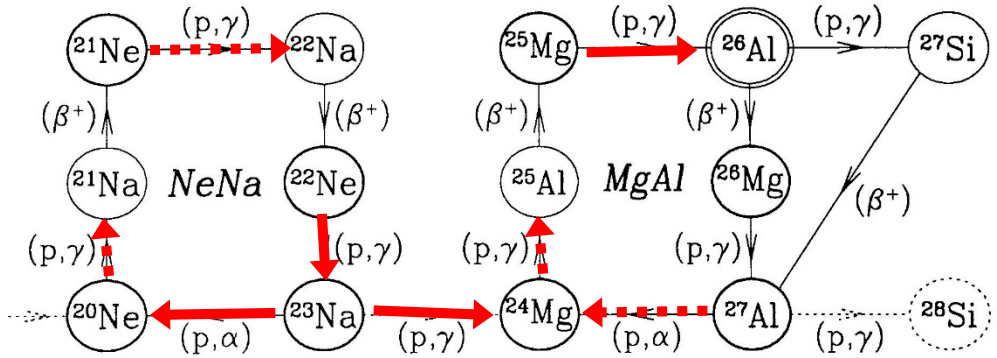


The revised astrophysical factor for the ^{13}C(α,n)^{16}O reaction. R-matrix best fits are shown (lines), while the shaded area represents the Gamov's peak corresponding to the temperature of a typical s-process nucleosynthesis episode taking place in AGB stars.

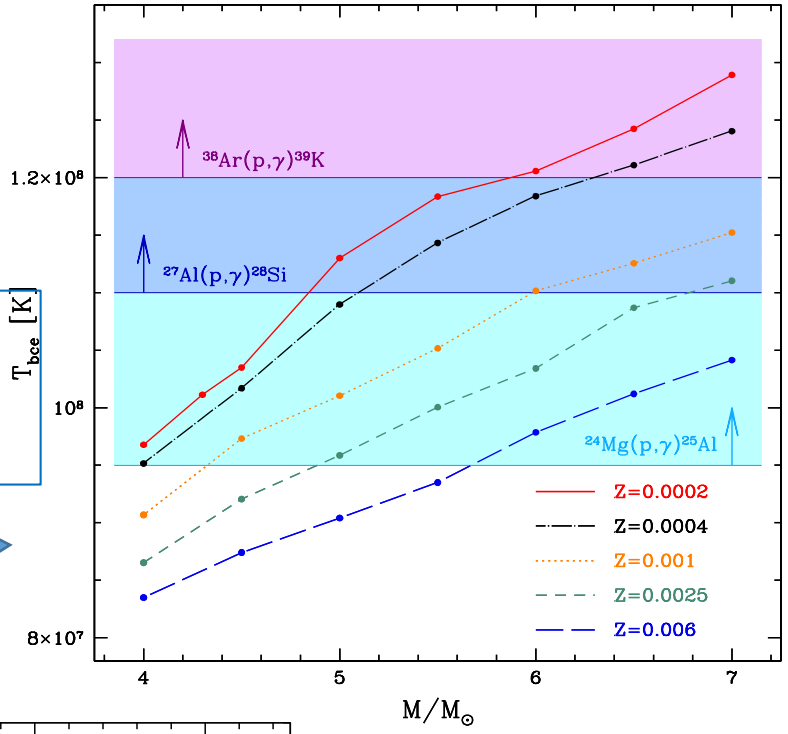
Multiple populations in GCs: C,N,O,Ne,Na,Mg,Al isotopes - Link to STARDUST project (Paolo Ventura)

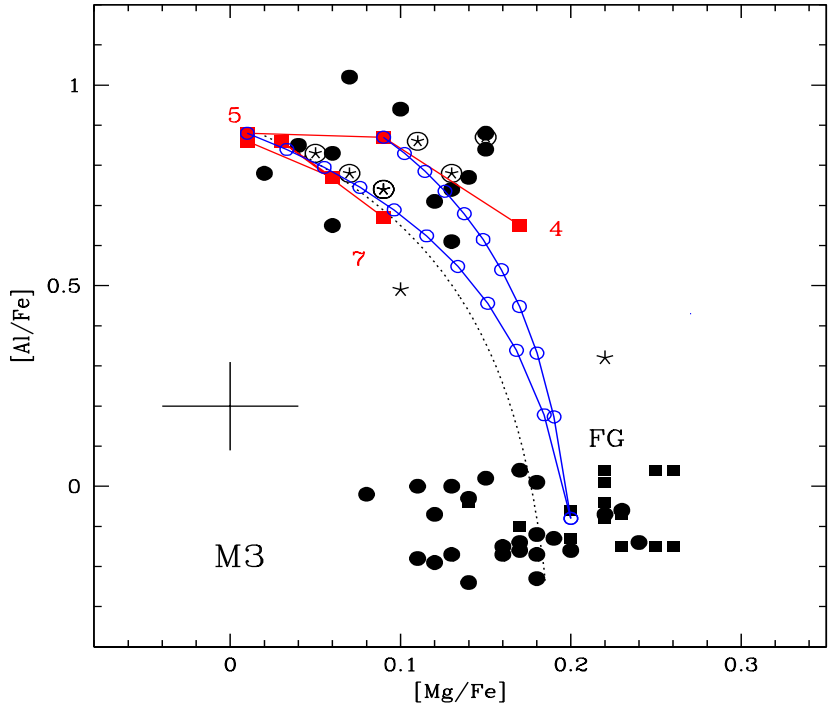
In red, reaction measured at LUNA 400 kV





T at the base of the convective envelope of a massive AGB





Predicted vs observe Mg-Al anticorrelation in GC stars.

Dell'Agli et al. 2018, MNRAS, 475, 3098

Type Ia supernovae and their progenitors

Link to APES project (Luciano Piersanti)

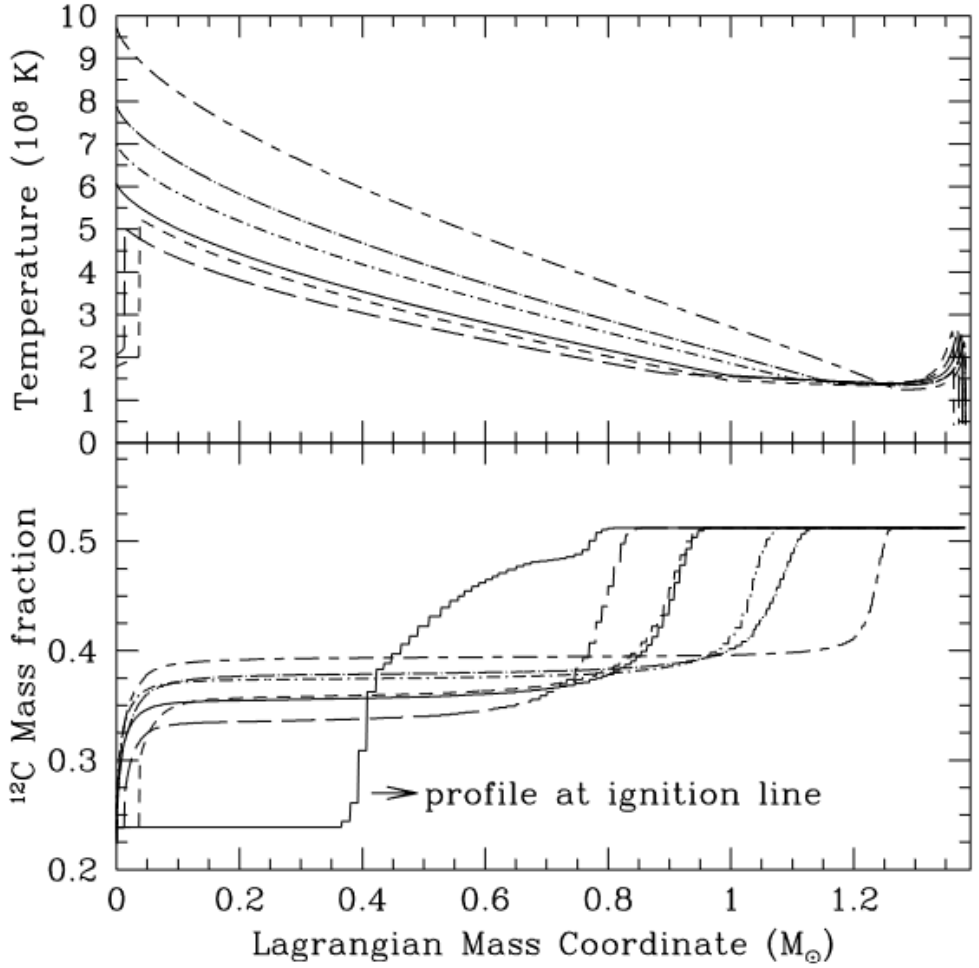
Type Ia supernovae and the $^{12}C+^{12}C$ reaction
Bravo et al. A&A 2011

The carbon simmering phase precedes the thermonuclear explosion and determines the explosive conditions. C-burning rates is a fundamental ingredients.

The astrophysical S factor of $^{12}C(\alpha,\gamma)^{16}O$ at stellar energy
Physics Letters B, 2012 (ERNA collab.)

Measurement of the $^{12}C(^{12}C,p\ )^{23}Na$ cross section near the Gamow energy
Physical Review C, 2018 (ERNA collab.)

Thermal (upper) and chemical (lower) profiles for different 12C+12C rates



COMING SOON. The direct measurement of the $^{12}C+^{12}C$ cross-section is the most appealing scientific case for the new LUNA MV facility. The accelerator will be mounted in the underground lab (LNGS) before the end of 2021.

Team, only INAF astrophysicists (or associated) that are members of at least one of the 4 collaborations (LUNA,nToF, ERNA, Pandora):

- Oscar Straniero (INAF) 0.3 fte/yr
- Luciano Piersanti (INAF) 0.3 fte/yr
- Sergio Cristallo (INAF) 0.3 fte/yr
- Paola Marigo (UniPD) 0 fte/yr

At present, 3 students are directly involved in the GIANTS reaserch program:

- Mario Cirillo (PhD, joint program Sapienza/Tor Vergata/INAF),
- Andrea Ercolino and Daniele Vannini (Laurea Magistrale, Rome “Sapienza”)

Funds (limited to astrophysics)*

- **Past:**
  - MIUR (PRIN+FIRB) **210** Keuro (closed)
  - VALERE2019 UniCampania **30** Keuro (open)
  - INFN commission III **20** Keuro/yr (till 2021)
- **Future (to be approved):**
  - PRIN2020 **170** Keuro
  - FARE2020 MIUR **120** Keuro (2 yr postdoc)
  - INFN commission III **20** Keuro/yr

*THE RUNNING COSTS OF THE 4 EXPERIMENTAL FACILITIES (A FEW Meuro/yr) are mainly covered by the host institutions

Critical Issues:

- **Man power**
  - **Formation**, it requires involvement in Master and PhD programs. Specific funds for student fellowships needed.
  - Recruitment of **post-doc researchers**.

Other connections/funds

- **CHETEC (**http://www.chetec.eu/), Chemical Elements as Tracers of the Evolution of the Cosmos. Supported by the COST action program. It is a European network of nuclear astrophysics.
- **IReNA** (https://www.irenaweb.org/). International Research Network for Nuclear Astrophysics. Supported by NSF. It is is a National Science Foundation AccelNet Network of Networks.

The **GIANTS initiative**, officially started in 1996, with the first workshop in Catania, aims to promote the Italian research in the field of nuclear astrophysics and wants to be the source of new initiatives to be proposed for the national research plans of INFN and INAF and for international scientific programs. In addition to the 4 collaboration mentioned in this INAF project, the AsFIN collaboration, based at LNS (INFN), is also very active in this research field and a pillar of the GIANTS initiative.

Have a look to the GIANTS newsletters, https://pandora.infn.it/public/giantsnews11/

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