Introduction of OMEG Institute
- 천체와 우주의 진화에서 보는 원소 및 우주물질의 기원 -

Myung-Ki Cheoun
(**Soongsil University**, **OMEG Institute**, Seoul, Korea)

한국 고에너지물리 학회 (KSHEP) 가을 학회 2022 11/17-11/19, Busan

Since 2021

우주물질연구소

OMEG institute

원소 및 물질의 기원 연구

Fermi

희귀동위원소에 대한 이론 모형 연구

- 핵자 사이의 핵력 (BCS 이론 등)
- 핵구조 및 열핵반응
- 핵구조 및 열핵반응 이론 연구로 확장
- 고밀도 핵물질

항성 및 은하의 진화 연구

Hubble

중성미자의 역할 연구

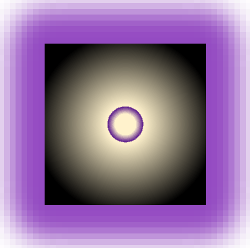
- 입자 및 강입자 이론 연구 기반
- 초기우주 시뮬레이션
- 자기유체역학
- 마그네타 하전 입자의 양자화 가능성

우주를 구성하는 원소와 물질의 기원에 대한 종합적 이해

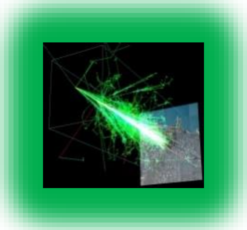
Preliminary

Periodic Table and Origins of Elements

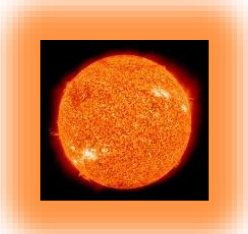
Periodic Table



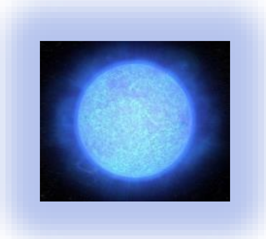
Bing Bang



Cosmic Rays



Dying Small Stars

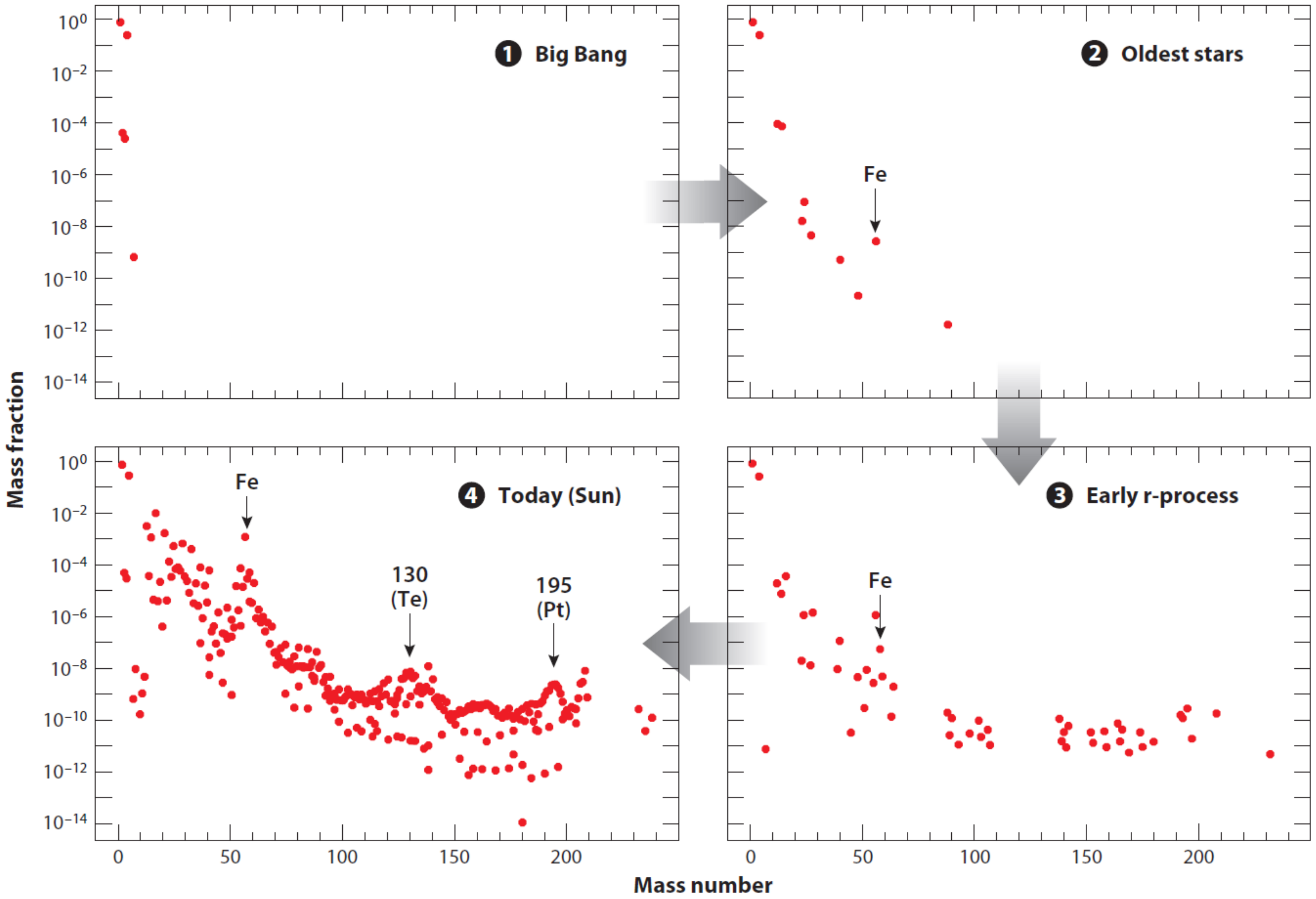


Exploding Massive Stars

Supernova & NS merge

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Preliminary Evolution of Element Abundances in the Universe Evolution

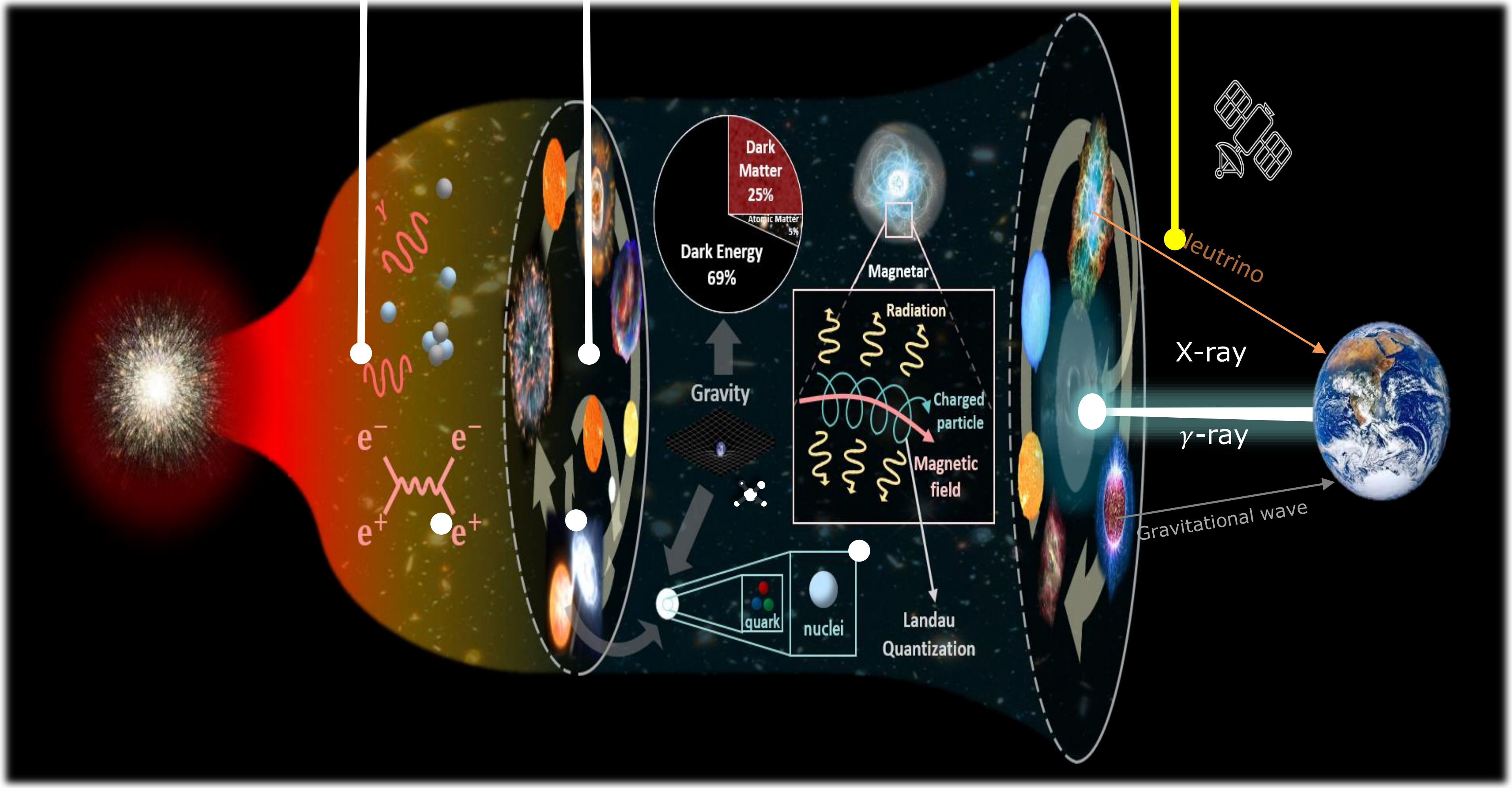


M. Wiescher et al., Annu. Rev. Astro. Astrophys. (2012)

Preliminary Cosmological Sources of elements in the Universe Evolution

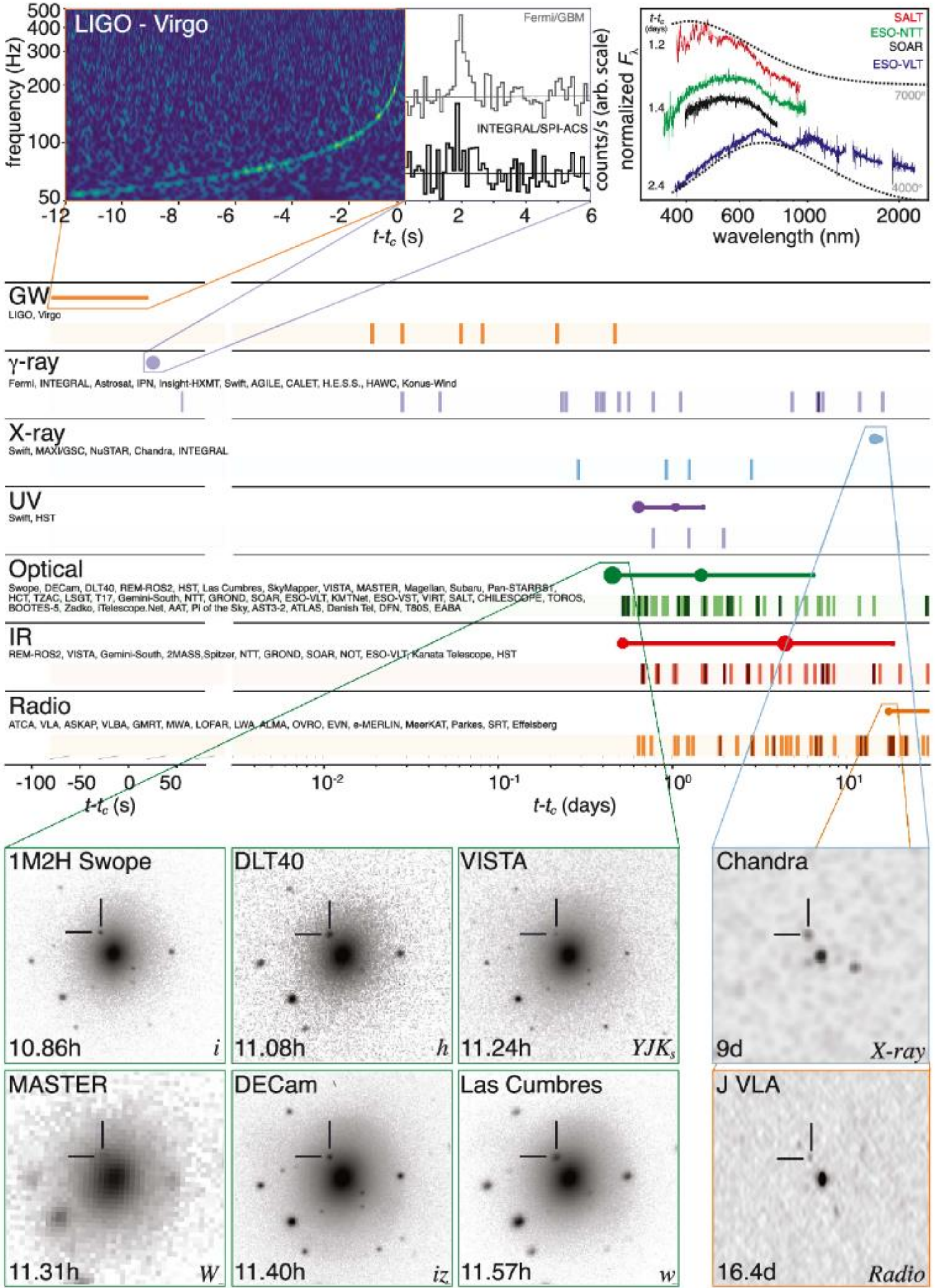
FAUST (Femtoscale Astrophysics for the Universe STudy)

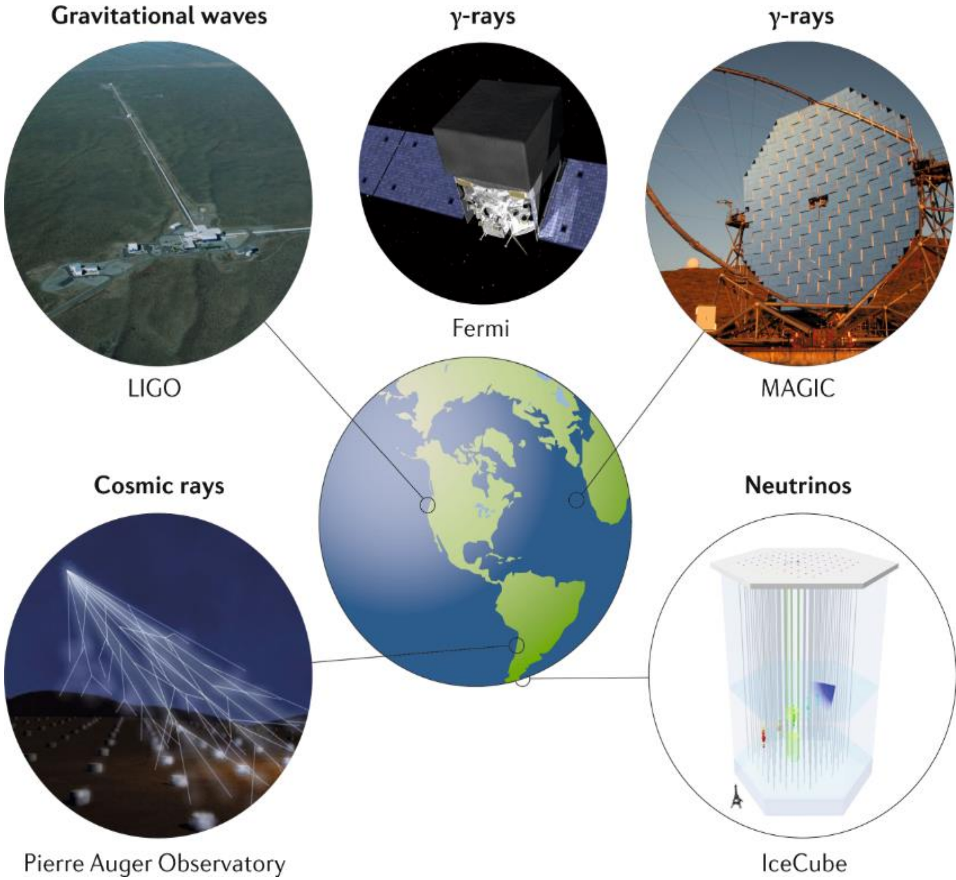
Early Universe & Big Bang | **Stellar and Galaxy Evolution** | **Multi-messenger Astrophysics**



Primordial Nucleosynthesis | **Nucleosynthesis in the Stellar evolution** | **Galaxy Chemical Evolution & Exotica Matter**

Preliminary Multi-messenger Astrophysics



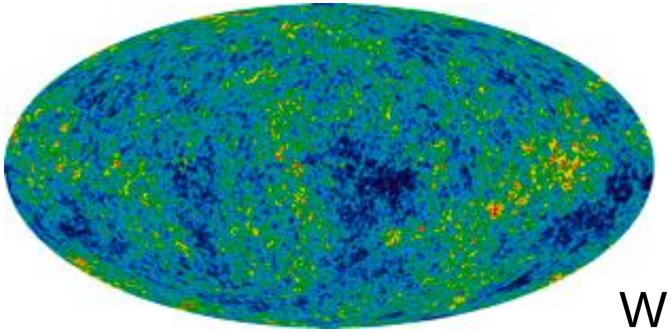


:e, Nov. 16-18,

Big Bang Nucleosynthesis Primordial abundances in BBN

Primordial abundances in BBN

- Standard big bang nucleosynthesis (SBBN)
  parameter: baryon-to-photon ratio η
- Observation of CMB →constraint on η



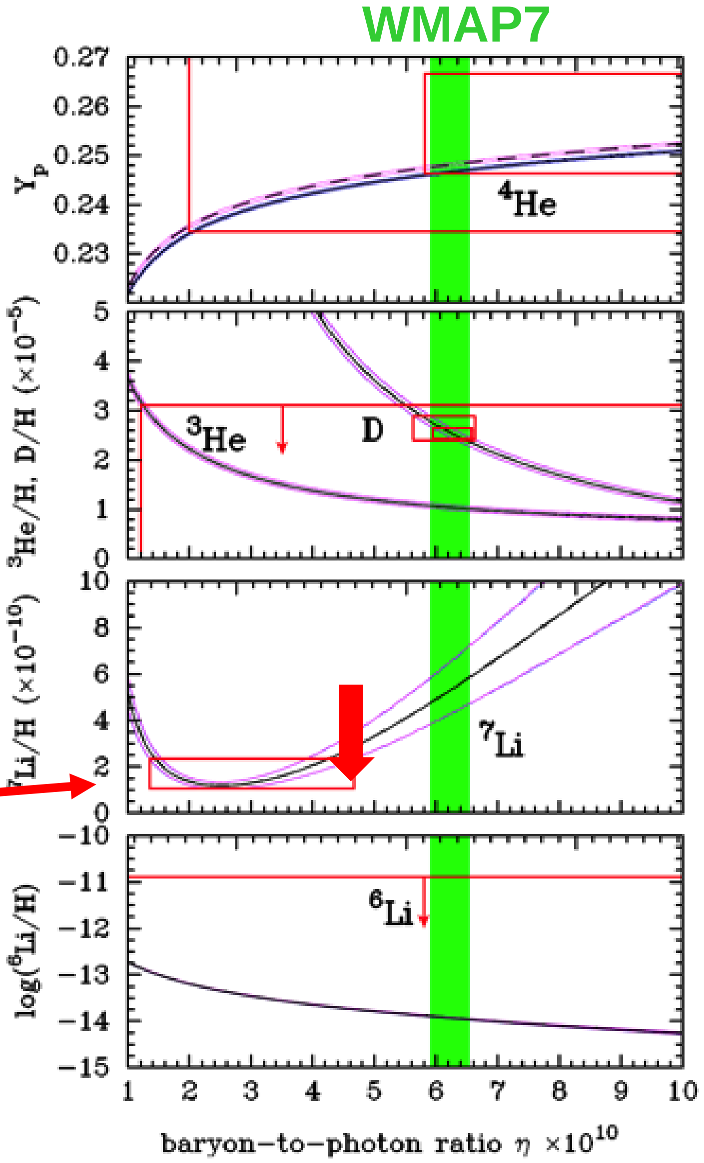
WMAP Science Team

- Observation of metal-poor stars (MPSs)
  - ✓^{7}Li abundance is smaller than theory by a factor of ~**3**

Signature of new physics?

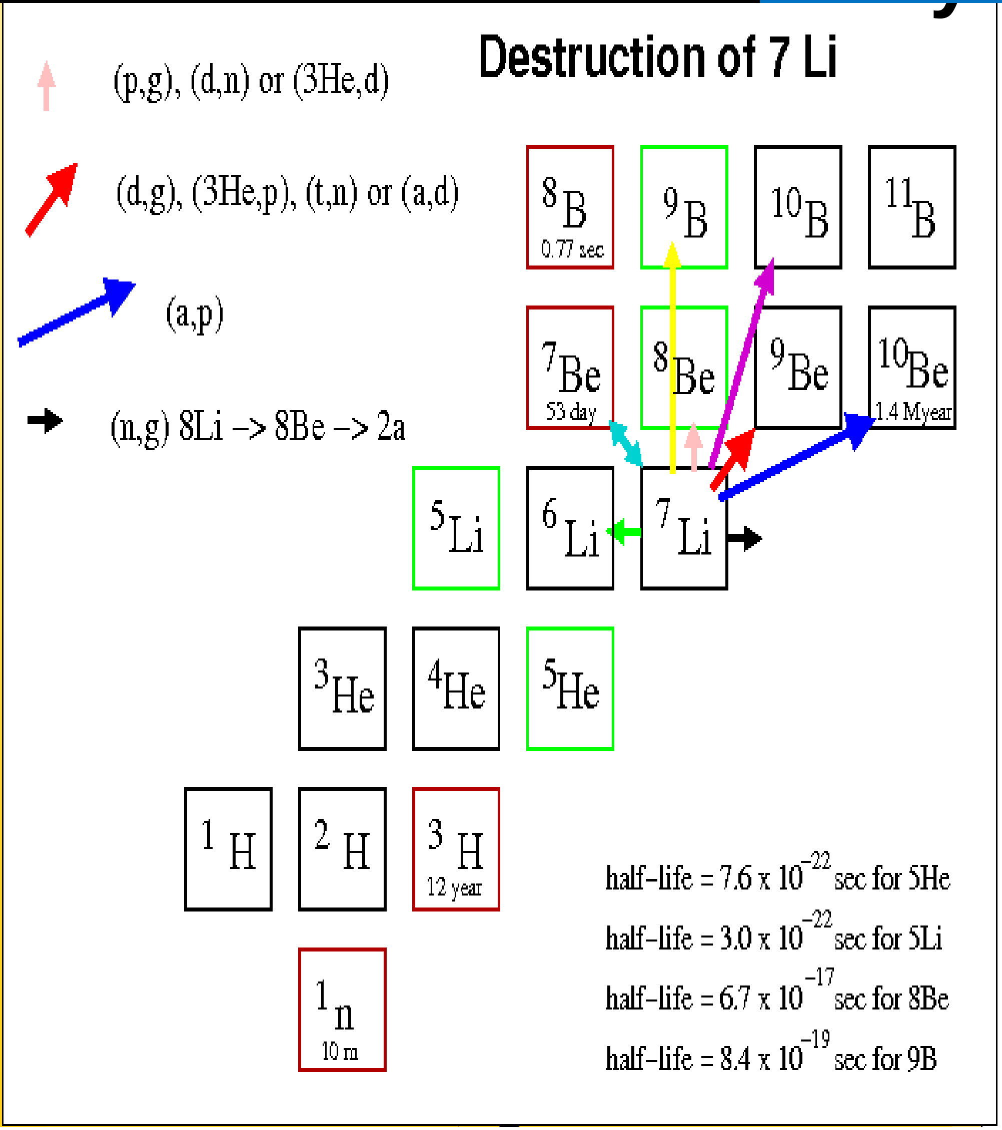
Goals

- Find the solution of the ^{7}Li problem,
  & identify the processes in the early universe
- Derive constraints on particle models and modified GR ??



Kawasaki & MK, PRD 86, 063003 (2012)

Big Bang Nucleosynthesis Main Nuclear Reactions for BBN



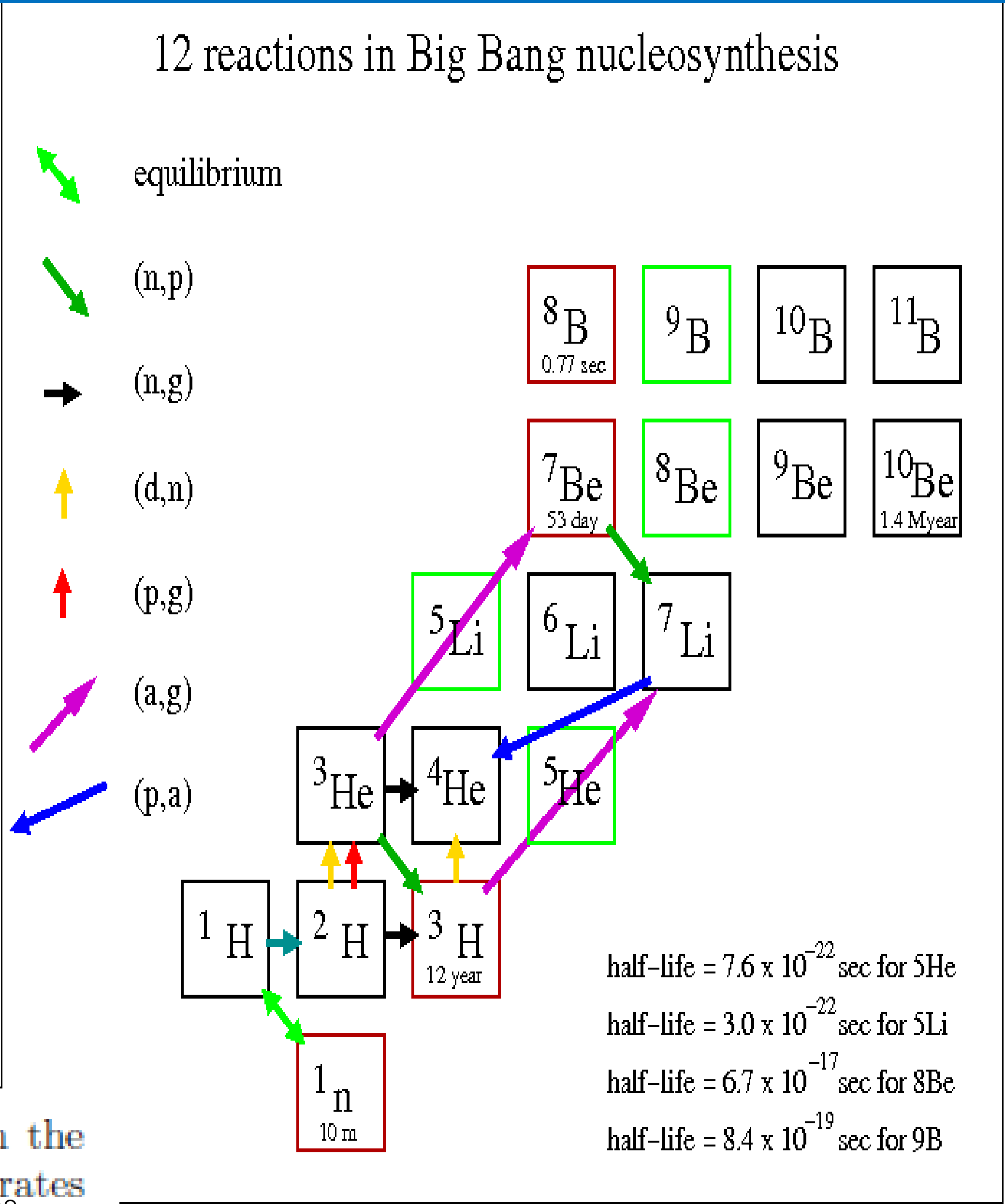
Destruction of 7 Li

half-life = 7.6×10^{-22} sec for 5He

half-life = 3.0×10^{-22} sec for 5Li

half-life = 6.7×10^{-17} sec for 8Be

half-life = 8.4×10^{-19} sec for 9B



12 reactions in Big Bang nucleosynthesis

half-life = 7.6×10^{-22} sec for 5He

half-life = 3.0×10^{-22} sec for 5Li

half-life = 6.7×10^{-17} sec for 8Be

half-life = 8.4×10^{-19} sec for 9B

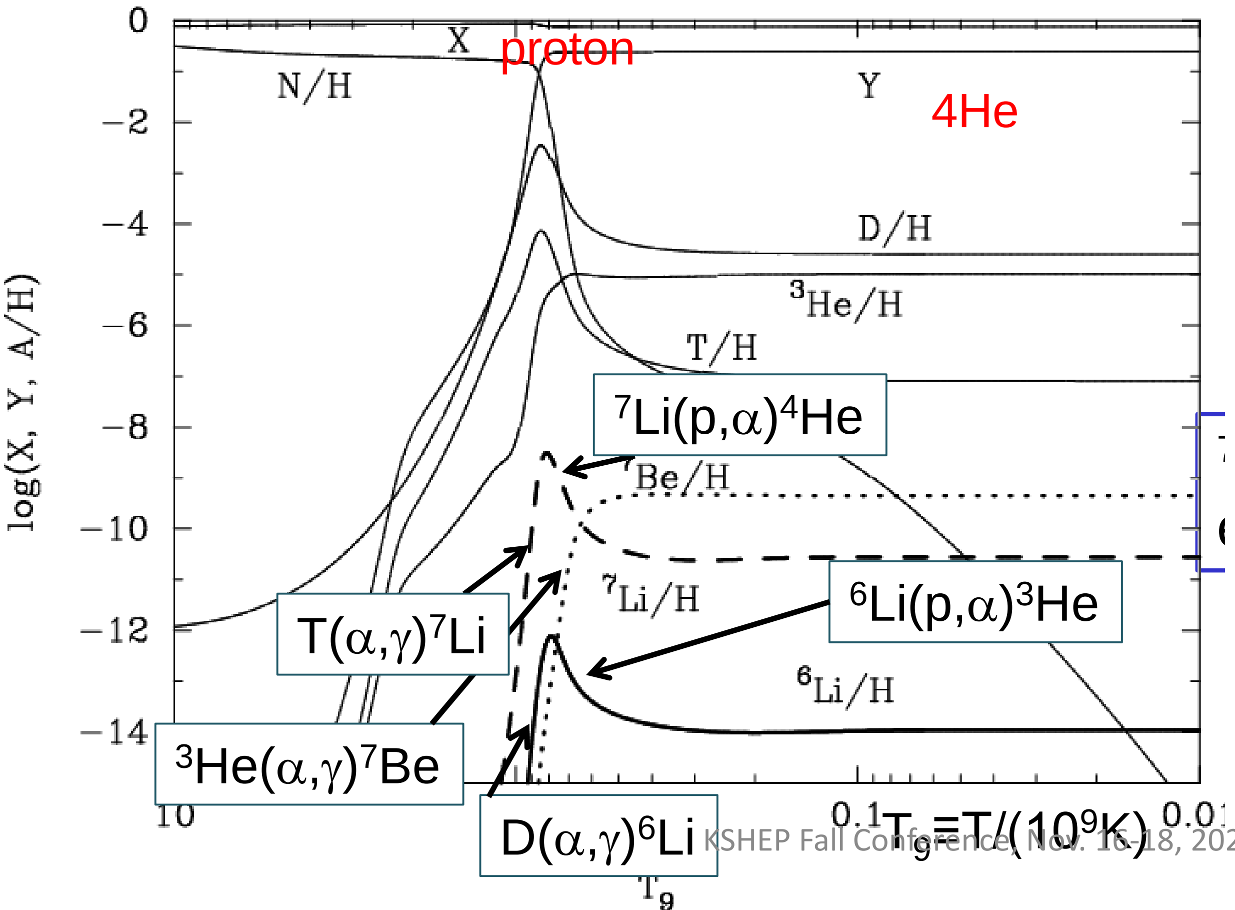
We use the BBN code by Kawano [86, 87] with the Sarkar's correction [88] to ^{4}He abundance. Reaction rates relating to light nuclei of mass number $A \le 10$ are updated with the JINA REACLIB Database V1.0 [89]. We adopt the neutron lifetime of $878.5 \pm 0.7_{\rm stat} \pm 0.3_{\rm sys}$ s [90].

[89] R. H. Cyburt, A. M. Amthor, R. Ferguson, Z. Meisel, K. Smith, S. Warren, A. Heger, R. D. Hoffman, T. Rauscher, A. Sakharuk, et al., Astrophys. J. Suppl. **189**, 240 (2010).

Big Bang Nucleosynthesis Standard BBN

- ➢n↔p equilibrium $(n/p)_{EQ}=\exp(-Q/T)$ $Q\equiv m_n-m_p=1.293\mathrm{MeV}$
- ➢t~1sec,$T=T_F\sim1\mathrm{MeV}$(weak interaction fi
  - ✓$\nu\nu \cancel{\longleftrightarrow} e^+e^- \longleftrightarrow \gamma\gamma$
  - ✓$n \cancel{\longleftrightarrow} p$
  - ✓$e^\pm \longrightarrow \gamma\gamma$ $(T\sim m_e/3)$

$$(n/p)_{\text{freeze-out}}=\exp(-Q/T_F)\sim1/6$$



^{7}Li(p,α)^{4}He

T(α,γ)^{7}Li

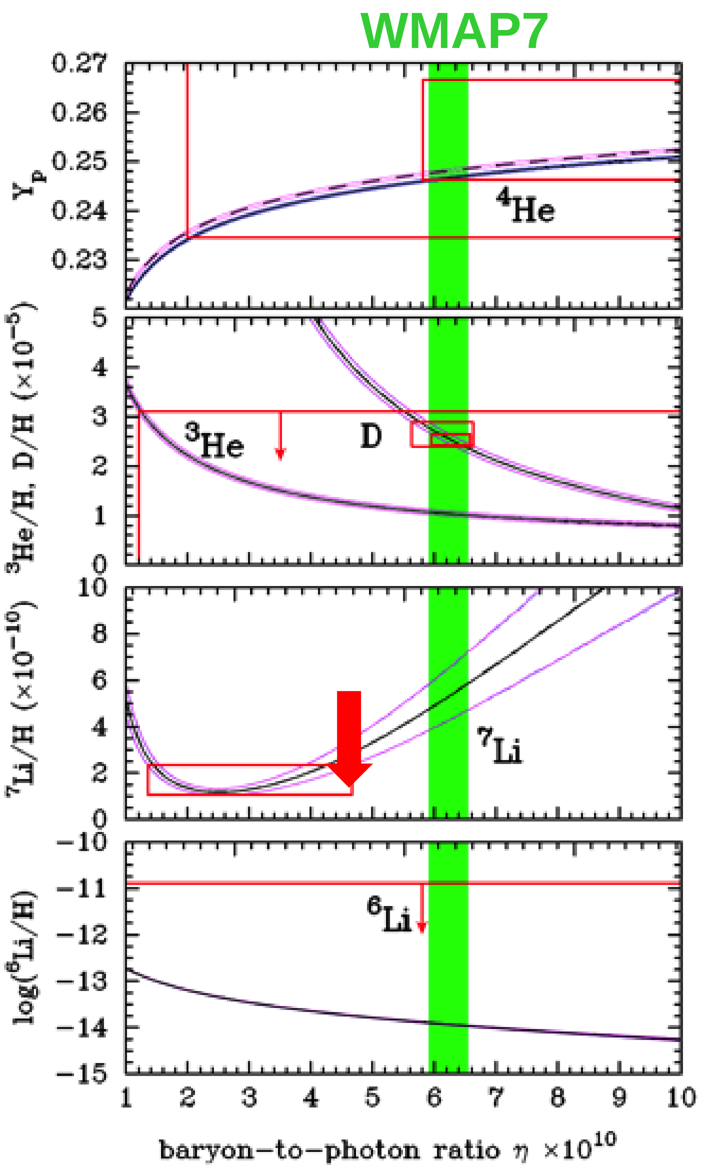
^{6}Li(p,α)^{3}He

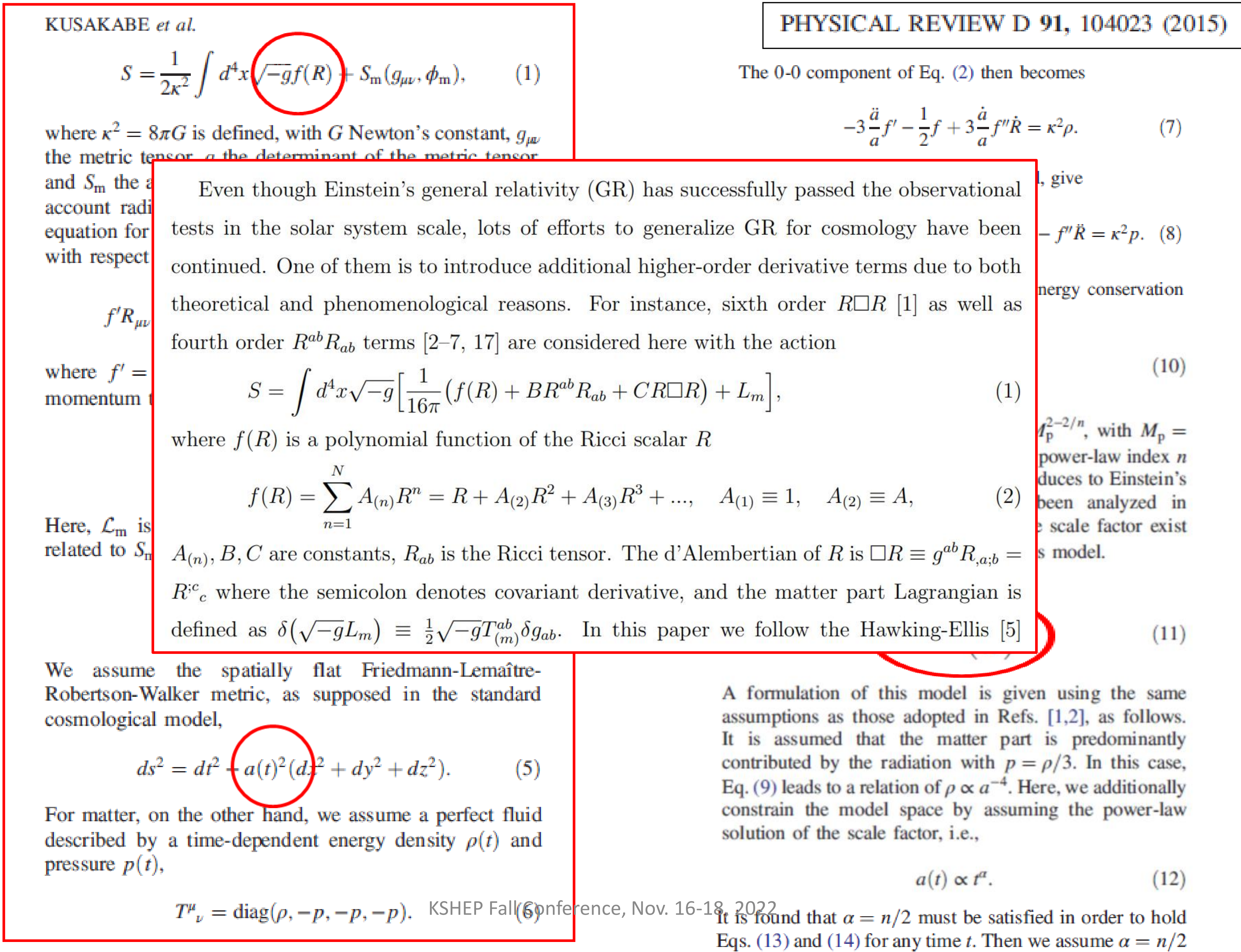
^{3}He(α,γ)^{7}Be

D(α,γ)^{6}Li

$T_9=T/(10^9\mathrm{K})$

WMAP7





KUSAKABE *et al.*

$$S=\frac{1}{2\kappa^2}\int d^4x\sqrt{-g}f(R)+S_\mathrm{m}(g_{\mu\nu},\phi_\mathrm{m}), \qquad (1)$$

where $\kappa^2 = 8\pi G$ is defined, with G Newton's constant, $g_{\mu\nu}$ the metric tensor, g the determinant of the metric tensor and S_m the

account radi

equation for

with respect

$f'R_{\mu\nu}$

where $f' =$

momentum t

Here, $\mathcal{L}_\mathrm{m}$ is

related to S_m

We assume the spatially flat Friedmann-Lemaître-Robertson-Walker metric, as supposed in the standard cosmological model,

$$ds^2 = dt^2 - a(t)^2(dx^2+dy^2+dz^2). \qquad (5)$$

For matter, on the other hand, we assume a perfect fluid described by a time-dependent energy density $\rho(t)$ and pressure $p(t)$,

$$T^\mu{}_\nu = \mathrm{diag}(\rho,-p,-p,-p). \qquad (6)$$

PHYSICAL REVIEW D **91,** 104023 (2015)

The 0-0 component of Eq. (2) then becomes

$$-3\frac{\ddot a}{a}f' - \frac{1}{2}f + 3\frac{\dot a}{a}f''\dot R = \kappa^2\rho. \qquad (7)$$

, give

$$- f''\ddot R = \kappa^2 p. \qquad (8)$$

nergy conservation

(10)

$M_\mathrm{p}^{2-2/n}$, with $M_\mathrm{p} =$

power-law index n

duces to Einstein's

been analyzed in

scale factor exist

s model.

(11)

A formulation of this model is given using the same assumptions as those adopted in Refs. [1,2], as follows. It is assumed that the matter part is predominantly contributed by the radiation with $p = \rho/3$. In this case, Eq. (9) leads to a relation of $\rho \propto a^{-4}$. Here, we additionally constrain the model space by assuming the power-law solution of the scale factor, i.e.,

$$a(t) \propto t^\alpha. \qquad (12)$$

It is found that $\alpha = n/2$ must be satisfied in order to hold Eqs. (13) and (14) for any time t. Then we assume $\alpha = n/2$

Even though Einstein's general relativity (GR) has successfully passed the observational tests in the solar system scale, lots of efforts to generalize GR for cosmology have been continued. One of them is to introduce additional higher-order derivative terms due to both theoretical and phenomenological reasons. For instance, sixth order $R\Box R$ [1] as well as fourth order $R^{ab}R_{ab}$ terms [2–7, 17] are considered here with the action

$$S=\int d^4x\sqrt{-g}\left[\frac{1}{16\pi}\left(f(R)+BR^{ab}R_{ab}+CR\Box R\right)+L_m\right], \qquad (1)$$

where $f(R)$ is a polynomial function of the Ricci scalar R

$$f(R)=\sum_{n=1}^{N}A_{(n)}R^n = R + A_{(2)}R^2 + A_{(3)}R^3 + \ldots, \quad A_{(1)}\equiv 1, \quad A_{(2)}\equiv A, \qquad (2)$$

$A_{(n)}, B, C$ are constants, R_{ab} is the Ricci tensor. The d'Alembertian of R is $\Box R \equiv g^{ab}R_{,a;b} = R^{;c}{}_{c}$ where the semicolon denotes covariant derivative, and the matter part Lagrangian is defined as $\delta(\sqrt{-g}L_m) \equiv \frac{1}{2}\sqrt{-g}T^{ab}_{(m)}\delta g_{ab}$. In this paper we follow the Hawking-Ellis [5]

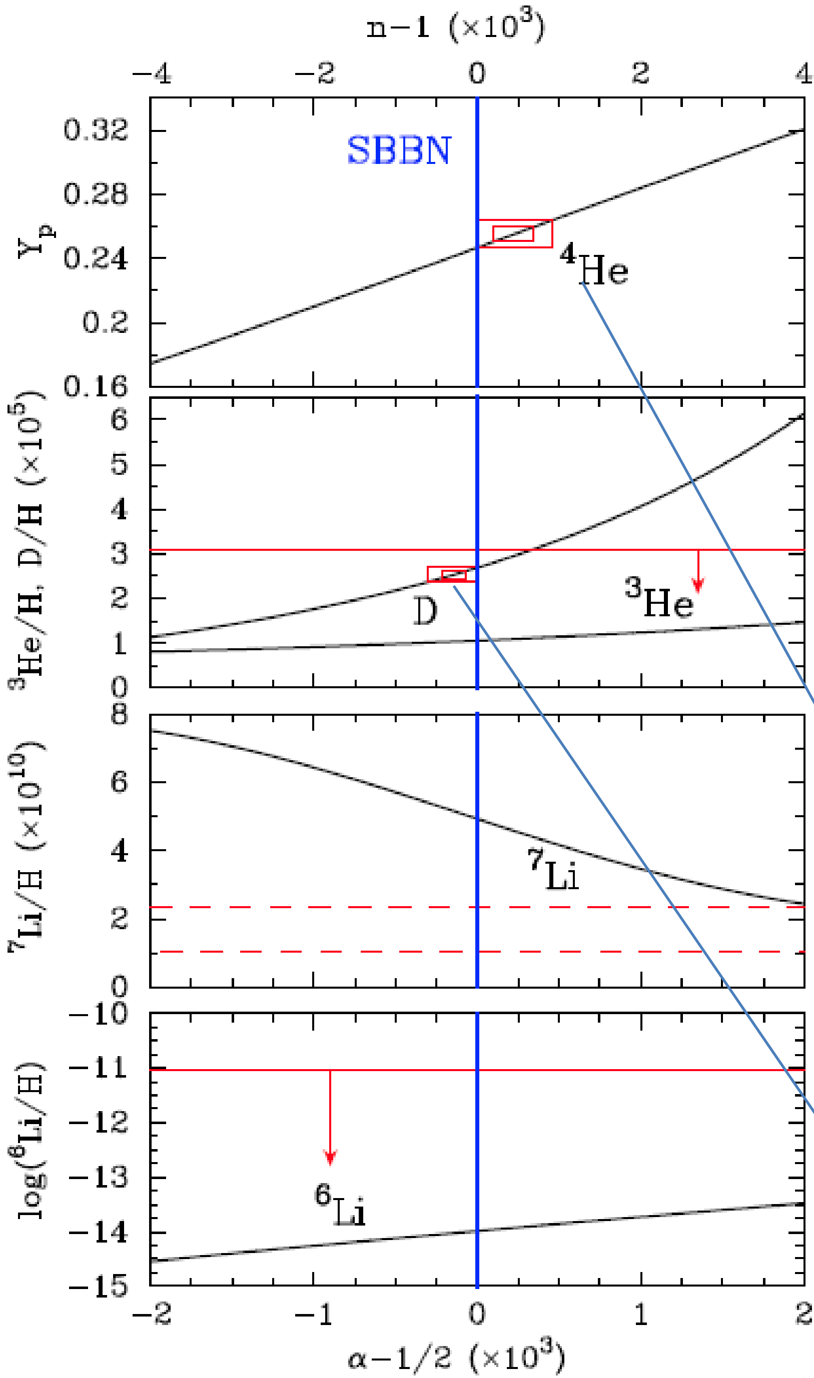


FIG. 1 (color online). ^{4}He mass fraction Y_p and number abundance ratios of D, ^{3}He, ^{7}Li, and ^{6}Li relative to H as a function of the power-law index of the scale factor $\alpha - 1/2$ or the $f(R)$ function $n - 1$. Solid curves show calculated results for the $f(R) \propto R^n$ model. The solid smaller and larger boxes of ^{4}He and D abundances correspond to the 2σ and 4σ limits, respectively, from adopted observational constraints. The dashed box corresponds to the 2σ limits of ^{7}Li abundance. The horizontal lines with downward arrows of ^{3}He and ^{6}Li abundances show observational upper limits. The result on the vertical line for $\alpha = 1/2$ or $n = 1$ is for the SBBN model. Note that the $f(R)$ function for $\alpha < 1/2$ was corrected in this paper so that the cosmological model connects to the present ΛCDM model.

result of a changed expansion rate as follows. First, when the expansion rate is larger, the freeze-out of weak reactions occurs earlier. The neutron abundance remaining after the freeze-out is then higher. Second, the time interval between the freeze-out and the ^{4}He synthesis is shorter because of faster cosmic expansion. Neutron abundances are larger because of the above two reasons. Almost all neutrons are processed to form ^{4}He nuclei at the ^{4}He synthesis epoch. The ^{4}He abundance is therefore larger for larger values of α.

$$-1 \times 10^{-5} \lesssim (\alpha - 1/2) \lesssim 5 \times 10^{-4}$$
$$-2 \times 10^{-5} \lesssim (n - 1) \lesssim 10^{-3}. \qquad (28)$$

When the 4σ limit of D is used, however, more stringent constraints are derived,

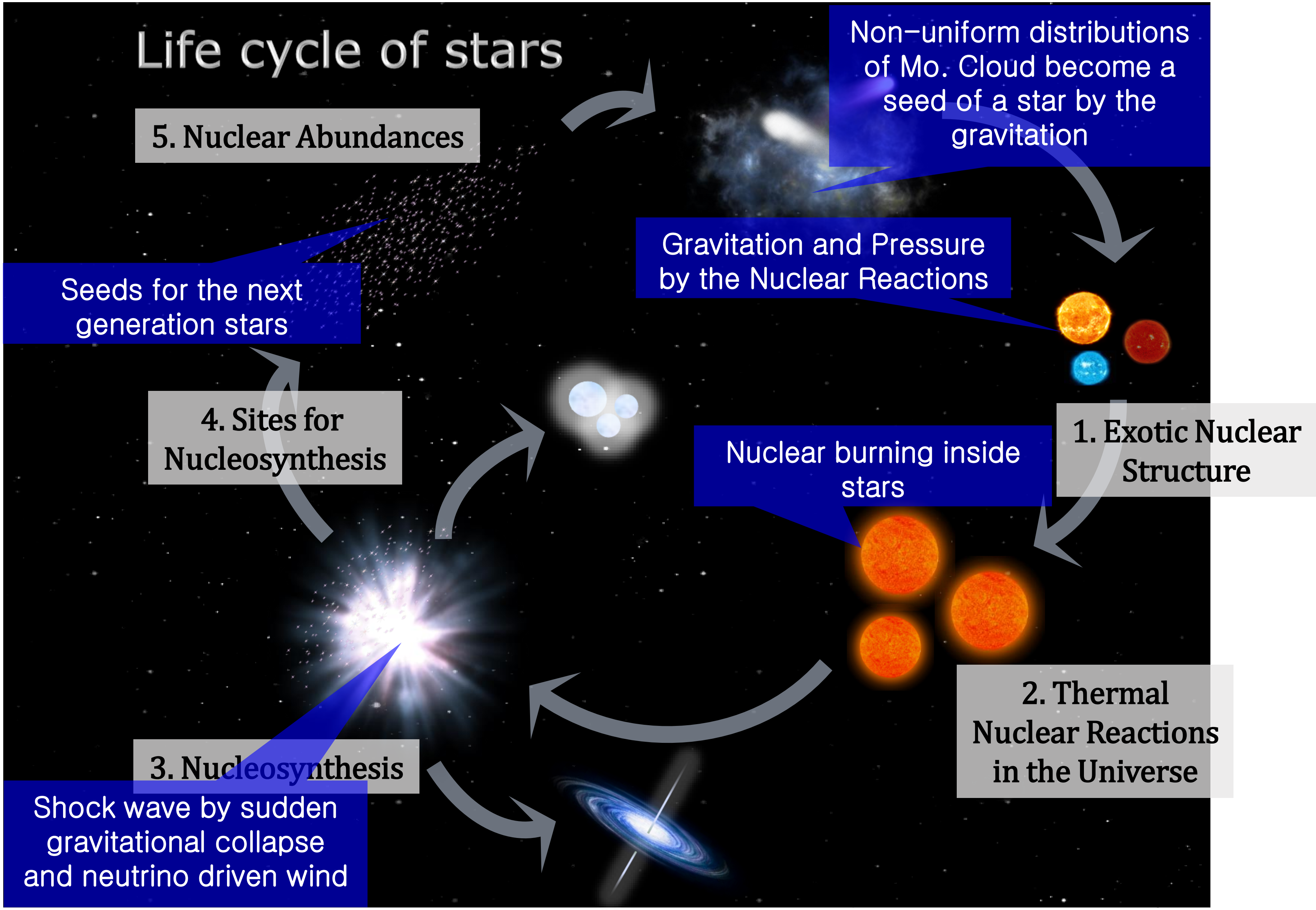
$$-3 \times 10^{-4} \lesssim (\alpha - 1/2) \lesssim 2 \times 10^{-6}$$
$$-6 \times 10^{-4} \lesssim (n - 1) \lesssim 4 \times 10^{-6}. \qquad (29)$$

Motivation

Stellar evolution & nucleosynthesis

Motivation

Stellar evolution & nucleosynthesis



Life cycle of stars

Non-uniform distributions of Mo. Cloud become a seed of a star by the gravitation

Gravitation and Pressure by the Nuclear Reactions

1. Exotic Nuclear Structure

Nuclear burning inside stars

2. Thermal Nuclear Reactions in the Universe

3. Nucleosynthesis

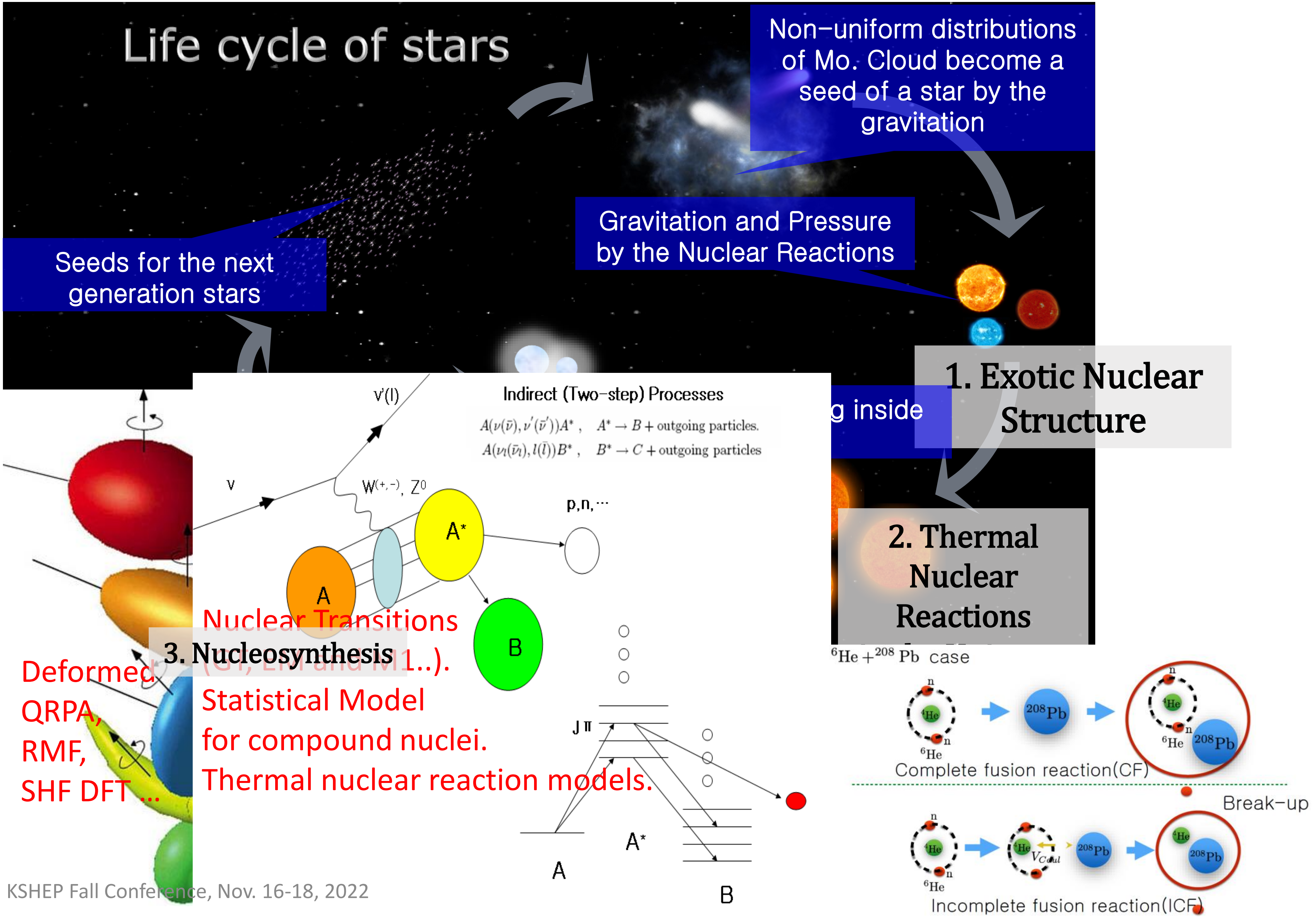
Shock wave by sudden gravitational collapse and neutrino driven wind

4. Sites for Nucleosynthesis

Seeds for the next generation stars

5. Nuclear Abundances

Motivation Exotic nuclear structures and reactions for nucleosynthesis



Non-uniform distributions of Mo. Cloud become a seed of a star by the gravitation

Gravitation and Pressure by the Nuclear Reactions

Seeds for the next generation stars

g inside

1. Exotic Nuclear Structure

2. Thermal Nuclear Reactions

3. Nucleosynthesis

Indirect (Two-step) Processes

$A(\nu(\bar{\nu}),\nu'(\bar{\nu}'))A^*$, $A^* \to B +$ outgoing particles.

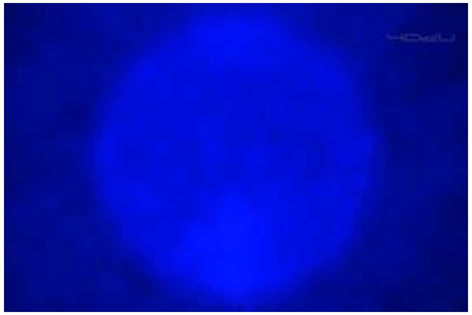
$A(\nu_l(\bar{\nu}_l),l(\bar{l}))B^*$, $B^* \to C +$ outgoing particles

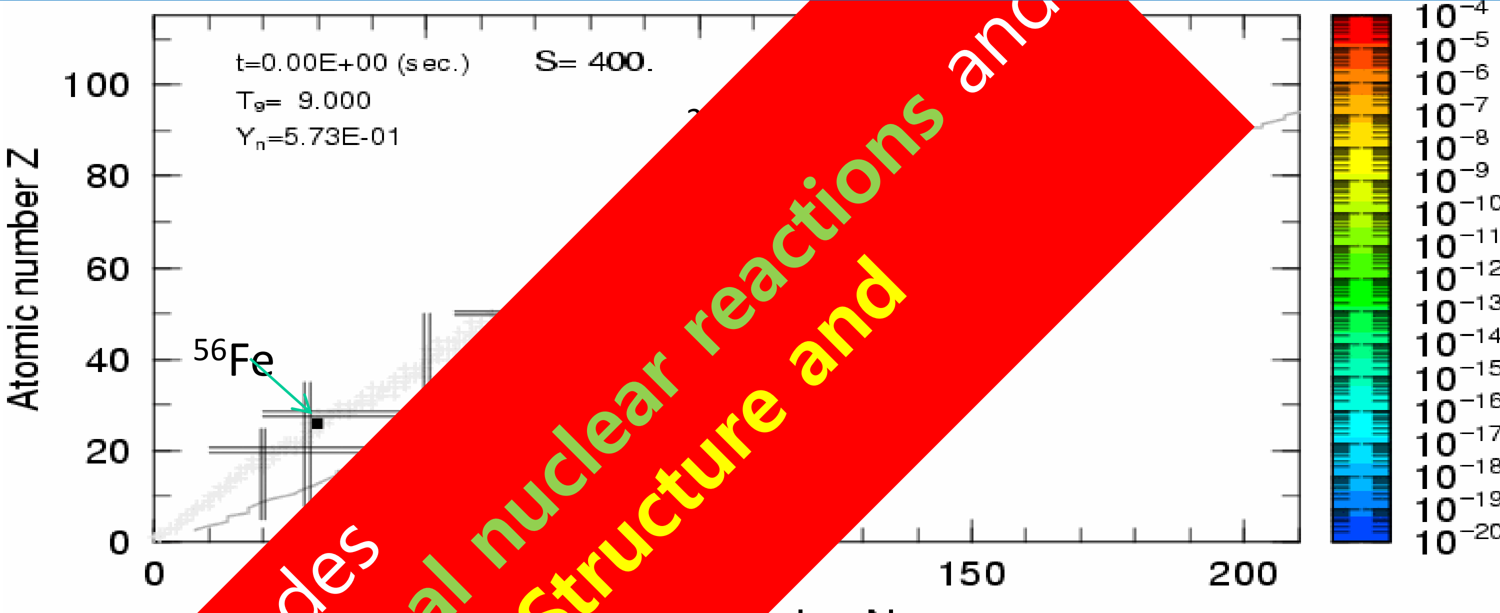
Deformed
QRPA,
RMF,
SHF DFT …

Nuclear Transitions (GT, EM and M1..).
Statistical Model
for compound nuclei.
Thermal nuclear reaction models.

Motivation Rapid process in SN and NS merge for nucleosynthesis

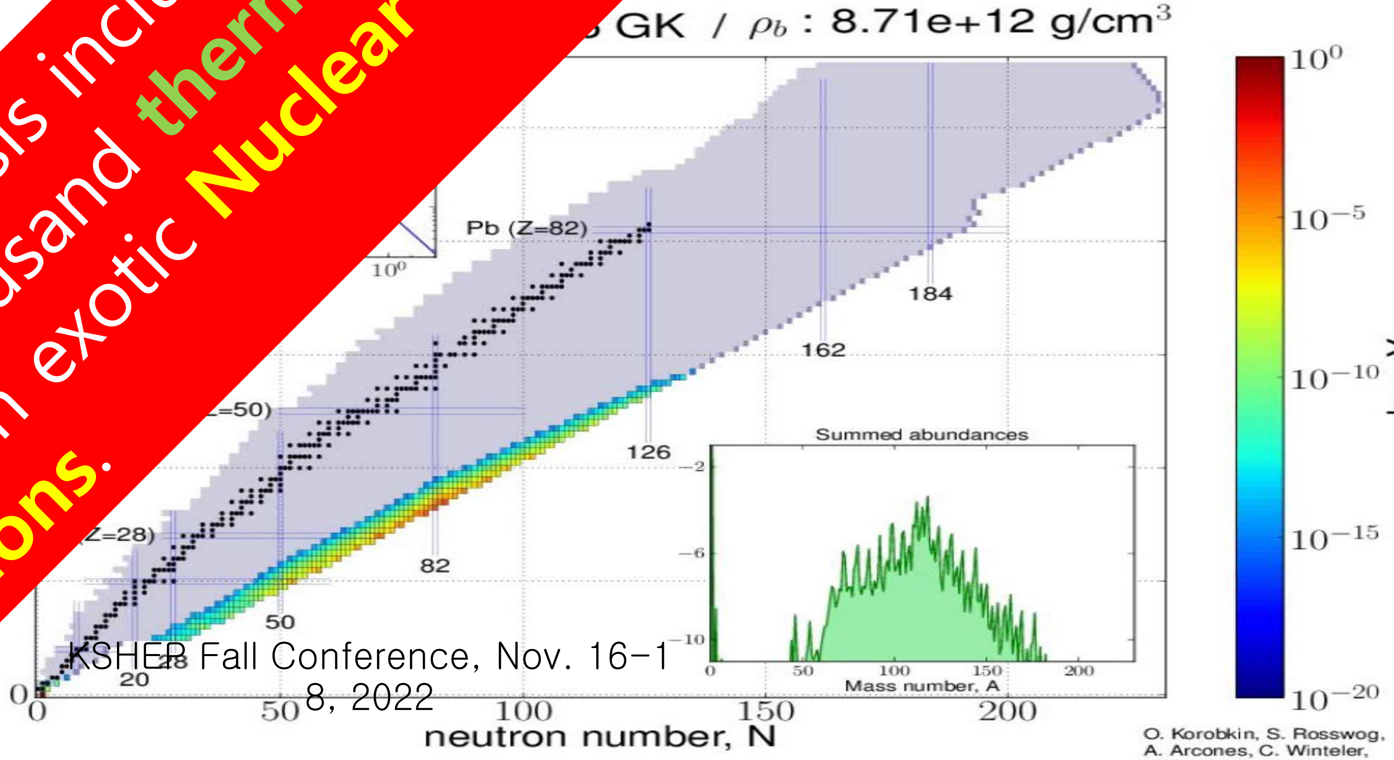
SN





by S. Chiba (JAEA

NS Merger

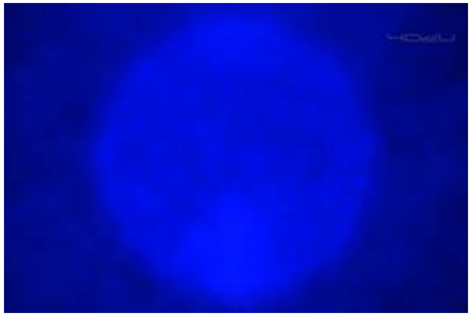


O. Korobkin, S. Rosswog, A. Arcones, C. Winteler, arXiv:1206.2379

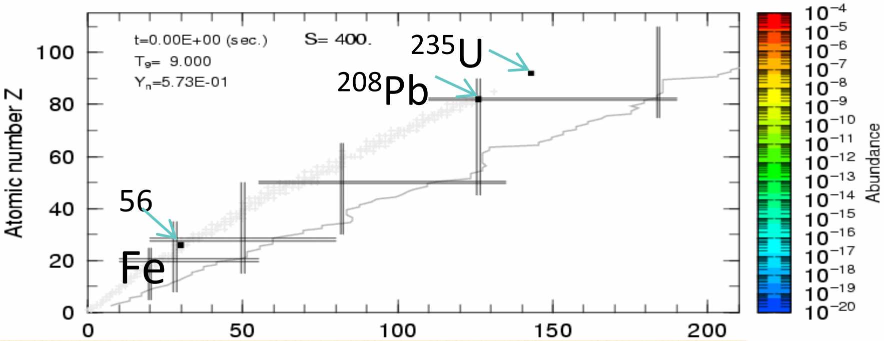
Nucleosynthesis includes tens of thousand thermal nuclear reactions and hinges on exotic Nuclear Structure and Reactions.

Motivation

Nucleosynthesis



r-process in SN



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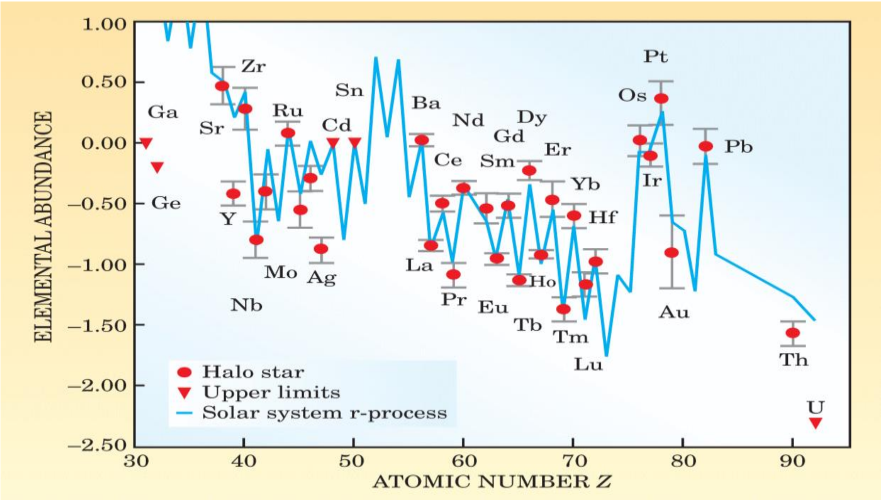
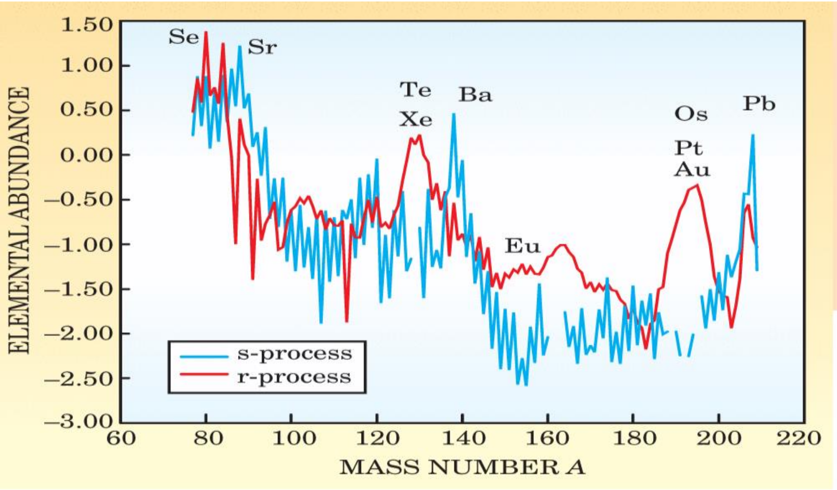
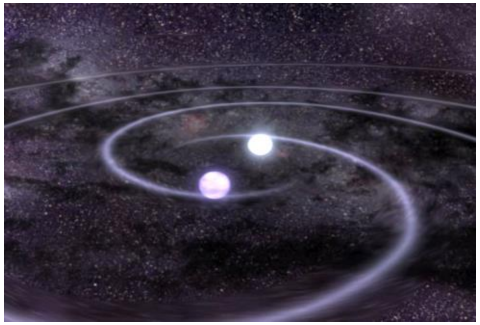
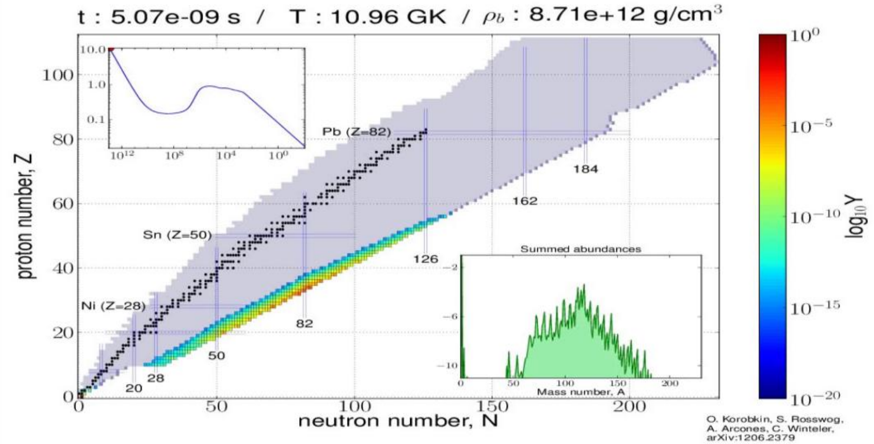






Nucleosynthesis
in
Neutron Star Merge

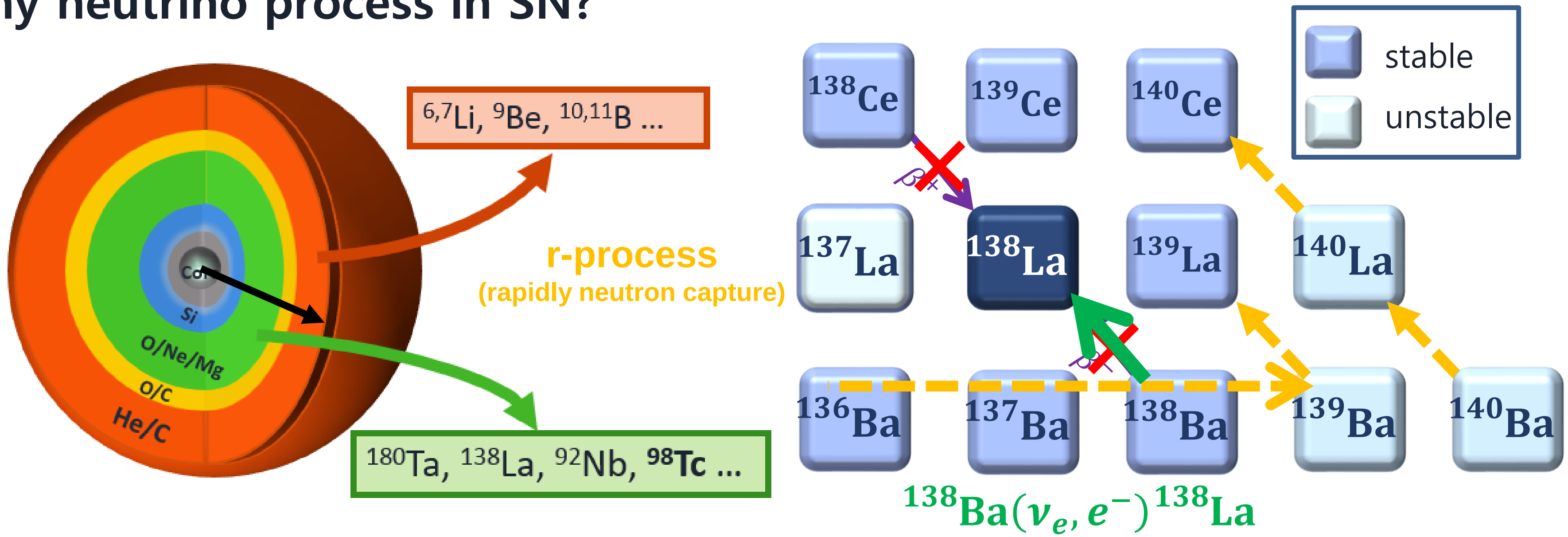


O. Korobkin, S. Rosswog,
A. Arcones, C. Winteler,
arXiv:1206.2379

Courtesy of T. Kajino

Introduction Neutrino Process in CCSN Explosion

Why neutrino process in SN?



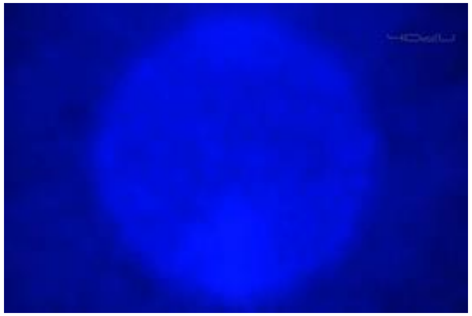
^{6,7}Li, ^{9}Be, ^{10,11}B ...

r-process
(rapidly neutron capture)

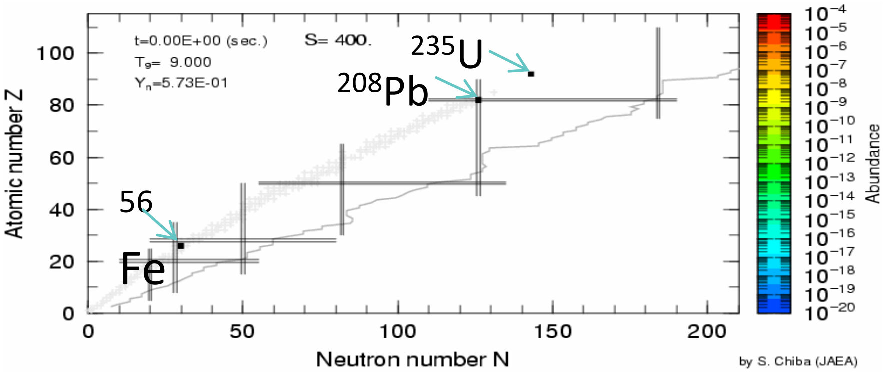
^{180}Ta, ^{138}La, ^{92}Nb, **^{98}Tc** ...

$$^{138}\mathrm{Ba}(\nu_e, e^-)^{138}\mathrm{La}$$

Motivation Nucleosynthesis



r-process in SN



by S. Chiba (JAEA)

PHYSICAL REVIEW LETTERS **121**, 102701 (2018)

H. Ko, M.K. Cheoun et al.

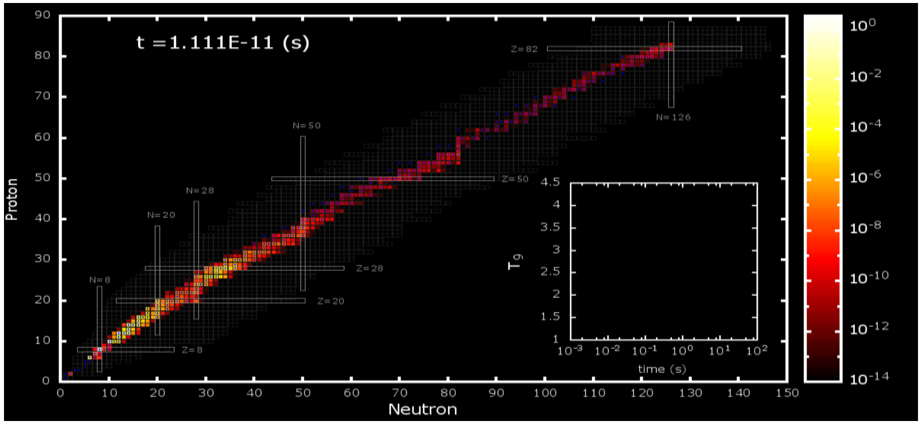
Short-Lived Radioisotope ^{98}Tc Synthesized by the Supernova Neutrino Process

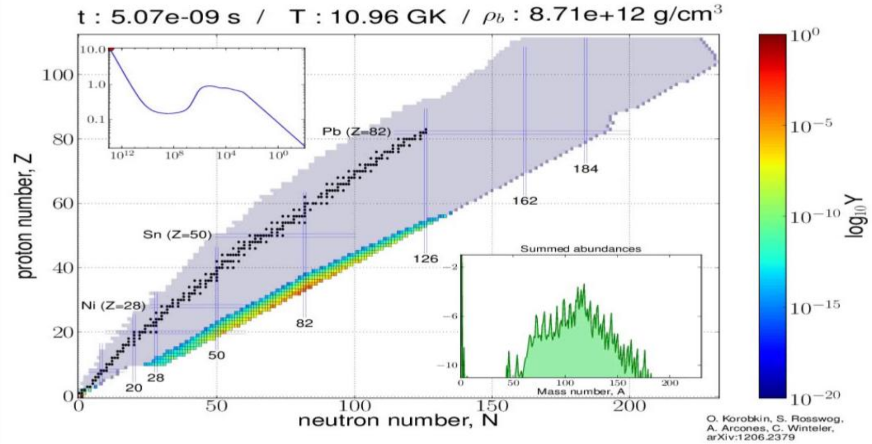
A Supernova Secret May Be Hidden Inside Meteorites

By Bill Andrews | September 4, 2018 3:50 pm

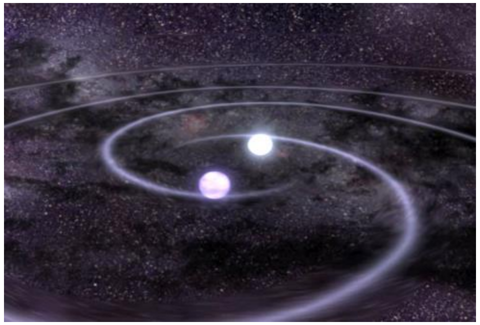
SCIENCE FOR THE CURIOUS

Discover





O. Korobkin, S. Rosswog, A. Arcones, C. Winteler, arXiv:1206.2379

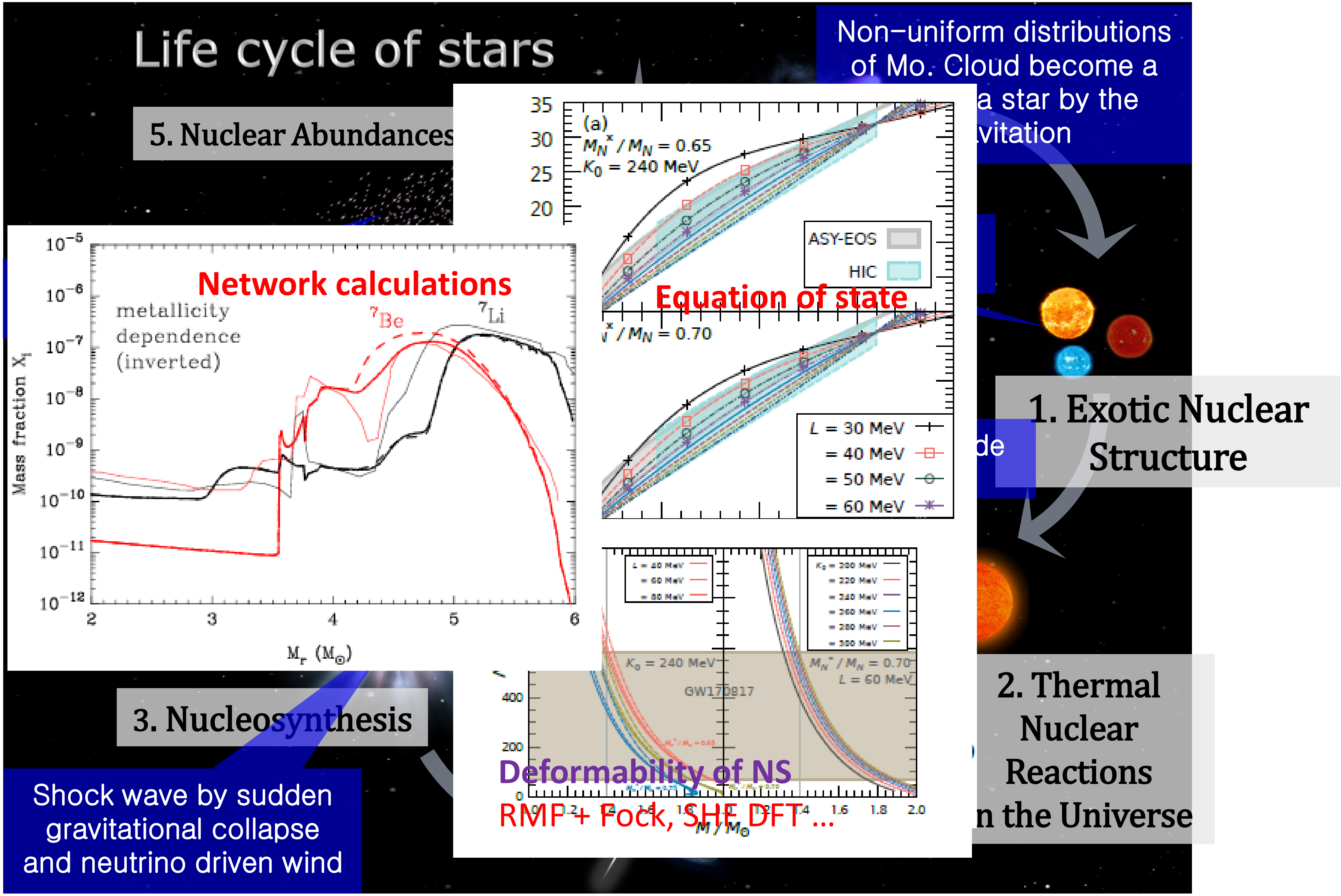


Nucleosynthesis
in
Neutron Star Merge

Courtesy of T. Kajino

Motivation

Cosmological sites for nucleosynthesis



Life cycle of stars

5. Nuclear Abundances

Non−uniform distributions of Mo. Cloud become a … a star by the …vitation

1. Exotic Nuclear Structure

2. Thermal Nuclear Reactions …n the Universe

3. Nucleosynthesis

Shock wave by sudden gravitational collapse and neutrino driven wind

Network calculations

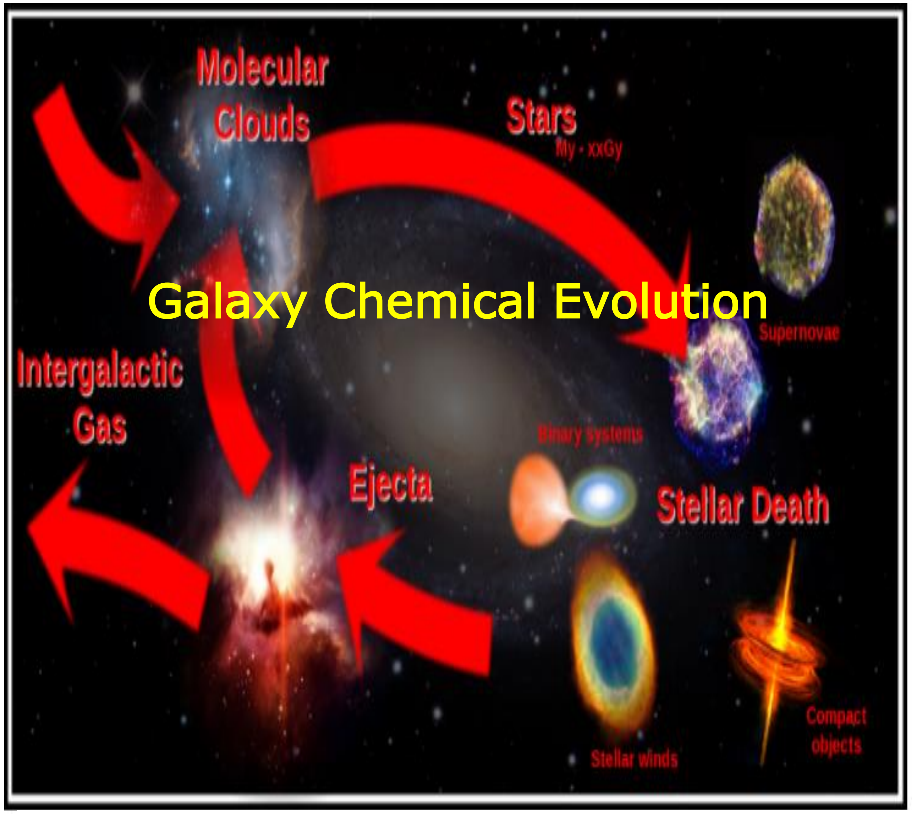
Equation of state

Deformability of NS

RMF + Fock, SHF, DFT …

Motivation Galaxy chemical evolution for cosmological matter

Motivation | Galaxy chemical evolution for cosmological matter

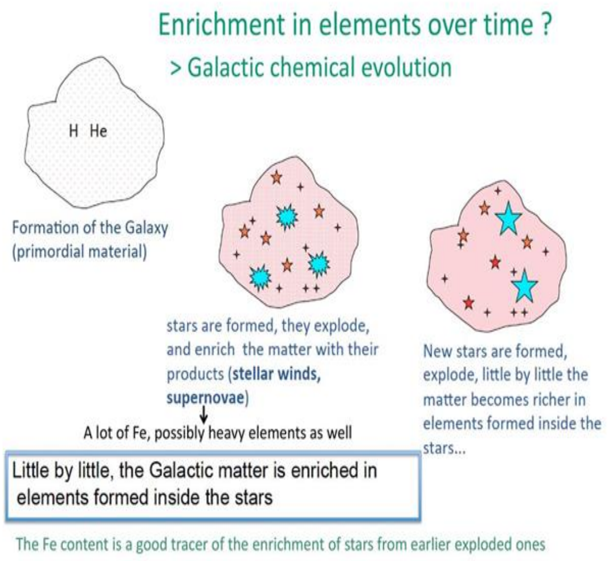


The equation of chemical evolution for the element *i* in each galactic shell takes the following form:

$$\begin{aligned}\frac{\mathrm{d}G_i(t)}{\mathrm{d}t} &= -\psi(t)X_i(t) + \int_{M_L}^{M_{\mathrm{B_m}}} \psi(t-\tau_m)Q_{\mathrm{mi}}(t-\tau_m)\phi(m)\mathrm{d}m \\ &+A\int_{M_{\mathrm{B_m}}}^{M_{\mathrm{B_M}}} \phi(m)\left[\int_{\mu_{\min}}^{0.5} f(\mu)Q_{\mathrm{mi}}(t-\tau_{\mathrm{m_2}})\psi(t-\tau_{\mathrm{m_2}})\mathrm{d}\mu\right]\mathrm{d}m \\ &+(1-A)\int_{\mathrm{M_{B_m}}}^{M_{\mathrm{B_M}}} \psi(t-\tau_m)Q_{\mathrm{mi}}(t-\tau_m)\phi(m)\mathrm{d}m \\ &+\int_{\mathrm{M_{B_M}}}^{M_U} \psi(t-\tau_m)Q_{\mathrm{mi}}(t-\tau_m)\phi(m)\mathrm{d}m \\ &+\left(\frac{\mathrm{d}G_i(t)}{\mathrm{d}t}\right)_{\mathrm{infall}}, \end{aligned} \tag{1}$$

where $G_i(t) = M_{\mathrm{gas}}(t)\ \ X_i(t)$ is the fractional mass of the element *i* at the time *t* in the ISM. The quantity $X_i(t)$ is defined as the abundance by mass of the element *i*. By definition $\sum_i X_i = 1$.

Star Formation rate


Enrichment in elements over time ?

> Galactic chemical evolution

Formation of the Galaxy (primordial material)

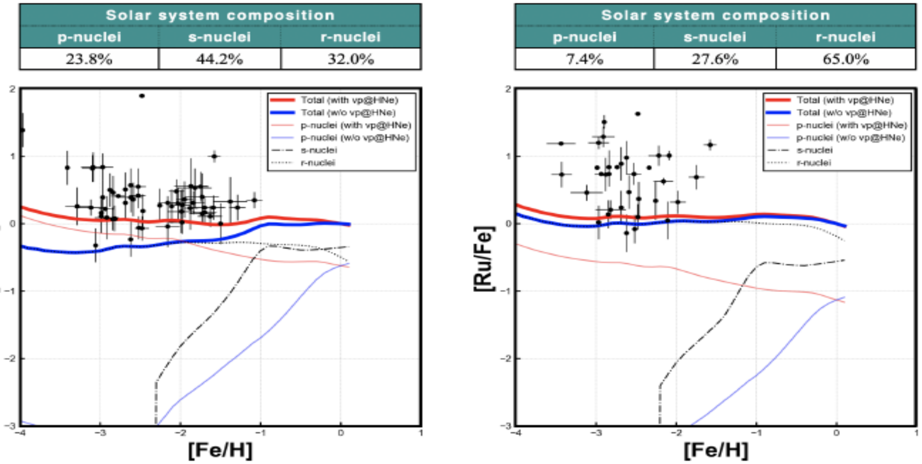
stars are formed, they explode, and enrich the matter with their products (**stellar winds, supernovae**)

A lot of Fe, possibly heavy elements as well

New stars are formed, explode, little by little the matter becomes richer in elements formed inside the stars...

Little by little, the Galactic matter is enriched in elements formed inside the stars

The Fe content is a good tracer of the enrichment of stars from earlier exploded ones



Solar system composition		
p-nuclei	s-nuclei	r-nuclei
23.8%	44.2%	32.0%

Solar system composition		
p-nuclei	s-nuclei	r-nuclei
7.4%	27.6%	65.0%

Figure 3. elemental (a) [Mo/Fe], (b) [Ru/Fe] vs. [Fe/H] //TODO

Motivation

Big Bang Chemistry and Inter stellar matter

IR spectra from ISM & Exotic Morecules

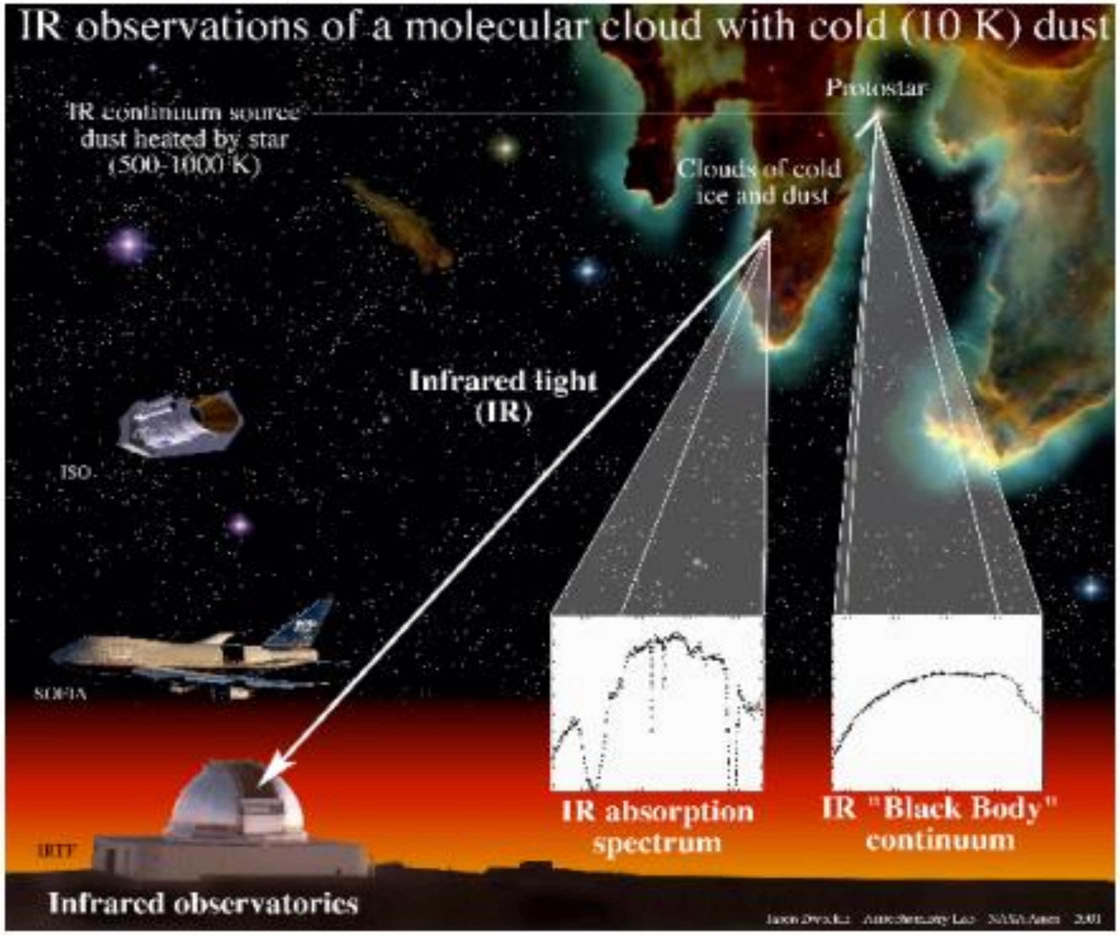
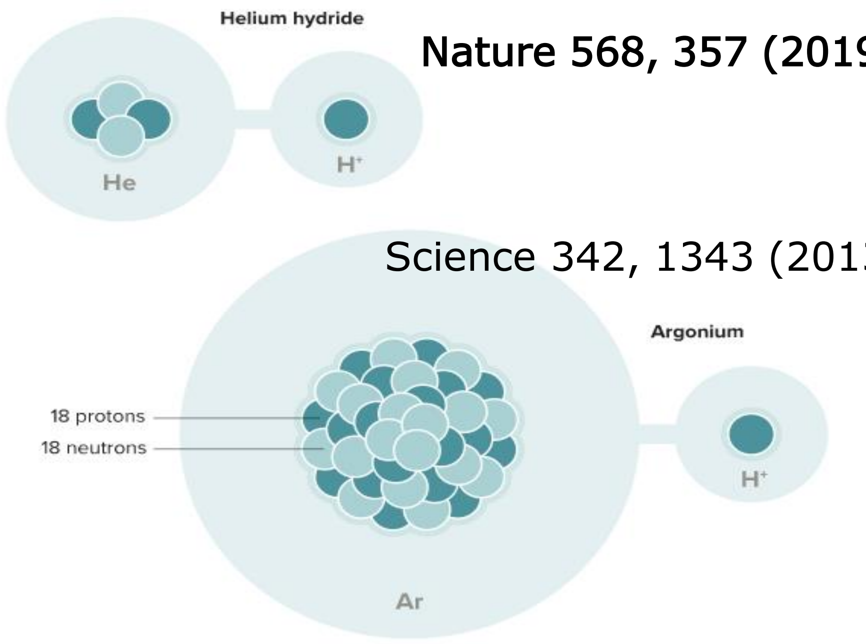


Plate 3. An illustration of how one measures the IR absoption spectra of interstellar clouds. A background star (protostar) serves as the IR source, the cloud is the sample, and the telescope gathers the light and sends it to a monochromator or spectrometer. The advent of airborne IR telescopes in the 70's and orbiting telescopes in the 80's made it possible to avoid IR absoptions by atmospheric H_2O, CO_2, and so on, opening a new window into the Cosmos. Figure courtesy of Dr. Jason Dworkin.

Space molecules



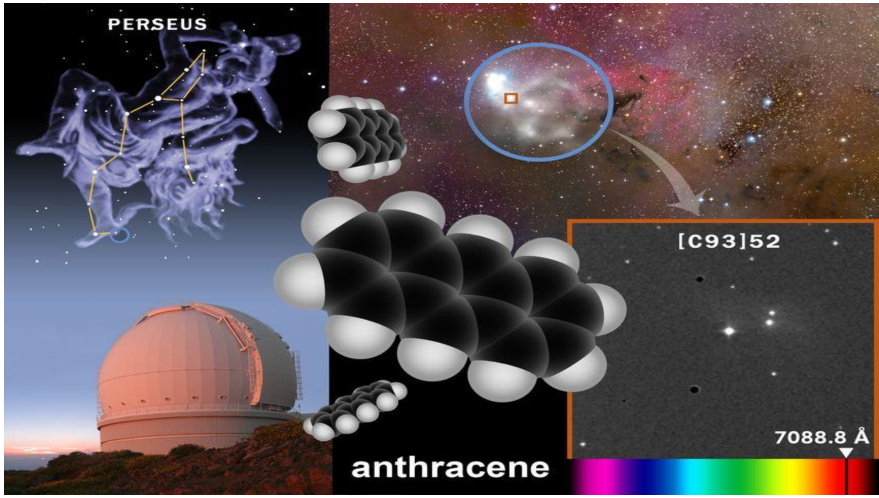
Nature 568, 357 (201

Science 342, 1343 (201

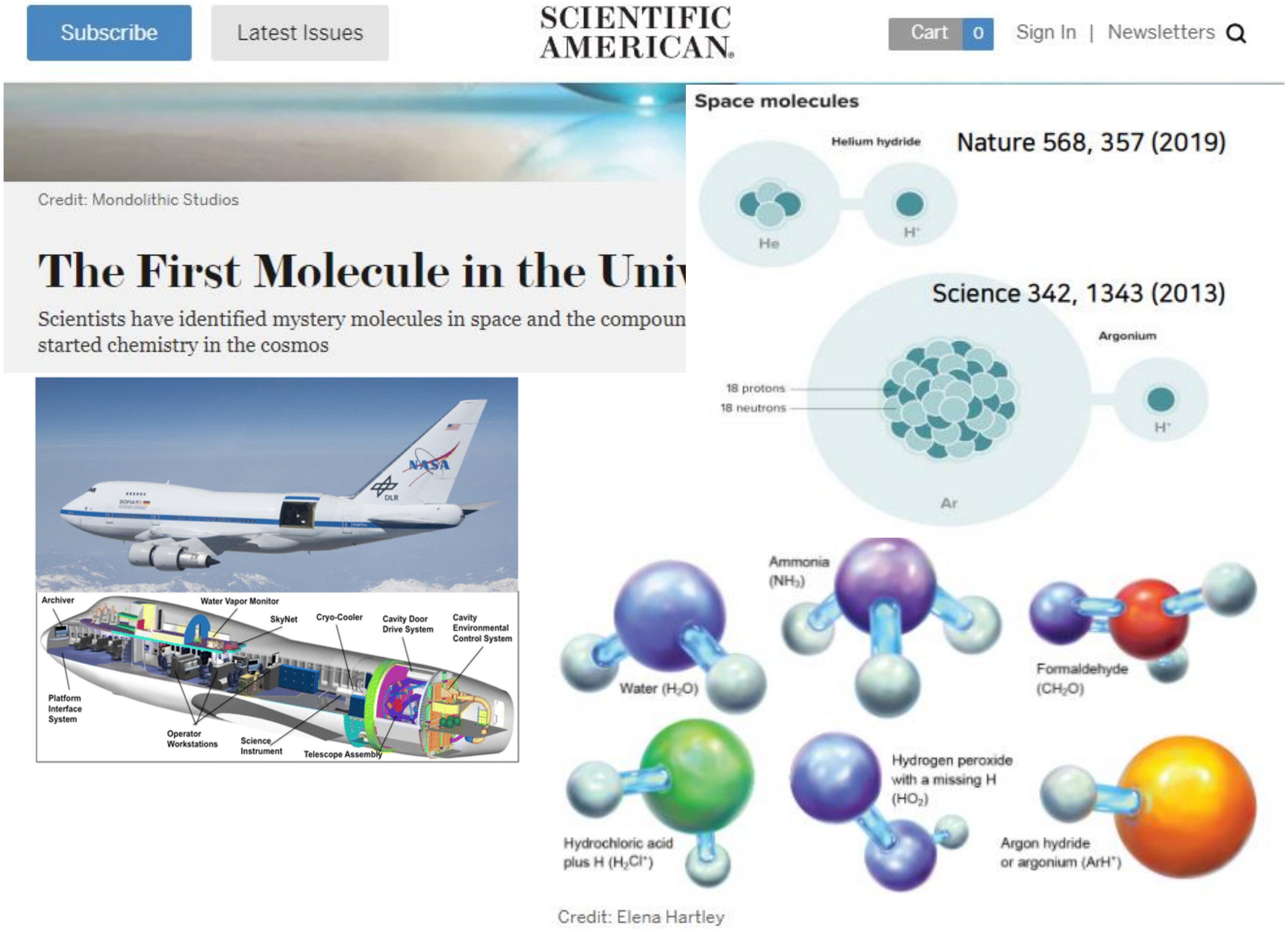
SOURCE: REPORTING BY K. CROSWELL

KNOWABLE MAGAZINE

Helium hydride and argonium are the two noble gas molecules astronomers have found in space.



Motivation First Molecule and Exotic Molecules



Credit: Mondolithic Studios

The First Molecule in the Uni

Scientists have identified mystery molecules in space and the compoun
started chemistry in the cosmos

Space molecules

Nature 568, 357 (2019)

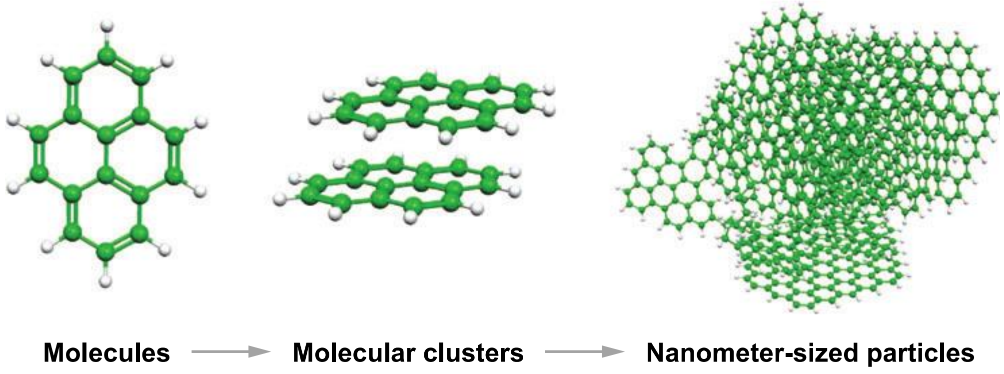
Science 342, 1343 (2013)

Credit: Elena Hartley

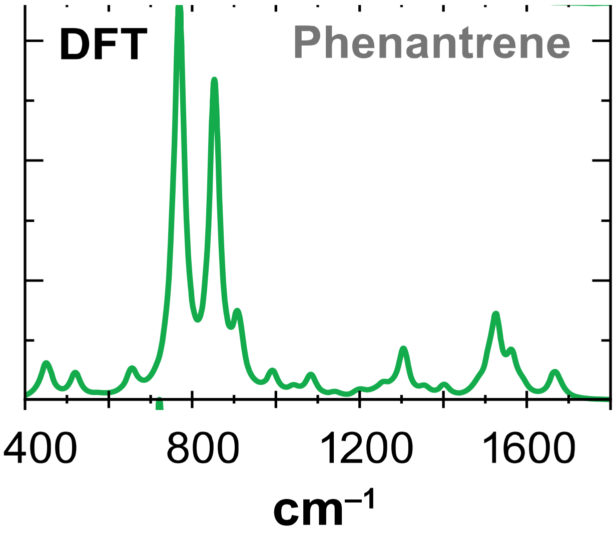
Motivation Dense matter in the Universe & DFT

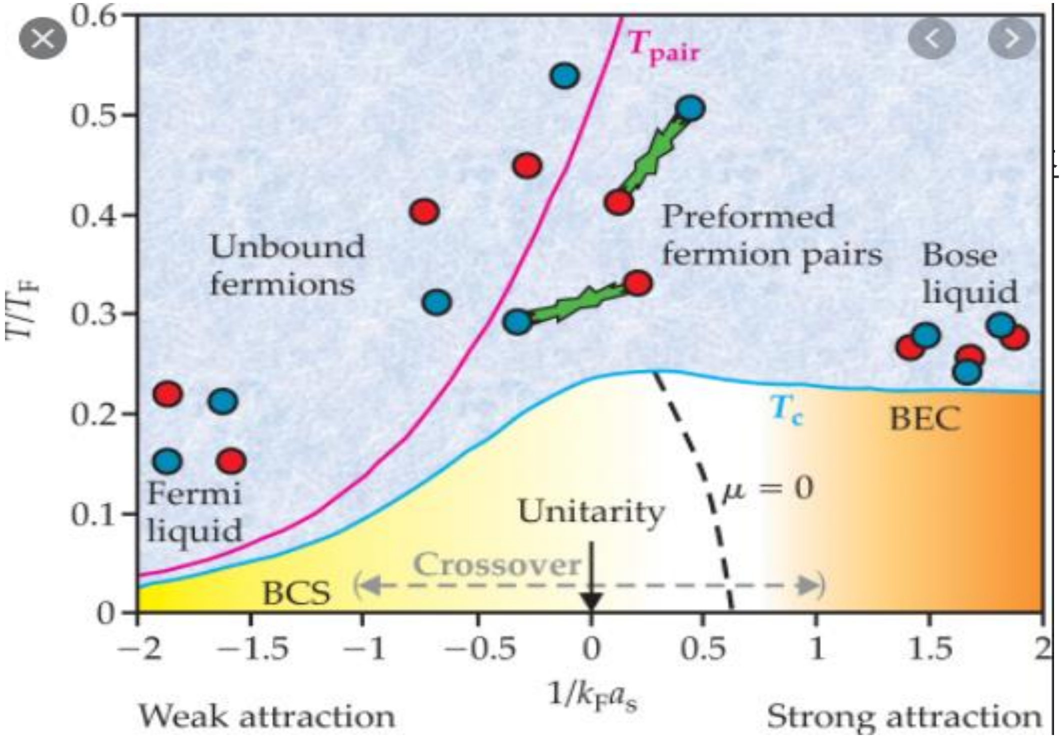
성간 분자 물질에 의한 적외선 스펙트럼 연구

- 크기에 따른 hydrocarbon 기반의 성간 우주물질

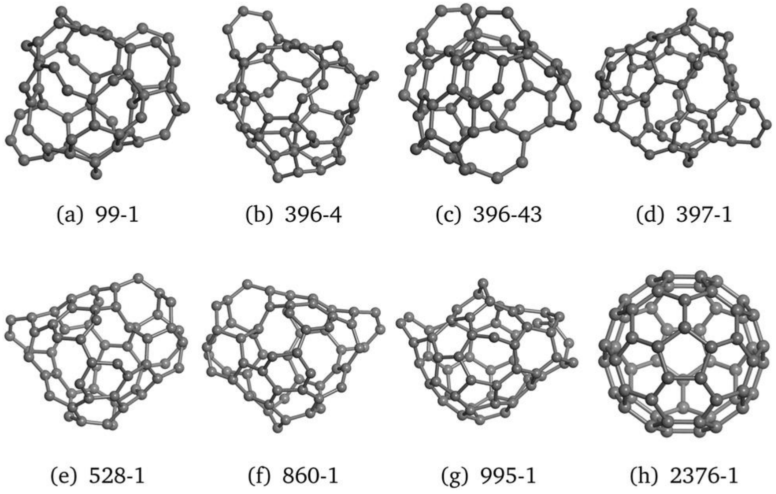


- 밀도 범함수 이론을 이용한 방출 스펙트럼 계산





- 탄소 기반의 국소적 안정 상태의 원자구조

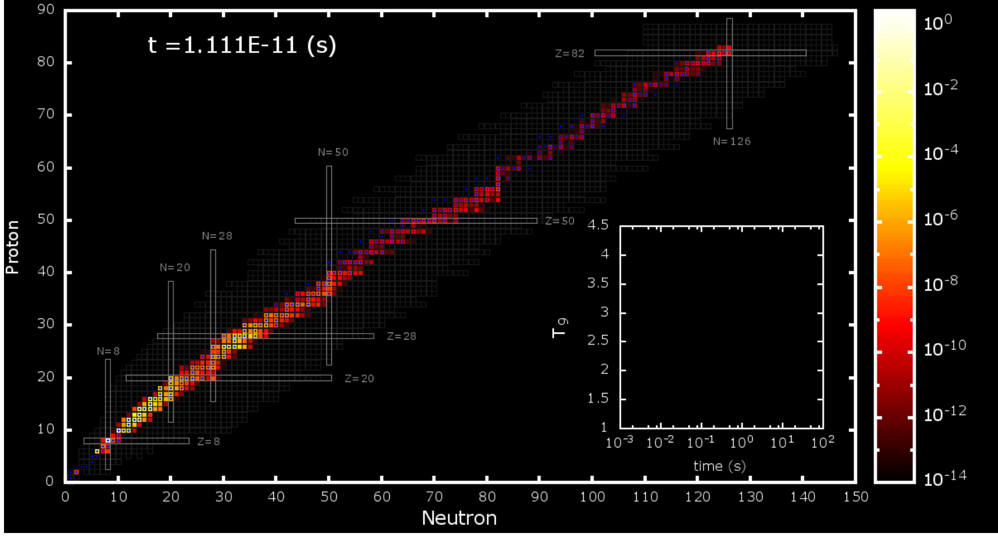

(a) 99-1 (b) 396-4 (c) 396-43 (d) 397-1
(e) 528-1 (f) 860-1 (g) 995-1 (h) 2376-1

Neutrino process Neut. Ham. for neutrino density propagation

JINA REALIB

Modified (n,g) Reactions

QRPA & Branching Ratios



Numerical results for elements abundances

1987 SN model

Pre-supernova Model

Hydrodynamics Model: HCK18, KCK19

Modified Neutrino Flux by Self-interaction : w/ and w.o/

Neutrino Luminosity : EQ and NEQ

Mass Hierarchy : NH and IH

Neutrino Reactions Rates with Nuclei

Network calculation for nucleosynthesis

$$\frac{dN_j}{dt} = N_i\,\lambda_{i,j} - N_j\,\lambda_{j,h} + \ \dots \rightarrow \frac{dY_j}{dt} = \boldsymbol{Y_i\,\lambda_{i,j} - Y_j\,\lambda_{j,h}} + \cdots$$

$$\boxed{Y_j = \frac{N_j}{\rho\,N_A}}$$

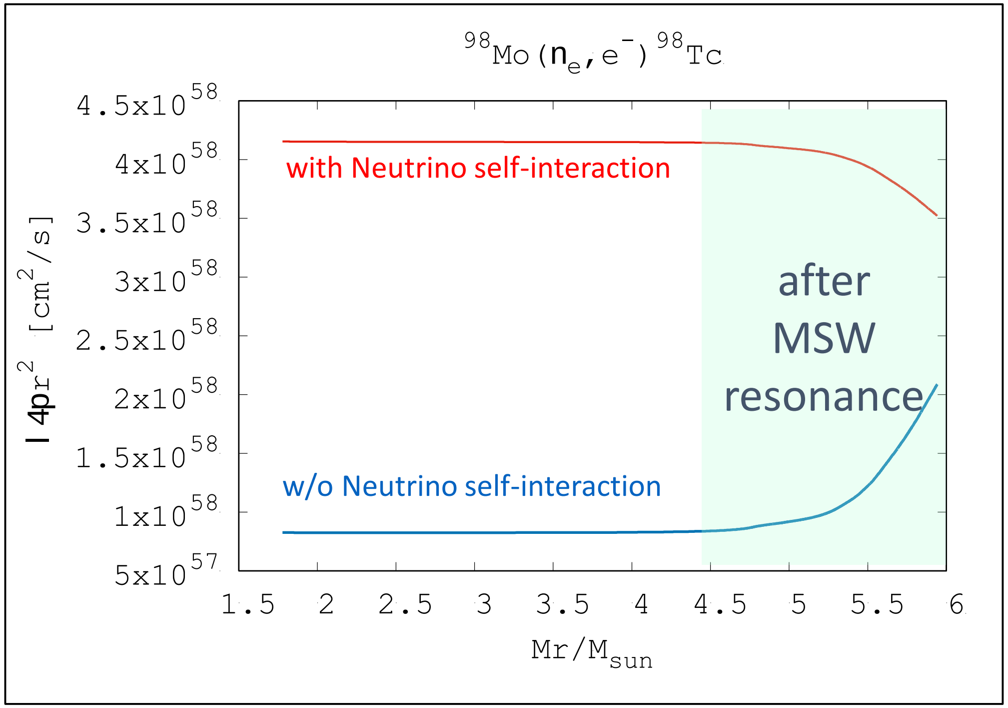
JINA REACLIB & Los Alamos (n,g) Data !

Kyushu-Tokyo Progenitor Model !

Part for neutrino reaction rates

$$\lambda_{\nu_\alpha}(r) = \sigma\,\phi$$
$$= \int_0^\infty \sum_{\alpha=e,\mu,\tau} \frac{d\phi_{\nu_\alpha}}{d\epsilon_\nu}\, Br(\epsilon)\, \sigma_{\nu_\alpha}(\epsilon_\nu) d\epsilon_\nu$$

Example: (EQ,IH)



Cross section data using QRPA

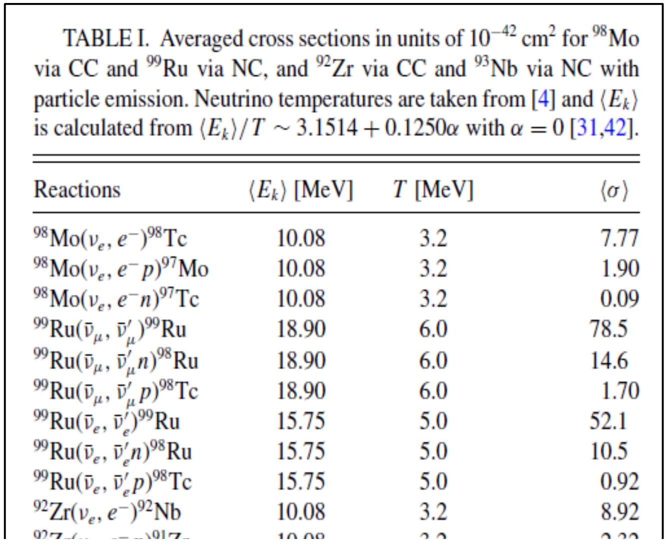


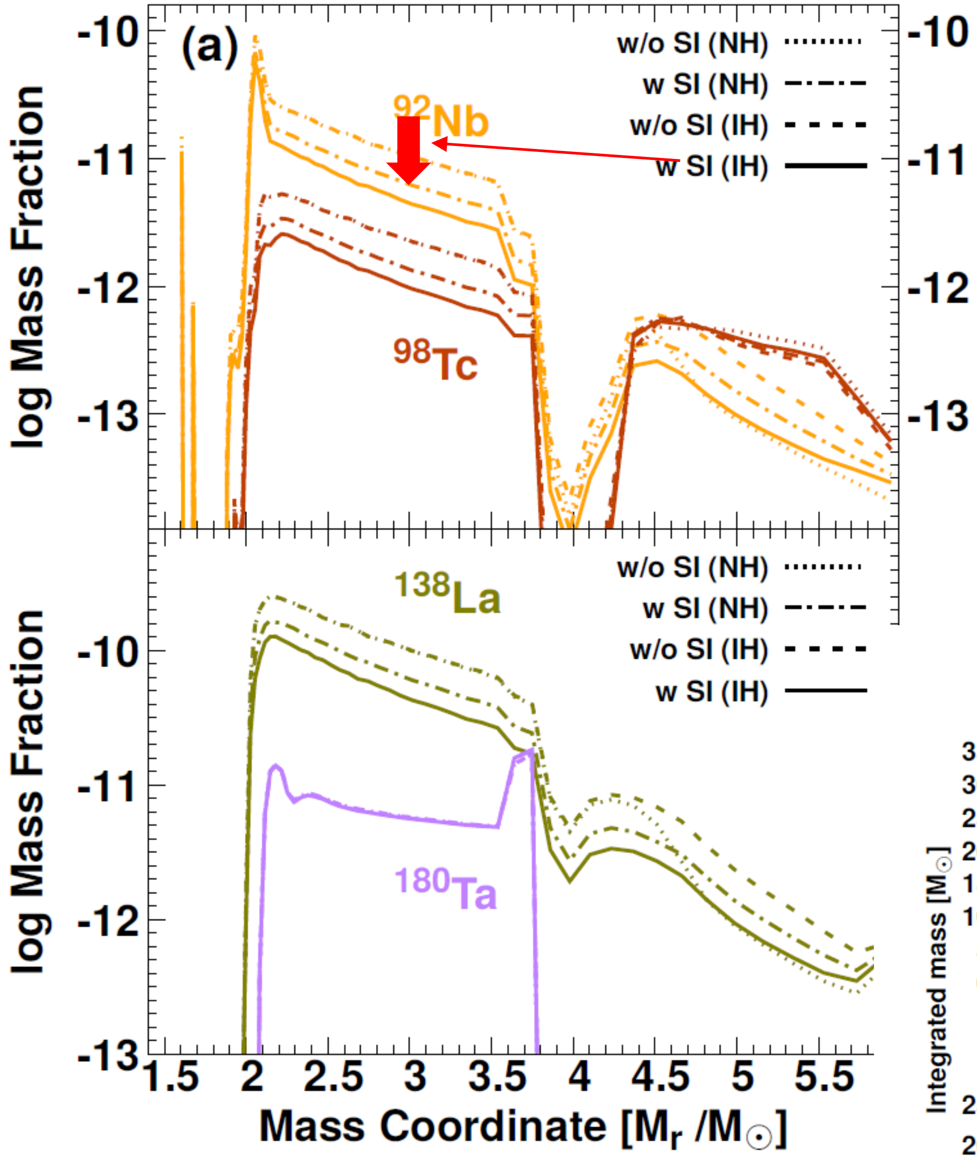
TABLE I. Averaged cross sections in units of 10^{-42} cm^2 for ^{98}Mo via CC and ^{99}Ru via NC, and ^{92}Zr via CC and ^{93}Nb via NC with particle emission. Neutrino temperatures are taken from [4] and $\langle E_k \rangle$ is calculated from $\langle E_k \rangle / T \sim 3.1514 + 0.1250\alpha$ with $\alpha = 0$ [31,42].

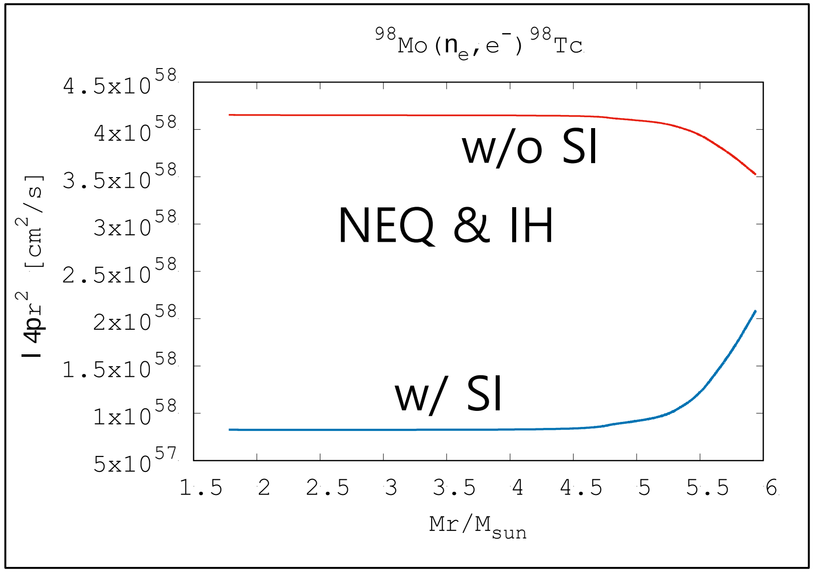
Reactions	$\langle E_k \rangle$ [MeV]	T [MeV]	$\langle \sigma \rangle$
^{98}Mo$(\nu_e, e^-)^{98}$Tc	10.08	3.2	7.77
^{98}Mo$(\nu_e, e^- p)^{97}$Mo	10.08	3.2	1.90
^{98}Mo$(\nu_e, e^- n)^{97}$Tc	10.08	3.2	0.09
^{99}Ru$(\bar{\nu}_\mu, \bar{\nu}'_\mu)^{99}$Ru	18.90	6.0	78.5
^{99}Ru$(\bar{\nu}_\mu, \bar{\nu}'_\mu n)^{98}$Ru	18.90	6.0	14.6
^{99}Ru$(\bar{\nu}_\mu, \bar{\nu}'_\mu p)^{98}$Tc	18.90	6.0	1.70
^{99}Ru$(\bar{\nu}_e, \bar{\nu}'_e)^{99}$Ru	15.75	5.0	52.1
^{99}Ru$(\bar{\nu}_e, \bar{\nu}'_e n)^{98}$Ru	15.75	5.0	10.5
^{99}Ru$(\bar{\nu}_e, \bar{\nu}'_e p)^{98}$Tc	15.75	5.0	0.92
^{92}Zr$(\nu_e, e^-)^{92}$Nb	10.08	3.2	8.92

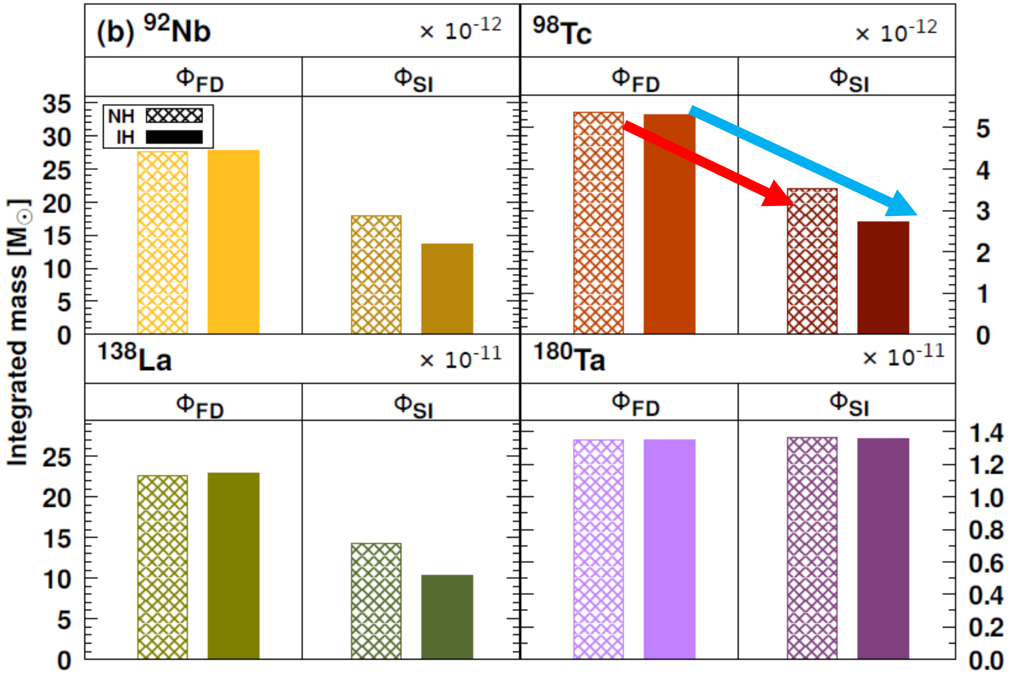
In MSW region, energetic e-neutrino is increased by the P(x-e) neutrino resonance (w/o SI).

But it is a bit decreased with the decrease of X-neutrino by the SI.

)

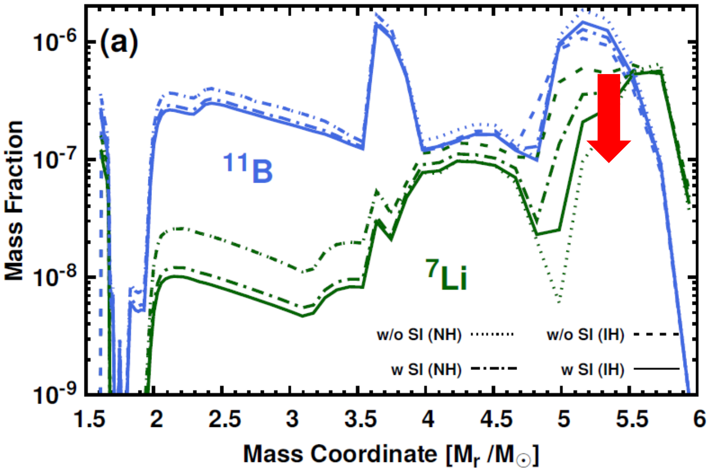

(a)
w/o SI (NH)
w SI (NH)
w/o SI (IH)
w SI (IH)
^{92}Nb
^{98}Tc
^{138}La
^{180}Ta
log Mass Fraction
-10
-11
-12
-13
1.5
2
2.5
3
3.5
4
4.5
5
5.5
Mass Coordinate [$M_r/M_\odot$]

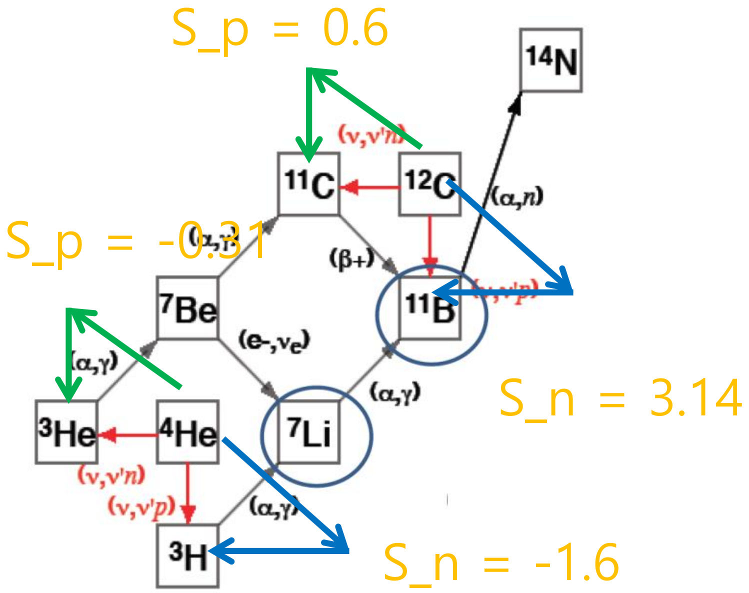

^{98}Mo$(n_e,e^-)^{98}$Tc
$I\,4pr^2$ [cm^2/s]
4.5x10^{58}
4x10^{58}
3.5x10^{58}
3x10^{58}
2.5x10^{58}
2x10^{58}
1.5x10^{58}
1x10^{58}
5x10^{57}
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Mr/M$_{sun}$
w/o SI
NEQ & IH
w/ SI

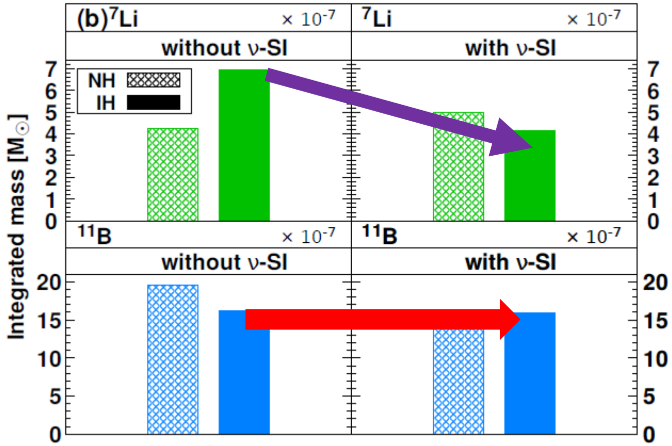

(b) ^{92}Nb
× 10^{-12}
^{98}Tc
× 10^{-12}
Φ_{FD}
Φ_{SI}
NH
IH
Integrated mass [M$_\odot$]
35
30
25
20
15
10
5
0
^{138}La
× 10^{-11}
^{180}Ta
× 10^{-11}
5
4
3
2
1
0
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0

Neutrino process

Results for Light Elements II







For 7Li, the main reactions are
both e- and anti-e- neutrino reactions via CC
which are larger than NC.
And e-CC reactions through 3He and 7Be
from 4He are larger than anti-e due to MSW.
=> Sensitive on the nu-SI.

But for 11B both electro-
and antielectron-neutrinos via CC and NC work.
=> Insensitive to the nu-SI.

Hydrodynamics : HKC18 and KCK19
Luminosity : EQ and NEQ
Neutrino Self Interaction : FD and SI
Mass Hierarchy : NH and IH

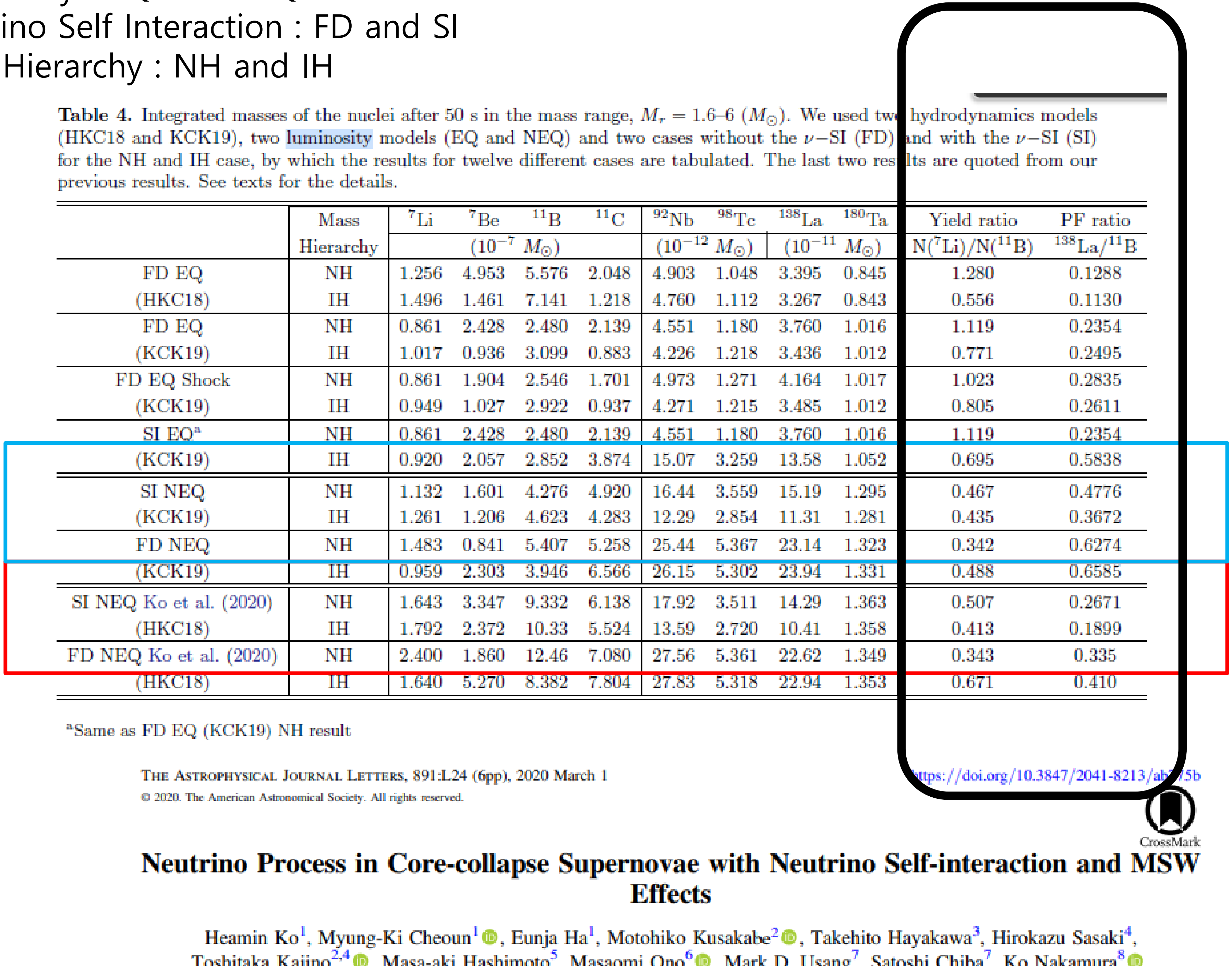


Table 4. Integrated masses of the nuclei after 50 s in the mass range, $M_r = 1.6$–6 ($M_\odot$). We used two hydrodynamics models (HKC18 and KCK19), two luminosity models (EQ and NEQ) and two cases without the ν−SI (FD) and with the ν−SI (SI) for the NH and IH case, by which the results for twelve different cases are tabulated. The last two results are quoted from our previous results. See texts for the details.

	Mass Hierarchy	^{7}Li	^{7}Be	^{11}B	^{11}C	^{92}Nb	^{98}Tc	^{138}La	^{180}Ta	Yield ratio	PF ratio
		(10^{-7} $M_\odot$)				(10^{-12} $M_\odot$)		(10^{-11} $M_\odot$)		N(^{7}Li)/N(^{11}B)	^{138}La/^{11}B
FD EQ	NH	1.256	4.953	5.576	2.048	4.903	1.048	3.395	0.845	1.280	0.1288
(HKC18)	IH	1.496	1.461	7.141	1.218	4.760	1.112	3.267	0.843	0.556	0.1130
FD EQ	NH	0.861	2.428	2.480	2.139	4.551	1.180	3.760	1.016	1.119	0.2354
(KCK19)	IH	1.017	0.936	3.099	0.883	4.226	1.218	3.436	1.012	0.771	0.2495
FD EQ Shock	NH	0.861	1.904	2.546	1.701	4.973	1.271	4.164	1.017	1.023	0.2835
(KCK19)	IH	0.949	1.027	2.922	0.937	4.271	1.215	3.485	1.012	0.805	0.2611
SI EQ[a]	NH	0.861	2.428	2.480	2.139	4.551	1.180	3.760	1.016	1.119	0.2354
(KCK19)	IH	0.920	2.057	2.852	3.874	15.07	3.259	13.58	1.052	0.695	0.5838
SI NEQ	NH	1.132	1.601	4.276	4.920	16.44	3.559	15.19	1.295	0.467	0.4776
(KCK19)	IH	1.261	1.206	4.623	4.283	12.29	2.854	11.31	1.281	0.435	0.3672
FD NEQ	NH	1.483	0.841	5.407	5.258	25.44	5.367	23.14	1.323	0.342	0.6274
(KCK19)	IH	0.959	2.303	3.946	6.566	26.15	5.302	23.94	1.331	0.488	0.6585
SI NEQ Ko et al. (2020)	NH	1.643	3.347	9.332	6.138	17.92	3.511	14.29	1.363	0.507	0.2671
(HKC18)	IH	1.792	2.372	10.33	5.524	13.59	2.720	10.41	1.358	0.413	0.1899
FD NEQ Ko et al. (2020)	NH	2.400	1.860	12.46	7.080	27.56	5.361	22.62	1.349	0.343	0.335
(HKC18)	IH	1.640	5.270	8.382	7.804	27.83	5.318	22.94	1.353	0.671	0.410

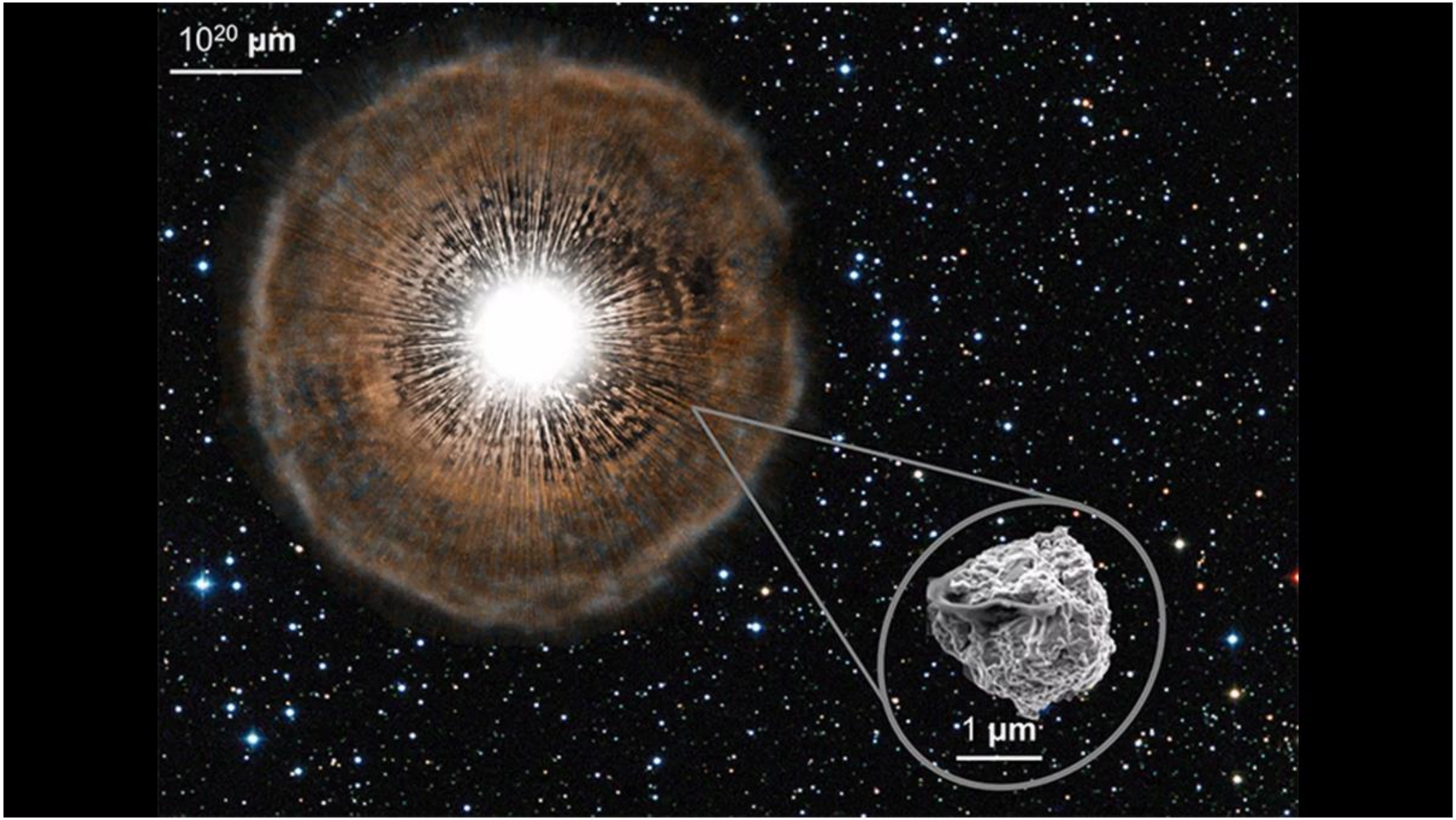
[a]Same as FD EQ (KCK19) NH result

The Astrophysical Journal Letters, 891:L24 (6pp), 2020 March 1
https://doi.org/10.3847/2041-8213/ab775b

Neutrino Process in Core-collapse Supernovae with Neutrino Self-interaction and MSW Effects

Heamin Ko[1], Myung-Ki Cheoun[1], Eunja Ha[1], Motohiko Kusakabe[2], Takehito Hayakawa[3], Hirokazu Sasaki[4],
Toshitaka Kajino[2,4], Masa-aki Hashimoto[5], Masaomi Ono[6], Mark D. Usang[7], Satoshi Chiba[7], Ko Nakamura[8]

Meteorite Analysis : Analysis of SiC in stardust grain (Pre-solar grain) from Murchinson meteorite



An electron microscope image of a micron-sized silicon carbide stardust grain extracted from the Murchinson meteorite. (Image credit: NASA, Nan Liu and Andrew Davis)

Mass Fraction ratio of 7Li/11B and PF ration of 138La/11B

- The yield ratio of [7Li/11B]

$^{7}\mathrm{Li}/^{11}\mathrm{B} = -0.31 \pm 0.42$ **<0.53 (2 sigma)**

Spectra	FD	+SI	FD	+SI
Mass Hierarchy	IH	IH	NH	NH
Yield Ratio	0.671(0.488)	0.413(0.435)	0.343(0.342)	0.507(0.467)

- The production factor ratio of [138La/11B]

> 0.41 (lower limit)

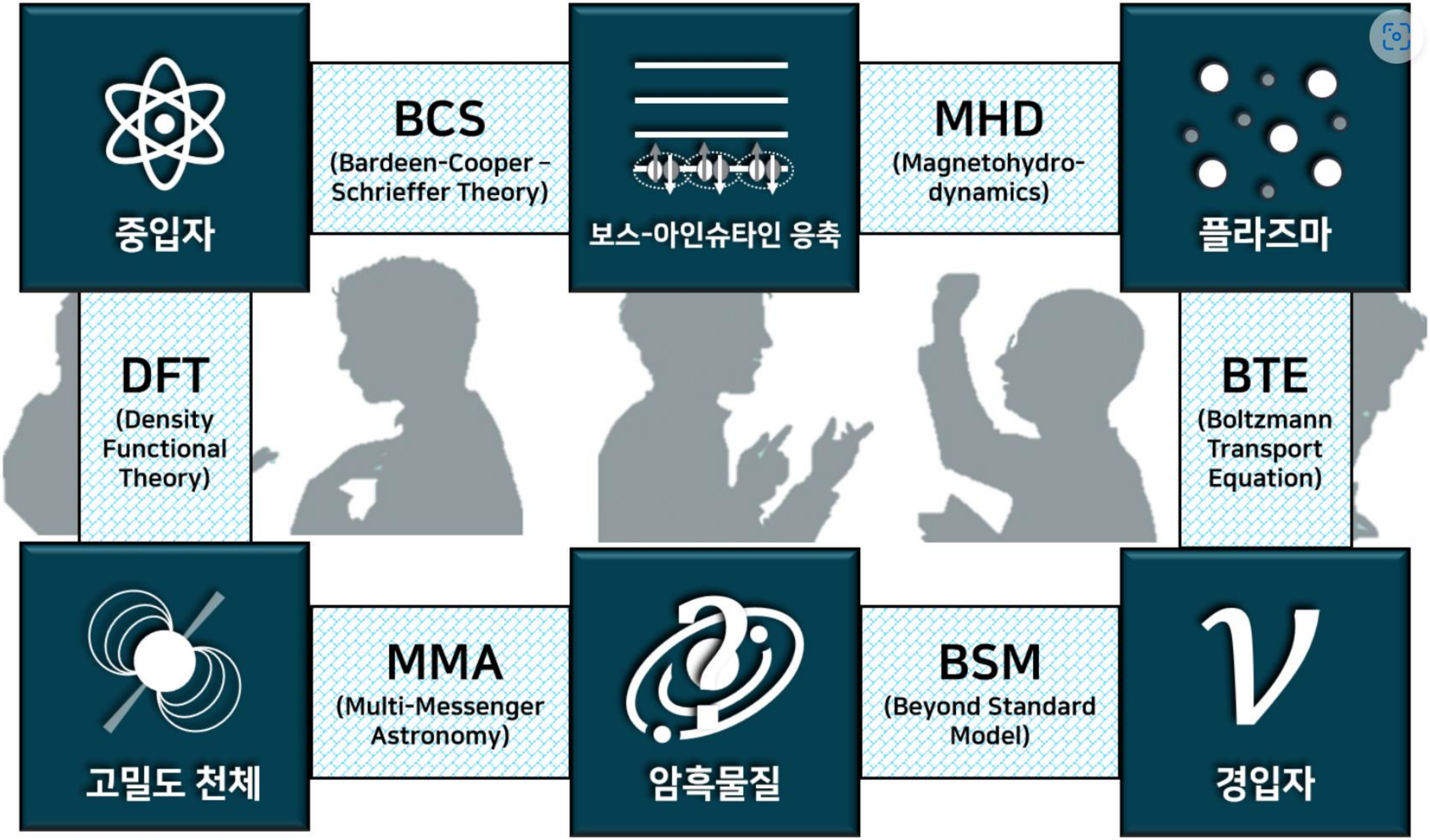
$\mathrm{PF[A]} = X_A/X_{A\odot}$ with X_A the mass fraction of A

Spectra	FD	+SI	FD	+SI
Mass Hierarchy	IH	IH	NH	NH
PF ratio	0.410(0.6585)	0.1899(0.3672)	0.335(0.6274)	0.2671(0.4776)

NH is favored !!!

However, is this the last story ?
but
the least ??? Other effects ?

Sterile Neutrino,
Magnetic field,
Polarized Electron Density
Neutrino Fast Oscillation..


중입자
BCS
(Bardeen-Cooper – Schrieffer Theory)
보스-아인슈타인 응축
MHD
(Magnetohydro-dynamics)
플라즈마
DFT
(Density Functional Theory)
BTE
(Boltzmann Transport Equation)
고밀도 천체
MMA
(Multi-Messenger Astronomy)
암흑물질
BSM
(Beyond Standard Model)
ν
경입자

Member of OMEG (Origin of Matter and Evolution of Galaxies)

박세영 교수+

소속 우주물질연구소/물리학과 직위 교수
직급 조교수
전화번호 02-820-0406
e-mail sp2829@ssu.ac.kr

김희상 교수+

소속 우주물질연구소/물리학과 직위 교수
전공 초전도
전화번호 02-820-0428
e-mail hskim@ssu.ac.kr

김진민 교수+

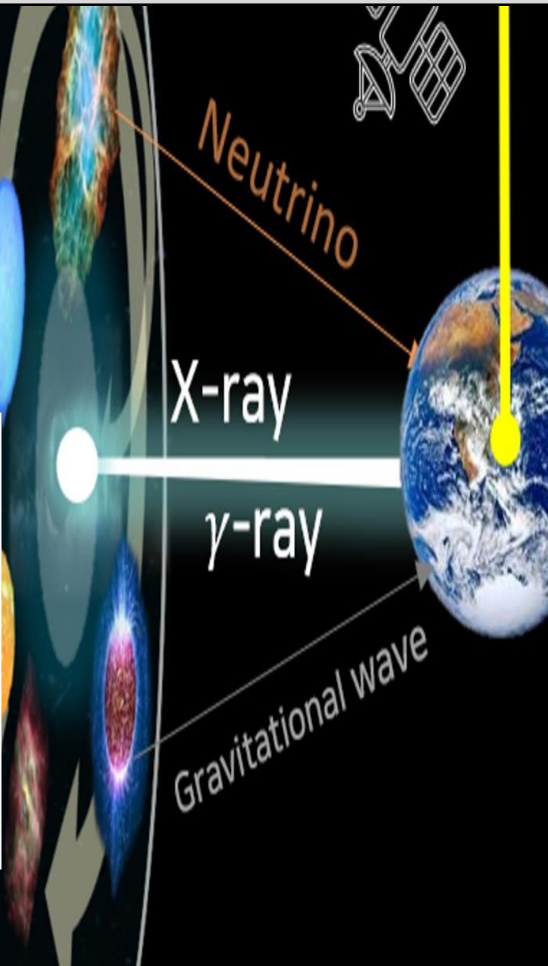
소속 우주물질연구소/물리학과 직위 교수
직급 교수 전공 통계물리
연구실 http://statphys.ssu.ac.kr/
전화번호 02-820-0421
e-mail jmkim@ssu.ac.kr

이태훈 교수+

소속 우주물질연구소/물리학과 직위 교수
전공 소립자 물리
전화번호 02-820-0425
e-mail thlee@ssu.ac.kr

김양수 교수+

소속 우주물질연구소/물리학과 직위 교수
직급 부교수 전공 입자물리 실험
전화번호 02-820-0427
e-mail dorisykim@ssu.ac.kr

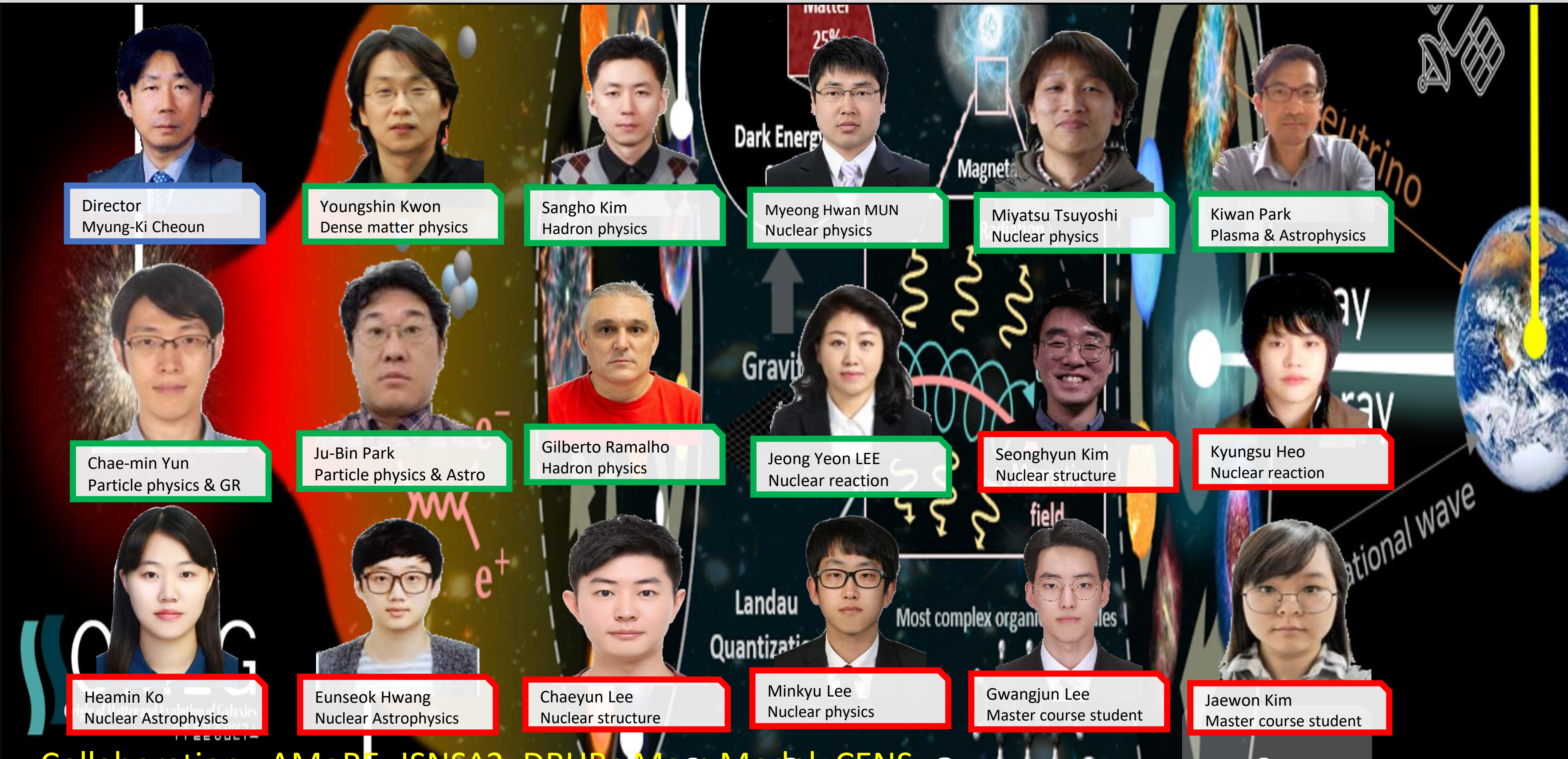


OMEG
Origin of Matter and Evolution of Galaxies
우주 물질 중점연구소

Collaboration : AMoRE, JSNS^2, DRHBc Mass Model, CENS
Colleagues : Kyungsik Kim, K. Choi (KAU), Eunja Ha (Hanyang), W. Y. SO(Kangwon), C. Hyun (Daegu)…
T. Kajino, M. Kusakabe (Beihang), B. Balantekin (Wisconsin), G. Mathews (Nortre Dame),
T. Maruyama (Nihon), H. Sagawa (RIKEN), K. Hagino(Kyoto), E. Hiyama (Tohoku), T. Kawano (BNL)….

for Multi-messenger Nuclear Astrophysics

Member of OMEG (Origin of Matter and Evolution of Galaxies)



Director
Myung-Ki Cheoun

Youngshin Kwon
Dense matter physics

Sangho Kim
Hadron physics

Myeong Hwan MUN
Nuclear physics

Miyatsu Tsuyoshi
Nuclear physics

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Nuclear reaction

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Nuclear Astrophysics

Eunseok Hwang
Nuclear Astrophysics

Chaeyun Lee
Nuclear structure

Minkyu Lee
Nuclear physics

Gwangjun Lee
Master course student

Jaewon Kim
Master course student

Collaboration : AMoRE, JSNS^2, DRHBc Mass Model, CENS
Colleagues : Kyungsik Kim, K. Choi (KAU), Eunja Ha (Hanyang), W. Y. So(Kangwon), C. Hyun (Daegu)…
T. Kajino, M. Kusakabe (Beihang), B. Balantekin (Wisconsin), G. Mathews (Nortre Dame),
T. Maruyama (Nihon), H. Sagawa (RIKEN), K. Hagino(Kyoto), E. Hiyama (Tohoku), T. Kawano (BNL)….

Recruitment : We are looking for researchers to join this project !!! Achieve Your Dreams With

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OMEG

Origin of Matter and Evolution of Galaxies

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