Summary Report for Contract TAL-NAPC20210119-005

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Motivation

Introduction and partial release of a new online database for cross sections relevant to the s process – ASTRAL.

Introduction

This report describes the first stage of an upgraded version of the KADONIS database [1] https://exp-astro.de/kadonis1.0/ The KADONIS database was founded as a follow-up of the paper by Bao et al 2000 [2], where for the first time a complete set of recommended neutron capture cross sections necessary for s-process nucleosynthesis calculations was published. The idea of KADONIS was to keep this collection alive and up to date. However, until now, there is no official release of version 1.0, only version 0.3 is frozen and released.

The underlying problem was the huge amount of work necessary with every release. In particular a significant change of the widely used reference cross section, ^{197}Au(n,γ), required a revisit of every single reaction rate in the database. Over a long time, the absolute activation-based spectrum averaged cross section [3]

$$SACS = \frac{\int_{E1}^{E2} \phi(E)\,\sigma(E)\,dE}{\int_{E1}^{E2} \phi(E)\,dE}$$

closely resembling a Maxwellian spectrum with kT≈25 keV served as a standard for almost all s-process related cross section measurements. Ever improved time-of-flight measurements [4, 5], however, lead to a re-evaluation of the standard cross section [6]. It turned out that a small systematic effect of the backing of the neutron-producing lithium layer was not considered in the original activation measurement. Therefore, the recommended Maxwellian averaged cross section

$$MACS = \frac{2}{\sqrt{\pi}} \frac{1}{(kT)^2} \int_0^\infty \phi(E)\,\sigma(E)\,dE$$

at kT=30 keV changed from 582±9 mb (Kadonis 0.3 and earlier) to 612±6 mb [6].

The ASTRAL database

In 2018, the idea for a completely new and independent database was therefore born. The main difference is that instead of actual cross sections, the experimentally determined raw data are stored. The measured data are typically cross section ratios between the isotope under investigation and the reference cross section. The first release (version 0.1) of the ASTRAL database with about 70 isotopes occurred in 2018 [6, 7]. ASTRAL stands for ASTrophysical Rate and rAw data Library and is available online at https://exp-astro.de/astral/ .

Along with this report, the version 0.2 will be released. It contains an updated version of the 70 isotopes already evaluated in version 0.1 and in addition 50 new isotopes. The foundation for these additional 50 isotopes was laid in 2021 [8]. It is foreseen to release the first full dataset as version 1.0 before within 2022.

ASTRAL – Version 0.2

The main difference between ASTRAL version 0.1 and version 0.2 for the ~70 isotopes, which were already in version 0.1, is the use of current evaluated data. For all of the isotopes, time-of-flight data are available over a limited neutron energy range. The calculation of the Maxwellian-Averaged Cross Sections (MACS) as needed for nucleosynthesis calculations requires data between zero and infinity. The missing energies for the MACS calculation are taken from evaluated data sets, which are normalized to the measured data. While version 0.1 was largely based on ENDF-B/VII [9] and version 0.2 is mostly based on ENDF-B/VIII [10]. The only exceptions are the isotopes of Yb, where JENDL-4.0 was used and the isotopes of Ta, where JEFF-3.3 was used.

In addition, ~50 isotopes where the experiments were based on activations [8] were evaluated in a (completely) new way. In particular, the way activations with different energy regimes have been completely revised. This technique will soon be applied to all isotopes where activation data are available. The main idea is to calculate weighting factors based on the overlap between the experimental neutron spectra and the Maxwellian energy distribution. Hence, each activation has different relative weights for different temperatures. This approach ensures that the experimental spectrum, which is closest to the stellar energy distribution has the highest weight. Based on the weights, a normalization factor was determined to scale the evaluated cross sections. Based on this energy-dependent evaluated cross section, the MACS for each temperature was calculated. An excerpt for kT=30 kV is given in Table 1.

Table 1: Excerpt of the version 0.2 release of the ASTRAL database for the Maxwellian Averaged Cross Sections at kT=30 keV. The column "reaction" corresponds to total neutron capture (ng), capture to the ground state of the product (ng_0) and capture to the isomeric state (ng_1). "Z" is the atomic number of the isotopes, "A" the mass number.

Z	A	Reaction	MACS(mb)	dMACS(mb)
4	9	ng	9.08E-03	4.27E-04
6	13	ng	2.81E-02	6.45E-03
11	23	ng	1.52E+00	1.40E-02
18	36	ng	1.52E+00	1.07E-01
18	38	ng	9.34E-01	1.03E-01
20	40	ng	5.16E+00	3.04E-01
21	45	ng	5.53E+01	6.11E-01
26	58	ng	1.26E+01	3.39E-01
26	60	ng	4.93E+00	4.97E-01
27	59	ng	3.55E+01	2.05E-01
28	64	ng	7.11E+00	1.59E-01
29	65	ng	2.70E+01	7.10E-01
30	64	ng	4.89E+01	1.15E+00
30	70	ng	9.34E+00	5.91E-01
30	70	ng_0	3.52E+00	5.64E-01
30	70	ng_1	5.81E+00	1.74E-01
32	74	ng	3.59E+01	1.52E+00
33	75	ng	3.40E+02	8.85E+00
34	78	ng	5.64E+01	9.19E+00
35	79	ng	5.94E+02	2.74E+01
35	79	ng_0	4.31E+02	2.55E+01
35	79	ng_1	1.63E+02	9.83E+00
35	81	ng	2.12E+02	2.27E+00
37	85	ng	2.16E+02	3.27E+00
38	84	ng	2.83E+02	3.71E+00
38	84	ng_0	1.01E+02	2.64E+00
38	84	ng_1	1.82E+02	2.61E+00
39	89	ng	1.78E+01	2.62E-01
44	96	ng	1.86E+02	2.86E+00
45	103	ng	8.65E+02	1.18E+01
46	102	ng	3.60E+02	9.90E+00
48	110	ng	2.51E+02	3.17E+00
48	111	ng	7.99E+02	1.50E+01
48	112	ng	2.00E+02	2.69E+00
48	113	ng	7.05E+02	1.33E+01
48	114	ng	1.38E+02	2.01E+00
48	116	ng	7.98E+01	1.27E+00
50	114	ng	1.43E+02	2.21E+00
50	115	ng	3.76E+02	1.15E+01
50	116	ng	9.71E+01	1.30E+00
50	117	ng	3.37E+02	6.04E+00
50	118	ng	6.59E+01	9.08E-01

50	120	ng	3.88E+01	6.13E-01
51	121	ng	4.80E+02	5.26E+00
51	123	ng	2.87E+02	3.19E+00
52	120	ng	4.39E+02	8.12E+00
52	120	ng_0	3.74E+02	8.02E+00
52	120	ng_1	6.44E+01	1.23E+00
52	122	ng	3.29E+02	5.73E+00
52	123	ng	8.82E+02	3.50E+01
52	124	ng	1.63E+02	2.78E+00
52	125	ng	4.52E+02	1.87E+01
52	126	ng	8.64E+01	1.59E+00
52	128	ng	4.32E+01	6.23E-01
52	128	ng_0	3.84E+01	5.99E-01
52	128	ng_1	4.81E+00	1.68E-01
54	124	ng	5.76E+02	7.08E+01
54	126	ng	3.38E+02	4.75E+01
54	128	ng	2.78E+02	4.36E+00
54	129	ng	6.60E+02	1.40E+01
54	130	ng	1.41E+02	2.36E+00
54	132	ng	5.83E+01	2.66E+00
54	134	ng	2.06E+01	1.71E+00
54	136	ng	9.16E-01	7.74E-02
55	135	ng	1.53E+02	7.31E+00
56	130	ng	7.29E+02	1.17E+01
56	132	ng	3.82E+02	8.32E+00
56	132	ng_1	3.52E+01	1.16E+00
56	134	ng	1.86E+02	6.04E+00
56	135	ng	4.89E+02	1.54E+01
56	136	ng	6.74E+01	2.26E+00
56	137	ng	9.01E+01	3.36E+00
58	136	ng	3.21E+02	1.49E+01
58	136	ng_0	2.95E+02	1.49E+01
58	136	ng_1	2.61E+01	1.21E+00
58	138	ng	1.66E+02	2.88E+00
58	140	ng	1.05E+01	1.43E-01
58	142	ng	2.54E+01	3.54E-01
59	141	ng	1.18E+02	1.93E+00
60	142	ng	3.57E+01	6.60E-01
60	143	ng	2.58E+02	4.35E+00
60	144	ng	8.63E+01	1.56E+00
60	145	ng	4.51E+02	7.07E+00
60	146	ng	9.71E+01	1.46E+00
60	148	ng	1.53E+02	2.43E+00
60	150	ng	1.69E+02	6.68E+00
62	148	ng	1.05E+03	1.45E+01
62	149	ng	1.93E+03	2.93E+01

62	150	ng	4.47E+02	6.14E+00
62	151	ng	3.23E+03	7.61E+01
62	152	ng	4.96E+02	6.63E+00
62	154	ng	1.86E+02	2.90E+00
64	152	ng	1.10E+03	2.01E+01
64	154	ng	1.09E+03	1.67E+01
64	155	ng	2.81E+03	4.29E+01
64	156	ng	6.52E+02	8.67E+00
64	157	ng	1.45E+03	2.20E+01
64	158	ng	3.45E+02	4.78E+00
66	156	ng	1.54E+03	6.31E+01
66	160	ng	9.48E+02	1.68E+01
66	161	ng	2.09E+03	3.05E+01
66	162	ng	4.74E+02	6.61E+00
66	163	ng	1.18E+03	1.85E+01
66	164	ng	2.26E+02	3.99E+00
68	170	ng	1.46E+02	2.09E+00
70	168	ng	1.12E+03	1.08E+01
70	170	ng	8.16E+02	1.15E+01
70	171	ng	1.28E+03	1.83E+01
70	172	ng	3.64E+02	4.98E+00
70	173	ng	7.99E+02	1.17E+01
70	174	ng	1.60E+02	2.44E+00
70	176	ng	1.23E+02	2.48E+00
71	175	ng	1.30E+03	1.79E+01
71	176	ng	1.74E+03	2.46E+01
72	174	ng	9.41E+02	2.41E+01
72	176	ng	6.60E+02	1.31E+01
72	177	ng	1.65E+03	2.23E+01
72	178	ng	3.37E+02	4.46E+00
72	179	ng	9.85E+02	1.68E+01
72	180	ng	1.66E+02	2.48E+00
72	182	ng	1.37E+02	6.00E+00
73	180	ng	1.83E+03	1.18E+02
73	181	ng	8.18E+02	1.31E+01
74	180	ng	6.67E+02	4.40E+01
74	186	ng	1.77E+02	2.62E+00
75	187	ng	1.14E+03	3.10E+01
76	184	ng	5.61E+02	2.29E+01
76	190	ng	2.64E+02	5.95E+00
76	192	ng	1.51E+02	3.53E+00
77	191	ng	1.23E+03	3.44E+01
77	193	ng	8.99E+02	6.21E+01
78	190	ng	5.41E+02	2.20E+01
78	198	ng	8.43E+01	2.08E+00
79	197	ng	6.13E+02	6.03E+00

80	196	ng	1.95E+02	5.40E+00
80	196	ng_1	2.52E+01	8.48E-01

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