

Nuclear Astrophysics: From The Beginning of Time to the End of the Universe



Nuclear Physics, the Core of Matter, the Fuel of Stars (Schiffer Fest)

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Chemists like to say,
“Chemistry makes the world run, from energy
and materials to life here and beyond”

**However, without Nuclear Physics there
would only be Hydrogen and not much
chemistry. And nuclear energy is million
times as powerful as chemical energy!**

Nuclear Astrophysics: The Interesting Journey from Quarks to the Periodic Table



A periodic table of elements enclosed in a red rounded rectangle. The elements are color-coded by groups: Group 1 (red), Group 2 (pink), Groups 13-18 (green, orange, yellow), Groups 3-10 (blue), Groups 11-12 (light blue), and Groups 13-18 (light green, light orange, light yellow). The lanthanide and actinide series are shown as separate rows at the bottom.

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt									
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

ORDINARY MATTER: FROM QUARKS TO US

INFLATION
BARYOGENESIS



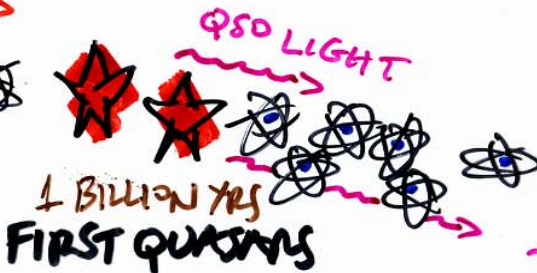
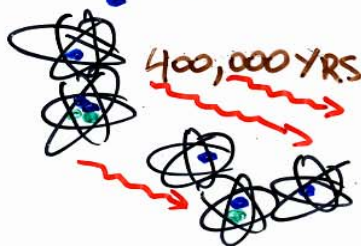
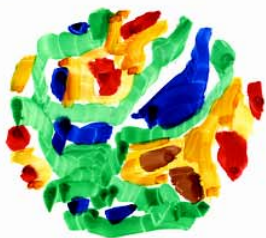
TRANSITION FROM
QUARKS \rightarrow NEUTRONS, PROTONS



BBN
 $D/H = (3 \pm 0.2) \times 10^{-5}$
 $\Omega_B = 0.04 \pm 0.002$

BIG-BANG
NUCLEOSYNTHESIS
Formation of H, D,
He, He-3, Li

FORMATION OF ATOMS
COSMIC MICROWAVE
BACKGROUND



(Ω_B / ρ) TODAY
 $\Omega_B / \Omega_M = 0.15 \pm 0.01$
 $\Omega_{bh} = 0.20 \pm 0.01$
 $\Omega_B = 0.04 \pm 0.002$
CMB

CMB

RATIO OF FIRST-TO-
SECOND PEAKS: 2/1

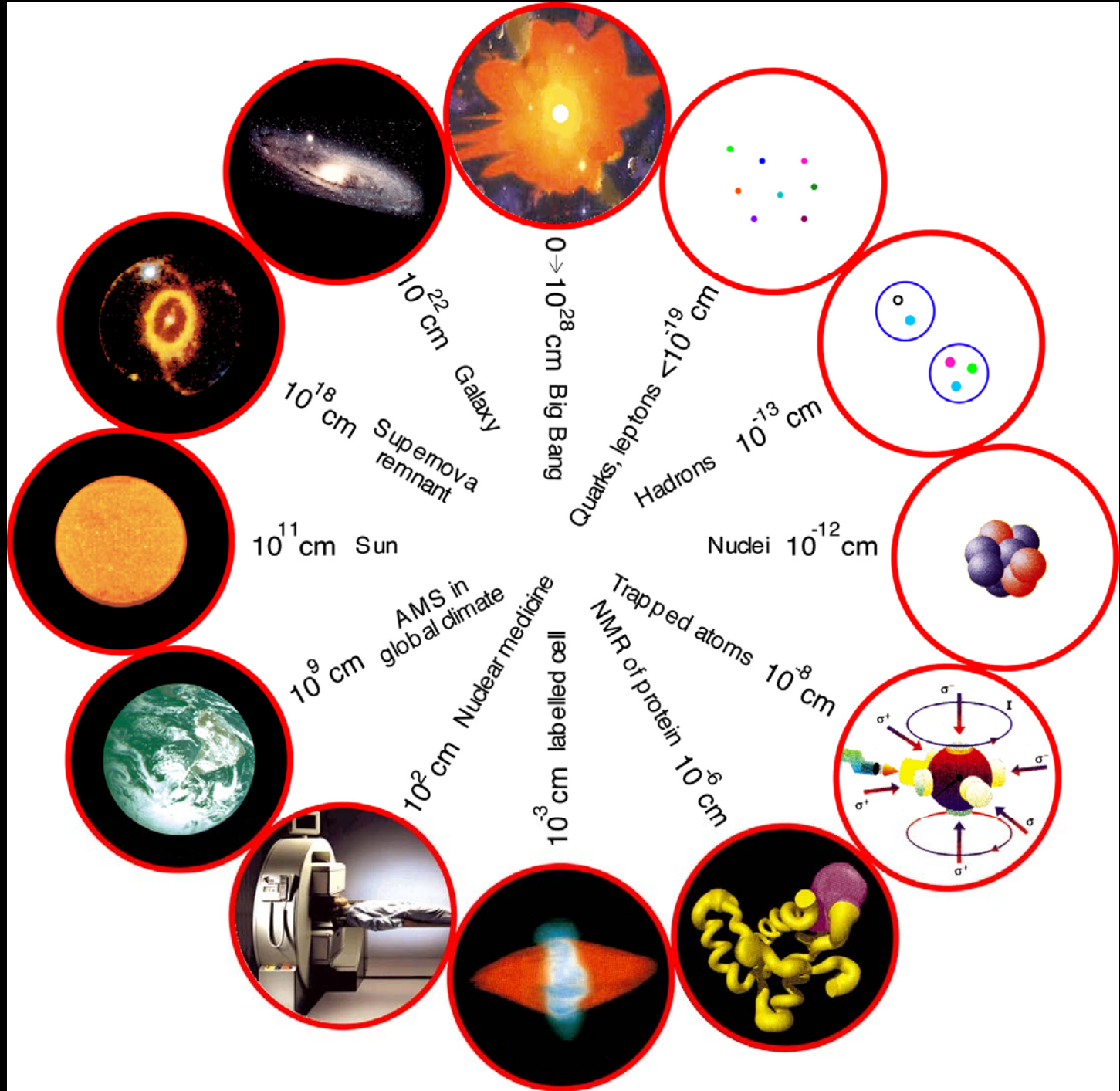
$\Omega_B = 0.045 \pm 0.006$

INTERGALACTIC GAS

ABSORPTION OF
QUASAR LIGHT
BY HYDROGEN

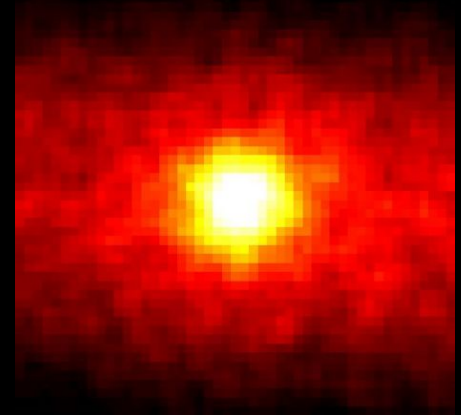
$\Omega_B \geq 0.04$

HERE & NOW
14 Billion YRS
stars, gas,
dust, ...
BAM, NISZ,
people ...



Successes

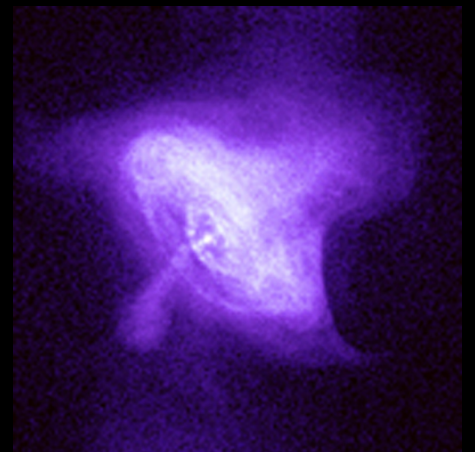
- Origin of the Periodic Table
 - Big bang; cosmic rays; main-sequence stars; novae and supernovae
- Standard Solar Model
 - Fusion power plant tested to better than 1%
- Macroscopic nuclear matter
 - Neutron stars, pulsars, highest T_c superconductor
- Nuclear power plants (stars) and explosions
- Big Bang Nucleosynthesis
 - Nuclear physics in an old, quenched reactor
- Neutrinos!: SN87a, solar, atmospheric, reactors
- Quark/Gluon Plasma on the lattice and in the lab(?)

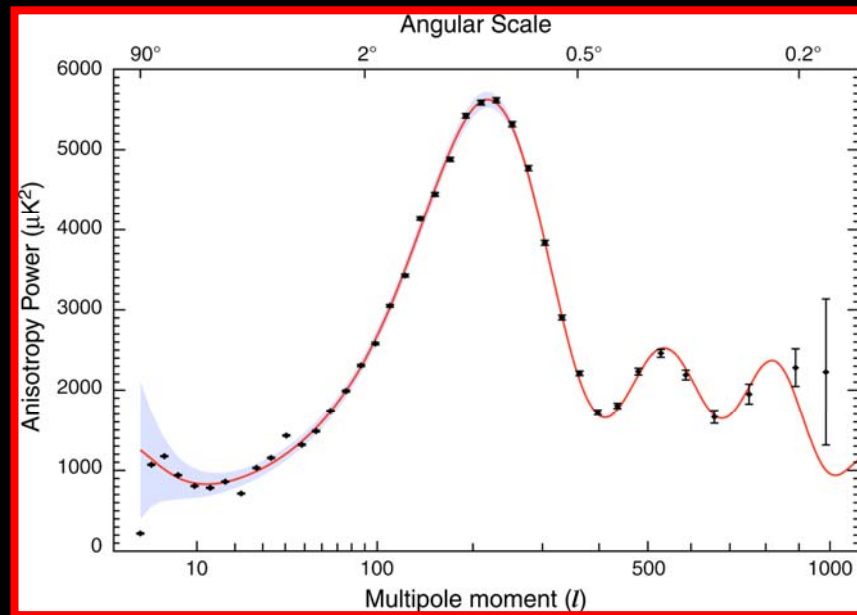
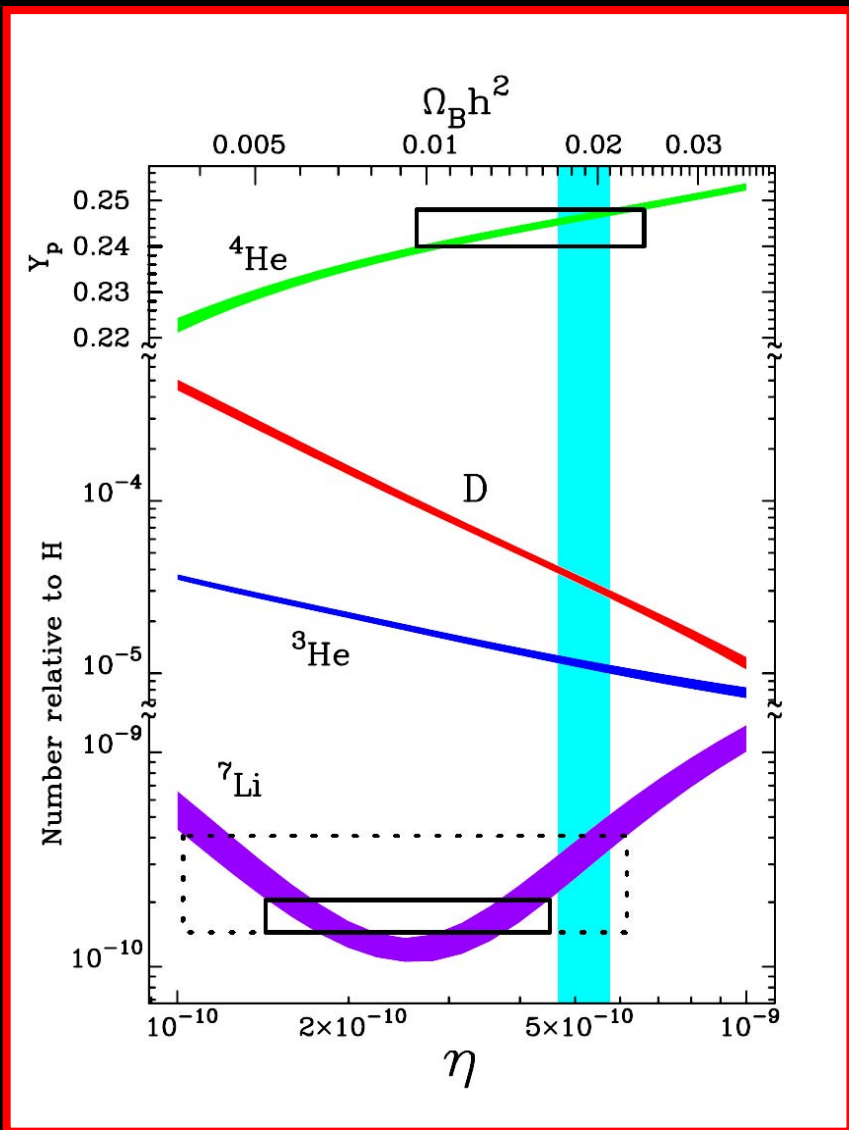


Supernova 1987A Rings



Hubble Space Telescope
Wide Field Planetary Camera 2





CMB (first to second peak)

$$\Omega_b h^2 = 0.022 \pm 0.001$$

BBN (Deuterium)

$$\Omega_b h^2 = 0.020 \pm 0.001$$

$\Omega_b = 4\% \text{ to } 5\%!$

TWO COSMIC ACTING

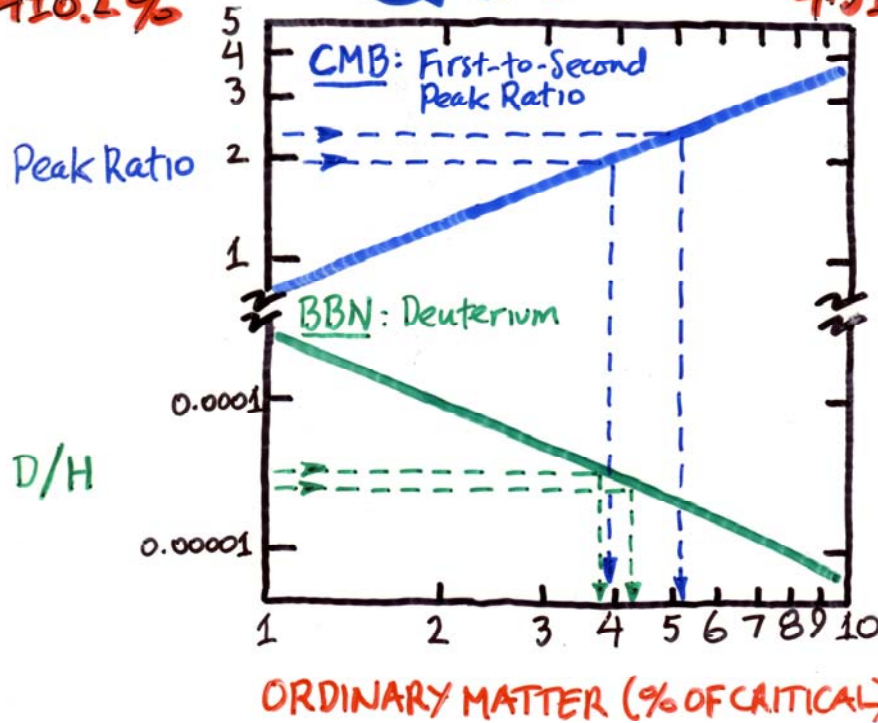
NUCLEAR PHYSICS
@ 1 SEC

GRAVITY
@ 400,000 YRS

AGREE

$4 \pm 0.2\%$

$4.5 \pm 0.6\%$

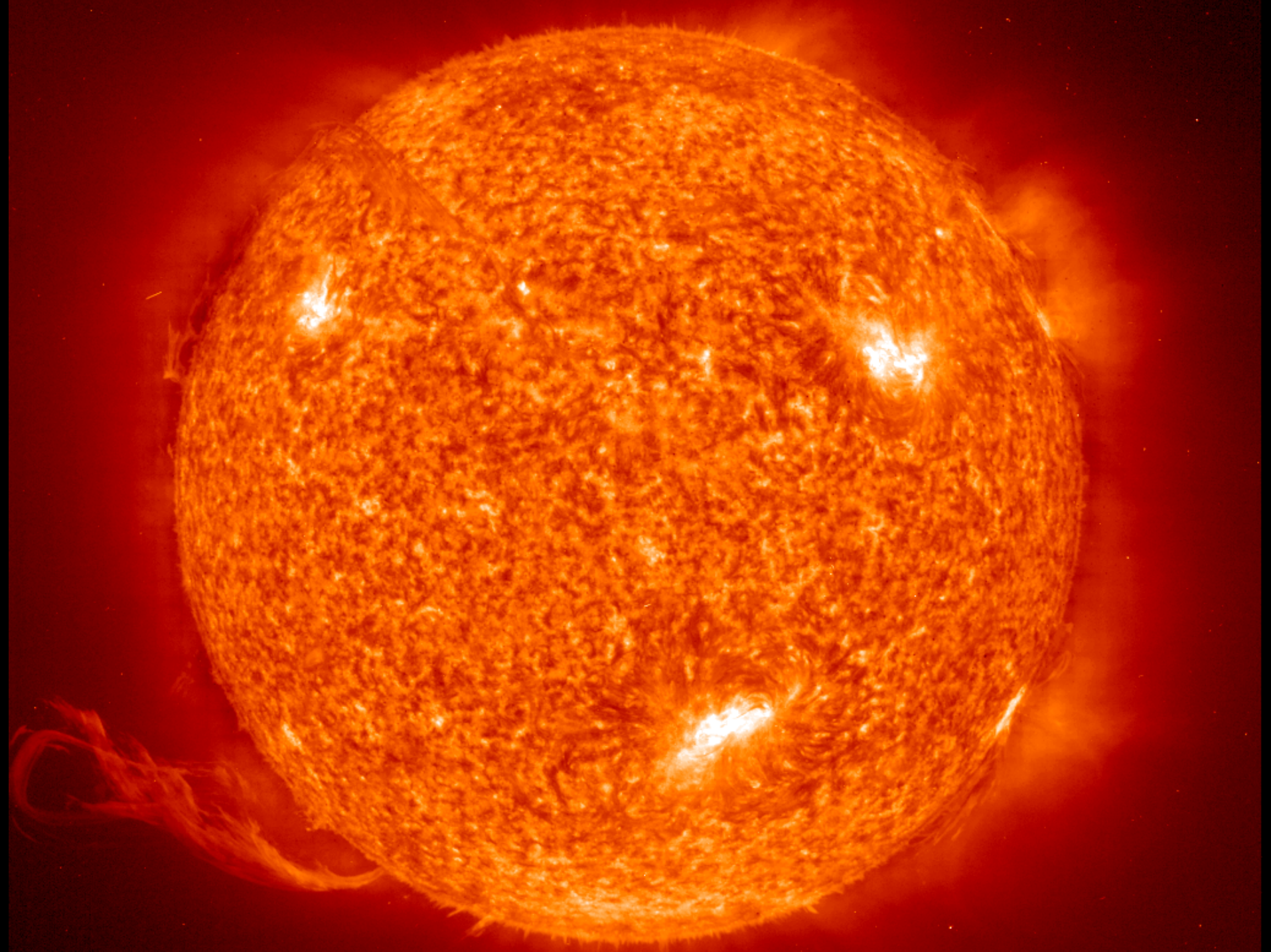


$H_0 = 70.7 \text{ km s}^{-1} \text{ Mpc}^{-1}$

ORDINARY MATTER
ACCTS FOR $\frac{1}{8}$ th DARK MATTER

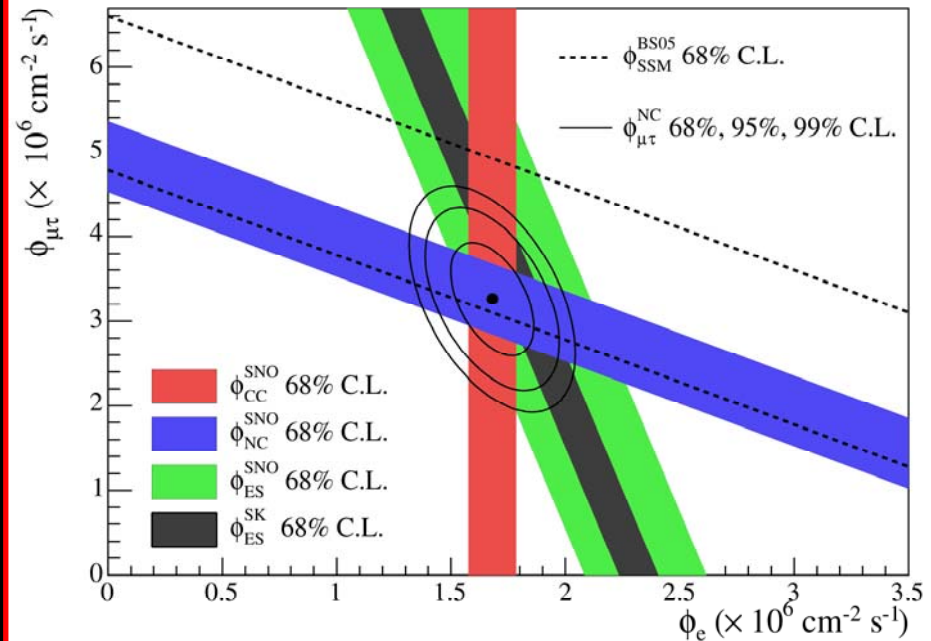
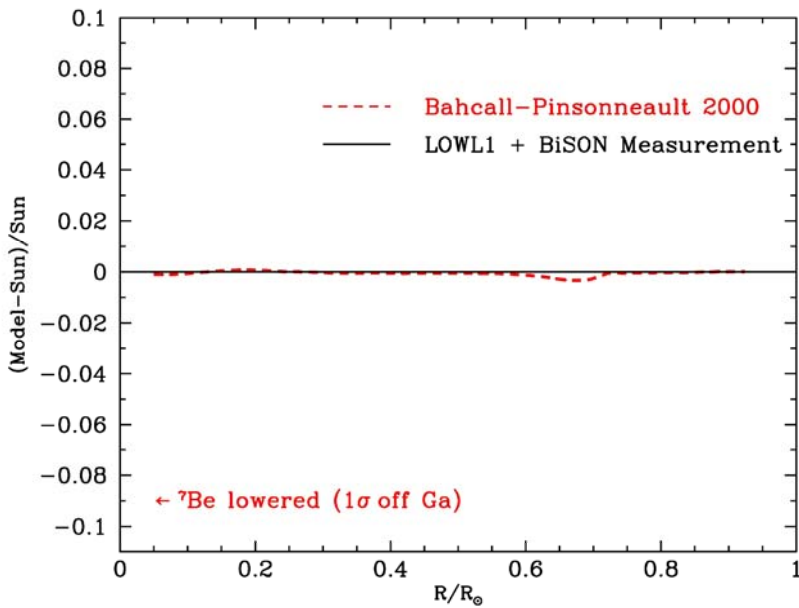
Consistency!

- Earliest test of big-bang cosmology
- Stringent test of constancy of laws of physics (gravity, nuclear, and otherwise)
- Probe of fundamental physics ($N_\nu < 3.2$)
- Probe of cosmology: $\Omega_B = 4\%$ to 5%



REACTION	TERM. (%)	ν ENERGY (MeV)
$p + p \rightarrow {}^2\text{H} + e^+ + \nu_e$	(99.96)	≤ 0.423
or		
$p + e^- + p \rightarrow {}^2\text{H} + \nu_e$	(0.44)	1.445
${}^2\text{H} + p \rightarrow {}^3\text{He} + \gamma$	(100)	
${}^3\text{He} + {}^3\text{He} \rightarrow \alpha + 2p$	(85)	
or		
${}^3\text{He} + {}^4\text{He} \rightarrow {}^7\text{Be} + \gamma$	(15)	
${}^7\text{Be} + e^- \rightarrow {}^7\text{Li} + \nu_e$	(15)	$\left\{ \begin{array}{l} 0.863 \text{ } 90\% \\ 0.385 \text{ } 10\% \end{array} \right.$
${}^7\text{Li} + p \rightarrow 2\alpha$		
or		
${}^7\text{Be} + p \rightarrow {}^8\text{B} + \gamma$	(0.02)	
${}^8\text{B} \rightarrow {}^8\text{Be}^* + e^+ + \nu_e$		< 15
${}^8\text{Be}^* \rightarrow 2\alpha$		
or		
${}^3\text{He} + p \rightarrow {}^4\text{He} + e^+ + \nu_e$	(0.00003)	< 18.8

Gravitational Confined Fusion Reactor

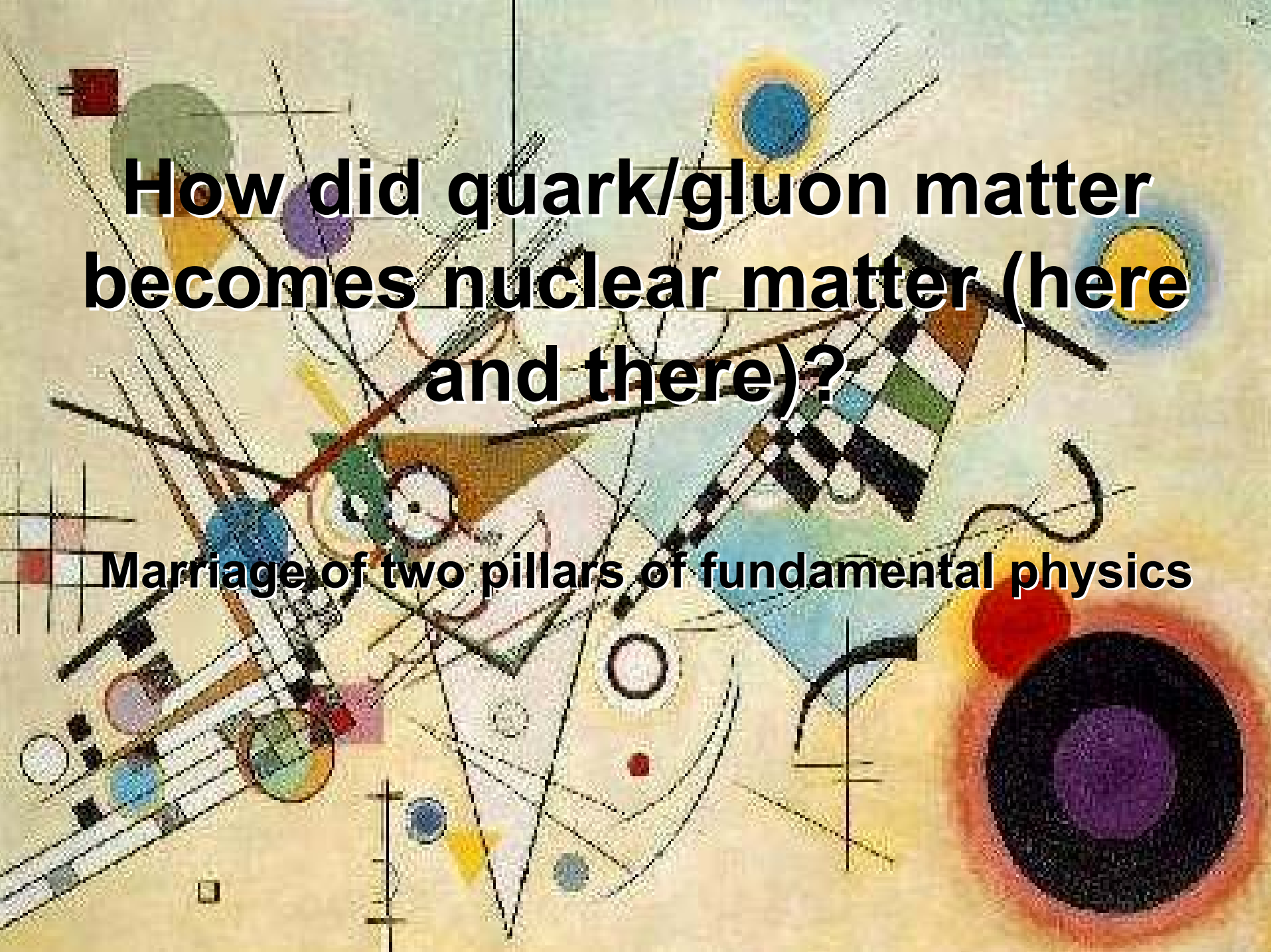


Standard Solar Model vs. Helioseismology

Standard Solar Model vs. Neutrinos

The Very Bright and Exciting Nuclear Frontier: Quarks to the Cosmos

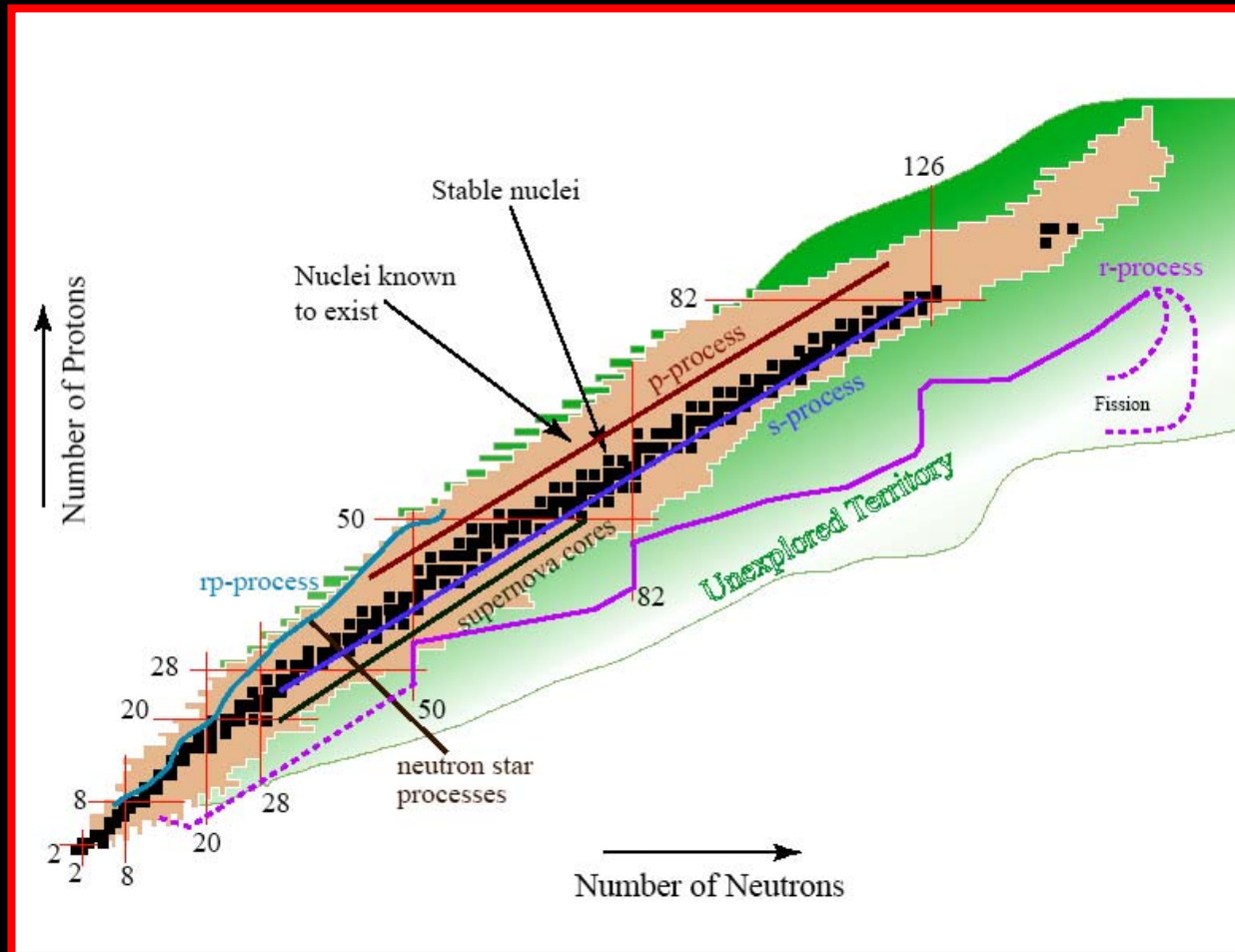
Bright enough to
continue to attract the
next generation of
John Schiffers



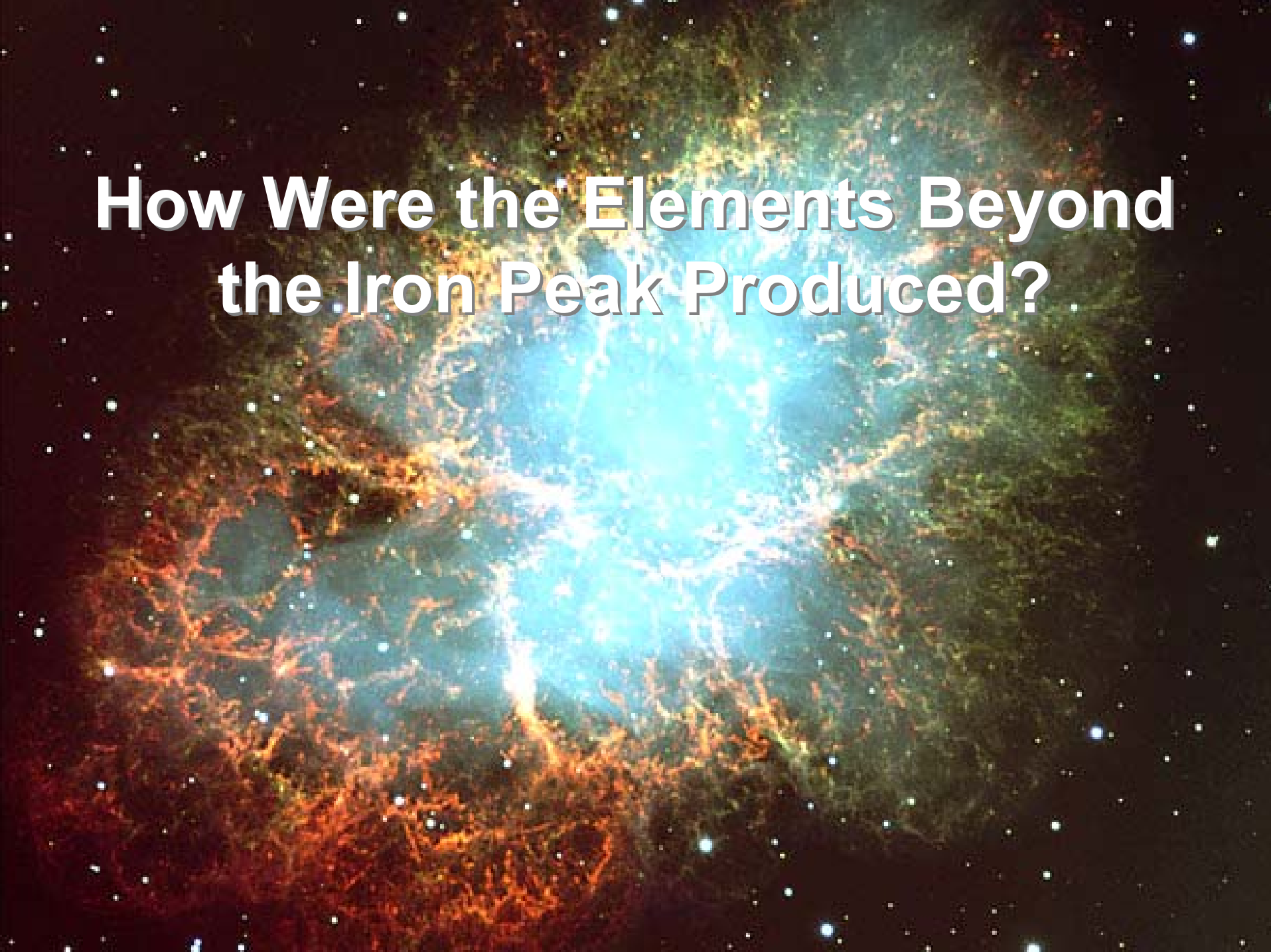
**How did quark/gluon matter
becomes nuclear matter (here
and there)?**

Marriage of two pillars of fundamental physics

What is the Complete Periodic Table of Elements and Nuclides?

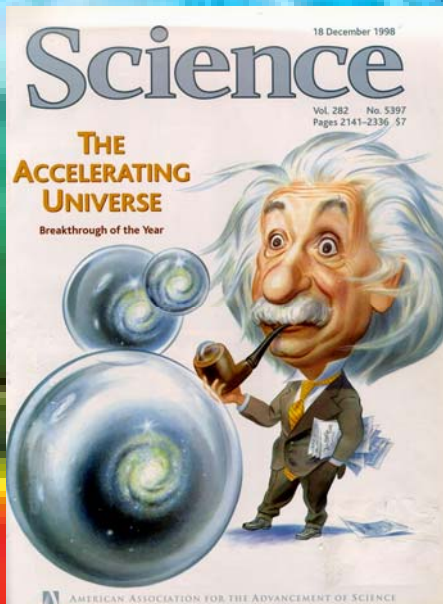


How Were the Elements Beyond the Iron Peak Produced?



How Do Massive Stars Explode?

Both thermonuclear and gravitational explosions

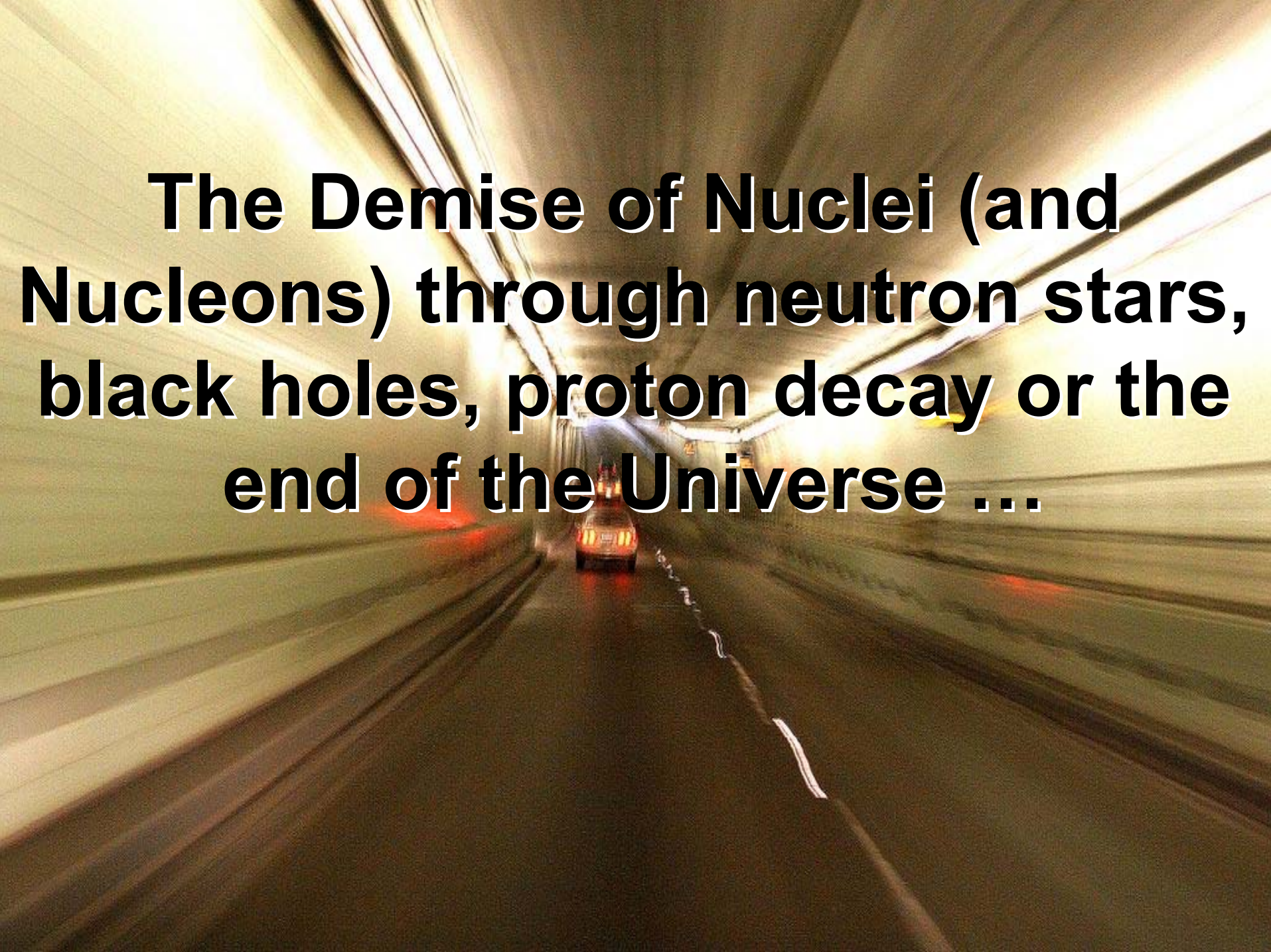


How Do Neutrinos Shape the Universe?

Origin of baryons, large-scale structure, stellar explosions, stellar nucleosynthesis, ...



**Measuring Critical Nuclear
Properties for Applied Science,
Astrophysics and National
Security**



The Demise of Nuclei (and Nucleons) through neutron stars, black holes, proton decay or the end of the Universe ...