Nucleosynthesis in the Universe

An Introduction Kelsey Lund

Nuclear Astrophysics

Where do things come from?

How do processes on small (**nuclear**) scales affect large-scale systems in the Universe (**astro**)







Nuclear Astrophysics

- Atoms as a basic building block of matter: kind of

Nuclear Astrophysics

- Atoms as a basic building block of matter: kind of
- Consist of protons, neutrons, and electrons



- Organize atoms by proton number (Z)
- Useful for chemical properties
- "Protons give an atom its identity, electrons its personality"

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н											About Chemistry					He	
1.00794	2A											ЗA	4A	5A	6A	7A	4.002602
3	4											5	6	7	8	9	10
Li	Be											в	С	N	0	F	Ne
6.941	9.012182											10.811	12.0107	14.0067	15.9994	18.9984032	20.1797
11	12											13	14	15	16	17	18
Na	Mg											AI	Si	Р	S	CI	Ar
22.989769	24.3050	3B	4B	5B	6B	7B		— 8B —		1B	2B	26.9815386	28.0855	30.973762	32.065	35.453	39.948
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
к	Ca	Sc	Ti	v	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
39.0983	40.078	44.955912	47.867	50.9415	51.9961	54.938045	55.845	58.933195	58.6934	63.546	65.38	69.723	72.64	74.92160	78.96	79.904	83.798
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	Sr	Y	Zr	Nb	Мо	Тс	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Те	1	Хе
85.4678	87.62	88.90585	91.224	92.90638	95.96	[98]	101.07	102.90550	106.42	107.8682	112.411	114.818	118.710	121.760	127.60	126.90447	131.293
55	56	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	Ba		Hf	Та	w	Re	Os	lr 🛛	Pt	Au	Hg	ті	Pb	Bi	Po	At	Rn
132.9054519	137.327	Lanthanides	178.49	180.94788	183.84	186.207	190.23	192.217	195.084	196.966569	200.59	204.3833	207.2	208.98040	[209]	[210]	[222]
87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	FI	Uup	Lv	Uus	Uuo
[223]	[226]	Actinides	[267]	[268]	[271]	[272]	[270]	[276]	[281]	[280]	[285]	[284]	[289]	[288]	[293]	[294]	[294]
			57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
Lanthanides		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Но	Er	Tm	Yb	Lu	
			138.90547	140,116	140.90765	144.242	[145]	150.36	151.964	157.25	158.92535	162.500	164.93032	167.259	168.93421	173.054	174.9668
			89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Actinides			Ac	Th	Ра	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
			[227]	232.03806	231.03588	238.02891	[237]	[244]	[243]	[247]	[247]	[251]	[252]	[257]	[258]	[259]	[262]

- Organize atoms by proton number (Z)
- Useful for chemical properties
- "Protons give a nucleus its identity, neutrons its personality"

Ba 137.327 88 Ra [226]	Lanthanides 89-103 Actinides	Hf 178.49 104 Rf [267] 57 La 138.90547 89 Ac	Ta 180.94788 105 Db [268] 58 Ce 140.116 90 Th	W 183.84 106 Sg [271] 59 Pr 140.90765 91 Pa	Re 186 207 107 Bh [272] 60 Nd 144 242 92 11	0 0 190.23 108 HS [270] 61 Pm [145] 93 Nn	Ir 192.217 109 Mt [276] 62 Sm 150.36 94 Pu	Pt 195.084 110 Ds [281] 63 Eu 151.964 95 Am	Au 196.966569 111 Rg [280] 64 Gd 157.25 96 Cm	Hg 200.59 112 Cn [285] 65 Tb 158.92535 97 Bk	TI 204.3833 113 Uut [284] 66 Dy 162.500 98 Cf	Pb 207.2 114 Fl [289] 67 HO 184.93032 99 Fs	Bi 208.99040 115 Uup [288] 68 Er 167.259 100 Em	84 Po [209] 116 Lv [293] 69 Tm 168.93421 101 Md	85 At [210] 1117 Uus [294] 70 Yb 173.054 102 No	Rn [222] 118 Uuo [294] 71 Lu 174.9668 103 L r
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Ba		Hf	Та	w	Re	Os	Ir	Pt	Au	Hg	ті	Pb	Bi	Po	At	Rn
36				74	75	10							05	84	85	00
50	57-71	72	73	74	75	76	77	78	79	80	81	82	83		0.5	96
87.62	88.90585	91.224	92.90638	95.96	[98]	101.07	102.90550	106.42	107.8682	112.411	114.818	118.710	121.760	127.60	126.90447	131.293
Sr	Y	Zr	Nb	Мо	Тс	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Те	1	Xe
38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
40.078	44.955912	47.867	50.9415	51.9961	54.938045	55.845	58.933195	58.6934	63.546	65.38	69.723	72.64	74.92160	78.96	79.904	83.798
Ca	Sc	Ti	v	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
24.3050	3B	4B	5B	6B	7B		— 8B —		1B	2B	26.9815386	28.0855	30.973762	32.065	35.453	39.948
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12											13	14	15	16	17	18
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- "Protons give a nucleus its identity, neutrons its personality" -
- Chart of the nuclides organizes by proton number (Z) and neutron number (N)
- Contains everything we have ever measured



NUCLEOSYNTHESIS

The process of making new nuclei from existing nuclei and nucleons (protons, neutrons)



The first few minutes



Hundreds of millions of years later...



Stellar Nucleosynthesis: Proton-Proton Chain







Eventually, the Sun will run out of fuel



Radiation pressure

Gravity





Massive Stars: Core-Collapse



Gravity







Explosive Nucleosynthesis!



7



An even longer time later....

Neutron Star Mergers



Neutron Star Mergers





Big Picture



Thank you!

kalund@ncsu.edu

Stellar Nucleosynthesis: CNO Cycle



Occurs in larger stars (>1.3 M_{\odot}), where higher temperatures are possible

Stellar Nucleosynthesis: Triple-α Process



Needs very high temperatures!