Activities and Collaborations

Nuclear Theory Group
Division of Astrophysics and Nuclear Physics

K. YABANA

Group Leader of Nuclear Physics Group and Quantum Condensed Matter Physics

T. NAKATSUKASA

RIKEN Nishina Center, CCS (2014.4-)

Faculty members of Nuclear Theory Group

Kazuhiro YABANA (professor, group leader)

Jun TERASAKI (assoc. professor, HPCI project, 2011.5-)

Yukio HASHIMOTO (lecturer)

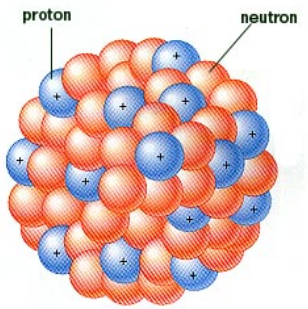
Takashi NAKATSUKASA (2014. 4- , professor, new group leader)

All members affiliated also to Dept. of Physics,
Graduate School of Pure and Applied Sciences.

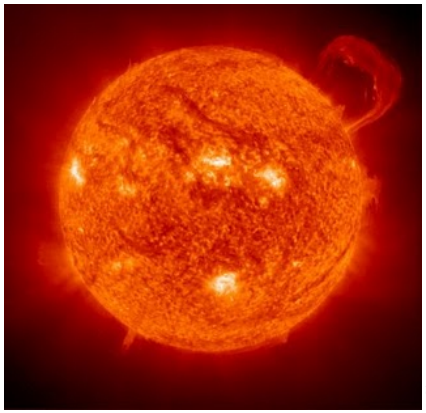
Atomic nuclei

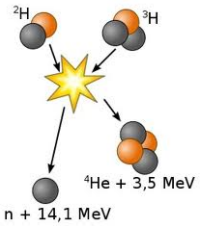
Quantum many-body system of protons and neutrons described by Schrödinger equation

$$\left[\sum_{i=1}^{N} -\frac{\hbar^2}{2m}\Delta_i + \sum_{i<j}^{N} v(x_i, x_j)\right]\Psi(x_1, x_2, \cdots, x_N, t) = i\hbar\frac{\partial}{\partial t}\Psi(x_1, x_2, \cdots, x_N, t) \quad x = (\vec{r}, \sigma)$$



Fuel of Stars

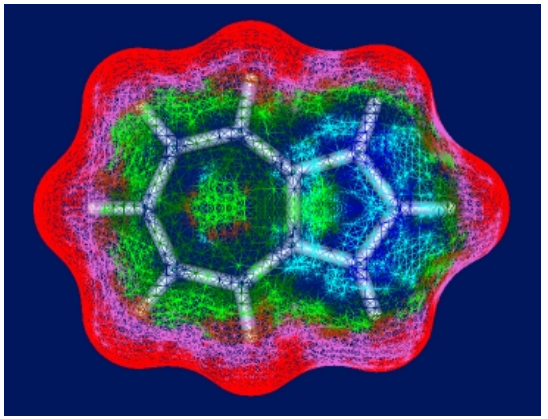




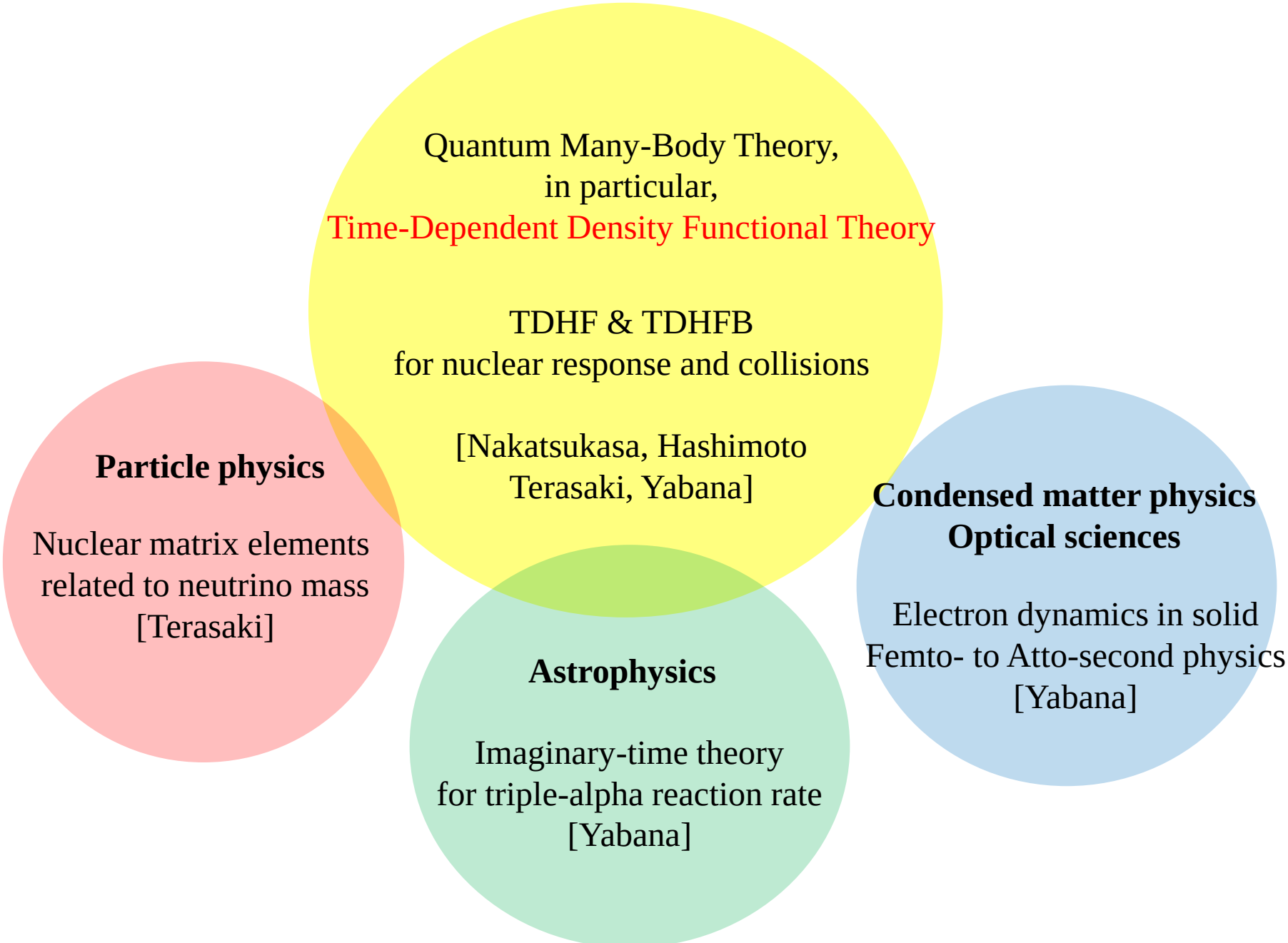
Origin of elements

Crab nebula (1054)

Common features with
Atoms, molecules, solids as
Quantum many-body systems



Researches activities of Nuclear Theory Group in Univ. Tsukuba



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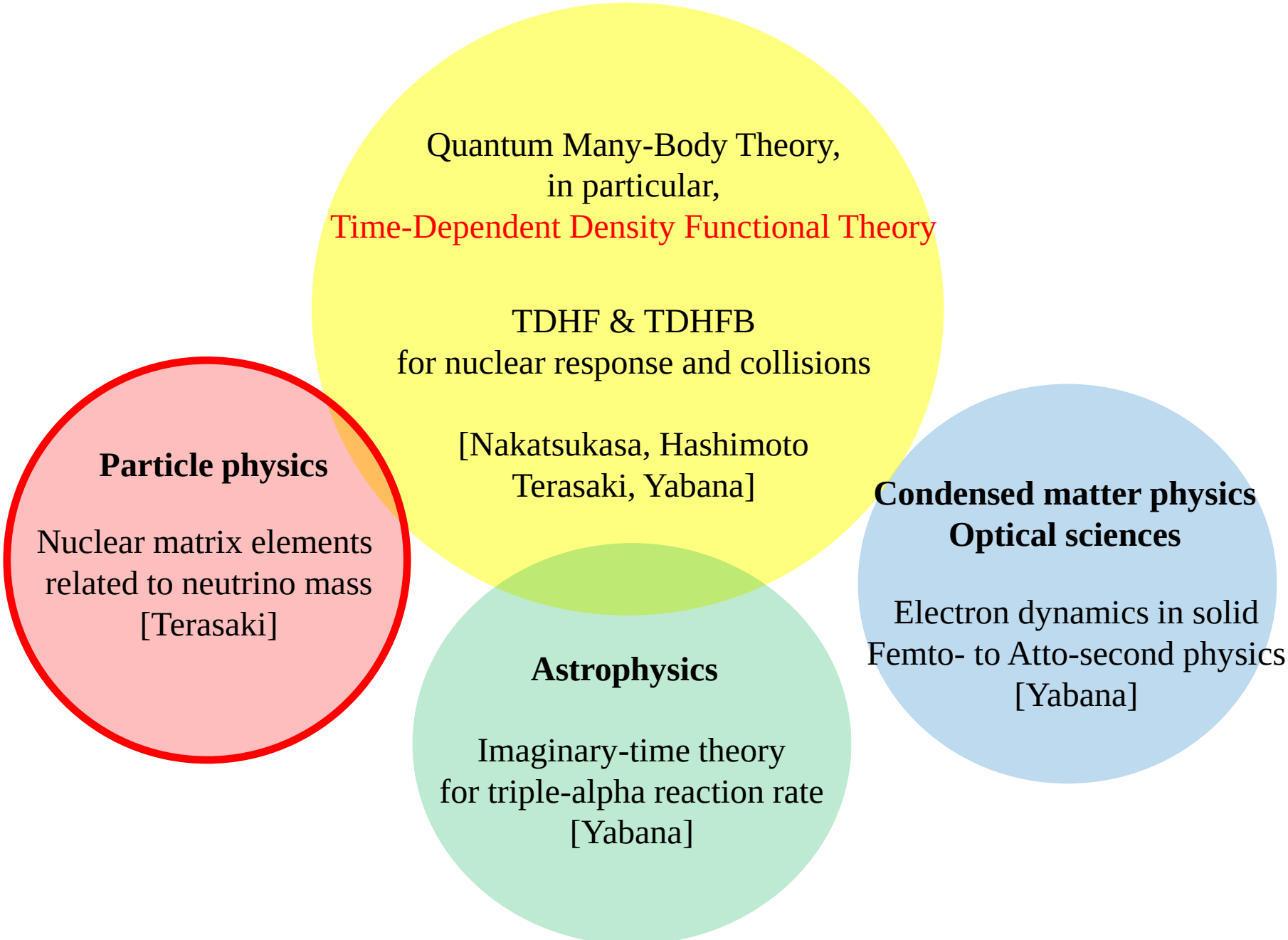


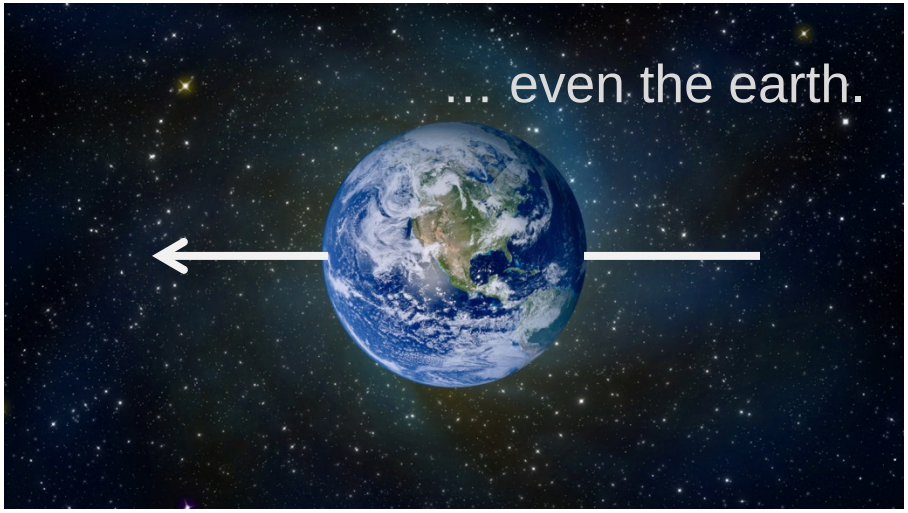
Nuclear matrix element in neutrinoless double-beta decay

J. Terasaki, Univ. of Tsukuba

Purpose

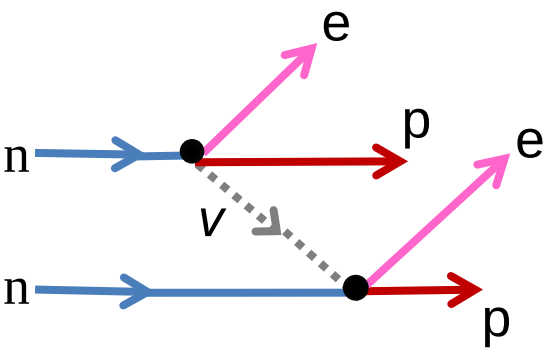
Determination of Effective neutrino mass using the neutrinoless double-beta decay

Neutrino *v* : very light particle penetrating materials very easily;



It has been proven recently that the neutrino has a mass, but the value of the mass has yet to be known.

Neutrinoless double beta-decay



Neurtinoless double beta decay in a nucleus. If the neutrino is a Majorana particle, this decay occurs.

Lifetime ← Experiment

x

Nuclear matrix element^2

x

The factor carried by electron

Theory

Determination of effective neutrino mass

My mission : to provide the nuclear matrix element and the electron factor

Physics needs the neutrino mass.

J.T. PRC **86**, 021301(R) (2012), **87** 024316 (2013)

What needs much effort is the calculation of the nuclear matrix element :

$$\sum_{b_f b_i}\sum_{\alpha\alpha':p}\sum_{\beta\beta':n}\left\langle\alpha\alpha'\left|h_+(r_{12},\bar{E}_a)\left(\boldsymbol{\sigma}(1)\cdot\boldsymbol{\sigma}(2)-\frac{g_V^2}{g_A^2}\right)\tau^+(1)\tau^+(2)\right|\beta\beta'\right\rangle$$
$$\times\left\langle 0_f^+\left|c_{\alpha'}^+c_\alpha^+\right|b_f\right\rangle\left\langle b_f\left|b_i\right\rangle\left\langle b_i\left|c_\beta c_{\beta'}\right|0_i^+\right\rangle$$

$\alpha\ \alpha'\beta\ \beta'$: proton or neutron states

$h_+(r_{12},\bar{E}_a)$: neutrino potential

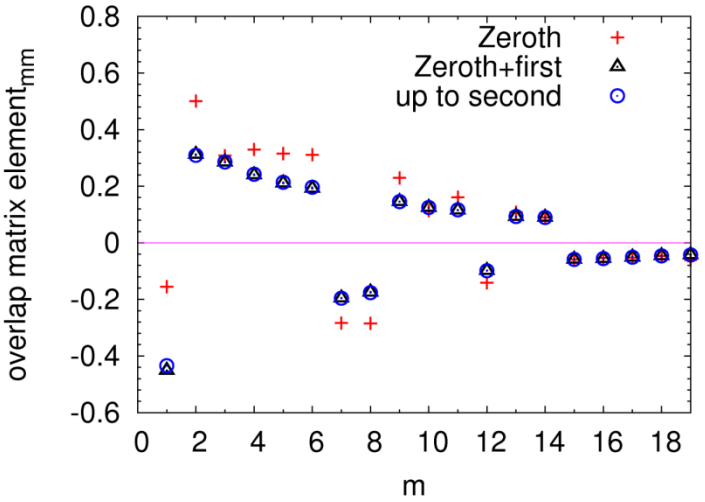
$\bar{E}_a$: mean energy of the intermediate nuclear states b_i and b_f

g_V, g_A: vector and axial- vector strength

τ^+ changes n to p

$0_f^+, 0_i^+$: nuclear final and initial states, respectively

NEW

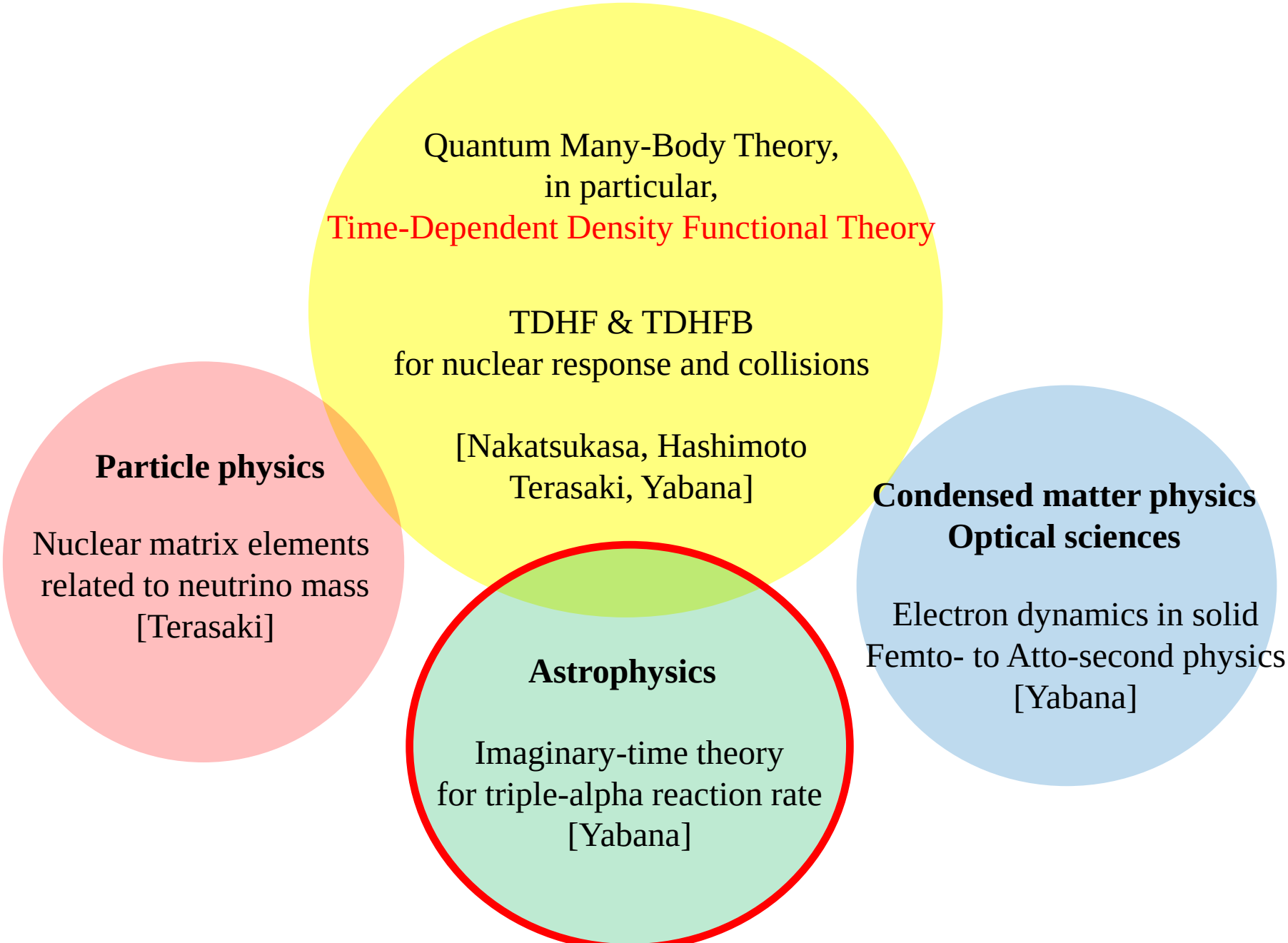


Overlap of two QRPA intermediate states $\langle b_f|b_i\rangle$ by the expansion method with respect to the operator to bring the QRPA correlations. ^{26}Mg-^{26}Si is used for test with SkM* and the volume pairing.

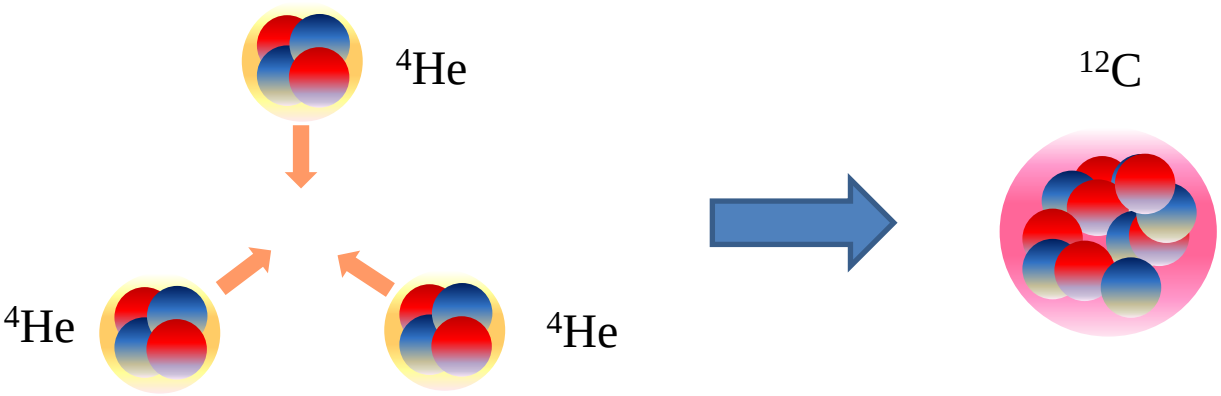
A referee's comment: "***For the first time the calculation within (like) QRPA is pulled through in full.***"

The calculation of the nuclear matrix element of ^{150}Nd →^{150}Sm is in progress.

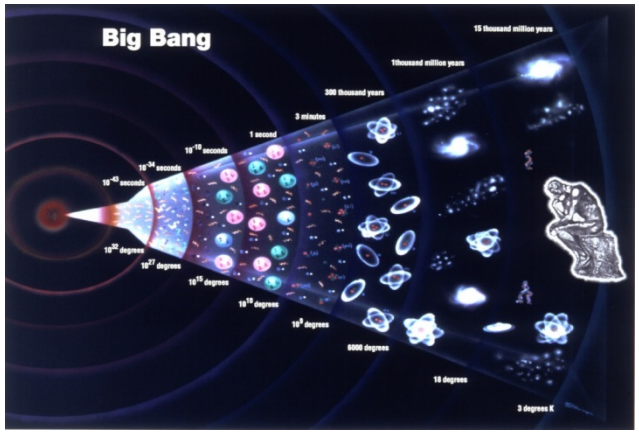
Researches activities of Nuclear Theory Group in Univ. Tsukuba



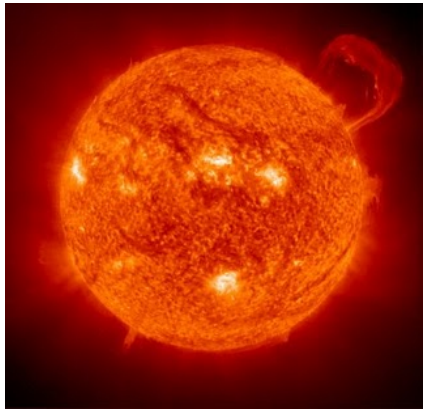
Triple-alpha reaction to synthesize ^{12}C nucleus



Immediately after the Big Bang, only H, D, ^{3}He, ^{4}He, and some Li, Be are synthesized.

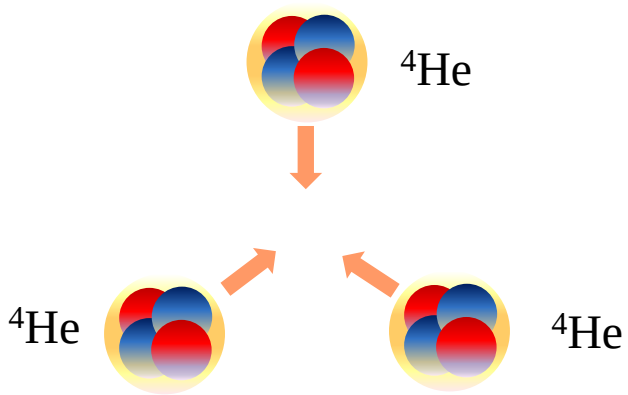


All heavy elements are synthesized inside starts through triple-alpha reaction



Difficulties of triple-alpha reaction rate

- Experiments not possible
- Very small reaction rate due to quantum tunneling nature
- There is no formal scattering theory for charged three particles

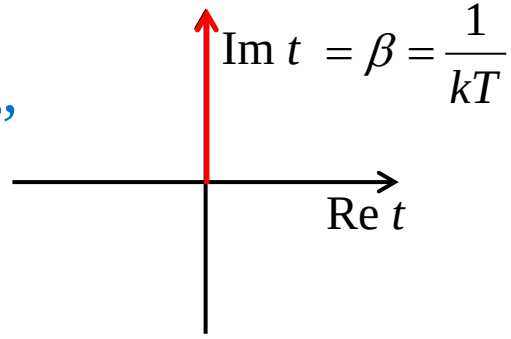


We (believe to) have solved the problem.

K. Yabana, Y. Funaki, Phys. Rev. C85, 055803 (2012).
T. Akahori, Y. Funaki, K. Yabana, to be accepted soon.

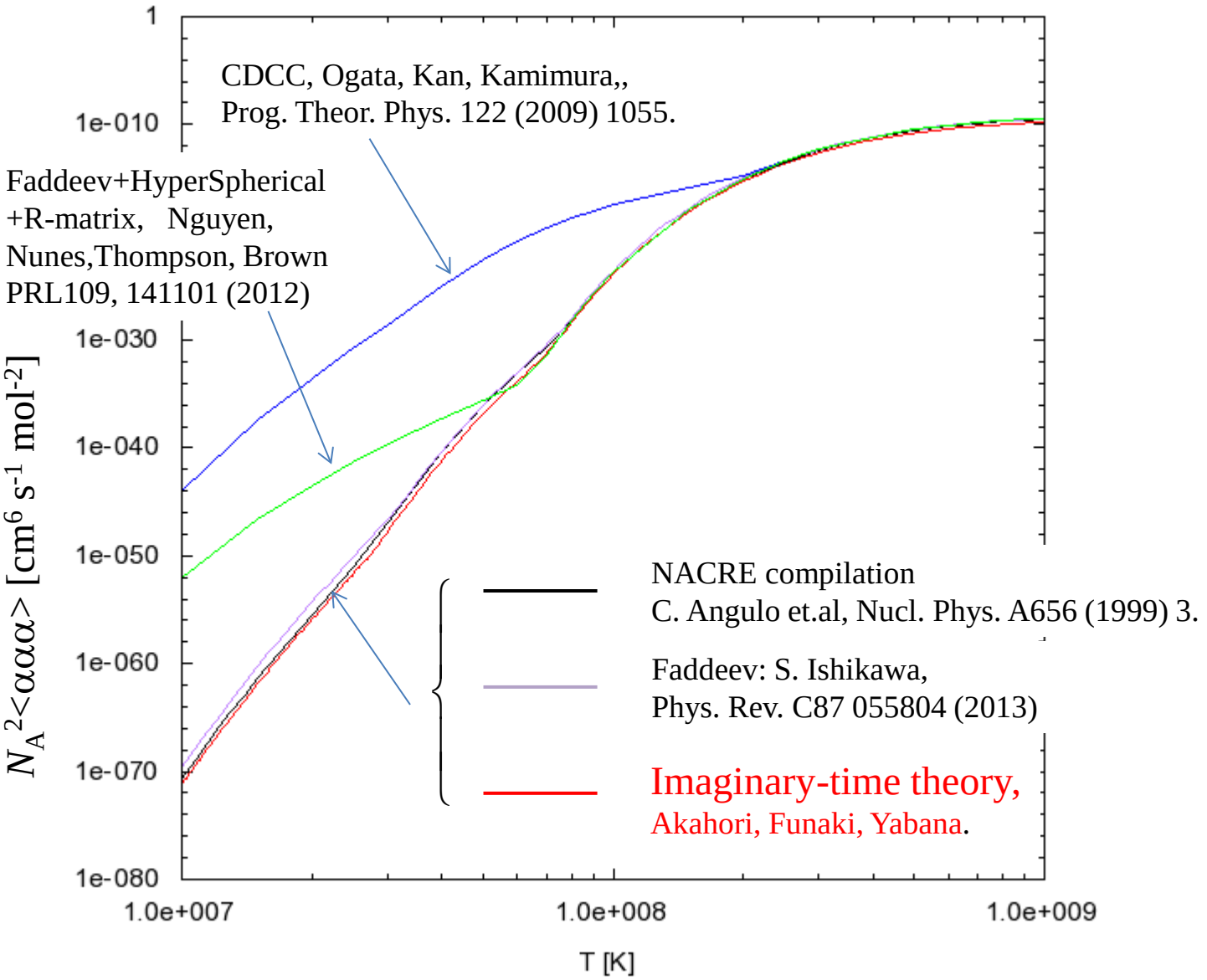
"Imaginary-time theory for triple-alpha reaction rate"

$$-\frac{\partial}{\partial\beta}\psi(\beta)=H\psi\ (\beta)$$

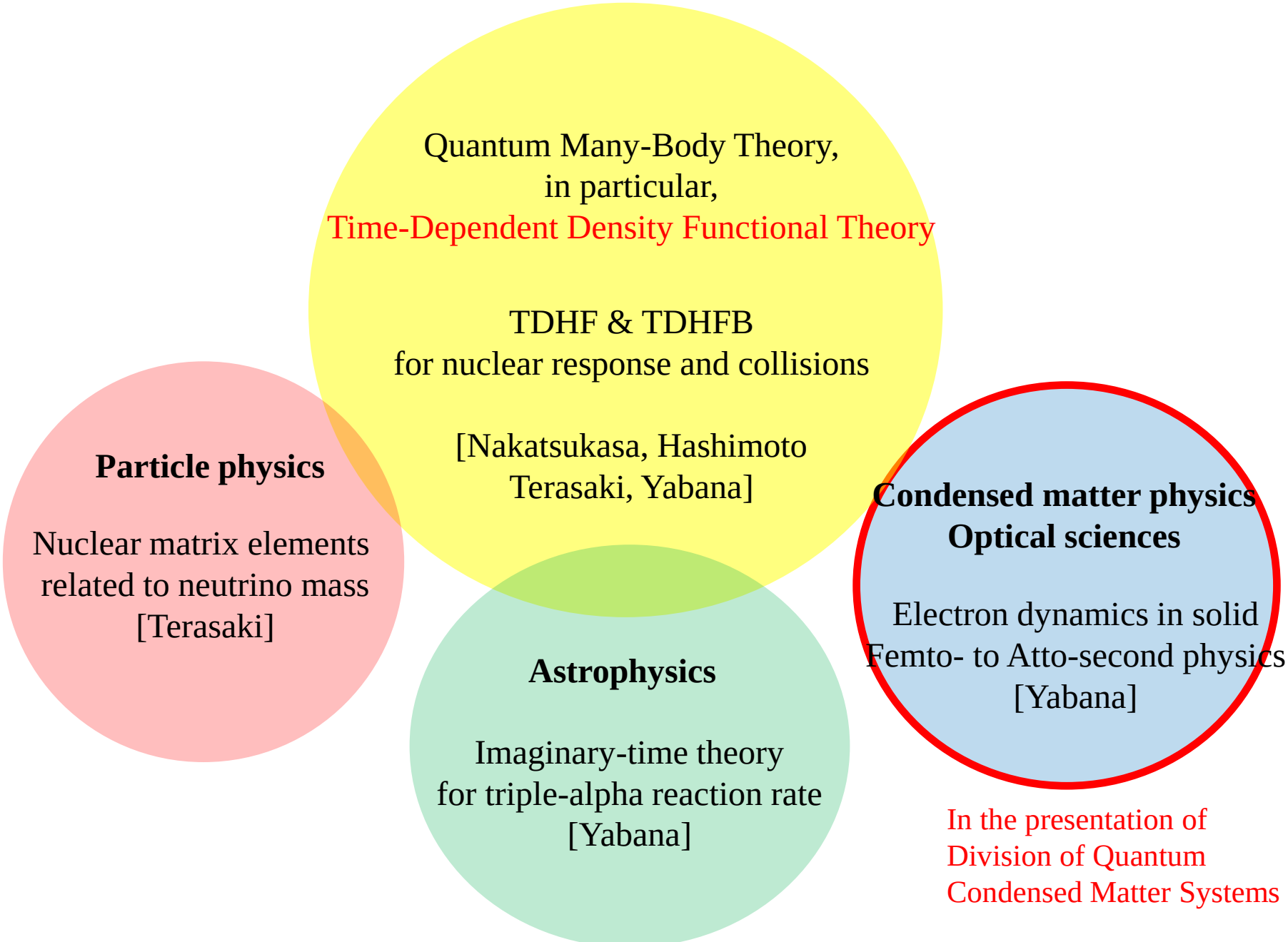


Recent theoretical Controversy

10^{26} order of magnitude difference at 10^{7} K



Researches activities of Nuclear Theory Group in Univ. Tsukuba



In the presentation of
Division of Quantum
Condensed Matter Systems

Researches activities of Nuclear Theory Group in Univ. Tsukuba

By Dr. T. Nakatsukasa

Quantum Many-Body Theory,
in particular,
Time-Dependent Density Functional Theory

TDHF & TDHFB
for nuclear response and collisions

[Nakatsukasa, Hashimoto
Terasaki, Yabana]

Particle physics

Nuclear matrix elements
related to neutrino mass
[Terasaki]

Astrophysics

Imaginary-time theory
for triple-alpha reaction rate
[Yabana]

Condensed matter physics
Optical sciences

Electron dynamics in solid
Femto- to Atto-second physics
[Yabana]